The Belle II / SuperKEKB Commissioning Detector - Results from the First Commissioning Phase

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on behalf of the BEAST II Collaboration

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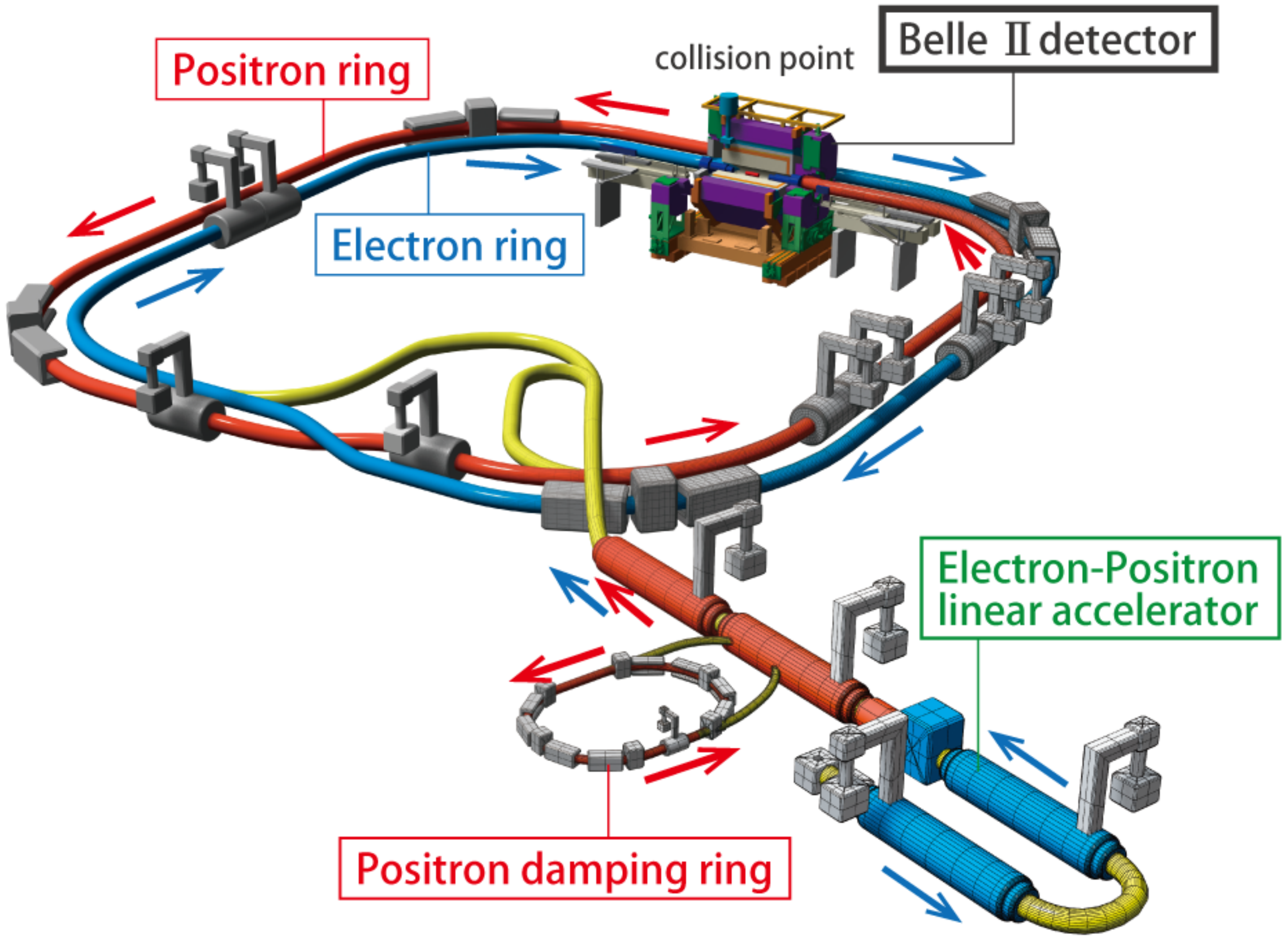
The SuperKEKB Accelerator: upcoming *B*-factory at KEK

Schematic overview of SuperKEKB layout:



Planed to increase luminosity of KEKB by a *factor of 40* (Goal: 8x10^{35} *cm*^{2}*s*$^{-1}$ instantaneous & 50 *ab*$^{-1}$ integrated luminosity):

$$L = 8 \times 10^{35} cm^2 s^{-1} \propto \left(\frac{I_{\pm}\epsilon_{y\pm}}{\beta^*_{y\pm}} \right)$$

- "***Nano-beam***" scheme (vertical beam size β^*_y)
- ***doubled beam currents*** (current ***I***)
- numerous upgrades to RF, magnet, vacuum and damping systems

***Highly increased Beam Backgrounds* will represent a significant challenge for Belle II:**

- limit to beam lifetime, reduced survival time, instantaneous damage, hit occupancy, non-reducible analysis background

The SuperKEKB Accelerator: First Circulating Particles

Feb. 10, 2016: first circulating particles in a brand new accelerator! Very exciting times!

NEW FACILITIES

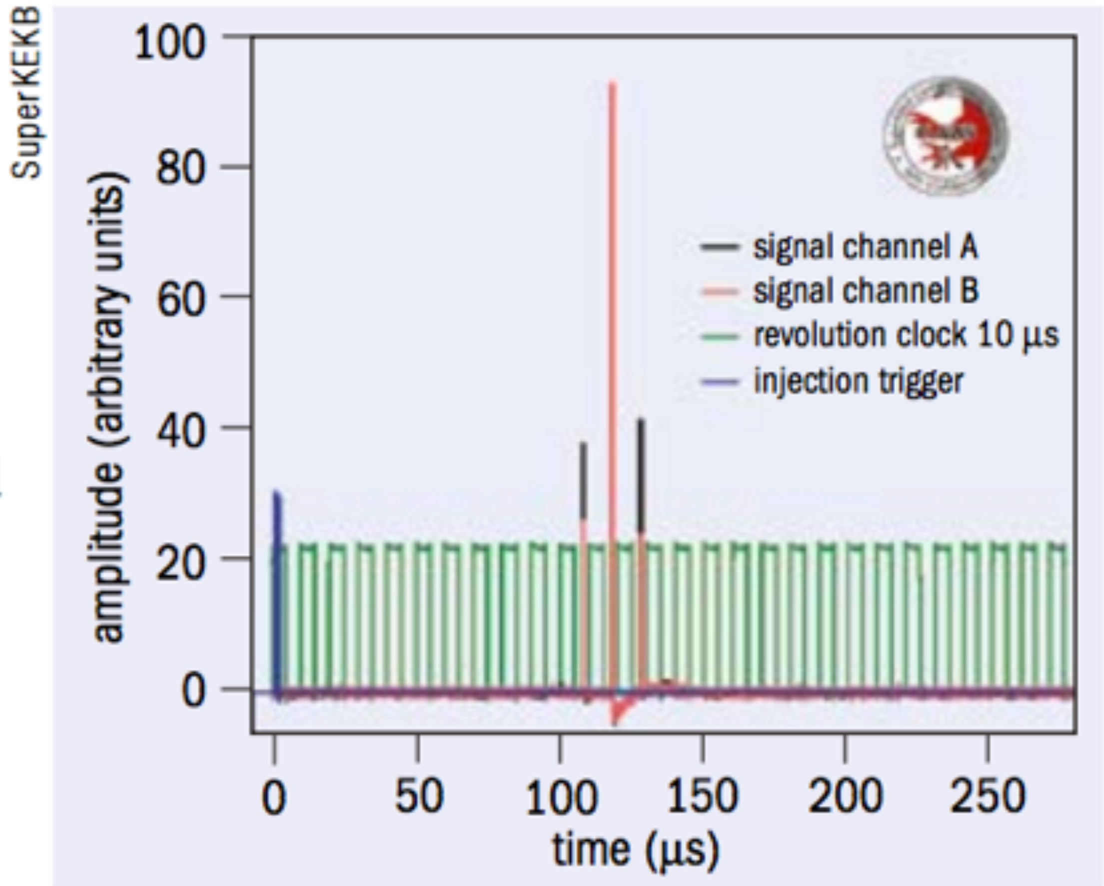
'First turns' for SuperKEKB

On 10 February, the SuperKEKB electron–positron collider in Tsukuba, Japan, succeeded in circulating and storing a positron beam moving close to the speed of light through 1000 magnets in a narrow tube around the 3 km circumference of its main ring. And on 26 February, it succeeded in circulating and storing an electron beam around its ring of magnets in the opposite direction.

The achievement of "first turns", which means storing the beam in the ring through many revolutions, is a major milestone for any particle accelerator.

