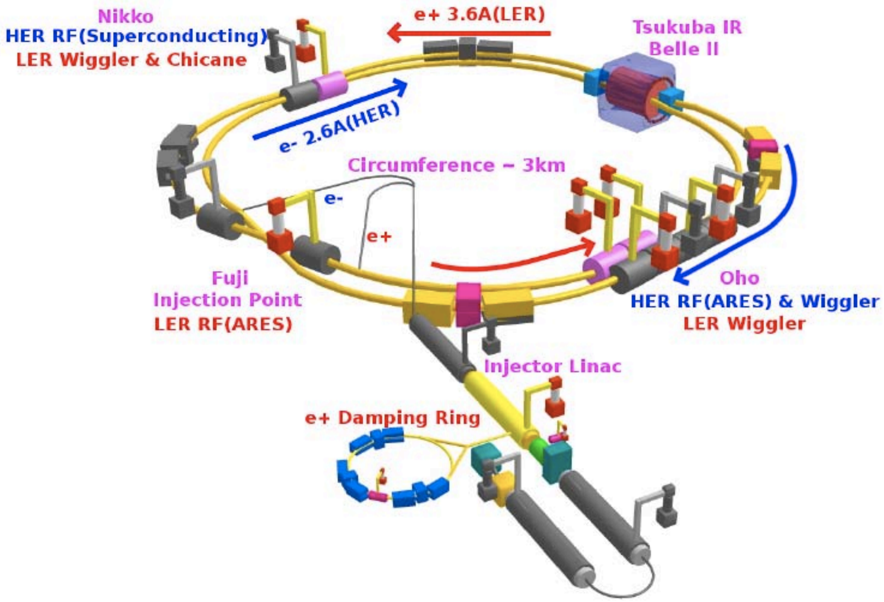
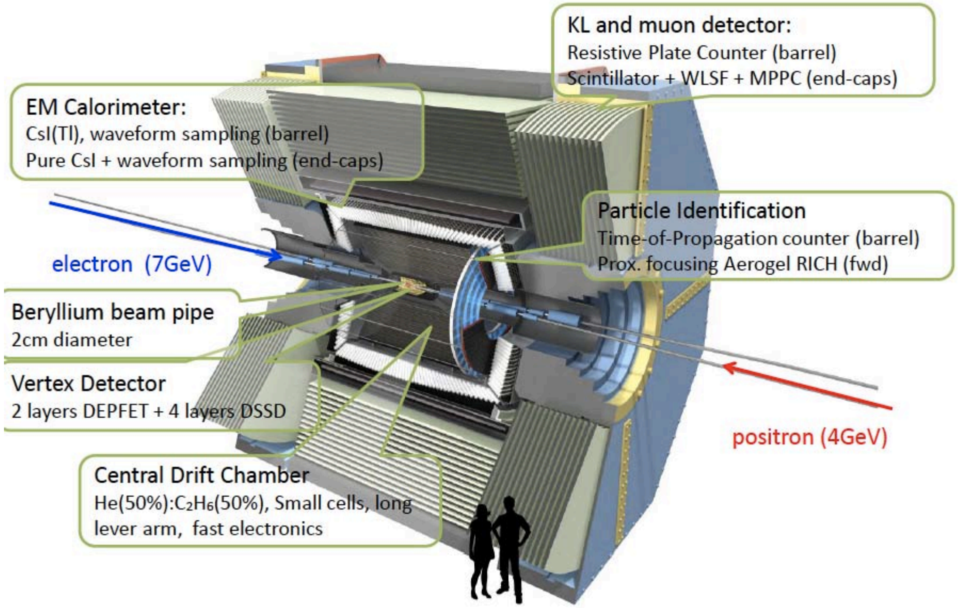
Status of SuperKEKB/Belle-II project

Hiroyuki Nakayama (KEK)

2011.07.13 ICRR seminar



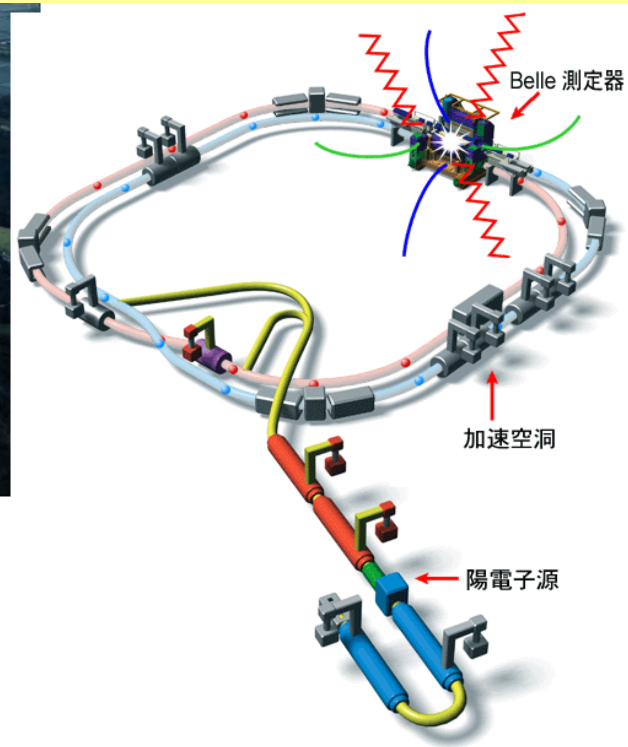


- KEKB and Belle: successful
- Physics prospects for Super B factory
- Status of SuperKEKB/Belle-II
- Beam background estimation

KEK and KEKB

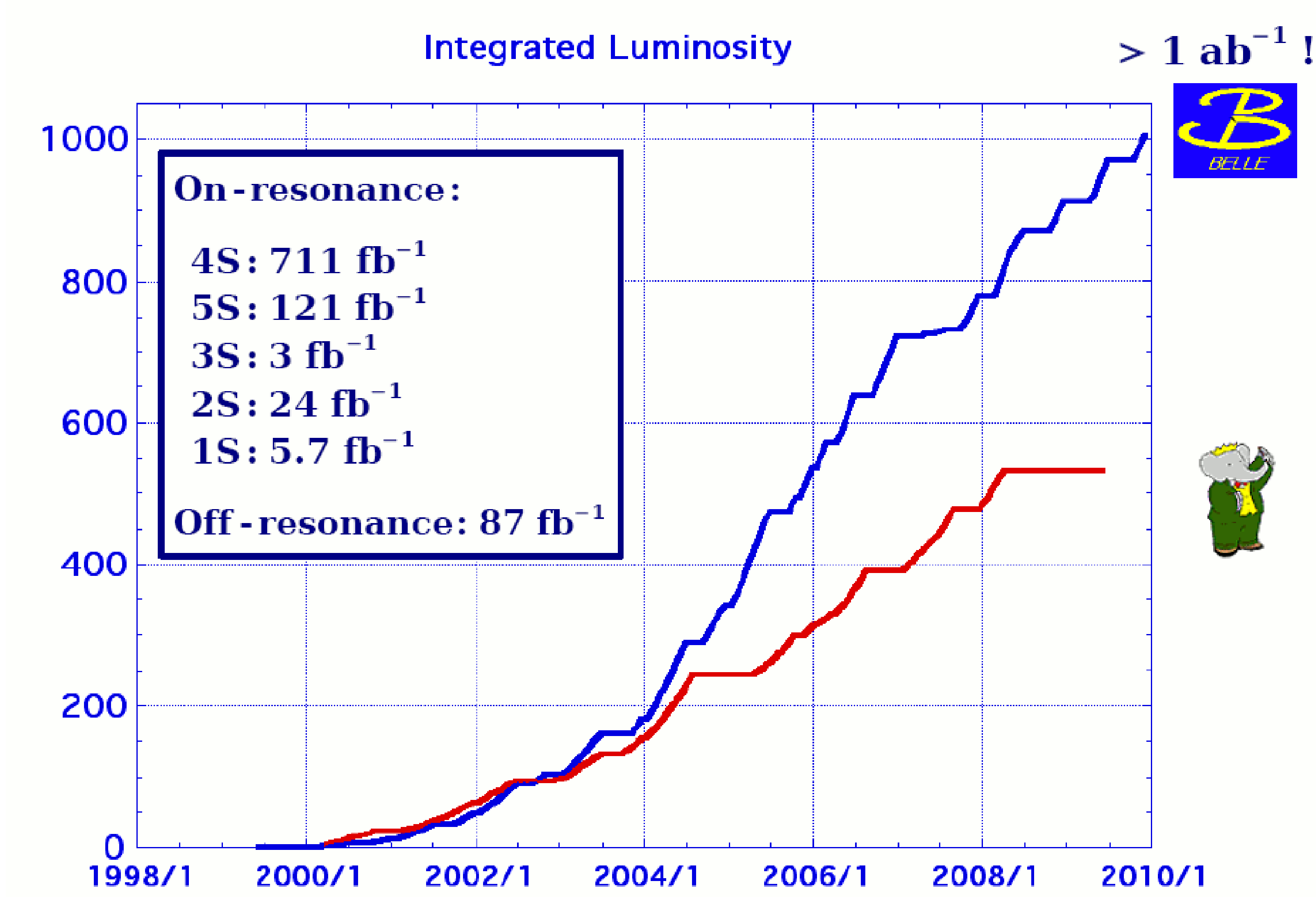
3.5 GeV e^{+} X 8.0 GeV e^{-}

crossing angle = ± 11 mrad.



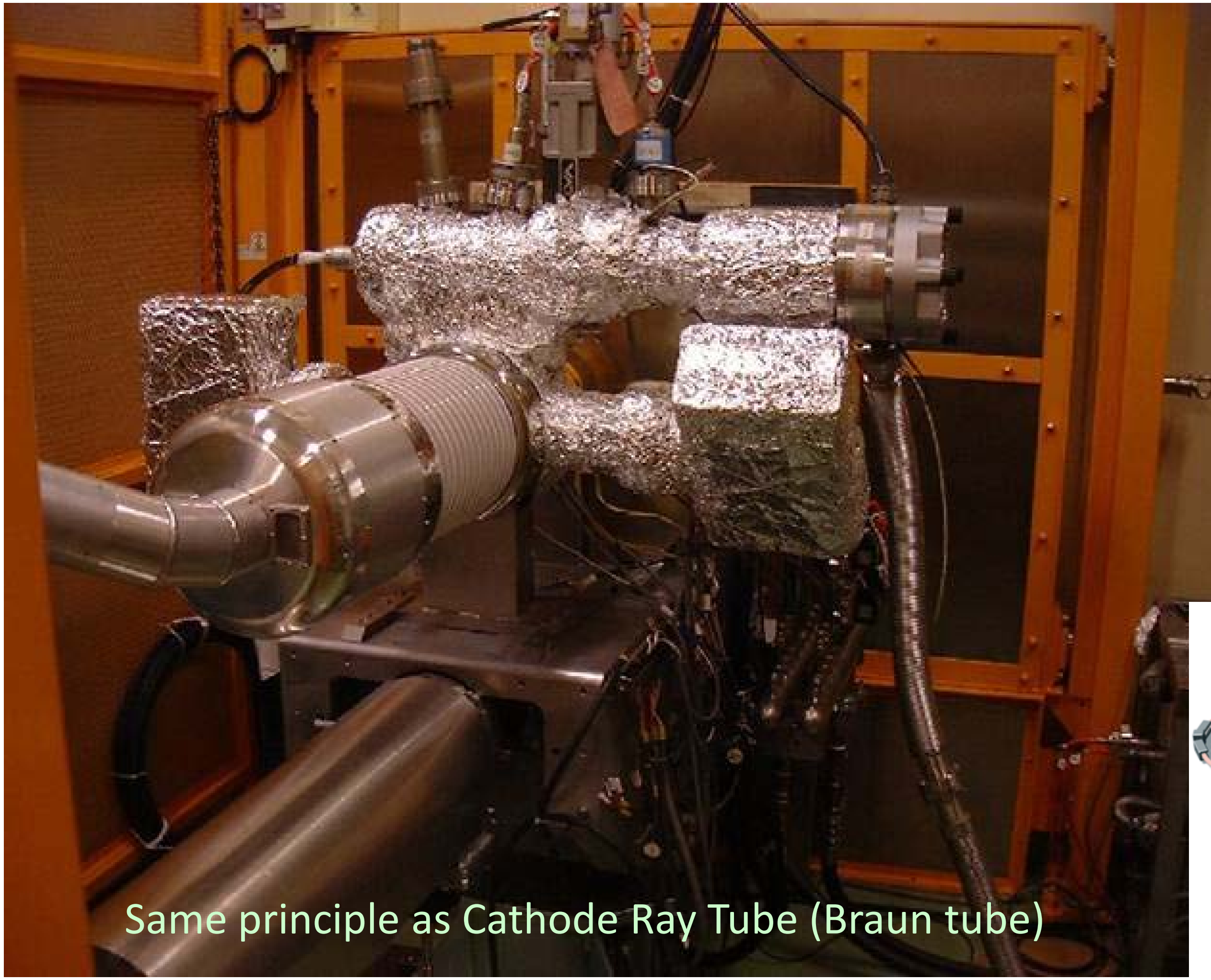
Belle/KEKB Integrated luminosity passed 1000 fb^{-1}

(➔have to switch to new units, 1 ab^{-1})

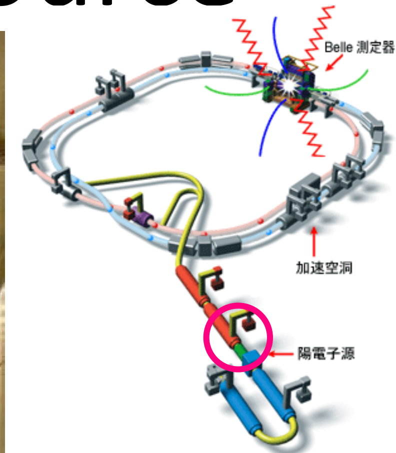


Peak lumi record at KEKB: L=2.1 x $10^{34}/cm^2/sec$ with crab cavities

KEKB tunnel tour: Electron gun

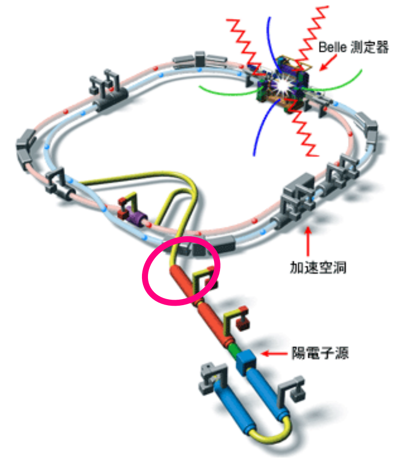


KEKB tunnel tour: Positron source

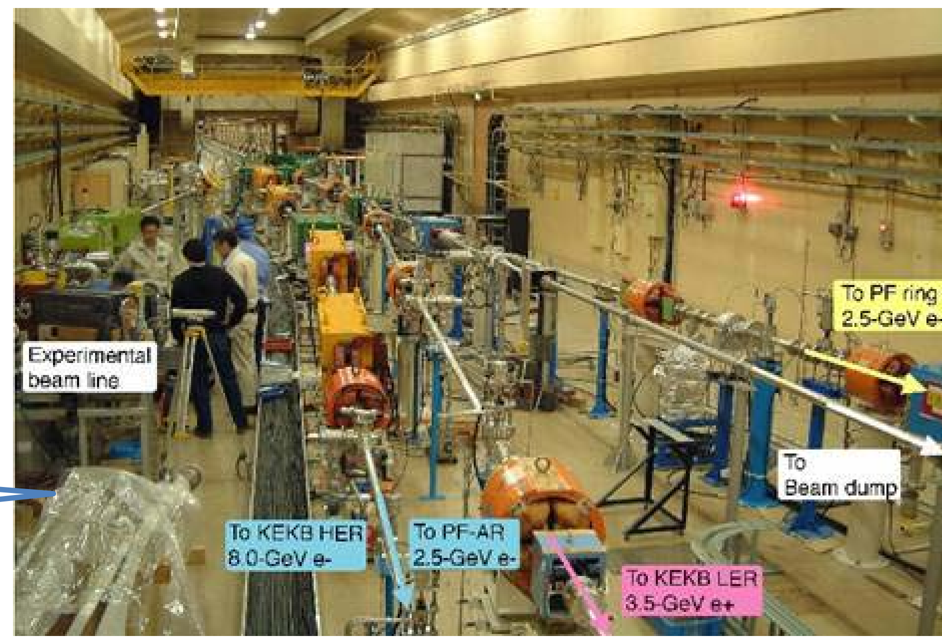


KEKB tunnel tour: LINAC（Injector）

500m linear tunnel



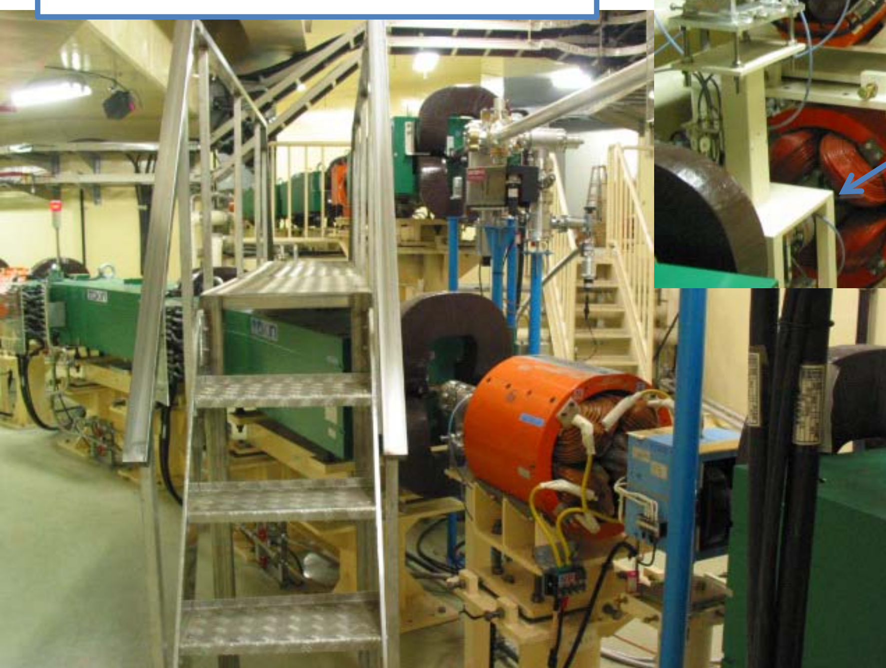
Branches at the end of LINAC

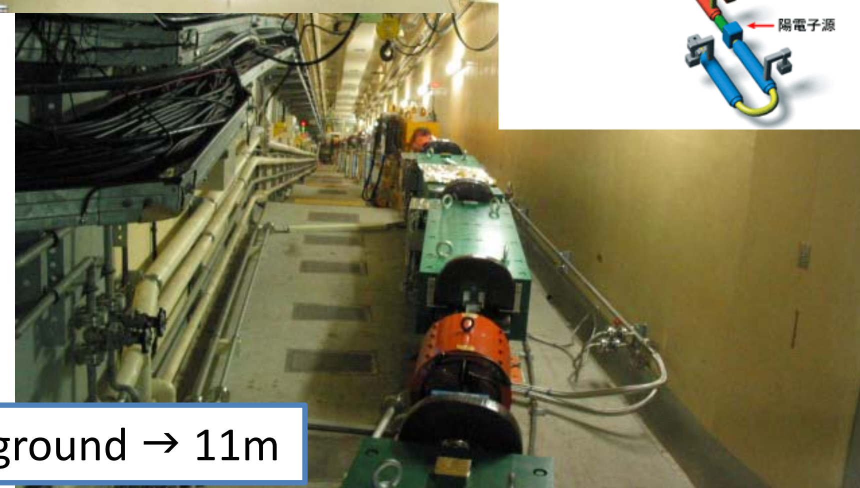


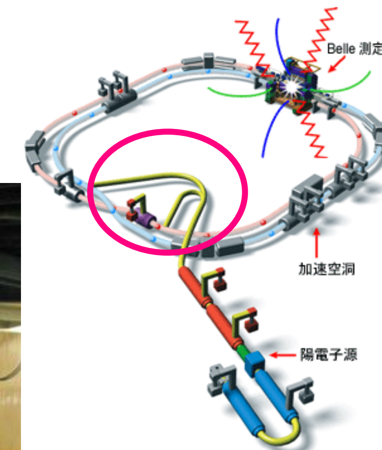
KEKB tunnel tour: Beam Transport Line

Two lines from LINAC, one on another

Goes to different direction

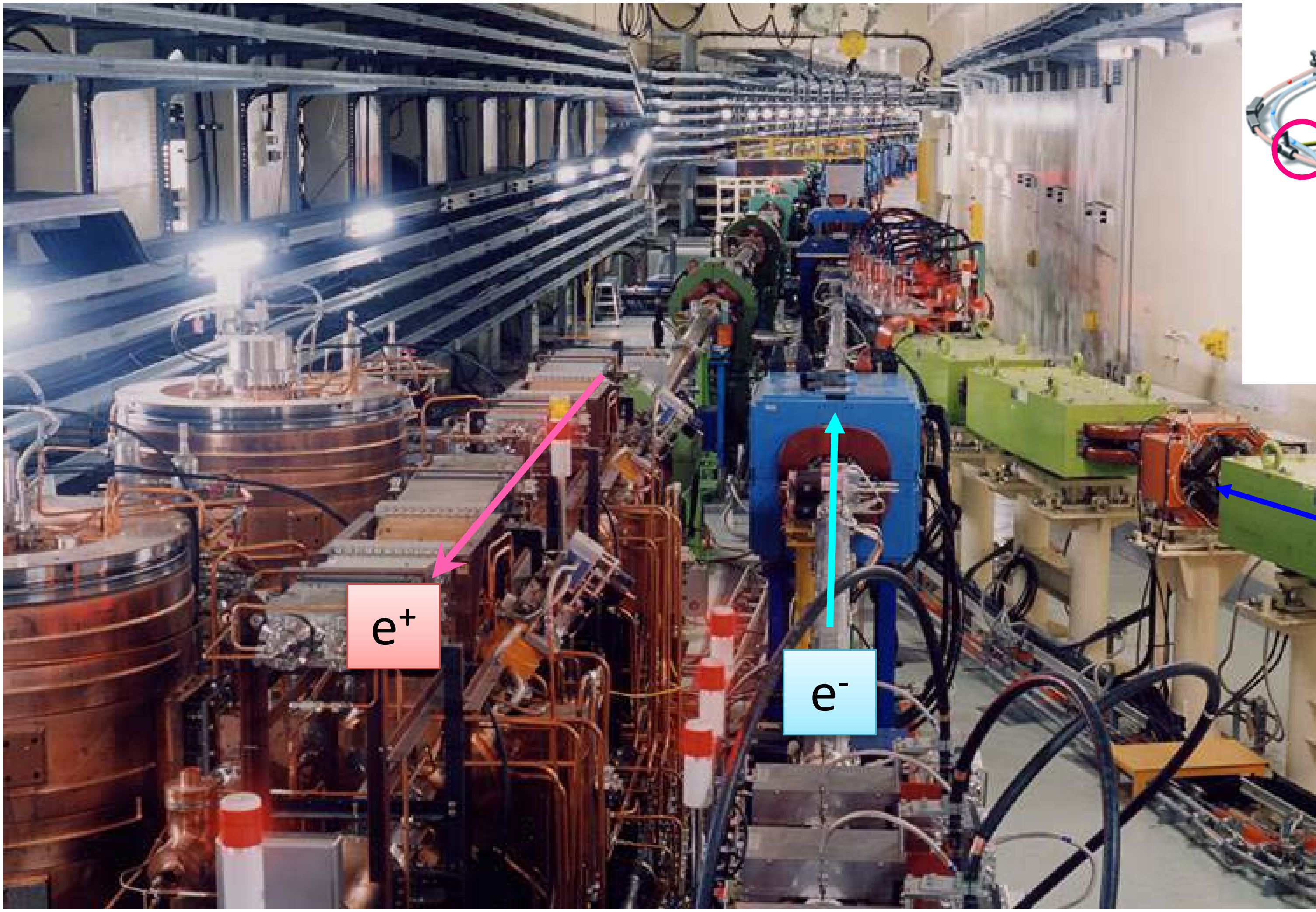


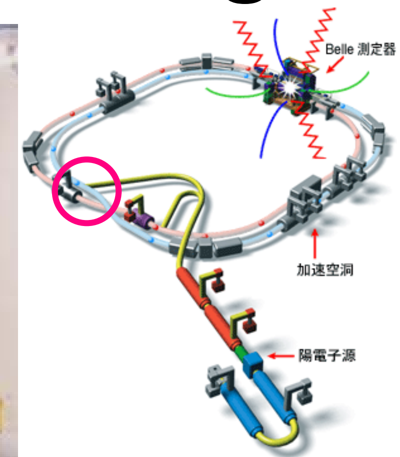




5m below ground → 11m

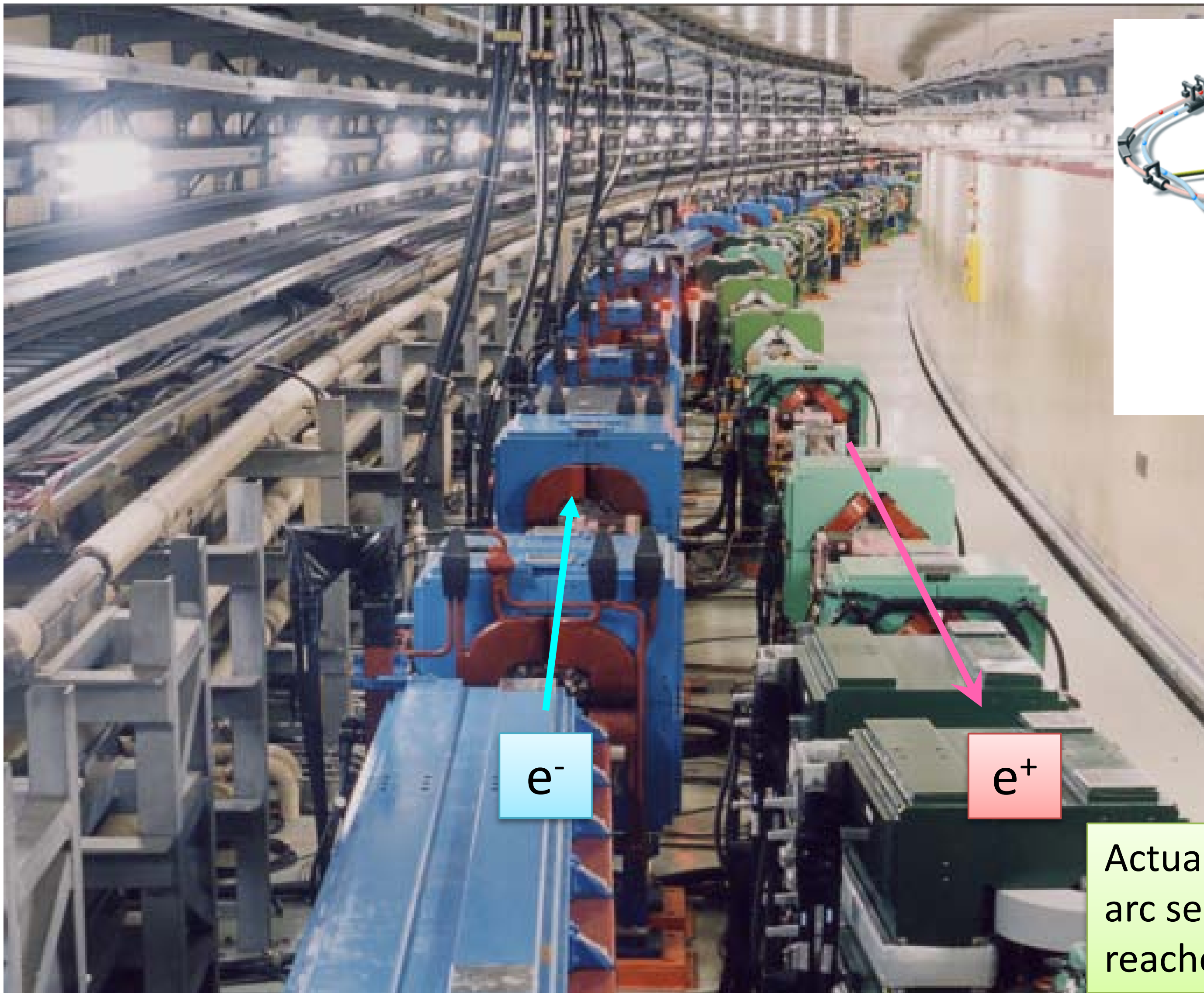
KEKB tunnel tour: Into the Main Ring





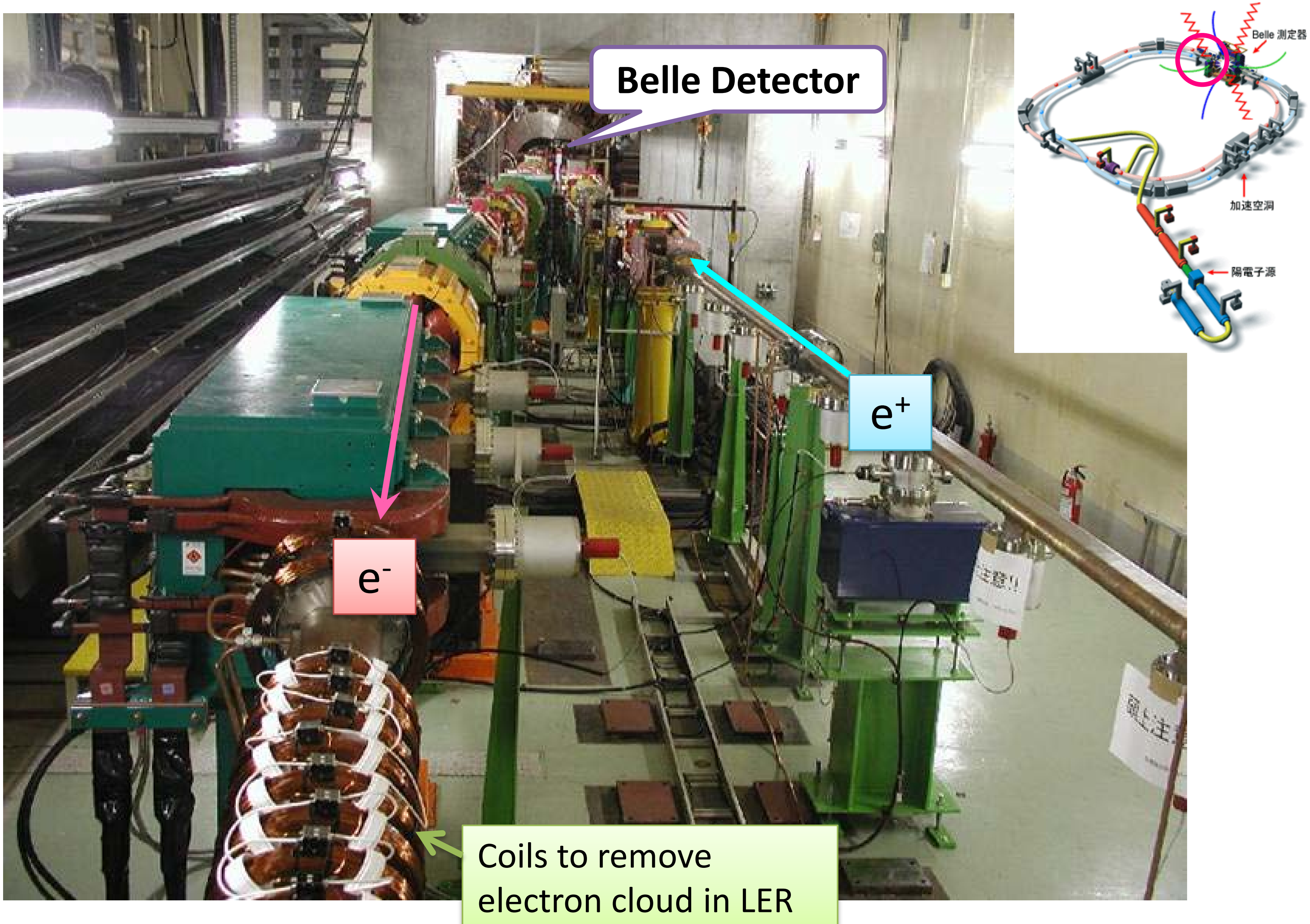
e^- from LINAC

KEKB tunnel tour: Arc Section

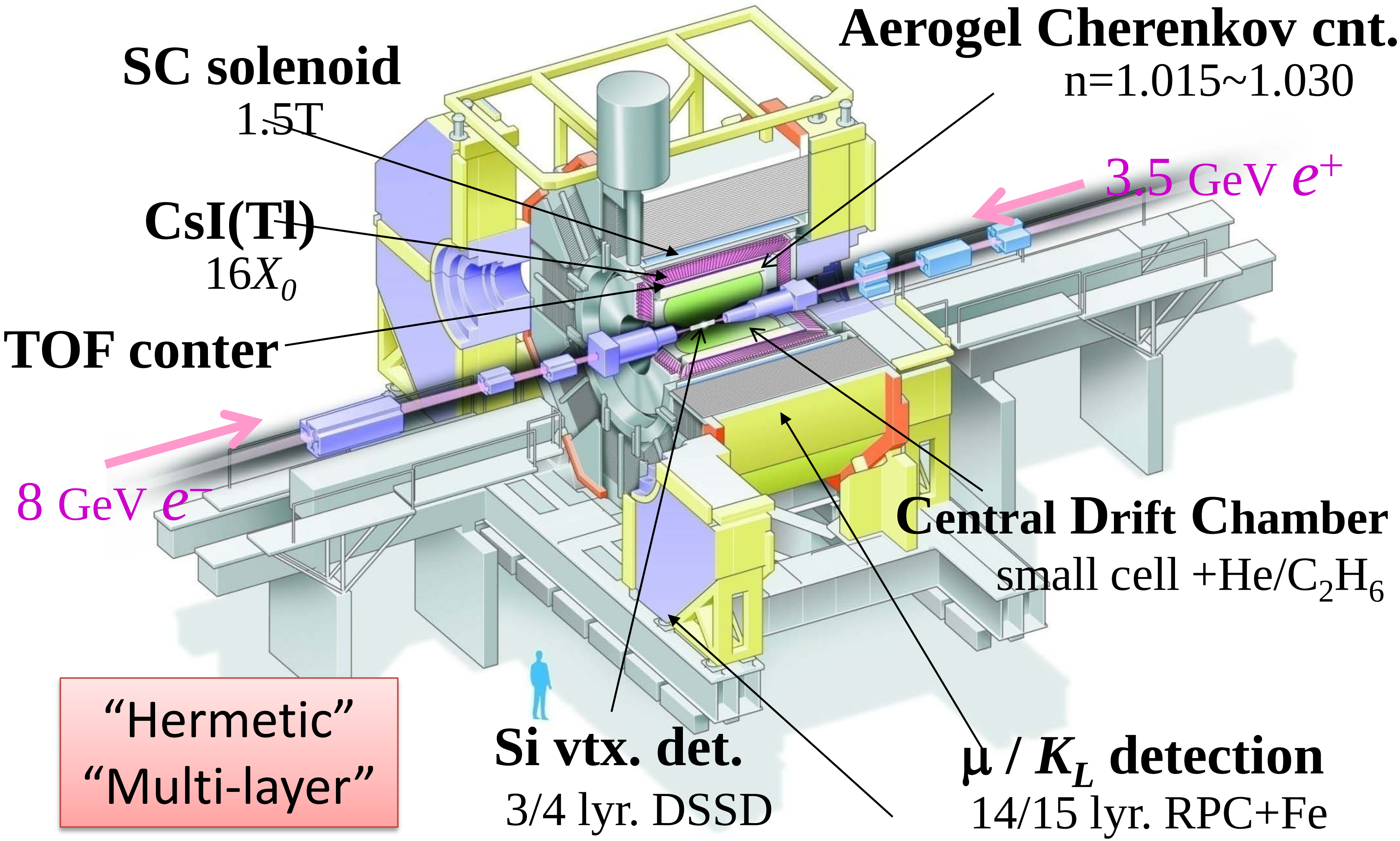


Actually, this is a arc section after e^- reaches Belle

KEKB tunnel tour: Interaction Region



Belle Detector



"Hermetic"
"Multi-layer"

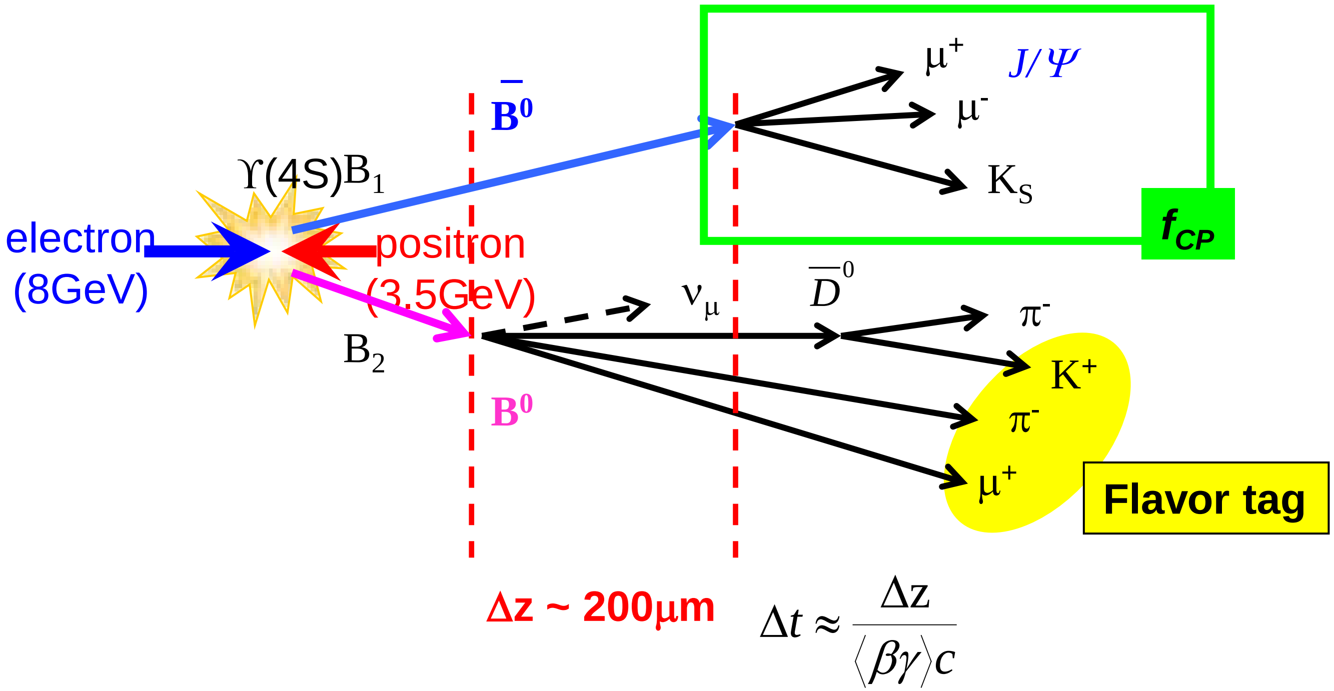
Important features of Belle detector

General features in HEP experiment:

- measure trajectory and momentum of charged particle
- measure energy of gamma
- identify muon
- …

+ Special features for B-physics

- Measure the <u>decay vertex position of B meson (asymmetric beam energy)</u>
- Particle identification (K/π)
- …



Why Do We Need an Asymmetric Collider?

