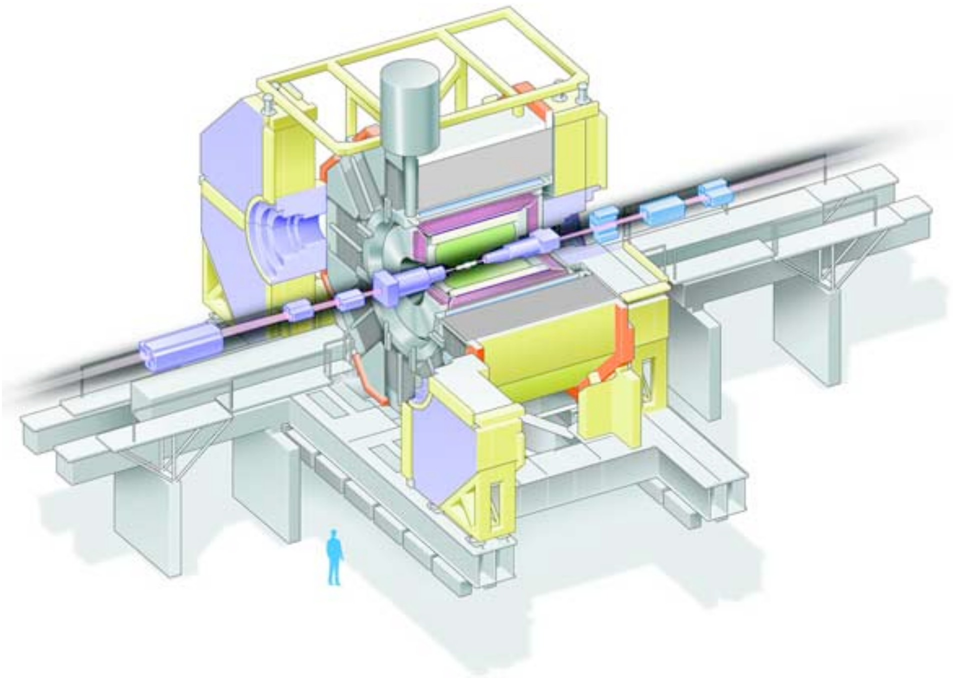
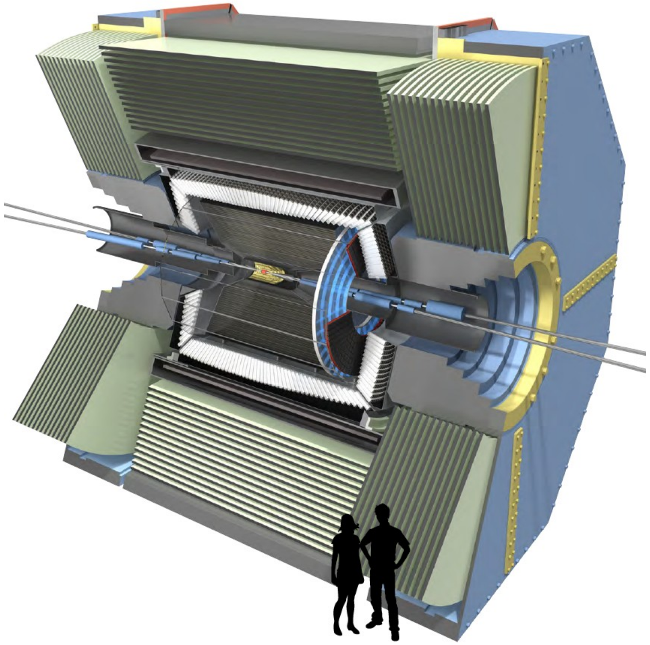
Belle & Belle II





Simon Wehle & Ami Rostomyan

80th PRC Open Session

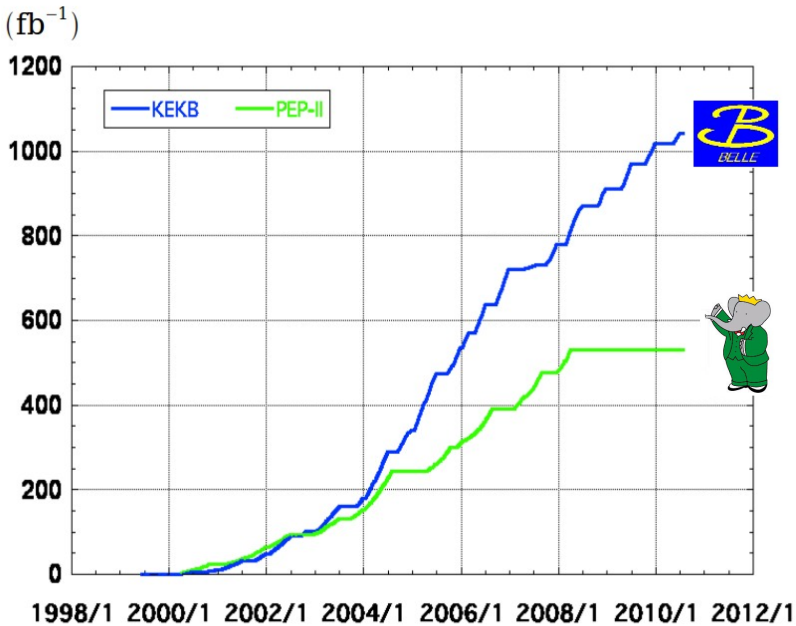
Hamburg, 22.10.2015

HELMHOLTZ ASSOCIATION

DESY

First Generation of B-Factories

B factories collected a lot of data



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

- Confirmation of Kobayashi-Maskawa mechanism of CP violation in the SM
- Precise measurements of CKM elements and angles of UT
- Measurements of rare B-decays
- New sources of CPV: b→s transitions
- Observation of D mixing (charm factory)
- Searches for LFV tau decays (tau factory)
- …

Belle:

- ~ 771 M BB pairs
- ~ 900 M tau and muon pairs
- Results compatible with SM
- Not significant hints on deviations from SM

Still many analysis limited in statistics!

First Generation of B-Factories

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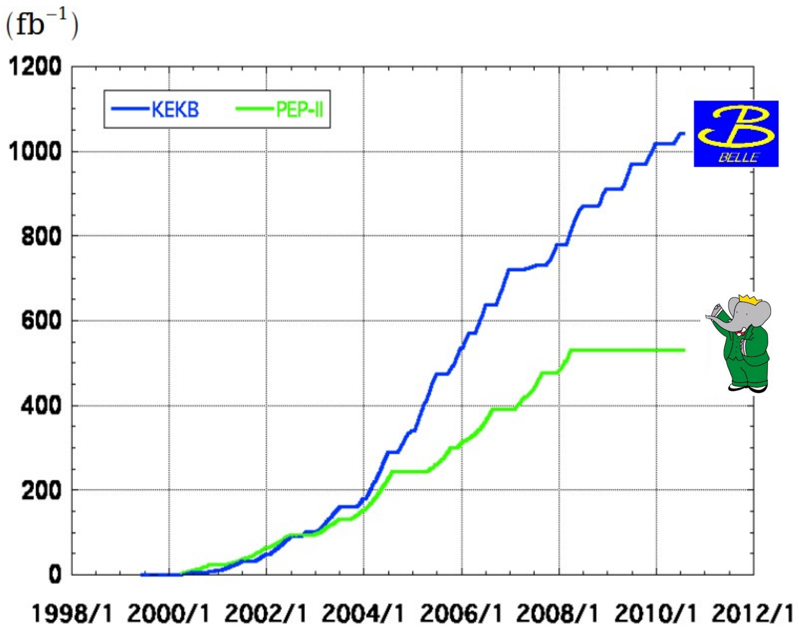

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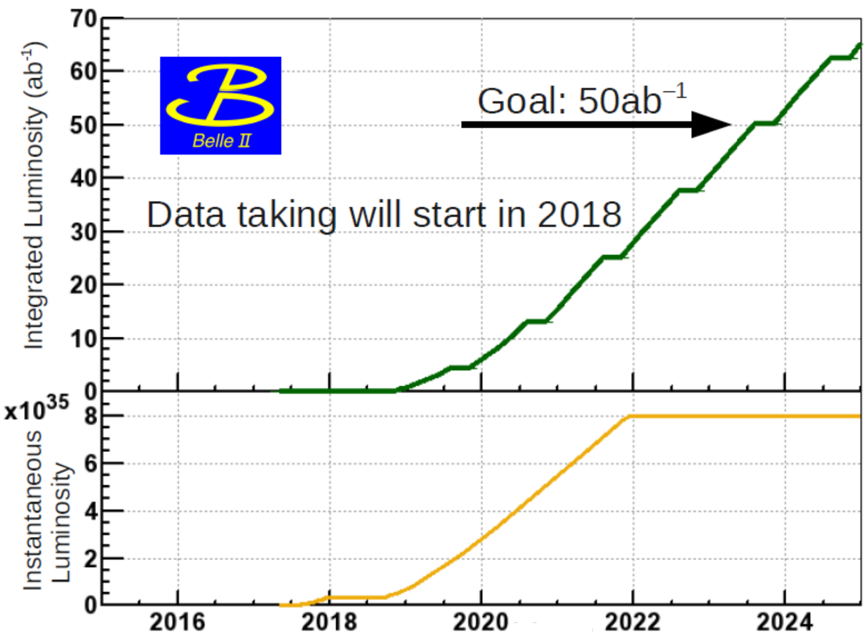

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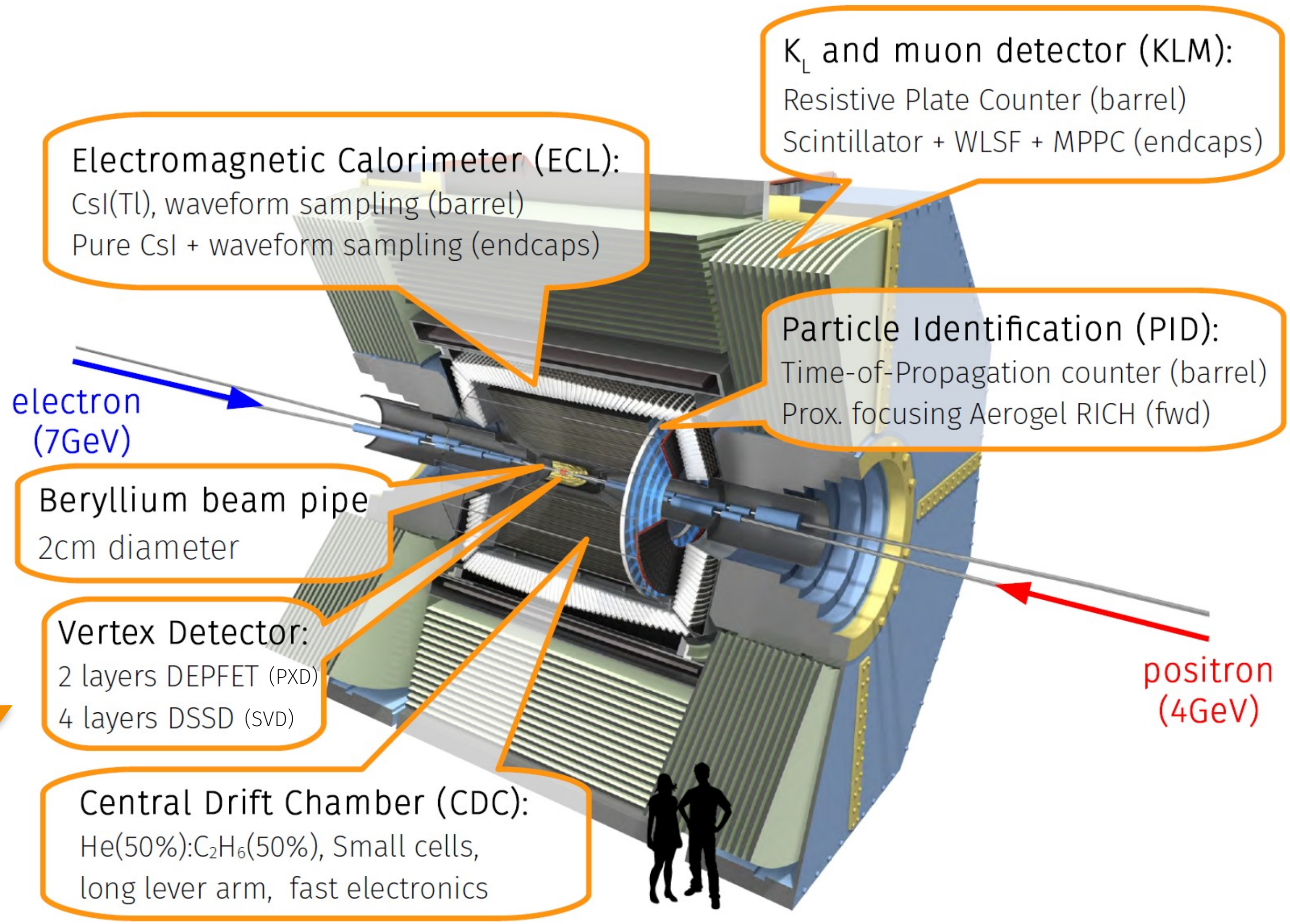
Still many analysis limited in statistics!

Belle→Belle II

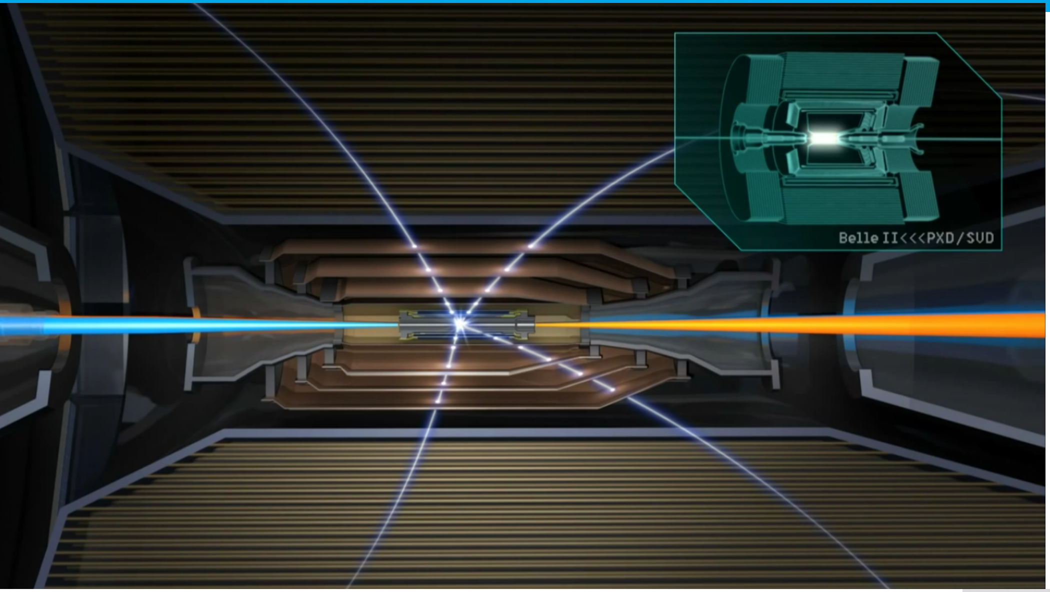
Upgrade of all Belle sub-detectors to cope with higher particle fluxes associated with higher luminosity and beam currents.



