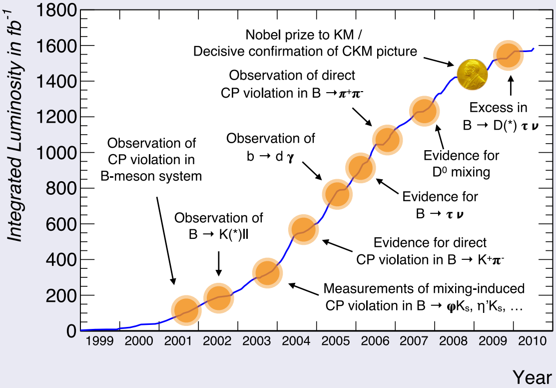
Belle II

Physics Prospects at Belle II

Outline

1. Introduction
2. Brief Belle II overview
3. CKM matrix and the Unitarity Triangle
4. Semitauonic B decays
5. Lepton Flavor Violation
6. Hadron spectroscopy
7. Low multiplicity signatures

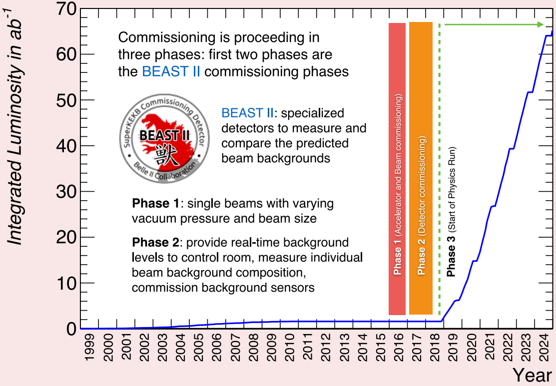
Last decade rich harvest of Belle and BaBar



It seems the more we know the more questions arise

- SM, the best tested theory, does not explain many things
- Need for more good quality data to find answers
- Belle II plans to collect $50ab^{-1}$ integrated luminosity

Belle II / SuperKEKB luminosity projections



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- SM, the best tested theory, does not explain many things
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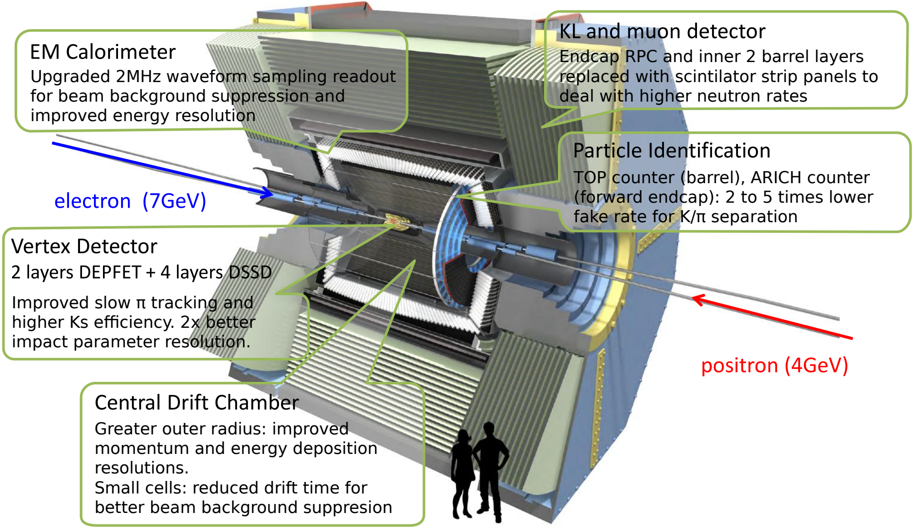
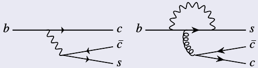
The Belle detector has been significantly upgraded to form Belle II. Several subdetectors have been completely replaced to support higher rates and challenging physics program.

