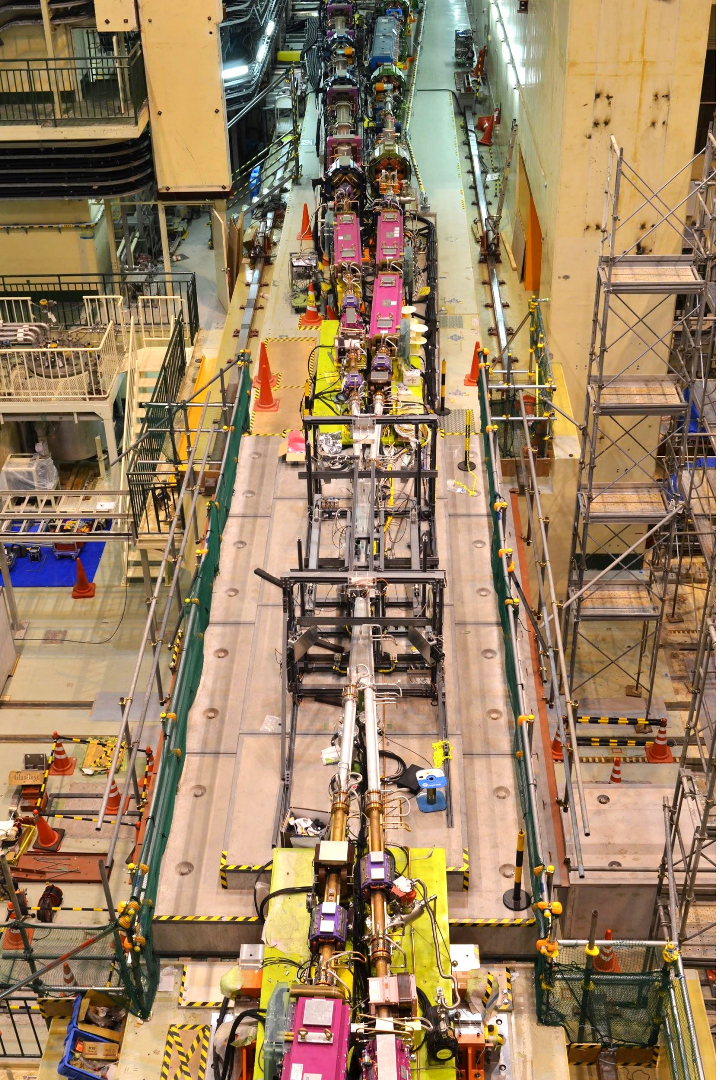


Beam background detection at SuperKEKB/Belle II

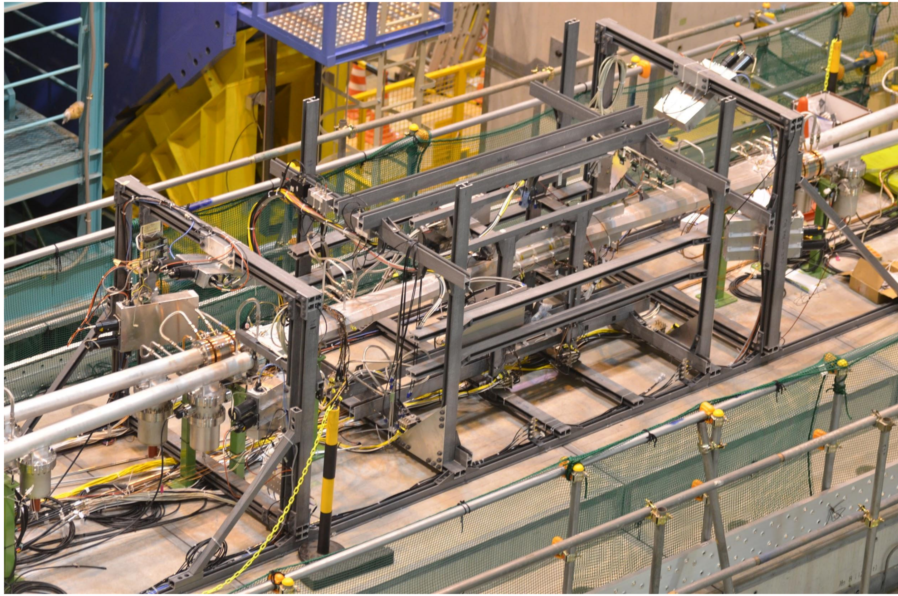
Peter M. Lewis on behalf of the BEAST II Collaboration
University of Hawai'i at Mānoa

27 February 2017
INSTR-17

Overview

This talk

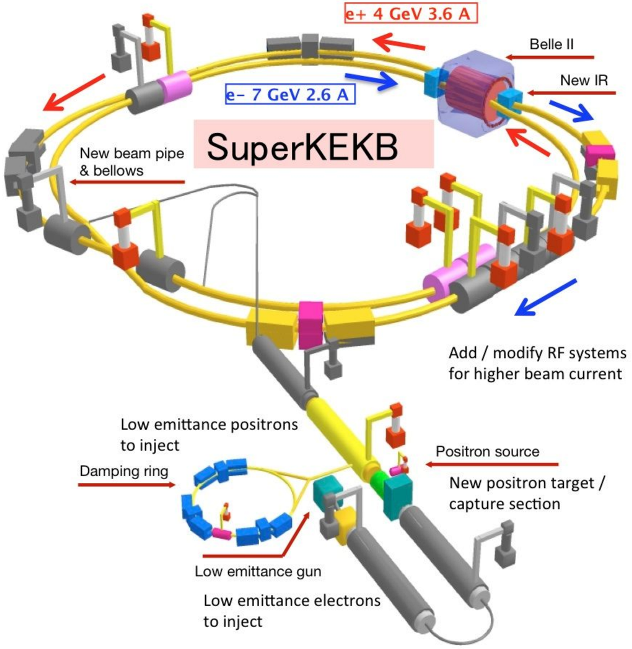
- About BEAST II: a suite of detectors for measuring beam backgrounds at SuperKEKB during commissioning
- Preliminary BEAST II results from the first phase of SuperKEKB operation