DESY contributes to

Hardware

Belle II Vertex Detectors (VXD)



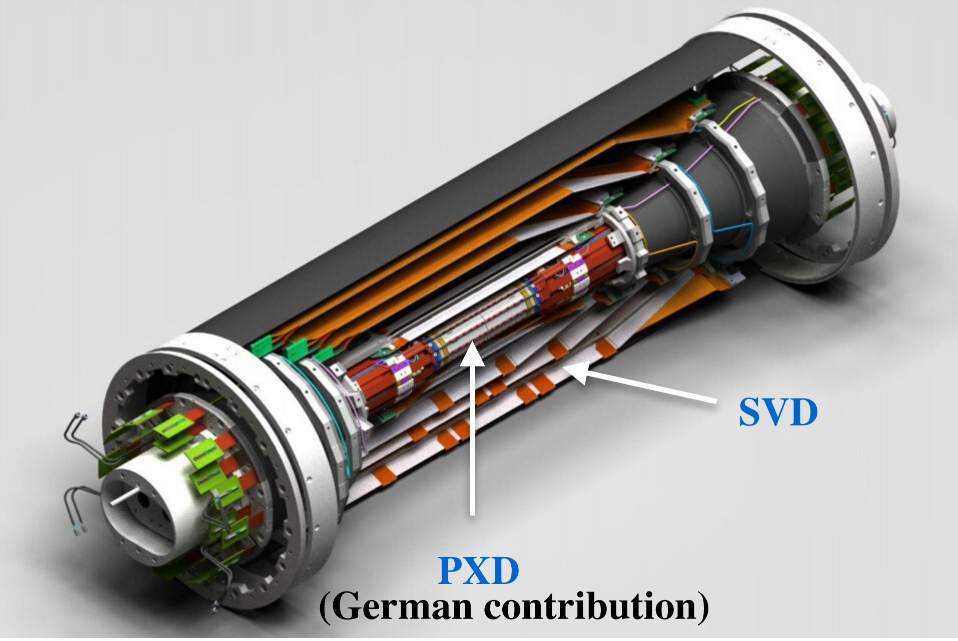
VXD consists of:

- Pixel Vertex Detector (PXD)
- Silicon Vertex Detector (SVD)
  - share a common volume

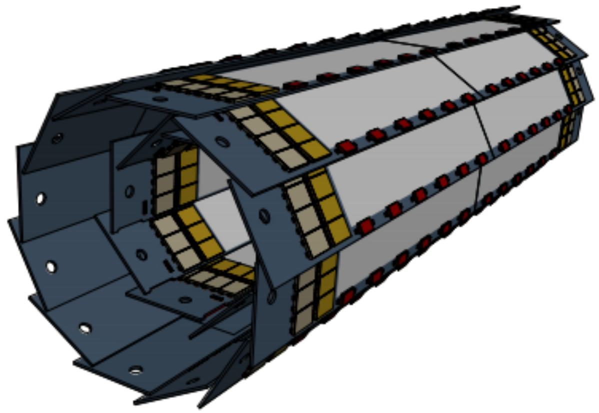
PXD and SVD - one integrated system

DESY contribution:

- CO_2 cooling tests
- Test beam (next planned in April 2016 at DESY)
- Installation
- Commissioning



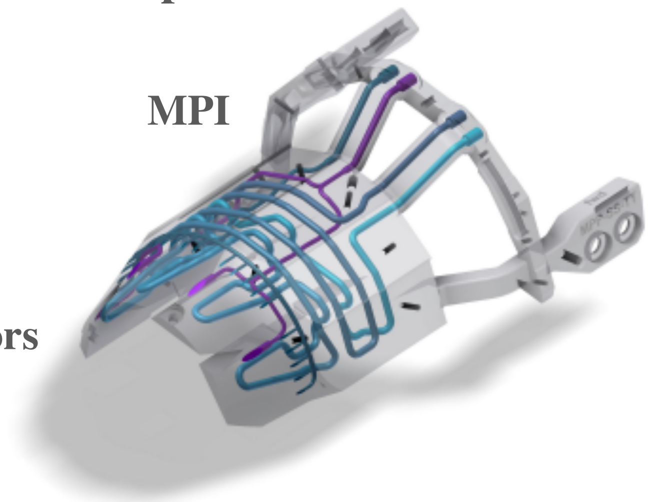
Belle II Vertex Detector and Cooling System



2 layers with 40 DEPFET pixel sensors with 8 million pixels in sensitive area

SCB (Support & Cooling Block)

with 2-phase CO_2 and N_2 channels



Requirements (PXD):

- Sensor: < 25°C
  → minimise noise due to leakage currents
- Read out: < 50°C
  → avoid risk of electro-migration
- Total energy dissipation ~360W

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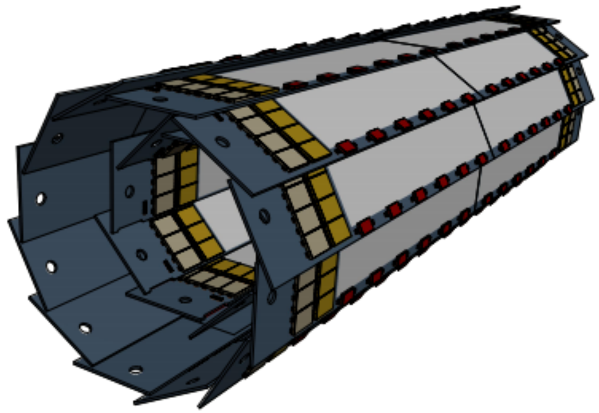

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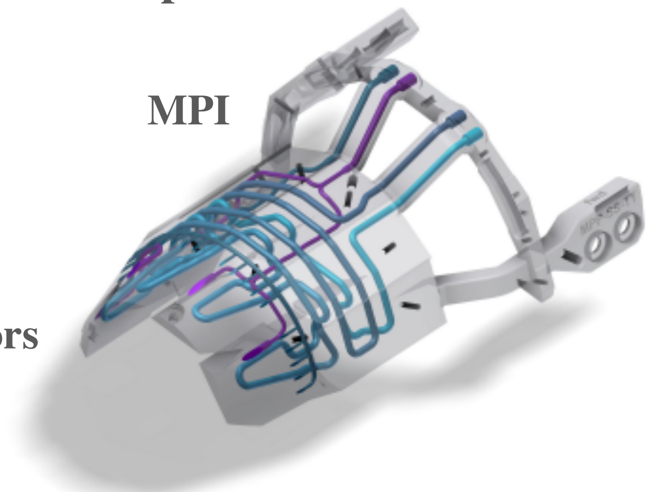

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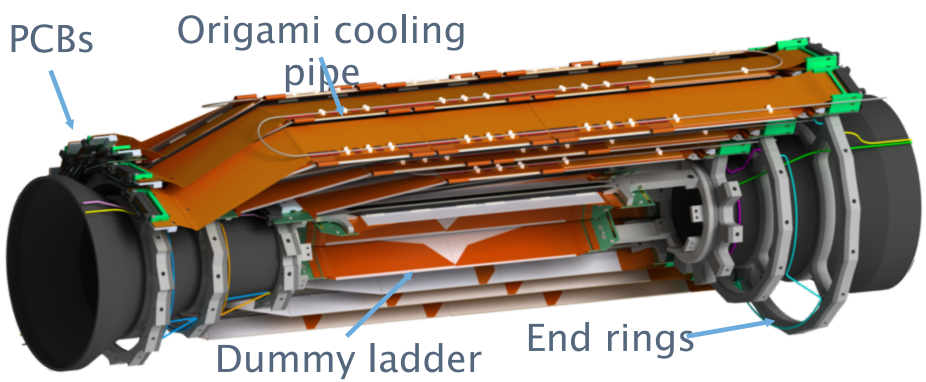


4 layers of double-sided Silicon Strip Detectors (DSSD).

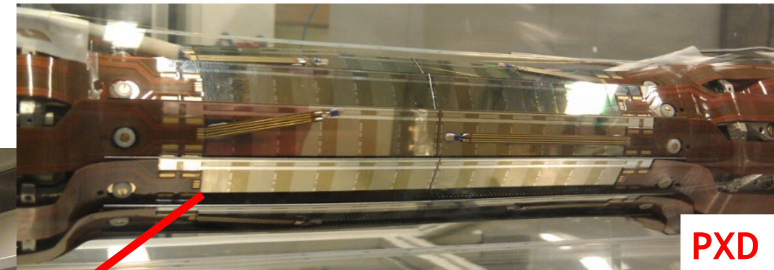
Requirements: (SVD):

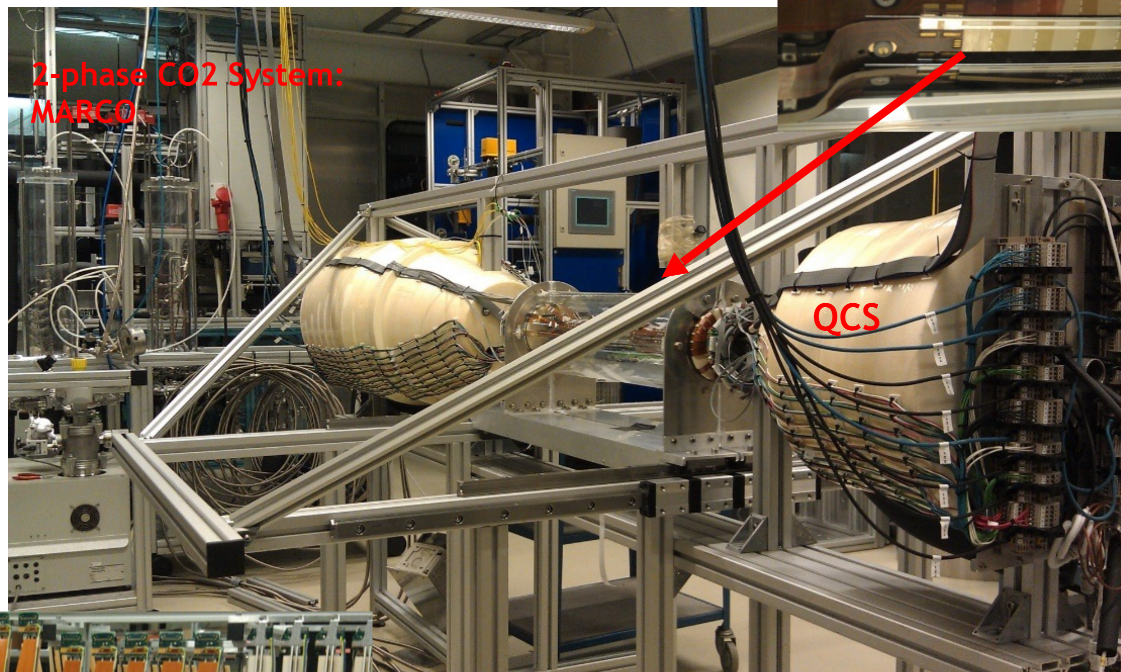
- Read out chips' (APV25) surface at about 0°C

  → SNR improvement
- Total energy dissipation ~700W

VXD Thermal Mock-up at DESY

The thermal mock-up is built to study and optimise the cooling system for the Belle II vertex detector.





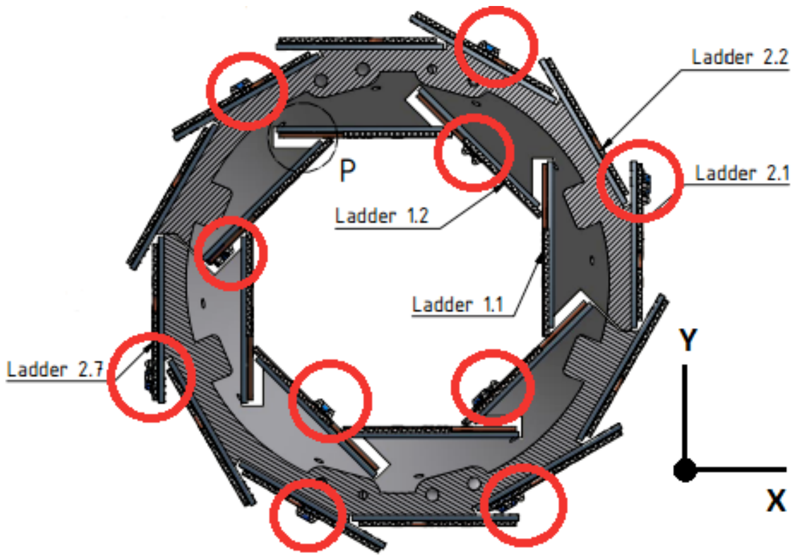
SVD Dummy ladders

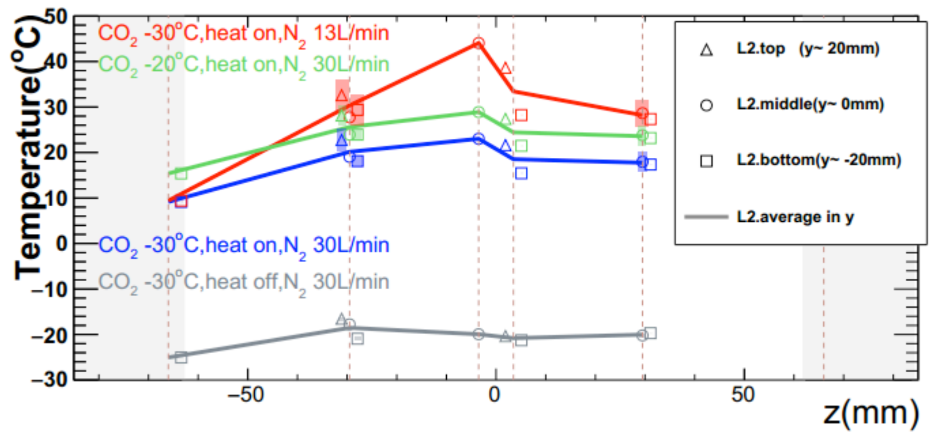
SVD parts are under preparation.

