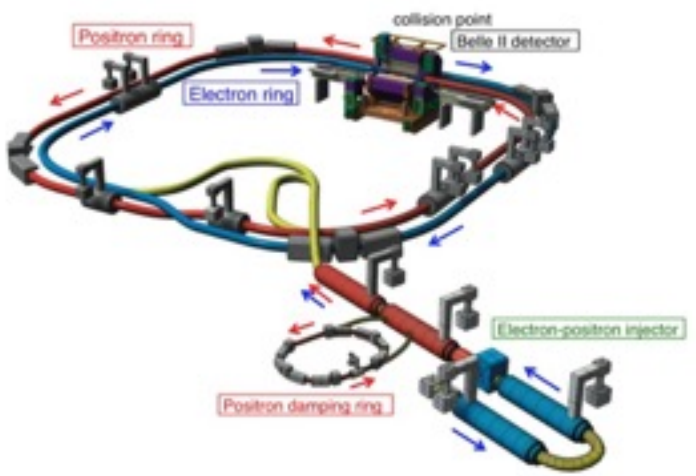
B Physics: New Physics and The Next Generation

Tom Browder (University of Hawai'i at Manoa)



KEK in Tsukuba, Japan

<u>Complex phases in the weak interaction</u>: V_{td} and V_{ts} and associated CPV asymmetries

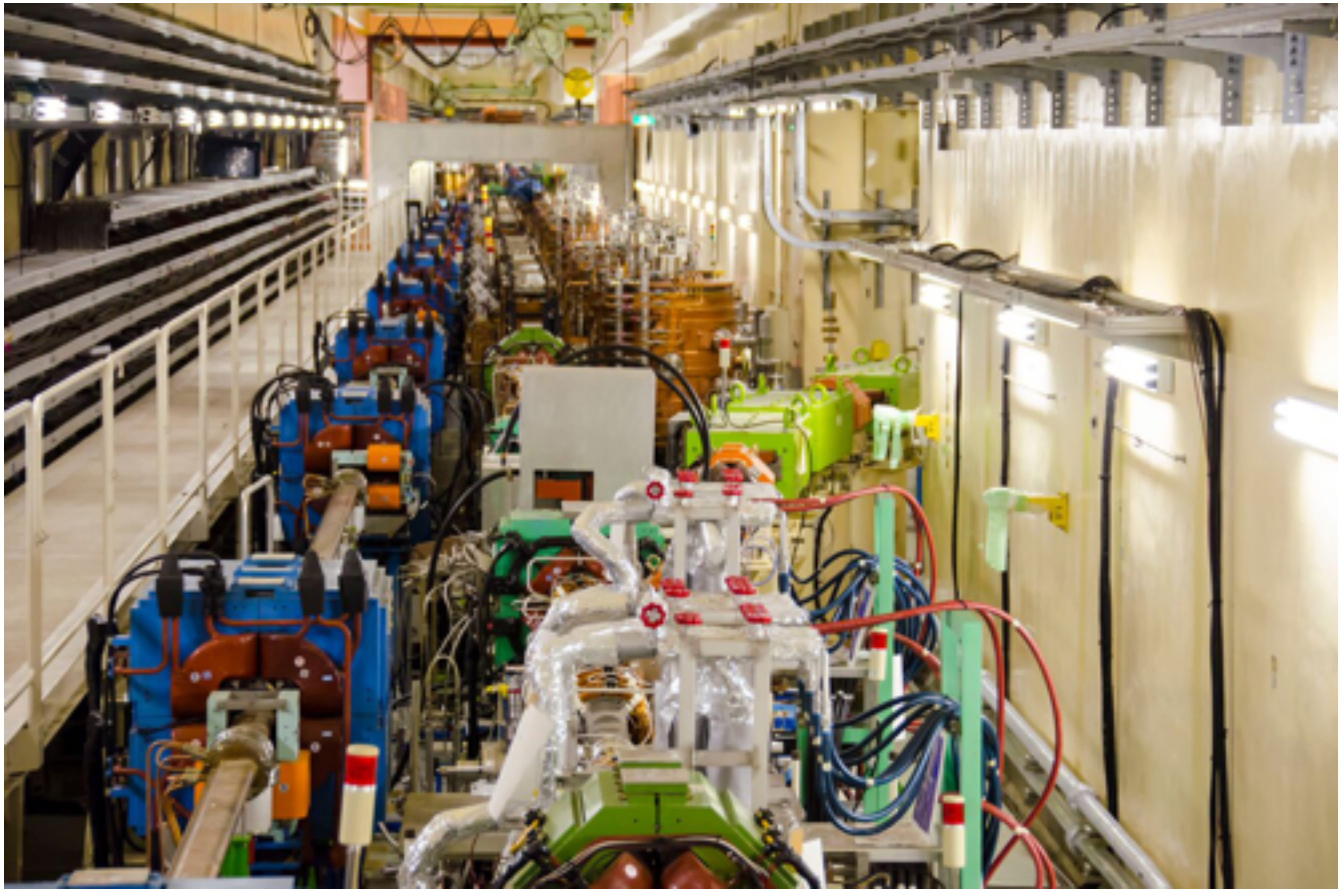
<u>Excitement in Flavor Physics:</u>

-Connections to the *<u>charged Higgs</u>*
-Rare B Decays + <u>NP</u>

Flavor Physics, The Next Generation:
<u>Belle II and the LHCb upgrade</u>

Apologies: I have borrowed slides from many excellent physicists and will aim for the "big picture" but skip most details.

Feb 2016 News: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)



April 19, 2016 (LER beam current at 540 mA, HER at 480 mA)

First new particle collider since the LHC (*intensity frontier* rather than energy frontier; $e^+ e^-$ rather than p p)

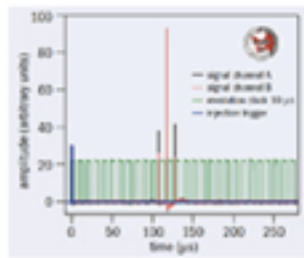
Feb 2016 News: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)

CERN
COURIER

CERN COURIER

Mar 18, 2016

'First turns' for SuperKEKB


Signals from CLAWS

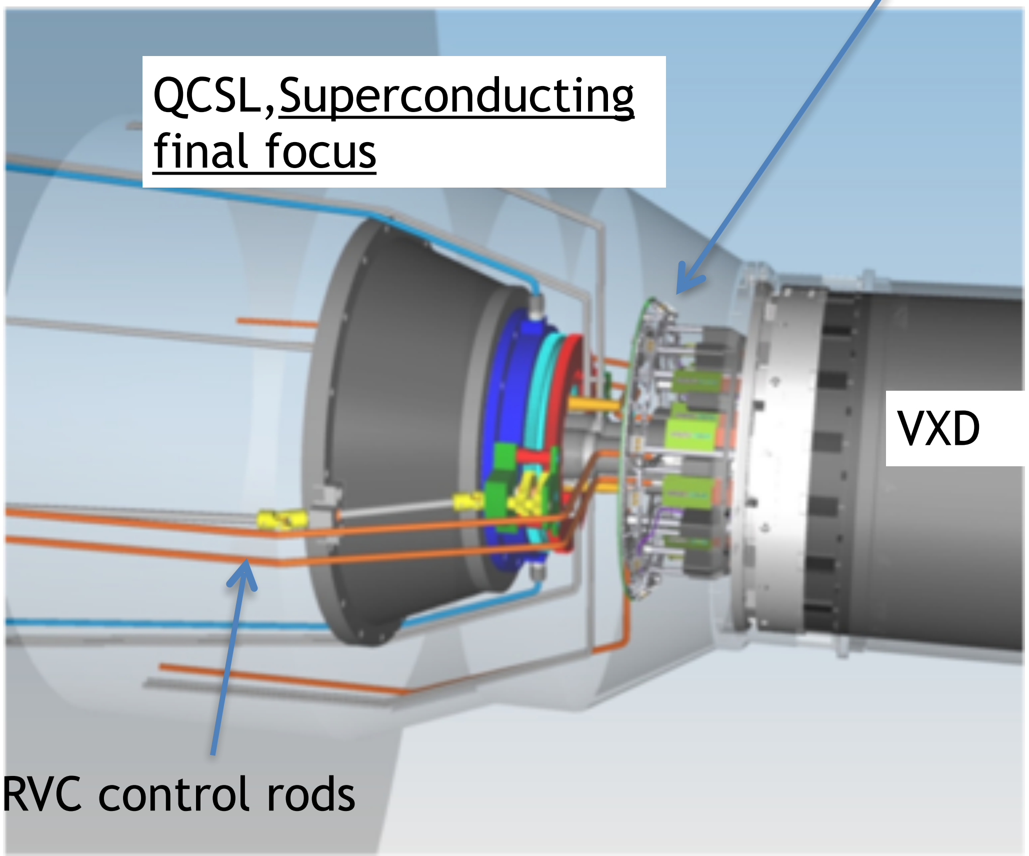
On 10 February, the SuperKEKB electron–positron collider in Tsukuba, Japan, succeeded in circulating and storing a positron beam moving close to the speed of light through 1000 magnets in a narrow tube around the 3 km circumference of its main ring. And on 26 February, it succeeded in circulating and storing an electron beam around its ring of magnets in the opposite direction.

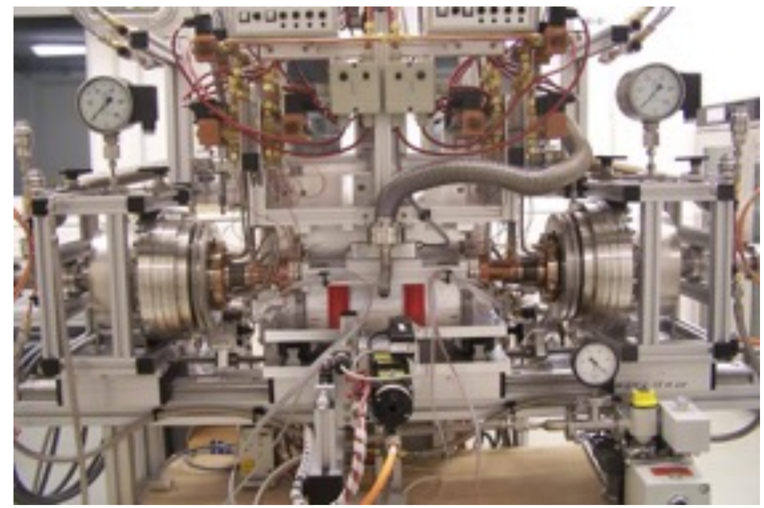
The achievement of "first turns", which means storing the beam in the ring through many revolutions, is a major milestone for any particle accelerator.

<u>First detection of "first turns"</u> in BEAST background detector by F. Simon et al (MPI) using CLAWs (scintillators with SiPM's), which originated at DESY (i.e. CALICE AHCAL)

DESY contributions to SuperKEKB

RVC= Remote Vacuum Connection





Realization of RVC at DESY

Also SuperKEKB beam background simulation:
Synchrotron Radiation (SR)

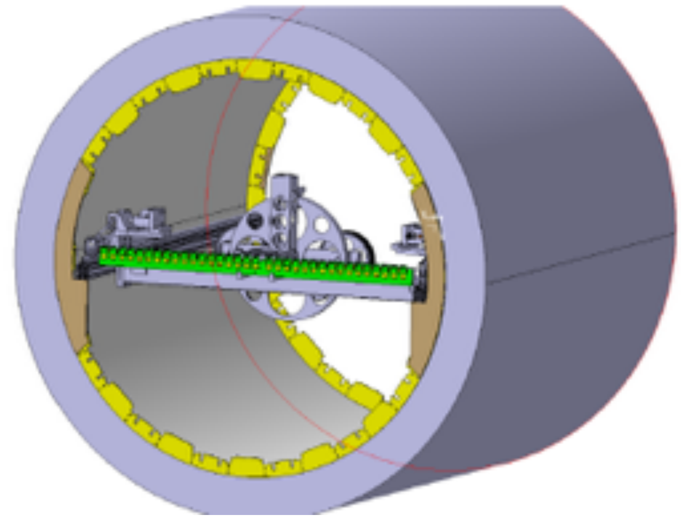
Major DESY *contributions* to Belle II

Thermal mockup of the vertex detectors/CO_2 cooling

(many initial results, on-going)

Precise mapping of the 1.5 T B field of the Belle II superconducting solenoid

(starts June 2016)



Software Alignment of Belle II detectors

(standard Belle II package)

GRID computing and Collaborative Computing Services for Belle II (starts summer 2016)

Not a complete list !

Amplitudes and *Phases* in the Weak Interaction

N. Cabibbo M.Kobayashi T.Maskawa

$$V_{\mathrm{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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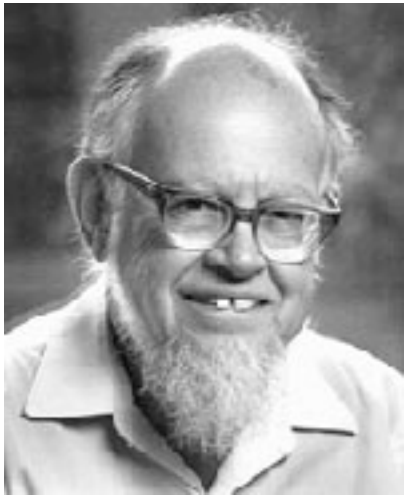

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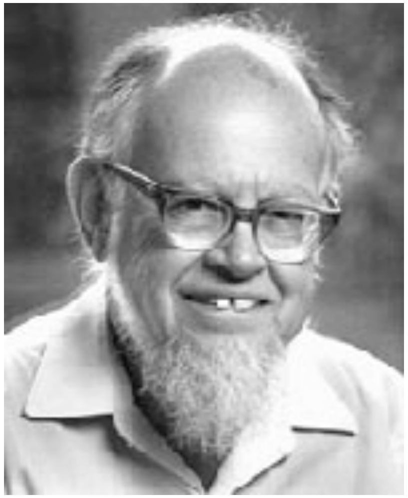

L. Wolfenstein (1923-2015)

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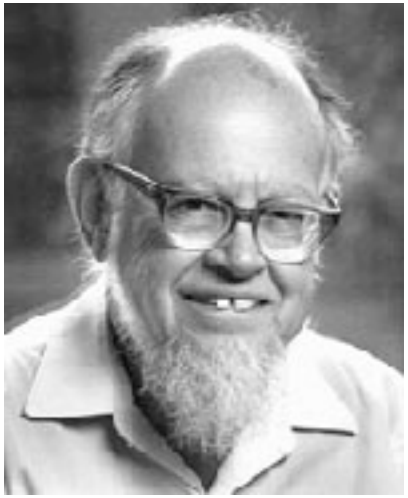

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$$V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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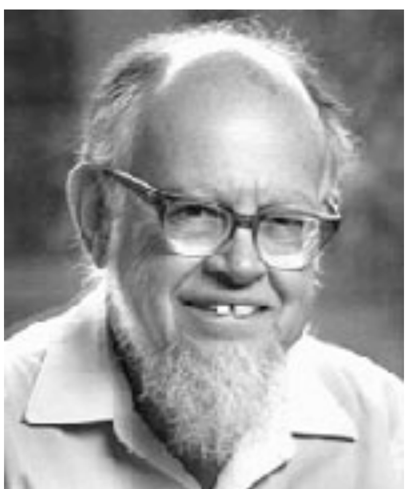

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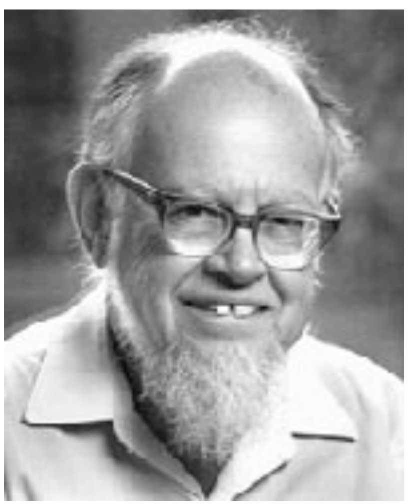

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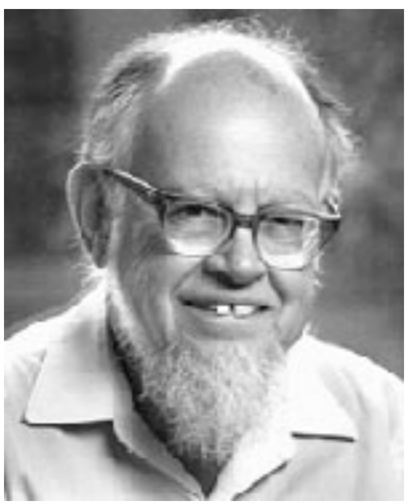

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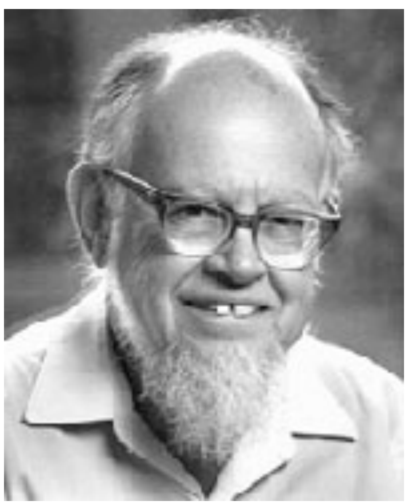

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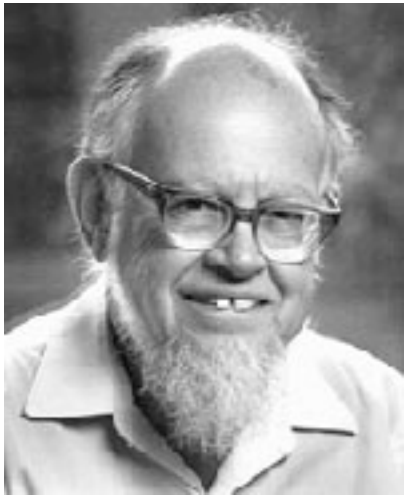

to O(λ³)

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L. Wolfenstein (1923-2015)

Three Angles: (φ_1,φ_2,φ_3) or (β, α, γ)

Recent Belle
result on B→$\rho^+ \rho^-$

Three Angles: ($\varphi_1,\varphi_2,\varphi_3$) or (β, α, γ)

Recent Belle result on $B \rightarrow \rho^+ \rho^-$

Unitarity implies that the weak couplings and phases form a triangle in the complex plane.

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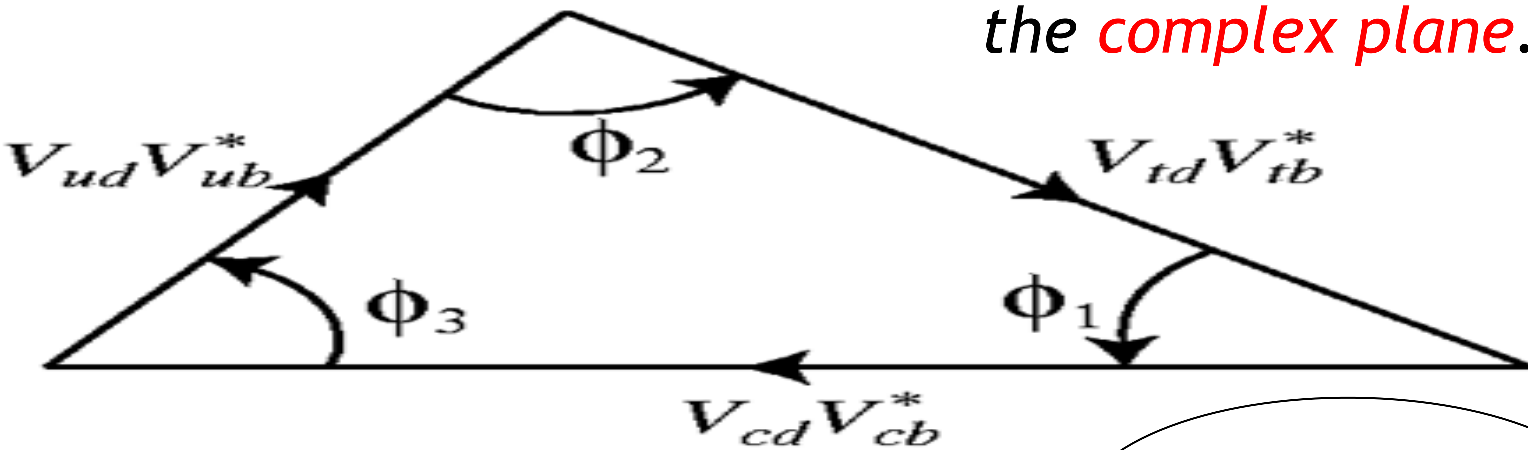

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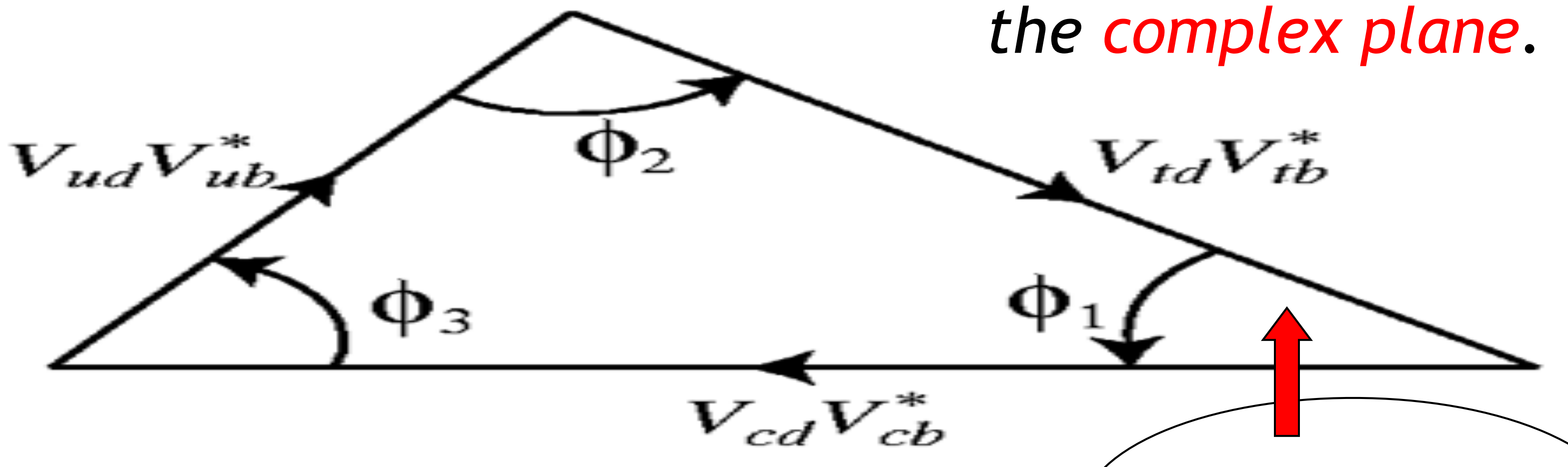

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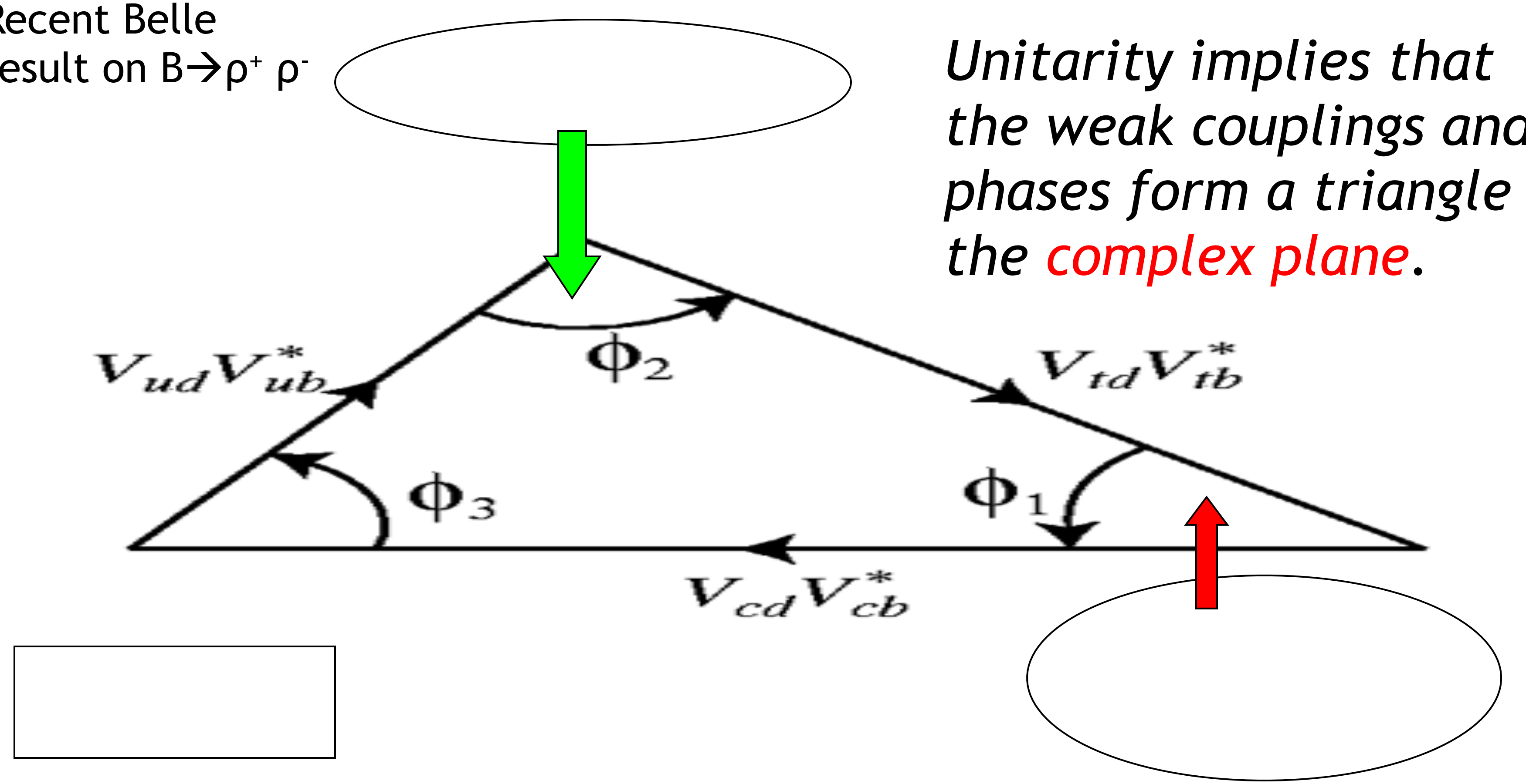

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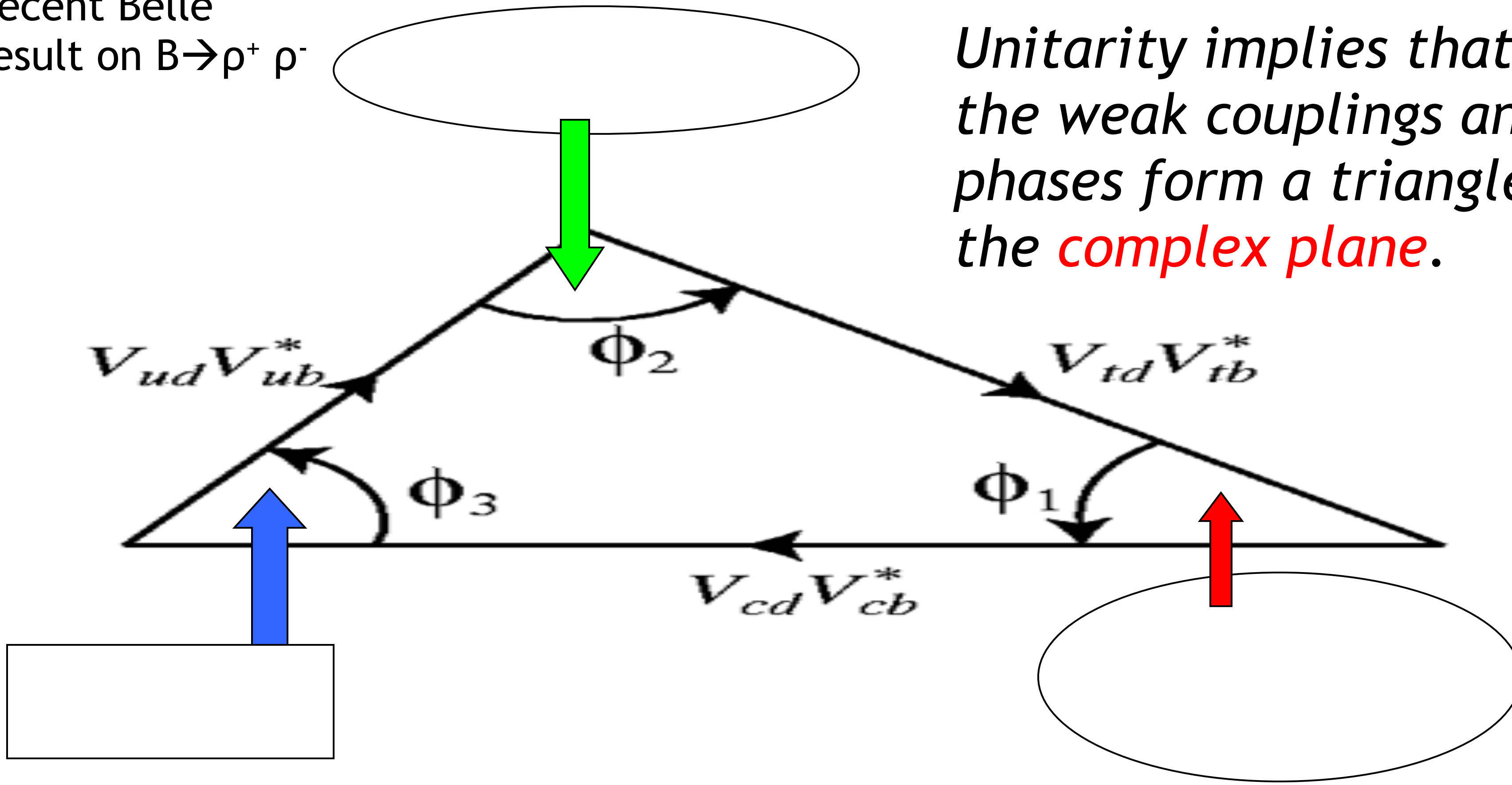

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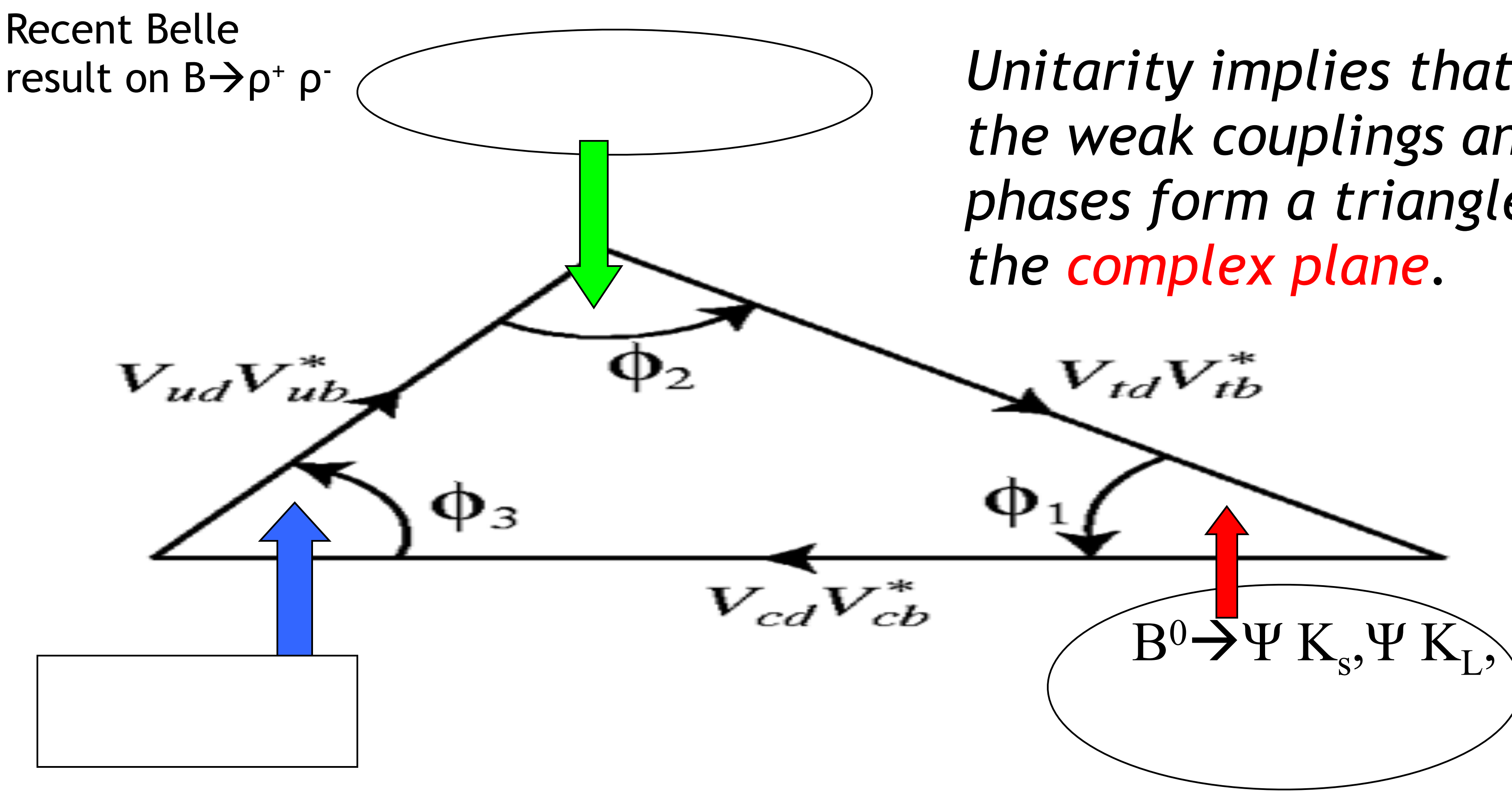

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Recent Belle result on B→ρ⁺ ρ⁻

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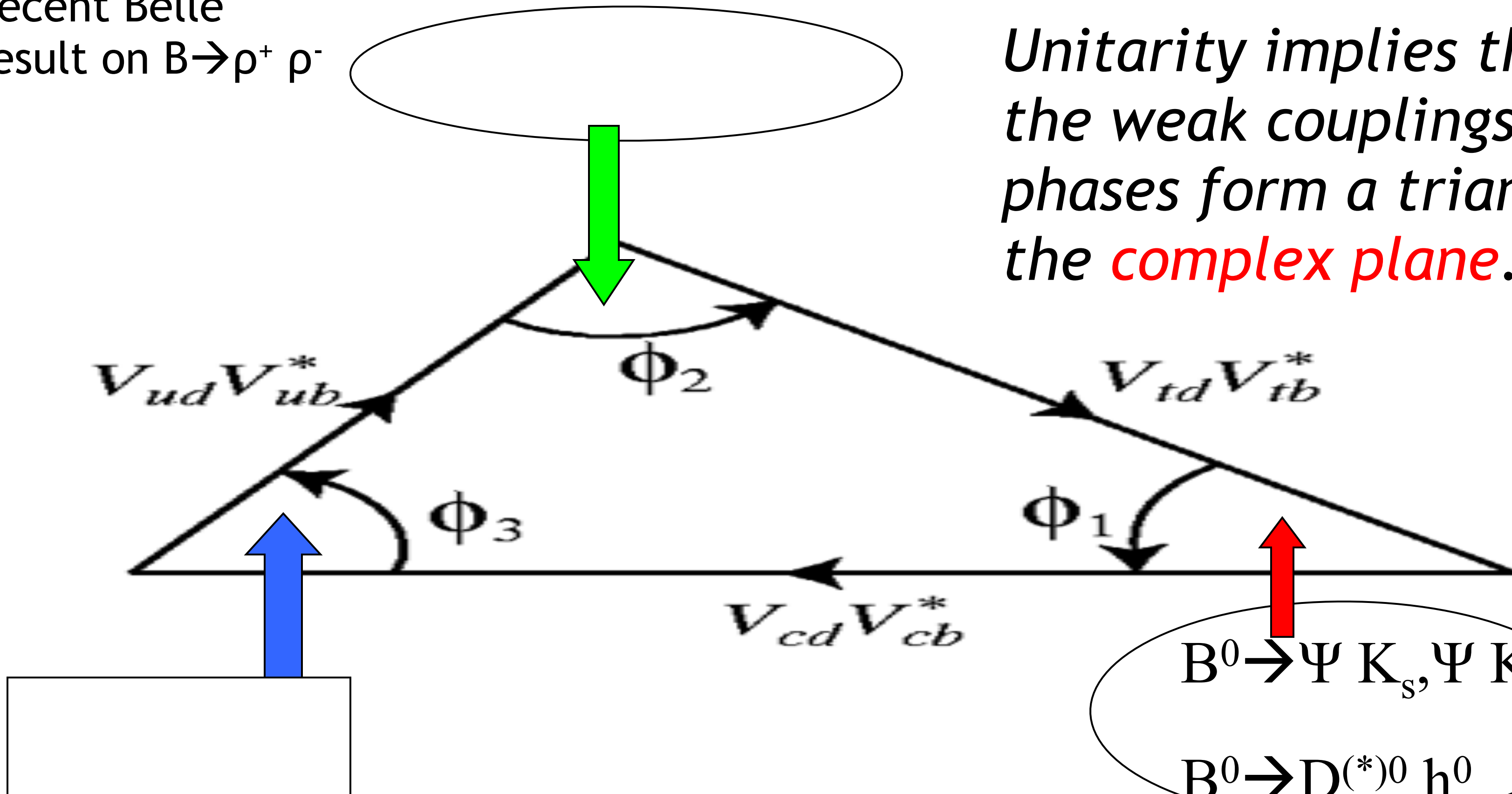

$B^0 \rightarrow \Psi K_s, \Psi K_L,$

$B^0 \rightarrow D^{(*)0} h^0$

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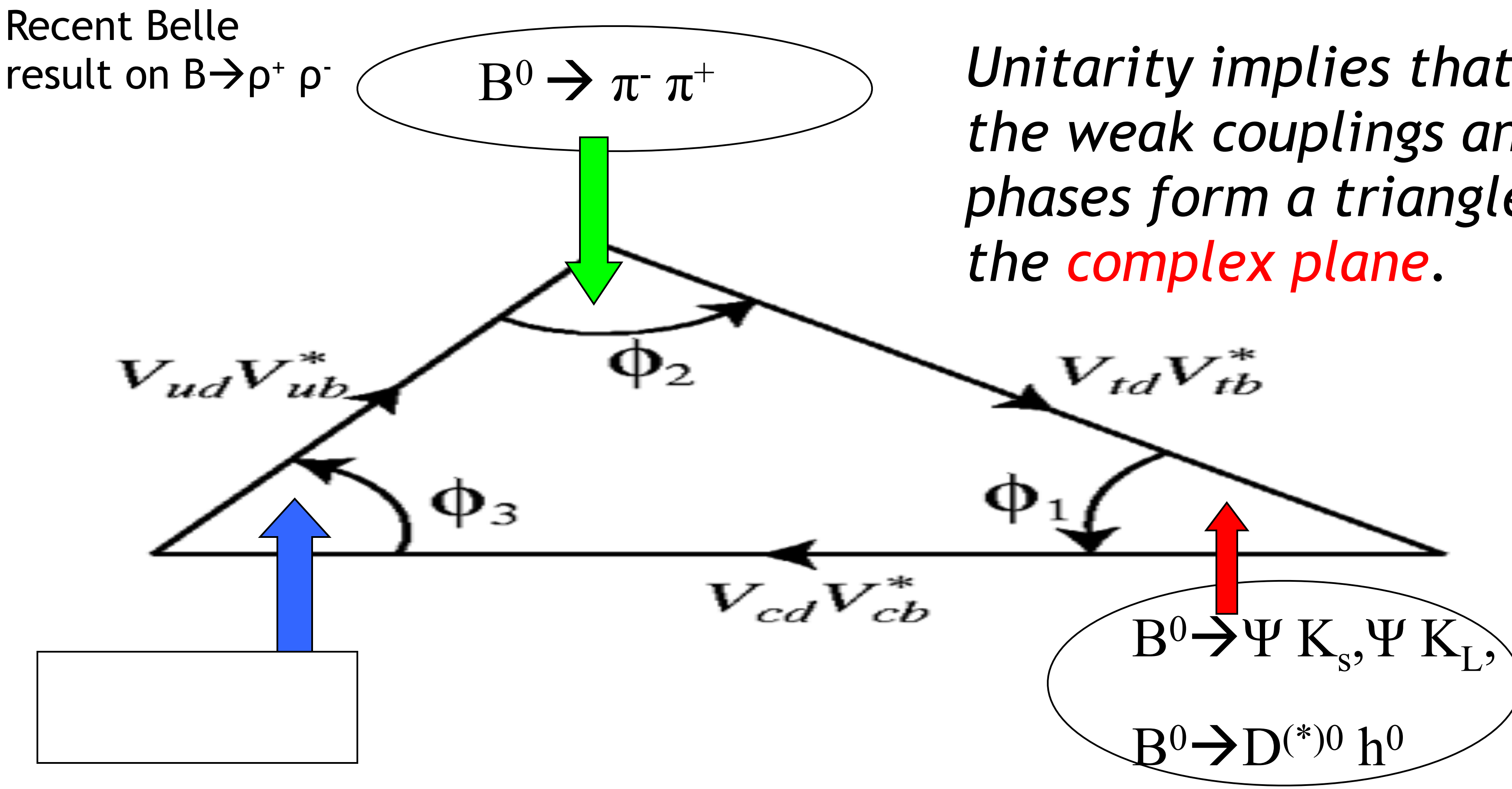

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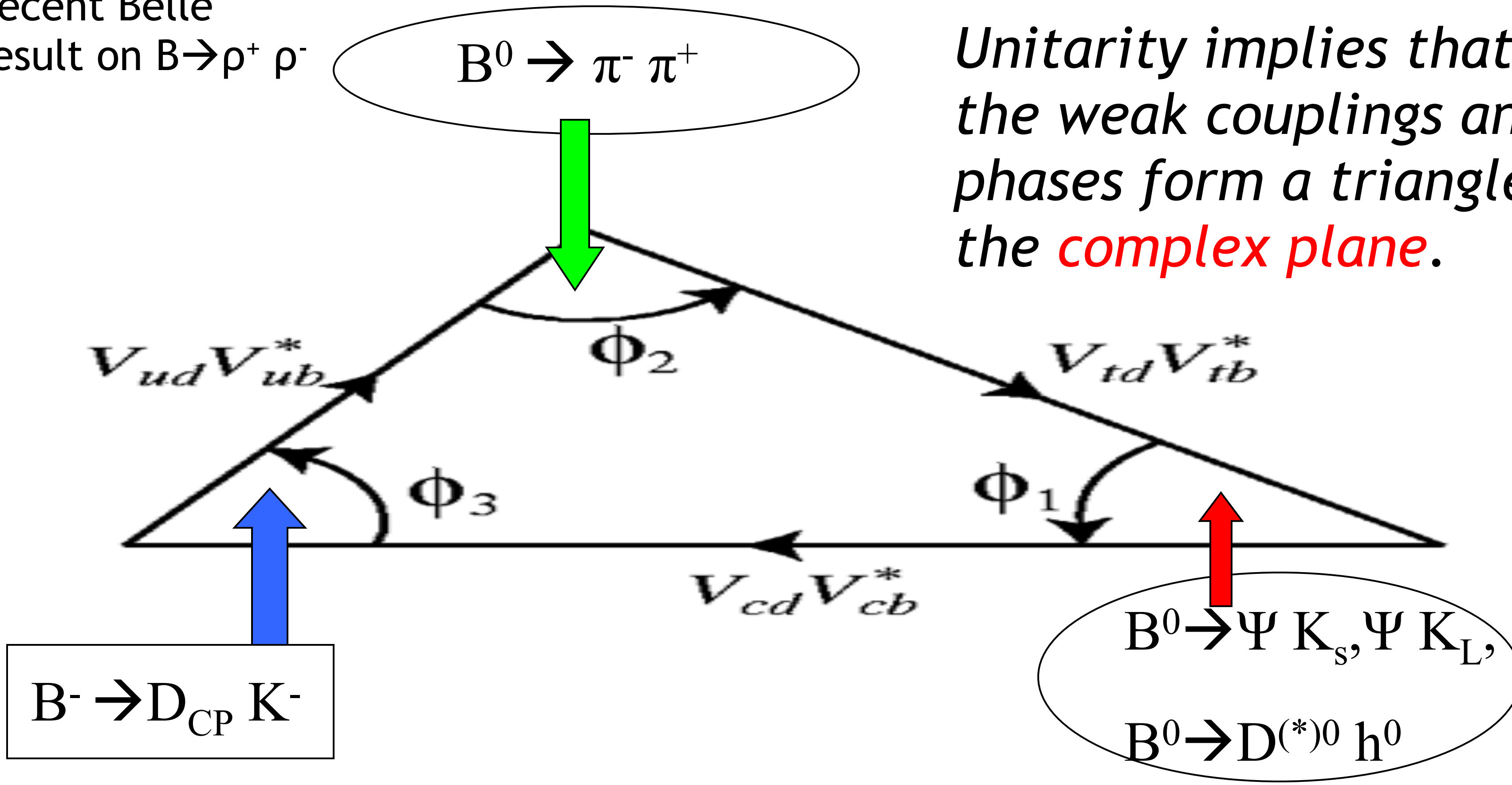

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$B^0 \rightarrow \pi^- \pi^+$

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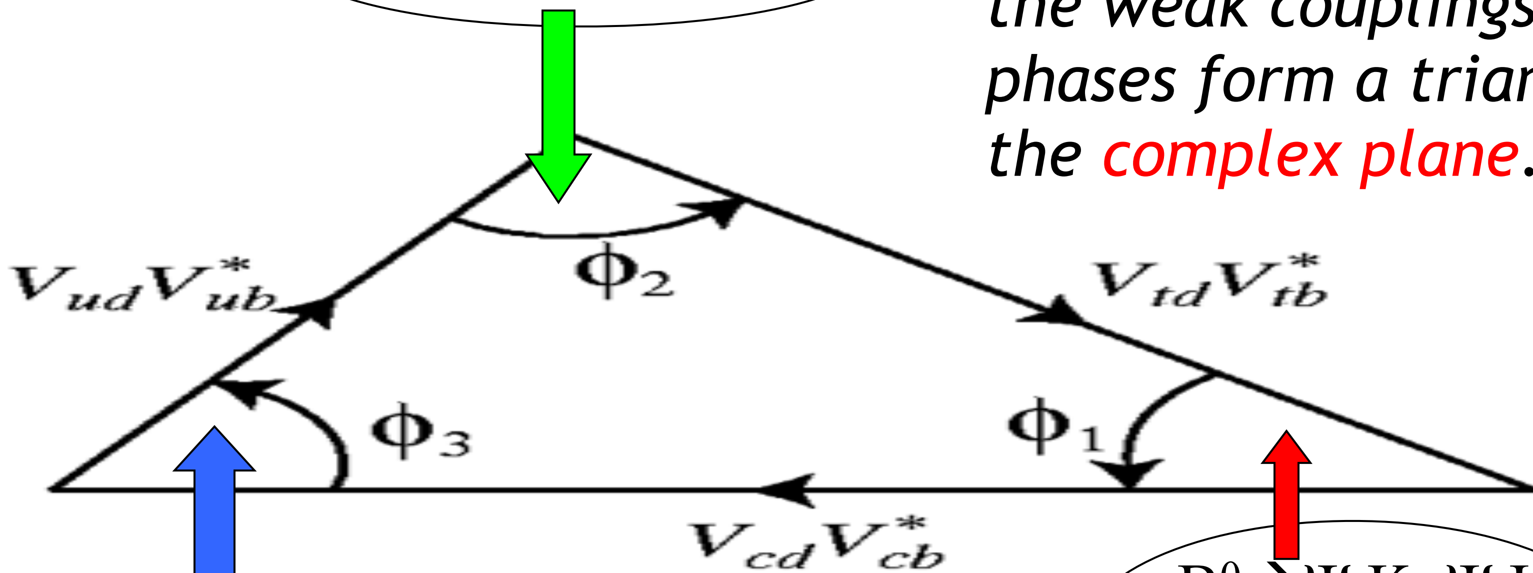

$B^- \rightarrow D_{CP} K^-$

Recent LHCb results on CPV in $B_s \rightarrow D_S^{-(*)} K^+$

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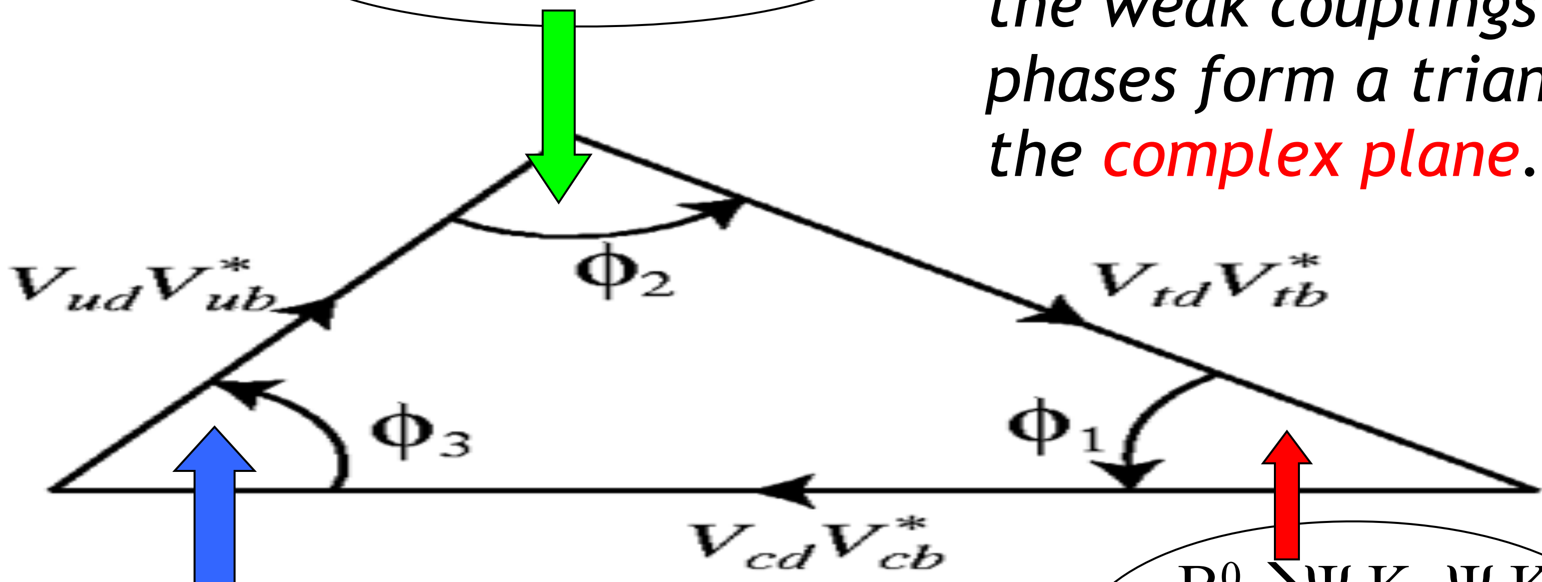

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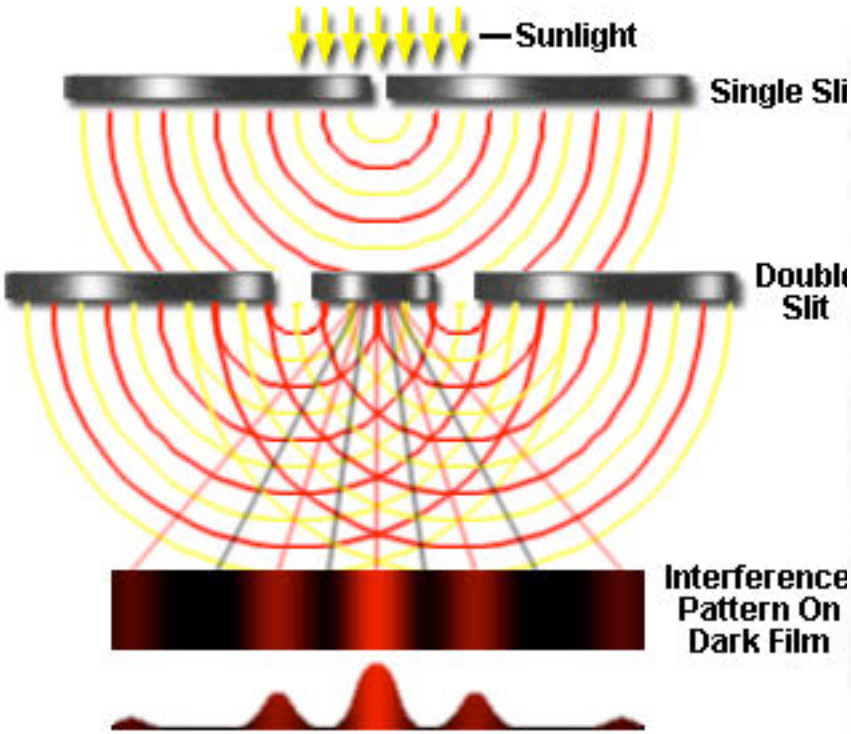
Big Questions: *Are determinations of angles consistent with determinations of the sides of the triangle ? Are angle determinations from loop and tree decays consistent ?*

Time-dependent *CP* violation is

"*A Double-Slit experiment*" with particles and antiparticles

QM interference between two diagrams



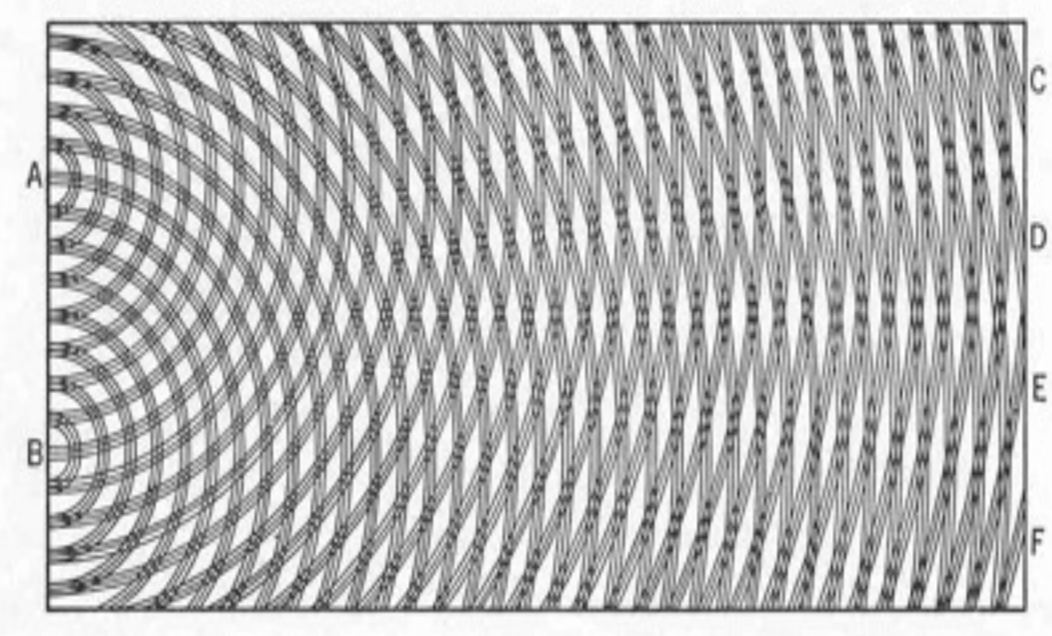


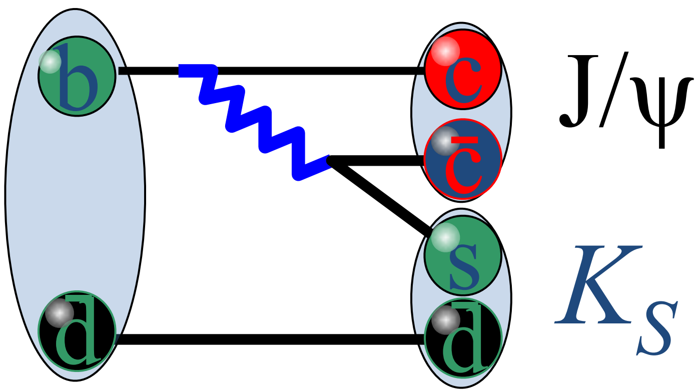
FIG. 1

Time-dependent *CP* violation is

"*A Double-Slit experiment*" with particles and antiparticles

QM interference between two diagrams

tree diagram



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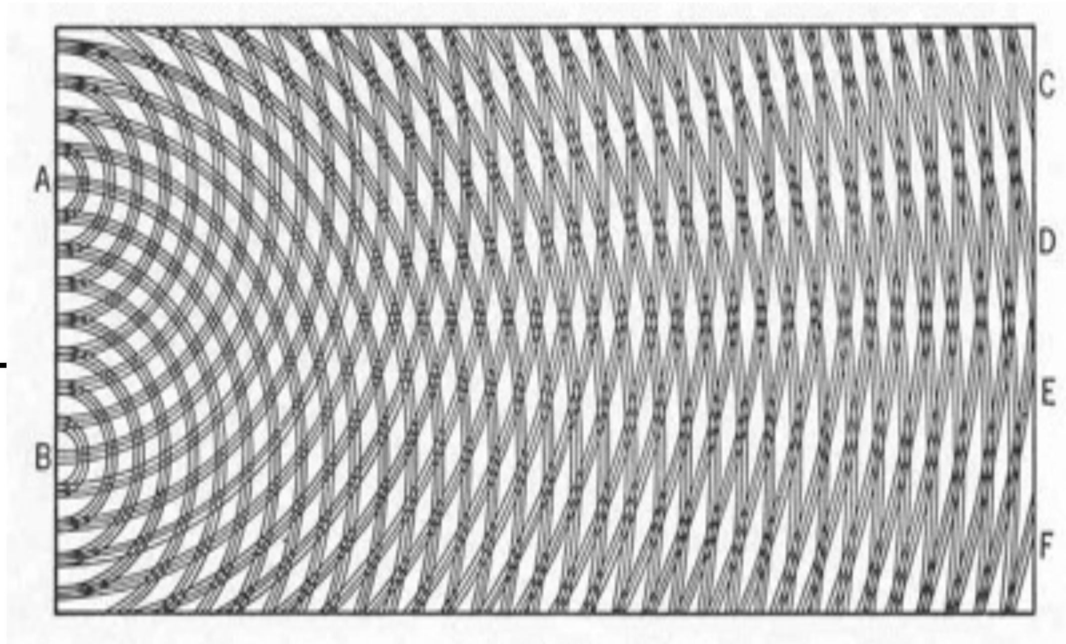

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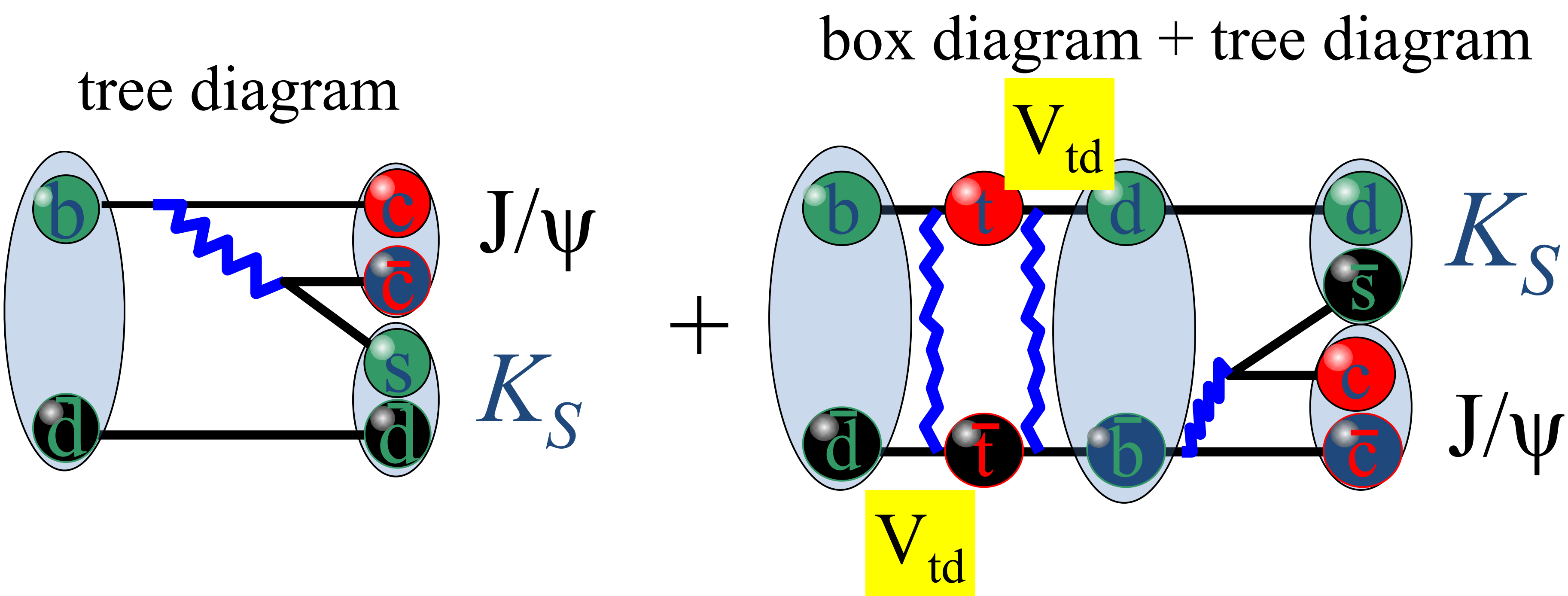

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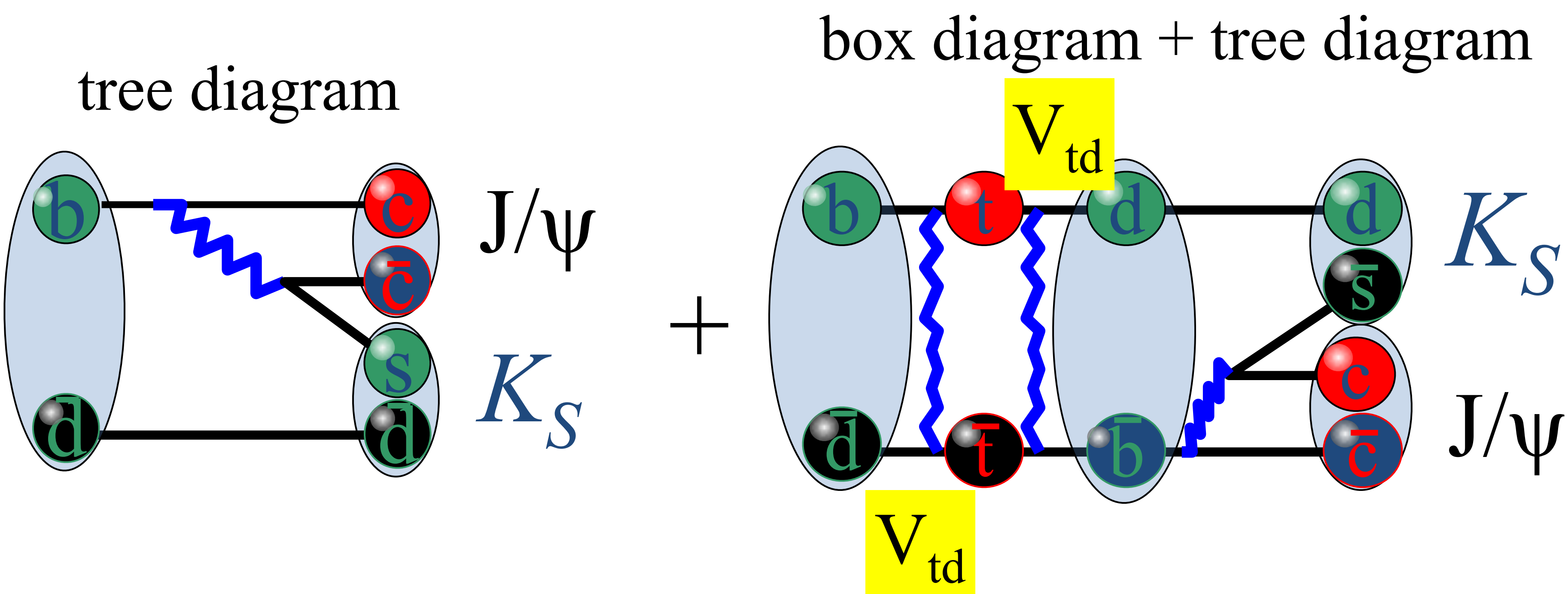

Measures the phase of V_{td} or equivalently the phase of

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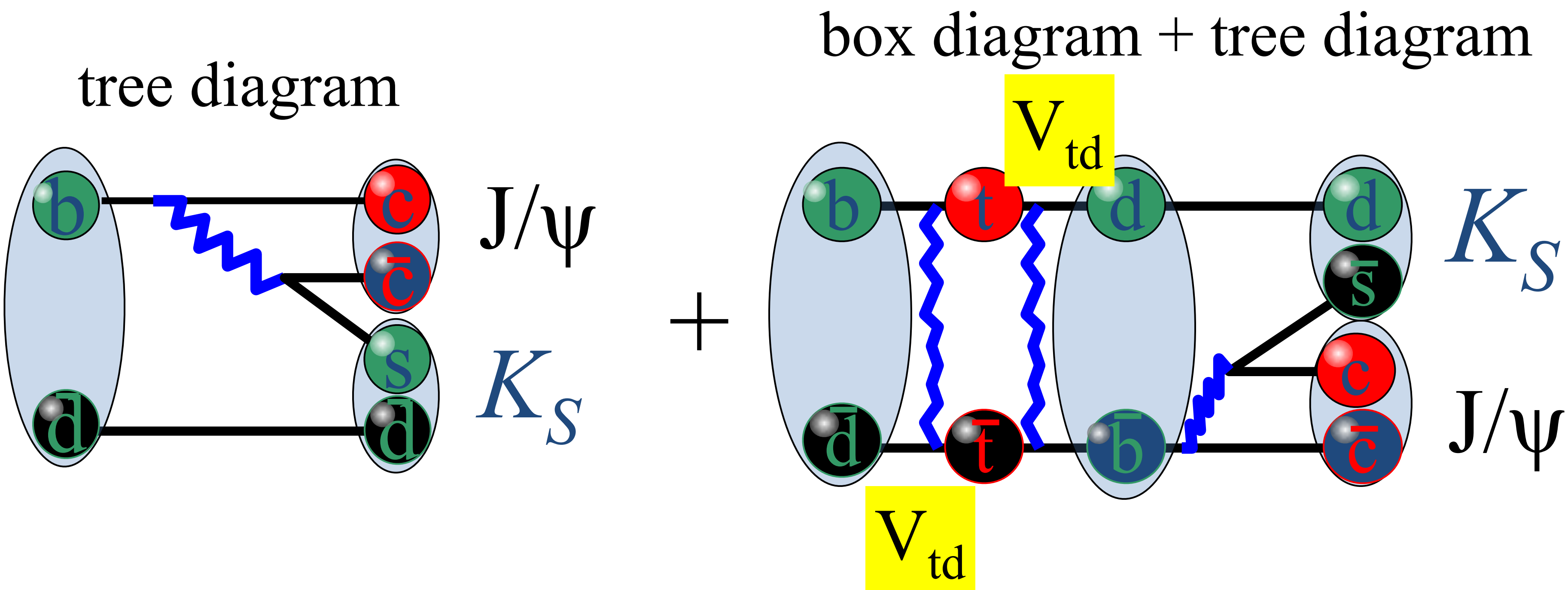
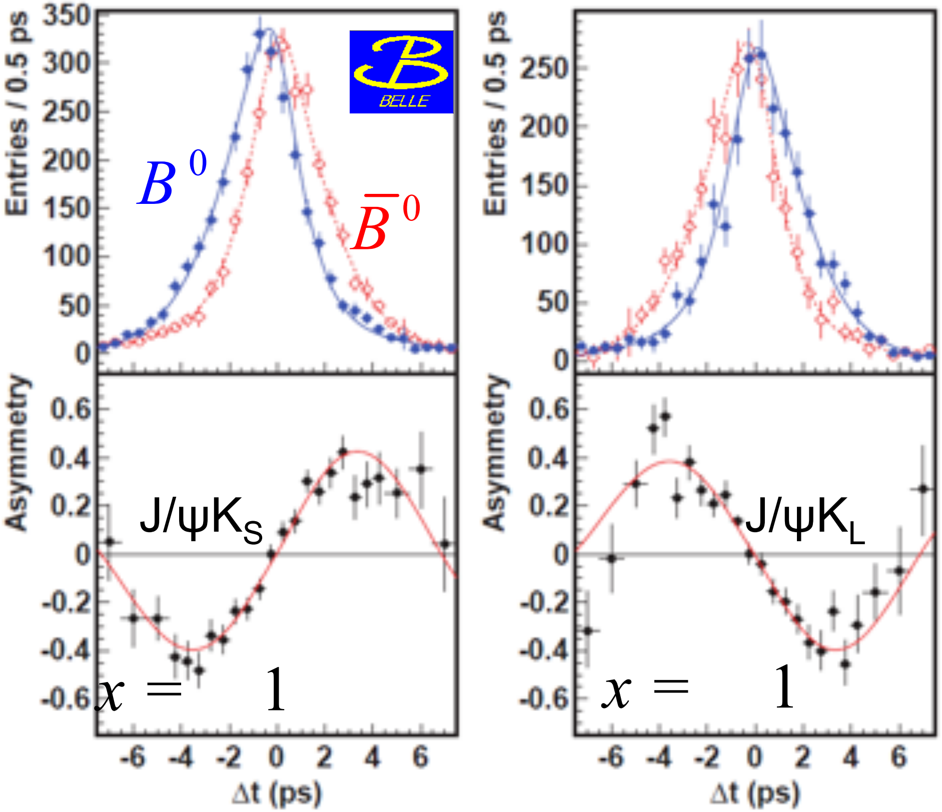
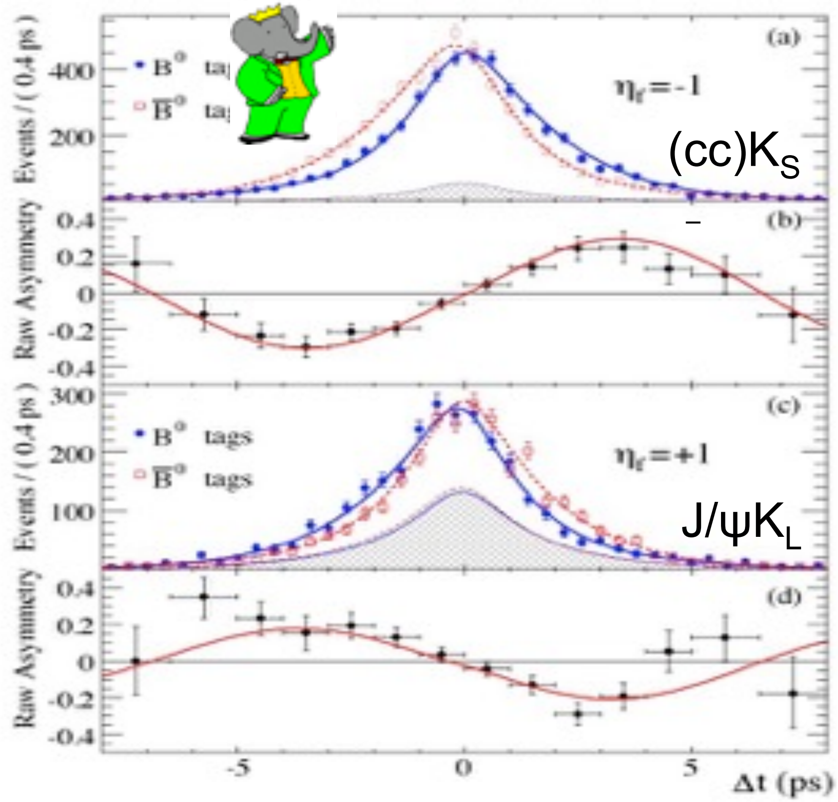


Measures the phase of V_{td} or equivalently the phase of B_d–anti B_d mixing.

