Status Report from Belle II

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for the Belle II collaboration

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LES RENCONTRES DE PHYSIQUE
DE LA VALLÉE D'AOSTE

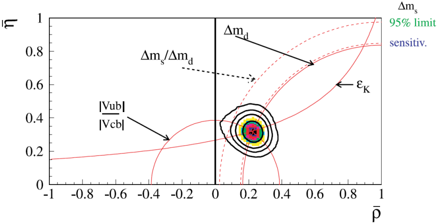
Outline

- Introduction
- Physics case for Belle II
- Accelerator – Super KEKB
- Detector – Belle II
- Status and prospects

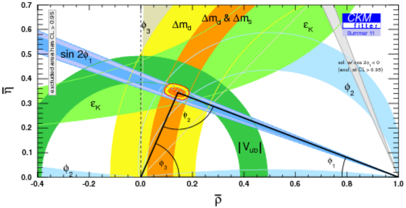
B-factories *v1.0*: test of the Flavor Sector of the SM

- BaBar (PEPII@SLAC) and Belle (KEKB@KEK)
    - Together recorded over 10^9 $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ events
    - among others made:
        - discovery of CPV in B meson system
        - measurements of the CKM matrix elements and angles of the unitarity triangle
        - measurements of rare (semi-)leptonic B decays
        - observation of mixing in charm system
        - searches for rare τ decays
        - observations of new hadrons

UT @ 2000 [J.Phys.G:Nucl.Part.Phys.27,1101]



UT @ 2011 [CKM fitter]



Confirmation of the Kobayashi-Maskawa mechanism of CPV.

B-factory *v2.0*: quest for New Physics

Belle II at Super-KEKB:

- an intensity frontier experiment being built in Tsukuba, Japan
  - aims to collect $\sim$50x larger data sample compared to Belle+BaBar in the next decade to reveal new physics through precision studies of rare or suppressed decays

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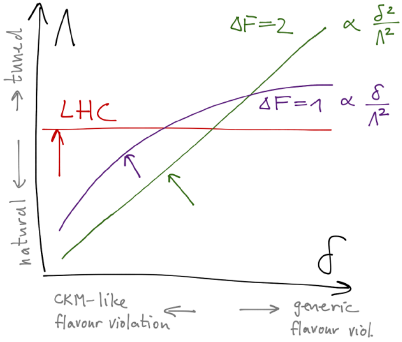
D.Straub@Wednesday

Energy vs. Intensity frontiers



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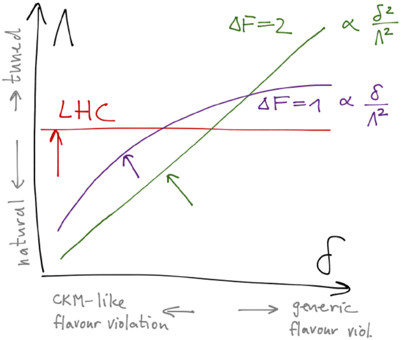

Spectacular examples from history:

- $\Gamma(K_L^0 \to \mu\mu) \ll \Gamma(K \to \mu\nu_\mu) \Rightarrow$ Charm [GIM, 1970]
- $\Delta m_K \Rightarrow m_c \sim 1.5$ GeV [Gaillard -Lee, 1974]
- $\varepsilon_K \neq 0 \Rightarrow 3$ generations [KM, 1973]
- $\Delta m_B \Rightarrow m_t \gg m_W$ [various, 1986]

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Key observables

Belle II vs. **LHCb**

Observable	SM theory	Current measurement (early 2013)	Belle II ($50\,\mathrm{ab}^{-1}$)
$S(B \to \phi K^0)$	0.68	0.56 ± 0.17	± 0.03
$S(B \to \eta' K^0)$	0.68	0.59 ± 0.07	± 0.02
α from $B \to \pi\pi,\ \rho\rho$		$\pm 5.4^\circ$	$\pm 1.5^\circ$
γ from $B \to DK$		$\pm 11^\circ$	$\pm 1.5^\circ$
$S(B \to K_S \pi^0 \gamma)$	< 0.05	-0.15 ± 0.20	± 0.03
$S(B \to \rho\gamma)$	< 0.05	-0.83 ± 0.65	± 0.15
$A_{\mathrm{CP}}(B \to X_{s+d}\,\gamma)$	< 0.005	0.06 ± 0.06	± 0.02
A^d_{SL}	-5×10^{-4}	-0.0049 ± 0.0038	± 0.001
$\mathcal{B}(B \to \tau\nu)$	1.1×10^{-4}	$(1.64 \pm 0.34) \times 10^{-4}$	$\pm 0.05 \times 10^{-4}$
$\mathcal{B}(B \to \mu\nu)$	4.7×10^{-7}	$< 1.0 \times 10^{-6}$	$\pm 0.2 \times 10^{-7}$
$\mathcal{B}(B \to X_s\gamma)$	3.15×10^{-4}	$(3.55 \pm 0.26) \times 10^{-4}$	$\pm 0.13 \times 10^{-4}$
$\mathcal{B}(B \to X_s \ell^+\ell^-)$	1.6×10^{-6}	$(3.66 \pm 0.77) \times 10^{-6}$	$\pm 0.10 \times 10^{-6}$
$\mathcal{B}(B \to K\nu\bar{\nu})$	3.6×10^{-6}	$< 1.3 \times 10^{-5}$	$\pm 1.0 \times 10^{-6}$
$A_{\mathrm{FB}}(B \to K^*\ell^+\ell^-)_{q^2<4.3\,\mathrm{GeV}^2}$	-0.09	0.27 ± 0.14	± 0.04
$s_0\,A_{\mathrm{FB}}(B^0 \to K^{*0}\ell^+\ell^-)$	0.16	0.029	0.008
$\lvert V_{ub}\rvert$ from $B \to \pi\ell^+\nu$ ($q^2 > 16\,\mathrm{GeV}^2$)	$9\% \to 2\%$	11%	2.1%

