The Belle II Experiment and SuperKEKB Upgrade

Wang, Boqun (University of Cincinnati)
On Behalf of Belle II Collaboration

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The B Factories

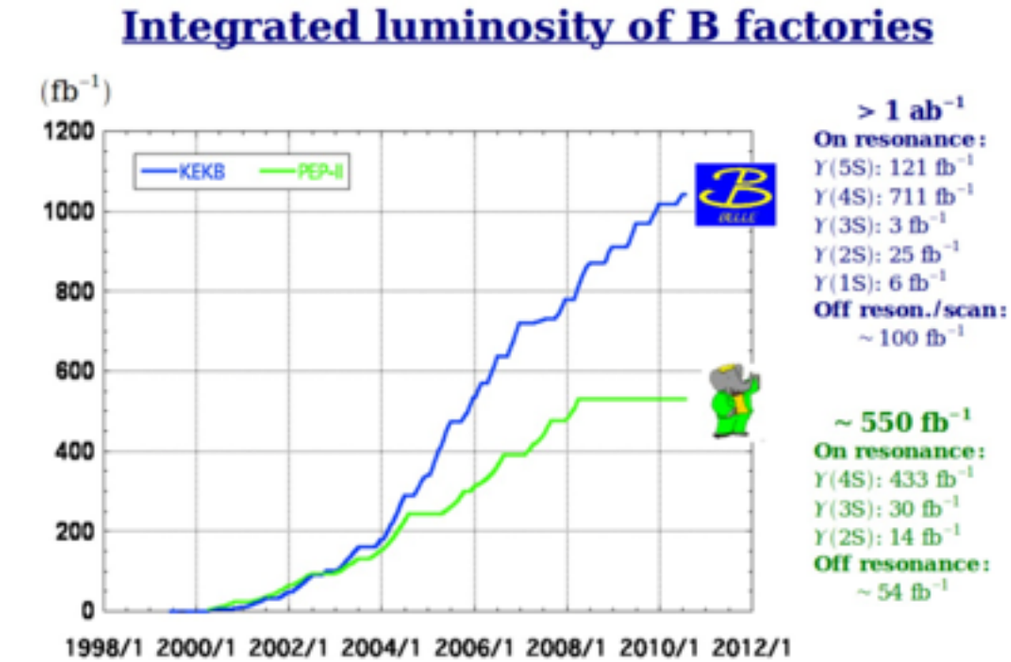
A e^+e^- collider runs at Y(4S) resonance to produce B meson pairs.

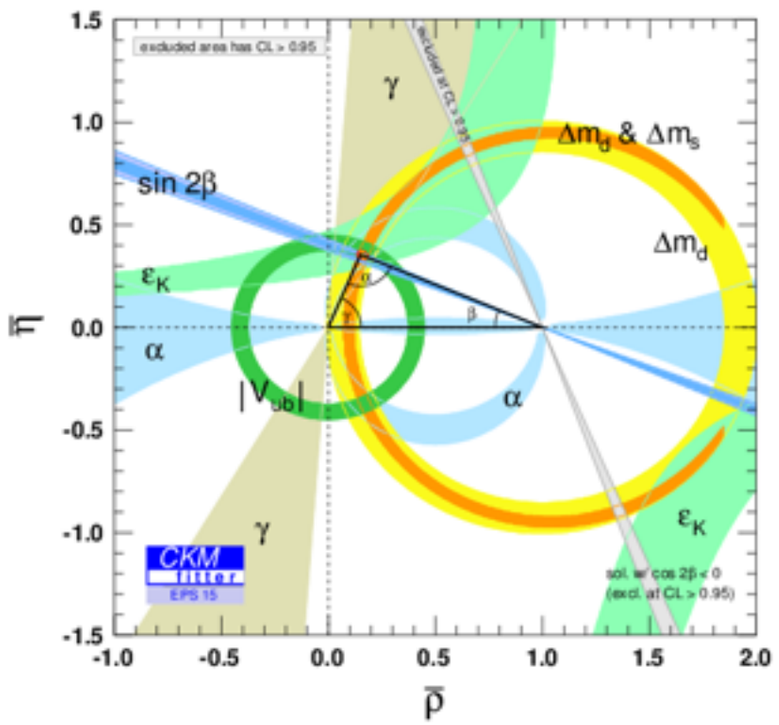
Belle/KEKB at KEK (Japan)

BaBar/PEP-II at SLAC (USA)

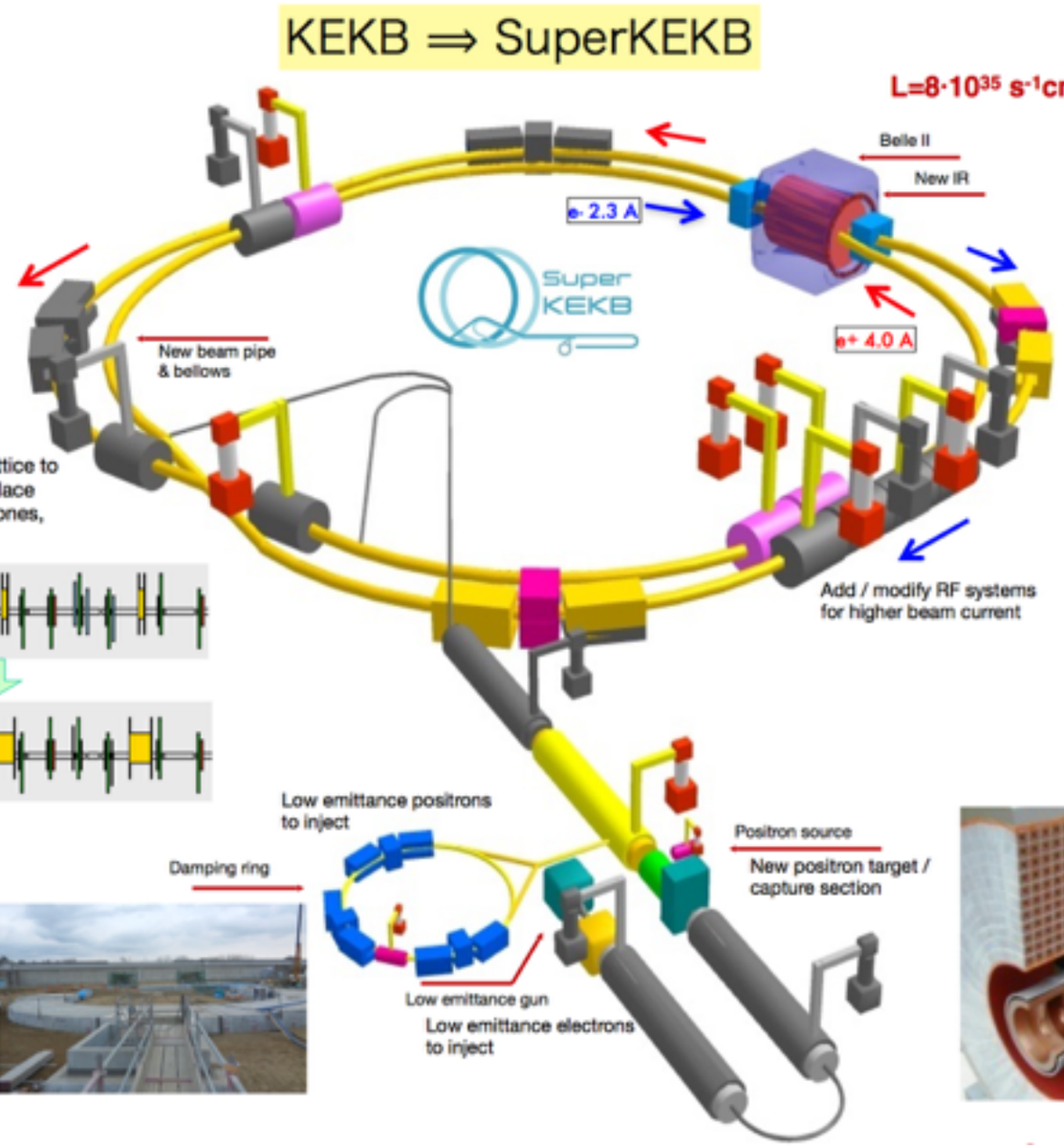
Physics Highlights

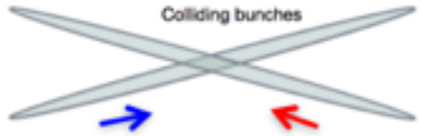
- Collected ~1.5 ab^{-1} of data
- Measurement of the Unitarity triangle, and CKM parameters
- Observation of direct CP violation in B decays
- Observation of D meson mixing
- Observation of new (X, Y, Z) hadrons
- Search for rare tau decays
- Constraints on new physics
- Direct searches for light Higgs, dark photon, etc.



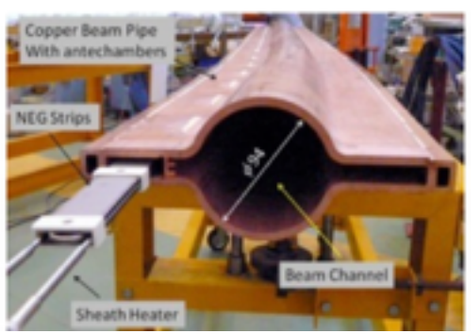


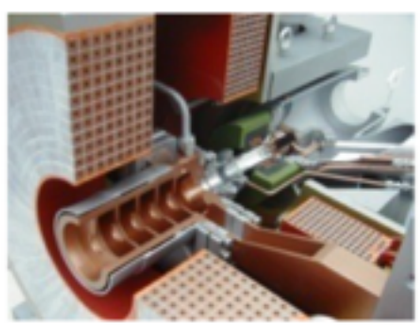
Super-KEKB





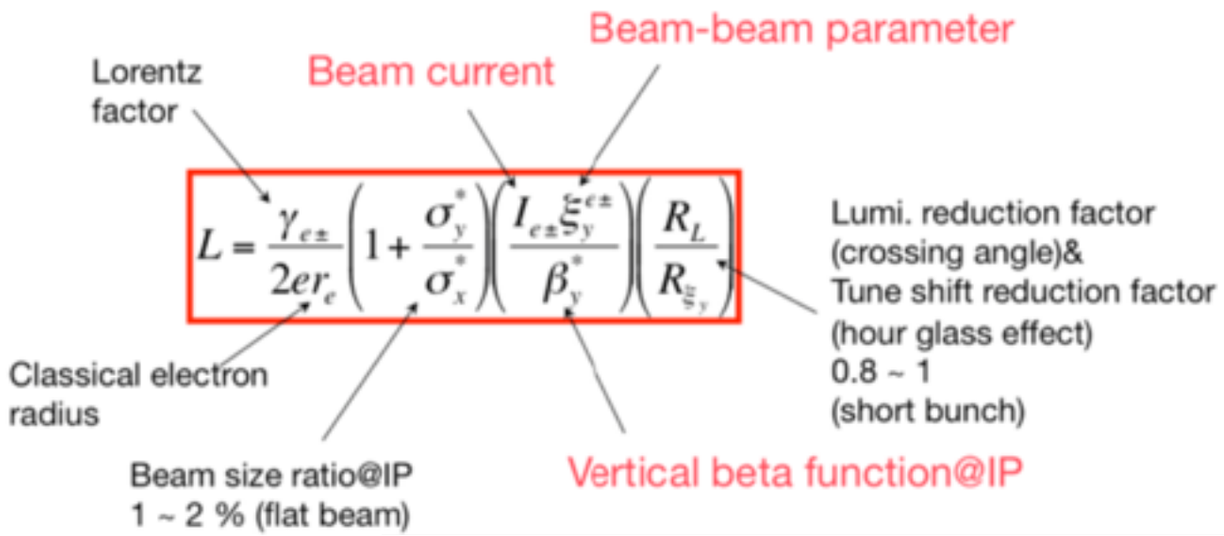
Replace beam pipes with TiN-coated beam pipes with antechambers (reduced Sync Rad.)



