The Belle-II Detector and KEKB Accelerator Upgrades, Physics Prospects at Belle-II

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On Behalf of Belle II Collaboration

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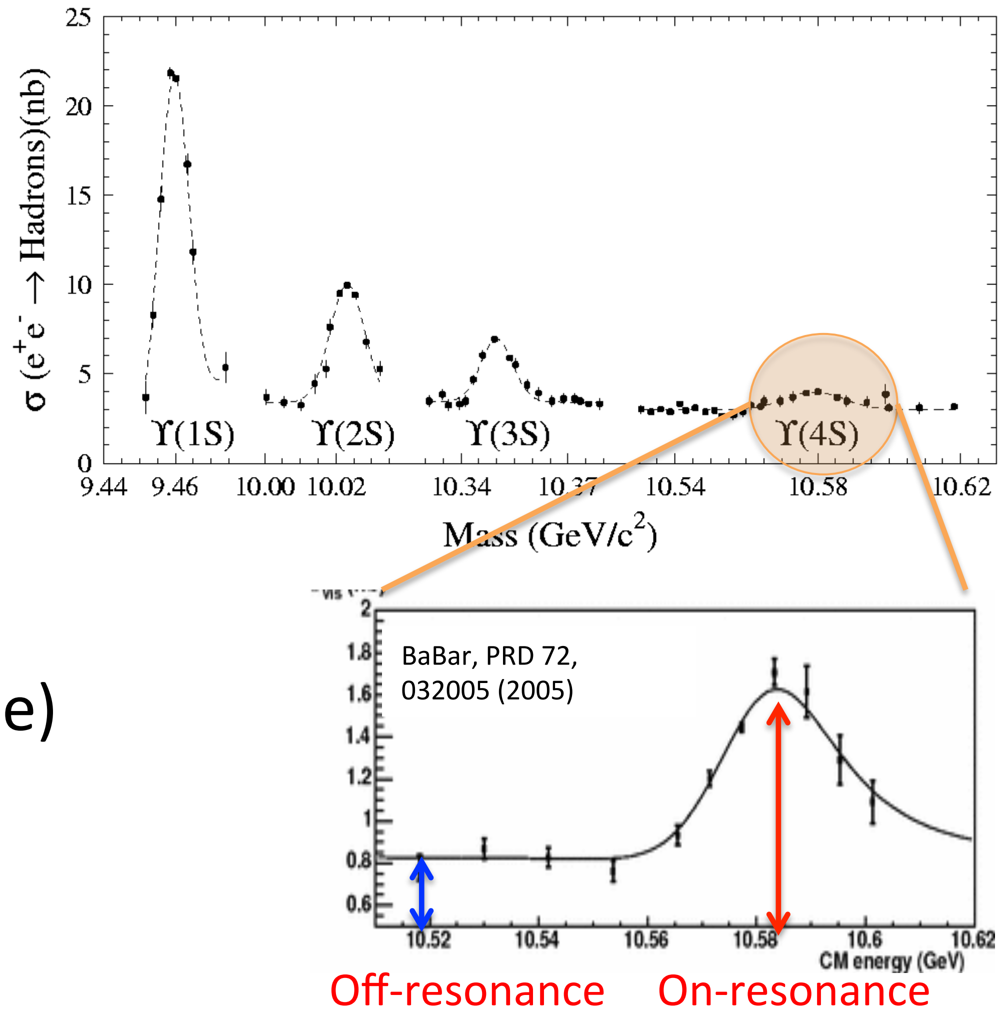
Lake Louise Winter Institute, Canada

Outline

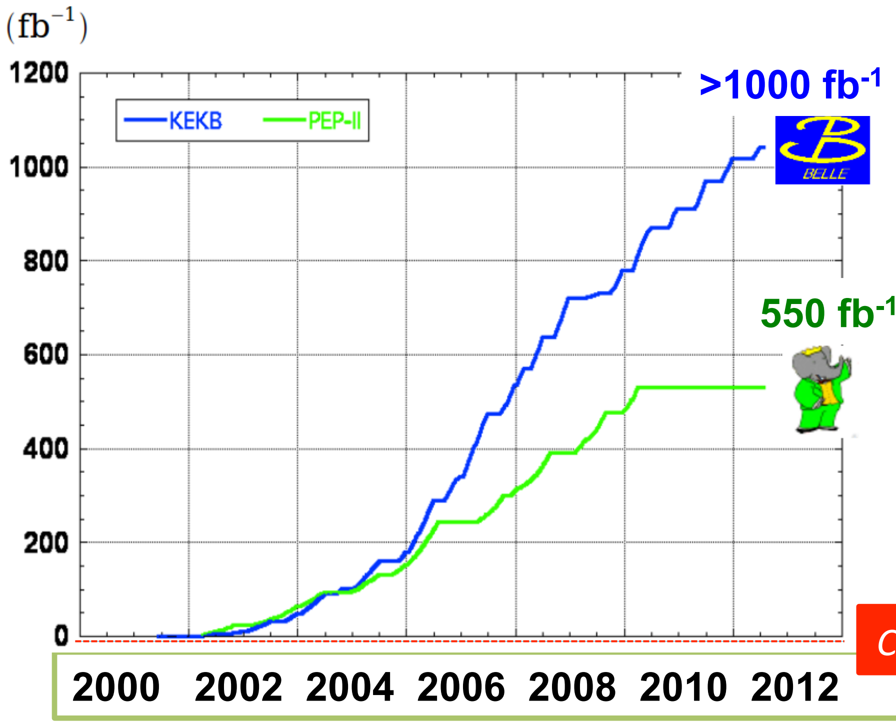
- Super KEKB accelerator
- Belle II detector
- Physics Prospects at Belle-II
- Summary

The B Factories

- Belle at KEKB
  BABAR at PEP-II
- Very high luminosity:
  – ~$2\times10^{34}/cm^2/s$ (Belle)
    (twice the design value)
- Asymmetric beams:
  – 8GeV e^-/3.5 GeV e^+ (Belle)
    → Boosted BB pairs
      (→ time dep. CPV)



The Belle + BaBar Era



CLEO 11 fb^{-1}

Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

Belle-II Goal: *40 x present = 4 x 10^{10} BB pairs* ***...but how to do it?***

How to achieve 40x luminosity? Super-KEKB

Lorentz factor

Beam current

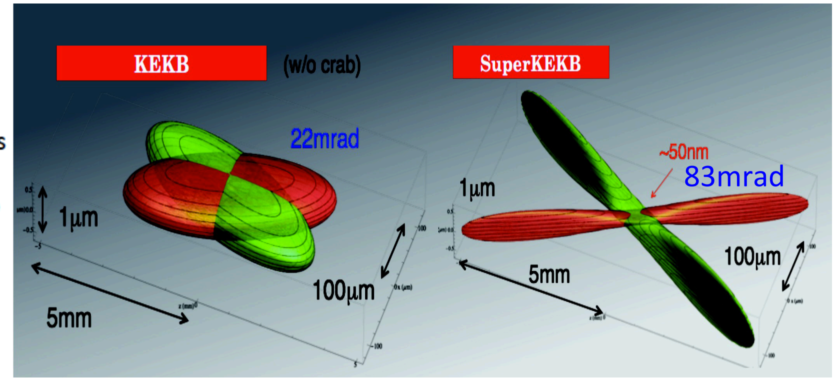
Beam-Beam parameter

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

Geometrical reduction factors (crossing angle, hourglass effect)
(0.8-1.0)

Vertical beta function at IP

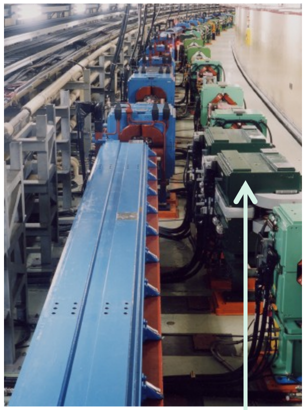
Beam aspect ratio at IP
(0.01-0.02)



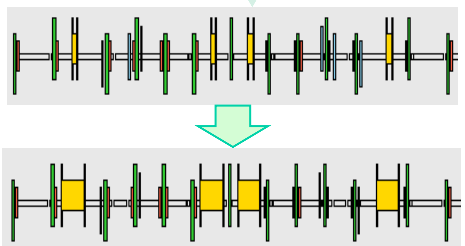
	KEKB Achieved	SuperKEKB
Energy (GeV) (LER/HER)	3.5/8.0	4.0/7.0
ξ_y	0.129/0.090	0.090/0.088
β_y^* (mm)	5.9/5.9	0.27/0.41
I (A)	1.64/1.19	3.60/2.62
Luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$)	2.11	80

beam size: *100 µm(H) x 2 µm(V) → 10 µm(H) x 59 nm(V)*

KEKB→SuperKEKB

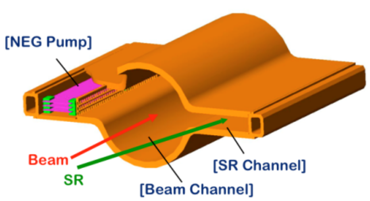


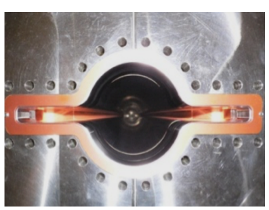
Replace short dipoles with longer ones (LER)

