Belle II — searching for new physics in the heavy flavor sector

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University of British Columbia / IPP
June 16, 2014

Belle / BaBar

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

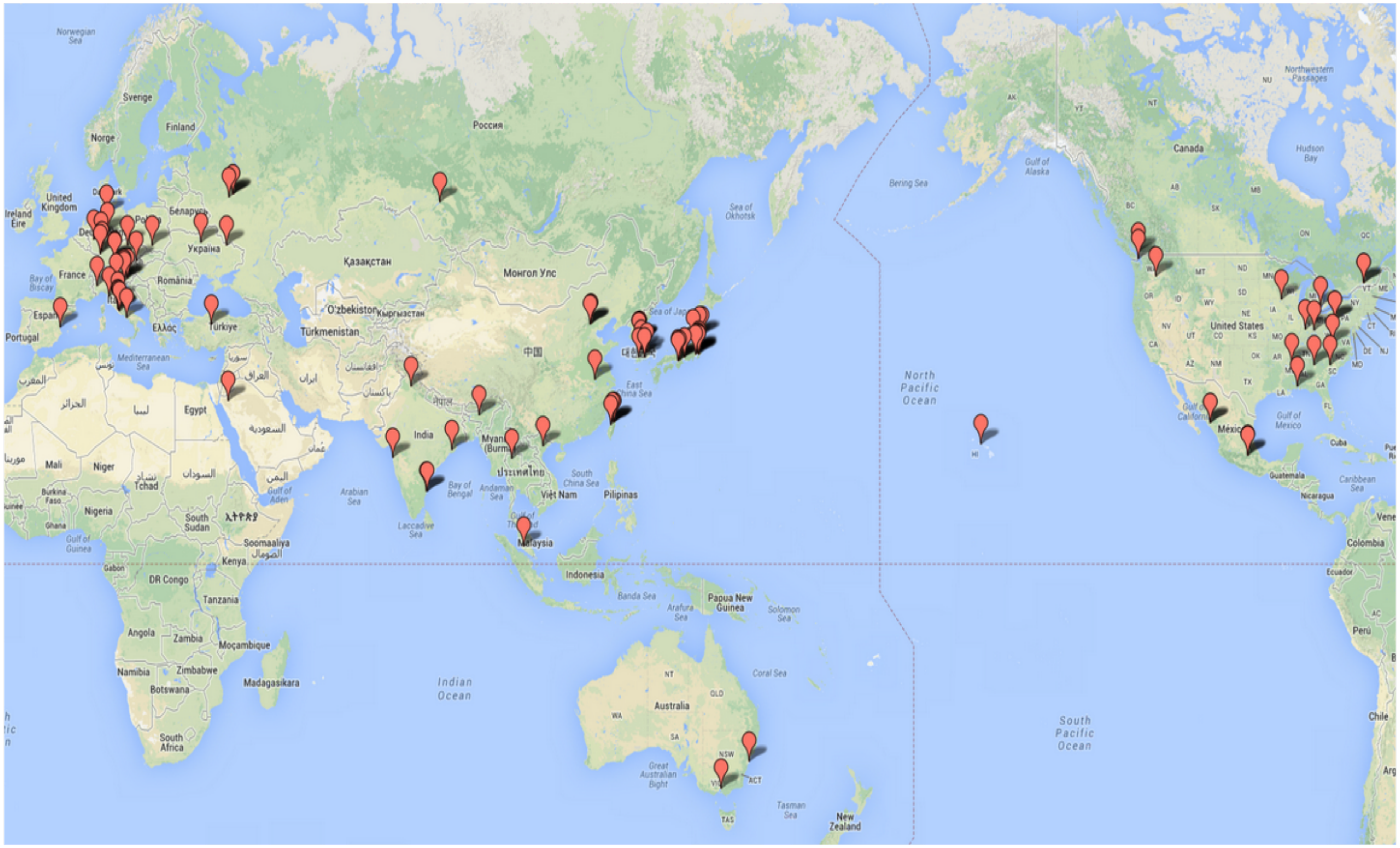
- Core program: weak force, especially CP violation

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

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

Belle II

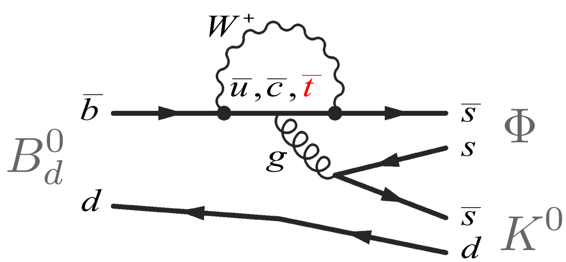
- Upgrade of Belle, located at SuperKEKB.
- 40x the peak luminosity of KEKB; 30x the combined integrated luminosity of BaBar + Belle.

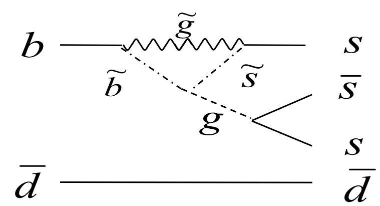


- 23 countries, 97 institutions, 600 collaborators, including 320 PhD physicists.
- Canada joined in March 2013; Italy and Mexico in July 2013 (SuperB refugees).

Physic goals

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





Standard model process (left) is modified by the SUSY contribution on the right

- 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.

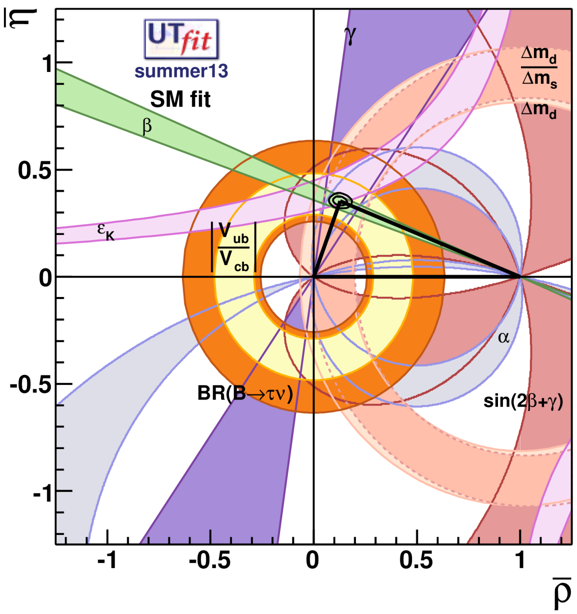
Subset of the modes to be measured by Belle II

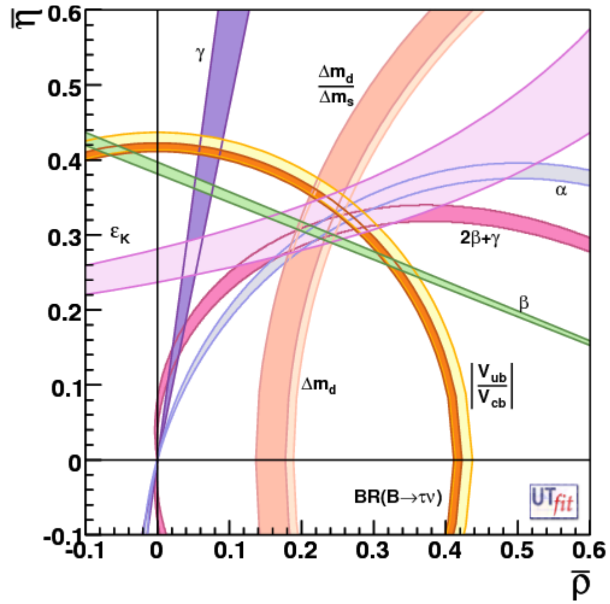
Observable/mode	Current now	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Belle-II (2021) $50\,\mathrm{ab}^{-1}$	LHCb upgrade (2028) $50\,\mathrm{fb}^{-1}$	theory now
τ Decays					
$\tau \to \mu\gamma$ ($\times 10^{-9}$)	< 44		< 3		
$\tau \to e\gamma$ ($\times 10^{-9}$)	< 33		< 3.7 (est.)		
$\tau \to \ell\ell\ell$ ($\times 10^{-10}$)	$< 150 - 270$	< 244	< 10	< 24	
$B_{u,d}$ Decays					
BR($B \to \tau\nu$) ($\times 10^{-4}$)	1.64 ± 0.34		0.04		1.1 ± 0.2
BR($B \to \mu\nu$) ($\times 10^{-6}$)	< 1.0		0.03		0.47 ± 0.08
BR($B \to K^{*+}\nu\bar{\nu}$) ($\times 10^{-6}$)	< 80		2.0		6.8 ± 1.1
BR($B \to K^{+}\nu\bar{\nu}$) ($\times 10^{-6}$)	< 160		1.6		3.6 ± 0.5
BR($B \to X_s\gamma$) ($\times 10^{-4}$)	3.55 ± 0.26		0.13	0.23	3.15 ± 0.23
$A_{CP}(B \to X_{(s+d)}\gamma)$	0.060 ± 0.060		0.02		$\sim 10^{-6}$
$B \to K^*\mu^+\mu^-$ (events)	250	8000	7-10k	100,000	-
BR($B \to K^*\mu^+\mu^-$) ($\times 10^{-6}$)	1.15 ± 0.16		0.07		1.19 ± 0.39
$B \to K^*e^+e^-$ (events)	165	400	7-10k	5,000	-
BR($B \to K^*e^+e^-$) ($\times 10^{-6}$)	1.09 ± 0.17		0.07		1.19 ± 0.39
$A_{FB}(B \to K^*\ell^+\ell^-)$	0.27 ± 0.14	?	0.03		-0.089 ± 0.020
$B \to X_s\ell^+\ell^-$ (events)	280		7,000		-
BR($B \to X_s\ell^+\ell^-$) ($\times 10^{-6}$)	3.66 ± 0.77		0.10		1.59 ± 0.11
S in $B \to K^0_S\pi^0\gamma$	-0.15 ± 0.20		0.03		-0.1 to 0.1
S in $B \to \eta' K^0$	0.59 ± 0.07		0.02		± 0.015
S in $B \to \phi K^0$	0.56 ± 0.17	0.15	0.03	0.03	± 0.02
B^0_s Decays					
BR($B^0_s \to \gamma\gamma$) ($\times 10^{-6}$)	< 8.7		$0.2 - 0.3$		0.4 - 1.0
A^s_{SL} ($\times 10^{-3}$)	-7.87 ± 1.96	?	5.		0.02 ± 0.01
BR($B_s \to \mu\mu$) ($\times 10^{-9}$)	2.9 ± 1.0	± 1		± 0.3	
$2\beta_s$ from $B^0_s \to J/\psi\phi$	0.13 ± 0.19	0.019	-	0.006	
S in $B_s \to \phi\gamma$	0.07	-	0.02		
D Decays					
x	$(0.63 \pm 0.20\%$	0.06%	0.04%	0.02%	$\sim 10^{-2}$
y	$(0.75 \pm 0.12)\%$	0.03%	0.03%	0.01%	$\sim 10^{-2}$
y_{CP}	$(1.11 \pm 0.22)\%$	0.02%	0.05%	0.01%	$\sim 10^{-2}$
$\arg\{q/p\}$ ($^\circ$)	-10.2 ± 9.2	4.4°	1.4°	2.0°	$\sim 10^{-3}$

