INSTITUTE OF PARTICLE PHYSICS

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Belle II input to the IPP long-range-planning brief

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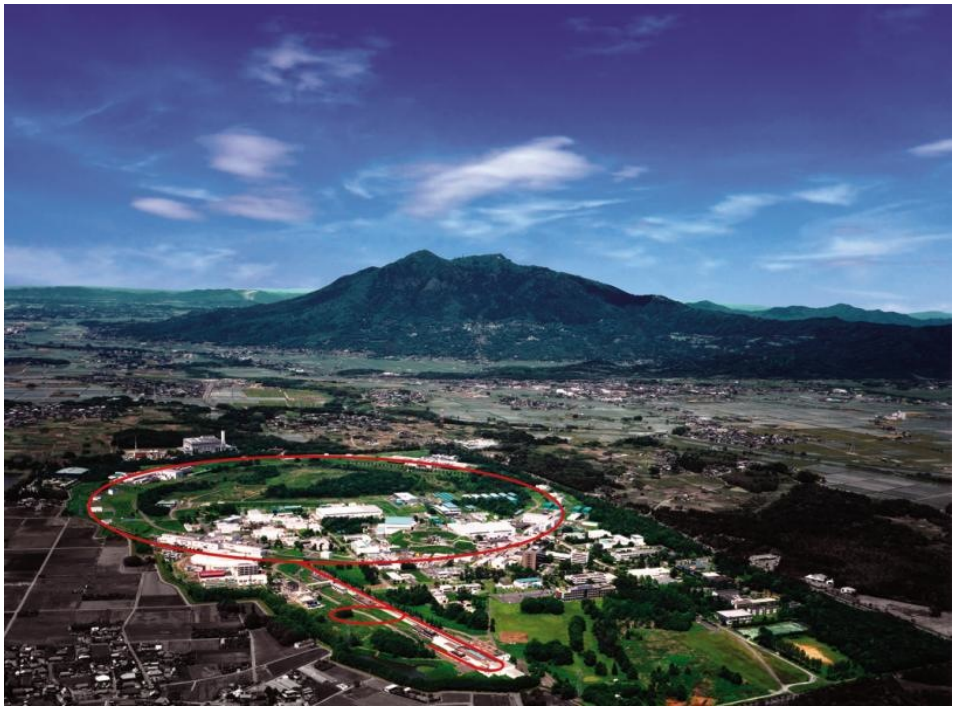
On behalf of the Canadian Belle II group

Belle II

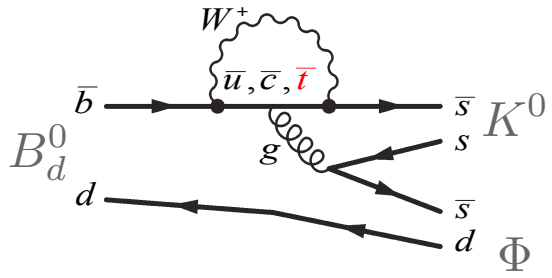
- Upgrade of Belle, located at the SuperKEKB e^+e^- collider in Tsukuba Japan.

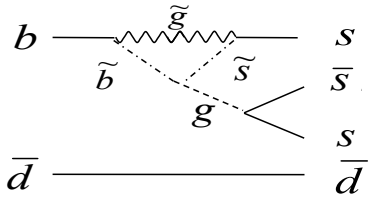
- 40x the peak luminosity of KEKB; 30x the combined integrated luminosity of BaBar + Belle.



Physics goals

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

- If new physics is found at the LHC, Belle II observations will help explain it. If not, Belle II can still observe deviations from the SM — mass reach can exceed LHC direct production.

- Continued exploration of the weak force and CP violation.

