The Belle II Experiment at the SuperKEKB e^+e^- Collider

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Belle II Canada Team

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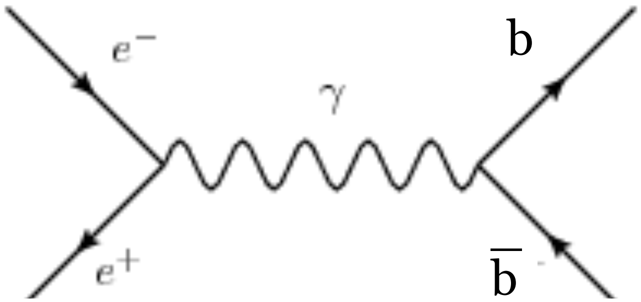
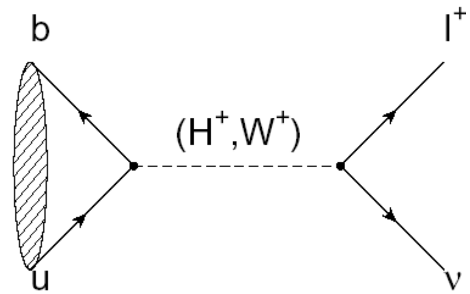
	Randy Sobie	Faculty

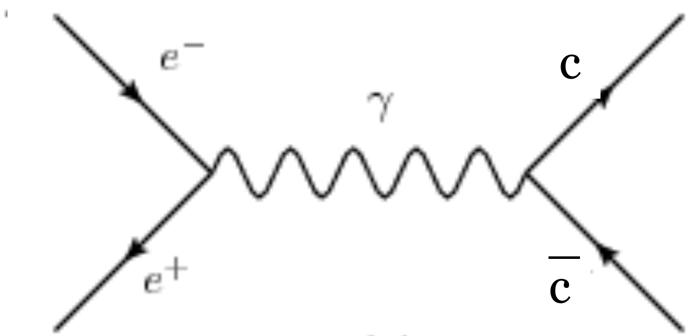
Student
Postdoc
Faculty

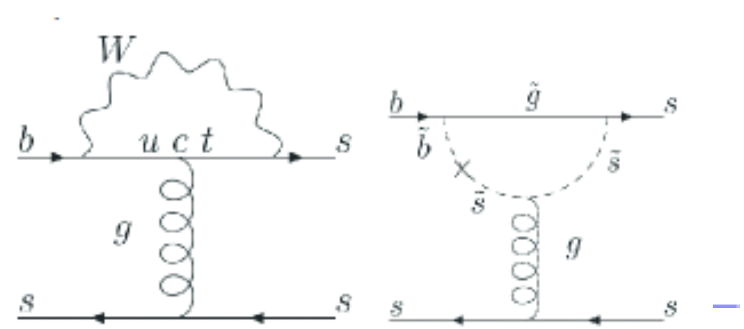
High luminosity e^+e^- collisions at B meson threshold: exquisite tool for discovering new physics

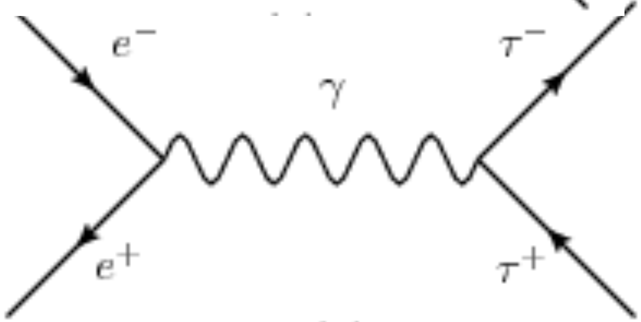
1) Deviations from SM in precision measurements
2) Direct searches for SM-forbidden processes

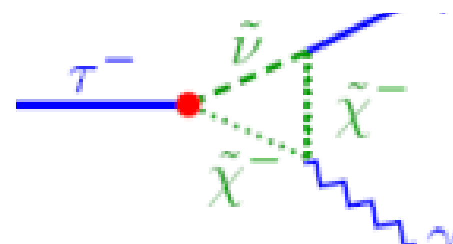




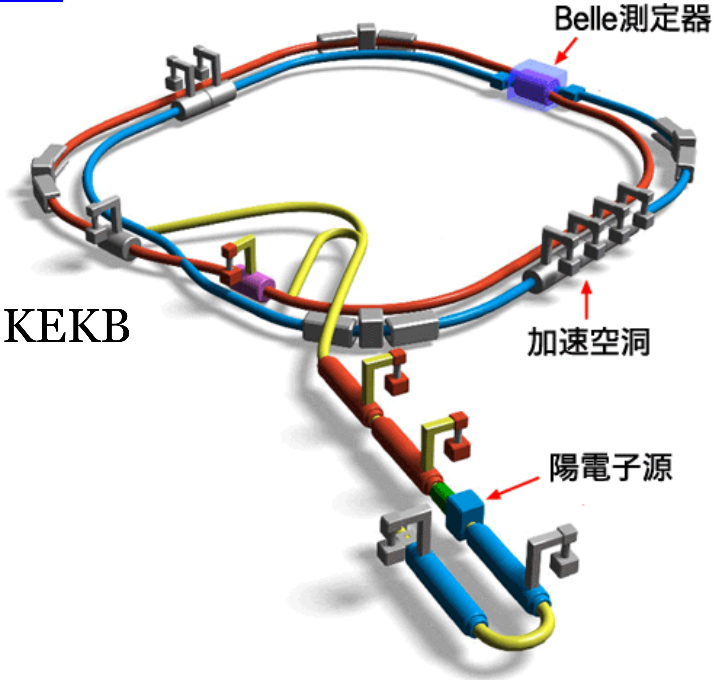


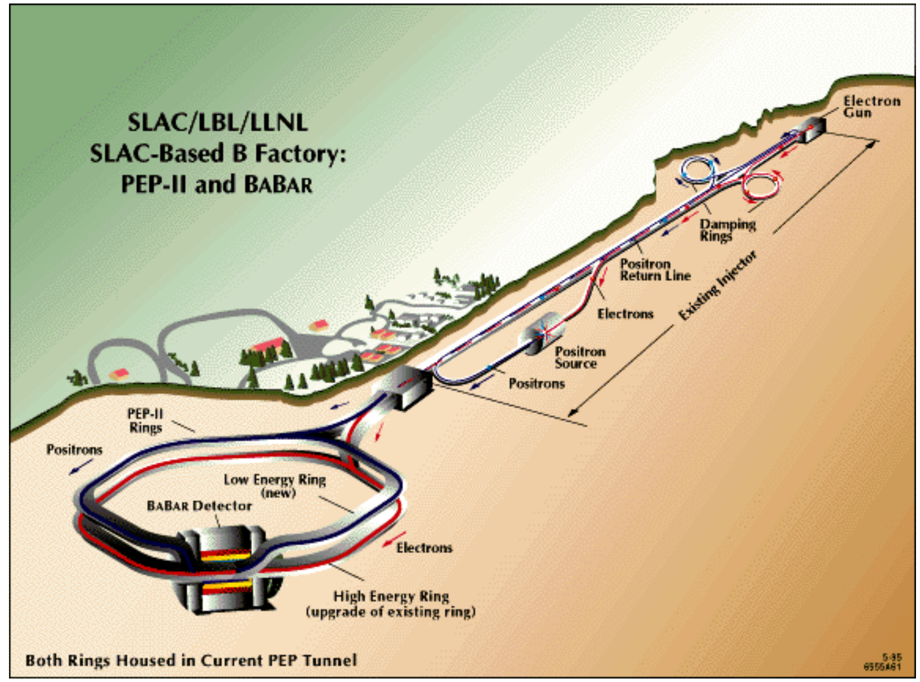






asymmetric B factories





$\sqrt{s}$=10.58 GeV

$e^+ \rightarrow \Upsilon(4s) \leftarrow e^-$

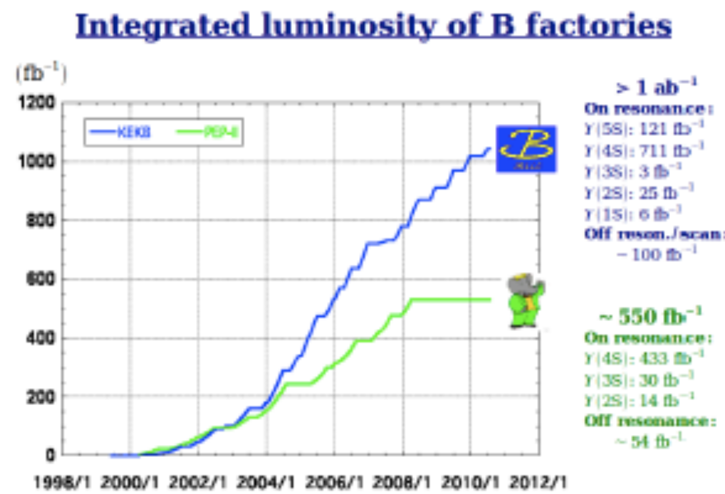
$\Upsilon(4s) \rightarrow B\,\bar{B}$

$\Delta z \sim c\beta\gamma t_B \sim 200\mu m$

BaBar $p(e^-)$=9 GeV $p(e^+)$=3.1 GeV $\beta\gamma$=0.56

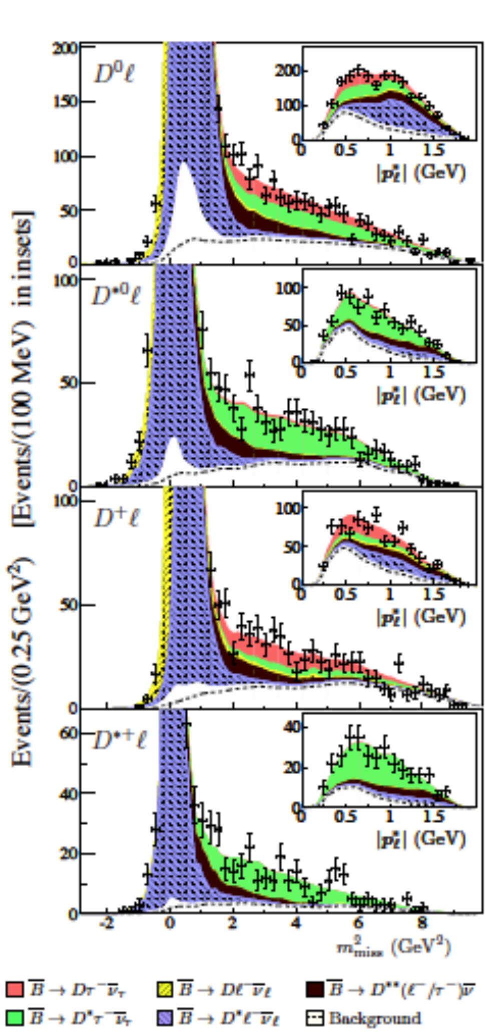
Belle $p(e^-)$=8 GeV $p(e^+)$=3.5 GeV $\beta\gamma$=0.42

- BaBar: PEP-II e^+e^- collider, SLAC, USA, 1999–2008.
- Belle: KEKB e^+e^- collider, KEK, Tsukuba, Japan, 1999–2010.



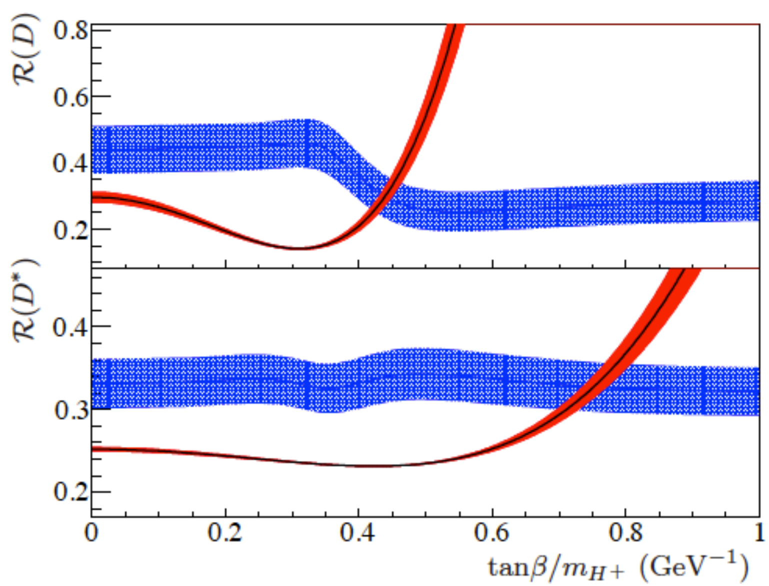
- Combined BaBar and Belle luminosity is ~1.5 ab^{-1} (1.25×10^9 BB).
- Main focus: CP violation (published in 2001)
  - Also B-decays, CKM parameters, charmonium(-like), charm- and τ-physics etc.
  - 500+ publications from BaBar, 400+ from Belle.
  - But no observation of New physics (NP)!