adapted from “The impact of SuperB on flavour physics”, arXiv:1109.5028 [hex-ex]

CKM fits

- Need lattice improvements to fully exploit Belle II





Complementarity

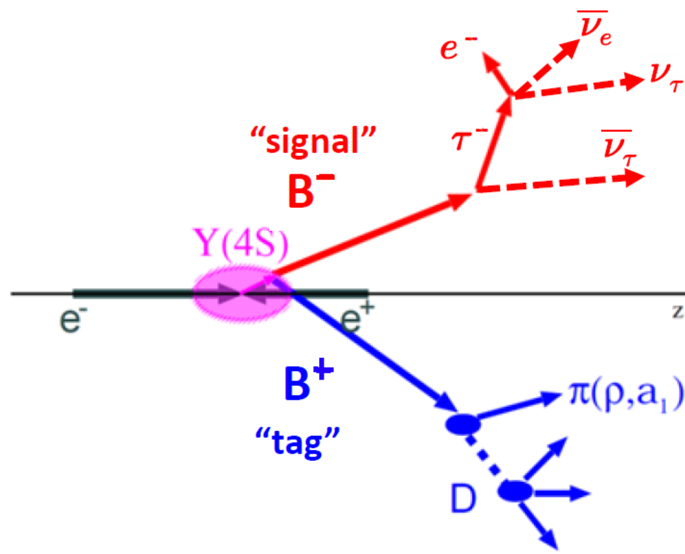
- If the LHC sees direct evidence of new physics, the corresponding deviations from the standard model predictions can identify its nature.

- 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; tau physics.

Fully reconstructed B sample

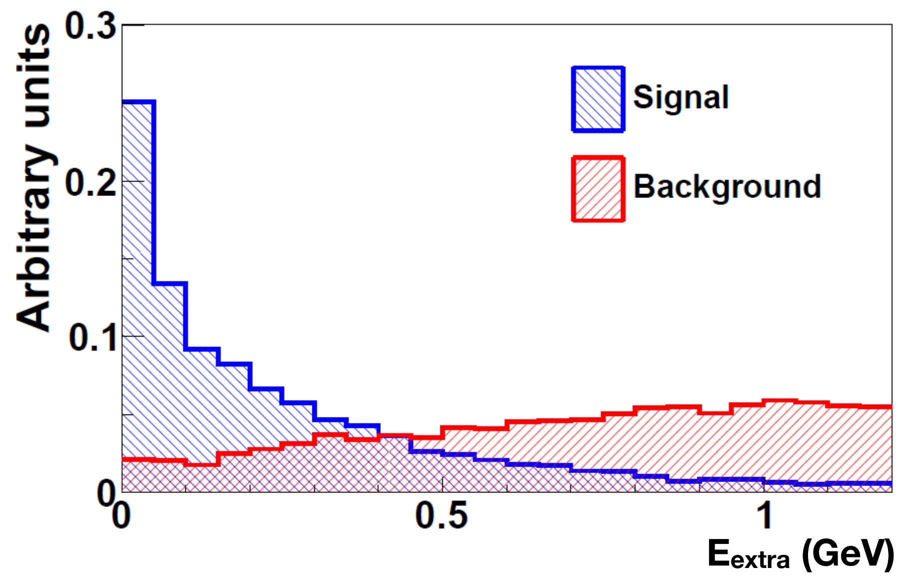
- A unique and powerful tool of Belle II
- Can also use $B \to D^{(*)}\ell\nu$ decays



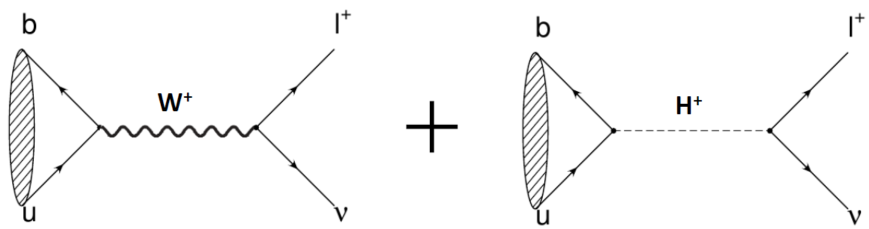
reconstruct signal B from remaining particles

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

- For signal events there should be ~0 additional energy (E_{extra}) present in the calorimeter.



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

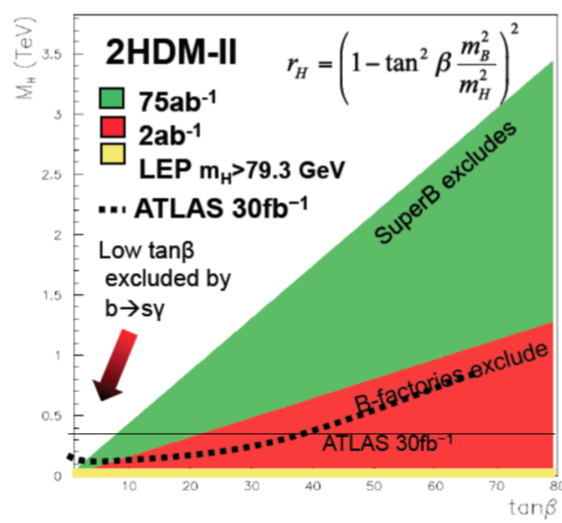


$$\mathcal{B} = \mathcal{B}^{SM} \times \left(1 - m_B^2 \tan^2\beta / m_{H^\pm}^2\right)^2$$

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

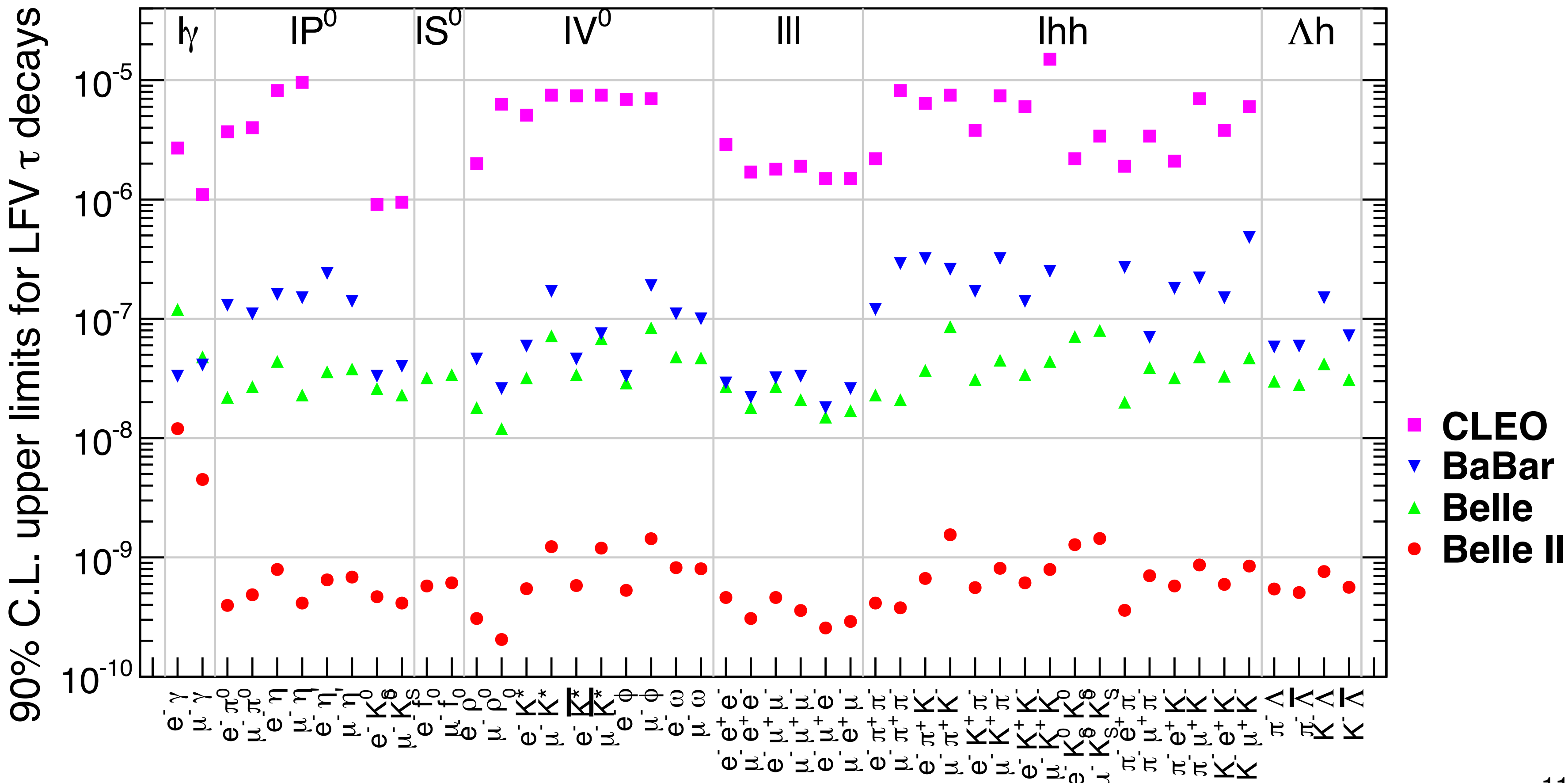
- Enhance or suppress
- Same percentage effect for $B^+ \to \tau^+ \nu$ and $B^+ \to \mu^+ \nu$

