The SuperKEKB project and Belle II

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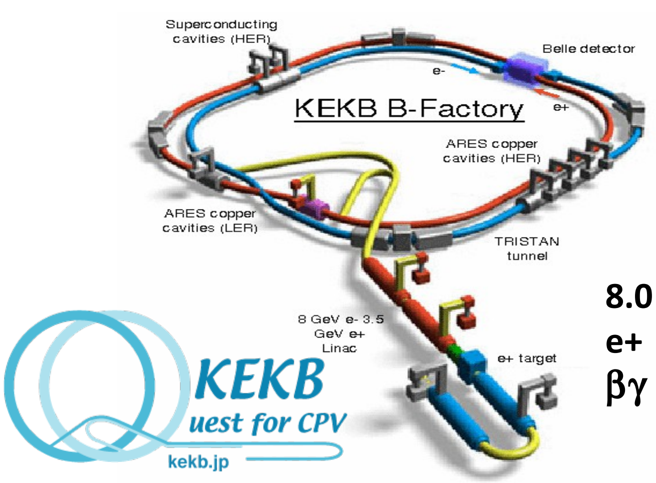
H.Kakuno
Tokyo Metropolitan University

LES RENCONTRES DE PHYSIQUE DE LA VALLEE D'AOSTE
La Thuile 24 February – 2 March, 2013

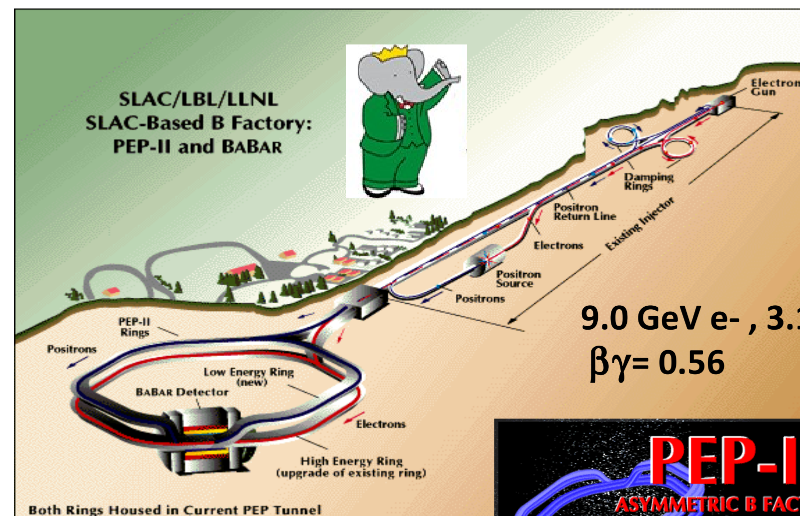
B-factories: Belle & BaBar

-Asymmetric energy $e^+ e^-$ collider experiment in past 10-15 years.



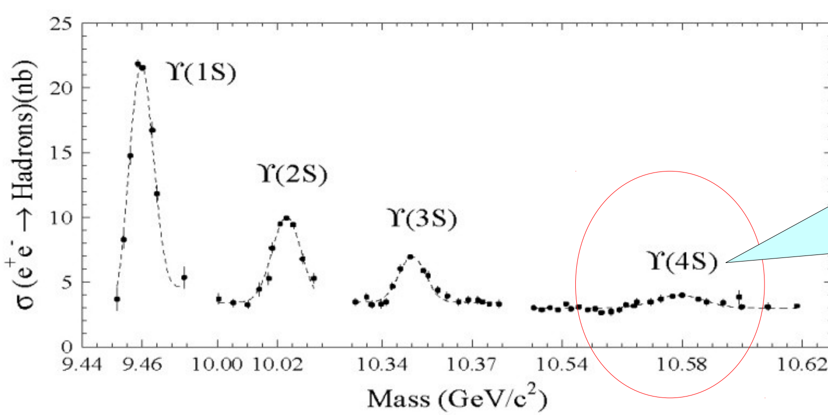
BELLE

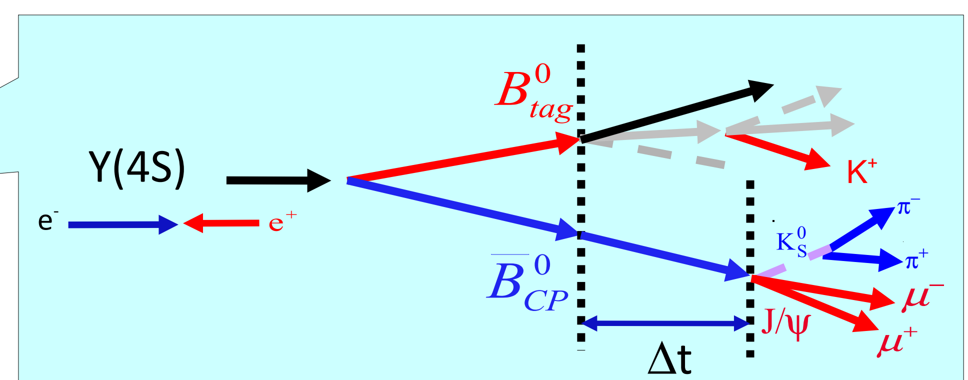
8.0 GeV e- , 3.5 GeV e+
$\beta\gamma$ = 0.42



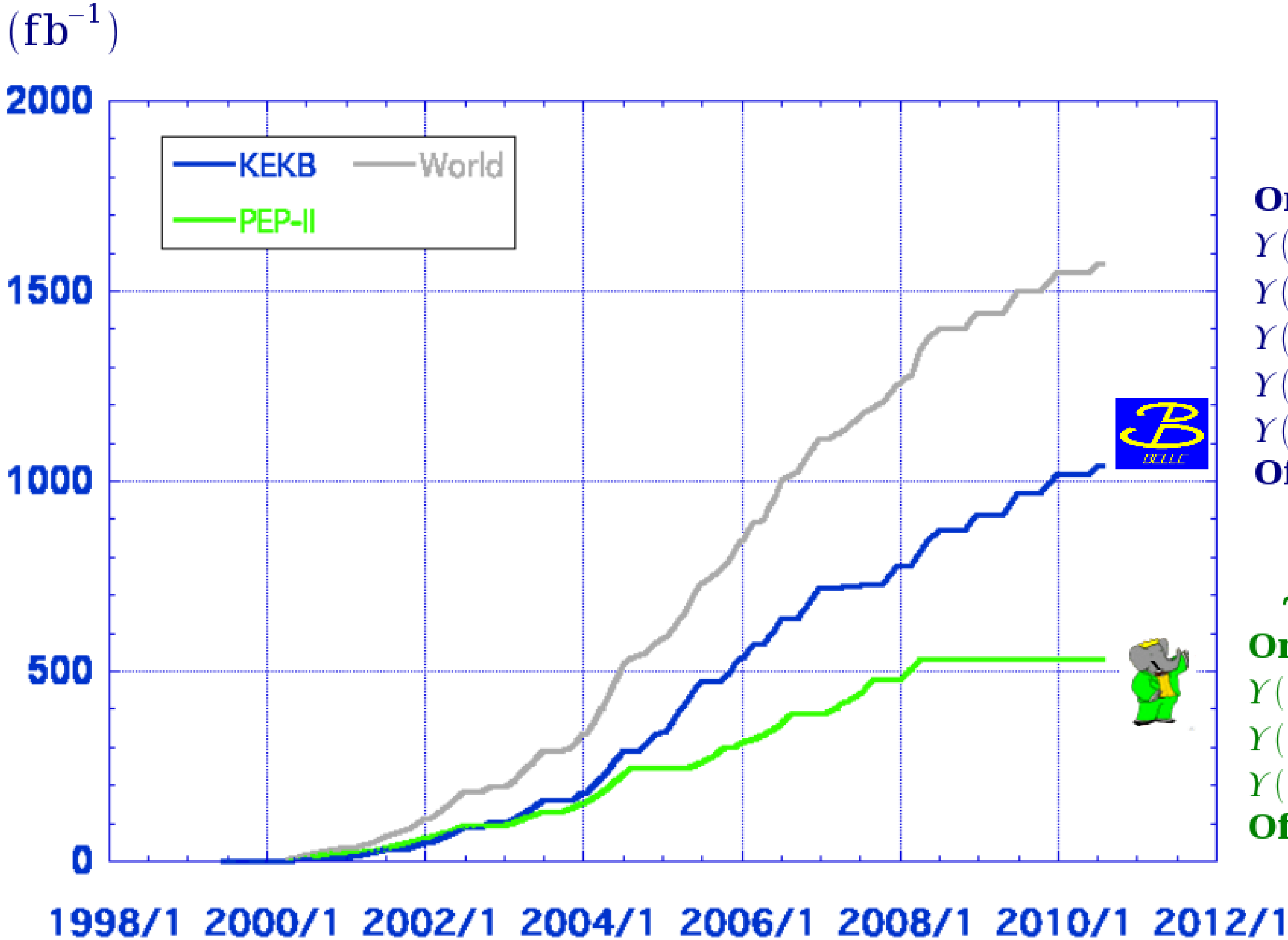
9.0 GeV e- , 3.1 GeV e+
$\beta\gamma$= 0.56

PEP-II
ASYMMETRIC B FACTORY
SLAC/LBL/LLNL





Luminosity at B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

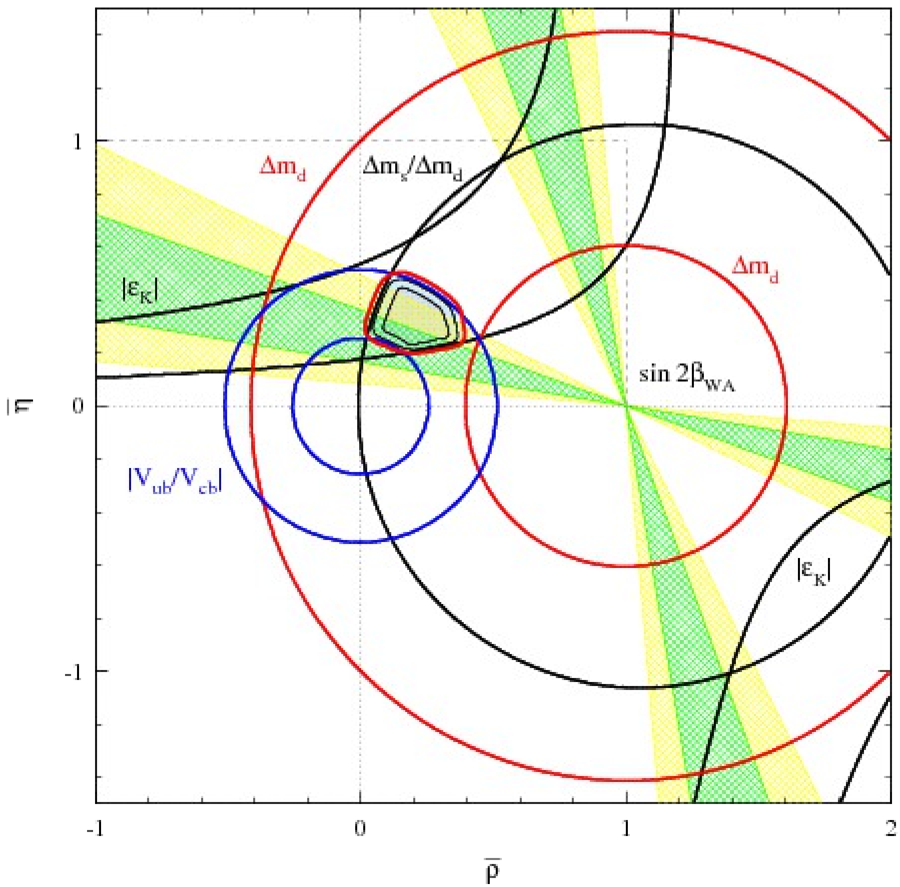
$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

