SuperKEKB, BEAST

Minakshi Nayak (Wayne State University/KEK)
On behalf of the Belle II collaboration

Post CKM School, TIFR, Mumbai
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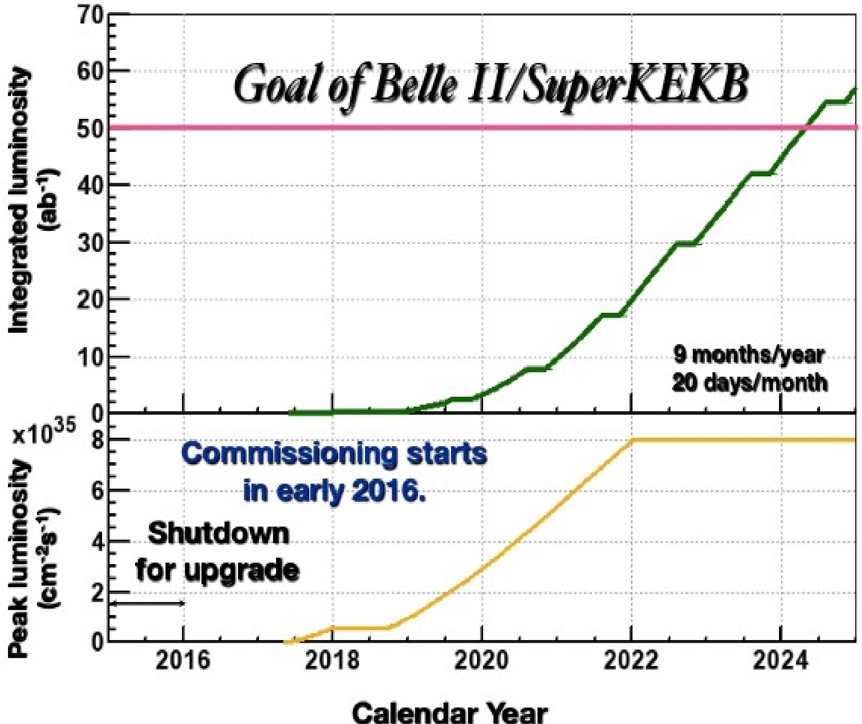
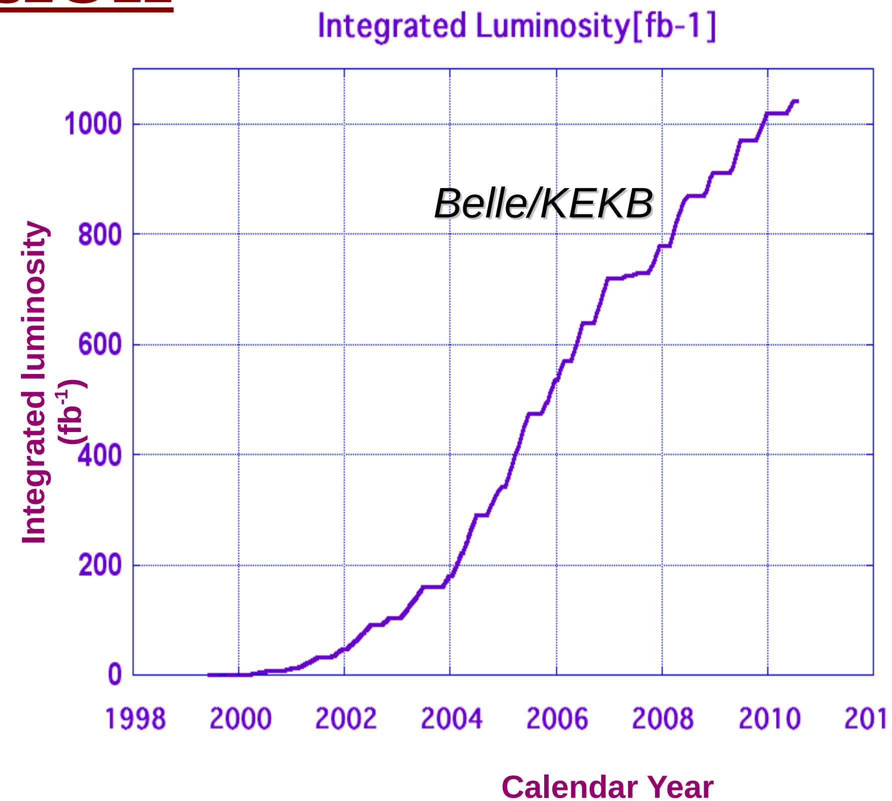
Talk outline

- Motivation
- SuperKEKB (description, operation)
- Beam Backgrounds
- Commissioning (BEAST II)
- Conclusion

Motivation





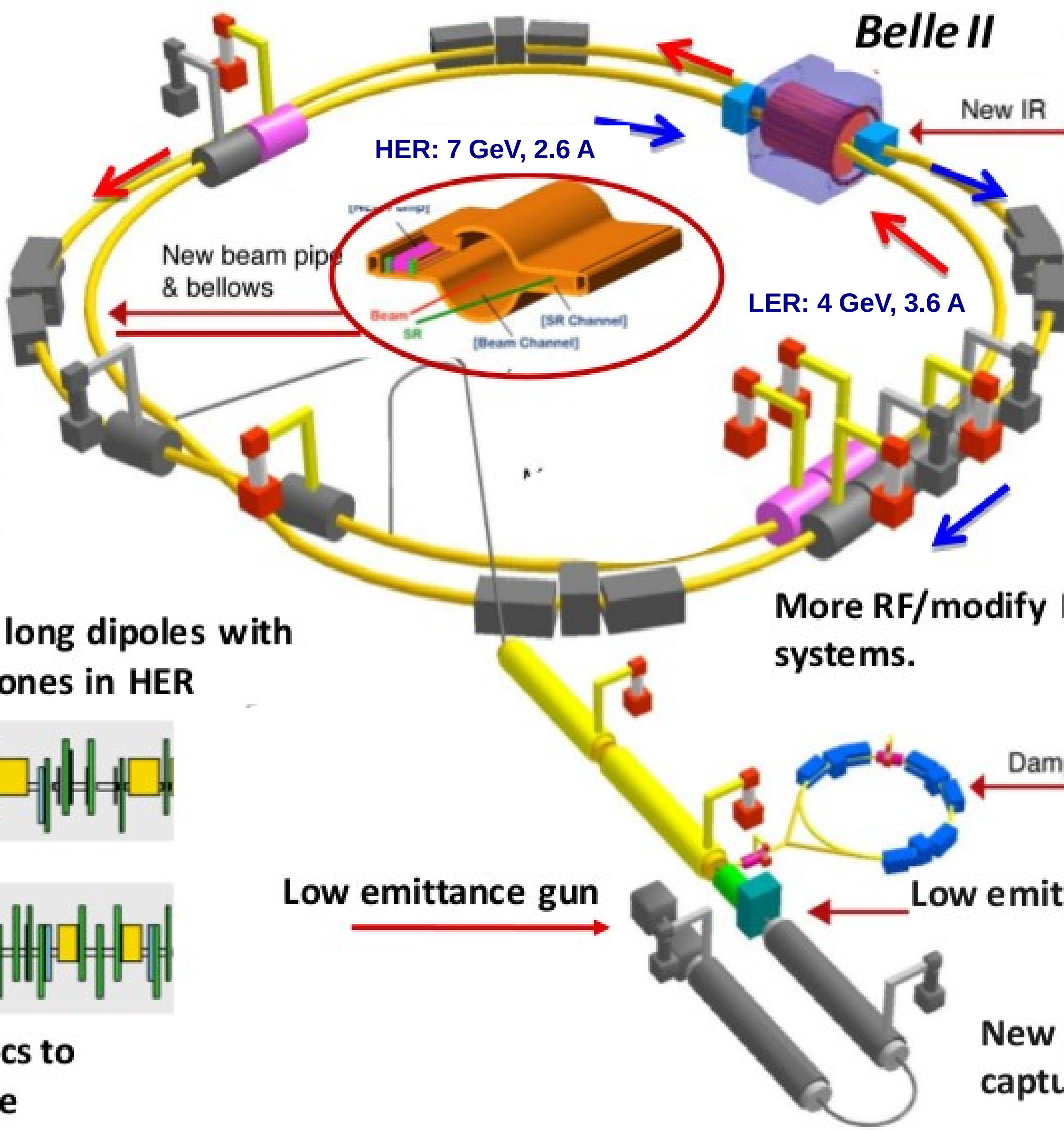
L_{int} = 50 ab^{-1} by 2025 (50 x KEKB)