Limits on H+ mass can greatly exceed direct LHC values



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

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

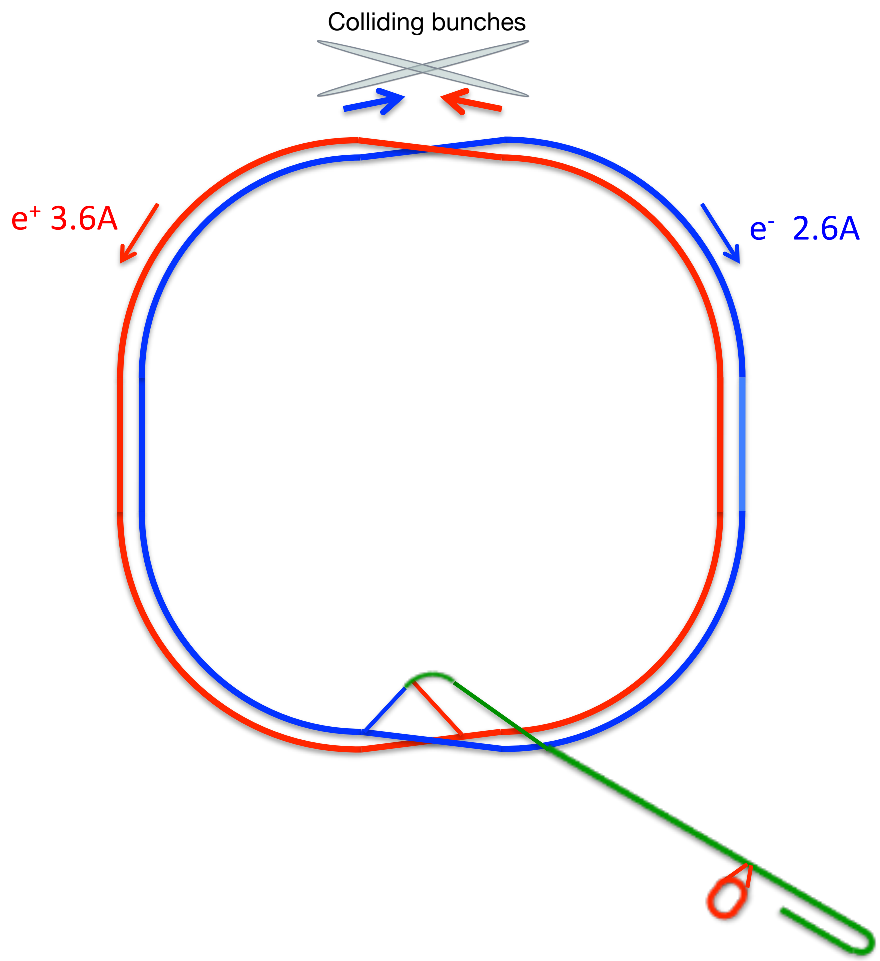


1–2 order of magnitude improvement

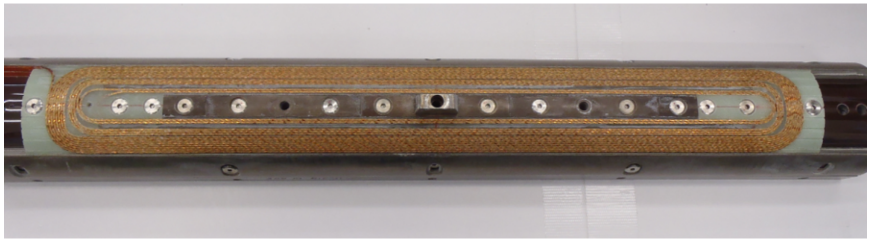
SuperKEKB

- Huge increase in luminosity comes from a 2x increase in current and a ~15x decrease in beam size. Upgrades to most systems.

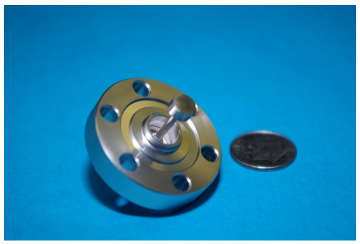
- 2.6A of e^- @ 7 GeV
  3.6A of e^+ @ 4 GeV
  8×10^{35} $cm^{-2}s^{-1}$



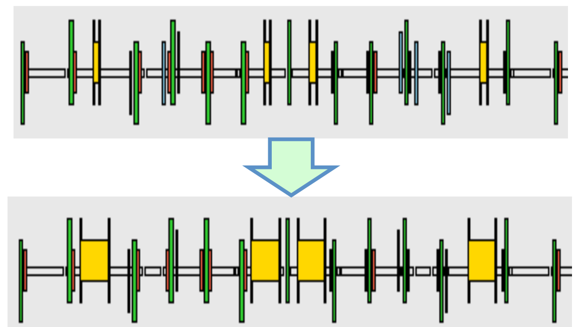
New superconducting final focus
magnets near the interaction point