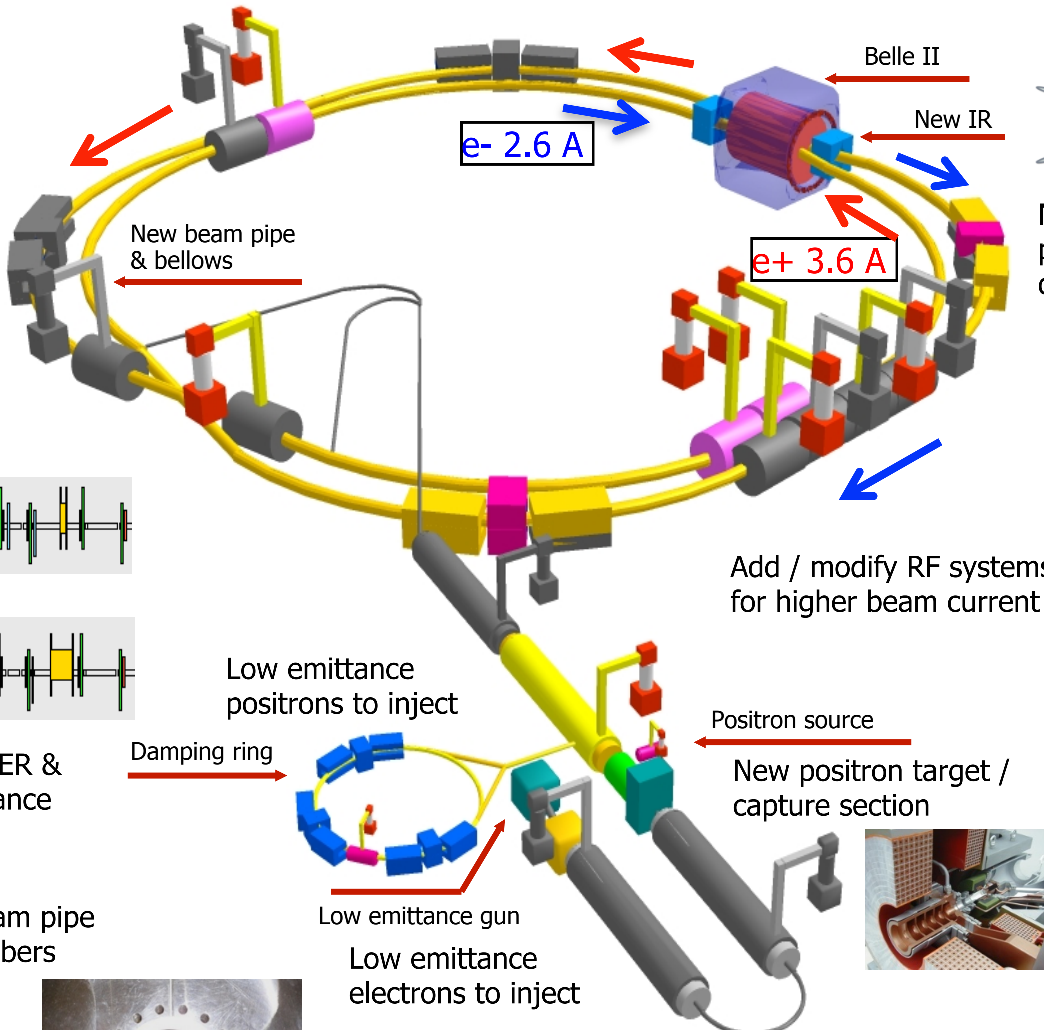


Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers



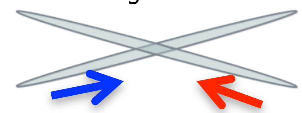




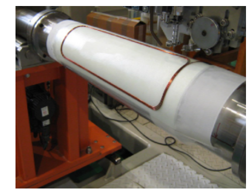
Low emittance positrons to inject

Low emittance electrons to inject

Colliding bunches



New superconducting / permanent final focusing quads near the IP

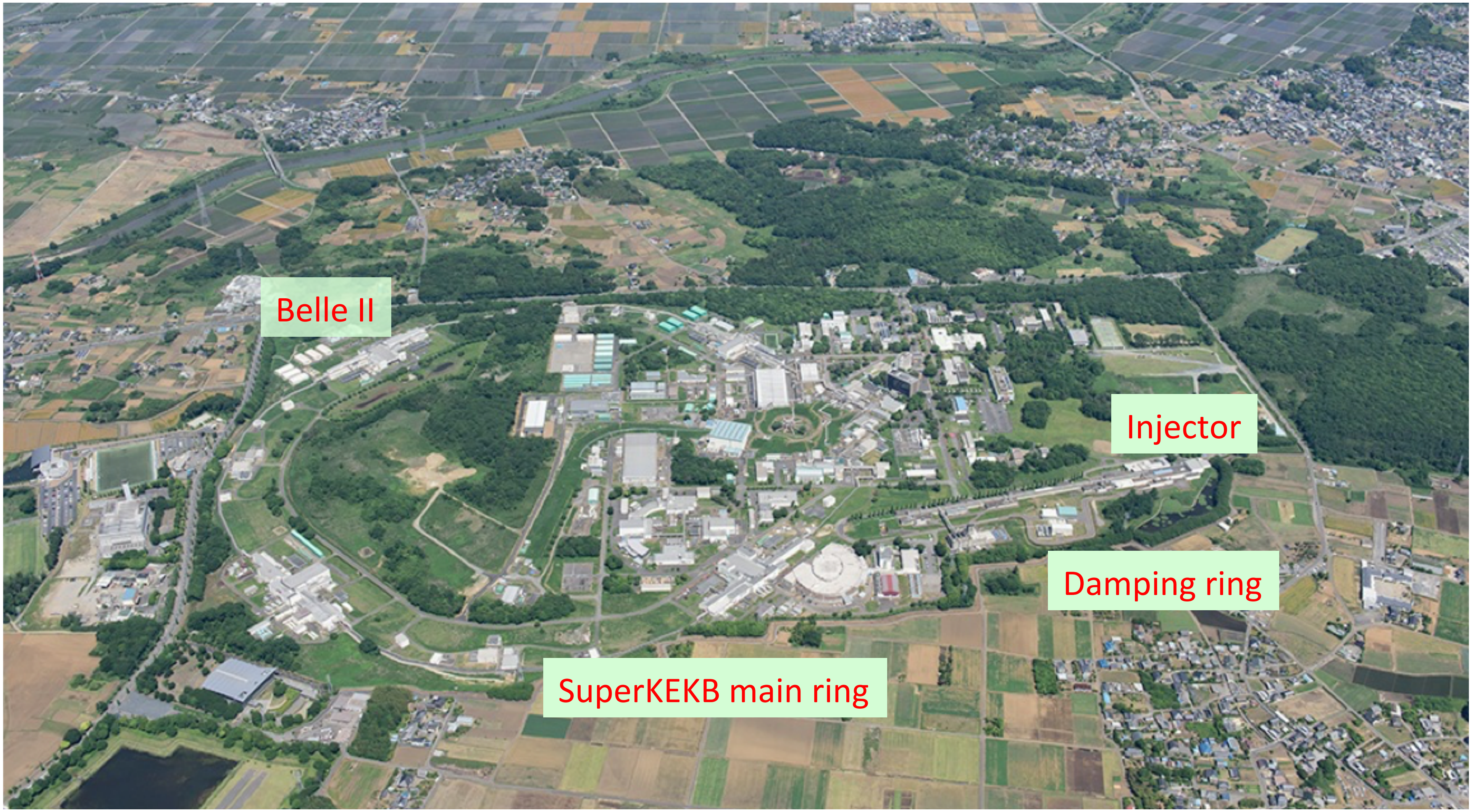


Add / modify RF systems for higher beam current

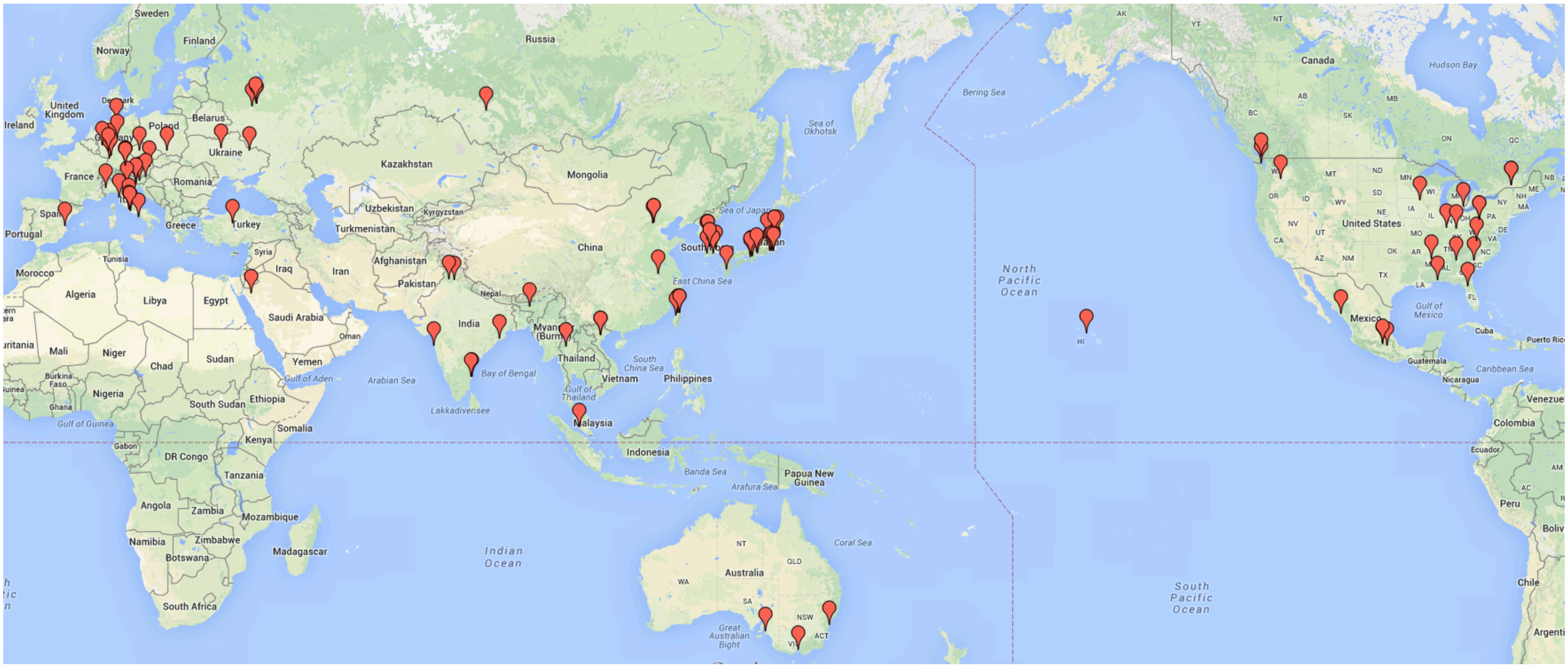
New positron target / capture section

To get 40x higher luminosity

SuperKEKB and Belle II



Belle II collaboration



http://belle2.kek.jp

Base on Belle collaboration. Many people from Belle and Babar.

