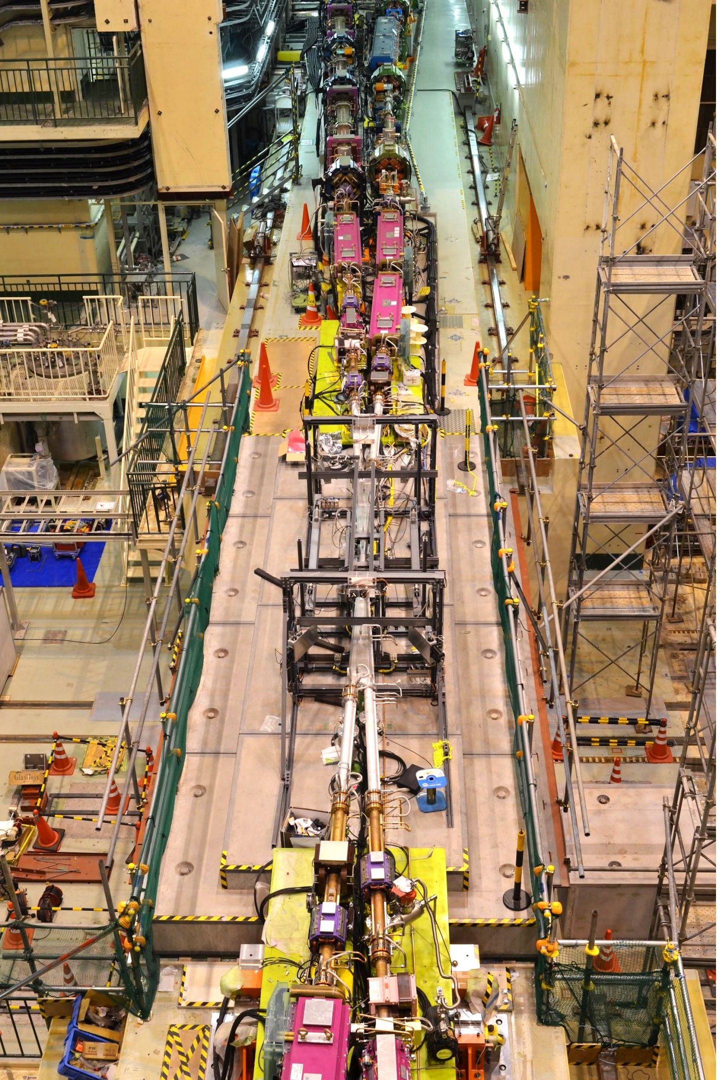


Machine-detector interface at SuperKEKB/Belle II

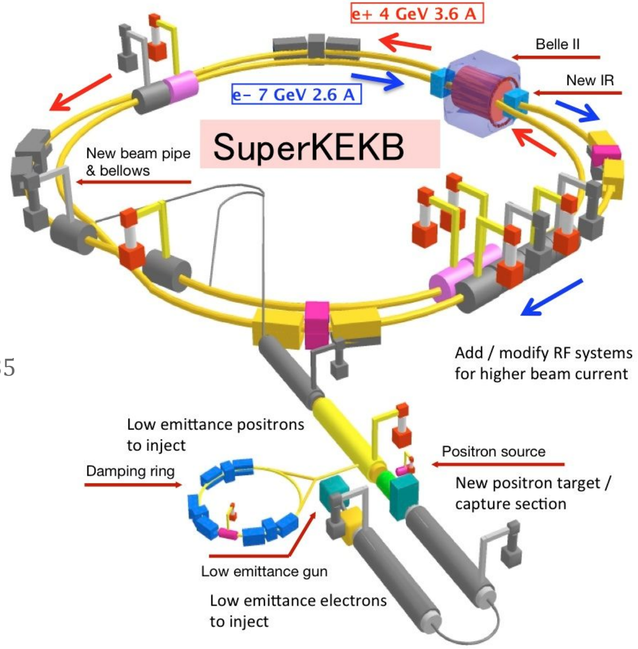
Peter M. Lewis on behalf of the BEAST II Collaboration and Belle II beam background group
University of Hawai'i at Mānoa

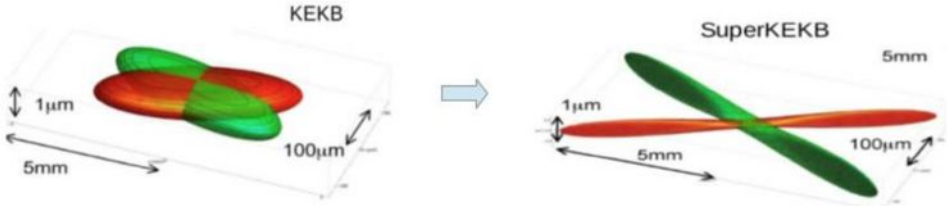
7 November 2017
CEPC Workshop, Beijing

SuperKEKB

The super ***B*-factory** at KEK (2018 start)

- Asymmetric-energy 10.57 GeV (c.o.m.) $e^{+}-e^{-}$ collider
- A planned **40-fold** increase in luminosity over KEKB (target: 8×10^{35} $cm^{-2}s^{-1}$ instantaneous, **50ab^{-1}** integrated), due to major upgrades:
  - **"Nano-beam" scheme** (below)
  - **Doubled beam currents**
  - (large number of upgrades to RF, magnet, vacuum, damping systems)
- **First turns Feb. 10, 2016! Exciting times!**





~x2 in beam current

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8\times10^{35} cm^2 s^{-1}$$