In order to measure time we must measure distance: t=L/v.

How far do B mesons travel after being produced by the Y(4S) (at rest) at a symmetric e^+e^- collider?

At a symmetric collider we have for the B mesons from Y(4S) decay:

p_{lab} =0.3 GeV, m_B=5.28 GeV

$\tau_B = 1.6\times10^{-12}$ sec

Average flight distance <L>= $(\beta\gamma)c\tau_B$= (p/m)(468μm)=(0.3/5.28)(468μm)=(27μm)

This is too small to measure!!

If the beams have unequal energies then the entire system is Lorentz Boosted:

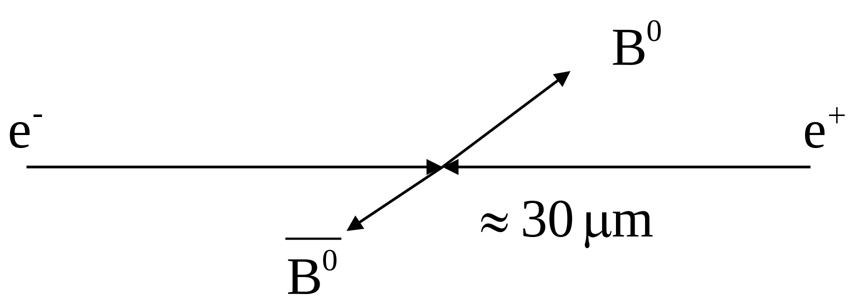
$\beta\gamma = p_{lab}/E_{cm} = (p_{high}-p_{low})/E_{cm}$

SLAC: 9 GeV+3.1 GeV $\beta\gamma = 0.55$ <L>= 257μm

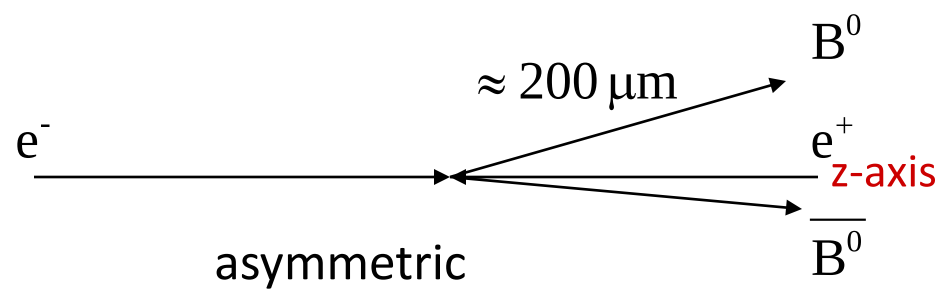
KEK: 8 GeV+3.5 GeV $\beta\gamma = 0.42$ <L>= 197μm

We can measure these decay distances !

Because of the boost and the small p_{lab} the time measurement is a z measurment.



symmetric
CESR

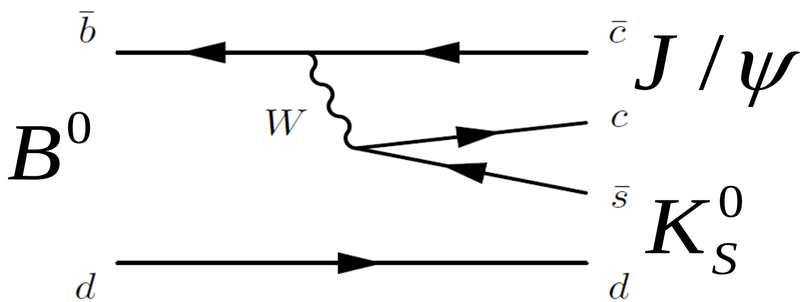


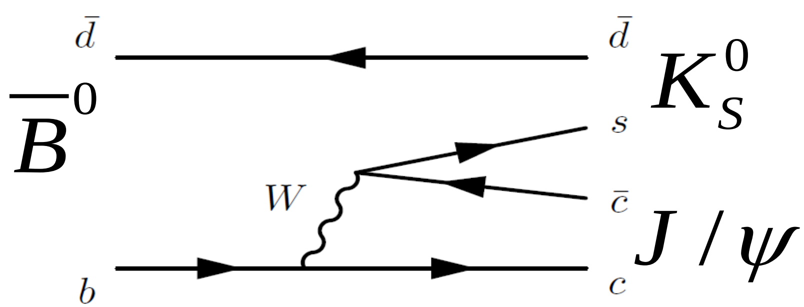
asymmetric
SLAC, KEK

“Golden mode”: B→J/ψ K_s^0

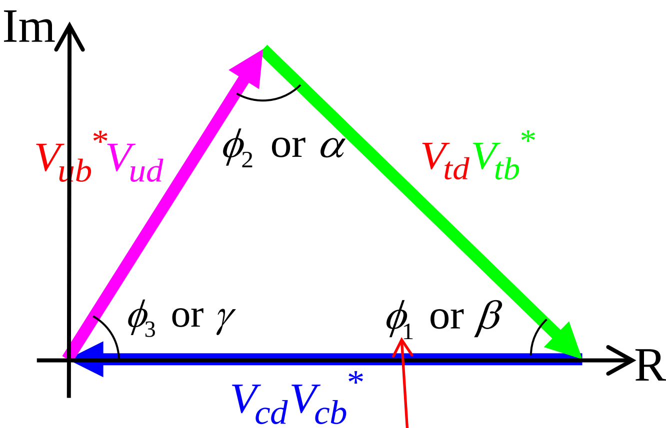
B→J/ψK_S TCPV measurement is a good test of KM theory!
Advocated by Bigi, Carter, and Sanda (1980)

Both B^0 and $\overline{B}^0$ can decay to $J/\psi K_S$.





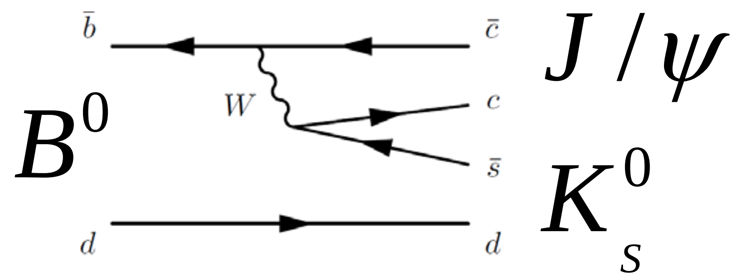
$B^0 \rightarrow \bar{B}^0$ mixing



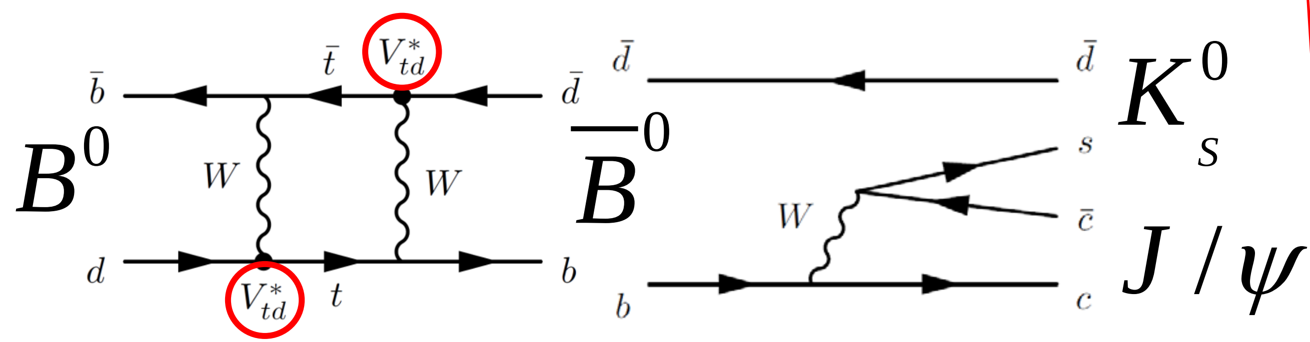
①Direct $B^0 \rightarrow J/\psi K_S$ decay

②$B^0 \rightarrow \bar{B}^0$ mixing and then $B^0 \rightarrow J/\psi K_S$ decay

①



②



$$\left|B^0(t)\right\rangle = e^{-\frac{\Gamma t}{2}}\left\{\cos\left(\frac{\Delta m t}{2}\right)\left|B^0\right\rangle + \underline{ie^{-2i\phi_1}}\sin\left(\frac{\Delta m t}{2}\right)\left|\bar{B}^0\right\rangle\right\}$$

ϕ_1

Time-dependent CP asymmetry

$$i = e^{i\frac{\pi}{2}}$$

$$CP\left|J/\psi K_S^0\right\rangle = -\left|J/\psi K_S^0\right\rangle$$

$$\left\langle J/\psi K_S^0 \middle| B^0\right\rangle = \left\langle J/\psi K_S^0 \middle| \overline{B}^0\right\rangle$$

$$\left|B^0(t)\right\rangle = e^{-\frac{\Gamma t}{2}}\left\{\cos\left(\frac{\Delta m t}{2}\right)\left|B^0\right\rangle + e^{i\left(\frac{\pi}{2}-2\phi_1\right)}\sin\left(\frac{\Delta m t}{2}\right)\left|\overline{B}^0\right\rangle\right\}$$

$$\left|\left\langle J/\psi K_S^0 \middle| B^0(t)\right\rangle\right|^2 \propto e^{-\Gamma t}\left\{1-\cos\left(\frac{\pi}{2}-2\phi_1\right)\sin\Delta m t\right\} = e^{-\Gamma t}\left(1-\sin 2\phi_1 \sin\Delta m t\right)$$

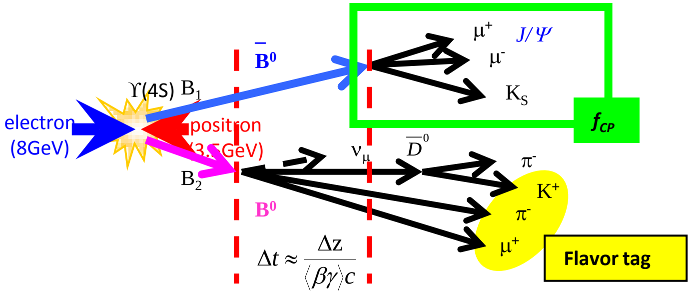
$$\left|\left\langle J/\psi K_S^0 \middle| \overline{B}^0(t)\right\rangle\right|^2 \propto e^{-\Gamma t}\left(1+\sin 2\phi_1 \sin\Delta m t\right)$$

Asymmetry of CPV is:

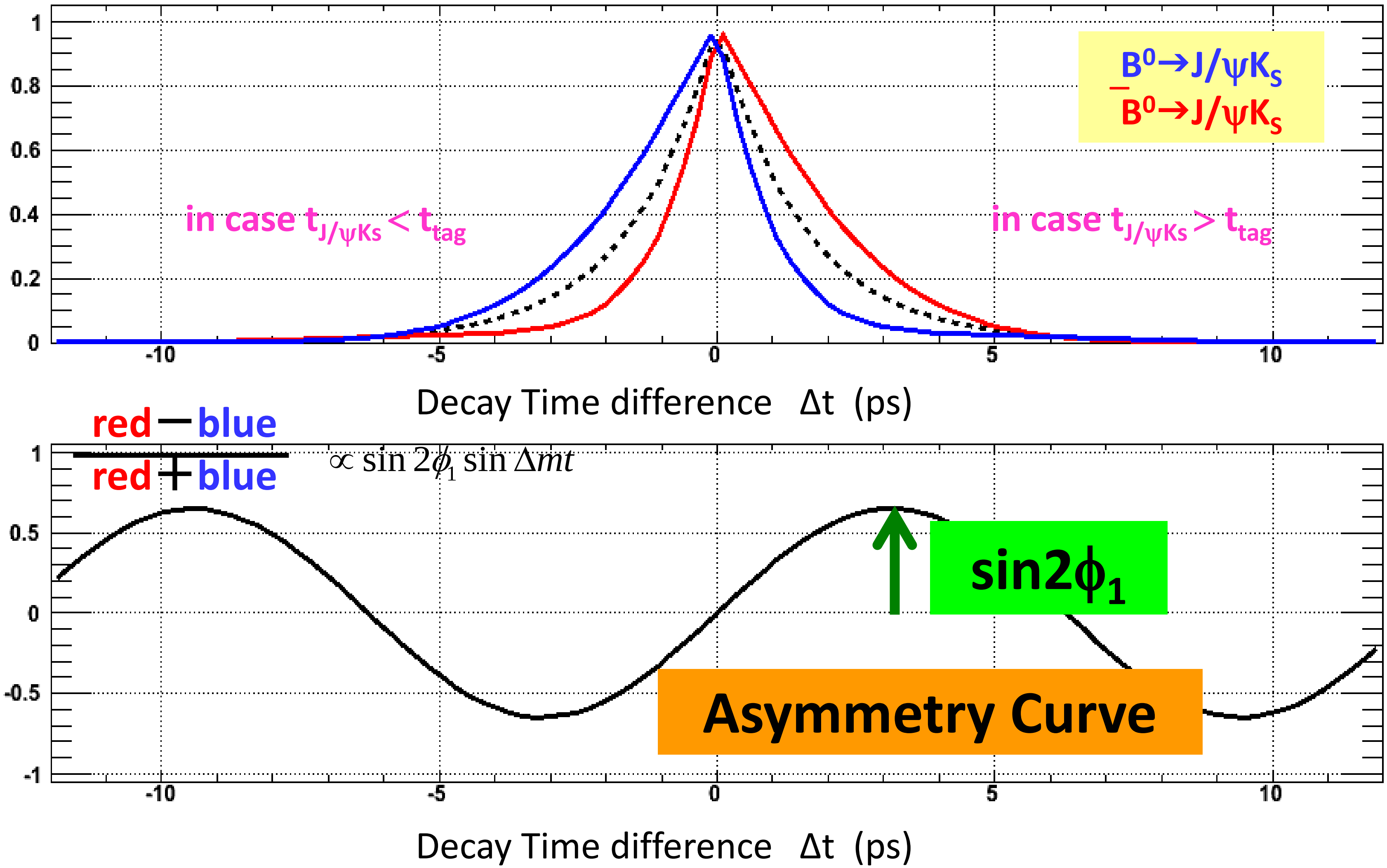
$$Asym(t) = \frac{\left|\left\langle J/\psi K_S^0 \middle| \overline{B}^0(t)\right\rangle\right|^2 - \left|\left\langle J/\psi K_S^0 \middle| B^0(t)\right\rangle\right|^2}{\left|\left\langle J/\psi K_S^0 \middle| \overline{B}^0(t)\right\rangle\right|^2 + \left|\left\langle J/\psi K_S^0 \middle| B^0(t)\right\rangle\right|^2} = \sin 2\phi_1 \sin\Delta m t$$

Time-dependent CP asymmetry (TCP)

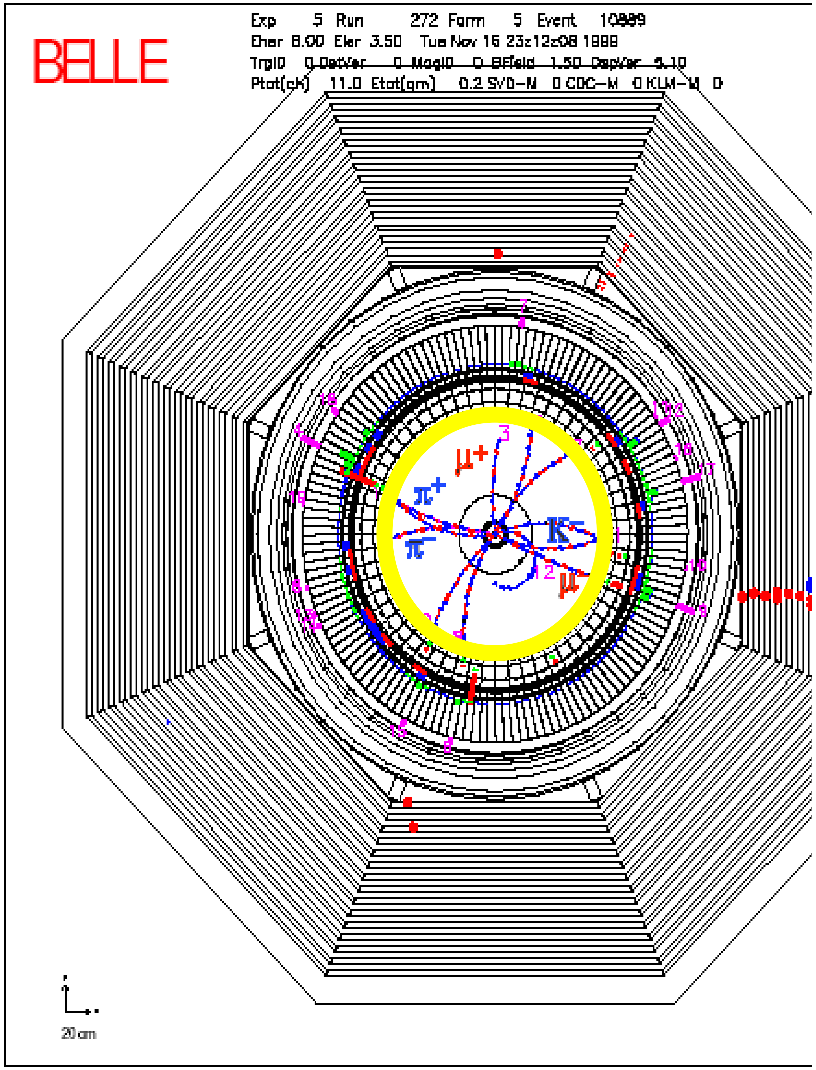
A_{CP} oscillates as function of time, A_{CP} amplitude $\propto \sin 2\phi_1$

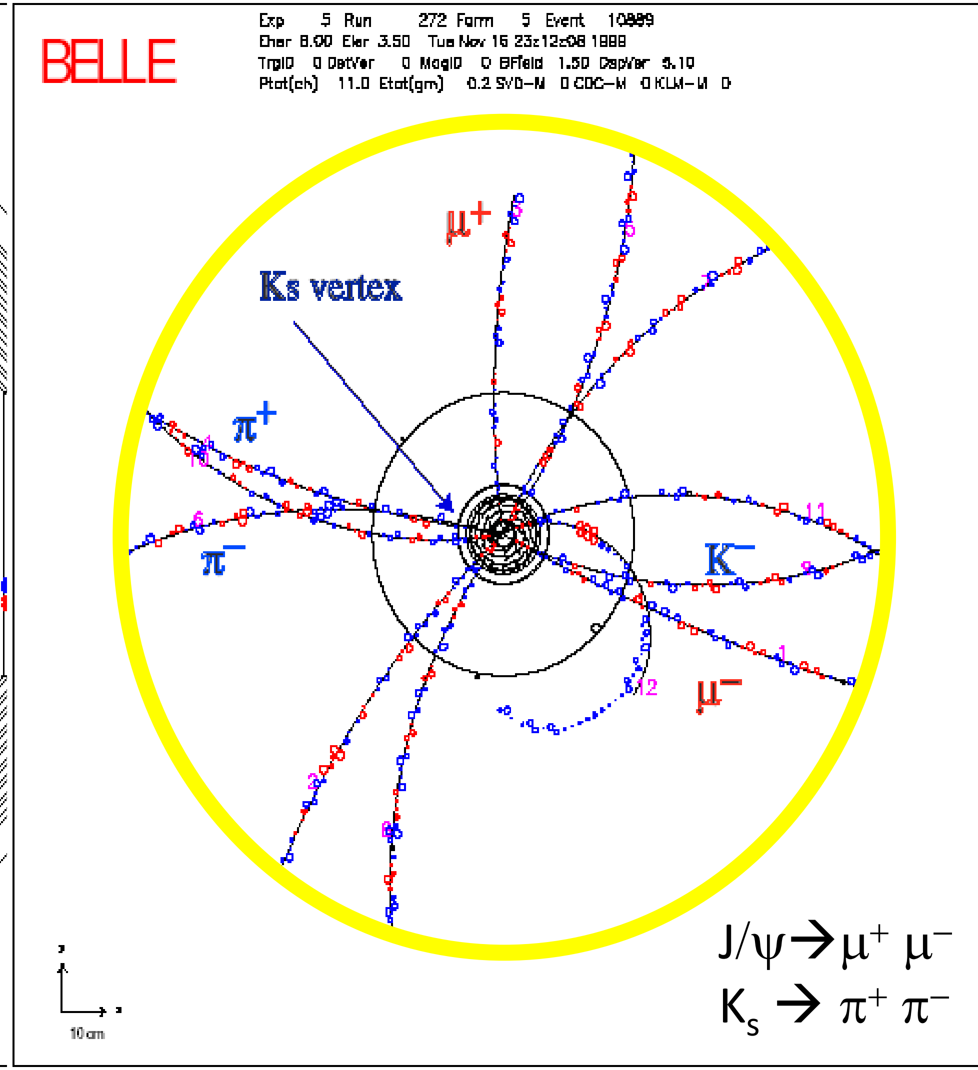


$$\Delta t = t_{J/\psi Ks} - t_{tag}$$

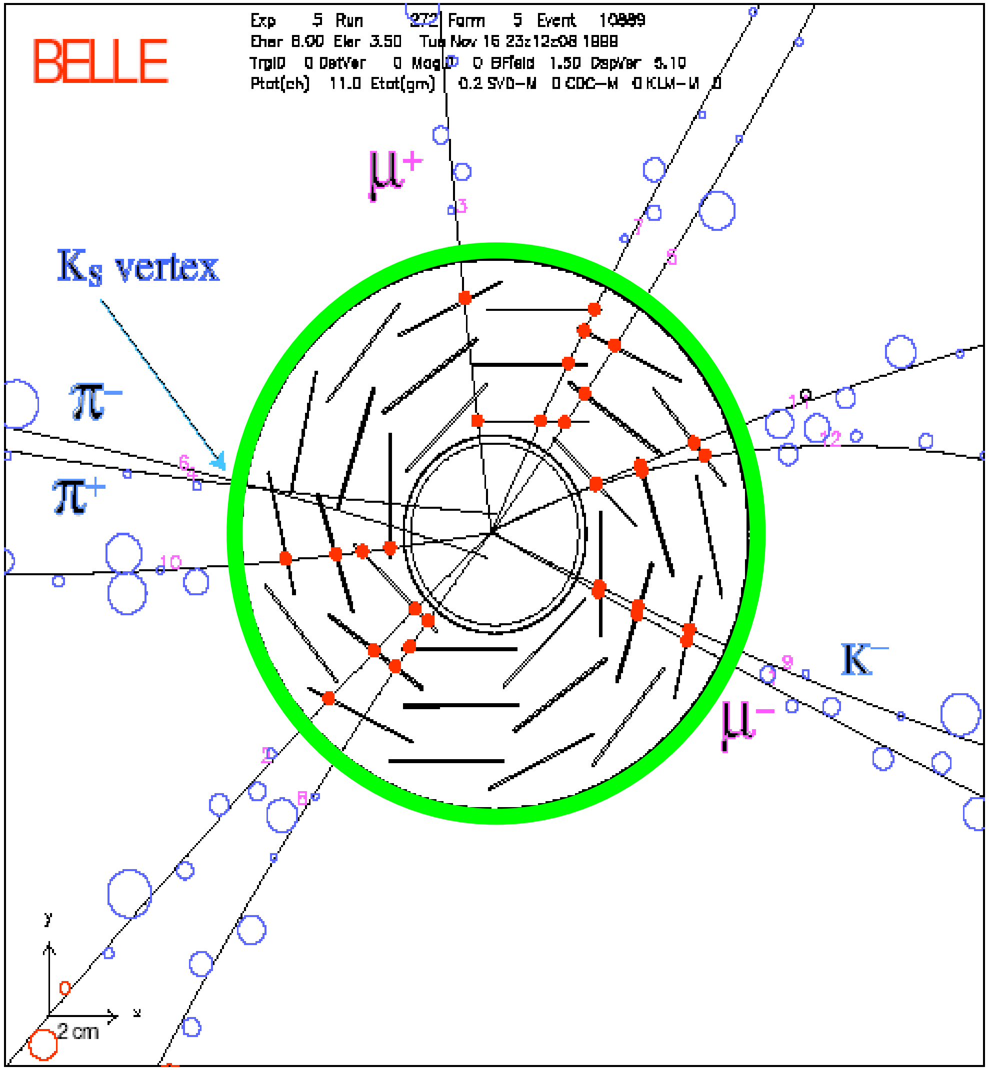


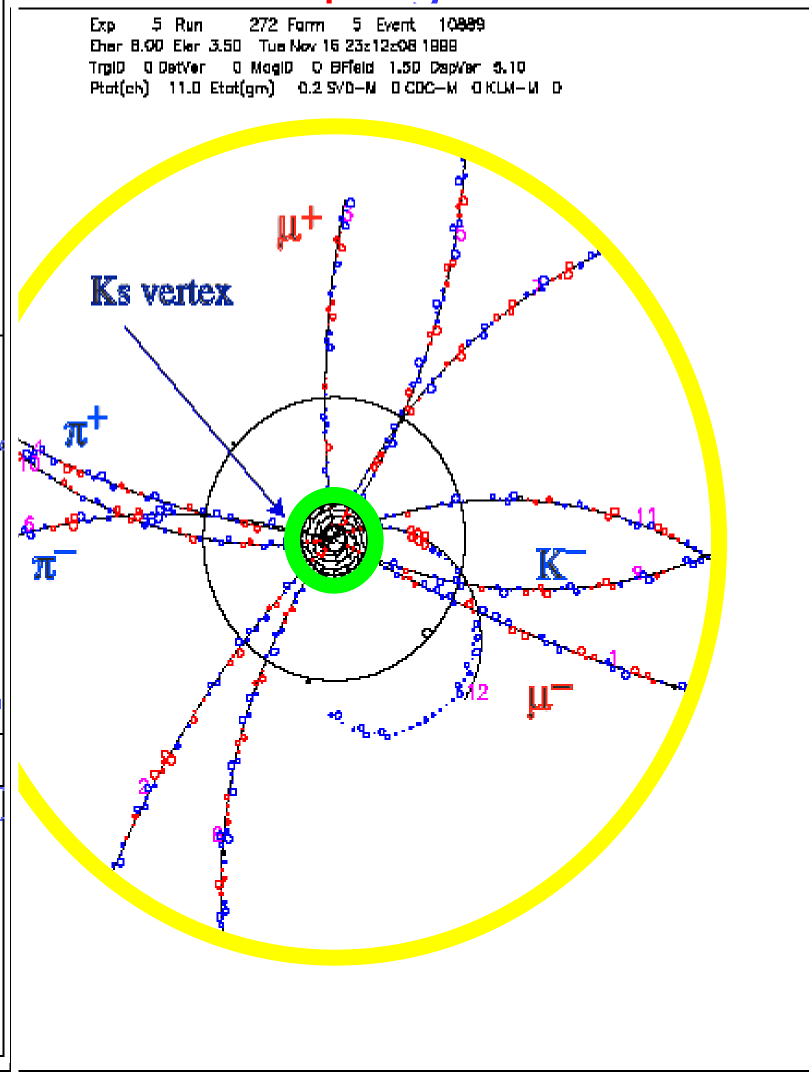
Event Display of $B^0 \rightarrow J/\psi K_S$



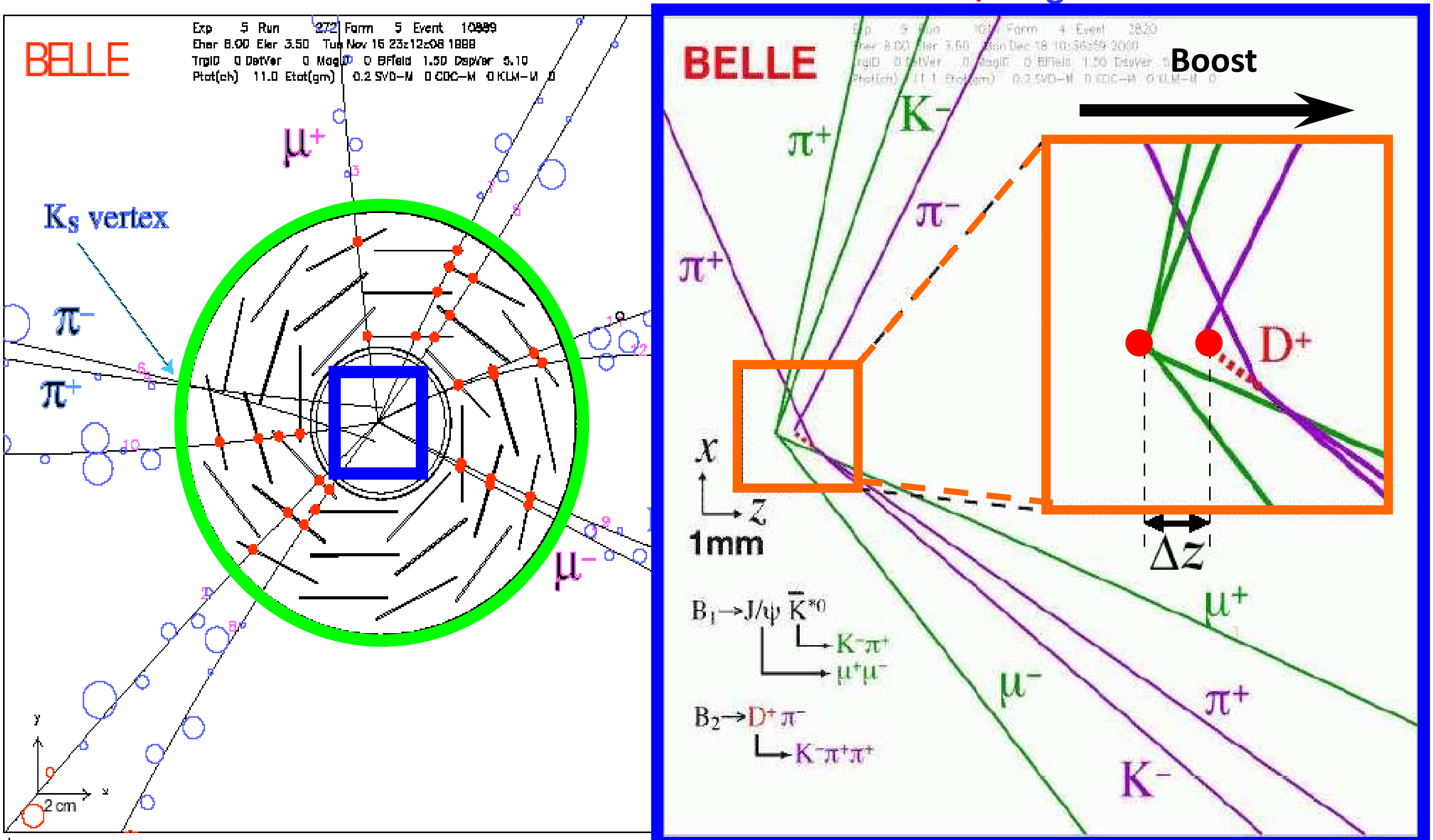


Event Display of $B^0 \to J/\psi K_S$

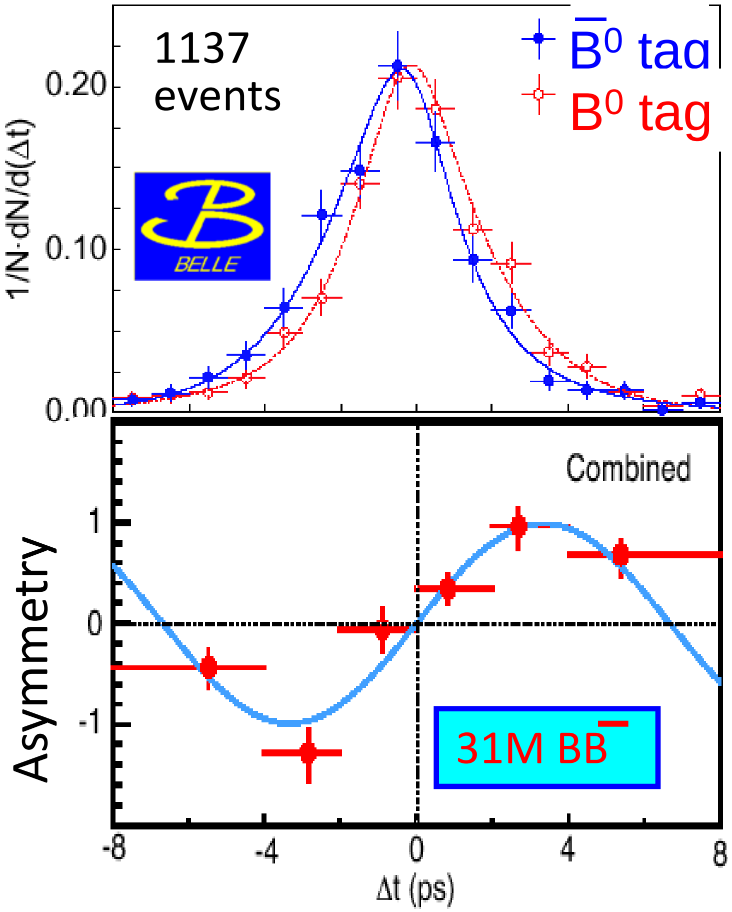




Event Display of $B^0 \rightarrow J/\psi K_0^{(*)}$



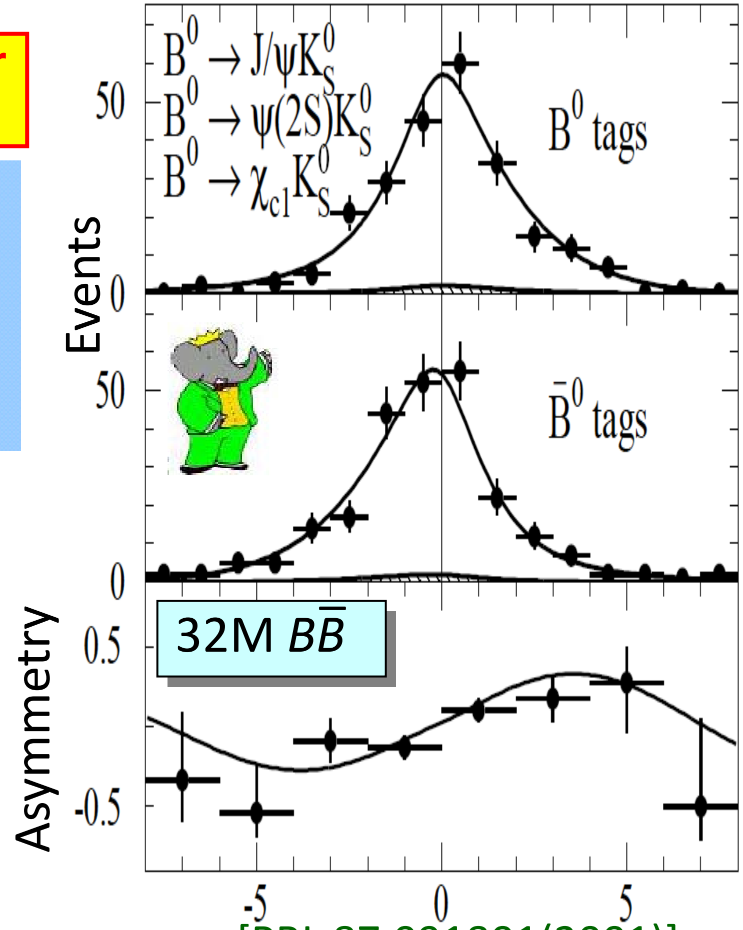
First Observation: CPV in B



[PRL 87,091802(2001)]