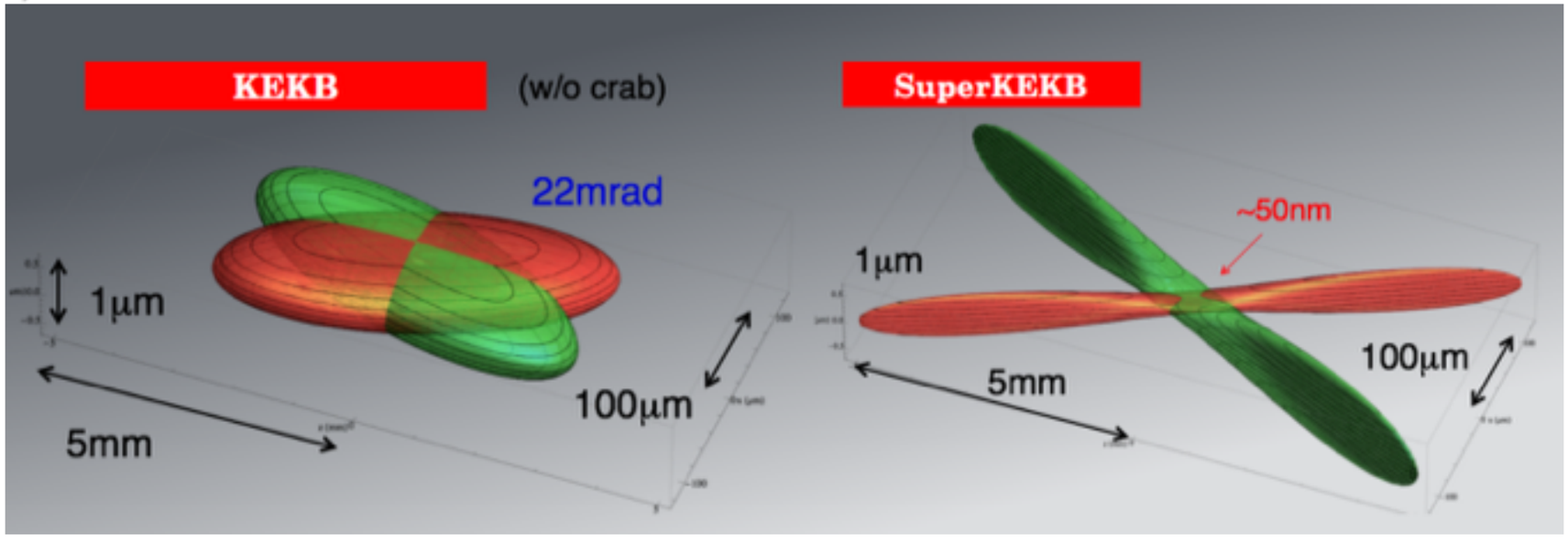


Target integrated luminosity for Belle II/SuperKEKB: ~50 ab^{-1}

How to achieve 40x luminosity

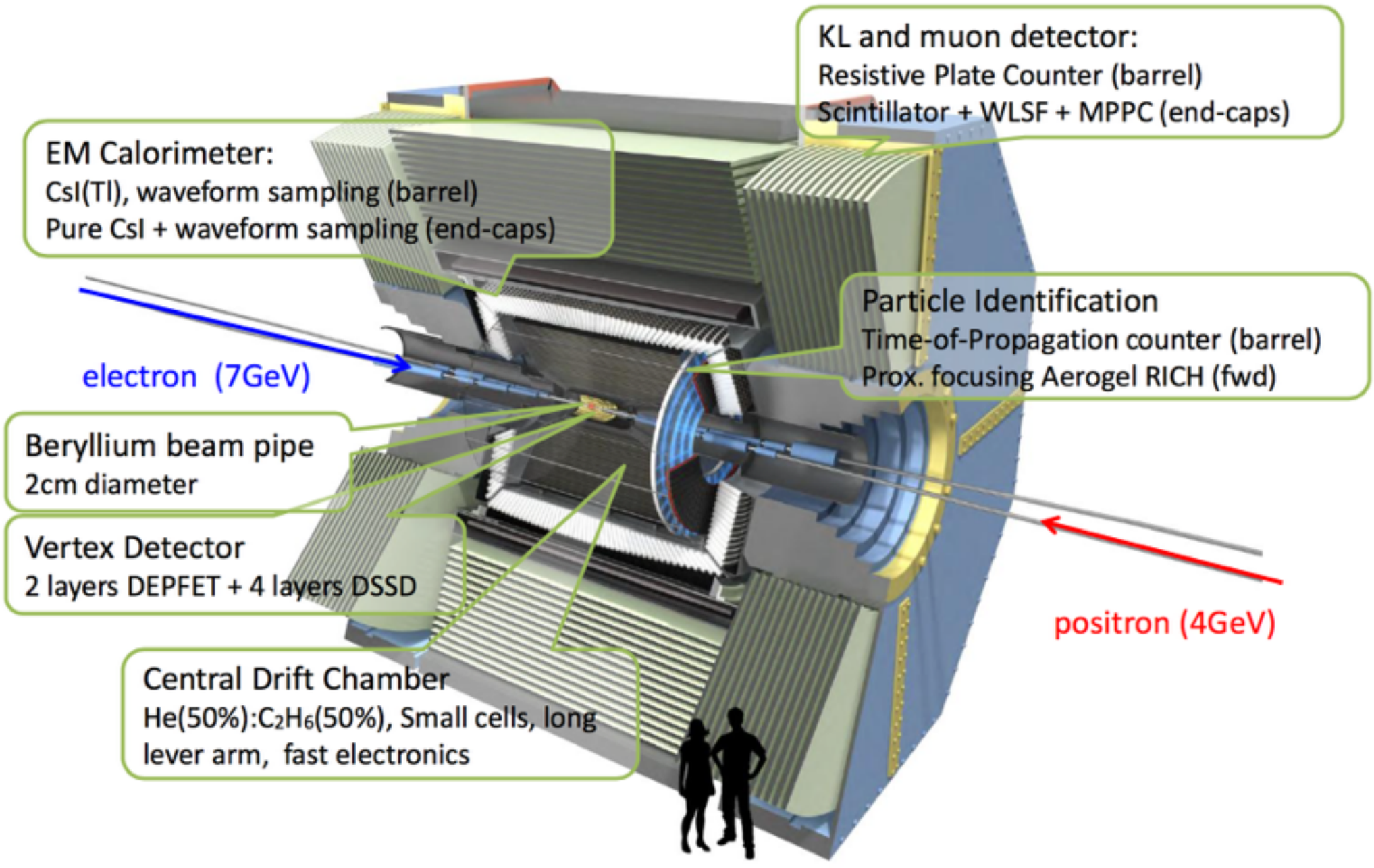


- Nano beam:
  - Small current increase (2-3x)
  - Smaller β_y^* (20x) via superconducting focus magnets
- Challenge of beam backgrounds

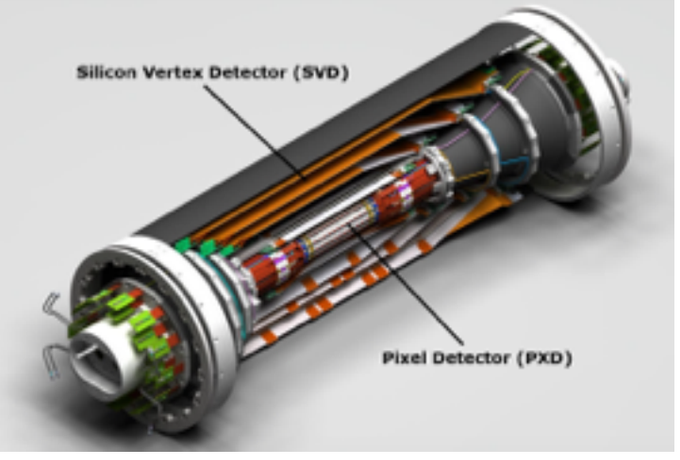


	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

Belle II Detector



Belle II: VXD



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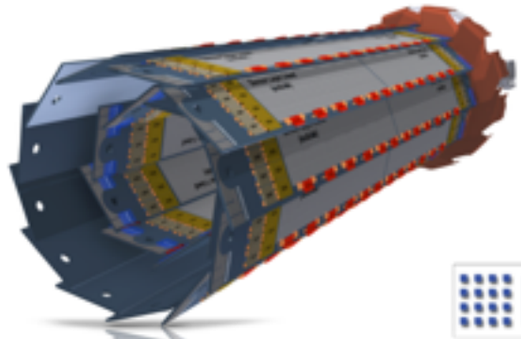
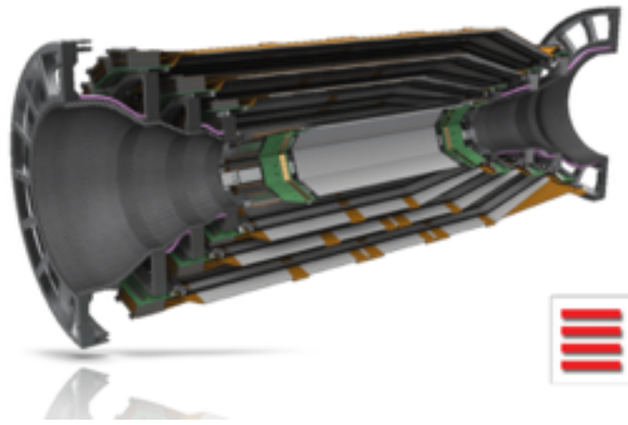


PXD

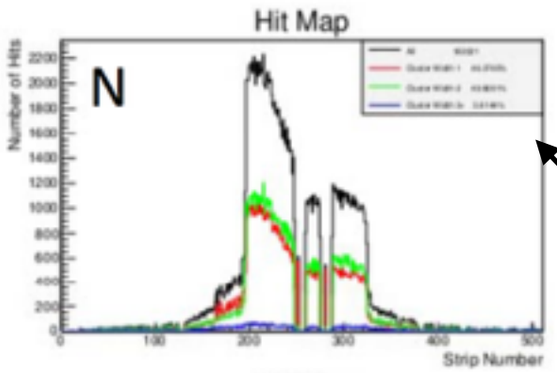
+

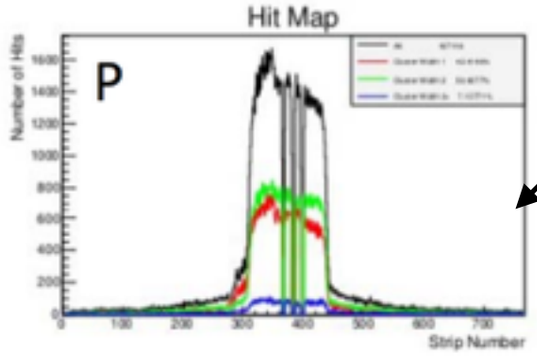


SVD

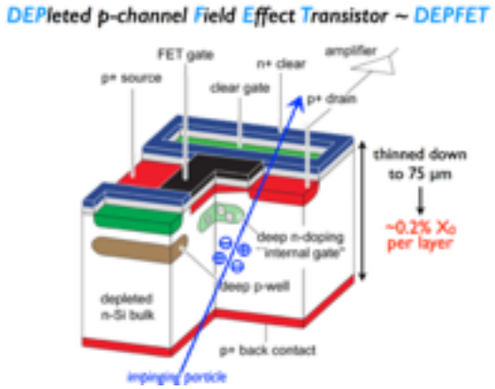
VXD

Hit map example (CE)