Measurement of $\sin(2\varphi_1)/\sin(2\beta)$ in $B \rightarrow$ Charmonium K^0 modes





$\sin 2\varphi_1 = 0.667 \pm 0.023 \pm 0.012$	$\sin 2\varphi_1 = 0.687 \pm 0.028 \pm 0.012$
$A_f = 0.006 \pm 0.016 \pm 0.012$	$A_f = -0.024 \pm 0.020 \pm 0.016$
PRL108,171802 (2012)	PRD79,072009 (2009)

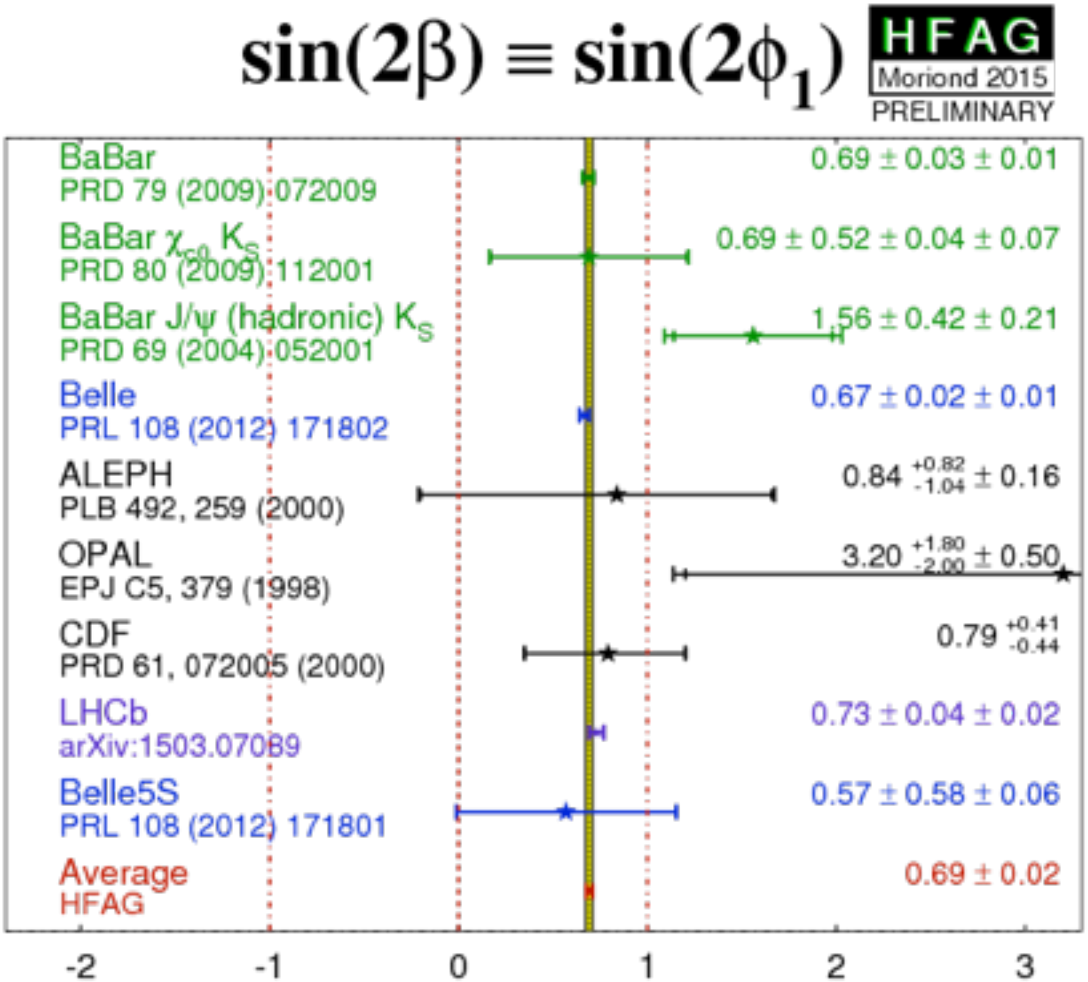
Overpowering evidence for CP violation (matter-antimatter asymmetries).
>>>> The phase of V_{td} is in good agreement with Standard Model expectations. *This is the phase of B_d mixing.*

News from Utah, April 2016: APS Panofsky Prize for *Experimental Particle Physics* Awarded to

Steve Olsen, Dave Hitlin, Jonathan Dorfan, and Fumihiko Takasaki

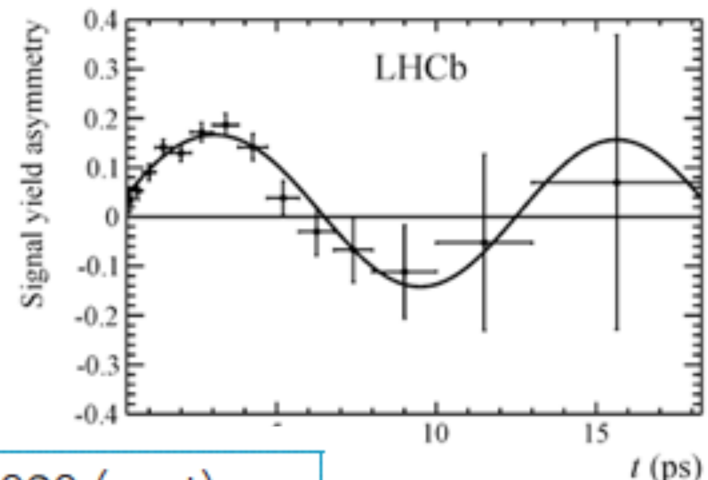
"Founding Fathers of the B Factories"

Front row 2008 Physics Nobelists: T. Maskawa, M. Kobayashi



B factories: High precision CPV measurement and a calibration for NP.

2013: LHCb joins the game [±0.07(stat)]
2015: *Latest LHCb measurement is comparable in precision to B factories* (now uses same-side B tagging)



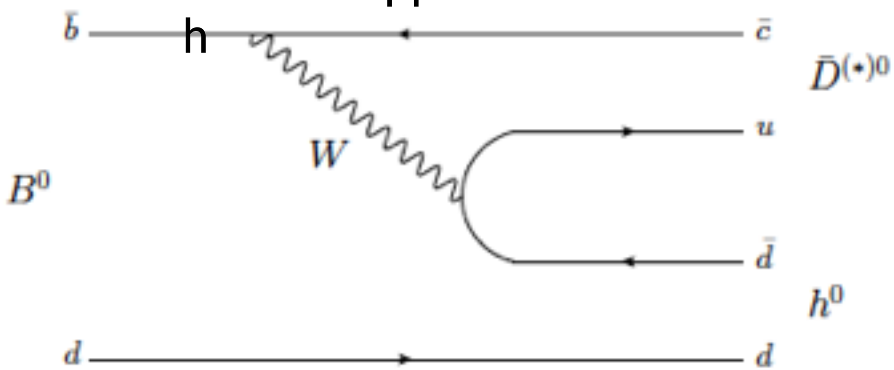
$$S(B^0 \to J/\psi K^0_S) = 0.731 \pm 0.035\,(\text{stat}) \pm 0.020\,(\text{syst}),$$
$$C(B^0 \to J/\psi K^0_S) = -0.038 \pm 0.032\,(\text{stat}) \pm 0.005\,(\text{syst}).$$

B factories: *Check CP violation in b→c [ubar d] processes*

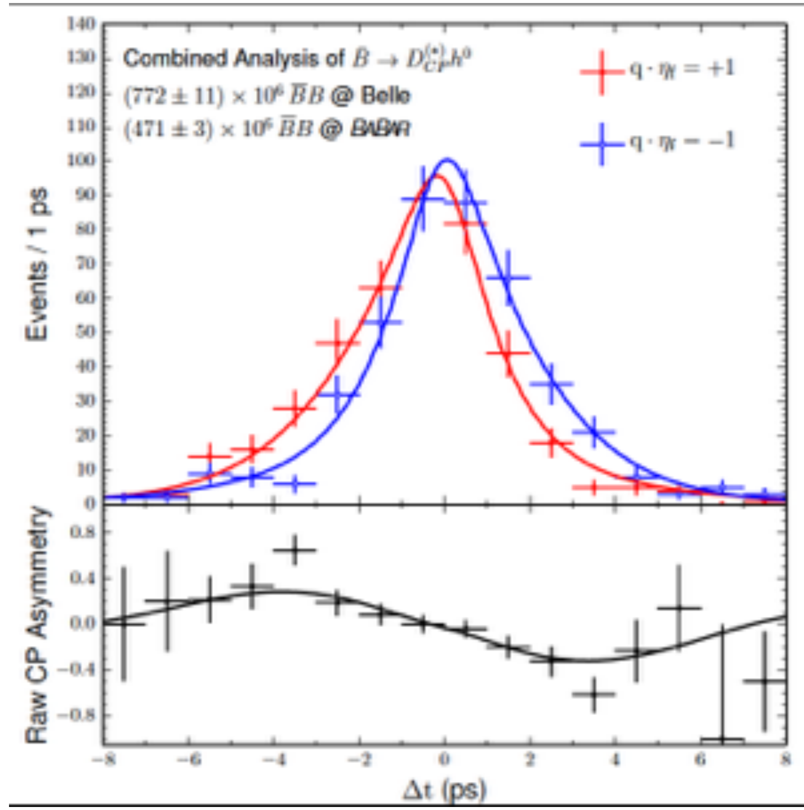
2015: First joint BaBar-Belle data analysis

M. Rohrken et al

"Color-suppressed" B→D h



where D^0 is a CP eigenstate and $h^0=\pi^0$, η, ω



Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal→<u>First observation</u>

$\sin(2\beta_{eff})=0.66\pm0.10(stat)\pm0.06(sys)$

Phys. Rev. Lett. 115, 121604 (201

B factories: *Check CP violation in b→c [ubar d] processes*

2015: First joint BaBar-Belle data analysis M. Rohrken et al

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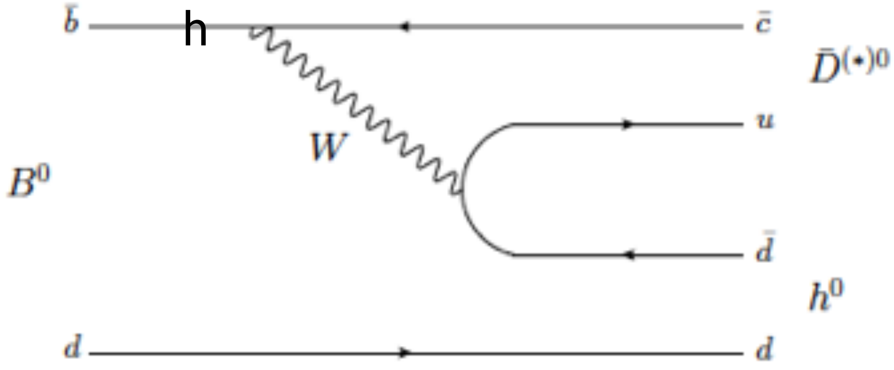

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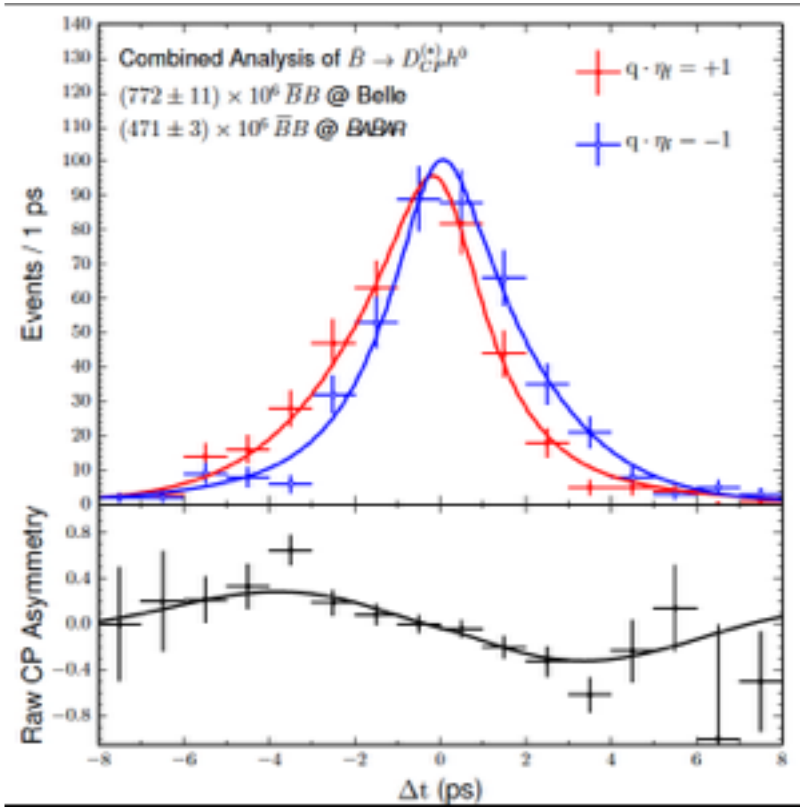

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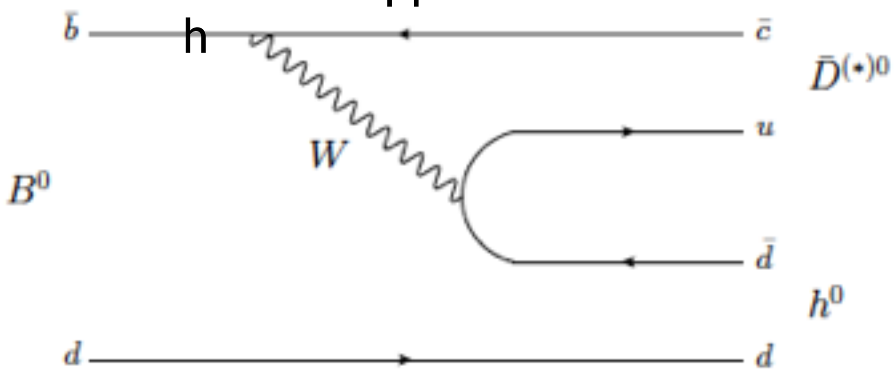

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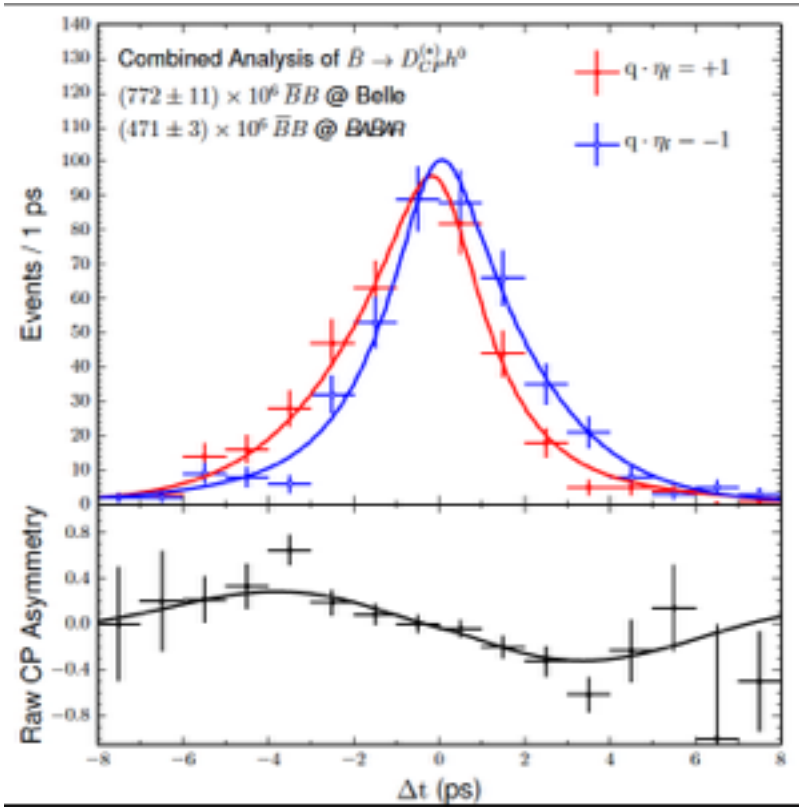

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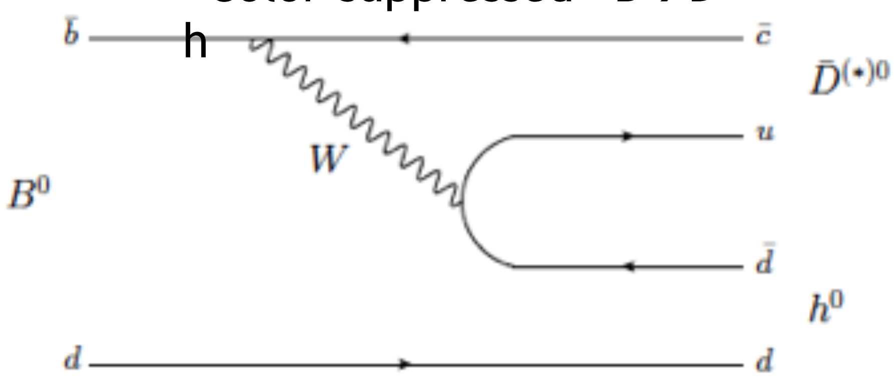

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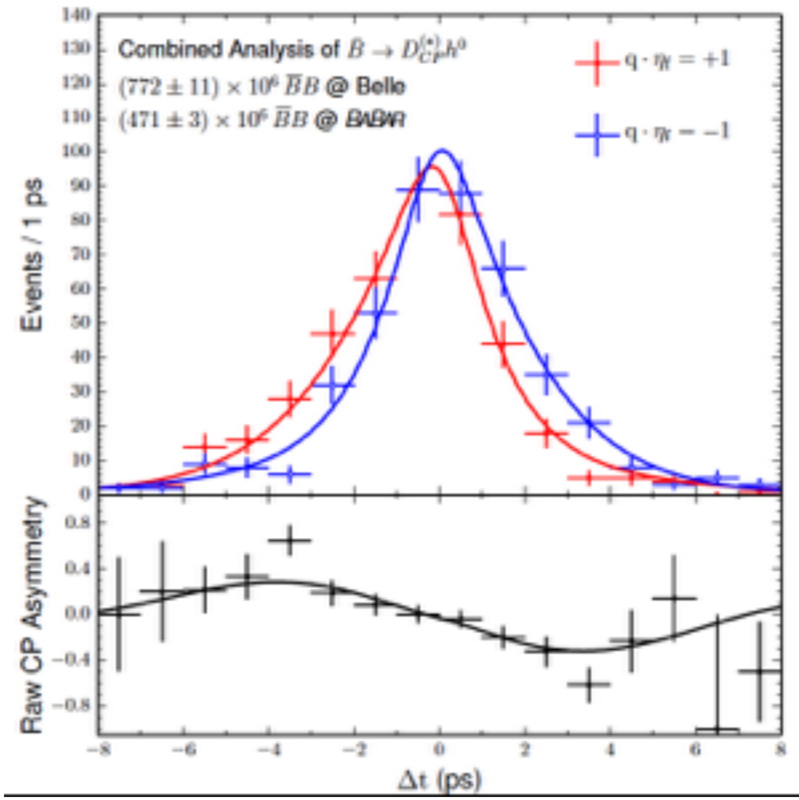

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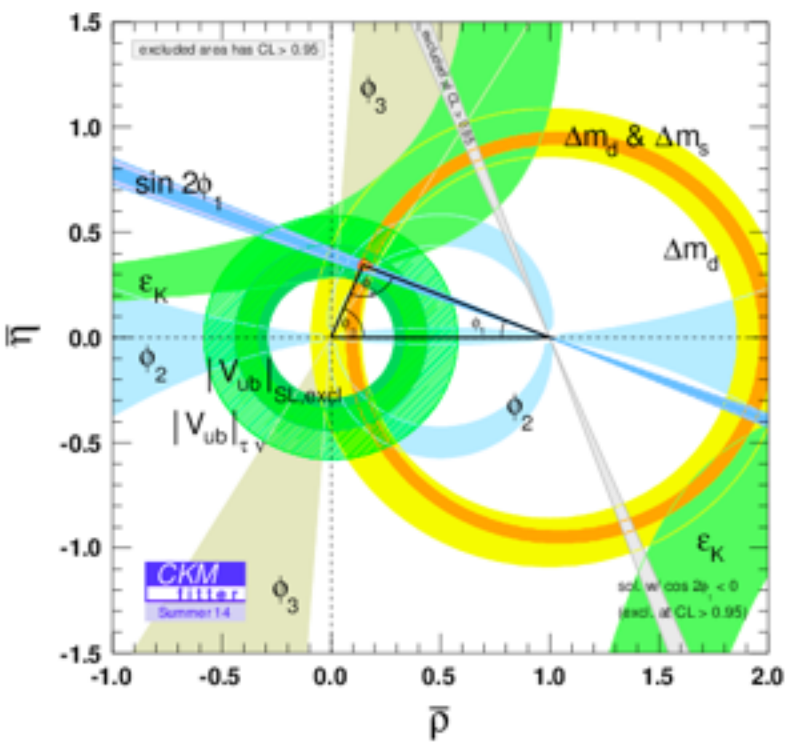
Phase of V_{td} again

Conclusion: CP violation in b→c ubar d modes is the same as in b→c cbar s modes (e.g. B→J/ψ K_S)

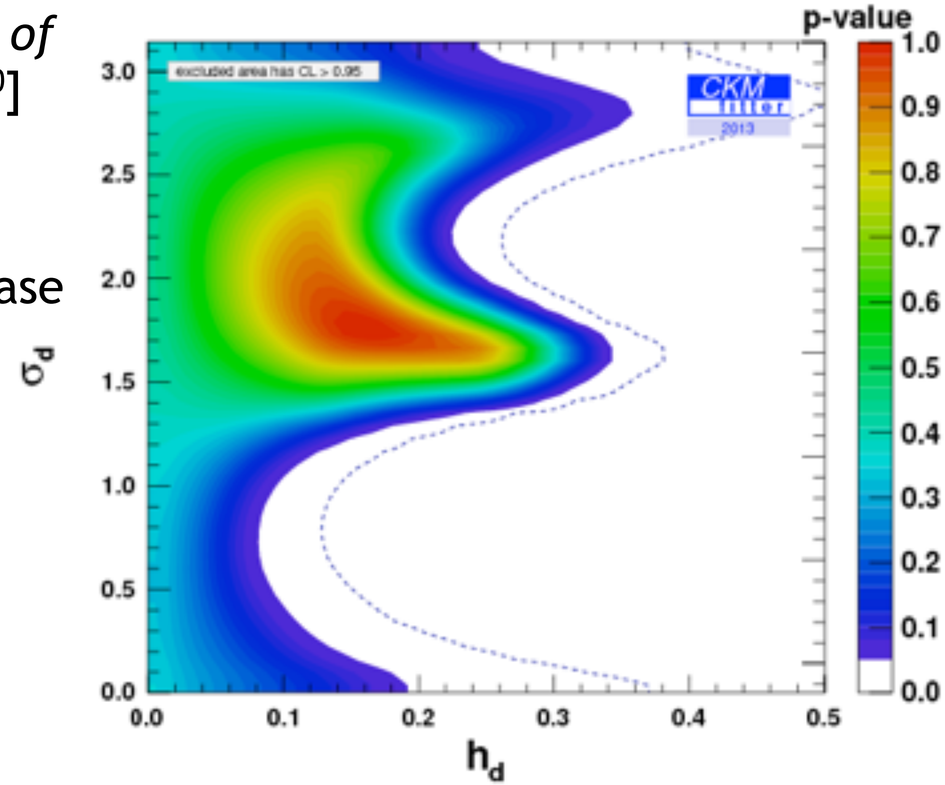
Results from Global Fits to Data (CKMFitter Group)

Great progress on ϕ_3 or γ (first from B factories and now in the last two years from LHCb). *These measure the phase of V_{ub}* [CKM2014, K. Trabelsi's review: $\pm 7^0$]



Similar results from UTFIT as well from G. Eigen et al.

NP Phase



NP/SM amplitude ratio

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(except for an issue with $|V_{ub}|$)

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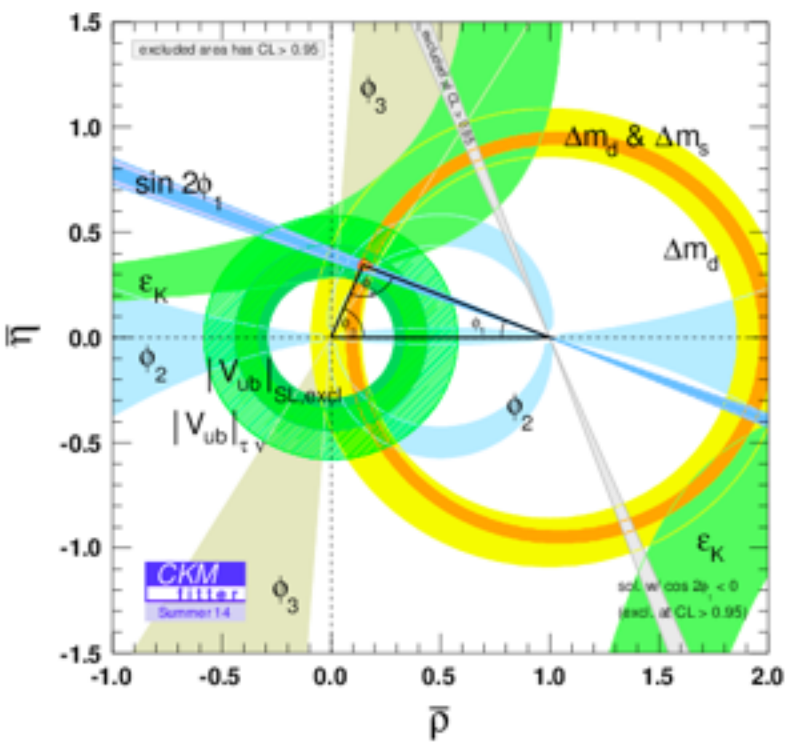

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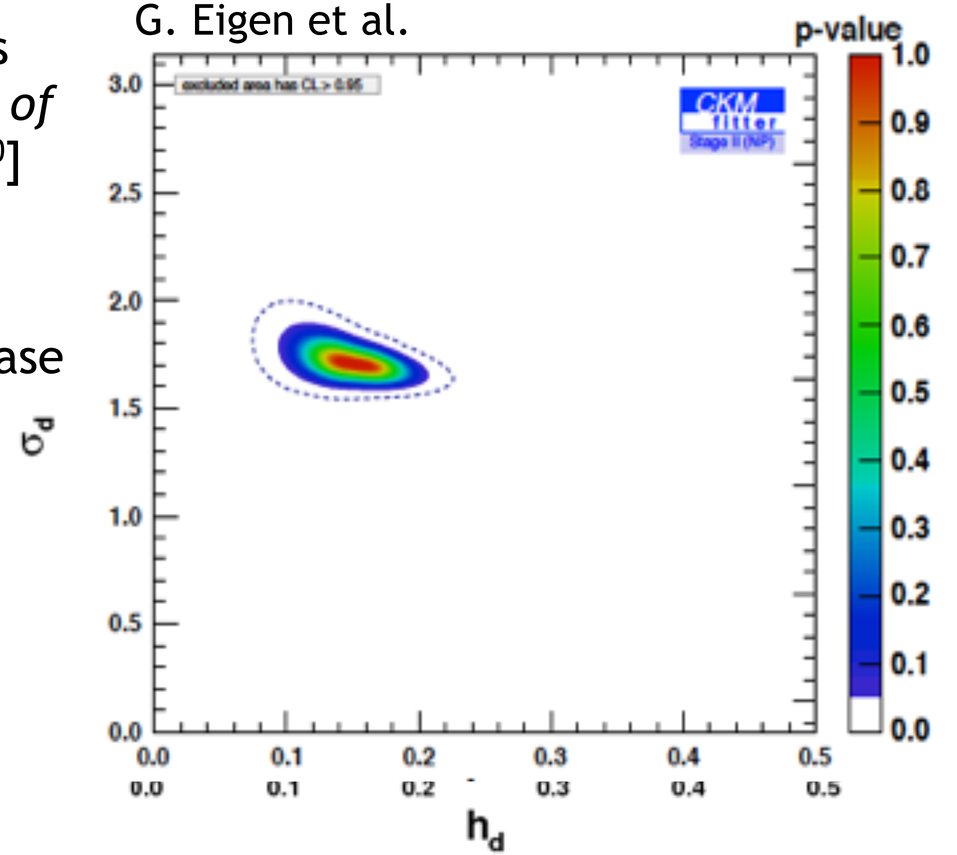

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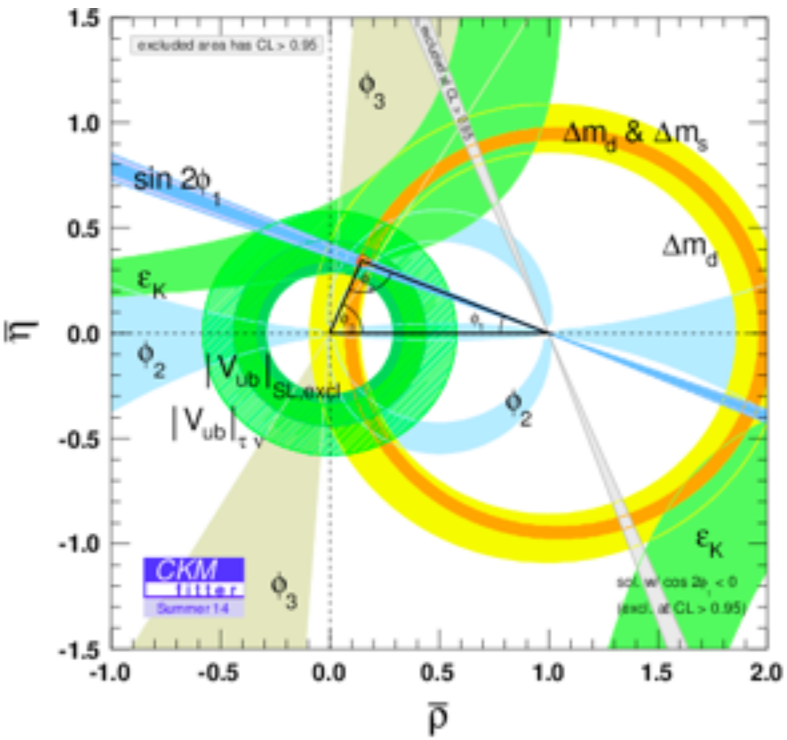

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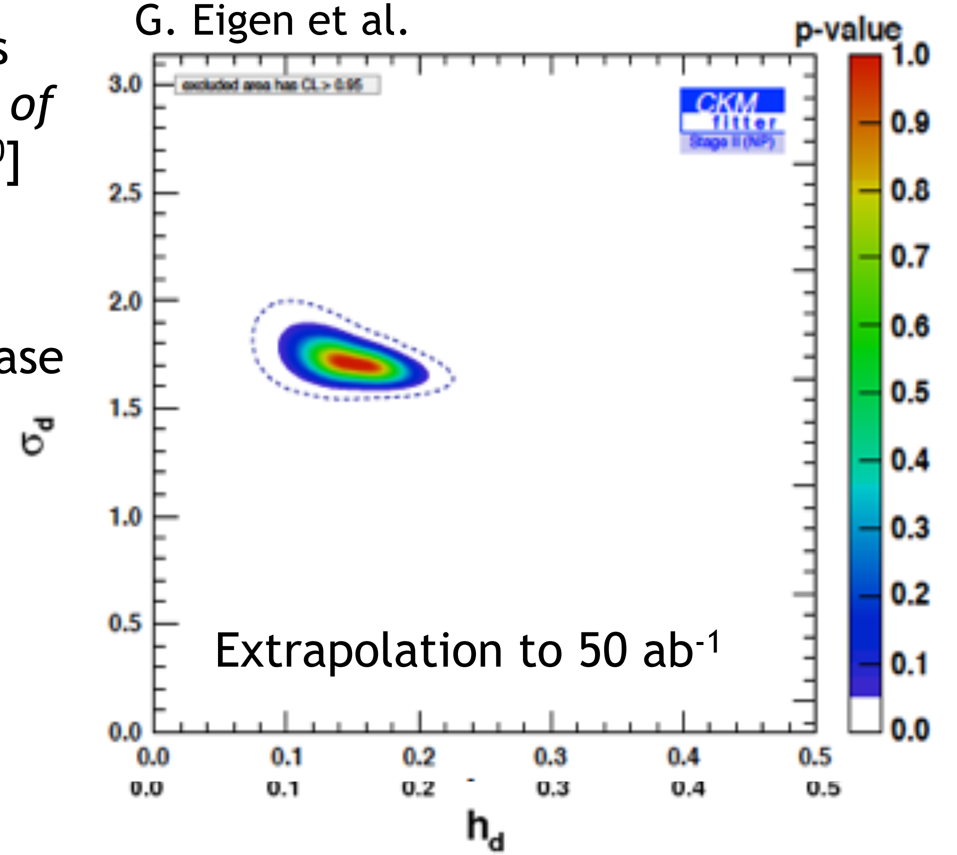

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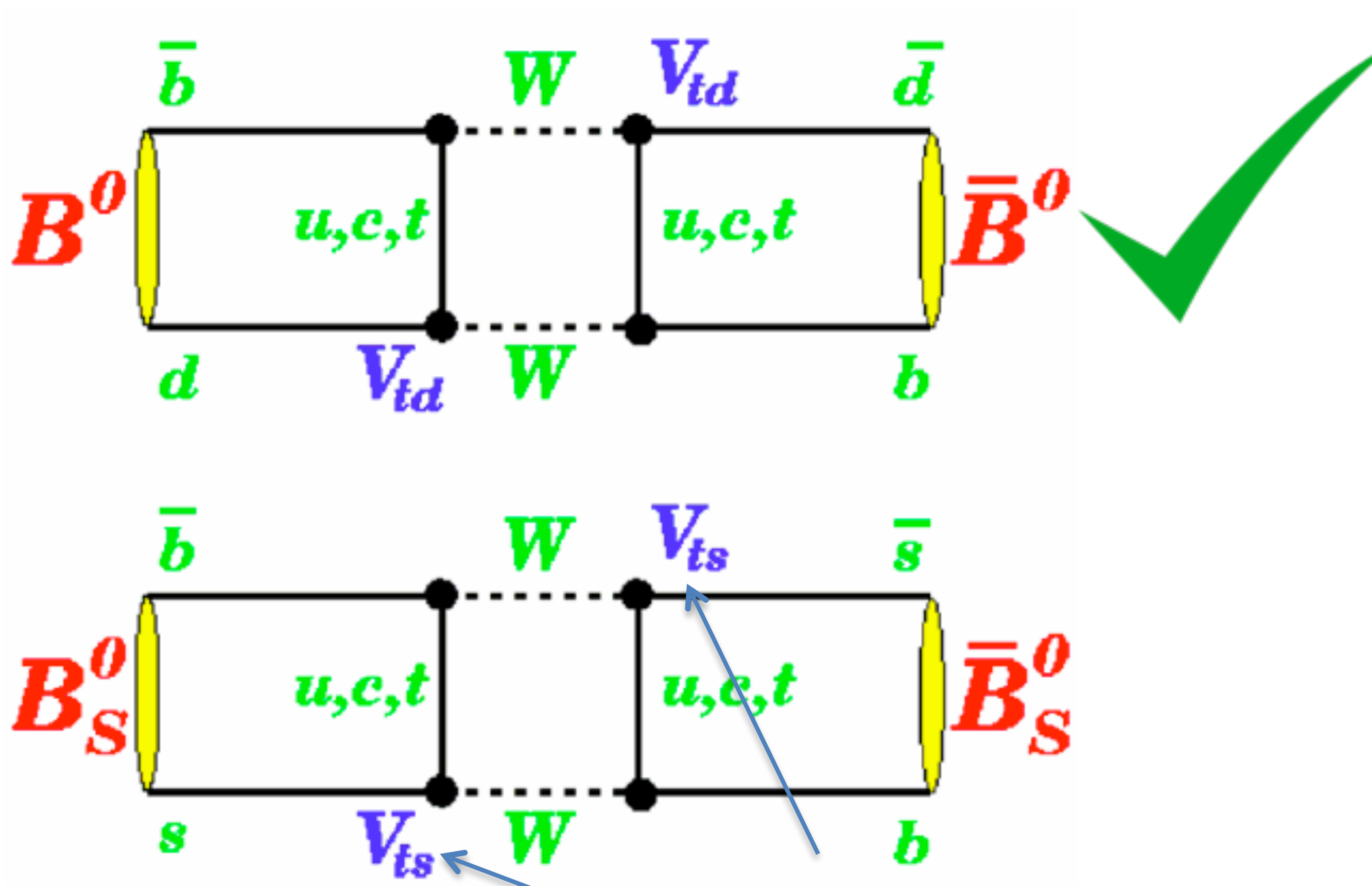
Boxes



Although B factories can run on the Upsilon(5S), LHCb dominates here

No phase expected from SM but possible from NP particles

$B_s \rightarrow J/\psi\phi$, a pseudoscalar to vector-vector mode, is usually used.

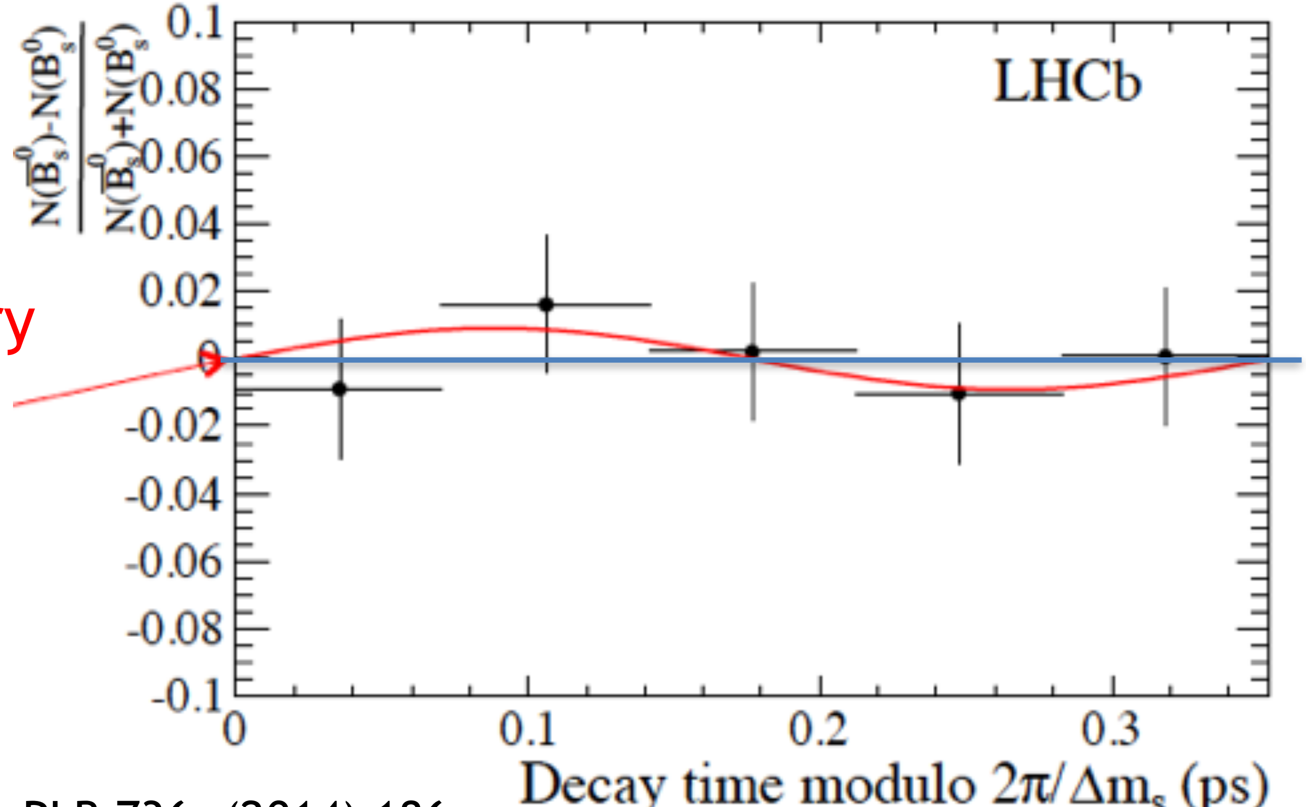
However, $B_s \rightarrow J/\psi\ f_0(980)$ is a pure CP eigenstate since the f_0 (980) is a scalar.

Stone & Zhang pointed out that this mode provides more statistics and a more straightforward analysis. Phys. Rev. D79 (2009) 074024.

Φ_s=(70±68±8) mrad

Red curve: expectation for Φ_s = 70 mrad

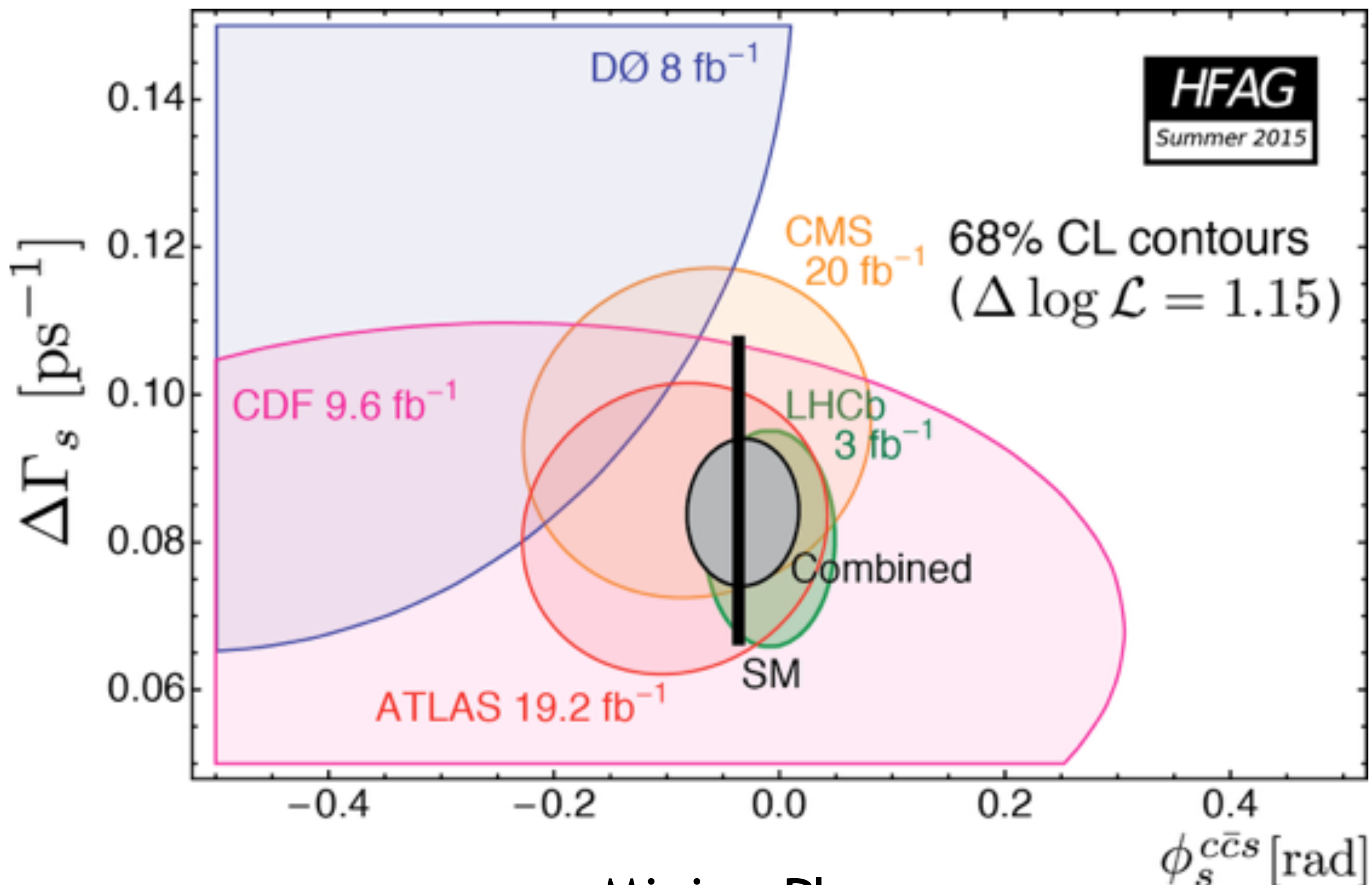
Asymmetry



R. Aaij et al., PLB 736, (2014) 186

Results on the phase of B_s-anti B_s mixing (i.e. phase of V_{ts}) [use $B_s \rightarrow J/\psi\phi$; $J/\psi\pi\pi$ modes]

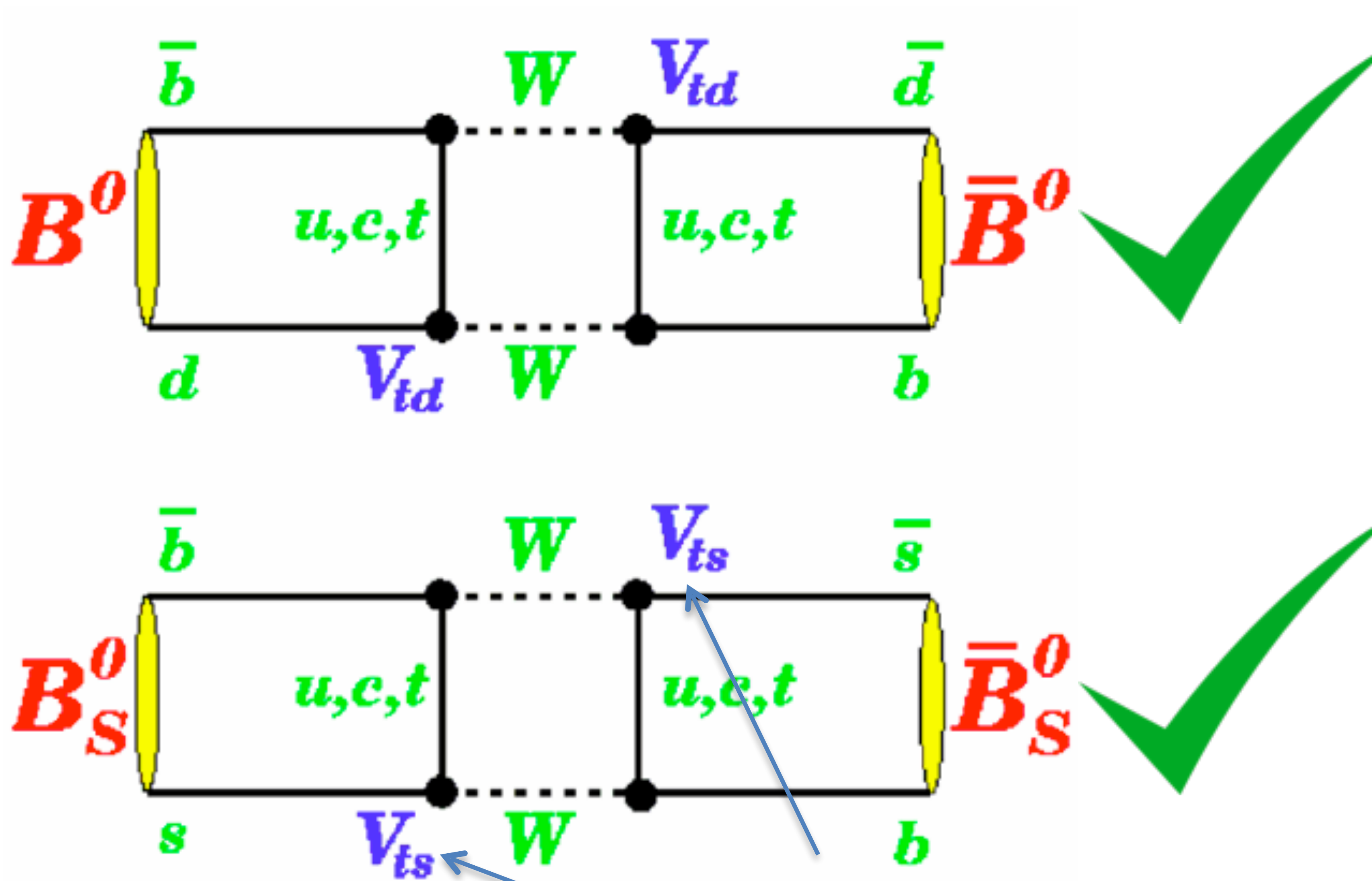
Width difference



Mixing Phase

(Includes the most recent LHCb prelim result, gives WA of -36 ±13 mrad)

Boxes



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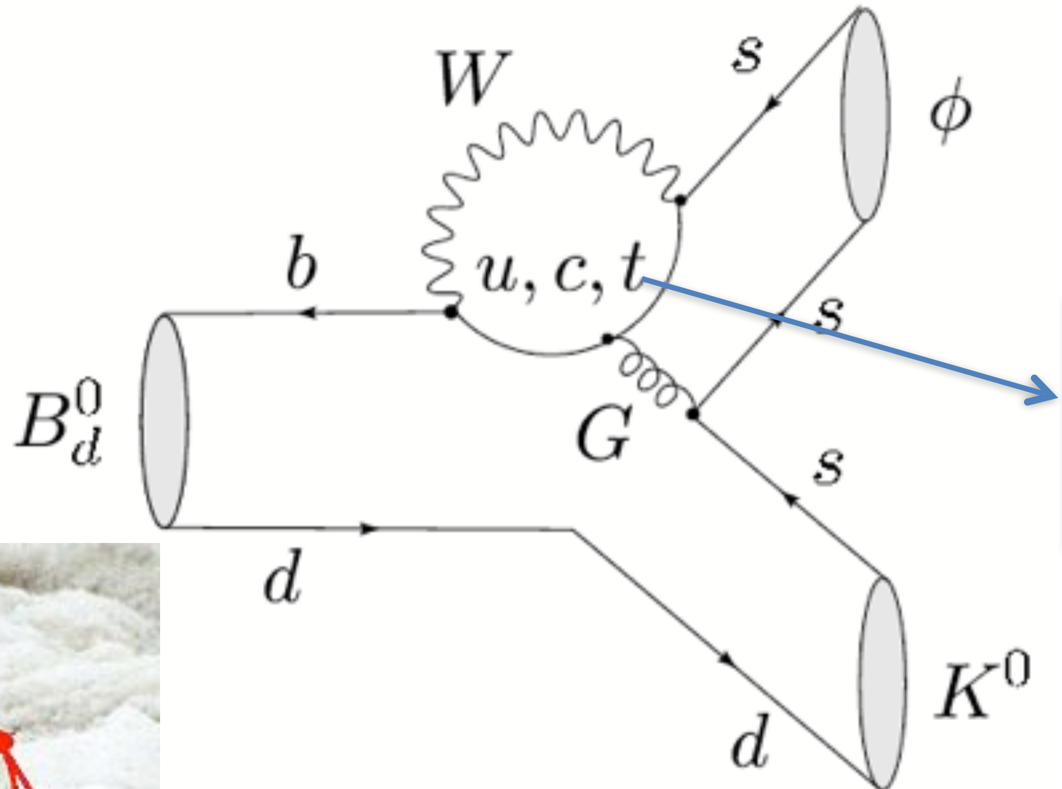
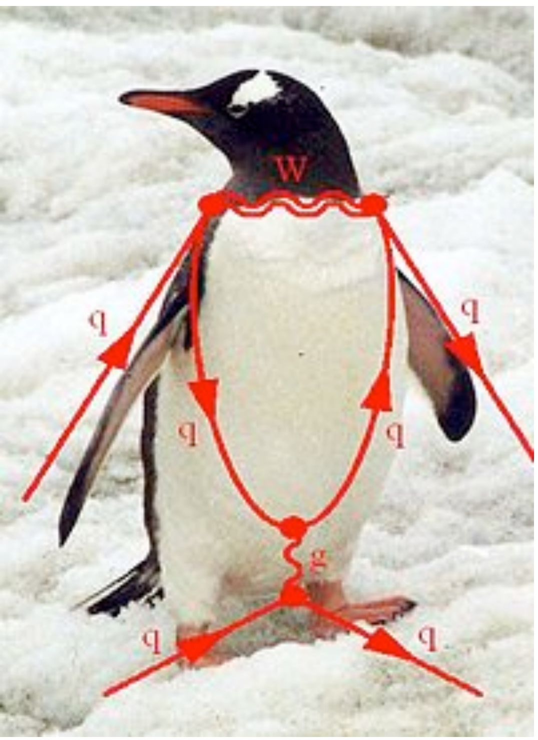
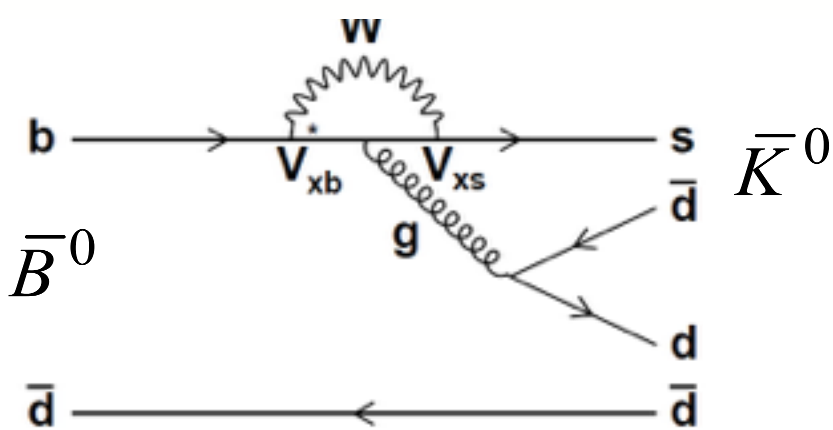
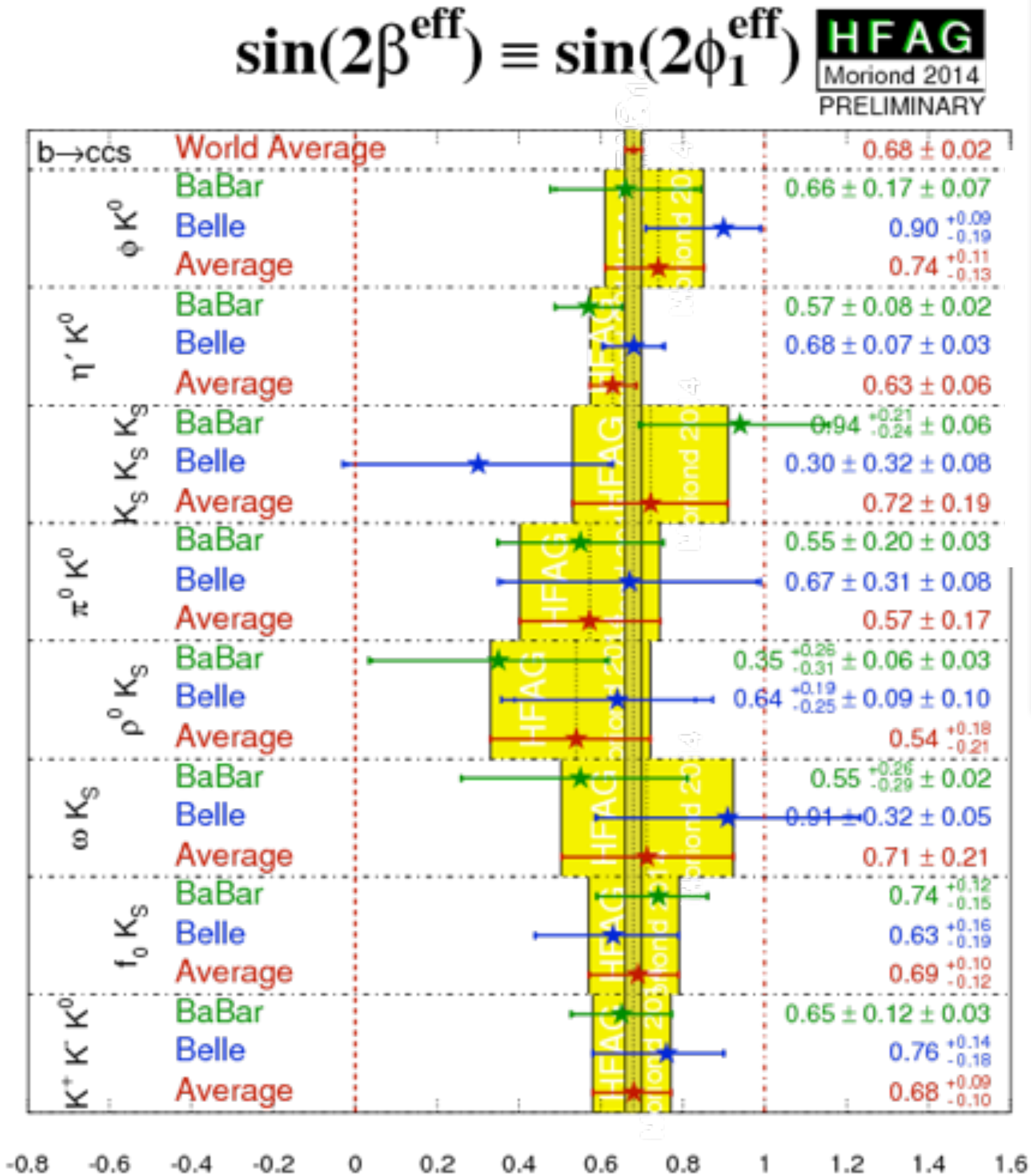


Phase of V_{ts}

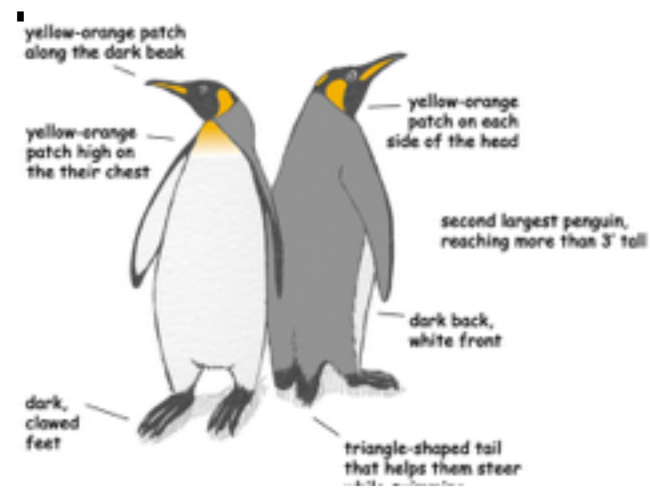




Recent Belle results on $B \to \omega K_S$, $B \to \eta' K_S$



New Physics Phases in Penguin b→s



No evidence for NP at current level of sensitivity

LHCb is absent from this game (lower K_S eff and flavor tagging eff) but contributes in B_S modes.

“Missing Energy” Decays

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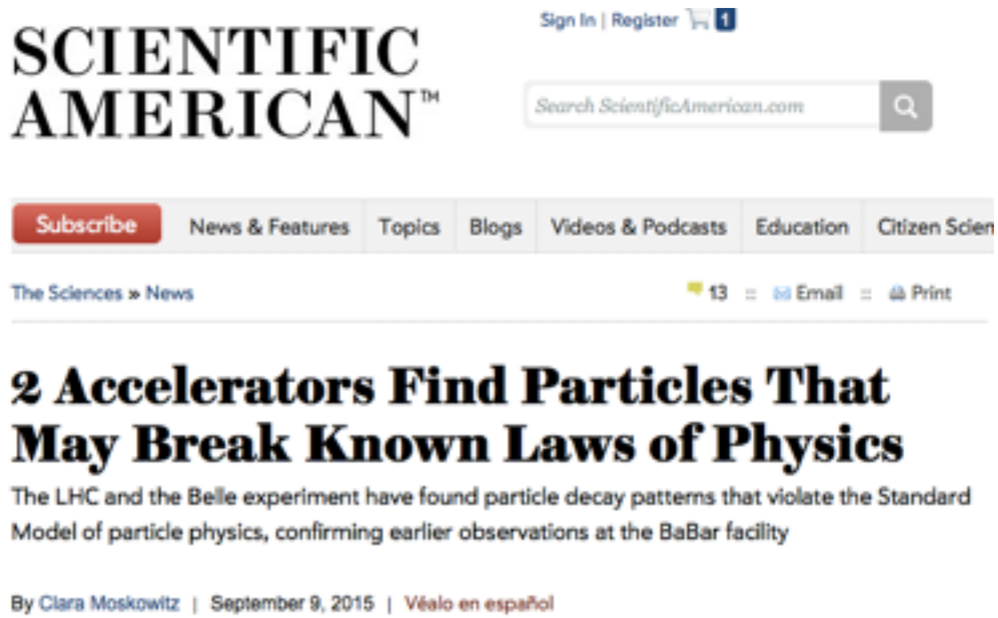

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2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español

"Missing Energy" Decays

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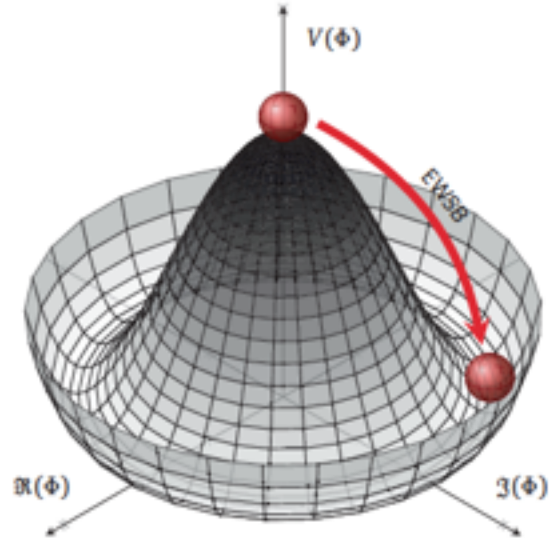
Democracy suffers a blow—in particle physics

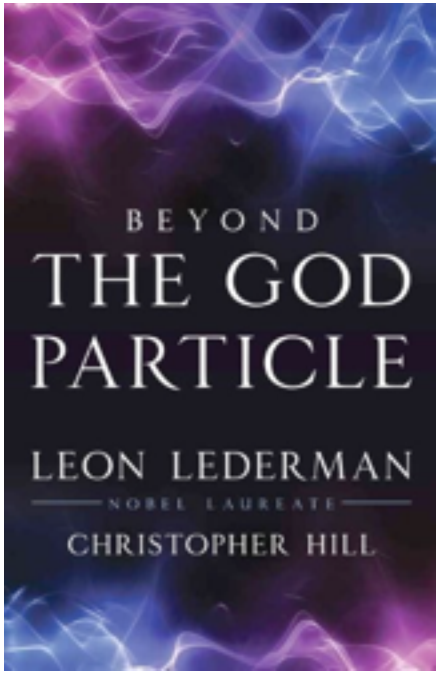
Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

Steven K. Blau 17 September 2015

The BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for future Higgs flavor factory facilities* .
(e.g ILC, HL-LHC, FCC, CEPC).



