Belle II

Christopher Hearty
University of British Columbia / IPP
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Belle / BaBar

- BaBar: PEP-II e^+e^- collider, Stanford linear accelerator center, 1999–2008.
  Belle: KEKB collider, KEK laboratory, Tsukuba, Japan, 1999–2010.

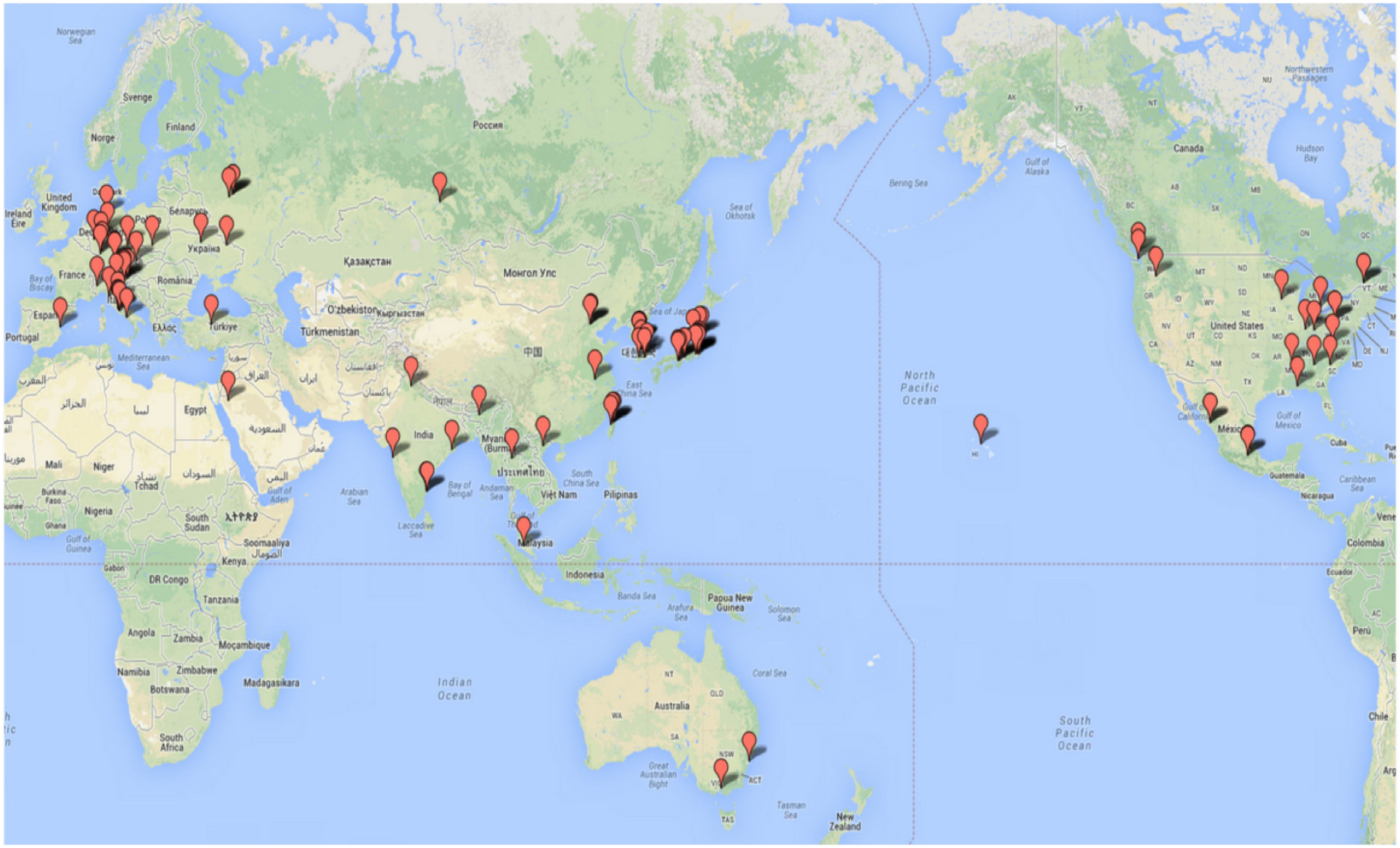
- Core program: weak force, especially CP violation

- >500 publications (BaBar); >400 (Belle)

The announcement of the 2008 Nobel prize in physics cited the experimental results from Belle and BaBar

Belle II

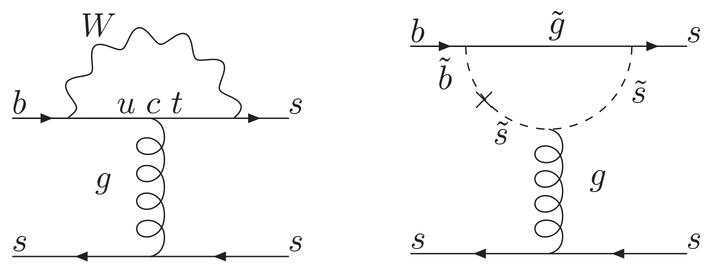
- Upgrade of Belle, located at SuperKEKB.
- 40x the peak luminosity of KEKB; 30x the combined integrated luminosity of BaBar + Belle.



- 97 institutions in 23 countries, 600 collaborators, including 320 PhD physicists.
- Canada joined in March 2013; Italy and Mexico in July 2013 (SuperB refugees).

Physic goals

- To seek evidence for new physics through a wide range of measurements sensitive to the presence of virtual heavy particles.



- Asymmetries, rare decays, forbidden decays. Modes with well-known uncertainties in the standard model, and testable predictions in new physics models.

- Continued exploration of the weak force and CP violation.