…an intriguing 3σ effect in the flavour sector



BABAR's 3.4σ evidence for an excess of B decays to D(*)τν compared to SM expectations

$$\mathrm{BF}(B \to D^{(*)}\tau\upsilon)/\mathrm{BF}(B \to D^{(*)}\ell\upsilon)$$



Measure the ratios to minimize systematic errors

NB:this result kills Type II 2HDM

Belle published B→D(*) τν before BaBar … but not R

A. Bozek's interpretation of earlier Belle measurement…

R measurement

SM expectations: (S.Fajfer, J.Kamenik, I.Nisandzic, PRD **85**, 094025 (2012))

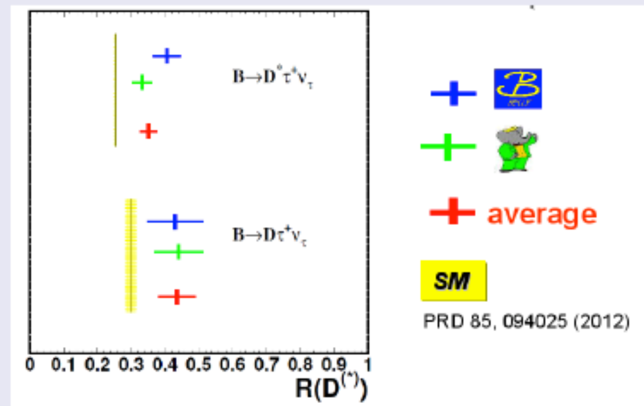
$R(D) = 0.297 \pm 0.017,\ R(D^*) = 0.252 \pm 0.003$

BABAR SM deviations

- $R(\overline{D}^*)$ 2.7σ
- $R(\overline{D})$ 2.0σ
- $R(\overline{D}^{(*)})$ 3.4σ

Belle average SM deviations

- $R(\overline{D}^*)$ 3.0σ
- $R(\overline{D})$ 1.4σ
- $R(\overline{D}^{(*)})$ 3.3σ



private average of Belle results

Belle and BABAR average deviation from SM

- $R(\overline{D}^*)$ 3.8σ
- $R(\overline{D})$ 2.4σ
- $R(\overline{D}^{(*)})$ 4.8σ

Observed deviations between observable and SM expectations for $R_{D(*)}$ are not only due to improvement of experimental results but also reduction theoretical uncertainties.

LQCD expectations . A. Bailey, *et al.*, Phys. Rev. Lett. **109**, 071802, (2012), arXiv:1206.4992 [hep-ph].

$R(D) = 0.316 \pm 0.012 \pm 0.007$

Andrzej Bożek @ FPCP 2013 Buzios | The $B \to \tau\nu$ and $B \to \overline{D}^{(*)}\tau^+\nu$ measurements | 18

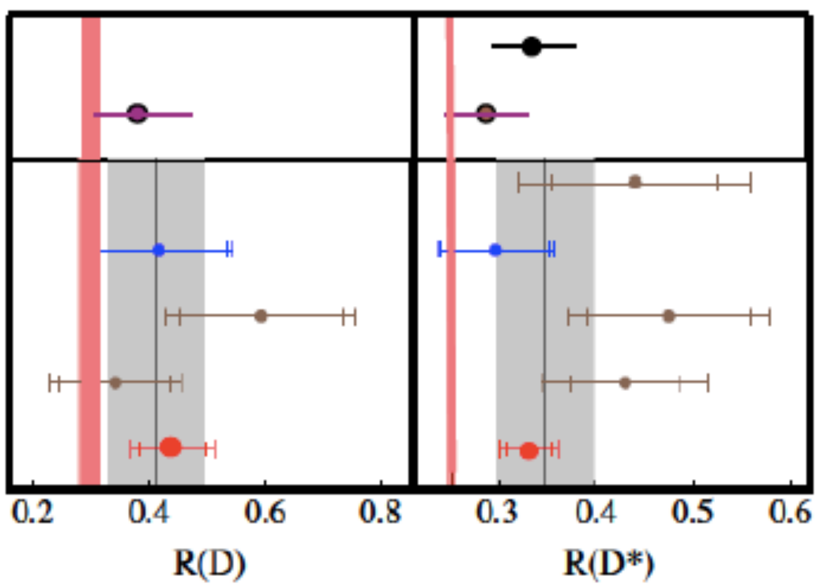
New LHCb and Belle Results from FPCP 2015 talks in late May

via Vera Luth summary

	R	stat	syst	R*	stat	syst
BABAR	0.440±0.058±0.042	13%	10%	0.332±0.024±0.018	7%	5%
BELLE	0.375±0.064±0.026	17%	7%	0.293±0.039±0.015	13%	5%
LHCb				0.336±0.027±0.030	8%	9%
SM	0.297±0.017	6%		0.252±0.003	1.2%	

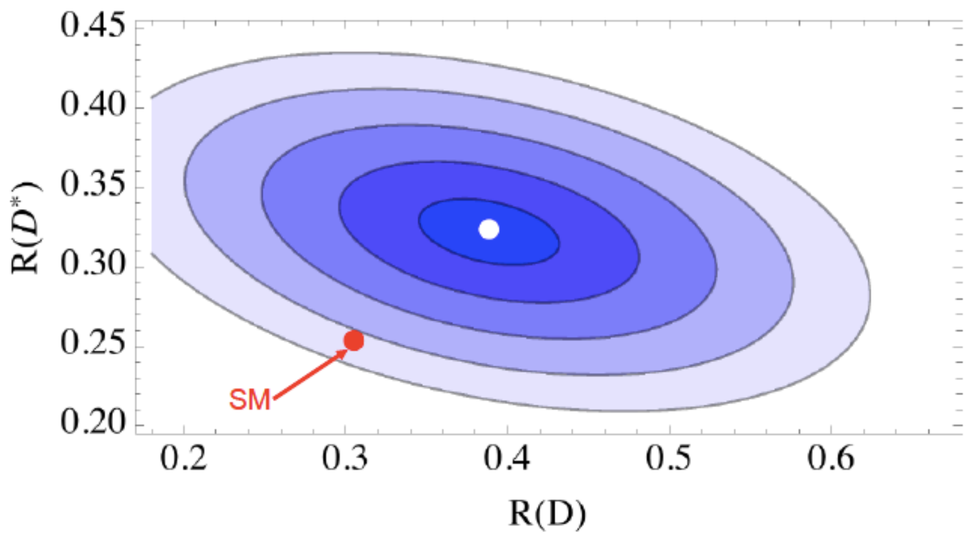
The 3 newest measurements of R(*) have significantly reduced stat. and syst. uncertainties

Improved selection, and tagging, scrutiny of MC predictions with data control samples !



All measurements are consistent within errors !

All measured values of R and R* are somewhat larger than the SM predictions !

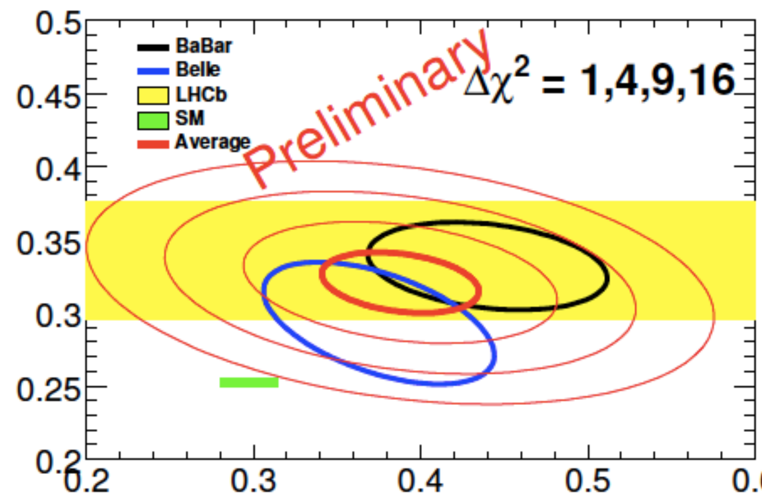


Combination by Ryoutaro Watanabe

via Vera Luth

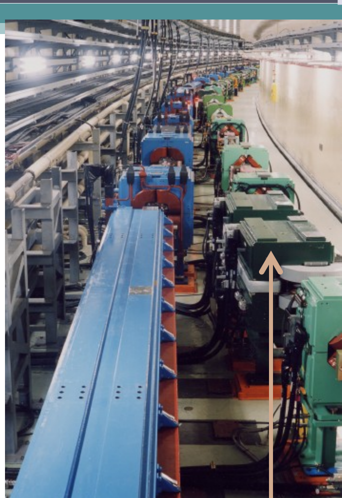
Combination by Marcello Rotondo

via Zoltan Ligeti

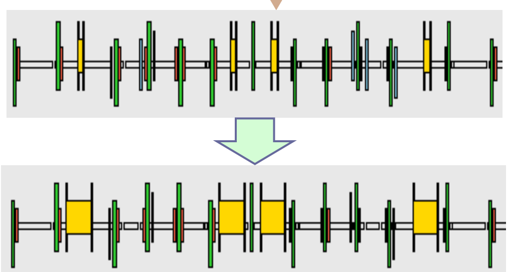


[Thanks to M. Rotondo]

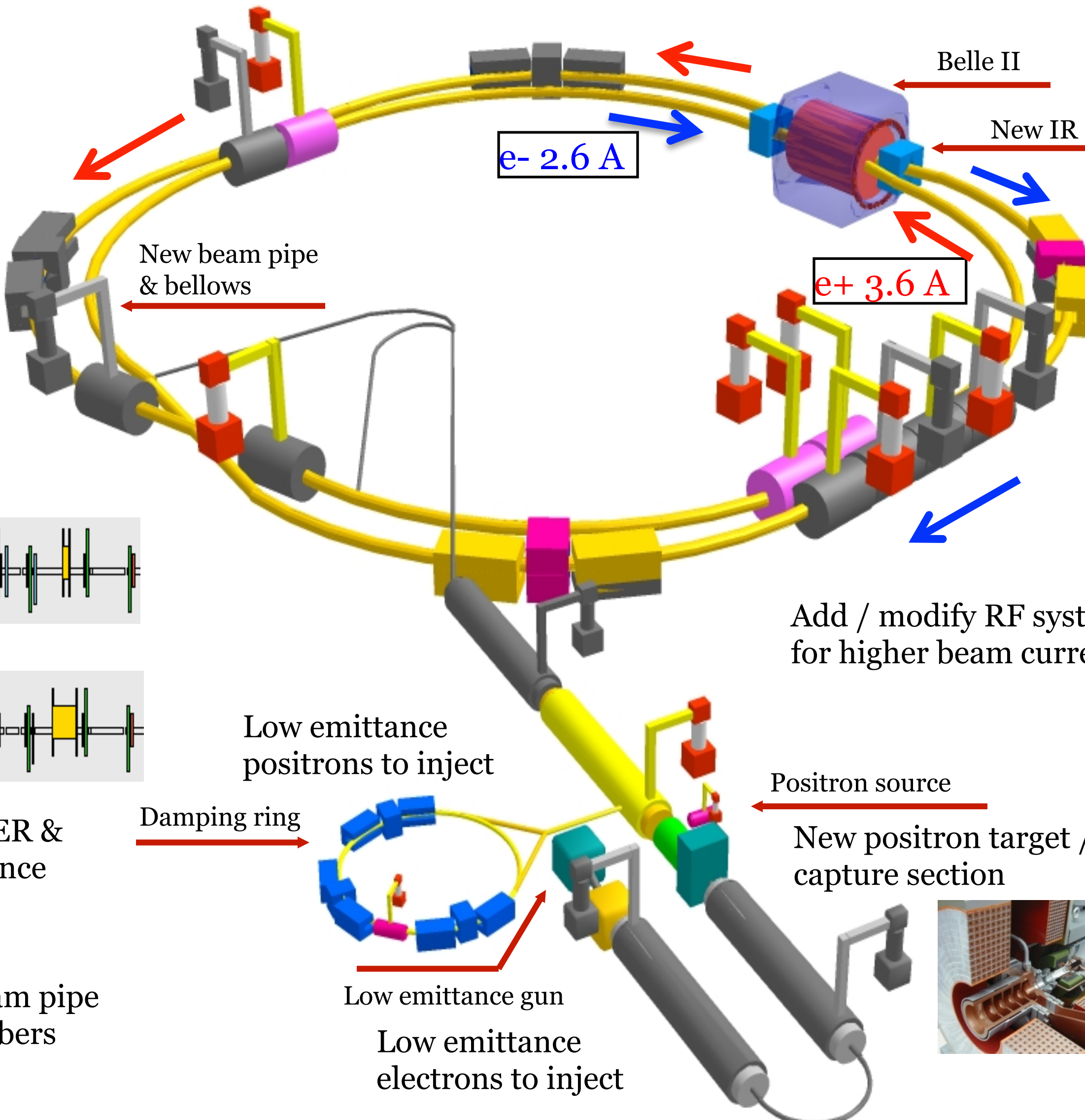
KEKB to SuperKEKB



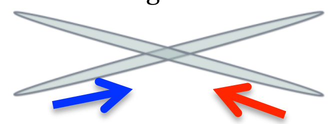
Replace short dipoles with longer ones (LER)



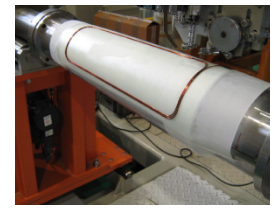
Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches



New superconducting / permanent final focusing quads near the IP

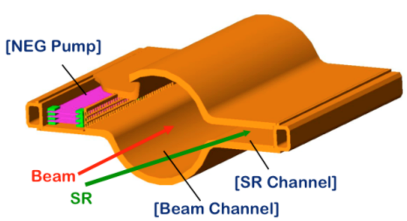


Add / modify RF systems for higher beam current

New positron target / capture section

Low emittance electrons to inject

TiN-coated beam pipe with antechambers



To obtain x40 higher luminosity

How to get to $\mathcal{L}$=8x10^{35} cm^{-2}s^{-1} …

- There are two ways to increase luminosity:
  - Increase beam currents
  - Decrease beam size
- SuperKEKB uses ~2x increase in currents and “nano-beams”
- 40x luminosity

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

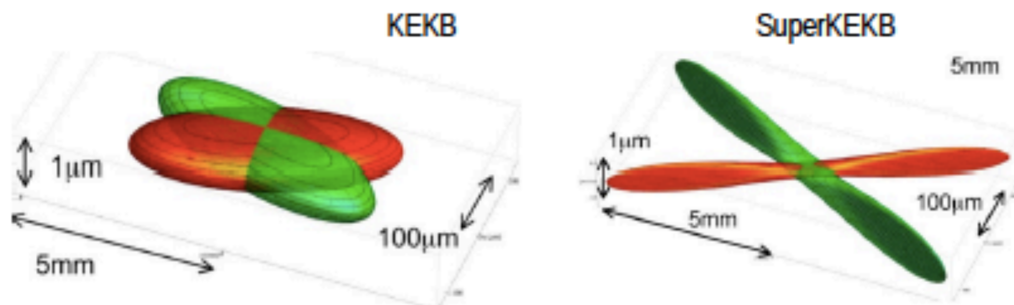
Beam-Beam parameter

Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

Vertical beta function at IP

Minimum value is limited by hourglass effect



	E(GEV) HER/LER	β^*_y(mm) HER/LER	β^*_x(mm) HER/LER	2φ (mrad)	I(A) HER/LER	L (cm^{-2}s^{-1})
KEKB	3.5/8.0	5.9/5.9	120/120	22	1.6/1.2	2.1x10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	83	3.6/2.6	80x10^{34}

Physics at the Belle II e^+e^- Super Flavour Factory

- Test CKM at 1% level
  - CPV in B decays from new physics (non-CKM)
- B-recoil technique for $B \to K^{(*)}\ell^+\ell^-$, $B \to \tau\nu$, $B \to D^{(*)}\tau\nu$
- τ physics: lepton flavour violation, g-2, EDM, CPV, $|V_{us}|$...
- Charm: mixing, CPV,...
- Many other topics:
  - ϒ(5S) physics, , ISR radiative return, spectroscopy, Dark Sector probe, low mass Higgs...
- Physics motivation is independent of LHC
  - If LHC finds NP, precision flavour input essential
  - If LHC finds no NP, high statistics B and τ decays are unique way of probing >TeV scale physics

Some fundamental questions to be addressed with the $50ab^{-1}$ e^+e^- dataset of Belle II:

- Are there new CP violating phases?
- Are there right-handed currents from New Physics?
- Are there flavour-changing neutral currents in the quark sector associated with New Physics?
- Are there sources of lepton flavour violation beyond the standard model?
- Are there new operators involving quarks enhanced by New Physics?
- Do Higgs bosons multiplets exist with a low-mass Higgs?
- What are the exotic QCD states?
- Is there a hidden dark sector that explains dark matter?