L_{peak} = 8 x 10^{35}cm^{-2}s^{-1} (40 x KEKB)

New physics opportunities:

- Precise measurement of UT parameters
- Search for charged Higgs
- New sources of CP violation
- Lepton Flavour Violation in B and τ decays
- New physics search in missing energy modes of B decays
- Search for Dark matter, etc..

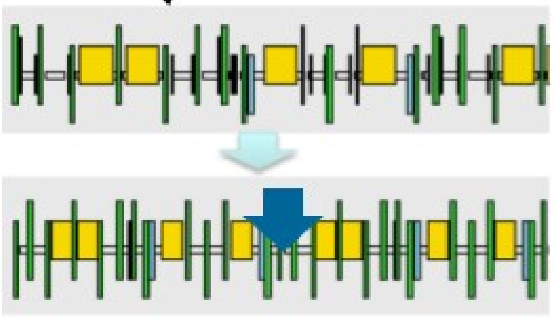
KEKB upgrade → SuperKEKB(nano-beam)



Two separate focusing quads/each 2 beams closer to IP; Superconducting / permanent magnets

More RF/modify RF systems.

Replace long dipoles with shorter ones in HER



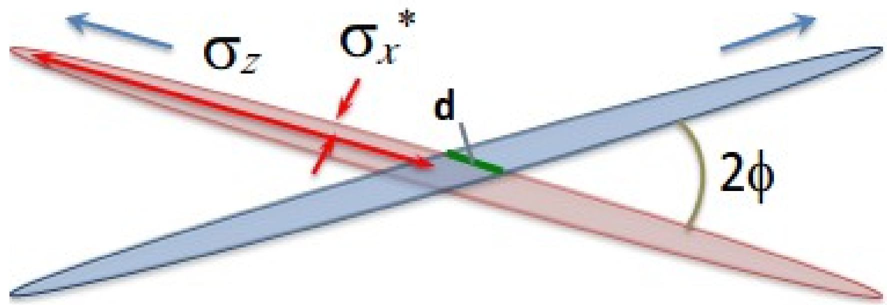
Redesign the HER arcs to reduce the emittance

New positron target / capture section

Nano-Beam Scheme to increase Luminosity

L_{int} = 50 ab^{-1} by 2025 (50 x KEKB)
L_{peak} = 8 x $10^{35} cm^{-2}s^{-1}$ (40 x KEKB)

Nano-Beam Scheme



KEKB → SuperKEKB

	Energy (GeV) LER/HER	β_y^* (mm) LER/HER	ε_x (nm) LER/HER	ξ_y LER/HER	φ (mrad)	I_{beam} (A) LER/HER	Luminosity ($cm^{-2}s^{-1}$) x 10^{34}
KEKB Achieved	3.5/8.0	5.9/5.9	18/24	0.129/0.090	11	1.64/1.19	2.11
SuperKEKB	**4.0/7.0**	**0.27/0.41**	**3.2/2.4**	**0.09/0.09**	**41.5**	**3.6/2.62**	**80**

- Reduced beam spot size using nanobeams: $\beta_y^*/20$
- Increased beam currents by a factor of two
- Larger crossing angle (2φ = 83 mrad)
- Increased LER energy

Beam current

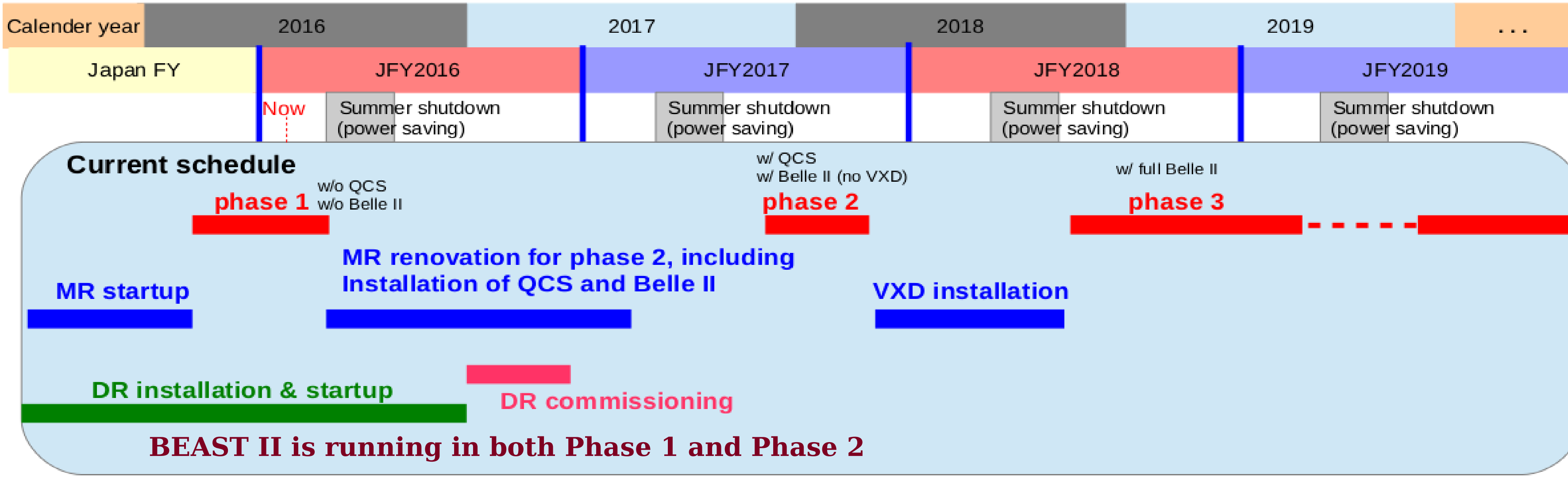
Beam-Beam parameter

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

Vertical beta function at IP

Geometrical reduction factor

SuperKEKB Operation Schedule



Phase1 status:

first week (Feb. 1st - Feb. 7th)

- Tuning of Beam Transport Lines (e^-/e^+)

next two weeks (Feb. 8th - Feb. 21st)

- Commissioning of LER (e^+ ring)
- Hardware check → Beam storage → vacuum scrubbing → (target) 100mA
- Circumference check with wigglers

next two weeks (February 22nd - Mar. 5th)

- Commissioning of HER (e^- ring)
- Hardware check → Beam storage → vacuum scrubbing → (target) 100mA
- In parallel with LER vacuum scrubbing and possible studies at LER

Completed!