Vertical beta function reduction (5.9→0.3 mm) gives x20

Beam Energies 8.0/3.5→7.0/4.0

Belle II

Central beam pipe: 2cm diameter, Beryllium with gold coating on inside

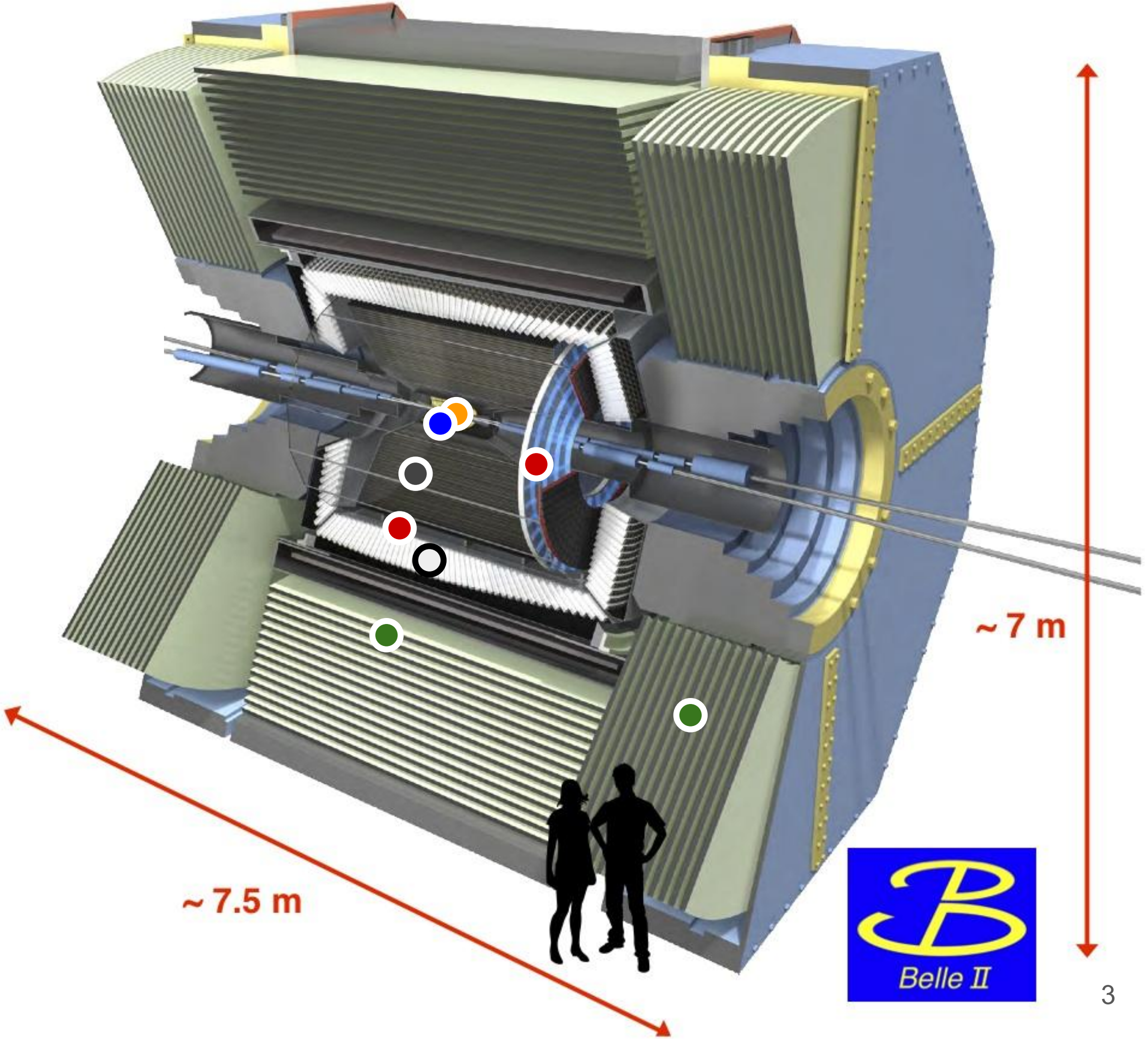
Vertexing: new 2 layers of pixels, 4 double-sided layers of silicon strips

Tracking: 14336-wire drift chamber

PID: time-of-flight (barrel) and proximity focusing aerogel (endcap) Cherenkov detectors

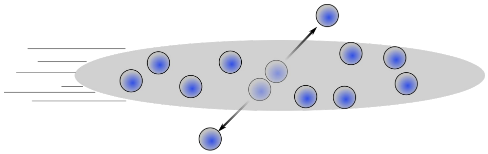
EM calorimetry: CsI(Tl) crystals

***K_L* and *μ*:** scintillators (endcap and inner two layers of barrel) and RPCs (remainder of barrel)

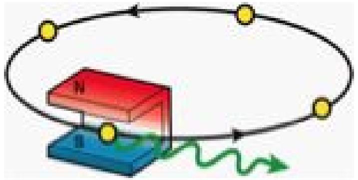


(Some) important beam backgrounds at Belle II

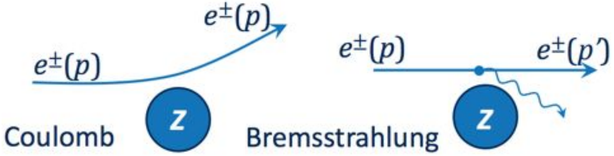
- **Touschek**: intra-bunch Coulomb scattering
  - Squeeze beam → more background



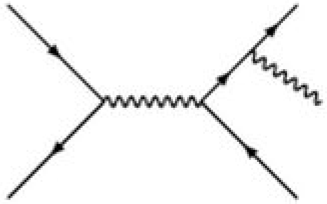
- **Synchrotron**: generated by upstream bending magnets



- **Beam-gas**: Coulomb or bremsstrahlung scattering of beam particles with gas in beampipe



- **Radiative Bhabha** (with collisions):



- **Injection**: particles injected from linac off-orbit

SuperKEKB vs. CEPC

A *very* simplistic scaling

Parameter x [unit]	**Background (scaling)**	**SuperKEKB** [LER/HER]	**CEPC/SuperKEKB**
Current [mA]	Beam-gas (x) Synchrotron (x)	**3600/2600**	**1/180**
Bunch current [mA]	Touschek (x^2)	**1.4/1.0**	**1/4**
Number of filled bunches	Touschek (x)	**2503**	**1/50**
Luminosity [$\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$]	Radiative Bhabha (x)	**8×10^{35}**	**1/40**
Beam energy [GeV]	Touschek (x^{-3}) Synchrotron (x^4)	**4/7**	**25**
β_y^* [μm]	Touschek (x^{-1})	**270-300**	**4**

