e^+e^- Future B Factory.

SuperKEKB / Belle II

BEAUTY 2013

14th International Conference on B-Physics at Hadron Machines

Sergey Yashchenko (DESY)
for the Belle II Collaboration
e^+e^- Future B Factory (SuperKEKB / Belle II)
Bologna, Italy, 12.04.2013

HELMHOLTZ ASSOCIATION

Super KEKB

Belle II

DESY

Achievements of e+e- B Factories

> e+e- B Factories: Belle at KEKB and BaBar at PEP-II

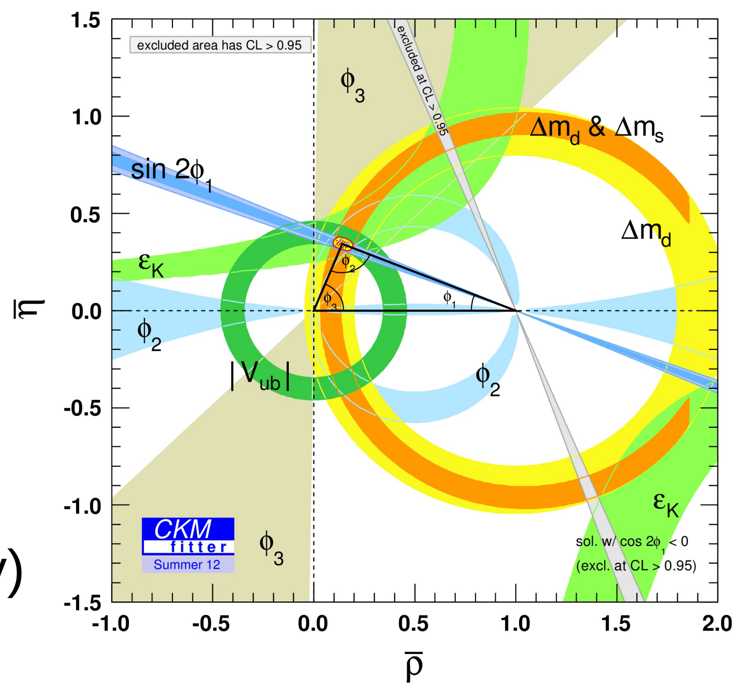
> Successful confirmation of Kobayashi-Maskawa mechanism of CP violation in the Standard Model

- Nobel Prize for Kobayashi and Maskawa in 2008

> Precise measurements of CKM elements and angles of UT

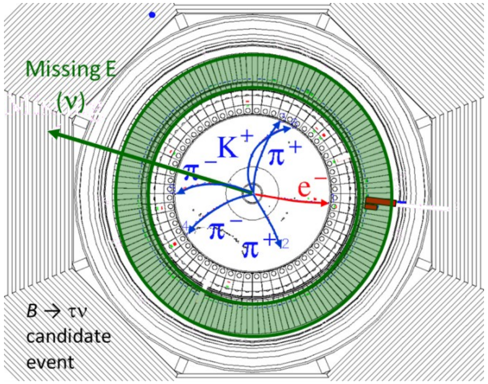
> Much more

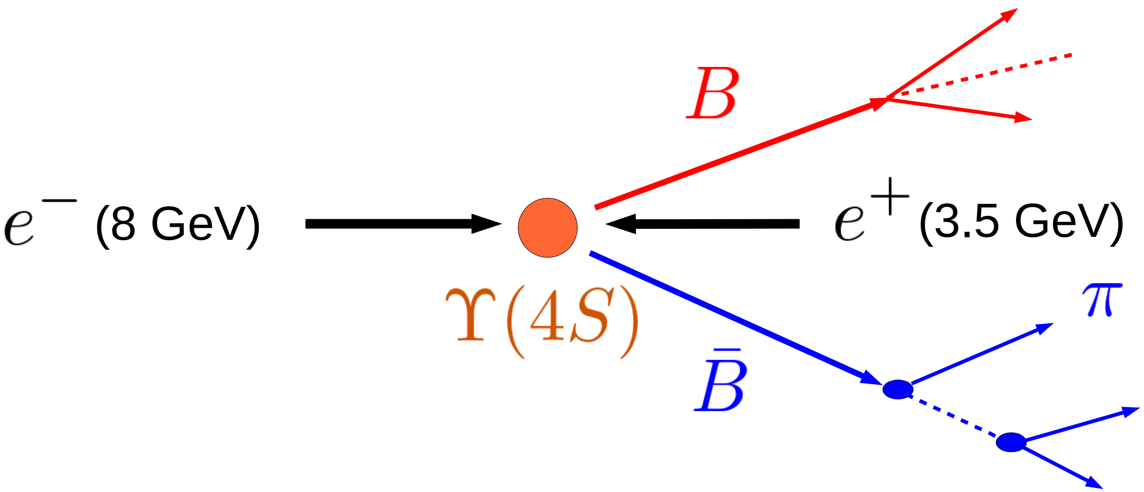
- Measurements of rare B-decay modes
- b → s transitions: new sources of CPV
- Observation of D mixing (charm factory)
- Searches for LFV tau decays (tau factory)
- Observation of exotic hadrons



Unique Capabilities of e^+e^- B Factories

- Clean event environment
- Detection of neutral particles
- Example: full reconstruction method





Decays of interest

$B \to \tau\nu,\ D\tau\nu$

$B \to X_u l\nu$

$B \to K\nu\nu$

$\ldots$

Full reconstruction

$B \to D\pi\ etc$

(0.1–0.3%)

Semileptonic tagging

- Effective offline B meson beam

Why Upgrade?

- Belle and BaBar collected about 1.5 ab^{-1} high-quality data
  - World record luminosity 2.1 x 10^{34} $cm^{-2}s^{-1}$ at Belle → twice design
- Most of the results compatible with the Standard Model
- Some hints for deviations from the Standard Model (e.g., in $B \to D(^*)\tau\nu$, see talk of Y. Horii)
- Many measurements can only be done at B Factories and still limited in statistics
- Goal of Belle II at SuperKEKB: collect 50 ab^{-1} by 2023

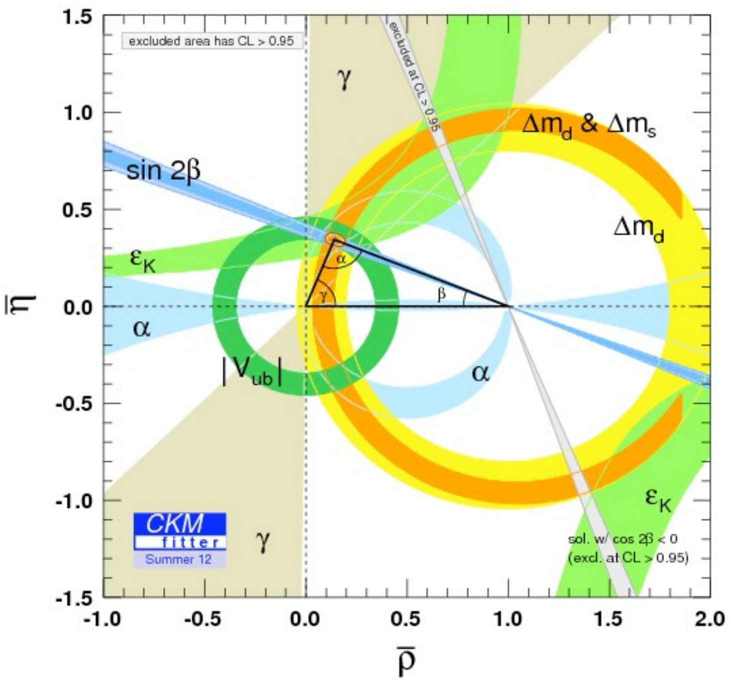
Search for New Physics at Belle II

- Precision test of CKM unitarity
- Search for New Physics in B decays with missing energy $(B \to \tau\nu, D(^*)\tau\nu, K\nu\nu, \ldots)$
- Search for lepton flavor violation in B and tau decays
- Flavor changing neutral currents (virtual contributions of new, heavy particles in loops)
- Charm physics

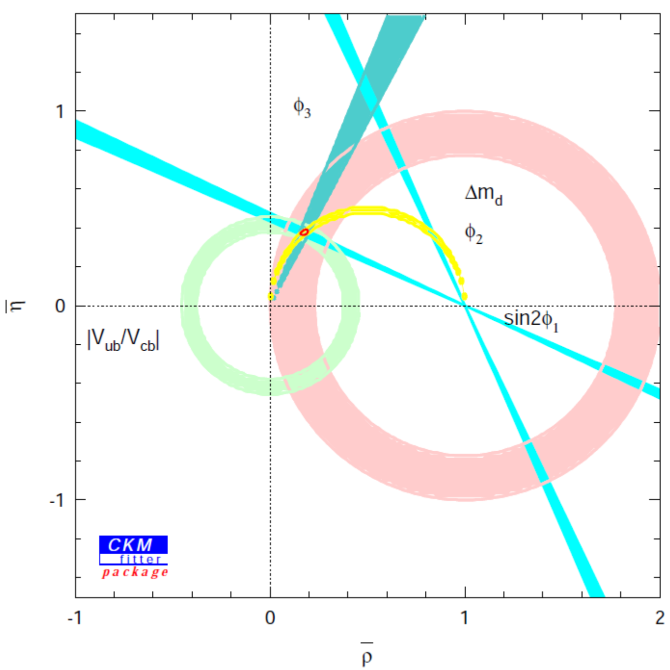
Precision Tests of CKM

- > Much more improved measurements
- > Overconstrain Unitarity Triangle
- > Discrepancy between measurements → new physics?