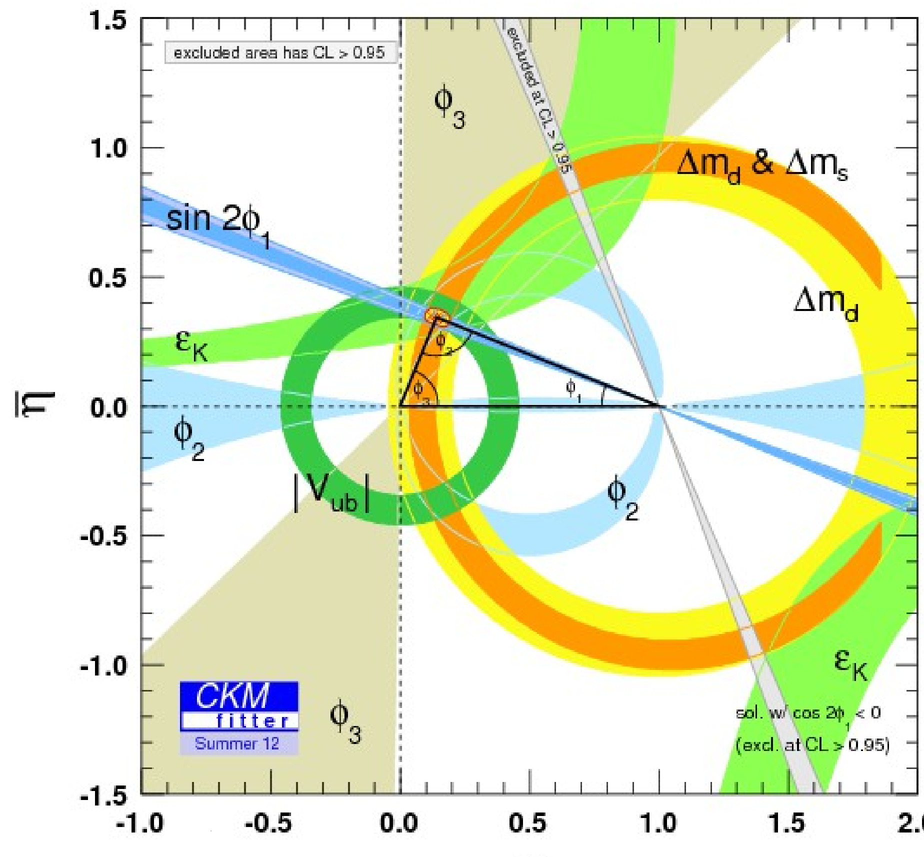
$\sim$54 fb^{-1}

Improvement on the UT triangle

2001 May
(few 10 fb^{-1} @ Belle&BaBar)



2012 Now
(~1000 fb^{-1} @ Belle&BaBar)



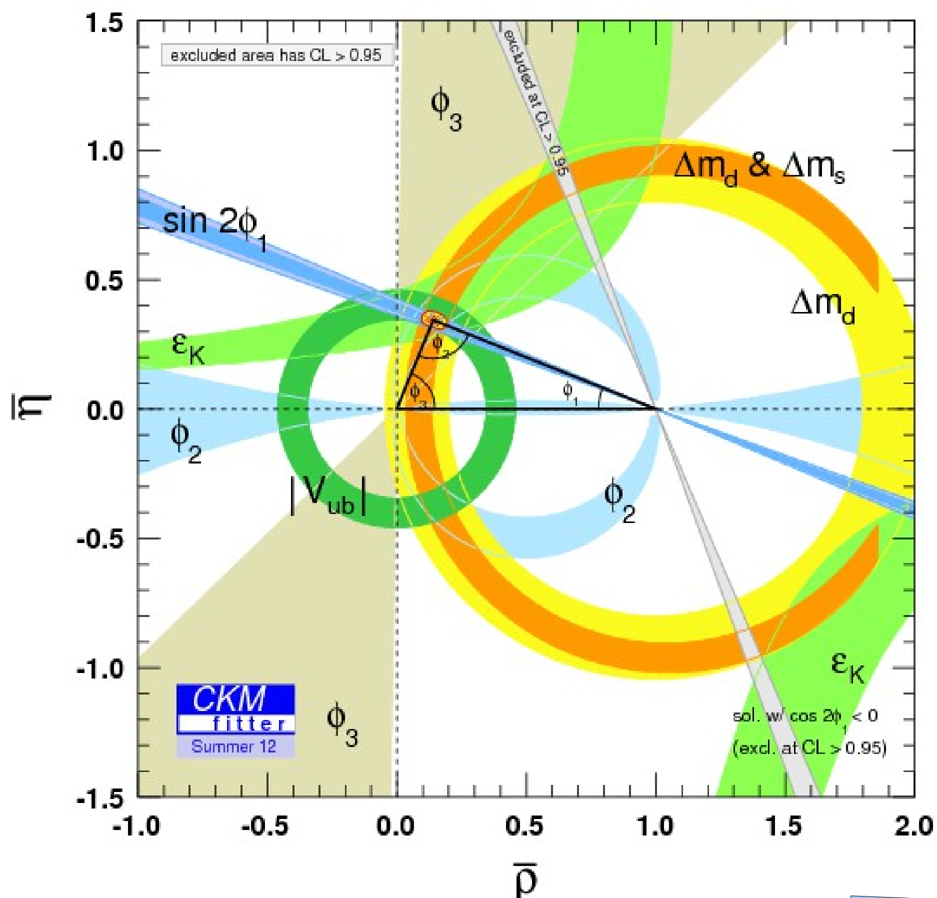
~40 times more statistics from B-factories

Discovery of CPV in B-meson system
- Precise measurements of ϕ_1, ϕ_2
- First measurement of ϕ_3
- Improvement of $|V_{cb}|$, $|V_{ub}|$
- Many rare B decays

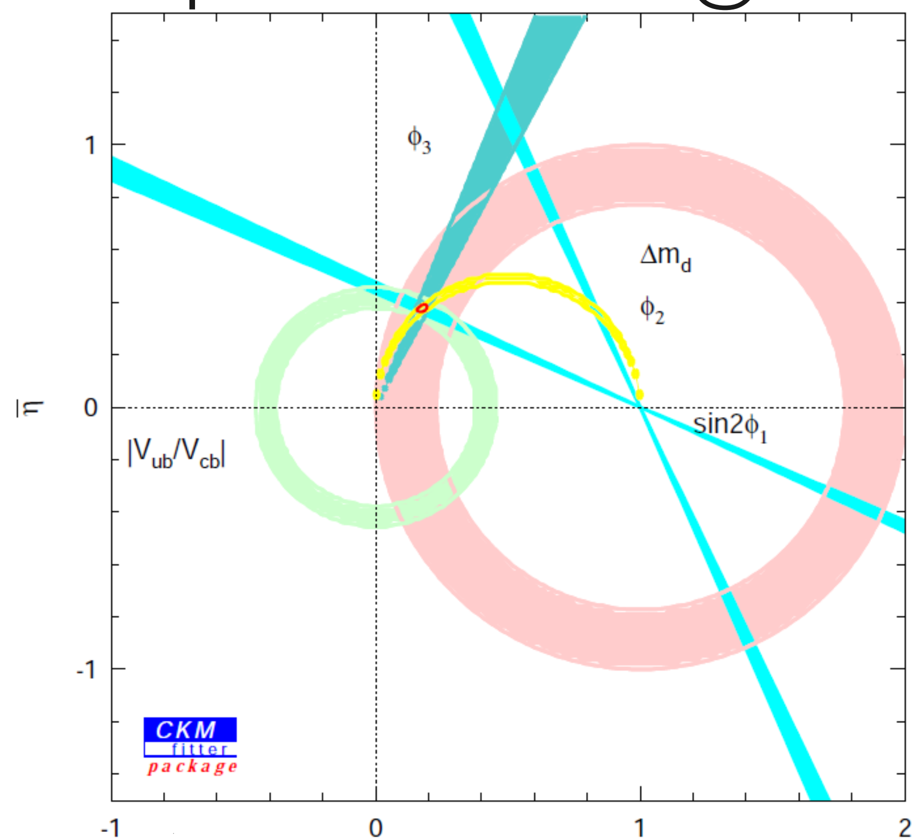
Further improvement on the UT triangle

2012 Now

(~1000 fb^{-1} @ Belle&BaBar)



Expected constraint @50 ab^{-1}



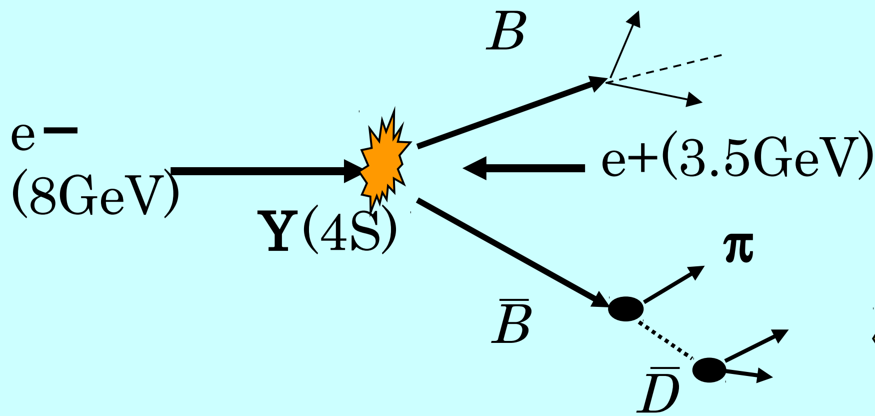
~40 times more statistics

- -Much more improved measurements
- -Overconstrain UT triangle
- - Discrepancy among measurements indicates new physics

Example of accessible modes @Super B factory

Full reconstruction of associated B

← powerful tool, only valid for e^+e^-

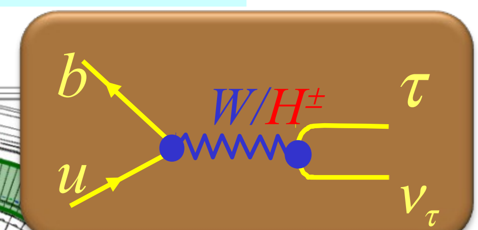


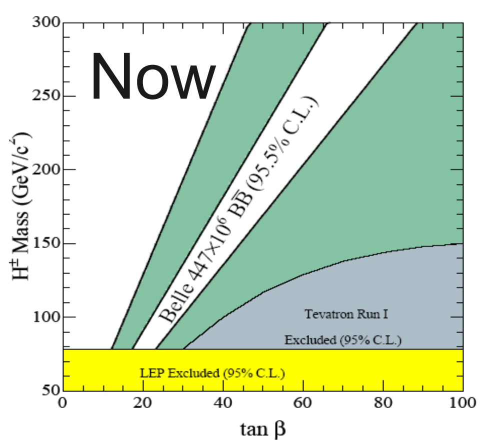
Decays of interest
- $B \to X_u l \nu$,
- $B \to K \nu\nu$
- $B \to D\tau\nu$, $\tau\nu$
- $B \to \nu\nu$

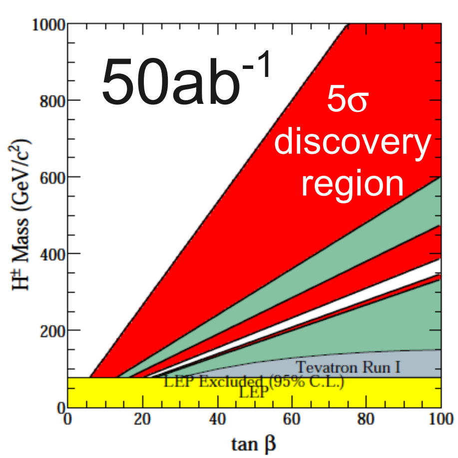
full reconstruction
$B \to D\pi$ etc.
(Efficiency: 0.1~0.3%)

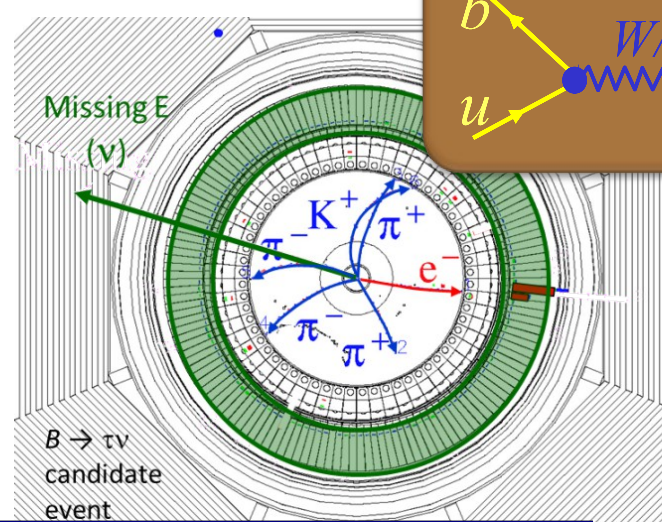
B decays having multiple νs are accessible

