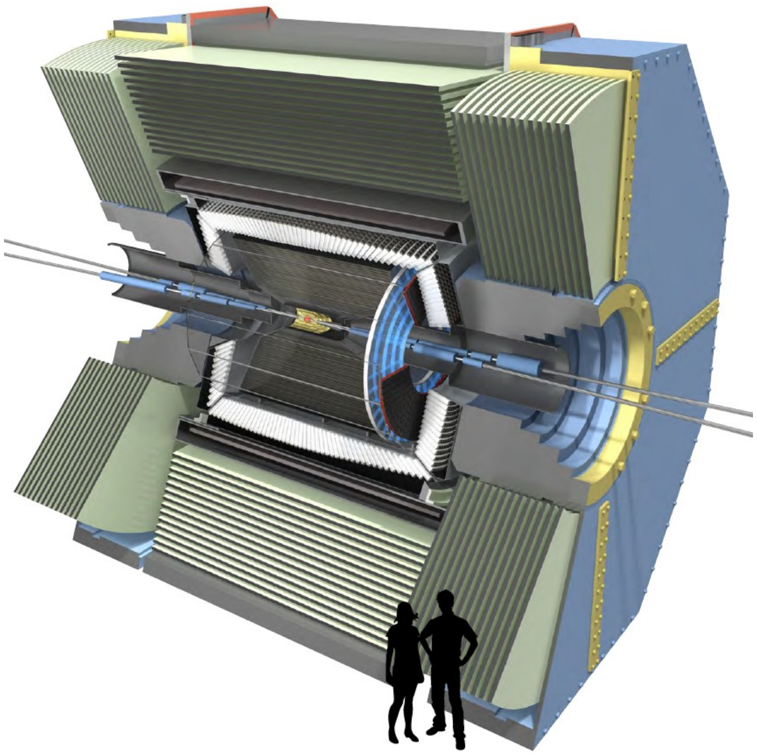


Belle and Belle II

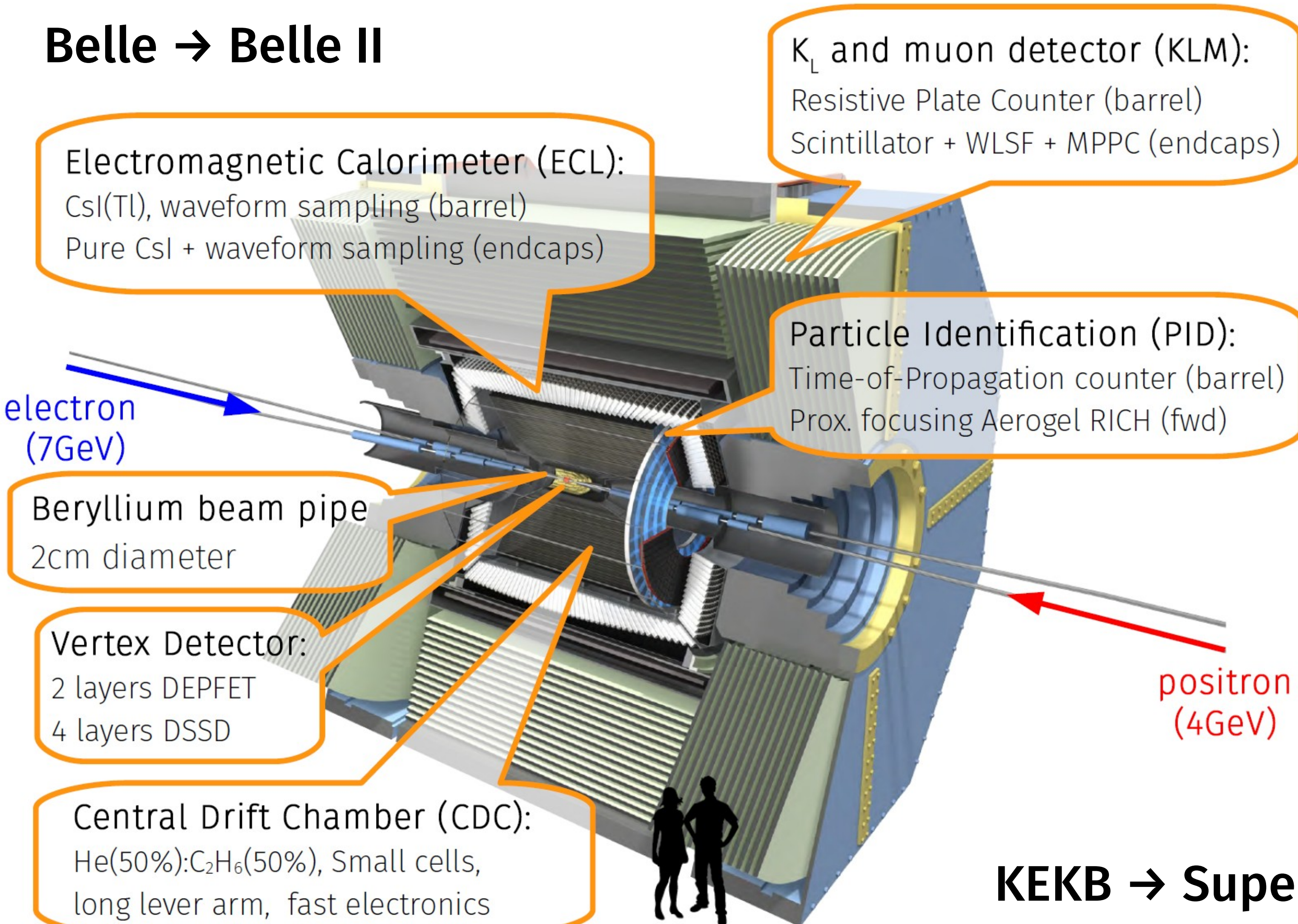
Torben Ferber (torben.ferber@desy.de)
79th PRC, Open Session
DESY, 11.05.2015

HELMHOLTZ ASSOCIATION

Belle   Belle II   DESY

Belle II Experiment.

Belle → Belle II



KEKB → SuperKEKB:

Instantaneous Luminosity x40

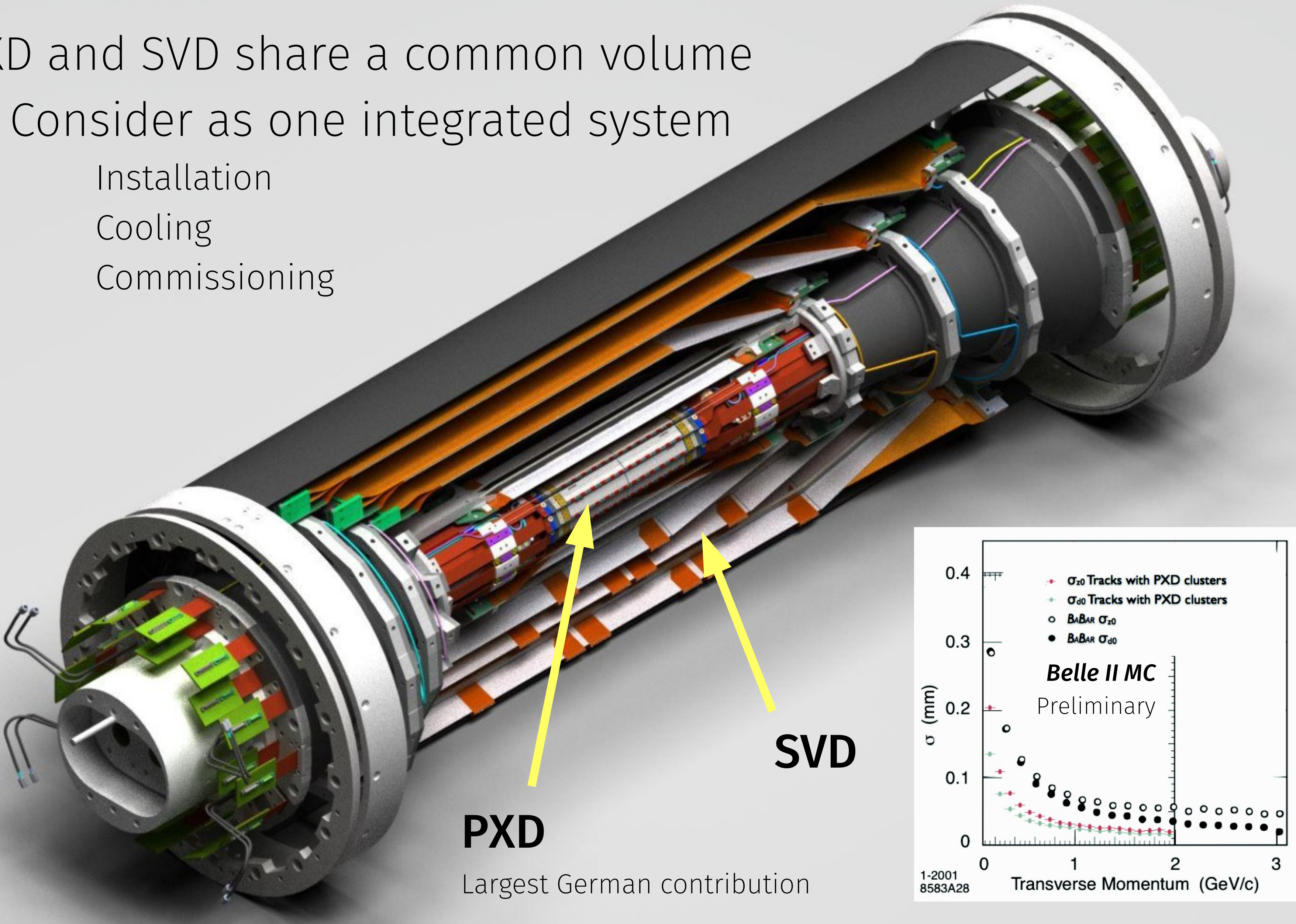
Belle II Hardware

Belle II Detector: Vertex Detectors (VXD).

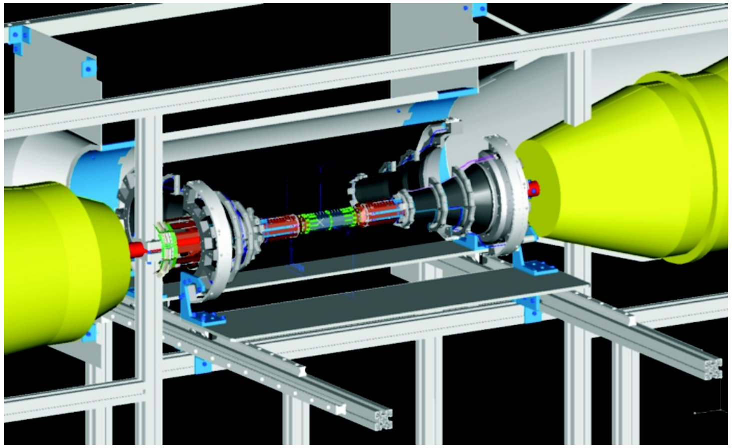
PXD and SVD share a common volume

→ Consider as one integrated system

- Installation
- Cooling
- Commissioning



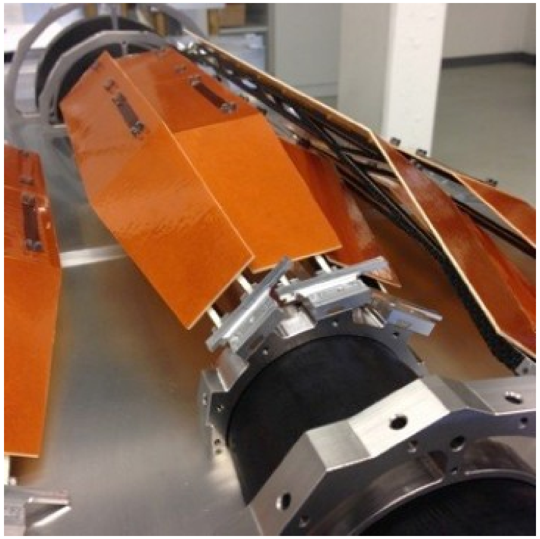
Belle II Detector: Thermal Mock Up.