2012 (~1000 fb^{-1} at Belle and BaBar)

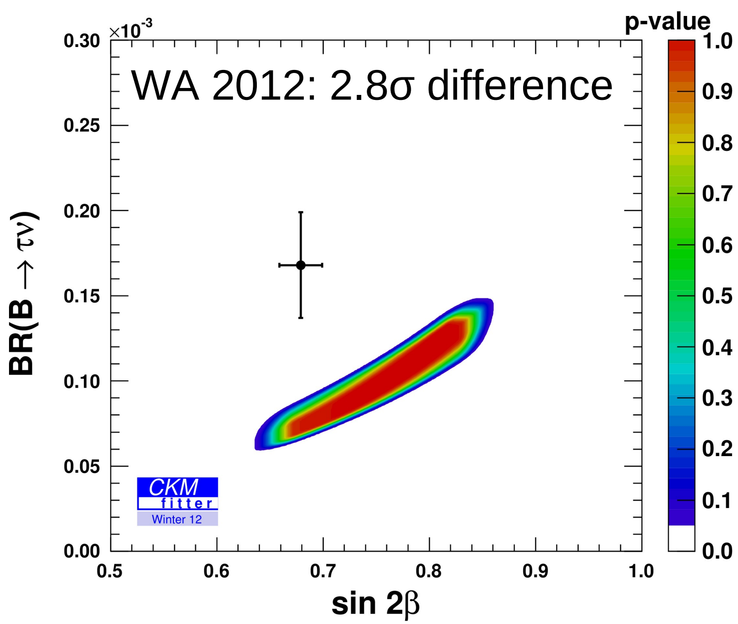


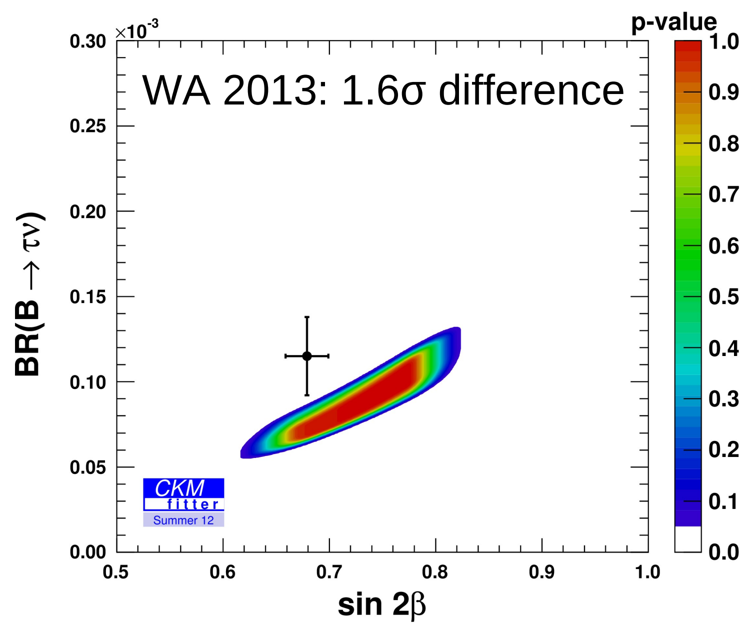
Expected constraint at 50 ab^{-1}



Search for New Physics: B Decays with Tau Lepton

- $B \to \tau\nu$ *PRL 110, 131801 (2013)*
- Full reconstruction method
- Results consistent with SM
- $Br(B \to \tau\nu) = [0.72^{+0.27}_{-0.25}(\mathrm{stat}) \pm 0.11(\mathrm{syst})] \times 10^{-4}$

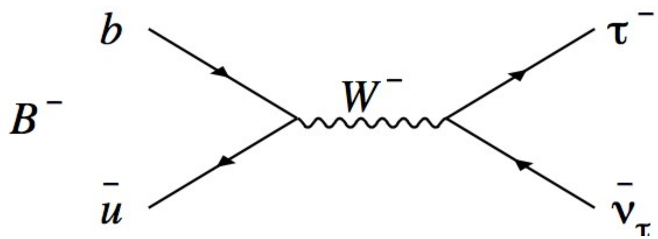




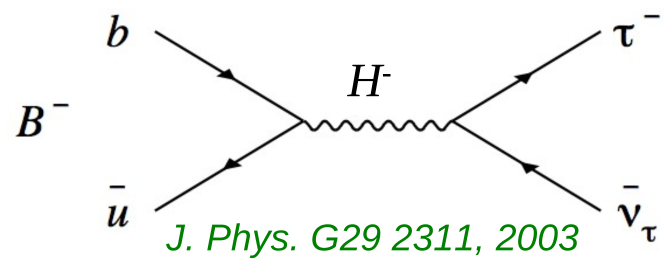
Search for New Physics: B Decays with Tau Lepton

> Sensitive to charged Higgs

Standard Model

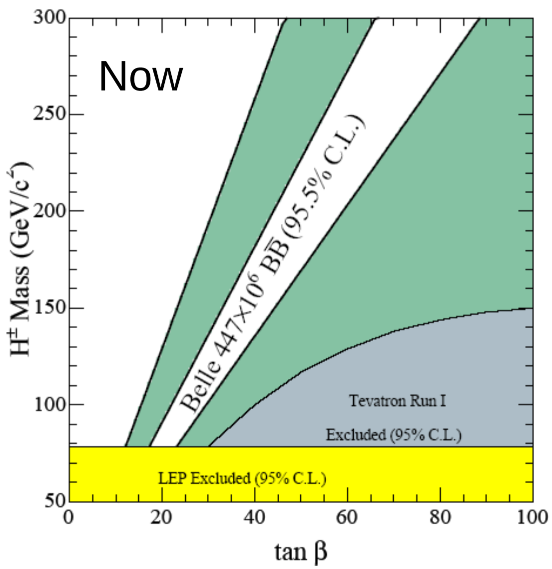


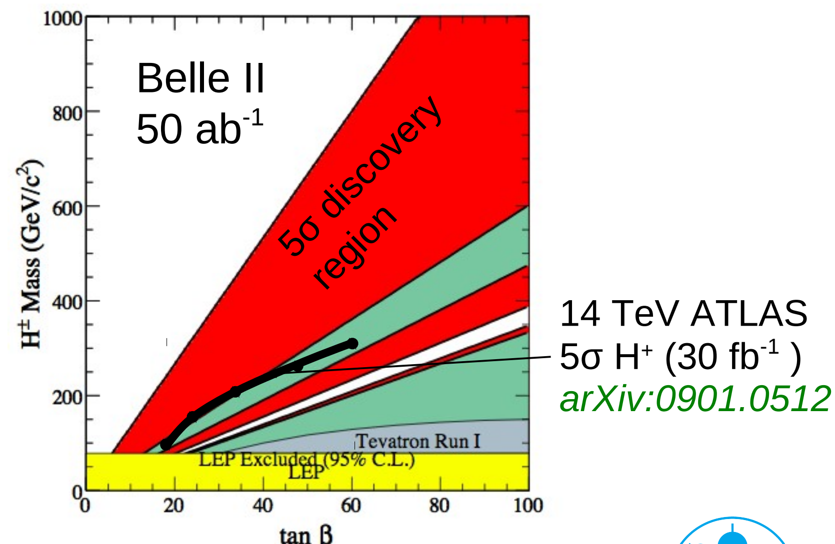
Type II Higgs doublet models



J. Phys. G29 2311, 2003

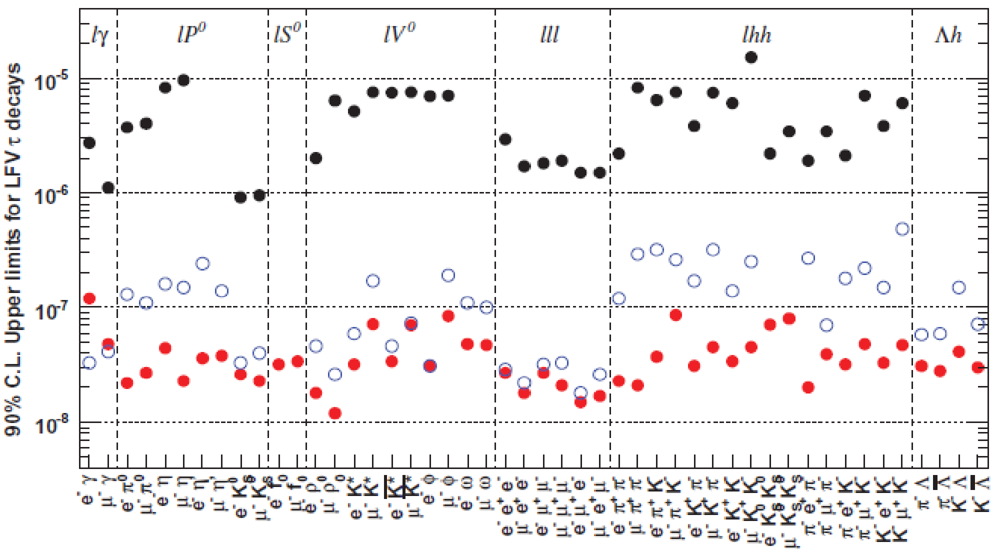
$$\Gamma(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_l^2 f_B^2}{8\pi} |V_{ub}|^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 \times r_H \qquad r_H = [1 - \tan^2\beta (m_B^2 / m_{H^\pm}^2)]^2$$





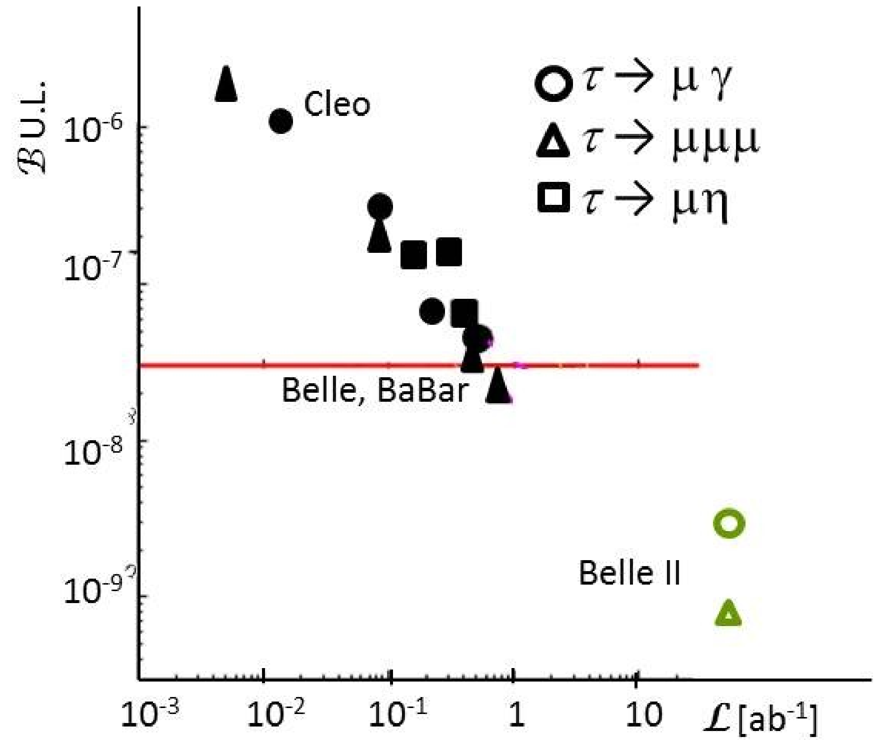
Search for New Physics: LFV in Tau Decays

- Strongly suppressed in SM
  Br ~ 10^{-53}-10^{-49}
- In New Physics models LFV up to $O(10^{-9}$-$10^{-7})$
- Current limits from B factories



