Super KEKB Quest for BSM and Belle II

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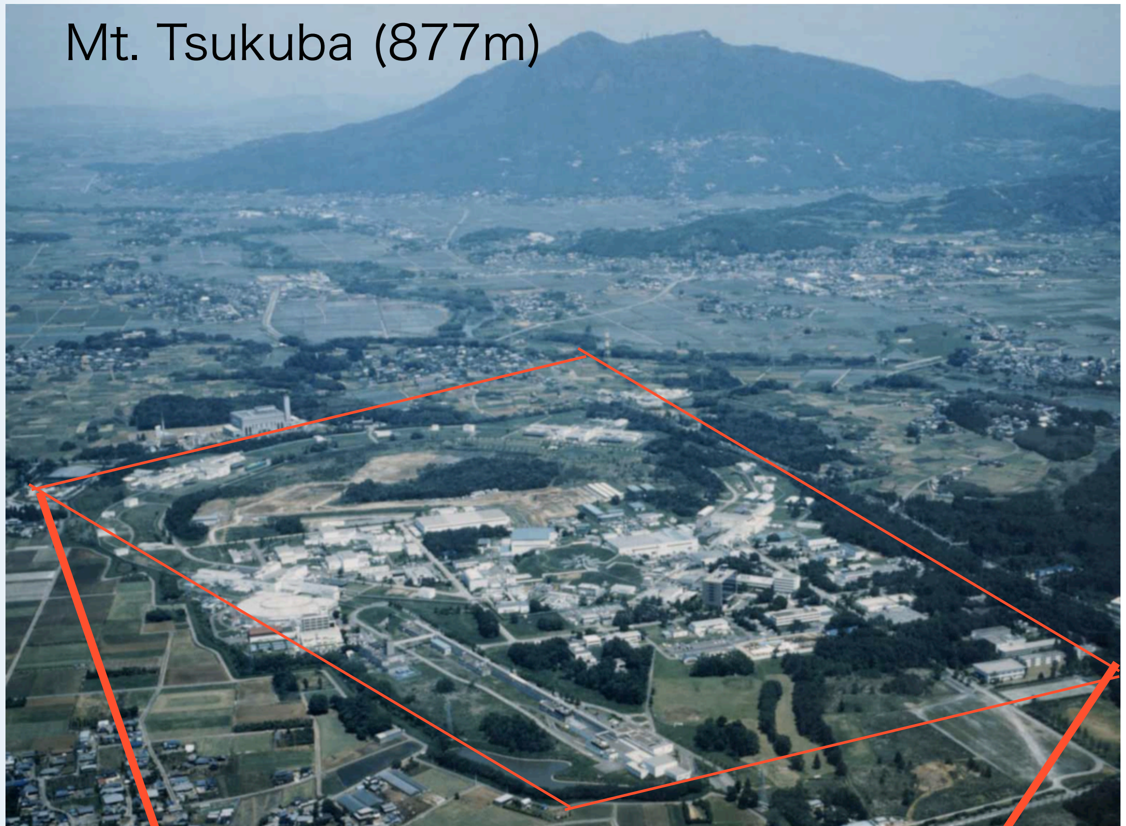
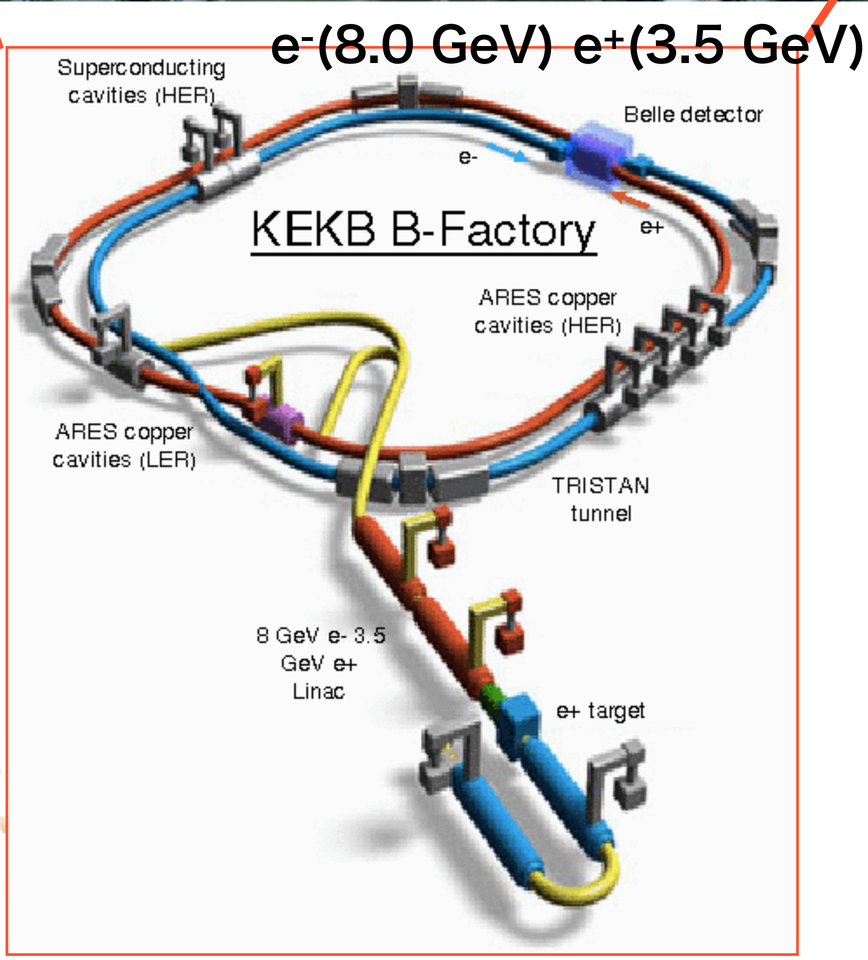
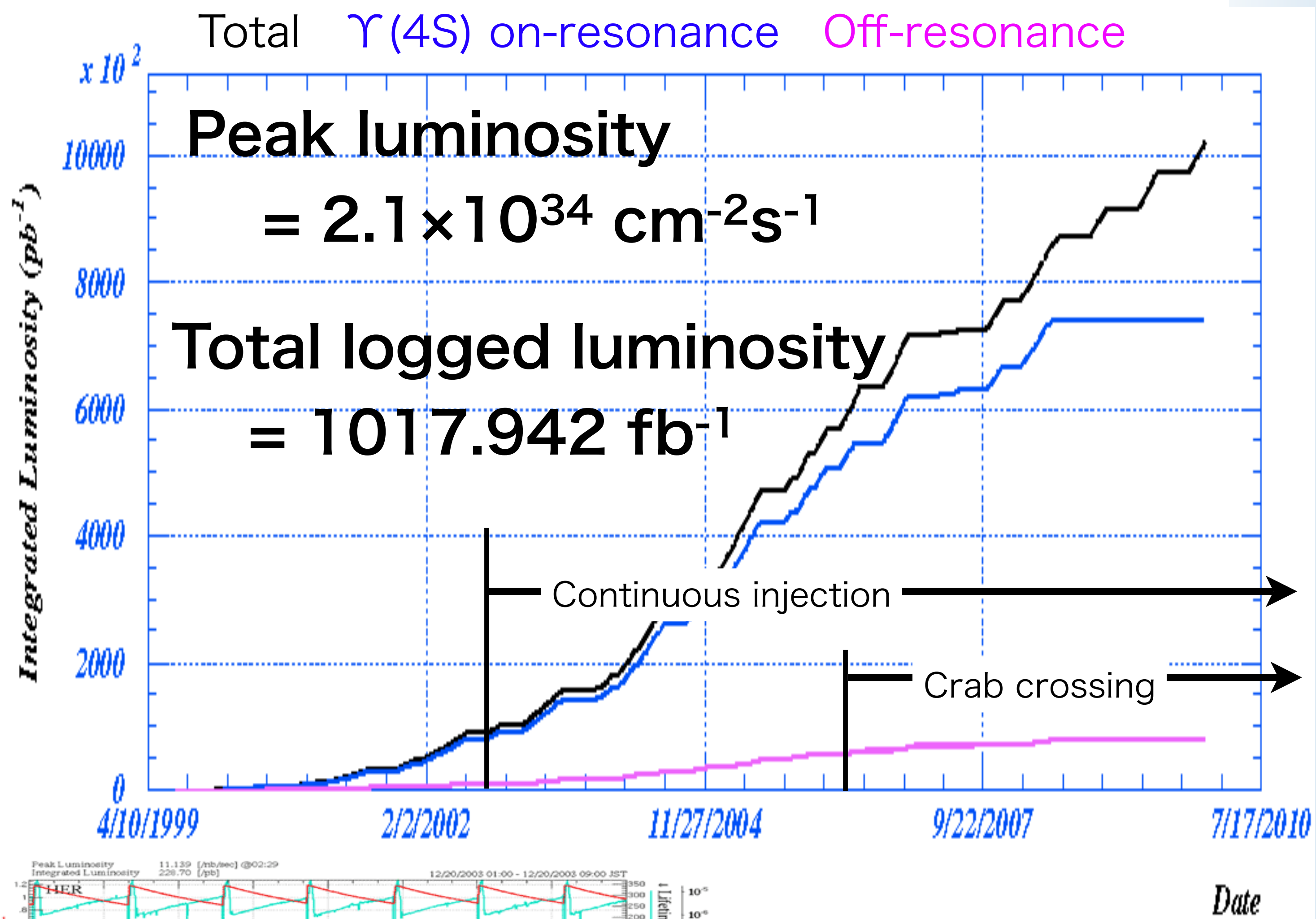
for the Belle II collaboration
Virginia Tech

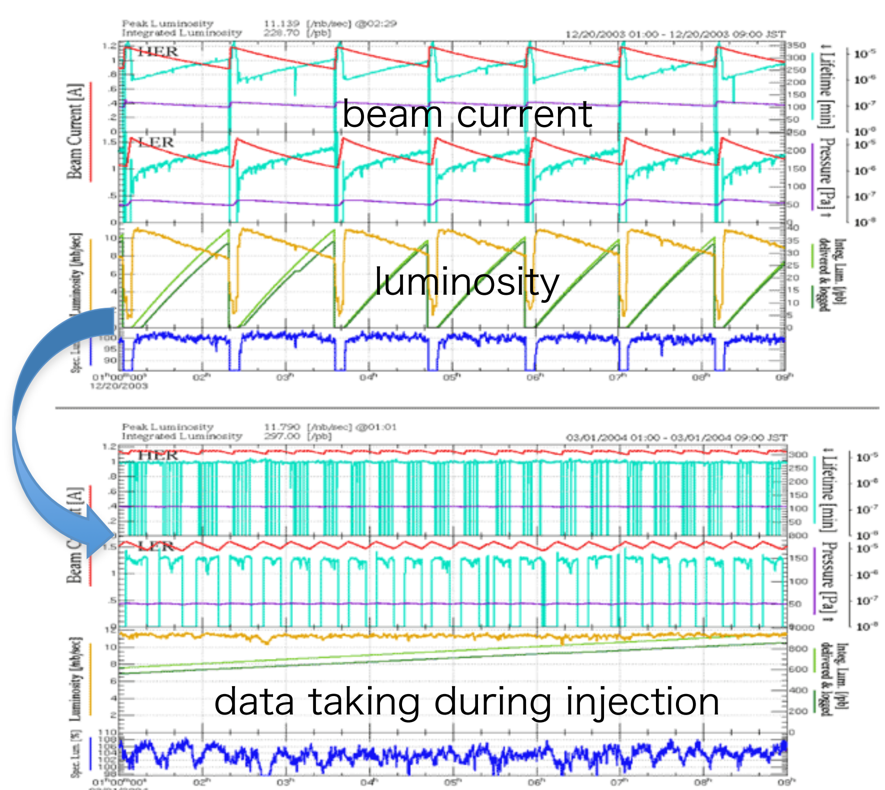
“Super KEKB and Belle II” Lake Louise Winter Institute 2010, 17 Feb 2010