Machine Stydy done:

- Vacuum scrubbing
- Optics study
- BEAST dedicated machine study during mid May
- Other study and tuning
- Achieved Expected highest HER and LER current 1A

SuperKEKB commissioning detector (BEAST II)

- Due to high beam currents, small beam size and higher luminosity, predicted SuperKEKB Beam background: 40 x KEKB
- Background reduced below this simple expectation by installing moveable collimators and adding shielding near the QCS magnets
- **B**eam **E**xorcism for a **S**table ExperimenT **II (BEAST II):** measure and characterize beam background for safe roll-in of Belle II
- Provide feedback to SuperKEKB
- First comparison of simulation with experimental data
- Seven independent **BEAST II** sub-detectors to measure beam loss backgrounds
- Phase1 (no collision) : 1st Feb – 30th June

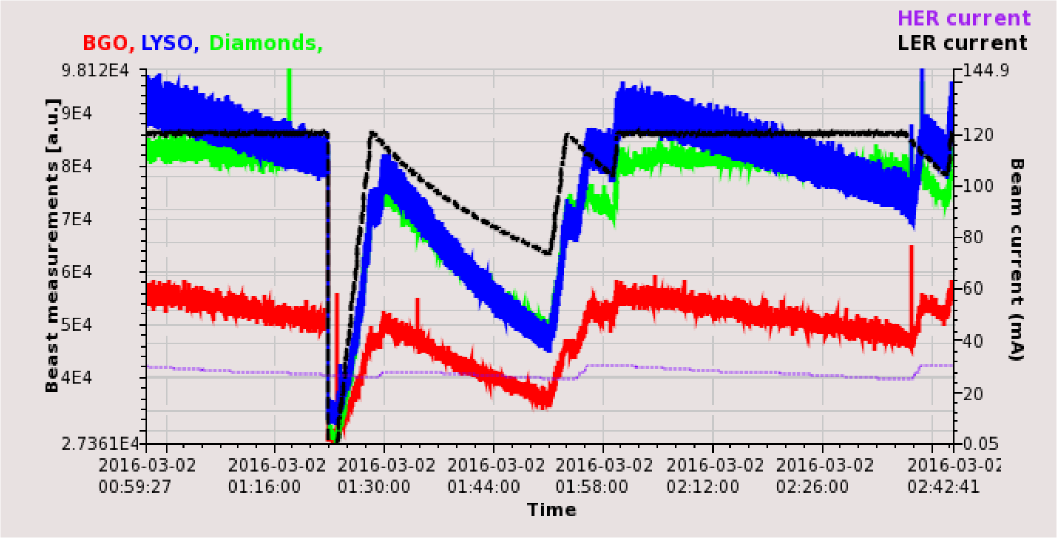
Sources of background:

- Touschek scattering
- Beam gas scattering
- Synchrotron radiation
- Radiative Bhabha event
- 2 – photon process event

Fake hits, pile-up etc.

BEAST II cage at IR

BEAST II Online monitor display



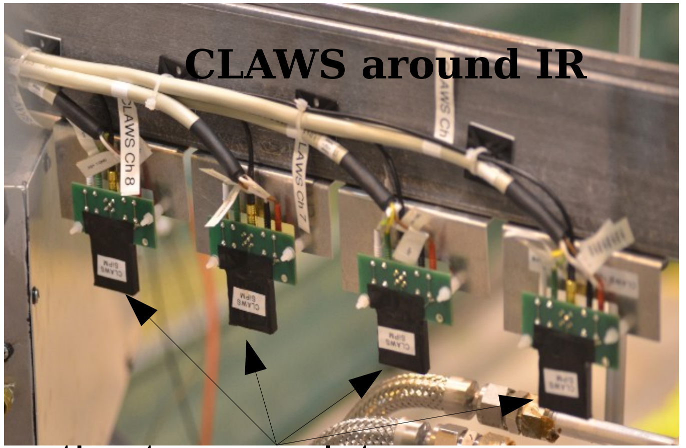
Systems	Number of Detectors Installed	Unique Measurement
"CLAWS" Scintillator	8	Injection backgrounds
Diamonds	4	ionizing radiation dose
PIN Diodes	64	Neutral vs charged radiation dose
BGO	8	luminosity
Crystals	6 CsI(Tl) 6 CsI 6 LYSO	EM energy spectrum
He-3 tubes	4	thermal neutron flux
Micro-TPCs	2	fast neutron flux

- SuperKEKB and BEAST II in operation mode with many exciting results.
- Phase1 Goal achieved: 1 Amp (LER/HER)

Phase1 goals achieved

- Measured various background (X-ray, charged track, neutron) levels near IP
- Online feedback to SuperKEKB
- Offline analysis of various backgrounds to understand their level
- Test and calibrate various background detectors for phase2.
- Measurement of superKEKB injection backgrounds (specifically CLAWS detector
- Comparision between simulated SuperKEKB beam loss with data
- etc...

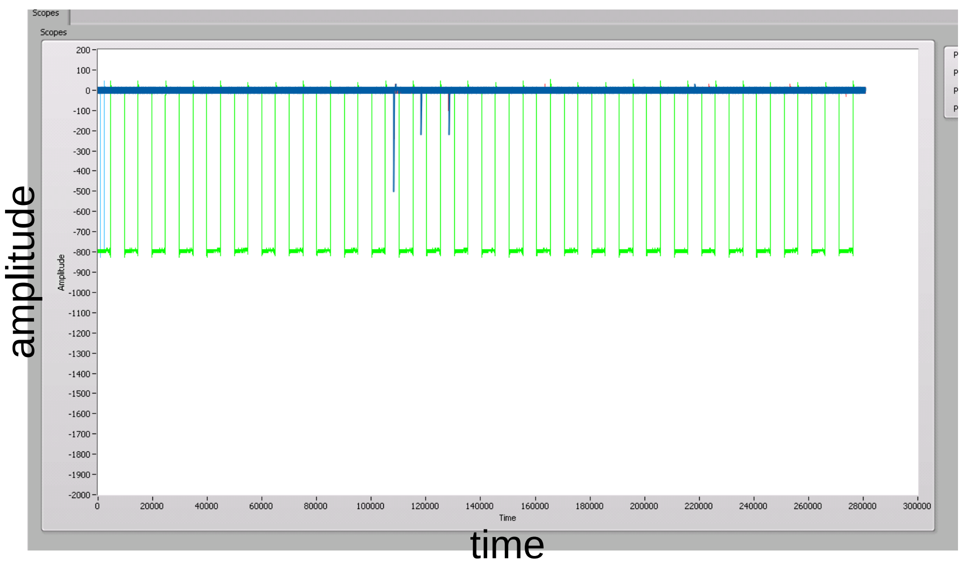
First signal from SuperKEKB



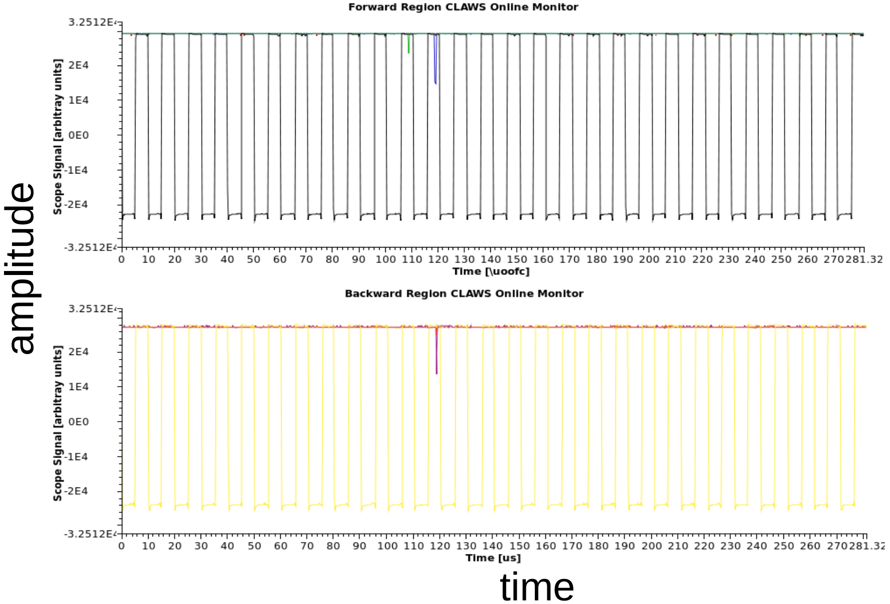
CLAWS (sCintillation Light And Waveform Sensors)