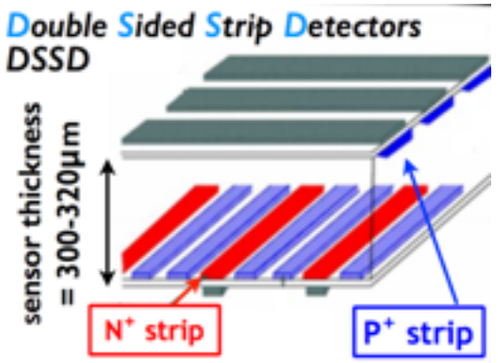




SVD Beam Test Results



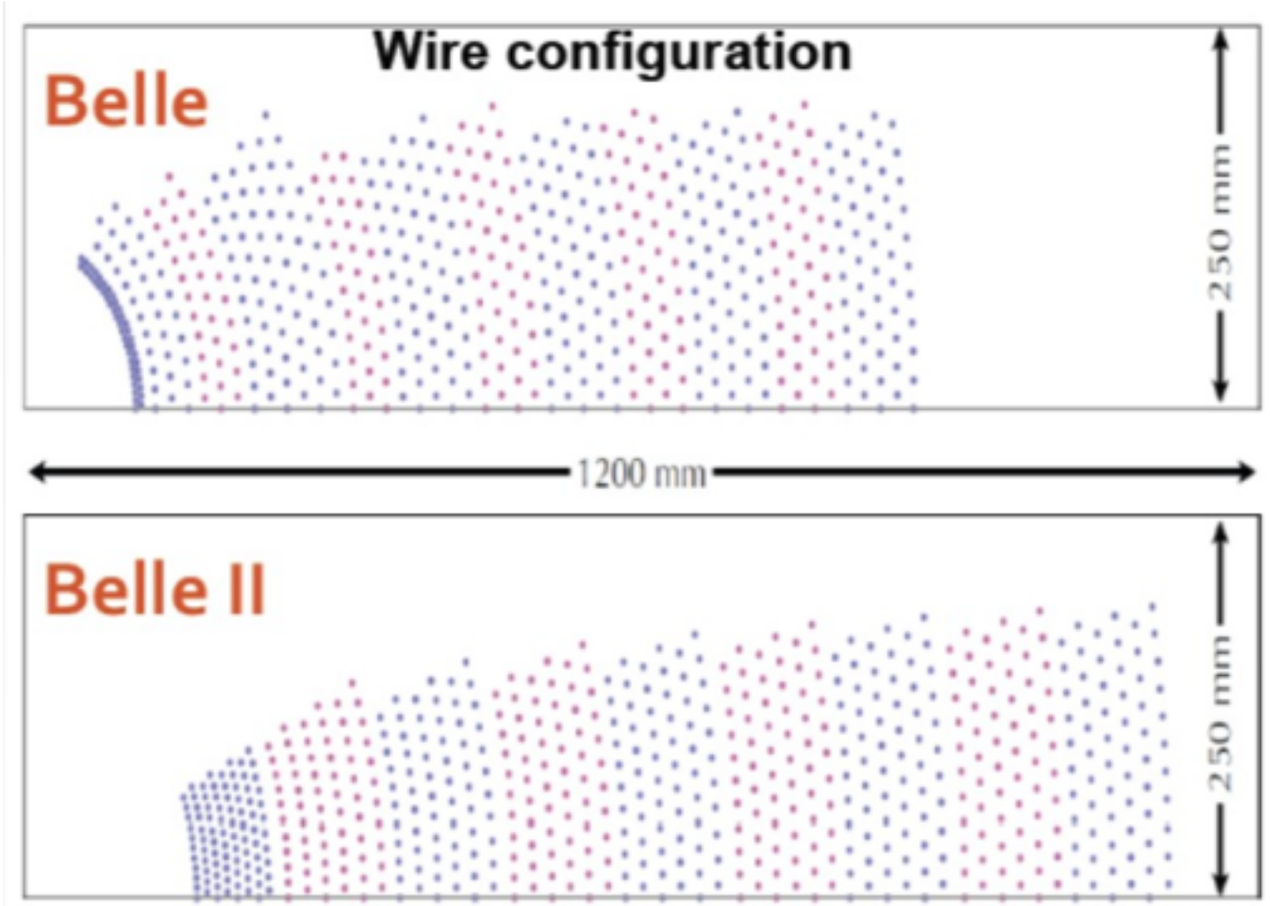
PXD: 2 layers of DEPFET

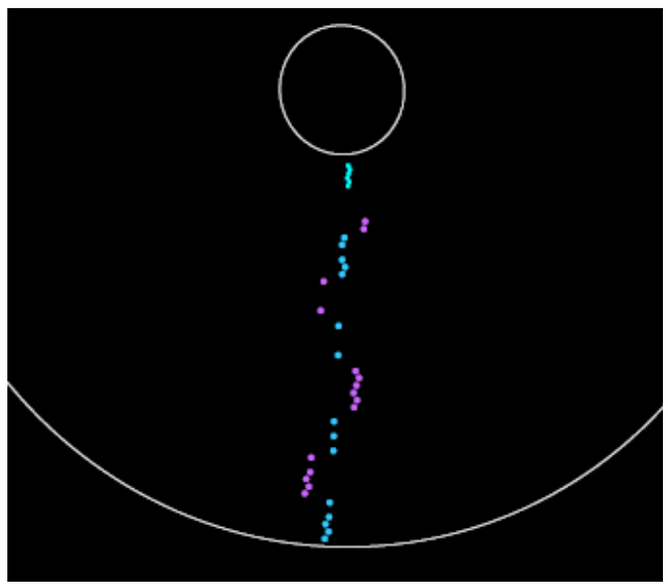


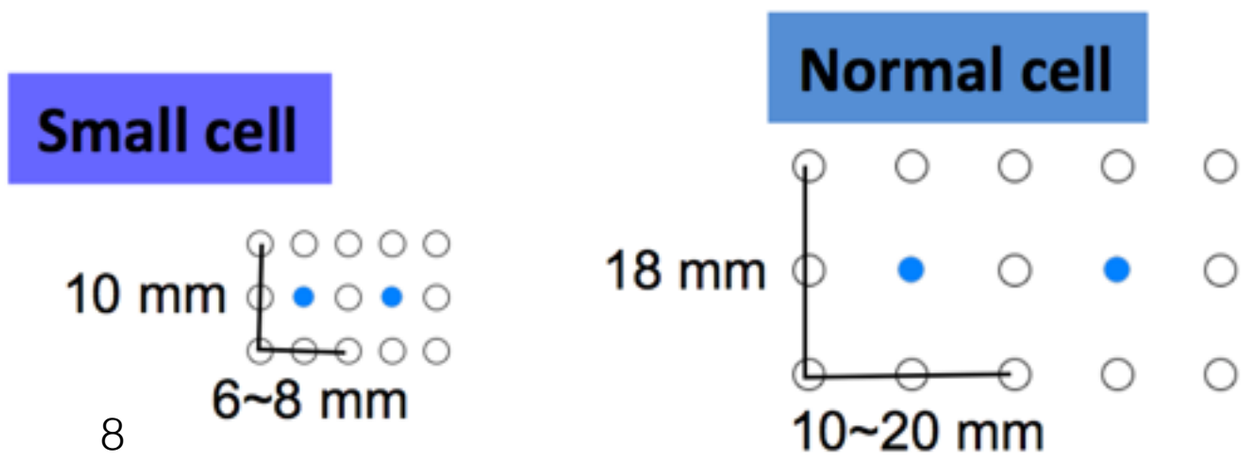
SVD: 4 layers of DSSD

Belle II: CDC

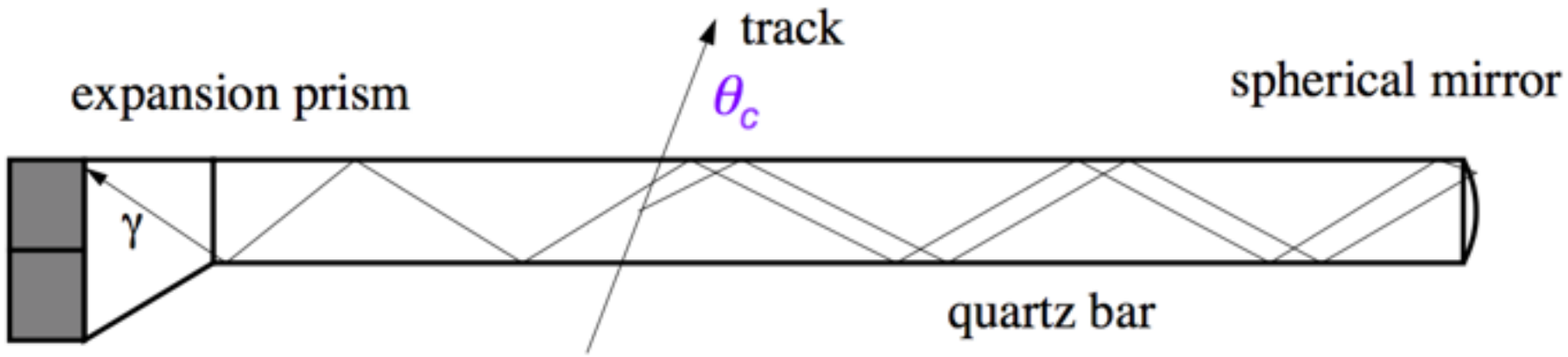
- Belle II CDC will be larger than Belle CDC with smaller cells
- Improved p and dE/dx resolution
- Stringing completed in January 2014 with 51456 wires
- Commissioning with cosmic rays