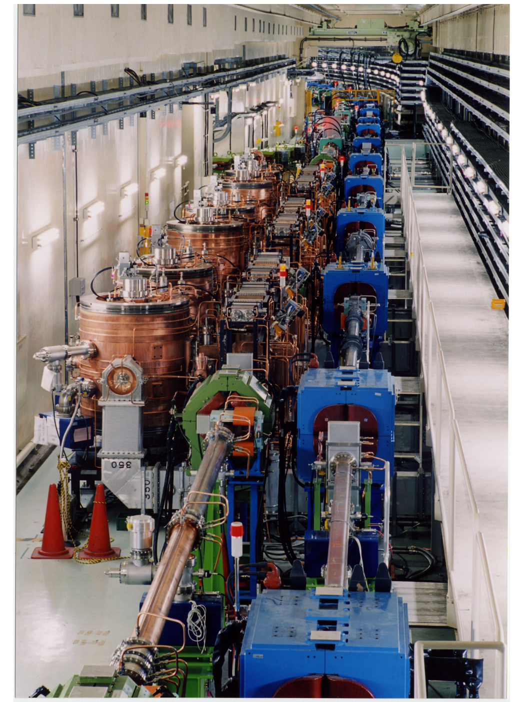


Improved monitors and controls



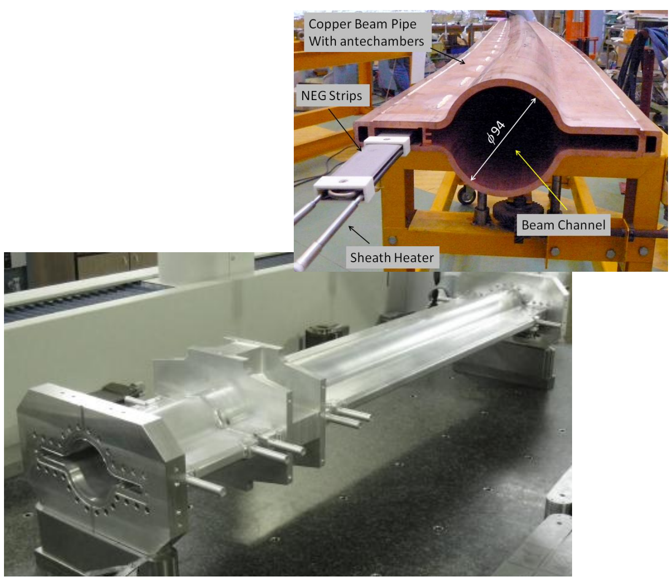
Redesigned lattice





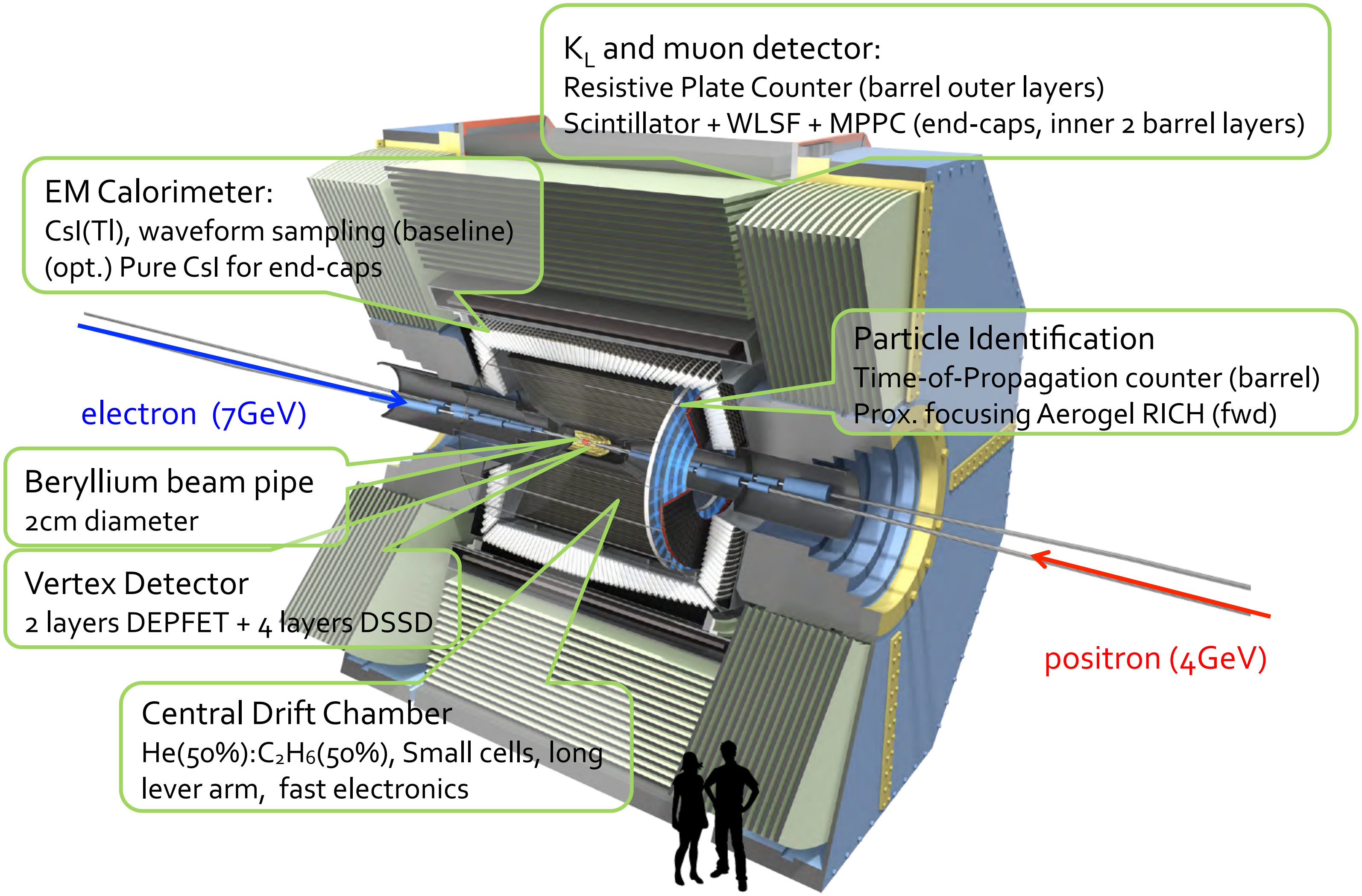
Additional RF for beam current

Replace beam pipes with TiN-coated
beam pipes with antechambers



New e^+ damping ring

The Belle II detector

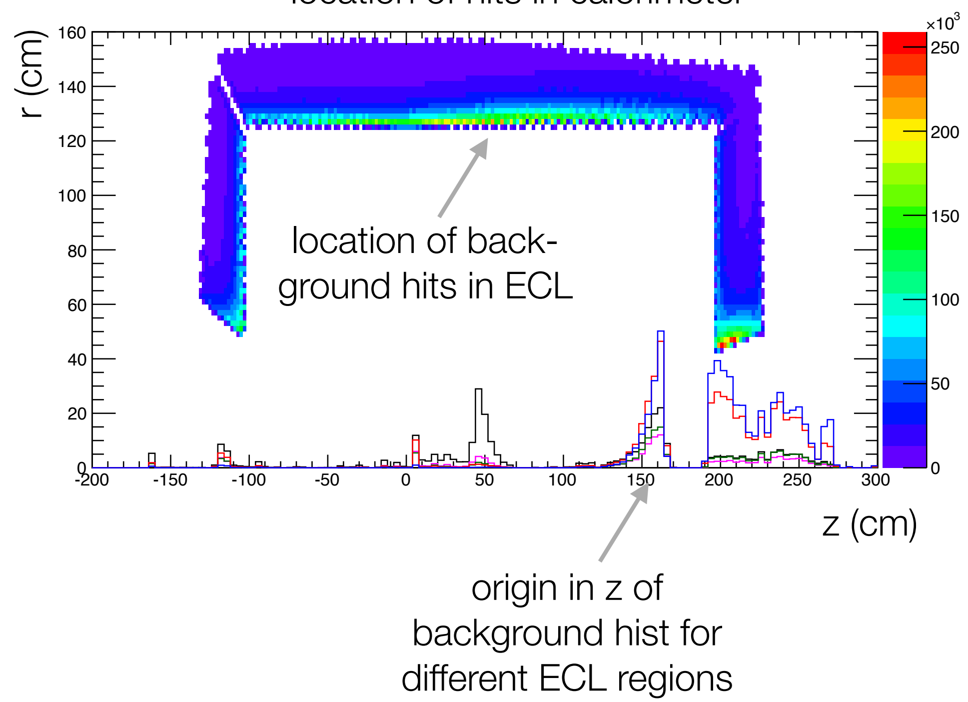


- Upgrades aim for best possible performance in the face of high event rates and high backgrounds.

