Status of Belle II

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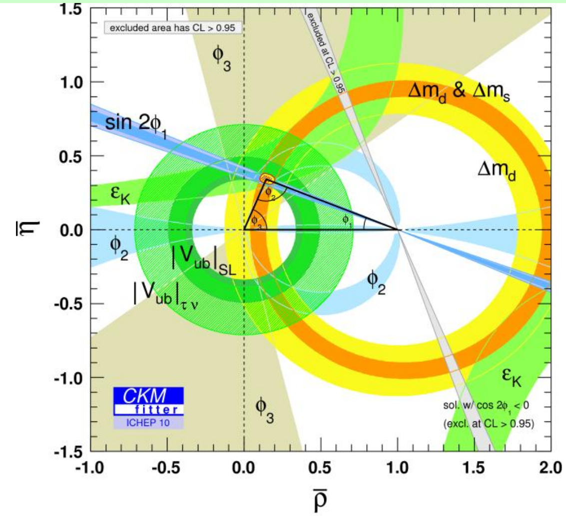
(Belle/Belle II Collaboration)

- Physics motivation
- Super KEKB design
- Belle II detector
- Some physics
- Summary

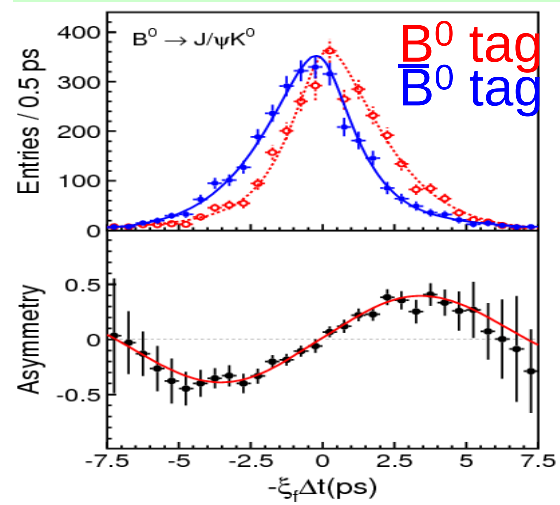
B- Factories (KEKB&PEP-II): A Success Story

- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decays (e.g., $B \rightarrow \tau\nu$, $D\tau\nu$)
- $b \rightarrow s$ transitions: probe for new sources of CPV and constraints from the $b \rightarrow s\gamma$ branching fraction
- Forward-backward asymmetry (A_{FB}) in $b \rightarrow sll$ has become a powerfull tool to search for physics beyond SM.
- Observation of D mixing
- Searches for rare τ decays
- Observation of new hadrons

Measurements of the CKM matrix elements



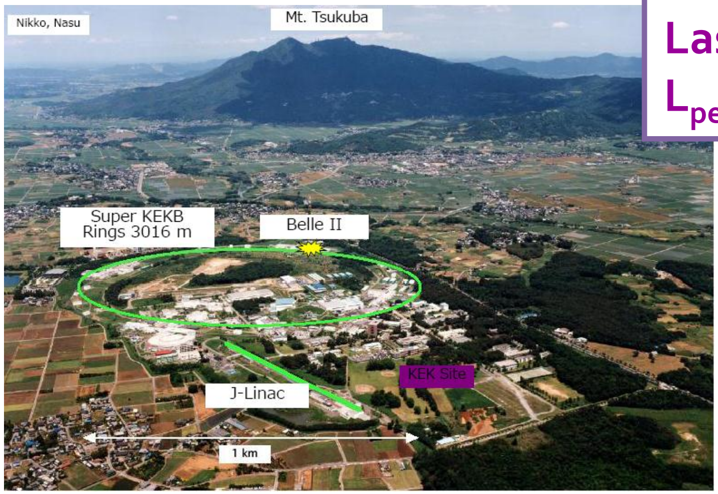
Discovery of *CP* violation in the B system

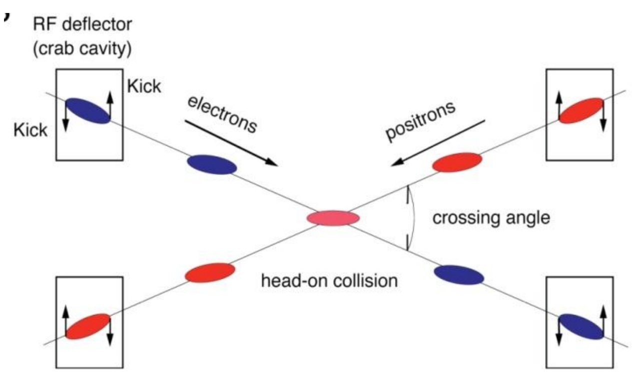


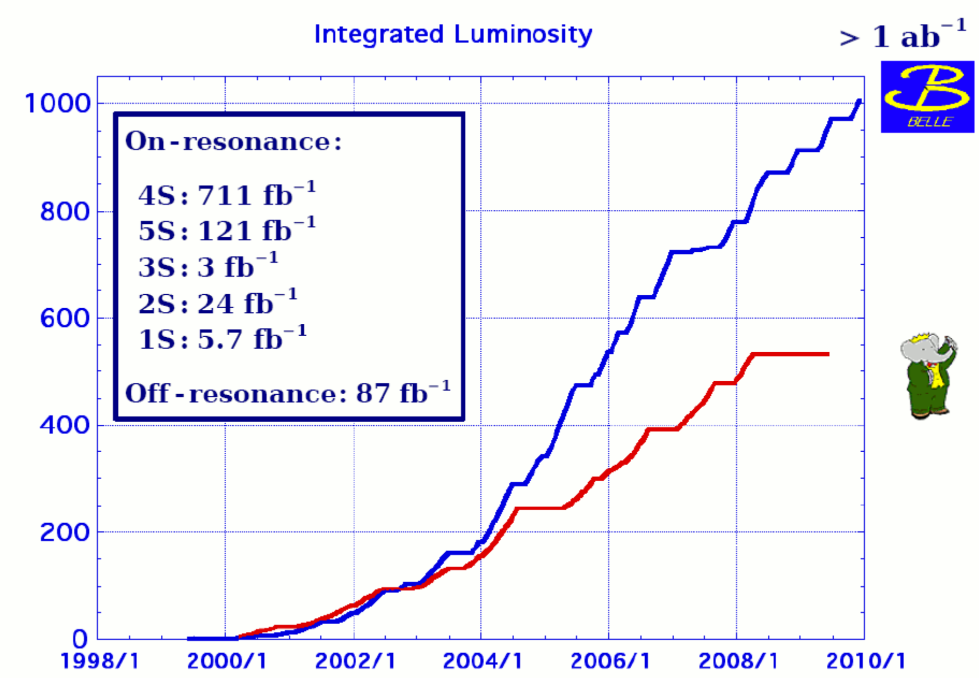
World maximum luminosity – at KEKB

KEKB:
HER: 8.0 GeV
LER: 3.5 GeV
crossing: 22 mrad
E_{CMS}=M(U(4S))
bg=0.425

First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1\times10^{34}/cm^2/s$ Ltot > $1ab^{-1}$





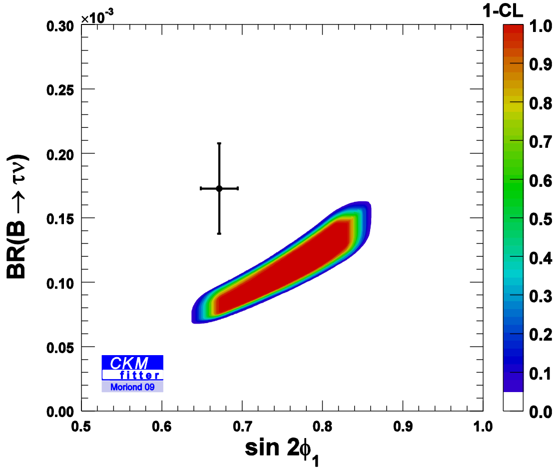


Peak lumi record at KEKB: L=2.1 x 10^{34}/cm^2/sec with crab cavities

Why to upgrade?

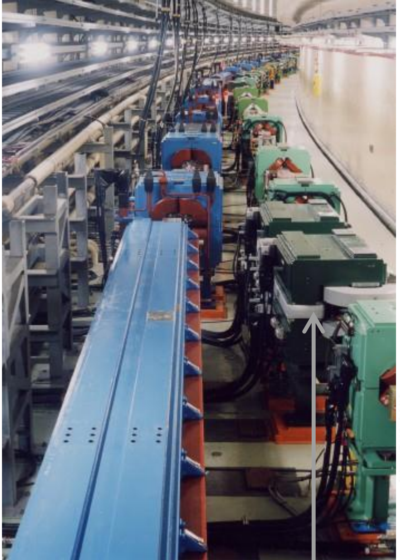
- B factories → is SM with CKM right?
  - ✓ Success of B-Factories: confirmation of KM mechanism of CPV
  - ✓ Standard Model works well in this flavor sector
- Super B factories → How is the SM wrong?
  - ☐ Still room for corrections from New Physics at O(10%)
  - ☐ Hints of NP: tensions between results from B-Factories

  Much larger dataset is NEEDED

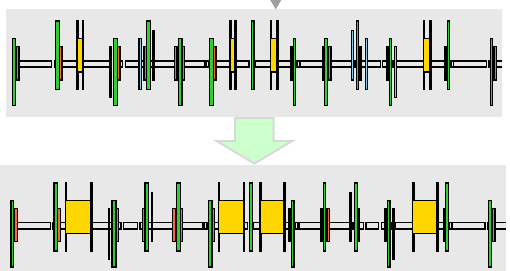


- **Key Measurements of Super KEKB:**
  - Measurement of the Unitary Triangle, but with a precision an order of magnitude better than what we have now.
  - Other potential measurements that are sensitive to BSM.
- **Physics motivation is independent of LHC.**
  - If LHC finds NP, precision flavor physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be a unique way to search for the physics far beyond the TeV scale.

KEKB to Super KEKB



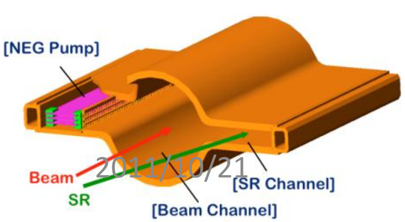
Replace short dipoles with longer ones (LER)

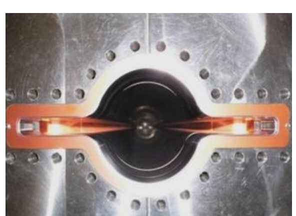


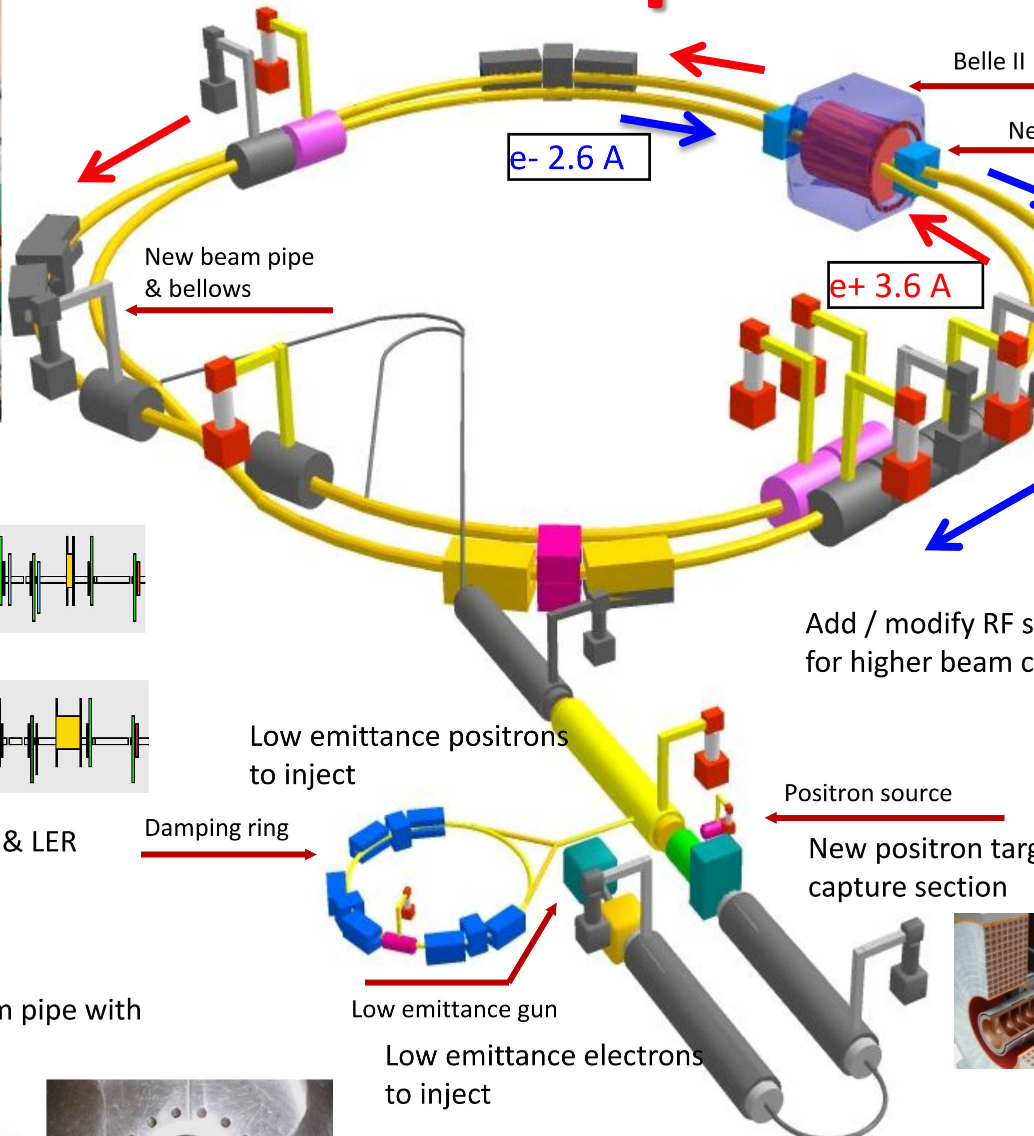
Redesign the lattices of HER & LER to squeeze the emittance

Nano-beams!