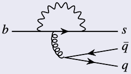


Over-constraining the UT to test the SM

- Current precision leaves room for NP
- Search for new sources of CPV (disagreement between *loop* and *tree* processes)
- Better measurements of $\sin 2\beta$



Error on $\sin(2\beta)$	stat.	tot.
B-Factories	3.5%	3.9%
Belle II 5/ab	1.3%	1.8%
Belle II 50/ab	0.4%	**1.2%**



$B \to \eta' K^0$

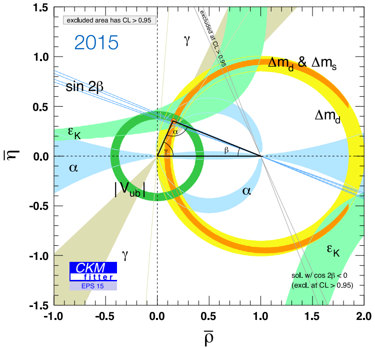
Error on $\sin(2\beta)$	tot.
B-Factories	9.4%
Belle II 5/ab	4.2%
Belle II 50/ab	**1.6%**

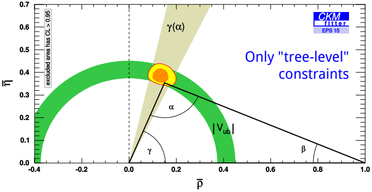
$B \to \phi K^0$

Error on $\sin(2\beta)$	tot.
B-Factories	17.8%
Belle II 5/ab	7.9%
Belle II 50/ab	**2.7%**

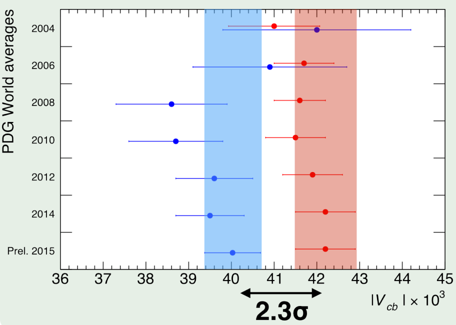
$B \to K^0 K^0 K^0$

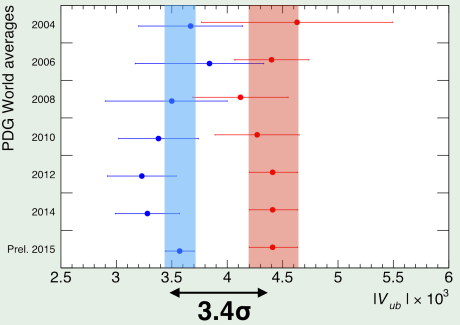
Error on $\sin(2\beta)$	tot.
B-Factories	33.9%
Belle II 5/ab	15.1%
Belle II 50/ab	**4.9%**

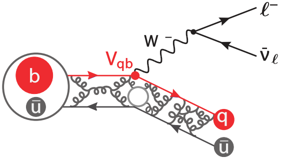




Sizeable tension in *exclusive* and *inclusive* measurements of $|V_{ub}|\&|V_{cb}|$







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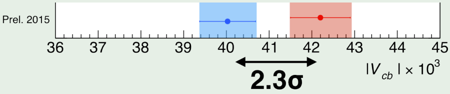
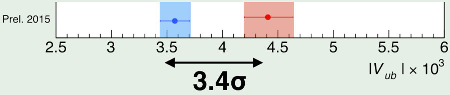




Improved precision should help to resolve this tension

had. tagged
$B \to D^* \ell \bar{\nu}_\ell$

Error on $|V_{cb}|$	stat.	tot.
B-Factories	0.6%	3.6%
Belle II 5/ab	0.2%	1.8%
Belle II 50/ab	0.1%	**1.4%**

had. tagged
$B \to \pi \ell \bar{\nu}_\ell$

Error on $|V_{ub}|$	stat.	tot.
B-Factories	5.8%	10.8%
Belle II 5/ab	2.2%	4.7%
Belle II 50/ab	0.7%	**2.4%**

untagged
$B \to \pi \ell \bar{\nu}_\ell$

Error on $|V_{ub}|$	stat.	tot.
B-Factories	2.7%	9.4%
Belle II 5/ab	1.0%	4.2%
Belle II 50/ab	0.3%	**2.2%**

