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PHYSICS

a place of mind

The Belle II Experiment

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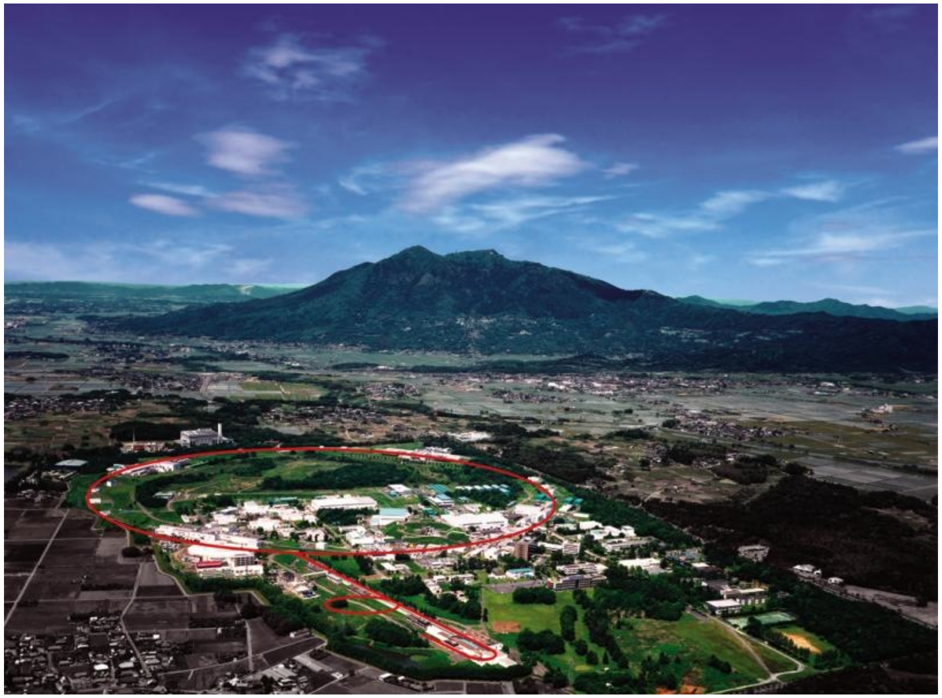
University of British Columbia / IPP
May 28, 2017

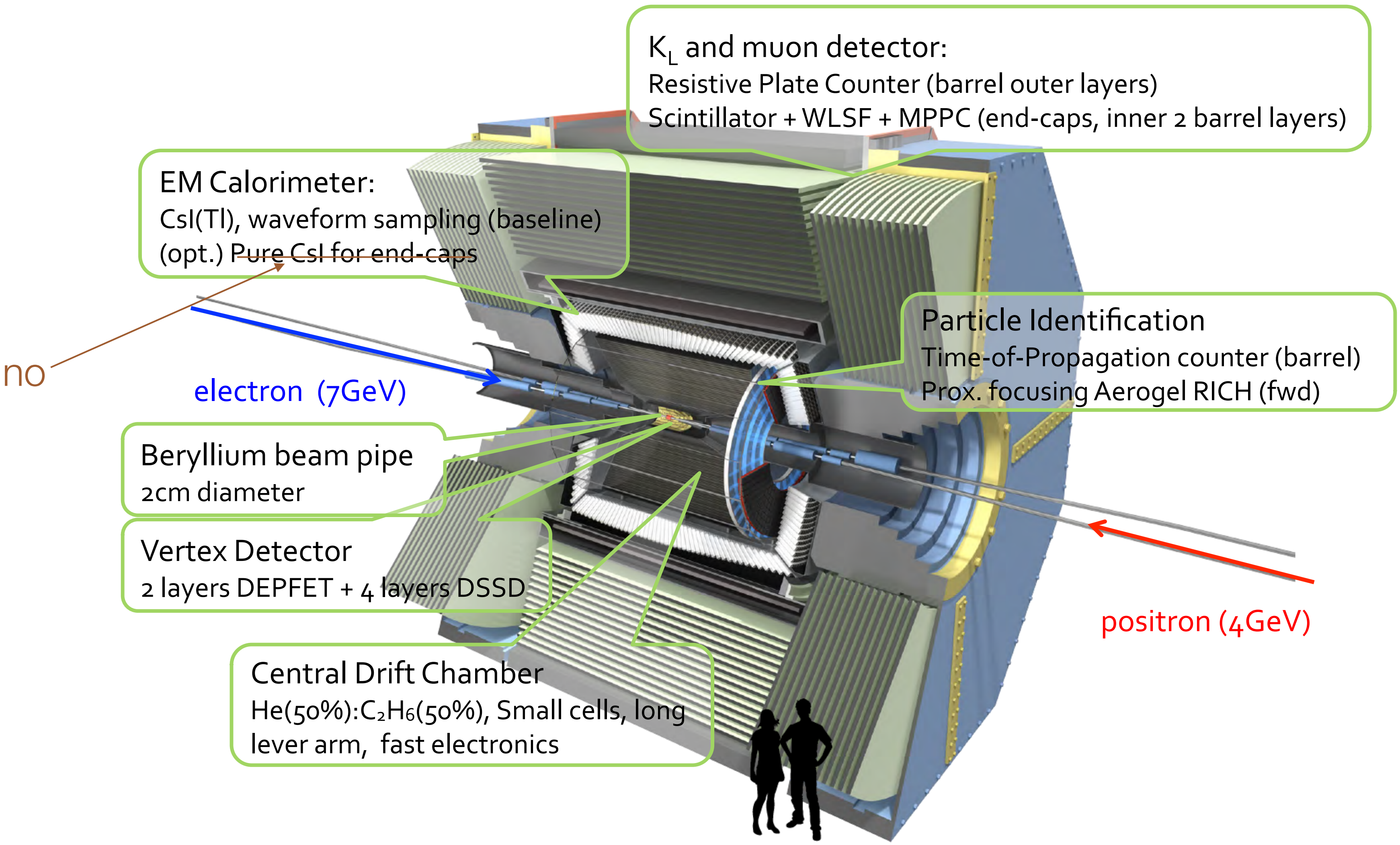
Belle II

- Next generation B-factory, located at the SuperKEKB asymmetric e^+e^- collider.

- 40x the peak luminosity of KEKB; 50 ab^{-1} integrated luminosity = 30x the combined of BaBar and Belle.

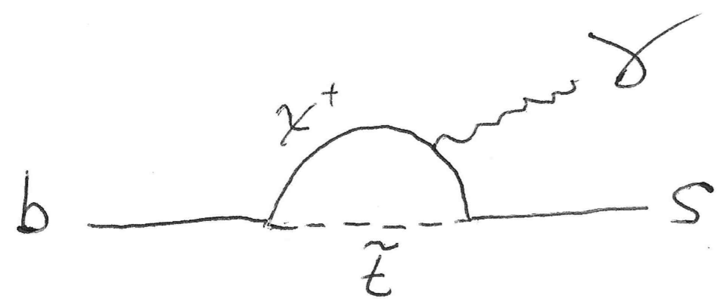


- Detector is an upgrade of Belle. New tracking and particle ID; upgrades to calorimeter and muon systems.