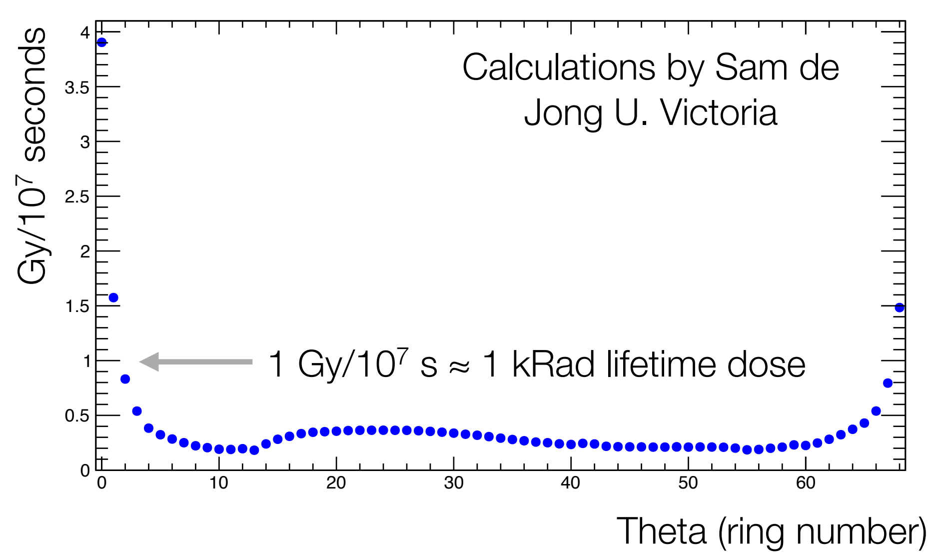
Backgrounds

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

Impact point on beam line and location of hits in calorimeter

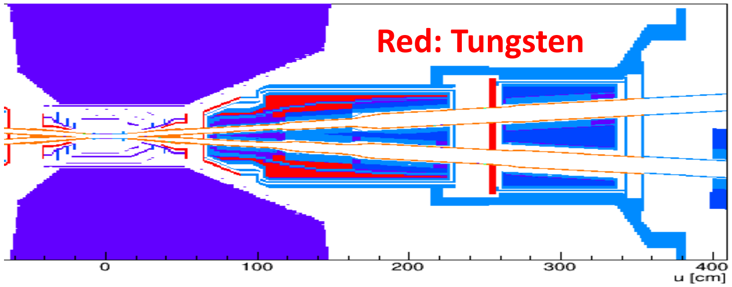


Resulting radiation dose in ECL

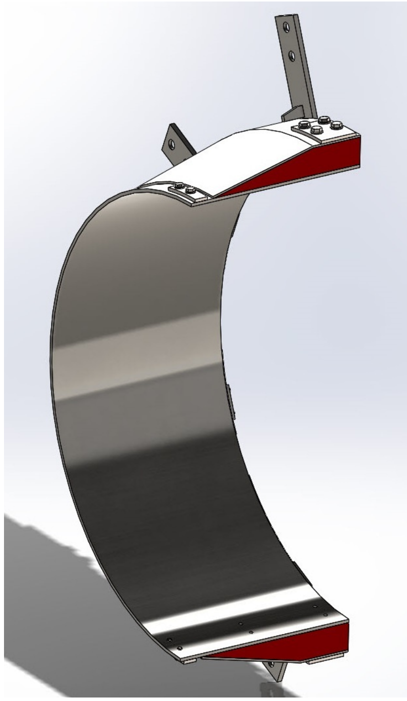


Background shielding

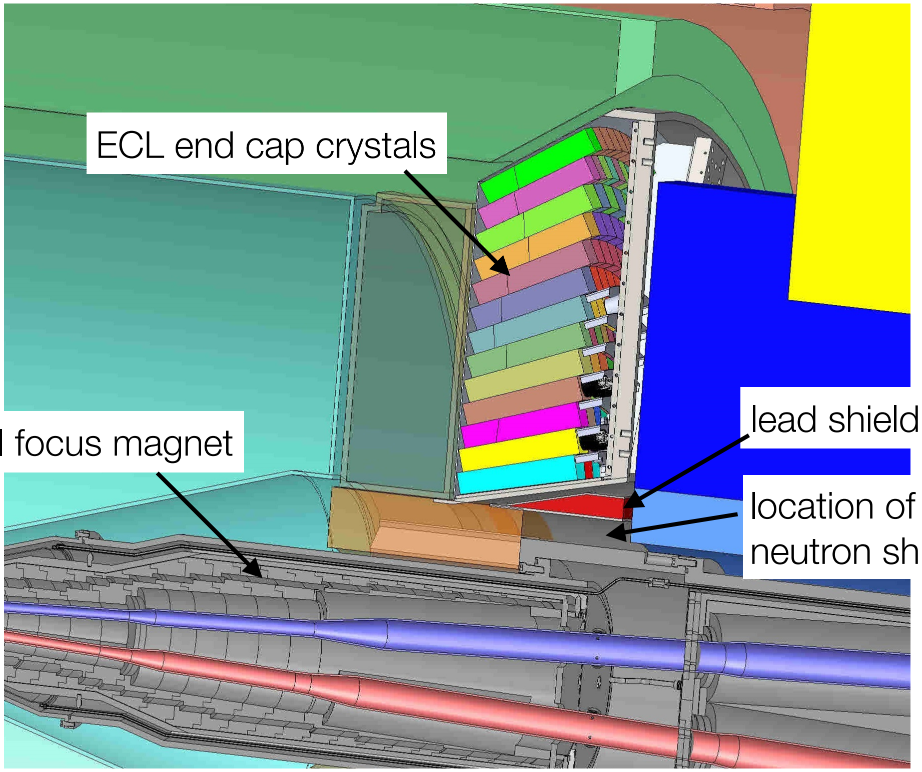
- Tungsten shielding in magnets.



- ECL shield will be lead + neutron absorber; reduces peak dose by a factor of 2.



ECL shield, lead only

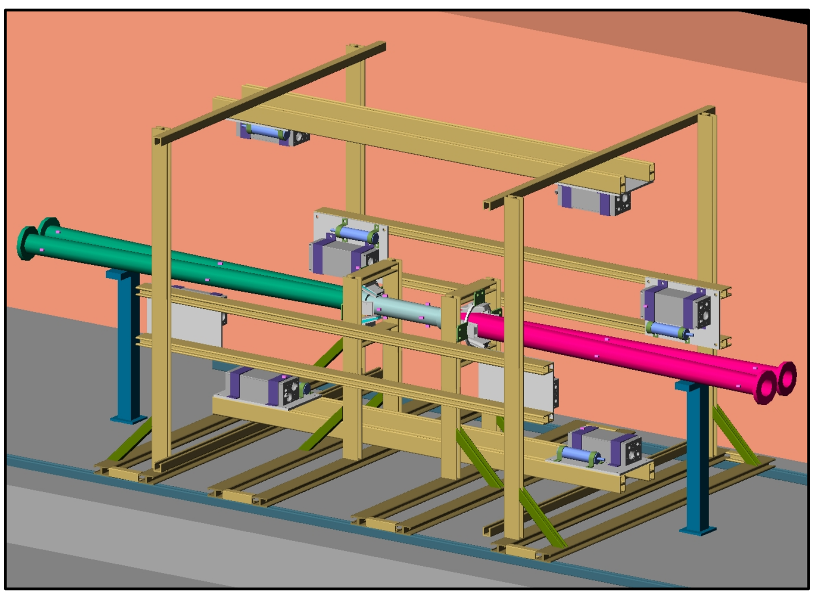


A. Beaulieu

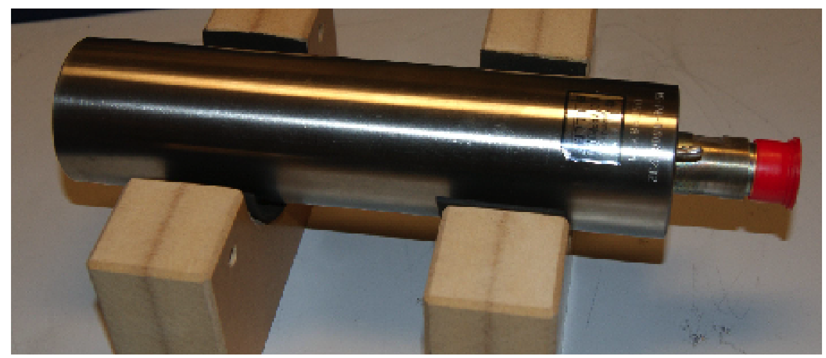
See Alex Beaulieu's talk in session T1-2 on Tuesday

Commissioning detector—BEAST II

- Important to characterize backgrounds and compare to simulation prior to start of physics.
- Variety of detectors for phase I (Oct 2015, before Belle II roll-on); vertex detectors only for phase II.



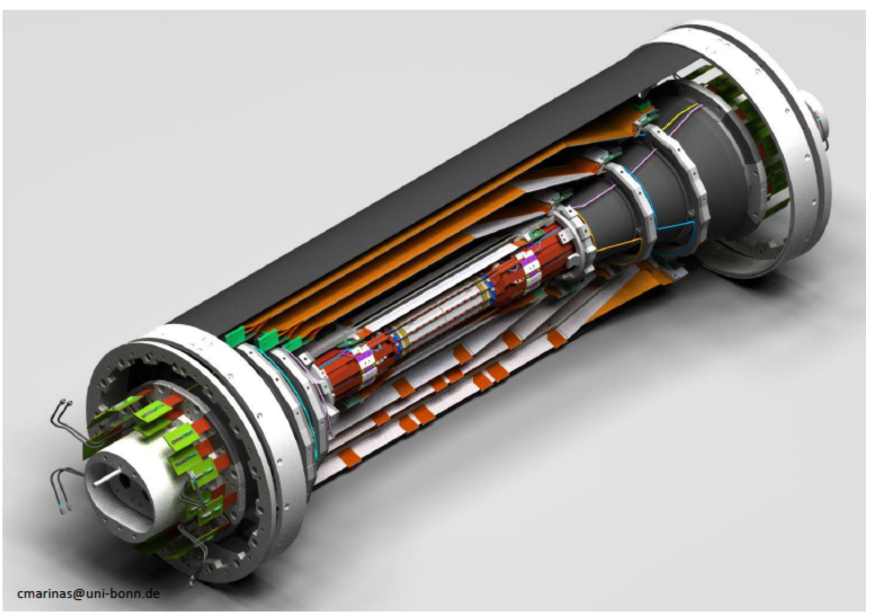
M. Rosen



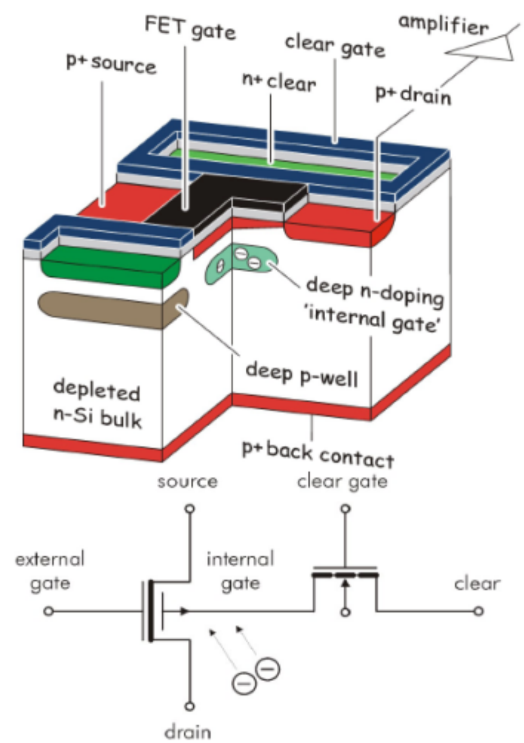
Sam de Jong (Victoria PhD student) is developing thermal neutron detectors

Vertex detector

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



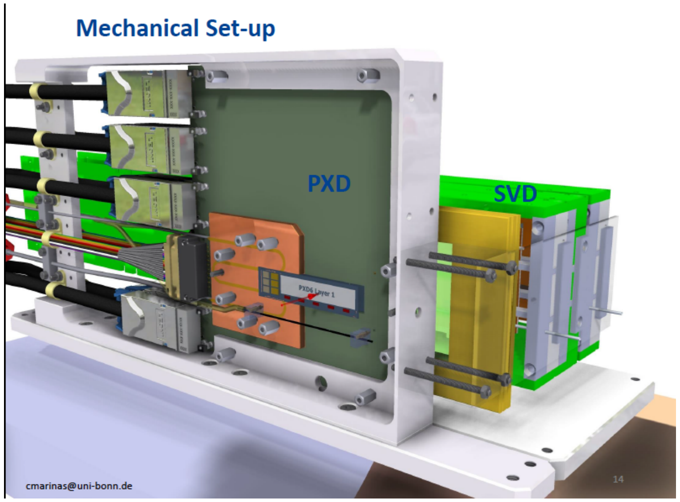
DEpleted P-channel FET



Vertex detector beam test

- One pixel (PXD) layer with four layers of silicon strips (SVD). Full readout chain, 1 T magnetic field.