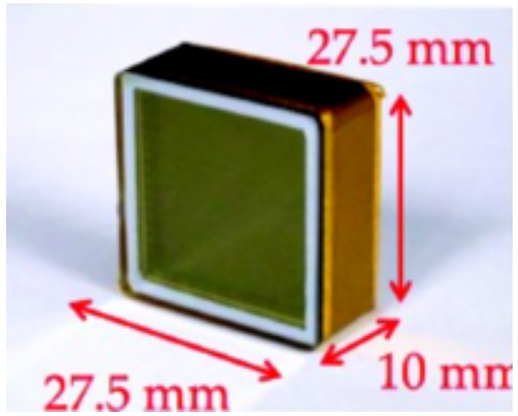


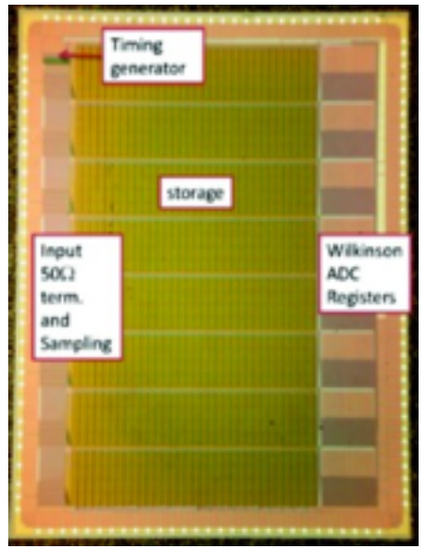


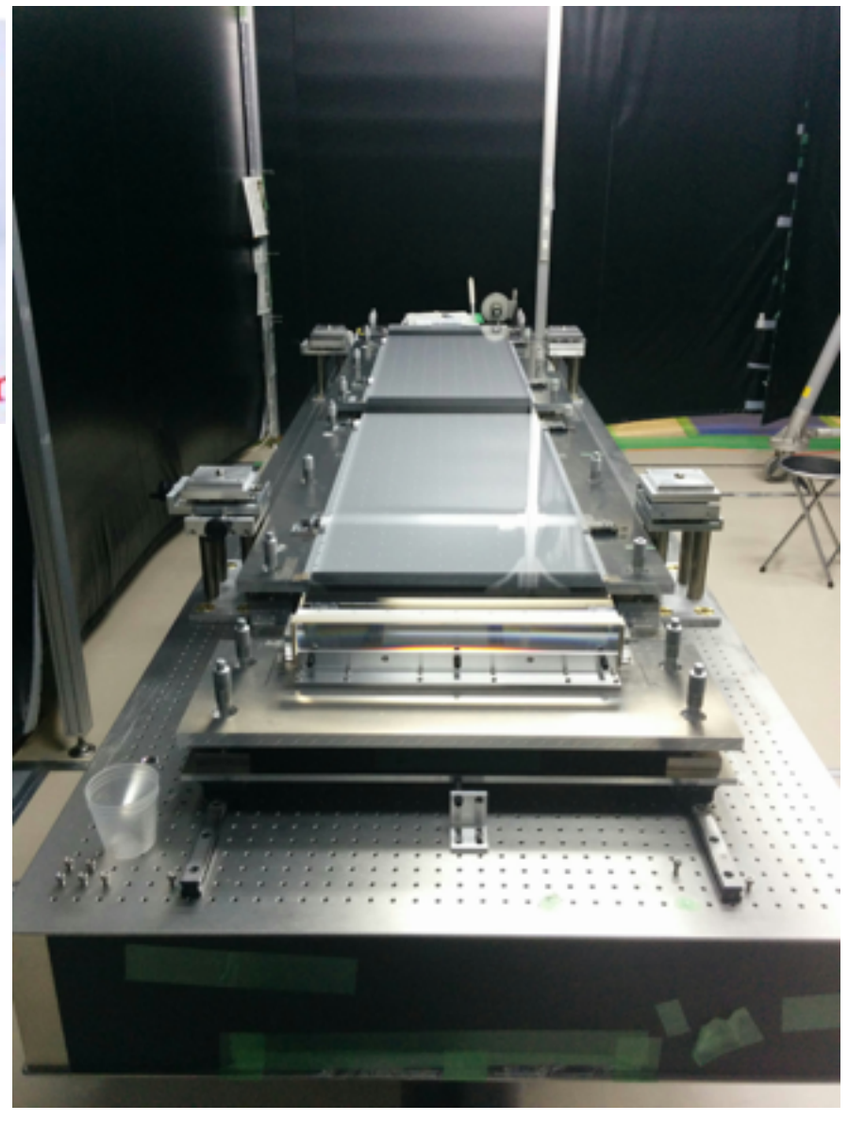
Belle II: TOP



- The imaging Time of Propagation sub-detector (TOP or iTOP) 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

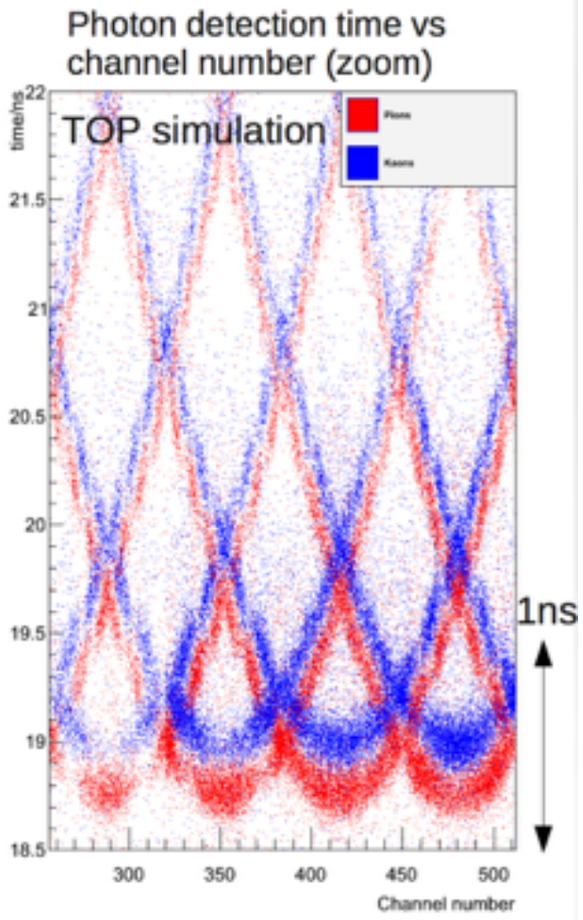


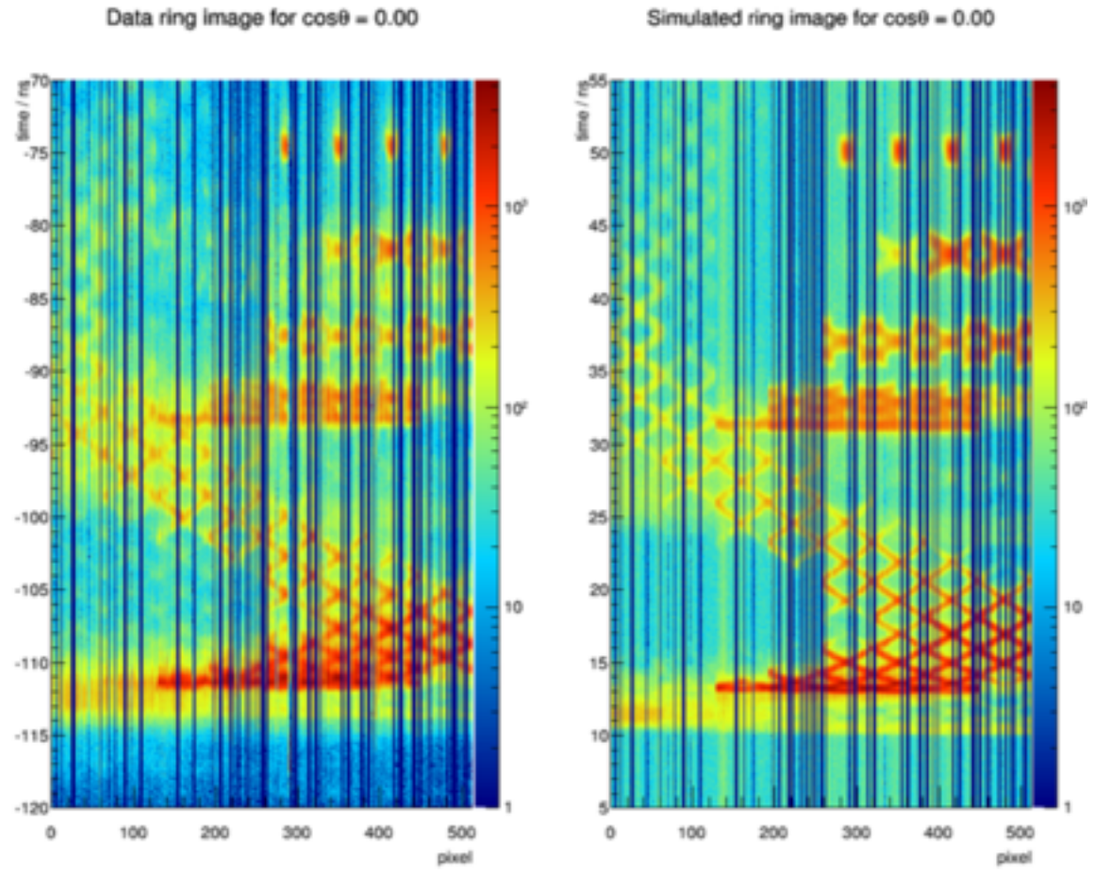




Belle II: TOP

Beam Test at LEPS (June 2013)

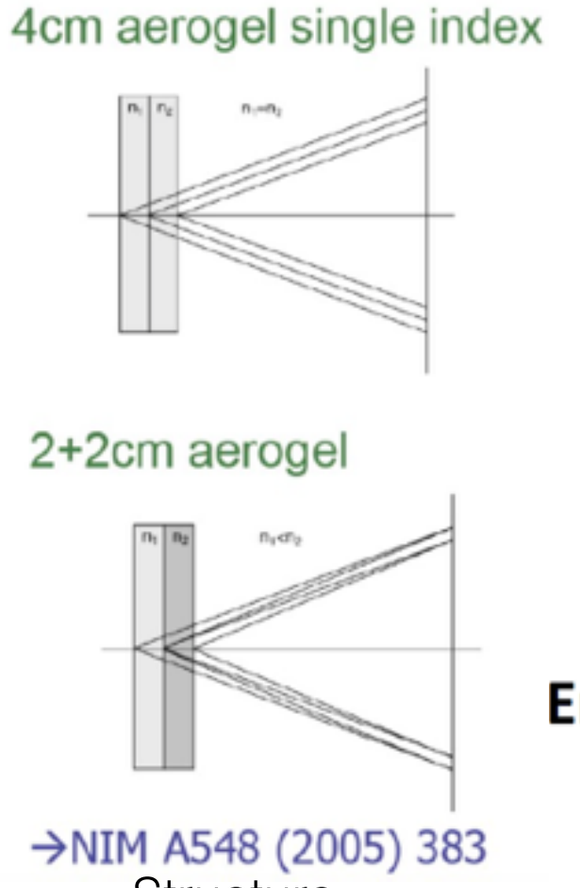


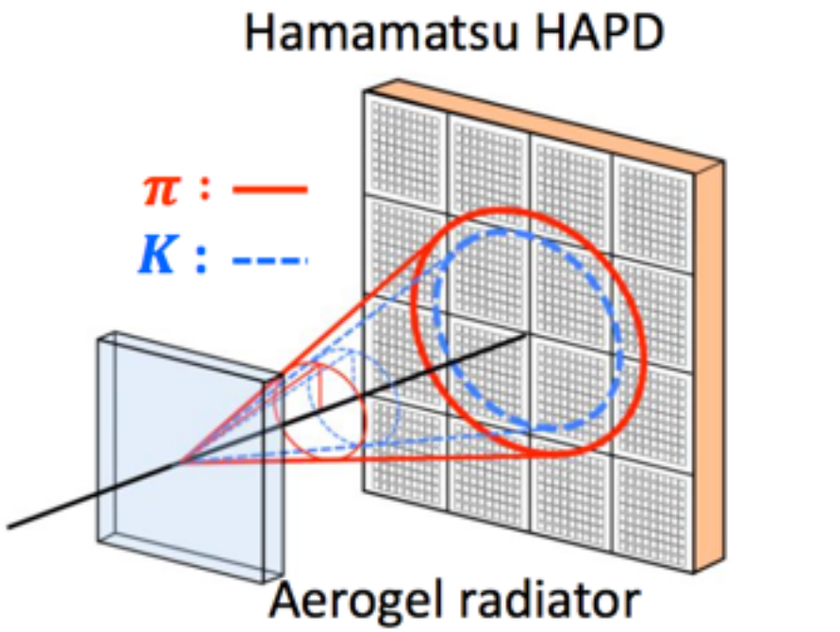


- TOP modules have been tested at beam test at SPring-8 LEPS in 2013, and good agreement between data and MC simulation has been obtained, with timing requirement ~O(100ps)
- 9 out of 16 modules have been assembled (the optical and mechanical parts). The assembly of the 10th module is on going in KEK
- Commissioning with cosmic rays is under way

