SuperKEKB and Belle II

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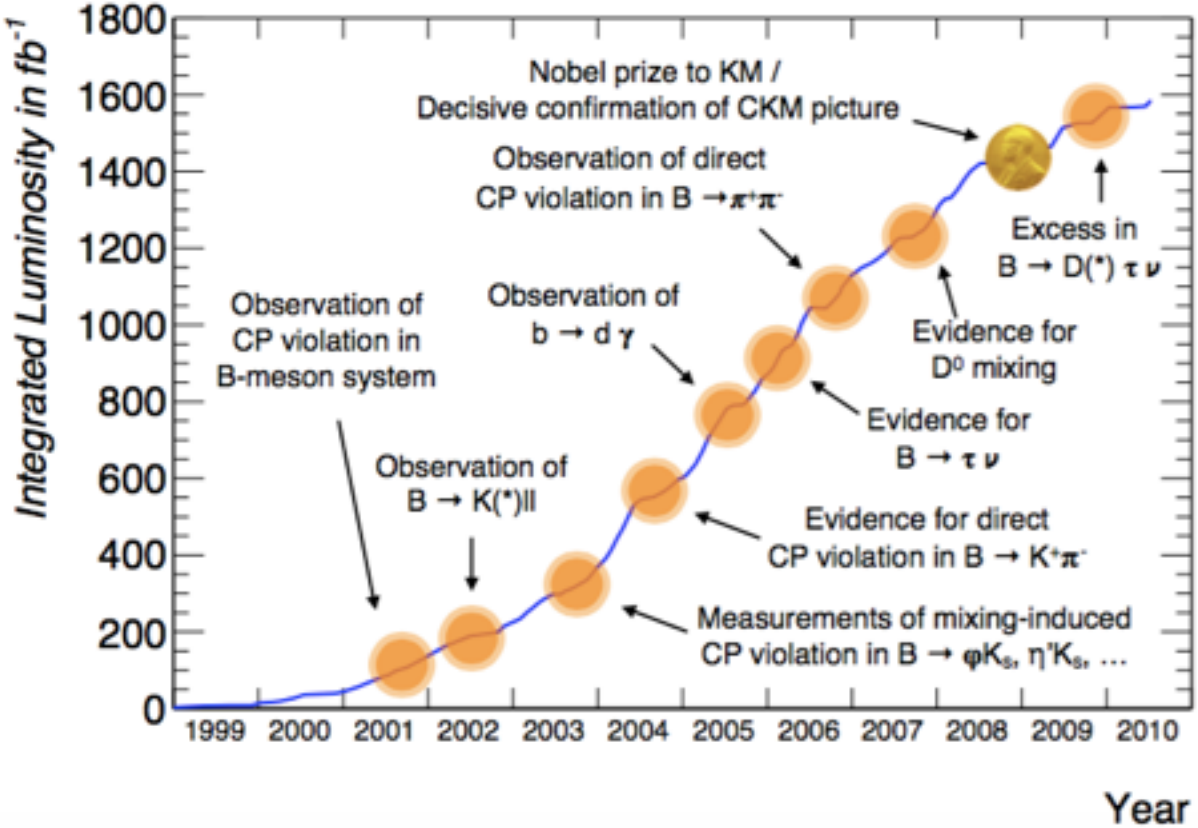
On behalf of the Belle II collaboration

HQL May 22-27, 2016

Outline:
- Introduction
- SuperKEKB
- Belle II Detector
- Physics at Belle II

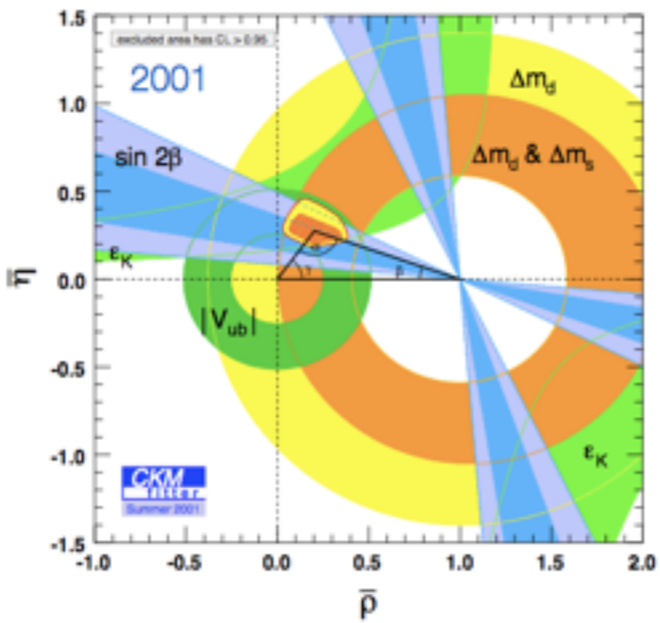
B-factory Achievements

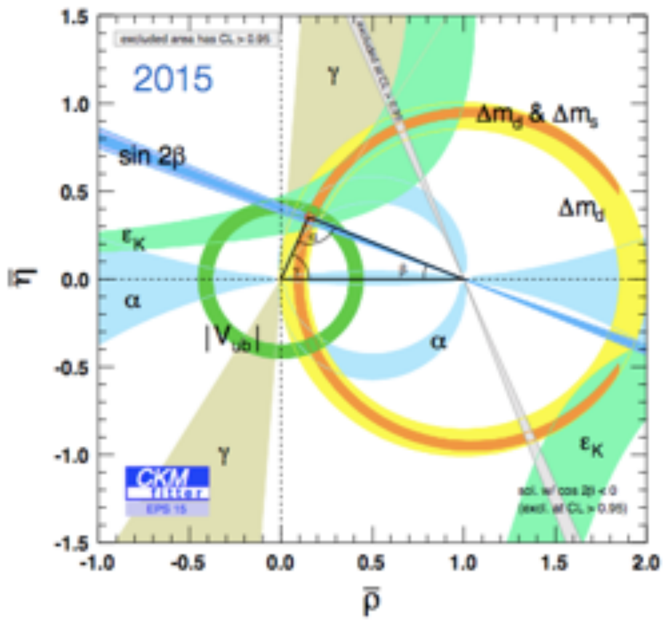
- **Belle** (KEKB@KEK) and **BaBar** (PEPII@SLAC)
- Integrated luminosity: Belle >1 ab^{-1}, BaBar ~550 fb^{-1}



Search for new physics

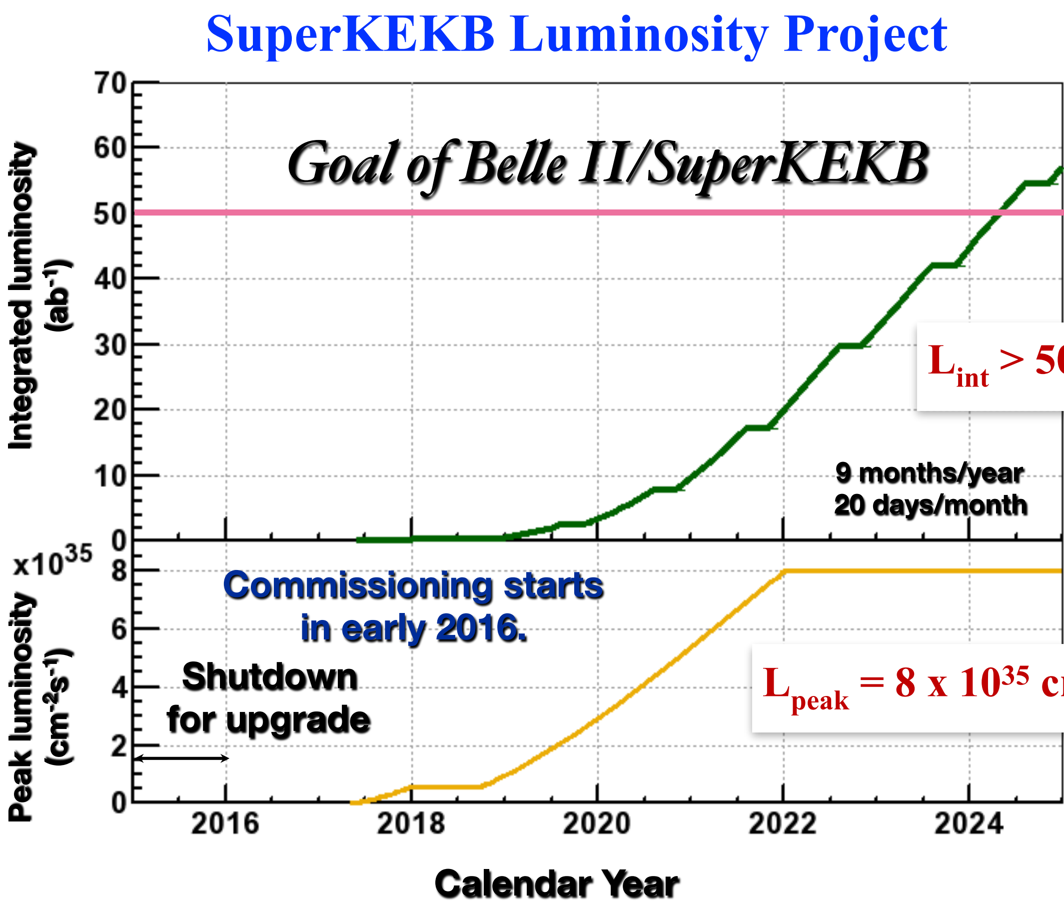
- There is still space for new physics contributions
- Open questions, e.g.
  - New CPV phases?
  - Sources of LFV beyond the SM?
  - Multiple Higgs bosons, dark sectors?
  - Discrepancies between experimental results and SM predictions (e.g enhancements in semi-tauonic decays)?