TiN-coated beam pipe with antechambers

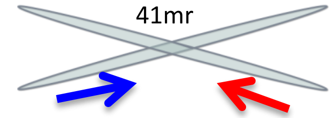






Low emittance positrons to inject

Low emittance electrons to inject



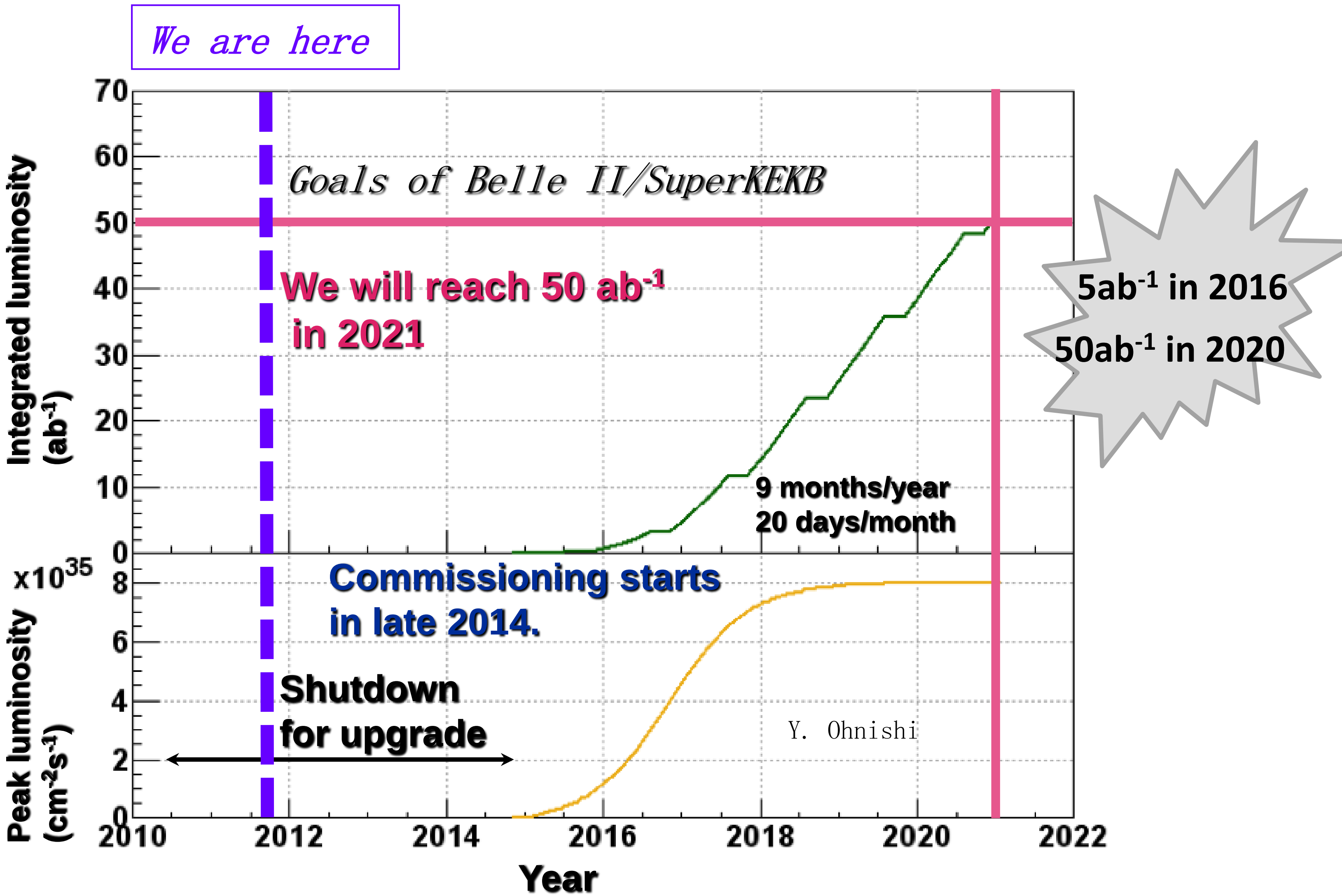
New superconducting /permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

To get x40 higher luminosity 8x10^{35}

Super KEKB luminosity profile

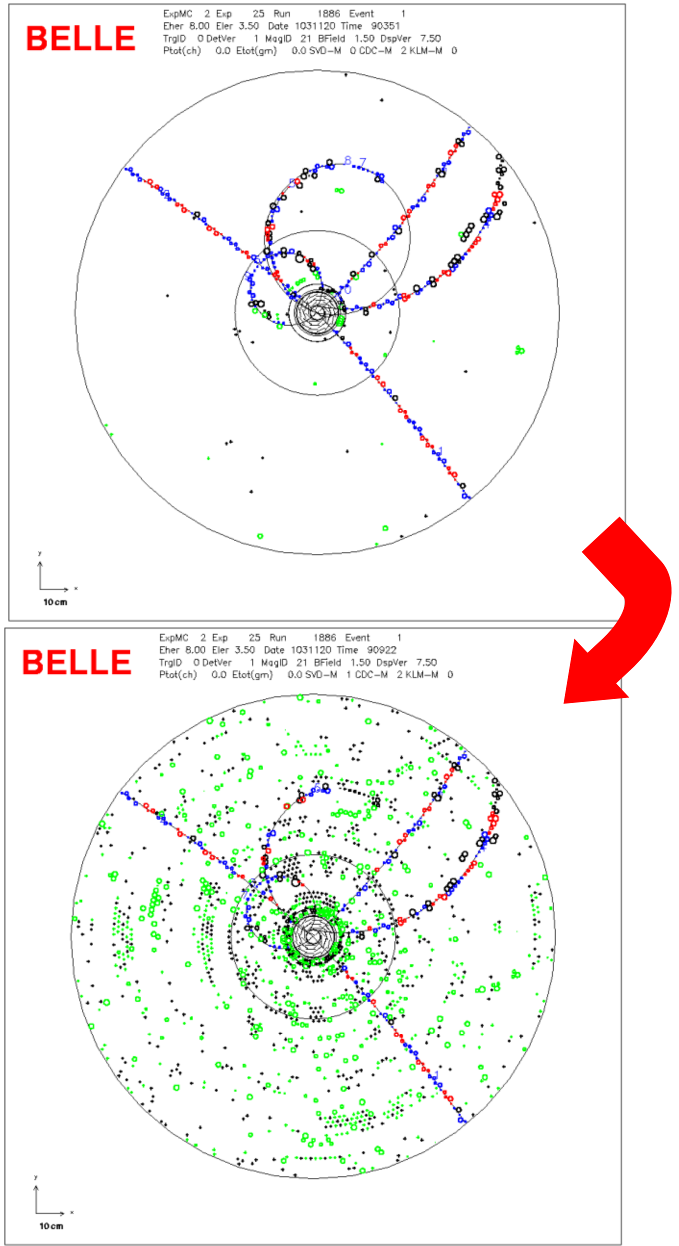


Requirements for the Belle II detector

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 *p* μ identification ← sμμ recon. eff.
  - hermeticity ← **ν** "reconstruction"

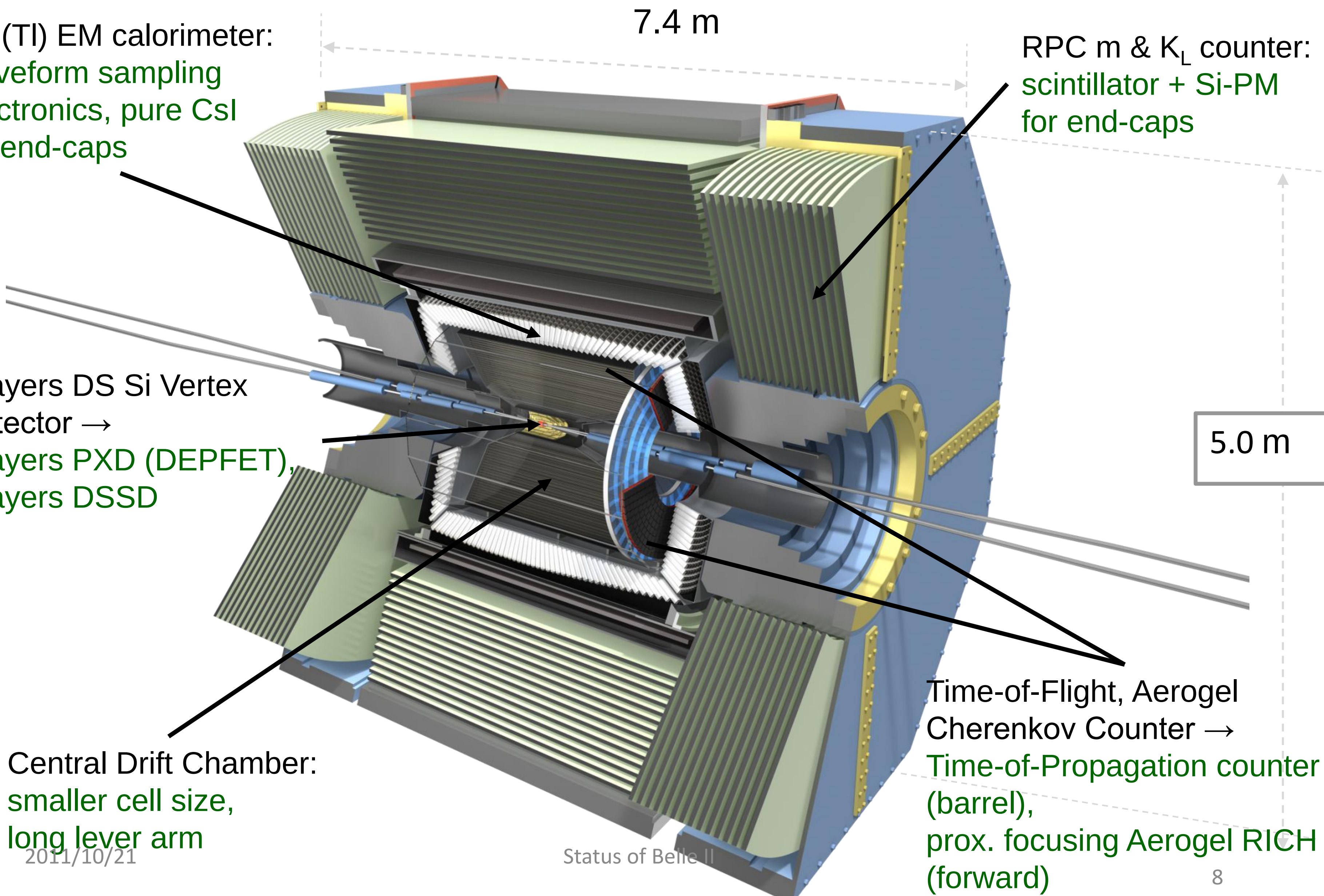
Result: significant upgrade



Belle II: design concept

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

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

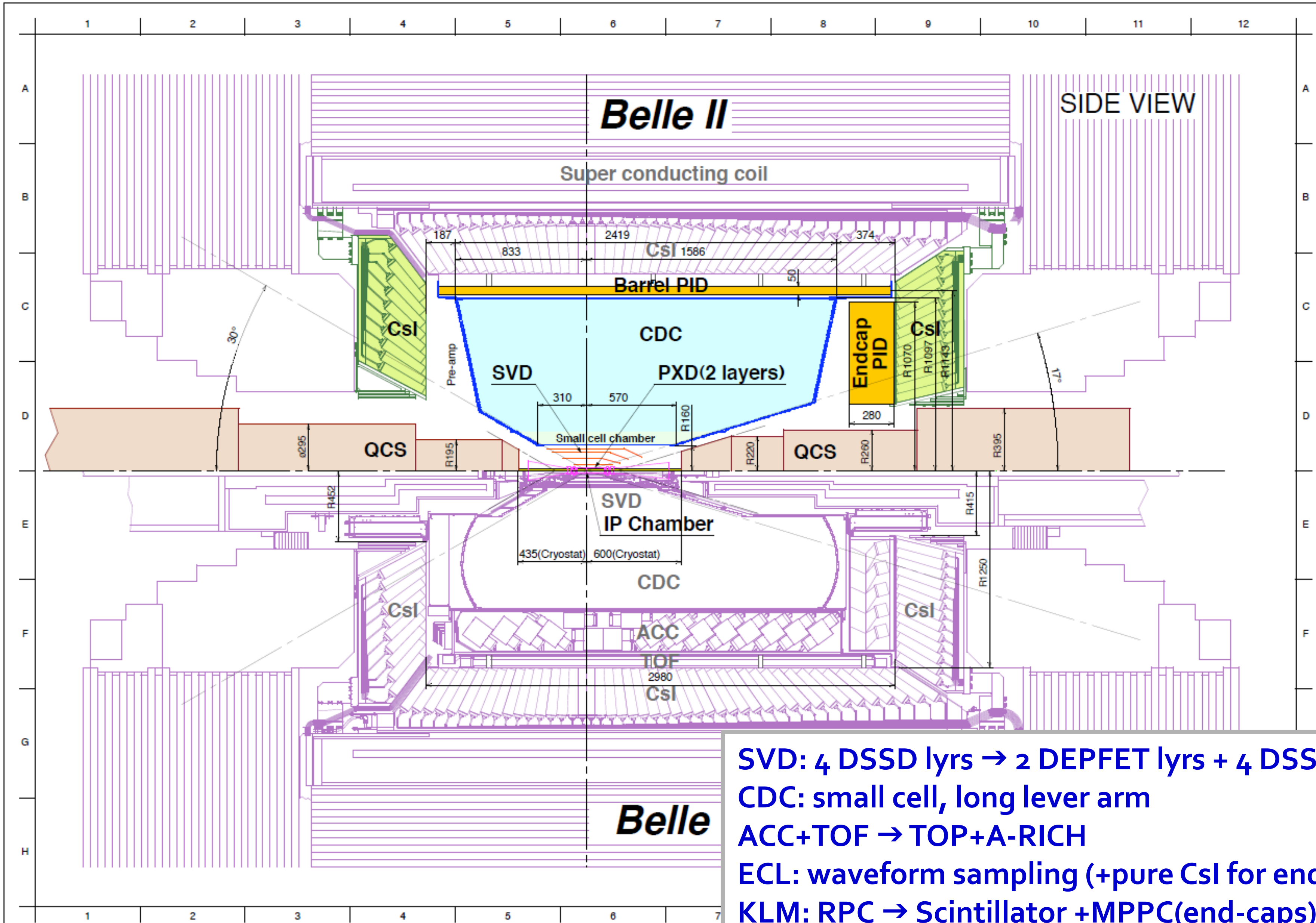


4 layers DS Si Vertex Detector →
2 layers PXD (DEPFET), 4 layers DSSD

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)