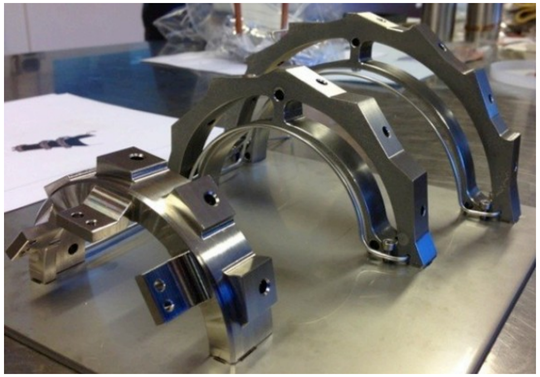


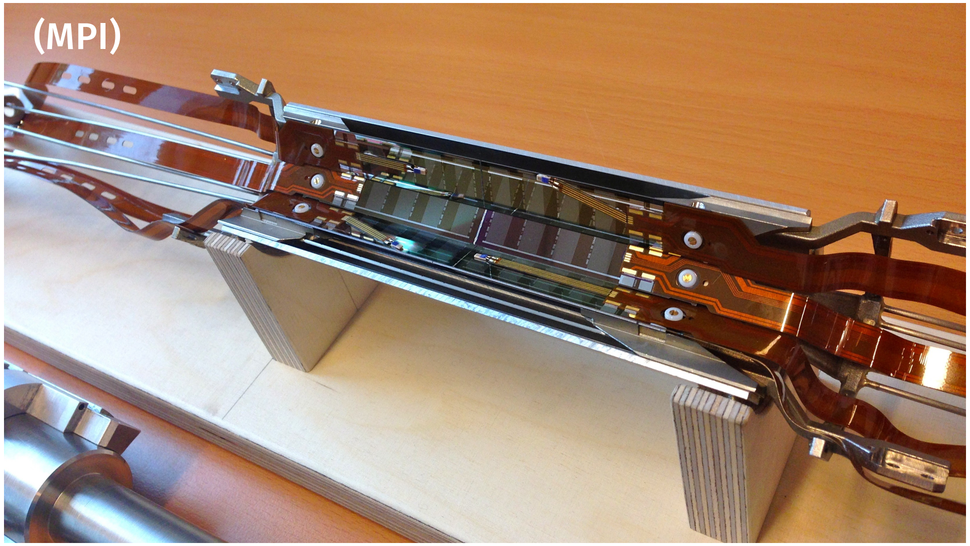
Full Mock Up

SVD

Dummy ladder and end rings

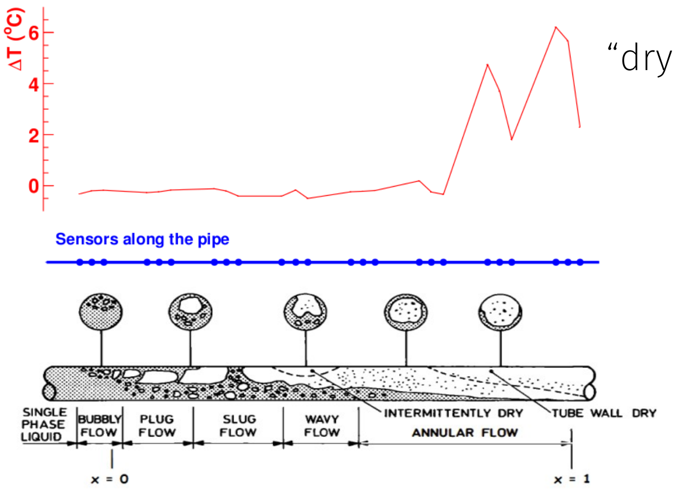


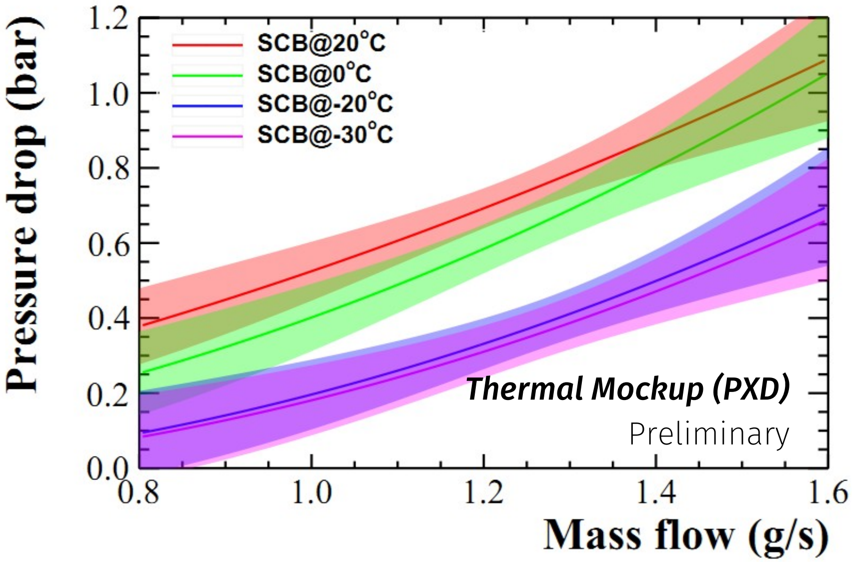


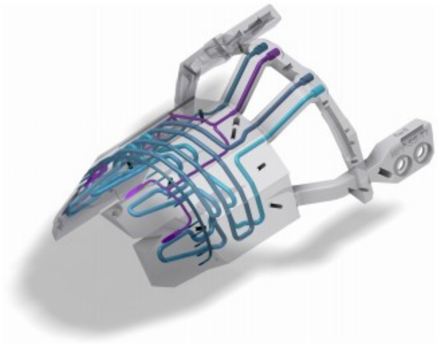


PXD

Belle II Detector: Thermal Mock Up.

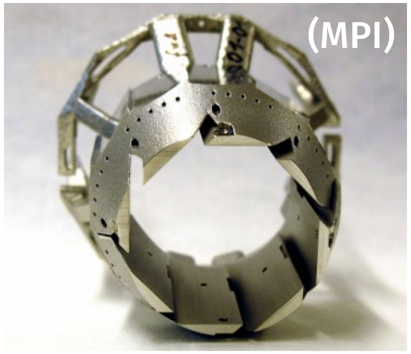






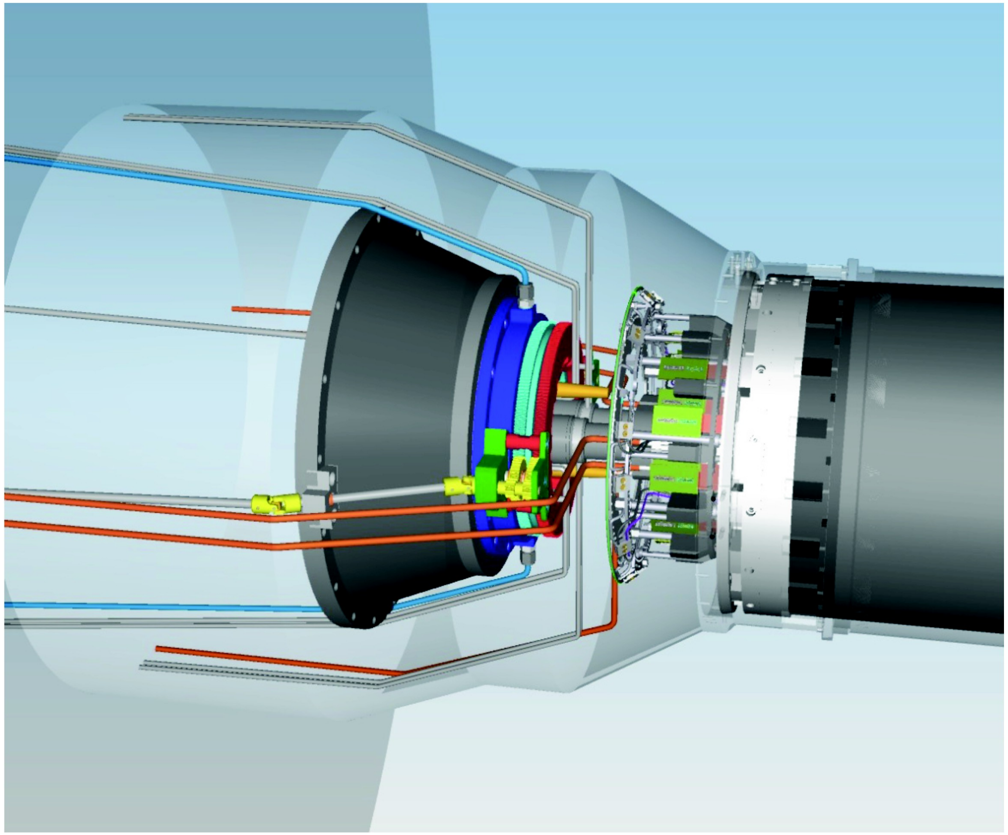
PXD

Support cooling block (SCB)

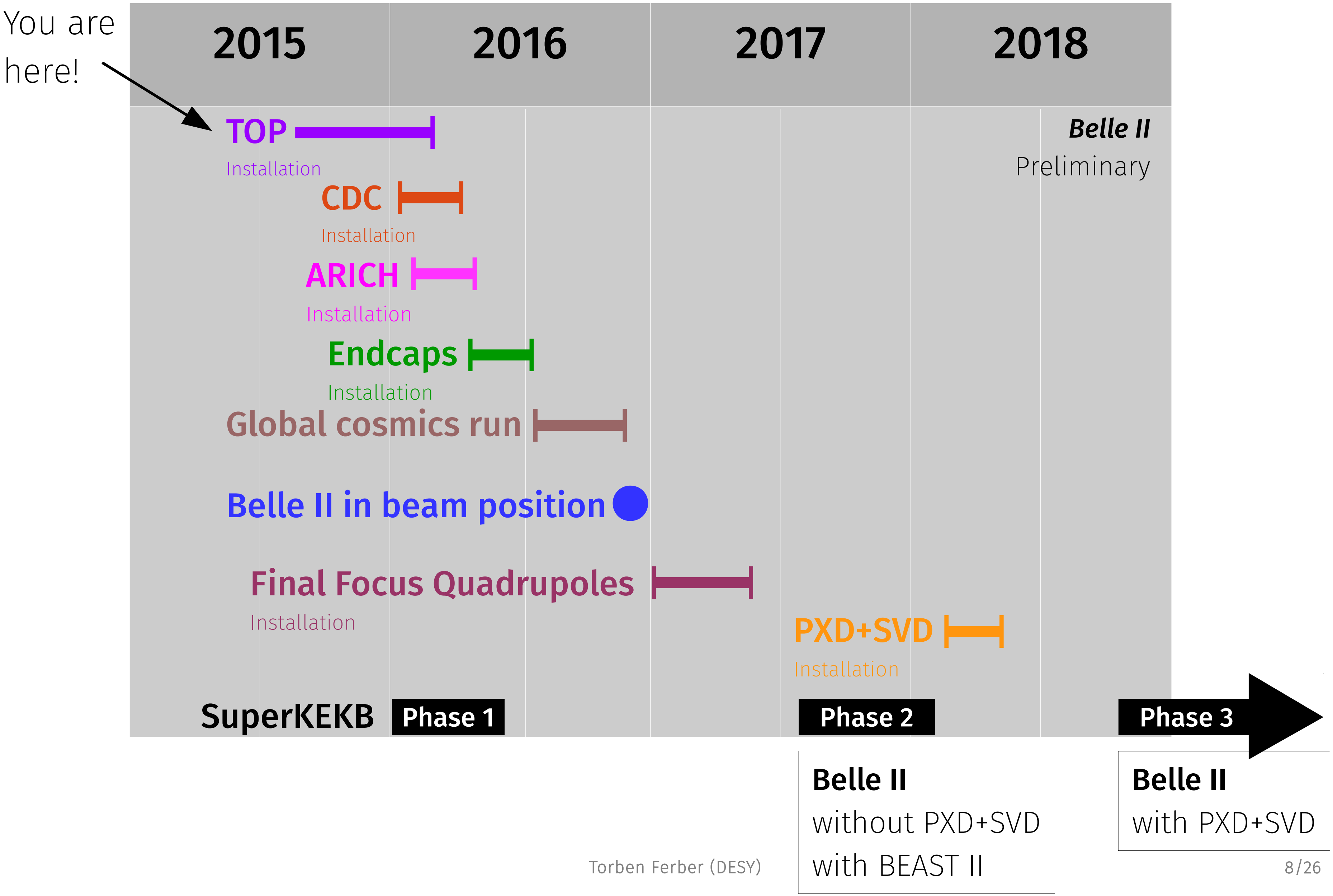


Belle II Detector: Remote Vacuum Connection (RVC).

- Decision to use RVC taken in summer 2014
- Finalizing design of RVC and Final Focus Quadrupole end flange region at DESY
- RVC to be installed in spring 2017 for “Phase 2”

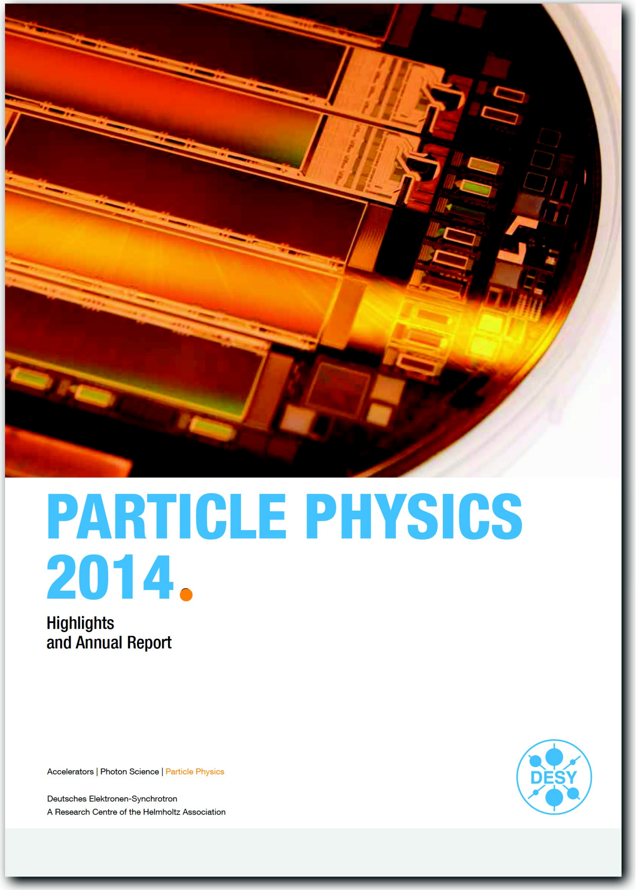


Belle II Schedule.



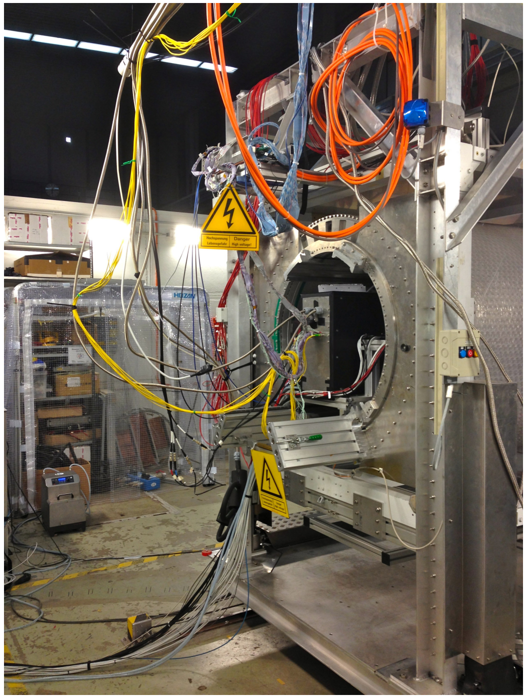
Belle II Testbeam at DESY.