Physics

- Primary goal is to seek evidence for new physics through a wide range of measurements that are sensitive to the presence of heavy virtual particles.
  - asymmetries, rare decays, forbidden decays.

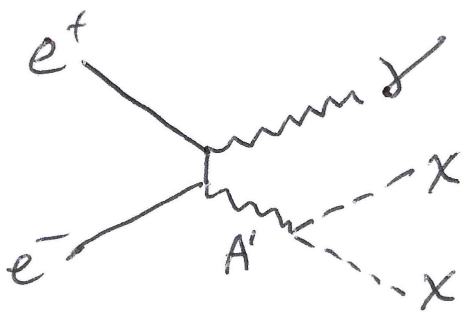


- Also direct searches for new physics;
- investigations of the nature of QCD through the studies of new bound states (XYZ);
- exploration of CP violation and the weak force.

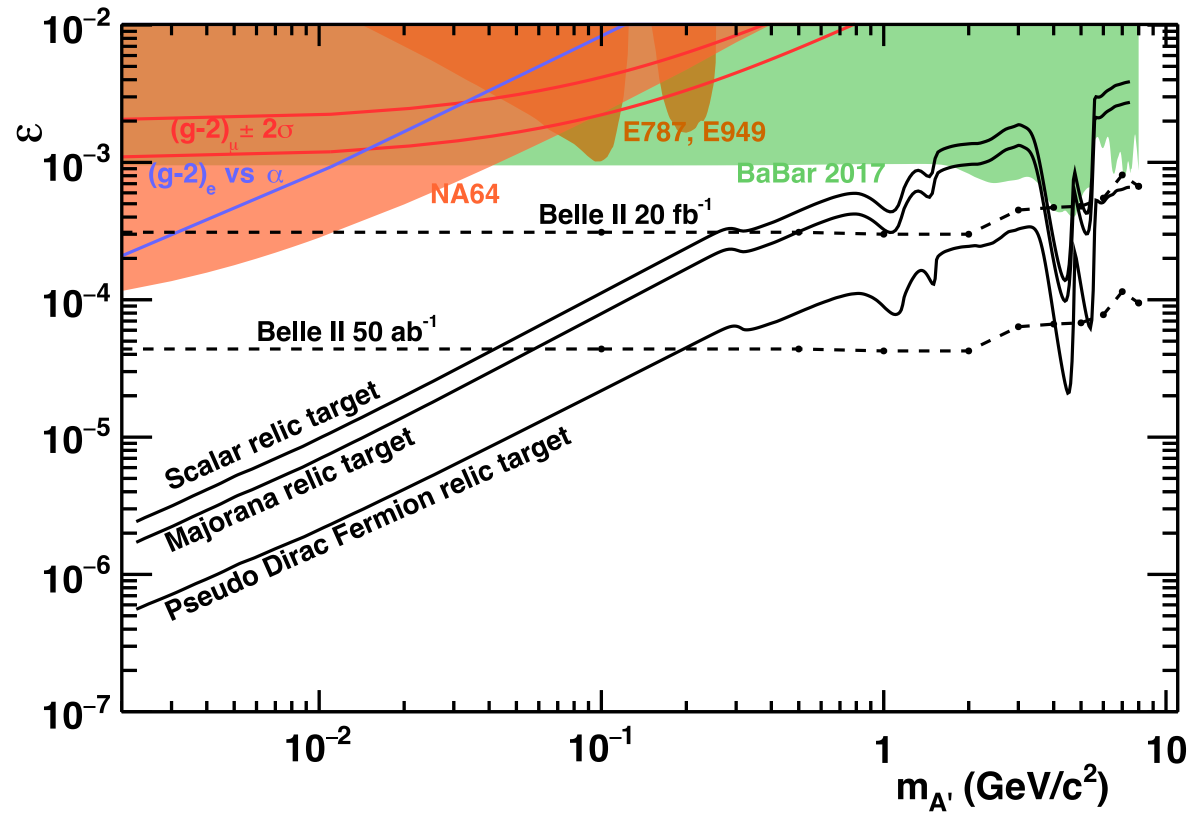
- B physics; charm; tau (including lepton flavour violation); initial-state radiation production of $\pi^+\pi^-$ and other hadronic states; Upsilon decays

Search for light dark matter using $e^+e^- \rightarrow \gamma$ + invisible

- Dark Sector models include light dark matter χ accessible through decay of a dark photon A' that mixes with γ with strength ε. Belle II will have unique capabilities, even with the initial small dataset.



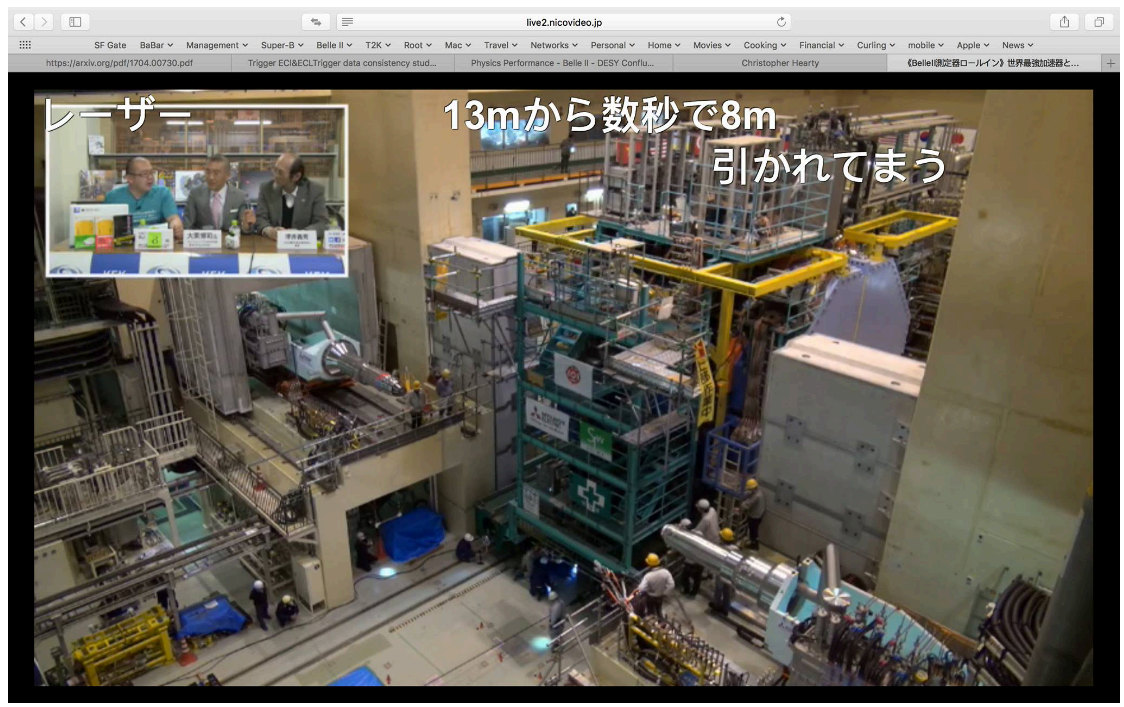
BaBar arXiv:1702.03327; NA64 curve Renat Dusaev; g-2 & $\pi\nu\nu$ Rouven Essig; relic densities adapted from E. Izaguirre, G. Krnjaic, P. Schuster, N. Toro, PRL 115, 251301 (2015) ; Belle II C. Hearty /Torben Ferber;



Schedule / Status

- SuperKEKB commissioned with single beams in Spring 2016 (Phase 1 commissioning).