SuperKEKB

An asymmetric electron-positron collider at KEK, Japan
e^+~ 4GeV e^-~ 7GeV

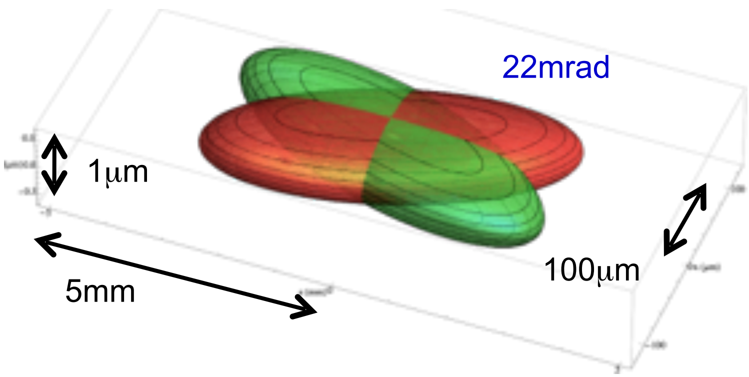


L_{int} > 50 ab^{-1} by 2024 (50 x Belle)

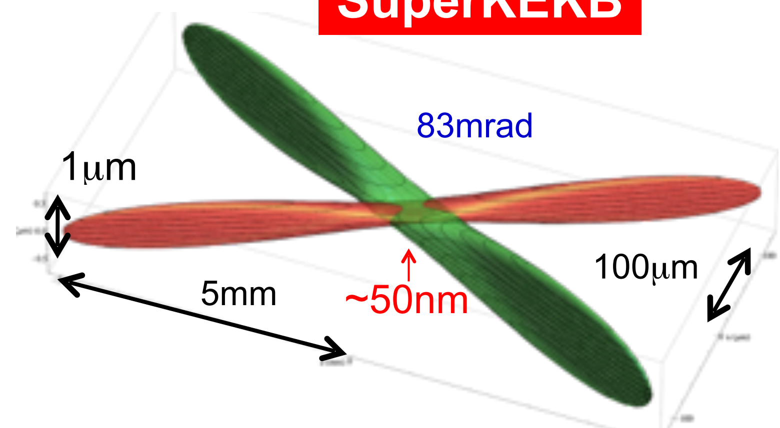
L_{peak} = 8 x 10^{35} $cm^{-2}s^{-1}$ (40 x KEKB)

Nano-Beam Scheme

KEKB



SuperKEKB



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

	E(GeV) LER/HER	β^*_y (mm) LER/HER	ξ_y LER/HER	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	0.129/0.090	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	0.0881/0.0807	3.6/2.6	80×10^{34}
		x 20		***x 2***	***x 40***

Lorentz factor

Beam current

Beam-Beam parameter

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma^*_y}{\sigma^*_x}\right)\left(\frac{I_{\pm}\xi_{y\pm}}{\beta^*_{y\pm}}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

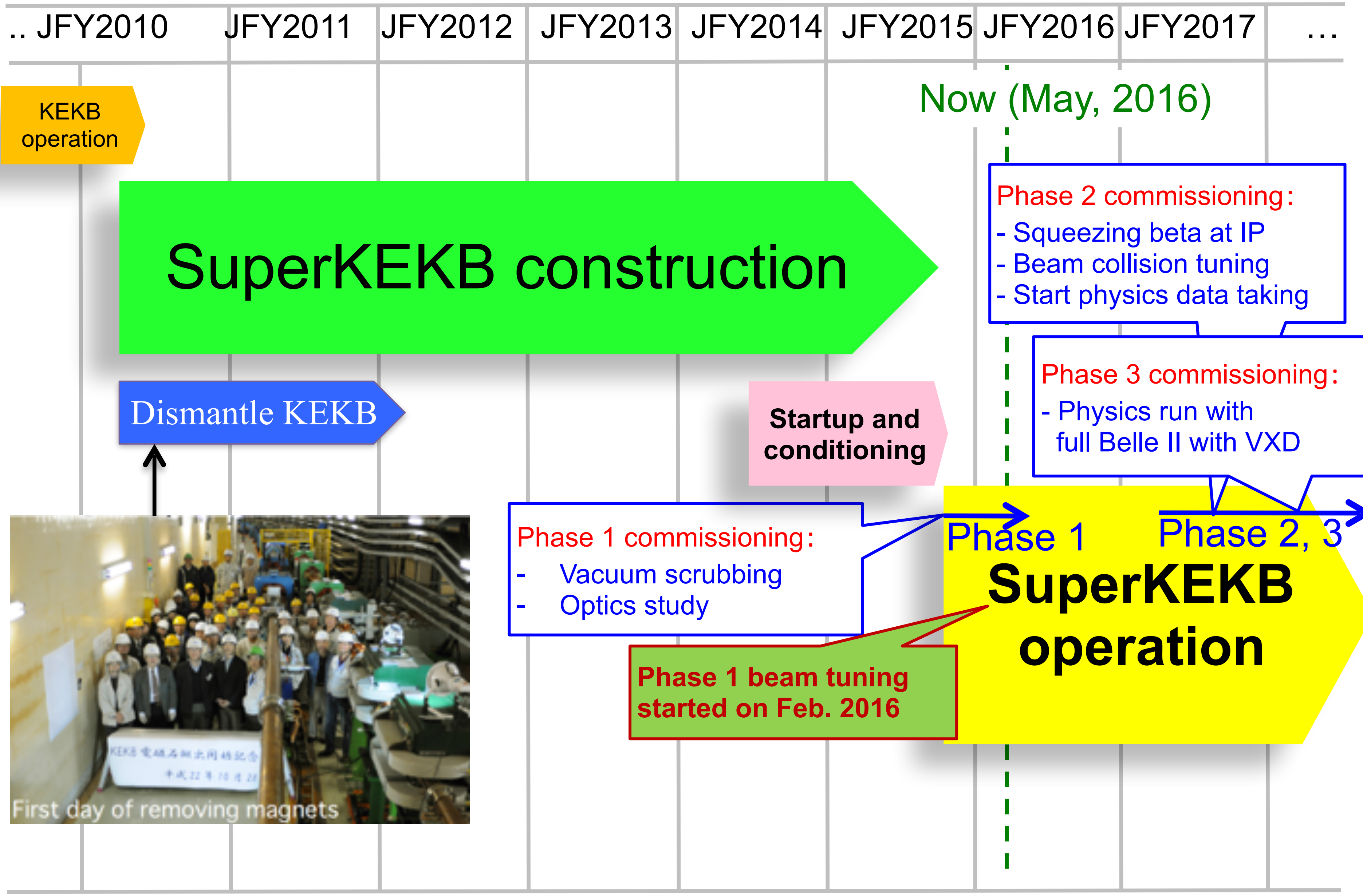
Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

Vertical beta function at IP

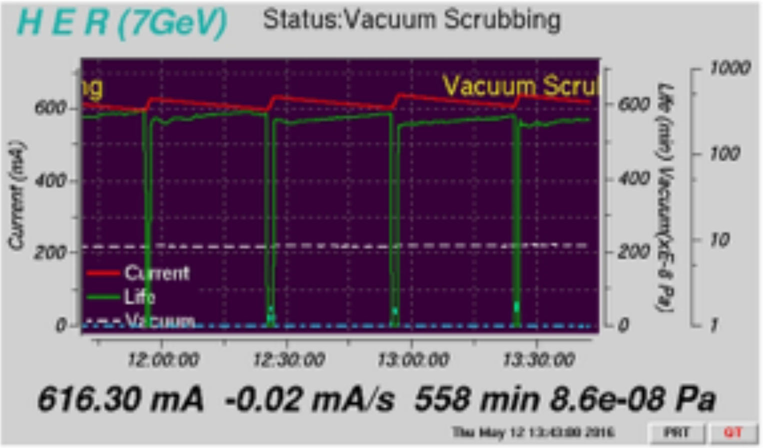
Minimum value is limited by hourglass effect

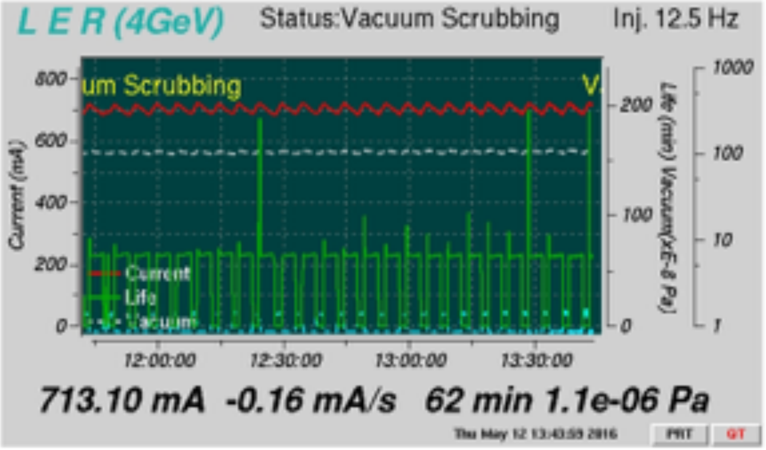
SuperKEKB Master Schedule



Phase 1 Commissioning

- **Feb. 1st - Feb. 7th**
  - Tuning of Beam Transport Lines (e-/e+)
- **Feb. 8th - Feb. 21st**
  - Commissioning of LER (e+ ring)
  - Circumference check with wigglers
- **February 22nd - Mar. 5th**
  - Commissioning of HER (e- ring)
  - In parallel with LER vacuum scrubbing and possible studies at LER
- **Current status:**
  - Current: HER~0.6A, LER~0.7A
  - Vacuum scrubbing
  - Optics study
  - Background study with BEAST II.
  - Expected highest HER and LER current 1A