Observable	SM theory uncertainty	Precision as of 2013	LHCb ($6.5\ \mathrm{fb}^{-1}$)	LHCb Upgrade ($50\ \mathrm{fb}^{-1}$)
$2\beta_s(B_s \to J/\psi\phi)$	~ 0.003	0.09	0.025	0.008
$\gamma(B \to D^{(*)}K^{(*)})$	$< 1^\circ$	8°	4°	0.9°
$\gamma(B_s \to D_s K)$	$< 1^\circ$	—	$\sim 11^\circ$	2°
$\beta(B^0 \to J/\psi K^0_S)$	small	0.8°	0.6°	0.2°
$2\beta_s^{\mathrm{eff}}(B_s \to \phi\phi)$	0.02	1.6	0.17	0.03
$2\beta_s^{\mathrm{eff}}(B_s \to K^{*0}\bar{K}^{*0})$	< 0.02	—	0.13	0.02
$2\beta_s^{\mathrm{eff}}(B_s \to \phi\gamma)$	0.2%	—	0.09	0.02
$2\beta^{\mathrm{eff}}(B^0 \to \phi K^0_S)$	0.02	0.17	0.30	0.05
A^s_{SL}	0.03×10^{-3}	6×10^{-3}	1×10^{-3}	0.25×10^{-3}
$\mathcal{B}(B_s \to \mu^+\mu^-)$	8%	42%	15%	5%
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s \to \mu^+\mu^-)$	5%	—	$\sim 100\%$	$\sim 35\%$
$s_0\,A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	7%	18%	6%	2%

[arXiv:1311.1076]

Need both LHCb and super B factory (as well as precise theoretical predictions!) to cover all aspects of precision flavor physics.

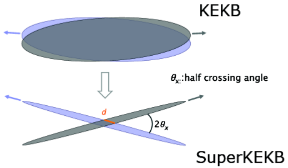
Super-KEKB

Increase luminosity by factor of 40 by:

- double the beam currents
- **squeeze the beam at IP by 1/20**

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

(Nano-beam design by P. Raimondi for SuperB)



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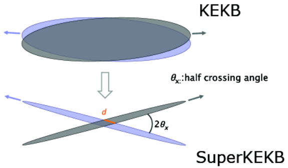
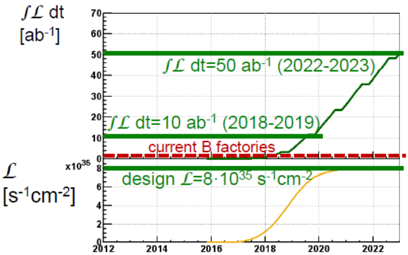
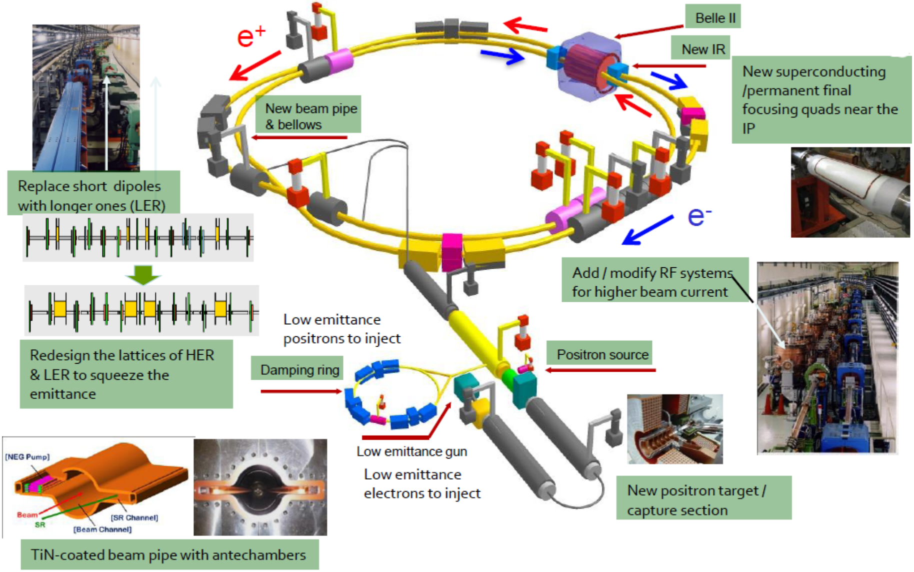


