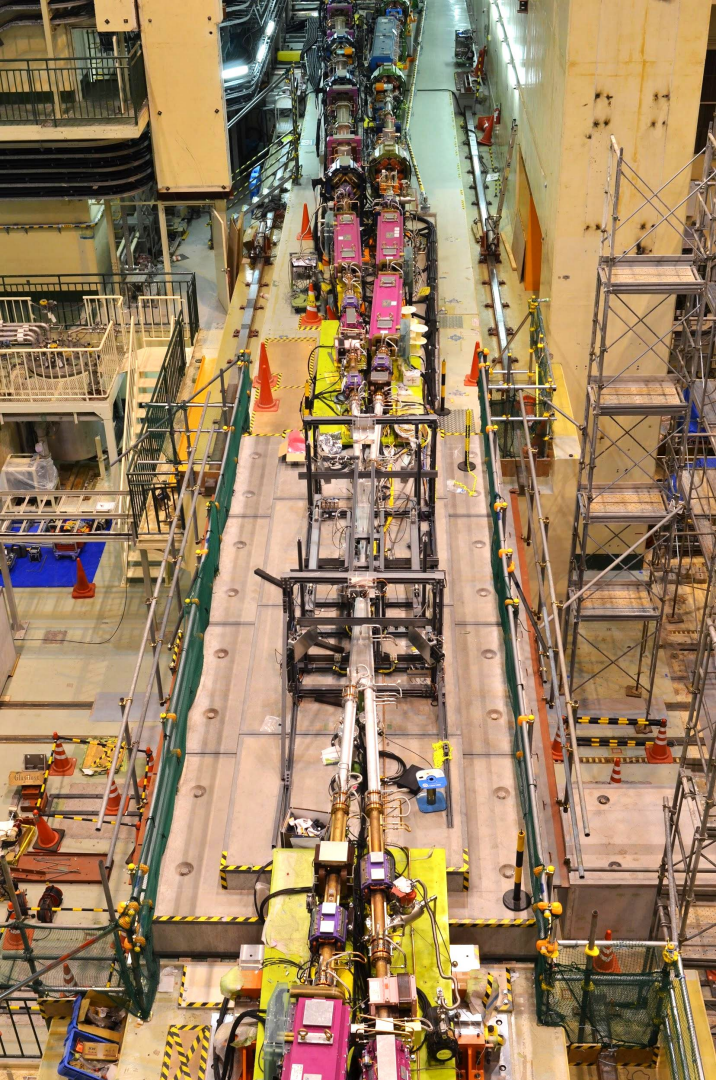


BEAST II

The commissioning detector for Belle II and SuperKEKB, **part II**

Peter M. Lewis
UH Manoa
PNNL Belle II summer school 8.18.16

The metatalk

First session (done)

Second session (this one)

- **Integration** and **operation**
- The **dirty underbelly of the BEAST**: detector-by-detector discussion of **performance and difficulties**
- **Preliminary results**

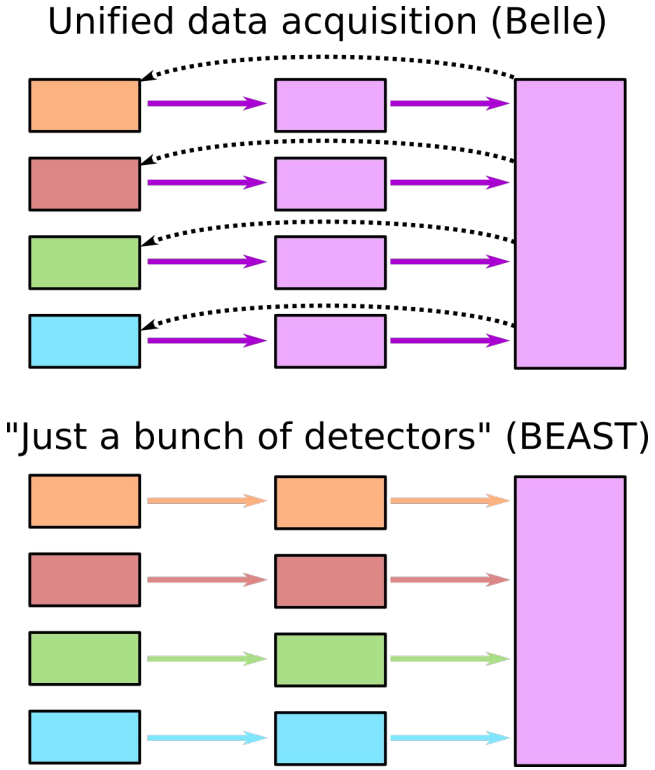
BEAST integration

Making a whole BEAST out of a collection of parts

DAQ integration

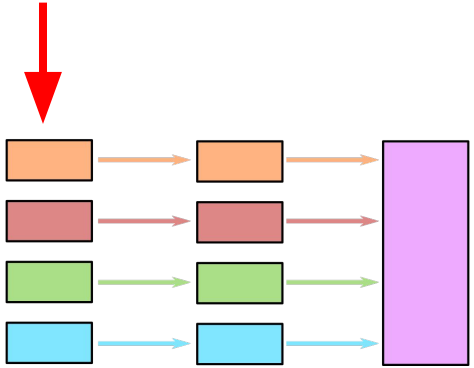
Unifying many detectors

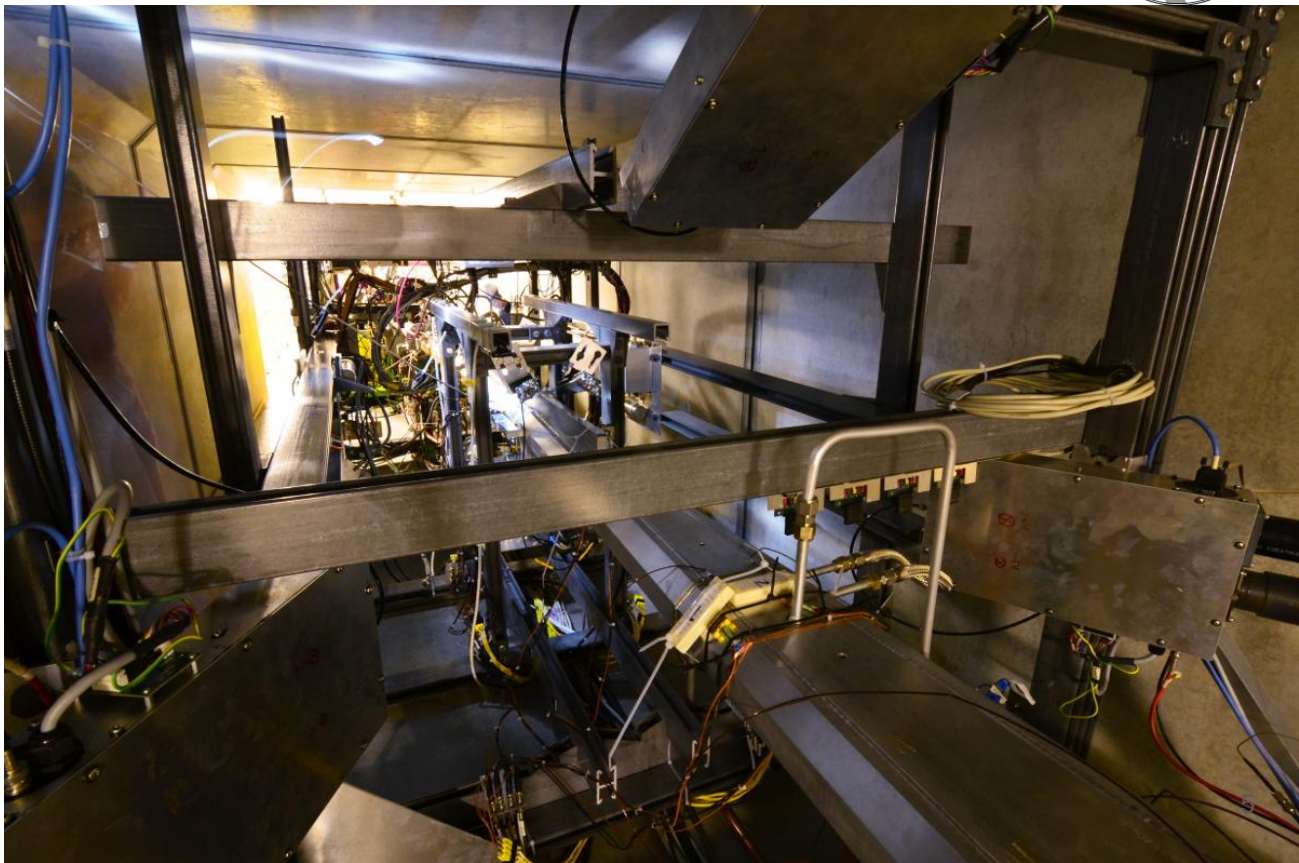
- Full-scale particle physics experiments (top):
  - Detectors receive *global* triggers
  - Detectors use common hardware and software as far "*upstream*" as possible
  - **Belle** (plus all other major HEP experiments)
- JBOD experiments ("just a bunch of detectors"--bottom)
  - Cowboy DAQ
  - No global trigger
  - Each detector has its own hardware and software
  - Unified into a common system only at the highest, most "*down-stream*" level
  - **BEAST**