Does the GP (Brout-Englert-Higgs particle) have a "brother" i.e. the charged Higgs ?

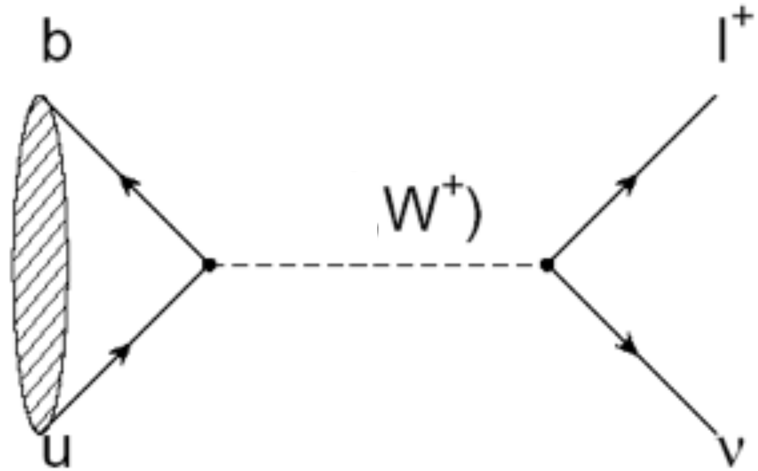


Y. Nambu, 1921-2015

Measurements at Belle II and direct searches at hadron colliders take *complementary* approaches to this important question.

B→τ ν

(Decay with *Large* Missing Energy)



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

The B meson decay constant, determined by the B wavefunction at the origin

($|V_{ub}|$ taken from indep. measurements.)

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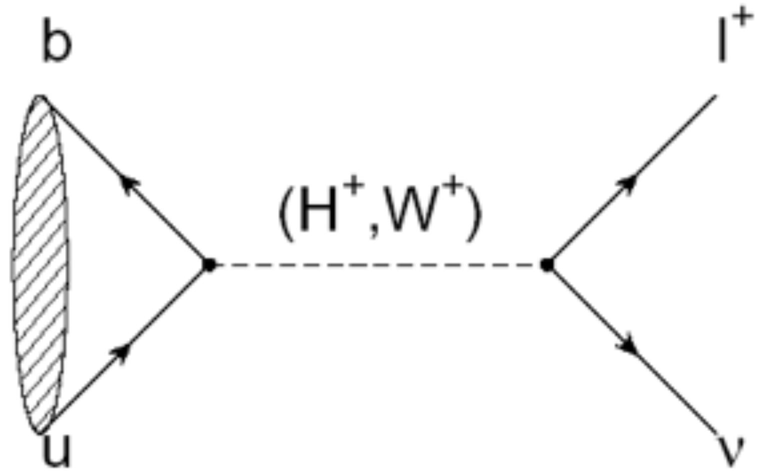

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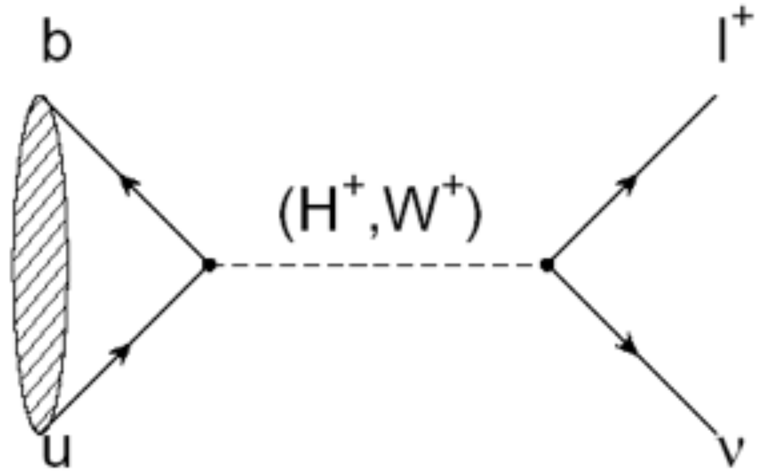
Sensitivity to new physics from a *charged Higgs*



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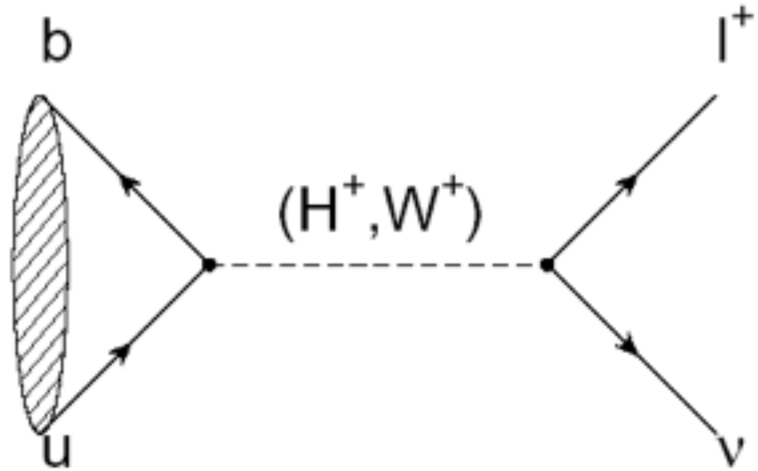

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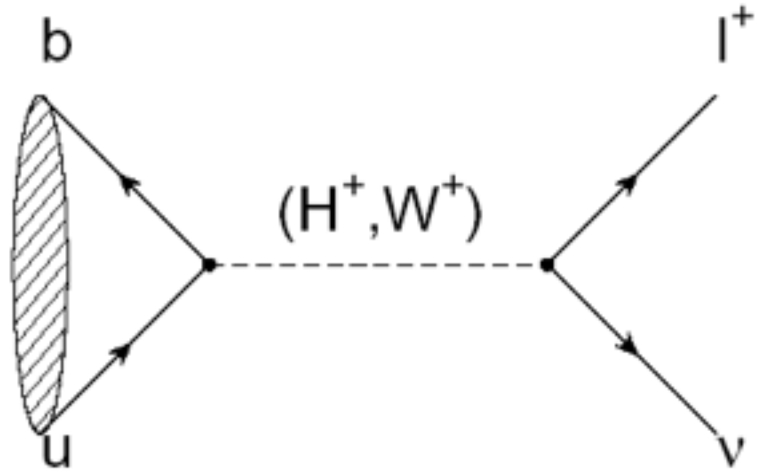

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W.S.Hou,. PRD 48, 2342 (*1993*)

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Consumer's guide to charged Higgs

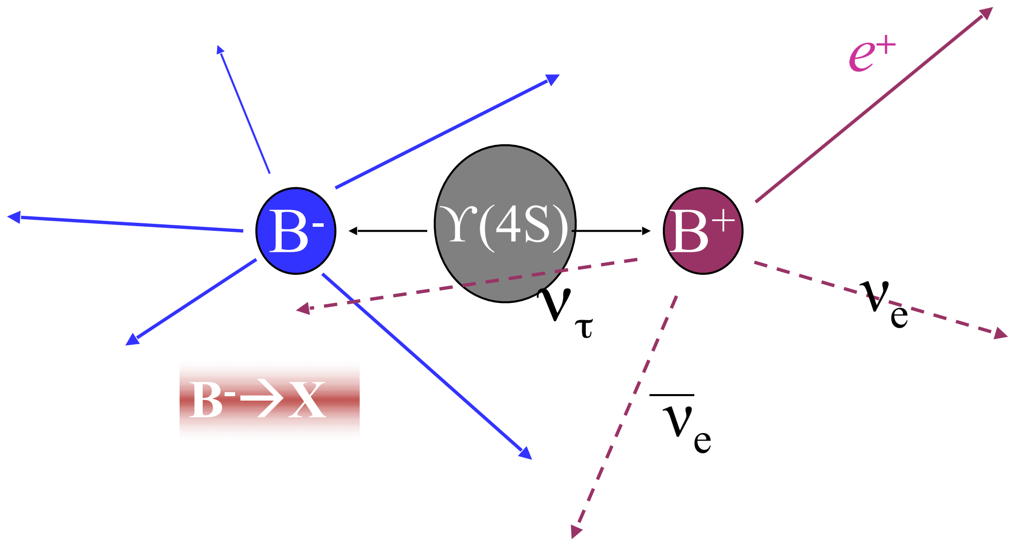
- *Higgs doublet of type I* (φ_1 couples to upper (u-type) and lower (d-type) generations. No fermions couple to φ_2)

- *Higgs doublet of type II* (φ_u couples to u type quarks, φ_d couples to d-type quarks, u and d couplings are different; $\tan(\beta) = v_u/v_d$) [favored NP scenario e.g. MSSM, generic SUSY]

- *Higgs doublet of type III* (not type I or type II; anything goes. "FCNC hell"→many FCNC signatures)

Thanks to theorist Xerxes Tata

Why measuring $B^+ \to \tau^+ \nu$ is non-trivial



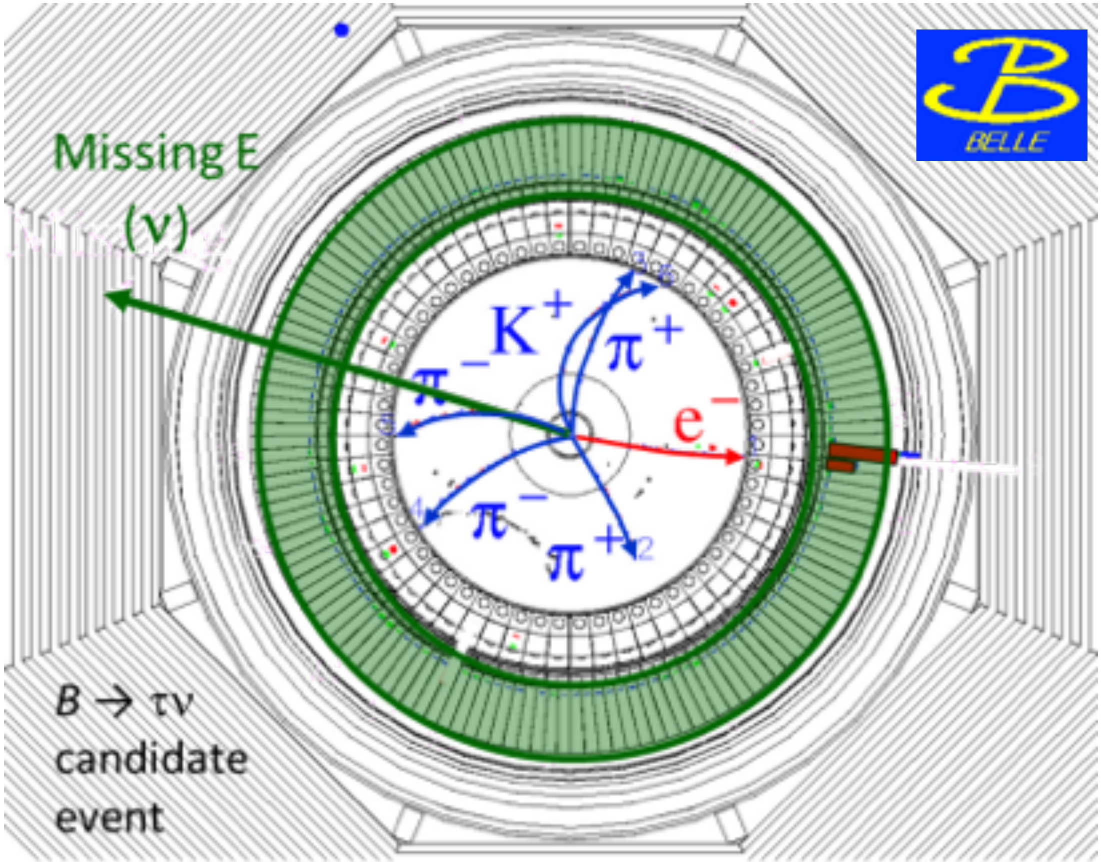
Most of the sensitivity is from tau modes with 1-prongs.

The experimental signature is rather difficult: B decays to a single charged track + nothing

(This may be hard at a hadron collider)

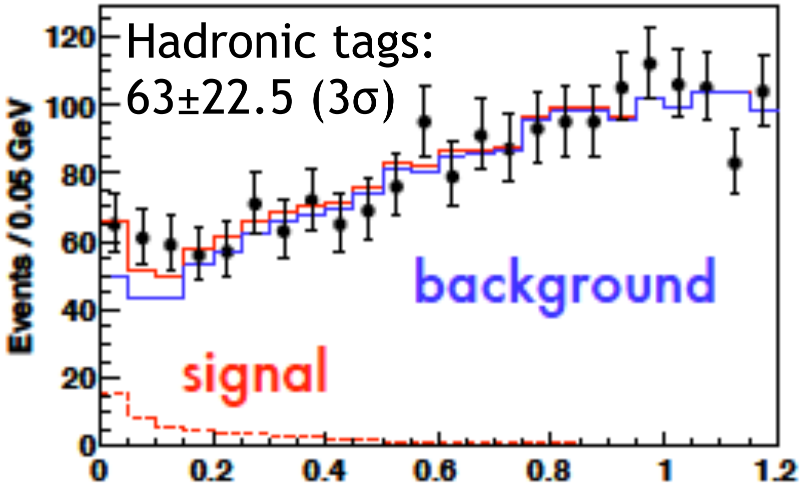
Example of a Missing Energy Decay (B→τν) *in* *Data*

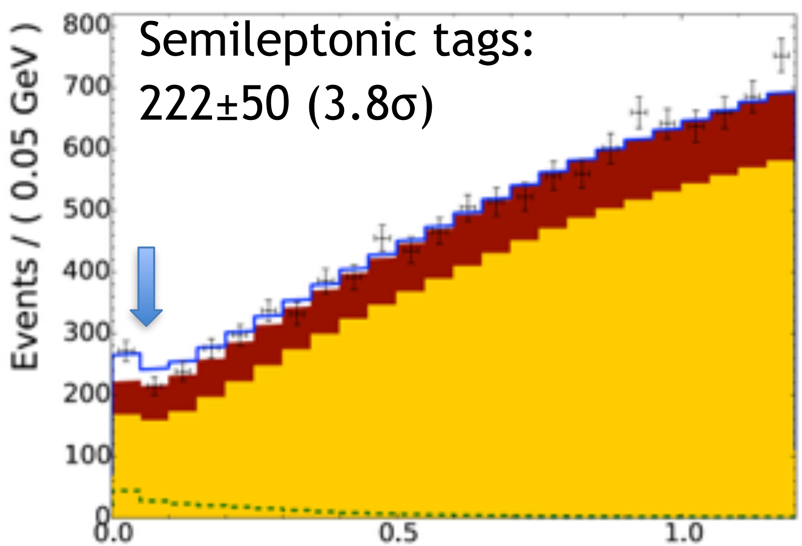
$$B^+ \to D^0\pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$



The clean e+e- environment makes this possible

Example: Belle B→τν results with full *reprocessed* data sample and either hadronic or semileptonic tags (arXiv: 1409.5269→PRD)





Idea: With the "single B meson beam", we look for a single track from a τ, missing energy/momentun and <u>extra calorimeter energy close to zero.</u>

With the full B factory statistics only "evidence". No single observation from either Belle or BaBar.

The horizontal axis is the "Extra Calorimeter Energy"

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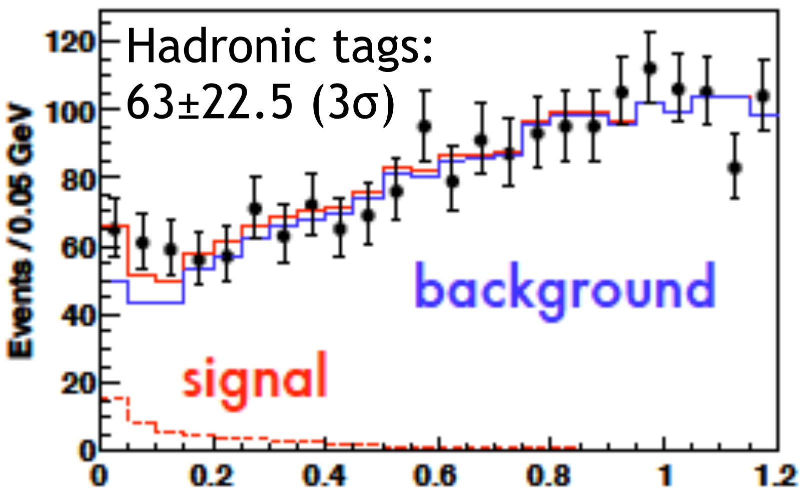

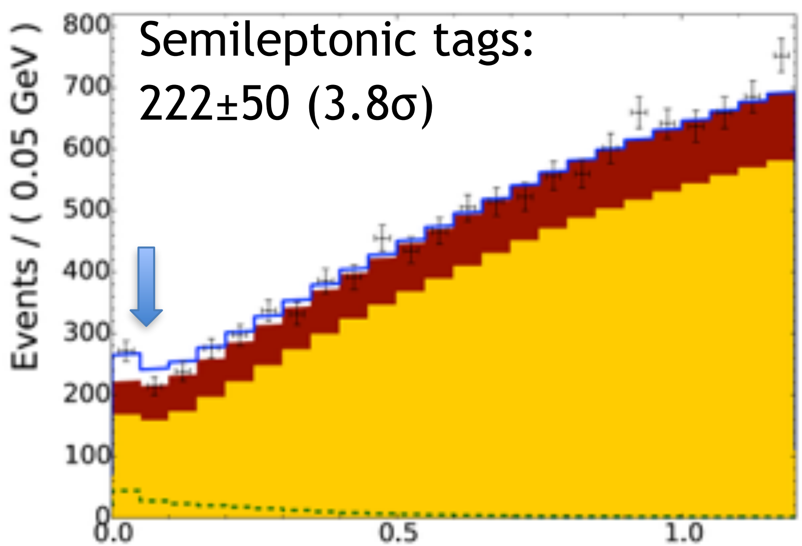

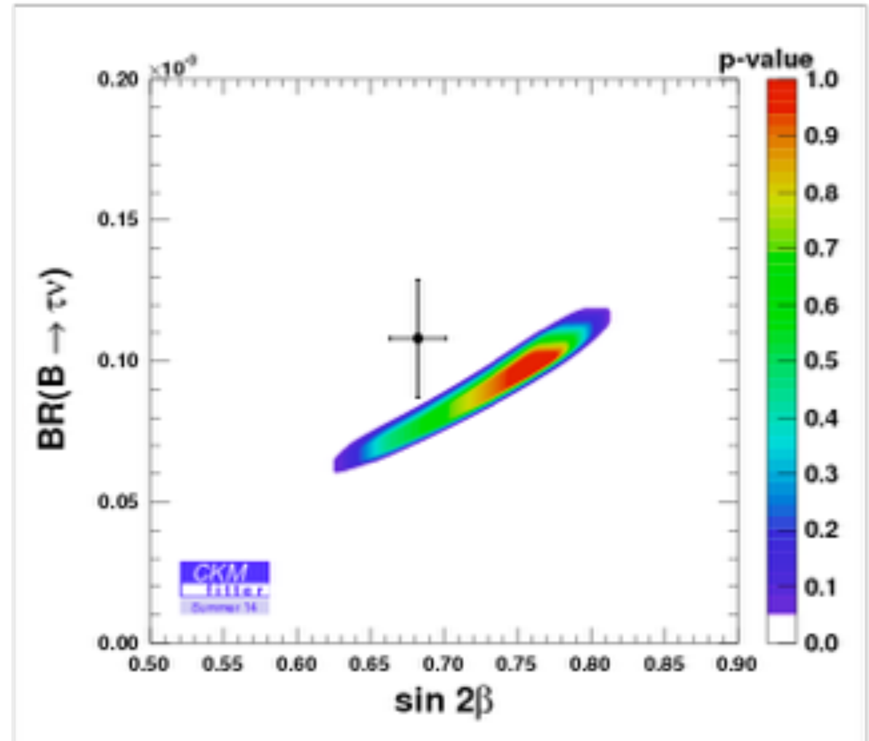

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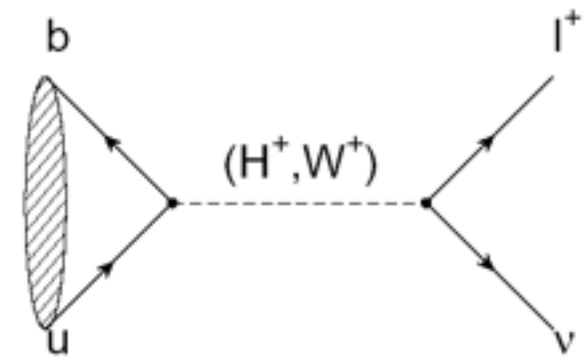
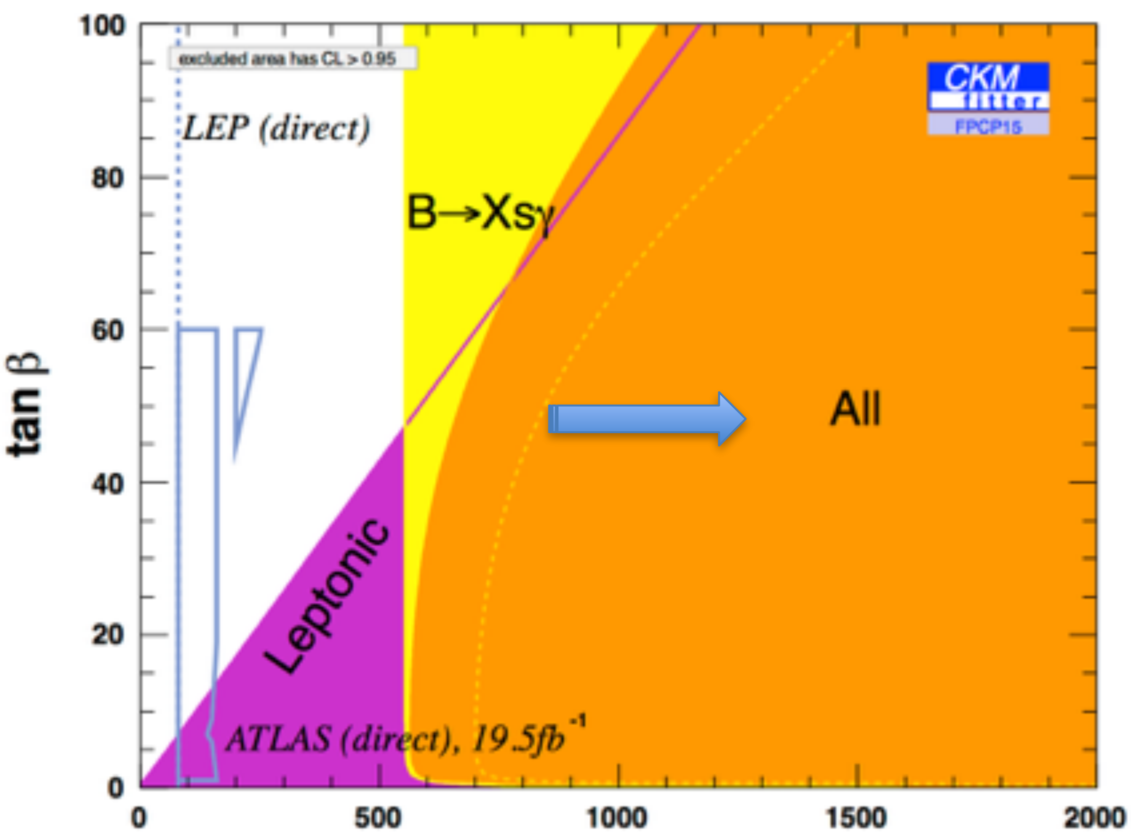
Complementarity of e+ e- factories and LHC

(Slide adapted from A. Bevan)

The current combined B→τυ limit places a stronger constraint than direct searches from LHC exps. for the next few years.





$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

Currently inclusive b→sγ rules out m_{H+} below ~480 GeV/c² range at 95% CL (independent of tanβ), M. Misiak et al. (assuming no other NP)

http://arxiv.org/abs/1503.01789

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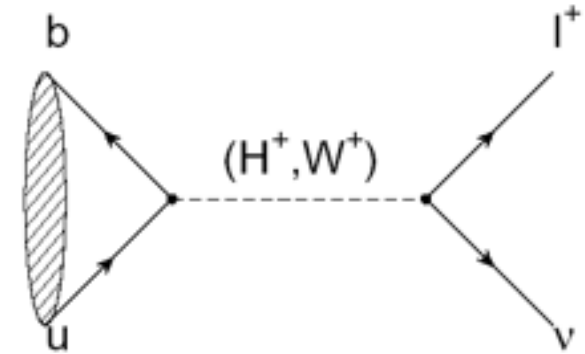

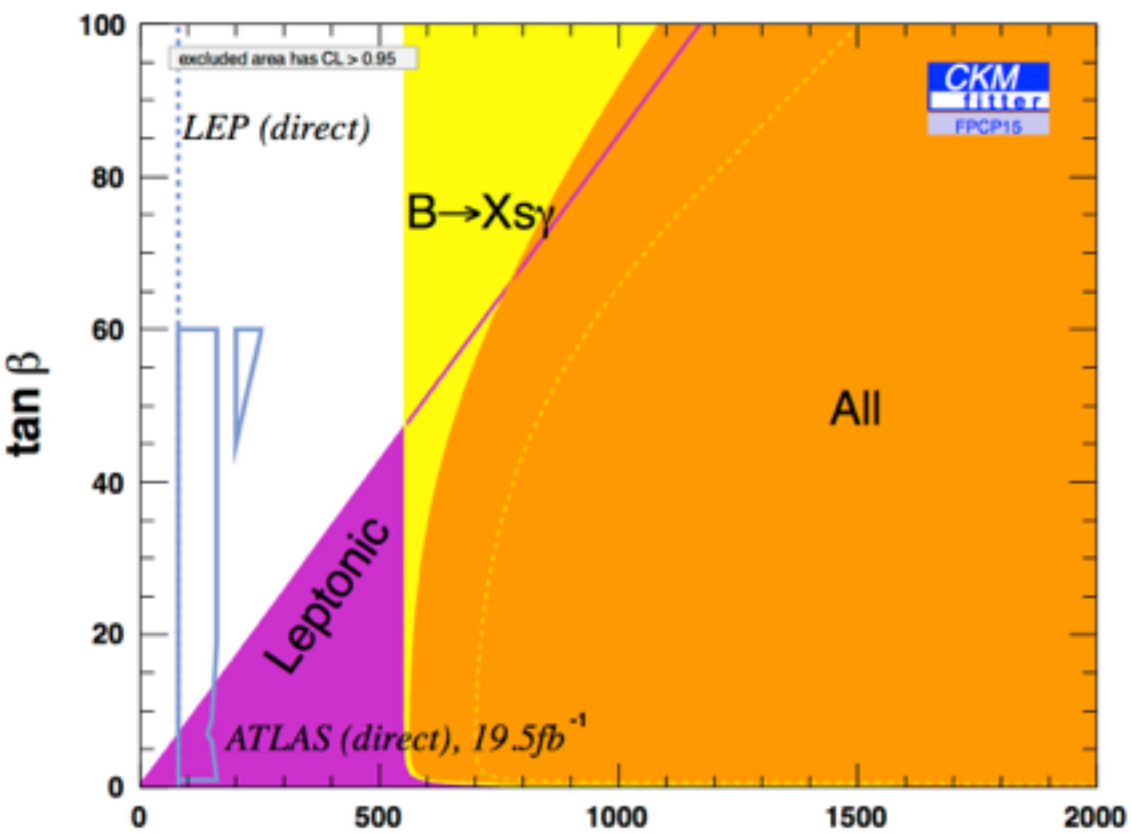

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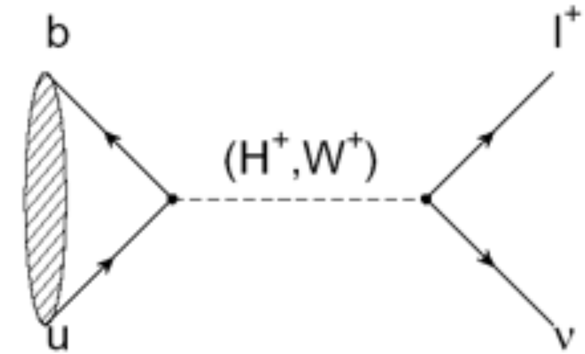
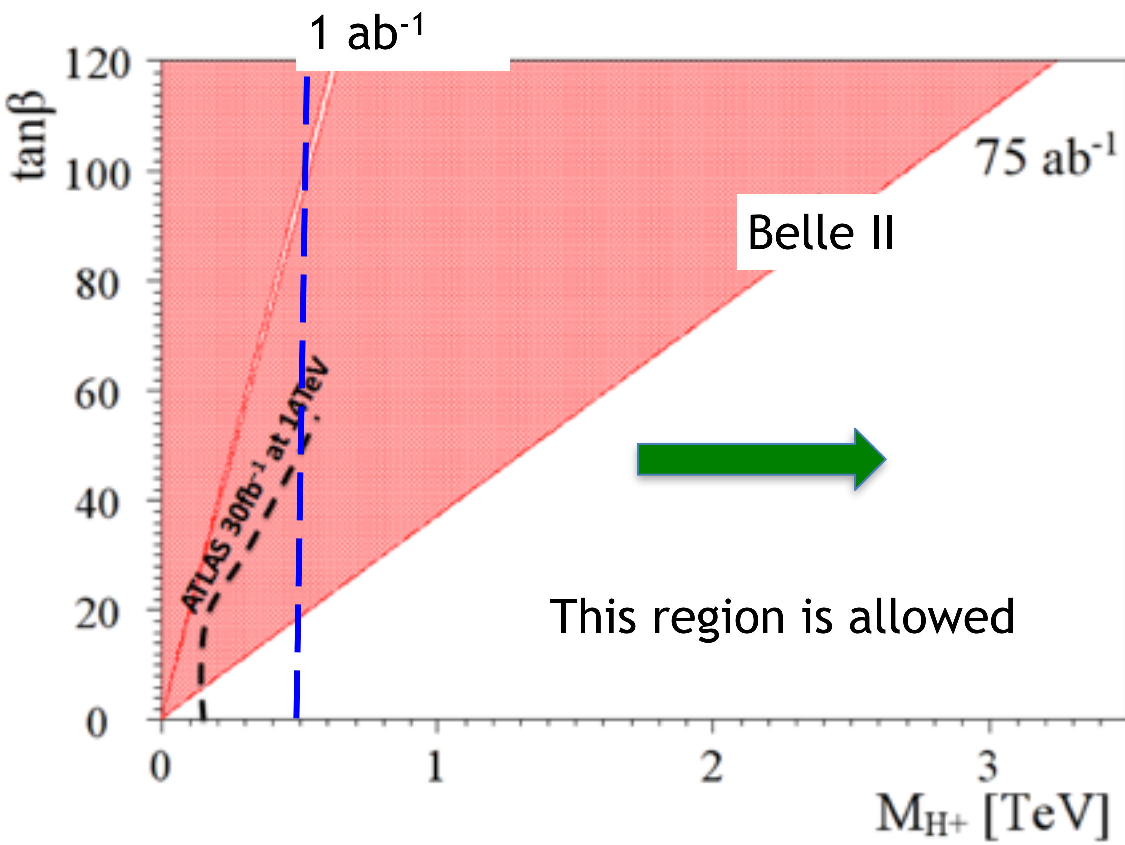


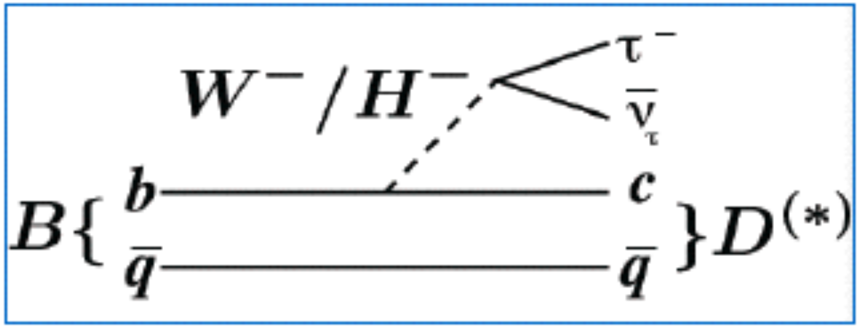


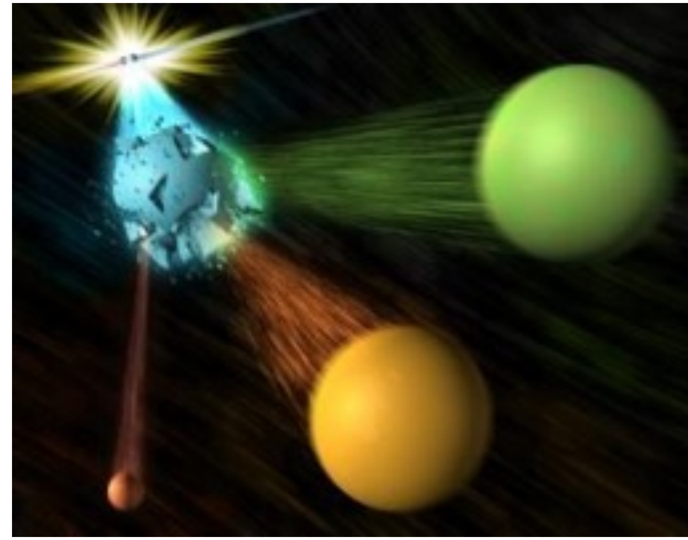
$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

Currently inclusive b→sγ rules out m_{H+} below ~480 GeV/c² range at 95% CL (independent of tanβ), M. Misiak et al. (assuming no other NP)

http://arxiv.org/abs/1503.01789

A three-body tale





$$\mathcal{R}(D^{(*)})_{2\mathrm{HDM}} = \mathcal{R}(D^{(*)})_{\mathrm{SM}} + A_{D^{(*)}} \frac{\tan^2\beta}{m_{H^+}^2} + B_{D^{(*)}} \frac{\tan^4\beta}{m_{H^+}^4}$$

	Dτν	**D*τν**
$A_{D^{(*)}}$ (GeV^2)	-3.25 ± 0.32	-0.230 ± 0.029
$B_{D^{(*)}}$ (GeV^4)	16.9 ± 2.0	0.643 ± 0.085

$$R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$$

⟶ Signal

⟶ Normalization ($l = e$ or μ)

Slide adapted from A. Soffer

Example from a BaBar paper

<u>Signals in $B \rightarrow D^{(*)} \tau \nu$ (489±63, 888±63)</u>

Missing mass variable:

$m_{miss}^2 = p_{miss}^2 = (p[e^+e^-] - p_{tag} - p_{D(*)} - p_l)^2$

P_l^* = momentum of lepton in B rest frame

Production of B meson pairs at threshold is critical to the separation of backgrounds from the missing energy/ momentum signal.

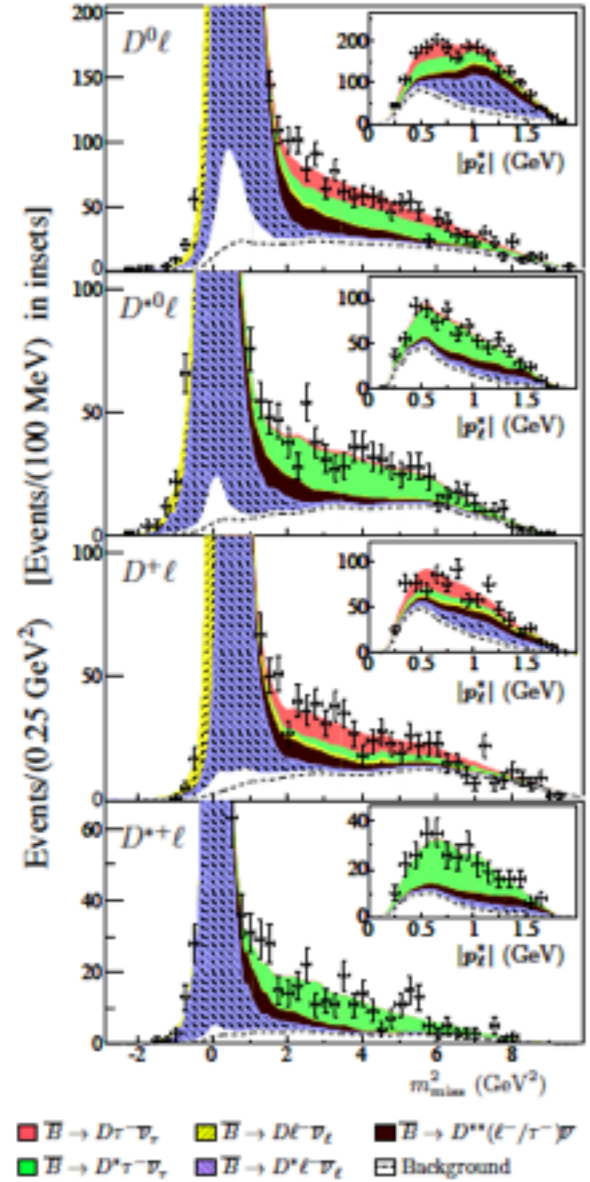


FIG. 1. (Color online) Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p^*_\ell|$ projections for $m^2_{miss} > 1\,\mathrm{GeV}^2$, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds to charge cross-feed, and the region below corresponds to continuum and $B\overline{B}$.

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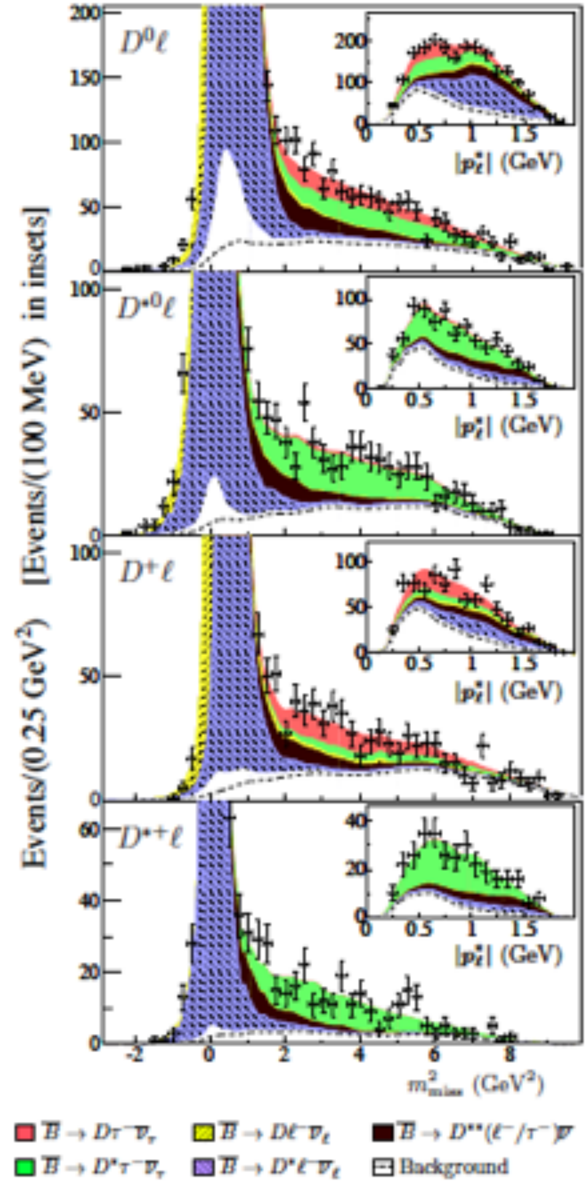
But wait !!! Now *possible* at LHCb.

Production of B meson pairs at threshold is critical to the separation of backgrounds from the missing energy/ momentum signal.



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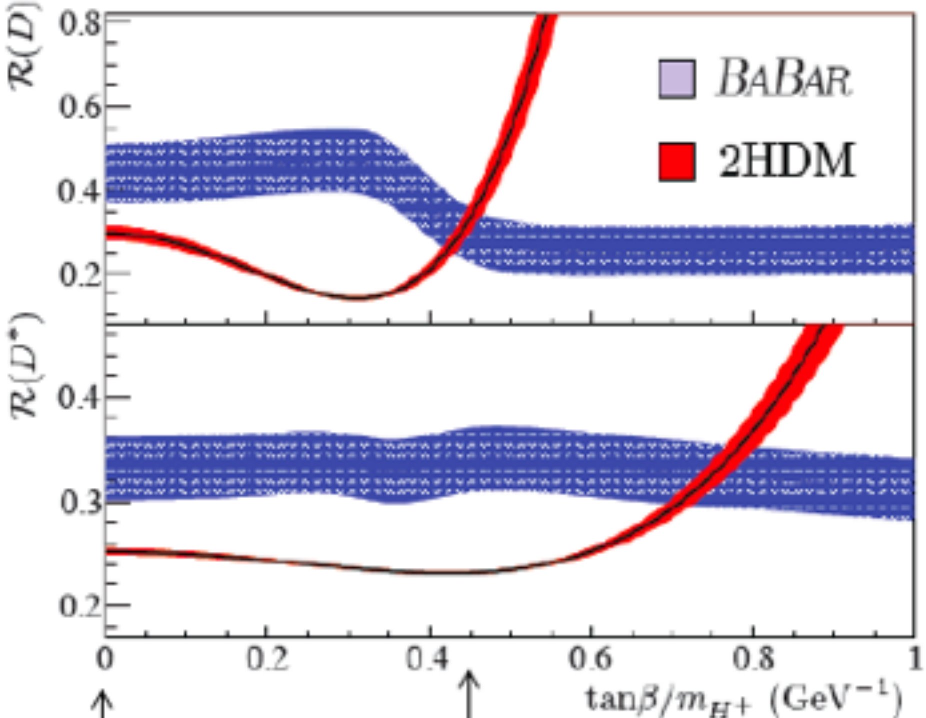
Too technical

Limits on type-II 2HDM

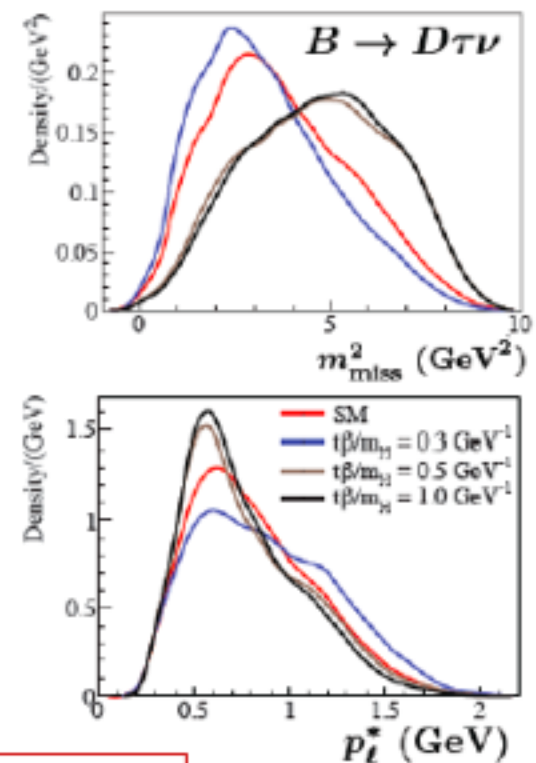


$\tan\beta/m_{H^+} =$
0.44 ± 0.02 GeV^{-1}

$\tan\beta/m_{H^+} =$
0.75 ± 0.04 GeV^{-1}

SM

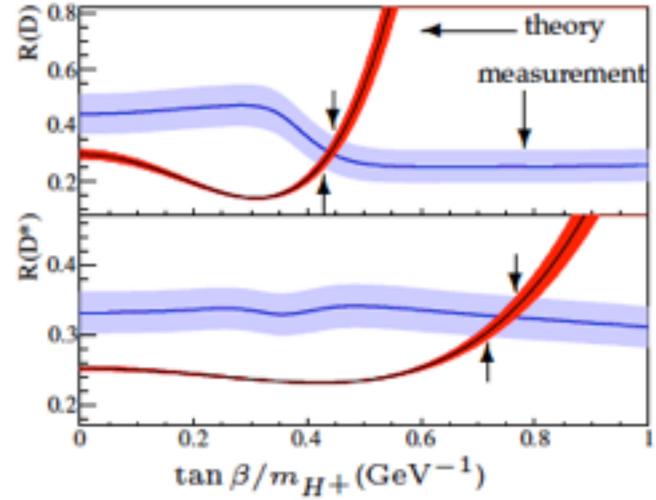
2HDM modifies fit-variable distribution and hence the efficiency



Best point is $\tan\beta/m_{H^+} = 0.45$ GeV^{-1}, excluded at 99.8% CL (3.1 σ).
All other values (with $m_{H^+} > 15$ GeV) are worse.

BaBar collaboration, Phys. Rev. Lett. 109, 101802 (2012)

"However, the combination of R(D) and R(D*) excludes the type II 2HDM charged Higgs boson with a 99.8% confidence level for any value of tan(β)/m_{H+}"



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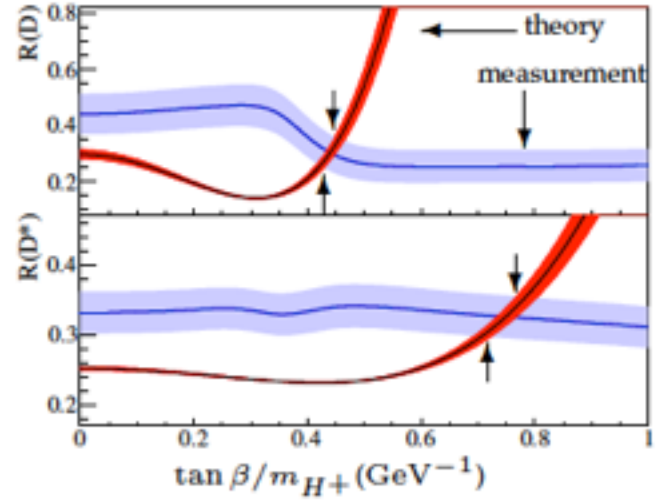


In other words, found NP but *killed* the 2HDM NP model.

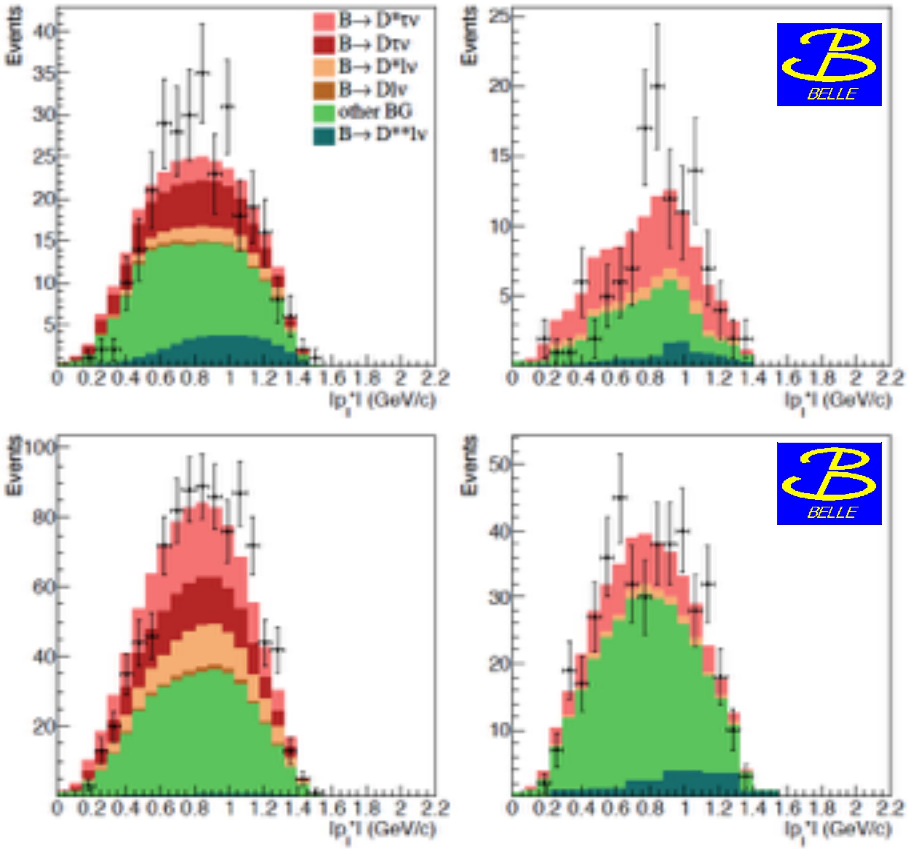
Latest Belle result with hadronic tags

May 25 2015, Nagoya FPCP

T. Kuhr

http://xxx.lanl.gov/abs/1507.03233; Phys Rev D 92, 072014(2015)

Warning: color-coding different from BaBar



IG. 6. Projections of the fit results and data points with statistical uncertainties in a signal enhanced region of $M^2_{miss} >$ 2.0 GeV$^2/c^4$ in the p^*_ℓ dimension. Top left: $D^+\ell^-$; top right: $D^{*+}\ell^-$; bottom left: $D^0\ell^-$; bottom right: $D^{*0}\ell^-$.

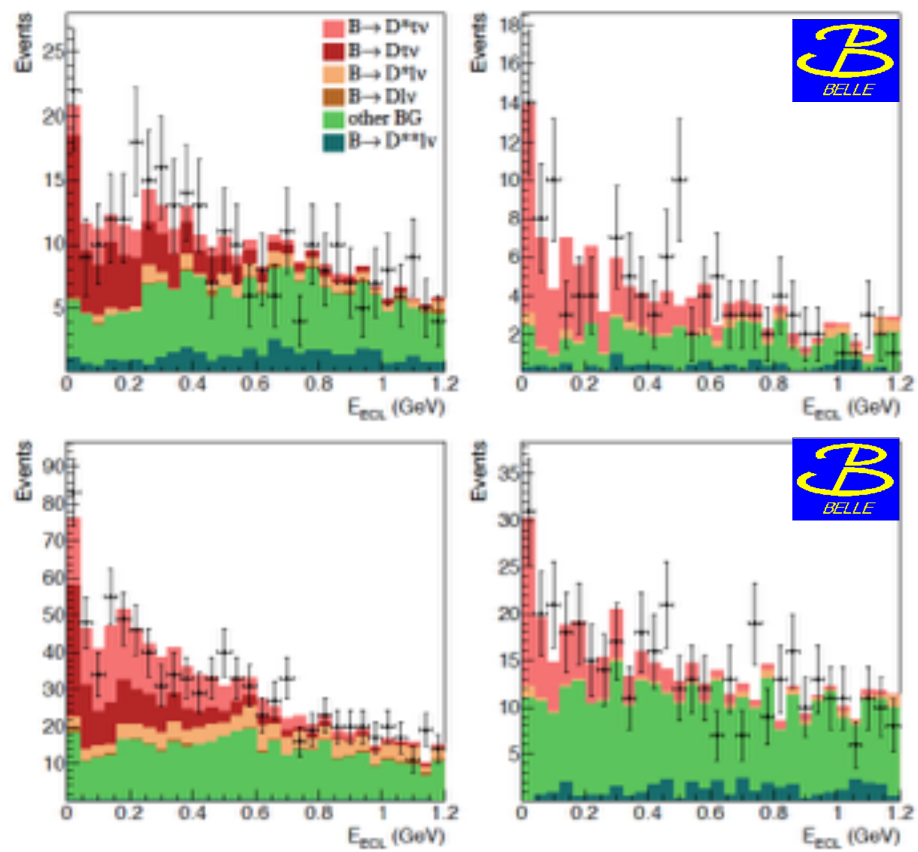


FIG. 5. Projections of the fit results and data points with statistical uncertainties in a signal enhanced region of $M^2_{miss} >$ 2.0 GeV$^2/c^4$ in the E_{ECL} dimension. Top left: $D^+\ell^-$; top right: $D^{*+}\ell^-$; bottom left: $D^0\ell^-$; bottom right: $D^{*0}\ell^-$.

Signal enhanced projections of lepton momenta in the high M^2_{miss} region

Signal enhanced projections of extra calorimeter energy in the high M^2_{miss} region

Latest Belle result with hadronic tags

May 25 2015, Nagoya FPCP

http://xxx.lanl.gov/abs/1507.03233; Phys Rev D 92, 072014(2015)

Compatible with both BaBar and the 2HDM model (and SM !).

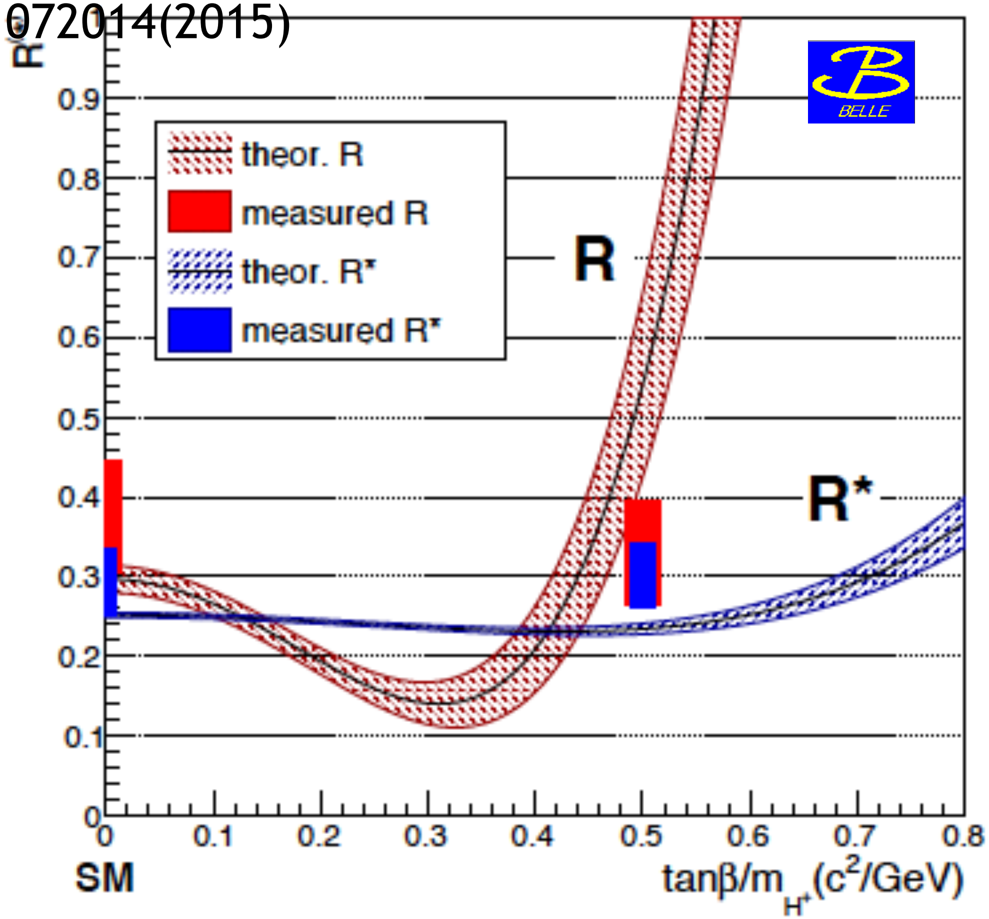


FIG. 8. Theoretical predictions with 1σ error ranges for R (red) and R^* (blue) for different values of $\tan\beta/m_{H^+}$ in the 2HDM of type II. This analysis' fit results for $\tan\beta/m_{H^+} = 0.5\,c^2/\text{GeV}$ and SM are shown with their 1σ ranges as red and blue bars with arbitrary width for better visibility.

Need *more* data

New LHCb result

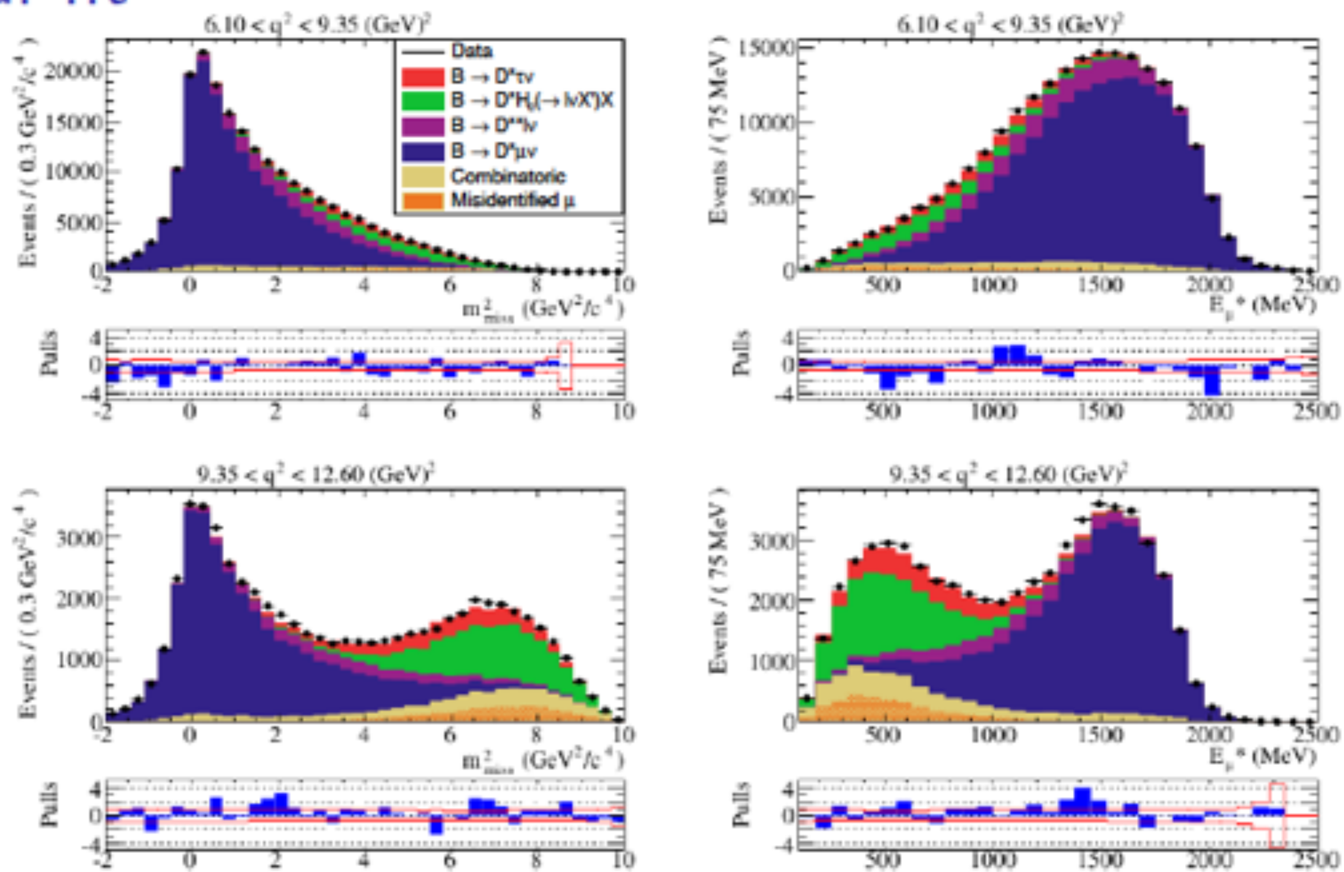
May 25 2015, Nagoya FPCP

Compatible with BaBar $D^*\tau\upsilon$ BF ($B \rightarrow D\tau\upsilon$ in the pipeline)

Published in **Phys. Rev. Lett. 115, 111803** (2015)

3. $B \rightarrow D^* \tau \nu$ (LHCB-PAPER-2015-025)

Signal fit



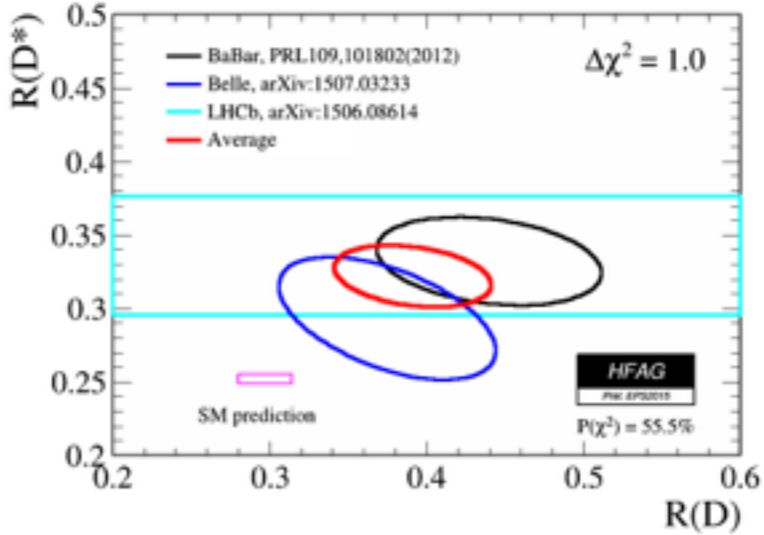
Mass resolution is poor but vertex isolation is very powerful

Oui, c’est possible !

G. Ciezarek

Apres Nagoya: *World Averages* for R(D) and R(D*)

July 23, 2015



Now 3.9σ from SM

	$R(D)$	$R(D^*)$
BaBar	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$
Belle	$0.375^{+0.064}_{-0.063} \pm 0.026$	$0.293^{+0.039}_{-0.037} \pm 0.015$
LHCb		$0.336 \pm 0.027 \pm 0.030$
Average	0.388 ± 0.047	0.321 ± 0.021
SM expectation	0.300 ± 0.010	0.252 ± 0.005
Belle II, 50/ab	± 0.010	± 0.005

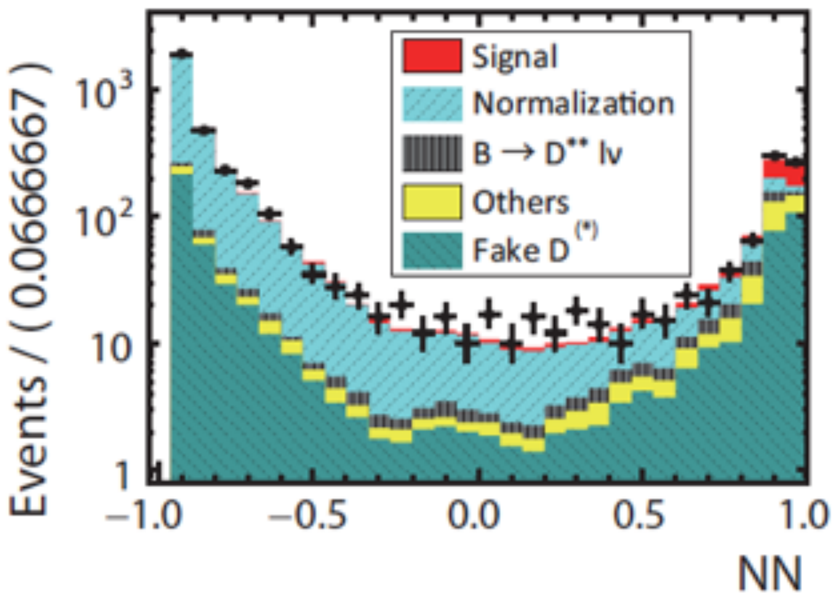
It is *obvious* that we need two orders of magnitude of data to solve these issues related to the *charged Higgs*.

