INSTITUTE OF PARTICLE PHYSICS

a place of mind
UBC

The Belle II experiment

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On behalf of the Canadian Belle II group

Belle II

- Upgrade of Belle, located at the SuperKEKB e^+e^- collider in Tsukuba Japan.

- Goal is 30x the combined integrated luminosity of BaBar + Belle, primarily recorded at the Y(4S) (10.58 GeV/c^2)

Physics

- Search for new physics in a wide range of final states with precise Standard Model predictions:
  - rare decays, including τ;
  - forbidden decays (e.g. lepton flavour violation);
  - symmetries (e.g. CP violation).

  - Indirect mass reach of these complement and can exceed LHC direct search limits.

- Continued investigation of the weak force.

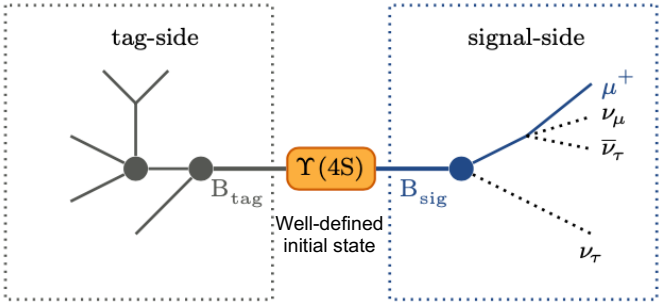
- Direct searches for non-SM particles (e.g. dark sector).

Semileptonic and missing energy B decays

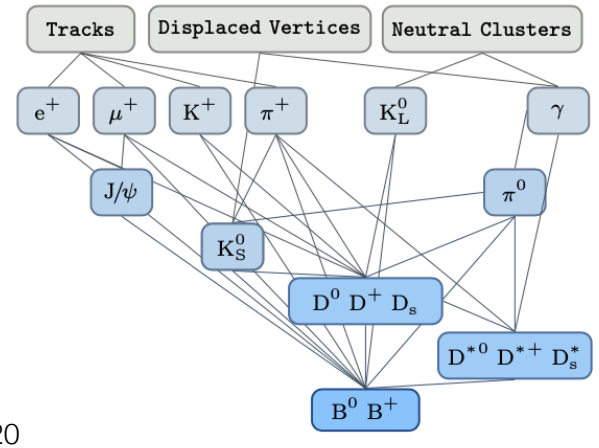
- Largest physics working group; significant Canadian leadership, including:
  - Racha Cheaib (UBC postdoc): co-convenor
  - Steve Robertson: leptonic subgroup co-convenor
  - Robert Kowalewski: semi-tauonic subgroup co-convenor

- Full-event interpretation enables reconstruction of events with neutrinos in the final state.