Predicted uncertainties on a selection of proposed Belle II measurements

Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	$\mathcal{L}_s$ [ab^{-1}]
$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$	± 0.012	± 0.008	6
α		$\pm 2^\circ$	$\pm 1^\circ$	
γ	$\pm 14^\circ$	$\pm 6^\circ$	$\pm 1.5^\circ$	
$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	± 0.053	± 0.018	>50
$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	± 0.028	± 0.011	>50
$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	± 0.100	± 0.033	44
$\lvert V_{cb}\rvert$ incl.	$\pm 2.4\%$	$\pm 1.0\%$		< 1
$\lvert V_{cb}\rvert$ excl.	$\pm 3.6\%$	$\pm 1.8\%$	$\pm 1.4\%$	< 1
$\lvert V_{ub}\rvert$ incl.	$\pm 6.5\%$	$\pm 3.4\%$	$\pm 3.0\%$	2
$\lvert V_{ub}\rvert$ excl. (had. tag.)	$\pm 10.8\%$	$\pm 4.7\%$	$\pm 2.4\%$	20
$\lvert V_{ub}\rvert$ excl. (untag.)	$\pm 9.4\%$	$\pm 4.2\%$	$\pm 2.2\%$	3
$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	96 ± 26	$\pm 10\%$	$\pm 5\%$	46
$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7	5σ	$>> 5\sigma$	>50
$R(B \to D\tau\nu)$	$\pm 16.5\%$	$\pm 5.6\%$	$\pm 3.4\%$	4
$R(B \to D^*\tau\nu)$	$\pm 9.0\%$	$\pm 3.2\%$	$\pm 2.1\%$	3
$\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ [10^{-6}]	< 40		$\pm 30\%$	>50
$\mathcal{B}(B \to K^{+}\nu\overline{\nu})$ [10^{-6}]	< 55		$\pm 30\%$	>50
$\mathcal{B}(B \to X_s\gamma)$ [10^{-6}]	$\pm 13\%$	$\pm 7\%$	$\pm 6\%$	< 1
$A_{CP}(B \to X_s\gamma)$		± 0.01	± 0.005	8
$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	± 0.11	± 0.035	> 50
$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	± 0.23	± 0.07	> 50
C_7/C_9 $(B \to X_s\ell\ell)$	$\sim 20\%$	10%	5%	
$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	± 0.3		
$\mathcal{B}(B_s \to \tau^+\tau^-)$ [10^{-3}]		< 2		

Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	$\mathcal{L}_s$ [ab^{-1}]
$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \times 10^{-3}(1 \pm 0.053 \pm 0.038)$	$\pm 2.9\%$	$\pm$(0.9%-1.3%)	> 50
$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \times 10^{-3}(1 \pm 0.037 \pm 0.054)$	$\pm$(3.5%-4.3%)	$\pm$(2.3%-3.6%)	3-5
y_{CP} [10^{-2}]	$1.11 \pm 0.22 \pm 0.11$	$\pm$(0.11-0.13)	$\pm$(0.05-0.08)	5-8
A_Γ [10^{-2}]	$-0.03 \pm 0.20 \pm 0.08$	± 0.10	$\pm$(0.03-0.05)	7 - 9
$A_{CP}^{K^+K^-}$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$	± 0.11	± 0.06	15
$A_{CP}^{\pi^+\pi^-}$ [10^{-2}]	$0.55 \pm 0.36 \pm 0.09$	± 0.17	$\pm$ 0.06	> 50
$A_{CP}^{\phi\gamma}$ [10^{-2}]	$\pm$ 5.6	± 2.5	± 0.8	> 50
$x^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	± 0.14	± 0.11	3
$y^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	± 0.08	± 0.05	15
$\lvert q/p\rvert^{K_S\pi^+\pi^-}$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	± 0.10	± 0.07	5-6
$\phi^{K_S\pi^+\pi^-}$ [$^\circ$]	$-6 \pm 11 \pm {}^{4}_{5}$	± 6	± 4	10
$A_{CP}^{\pi^0\pi^0}$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	± 0.29	± 0.09	> 50
$A_{CP}^{K^0_S\pi^0}$ [10^{-2}]	$-0.10 \pm 0.16 \pm 0.09$	± 0.08	± 0.03	> 50
$Br(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5	$\pm 30\%$	$\pm 25\%$	2
	$\tau \to \mu\gamma$ [10^{-9}]	< 45	< 14.7	< 4.7
	$\tau \to e\gamma$ [10^{-9}]	< 120	< 39	< 12
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0	< 3.0	< 0.3

- A pattern of deviations from the SM could elucidate the nature of the new physics.