BEAST upstream

The detectors around the IP

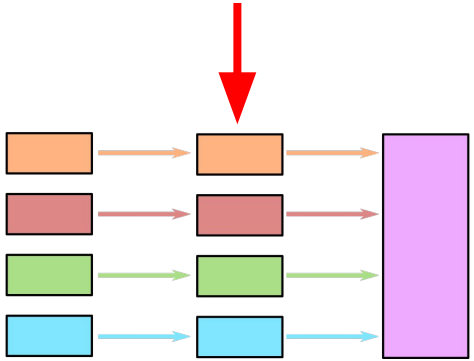


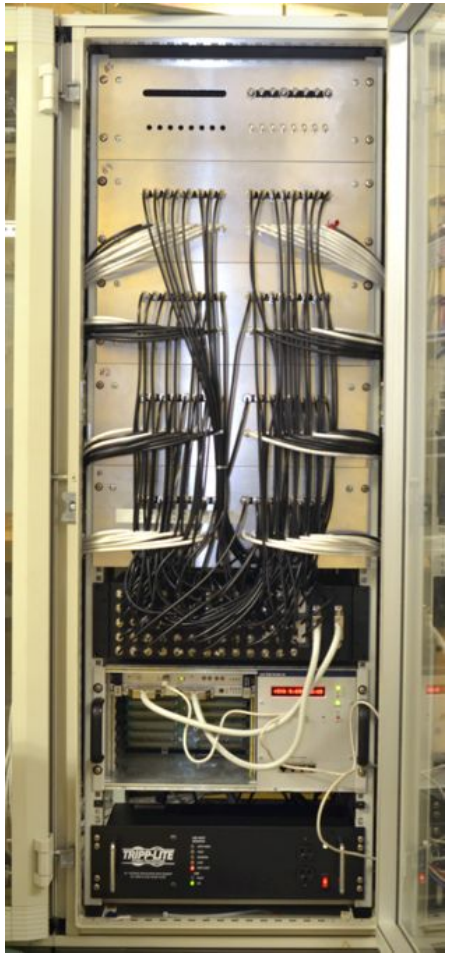


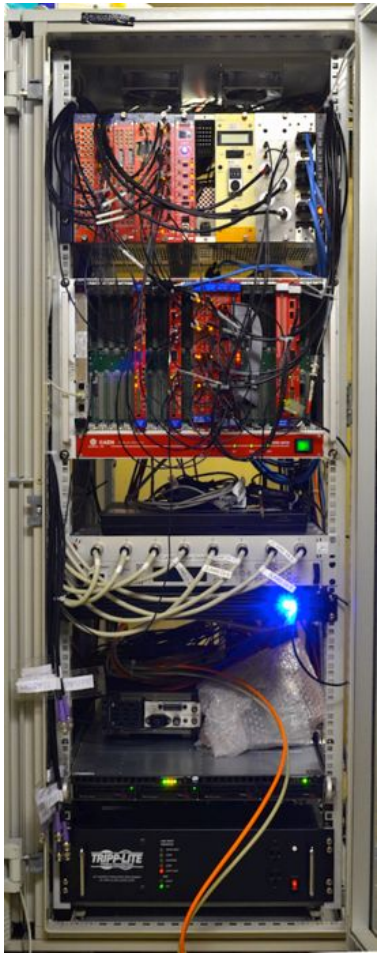
BEAST midstream

Three racks in electronics room

- 37m from IP, Tsukuba B4
- Amplification, digitization, slow control, databasing, networking, etc.



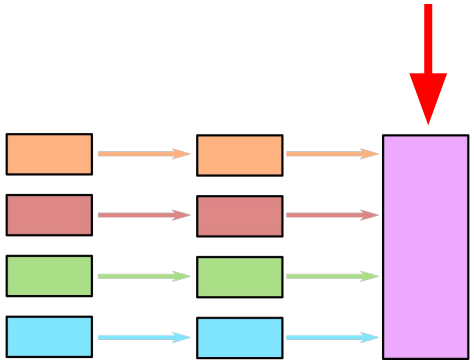


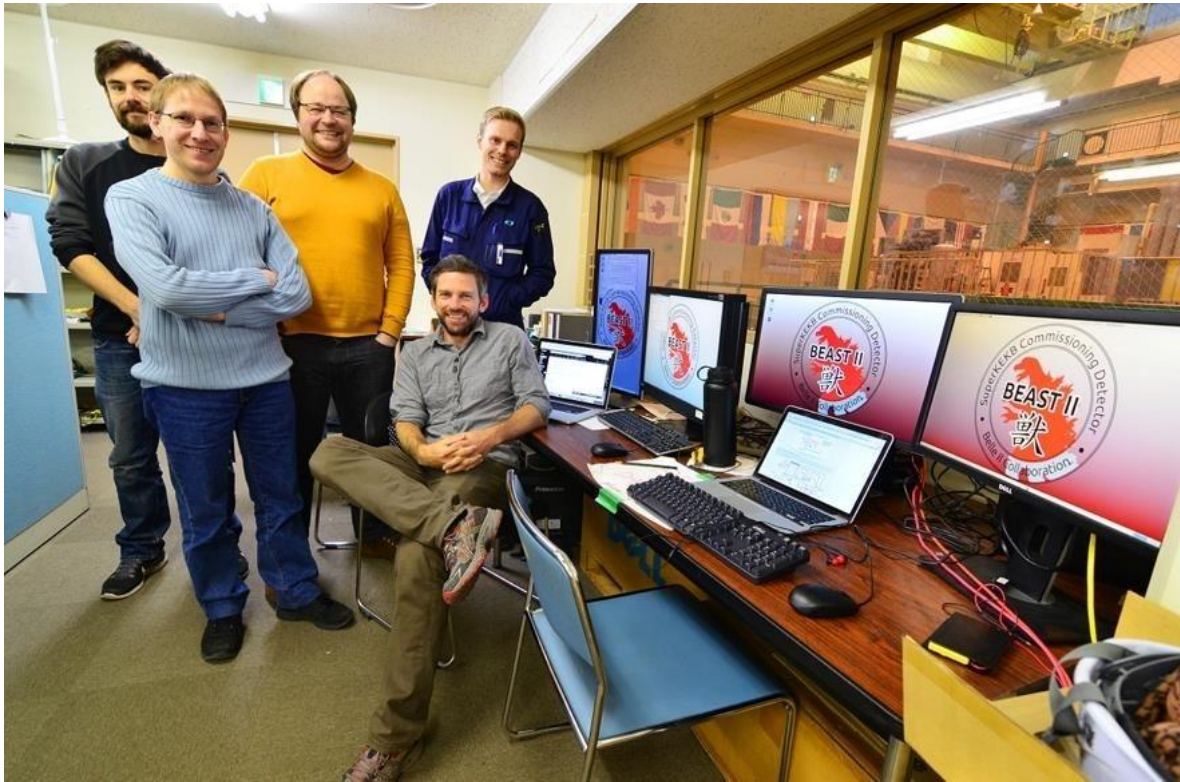


BEAST downstream

Control room

- Tsukuba B3
- The desk of **perpetual horrors and wonders** (right)

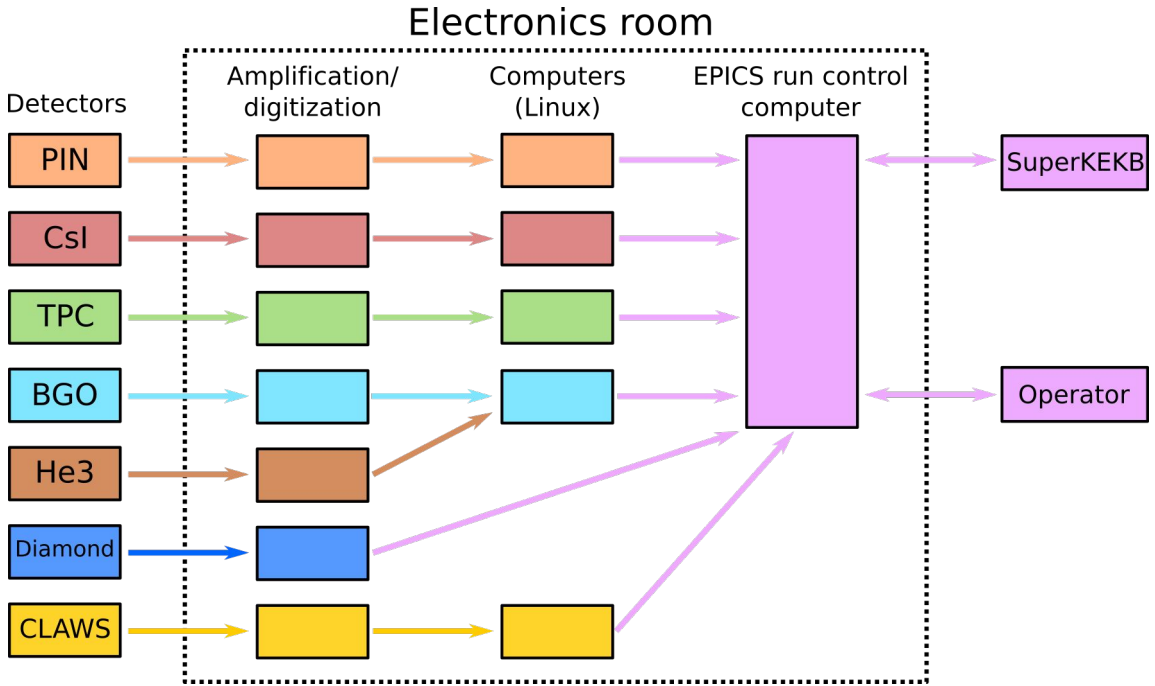




DAQ integration

EPICS

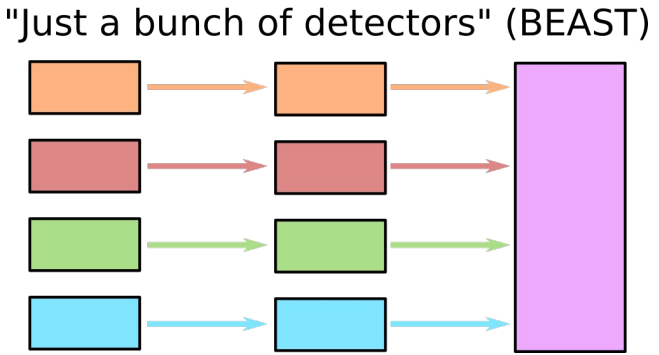
- “Experimental Physics and Industrial Control System”
- Pink arrows and boxes: used in BEAST for unifying detectors
- Network-based sharing of scalars between *N* hosts
- Issuing commands/making decisions
- Handling alarms
- Controlling and monitoring power supplies, etc.
- User interface for operators