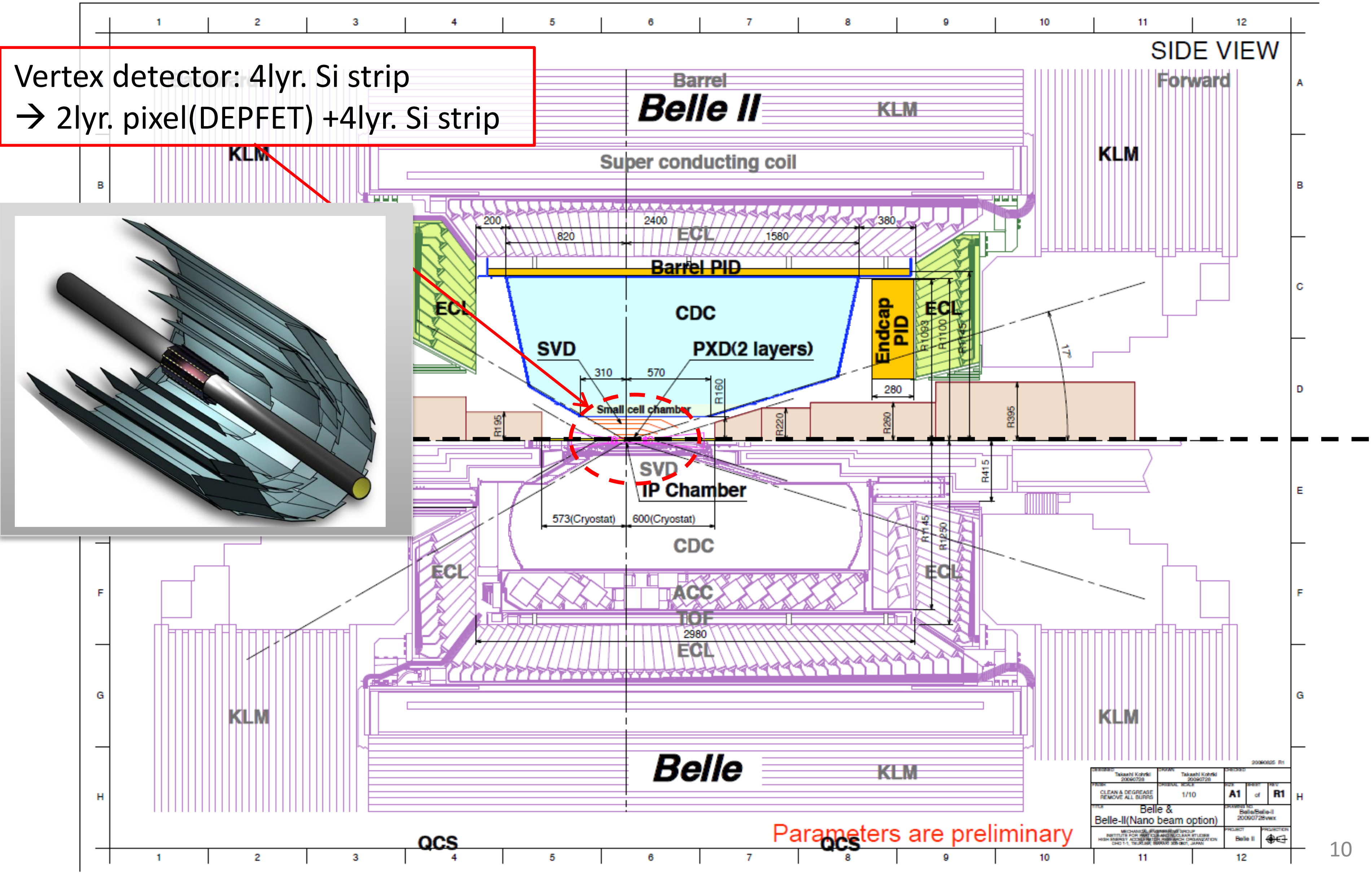
Belle II Detector (in comparison with Belle)



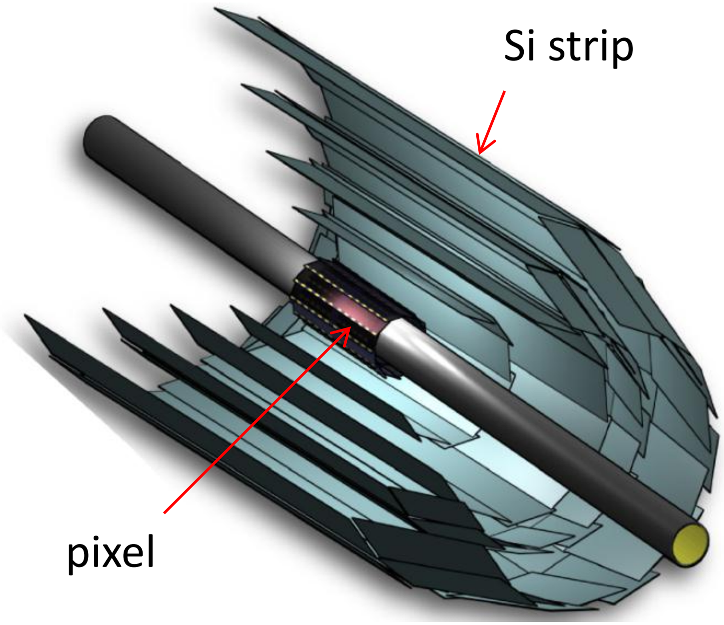
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for end-caps)
KLM: RPC → Scintillator +MPPC(end-caps)

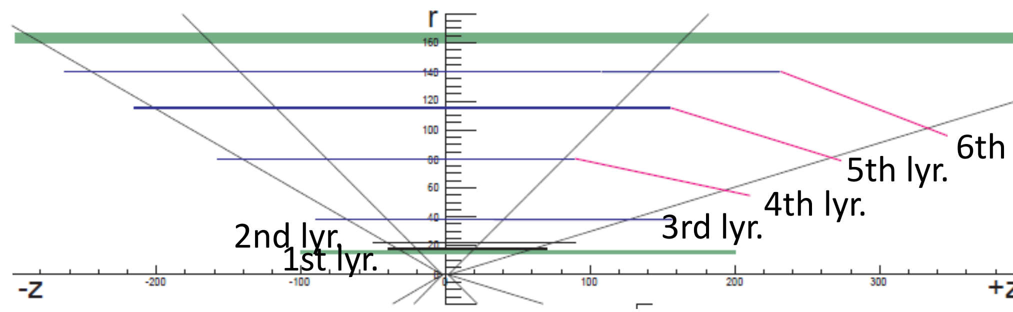
Detector upgrade

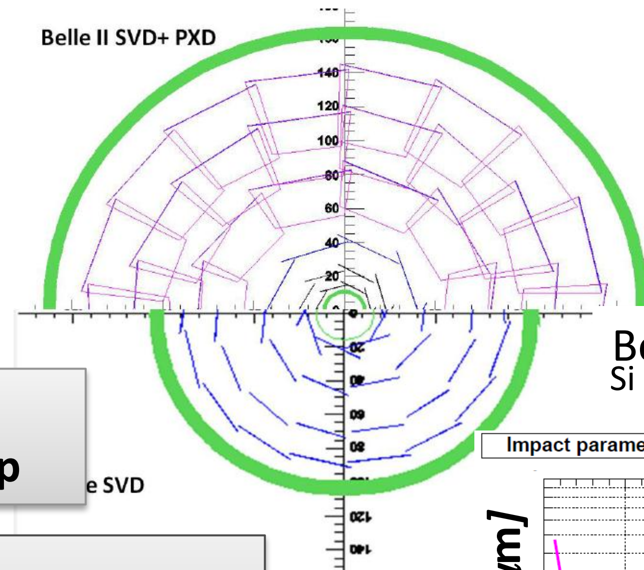
Vertex detector: 4lyr. Si strip
→ 2lyr. pixel(DEPFET) +4lyr. Si strip



Belle-II vertex detector





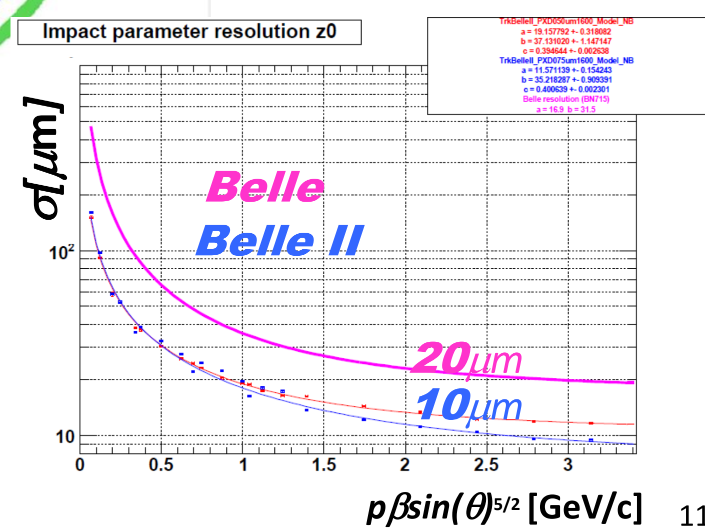


Belle-II
Pixel: r=14/22mm
Si strip: r=38/80/115/140mm

Belle
Si strip: r=20/43.5/70/88mm

4lyr. Si strip
→ 2lyr. pixel(DEPFET) + 4lyr. Si strip

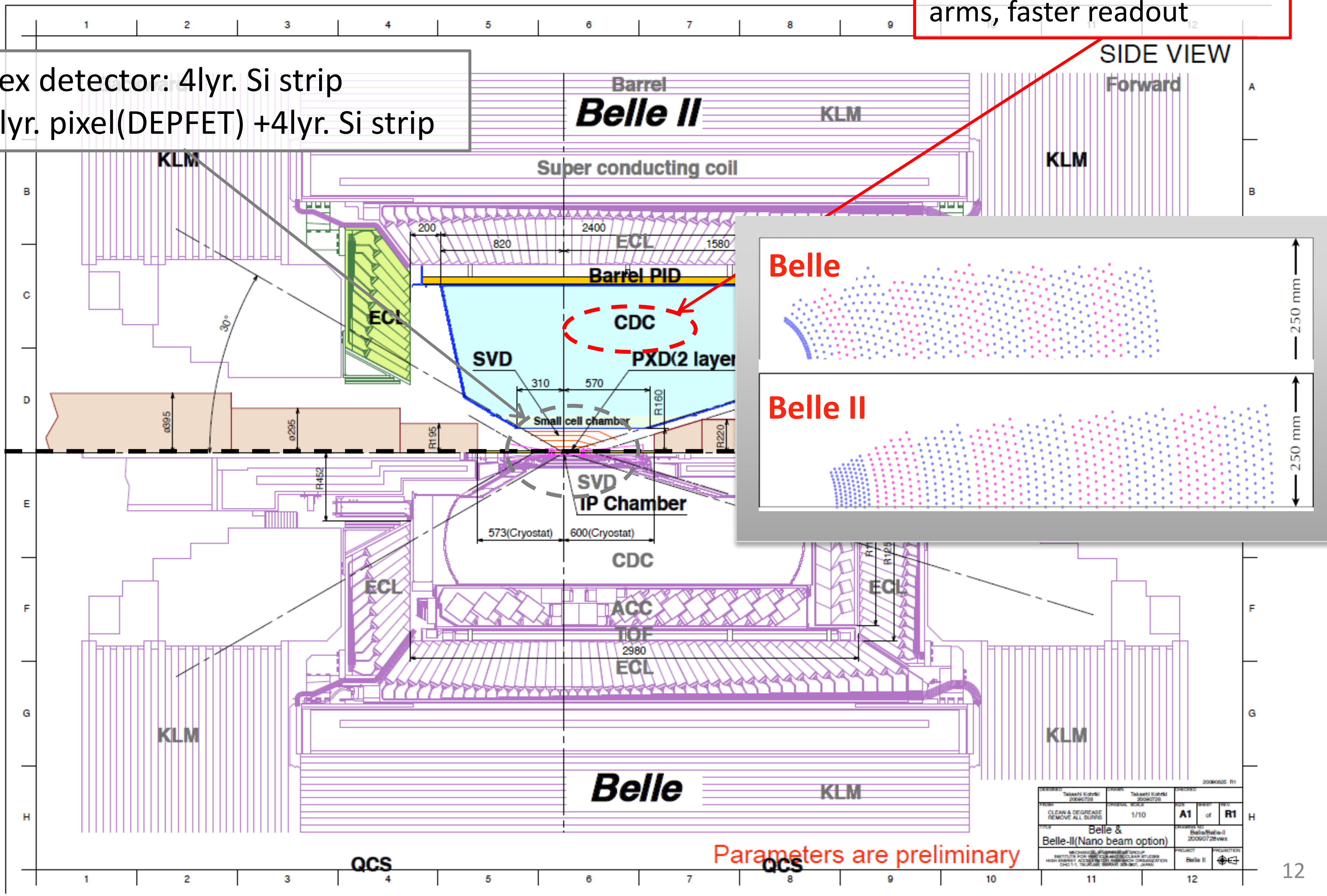
Pixel detector closer to IP
→ 25% Improved decay vertex resolution
Increased radial coverage
→ 30% higher efficiency of $K_S \to \pi^+\pi^-$
better reconstruction of p_T<100MeV tracks.



