Belle II

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IPP AGM
Laurentian University
June 15, 2014

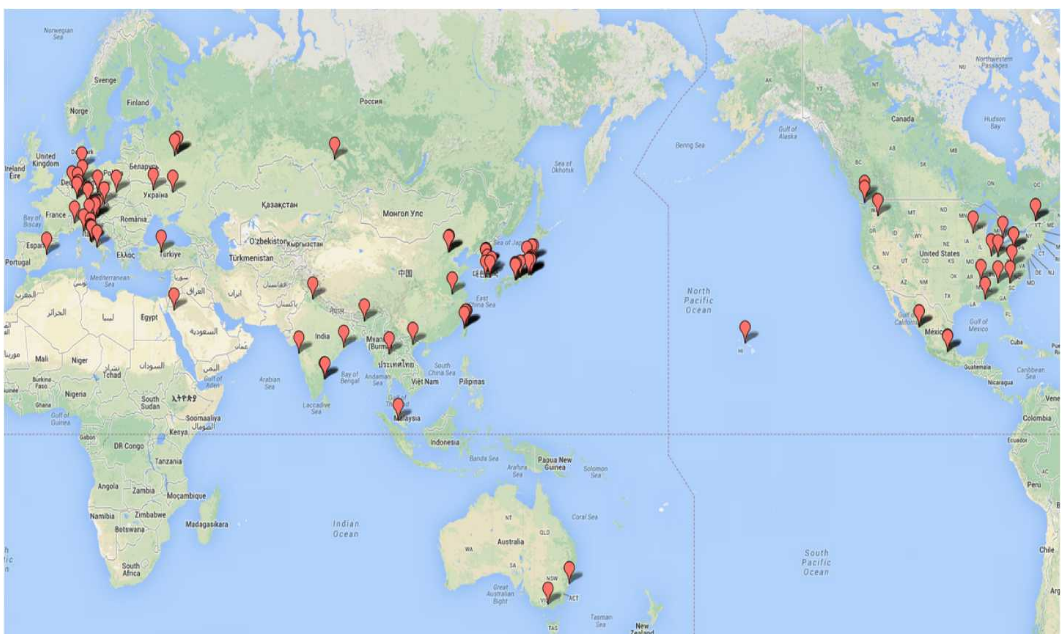
INSTITUTE OF PARTICLE PHYSICS

McGill

Belle II

The Belle II experiment is a upgrade of the Belle at the KEK laboratory

- Target data set of 30x the combined integrated luminosity of BABAR + Belle
- Currently 600 collaborators from 97 institutions in 23 countries



KEKB accelerator substantially modified to provide beams for Belle II at up to $8x10^{35}$ $cm^{-2}s^{-1}$ luminosity

- 2.6A of e^- @ 7 GeV and 3.6A of e^+ @ 4 GeV (currents 2x Belle)
- low-emittance ("nano-beam") design exploiting ILC and light-source technologies

Canadian involvement

Canadian groups joined Belle II in March 2013, following demise of Italian SuperB project

Participants:

U. British Columbia: C. Hearty, J. McKenna, T. Mattison, D. Fujimoto, (Chelsea Dunning)

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, (A. Kollek)

U. Montreal: J.P. Martin, P. Taras, N. Starinski

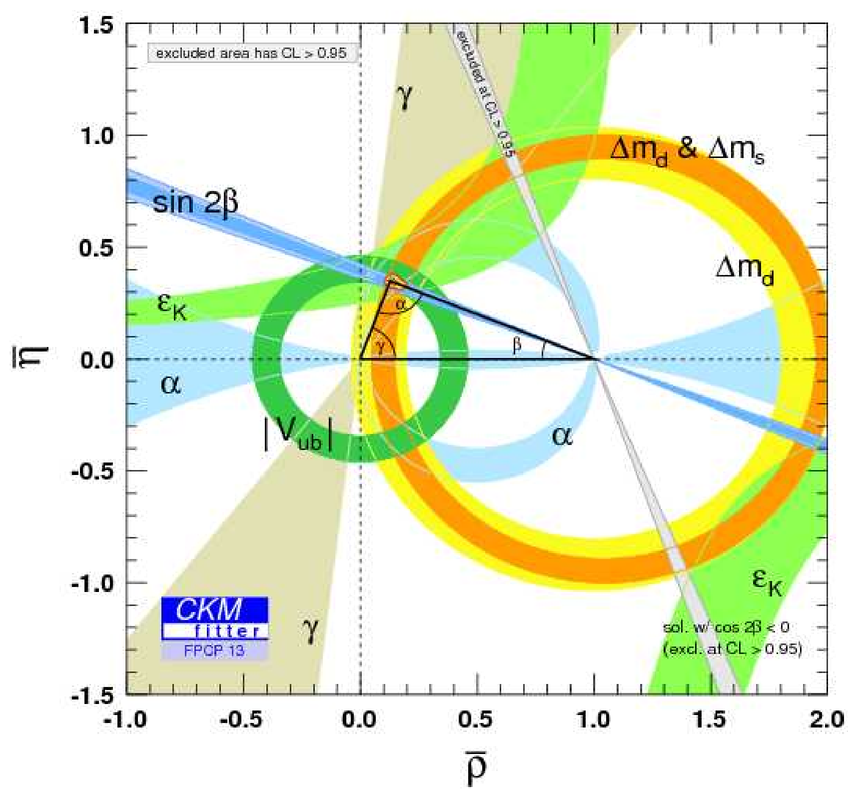
Canadian groups responsible for upgrading the endcap calorimeter

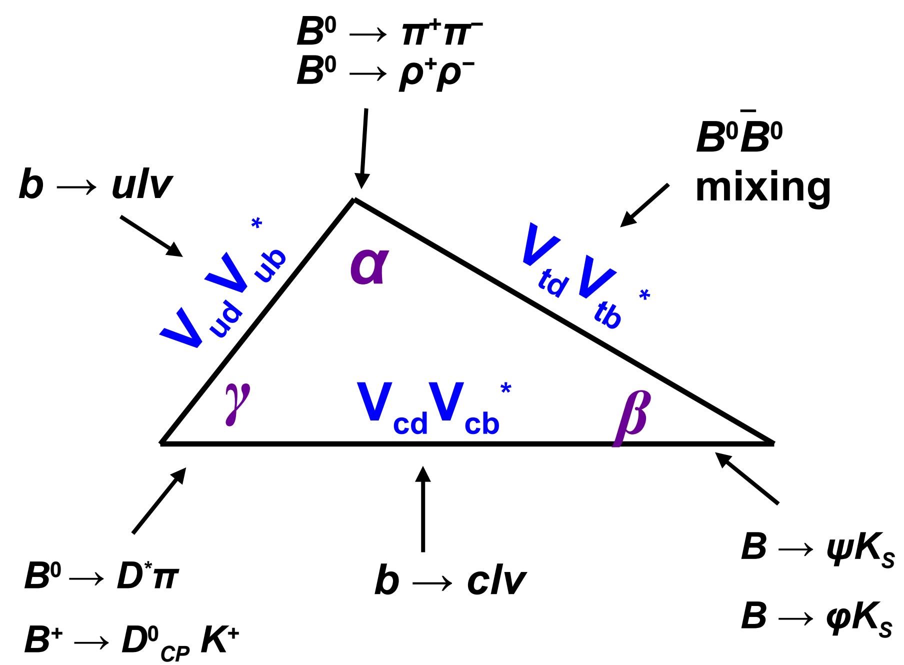
- NSERC project grant (1-year) awarded in April 2013; project grant and RTI (CsI calorimeter R&D) awards for 2014
- Granted IPP project status
- TRIUMF Gate process in progress