Luminosity Projection

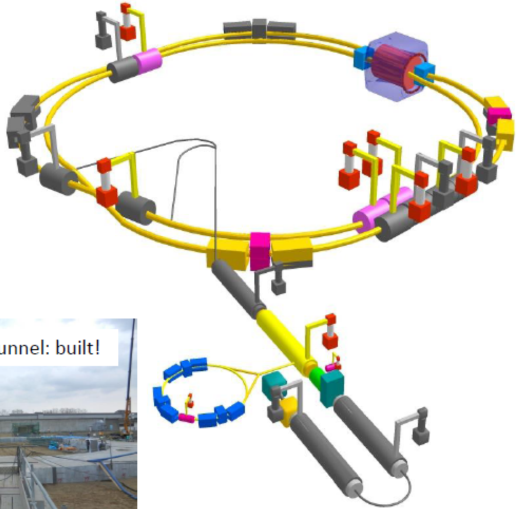


SuperKEKB

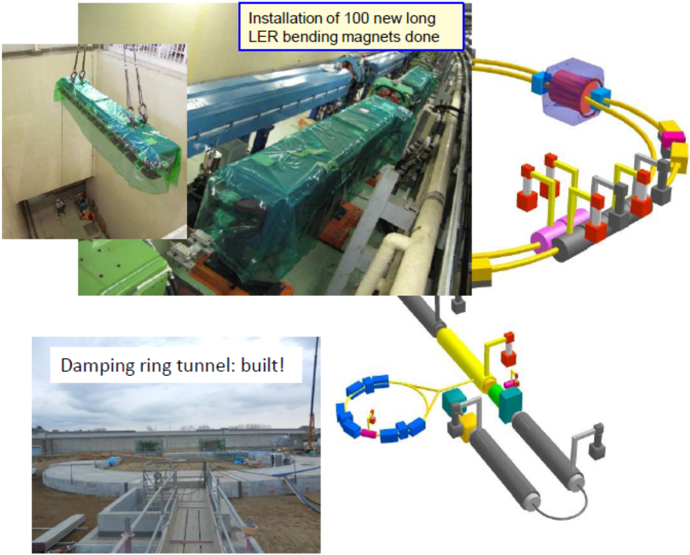


e+
e-
Belle II
New IR
New superconducting /permanent final focusing quads near the IP
New beam pipe & bellows
Replace short dipoles with longer ones (LER)
Redesign the lattices of HER & LER to squeeze the emittance
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Positron source
Damping ring
Low emittance gun
Low emittance electrons to inject
New positron target / capture section
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN-coated beam pipe with antechambers

SuperKEKB



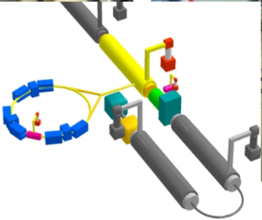
SuperKEKB


Installation of 100 new long
LER bending magnets done
Damping ring tunnel: built!

SuperKEKB

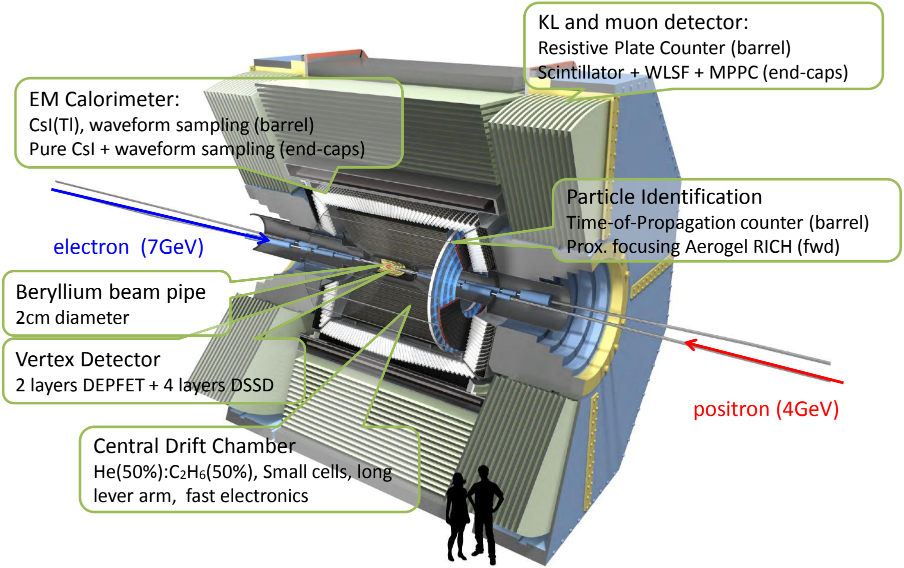
Installation of 100 new long LER bending magnets done

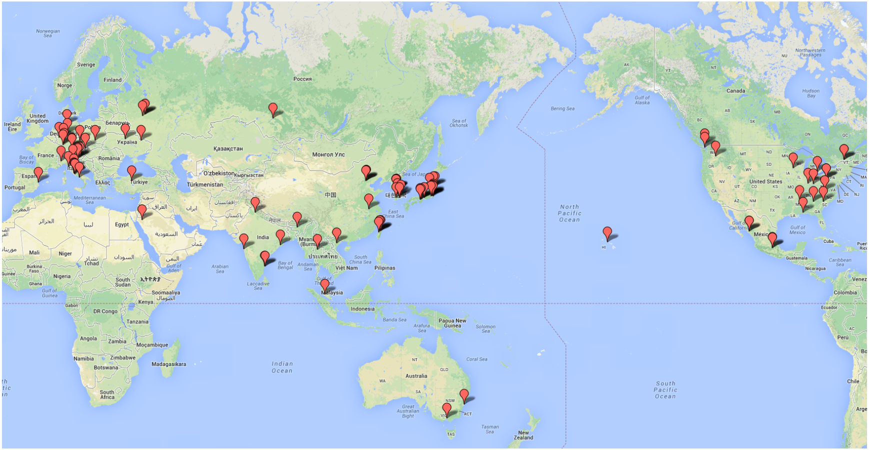
Installation of HER and LER wiggler chambers in Oho straight section is done.



Damping ring tunnel: built!