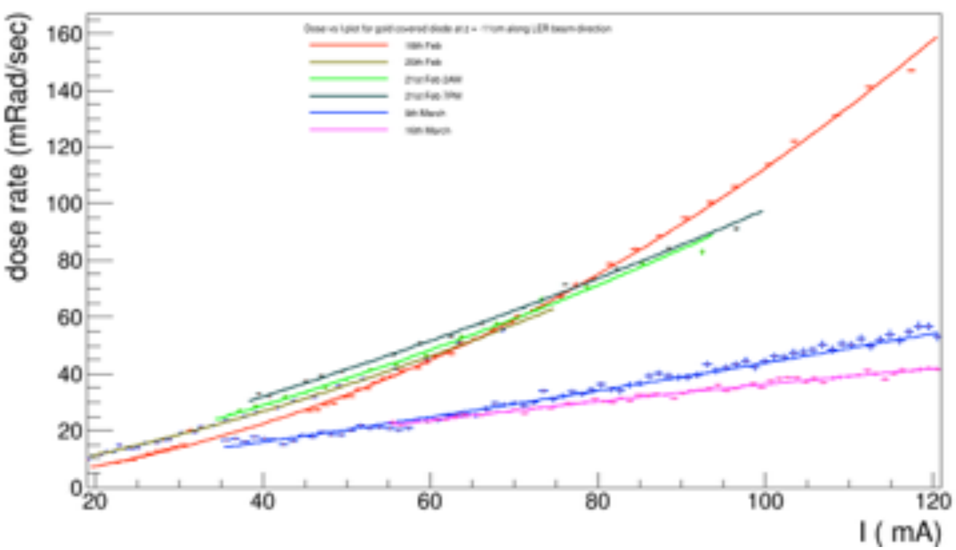




SuperKEKB commissioning detector

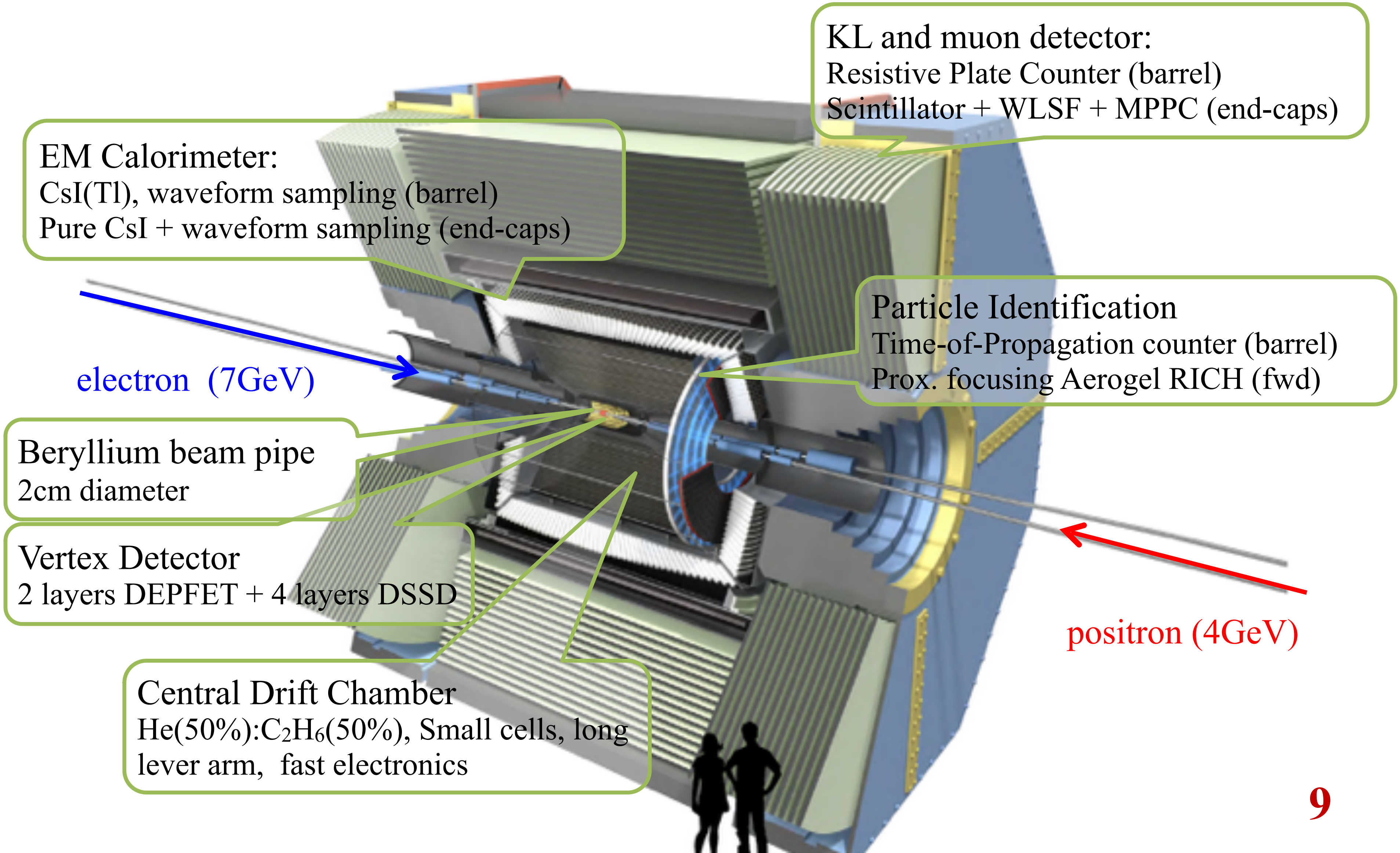
- **B**eam **E**xorcism for a **S**table Experimen**T II (BEAST II):**
  - characterize beam backgrounds near the interaction point (IP)
  - Independent detectors to measure beam backgrounds

Beam Gas Background in LER vs time



- **Beam backgrounds**
  - Touschek effect (inverse beam size, current)
  - Beam-gas interactions (current, vacuum level)
  - Synchrotron radiation
  - Radiative Bhabha scattering (Lum.)
  - 4-fermion final state QED process (Lum.)
- Total background 40 times larger than Belle

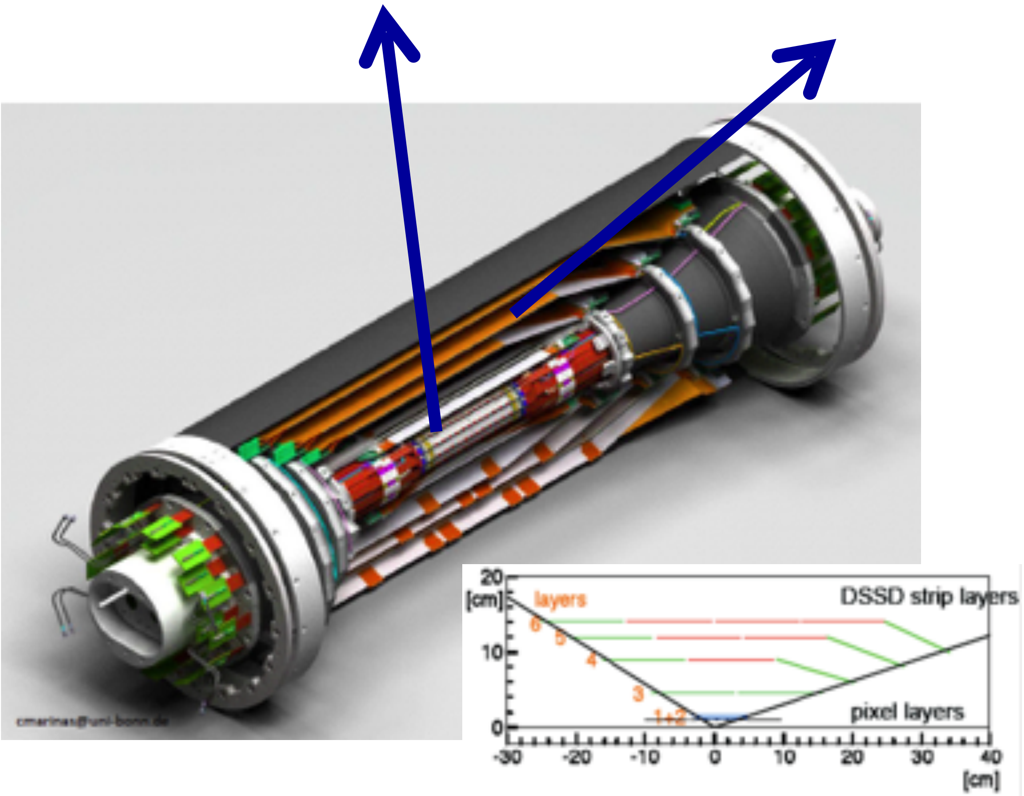
Belle II Detector

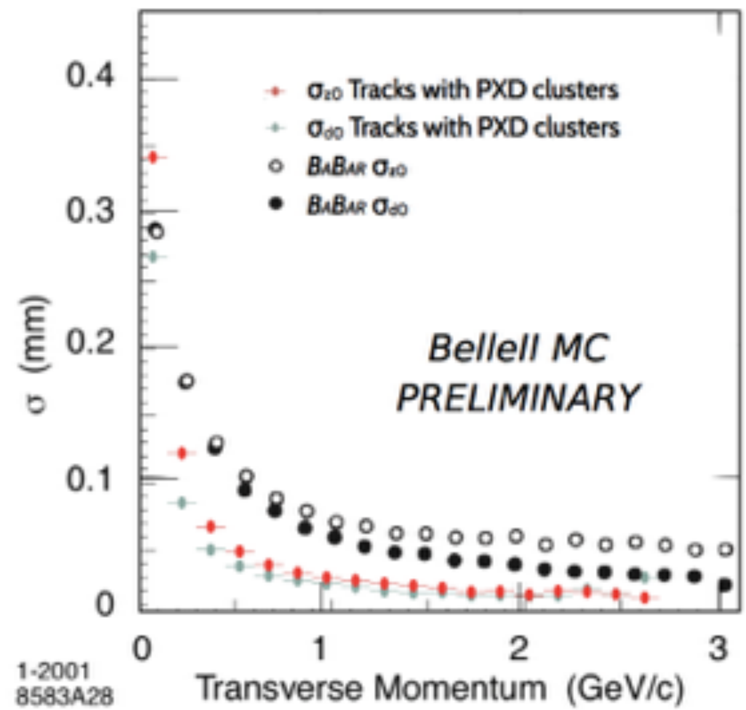


Vertex Detector (PXD+SVD)