full reconstruct this B

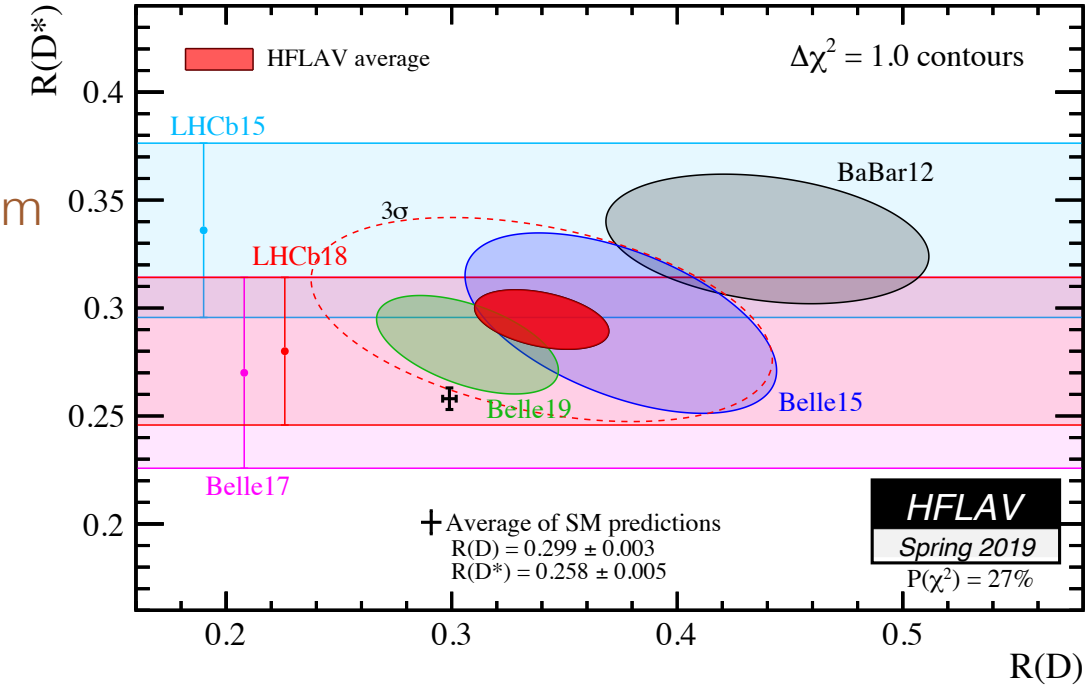


look for desired decay of this B



- High priorities include investigating anomalies in $R(D^{(*)}) \equiv B \to D^{(*)}\tau\nu_\tau / B \to D^{(*)}\ell\nu_\tau$ and $R_{K^{(*)}} \equiv B^+ \to K^{(*)+}\mu^+\mu^- / B^+ \to K^{(*)+}e^+e^-$.

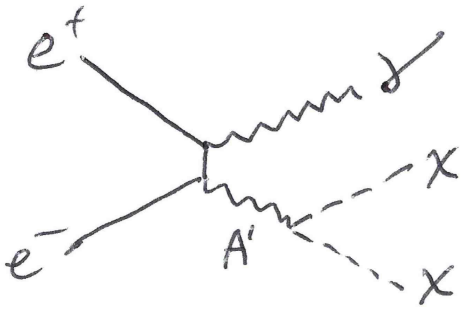
3σ deviation from SM in $R(D^{(*)})$



- Belle II can also measure related modes, such as $B \to K^{(*)}\tau^+\tau^-$ and $B \to K^{(*)}\nu\bar{\nu}$

Dark sector

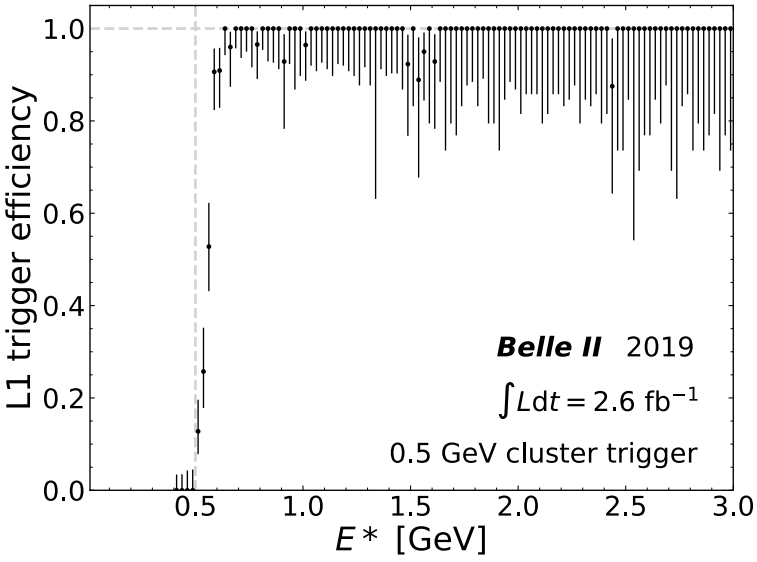
- Increasingly popular model for beyond-the-SM physics. Mediators/dark matter can be light enough for direct production at Belle II.



