The Belle II Experiment at SuperKEKB

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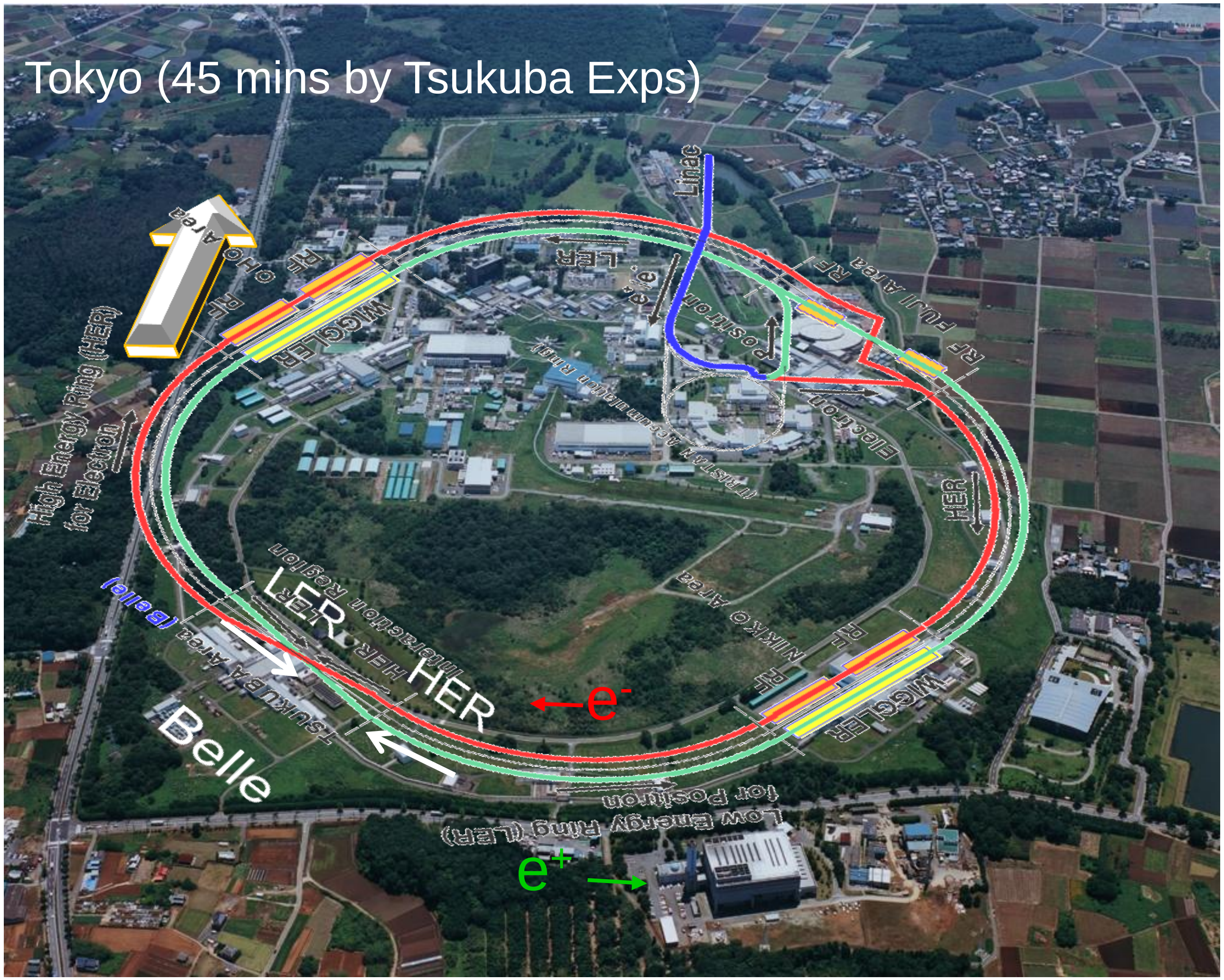
(for the Belle II Collaboration)
IHEP, Beijing

Hefei, May 25, 2012

Belle / KEKB / KEK



KEKB:

e^- (HER): 8.0 GeV
e^+ (LER): 3.5 GeV

crossing angle:
22 mrad

E_{CM}=M(Υ(4S))
also at 1S, 2S, 5S

$$\int_{1999}^{2010} \mathcal{L}dt = 1020\ \mathrm{fb}^{-1}$$

(1.02 ab^{-1})

Peak lumi record at KEKB: L=2.1 x $10^{34}/\mathrm{cm}^2/\mathrm{s}$ with crab cavities

Physics at a SuperB Factory

- There is a good chance to see new phenomena:
  - **CPV in from the new physics (non KM).**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constrain (if not found) new physics models.
- $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs in large tanβ region.
- **Physics motivation is independent of LHC.**
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be a unique way to search for the >TeV scale physics [very probably if M_{higgs}~125 GeV].

There are many more topics: CPV in charm, new hadrons, …

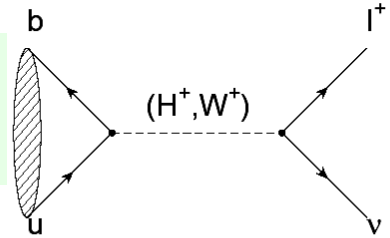
Recent update of the physics reach with 50 ab^{-1} (75 ab^{-1}):
Physics at Super B Factory (Belle II authors + guests) hep-ex > arXiv:1002.5012
SuperB Progress Reports: Physics (SuperB authors + guests) hep-ex > arXiv:1008.1541

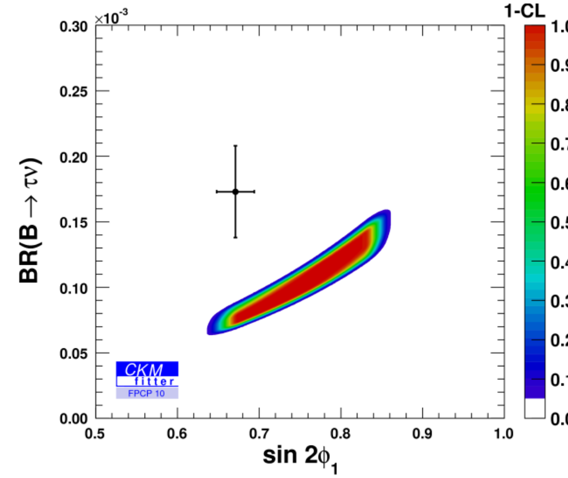
Search for New Physics

Sensitivity to new physics with charged Higgs

$$B^+ \to \tau^+ \nu_\tau$$

$$Br(B^+ \to \tau\nu) = (1.65 \pm {}^{0.38}_{0.37} \pm {}^{0.35}_{0.37}) \cdot 10^{-4}$$





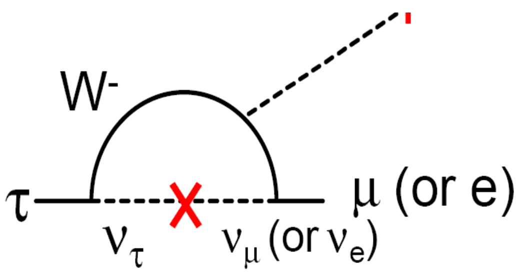
In the SM

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

$$0.76^{+0.11}_{-0.06} \times 10^{-4}$$

CKM fit

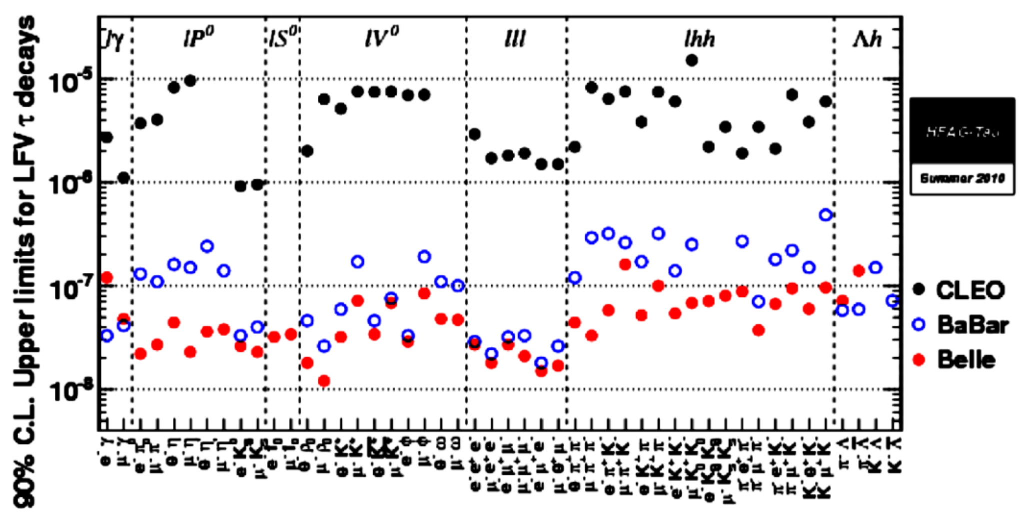
Searches for lepton flavour violation in tau decays



In the SM the lepton flavour violation decays are extremely small:

$Br(\tau \to l\gamma) \sim 10^{-54}$

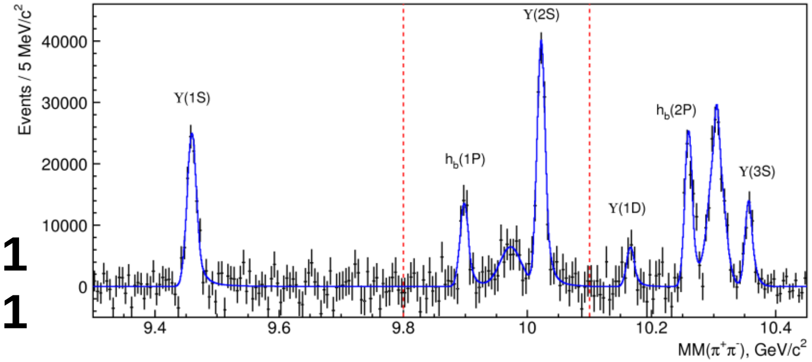
$Br(\tau \to 3\ \text{leptons}) \sim 10^{-14}$