Detector upgrade

Drift chamber for tracking: Small cells, longer lever arms, faster readout

Vertex detector: 4lyr. Si strip
→ 2lyr. pixel(DEPFET) +4lyr. Si strip

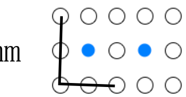


Parameters are preliminary

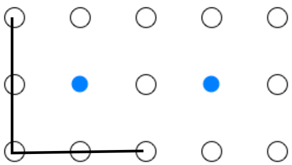
Central Drift Chamber

small cell
smaller hit rate for each wire
shorter maximum drift time

small cell



normal cell

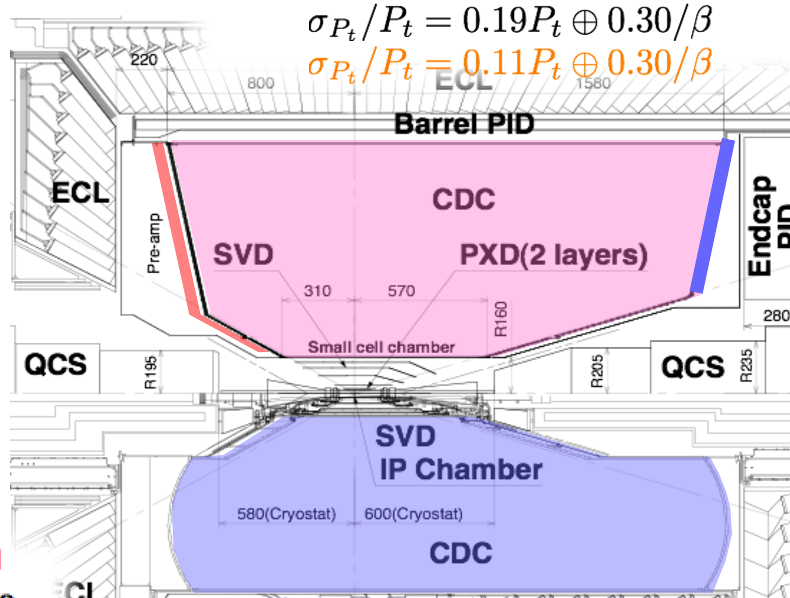


new readout system
dead time 1-2μs → 200ns

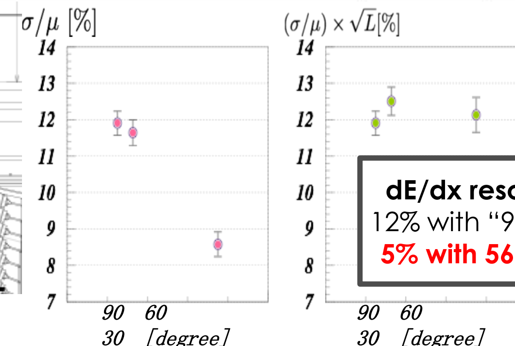
longer lever arm
improve resolution of momentum and dE/dx

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

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

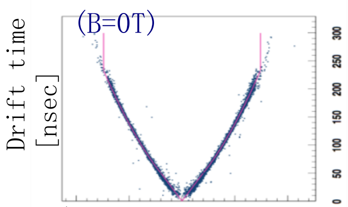


	Belle	Belle II
Radius of inner cylinder (mm)	77	160
Radius of outer cylinder (mm)	880	1120
Radius of innermost sense wire (mm)	88	168
Radius of outermost sense wire (mm)	863	1073.8
Number of layers	50	56
Number of sense wires	8,400	14,336
Gas	He–C_2H_6	He–C_2H_6
Diameter of sense wire (μm)	30	30

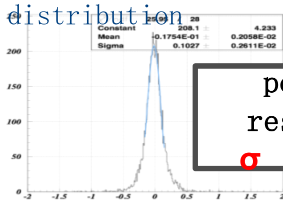


dE/dx resolution
12% with "9" layers
5% with 56 layers

X-t relation (B=0T)



Residual distribution



position resolution
σ ~ 100μ m

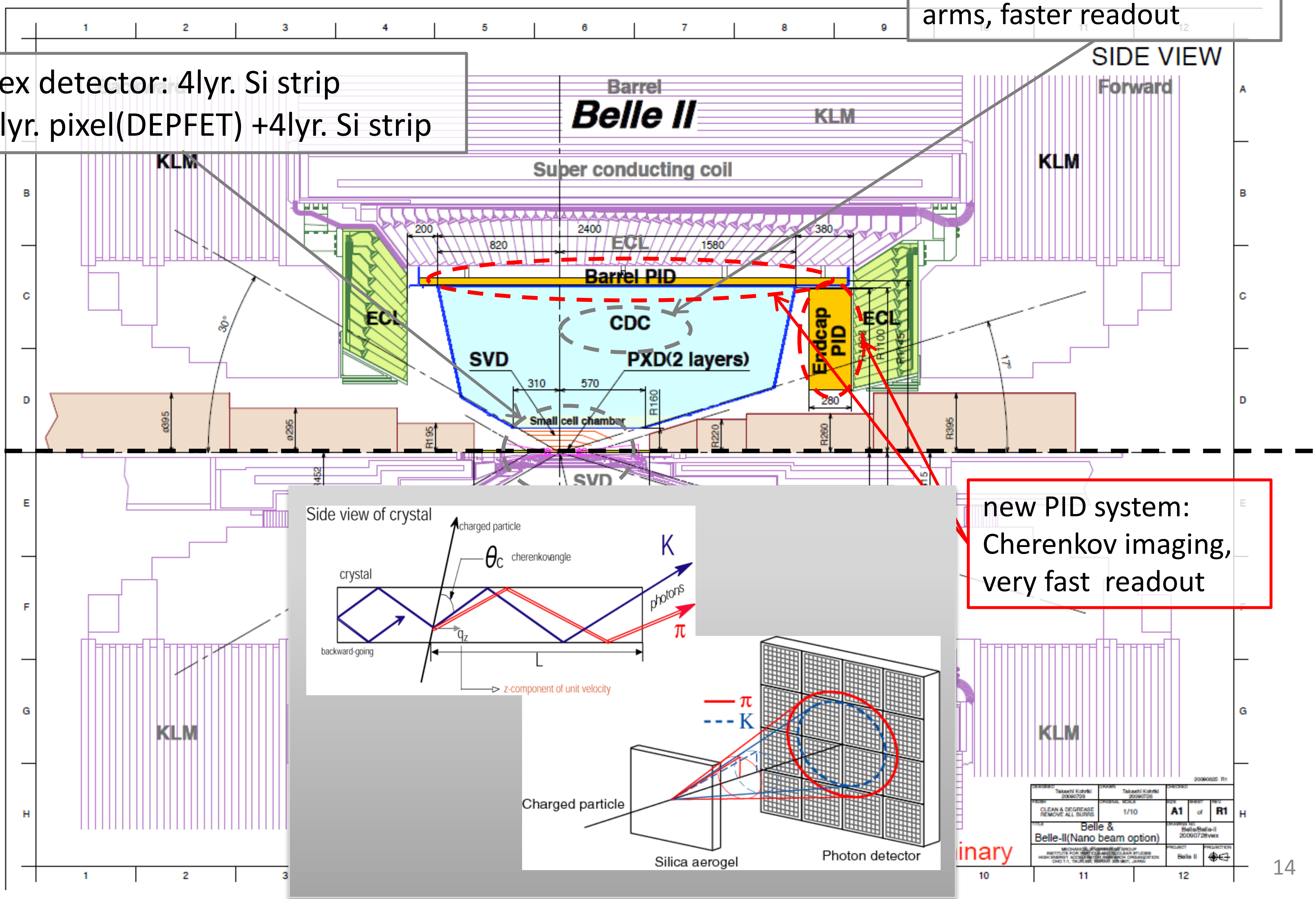
- **Extended outer radius, smaller cells near beampipe, faster readout electronics.**
- **Maintains high efficiency and momentum resolution in spite of higher background**

Detector upgrade

Drift chamber for tracking: Small cells, longer lever arms, faster readout

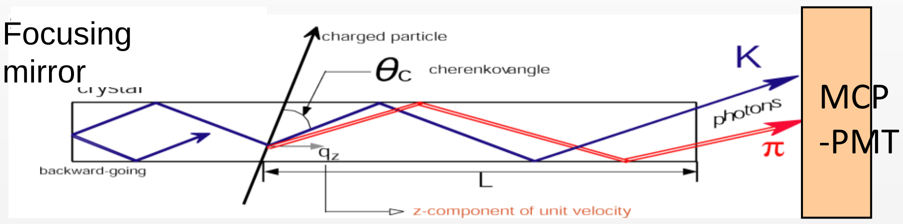
Vertex detector: 4lyr. Si strip
→ 2lyr. pixel(DEPFET) +4lyr. Si strip

new PID system: Cherenkov imaging, very fast readout



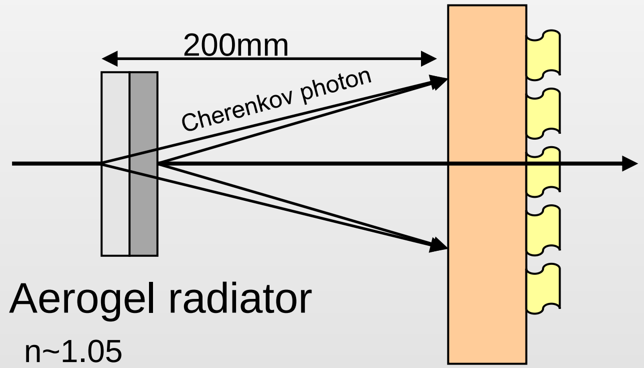
Belle-II Particle Identification System

Barrel PID: Time of Propagation Counter (TOP)



Thin quartz bar with very flat surface
Precise timing measurement with MCP-PMT

Endcap PID: Aerogel RICH (ARICH)

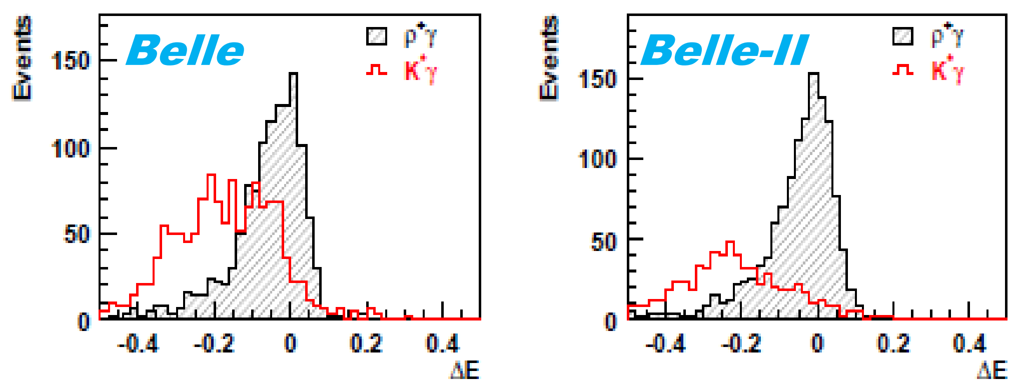


Aerogel radiator
n~1.05

Hamamatsu HAPD
+ new ASIC

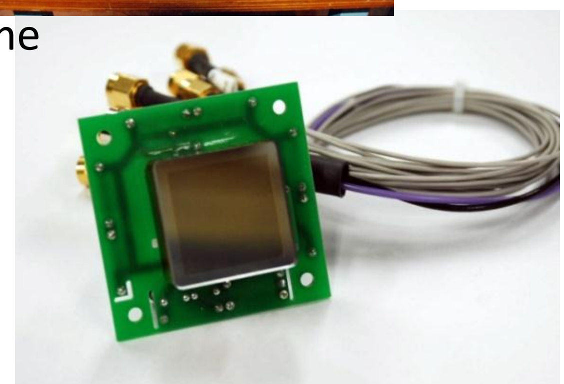
Completely different from Belle PID:
- better K/π separation
- more tolerance for BG
- less material
  (better calorimeter resolution)

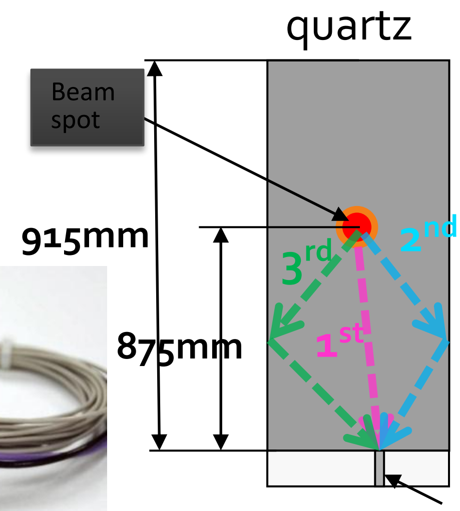
$B^+ \rightarrow \rho^+\gamma$ analysis

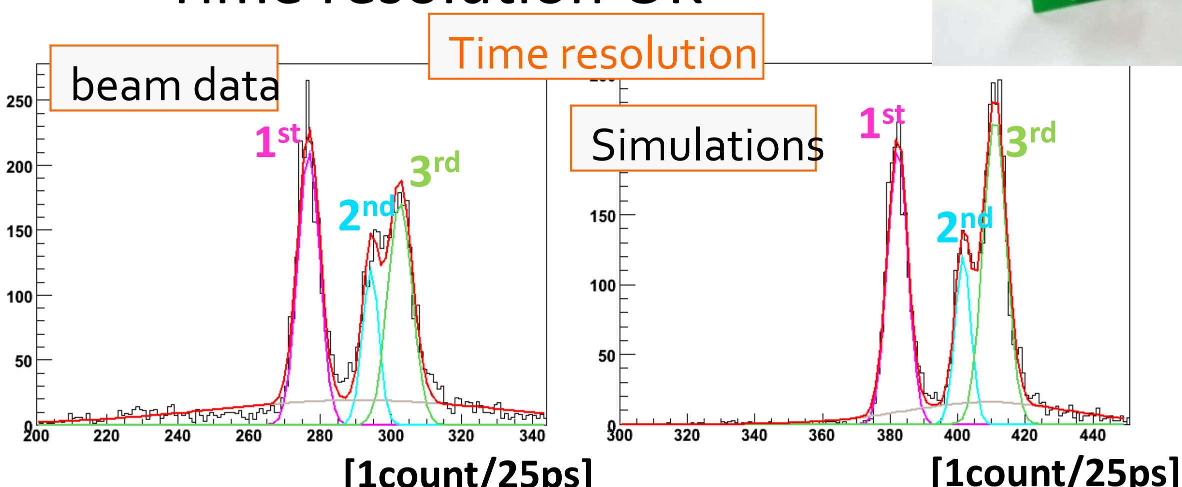


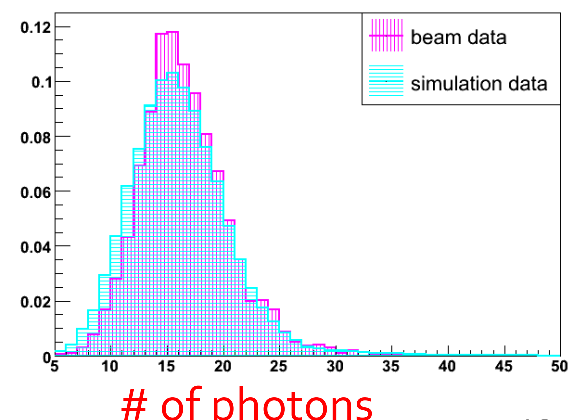
TOP (Barrel PID)

- 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 done in 2009
  - # of photons consistent
  - Time resolution OK