Subset of the modes that can be measured by Belle II

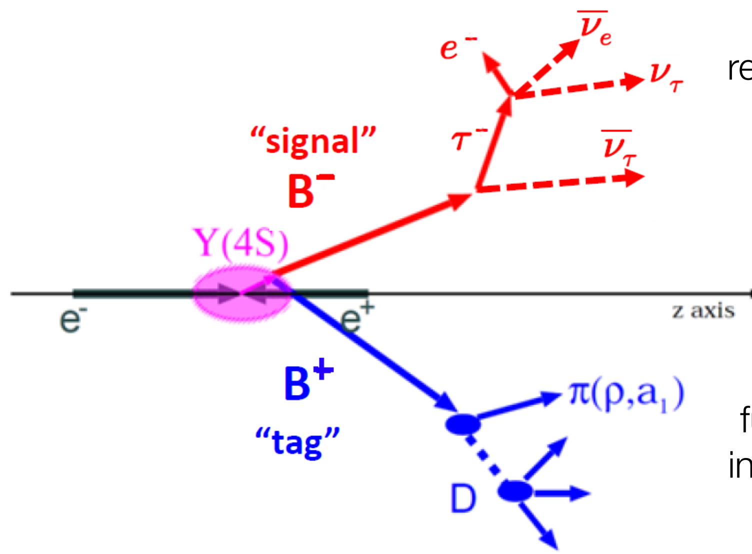
Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$	± 0.012	± 0.008
α		$\pm 2°$	$\pm 1°$
γ	$\pm 14°$	$\pm 6°$	$\pm 1.5°$
$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	± 0.053	± 0.018
$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	± 0.028	± 0.011
$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	± 0.100	± 0.033
$\lvert V_{cb}\rvert$ incl.	$\pm 2.4\%$	$\pm 1.0\%$	
$\lvert V_{cb}\rvert$ excl.	$\pm 3.6\%$	$\pm 1.8\%$	$\pm 1.4\%$
$\lvert V_{ub}\rvert$ incl.	$\pm 6.5\%$	$\pm 3.4\%$	$\pm 3.0\%$
$\lvert V_{ub}\rvert$ excl. (had. tag.)	$\pm 10.8\%$	$\pm 4.7\%$	$\pm 2.4\%$
$\lvert V_{ub}\rvert$ excl. (untag.)	$\pm 9.4\%$	$\pm 4.2\%$	$\pm 2.2\%$
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	96 ± 26	$\pm 10\%$	$\pm 3\%$
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	5σ	$>> 5\sigma$
$R(D\tau\nu)$	$\pm 16.5\%$	$\pm 5.2\%$	$\pm 2.5\%$
$R(D^*\tau\nu)$	$\pm 9.0\%$	$\pm 2.9\%$	$\pm 1.6\%$
$\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ $[10^{-6}]$	< 40		$\pm 30\%$
$\mathcal{B}(B \to K^{+}\nu\overline{\nu})$ $[10^{-6}]$	< 55		$\pm 30\%$
$\mathcal{B}(B \to X_s\gamma)$ $[10^{-6}]$	$\pm 13\%$	$\pm 7\%$	$\pm 6\%$
$A_{CP}(B \to X_s\gamma)$		± 0.01	± 0.005
$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$	± 0.11	± 0.035
$\mathcal{B}(B \to X_d\gamma)$ $[10^{-6}]$			
$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	± 0.23	± 0.07
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7	± 0.3	
$\mathcal{B}(B_s \to \tau^+\tau^-)$ $[10^{-3}]$		< 2	
$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \times 10^{-3}(1 \pm 0.053 \pm 0.038)$	$\pm 2.9\%$	$\pm(0.9\%$-$1.3\%)$
$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \times 10^{-3}(1 \pm 0.037 \pm 0.054)$	$\pm(3.5\%$-$4.3\%)$	$\pm(2.3\%$-$3.6\%)$
y_{CP} $[10^{-2}]$	$1.11 \pm 0.22 \pm 0.11$	$\pm(0.11$-$0.13)$	$\pm(0.05$-$0.08)$
A_Γ $[10^{-2}]$	$-0.03 \pm 0.20 \pm 0.08$	± 0.10	$\pm(0.03$-$0.05)$
$A_{CP}^{K^+K^-}$ $[10^{-2}]$	$-0.32 \pm 0.21 \pm 0.09$	± 0.11	± 0.06
$A_{CP}^{\pi^+\pi^-}$ $[10^{-2}]$	$0.55 \pm 0.36 \pm 0.09$	± 0.17	$\pm$ 0.06
$A_{CP}^{\phi\gamma}$ $[10^{-2}]$	$\pm$ 5.6	± 2.5	± 0.8
$\tau \to \mu\gamma$ $[10^{-8}]$	< 4.5		< 0.1
$\tau \to e\gamma$ $[10^{-8}]$	< 12.0		
$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 4.5	< 0.9

Complementarity

- If the LHC sees direct evidence of new physics, the corresponding deviations from the standard model predictions can identify its nature.
- LHCb: great B and charm statistics, charged particle reconstruction.
- Belle II: well-defined initial state; ability to reconstruct final states with photons (π^0 mesons) and neutrinos.

Fully reconstructed B sample

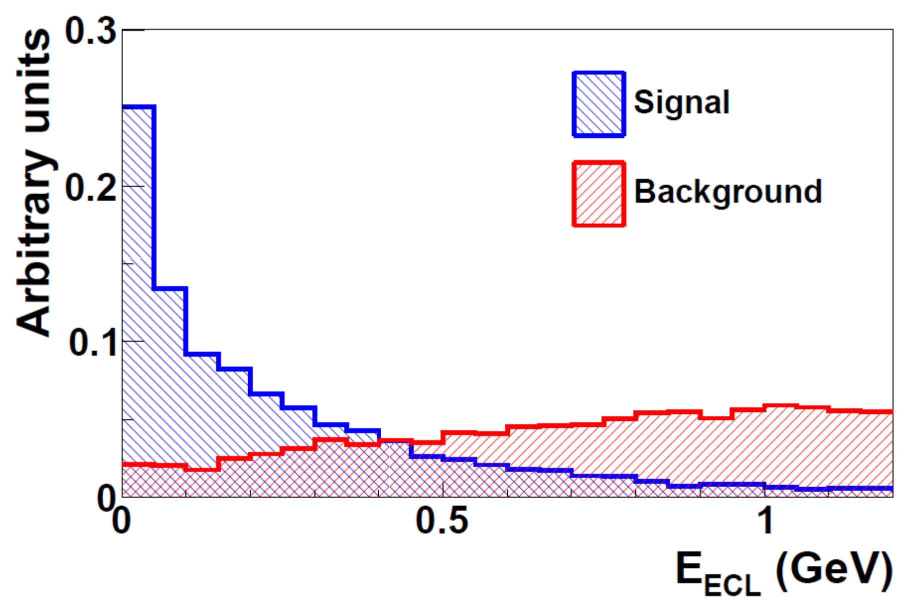
- A unique and powerful tool of Belle II
- Can also use $B \to D^{(*)}\ell\nu$ decays



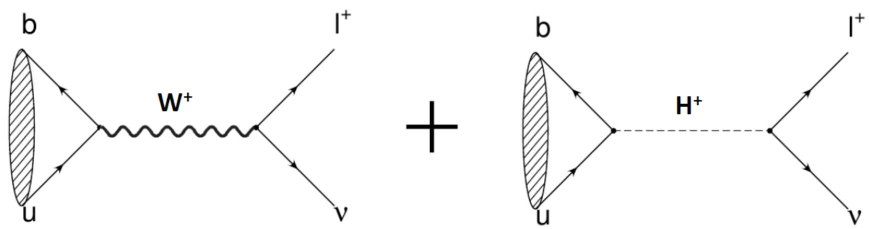
reconstruct signal B from remaining particles

fully reconstruct this B in ~2000 modes: D, D_s, J/ψ + hadrons

- For signal events there should be ~0 additional energy present in the calorimeter.



$B^+ \to \tau^+ \nu_\tau$



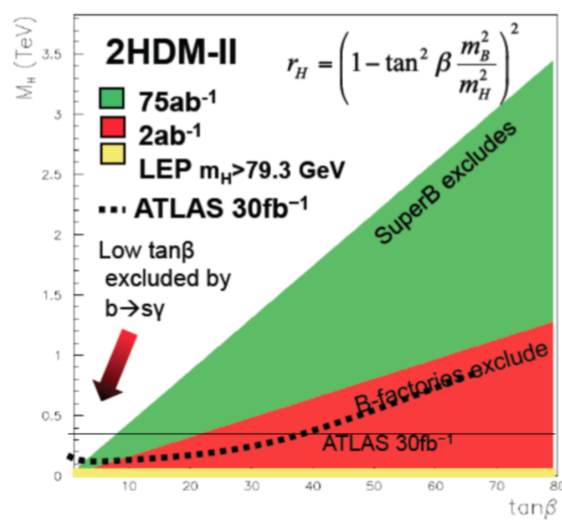
$$\mathcal{B} = \mathcal{B}^{SM} \times \left(1 - m_B^2 \tan^2 \beta / m_{H^\pm}^2\right)^2$$

$$\mathcal{B}^{SM} = 1.0 \times 10^{-4}\ (\tau)$$
$$= 4.5 \times 10^{-7}\ (\mu)$$
$$= 8 \times 10^{-12}\ (e)$$