PXD: 1-2 layers
- 2 layers of pixel detectors
- Inner most layer very close to IP (r = 1.4cm)
- Excellent spatial granularity ($\sigma \leq 15\mu m$)

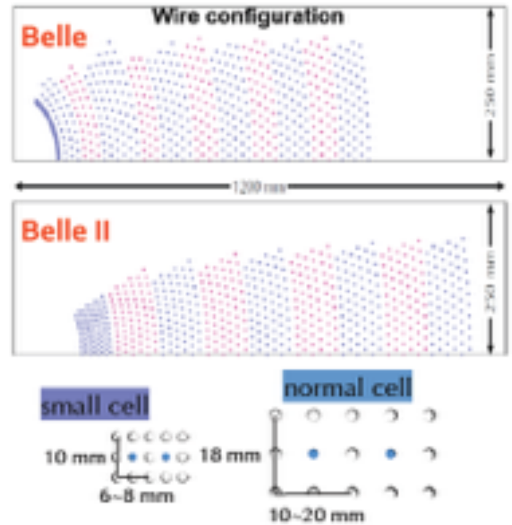
SVD: 3-6 layers
- 4 layers of strip detectors
- Excellent timing resolution ($\sigma \sim$ 2-3 ns)
- covers the full Belle II angular acceptance of $17^o < \theta < 150^o$

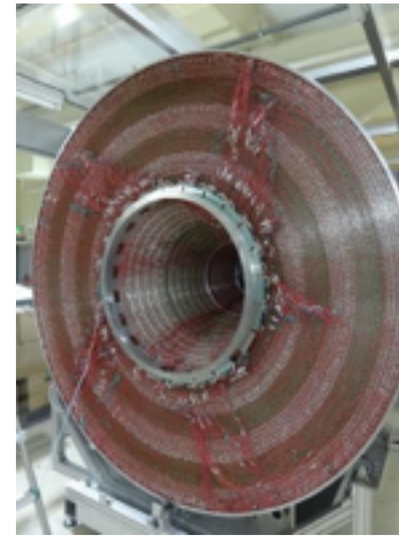


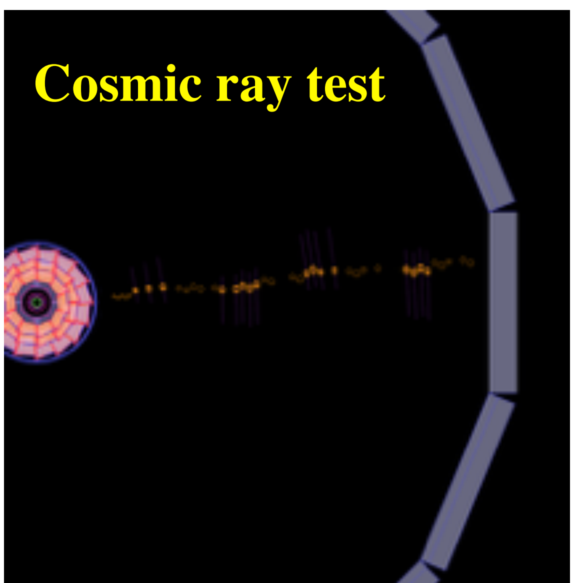


Central Drift Chamber (CDC)

- Upgrade
  - Extended outer radius
  - Smaller cell size
  - More layers for dE/dx measurements
  - Faster readout electronics
  - 3D trigger information
- Current status
  - Ready for installation



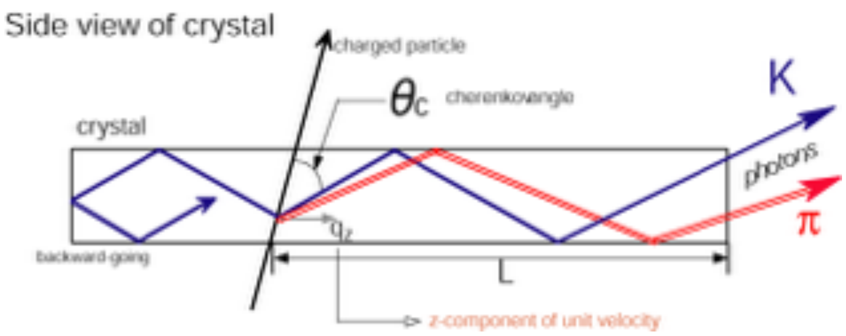


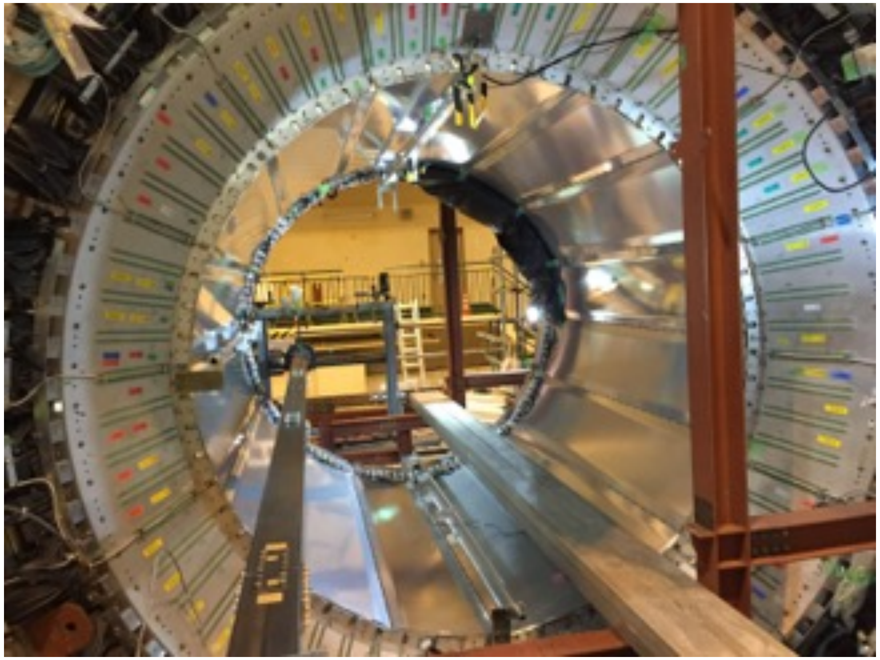


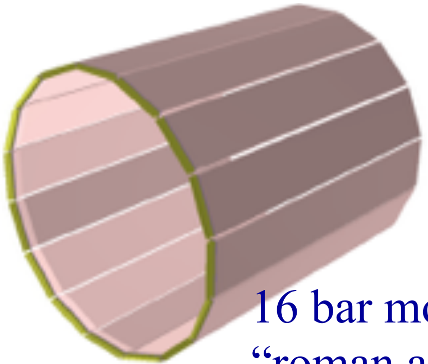
	Belle	Belle II
Radius of inner boundary (mm)	88	168
Radius of outer boundary (mm)	863	1111
Number of layers	50	56
Number of total sense wires	8400	14336
Gas	He-C_2H_6	He-C_2H_6
Diameter of sense wire (mm)	30	30

Particle ID (Barrel)

- Time Of Propagation (TOP)
  - Cherenkov detector, quartz radiator
  - Cherenkov ring imaging with precision time measurement
  - Resolution for signal photons < 100ps
- Installation completed on May 11, 2016!