KEKB Accelerator

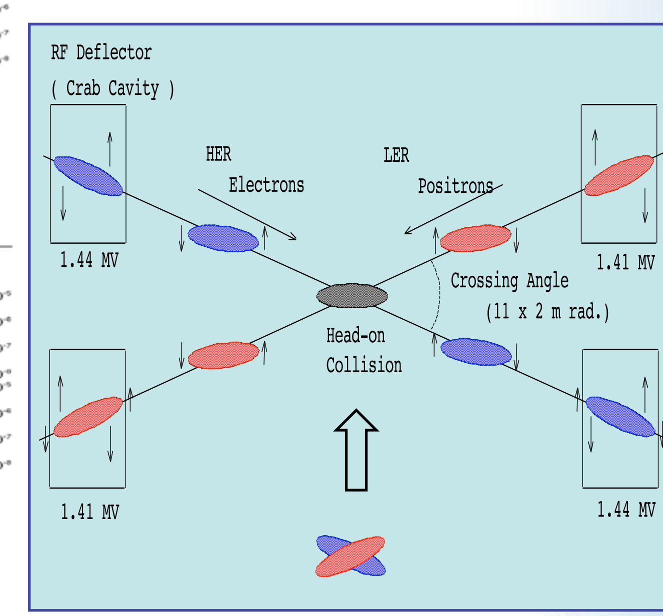








Crab crossing scheme



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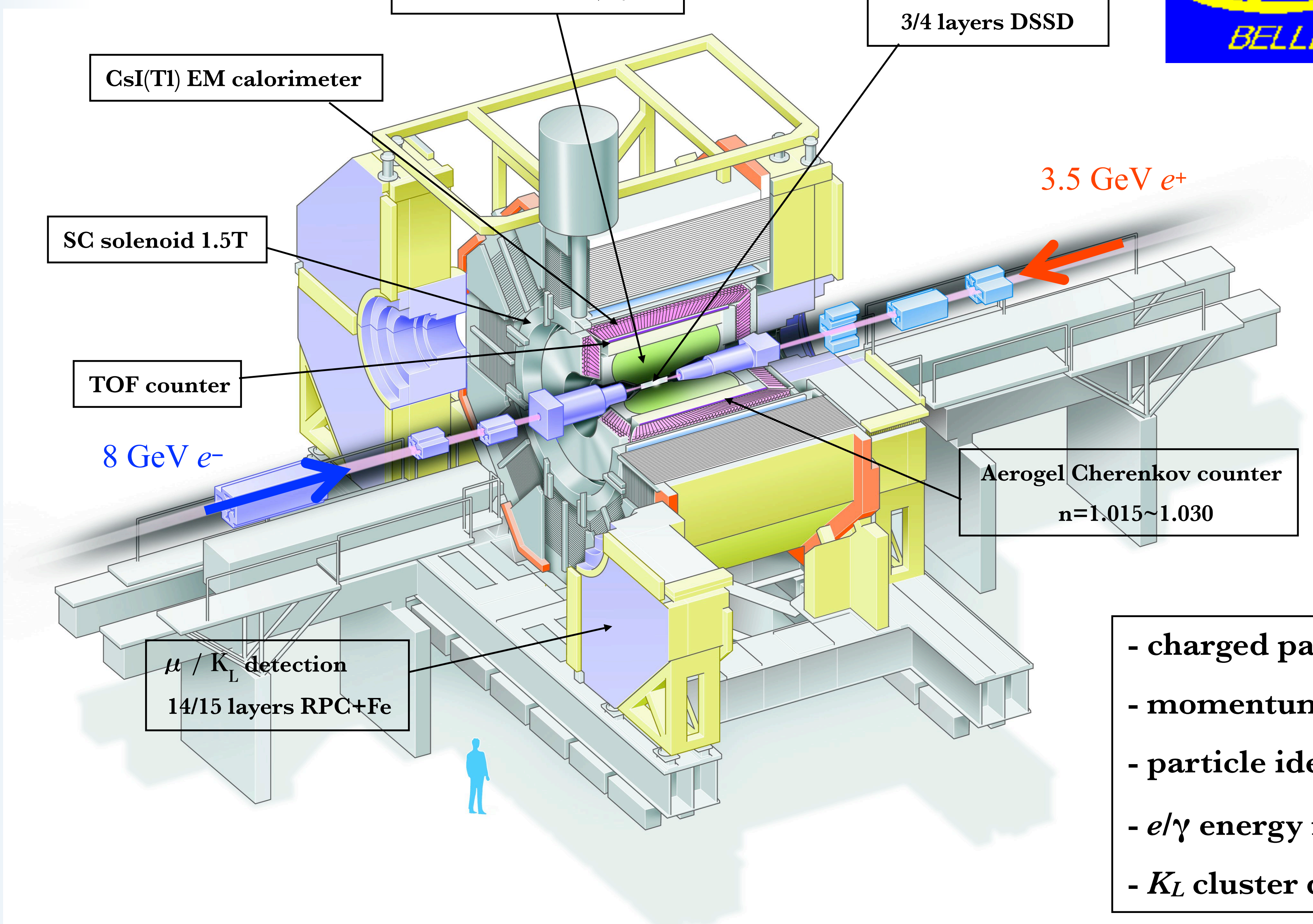
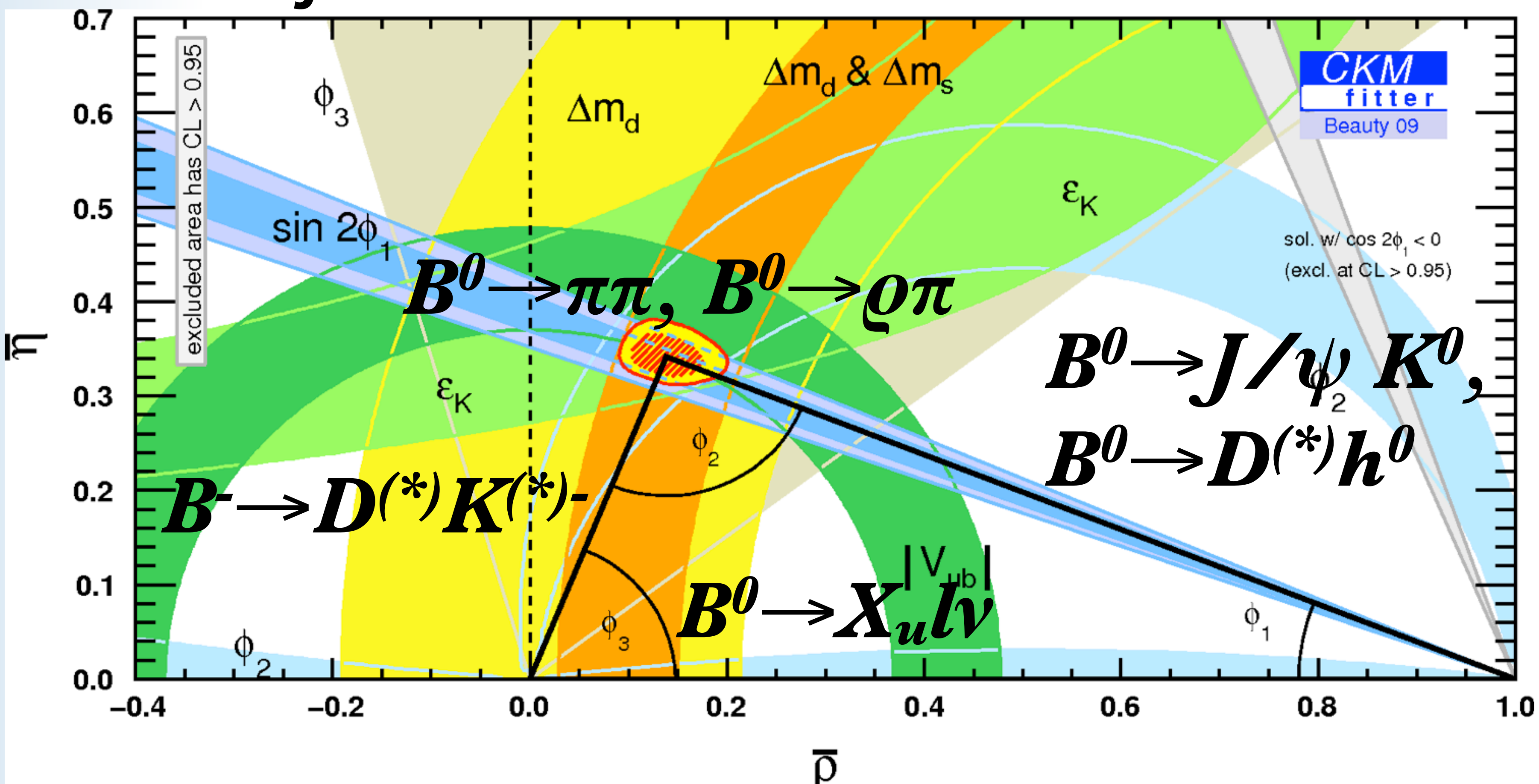
Belle Detector



- charged particle tracking
- momentum measurement
- particle identification
- e/γ energy measurement
- K_L cluster detection

We have achieved many results

- Many remarkable measurements on CKM unitary triangle.



$\phi_1 = (21.2 \pm 0.9)^\circ$

$\phi_2 = (89 \pm 4)^\circ$

$\phi_3 = (73^{+22}_{-25})^\circ$

$\Delta V_{ub} \sim 10\%$

(CKMfitter global fit for dir. meas.)

- Direct CP violation in $B \to K\pi$
- D^0-$\bar{D}^0$ mixing
- New resonance $X(3872)$, $Y(3940)$, $Z(4430)$...
- New physics searches

  $b \to sq\bar{q}$ / $b \to sll/s\gamma$ gluonic- / electroweak- penguin,

  $B \to D^*\tau\nu$, $B \to \tau\nu$, τ lepton flavor violation ...and more.

~300 journal papers has published.

Belle results lead to Nobel Prize for Kobayashi & Maskawa

| 日本語 (Japanese) |

The 2008 Physics Nobel Prize was awarded to Kobayashi, Maskawa and Nambu for their work on the breaking of symmetries.

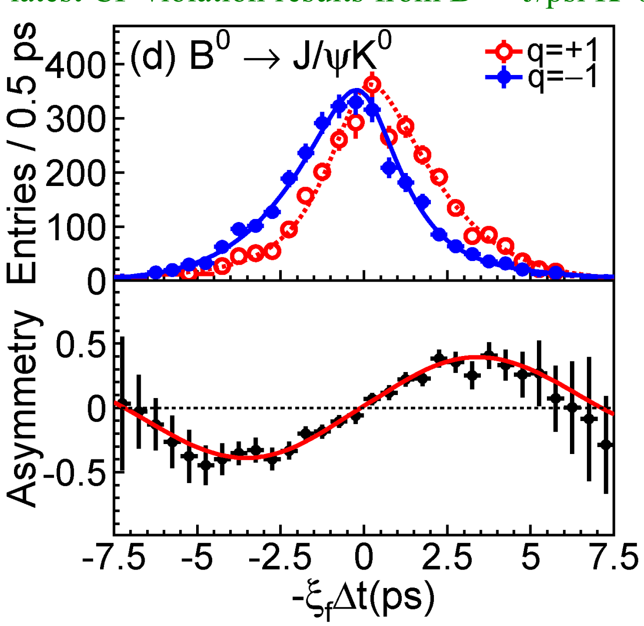
Kobayashi and Maskawa's explanation of the origin of CP symmetry violation predicted that large CP asymmetries could be observed in the decays of particles containing b-quarks. Verification of their hypothesis was one of the primary goals of the B-factory experiments, Belle at KEKB and BaBar at PEP-II. As indicated in the press release from the Nobel foundation the experimental results confirmed that Kobayashi and Maskawa's brillant and bold hypothesis that all CP violation is due to a single complex number was indeed correct.

See also: Nobel prize Physics 2008 page , KEK Press Release , Nature , Science

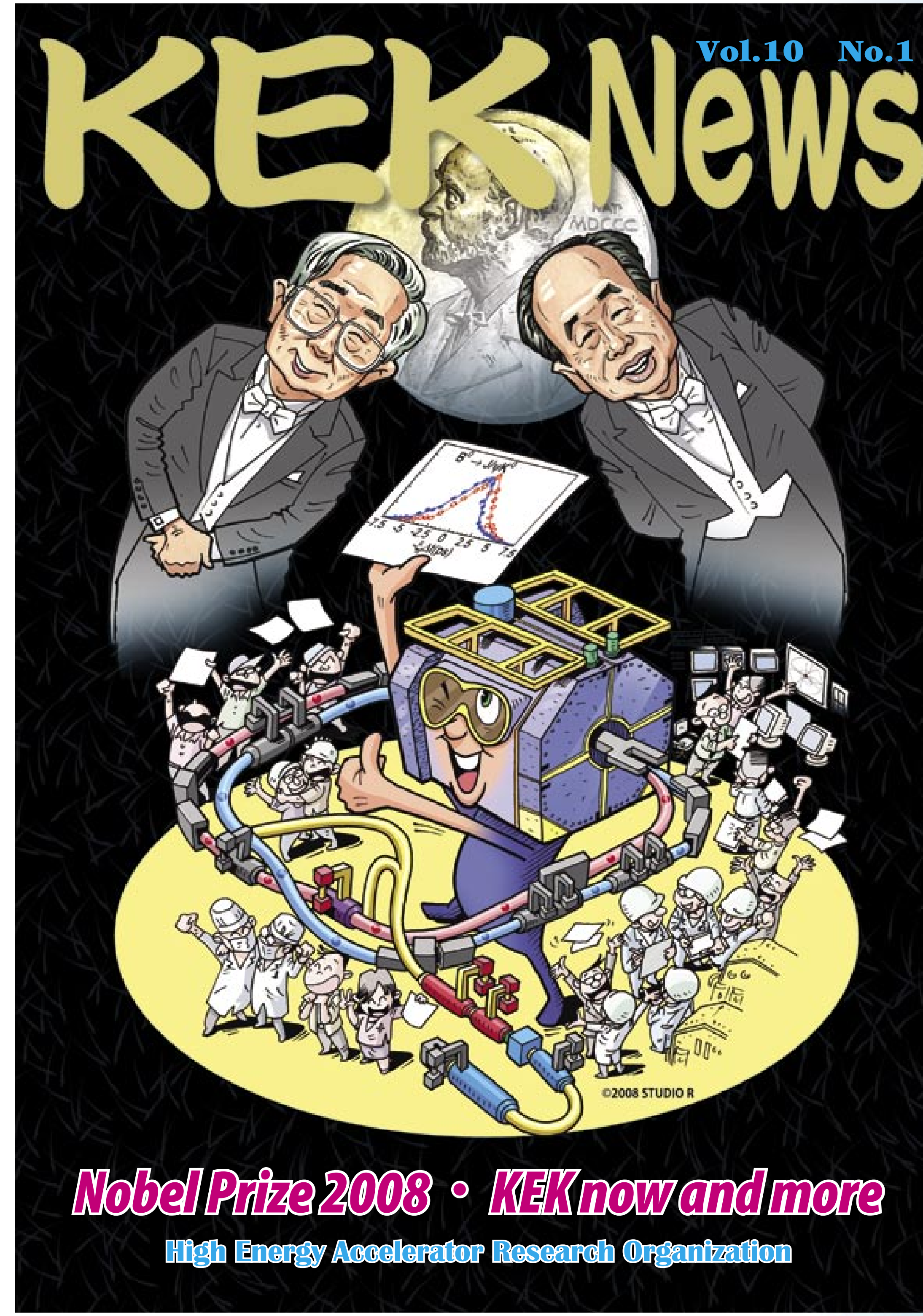
Belle results:

The first observation of CP violation in the Neutral B Meson System
[PRL 87, 091802 (2001)](access is limited)
[hep-ex/0107061]

The latest CP violation results from B -> J/psi K^0



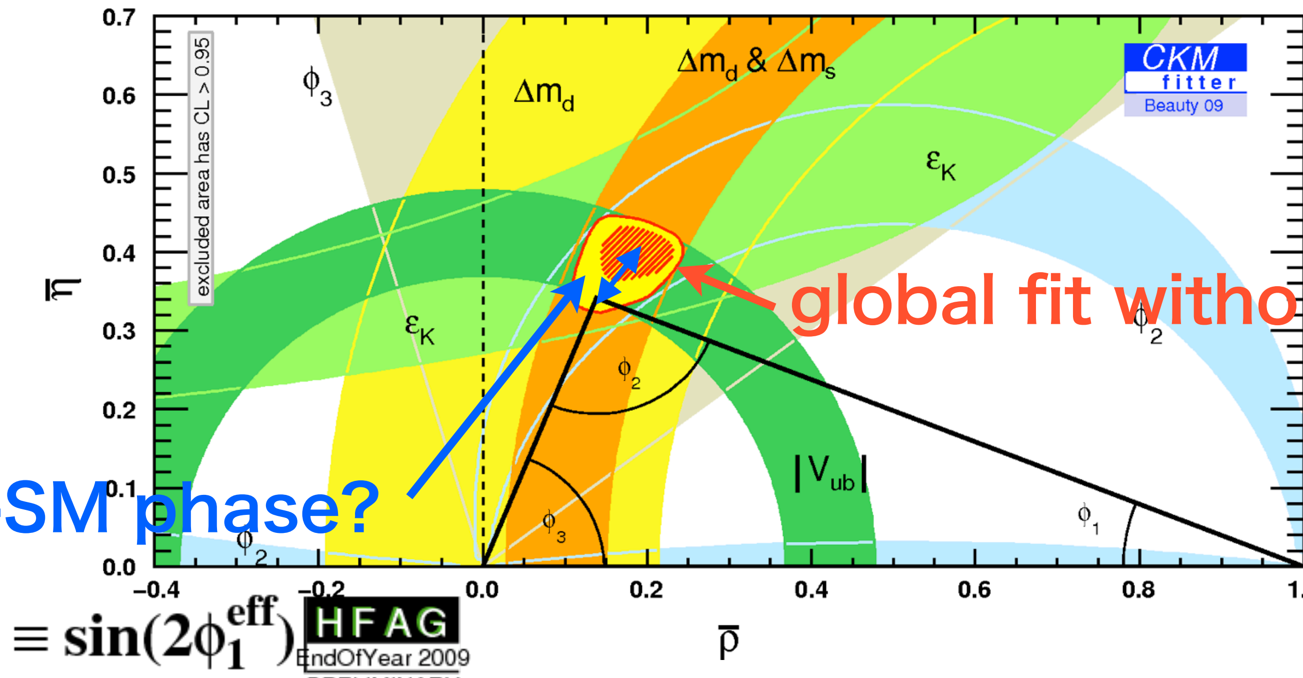
http://belle.kek.jp/belle/km_nobel/index.html