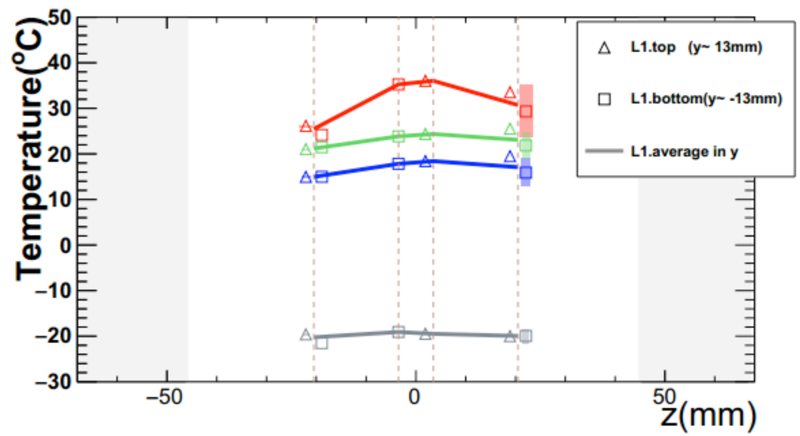
End rings

Belle II Detector: Temperature Gradient on PXD Ladders

Pt100s on PXD

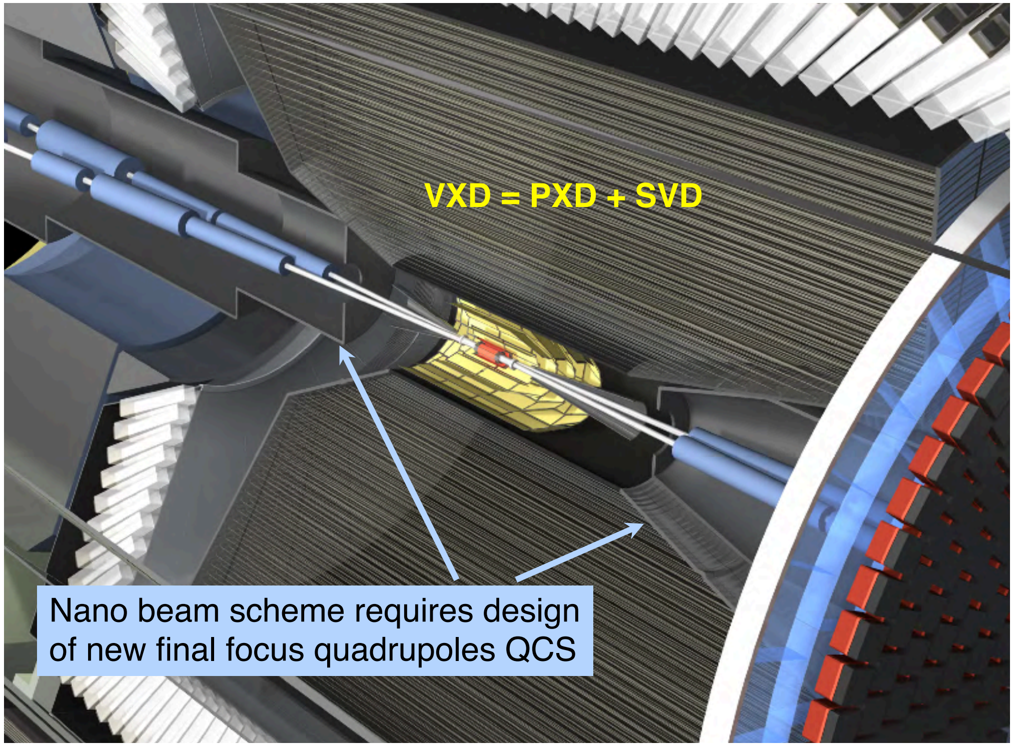






Belle II Detector: Remote Vacuum Connection

RVC is essential component to interface SuperKEKB with Belle II



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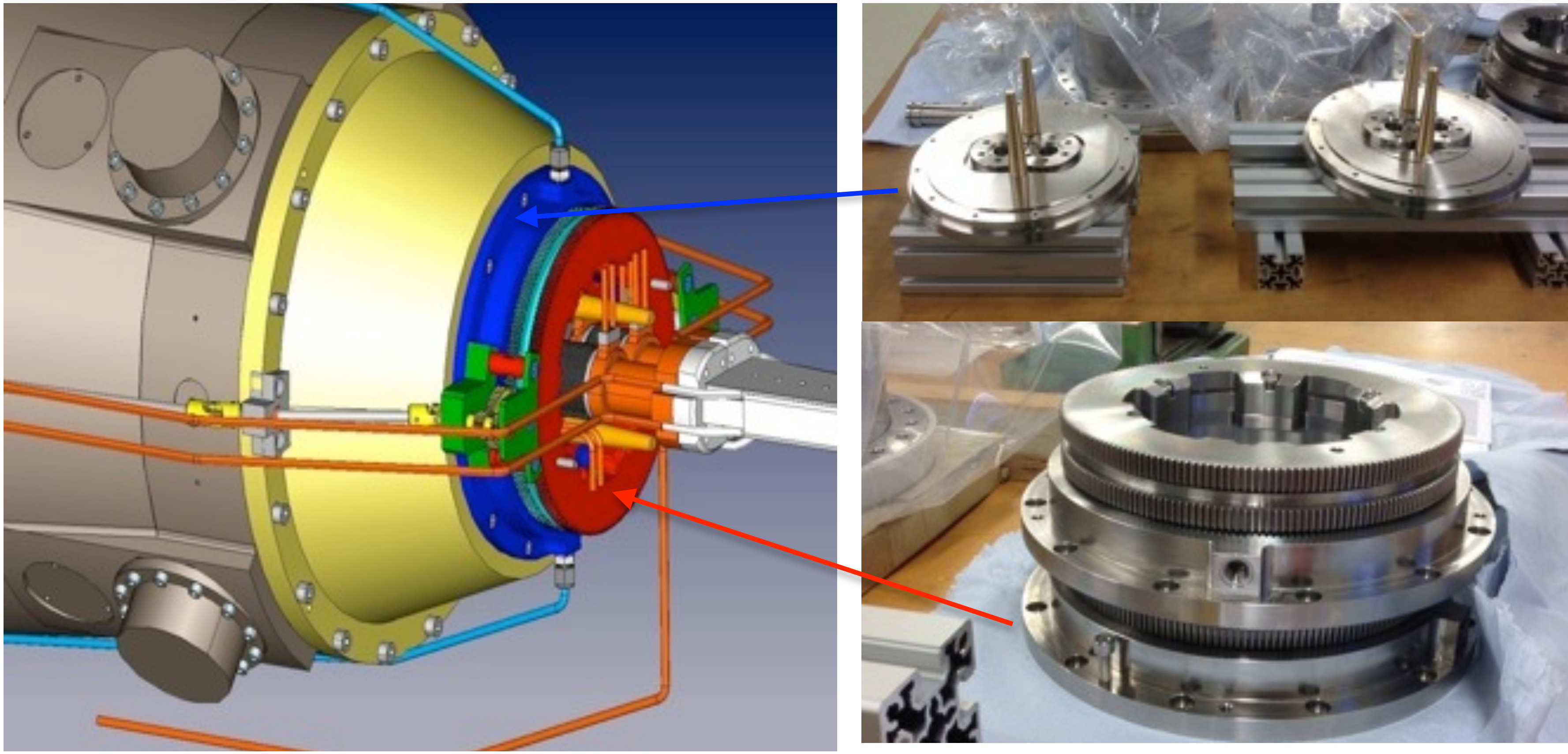

- All components for forward and backward RVC ready at DESY
- Detailed mechanical and vacuum tests in the coming months
- Installation at KEK in spring 2017

Software

Belle II Software: Experimental Challenges

10-20 times higher background than at Belle → fake hits, radiation damage…

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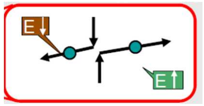
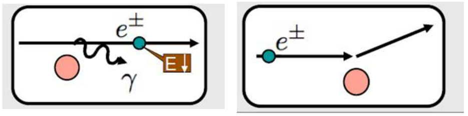
- Main background sources from

1. scattered beam particles

Touschek scattering

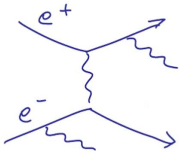


Beam-gas scattering

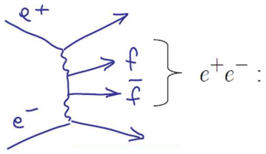


2. physics processes

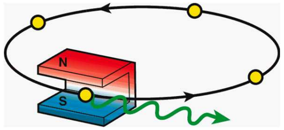
Radiative Bhabha



2-photon process



3. synchrotron radiation



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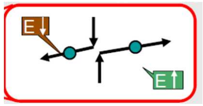

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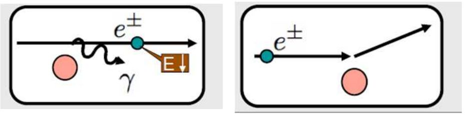

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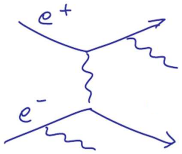

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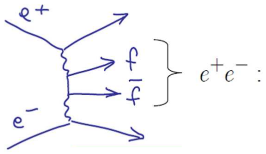

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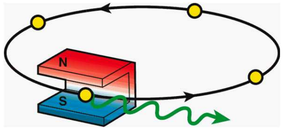

DESY contribution: estimate the synchrotron radiation

- PXD: allowed limit for occupancy from all background sources: 3%
  - all sources except synchrotron radiation: ~ 1%
  - the limit of occupancy for synchrotron radiation (with a safety margin of 1%): ~ 1%
- Result of synchrotron radiation simulation essential for decision on beam pipe coating

Simulation is basis for decision on thickness of beam pipe coating

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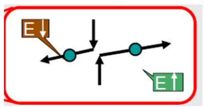

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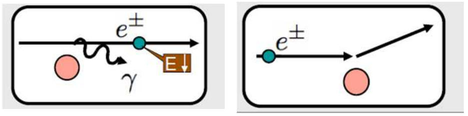

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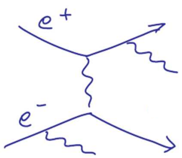

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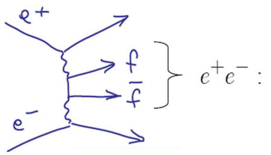

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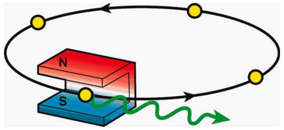

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- Result of synchrotron radiation simulation essential for decision on beam pipe coating

Simulation is basis for decision on thickness of beam pipe coating

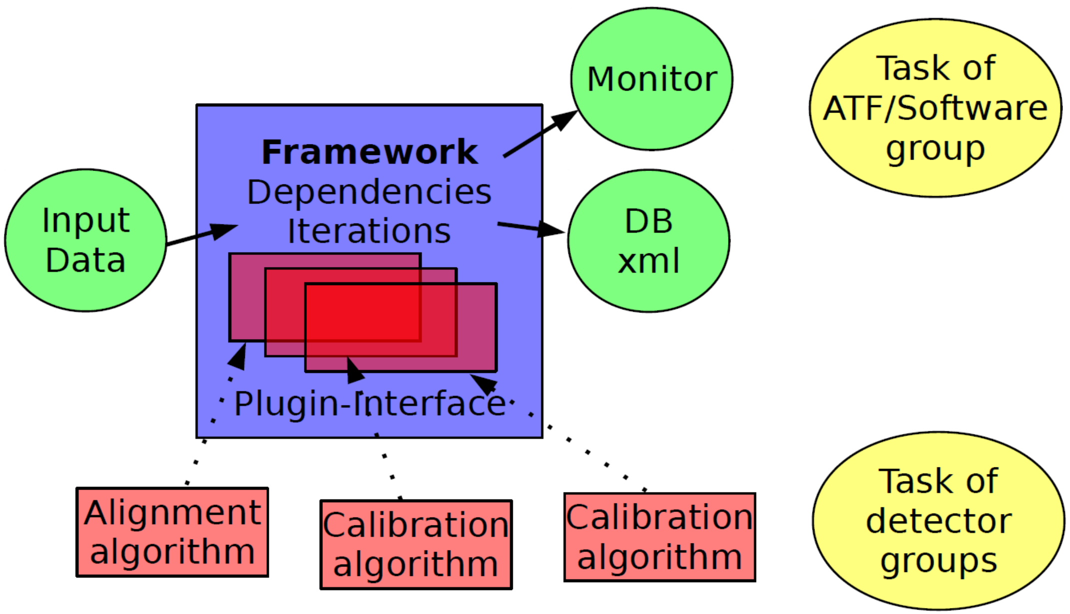
Choices of beam pipe coating thickness → will be decided this week

- thinner gold coating → better vertex resolution
- thicker gold coating → better absorption of synchrotron radiation

Belle II Software: Alignment and Calibration

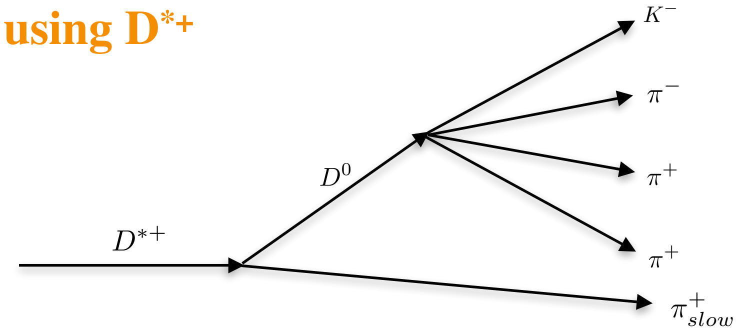
DESY leads the alignment and calibration group

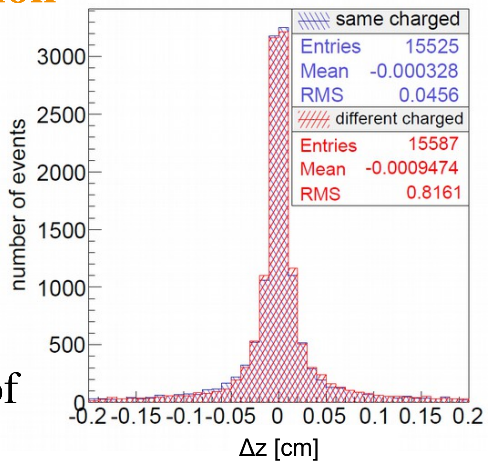
- Alignment:
  - tracking detectors integrated in the framework
  - using Millepede II and General Broken Line (GBL) track fit
  - Tested for PXD, SVD and CDC on Monte Carlo and beam-test data
  - Tracking with GBL ready for KLM → alignment of KLM in progress
- General Calibration activity → calibration framework
  - separate common alignment/calibration tasks from individual detector algorithm implementations
  - first example of non-alignment calibration (KLM) included

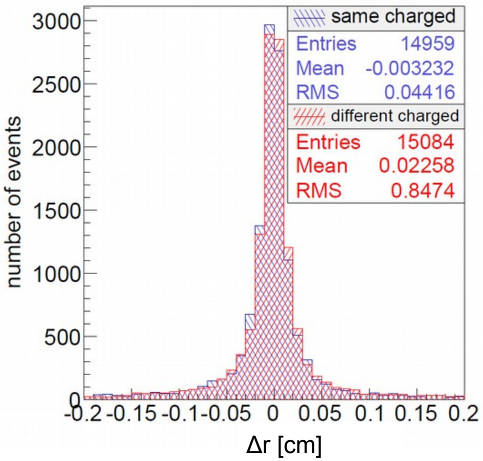


Belle II Software: Alignment Validation Tools

1. DESY contribution: Alignment validation using D^{*+}







- Vertex reconstruction of D^0 using vertices of two pairs (same charge, different charge)