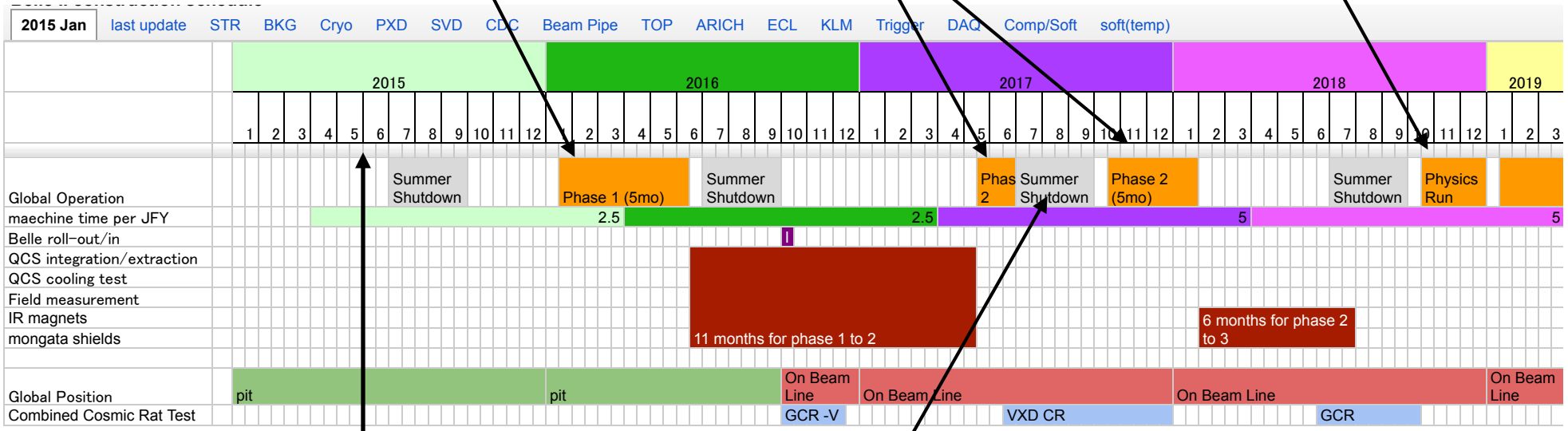
luminosity at which stat err = sys err

Super KEKB schedule, now through 2018

phase 1 (without Belle II) in <1 year

phase 2 is Belle II without vertex detectors

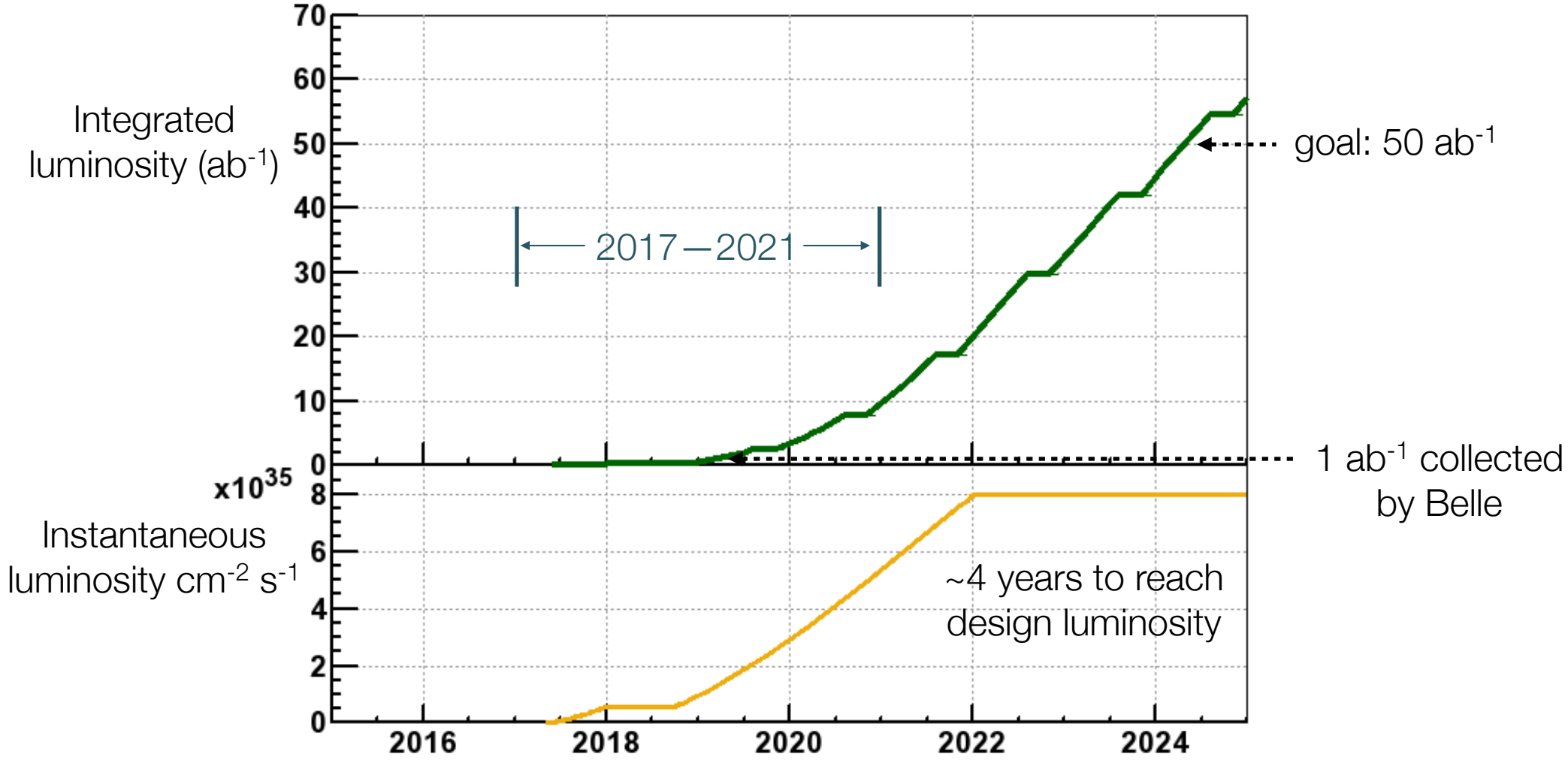
phase 3 has full Belle II detector



now

no summer operations (power)

Longer term schedule



- Time period will include commissioning and accumulation of a data set ~10× Belle.

Status of Belle II detector

- Magnet, calorimeter crystals, part of muon system are reused. Tracking and particle ID are new.

- Construction of TOP Cherenkov radiation particle identification system has been challenging.

- Full detector will be completed and assembled for integrated cosmic ray testing in Fall 2016 (off beam line).

Canadian Belle II group

- Ten faculty at four universities. Currently 5.6 FTE; expect this to ramp up slightly. BaBar was 7 FTE at its peak.

- One postdoc; 2nd one starting Oct 1. Project four postdocs by 2017; five by 2019.

- Eleven graduate students (6 MSc, 5 PhD). Project an increase to 14 by 2021.
  - more PhD than MSc by 2021;
  - average ~2 graduates per year.
  - some current students are doing BaBar analysis in conjunction with Belle II hardware projects. Belle II activities are discussed on following pages.

Faculty FTE on Belle II in fiscal year 2015

UBC	Christopher Hearty	0.90
	Tomas Mattison	0.50
	Janis McKenna	0.80
Victoria	Robert Kowalewski	0.15
	J. Michael Roney	0.80
	Randall Sobie	0.25
Montreal	Jean-Pierre Martin	0.40
	Paul Taras	1.00
McGill	Steven Robertson	0.50
	Andreas Warburton	0.25
TOTAL		5.6

Canadian Belle II activities

- Canada is associated with the calorimeter group, an area that needed manpower when we joined Belle II. Also possible upgrade from CsI(Tl) to pure CsI.

- Two major calorimeter software/operations responsibilities: calibration and simulation. Calibration in particular will be an on-going multi-person effort.

- Non-ECL software/operations responsibility: determining and comparing the distribution of detector material in simulation and reality.
  - critical for precision, systematics-limited measurements