SuperKEKB vs. CEPC

A *very* simplistic scaling

- **This gives some context to my remaining slides**
- Expected CEPC backgrounds compared to SuperKEKB
  - **Touchek**: factor of **1/4** $\times$ **(1/25)^3** $\times$ **1/4 = 10^6** lower
  - **Beam-gas**: factor of **180** lower
  - **Radiative Bhabha**: factor of **40** lower
  - **Synchrotron**: factor of **1/180** $\times$ **25^4 = 2000** higher
  - **Beamstrahlung**: average parameter Υ is a factor **60** higher
- Of course, **design choices** matter
  - In Belle, S.R. severely damaged original silicon vertex detector
  - ***~No S.R.*** in Belle **II** due to geometry and beam-pipe design
  - **The above S.R. estimate does not reflect realistic CEPC geometry and details of magnet system**

Commissioning of SuperKEKB

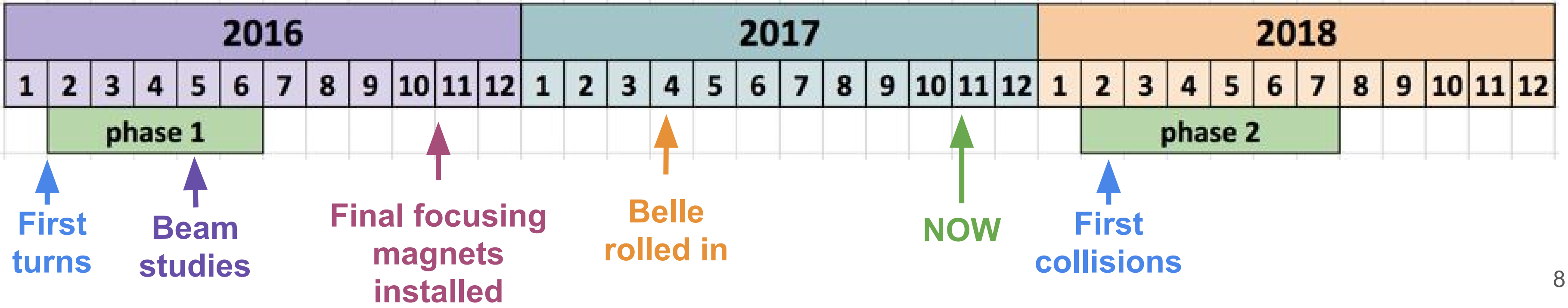
Schedule: beam commissioning phases

Phase I (2016)

- Circulate both beams; **no collisions**
- No Belle
- Tune accelerator optics
- Vacuum scrub
- **Beam studies**

Phase II (2018)

- **First collisions**
- Belle outer detectors
- Develop beam abort
- Achieve nano-beam
- Beam studies



Enter the BEAST

What is it?

- A collection of **detector systems** for background measurements in Phases 1+2
- A group of accelerator and detector **collaborators** dedicated to studying beam backgrounds
  - Simulation
  - Detection and characterization
  - Mitigation

*Belle had its own BEAST

Enter the BEAST

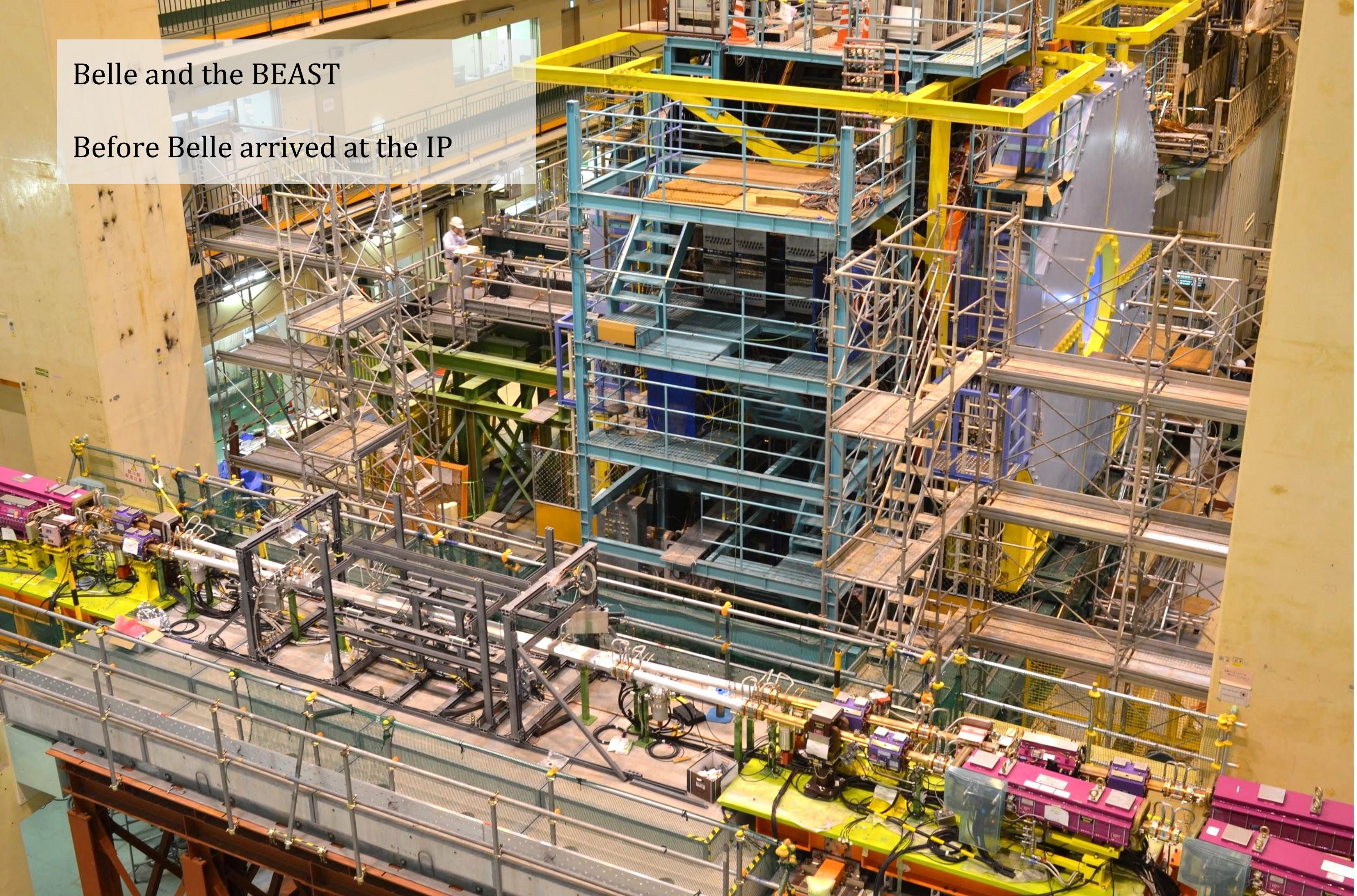
Primary detectors in BEAST II* for Phase 1:

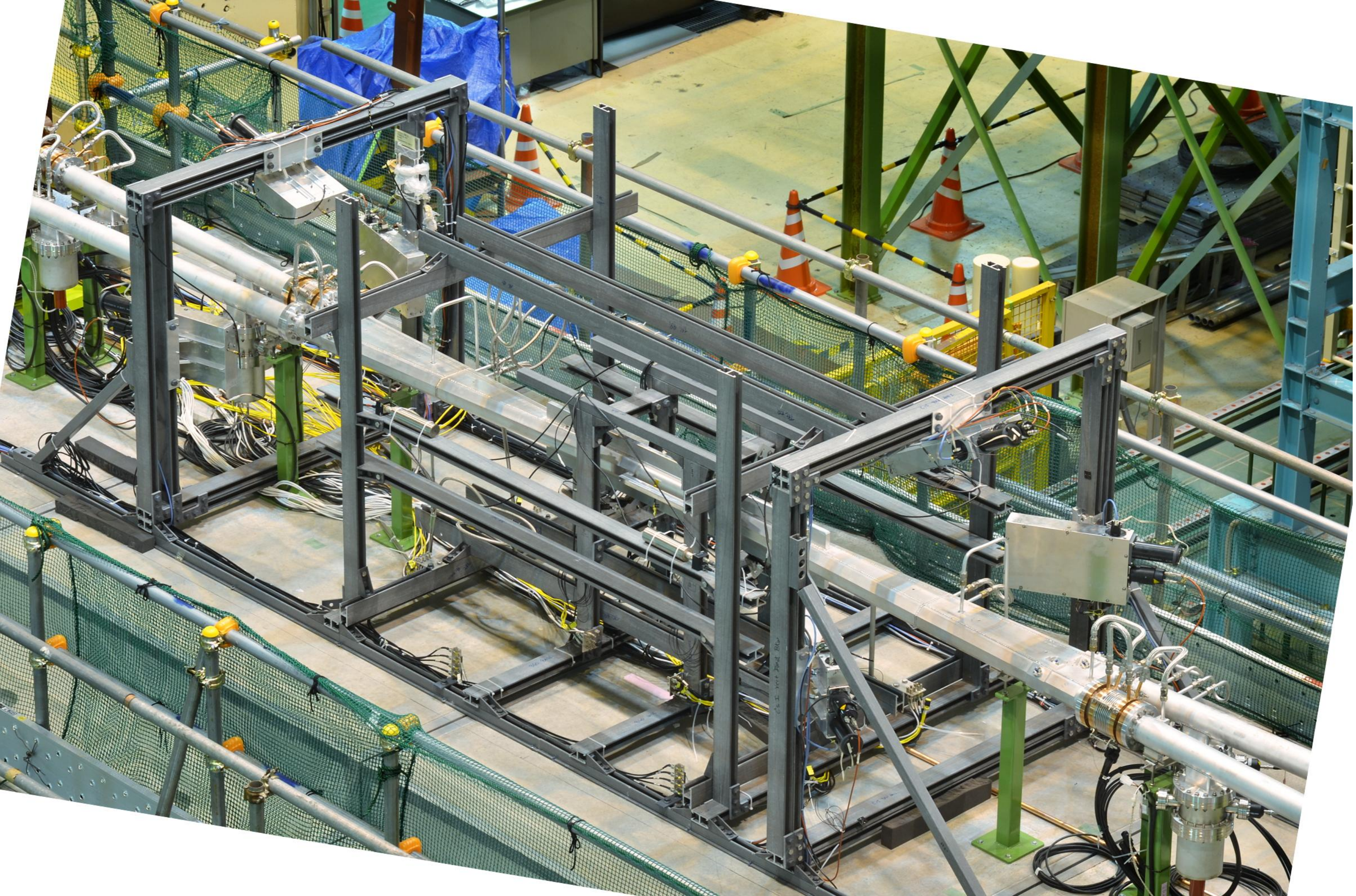
System	#	Unique measurement
PIN diodes	64	Neutral vs. charged dose rate
Time Projection Chambers	4	Fast neutron flux and tracking
Diamonds	4	Beam abort
He3 tubes	4	Thermal neutron rate
CsI(Tl) crystals	6	EM energy spectrum, injection backgrounds
CsI+LYSO crystals	6+6	
BGO crystals	8	EM dose rate
CLAWS plastic scintillators	8	Fast injection backgrounds