Belle II Detector





599 Collaborators, 97 institutes, 23 countries

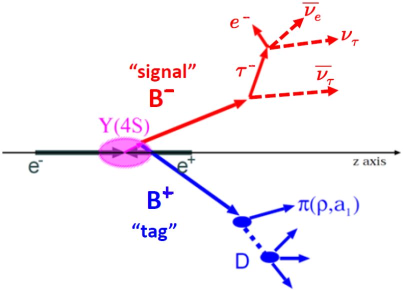
Belle II – benchmark physics modes

Methods and processes where Super B-factory can provide important insight into NP complementary to other experiments:

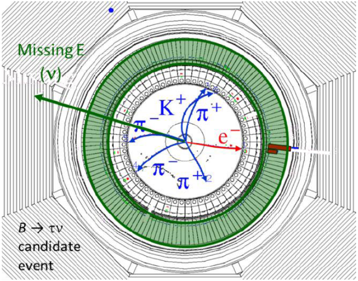
- Missing energy modes
  - $B^+ \to \ell^+ \nu_\ell \qquad (\ell^+ = e^+,\ \mu^+,\ \tau^+)$
  - $B \to D^* \tau \nu_\tau$, $B \to X_c \ell \nu_\ell$, $B \to X_u \ell \nu_\ell$, $B \to K^{(*)} \nu \overline{\nu}$
- Inclusive measurements
  - $B \to X_s \gamma$, $B \to X_s \ell \ell$
- Decay modes with neutrals in the final state
  - $B \to K_S^0 \pi^0 \gamma$, $B \to \eta' K_S^0$
  - $B \to \gamma\gamma$
- excellent flavor tagging performance (10$\times$ better than at hadron colliders)
- Lepton Flavor Violating τ decays

Detailed description of physics program at Super B-factories described in arXiv: 1002.5012 and arXiv: 1008.1541.

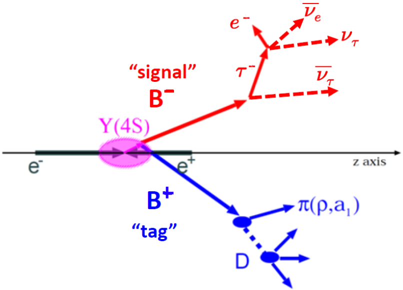
Missing energy modes

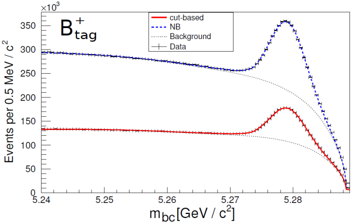


Example Belle B → τν candidate



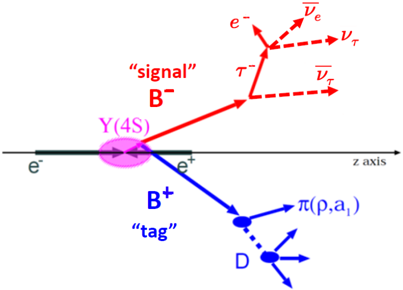
Missing energy modes

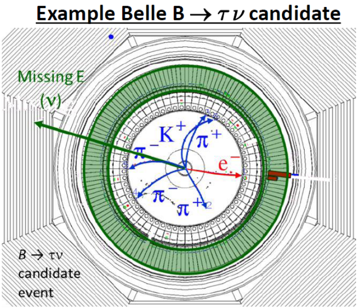




1. Reconstruct one of the B mesons ($B_{\rm tag}$) in the event
   - typically $\varepsilon(B_{\rm tag}) \sim 0.20\% - 0.25\%$ at 20% purity

Missing energy modes





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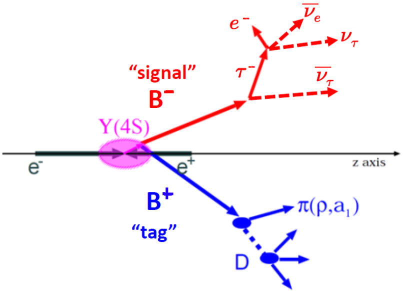
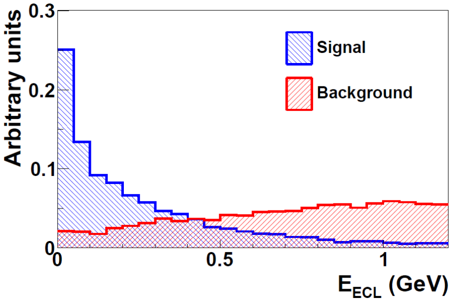
2. All remaining particle(s) in the detector originate from the decay of other B
   - What is the number of remaining charged tracks?
   - Is it kaon, pion, electron, or ....?





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2. All remaining particle(s) in the detector originate from the decay of other B
   - What is the number of remaining charged tracks?
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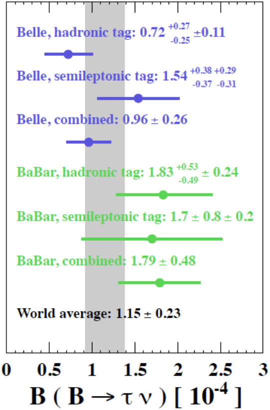
   - Is there any additional activity in the calorimeter?

Missing energy modes: $B^+ \to \tau^+ \nu_\tau$

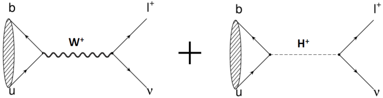
B-factories



$$r_H = 1.14 \pm 0.40$$

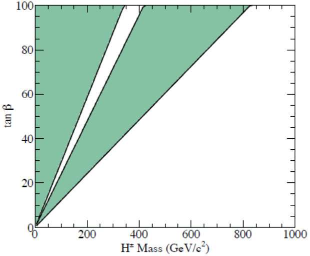
using $V_{ub} = 3.95 \pm 0.54$ and

$f_B = 191 \pm 9$



SM — 2HDM(TypeII)

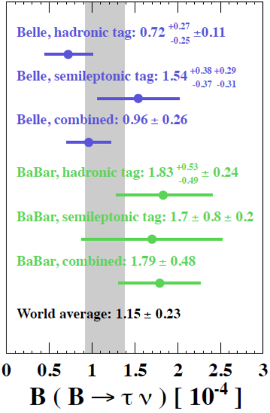
$$\mathcal{B} = \underbrace{\frac{G_F^2}{8\pi}\tau_B f_B^2 |V_{ub}|^2 m_B^3 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left(\frac{m_\tau}{m_B}\right)^2}_{\equiv \mathcal{B}^{SM}} \times \underbrace{\left(1 - m_B^2 \frac{tan^2\beta}{m_{H\pm}^2}\right)^2}_{\equiv r_H}$$