678 colleagues, 103 institutions, 25 countries/regions

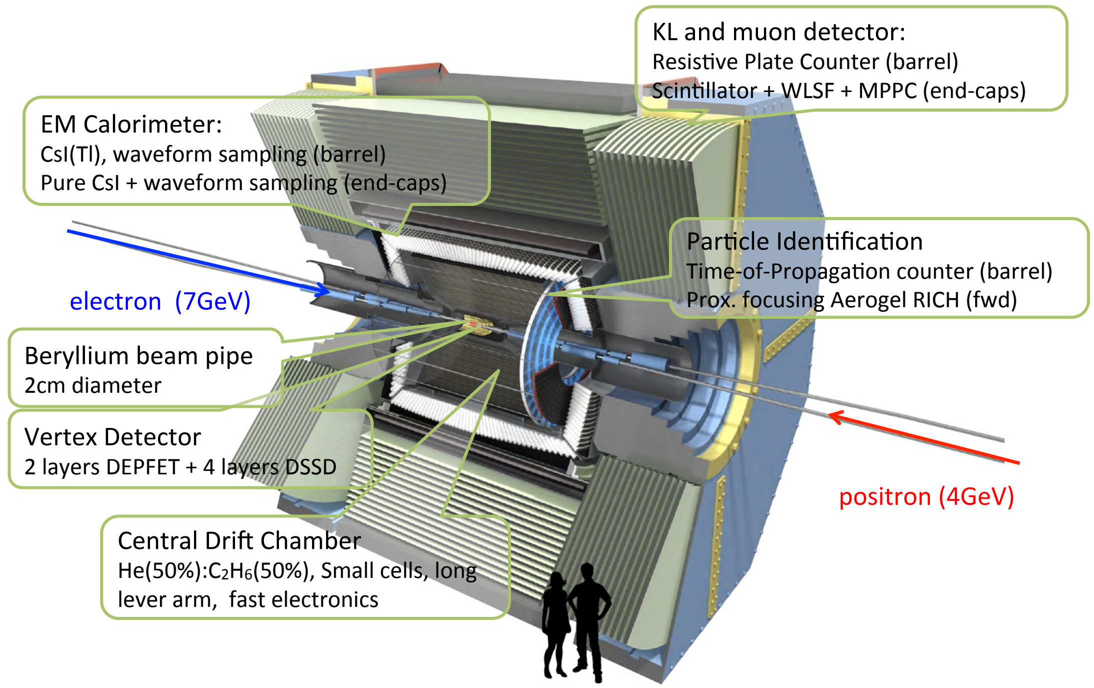
Requirements for detector

- Higher beam-related and QED backgrounds
- L1 trigger rate 30kHz vs 500Hz for Belle
  - Stability to high background; fast readout
  - Better performance (vertex resolution, tracking, PID, esp. improve K/π separation)
  - ……

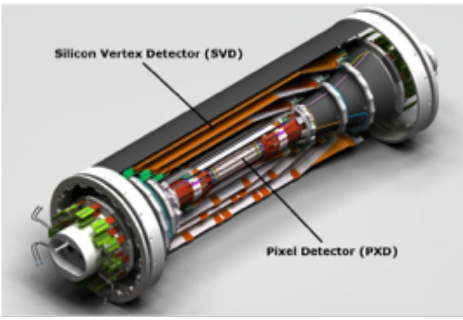
Belle II detector

Belle II is built on the base of Belle

- Main structure and magnet are reused
- ECL and KLM are mostly reused
- Vertex, drift chamber, PID, partially KLM are upgraded
- All electronics are replaced



BELLE II: VXD



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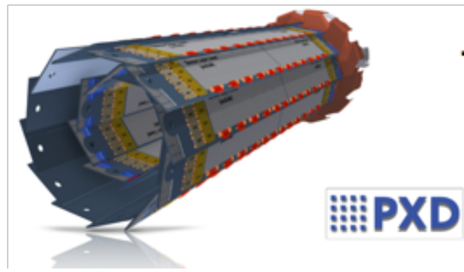

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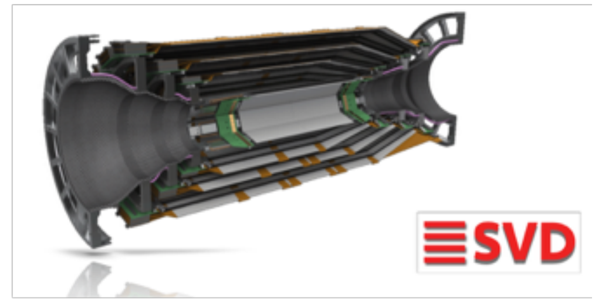
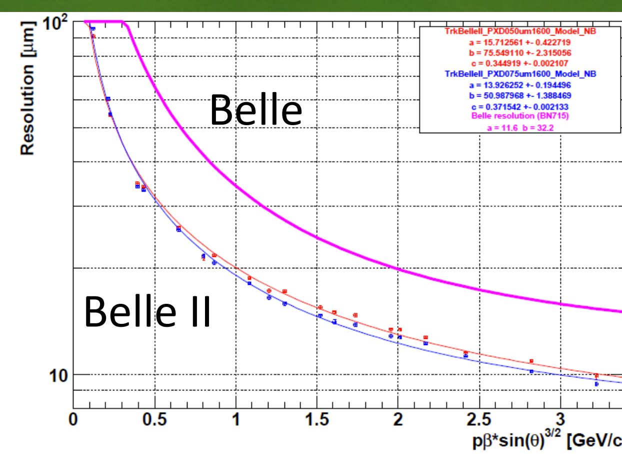


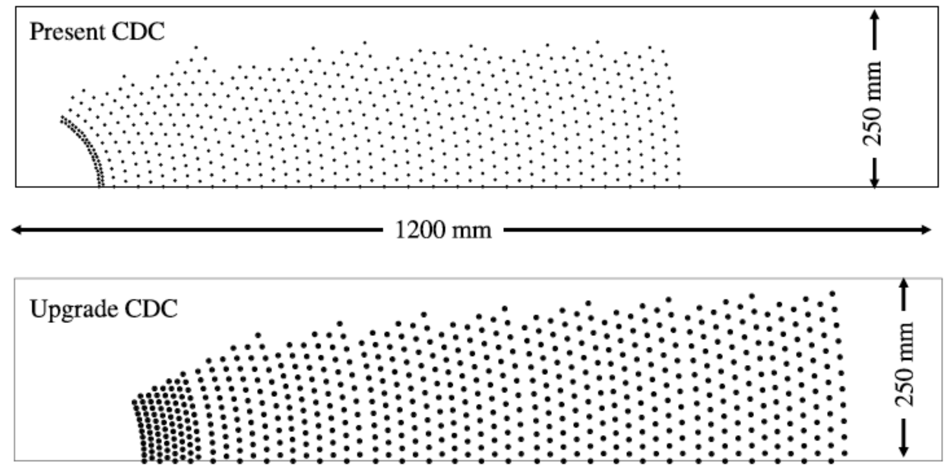
- Layers 1-2: Pixel detectors (PXD)
- Layers 3-6: Strip detectors (SVD)
- Smallest radius 14mm (vs 20mm for Belle)
- Largest radius 135mm (vs 88mm for Belle)
- Much lower momentum tracking can be tracked

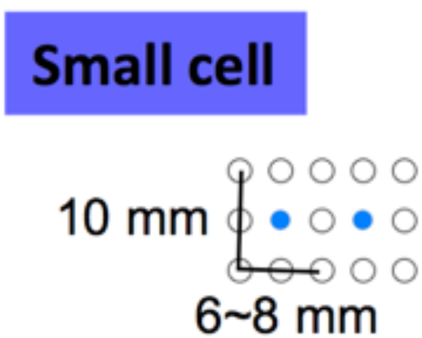


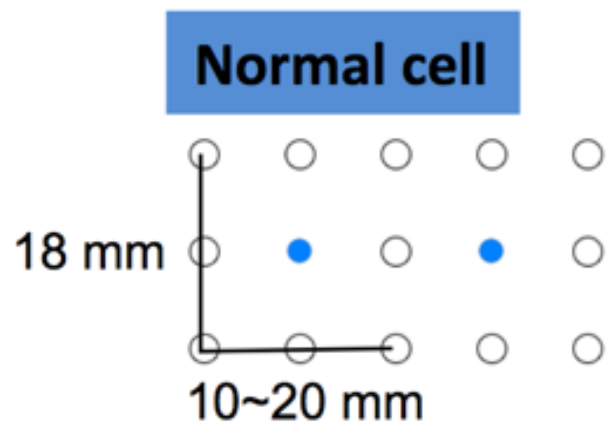
Belle II: CDC

Much better momentum and dE/dx resolution than Belle CDC

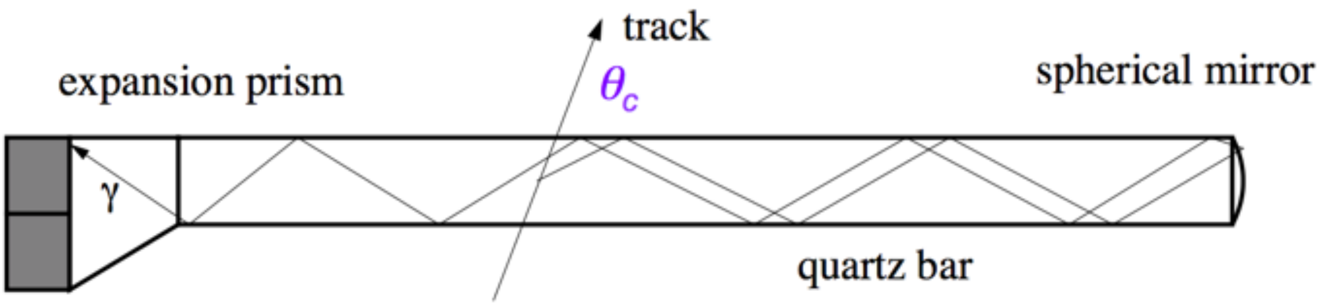
	Belle	Belle II
Radius of inner cylinder (mm)	77	160
Radius of outer cylinder (mm)	880	1130
Radius of innermost sense wire (mm)	88	168
Radius of outermost sense wire (mm)	863	1111.4
Number of layers	50	56
Number of sense wires	8,400	14,336
Gas	He–C_2H_6	He–C_2H_6
Diameter of sense wire (μm)	30	30