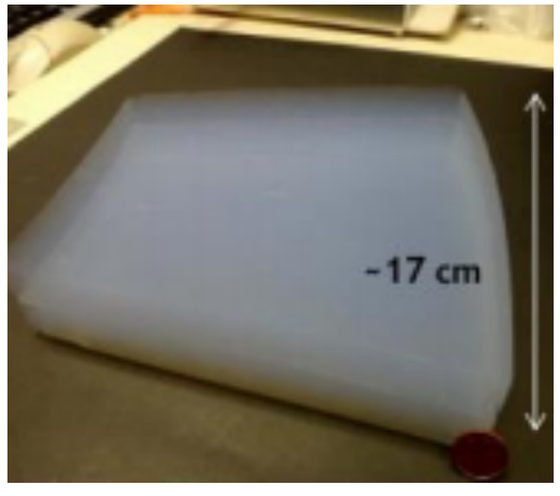
Belle II: ARICH

- Aerogel Ring Imaging Cerenkov (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

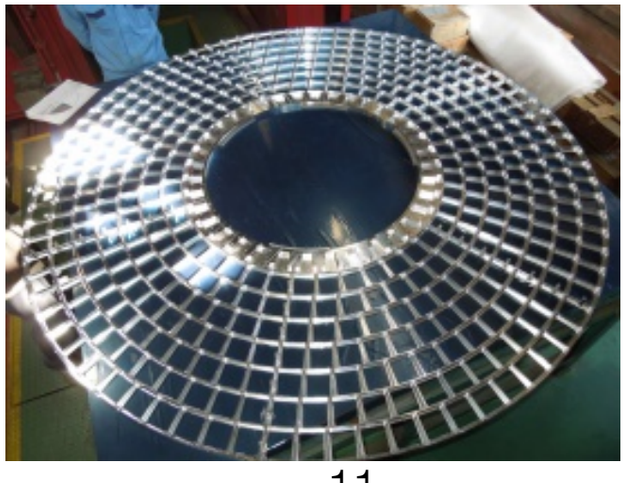




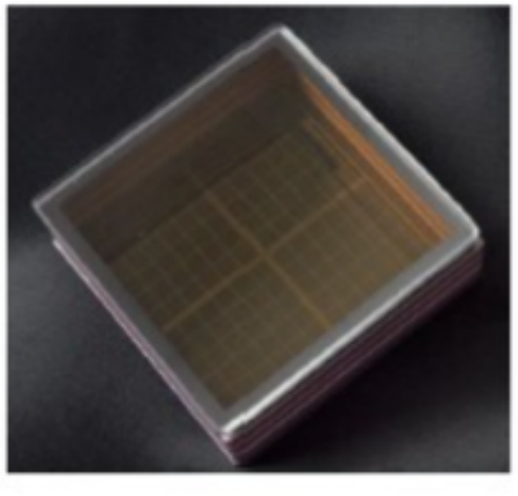
Aerogel



Structure

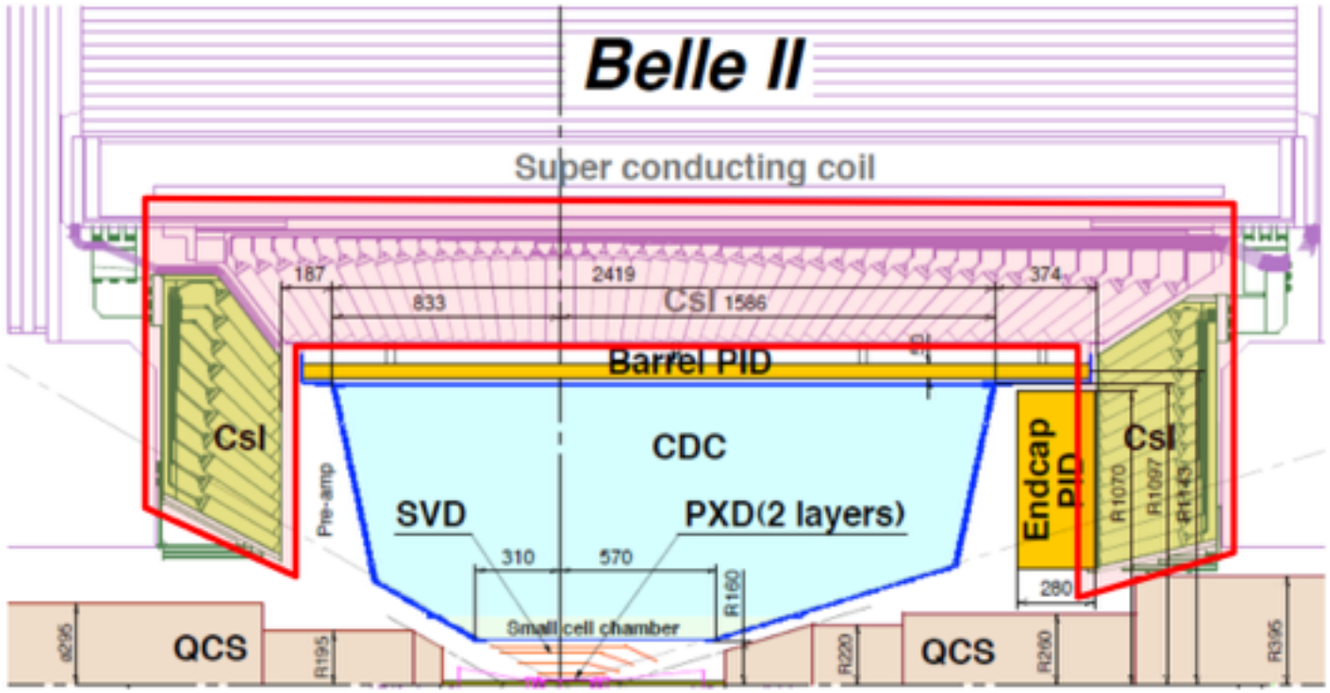


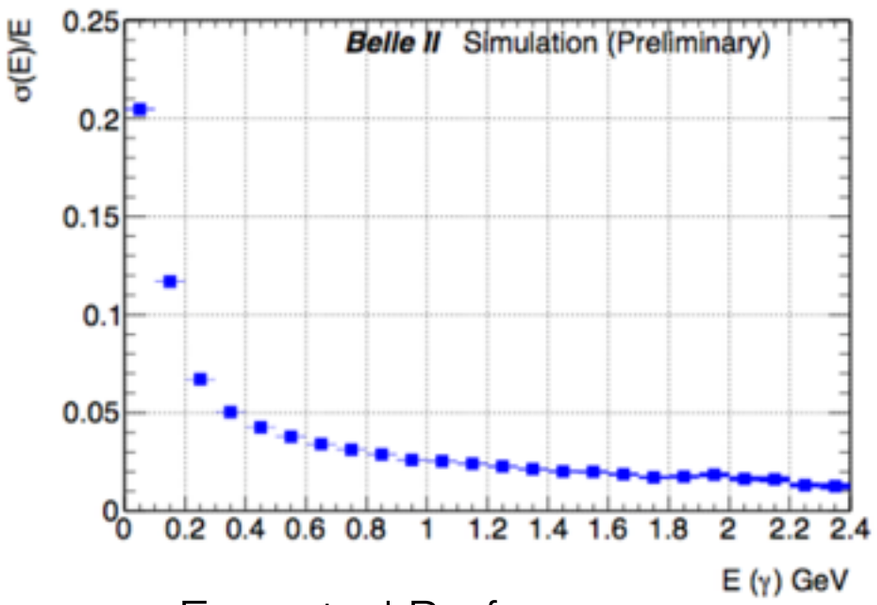
HAPD



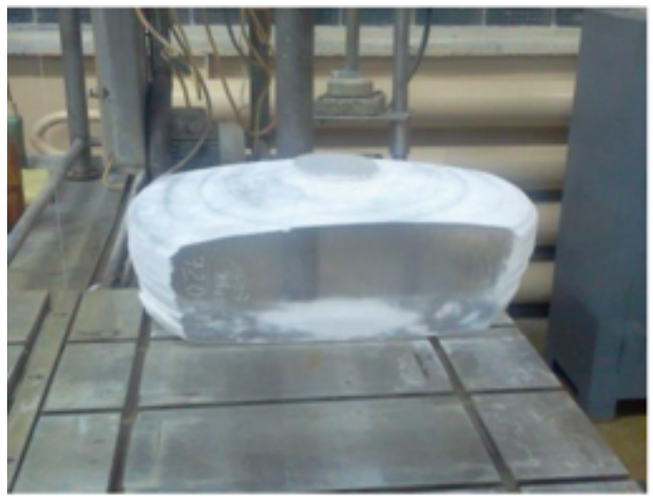
Belle II: ECL

- Upgrades for high backgrounds:
  - Barrel: CsI(Tl) crystals reused, new electronics for waveform sampling
  - Endcaps: old crystals refurbished, bias filter is modified
- Cosmic ray test is on going





Expected Performance

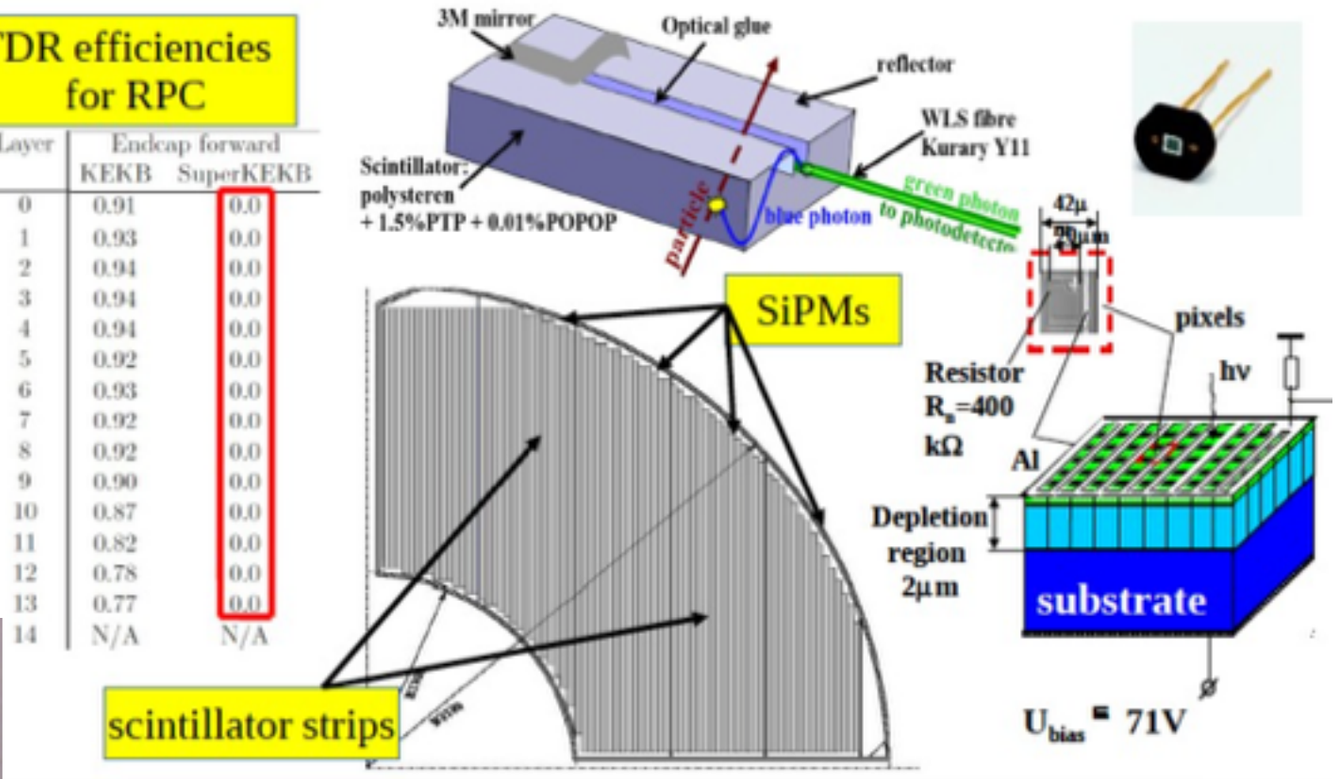


Belle II: KLM

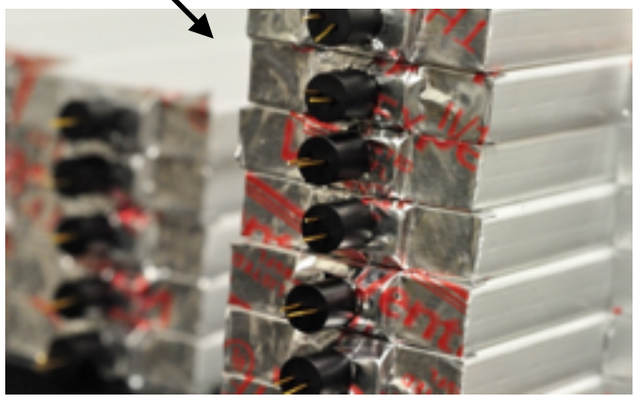
- Endcaps and parts of the barrel KLM RPCs of Belle will be replaced with scintillators due to increased backgrounds expected in Belle II
- Barrel KLM was the first sub-detector to be installed in Belle II