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 $(B \to X_s\ell\ell)$	~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
$A^{K^+K^-}_{CP}$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$	± 0.11	± 0.06	15
$A^{\pi^+\pi^-}_{CP}$ [10^{-2}]	$0.55 \pm 0.36 \pm 0.09$	± 0.17	± 0.06	> 50
$A^{\phi\gamma}_{CP}$ [10^{-2}]	± 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
$A^{\pi^0\pi^0}_{CP}$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	± 0.29	± 0.09	> 50
$A^{K^0_S\pi^0}_{CP}$ [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

Belle2-Note-021

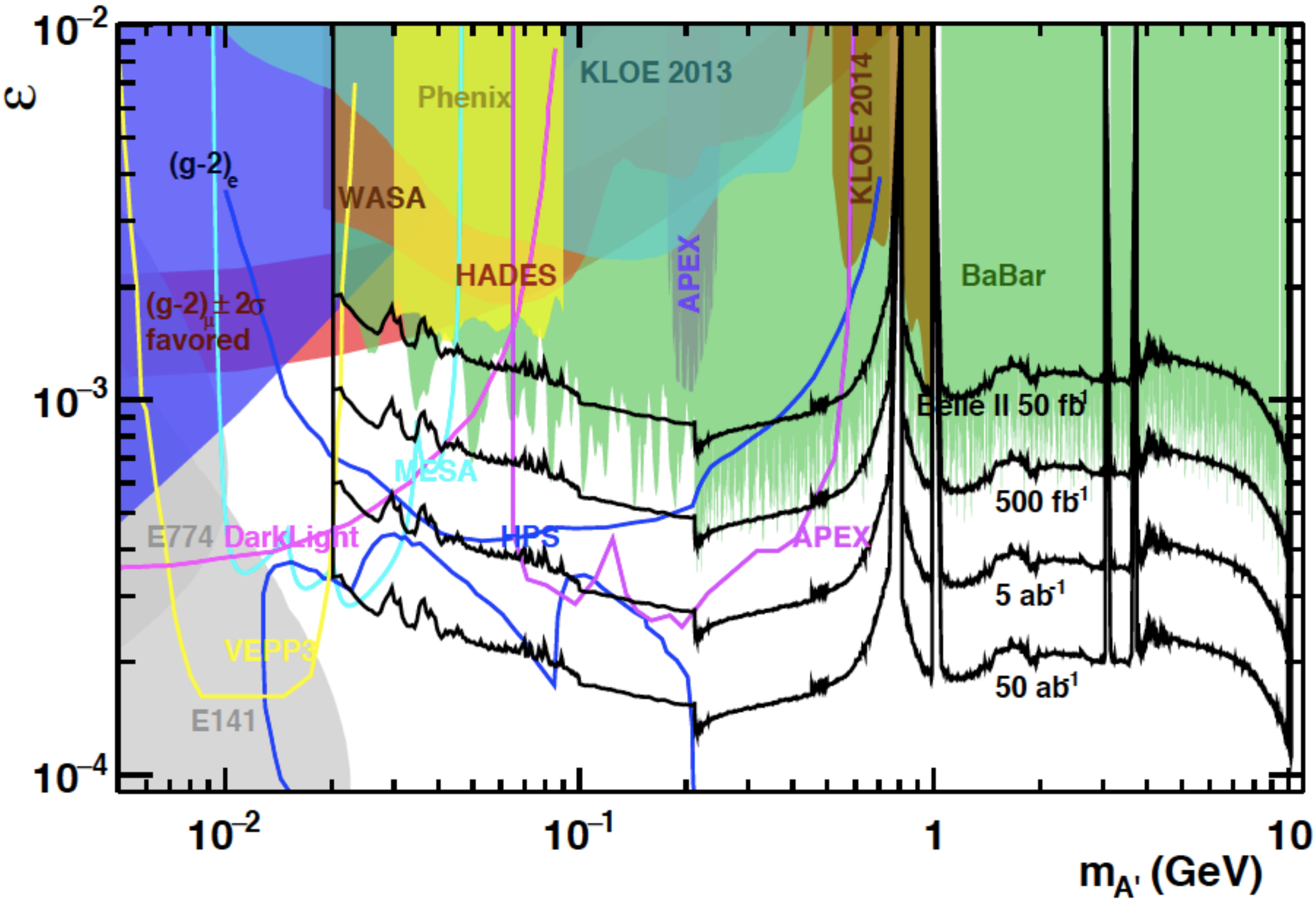
luminosity where
stat err = sys err

Strategy:

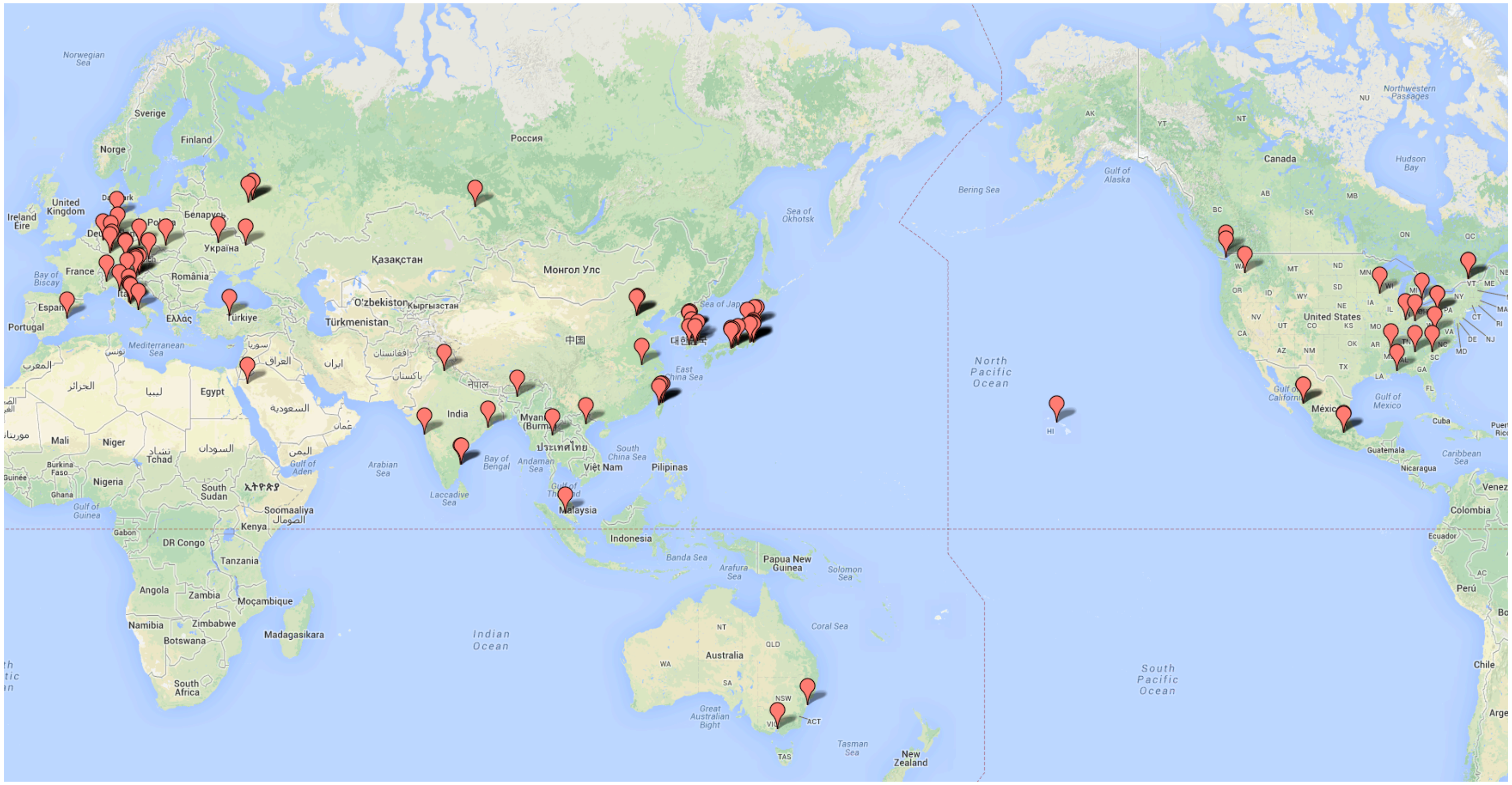
- Search for deviations from the SM in broad programme of physics
- If new physics is discovered, the pattern of deviations could elucidate its nature

Searching for Dark Photons at Belle II

(C .Hearty – Author/Ed. Dark Sector and Light Higgs chapter
Belle II First Year Physics Task Force Report)



Belle II Collaboration



~626 physicists (incl. students), 99 institutions, 25 countries

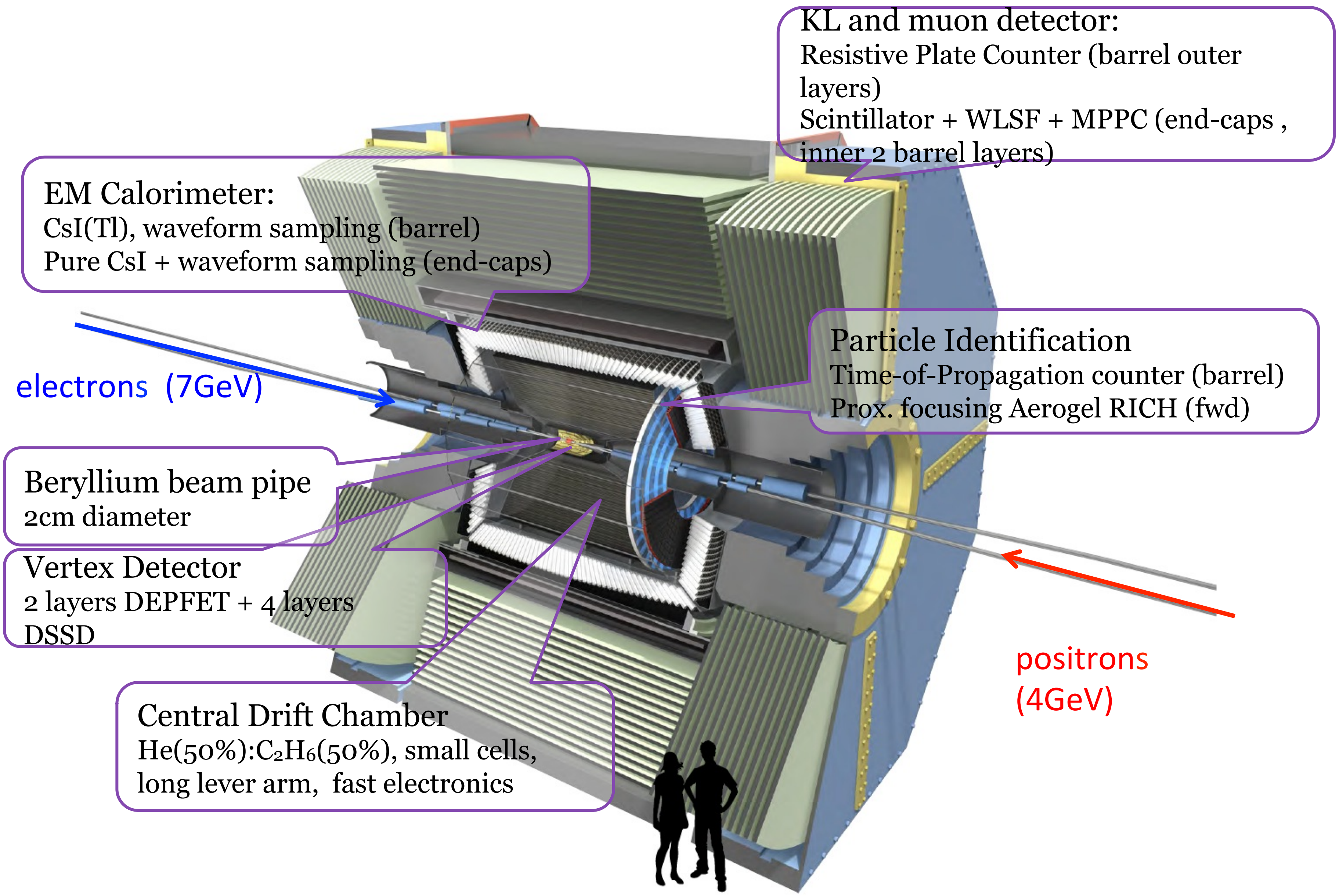
1/3 Japanese

1/3 European (Czech, Germany, Italy, Poland, Russia, Slovenia, Spain,Ukraine)