"single photon" analysis

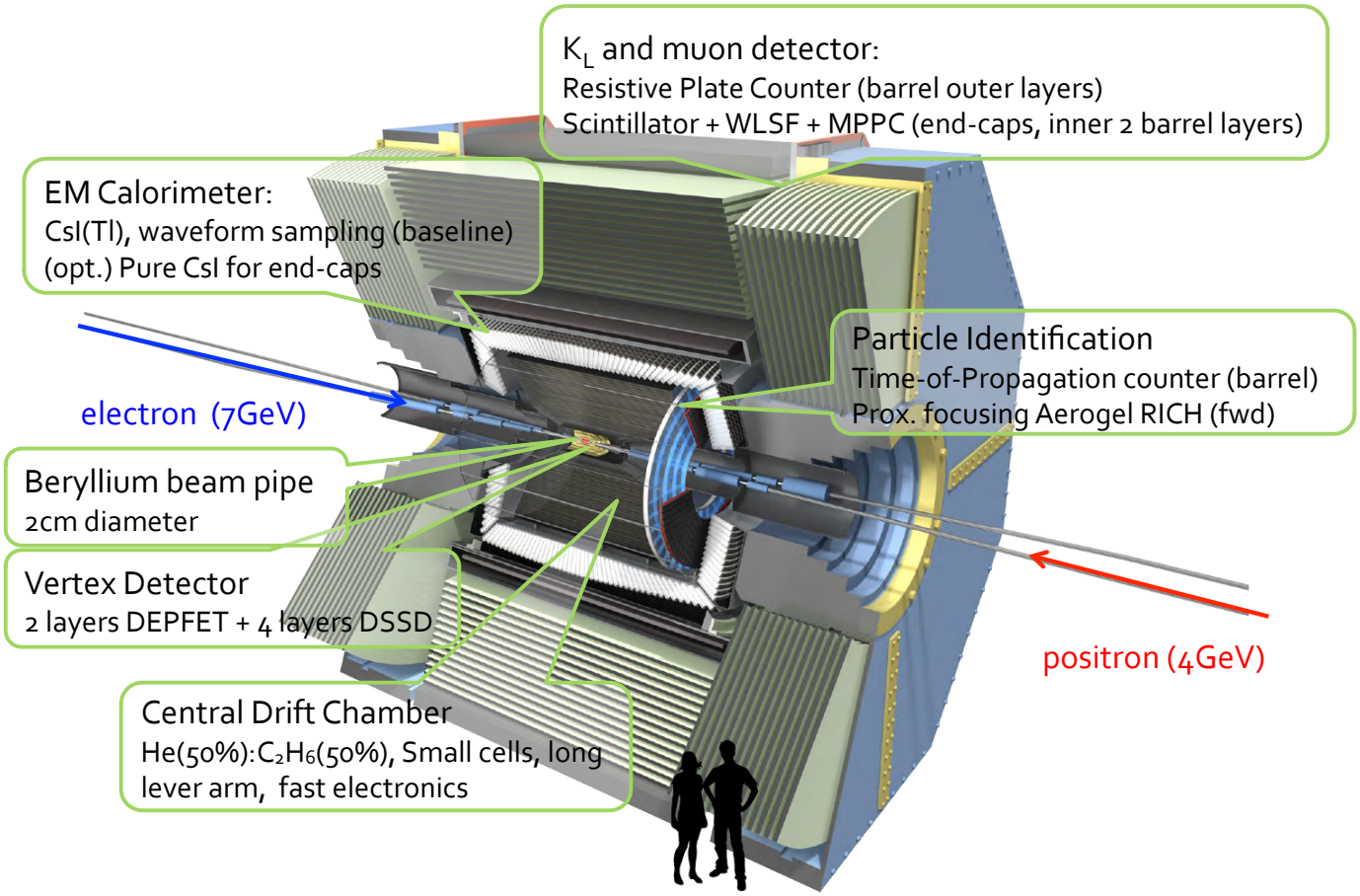
invisible

0.5 GeV single photon trigger will enable dark photon searches up to 10 GeV/c²



- High priority analyses with strong Canadian component.
  - competitive with small datasets.