Example: $B \to \tau\nu$







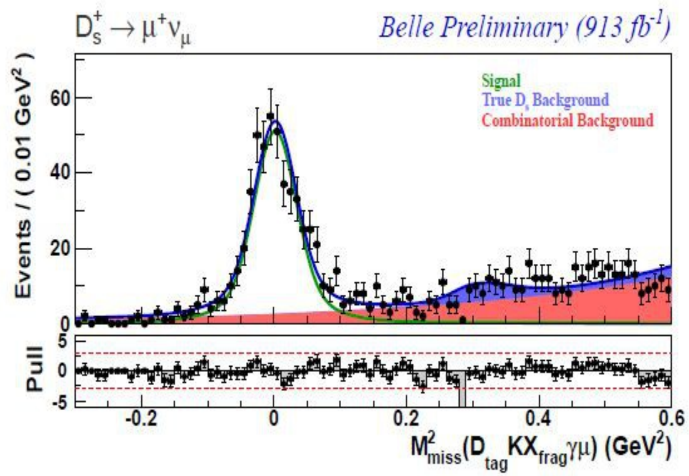


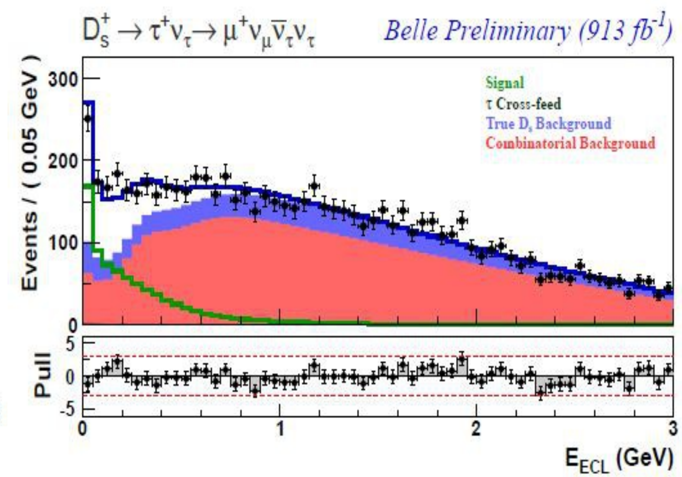
Physics at Super B factory: arXiv:1002.5012v1

Super B factory is also a Super τ/charm factory

Charm Physics

- Semileptonic & leptonic D-decays
- D^0-$\overline{D^0}$ mixing & CP violation
- Spectroscopy: Chamonium-like states



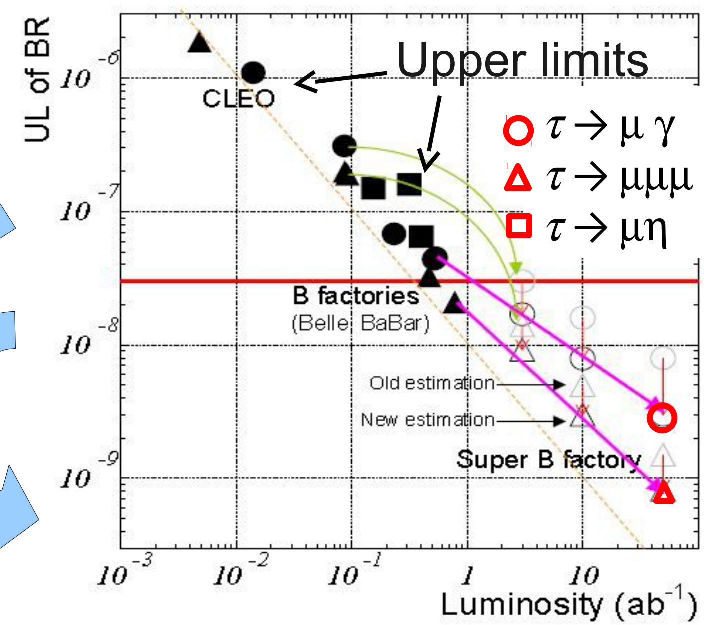


Search for LFV τ decays

CLEO
→Belle&BaBar:
50~70 times more statistics

Belle
→SuperKEKB/Belle II:
~50times more statistics

Accessible to NP models beyond the SM



Physics at Super B factory: arXiv:1002.5012v1

More physics @ Super B factory

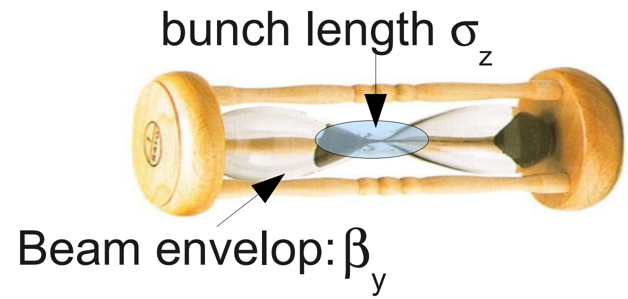
Observable	Belle 2006	SuperKEKB		†LHCb	
	(~0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
Hadronic $b \to s$ transitions					
$\Delta\mathcal{S}_{\phi K^0}$	0.22	0.073	0.029		0.14
$\Delta\mathcal{S}_{\eta' K^0}$	0.11	0.038	0.020		
$\Delta\mathcal{S}_{K_S^0 K_S^0 K_S^0}$	0.33	0.105	0.037	-	-
$\Delta\mathcal{A}_{\pi^0 K_S^0}$	0.15	0.072	0.042	-	-
$\mathcal{A}_{\phi\phi K^+}$	0.17	0.05	0.014		
$\phi_1^{eff}(\phi K_S)$ Dalitz		3.3°	1.5°		
Radiative/electroweak $b \to s$ transitions					
$\mathcal{S}_{K_S^0 \pi^0 \gamma}$	0.32	0.10	0.03	-	-
$\mathcal{B}(B \to X_s \gamma)$	13%	7%	6%	-	-
$A_{CP}(B \to X_s \gamma)$	0.058	0.01	0.005	-	-
C_9 from $\overline{A}_{\rm FB}(B \to K^* \ell^+ \ell^-)$	-	11%	4%		
C_{10} from $\overline{A}_{\rm FB}(B \to K^* \ell^+ \ell^-)$	-	13%	4%		
C_7/C_9 from $\overline{A}_{\rm FB}(B \to K^* \ell^+ \ell^-)$	-		5%		7%
R_K		0.07	0.02		0.043
$\mathcal{B}(B^+ \to K^+ \nu\nu)$	†† $< 3\ \mathcal{B}_{\rm SM}$		30%	-	-
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu})$	†† $< 40\ \mathcal{B}_{\rm SM}$		35%	-	-
Radiative/electroweak $b \to d$ transitions					
$\mathcal{S}_{\rho\gamma}$	-	0.3	0.15		
$\mathcal{B}(B \to X_d \gamma)$	-	24% (syst.)		-	-
Leptonic/semileptonic B decays					
$\mathcal{B}(B^+ \to \tau^+ \nu)$	3.5σ	10%	3%	-	-
$\mathcal{B}(B^+ \to \mu^+ \nu)$	†† $< 2.4\mathcal{B}_{\rm SM}$	4.3 ab^{-1} for 5σ discovery		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	8%	3%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	30%	10%	-	-
LFV in τ decays (U.L. at 90% C.L.)					
$\mathcal{B}(\tau \to \mu\gamma)$ [10^{-9}]	45	10	5	-	-
$\mathcal{B}(\tau \to \mu\eta)$ [10^{-9}]	65	5	2	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ [10^{-9}]	21	3	1	-	-
Unitarity triangle parameters					
$\sin 2\phi_1$	0.026	0.016	0.012	~0.02	~0.01
ϕ_2 ($\pi\pi$)	11°	10°	3°	-	-
ϕ_2 ($\rho\pi$)	$68° < \phi_2 < 95°$	3°	1.5°	10°	4.5°
ϕ_2 ($\rho\rho$)	$62° < \phi_2 < 107°$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1°$	10°	4.5°
ϕ_3 ($D^{(*)}K^{(*)}$) (Dalitz mod. ind.)	20°	7°	2°	8°	
ϕ_3 ($DK^{(*)}$) (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 ($D^{(*)}\pi$)	-	18°	6°		
ϕ_3 (combined)		6°	1.5°	4.2°	2.4°
$\|V_{ub}\|$ (inclusive)	6%	5%	3%	-	-
$\|V_{ub}\|$ (exclusive)	15%	12% (LQCD)	5% (LQCD)	-	-
†††$\bar{\rho}$	20.0%		3.4%		
†††$\bar{\eta}$	15.7%		1.7%		

Observable	Belle	Belle/SuperKEKB		LHCb†	
				(2 fb^{-1})	(10 fb^{-1})
B_s physics	(25 fb^{-1})	(	5 ab^{-1})		
$\mathcal{B}(B_s \to \gamma\gamma)$	$< 8.7 \times 10^{-6}$	0.25×10^{-6}		-	-
$\Delta\Gamma_s^{CP}/\Gamma_s$ ($Br(B_s \to D_s^{(*)} D_s^{(*)})$)	3%	1% (model dependency)		-	-
$\Delta\Gamma_s/\Gamma_s$ ($B_s \to f_{CP}$ t-dependent)	-	1.2%		-	-
ϕ_s (with $B_s \to J/\psi\phi$ etc.)	-	-	-	0.02	0.01
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-			6 fb^{-1} for 5σ discovery	
ϕ_3 ($B_s \to KK$)	-			7-10°	
ϕ_3 ($B_s \to D_s K$)	-			13°	
Υ decays	(3 fb^{-1})	(500 fb^{-1})			
$\mathcal{B}(\Upsilon(1S) \to$ invisible)	$< 2.5 \times 10^{-3}$	$< 2 \times 10^{-4}$			
	(~0.5 ab^{-1})‡	(5 ab^{-1})	(50 ab^{-1})		
Charm physics					
D mixing parameters					
x	0.25%	0.12%	0.09%		0.25%††
y	0.16%	0.10%	0.05%		0.05%††
$\delta_{K\pi}$	10°	6°	4°		
$\|q/p\|$	0.16	0.1	0.05		
ϕ	0.13 rad	0.08 rad	0.05 rad		
A_D	2.4%	1%	0.3%		
New particles$^{\aleph}$					
$\gamma\gamma \to Z(3930) \to D\bar{D}^*$		$> 3\sigma$			
$B \to KX(3872)(\to D^0\bar{D}^{*0})$		400 events			
$B \to KX(3872)(\to J/\psi\pi^+\pi^-)$		1250 events			
$B \to KZ^+(4430)(\to \psi'\pi^+)$		1000 events			
$e^+e^- \to \gamma_{\rm ISR}Y(4260)(\to J/\psi\pi^+\pi^-)$		3000 events			
Electroweak parameters		(~10 ab^{-1})			
$\sin^2\Theta_W$	-	3×10^{-4}			

Very broad physics program.
For more, see the following article

Physics at Super B factory: arXiv:1002.5012v1

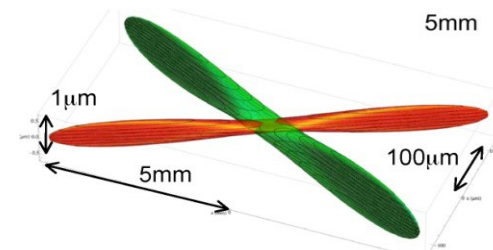
Strategy for SuperKEKB



Nano beam scheme

Invented by Pantaleo Raimondi

-Focused on small β^*_y



Beam-beam parameter

Lorentz factor

Beam current

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1 + \frac{\sigma^*_y}{\sigma^*_x}\right)\left(\frac{I_{e\pm}\xi^{e\pm}_y}{\beta^*_y}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 ~ 1
(short bunch)

Classical electron radius

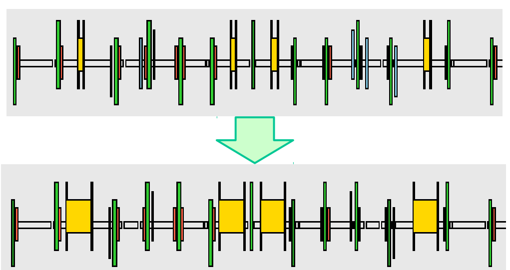
Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