Summer 2001

$J/\Psi\ K_S$
$\Psi(2S)\ K_S$
$\chi_{c1} K_S$
$(\eta_c K_S)$
$J/\Psi\ K_L$
$J/\psi\ K^{*0}$



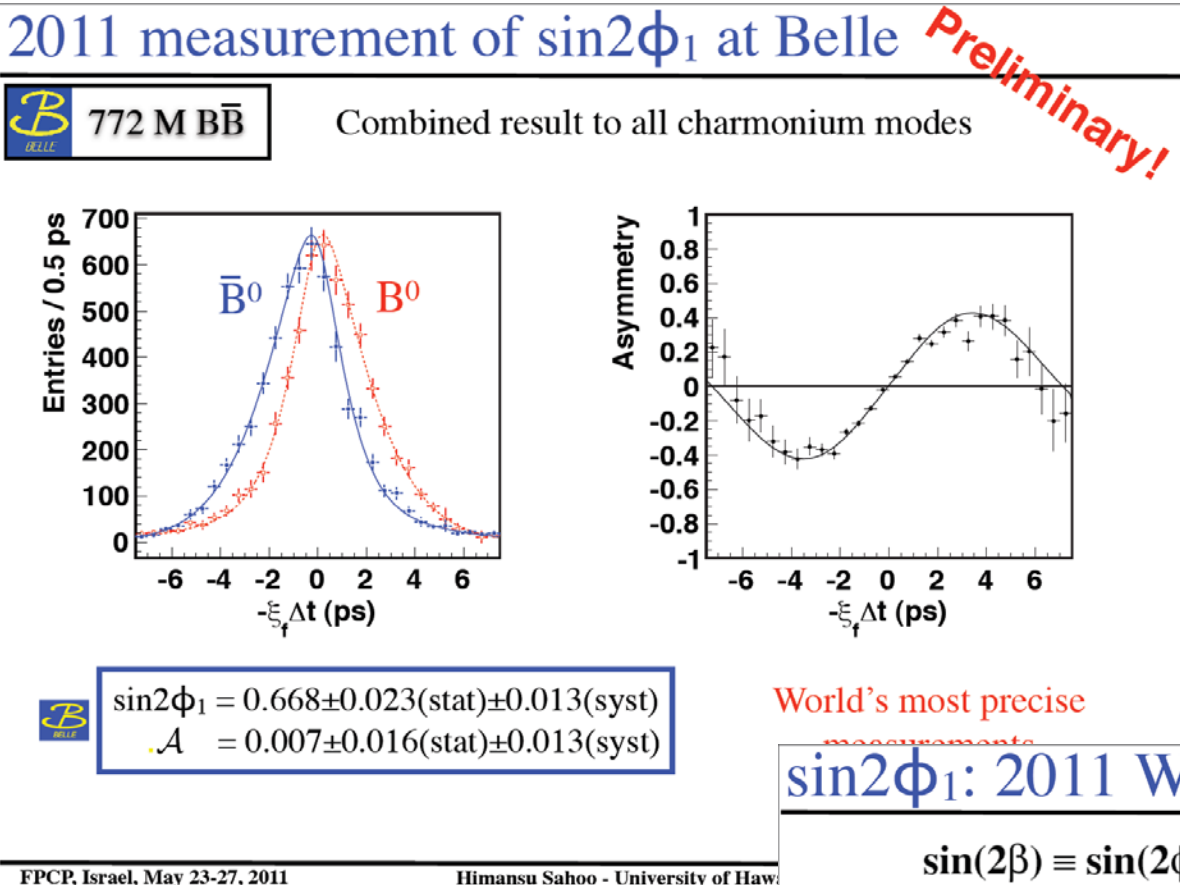
[PRL 87,091801(2001)]

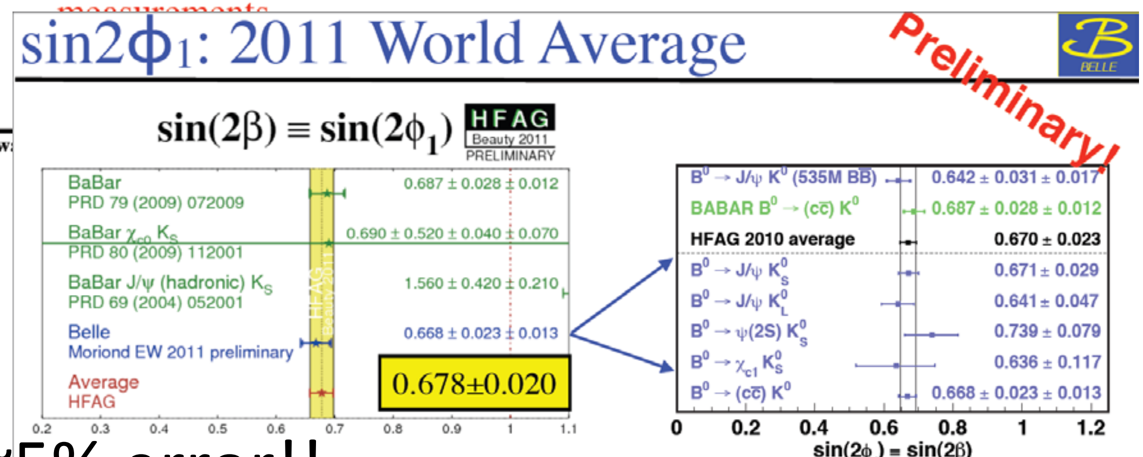
$sin2\phi_1 = 0.99 \pm 0.14 \pm 0.06$

$0.59 \pm 0.14 \pm 0.05$

~20% error

Latest measurement of $\sin 2\phi_1$



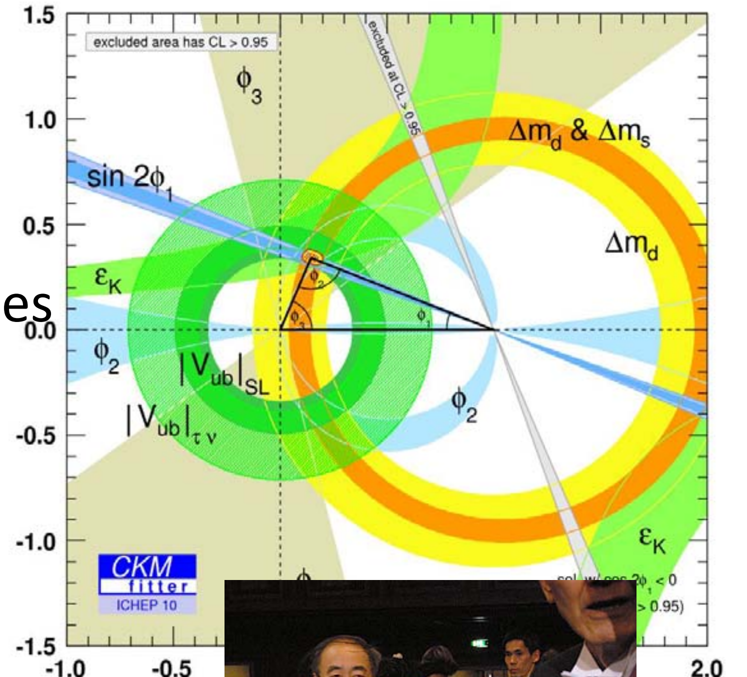


Only ~5% error!!

Physics results achieved by Belle

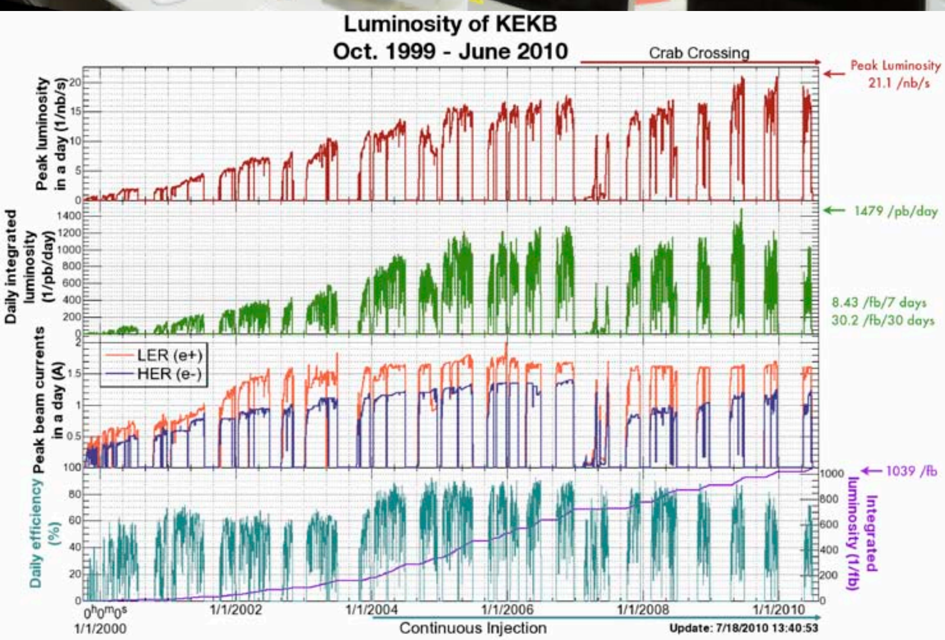
Belle have made a wide variety of achievements over ~10 year running period:

- CKM triangle measurements
  - Matrix elements, Unitary triangle angles
- Direct CP violation:
  - B→ K+ π−, B→π+π−
- New hadronic states:
  - X, Y, Z mesons
- Rare probes of new physics
  - b→s γ, b→s l+l-



2008 physics Nobel prize

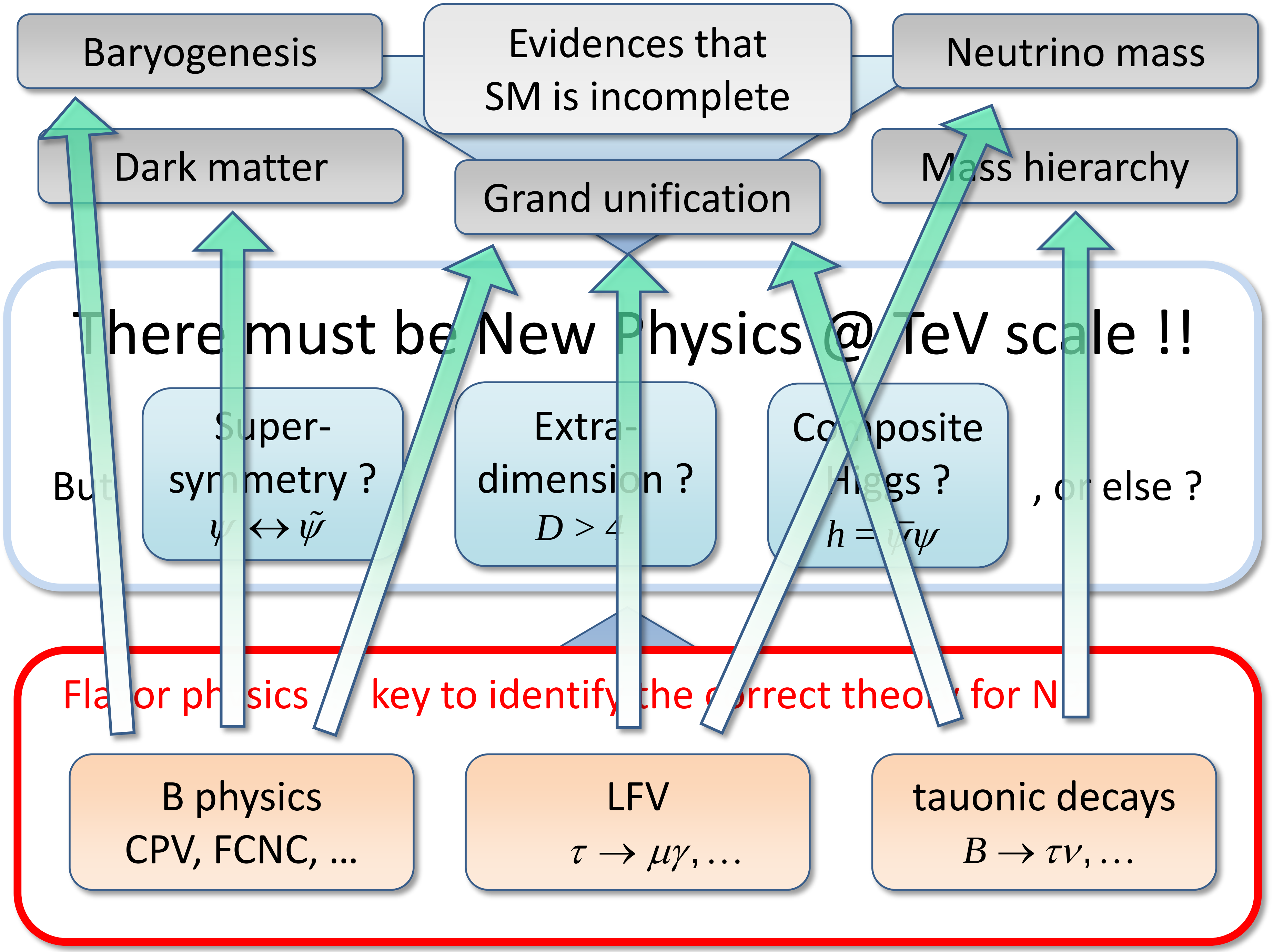
The last beam abort of KEKB on June 30, 2010



First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1 \times 10^{34}/cm^2/s$
$L > 1ab^{-1}$

Happy end of a story,

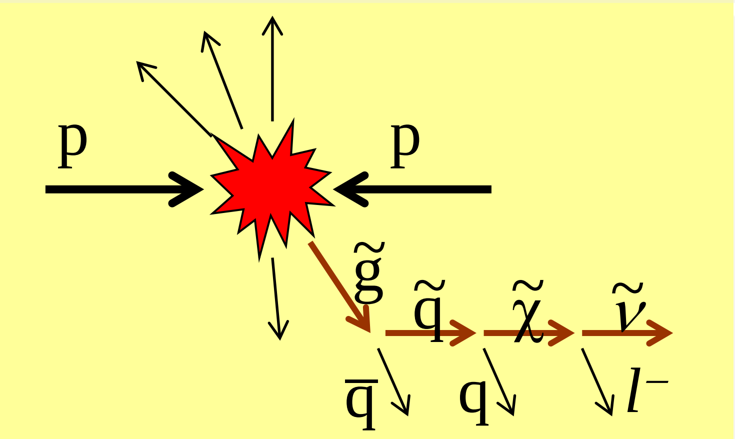
but not the end of the B-factory.



Baryogenesis
Evidences that SM is incomplete
Neutrino mass
Dark matter
Grand unification
Mass hierarchy
There must be New Physics @ TeV scale !!
Bu
Super-symmetry ?
$\psi \leftrightarrow \tilde{\psi}$
Extra-dimension ?
$D > 4$
Composite Higgs ?
$h = \bar{\psi}\psi$
, or else ?
Fla or ph sics key to identify the correct theory for N
B physics
CPV, FCNC, ...
LFV
$\tau \to \mu\gamma, \ldots$
tauonic decays
$B \to \tau\nu, \ldots$

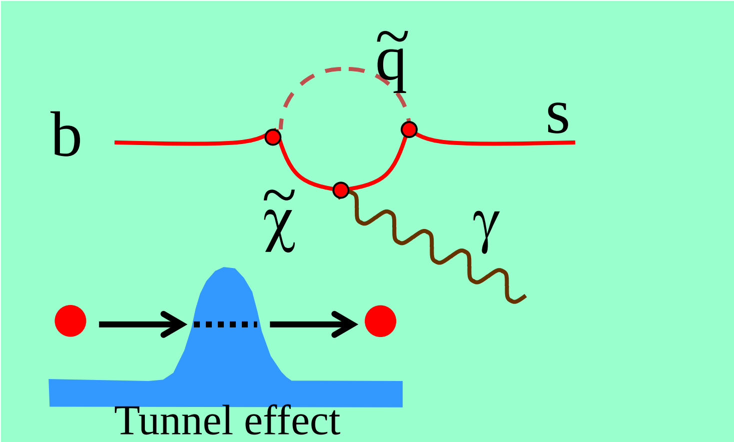
Energy Frontier and Luminosity Frontier

Direct Production by High Energy Coll.



Energy Frontier

Virtual Production via Quantum Eff.



Luminosity Frontier

Even if no new particles are found in Energy Frontier experiment (which is not exciting), Luminosity Frontier experiment can search for new physics. With more accumulated data, sensitivity to higher energy scale is achieved.

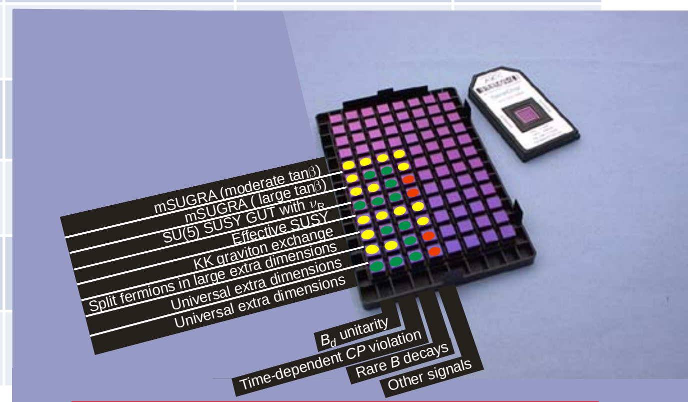
Flavor Physics: sensitivity to each NP model

Popular SUSY models →

Observables ↓	mSUGRA	MSSM+ν_R degenerate	MSSM+ν_R non-degenerate	SU(5)+ν_R degenerate	SU(5)+ν_R non-degenerate	U(2) FS	…
$A_{CP}(s\gamma)$						✓	
$S(K^*\gamma)$				✓	✓	✓	
$S(\rho\gamma)$				✓	✓	✓	
$S(\phi K_S)$							
$S(B_s \to J/\psi\ \phi)$							
$\mu \to e\gamma$		✓					
$\tau \to \mu\gamma$		✓	✓				
$\tau \to e\gamma$			✓				
⋮							

✔: deviation from SM

[based on T.(… 2008)]



Flavor Physics:
DNA identification of NP

Physics topic @ Belle-II

Just a few examples…

– Modes with missing energy: $B \rightarrow K\nu\bar{\nu}$

– Direct CP violation: $B \rightarrow K\pi$

– Mixing-induced CP violation: $b \rightarrow s\gamma$

– etc…

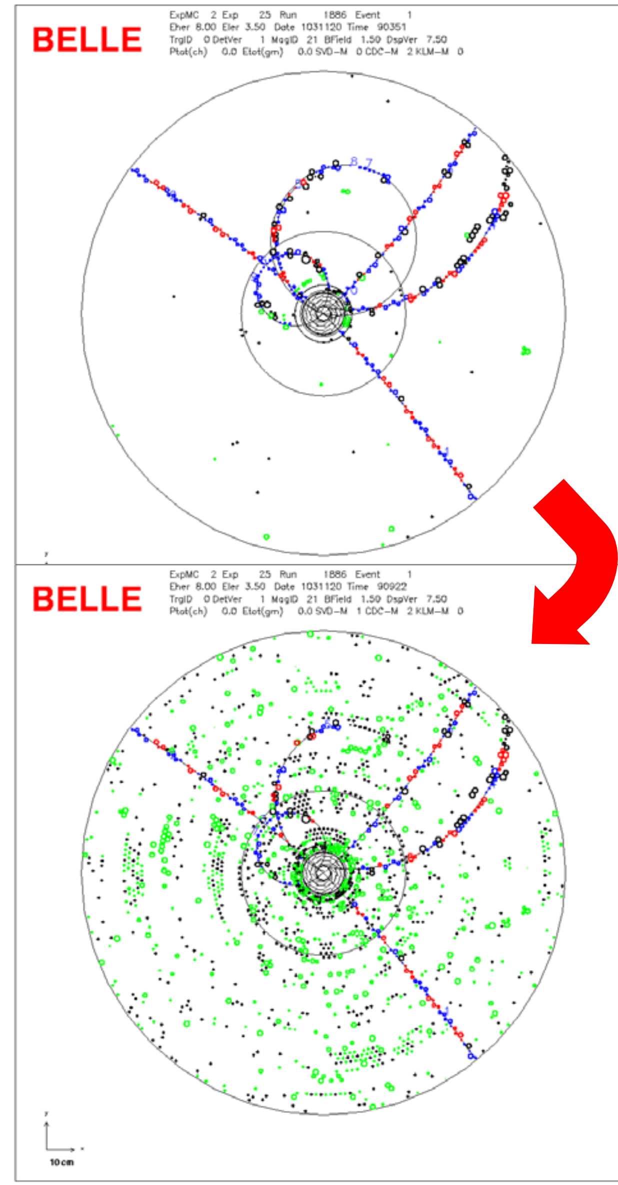
Many more available at:
http://belle2.kek.jp/physics.html and
arXiv:1002.5012

Features of Belle II detector@SuperKEKB

- High momentum PID with low fake rates to observe and study b→s and b→d *penguins*
- In contrast to LHCb, superb neutral detection capabilities.

  e.g. $B \to K_S \pi^0 \gamma$ (to detect right-handed currents), Direct CPV in $B \to K_s^0 \pi^0$

- Capable of observing rare "missing energy modes" such as $B \to K \nu \bar{\nu}$ with B tags. Hermeticity is critical.

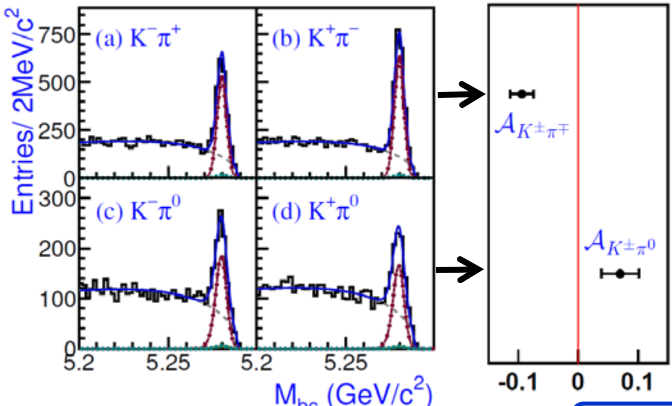


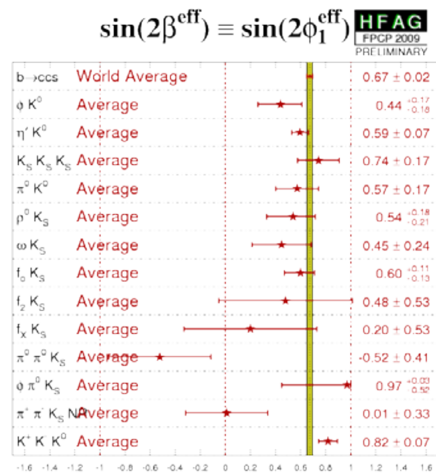
NP indication(?) seen with Belle-I

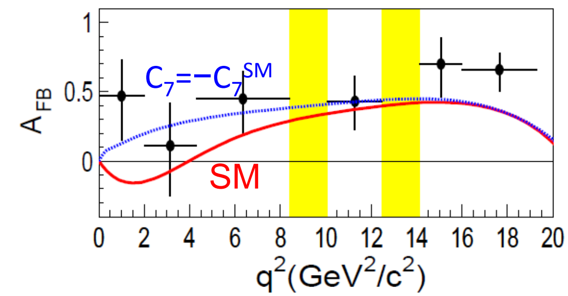
b→s遷移でCP非対称性に異常？

B→K*ℓ⁺ℓ⁻の前後方非対称性に異常？

B^0 と $B^{\pm}$ で A_{CP} 非対称性の大きさに差異



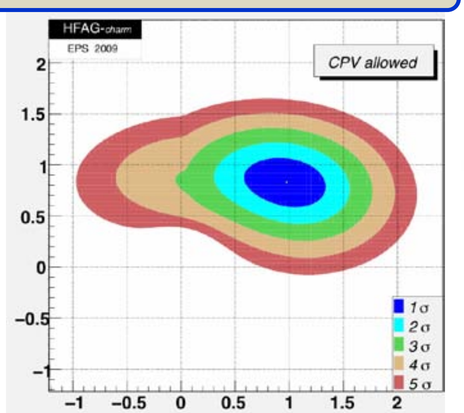


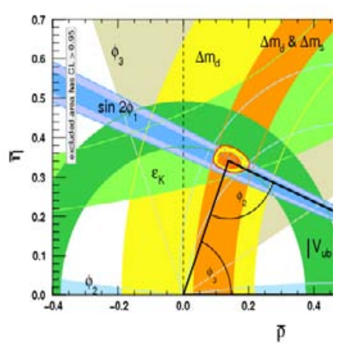


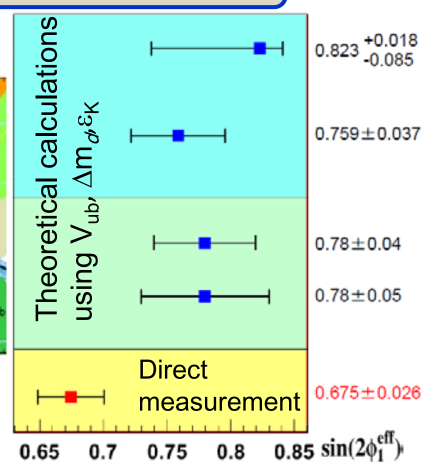
Belleでも新物理の信号が見え始めている？

ユニタリティー三角形に矛盾？

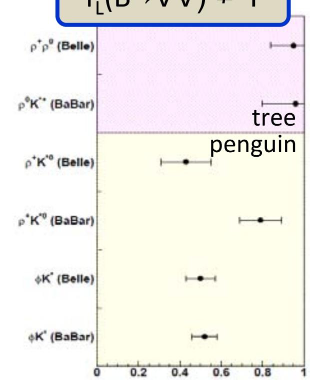
予想外に大きなD^0-$\bar{D}^0$混合







$f_L(B \to VV) \neq 1$

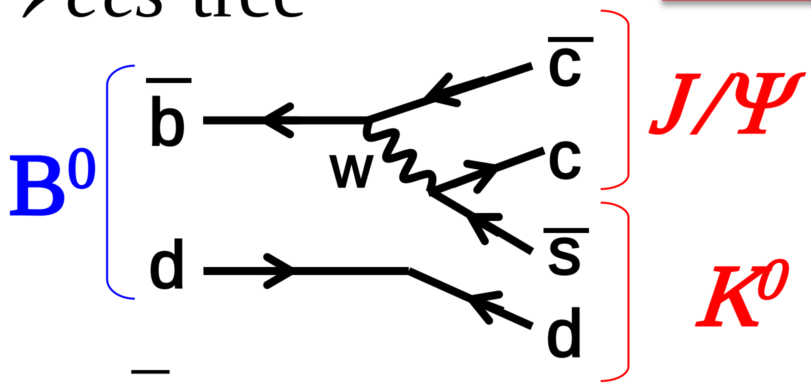


.....

$\sin 2\phi_1$ in $b \to sqq$:

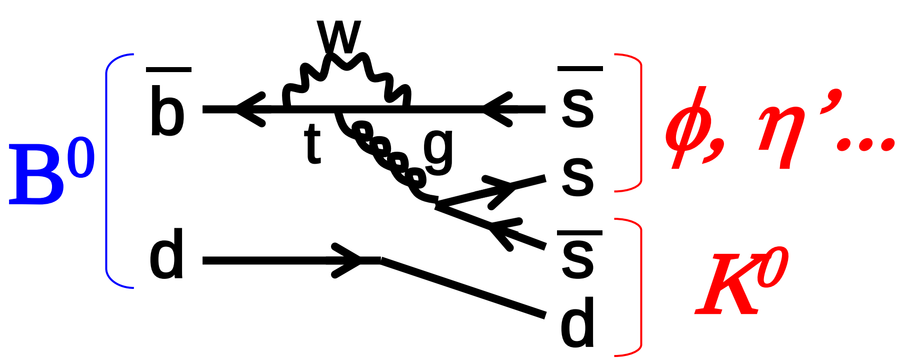
SM case

$b \to c\bar{c}s$ tree



$$A \approx 0$$
$$S = -\xi_f \sin 2\varphi_1$$

$b \to s\bar{q}q$ penguin

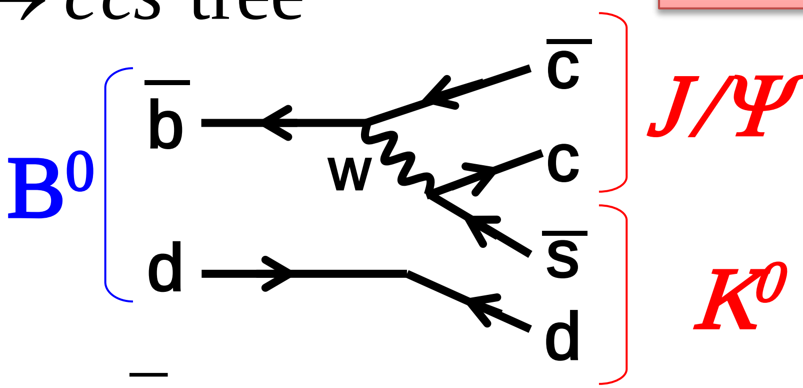


$$A \approx 0$$
$$S = -\xi_f \sin 2\varphi_1$$

$\sin 2\phi_1$ in $b \to sqq$

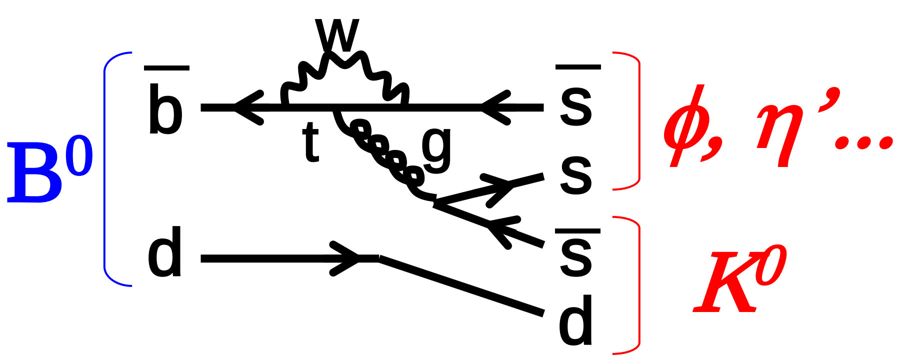
NP case

$b \to c\bar{c}s$ tree

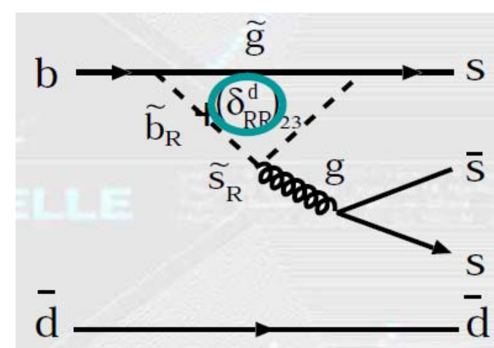


$A \approx 0$
$S = -\xi_f \sin 2\varphi_1$

$b \to sq\bar{q}$ penguin



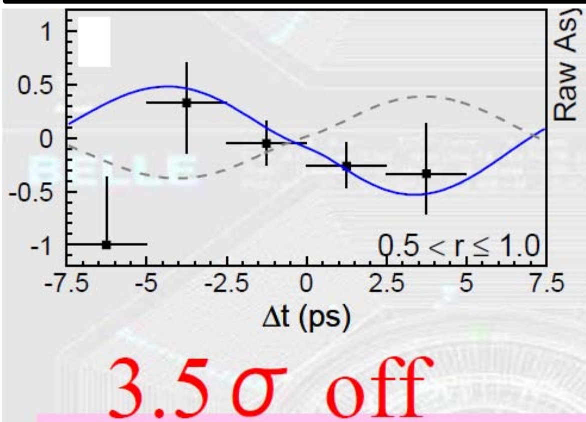
+

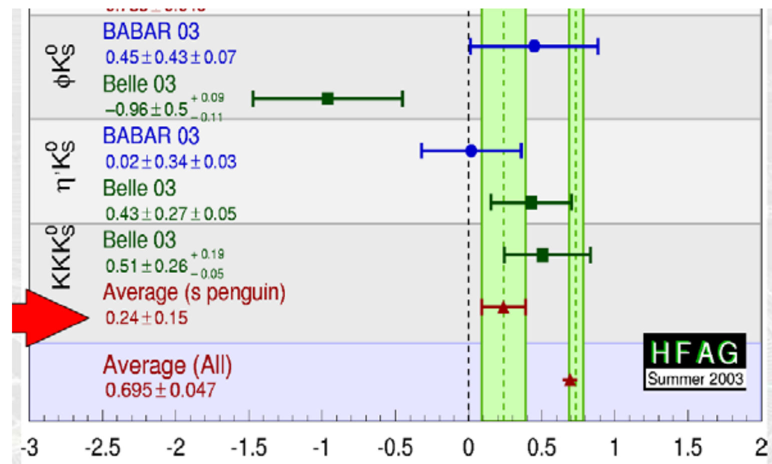


$A \approx 0$
$S \neq -\xi_f \sin 2\varphi_1$

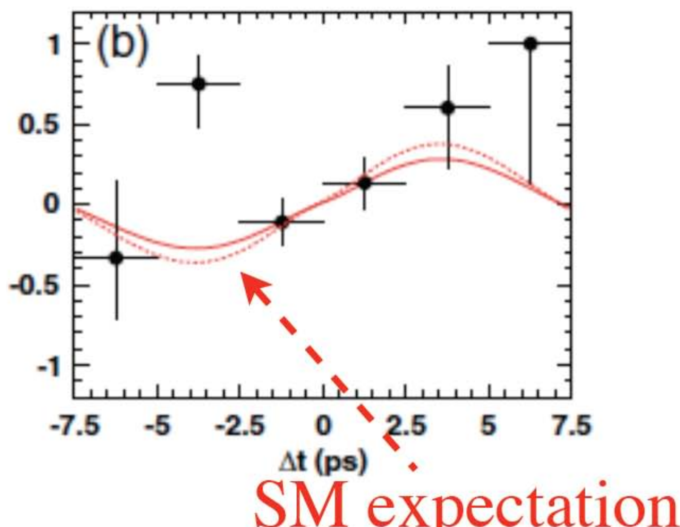
Anomaly in 2003 and now

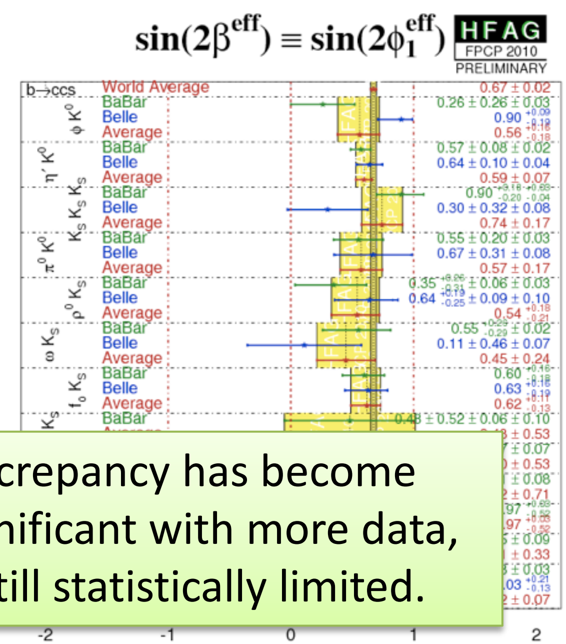
Blue line : fitted
Black dashed line : $\sin 2\phi_1$