- Enhance or suppress

- Same size effect for $B^+ \to \tau^+ \nu$ and $B^+ \to \mu^+ \nu$

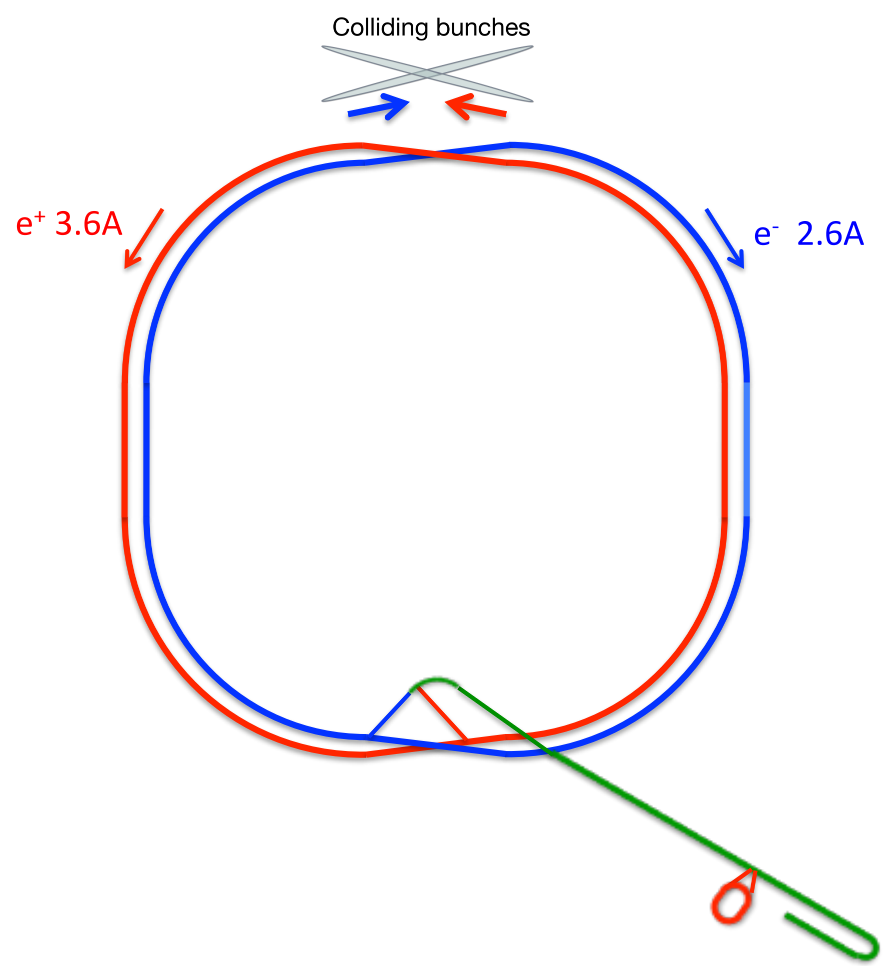
Limits on H+ mass can greatly exceed direct LHC values



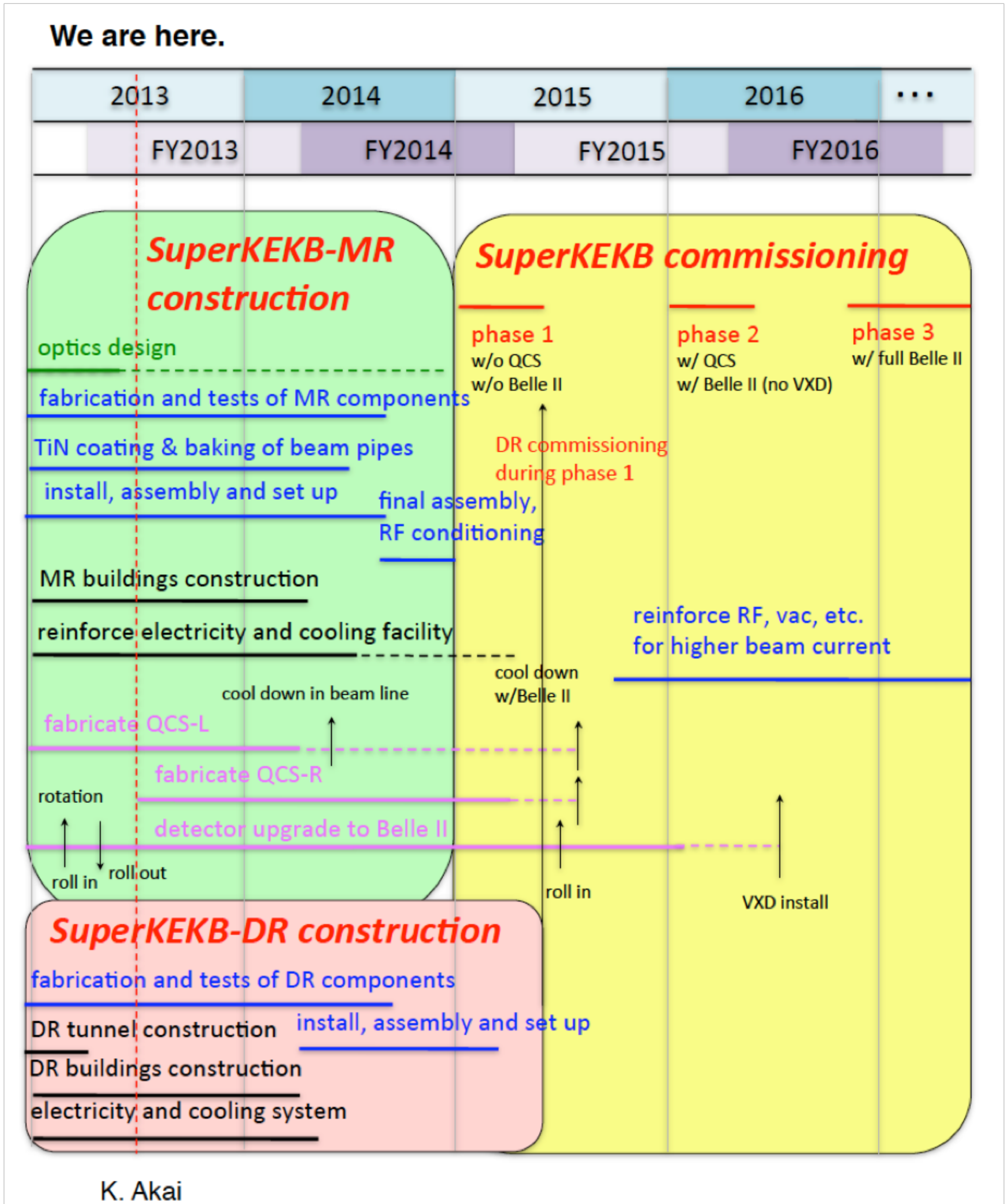
SuperKEKB

- Huge increase in luminosity comes from a 2x increase in current and a large decrease in beam size. Upgrades to most systems.