Belle, BaBar, Cleo

- With 50ab^{-1} sensitivity will reach $O(10^{-9})$



Broad Physics Program at Belle II

Observable		SM prediction	Theory error	Present result	Future error	Future Facility
$\lvert V_{us}\rvert$	$[K \to \pi \ell \nu]$	input	$0.5\% \to 0.1\%_{\rm Latt}$	0.2246 ± 0.0012	0.1%	K factory
$\lvert V_{cb}\rvert$	$[B \to X_c \ell \nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\lvert V_{ub}\rvert$	$[B \to \pi \ell \nu]$	input	$10\% \to 5\%_{\rm Latt}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ	$[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \to \psi K}$		$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi \phi}$		0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$		$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi \phi}$		0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^* \gamma}$		few $\times$ 0.01	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi \gamma}$		few $\times$ 0.01	0.01	—	0.05	LHCb
$A^d_{\rm SL}$		-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
$A^s_{\rm SL}$		2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$		< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau\nu)$		1×10^{-4}	$20\% \to 5\%_{\rm Latt}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu\nu)$		4×10^{-7}	$20\% \to 5\%_{\rm Latt}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+\mu^-)$		3×10^{-9}	$20\% \to 5\%_{\rm Latt}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+\mu^-)$		1×10^{-10}	$20\% \to 5\%_{\rm Latt}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\rm FB}(B \to K^*\mu^+\mu^-)_{q_0^2}$		0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K\nu\bar{\nu}$		4×10^{-6}	$20\% \to 10\%_{\rm Latt}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\lvert q/p\rvert_{D-{\rm mixing}}$		1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D		0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$		8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$		2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \to \pi\ell\nu)$		2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \to cZ, \gamma)$		$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb^{-1})
$B(B \to Xs\gamma)$					6%	Super-B
$B(B \to Xd\gamma)$					20%	Super-B
$S(B \to \rho\gamma)$					0.15	Super-B
$B(\tau \to \mu\gamma)$					$3 \cdot 10^{-9}$	Super-B (90% U.L.)
$B(B+ \to D\tau\nu)$					3%	Super-B
$B(Bs \to \gamma\gamma)$					$0.25 \cdot 10^{-6}$	Super-B (5 ab-1)
$\sin 2\theta W$ @ $\Upsilon(4S)$					$3 \cdot 10^{-4}$	Super-B

- Physics at Super B factory: *arXiv:1002.5012* *arXiv:1008.1541*
- Belle II and LHCb will provide complementary information

Adopted from *G. Isidori et al., Ann.Rev.Nucl.Part.Sci. 60, 355 (2010)*

Super B factory

LHCb

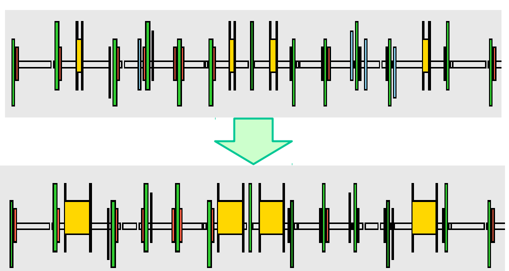
K experiments

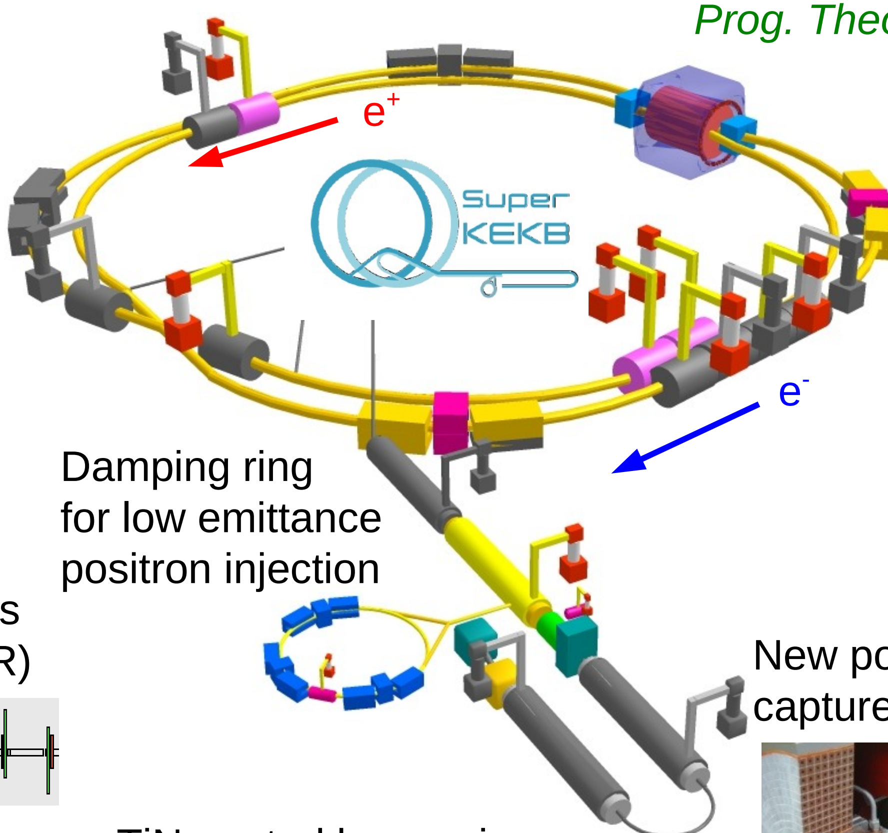
SuperKEKB: Accelerator Design

Prog. Theor. Exp. Phys. 2013, 03A011

Low emittance lattice

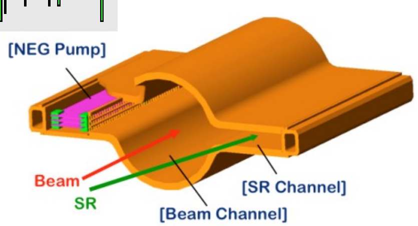
Replace short dipoles with longer ones (LER)

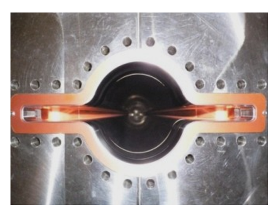




Damping ring for low emittance positron injection

TiN-coated beam pipe with antechambers

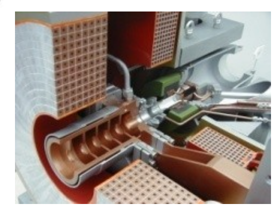




New superconducting/ permanent final focusing quadrupole near the IP

Add RF systems for higher beam current

New positron capture section



Strategy for SuperKEKB

Lorentz factor

Beam current

Beam-beam parameter

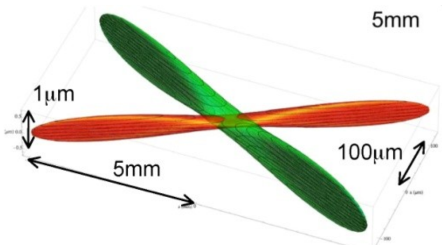
$$L = \frac{\gamma_{e^\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e^\pm}\xi_y^{e^\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Geometrical reduction factors (crossing angle, hourglass effect)

Classical electron radius

Beam size ratio at IP 1-2% (flat beam)

Vertical beta function at IP



Nano-beam scheme:

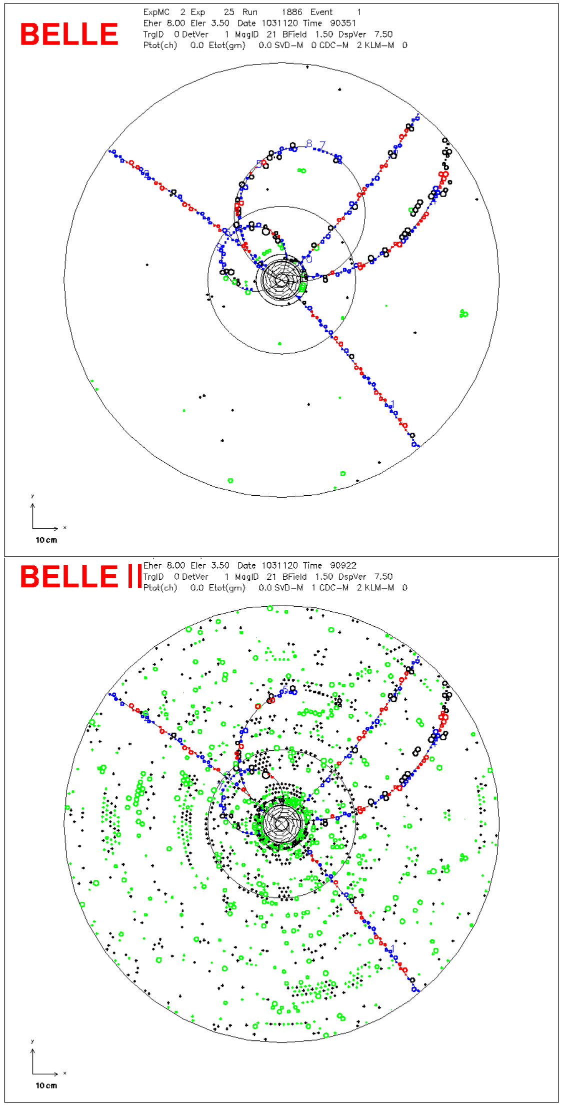
P. Raimondi for SuperB

http://www.lnf.infn.it/conference/superb06/talks/raimondi1.ppt

	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}

Experimental Challenges at High Luminosity

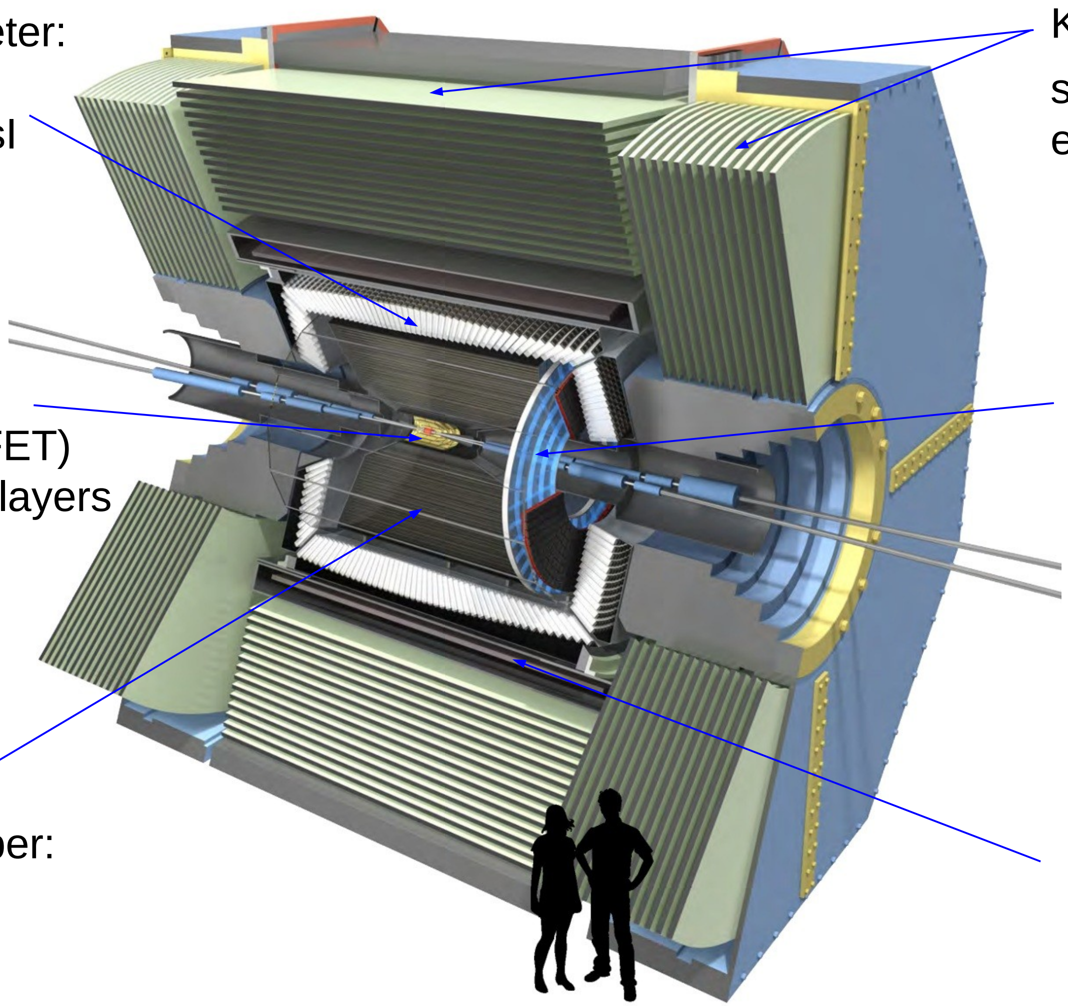
- High background (10-20 times higher than at Belle)
  - Fake hits, pile up, radiation damage
- Higher trigger rate
  - Typical Level1 trigger rate: 20kHz
  - High performance DAQ
- Important improvements
  - Hermeticity for full reconstruction analyses
  - IP and secondary vertex resolution
  - K_S and π^0 identification efficiency
  - Improve Kaon/pion separation
- Details in TDR *arXiv:1011.0352*



Belle II Detector

CsI(Tl) EM calorimeter:
waveform sampling
electronics, pure CsI
for endcups

K_L and muon counter:
scintillator + Si-PM for
end-caps



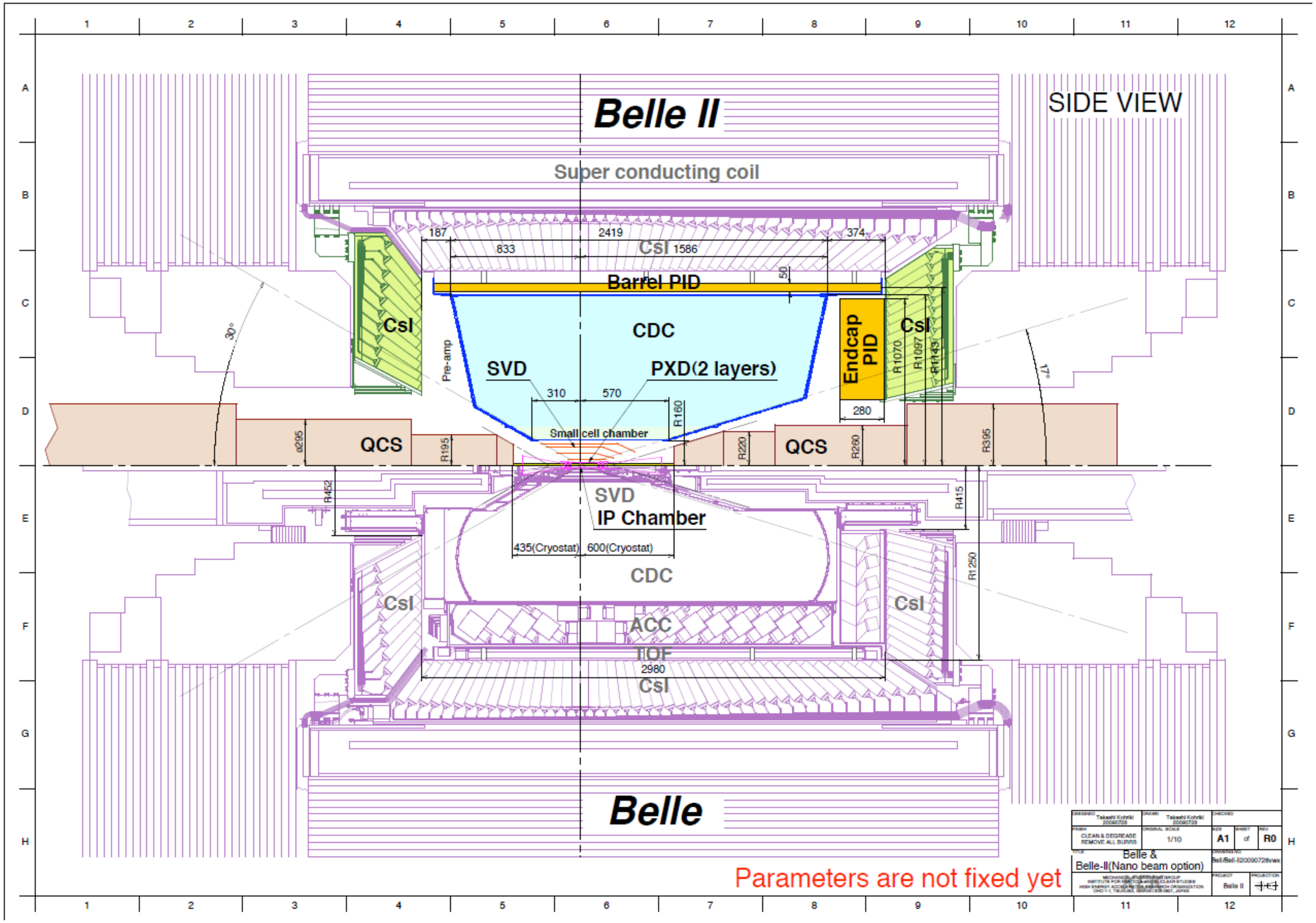
Vertex detector:
2 pixel layers (DEPFET)
4 double-sided strip layers

Aerogel RICH
(forward)

Central drift chamber:
longer lever arm
smaller cell size

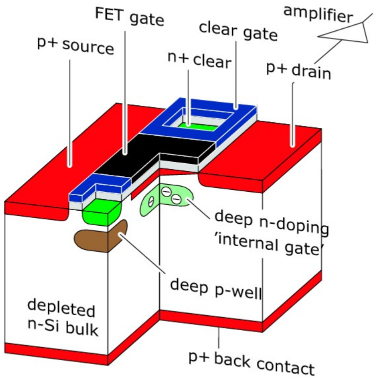
Time-of-propagation
(barrel)

Belle II in Comparison with Belle

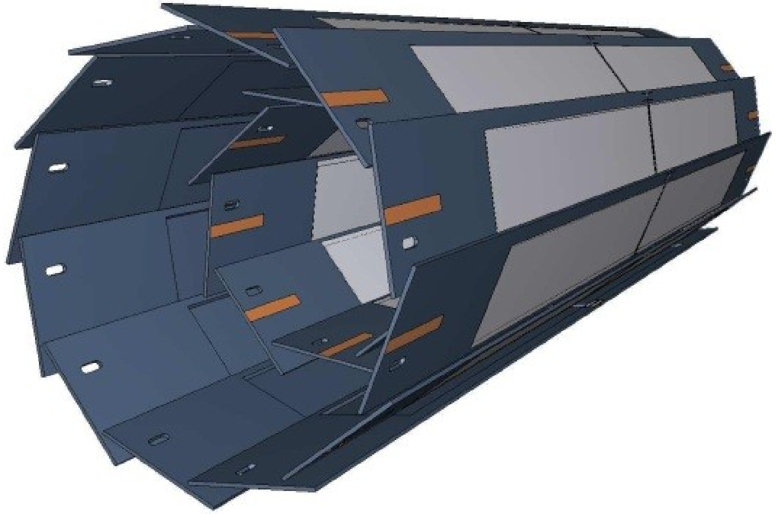


Pixel Vertex Detector (PXD)

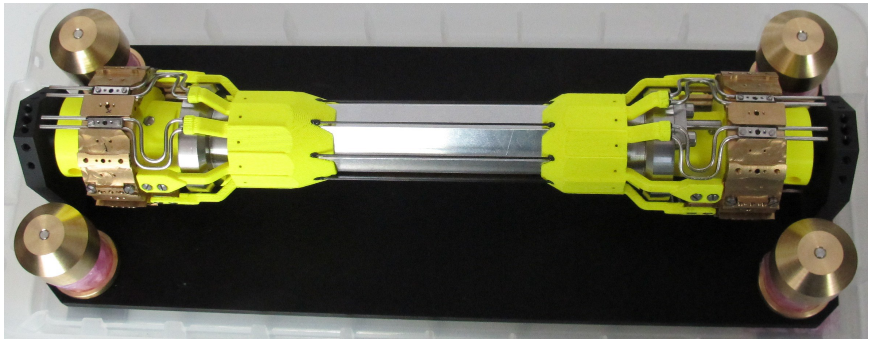
- > DEPFET technology: thin (75µm) sensors
- > Work in high occupancy close to the interaction region
- > Fast readout