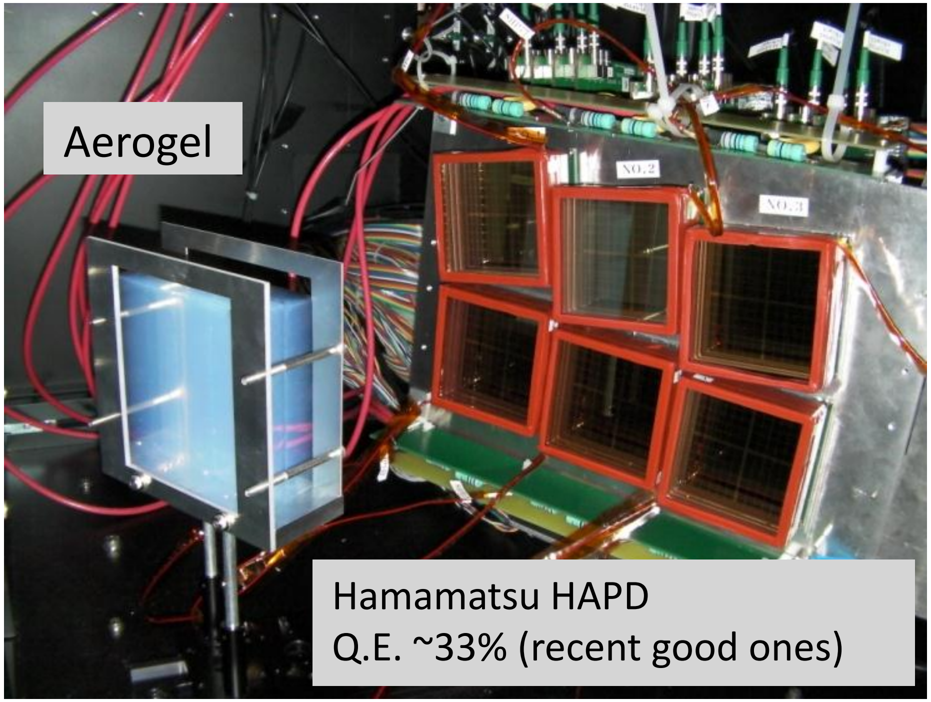


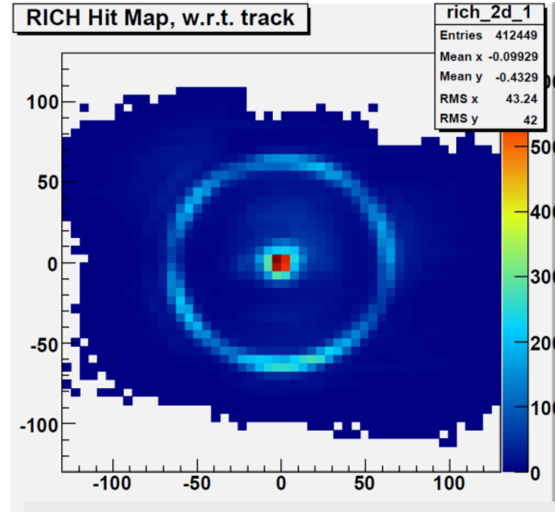






Aerogel RICH (endcap PID)

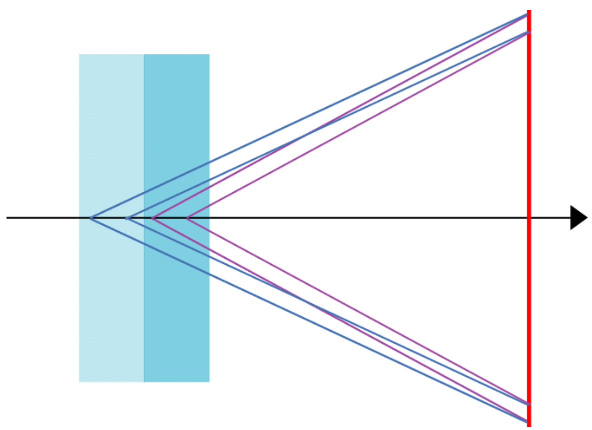




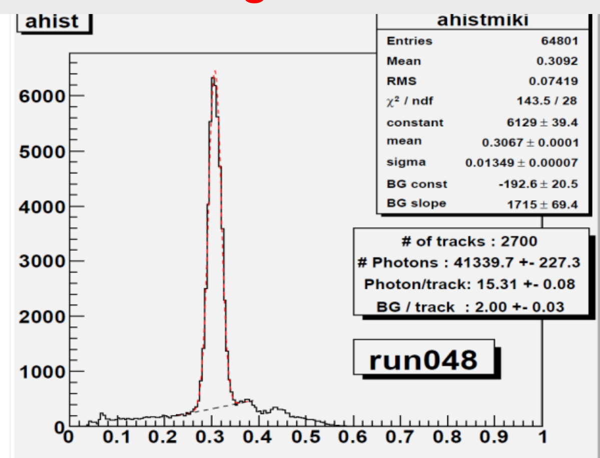
Clear Cherenkov image observed

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.



Cherenkov angle distribution



6.6 σ π/K at 4GeV/c !

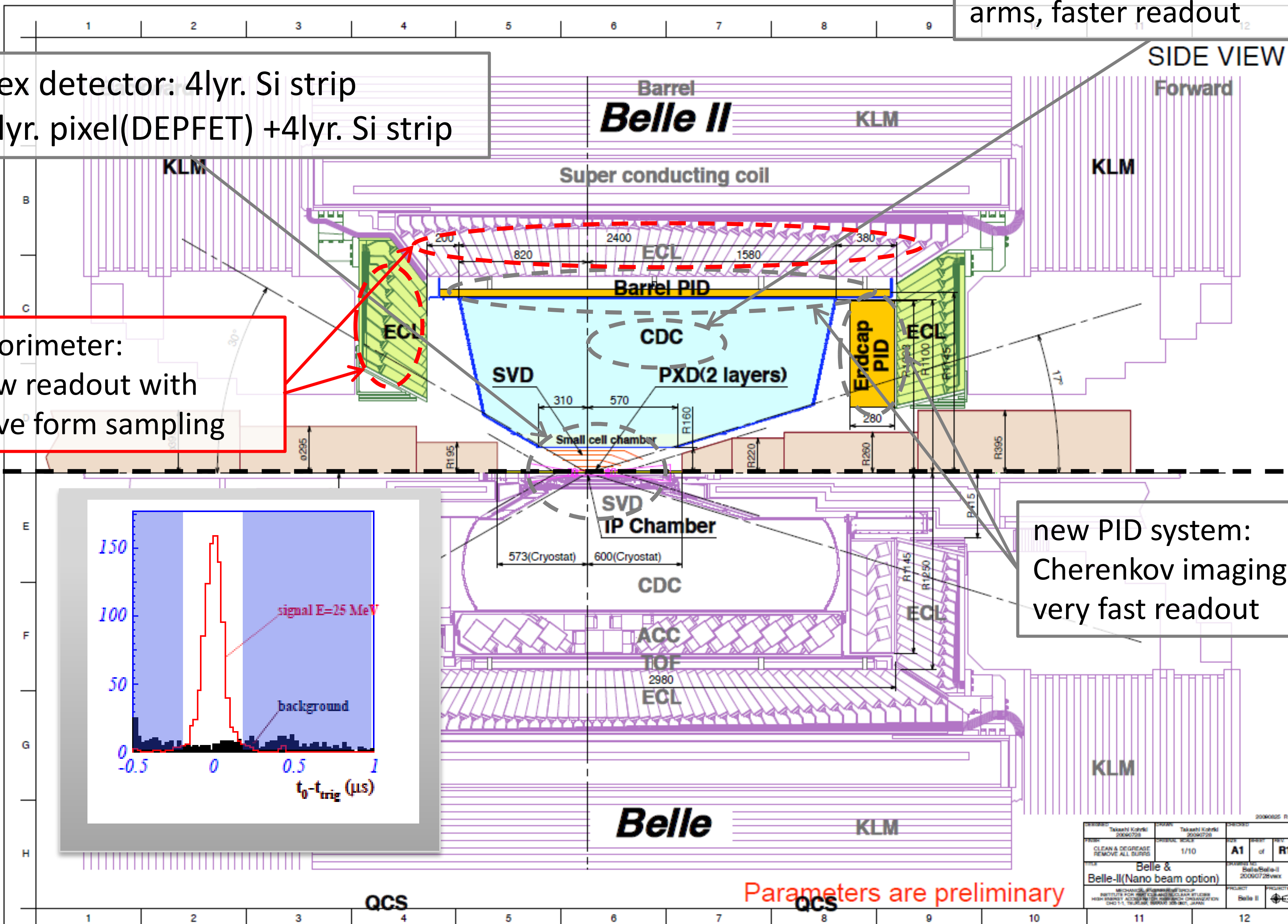
Detector upgrade

Drift chamber for tracking: Small cells, longer lever arms, faster readout

Vertex detector: 4lyr. Si strip
→ 2lyr. pixel(DEPFET) +4lyr. Si strip

Calorimeter:
New readout with wave form sampling

new PID system:
Cherenkov imaging, very fast readout



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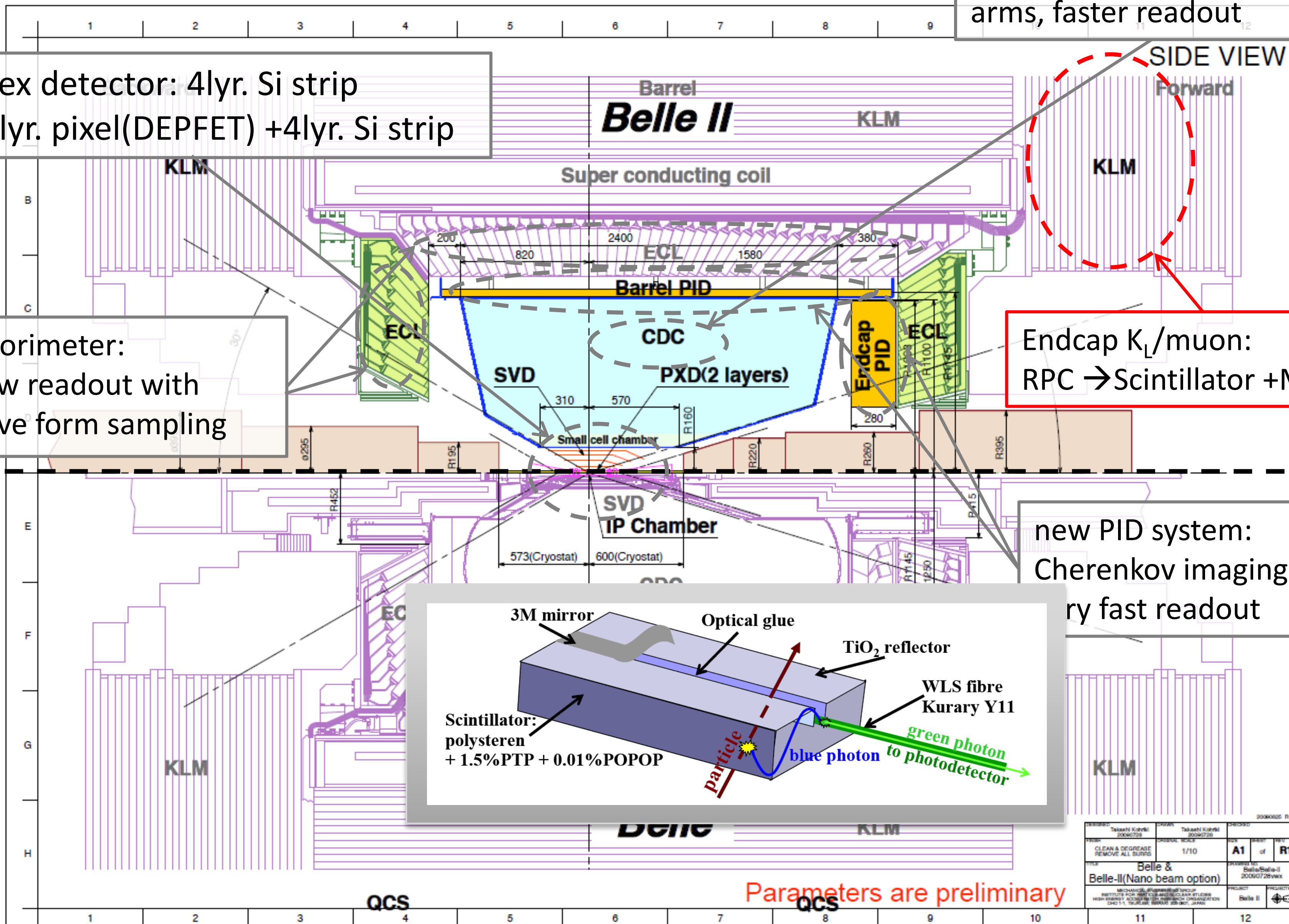
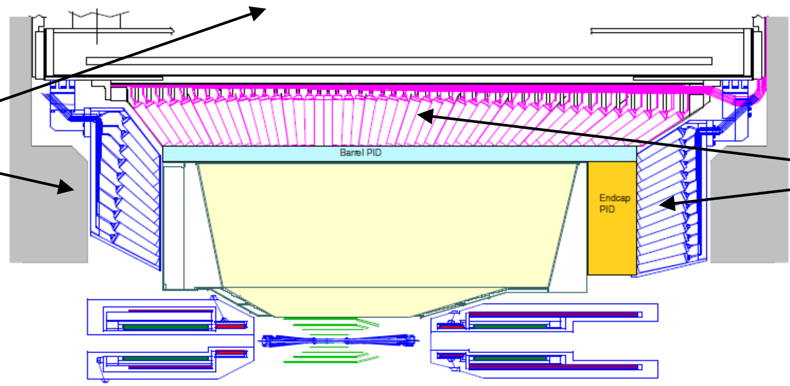
Endcap K_L/muon:
RPC →Scintillator +MPPC

new PID system:
Cherenkov imaging,
[v]ery fast readout



ECL and KLM

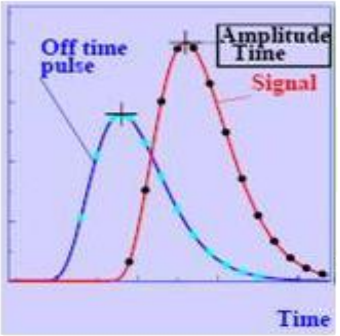


K_L - μ detection with KLM

- Resistive Plate Chambers to measure hadronic K_L showers and muon tracks
- Background in barrel consistent with cosmic ray flux →no change needed
- Background increase in endcaps by factor 20-40 (worse shielding of neutrons along beams)
- Endcap RPCs will be replaced with scintillators→better beam-background tolerance