The Belle II detector



- Reusing solenoid, iron, part of muon system, calorimeter crystals. Remainder optimized for rates and high backgrounds

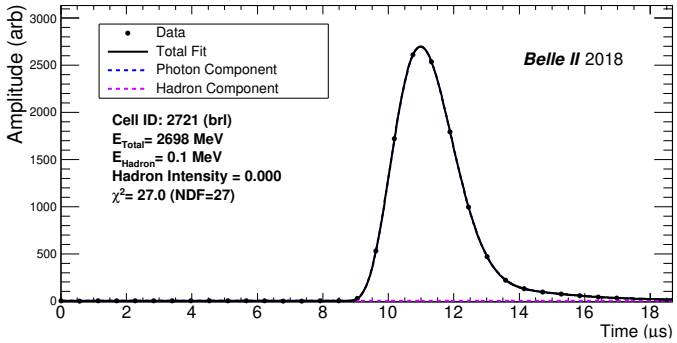
Canadian calorimeter activities

- Canada joined after the major hardware construction was well under way. We have taken on significant software and operational responsibilities for the calorimeter.
  - Reconstruction code, simulation, conceptual design of calibration system, particle identification.
  - Calibration operations; software validation; shifts.

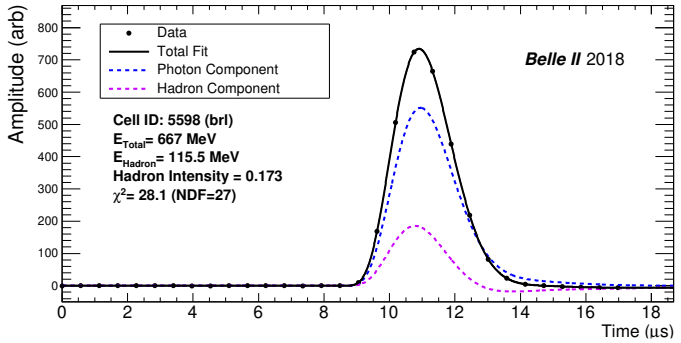
Identifying hadronic interactions using pulse shape discrimination

- Graduate student Savino Longo developed techniques to distinguish hadrons from photons based on the difference in pulse shape from the heavily ionizing component.
  - first application in collider environment.