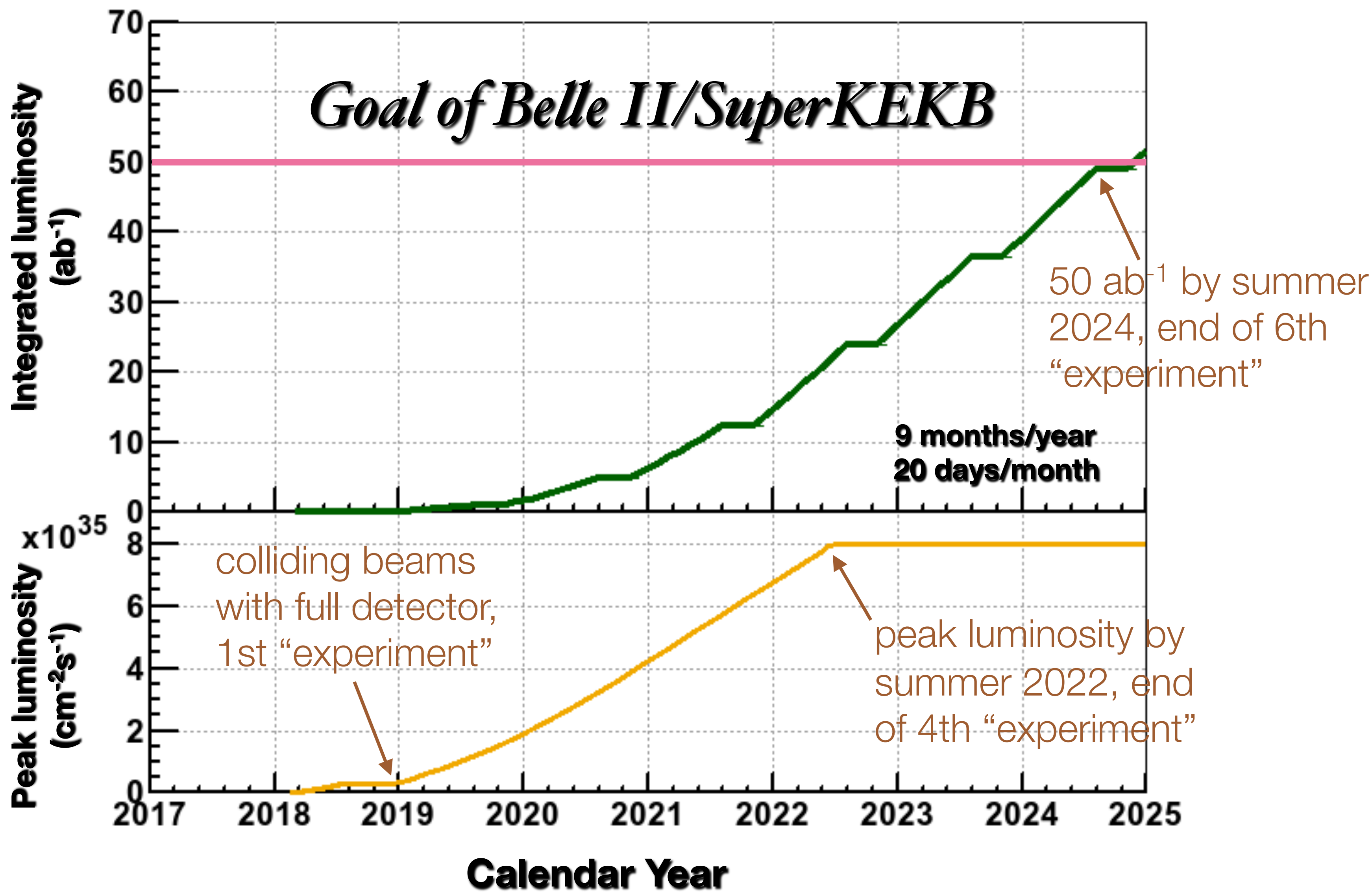
- Detector moved onto beam line April 2017.



- 1st collisions, no vertex detectors: Feb. 2018 (Phase 2).

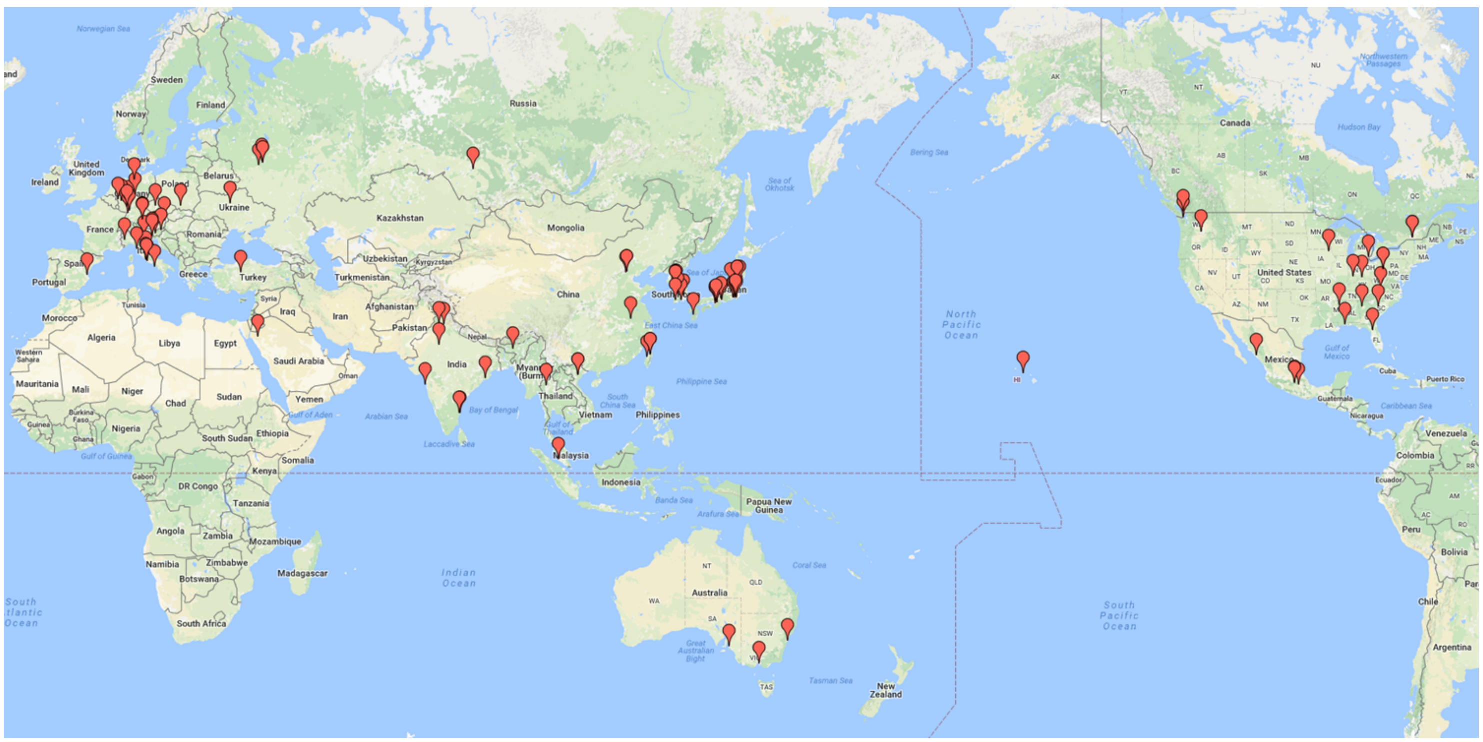
- Collisions with full detector: Jan. 2019 (Phase 3).