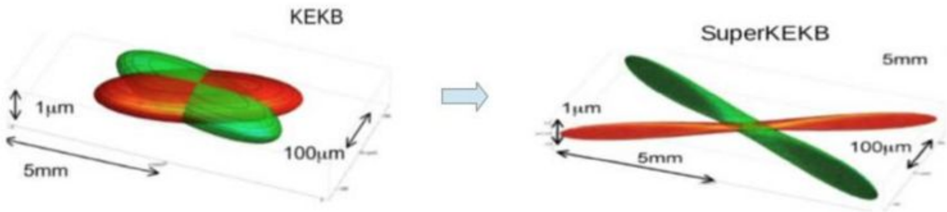


SuperKEKB

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

- A planned **40-fold** increase in luminosity over KEKB (target: $8x10^{35}$ $cm^{-2}s^{-1}$ 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

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

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

Beam Energies 8.0/3.5→7.0/4.0

Commissioning of SuperKEKB

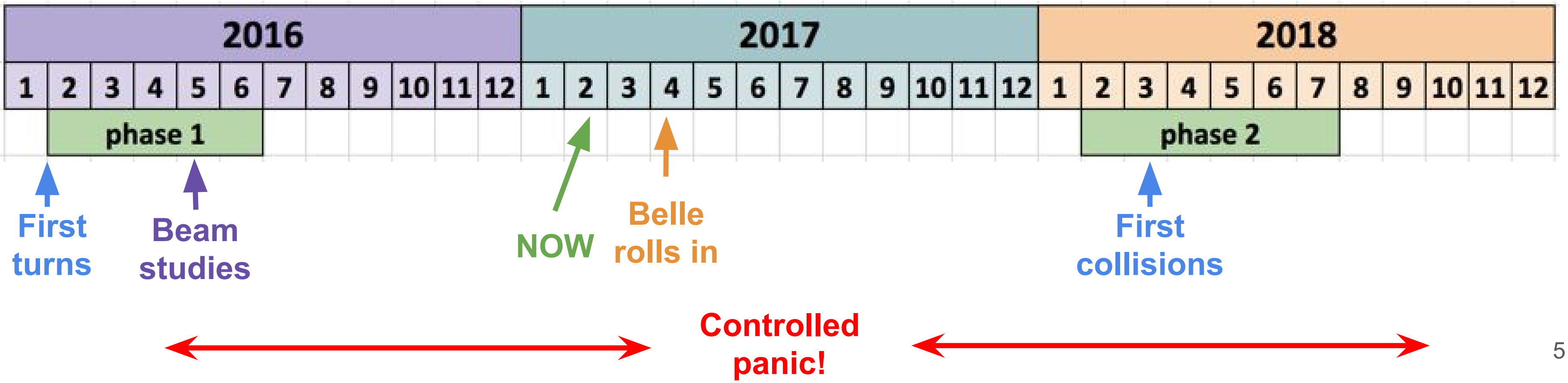
Schedule: beam commissioning phases

Phase I (2016)

- Circulate both beams; **no collisions**
- Tune accelerator optics, etc.
- Vacuum scrub
- **Beam studies**

Phase II (2018)

- First collisions
- Develop beam abort
- Tune accelerator optics, etc. (nano-beam)
- Beam studies



Commissioning requirements

SuperKEKB

- Real-time **monitoring** of beam conditions
- **Quantify** effects of tuning, collimators, etc., on beam loss
- Isolate the **type and source** of beam loss
- Inform beam loss **simulations** to optimize performance

Belle II

- Guarantee a **safe**-enough radiation environment for Belle II (beam backgrounds can be **dangerous** to detectors)
- **Mitigate** beam backgrounds (with physical shielding, electronic gating, magnet tuning, etc.) around interaction point
- Inform beam background **simulations** so they are properly accounted for in physics analysis (where they can cause **lower sensitivities**)