PRD 82, 073011 (2010) 657MBB

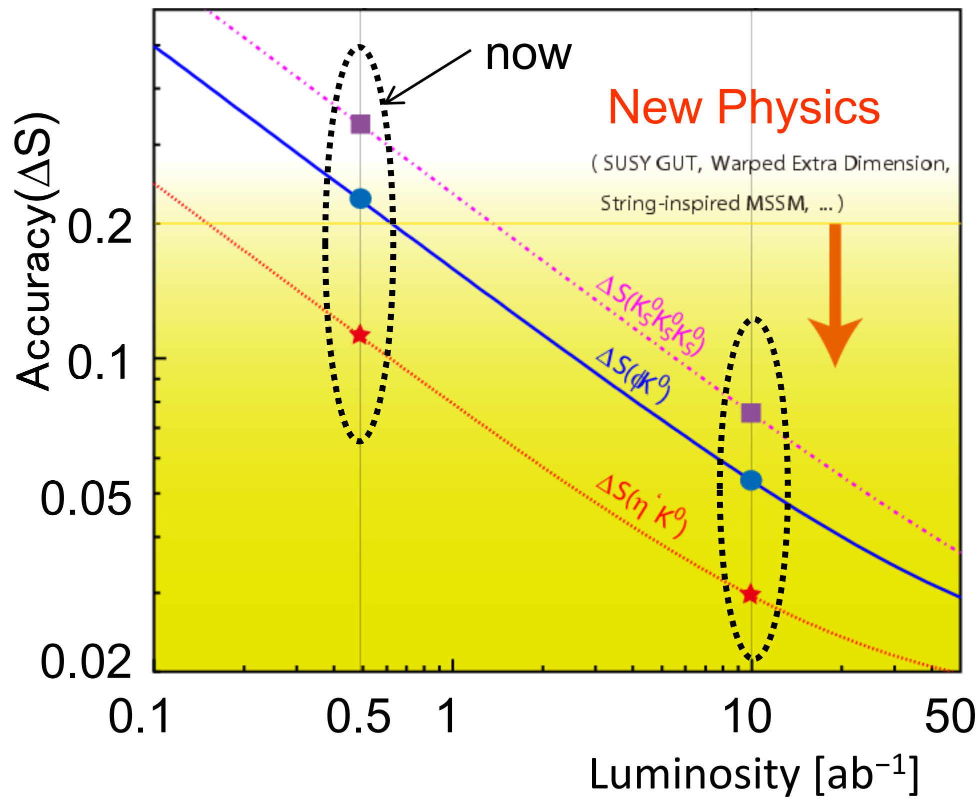


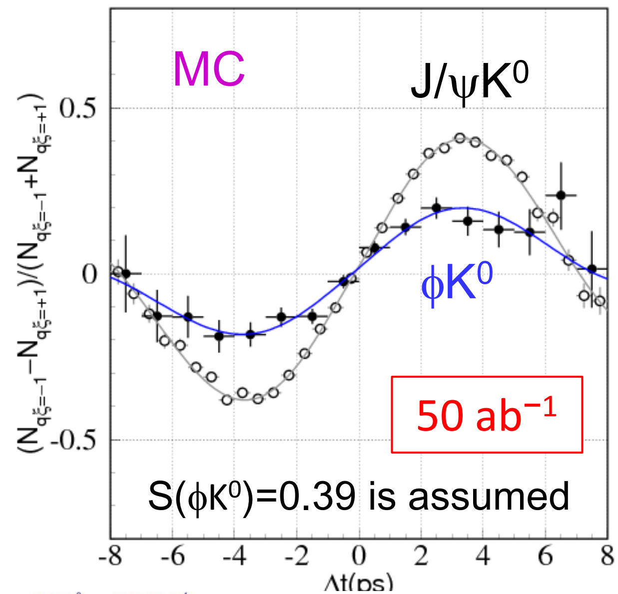


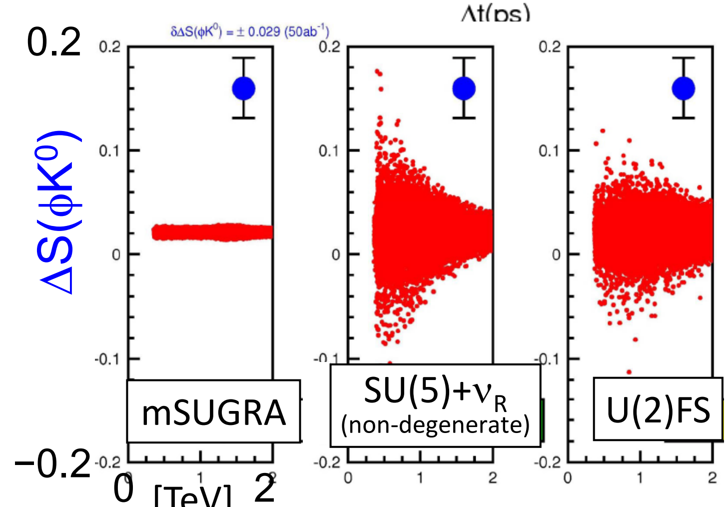
The discrepancy has become less significant with more data, but is still statistically limited.

A_{CP} in b→s transition @Belle-II

With 10-50 ab^{-1} data, accuracy ~ O(0.01)



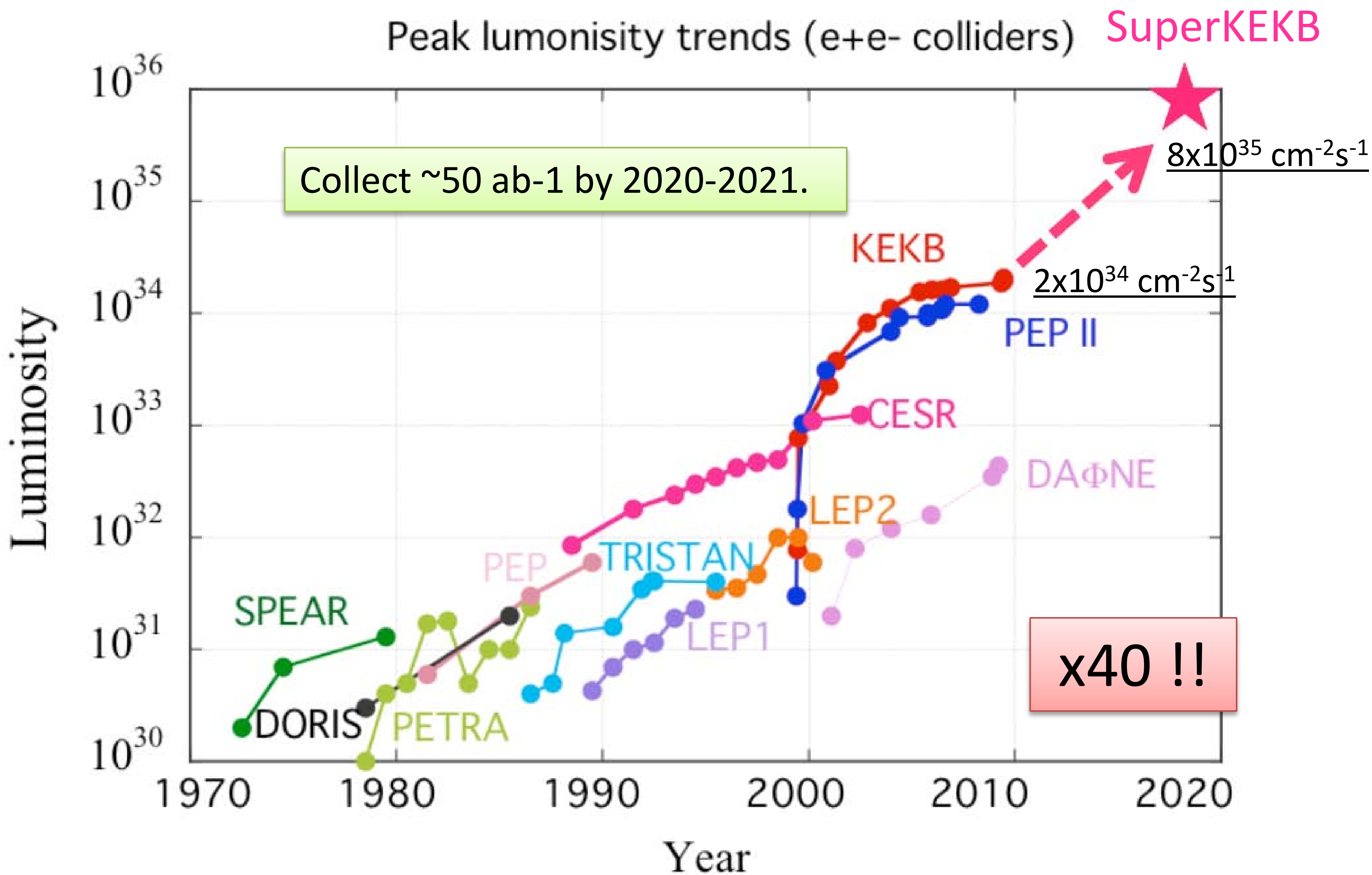




Can be used to distinguish several SUSY models.

SuperKEKB

SuperKEKB Luminosity Target



Accelerator upgrade

At SuperKEKB, we increase the luminosity based on "Nano-Beam" scheme, which was originally proposed for SuperB by P. Raimondi.

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

Luminosity Gain

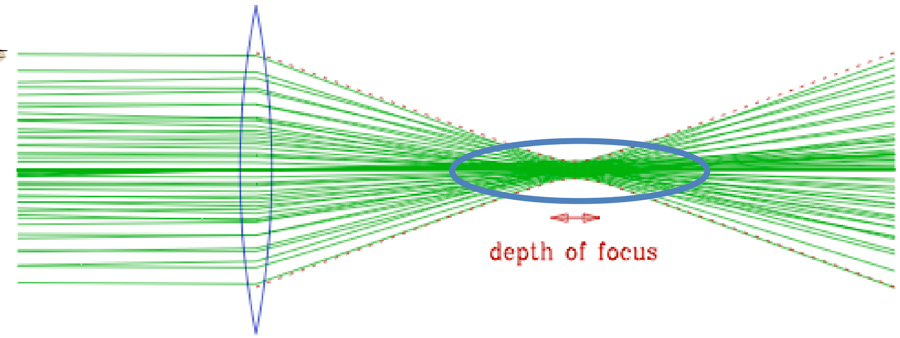
- Vertical β function at IP: 5.9 → 0.27/0.30 mm (x20)
- Beam current: 1.7/1.4 → 3.6/2.6 A (x2)

→ L = $2\text{x}10^{34}$ → $8\text{x}10^{35}$ $\text{cm}^{-2}\text{s}^{-1}$ (x40)

Dilemma in Straightforward Upgrade

Hourglass Effect

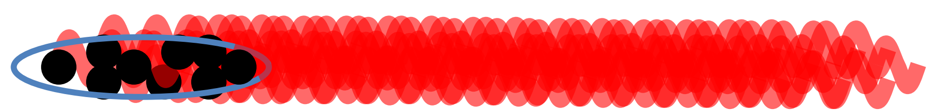
Bunch length must be well shorter than the vertical beam size. Otherwise collisions in skirts deteriorate luminosity (make even worse).



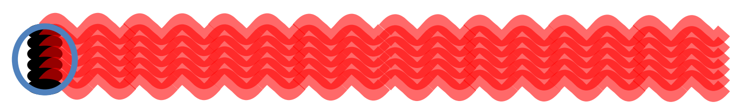
Coherent SR

Bunch length must be long enough so that the SR won't be coherent. CSR increases energy spread, beam size; and deteriorates luminosity.

$\lambda \ll \sigma_z$ Incoherent SR $I \propto Ne^2$



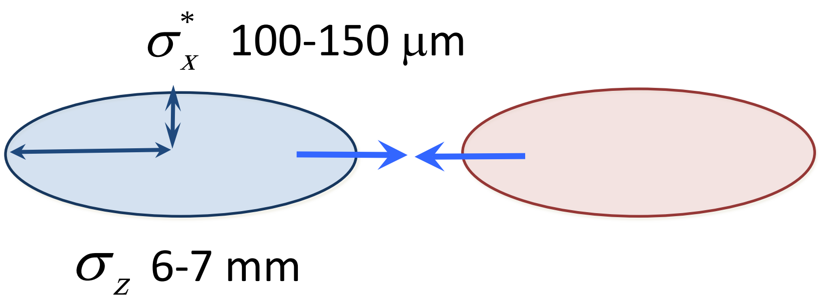
$\lambda \sim \sigma_z$ Coherent SR $I \propto (Ne)^2$



Reaches a ceiling at L=2-6 × 10^{35} $cm^{-2}s^{-1}$

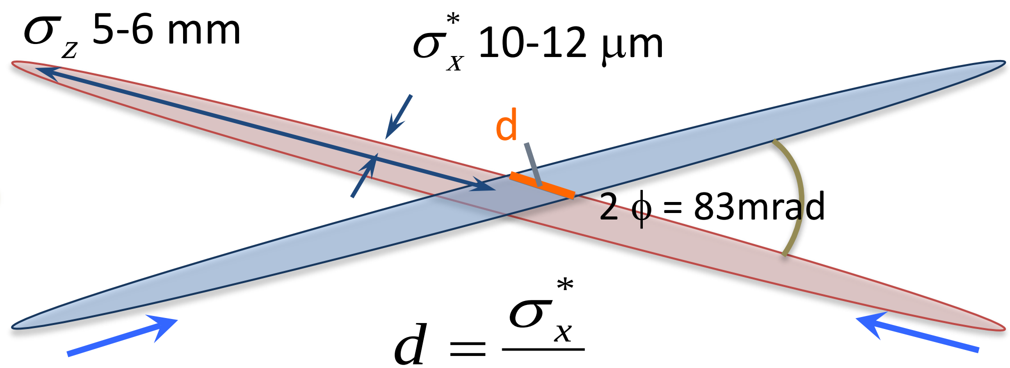
Collision Scheme

KEKB head-on (crab crossing)



overlap region = bunch length

Nano-Beam SuperKEKB



$$d = \frac{\sigma_x^*}{\phi}$$

Half crossing angle: ϕ

overlap region << bunch length

Hourglass requirement

$$\beta_y^* \geq \sigma_z \quad \sim 6 \text{ mm}$$

$$\beta_y^* \geq \frac{\sigma_x^*}{\phi} \quad \sim 300 \text{ μm}$$

Vertical beta function at IP can be squeezed to ~300μm.
Need small horizontal beam size at IP.
→ low emittance, small horizontal beta function at IP.

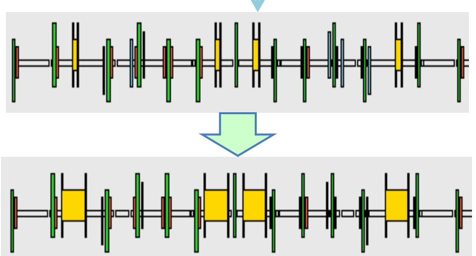
Machine Design Parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Half crossing angle	φ	11		41.5		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	5.3	nm
Emittance ratio	κ	0.88	0.66	0.27	0.24	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam param.	ξ_y	0.129	0.090	0.0886	0.081	
Bunch Length	σ_z	6.0	6.0	6.0	5.0	mm
Horizontal Beam Size	σ_x^*	150	150	10	11	um
Vertical Beam Size	σ_y^*	0.94		0.048	0.062	um
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

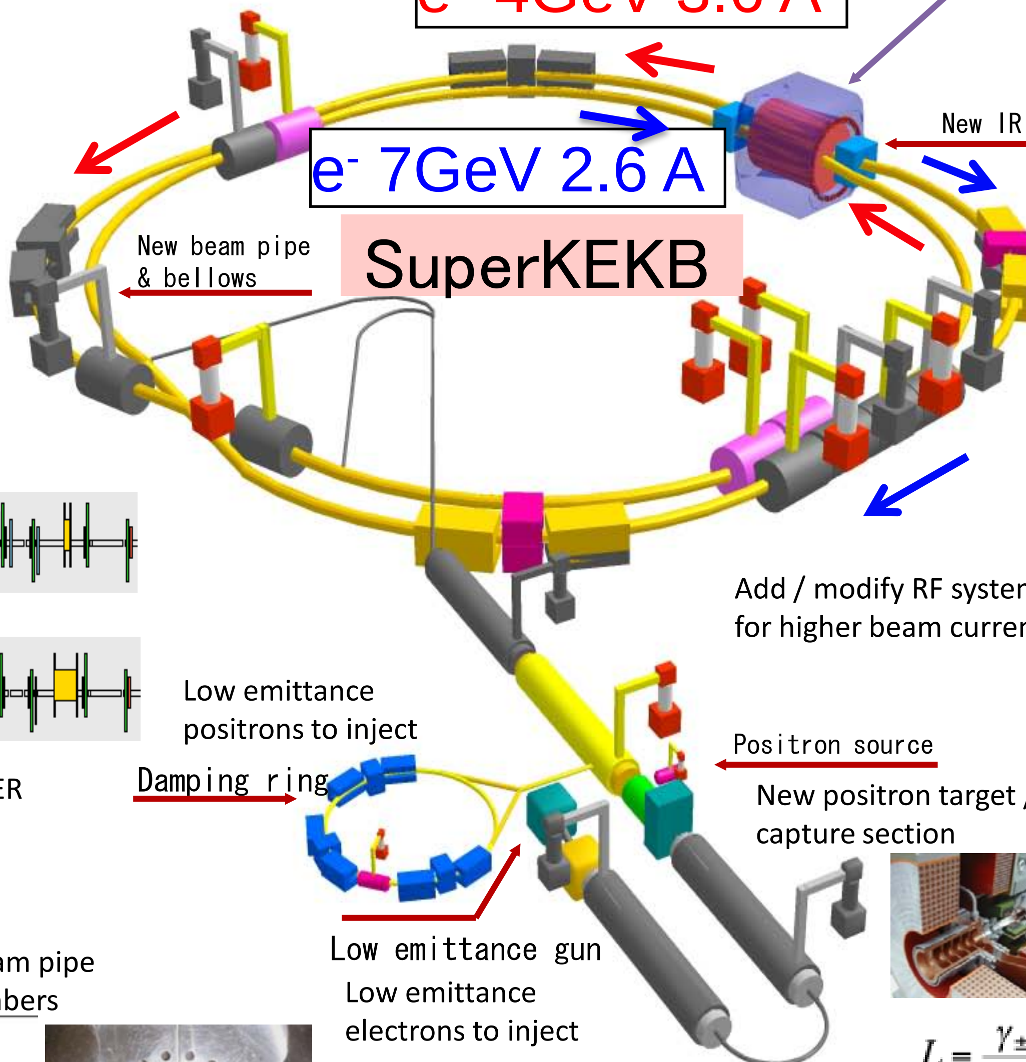
What's new at SuperKEKB

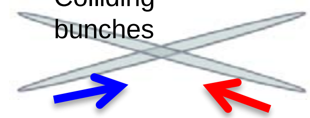
Belle II

Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance





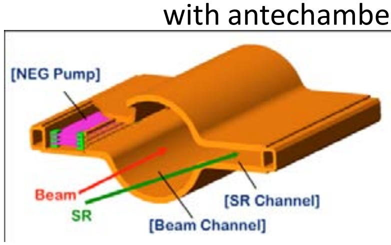
New superconducting /permanent final focusing quads near the IP

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 = $8 \times 10^{35}/cm^2/s$

Major Items to Upgrade

- Rebuild IR
- Optics improvements:
  - Tsukuba straight section
  - Arcs
  - Wiggler sections
- Magnets
  - Build or rearrange many magnets
  - Survey and alignment
- New LER beam pipes for electron-cloud suppression
- Strengthen RF system
- Improve speed and resolution of beam monitor and control system:
  - Position: BPMs, digital Bunch-by-bunch feedback
  - Size: (SRM, X-ray)
  - Collision monitors: Large Angle Beamstrahlung Monitor (G. Bonvicini)
  - Damping ring monitors
- Upgrade the injector linac and beam transport system
- Install a 1.1 GeV positron damping ring
- Increase capacity of cooling system for the magnets and vacuum system

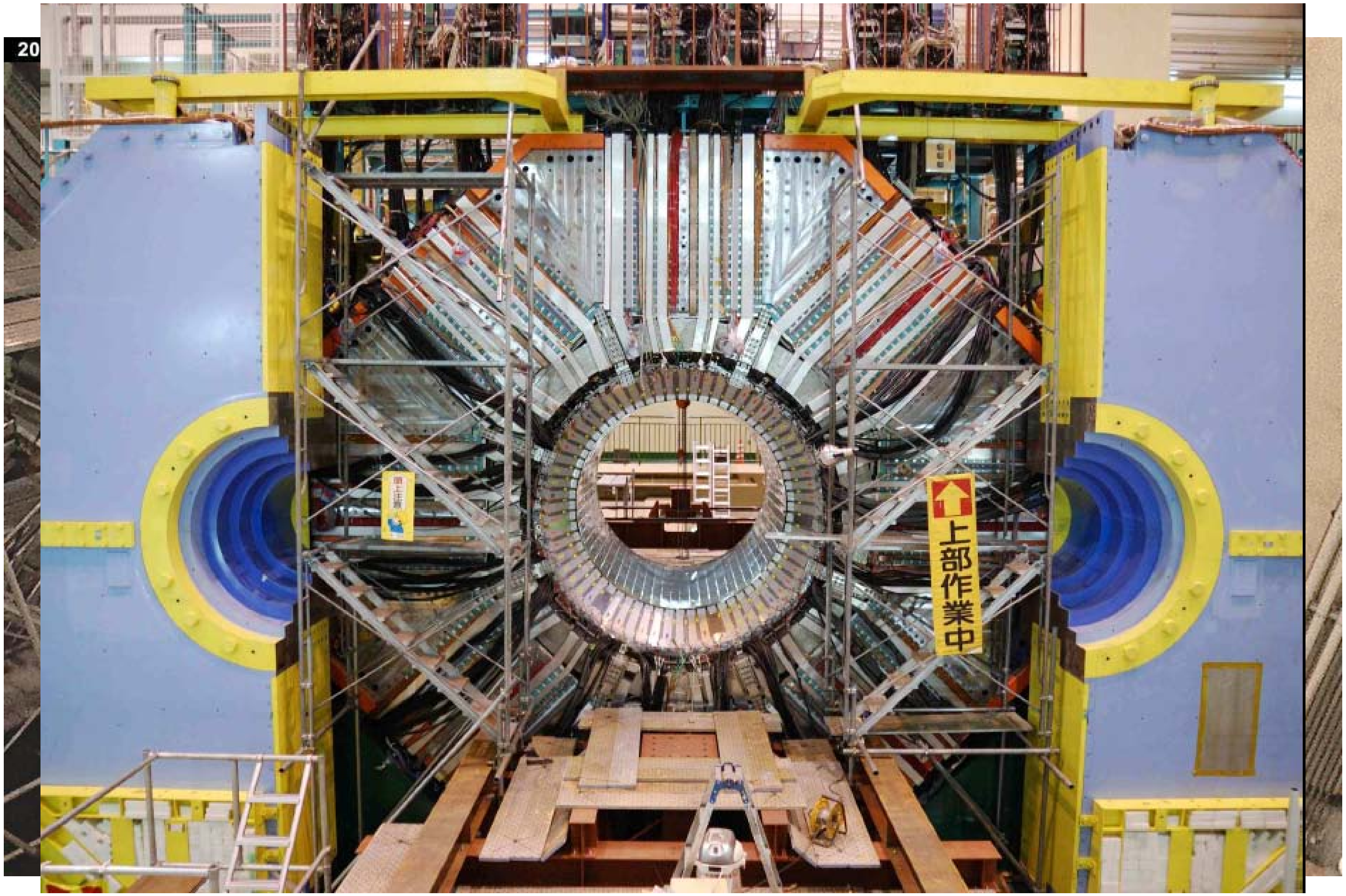
Design Concept of SuperKEKB

- Re-use the KEKB tunnel.
- 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.

Removal of ring magnets

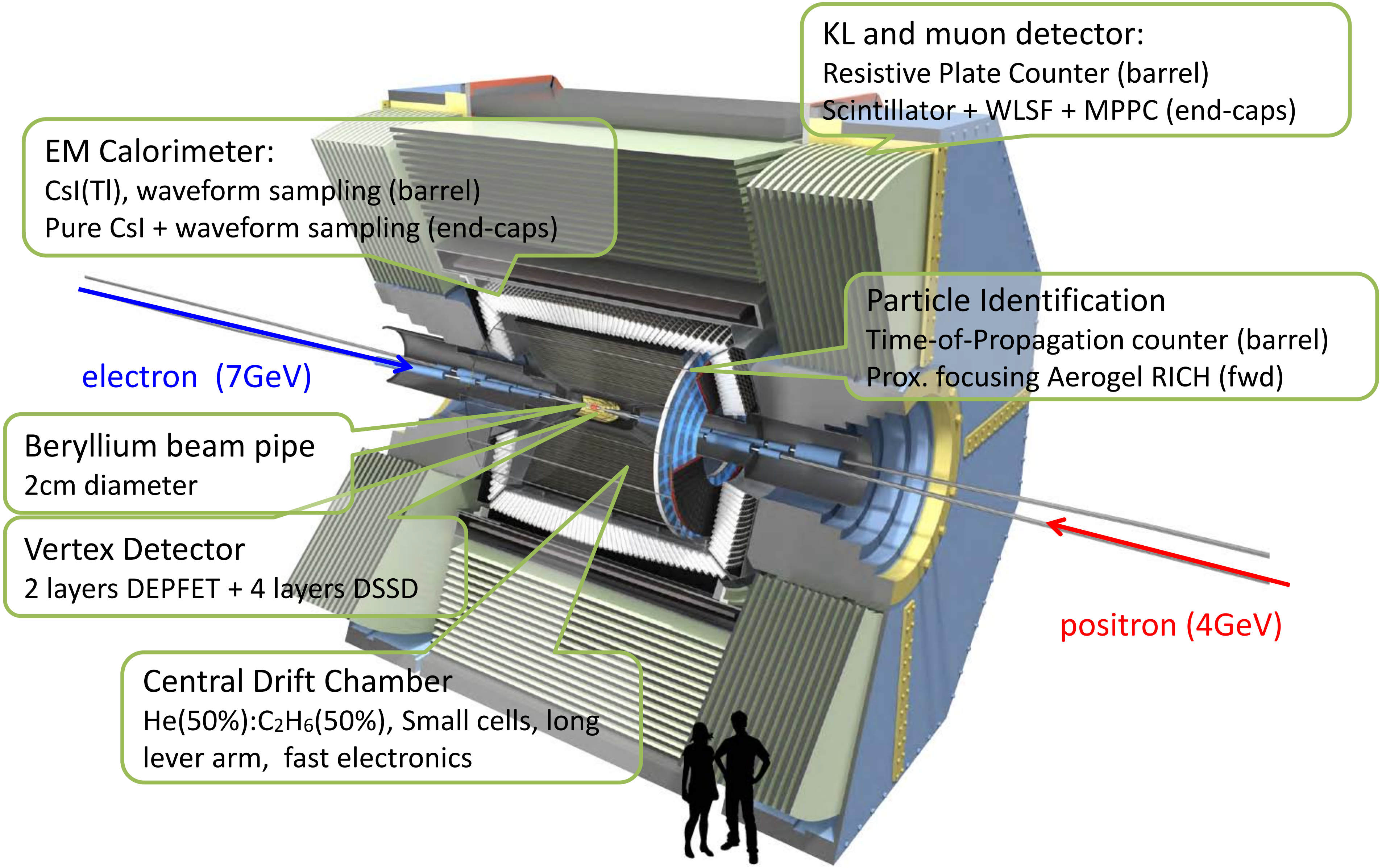
Belle-II detector

Belle-I disassembly has finished

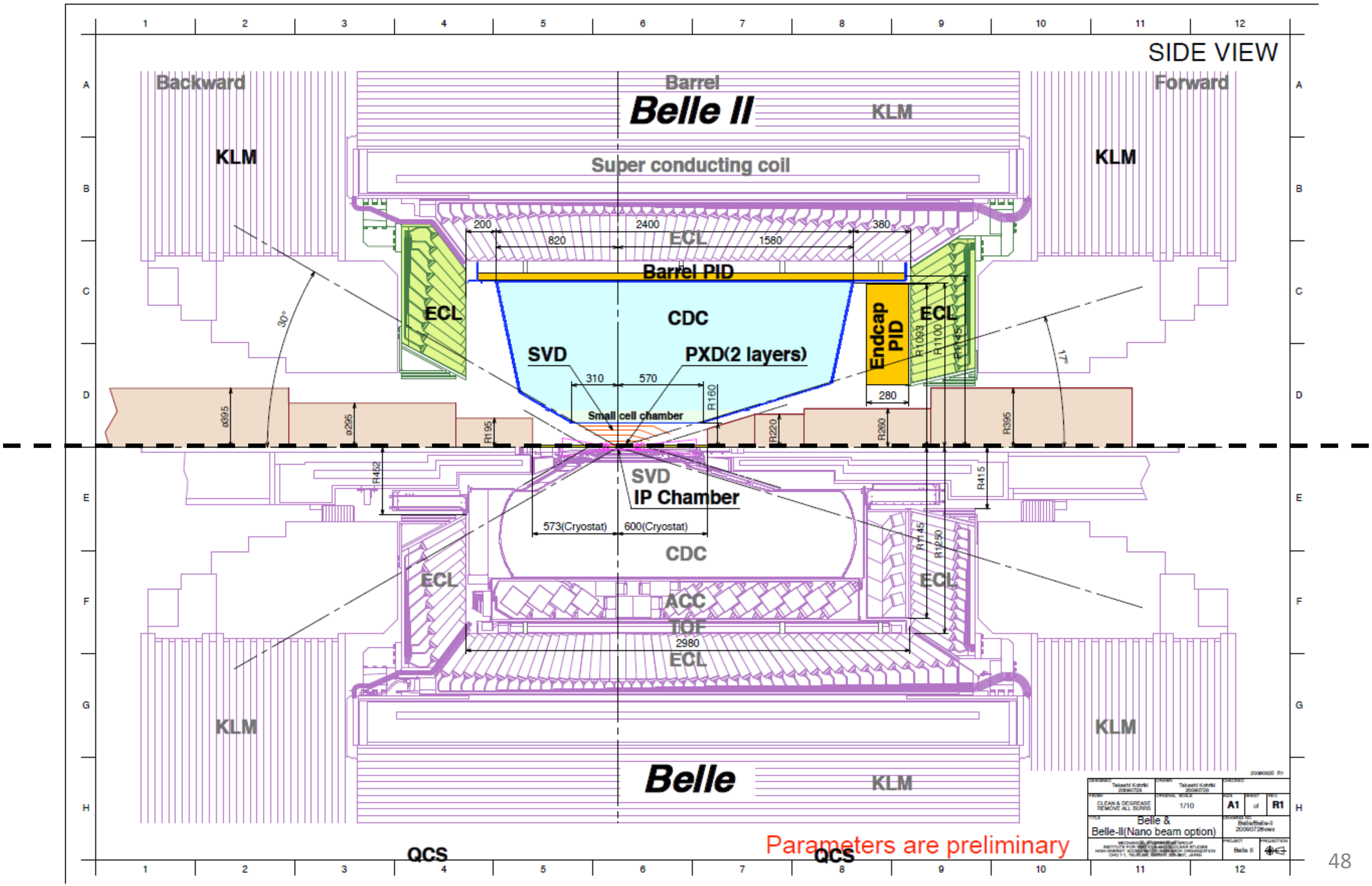


Beam Pipe and Vertex Detector extraction: on Nov. 10, 2010
Belle Detector Roll-out: Dec. 9, 2010
End-caps, CDC, B-ACC, TOF extraction: in Jan. 2011