PXD design



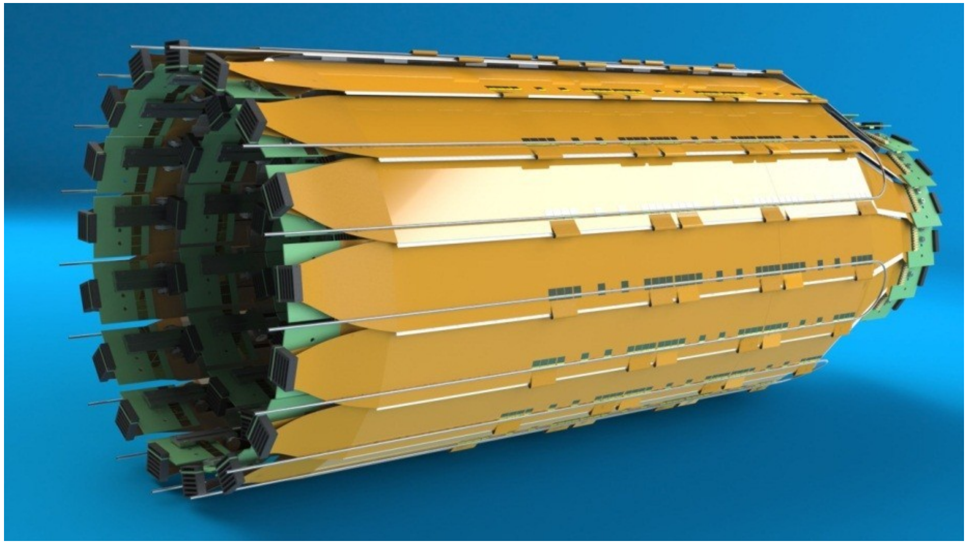
PXD mockup



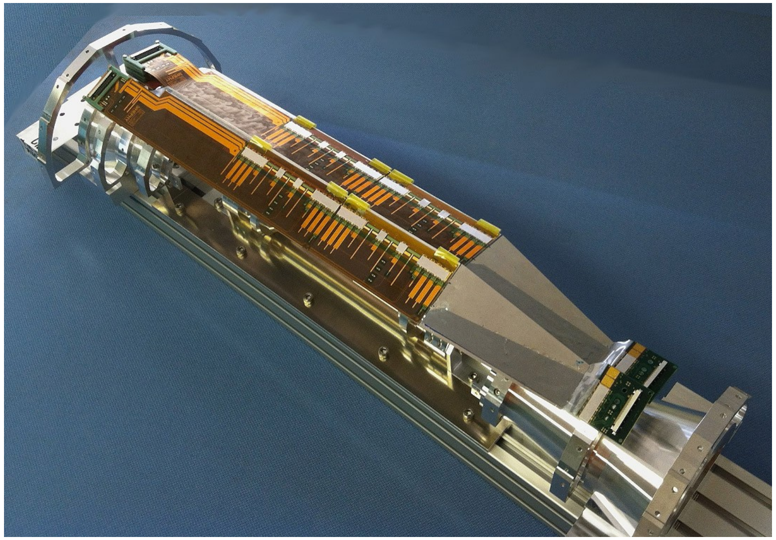
Silicon Vertex Detector (SVD)

- Double-sided silicon strip detectors
- Pipelined readout to reduce dead time, pile-up rejection
- Larger acceptance (by 30%) for detection of pions from K_S decay → significant improvement in $\delta S(K_S \pi^0 \gamma)$

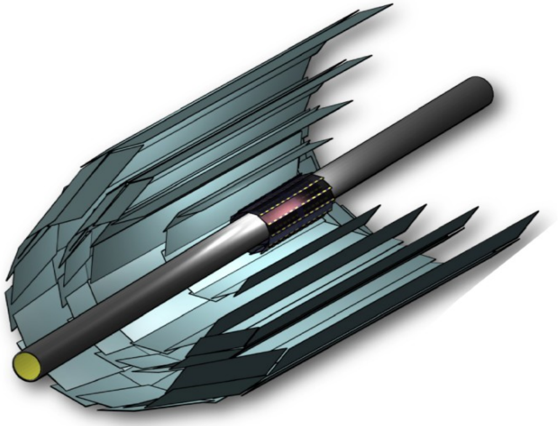
SVD design

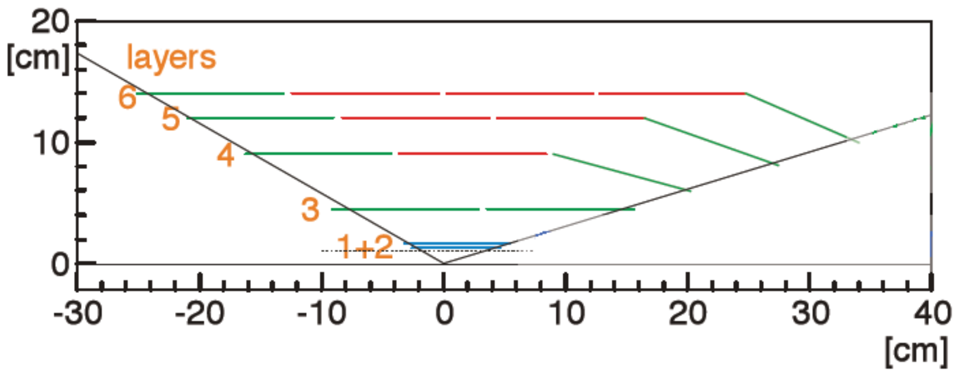


SVD mockup



Vertex Detector: PXD+SVD

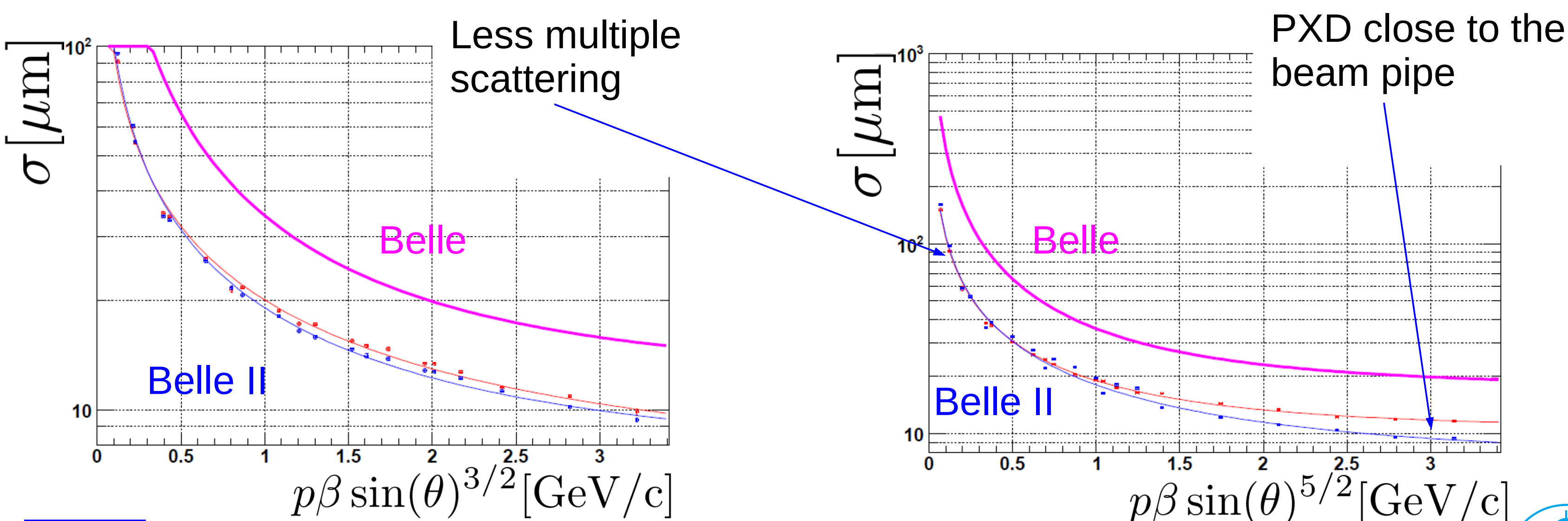




> Significant improvement in IP resolution

Closest approach resolution

Z resolution

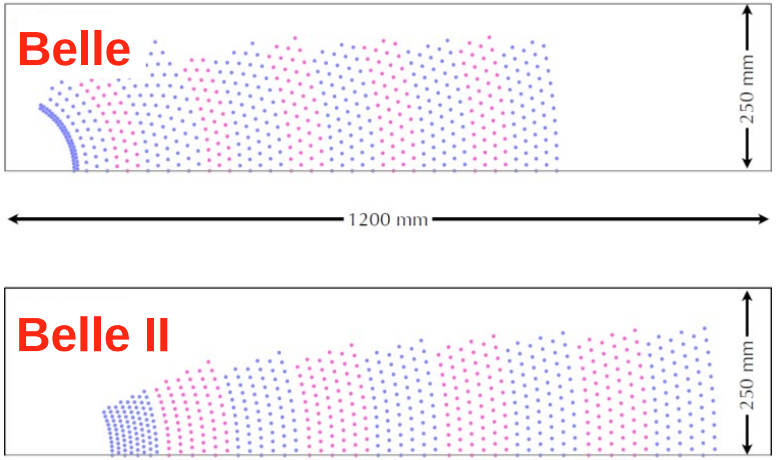


Central Drift Chamber (CDC)

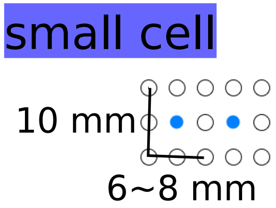
- Smaller cells near beam pipe
- Extended outer radius for better momentum resolution
- Faster readout electronics to reduce dead time

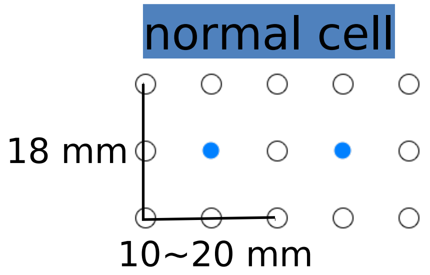
$\sigma_p/p \sim 0.3\% + 0.1\% \times p(\mathrm{GeV})$ in $B = 1.5\mathrm{T}$

$\sigma(\mathrm{d}E/\mathrm{d}x) \sim 6\%$



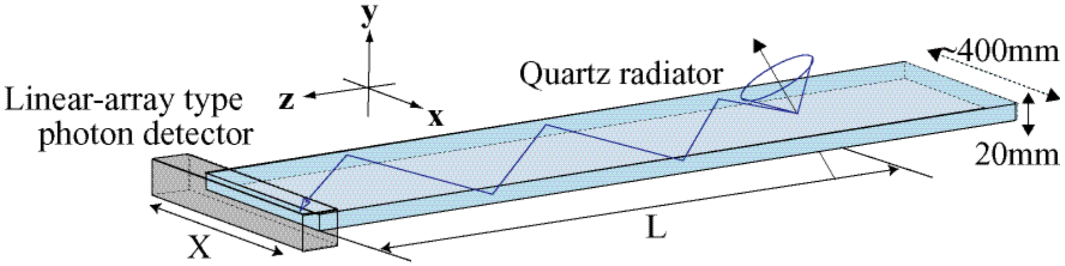
	Belle	Belle II
Innermost sense wire	R=88mm	R=168mm
Outermost sense wire	R=863mm	R=1111.4mm
Number of layers	50	56
Total number of sense wires	8400	14336
Gas	He : C_2H_6	He : C_2H_6
Sense wires	W(Ø30µm)	W(Ø30µm)
Field wires	Al(Ø120µm)	Al(Ø120µm)