Hints of new physics

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

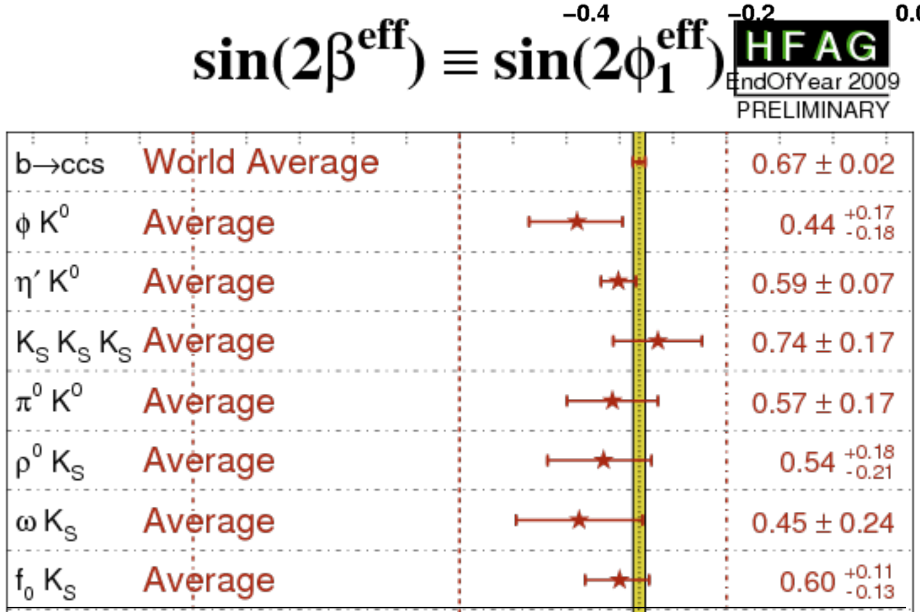
M. Bona *et al.* (UTfit Collaboration), "Model-independent constraints on Delta F=2 operators and the scale of New Physics"
arXiv: hep-ph/0707.0636



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

Extra *CP* phase in gluonic penguin loop?

arXiv:hep-ph/0409245
arXiv:hep-ph/0411178
arXiv:hep-ph/0411151
arXiv:hep-ph/0502076



$\sin 2\phi_1(b \to c s\bar{s}) \neq$
$\sin 2\phi_1(b \to s q\bar{q})$?

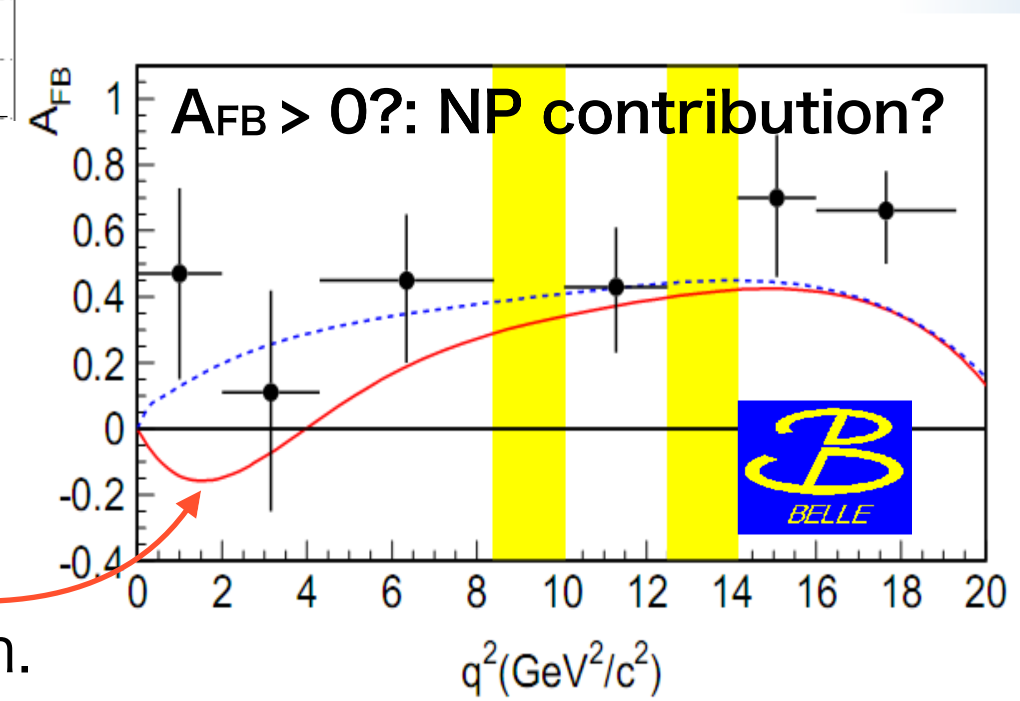
- Angular analysis of $B^0 \to K^{(*)}ll$

Forward-backward asymmetry A_{FB}

$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

W/Z box　　γ penguin

Ali, Mannel, Morozumi, PLB273, 505 (1991)



New physics: change coefficients or additional term.

Hints of new physics

- $B \to l\nu$

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

$= (0.92^{+0.10}_{-0.11}) \times 10^{-4}$ (CKMfitter global fit)

Higgs contributes to enlarge BF.

Mode	PDG2008 Avg.	BABAR	Belle	CLEO	CDF	DØ	New Avg.
$e^+\nu$	< 9.8	< 1.9	< 1.0	< 15	—	—	< 1.0
$\mu^+\nu$	< 1.7	< 1.0	< 1.7	< 21	—	—	< 1.0
$\tau^+\nu$	140 ± 40	$120 \pm 40 \pm 36$	165^{+38+35}_{-37-37}	< 840	—	—	143 ± 37

(Summaries in HFAG, $\times 10^{-6}$)

- $\tau \to l\gamma$, $\tau \to lll$, $\tau \to lh$

Lepton flavor violation:

forbidden in SM

↕

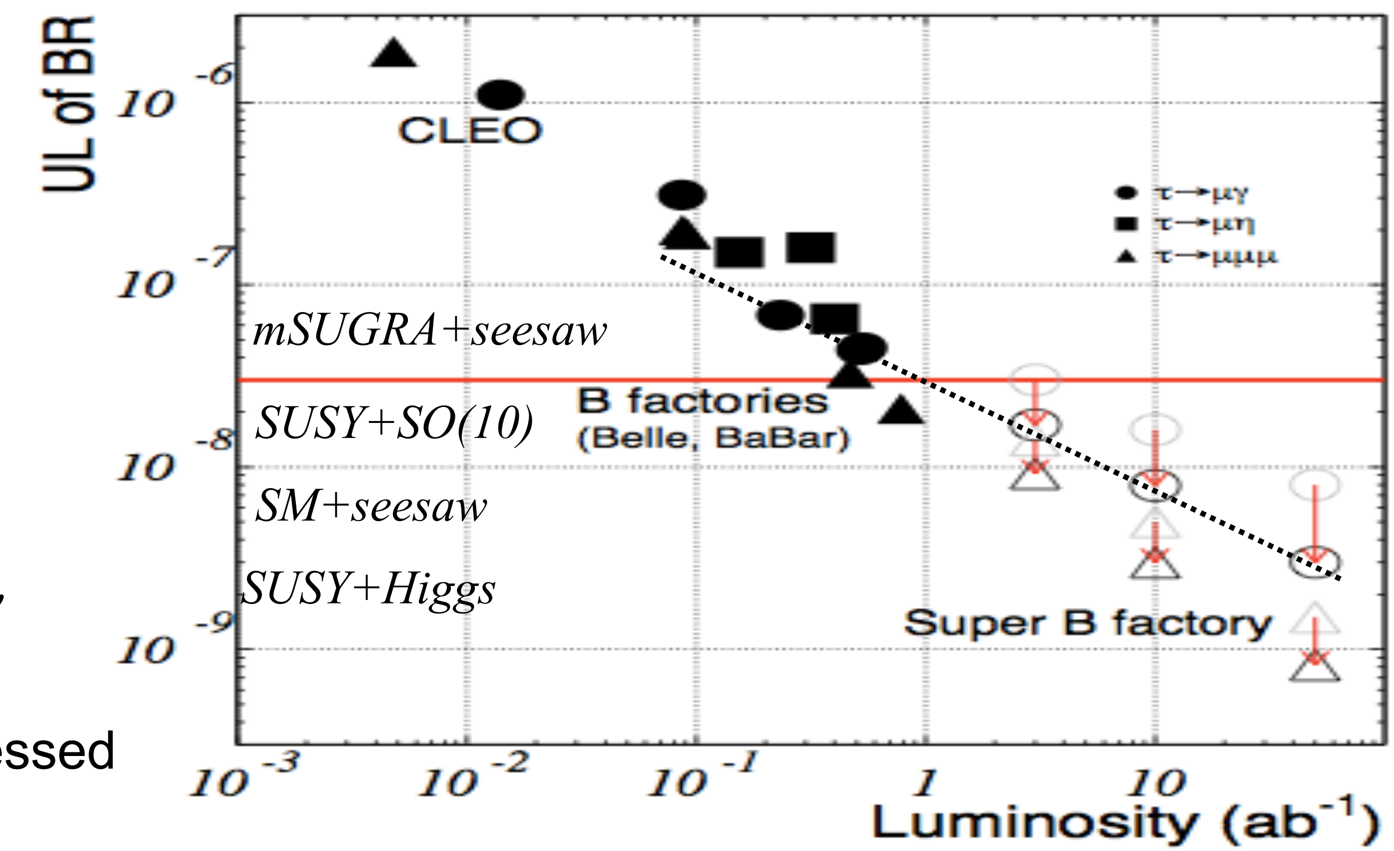
Enhanced in several scheme of new physics

- $\tau \to l\gamma$, $\mu\eta$, $l\varrho$: large background from γ

  BF ∝ 1/√(Luminosity)

- $\tau \to lll$, $\mu\eta(\pi^+\pi^-\pi^0)$: background suppressed

  BF ∝ 1/(Luminosity)



... and many in other B,D,τ decay modes.

To explore these hints, we need more statistics.

Upgrade of KEKB

beam current
1.7 / 1.4 A (e^+/e^- KEKB achieved)
3.6 / 2.6 A (e^+/e^- SKEKB design)

beam-beam parameter
0.09 (KEKB achieved)
0.09 (SKEKB design)

Lorentz factor

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

classical electron radius

Beam aspect ratio at IP
0.5 ~ 1 % (flat beam)

Geometrical reduction factors
(crossing angle, hourglass effect)
0.8 ~ 1 (short bunch)

Luminosity
2.1×10^{34} cm^{-2} s^{-2} (KEKB achieved)
8.0×10^{35} cm^{-2} s^{-2} (SKEKB design)
x 40

vertical βy function at IP
6.5 / 5.9 mm (KEKB achieved)
0.27 / 0.41 mm (SKEKB design)

To get higher luminosity

- Higher beam current

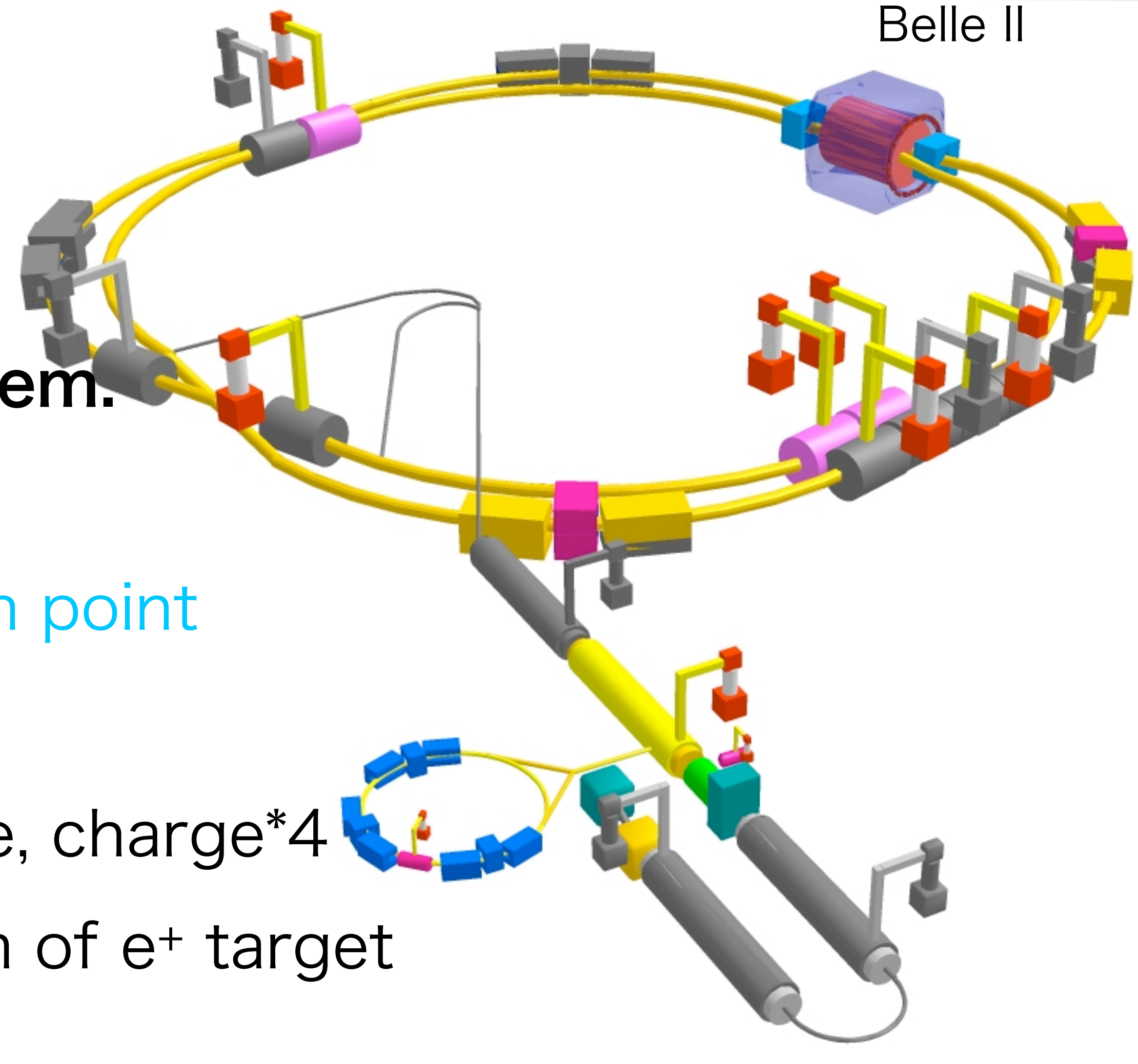
- Smaller beam size at interaction point (low β)

We have decided to upgrade as "nano-beam" option.