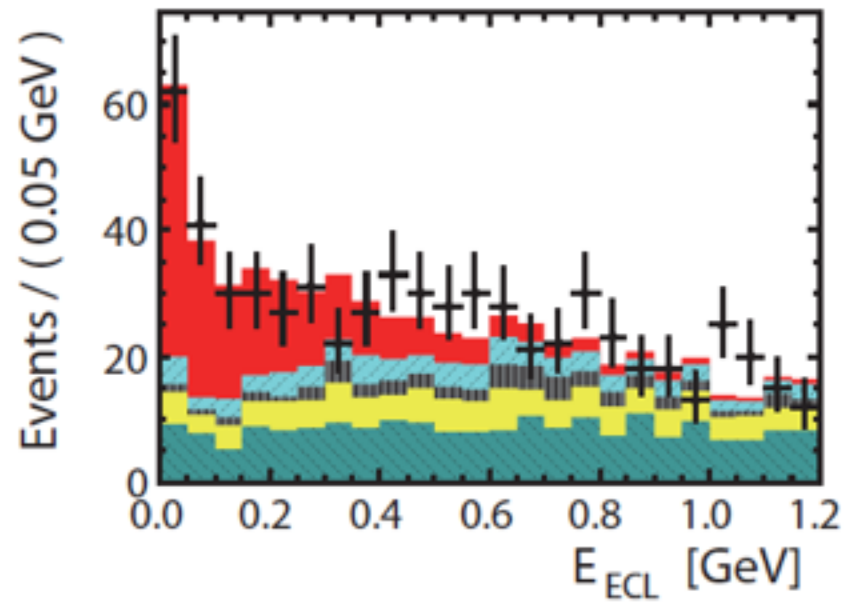
One more Belle update, March 2016 (Moriond)

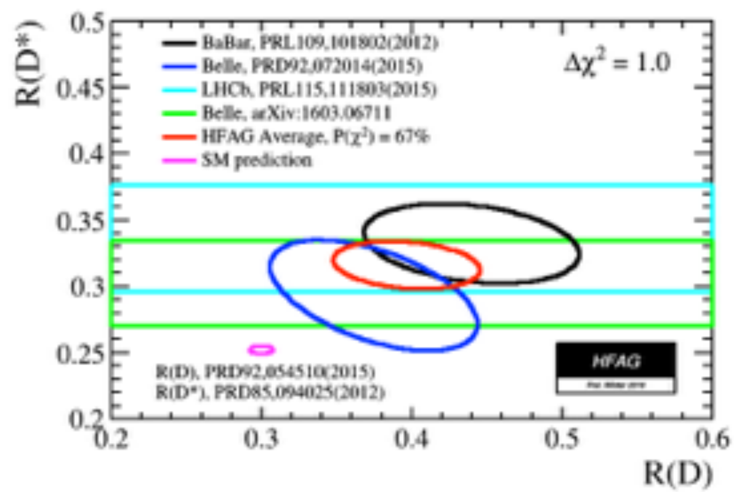
Talk by P. Goldenzweig (Karlsruhe)

Uses semileptonic tagging

$$\mathcal{R}(D^*) = 0.302 \pm 0.030(\mathrm{stat}) \pm 0.011(\mathrm{syst}$$







April 2016:
The WA is now
4.0σ from the SM

arXIv: 1603.06711

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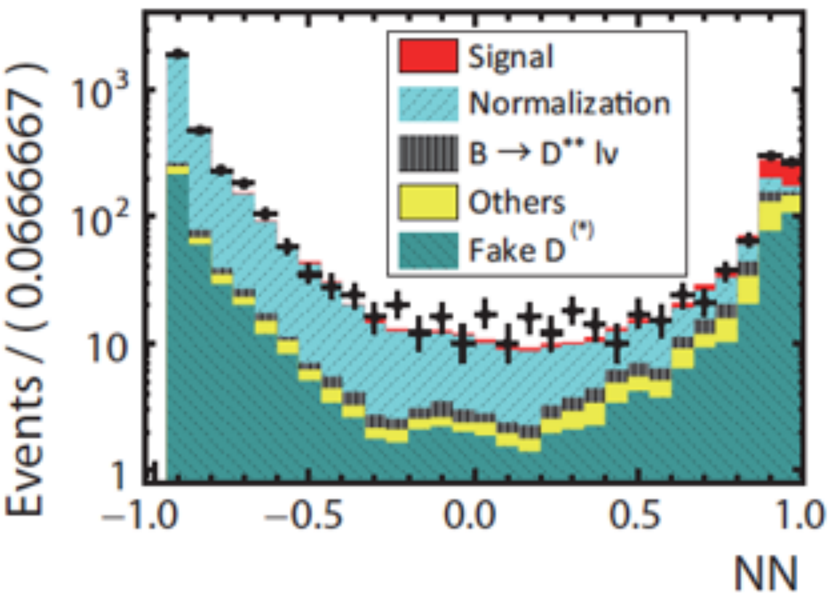
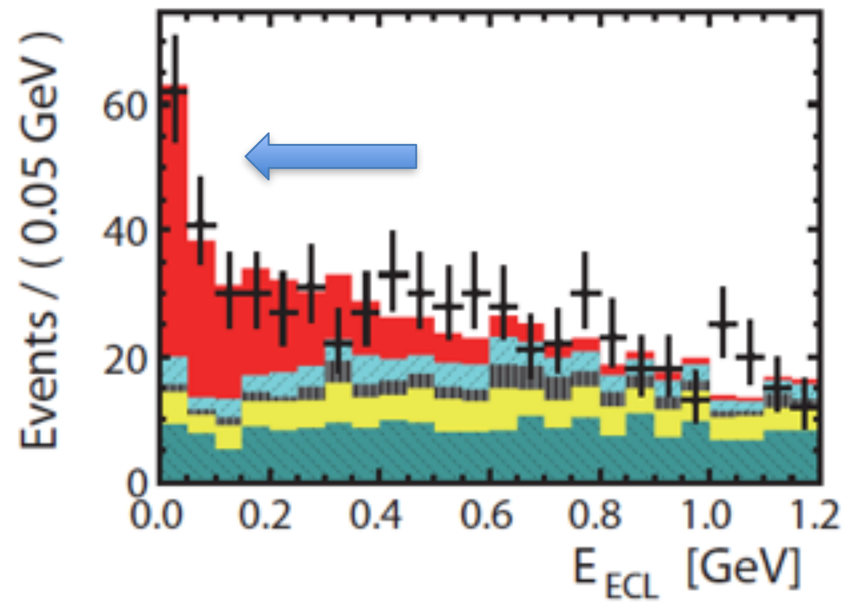
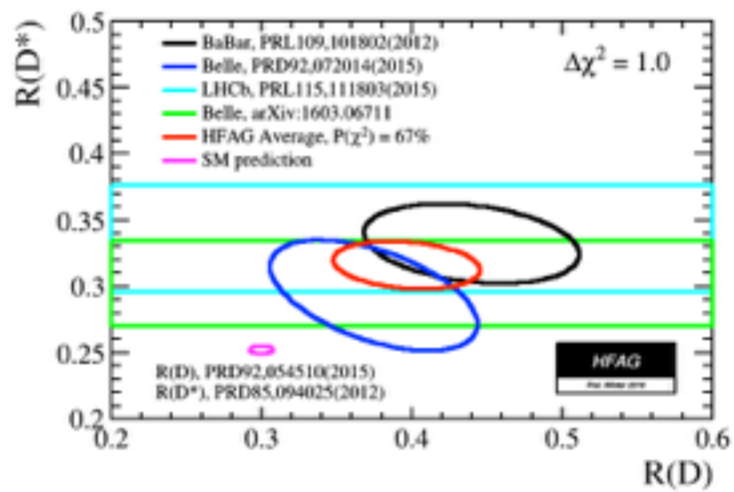






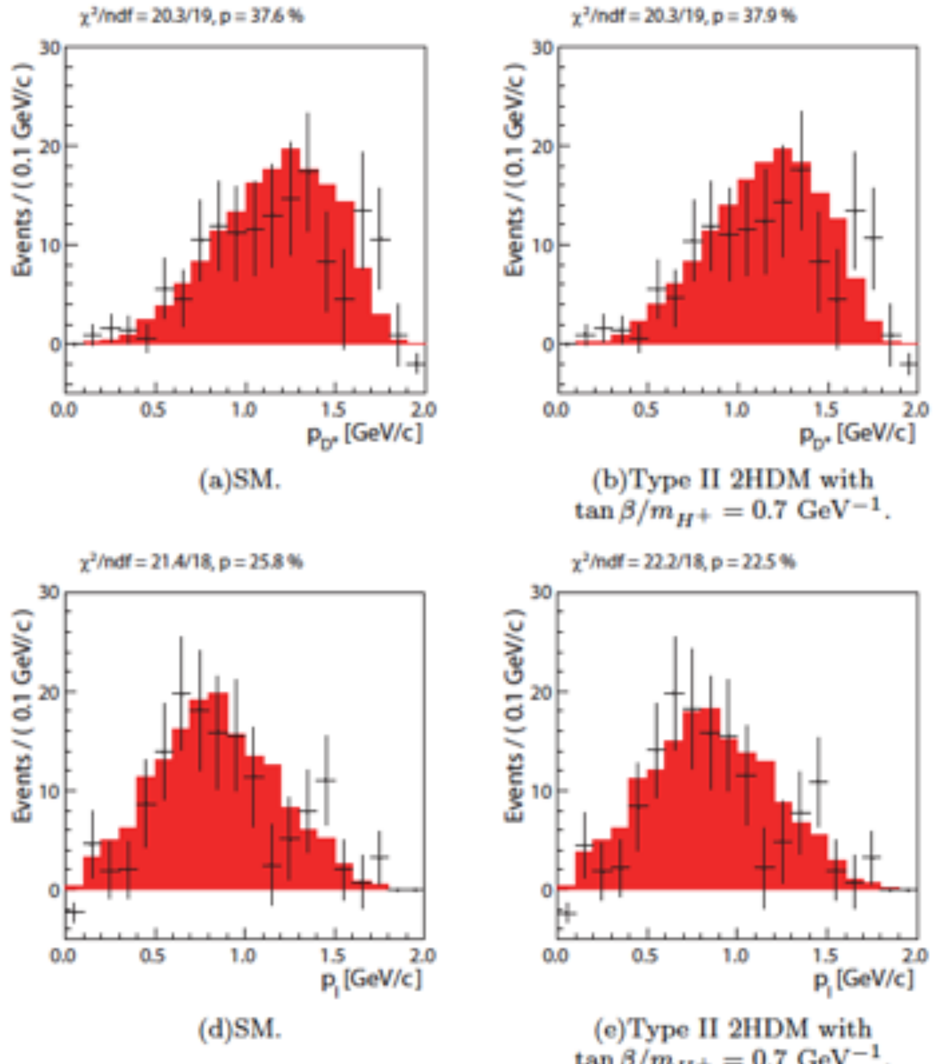
April 2016:
The WA is now
4.0σ from the SM

arXIv: 1603.06711

Last Belle update, March 2016 (Moriond)

Skip today

Try to distinguish SM and charged Higgs in kinematic distributions.



Both fit well.

Can also constrain other types of NP couplings (e.g. leptoquarks) , *but need much more data*

Credit: Djouadi

Simple message from the world's flavor physicists:

With apologies to Herodotus, Thucydides, Sparta, Persia…

Initial Belle II projections for charged Higgs sensitivity

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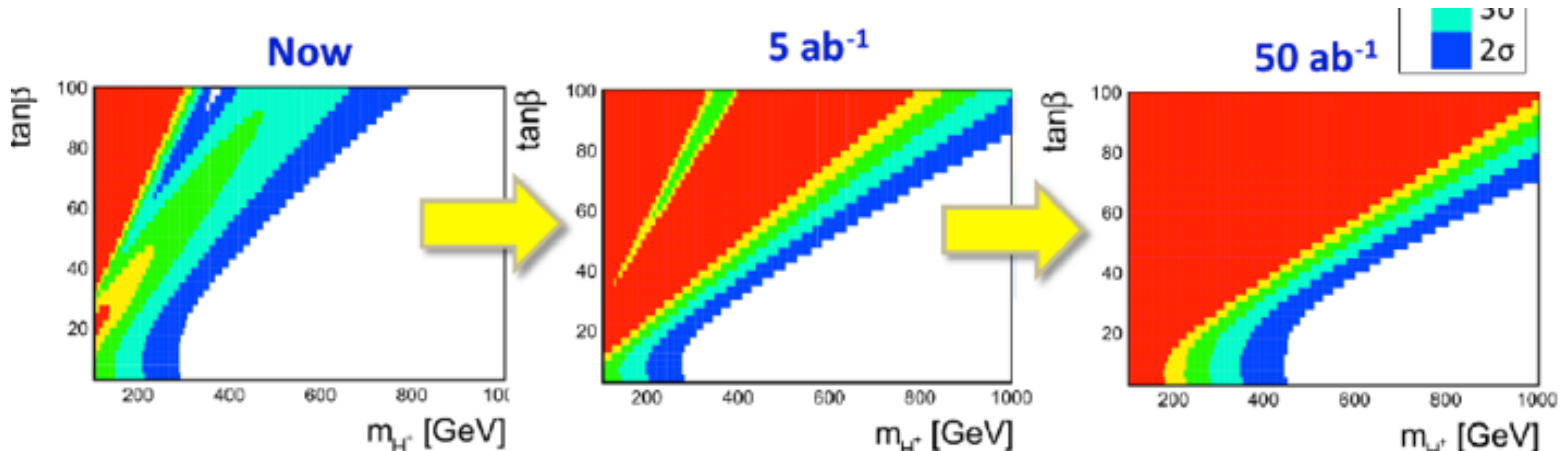
Initial Belle II projections for charged Higgs sensitivity



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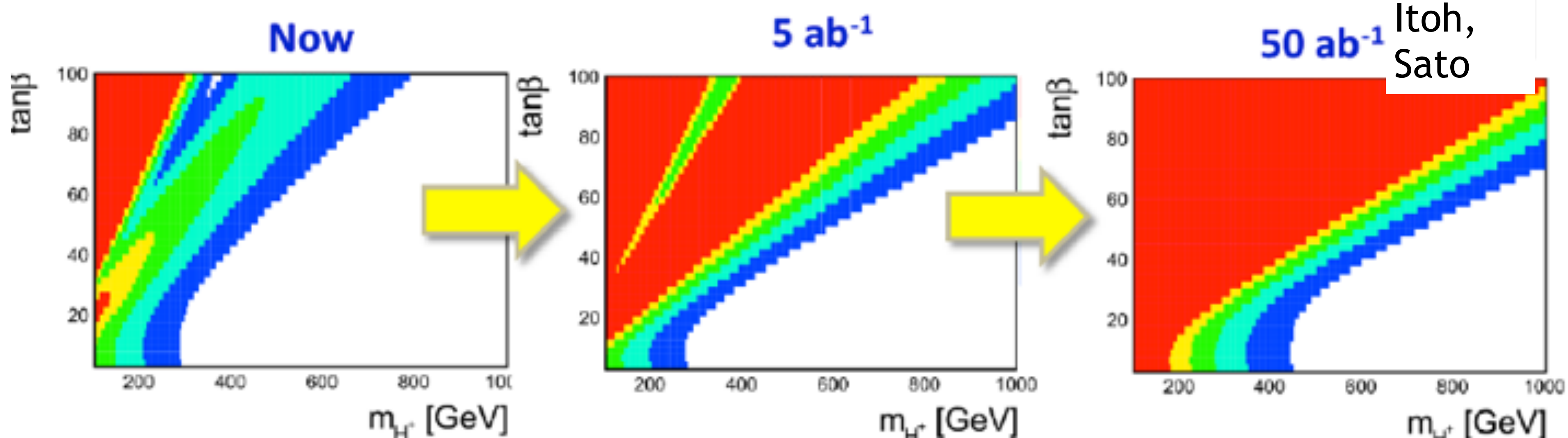
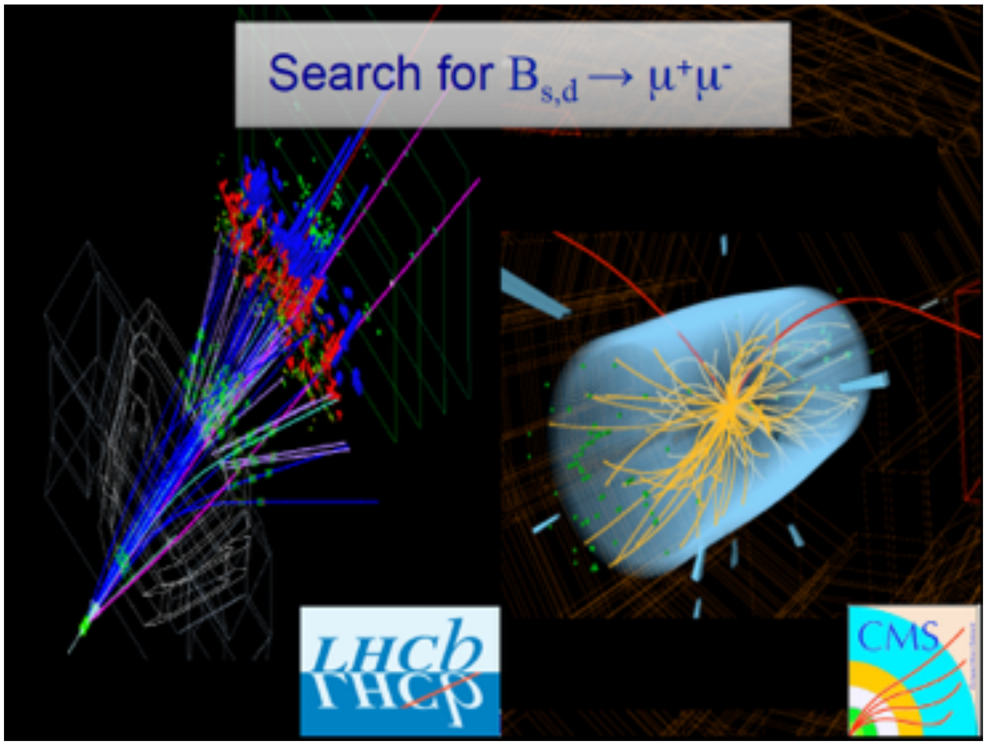
Initial Belle II projections for charged Higgs sensitivity



Rare B Decays

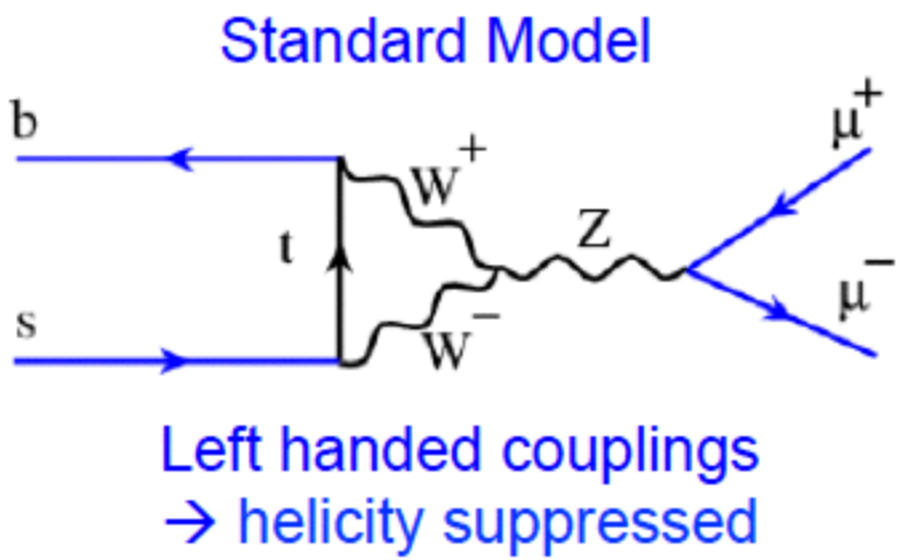
Two event displays



J. Albrecht

Goa, India

LHC found the rarest B decay; $B_s \rightarrow \mu^+ \mu^-$

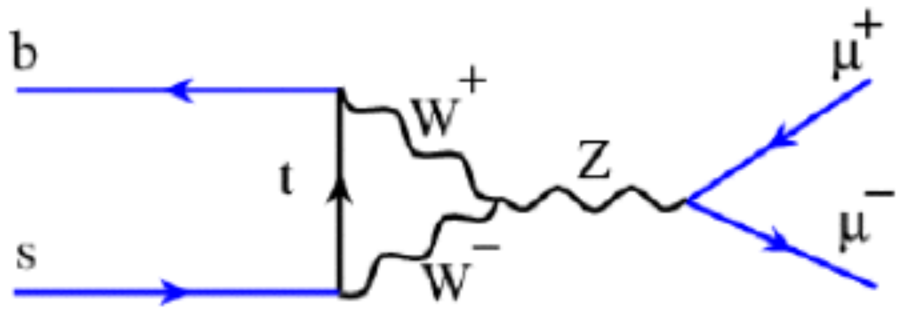


BF ~O(10^{-9})

N. B. Here and in $b \rightarrow s\, l^+ l^-$ all the heavy particles of the SM enter as virtual particles in the Feynman diagrams

LHC found the rarest B decay; $B_s \rightarrow \mu^+ \mu^-$

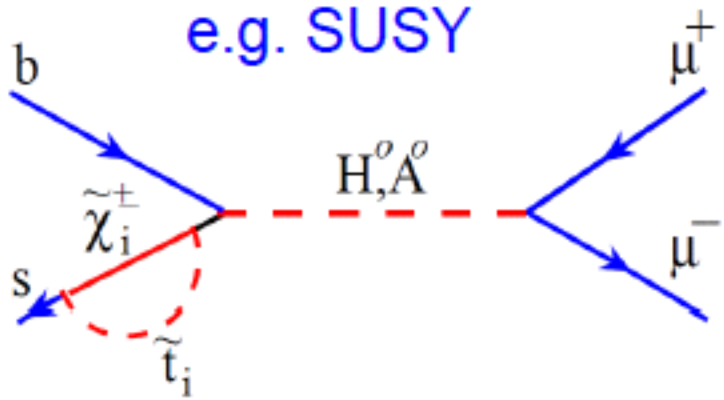
Standard Model



$BF \sim O(10^{-9})$

Left handed couplings
→ helicity suppressed

e.g. SUSY

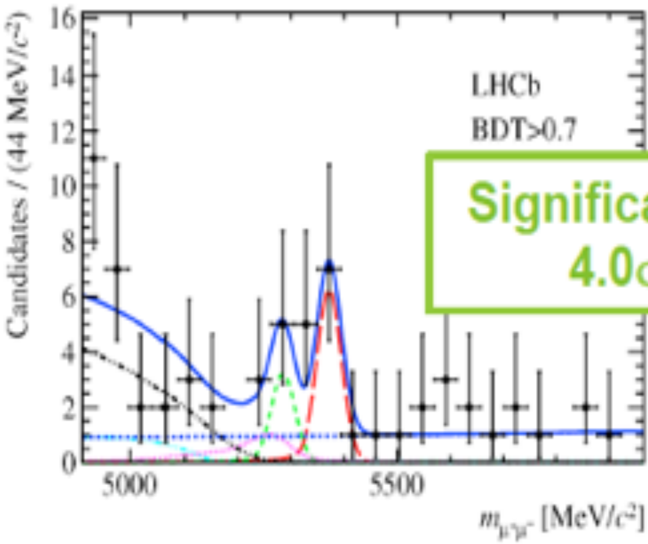


N. B. Here and in $b \rightarrow s\, l^+ l^-$ all the heavy particles of the SM enter as virtual particles in the Feynman diagrams

LHCb

PRL 111 (2013) 101805

- Update: full dataset: $3 fb^{-1}$
  - Improved BDT
  - Expected sensitivity: **5.0σ**



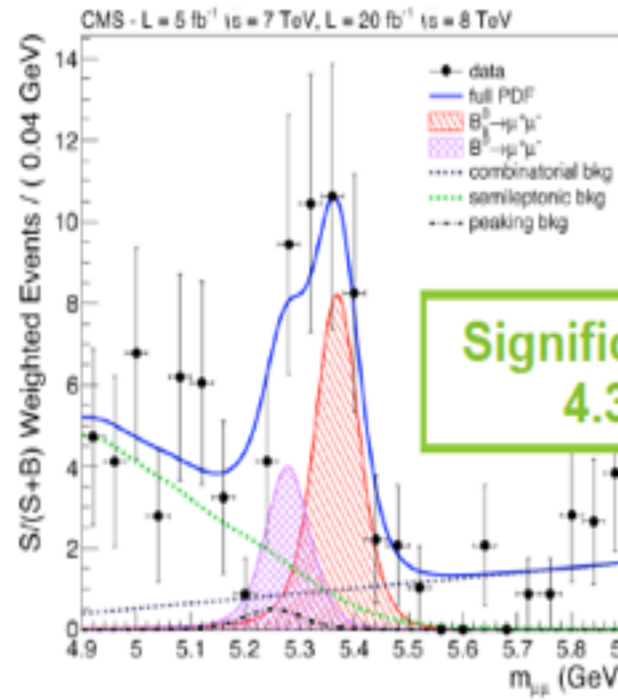
Significance: 4.0σ

$$BR(B_s \to \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}) \times 10^{-9}$$

$$BR(B^0 \to \mu^+\mu^-) = (3.7^{+2.4}_{-2.1}) \times 10^{-10}$$

$$BR(B^0 \to \mu^+\mu^-) < 7 \times 10^{-10} \,@95\%CL$$

CMS



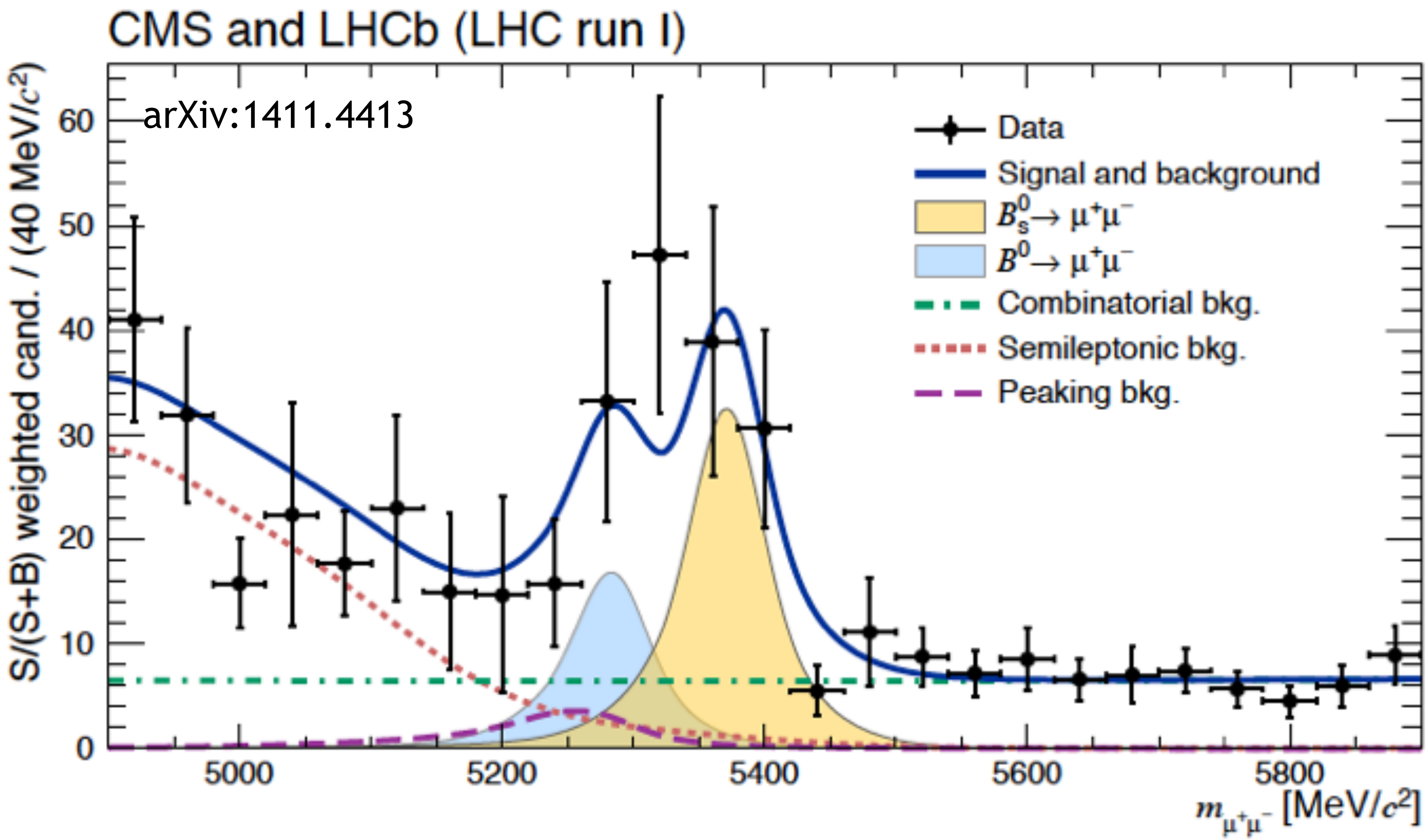
Significance: 4.3σ

$$BR(B_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$$

$$BR(B^0 \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.8}) \times 10^{-10}$$

$$BR(B^0 \to \mu^+\mu^-) < 11 \times 10^{-10} \,@95\%CL$$

PRL 111 (2013) 101804

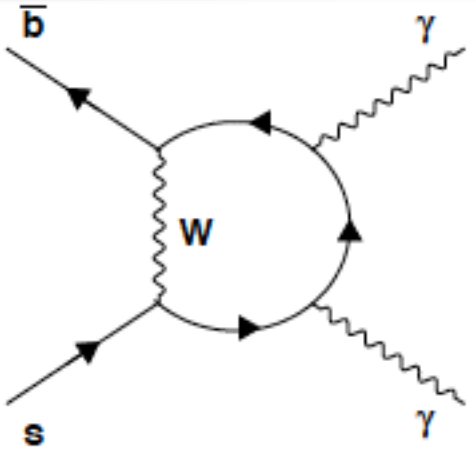


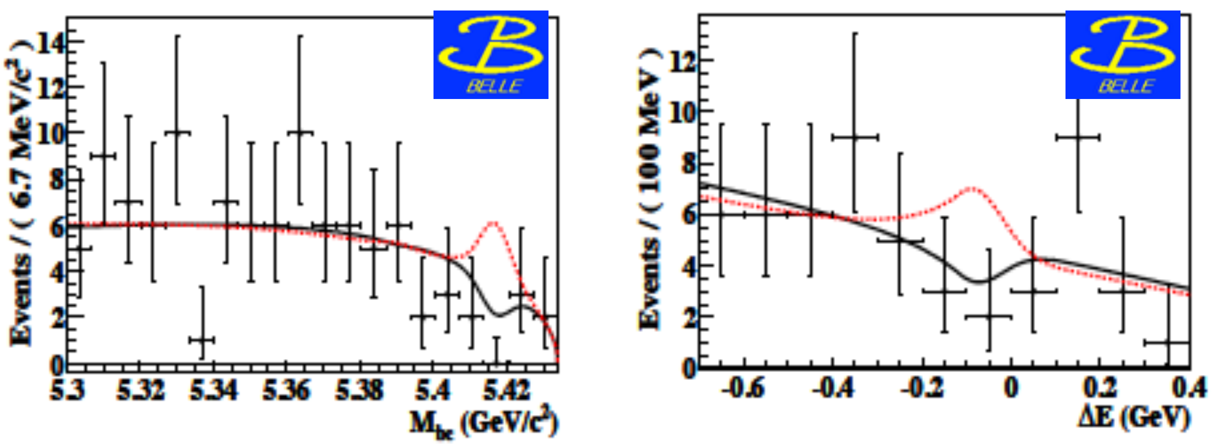
Published in Nature: June 4, 2015

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.6\,^{+1.6}_{-1.4}) \times 10^{-10}$$

SM: $BR(B_s) = (3.65 \pm 0.23)\ 10^{-9}$
$BR(B^0) = (1.1 \pm 0.1)\ 10^{-10}$
PRL 112 101801 (2014)

Combining evidence from two LHC experiments (LHCb and CMS), $B_s \to \mu^+ \mu^-$ is *observed* with 6.2σ significance. The corresponding B_d decay is not clearly seen yet.





BF ($B_s \to \gamma\gamma$) $<3.1 \times 10^{-6}$

D. Dutta et al (Belle)
Phys. Rev. D 91, 011101(R), 201

Complementarity [*uses and requires Upsilon(5S) data*]

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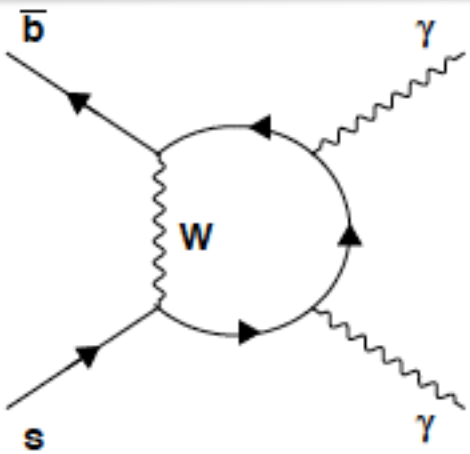

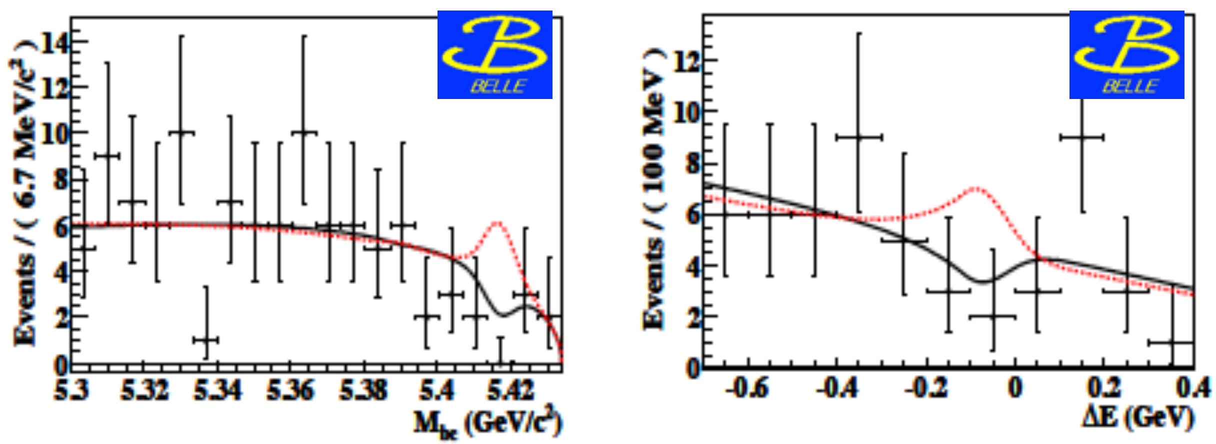

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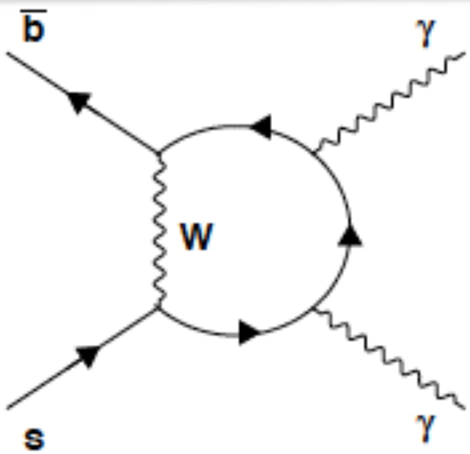

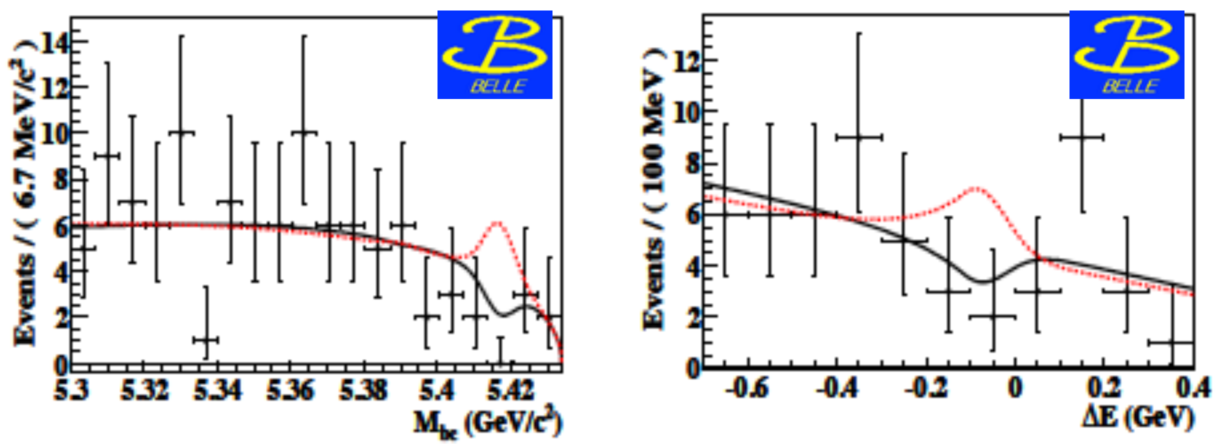

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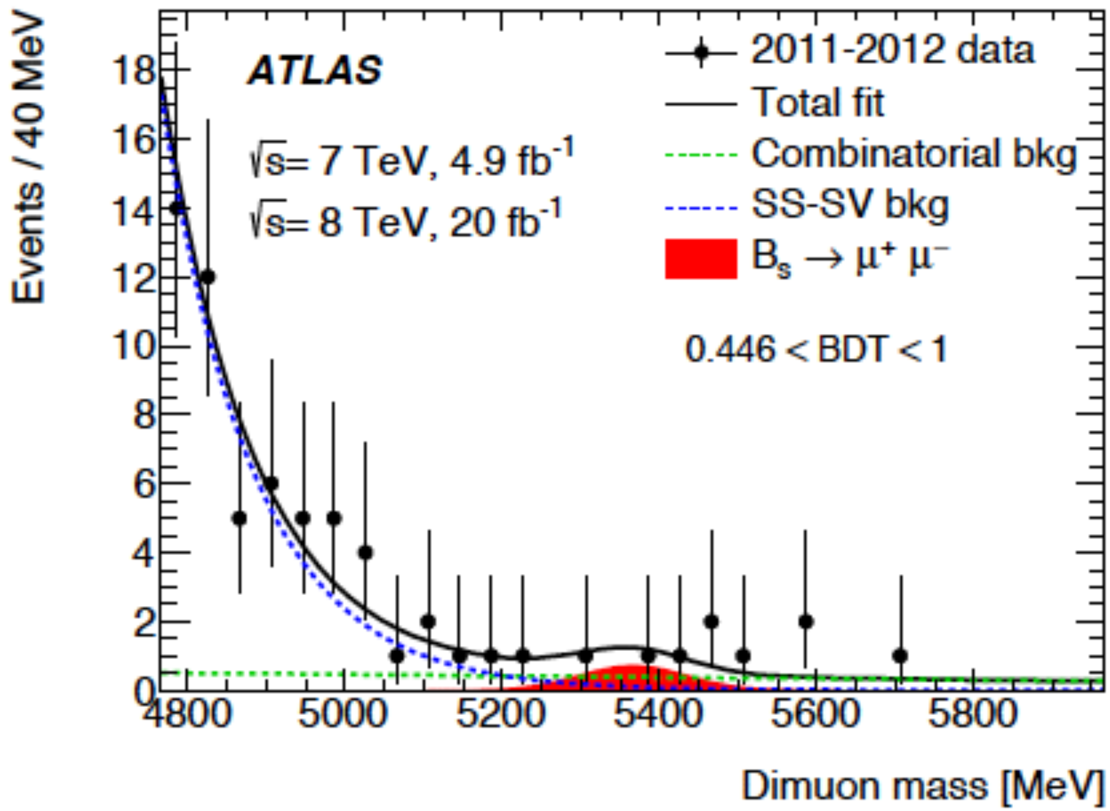
D. Dutta et al (Belle)
Phys. Rev. D 91, 011101(R), 201

Complementarity [*uses and requires Upsilon(5S) data*]

(skip today)

April 2016: ATLAS update on $B_s \rightarrow \mu^+\mu^-$



$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = \left(0.9^{+1.1}_{-0.8}\right) \times 10^{-9} .$$

hep-ex 1604.04263

Red Hot Flavor Physics

High Energy Physics History: finding NP in A_{FB} (using interference)

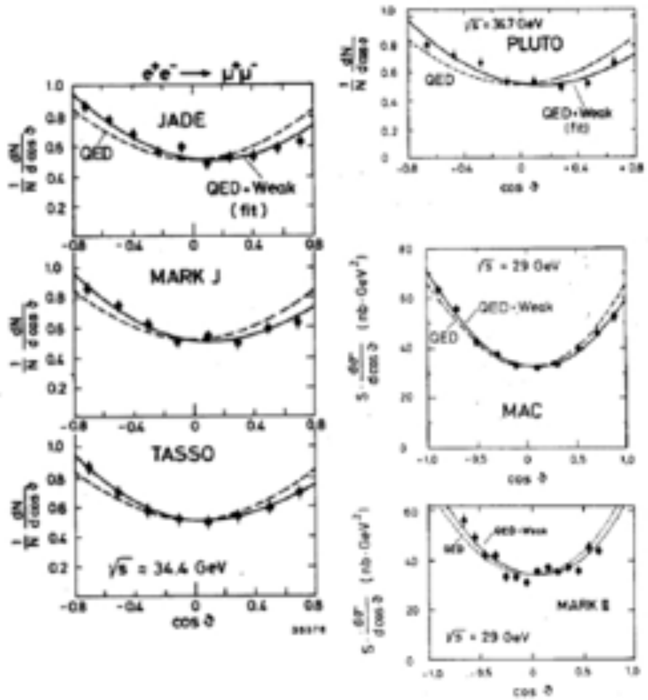
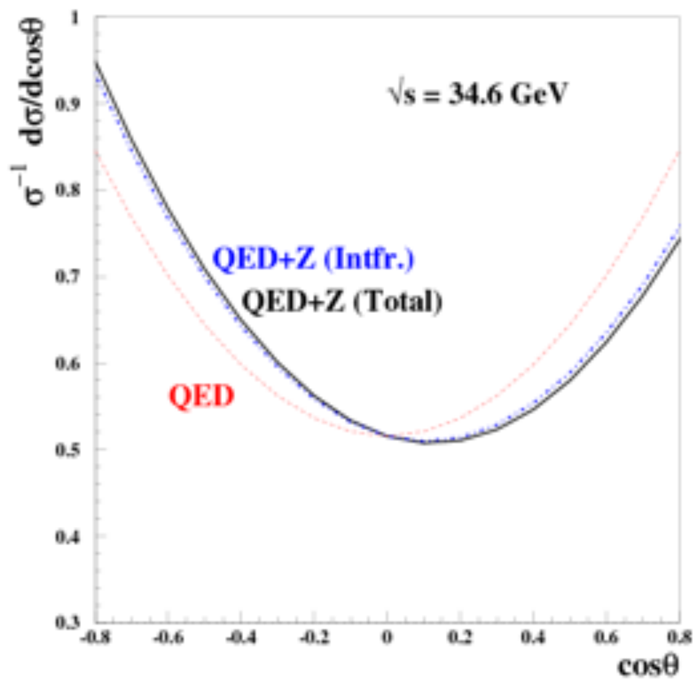
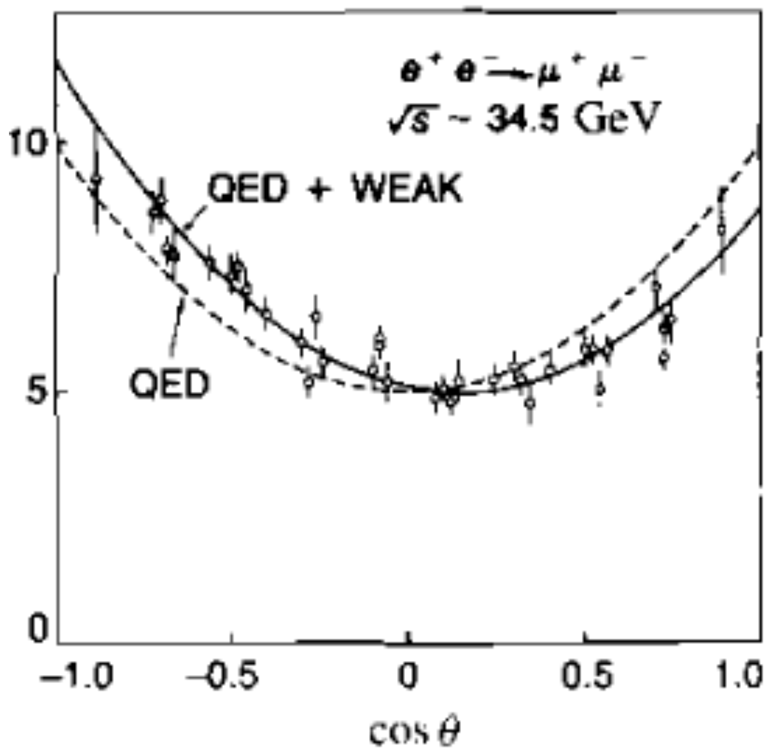


Fig. 5 Measurements of the angular distribution of $e^+e^- \rightarrow \mu^+\mu^-$ compared to the prediction of QED (dashed line) and to a fit including the weak interaction (solid line).

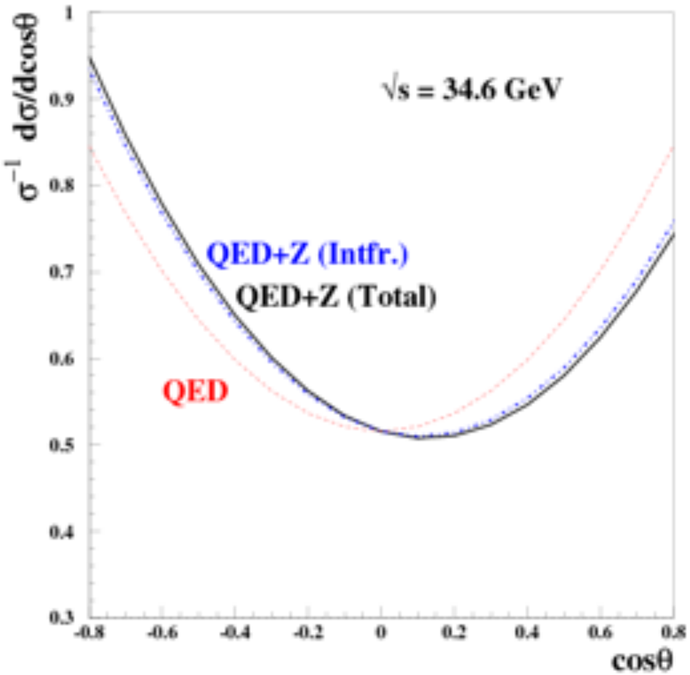


Conclusion: There is a Z boson at higher energy even though colliders of the time did not have enough $\sqrt{s}$ to produce it

High Energy Physics History: finding NP in A_{FB} (using interference)



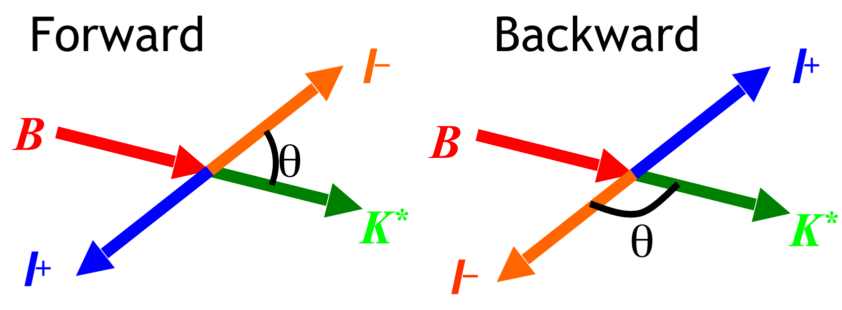
a fit including the weak interaction (solid line).



Conclusion: There is a Z boson at higher energy even though colliders of the time did not have enough $\sqrt{s}$ to produce it

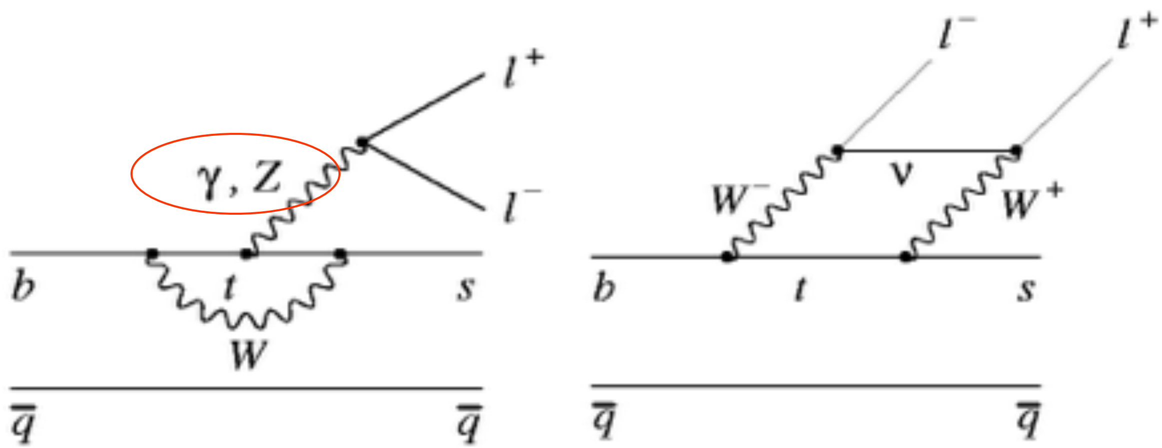
$A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$

The SM forward-backward asymmetry in $b \rightarrow s\ l^+\ l^-$ arises from the ***interference*** *between γ and Z^0 contributions.*



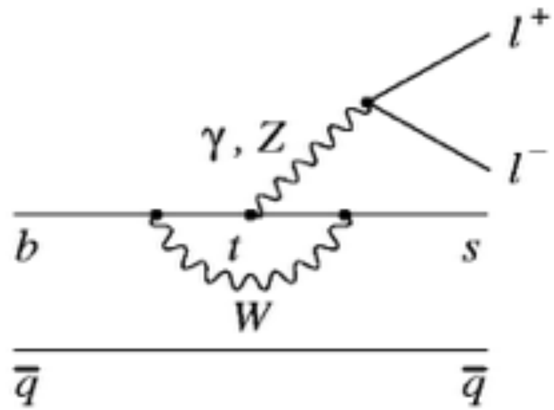
$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)



Note that all the heavy particles of the SM (W, Z, top) enter in this decay.

More on $A_{FB}(B \rightarrow K^{*} l^{+} l^{-})(q^2)$



Can in effect vary √s for NP

A_{FB} depends on $q^2 = M^2(l^+ l^-)$

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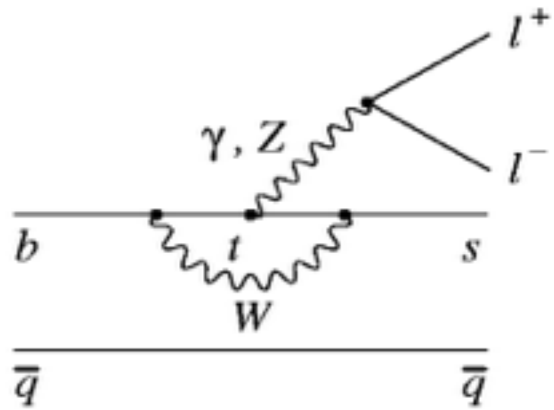

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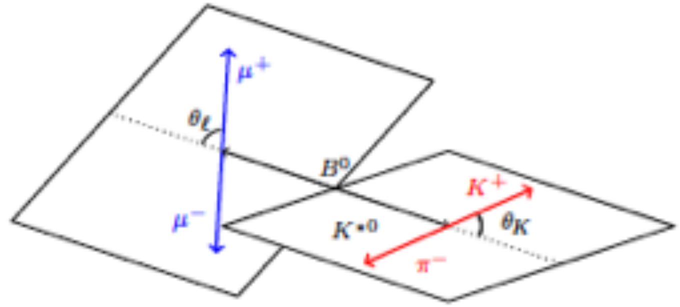
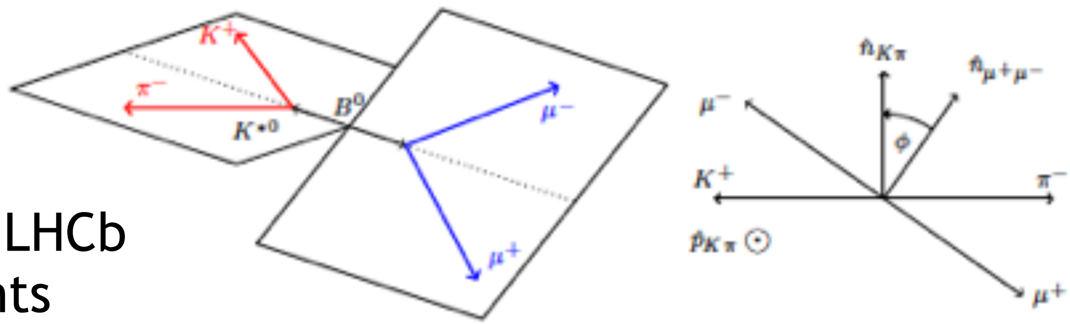
The "zero-crossing" of A_{FB} depends only on a ratio of form factors and is a *clean* observable.

B→K* l l angular variables



(a) θ_K and θ_ℓ definitions for the B^0 decay

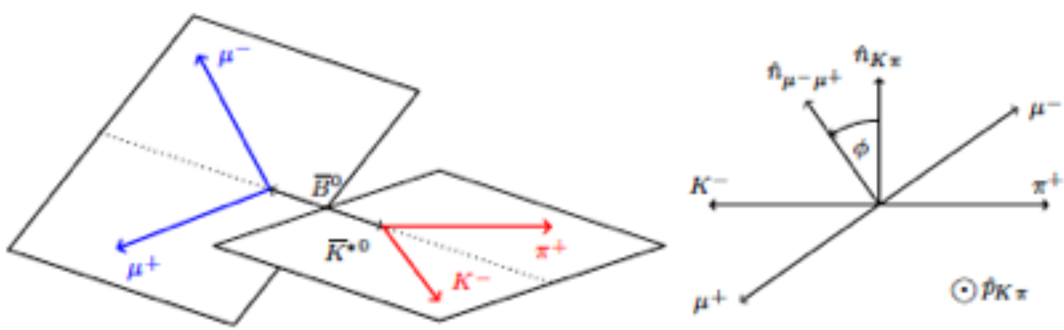
K* and l+ l- helicity angles



(b) ϕ definition for the B^0 decay

Angle between *the normals* to the two decay planes.

N.B. Recent LHCb measurements include φ angle data



(c) ϕ definition for the $\overline{B}^0$ decay

From the 2013 LHCb paper

$B \rightarrow K^{*} l^{+} l^{-}(q^2)$ bootcamp (*skip today*)

Angular dependence

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^3(\Gamma \pm \bar{\Gamma})}{d\vec{\Omega}} =$$

$$\frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\vartheta_K + F_L\cos^2\vartheta_K$$

$$+\frac{1}{4}(1-F_L)\sin^2\vartheta_K\cos 2\vartheta_L$$

$$-F_L\cos^2\vartheta_K\cos 2\vartheta_L + S_3\sin^2\vartheta_K\sin^2\vartheta_L\cos 2\phi$$

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(-) means the term is only in $\Gamma - \bar{\Gamma}$

Thanks to Rahul Sinha

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F_L is the longitudinal polarization fraction.

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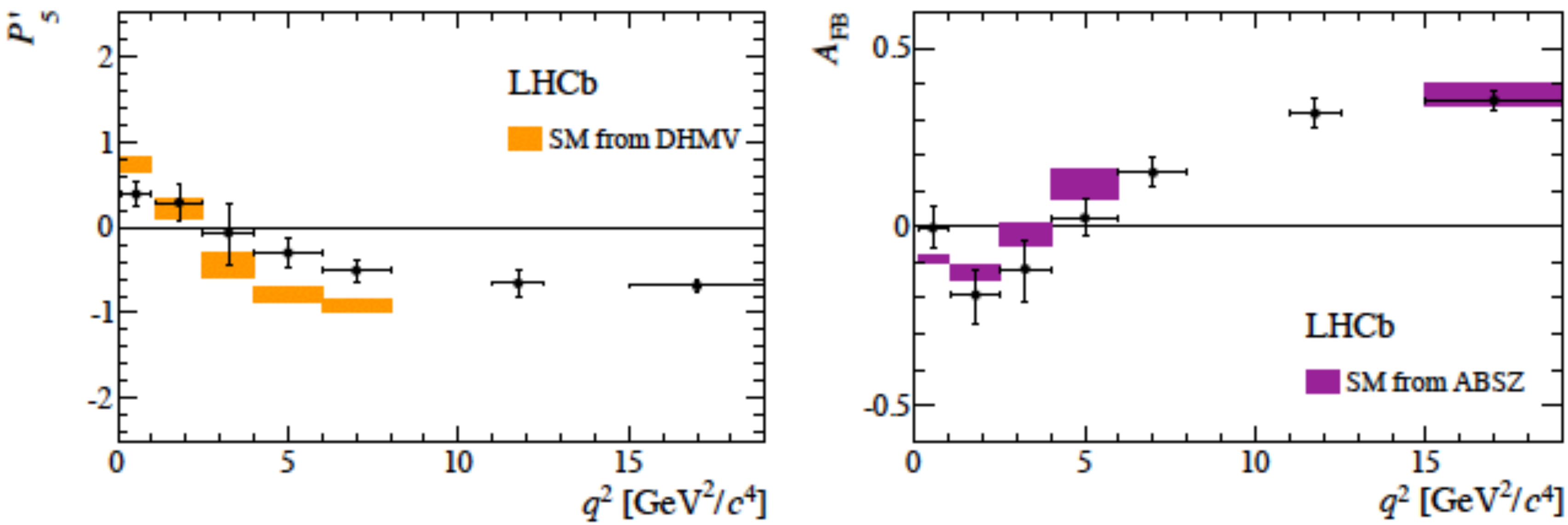
Introduce $P_{4,5}' = S_{4,5}/sqrt[F_L(1-F_L)]$ to reduce/eliminate dependence on form factors

Thanks to Rahul Sinha

LHCb 3fb^{-1} results on $B \rightarrow K^* \mu^+\mu^-$ (q^2)

Angular Asymmetries based on 2398±57 signal events



Blank regions are the J/ψ and ψ' vetos

Theory from http://arxiv.org/abs/1510.04329

R. Aaij et al., JHEP 1602, 104 (2016)

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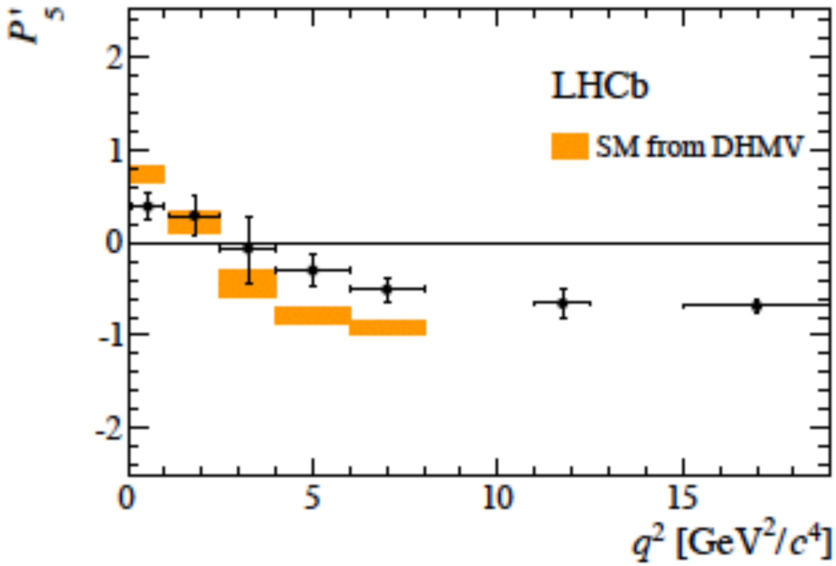

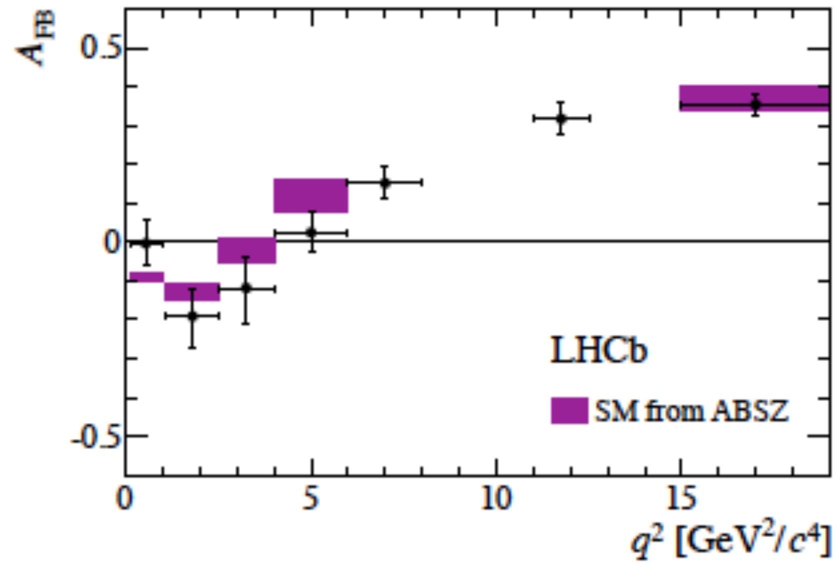

"The P_5' measurements <u>are only compatible with the SM prediction at a level of 3.7σ</u>…..A mild tension can also be seen in the A_{FB} distribution, where the measurements are systematically <=1σ below the SM prediction in the region $1.1<q^2< 6.0$ GeV^2"

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Recent LHCb results on $B \rightarrow K^* \mu^+\mu^- (q^2)$

Is HEP History repeating itself ? *[But be sure this is not a tricky SM form factor effect.]*

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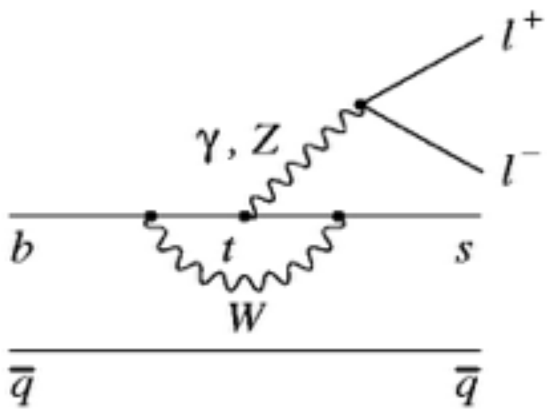

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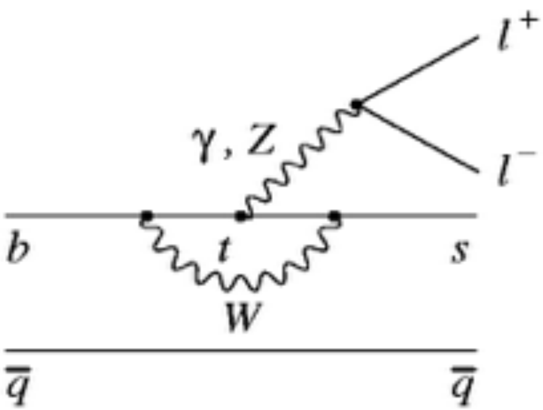

Possible answer: All the heavy particles of the SM (t, W, Z) and maybe NP (except the Higgs) appear here. Sensitive to NP via interference (linear effects and many types of couplings).

NP could mean "new particles" (bump in some mass spectrum at the LHC) or "new couplings" (flavor physics)

We would be happy to break the Standard Model.