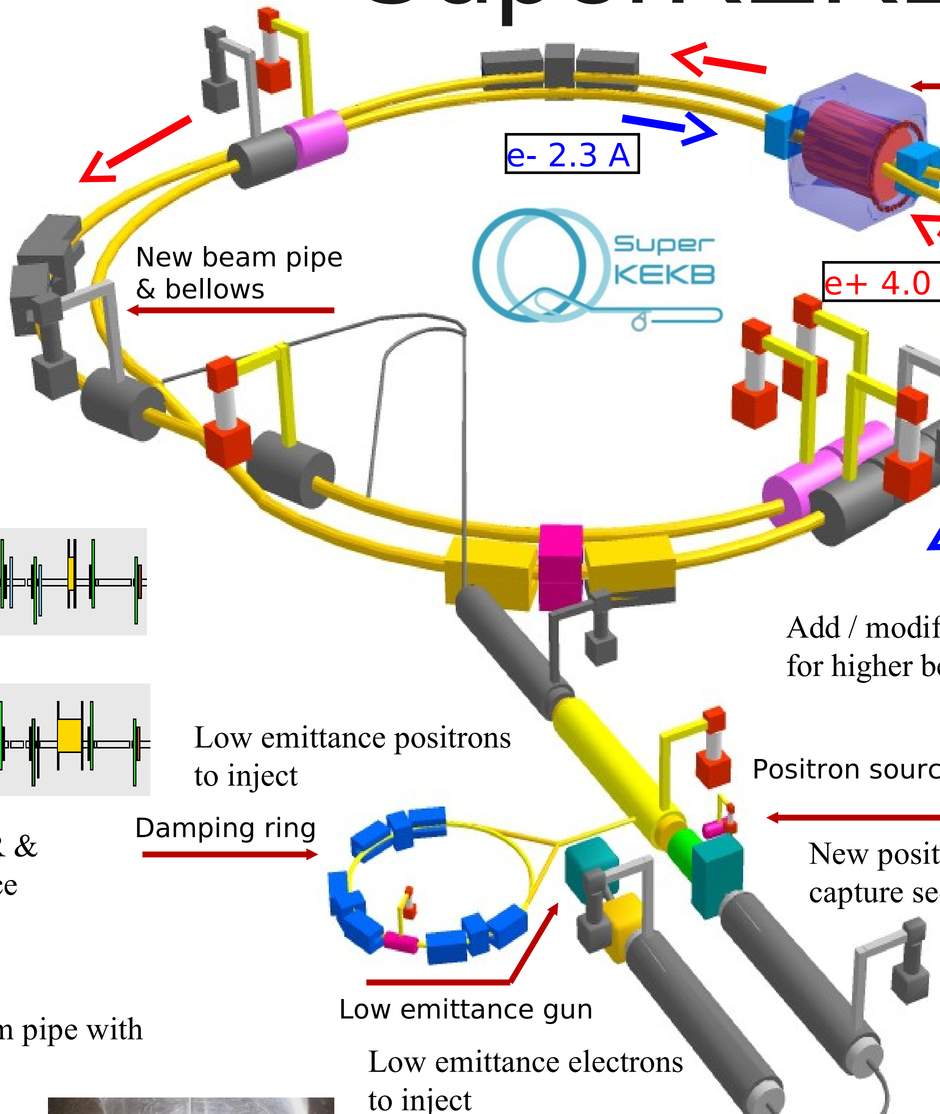
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	ε_x (nm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	18/24	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	3.2/5.3	41.5	3.6/2.6	80x10^{34}

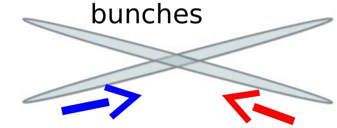
SuperKEKB

Replace short dipoles with longer ones (LER)

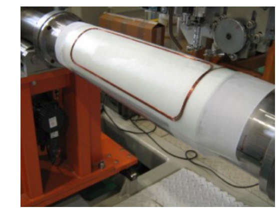


Redesign the lattices of HER & LER to squeeze the emittance





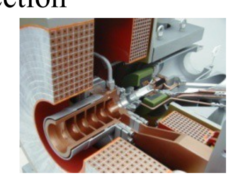
New superconducting /permanent final focusing quads near the IP



Add / modify RF systems for higher beam current

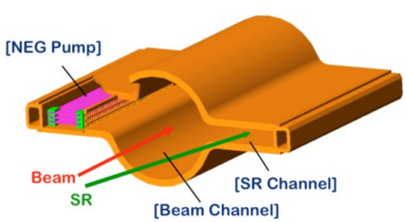
Low emittance positrons to inject

New positron target / capture section



Low emittance electrons to inject

TiN-coated beam pipe with antechambers



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

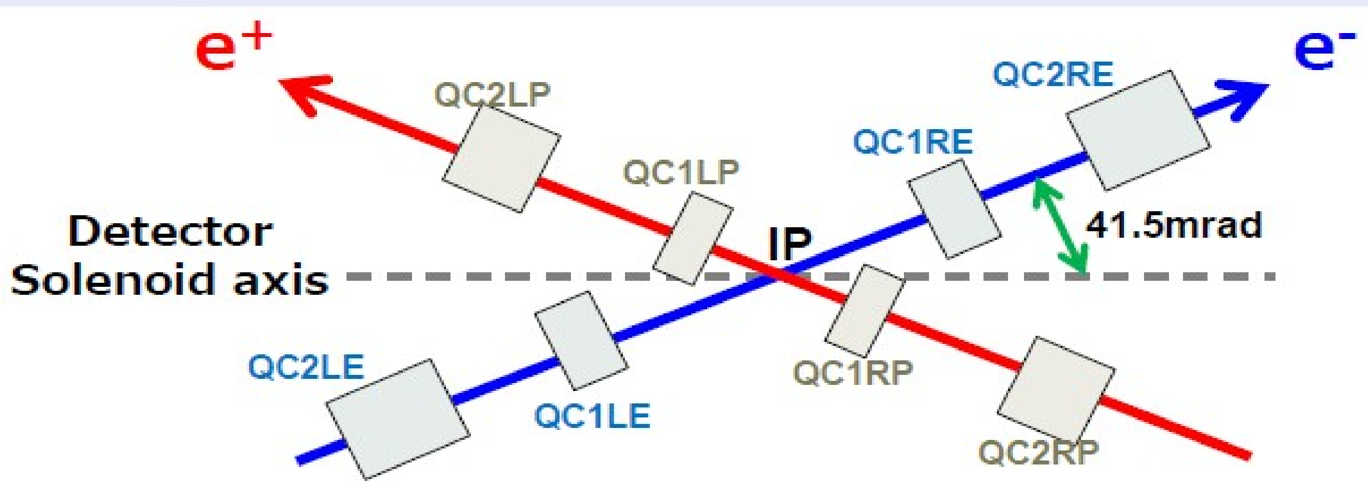
L=8·1035 s-1cm-2

x 40 Gain in Luminosity

Interaction Region

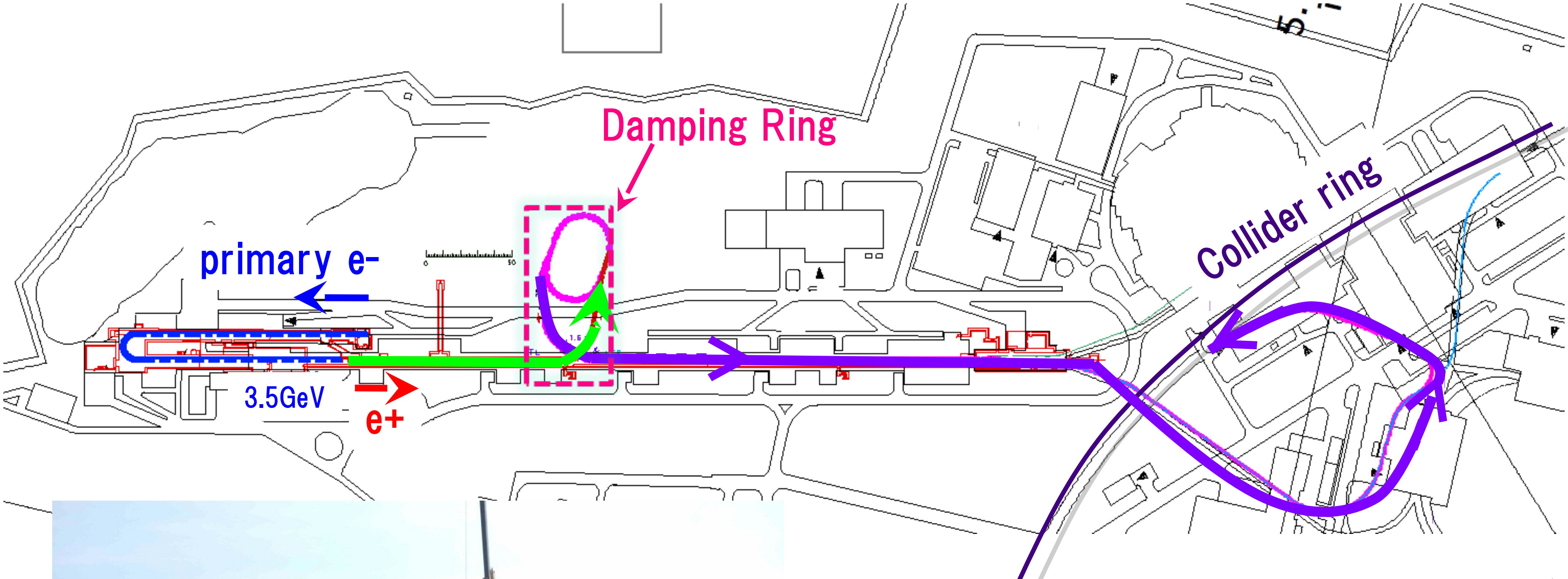
IR layout

- New final focusing system based on the nano-beam scheme has been designed.
  - Consists of **8 superconducting magnets**
  - Final focusing Q-magnets **for each beam**
  - **Crossing angle 83 mrad** to bring the FF magnets closer to IP (cf. 22Mrad @Belle)



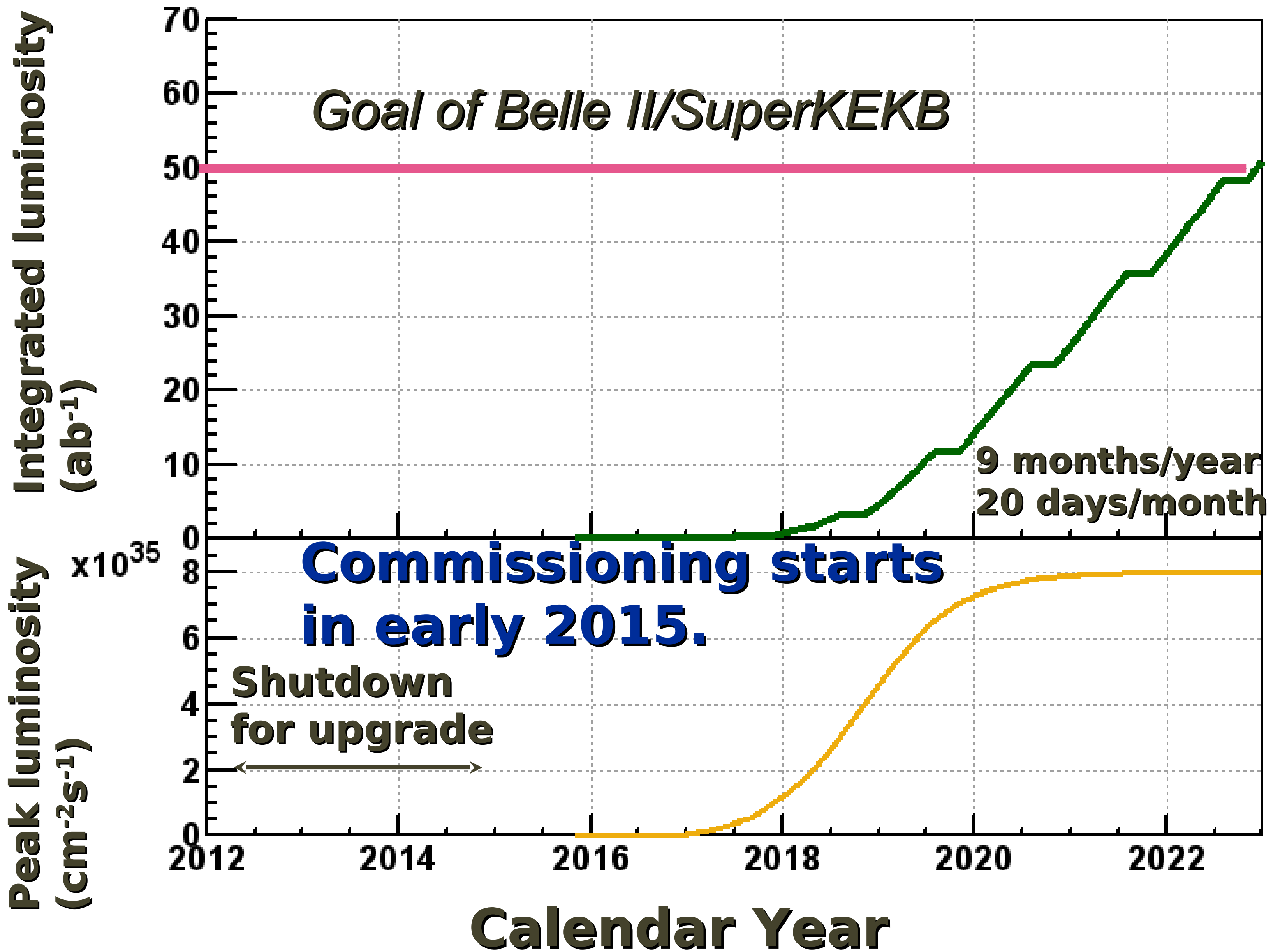
N.Ohuchi

SuperKEKB: Dumping ring construction



- Fabrication of accelerator components ongoing.
- Buildings will be constructed in 2012-14 after the tunnel is completed
- Damping ring will be completed at early 2015.