$B \to X_c \ell \bar{\nu}_\ell$

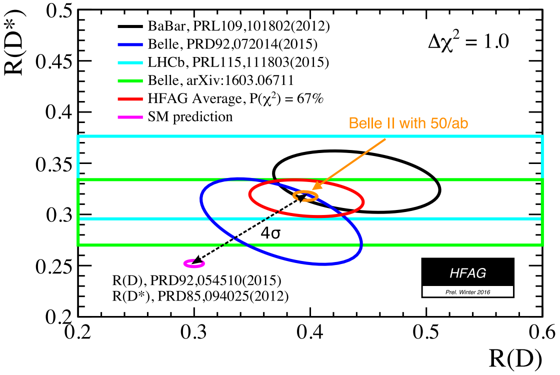
Error on $|V_{cb}|$	stat.	tot.
B-Factories	1.5%	1.8%
Belle II 50/ab	0.5%	**1.2%**

$B \to X_u \ell \bar{\nu}_\ell$

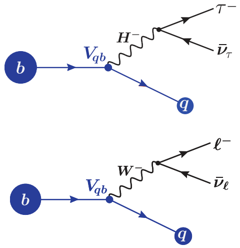
Error on $|V_{ub}|$	stat.	tot.
B-Factories	4.5%	6.5%
Belle II 5/ab	1.1%	3.4%
Belle II 50/ab	0.4%	**3%**

$B \to D^{(*)}\tau\bar{\nu}_\tau$

- Sensitive to extended Higgs sector – new physics at tree level
- About 4σ disagreement between SM expectation and observation
- Deviations not compatible with type II 2HDM
- Sensitive observables *e.g.* τ polarization – possible $\mathcal{O}(1)$ effects

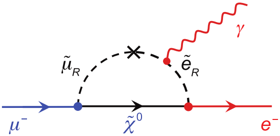


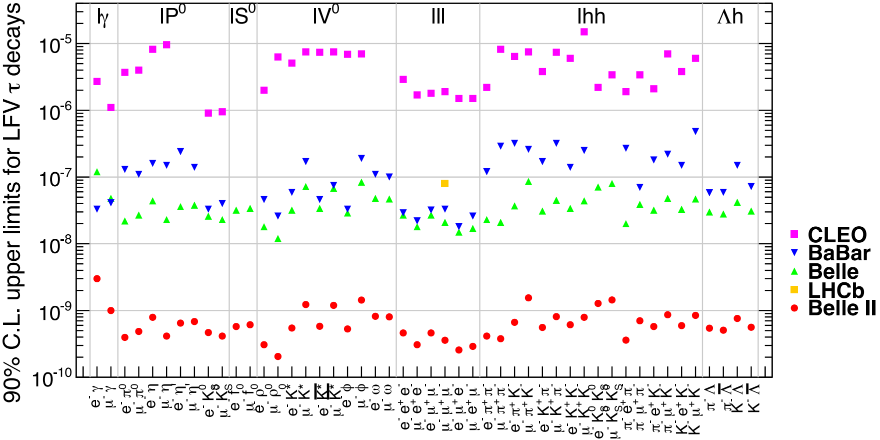
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu}_\ell)}$$



LFV signals are expected in many beyond SM scenarios.

Belle II will be able to improve current limits by a factor of 100 for $\tau \to 3\ell$ and (at least) a factor of 10 for $\tau \to \ell\gamma$.