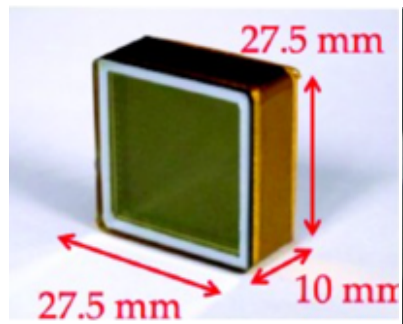


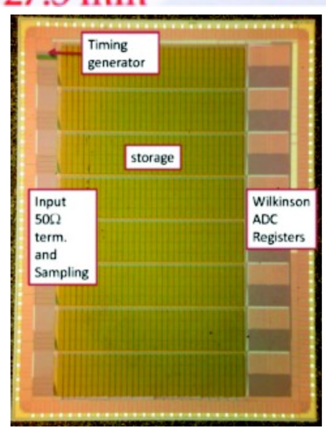


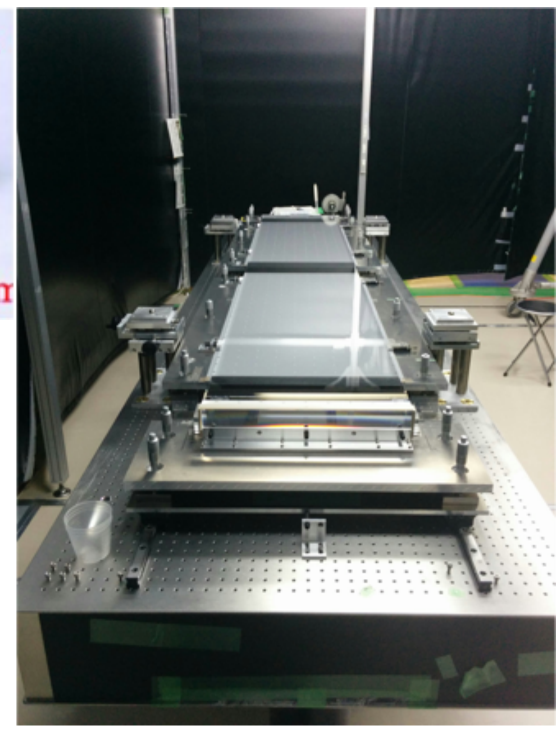
Belle II: TOP



- The imaging Time of Propagation sub-detector (TOP) will be used for particle identification in the barrel region of Belle II
- Each TOP module consists of two quartz bars, one mirror, one prism, and an array of photo-detectors to collect Cerenkov photons from charged tracks
- To distinguish between kaons and pions, the photo-detectors should have excellent position and timing resolution
- This is achieved by using MCP-PMTs and new waveform sampling electronics

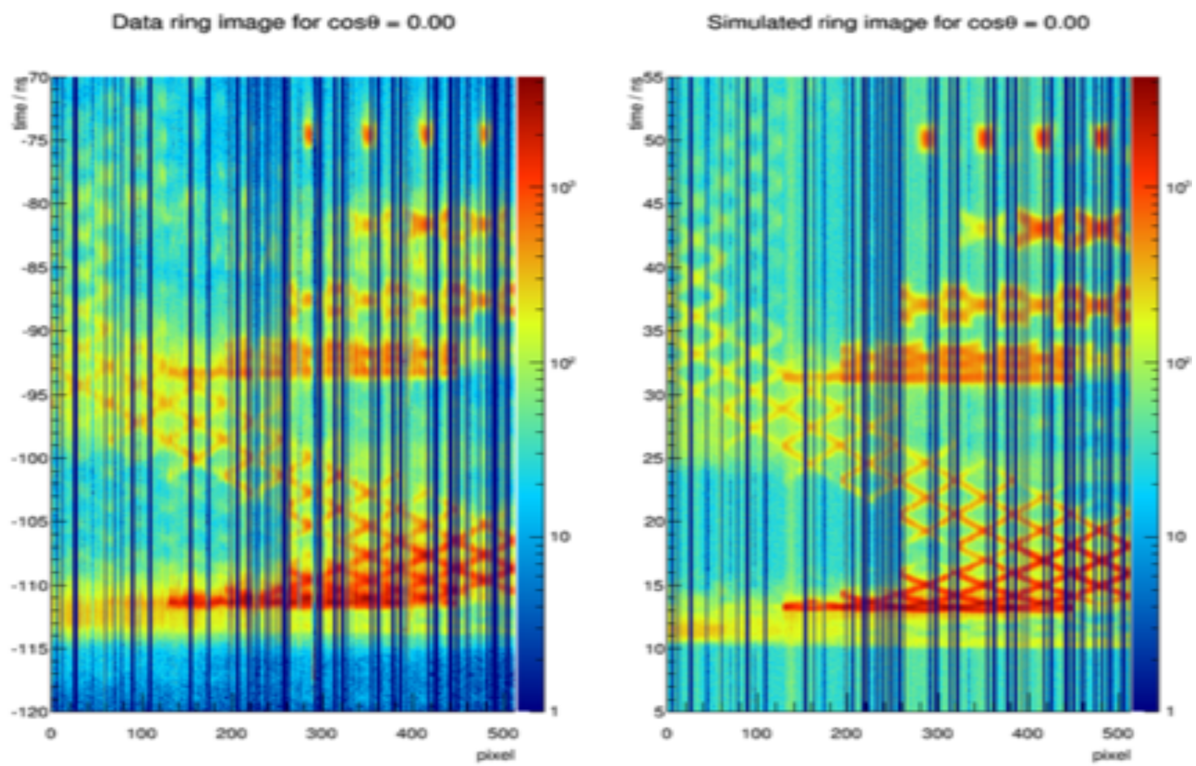






BELLE II: TOP

Beam Test at LEPS (June 2013)

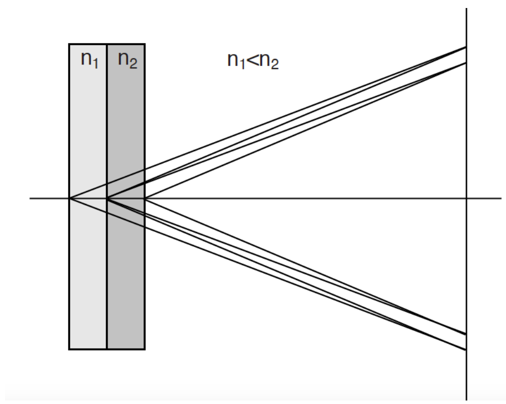


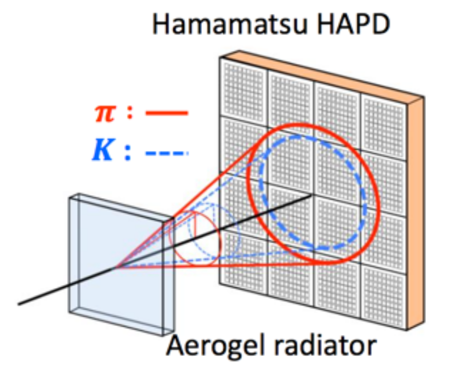
- TOP modules have been tested at beam test at SPring-8 LEPS in 2013, and good agreement between data and MC simulation has been obtained, with timing requirement ~O(100ps)
- All 16 modules have been assembled (the optical and mechanical parts).
- Transportation of three modules to Tsukuba hall took place in early Feb. 2016, one module has been installed in the Belle II detector on Feb. 10 successfully, another 15 modules will be installed over the next several months.

Installation of first TOP module

BELLE II: ARICH

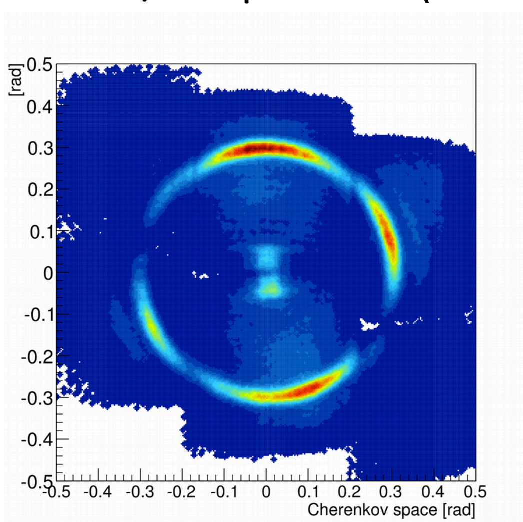
- Aerogel Ring Imaging Cherenkov (ARICH) detector will be used for particle identification in the forward end cap
- 420 Hybrid Avalanche Photo Detectors (HAPD), each with 144 channels
- Two layers of aerogel lead to better photon yield, while not affecting resolution



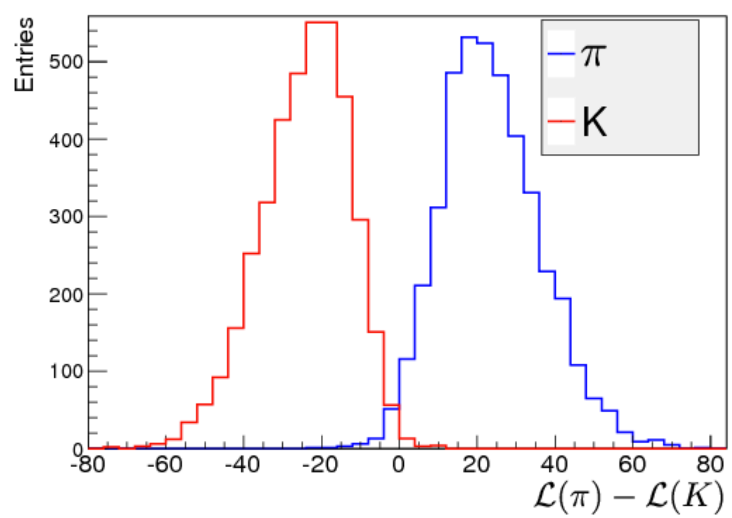


End-cap PID: Aerogel RICH (ARICH)