TDR efficiencies for RPC

Layer	Endcap forward	
	KEKB	SuperKEKB
0	0.91	0.0
1	0.93	0.0
2	0.94	0.0
3	0.94	0.0
4	0.94	0.0
5	0.92	0.0
6	0.93	0.0
7	0.92	0.0
8	0.92	0.0
9	0.90	0.0
10	0.87	0.0
11	0.82	0.0
12	0.78	0.0
13	0.77	0.0
14	N/A	N/A

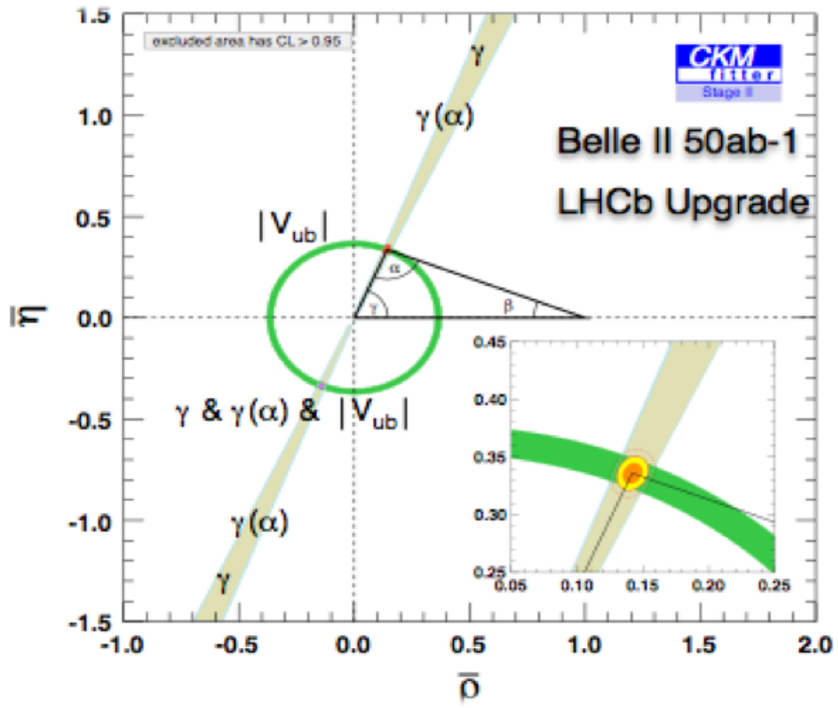


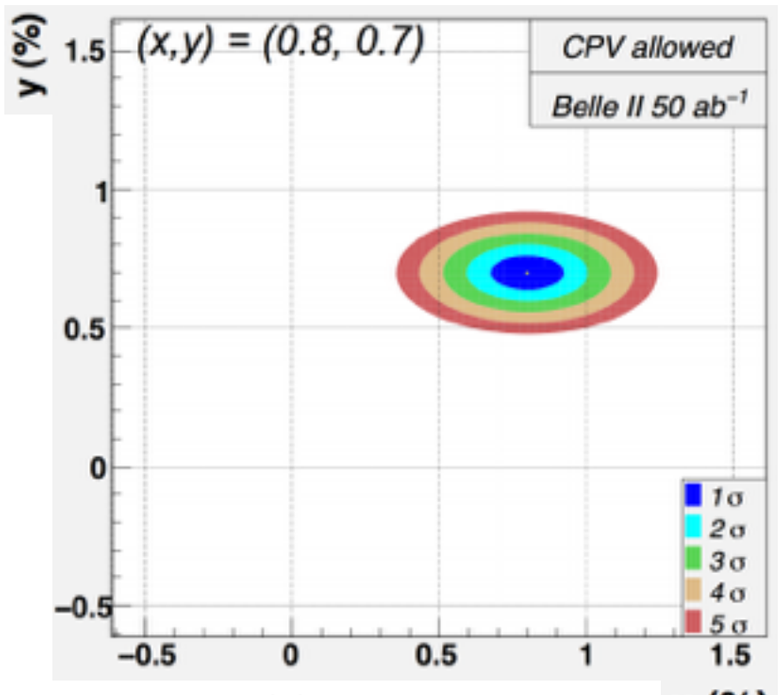
Scintillators for barrel and endcap

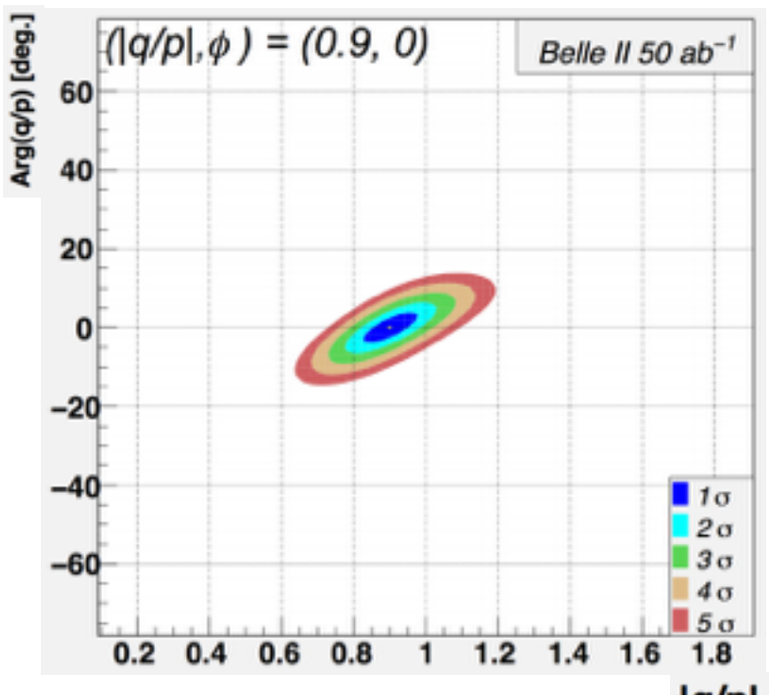


Physics Opportunities

- Potential signals for new physics:
  - Flavor changing neutral currents
  - Probing charged Higgs
  - New sources of CPV
  - Lepton Flavour Violation decays
  - Dark sectors
- Belle II physics programme will be complementary with LHCb.







Summary of Belle II Physics

Observables	Belle	Belle II		$\mathcal{L}_s$
	(2014)	5 ab^{-1}	50 ab^{-1}	[ab^{-1}]
$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$	± 0.012	± 0.008	6
α		$\pm 2°$	$\pm 1°$	
γ	$\pm 14°$	$\pm 6°$	$\pm 1.5°$	
$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	± 0.053	± 0.018	>50
$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	± 0.028	± 0.011	>50
$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	± 0.100	± 0.033	44
$\lvert V_{cb}\rvert$ incl.	$\pm 2.4\%$	$\pm 1.0\%$		< 1
$\lvert V_{cb}\rvert$ excl.	$\pm 3.6\%$	$\pm 1.8\%$	$\pm 1.4\%$	< 1
$\lvert V_{ub}\rvert$ incl.	$\pm 6.5\%$	$\pm 3.4\%$	$\pm 3.0\%$	2
$\lvert V_{ub}\rvert$ excl. (had. tag.)	$\pm 10.8\%$	$\pm 4.7\%$	$\pm 2.4\%$	20
$\lvert V_{ub}\rvert$ excl. (untag.)	$\pm 9.4\%$	$\pm 4.2\%$	$\pm 2.2\%$	3
$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	96 ± 26	$\pm 10\%$	$\pm 5\%$	46
$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7	5σ	$>> 5\sigma$	>50
$R(B \to D\tau\nu)$	$\pm 16.5\%$	$\pm 5.6\%$	$\pm 3.4\%$	4
$R(B \to D^*\tau\nu)$	$\pm 9.0\%$	$\pm 3.2\%$	$\pm 2.1\%$	3
$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40		$\pm 30\%$	>50
$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55		$\pm 30\%$	>50
$\mathcal{B}(B \to X_s\gamma)$ [10^{-6}]	$\pm 13\%$	$\pm 7\%$	$\pm 6\%$	< 1
$A_{CP}(B \to X_s\gamma)$		± 0.01	± 0.005	8
$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	± 0.11	± 0.035	> 50
$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	± 0.23	± 0.07	> 50
C_7/C_9 $(B \to X_s\ell\ell)$	$\sim 20\%$	10%	5%	
$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	± 0.3		
$\mathcal{B}(B_s \to \tau^+\tau^-)$ [10^{-3}]		< 2		

Observables	Belle	Belle II		$\mathcal{L}_s$
	(2014)	5 ab^{-1}	50 ab^{-1}	[ab^{-1}]
$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \times 10^{-3}(1 \pm 0.053 \pm 0.038)$	$\pm 2.9\%$	$\pm$(0.9%-1.3%)	> 50
$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \times 10^{-3}(1 \pm 0.037 \pm 0.054)$	$\pm$(3.5%-4.3%)	$\pm$(2.3%-3.6%)	3-5
y_{CP} [10^{-2}]	$1.11 \pm 0.22 \pm 0.11$	$\pm$(0.11-0.13)	$\pm$(0.05-0.08)	5-8
A_Γ [10^{-2}]	$-0.03 \pm 0.20 \pm 0.08$	± 0.10	$\pm$(0.03-0.05)	7 - 9
$A_{CP}^{K^+K^-}$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$	± 0.11	± 0.06	15
$A_{CP}^{\pi^+\pi^-}$ [10^{-2}]	$0.55 \pm 0.36 \pm 0.09$	± 0.17	± 0.06	> 50
$A_{CP}^{\phi\gamma}$ [10^{-2}]	± 5.6	± 2.5	± 0.8	> 50
$x^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	± 0.14	± 0.11	3
$y^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	± 0.08	± 0.05	15
$\lvert q/p\rvert^{K_S\pi^+\pi^-}$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	± 0.10	± 0.07	5-6
$\phi^{K_S\pi^+\pi^-}$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	± 6	± 4	10
$A_{CP}^{\pi^0\pi^0}$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	± 0.29	± 0.09	> 50
$A_{CP}^{K^0_S\pi^0}$ [10^{-2}]	$-0.10 \pm 0.16 \pm 0.09$	± 0.08	± 0.03	> 50
$Br(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5	$\pm 30\%$	$\pm 25\%$	2
	$\tau \to \mu\gamma$ [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