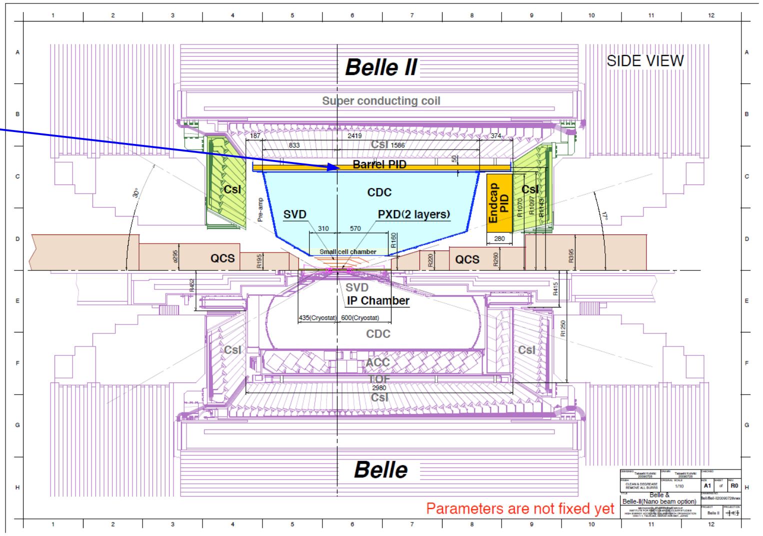


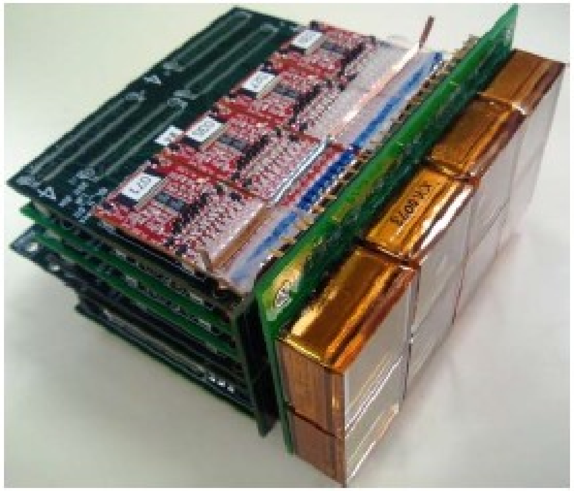


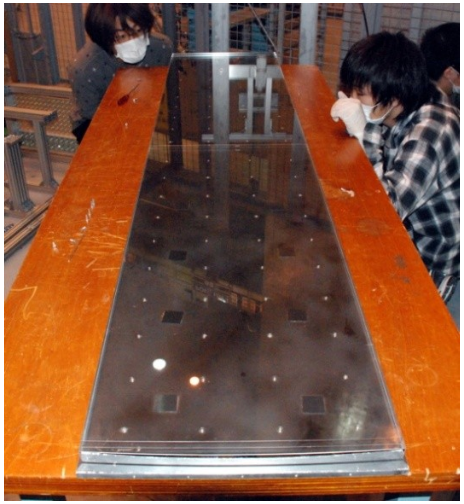
Barrel PID: Time of Propagation Detector (TOP)

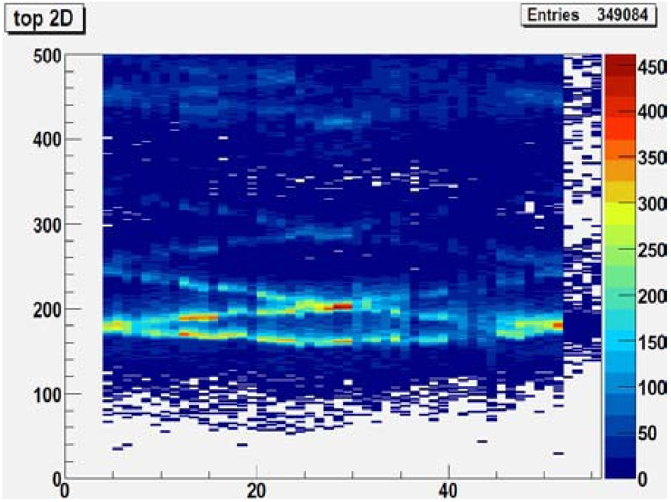
- Compact design
- Improved K/π separation





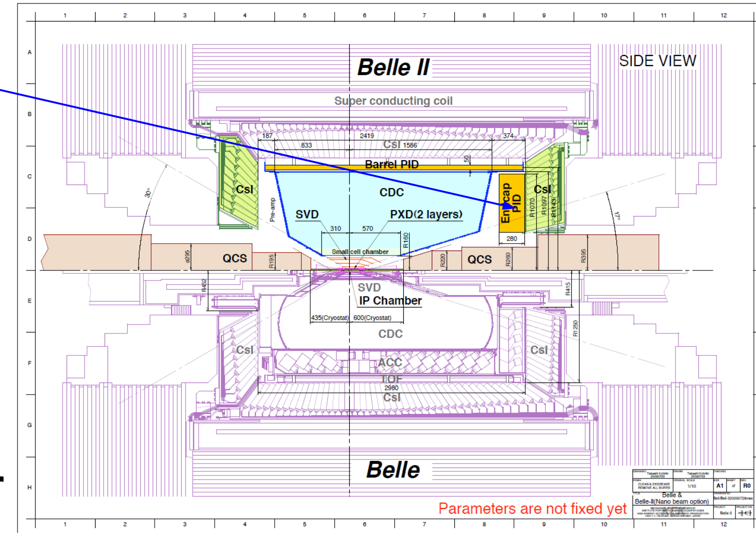


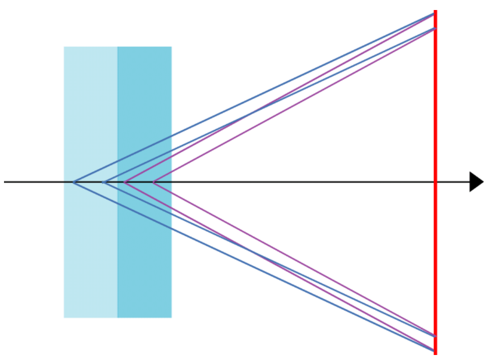




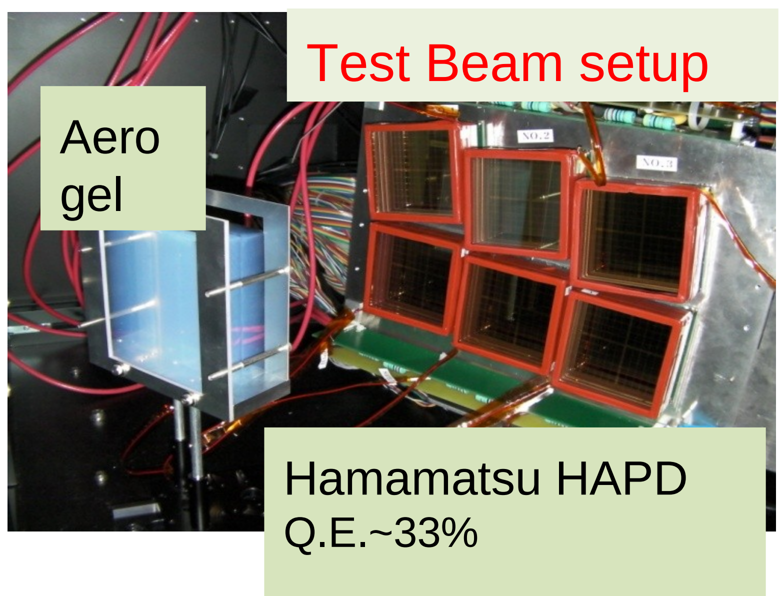
Endcap PID: Aerogel RICH

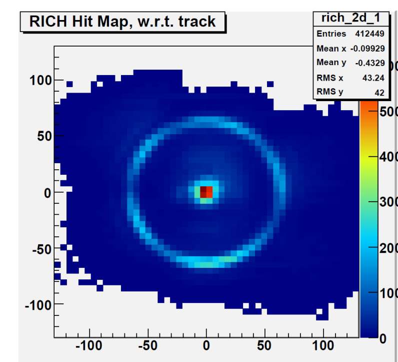
- Novel proximity-focusing two-layer radiator
- Employ multiple layers with different refractive indices
- Cherenkov images from individual layers overlap on the photon detector





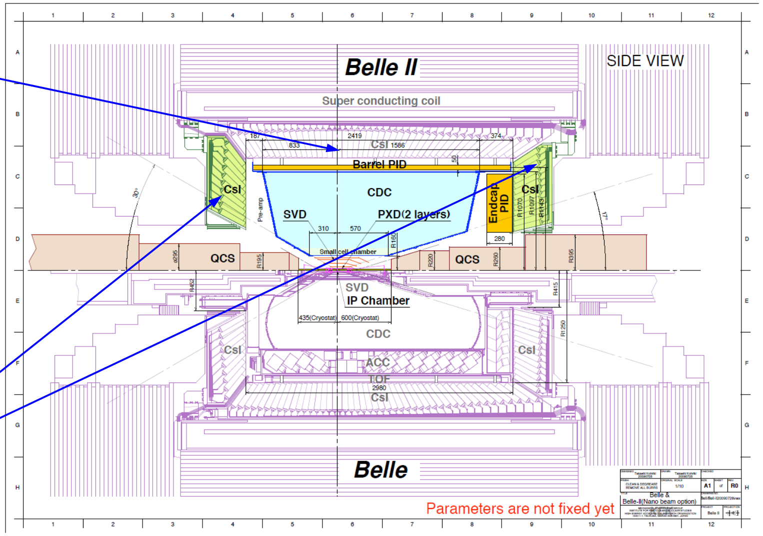
NIM A548 (2005) 383



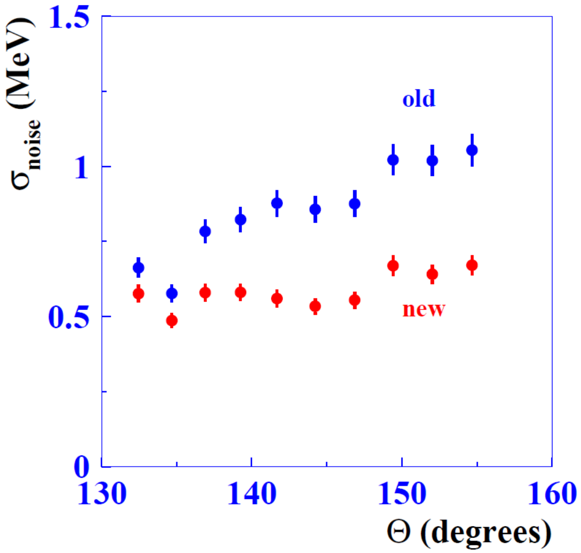


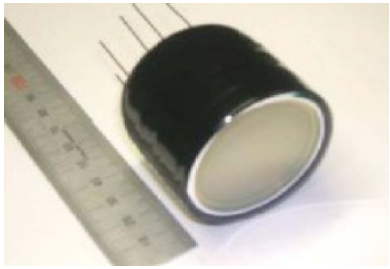
Electromagnetic Calorimeter

- Barrel: reuse existing CsI(Tl)
- Readout electronics:
  - Upgrade to 2 MHz waveform sampling
  - Online signal processing
- Endcaps: considering upgrade to pure CsI
- Better performance & radiation hardness
- Improved energy resolution



