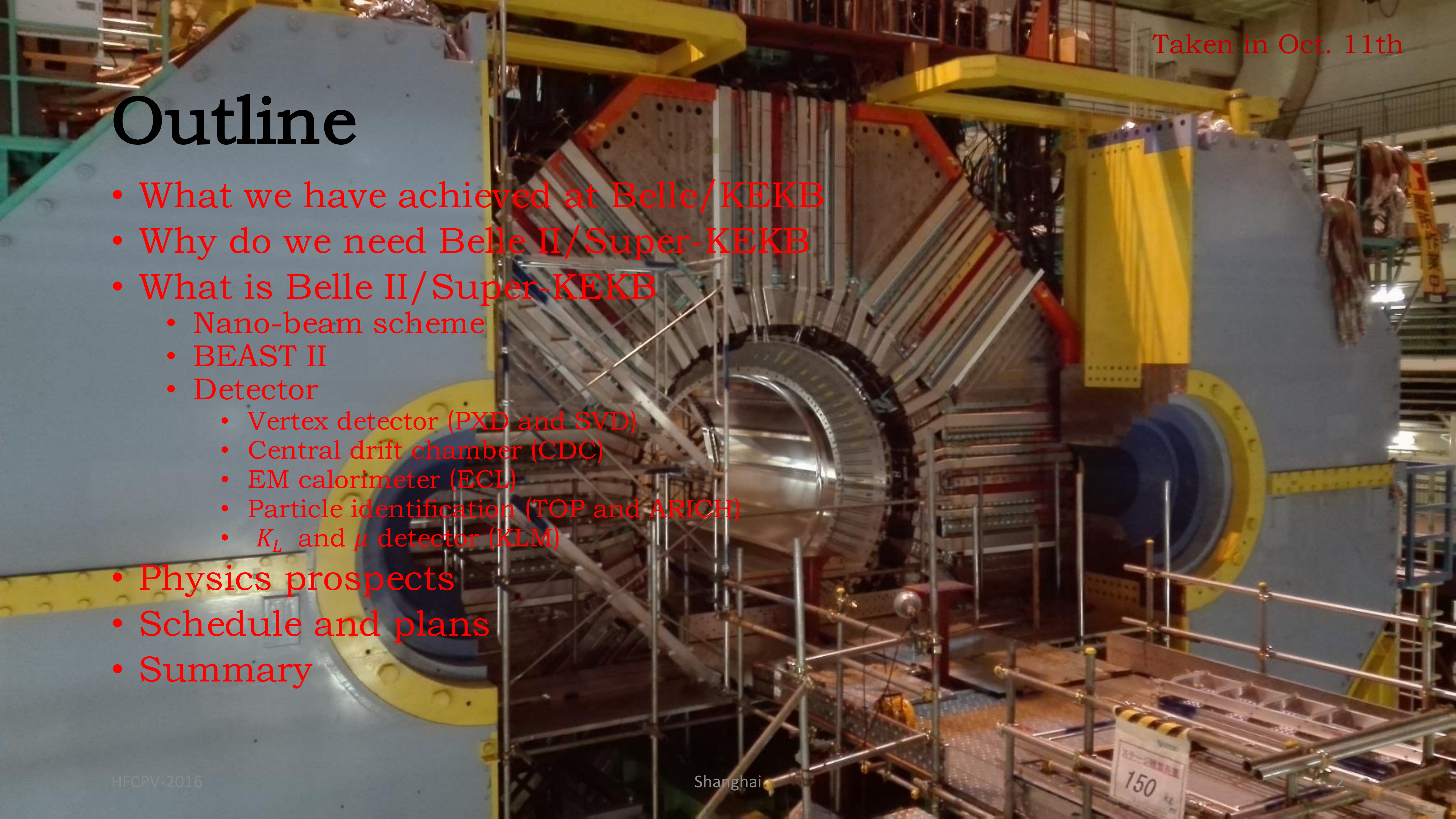
Belle II status

Li Ke (like@ihep.ac.cn)
Shandong University &
Institute of High Energy Physics

全国第十四届重味物理和CP破坏研讨会



Taken in Oct. 11th

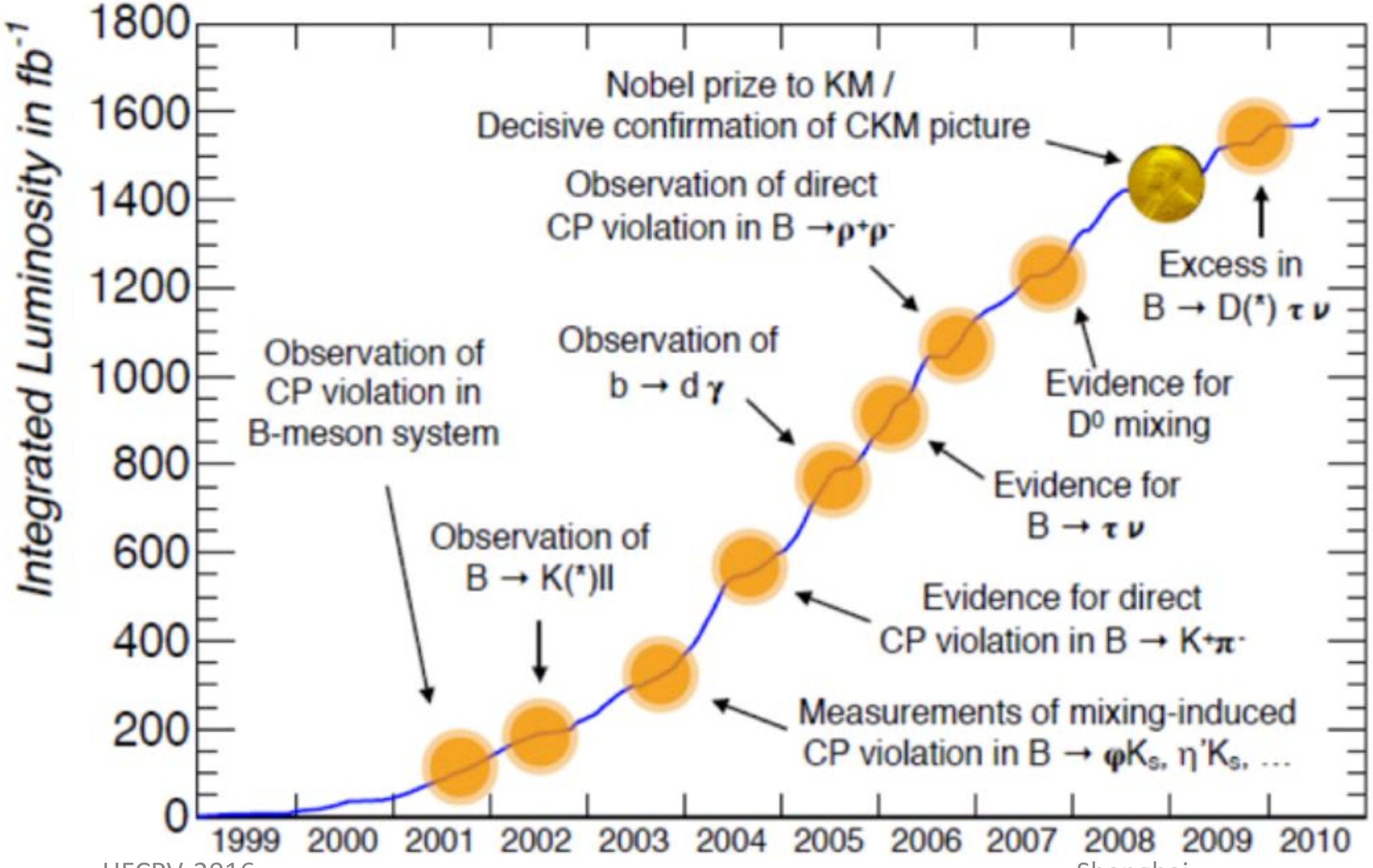
Outline

- What we have achieved at Belle/KEKB
- Why do we need Belle II/Super-KEKB
- What is Belle II/Super-KEKB
  - Nano-beam scheme
  - BEAST II
  - Detector
    - Vertex detector (PXD and SVD)
    - Central drift chamber (CDC)
    - EM calorimeter (ECL)
    - Particle identification (TOP and ARICH)
    - K_L and μ detector (KLM)
- Physics prospects
- Schedule and plans
- Summary

What we have achieved at Belle/KEKB

Belle: highest luminosity, intensity frontier

targeted CP-violation using a huge number of B meson pairs
operated from 1999 to 2010



B-factory:

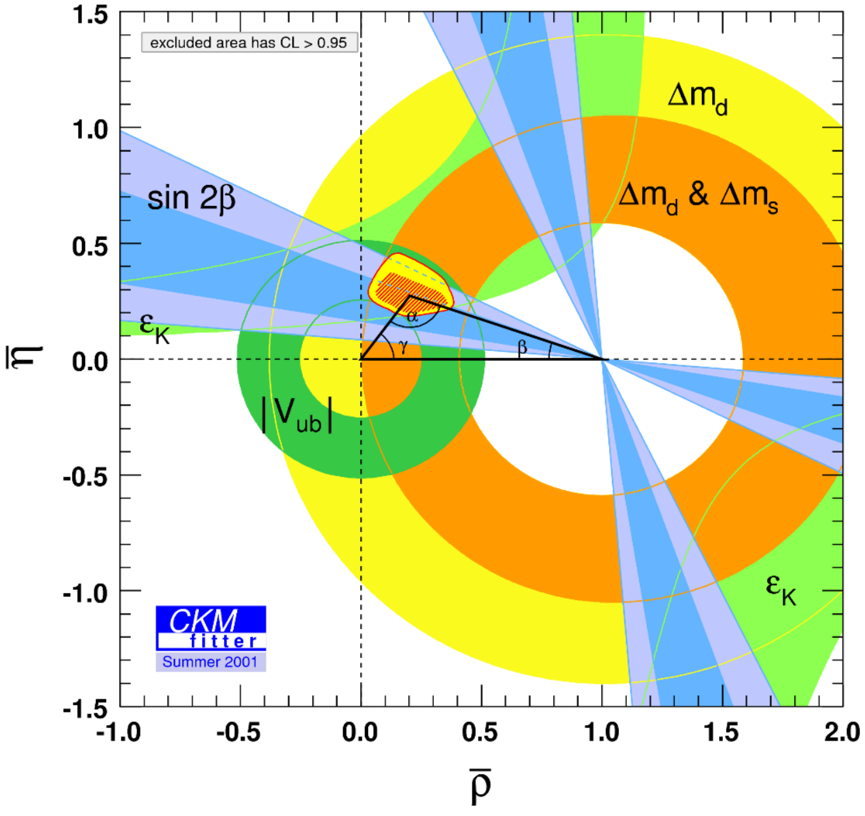
Belle (> 1 ab^{-1}) and BaBar (~550 fb^{-1})
Fruitful works with $1.25 \times 10^9\ B\bar{B}$

What if we have ~50 ab^{-1} data

Super B-factory

Results available by summer 2001:

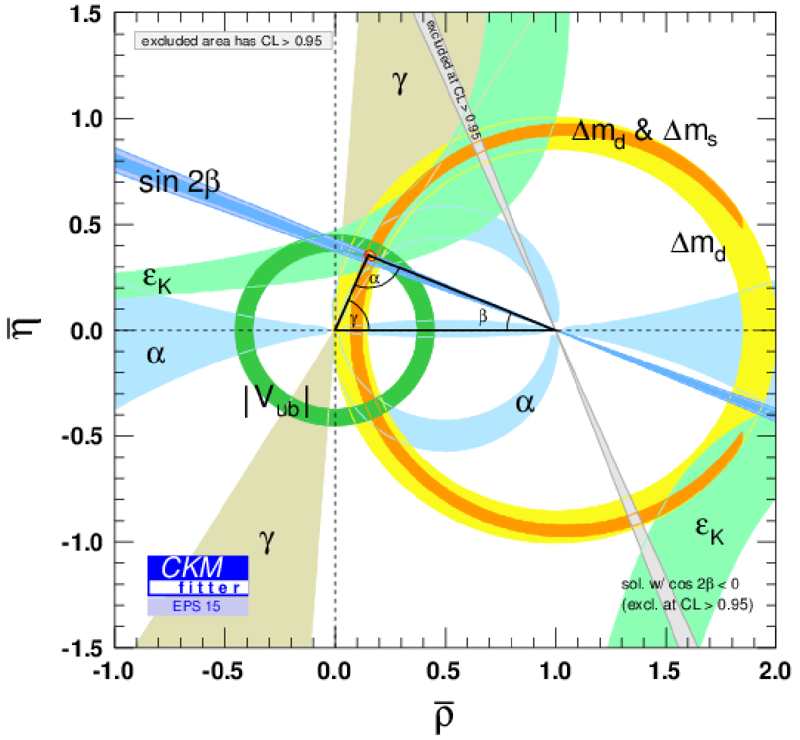
CP violation on the B system is established following the first measurements of the CKM parameter sin2β by BaBar and Belle



2001

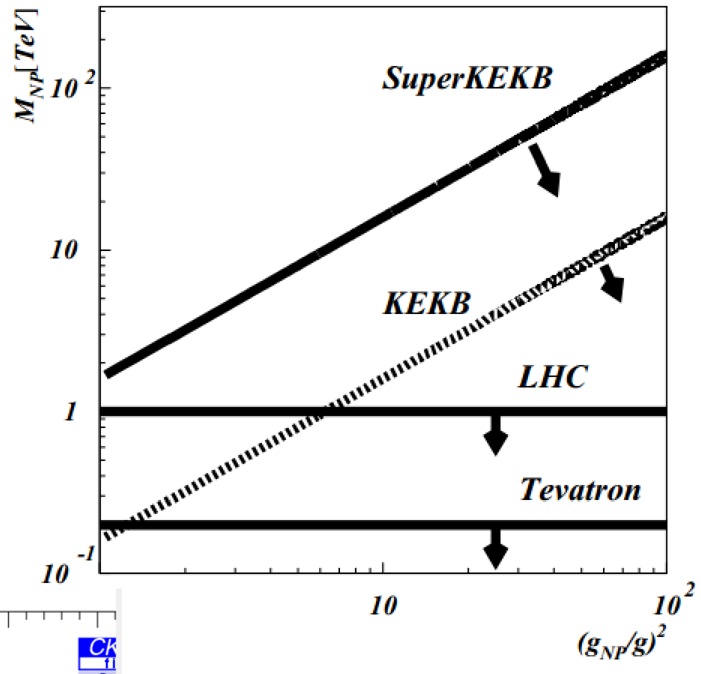
2015

Belle, BaBar, LHCb, …



from CKM fitter group

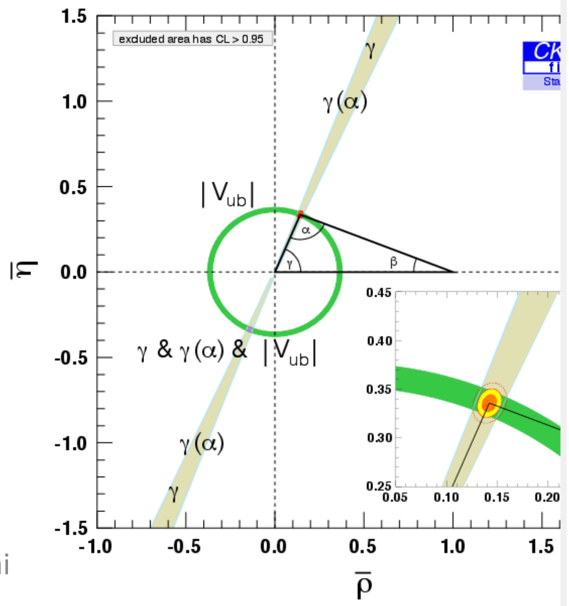
Why do we need Belle II/Super-KEKB



Search for new physics

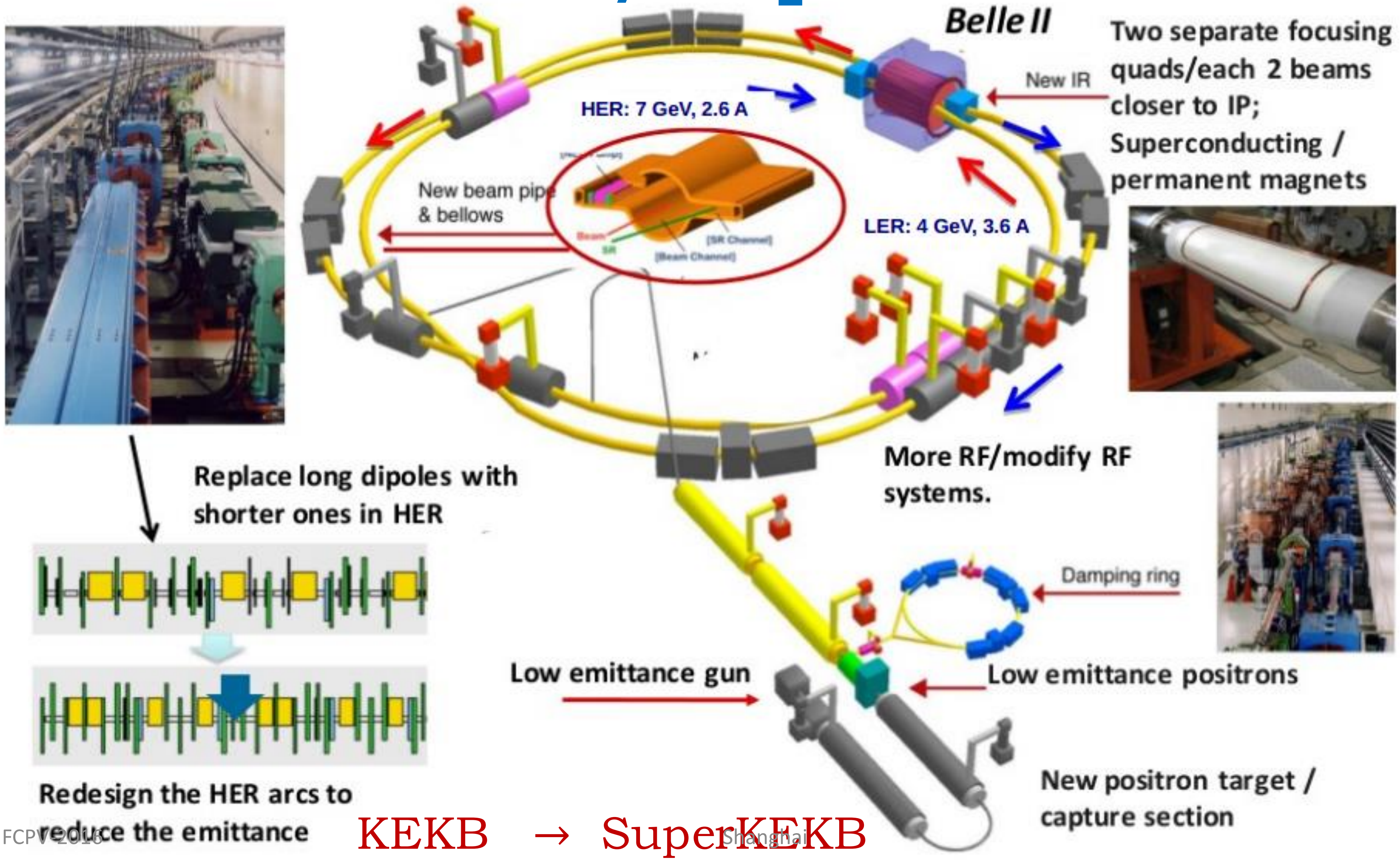
- One approach is the precision/intensity frontier
- The mass reach for new particle/process effects can be as high as ~100 TeV if the couplings are enhanced
- Suppressed flavor physics reactions deviation from SM predictions
- CKM, precisely
- QCD exotics (XYZ)
- Dark matter searched…

All of them need more data!



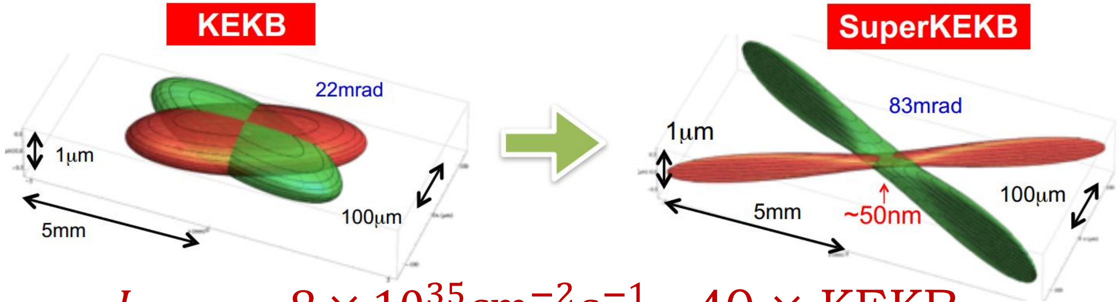
PRD 89,033016

What is Belle II/SuperKEKB



KEKB → SuperKEKB

Nano-beam scheme to increase luminosity



$L_{peak} = 8 \times 10^{35}\mathrm{cm}^{-2}s^{-1}$, $40 \times$ KEKB

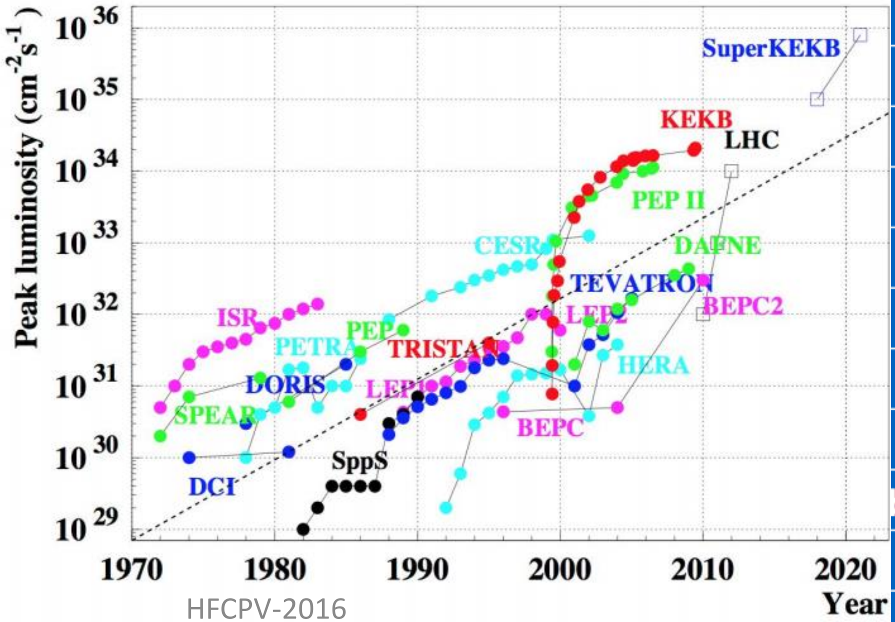
Lorentz factor, Beam current, Beam-Beam parameter