SuperKEKB, along with the Belle II detector, is designed to search for new physics beyond the Standard Model by measuring rare decays of elementary particles such as beauty quarks, charm quarks and τ leptons.

Unlike the LHC, which is the world's highest-energy machine, SuperKEKB/



The three middle "spikes" are signals from CLAWS, a subsystem of the BEAST II detector triggered by the SuperKEKB injection signal.

Belle II is designed to have the world's highest luminosity – a factor of 40 higher than the earlier KEKB machine, which holds many records for accelerator performance. SuperKEKB will therefore be the leading accelerator on the "luminosity frontier".

The Belle II detector at SuperKEKB was designed and built by an international collaboration of more than 600 physicists from 23 countries. This collaboration is working closely with SuperKEKB accelerator experts to optimise the machine performance and backgrounds.

At the same time as first turns were achieved, the BEAST in its cave at Tsukuba Hall awakened from its slumber. The BEAST II detector is a system of detectors designed to measure the beam backgrounds of the SuperKEKB accelerator. The parasitic radiation produced by electromagnetic showers when the beam collides with the walls of the vacuum pipe not only obscure the signals that we wish to observe, but can also damage the detector. Therefore, when operating the new accelerator, these beam backgrounds must be well understood.

The BEAST II detector will collect data in the unique environment produced by SuperKEKB's first beams, allowing Belle II to safely roll into the beam in 2017.

● **Further reading**

https://twitter.com/belle2collab and https://www.facebook.com/belle2collab/.

Screenshot taken from CERN Courier April 2016

Commissioning of the SuperKEKB Accelerator

Commissioning of SuperKEKB: Goals and Schedule

Starting an accelerator: Simply get in and drive off??? …

First accelerator commissioning phase (Phase 1): overview and overall goals

- **no Belle II detector**; no final focusing
- circulate both beams; **no collisions**
- improvement of vacuum conditions & accelerator tuning
- study **beam properties**

2016												2017												2018											
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
	Phase 1																								Phase 2										

talk by Hua Ye

Resulting Phase 1 requirements:

- real time monitoring of beam conditions and quantification of tuning effects
- guarantee radiation safe environment for Belle II operation
- **measure and understand beam backgrounds and improve and validate simulation (=impact on analysis)**

Sources of Beam Background at SuperKEKB:

- ***Touschek*** **scattering: intra-bunch scattering process**
  - dominant with highly compressed beams, expected to be 20 time higher
- **Beam-gas scattering: Bremsstrahlung and Coulomb interactions with residual gas atoms & molecules**
  - Bremsstrahlung negligible, Coulomb interactions up to 100 times higher
- **Synchrotron radiation: emission of photons by charged particles (e^+e^-) when deflected in *B*-field**
- **Injection Background:**
  - covered later in the talk
- ***Radiative Bhabha*** **process: photon emission prior or after *Bhabha* scattering**
  - interaction with iron in the magnets leads to neutron background
- ***Two photon*** **process: very low momentum e^+e^- pairs**
  - increased hit occupancy in inner detectors

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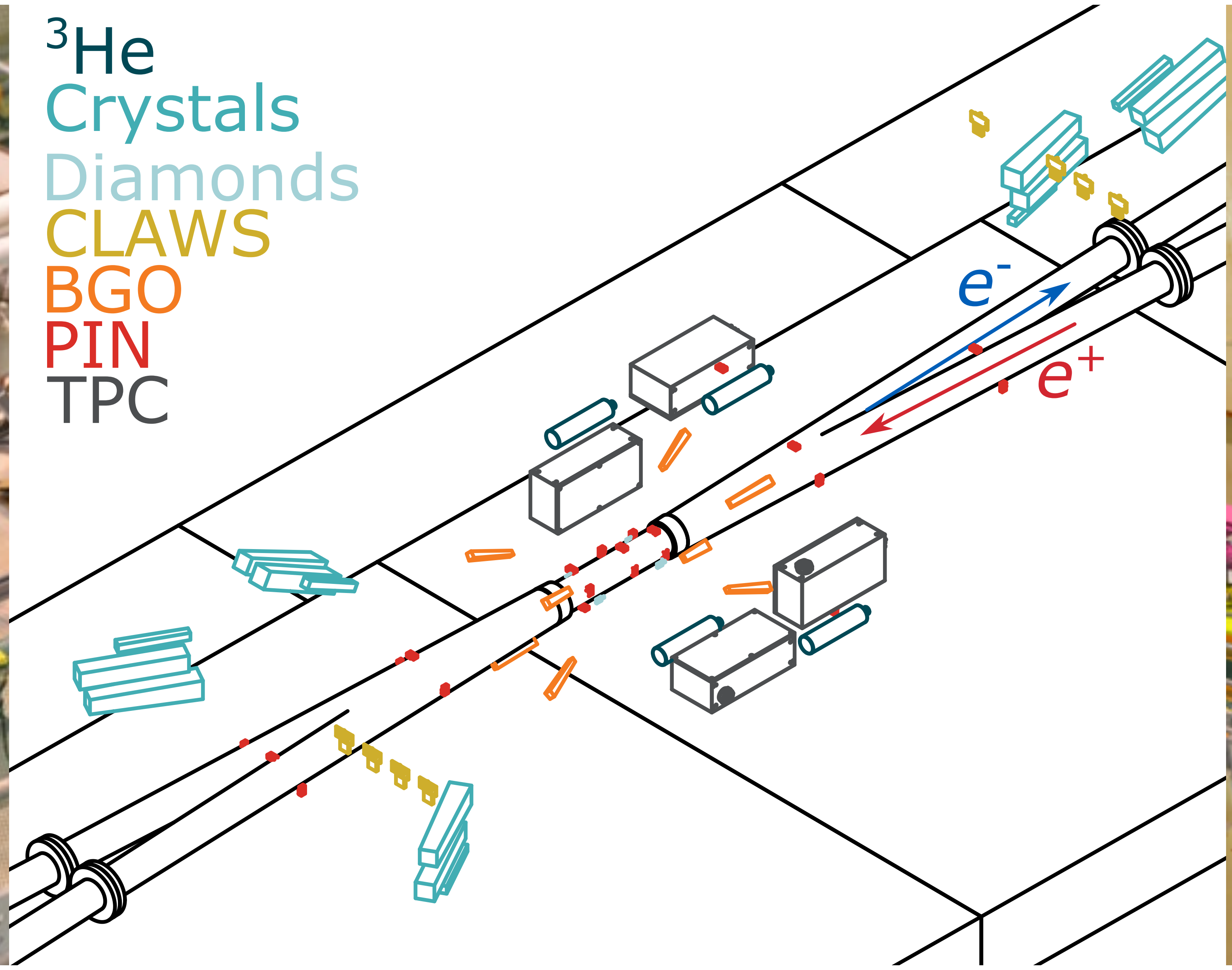
Can not be measured during in Phase 1

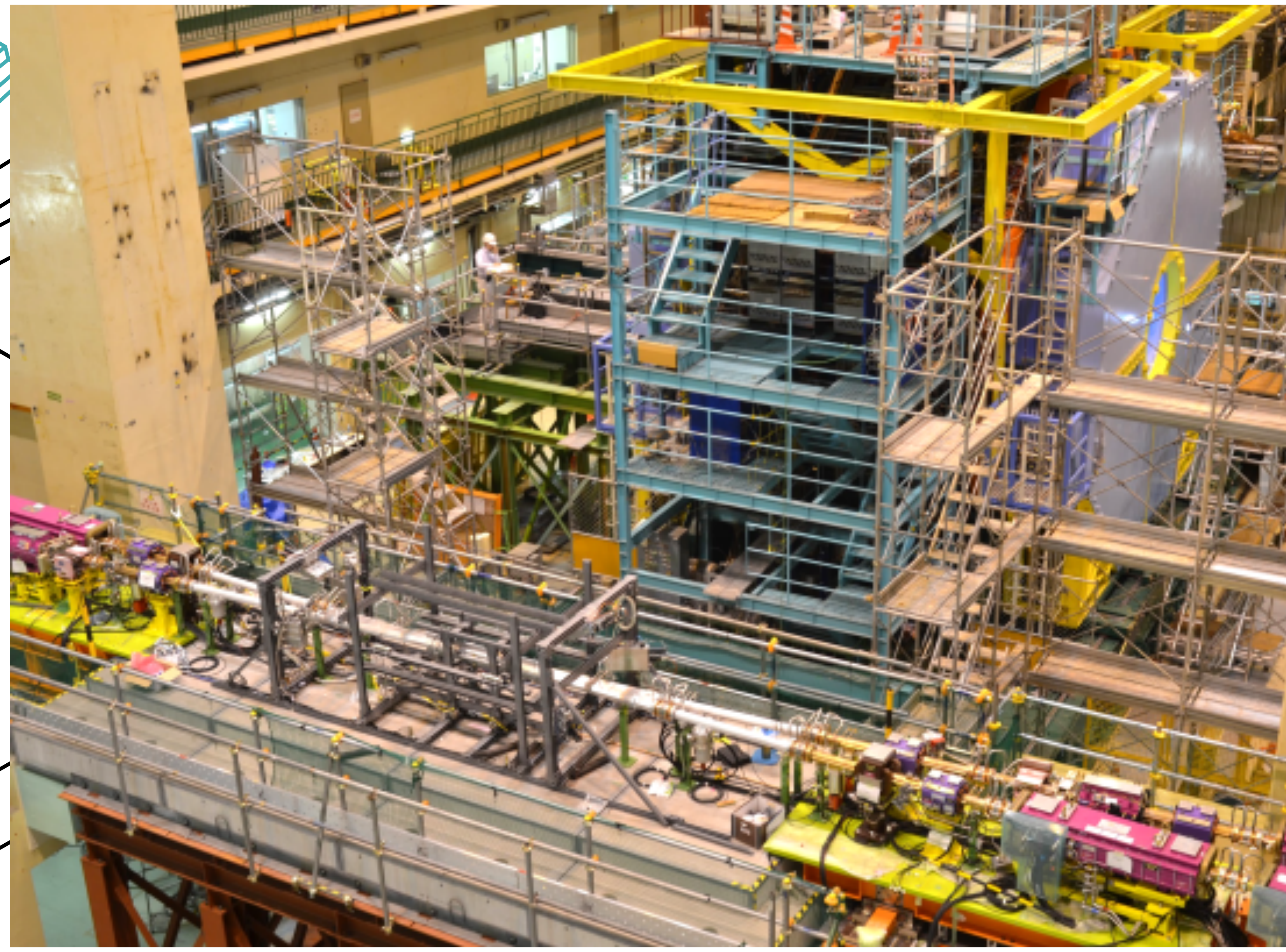
First Phase of SuperKEKB Commissioning:
the *BEAST* Experiment