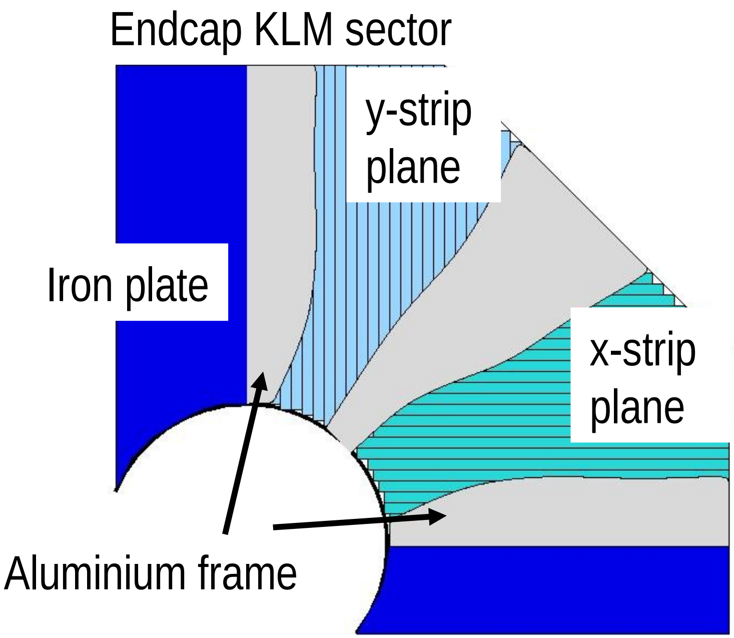
Better signal-to-background separation

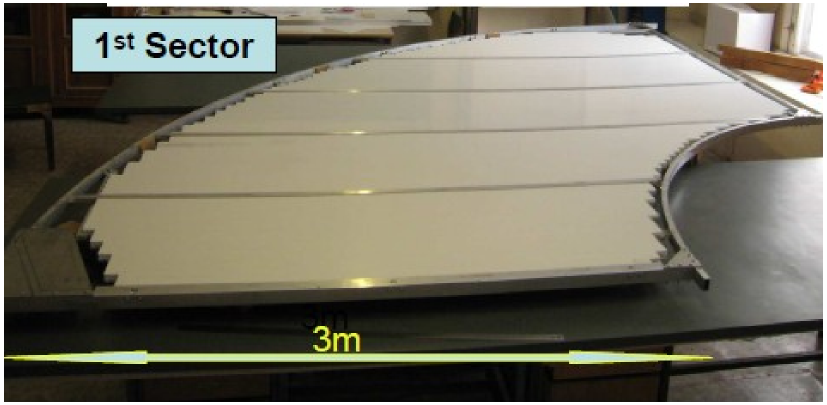


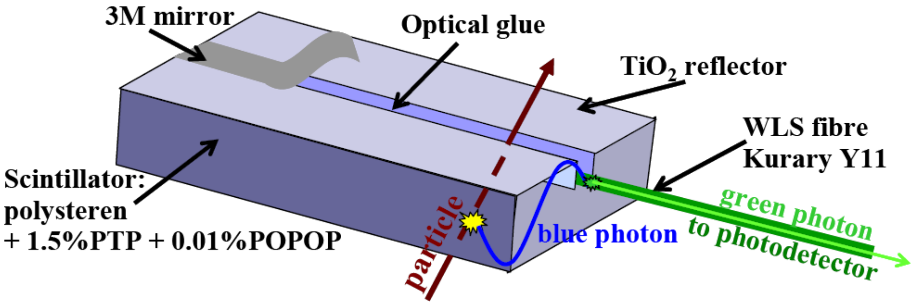


K_L and μ Detection (KLM)

- End-caps upgrade: Resistive Plate Chambers → scintillator-based KLM
- Scintillators + SiPM → better beam-background tolerance
- Barrel KLM: some RPC layers may be replaced as background increases with luminosity