- 2.6A of e^- @ 7 GeV
  3.6A of e^+ @ 4 GeV
  8×10^{35} $cm^{-2}s^{-1}$

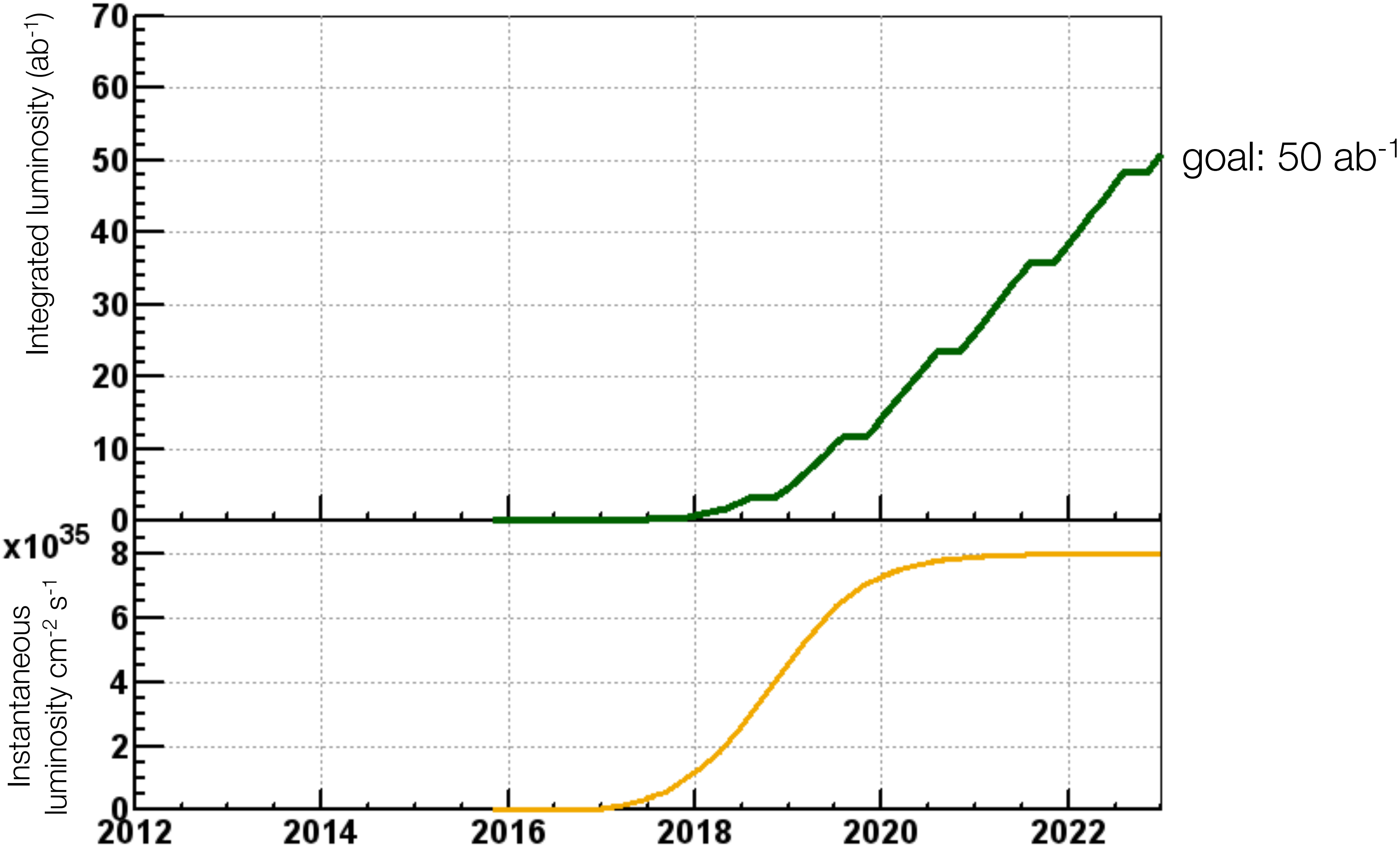


Schedule



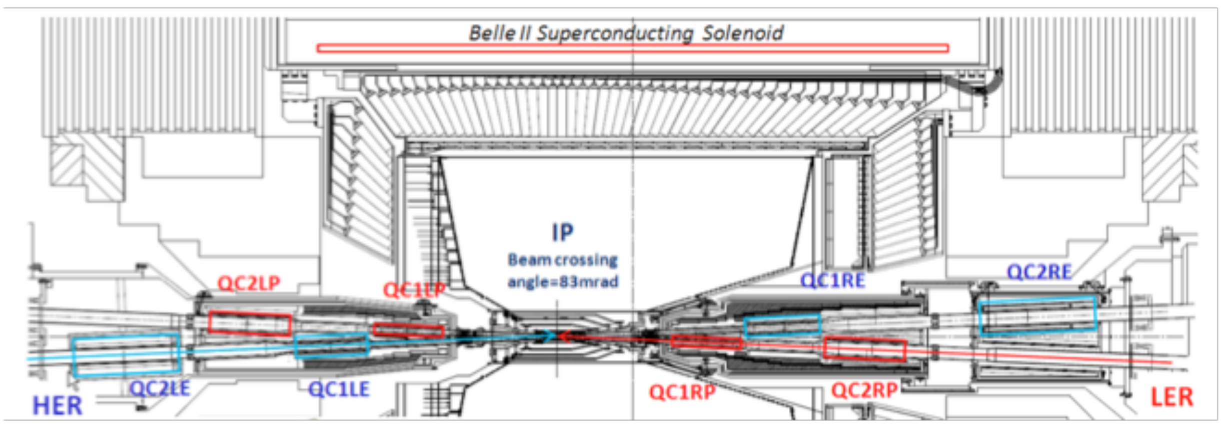
- Phase 1 (Jan – May 2015)
  No superconducting IR magnets; no Belle II.
  - Basic tuning, vacuum scrubbing
- Phase 2 (Feb – June 2016)
  Full accelerator; Belle II except vertex detector.
  - beam collision tuning, background studies
- Phase 3 (late 2016)
  First physics. L = 10^{34} $cm^{-2}s^{-1}$