The *BEAST* Experiment: Overview

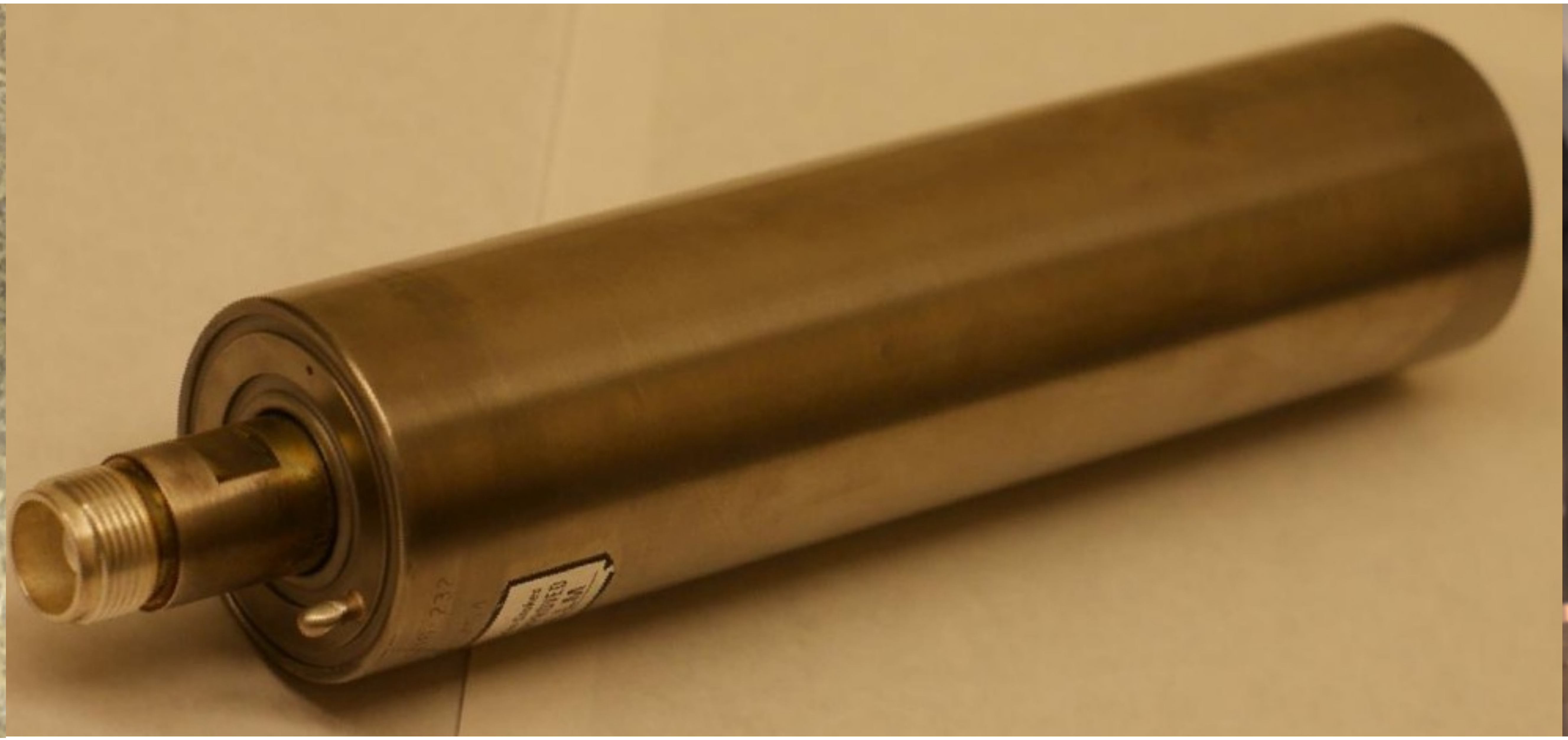
The BEAST Experiment:
"…a system of dedicated commissioning detectors, collectively known as BEAST II, during the so-called phase 1 run of the collider… to measure beam background from the beams…"

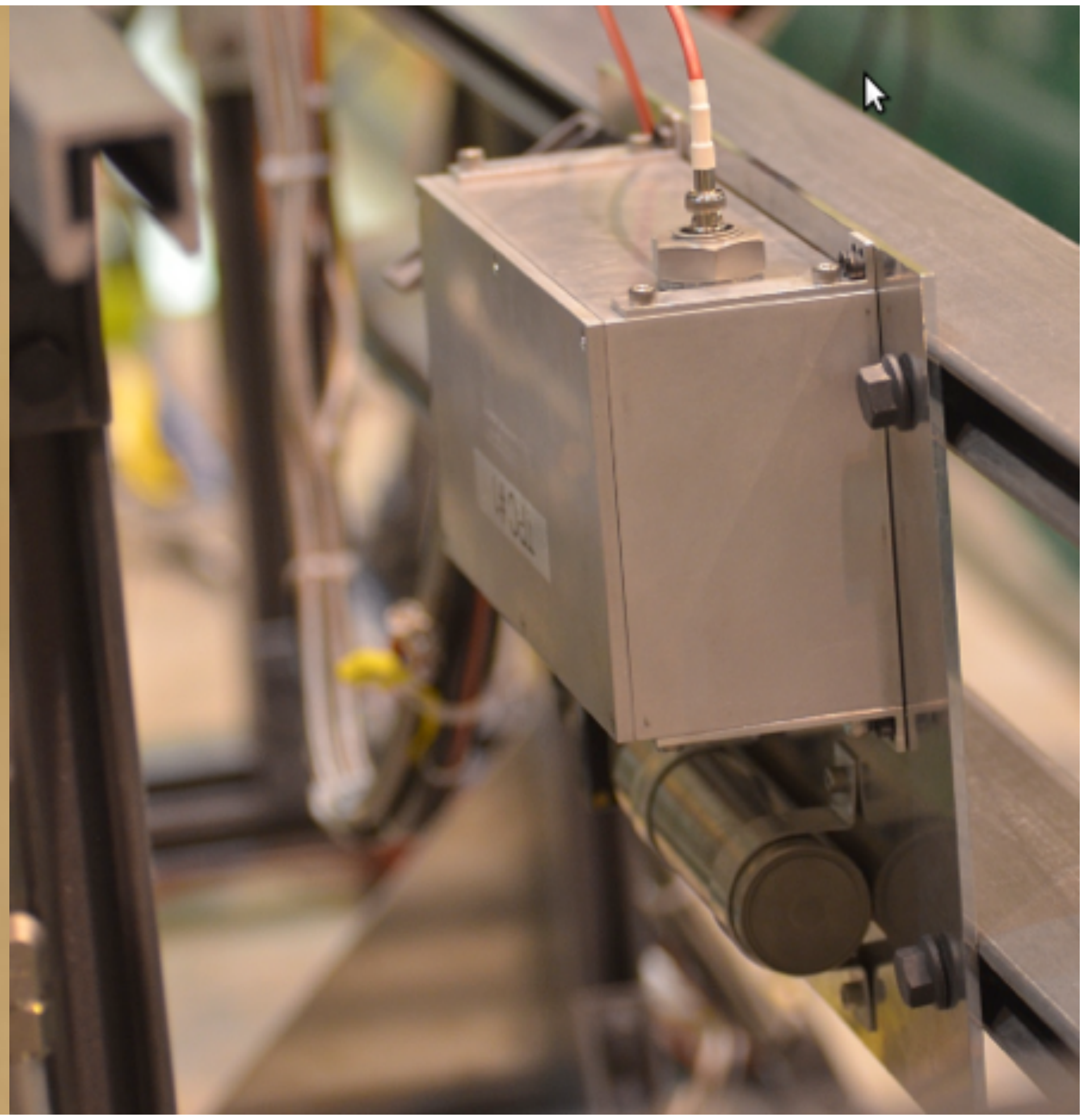
- 24/7 operation for 5 month
- two weeks of dedicated beam study runs
- monitoring of beam background and feedback to SuperKEKB group in real-time