ARICH testbeam: K/π separation (3GeV) at 5σ

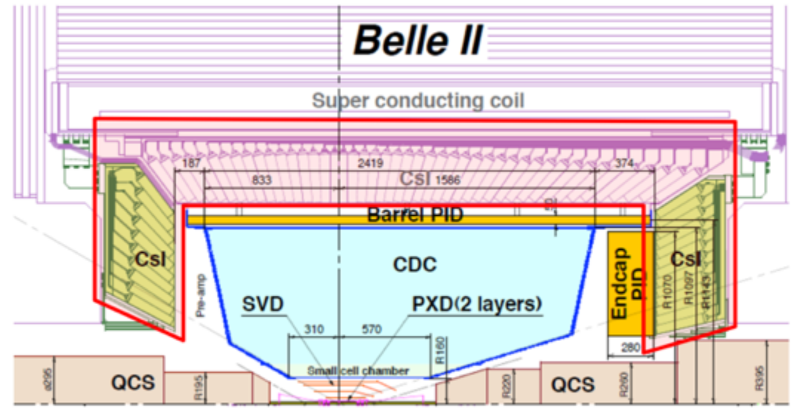


ARICH simulation: likelihood of K/π ID

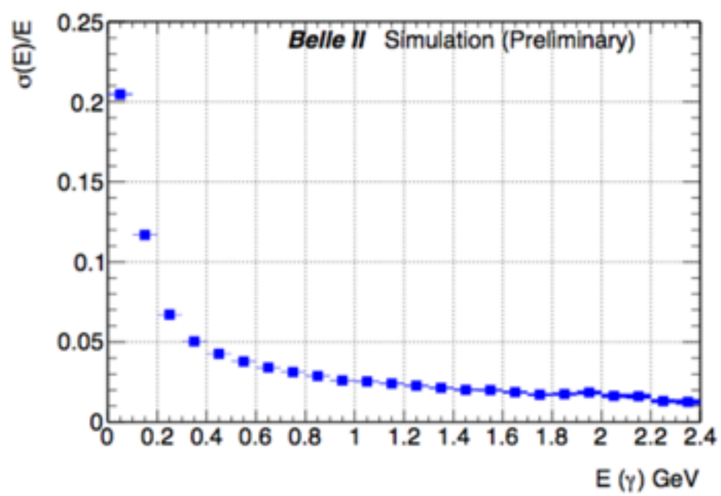


BELLE II: ECL

- Upgrades for high backgrounds:
  - Barrel: CsI(Tl) crystals reused, new electronics for waveform sampling
  - Endcaps: old crystals refurbished, bias filter is modified
- Hardware tests have been carried out in the past years
  - pure CsI + APD can fit the requested performance in terms of signal to noise ratio
- FE electronics has been developed for the readout of the system



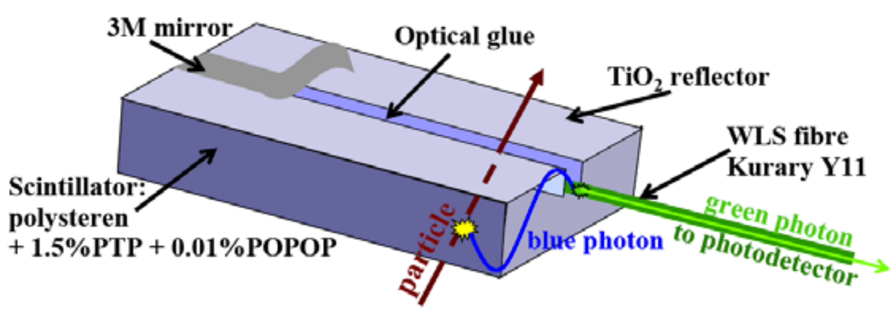
Expected performance

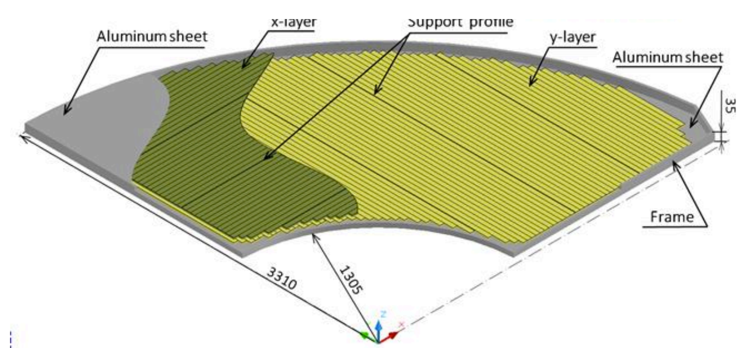


BELLE II: KLM

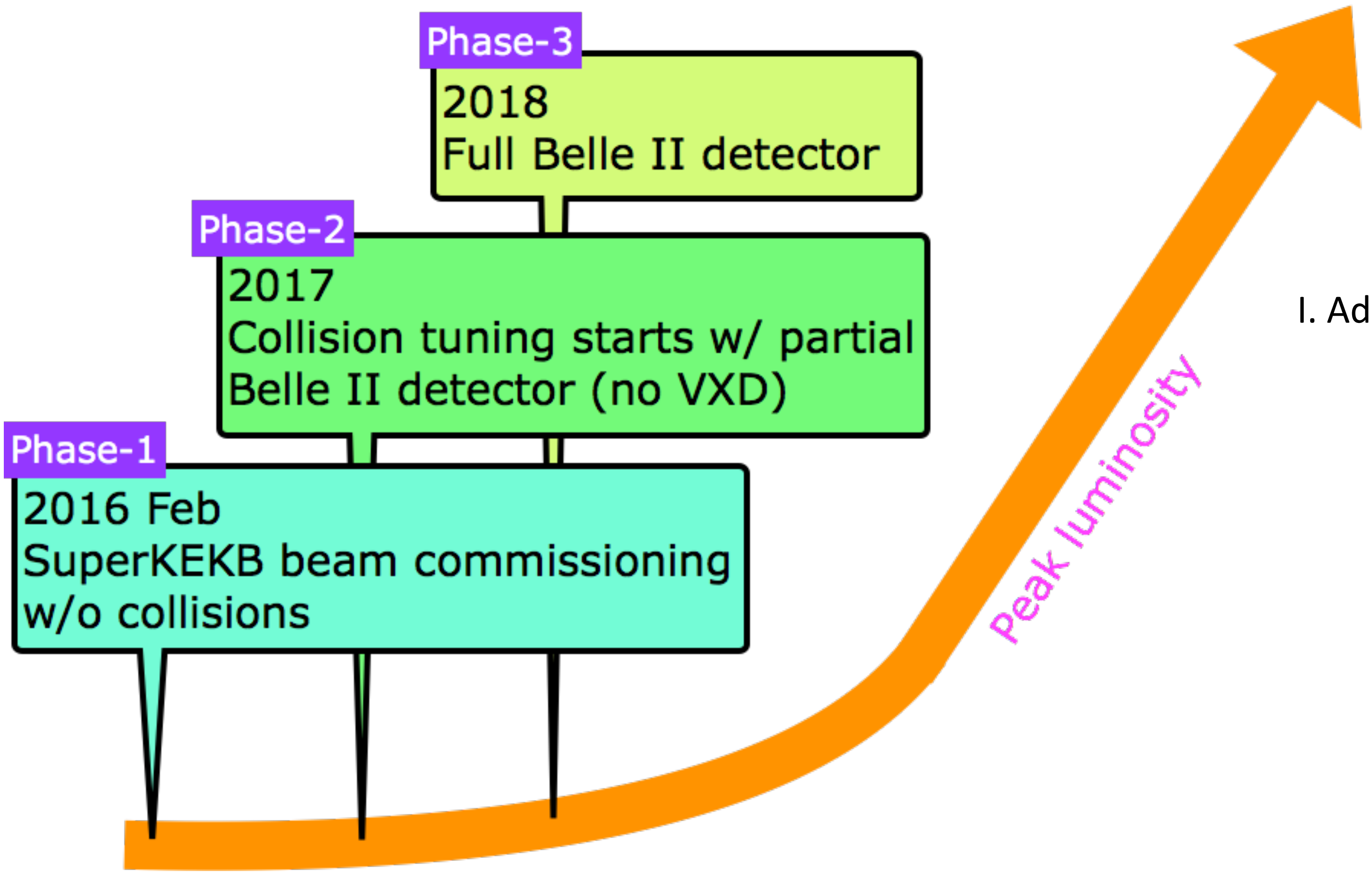
The outermost detector for K_L – μ detection

- Replace RPCs in the endcaps and two inner barrel layers with scintillator (strips with WLS fibers and MPPC detectors).
- Installation completed.
  - Barrel : 2013
  - End-cap : 2014 summer
  - Pol. shield : 2015 spring
  - Checking raw signal done.