SuperKEKB luminosity projection

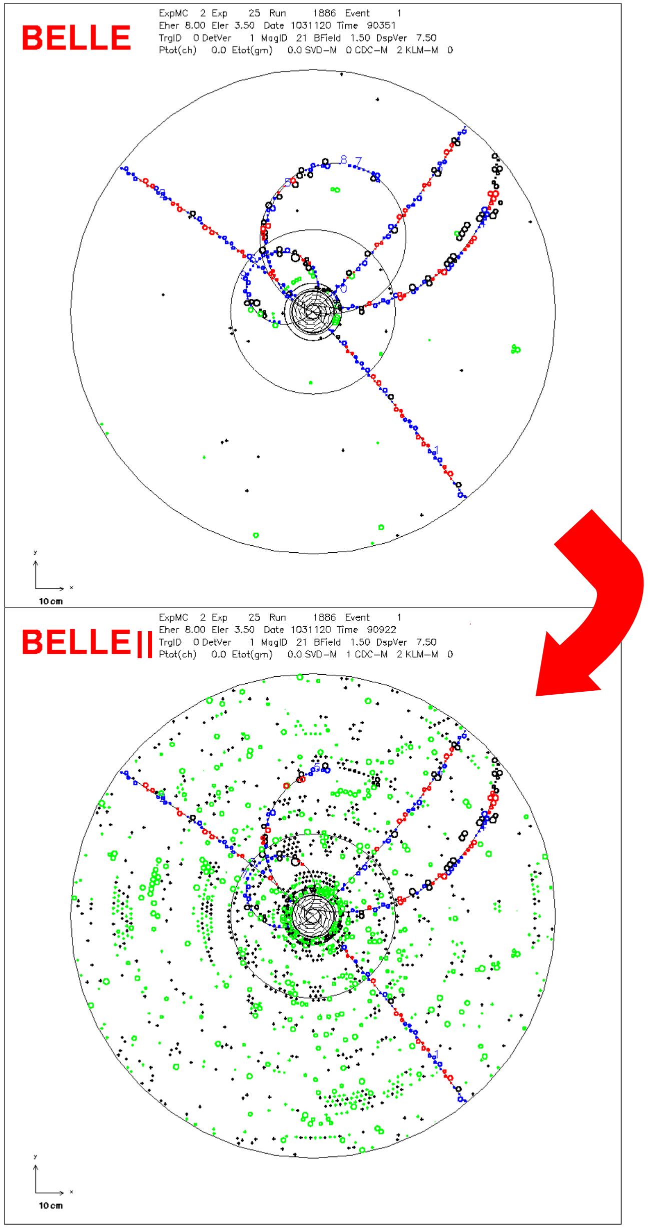


Belle II detector: challenges

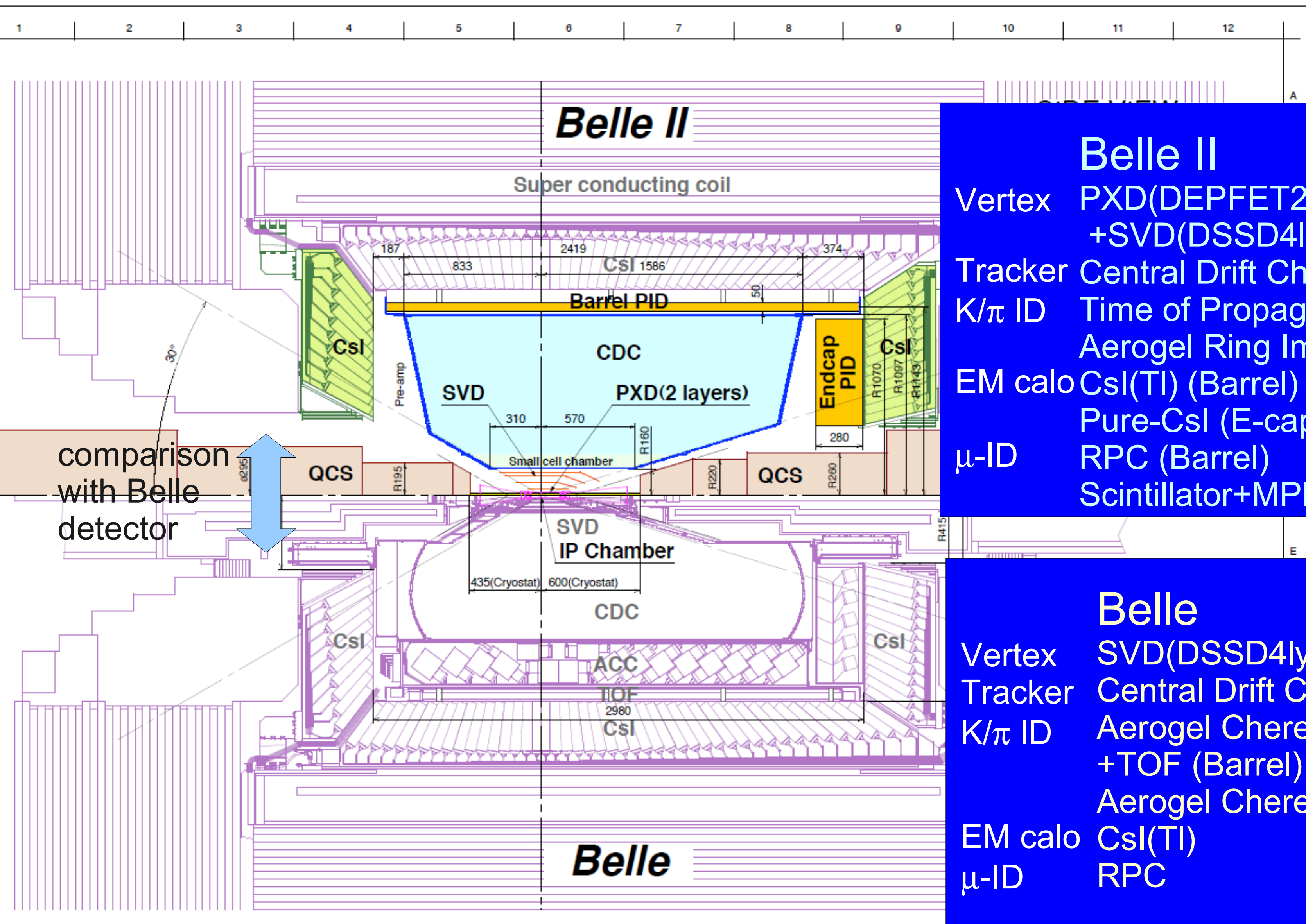
1. High background
   -10～20 times higher than that of Belle
   → fake hits, pile up, radiation damage

2. High trigger rate
   -Typical Level1 trigger rate: 20kHz
   -Data size also increase
   → require high performance DAQ

3. Physics sensitivity
   -good hermeticity for events having ν s
   -good background rejection for
   ultra rare B and τ decays



Belle II detector



Belle II

Vertex	PXD(DEPFET2lyrs) +SVD(DSSD4lyrs)
Tracker	Central Drift Chamber(small cell)
K/π ID	Time of Propagation(Barrel) Aerogel Ring Image Cherenkov(E-cap)
EM calo	CsI(Tl) (Barrel) Pure-CsI (E-cap)
μ-ID	RPC (Barrel) Scintillator+MPPC (E-cap)

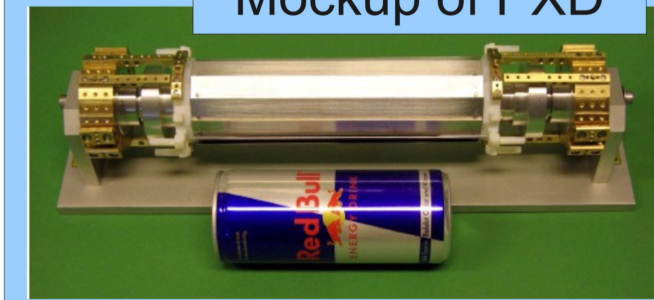
Belle

Vertex	SVD(DSSD4lys)
Tracker	Central Drift Chamber
K/π ID	Aerogel Cherenkov counter +TOF (Barrel) Aerogel Cherenkov counter(E-cap)
EM calo	CsI(Tl)
μ-ID	RPC

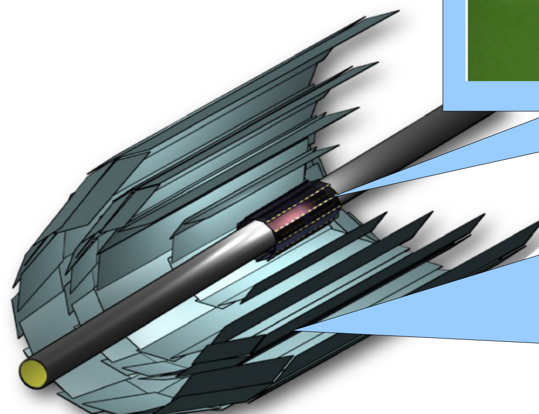
Belle II Technical Design Report: arXiv:1011.0352v1

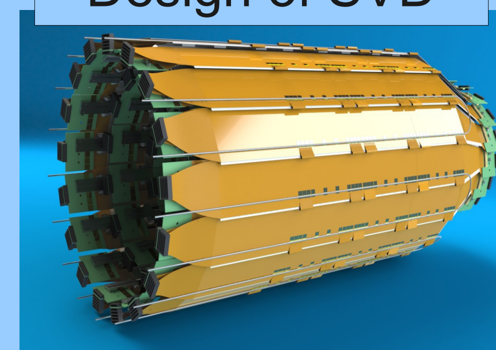
Vertex detector

- Configuration: 4 layers → 6 layers (outer radius = 8cm→14cm)
  - More robust tracking
  - Higher Ks vertex reconstr. efficiency
- Inner radius: 1.5cm → 1.3cm
  - Better vertex resolution
- DEPFET Pixel sensors (PXD) for the two innermost layers
- Normal double sided Si detectors (SVD) for the outer 4 layers
- Strip readout chip: VA1TA → APV25
  - Pipelined readout to reduce dead time, pile-up rejection.