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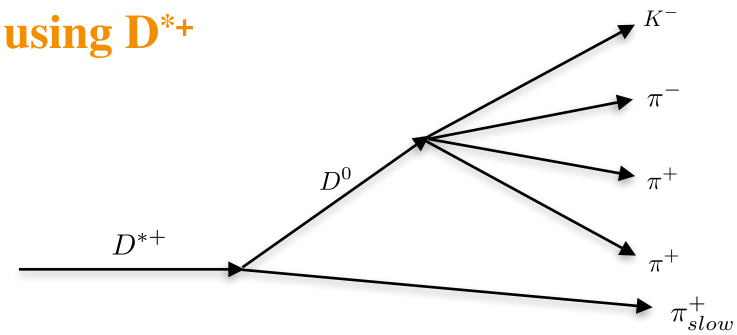
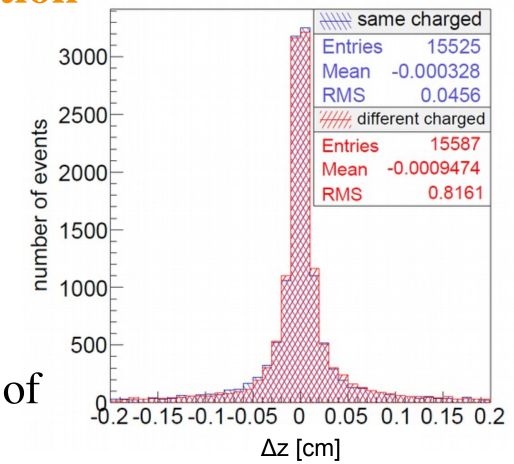
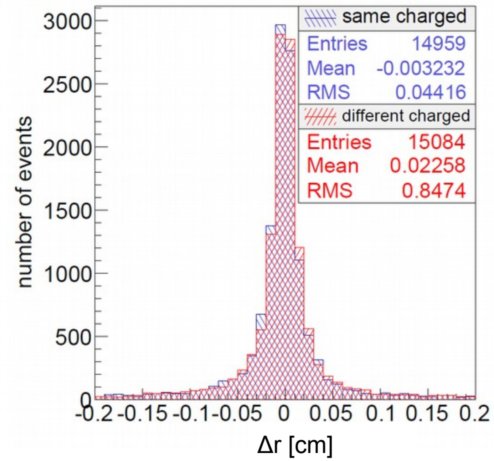
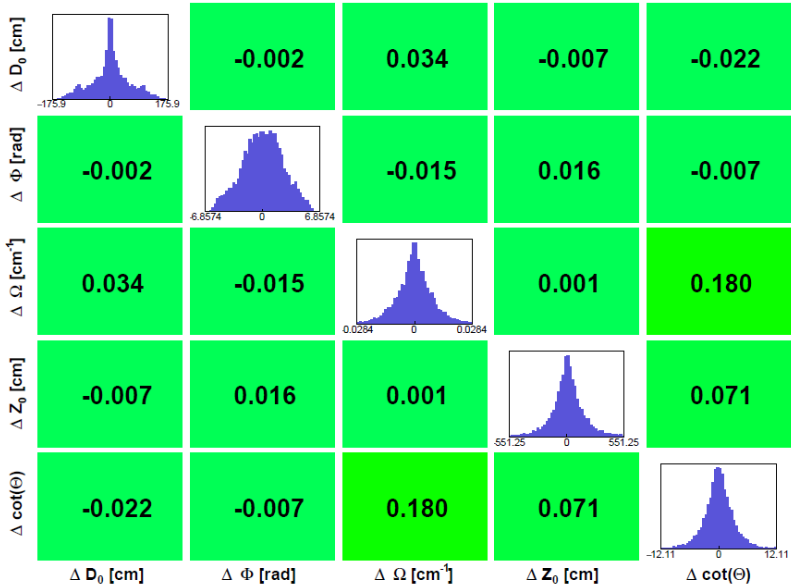






- Vertex reconstruction of D^0 using vertices of two pairs (same charge, different charge)

(helix representation)



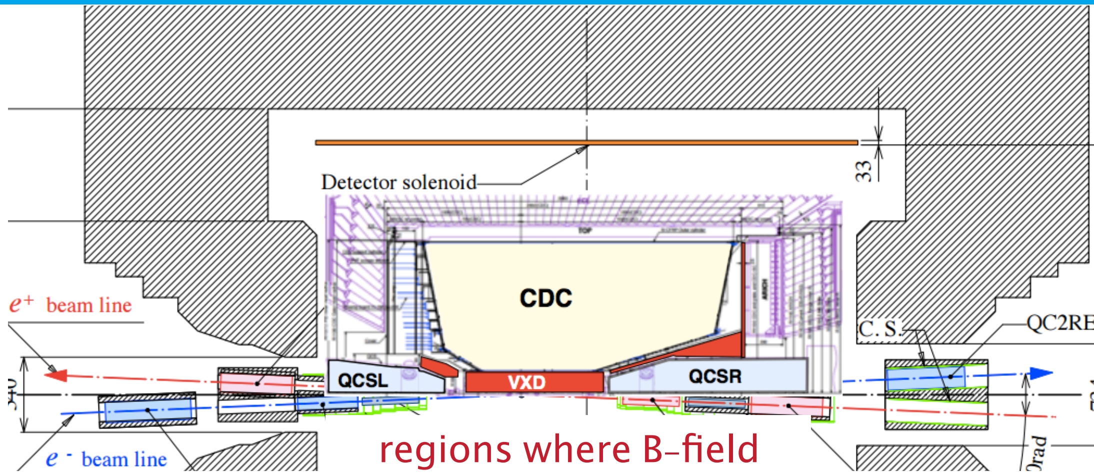
2. DESY contribution: Validation procedure using cosmic rays

- Generation of cosmic-ray muons using cosmic-shower generator
- Comparison of reconstructed track parameters in top vs bottom
- For ideal alignment
  - No difference between mean values
  - No correlations

Belle II: B-Field

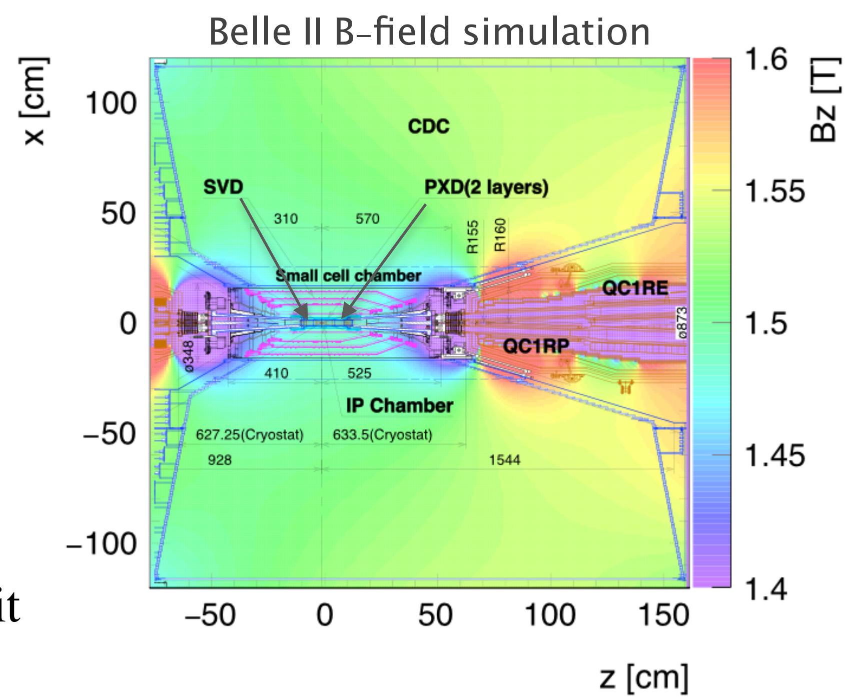
Precise knowledge of the magnetic field is essential in the presence of the final focus magnets.

Goal: $\Delta B/B < 0.1\%$



regions where B-field measurement is possible

- B-field measurement possible only
  - before VXD installation
  - in limited regions
- Rely on calculation/simulation
  - 3D calculation of Belle II B-field



DESY leading B-field measurement task force:

- Implications on physics performance studies using 3D simulation of Belle II B-field
- Constrain B-field from data within alignment & calibration using Millepede II / GBL track fit → DESY expertise

Belle

Belle II

Analysis

Standard Model

(SM)

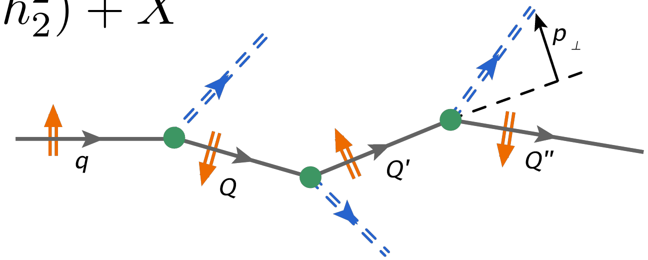
Searches for

New Physics

(NP)

Belle Analysis: Light Quark Fragmentation

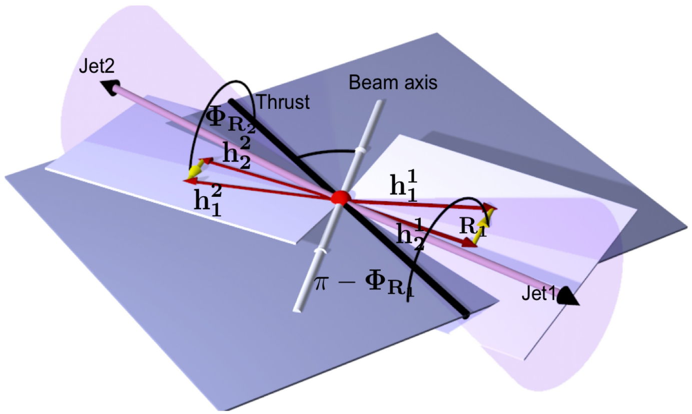
$$e^+ + e^- \to \gamma^* \to (h_1^1 h_2^1) + (h_1^2 h_2^2) + X$$



Study the spin-dynamics of hadronisation

- measure azimuthal correlations between two pairs of charged pions in opposite hemispheres

fragmentation of *transversely* polarised quarks:	$H_1^\perp,\ H_1^\sphericalangle$
fragmentation of *longitudinally* polarised quarks:	$G_1^\perp$



$H_1^\perp$ $\qquad$ $G_1^\perp$ $\qquad$ $H_1^\sphericalangle$

$$\sigma \propto 1 + A^{\cos(\phi_1+\phi_2)}\cos(\phi_1+\phi_2) + A^{\cos 2(\Phi_{R1}-\Phi_{R2})}\cos 2(\Phi_{R1}-\Phi_{R2}) + A^{\cos(\Phi_{R1}+\Phi_{R2})}\cos(\Phi_{R1}+\Phi_{R2})$$

Belle Analysis: Light Quark Fragmentation

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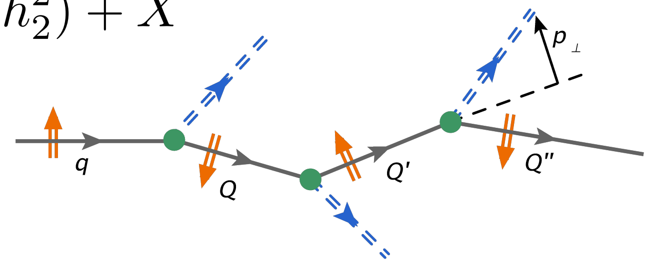

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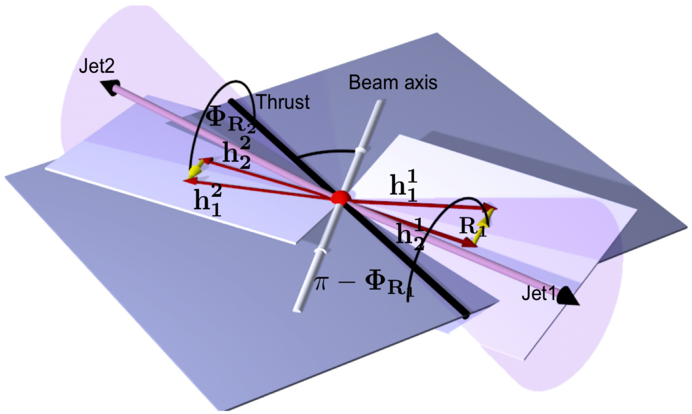

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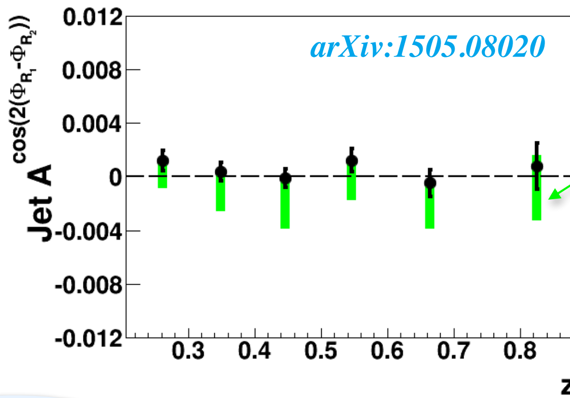


systematic uncertainties

Belle: first pub. in 2011

$$\sigma \propto 1 + \underbrace{A^{\cos(\phi_1+\phi_2)}}_{H_1^\perp} \cos(\phi_1+\phi_2) + \underbrace{A^{\cos 2(\Phi_{R1}-\Phi_{R2})}}_{G_1^\perp} \cos 2(\Phi_{R1}-\Phi_{R2}) + \underbrace{A^{\cos(\Phi_{R1}+\Phi_{R2})}}_{H_1^\sphericalangle} \cos(\Phi_{R1}+\Phi_{R2})$$

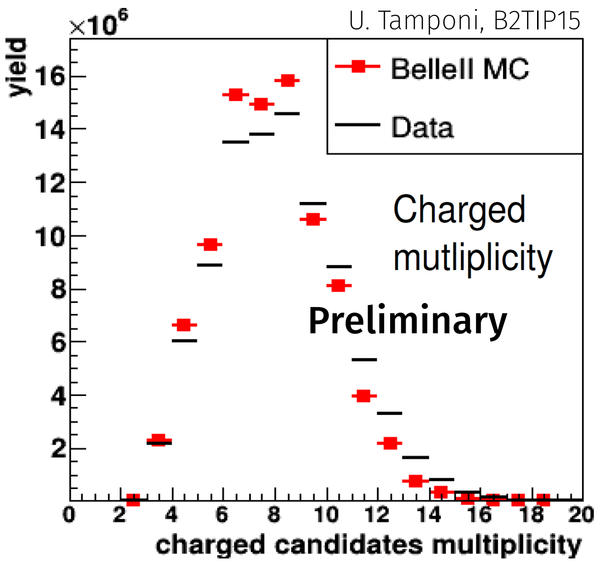
ongoing analysis

close to publication

ongoing analysis

→ expand to partial wave analysis

Belle → Belle II: PYTHIA8 tuning



Understanding of the continuum spectrum

- important task for itself
- background in, e.g., B decays

Continuum simulation in BASF2:

- old framework: EvtGen + PYTHIA

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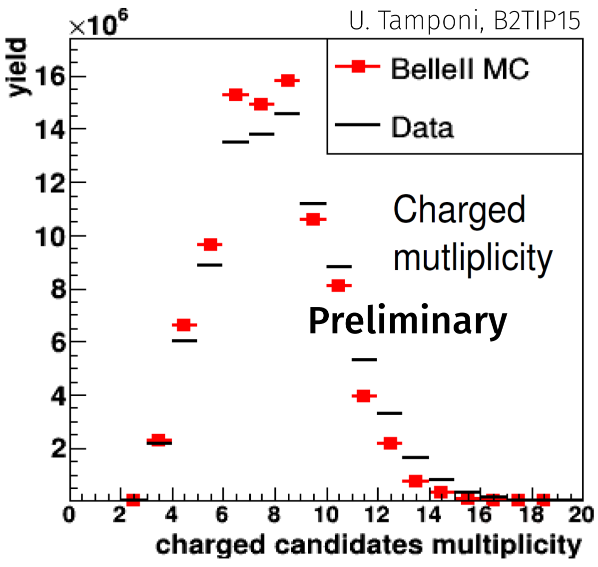

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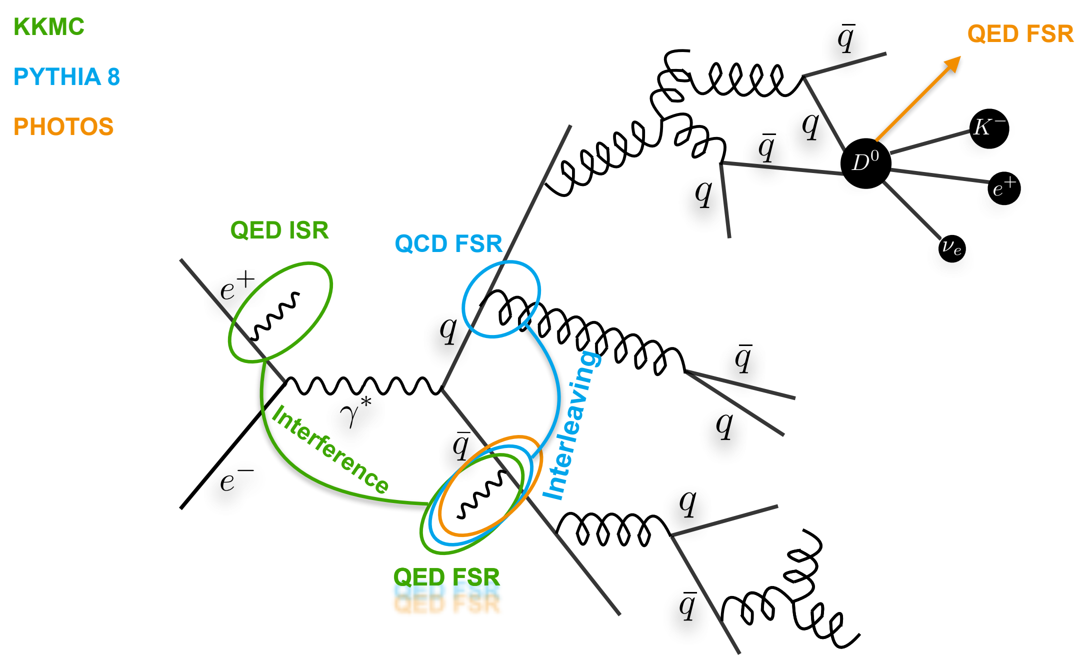

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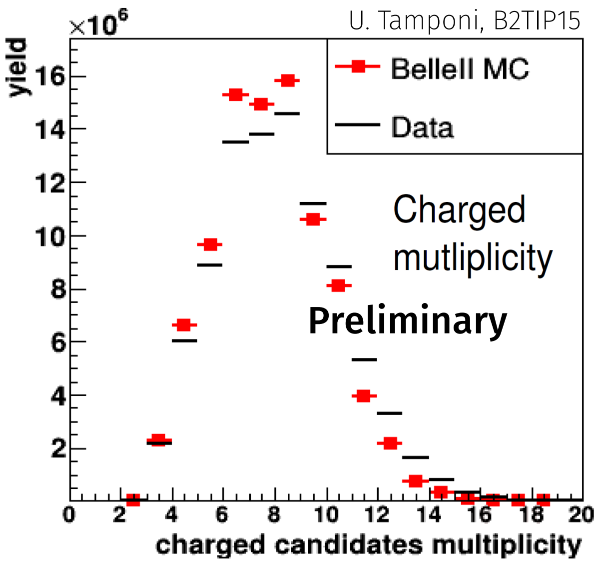

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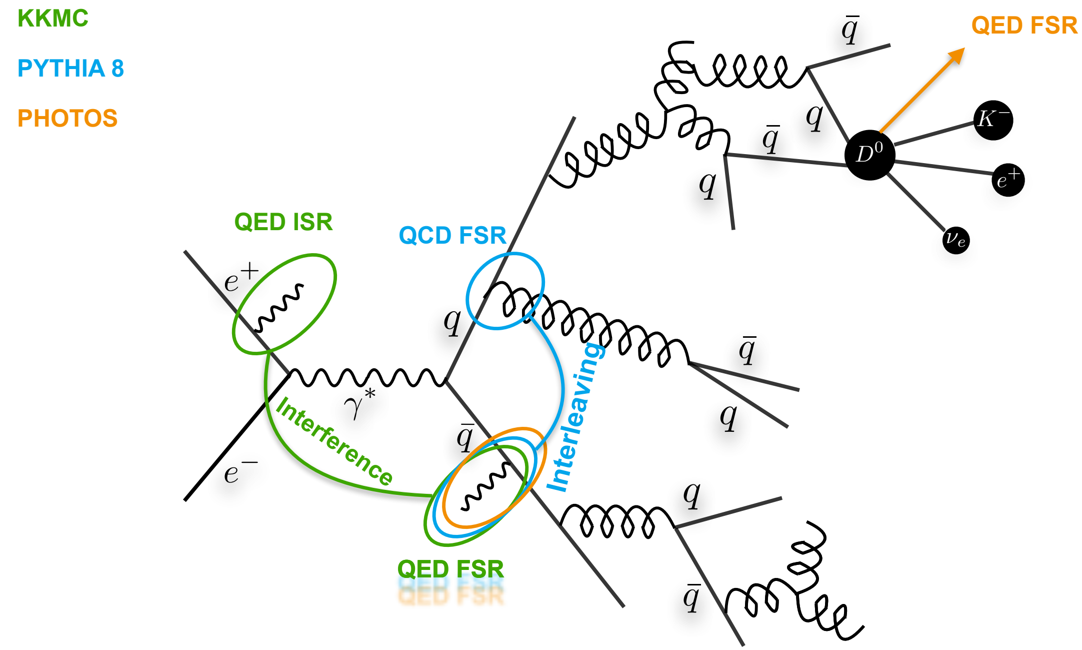
DESY contribution:

The new framework of continuum generation is ready and validated

- towards the Pythia8 tuning
  - tuning tool for Monte Carlo generators: Professor



Belle Analysis: Angular Analysis of $B \to K^* l^+ l^-$

$B \to K^* l^+ l^-$:

$\to$ $b \to s$ flavour-changing neutral current

$\to$ suppressed within the SM

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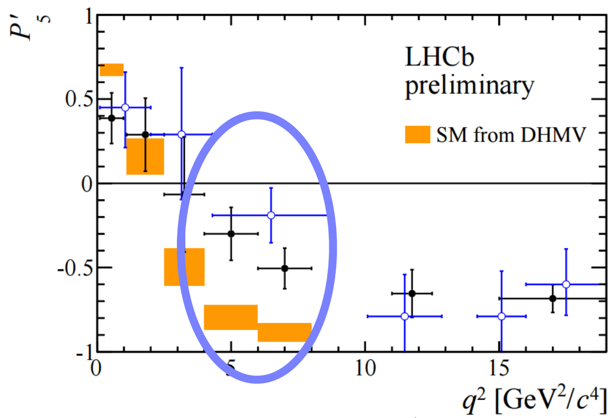
Phys. Rev. Lett. 111 (2013), 191801



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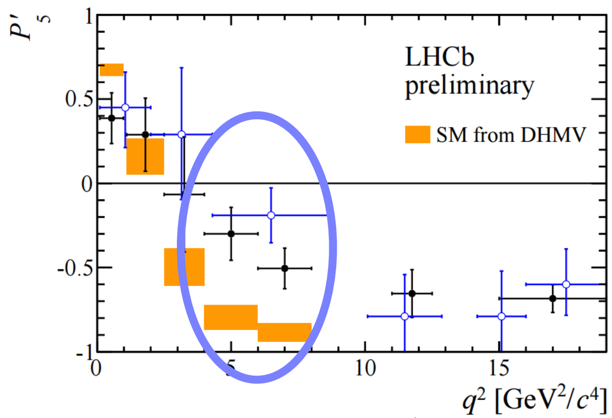

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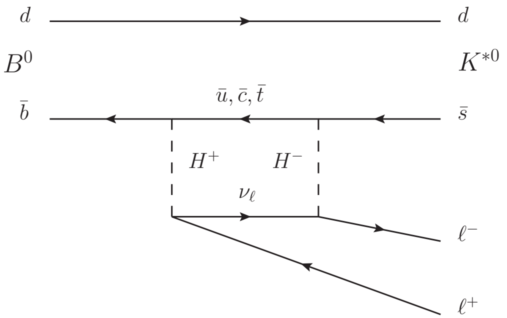

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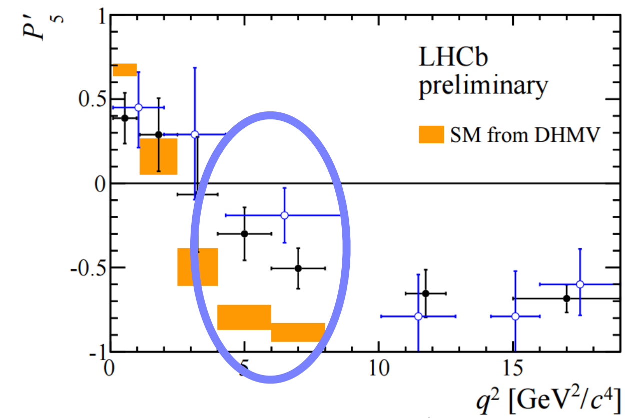

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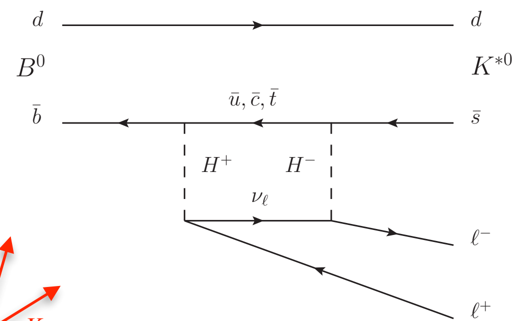
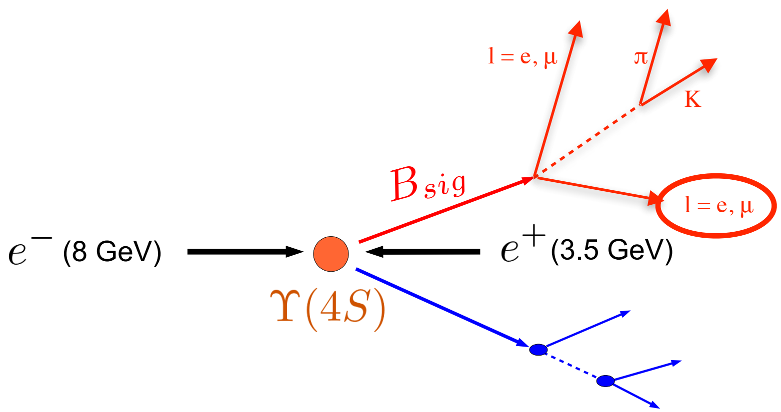
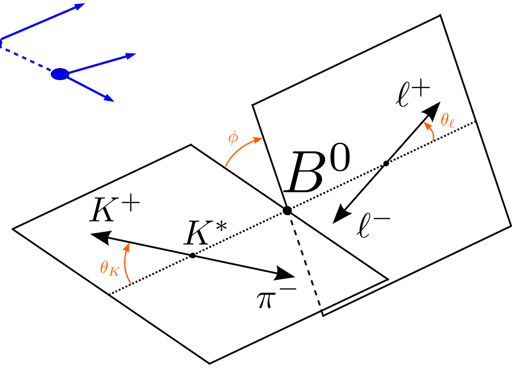


Why at Belle?

