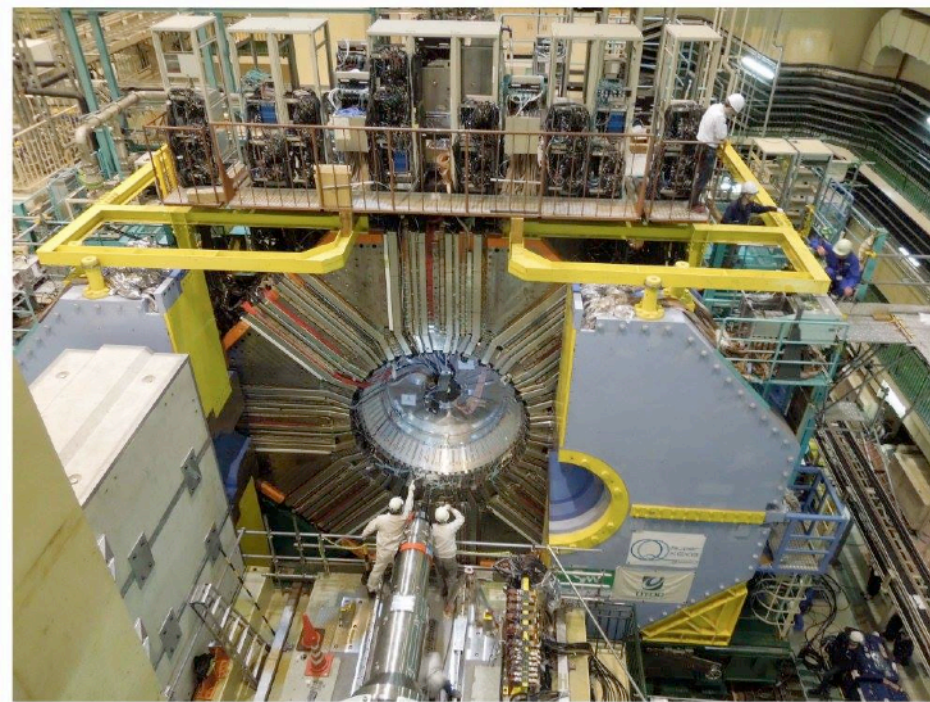


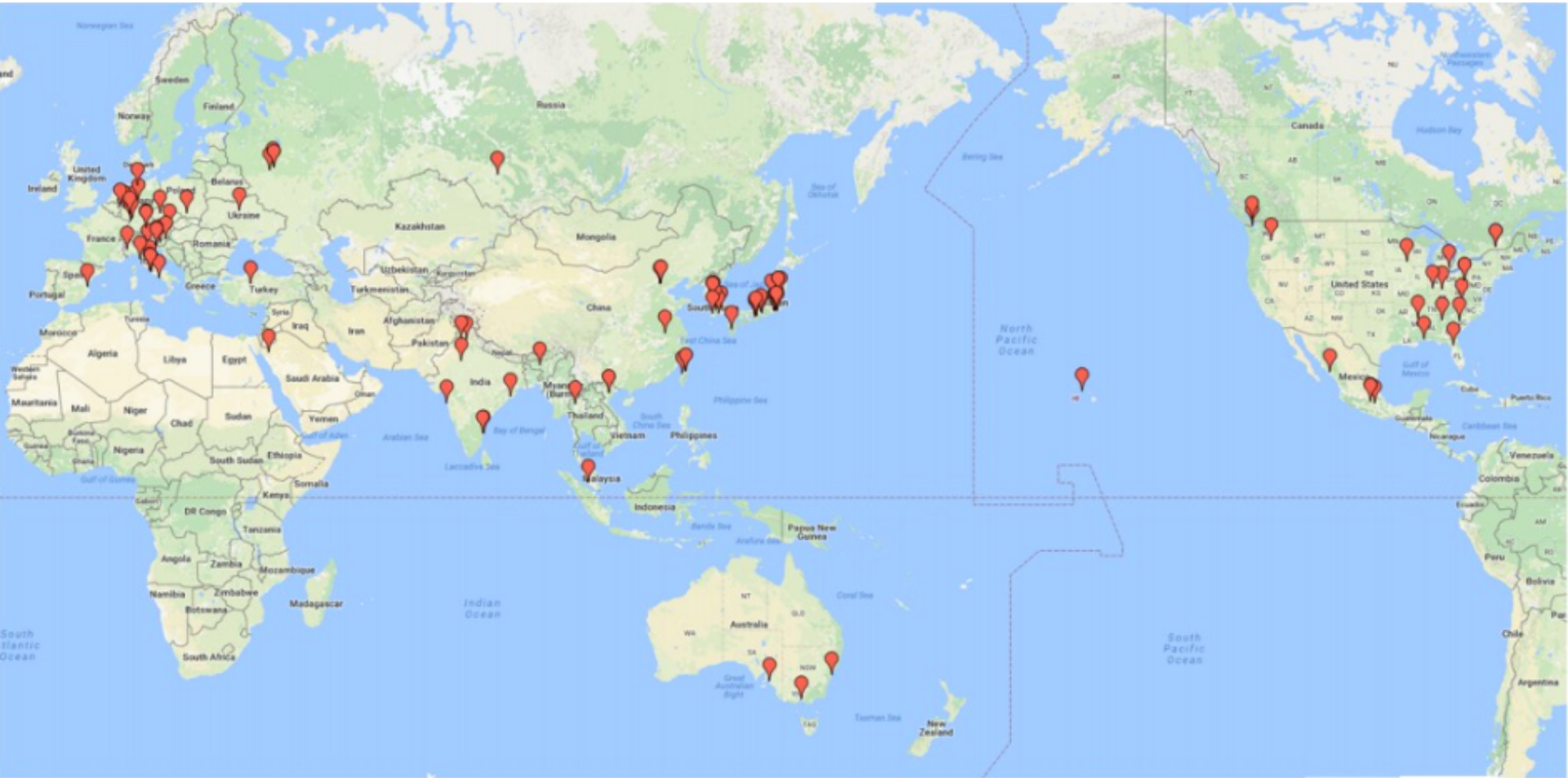
Lepton Number and Universality Violation at Belle

David Cinabro (Wayne State University)
for the Belle Collaboration



Belle II installed at the SuperKEKB interaction point, 11 April

Belle II Collaboration



~100 Institutions, ~700 Members

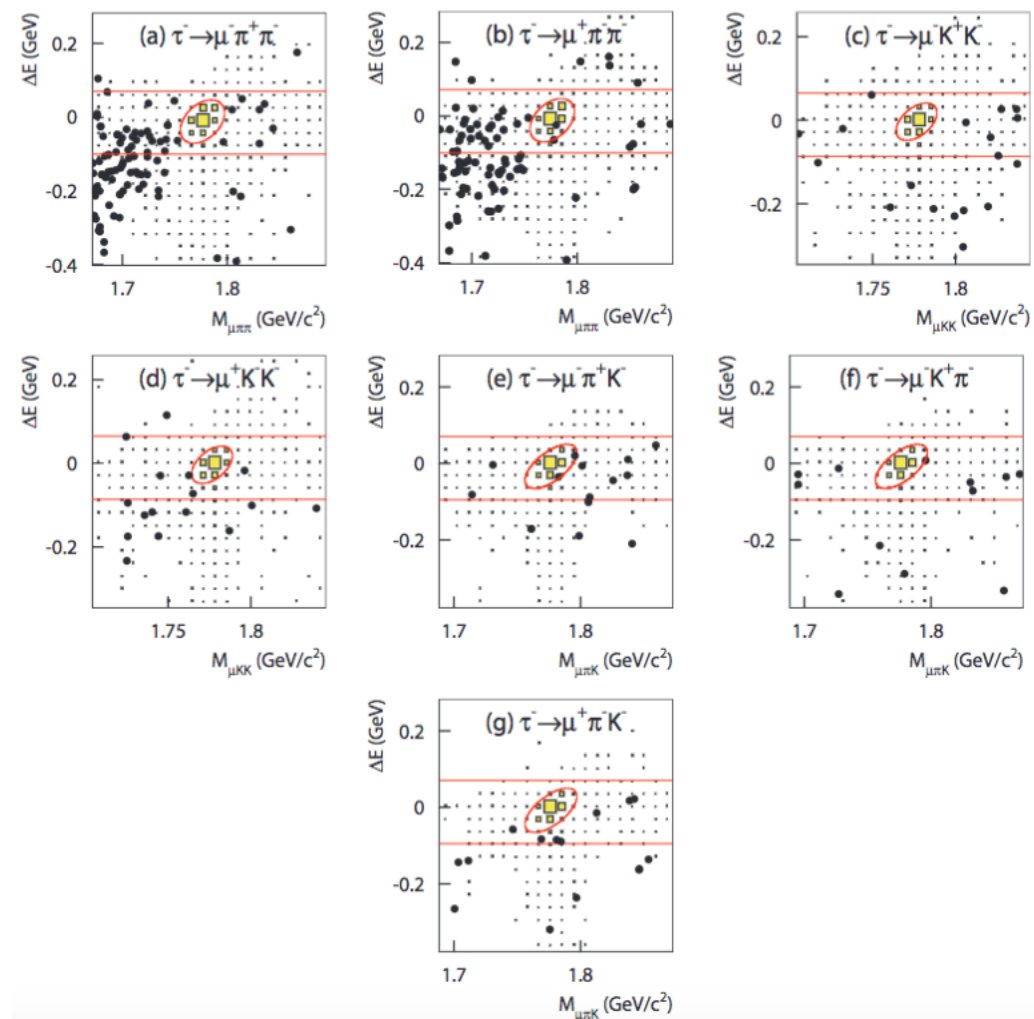


Outline

- Previous results (brief review of published results)
 - Lepton number violation in τ decays
 - Violation of lepton universality in $b \rightarrow s \ell \ell$
 - Violation of lepton universality in $b \rightarrow c(\tau/\ell)\nu$
- Present (very brief, no new results)
- Future (most of the talk)
 - Status and future for Belle II
 - Some projections on physics reach in Belle II