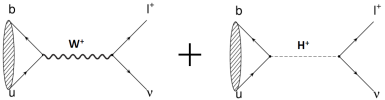
B-factories exclusion plot

Missing energy modes: $B^+ \to \tau^+ \nu_\tau$

B-factories



Aim to measure $\mathcal{B}(B \to \tau\nu)$ with precision of 3-5%



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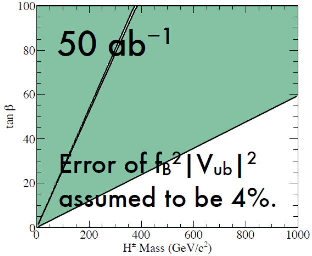
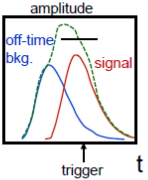


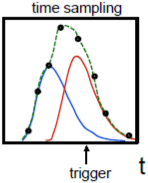
Super B-factory exclusion plot

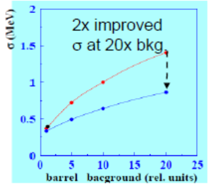
EM Calorimeter

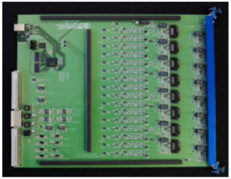
Re-usage of the Belle's CsI(Tl) crystal calorimeter, but with

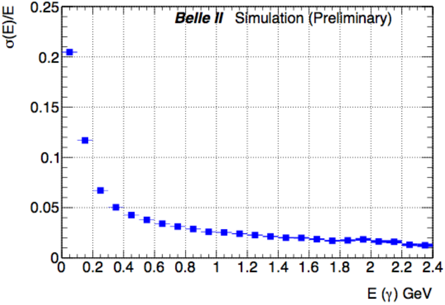
- **barrel:** new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(Tl) signals
- **forward endcap:** CsI(Tl) ⇒CsI for faster performance and better radiation hardness (not from the beginning of data-taking)











Muon/K_L detection

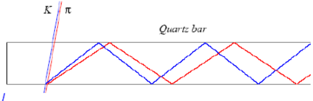
- Endcap RPCs and two layers of the barrel have to be replaced with scintillators to handle higher backgrounds (mainly from neutrons)

  ↪ Expected to improve K_L and muon detection efficiency beyond Belle performance

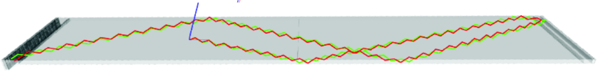
Virginia Tech crew

Barrel KLM installation completed – first new Belle II detector subsystem installed.

Barrel: Time of Propagation counter



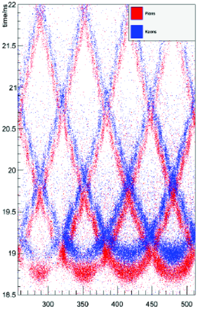
measure t and x of single γ with pixelated PMT

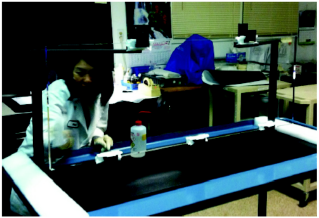


time (ns)

need resolution < 100 ps

500 ps

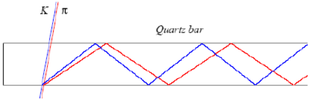




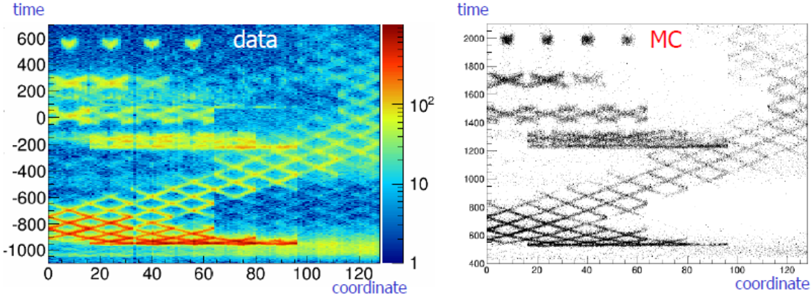
- Procurement of precision optical components has been difficult, but production is now under way

Particle identification detectors

Barrel: Time of Propagation counter



- Pattern in the coordinate-time space ('ring') is different for kaons and pions



Excellent agreement between beam test data and MC simulated patterns

Particle identification detectors

Barrel: Time of Propagation counter

Decay mode	π efficiency with 2% K fakes π rate 100ps electronics jitter	π efficiency with 4% K fakes π rate 100ps electronics jitter	π efficiency with 4% K fakes π rate 50ps electronics jitter
$B \to \pi\eta\gamma$ vs $K\eta\gamma$	84.28 +/- 0.91	94.13 +/- 0.57	93.22 +/- 0.52
$B^+ \to \rho\gamma$ vs $K^*\gamma$	80.71+/-1.07	93.19+/-0.67	92.55 +/- 0.62
$B^0 \to \rho\gamma$ vs $K^*\gamma$	81.50+/- 0.78	92.63+/-0.49	92.13 +/- 0.46
$B^+ \to \pi\pi\pi^0\gamma$ vs $K\pi\pi^0\gamma$	83.55+/-0.76	94.03+/-0.46	93.47 +/- 0.43
$B^0 \to \pi\pi\pi\gamma$ vs $K\pi\pi\gamma$	79.50 +/- 0.67	91.48+/-0.45	92.56 +/- 0.38
$B^+ \to \pi\pi\pi\pi^0\gamma$ vs $K\pi\pi\pi^0\gamma$	75.00+/-0.72	90.50 +/-0.44	91.01 +/- 0.38
$B^0 \to \pi\pi\pi\pi\gamma$ vs $K\pi\pi\pi\gamma$	76.33+/-0.37	90.00+/-0.33	92.20 +/- 0.31