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”:



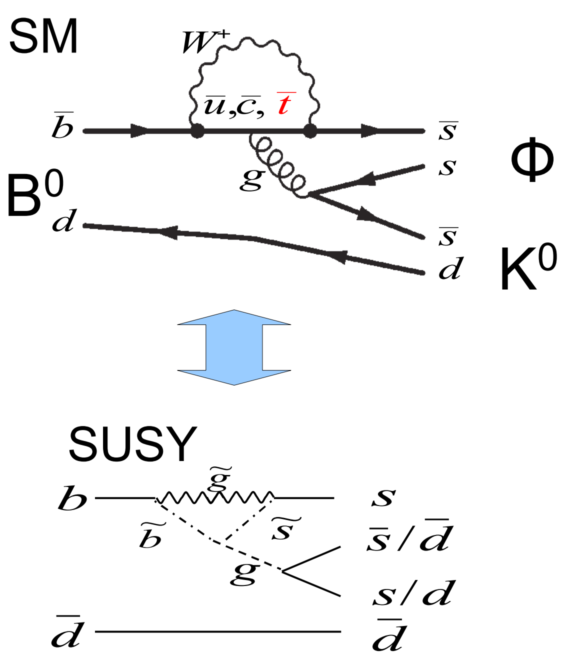


Belle II physics program

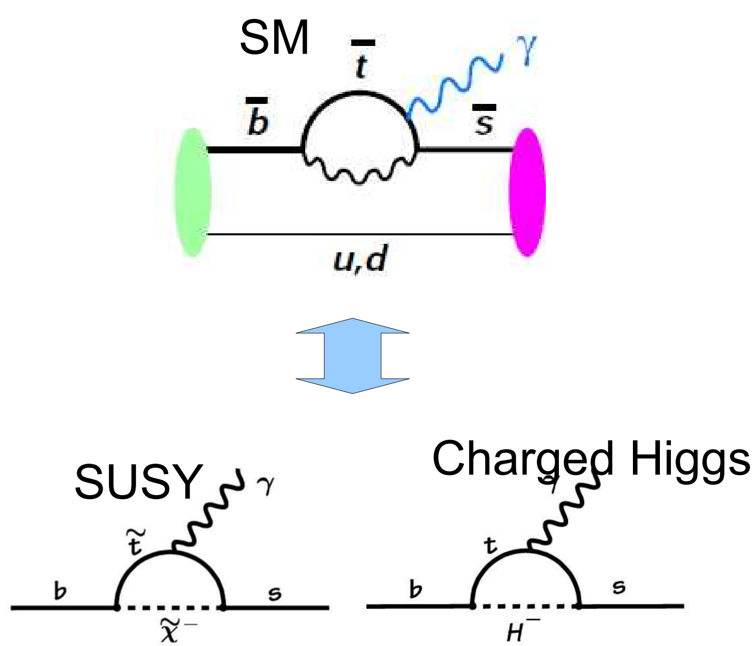
Very large, clean data samples of B and charm mesons, tau leptons and other e^+e^- interaction products can be used to search for evidence of new particles or interactions in virtual loops

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

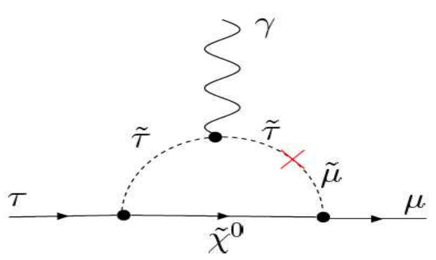
Hadronic decays:



Electroweak FCNCs:



Rare/forbidden decays:



Belle II physics program

Observable/mode	Current now	LHCb (2017) 5 fb^{-1}	Belle-II (2021) 50 ab^{-1}	LHCb upgrade (2028) 50 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($B \to K^{*+}\nu\overline{\nu}$) ($\times 10^{-6}$)	< 80		2.0		6.8 ± 1.1
BR($B \to K^{+}\nu\overline{\nu}$) ($\times 10^{-6}$)	< 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 $B \to K_S^0\pi^0\gamma$	-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_s^0 Decays					
BR($B_s^0 \to \gamma\gamma$) ($\times 10^{-6}$)	< 8.7		$0.2 - 0.3$		0.4 - 1.0
A_{SL}^s ($\times 10^{-3}$)	-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 $B_s^0 \to J/\psi\phi$	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%	$\sim 10^{-2}$
$\arg\{q/p\}$ (°)	-10.2 ± 9.2	4.4°	1.4°	2.0°	$\sim 10^{-3}$

Belle-II program spans wide range of topics in CKM and rare decay physics

In addition:

- Quarkonium spectroscopy and new states
- $e^+e^- \to$ hadrons (muon g-2)
- Light Higgs, dark matter/forces searches

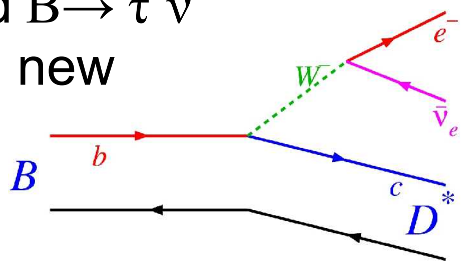
Complementary to LHCb due to clean analysis environment, and ability to reconstruct neutrals and missing energy

Adapted from Meadow's et al arXiv:1109.5028

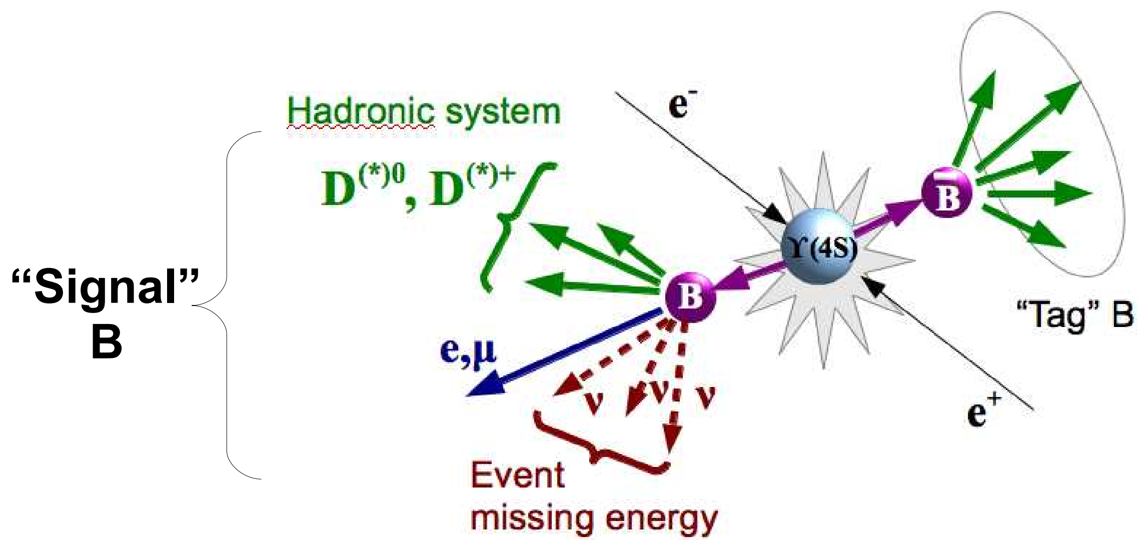
Missing energy modes

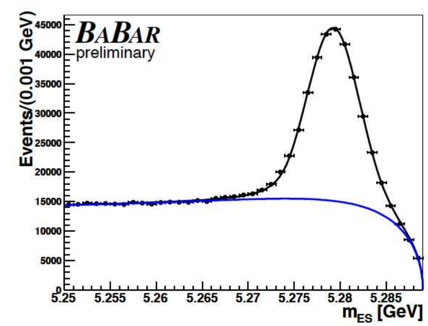
Unique capability to study modes with missing energy