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

Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP, Vertical beta function at IP

Next intensity frontier



Parameter		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function 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 parameter	ξ_y	129	90	0.881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathcal{L}$	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

SuperKEKB commissioning detector

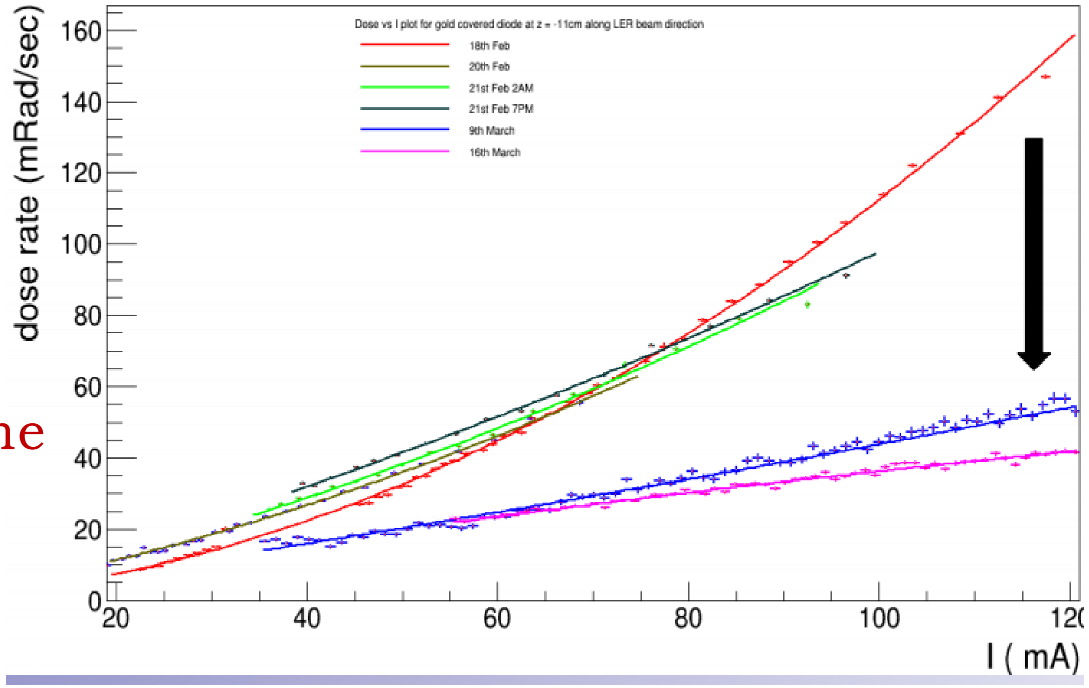
Beam Exorcism for A StableExperimenT II
(BEAST II)

measure and characterize beam backgrounds
independent detectors

- Expected Beam background: 40 times than Belle
- Beam-gas interactions (current, vacuum level)
- Synchrotron radiation
- Touschek effect (current,inverse beam size)
- Fake hit
- radiative Bhabha scattering (luminosity)

……

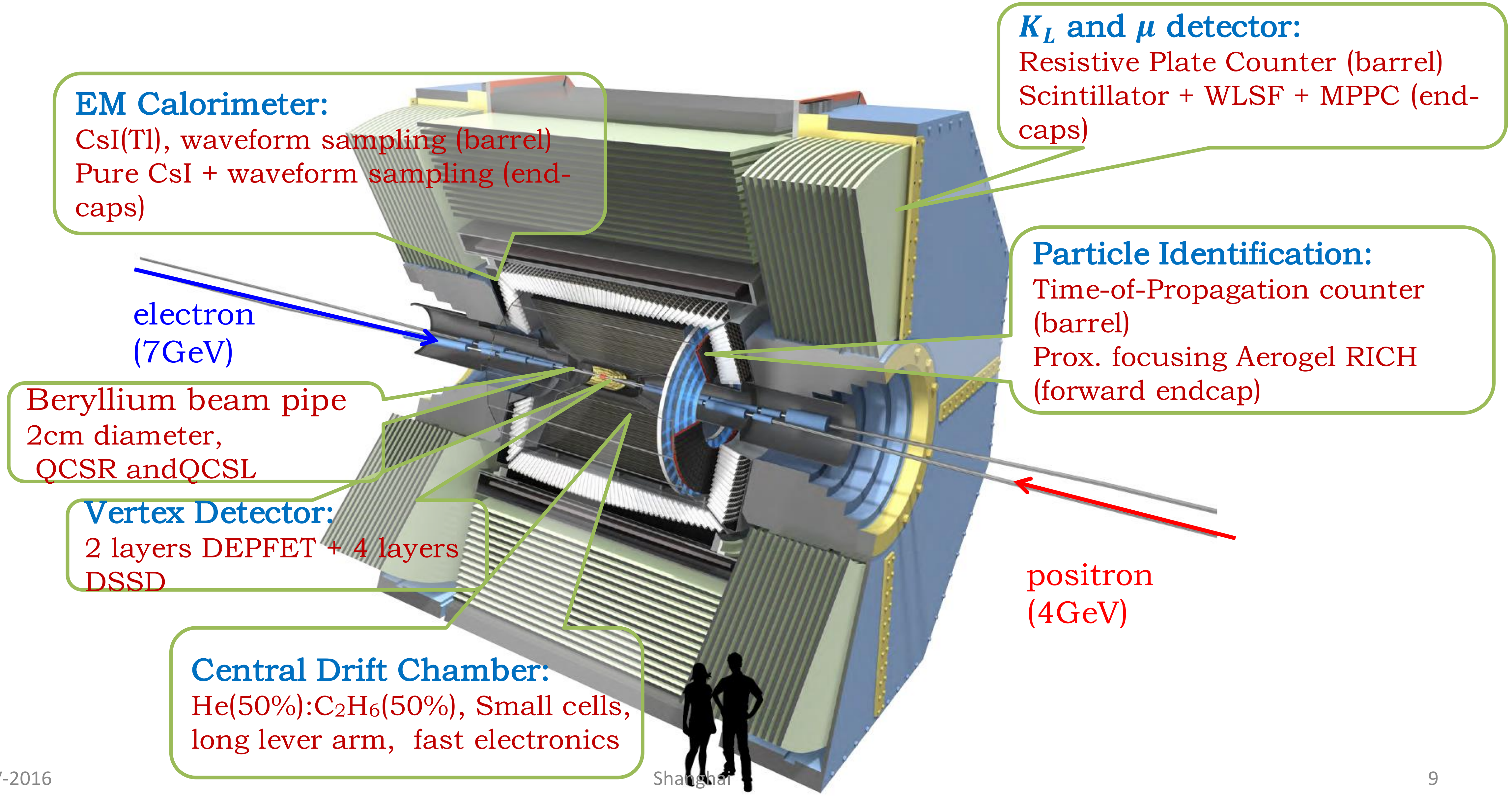
BEAST background in the LER vs time



shows the backgrounds decreasing
as vacuum scrubbing proceeds

Works well!

Belle II Detector

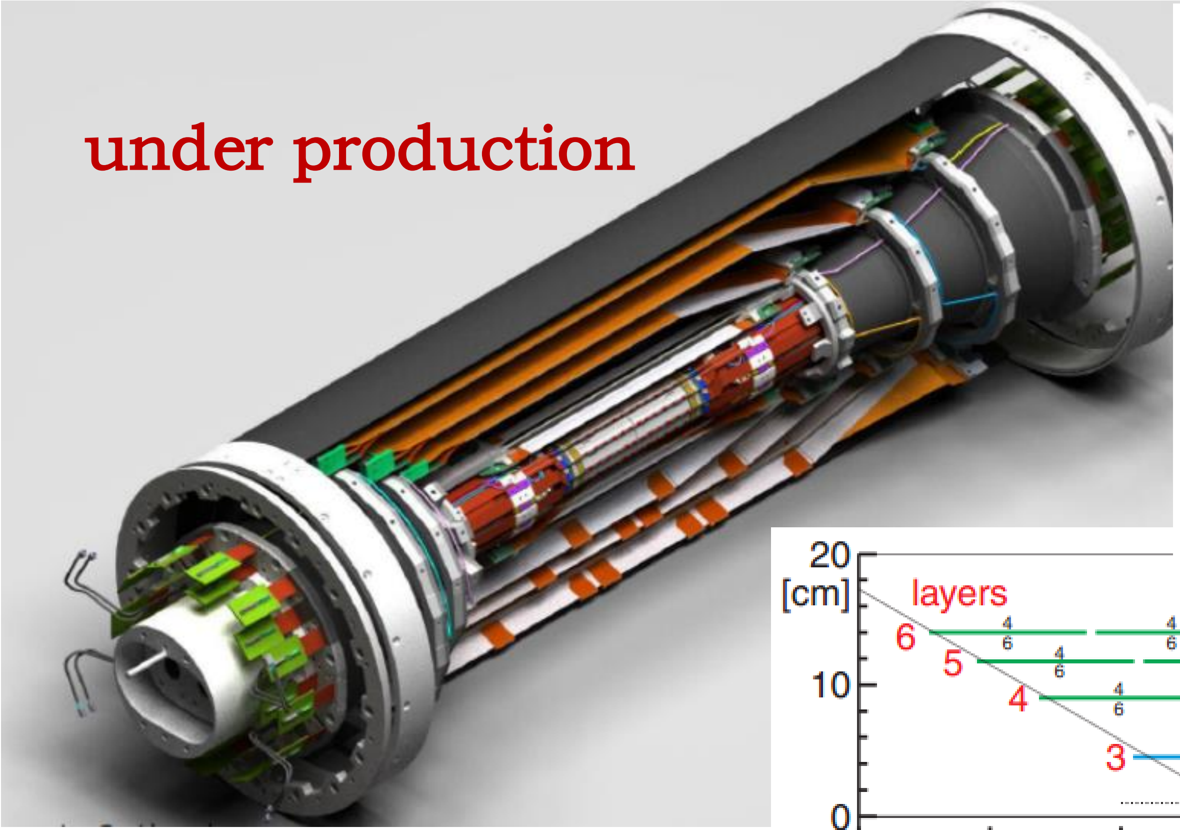


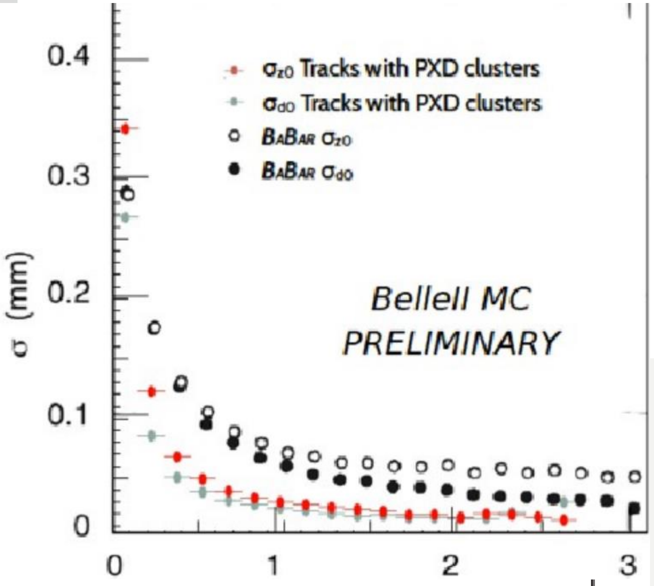
Important improvements in detector performance from Belle to Belle II