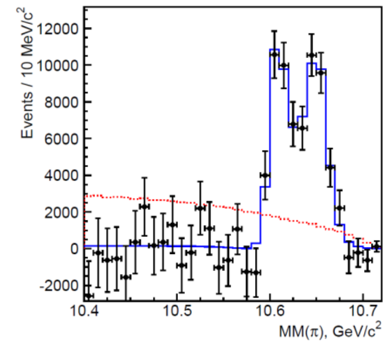


Hadron spectroscopy at B factories - examples

b family
– new states

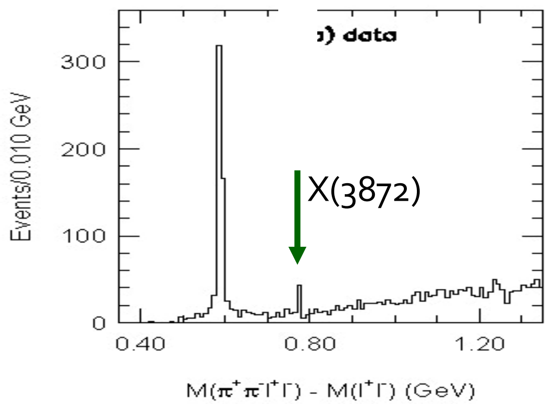
PRL 108, 122001
PRL 108, 032001

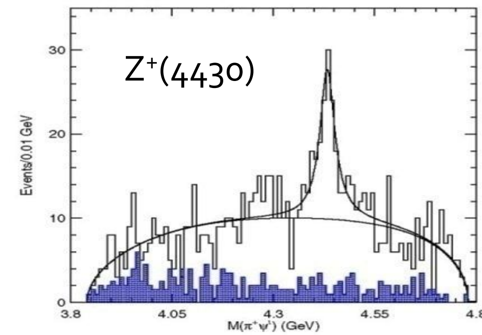




c family
– XYZ states

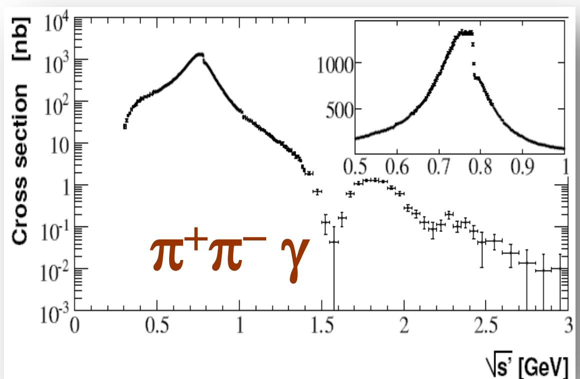
Review in
EPJC71, 1534

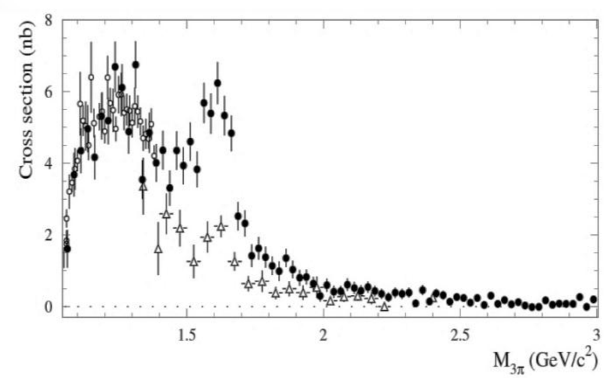




Light hadrons
spectroscopy
via ISR: g-2, …

PRL 103, 231801
PRD 70, 072004





Physics sensitivity at Belle II

Observable	Belle 2006	SuperKEKB		†LHCb	
	($\sim$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 $A_{FB}(B \to K^*\ell^+\ell^-)$	-	11%	4%		
C_{10} from $A_{FB}(B \to K^*\ell^+\ell^-)$	-	13%	4%		
C_7/C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	-		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.)		-	-

Physics sensitivity at Belle II

Observable	Belle 2006	SuperKEKB		†LHCb	
	(∼0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
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%		

Strategies to increase luminosity

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

Lorentz factor

Beam current

Beam-beam parameter

Classical electron radius

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

Vertical beta function@IP

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

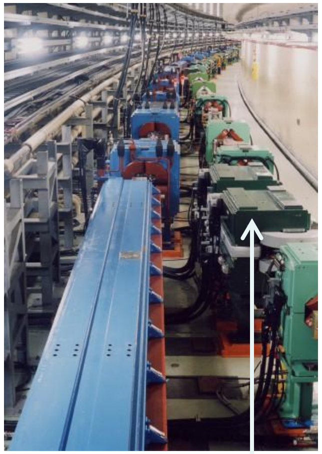
(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

← **"Nano-Beam" scheme**

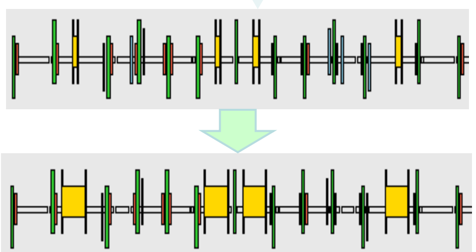
Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

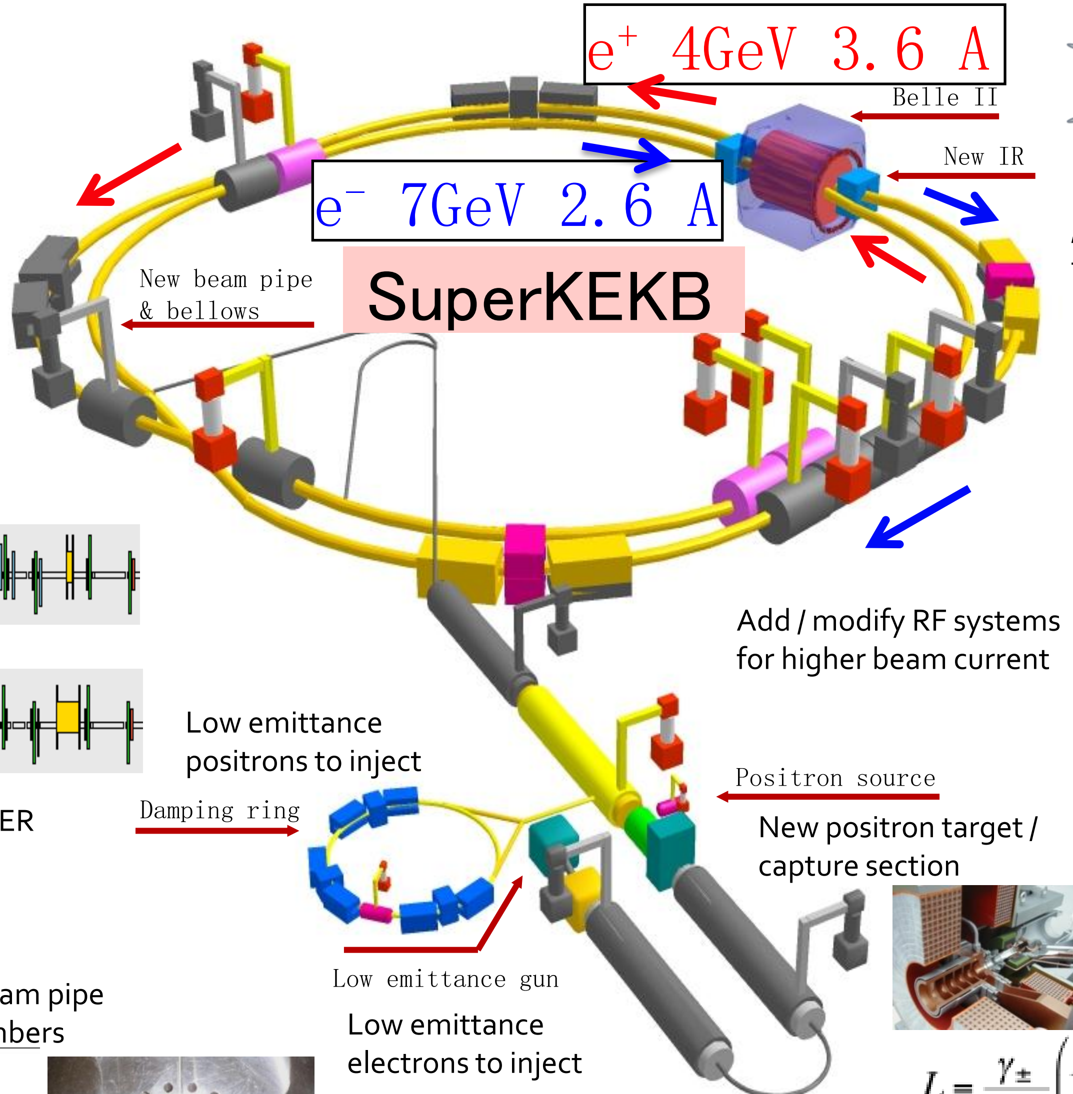
SuperKEKB collider

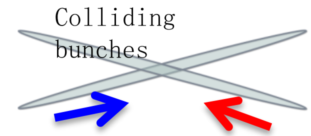


Replace short dipoles with longer ones (LER)