- Semileptonic B decays such as $B\to D^{(*)}l\nu$, $B\to \mu^+\nu$, and $B\to \tau^+\nu$ provide access to $|V_{ub}|$, $|V_{cb}|$ and potentially to tree-level new physics, e.g H^+



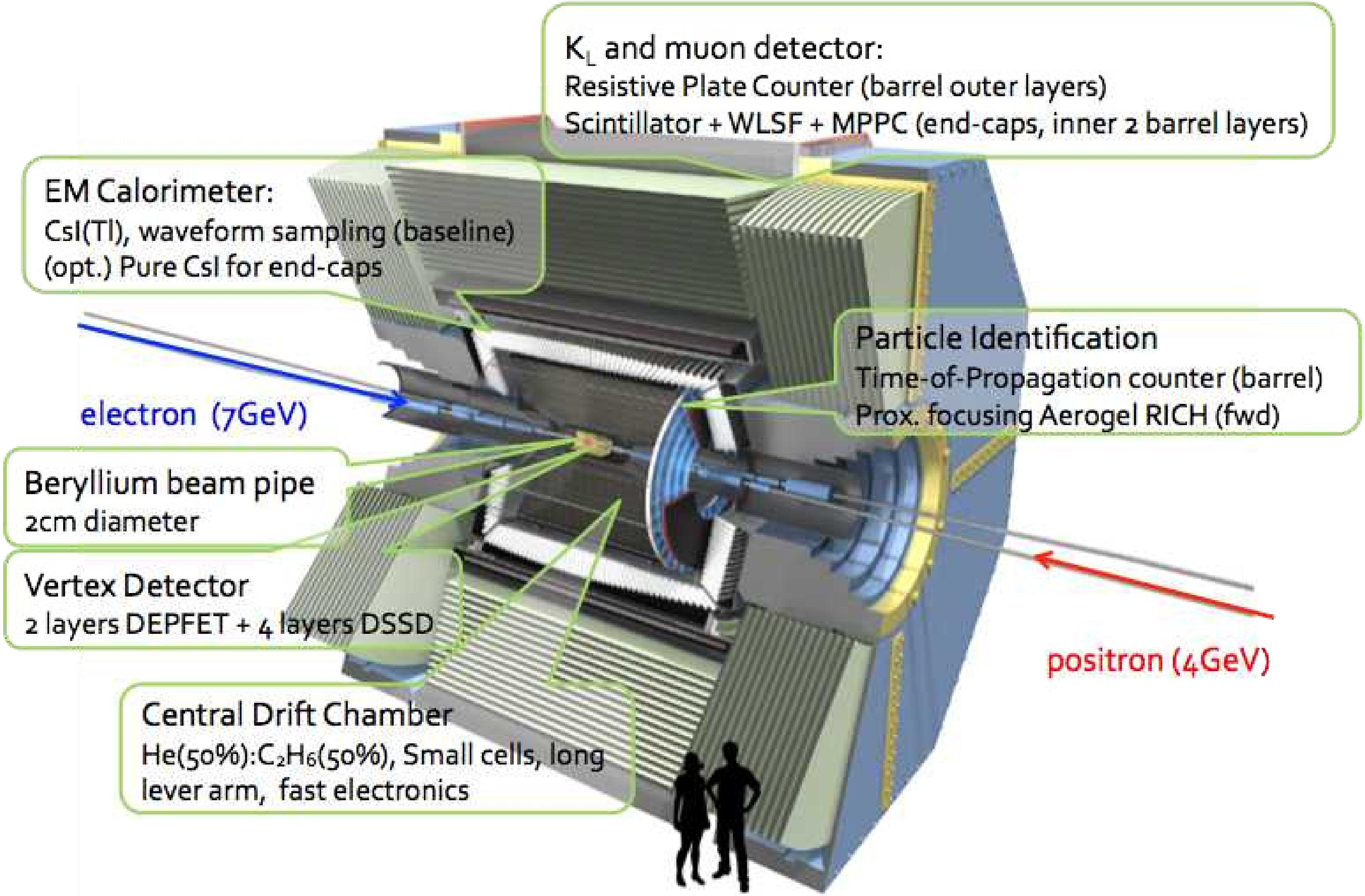
- Also FCNC modes e.g. $B\to K^{(*)}\nu\bar{\nu}$, $B\to\Lambda p\nu\bar{\nu}$, $B\to\nu\bar{\nu}$ etc
- Not accessible at hadron colliders, but can be studied at Belle II using **hadronic B-tag reconstruction** method:





$$m_{\rm ES} \equiv \sqrt{E^{*2}_{\rm beam} - p^{*2}_B}$$
$$\Delta E^* \equiv E^*_B - E^*_{\rm beam}$$

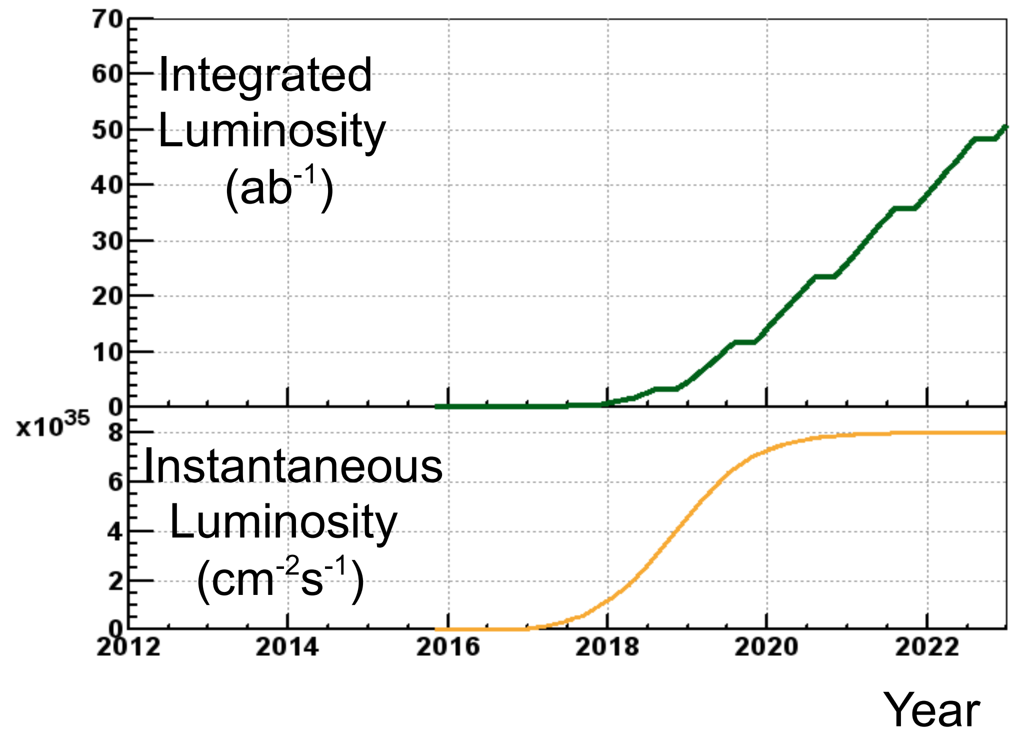
Belle II detector



Schedule

Accelerator commissioning to begin in 2015, with first physics data taking by end of 2016