Electromagnetic Calorimeter

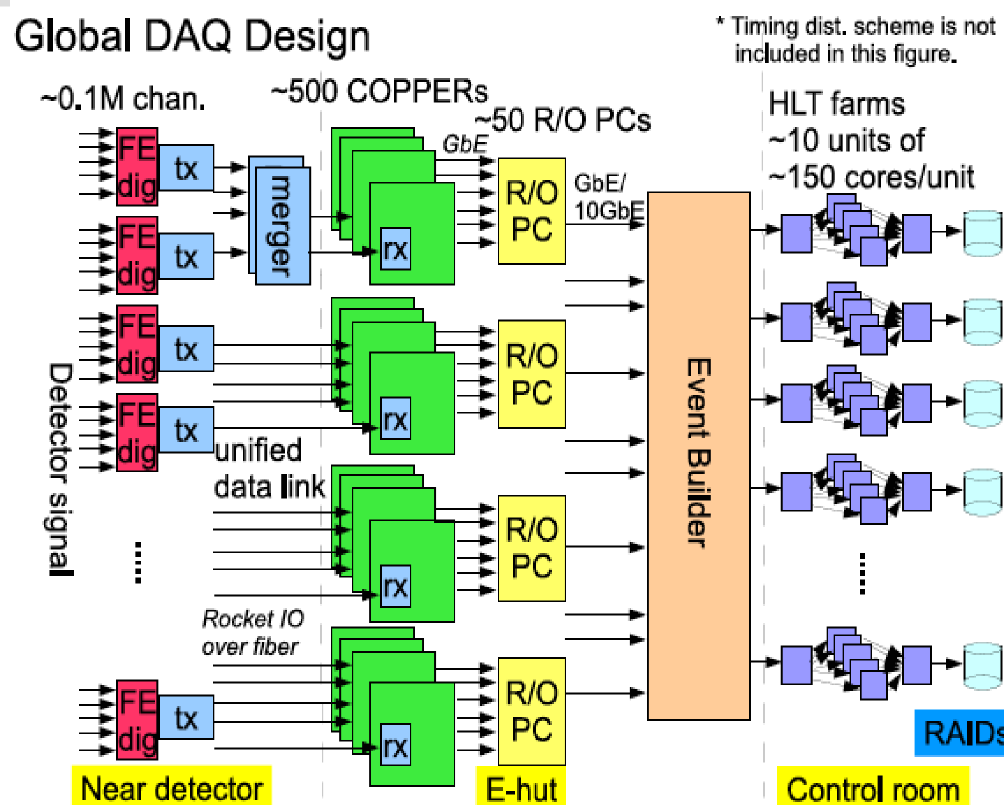
- Background: pile up noise by soft background photons, fake clusters from high energy photons 10 times higher
- Degradation of crystals in endcaps due to high radiation dose→ Replace CsI(Tl) with pure CsI in endcaps
- New electronics with waveform sampling to measure time and amplitude: fake clusters suppresed by factor 7
- Expected performance: 5-10% lower efficiency with similar S/B level



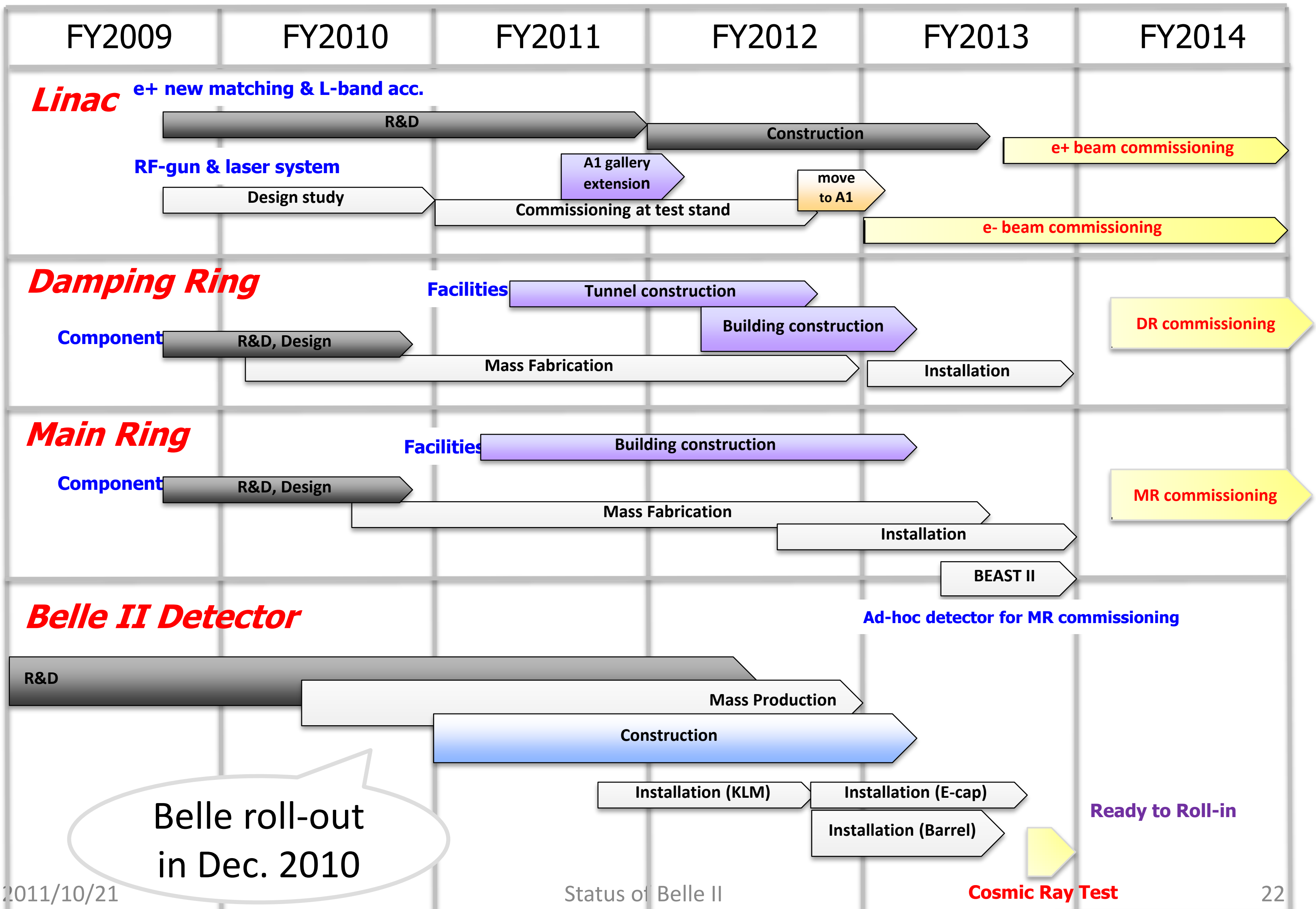
DAQ Overview

- At full luminosity, the data rate is 600 MB/sec.
- A high performance DAQ system is being designed by KEK and IHEP Beijing

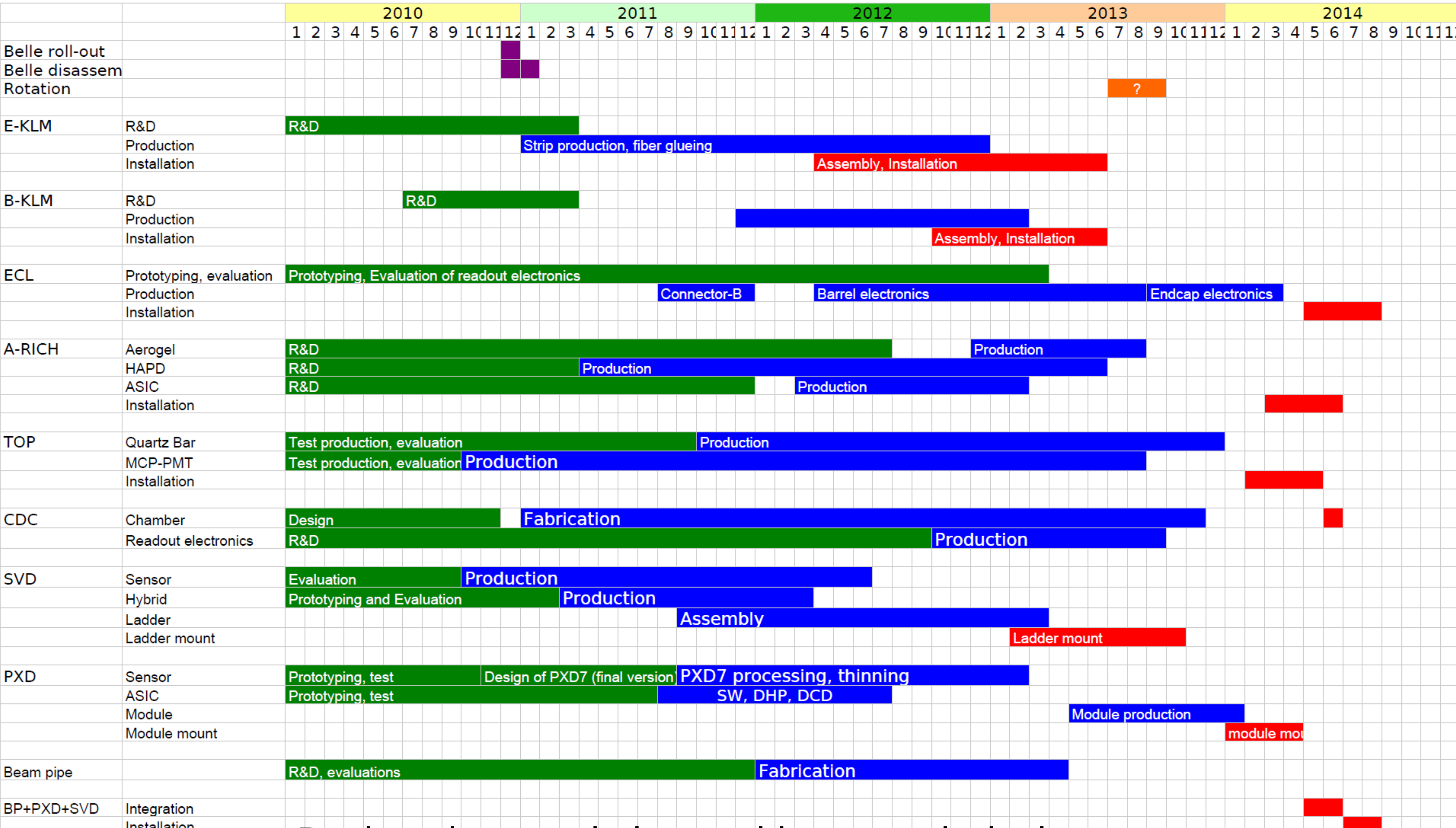
		Belle	Belle II
Level 1 Trigger	Trigger rate (kHz)	0.3-0.5	20-30
	Event size (kBytes)	40	300
	Data rate (MB/s)	20	6000
High Level Trigger	Reduction	1/ 2	1/10
	Storage Bandwidth (MB/s)	20	600



Construction Schedule of Super KEKB/Belle II



Status: approved, under construction



Designed to match the machine commissioning schedule and keep up with flavor physics at LHC

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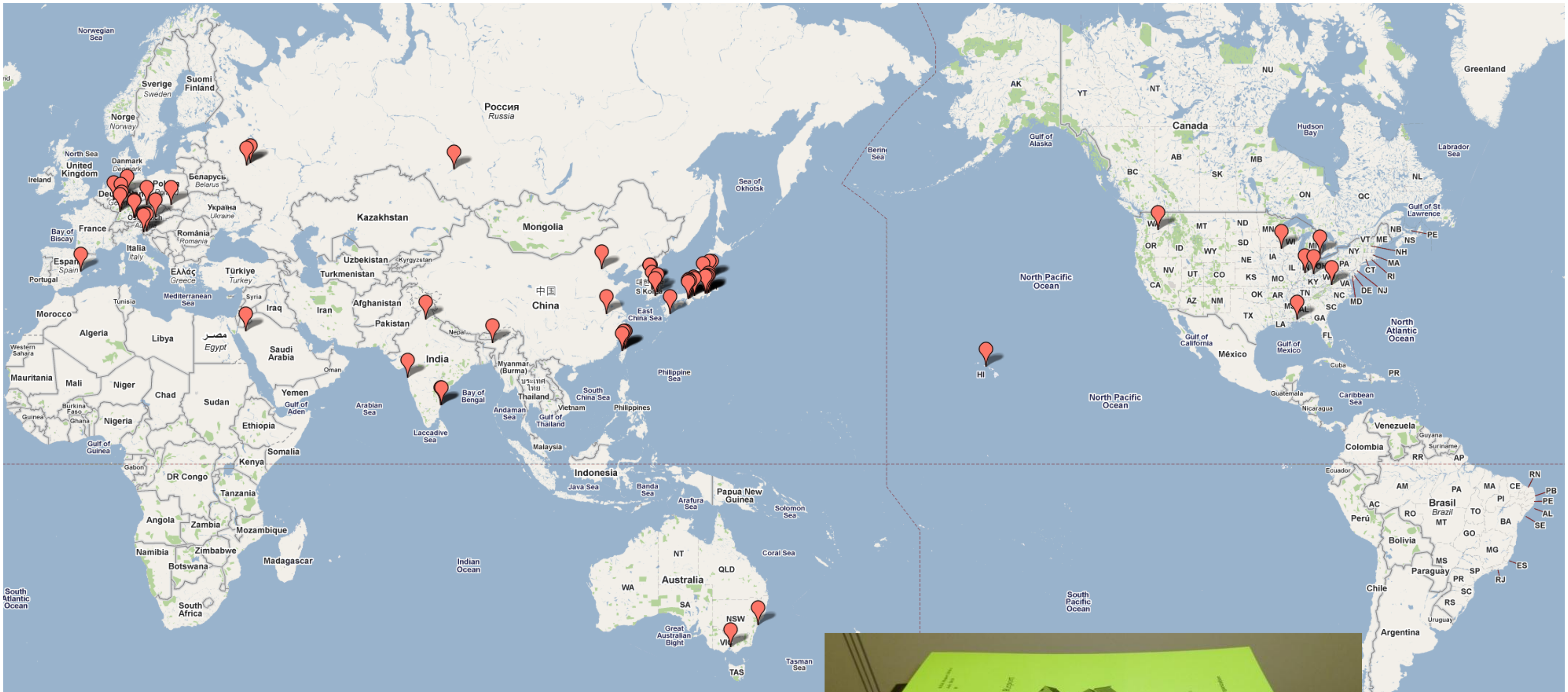
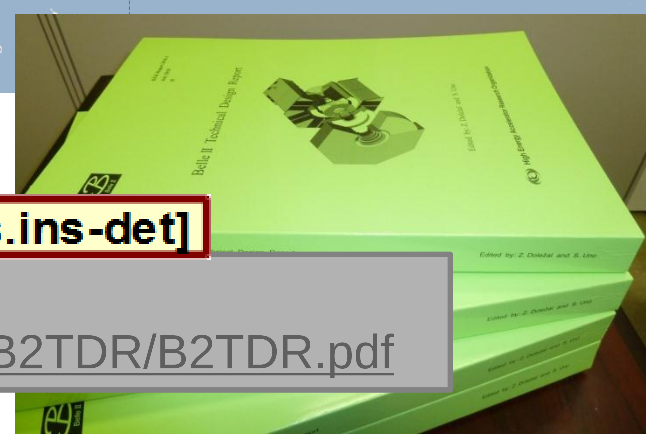
Belle II Collaboration