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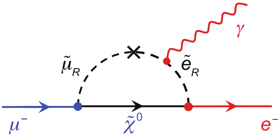

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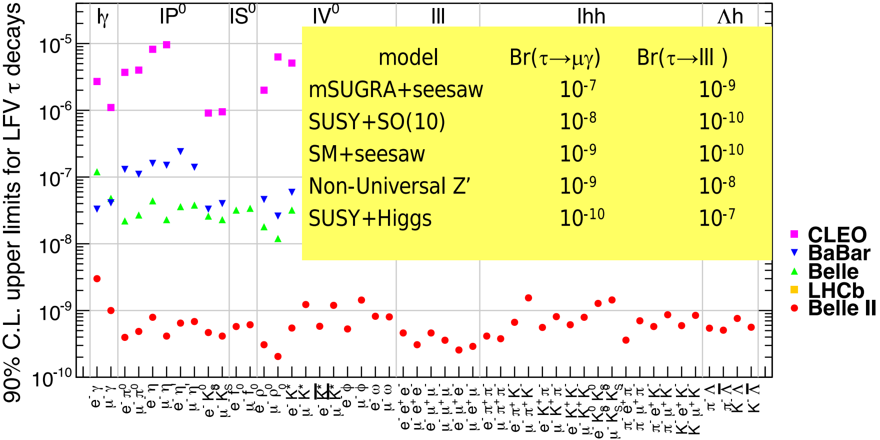
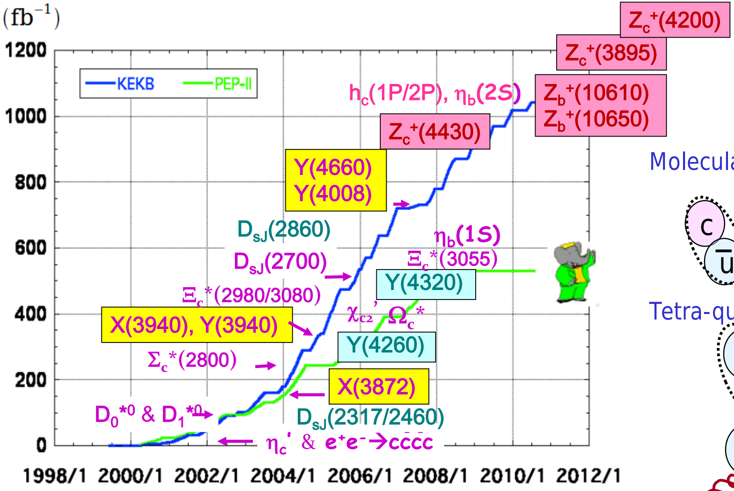
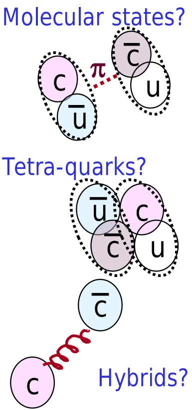


model	Br(τ→μγ)	Br(τ→lll)
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z’	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

Many new states are observed, which do not fit in the traditional quark model.
More are expected in Belle II, opening a door for exotic state studies.





Coloured boxes: exotic candidates

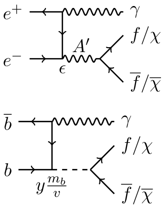
Belle II can probe ‘dark forces’ with dedicated Triggers

- ‘dark forces’: involving dark-matter particles that serve as ‘portals' between the SM and a dark-matter sector

dark photon mass coupling strength

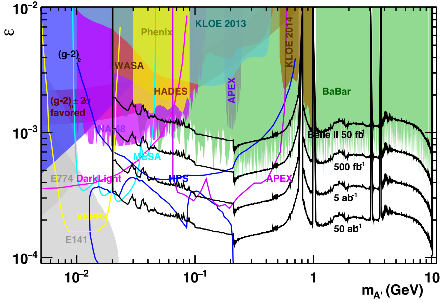
$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m^2_{A'}}{2}A'_{\mu}A'^{\mu} - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}$$

- Motivated by rise in cosmic-ray positron fraction (which does not necessarily have to be due to New Physics)
- Also models with dark Higgs bosons that could be produced in Y(nS) decays.