Places where we might find New couplings

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$$Q_7 = \frac{e}{g^2} m_b \bar{s}\sigma^{\mu\nu}(1+\gamma_5)F_{\mu\nu}\, b \quad \text{[real or soft photon]}$$

$$Q_9 = \frac{e^2}{g^2} \bar{s}\gamma_\mu(1-\gamma_5)b\, \bar{\ell}\gamma_\mu \ell \quad [b \to s\mu\mu \text{ via } Z/\text{hard } \gamma]$$

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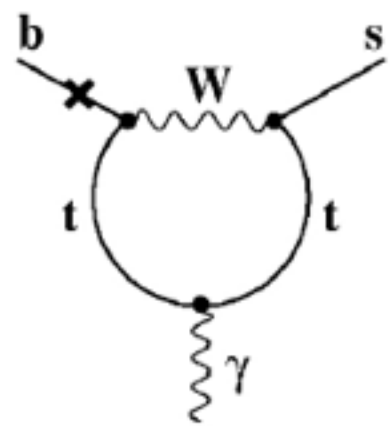

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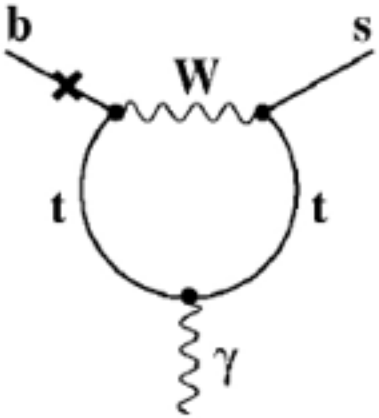
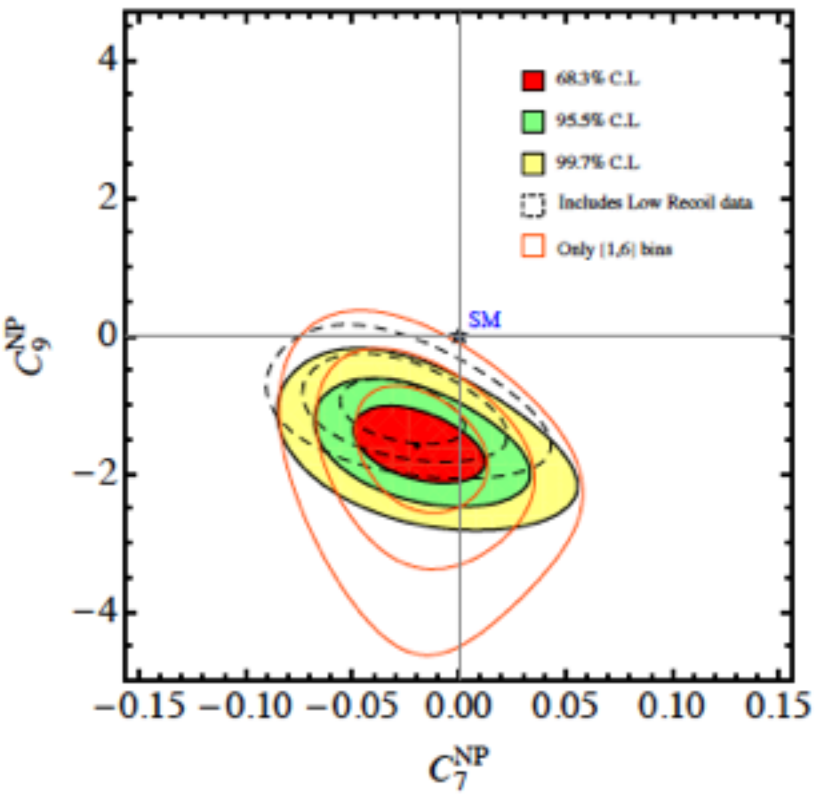


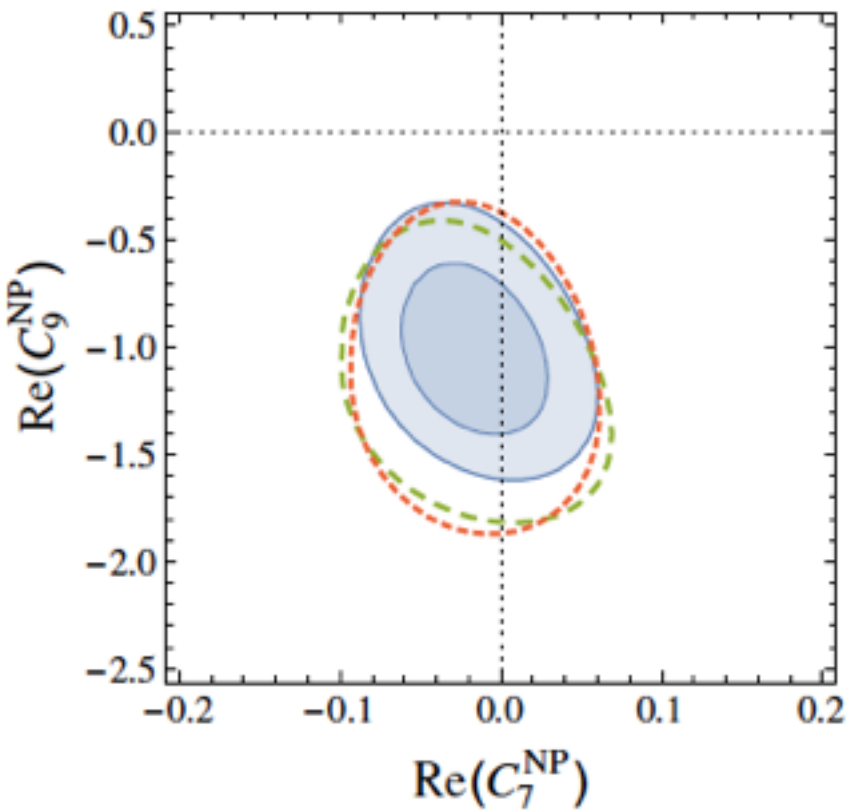
Right-handed currents: $1-\gamma_5 \rightarrow 1+\gamma_5$

Some examples of NP Fits to B→K*l l data

Descotes-Genon, Matias, JV 1307.5683



Altmannshofer, Straub 1503.06199



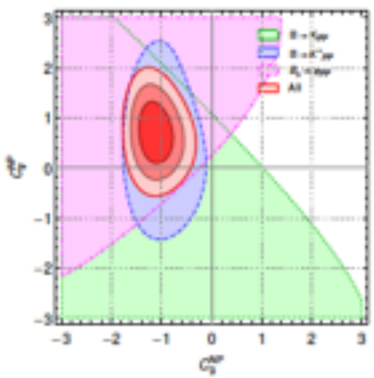
Not complete: many theorists are trying this

Recent example of NP Fits to B→s l l data

L. Hofer et al., Moriond March 2016

		C_7^{NP}	C_9^{NP}	C_{10}^{NP}	$C_{7'}^{NP}$	$C_{9'}^{NP}$	$C_{10'}^{NP}$
C_9^{NP}	4.47	0.07	*	1.54	0.92	2.00	1.89

$(C_9^{NP}, C_{9'}^{NP})$
$(-1.12, 0.77)$
4.5



(C_9^{NP}, C_{10}^{NP})
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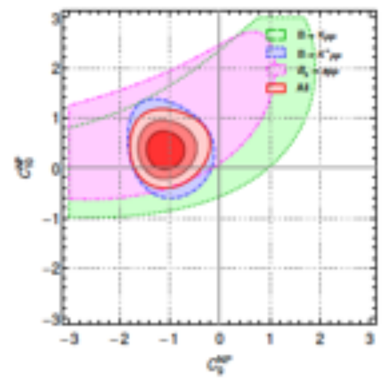
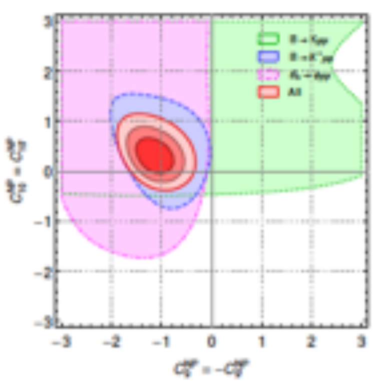
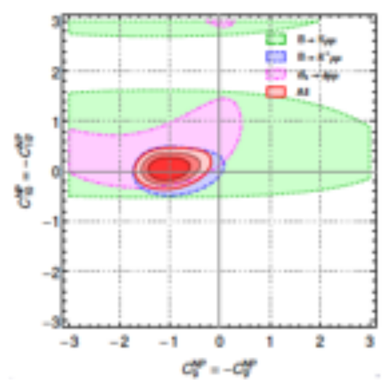
4.3



$(C_9^{NP} = -C_{9'}^{NP}, C_{10}^{NP} = C_{10'}^{NP})$
$(-1.15, 0.34)$
4.7



$(C_9^{NP} = -C_{9'}^{NP}, C_{10}^{NP} = -C_{10'}^{NP})$
$(-1.06, 0.06)$
4.4



Fits use LCSR at low q^2 and lattice form factors at high q^2 and all data on b→s l l

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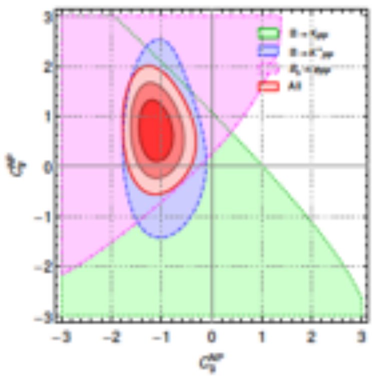

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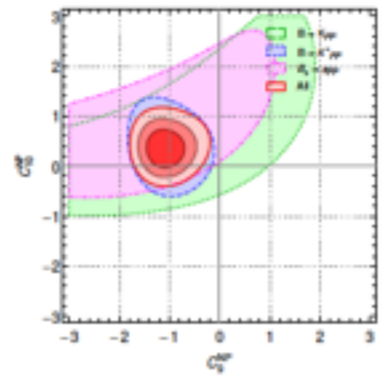

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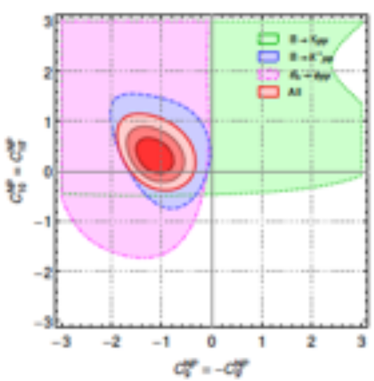

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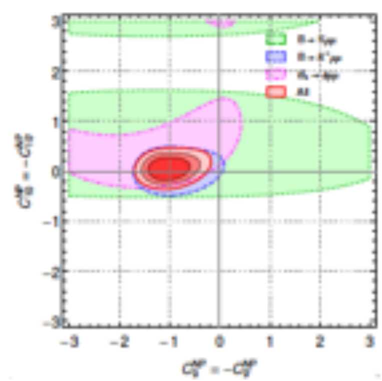

Fits use LCSR at low q^2 and lattice form factors at high q^2 and all data on b→s l l

These plots mean there are NP coupling(s) in the weak interaction

Theory issues on B→K $\mu^+\mu^-$ (q^2)*

Major concern

Theory issues on $B \rightarrow K^* \mu^+\mu^- (q^2)$

➔ Check dependence on light-cone form factors (some checks already done by Lattice QCD groups)

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Major concern

→ Can tails of large B→K* [c-cbar] or *non-factorizable effects* produce the anomalies found in the angular distributions ? (If all non-perturbative effects float with arbitrary normalization in the fit then the data can explained)

→ Use data near $q^2 = q^2_{max}$ (K* at rest), where symmetry works (Heavy Quark Effective Theory) and constrains ratio of polarizations (no hadronic corrections)→Still find NP

Fit LHCb angular data at q^2_{max} (<u>HQET limit</u>)

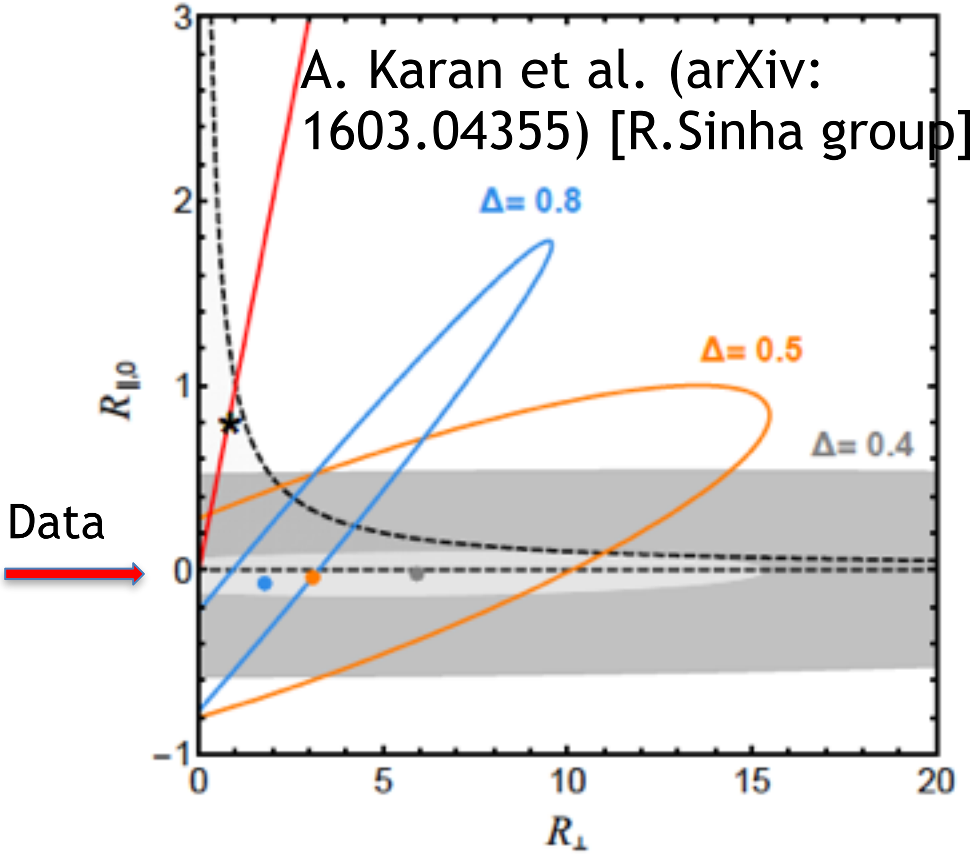
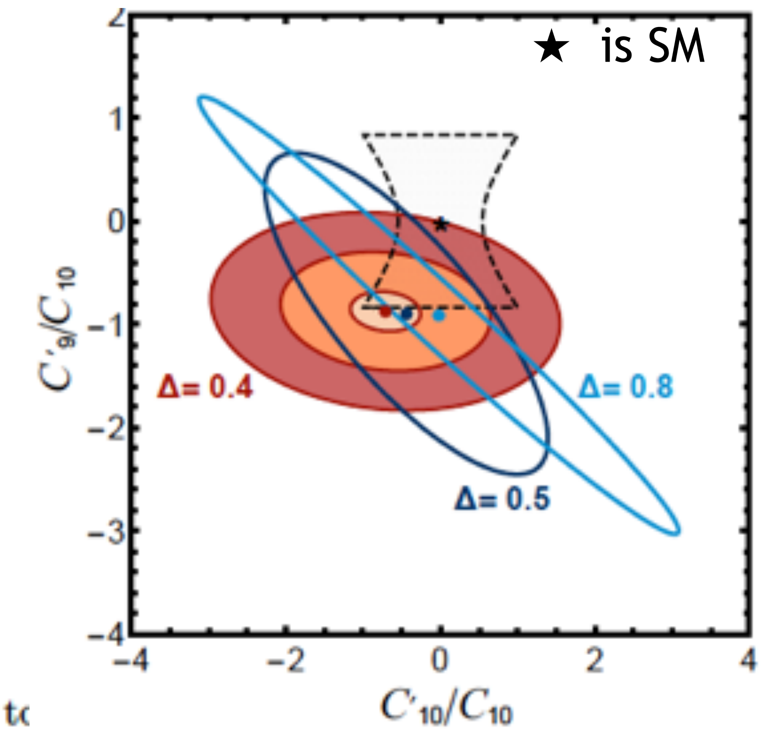


FIG. 2. Allowed regions in $R_\perp - R_{\parallel,0}$ plane corresponding tc different values of Δ are shown. The solid red straight line on the far left corresponds to the case $R_\perp = R_{\parallel,0}$. The SM value is indicated by the star. The gray, orange and blue points correspond to the best fit central values for $\Delta = 0.4$, 0.5 and 0.8, respectively. The light and dark gray contours correspond to 1σ and 5σ confidence levels for $\Delta = 0.4$. The orange and blue contours represent the 5σ confidence regions for $\Delta = 0.5$ and 0.8, respectively. Only the region bounded by the black dashed curves is physically allowed from the constraint $\omega_2 \geq \omega_1 \geq 1$ (See text for details).



5σ signal for NP, requires <u>right-handed currents</u>

Fit LHCb angular data at q^2_{max} (HQET limit)

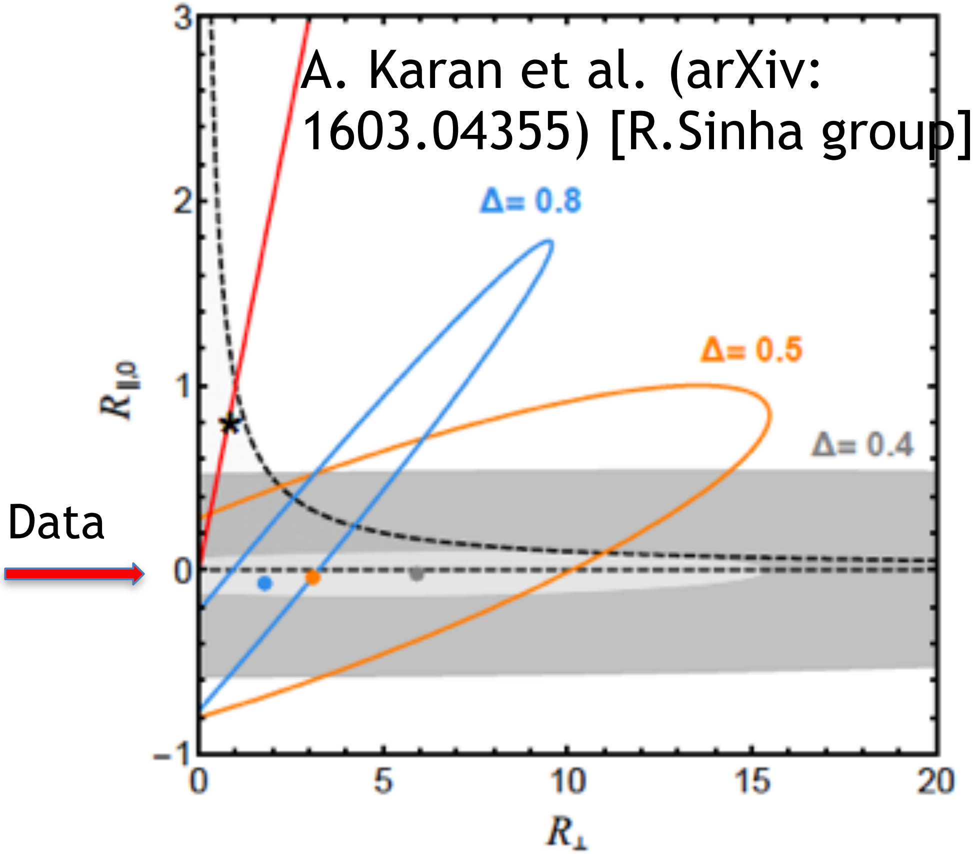
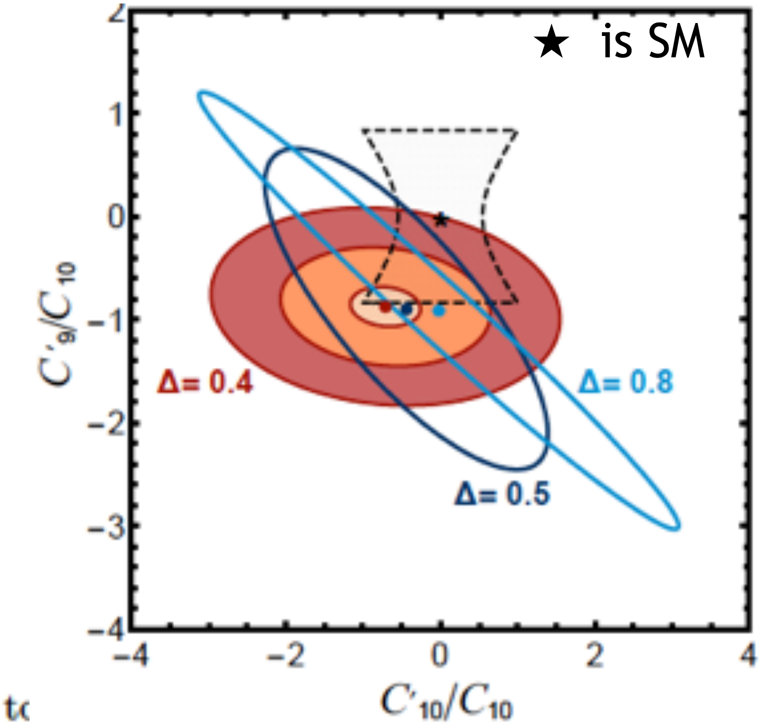


FIG. 2. Allowed regions in $R_{\perp} - R_{\parallel,0}$ plane corresponding tc different values of Δ are shown. The solid red straight line on the far left corresponds to the case $R_{\perp} = R_{\parallel,0}$. The SM value is indicated by the star. The gray, orange and blue points correspond to the best fit central values for $\Delta = 0.4$, 0.5 and 0.8, respectively. The light and dark gray contours correspond to 1σ and 5σ confidence levels for $\Delta = 0.4$. The orange and blue contours represent the 5σ confidence regions for $\Delta = 0.5$ and 0.8, respectively. Only the region bounded by the black dashed curves is physically allowed from the constraint $\omega_2 \geq \omega_1 \geq 1$ (See text for details).

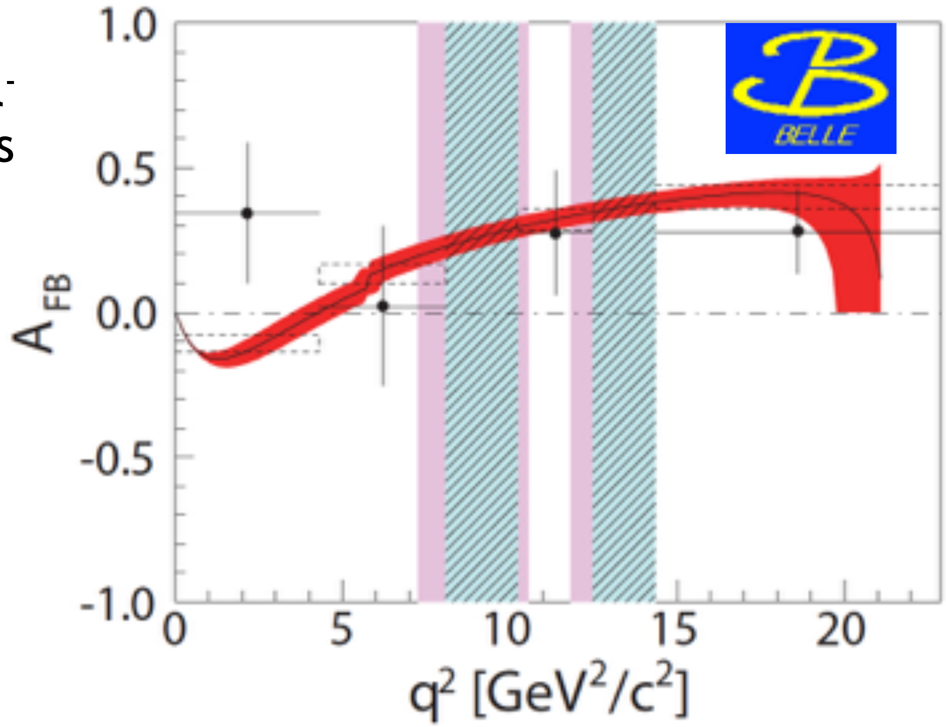


5σ signal for NP, requires ***right-handed currents***

Still confirmation and more data is needed to close the case for NP

Paths to the future: $A_{FB}(q^2)$ for Inclusive $b \to s\, l^+ l^-$

~301 $b \to s\, l^+ l^-$ signal events



No form factors

Where is the zero crossing ?

Precise result useful for NP diagnosis

http://arxiv.org/abs/1402.7134
To appear in PRD.

TABLE II. Fit results for the four q^2 bins. For $\mathcal{A}_{FB}$, the first uncertainty is statistical and the second uncertainty is systematic. $\mathcal{A}_{FB}$ values predicted by the SM [4, 7] are also shown with systematic uncertainties. For the signal yields, only statistical uncertainties are shown. The uncertainties of α and β are due to the statistical uncertainties of the MC.

	1st bin	2nd bin	3rd bin	4th bin
q^2 range [GeV$^2/c^2$] ($B \to X_s e^+ e^-$)	[0.2,4.3]	[4.3,7.3]	[10.5,11.8]	[14.3, 25.0]
($B \to X_s \mu^+ \mu^-$)		[4.3,8.1]	[10.2,12.5]	
$\mathcal{A}_{FB}$	$0.34 \pm 0.24 \pm 0.02$	$0.04 \pm 0.31 \pm 0.05$	$0.28 \pm 0.21 \pm 0.01$	$0.28 \pm 0.15 \pm 0.01$
$\mathcal{A}_{FB}$ (theory)	-0.11 ± 0.03	0.13 ± 0.03	0.32 ± 0.04	0.40 ± 0.04
N_{sig}^{ee}	45.6 ± 10.9	30.0 ± 9.2	25.0 ± 7.0	39.2 ± 9.6
$N_{sig}^{\mu\mu}$	43.4 ± 9.2	23.9 ± 10.4	30.7 ± 9.9	62.8 ± 10.4
α^{ee}	1.289 ± 0.004	1.139 ± 0.003	1.063 ± 0.003	1.121 ± 0.003
$\alpha^{\mu\mu}$	2.082 ± 0.010	1.375 ± 0.003	1.033 ± 0.003	1.082 ± 0.003
β	1.000	1.019 ± 0.003	1.003 ± 0.000	1.000

How can we establish NP in B→K* l^-l^+ ?

Answer from Buras et al.

R. Aaij et al. (LHCb collab); PRL 113, 151601 (2014)

How can we establish NP in B→K* l^-l^+ ?

Ans: Observe and measure the rate for $B \to s\nu\bar{\nu}$ and thus isolate the Z' penguin (C_9) at *Belle II*

Answer from Buras et al.

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How can we establish NP in B→K* l⁻l⁺ ?

TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)}\nu\bar{\nu}$ branching fractions.

Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\text{Backg.}}$ 711 fb^{-1} Belle	$N_{\text{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\text{Backg.}}$ 50 ab^{-1} Belle II	$N_{\text{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+\nu\bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_S\nu\bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \to K^{*+}\nu\bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
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$B \to K^*\nu\bar{\nu}$ combined							15%	17%

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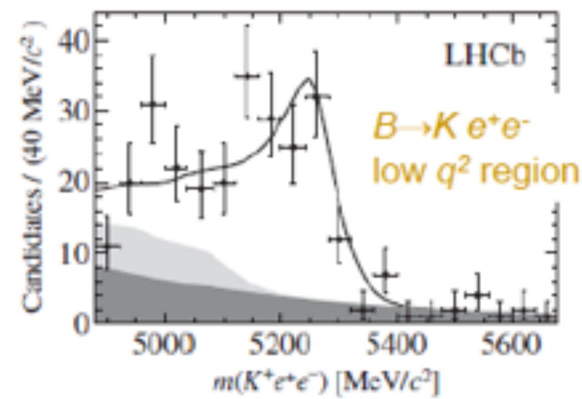

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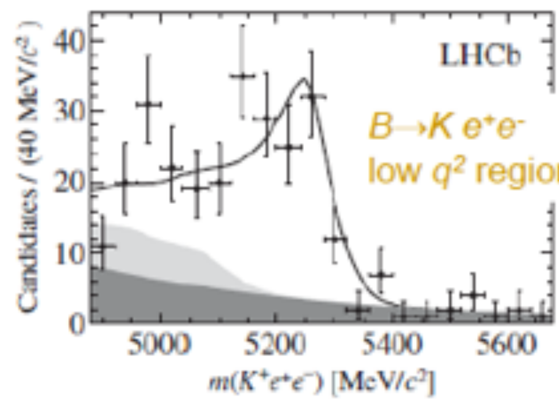
Control region gives R_K consistent with unity.
Interesting, low q^2 region gives:

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

which is 2.6σ from unity, 3σ if BaBar included.



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Ans: Verify hint of lepton universality breakdown at Belle II (good electron eff)

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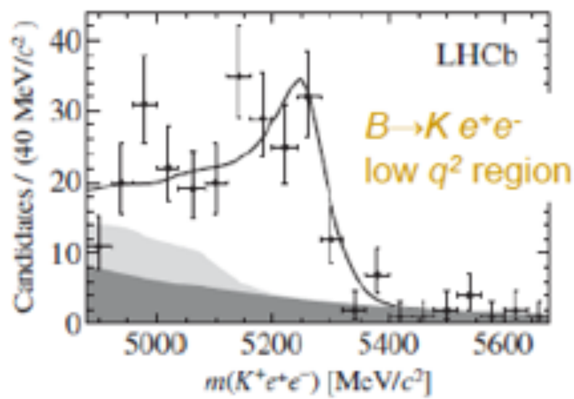

“We need more data !!”

Apologies to Director Akira Kurosawa

To find out whether there are NP couplings in the weak interaction

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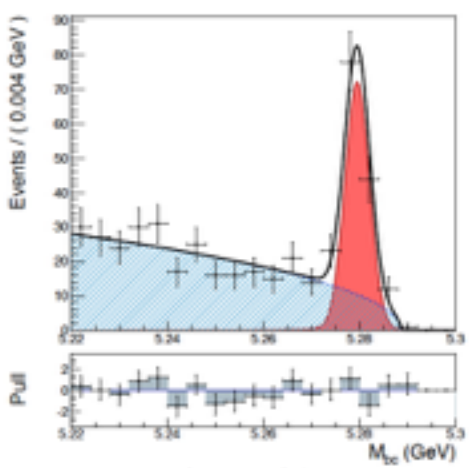
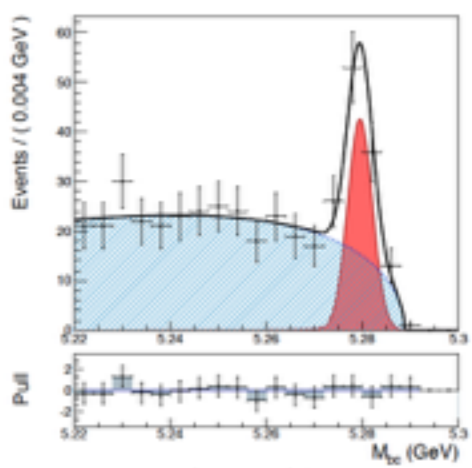


(a) $B^0 \to K^*(892)^0\mu^+\mu^-$



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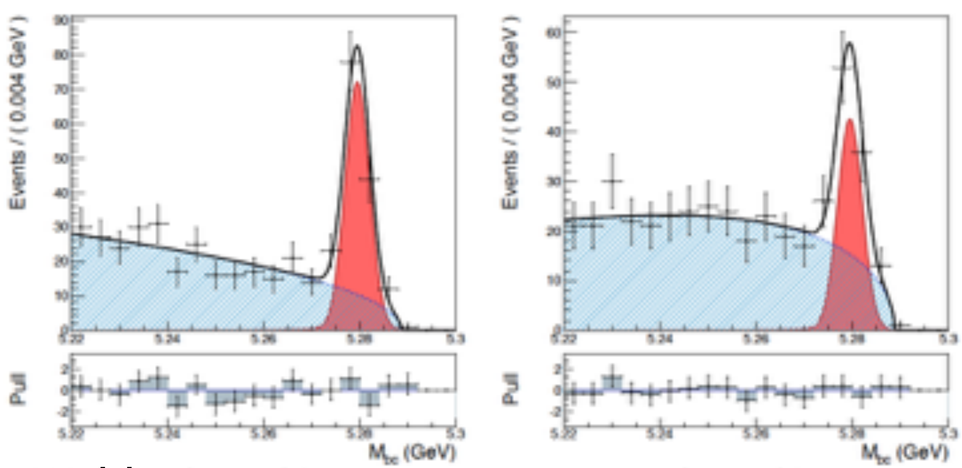

Belle I data S. Wehle,

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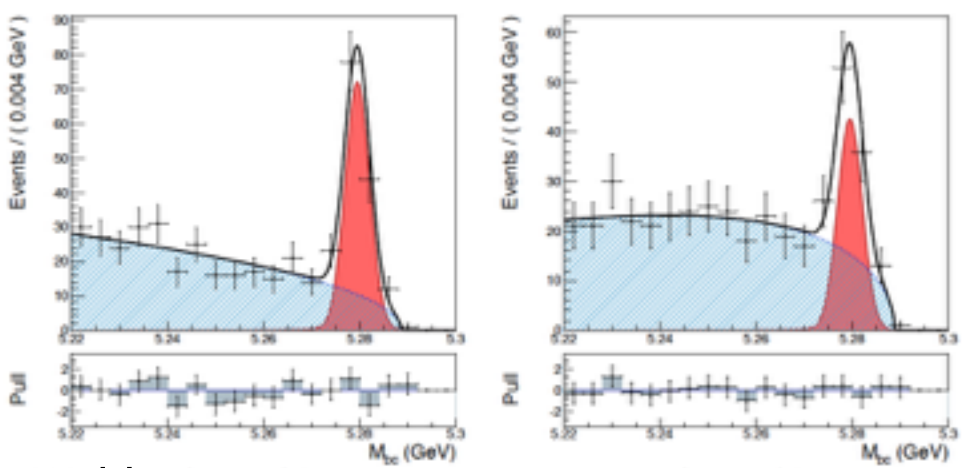

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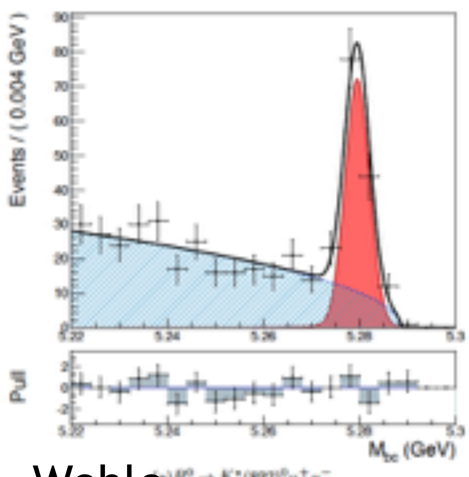

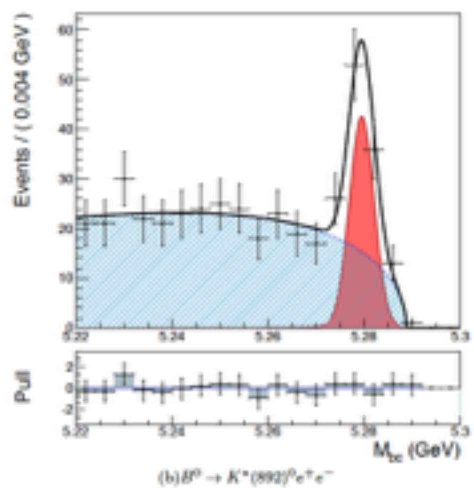

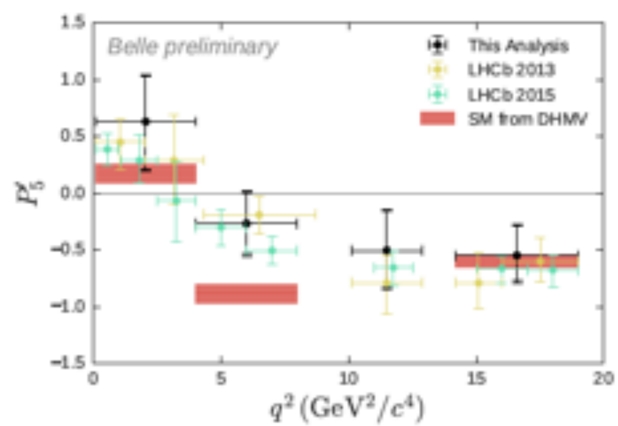

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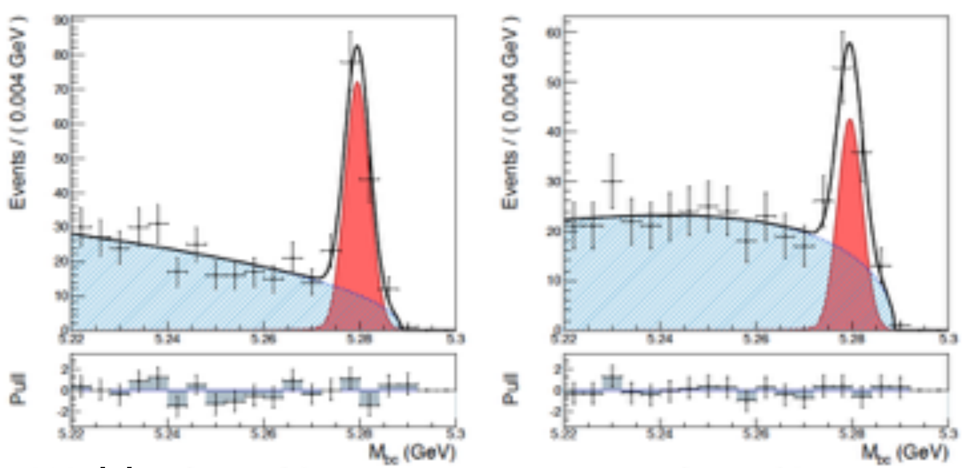
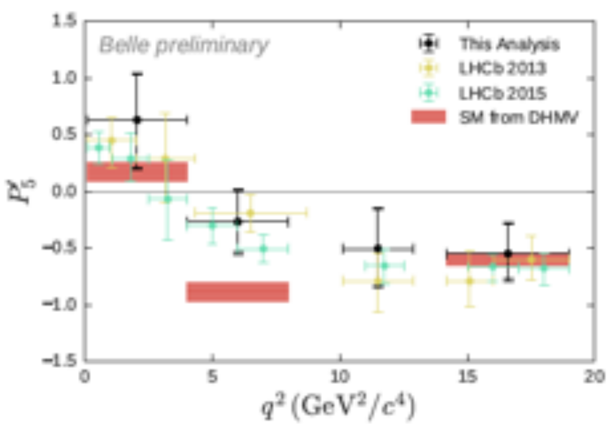
Signal of ~187 events



(a) $B^0 \to K^*(892)^0 \mu^+\mu^-$ (b) $B^0 \to K^*(892)^0 e^+e^-$



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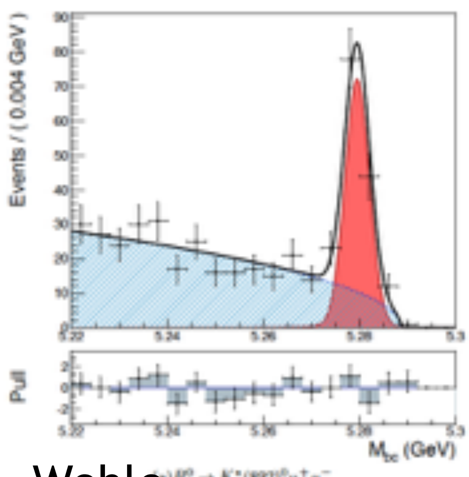

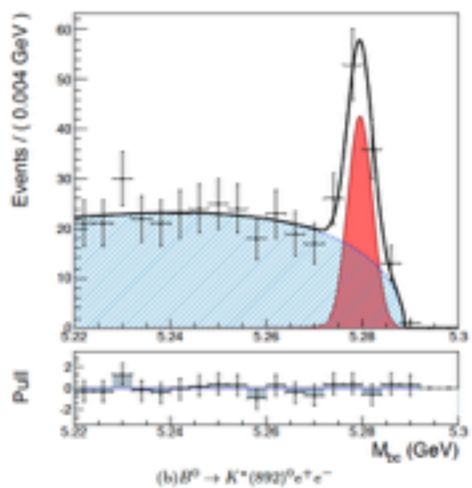

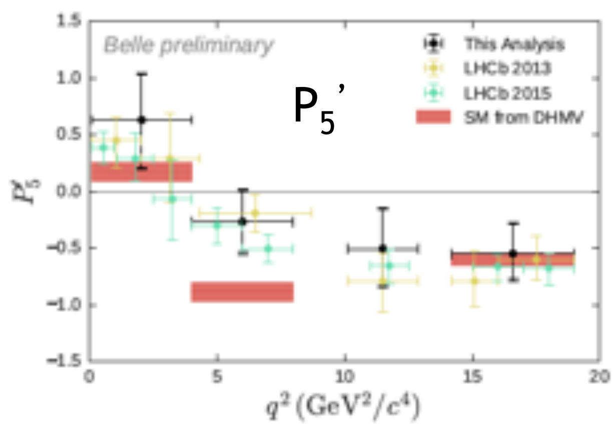

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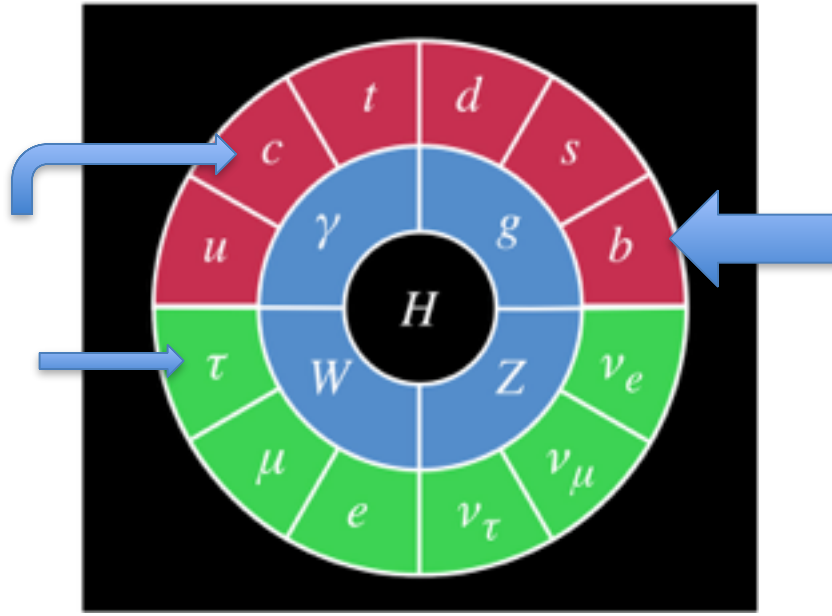
2014 was the 50th anniversary of the discovery of CP violation in the kaon sector [see http://pprc.qmul.ac.uk/research/50-years-cp-violation



The Next Generation

Belle II and the LHCb upgrade

US P5 report (p. v): "Explore the unknown: new particles, interactions, and physical principles"

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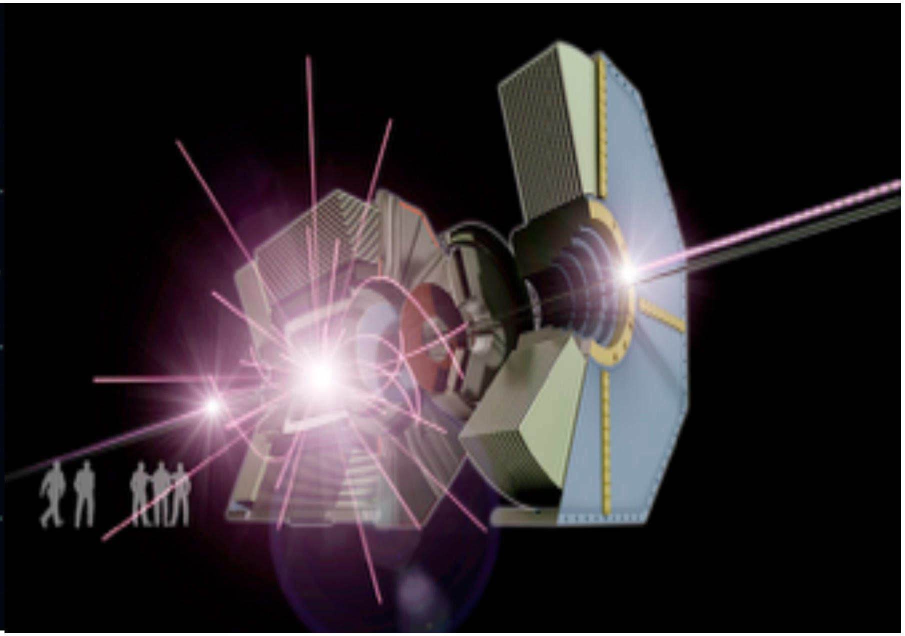

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Physics Reach of Belle II and the LHCb upgrade

Competition and complementarity

Gelato flavors in Asakusa

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K^0_S$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K^0_S \pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
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$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
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$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
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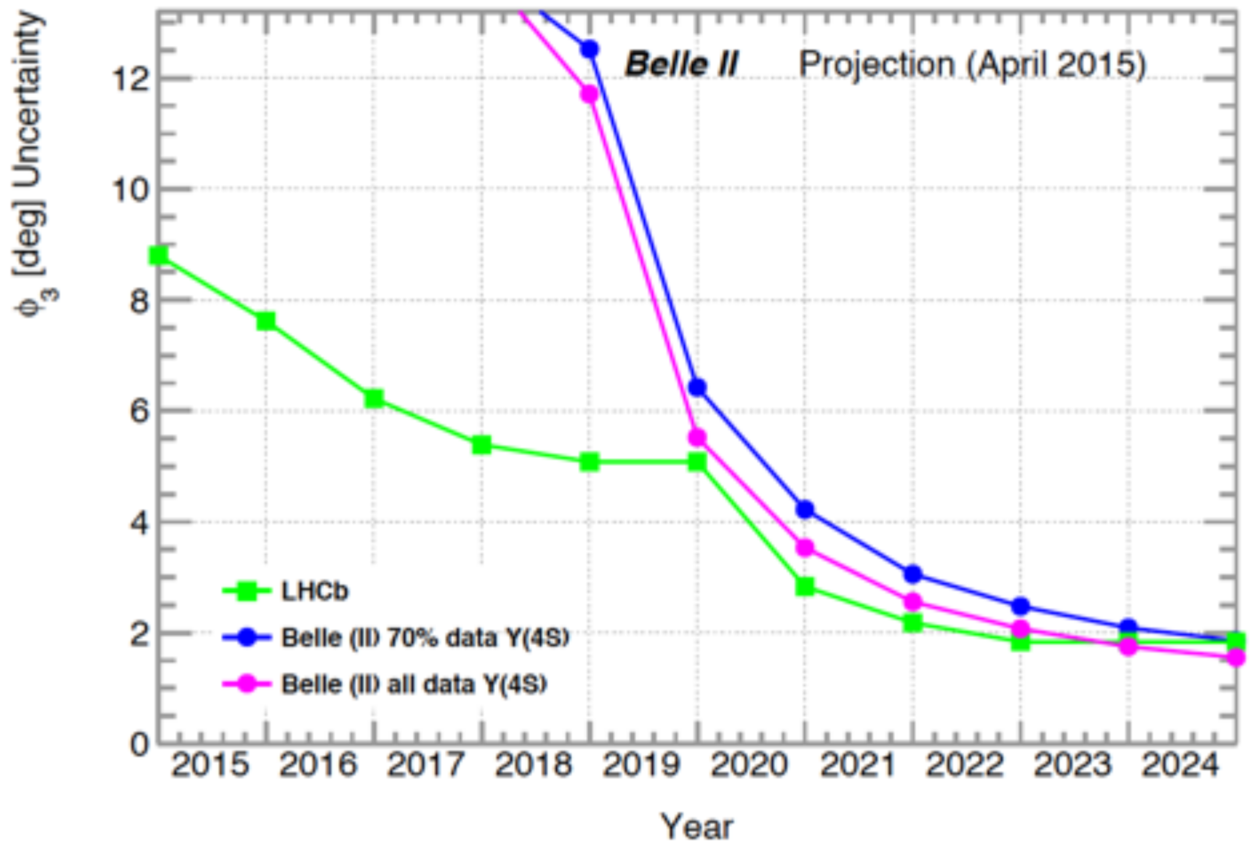
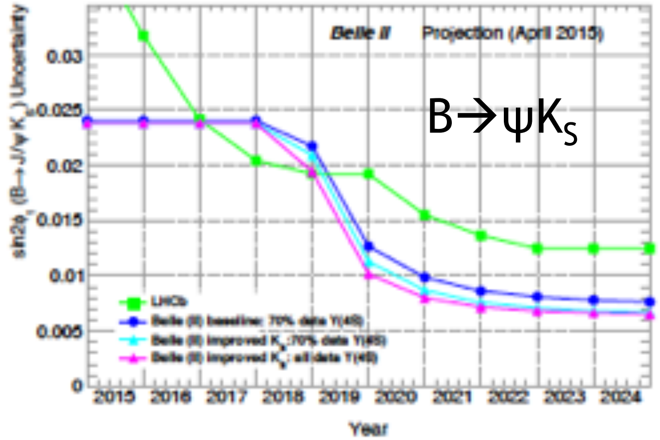
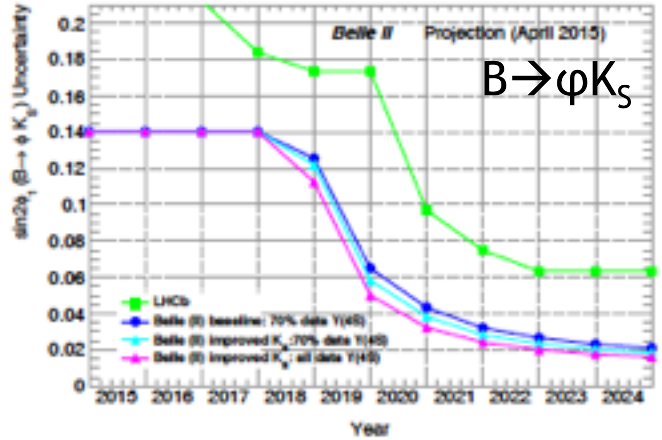
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II



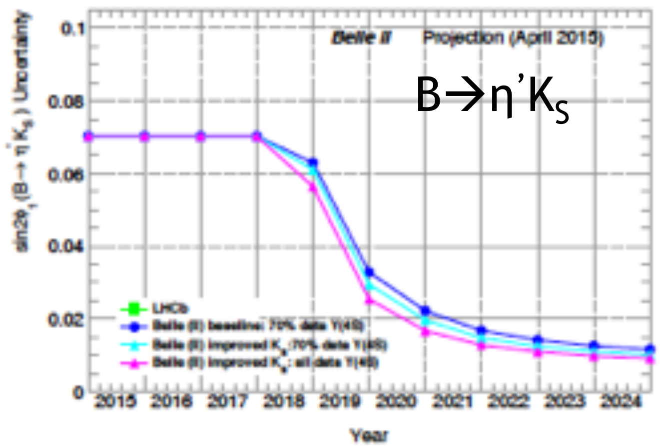
Tight race





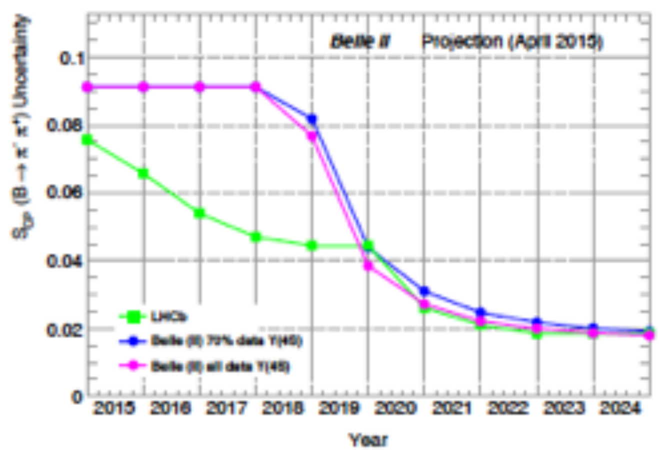
Belle II ahead

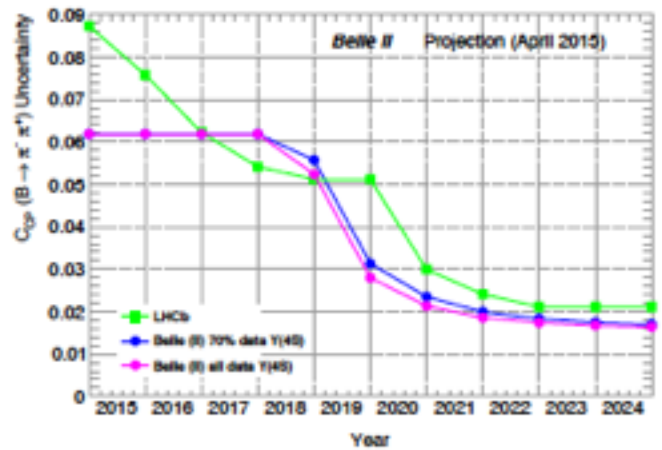
Belle II dominates here



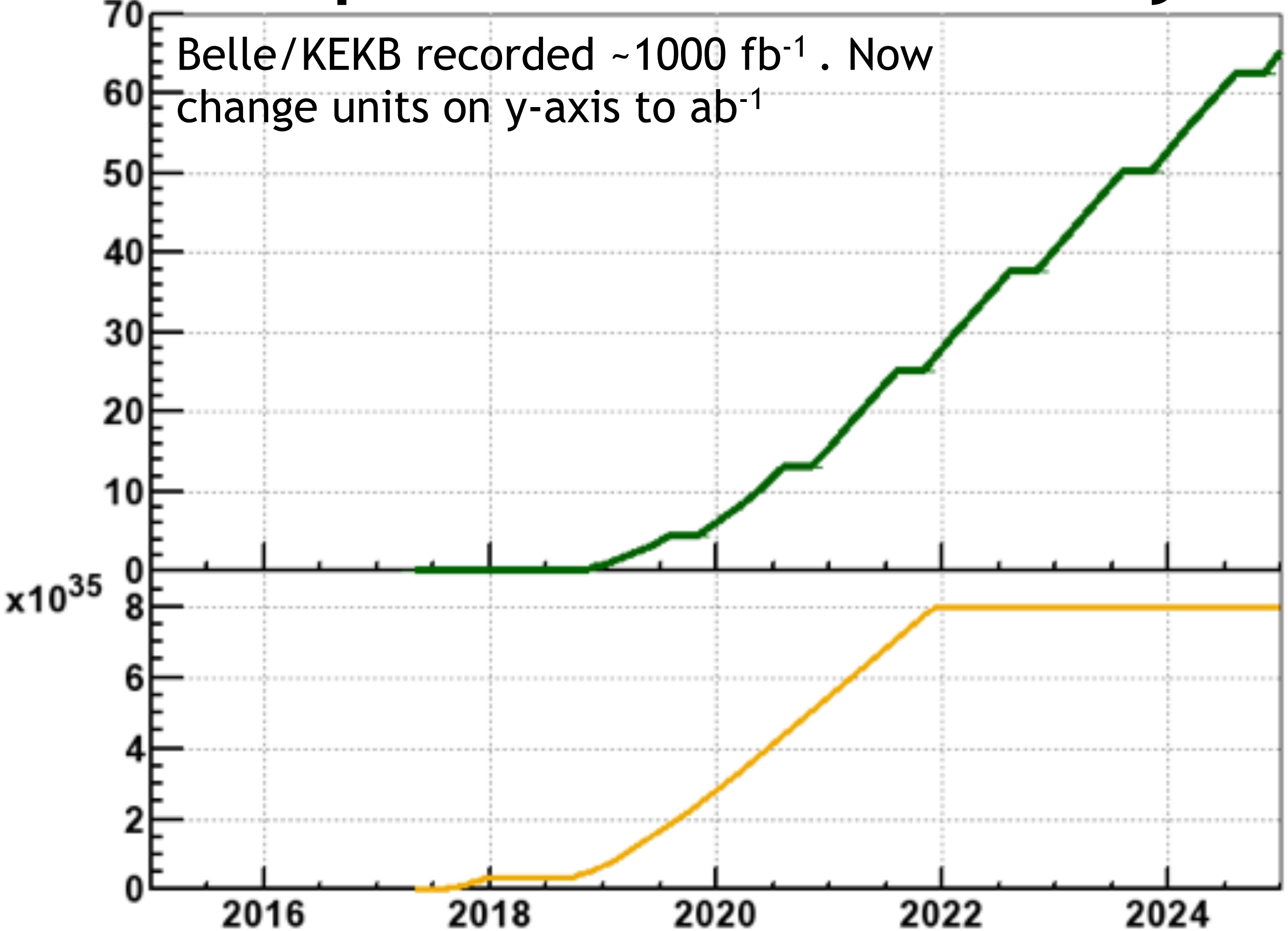
Tight race

B→π$^+$ π$^-$ CPV





Latest SuperKEKB Luminosity Profile



N.B. To realize this steep turn-on, requires close cooperation between Belle II and SuperKEKB [and *international collaboration* on the accelerator].

This plot assumes *full* and *stable* operation funding profile.

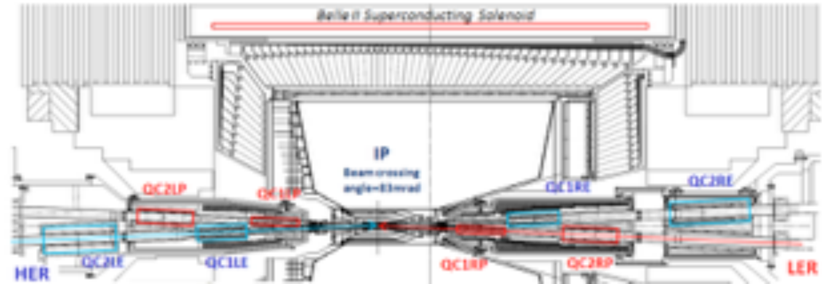
Compare the Parameters for KEKB and SuperKEKB

	KEKB Design	KEKB Achieved : with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y / \varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(mm)	1.9	0.94	0.048/0.062
σ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

Nano-beams are the key (vertical spot size is ~50nm !!)

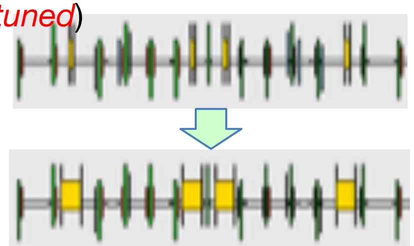
This is not a typo

2016: Basic hardware (except final focus) now in place



New superconducting final focusing magnets near the IP

Redesign the lattice to reduce the emittance (replace short dipoles with longer ones, increase wiggler cycles) (*being tuned*)



e⁺ 3.6A

e⁻ 2.6A

KEKB to SuperKEKB

- Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- Beam current X 2

$$L = \frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

~~40 times higher luminosity~~

$2.1\times10^{34} \rightarrow 8\times10^{35}\ cm^{-2}s^{-1}$

Reinforce RF systems for higher beam currents

Improve monitors and control system

Replace beam pipes with TiN-coated beam pipes with antechambers (*works well*)

Injector Linac upgrade

Upgrade positron capture section

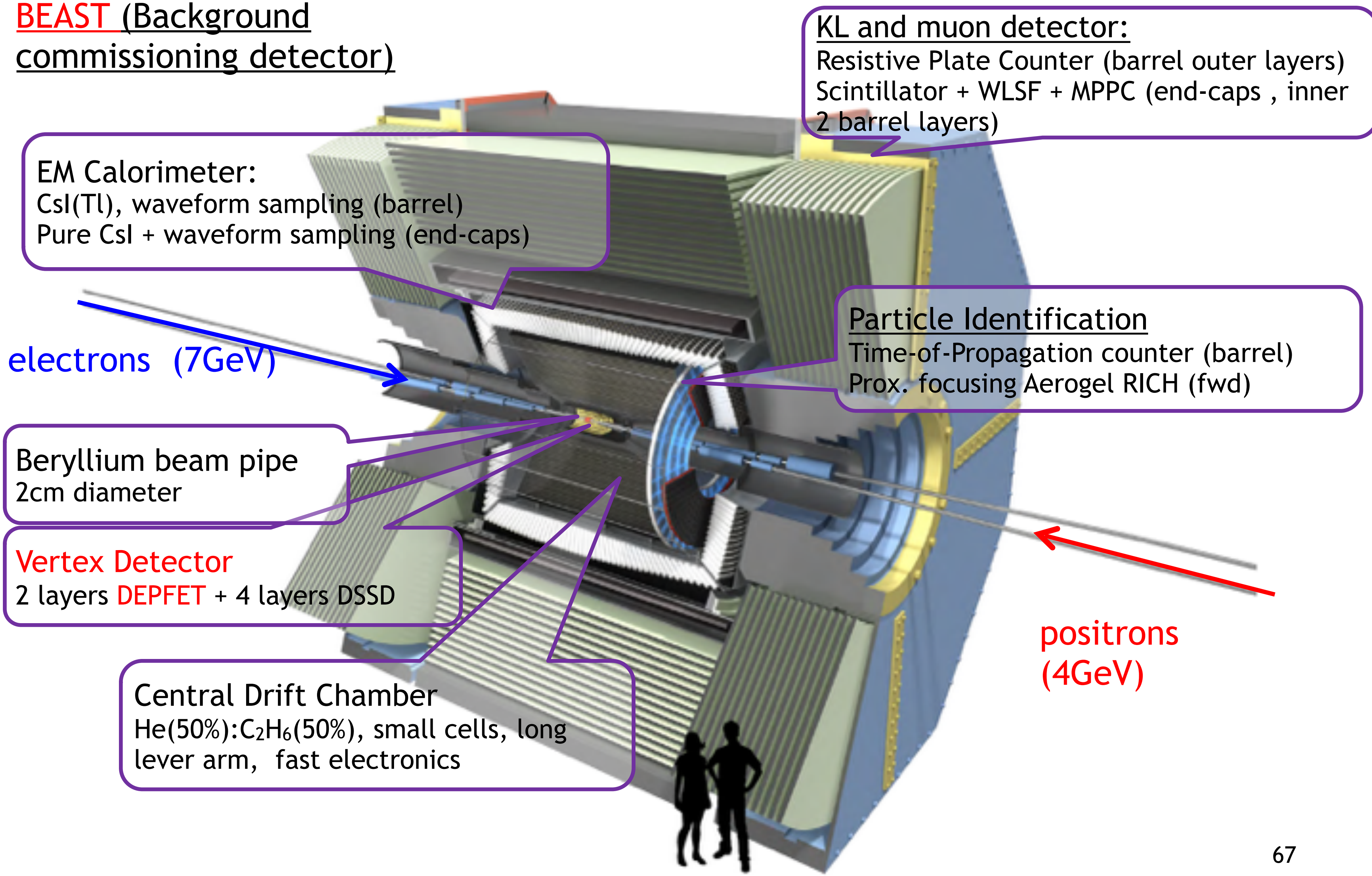
New e+ Damping Ring constructed

Low emittance RF electron gun

German
contribution

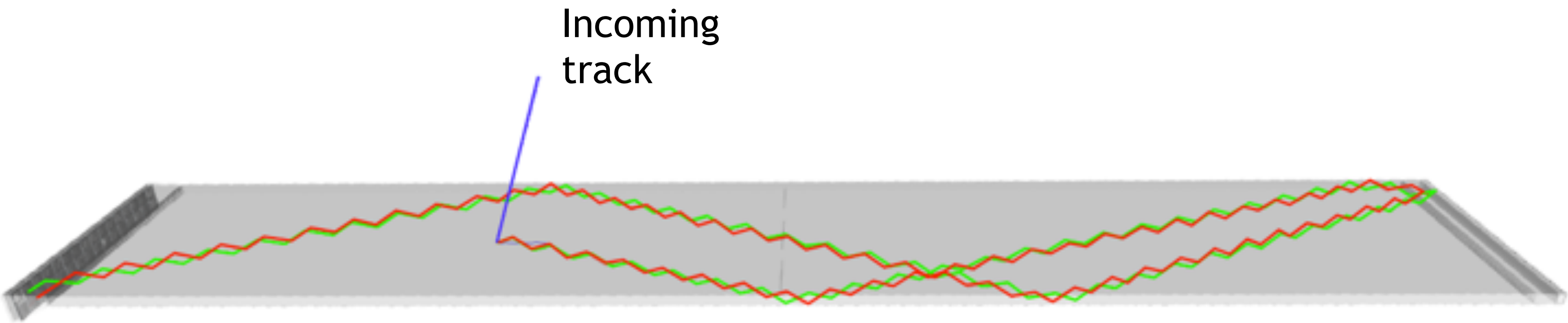
Belle II Detector

BEAST (Background
commissioning detector)

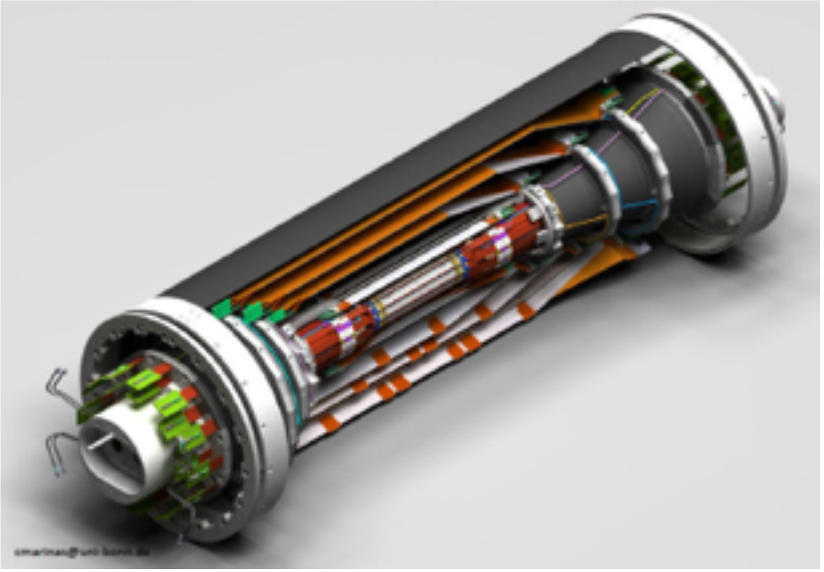


Barrel Particle Identification

A GEANT4 event display of a 2 GeV pion and kaon interacting in a TOP [time of propagation] quartz bar. (Japan, US, Slovenia, Italy)

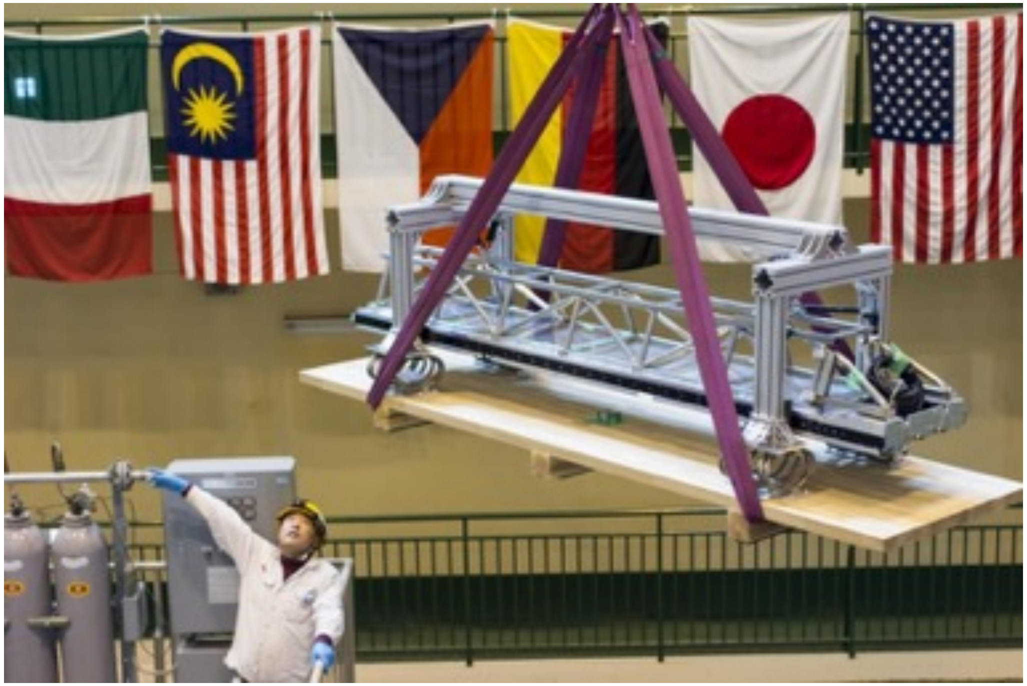


Vertexing/Inner Tracking



Beampipe r= 10 mm
DEPFET pixels
(Germany, Czech Republic, Spain…)
Layer 1 r=14 mm
Layer 2 r= 22 mm
DSSD (double sided silicon detectors) FWD/BWD Italy
Layer 3 r=38 mm (Australia)
Layer 4 r=80 mm (India)
Layer 5 r=115 mm (Austria)
Layer 6 r=140 mm (Japan)
+Poland, Korea

TOP detector at Tsukuba Hall



First TOP module arriving at Tsukuba Hall

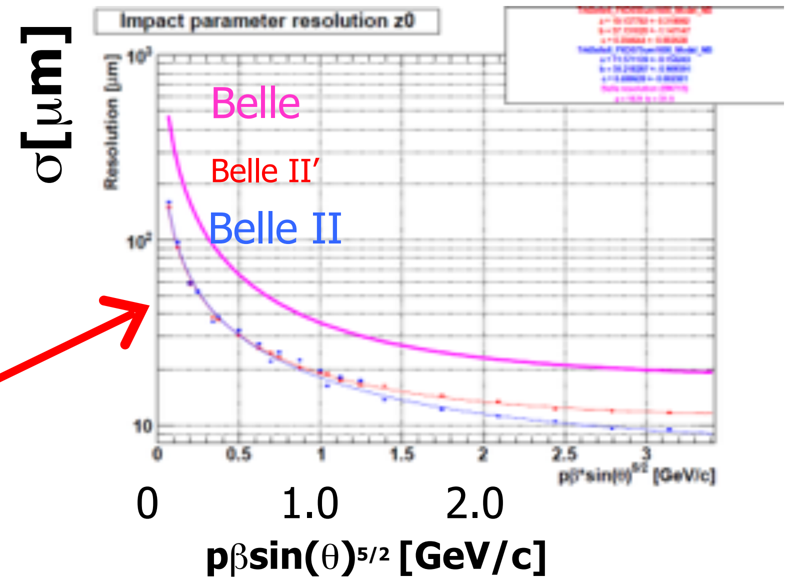
April 2016: Belle II structure

CDC (Central Drift Chamber)

Update: April 20, 2016 8/16 TOP modules were installed into the Belle II structure. Magnetic field mapping then CDC installation in the summer.

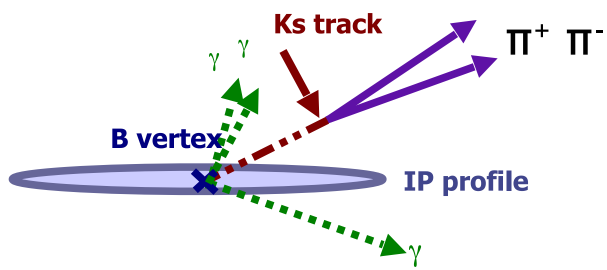
In $e^+ e^-$ scattering at 10-11 GeV, a *critical issue* for vertexing is multiple scattering.

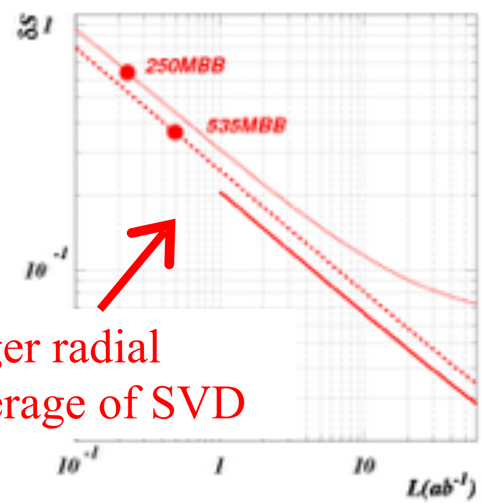
Reduce the multiple scattering lever arm; reduce X_0



Belle: r(beampipe) 2 cm→1.5 cm
Belle II: r(beampipe) 1cm

Large improvement in $\Delta S(B \to [K_S\pi^0]\ \gamma)$



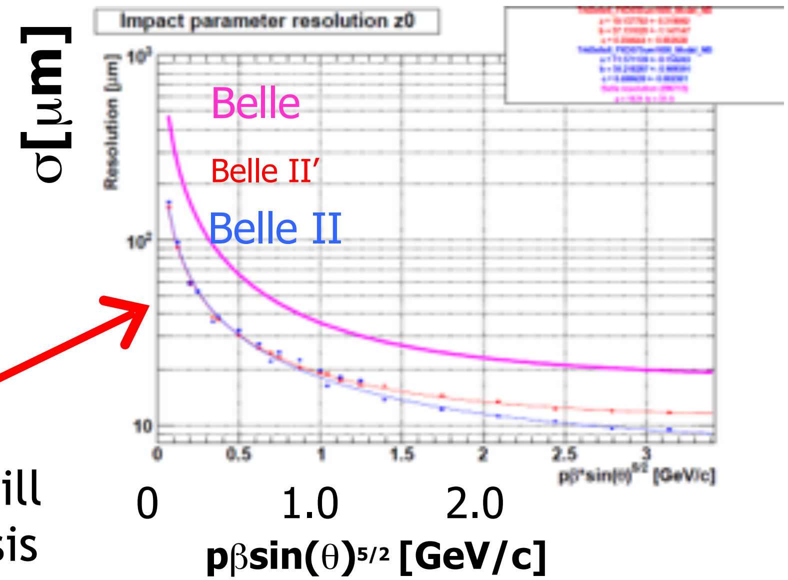


Larger radial coverage of SVD

B decay point reconstruction from the K_S vertex, used in searches for NP right handed currents.