- clean event environment



- full angular analysis



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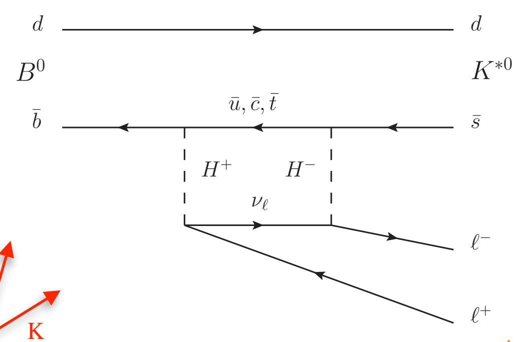

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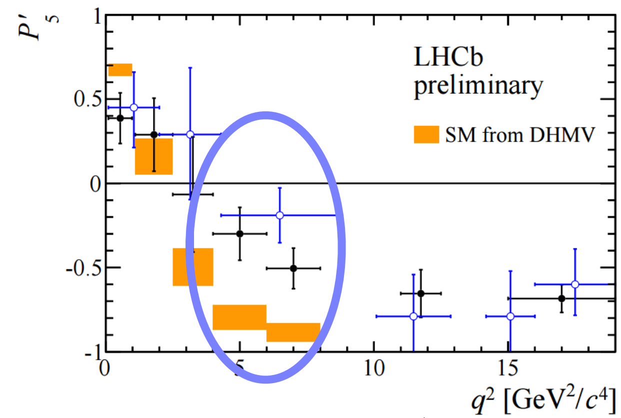

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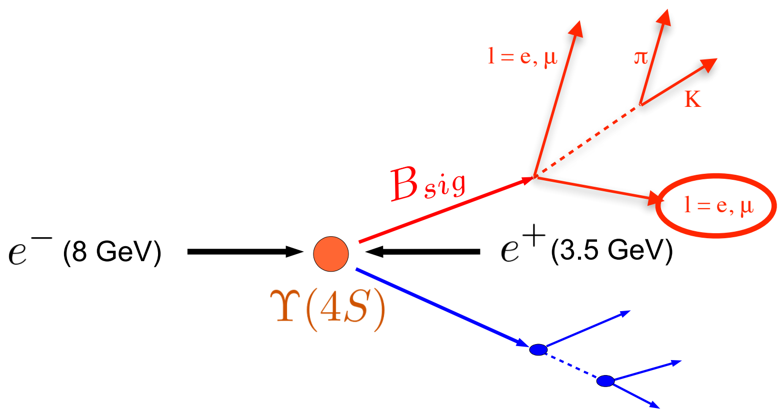

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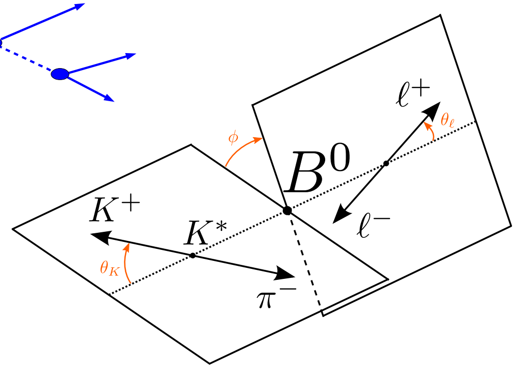
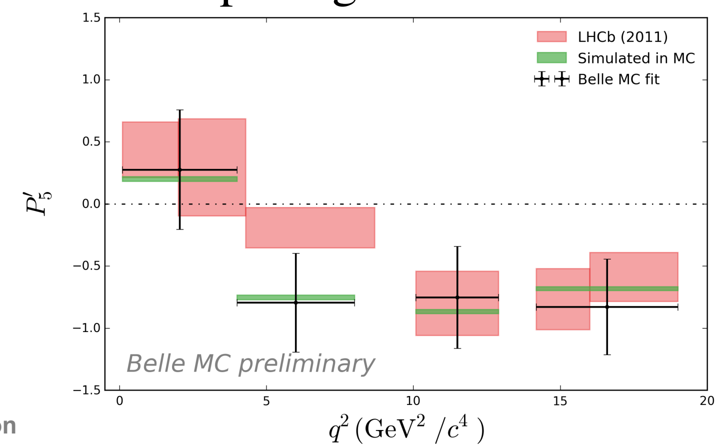


Analysis in the internal review

> preliminary results on Belle MC

> box opening in the next weeks



Belle Analysis: Rare Decay $B \rightarrow K\tau^+\tau^-$

- LHCb: hints for R_K anomaly
  - standard model: $R_K = 1$
  - discrepancy: ~ 2.6σ
  - possible interpretation: Z' coupling causes violation of lepton universality

$$\boxed{R_K \equiv \frac{\mathcal{B}(B^+ \to K^+\mu\mu)}{\mathcal{B}(B^+ \to K^+ee)} = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})}$$

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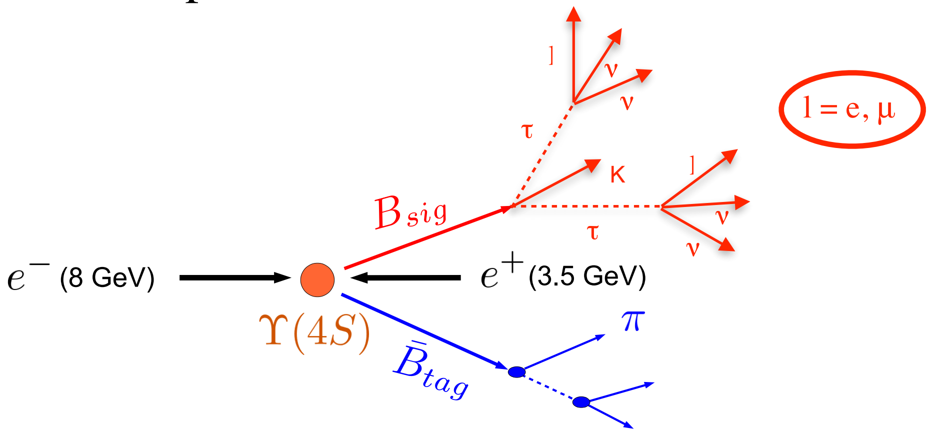
- Belle: B →Kτ+τ−
  - SM expectation BR ~$1.5\mathrm{x}10^{-7}$



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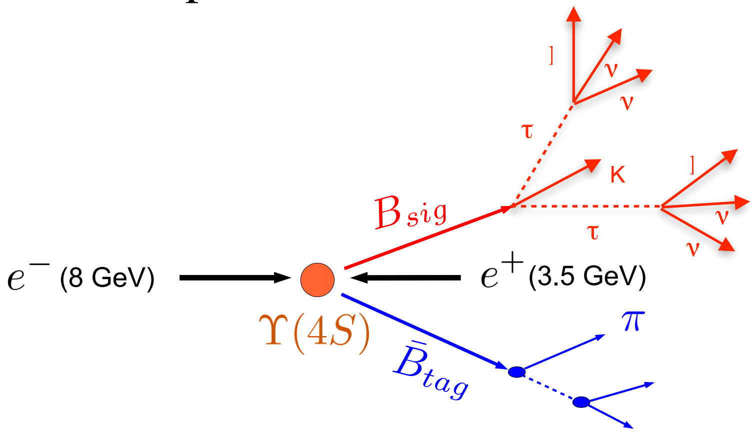
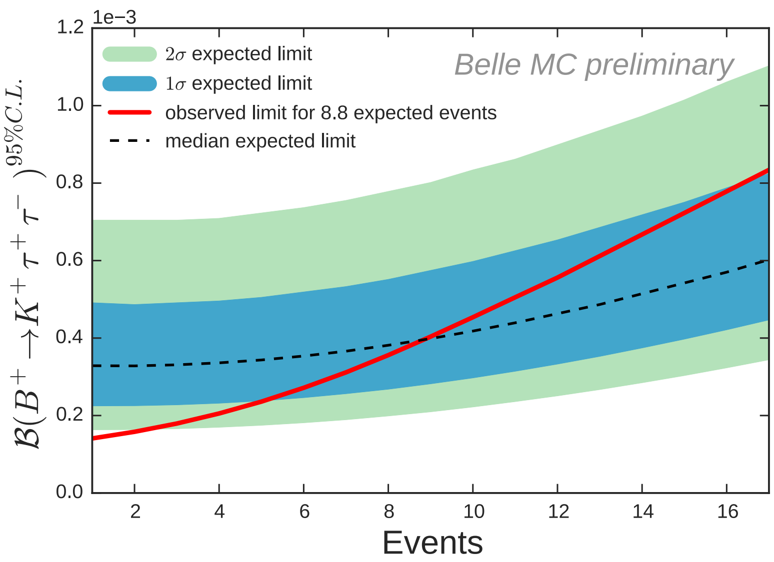


- BaBar: B →Kτ⁺τ⁻ (preliminary) *SLAC-PUB-15513 (2010)*
  - upper limit of 3.3 × 10⁻³ at 90% C.L.

Expected Belle sensitivity based on MC data

- upper limit of ~ 4 × 10⁻⁴ at 95% C.L.
- box opening in the next weeks



Belle → Belle II Analysis: Rare Decay $B \to K^{(*)}\nu\nu$

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→ b→s flavour-changing neutral current

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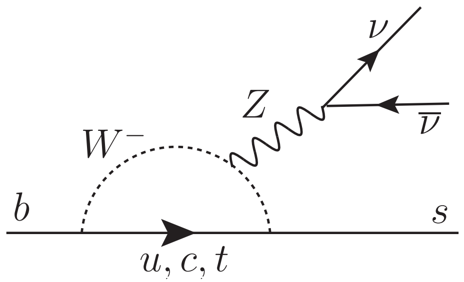
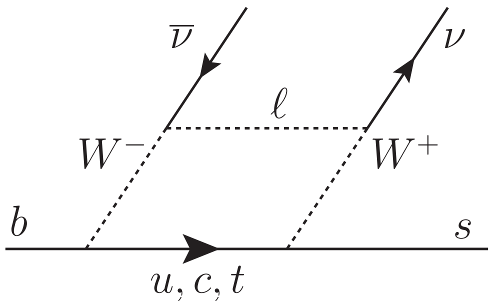
→ golden mode of Belle II because theoretically very clean: free of uncertain long-distant hadronic effects





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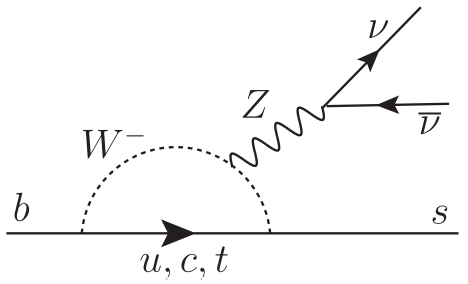

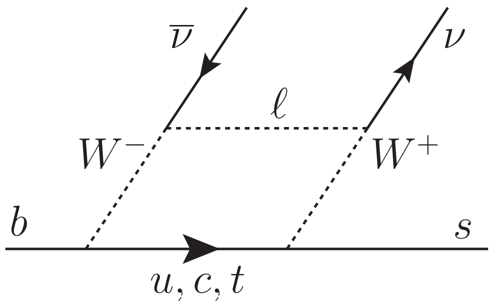

Why at Belle II?

- Can be measured only in e^+e^-, experimentally challenging
- Existing limits from BABAR and Belle leave room for NP

$$\mathcal{BR}(B^+ \to K^+ \nu\bar{\nu})_{(SM)} = (3.98 \pm 0.43 \pm 0.19) \times 10^{-6}$$

$< 1.7 \times 10^{-5}$ (BaBar)

$$\mathcal{BR}(B^0 \to K^{*0} \nu\bar{\nu})_{(SM)} = (9.19 \pm 0.86 \pm 0.50) \times 10^{-6}$$

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JHEP 1502, 184 (2015)

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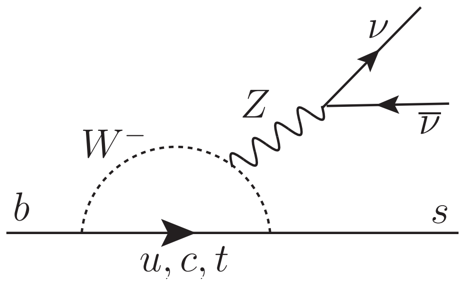

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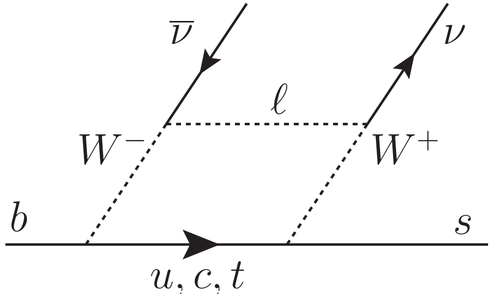

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JHEP 1502, 184 (2015)

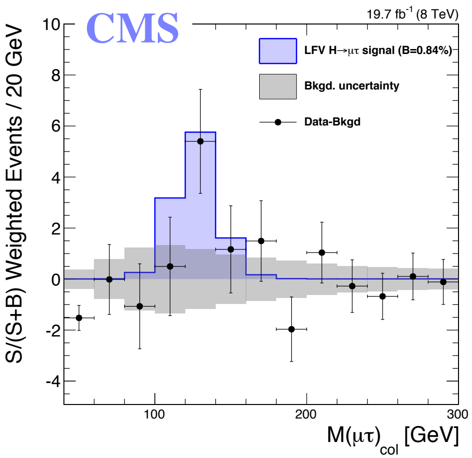
Sensitivity with full Belle II data

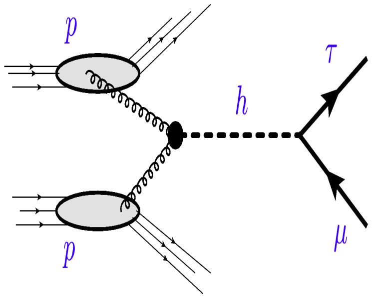
- SM expectation for exclusive $B \to K^{(*)}\nu\nu$ can be probed at 5σ level

Belle II Analysis: Lepton Flavour Violation in τ Decays

high energy

h→τμ





Higgs mediated prediction:

> consistent by 1 order of magnitude

high energy

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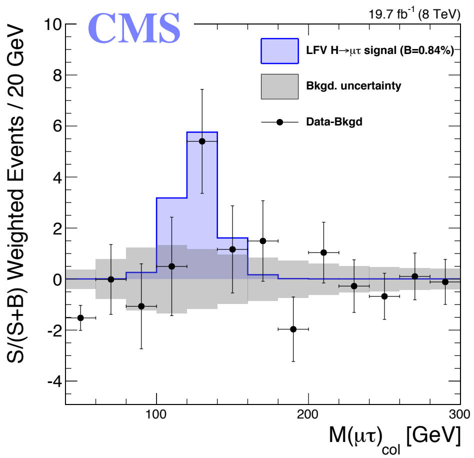

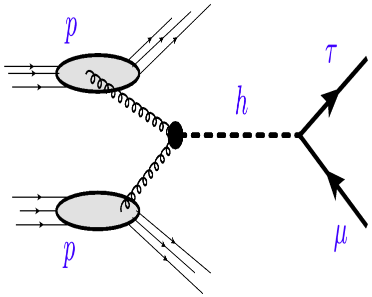

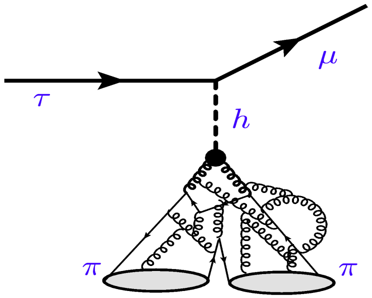

low energy

τ→μππ

- the same effective coupling of the Higgs to gluons
- different energy scales

Higgs mediated prediction:

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Why at Belle?