The *BEAST* Experiment: PIN diodes, ^{3}HE tubes and BGO crystals





PIN Diode Array (32x2):

- unbiased off the shelf PIN diodes from Siemens
- gold shielded/unshielded pair of diodes
- unique measurement:

charged vs X-ray radiation dose rate

^{3}He Tubes (4):

- Helium-3 proportional counter
- mounted at ϕ = 0, 90, 180 and 270 around the IP
- unique measurement:

thermal neutron rate

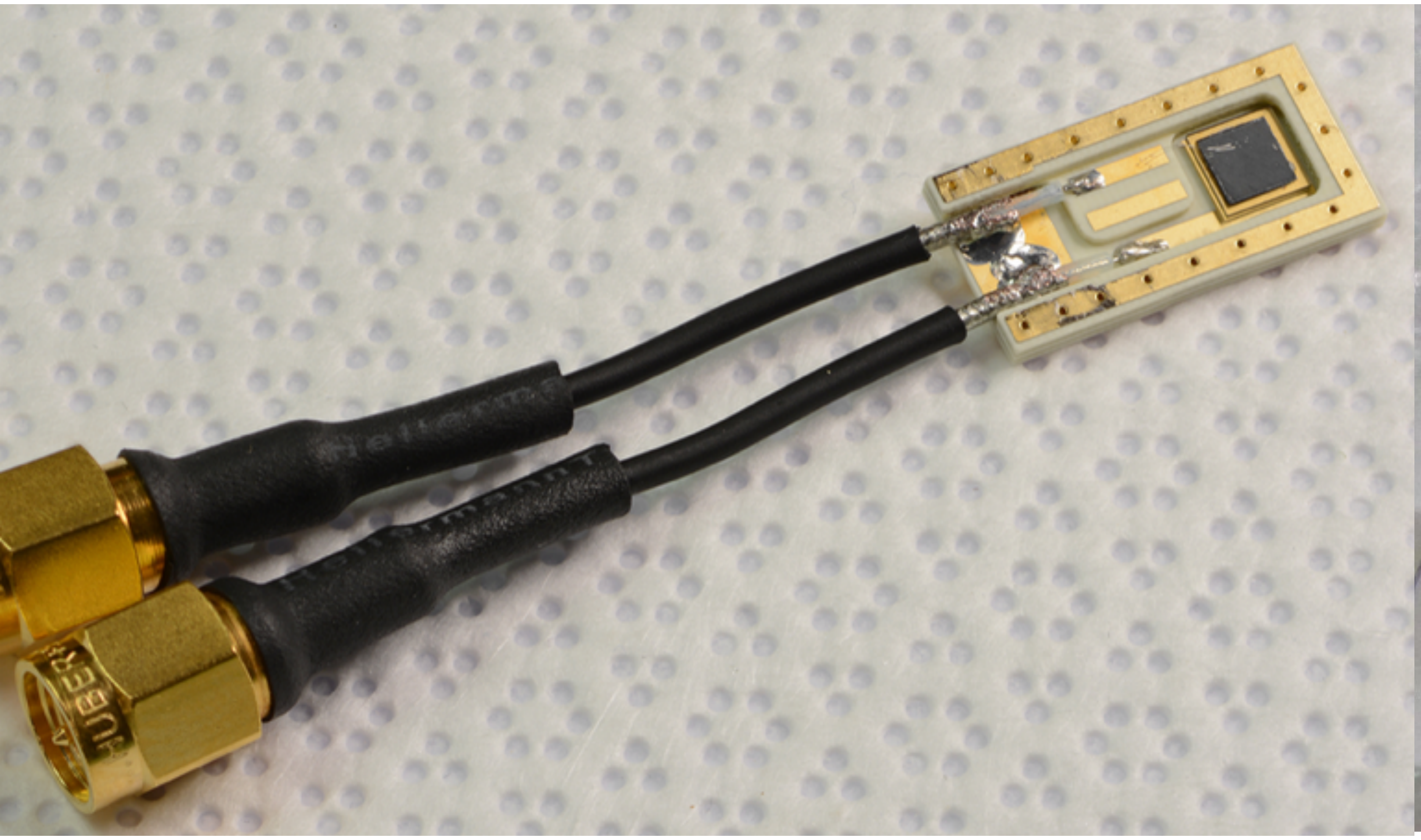
Micro Time Projection Chambers (TPC) (4):

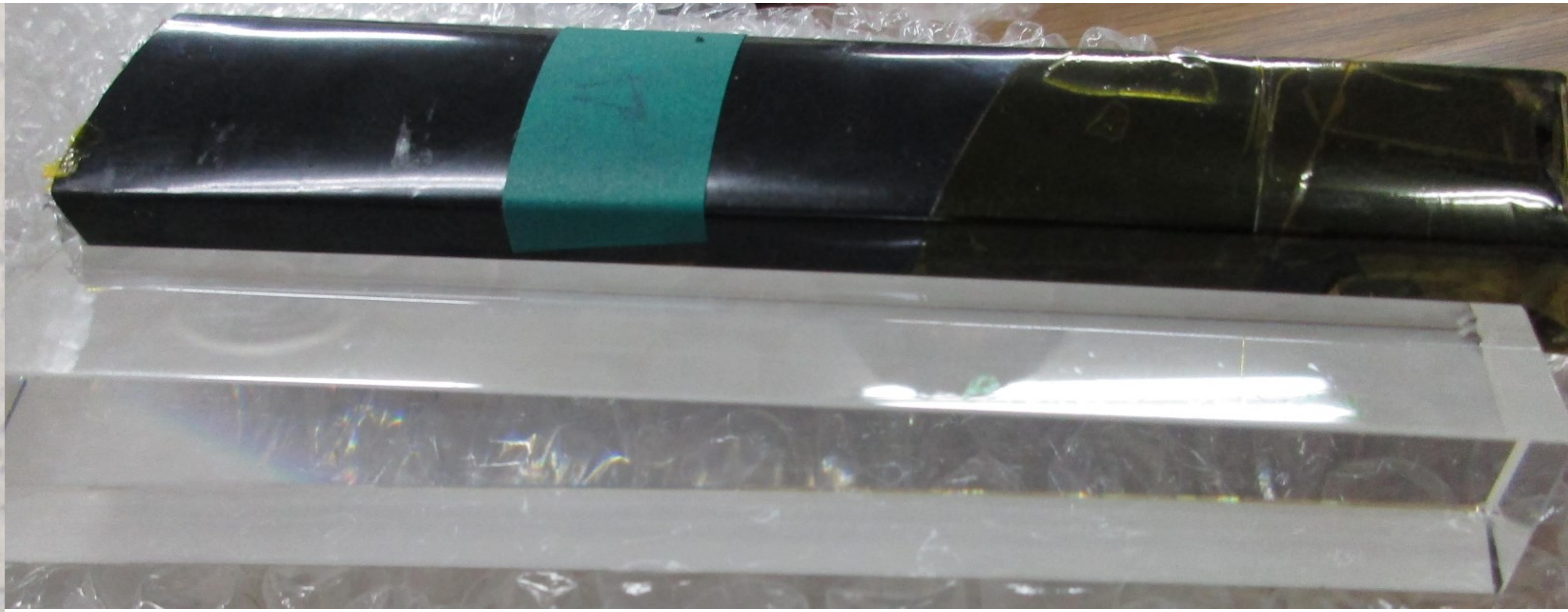
- 70% He - 30% CO_2 gas mixture read out by Gas Electron Multipliers (GEMs)
- unique measurement:

fast neutron flux and tracking

talk by Igal Jaegel

The *BEAST* Experiment: Diamonds and TPCs





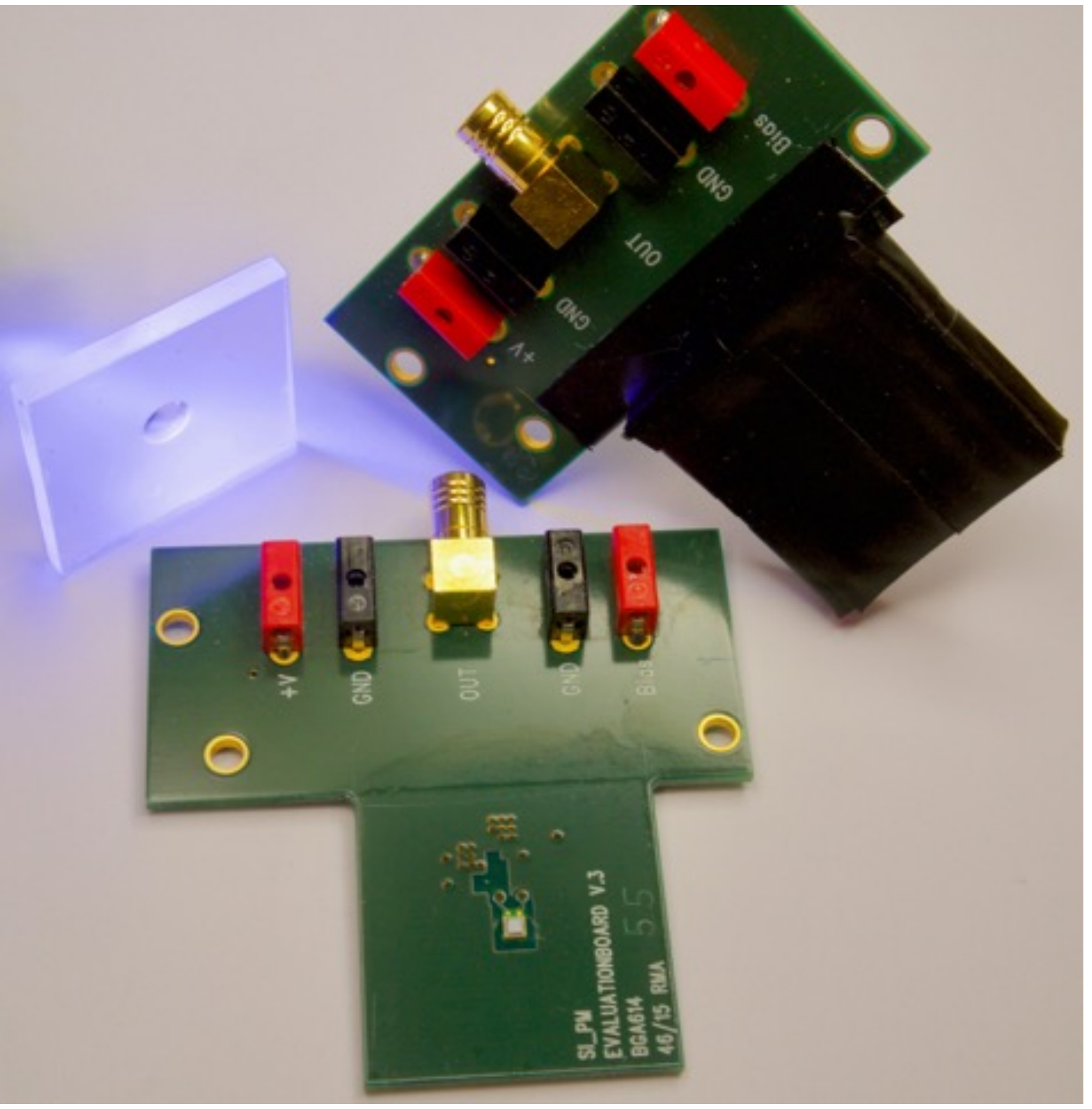
Diamonds Sensors (4):

- mounted in the horizontal plane $\phi = 0°$ and 180° at around +-10 cm from the IP
- prototype for later Belle 2 Beam Abort system
- unique measurement:
  beam abort (integrated & instaneous radiation dose)

BGO Crystals (8):

- bismuth germanium oxide (BGO) crystals - from Belle ECal - read out by photo-multiplier tubes (PMTs)
- prototype for phase 2 luminosity monitor (Bhabha scattering)
- unique measurement:
  luminosity and EM rate

The *BEAST* Experiment: CLAWS and Crystals



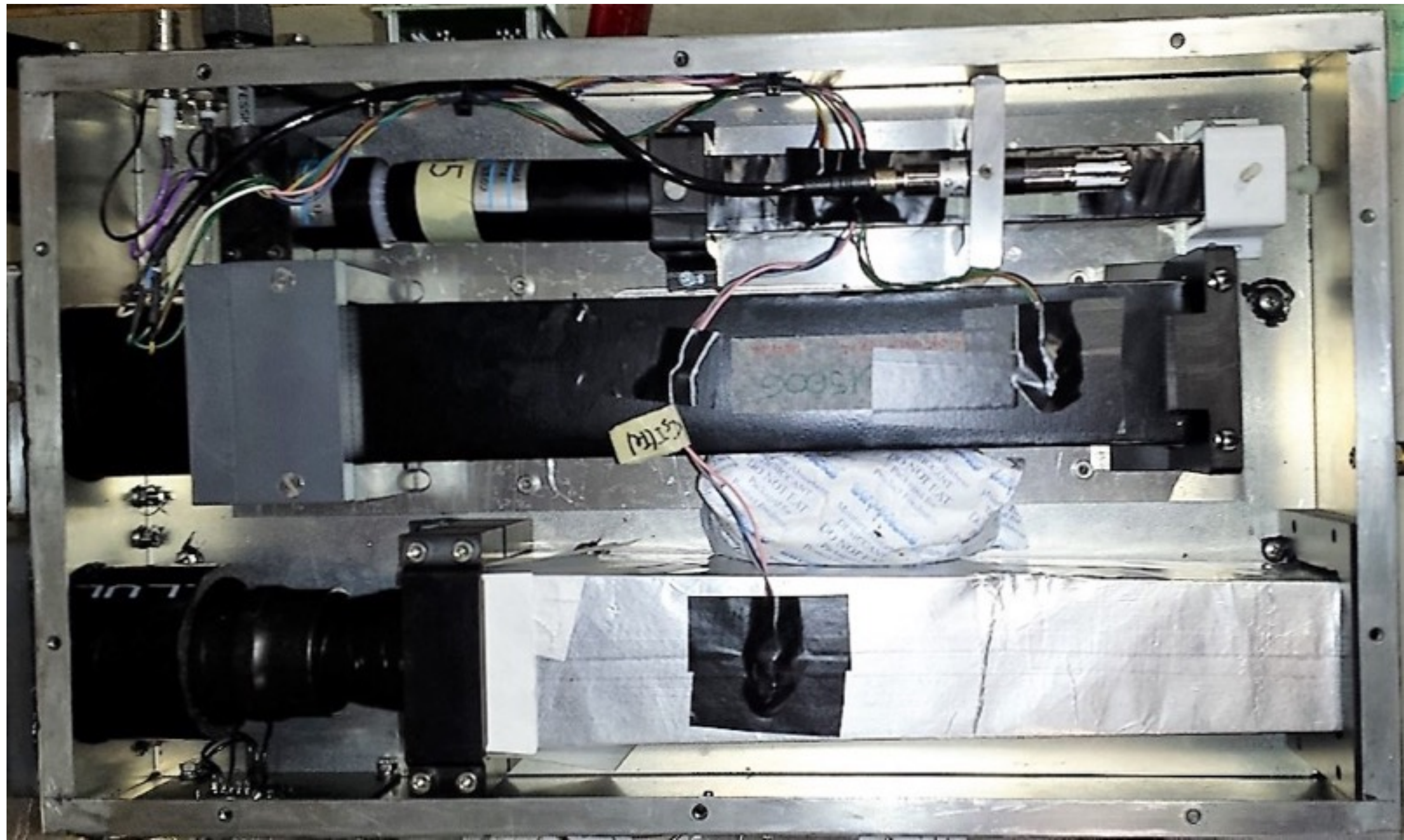
CLAWS Plastic Scintillators (8):

- plastic scintillators read out by silicon photomultiplier (SiPM)
- primarily sensitive to charged particles
- sub-nanosecond time resolution sampled continuously over ms
- unique measurement:
  fast injection background (bunch-by-bunch structure)

talk by Hendrik Windel

Electromagnetic counter and calorimeters (Crystals) (6):

- mounted at end-caps position at $\phi = 0$, 90 and 180 at position of later Belle II electromagnetic calorimeter
- LYSO + CsI (pure) + CsI(Tl) inorganic crystals read out by PMTs
- unique measurement:
  EM energy spectrum & fast injection background



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Selected Results from the *BEAST* Experiment