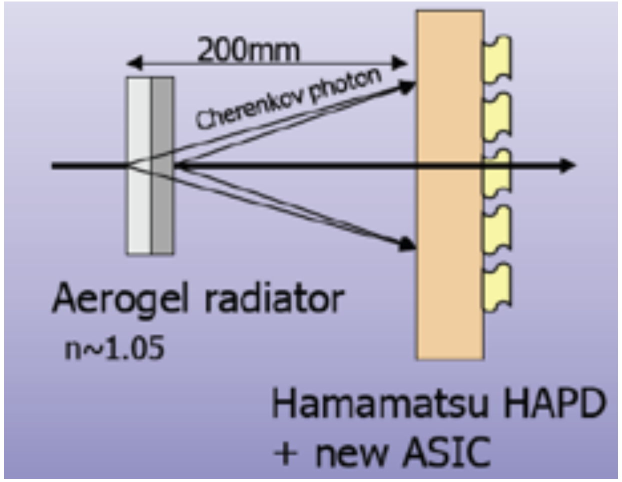


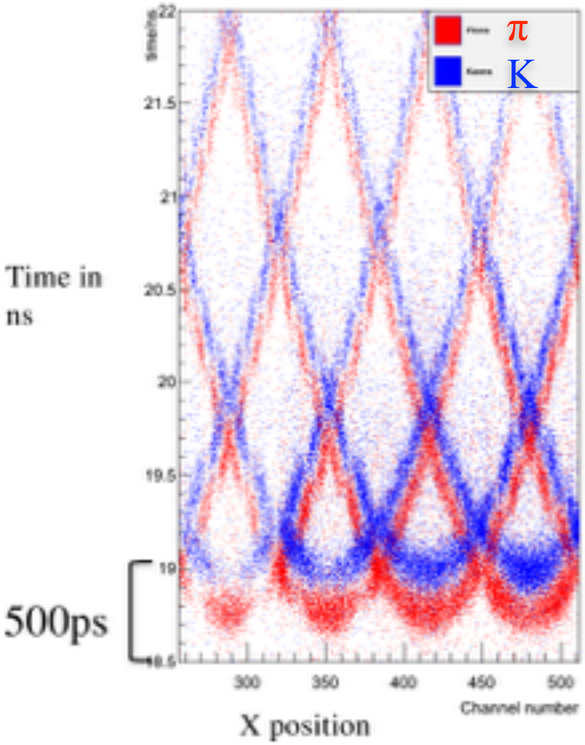


16 bar modules arranged in a “roman arch”

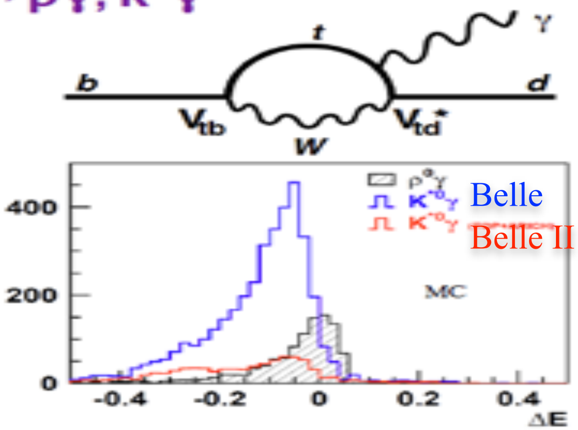
Particle ID

- Forward endcap: Aerogel RICH:
- K/π separation: 6σ at 4 GeV/c
- Successful magnetic field test, installation in Autumn.





PID impact on Rare b→d Penguins: B→ργ, K*γ

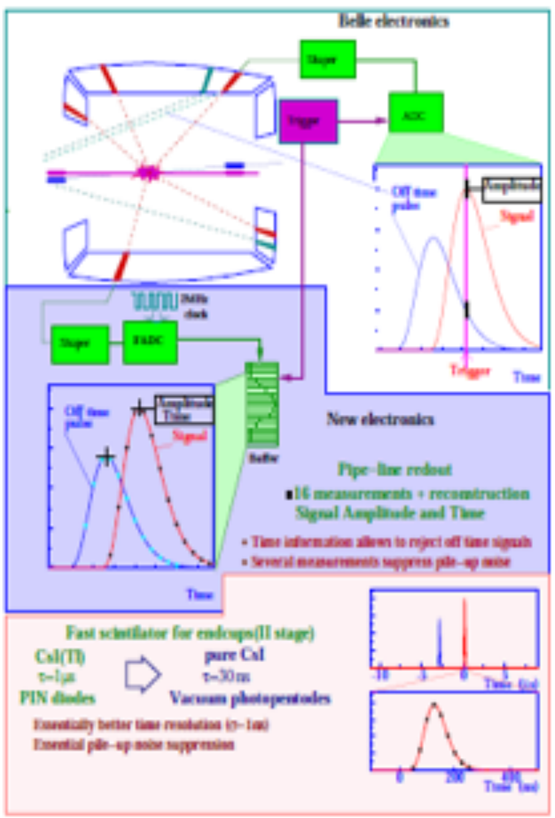


Dominate background B→K* γ greatly suppressed

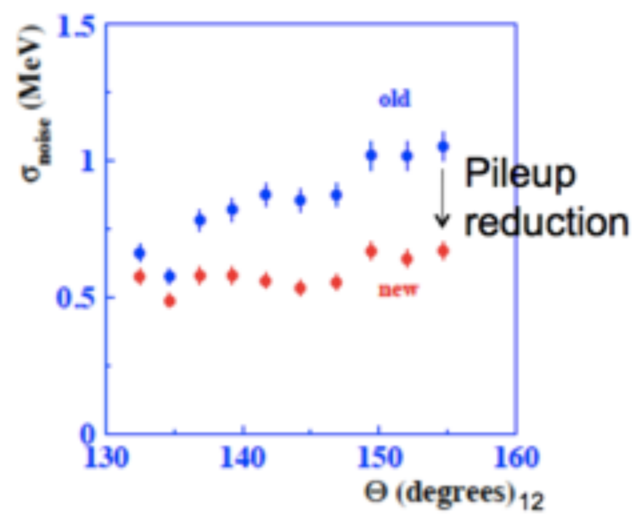
EM Calorimeter

Cope with higher particle rate

1. Electronics upgrade: waveform sampling & fitting
2. Endcap crystal update: (baseline option) pure CsI (short decay time)+ photopentode

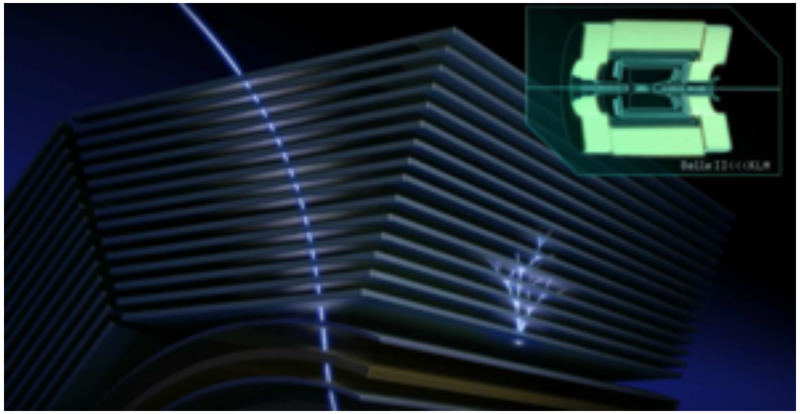


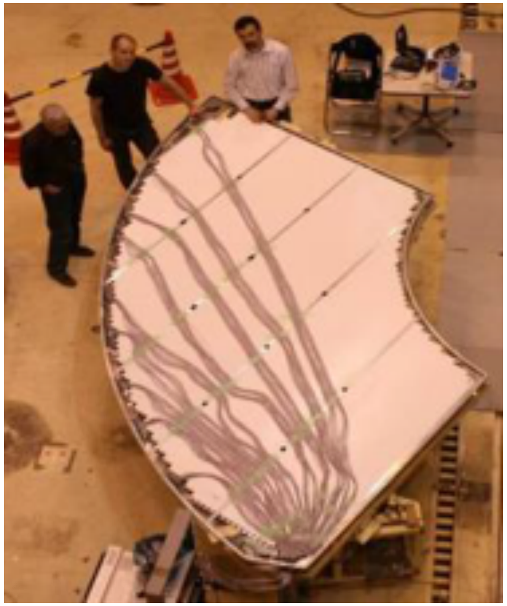
Early prototype tested at Belle



K_L and Muon Systems (KLM)

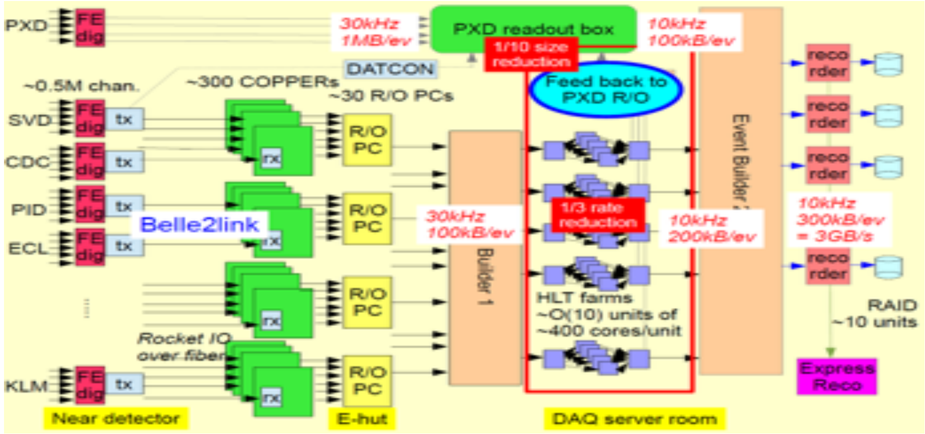
- Endcaps and two innermost barrel RPC layers of Belle were replaced with scintillators due to the increased backgrounds.
- Installation completed
- Commissioning in progress with cosmic rays





Trigger and DAQ

- Challenge
  - High luminosity, high background
  - Low multiplicity signatures challenge trigger
- Trigger
  - Hardware based Level 1 (L1) + software based High Level Trigger (HLT)
  - Develop trigger menu
- DAQ
  - Maximum readout rate ~30 kHz
  - Event rate after HLT ~10 kHz
  - Parallel processing ~ 3000 cores