- Successful test, including "regions of interest" readout. To reduce data rate, project SVD tracks into pixels and read only those regions.

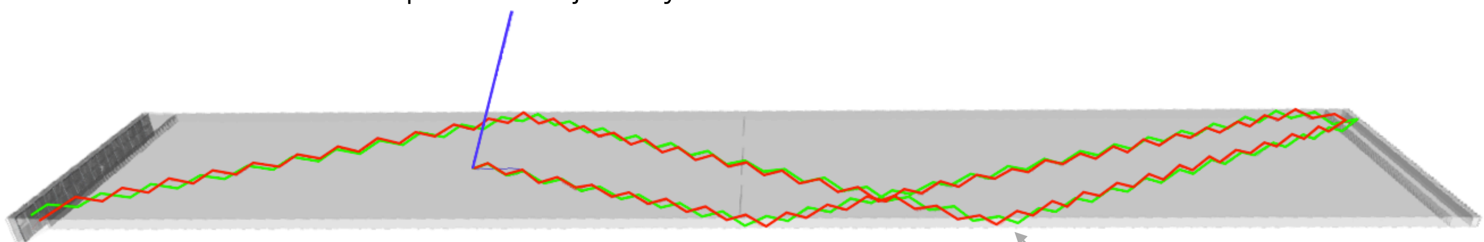


- Focus now on production; little schedule contingency.

iTOP: particle ID using Cherenkov radiation in fused silica bars

particle trajectory

measure t and x of single γ with pixelated PMT

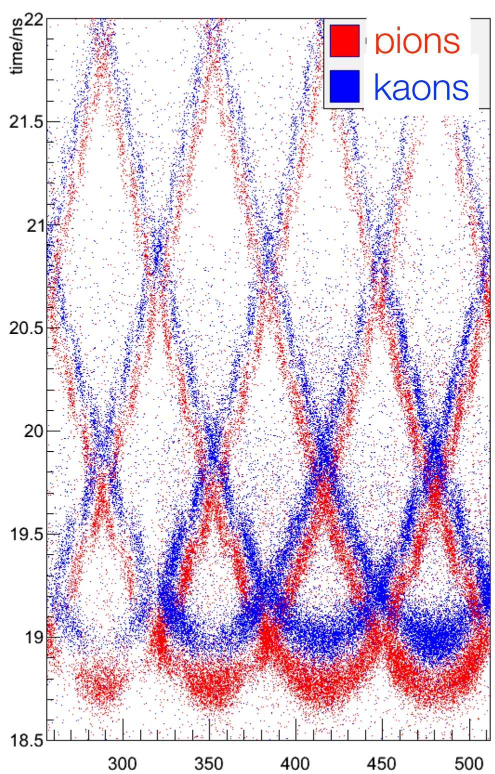


sample γ trajectory for π and K

time (ns)

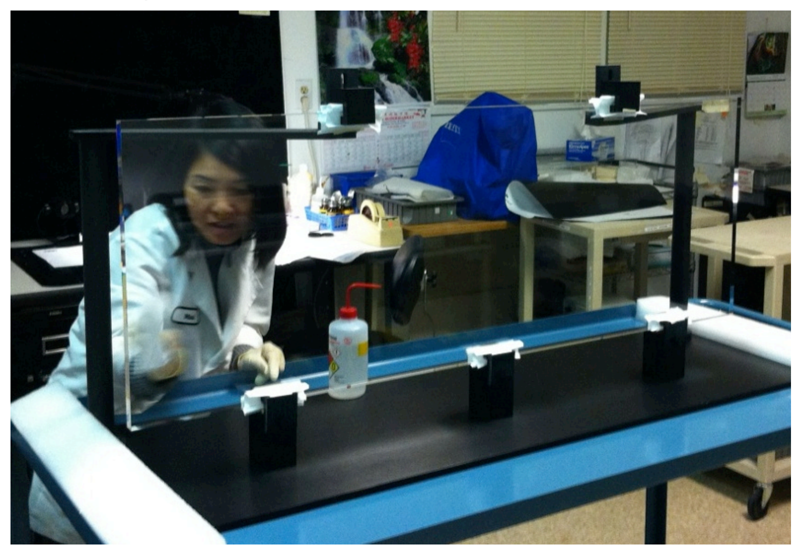
need resolution < 100 ps

500 ps



position (pixel number)

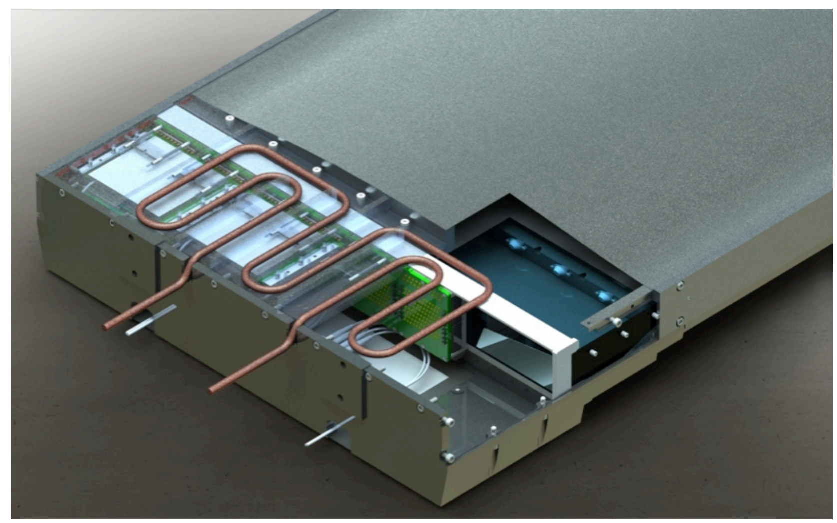
Zygo fused silica bar (two glued to form complete bar)



Jim Fast

iTOP status

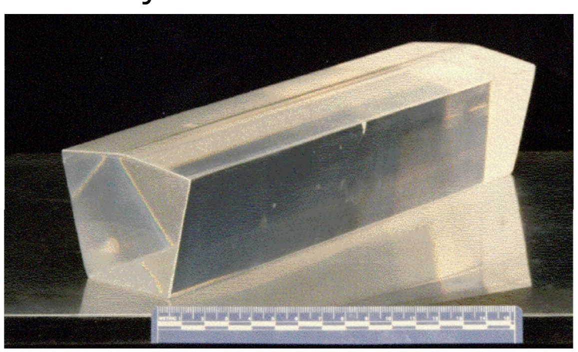
- Procurement of precision optical components has been difficult. Production is under way. Two vendors for bars.
- Design of complex opto-mechanical system is close to finalized
- Passed DOE CD-2/3 review
- ~1/2 of iTOP will be in place for first physics run.



Calorimeter

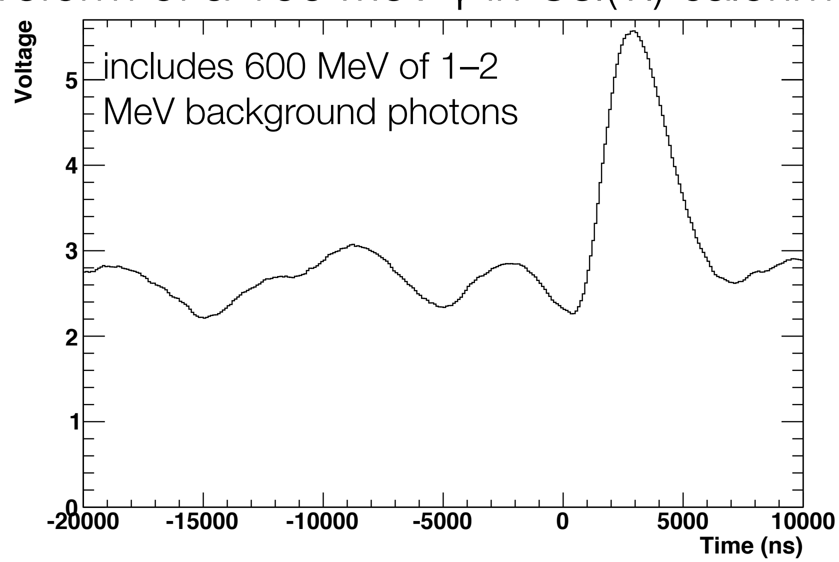
- Precise measurements of γ (π^0) and E_{extra} is critical to our physics program, particular with respect to LHCb.
- Belle II is reusing the CsI(Tl) crystal calorimeter from Belle, with new digitization and waveform fitting electronics. Excellent resolution, but quite slow.