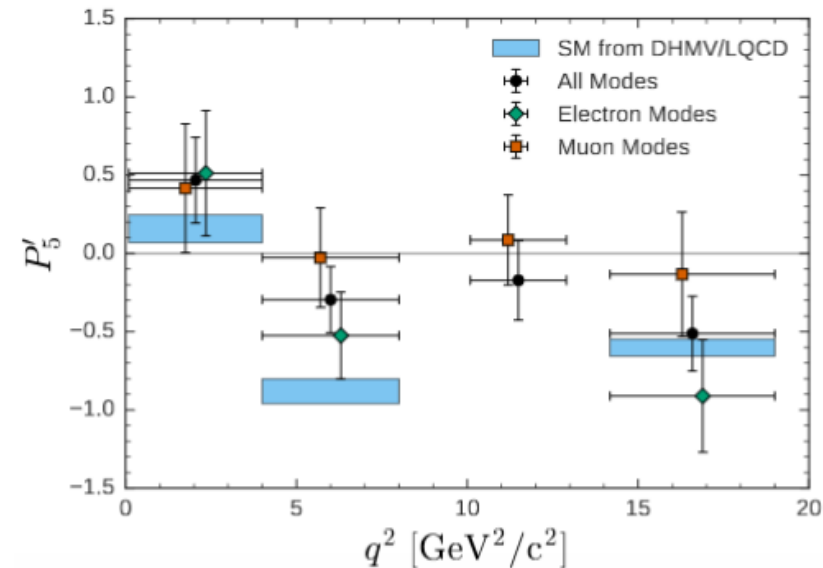
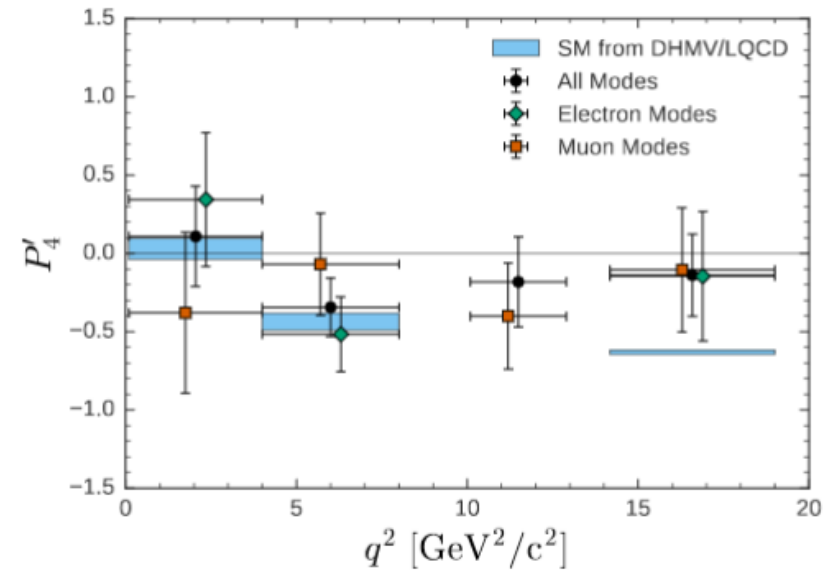
Lepton Number Violation

- Y. Miyazaki et al.
(Belle Collaboration)
Phys Lett. B 719
(2013) 346
- Full Belle data sample
- Search for $\tau \rightarrow \ell h h$
opposite single track τ
decay
- BF limits in the (2-8) $\times 10^{-8}$ range

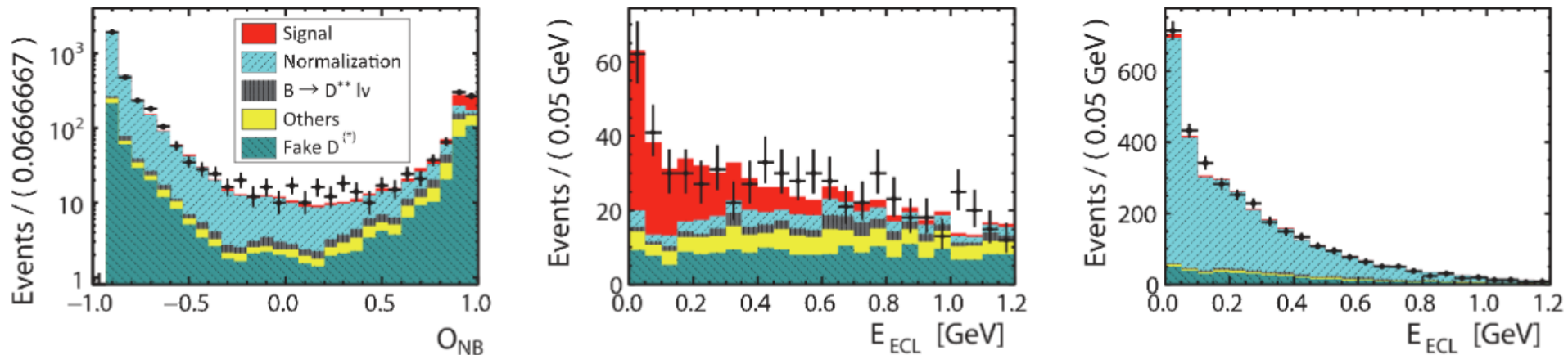


Angular Analysis of $B \rightarrow K^* \ell \ell$

- S. Wehle et al. (Belle Collaboration) Phys. Rev. Lett. 118 (2017) 111801
- Full Belle data sample (127±15 in ee, 185±17 in $\mu\mu$)
- Agrees well with SM. Largest discrepancy is 2.6σ in P'_5 $\mu\mu$ $4 \text{ GeV}^2 < q^2 < 8 \text{ GeV}^2$ bin, same place as LHCb



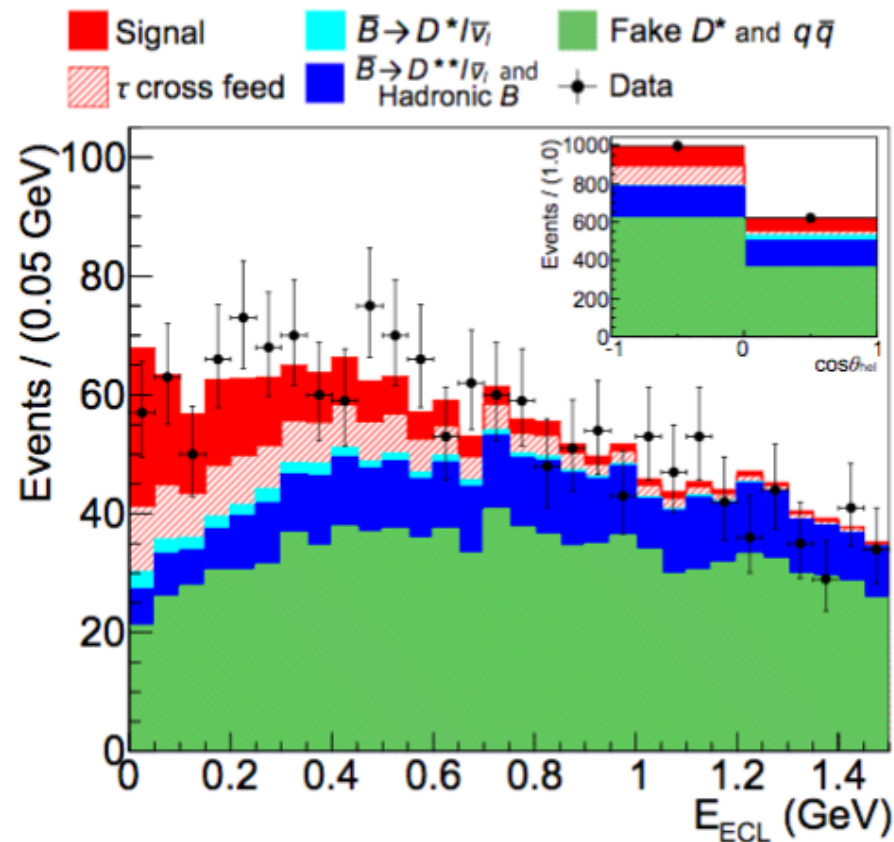
Measure of $R(B \rightarrow D^* (\tau/\ell)\nu)$



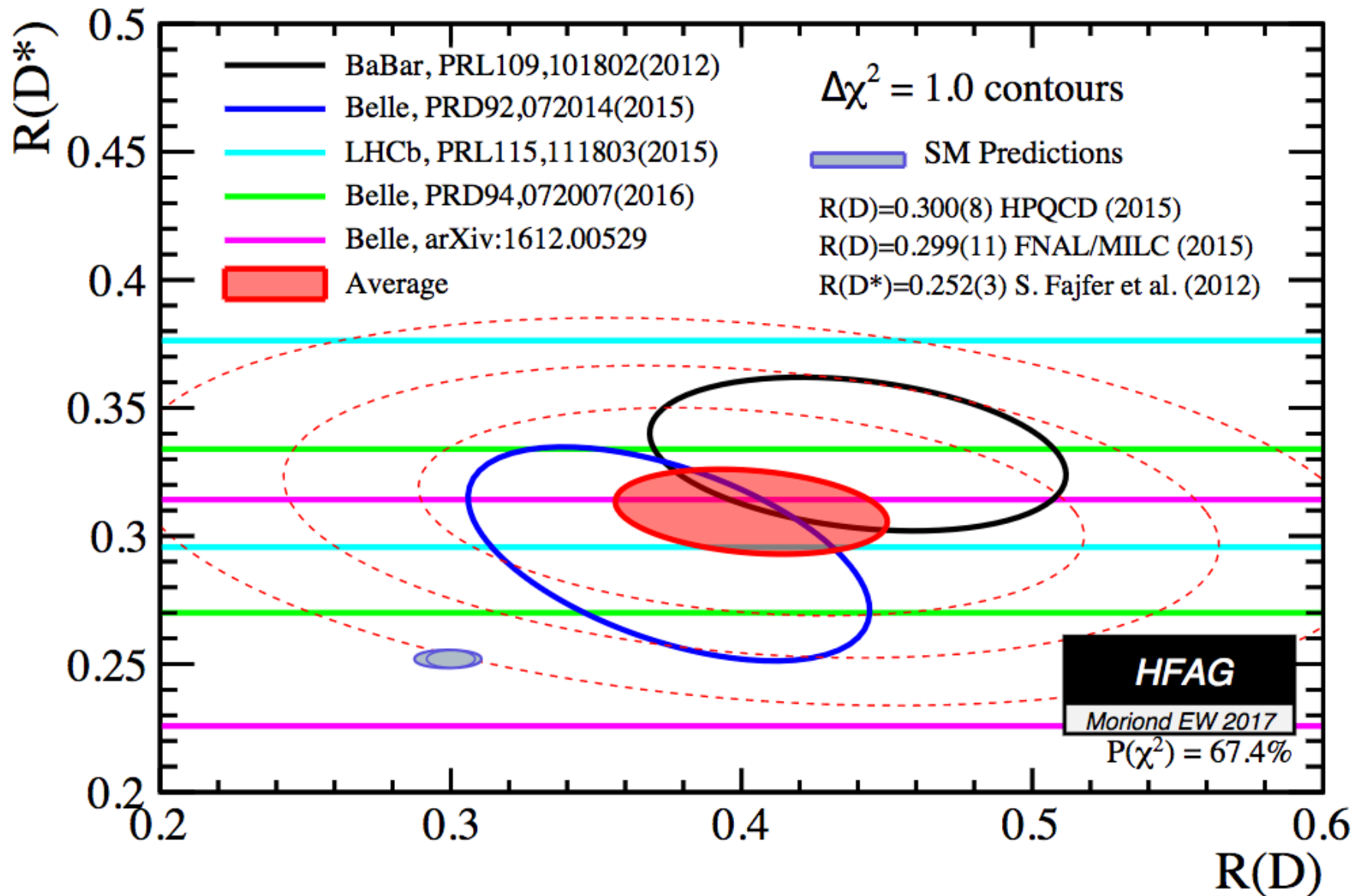
- Y. Sato et al. (Belle Collaboration) Phys. Rev. D 94 (2016) 072007
- Full Belle data sample ($231 \pm 23 \tau$, $2800 \pm 57 \ell$)
- $R(D^*) = 0.302 \pm 0.030 \pm 0.011$, 1.6σ larger than SM