400 members - 60 institutions - 15 countries





TDR published arXiv:1011.0352v1 [physics.ins-det]

Belle II web page:
http://b2comp.kek.jp/~twiki/pub/Organization/B2TDR/B2TDR.pdf

TDR

Physics at Super KEKB/Belle II

- Key Measurements of Belle II:
  - Measurement of the Unitary Triangle, but with a precision an order of magnitude better than what we have now.
  - Other potential measurements that are sensitive to NP.
    - CPV in $b \to s$ penguins decays, $B \to \tau\nu$, $B \to D\tau\nu$, LFV in τ decays
    - A_{FB} in $B \to K^* l^+ l^-$, DCPV in $B \to K\pi$, etc.
- Measurements related to charm physics
  - D^0-D^0bar Mixing and CPV
  - Measurement of ϕ^3
  - Rare and (semi)lepton D decay
  - ISR

D^0-D^0bar mixing and CP violation

The mixing parameters x, y can be expected within the SM:

$|x|,|y| \sim O(10^{-2})$

World averages relating to D^0-D^0bar mixing and CPV while CPV allowed:

$$|q/p| = 0.89^{+0.17}_{-0.15}$$

$$Arg(q/p) = (-10.1^{+9.4}_{-8.8})^o$$

$$x = (0.63^{+0.19}_{-0.20})\%$$

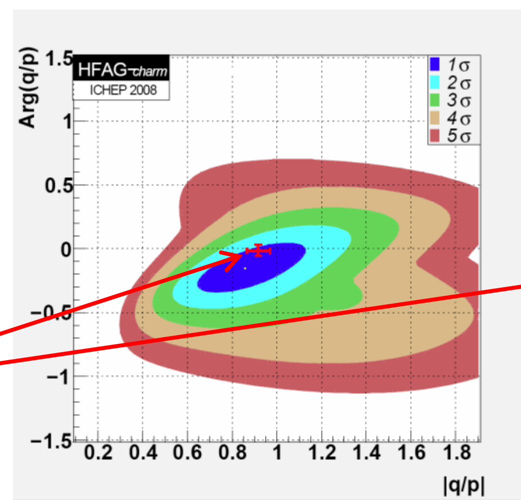
$$y = (0.75 \pm 0.12)\%$$

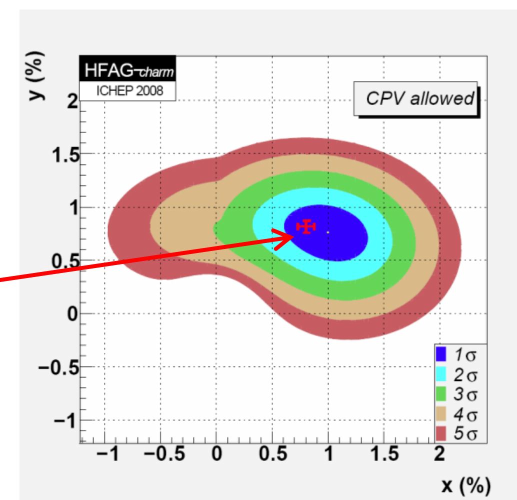
No mixing excluded at 10.1σ

Consistent with CP conservation

		$L=5$ ab^{-1}		$L=50$ ab^{-1}	
Parameter	Current		Combined		Combined
y_{CP} [%]	$\pm0.39 \pm 0.10$	$\pm0.12 \pm 0.10$		$\pm0.05 \pm 0.10$	
A_Γ [%]	$\pm0.33 \pm 0.06$	$\pm0.10 \pm 0.06$		$\pm0.04 \pm 0.06$	
x [%]	$\pm0.31 \pm 0.10$	$\pm0.10 \pm 0.10$	±0.12	$\pm0.03 \pm 0.10$	±0.09
y [%]	$\pm0.26 \pm 0.07$	$\pm0.08 \pm 0.07$	±0.09	$\pm0.03 \pm 0.07$	±0.06
$\lvert q/p \rvert$	$\pm0.30 \pm 0.08$	$\pm0.10 \pm 0.16$	±0.08	$\pm0.03 \pm 0.16$	±0.06
ϕ [rad]	$\pm0.30 \pm 0.06$	$\pm0.10 \pm 0.06$	±0.08	$\pm0.03 \pm 0.05$	±0.05
x'^2 [10^{-3}]	$\pm0.23 \pm 0.09$	$\pm0.07 \pm 0.09$		$\pm0.02 \pm 0.09$	
y' [%]	$\pm0.42 \pm 0.16$	$\pm0.12 \pm 0.16$		$\pm0.04 \pm 0.16$	
$\delta_{K\pi}$ [rad]			±0.11		±0.08

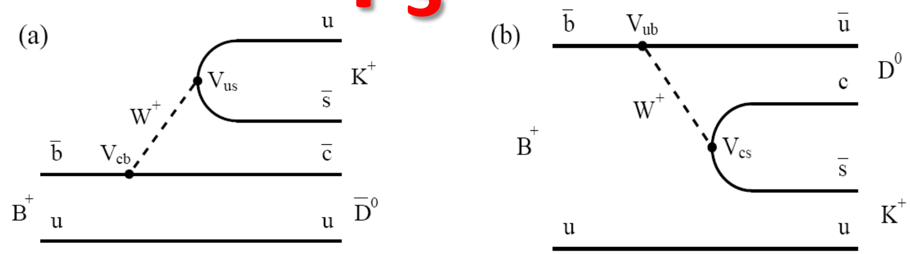
Expected accuracy
With 50 ab-1





Measurement of ϕ_3

$$\phi_3 \equiv -\arg\left[\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right] \equiv \arg V_{ub}^*$$



$$r_B = \frac{\left|A(B^- \to \overline{D}^0 K^-)\right|}{\left|A(B^- \to D^0 K^-)\right|} = \frac{\left|A(B^+ \to D^0 K^+)\right|}{\left|A(B^+ \to \overline{D}^0 K^+)\right|}$$

$$\arg\frac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)} = \delta_B - \phi_3 \quad \arg\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D}^0 K^+)} = \delta_B + \phi_3$$

$$B^\pm \to D^{(*)}K^\pm \quad D^0 \to K_s^0 \pi^+ \pi^-$$

by Belle, 605fb^{-1} model-dept dalitz method

PRD 81, 112002(2010)

$$\phi_3 = 76^{\circ}{}^{+12^\circ}_{-13^\circ}(stat) \pm 4^\circ(syst) \pm 9^\circ(\mathrm{model})$$

$$M_\mp = A[f(m_\pm^2, m_\mp^2) + r_B e^{i(\delta_B \mp \phi_3)} f(m_\mp^2, m_\pm^2)]$$

by Belle, 710fb^{-1} model-indept dalitz method

$$\phi_3 = 77.3^{\circ}{}^{+15.1^\circ}_{-14.9^\circ}(stat) \pm 4.1^\circ(syst) \pm 4.3^\circ(c_i, s_i)$$

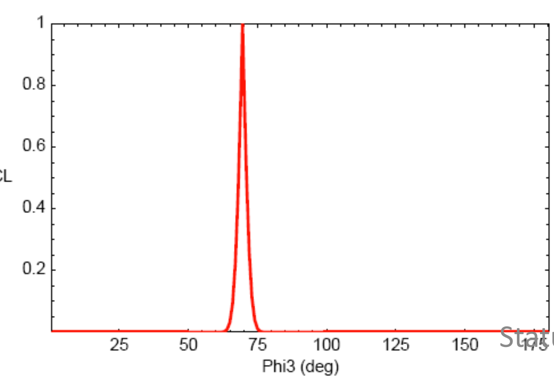
$$\langle N_i \rangle = h_B[K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(xc_i + ys_i)]$$

$$x_\pm = r_B \cos(\delta_B \pm \phi_3), y_\pm = r_B \sin(\delta_B \pm \phi_3)$$

$$c = \cos(\delta(m_+^2, m_-^2) - \delta(m_-^2, m_+^2))$$

$$s = \sin(\delta(m_+^2, m_-^2) - \delta(m_-^2, m_+^2))$$

scale to 50ab^{-1} Υ(4S), 15fb^{-1} ψ(3770):



$\Psi(3770) \to D^0\overline{D}^0, D \to K_0\pi^+\pi^-$ is sensitive to c,s.

Semileptonic D meson decays

$D^0 \to \pi l \nu$ 282 fb^{-1} by Belle, PRL 97,061804

$$f_+^{\pi}(0) = 0.624 \pm 0.020 \pm 0.030$$

$$f_+^{\pi}(0)^{LQCD} = 0.64 \pm 0.03 \pm 0.06$$

$D^0 \to \mu \nu$ 548 fb^{-1} by Belle, PRL 100,241801

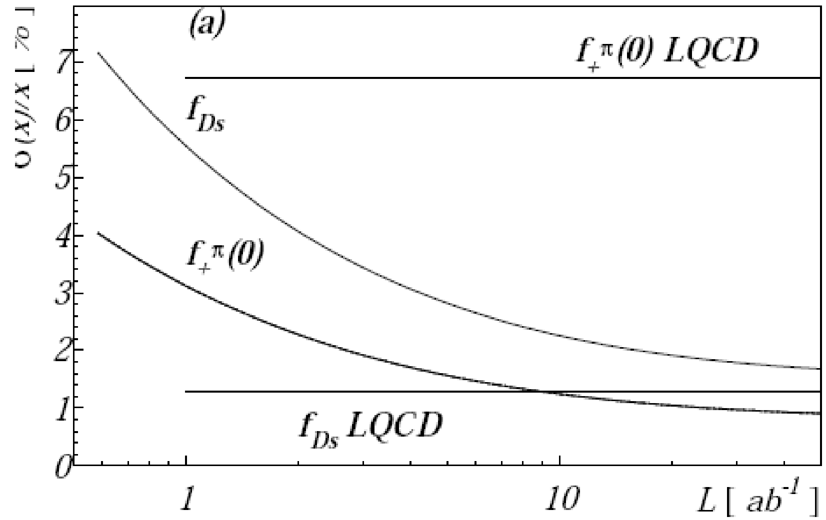
$$f_{D_s}{}^{LQCD} = (241 \pm 3) MeV$$

$$f_{D_s} = (275 \pm 16 \pm 12) MeV$$

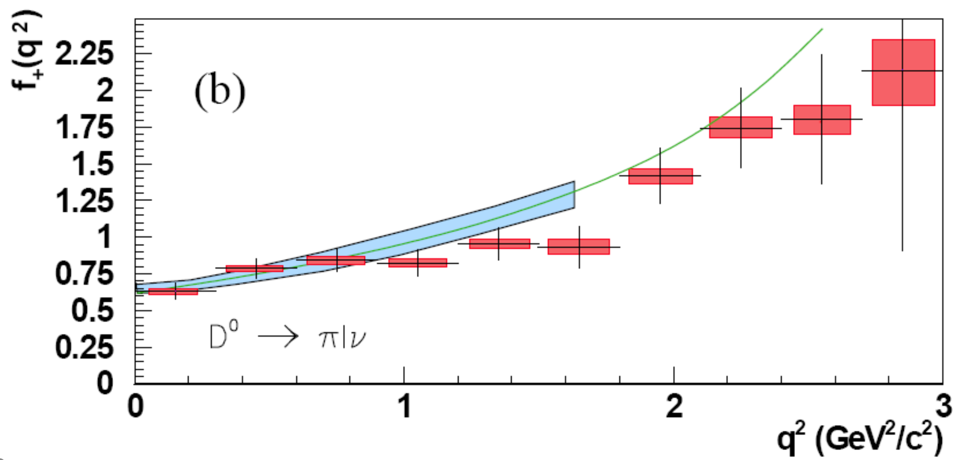
$D^0 \to \phi l \nu$ 78 fb^{-1} by BaBar, arXiv:hep-ex/0607085

$$r_V = 1.636 \pm 0.067 \pm 0.038$$

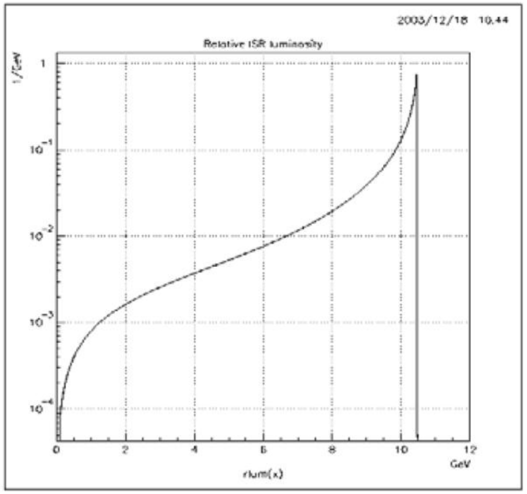
$$r_2 = 0.705 \pm 0.056 \pm 0.029$$



Decay mode	parameter	$L = 5$ ab^{-1}		$L = 50$ ab^{-1}	
		σ_{stat} [%]	σ_{syst} [%]	σ_{stat} [%]	σ_{syst} [%]
$D^0 \to \pi \ell \nu$	$f_+^{\pi}(0)$	1	1.5	0.2	1
$D_s \to \mu \nu$	f_{D_s}	2	2	0.6	1.5
$D_s \to \phi \ell \nu$	r_V	0.6	1.0	0.2	1.0
$D_s \to \phi \ell \nu$	r_2	1.0	2.4	0.3	2.4



Potential of ISR: competition or complementarity?



$$\frac{dl}{Ldm} = \frac{2\alpha m}{\pi s}\left\{\frac{s+m^4}{s(s-m^2)}(\ln\frac{s}{m_e^2}-1)\right\}$$

Number of events of the vector meson production at 8000 fb^{-1} (@Υ(4s))

φ	1.5×10^8
ψ	2.3×10^8
ψ(2S)	7.8×10^7
ψ(3770)	9.7×10^6
Υ(1s)	1.3×10^8
Υ(2s)	1.2×10^8
Υ(3s)	2.4×10^8

