The Belle II Experiment

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Belle II

Belle II is a high luminosity B Factory experiment at the KEK laboratory

- Target data set of 30 times the combined integrated luminosity of BABAR and Belle
- 620 collaborators from 100 institutions, including 220 graduate students; ~25% Japanese

KEKB accelerator substantially modified to provide beams for Belle II at up to $8 \times 10^{35}$ cm$^{-2}$s$^{-1}$ luminosity

- $e^- : 2.6A \ @ \ 7 \ GeV$
- $e^+ : 3.6A \ @ \ 4 \ GeV$ (currents 2x Belle)

- low-emittance “nano-beam” design exploiting ILC and light-source technologies
Belle II

Very substantial “upgrades” to the original Belle detector:

- Replacement of beam pipe and redesign of entire inner detector (including vertex and drift chambers)
- New quartz-bar Time-of-Propagation PID in barrel region
- Retain existing CsI(Tl) calorimeter crystals, but front-end electronics, feature extraction and reconstruction software entirely new
- Entirely new software framework and distributed computing environment

For all intents and purposes, an entirely new experiment
Belle II physics program

Heavy flavour provides an ideal testing ground for precision probes of physics beyond the Standard Model

- Precision measurements across a large variety of independent decay channels provide stringent tests of the underlying physics, e.g. BABAR/Belle constraints on the CKM “unitarity triangle”: 

\[
\begin{align*}
B & \rightarrow \psi K_S \\
B & \rightarrow \phi K_S \\
B^0 \rightarrow \pi^+\pi^- \\
B^0 \rightarrow \rho^+\rho^- \\
b & \rightarrow ulv \\
b & \rightarrow clv \\
B^0 \rightarrow D^+\pi \\
B^+ \rightarrow D_{CP}^0 K^* \\
B^0 \rightarrow \pi^+\pi^- \\
\end{align*}
\]
Belle II physics program

Very large, clean data samples of B and charm mesons, tau leptons and other \( e^+e^- \) interaction products can be used to search for evidence of new particles or interactions in virtual loops

- Many observables sensitive to new physics: branching fractions, CP asymmetries, kinematic distributions, angular observables and asymmetries

Hadronic decays:

- SM
- \( B^0 \) \( d \rightleftharpoons s \)
- \( K^0 \) \( u,d \)

Electroweak FCNCs:

- SM
- \( t \rightarrow s \gamma \)

Rare/forbidden decays:

- SUSY
- Charged Higgs
- Precision measurements of one-loop processes can probe new physics mass scales which far exceed direct searches
Commissioning in three phases:

- Phase 1 commissioning began in early 2016, with first turns achieved in February
  - “BEAST2” commissioning detector
- Physics running with full detector beginning in 2018

Luminosity to $\sim 8 \times 10^{35}$ by 2020 with ultimate target of 50 ab$^{-1}$ recorded.
Canadian participation

Canadian group joined the Belle II experiment in 2013, mostly bridging effort from previous BABAR group:

- 10 grant-eligibles (~6FTEs) at 4 universities, 2 postdocs; 9 grad students
  
  **UBC:**
  C. Hearty, J. McKenna, T. Mattison, T. Ferber (Postdoc), A. Hershenhorn (PhD)

  **UVic:**
  M. Roney, R. Kowalewski, R. Sobie, A. Sibidanov (postdoc),
  A. Beaulieu (PhD), S. de Jong (PhD), S. Longo (PhD)

  **McGill:**
  S. Robertson, A. Warburton, R. Seddon (PhD), A. Fodor (MSc),
  H. Pikhartova (MSc), W. Ahmed (MSc)

  **UdeM:**
  J.P. Martin, P. Taras, S. Lagrange (MSc)

- Six Canadian students have already completed graduate degrees supported by the Belle II project grant
  
  - Includes Belle II detector hardware studies, and BABAR physics analyses

- Extensive work in previous years to study calorimeter performance in the context of a possible upgrade of the endcap calorimeters to pure CsI
Beam background studies

High beam currents, bunch densities and luminosity imply potential for high detector occupancies and radiation doses from beam backgrounds

• Important to understand background environment prior to physics data taking

Simulation studies of background sources used to understand detector impacts, and to study potential for remediation and monitoring

• Several Canadian students participating
Phase 1 commissioning

Initial accelerator commissioning performed without Belle II detector (and final focus magnets) present

- “BEAST2” commissioning detector positioned at nominal IP to evaluate beam backgrounds representative of various Belle II subsystems
  - PIN diodes, diamond detectors, Micro-TPCs, $^3$He tubes, BGO, scintillating crystals (CsI, CsI(Tl) and LYSO) and “CLAWS” silicon detectors

- Direct participation in installation, commissioning, data taking and analysis by several Canadian students
Background measurements

Canadian groups are responsible for $^{3}$He detectors, and for aspects of scintillating crystal detectors

- Commercial $^{3}$He detectors to characterize (difficult to simulate) thermal neutrons, which cause aging of ECL photodiodes and other detector components (de Jong – UVic)

- Scintillating crystals used to measure background photon energy spectrum and injection backgrounds (Beaulieu - UVic)