- Pilot-run sensors to be tested in DESY test beam end of 2015
- Full VXD system test at DESY with final ASICS beginning of 2016



Pilot production run wafers

with PXD sensors

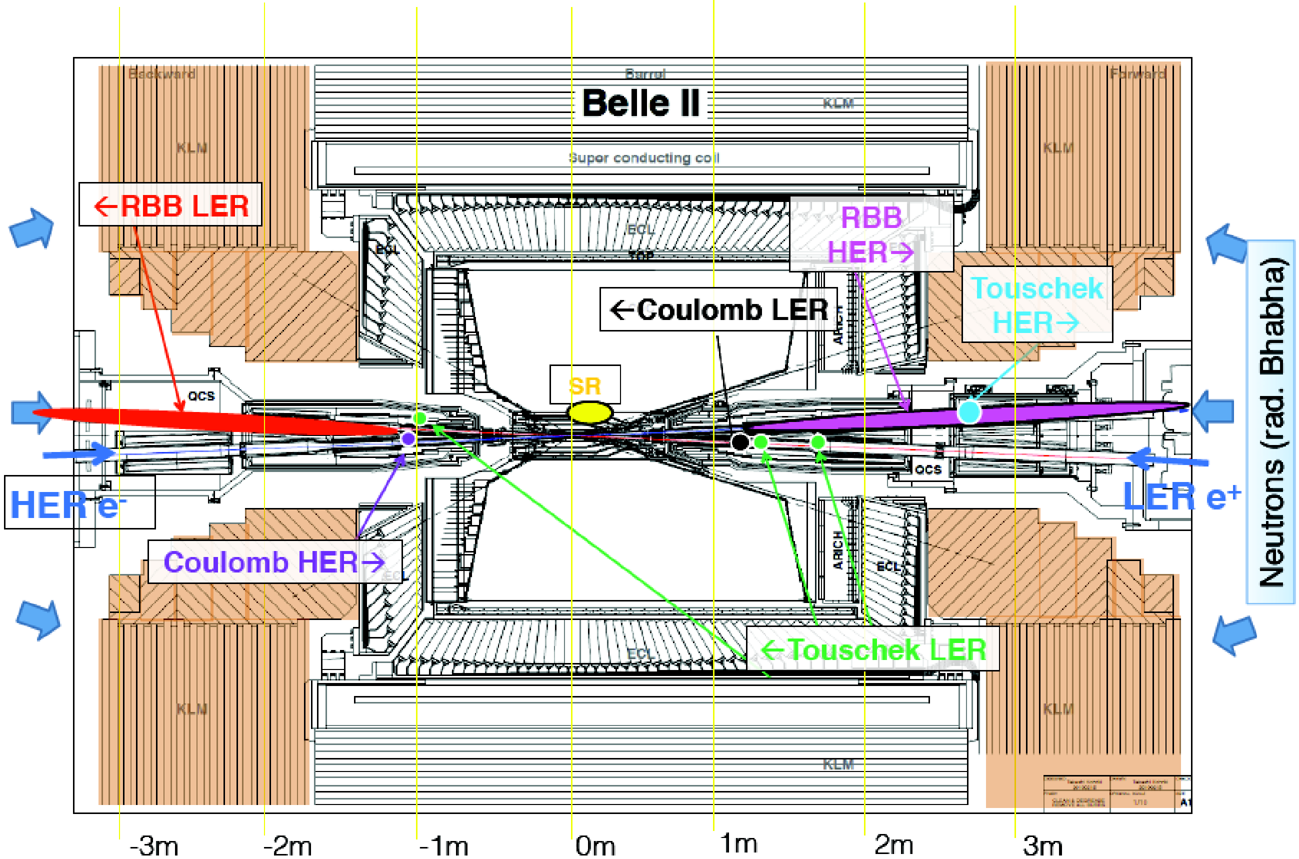


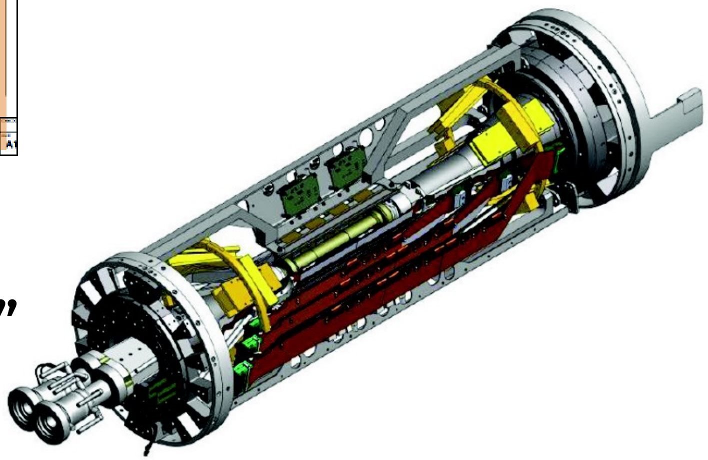
PXD/SVD in PCMAG

Integrated Belle II system test TB24/1@DESY (2014)

Belle II Software

Belle II Background.





BEASTII detector instead of VXD in “Phase 2”

Measure beam backgrounds

Calibrate background MC

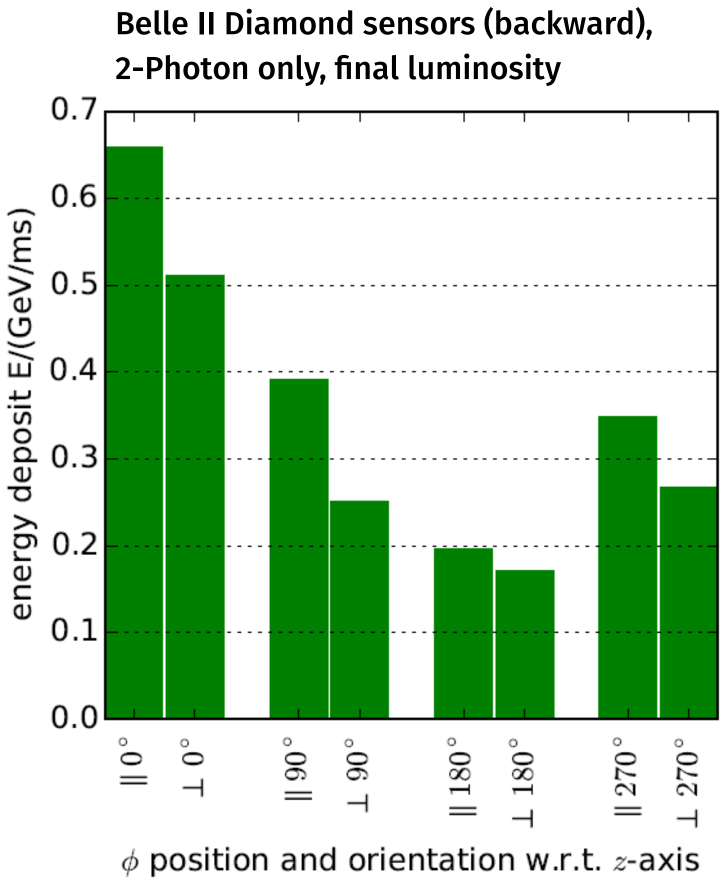
Need to extrapolate for factor >40 instantaneous lumi increase in phase 3

Belle II Background Simulations.

Positioning of Diamond sensors

Radiation monitor

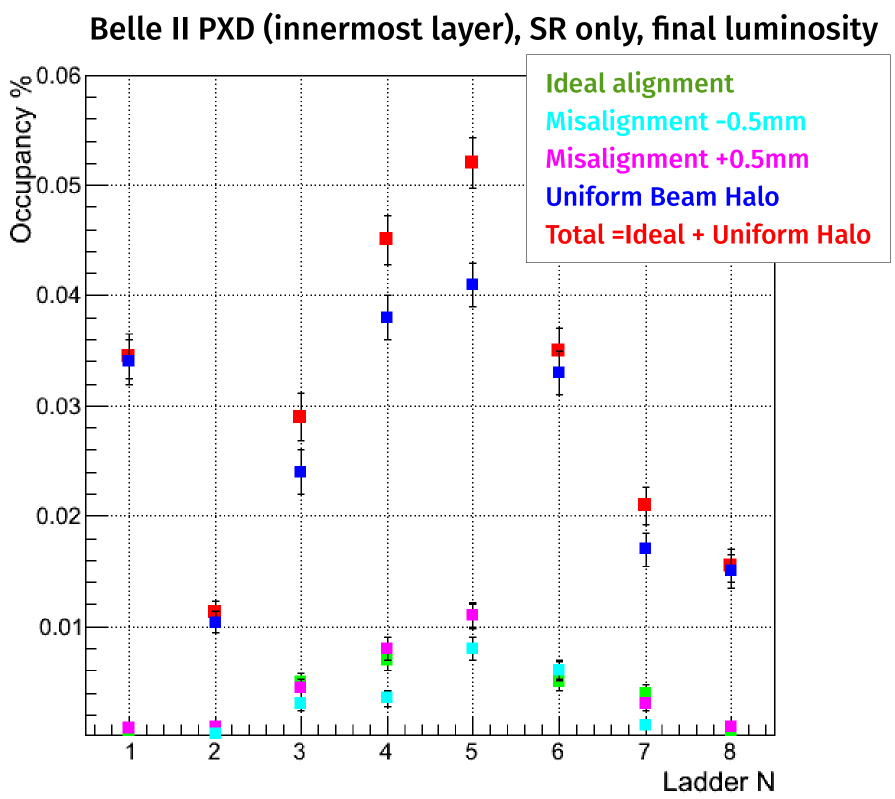
Beam abort system



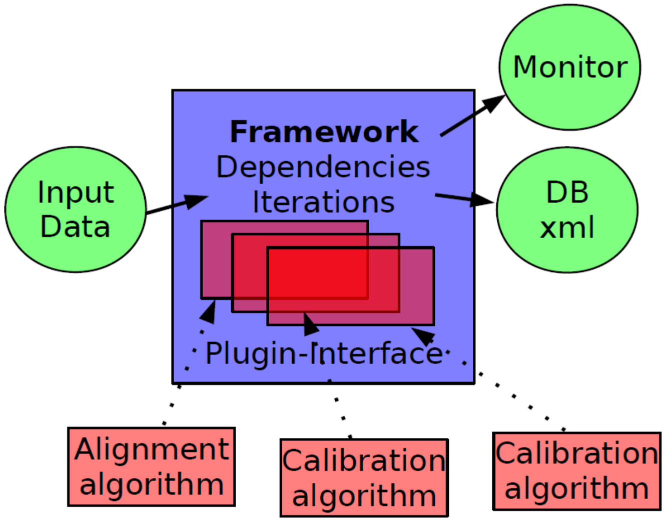
Synchrotron Radiation (SR)

Bandwidth limit for PXD: 2%

Non-Synchrotron backgrounds: ~1%



Belle II Software: Alignment and Calibration.



> Common calibration framework

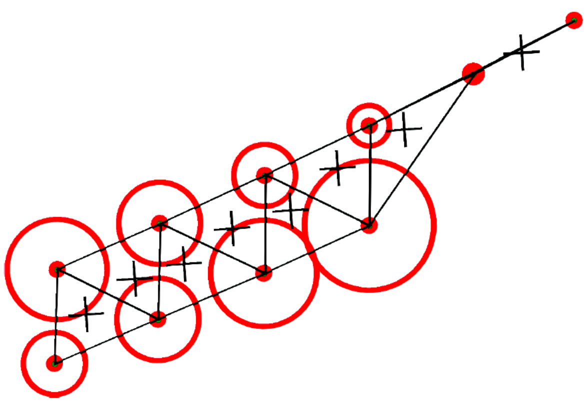
- Calibration framework main functionality implemented
- VXD and CDC alignment and calibration as first example
- Will be used for other detector calibration

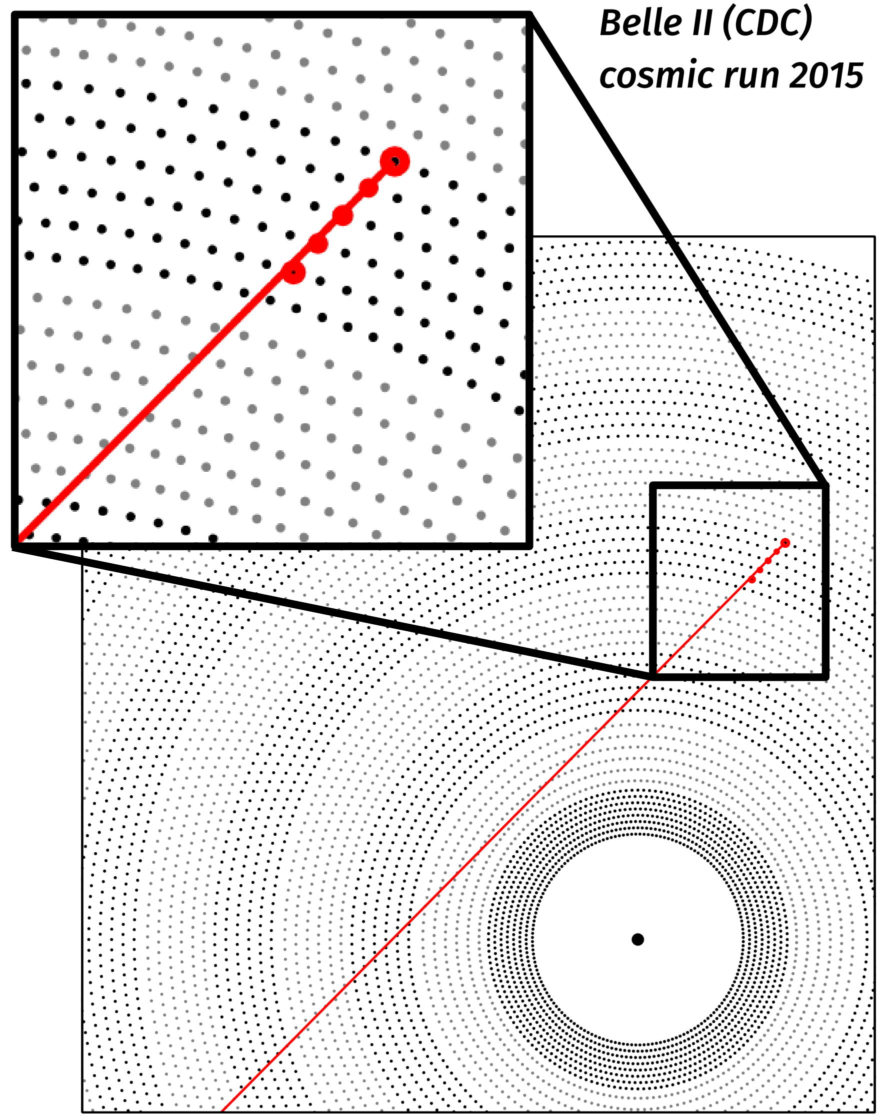
> Alignment and calibration for VXD and CDC

- VXD: Verified on Monte Carlo and DESY testbeam data
- CDC: Tested on Monte Carlo, cosmic data coming soon
- First checks of CDC drift velocity calibration successful
- Fully working in the common calibration framework

Belle II Software: Track Finding.