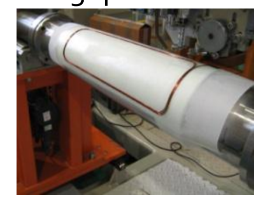


Redesign the lattices of HER & LER to squeeze the emittance





New superconducting /permanent final focusing quads near the IP

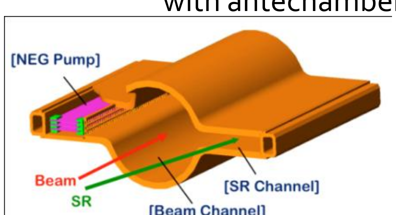


Add / modify RF systems for higher beam current

New positron target / capture section

Low emittance electrons to inject

TiN-coated beam pipe with antechambers



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

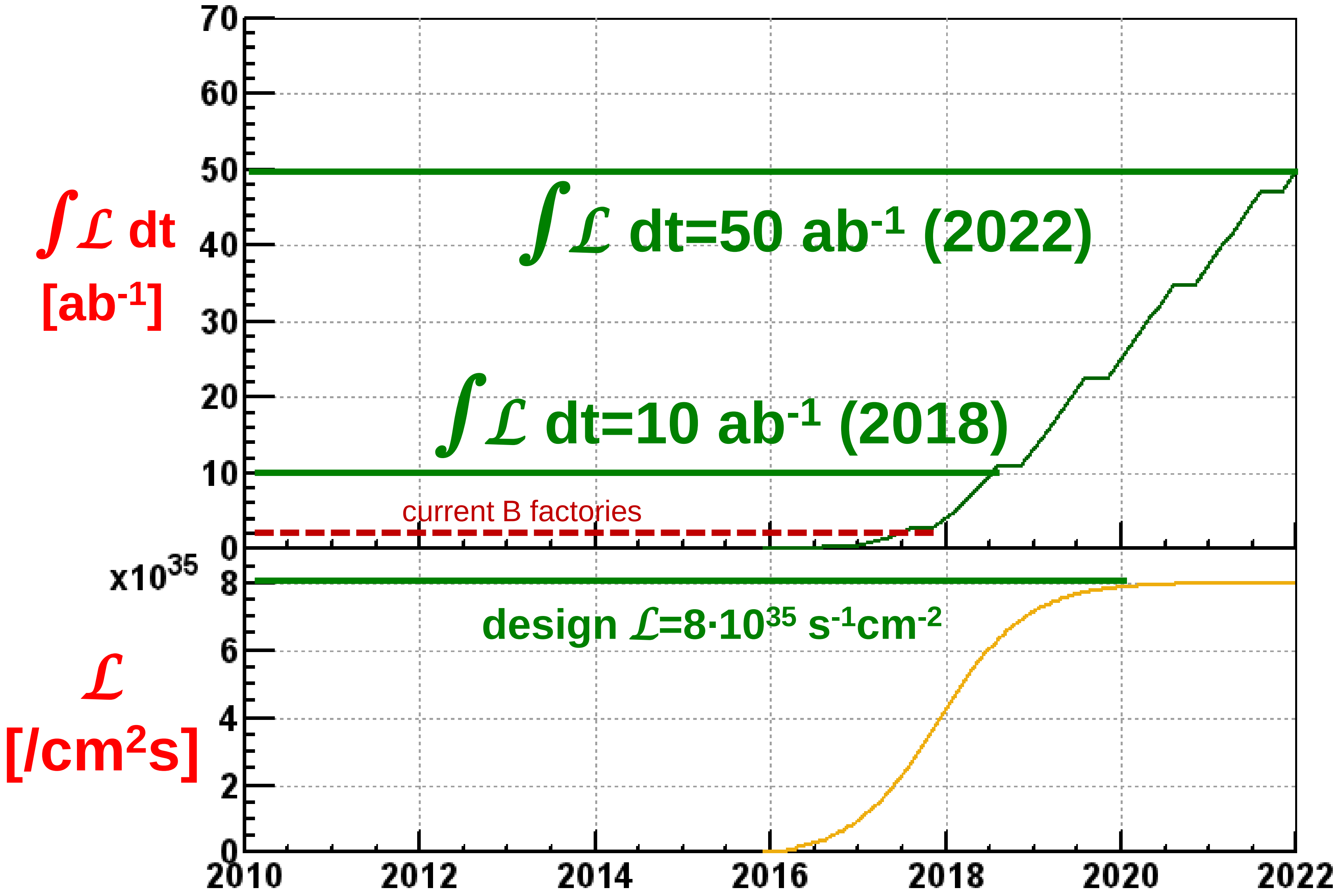
Target: L = $8\times10^{35}/cm^2/s$

Machine design parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	ϕ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.3-4.6	nm
Emittance ratio	K	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of LER short lifetime

Luminosity vs. time

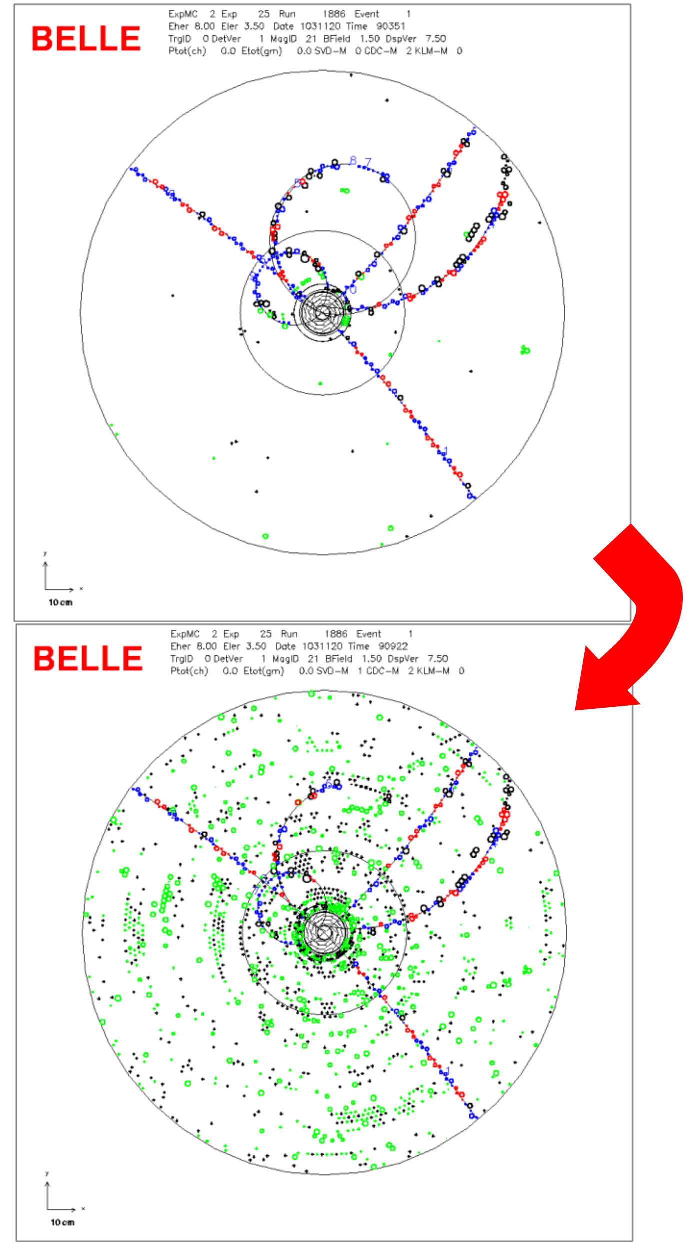


Requirements on the detector

Critical issues at L= 8 x 10^{35}/cm^2/sec

- **Higher background (×10-20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM Calorimeter
- **Higher event rate (×10)**
  - higher rate trigger, DAQ and computing
- **Special features required**
  - low momentum μ identification
  - Hermeticity, ν “reconstruction”

Result: significant upgrade

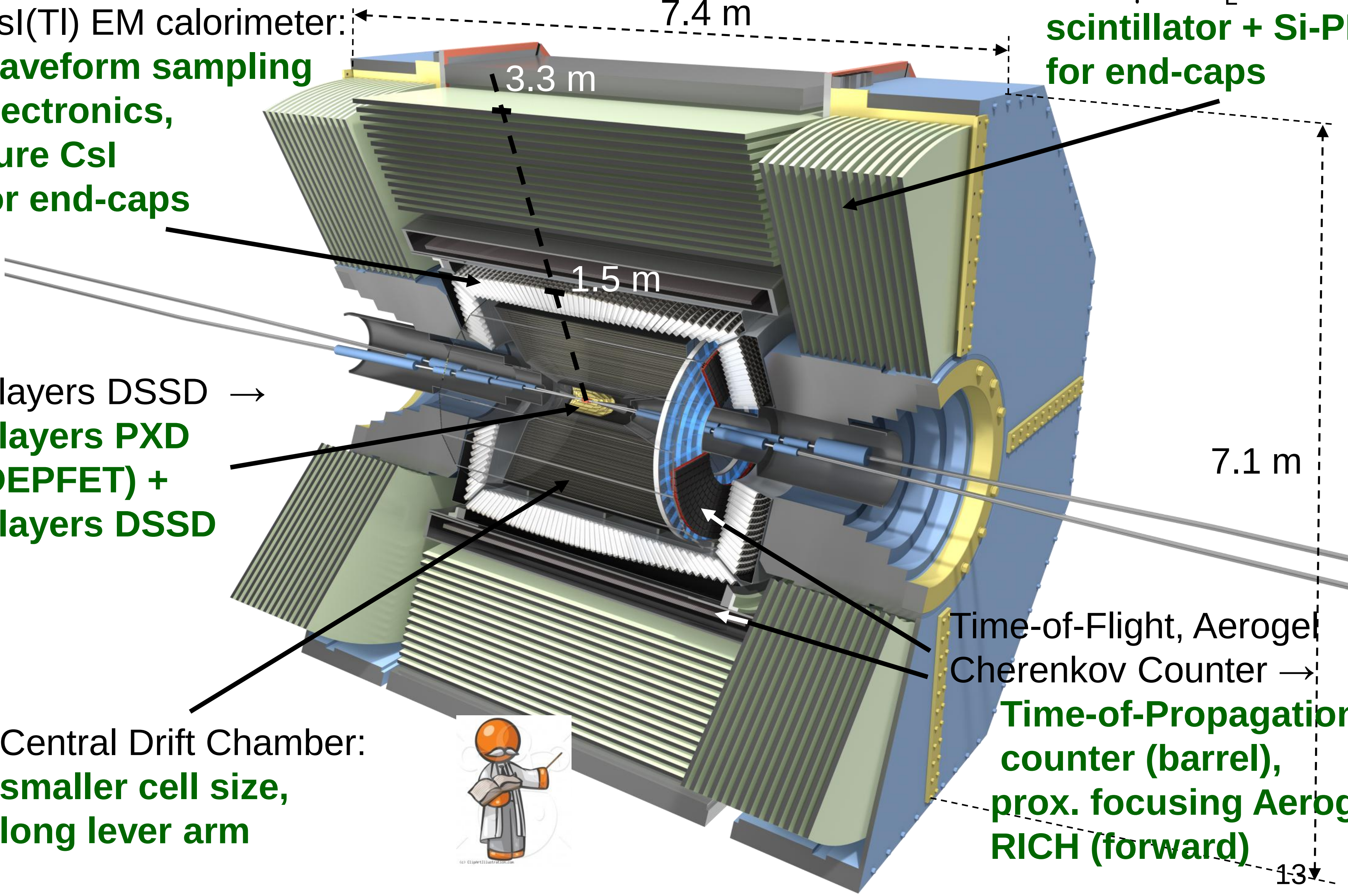


Belle II detector upgrade

Belle II

CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for end-caps

RPC μ & K_L counter:
scintillator + Si-PM for end-caps



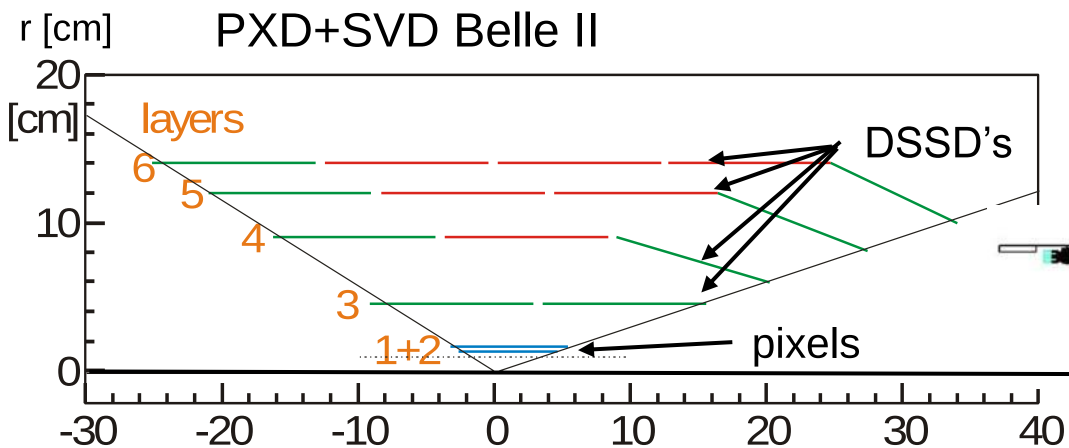
4 layers DSSD →
2 layers PXD (DEPFET) + 4 layers DSSD

Central Drift Chamber:
smaller cell size, long lever arm

Time-of-Flight, Aerogel Cherenkov Counter →
Time-of-Propagation counter (barrel), prox. focusing Aerogel RICH (forward)