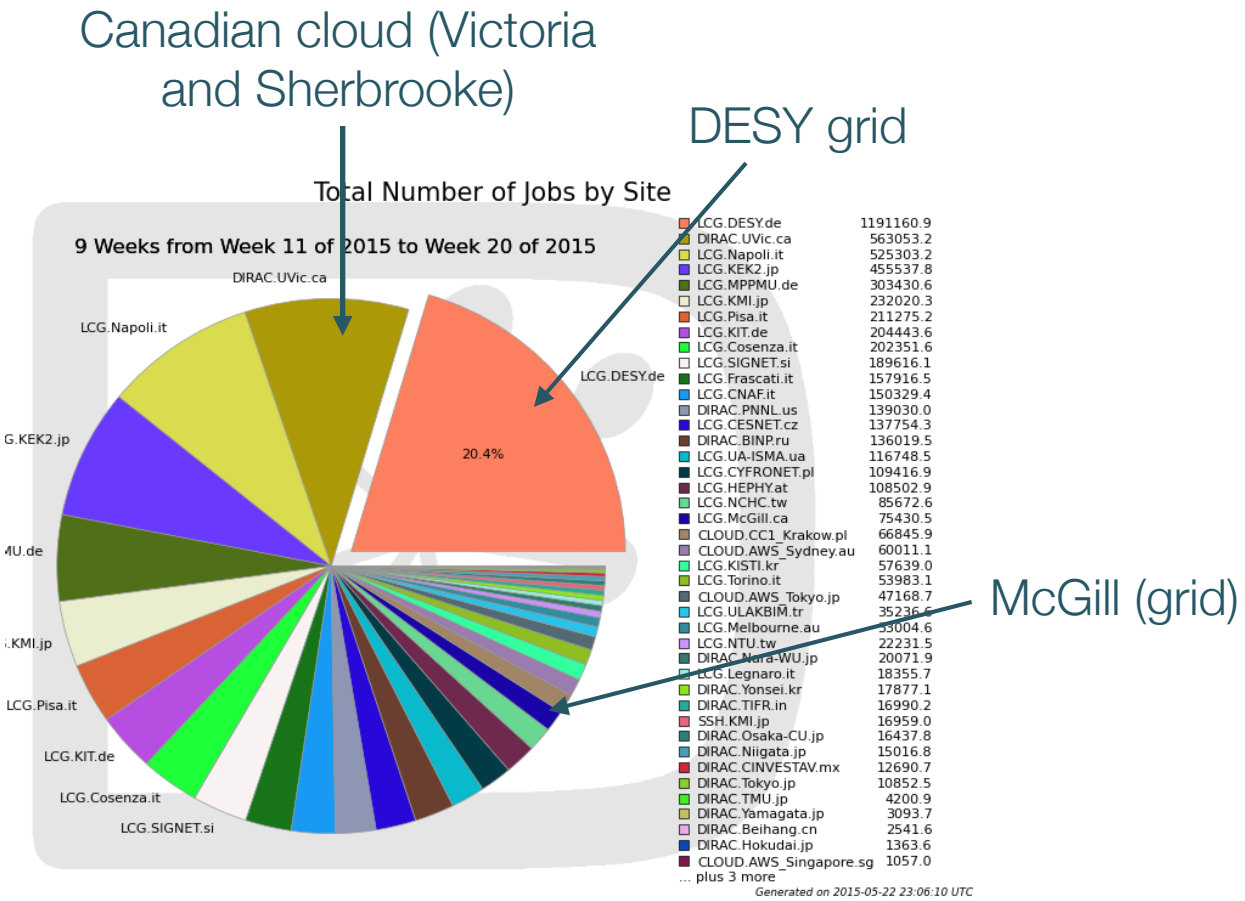
- Projects to monitor beam background during commissioning (BEAST) and operations (ECL analog real-time background monitoring; thermal neutron detectors) installed by 2017 $\Longrightarrow$ operations & analysis of data.

- Students, faculty, and postdocs are preparing for physics analysis.

- A variety of projects related to the possible upgrade to pure CsI: electronics development (Montreal); photosensor studies; crystal radiation damage; beam test. Currently, it appears that we will not propose a significant hardware project. If so, this set of projects will be essentially completed by 2017.

    - Significant amount of work in this area; see Mike Roney's talk on Thursday for details.

- Randy Sobie is leading the Canadian computing contribution. Focus is on cloud computing. Second largest MC production site so far in 2015. Will expand to include analysis.
  - large number of undergraduate projects.



Answers to specific requests for information

1. Physics

- See slides 3—4
- Examples of areas of Canadian interest include:
  - direct searches for new physics particles (including during Phase 2 commissioning)
  - rare B decays using fully-reconstructed B samples
  - V_{ub}
  - charged lepton flavor violation

2. HQP: numbers and roles

- See slides 8—11

- Typically 12—14 graduate students at any one time, 2017—2021. ~2 graduates per year.

- Expect 4 postdocs 2017, increasing to 5 by 2019.

3. Equipment needs

- We currently have no plans to request funds for a major detector project.

4. Computing requirements

- CPU: We need to make 5.8 kHepSPEC available to the collaboration in 2017, increasing to 20.0 by 2021.
- Disk space: Make 170 TB available in 2017 → 1390 TB by 2021
- Assumes 1 copy of data at KEK, 1 outside of KEK. Reprocessing of raw data starting in 2021. Our fraction is based on size of Canadian group.
- We are assuming a Compute Canada allocation for the disk space and most of the CPU.