Offline integration

Building a set of common ntuples

- Diagram still works (right)
- Challenge: no common trigger, no common DAQ
- Based on 1s “pseudo-event” summaries
- Crucial for cross-correlating BEAST detectors and comparing with SuperKEKB conditions
- Draws from 10 sets of raw data with varying formats
- Includes **a set of ~250 accelerator parameters recorded live through EPICS**



BEAST operation

Training and handling of the BEAST

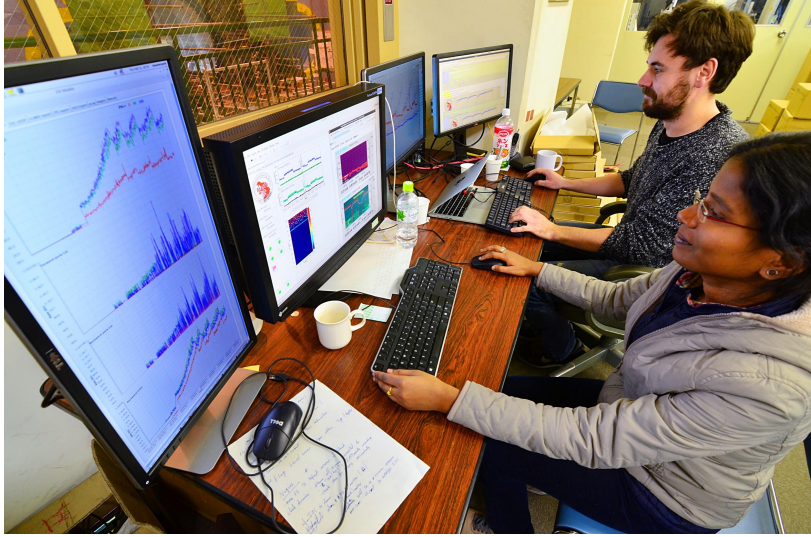
BEAST operation

Real-time monitoring (via EPICS)

- BEAST systems and SuperKEKB conditions monitored by shifters (**top**): **expert** (near) and **operator** (far)
- BEAST live monitors shared with SuperKEKB control room (**bottom**)
- BEAST liaison in SuperKEKB control room during key beam study days

Offline

- Collected ~20 TB of data throughout phase I
- Simulation of loss distribution and detectors ongoing
- Analysis ongoing; main goal is to **inform simulations with data**



BEASTexpertRIGHT.opi

Expert Top | TPC Performance | TPC slow control | CLAWS

SuperKEKB Commissioning Detector — BEAST II — Belle II Collaboration

BEAST RC status
Disconnected
Running

BEAST system status monitors

IOCs

PINmaster
- VME crate
- Keithley 2701
- MADC 2508
- PV Monitor

TPCmaster
- TPC online fitter
- Keithley 2231A
- CAEN 1470
- GF100

HE3master
- He3 DAQ

CSImaster
- CsI DAQ
- uSOP 1
- uSOP 2

BEASTmaster
- BGO DAQ

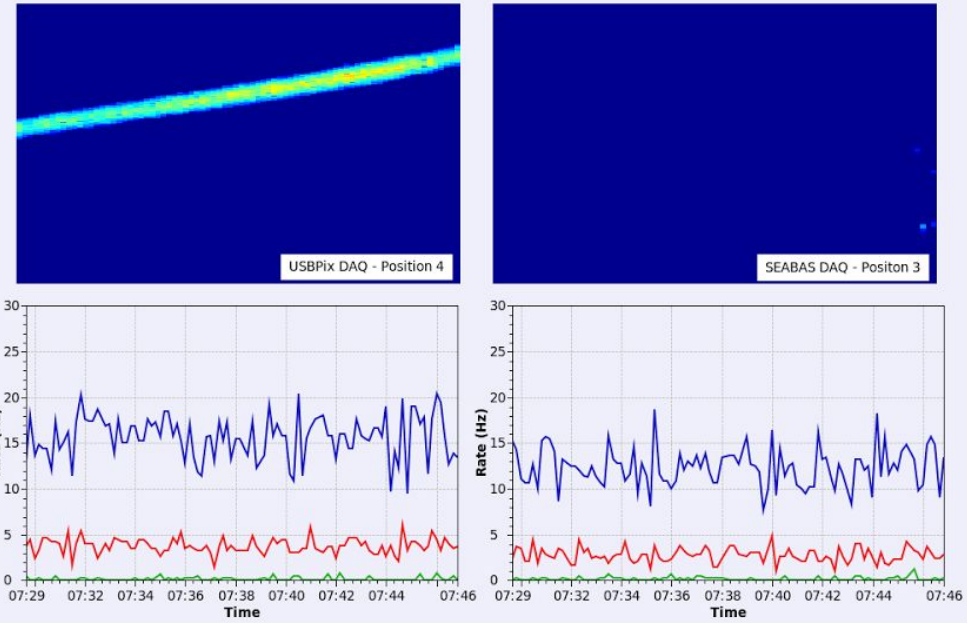
DIAMONDSmaster
- Diamond DAQ

CLAWSmaster
- CLAWS DAQ

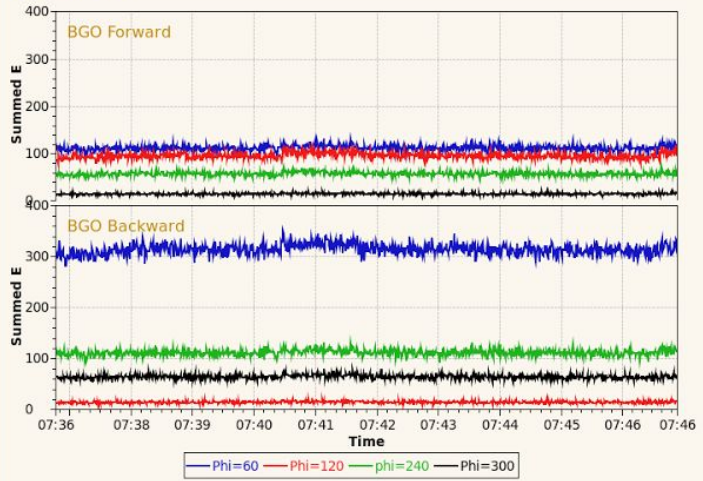
tpc_daq
- PyBar

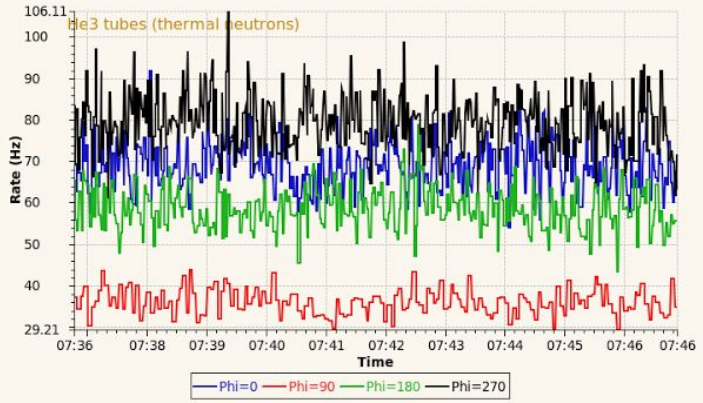
Other system monitors
- CsI HV trip
- BGO HV trip

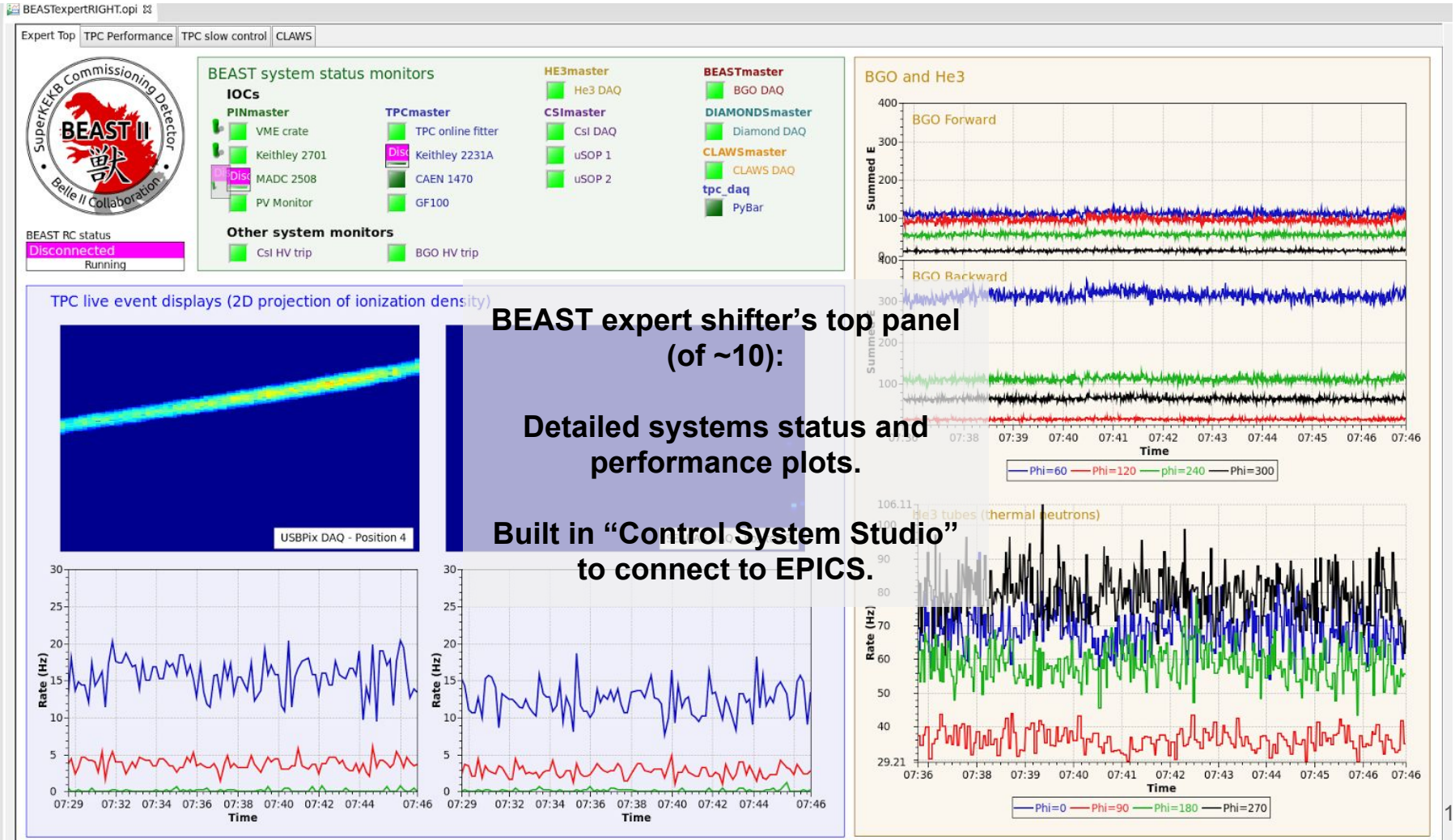
TPC live event displays (2D projection of ionization density)