- **Smaller beam pipe radius**
  - Innermost PXD layer sit closer to IP (r=1.4 cm)
  - Significantly improve the resolution along Z direction
- **Larger tracker SVD and CDC**
  - Increase K_S efficiency, excellent momentum resolution, dE/dx…
  - Better flavor tagging
- **TOP and ARICH**
  - Better K/π separation covering whole range momentum in Barrel and Endcap region
- **ECL and KLM**
  - Improvement in ECL and KLM to compensate larger beam background
- **Improved trigger and DAQ**
  - 30 kHz , >1 M/event

Vertex detector

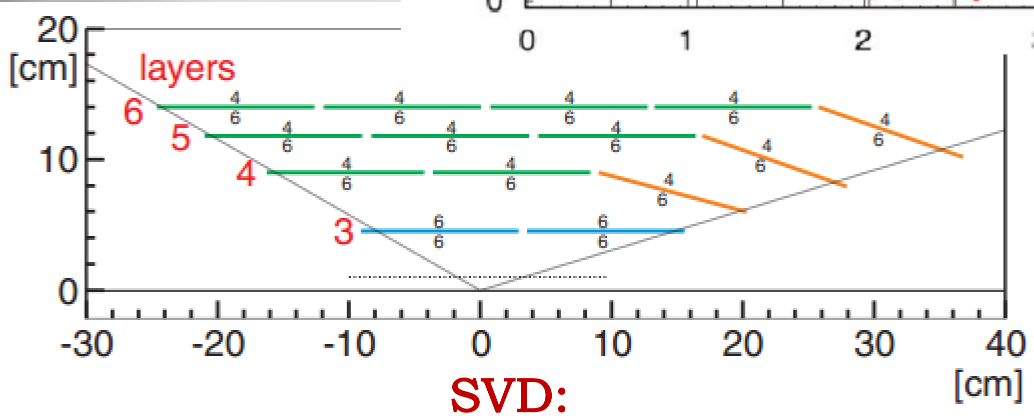
under production

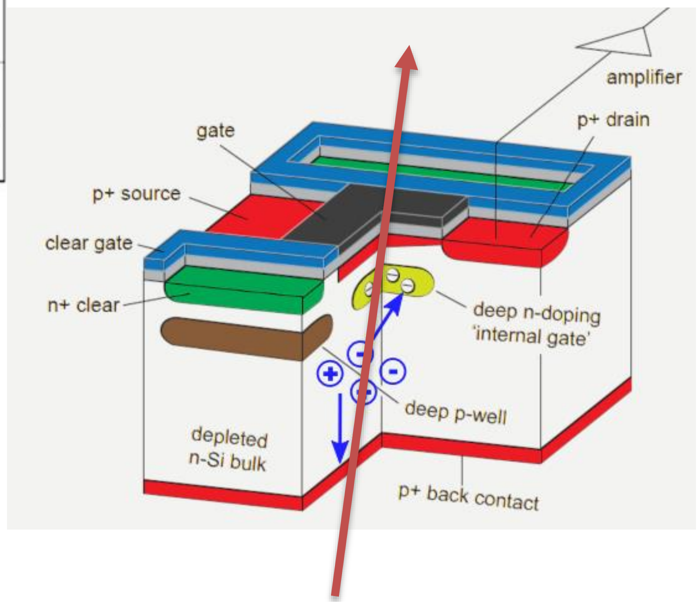




Pixel detector (PXD) and silicon vertex detector (SVD)

Precise measurement of the primary and secondary vertices of short lived particles





PXD:

2 layers of DEPFET pixels

Very thin (50μm) pixel sensor

Inner layer close to IP

Excellent resolution

SVD:

4 layer of DSSD detectors

Excellent timing resolution (2-3 ns)

Large outer radius (6.05 -> 14 cm)

Covers full BelleII angular acceptance

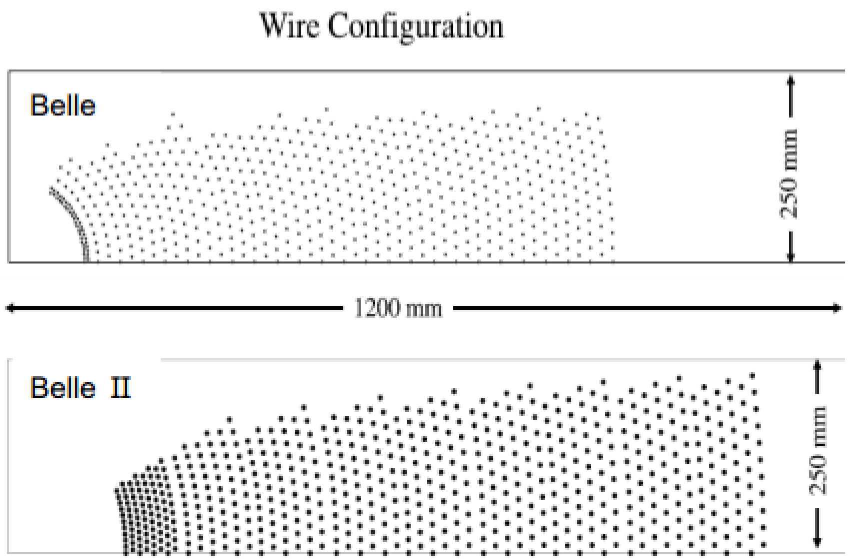
Central drift chamber (CDC)

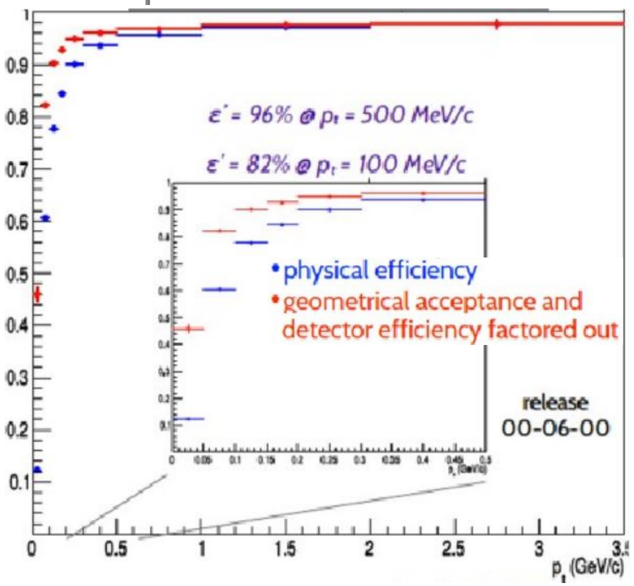
Compared to Belle

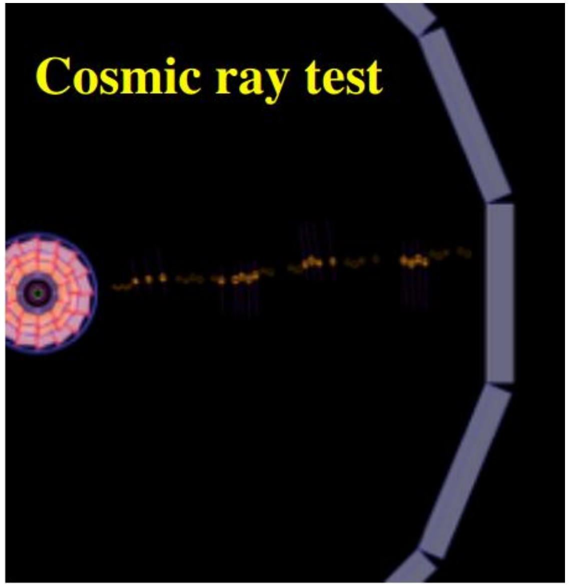
- Extended outer radius
- Smaller drift cell
- better momentum reconstruction
- better dE/dx measurement
- 3D trigger information

Just installed in Oct. 2016

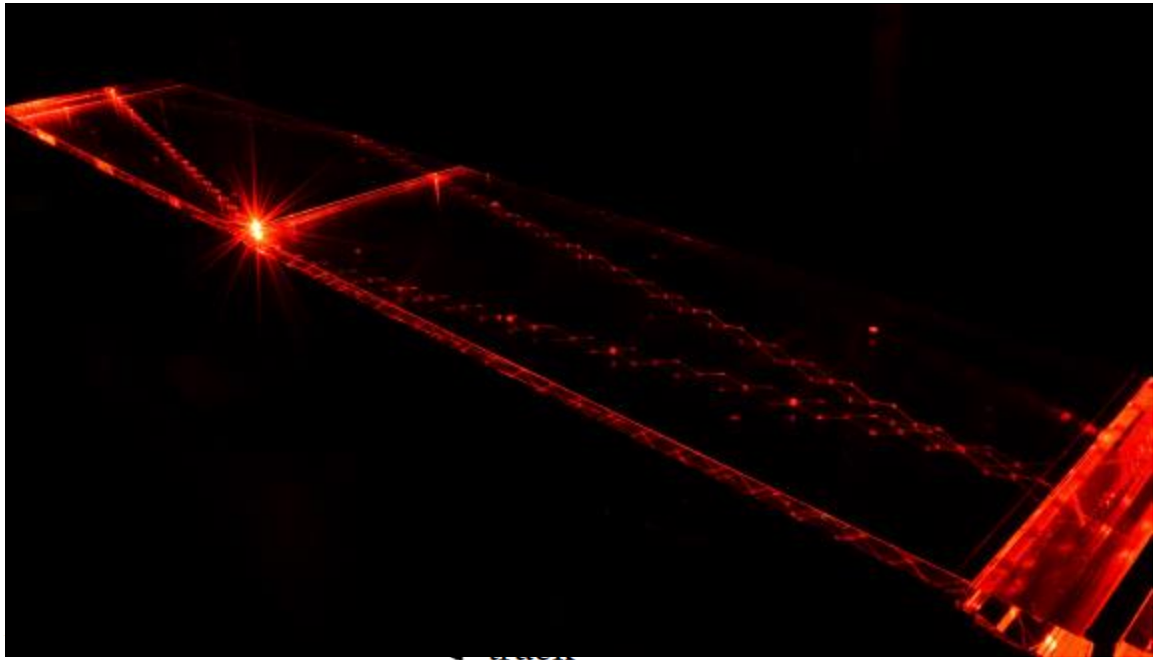
	Belle	Belle II
Radius of inner boundary (mm)	88	168
Radius of outer boundary (mm)	863	1111
Number of layers	50	56
Number of total sense wires	8400	14336
Gas	$He\text{-}C_2H_6$	$He\text{-}C_2H_6$
Diameter of sense wire (µm)	30	30