SuperKEKB luminosity projection



Collaboration

- 23 countries, 100 institutions, 750 collaborators, including 380 PhD physicists & 260 graduate students.
- Canada joined in March 2013.



Canadian group: 10 faculty, 9 current and 4 completed grad students, 2 postdocs

- **UBC**: C. Hearty, J. McKenna, T. Mattison, T. Ferber, A. Hershenhorn
- **Victoria**: J. M. Roney, R. Kowalewski, R. Sobie, A. Sibidanov, A. Beaulieu, S. de Jong, S. Longo, C. Miller
- **McGill**: S. Robertson, A. Warburton, W. Ahmed, A. Fodor, H. Pikhartova, R. Seddon
- **Montreal**: J.-P. Martin, P. Taras, N. Starinski

faculty, postdoc, student, technical

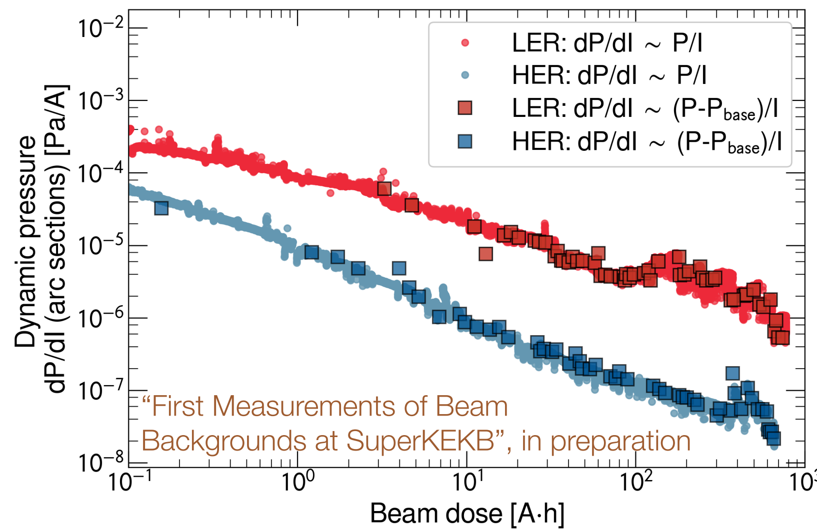
Canadian activities

- Preparations for physics (including single photon);
- Background measurements and remediation;
- Calorimeter reconstruction and calibration.
- Detector material studies → not in my talk
- Computing (particularly cloud) → not in my talk
- *Four students talks Monday 11:30 AM Botterell B139*
  Steve Robertson overview Thursday 8 AM Botterell B139

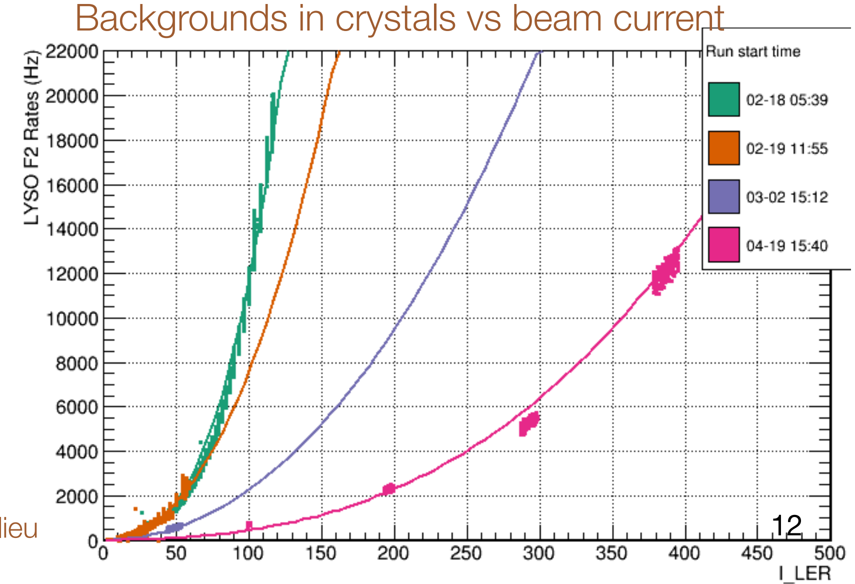
Single beam commissioning

- Initial commissioning;
- Vacuum scrubbing;
- Studies of non-luminosity backgrounds using specialized detectors ("BEAST")
  - ^{3}He tubes for thermal neutrons; Sam DeJong (UVic)
  - CsI/CsI(Tl)/LYSO crystals; Alex Beaulieu (UVic)