BGO and He3



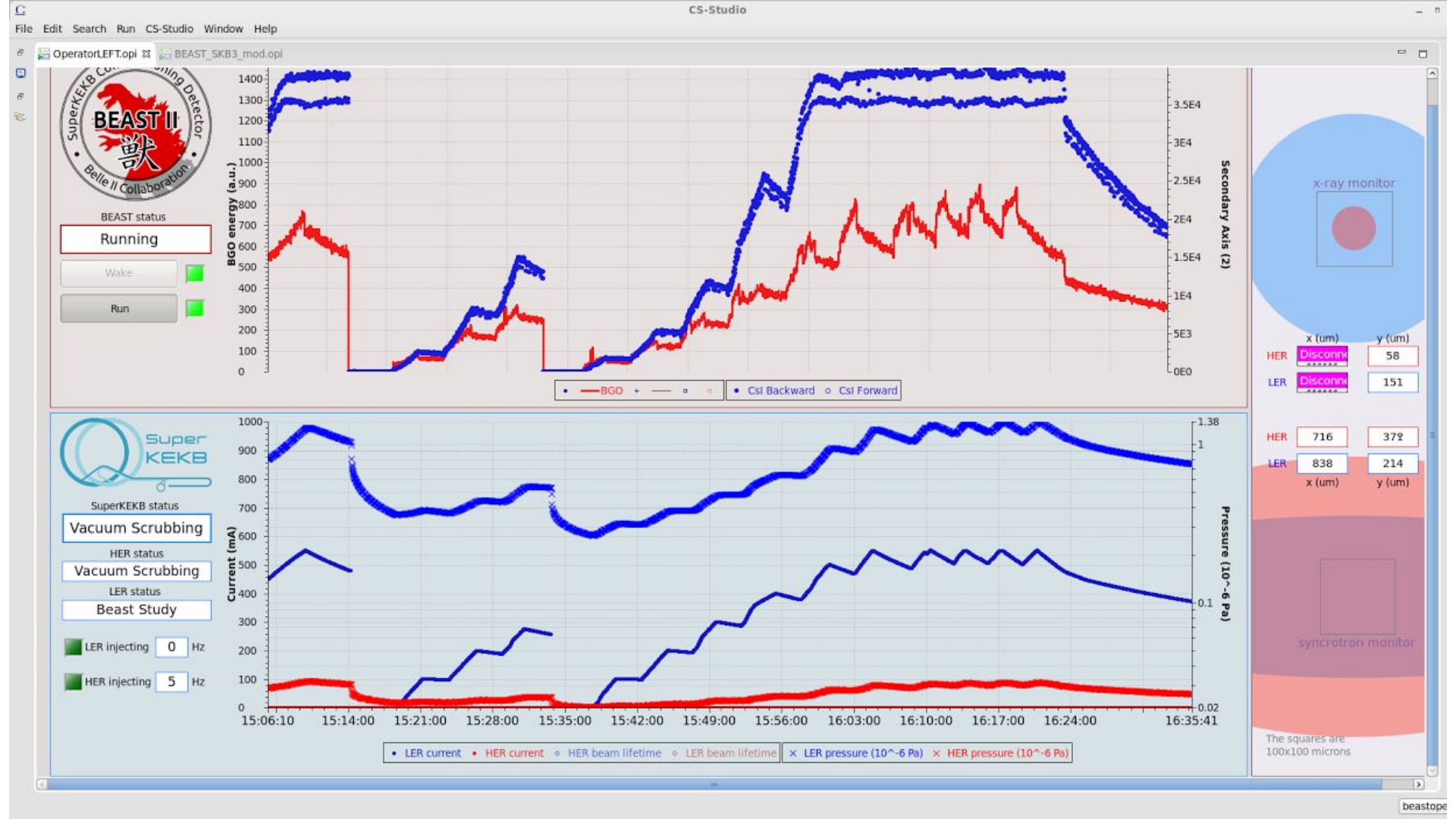


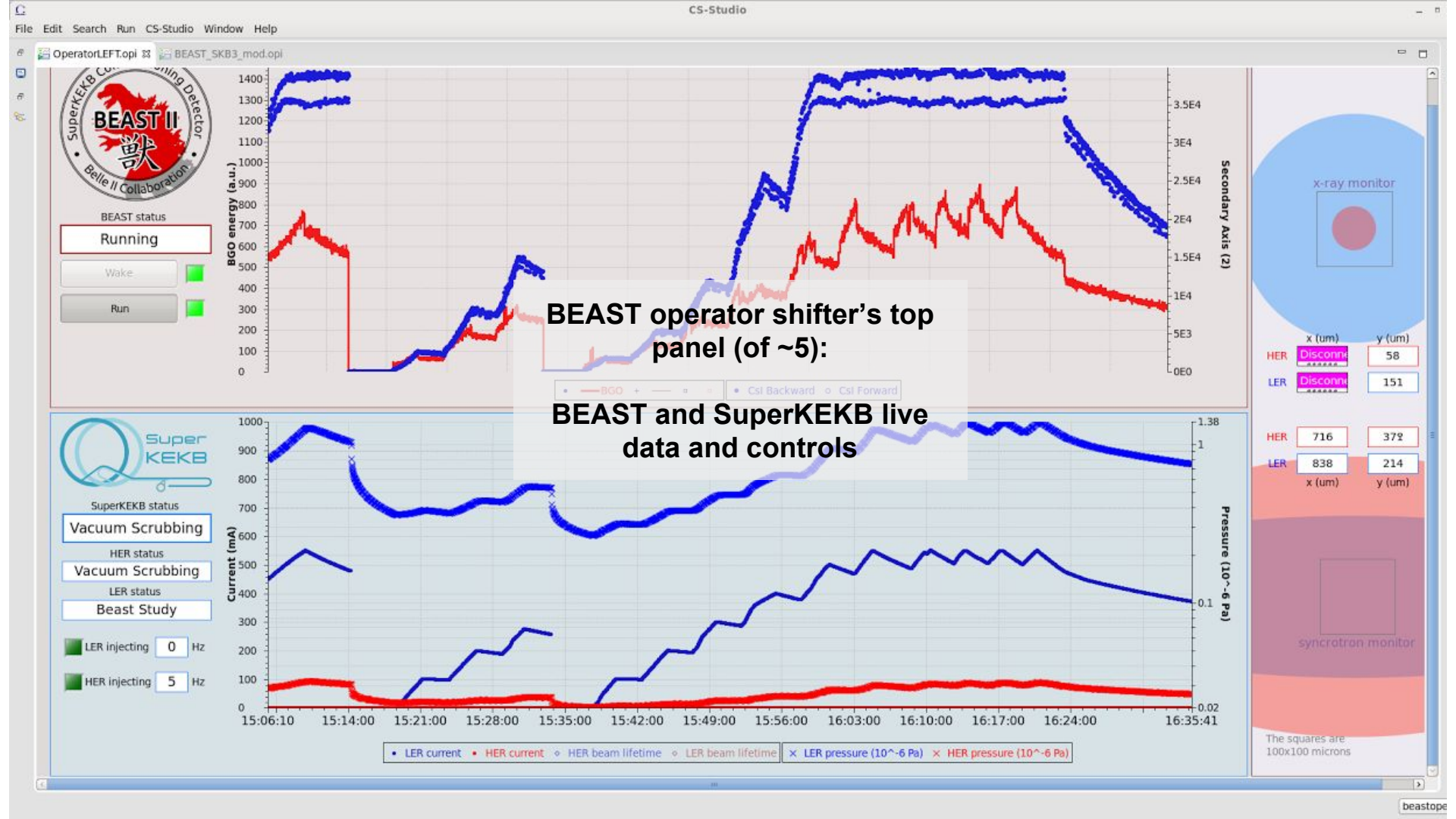


BEAST expert shifter's top panel (of ~10):

Detailed systems status and performance plots.

Built in "Control System Studio" to connect to EPICS.