Luminosity projection

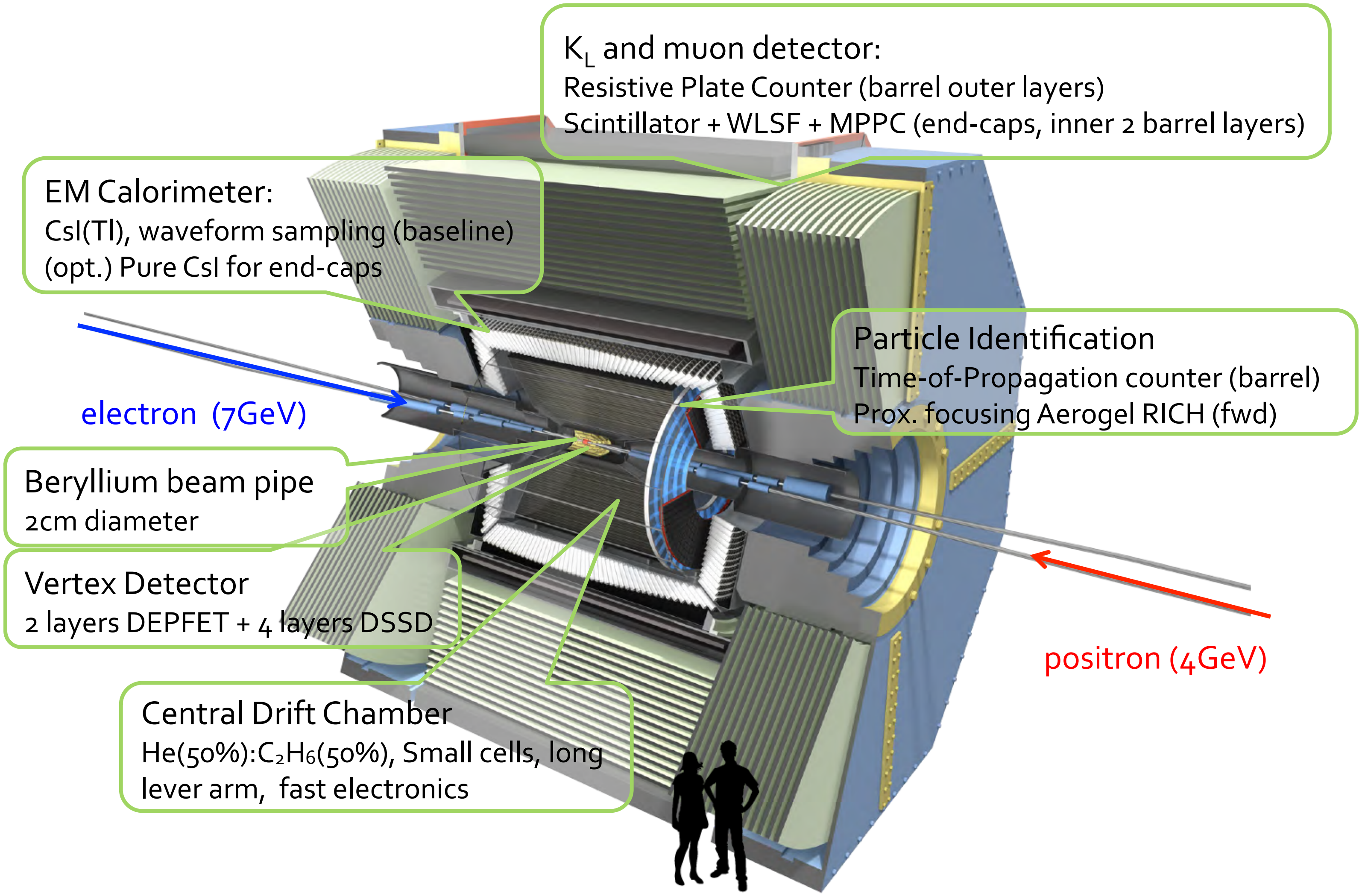


Backgrounds

- High luminosity ⇒ high rate of $e^+e^- \to \gamma e^+e^-$
  - radiation damage, photosensor aging, pileup



The Belle II detector

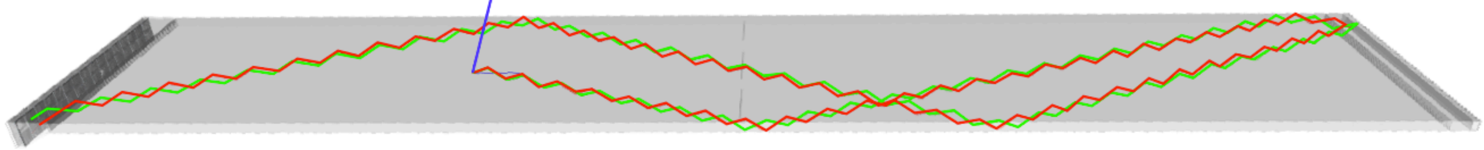


- Upgrades aim for best possible performance in the face of high event rates and high backgrounds.

iTOP

- Particle ID using Cherenkov radiation in fused silica bars.

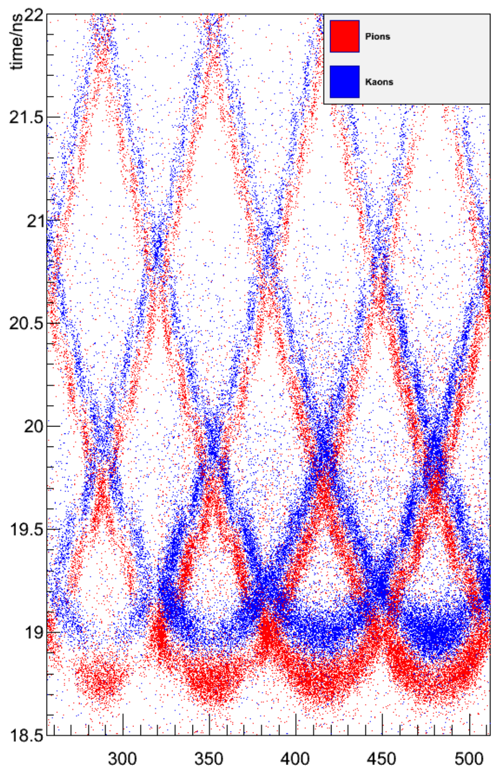
measure t and x of single γ with pixelated PMT



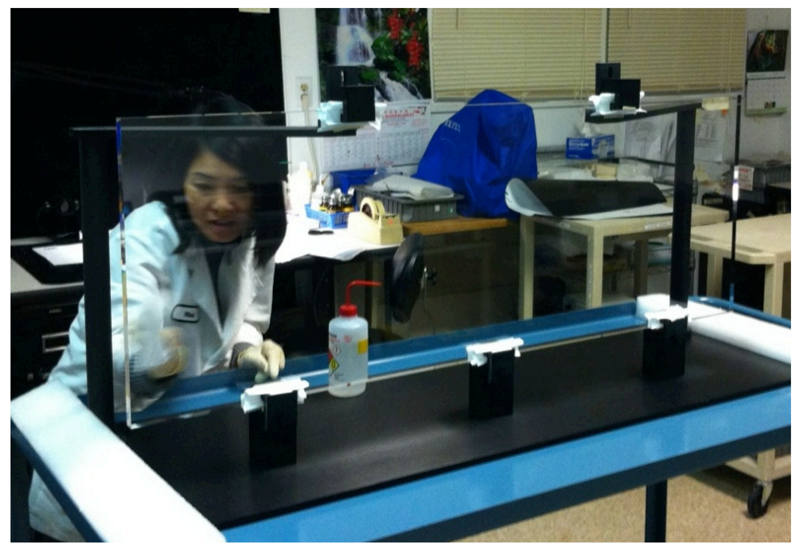
time (ns)

need resolution < 100 ps

500 ps

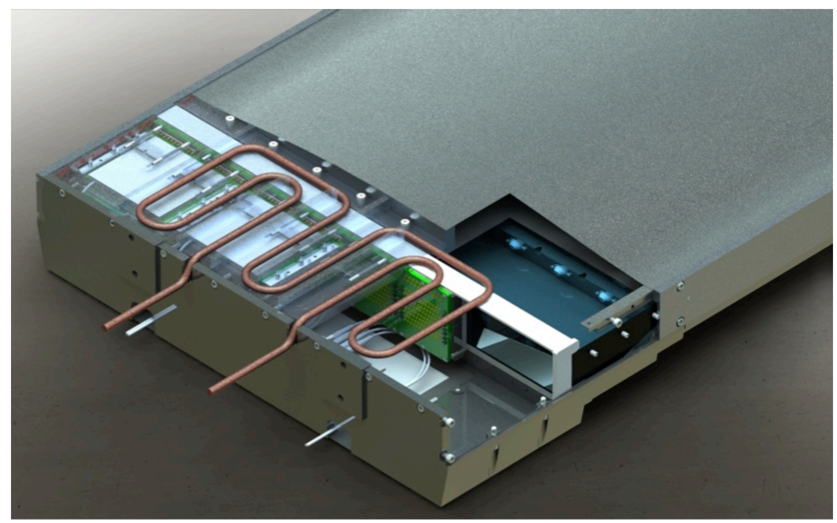


position



iTOP status

- Procurement of precision optical components has been difficult, but production is now under way.
- Successful review of complex opto-mechanical system last week.
- DOE CD-2/3 review in March.
- ~1/2 of iTOP will be in place for first physics run. Remainder will be installed in summer 2017.

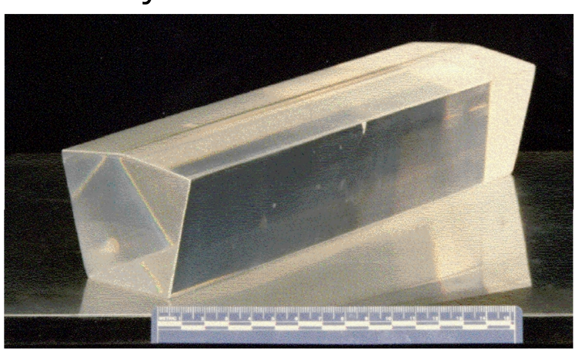


- First physics run may not be at the Y(4S).