1/3 Other (Australia, Canada, China, India, Korea, U.S. etc)

Canada voted into Belle II March 2013 and approved as IPP Project April 2013

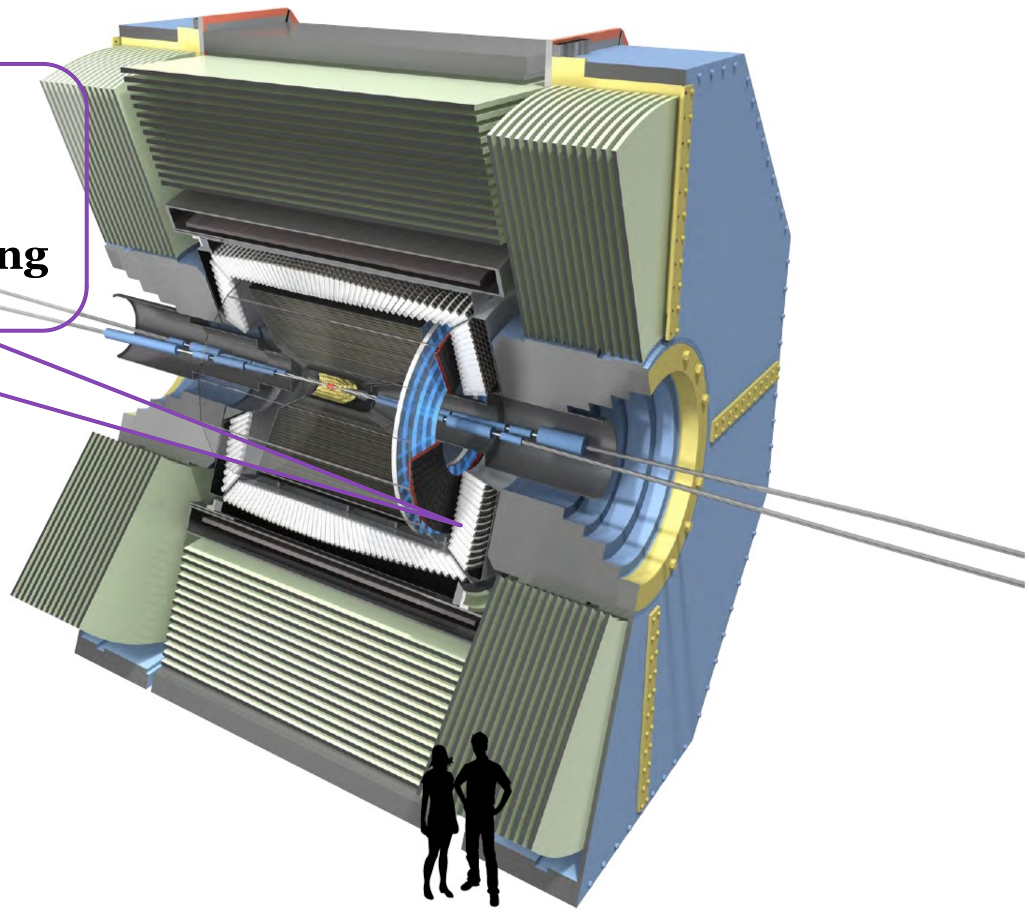
Belle II Detector



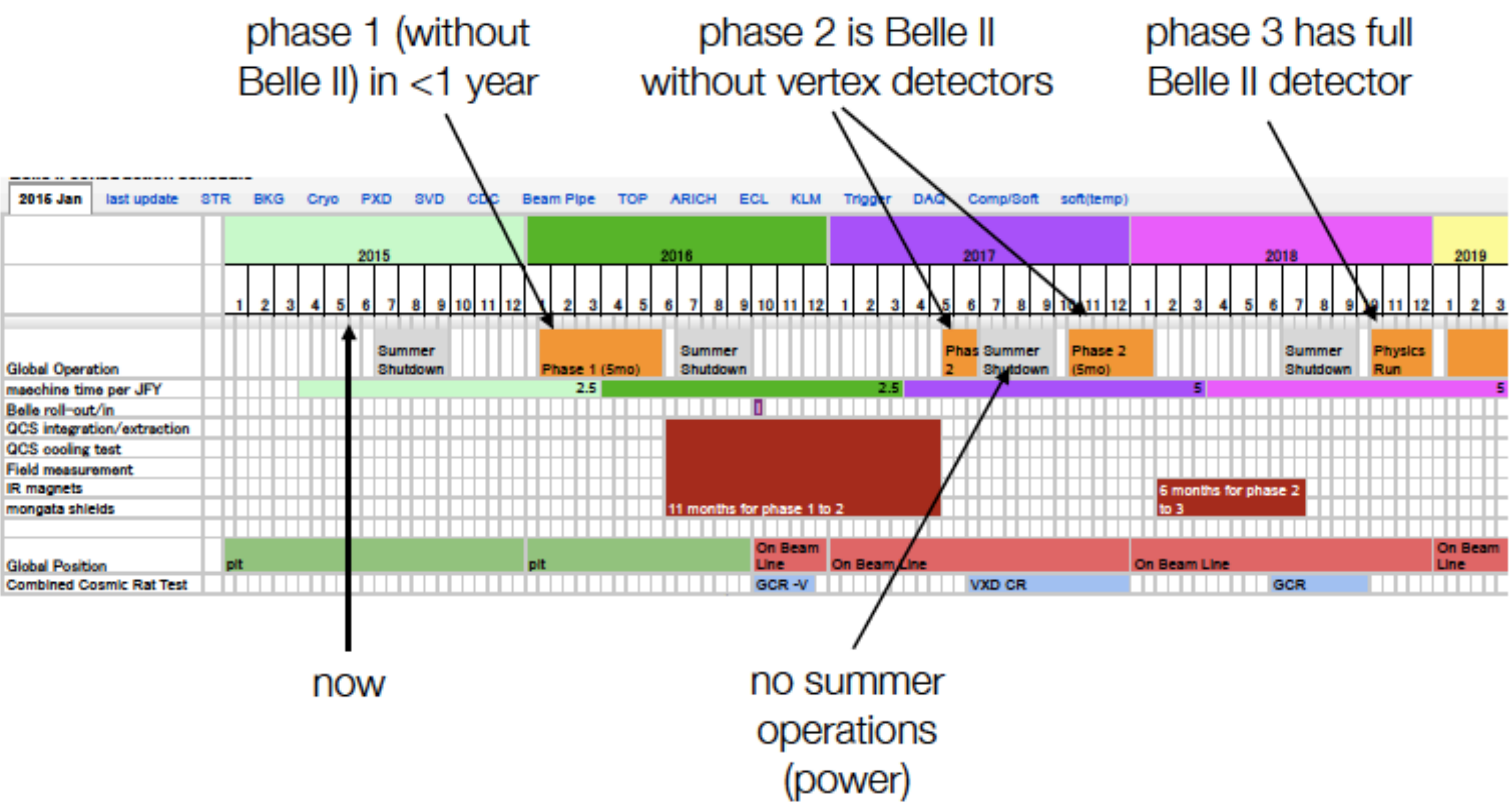
Belle II Detector

EM calorimeter: upgrade needed because of higher rates barrel: waveform sampling electronics
endcap: CsI(Tl) → pure CsI + waveform sampling electronics in original plan

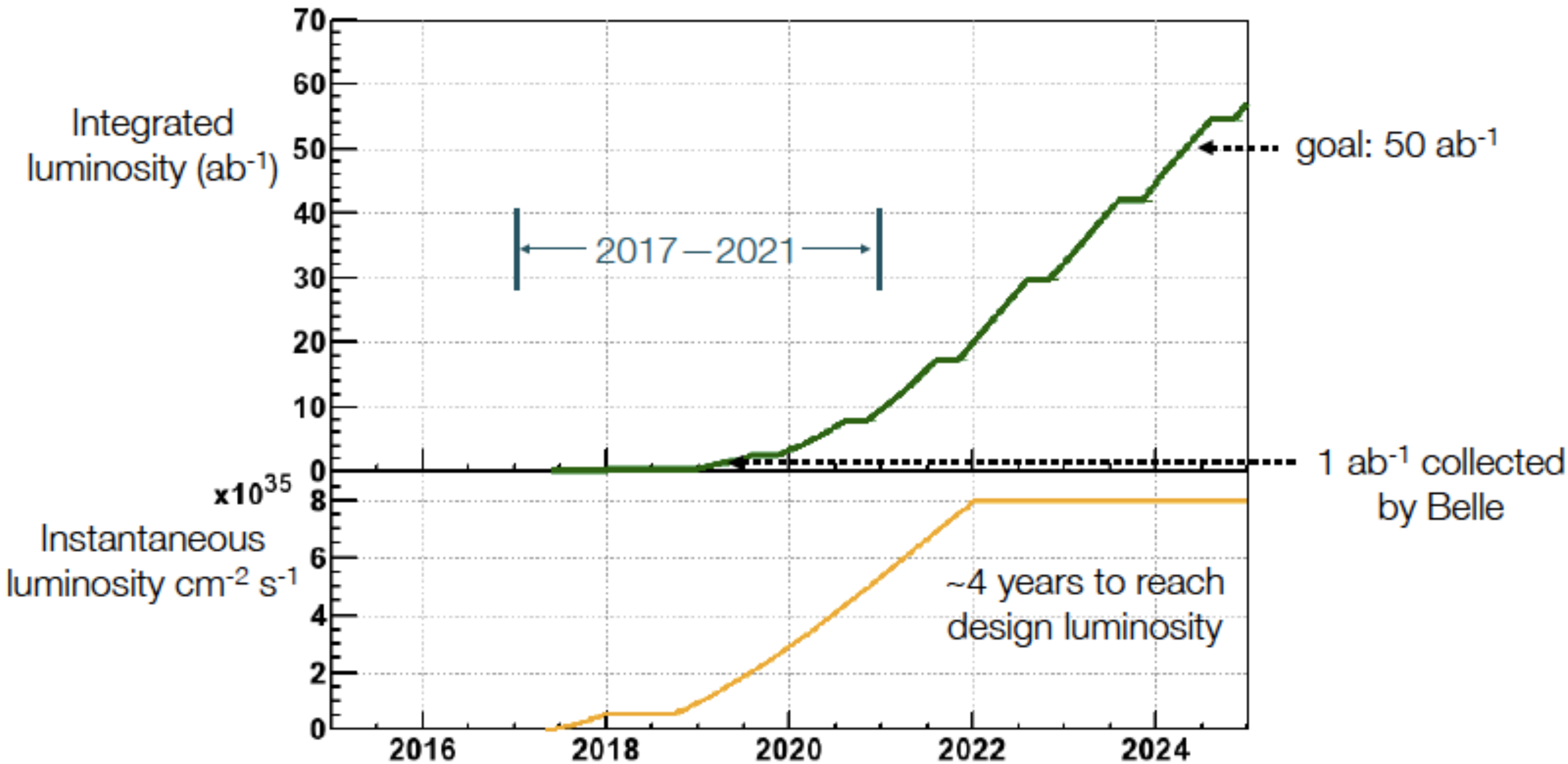
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)



SuperKEKB Construction and Commissioning Schedule



SuperKEKB/Belle II Schedule: Luminosity



J. Michael Roney

Canadian Group Contributions

Entry required significant contributions Belle II - invited to lead the upgrade of endcap electromagnetic calorimeter (ECL) with pure CsI crystals

- Join the ECL team and contribute:
  - Background and shielding studies
  - Design of new shielding for ECL
  - Background monitor to provide signal to SuperKEKB control room
- Prepare for pure CsI upgrade of regions of endcap; require combination of:
  - Physics studies with degraded resolution predicted by SuperKEKB simulated backgrounds and new shielding; determine physics impact using *BABAR* data and Monte Carlo and Belle II simulated backgrounds
  - Detector R&D for a pure CsI calorimeter:
    - electronics development with photopentodes
    - radiation damage of CsI →See SAVINO LONGO's presentation this morning
    - aging studies of photopentodes cathodes
- 2016 Commissioning of SuperKEKB Accelerator
  - Measure neutron and photon backgrounds in commissioning phase; use to determine accuracy of simulations of accelerator backgrounds

Canadian Group Contributions

- Software and Calibration of Full ECL detector in preparation for first physics
  - ECL reconstruction software with new readout electronics
  - Develop ECL simulation incorporating new readout electronics
  - Calibration of ECL with cosmic rays and prepare for calibration with control samples when first collisions arrive
  - Timing resolution studies with new Belle II electronics and SuperKEKB backgrounds – develop feature extraction algorithms
- Distributed computing – leadership in cloud computing
- Preparing for first physics

Canadian group determines that upgrade with pure CsI appears to yield small improvements, focus efforts on general ECL needs and prepare for possible upgrade if radiation damage studies justify this. Italian group is working towards full simulation with Belle II to re-evaluate physics case – should this come to a different conclusion, we will do the upgrade.

M11 Test Beam tests at TRIUMF Summer 2015

- Measure single crystal timing resolutions of CsI(Tl) and CsI under various **Belle II estimated background levels** and with different **digital filtering algorithms.**

Timing Resolution Studies (A. Hershonhorn, C. Hearty, UBC)

- **Advantages of good timing resolution**
  - Allows rejection of background which is uniformly distributed in time - improving energy resolution.
  - Accurate timing will probably be important in event reconstruction.