Higher luminosity with low beam current.

Many technical issue. (hardware development, parameter tuning)

Upgrade of KEKB



- **Low emittance**

  Redesign of arc optics.

- **Reduce β at interaction point.**

  Modification of final focusing system.

  → Touschek lifetime

  - Achromaticity around interaction point
  - Augmentation of injection beam

    RF electron gun: low emittance, charge*4

    Focusing system in downstream of e^+ target

    e^+ damping ring

- **Hardware update**

  - Vacuum system: Ante-chamber, pumps
  - RF modification
  - Crab cavity for higher current
  - Beam monitor system

All the stuffs are on going!

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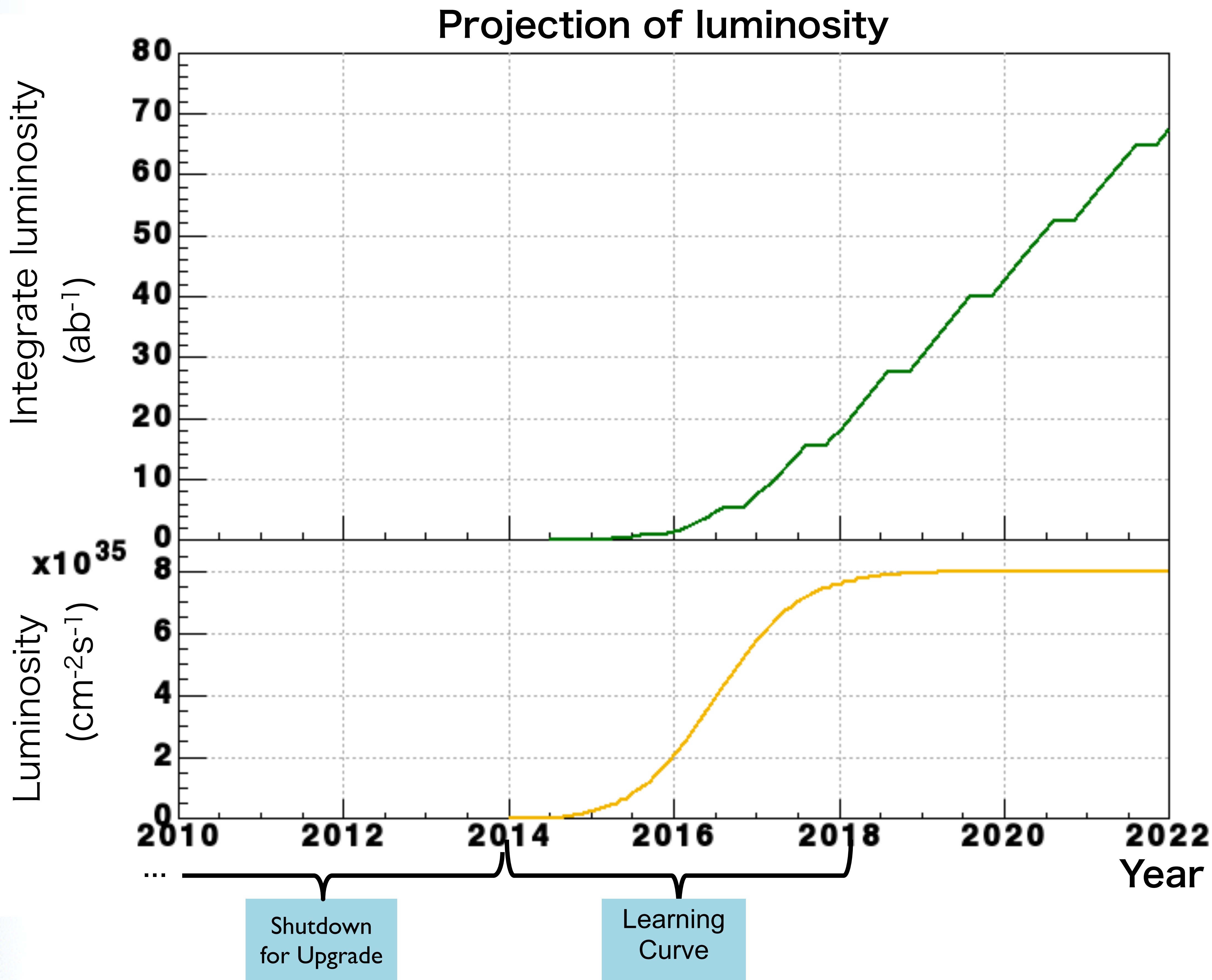
Upgrade of KEKB



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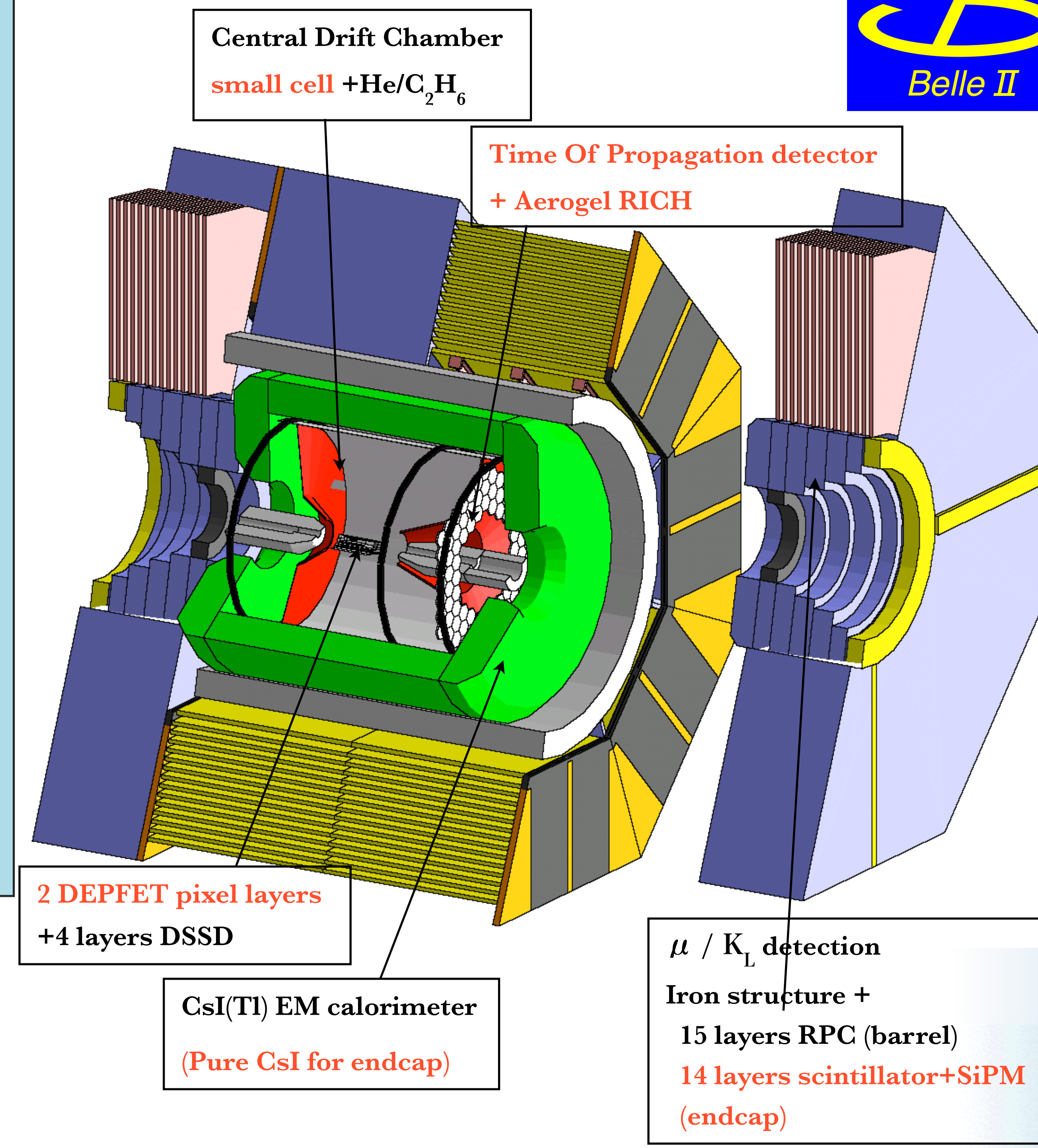
Upgrade of Belle detector

- **Higher beam background**
  - Non-physics process hit reduction
  - Radiation hardness
- **Higher event rate**
  - High speed DAQ and computing
  - More intelligent trigger
- **Performance improvement**
  - ・More precise vertex reconstruction and particle identification with new technology.
    (systematic error of CP measurements, decay modes in which K/π in final states)

Belle-II detector



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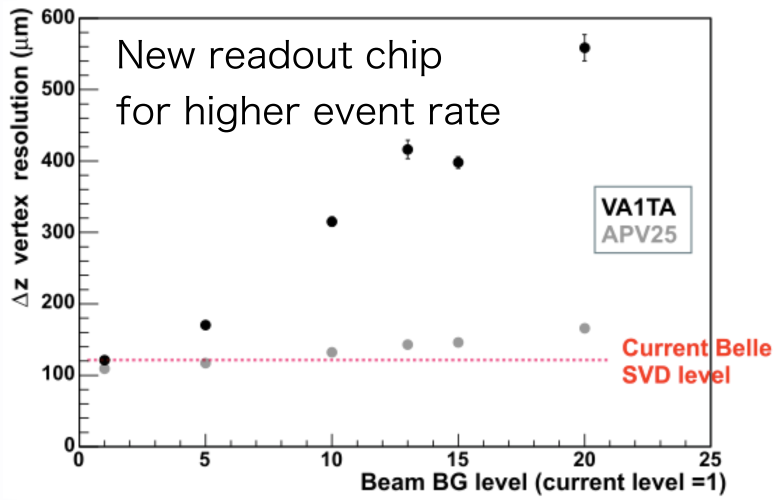
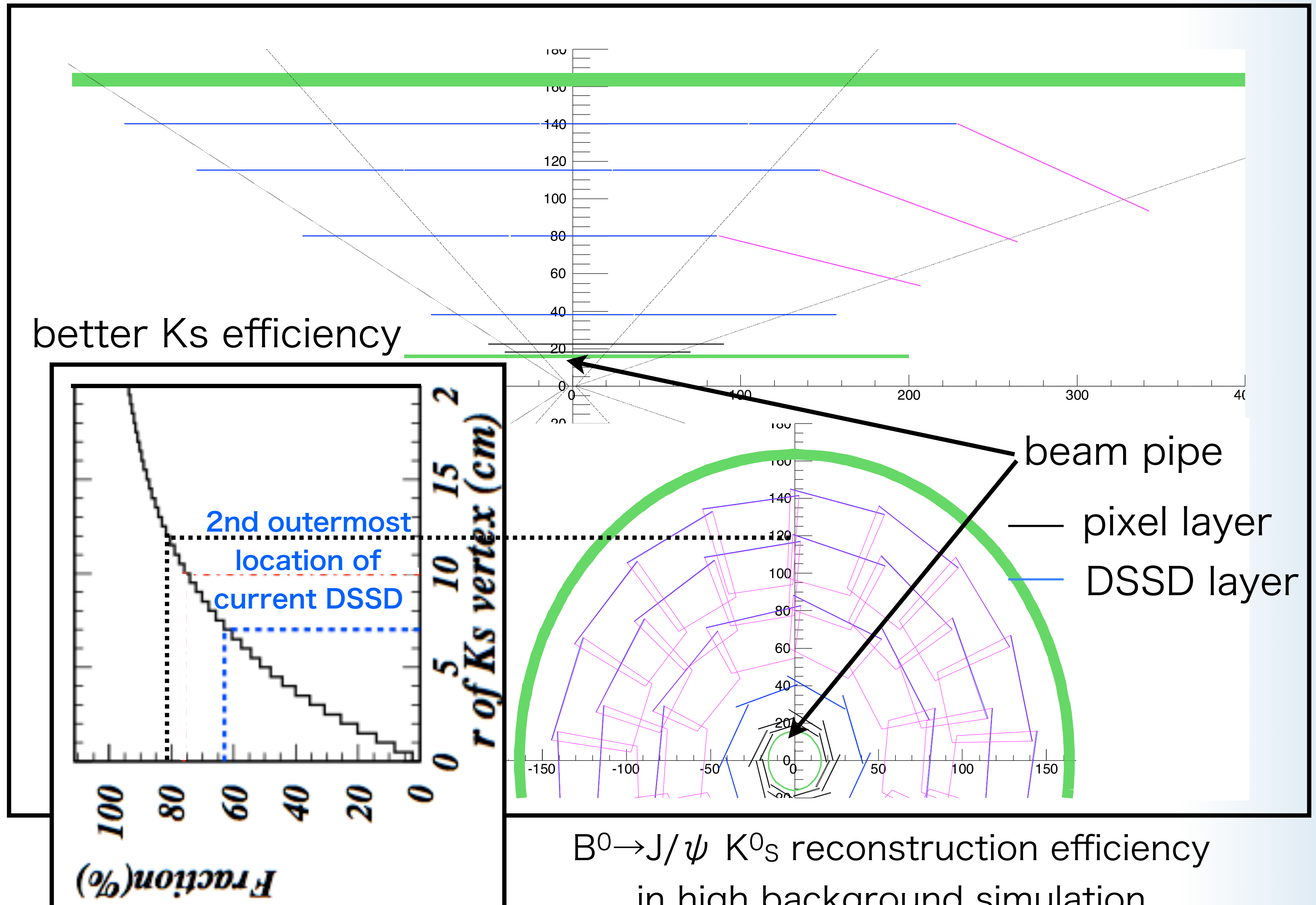
Upgrade of Belle detector

- Vertex detectors

Innermost DSSD (Double-Sided Silicon Detector) layer is replaced to DEPFET (DEpleted P-channel FET) pixel detector.