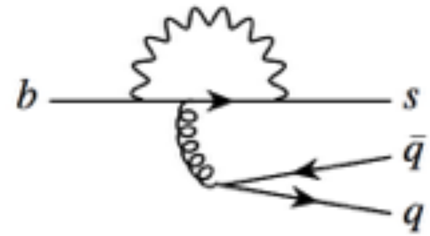


Physics Prospects

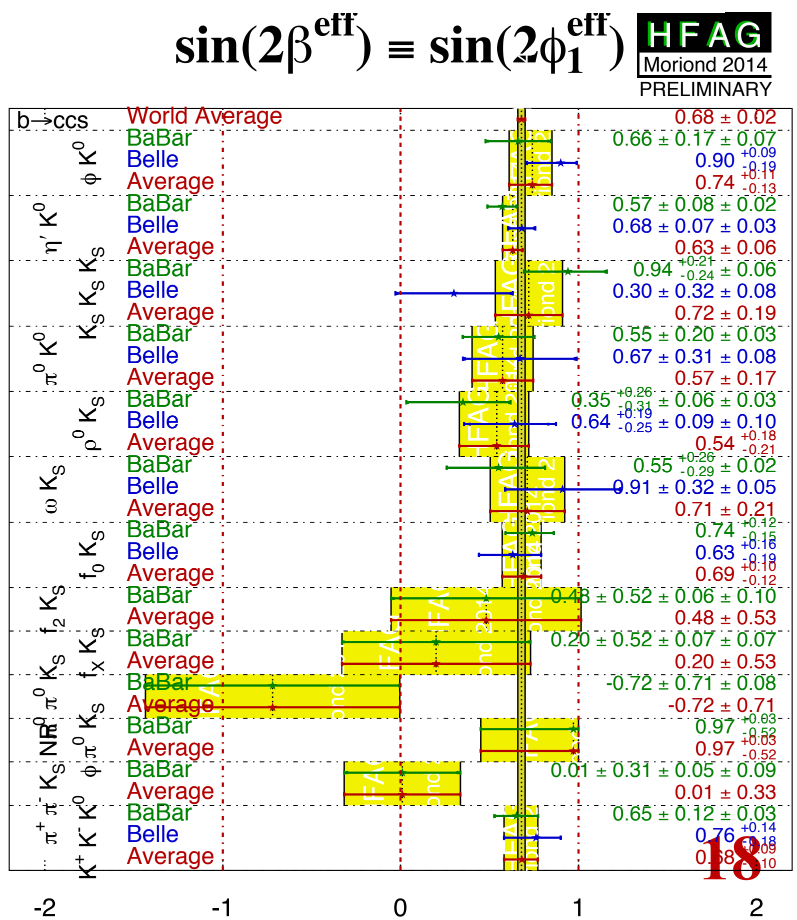
- B and D decays
  - precision measurements of CKM elements
  - rare B and D decays
- Beyond the Standard Model
  - new Higgs
  - dark photons or other dark matter particles
  - LFV
- Hadron spectroscopy
  - 4-quark states
  - bottomonium spectrum
  - exotics states

Penguin b→s decays

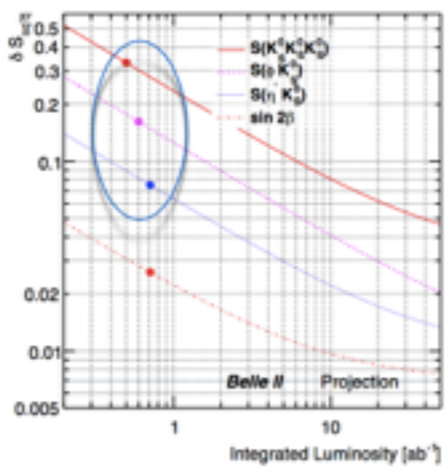
- Precision measurements of sin(2***β***) is important for the search of new sources of CPV



- b→s transition via penguin diagram
- sensitive to possible new heavy particle contributions



- Belle II



sin(2β)	σ(stat)@ Belle	σ(stat)@Belle II 50 ab^{-1}
B→ΦK^0	0.09	0.018
B→η'K^0	0.07	0.011
B→KsKsKs	0.32	0.033

EWP: B→K$^{(*)}$ νν

- SM: penguin + box digram

  $B_{SM}(B^+ \to K^+\nu\nu) = (4.0\pm0.5)\times10^{-6}$

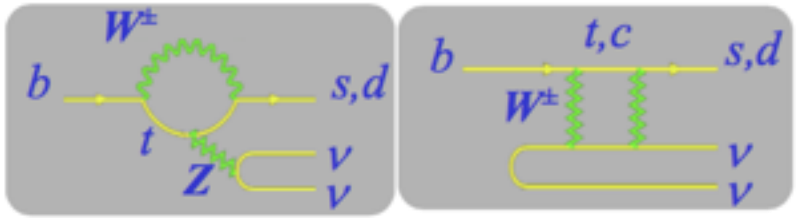
  $B_{SM}(B^0 \to K^{*0}\nu\nu) = (9.2\pm1.0)\times10^{-6}$

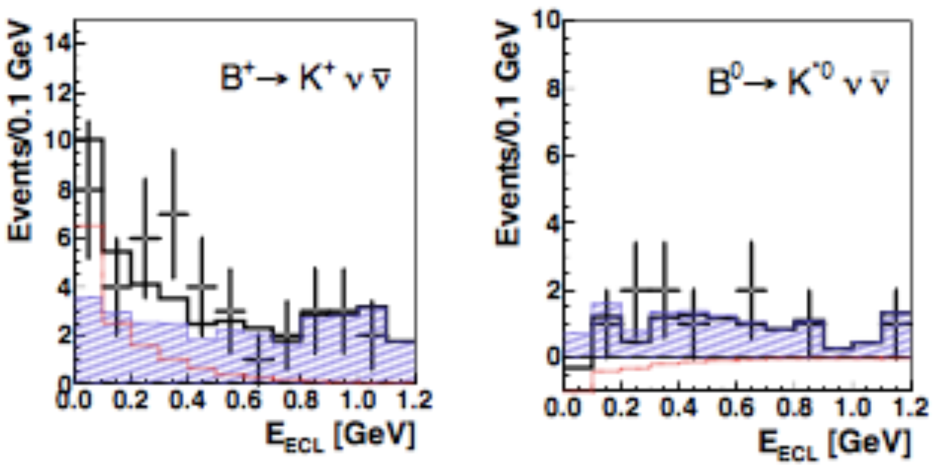
  arXiv: 1409.4557

- Belle:

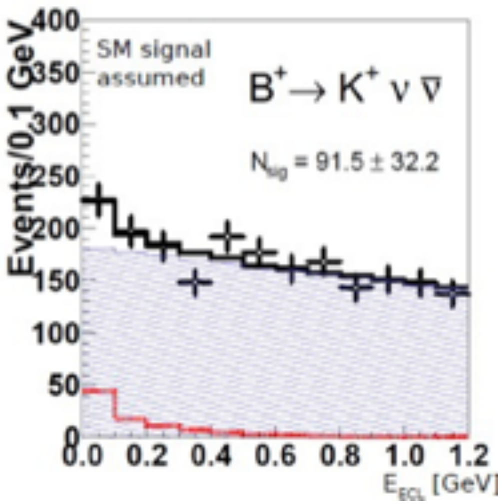
  $B(B^+ \to K^+\nu\nu) < 5.5\times10^{-5}$,
  Nsig=13.3+7.4-6.6, 2.0σ

  $B(B^0 \to K^{*0}\nu\nu) < 5.5\times10^{-5}$





Belle, PRD 87, 111103(R) (2013)

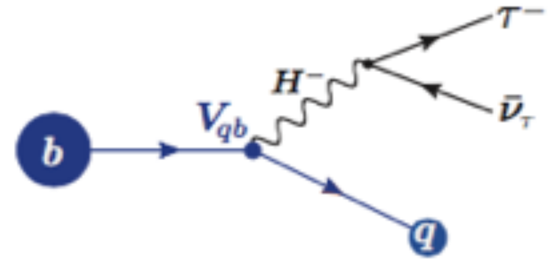


Belle II:
Nsig~91.5±32.2@50 ab^{-1}

Semi-leptonic B decays

Semi-tauonic decay modes are highly sensitive to new physics

$B \to D^{(*)} \tau\nu$: WA is ~4σ from the SM!



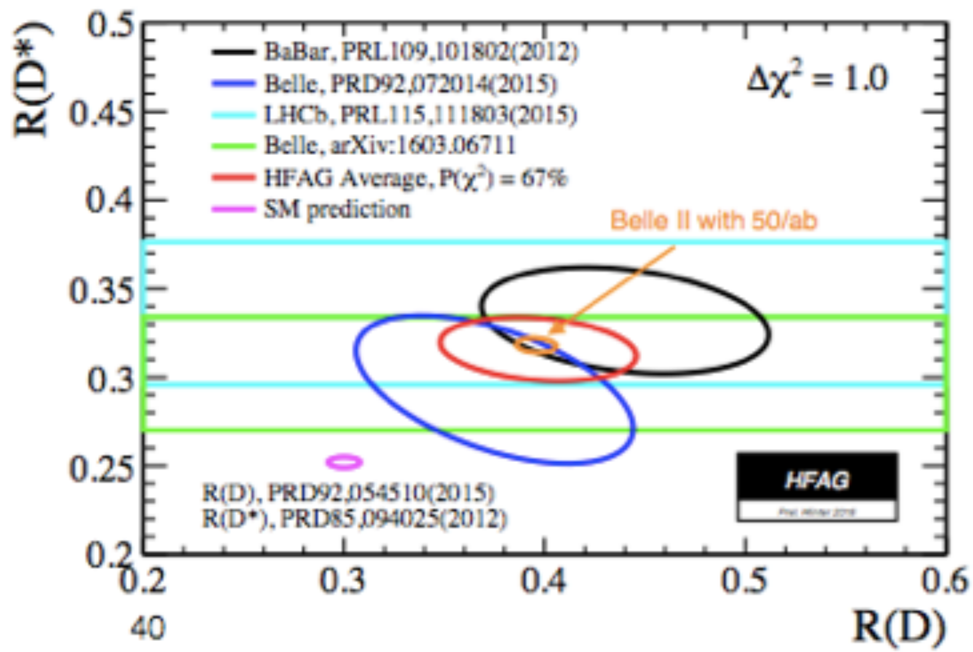
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\,\ell\,\bar{\nu}_\ell)}$$