CsI crystal



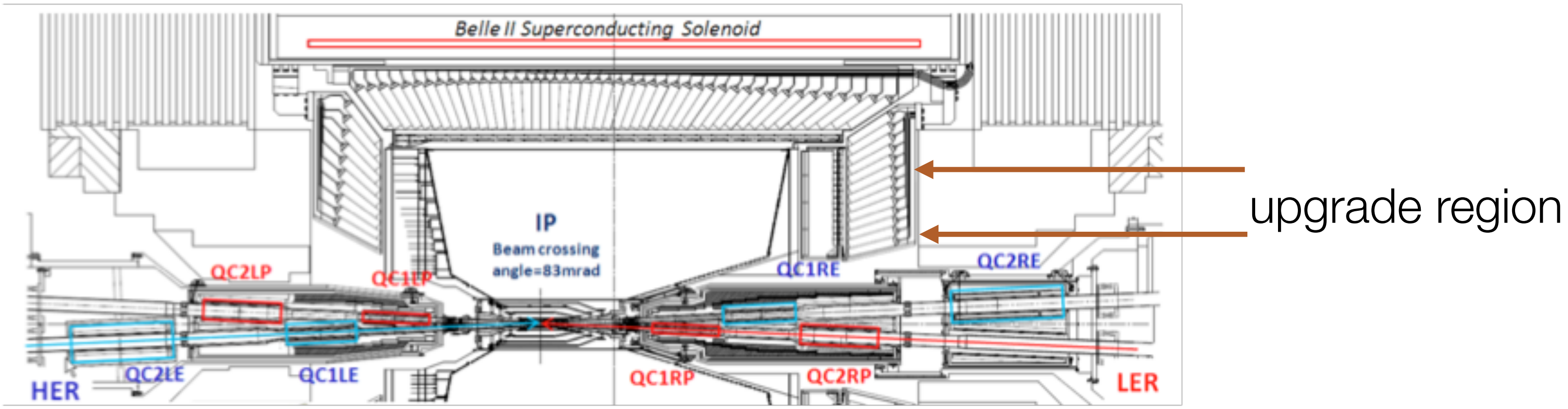
Chloe Malbrunot

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



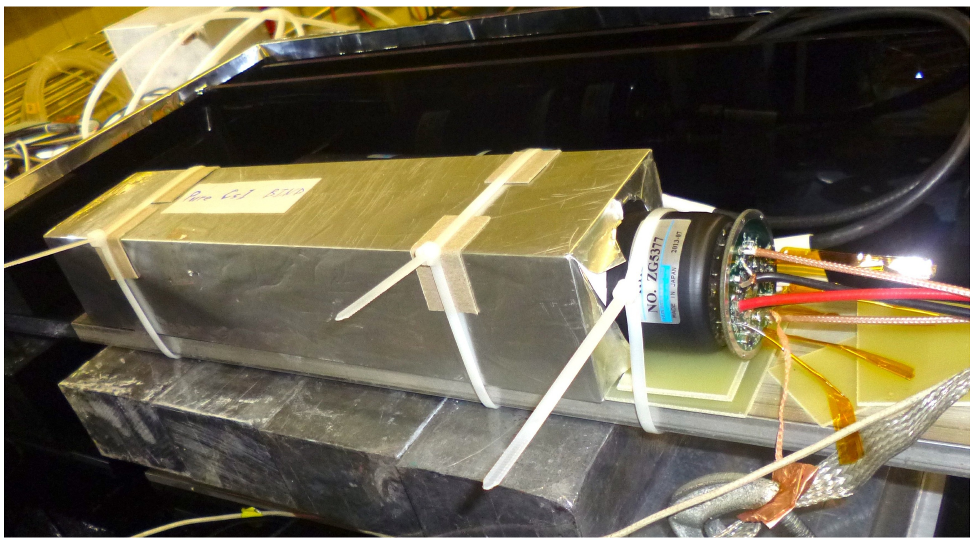
Pure CsI upgrade

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

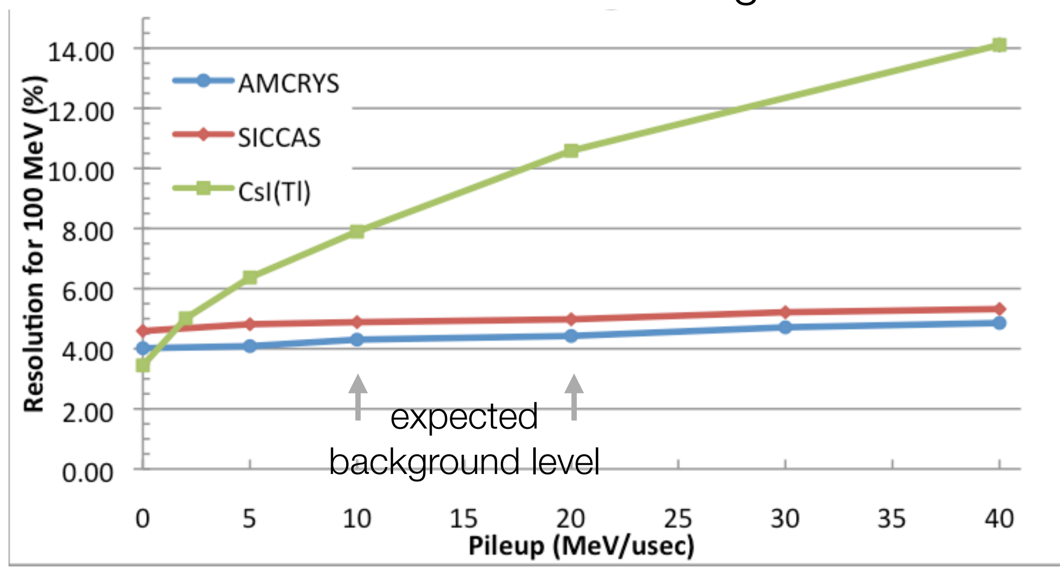


- Preamp & digitizing electronics under development at U. Montreal. Electronic noise equivalent energy ~70 keV; much better than existing CsI(Tl)

Fine mesh PMT with prototype preamp on pure CsI crystal

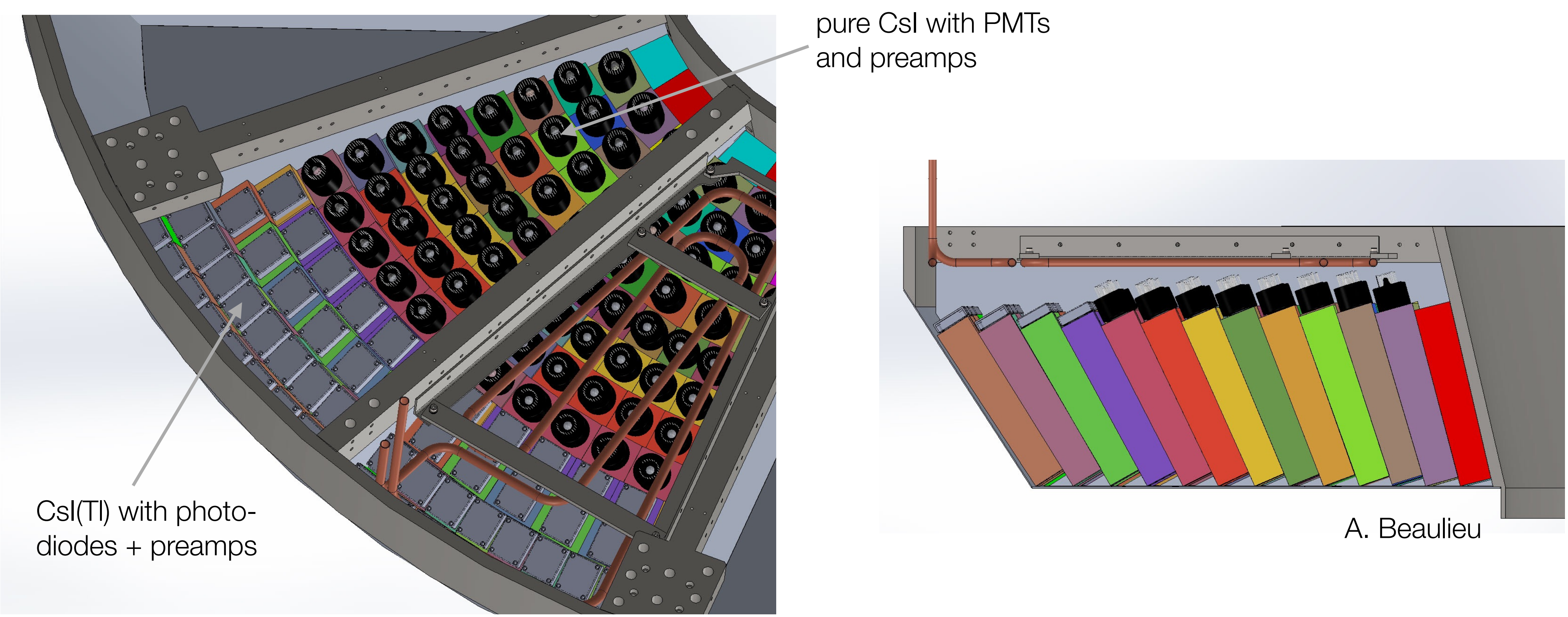


Simulated resolution vs background level



Mechanical modifications

- PMTs are larger than existing photodiodes, so mechanical structure requires modification.



Status of pure CsI upgrade

- Although the pure CsI clearly has better energy and timing resolution, we have not established that we will get significantly better physics results.
- Current background estimations, including shielding, predict radiation doses in the CsI(Tl) crystals within safe operating limits.
- We are not submitting an application to CFI for this round.
- We will continue to work within the ECL group to ensure the best possible calorimeter performance.
    - e.g., beam test of irradiated CsI(Tl) prototype at M11

Schedule

- Accelerator construction for phase I will be completed by March 2015 (FY14). Commissioning in three phases:
- Phase 1: No superconducting IR magnets; no Belle II.
  - Basic tuning, vacuum scrubbing
- Phase 2: Full accelerator; Belle II except vertex detector and TOP.
  - beam collision tuning, background studies
- Phase 3: Full detector, with ~1/2 of TOP
  - First physics. $L = 10^{34}$ $cm^{-2}s^{-1}$

Schedule II

- Significant cuts to KEK operations budget this year will delay start of commissioning to FY15 (spring/fall 2015).