τ Polarization in $B \rightarrow D^* \tau \nu$

- S. Hirose et al. (Belle Collaboration) arXiv: 1612.00529 [hep-ex], accepted at PRL
- Full Belle data sample ($298 \pm 29 \tau$, $7212 \pm 96 \ell$)
- Independent measure of $R(D^*) = 0.270 \pm 0.035^{+0.028}_{-0.025}$
- $P_\tau(D^*) = -0.38 \pm 0.51^{+0.21}_{-0.16}$



Current HFAG R

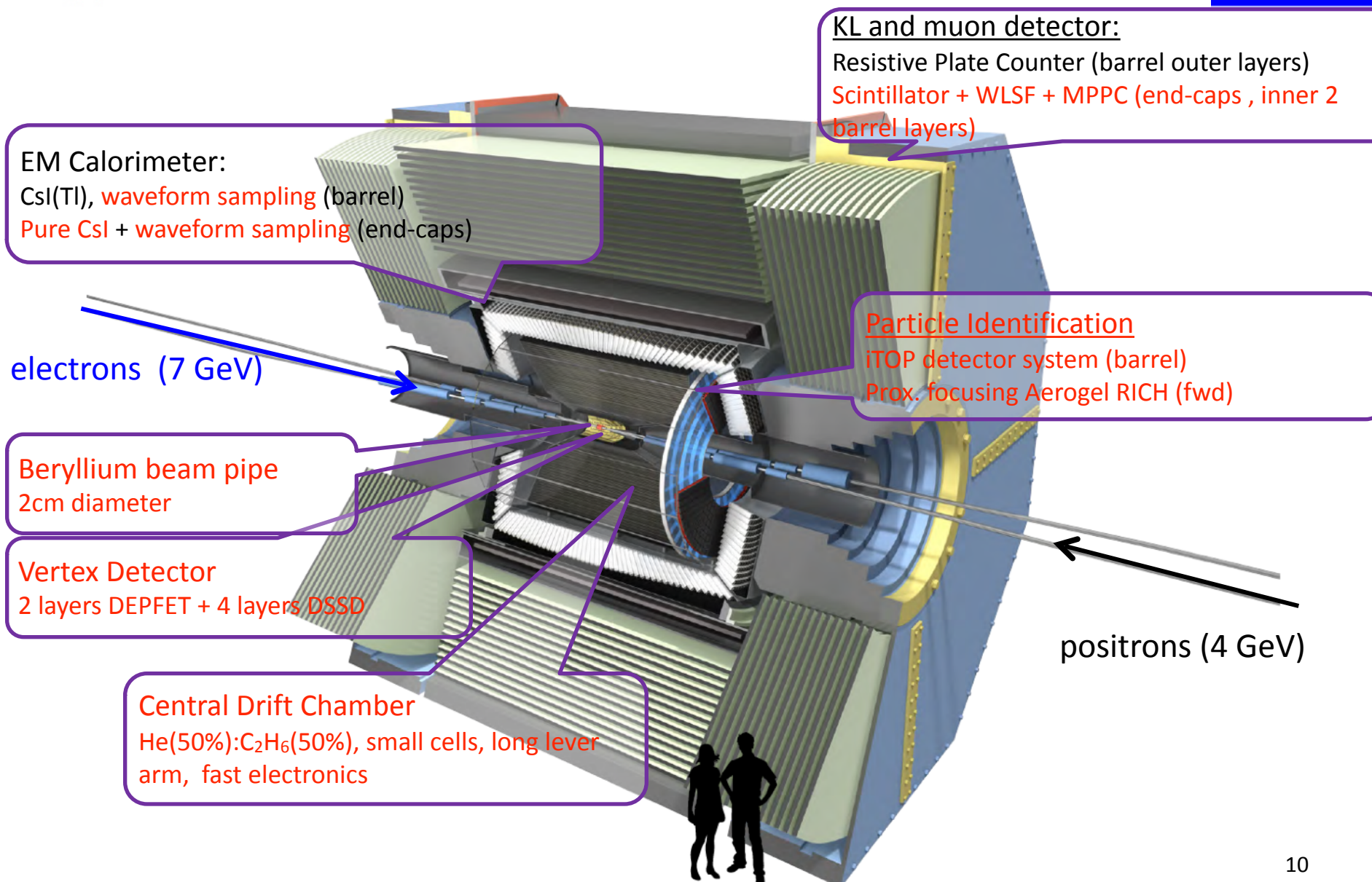




Present Work

- Analysis in progress on $B \rightarrow K\ell\ell$ with the existing full Belle data sample
- We hope to show preliminary results on this during the summer conference season
- Unlikely to be able to be definitive given the size of the sample we will have

Belle II Detector



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

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

electrons (7 GeV)

Particle Identification
iTOP detector system (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

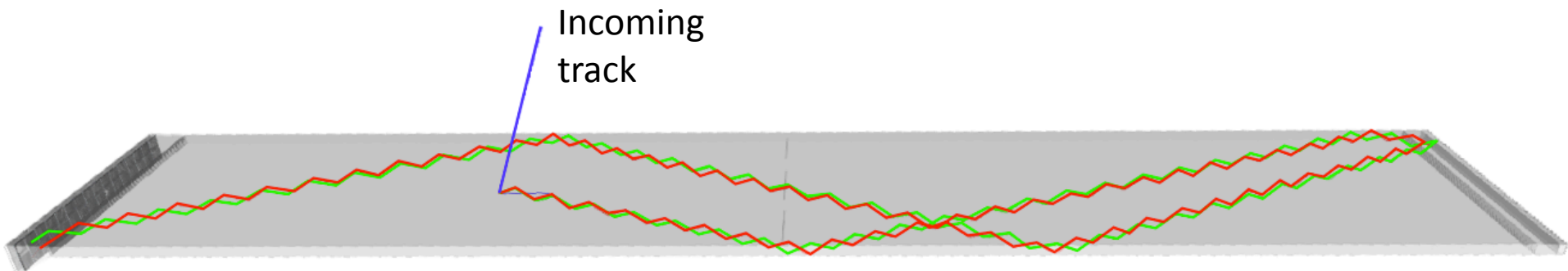
Vertex Detector
2 layers DEPFET + 4 layers DSSD

positrons (4 GeV)

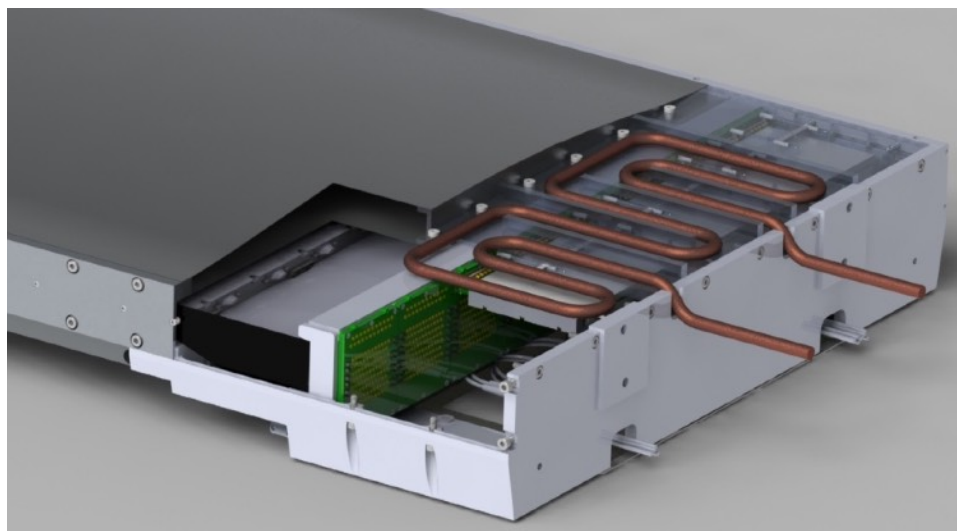
Central Drift Chamber
He(50%):C₂H₆(50%), small cells, long lever arm, fast electronics



A GEANT4 event display of a 2 GeV **pion** and **kaon** interacting in a iTOP [imaging Time Of Propagation] quartz bar.

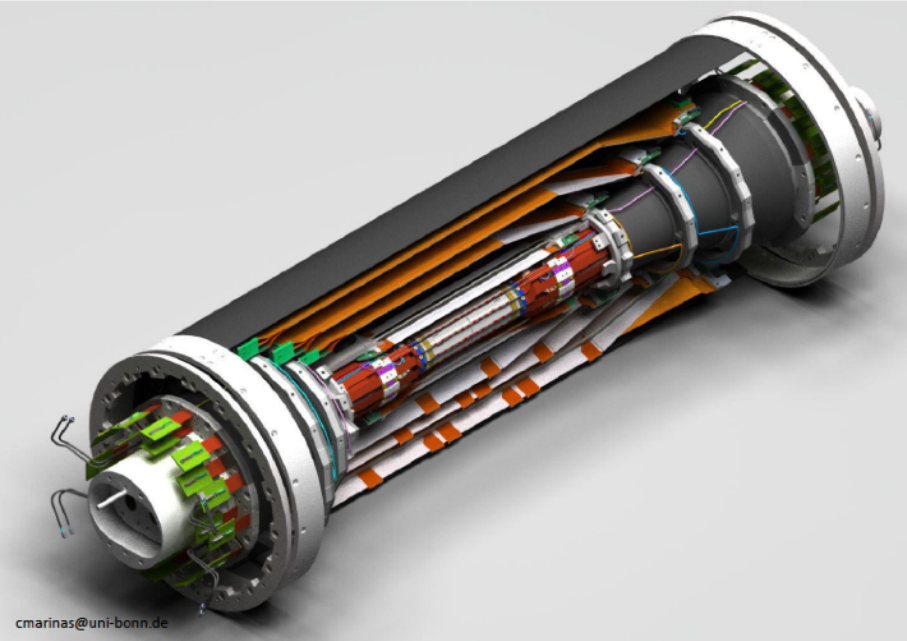


CAD view of an iTOP readout module



Uses the IRSX readout ASIC for fast waveform sampling with a large buffer depth.