Mockup of PXD





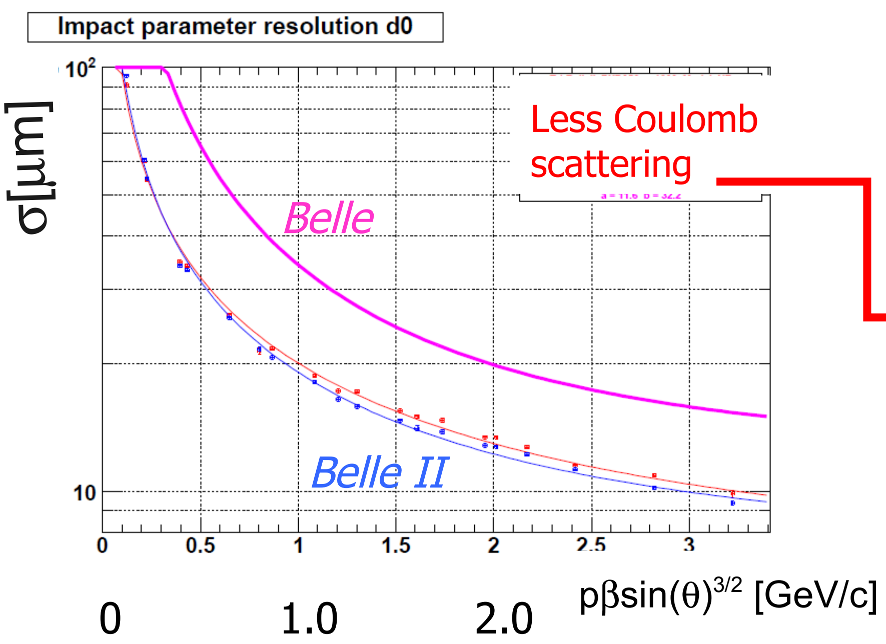
Design of SVD

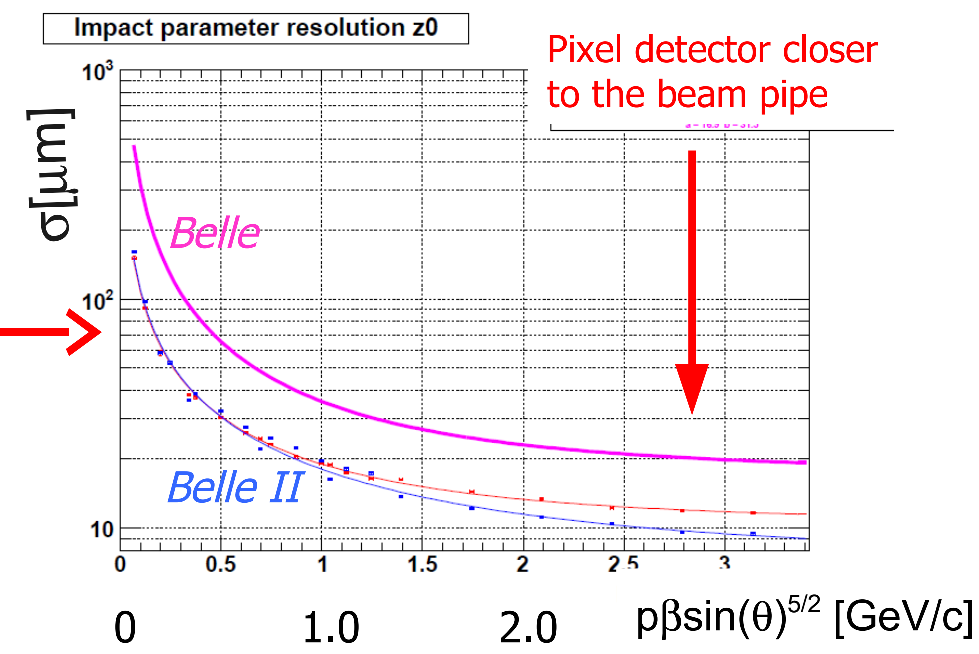
	Belle II	Belle
Beam Pipe	r = 10mm	15mm
PXD		
Layer 1	r = 14mm	
Layer 2	r = 22mm	
SVD		
Layer 3	r = 38mm	20mm
Layer 4	r = 80mm	43.5mm
Layer 5	r = 115mm	70mm
Layer 6	r = 140mm	88mm

Improvement of the Impact Parameter resolution

Significant improvement in IP resolution!

$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$





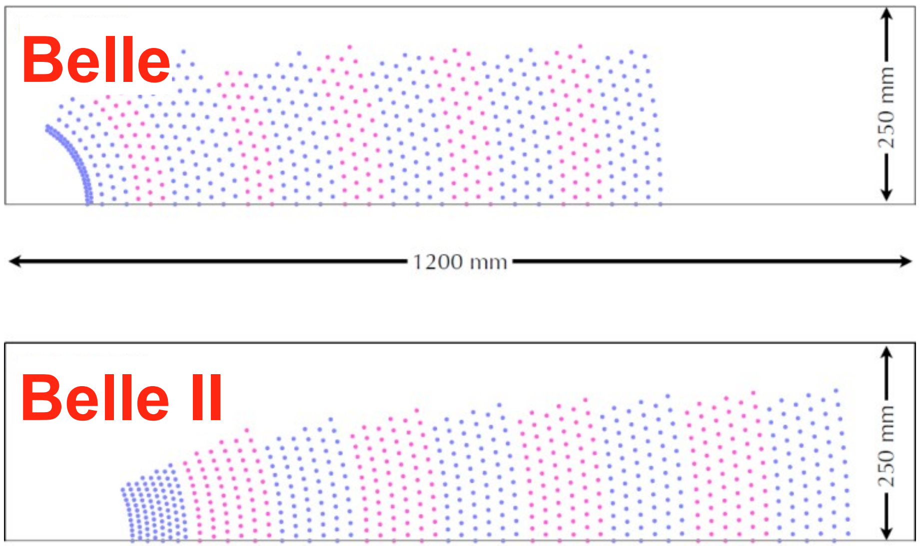
Closest approach

Z-resolution

Main Tracker: CDC

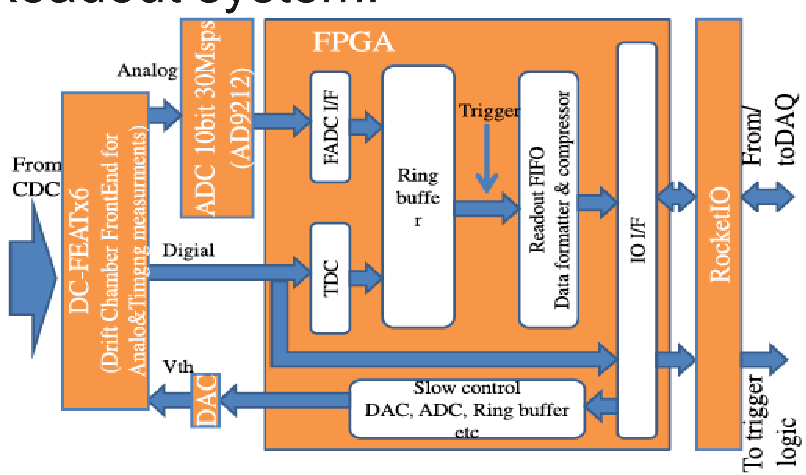
	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	He:C2H6	He:C2H6
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

Larger volume
(Belle:863mm→BelleII:1111.4mm):
→ Improve momentum and dE/dx resolution



Larger radius of innermost layer
→ avoid background hits

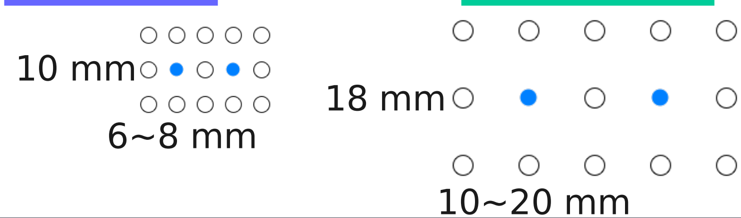
Readout system:



-drift time → FPGA based TDC
-charge → 30MS/s FADC

small cell

normal cell



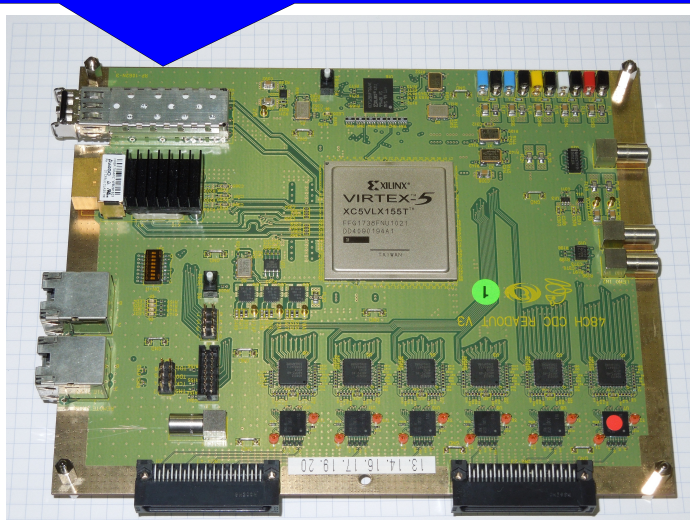
Small cell:
(1) reduce occupancy
(2) tolerate to high rate by shorten drift time

Main tracker: CDC(cont'd)

Nov. 21, 2012: chamber is delivered

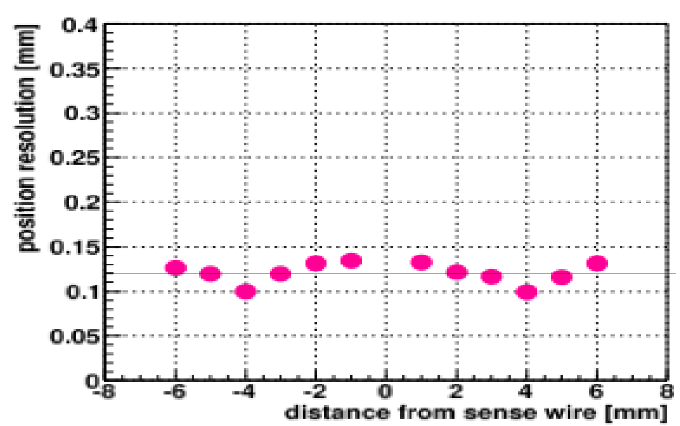
Dec. 18, 2012: start wire stringing

Faster readout electronics
→ handle higher trigger rate (~30kHz) with less dead time



prototype of readout board

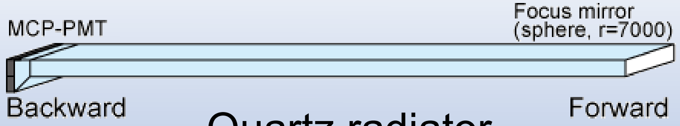
Test beam results (1GeV/c electron)



~120um

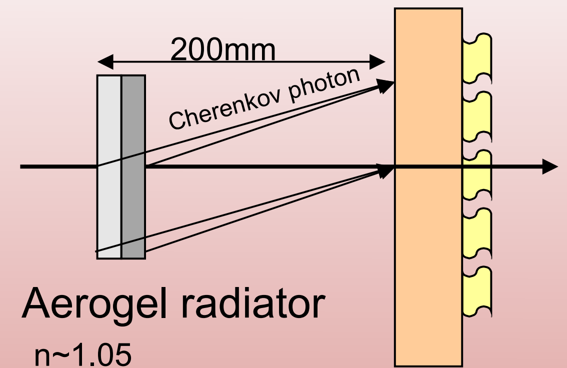
Particle Identification Device

Barrel PID: Time of Propagation Counter (TOP)



- Quartz radiator
- Focusing mirror
- Small expansion block
- Hamamatsu MCP-PMT (measure t, x and y)