CS-Studio
File Edit Search Run CS-Studio Window Help
OperatorLEFT.opi
BEAST_SKB3_mod.opi
BEAST II
SuperKEKB Commissioning Detector
Belle II Collaboration
BEAST status
Running
Wake
Run
BGO energy (a.u.)
Secondary Axis (2)
BGO
CsI Backward
CsI Forward
x-ray monitor
x (um)
y (um)
HER
LER
Disconn
58
151
716
372
838
214
SuperKEKB status
Vacuum Scrubbing
HER status
Vacuum Scrubbing
LER status
Beast Study
LER injecting
0
Hz
HER injecting
5
Hz
Current (mA)
Pressure (10^-6 Pa)
15:06:10
15:14:00
15:21:00
15:28:00
15:35:00
15:42:00
15:49:00
15:56:00
16:03:00
16:10:00
16:17:00
16:24:00
16:35:41
LER current
HER current
HER beam lifetime
LER beam lifetime
LER pressure (10^-6 Pa)
HER pressure (10^-6 Pa)
syncrotron monitor
The squares are
100x100 microns


CS-Studio
File Edit Search Run CS-Studio Window Help
OperatorLEFT.opi
BEAST_SKB3_mod.opi
BEAST II
SuperKEKB Commissioning Detector
Belle II Collaboration
BEAST status
Running
Wake
Run
BGO energy (a.u.)
Secondary Axis (2)
BGO
CsI Backward
CsI Forward
x-ray monitor
x (um)
y (um)
HER
LER
58
151
716
372
838
214
SuperKEKB status
Vacuum Scrubbing
HER status
Vacuum Scrubbing
LER status
Beast Study
LER injecting 0 Hz
HER injecting 5 Hz
Current (mA)
Pressure (10^-6 Pa)
15:06:10
15:14:00
15:21:00
15:28:00
15:35:00
15:42:00
15:49:00
15:56:00
16:03:00
16:10:00
16:17:00
16:24:00
16:35:41
LER current
HER current
HER beam lifetime
LER beam lifetime
LER pressure (10^-6 Pa)
HER pressure (10^-6 Pa)
syncrotron monitor
The squares are 100x100 microns
BEAST operator shifter's top panel (of ~5):
BEAST and SuperKEKB live data and controls

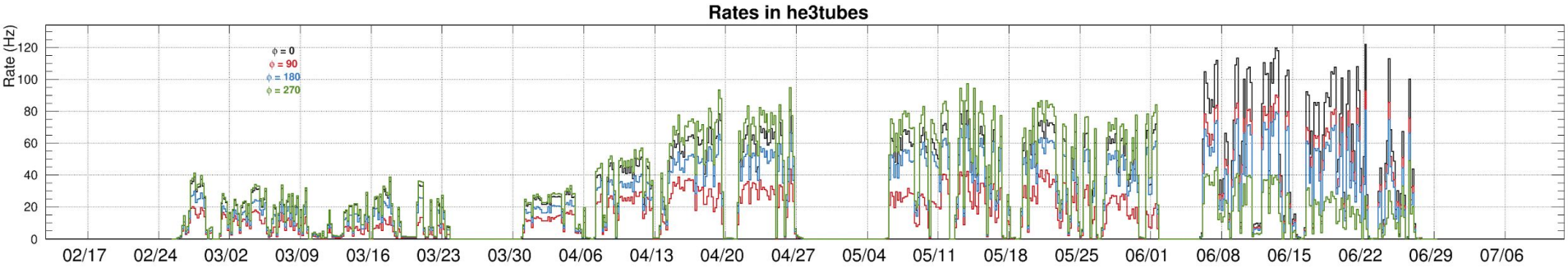
Detector performance

Some things that did not go as planned

Overall performance

Phase I uptime

- BEAST as a system ran **~continuously** throughout phase I, with **>90% uptime** for all systems
- BGO: **7/8** crystals calibratable
- PIN diodes lacked sensitivity for significant results away from central beam pipe (**~24/64** diodes useable; see next slides)
- Used **2/4** TPCs , due to difficulties parallelizing DAQ
- Still **more than sufficient** for our purposes in phase I (He3 rates for all of phase I, below)

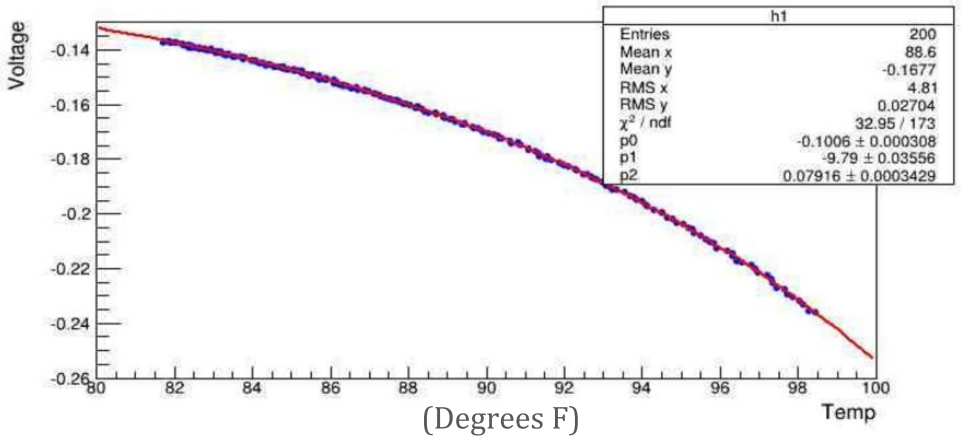


PIN diodes

Diode calibration **in theory**

- **Dark current** comes from thermally-generated pairs (**right**)
- At room temperature, a variation in diode temperature of ~2°C changes output voltage by ~10 times digitizer sensitivity
- Calibration procedure:
  - **Measure V vs T curve without beam**
  - **Fit** with polynomial
  - During running, **subtract predicted thermal voltage** from each data point based on current temperature of each diode to get **instantaneous dose**

PIN dark voltage vs. temperature in the lab (no light or radiation)

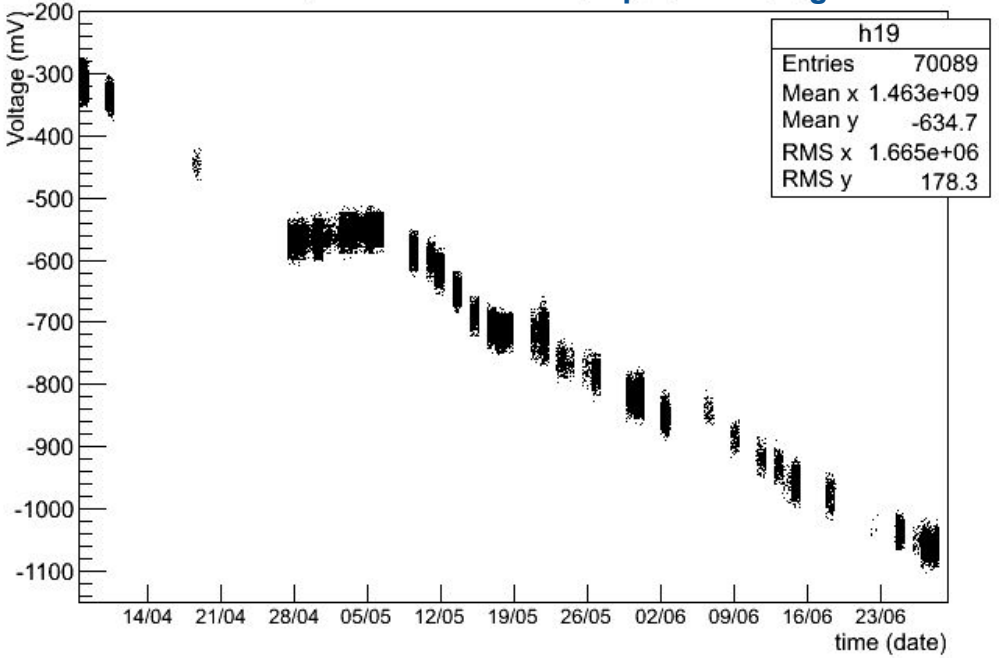


PIN diodes

Diode calibration **in reality**

- **Radiation damage** accumulates in the diodes, causing the **pedestals to drift (right), invalidating dark current fits**
- **Noise:** huge RF noise on most channels, due to **ground loops** and **pinched cables**.
- **Solutions:**
  - Parameterize **V vs. T vs. integrated beam current** (ongoing)
  - **Time-average** data heavily

Pedestal drift: PIN dark voltage vs. time (2.5 months) with beams off in narrow temperature range

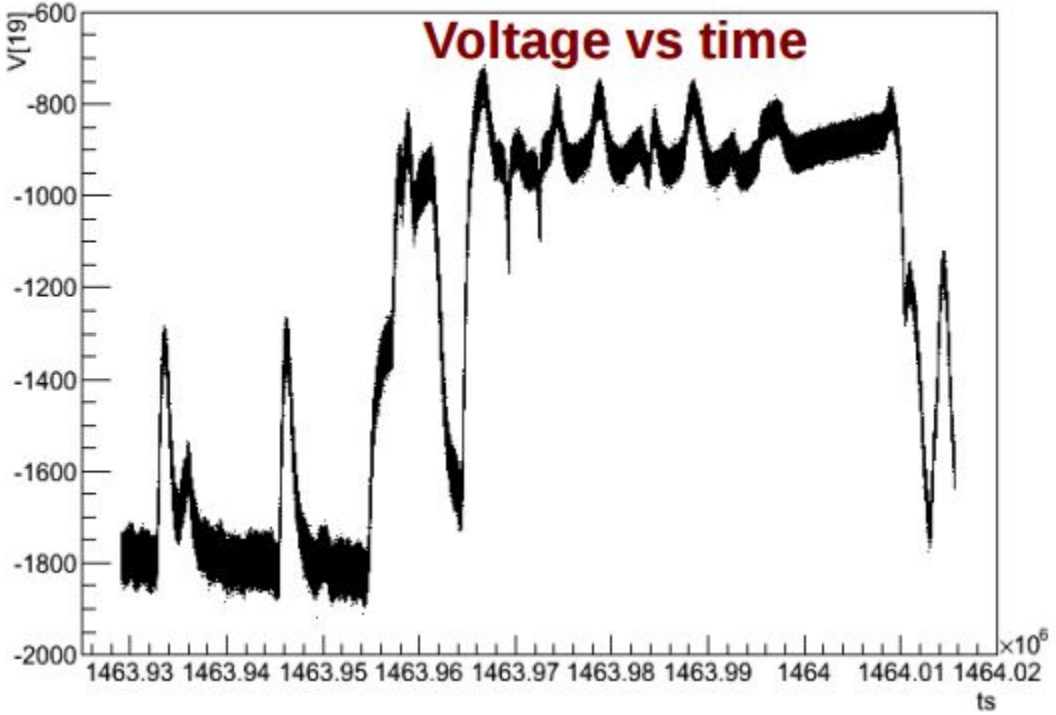


PIN diodes

Lessons learned for phase II

- Use **bigger** diodes
- Avoid all **ground loops** and **pinched cables**; understand noise better
- Use **longer-shaping-time preamps** to maximize pileup (measuring DC voltage--pileup is good)
- Careful **study of radiation damage** on dark current
- Still, we have **solid results from innermost diodes throughout phase I (right)**