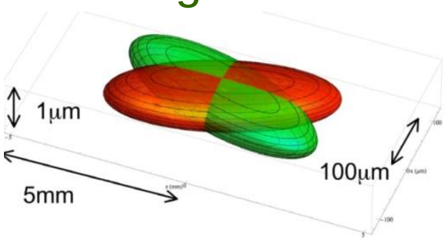
	KEKB	VEPP-2000	BEPC-II
Luminosity, см$^{-2}$ s^{-1}	$8\cdot10^{35}$	10^{32}	10^{33}
Integrated lum. (per 10^7 s)	8000 fb^{-1}	1 fb^{-1}	10 fb^{-1}
Integrated in the range [1-2] GeV	8 fb^{-1} (~0.8 @ θ>0.7)	1 fb^{-1}	
Integrated in the range [2-3] GeV	20 fb^{-1} (~2 @ θ>0.7)		10 fb^{-1}

Summary

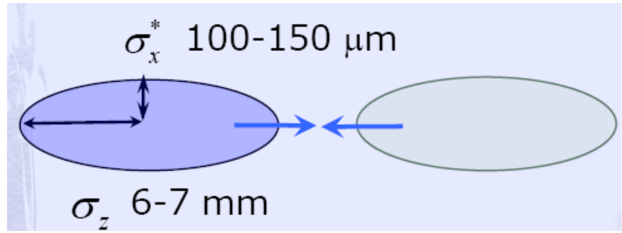
- Super KEKB/Belle II aims for (discovering and) understanding the New Physics. Target Luminosity of Super KEKB is $8 \times 10^{35}/cm^2/s$, will provide $50ab^{-1}$ by 2020-2021.
- The upgrade project is already approved by Japanese government and construction has been started.
- Belle II will give similar or better performance than Belle even under higher beam background.
- Belle II will start data taking in 2014. We can wait for new exciting results in the next decade

BACKUP

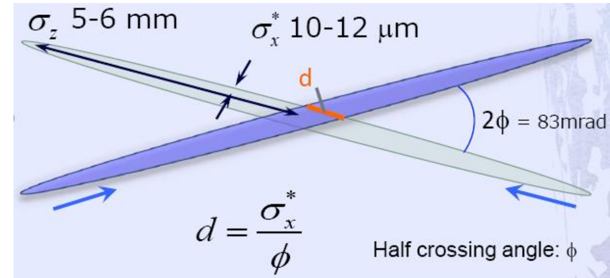
KEKB – no crab crossing



KEKB head-on (crab crossing)



Nano-Beam SuperKEKB



Design Concept of SuperKEKB

- Increase the luminosity by 40 times based on "Nano-Beam" scheme, which was first proposed for SuperB by P. Raimondi.

Luminosity Gain

- Vertical β function at IP: 5.9 → 0.27/0.30 mm (× 20)
- Beam current: 1.7/1.4 → 3.6/2.6 A (× 2)
- Beam-beam parameter: .09 → .09 (× 1)

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
HER : Lower emittance and lower SR power

❖Re-use the KEKB tunnel.
❖We have no option for polarization at present.
❖Re-use KEKB components as much as possible.
❖Preserve the present cells in HER.
❖Replace dipole magnets in LER, re-using other main magnets in the LER arcs.

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	κ	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

Demands on the detector

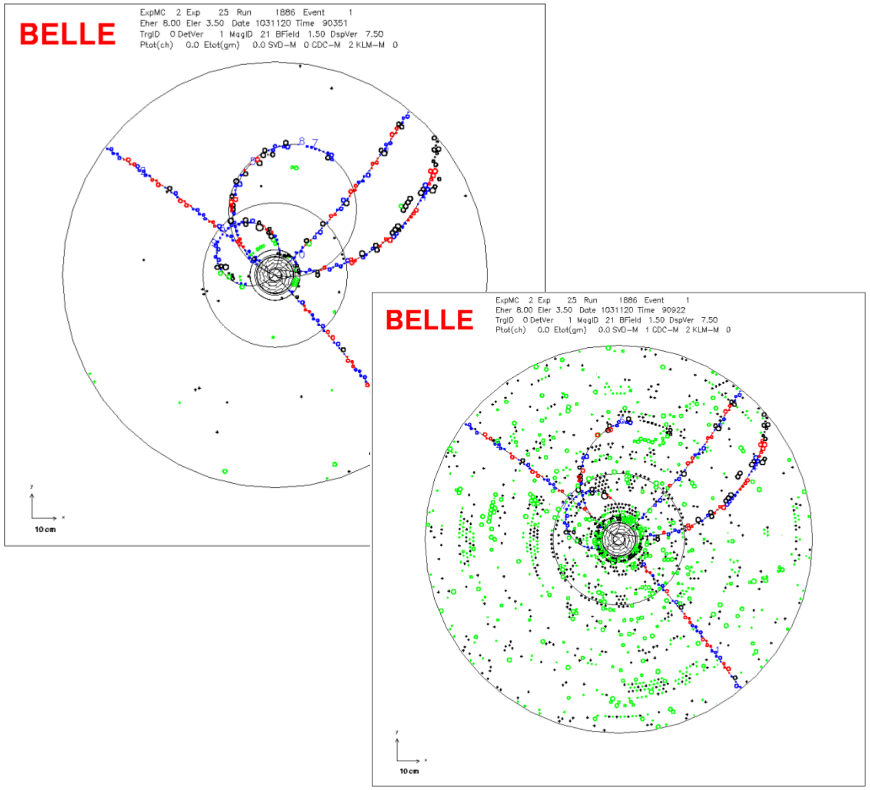
Total cross section and trigger rates with $L = 8 \times 10^{35}$ $cm^{-2}\ s^{-1}$ from various physics processes at Υ(4S).

Physics process	Cross section (nb)	Rate (Hz)
Υ (4S) $\rightarrow$BB	1.2	960
Hadron production from continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha (θlab> 17°)	44	350[(a)]
$\gamma\gamma$ (θlab> 17°)	2.4	19 [(a)]
2γ processes (θlab> 17°, pt > 0.1GeV/c)	~80	~ 15000
Total	~130	~20000

(a) rate is pre-scaled by a factor of 1/100

The requirements for the trigger system are:

1. high efficiency for hadronic events;
2. maximum average trigger rate of 30 kHz;
3. fixed latency of about 5 μs;
4. timing precision of less than 10 ns;
5. minimum two-event separation of 200 ns;
6. trigger configuration that is flexible and robust.



SuperKEKB/Belle II funding Status

KEKB upgrade has been approved

- 5.8 oku yen (~MUSD) for Damping Ring (FY2010)
- 100 oku yen for machine -- Very Advanced Research Support Program (FY2010-2012)
- Full approval by the Japanese government by December 2010; the project is in the JFY2011 budget as approved by the Japanese Diet end of March 2011

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大学共同利用機関法人 KEK 高エネルギー加速器研究機構

Press Release

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>Top >PressRelease >this page last update: 10/06/23

Press Release

KEKB upgrade plan has been approved

June 23, 2010
High Energy Accelerator Research Organization (KEK)

The MEXT, the Japanese Ministry that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx $110M) over the next three years starting this Japanese fiscal year (JFY2010) for the high performance upgrade program of KEKB. This is part of the measures taken under the new "Very Advanced Research Support Program" of the Japanese government.

"We are delighted to hear this news," says Masanori Yamauchi, former spokesperson for the Belle experiment and currently a deputy director of the Institute of Particle and Nuclear Studies of KEK. "This three- year upgrade plan allows the Belle experiment to study the physics from decays of heavy flavor particles with an unprecedented precision. It means that KEK in Japan is launching a renewed research program in search for new physics by using a technique which is complementary to what is employed at LHC at CERN."

[Media Contact] Youhei Morita,
Head of Public Relations Office, KEK
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1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan

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Several non-Japanese funding agencies have also already allocated sizable funds for the upgrade.

→construction started!

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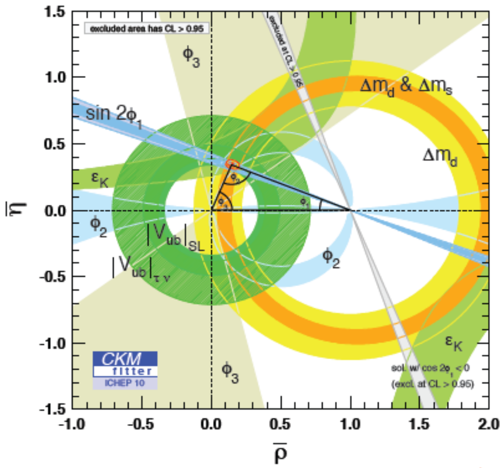
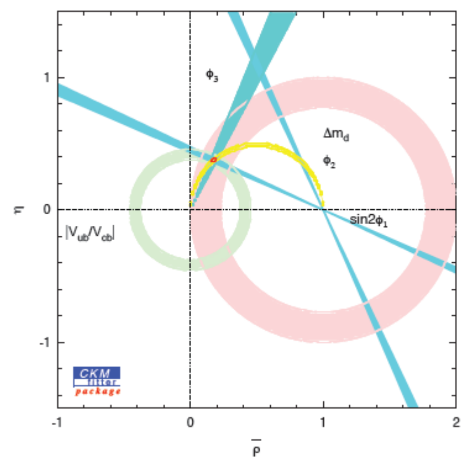
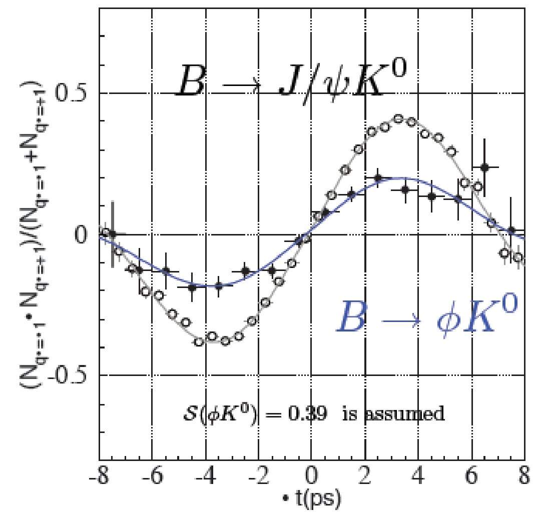
Physics at 50/ab, a few examples

2010 ICHEP



202X@50/ab





B → K*γ t-dependent CPV

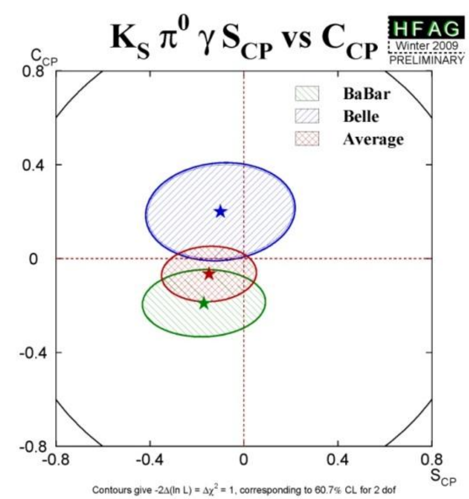
SM: $S_{CP}^{K^*\gamma} \sim (2m_s/m_b)\sin2\phi_1 \sim -0.04$

$S_{CP}^{K_S\pi^0\gamma} = -0.15 \pm 0.20$

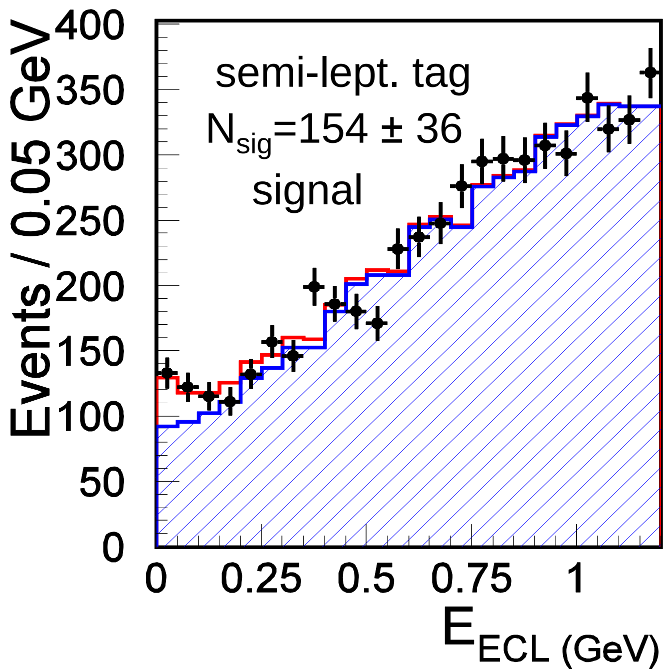
$A_{CP}^{K_S\pi^0\gamma} = 0.07 \pm 0.12$

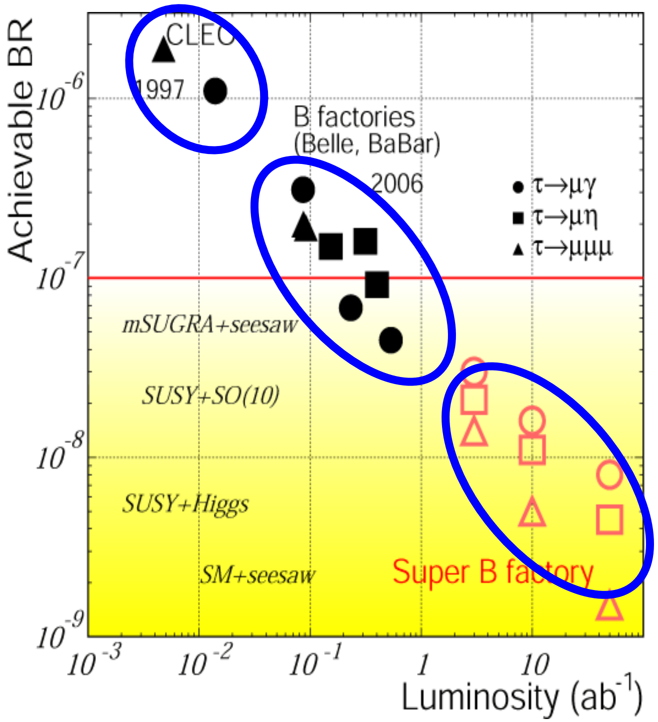
Expected sensitivity - 0.03 for

S in Ks pi0 gamma with 50 ab-1



NP search with 50 ab^{-1}





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

Belle, arXiv: 0809.3834, 600 fb^{-1}

$$\sigma(\Gamma/\Gamma_{SM}) \approx 0.08$$

Expected sensitivity

τ→ℓγ Br~O($10^{-8\sim9}$)

τ→ℓℓℓ, l+meson Br~O($10^{-9\sim10}$)

includes uncertainties from theory (on Vub and f_B), 0.04 purely exp.