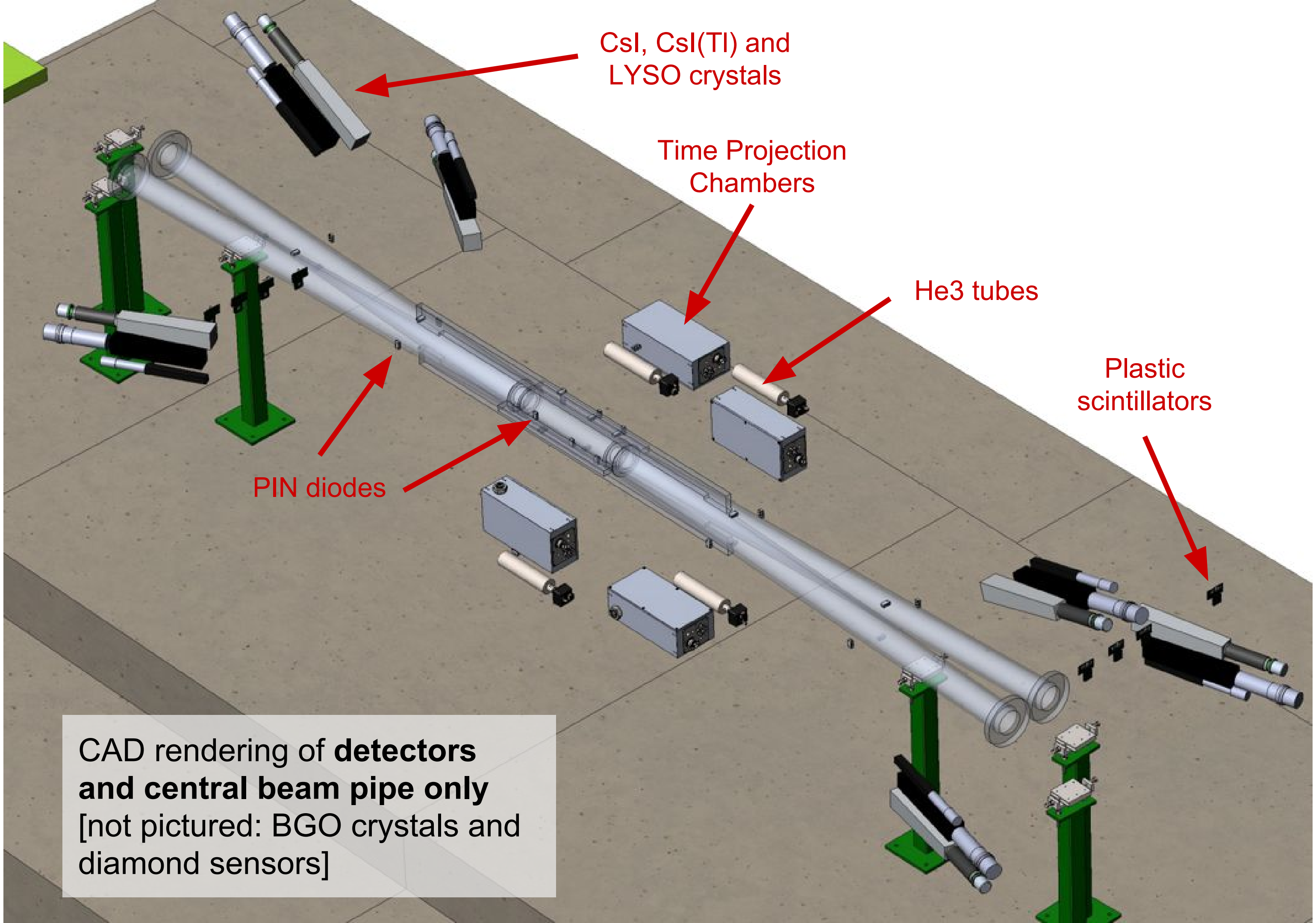
*Belle had its own BEAST

Belle and the BEAST

Before Belle arrived at the IP







CAD rendering of **detectors and central beam pipe only** [not pictured: BGO crystals and diamond sensors]

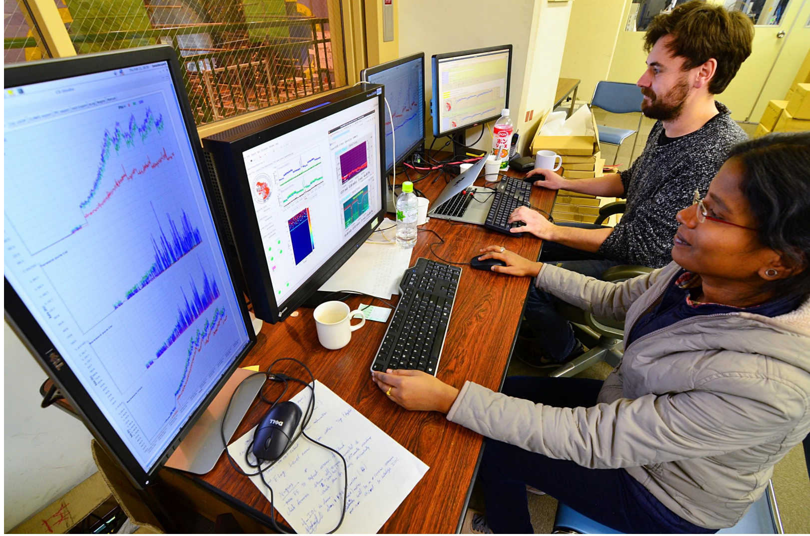
BEAST operation in phase I

Completed

- 24/7 operation for 5 months (top)
- Throughout: beam scrubbing and tuning
- Two weeks of dedicated beam study runs
- Real-time background monitoring and feedback to SuperKEKB group (bottom)
- Dismantled BEAST Phase 1 to make way for Belle II outer detectors and BEAST Phase 2

In progress

- Preparing Phase 1 results for publication (next slides)
- Commissioning BEAST Phase 2



Preliminary BEAST II Phase 1 results

How well do we understand beam backgrounds?