"dynamic" pressure improved by scrubbing, but not yet at goal

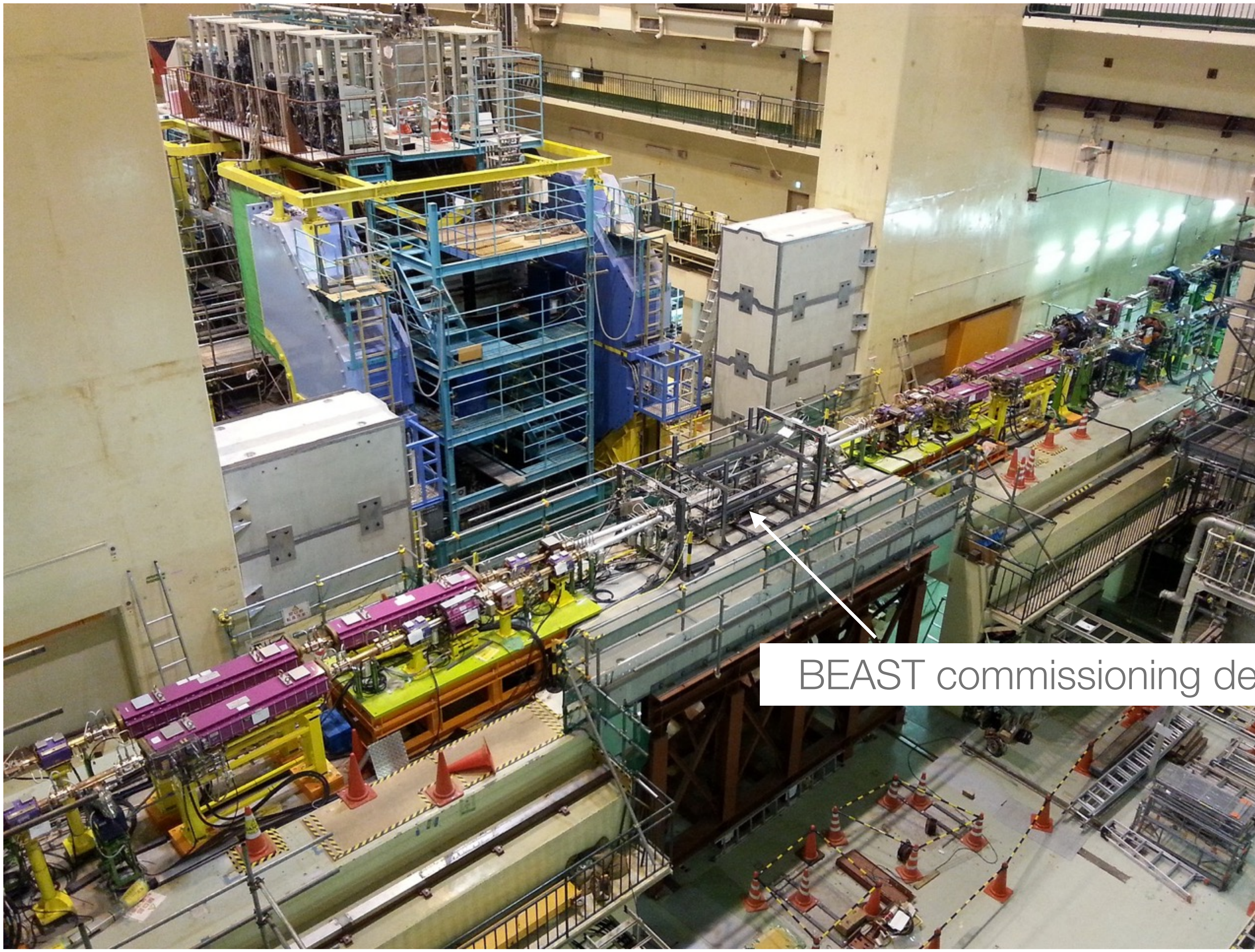


Backgrounds in crystals vs beam current



Alex Beaulieu

BEAST commissioning detectors



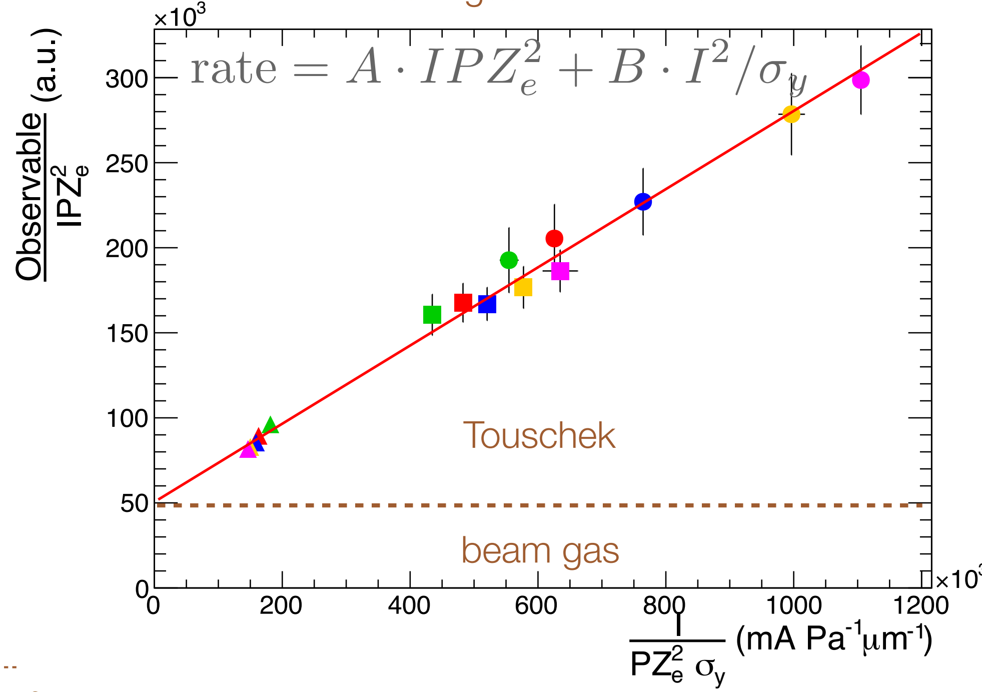
BEAST commissioning detectors

Background measurements during Phase 1 commissioning

- Study beam gas scattering by varying pressure & current; Touschek (scattering within a bunch) by varying size & current.

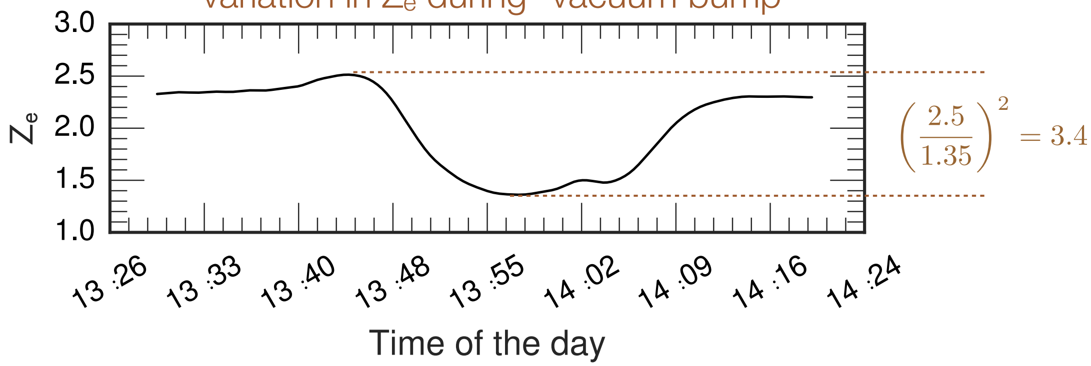
- Critical point is to use residual gas analyzers to correct for the effective atomic number Z_e of the gas.

rate = beam gas + Touschek



"First Measurements of Beam Backgrounds at SuperKEKB", in preparation

variation in Z_e during "vacuum bump"