- Weighted cellular automaton trackfinder:
  - Low momentum range
  - Decays in flight
  - Comics tracks
- Loop-free directed graph:



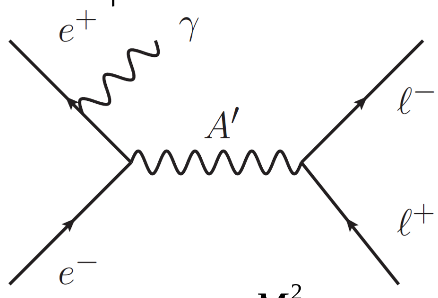


Belle Analysis

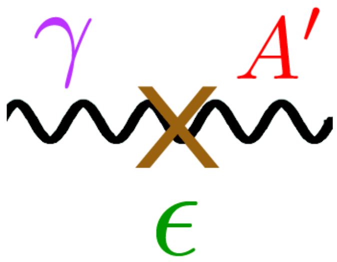
Belle: Search for long lived particles.

- Search for long-lived Particle $A' \to l^+l^- / \pi^+\pi^-$
  - $0.3\text{GeV} < m_{A'} < 10\text{GeV}$
  - $1\text{cm} < \text{vtx} < 25\text{cm}$
- Using unskimmed data at DESY, almost back-ground free
- Trigger feedback also for Belle II

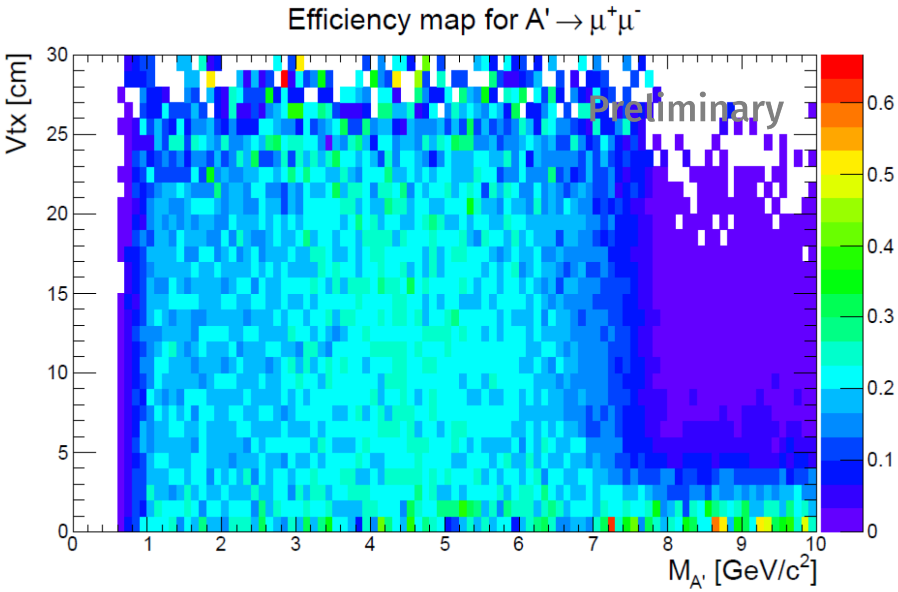
Example: Dark Photon



$$E_\gamma = \frac{s - M_{A'}^2}{2\sqrt{s}}$$

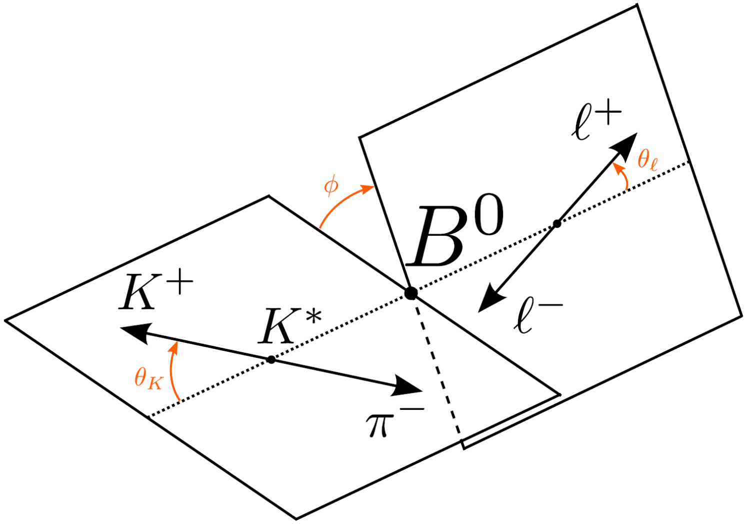


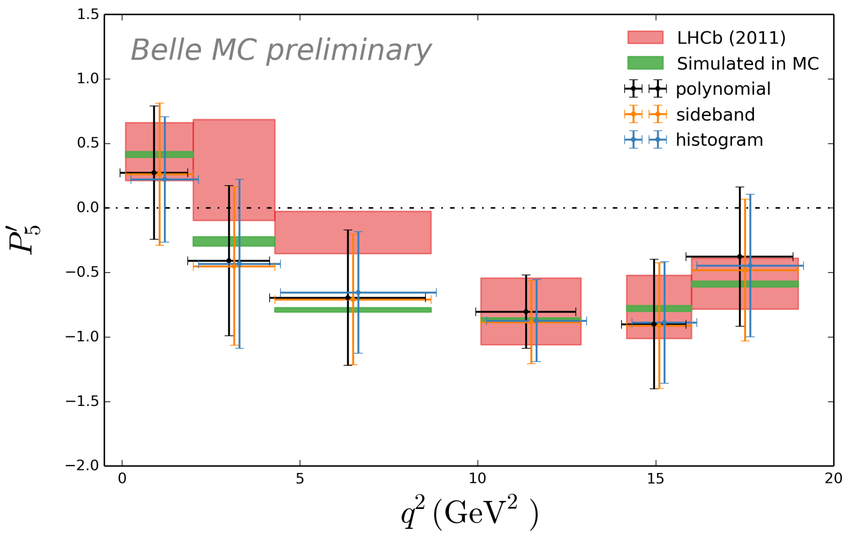
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

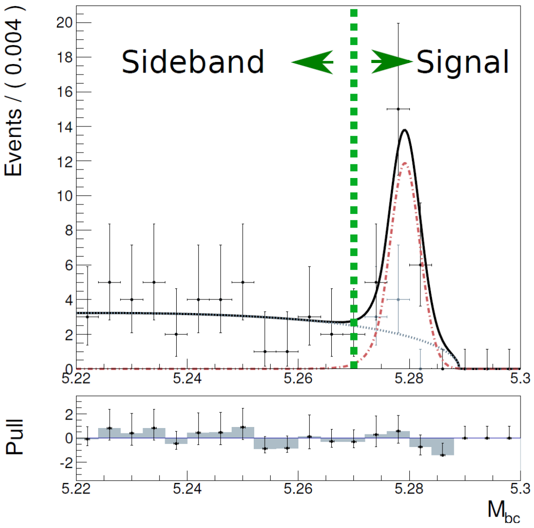


Belle: B→K*ll.

- Full angular analysis
  - LHCb discrepancy for P_5': ~3.7σ
    R. Aaij et al. , Phys. Rev. Lett. 111 (2013)
- Analysis in internal review
- Box opening and preliminary results planned for “Lepton Photon 2015”

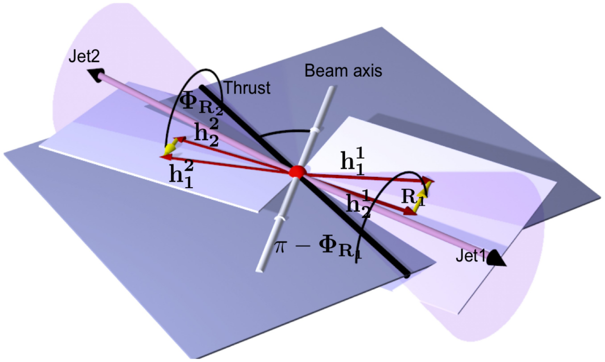




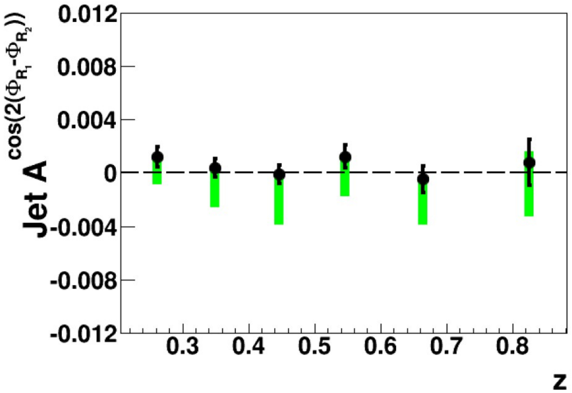


Belle: Light quark fragmentation.

- Measure azimuthal correlations between two pairs of charged pions in opposite hemispheres
- Helicity dependent fragmentation function $G_1^\perp$ is consistent with zero
- Analysis in internal review



BELLE-CONF-1502



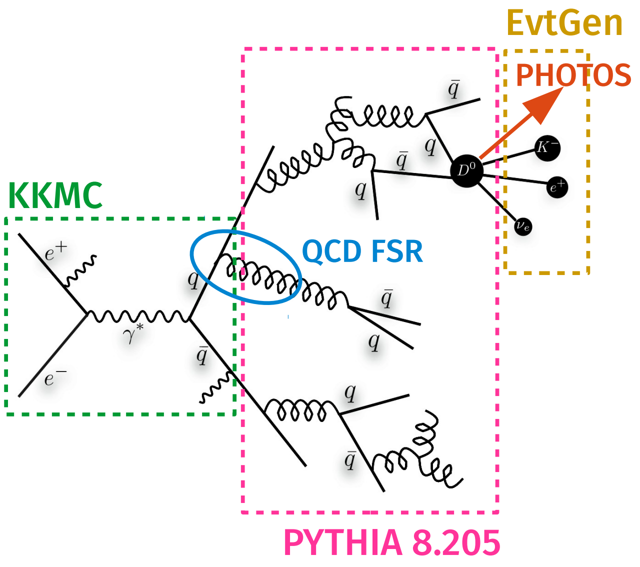
$H_1^\perp$ $G_1^\perp$ $H_1^\sphericalangle$

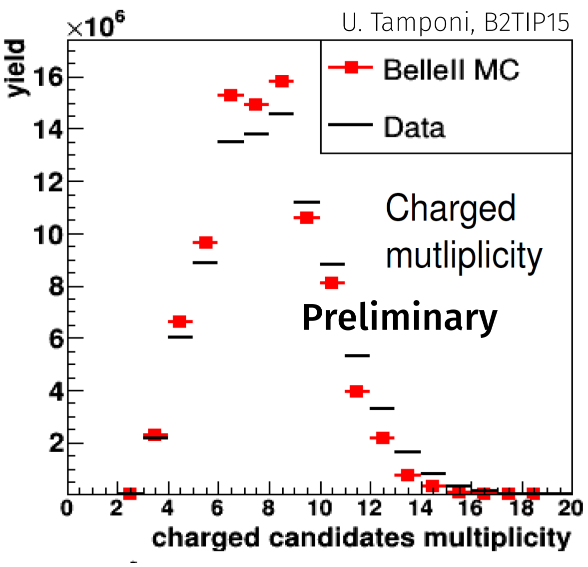
$$\sigma \propto 1 + A^{\cos(\phi_1+\phi_2)}\cos(\phi_1+\phi_2) + A^{2\cos(\phi_R-\phi_{\bar{R}})}\cos 2(\phi_R-\phi_{\bar{R}}) + A^{\cos(\phi_R+\phi_{\bar{R}})}\cos(\phi_R+\phi_{\bar{R}})$$

ongoing analysis | close to publication | ongoing analysis | first published in 2011

Belle → Belle II: PYTHIA8 tuning.