$R(D)$

Error	stat.	tot.
B-Factories	13%	16.2%
Belle II 5/ab	3.8%	5.6%
Belle II 50/ab	1.2%	**3.4%**

$R(D^*)$

Error	stat.	tot.
B-Factories	7.1%	9.0%
Belle II 5/ab	2.1%	3.2%
Belle II 50/ab	0.7%	**2.1%**



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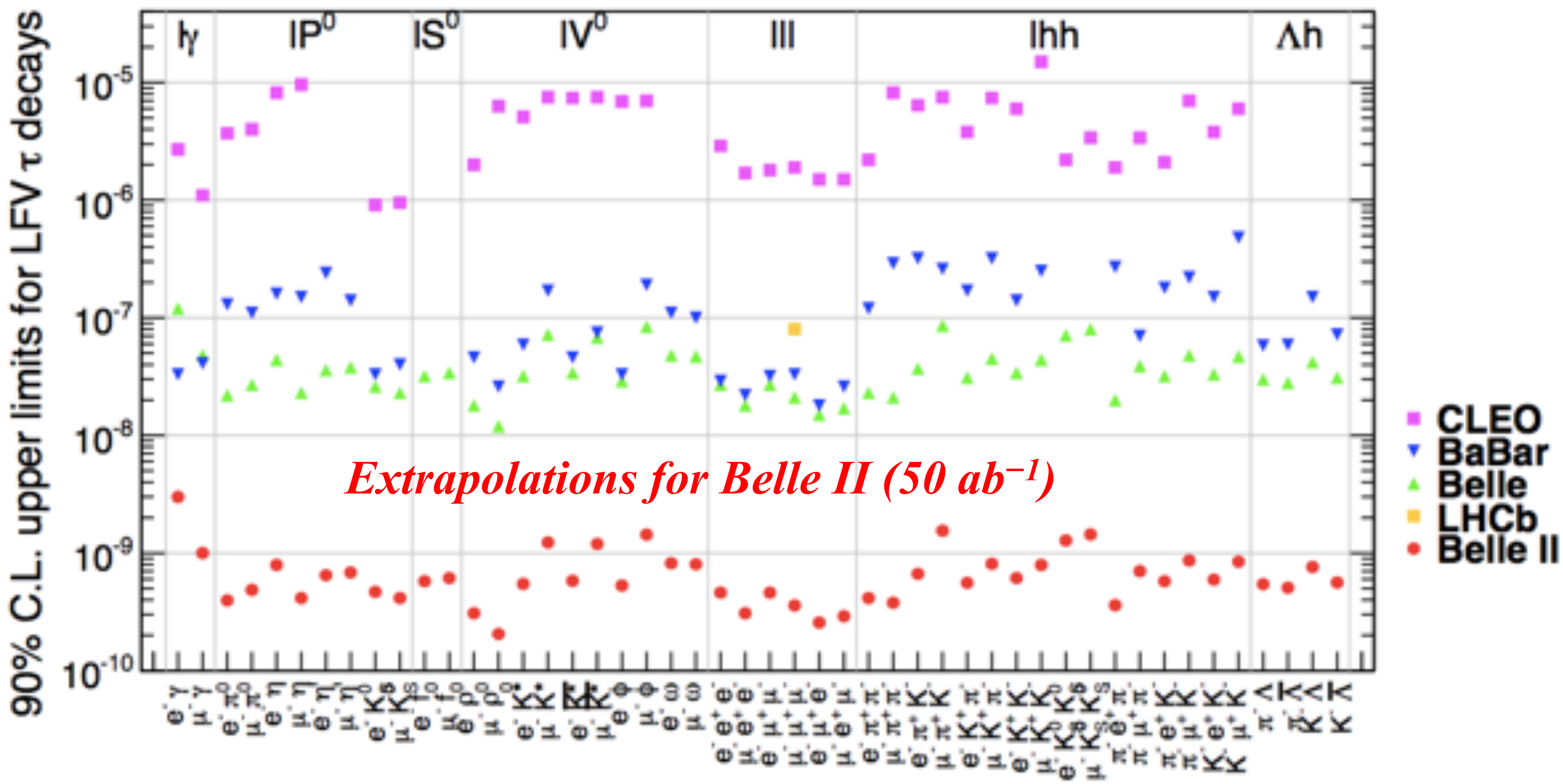
LFV τ decays

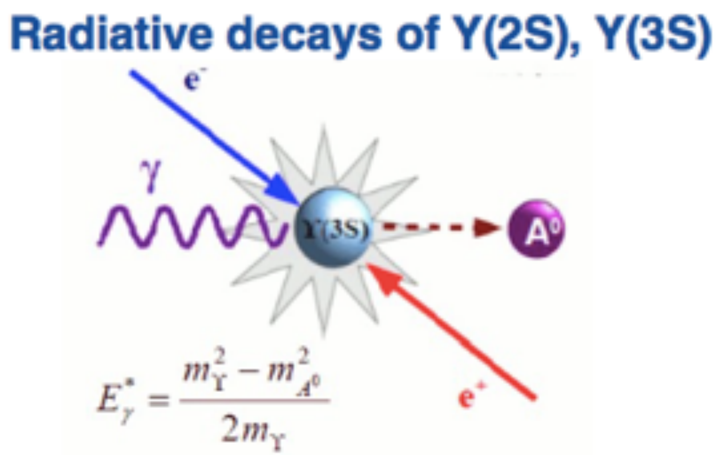
- Lepton Flavour Violation is highly suppressed in the SM (e.g. $Br(\tau \to \mu\gamma) \sim 10^{-40}$), LFV τ decays are clean probes for New Physics effects



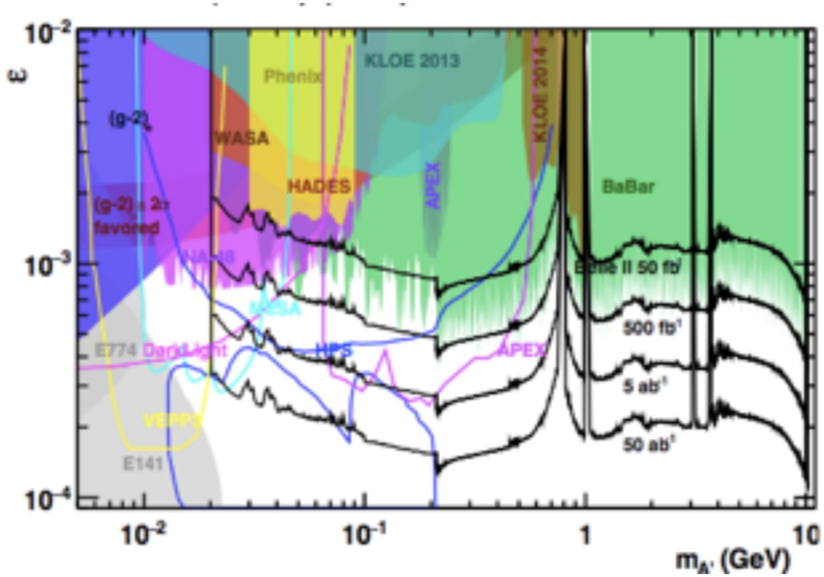
- Belle II : Sensitivity for LFV decay rates is at least one order higher than Belle

Dark Sector

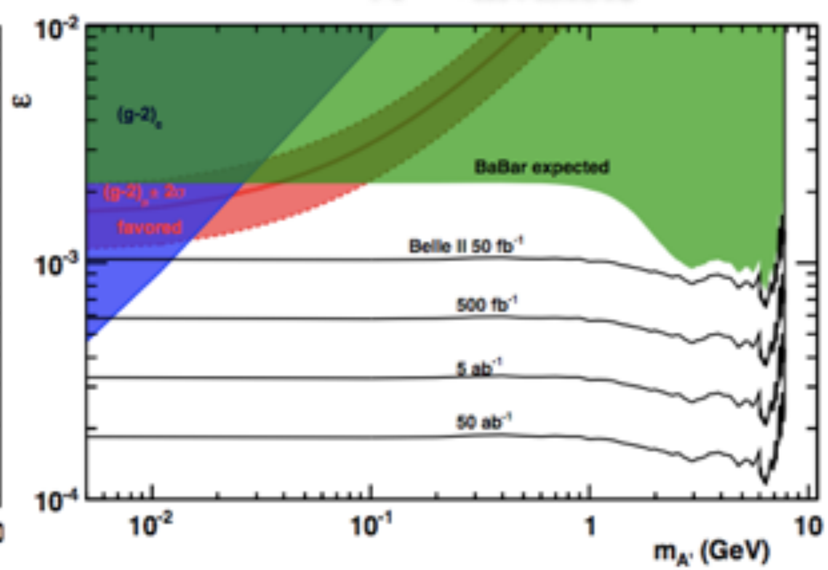
- Dark photon A', motivated be in MeV-GeV mass
    - probe leptonicaly decaying dark photons through mixing
    - probe sub-GeV dark matter in invisible decays



A' →ll



A' →invisible

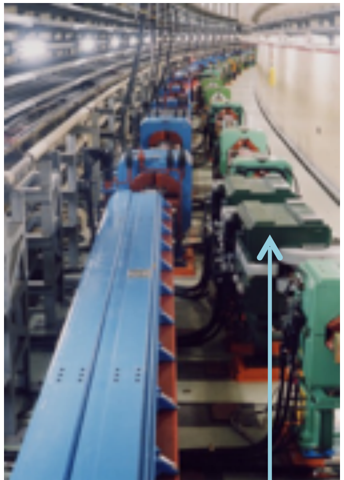


Summary

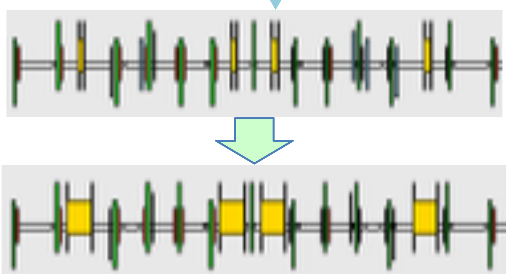
- Rich physics at Belle II, e.g. new CPV phases, LFV, dark sectors, exotic states.
- Many upgrades: accelerator, detector, trigger, and DAQ etc.
- SuperKEKB phase 1 commissioning has started.
- Belle II will start physics data taking in 2017 with part detectors (no VXD) and with all detectors in 2018.