- less influential high energy dynamics
- model-independent connection with the search for LFV Higgs decays at the LHC

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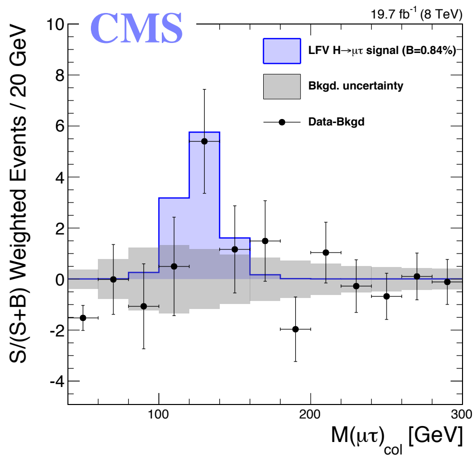

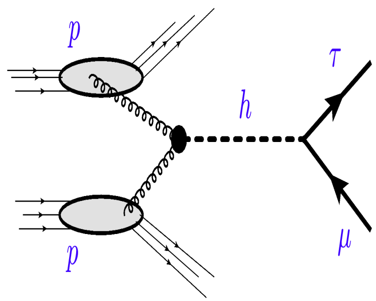

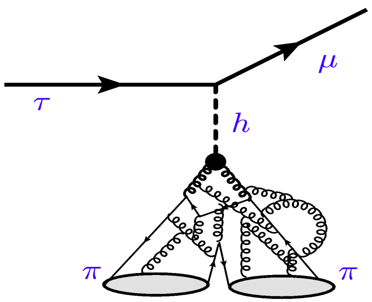

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Higgs mediated prediction:

- **consistent by 1 order of magnitude**

upper limits for LFV τ decays:

Belle: 10^{-8} with 90% C.L.

Belle II sensitivity: currently under a study

τ→lhh ⟶ **l = e, μ**
h = π, K

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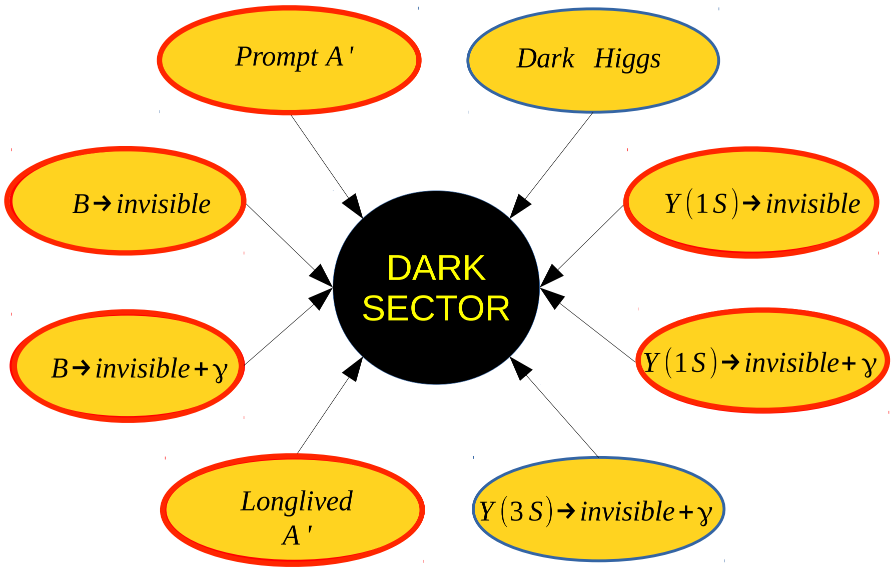
Belle & Belle II Analysis: Searches of Dark Matter



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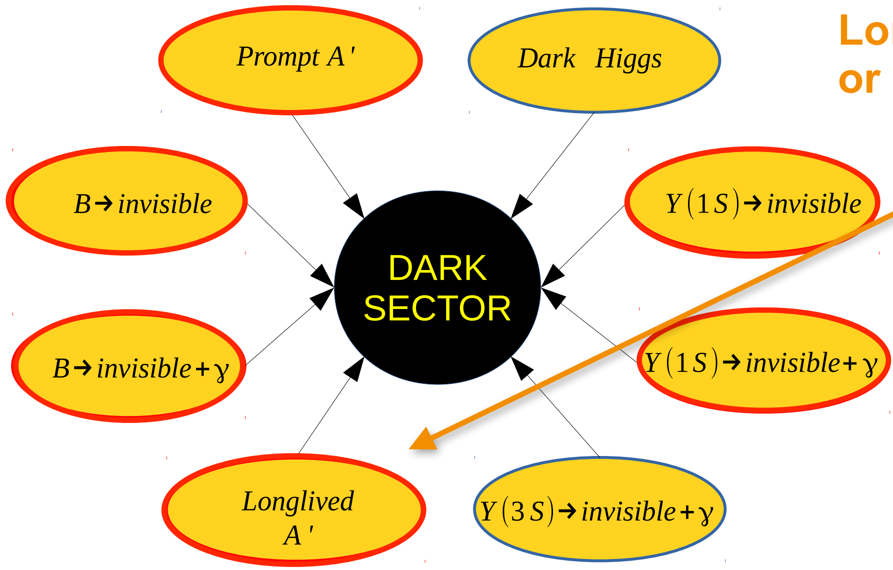
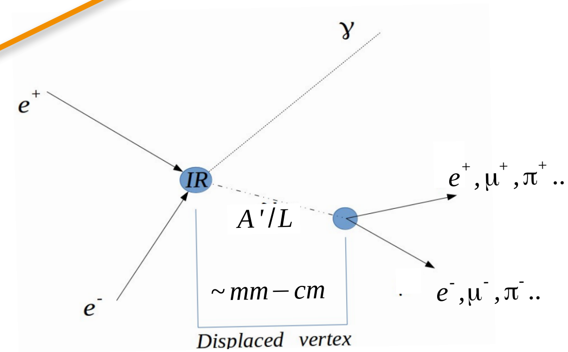
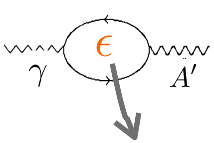


Long lived dark photon or gauge bosons visible decay

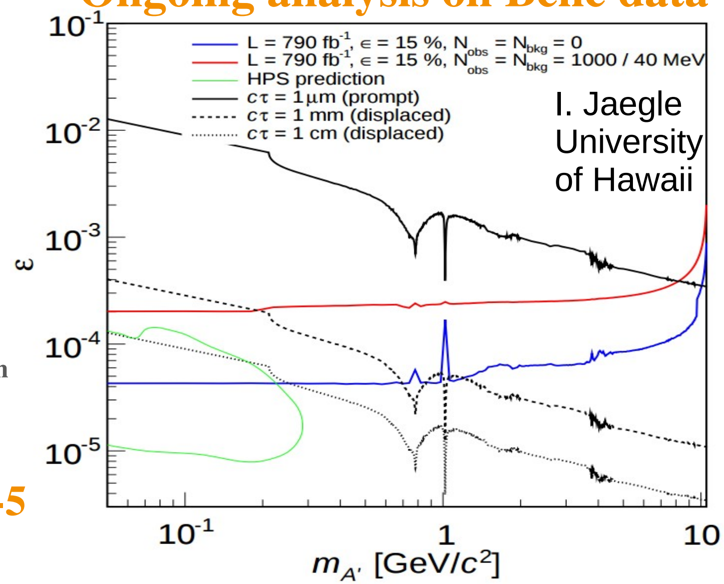


Ongoing analysis on Belle data



kinetic mixing strength

Belle II: $\varepsilon<10^{-5}$



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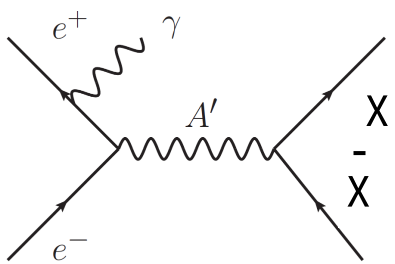
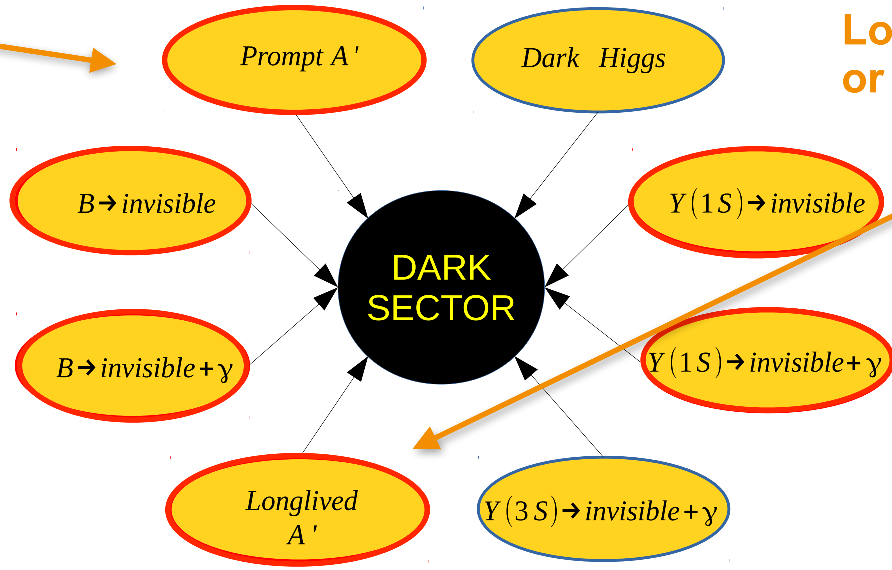
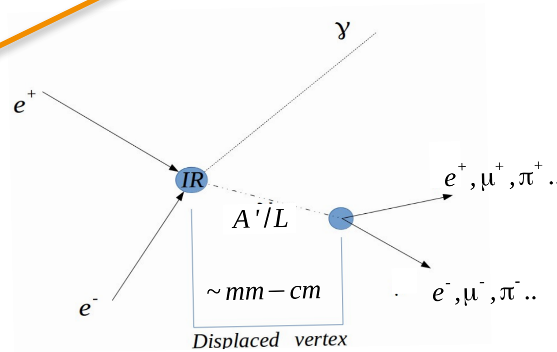
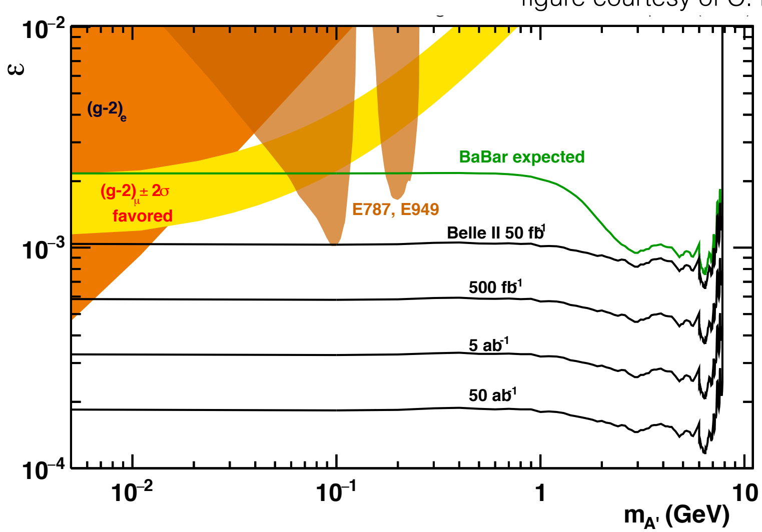


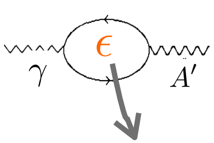




Foreseen at Belle II

figure courtesy of C. Hearty





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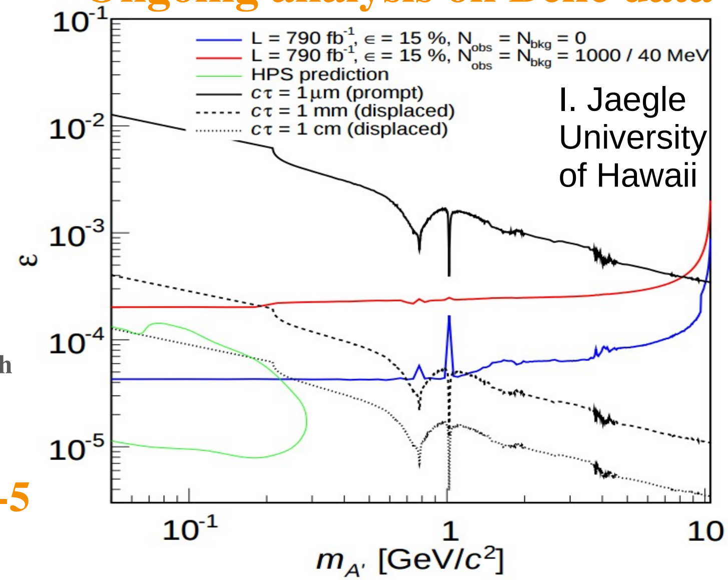
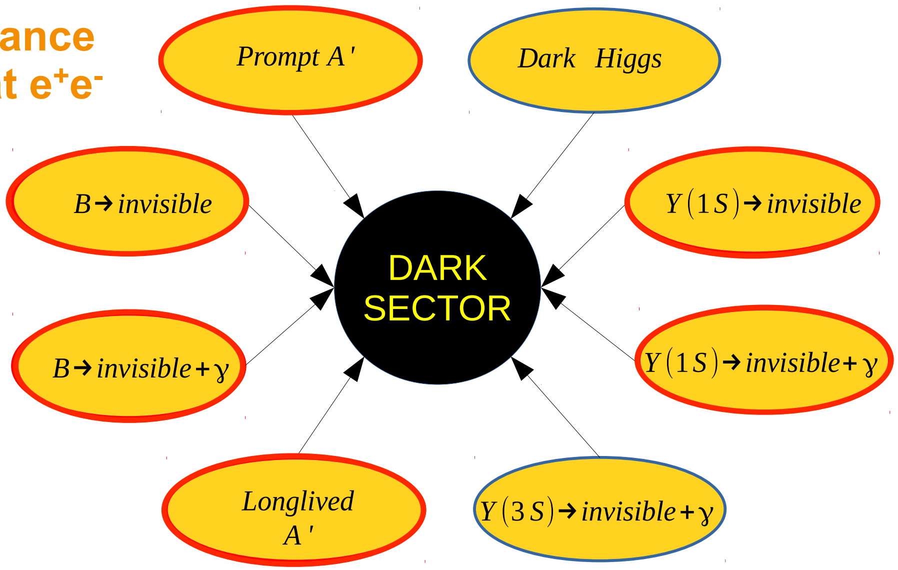
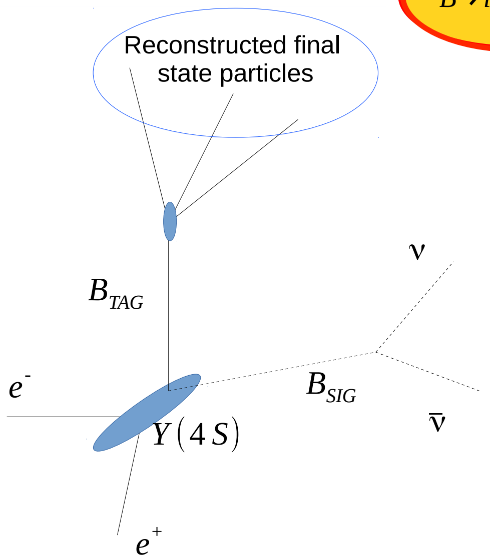