In $e^+ e^-$ scattering at 10-11 GeV, a *critical issue* for vertexing is multiple scattering.

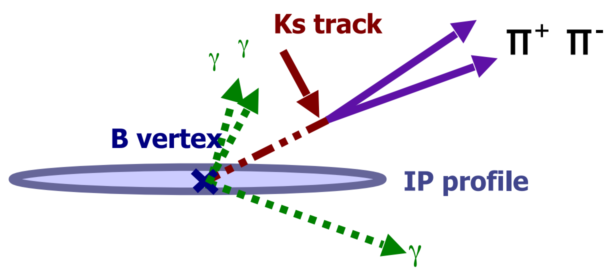
Reduce the multiple scattering lever arm; reduce X_0

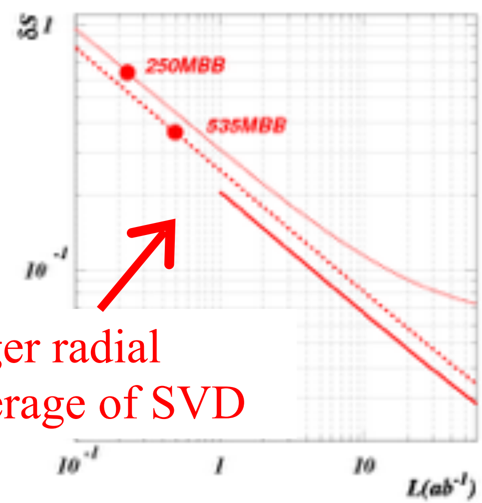


Belle: r(beampipe) 2 cm→1.5 cm
Belle II: r(beampipe) 1cm

Improved resolution and nano-beams will open new possibilities for vertex analysis

Large improvement in $\Delta S(B \rightarrow [K_S \pi^0] \gamma)$

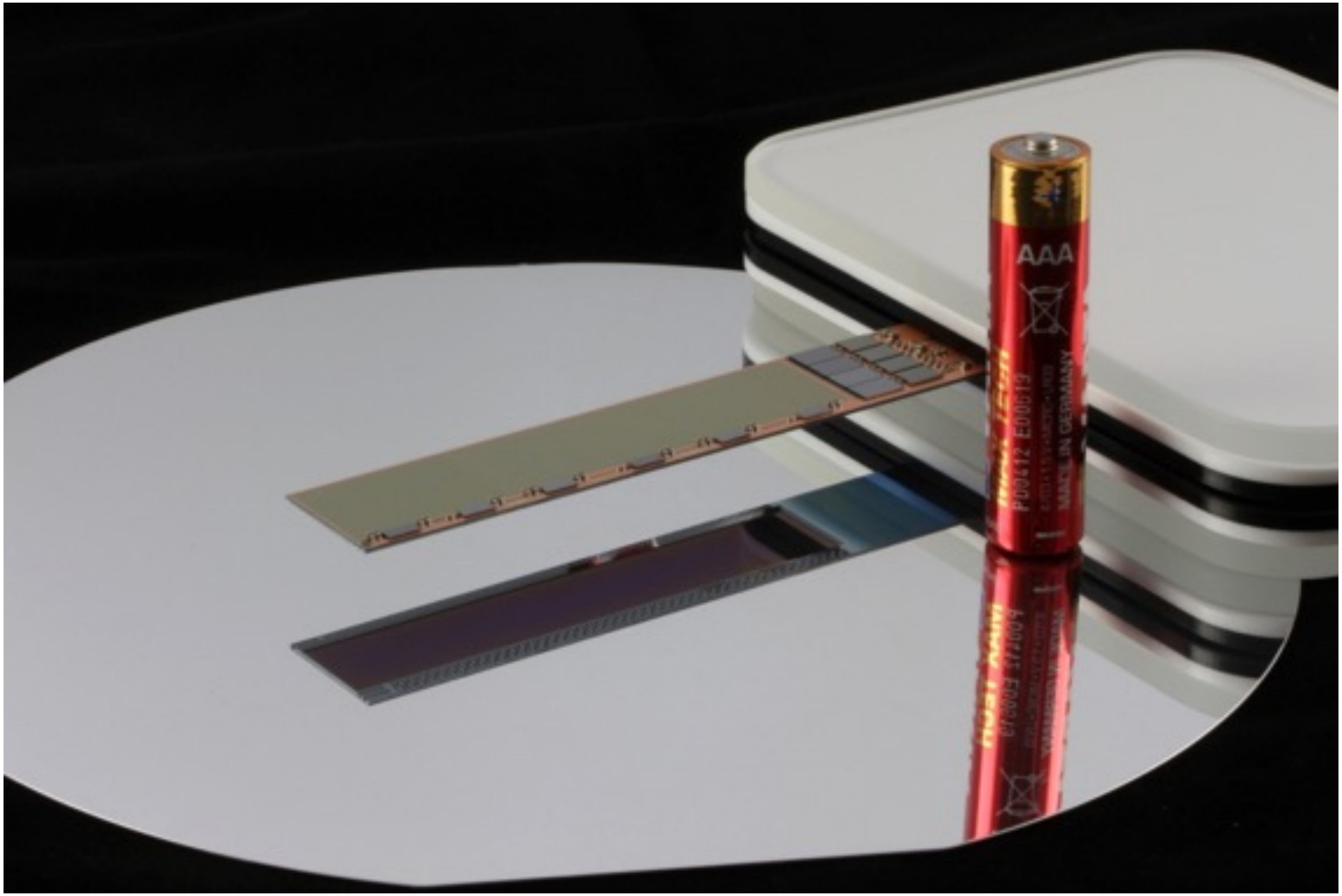




Larger radial coverage of SVD

B decay point reconstruction from the K_S vertex, used in searches for NP right handed currents.

“Full sized” pixel detector module 0

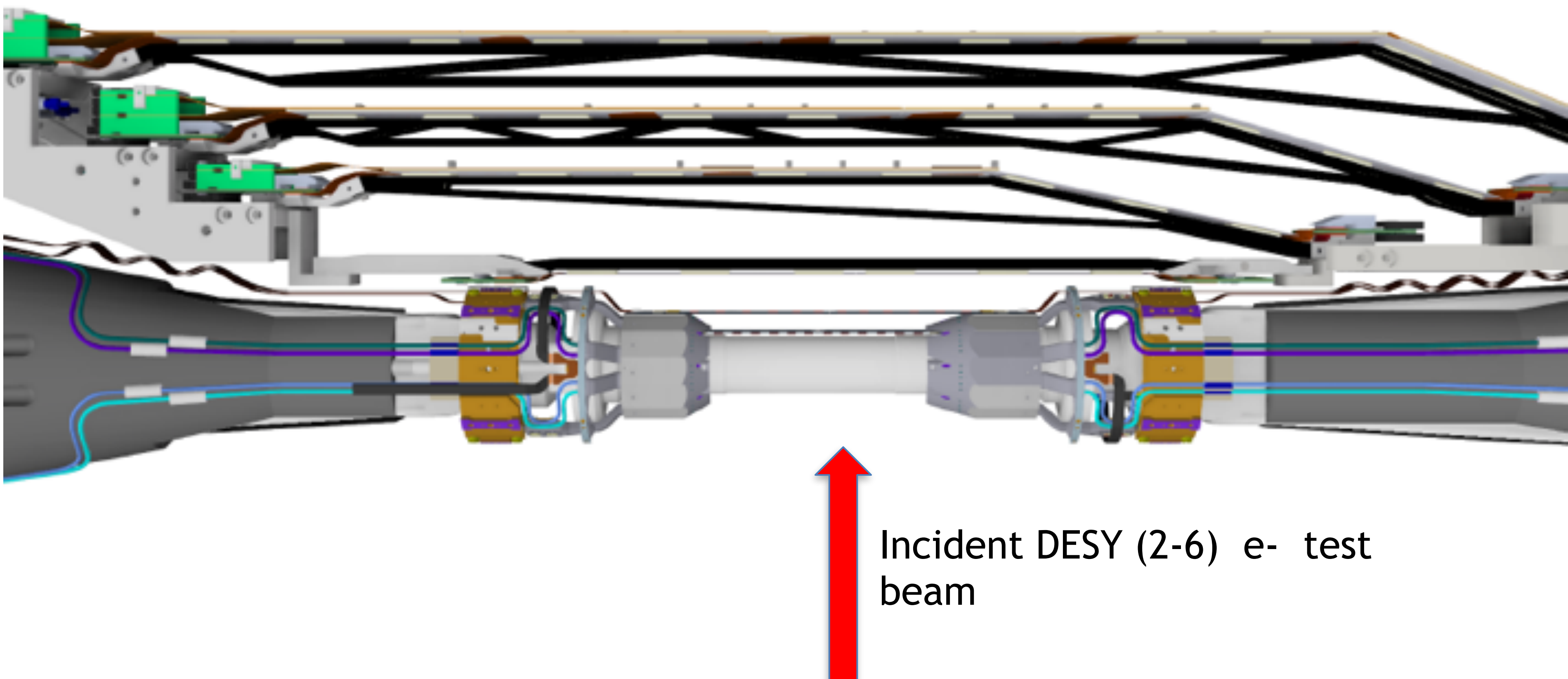


75 µm thick

Pixel detector group from many institutes and universities in Germany

April 2016: Belle II VXD beam test at DESY

(DESY provides the infrastructure and facilities for this critical beam test)

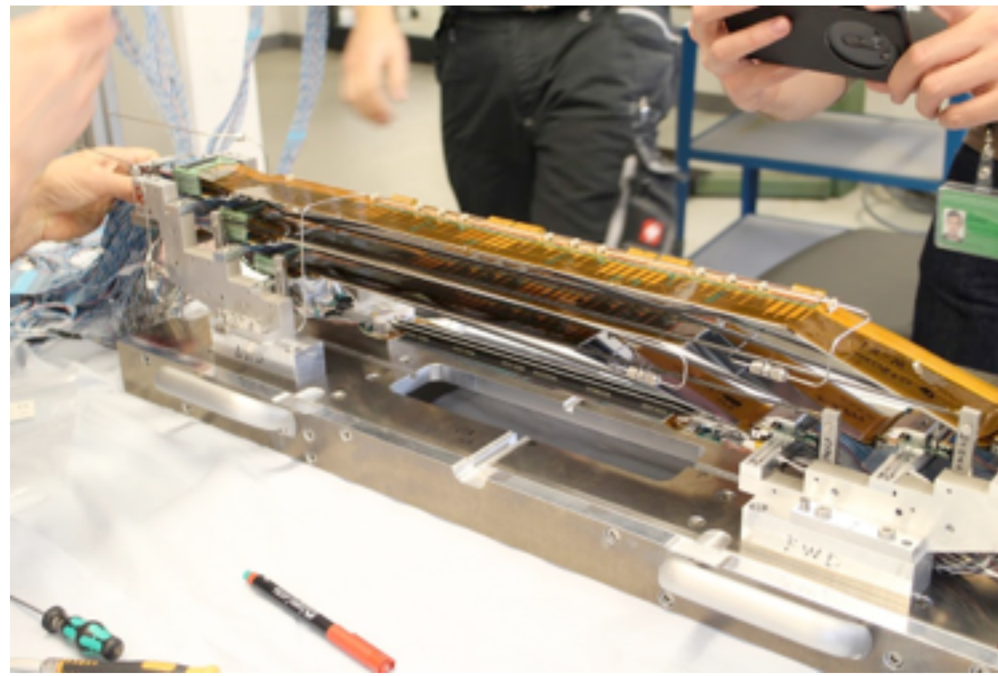


Incident DESY (2-6) e- test beam

April 2016: Two *full-sized* Belle II DEPFET pixel detector modules at DESY (readout full system with beam this morning)

Test full-sized PXD modules in a beam. [Measure efficiency and S/N].

Working examples of L3, L4, L5, L6 SVD ladders



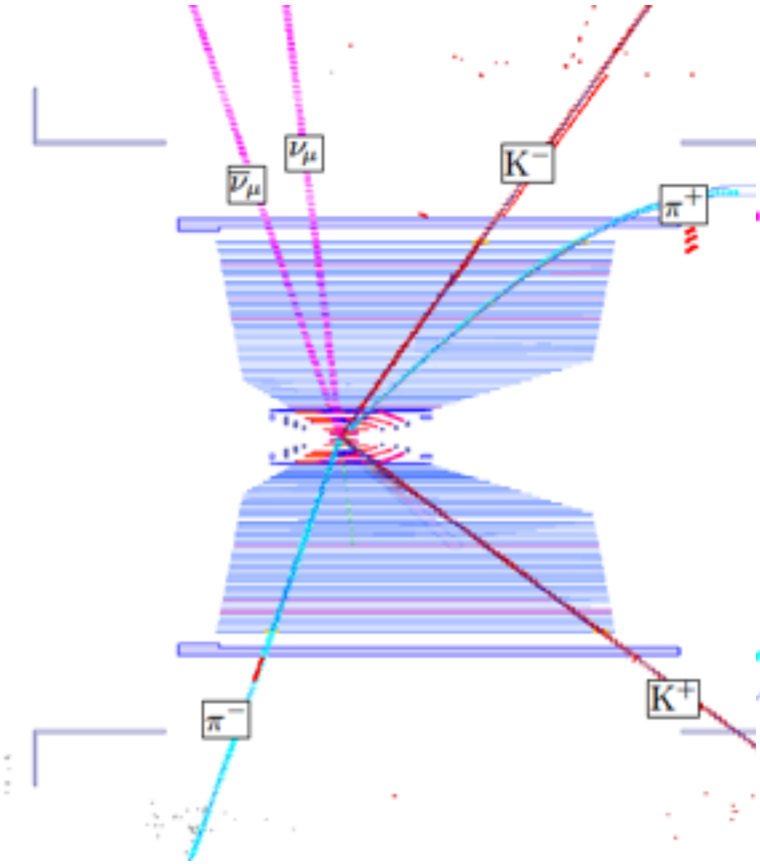
Test the integrated PXD-SVD system. This includes ROI (region of interest) extrapolation from the SVD tracker to the PXD, which is needed to reduce the *large data volume*.

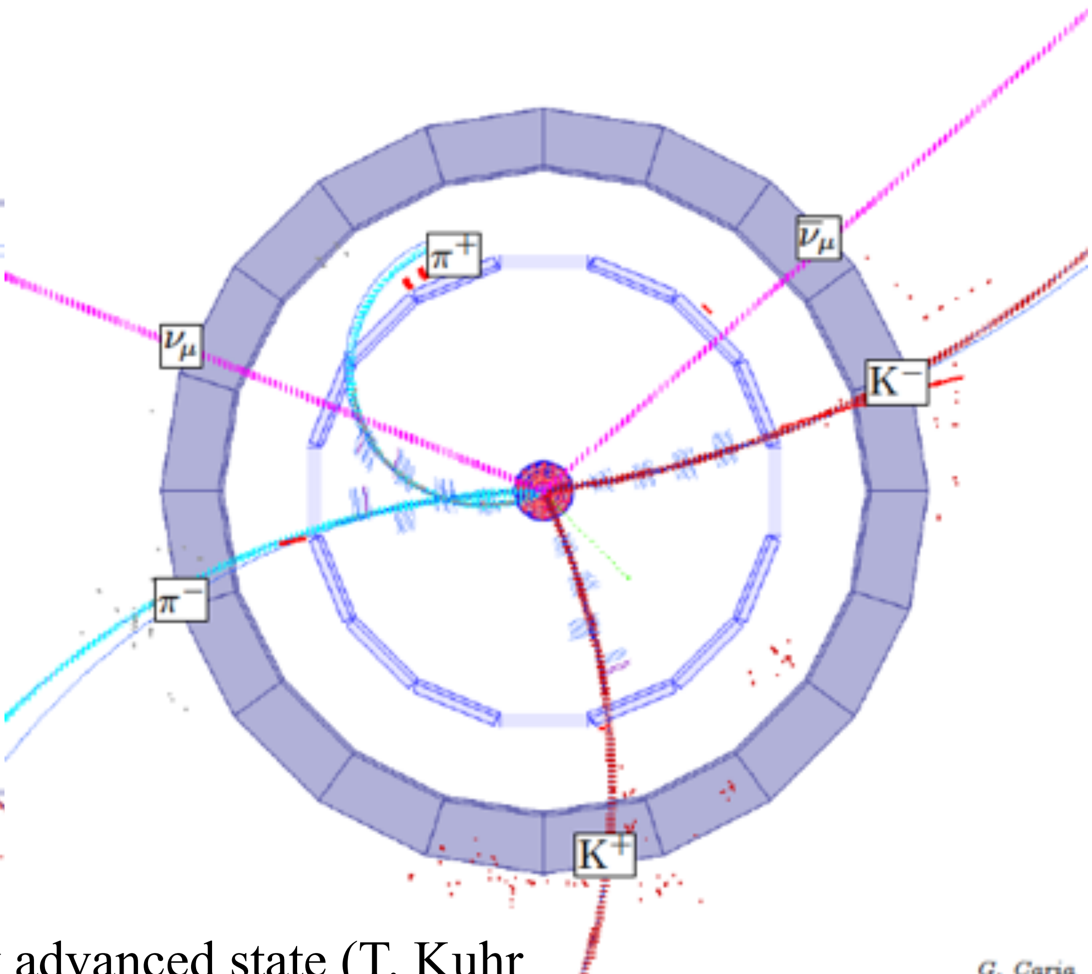
“Missing Energy Decay” in a Belle II GEANT4 MC simulation

Signal B→K ν ν   tag mode: B→Dπ; D→Kπ

View in r-z

Zoomed view of the vertex region in r--phi





→Belle II Software is in a fairly advanced state (T. Kuhr (LMU) is the Belle II software coordinator)

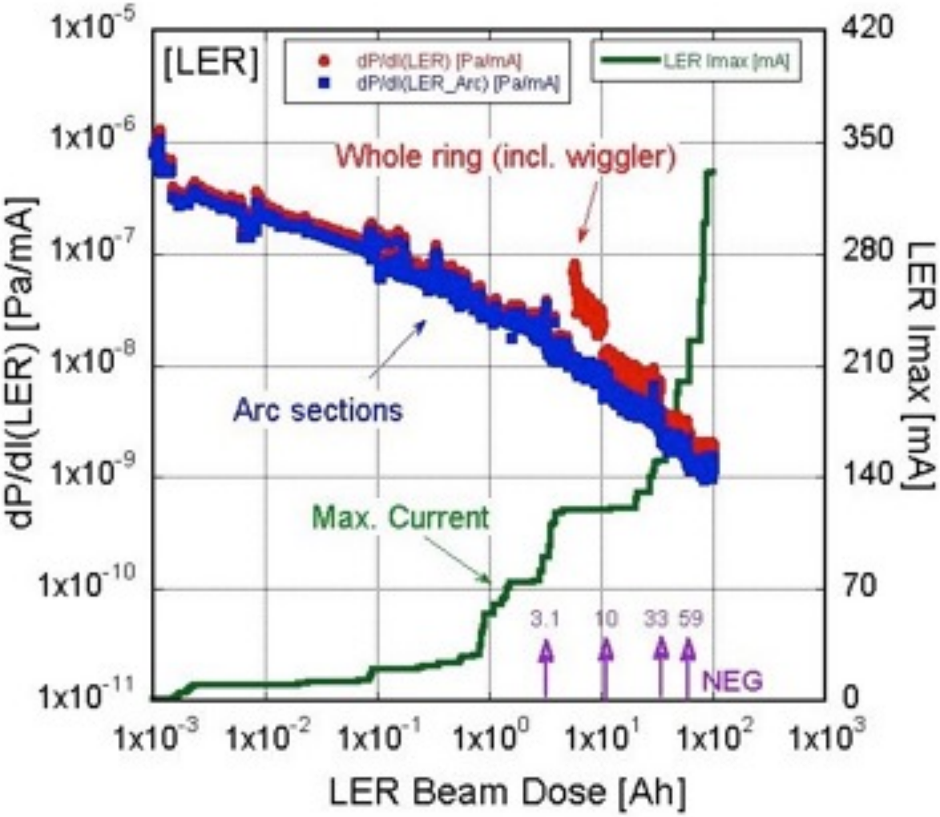
Some Belle II jargon

BEAST PHASE I: Simple background commissioning detector (diodes, TPCs, crystals). No final focus. Only *single* beam background studies possible [started in Feb 2016].

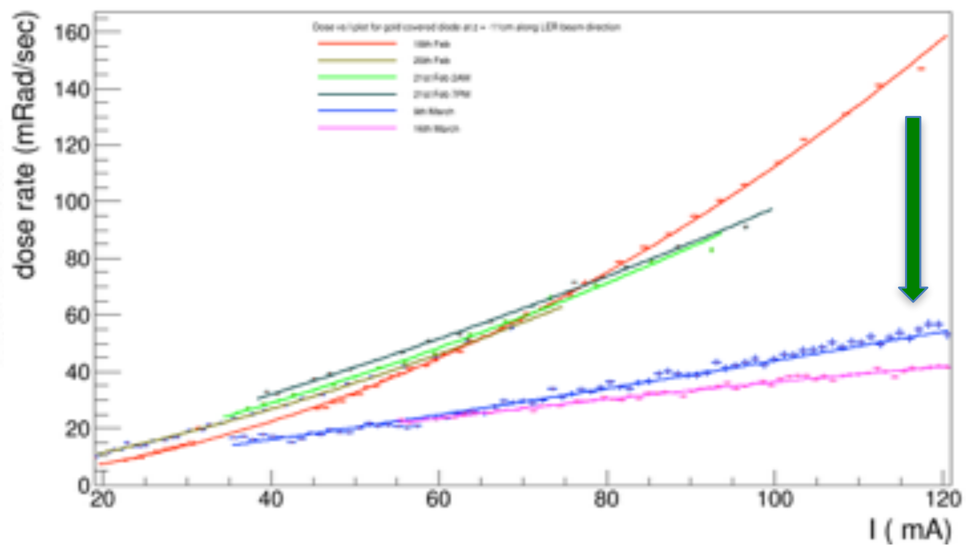
BEAST PHASE II: More elaborate inner background commissioning detector. Full Belle II outer detector. Full superconducting final focus. *No vertex detectors*.

SuperKEKB vacuum scrubbing to reduce beam gas backgrounds in Belle II

LER integrated beam dose > 100 A-h

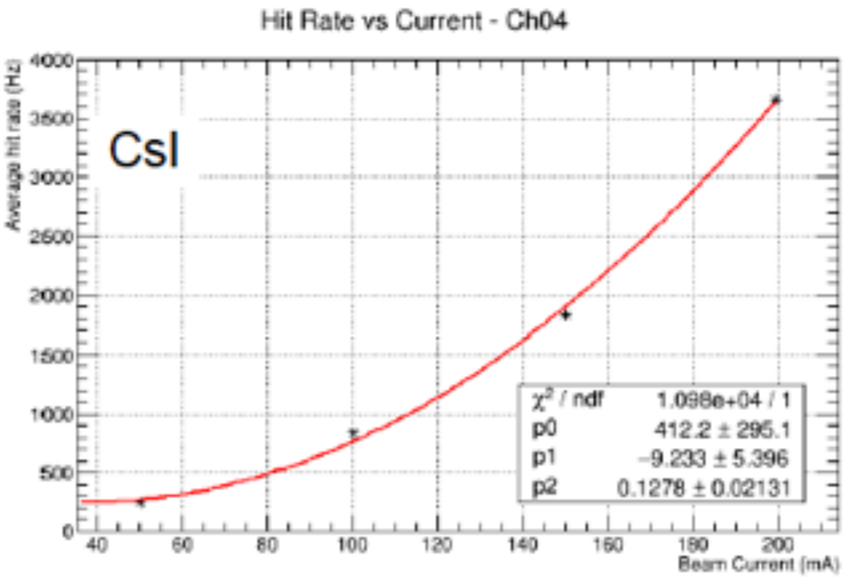


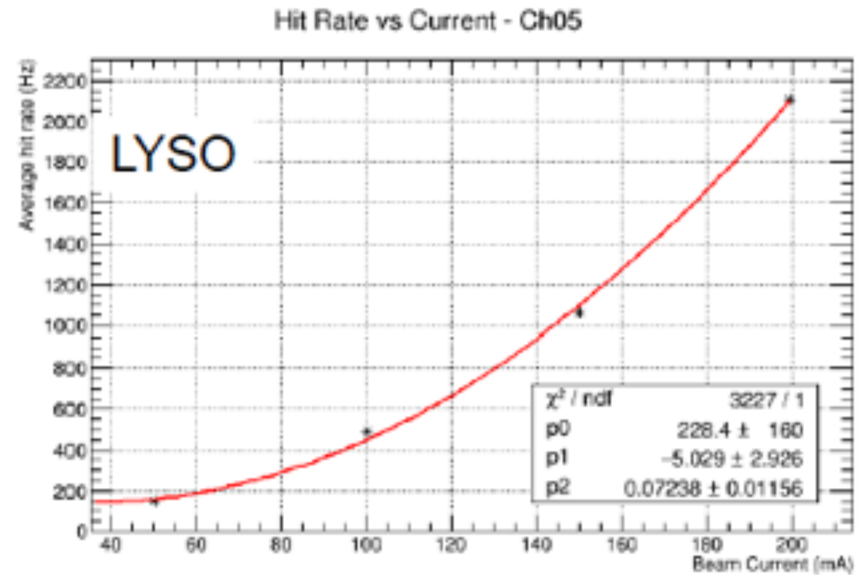
BEAST background in the LER vs time



BEAST data shows the LER backgrounds decreasing as vacuum scrubbing proceeds.

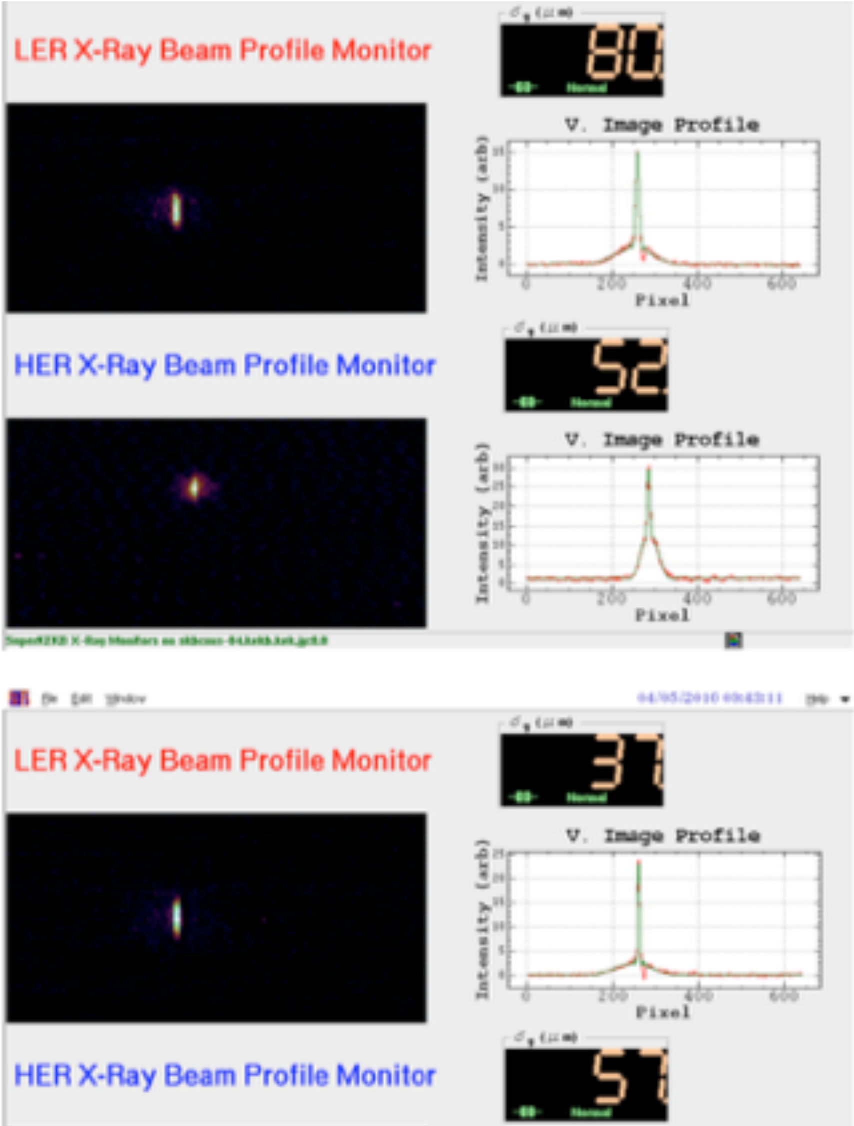
SuperKEKB vacuum scrubbing to reduce beam gas backgrounds in Belle II





HER beam background vs current (April 7, 2016)

“Cool” (low-emittance) and *flat* beams in SuperKEKB



ε_y = 96 pm (β_y = 67 m@source)
$\varepsilon_y / \varepsilon_x$= 5.3 % ($\varepsilon_x$ = 1.8 nm)

March 23, 2016

ε_y = 280 pm (β_y = 9.7 m@source)
$\varepsilon_y / \varepsilon_x$= 5.3 % ($\varepsilon_x$ = 5.3 nm)

April 5, 2016

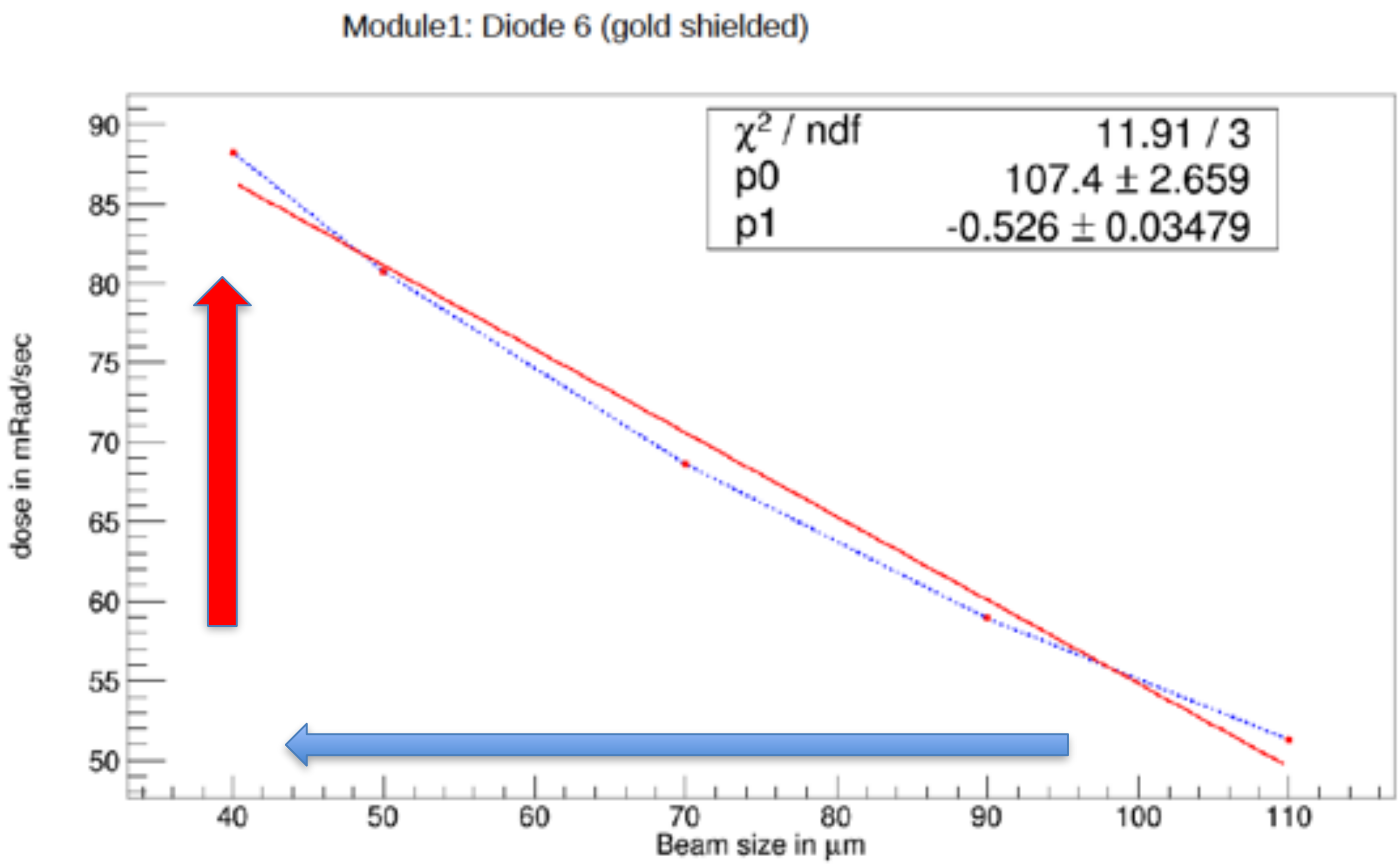
ε_y = 20 pm (β_y = 67 m@source)
$\varepsilon_y / \varepsilon_x$= 1.1 % ($\varepsilon_x$ = 1.8 nm)

HER to be remeasured soon
after optics tuning.

Improved calibration of X-ray monitor beam size monitor will be done shortl

April 2016: Large Touschek background observed in the LER

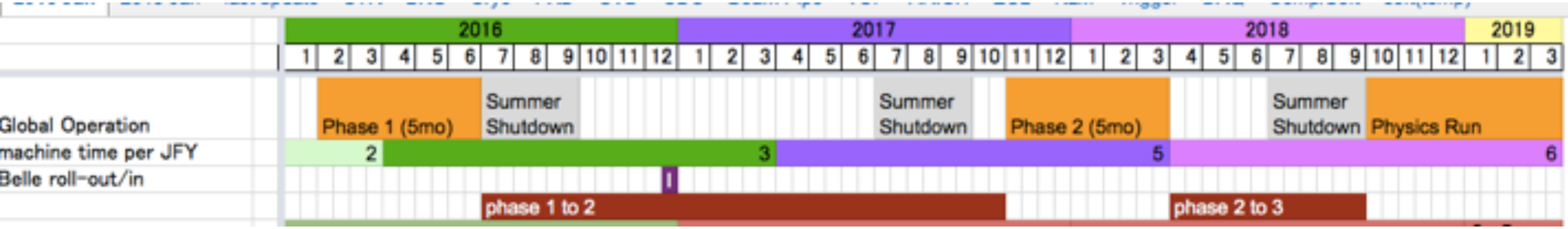
Bkg in BEAST



Vertical beam size from size monitor (not measured at IP)

→Will need excellent collimators to handle nano-beam backgounds.

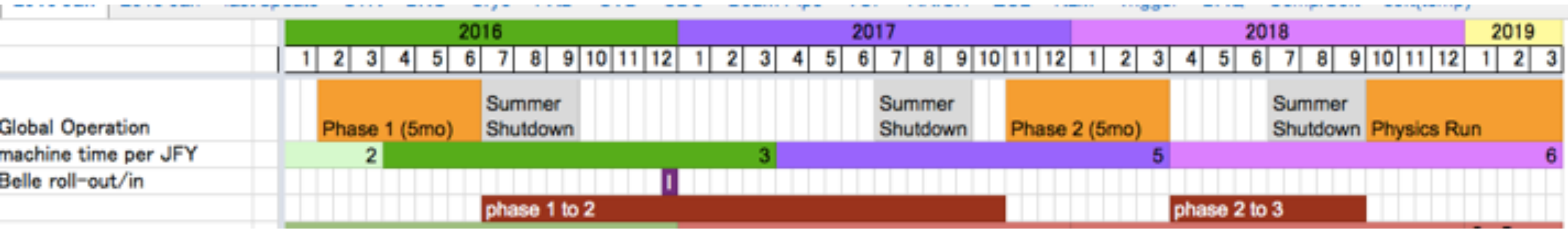
Belle II Schedule



When do we start Belle II ?

QCSL at KEK, Dec 2015

Belle II Schedule



When do we start Belle II ?

BEAST PHASE I: Started in Feb 2016 (Belle II roll-in at the end of the year)

BEAST PHASE II: Starts in Nov 2017 [first collisions, limited physics without vertex detectors]

<u>Belle II Physics Running</u>: Fall 2018 [vertex detectors in]

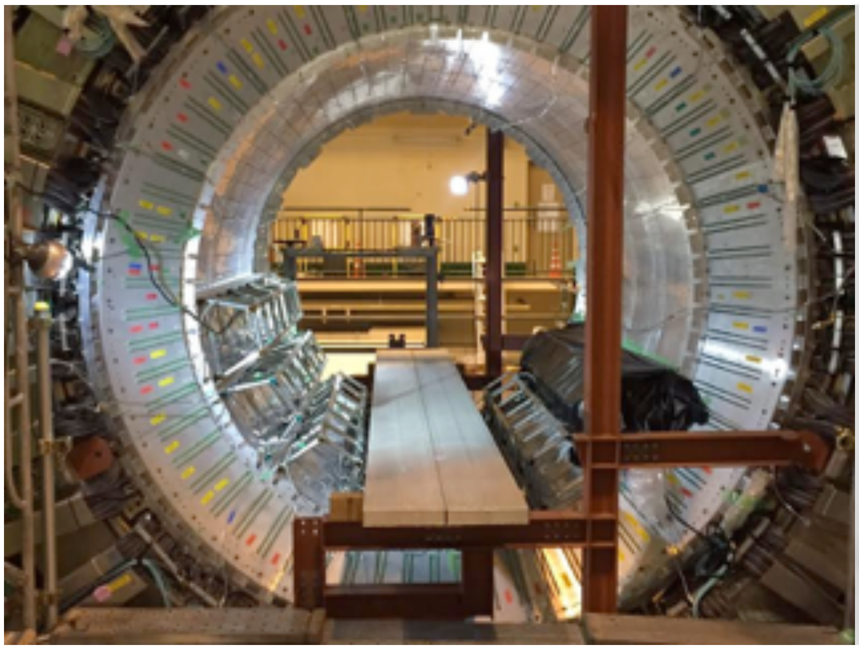
QCSL at KEK, Dec 2015

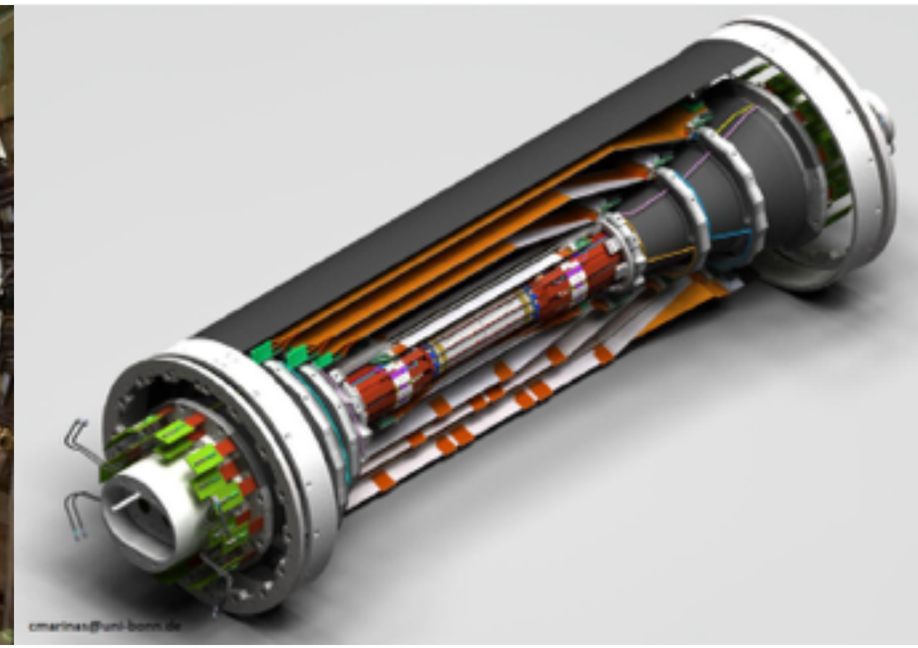
Conclusion/Next Generation

- Flavor physics is exciting and fundamental. *Did we just find NP via new weak interaction couplings ?*
- *Flavor could be the path for the future of HEP but we need much more data.*
- *Time for a Paradigm Shift ?*

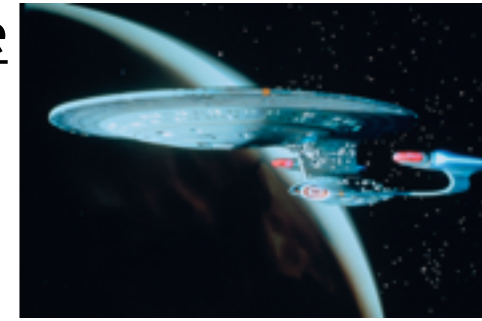
SuperKEKB commissioning started in February. Belle II rolls in at the end of the year. First collisions in fall 2017. Belle II physics runs in 2018 and the LHCb upgrade in ~2021. These facilities will inaugurate a new era of flavor physics and the study of CP violation.

Backup slides





Innovative Technologies in Belle II



<u>Pixelated photo-sensors play a central role</u>

MCP-PMTs in the iTOP
HAPDs in the ARICH
SiPMs in the KLM, DEPFET pixels

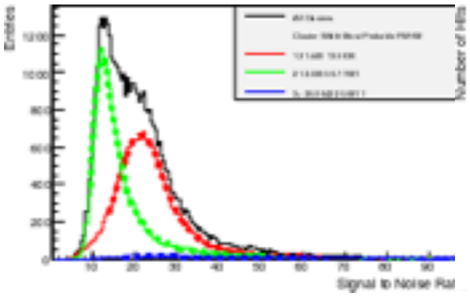
<u>Waveform sampling with precise timing is "saving our butts".</u>
Front-end custom ASICs (Application Specific Integrated Circuits) for all subsystems ➔<u>a 21st century HEP experiment.</u>

Pixel detector [3 custom German ASICs: DCD, DHP, Switcher]
KL/muon detector (TARGETX ASIC)
Electromagnetic calorimeter
(New waveform sampling backend with good timing)
iTOP particle identification (IRSX ASIC)
Aerogel RICH (KEK custom ASIC)
Central Drift Chamber (KEK custom ASIC)
SVD (APV2.5 readout chip adapted from CMS)

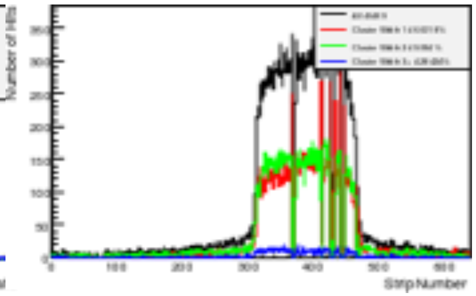
Highlights of Belle II construction

SuperKEKB hardware is being finalized.

BEAST PHASE I beampipe installed

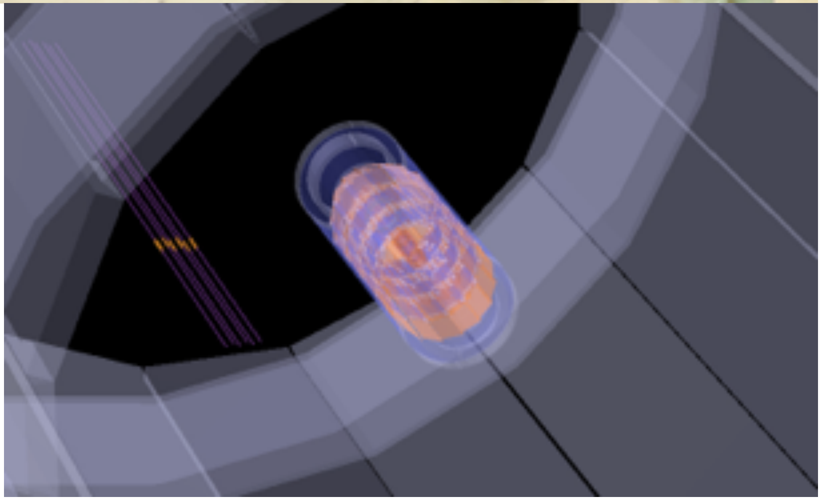


S/N



Hits

Final Belle II SVD ladder in CERN beam in June (working well !)



(a) CDC arriving at Tsukuba Hall; (b) first cosmics with partly instrumented electronics (6 layers)

Belle II construction status

"Tensions are high, tempers are short."

Name	Institution	Country
Andricek, Ladislav	MPG HLL	GERMANY
Bacher, Szymon	IFJ	POLAND
Bilka, Tadeas	Charles University	CZECH REPUBLIC
Buchsteiner, Florian	HEPHY Vienna	AUSTRIA
Bulla, Lukas	HEPHY Vienna	AUSTRIA
Caria, Giacomo	University of Melbourne	AUSTRALIA
Casarosa, Giulia	INFN Pisa	ITALY
Deschamps, Bruno	University of Bonn	GERMANY
Dutta, Deepanwita	Tata Institute of Fundamental Research	INDIA
Friedl, Markus	HEPHY Vienna	AUSTRIA
Germic, Leonard	University of Bonn	GERMANY
Gessler, Thomas	KEK/JSPS	JAPAN
Getzkow, Dennis	University Giessen	GERMANY
Gonzalez Sanchez, Francisco Javier	Instituto de Fisica de Cantabria (IFCA)	SPAIN
Guo, Aiqiang	DESY and IHEP	GERMANY
Hoek, Matthias	JGU Mainz	GERMANY
Irmler, Christian	HEPHY Vienna	AUSTRIA
Itoh, Ryosuke	KEK	JAPAN
Joo, Changwoo	Seoul	KOREA
Kiesling, Christian	Max-Planck-Institut für Physik	GERMANY
Kodys, Peter	Charles University	CZECH REPUBLIC
Koffmane, Christian	Halbleiterlabor der Max-Planck-Gesellschaft	GERMANY
Konno, Tomoyuki	KEK	JAPAN
Konorov, Igor	TU Munich	GERMANY
Kühn, Wolfgang	JLU Giessen	GERMANY
Kvasnicka, Peter	Charles University	CZECH REPUBLIC
Lanceri, Livio	University of Trieste and INFN	ITALY
Lange, Jens Sören	University Giessen	GERMANY
Lautenbach, Klemens	JLU Giessen	GERMANY
Leitl, Philipp	Max-Planck-Institut für Physik	GERMANY
Lettenbichler, Jakob	HEPHY	AUSTRIA
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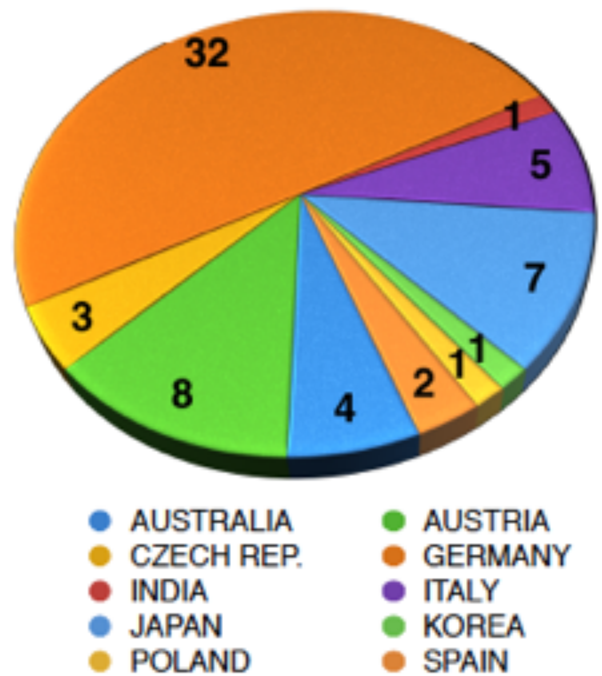
Lueck, Thomas	INFN - sezione di Pisa	ITALY
Lütticke, Florian	Bonn University	GERMANY
Marinas, Carlos	University of Bonn	GERMANY
MARTIN, David	Instituto de Fisica de Cantabria (IFCA)	SPAIN
Moser, Hans-Günther	Max-Planck-Institut für Physik	GERMANY
Müller, Felix	MPI for Physics	GERMANY
Nakamura, Katsuro	KEK	JAPAN
Nakao, Mikihiko	KEK	JAPAN
Niebuhr, Carsten	DESY	GERMANY
Paoloni, Eugenio	INFN	ITALY
Paschen, Botho	University of Bonn	GERMANY
Prinker, Eduard	Max Planck Society	GERMANY
Ritzert, Michael	Heidelberg University	GERMANY
Röder, Thorsten	Max Planck Institut für Physik	GERMANY
Rummel, Stefan	LMU	GERMANY
Schreeck, Harrison	University of Göttingen	GERMANY
Schwanda, Christoph	HEPHY Vienna	AUSTRIA
Schwenker, Benjamin	Universität Göttingen	GERMANY
Soloviev, Yuri	DESY	GERMANY
Soltau, Julian Martin	Georg-August-Universität Göttingen	GERMANY
Spruck, Bjoern	Institut fuer Kernphysik, Universitaet Mainz	GERMANY
Stever, Reimer	Deutsches Elektronen-Synchrotron DESY	GERMANY
Stolzenberg, Ulf	Universität Göttingen	GERMANY
Suzuki, Soh	KEK	JAPAN
Taylor, Geoffrey	University of Melbournbe	AUSTRALIA
Thalmeier, Richard	HEPHY Vienna	AUSTRIA
Vitale, Lorenzo	INFN and Univ. Trieste ITALY	ITALY
Webb, James	University of Melbourne	AUSTRALIA
Wessel, Christian	University of Bonn	GERMANY
Williams, Scott	University of Melbourne	AUSTRALIA
Yamada, Satoru	KEK	JAPAN
Yin, Hao	HEPHY Vienna	AUSTRIA

Registered Participants



arXiv:1603.04355

zero, the amplitudes reduce to the SM ones in Eq. (1).

Introducing new variables

$$\xi = \frac{C'_{10}}{C_{10}} \text{ and } \xi' = \frac{C'_9}{C_{10}} \tag{12}$$

the observables $F_\perp$, $F_\parallel$, $A_{\rm FB}$, A_5 (Eqs. (6) – (8)) can be expressed as,

$$F_\perp = 2\zeta\,(1+\xi)^2(1+R_\perp^2) \tag{13}$$
$$F_\parallel \mathsf{P}_1^2 = 2\zeta\,(1-\xi)^2(1+R_\parallel^2) \tag{14}$$
$$F_L \mathsf{P}_2^2 = 2\zeta\,(1-\xi)^2(1+R_0^2) \tag{15}$$
$$A_{\rm FB}\mathsf{P}_1 = 3\zeta\,(1-\xi^2)\big(R_\parallel + R_\perp\big) \tag{16}$$
$$\sqrt{2}A_5\mathsf{P}_2 = 3\zeta\,(1-\xi^2)\big(R_0 + R_\perp\big) \tag{17}$$

where $\mathsf{P}_1 = \dfrac{\mathcal{F}_\perp}{\mathcal{F}_\parallel}$, $\mathsf{P}_2 = \dfrac{\mathcal{F}_\perp}{\mathcal{F}_0}$, $\zeta = \dfrac{\mathcal{F}_\perp^2 C_{10}^2}{\Gamma_f}$,

$$R_\perp = \frac{\frac{r_\perp}{C_{10}} - \xi'}{1+\xi},\; R_\parallel = \frac{\frac{r_\parallel}{C_{10}} + \xi'}{1-\xi},\; R_0 = \frac{\frac{r_0}{C_{10}} + \xi'}{1-\xi}. \tag{18}$$

arXiv:1603.04355

The expressions for R_λ in the limit $q^2 \to q^2_{\rm max}$ are

$$R_\perp(q^2_{\rm max}) = \frac{8A^{(1)}_{\rm FB}(-2A^{(2)}_5 + A^{(2)}_{\rm FB}) + 9(3F^{(1)}_L + F^{(1)}_\perp)F^{(1)}_\perp}{8\,(2A^{(2)}_5 - A^{(2)}_{\rm FB})\sqrt{\frac{3}{2}F^{(1)}_\perp - A^{(1)\,2}_{\rm FB}}}$$

$$= \frac{\omega_2 - \omega_1}{\omega_2\sqrt{\omega_1 - 1}}, \qquad (30)$$

$$R_\parallel(q^2_{\rm max}) = \frac{3(3F^{(1)}_L + F^{(1)}_\perp)\sqrt{\frac{3}{2}F^{(1)}_\perp - A^{(1)\,2}_{\rm FB}}}{-8A^{(2)}_5 + 4A^{(1)}_{\rm FB} + 3A^{(1)}_{\rm FB}(3F^{(1)}_L + F^{(1)}_\perp)}$$

$$= \frac{\sqrt{\omega_1 - 1}}{\omega_2 - 1} = R_0(q^2_{\rm max}) \qquad (31)$$

where

$$\omega_1 = \frac{3}{2}\frac{F^{(1)}_\perp}{A^{(1)\,2}_{\rm FB}} \quad \text{and} \quad \omega_2 = \frac{4\,(2A^{(2)}_5 - A^{(2)}_{\rm FB})}{3\,A^{(1)}_{\rm FB}(3F^{(1)}_L + F^{(1)}_\perp)}. \qquad (32)$$

Updated projections for B→K(*) nu nubar modes

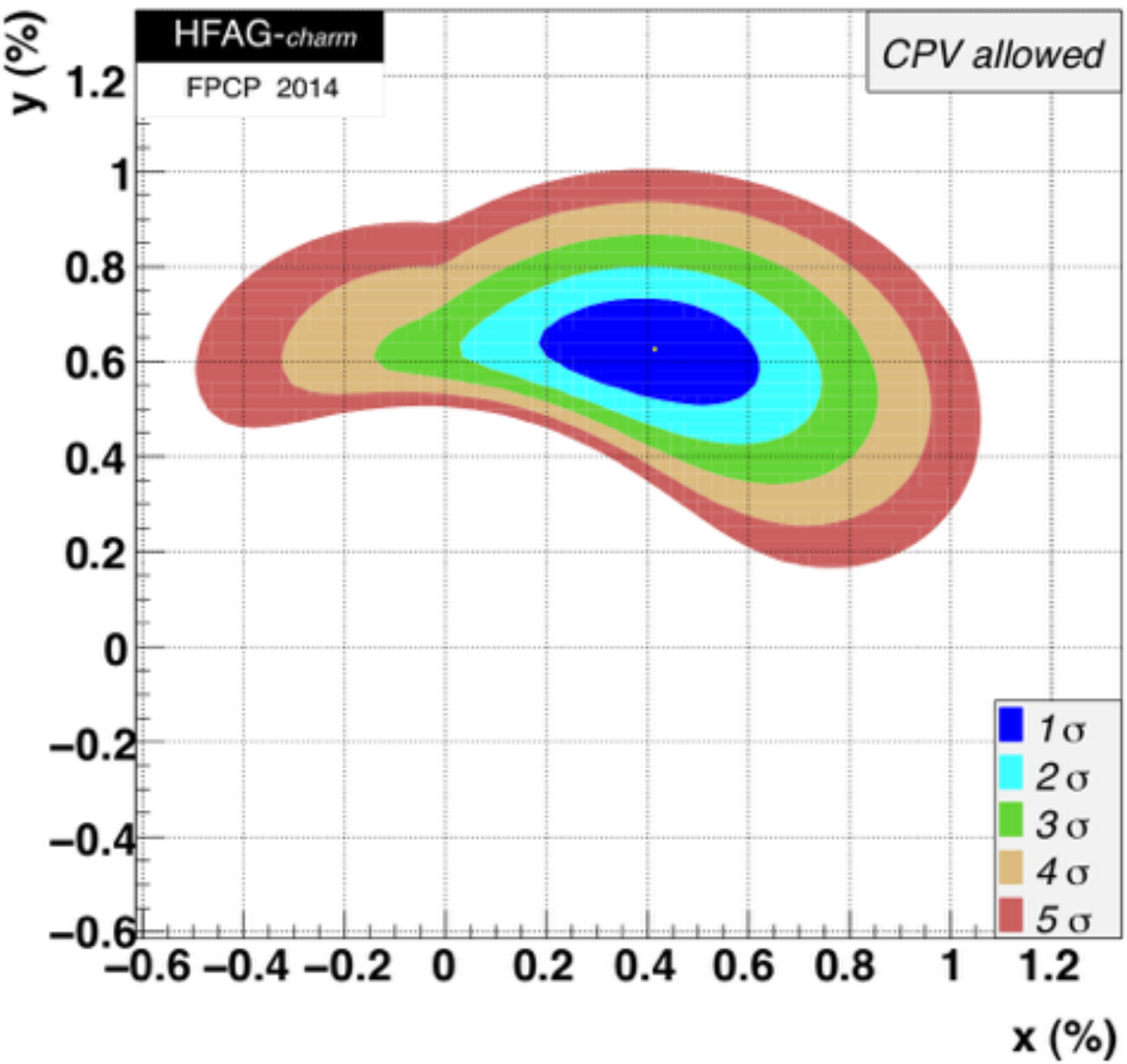
TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)}\nu\bar{\nu}$ branching fractions.

Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\rm Backg.}$ 711 $\rm fb^{-1}$ Belle	$N_{\rm Sig-exp.}$ 711 $\rm fb^{-1}$ Belle	$N_{\rm Backg.}$ 50 $\rm ab^{-1}$ Belle II	$N_{\rm Sig-exp.}$ 50 $\rm ab^{-1}$ Belle II	Statistical error 50 $\rm ab^{-1}$	Total Error
$B^+ \to K^+\nu\bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_S\nu\bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \to K^{*+}\nu\bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0}\nu\bar{\nu}$	9.19	1.44	5	2.0	704	143	20%	22%
$B \to K^*\nu\bar{\nu}$ combined							15%	17%

[1] A. J. Buras, J. Girrbach-Noe, C. Niehoff and D. M. Straub, JHEP **1502**, 184 (2015) [arXiv:1409.4557 [hep-ph]].
[2] O. Lutz *et al.* [Belle Collaboration], Phys. Rev. D **87**, no. 11, 111103 (2013) [arXiv:1303.3719 [hep-ex]].
[3] T. Kuhr, "$B \to h^{(*)}\nu\bar{\nu}$" , KEK-FF Workshop (2013).