photon pulse shape



hadron pulse shape

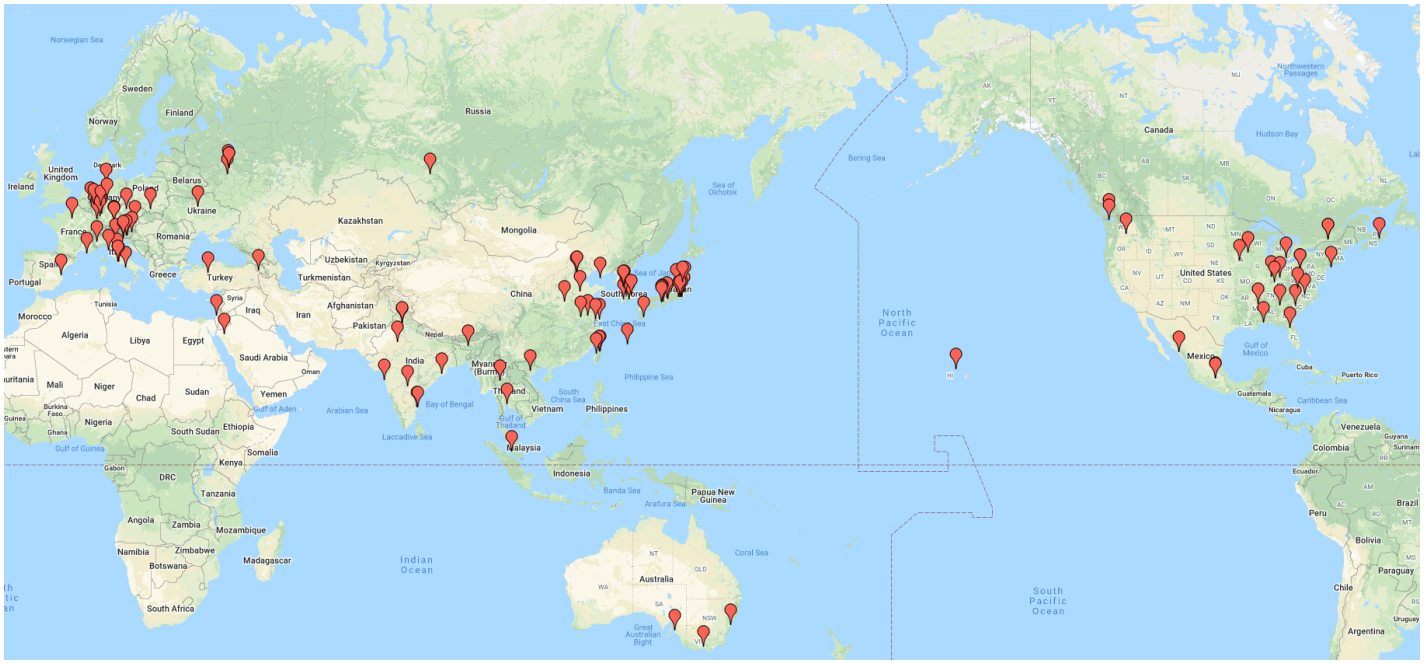


- CAP particle physics division thesis award for 2020.

Belle II collaboration

- 980 members, 117 institutions, 26 countries.
  - 980 = 289 faculty/staff + 149 postdoc/RA + 354 GS + 13 emeritus + 175 tech

  women: 13% 25% 23% 8% 10%
  - 20% Japan, 40% Europe, 20% Asia/Australia, 20% North America



Canadian group

Name	Institution	FTE
Christopher Hearty	UBC	1
Janis McKenna		1
Steven Robertson	McGill	0.5
Andreas Warburton		0.4
Robert Kowalewski	Victoria	0.5
Michael Roney		0.7
Randall Sobie		0.3
Hossein Ahmed	St. Francis Xavier	1
Total FTE		5.4

- 29 group members:
  - 8 Grant eligible [1 woman]
  - 3 postdocs / RA [1]
  - 10 graduate students [3]
  - 8 technical [0]

} 2.5% of PhD physicists

2.8% of graduate students

Funding

- NSERC project grant for operations, with the occasional RTI for in-kind contributions to common fund.

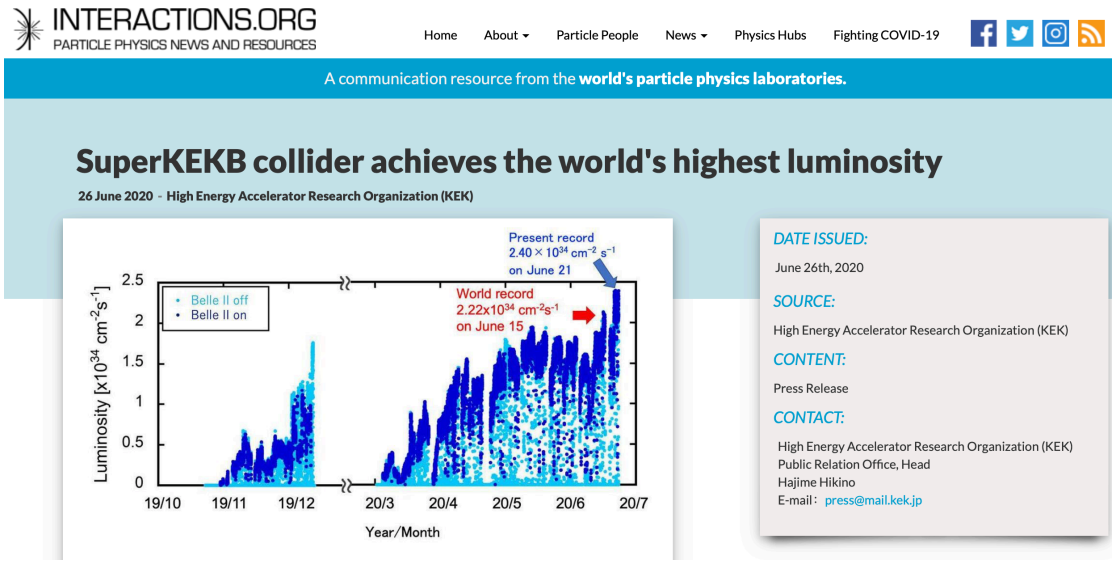
- Do not anticipate contributing to a major detector upgrade.
  - Canadian studies indicate calorimeter will survive with good performance.
  - Chiral Belle proposal for polarized e^- beam would involve hardware for spin rotators and polarimeter.