- CLAWS saw 1st SuperKEKB injection signal on 8th Feb.
- Measure the time evolution of the injection background at the IR
- CLAWS measures backgrounds particularly connected to the injection, with a time resolution better than the bunch crossing frequency.
- The detectors primarily measure background from charged particles, high energy photons, MeV neutrons
- Detect MIPs with < 1 ns resolution and see bunch by bunch injection background
- Fast feedback to accelerator group at the very beginning of LER commissioning with no delay

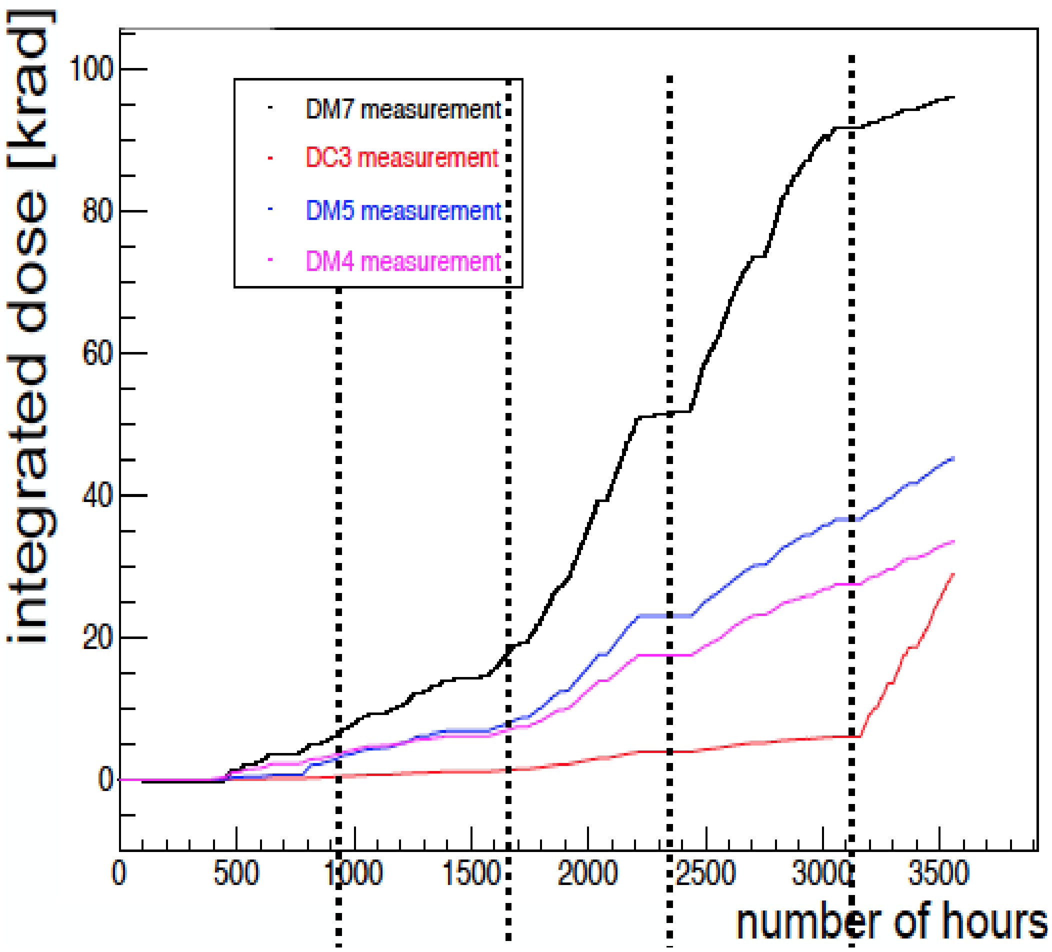
LER first turns

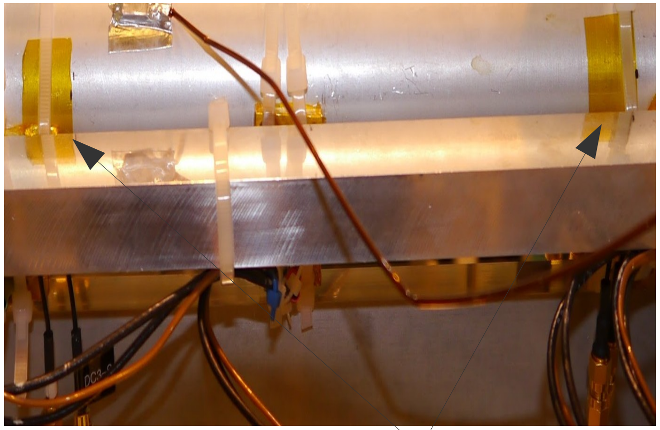


HER first turns



Diamonds

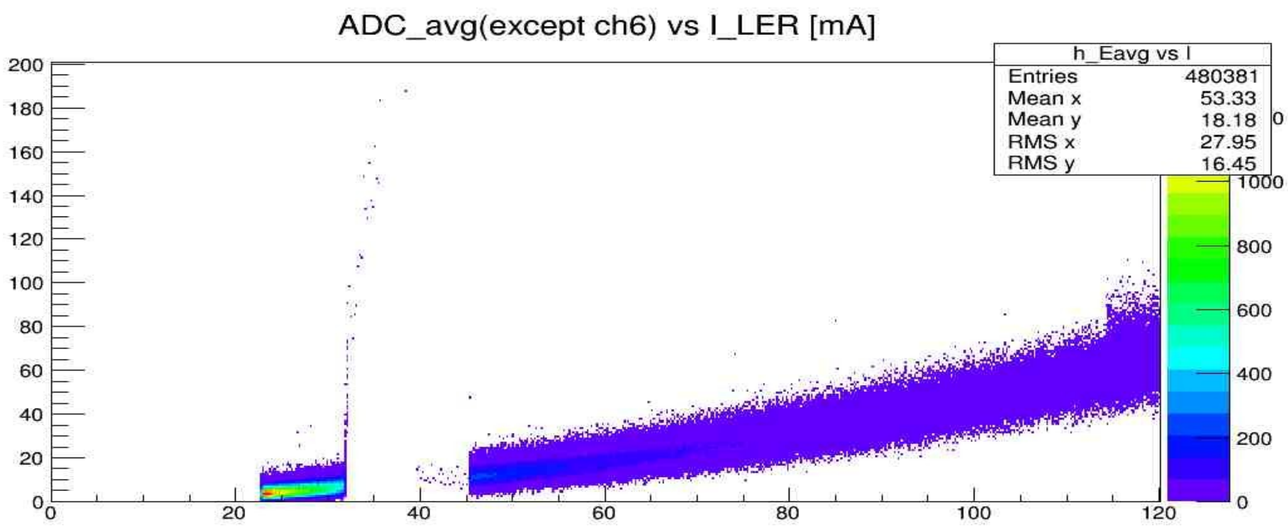




Diamond sensor around IR

Integrated dose (from Ionizing current) seen by diamond sensors at various locations during vacuum scrubbing