Particle ID (barrel)



Time of Propagation (TOP)

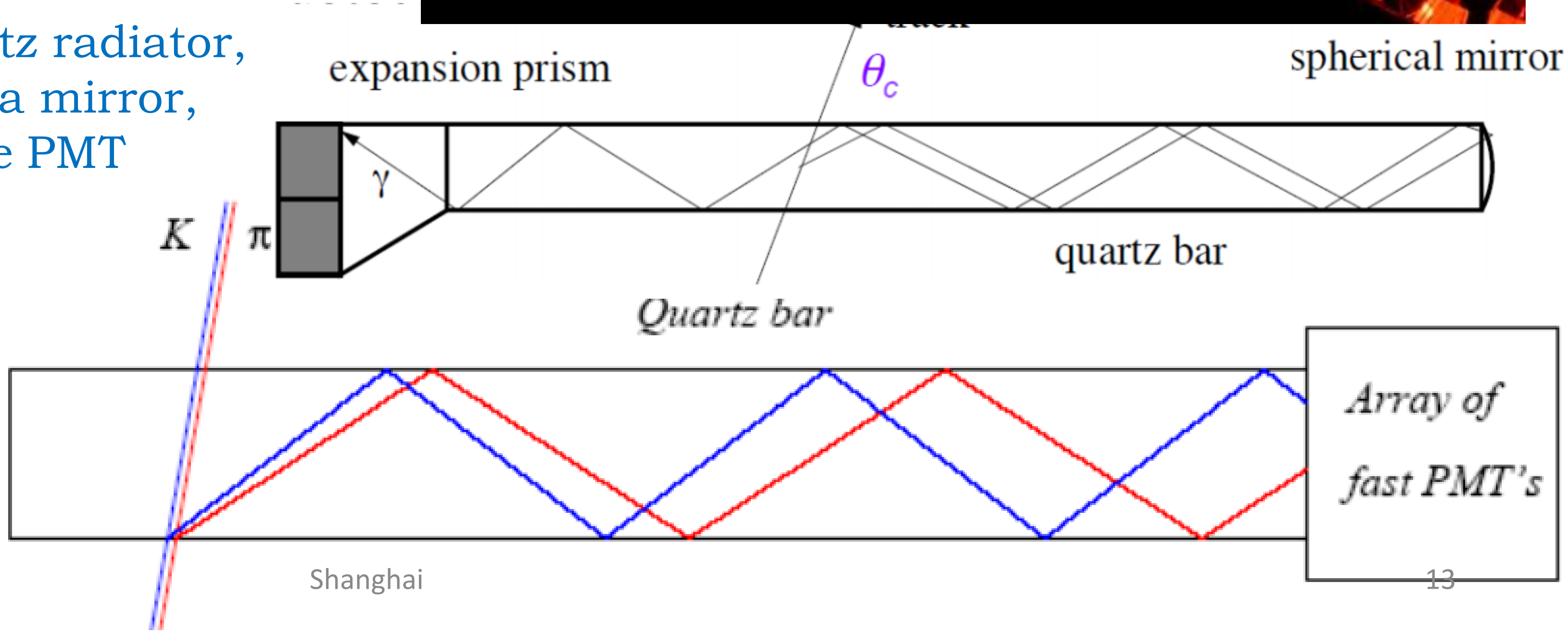
Cherenkov detector, quartz radiator

Cherenkov ring imaging with precision time measurement.

Installation completed on May 11, 2016.

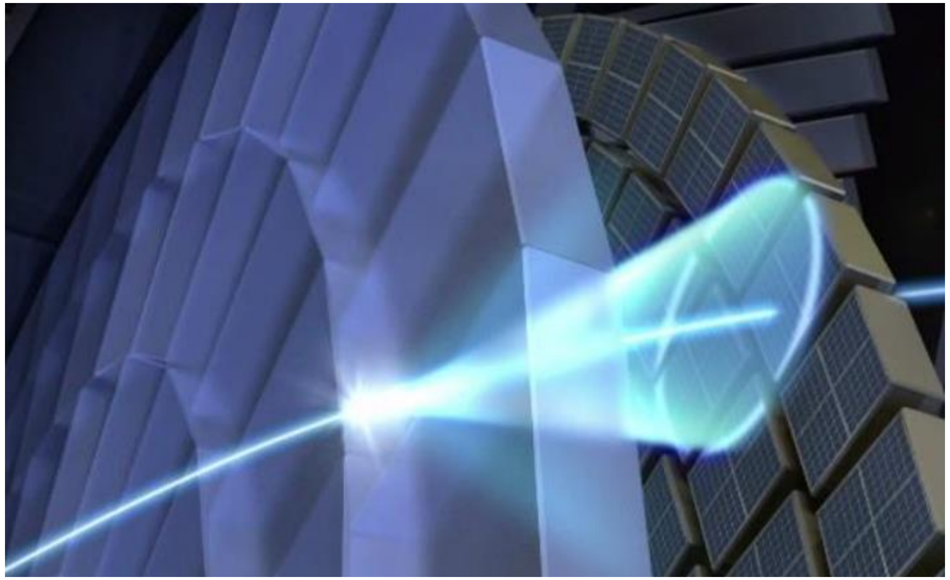
Cherenkov photons emitted in quartz radiator, total internal reflection, focused by a mirror, detected by a fast position sensitive PMT

K/π different θ_C, different path, different time of propagation

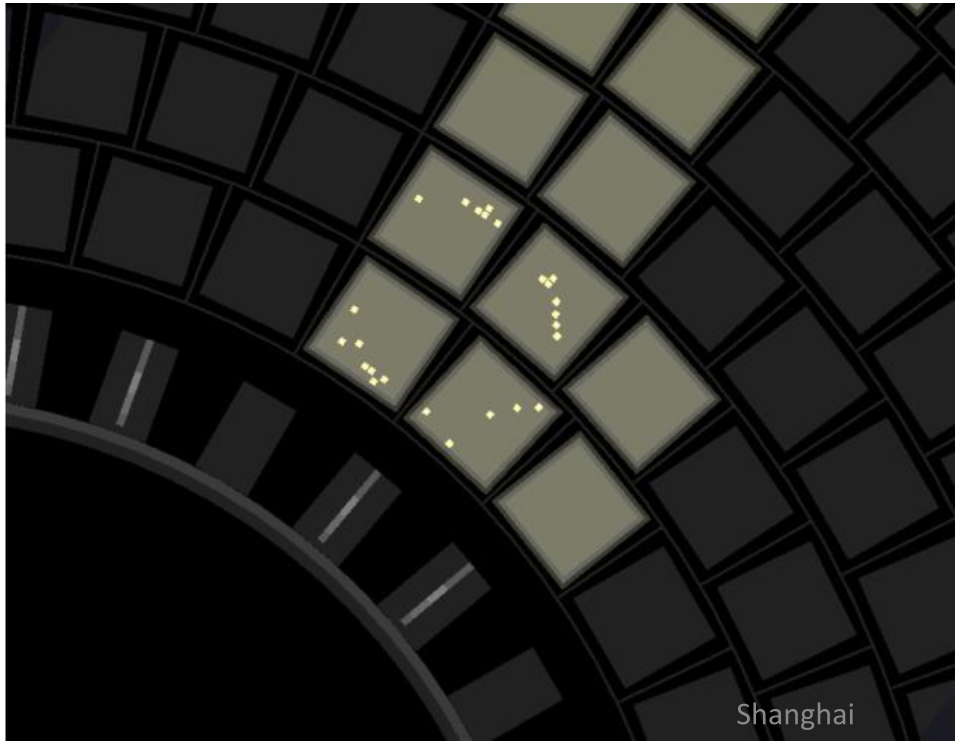


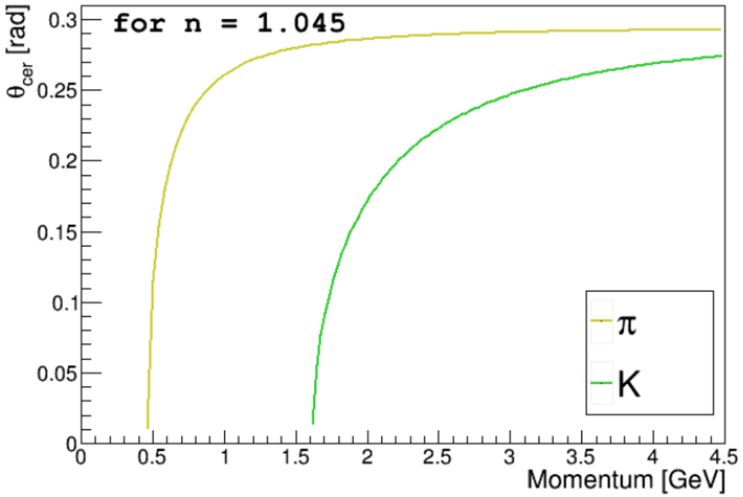
Particle ID (forward End-cap)

- Aerogel proximity focusing RICH (ARICH)
- In the front-end endcap region
- Measure the angle θ_C
- Good separation (>4σ) for K/π in (-0.5-4.0 GeV)
- One sector has been instrumented.



First ring from cosmic ray. Aug 10.





Cherenkov angle vs. particle momentum

EM calorimeter (ECL)

Reuse barrel crystals from Belle (new electronics)
refurbished endcap crystals (CsI(TI)-> CsI)

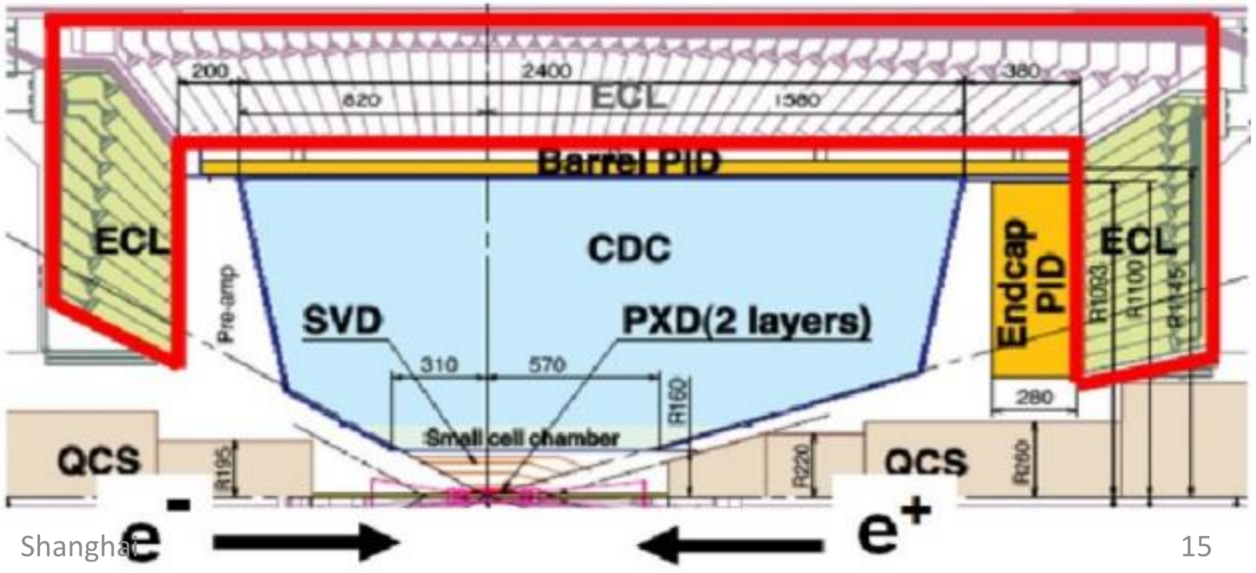
- Detect photon with precision measurement
- Identify electrons
- Help detect K_L together with KLM
- Used to trigger

Barrel ECL already installed.