Background shields

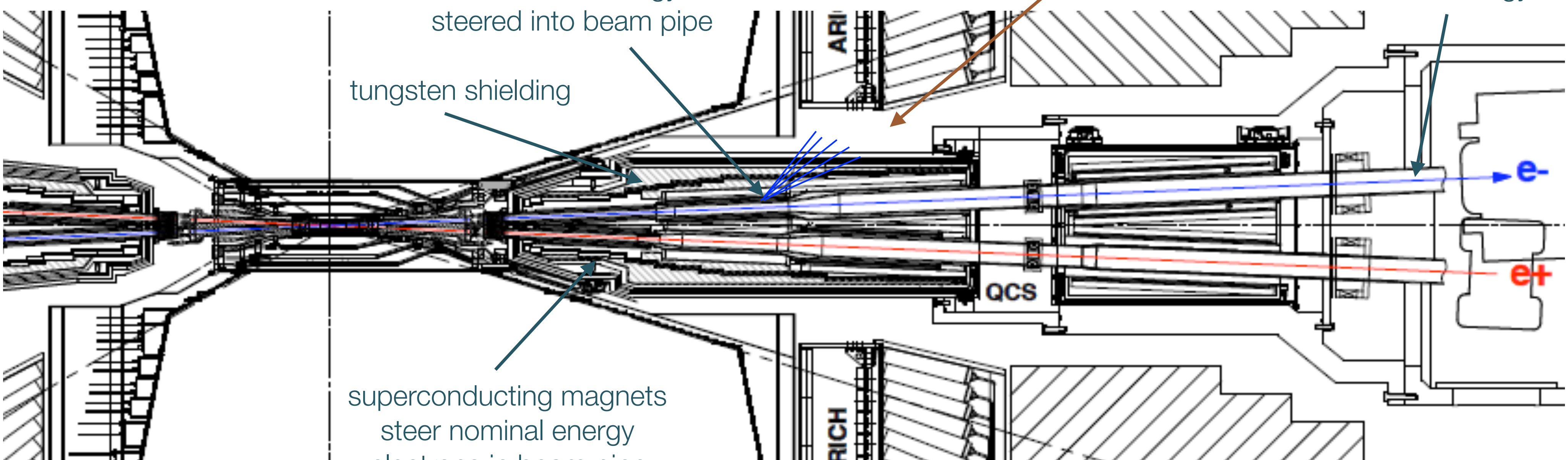
- Considerable shielding built into final focus magnets.

- Canadian group is providing lead/polyethylene shields, particularly for calorimeter endcaps; factor of 2 reduction in peak rates.
  - Alex Beaulieu

- First job of this type for contractor, Turbulent Diffusion Technology.

Radiative Bhabha beam backgrounds

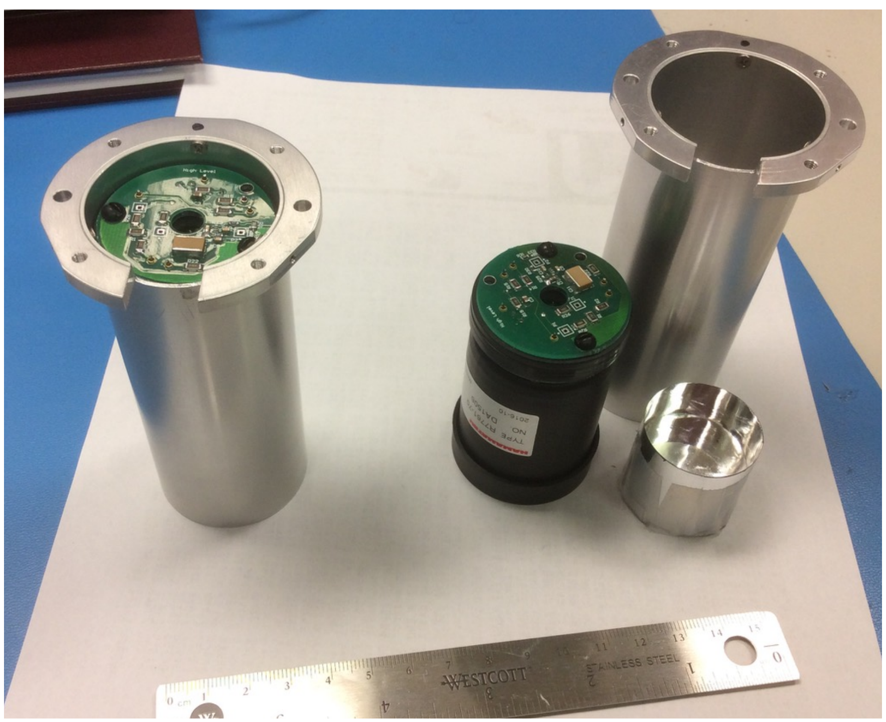
- Biggest source of beam backgrounds are radiative Bhabhas, $e^+e^- \rightarrow e^+e^-\gamma$. ~3500 per beam crossing.
  - low energy γ and n; shower debris



- Despite shielding, many 1—2 MeV photons reach the detector.

Background monitors

- McGill and Montreal groups are developing background monitors embedded in the shields to provide real-time feed back to operators:
  - collimator adjustments
  - characterizing injection background



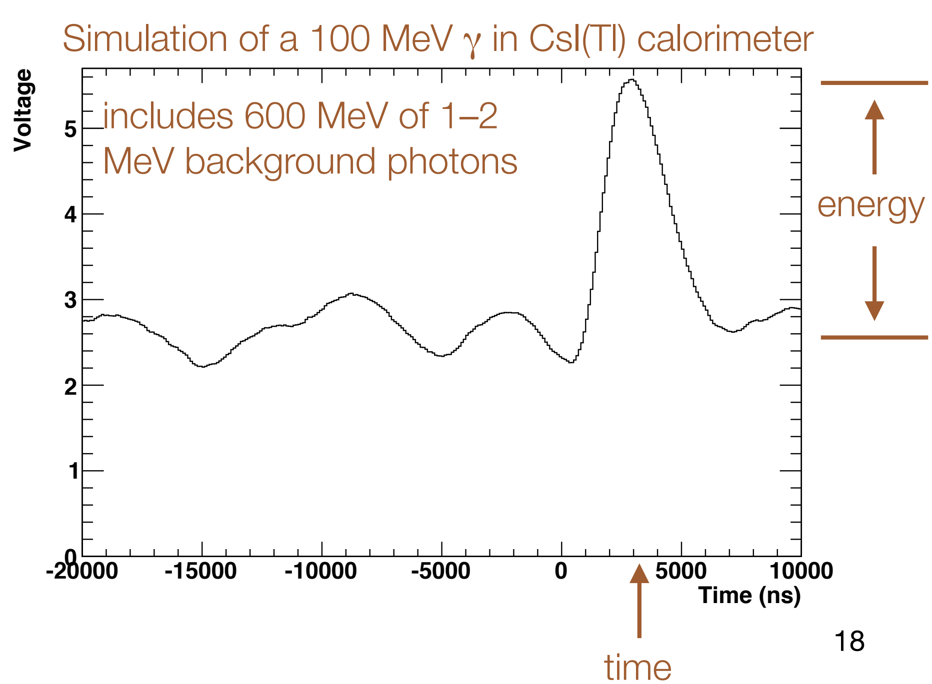
Hardware developed by Montreal electronics group headed by J. P. Martin:

- LYSO crystal
- fine-mesh PMT
- pseudo differential readout
- 258 MHz ADC = bunch spacing
- can synchronize with trickle injection