- **CsI versus CsI(Tl)**
  - CsI's fast component decay time (20-30 ns) is much faster than CsI(Tl) (1 μs).
    CsI should have better timing resolution.

The M11 Beam

e, μ, π in momentum range 60-450 MeV/c

Rate of 10-50 Hz

Need to separate e, μ, π with TOF

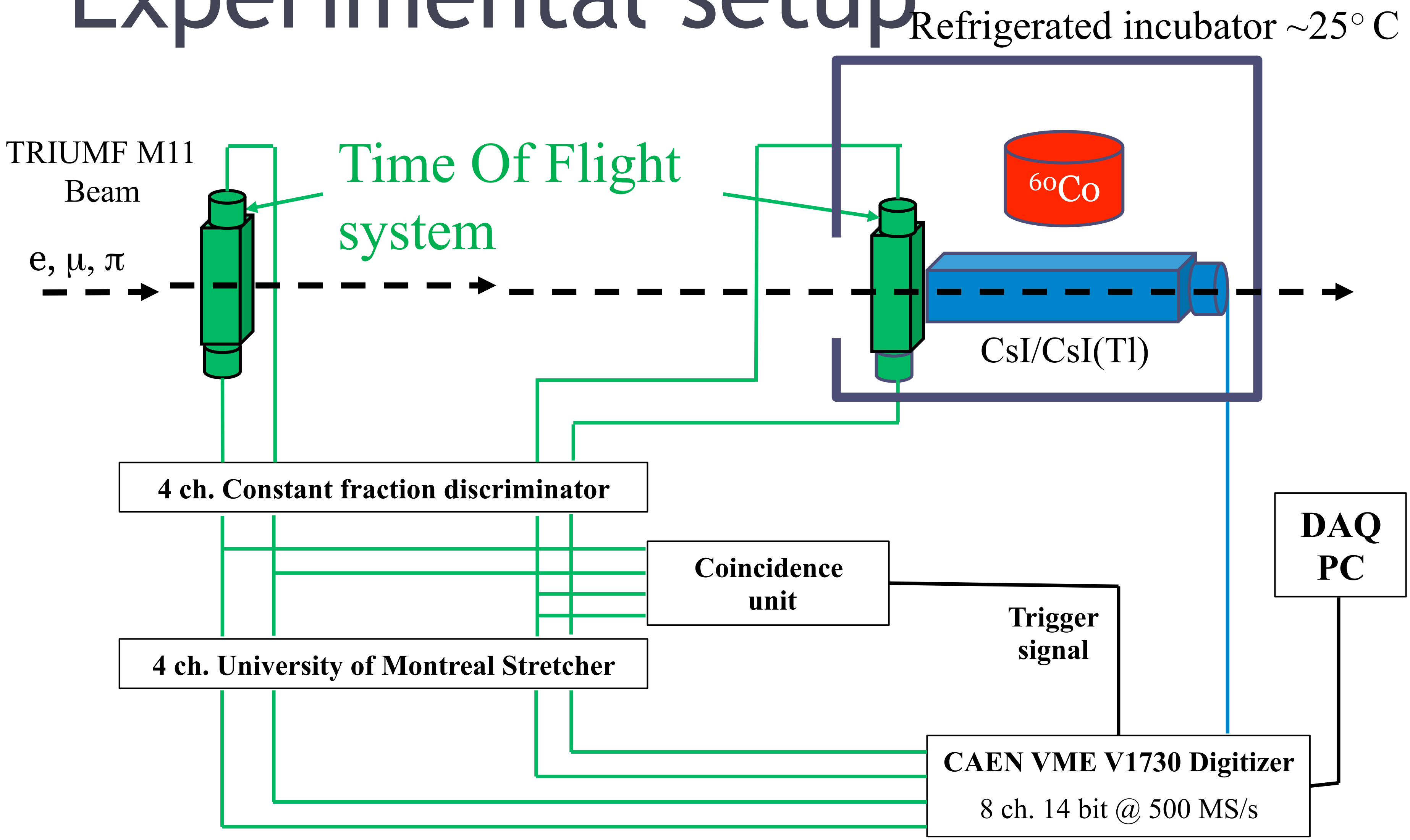
Crystals and Preamps

- **Pure CsI**
  - 2 Crystals from different manufacturers
    - Ukrainian – AMCRYS; 30×8×6.5 cm; S/N 122
    - Chinese – SICCAS; 30×8×6 cm; S/N 8
  - Hamamatsu R11283 Photopentode + custom Montreal preamp/voltage divider

- **Spare Belle CsI(Tl) barrel crystal; S/N 21745**
  - Standard Belle PIN diodes and preamps

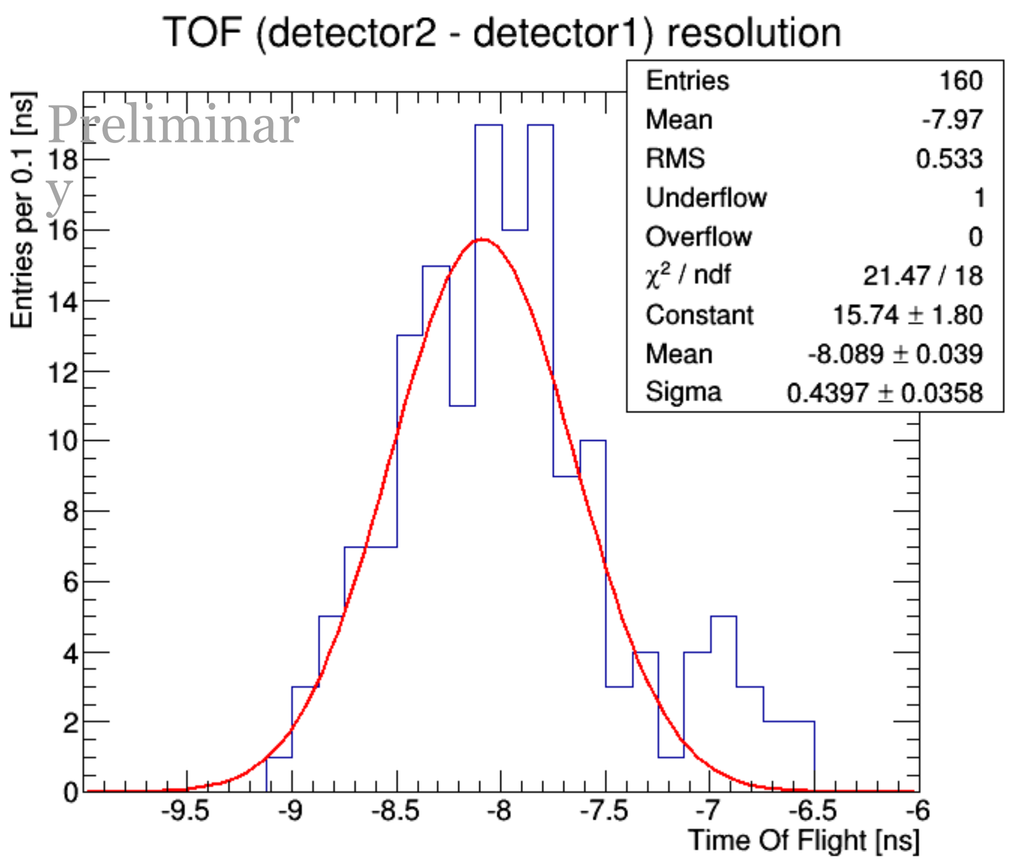
- **Radiation damaged CsI(Tl) endcap crystal** – if available after University of Victoria finishes their studies on it

Experimental setup



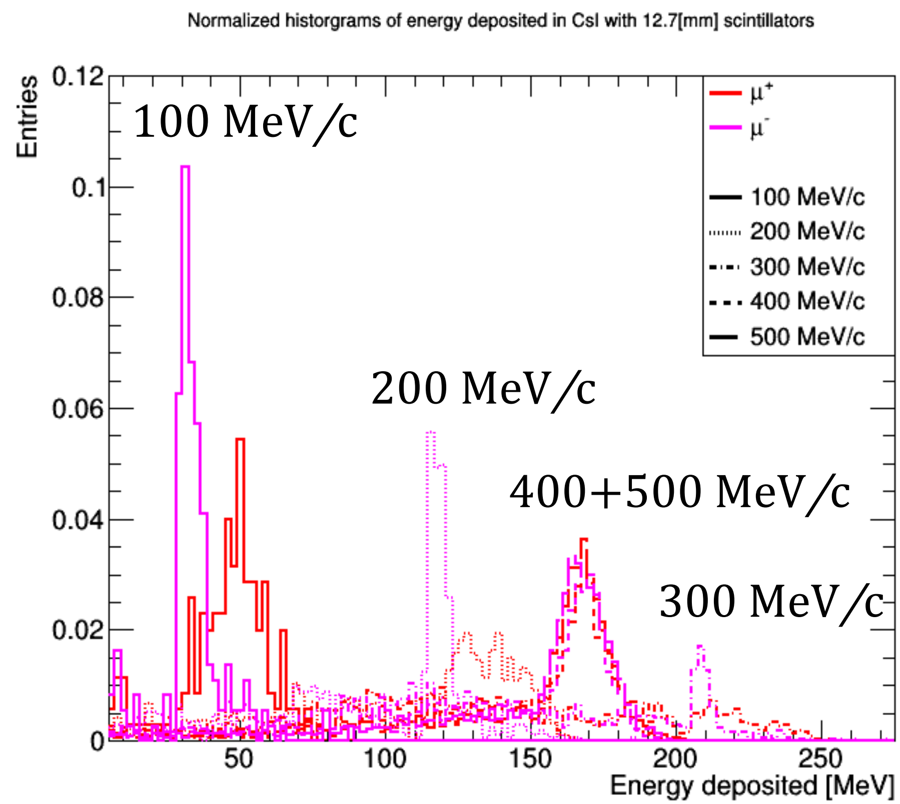
TOF timing resolution

- Using cosmic events and the stretcher.
- TOF timing resolution : **440 ps**.



GEANT simulation of beam test

- Energy deposited by muons with different momenta
  - 200 MeV/c muons might be used to try to measure energy resolution of the crystals.



Electronics ECL development at Montreal

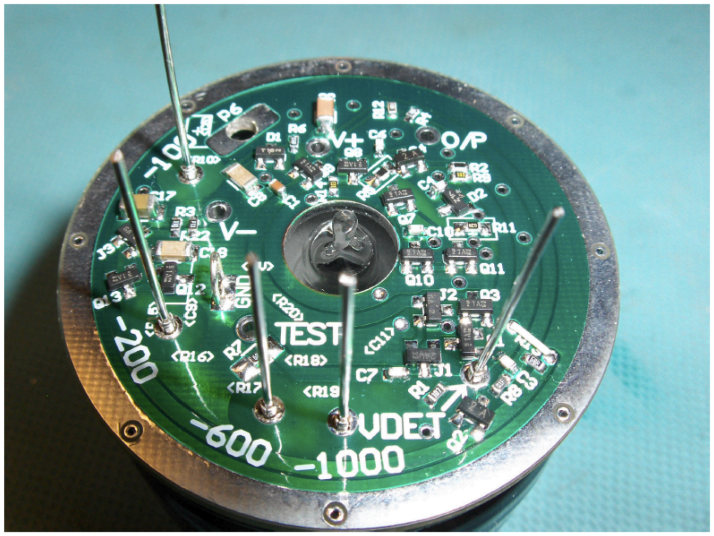
U. de Montreal Group: J.-P. Martin, N.A. Starinski, P. Taras

- **Preamp development for photopentode used with pure CsI crystal in a 1.5T magnetic field**
- **Digital Signal Processor – will be used in the TRIUMF M11 test beam experiment**
- **Pulse Stretcher used for test beam**

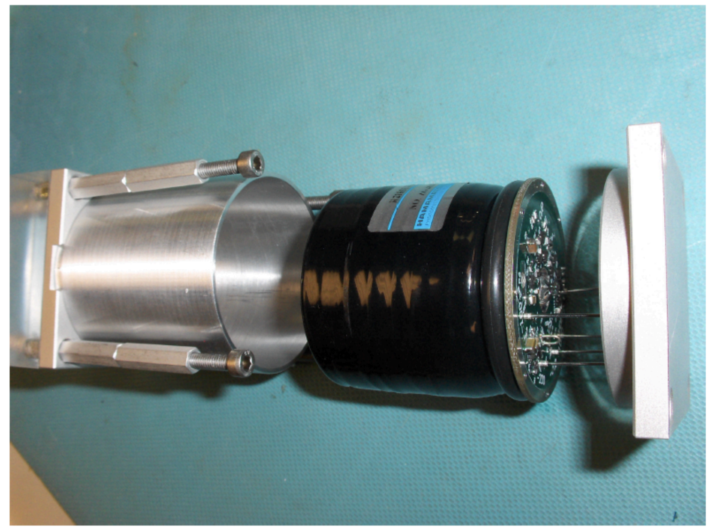
Fast charge-sensitive preamplifier for pure CsI crystals