Beam test performance adequate to do 1–2% measurement of $|V_{td}|/|V_{ts}|$

Neutrals: t-dependent CP asymmetry in $B \to K^*(K_S^0\pi^0)\gamma$

$$\mathcal{A}(\Delta t) = Ssin(\Delta m \Delta t) + Acos(\Delta m \Delta t)$$

Possible due to interference with mixing between dominant decay helicities

$$b \to s\gamma_L \qquad \text{or} \qquad \overline{b} \to \overline{s}\gamma_R$$

and suppressed decay helicities:

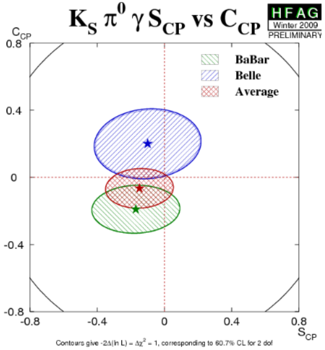
$$b \to s\gamma_R \qquad \text{or} \qquad \overline{b} \to \overline{s}\gamma_L$$

In SM one naively expects:

$$S_{K_S^0\pi^0\gamma} = -2\frac{m_s}{m_b} sin2\phi_1 \sim -0.03$$

Sensitive to helicity-changing NP contributions.
Example: Left-Right symmetric model $\to S_{K_S^0\pi^0\gamma} \sim 0.67 \cos 2\phi_1 \sim 0.5$

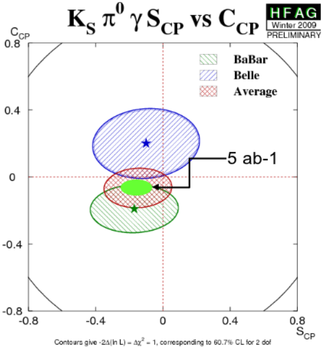
Neutrals: $B \to K^*(K_S^0\pi^0)\gamma$ at B-factories



$$S = -0.16 \pm 0.22 \qquad C = -0.04 \pm 0.14$$

Measurements stat. limited

Neutrals: $B \to K^*(K_S^0\pi^0)\gamma$ at B-factories



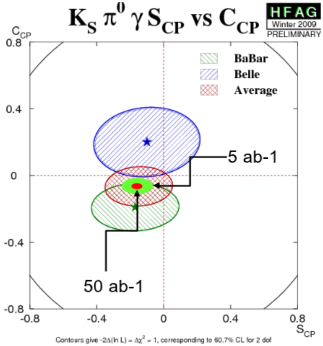
$$S = -0.16 \pm 0.22 \qquad C = -0.04 \pm 0.14$$

Measurements stat. limited

$$\Downarrow$$

$$\sigma(S_{K^*\gamma}) \approx 0.09 \;\; @ \;\; 5\ \text{ab}^{-1}$$

Neutrals: $B \to K^*(K^0_S\pi^0)\gamma$ at B-factories



$$S = -0.16 \pm 0.22 \qquad C = -0.04 \pm 0.14$$

Measurements stat. limited

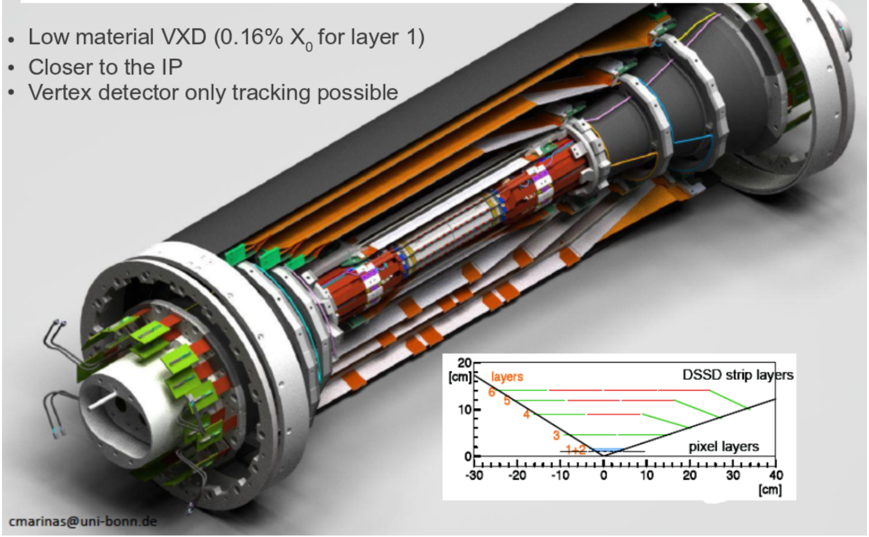
$$\Downarrow$$

$$\sigma(S_{K^*\gamma}) \approx 0.09 \;\; @ \;\; 5 \text{ ab}^{-1}$$
$$\approx 0.03 \;\; @ \;\; 50 \text{ ab}^{-1} \; (\sim \text{SM prediction})$$