- Luminosity to ~8×10^{35} by 2020 with ultimate target of 50 ab^{-1} recorded
- Commissioning in three phases:



  - Phase 1 (Jan - May 2015): No superconducting IR magnets and no Belle II detector; basic tuning, vacuum scrubbing
  - Phase 2 (Feb - June 2016): Full accelerator and Belle II except vertex detector; beam collision tuning and background studies
  - Phase 3 (late 2016): First physics with full detector (except partial iTOP) $L = 10^{34}\ cm^{-2}s^{-1}$ (comparable to BABAR/Belle)

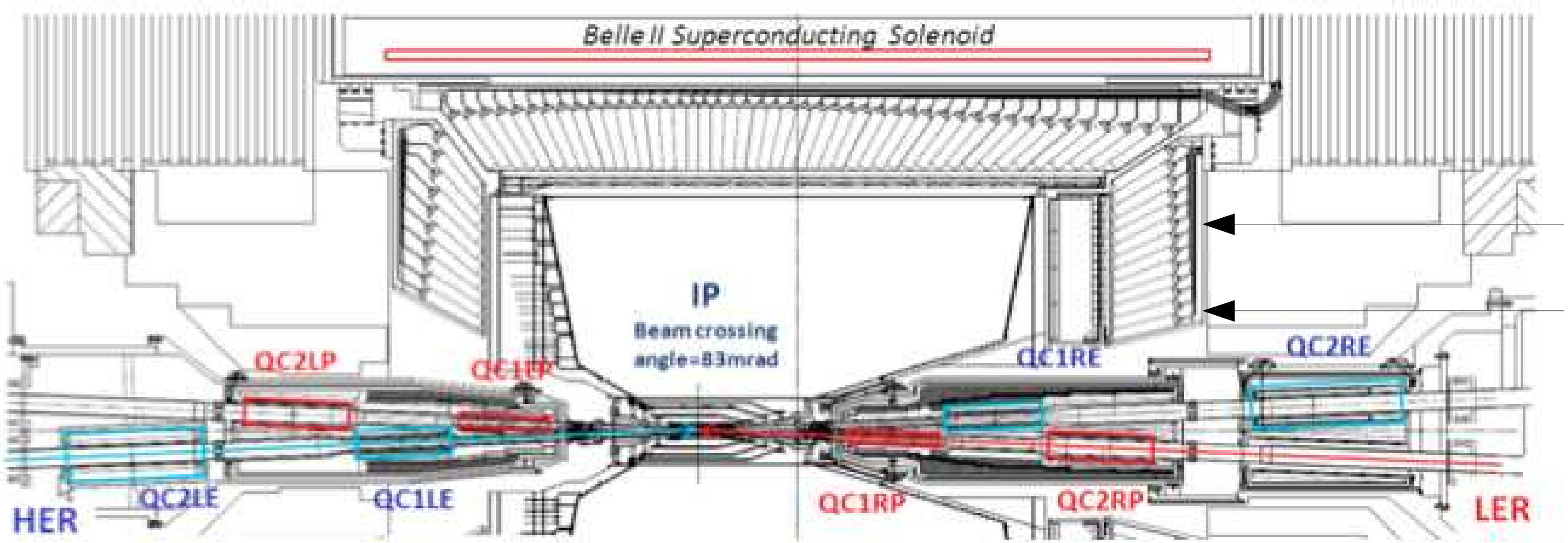
Canadian activities

Belle II proposal to upgrade CsI(Tl) endcap calorimeters with pure CsI, based on rate and radiation damage extrapolations from Belle/KEKB experience

- Canadian effort to focus on most critical region (inner rings in forward endcap); Italian and Russian groups to contribute additional rings

Pure CsI is more radiation hard, gives much faster signals (for pileup suppression) but also much less light

- Replace existing photodiodes with fine mesh PMTs, HV, new preamps, shapers and waveform digitization



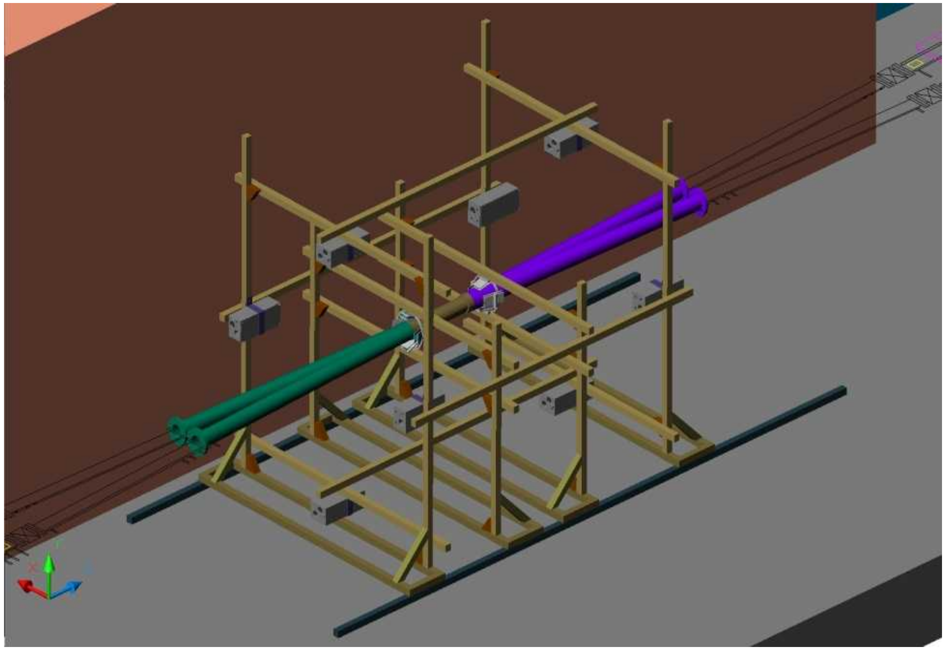
Upgrade region

BEAST

Understanding and managing the radiation and beam background environment is critical for detector performance

- BEAST detector to be used for Phase 1 commissioning
  - PIN diode system (x-rays and neutrals) BGOs (luminosity monitors), TPCs (fast neutrons), He-3 tubes (thermal neutrons), Diamond sensor VXD beam abort system
- UVic group (Sam de Jong) developing thermal neutral detectors