Vertexing/Inner Tracking



Smaller beampipe;
shorter lever arm for
multiple scattering.

Goes further out in r
(important for K_S
vertexing and low
momentum stand-alone
tracking).

CO₂ cooling

Beampipe $r=10$ mm

DEPFET pixels

Layer 1 $r=14$ mm

Layer 2 $r=22$ mm

DSSD (double sided silicon detectors) FWD/BWD

Layer 3 $r=38$ mm

Layer 4 $r=80$ mm

Layer 5 $r=115$ mm

Layer 6 $r=140$ mm

3 Custom
readout ASICs

Uses CMS APV25
chip for readout.

Plans for Belle II Running SuperKEKB Accelerator

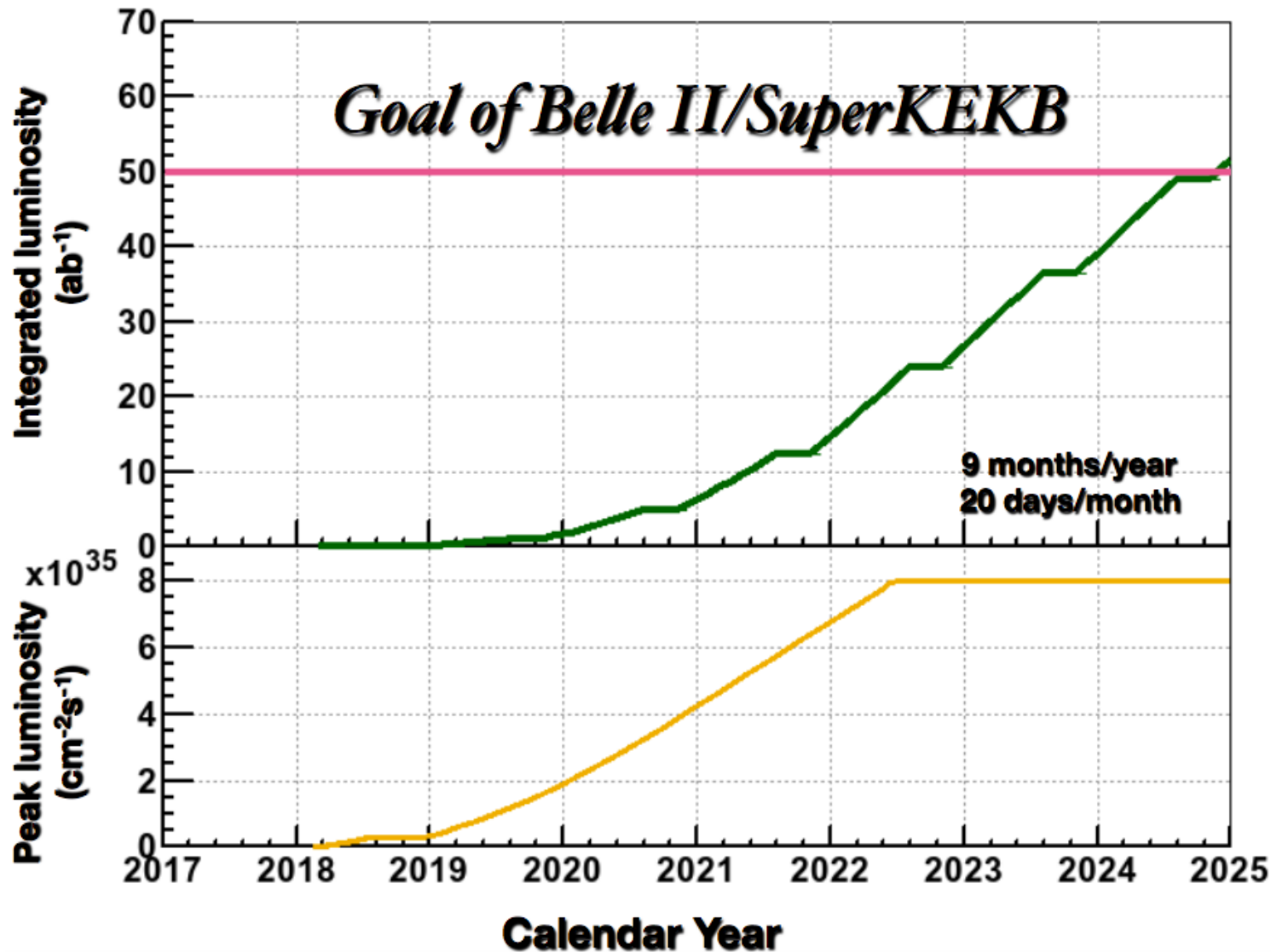
	LER (e^+)	HER (e^-)	
Energy	4.0	7.0	GeV
Half crossing angle		41.5	mrad
Horizontal emittance	3.2	4.6	nm
Emittance ratio	0.27	0.25	%
Beta functions at IP (x/y)	32 / 0.27	25 / 0.30	mm
Beam currents	3.6	2.6	A
Beam-beam parameter	0.0881	0.0807	
Luminosity		8×10^{35}	$\text{cm}^{-2}\text{s}^{-1}$

New e^+ Damping Ring

New e^+ Nano Beam Final Focus

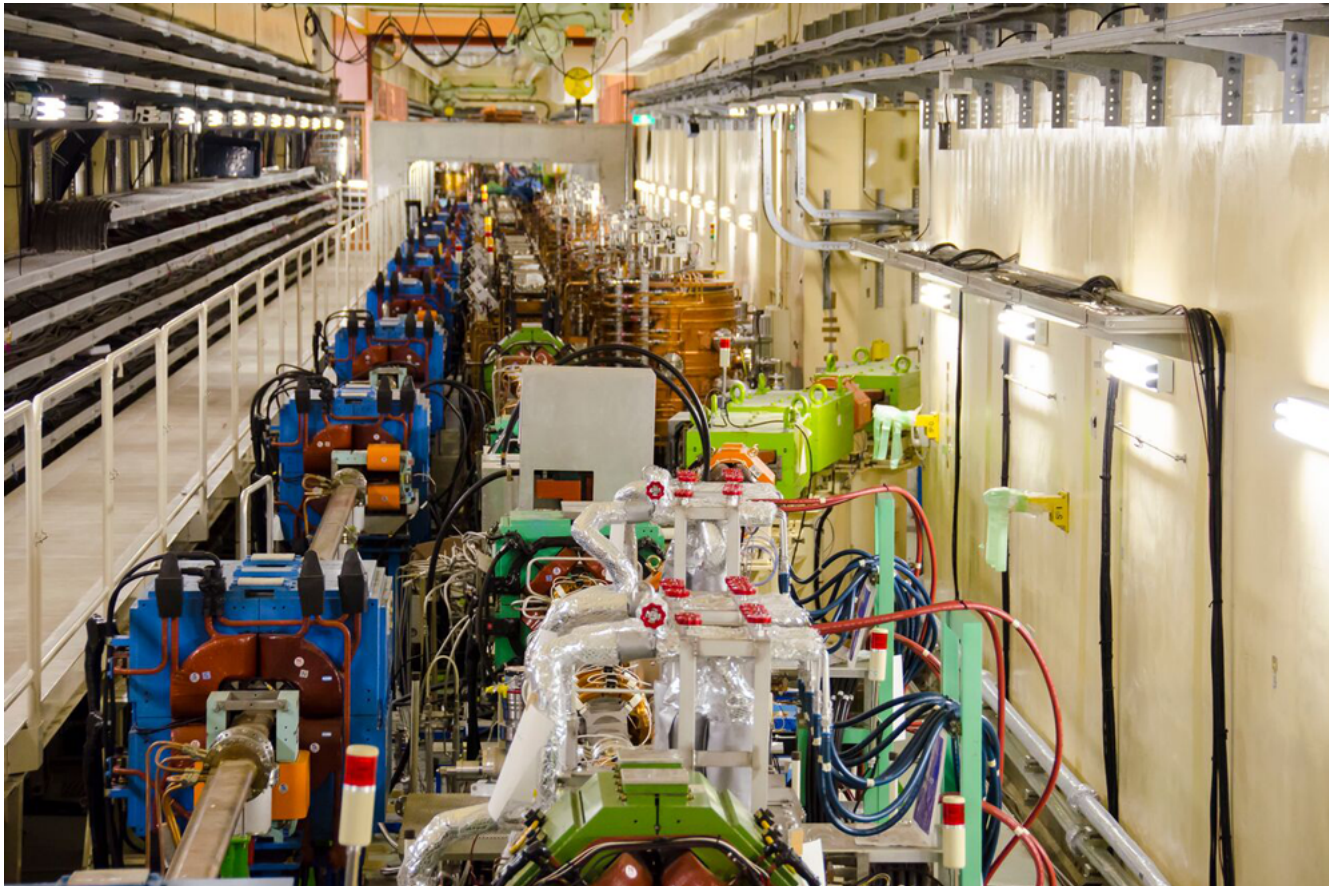
40x KEKB

Plans for Belle II Running



~50x Belle Sample
~10¹¹ B-Meson
Decays

Feb 2016: First Turns at SuperKEKB (4 GeV e⁺'s and 7 GeV e⁻'s)



June 28, 2016 (LER beam current at 1000 mA, HER at 870 mA)



So when do we start Belle II ?

Beast Phase 1:

Feb-June 2016

(Belle II roll-in, April 11, 2017).