→ **This is where BEAST comes in...**

Enter the BEAST

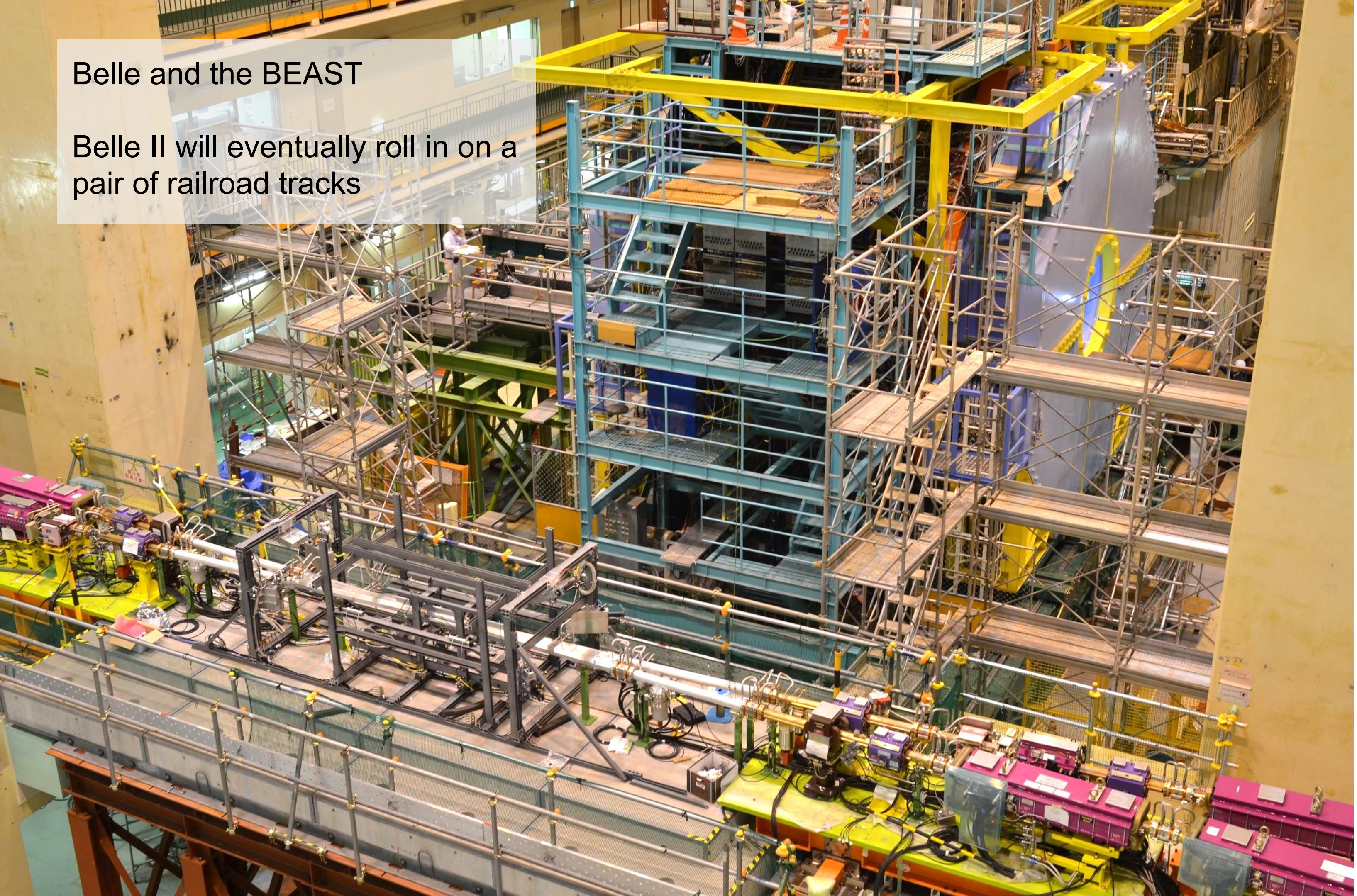
Primary detectors in BEAST II* for phase I:

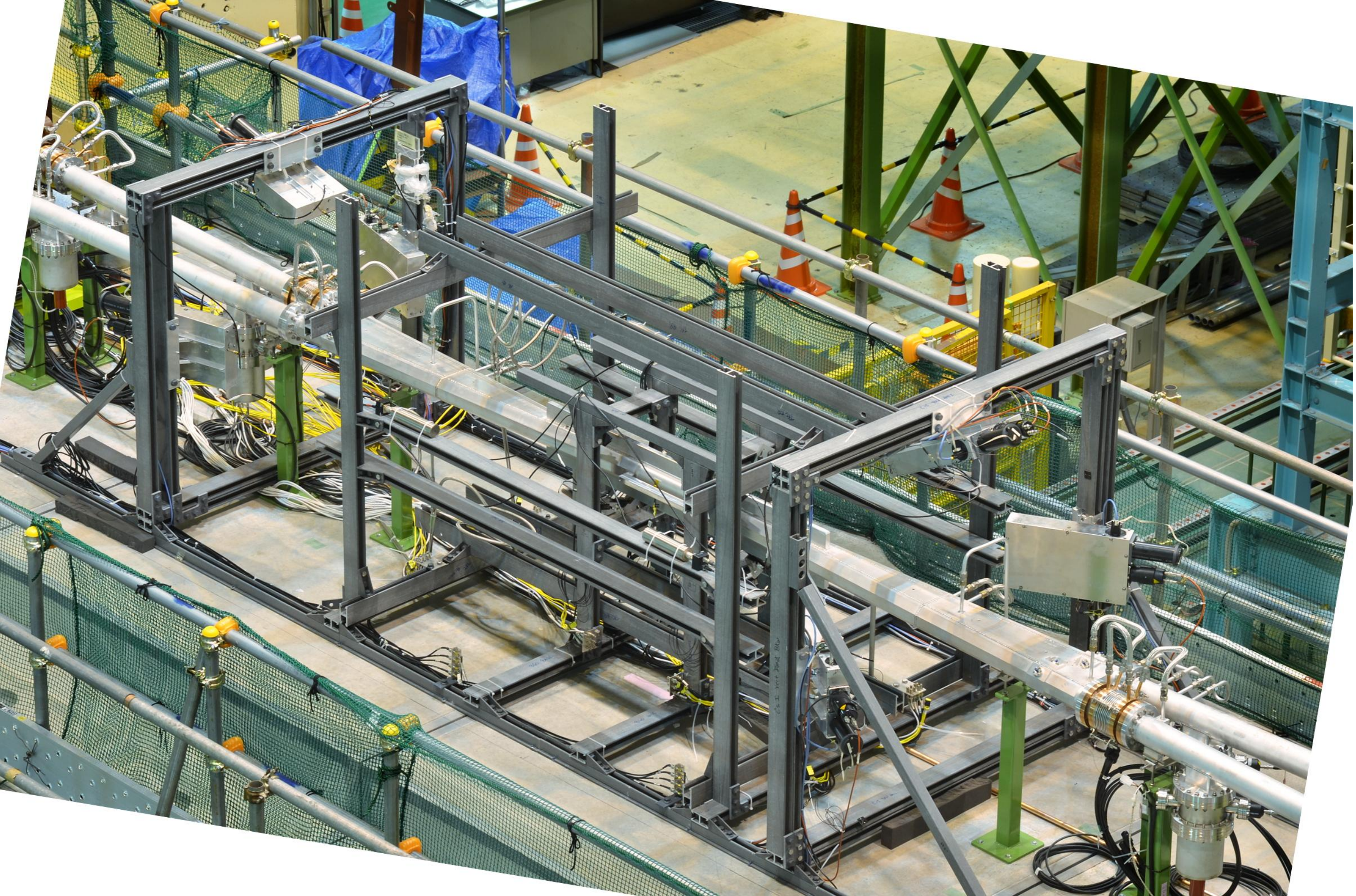
System	Institution	#	Unique measurement
PIN diodes	Wayne St.	64	Neutral vs. charged dose rate
Time Projection Chambers	U. Hawaii	4	Fast neutron flux and tracking
Diamonds	INFN Trieste	4	Beam abort
He3 tubes	U. Victoria	4	Thermal neutron rate
CsI(Tl) crystals	U. Victoria	6	EM energy spectrum, injection backgrounds
CsI+LYSO crystals	INFN Frascati	6+6	
BGO crystals	National Taiwan U.	8	Luminosity and EM rate
CLAWS plastic scintillators	MPI Munich	8	Fast injection backgrounds