Photo by Sam de Jong

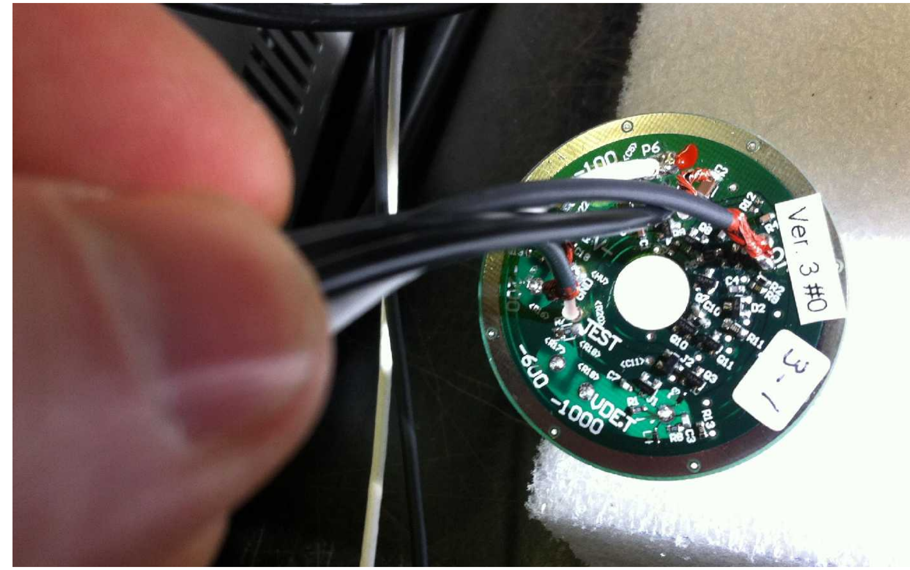


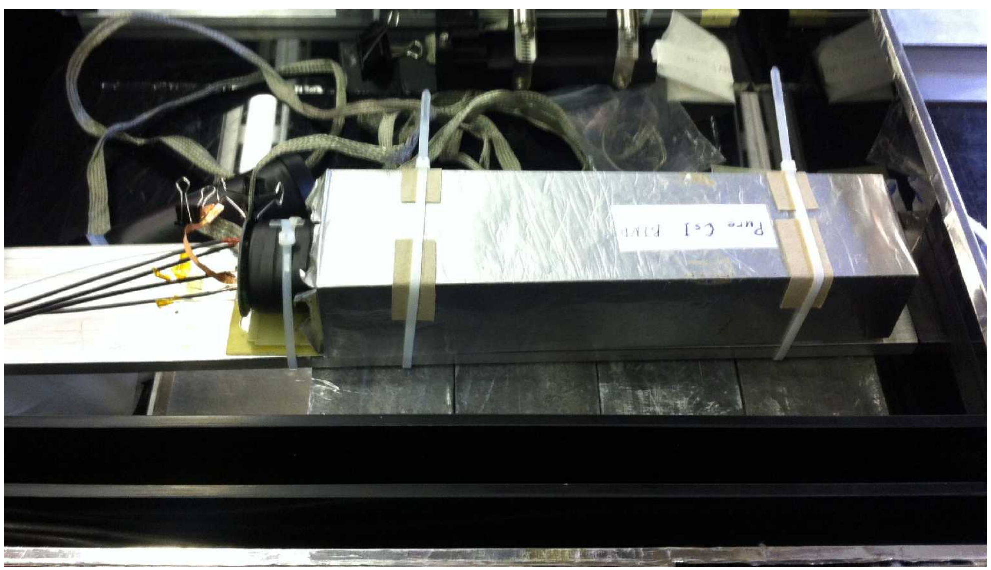
Electronics and performance

Preamplifier and shaper/digitizer being developed at UdM

- excellent performance from prototype preamp boards

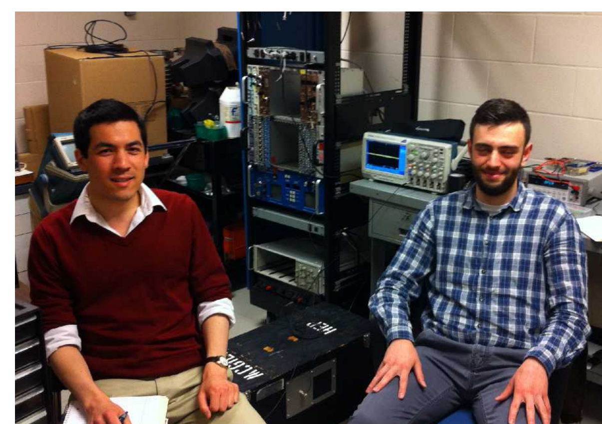
PMT characterization and stability tests being developed by UBC group



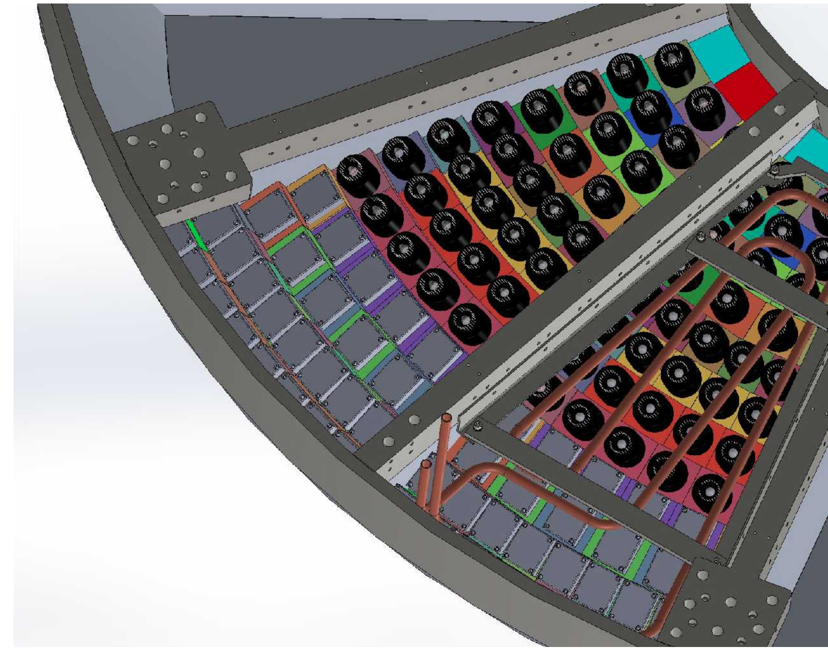


Prototype preamp undergoing testing with CsI crystal and PMT at TRIUMF

McGill group working on development of Xenon-strobe light pulser calibration system

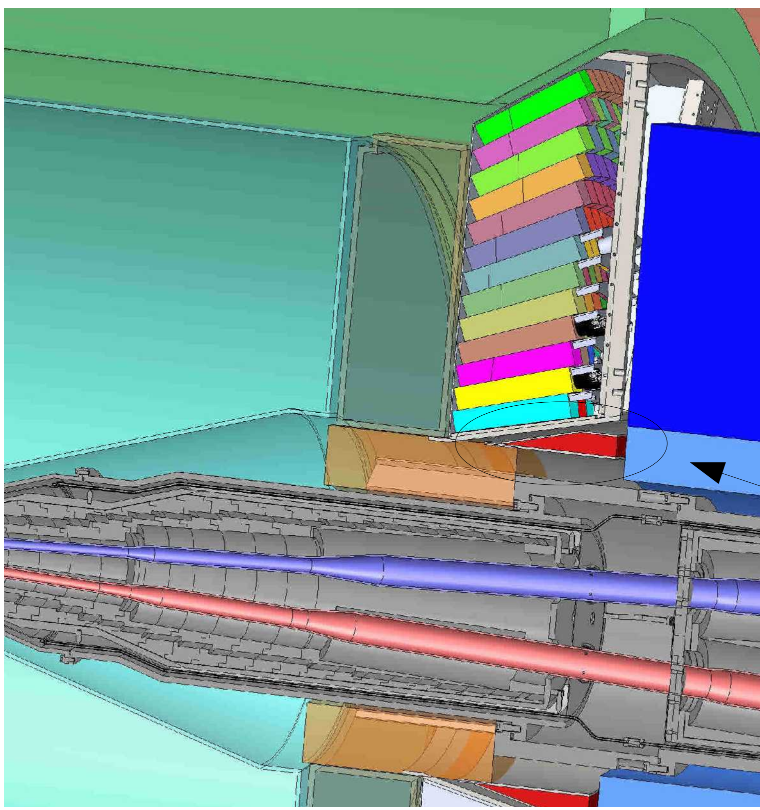


Mechanical design and shielding



Although CsI crystals are geometrically identical to existing CsI(TI), PMT size, HV distribution, cooling, etc. impact detector layout