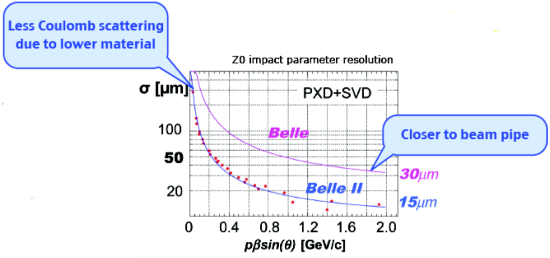
Vertex detectors

- 2 layers of DEPFET pixel sensors in the innermost part
- 4 layers of double-sided silicon strip sensors

- Low material VXD (0.16% X_0 for layer 1)
- Closer to the IP
- Vertex detector only tracking possible



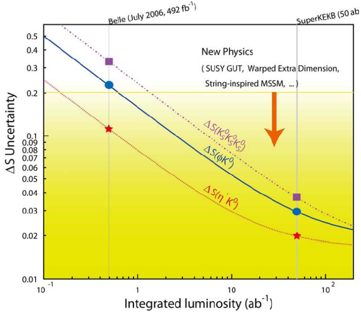
Vertex detectors



$$\sigma = a + b/(p\beta\sin^{\nu}\theta)$$

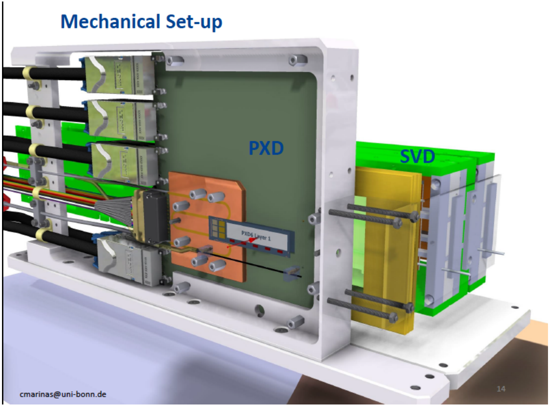
- in addition, bigger fraction of K_S^0 that have both pions with VXD hits

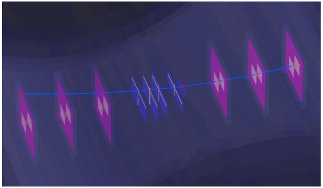
arXiv:1002.5012



Belle II can provide precision measurements of $\Delta S = S_{s\bar{s}s} - S_{c\bar{c}s}$, up to the limit of hadronic uncertainties, which will be at a few percent level.

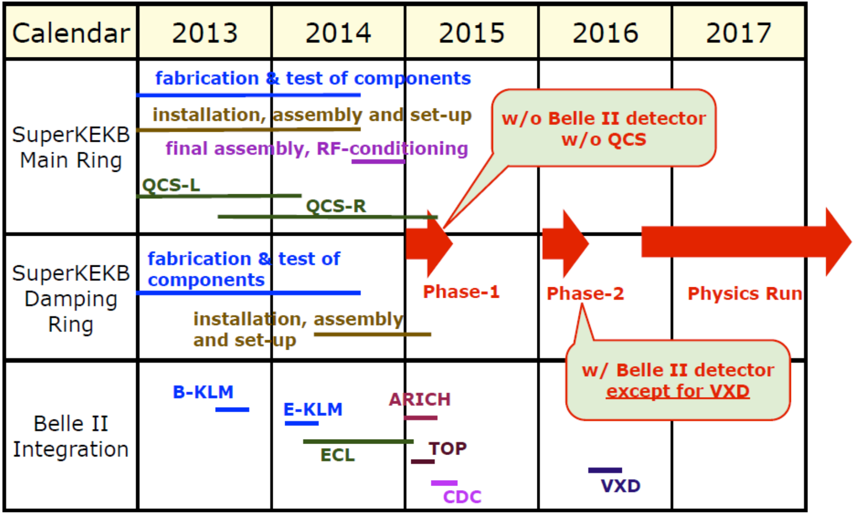
DESY Beam Test in January '14





Read out "Region Of Interest" scheme in PXD works!
(To reduce the Gbit/s data volume from pixels)

Construction and Commissioning Schedule



Belle II physics program summary

- rich physics program, complementary to existing experiments
- physics benchmark modes and methods are known from B factories, however we also need to think about modification of those and try to identify new ones more appropriate for huge statistics

Observable	SM theory	Current measurement (early 2013)	Belle II ($50\,\mathrm{ab}^{-1}$)
$S(B \to \phi K^0)$	0.68	0.56 ± 0.17	± 0.03
$S(B \to \eta' K^0)$	0.68	0.59 ± 0.07	± 0.02
α from $B \to \pi\pi,\ \rho\rho$		$\pm 5.4^\circ$	$\pm 1.5^\circ$
γ from $B \to DK$		$\pm 11^\circ$	$\pm 1.5^\circ$
$S(B \to K_S \pi^0 \gamma)$	< 0.05	-0.15 ± 0.20	± 0.03
$S(B \to \rho\gamma)$	< 0.05	-0.83 ± 0.65	± 0.15
$A_{\mathrm{CP}}(B \to X_{s+d}\,\gamma)$	< 0.005	0.06 ± 0.06	± 0.02
A_{SL}^d	-5×10^{-4}	-0.0049 ± 0.0038	± 0.001
$\mathcal{B}(B \to \tau\nu)$	1.1×10^{-4}	$(1.64 \pm 0.34) \times 10^{-4}$	$\pm 0.05 \times 10^{-4}$
$\mathcal{B}(B \to \mu\nu)$	4.7×10^{-7}	$< 1.0 \times 10^{-6}$	$\pm 0.2 \times 10^{-7}$
$\mathcal{B}(B \to X_s\gamma)$	3.15×10^{-4}	$(3.55 \pm 0.26) \times 10^{-4}$	$\pm 0.13 \times 10^{-4}$
$\mathcal{B}(B \to X_s \ell^+\ell^-)$	1.6×10^{-6}	$(3.66 \pm 0.77) \times 10^{-6}$	$\pm 0.10 \times 10^{-6}$
$\mathcal{B}(B \to K\nu\overline{\nu})$	3.6×10^{-6}	$< 1.3 \times 10^{-5}$	$\pm 1.0 \times 10^{-6}$
$A_{\mathrm{FB}}(B \to K^*\ell^+\ell^-)_{q^2 < 4.3\,\mathrm{GeV}^2}$	-0.09	0.27 ± 0.14	± 0.04
$s_0\,A_{\mathrm{FB}}(B^0 \to K^{*0}\ell^+\ell^-)$	0.16	0.029	0.008
$\lvert V_{ub}\rvert$ from $B \to \pi\ell^+\nu$ ($q^2 > 16\,\mathrm{GeV}^2$)	$9\% \to 2\%$	11%	2.1%