- CFI proposal (R. Sobie) for a Belle II data center (15% of one copy of the data) is under review.

Status and outlook

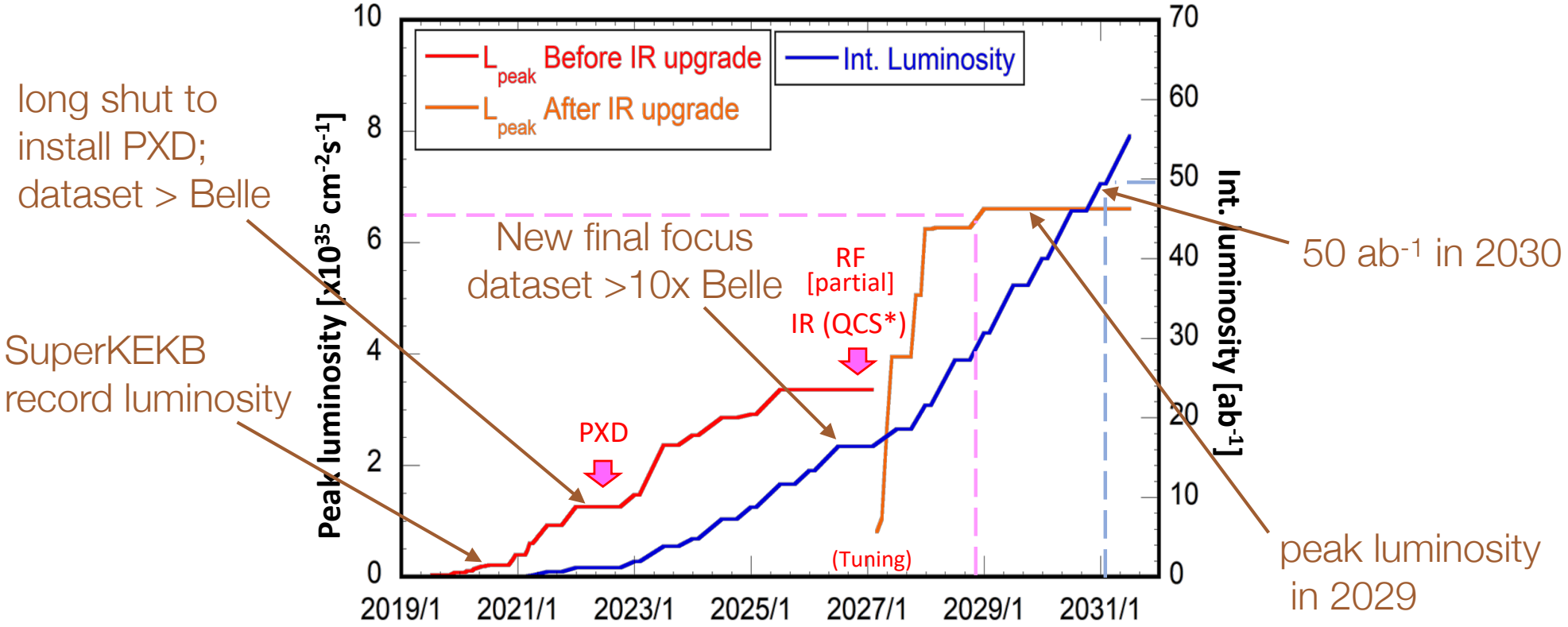
- First colliding beam data with full detector in Spring 2019.