Vacuum Scrubbing: or how to Clean a Beam Pipe

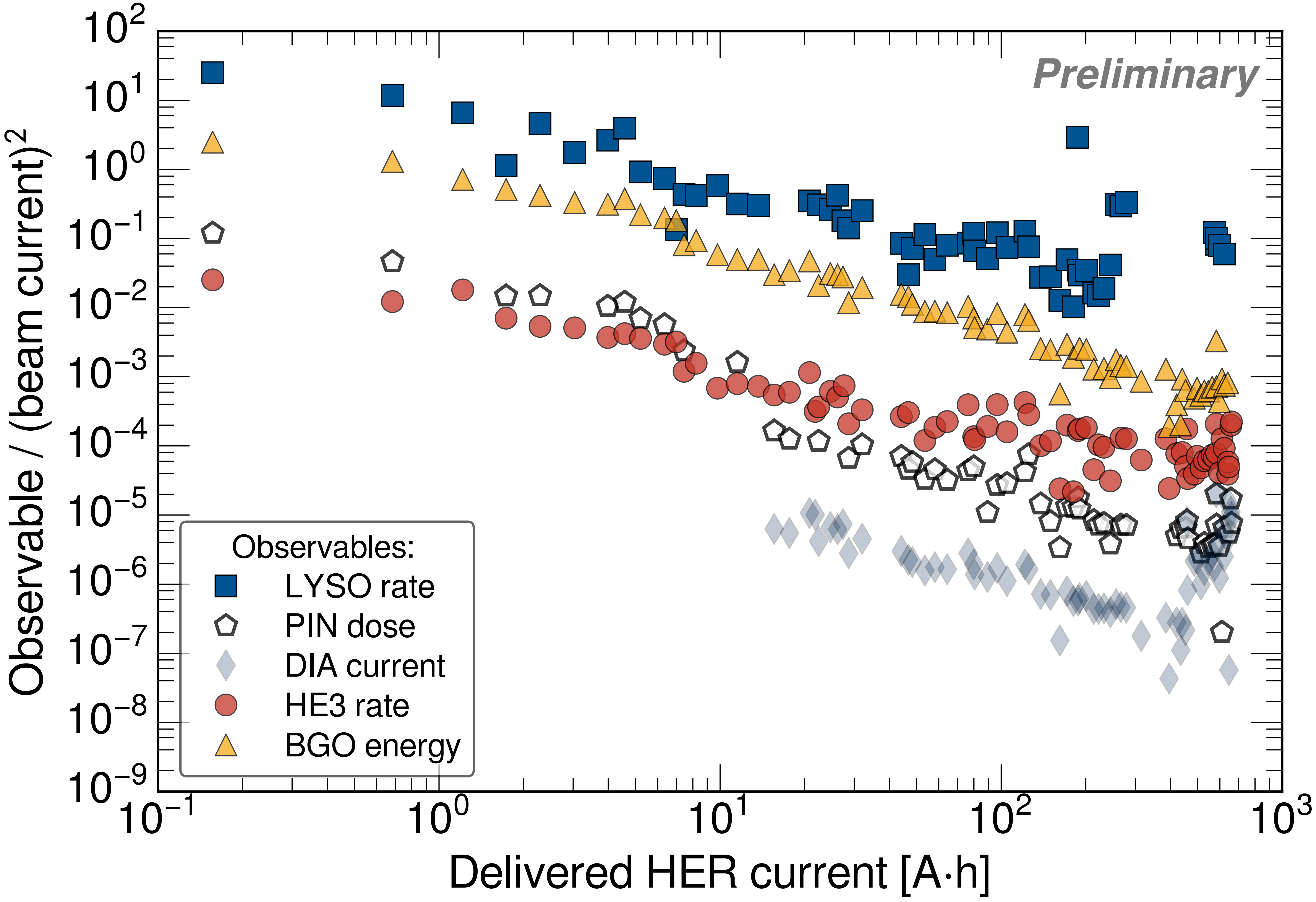
High currents lead to desorption of impurities on beam pipe walls (Vacuum Scrubbing):

- improving vacuum over time leads to reduced beam-gas background

BEAST measurements confirm improvement:

- reduced background allows for combined measurement of Touschek & beam-gas backgrounds

Background rate normalised to current over total delivered current x time:



Combined Beam Gas & Touschek BG Measurement

Dedicated Measurement: Size-sweep Scan

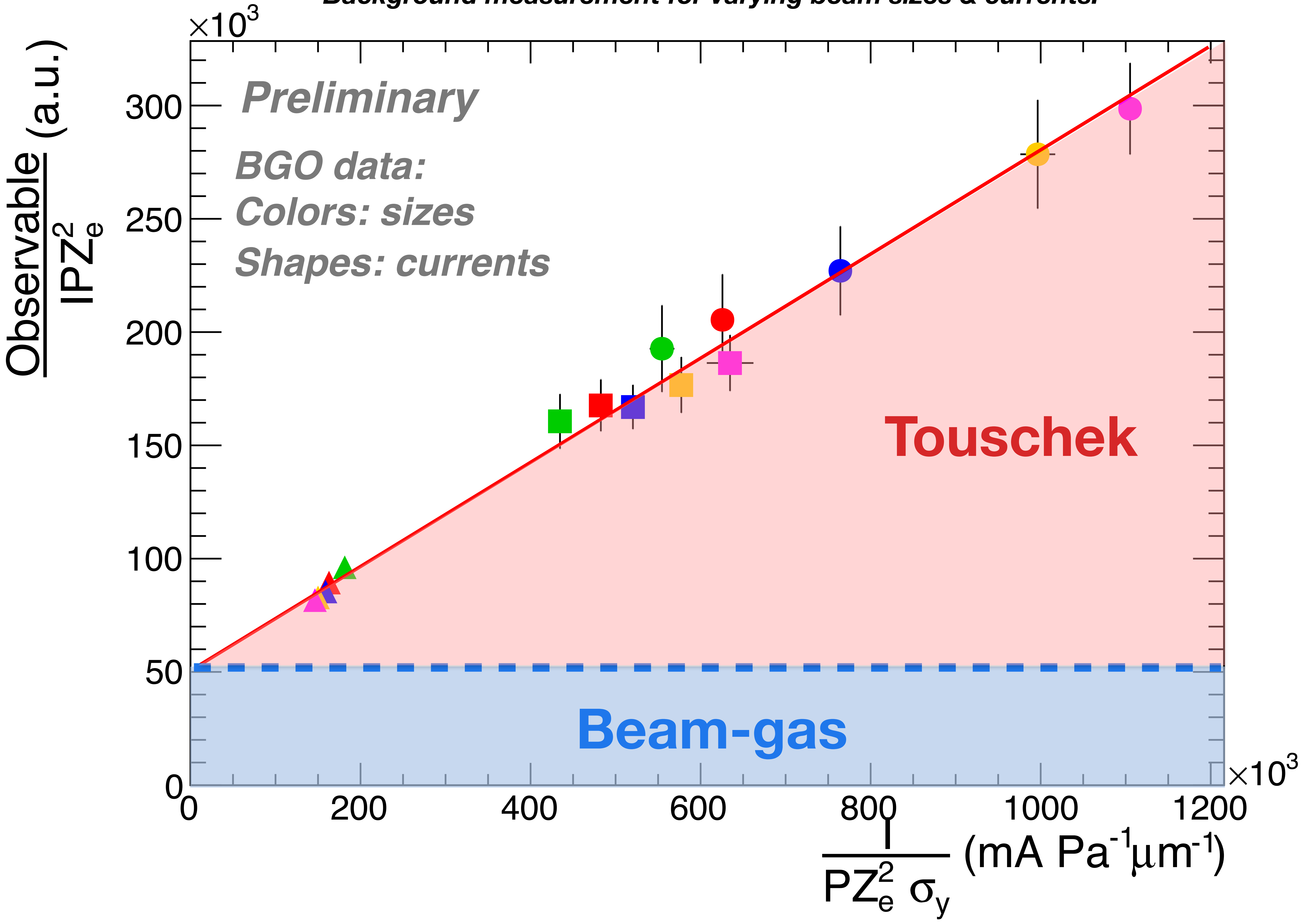
- probing 5 beam sizes and 3 currents = **15 runs**

Combined Model for Touschek and Beam-Gas Rate:

- **data and fit in good agreement**, validating loss rate model
- sensitivities ***B*** (offset) & ***T*** (slope) extracted from fit

$$\frac{BG}{IPZ_e^2} = A + B \times \frac{I}{PZ_e^2\sigma_y}$$

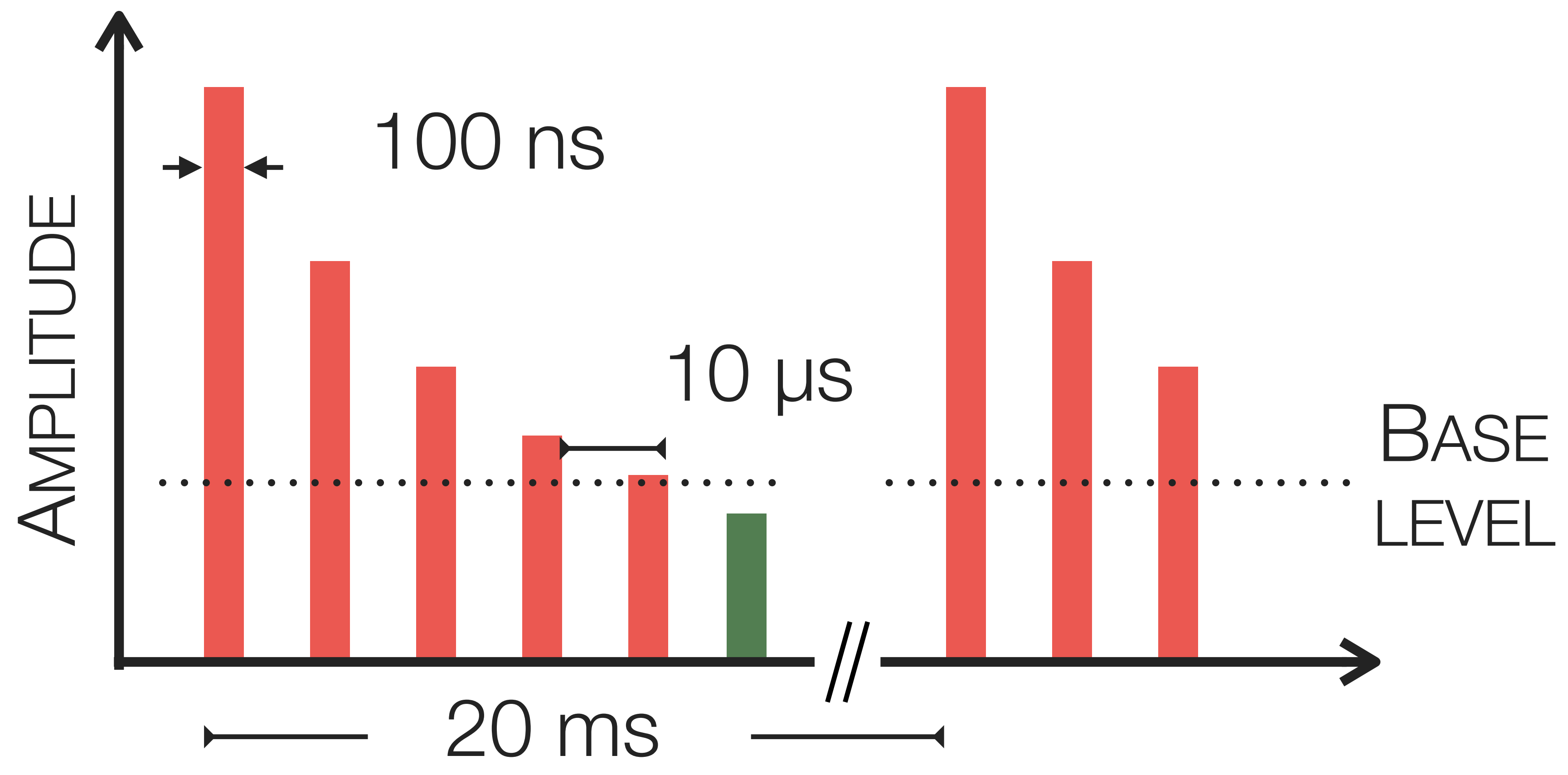
Background measurement for varying beam sizes & currents:



Injection Backgrounds: Reason and Problem behind them

Reason for Injection Backgrounds: Top-Up Injection Scheme

- to achieve unmatched luminosities, beams in SuperKEKB will be continuously circulated
- to compensate for beam loss and collisions **new particles injected directly into circulating bunches**
- injected bunches result in considerable backgrounds for first several turns



Problem of Injection Backgrounds: Impact on the Belle 2 Vertex Detector

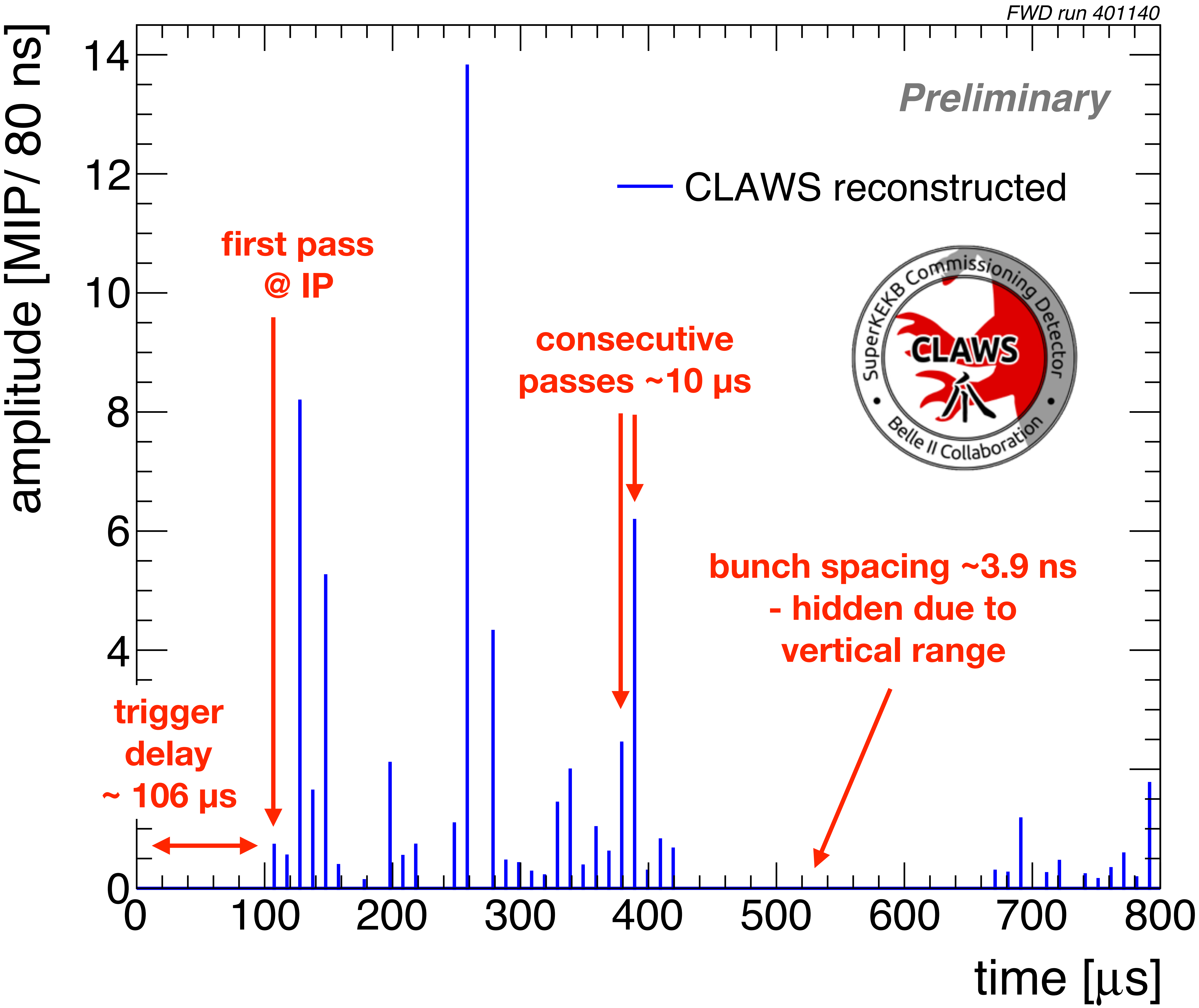
- injection background saturates Belle 2 pixel detector
- precise knowledge vital for later pixel operation: gating while passing injection bunches

Dedicated Measurements of Bunch-by-bunch Structure by Beast subsystems CLAWS and Crystals