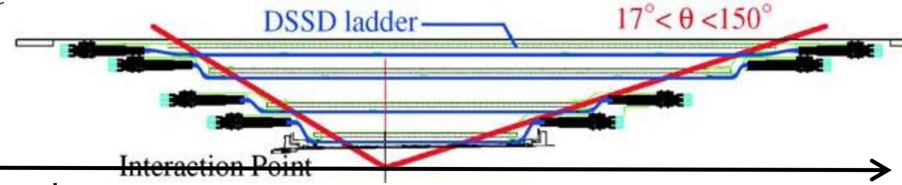
Vertex detector

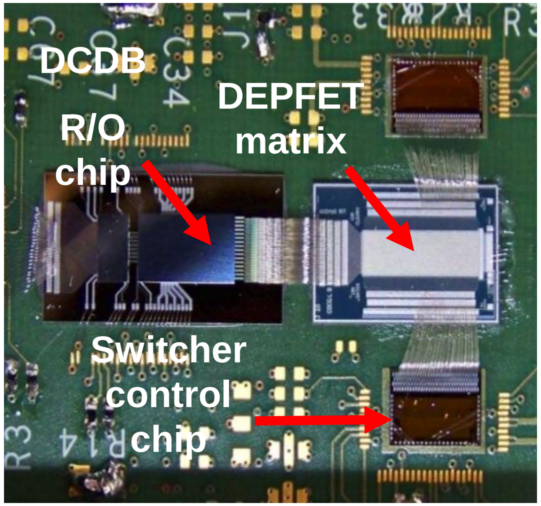
PXD+SVD Belle II



sBelle Design Group, KEK Report 2008-7

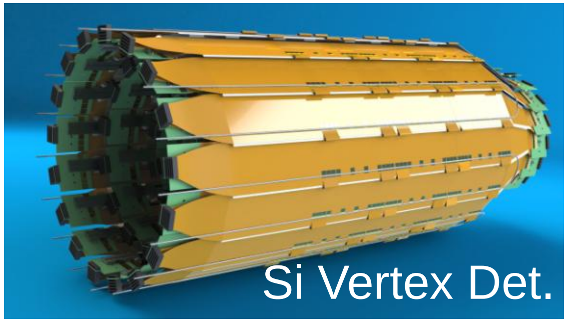
SVD Belle

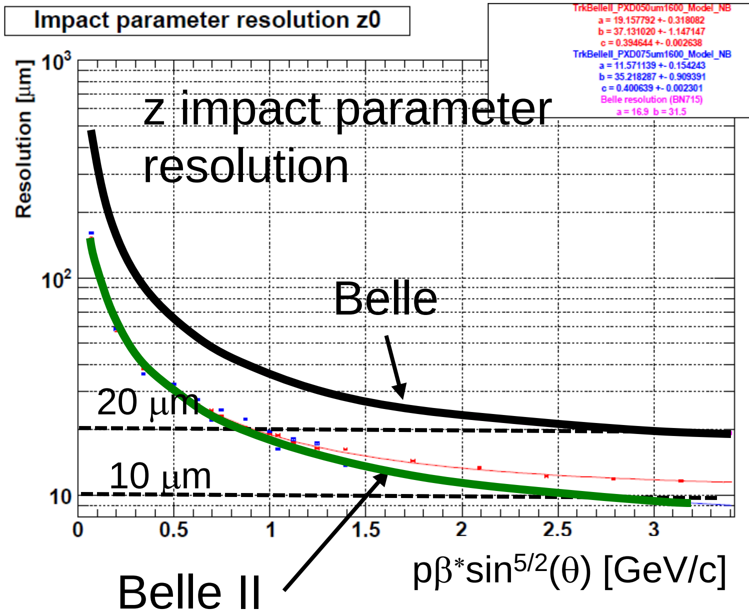




prototype DEPFET sensor

DEPFET mockup

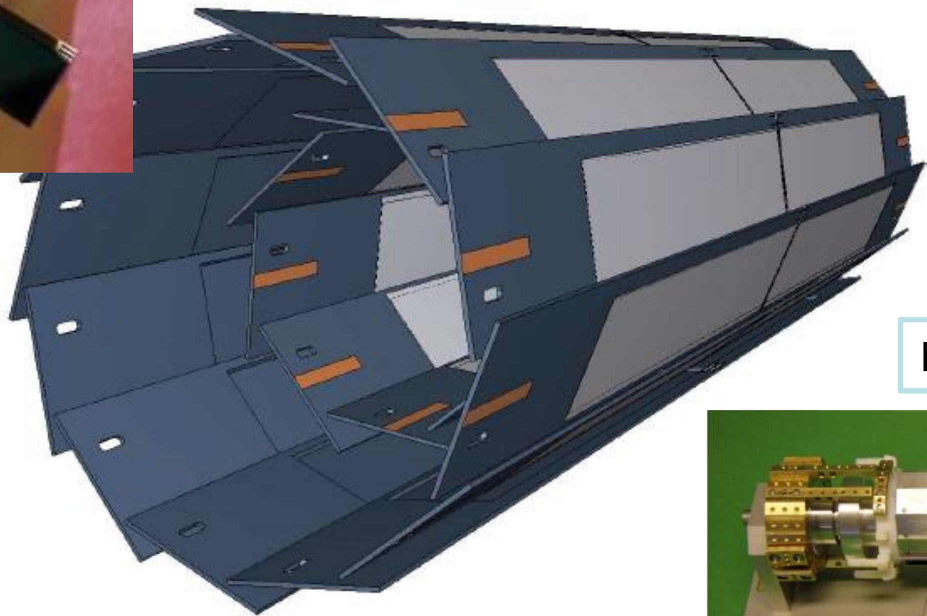


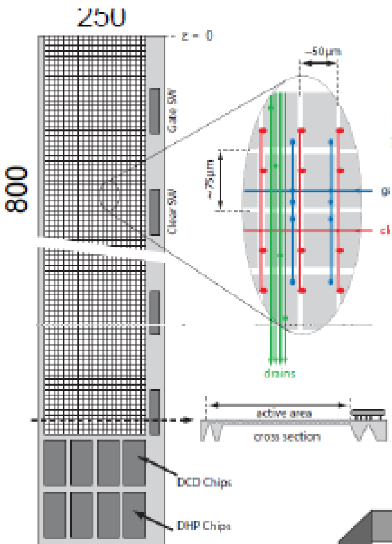


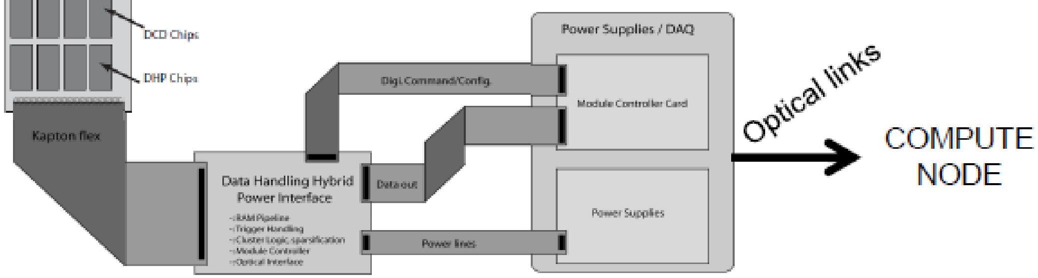
DEPFET pixels for Belle II

	radius	pixel	thickness
Layer 1	r = 14mm	50x50µm²	75µm(0.18%X0)
Layer 2	r = 22mm	50x75µm²	75µm