Hit rate in LYSO vs beam current and vacuum pressure

Dedicated experiments with specific beam conditions used to characterize background environment
Shielding

- Simulation studies suggest that high calorimeter background rates can be reduced by addition of lead/HDPE shield between the endcaps and beam line
  - Optimization and mechanical design by A. Beaulieu (UVic)
  - Will be installed along with calorimeter endcaps for phase 2 commissioning and remain for life of experiment

- To be fabricated in Canada and shipped to KEK as a hardware contribution to Belle II; design completed, tendering in process
Beam background monitors

- Fast background monitors needed to measure “trickle injection” backgrounds from lost beam particles as individual bunches are topped up during live data-taking
  - Provide fast feedback directly to SuperKEKB control room for accelerator tuning
  - Distribution around beam axis can be used to disentangle various beam background sources

- 2016 Belle II RTI request (led by A. Warburton, McGill) to fund hardware for 8 crystal-based beam background monitors
  - Recesses built into the shield HDPE can be used to house scintillating crystals
  - Collaboration with UdeM for electronics design and testing
  - Studies of timing resolution of LYSO and pure CsI crystals in progress; benefit from BEAST crystal work
  - McGill students also collaborating with NWU (Japan) and KEK personnel on a related fast-scintillator background monitor for inner tracking detectors
Software development

Canadian group has major responsibilities for calorimeter software development (ongoing, for life of experiment)

- Both current postdocs (Ferber, Sibidanov) contributing; Ferber currently heads software group.
- New hypothesis-based clustering algorithm under development
- Responsibility for GEANT4 calorimeter model

C. Hearty responsible for calorimeter calibration

- Single crystal calibration under development, based on $e^+e^-\rightarrow\gamma\gamma$
- Detailed MC/data comparisons beginning with first cosmics running in 2017

S. Robertson responsible for overall GEANT4 material model validation

- W. Ahmed (MSc) working on pre-datataking studies
Computing

Belle II computing requirements ultimately will be similar to current ATLAS usage

- UVic and McGill currently providing grid/cloud-based resources
- R. Sobie leading Canadian computing effort, with substantial contributions to cloud development
Preparations for physics

Physics data taking to begin in late-2018 at a target luminosity of \( \approx 1 \times 10^{34} \); comparable to BABAR and Belle at end of their programs

- Will take some time to accumulate competitive \( Y(4S) \) data sample, but many opportunities in non-(4S) physics due to improvements in detector, trigger etc.

Canadian focus on low multiplicity physics

- Extensive BABAR experience in \( \tau/\text{QED} \), narrow-\( Y \), light Higgs and dark matter/forces physics, some of which is potentially accessible with relatively small data samples (Ferber co-covenes low multiplicity physics group)
- Development of event generators (Ferber convenes generator group)
- Development of low-multiplicity (L1) trigger menu (Hearty & Ferber)

Optimization of B counting and luminosity selection (Seddon)

- Needed for absolute branching fraction measurements from the beginning of data taking
Science Minister Visit

Minister of Science Kirsty Duncan visit to KEK May 15, 2016

- Visit attended by Mike Roney and three Canadian Belle II students (A Beaulieu, S. De Jong and R. Seddon)
- Tour of Belle II experimental area led by UVic PhD student Alex Beaulieu

Left to Right: Minister Kirsty Duncan, Y. Ushiroda (KEK), H. Koiso (KEK), T. Browder (Belle II Spokesperson, U Hawaii), M. Roney (UVic), A. Beaulieu (UVic Phd student),
Grant requests

Two Belle II grants in front of SAPES this year:

- Project grant
- RTI for hardware for beam background monitors ($60k)

2015 funding:

- at level of ~$70k/FTE, including 2 supported postdocs and 10 graduate students

2016 project grant request:

- Request was at level of ~100k/FTE for ~6FTE grant eligibles, increasing to ~150k/FTE in third year (i.e. start of nominal physics program)
- Award is ~15% cut relative to 2015, ~$55k/FTE, returning to ~2015 level in subsequent years:

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
<th>Percentage</th>
<th>Note</th>
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<tbody>
<tr>
<td>2015</td>
<td>$394,000</td>
<td></td>
<td>RTI funding</td>
</tr>
<tr>
<td>2016</td>
<td>$342,000</td>
<td>(55%)</td>
<td>RTI funding $60k</td>
</tr>
<tr>
<td>2017</td>
<td>$399,000</td>
<td>(54%)</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>$413,300</td>
<td>(48%)</td>
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- RTI was (essentially) fully funded
Implications and plans

• Current year (FY2016) funding insufficient to support existing (2) postdocs and students, plus common-fund contribution, even if all travel and other operations zeroed-out
  - By delaying 2016 common-fund payment to next year, can pay existing personnel and free up some limited operating money for current year
  - Very little travel money; limited Canadian presence at KEK during Belle II commissioning and first data taking
  - Beam background monitor RTI fully supported, but no project support for installation, commissioning and operations

• Negative impact on HQP and faculty participation
  - Qualified students turned away at UVic this year in spite of available supervisor
  - One existing McGill student will not be continued next year; no new students for duration of grant
  - Requested 3rd postdoc (McGill) and computing professional (UVic) not funded; budget barely supports existing two postdocs