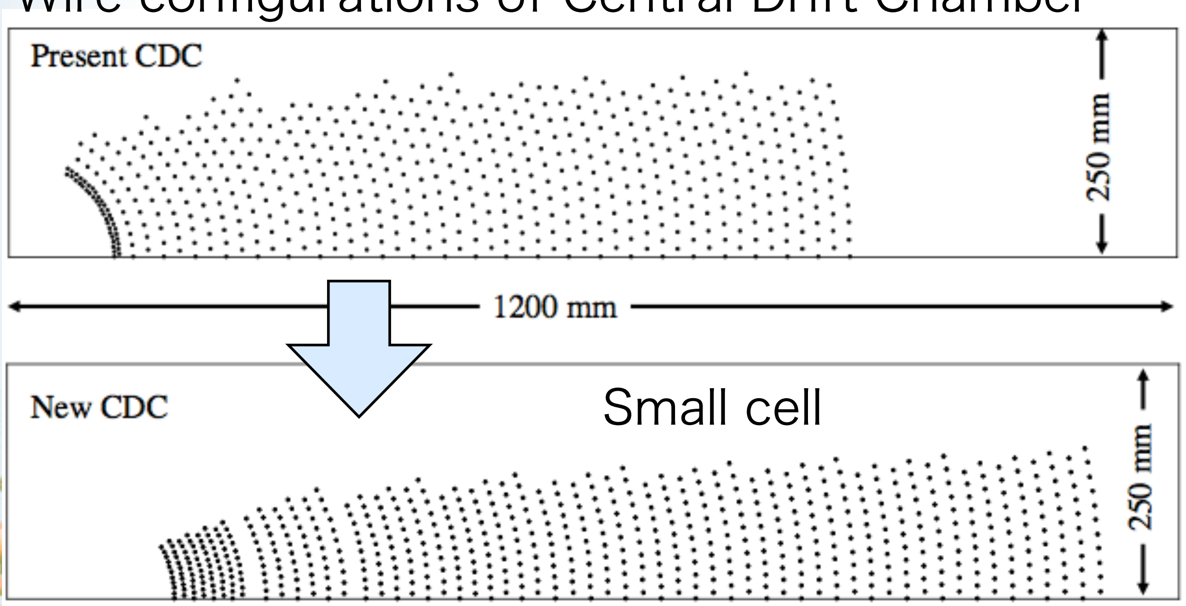


$B^0 \to J/\psi\ K^0_S$ reconstruction efficiency in high background simulation

bkg level	eff. (%)	eff. ratio - 1 wrt 1× bkg (%)	eff. ratio - 1 wrt Belle (%)
1× bkg	58.7	≡ 0	+11.3
5× bkg	57.7	−1.7	+ 9.4
20× bkg	53.6	−8.8	+ 1.5
1× bkg (Belle)	52.7	-	≡ 0

- Central Drift Chamber

Wire configurations of Central Drift Chamber



Dead time reduction by new electronics, small cell and software updates.

→ Keep efficiency in higher background environment.

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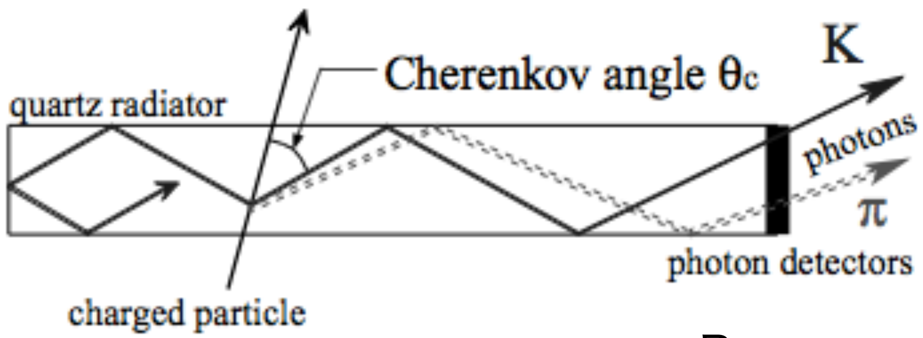
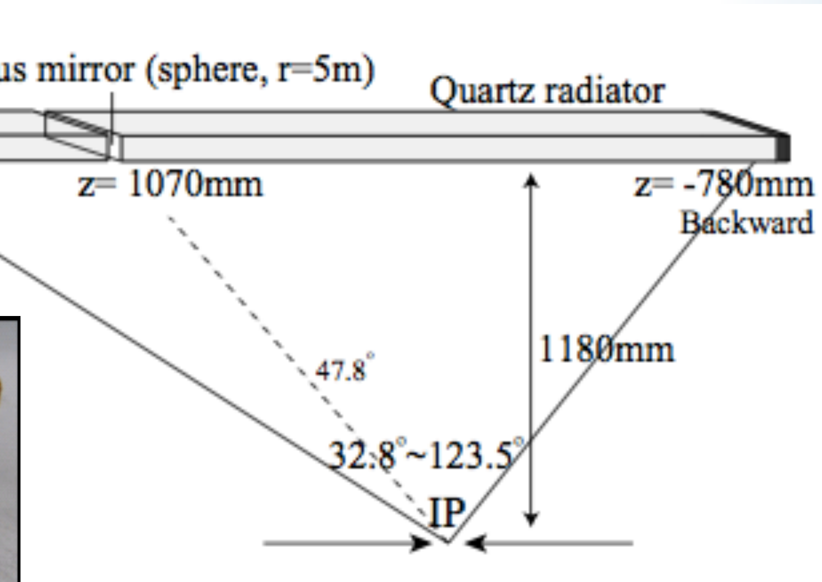
Upgrade of Belle detector

- Particle identification detectors

Barrel PID: Time Of Propagation counter

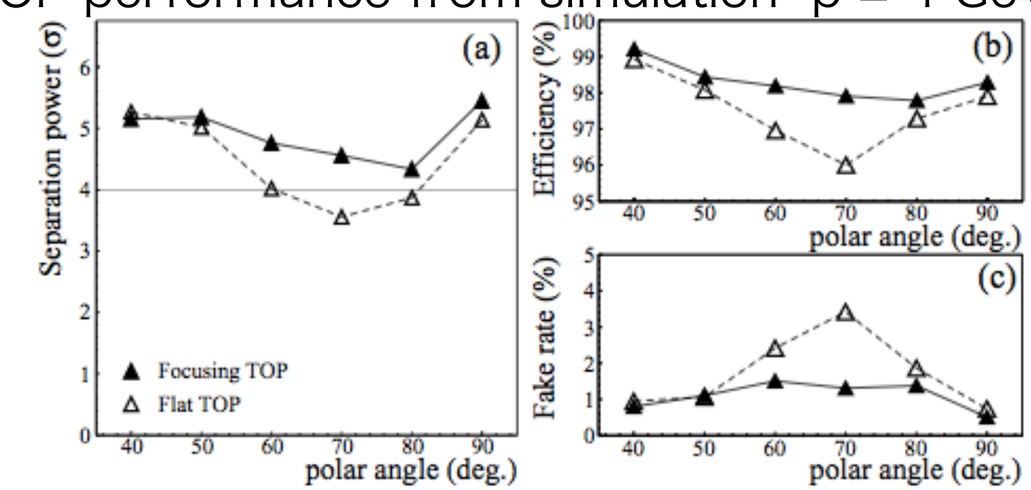
Identify particles by measuring propagation time of Cherenkov light in quartz bar.





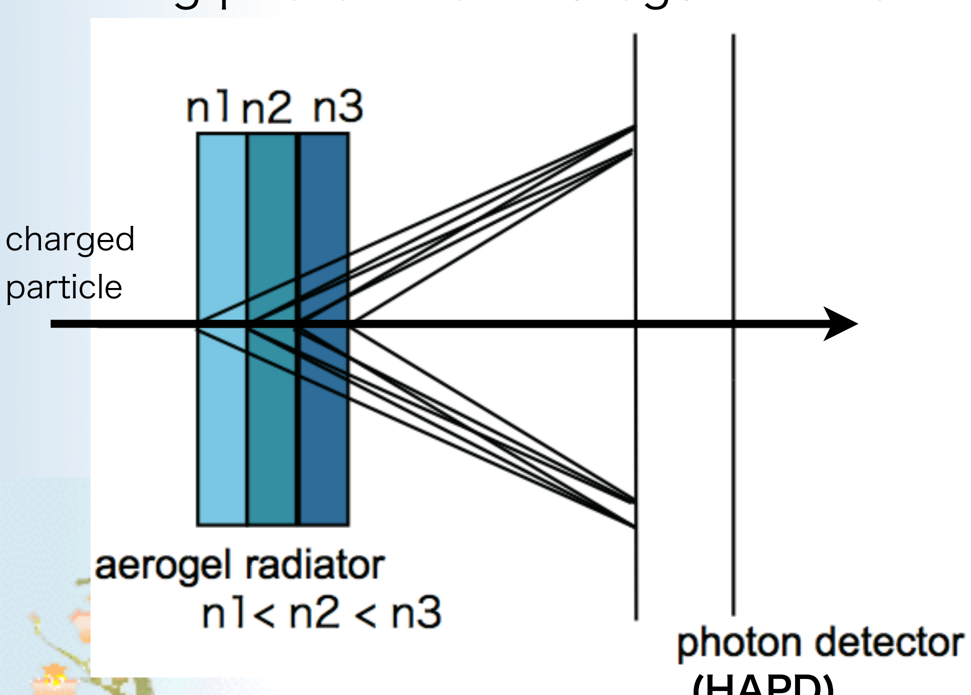
MCP-PMT

TOP performance from simulation p = 4 GeV/c



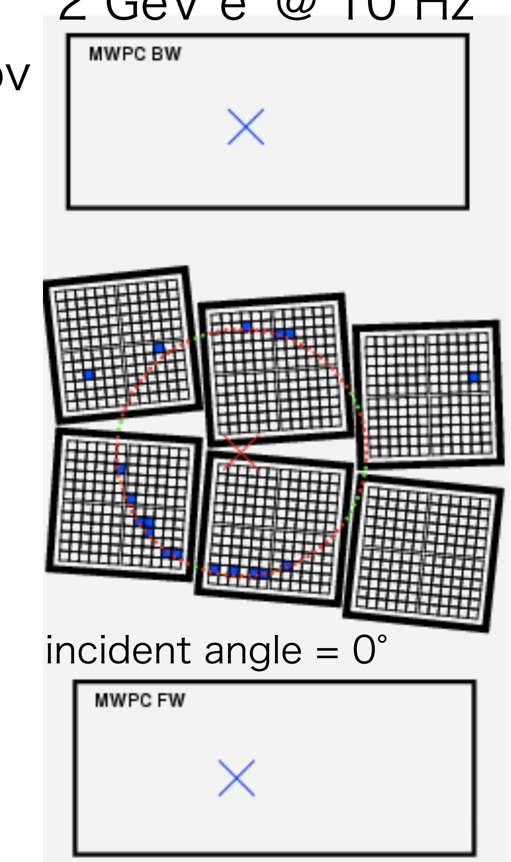
Endcap PID: Aerogel RICH

Identify particles by detecting Cherenkov ring photon from aerogel radiator.

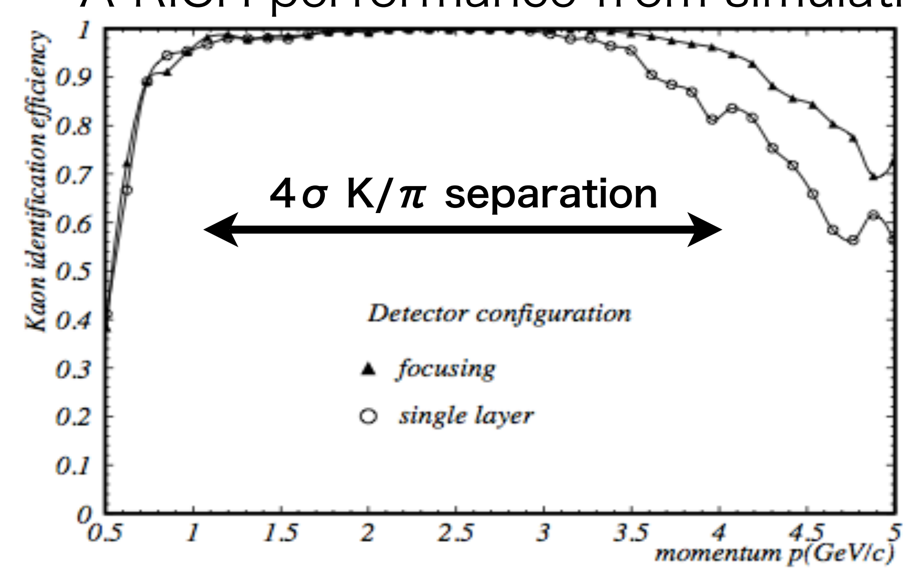


Beam test

2 GeV e⁻ @ 10 Hz



A-RICH performance from simulation



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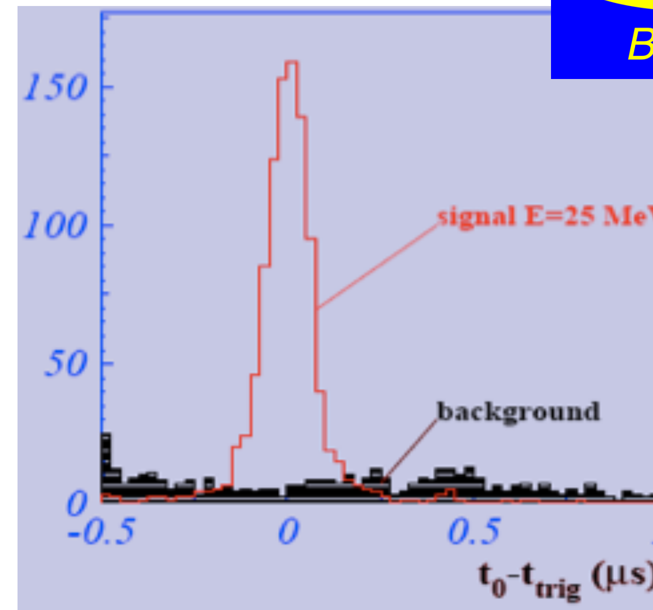
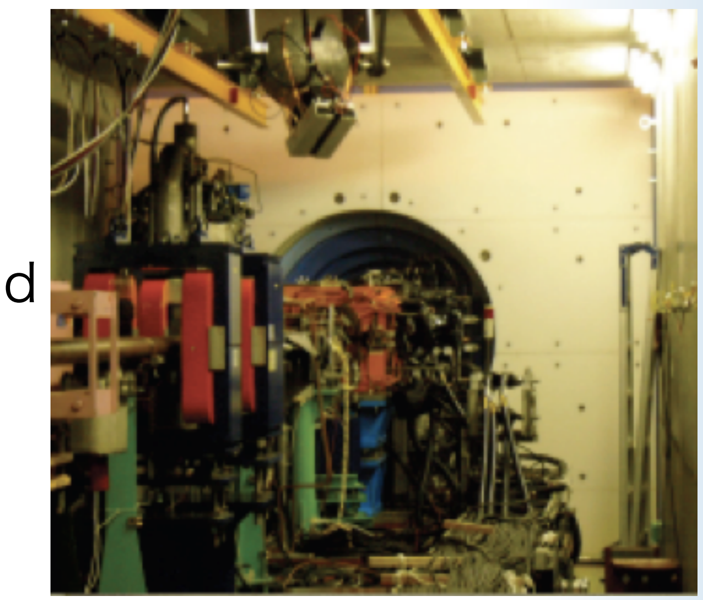
Upgrade of Belle detector