A heuristic equation

- **Hypothesis**: beam-gas and Touschek explain ~*all* of BEAST observables when not injecting
- **Parametrize** observables as functions of accelerator conditions (I, P, gas composition Z_e, beam size σ_y)
- Use this to separately measure beam-gas and Touschek, compare to simulation

$$Observable = B \cdot IPZ_e^2 + T \cdot \frac{I^2}{\sigma_y}$$

Intro: Size-sweep scans

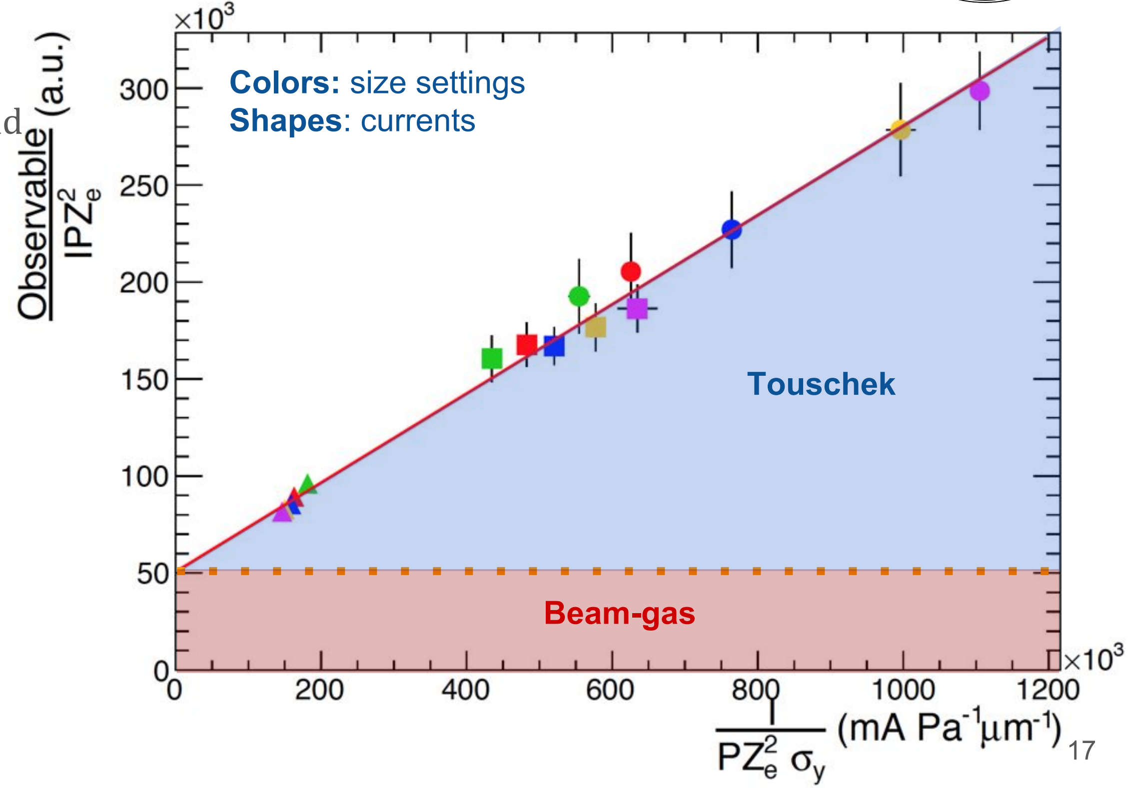
$$Observable = B \cdot IPZ_e^2 + T \cdot \frac{I^2}{\sigma_y}$$

Targeting Touschek

- Ran beam at 5 different beam sizes and at 3 currents (15 runs total)
- Rewrite heuristic so beam-gas is flat:

$$\frac{Observable}{IPZ_e^2} = B + T \cdot \frac{I}{PZ_e^2 \sigma_y}$$

- Fit measures sensitivities B (offset) and T (slope)
- Example, right
  - Observable from BGOs
  - Quality of linear fit **validates model**

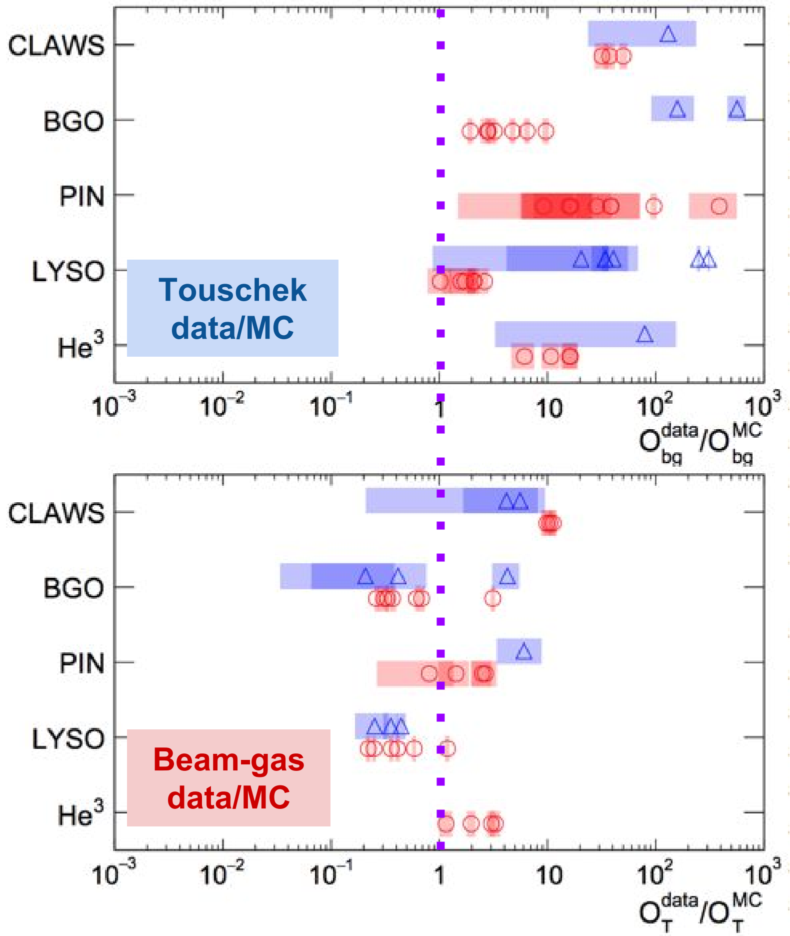


Results: data/MC comparison

From size sweep scans

- **Data/MC ratios** for beam-gas and Touschek, right (1 is perfect agreement)
  - One point per detector channel
  - **Red**: positron beam
  - **Blue**: electron beam
- **The conclusion**: simulating beam-gas is *very hard*
  - Gas conditions are *highly local* and *poorly known*