U. de Montreal Group: J.-P. Martin, N.A. Starinski, P. Taras

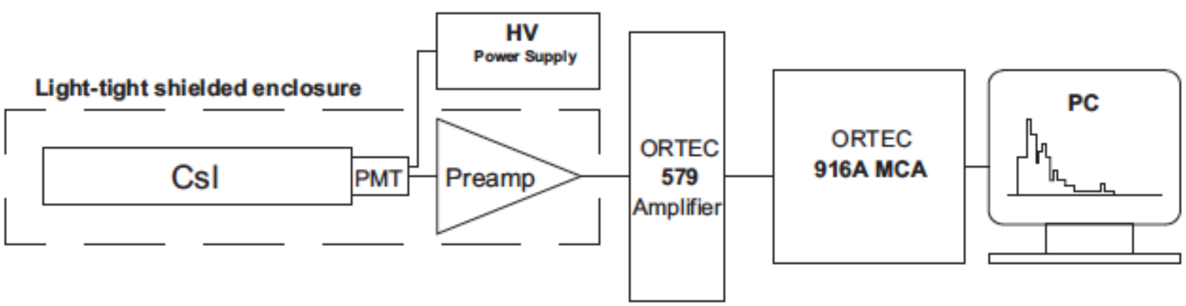
Nucl. Instr. Methods, A778(2015)120-125



Preamplifier with HV divider



Photomultiplier mounted with preamplifier and Faraday cage



Fast charge-sensitive preamplifier for pure CsI crystals

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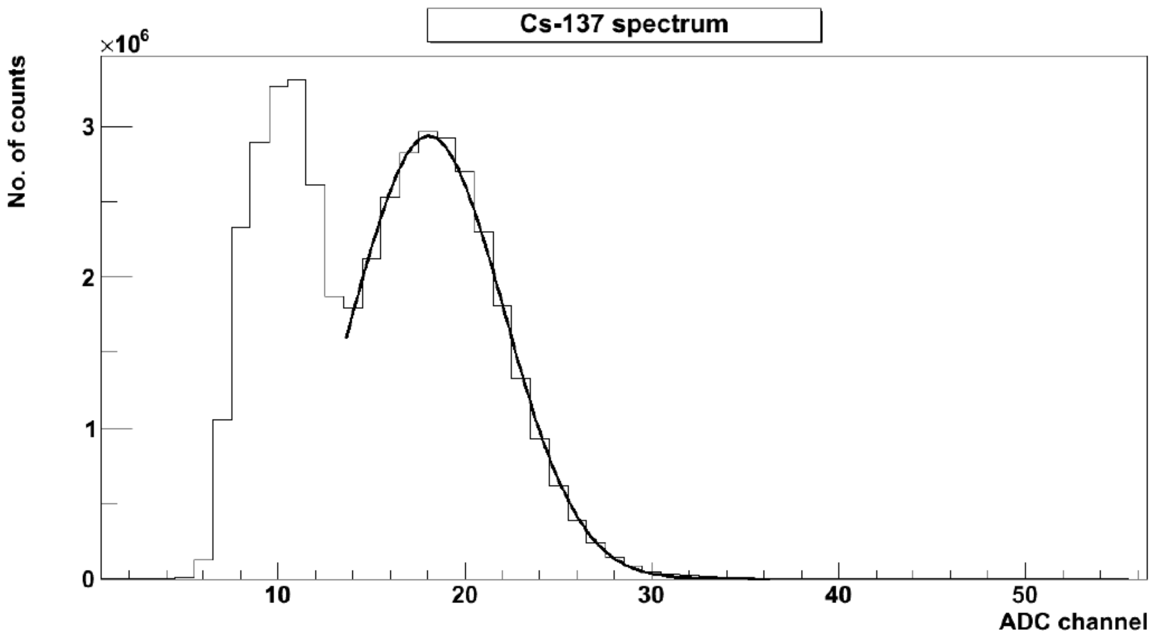
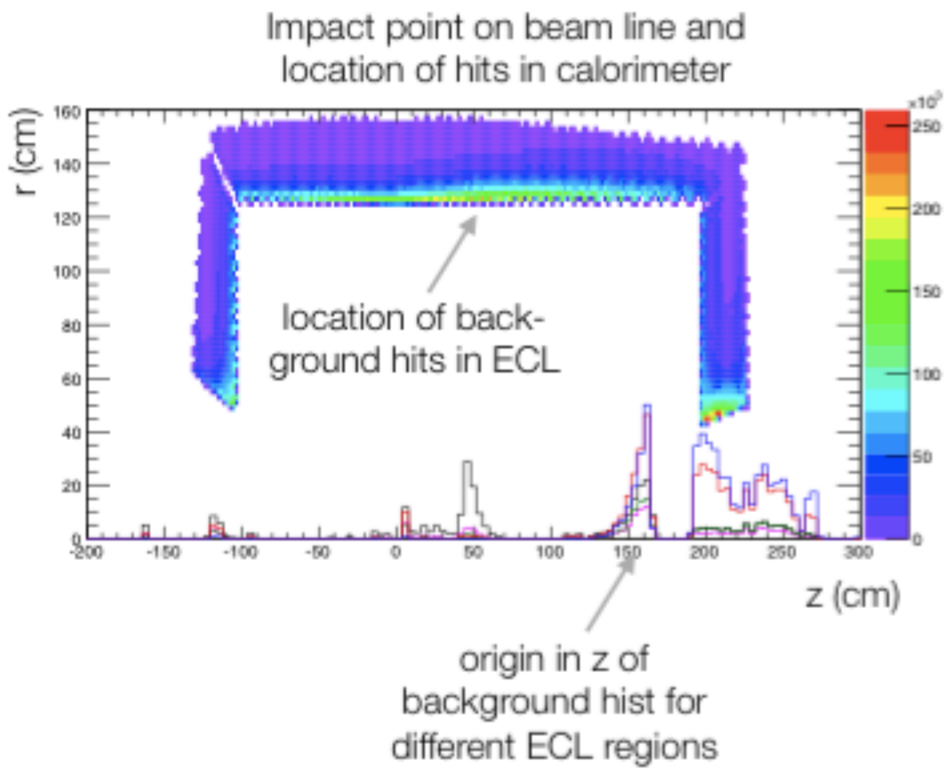
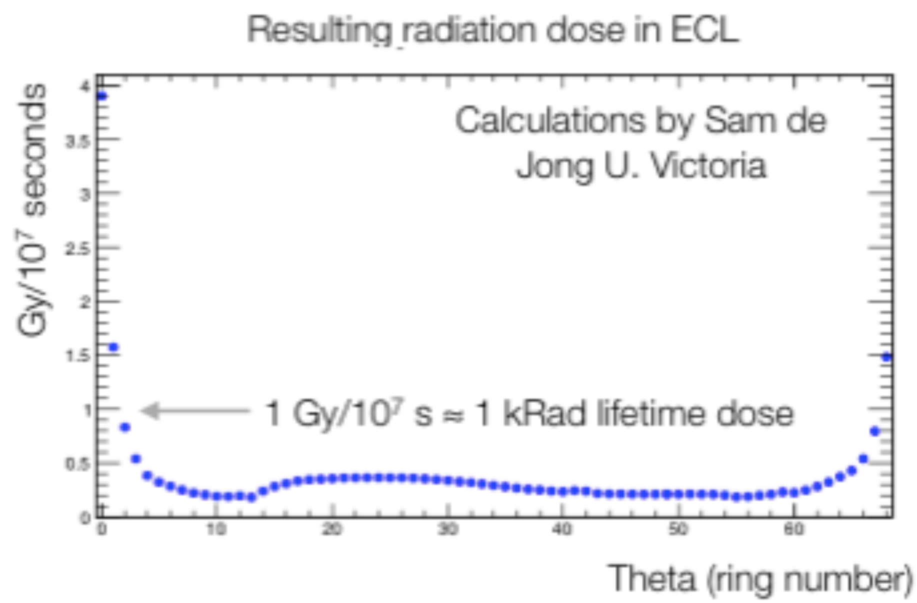


^{137}Cs spectrum measured with a pure CsI crystal, photopentode, and Montreal preamplifier

Preamplifier meets all required specs:

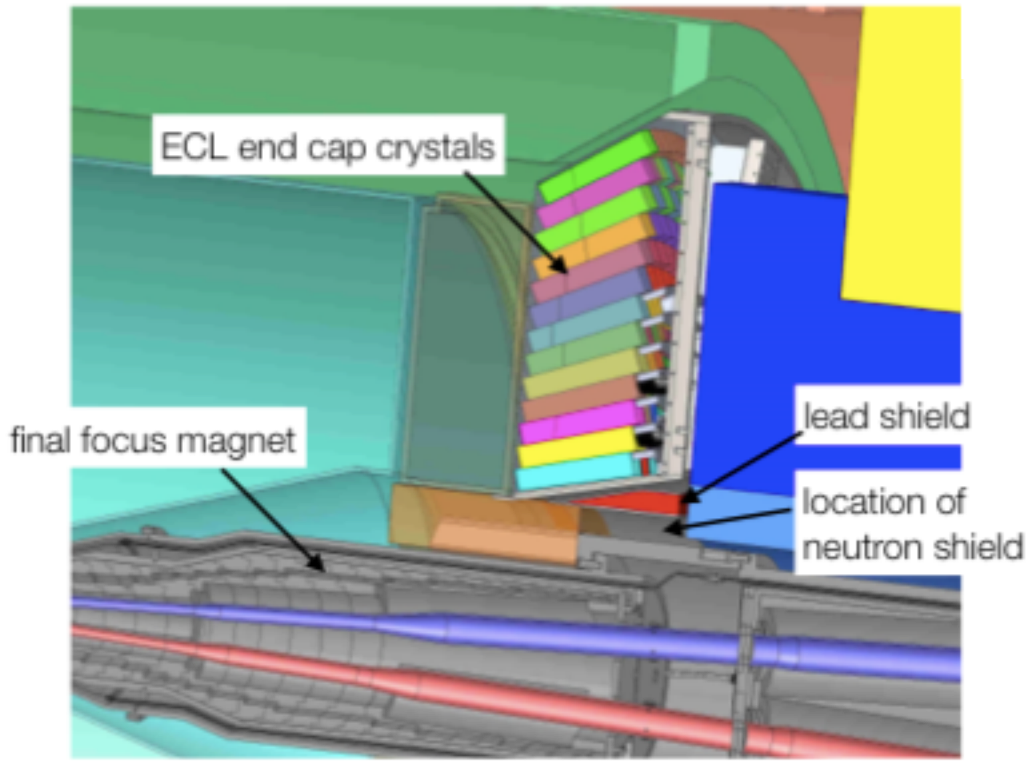
- good energy resolution:
  - 50ns shaping time → σ = 120keV for 662keV ^{137}Cs photon
  - 500ns shaping time → σ = 70keV
- low electronic noise: → σ = 40keV – much better than existing CsI(Tl)
- acceptably low power dissipation: 140 mW


Impact point on beam line and
location of hits in calorimeter
r (cm)
z (cm)
location of back-
ground hits in ECL
origin in z of
background hist for
different ECL regions


Resulting radiation dose in ECL
Gy/10^7 seconds
Calculations by Sam de
Jong U. Victoria
1 Gy/10^7 s ≈ 1 kRad lifetime dose
Theta (ring number)

Shield to be lead + polyethylene (neutron absorber)
- designed by Alex Beaulieu, who is overseeing its construction in Canada

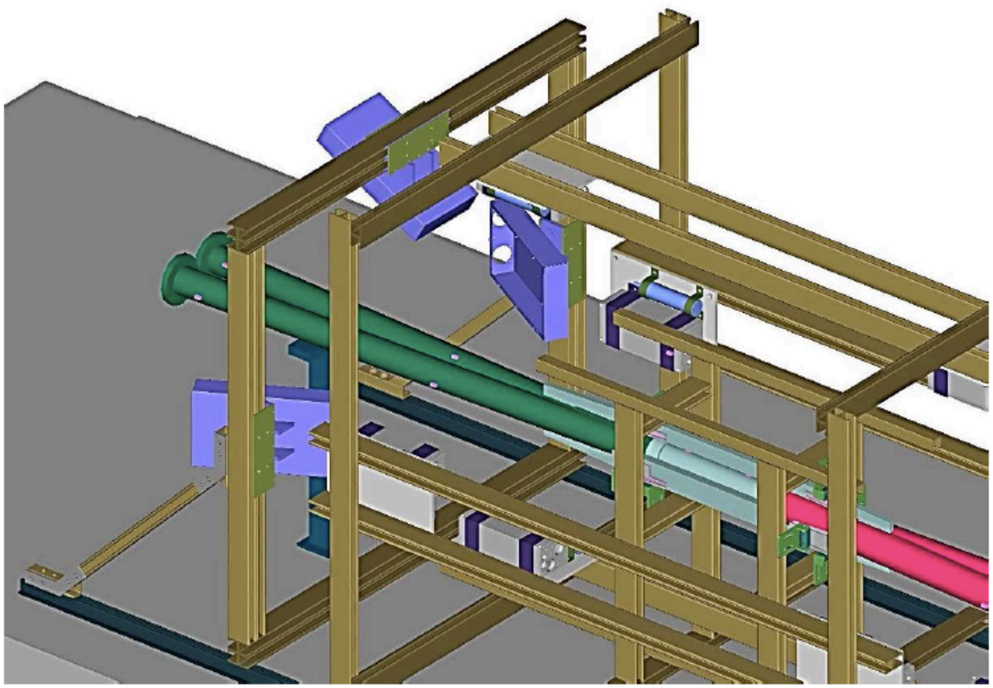
ECL shield, lead only

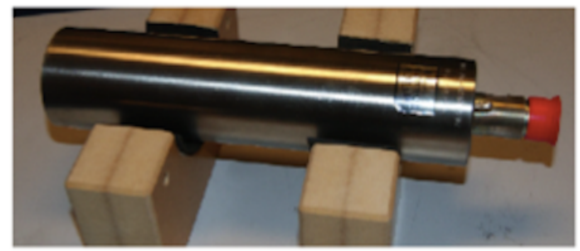


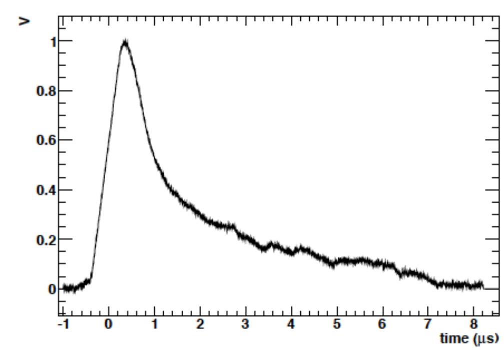
Thermal Neutron Detector System in 'BEAST II' Commissioning Detector