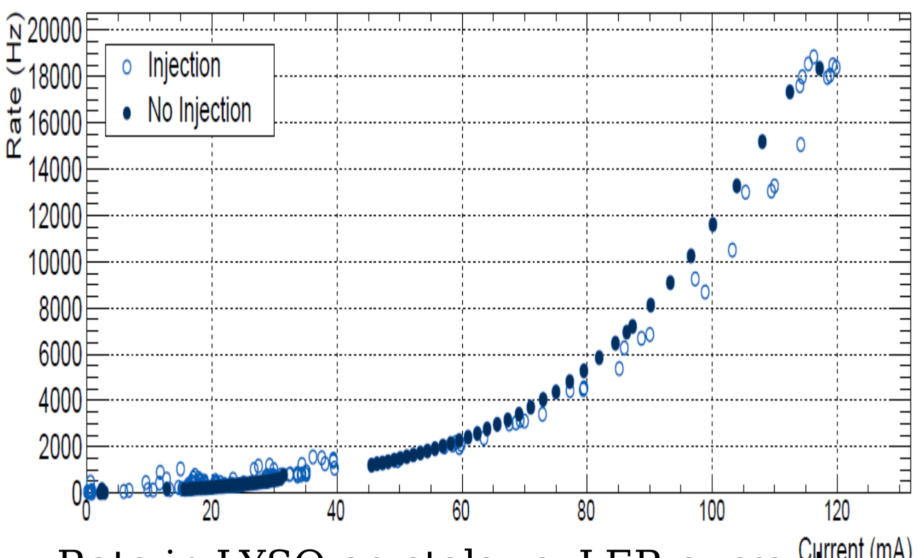
BGO



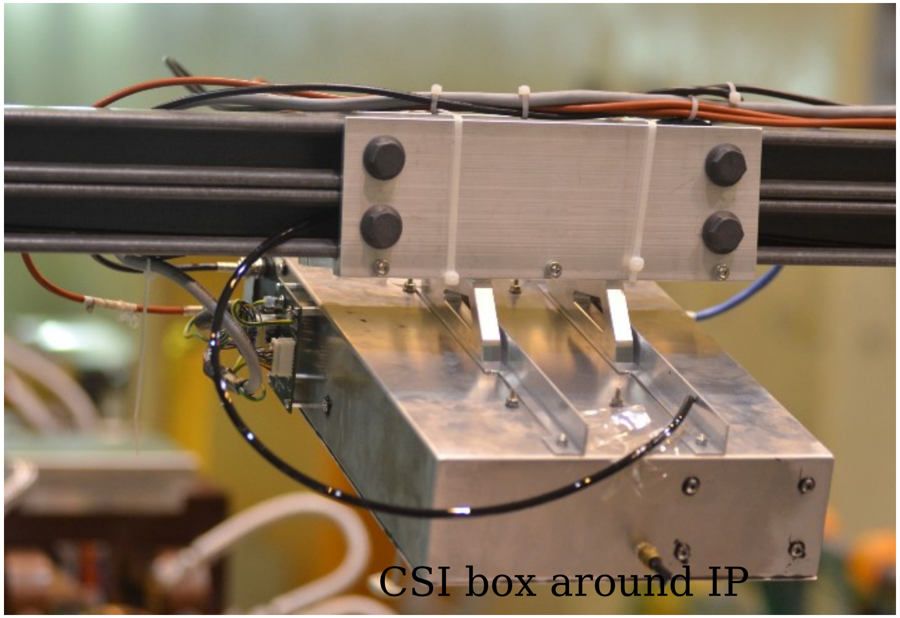
BGO see beam gas very clearly

BGO around IP

CSI crystal

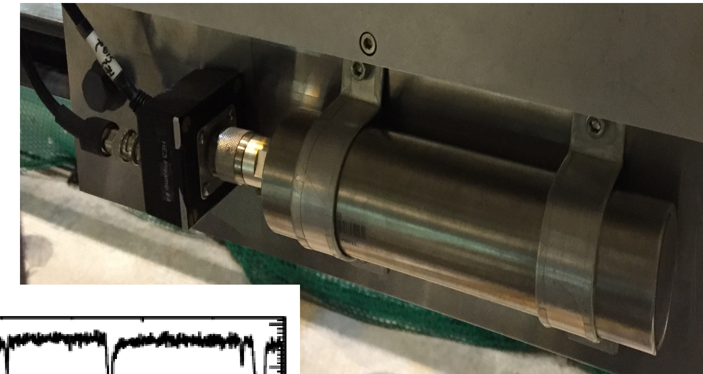


Rate in LYSO crystals vs. LER current

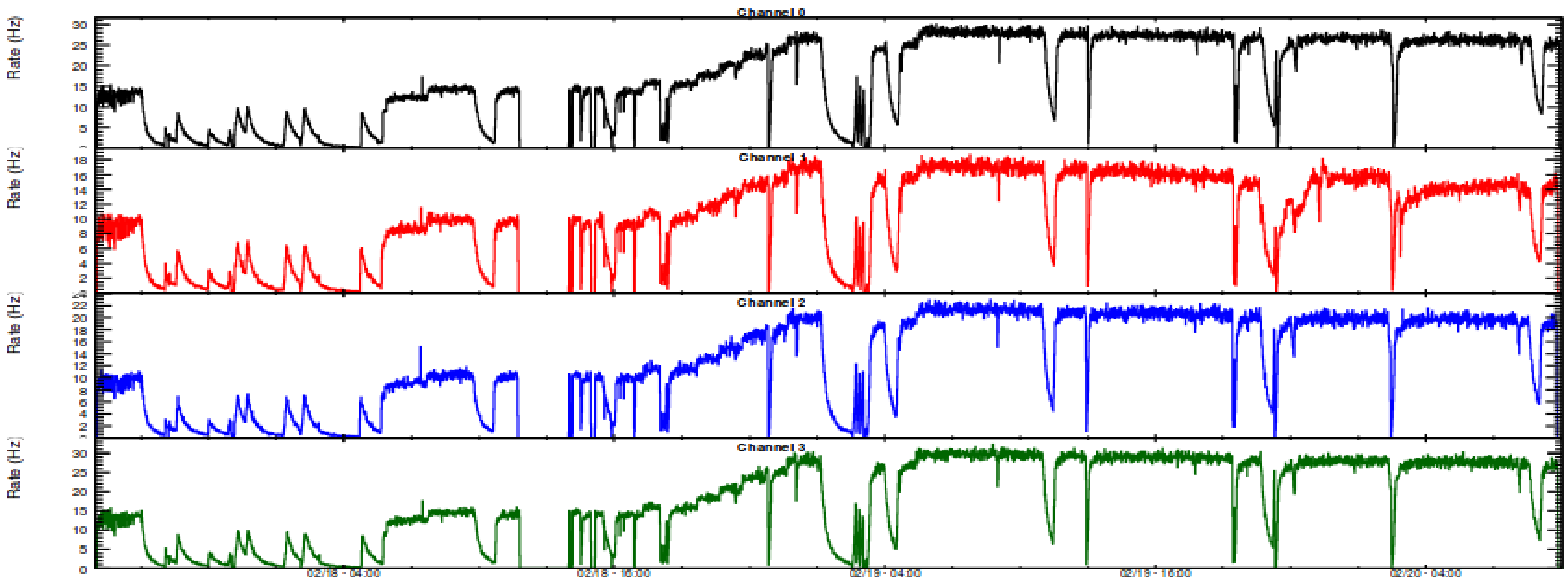


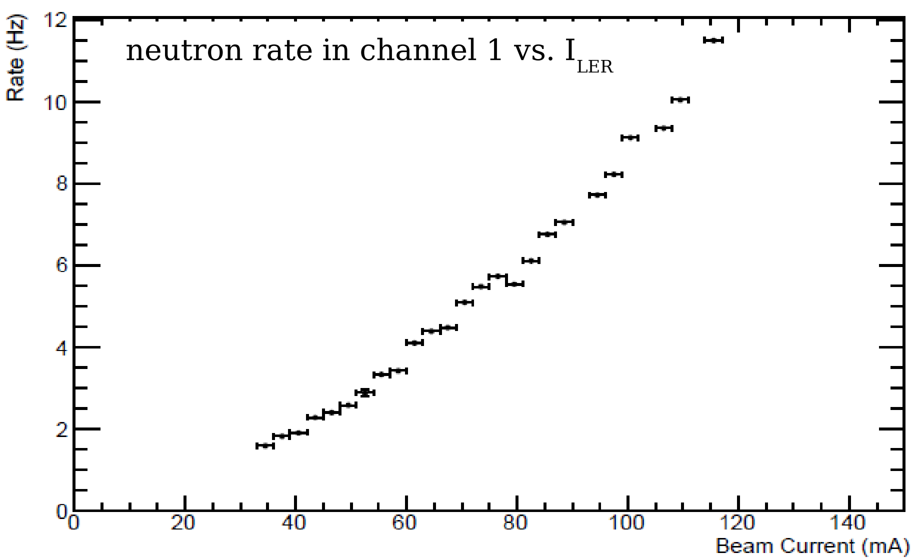
CSI box around IP

He3-tubes: thermal neutron



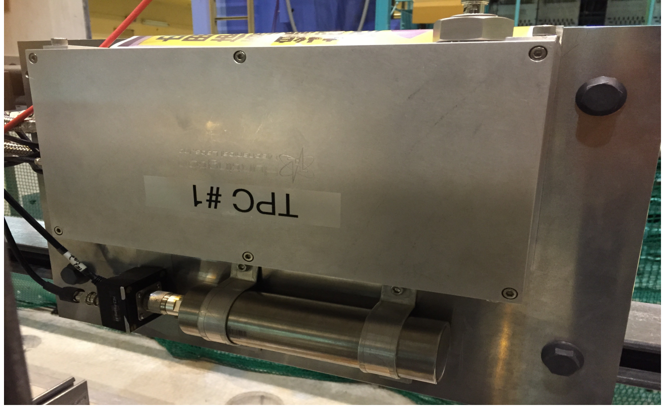