Belle II Analysis: Possible Extensions

B meson disappearance
→ possible only at e^+e^-





Foreseen at Belle II

$$\mathcal{BR}(B_0 \to \nu\bar{\nu}) \simeq \begin{cases} 10^{-25} & \text{(SM)} \\ 10^{-6} & \text{(NP)} \\ 10^{-6} & \text{(sensitivity at BelleII)} \end{cases}$$

Phys. Rev. D 65, 015001 (2002)

Belle II Analysis: Possible Extensions

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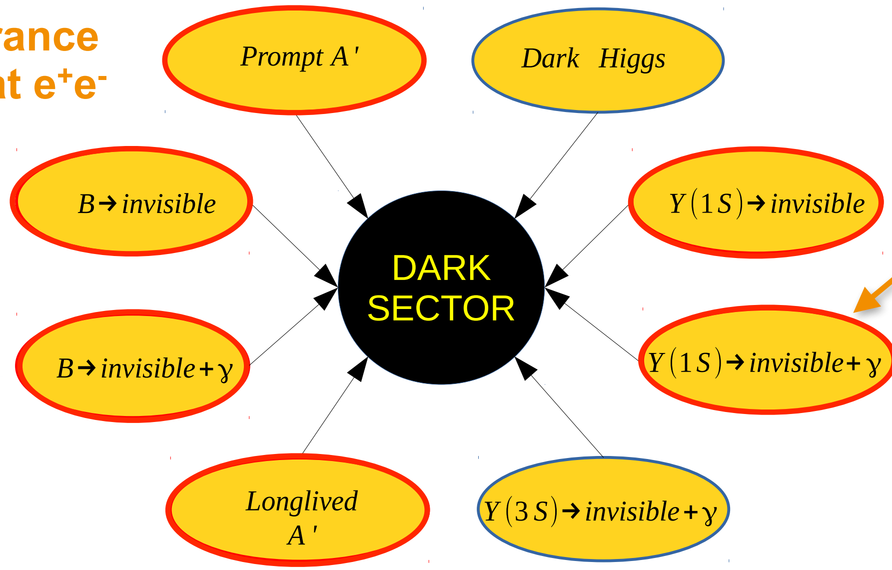
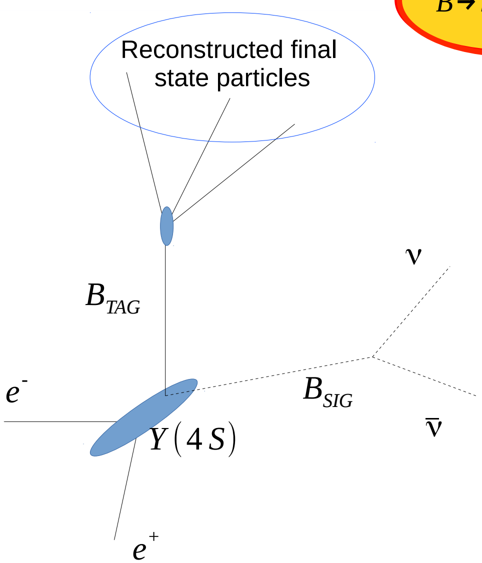
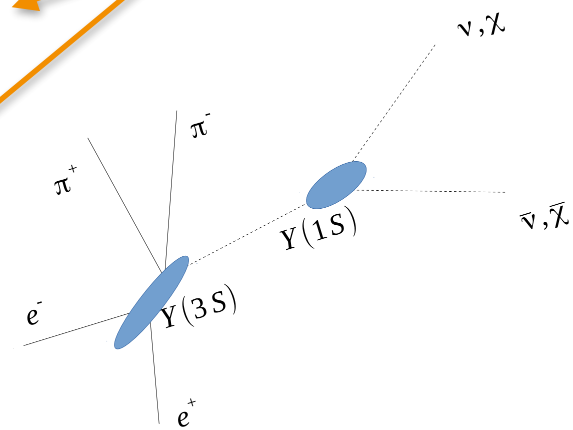
Y(1S) invisible decays
→ possible only at e^+e^-







$$\mathcal{BR}(Y(1S) \to \nu\bar{\nu}) \simeq \begin{cases} 10^{-5} & \text{(SM)} \\ < 2.5 \times 10^{-4} & \text{(BaBar)} \\ 10^{-5} & \text{(sensitivity at BelleII)} \end{cases}$$

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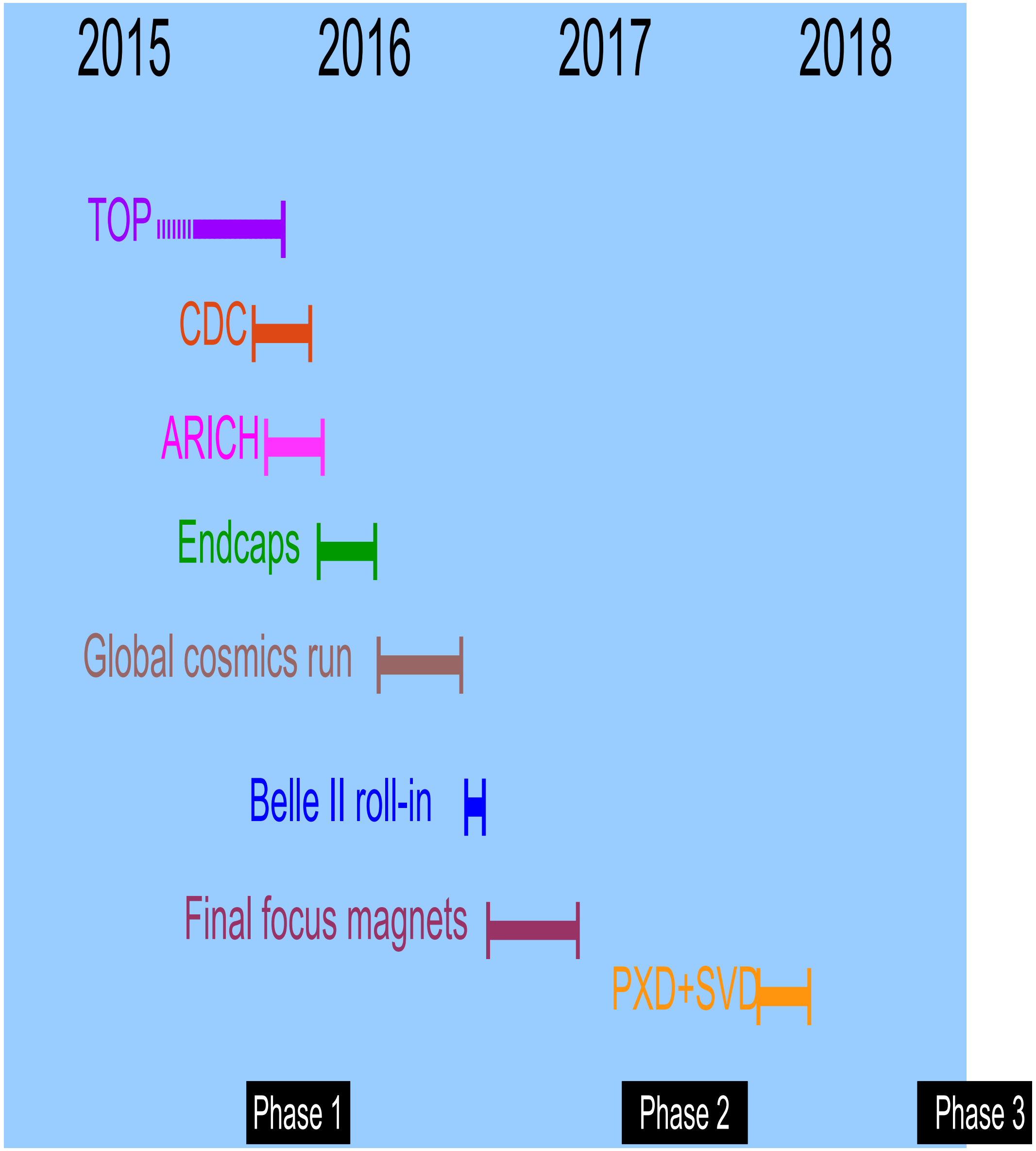
Phys. Rev. D 65, 015001 (2002)

Outlook

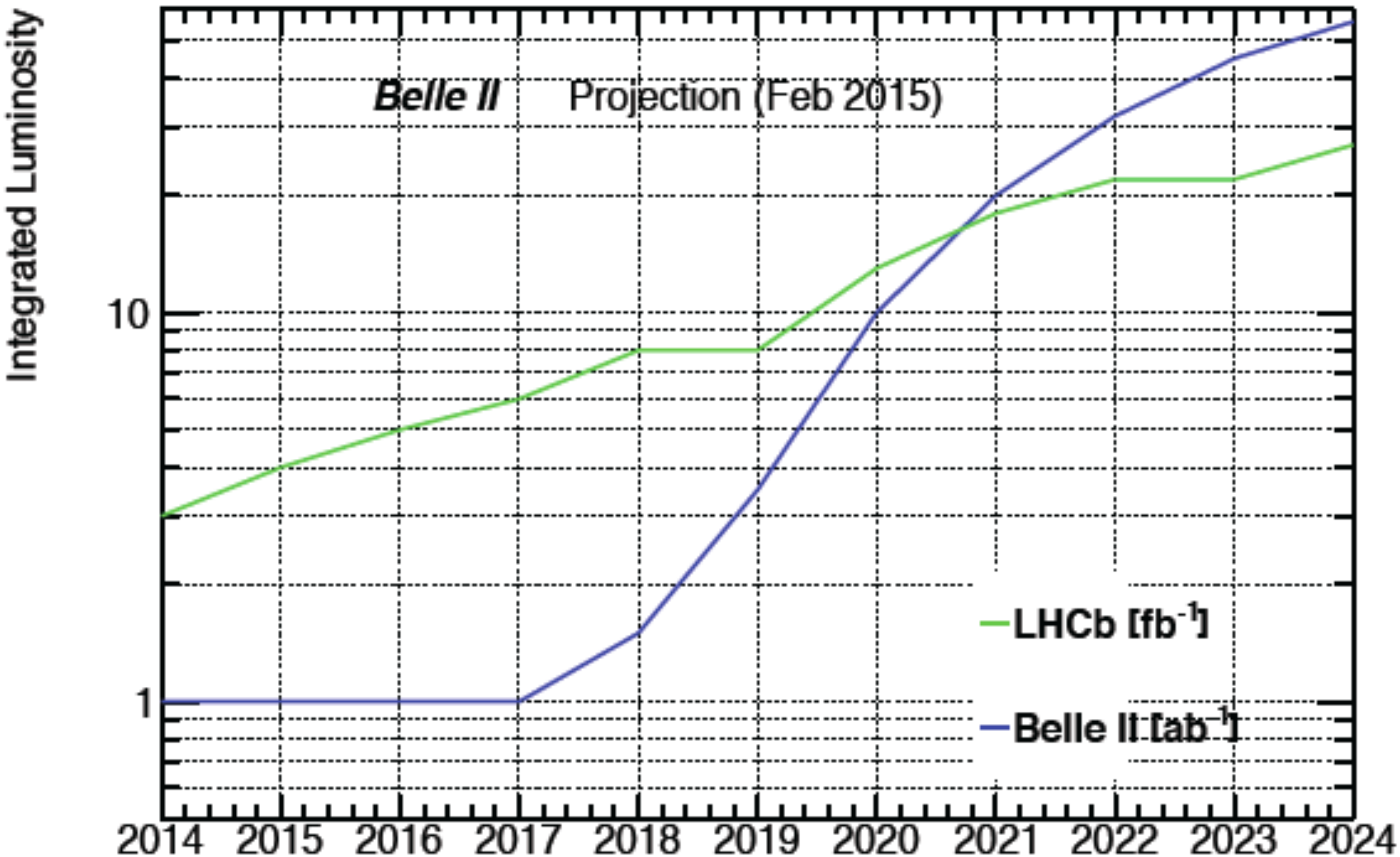
DESY

- Prominent **hardware** contributions
- Important **software** contributions
- Strong **computing** contribution
  - usage of the NAF2.0
  - GRID resources for MC simulation
- **Belle analyses**
  - approach publication stage
  - in the internal reviews
- **Belle II analysis**
  - preparation for searches for New Physics complementary to LHC experiments



Back up

Belle II and LHCb Luminosity Projections

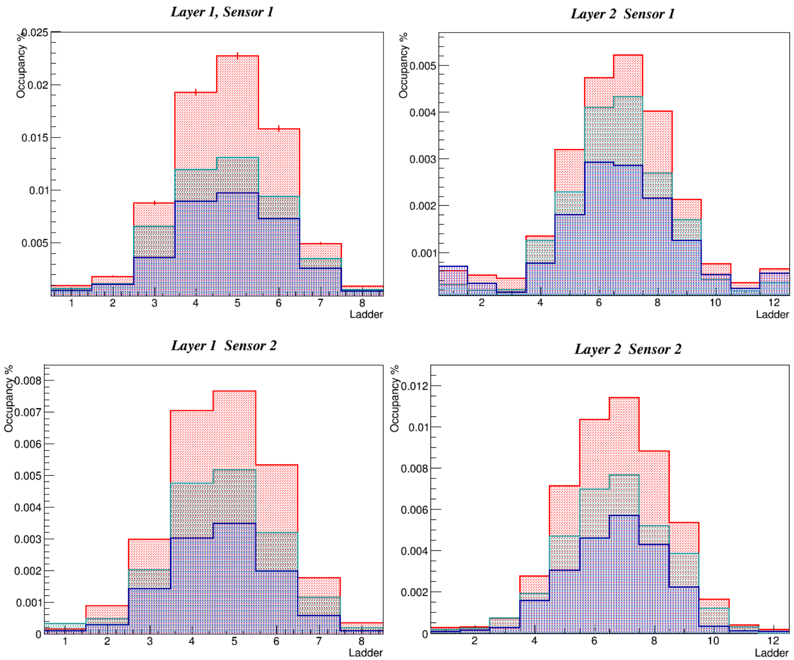


Belle II Software: Estimation of the Synchrotron Radiation

Choices of beam pipe thickness:

- thinner gold plate → better vertex resolution
- thicker gold plate → better absorption of synchrotron radiation
  - for Phase 2 → 6.6μm
  - for Phase 3 → will be decided this week

Color Code:
Phase3,gold 10μ; Phase2,gold 6.6μm; Phase3,gold 5μm;



PXD occupancy (HER) normalised to Phase3 beam current

Synchrotron background simulation for phase 2 and 3 (PXD and SVD installed) for different thickness of gold plating

Maximum occupancy for Phase3

10μm	6.6μm	5μm
(0.01 — 0.05)%	(0.015 — 0.1)%	(0.025 — 0.15)%

Still acceptable occupancy values for PXD even for 5μm of gold plating.

Impact of Belle II on flavour physics

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}).