- Table shows the total amount of resources to be made available in that year, not the additional amount of resources to be acquired in that year.

Site or Tier 1 fraction	Canada	This can be a site name as given on the Sites sheet or a numbe
Data faction		If this is empty the data fraction will be equal to the number given on the Sites sheet or 0 for numberical Tie
Used Tier 1 facrion	0.03	*The fraction of MC production and user analysis done at the site*
Used data fraction	0.10	*The fraction of mDST data stored at the site*

Regional Center resources

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Tape (raw data) [PB]	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.94**	**4.38**	**6.91**	**9.45**
Disk (data) [PB]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.35	0.52	0.95	1.40	1.85
Disk (MC) [PB]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.52	0.65	1.02	1.42	1.81
Disk (analysis) [PB]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.23	0.41	0.61	0.81
Disk (challenges) [PB]	0.00	0.03	0.06	0.12	0.15	0.17	0.20	0.23	0.00	0.00	0.00	0.00	0.00
Disk [PB]	**0.00**	**0.03**	**0.06**	**0.12**	**0.15**	**0.17**	**0.21**	**0.47**	**0.94**	**1.39**	**2.39**	**3.43**	**4.47**
CPU (raw pro) [kHepSPEC]	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**4.42**	**5.56**	**5.78**	**5.81**
CPU (raw repro) [kHepSPEC]	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**5.07**	**11.44**	**18.06**	**24.71**
CPU (MC) [kHepSPEC]	0.00	0.00	0.00	0.00	0.00	0.00	0.09	4.53	7.79	8.06	11.50	14.23	16.80
CPU (an.) [kHepSPEC]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.81	2.41	4.43	6.53	8.64
CPU (ch.) [kHepSPEC]	0.00	1.83	3.87	3.87	4.84	5.81	6.78	4.12	0.00	0.00	0.00	0.00	0.00
CPU [kHepSPEC]	**0.00**	**1.83**	**3.87**	**3.87**	**4.84**	**5.81**	**6.87**	**8.76**	**8.60**	**19.97**	**32.95**	**44.60**	**55.96**
CPU [# of cores 14.72HS/core]	**0.00**	**124.26**	**263.14**	**263.14**	**328.93**	**394.71**	**467.04**	**595.43**	**583.91**	**1,356.51**	**2,238.15**	**3,029.66**	**3,801.95**
WAN (raw) [Gbit/s] (inward)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	1.47	1.53	1.54
WAN (data) [Gbit/s] (inward)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.10	0.13	0.19	0.24	0.28
WAN (MC) [Gbit/s] (outward)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.04	0.06	0.08	0.09
WAN (MC) [Gbit/s] (inward)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.13	0.09	0.12	0.15	0.18
WAN (ch.) [Gbit/s](in/out)	0.00	0.05	0.09	0.09	0.19	0.19	0.14	0.14	0.00	0.00	0.00	0.00	0.00
WAN [Gbit/s] (outward)	**0.00**	**0.05**	**0.09**	**0.09**	**0.19**	**0.19**	**0.14**	**0.17**	**0.06**	**0.04**	**0.06**	**0.08**	**0.09**
WAN [Gbit/s] (inward)	**0.00**	**0.05**	**0.09**	**0.09**	**0.19**	**0.19**	**0.14**	**0.22**	**0.23**	**1.39**	**1.79**	**1.92**	**2.00**

5. Technical support from TRIUMF, SNOLAB, MRS

- Nothing significant

6. Relationships with other Canadian projects

- By 2017, there will be only a minor overlap with BaBar.
- Faculty whose research time is not 100% Belle II generally spend the remainder on ATLAS.