- Focus has been on increasing the instantaneous luminosity, not on integrating data.
  - SuperKEKB set world record in June.



Longer term Belle II run plan

- Run through 2030 to get full data set.
- New 2-layer pixel detector in 2022; new final focus 2026.



New final focus

- KEK is planning a 8-month shut down (+commissioning) to rebuild the SuperKEKB final focus in 2026. Will address the challenges the collider has had in achieving the luminosity targets.
  - Strong beam-beam effects. Thought to be due to interaction of detector solenoid with final focus quadrupoles.
  - Move to smaller beam sizes and lower currents (i.e. lower electricity cost) reflects reality of operating budgets.

- Larger aperture and better shielding to improve backgrounds and operating stability.

- The new final focus and operating plan should enable Belle II to reach its luminosity target, albeit at a significant delay compared to the schedule from the LRP of five years ago.
  - provides a natural break for the possible polarization upgrade.

Equity diversity inclusion

- Code of conduct:

  The Belle II collaboration is committed to fostering an open, diverse, and inclusive working environment that nurtures growth and development of all, and believes that an array of values, interests, experiences, and cultural viewpoints enriches our learning and our workplace. Thus, members shall not engage in violent, harassing, sexist, racist, or discriminatory behaviour.

- Active diversity and inclusion group, headed by two diversity officers.

- Collaboration has focused on improving diversity in leadership positions. Four of the ten physics working groups are currently co-convened by women, compared to one five years ago.

HQP / Broader societal impact

- 24 graduate degrees awarded since 2010.
  - BaBar, SuperB, and Belle II

- Should remain at 10–12 graduate students and 3 postdocs for the foreseeable future.

- See backup for notable examples of HQP career paths.

Backup

A few notable examples

- **Rocky So:** Rocky is data engineer at Softmax Data, a consulting firm, and at delecta Technologies, a start up, both based in Vancouver. In one of his projects, he worked with Technical Safety BC to develop methods to identify abnormalities in elevator operations using internet-connected accelerometers, a project that was beyond the capabilities of the in-house data scientists.
- **David Asgeirsson:** David's career has included being the Chief Operating Officer of QD Solar, a start up developing new solar energy technology, and the Director of Business Development for physical sciences at TRIUMF. He is currently the president of Runewheel Management Services, a technology venture consulting firm specializing in academic spinoffs.
- **Alexandre Beaulieu:** Alex's undergraduate training as an engineer, combined with his PhD in particle physics, has led him into career in an engineering consulting firm. He is the Regional Director of LTI Software + Engineering in Montreal, with a focus on helping manufacturers improve productivity through the application of science and technology.
- **Torben Ferber:** Torben was a postdoc at UBC on Belle II prior to the start of data taking. He was the head of the event generators group, and co-convenor of the low-multiplicity physics working group. This group includes high priority topics such as searches for Dark Photons and other Dark Sector physics. He wrote the corresponding chapter of the Belle II physics book. As part of the Canadian contribution to the calorimeter, he took on a complete rewrite of the reconstruction code, and was head of the calorimeter software group. He is now a Helmholtz Young Investigators Group Leader at DESY and the University of Hamburg.
- **Savino Longo**: As a graduate student at the University of Victoria, Savino recognized that the CsI(Tl) crystals that made up the Belle II calorimeter could also be used to distinguish hadronic from electromagnetic showers on the basis of the time structure of the deposited energy. He demonstrated the concept first in simulation, then undertook a beam test at TRIUMF to demonstrate it experimentally. He proposed changes to the calorimeter electronics readout to get access to the required waveforms in real data, and developed the software tools to make the method available to the full collaboration. For this work, Savino was awarded the 2020 Thesis Award by the Particle Physics Division of the CAP. He is now a postdoctoral fellow at DESY.