Belle II and Belle ECL trigger efficiency (simulation)

Physics trigger: E_{tot} > 1 GeV

	ε_{phys} (total)	ε_{signal}	ε_{bkg}
Belle	99.42 %	88.70 %	10.72 %
Belle II	99.90 %	99.12 %	0.78 %

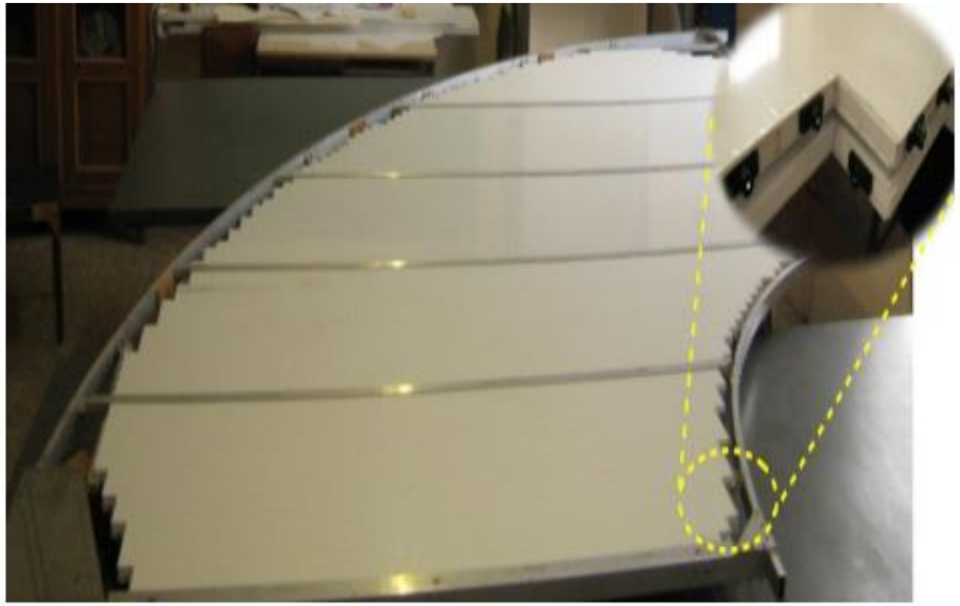


K_L and μ detector (KLM)

Alternating layers of iron plates and detector components
Iron plates:

- K_L shower hadronically
- Flux return for magnet

replaced endcap and inner-most barrel RPCs with scintillators
Barrel (endcap) installed in 2013 (2014).



Physics prospects

Expected uncertainties on several selected flavor observables with an integrated luminosity of 5 ab^{-1} and 50 ab^{-1}

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [56]	0.012	0.008
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1
	γ [°]	68 ± 14 [13]	6	1.5
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [57]	0.028	0.011
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$ [17]	0.100	0.033
	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [58]	0.07	0.04
UT sides	$\lvert V_{cb} \rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\lvert V_{cb} \rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{ex.} \pm 2.7\%_{th.})$ [10]	1.8%	1.4%
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{ex.} \pm 2.5\%_{th.})$ [5]	3.4%	3.0%
	$\lvert V_{ub} \rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 9.5\%)$ [7]	4.4%	2.3%
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 27\%)$ [26]	10%	5%
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7 [59]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.2%	3.4%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	2.9%	2.1%
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40 [31]	< 15	20%
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55 [31]	< 21	30%
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$ [60]	1	0.5
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$[20]	0.11	0.035
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$ [21]	0.23	0.07
	C_7/C_9 $(B \to X_s \ell\ell)$	~20% [37]	10%	5%
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7 [40]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2 [42]‡	–

Rich physics:

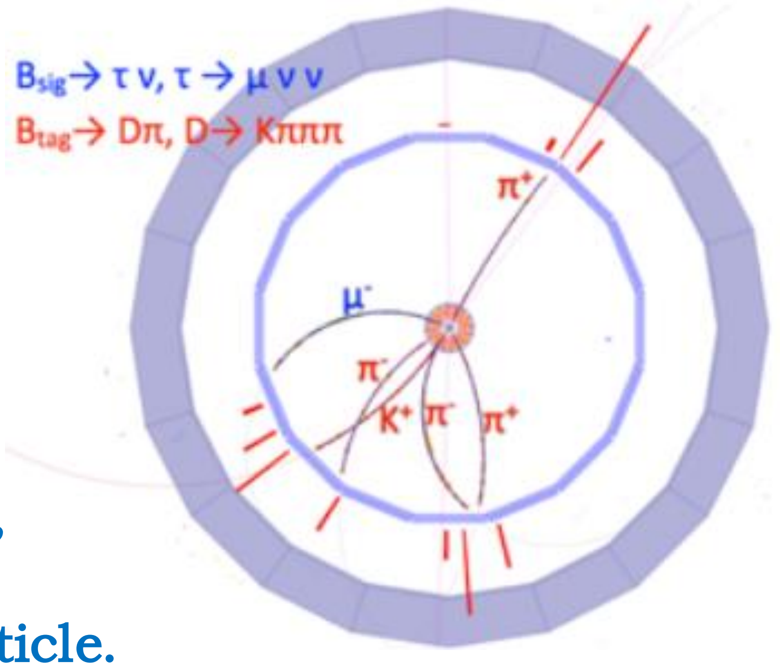
precision CKM,
new source of CP violation
Lepton flavor vioiation
Dark sector,
Bottomonium and charmonium spectroscopy
QCD exotics

Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$ [44]	2.9%	0.9%
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$ [44]	3.5%	3.6%
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5 [47]	30%	25%
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$ [61]	0.11	0.06
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$ [62]	0.29	0.09
	$A_{CP}(D^0 \to K^0_S\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$ [62]	0.08	0.03
Charm Mixing	$x(D^0 \to K^0_S\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$ [50]	0.14	0.11
	$y(D^0 \to K^0_S\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$ [50]	0.08	0.05
	$\lvert q/p \rvert (D^0 \to K^0_S\pi^+\pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$ [50]	0.10	0.07
	$\phi(D^0 \to K^0_S\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm ^{4}_{5}$ [50]	6	4
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45 [63]	< 14.7	< 4.7
	$\tau \to e\gamma$ [10^{-9}]	< 120 [63]	< 39	< 12
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0 [64]	< 3.0	< 0.3

P. Urquijo / Nuclear and Particle Physics Proceedings 263–264 (2015) 15–23

Belle II advantages

- Very clean sample of $B\overline{B}$ pairs
- High reconstruction efficiency
  - charged tracks
  - neutrals ($\pi^0\eta\cdots$)
- High flavor-tagging efficiency
  - Belle II ~34% vs. LHCb ~3%
- Measure K_S and K_L , important to most time dependent CPV measurements
- Full reconstruction one B to tag the flavor of the other B, determine momentum···
- Clean and excellent useful for analyses with missing particle.
- Also large sample of τ
  - rare decays
  - LFV search

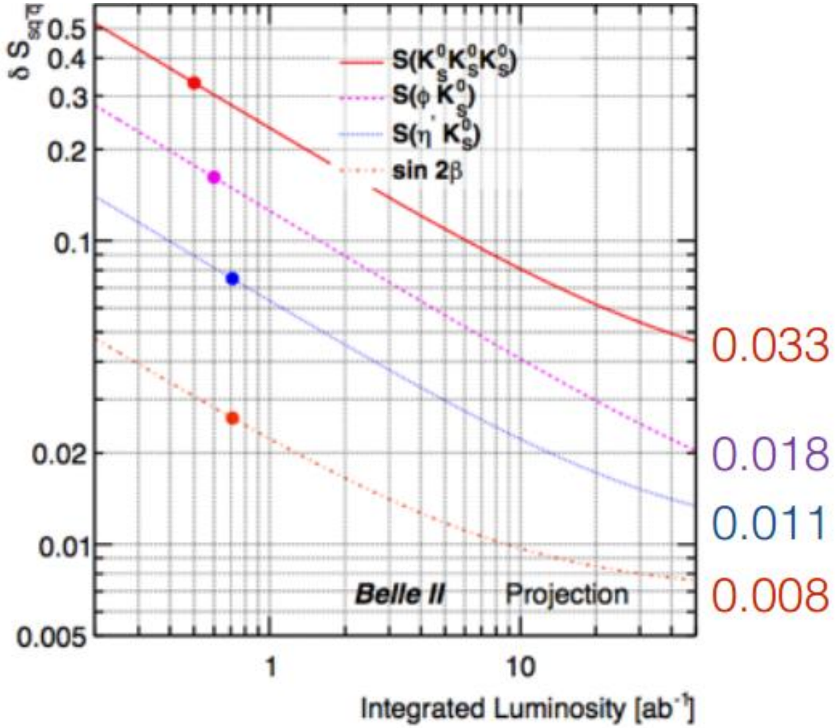


Search for new CP violation sources

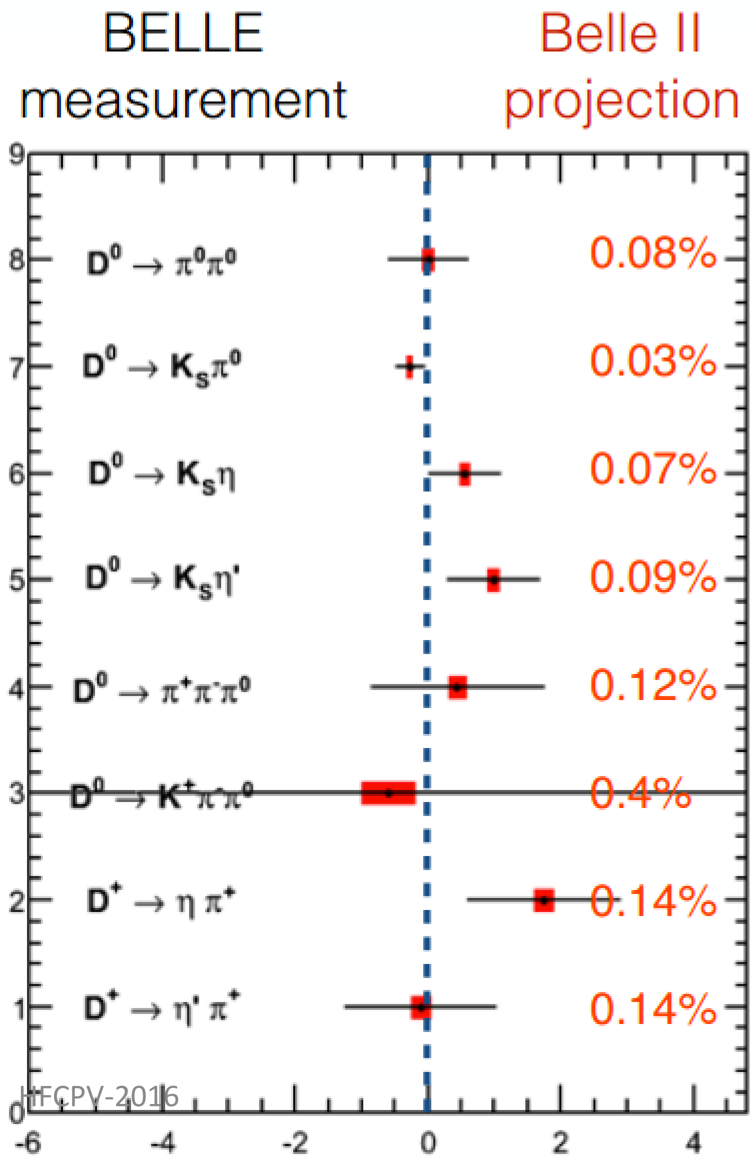
NP from rare or precise measurements.