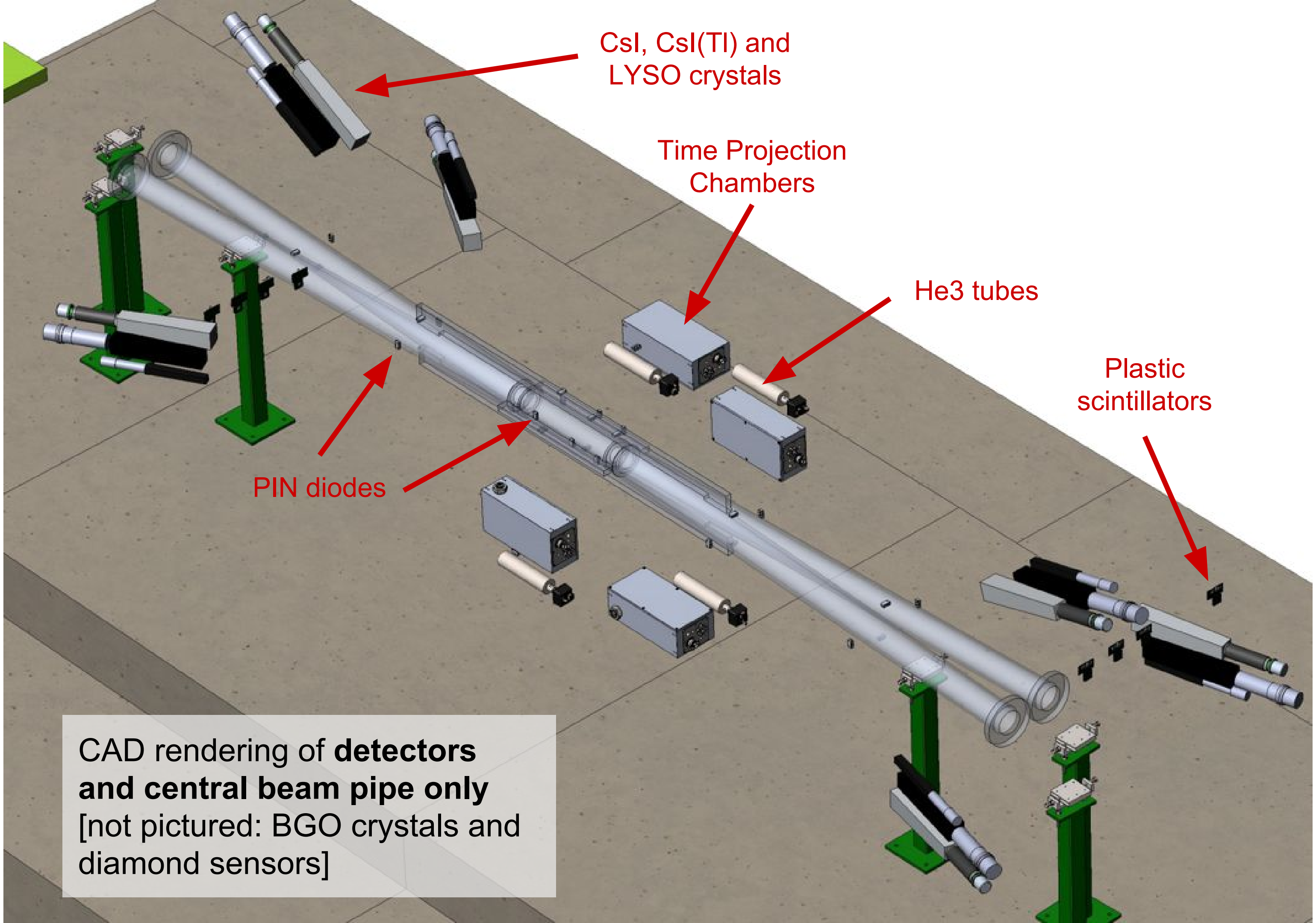
*Belle had its own BEAST

Belle and the BEAST

Belle II will eventually roll in on a pair of railroad tracks







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

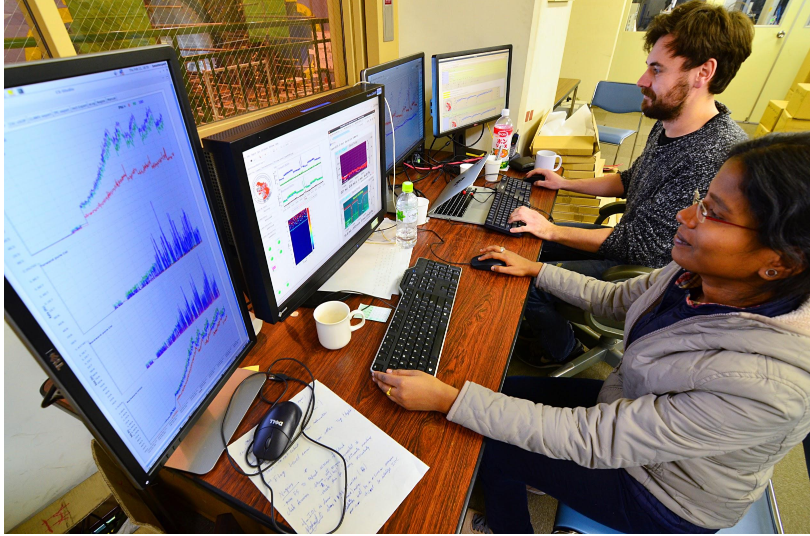
BEAST operation in phase I

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 II to make way for Belle II

In progress

- Preparing final results for publication (next slides)
- Working on phase II version of BEAST



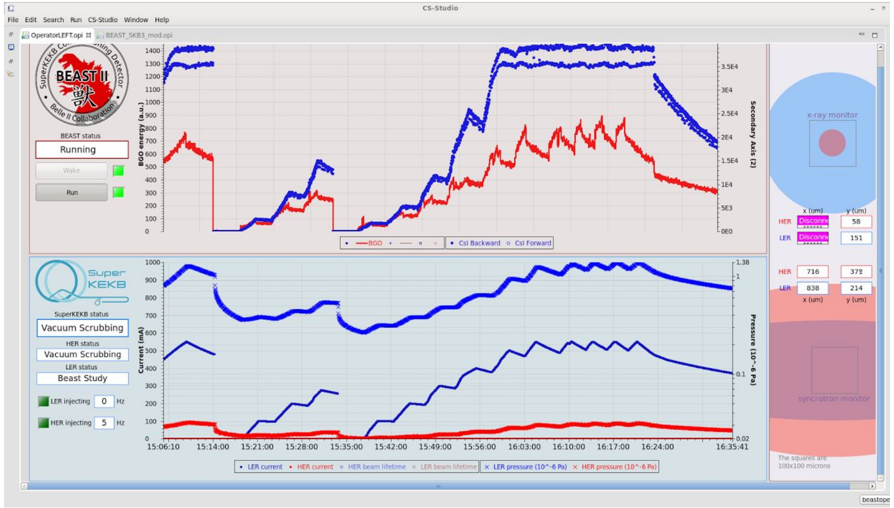
Preliminary BEAST II phase I results

Building a model

$$Observable = \textbf{?}$$

How well can we *predict* beam backgrounds?

- We want **simulation to match data**
- How do we expect **detector observables** to behave as a function of **beam parameters**?
- There are **too many unknown parameters** in the beam to do this in terms of fundamental physics
- Instead we create a “**heuristic** model”
  - Composed of **physics-motivated** contributions from **known background processes**
  - Takes as inputs recorded beam conditions