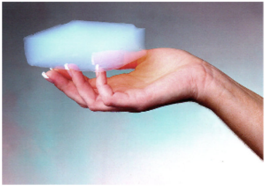
Conclusions

- Belle II detector construction is proceeding according to schedule
- SuperKEKB commissioning starts in Jan 2015
- Belle II roll-in in 2016 with first physics runs. This will inaugurate a new era of flavor physics.

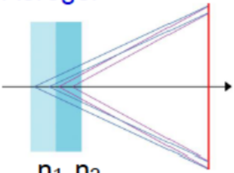
Backup

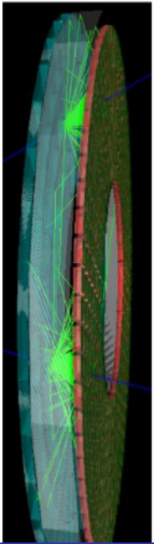
Particle identification

Aerogel RICH (endcap PID)

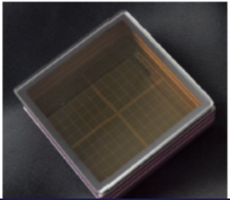


To distinguish kaons and pions in the forward endcap, use an aerogel RICH.





HAPD

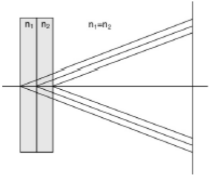


- PID in forward endcap.
- Two-layer aerogel as radiator
- 420 of 144-channel Hybrid Avalanche Photo Detector (HAPD).

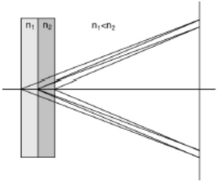
Aerogel RICH (endcap PID)

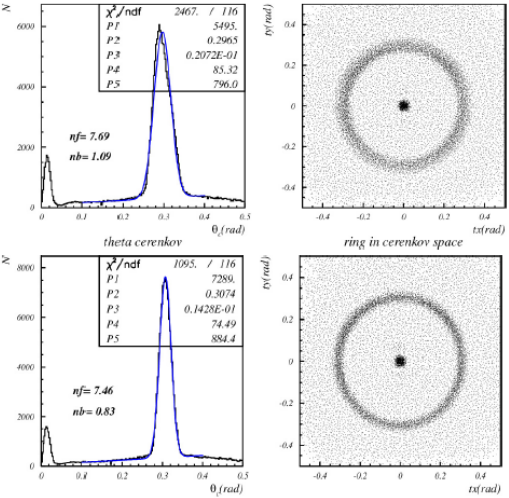
Increases the number of photons without degrading the resolution

4cm aerogel single index



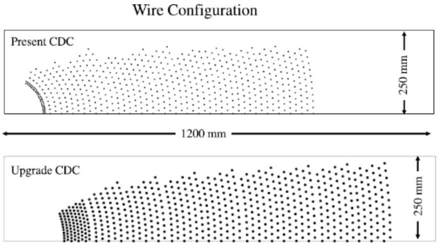
2+2cm aerogel

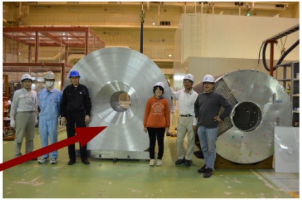




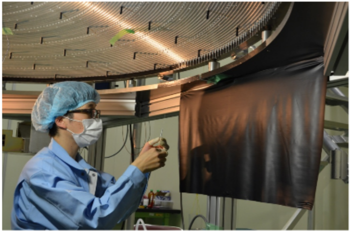
→NIM A548 (2005) 383

Central Drift Chamber



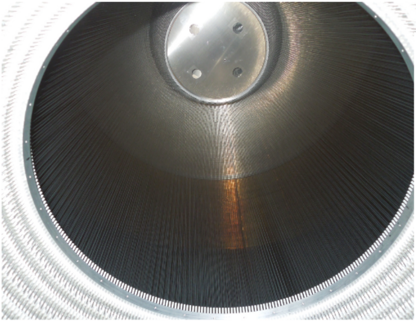


Longer lever arm than in Belle!



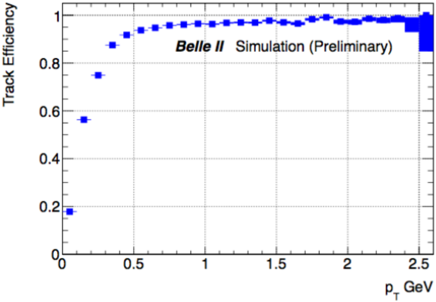
Wire stringing in a clean room in Fuji Hall

CDC wire stringing is done (~51k wires done)



CDC viewed from the backward side

Expected performance using Kalman filter and GEANT4 simulation



- Raw data storage and processing at KEK; duplicated at PNNL. Physics data distributed for analysis. Grid + cloud for MC production.

- Hardware requirements are comparable LHC.