Phase 2 Operation:

Starts in ~Nov 2017 [Begin with e^+ damping ring commissioning;

Main ring (**Feb 2018**); First collisions; *limited physics without vertex detectors*]

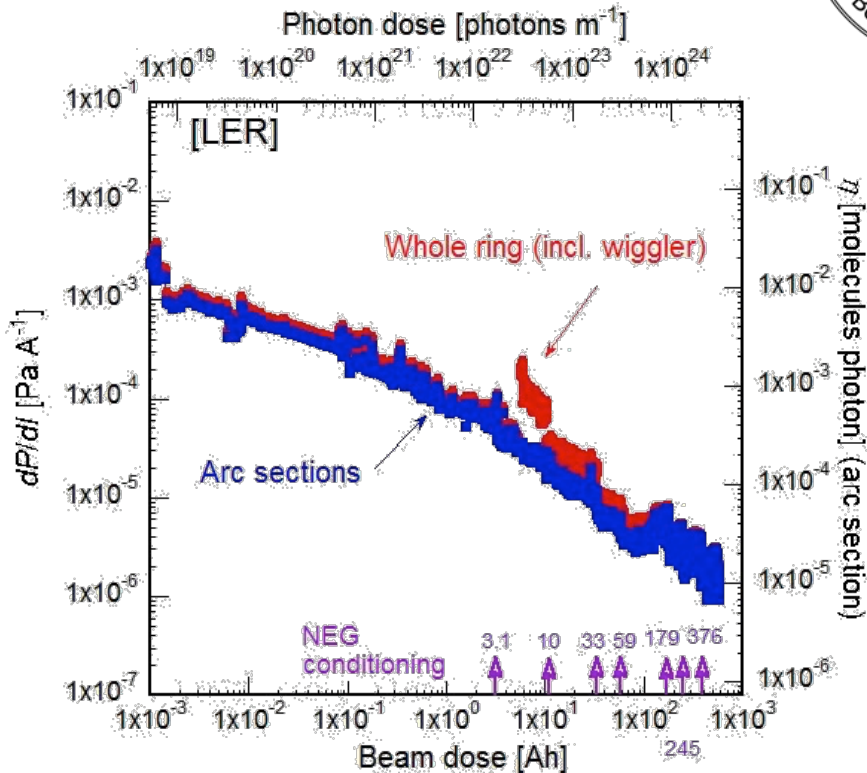
Phase 3: Belle II Physics Running: **end of 2018 [vertex detectors in]**

SuperKEKB vacuum scrubbing to reduce LER beam gas backgrounds in Belle II

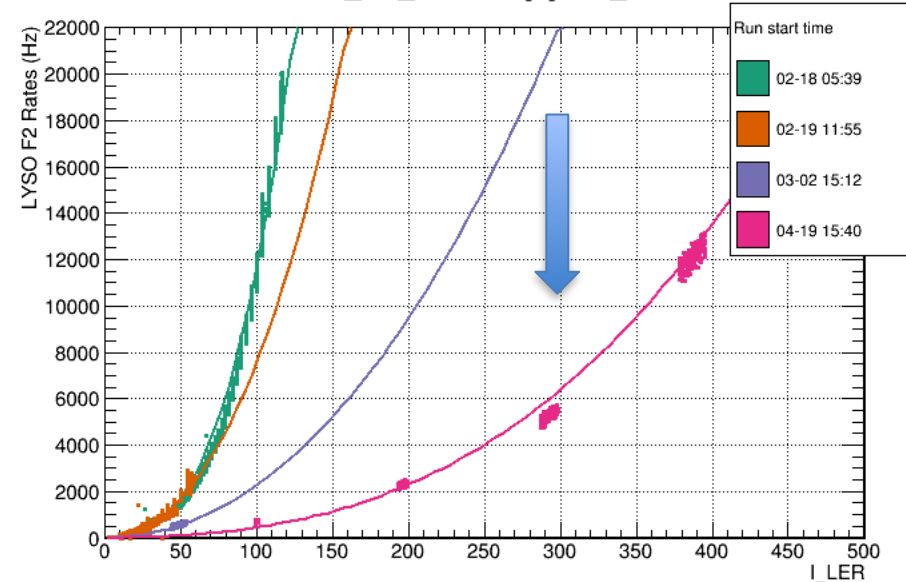
“Brand new” 3km long beampipe
 LER integrated beam dose > 500 A-h



BEAST background in the LER vs time
 (BEAST is the precursor detector focused on measuring beam backgrounds.)

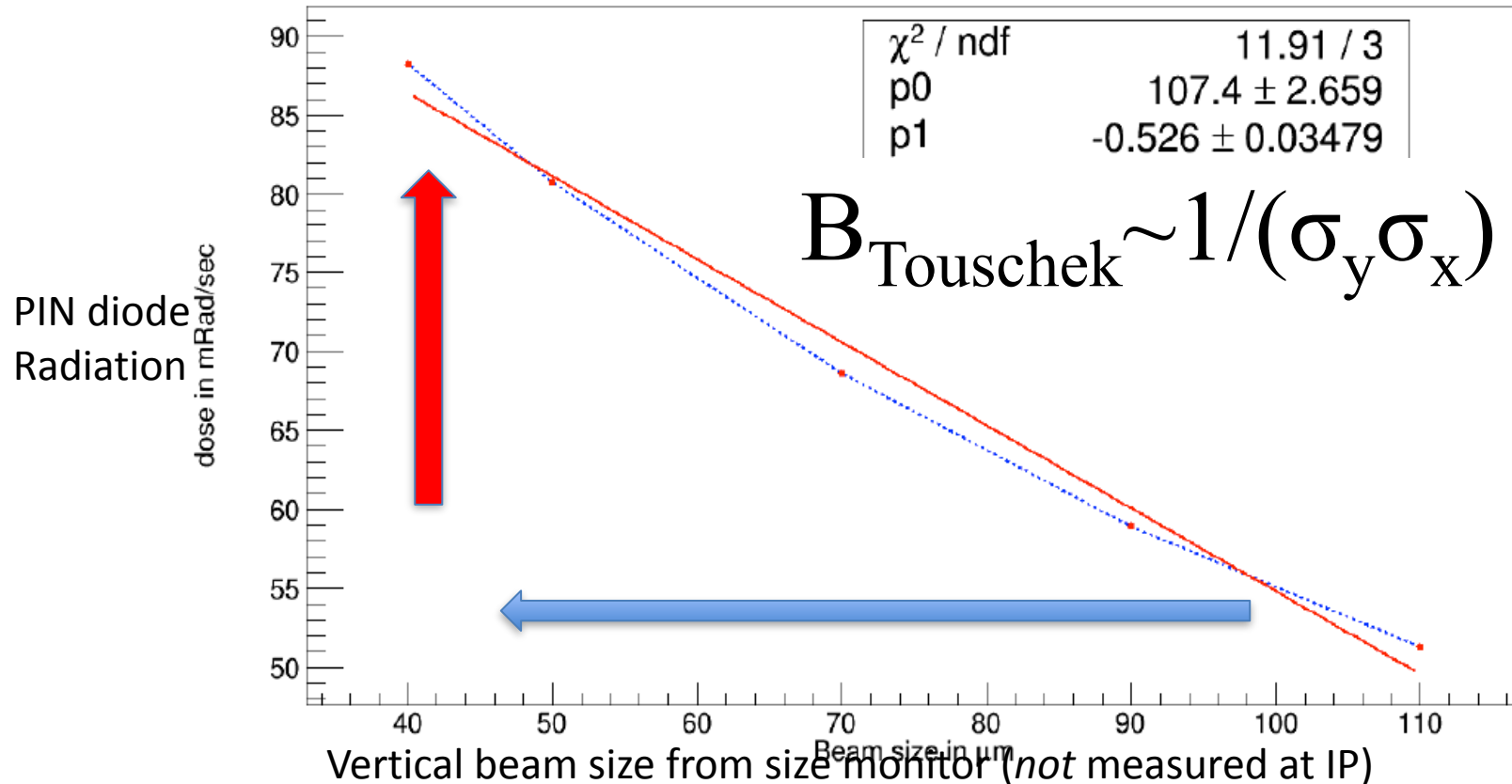


Run LER_Fill_1, Rates[5] vs I_LER



Preliminary BEAST data shows the LER backgrounds decreasing as vacuum scrubbing proceeds.

April 2016: Large Touschek background observed in the LER (extensively studied in dedicated runs)



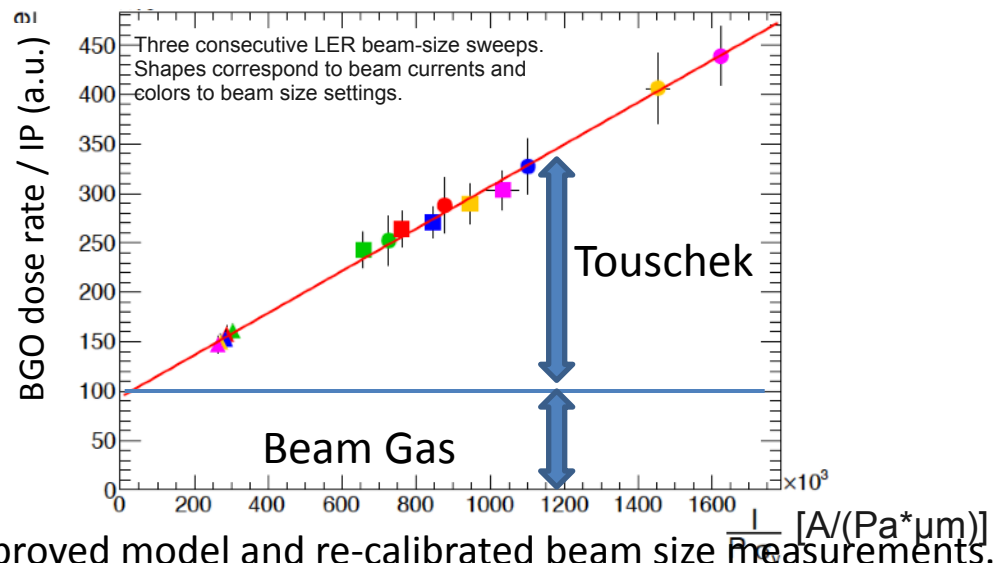
→ Will need excellent collimators to handle nano-beam backgrounds (only a small subset of these available in Phase 1)

First Measurements of Beam Backgrounds at SuperKEKB ^{*}

A. Aloisio^a, F. Ameli^a, A. Beaulieu^a, L. Bosio^a, P. Branchini^a, T. Browder^d, A. Budano^j, G. Cautero^b, Y.-T. Chen^o, K.-N. Chu^p, D. Cinabro^q, P. Cristaud^o, S. de Jong^r, R. de Sangro^s, G. Finocchiaro^s, J. Flanagan^s, Y. Funakoshi^m, M. Gabriele^r, R. Giordano^o, D. Giuresi^o, M. T. Hedges^d, N. Honkanen^r, H. Ikeda^a, T. Ishibashi^q, I. Jaegle^o, H. Kaji^q, K. Kanazawa^a, C. Kiesling^l, S. Koirala^o, C. La Licata^q, L. Lanceri^q, P. M. Lewis^q, J.-J. Liau^q, F.-H. Lin^q, J.-C. Lin^q, A. Morita^m, M. Naka^o, H. Nakayama^q, M. Nayak^k, Y. Ohnishi^q, A. Passeri^l, P. Poffenburger^q, M. Ritzert^q, M. Roney^q, A. Rossi^q, T. Röder^d, R. M. Seddon^m, I. S. Seong^q, J.-G. Shiu^q, F. Simon^l, Y. Soloviev^q, Y. Suetsugu^q, M. Szalay^q, S. Terui^q, G. Tortone^q, S. E. Vahsen^q, N. van der Kolk^l, L. Vitale^q, M.-Z. Wang^q, H. Windel^l, S. Yokoyama^q