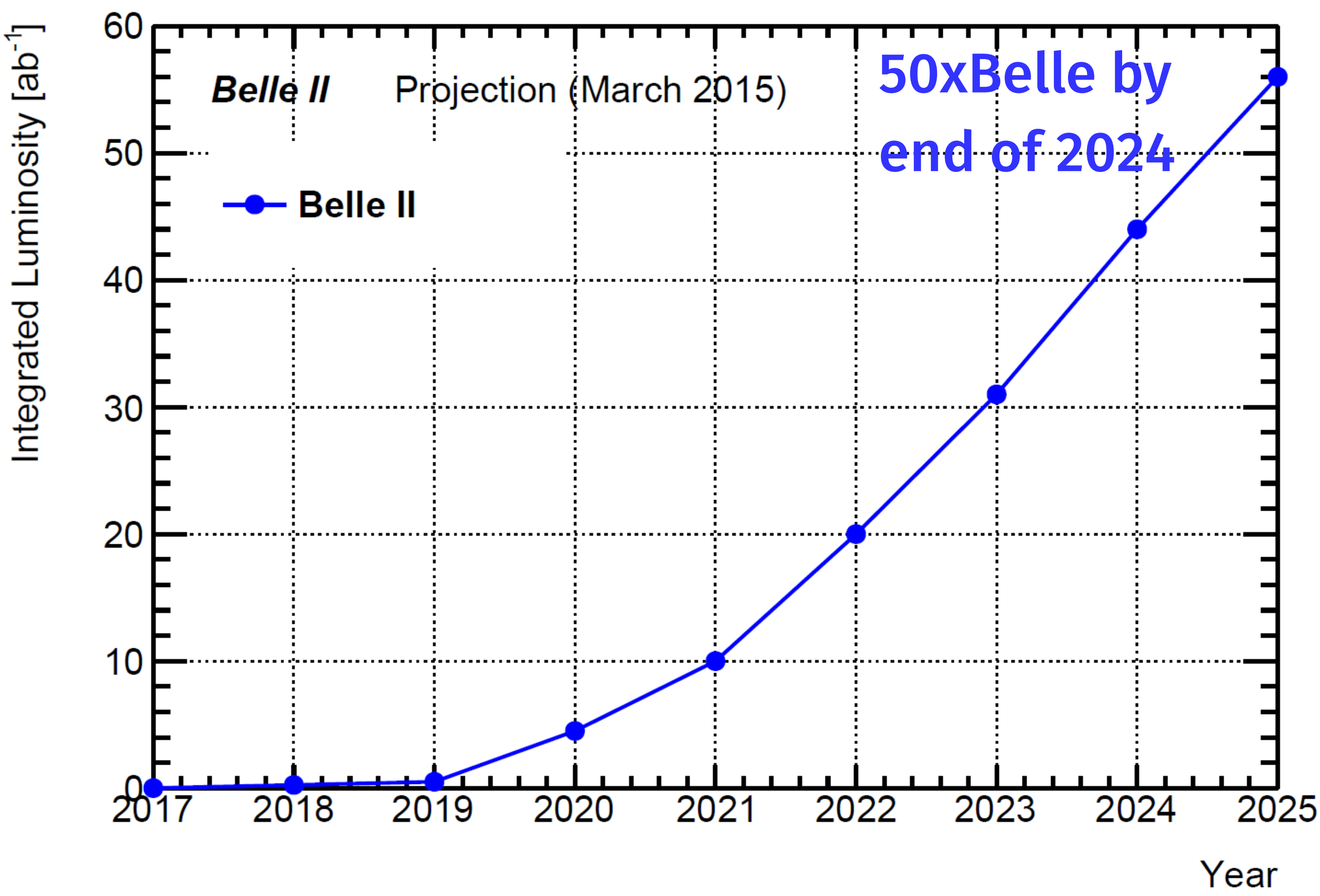
- Tuning of the Belle II generators using Belle data
  - Combine fragmentation and generator expertise at DESY
- Some Belle analyses affected by background uncertainty from data/MC differences (PYTHIA6)



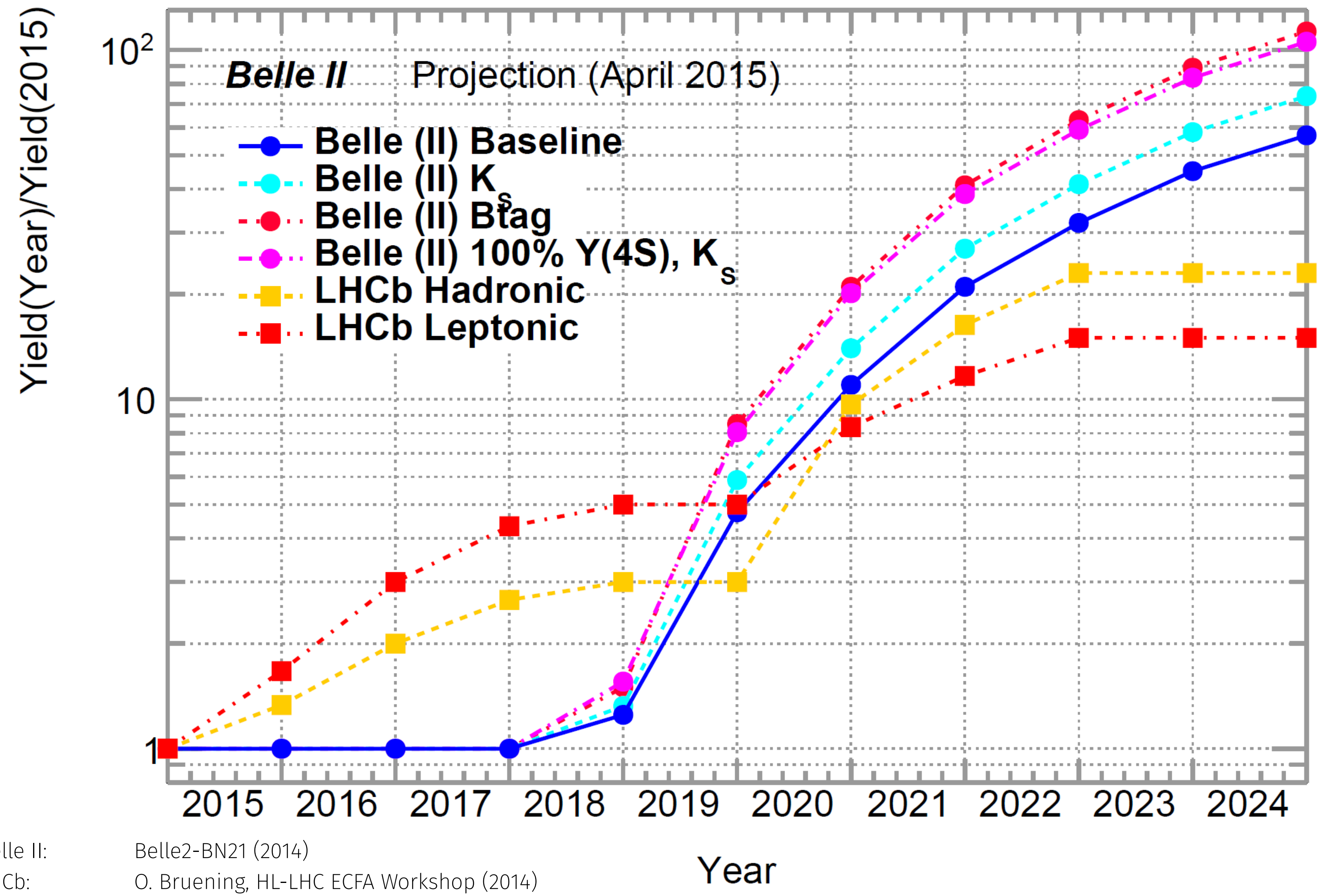


Belle II Physics Studies

Projected Belle II Integrated Luminosity.



Belle+Belle II vs. LHCb.



Belle II: Belle2-BN21 (2014)

LHCb: O. Bruening, HL-LHC ECFA Workshop (2014)
LHCb-PUB-2014-040 (2014)
EPJ C 73, 2373 (2013)

First Physics at Belle II and B2TIP.

First Physics:

- Under study: Physics in phase II (2017+, without VXD)
- “Maximize original research in the first year” (2018+)
  → ~300fb^{-1} non-Υ(4S) data
- Possible caveats: PID calibration, VXD alignment, Backgrounds
- Potential benefits: Looser trigger, varying beam energies
- DESY: Dark Photon, Fragmentation, Low Multiplicity Trigger,
  Event generators

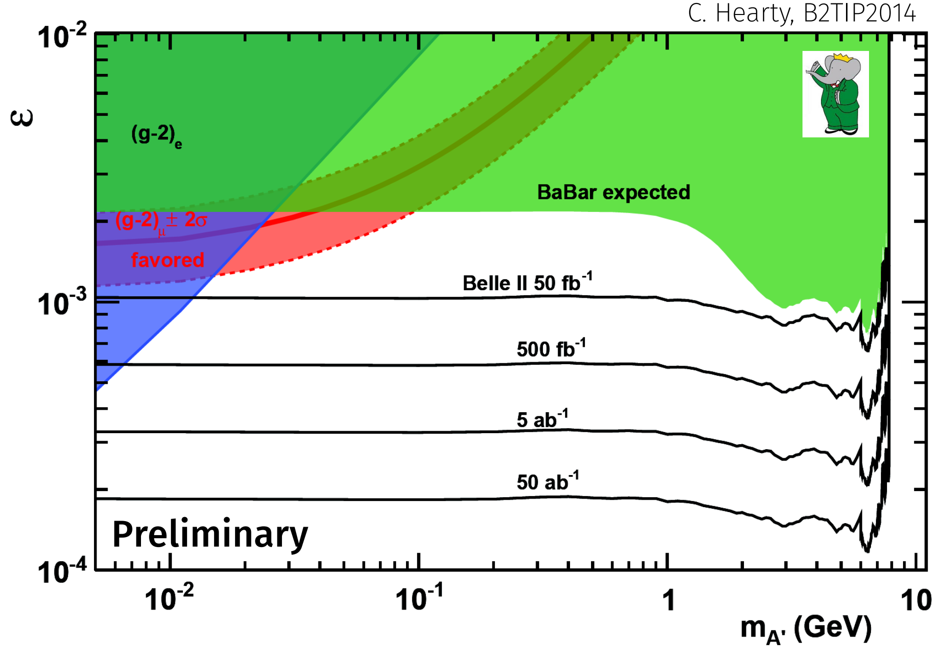
B2TIP (Belle II Theory Interface Platform):

- Joint theory-experiment effort to study the potential impacts of the Belle II program with milestones and golden modes (KEK Green Report)
- DESY: WG8 (Tau and low multiplicity), Event generators

Belle II: Dark Photon A → Invisible.

- If A' is not the lightest "Dark Sector" particle:
  - Annihilation into dark matter (A' → χχ) dominates
- Signal: Single, mono-energetic photon γ_{ISR}: $E_\gamma = \frac{s - M_{A'}^2}{2\sqrt{s}}$
- Belle II First Physics: Dedicated "single photon trigger" at E_γ~2 GeV
  - Also needed for search of a weakly interacting particle in non resonant ee →γχχ (via overall γ-rate increase)

Υ(3S) →γA⁰[A⁰-> Invisible], arXiv: 080.0017
limit: e.g. Essig et al., arXiv:1309.5084
C. Hearty, B2TIP2014

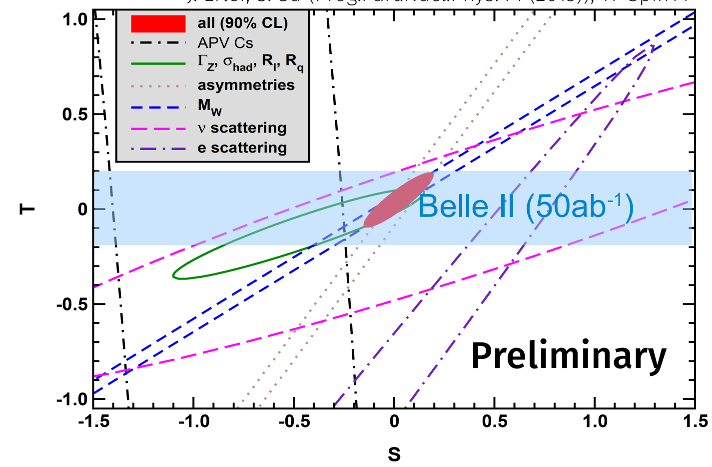


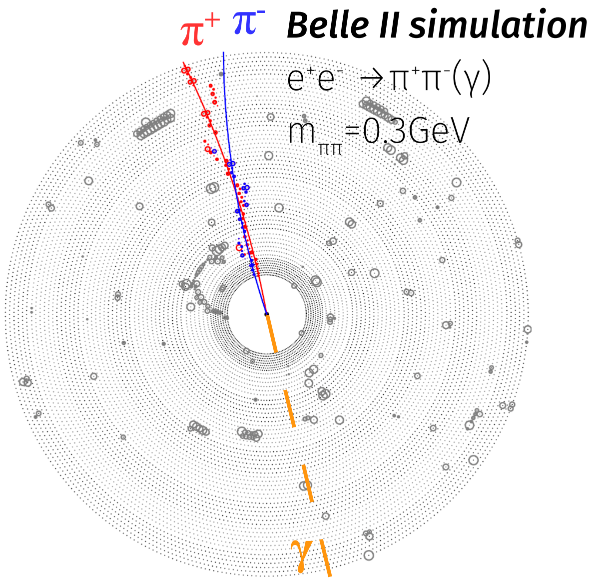
B2TIP WG8 Golden mode

Belle II: High precision two track physics.

- $50ab^{-1}$ at any energy (50x Belle):
  - Measurement of the SM ρ-parameter ($\sigma_{rel}(A_{FB})$=0.1%), trigger and tracking improvements based on Belle experience and data at DESY
- $5ab^{-1}$ at any energy (5-10x Belle):
  - Search for a Dark Photon $A \to l^+l^-$ and $A \to \pi^+\pi^-$
  - Measure cross section $\sigma_{rel}(\sigma_{ee\to\pi\pi})$=0.5% for g-2
- $0.3ab^{-1}$ scan at Υ(3S) (unique data):
  - Measure $\sigma_{Y(3S)\to l+l-}$: Γ_{ee}, lepton univ., $\alpha_{QED}(s)$

J. Erler, S. Su (Prog.Part.Nucl.Phys. 71 (2013)), TF Spin14

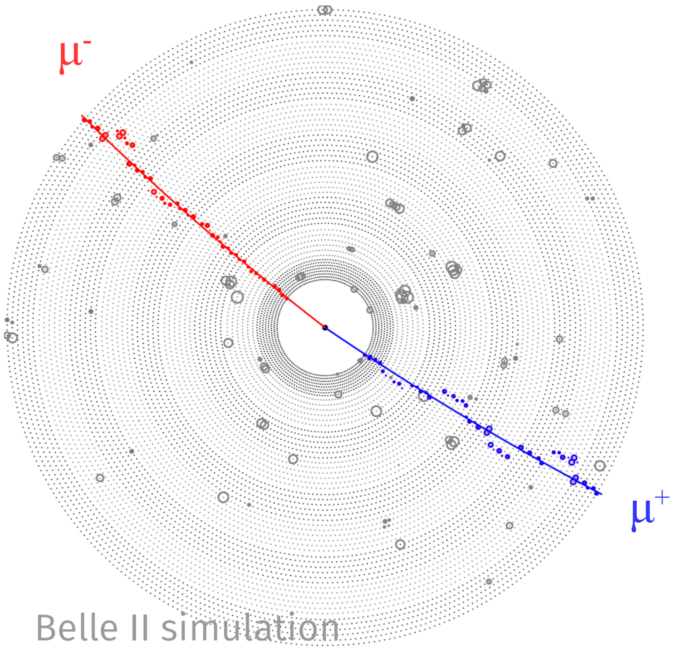




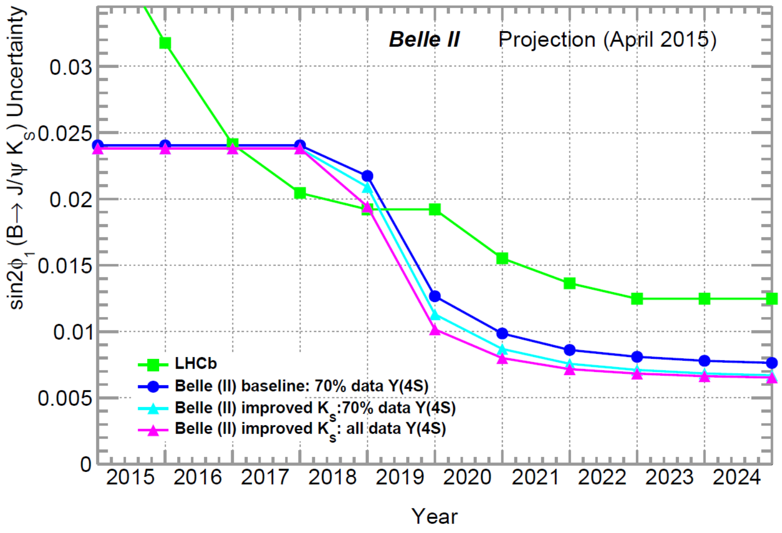
Summary.