Belle II Detector

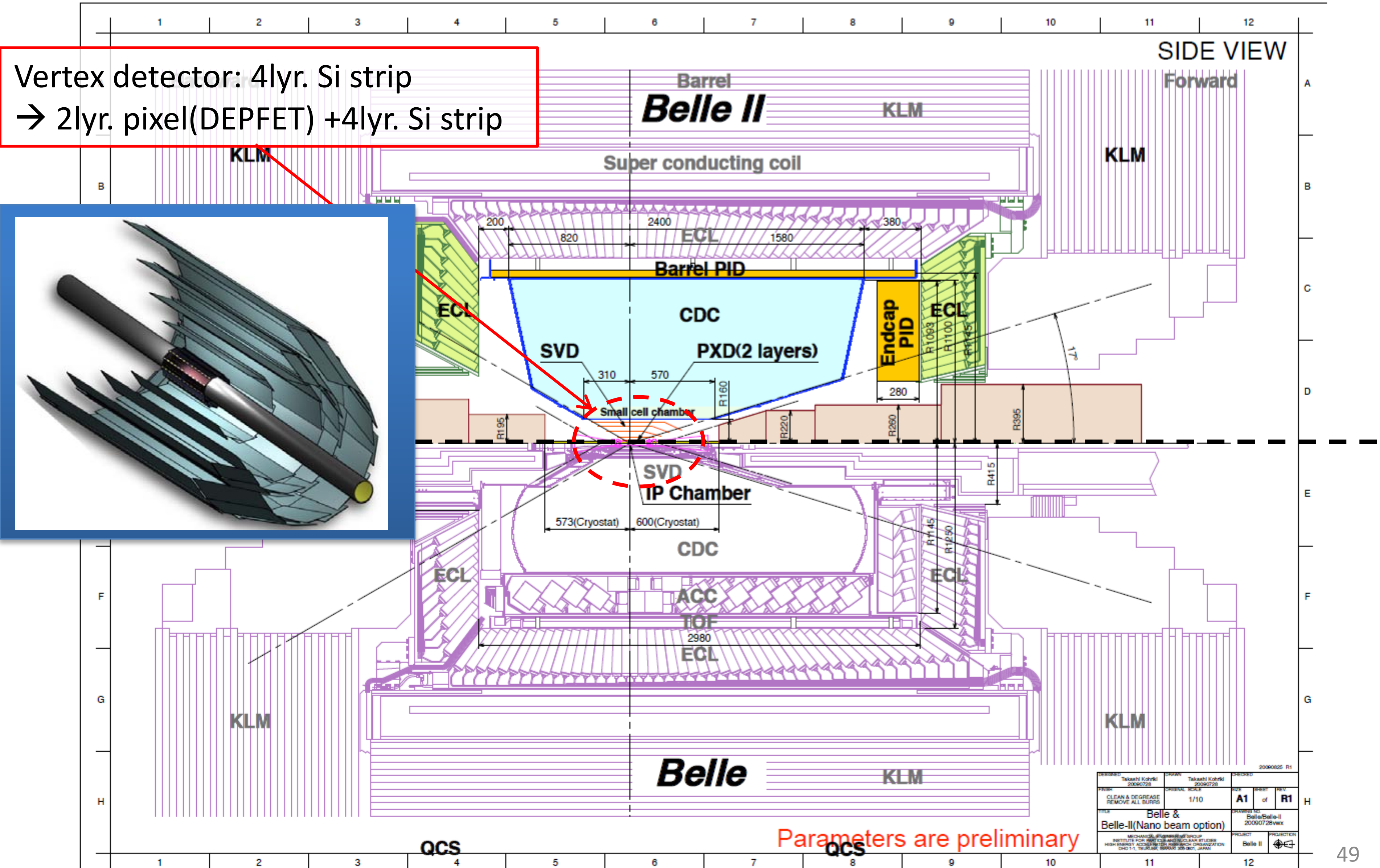


Detector upgrade



Detector upgrade

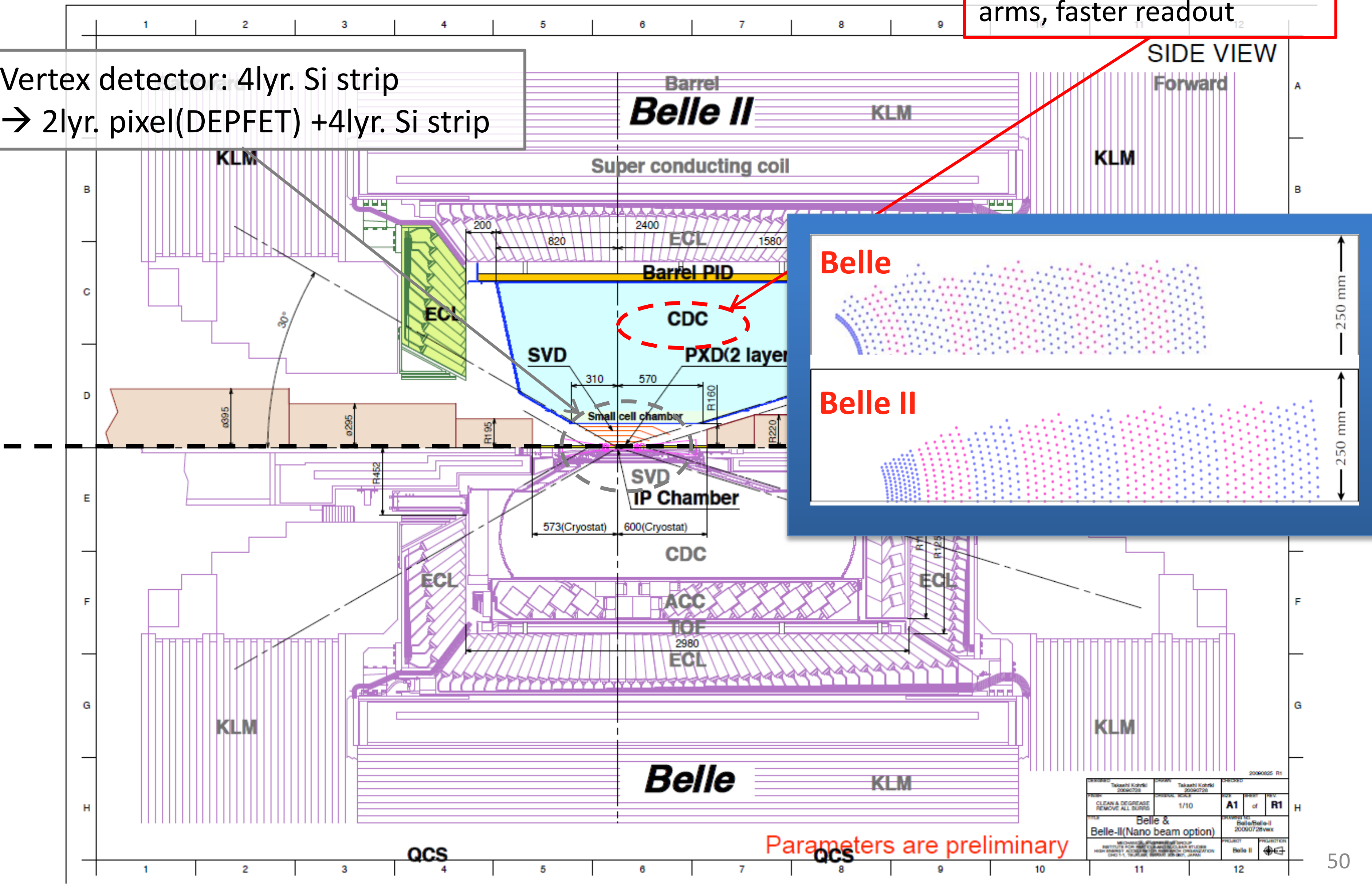
Vertex detector: 4lyr. Si strip
→ 2lyr. pixel(DEPFET) +4lyr. Si strip



Detector upgrade

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

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

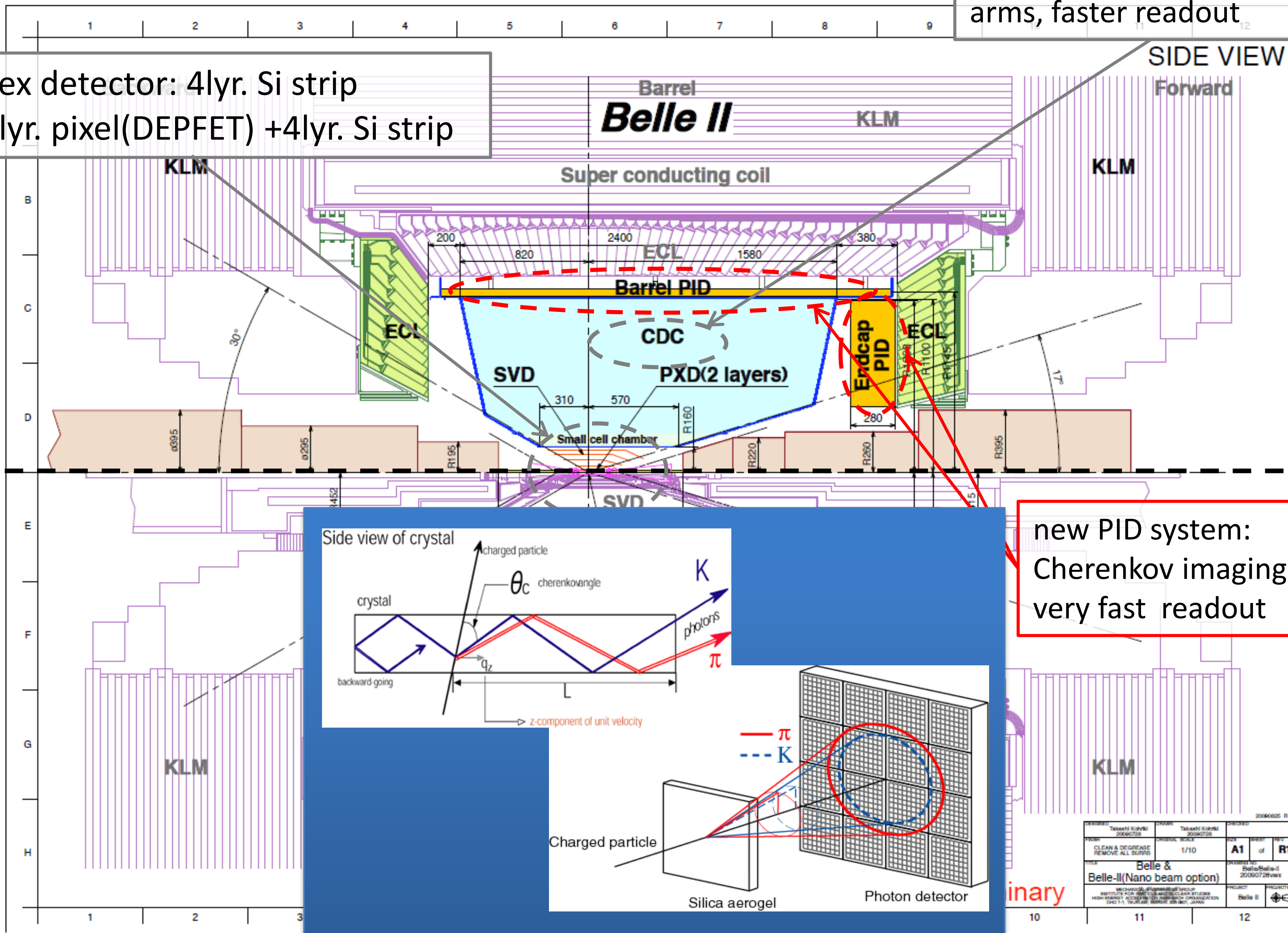


Detector upgrade

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



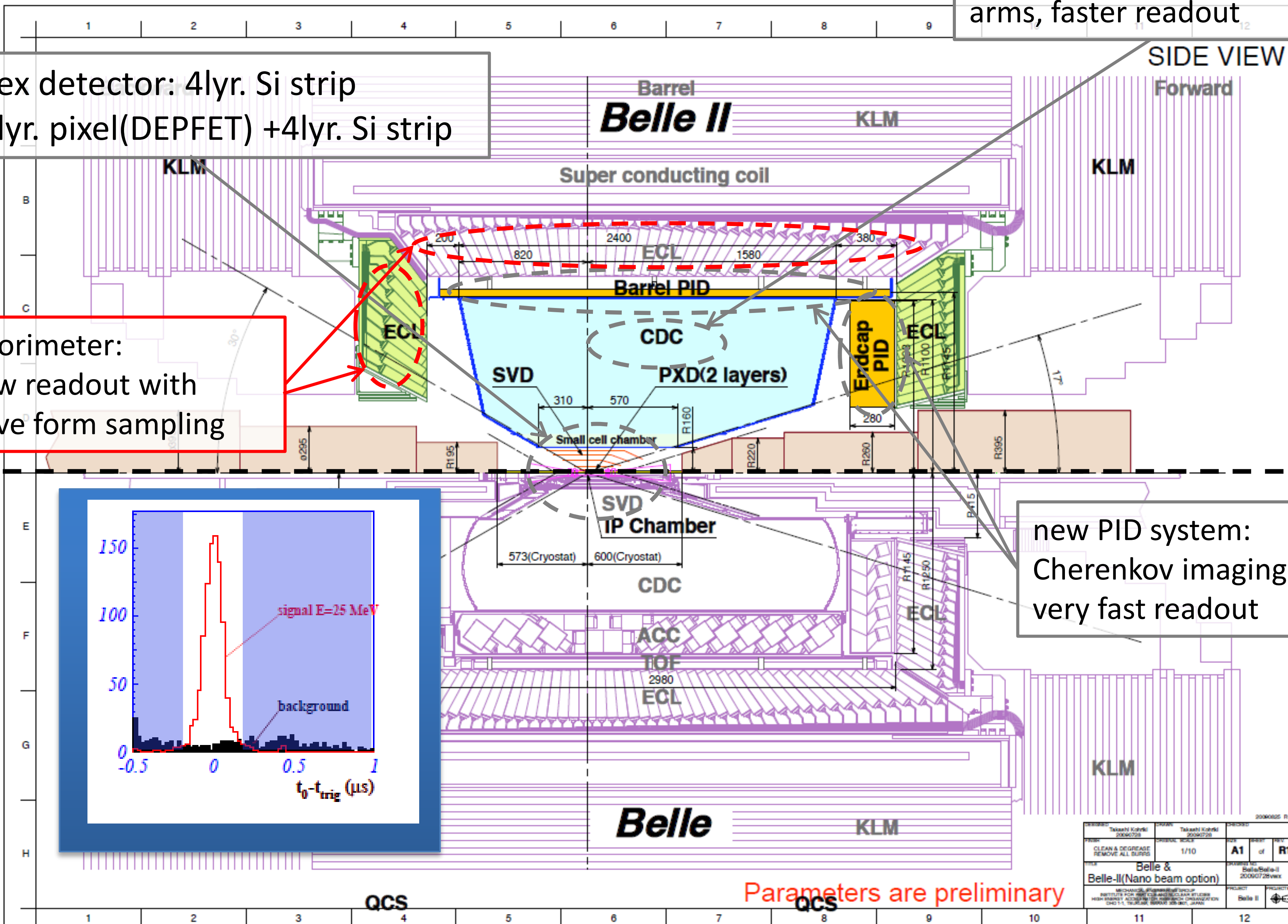
Detector upgrade

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



Parameters are preliminary

Detector upgrade

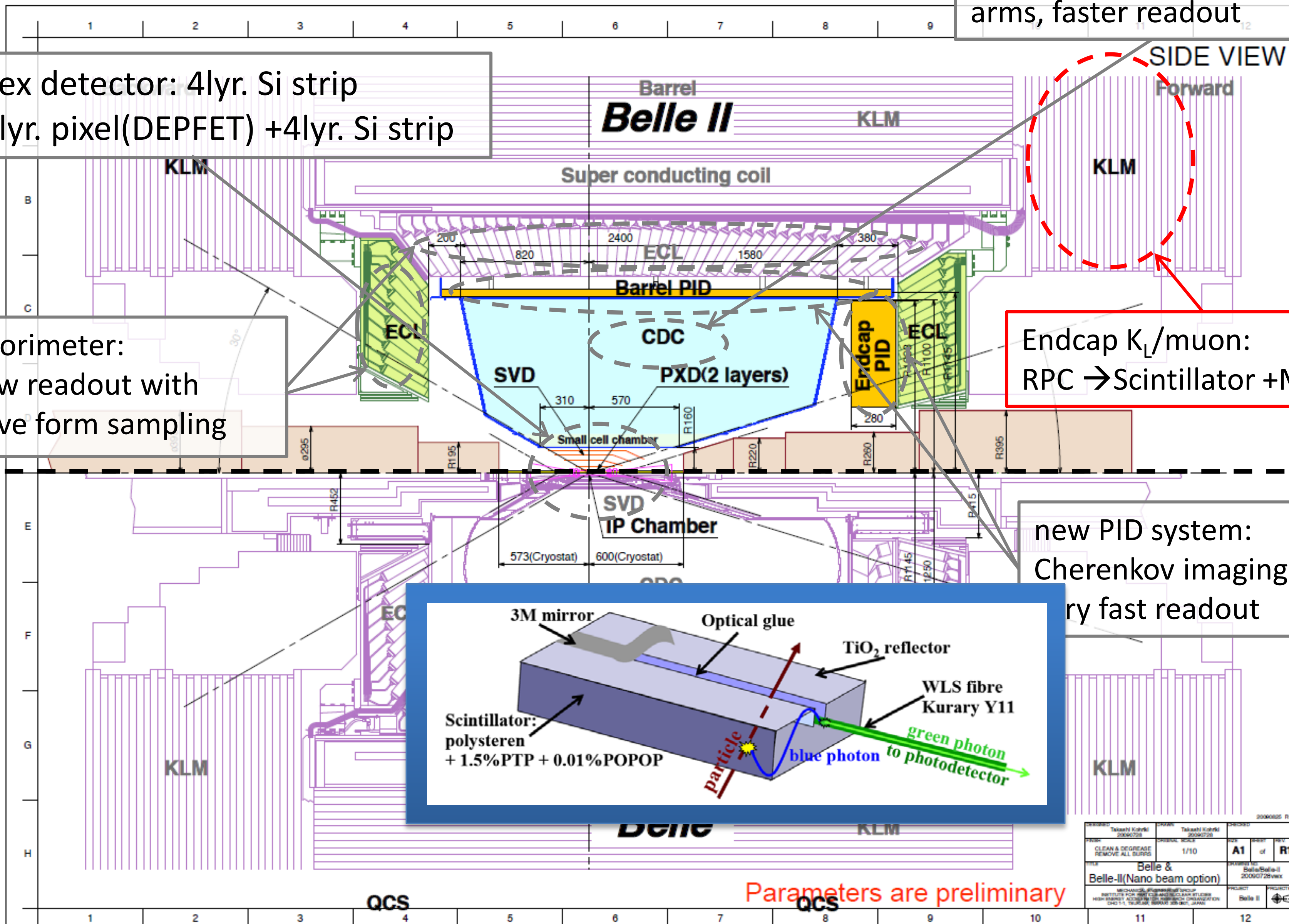
Drift chamber for tracking:
Small cells, longer lever arms, faster readout

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

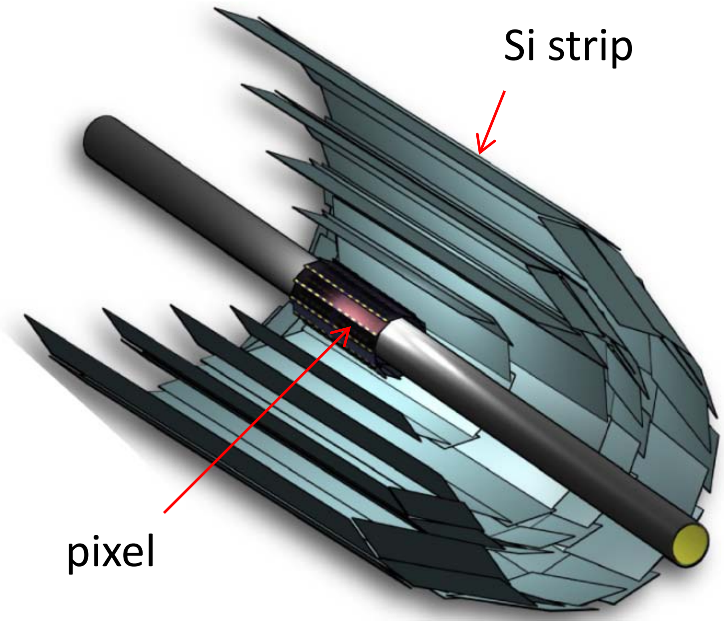
Calorimeter:
New readout with wave form sampling

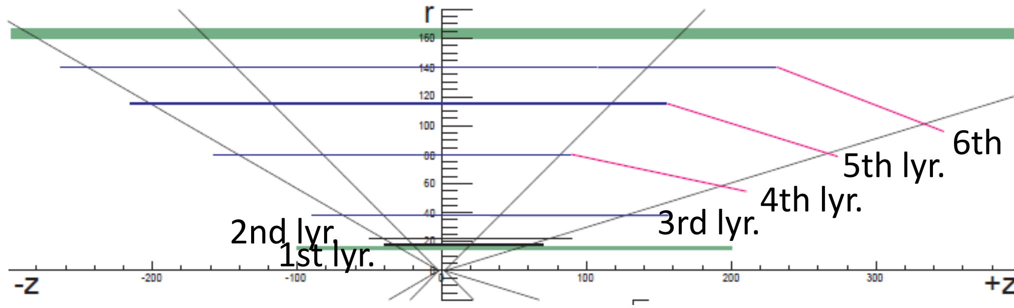
Endcap K_L/muon:
RPC →Scintillator +MPPC

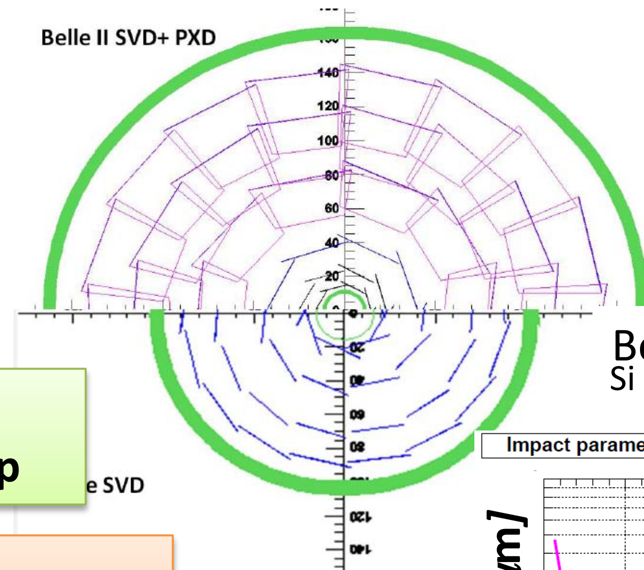
new PID system:
Cherenkov imaging,
…ry fast readout



Belle-II vertex detector





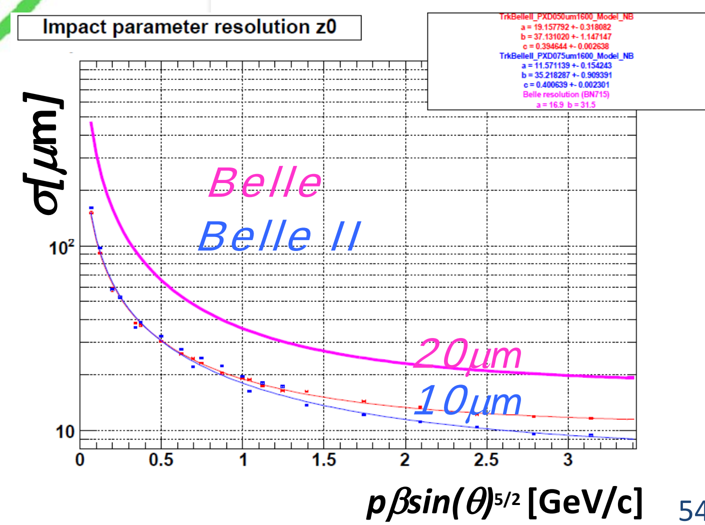


Belle-II
Pixel: r=14/22mm
Si strip: r=38/80/115/140mm

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

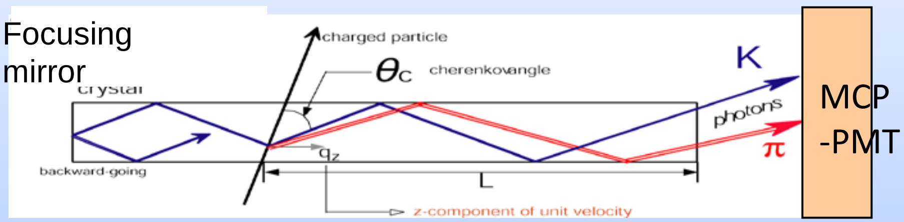
4lyr. Si strip
→ 2lyr. pixel(DEPFET) + 4lyr. Si strip

Pixel detector closer to IP
→Improved decay vertex resolution
Increased radial coverage
→ better K_s acceptance



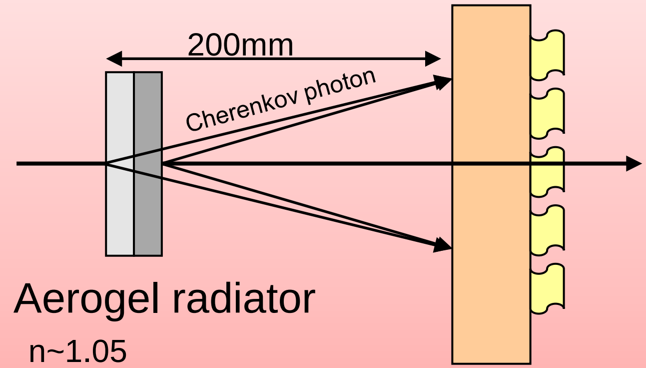
Belle-II Particle Identification System

Barrel PID: Time of Propagation Counter (TOP)



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

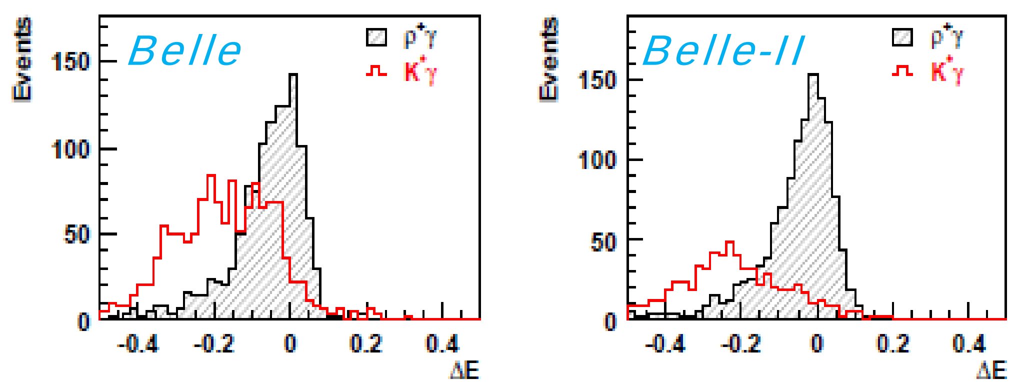
Endcap PID: Aerogel RICH (ARICH)



Hamamatsu HAPD
+ new ASIC

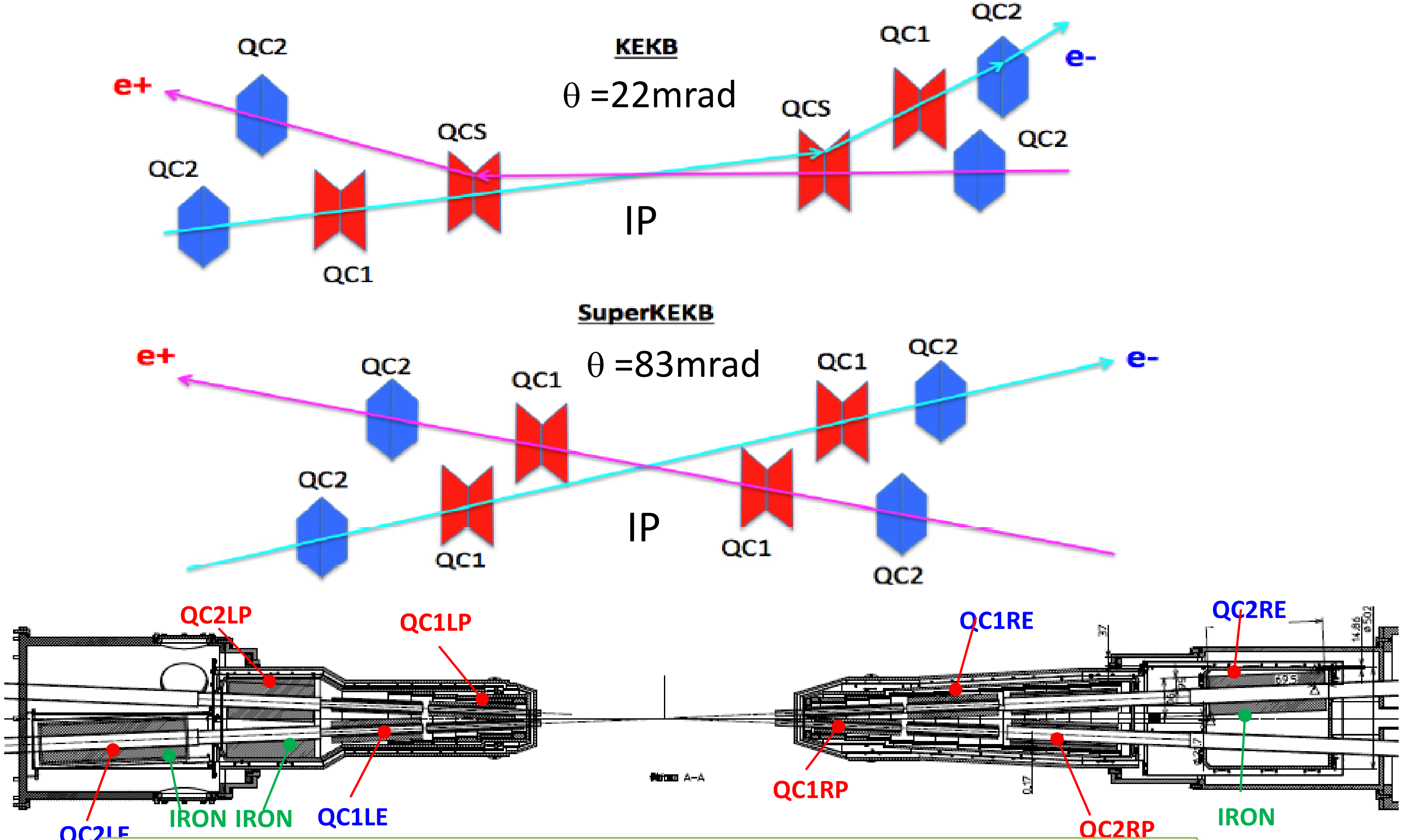
Completely different from Belle PID:
- better K/π separation
- more tolerance for BG
- less material
  (better calorimeter resolution)

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



Interaction Region Design and Beam Background

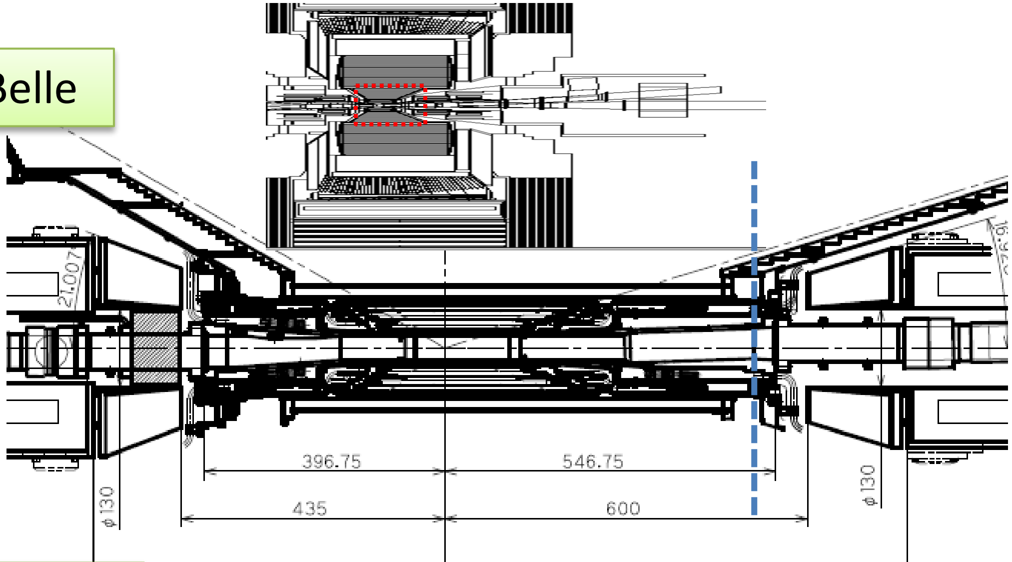
Final focusing magnets



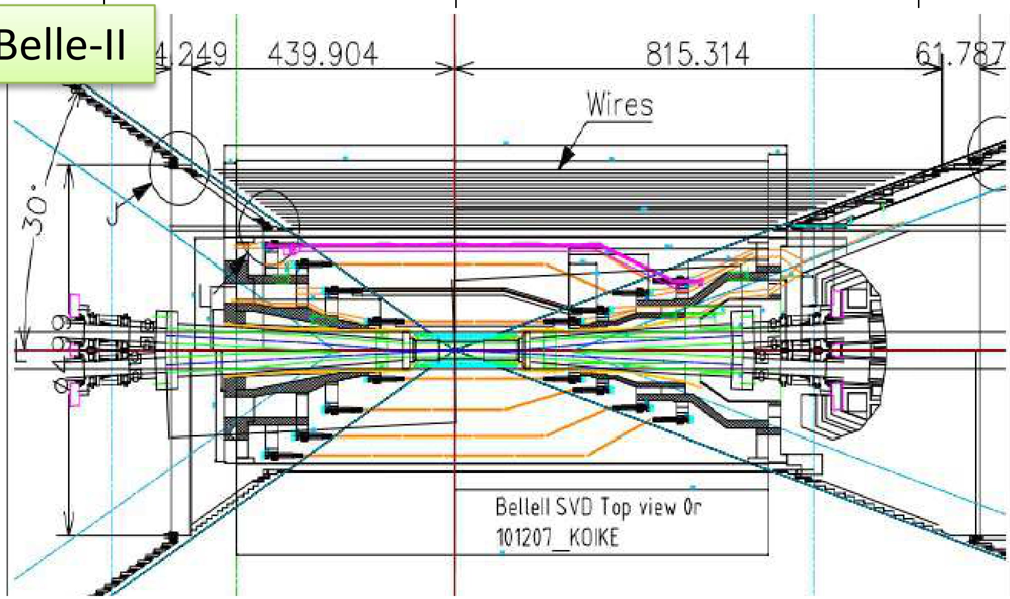
- Larger crossing angle θ
- Final Q for each ring→ more flexible optics design
- No bend near IP→ less emittance, less background