total of 8 M pixels







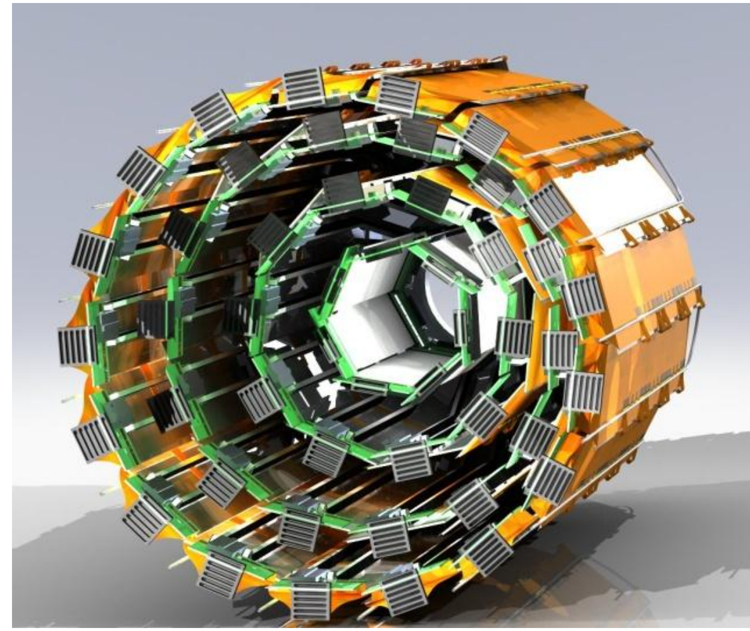
Mechanical mockup

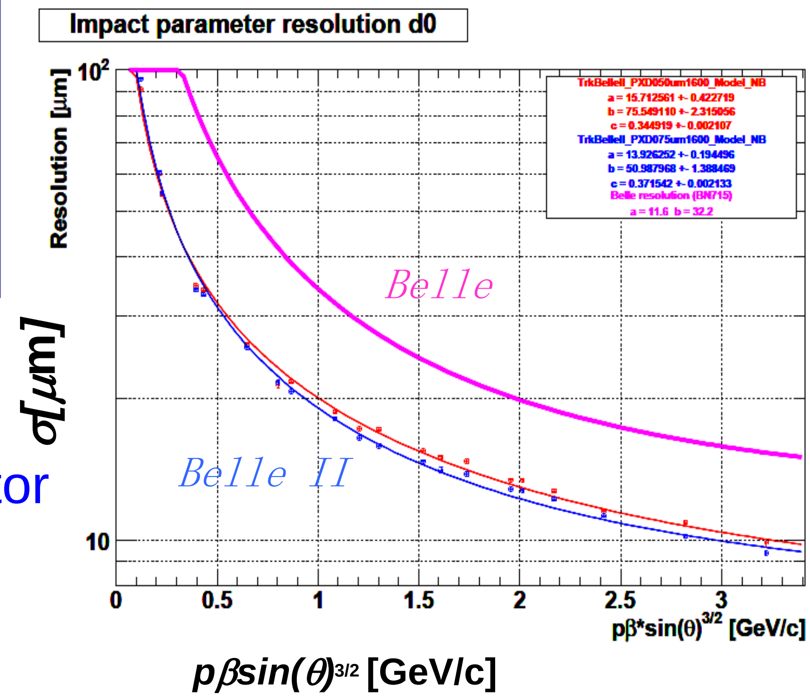
像素探测器

Power consumption in sensitive area: 0.1W/cm² => air-cooling sufficient

DSSDs

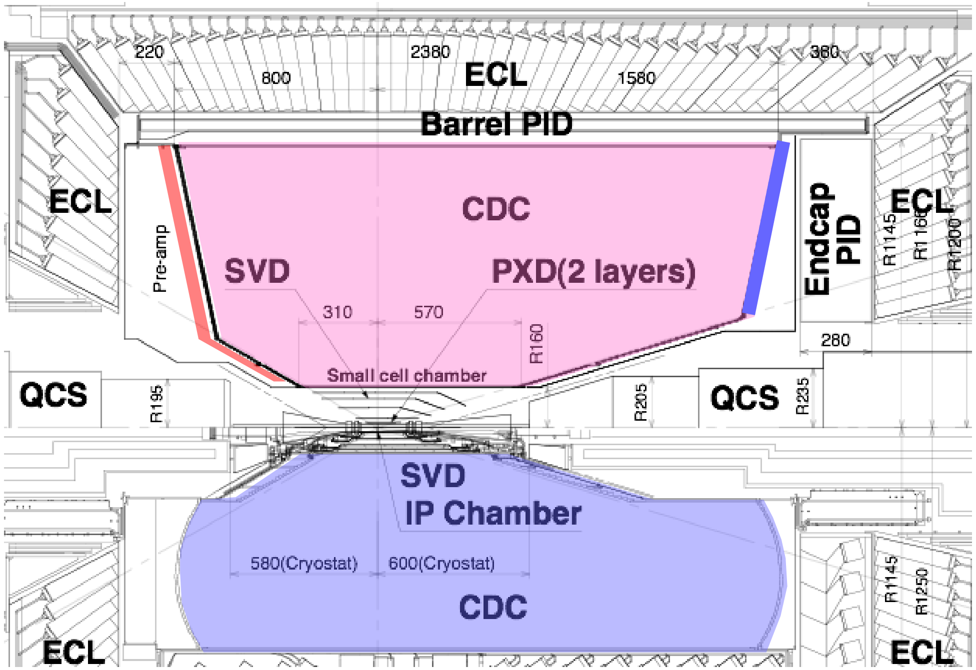
	Belle II	Belle
Beam Pipe	r = 10 mm	15 mm
DEPFET		
Layer 1	r = 14 mm	
Layer 2	r = 22 mm	
DSSD		
Layer 3	r = 38 mm	20 mm
Layer 4	r = 80 mm	43.5 mm
Layer 5	r = 115 mm	70 mm
Layer 6	r = 140 mm	88 mm





Less Coulomb Scattering & Pixel detector closer to the beam pipe improve the vertex resolution significantly.

Central Drift Chamber



longer lever arm

Improved momentum resolution and dE/dx

$$\sigma_{P_t}/P_t = 0.19 P_t \oplus 0.30/\beta$$

$$\sigma_{P_t}/P_t = 0.11 P_t \oplus 0.30/\beta$$

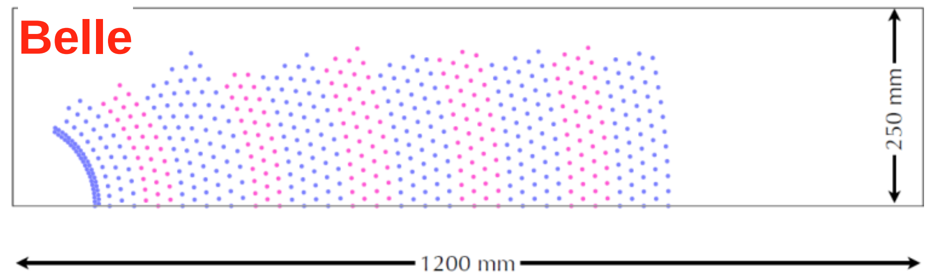
new readout system

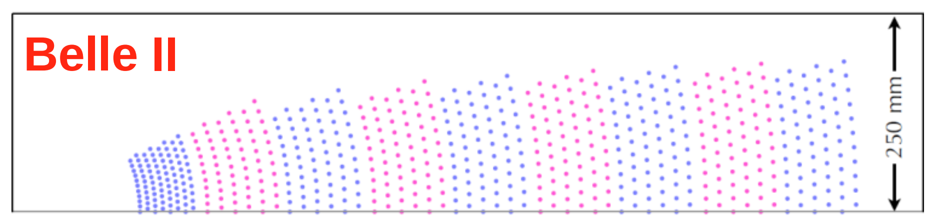
dead time 1-2μs → 200ns

small cell

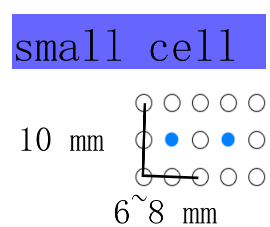
smaller hit rate for each wire

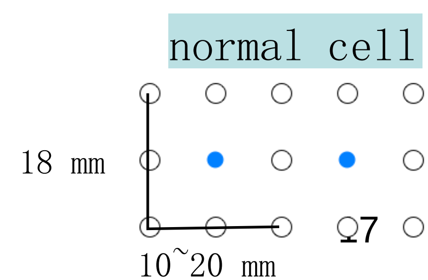
shorter maximum drift time





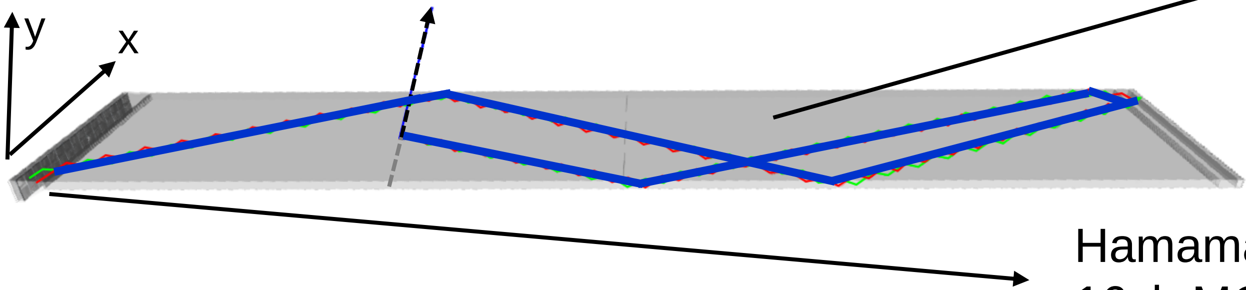
	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	He:C_2H_6	He:C_2H_6
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

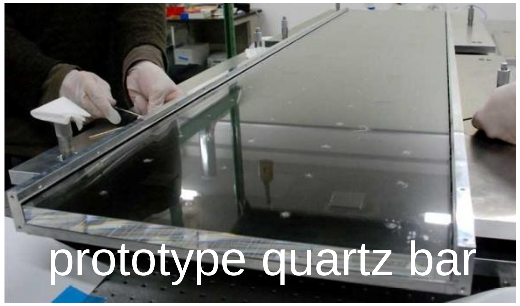




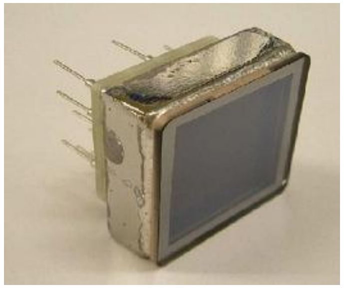
PID

Time Of Propagation counter (barrel)



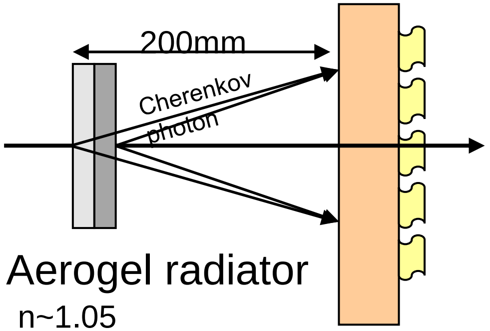


Hamamatsu
16ch MCP-PMT



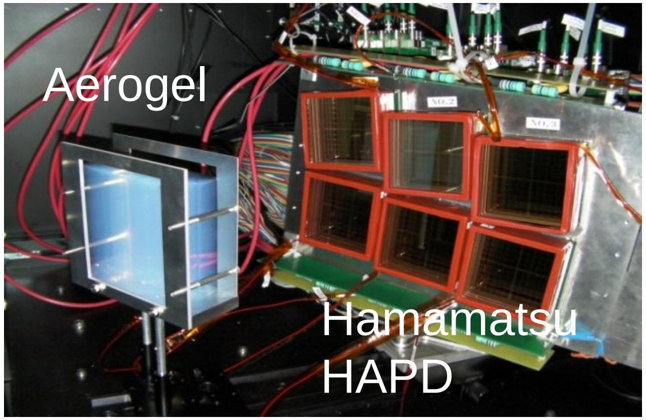
partial Cerenkov ring reconstruction
from x, y and t of propagation

Proximity focusing Aerogel RICH (endcap)

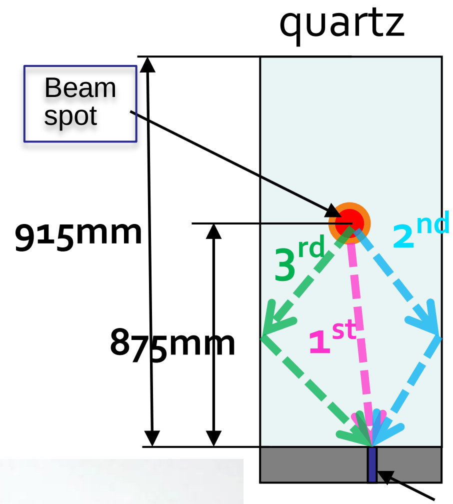


Aerogel radiator
n~1.05

Hamamatsu HAPD

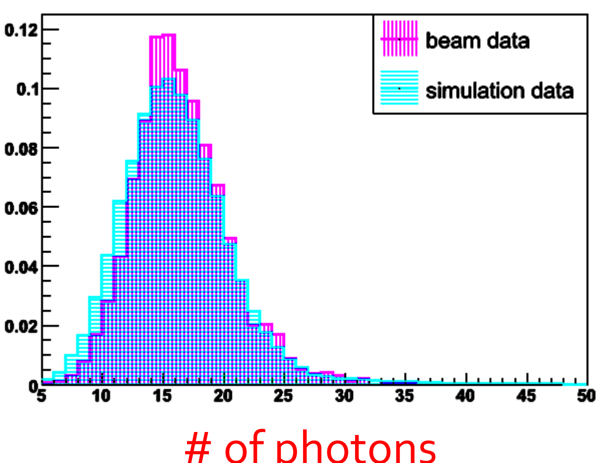


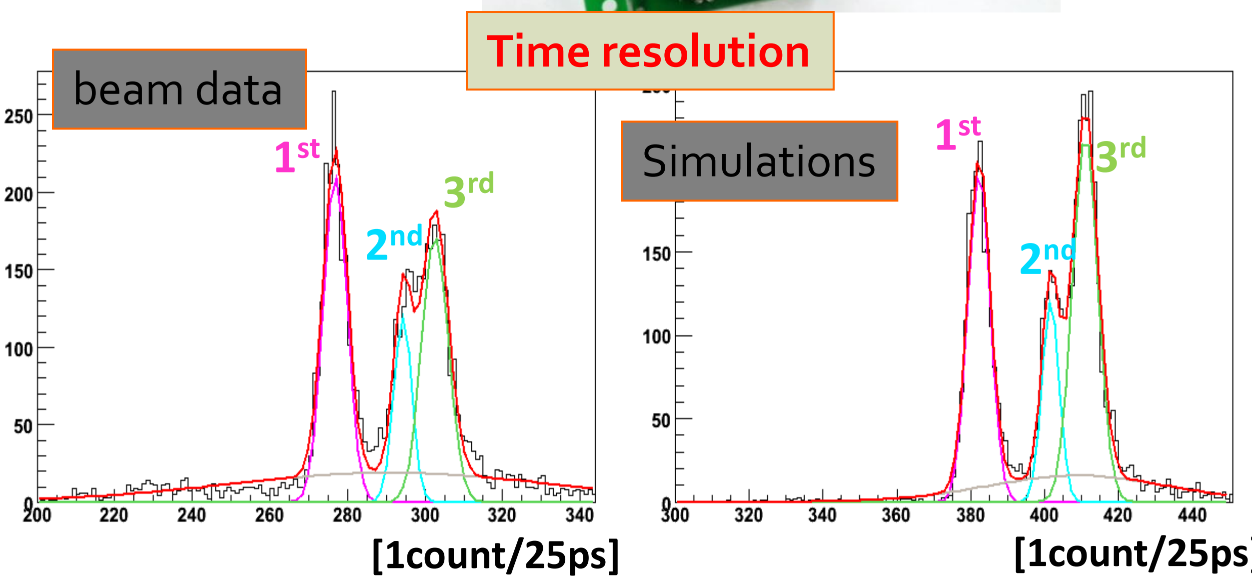
TOP (Barrel PID)