  - Must explain variations in **observables** recorded by various BEAST detectors



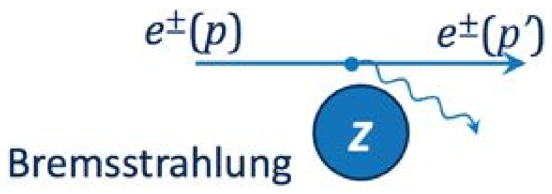
Building a model

$$Observable =$$

Beam-gas scattering

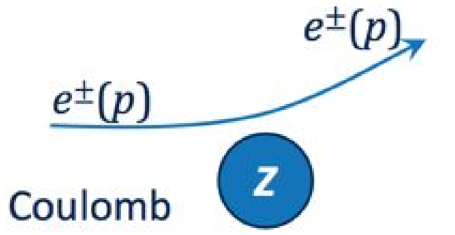
- Includes (inelastic) **Bremsstrahlung** (Z is atomic number, *a* and *b* are parameters, I and P are current and pressure):

$$O_{brem} \propto I \cdot P \cdot Z^2 [log(\frac{a_b}{Z^{1/3}}) + b_b]$$



- Includes (elastic) **Coulomb** scattering:

$$O_{Cou} \propto I \cdot P \cdot Z^2 \left[\frac{1}{a_C + (b_C Z^{1/3})^2} \right]^2$$

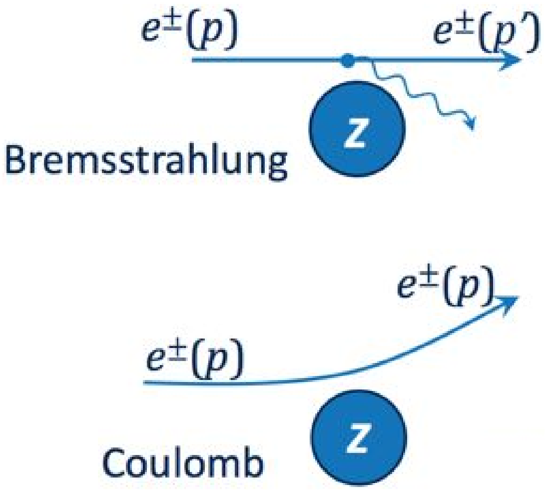


Building a model

$$Observable = B \cdot IPZ_e^2$$

Beam-gas scattering

- Call these both "**beam-gas background**" and parameterize them based on what we know
  - B: **beam-gas sensitivity** for each channel; can be measured in MC and data
  - I: Beam current
  - P: "Local" pressure
  - Z_e: An "effective" atomic number taking into account the gas mixture recorded by a residual gas analyzer
- This is the **first term** in our heuristic model...