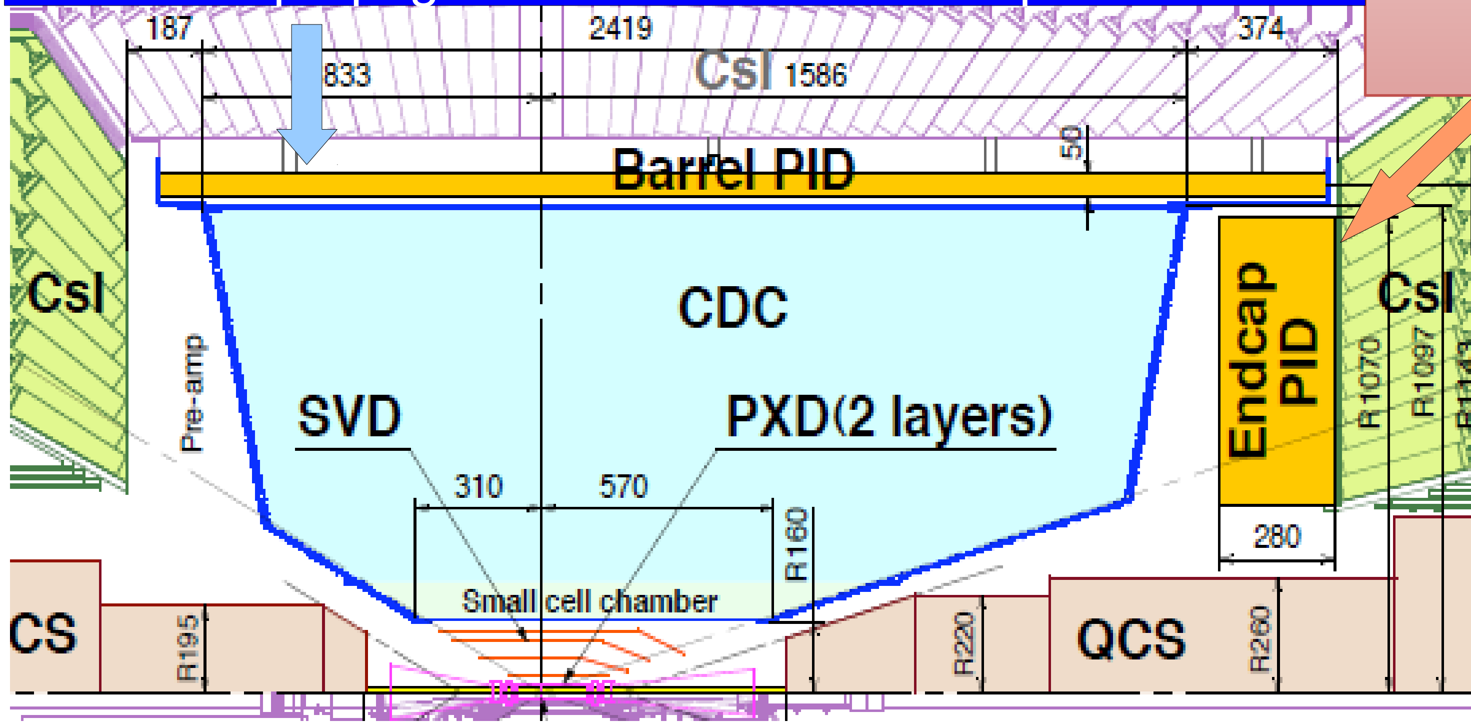
Endcap PID: Aerogel RICH (ARICH)



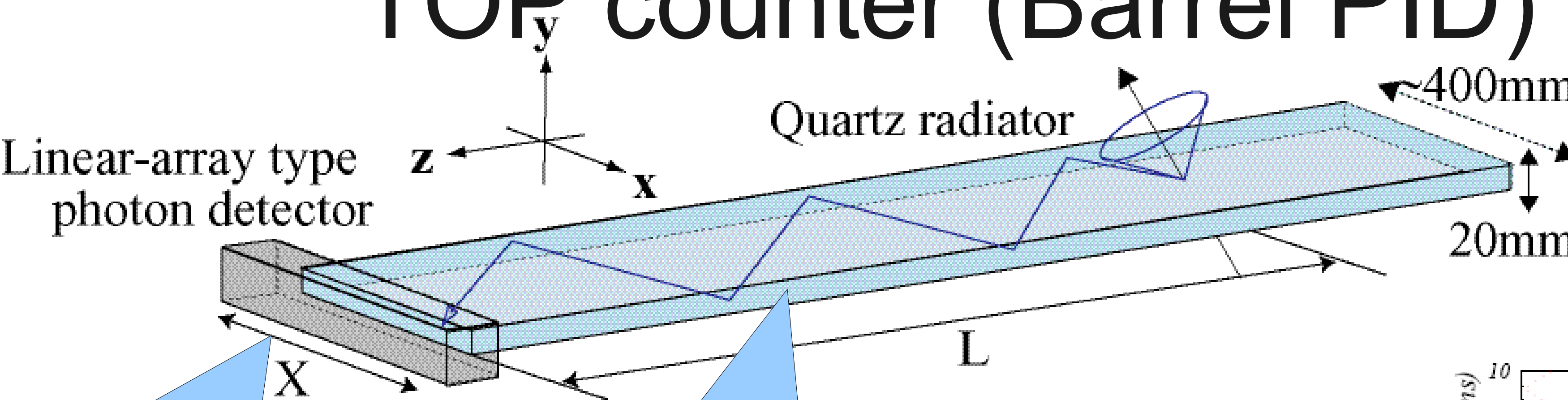
- Aerogel radiator n~1.05
- Hamamatsu HAPD + new ASIC

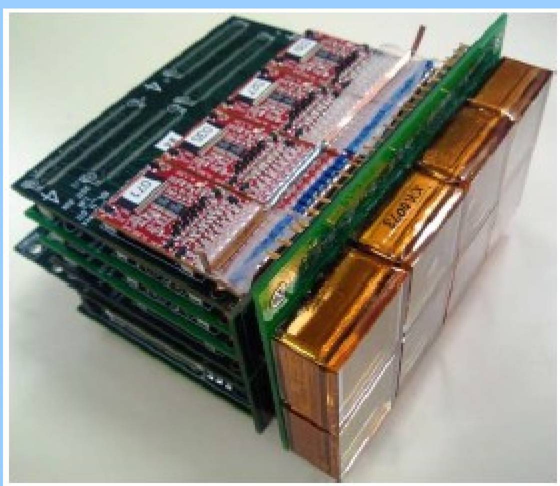
Position & propagation time of Cherenkov photon + TOF

Position information of Cherenkov photon

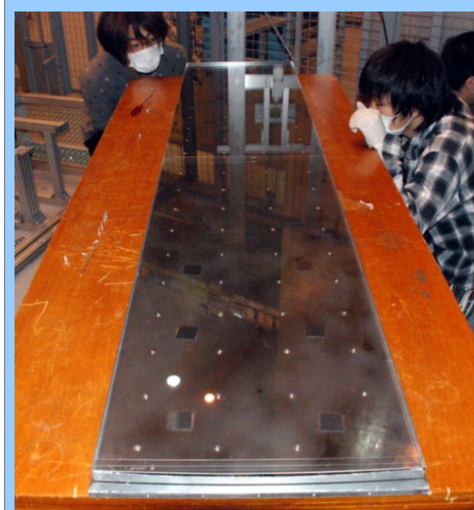


TOP counter (Barrel PID)

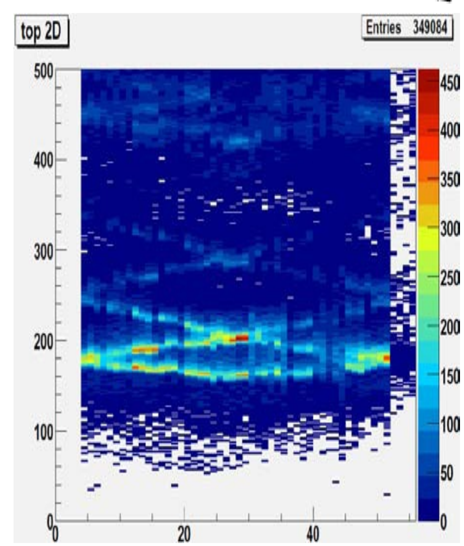


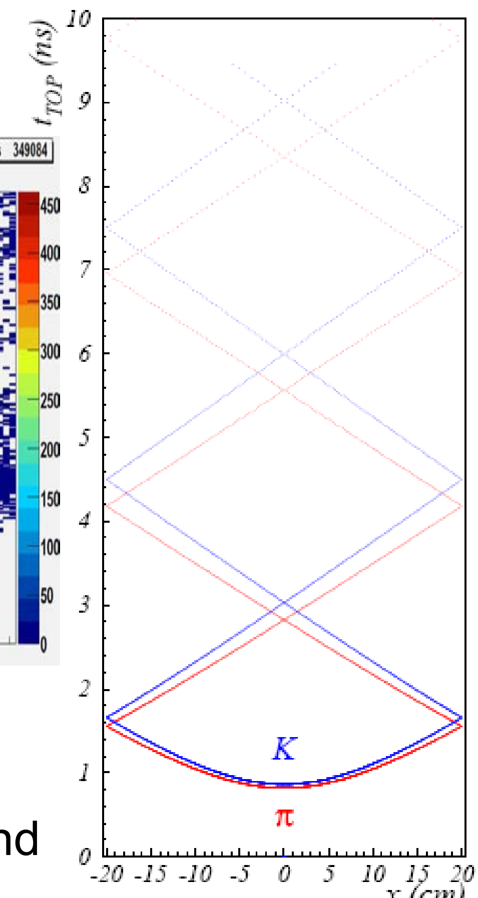


16ch Multi Channel Plate-PMTs
Hamamatsu SL10:



Quartz radiator





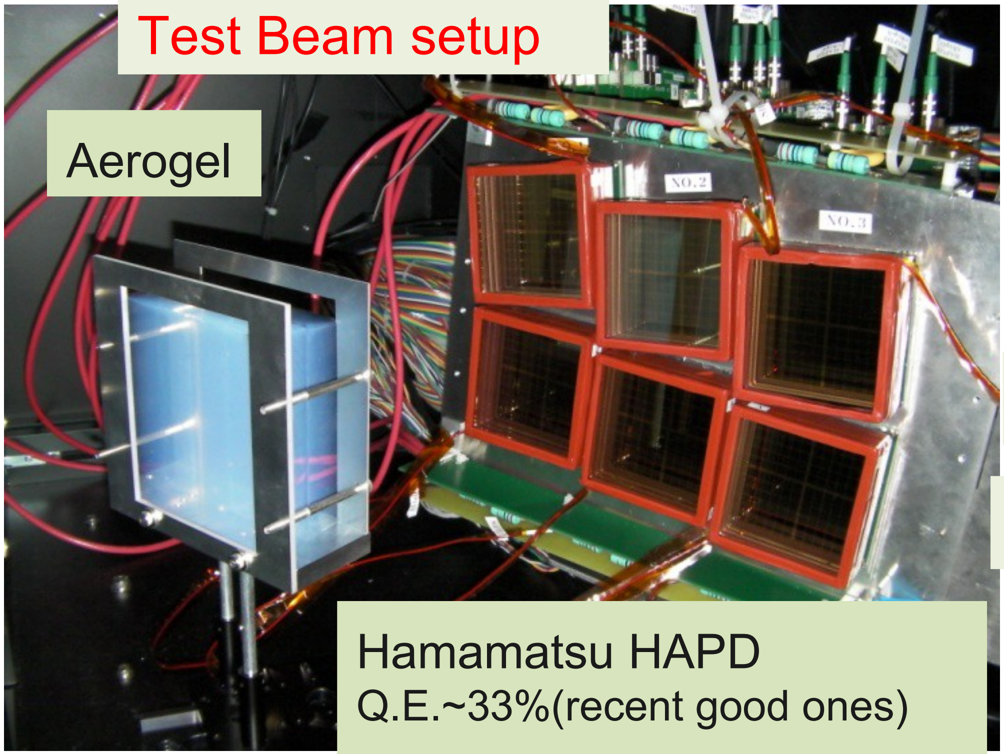
Compact version of detection of internally reflected Cherenkov (DIRC):

- Measure internally reflected Cherenkov pattern in two hit coordinates and time of propagation.
- require good timing resolution (~40ps)

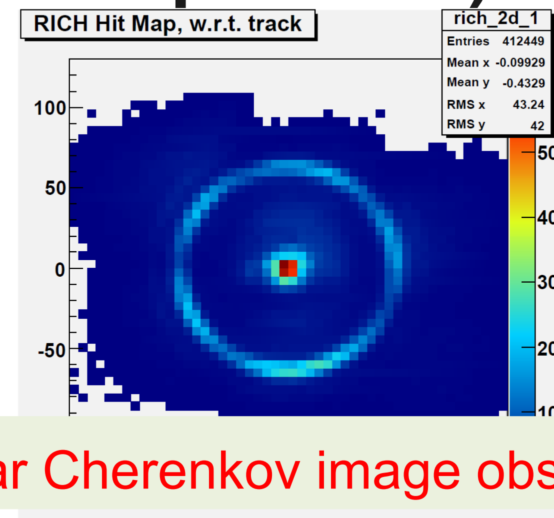
Aerogel RICH (End-cap PID)