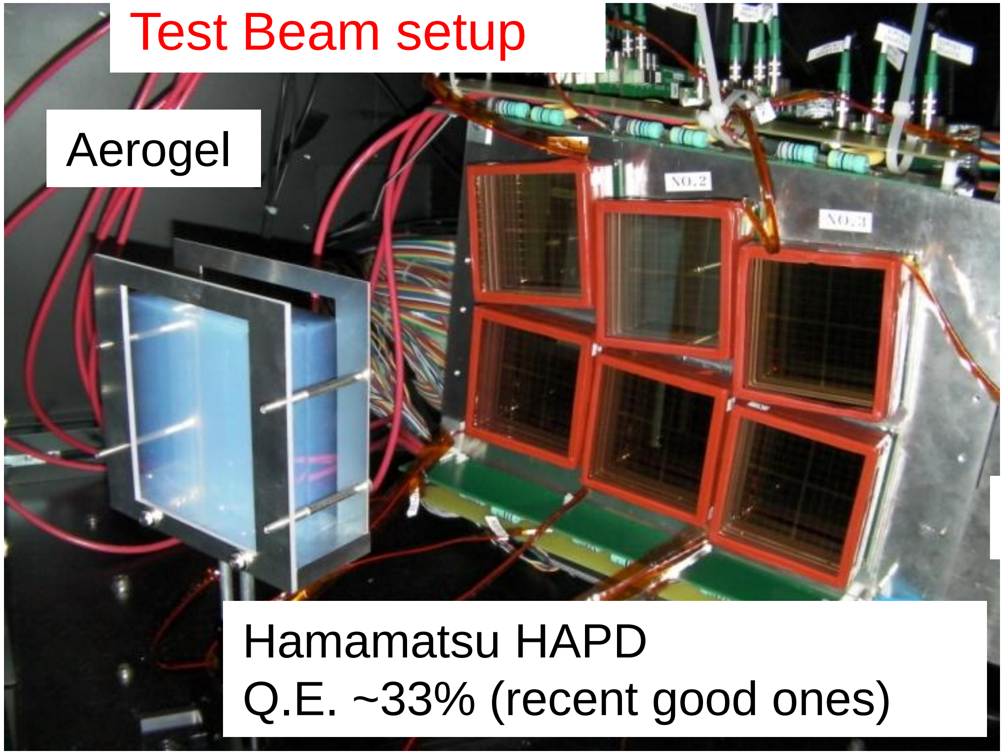
- Quartz radiator
  - 2.6m^L x 45cm^W x 2cm^T
  - Excellent surface accuracy
- MCP-PMT
  - Hamamatsu 16ch MCP-PMT
    - Good TTS (<35ps) & enough lifetime
    - Multialkali photo-cathode → SBA

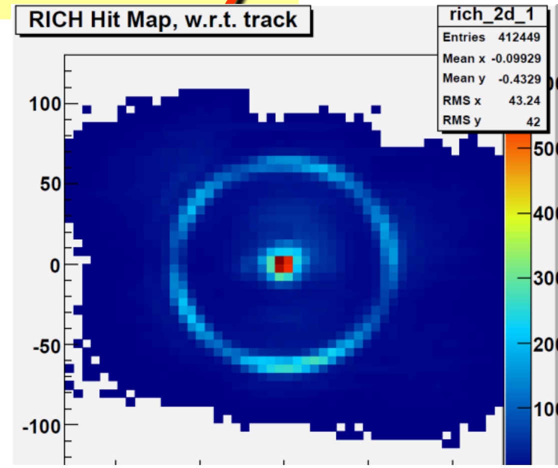
- Beam test was done
  - # of photons consistent
  - σ_T OK





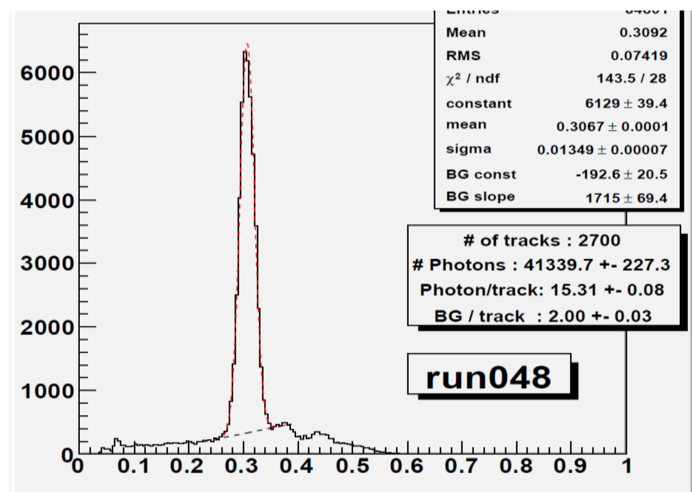
Aerogel RICH (endcap PID)





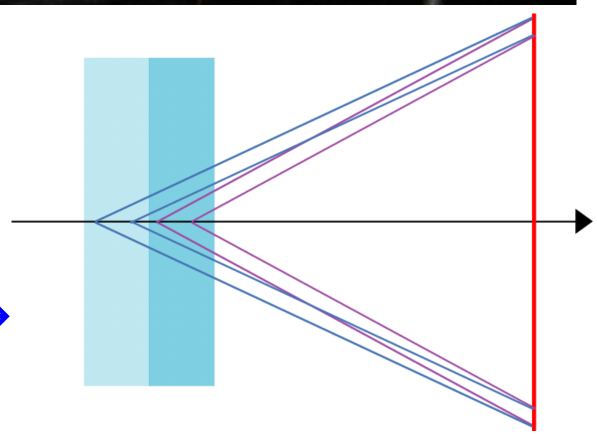
Clear Cherenkov image observed

Cherenkov angle distribution



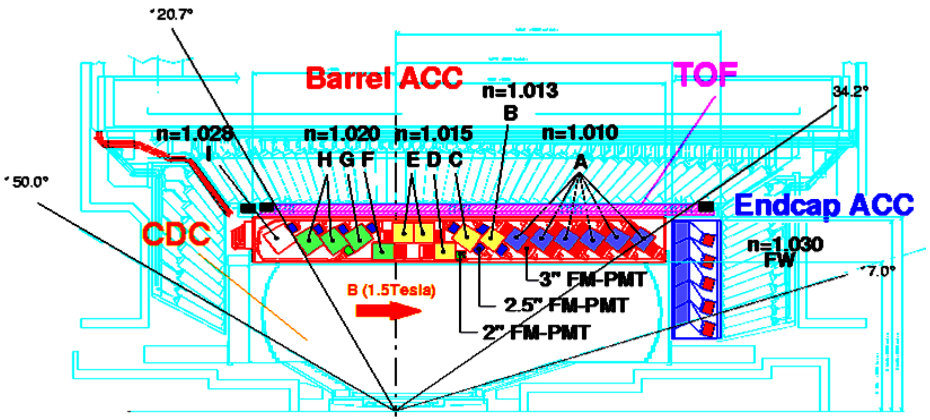
RICH with a novel "focusing" radiator --- a two-layer radiator

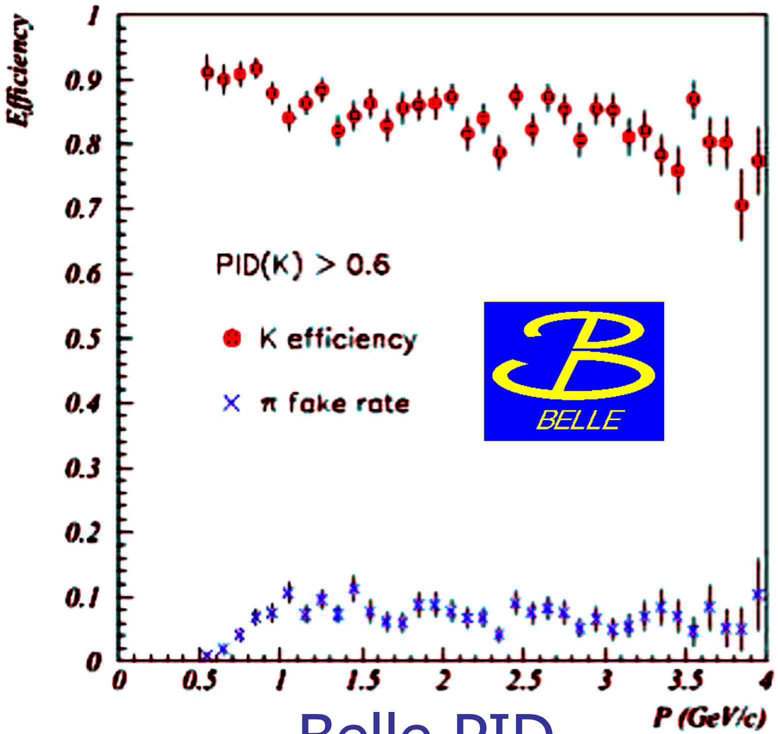
Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.