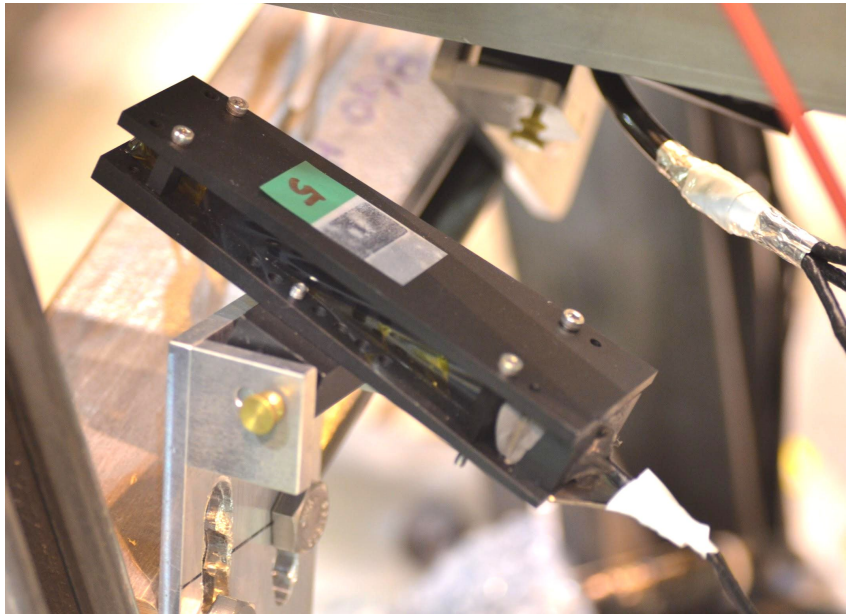
Raw PIN voltage vs. time during a beam study



BGO crystals

Radiation damage and attenuation

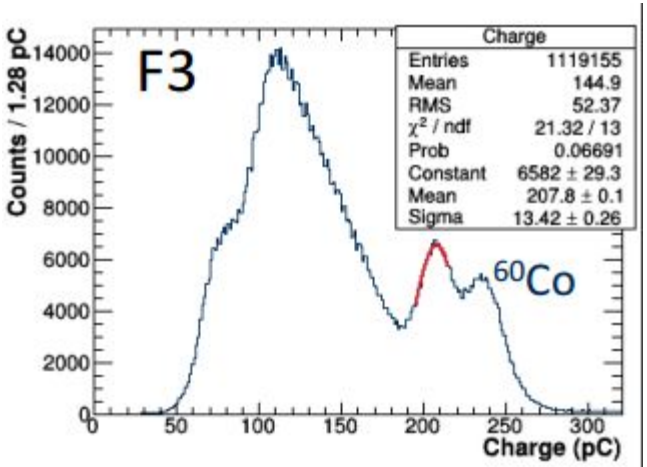
- Attenuation in 40m fibers between crystals and PMTs varied by a factor of 40 from crystal-to-crystal.
    - An **emergency attenuation test** was performed the day after the beam shut down
- Possible (suspected) **radiation damage** contributed to decreasing sensitivity throughout phase I
    - Careful **cross-correlation with PIN diodes** necessary

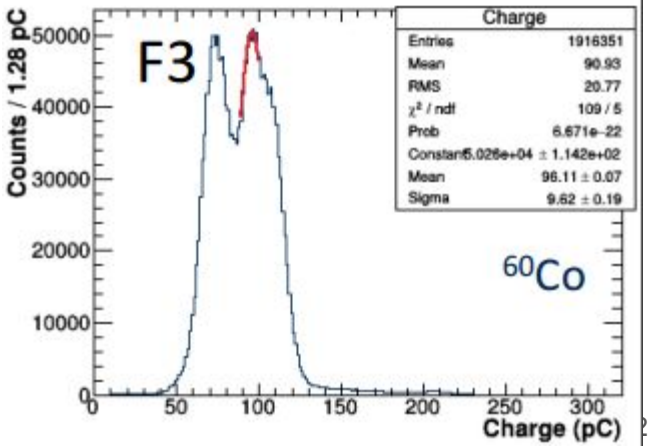


CsI crystals

Radiation damage

- **Calibration runs with external sources** before (top) and in middle (bottom) of phase I
- **Decreased gain** in all crystals, 20-30% [CsI(Tl)], 40-50% (LYSO; red peak fit moves left)
- Complex additional structures arise in some cases, perhaps due to **activation**
- **Crystal and/or PMT damage?**
- A main goal of the CsI/LYSO crystal effort is to **understand crystal damage** for the most vulnerable crystals in Belle II--**this must be understood**

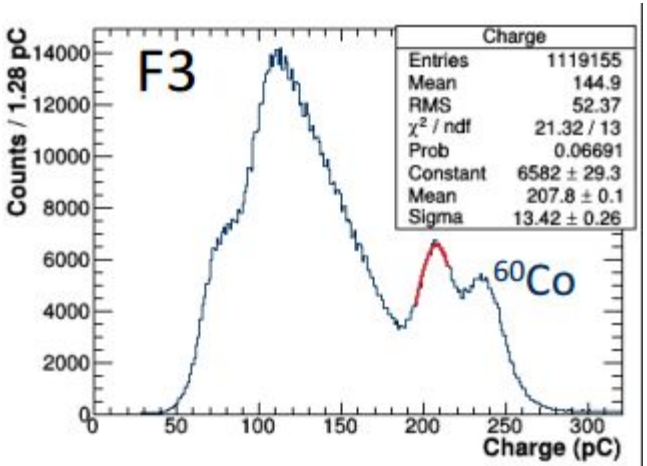


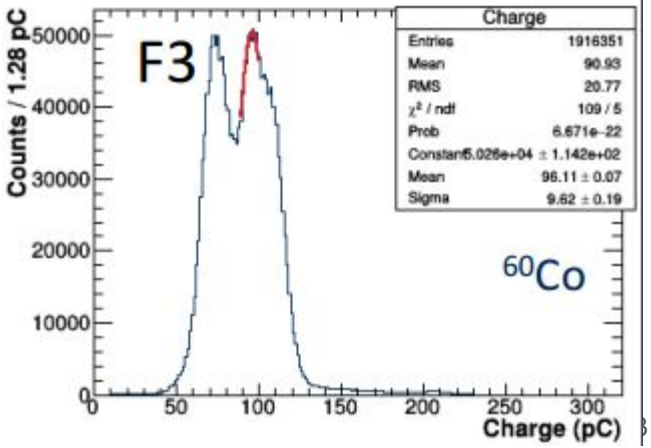


CsI crystals

Path forward

- Use multiple **source calibration runs**, **cosmic runs**, and the **natural radioactivity of LYSO** to investigate
- (ongoing)
- Quantifications of PMT and crystal damage difficult, but probable





Phase I commissioning

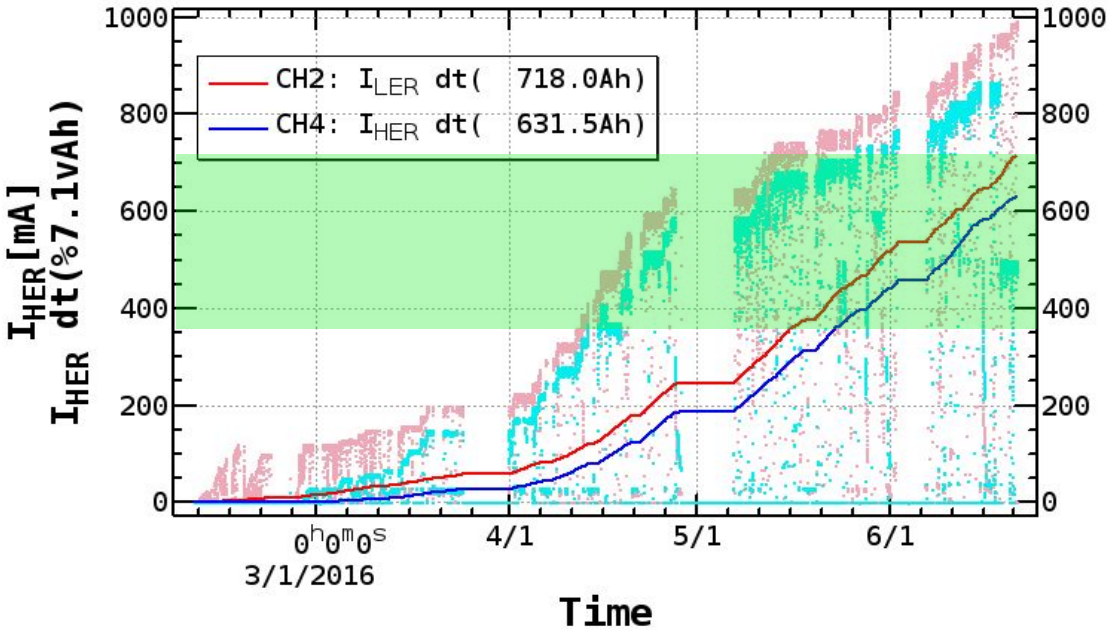
What went down, including preliminary results