- Ongoing work by UVic group



Forward region of detector is high radiation environment, in part due to proximity to machine elements

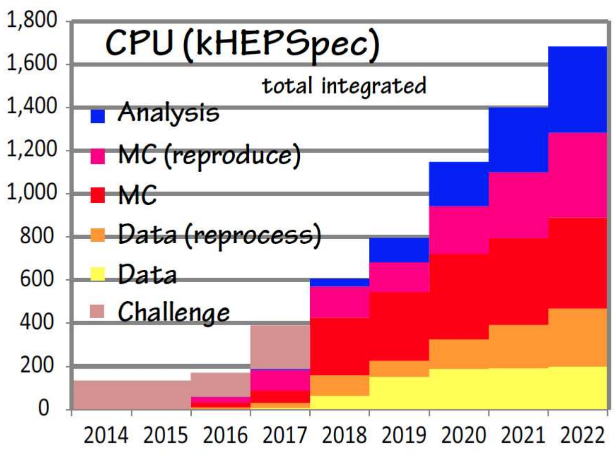
- Addition of lead/steel shielding substantially reduces rates and dose
- Neutron shielding studies in progress

See talk by Alex Beaulieu

Computing

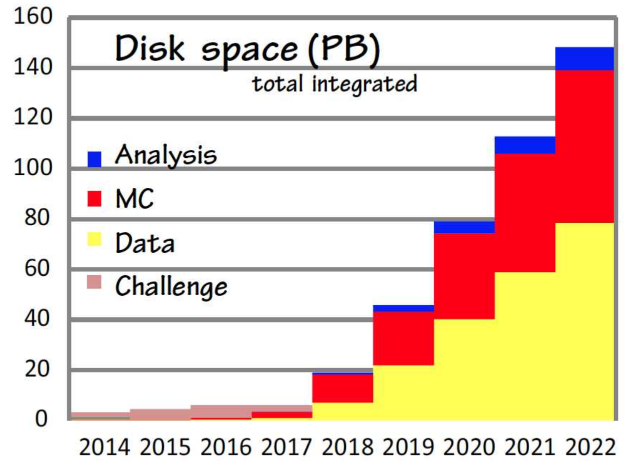
Belle II computing needs, collaboration wide, are of the same scale as the LHC experiments

- Computing model foresees hosting RAW data at KEK, with second copy distributed worldwide
- Canadian groups nominally responsible for ~4% of computing resources; in 2020 this amounts to ~1800 cores, ~3PB of storage



Compute Canada request for 2014 Belle II allocation for development of cloud (UVic) and grid (CLUMEQ) capabilities

- UVic developing "Infrastructure as a Service (IaaS)" cloud MC production on OpenStack, Nimbus and commercial clouds (Amazon, Google etc)
- McGill HPC / CLUMEQ site operational since beginning
- of 2014, with sustained production on up to ~100 cores.



Recent News

Detailed simulation and physics studies by the Canadian group indicate that redesigned shielding, in combination with the ongoing electronics upgrade, substantially alleviate the rate/occupancy issues which motivate the calorimeter endcap upgrade:

- predicted crystal light loss due to radiation damage has not been demonstrated to lead to a measurable impact on physics
- beam background photons that make it past the shielding are heavily suppressed by improved feature extraction and timing information
- missing energy resolution dominated by hadronic shower fragments ("split-offs") rather than beam backgrounds
- no demonstrable impact on π^0 mass resolution

Currently in discussion with Belle II management as to how to proceed

⇒ Will not submit a CFI-8 proposal to fund the endcap upgrade

- continuing to work with calorimeter group to ensure best possible performance

Outlook and Future Plans

Will continue to participate in ongoing calorimeter group activities, while discussing plans for future contributions with Belle II management

- Accelerator/detector commissioning (BEAST)
- Shielding design
- Calorimeter reconstruction software development and simulation studies

NSERC project grant application (and possibly RTI application) to be submitted this fall

- does not preclude possibility of future CFI application for Belle II detector hardware in future years

Currently "modest" computing needs will increase rapidly in future years as data taking and physics analysis activities ramp up

See Belle II overview talk by Chris Hearty for more details

Backup material

Computing needs

Canadian group are nominally responsible for ~5% of Belle II computing resources

- 10% of mDSTs, 3% of simulation and 5% of RAW

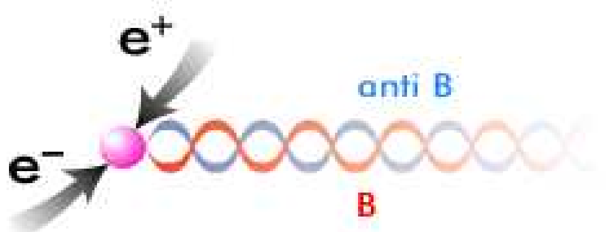
Estimated Canadian shares

Year (PB)	CPU		Storage	
	HEPSpec	Cores	Disk	Tape
2014	4.3	300	0.0	0
2015	4.3	300	0.15	0
2016	5	330	0.2	0
2017	9	630	0.4	0
2018	9	630	0.4	0
2019	16	1100	1.0	1
2020	27	1800	1.6	2
2021	34	2300	2.4	3
2022	43	2900	3.1	5

Asymmetric B Factories

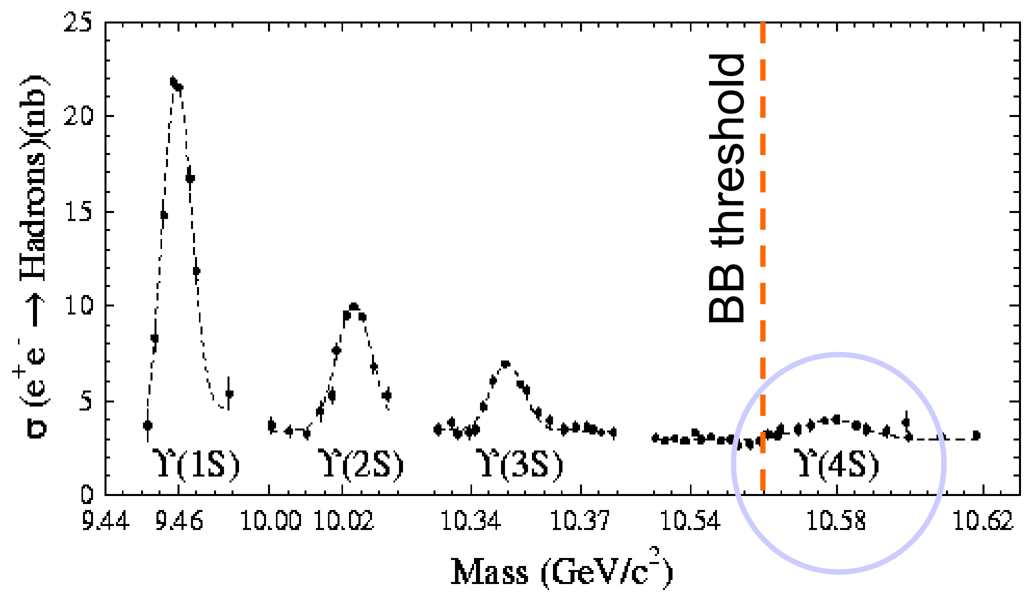
ϒ(4S) resonance lies just above the mass threshold for production of $B\bar{B}$ meson pairs