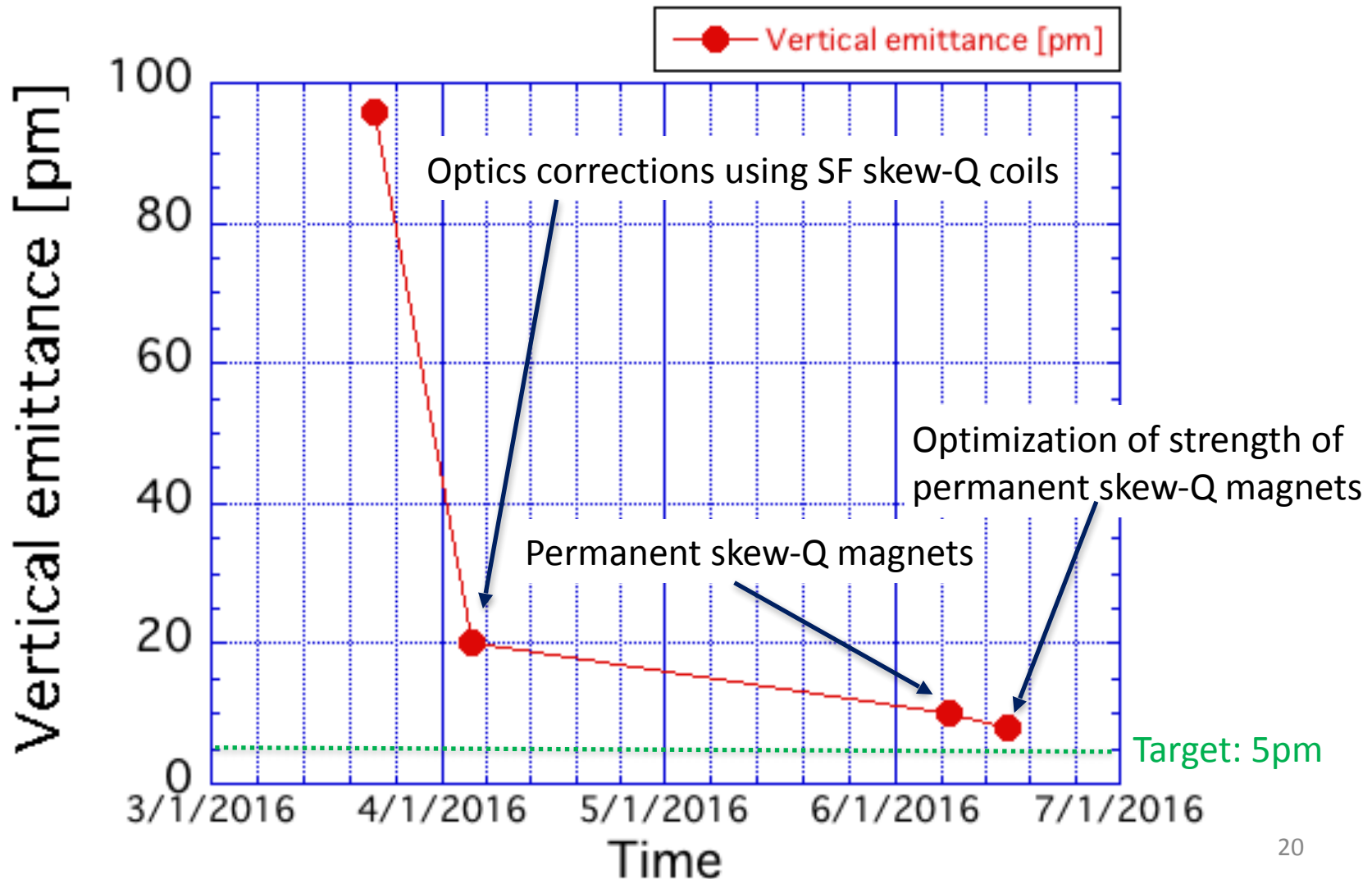
^aDeutsches Elektronen-Synchrotron, Notkestrasse 85, 22607 Hamburg, Germany
^bElettra - Sincrotrone Trieste S.C.p.A., ARCA Science Park, 34149 Basovizza, Trieste, Italy
^cUniversity of Florida, Department of Physics, P.O. Box 118440, Gainesville, FL 32611, USA
^dUniversity of Hawaii, Department of Physics and Astronomy, 2505 Correa Road, Honolulu, HI 96822, USA
^eHeidelberg University, Institute of Computer Engineering, B6, 26, 68159, Mannheim, Germany
^fHigh Energy Accelerator Research Organization (KEK), Institute of Particle and Nuclear Studies, Tsukuba, Japan
^gHigh Energy Accelerator Research Organization (KEK), Accelerator Laboratory, Tsukuba, Japan
^hINFN - Sez. di Perugia, Via A. Pascoli, 06123, Perugia, Italy
ⁱINFN - Sez. ROMA, P.le Aldo Moro, 2 00185, Roma, Italy
^jINFN - Sez. ROMA 3, V. della Vasca Navale, Roma, Italy
^kLaboratori Nazionali di Frascati dell'INFN, Via E. Fermi 40, I-00044, Frascati, Italy
^lMax-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany
^mMcGill University, Department of Physics, 3600 rue University, Montreal, QC H3A 2T8, Canada
ⁿUniv. of Naples Federico II & INFN Sezione di Napoli, Italy
^oNara Women's University, Nara 630-8506, Japan
^pNational Taiwan University, Department of Physics, No.1 Sec.4 Roosevelt Road Taipei 10617, Taiwan
^qUniversity of Trieste, Department of Physics, and INFN, Via Valerio 2, 34127 Trieste, Italy
^rUniversity of Victoria, Department of Physics and Astronomy, 3800 Finlayson Rd., Victoria BC, V8P 5C2, Canada
^sWayne State University, Department of Physics and Astronomy, 666 W. Hancock, Detroit, MI 48202, USA

- Preliminary BEAST Phase 1 analyses now near completion, documented in a 100 page NIM note (and growing)
- A number of new techniques developed
- Current focus: ensure internal consistency, consult with SuperKEKB group, extrapolate to phase 3



Improved model and re-calibrated beam size measurements. BGs for a wide range of beam currents and beam sizes now described consistently by a single set of parameters.

SuperKEKB Highlight from Phase I: “Cool” flat beams (LER plot below)