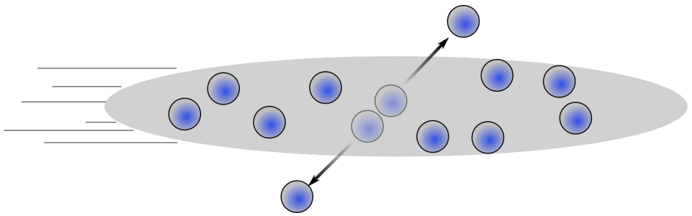


Building a model

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

Touschek scattering

- Intra-beam Coulomb scattering
- Becomes dominant with **highly compressed beams** or bunches with a high density of particles
  - A **major concern** for SuperKEKB due to nano-beam scheme
- Depends on many factors; most of which do not vary during normal operation, except:
  - $\boldsymbol{\sigma}_y$: the vertical beam size
  - *I*: current
- The **touschek sensitivity *T*** is constant for each channel and can be measured in MC and data



Testing the model

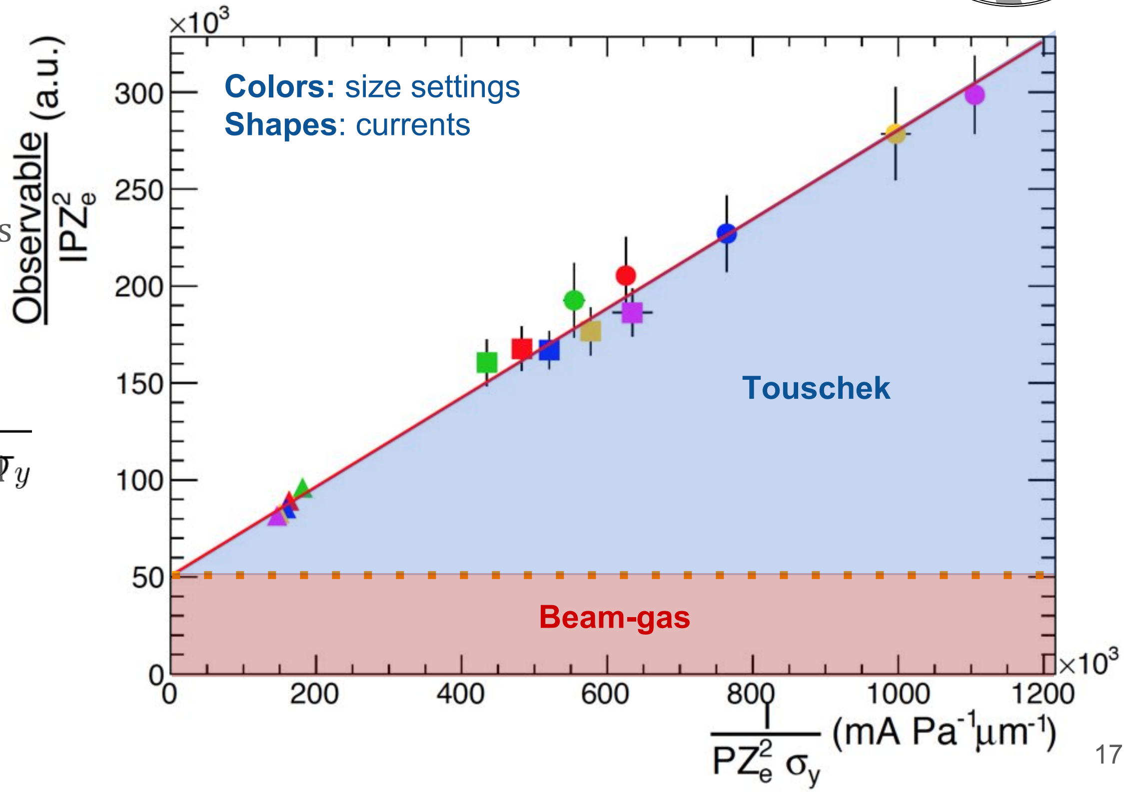
$$Observable = B \cdot IPZ_e^2 + T \cdot \frac{I^2}{\sigma_y}$$

Size-sweep scans

- Run beam at 5 different beam sizes and at 3 currents (15 runs total)
- Observable comes from BGO crystals
- Rewrite so beam-gas is flat:

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

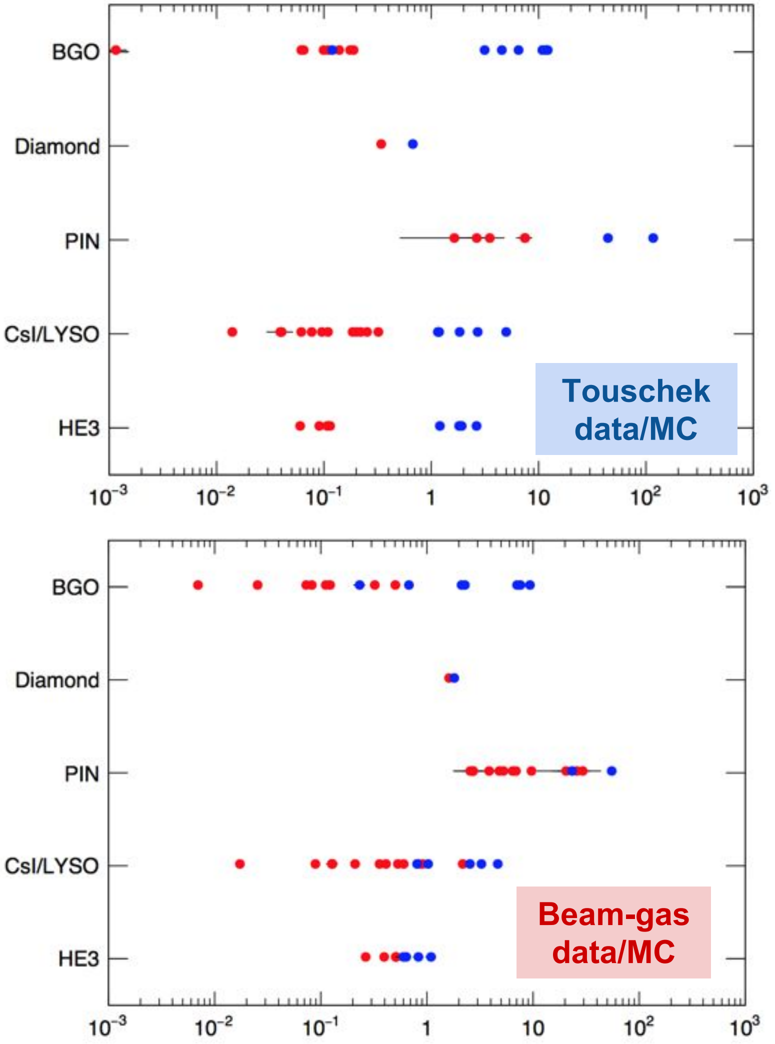
- Quality of linear fit **validates model**
- Fit measures sensitivities B (offset) and T (slope)



Comparison with MC

Ratios of sensitivities

- **Data/MC ratios** for beam-gas and Touschek sensitivities, right (1 is perfect agreement)
  - One point per detector channel
  - **Red**: positron beam
  - **Blue**: electron beam
- The conclusion: MC and data don't agree well at all!
  - (Not *yet)*
- We understand **some** of the disagreement but not all of it
  - This is ***good***, it proves why we needed BEAST!
  - We're working hard on refining our understanding of SuperKEKB, BEAST and simulation so we can enter phase II with confidence



Other results: injection

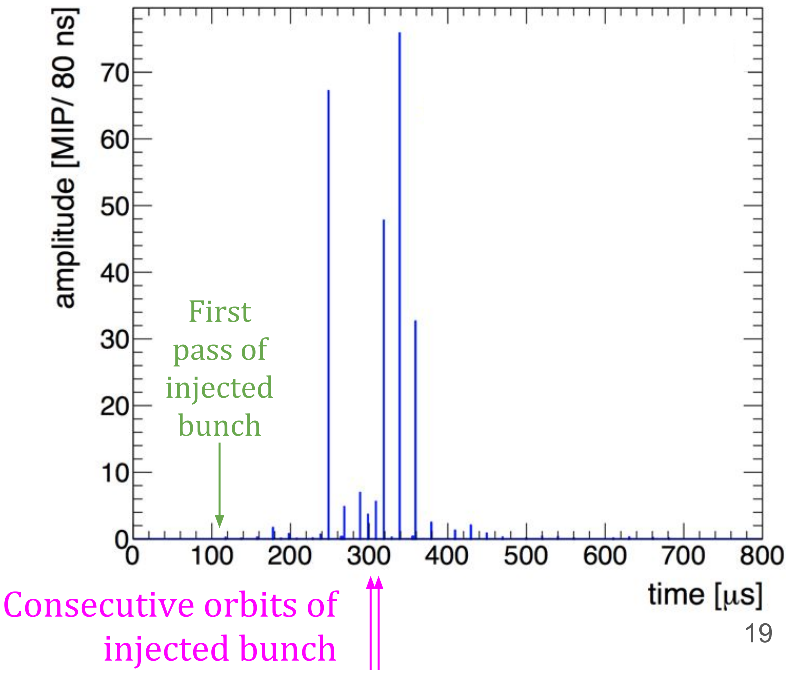
Injection backgrounds

- New charge is periodically injected into bunches
- These bunches are “dirty” for some time, showing short (~ns), medium (~μs) and long (~ms) time structure
- Not simulated and potentially dangerous, this **must be understood in detail**

Fast BEAST detectors

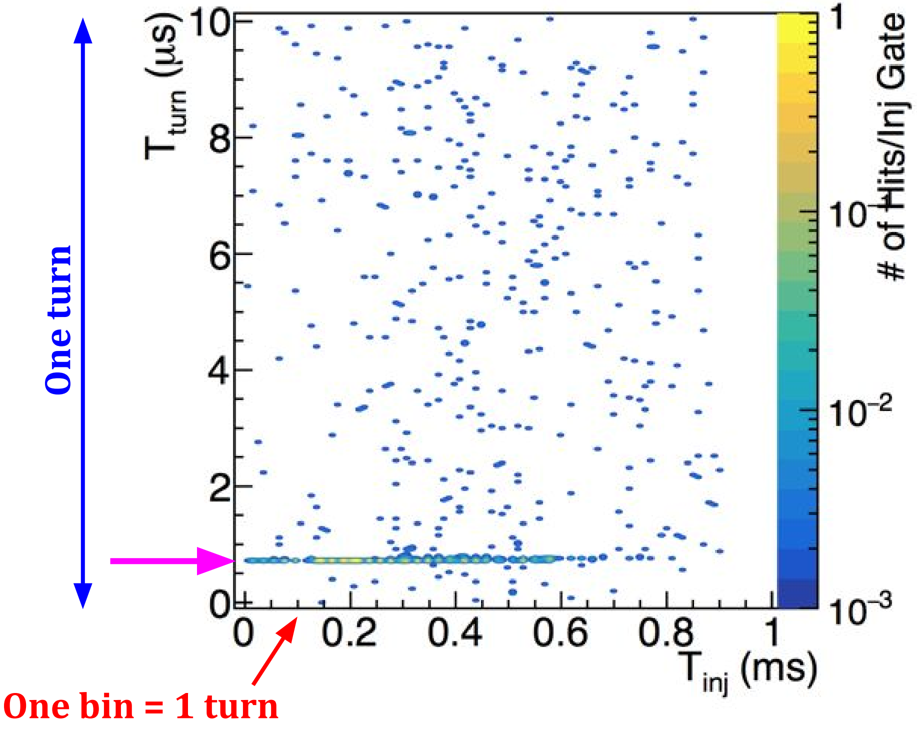
- **Plastic and crystal scintillators**
- **Excellent (~ns) timing** to see bunch-by-bunch structure
  - Bunch spacing: 6.3ns
  - Orbit time: 10μs