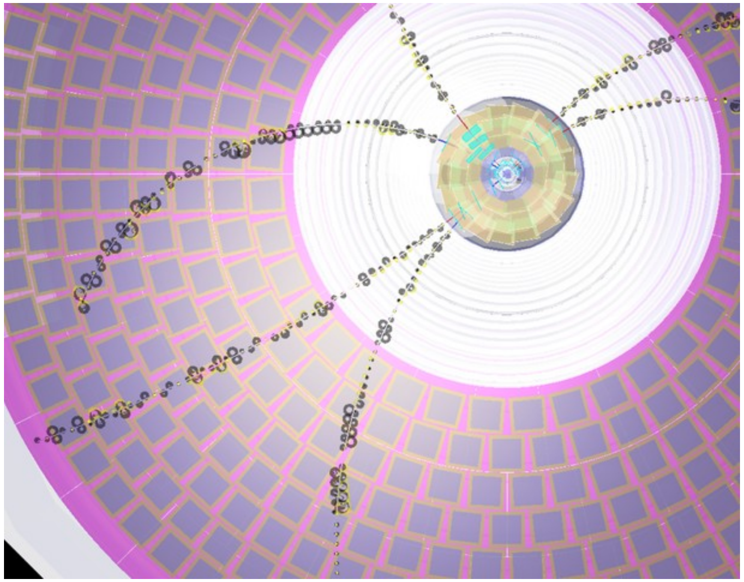


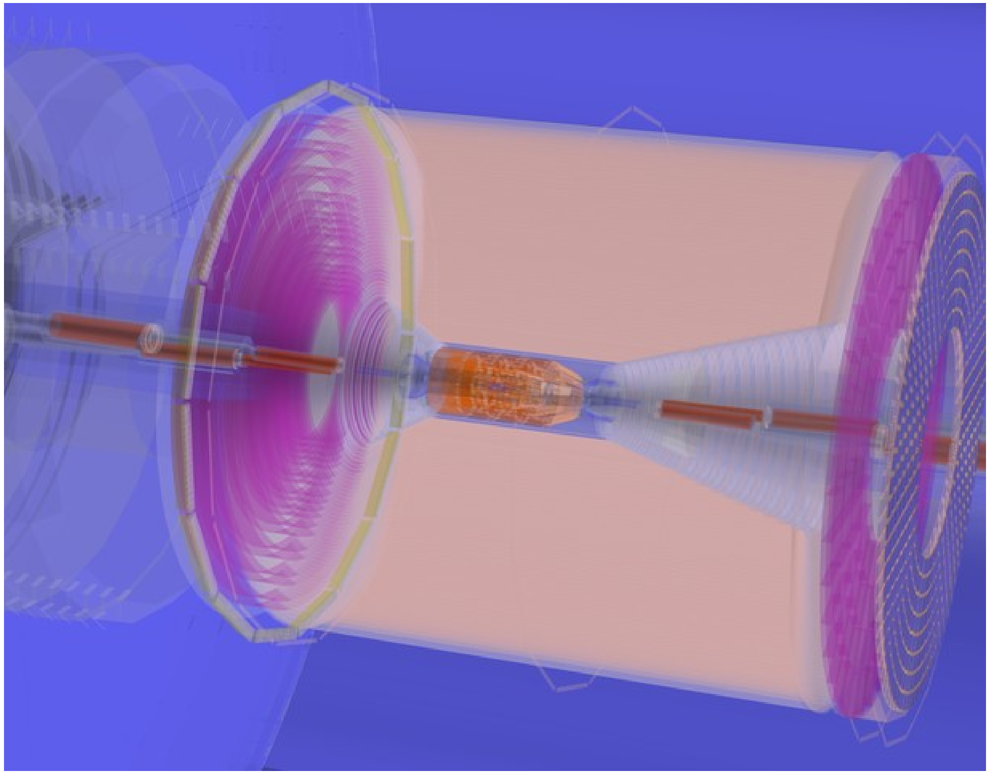




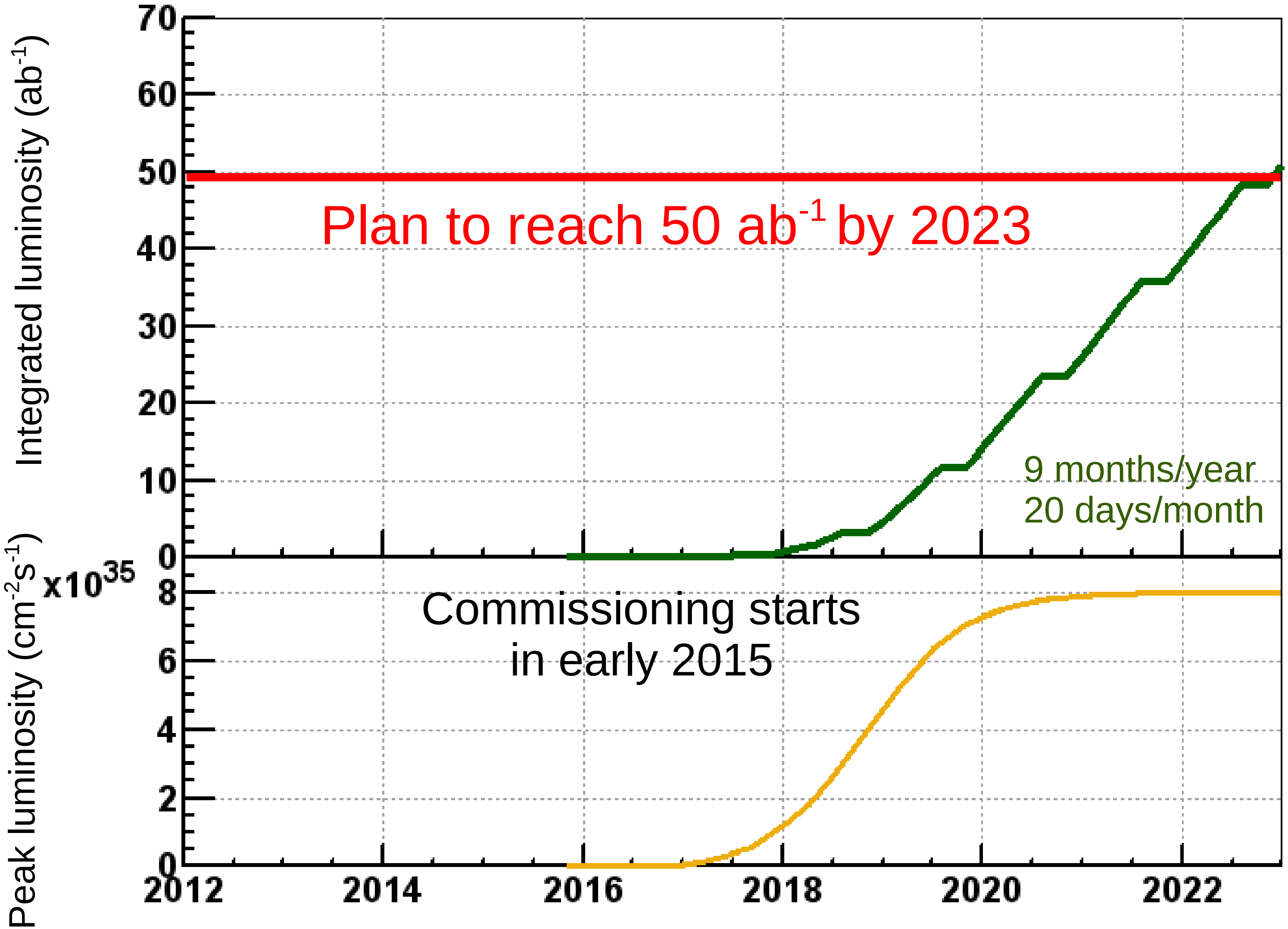
Software Upgrade

- New framework with dynamic module loading, parallel processing, python steering, root I/O, and use of GRID
- Full detector simulation with Geant4
- Tracking with GenFit
- Alignment with Millepede II

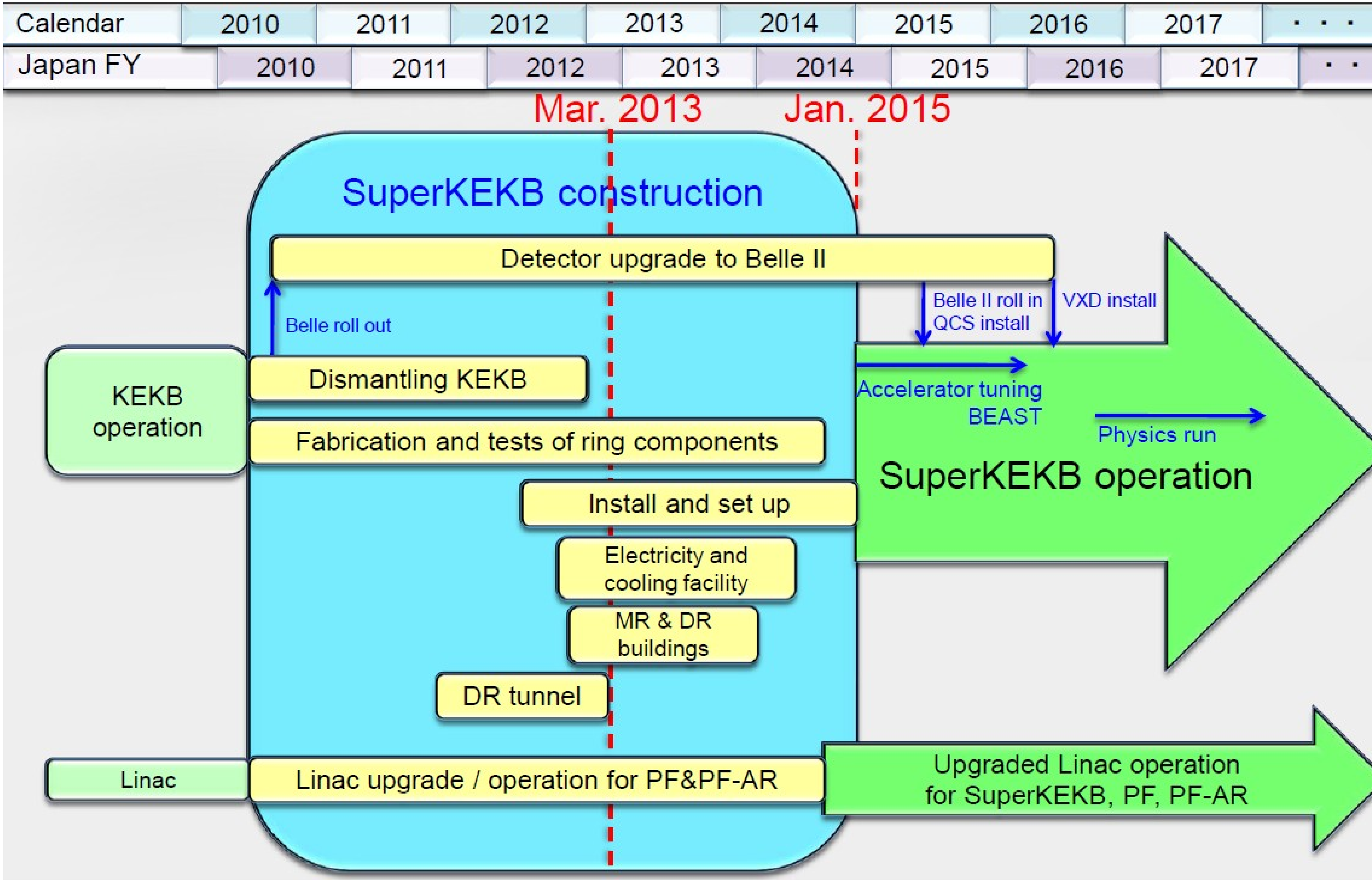




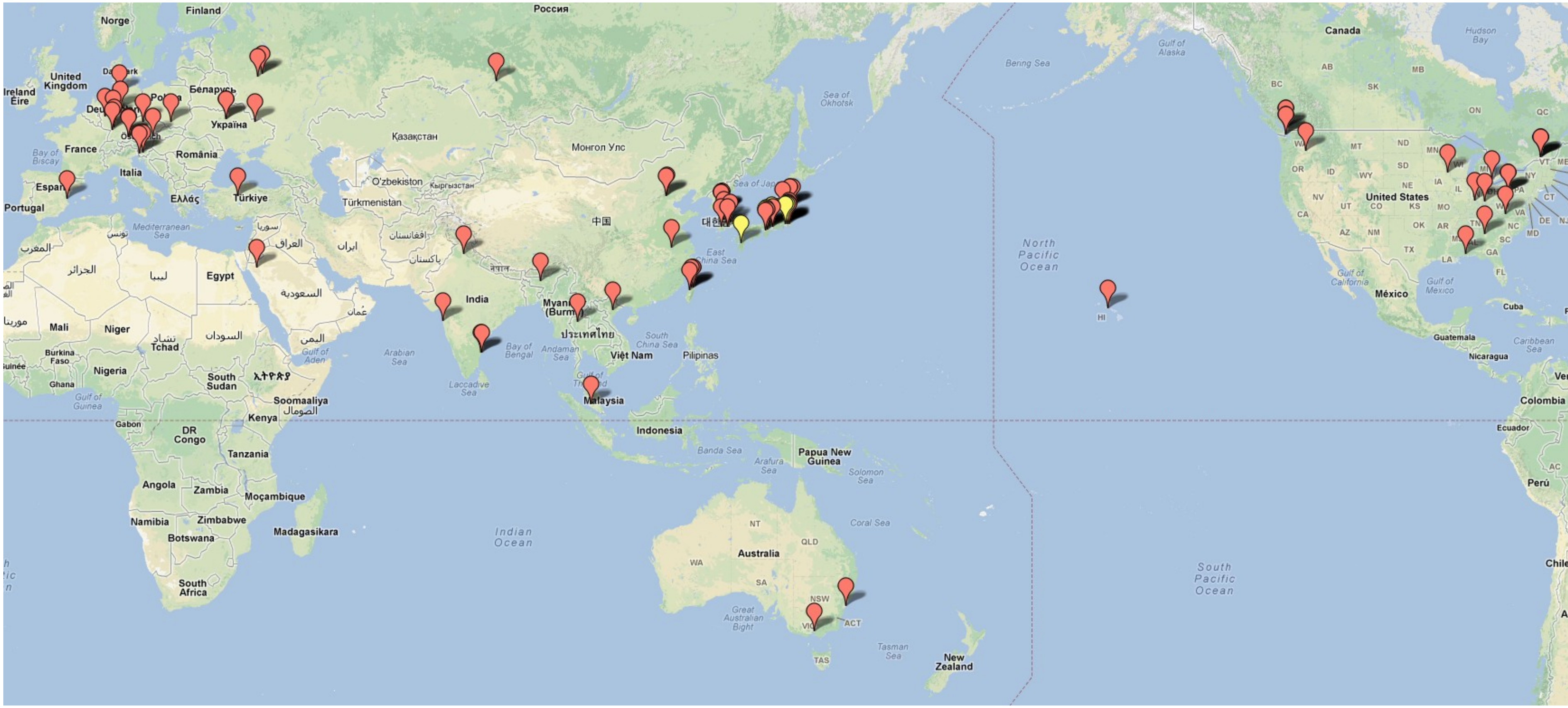
Timelines and Goal of SuperKEKB / Belle II



SuperKEKB / Belle II Schedule



Belle II Collaboration



> 21 countries/regions, 76 institutions, ~480 collaborators

Summary

> Very successful e^+e^- B Factories: Belle and BaBar

> Major upgrade: SuperKEKB and Belle II

> 50 times larger integrated luminosity compared to Belle
  - Challenges to both accelerator and detector

> Fully approved and construction is ongoing

> First physics run in 2016

> New era of discoveries, complementary to LHC

Groundbreaking Ceremony, November 18th, 2011