Backup

KEKB → SuperKEKB

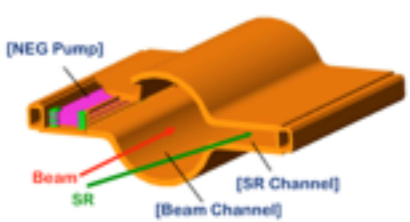


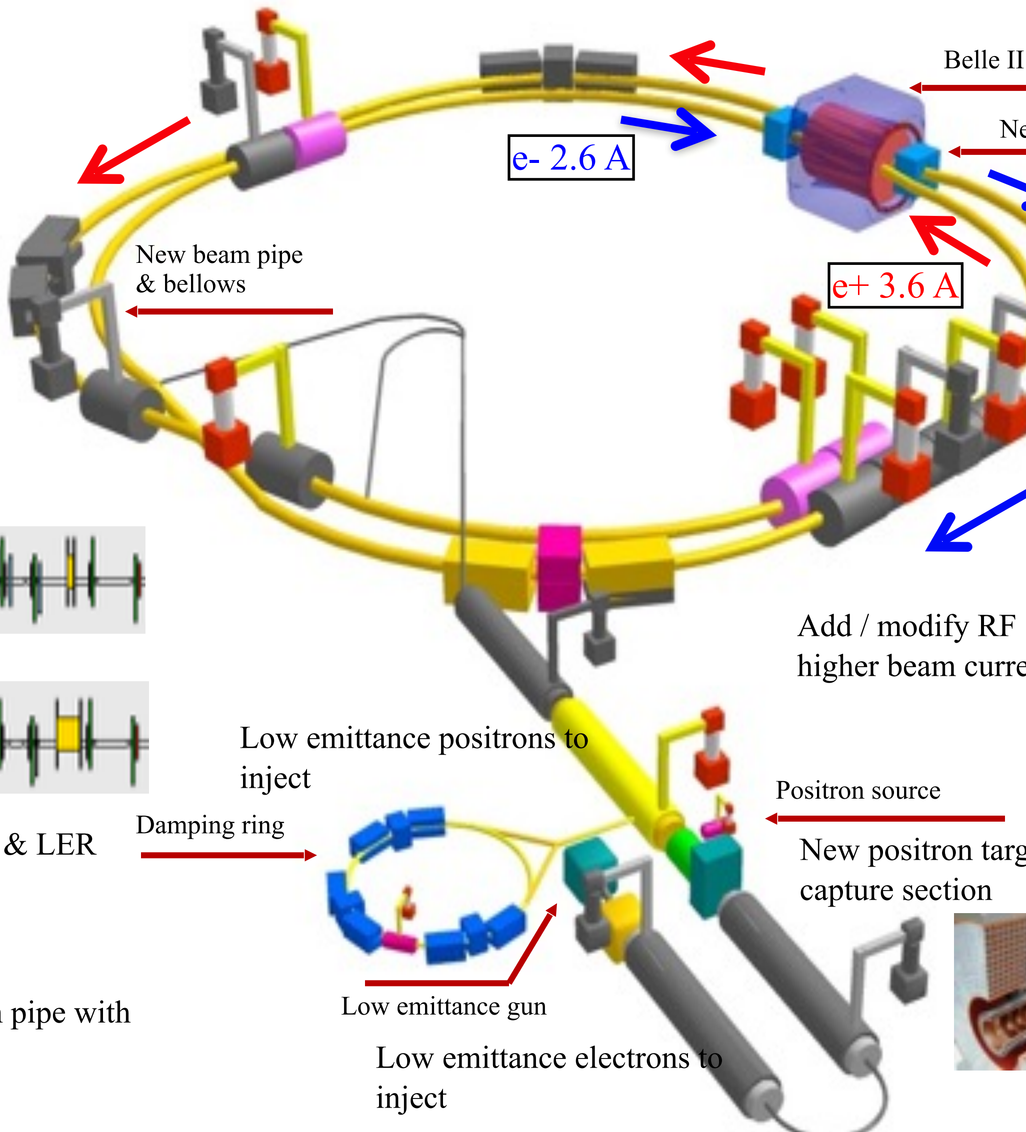
Replace short dipoles with longer ones (LER)



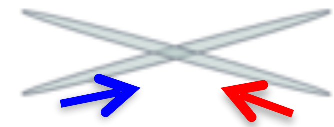
Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers





Colliding bunches



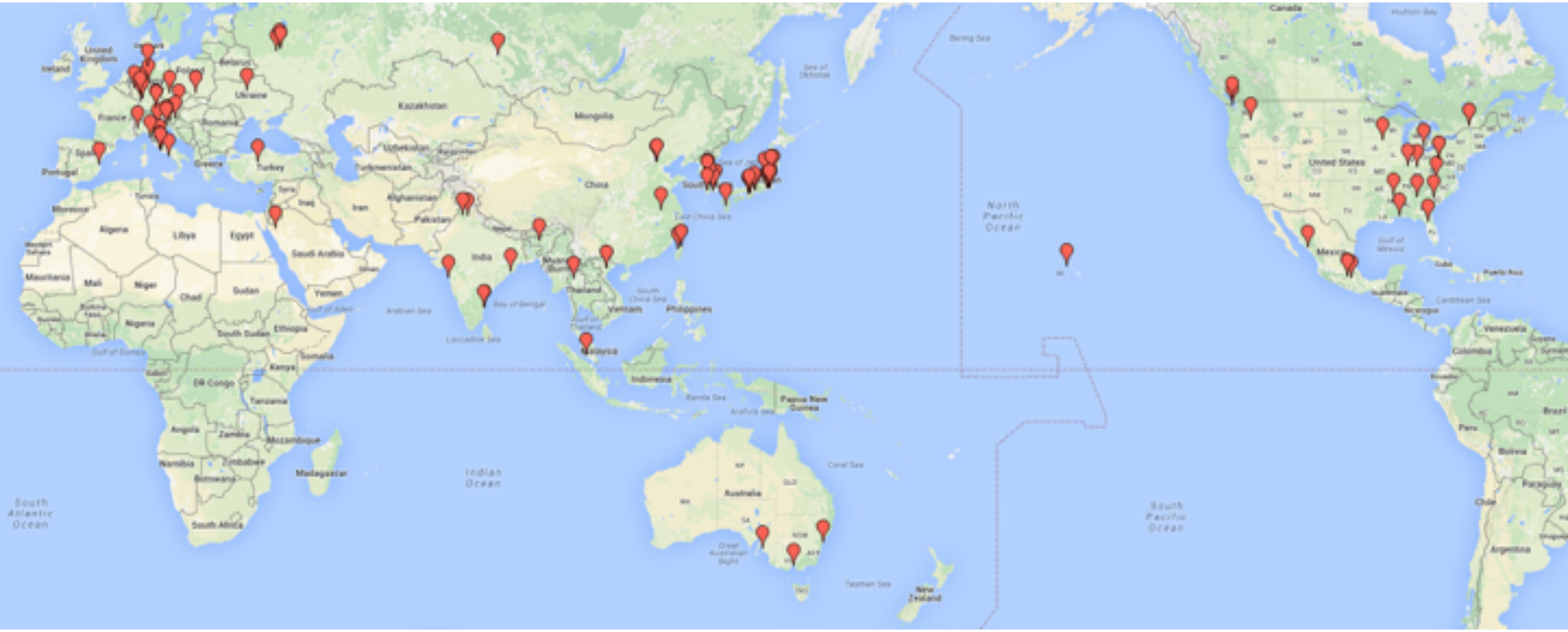
New superconducting / permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

To obtain x40 higher luminosity

Belle II Collaboration



570 Members
98 Institutions
23 Countries/regions

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (0.9^\circ)$	0.4°	0.3°	0.6°	0.3°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)}K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s(B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta_s^{\rm eff}(B_s \to K^{*0}\bar{K}^{*0})$ [rad]	–			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0\pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		
UT sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$	1.8%	1.4%		
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$	3.4%	3.0%		
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 10.8\%)$	4.7%	2.4%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440(1 \pm 16.5\%)^\dagger$	5.6%	3.4%		
	$R(B \to D^*\tau\nu)^\dagger$ [Had. tag]	$0.332(1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...	
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$2\beta_s^{\rm eff}(B_s \to \phi\gamma)$	–			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40	< 15	30%		
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s\ell\ell)$	~20%	10%	5%		
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ [10^{-9}]	$2.9^{+1.1}_{-1.0}{}^*$			0.5	0.2

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 2018	LHCb 50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-4}]	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ [10^{-3}]	3.4^*			0.5	0.1
	A_Γ [10^{-2}]	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K^0_S\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K^0_S\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K^0_S\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p\rvert(D^0 \to K^0_S\pi^+\pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K^0_S\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm ^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ [10^{-9}]	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0	< 3.0	< 0.3		