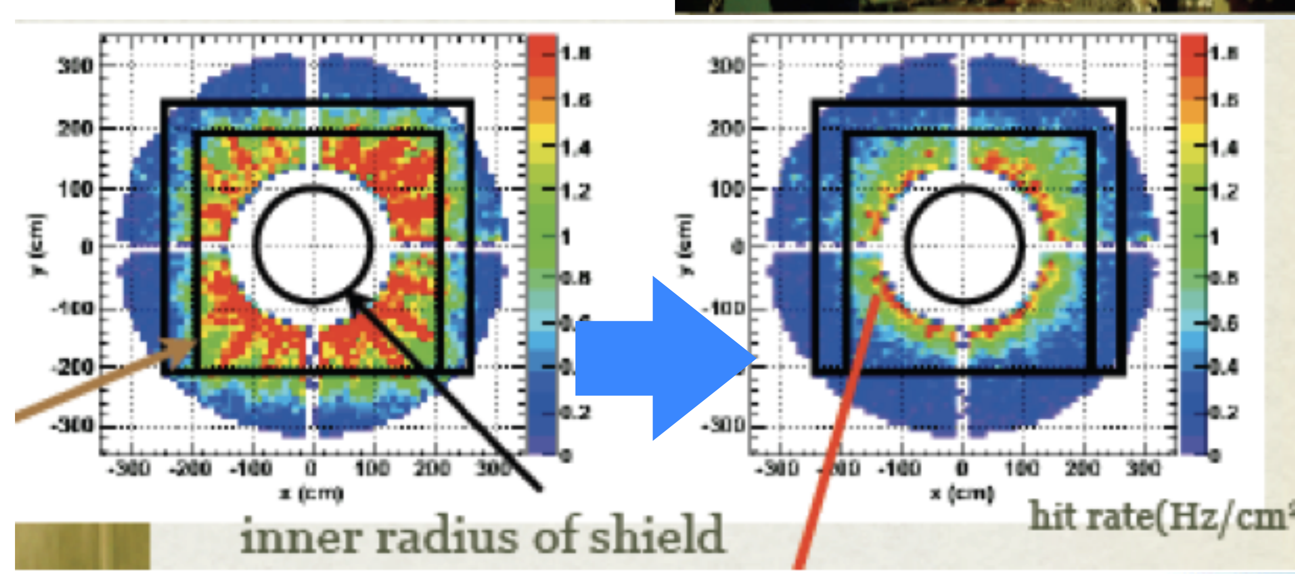
- **Electromagnetic Calorimeter**
  - New readout electronics
    Pipeline readout with **wave form analysis**.
    Timing information is useful to reduce fake clusters.
  - Higher background in endcap part
    CsI(Tl) + pin dinodes → **Pure CsI** + photopentonodes
    Better time resolution: **BG→1/30**

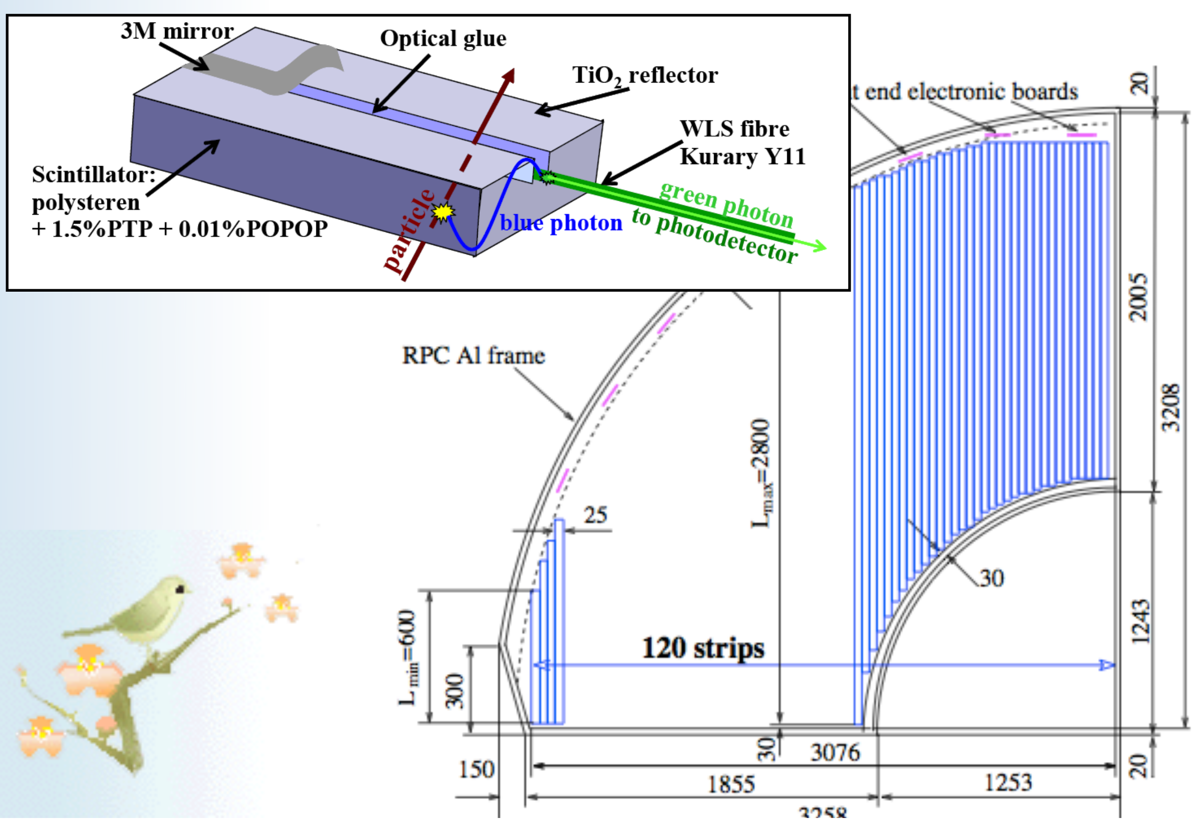


- **K_L/Muon detector**
  - Higher background in endcap part
    RPC → **Scintillator strip + WLS + SiPM**

Polyethylene Shield
for neutron background
from upper stream of
accelerator.







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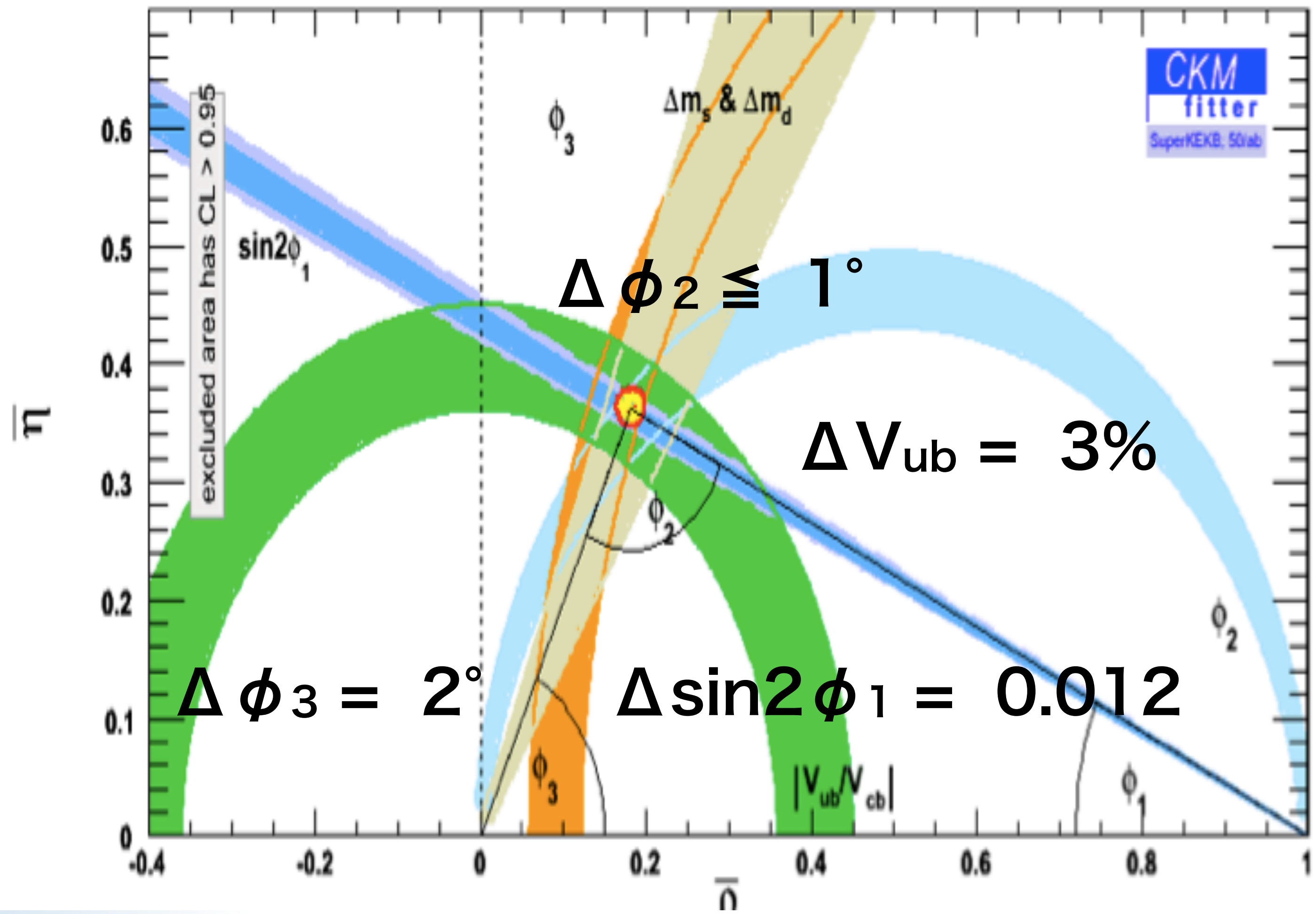
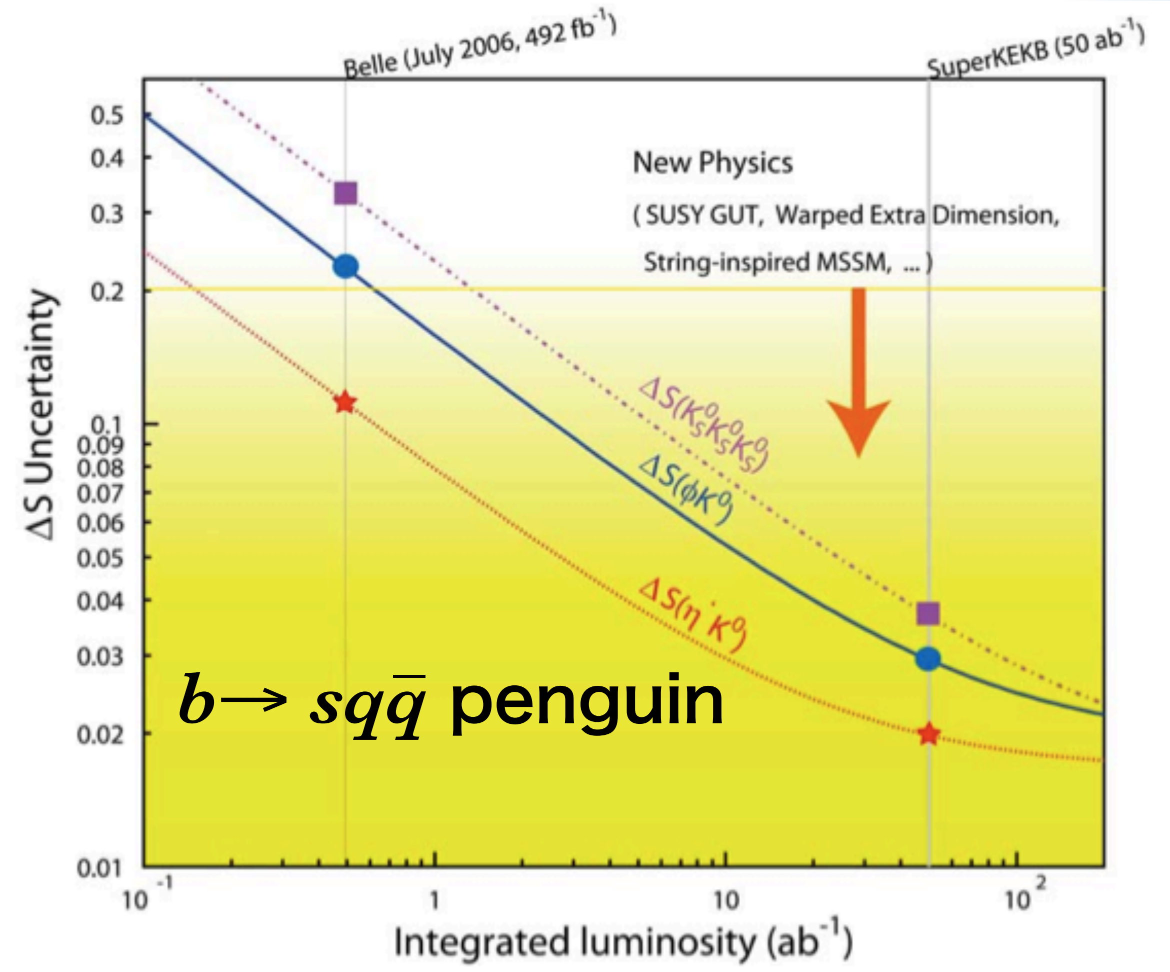
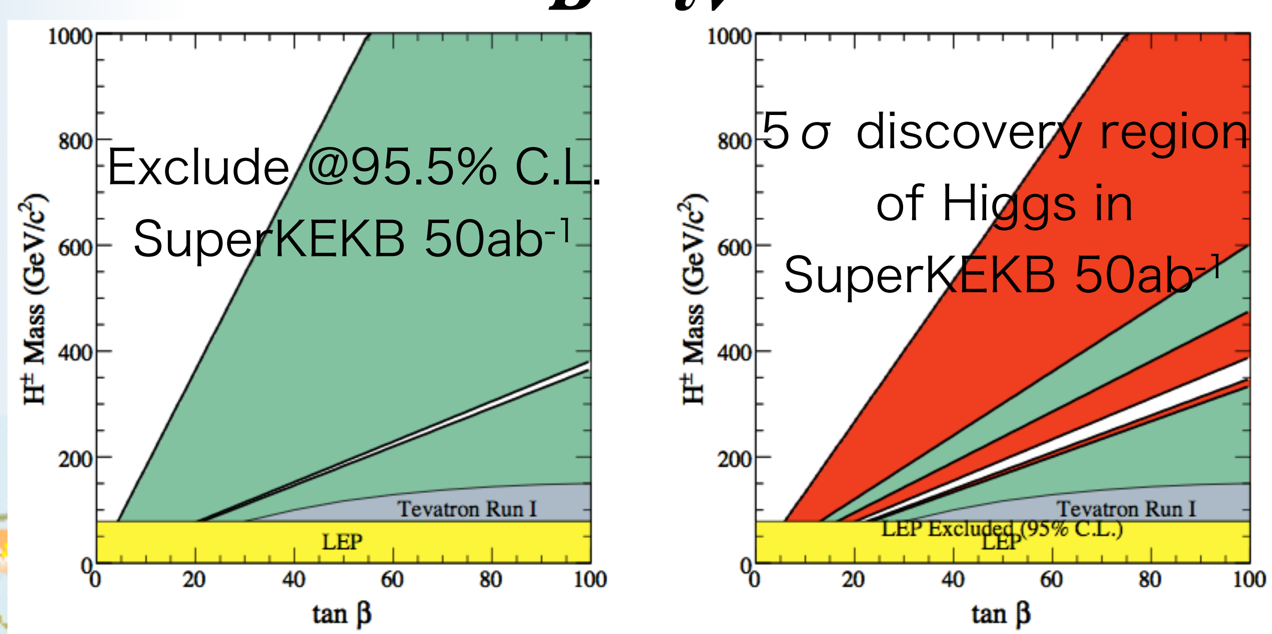
Many prospects of physics analysis