Thermal neutron rate vs. time by different channels





lot of thermal neutrons produced by beam-gas events

Micro-TPC: fast neutron

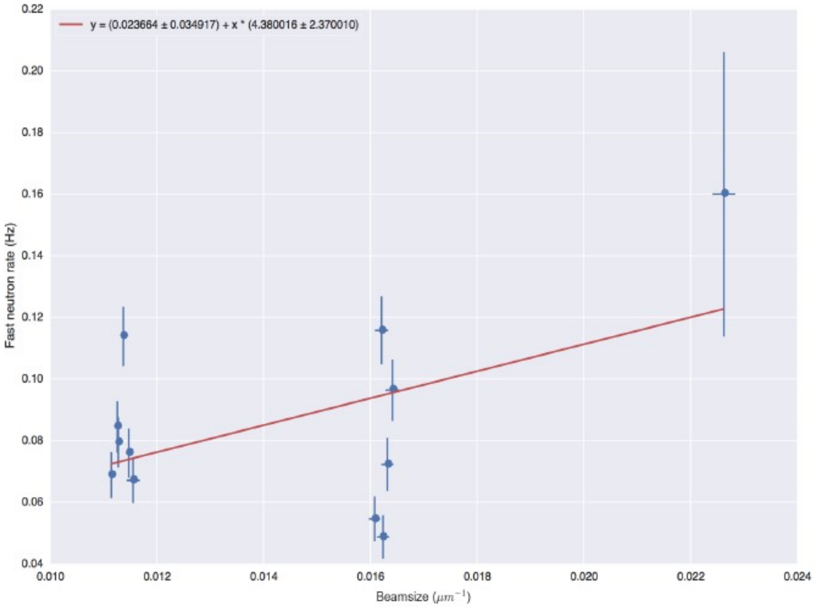


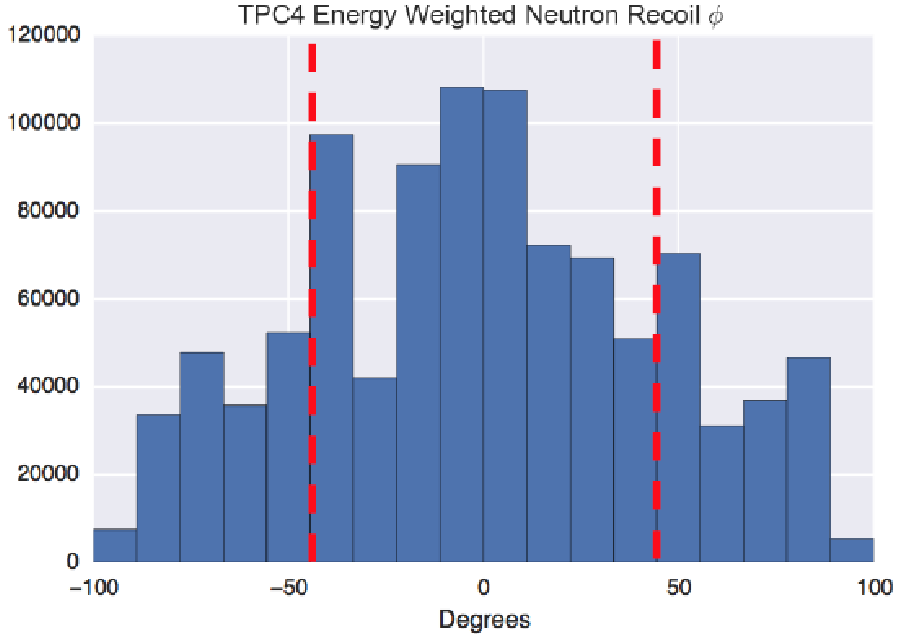
- Fast neutrons produce ionizing tracks by heavy nuclear recoil in the gas volume

- Measure energy of fast neutrons with direction using high resolution charge readout .