Interaction region design

Belle



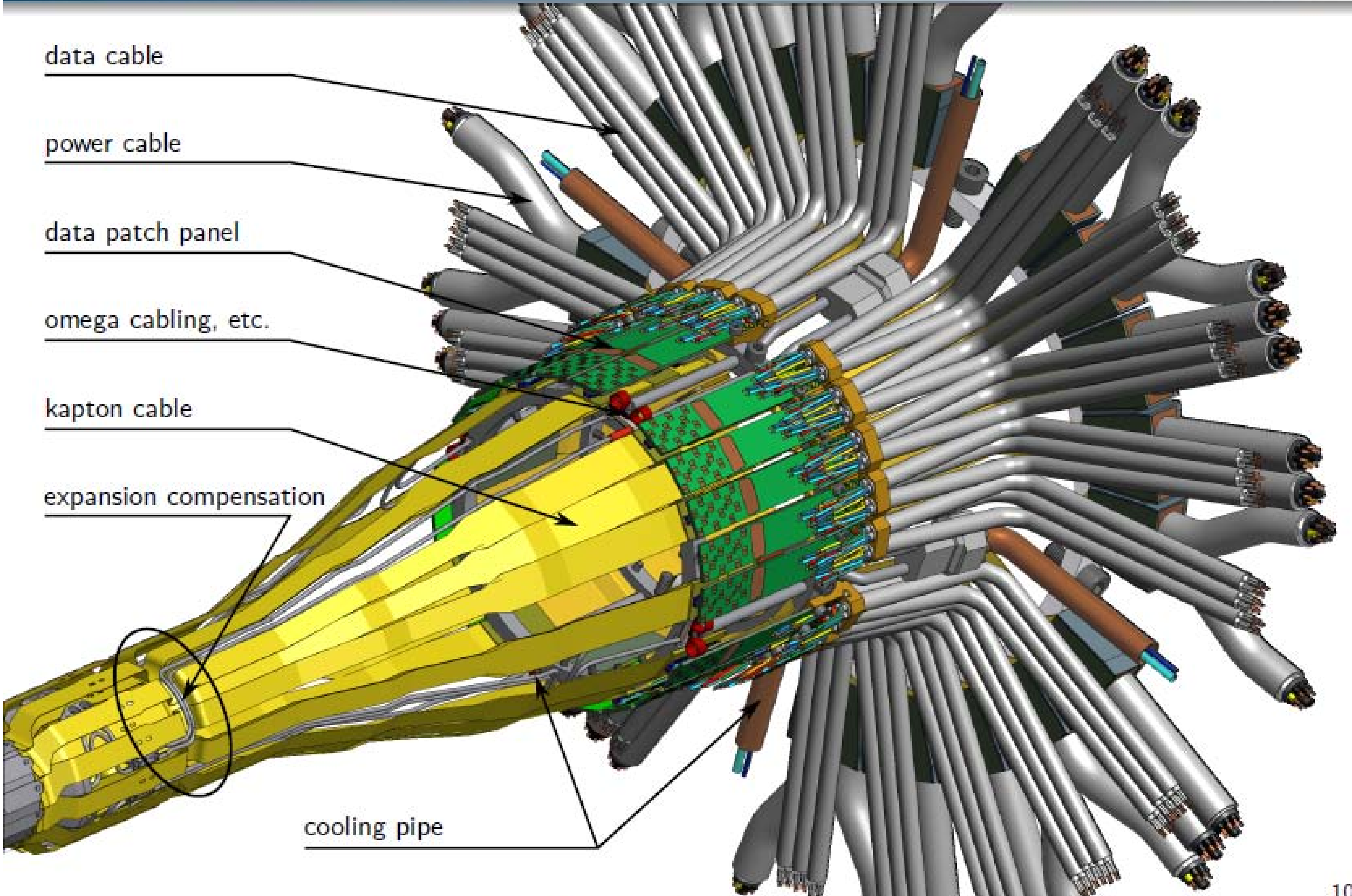
Belle-II



<Belle-II>

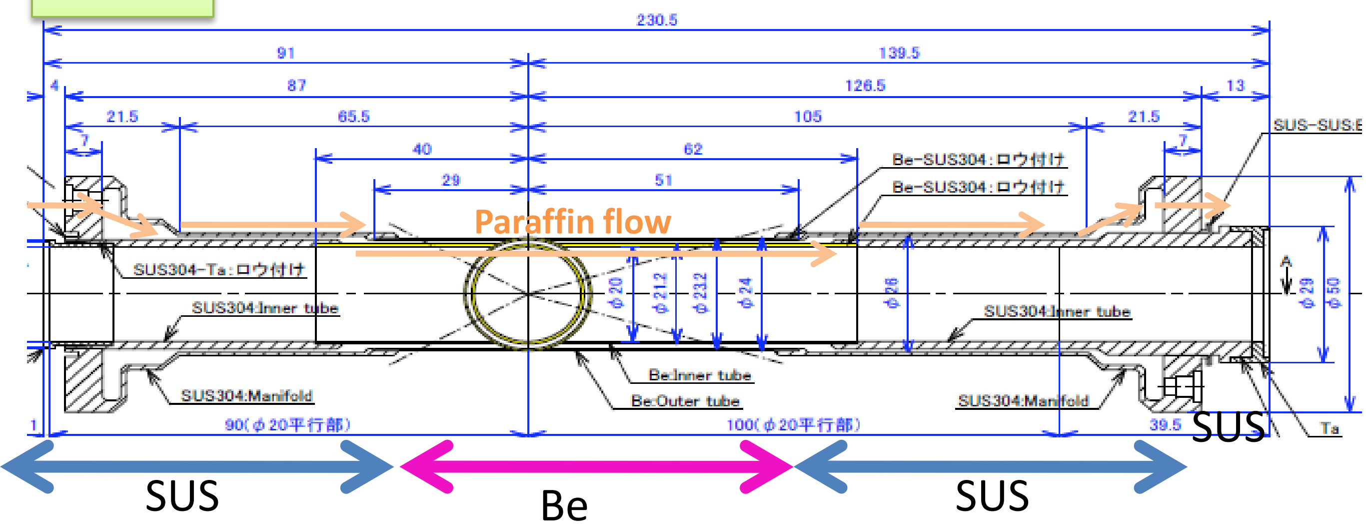
- Smaller beam pipe radius （r=15mm⇒10mm）
- Wider beam crossing angle （22mrad⇒83mrad）
- Pipe crotch starts from closer to IP, complicated structure
- New detector: PXD （more cables&pipes）

PXD cables & pipes



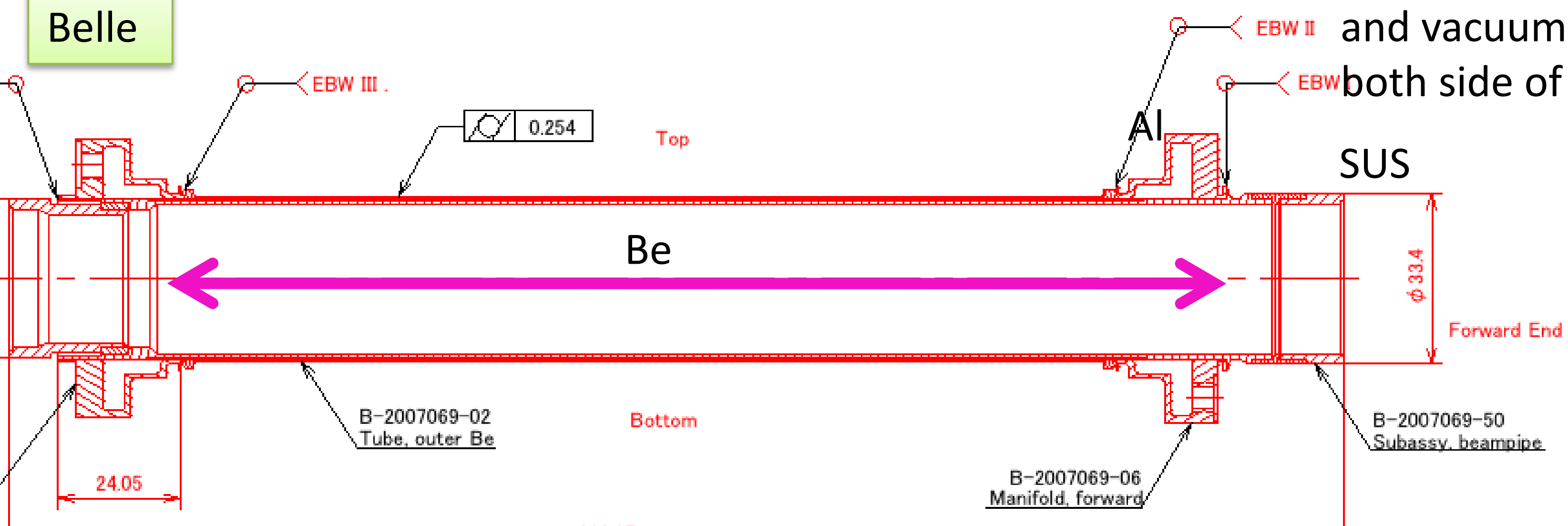
IP beam pipe

Belle-II



- Light material (Be) inside detector acceptance
- Paraffin ($C_{10}H_{22}$)flow to remove heat from mirror current (~80W)
- Gold plating (~10um) on inner wall to stop SR
- Much simpler Be shape (also much cheaper) since we allow Paraffin and vacuum to attach both side of welding

Belle



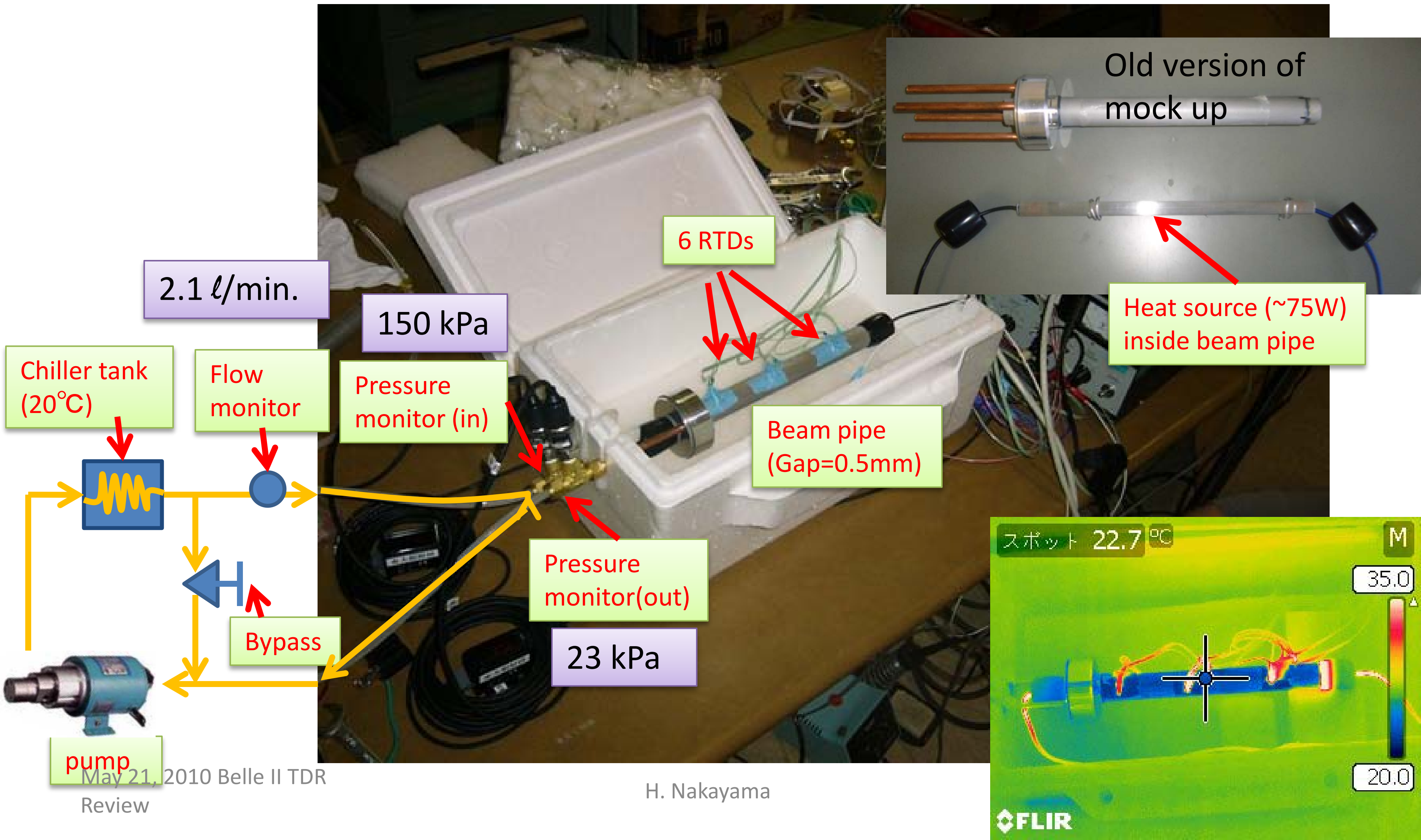
Beam pipe mock up for cooling test

SUS mockup

We need to remove ~80W by paraffin flow.

<Items to check>
- Laminar or turbulence?
- Required Paraffin flow rate?
- Tolerable pressure drop inside beam pipe?
- Paraffin temperature rise?
- Pump, pipes, valves, etc…

Cooling test



Beam background

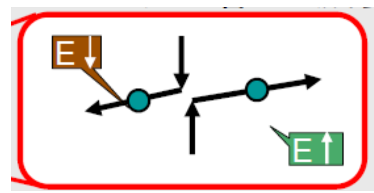
- At SuperKEKB with x40 larger Luminosity, beam background will also increase drastically.

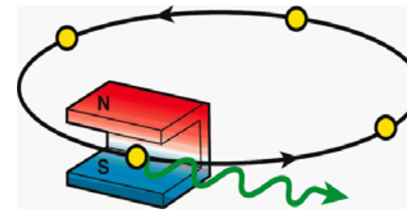
Beam-origin

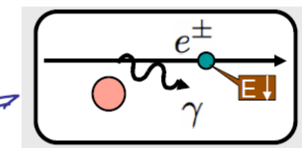
  - <u>Touschek scattering</u>
  - Beam-gas scattering
  - Synchrotron radiation

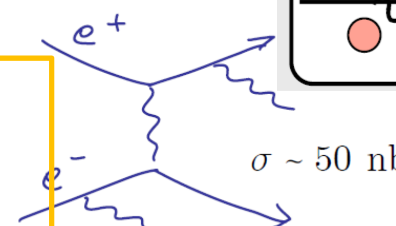
Luminosity dependent

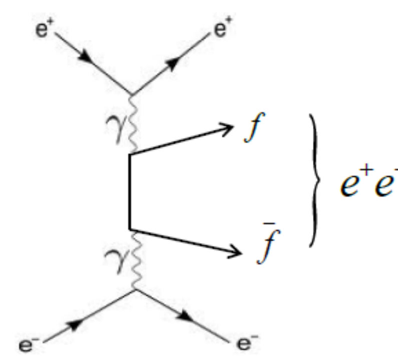
  - Radiative Bhabha event: emitted γ
  - Radiative Bhabha event: spent e+/e-
  - 2-photon process event: e+e-→e+e-e+e-
  - Beam-beam scattering
  - etc…

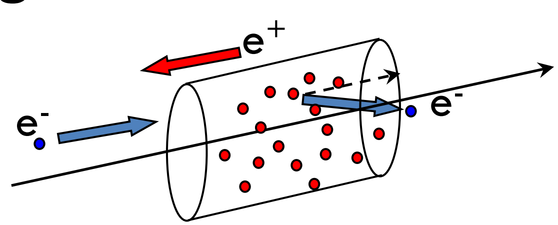






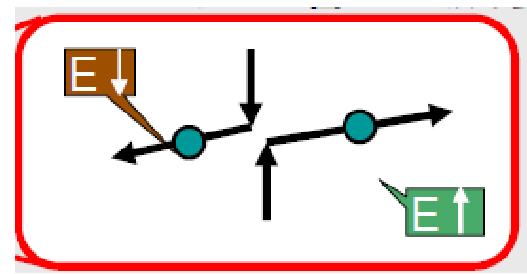






Background sources
~1. **Scattered beam particles**~

Touschek



<u>Touschek scattering</u>

Intra-bunch scattering

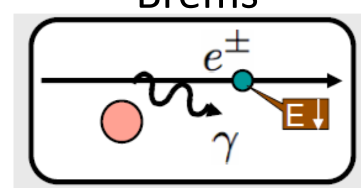
–Rate∝(beam size)-1

- Vertical beam size: 0.94um→0.048/0.062um
- Increase drastically (x20) at SuperKEKB

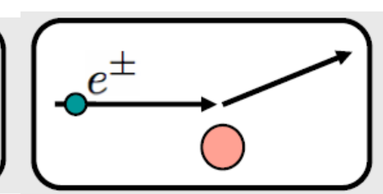
–Rate∝(beam energy)-3

- Beam energy asymmetry is relaxed: 3.5/8.0GeV→4.0/7.5GeV

Brems



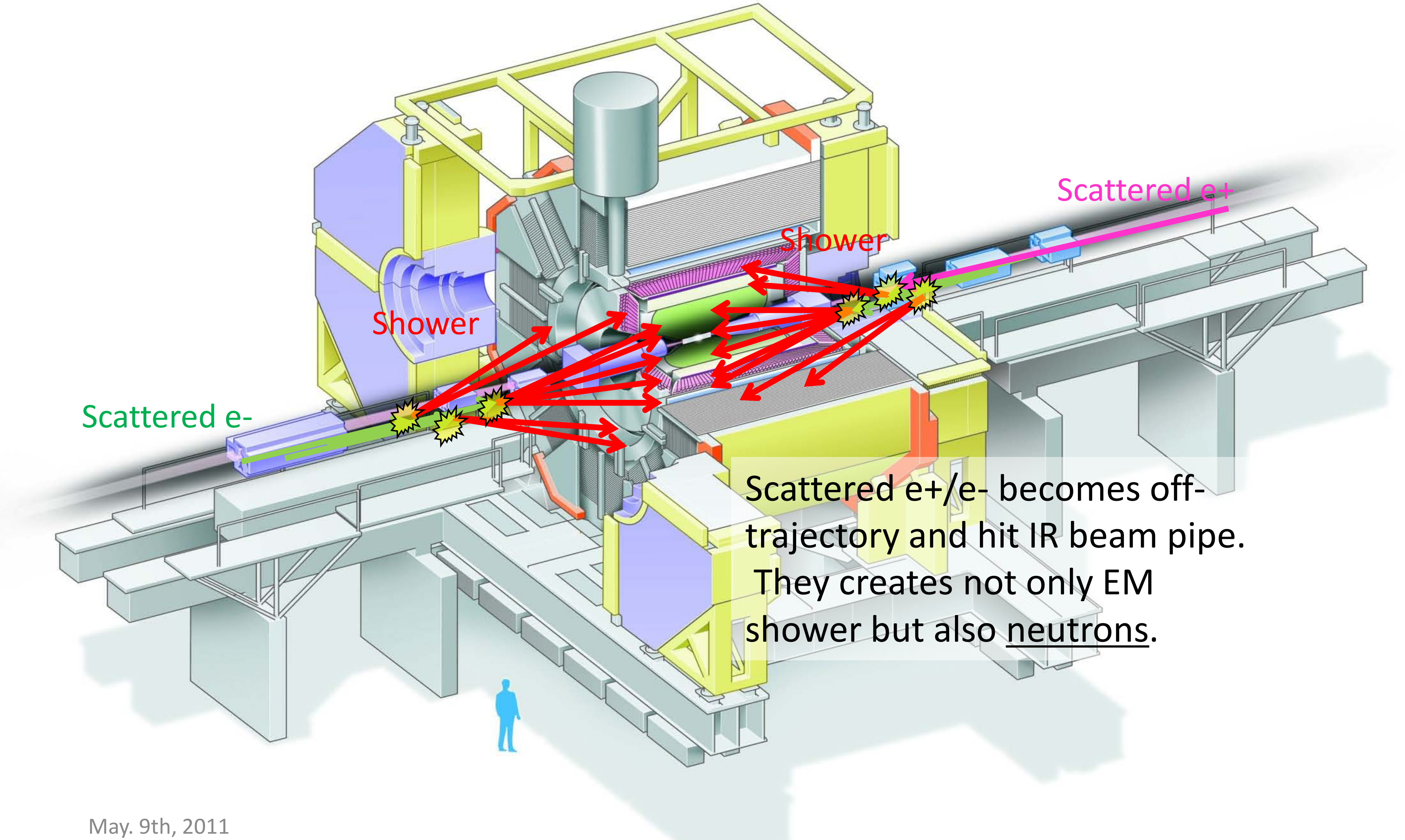
Coulomb



<u>Beam-gas scattering</u>

- Scattering by remaining gas, Rate ∝IxP
- Vacuum level at SuperKEKB will be similar to KEKB, so less dangerous compared to Touschek scattering
- Vacuum level in IR region could be worse than KEKB, but particles scattered in IR region will be lost far downstream IP and will not be dangerous for the detector

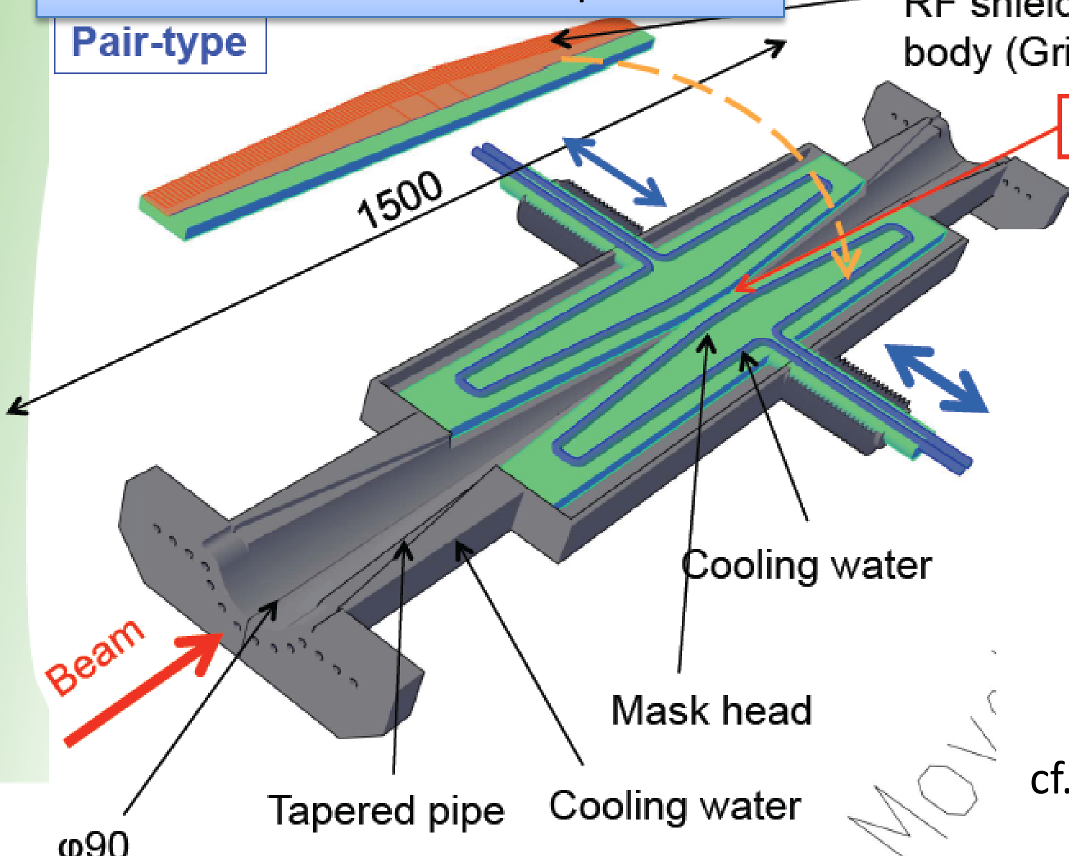
Touschek/Beam-gas background



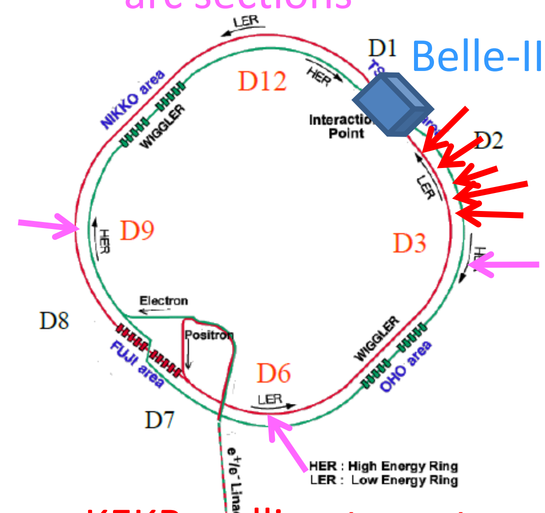
Scattered e+/e- becomes off-trajectory and hit IR beam pipe. They creates not only EM shower but also neutrons.

Countermeasure: Collimators

Horizontal collimator @ SuperKEKB

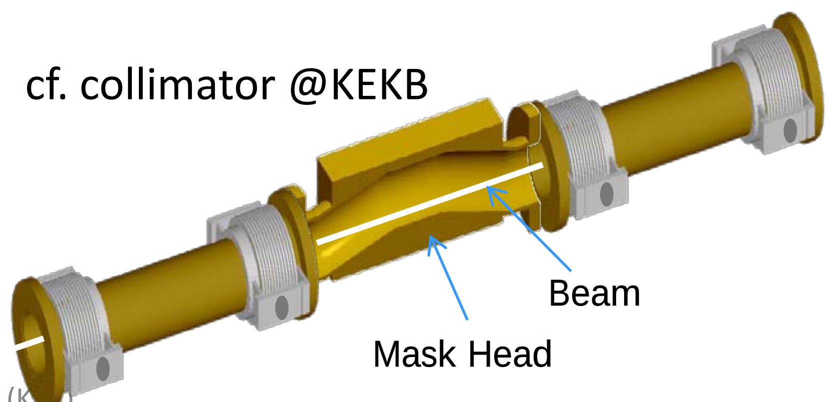


Collimators at arc sections



For SuperKEKB, collimators at -200m~-20m from IP is effective

cf. collimator @KEKB

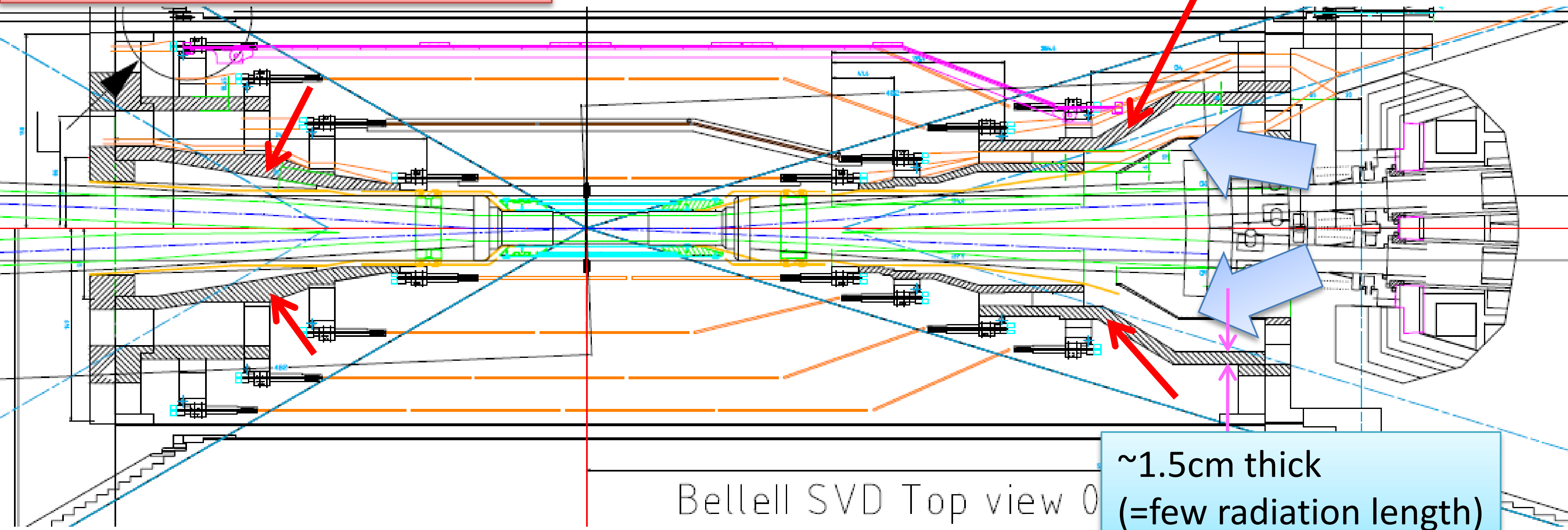


At SuperKEKB, beam is collimated from both side (inner/outer).
(cf. KEKB: from inner side only)

Countermeasure: Heavy-metal shield

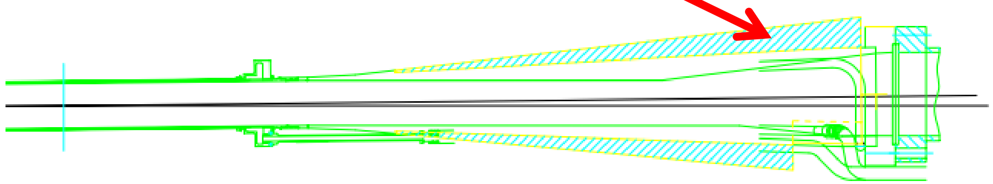
Belle-II IP design (Preliminary)

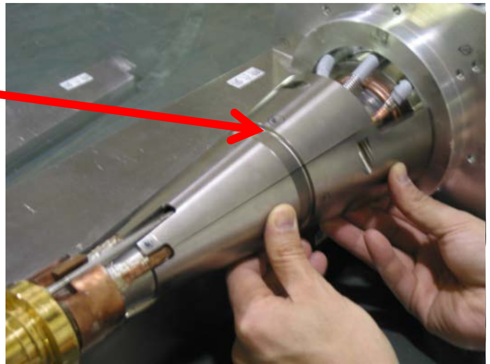
Heavy-metal shield to protect PXD/SVD from showers coming from upstream.



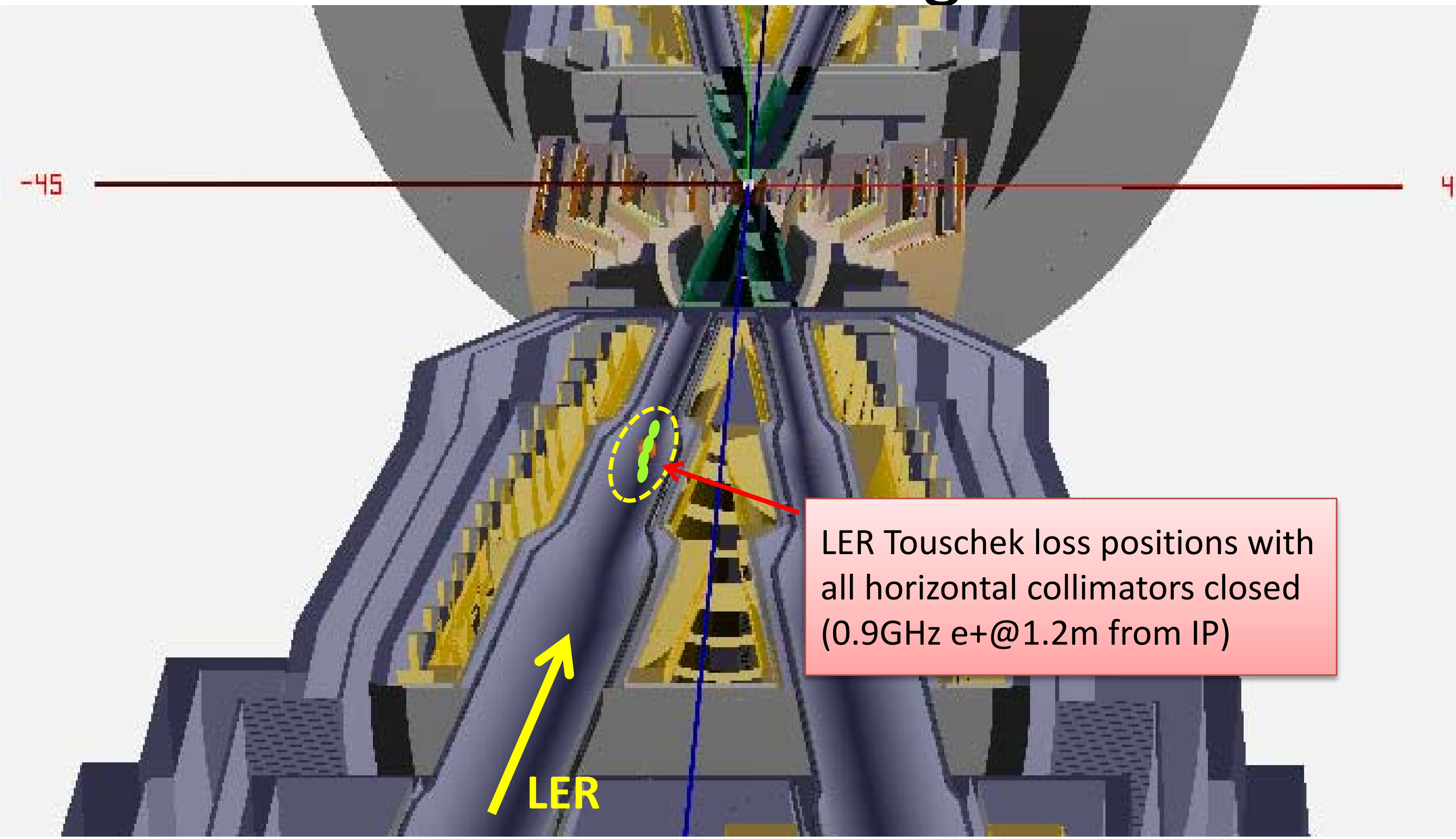
~1.5cm thick
(=few radiation length)