Test Beam setup

Aerogel

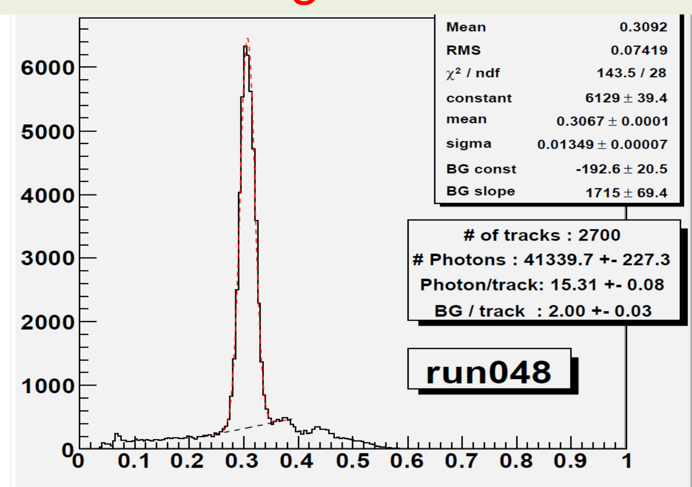


Hamamatsu HAPD
Q.E.~33%(recent good ones)

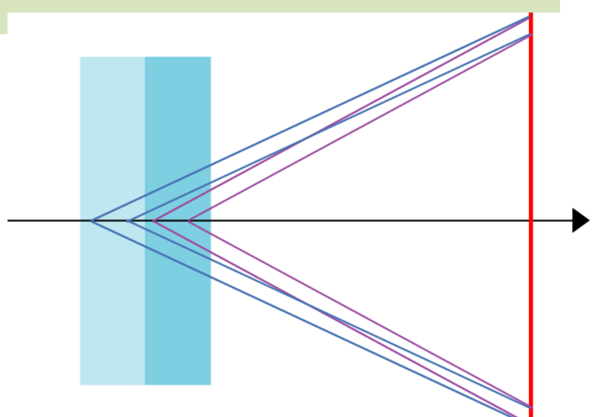


Clear Cherenkov image observed

Cherenkov angle distribution



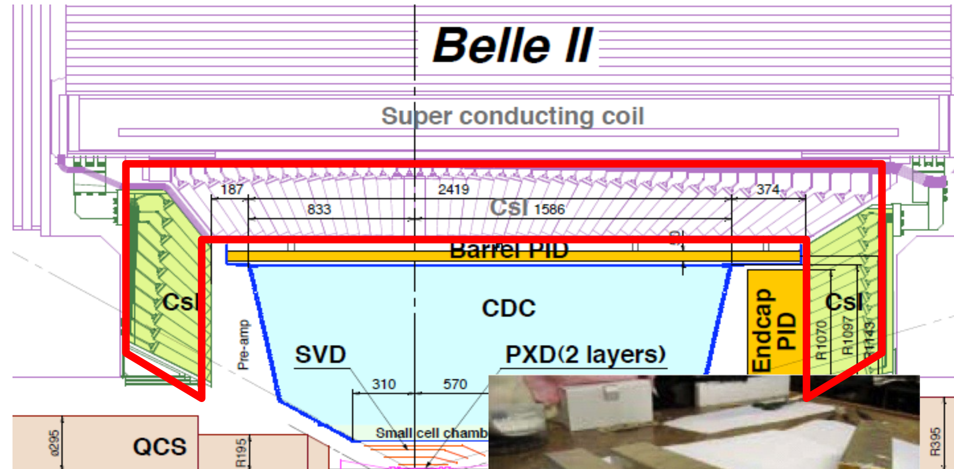
RICH with a novel "focusing" radiator – a two layer radiator

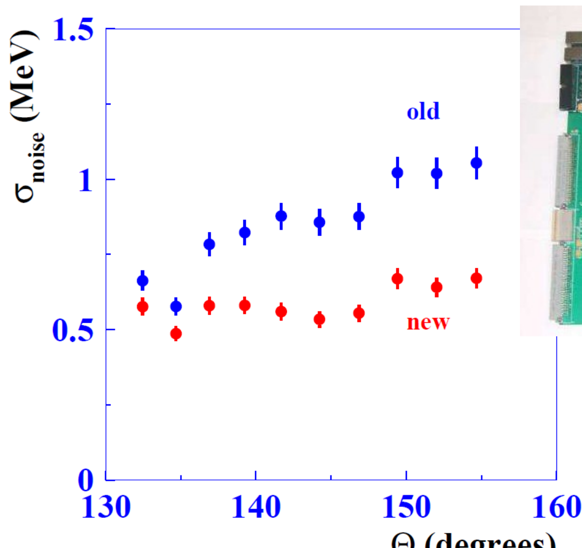


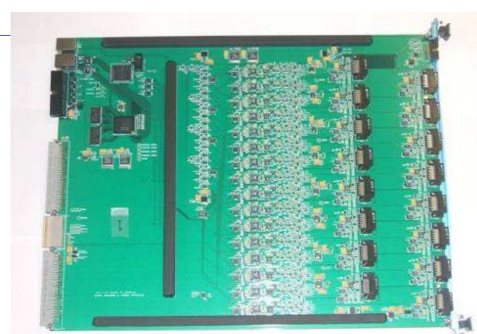
Employ multiple layers with different refractive indicesà Cherenkov images from individual layers overlap on the photon detector.

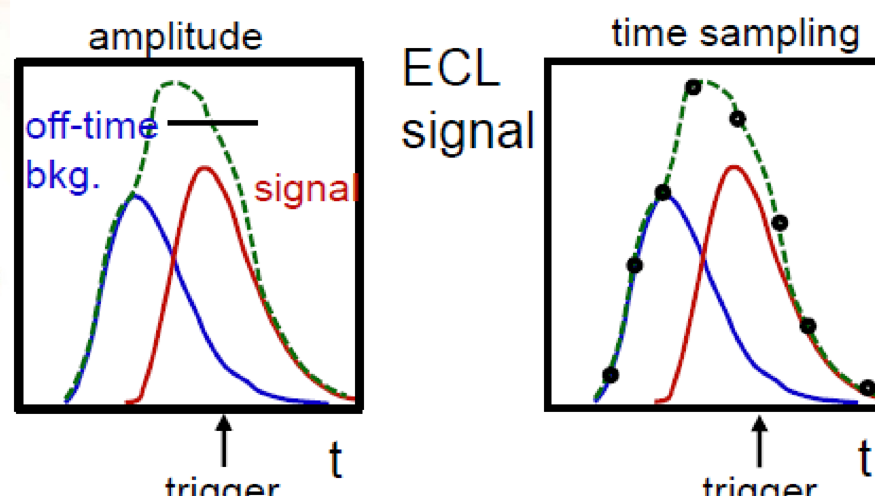
Electromagnetic Calorimeter

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







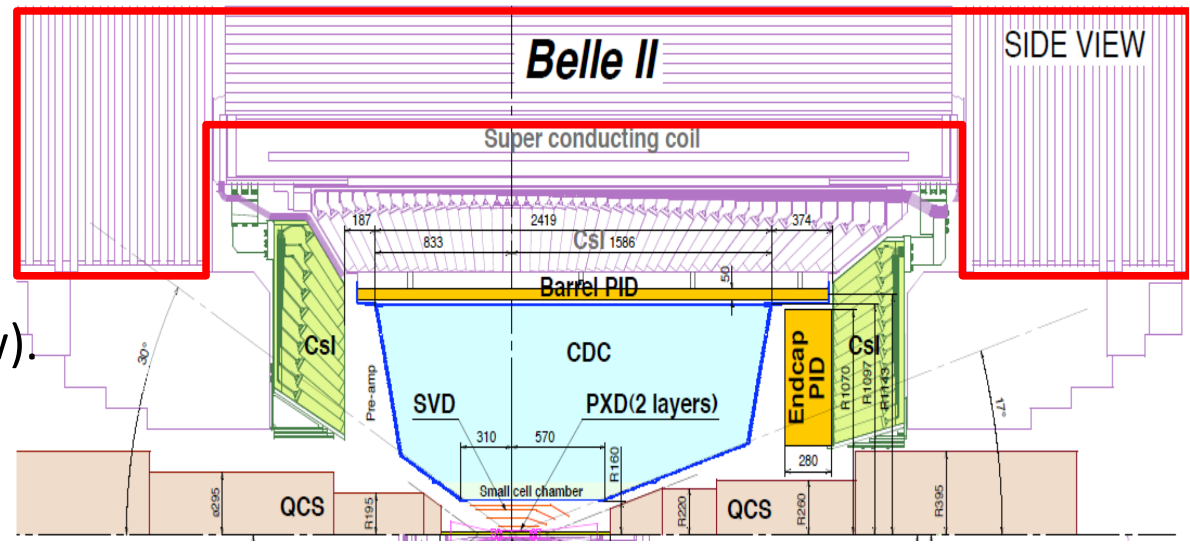


K_L & muon Derecttor

Barrel:

Belle RPCs mostly to be reused.

Inner two layers ➔ scintillator (see below).

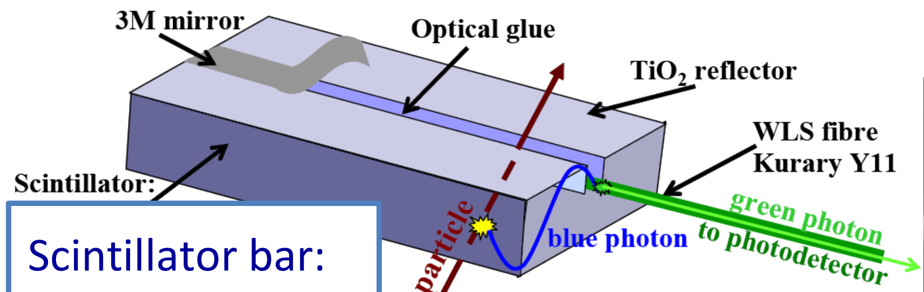


Endcap:

Replace to:

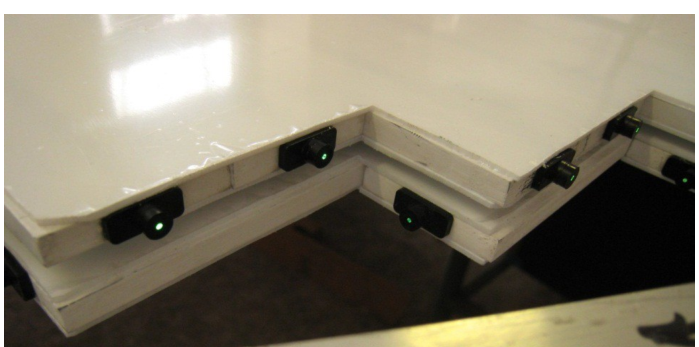
Scintillators + WLS + MPPC

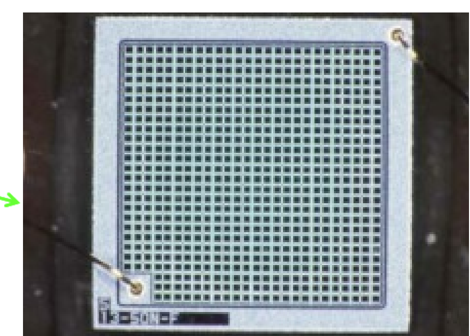
← tolerate high BG



Scintillator bar: Vladimir (Russia)

fiber: Kuraray Y11 MC





MPPC:Hamamatsu
1.3×1.3 mm
667 pixels

Summary

SuperKEKB/ Belle II is a next generation B-factory experiment
- 40 times higher luminosity compared to belle
  → challenges to both accelerator and detector
- Project is fully approved and construction is on going
- Commissioning is expected to be started in early 2015
- Total ~50ab^{-1} data is expected by around 2022

-Precise test of the SM (Unitarity test of the CKM matrix)
-Observation of direct CPV in many B & D decay modes
-Search for NP through rare B decays, LFV τ decays, and so on

backup

Expected BF for LFV τ decays

	reference	$\tau\to\mu\gamma$	$\tau\to\mu\mu\mu$
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

Ratios of LFV decay BFs make us distinguish between NP models.

	SUSY+GUT (SUSY+Seesaw)	Higgs mediated	Little Higgs	non-universal Z' boson
$\left(\frac{\tau\to\mu\mu\mu}{\tau\to\mu\gamma}\right)$	$\sim 2\times10^{-3}$	0.06~0.1	0.4~2.3	~16
$\left(\frac{\tau\to\mu ee}{\tau\to\mu\gamma}\right)$	$\sim 1\times10^{-2}$	$\sim 1\times10^{-2}$	0.3~1.6	~16
$Br(\tau\to\mu\gamma)$ @Max	$<10^{-7}$	$<10^{-10}$	$<10^{-10}$	$<10^{-9}$

Favorite modes $\tau\to\mu\gamma$ ⟷ $\tau\to\mu\mu\mu$