P. Urquijo et al.

Mixing and CP violation in the D system



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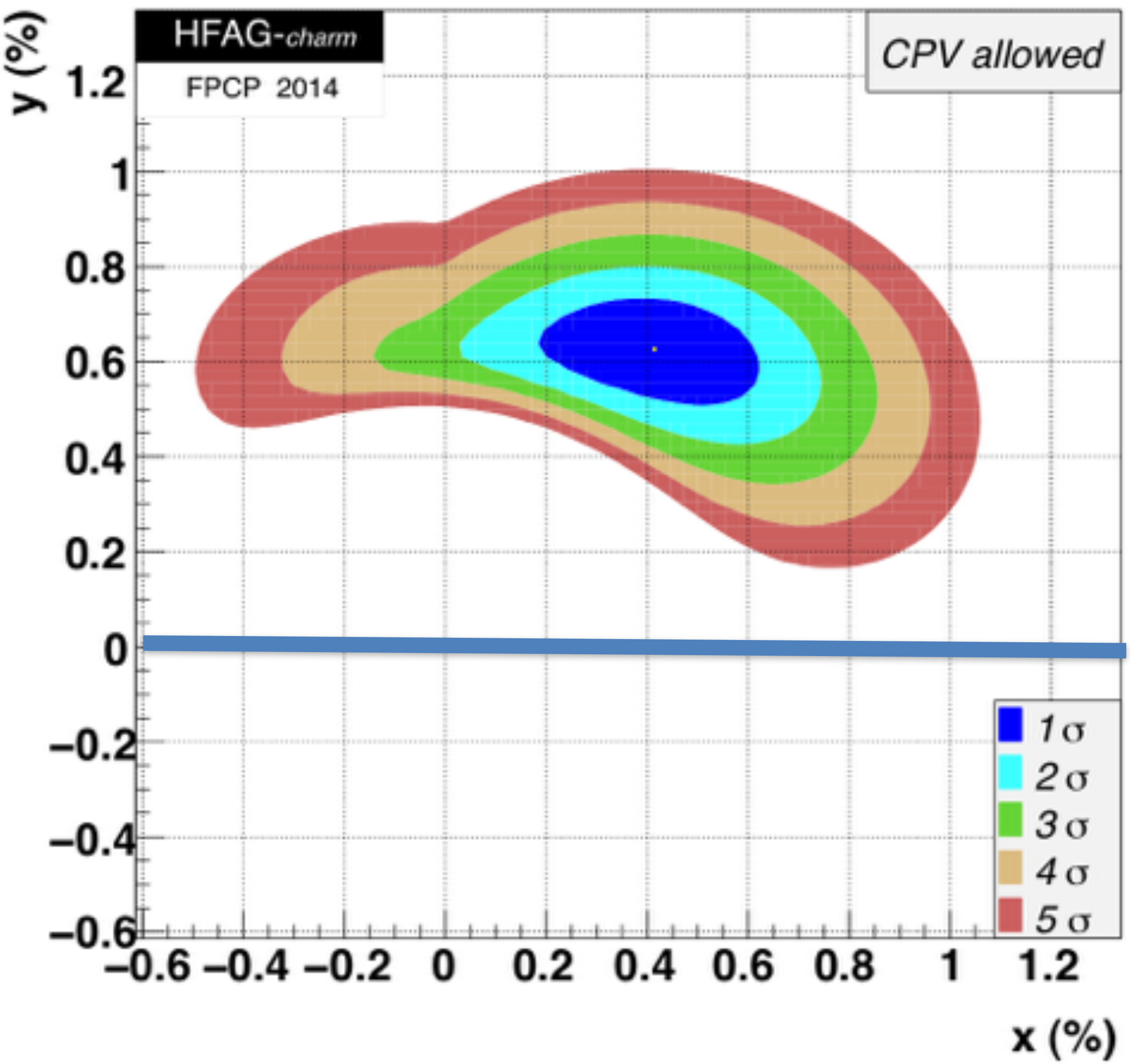

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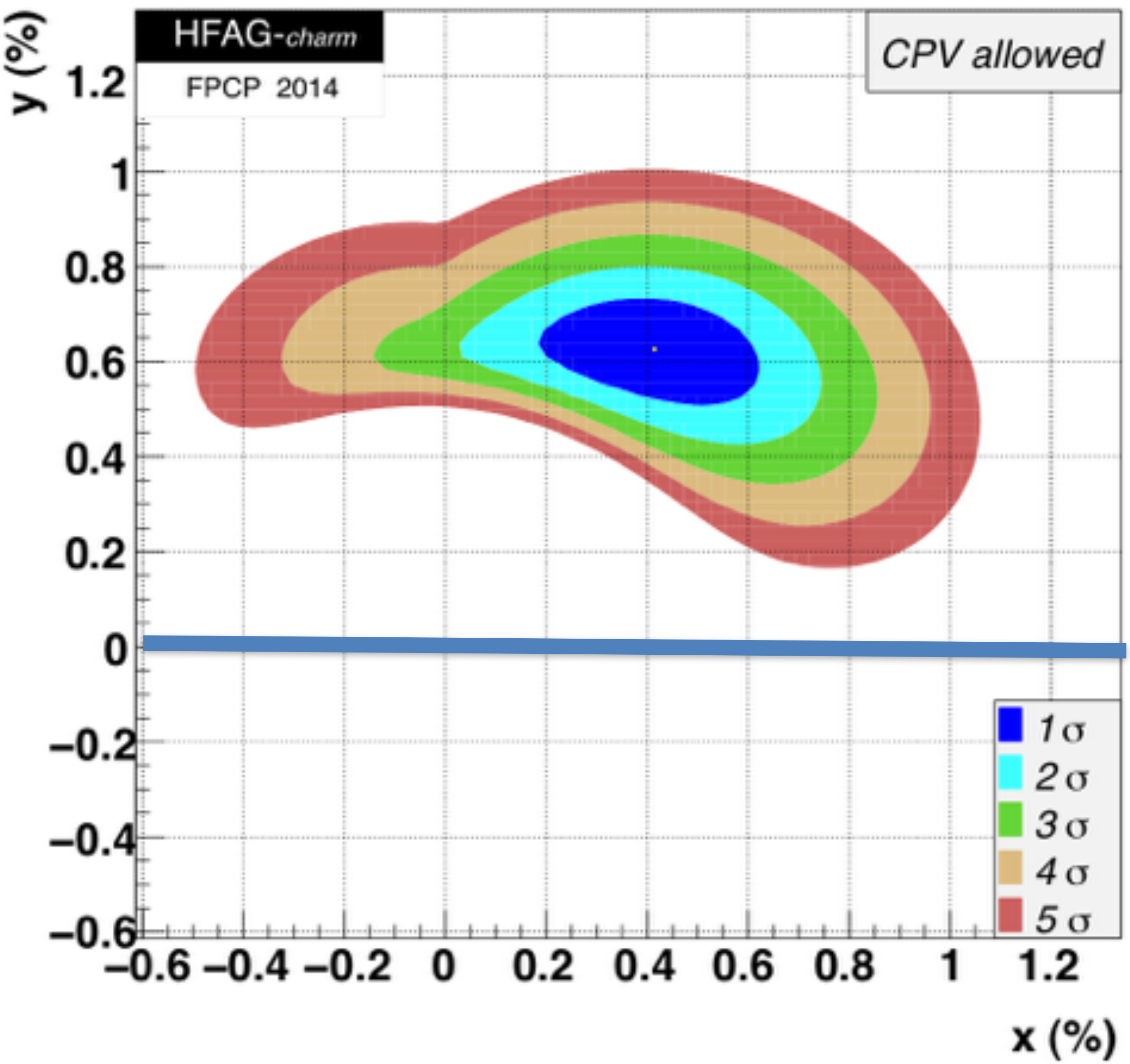
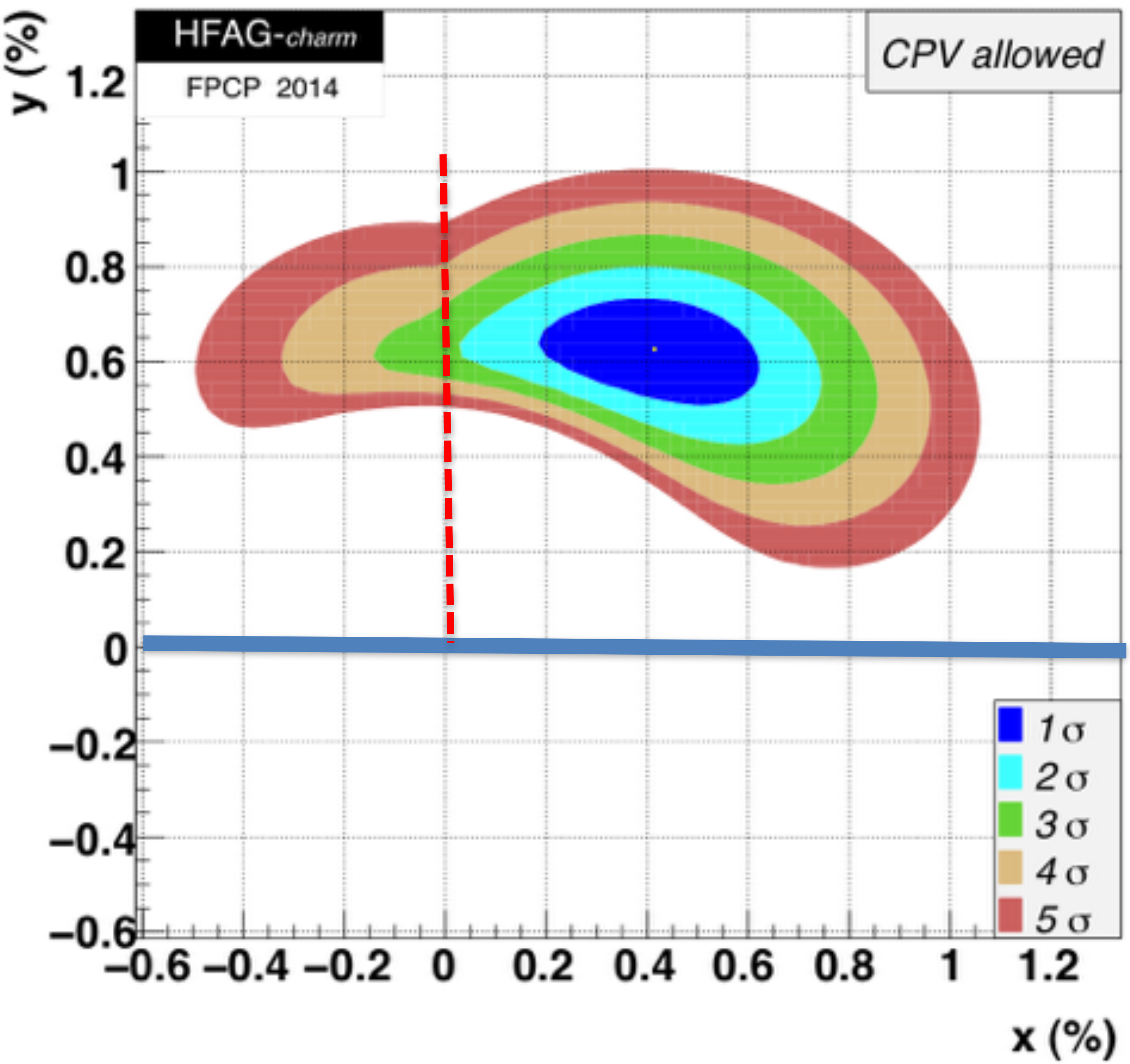


There is a very strong y signal

Mixing and CP violation in the D system



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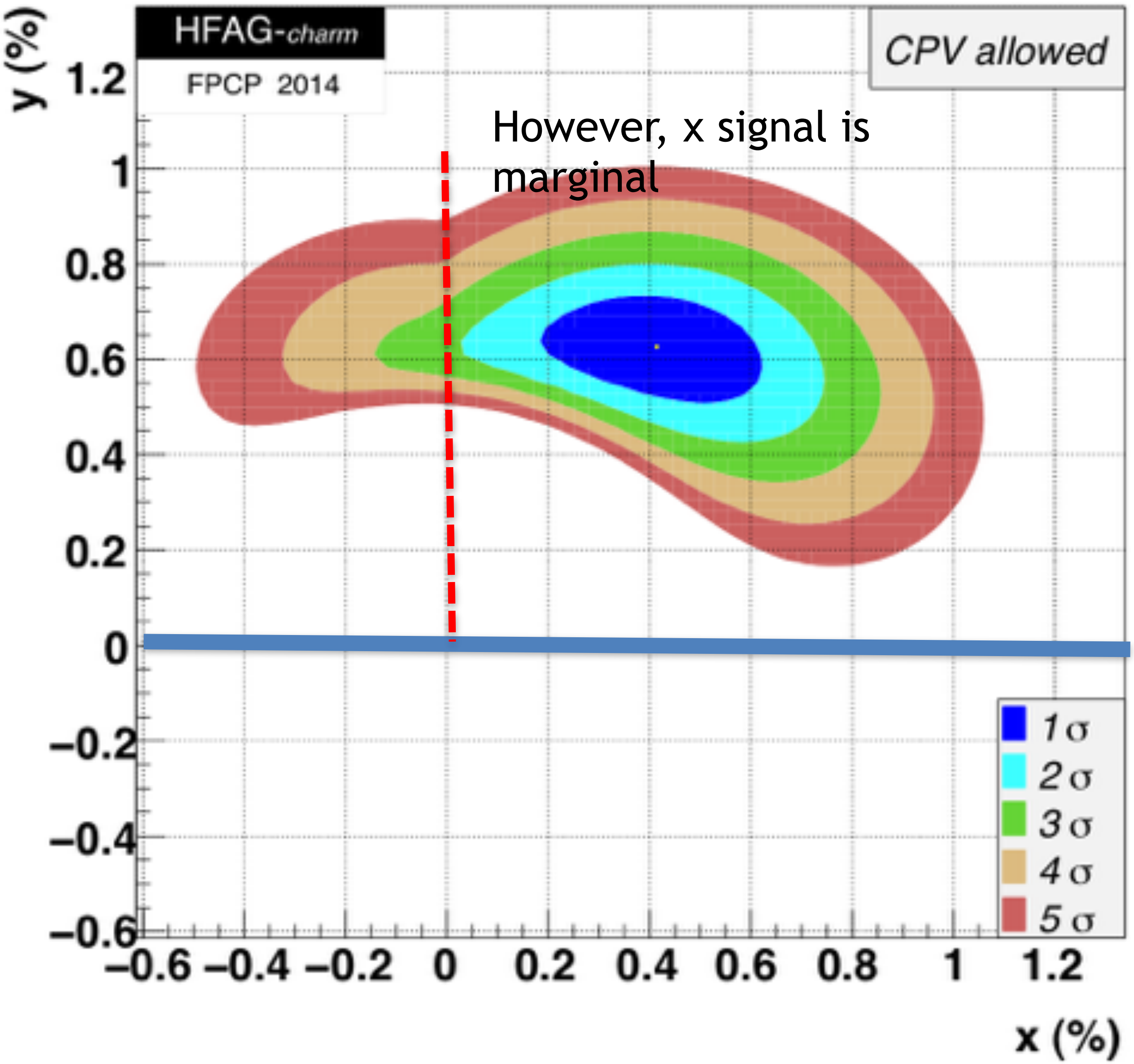


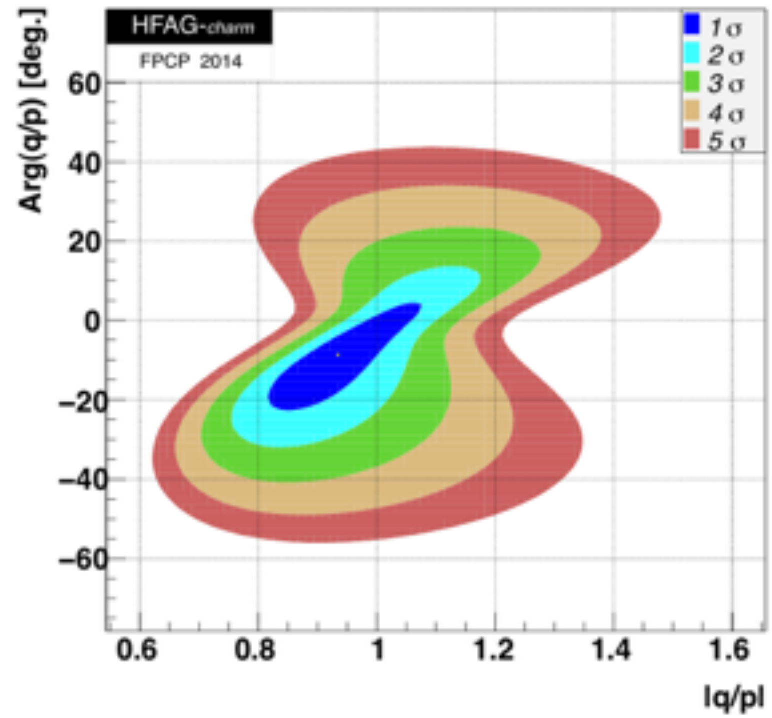
There is a very strong y signal

D mixing: Another new physics phase !

$$\varphi \sim \frac{2\eta A^2\lambda^5}{\lambda} \sim O(10^{-3})$$

CPV in D system negligible in SM

CPV in interf. mix./decay: $\mathrm{Im}\frac{q}{p}\frac{\overline{A}_f}{A_f} \equiv (1+\frac{A_M}{2})e^{i\varphi} \neq 0; \varphi \neq 0$



The existence of D mixing (if x is non-zero) allows us to look for another poorly constrained new physics phase but this time from up-type quarks.

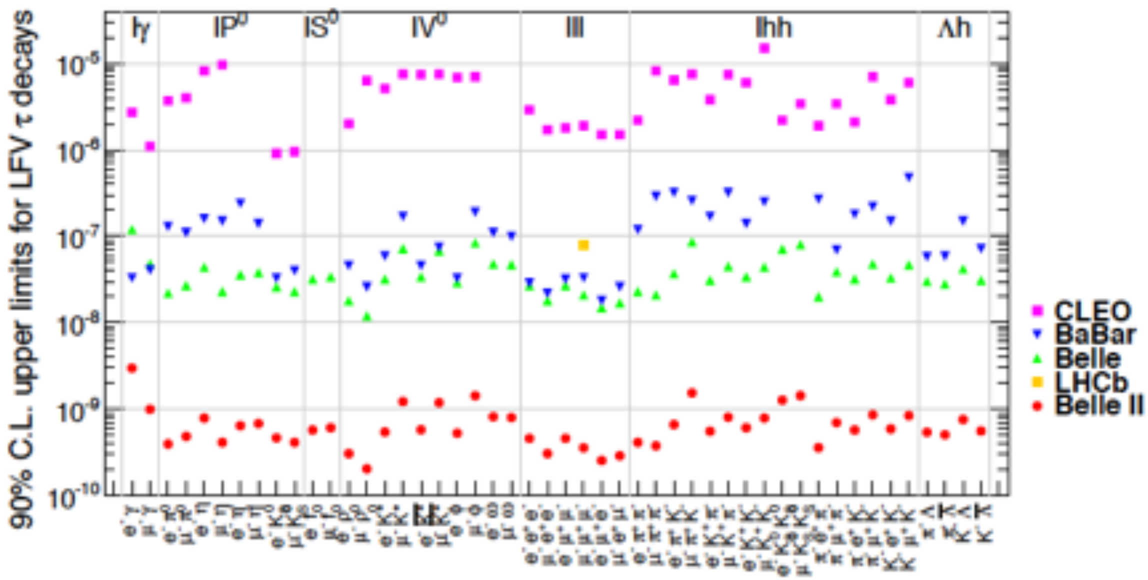
(c.f. CPV in B_s mixing)

Current WA sensitivity ~±20^0, 50 ab^{-1} go below 2^0

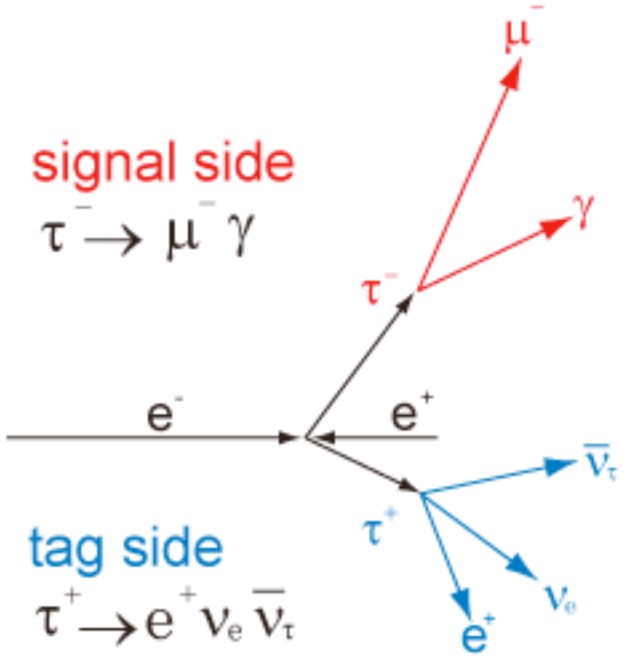
Belle I Drift Chamber and Vertex Detector in the Ueno Science Museum in Tokyo

Tau Lepton Flavor Violation

FIG. 5: LFV UL (90% C.L.) results from CLEO, BaBar and Belle, and extrapolations for Belle II (50 ab^{-1}) and LHCb updgrade (50 fb^{-1}).



Example of the decay topology



Belle II will push many limits below 10^{-9} ; LHCb has very limited capabilities.

CPV in the charged lepton sector

- There is mixing in the neutrino (neutral lepton) sector. CP violation is possible too.

BaBar rate anomaly ??

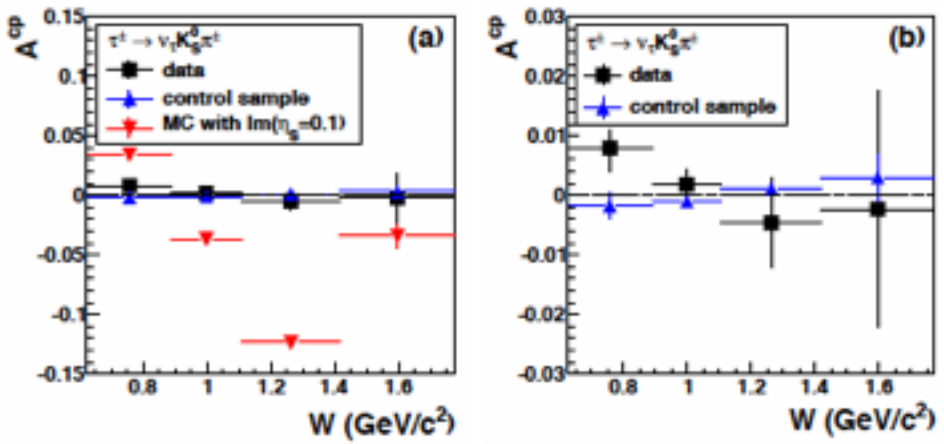


FIG. 2. (a) Measured CP violation asymmetry after background subtraction (squares). The vertical error bars are the statistical error and systematic errors added in quadrature. The CP asymmetry measured in the control sample is indicated by the blue triangles (statistical errors only) and the inverted red triangles show the expected asymmetry for $\Im(\eta_S) = 0.1$ [$\Re(\eta_S) = 0$]. (b) Expanded view (the vertical scale is reduced by a factor of five).

Can we explore at Belle II ?

Theoretical predictions for $\Im(\eta_S)$ can be given in context of a MHDM with three or more Higgs doublets [4, 5]. In such models η_S is given by [12]

$$\eta_S \simeq \frac{m_\tau m_s}{M_{H^\pm}^2} X^* Z \qquad (10)$$

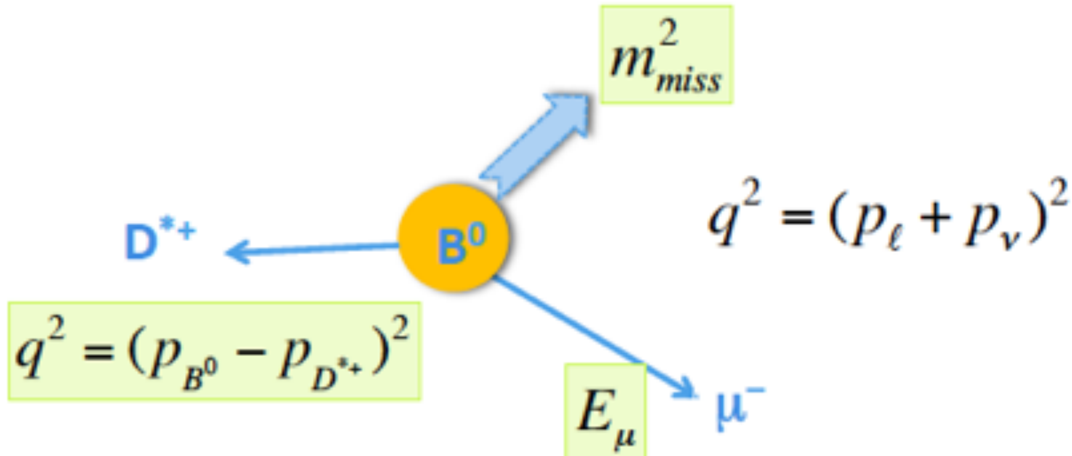
if numerically small terms proportional to m_u are ignored. Here, $M_{H^\pm}$ is the mass of the lightest charged Higgs boson and the complex constants Z and X describe the coupling of the Higgs boson to the τ and ν_τ and the u and s quarks, respectively (see [5, 12]). The limit $|\Im(\eta_S)| < 0.026$ is therefore equivalent to

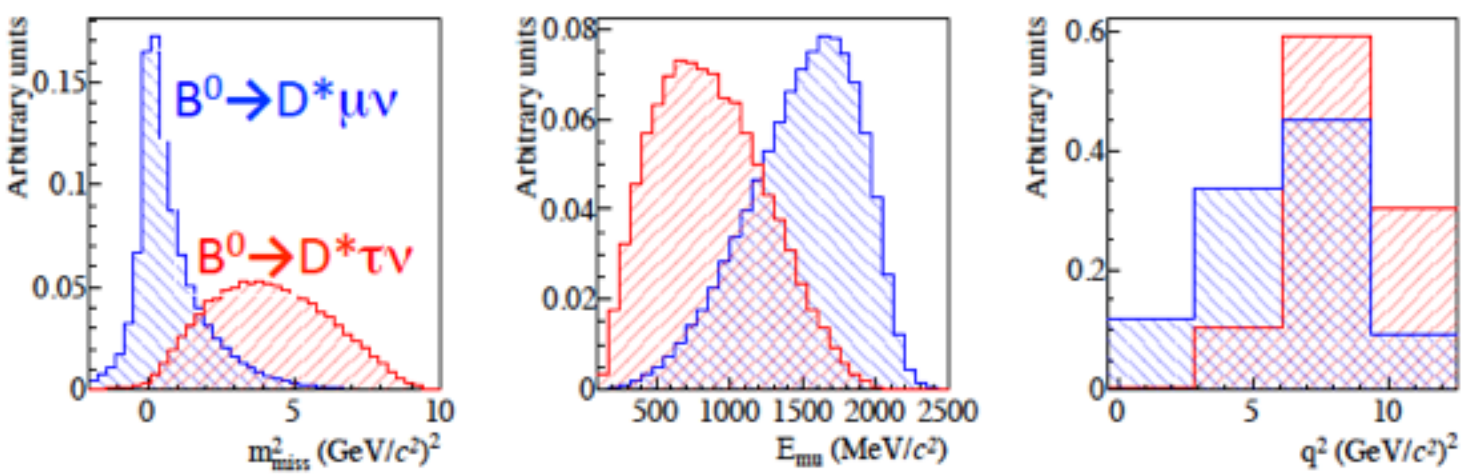
$$|\Im(XZ^*)| < 0.15 \frac{M_{H^\pm}^2}{1\,\mathrm{GeV}^2/c^4}. \qquad (11)$$

M. Bischofberger et al, Phys. Rev. Lett. 107, 131801 (2011)

Separating $B^0 \to D^*\tau\nu$ from $B^0 \to D^*\mu\nu$

- 3 key kinematic variables computed in the B rest frame



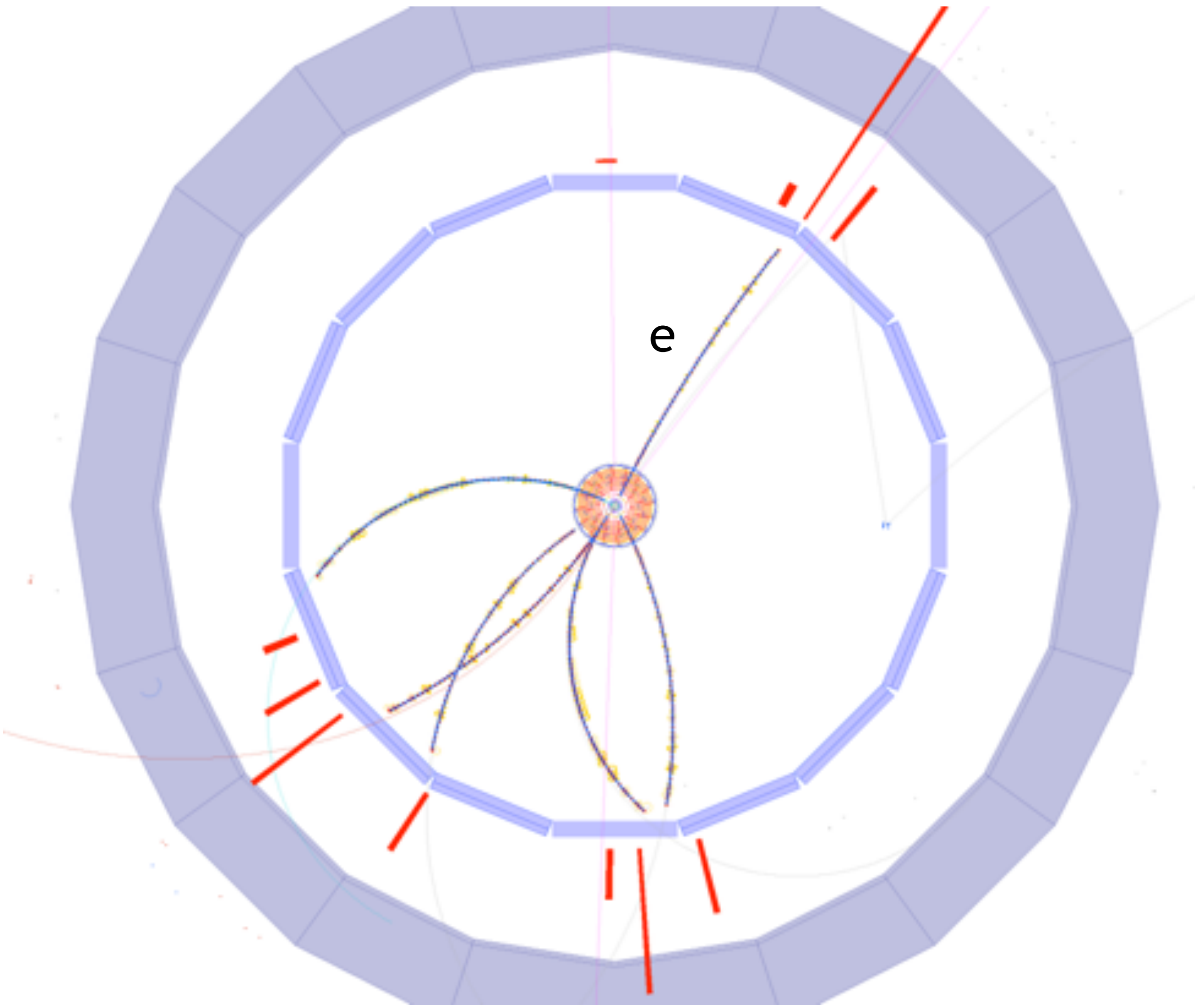


LHCb simulation

approximate B rest frame

“Missing Energy Decay” in a Belle II GEANT4 MC simulation

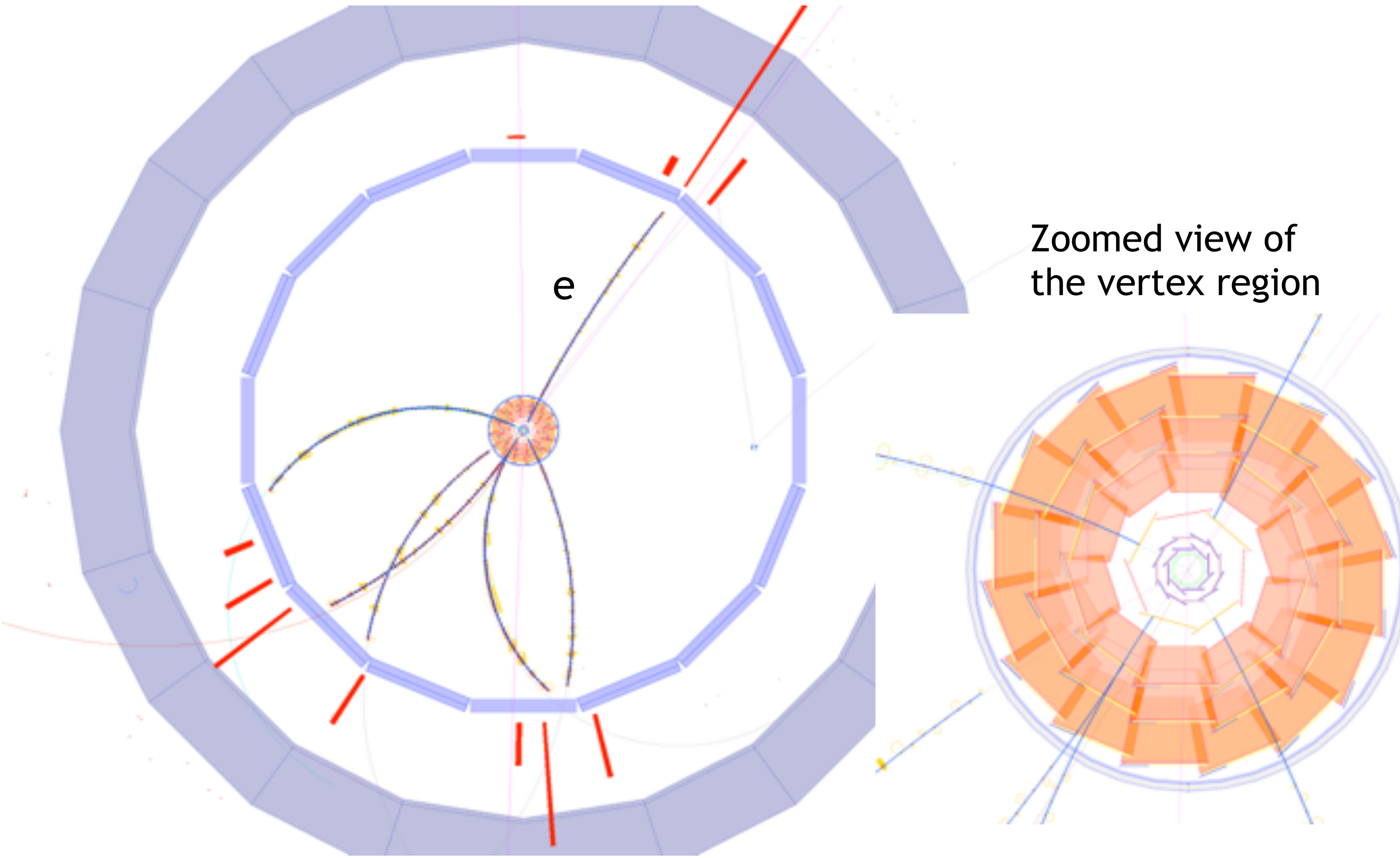
$B \rightarrow \tau\nu,\ \tau \rightarrow e\nu\nu$ $\quad$ $B \rightarrow D\pi,\ D \rightarrow K\pi\pi\pi$



Zoomed view of the vertex region

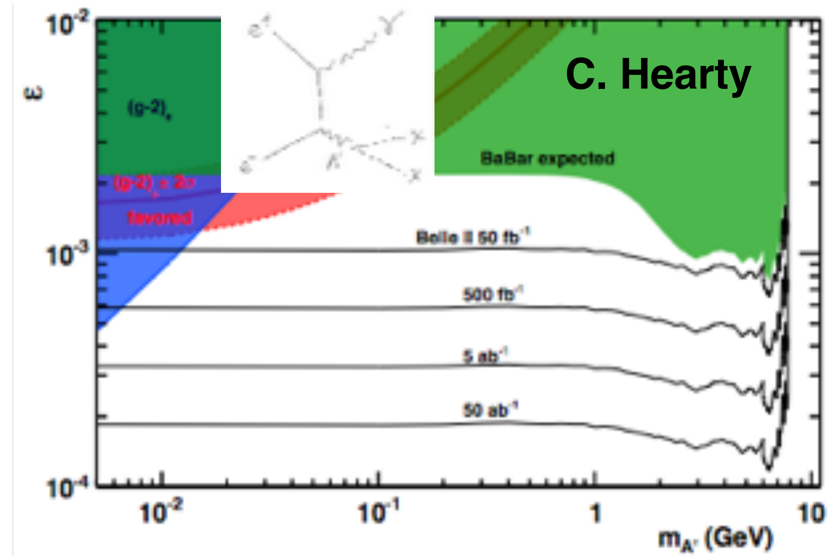
"Missing Energy Decay" in a Belle II GEANT4 MC simulation

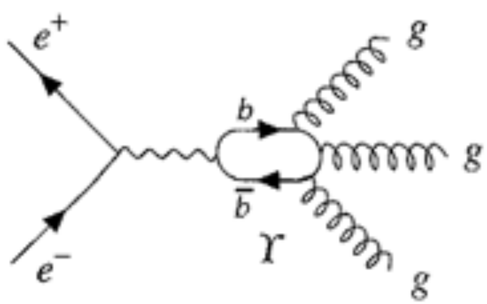
$B \rightarrow \tau\nu$, $\tau \rightarrow e\nu\nu$ $B \rightarrow D\pi$, $D \rightarrow K\pi\pi\pi$



Beast Phase II & New Triggers

- Update to First-physics report: [BELLE2-NOTE-PH-2015-003] Υ(2S), Υ(3S), Υ(6S), Scan proposals
- Beast Phase II Physics Task Force formed to study physics with this configuration (B. Fulsom).
- Belle Υ(1S) decay data used for Pythia 8 MC tuning in Belle II (U. Tamponi).





- HLT & L1 Trigger Menu under design. Evolving [Trigger Menu (Link)].

Triggers		Some Ideas **C-H. Li**
Single Photon (γ)		• Cascade: different thresholds with separate pre-scale factors • Use different pre-scale factors for Barrel and Endcap
e^+e^-		• two Bhabha triggers, "accept" and "veto" • "accept" : flattening scheme • "veto": 2D→3D ECL Bhabha is being investigated • salvage: retain a pre-scaled sample of physics triggers without veto
$\mu^+\mu^-$		• independent CDC and KLM triggers for luminosity systematics
γγ		• reduce pre-scale to 10 instead of 100
γ+ 2 trks	γe^+e^- [hlt]	• dedicated triggers for calibration (CDC,ECL)
	$\gamma\mu^+\mu^-$	• dedicated triggers for detectors study (CDC, ECL, KLM)
	γh^+h^-	• high efficiency for all γ energies and h^+h^- invariant masses • one high energy cluster in ECL, one track in opposite hemisphere
Additional trigger information		• CDC-TOP-ECL-KLM Matching • More detectors information……

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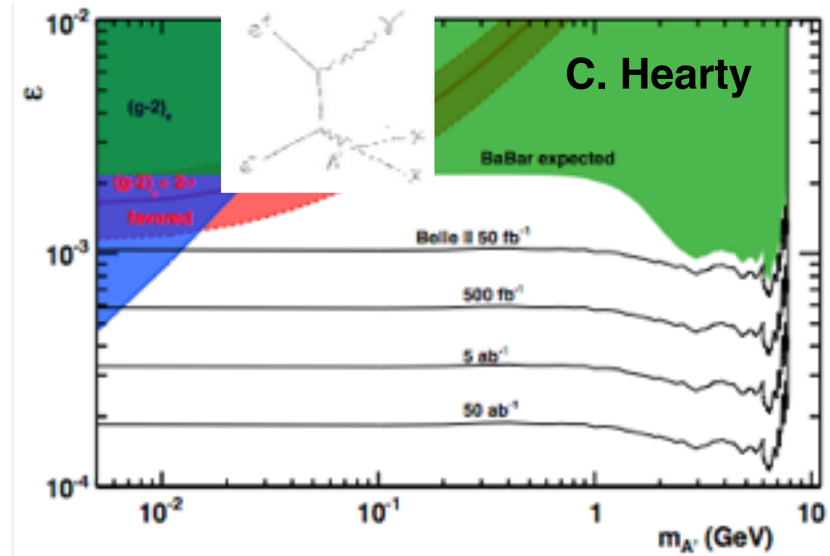

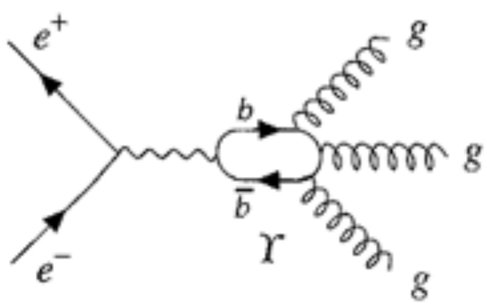

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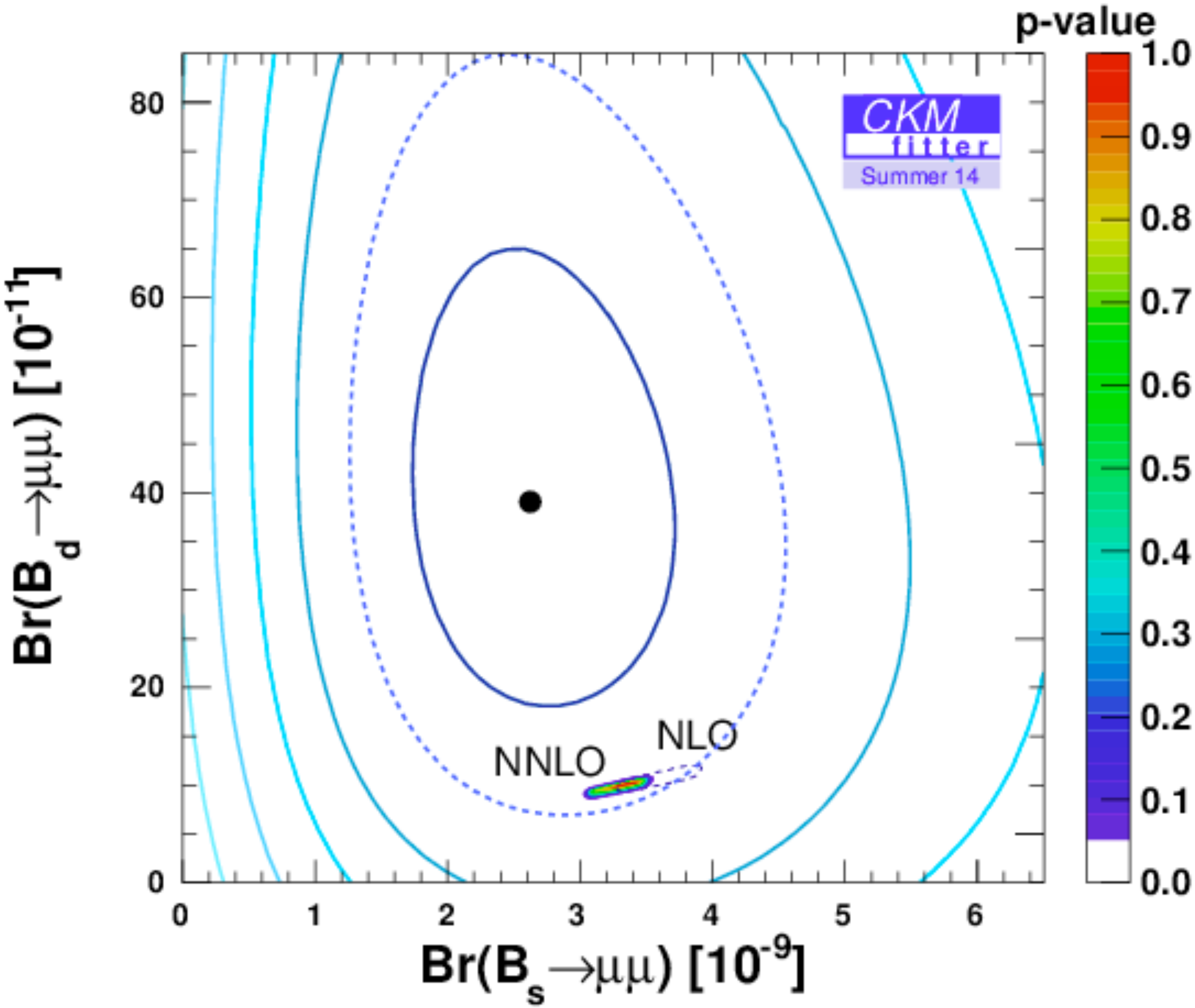
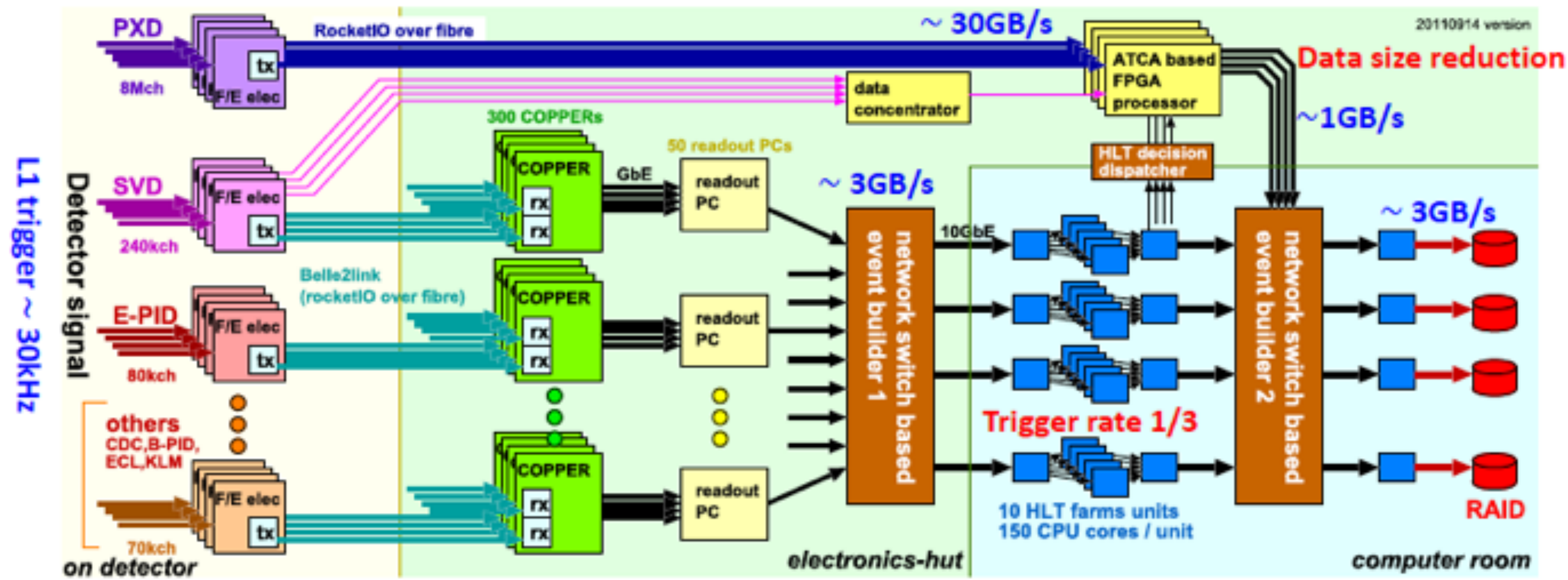


p-value
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CKM
fitter
Summer 14
80
60
40
20
0
0
1
2
3
4
5
6
NNLO
NLO
Br(B_d→μμ) [10^-11]
Br(B_s→μμ) [10^-9]

Belle II

Data acquisition system



<u>Discussion Topic</u>: What additional *Theoretical Work* is required to determine whether NP is present in B decays

<u>Participants</u>: Wolfgang Altmannshofer, Christoph Bobeth, Jorge Martin Camalich, Robert Fleischer, Zoltan Ligeti, Rahul Sinha

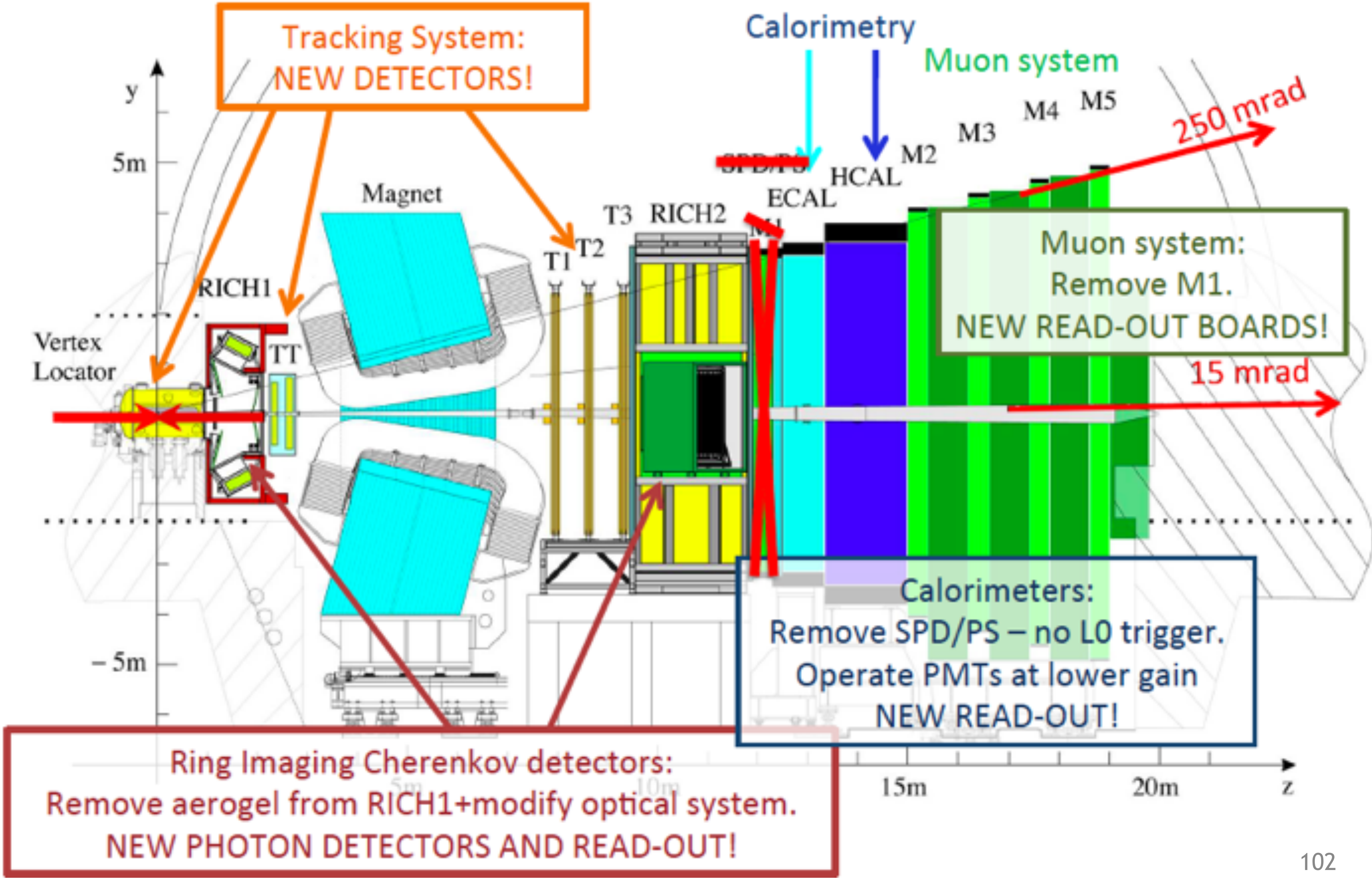
Nagoya
FPCP15
roundtable

鵜飼
"ukai"

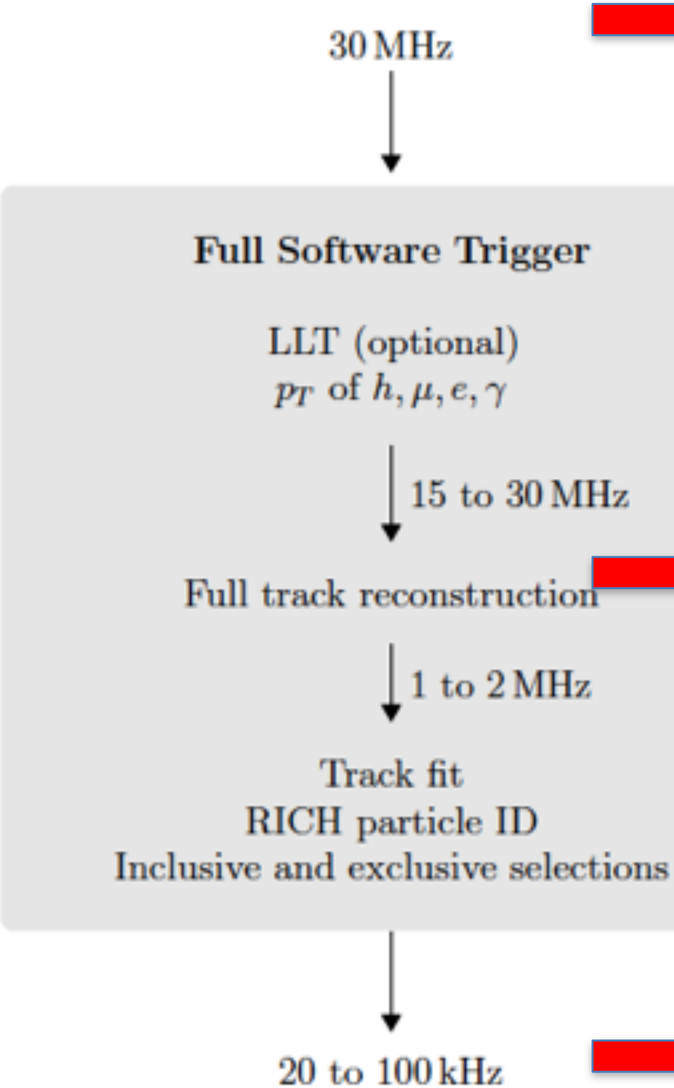
Cormorant Fishing on the Nagara River during the Edo Period

Discussed in Nakada-san's talk

Upgraded LHCb detector



LHCb Upgrade: *Key Feature* is Trigger-less readout



- Trigger-less read-out.
- Zero suppression in front-ends.
- Full detector data to Full Software Trigger.
- Inelastic collision rate is 30 MHz.

- Low level trigger as throttle.
- Partial information from muon system and calorimeters.

- Full event reconstruction.
- Run-by-run detector calibration.

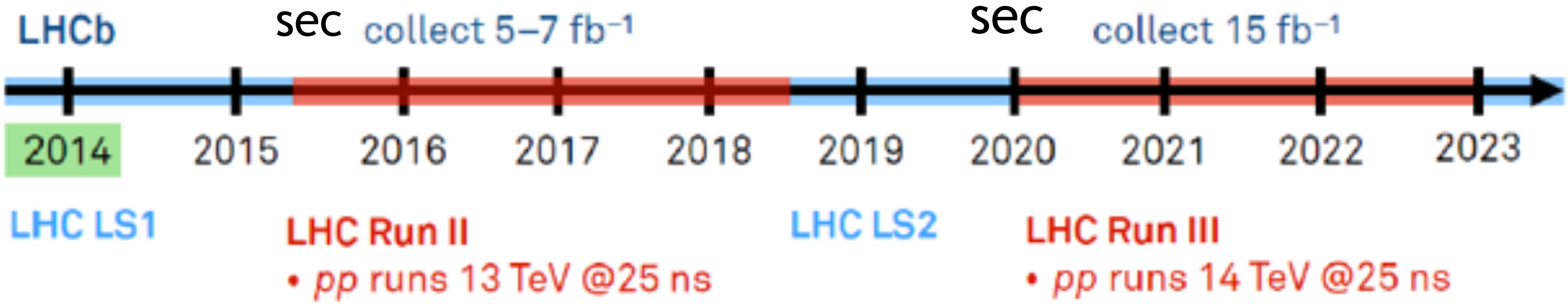
- Perform simplified Kalman track fit.
- Add RICH information.
- Inclusive and exclusive selections.

- 2 – 10 GBytes/s to storage.

LHCb upgrade timeline

Run at ~4 x 10^{32} /cm^2 / sec

Expect (1-2) x 10^{33} /cm^2 / sec



- Collect 50 fb^{-1} after upgrade.
- Continue taking data during HL-LHC.

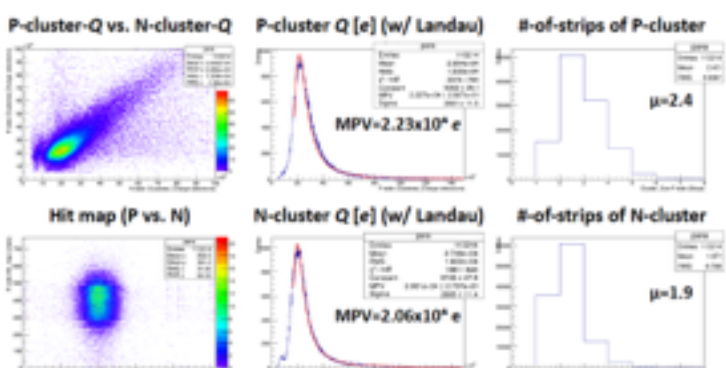
<u>Upgraded trigger and DAQ is the key feature</u>

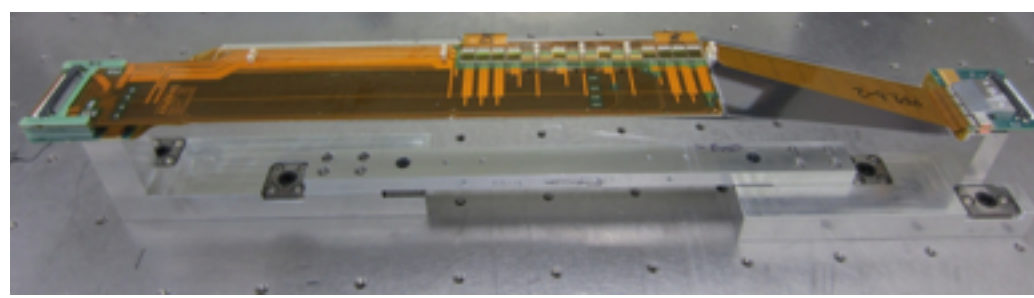
Belle II at IPMU in 柏の葉, Japan

Constructing two layers of the Belle II SVD detector in the clean room on the 1st floor. Dr T. Higuchi is the leader.

Japan (Layer 6) and India/Tata Institute (Layer 4)

^{90}Sr Source Test [2] (SBW990)





L4 mechanical prototype

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Test Production by late Sept;
Detector production starts ~ Nov 2015

Japan (Layer 6) and India/Tata Institute (Layer 4)

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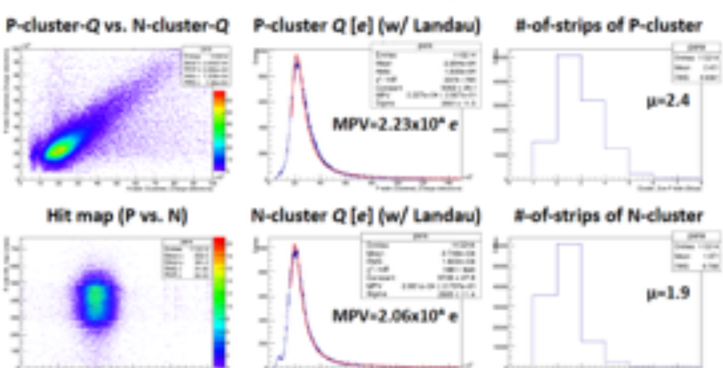
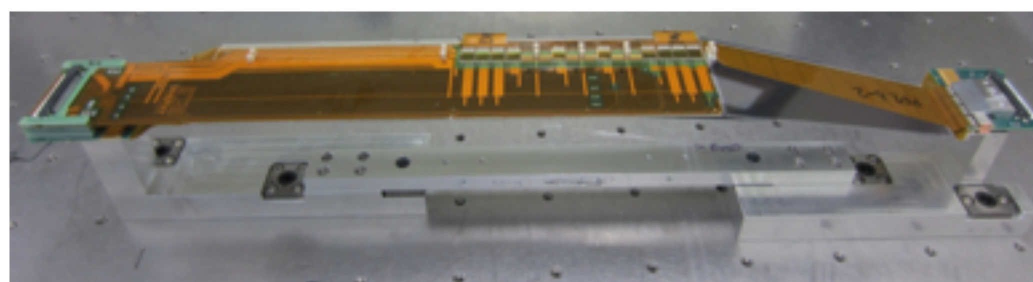
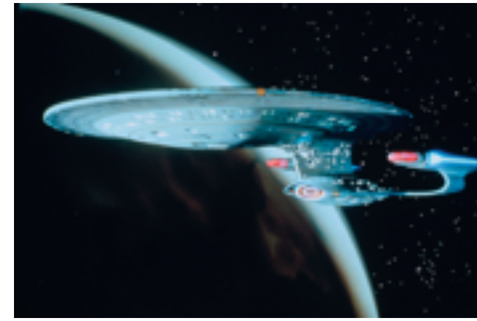




L4 mechanical prototype

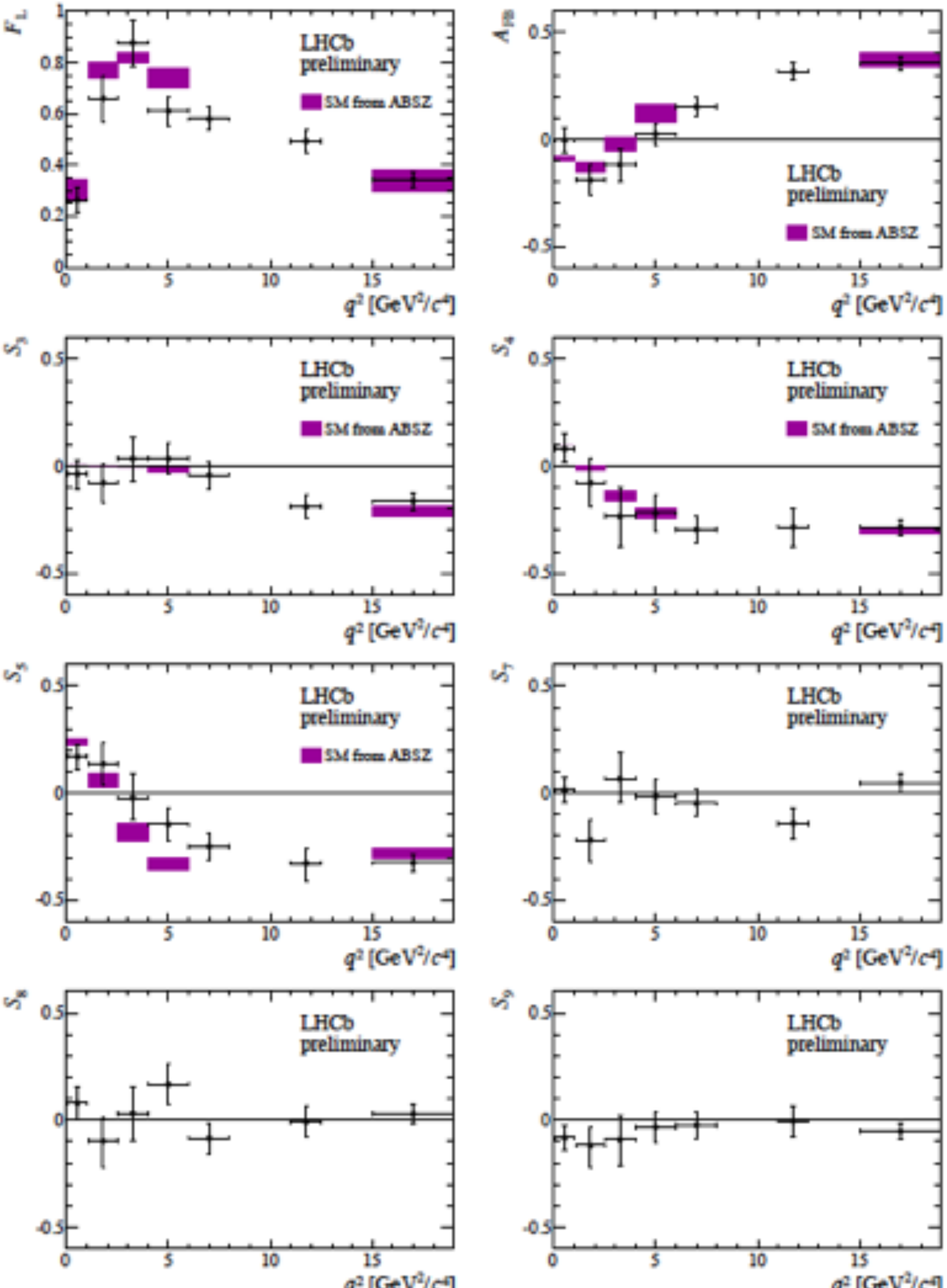
New Reference *for the Next Generation*



The Physics of the B Factories
http://arxiv.org/abs/1406.6311

This work is on the Physics of the B Factories. Part A of this book contains a brief description of the SLAC and KEK B Factories as well as their detectors, BaBar and Belle, and data taking related issues. Part B discusses tools and methods used by the experiments in order to obtain results. The results themselves can be found in Part C.