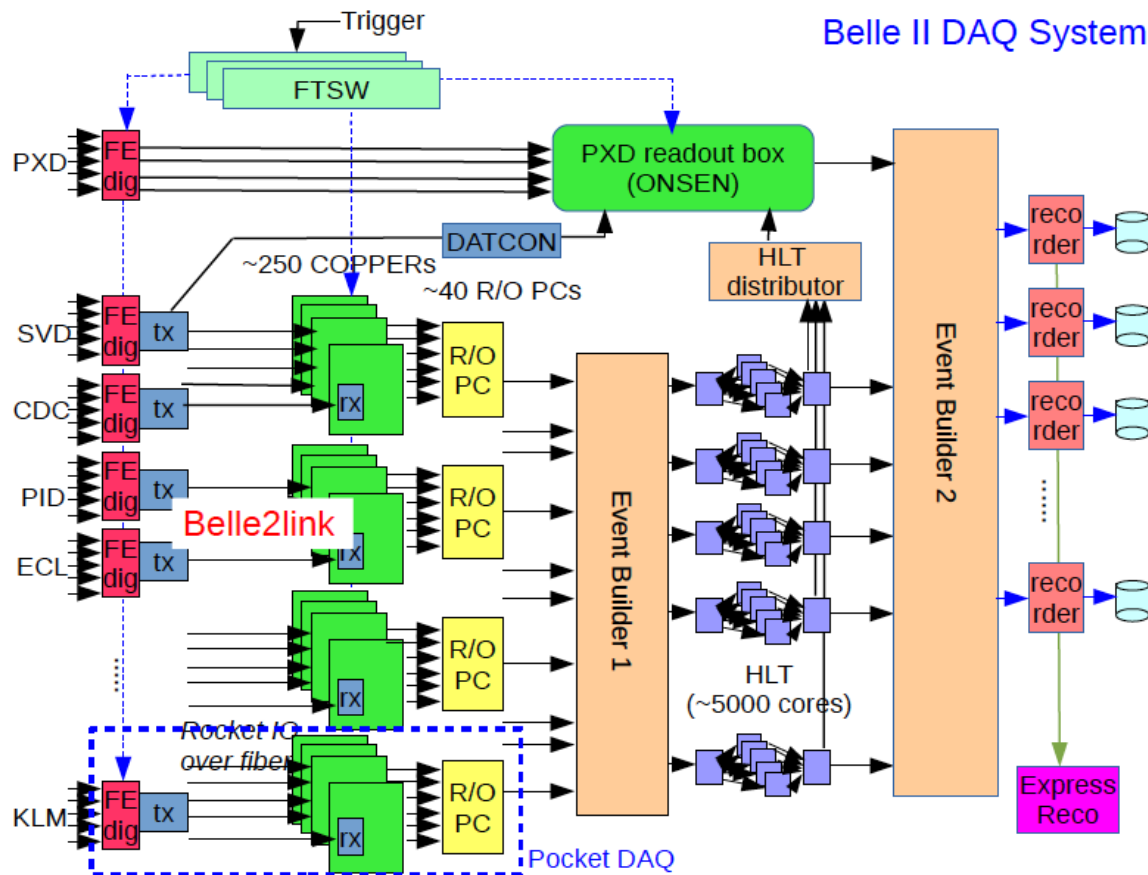


Short Term Plans



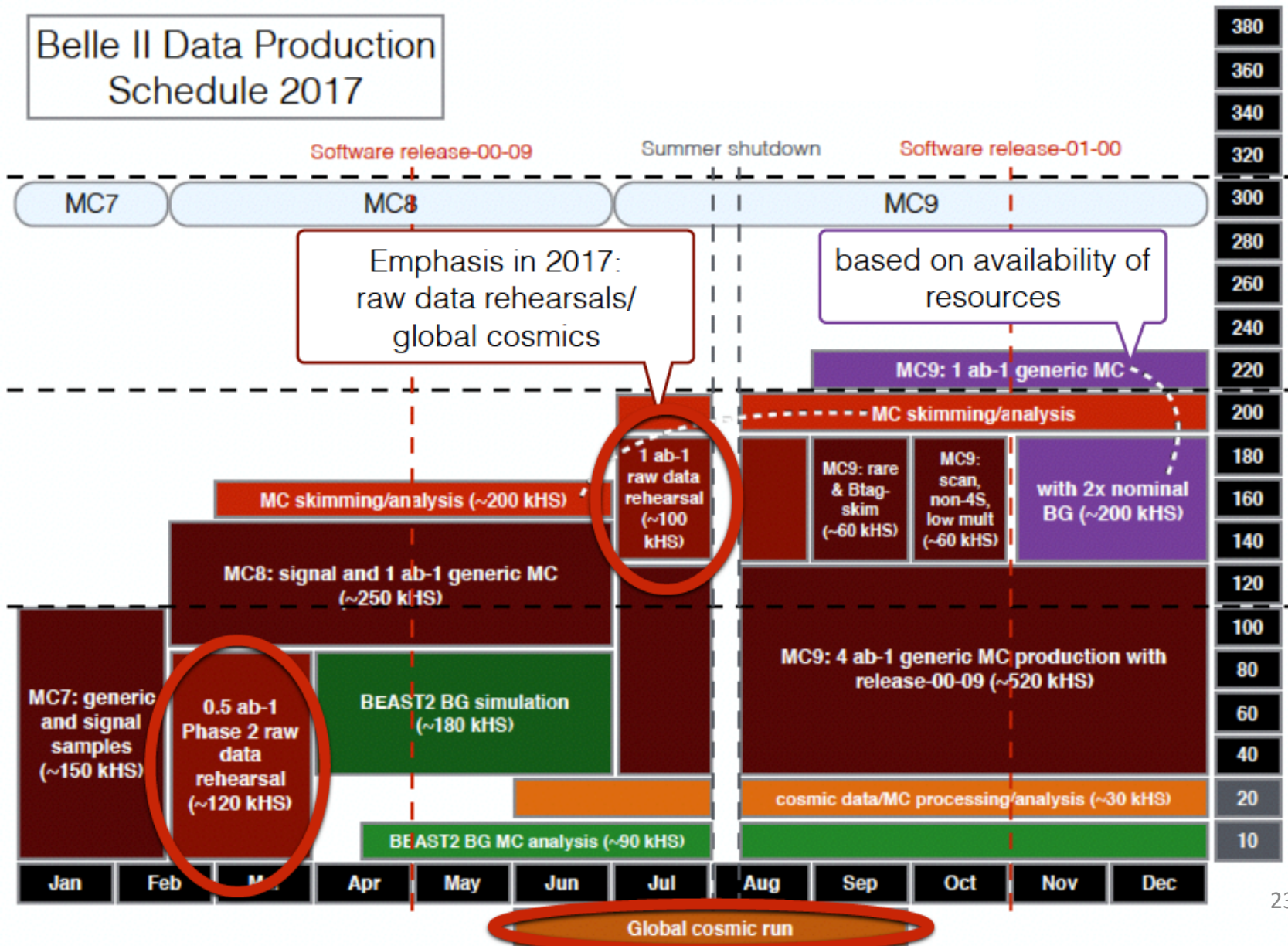
- Anticipate more progress including the **global** cosmic ray run in summer 2017 (June-August) with all outer detector subsystems [KLM,ECL,TOP,CDC]. *DAQ stress tests at 30 kHz.*
- Installation of RPC readout electronics in July 2017.
- “Dress rehearsal” for Phase 2 running.
- BEAST Phase 1 (Precursor Paper and refined predictions for Phase 2 and Phase 3 bkg.)
- Installation of ARICH in Sept 2017 followed by FWD ECL and BEAST Phase 2 hardware (Nov 2017).
- Release of the Belle II Physics Book.

DAQ and readout integration

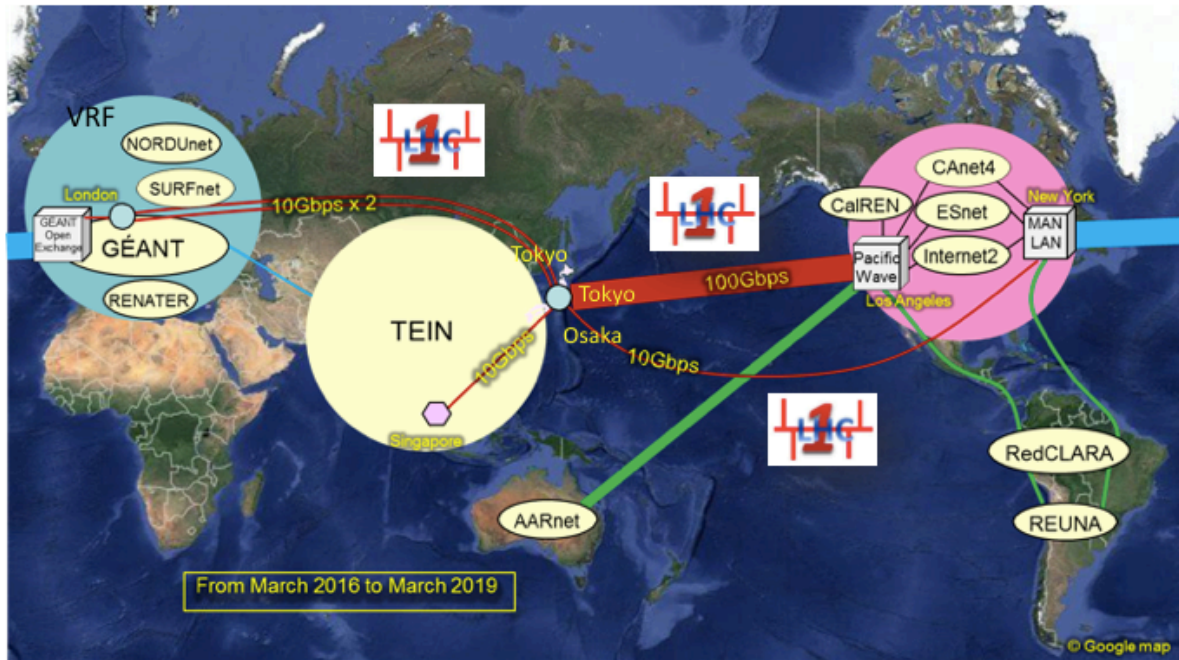


Note the distinction between Pocket DAQ (standalone) and full DAQ with event building. *Requires feature extracted TOP data to reduce the large data volume.*

Belle II Data Production Schedule 2017



Belle II: High Speed Networking is needed along with GRID computing

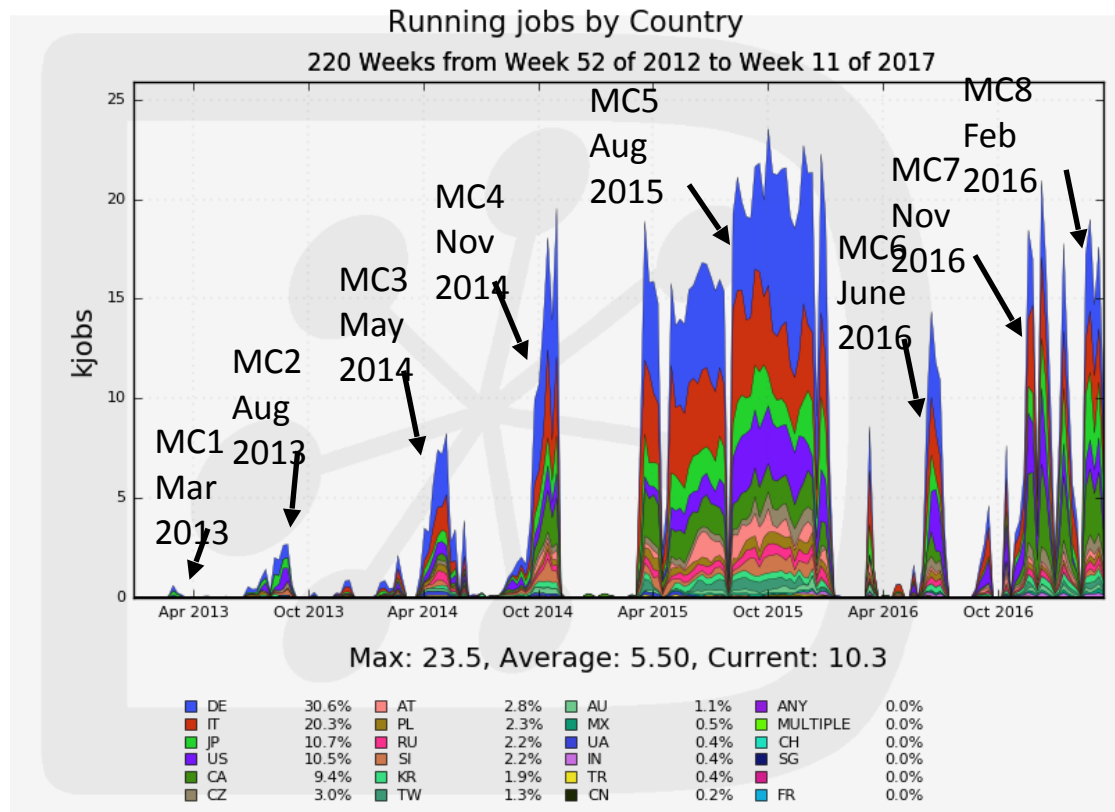


Recent WAN data challenge between major sites (KEK, PNNL, DESY, KIT, CNAF, Napoli, Signet) in Nov 2016.

→ Results demonstrate that the Belle II networking requirements are satisfied.

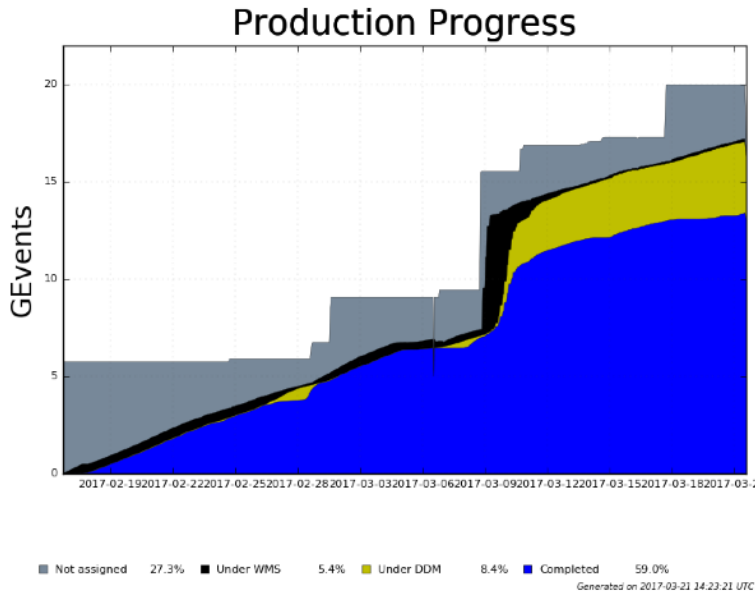
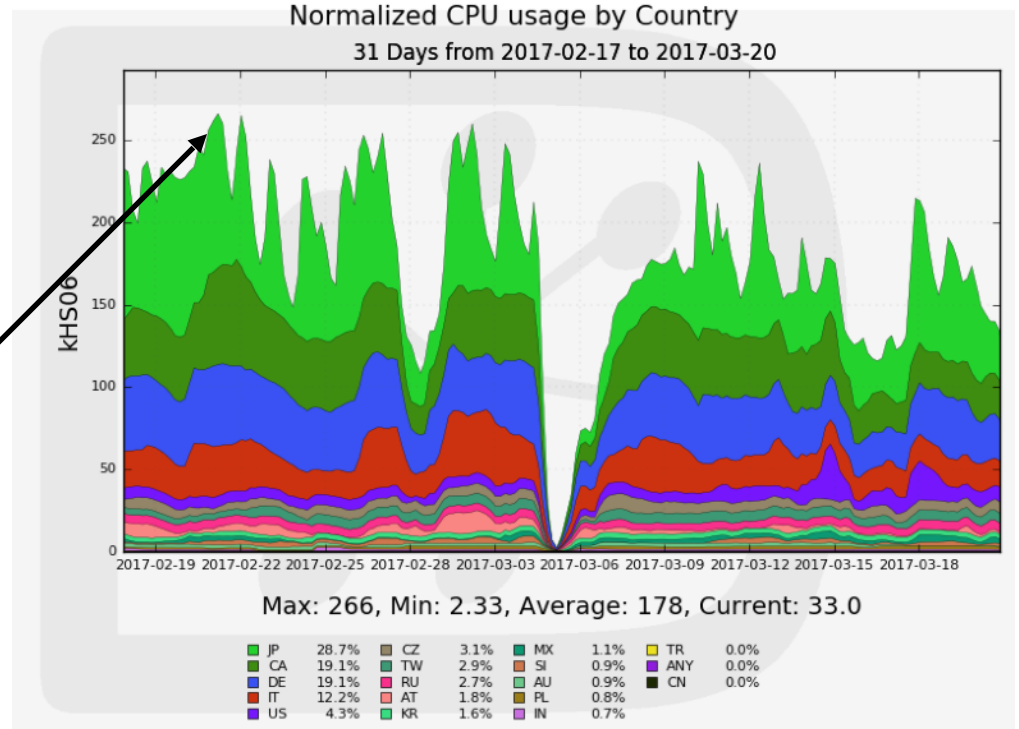
Belle II MC campaigns