$B^0\bar{B}^0$ pair is produced in a coherent L=1 state



The two B mesons evolve in phase until one decays (EPR situation)

Boost from asymmetric beam energies permits separation of (nearly at rest in CM frame) B meson decay vertices



Process	Cross section (nb)
bb	1.1
cc	1.3
light quark qq	~2.1
$\tau\tau$	0.9
ee	~40

~1.1 million BB pairs per fb^{-1}

Flavour and New Physics

Effective flavour-violating couplings

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{k=1} \left(\sum_i c_i^k \, Q_i^{(k+4)} \right) / \Lambda^k$$

New Physics scale

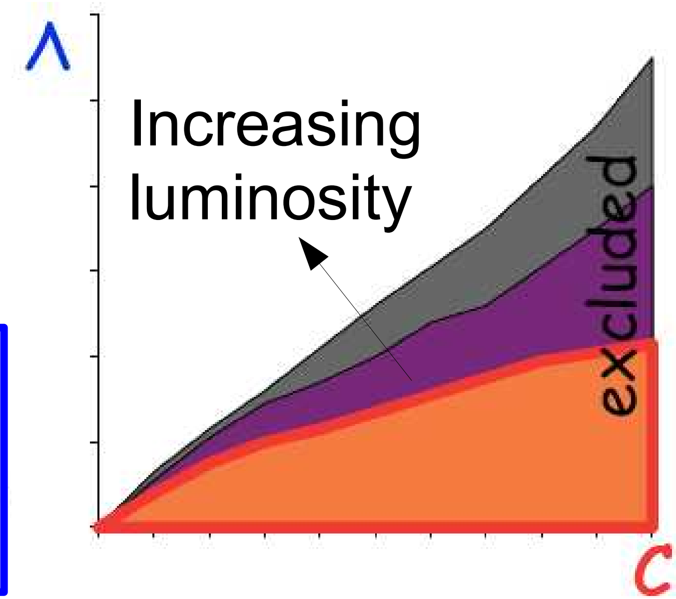
In explicit models:

- Λ ~ mass of virtual particles

  (e.g. Fermi theory: m_W)

- c ~ (loop coupling) x (flavour coupling)

  (e.g. SM/MFV: α_w x CKM)



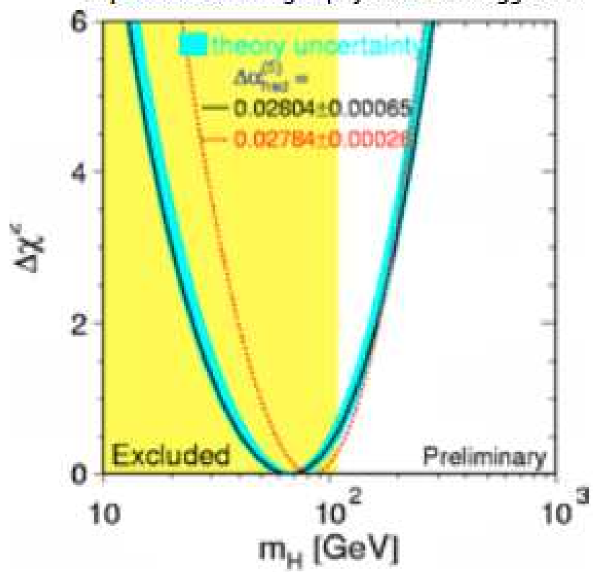
Precision flavour measurements provide bounds on ratio c / Λ i.e. constrain coupling strengths at any given mass scale

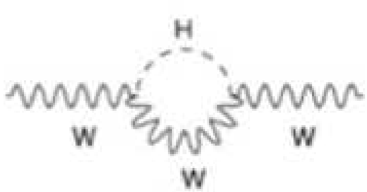
Structure at loop level

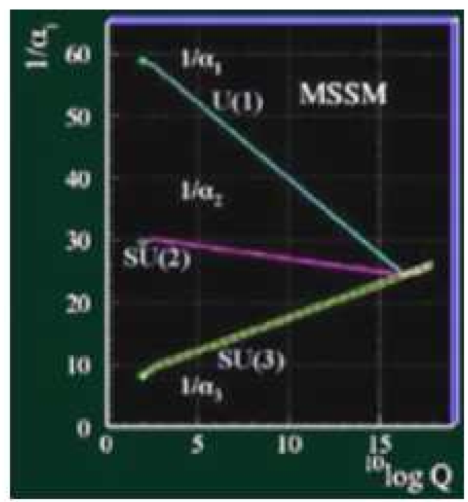
New structure often first appears through quantum corrections

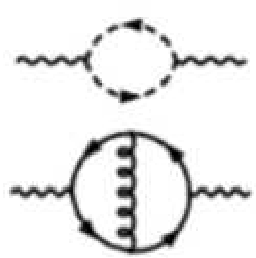
(aka radiative corrections, loop corrections, etc.)