Nick Starinsky

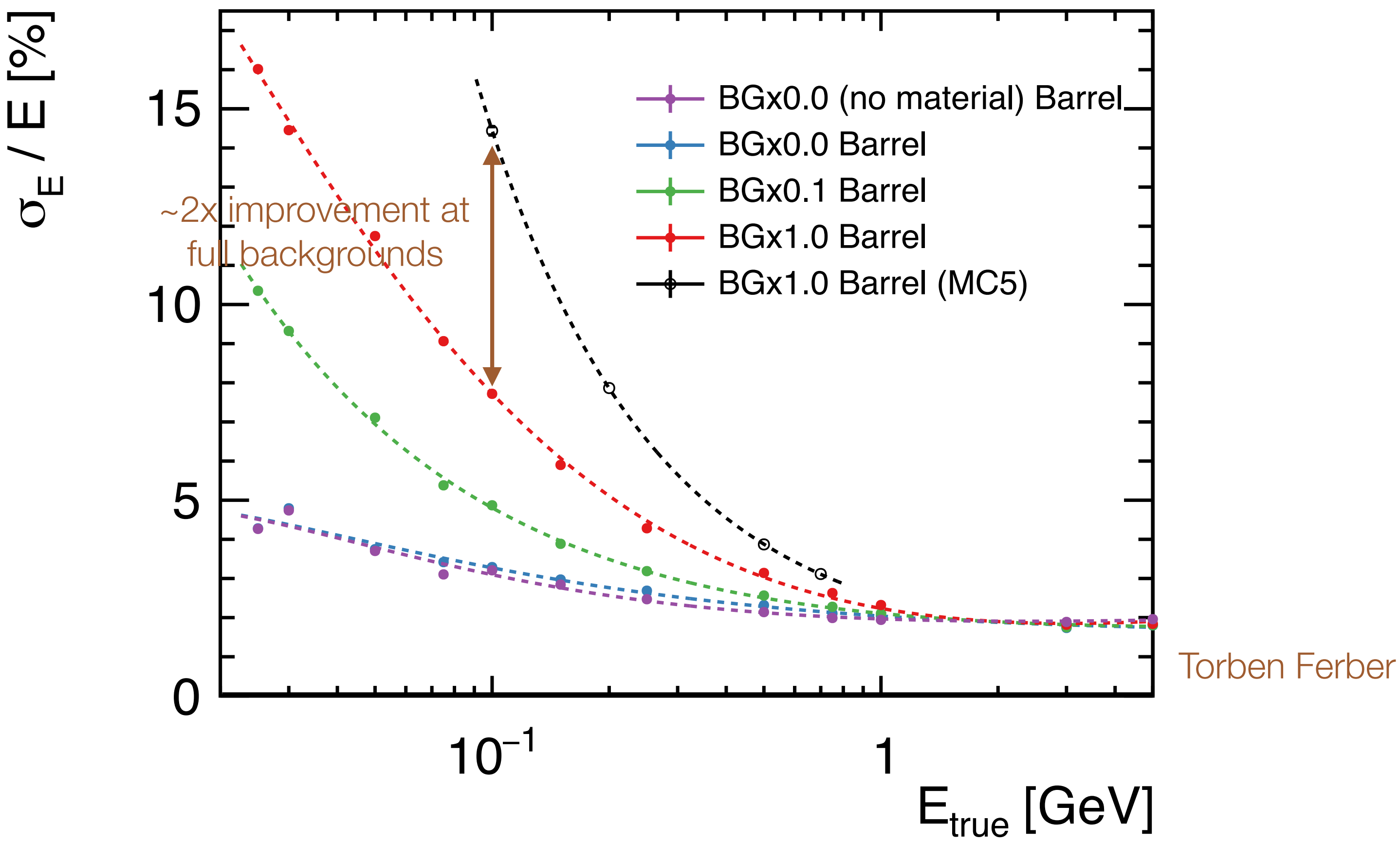
Calorimeter reconstruction

- Precision calorimetry is critical to the physics program, particularly with respect to LHCb.
- CLEO, BaBar, and Belle have all used CsI(Tl) before, but we will have much higher backgrounds.
- New readout electronics with waveform fitting gives much better timing resolution to reduce out-of-time backgrounds.



- Torben Ferber (UBC postdoc) has developed innovative reconstruction code for the calorimeter.
    - number of crystals included in the cluster varies with background level;
    - also depends on the hypothesis made on the particle type: hadron vs photon.
    - machine learning to reduce position bias compared to Belle and BaBar

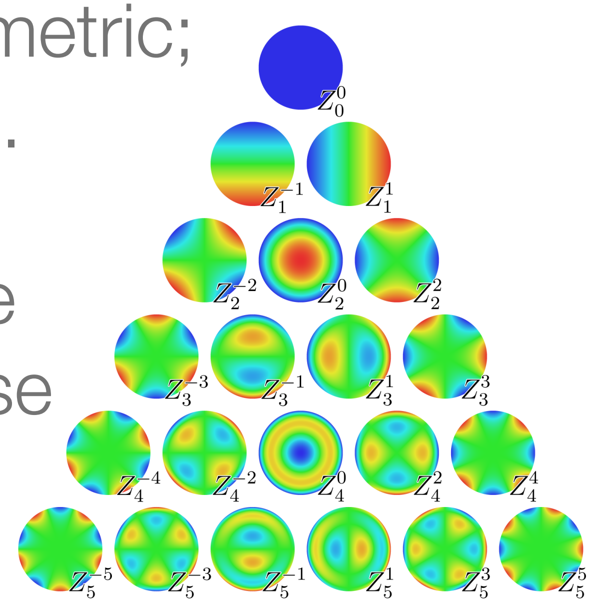
- Result is a dramatic improvement in energy resolution over existing algorithm.



Shower shapes

- Photon showers are regular shaped, symmetric; hadronic showers are much more variable.

- Alon Hershenhorn (UBC) has exploited the hypothesis-based clusters to quantify these differences using Zernike moments.
  - BDT with 11 moments vs 1 for BaBar



Zom-B, Wikipedia

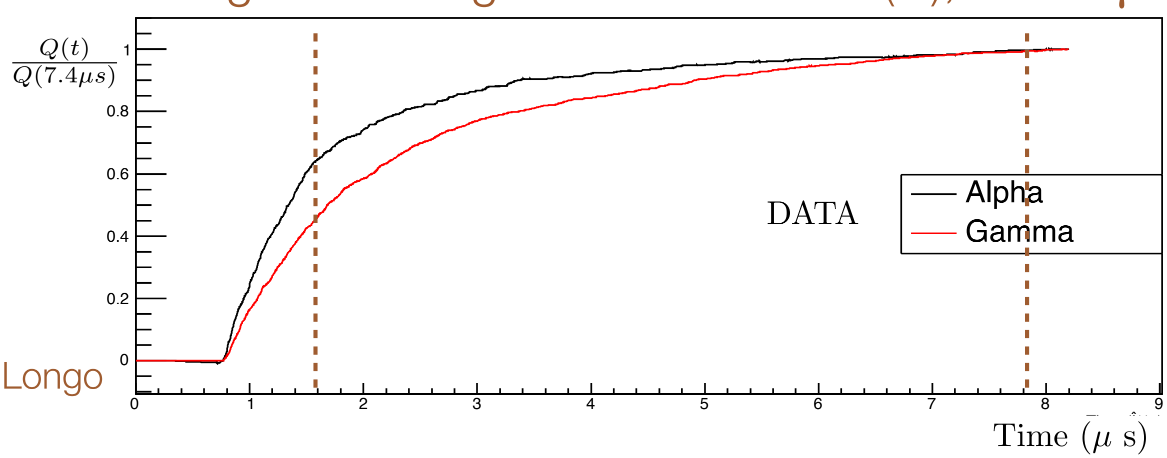
- Compare how much a shower looks a photon if we assume it is a photon to how much it looks like a photon if we assume it is a hadron.