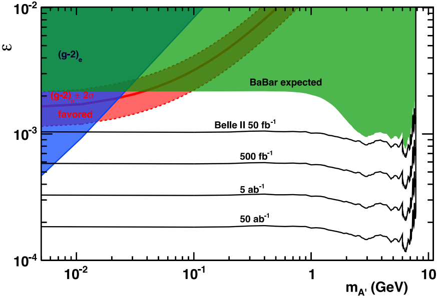


Belle II will probe a unique piece of phase space, and even a small data sample will have a sizeable impact on todays limits

(Prompt) dilepton final state



invisible final state

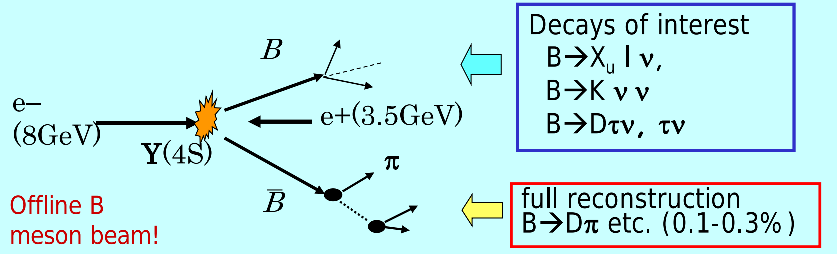


Summary

- There many interesting possibilities at Belle II
- Of course, we have no monopoly for quark-flavor physics, therefore competitive or complementary studies at LHC are welcomed.

BACKUP

An example of the power of a B factory: fully reconstruct one of the B's to tag B flavor/charge, determine its momentum, and exclude decay products of this B from further analysis (exactly two B's produced in $\Upsilon(4S)$ decays)

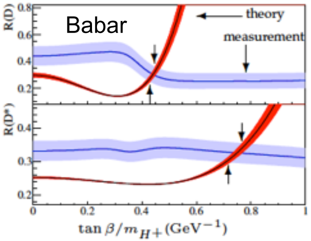


Powerful tool for B decays with neutrinos, used in several analyses

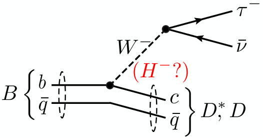
→unique feature at B factories

Peter Križan, Ljubljana

$\mathcal{B}(B\to D^*\tau\nu)$ and $\mathcal{B}(B\to D\tau\nu)$



BaBar: Neither R* nor R is a good match to the SM ($\tan\boldsymbol{\beta}/M_H = 0$) calculation.
Both can match the type II 2HDM but not at a consistent value of $\tan\boldsymbol{\beta}/M_H$.



In common with $\mathcal{B}(B\to\tau\nu)$ this process has good sensitivity to existence of a charged Higgs.

$$R(D^*) \equiv \frac{\mathcal{B}\left(\bar{B}\to D^*\tau\bar{\nu}\right)}{\mathcal{B}\left(\bar{B}\to D^*\ell\bar{\nu}\right)} \qquad \ell = e$$

or

$$R(D) \equiv \frac{\mathcal{B}\left(\bar{B}\to D\tau\bar{\nu}\right)}{\mathcal{B}\left(\bar{B}\to D\ell\bar{\nu}\right)} \qquad \ell = \mu$$

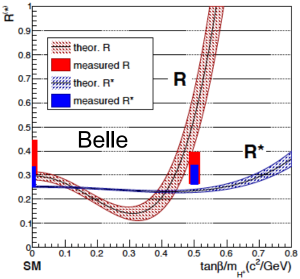


FIG. 8. Theoretical predictions with 1σ error ranges for R (red) and R^* (blue) for different values of $\tan\beta/m_{H+}$ in the 2HDM of type II. This analysis' fit results for $\tan\beta/m_{H+} = 0.5\,c^2/\mathrm{GeV}$ and SM are shown with their 1σ ranges as red and blue bars with arbitrary width for better visibility.