BELLE2-NOTE-0021

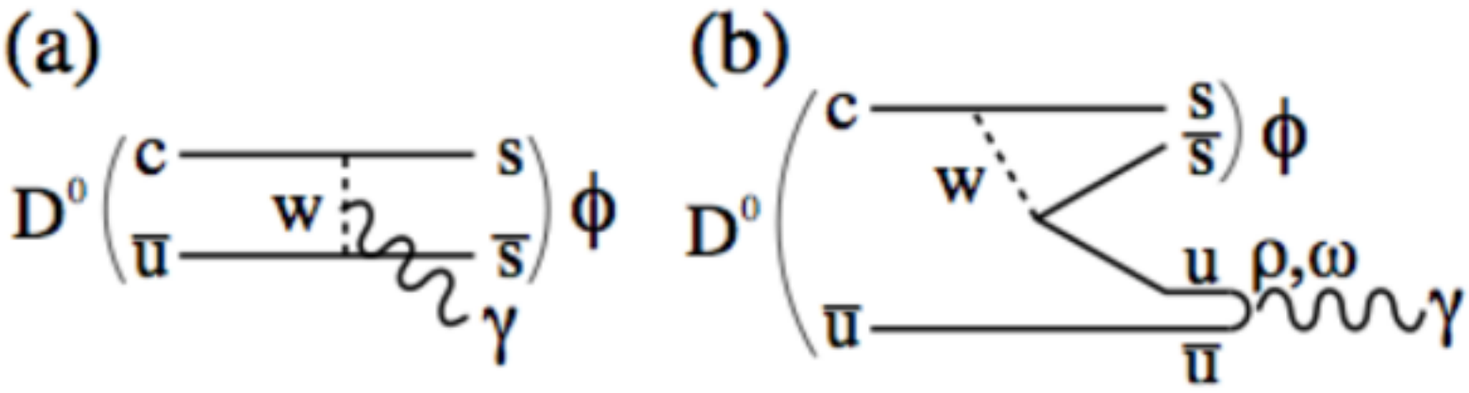
Direct CPV in $D^0 \to \Phi\gamma$, $\rho^0\gamma$

- Direct CPV in radiative decays can be enhanced to exceed 1%:
  - $D^0 \to \Phi\gamma$: A_{CP} up to 2%
  - $D^0 \to \rho^0\gamma$: A_{CP} up to 10%
- $D^0 \to \Phi\gamma$: first observation by Belle with 78 fb^{-1}:
  - Yield: $27.6^{+7.4+0.5}_{-6.5-1.0}$
  - relative error on yield ~25%
- A_{CP} sensitivity at 50 ab^{-1}: ~1%

Refs:

G. Isidori and J. F. Kamenik, PRL 109, 171801 (2012)

O. Tajima et al. (Belle Collaboration), PRL 92, 101803 (2004)



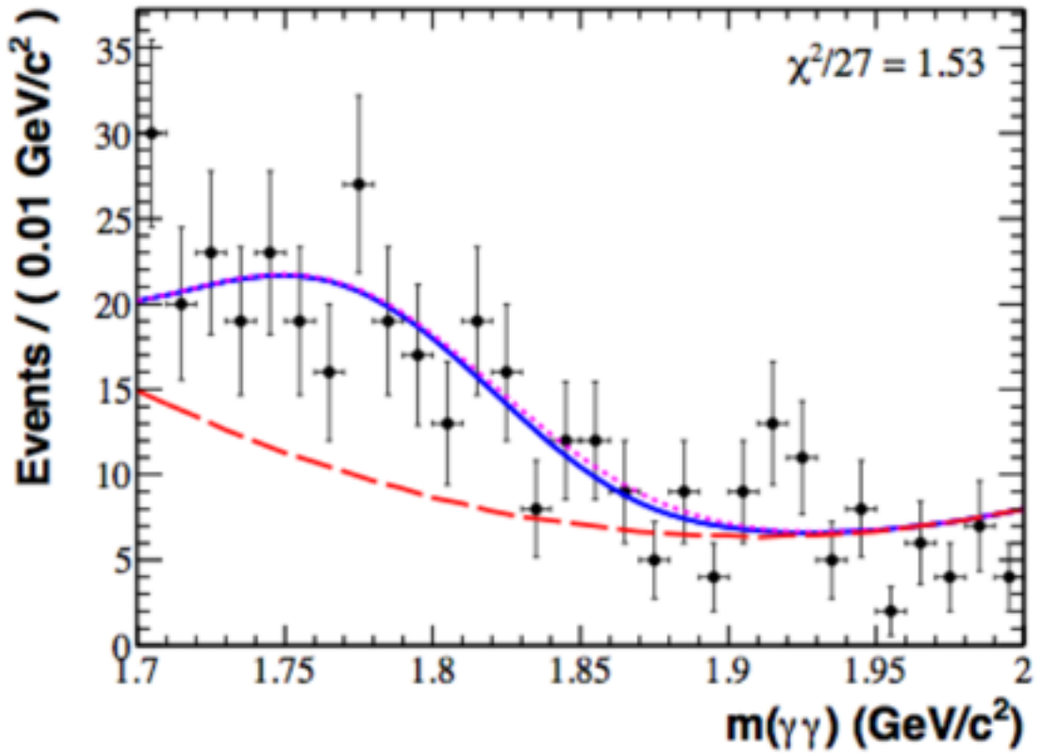
$D^0 \rightarrow \gamma\gamma$

- SM predictions with long distance effects domination: BR ~ 10^{-8}

- BaBar with 470 fb^{-1}: BR < 2.2×10^{-6} @ 90% CL

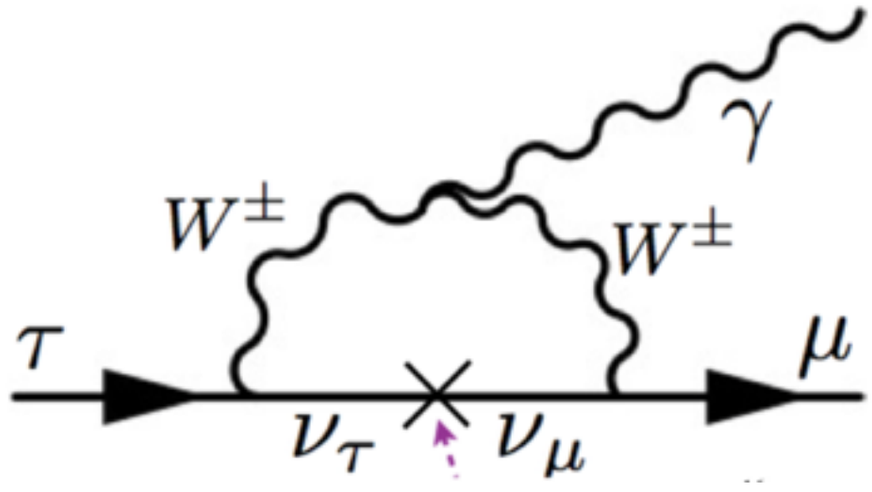
- Belle II with 50 ab^{-1}:
  - depends on how background behaves
  - UL ~ 2×10^{-8}, if UL scales with L
  - UL ~ 2×10^{-7}, if UL scales with $\sqrt{L}$