cf. Heavy-metal shield @ Belle



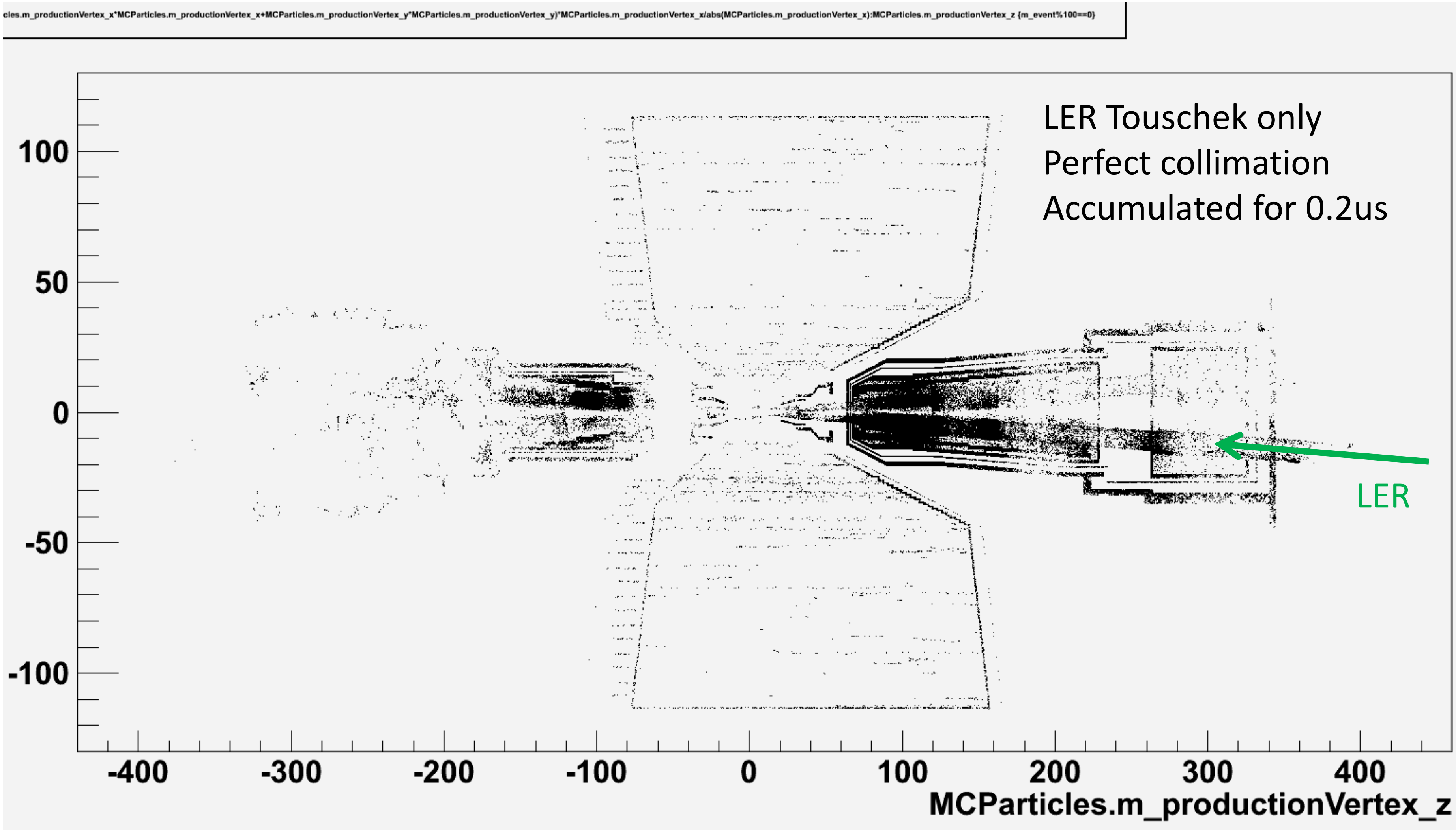


Loss position of LER Touschek background

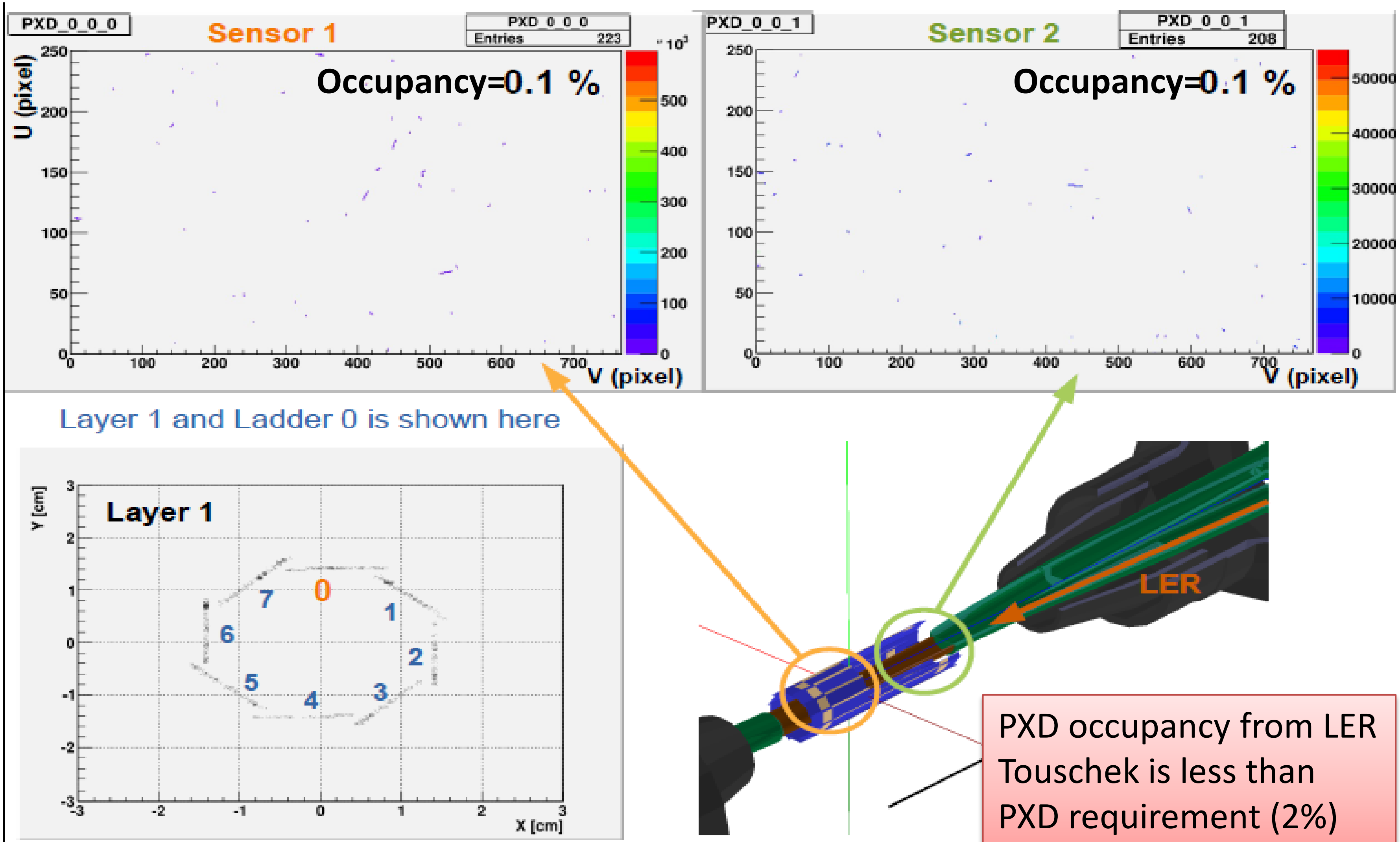


LER Touschek full simulation

Generated vertex of all MC particles

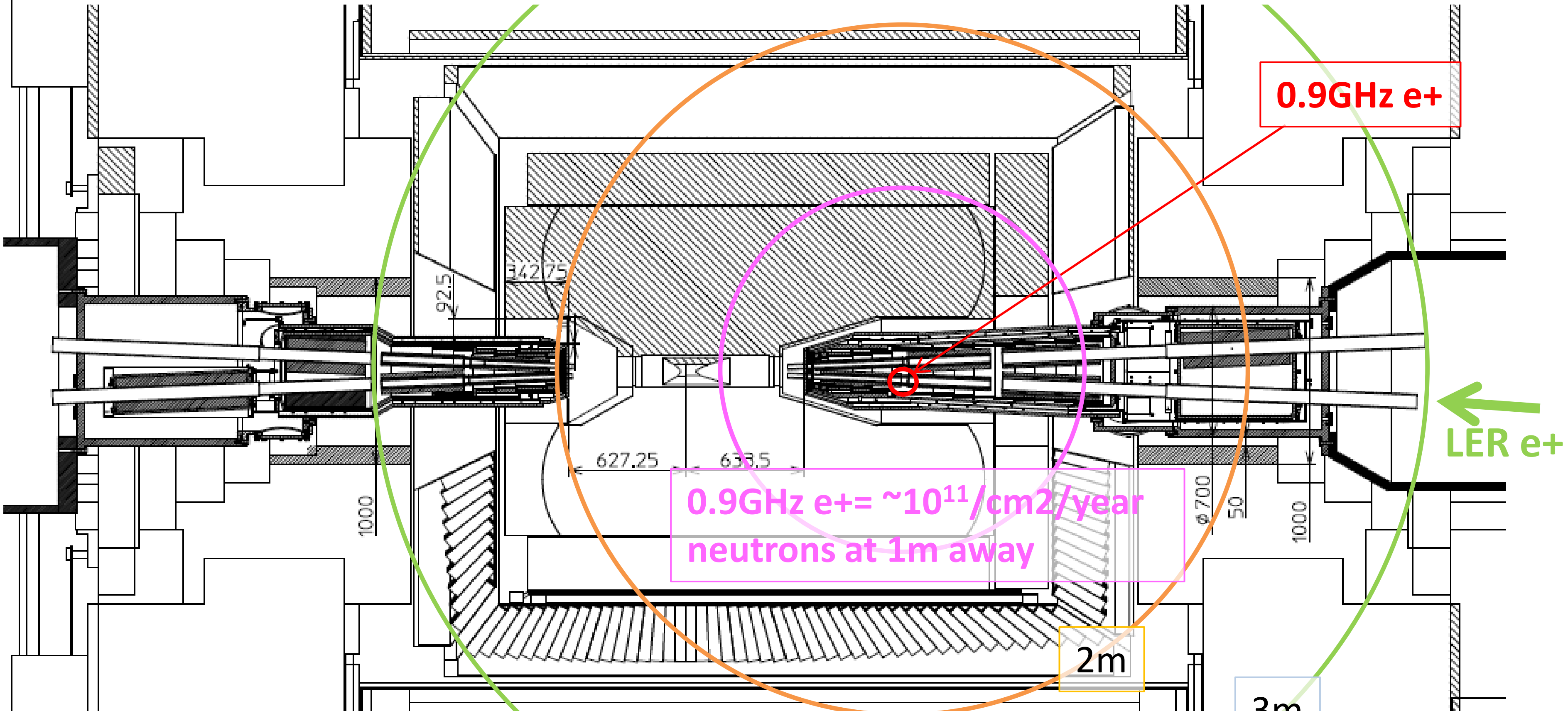


Simulated background hits on PXD



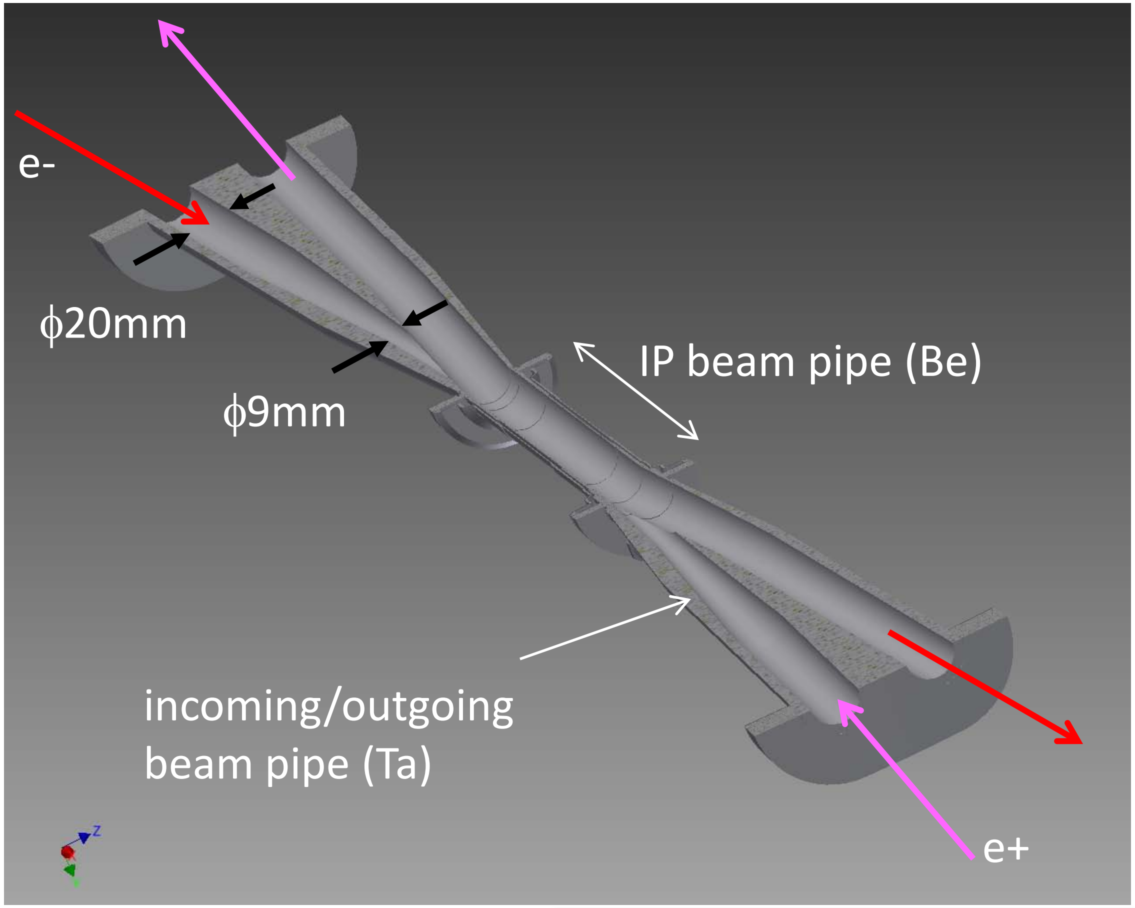
PXD occupancy from LER Touschek is less than PXD requirement (2%)

Neutron flux from LER Touschek

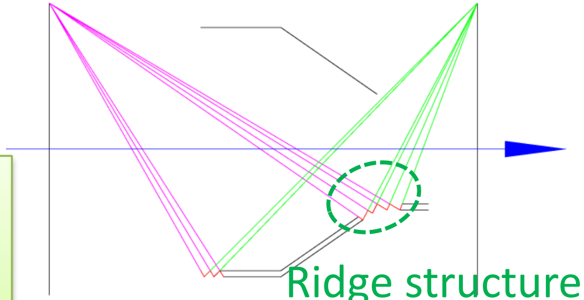


- γs in showers hit nuclei and generate 1~2 neutrons per e+ via "Giant Dipole Resonance".
- e+ hitting point is INSIDE detector. Almost no space to put neutron shield.
- 0.9GHz e+ = few*10^{11}/cm2/year neutrons (1MeV equiv.):
  → comparable to our assumption for detector R&D

Background sources
~2. Synchrotron radiation~



- ϕ20mm→ϕ9mm collimation on incoming beam pipe
- Most of SR photons are stopped by the collimation and direct hits on IP beam pipe is negligible
- HOM can escape from outgoing beam pipe
- To hide IP beam pipe from reflected SR, "ridge" structure on inner surface of collimation part.



~2x10^2/bunch (>5keV) photons hit beam pipe here
→ PXD occp. <<1%

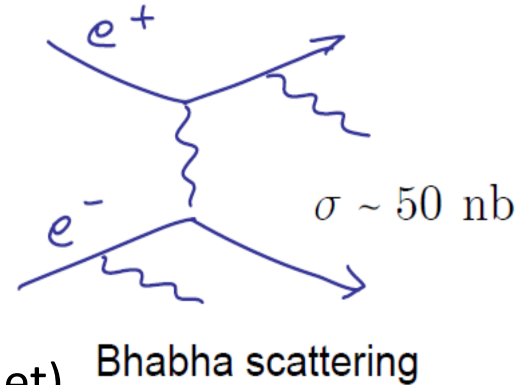
“Ridge” structure

Al mockup

Background sources (cntd.)
~3. Luminosity dependent~

Radiative Bhabha

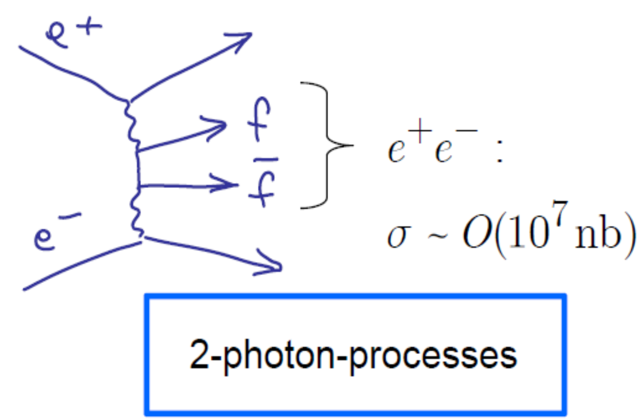
- Rate ∝ Luminosity (KEKBx40),
- EM shower from spent e+/e-:
  hit position is very far (~10m) from IP,
- Neutrons from emitted γ (hitting downstream magnet)
  Main BG for KLM. Need to increase neutron shields in the tunnel



2-photon process

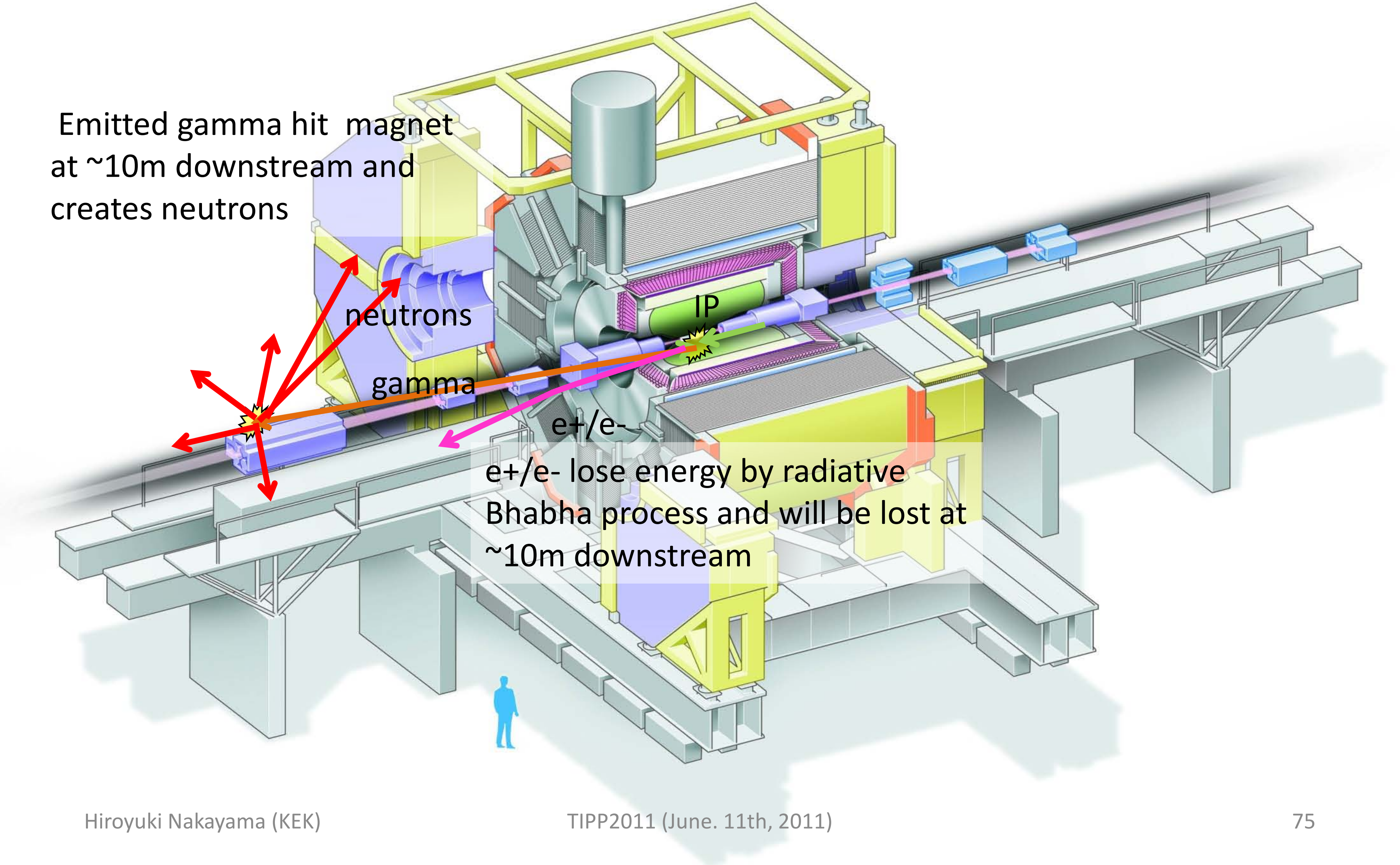
- Generated e+e- pair might hit PXD
- Confirms to be OK, according to KoralW
  simulation and KEKB machine study

"0.2%(<<2%) occupancy on PXD"



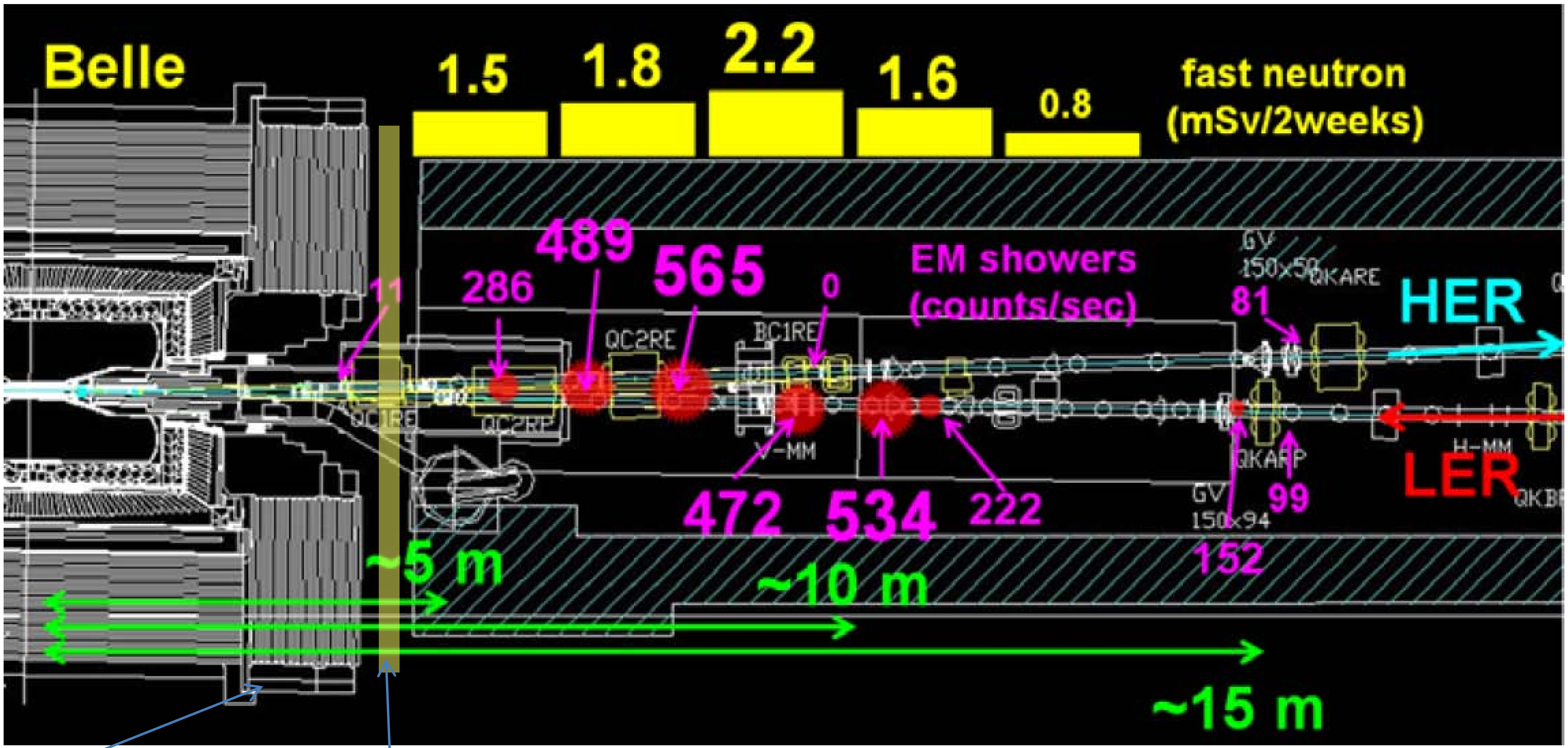
Radiative Bhabha

Emitted gamma hit magnet at ~10m downstream and creates neutrons



e+/e- lose energy by radiative Bhabha process and will be lost at ~10m downstream

Radiative Bhabha @Belle (photon → neutrons)



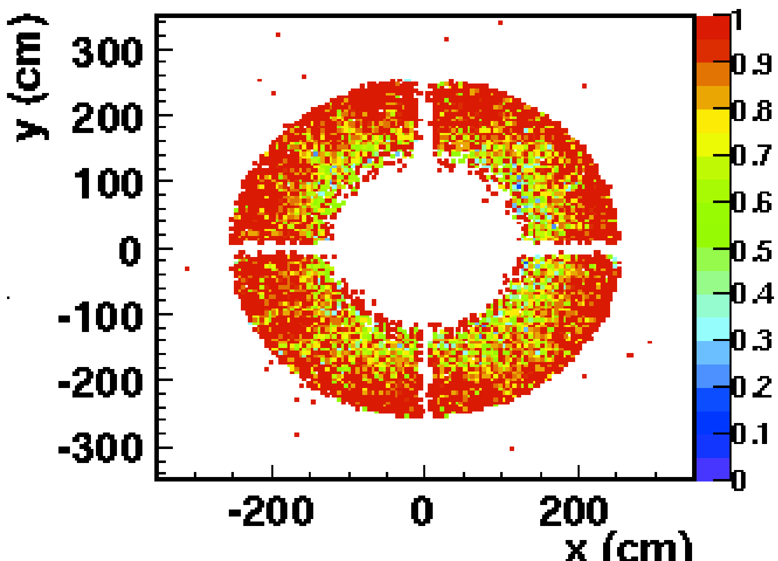
End-cap
KLM

Polyethylene shield
(10cm) at KEKB

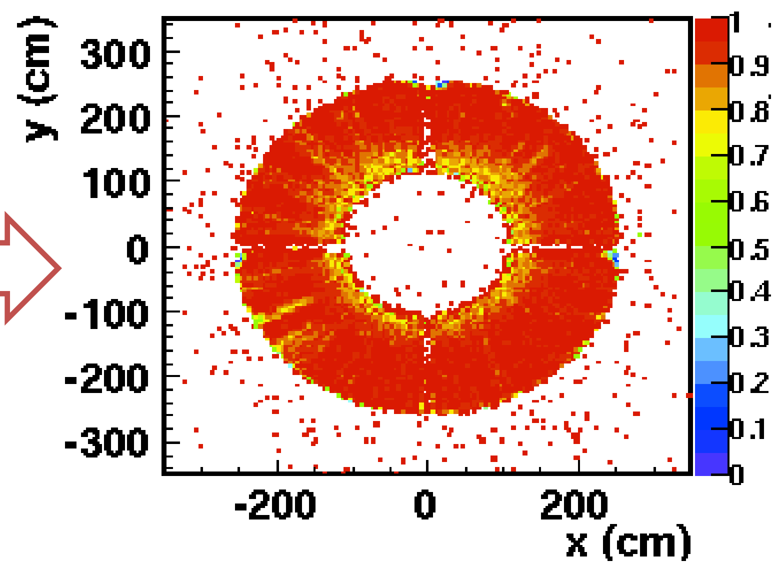
x40 at SuperKEKB!!

Polyethylene neutron shield at Belle

layer 9 before shield



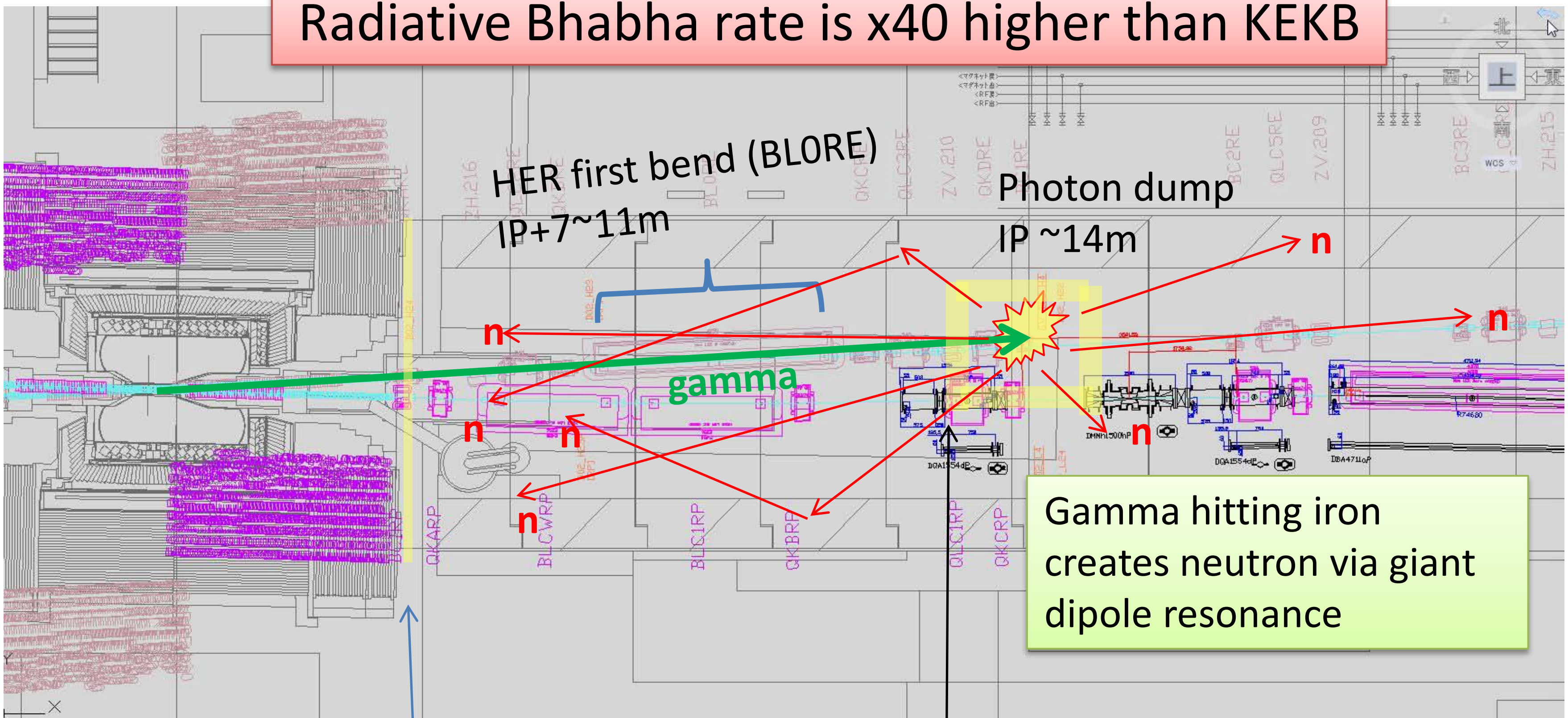
layer 9 after shield



KLM efficiency recovered!

Additional neutron shield around radiative Bhabha photon dump

Radiative Bhabha rate is x40 higher than KEKB

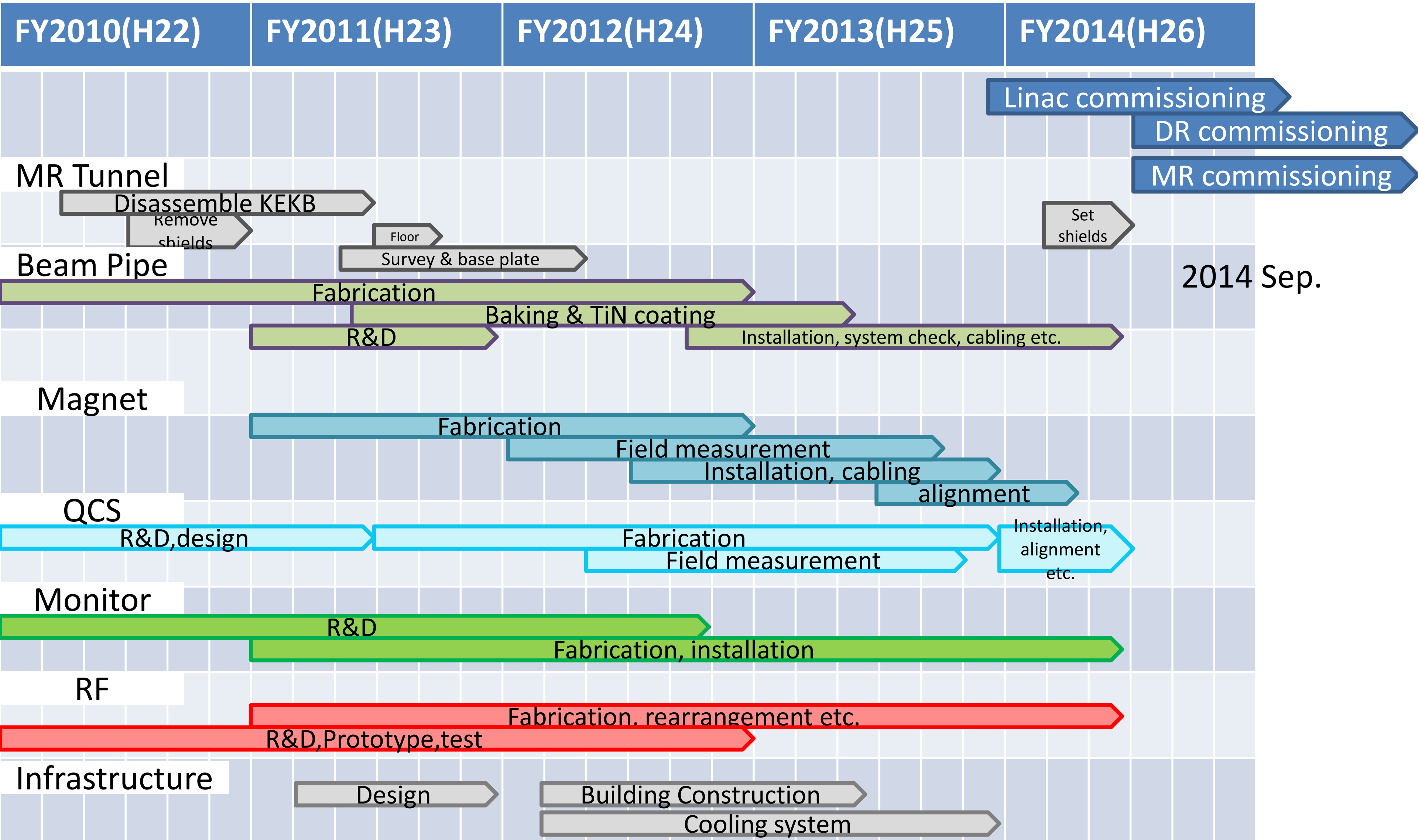


Polyethylene shield (10cm) at KEKB

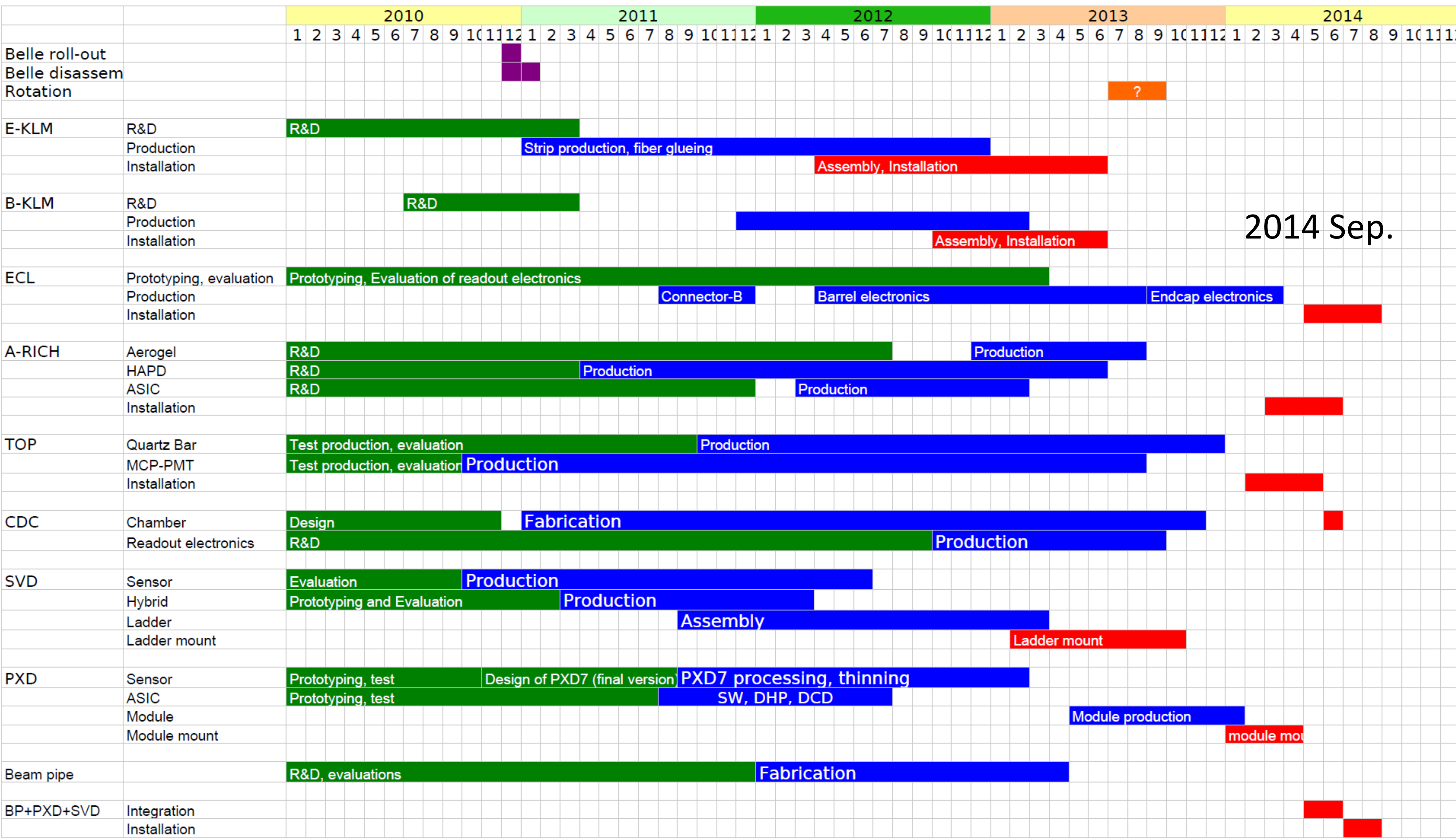
Additional neutron shield around photon dump is necessary