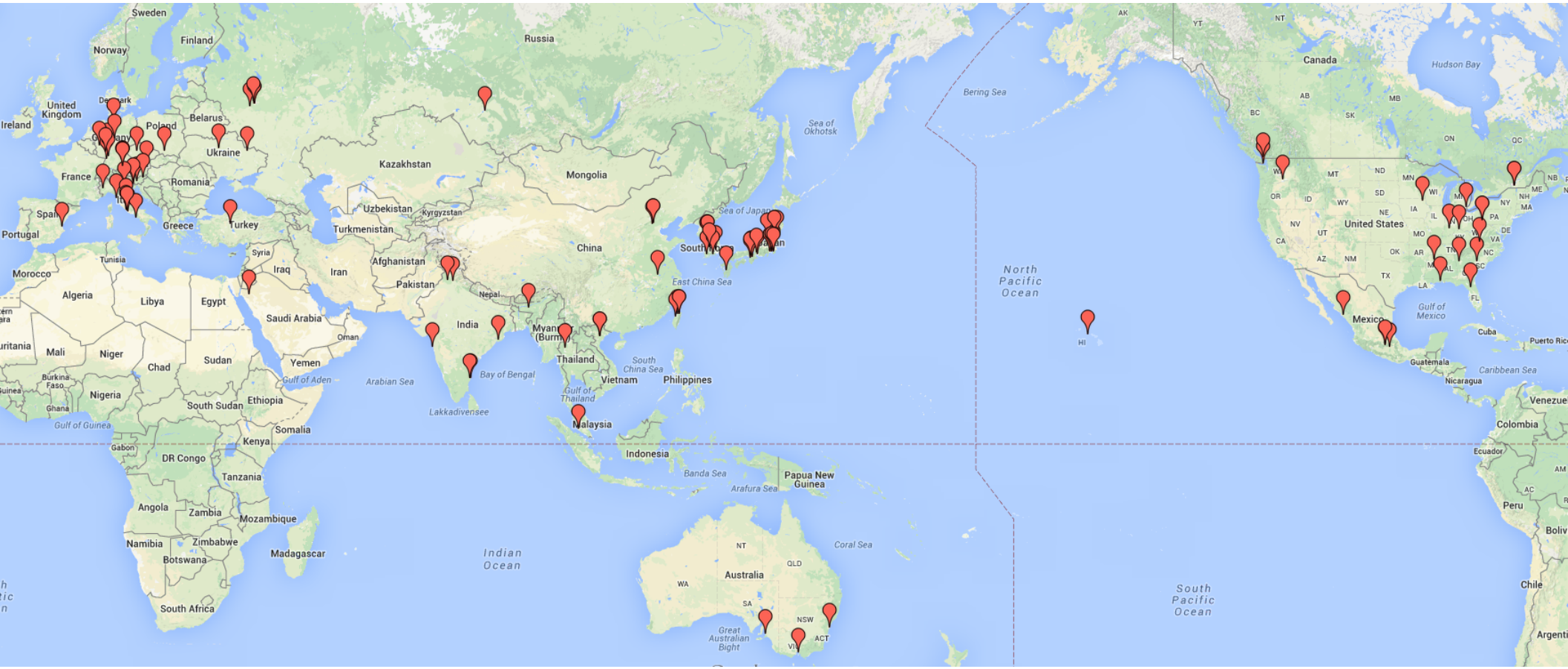
7. Relationships with international partners

- Belle II: 600 collaborators from 23 countries, including 360 PhD physicists and 170 graduate students.

- Canadian fractions:

  collaborators: 3.7%
  PhD physicists: 2.8%
  graduate students: 6.0%

- Within the calorimeter group, we collaborate with Russian, Japanese, Korean, and Italian groups.


Sweden
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Norway
Russia
United Kingdom
Ireland
Belarus
Poland
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France
Romania
Spain
Portugal
Greece
Turkey
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Mongolia
Uzbekistan
Kyrgyzstan
Turkmenistan
China
Syria
Iraq
Iran
Afghanistan
Pakistan
Nepal
India
Tunisia
Morocco
Algeria
Libya
Egypt
Saudi Arabia
Oman
Yemen
Mali
Niger
Chad
Sudan
Burkina Faso
Nigeria
Ghana
Ethiopia
South Sudan
Gulf of Aden
Arabian Sea
Bay of Bengal
Lakkadivensee
Gulf of Guinea
Somalia
Kenya
Gabon
DR Congo
Tanzania
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
South Africa
Indian Ocean
Myanmar (Burma)
Thailand
Vietnam
Philippines
South China Sea
Gulf of Thailand
Malaysia
Indonesia
Banda Sea
Arafura Sea
Papua New Guinea
Australia
NT
QLD
WA
SA
NSW
ACT
VIC
Great Australian Bight
Coral Sea
Sea of Okhotsk
Sea of Japan
East China Sea
Bering Sea
North Pacific Ocean
South Pacific Ocean
Canada
AK
YT
NT
BC
AB
SK
MB
ON
QC
Hudson Bay
United States
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Cuba
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Colombia
Ecuador
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Chile
Venezuela
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