Pulse shape discrimination (PSD)

- Heavily-ionizing particles produce CsI(Tl) signals with noticeably different time structures than photons.
  - well known in nuclear physics, but not used in previous collider experiments.

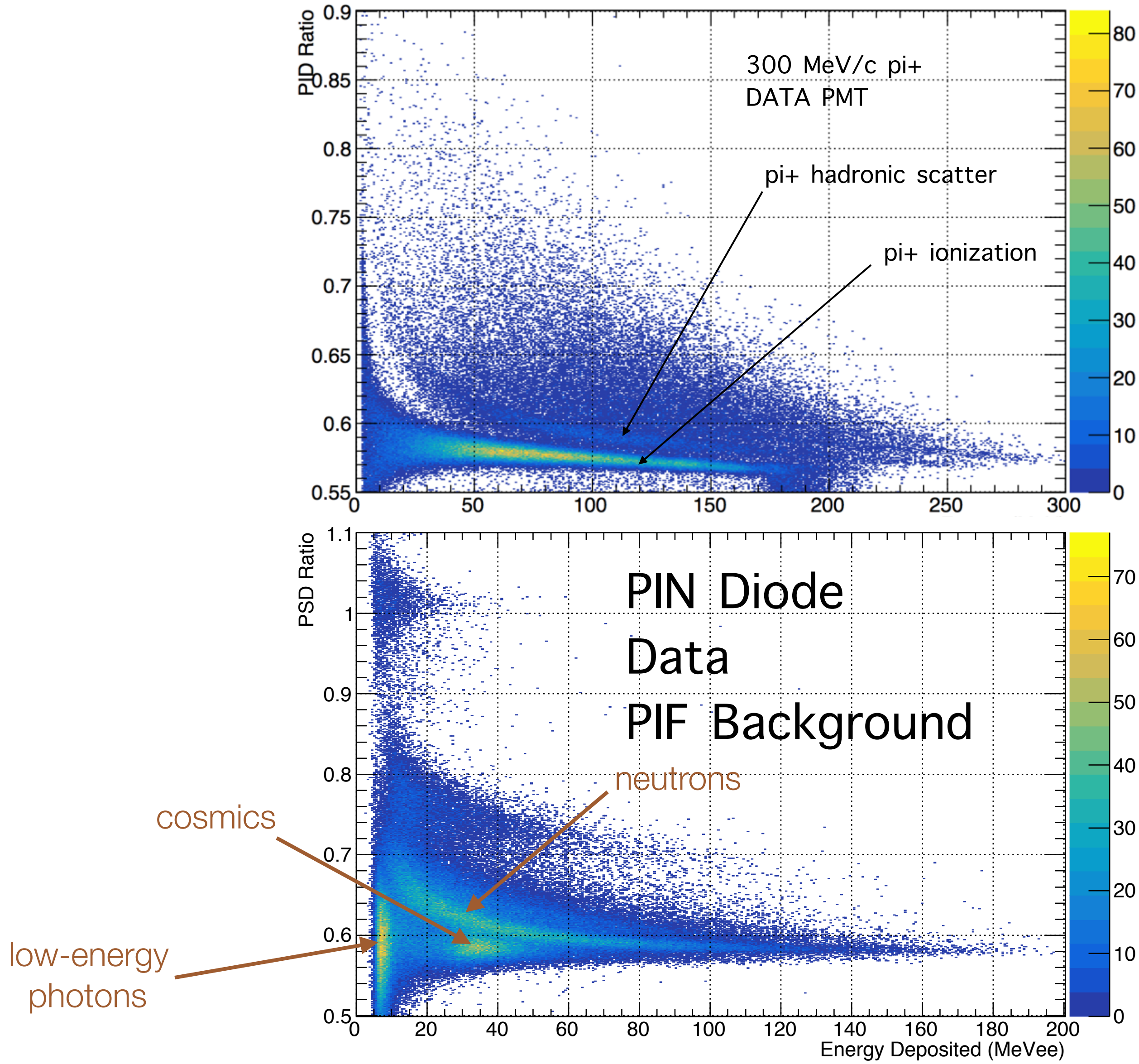
- Savino Longo (UVic) has proposed implementing PSD particle ID in Belle II: $R_{\text{PID}} \equiv Q(1.2\mu s)/Q(7.4\mu s)$

Integrated charge vs time from CsI(Tl), α and γ



Savino Longo

- Data from two beam tests at TRIUMF: M11 (summer 2015), and Proton/Neutron Irradiation Facility (fall 2016).



M11 300 MeV/c
BaBar crystal, PMT readout

Neutron and cosmic background events in PIF;
Belle II crystal, photodiode

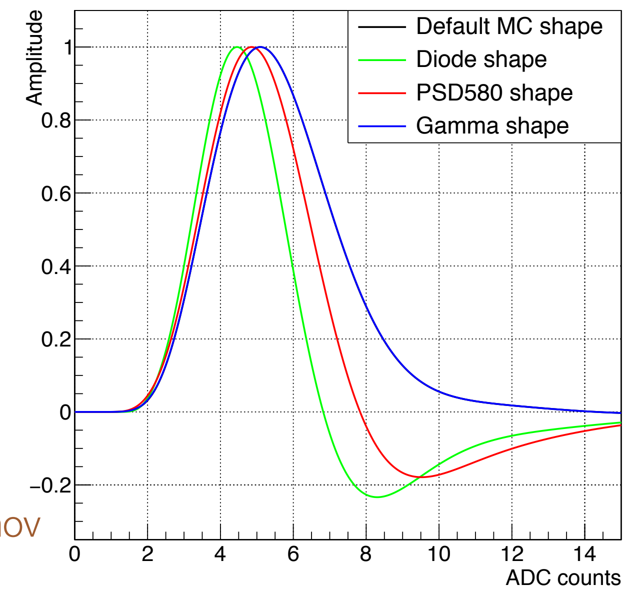
Savino Longo

Challenges in implementing PSD in Belle II

- Currently obtain amplitude and time of energy deposition in each crystal using a real-time waveform fit in an FPGA.

- Need a new FPGA algorithm that also extracts a PSD discriminator. Must be robust, fast, and not damage existing E and t measurements. Alexei Sibidanov UVic RA

    - template needs to be individually trained for each crystal using full waveforms, including hadrons



Alexei Sibidanov

- GEANT (at least, our model) does not produce a difference in pulse shape. Savino is working on this.

- Proposal is to record full waveforms for a fraction of the Phase 2 colliding beam data. May even test new FPGA code.

Summary

- Belle II will have first colliding beam data within a year. Physics opportunities with the first data include a search for light dark matter.

- Canadian group's contributions include:
  - physics
  - backgrounds: characterization, shields, monitor
  - calorimeter reconstruction, shower shapes, pulse shape discrimination

- Addition details in students' talks tomorrow and Steve Robertson's talk on Thursday.