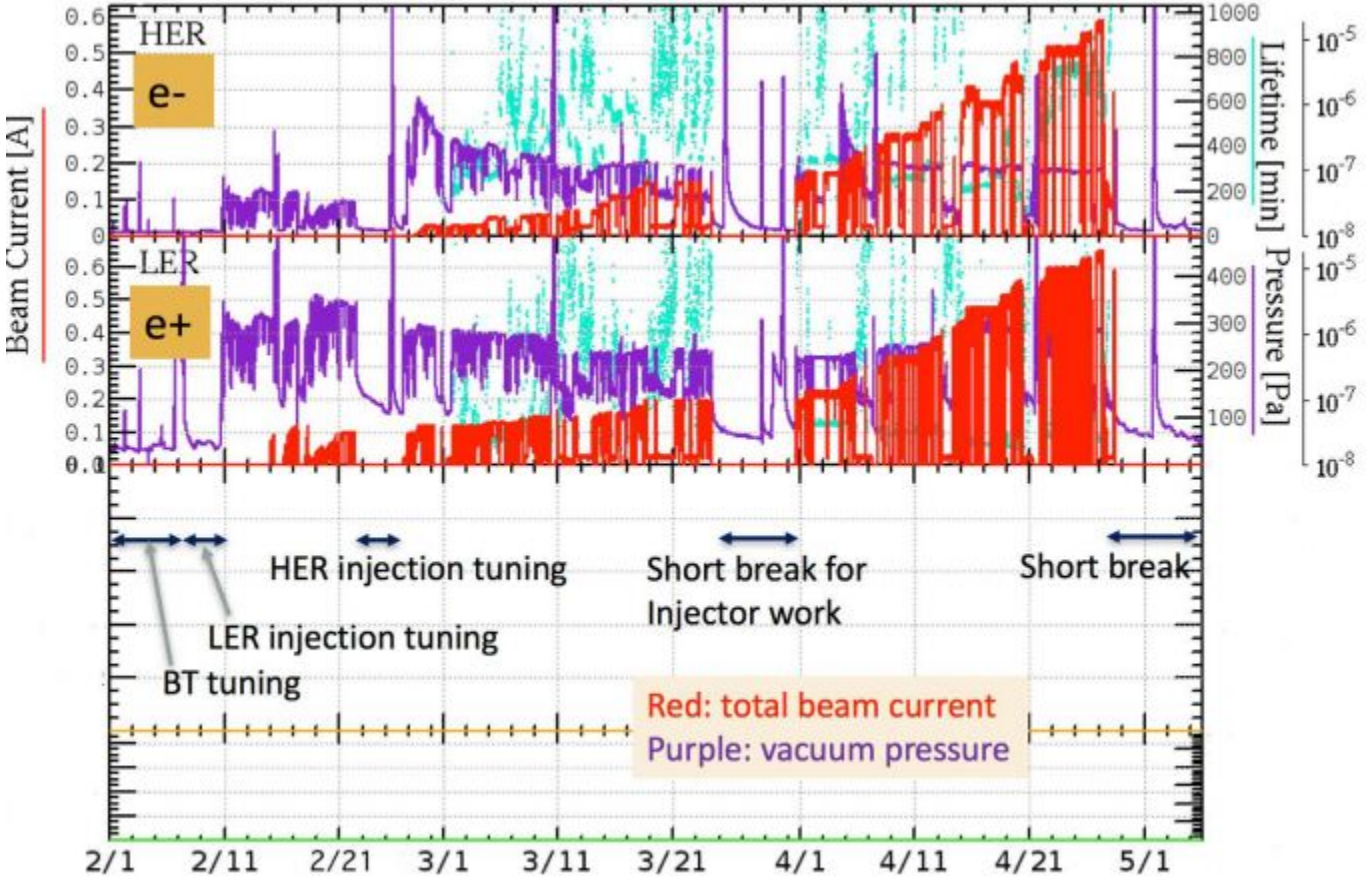
Beam scrubbing

Main use of beams in phase I:

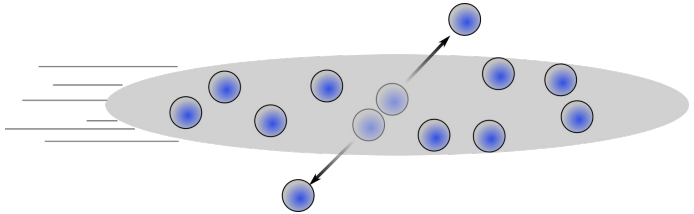
- Crank up current for as long as possible to stimulate desorption of impurities from inner beampipe wall, which are pumped out
- **LER beampipe is 98% new** and therefore quite dirty
- Target 360-720mA*hours **beam scrubbing met**
- Scrubbing and residual gas, next slide

SuperKEKB integrated and instantaneous currents in Phase I, with target




HER
e-
LER
e+
Beam Current [A]
Lifetime [min]
Pressure [Pa]
HER injection tuning
LER injection tuning
BT tuning
Short break for
Injector work
Short break
Red: total beam current
Purple: vacuum pressure
2/1
2/11
2/21
3/1
3/11
3/21
4/1
4/11
4/21
5/1

Beam studies



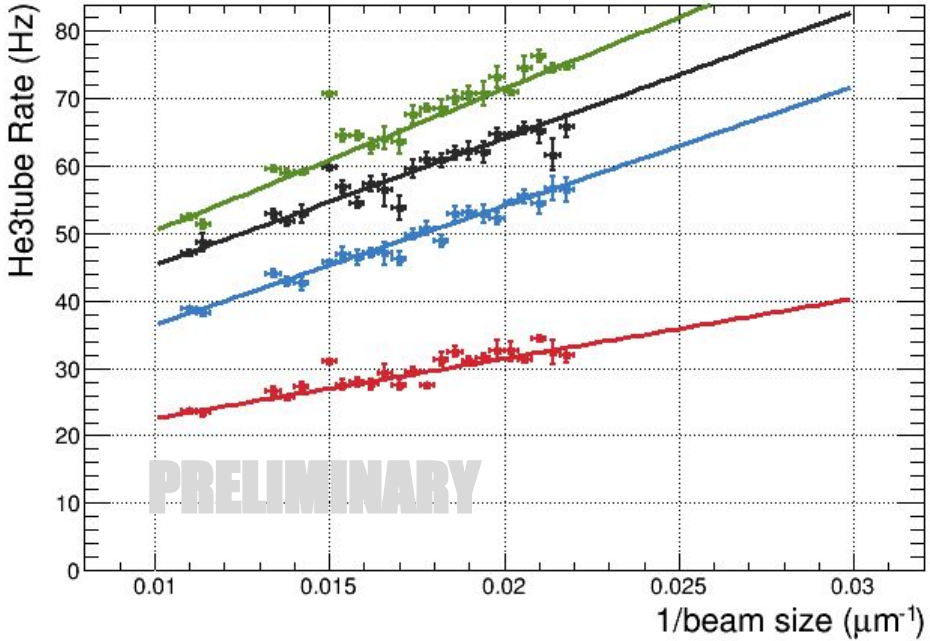
Touschek scattering

- Coulomb scattering between two particles in the same bunch
- Inverse lifetime is inversely proportional to the bunch size:

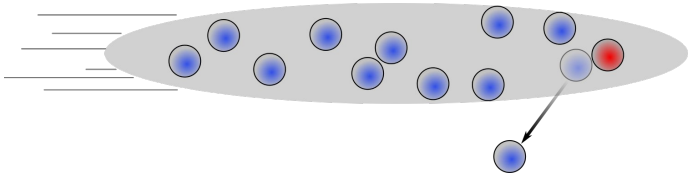
$$\frac{1}{\tau_T} \propto \frac{1}{\sigma_x \sigma_y \sigma_z}$$

- To measure, **hold beam currents constant and vary beam size [right]**

He3 tube thermal neutron rate vs. inverse beam size (Touschek is linear component)



Beam studies

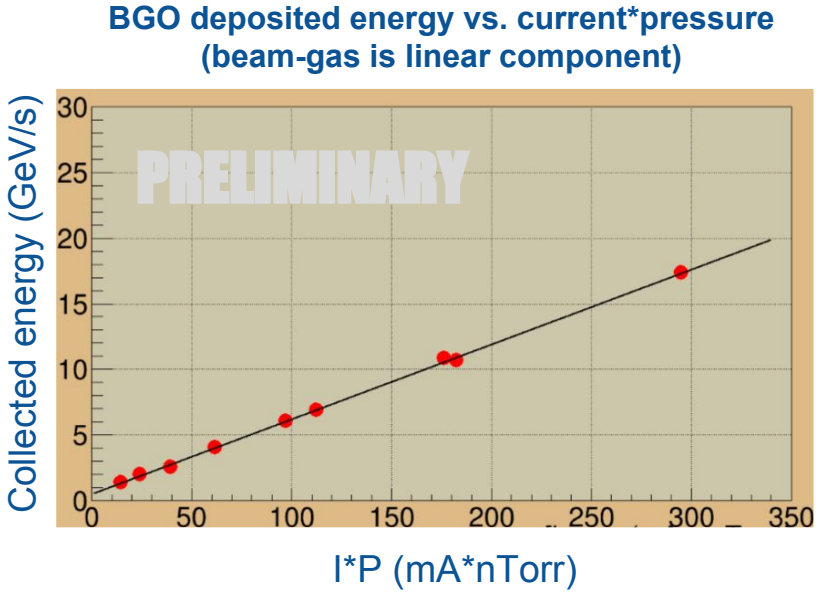


Beam-gas

- Coulomb scattering off residual gas in beam pipe
- Phase I consisted of mostly **beam scrubbing**
- Scattering rate is proportional to current times pressure:

$$R_{BG} \propto I \cdot P$$

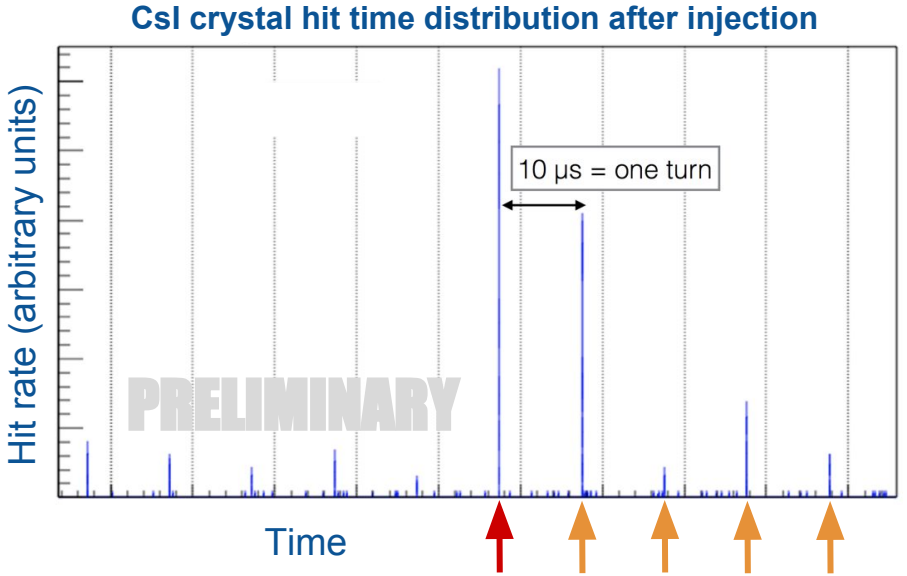
- **To measure, heat vacuum pump to inject gas [right]**