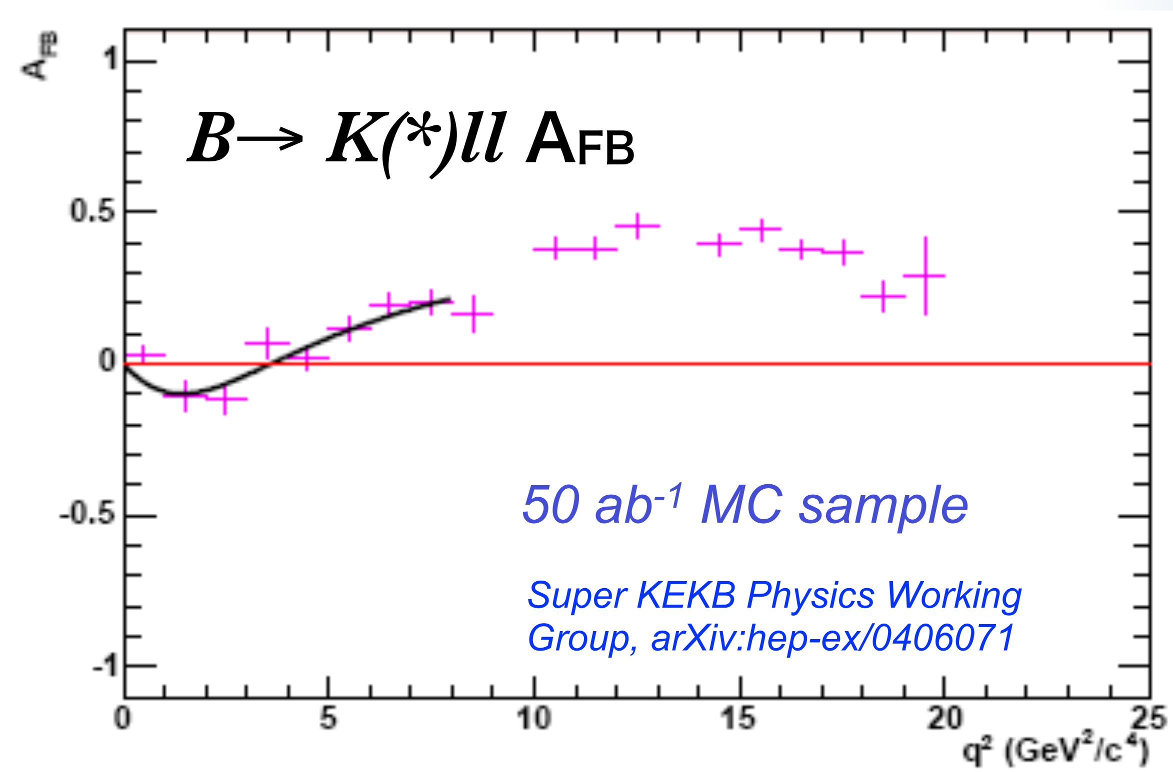
CKM global fit SuperKEKB 50ab-1





B→τν





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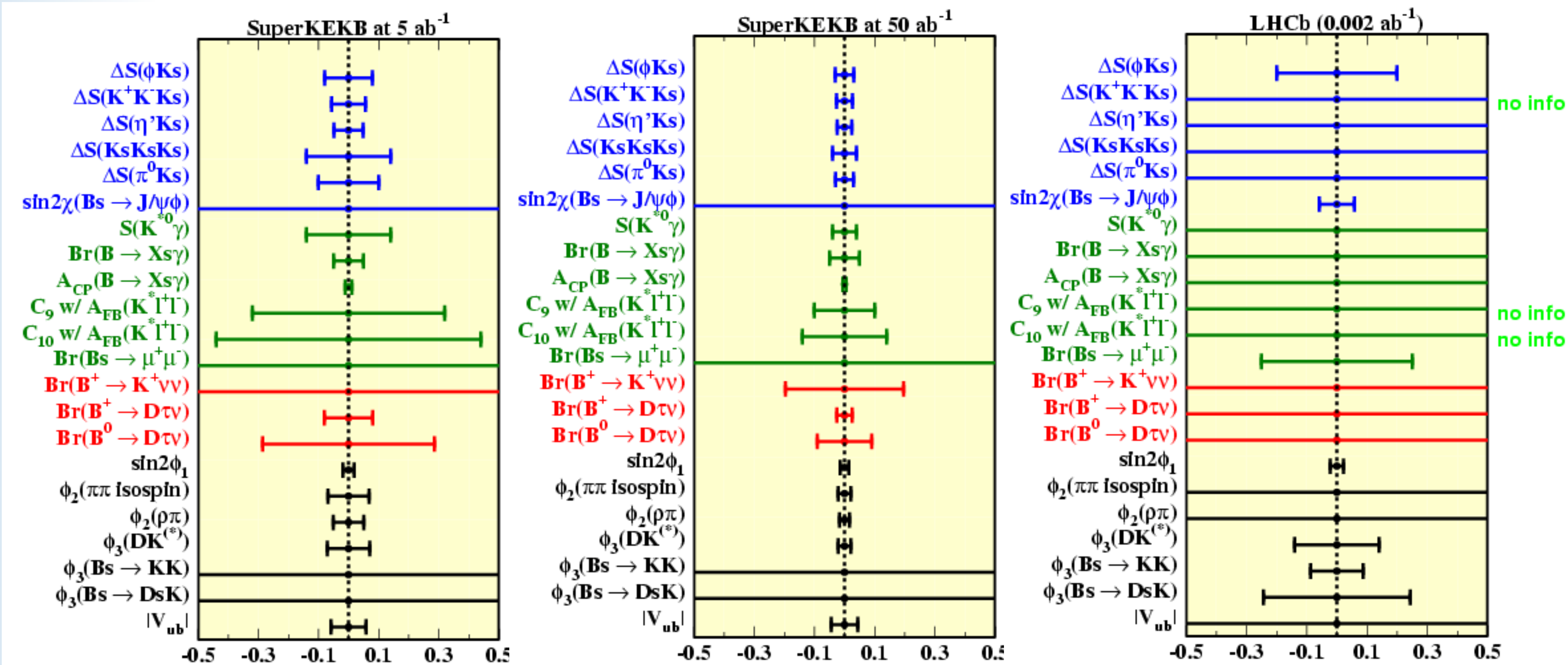
Prospects of physics analysis and competition with Hadron collider



Super B-factory is competitive to LHC and also complementary.

- Advantage on many flavor analysis to LHCb.
- Identify nature of new physics observed at ATLAS/CMS

(Higgs: $B \to \tau\nu$, SUSY: $b \to s q\bar{q}$ penguin, τ LFV, etc.)

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Summary

- CKM picture of CP violation confirmed by b-factories.
- Hints of discrepancies with SM exist, contributions of NP are expected in many decay modes.

  (not only B but also D and τ decays)

  ⇒ More data and more sensitive measurements would shed light on the situation
- High luminosity B-factory will be complementary to energy frontier experiments (LHC).
- R&D is carried out for both SuperKEKB and Belle II and upgrade will start in near future.

This is my second visit to beautiful snow resort.

- Lake Louise Winter Institute 2007

  "Measurement of ϕ_1 in $b \to c\bar{c}s$ and $sq\bar{q}$ decays from Belle"

- Lake Louise Winter Institute 2010

  "Belle II / SuperKEKB"

This is my second visit to beautiful snow resort.

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  "Measurement of ϕ_1 in $b \to c\bar{c}s$ and $sq\bar{q}$ decays from Belle"
- Lake Louise Winter Institute 2010

  "Belle II / SuperKEKB"

And in third(?) time...

- Lake Louise Winter Institute 201?

  "Measurement of ϕ_1 in $b \to c\bar{c}s$ and $sq\bar{q}$ decays and evidence of new physics contributions in B^0-$\bar{B}^0$ box and $b \to sq\bar{q}$ penguin diagrams from Belle II"

5th Open Meeting of the Belle II collaboration will be on March 31-April 2 at KEK, Japan:

http://belle2.kek.jp/B2GM/5th/index.html

Please come and join us!

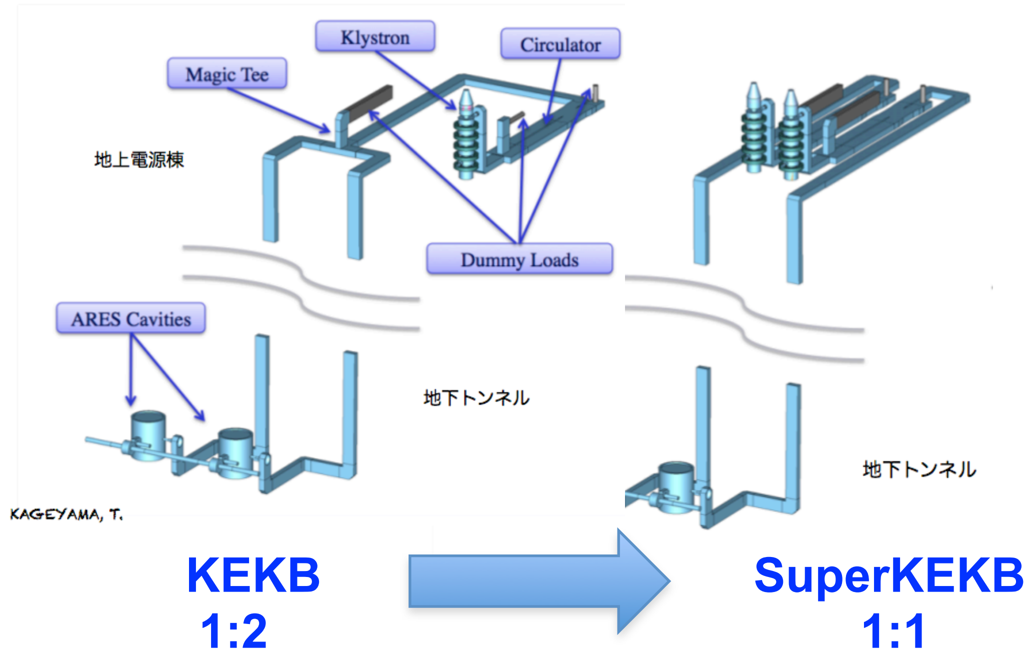
Details

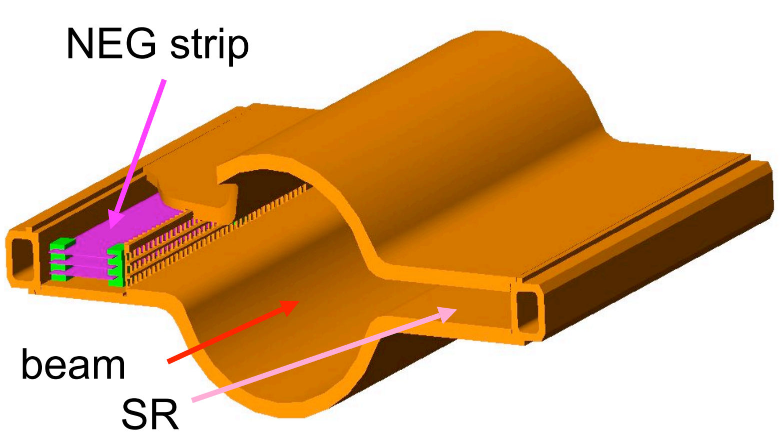
Upgrade of KEKB — toward 10^{36} $cm^{-2}s^{-1}$

Upgrade for injector

components		current	upgrade target
Energy		3.5 / 8 GeV	3.5 / 8 GeV
Electric charge		1 / 1 nC	4 / 3 nC
Normalized emittance*	x	2×10^{-3}/ 3×10^{-4} m	3.4×10^{-4} / 7.8×10^{-4} m
(1σ)	y	2×10^{-3}/ 3×10^{-4} m	1.4×10^{-5} / 3.1×10^{-5} m
Energy width (1σ)		0.15 / 0.15 %	0.15 / 0.15 %
Bunch width (1σ)		4.2 / 8.5 ps	4.2 / 8.5 ps
operation mode		simultaneous injection (except for AR)	simultaneous injection (Both ring)

Modification of RF system:
Input power will be twice (400 → 800 kW)