Transformation of a *B*-Factory into a **Super** *B*-Factory

To achieve the necessary sensitivity to further push the intensity frontier, the instantaneous luminosity needed to increase from **$2.1 \times 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$ to $8 \times 10^{35}\ \mathrm{cm^{-2}\ s^{-1}}$**

The key to this is a beam-configuration called the **nano-beam scheme** that squeeze the beam to have a very small vertical spot size of about 50 nm

LER / HER	KEKB	SuperKEKB
Energy [GeV]	3.5 / 8	4.0 / 7.0
β_y^* [mm]	5.9 / 5.9	**0.27 / 0.30**
β_x^* [mm]	1200	**32 / 25**
$I_\pm$ [A]	1.64 / 1.19	**3.6 / 2.6**
$\zeta_{\pm y}$	0.129 / 0.09	**0.09 / 0.09**
ε [nm]	18 / 24	**3.2 / 4.6**
# of bunches	1584	2500
Luminosity [$10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$]	2.1	80

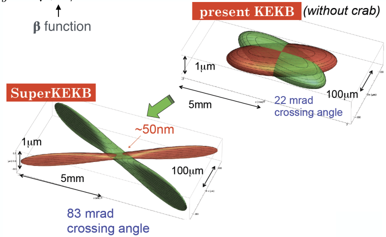
Major upgrade of existing accelerator needed

$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \zeta_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

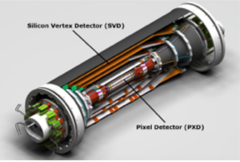
Lorentz factor: $\gamma_\pm$; beam current: $I_\pm$; beam-beam parameter: $\zeta_{\pm y}$; beam size aspect ratio: σ_y^*/σ_x^*; vertical β function: β_y^*; geometric factors: R_L/R_y

$$\zeta_{\pm y} \sim \sqrt{\beta^*/\epsilon}$$

β^*: β function; ϵ: emittance



Belle II: VXD



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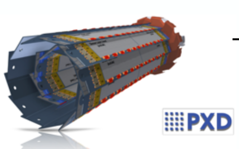

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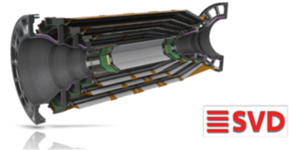
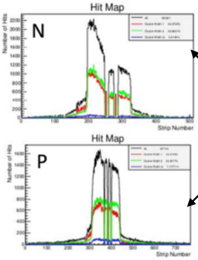
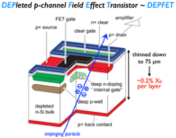


VXD

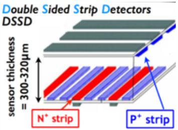
Hit map example (CE)



SVD Beam Test Results



PXD: 2 layers of DEPFET



SVD: 4 layers of DSSD

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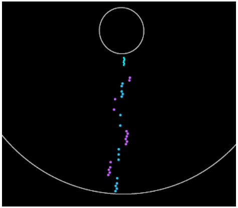
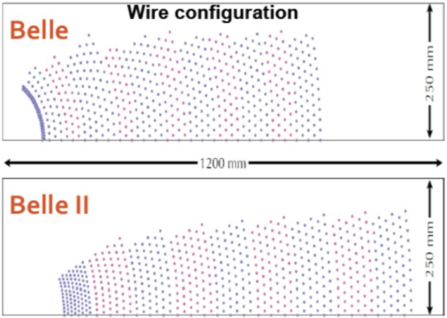
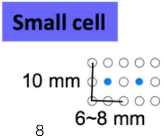
Belle II: CDC