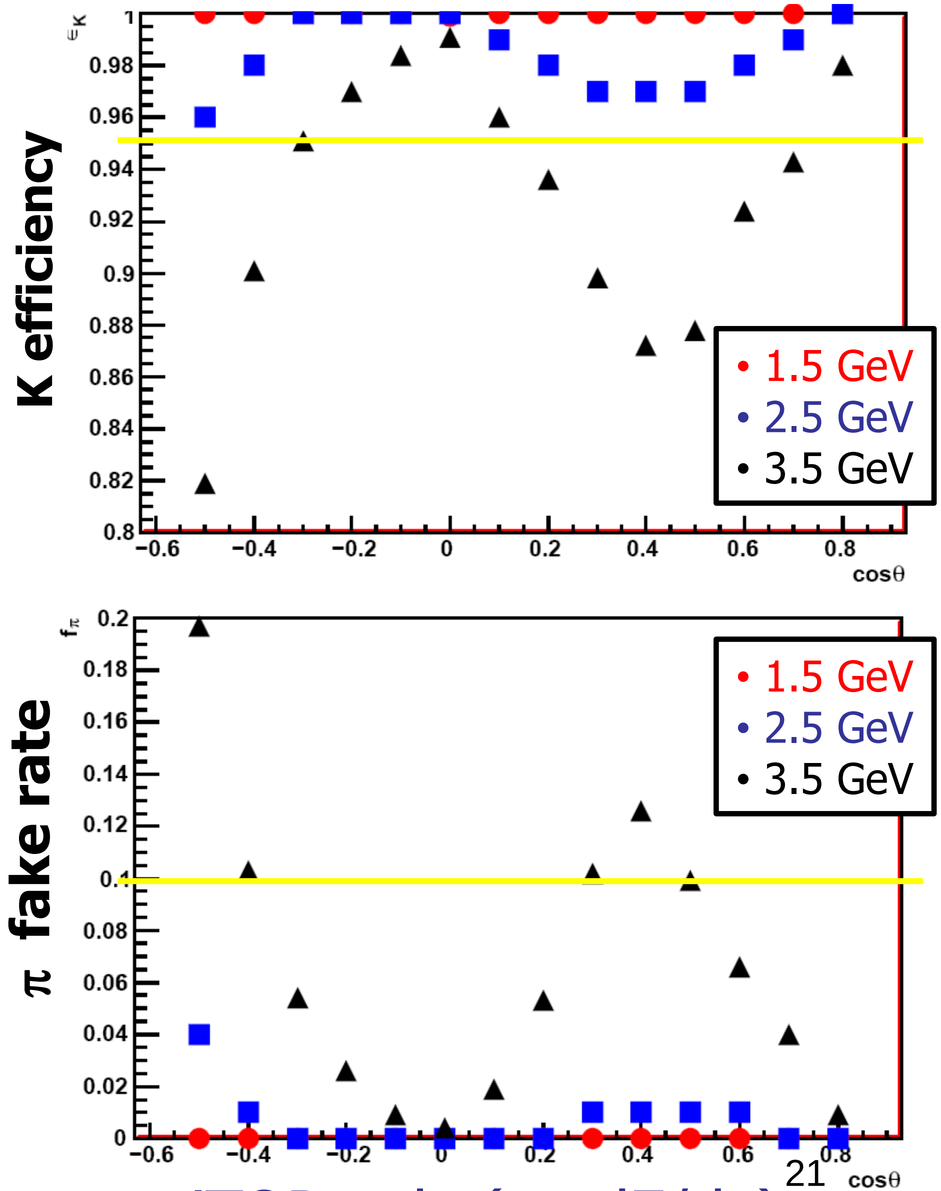
6.6 σ π/K at 4GeV/c !

Expected PID improvement





Belle PID

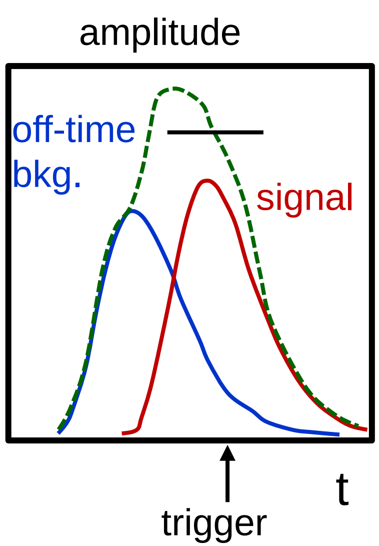


iTOP only (no dE/dx)

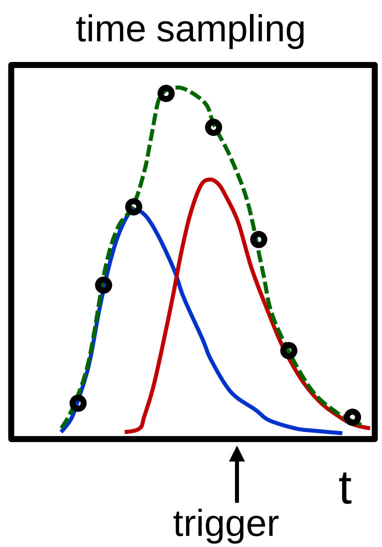
ECL (Electromagnetic Calorimeter)

1. Upgrade electronics to do waveform sampling & fitting
2. Upgrade endcap crystal (baseline option: pure CsI + photomultipliers); upgrade will have to be staged.

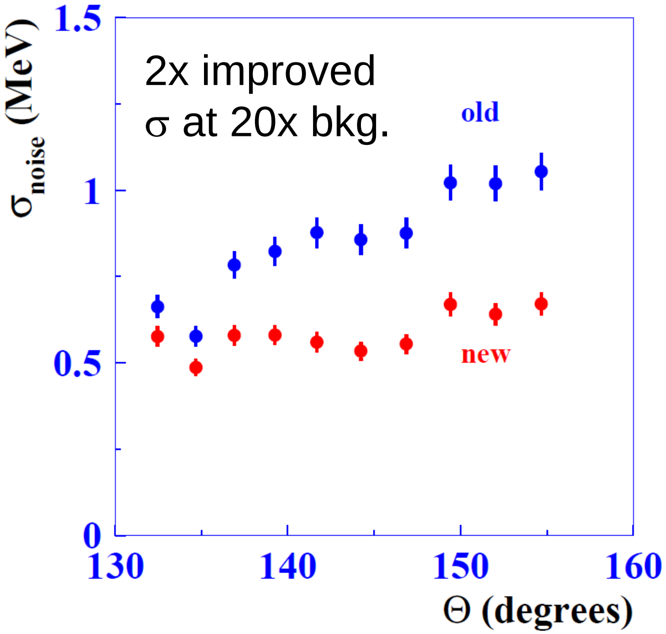
ECL signal



ECL signal



One module of new electronics tested in Belle



pure CsI crystals

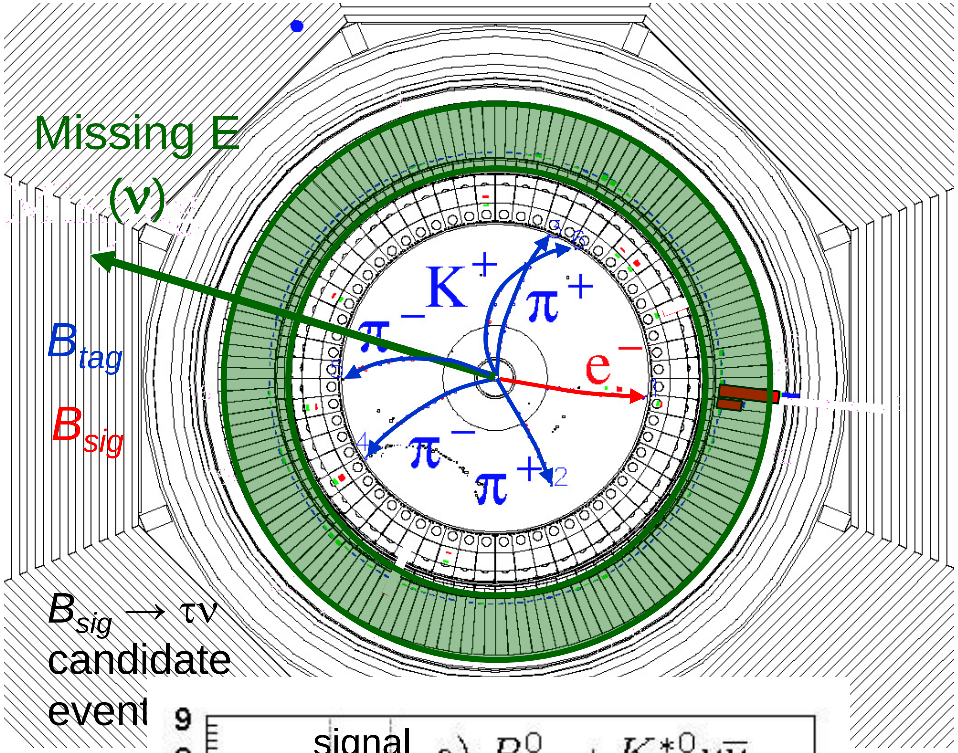
faster performance and better rad. hardness than Tl doped CsI

E_{miss} measurements

$B \to \tau\nu,\ h\nu\nu,\ \ldots$

fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig}\to h\nu\nu$ or $\tau(\to h\nu)\nu$;
no additional energy in EM calorim.;
signal at E_{ECL}~0;

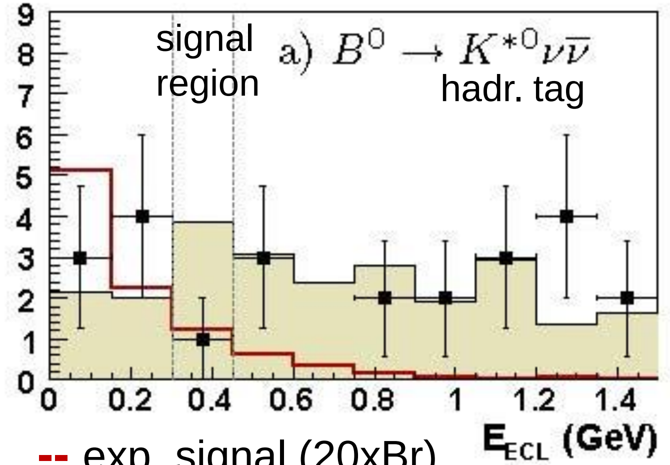
B_{tag} full reconstruction:
NeuroBayes;
TOP detector;
ECL, increased background;



Example of $B \to h\nu\nu$ measurement:

$\mathcal{B}(B^0 \to K^{*0}\nu\nu) <\ 3.4 \cdot 10^{-4}$ @ 90% C.L.