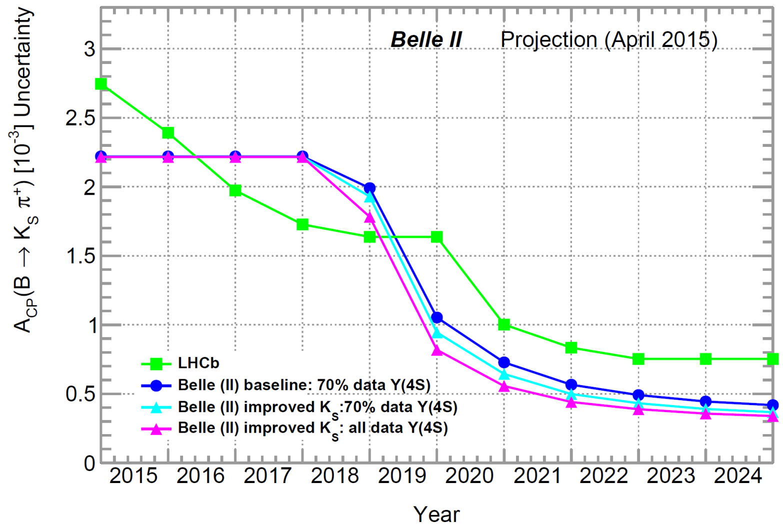
- Strong computing contribution and usage of the NAF2.0 at DESY
- First DESY-Belle analyses approach publication stage
- Belle II starts physics data taking 2018
- DESY contributions to Belle II:
  - Hardware: Thermal Mockup, RVC, CO_2 cooling, B-field measurements
  - Software: Event Generators (convenor), Alignment and Calibration (convenor), Trackfinding, Background studies
- DESY impact on Belle II physics program:
  - "Tau and low multiplicity" convenor, "First Physics" authors

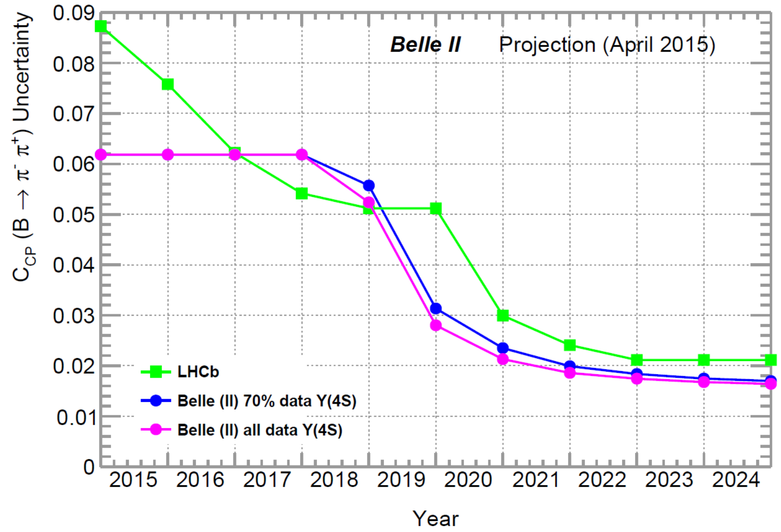
Backup

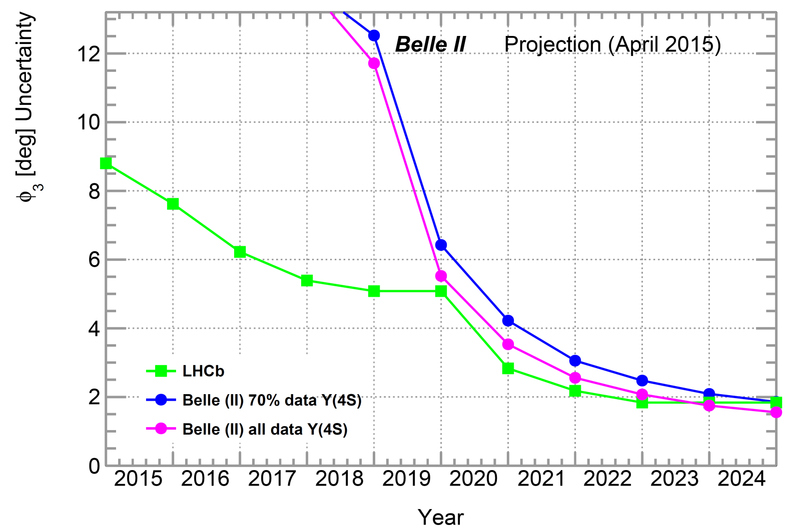


Belle II vs. LHCb: Competition.



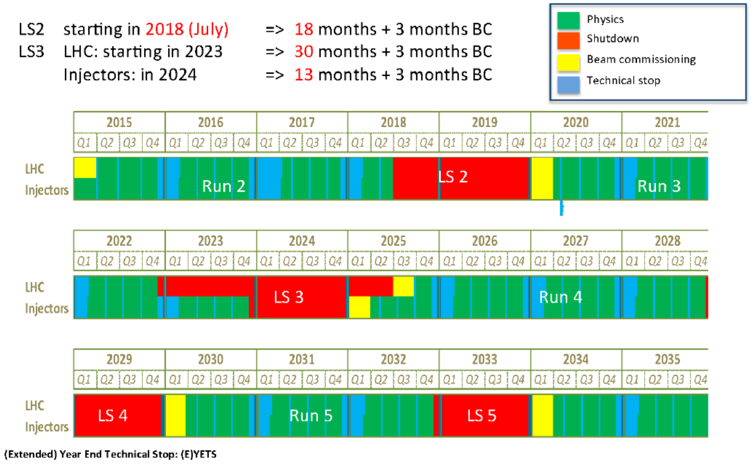




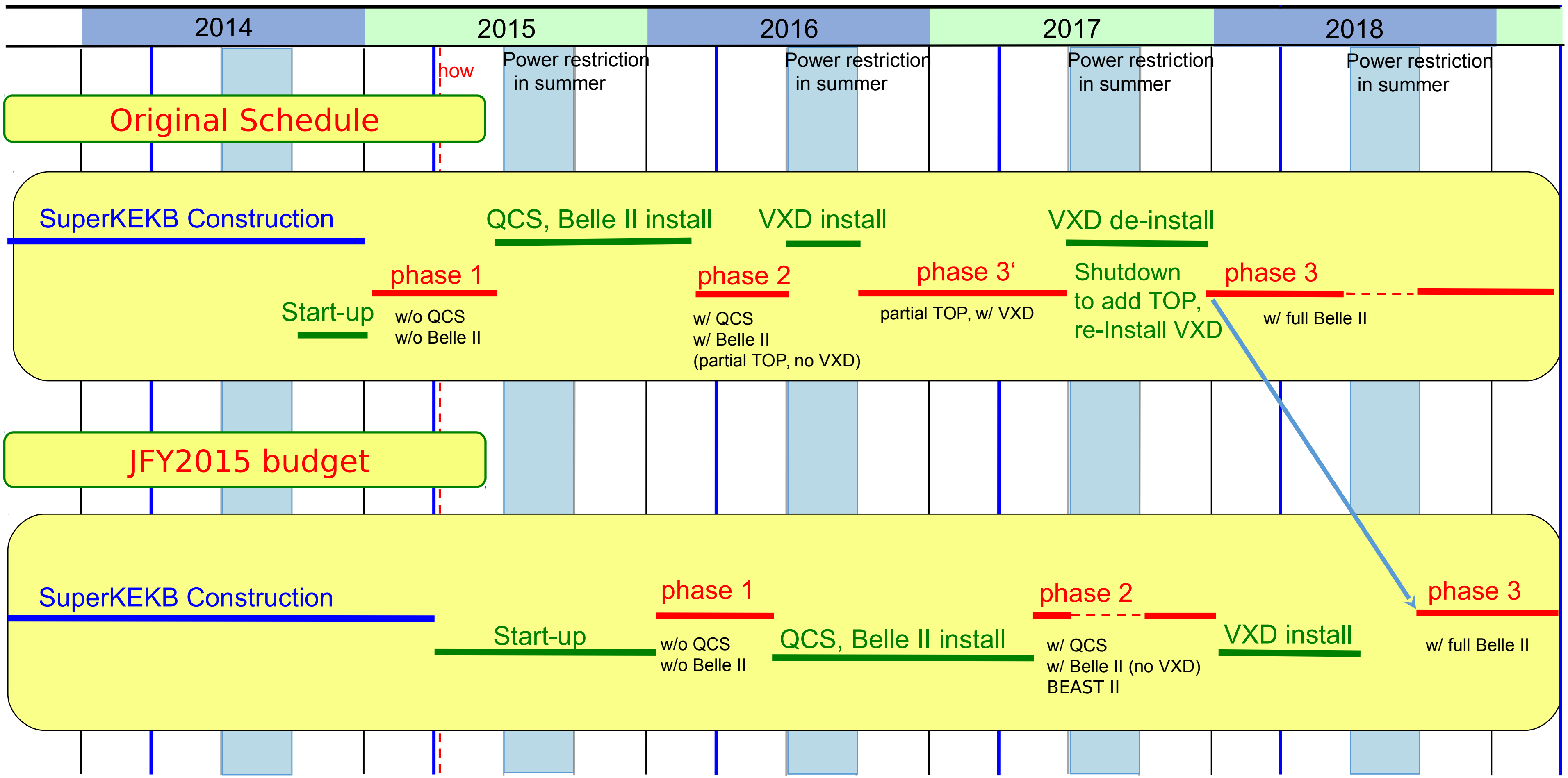


Belle II vs. LHCb: Competition.

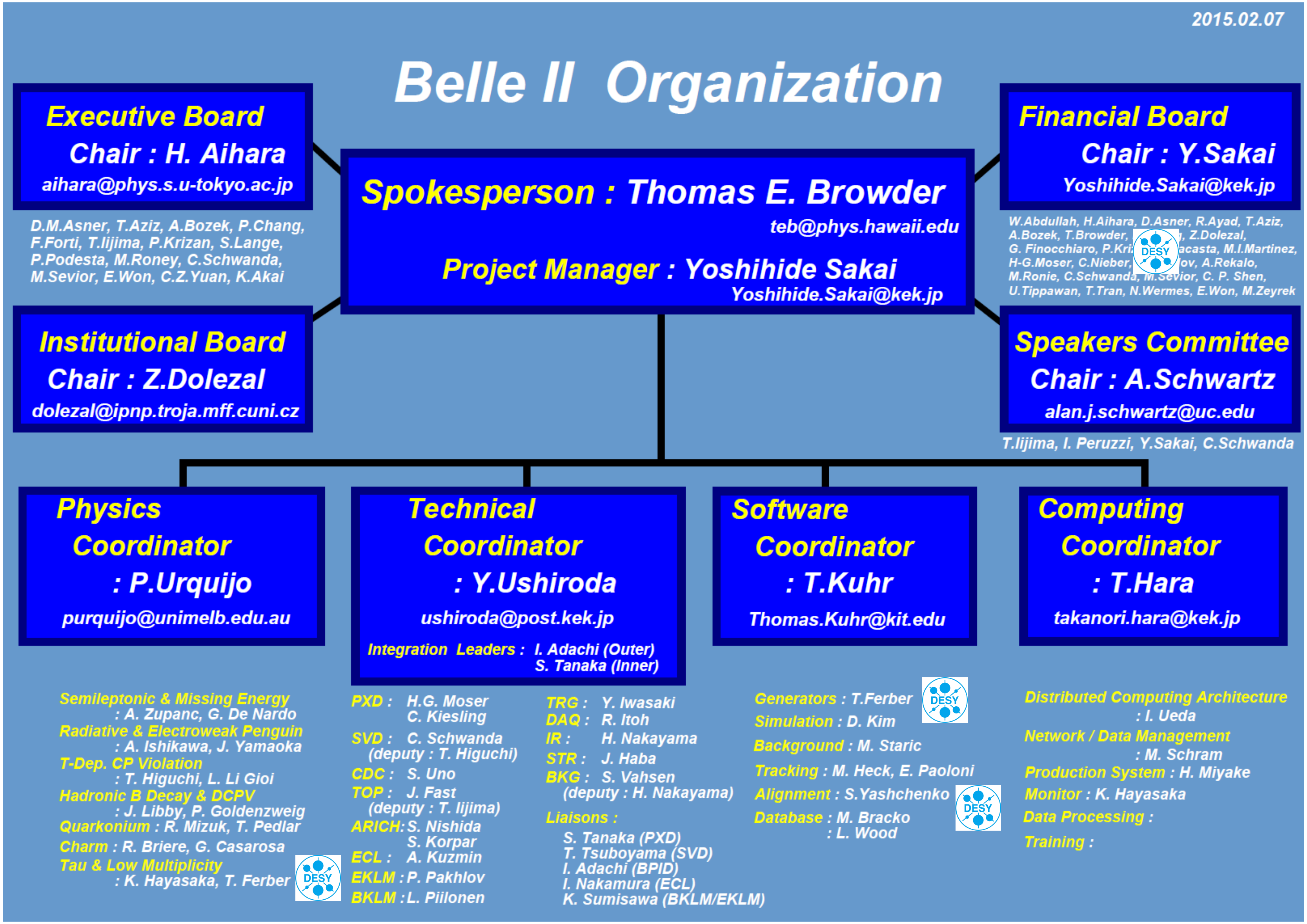
- The b and c quark production cross sections scale linearly with $\sqrt{s}$.
- Run-2 will operate at 13 TeV.
- Run-2 will be 50% less efficient than Run-1 for modes found by hadronic triggers.
- During long-shutdown-2 LHCb will upgrade its trigger system, removing the hardware trigger. This will increase the hadronic trigger efficiency by a factor of two with respect to Run-1. Muon trigger efficiencies will remain at their current levels.
- The LHC will shutdown again in 2023 for 2.5 years.