http://www-cdf.fnal.gov/physics/ewk/mhiggs.html

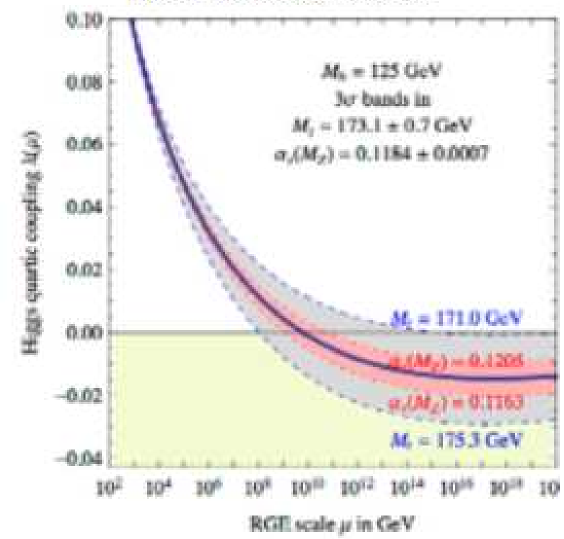


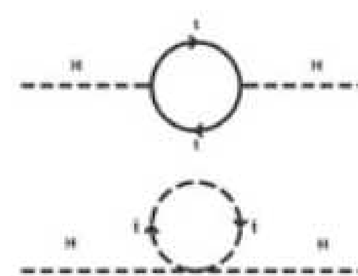




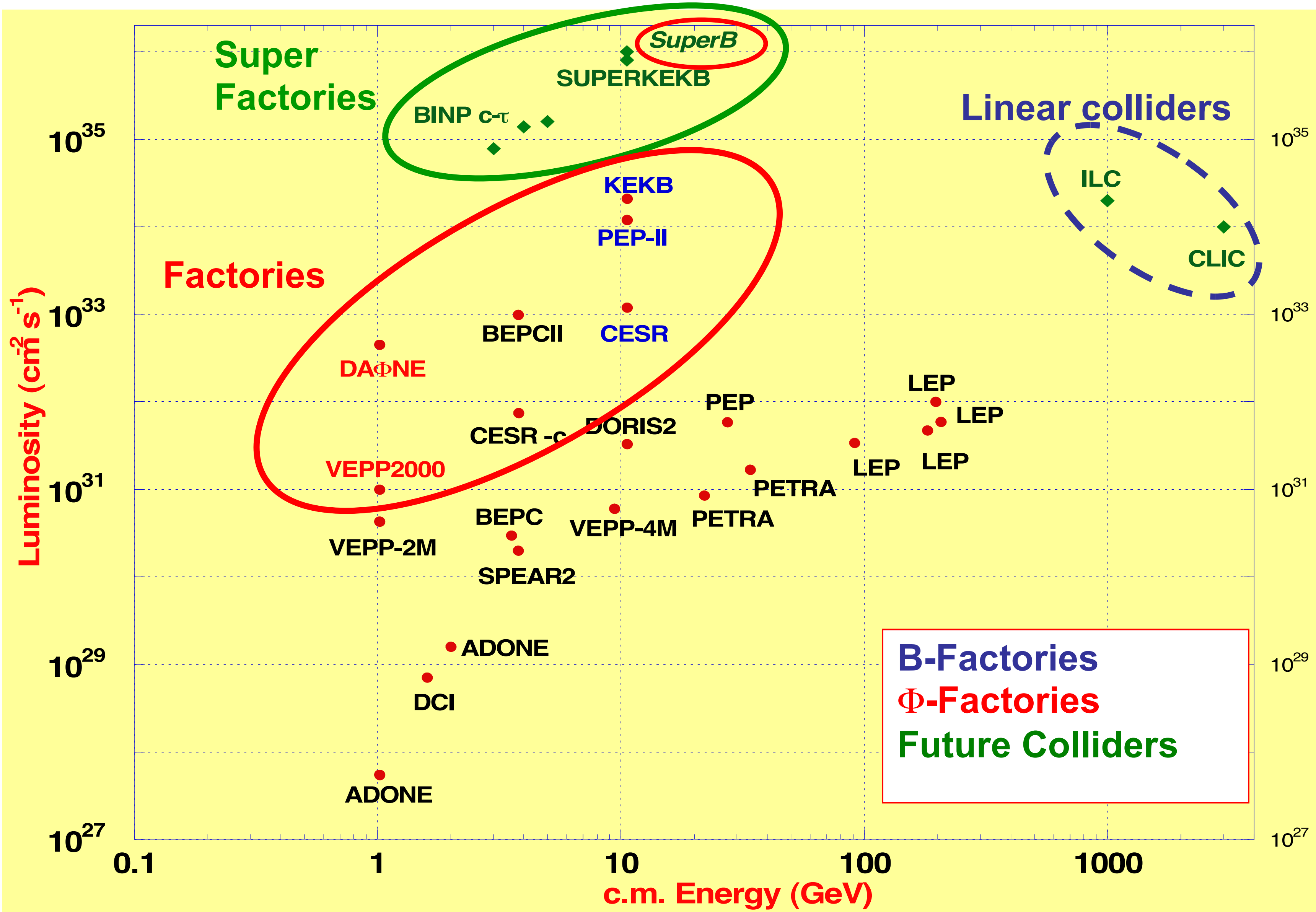


http://arxiv.org/abs/1205.6497



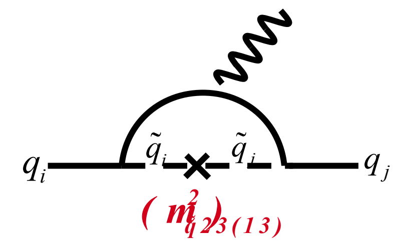


e^+e^- collider facilities



New Physics signatures

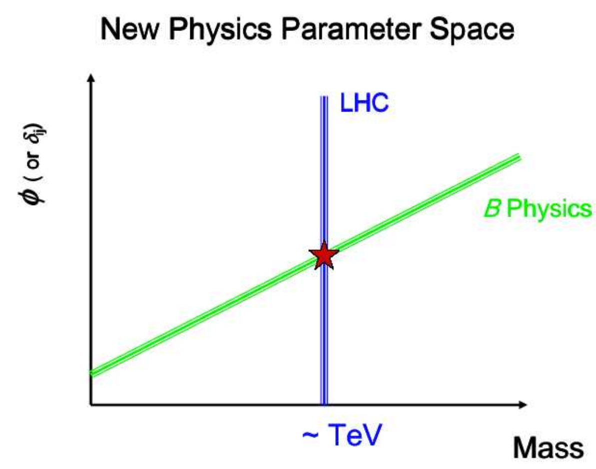
- Various New Physics scenarios predict different patterns of deviations in flavour physics observables
  - Complementary information to direct measurements at the LHC



$$\left(m^2_{\tilde{q}}\right)_{ij} = \begin{pmatrix} m^2_{11} & m^2_{12} & m^2_{13} \\ m^2_{21} & m^2_{22} & m^2_{23} \\ m^2_{31} & m^2_{32} & m^2_{33} \end{pmatrix}$$

	Model	B_d Unitarity	Time-dep. *CPV*	Rare B decay	Other signals
SUSY	mSUGRA(moderate $\tan\beta$)	-	-	-	-
SUSY	mSUGRA(large $\tan\beta$)	B_d mixing	-	$B \to (D)\tau\nu$ $b \to s\ell^+\ell^-$	$B_s \to \mu\mu$ B_s mixing
SUSY	SUSY GUT with ν_R	-	$B \to \phi K_S$ $B \to K^*\gamma$	-	B_s mixing τ LFV, n EDM
SUSY	Effective SUSY	B_d mixing	$B \to \phi K_S$	$A_{CP}^{b\to s\gamma}$, $b \to s\ell^+\ell^-$	B_s mixing
Large Extra Dimension models	KK graviton exchange	-	-	$b \to s\ell^+\ell^-$	-
Large Extra Dimension models	Split fermions in large extra dimensions	B_d mixing	-	$b \to s\ell^+\ell^-$	$K^0\overline{K}^0$ mixing $D^0\overline{D}^0$ mixing
Large Extra Dimension models	Bulk fermions in warped extra dimensions	B_d mixing	$B \to \phi K_S$	$b \to s\ell^+\ell^-$	B_s mixing $D^0\overline{D}^0$ mixing
Large Extra Dimension models	Universal extra dimensions	-	-	$b \to s\ell^+\ell^-$ $b \to s\gamma$	$K \to \pi\nu\overline{\nu}$

(2003 SLAC Super B Factory Workshop Proceedings)



How to get to high luminosity?

Luminosity equation

$$L = 2.17 \times 10^{34} \frac{n \xi_y E I_b}{\beta_y^*}$$

ξ_y	Vertical beam-beam parameter
I_b	Bunch current (A)
n	Number of bunches
β_y^*	IP vertical beta (cm)
E	Beam energy (GeV)

Present day B-factories:

	PEP-II	KEKB
E(GeV)	9x3.1	8x3.5
I_b	1x1.6	0.75x1
n	1700	1600
I (A)	1.7x2.7	1.2x1.6
β_y^* (cm)	1.1	0.6
ξ_y	0.08	0.11
L ($\times 10^{34}$)	1.2	2.0

Answer:

Increase I_b

Decrease β_y^*

Increase ξ_y

Increase n