PRD 85 (2012) 091107



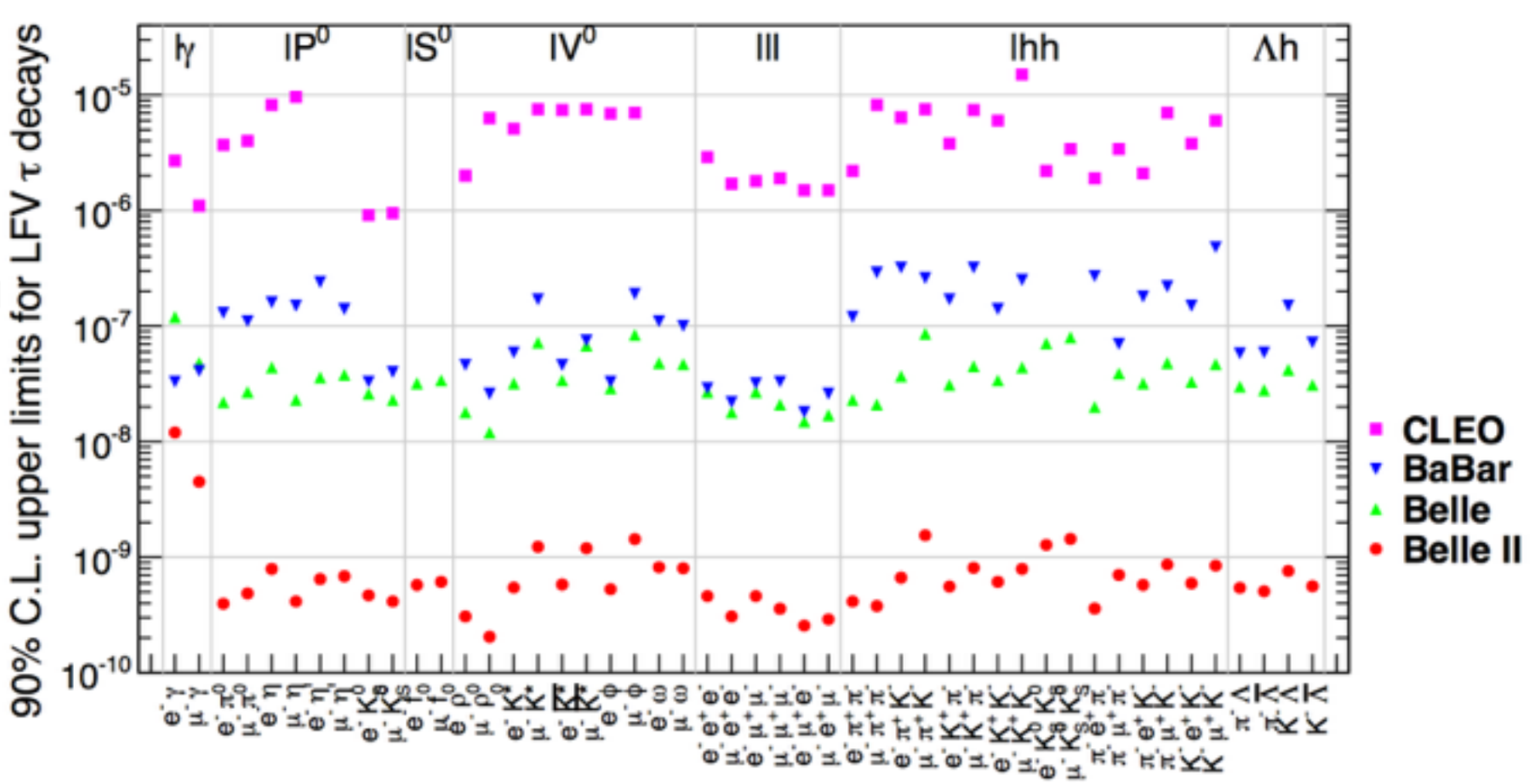
τ Lepton Flavour Violation

SM prediction:
BR(LFV) ~ 10^{-25}



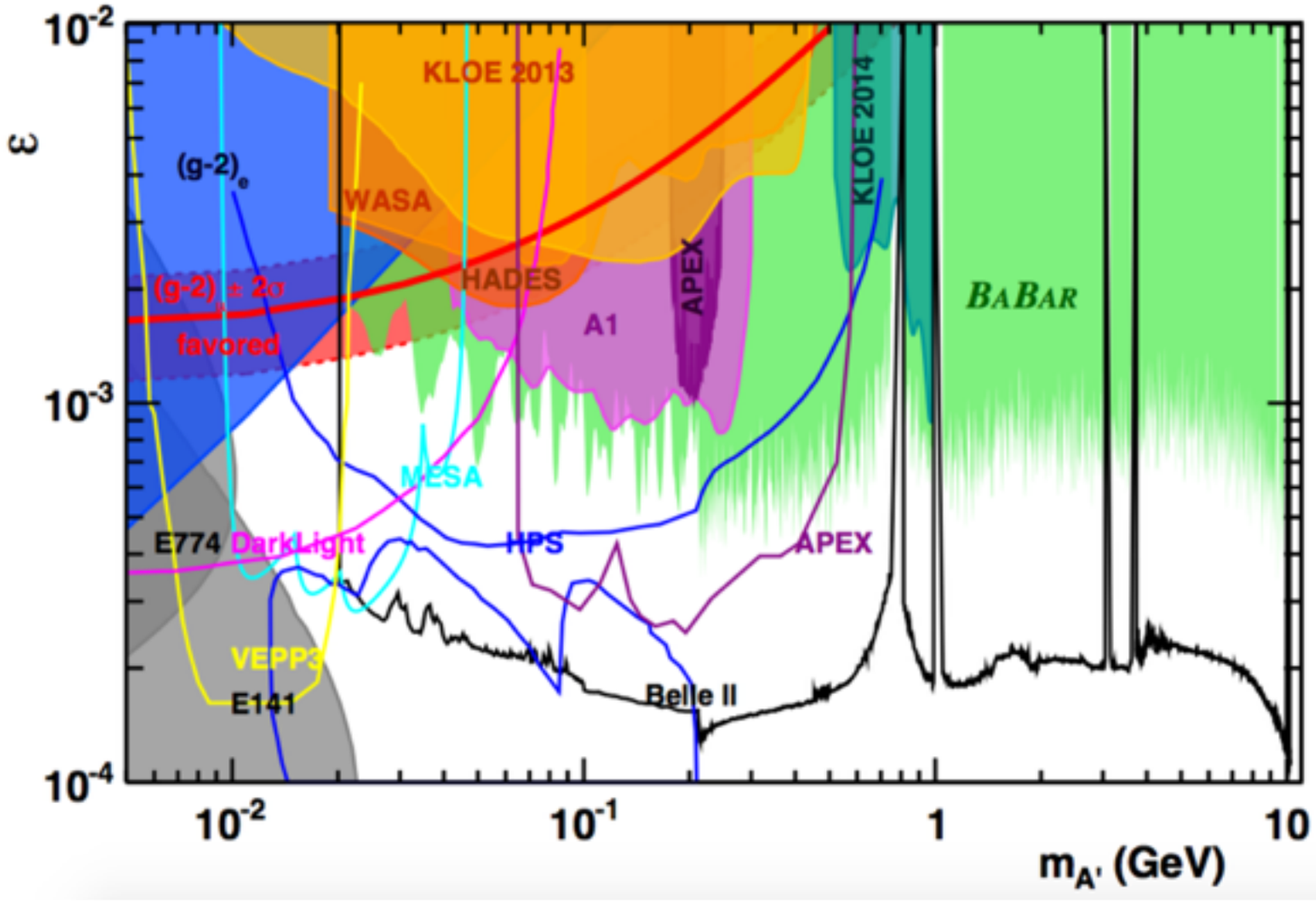
Possible NP in LFV:

- slepton mixing
- H^{++} Zee-Babu models
- Neutral Higgs boson
- Majorana neutrinos
- Seesaw mechanisms



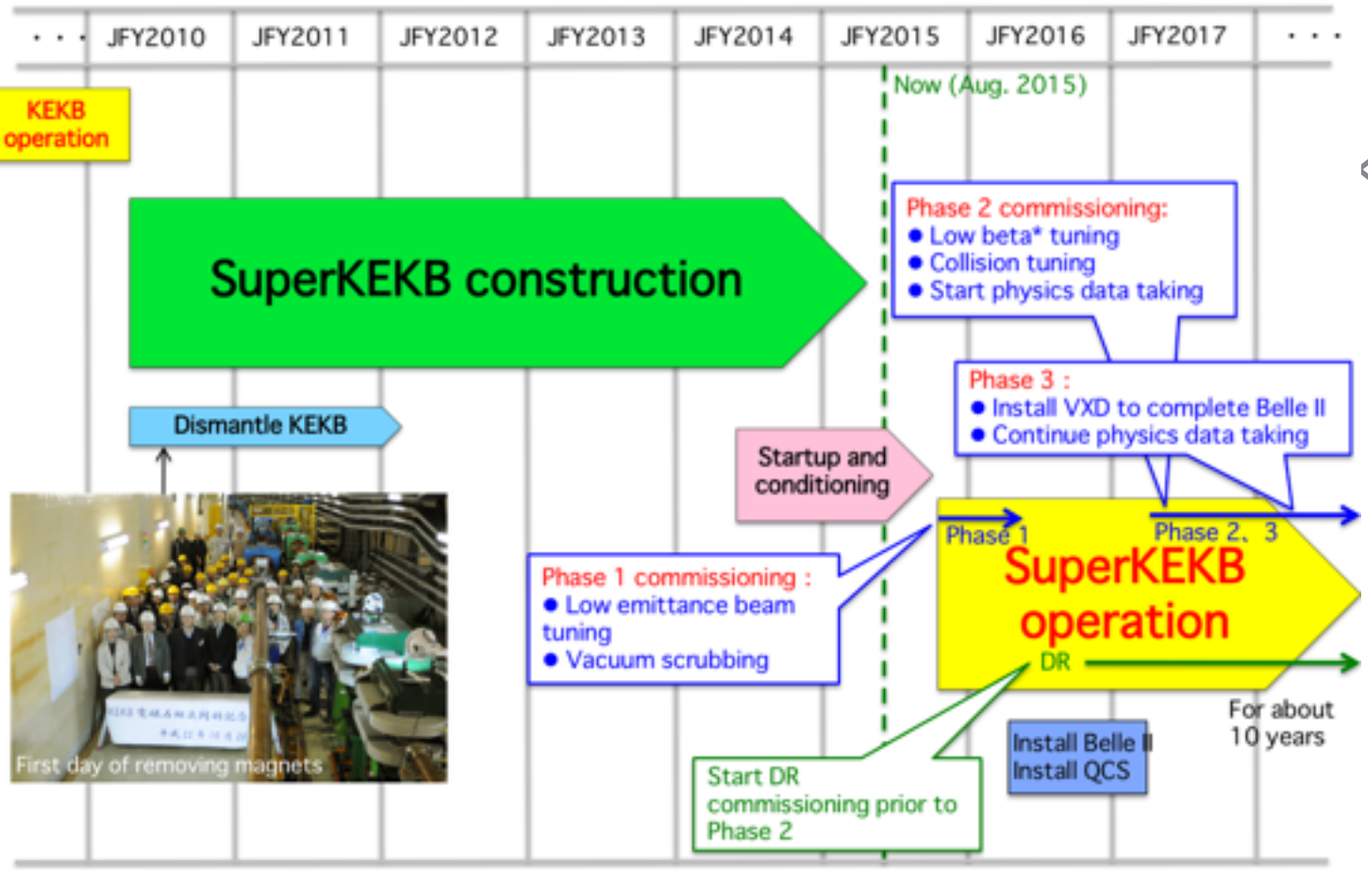
Dark Sector

- Dark matter suggests dark sector.
- Dark photon: A’, to be in MeV ~ GeV mass.
- Probing method:
  - Leptonicaly decaying dark photons through mixing.
- Sub-GeV dark matter in invisible decays.



Current and projected limits, radiative production of dark photon, decay to SM particles (C. Hearty, B2TIP 2014)

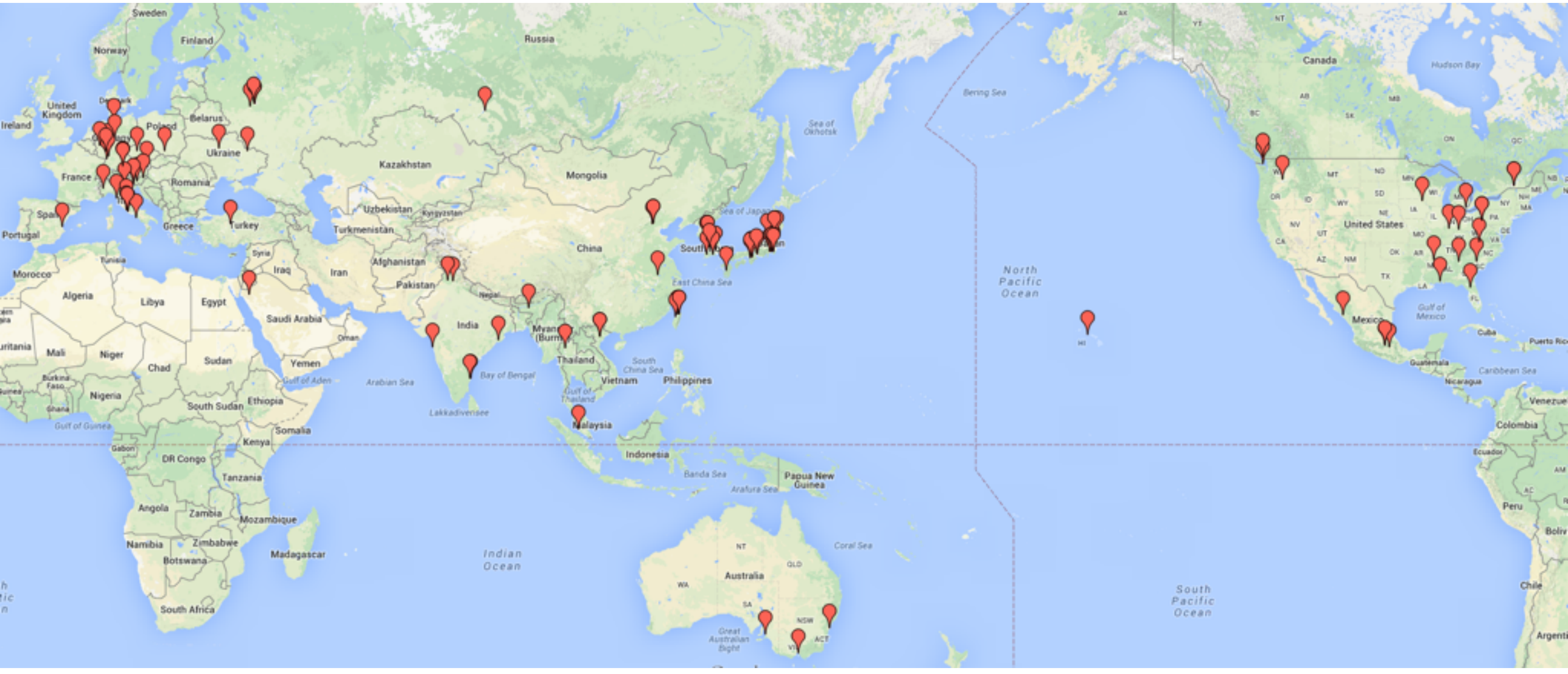
Schedule



Installation and commissioning plan

Luminosity schedule

Belle II Collaboration



~600 collaborators, 97 institutions, 23 countries

Summary

- B-factories had some rich and successful physics results and many hints of new physics.

- Belle will be upgraded to Belle II to further explore these opportunities.

- Belle II will start operation in 2016 and start taking physics data in 2018.

- The target integrated luminosity for physics data is 50 ab^{-1}, which is much larger than the current data set.