Beam studies

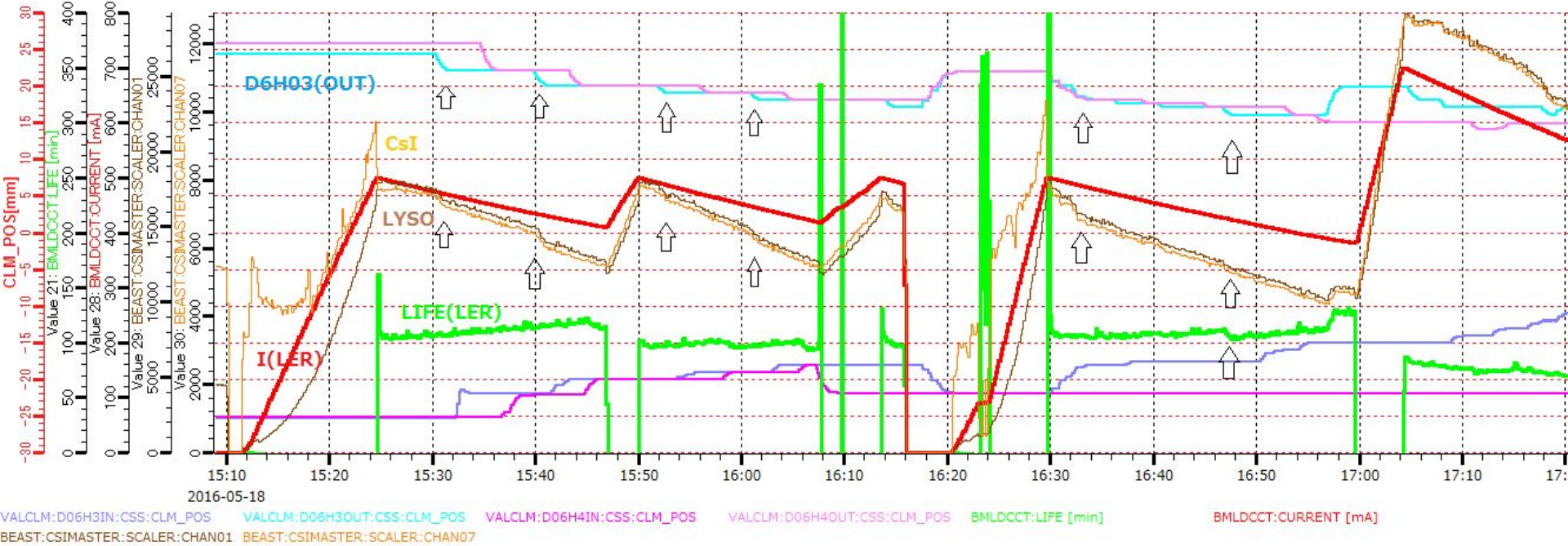
Injection

- Charge is regularly injected into stored beam to counteract beam loss
- For <1ms after injection, **topped-off bunches are messy**; off-orbit particles can slam into pipe walls and spawn EM showers
- CLAWS (plastic scintillators) and CsI/LYSO crystals have time resolution to see **bunch-by-bunch structure**
- **To measure, trigger on injection timing signal [right]**



Beam studies

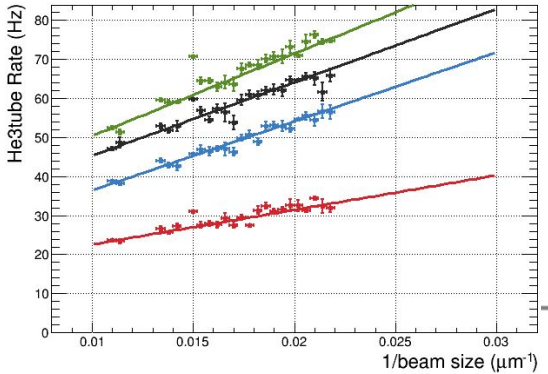
Collimator positions (scraping edge of beam to clean up before IP)

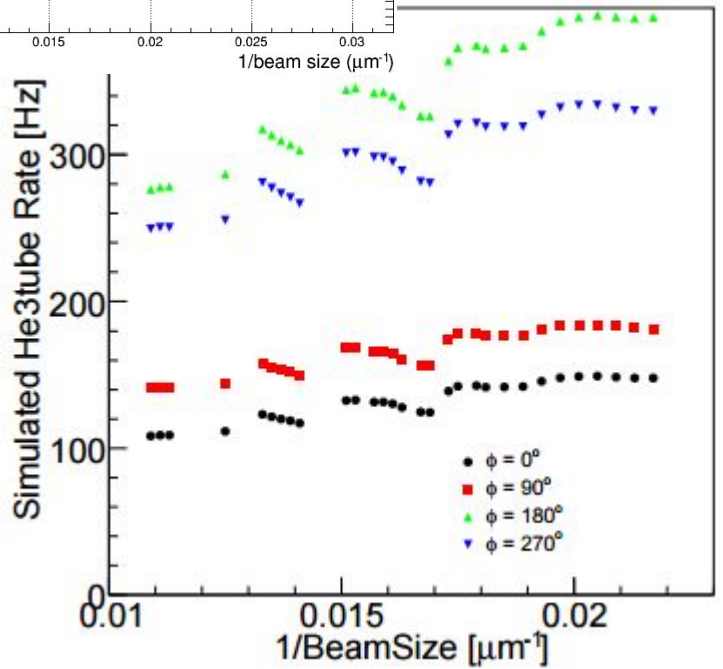


Simulation

From beam physics through BEAST digitization (SAD and GEANT4)

- **Matching data and simulation** is a huge challenge, but it is essential
- Simulated He3 Toushek contribution in beam size scan (**bottom**) high by a factor of ~5 vs. data (**inset**) (which is actually quite good)
- A lot of progress has been made in the last few weeks in reconciling data and simulation






SuperKEKB Commissioning Detector
BEAST II
獣
Belle II Collaboration

Summary

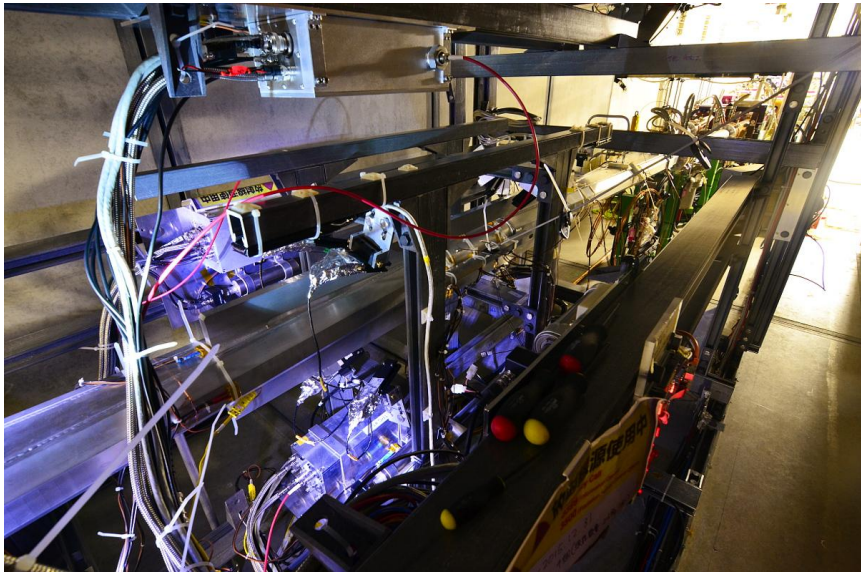
BEAST II status and milestones

Phase I success

- **Measurements** of all primary beam backgrounds
- **Live feedback** to SuperKEKB informed injector tuning, verification of vacuum scrubbing progress, etc.
- Detailed **tuning and verification of simulation** essential for Belle II operation; ongoing
- Analysis ongoing; look for a **paper in late 2016**

Phase II

- **4 new detector systems** to be embedded in inner region of Belle (see additional slides)
- Physical integration with Belle begins **October 2016**



The BEAST cave with BEAST, Feb. 2016

BEAST II status and milestones

Phase I success

- **Measurements** of all primary beam backgrounds
- **Live feedback** to SuperKEKB informed injector tuning, verification of vacuum scrubbing progress, etc.
- Detailed **tuning and verification of simulation** essential for Belle II operation; ongoing
- Analysis ongoing; look for a **paper in late 2016**

Phase II

- **4 new detector systems** to be embedded in inner region of Belle (see additional slides)
- Physical integration with Belle begins **October 2016**

The BEAST cave without BEAST, July 2016

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~~80	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 phase III
Belle II SVD	KEK	4 ladders	Radiation tolerance for phase III
FANGS	U. Bonn	15	Silicon pixel sensors (synchrotron x-ray spectrum)
PLUME	Strasbourg	2 ladders	Silicon pixel sensors (collimator adjustment)

BEAST's guts and decommissioning team, July 2016.

Best BEAST picture

(because this could have been an *epic* tangle of cables)