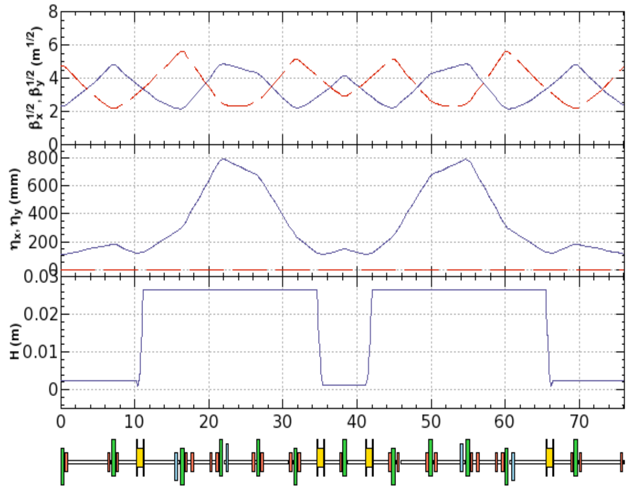


Upgrade of KEKB — toward 10^{36} $cm^{-2}s^{-1}$

LER arc design L_{bend} = 0.89 m → 4 m

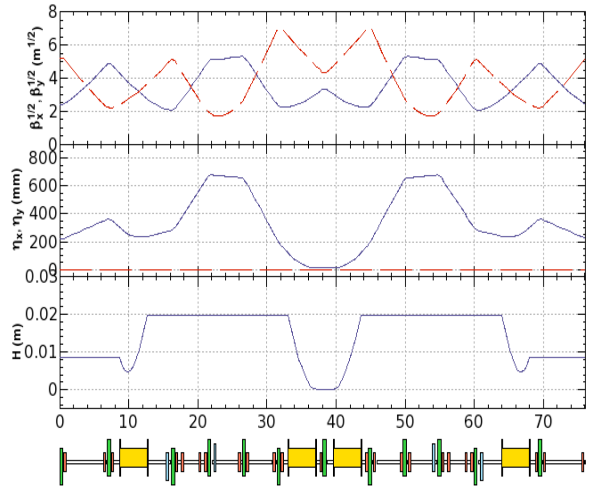
KEKB

ε_x = 8.8 nm α_p = 3.3x10^{-4}



SuperKEKB

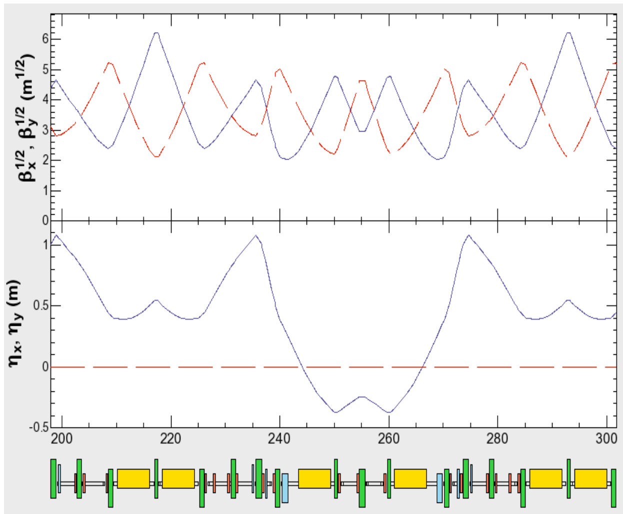
ε_x = 2 nm α_p = 4.4x10^{-4}



HER arc design: more cells

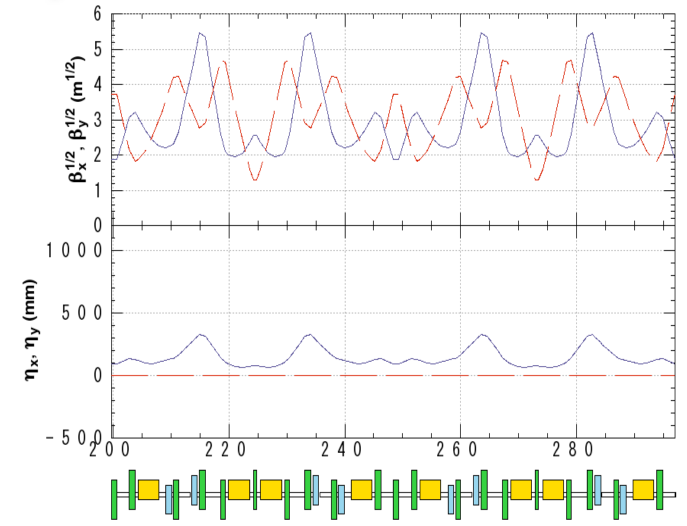
KEKB

24 nm



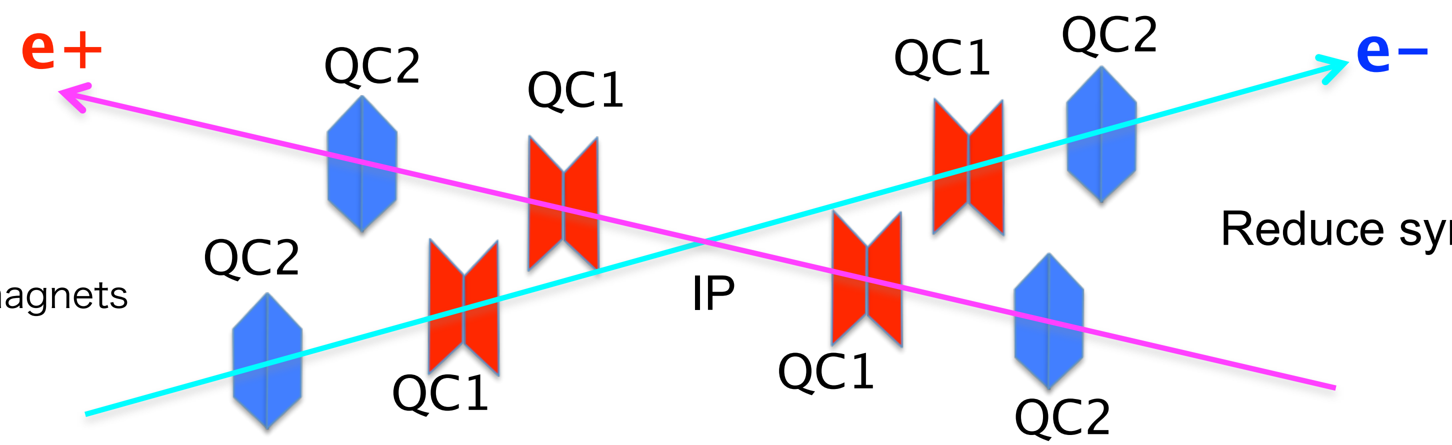
SuperKEKB

1.7 nm

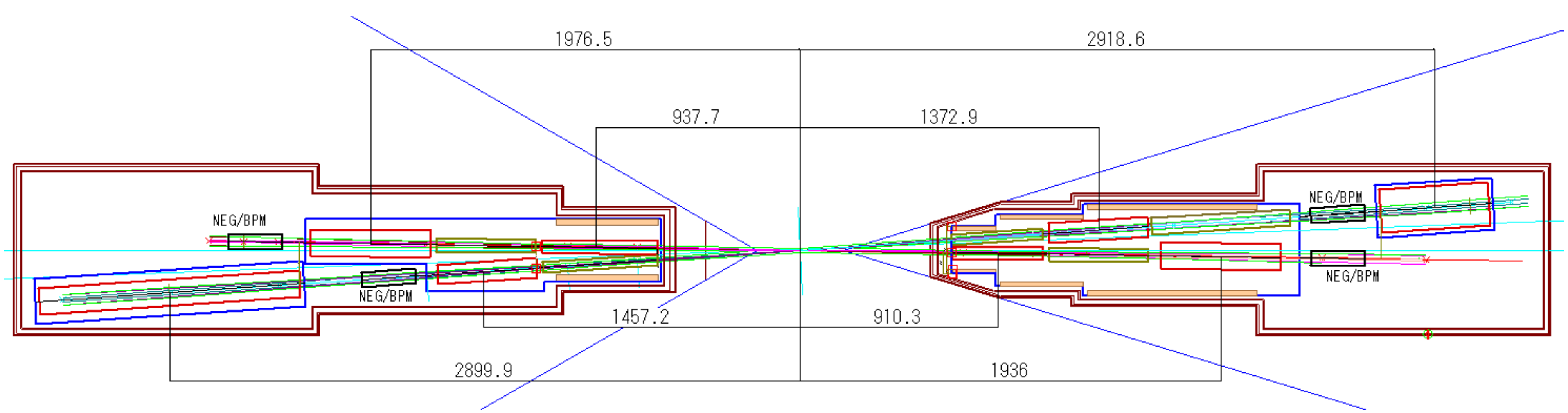


Final focusing system

beam run through center of magnets

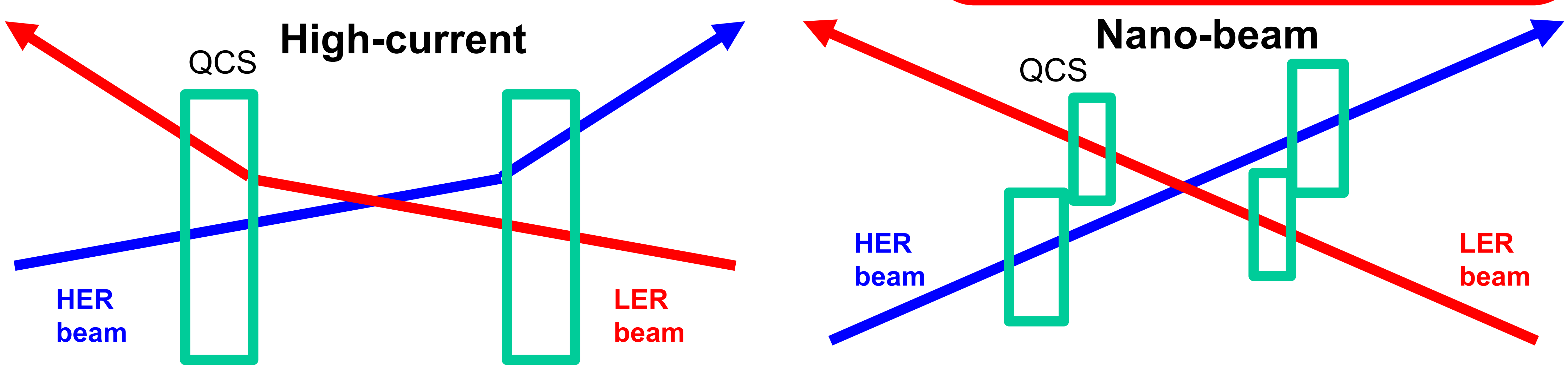


Reduce synchrotron radiation



Detector BG

	High current option	Nano-beam option
SR (upstream)	**Much higher** Large beam size at Q Very high current	**Lower? Higher?** Small beam size at Q But large bending magnet
SR (back-scatter)	**Higher** Strong QCS B-field	**Much lower** No QCS bending
Radiative-BhaBha	**Higher** Larger crossing angle Strong QCS B-field	**Much lower** Large crossing angle, but no QCS bending
Touschek	**Higher?** Small beam size	**Much higher?** Very small beam size
Beam-gas	**Higher** Very high current	**Higher?** High current



Observable	Belle 2006	SuperKEKB		†LHCb	
	(~0.5 ab^{-1})	(5 ab^{-1})	(50 ab^{-1})	(2 fb^{-1})	(10 fb^{-1})
Hadronic $b \to s$ transitions					
$\Delta\mathcal{S}_{\phi K^0}$	0.22	0.073	0.029		0.14
$\Delta\mathcal{S}_{\eta' K^0}$	0.11	0.038	0.020		
$\Delta\mathcal{S}_{K_S^0 K_S^0 K_S^0}$	0.33	0.105	0.037	-	-
$\Delta\mathcal{A}_{\pi^0 K_S^0}$	0.15	0.072	0.042	-	-
$\mathcal{A}_{\phi\phi K^+}$	0.17	0.05	0.014		
Radiative/electroweak $b \to s$ transitions					
$\mathcal{S}_{K_S^0 \pi^0 \gamma}$	0.32	0.10	0.03	-	-
R_K		0.07	0.02		0.043
$\mathcal{B}(B \to X_s\gamma)$	13%	7%	6%	-	-
$A_{CP}(B \to X_s\gamma)$	0.058	0.01	0.005	-	-
C_9 from $\overline{A}_{\rm FB}(B \to K^*\ell^+\ell^-)$	-	11%	4%		
C_{10} from $\overline{A}_{\rm FB}(B \to K^*\ell^+\ell^-)$	-	13%	4%		
C_7/C_9 from $\overline{A}_{\rm FB}(B \to K^*\ell^+\ell^-)$	-		5%		7%
$\mathcal{B}(B^+ \to K^+\nu\nu)$	†† $< 3\ \mathcal{B}_{\rm SM}$		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	0.1		
$\mathcal{B}(B \to X_d\gamma)$	-	24%		-	-
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		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	7.9%	2.5%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	28.5%	9.0%	-	-
LFV in τ decays					
$\mathcal{B}(\tau \to \mu\gamma)$ $[10^{-9}]$	< 45	< 30	< 8	-	-
$\mathcal{B}(\tau \to \mu\eta)$ $[10^{-9}]$	< 65	< 20	< 4	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ $[10^{-9}]$	< 209	< 10	< 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)	20°	7°	2.5°	8°	
ϕ_3 $(DK^{(*)})$ (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 $(D^{(*)}\pi)$	-	18°	6°		
ϕ_3 (combined)		6°	2°	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%		

"Physics at Super B Factory"
http://belle2.kek.jp/physics.html

Observable	Belle	Belle/SuperKEKB		LHCb†	
				(2 fb^{-1})	(10 fb^{-1})
B_s physics	(25 fb^{-1})	(	5 ab^{-1})		
$\mathcal{B}(B_s \to \gamma\gamma)$	$< 8.7 \times 10^{-6}$	0.25×10^{-6}		-	-
$\Delta\Gamma_s^{CP}/\Gamma_s$ $(Br(B_s \to D_s^{(*)} D_s^{(*)}))$	3%	1% (model dependency)		-	-
$\Delta\Gamma_s/\Gamma_s$ ($B_s \to f_{CP}$ t-dependent)	-	1.2%		-	-
ϕ_s (with $B_s \to J/\psi\phi$ etc.)	-	-	-	0.02	0.01
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-			6 fb^{-1} for 5σ discovery	
ϕ_3 ($B_s \to KK$)	-			7-10°	
ϕ_3 ($B_s \to D_s K$)	-			13°	
Υ decays	(3 fb^{-1})	(500 fb^{-1})			
$\mathcal{B}(\Upsilon(1S) \to \text{invisible})$	$< 2.5 \times 10^{-3}$	$< 2 \times 10^{-4}$			
	(~0.5 ab^{-1})‡	(5 ab^{-1})	(50 ab^{-1})		
Charm physics					
D mixing parameters					
x	0.25%	0.10%	0.07%		0.25%††
y	0.18%	0.08%	0.05%		0.05%††
$\delta_{K\pi}$	11°	6°	4°		
$\lvert q/p \rvert$	0.16	0.07	0.05		
ϕ	0.13 rad	0.07 rad	0.04 rad		
A_D	2.4%	1%	0.3%		
New particles[ℵ]					
$\gamma\gamma \to Z(3930) \to D\bar{D}^*$		$> 3\sigma$			
$B \to KX(3872)(\to D^0\bar{D}^{*0})$		400 events			
$B \to KX(3872)(\to J/\psi\pi^+\pi^-)$		1250 events			
$B \to KZ^+(4430)(\to \psi'\pi^+)$		1000 events			
$e^+e^- \to \gamma_{\text{ISR}} Y(4260)(\to J/\psi\pi^+\pi^-)$		3000 events			
Electroweak parameters		(~10 ab^{-1})			
$\sin^2\Theta_W$	-	3×10^{-4}			

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