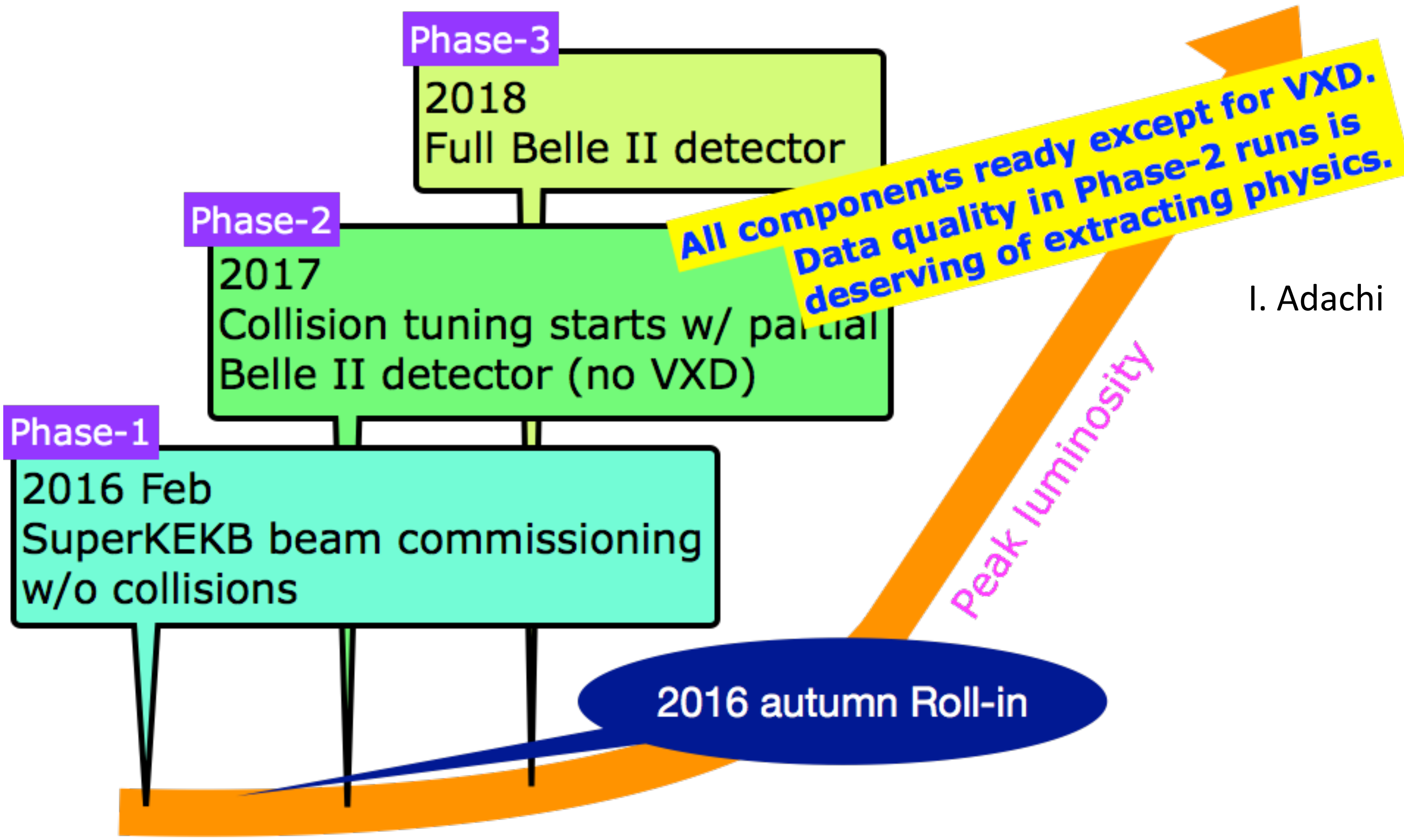


When will Belle II experiment start?



I. Adachi

When will Belle II experiment start?



I. Adachi

Physics Prospects at Belle-II

- Exotics state and Tetraquark search and study.
- Precise CKM measurements.
- Radiative and electroweak decays $b \to s\gamma$, $b \to d\gamma$ and $b \to sl^+l^-$ to probe new physics.
- Measuring direct CPV with $B \to K\pi$.
- D^0-$\bar{D}^0$ mixing and CPV search.
- Search for τ rare decay.
- …... (more details in back up)
- Many key observables are accessible only at the e^+e^- B factories, The advantage of the clean environment at SuperKEKB is clear.
- Belle II will be complementary and competitive with LHCb

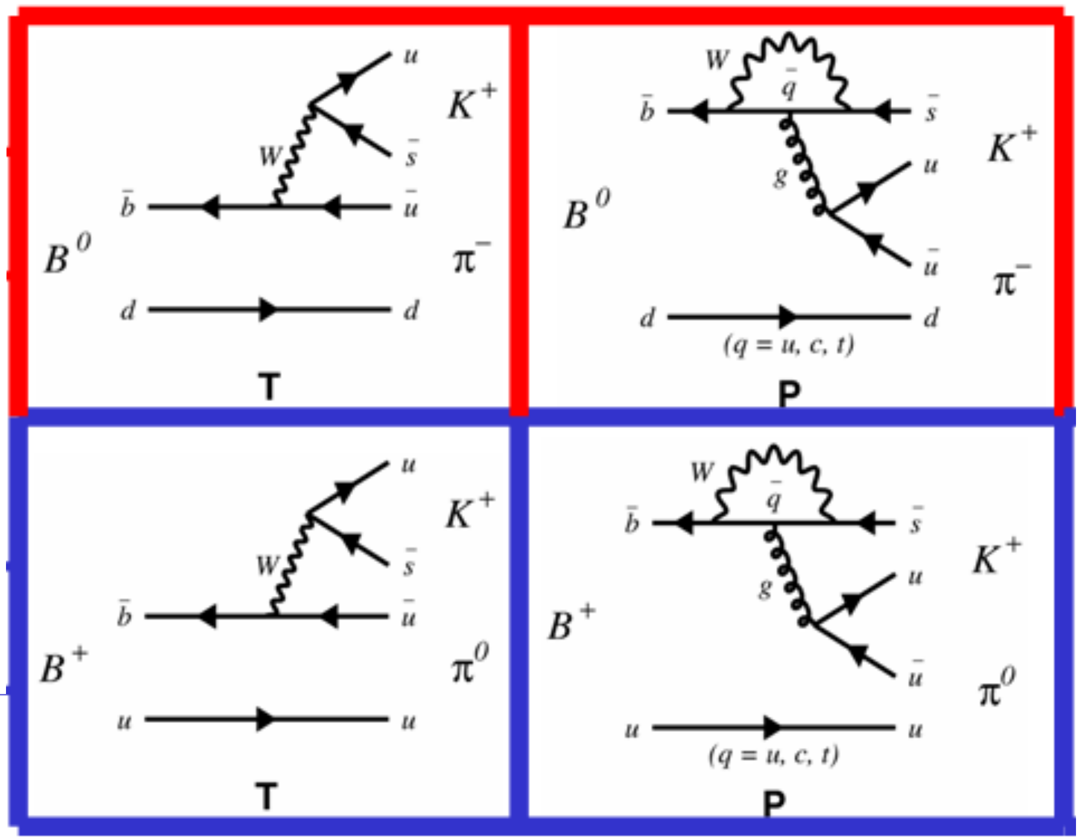
Measuring direct CPV

with B⟶ Kπ

$$A_{CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} \propto \sin\Delta\phi \sin\Delta\delta$$

$B^0 \to K^+\pi^-$

$B^+ \to K^+\pi^0$



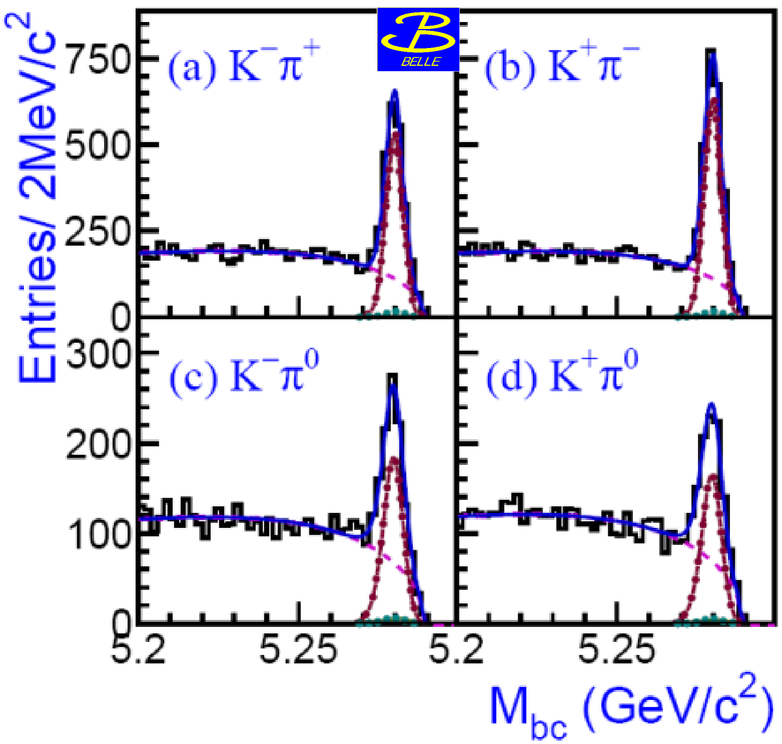
diagrams identical except for "spectator" quark

⇒ strong and weak phases are the same, A_{CP} should be the same and equal for neutral and charged B meson decays

Measuring direct CPV

with B$\rightarrow$ Kπ

But they are not: ***(Belle, Nature 452, p332, 2008):***



$B^0 \rightarrow K^+\pi^-$

$B^+ \rightarrow K^+\pi^0$

$A_{CP}(K^+\pi^-)$ =

-0.069 ± 0.016 (Belle)

-0.107 ± 0.017 (Babar)

-0.083 ± 0.013 (CDF)

-0.080 ± 0.008 (LHCb)

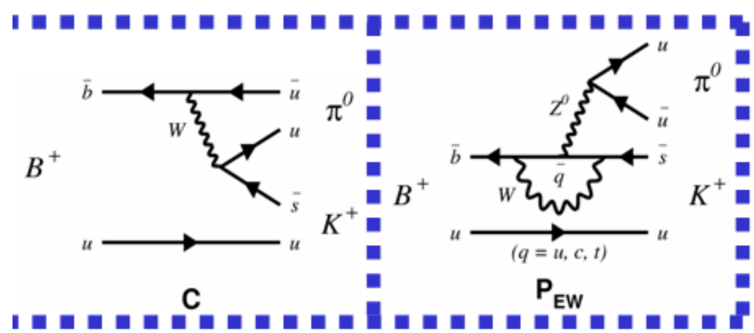
$A_{CP}(K^+\pi^0)$ =

+0.043 ± 0.024 (Belle)

+0.030 ± 0.040 (Babar)

$A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)$ = -0.122 ± 0.022

(5.6σ difference from zero)