- In parallel with physics data taking, corresponding MC samples must be produced - use MC “campaigns” to prepare for future data-MC production
- MC production requires a significant amount of effort to coordinate between the physics, software and computing groups and to prepare production scripts
- Previously managed by the computing coordinator
- As of September 2016, managed by data production coordinators



Eighth official MC production campaign (MC8)

- Production start: Feb. 16, 2017
- Ready for analysis Apr. 19 2017
- In total: ~2.1 million jobs, ~20 billion events (~100 TB)
- At maximum: 23.7k concurrent jobs and > 266 kHS06 (new record!)



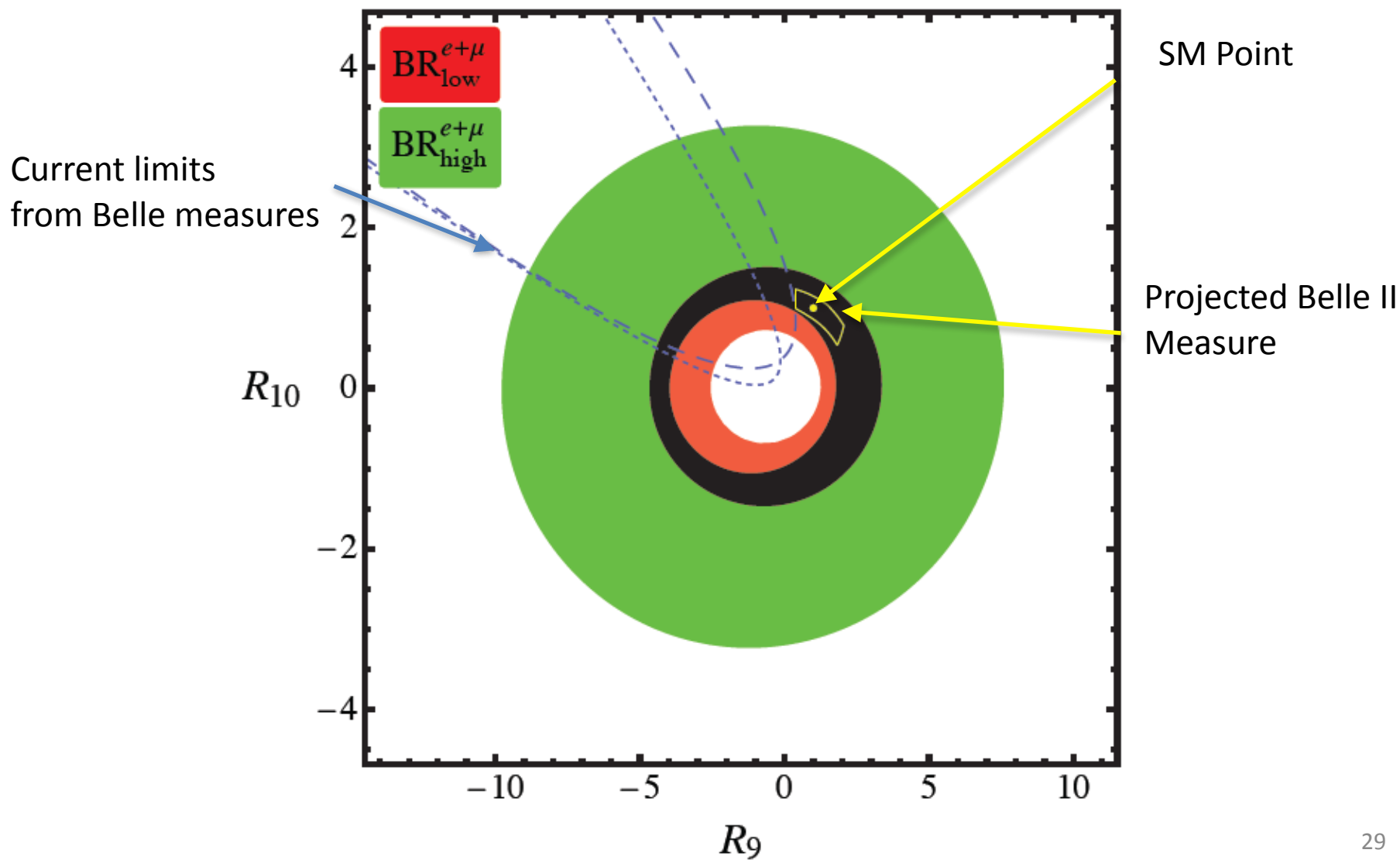
- Higher than expected resource usage
- MC8 will finish much earlier than expected
- Added a few samples based on additional resource available (eg. BGx2)



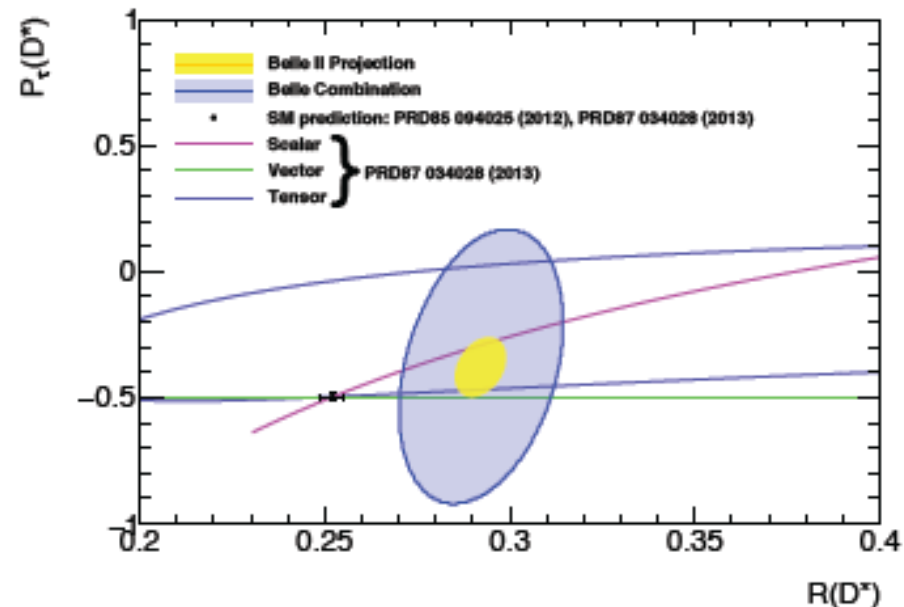
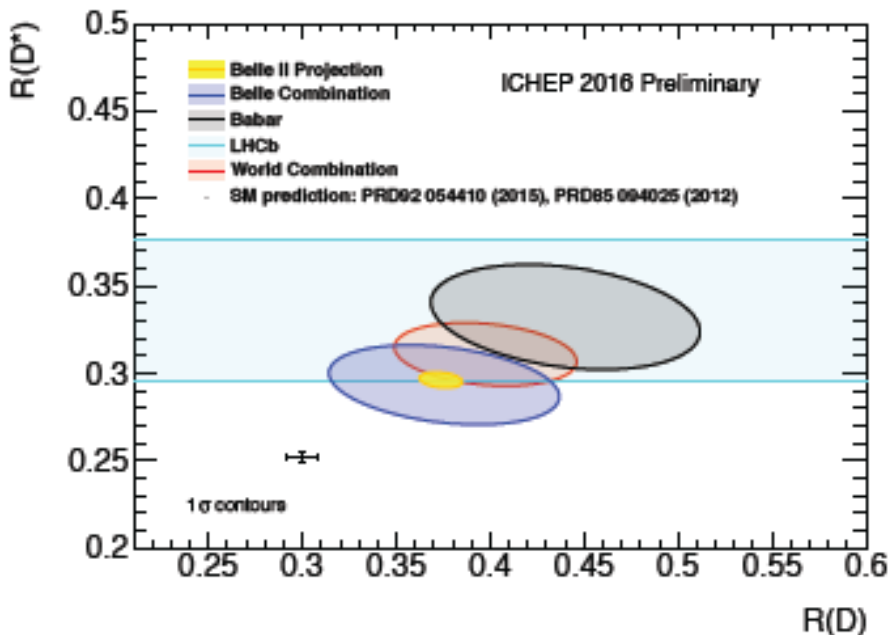
Physics Projections

- Why all this stuff on MC?
- Used to generate physics projections for Belle II, part of the draft Belle II Physics Book
- <https://confluence.desy.de/display/BI/B2TiP+WebHome>
- Editors Emi Kou (CNRS/LAL) and Phillip Urquijo (Melbourne)
- Here only a small fraction of the B2TiP effort

Physics Projections



Physics Projections



Belle II should deliver definitive results on both $b \rightarrow s \ell \ell$ and $B \rightarrow D^* (\tau/\ell) \nu$



Conclusion

- Existing Belle results on Lepton Number Violation and Lepton Flavor Universality Violation in B decays
- Belle II physics running to start in about a year.
50 x increase over the Belle data set
- The collaboration is ready to do physics
- Project definitive results on Lepton Number Violation in τ decays, $b \rightarrow s\ell\ell$, and $B \rightarrow D^*(\tau/\ell)\nu$