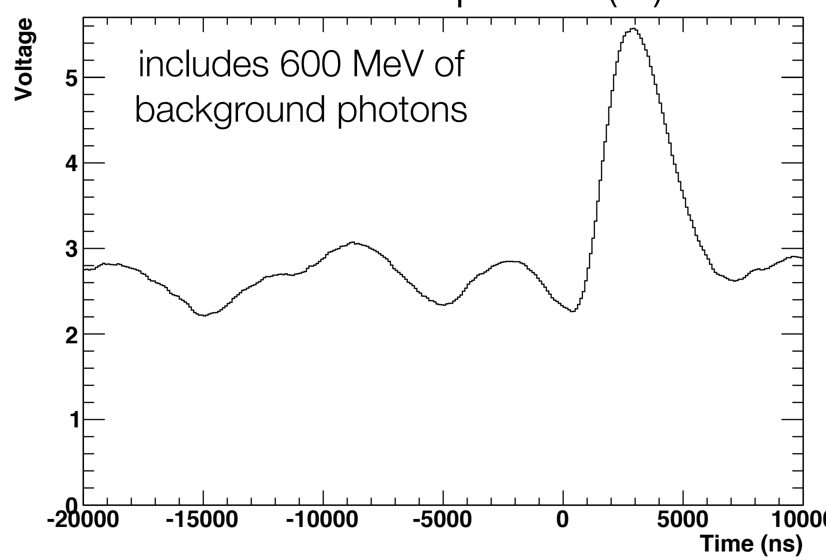
Calorimeter

- Precise measurements of γ (π^0) and E_{extra} is critical to our physics program, particular with respect to LHCb.
- Belle II is reusing the CsI(Tl) crystal calorimeter from Belle, with new digitization and waveform fitting electronics. Excellent resolution, but quite slow.

CsI crystal

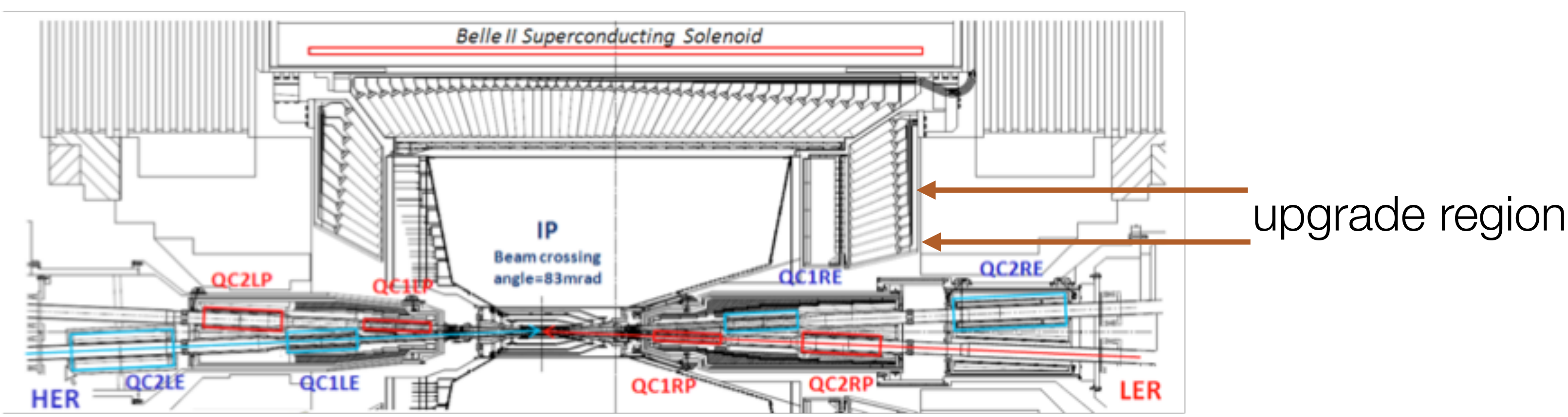


Waveform of a 100 MeV γ in CsI(Tl) calorimeter



Pure CsI upgrade

- Canadian and Italian groups are planning to upgrade the forward endcap calorimeter to pure CsI.
- 30x faster signals (so 30x less pileup) but 30x less light.
- Fine mesh PMTs with preamps/HV dividers, new shapers/waveform fitting.

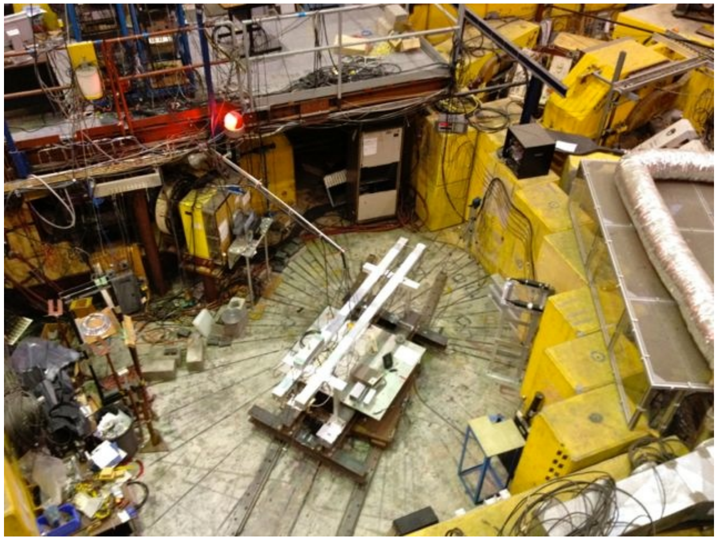


- Preamp & digitizing electronics under development at U. Montreal.

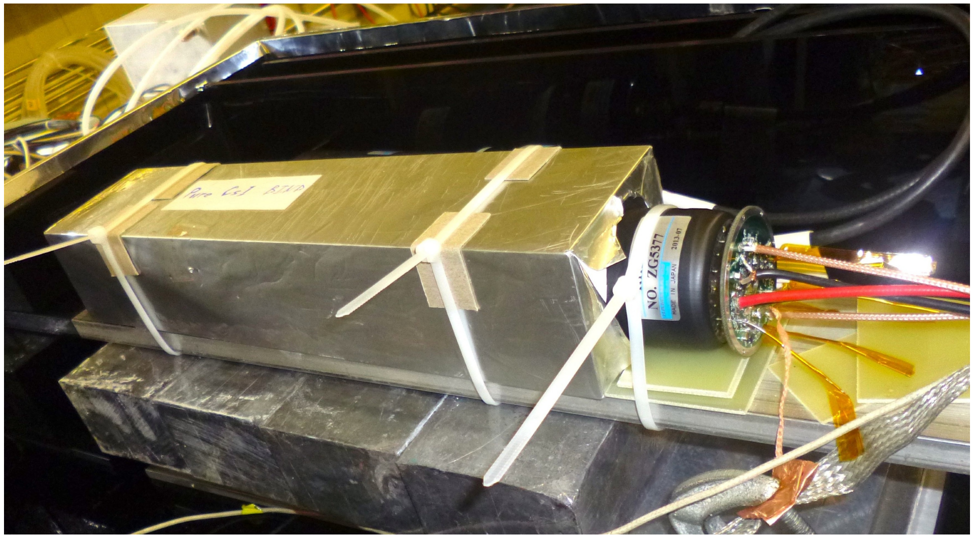
- Aim for a 25-crystal prototype beam test at TRIUMF in summer 2015.

- Upgrade summer 2018.

M11 test beam at TRIUMF



Fine mesh PMT with prototype preamp on pure CsI crystal



Summary

- Belle II has a physics program with unique capabilities and sensitivities to new physics.
- SuperKEKB is on track for the start of commissioning in less than one year.
- Detector construction is well underway, and moving towards integration.
- The Canadian group is working towards an upgrade of the calorimeter that will improve its performance at the highest luminosities.