Belle II Prospects for τ

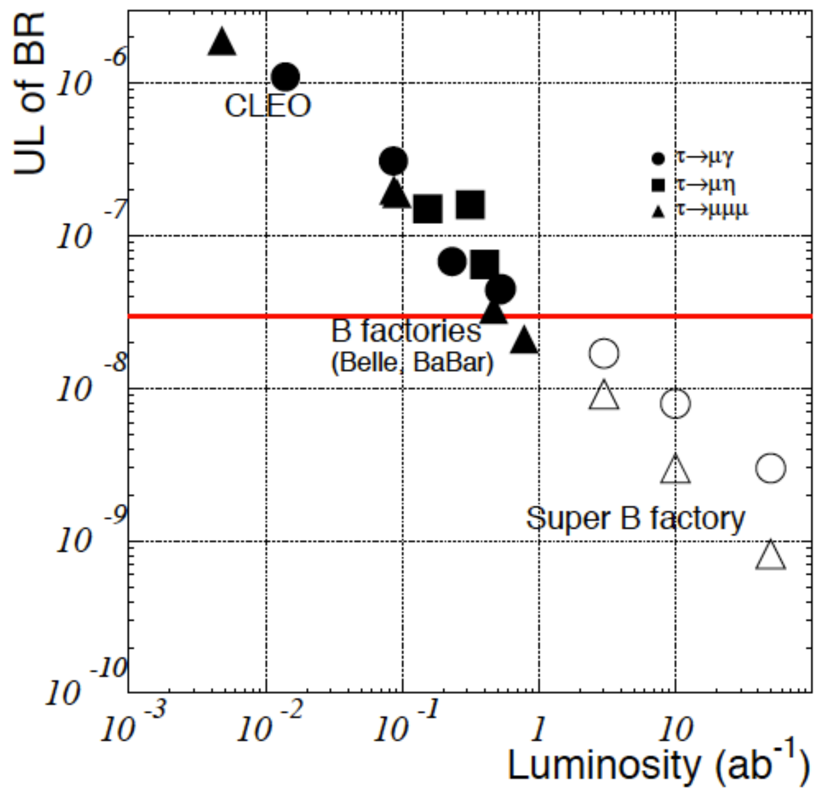
arXiv. 1002.5012

$\tau^+ \to \mu^+\gamma$

upper half of signal ellipse dominated by
$ee \to \mu\mu\, \gamma_{ISR}$
⇒ possible to reduce
⇒ sensitivity scales with $\sqrt{\mathcal{L}}$

$\tau^+ \to \mu^+\mu^+\mu^-$

very clean, essentially background-free up to 50 ab^{-1}
⇒ sensitivity scales linearly with $\mathcal{L}$



Upper Limits:

$\sigma(ee \to \tau\tau) = 0.92$ nb ⇒
4.6×10^{10} $\tau^+\tau^-$ in 50 ab^{-1}
⇒ $B(\tau^+ \to \mu^+\gamma) <$ ~10^{-9}
⇒ $B(\tau^+ \to \mu^+\mu^-\mu^+) <$ ~10^{-10}
This probes NP models

	reference	$\tau \to \mu\gamma$	$\tau \to \mu\mu\mu$
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

Summary

- B-factories have been achieving a tremendous success that lead to the confirmation of the Standard Model (SM) in the quark flavor sector
- Major upgrade at KEK in 2010-16 → Super B factory: $\mathcal{L}$ x 40. The target integrated luminosity for physics data is 50 ab^{-1}, which is much larger than the current Belle data set.
- Belle will be upgraded to Belle II, many detector components and most electronics will be replaced.
- The physics program at Belle II is complementary to those studied at LHCb, it will be a good place to probe new physics and will produce some rich and significant results

Back up

Why Belle II?

arXiv:1002.5012 (Belle II)

https://d2comp.kek.jp/record/230?ln=en

	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	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (0.9°)$	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

Why Belle II?

arXiv:1002.5012 (Belle II)

https://d2comp.kek.jp/record/230?ln=en

	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		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p \rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm^{0.16}_{0.15} \pm^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ $[^\circ]$	$-6 \pm 11 \pm^{4}_{5}$	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		

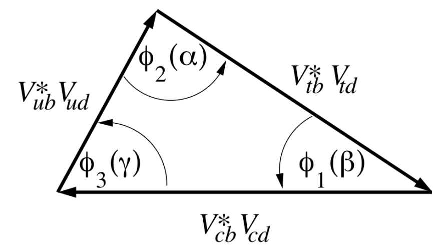
- Most of key observables are accessible only at the e^+e^- B factories
- The advantage of the clean environment at SuperKEKB is thus clear.
- The B physics program at hadron colliders has its own unique measurements that are not accessible at e^+e^- B factories (e.g. rare B_s decays such as $B_s \to \mu^+\mu^-$)

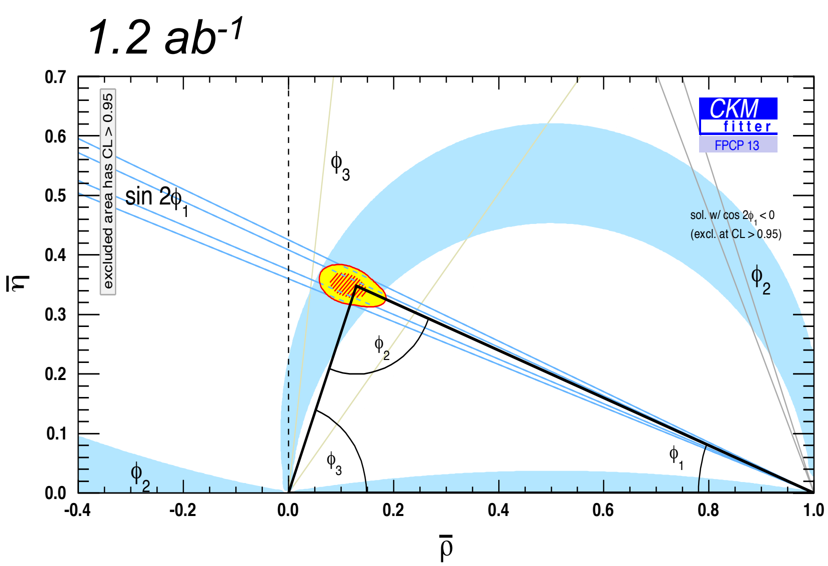
Constraining the CKM Unitarity Triangle:

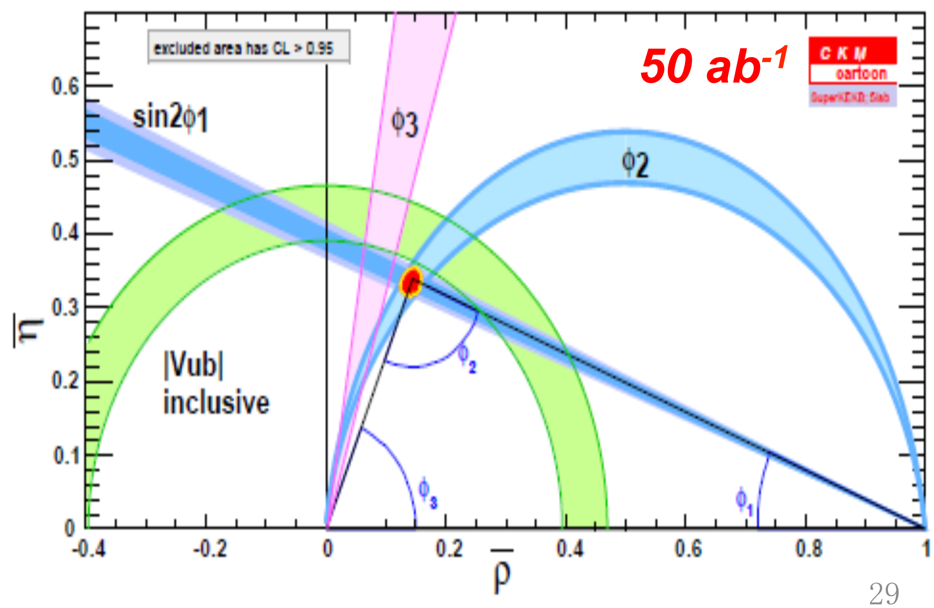
A main physics goal is to substantially reduce the uncertainties on the CKM UT triangle

12^{th} FPCP Alan's talk

UT	2014	Belle II
α	4° (WA)	**1°**
β	0.8° (WA)	**0.2°**
γ	8.5° (WA) 14°(Belle)	**1-1.5°**

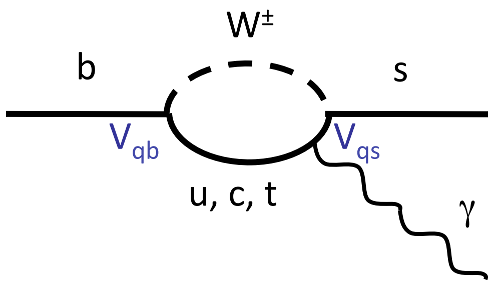


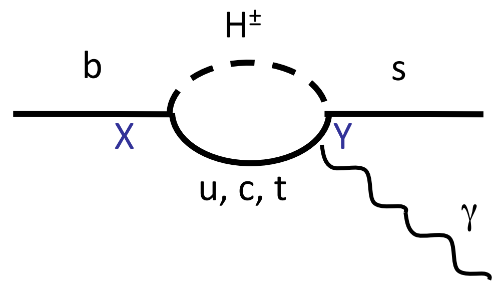




Radiative and electroweak decays
$b \to s\gamma$, $b \to d\gamma$ and $b \to sl^+l^-$

1-loop suppressed in SM ⇒ esp. sensitive to NP:





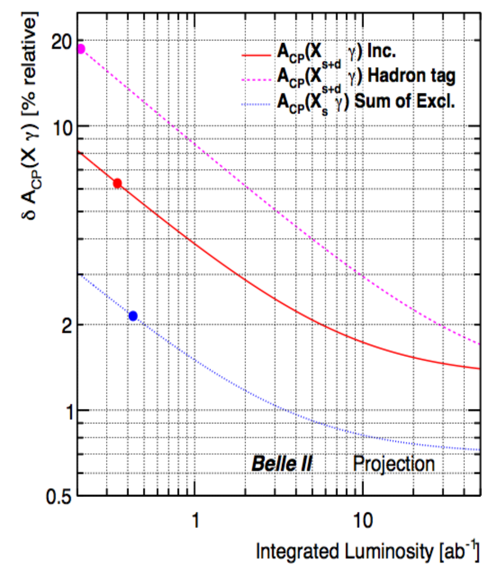
Many observables that probe new physics:

(inclusive: John Walsh's talk
exclusive: A. Ishikawa's talk)

- *measurement of inclusive $B \to X_s\gamma$ and $B \to X_d\gamma$ branching fractions*
- *direct CPV in $B \to X_s\gamma$, $B \to X_s l^+l^-$*
- *forward-backwards asymmetry and q^2 dependence in $B \to X_s l^+l^-$*