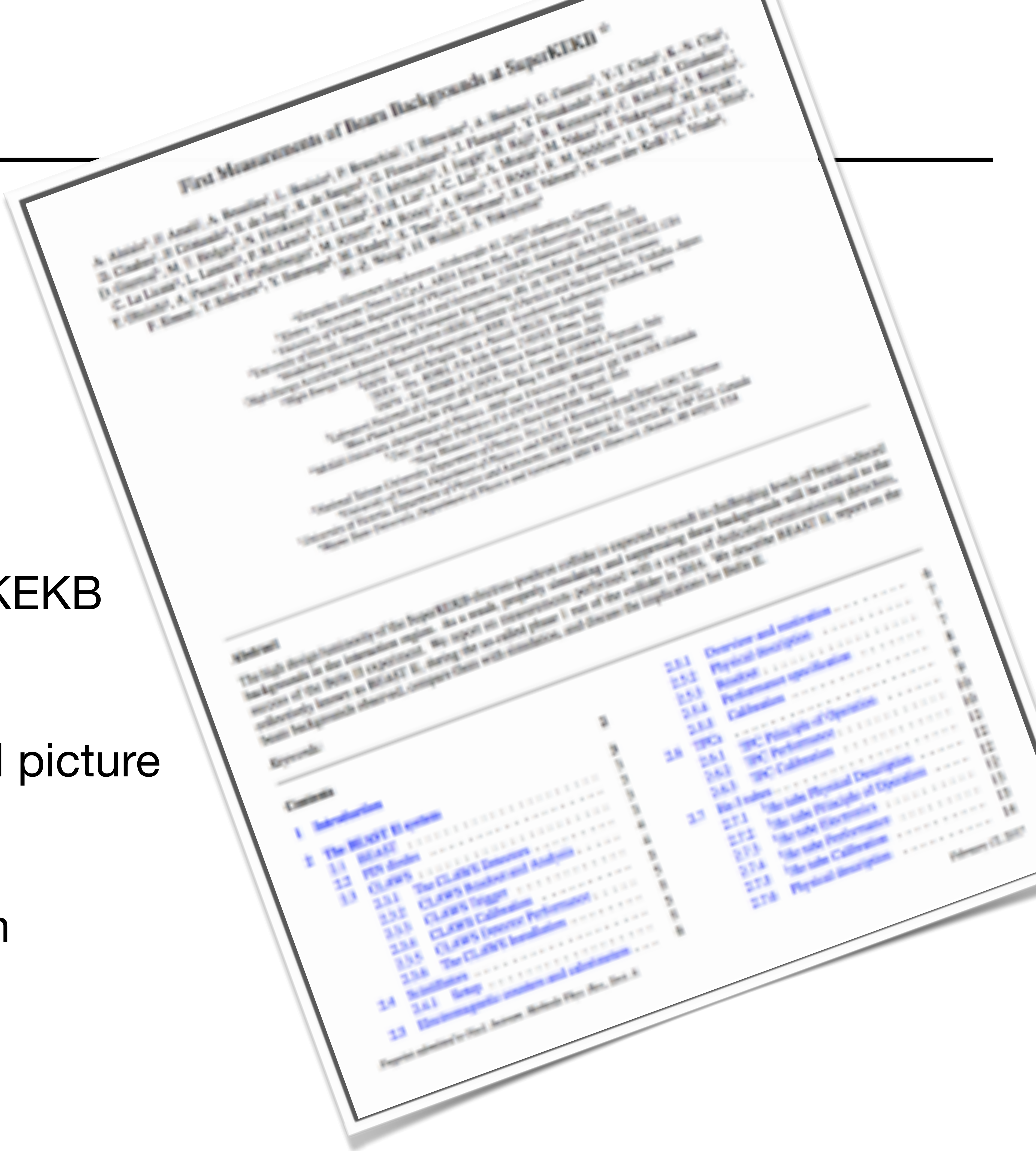
Injection Backgrounds: Measurement by CLAWS subsystem

Excellent Sub-nano-second Resolution, continuously sampled over MS, allows for Measurement of Bunch-by-Bunch Structure:

- detailed picture of processes at IP down to individual bunches!
- presence of short (~ns), medium (~µs) and long (~ms) time structures



Summary & Outlook


First Measurements of Beam Backgrounds at SuperKEKB

Summary:

- first phase of SuperKEKB commissioning completed
- beam backgrounds represent signification challenge for Belle II operation - **investigation of none-collision beam backgrounds** in first phase of SuperKEKB commissioning by the ***BEAST*** **experiment**
- successful measurement of Touschek and beam-gas backgrounds & detailed picture of injection backgrounds
- publication - including all ***BEAST*** results & comparison against simulation - in preparation: **very far progressed**

Phase 2 Outlook:

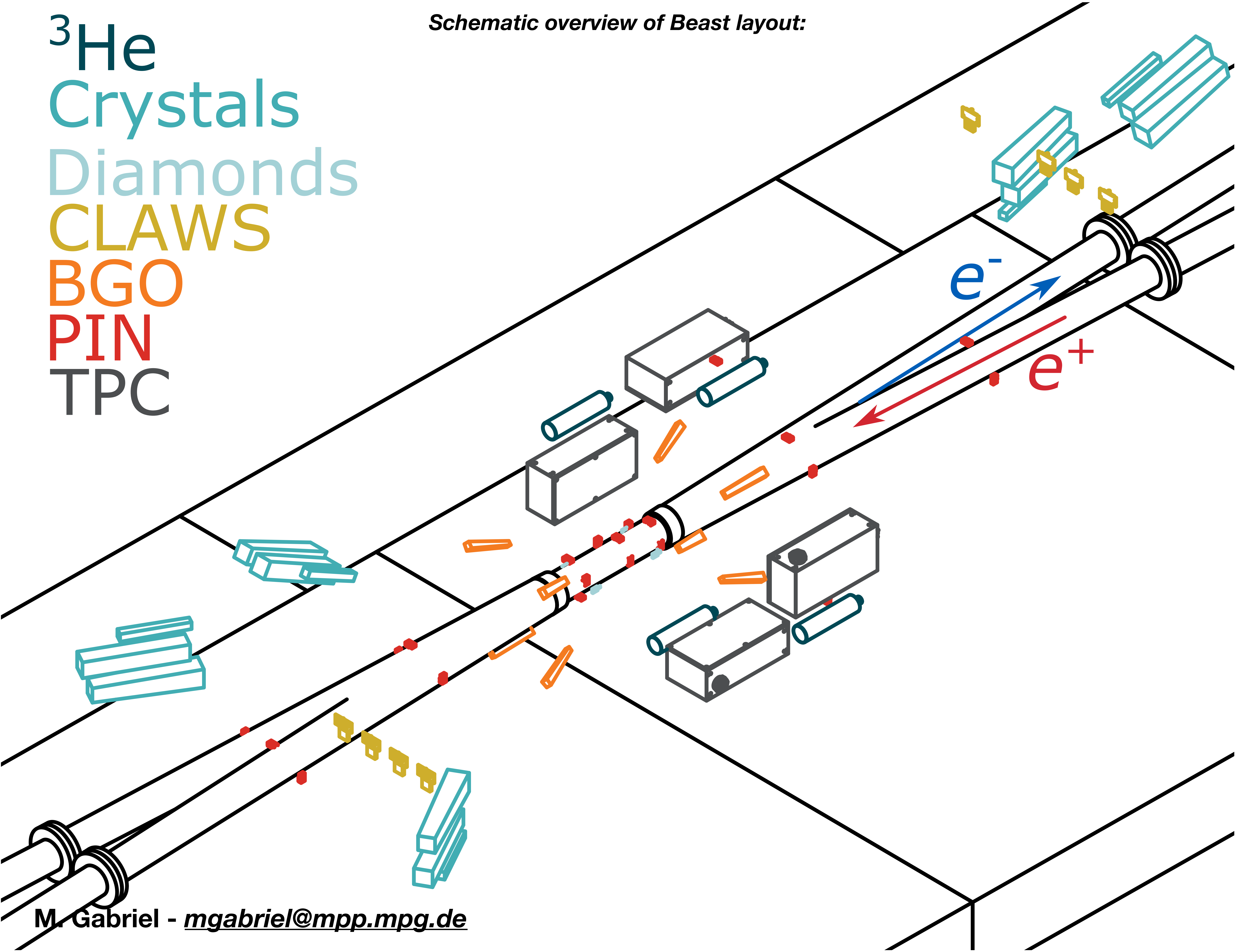
- **next talk by Hua Ye**

Backup

The Beast Experiment: Subsystem Overview & Capabilities

^{3}He
Crystals
Diamonds
CLAWS
BGO
PIN
TPC

Schematic overview of Beast layout:



Describing Regular Beam Backgrounds: Simple Data-driven Model

Beam-gas interactions with residual gas atoms/molecules:

- **Bremsstrahlung** & **Coulomb** scattering
- depending on current ***I***, pressure ***P***, effective atomic number ***Z*** and **beam-gas sensitivity *B***

$$\mathrm{BG_{beam-gas} = B \times IPZ_e^2}$$

Touschek intra-beam interactions:

- **intra-beam Coulomb** scattering
- dominant in high density beams: major concern for nano-beam scheme
- depending on current ***I***, vertical beam size **σ** and **touschek sensitivity T:**

$$\mathrm{BG_{touschek} = T \times \frac{I^2}{\sigma_y}}$$

Vacuum Scrubbing: LER (left) & HER (right) Results