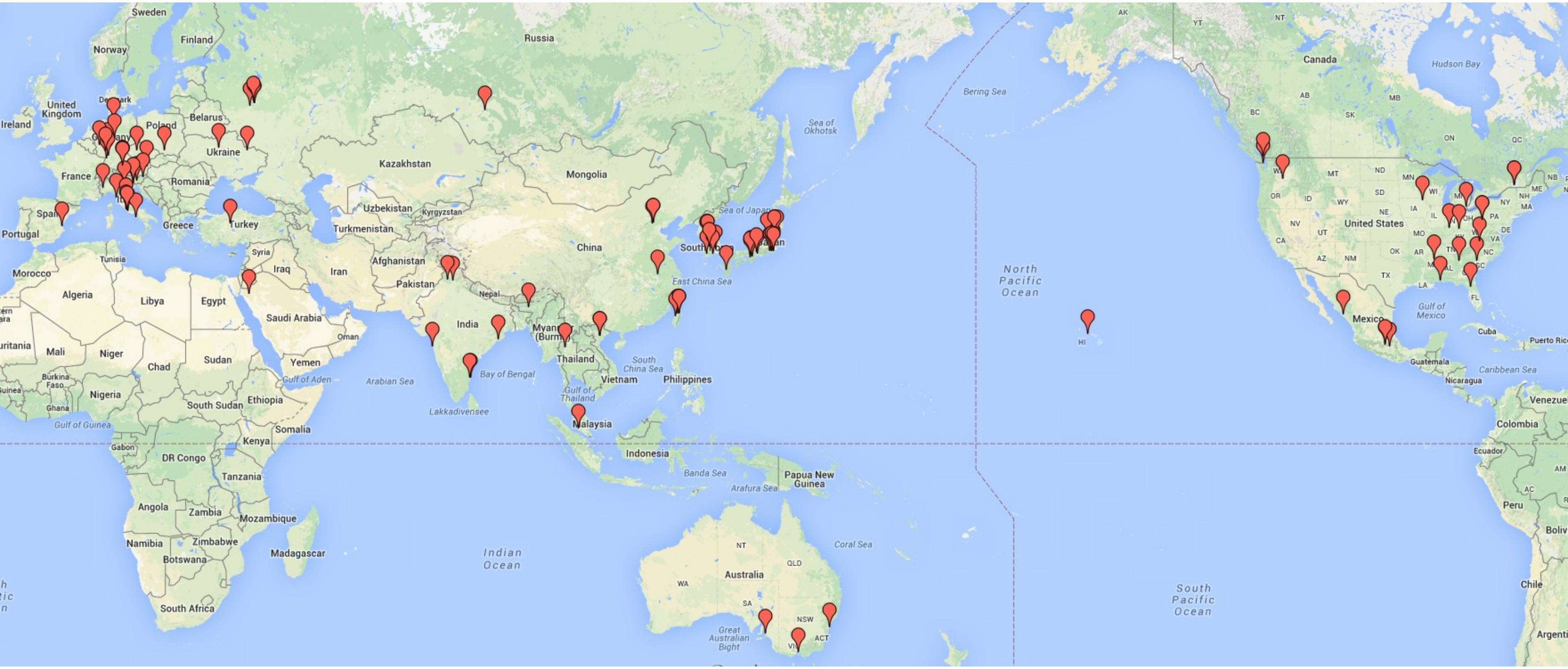
Belle II Schedule.



Belle II Organization Details.



Belle II Organization.



569 colleagues, 99 institutions, 23 countries/regions
(Germany: 75 colleagues, 11 institutes)

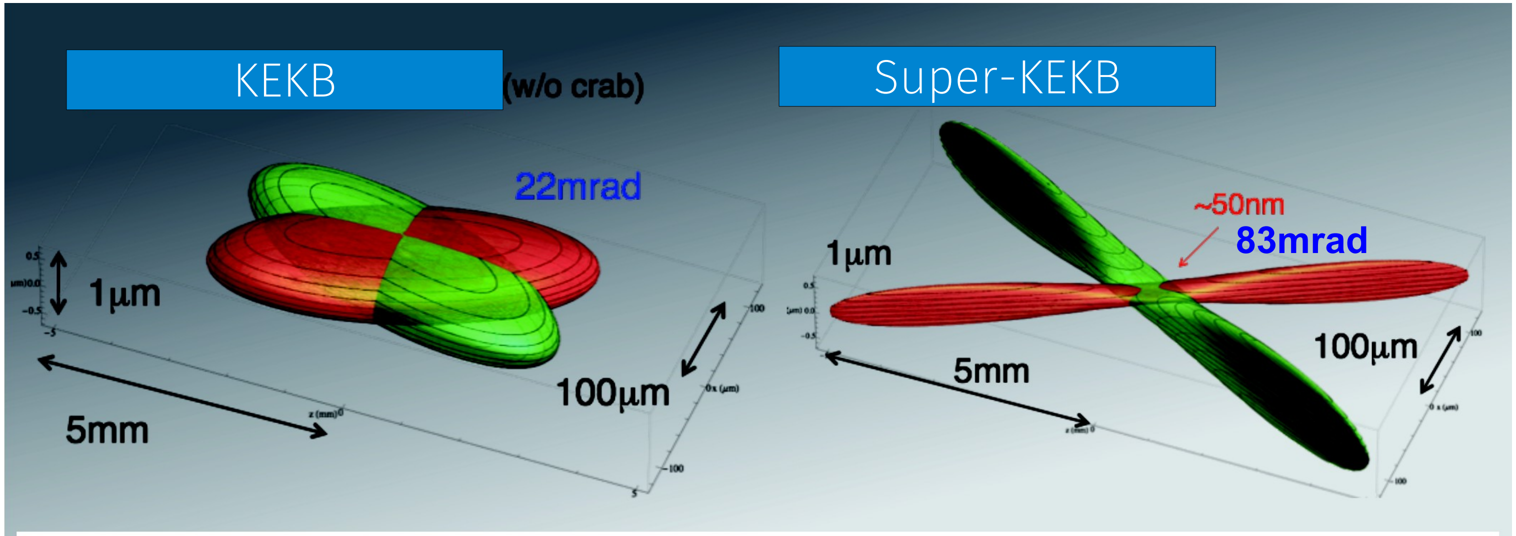
(last update: 01.05.2015)

Belle II Accelerator: Nano-beam scheme.

beam current

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

vertical beta function at IP

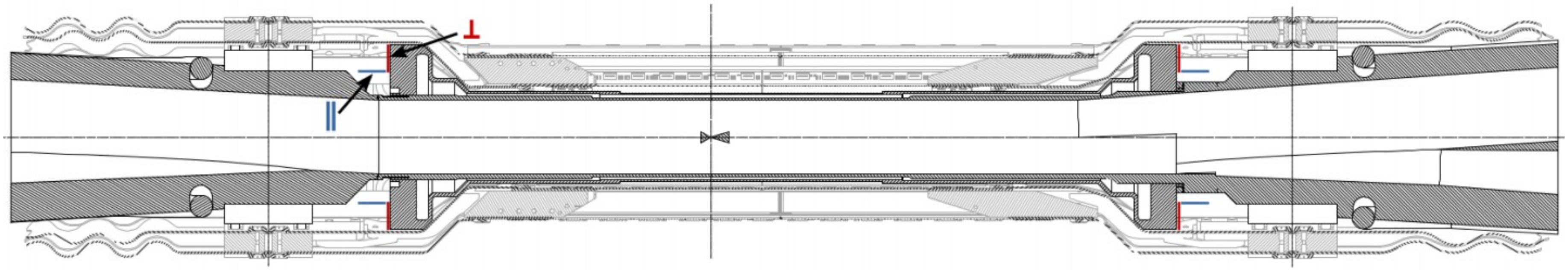


	E (GeV) LER/HER	β*$_y$ (mm) LER/HER	β*$_x$ (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

factor 20

factor 2-3

Positions of the diamond sensors.



The Standard Model (Born level): ee → μμ.

$$\frac{2s}{\pi}\frac{d\sigma}{d\cos(\theta^*)}(e^+e^- \to \mu^+\mu^-) =$$

$$\underbrace{|\alpha(s)|^2(1+\cos^2(\theta^*))}_{\sigma^\gamma}$$

$$\underbrace{+8\,\mathrm{Re}\left[\alpha^*(s)\chi(s)\left\{\mathcal{G}_{\mathrm{ve}}\mathcal{G}_{\mathrm{v}\mu}(1+\cos^2(\theta^*)) + 2\mathcal{G}_{\mathrm{ae}}\mathcal{G}_{\mathrm{a}\mu}\cos(\theta^*)\right\}\right]}_{\sigma^{\gamma-Z}}$$

$$\underbrace{\begin{array}{c} +\ 16|\chi(s)|^2\left[\left(|\mathcal{G}_{\mathrm{ve}}|^2 + |\mathcal{G}_{\mathrm{ae}}|^2\right)\left(|\mathcal{G}_{\mathrm{v}\mu}|^2 + |\mathcal{G}_{\mathrm{a}\mu}|^2\right)(1+\cos^2(\theta^*))\right. \\ \left. +8\,\mathrm{Re}(\mathcal{G}_{\mathrm{ve}}\mathcal{G}^*_{\mathrm{ae}})\,\mathrm{Re}(\mathcal{G}_{\mathrm{v}\mu}\mathcal{G}^*_{\mathrm{a}\mu})\cos(\theta^*)\right], \end{array}}_{\sigma^Z}$$

with

$$\chi(s) = \rho\frac{G_F}{8\pi\sqrt{2}}\frac{M_Z^2 s}{s - M_Z^2 + i\Gamma_Z M_Z}$$

$$\mathcal{G}_{\mathrm{V}f} = \sqrt{\mathcal{R}_f}\left(T_3^f - 2\sin^2\theta_W^{\mathrm{eff.}}\right)$$

rho parameter

weak mixing angle

Backup: Belle II and LHCb.

TABLE XLI: Expected errors on several selected flavour observables with an integrated luminosity of 5 ab^{-1} and 50 ab^{-1} of Belle II data. The current results from Belle, or from BaBar where relevant (denoted with a †) are also given. Items marked with a ‡ are estimates based on similar measurements. Errors given in % represent relative errors.

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (1.4°)$	0.7°	0.4°	1.6°	0.6°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)} K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s (B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\mathrm{eff}} (B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta_s^{\mathrm{eff}} (B_s \to K^{*0} \bar{K}^{*0})$ [rad]	–			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		
UT sides	$\lvert V_{cb} \rvert$ incl.	$41.6 \cdot 10^{-3} (1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb} \rvert$ excl.	$37.5 \cdot 10^{-3} (1 \pm 3.0\%_{\mathrm{ex.}} \pm 2.7\%_{\mathrm{th.}})$	1.8%	1.4%		
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3} (1 \pm 6.0\%_{\mathrm{ex.}} \pm 2.5\%_{\mathrm{th.}})$	3.4%	3.0%		
	$\lvert V_{ub} \rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3} (1 \pm 10.8\%)$	4.7%	2.4%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96 (1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440 (1 \pm 16.5\%)^\dagger$	5.6%	3.4%		
	$R(B \to D^* \tau\nu)^\dagger$ [Had. tag]	$0.332 (1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...	
Radiative	$\mathcal{B}(B \to X_s \gamma)$	$3.45 \cdot 10^{-4} (1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d} \gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$2\beta_s^{\mathrm{eff}} (B_s \to \phi\gamma)$	–			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+} \nu\bar{\nu})$ $[10^{-6}]$	< 40	< 15	30%		
	$\mathcal{B}(B \to K^+ \nu\bar{\nu})$ $[10^{-6}]$	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s \ell\ell)$	~20%	10%	5%		
	$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ $[10^{-9}]$	$2.9^{+1.1}_{-1.0}{}^*$			0.5	0.2

Backup: Belle II and LHCb.