- *exclusive $B \to K^*\gamma$ and $B \to \rho\gamma$ branching fractions*
- *forward-backwards asymmetry and q^2 dependence in $B \to K^* l^+l^-$*
- *direct CPV in $B^+ \to K^{*+}\gamma$*
- *time-dependent CPV in $B^0 \to K^{*0}\gamma$, $B^0 \to \rho^0\gamma$*

- *measurement of photon polarization with photon conversion*
- *lepton flavor dependence in $b \to sl^+l^-$*



D^0-$\bar{D}^0$ mixing and CPV:

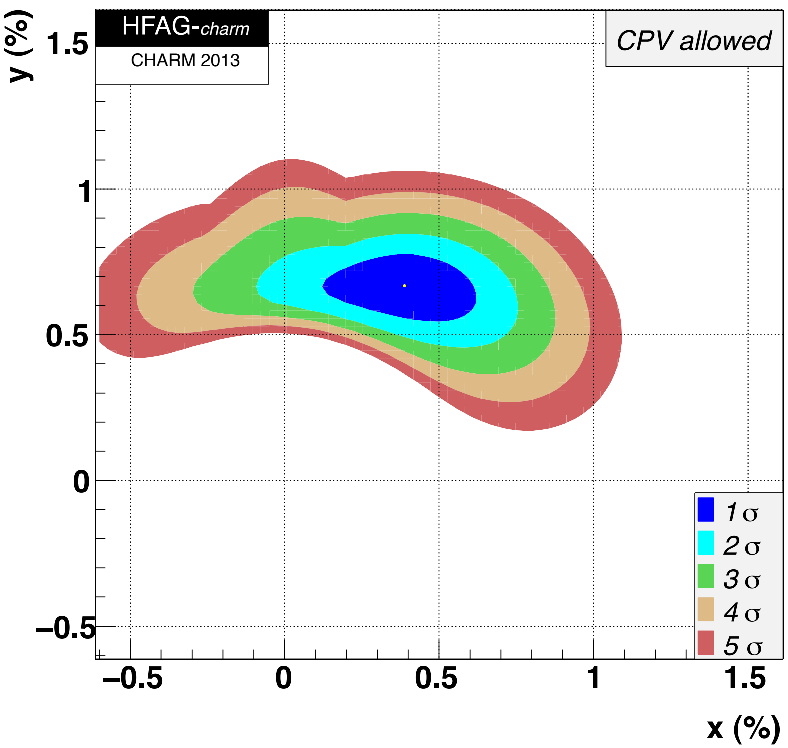
Expected Uncertaintes *(M. Staric, KEK FFW14)***:**

Analysis	Observable	Uncertainty (%)	
		Now ($\sim 1\ \mathrm{ab}^{-1}$)	$\mathcal{L} = 50\ \mathrm{ab}^{-1}$
$K^0_S\pi^+\pi^-$	x	0.21	0.08
	y	0.17	0.05
	$\lvert q/p\rvert$	18	6
	ϕ	0.21 rad	0.07 rad
$\pi^+\pi^-$, K^+K^-	y_{CP}	0.25	0.04
	A_Γ	0.22	0.03
$K^+\pi^-$	x'^2	0.025	0.003
	y'	0.45	0.04
	$\lvert q/p\rvert$	0.6	0.06
	ϕ	0.44	0.04 rad

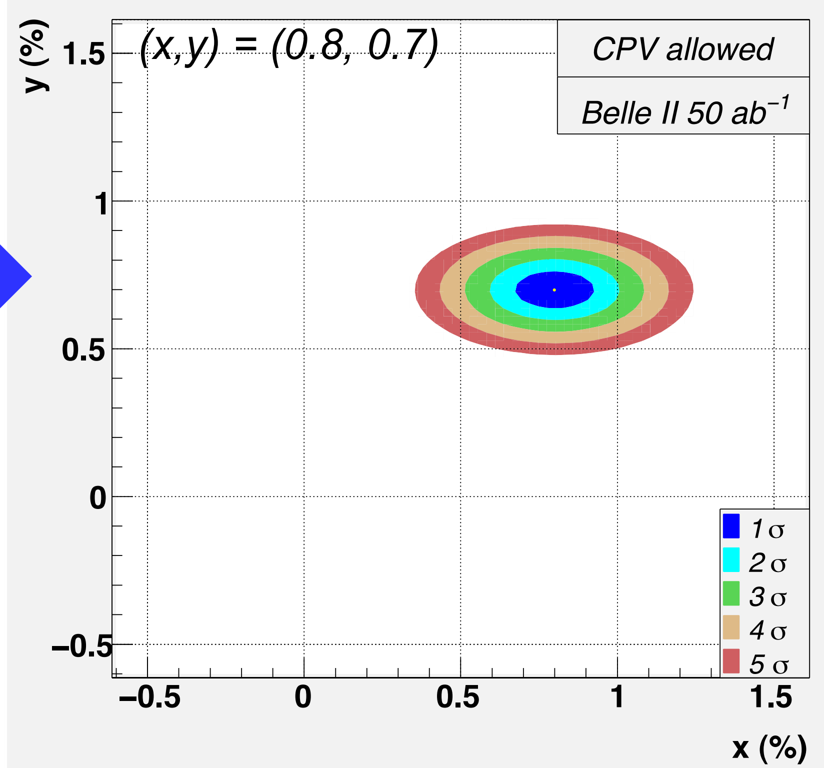
Note: *statistical error and some systematics scale by luminosity, but other systematics do not.*

CPV search in the D^0-$\bar{D}^0$ system:

Now:



50 ab^{-1}: A. Schwartz' *talk (12th FPCP)*

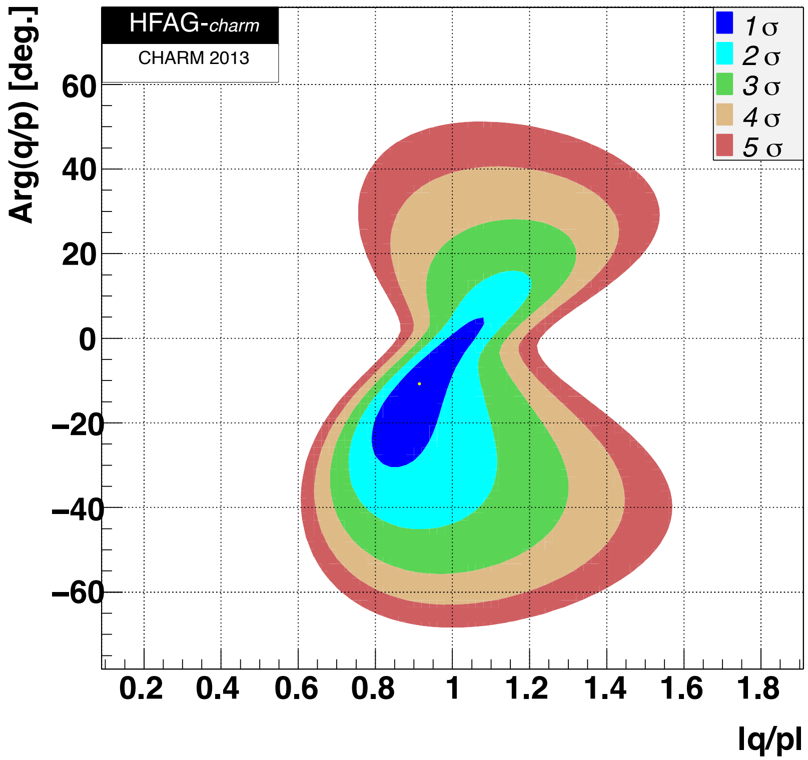


Current measurements of x, y give many constraints on NP models

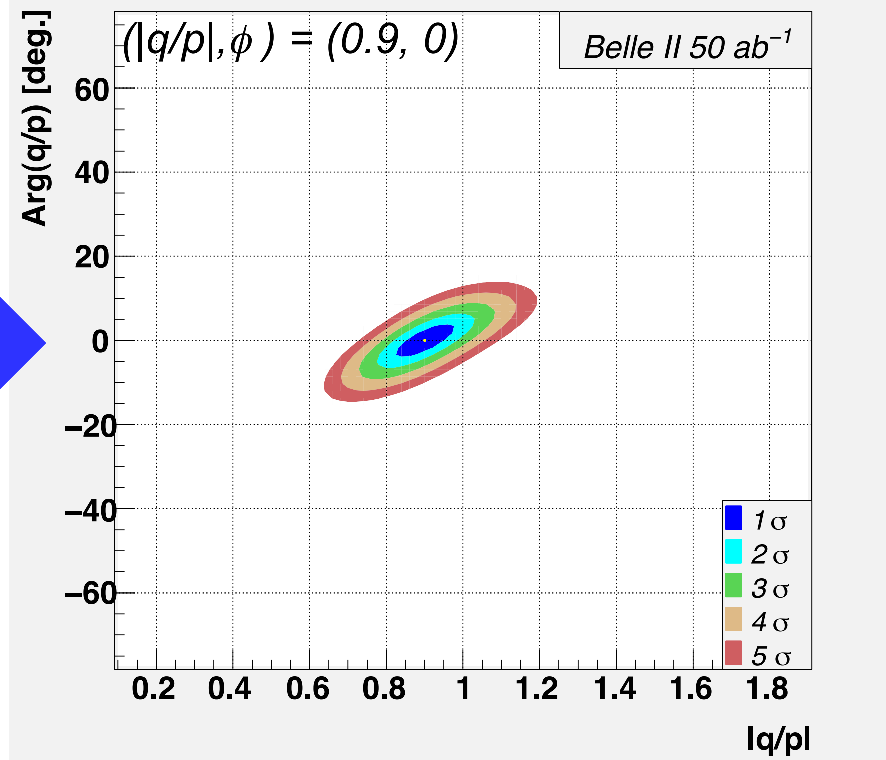
[see Golowich et al., PRD76, 095009 (2007); 21 models considered, e.g., 2-Higgs doublets, left-right models, little Higgs, extra dimensions, of which 17 give constraints]

CPV search in the D^0-$\bar{D}^0$ system:

Now:



50 ab^{-1}:



Note: *LHCb will dominate most of these measurements, but Belle II should be competitive in* y_{CP} *and possibly in* x'^2, y', $|q/p|$, ϕ *(see Staric, KEK FFW14). If LHCb sees new physics, it would be important for Belle II to independently confirm.*