  - The preparation work to be covered by the operation budget includes followings:
    - place radiation shields back at four experimental hall.
    - operate refrigerators and cool down superconducting cavities
    - startup klystrons and condition the ARES and SC cavities
    - startup and adjust magnets and power supplies
    - final precise alignment of magnets around the ring before beam operation
    - startup vacuum, monitor, and other systems
    - electricity charges for the above works (in particular, magnets, refrigerator, klystrons and cavities)
    - more operators for 24 hour shifts

- First physics run ~2 years later.

First year physics plan

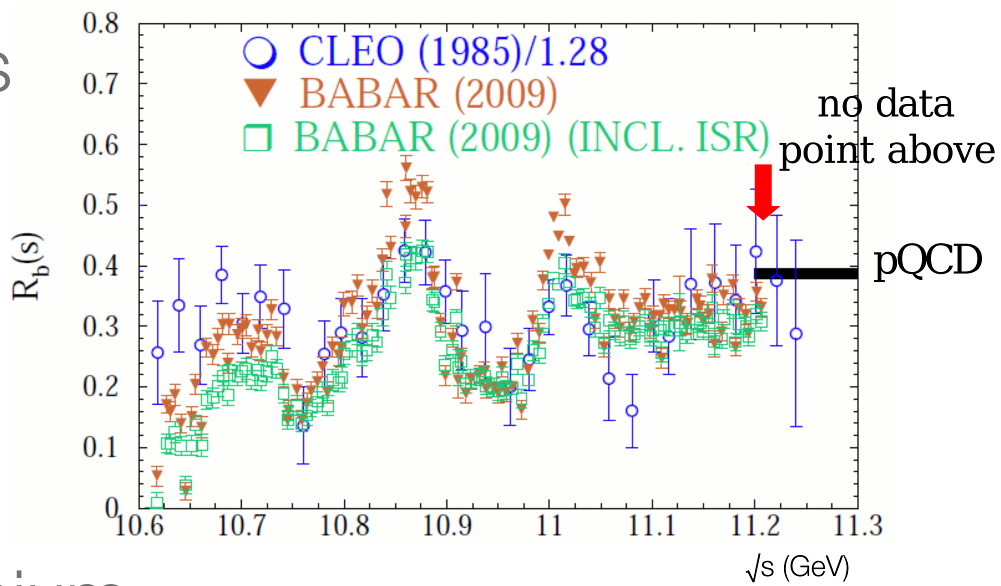
- B physics topics require high-momentum particle ID more than other topics. We are considering alternatives to the Υ(4S) for the first run. Maybe few hundred fb^{-1}.

- Υ(2S): dark forces, light Higgs

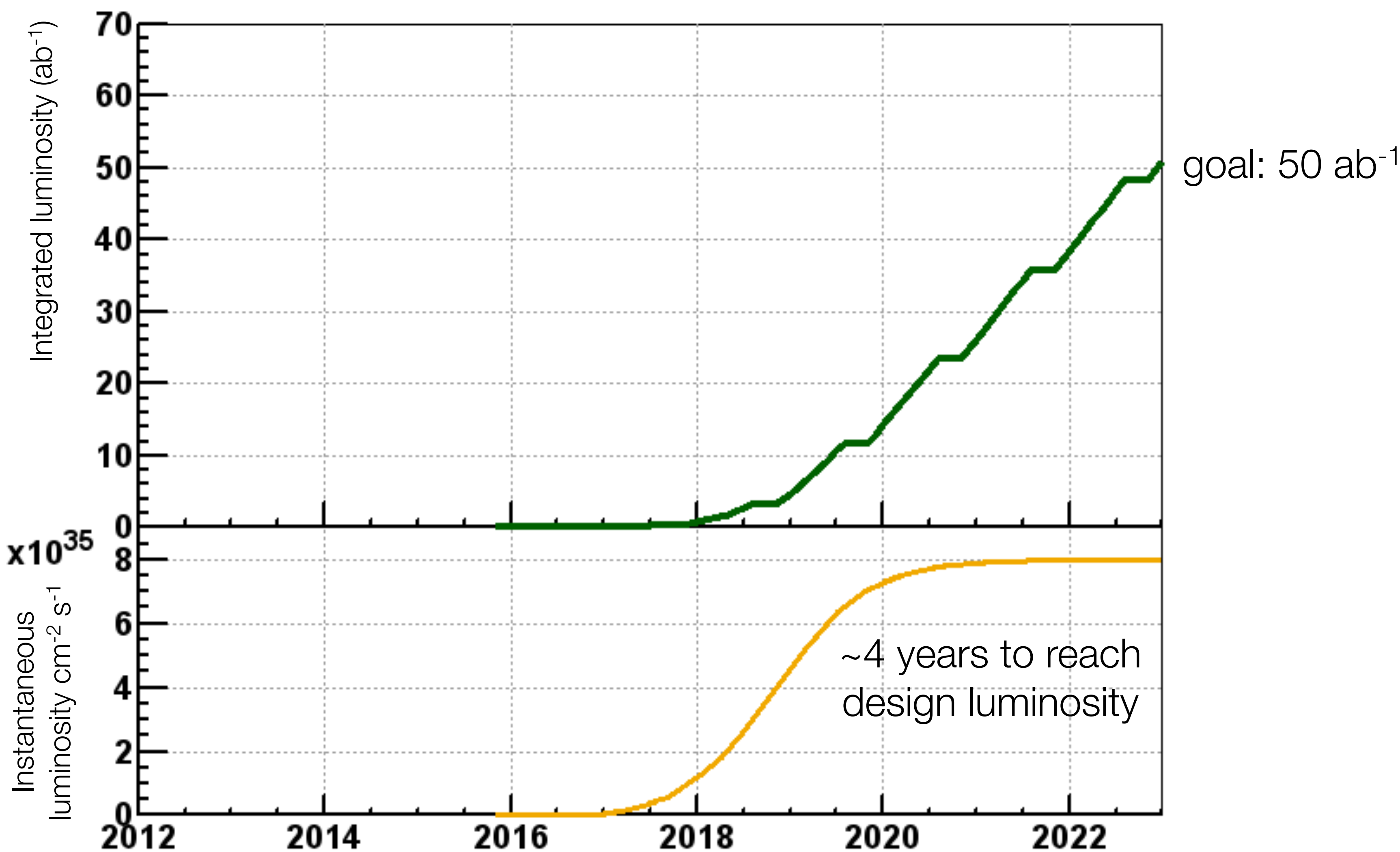
- Υ(6S): bottomonium, Z_b

- r_B scan

- Υ(3S): conventional bottomonium



Luminosity projection

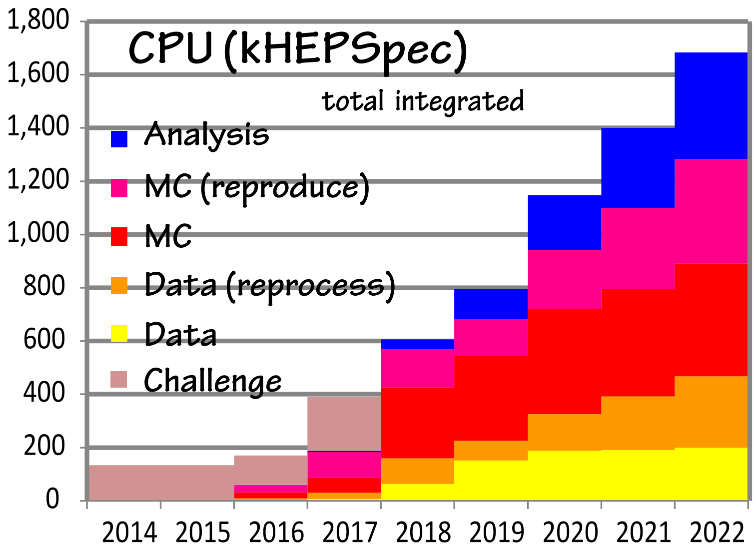


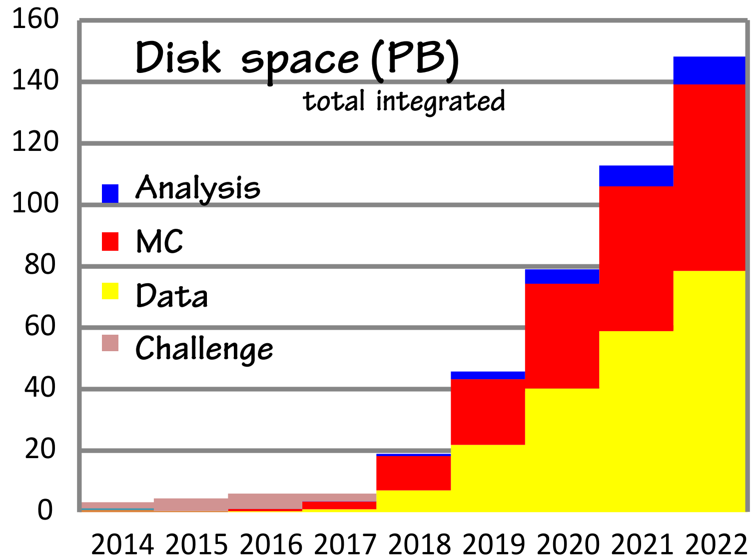
Computing

- Raw data storage and processing at KEK; second copy of raw data distributed elsewhere. Physics data distributed for analysis. Grid + cloud for MC production.
- Focus on MC production so for. Cloud computing at Victoria, “Infrastructure as a service”. Grid MC production at CLUMEQ (McGill).

Computing hardware outlook

- Hardware requirements are comparable to current LHC.
- Canada: 5% of raw; 10% of mDST; 3% of MC production.





Canada:
5 PB disk
3 PB tape
43 kHEPSpec
2900 cores

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*