In Phase 1 of commissioning – 2016 -

Measure neutron backgrounds from Tousheck and Beam-gas rates to validate/Correct MC simulation for projections to higher luminosities





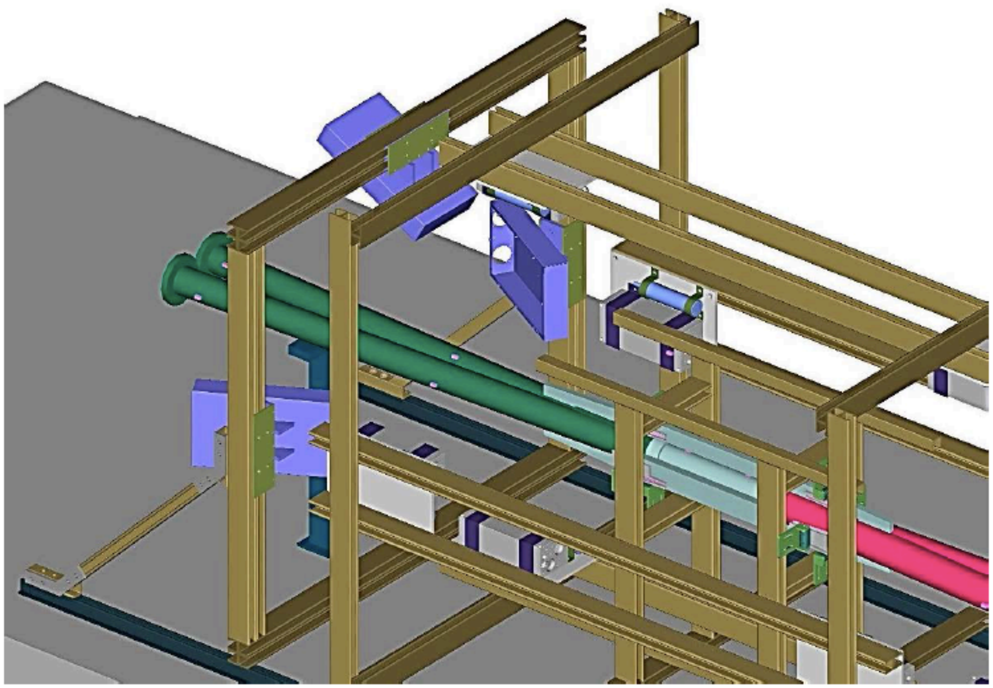


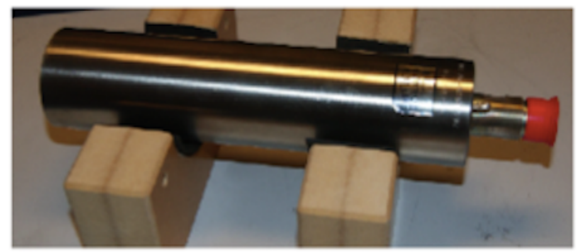
He-3 detector signal of thermal neutrons from UVic neutron source

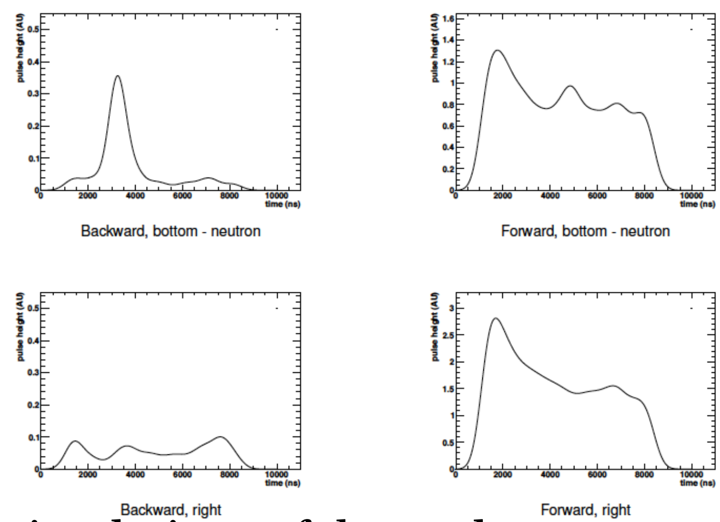
Thermal Neutron Detector System in 'BEAST II' Commissioning Detector

In Phase 1 of commissioning – 2016 -

Measure neutron backgrounds from Tousheck and Beam-gas rates to validate/Correct MC simulation for projections to higher luminosities





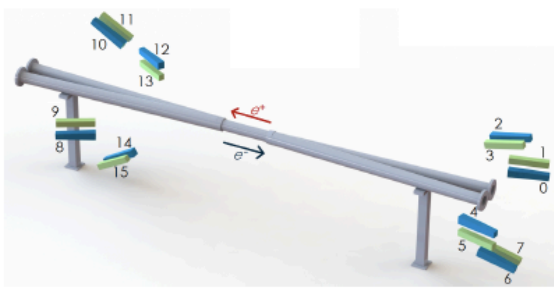


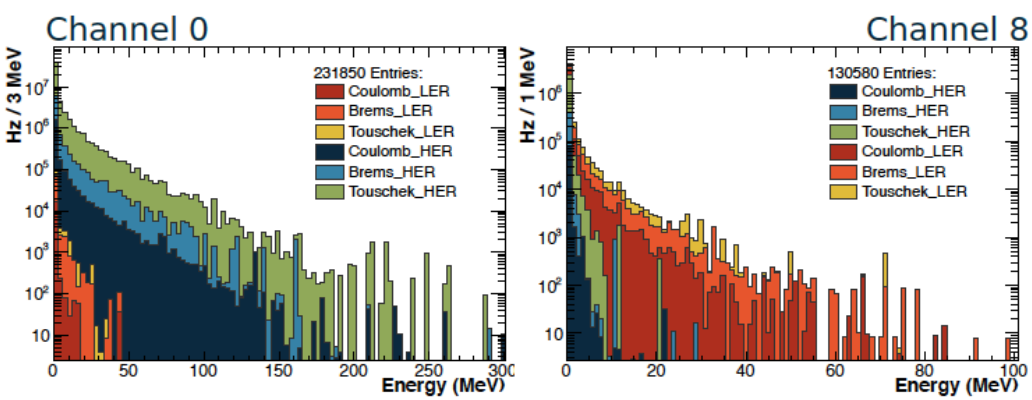
simulations of thermal neutron signals from Tousheck

CsI(Tl) Photon Detector System in 'BEAST II' Commissioning Detector - In Phase 1 of commissioning – 2016 -

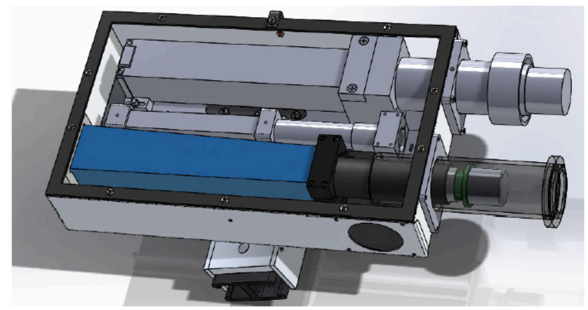
Measure photon backgrounds at position of ECL from Tousheck and Beam-gas rates to validate/Correct MC simulation for projections to higher luminosities

The expected background distributions





Mechanical Integration



Also: installation on phase 1 structure validated for all configurations. Total mass is 14.0kg.

Mechanical Integration

Also: installation on phase 1 structure validated for all configurations. Total mass is 14.0kg.

CsI(Tl) Photon Detector System in 'BEAST II' Commissioning Detector - In Phase 1 of commissioning – 2016 -

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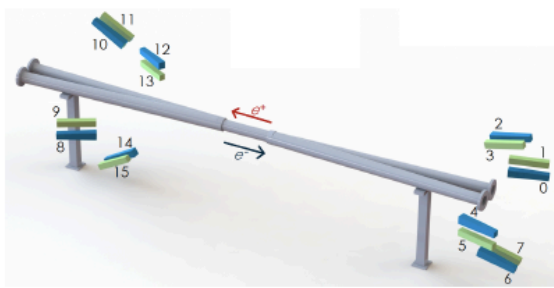
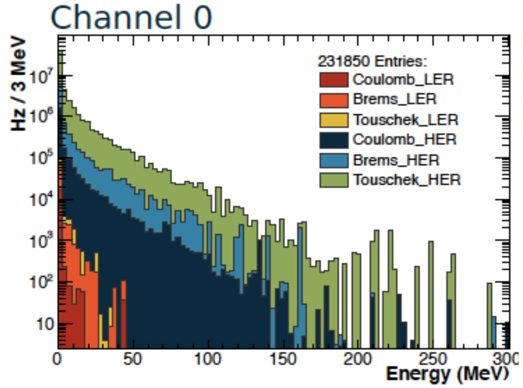
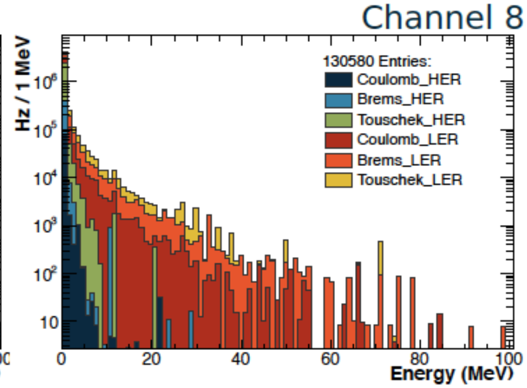
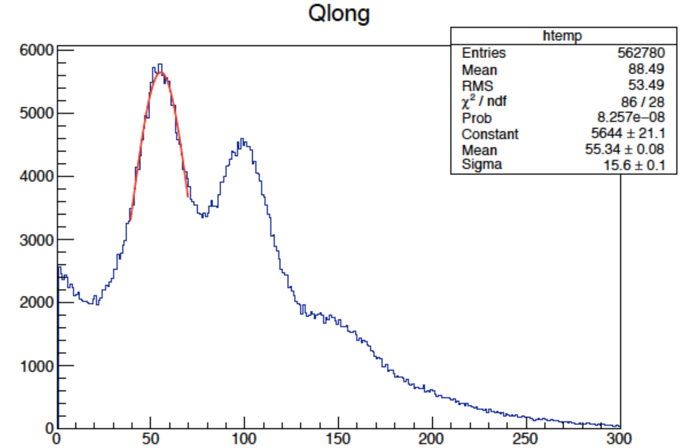




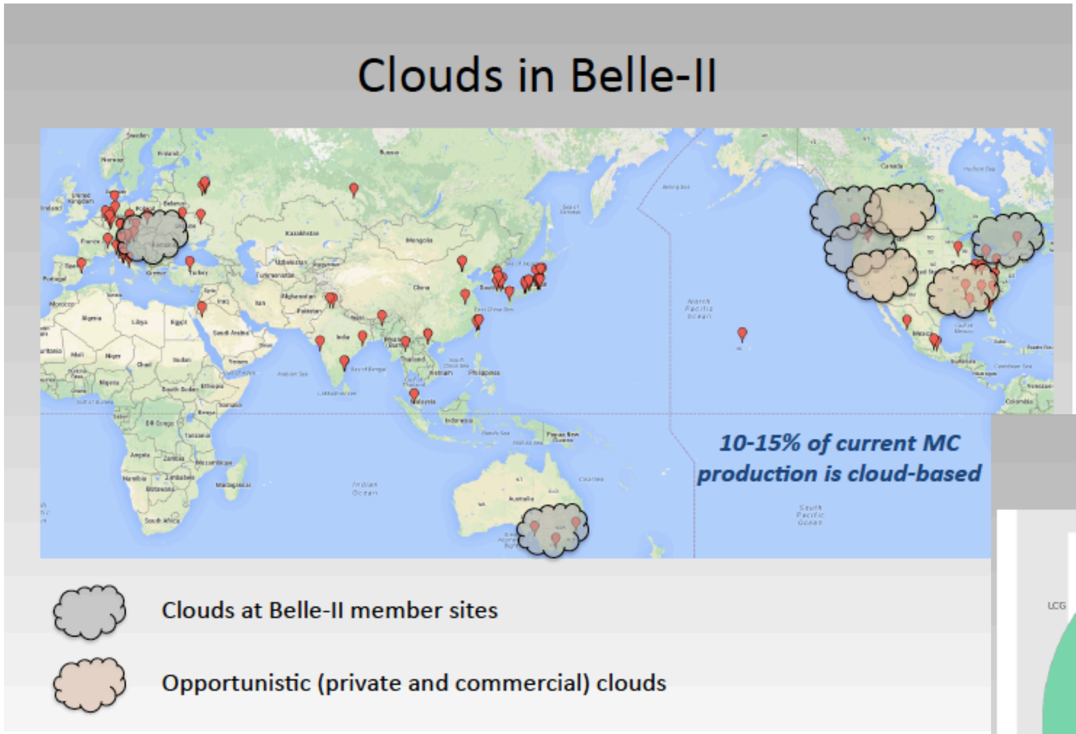


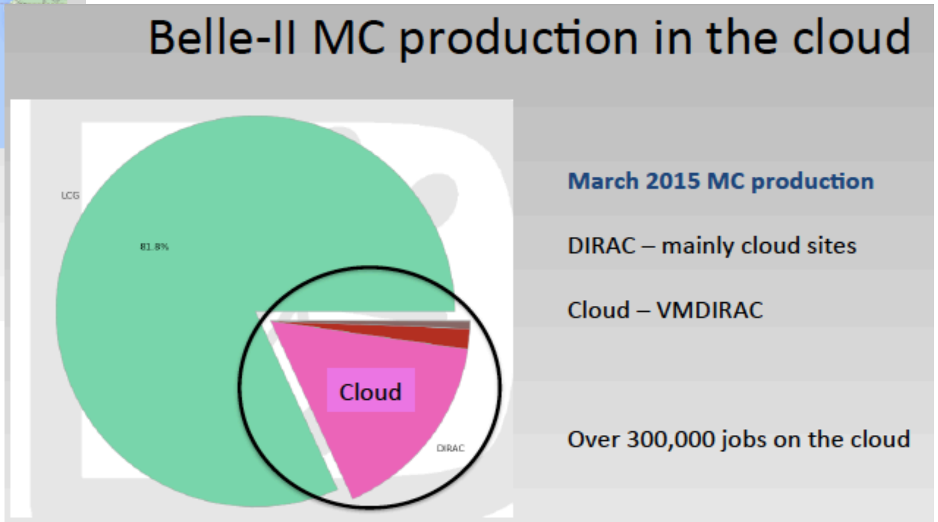


^{207}Bi spectrum from CsI(Tl) crystals at UVic

Belle II Computing

Randy Sobie heads Canada's effort and leads N. American cloud computing

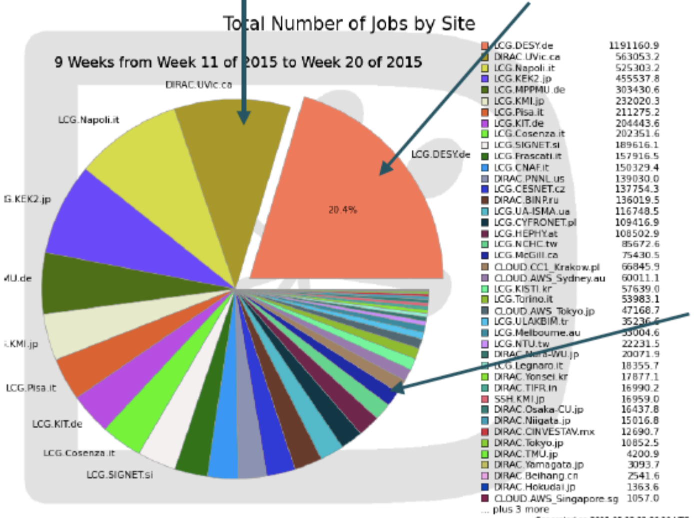




Belle II Cloud Computing
N. American lead: Randy Sobie (IPP)