Comments: 928 pages
Subjects: High Energy Physics - Experiment (hep-ex); High Energy Physics - Phenomenology (hep-ph)
Report number: SLAC-PUB-15968, KEK Preprint 2014-3



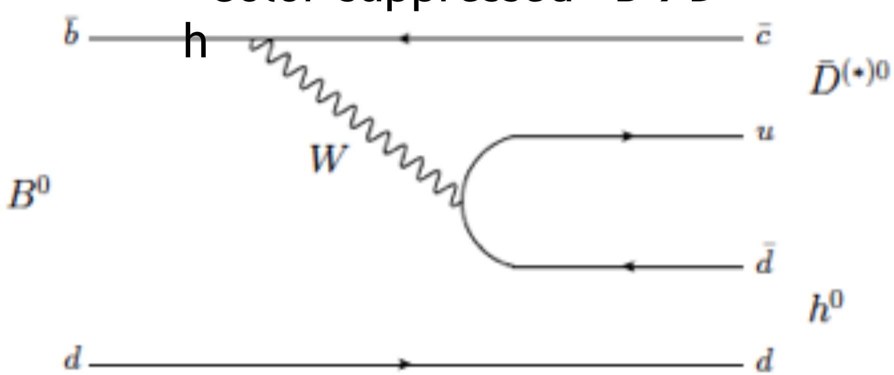
F_L
LHCb
preliminary
SM from ABSZ
q^2 [GeV^2/c^4]
A_{FB}
LHCb
preliminary
SM from ABSZ
q^2 [GeV^2/c^4]
S_3
LHCb
preliminary
SM from ABSZ
q^2 [GeV^2/c^4]
S_4
LHCb
preliminary
SM from ABSZ
q^2 [GeV^2/c^4]
S_5
LHCb
preliminary
SM from ABSZ
q^2 [GeV^2/c^4]
S_7
LHCb
preliminary
q^2 [GeV^2/c^4]
S_8
LHCb
preliminary
q^2 [GeV^2/c^4]
S_9
LHCb
preliminary
q^2 [GeV^2/c^4]

B factories: *Check CP violation in b→c [ubar d] processes*

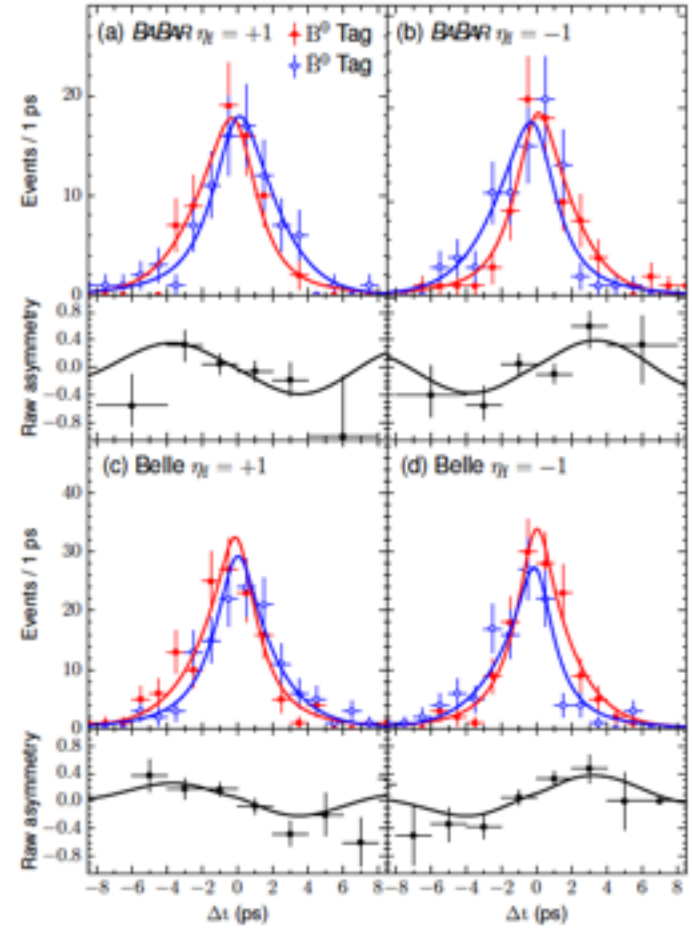
2015: First joint BaBar-Belle data analysis

M. Rohrken et al

"Color-suppressed" B→D h



where D^0 is a CP eigenstate and $h^0=\pi^0$, η, ω



Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal→First observation

$\sin(2\beta_{eff})=0.66\pm0.10(stat)\pm0.06(sys)$

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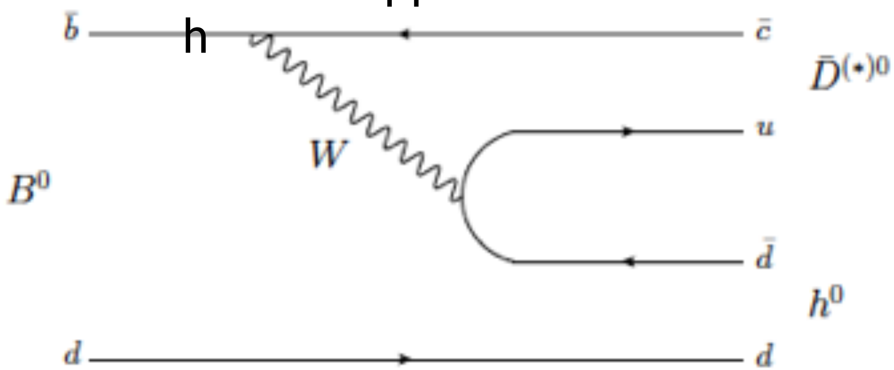

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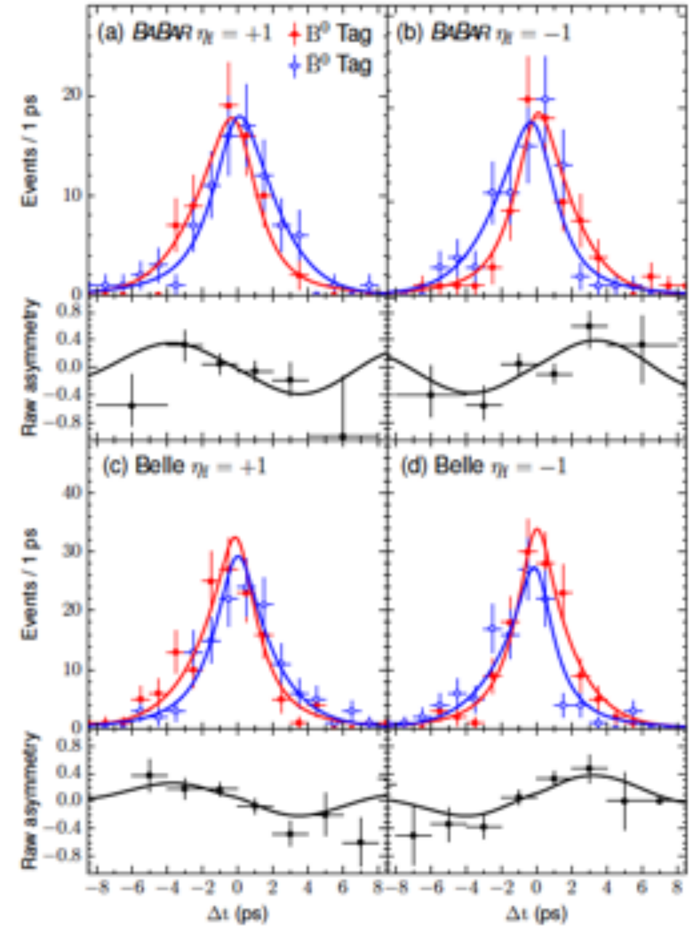

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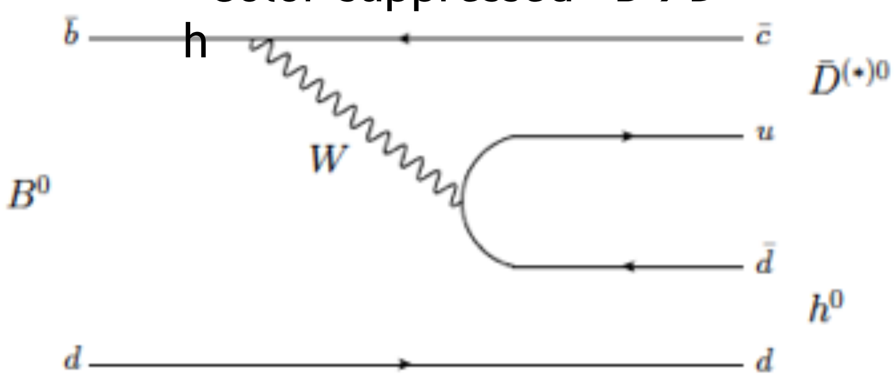

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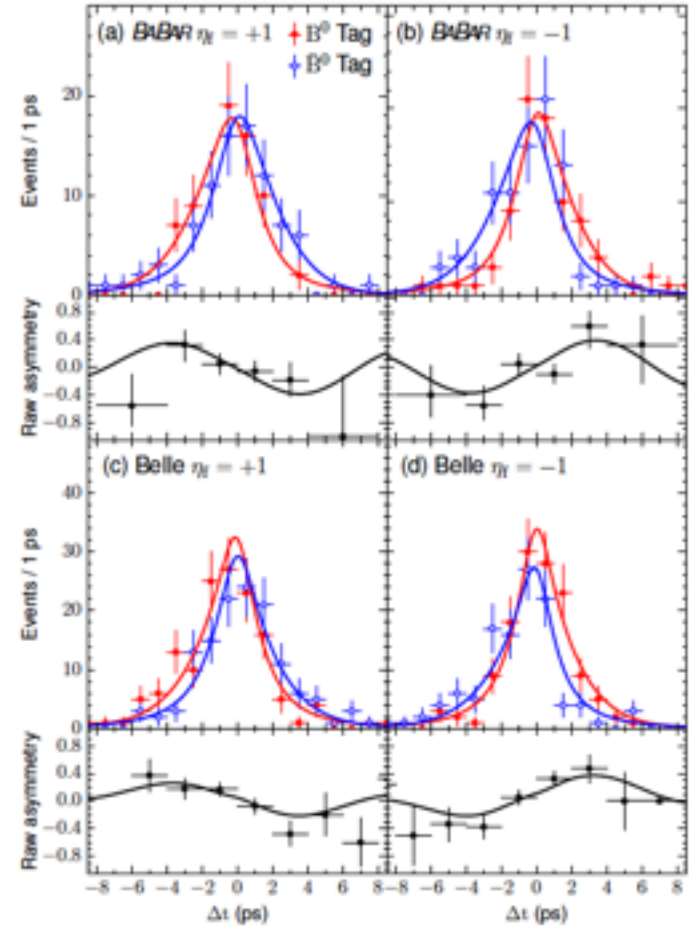

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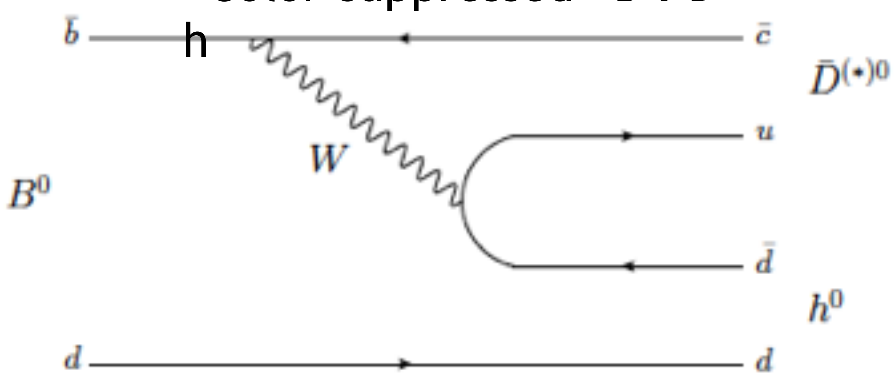
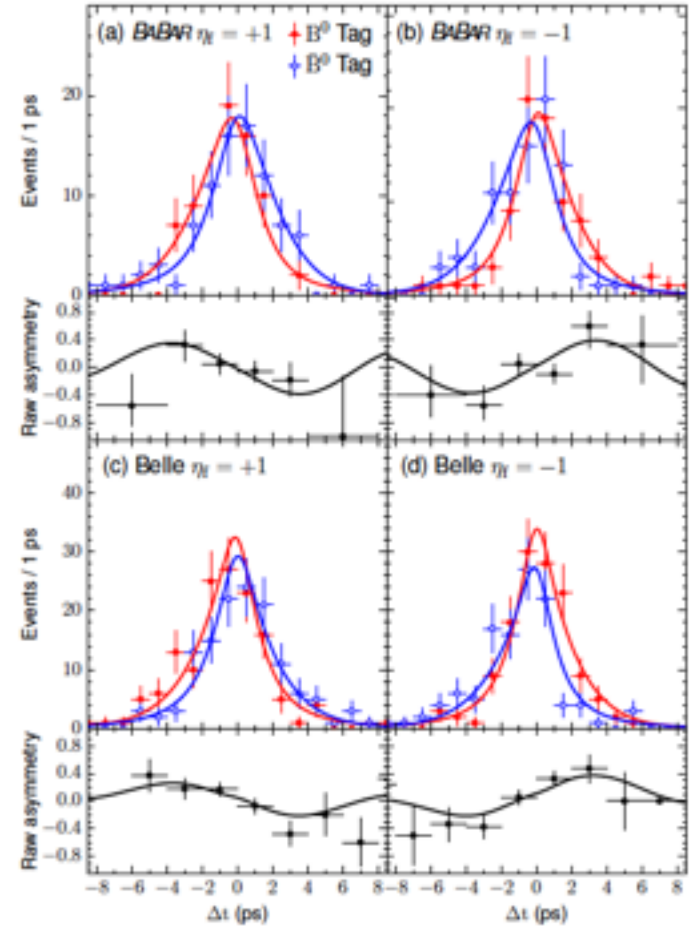
M. Rohrken et al

"Color-suppressed" B→D h



where D^0 is a CP eigenstate and $h^0=\pi^0, \eta, \omega$



Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal→First observation

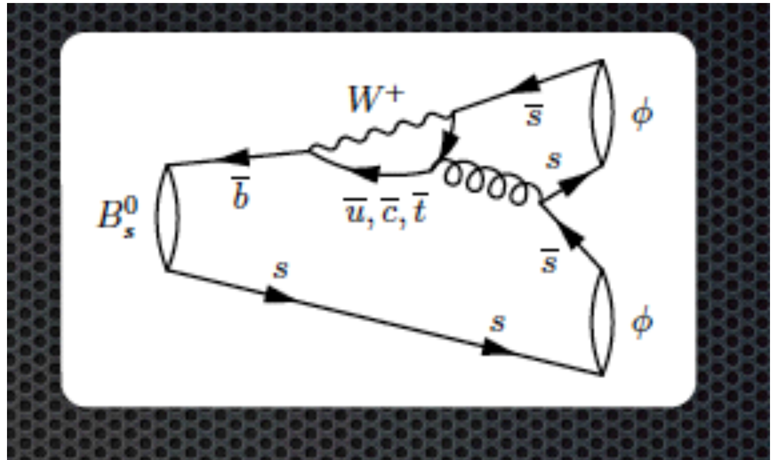
$\sin(2\beta_{eff})=0.66\pm0.10(stat)\pm0.06(sys)$

Phase of V_{td} again

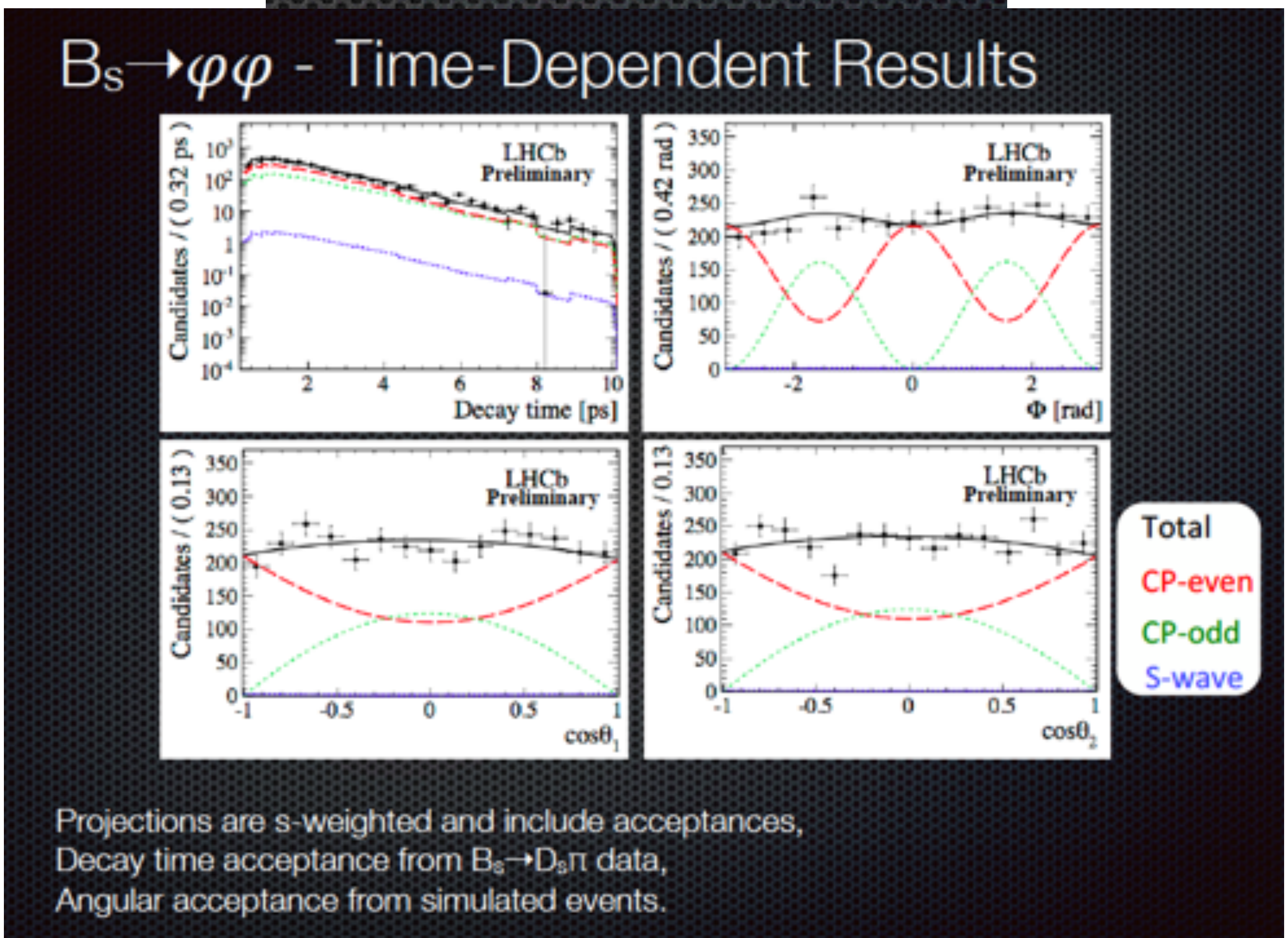
Conclusion: CP violation in b→c ubar d modes is the same as in b→c cbar s modes (e.g. B→J/ψ K_S)

More backup

But LHCb dominates on these B_s modes



M.Needham@ICHEP2014



Signal model

We use the same notations as LHCb [arXiv:1304.2600]:

$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = X(\Theta, \alpha, t) = \sum_{i=1}^{10} O_i(\alpha, t).g_i(\Theta),$$

$$O_i(\alpha, t) = N_i e^{-\Gamma_s t}\left[a_i \cosh(\frac{1}{2}\Delta\Gamma_s t) + b_i \sinh(\frac{1}{2}\Delta\Gamma_s t) + c_i \cos(\Delta m_s t) + d_i \sin(\Delta m_s t)\right]$$

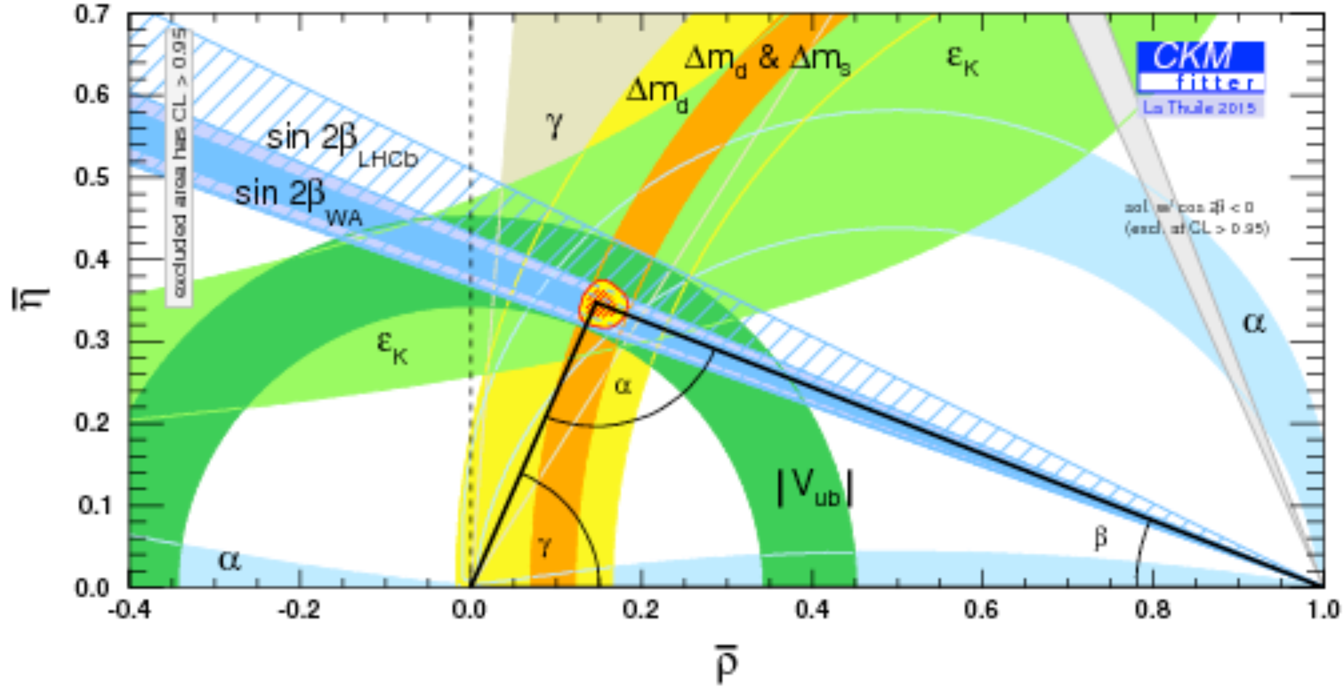
i	$g_i(\theta_T, \psi_T, \phi_T)$	N_i	a_i	b_i	c_i	d_i
1	$2\cos^2\psi_T(1 - \sin^2\theta_T\cos^2\phi_T)$	$\lvert A_0(0)\rvert^2$	1	D	C	$-S$
2	$\sin^2\psi_T(1 - \sin^2\theta_T\sin^2\phi_T)$	$\lvert A_\parallel(0)\rvert^2$	1	D	C	$-S$
3	$\sin^2\psi_T\sin^2\theta_T$	$\lvert A_\perp(0)\rvert^2$	1	$-D$	C	S
4	$-\sin^2\psi_T\sin 2\theta_T\sin\phi_T$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp - \delta_\parallel)$	$S\cos(\delta_\perp - \delta_\parallel)$	$\sin(\delta_\perp - \delta_\parallel)$	$D\cos(\delta_\perp - \delta_\parallel)$
5	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel - \delta_0)$	$D\cos(\delta_\parallel - \delta_0)$	$C\cos(\delta_\parallel - \delta_0)$	$-S\cos(\delta_\parallel - \delta_0$
6	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\sin\phi_T$	$\lvert A_0(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp - \delta_0)$	$S\cos(\delta_\perp - \delta_0)$	$\sin(\delta_\perp - \delta_0)$	$D\cos(\delta_\perp - \delta_0)$
7	$\frac{2}{3}(1 - \sin^2\theta_T\cos^2\phi_T)$	$\lvert A_S(0)\rvert^2$	1	$-D$	C	S
8	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$	$\lvert A_S(0)A_\parallel(0)\rvert$	$C\cos(\delta_\parallel - \delta_S)$	$S\sin(\delta_\parallel - \delta_S)$	$\cos(\delta_\parallel - \delta_S)$	$D\sin(\delta_\parallel - \delta_S)$
9	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$	$\lvert A_S(0)A_\perp(0)\rvert$	$\sin(\delta_\perp - \delta_S)$	$-D\sin(\delta_\perp - \delta_S)$	$C\sin(\delta_\perp - \delta_S)$	$S\sin(\delta_\perp - \delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\psi_T(1 - \sin^2\theta_T\cos^2\phi_T)$	$\lvert A_S(0)A_0(0)\rvert$	$C\cos(\delta_0 - \delta_S)$	$S\sin(\delta_0 - \delta_S)$	$\cos(\delta_0 - \delta_S)$	$D\sin(\delta_0 - \delta_S)$

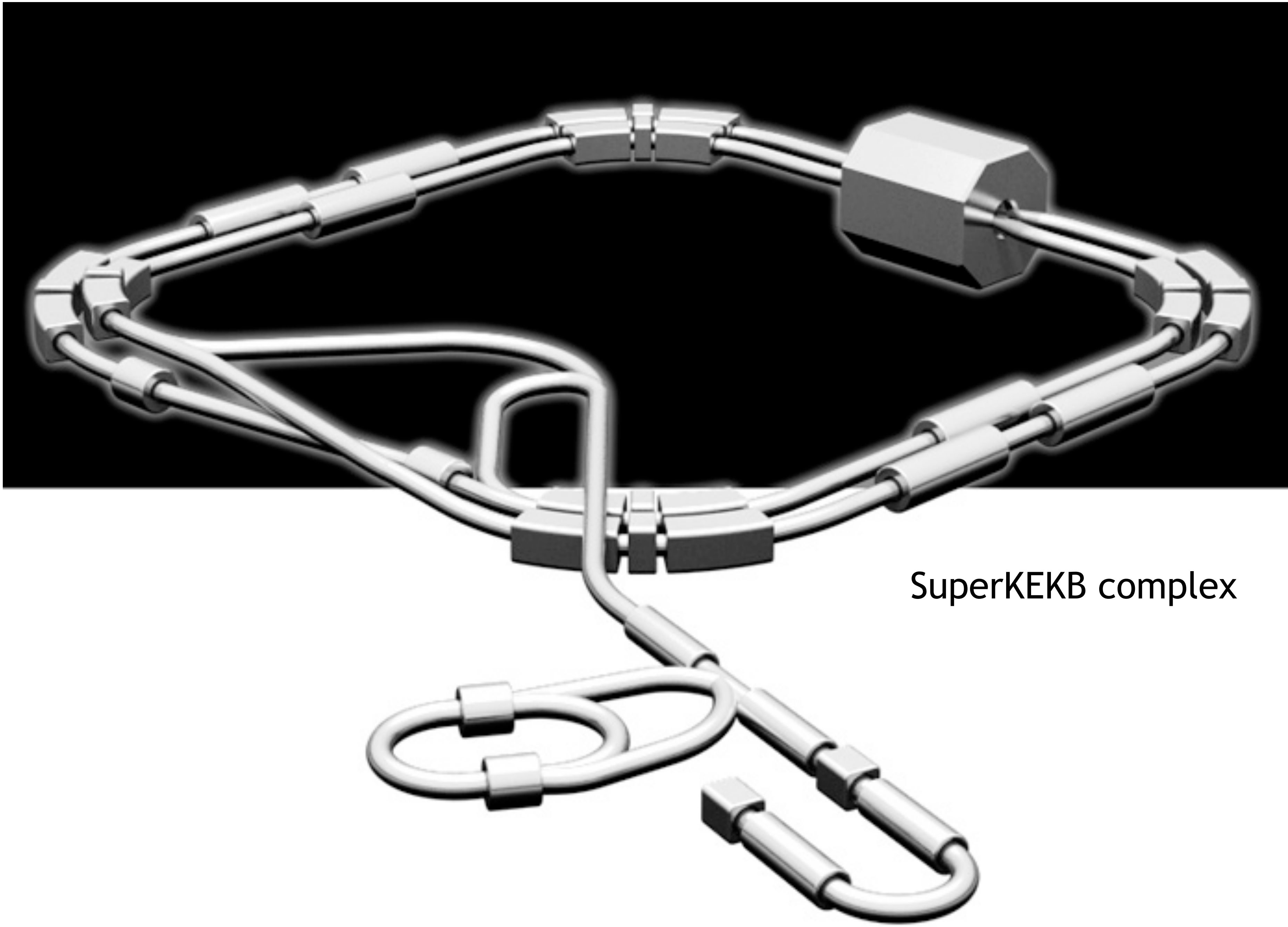
$$C = \frac{1 - |\lambda|^2}{1 + |\lambda|^2}, \qquad S = -\frac{2|\lambda|\sin\phi_s}{1 + |\lambda|^2}, \qquad D = -\frac{2|\lambda|\cos\phi_s}{1 + |\lambda|^2}$$

$|\lambda|$ includes possible contribution from CP violation in direct decay, we assume $|\lambda| = 1$ and we assign a systematics.

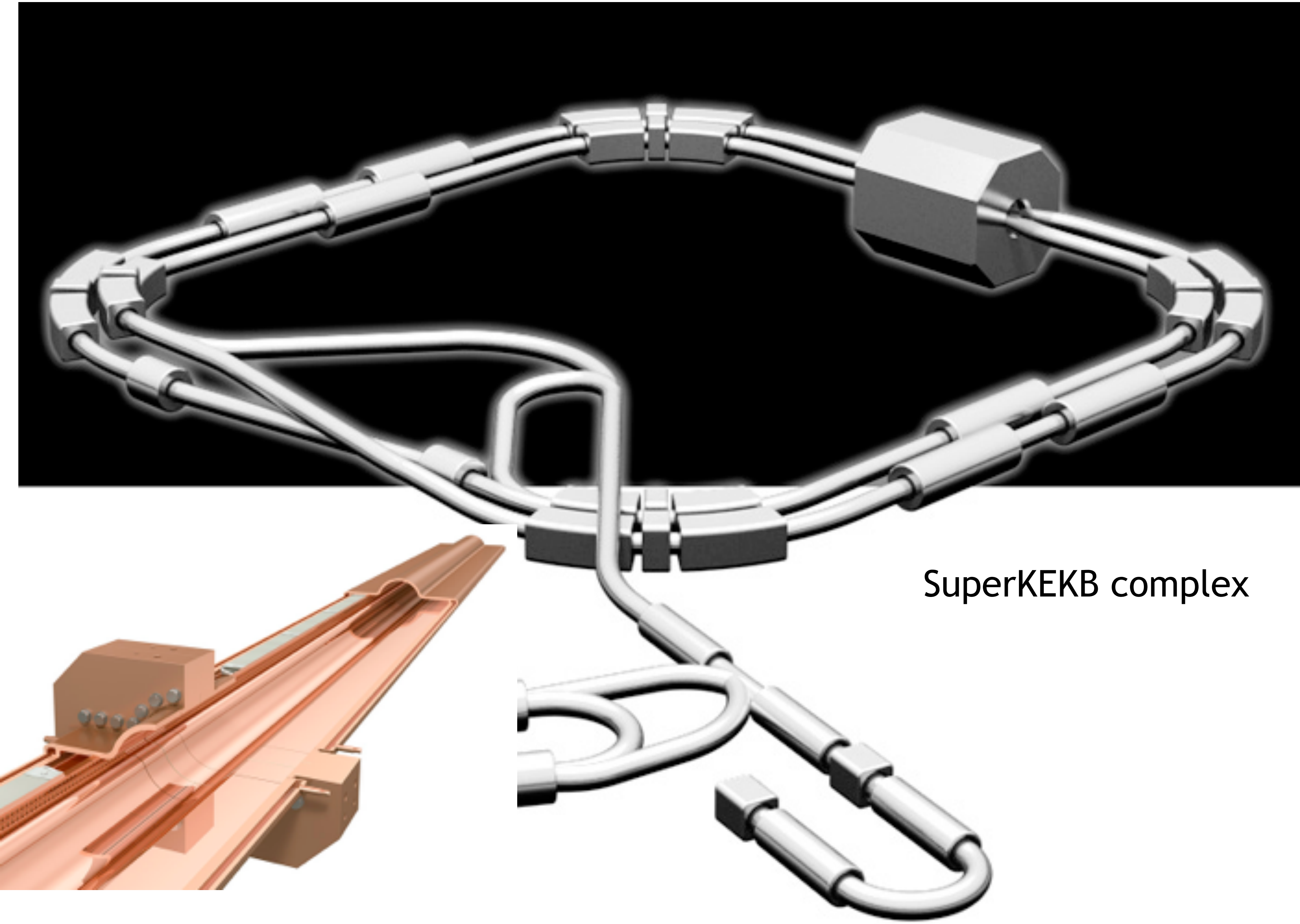
$\Delta\Gamma_s > 0$: we use previous LHCb results. α physics parameters ($\Delta\Gamma_s$, ϕ_s, $c\tau$, $|A_0|^2$, $|A_S|^2$, $|A_\perp^2|$, $\delta_\parallel$, $\delta_{S\perp}$, $\delta_\perp$)

CKMFitter with LHCb sin(2β) included



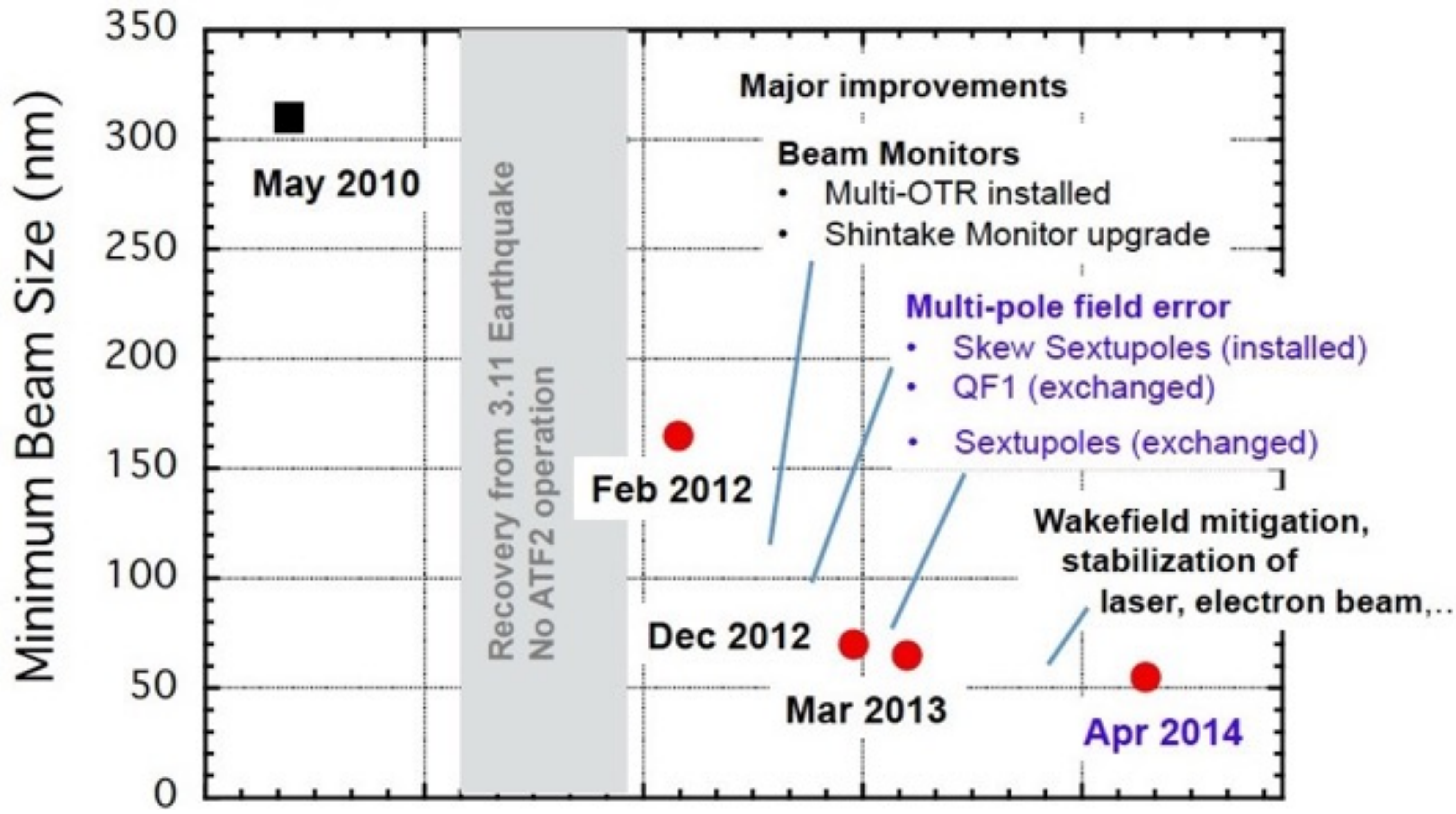


SuperKEKB complex



SuperKEKB complex

ATF2 nanobeams



“Missing Energy” Decays

Tokyo Sky Tree

Tsutentaku tower, Osaka

B→K* $l^+ l^-$ form factor ratios determined from *data* disagree with theory

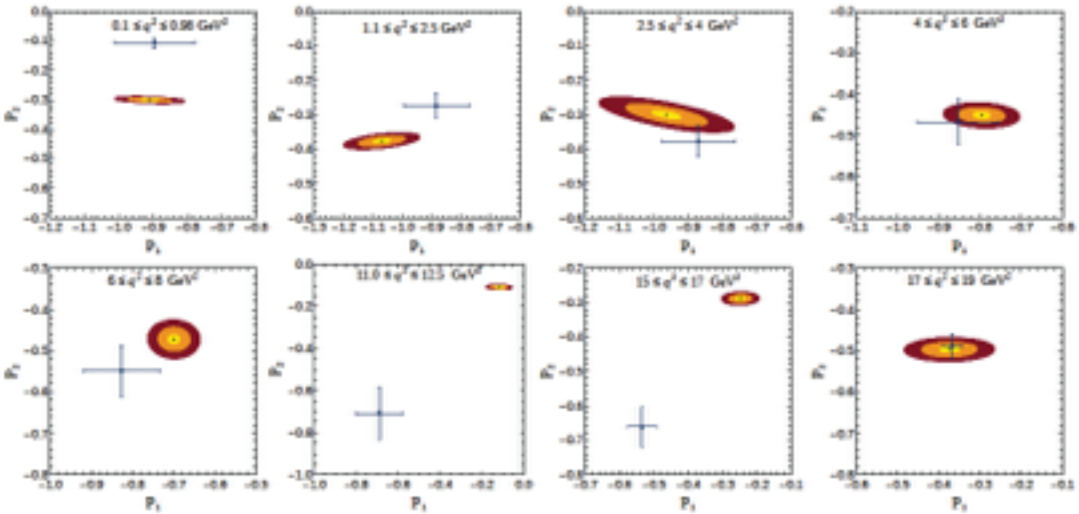


FIG. 1. (color online). The allowed region for P_1 versus P_2 plane. The innermost yellow (lightest), the middle one orange (light) and outer most red (dark) contours represent 1σ, 3σ and 5σ regions, respectively. The theoretically estimated values using Ref. [7] for $q^2 \le 8$ GeV^2 and Ref. [10] for $q^2 \ge 11$ GeV^2 are shown as points with error bars. In most cases, there is reasonable agreement between the theoretical values and those obtained from data. However, for the ranges $0.1 \le q^2 \le 0.98$GeV^2, $11.0 \le q^2 \le 12.5$ GeV^2 and $15 \le q^2 \le 17$ GeV^2 there are significant disagreements.

It is convenient to define P_1 and P_2 as,

$$P_1 = \frac{\mathcal{F}_\perp}{\mathcal{F}_\parallel}, \qquad P_2 = \frac{\mathcal{F}_\perp}{\mathcal{F}_0}. \qquad (8)$$

The observables $F_\perp$, F_L, A_{FB}, A_5 and A_4 can be written [2] as

$$F_\perp = u_\perp^2 + 2\zeta \qquad (9)$$

$$F_L P_2^2 = u_0^2 + 2\zeta \qquad (10)$$

$$A_{FB}^2 = \frac{9\zeta}{2P_1^2}(u_\parallel \pm u_\perp)^2 \qquad (11)$$

$$A_5^2 = \frac{9\zeta}{4P_2^2}(u_0 \pm u_\perp)^2 \qquad (12)$$

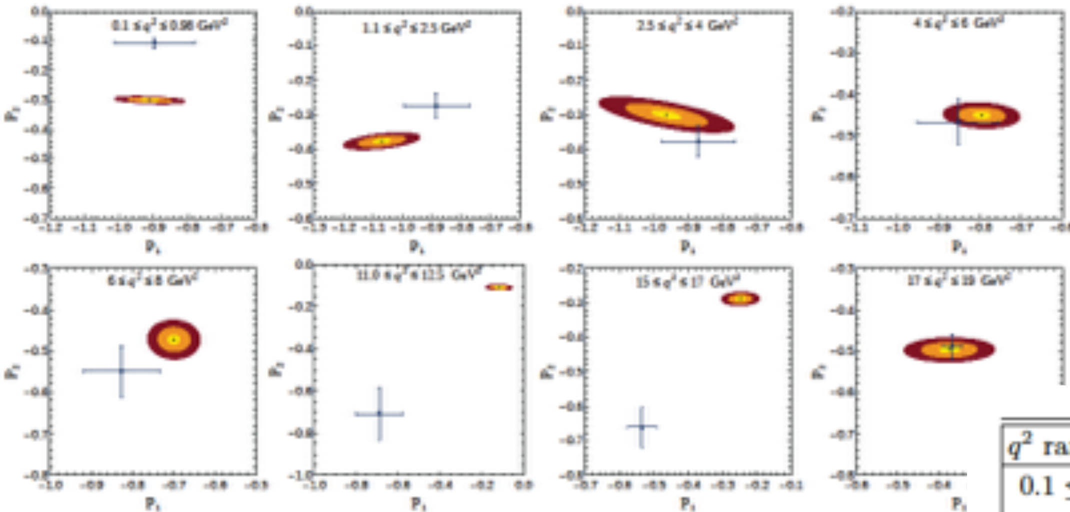
$$A_4 = \frac{\sqrt{2}}{\pi P_1 P_2}(2\zeta \pm u_0 u_\parallel) \qquad (13)$$

SKIP TODAY

Three form factors here

R. Mandal, R.Sinha, arXiv 1506:04535

B→K* $l^+ l^-$ form factor ratios determined from *data* disagree with theory



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R. Mandal, R.Sinha, arXiv 1506:04535

SKIP TODAY

Three form factors here

q^2 range in GeV^2	$V(q^2)$	$A_1(q^2)$	$A_{12}(q^2)$
$0.1 \leq q^2 \leq 0.98$	0.704 ± 0.404 (0.81σ)	0.538 ± 0.309 (0.79σ)	0.246 ± 0.141 (1.27σ)
$1.1 \leq q^2 \leq 2.5$	0.624 ± 0.081 (2.48σ)	0.384 ± 0.051 (1.42σ)	0.331 ± 0.052 (0.72σ)
$2.5 \leq q^2 \leq 4.0$	0.318 ± 0.185 (0.70σ)	0.204 ± 0.119 (0.89σ)	0.270 ± 0.177 (1.56σ)
$4.0 \leq q^2 \leq 6.0$	0.556 ± 0.026 (1.42σ)	0.398 ± 0.020 (2.02σ)	0.359 ± 0.032 (1.28σ)
$6.0 \leq q^2 \leq 8.0$	0.597 ± 0.017 (0.83σ)	0.437 ± 0.014 (2.74σ)	0.394 ± 0.022 (2.18σ)
$11.0 \leq q^2 \leq 12.5$	0.172 ± 0.006 (5.65σ)	0.539 ± 0.027 (2.43σ)	0.462 ± 0.028 (2.82σ)
$15.0 \leq q^2 \leq 17.0$	0.713 ± 0.004 (6.25σ)	0.638 ± 0.026 (3.36σ)	0.505 ± 0.016 (4.64σ)
$17.0 \leq q^2 \leq 19.0$	1.936 ± 0.007 (4.38σ)	0.678 ± 0.025 (3.82σ)	0.498 ± 0.014 (4.64σ)

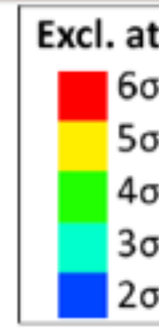
TABLE I. The form factor values obtained from fit to 3 fb^{-1} of LHC*b* data [4]. Round brackets indicate the standard deviation between fitted values and theoretical estimates [7, 10]. We find significant discrepancies for several values, especially for the large q^2 region.

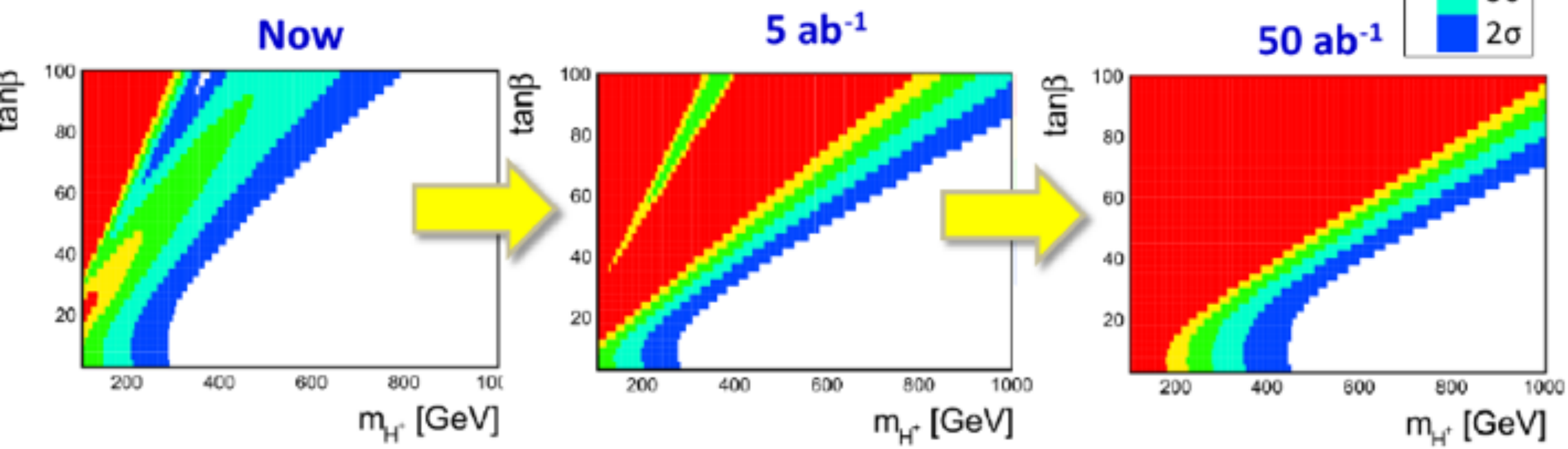
Initial Belle II projections for charged Higgs sensitivity

	Exp.			Th.
	Now	5 ab^{-1}	50 ab^{-1}	Now
$B \to \tau\nu$	25%	10%	3%	-7+14%
$B \to D\tau\nu$	30%	11%	4%	4%
$B \to D^{*}\tau\nu$	19%	7%	2%	2%
$B \to X_s\gamma$	7%	5%	4%	7%

Will improved by precise V_{ub} measurements.
My naive estimation assuming σ_{fB} ~1% :
~5% @Belle II era

My naive estimation



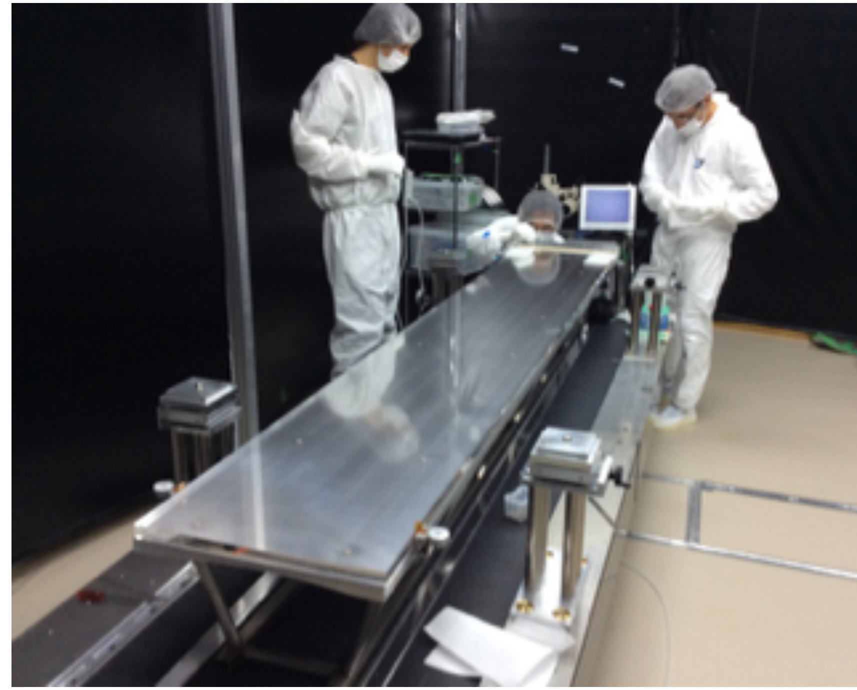


Yutaro Sato, R. Itoh et al

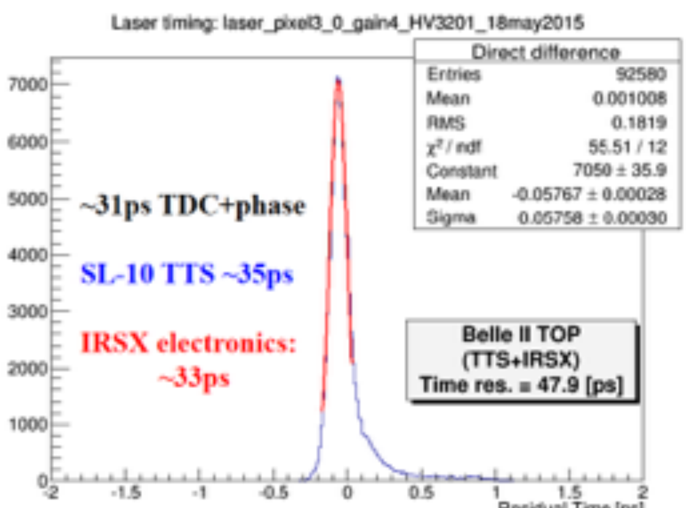
Charged Higgs: A strong case at Belle II

Belle II iTOP at Fuji Hall/Hawaii

Module 01 assembly at Fuji



Module 04 assembly at Fuji Hall

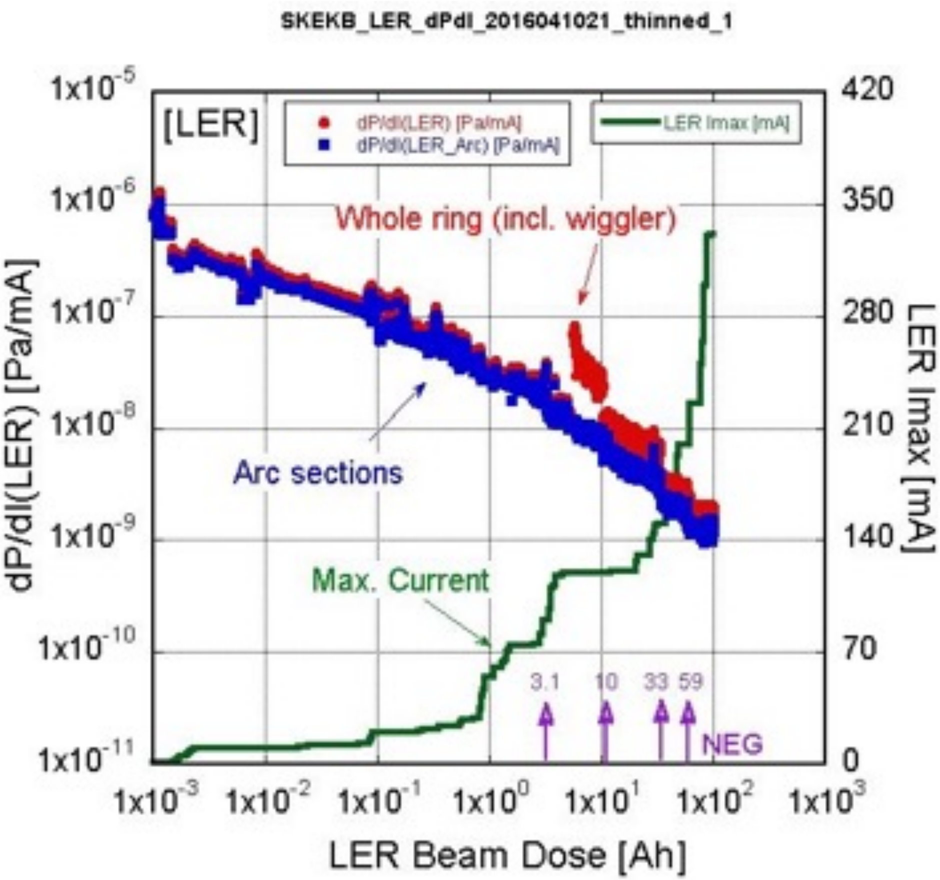


Production testing of readout with single photo-electron laser pulses in Hawaii; electronics resolution ~35ps

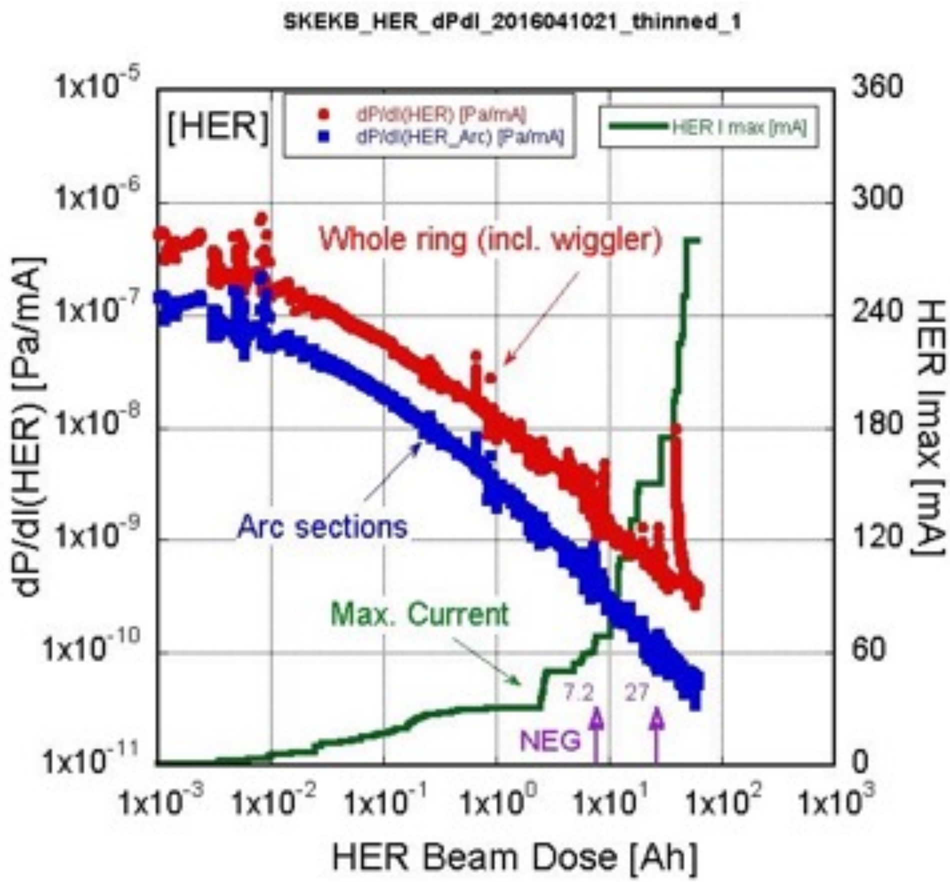
All quartz and electronics in hand; now testing and assembling.

Vacuum scrubbing

LER Beam dose > 100 Ah

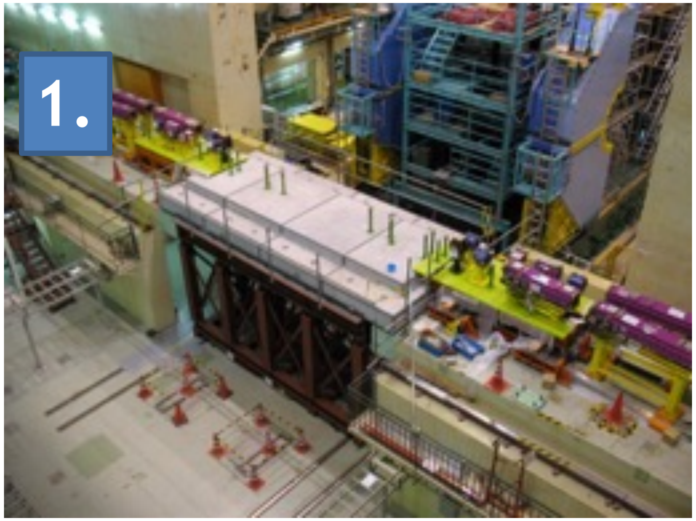


HER Beam dose > 60 Ah



BEAST Phase 1 Installation Sequence

1.

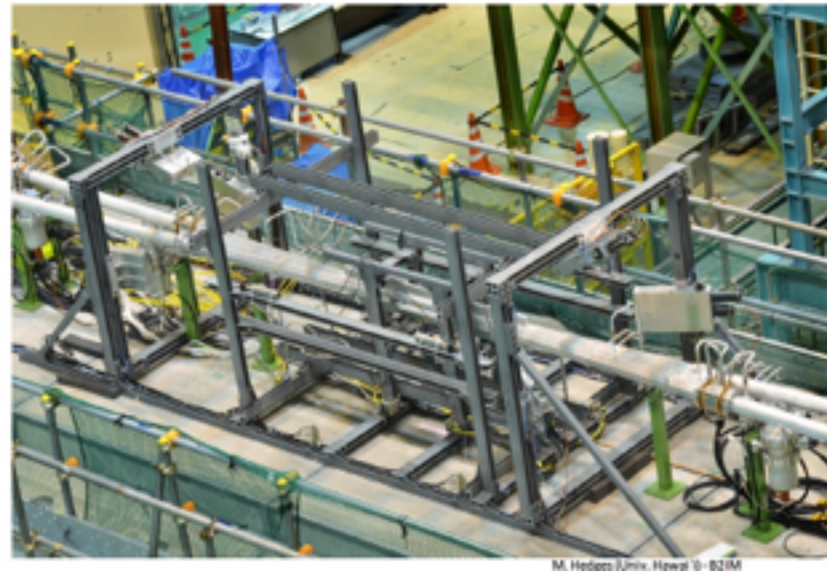


Install IP bridge: **Completed**

2. Install 6km cables: **Completed** June 25-28

3. Install IP chamber: **Completed** June 29th

4.



Install support structure and sensors: Aug 17- Sep

5.

Add IP shield wall w/ crane

BEAST Phase 1 Installation Sequence

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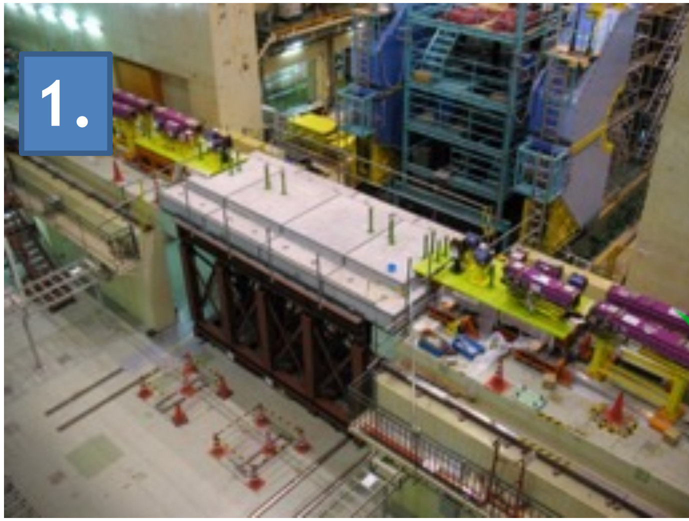

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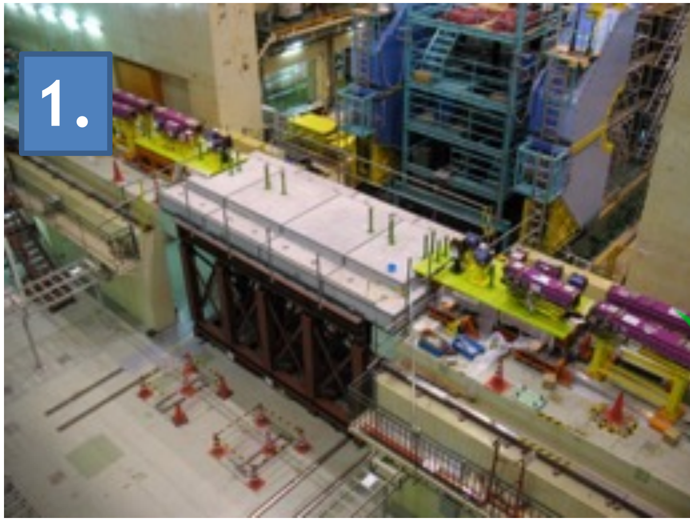

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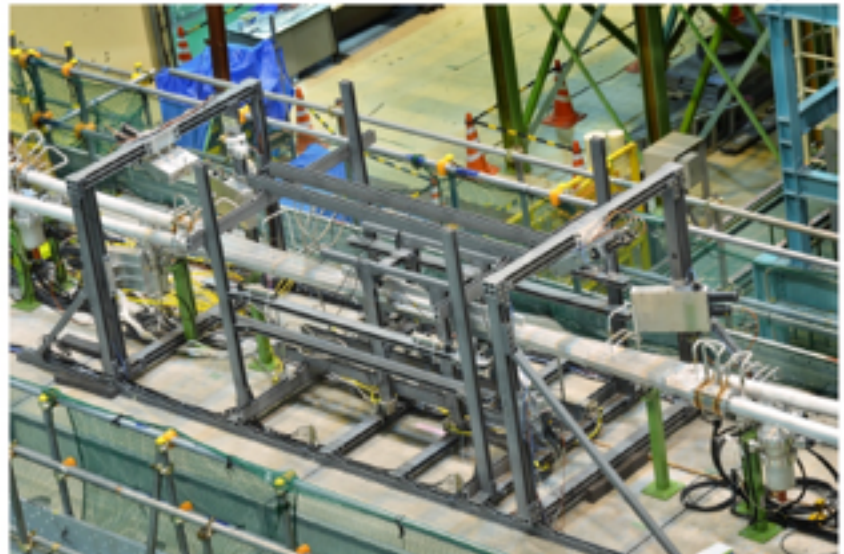

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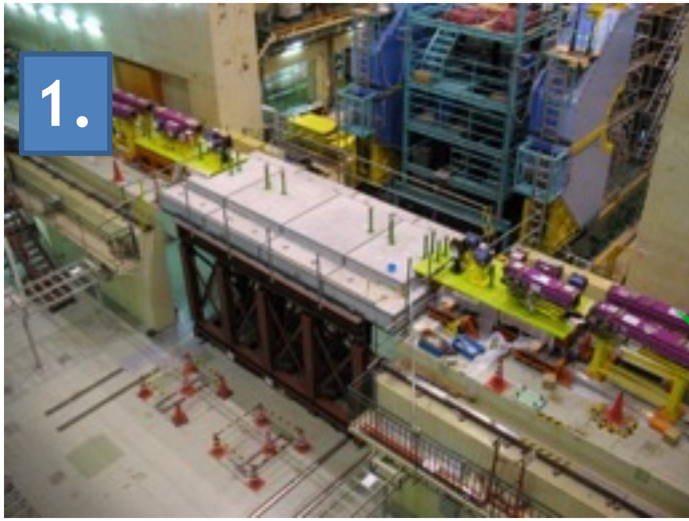

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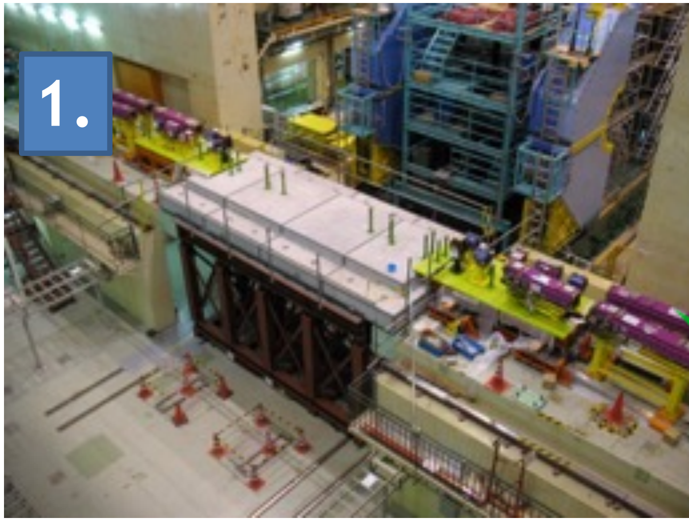

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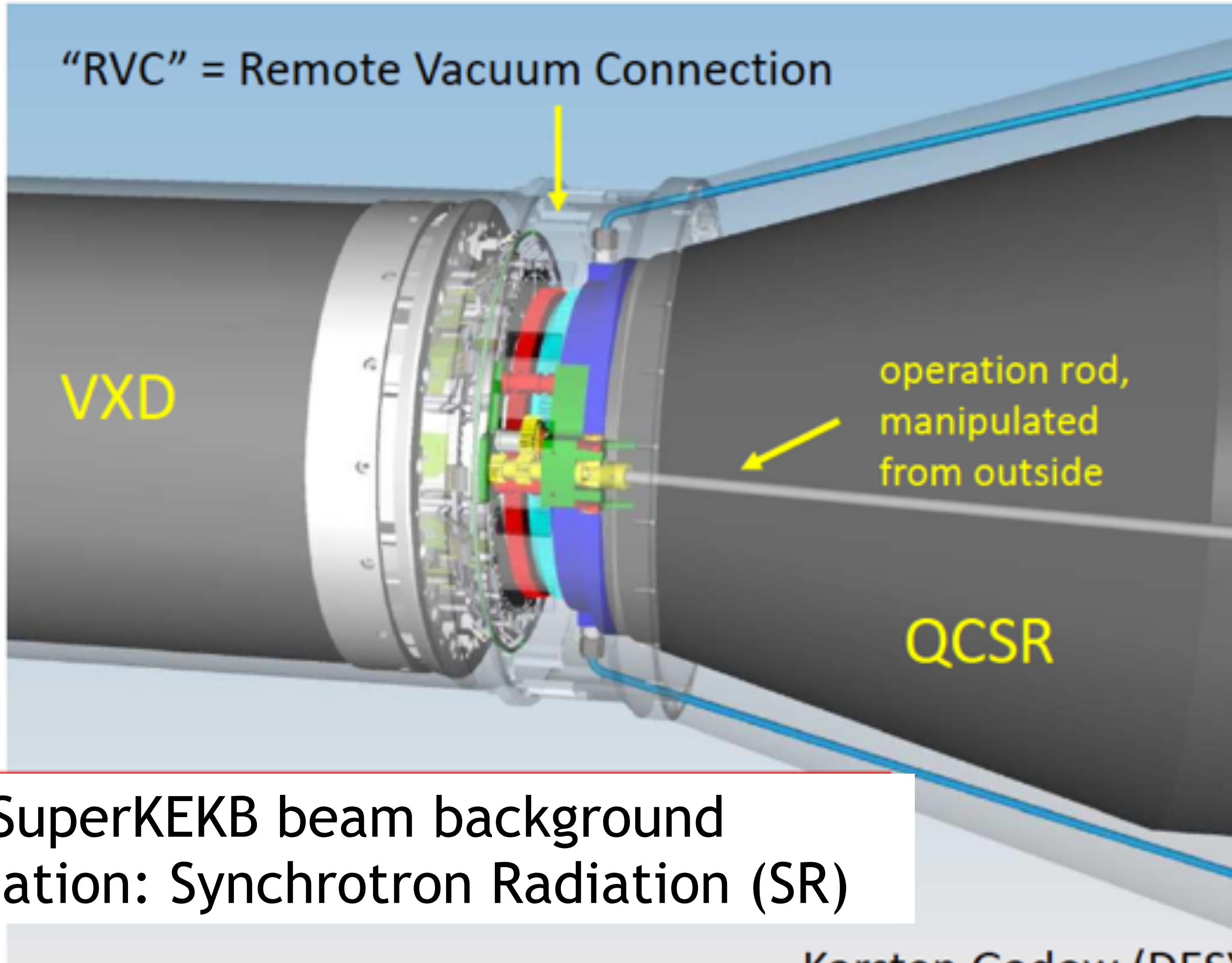
Conclusion/Next Generation

- The e+ e- B factories confirmed that the KM phase is responsible for most of the observed CPV [Physics Nobel Prize 2008]
- Nevertheless, 10-20% NP effects are consistent with all current flavor data.
- LHCb has ruled out large CPV phases from NP in the B_s sector.
- “Missing energy B decays” provide important high—mass sensitivity to the charged Higgs in the multi-TeV range.
- Angular anomalies in $B \to K^* l^+ l^-$ from LHCb with 3 fb^{-1}
- Belle II will soon join the game.
- *Flavor physics is exciting and fundamental. (Did we just find NP ? New Couplings; Flavor may be the path for the future of HEP but we need more data.)*

SuperKEKB commissioning started in February. Belle II rolls in at the end of the year. Belle II physics runs in 2018 and the LHCb upgrade in ~2020. These facilities will inaugurate a new era of flavor physics and the study of CP violation.

DESY contributions to SuperKEKB

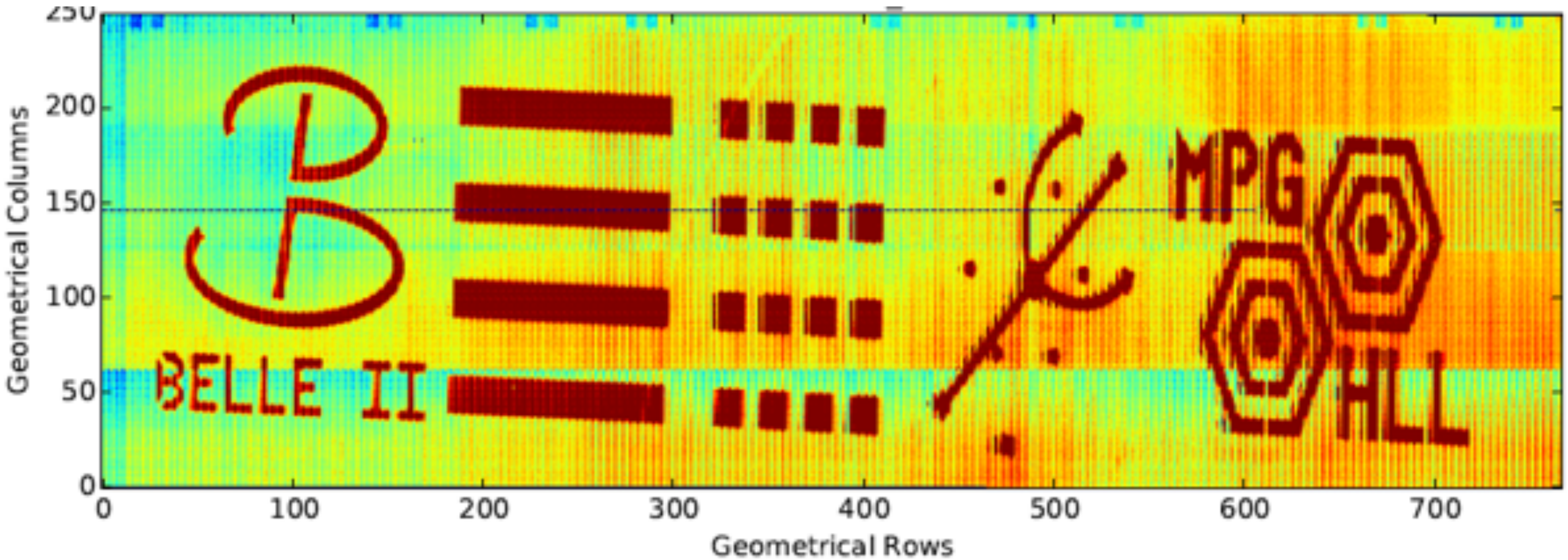
RVC *An important piece of SuperKEKB*



Also SuperKEKB beam background simulation: Synchrotron Radiation (SR)

Karsten Gadow (DESY)

“Full sized” pixel detector module 0



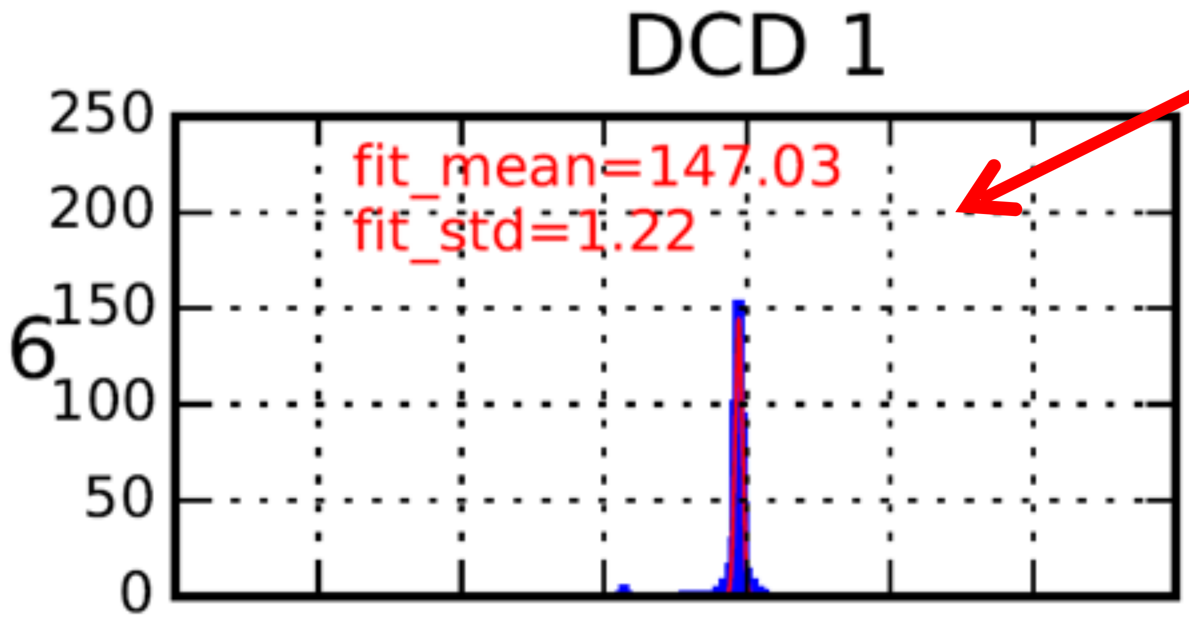
PXD9 illuminated through a mask

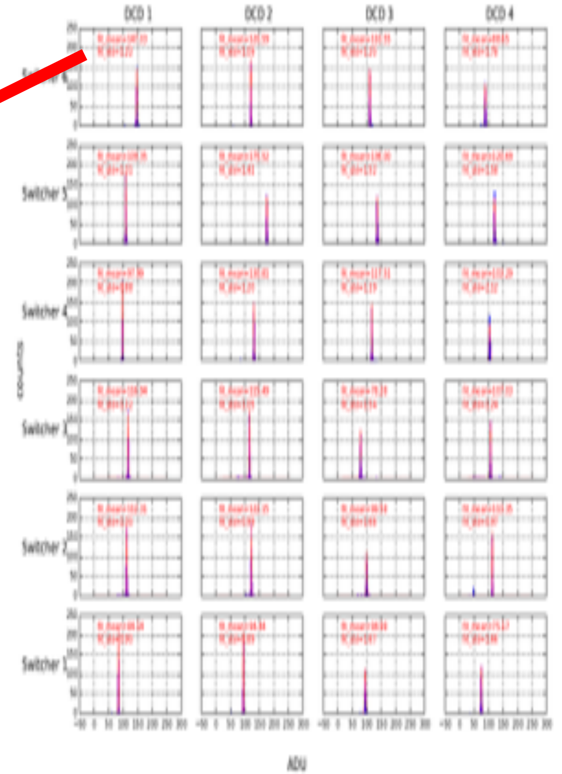
MPI and HLL are among the leading groups
of this large detector collaboration.

Full speed PXD readout – laser scan

:- laser spot at 1 pixel in each of the 24 regions, signal about 4 mip

:- <u>taken at **full read-out speed** (frame time 20µs)</u>





noise (laser system): 1-2 ADU

Laser signals are working well

→ First batch of final sensor production started