Most theories involving NP include additional CP violation sources
maybe large deviation from SM predictions for B meson decays
Search for new sources by comparing mixing-induced CP asymmetries in penguin transitions with tree-dominated modes
time dependent CPV in $b \to s$ decays, $B \to \phi K^0, \eta' K^0 \cdots\cdots$

Observables	Belle (2015)	Belle II 50 ab^{-1} 70%@$\Upsilon(4S)$, improved K_S	Belle II 50 ab^{-1}@$\Upsilon(4S)$	LHCb Run-1	LHCb 22 fb^{-1}
	$(\sigma_{\text{stat}}, \sigma_{\text{sys}})$	$(\sigma_{\text{stat}}, \sigma_{\text{sys}})$	$(\sigma_{\text{stat}}, \sigma_{\text{sys}})$	$(\sigma_{\text{stat}}, \sigma_{\text{sys}})$	$(\sigma_{\text{stat}}, \sigma_{\text{sys}})$
$\sin(2\phi_1)$ in $B \to J/\psi K_S$	(0.023, 0.011)	(0.003, 0.007)	(0.007)	(0.035, 0.020)	(0.012, 0.007#)
$\sin(2\phi_1)$ in $B \to \phi K_S$	(0.14)	(0.018)	(0.015)	(0.30)#	(0.06)
$\sin(2\phi_1)$ in $B \to \eta' K_S$	(0.07, 0.03)	(0.008, 0.008)	(0.009)	–	–
$S_{CP}(B \to \pi^+\pi^-)$	(0.08, 0.03)	(0.013, 0.015)	(0.018)	(0.13, 0.02)‡ 1 fb^{-1}	(0.018, 0.010)†
$C_{CP}(B \to \pi^+\pi^-)$	(0.06, 0.03)	(0.010, 0.015)	(0.016)	(0.15, 0.02)‡ 1 fb^{-1}	(0.021, 0.010)†



Direct CPV in Charm



$$A_{CP}^{f} = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to \overline{f})}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to \overline{f})}$$

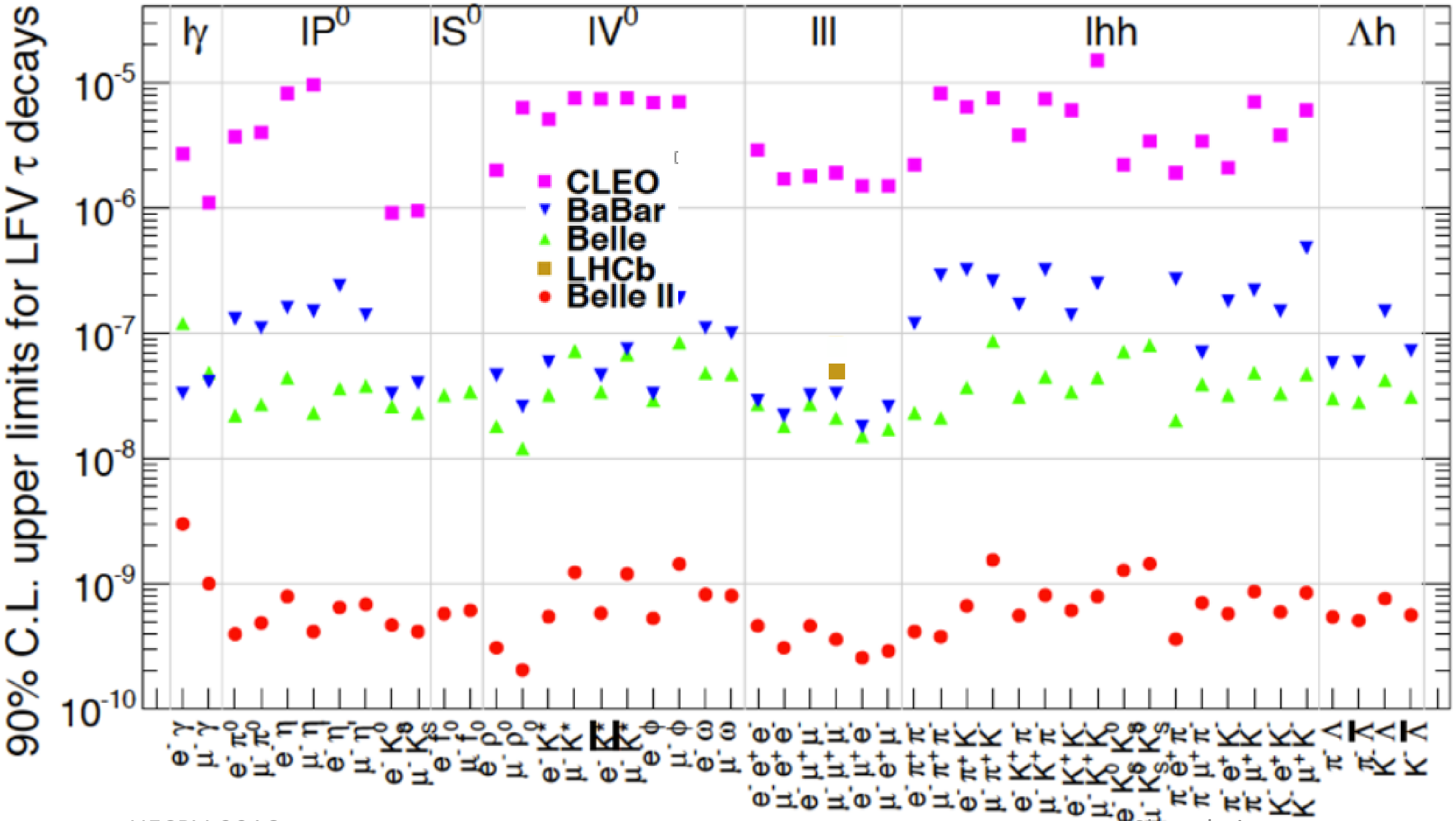
Belle II contribution will be in channels with neutrals final state
Most measurements will be dominated by sysmetatics

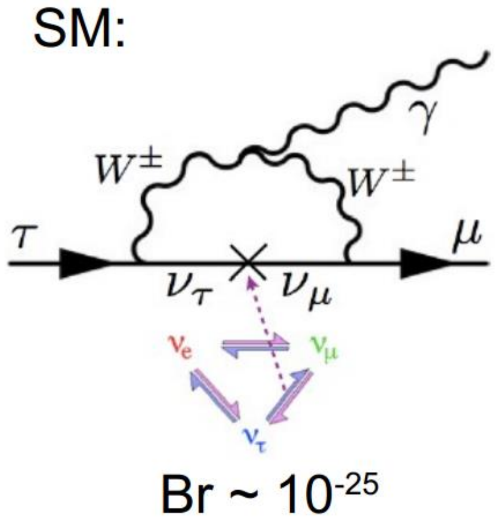
mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	976	$\sim \pm 0.60$	± 0.08
$D^0 \to K_s^0\pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.03
$D^0 \to K_s^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K_s^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K_s^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K_s^0K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D_s^+ \to K_s^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_s^0K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

(table by Marko Staric)

Lepton flavor violation

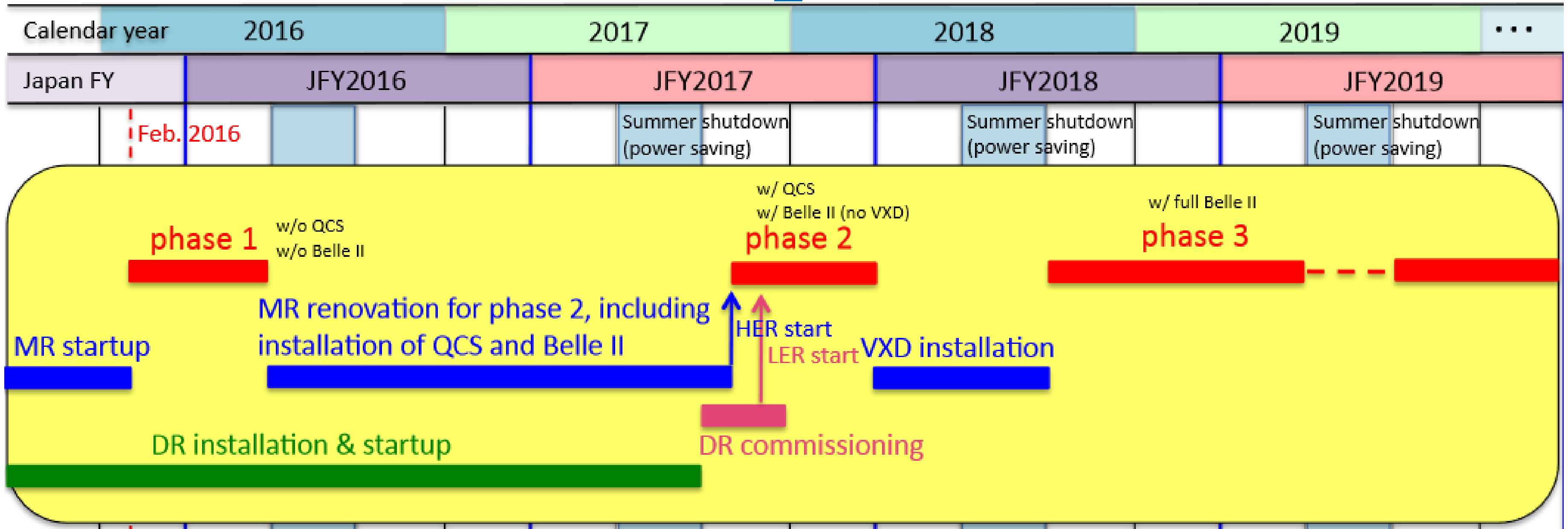
Belle II improves over 100 times than Belle





	$\tau \to \mu\gamma$	$\tau \to \mu\mu\mu$
SM+heavy Maj ν_R (PRD66,034008)	10^{-9}	10^{-10}
Non-universal Z' (PLB547,252)	10^{-9}	10^{-8}
SUSY SO(10) (PRD 68,033012)	10^{-8}	10^{-10}
mSUGRA+seesaw (PRD66,115013)	10^{-7}	10^{-9}
SUSY Higgs (PLB 566,217)	10^{-10}	10^{-7}

Schedule and plans



Phase I: successfully completed

Phase II: preparing

Feb. – Jun. 2016 Phase 1 commissioning (without Belle II)