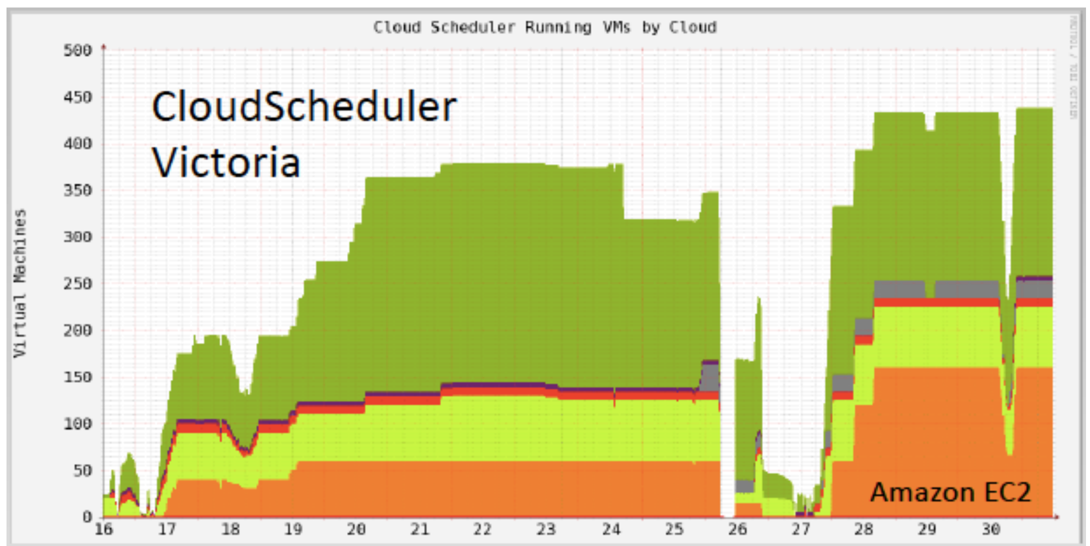
Canadian cloud (Victoria and Sherbrooke)

DESY grid



McGill (grid)

Also uses commercial cloud resources– e.g. grant from Amazon



UVic

Summary

- SuperKEKB e^+e^- flavour factory provides broad and exciting physics program with sensitivity to new physics that is complementary to the LHC
- Belle II and SuperKEKB are on track for Phase 1 commissioning in 2016, Phase 2 in 2017 and First Physics in 2018 at Phase 3
- Canadian team is contributing to the ECL effort, monitoring detectors, commissioning detectors and ECL shield
- Canadian team contributing to physics readiness
- Prepare for exciting times at the precision frontier!

Additional slides

Super Flavour Factory Physics Program Summary

B Physics at the $\Upsilon(4S)$

A. New Physics in CP violation
   1. ΔS measurements
B. Theoretical aspects of rare decays
   1. New physics in $B \to K^{(*)}\nu\bar{\nu}$ decays
   2. $\bar{B} \to X_s\gamma$ and $\bar{B} \to X_s\ell^+\ell^-$
   3. Angular analysis of $B \to K^* l^+ l^-$
   4. $\bar{B} \to X_d\gamma$ and $\bar{B} \to X_d\ell^+\ell^-$
C. Experimental aspects of rare decays
   1. $B \to K^{(*)}\nu\bar{\nu}$
   2. $B \to \ell\nu$ and $B \to \ell\nu\gamma$
   3. Experimental aspects of $\bar{B} \to X_s\gamma$
   4. Inclusive and exclusive $b \to s\ell^+\ell^-$
   5. More on $B \to X_{s/d}\ell^+\ell^-$ with a hadron tag
D. Determination of $|V_{ub}|$ and $|V_{cb}|$
   1. Inclusive Determination of $|V_{ub}|$
   2. Inclusive Determination of $|V_{cb}|$
E. Studies in Mixing and CP Violation in Mixing
   1. Measurements of the mixing frequency and CP asymmetries
   2. New Physics in mixing
   3. Tests of CPT
F. Why measure γ precisely (and how)?
G. Charmless hadronic B decays
H. Precision CKM

B Physics at the $\Upsilon(5S)$

1. Measurement of B_s Mixing Parameters
2. Time Dependent CP Asymmetries at the $\Upsilon(5S)$
3. Rare Radiative B_s Decays
4. Measurement of $B_s \to \gamma\gamma$
5. Phenomenological Implications

Super Flavour Factory Physics Program Summary

Electroweak neutral current measurements

Spectroscopy
A. Introduction
B. Light Mesons
C. Charmonium
D. Bottomonium
  1. Regular bottomonium
  2. Exotic bottomonium
E. Interplay with other experiments

Direct Searches
A. Light Higgs
B. Invisible decays and Dark Matter
C. Dark Forces

τ physics
A. Lepton Flavor Violation in τ decay
  Predictions from New Physics models
    LFV in the MSSM
    LFV in other scenarios
  Super*B* experimental reach
B. *CP* Violation in τ decay
C. Measurement of the τ electric dipole moment
D. Measurement of the τ $g-2$
E. Search for second-class currents

J. Michael Roney
UVic

Super Flavour Factory Physics Program Summary

Charm Physics

A. On the Uniqueness of Charm
B. $D^0 - \bar{D}^0$ Oscillations
   1. Experimental Status
   2. Combination of measurements and CPV
   3. Measurements of strong phases
   4. Theoretical Interpretation
   5. Measuring x_D and y_D at Super$B$
   6. Projections for mixing measurements at Super$B$
   7. Estimated sensitivity to CPV from mixing measurements
C. CP Violation
   1. Generalities
   2. SM Expectations
   3. Experimental Landscape
   4. Littlest Higgs Models with T Parity – A Viable Non-ad-hoc Scenario
D. Rare Decays
   1. $D^0 \to \mu^+\mu^-, \gamma\gamma$
   2. $D \to l^+l^-X$
E. Experimental possibilities for rare decay searches at Super$B$
   1. $D \to l^+l^-X$
F. A case for Running at the $D\bar{D}$ threshold?

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0]$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

Physics Reach of Belle II, LHCb and kaon experiment upgrades

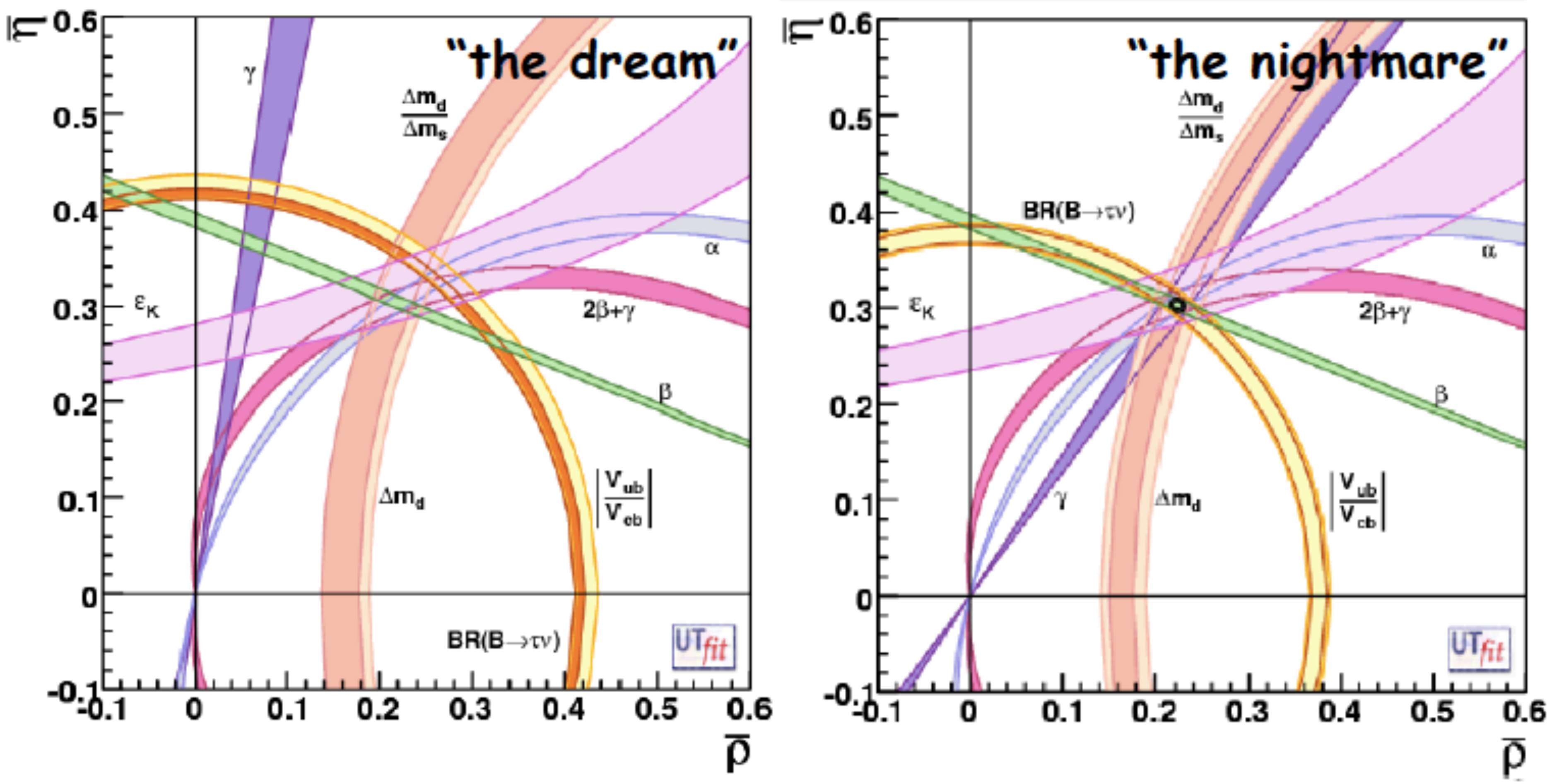
Expansive, rich programme of flavour physics complementary to LHC and LHCb

Continues to evolve in context of on going measurements from LHCb and new physics constraints from ATLAS and CMS

- LHCb is main competition in B and charm physics; but LHCb and Belle II are also complementary. LHCb has limited capabilities for decays that have photons or neutrinos whereas Belle II has advantages of
  - precisely known initial state (e^+e^-) providing additional powerful constraints used in searches involving invisible particles
  - inclusive trigger
  - hermetic detector

Belle II unique position to study inclusive processes and decays with neutrals and missing energy – *critical for Belle II to have excellent electromagnetic calorimetry*

End of next-generation flavour experiments



Future – CKMFitter Group

Future sensitivity to new physics in

Bd, *Bs* , and *K* mixings Phys. Rev. D 89, 033016 – Published 27 February 2014

We estimate, in a large class of scenarios, the sensitivity to new physics in B_d and B_s mixings achievable with $50\,\text{ab}^{-1}$ of Belle II and $50\,\text{fb}^{-1}$ of LHCb data. We find that current limits on new physics contributions in both $B_{d,s}$ systems can be improved by a factor of ~ 5 for all values of the CP-violating phases, corresponding to over a factor of 2 increase in the scale of new physics probed. Assuming the same suppressions by Cabbibo-Kobayashi-Maskawa matrix elements as those of the standard model box diagrams, the scale probed will be about 20 TeV for tree-level new physics contributions, and about 2 TeV for new physics arising at one loop. We also explore the future sensitivity to new physics in K mixing. Implications for generic new physics and for various specific scenarios, such as minimal flavor violation, light third-generation dominated flavor violation, or $U(2)$ flavor models are studied.

University of Montreal's Stretcher

- TOF signal rise times are ~1.6 ns. V1730 digitizer interval is 2 ns. In order to have better resolution we'll use university of Montreal's custom "Stretcher".

- Converts NIM pulse into a long tailed pulse (~ μs).
  - Allows many measurements of TOF pulse, improving TOF timing resolution.