Canadian group

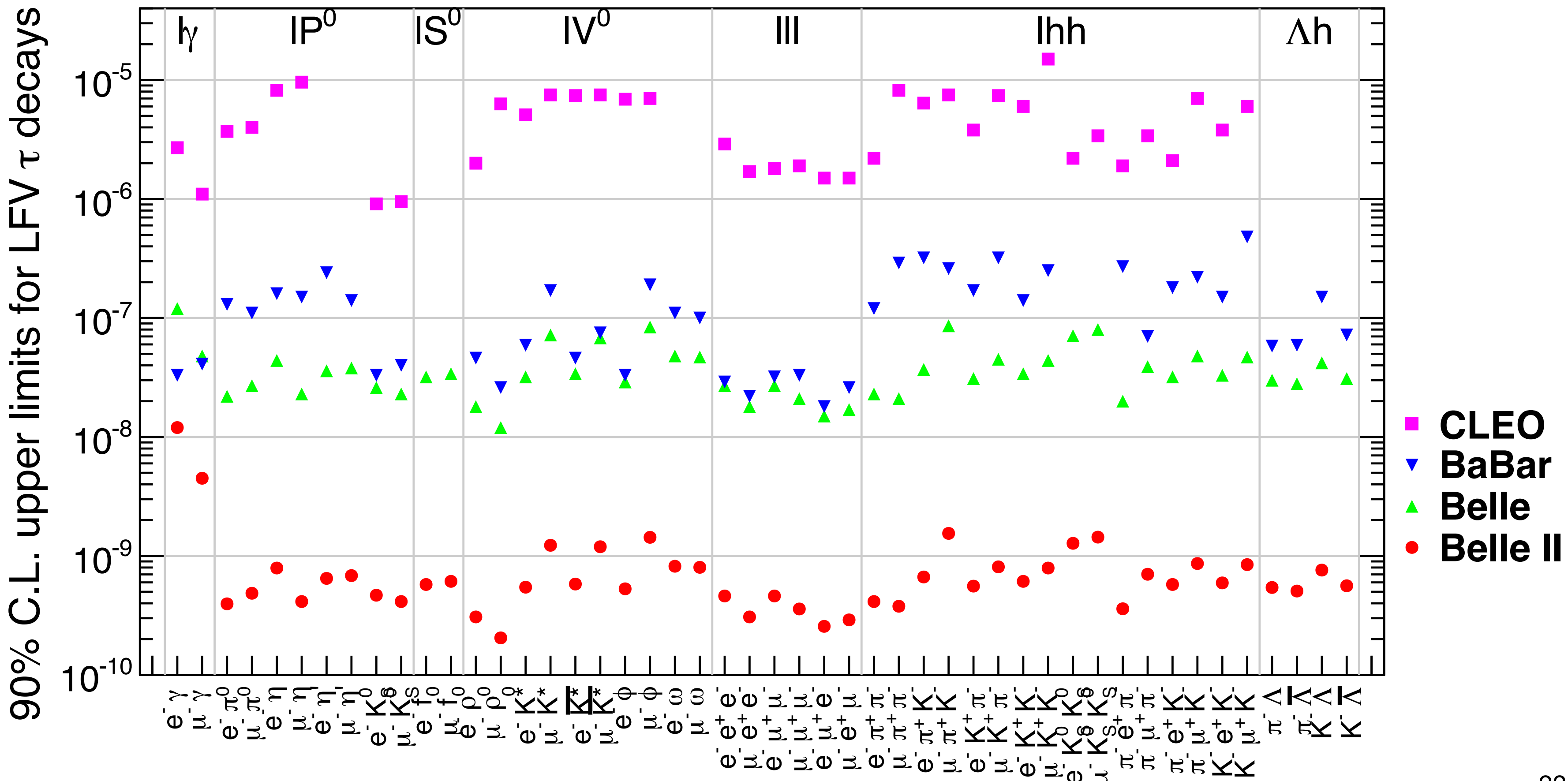
- U. British Columbia: C. Hearty, J. McKenna, T. Mattison, **D. Fujimoto**
- U. Victoria: M. Roney, R. Kowalewski, R. Sobie, **A. Beaulieu**, **S. de Jong**, **S. Longo**, *F. Berghaus, P. Poffenberger*
- McGill U.: S. Robertson, A. Warburton, **R. Cheaib**, **R. Seddon**
- U. Montreal: J.P. Martin, P. Taras, *N. Starinski*

Backup slides

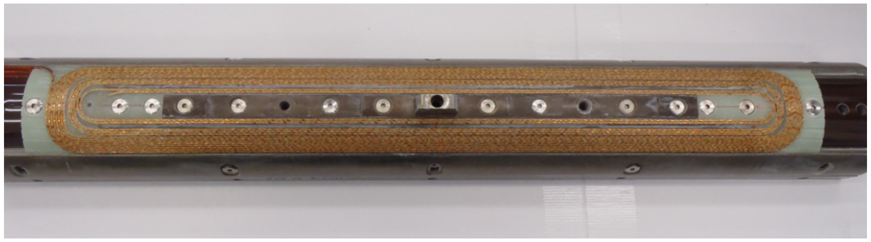
$\tau^+ \to \mu^+ \gamma$

- Unambiguous sign of new physics. Many charged flavor violating decays available.

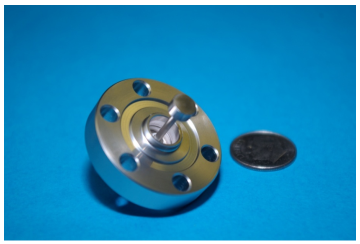
~two-order of magnitude improvement



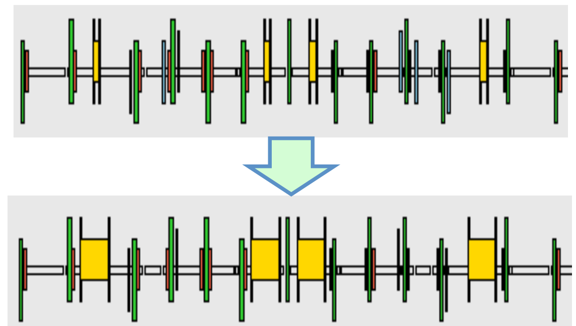
New superconducting final focus magnets near the interaction point