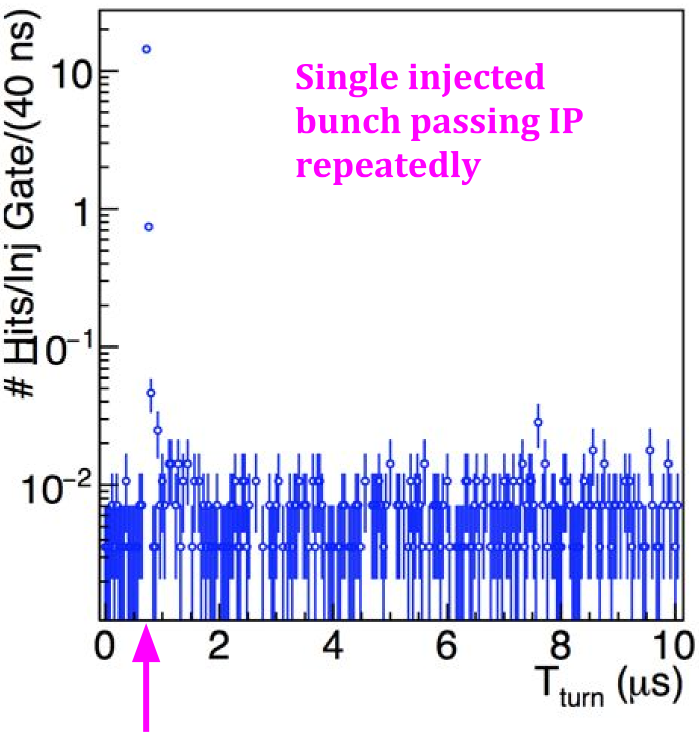
Injection time structure from **plastic scintillators**



Other results: injection

Injection time structure from **crystals**

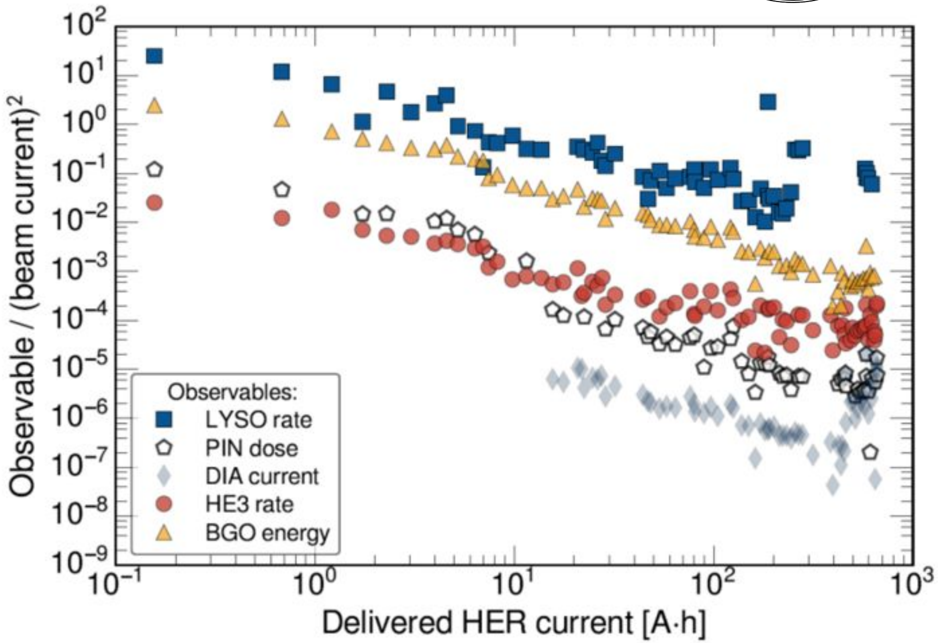




Other results: scrubbing

Cleaning new beam pipe

- A key goal of phase I was to “scrub” the beam pipes
  - High currents stimulate desorption of impurities from beampipe walls
  - Over time, **vacuum improves**, lowering beam-gas backgrounds
- BEAST quantified distinct improvements in beam-gas in phase I (right)
- Scrubbing **not yet** at final physics run quality



Status and near future

Paper in progress

- It’s going to be a beast!
- Many exciting results not shown today
- Look for publication in the summer

Phase II

- BEAST II and some Belle II detectors work together
- Phase I results suggest there will be no major surprises
- Many more questions to answer with narrower beams, collisions and final focusing magnets

First Measurements of Beam Backgrounds at SuperKEKB ☆

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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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Спасибо!

(This is the view ~right now at KEK: final focusing magnet commissioning at IP)
Photo courtesy R. Mussa

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)