Lesson from Phase 1: accurate simulation requires comprehensive and well-calibrated beam-size, pressure and composition measurements



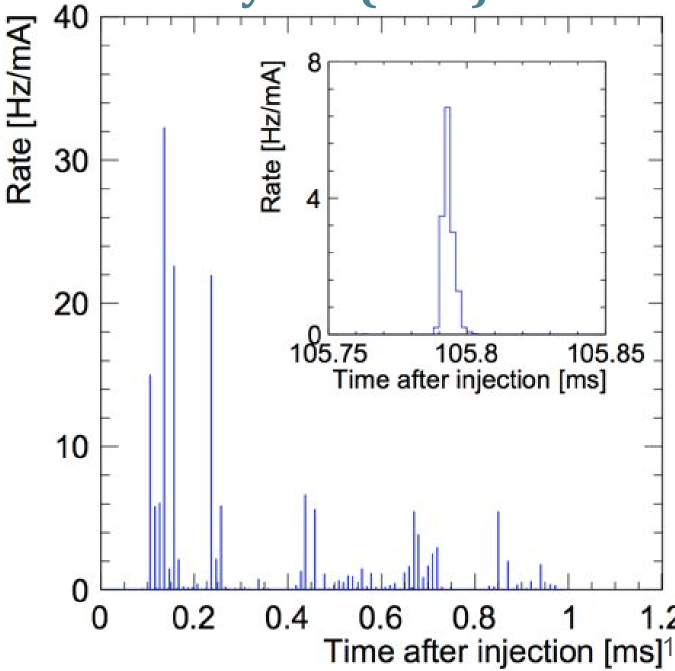
Results: injection background

Fast BEAST detectors

- Bunches are **hot** after charge has been injected
    - Not simulated
    - Dangerous (particularly for inner detectors)
- **Plastic and crystal scintillators** have sufficient **(~ns) timing** to see bunch-by-bunch structure
    - Bunch spacing: 6.3ns
    - Orbit time: 10μs
    - Approximate damping time for hot bunch: 1ms

Lesson from Phase 1: realtime injection time structure from BEAST shown at SuperKEKB control room was critical for tuning injection.

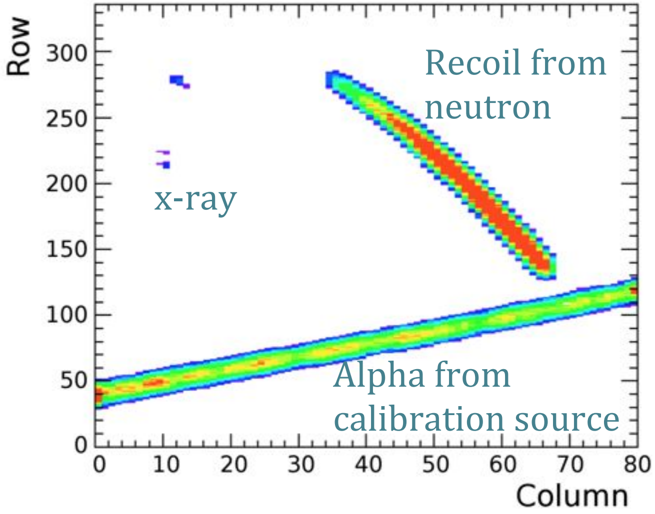
Injection time structure from **CsI crystal (HER)**

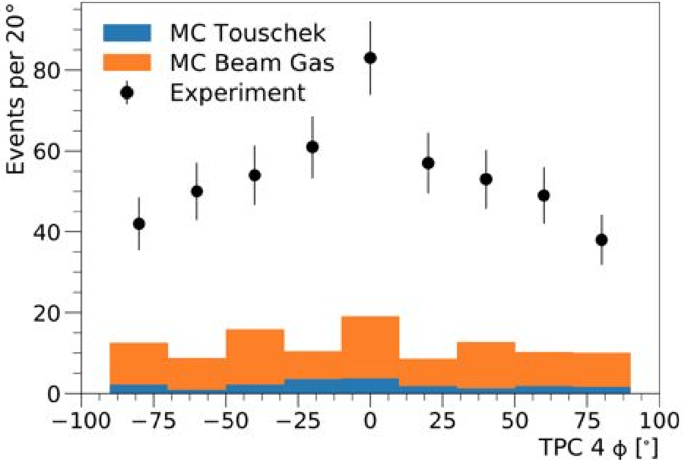


Results: fast neutrons

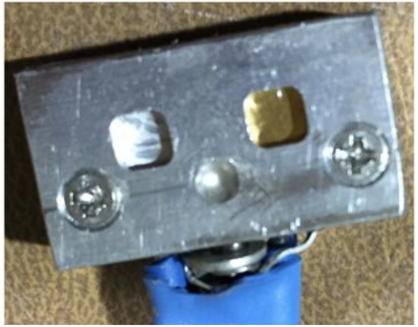
A major concern for Belle II

- 2 “micro” TPCs in Phase 1
  - Fast neutrons collide with He nucleus
  - Nucleus recoils and leaves ionization trail
  - Can fit recoil direction in 3D
  - **Goal**: measure rate of fast neutrons, point back to source, compare with simulation
- **Results** (bottom)
  - (ϕ=0 points to beam-pipe)
  - An excess of ~3 with respect to simulation
  - Similar excess for thermal neutron rate from He3 tubes
  - **Understanding the excess is key goal of Phase 2** (8 TPCs)