- Micro-TPC: fast neutron, charged track and X-rays

Fast neutrons from Touschek

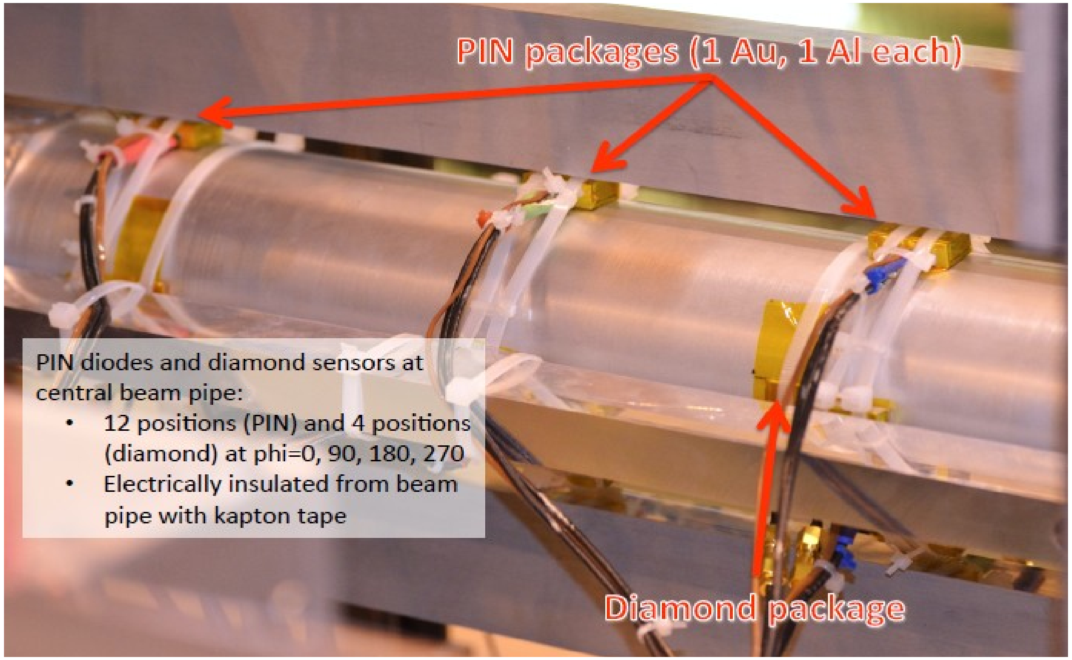




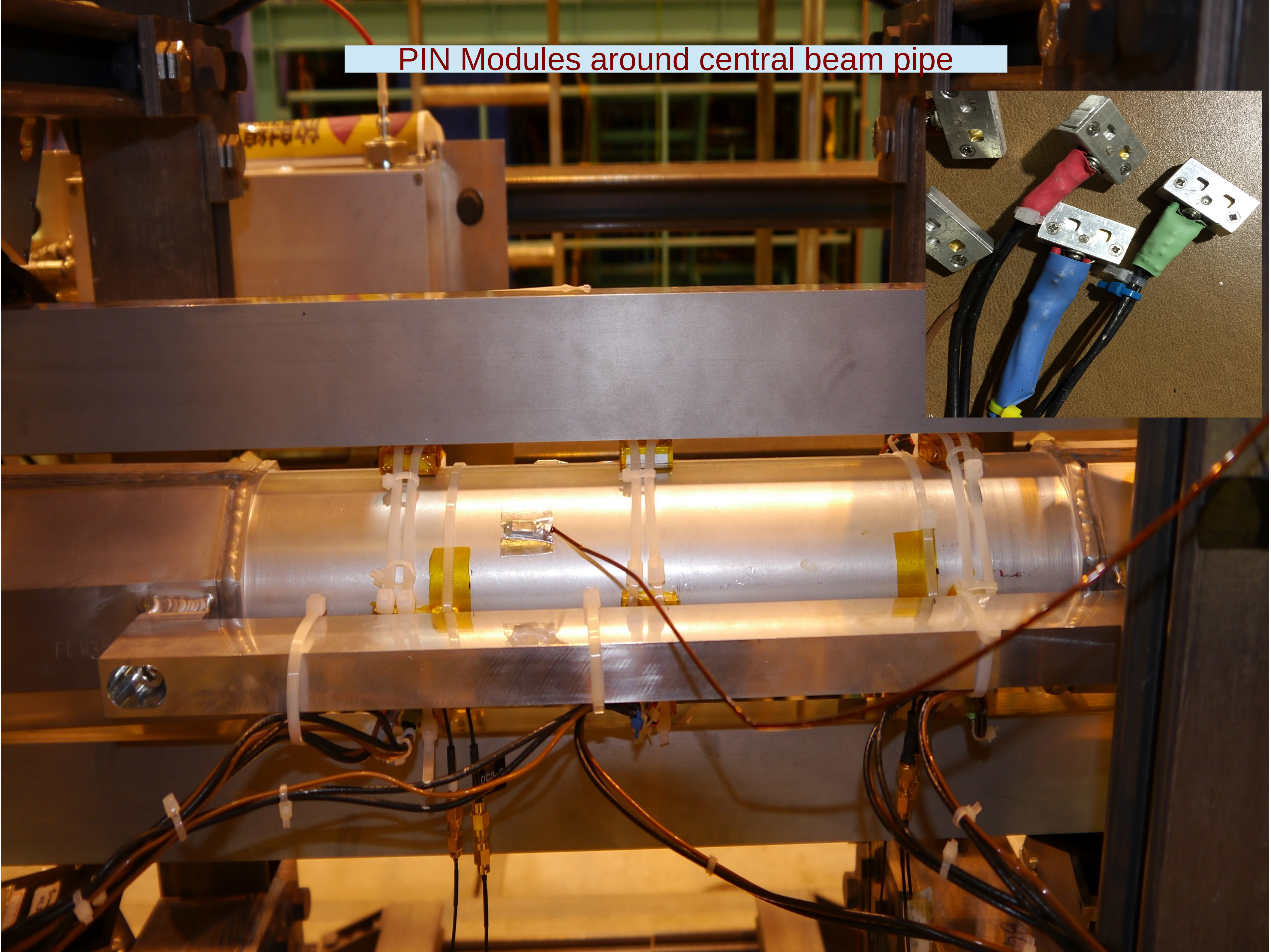
All sub-detectors more or less have common goal

Let me concentrate on the sub-detector (PIN diode) with which I am most comfortable