- 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







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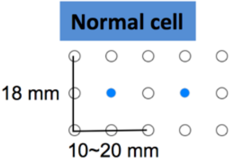
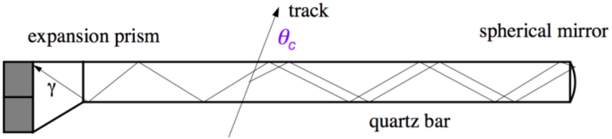
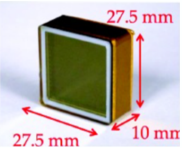
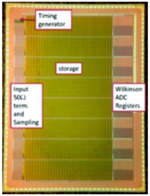


Belle II: TOP



- 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





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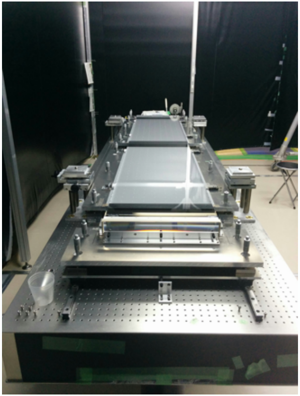
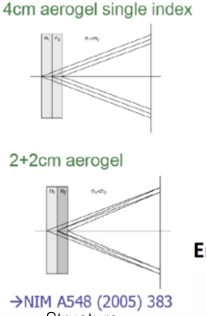
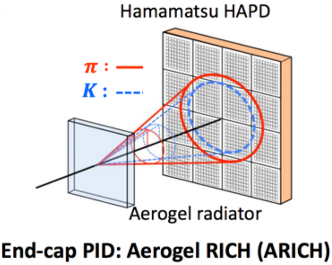


Belle II: ARICH

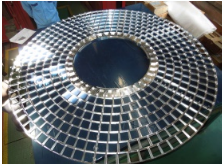
- Aerogel Ring Imaging Cerenkov (ARICH) detector will be used for particle identification in the forward end cap
- 420 Hybrid Avalanche Photo Detectors (HAPD), each with 144 channels
- Two layers of aerogel lead to better photon yield, while not affecting resolution





Aerogel

Structure



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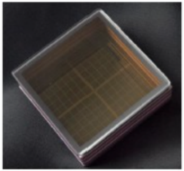
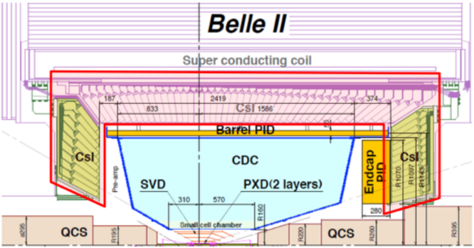
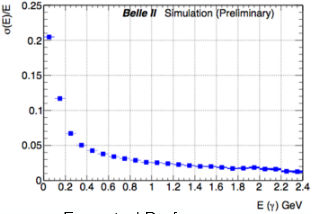
HAPD



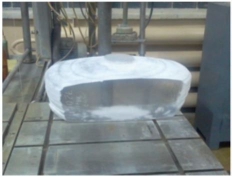
Belle II: ECL

- 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



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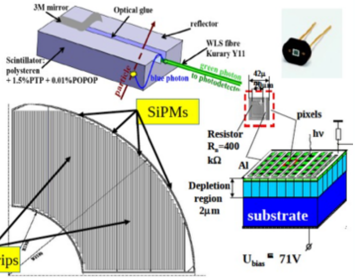
Belle II: KLM

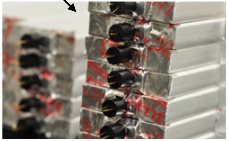
- Endcaps and parts of the barrel KLM RPCs of Belle will be replaced with scintillators due to increased backgrounds expected in Belle II
- Barrel KLM was the first sub-detector to be installed in Belle II

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



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