Belle, PRL99, 221802 (2007), 490 fb^{-1}

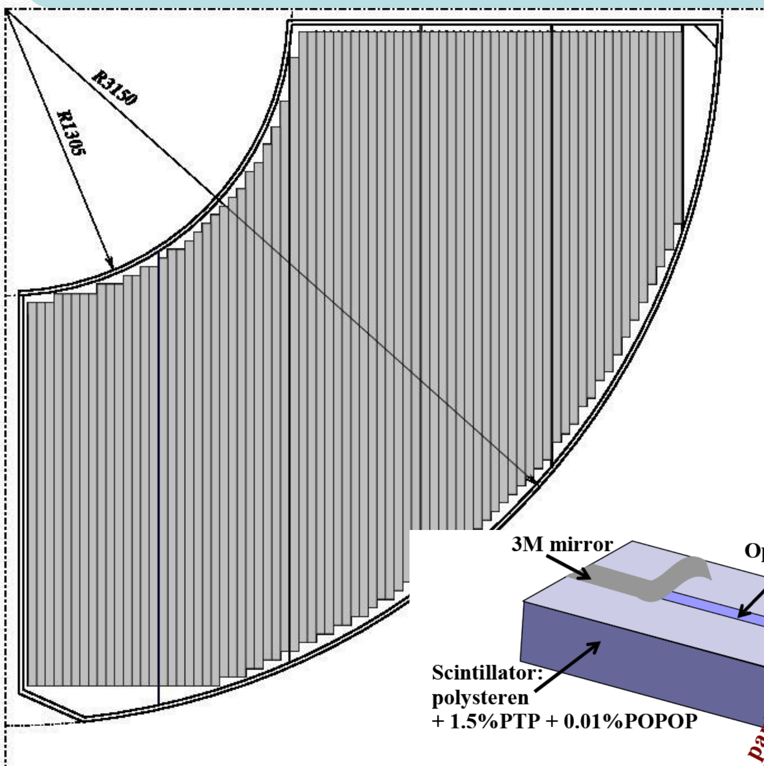


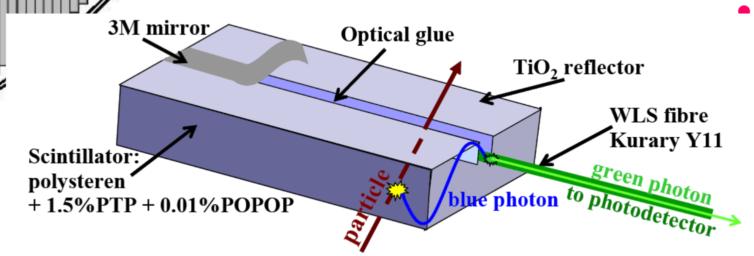
-- exp. signal (20xBr)
exp. bkg. (scaled to sideband)

$\mathcal{B}(B^+ \to K^{(*)+}\nu\nu)$ can be measured to ±30% with 50 ab^{-1}

KLM: K_L & Muon detector

RPC → Scintillator (Endcap)
also inner 1,2, or 3 layers of Barrel (TBD)

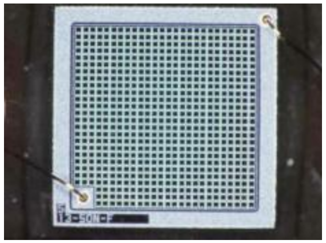




LAYOUT

- **One layer: 75 strips (4 cm width)/sector**
- **5 segments**
  1 segment = 15strips
- **Two orthogonal layer**
  = superlayer
- **F&B endcap KLM:**
  - **Total area ~1400 m^2**
  - **16800 strips**
  - **the longest strip 2.8 m; the shortest 0.6 m**
- **WLS fiber in each strip**
  Hamamatsu MPPC at one fiber end
  mirrored far fiber end

Endcap muon detection is already limited by bkgs. Endcap RPCs will not work at full luminosity and higher bkgs. Inner barrel is *marginal.*



MPPC: Hamamatsu 1.3×1.3 mm 667 pixels (used in T2K Near Detector)

Estimated Data Rates

Experiment	Event Size [kB]	Rate [Hz]	Rate [MB/s]
High rate scenario for Belle II DAQ:			
Belle II	300	6,000	1,800
LCG TDR (2005):			
ALICE (HI)	12,500	100	1,250
ALICE (pp)	1,000	100	100
ATLAS	1,600	200	320
CMS	1,500	150	225
LHCb	25	2,000	50

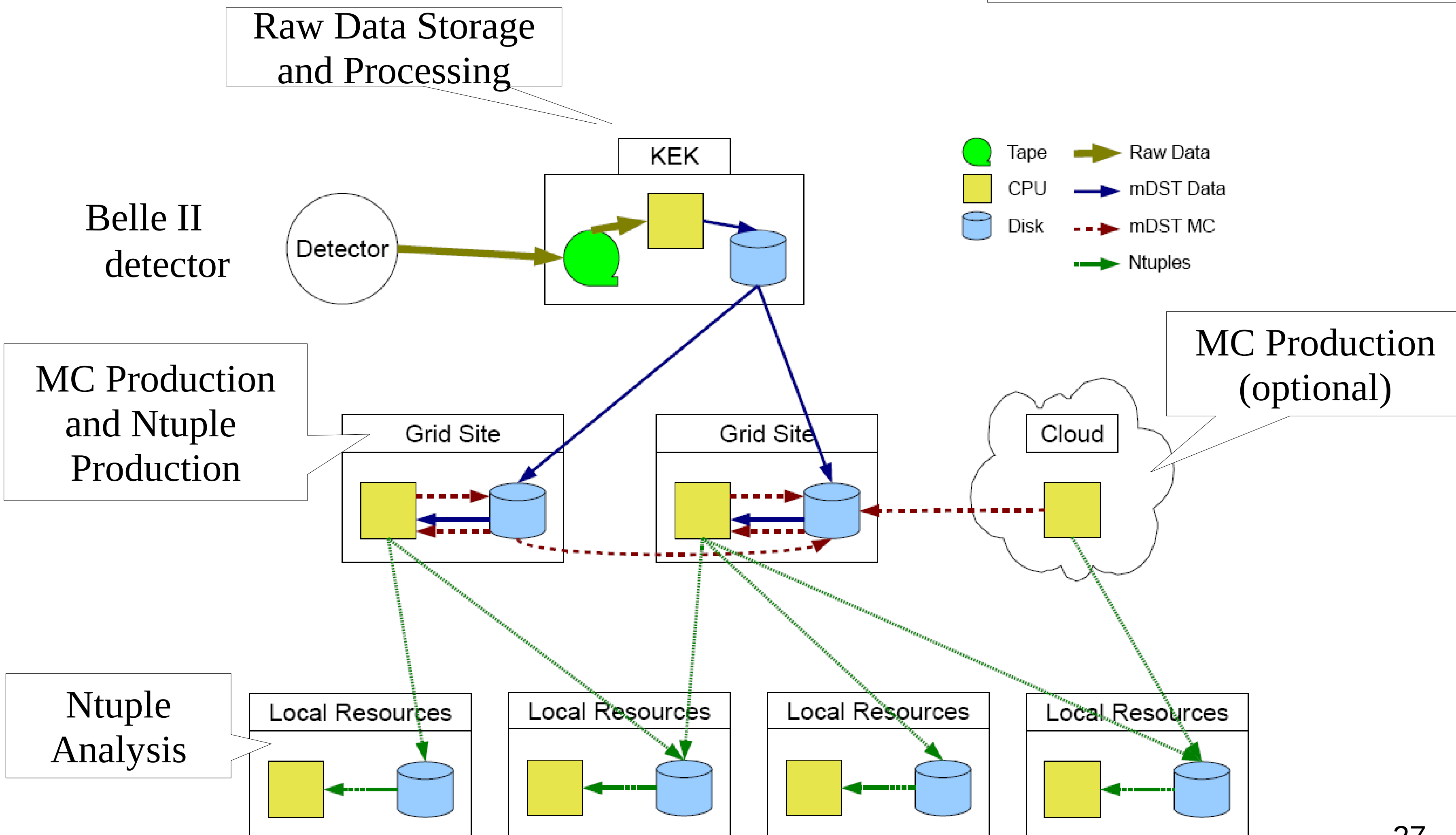
Belle II Collaboration

~ 400 members from 65 institutes in 19 countries

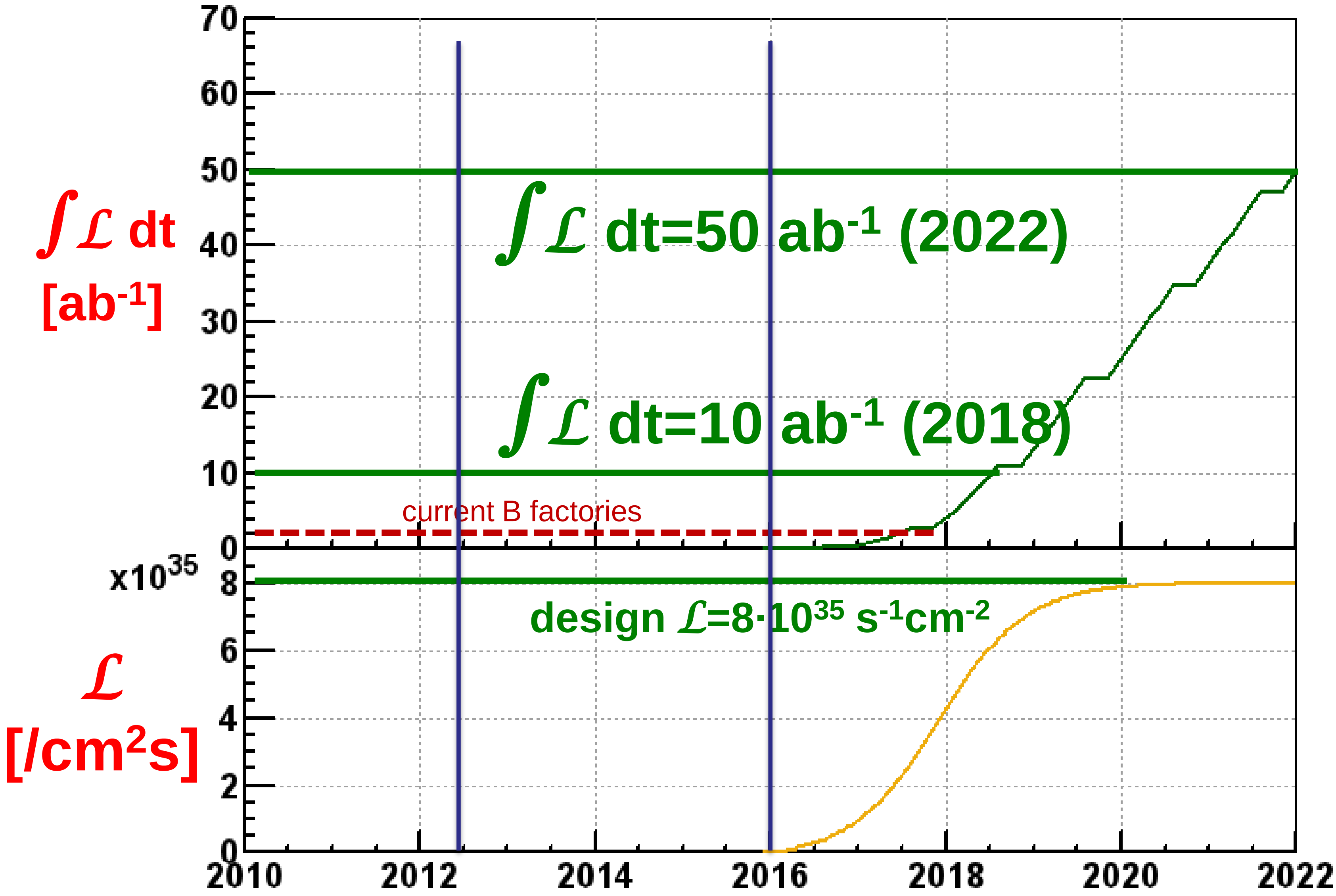
➔ Distributed collaboration ➔ distributed computing

Belle II Computing Model: Grid-based Distributed Computing

Common framework for DAQ and offline based on root I/O



Luminosity vs. time



Summary

- Belle II at SuperKEKB will enable a new generation of precision studies in flavor physics.
- Belle II and LHC experiments will be nicely complimentary.
- Significant opportunities both during data collection and with final dataset (50+ ab^{-1}).
  - for more information, see:
    - http://belle2.kek.jp/physics.html
    - Belle II Technical Design Report - arXiv:1011.0352

Thank you!