Schedule, collaboration

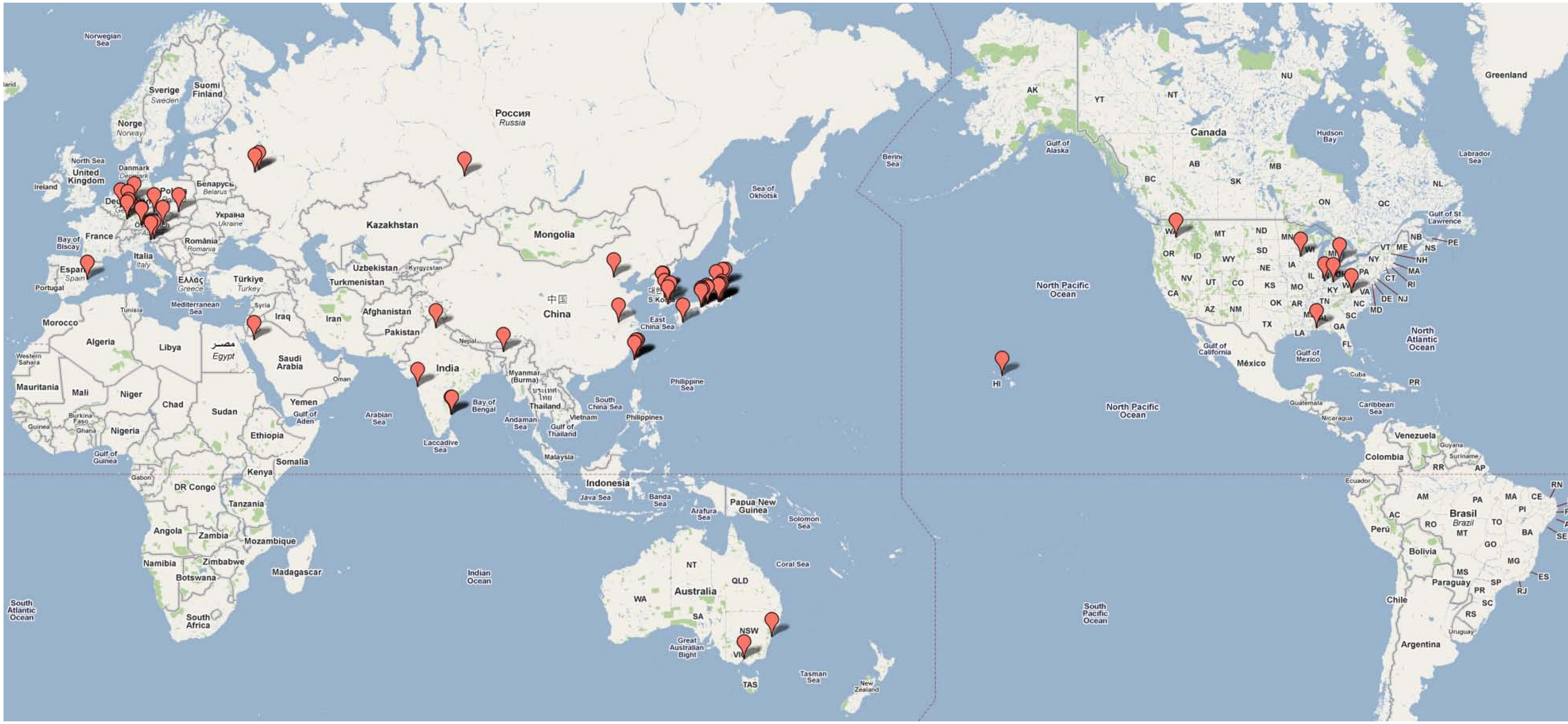
Main Ring construction schedule



Belle II Construction Schedule

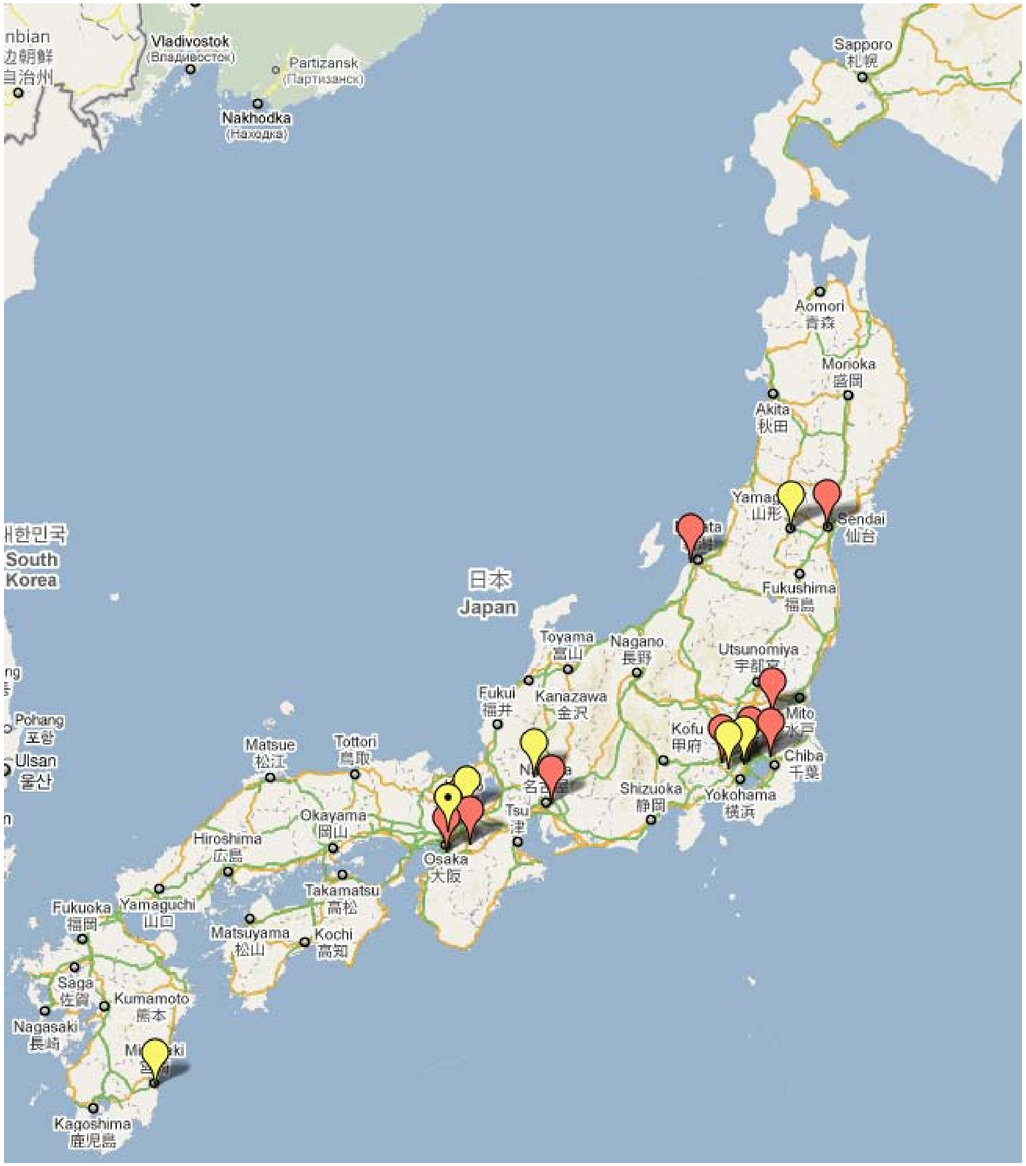


Belle II Collaboration



15 countries/regions, ~60 institutes, ~400 collaborators

Belle II Japan

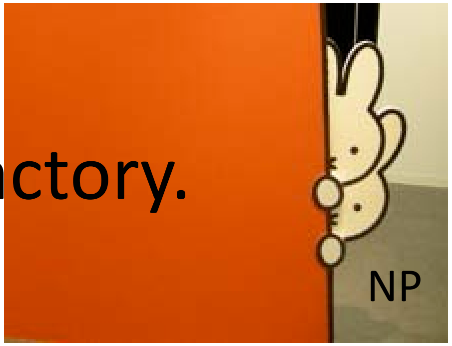


KEK	47
Nagoya Univ.	15
Nara Women's Univ.	10
Niigata Univ.	5
Osaka City Univ.	4
Toho Univ.	3
Tohoku Univ.	14
Tokyo Metropolitan Univ.	4
U-Tokyo	4
Nuclear Physics Consortium (NPC)	15

Summary

- B-factory has achieved good test of KM theory.
- Indication of NP(?) is already seen.

  NP search is the main aim of Super B-factory.



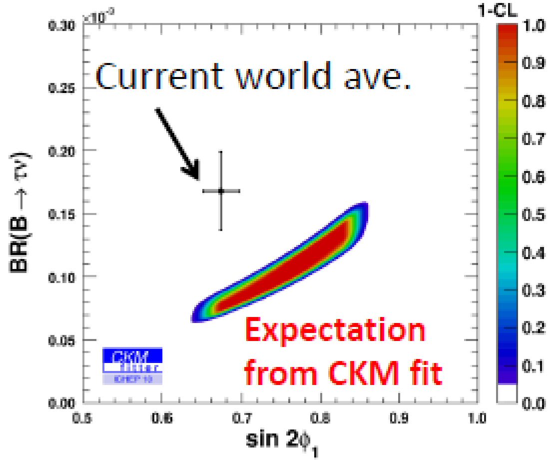
- SuperKEKB accelerator: x40 luminosity
- Belle II detector: better performance and survives under x20 background environment
- We have just start construction and start experiment in 2014.
- 参加してみようかなと思った人は是非ご一緒に

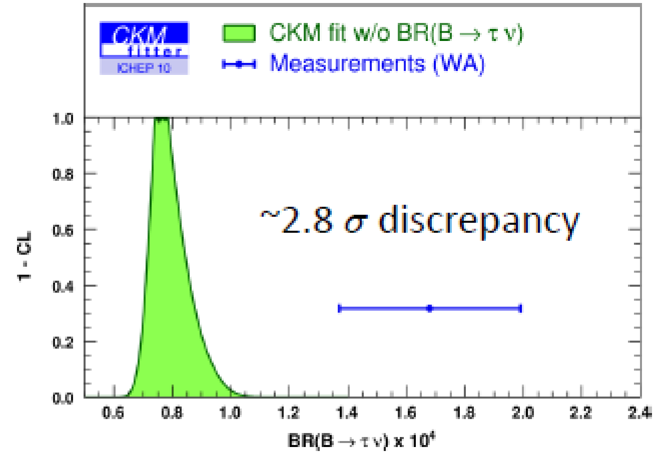
Thank you !!

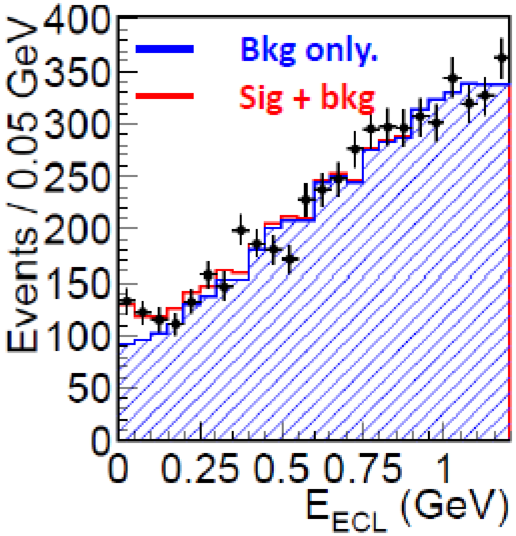
Backup: physics at Belle-II

Missing Energy Modes: $B^- \rightarrow \tau^- \nu$

- Tension between the global CKM fit and $\mathcal{B}(B \rightarrow \tau\nu)$:







- Better measurement of $\mathcal{B}(B \rightarrow \tau\nu)$ may reveal source of the tension.

➔Tag-side information vital when ≥ 2 ν's in final state! Signal is seen as zero excess E_{ECL}.

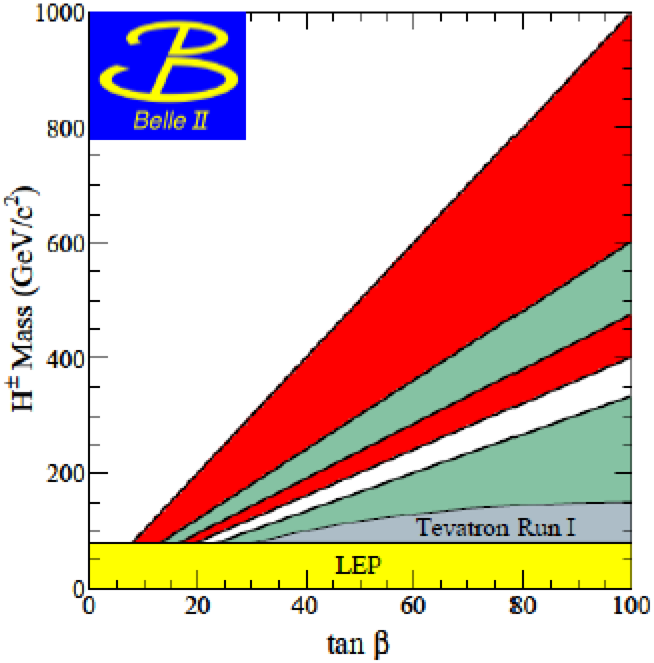
Example w/ semileptonic tag, 657M BB
PR**D82**:071101 (2010)

$$\mathcal{B}(B^- \rightarrow \tau^- \bar{\nu}_\tau) = (1.54^{+0.38}_{-0.37}(stat)^{+0.29}_{-0.31}(syst)) \times 10^{-4}$$

$B \to \tau \nu$ at Belle II

- Also sensitive to new physics:
  - In type-II Two-Higgs Doublet Model (THDM), the SM branching fraction of $B^- \to \tau^- \nu$ is modified:

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = \mathcal{B}_{\rm SM}(B^- \to \tau^- \bar{\nu}_\tau) \left[1 - \frac{m_B^2}{m_H^2} \tan^2 \beta\right]$$



Belle II discovery region with 5 ab^{-1}

- Assumes improvements in theory values:
  - 5% $|V_{ub}|$ error
  - 5% f_B error

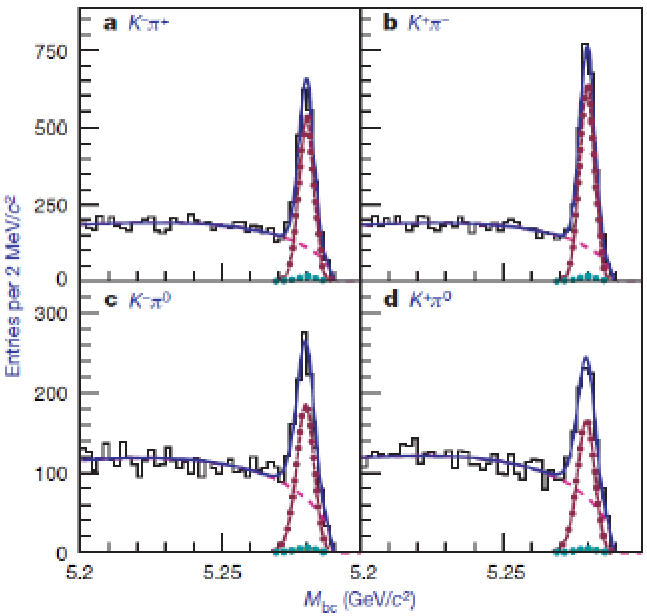
5 σ discovery region

current 95% exclusion

Direct CP Violation: $B \to K\pi$

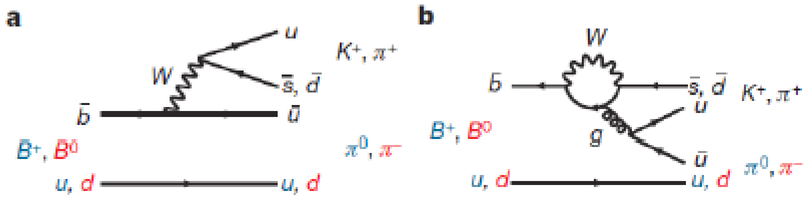
- Puzzle of direct CP violation in $K\pi$:
  - Difference in DCPV in charged/neutral B decays:

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$



$B \to K\pi$ w/ 535M BB
Nature **452**, 332 (2008).

- If the only diagrams are:



then we expect $\Delta\mathcal{A} = 0$

- Missing diagrams?
- Hadronic interactions?

➔ These result in large theoretical uncertainty…

CPV in $B \to K\pi$ at Belle II

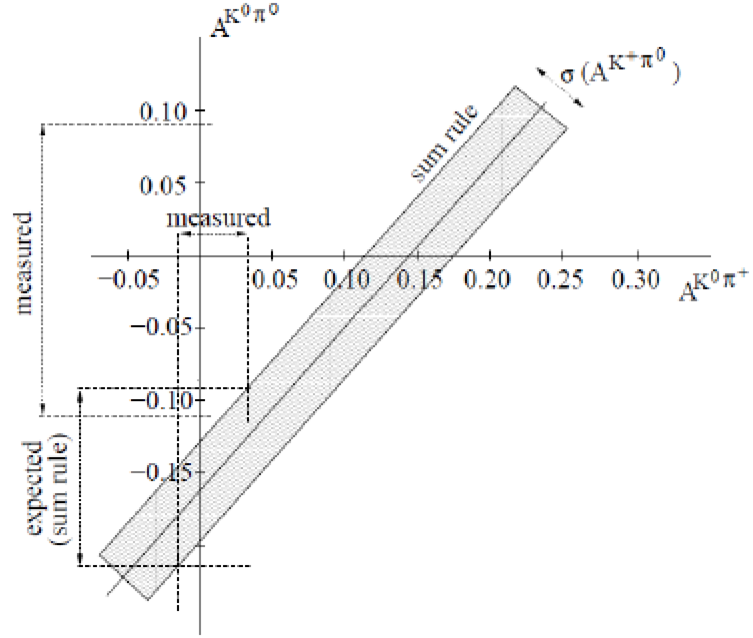
- However, we can compare to a **model independent** sum rule:

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

Gronau, PL**B627**, 82 (2005)

  - This rule is free of the previous theoretical complications.
  - Can be represented as a diagonal band:

- Current situation:



*Slope determined by branching fractions & lifetimes, fairly precisely known.

CPV in B $\rightarrow$ K π at Belle II

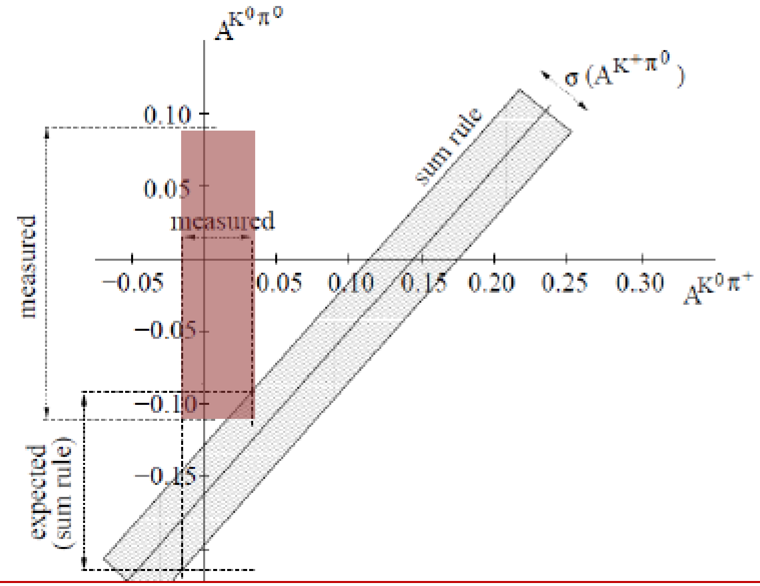
- However, we can compare to a **model independent** sum rule: $$\mathcal{A}_{\rm CP}(K^+\pi^-) + \mathcal{A}_{\rm CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{\rm CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{\rm CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

  Gronau, PL**B627**, 82 (2005)

  – This rule is free of the previous theoretical complications.
  – Can be represented as a diagonal band:

- Current situation:

Shaded region is overlap of $\mathcal{A}(K^0\pi^0)$ and $\mathcal{A}(K^0\pi^+)$.



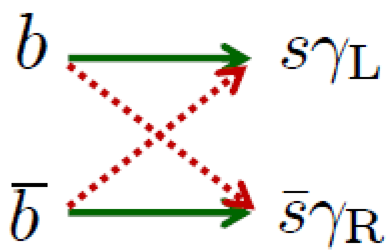
<u>Benefits from:</u>

✓ Charged K/π ID (TOP counter)
✓ $\pi^0 \rightarrow \gamma\,\gamma$ detection (ECL)
✓ K_S vertexing eff. (increased SVD radius)
✓ ...and of course, statistics

➔ **Belle II is especially well suited to measure the all neutral final state: $K^0\,\pi^0$**

Mixing Induced CP Violation in $b \to s\,\gamma$

- In SM, photon polarizations in $b \to s\,\gamma$ depend on b flavor:



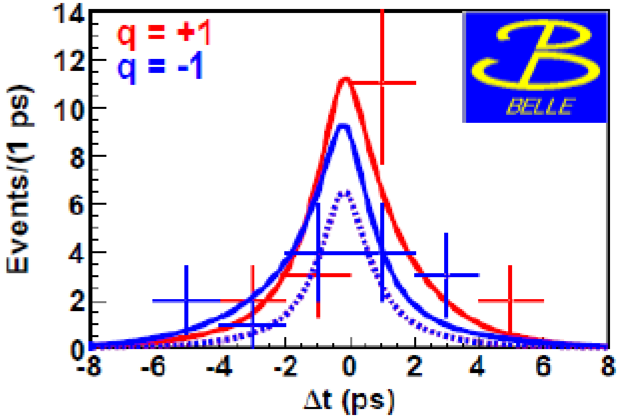
: Allowed

: Suppressed by m_s / m_b

- Presence of significant mixing-induced CP violation would indicate the presence of right handed currents and clear hints of new physics.
  - This type of new physics does not require a new phase.

Time Dependent CPV in $b \to s\,\gamma$

- A recent example:
  - Search for TCPV in $B \to \phi K \gamma$



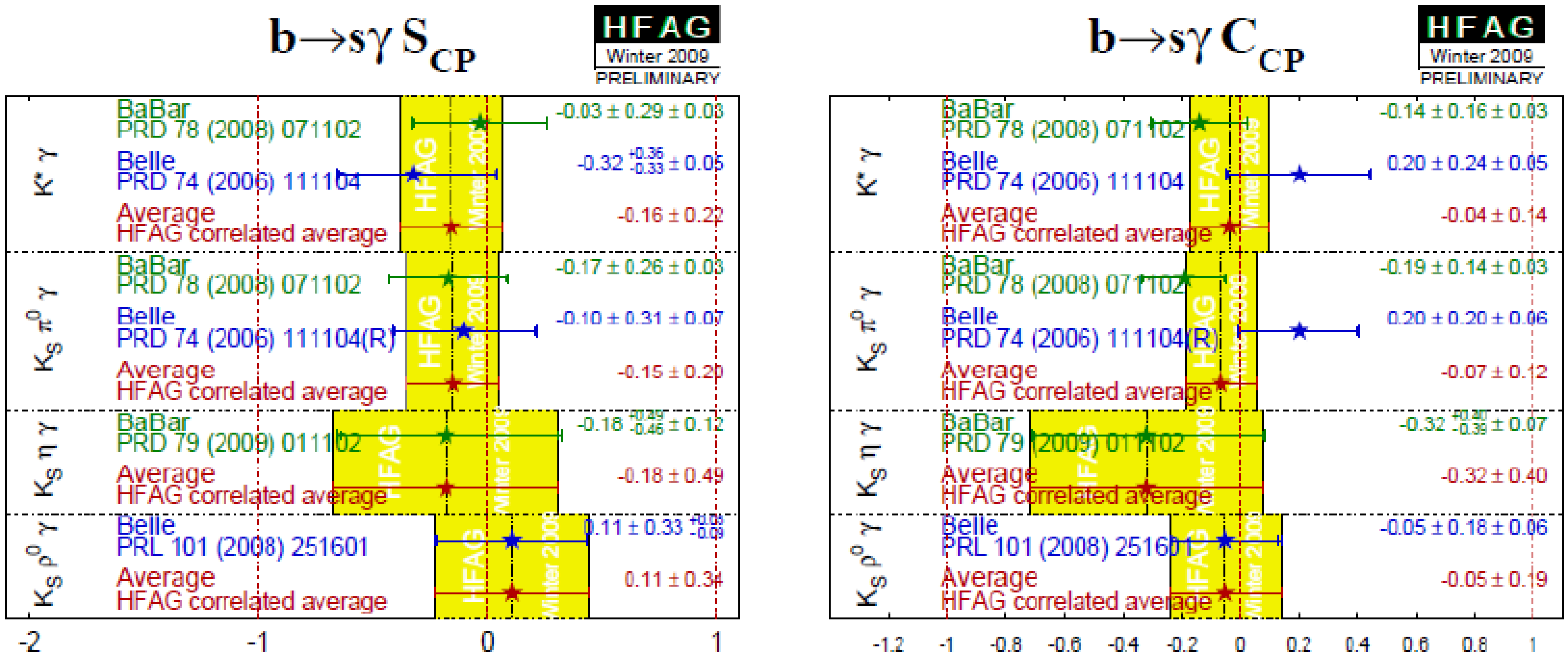
Belle preliminary, arXiv: 1012.0481
$B \to \phi K \gamma$ with 772M BB

$$\mathcal{S}(B \to \phi K\gamma) = +0.74^{+0.72}_{-1.05}(stat)^{+0.10}_{-0.24}(syst)$$

$$\mathcal{A}(B \to \phi K\gamma) = +0.35 \pm 0.58(stat)^{+0.23}_{-0.10}(syst)$$

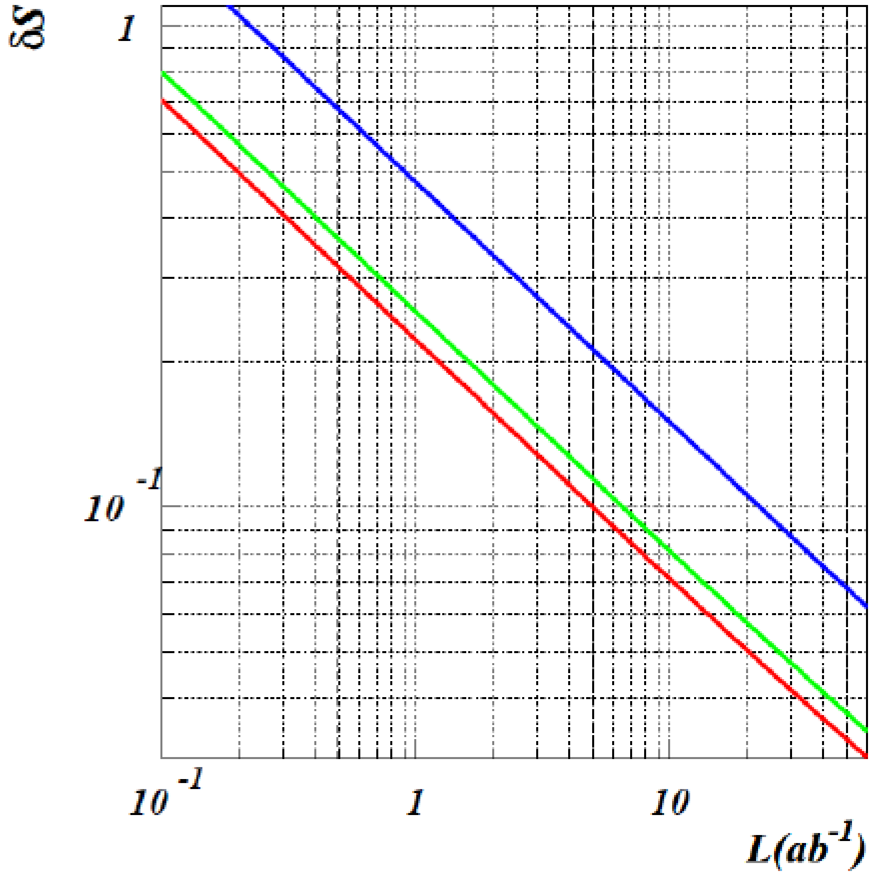
  - Measurements are statistics limited…
    - Also the case for similar modes: $B \to K_S\, \pi^o\, \gamma$, $B \to K^*\, \gamma$

Time Dependent CPV in $b \to s\,\gamma$



– Statistics limited for $\mathcal{S}(b \to s\,\gamma)$ in other modes

Time Dependent CPV in $b \to s\,\gamma$

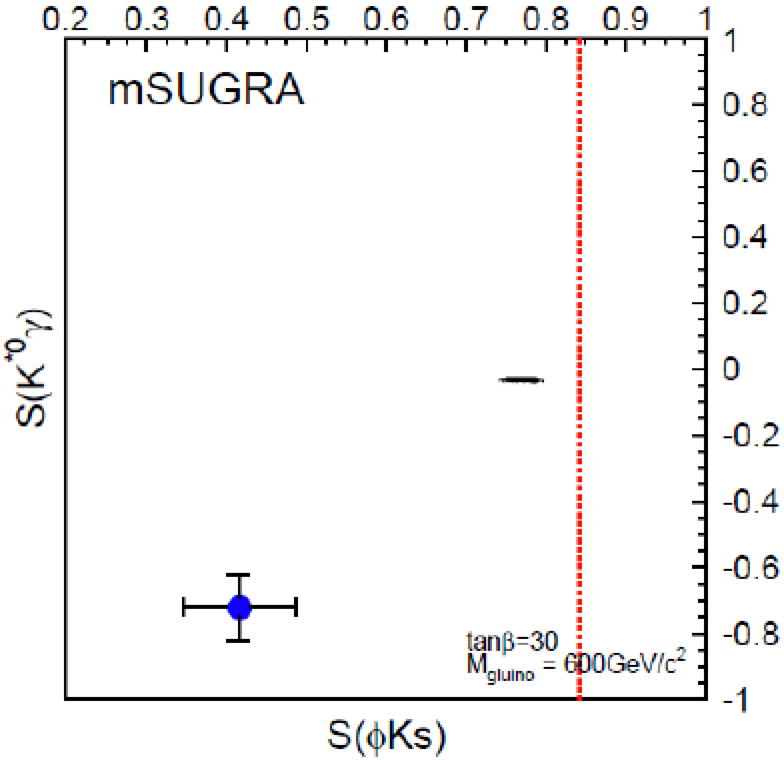


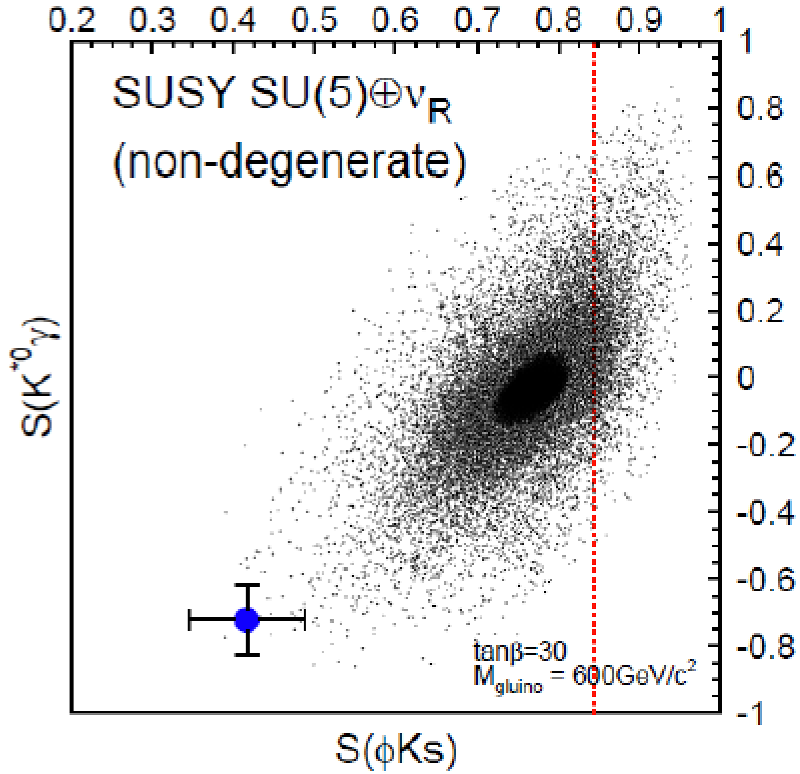
- Example improvements in the error of S as a function of integrated luminosity for:
  - Nonresonant $K_S\,\pi^o\,\gamma$
  - Resonant $K^{*0}\,\gamma$
  - All $K_S\,\pi^o\,\gamma$
- This sensitivity can help distinguish between models…

Belle II projected

✓ Efficiency for $K_S \to \pi^+\,\pi^-$ improves with SVD radius.

Identifying NP at Belle II





● Belle II — Projected with 5 ab^{-1}

● Randomly chosen parameter point

---- Current 99% CL on $\mathcal{S}(B \to \phi K_S)$

Belle II can identify the nature of NP, in some cases indistinguishable at LHC.

Physics sensitivity at Belle-II

Observable	Belle 2006	Belle II/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 $A_{FB}(B \to K^* \ell^+ \ell^-)$	-	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
$\mathcal{B}(B^+ \to K^+ \nu\nu)$	†† $< 3\ \mathcal{B}_{SM}$		30%	-	-
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu})$	†† $< 40\ \mathcal{B}_{SM}$		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%	-	-
$\mathcal{B}(B^+ \to \mu^+ \nu)$	†† $< 2.4\mathcal{B}_{SM}$	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%	-	-

Belle-II TDR

Physics sensitivity at Belle-II

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	$\sim$0.02	$\sim$0.01
ϕ_2 $(\pi\pi)$	11°	10°	3°	-	-
ϕ_2 $(\rho\pi)$	$68^\circ < \phi_2 < 95^\circ$	3°	1.5°	10°	4.5°
ϕ_2 $(\rho\rho)$	$62^\circ < \phi_2 < 107^\circ$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1^\circ$	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°
$\lvert V_{ub}\rvert$ (inclusive)	6%	5%	3%	-	-
$\lvert V_{ub}\rvert$ (exclusive)	15%	12% (LQCD)	5% (LQCD)	-	-
$\bar{\rho}$	20.0%		3.4%		
$\bar{\eta}$	15.7%		1.7%		

Backup: SuperKEKB

Luminosity

- よく知られているルミノシティの式

$$L = \frac{N_+ N_- f}{4\pi\sigma_x^* \sigma_y^*} R_L$$

バンチに含まれる陽電子の数 → N_+

バンチに含まれる電子の数 → N_-

バンチの衝突頻度 → f

$f = n_b f_0$　　n_b: バンチ数　f_0 : 周回周波数

幾何学的ロス → R_L

衝突点での水平方向のビームサイズ → σ_x^*

衝突点での垂直方向のビームサイズ → σ_y^*

ルミノシティに限界があるとすれば、
話は単純ではない。

ルミノシティには限界があって
ビーム・ビームで決まっている?

Lorentz factor

ビーム電流

ビーム･ビーム　パラメータ

衝突点でビームが互いに
及ぼし合う力の大きさ

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

古典電子半径

衝突点でのx方向と
y方向のビームサイズ
の比　0.5 ~ 1 % (flat beam)

衝突点での
y方向のβ関数

幾何学的な要因
による補正係数
0.8 ~ 1 (short bunch)

衝突点でのビームの絞り量「焦点深度」

ルミノシティーは、
ビーム電流とビーム･ビーム　パラメータの積に比例し、β_y* 関数に反比例する。