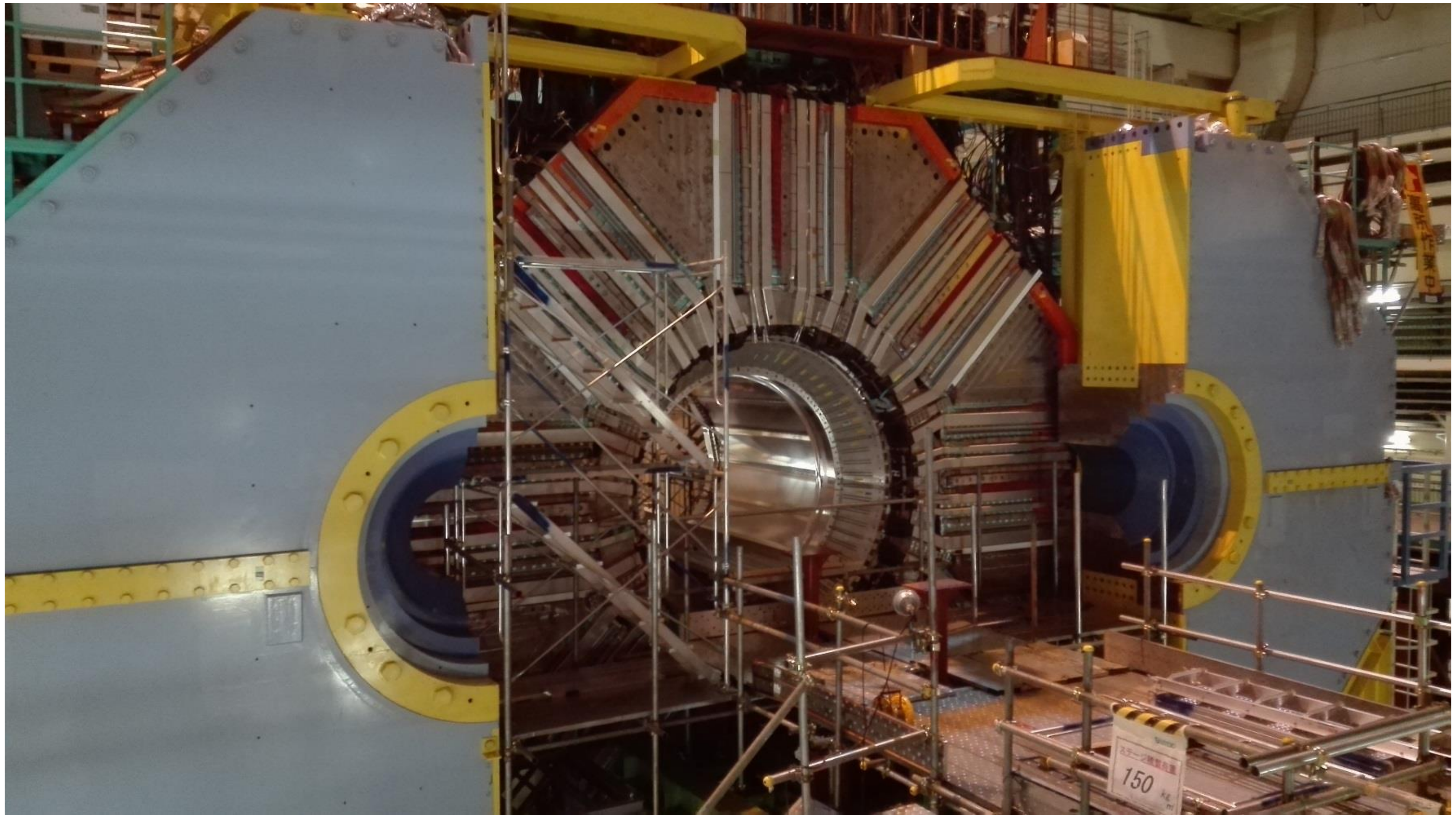
Jul. 2016 ~ Renovation for phase 2
- Installation of QCS and startup works, Belle II roll-in
- More collimators, more mitigation for electron cloud, etc.
- Completion of DR and startup works
- Improvements for Linac

Nov. 2017 ~ phase 2 commissioning with Belle II (w/o VXD)
- Low β_y^* tuning, collision tuning, luminosity tuning
- Low emittance beam injection with DR and improved Linac

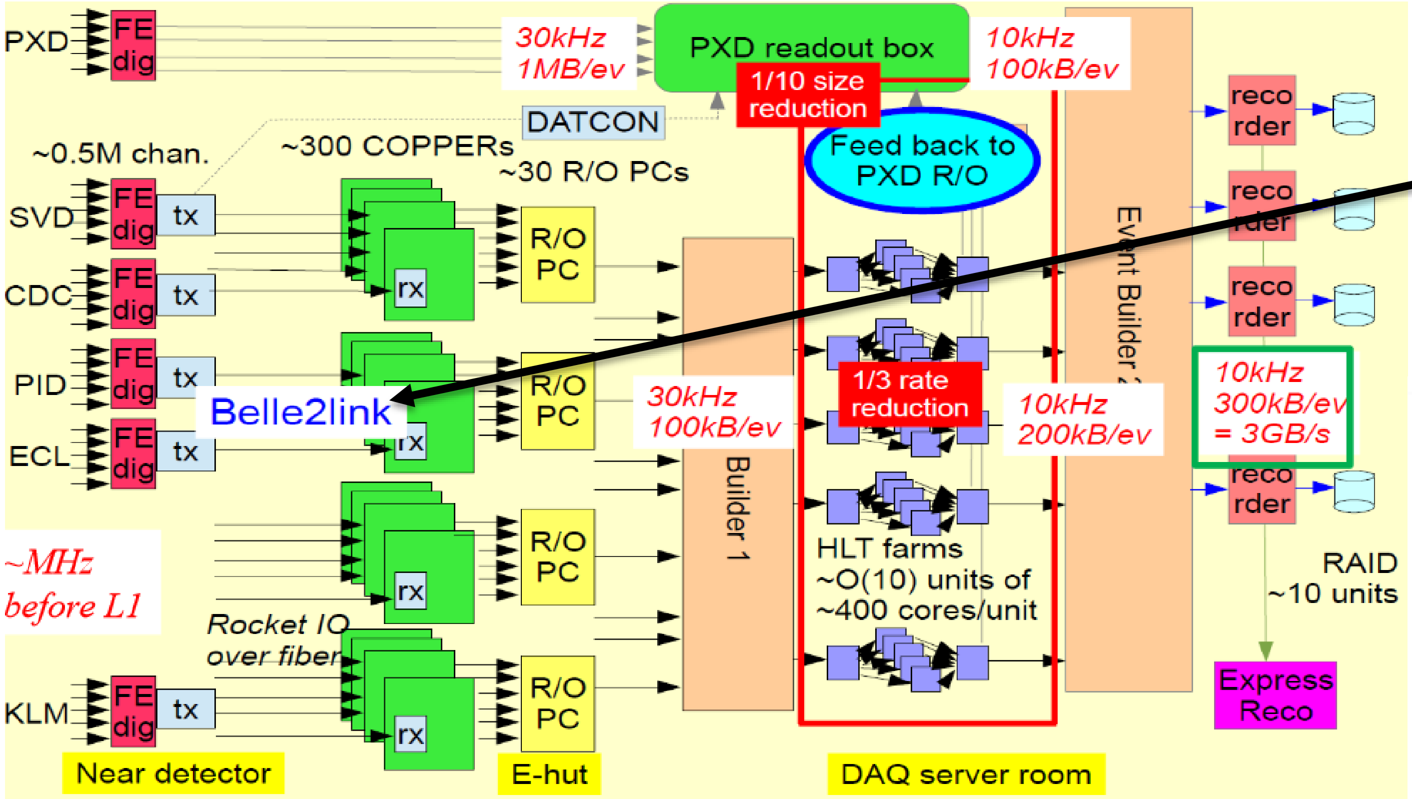
JFY2018 ~ phase 3 operation with full Belle II

K. AKAI, SuperKEKB schedule for phase 2, Oct. 17, 2016 @B2GM

Detectors, almost installed KLM,ECL,TOP,ARICH,CDC



Chinese group

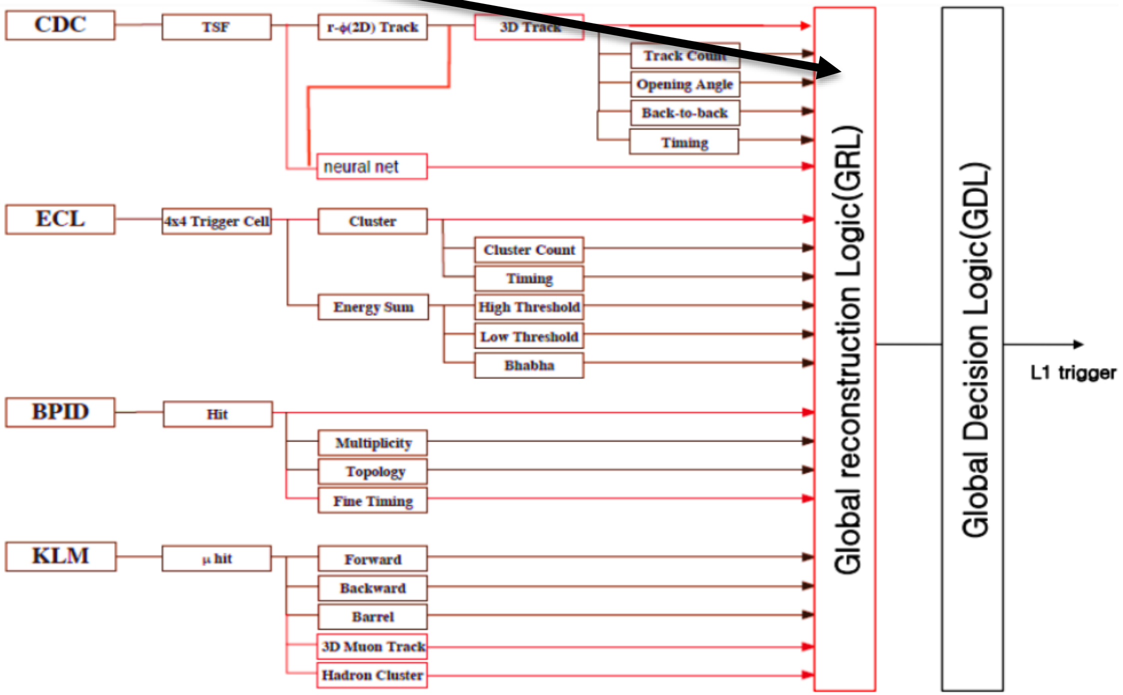


Contributions (up to now):

Belle2link (IHEP)

Computing (Beihang U.)

Trigger (IHEP)



Members (up to Oct. 26)

IHEP (10)

Beihang U. (9)

USTC (4)

Peking U. (3)

Summary

- The phase I is successful completed.
- Now moving to phase II, testing all the detectors.
- Commissioning without Vertex detector in Nov. 2017
- Full Belle II operation: 2018
- Physics studies ……

Everything goes smoothly up to now.

Rich physics topics.
Now MC simulations, tools developments.

Thanks for your attention.

Welcome comments and suggestions!