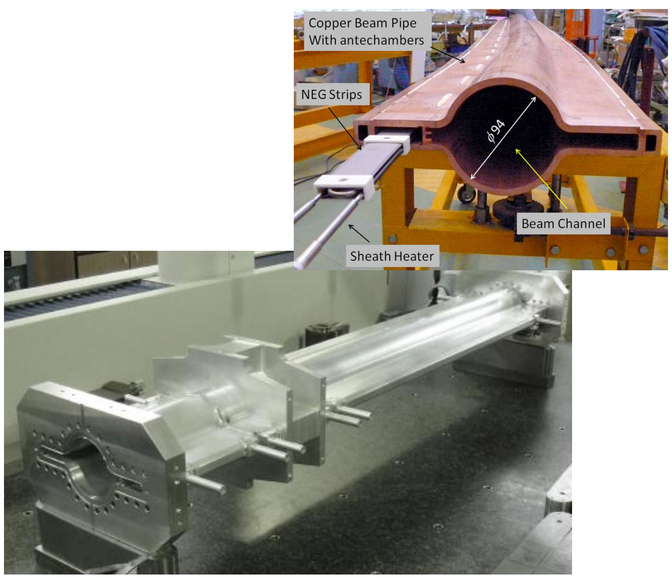
Improved monitors and controls



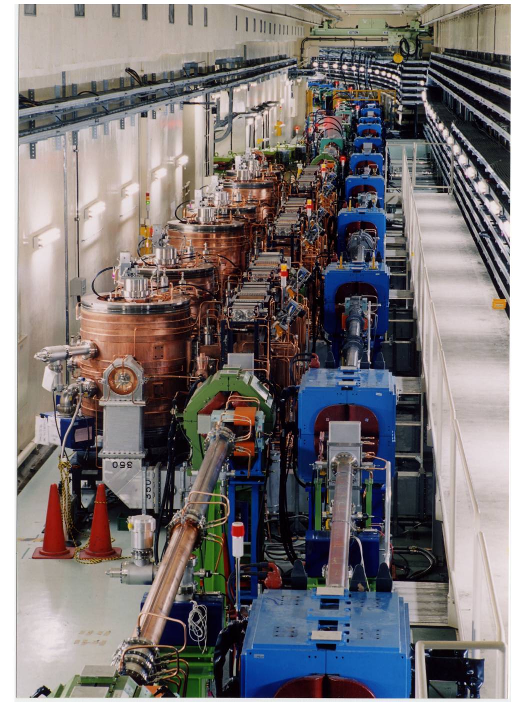
Redesigned lattice



Replace beam pipes with TiN-coated beam pipes with antechambers



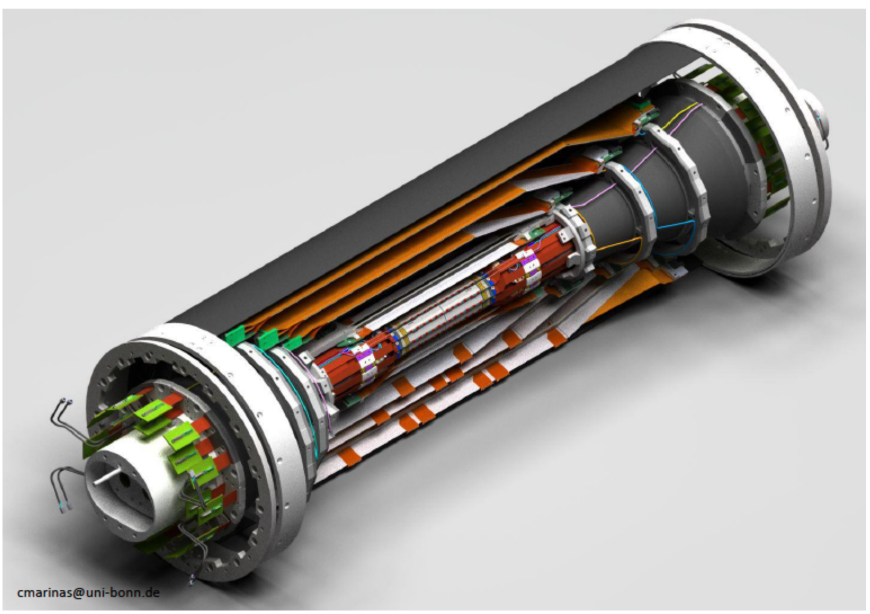
New e^+ damping ring



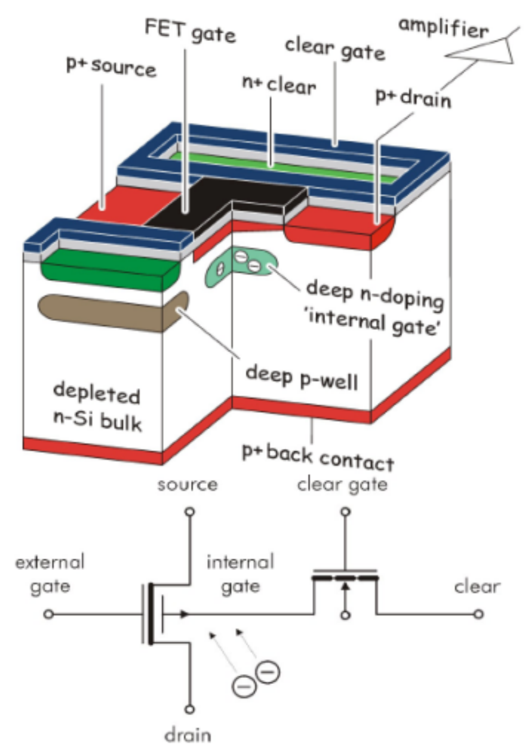
Additional RF for beam current

Vertex detector

- Two layers of pixels (DEPFETs) and four layers of silicon strips.
  - first layer at r = 14 mm; much less material than Belle

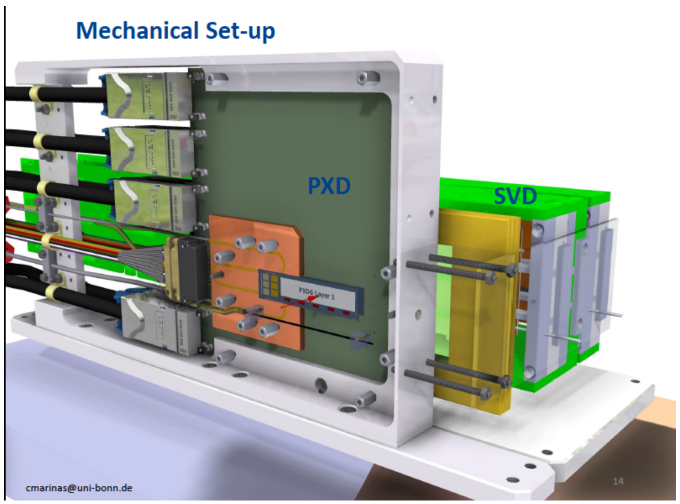


DEpleted P-channel FET



Vertex detector beam test

- One pixel layer with four layers of silicon strips with full readout chain. In a 1 T solenoid.
- Successful test, including "regions of interest" readout. To reduce data rate, project SVD tracks into pixels and read only those regions.



- Focus now on production; little schedule contingency.

First year physics plan

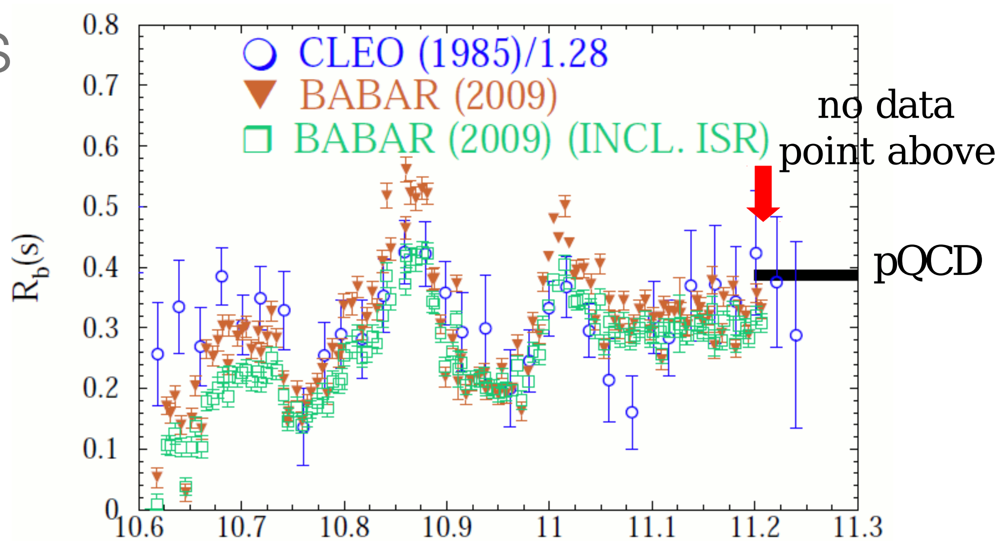
- B physics topics require high-momentum particle ID more than other topics. We are considering alternatives to the Y(4S) for the first run, late 2016 – early 2017. Maybe few hundred fb^{-1}.

- Y(2S): dark forces, light Higgs

- Y(6S): bottomonium, Z_b

- r_B scan

- Y(3S): conventional bottomonium



Computing

- 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.