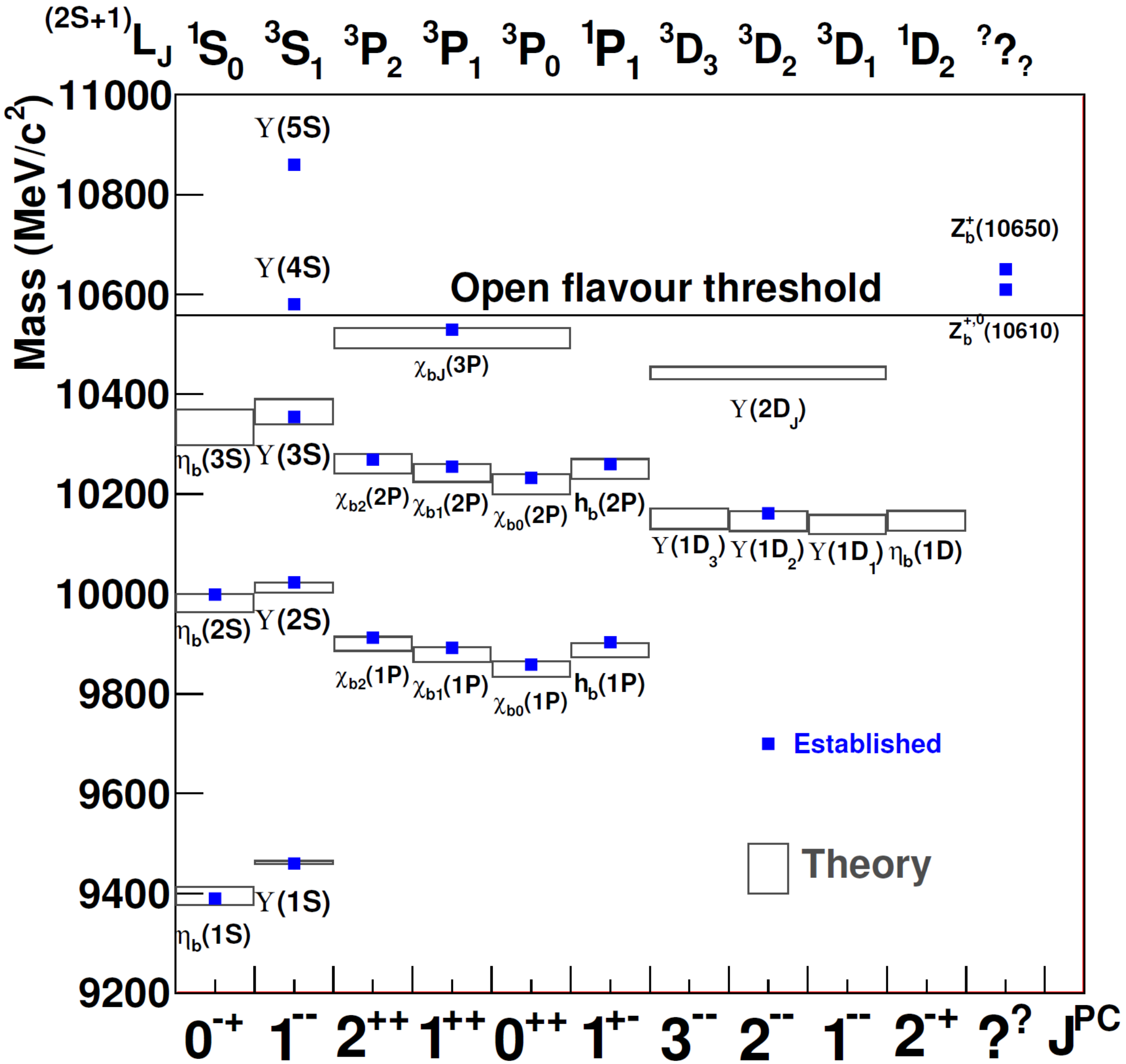
TABLE XLII: Continued from previous page.

	Observables	Belle	Belle II		LHCb	
		(2014)	5 ab^{-1}	50 ab^{-1}	2018	50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-4}]	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ [10^{-4}]	3.4*			0.5	0.1
	A_Γ [10^{-2}]	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ [10^{-9}]	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0	< 3.0	< 0.3		

Backup: First physics “Bottomonium below Υ(4S)”.

$\eta_b(1S)$	Resolve discrepancies on the mass and width, based on measurements of radiative transitions.
$\eta_b(2S)$	Independent confirmation of $\Upsilon(2S)$ properties, and tests of hyperfine splitting against theoretical predictions.
$\Upsilon(1^3D_1)$, $\Upsilon(1^3D_3)$	Precise measurement of multi-photon cascade decays to separate $J = 1,\ 3$ (not seen) states from the $J = 2$ (seen) state.
$\Upsilon(1^3D_1)$	Inclusive photon spectra of $\Upsilon(3S)$ decays.
R_b near $\Upsilon(3S)$, $\Upsilon(2^3D_2)$-triplet	Search for unseen $\Upsilon(1D)$ states and the unseen $\Upsilon(2^3D_2)$ triplet via R_b scan methods.
h_b	First observation and resonance characterisation.
Inclusive decays (χ_b, Υ)	Surveys of inclusive hadronic transitions of χ_b and $\Upsilon(2S,\ 3S)$.
Dipion transitions	Surveys of dipion transitions between χ_b states (analogous to Υ).

Backup: First physics "Bottomonium below Υ(4S)".

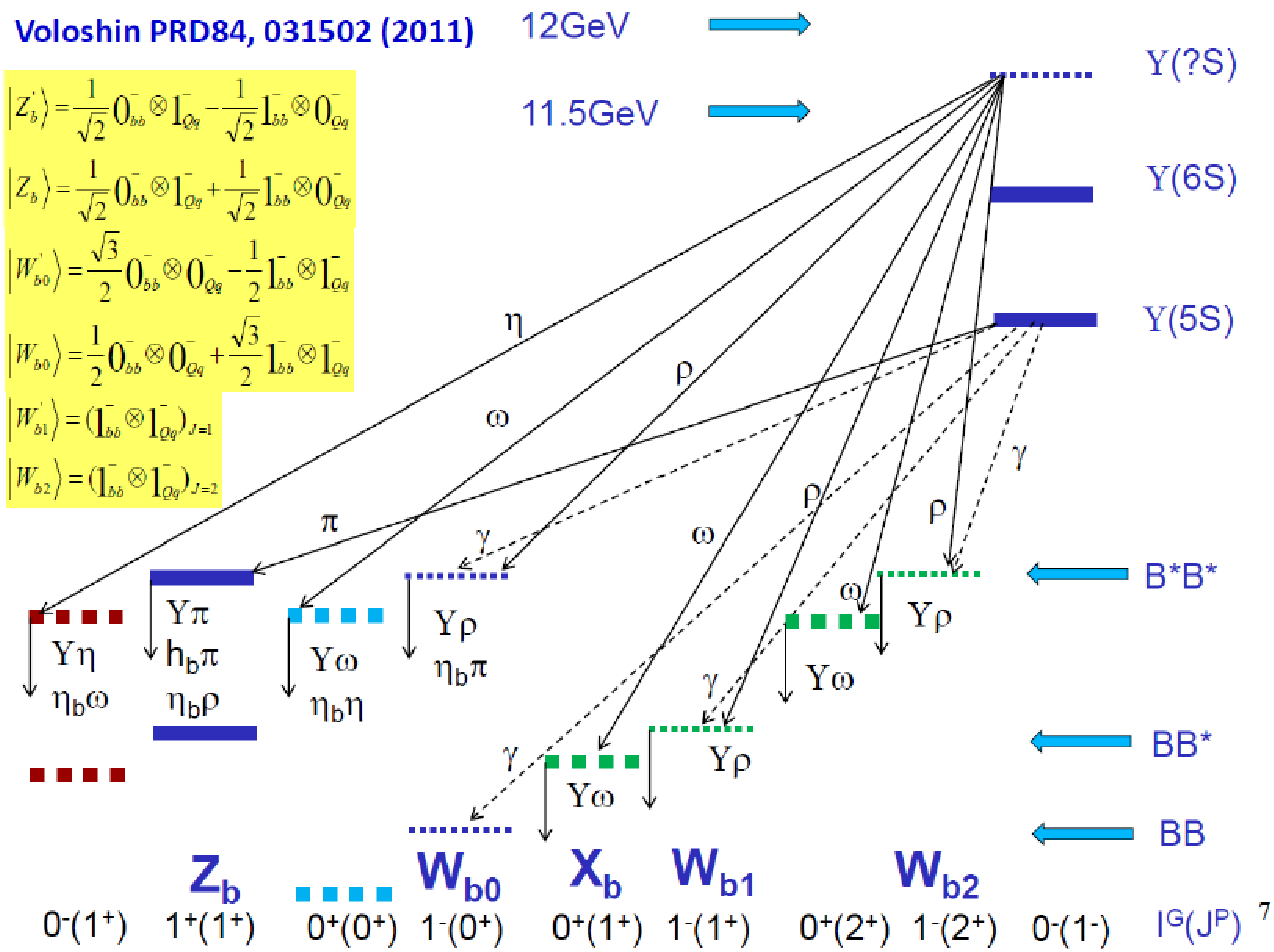


Backup: First physics “Bottomonium above Υ(4S)”.

R_b	Inclusive b cross section as a function of E_{CM} up to $\Upsilon(6S)$
Z_b from scans	Analysis of $\pi + Z_b$ substructure through $\sigma(\Upsilon + 2\pi)$ and $\sigma(h_b(nP) + 2\pi)$ through an E_{CMscan}
Z_b near resonance	Analysis of Z_b charged and neutral from $\Upsilon(6S)$
Tetra quark states	Analysis of radiative or 2π transitions from $\Upsilon(6S)$
Other exotica	Searches for exotic states with single π transitions from $\Upsilon(5S)$ and $\Upsilon(6S)$
$\sigma(B^{(*)}B^{(*)})$ and $\sigma(B_s^{(*)}B_s^{(*)})$	
W_b, X_b	Studies of radiative transitions from $\Upsilon(6S)$ to new bottomonium-like states and χ_{bJ}.
m_b	Accurate determination of m_b via bottomonium sum-rules. Precision tests of discrepancies between pQCD and e^+e^- data near the accelerator threshold region.

Backup: First physics “Bottomonium above Y(4S)”.

Voloshin PRD84, 031502 (2011)



Backup: Trigger Rates.

Physics process	Cross section [nb]
Y(4S) → BB	1.2
Light quark pairs	2.8
Muon pairs	1.1
Tau pairs	0.9
Bhabha (θ_{lab}>17°)	44
Photon pairs (θ_{lab}>17°)	2.4
Two photon (θ_{lab}>17°)	~80
Total	**~130**

	L1 rate	Physics rate	Event size
Belle	500 Hz	90 Hz	40kB
Belle II	30 kHz	3-10 kHz	200kB

Physics process	Cross section [nb]	Rate [Hz] @ final L.
Y(4S) → BB	1.2	960
quark pairs	2.8	2200
Muon pairs	1.1	880
Tau pairs	0.9	720
Bhabha (θ_{lab}>17°)	44	350*
γ pairs (θ_{lab}>17°)	2.4	19*
Two photon (θ_{lab}>17°)	~80	~15000
Total	~130	~20000

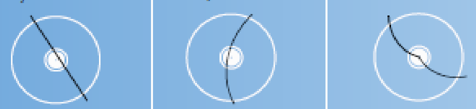
Backup: Alignment@ICHEP2015.

Test of simultaneous calibration and alignment of Belle II silicon vertex detector and central drift chamber

Simulated Track Sample

B = 0 T — 100,000 tracks

B = 1.5 T — 100,000 tracks | 100,000 tracks



Belle II cosmic ray μ generator using measured distribution at Belle

Belle II $e^+e^- \to \mu^+\mu^-$ pair generator

Alignment & Calibration Parameters

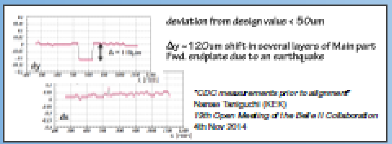
PXD + SVD: 20 + 187 sensors, 1242 parameters — Shifts $\Delta u, \Delta v, \Delta w$ alignment; Rotations $\Delta\alpha, \Delta\beta, \Delta\gamma$ alignment

CDC: 32 axial layers, 96 parameters — Shifts $\Delta x, \Delta y$ alignment; Drift velocity Δv_d calibration

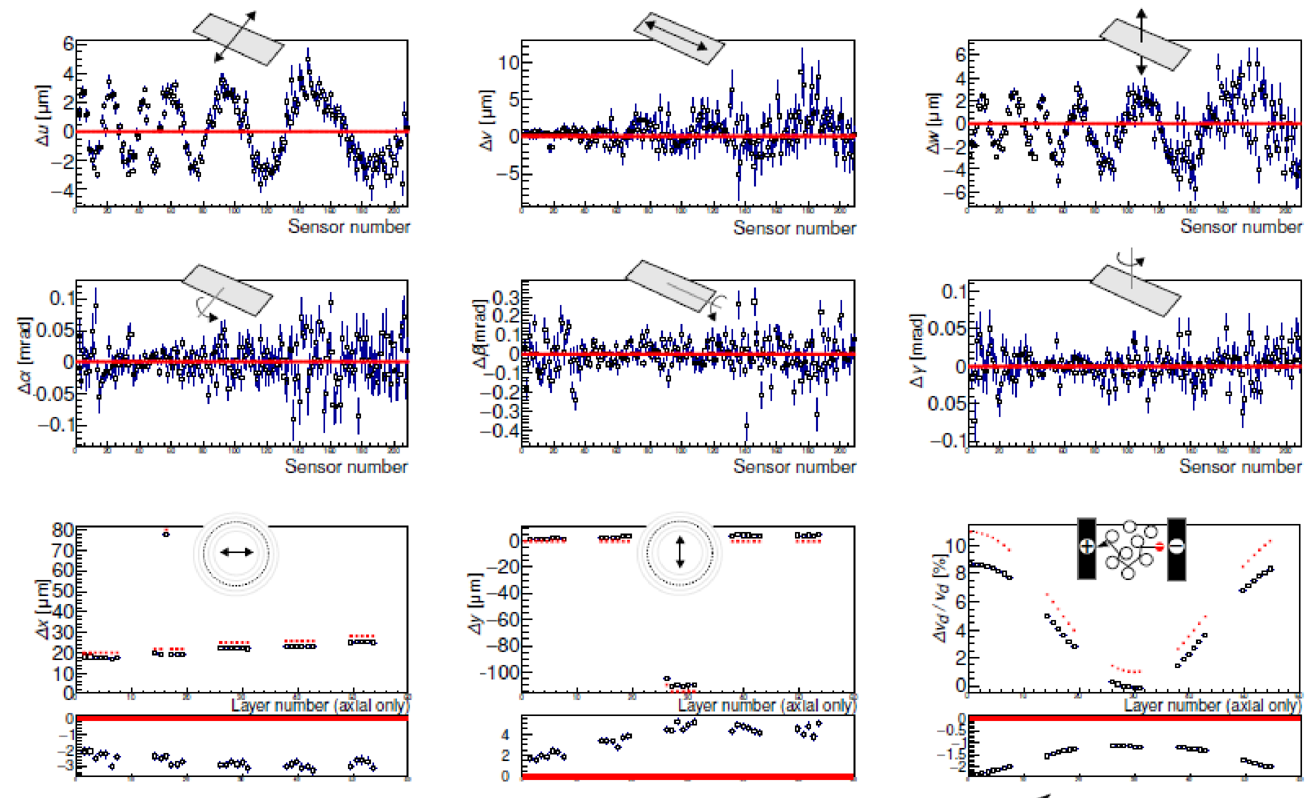
1338 global parameters - 10 fixed for reference = 1328 free

Mis-Alignment & Mis-Calibration

- No mis-alignment for VXD sensors to check for stability and possible weak modes
- Misalignment of axial CDC layers in $\Delta x, \Delta y$ similar to 2014 survey



- Mis-calibration of (linear) x-t relation by using layer - dependent Δv_d



Visible bias comming from simulations effects not yet taken into account in the reconstruction