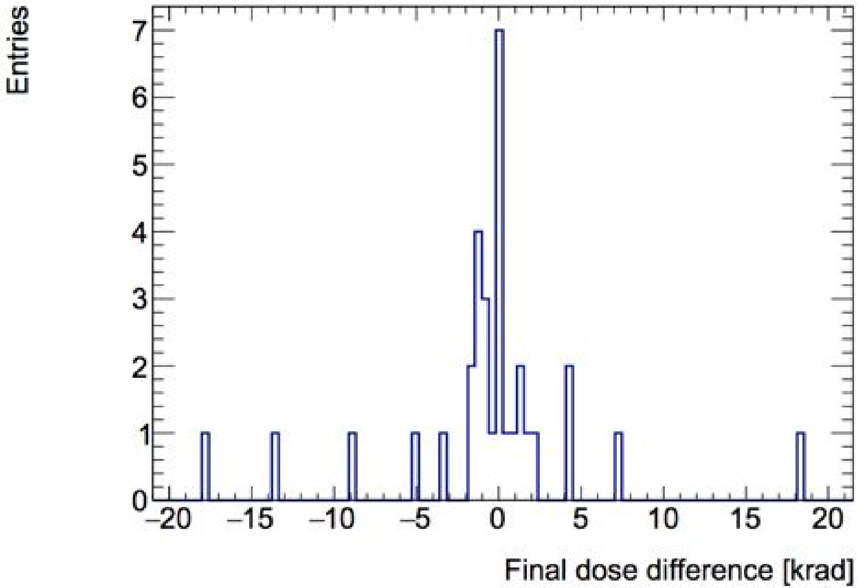


Results: synchrotron radiation



Using the PIN diode system

- 64 channels in 32 modules mounted directly on beam-pipe. Each module contains:
  - One diode with **Al** foil covering
  - One diode with **Au** foil covering
  - Thermocouple for thermal dark current subtraction
- SR (x-ray) signature: higher dose in Al-shielded diodes than neighboring Au-shielded diodes
- Plot, right: difference (**Al**−**Au**) in integrated dose for each pair of PIN diodes in Phase 1
  - **No significant SR detected**



Additional lessons learned

If we had to do this again

- Beam backgrounds need **organized collaboration** between accelerator and detector experts from the beginning. Work together on:
  - **Simulation** (including tracking code)
  - **Dedicated background detectors** near IP and around ring targeting key background types
  - A **commissioning campaign** with purpose-built detectors at the IP and dedicated beam studies
  - **Mitigation** efforts (shielding, collimation, etc.)
  - A shared **control and monitoring system** (such as EPICS)
- Design and operate accelerator conditions systems (beam size, vacuum pressure and composition) as part of a detector system

Status and near future

Phase 1 paper nearing submission

- It's a beast
- Many interesting results not shown today

Phase 2

- Many more questions to answer with narrower beams, collisions and final focusing magnets
- Additional beam background detectors in inner Belle II volume (see additional slides)

First Measurements of Beam Backgrounds at SuperKEKB ☆

A. Aloisio, F. Ameli, A. Beaulieu, L. Bosisio, P. Branchini, T. Browder, A. Budano, G. Cautero, Y.-T. Chen, D. Cinabro, P. Cristaudo, S. de Jong, R. de Sangro, G. Finocchiaro, J. Flanagan, Y. Funakoshi, M. Gabriel, D. Giuressi, M. T. Hedges, N. Honkanen, H. Ikeda, T. Ishibashi, I. Jaegle, H. Kaji, K. Kanazawa, C. Kiesling, S. Koirala, C. La Licata, L. Lanceri, P. M. Lewis, J.-J. Liau, F.-H. Lin, J.-C. Lin, A. Morita, M. Nakao, H. Nakayama, M. Nayak, Y. Ohnishi, A. Passeri, P. Poffenburger, M. Ritzert, M. Roney, A. Rossi, T. Röder, R. M. Seddon, I. S. Seong, J.-G. Shiu, F. Simon, Y. Soloviev, Y. Suetsugu, M. Szalay, S. Terui, G. Tortone, S. E. Vahsen, N. van der Kolk, L. Vitale, M.-Z. Wang, H. Windel, S. Yokoyama

Abstract

The high design luminosity of the SuperKEKB electron-positron collider is expected to result in challenging levels of beam-induced backgrounds in the interaction region. As a result, properly simulating and suppressing these backgrounds will be critical to the success of the Belle II experiment. We report on measurements performed with a system of dedicated commissioning detectors, collectively known as BEAST II, during the so-called phase 1 run of the collider in 2016. We describe BEAST II, report on the beam backgrounds observed, compare them with simulation, and discuss the implications for Belle II.

Keywords:

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Preprint submitted to Nucl. Instrum. Methods Phys. Res., Sect. A *February 12, 2017*

Thank you!

(additional slides)

BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

System	Institution	#	Unique measurement
PIN diodes	KEK	64	Neutral vs. charged dose rate
"Micro" Time Projection Chambers	U. Hawaii	~~4~~8	Fast neutron flux and tracking
Diamonds	INFN Trieste	~~4~~8	Ionizing radiation rate
He3 tubes	U. Victoria	4	Thermal neutron rate
CLAWS plastic scintillators	MPI Munich	~~8~~2 ladders	Fast injection backgrounds

...continued

BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

System	Institution	#	Unique measurement
Belle II PXD	U. Bonn	2 ladders	Radiation tolerance for final physics runs
Belle II SVD	KEK	4 ladders	Radiation tolerance for final physics runs
FANGS	U. Bonn	15	Silicon pixel sensors (synchrotron x-ray spectrum)
PLUME	Strasbourg	2 ladders	Silicon pixel sensors (collimator adjustment)

Intro: injection background

From inefficient injection

- Figure right:
  - **Black points**: predicted observable by heuristic
  - **Red points**: actual observable
  - **Blue**: the difference (injection background)