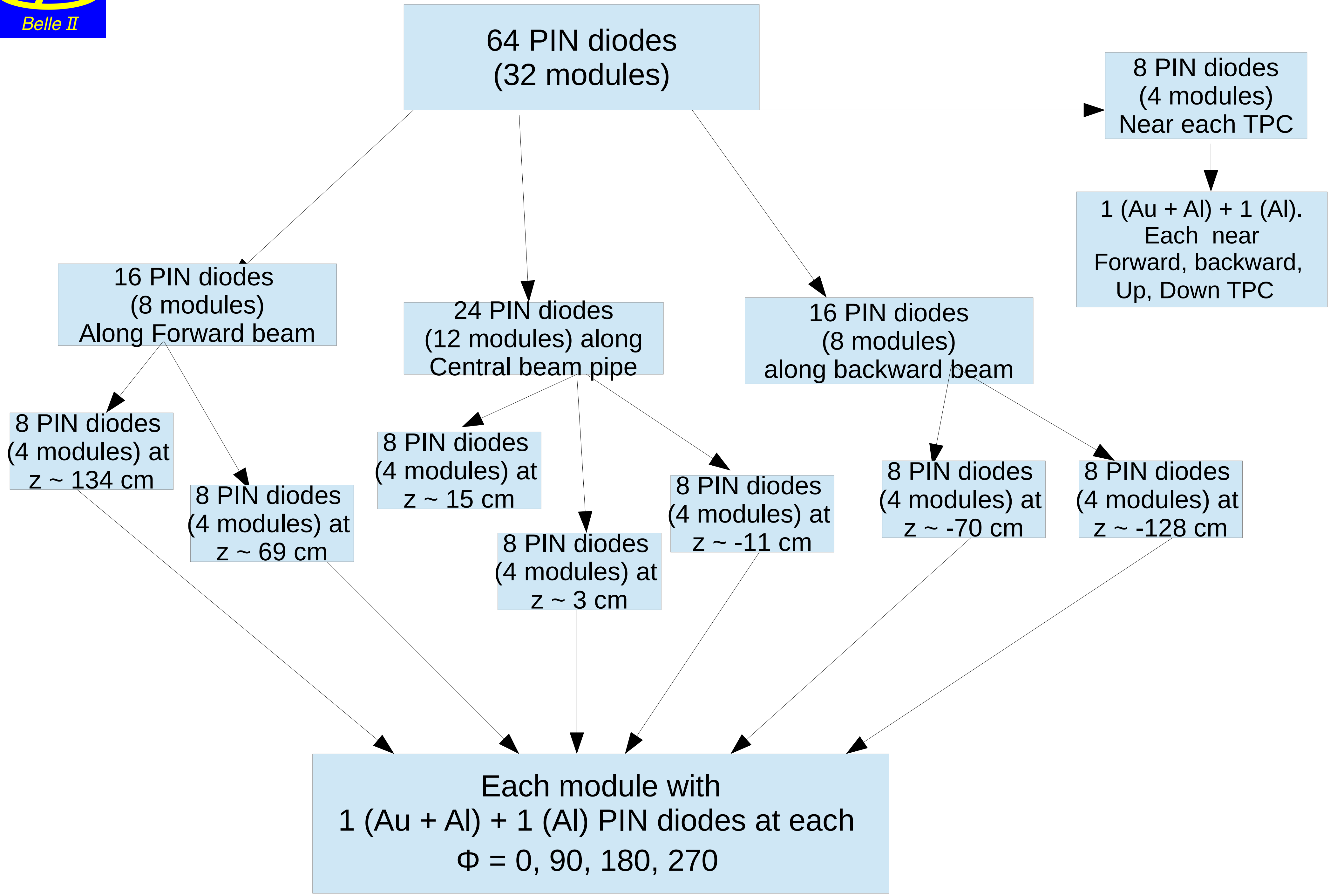
For such very small detector, let's discuss the beauty of data taking, calibration, analysis and result on small scale

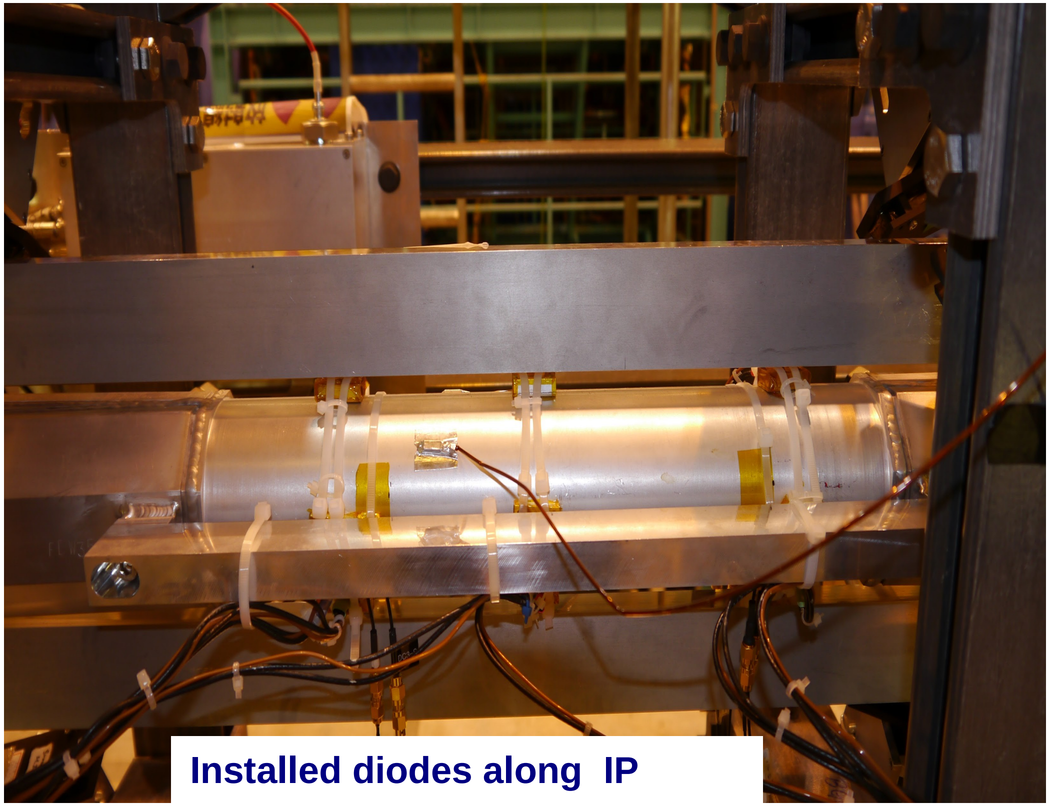


PIN Modules around central beam pipe

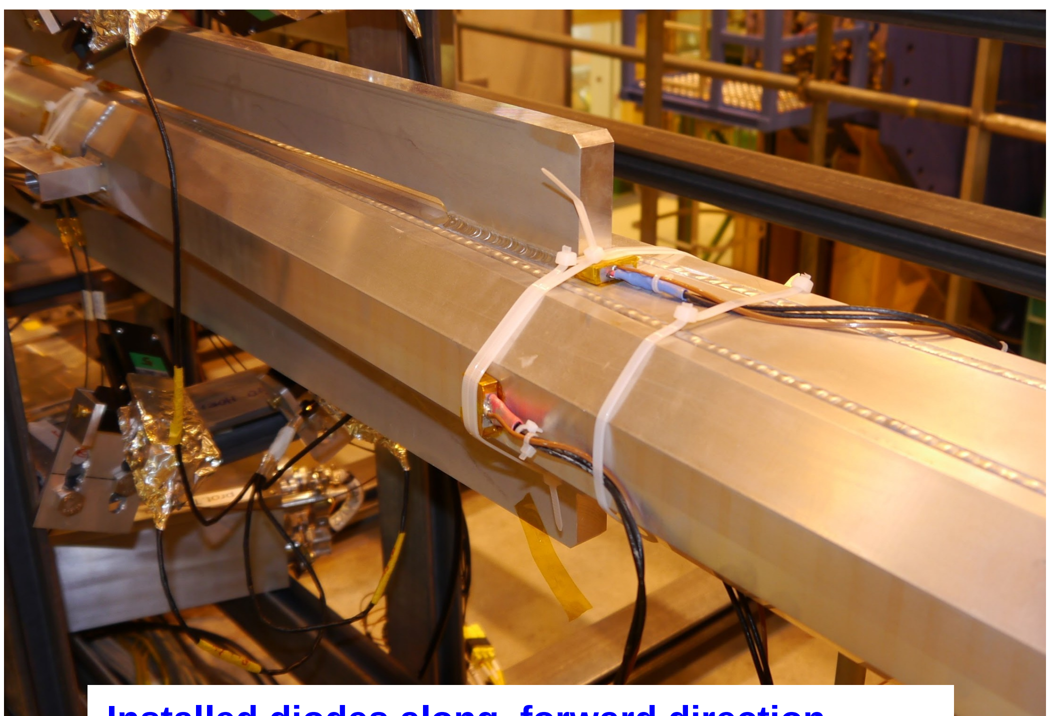


Different location of PIN diodes around IP to measure radiation dose

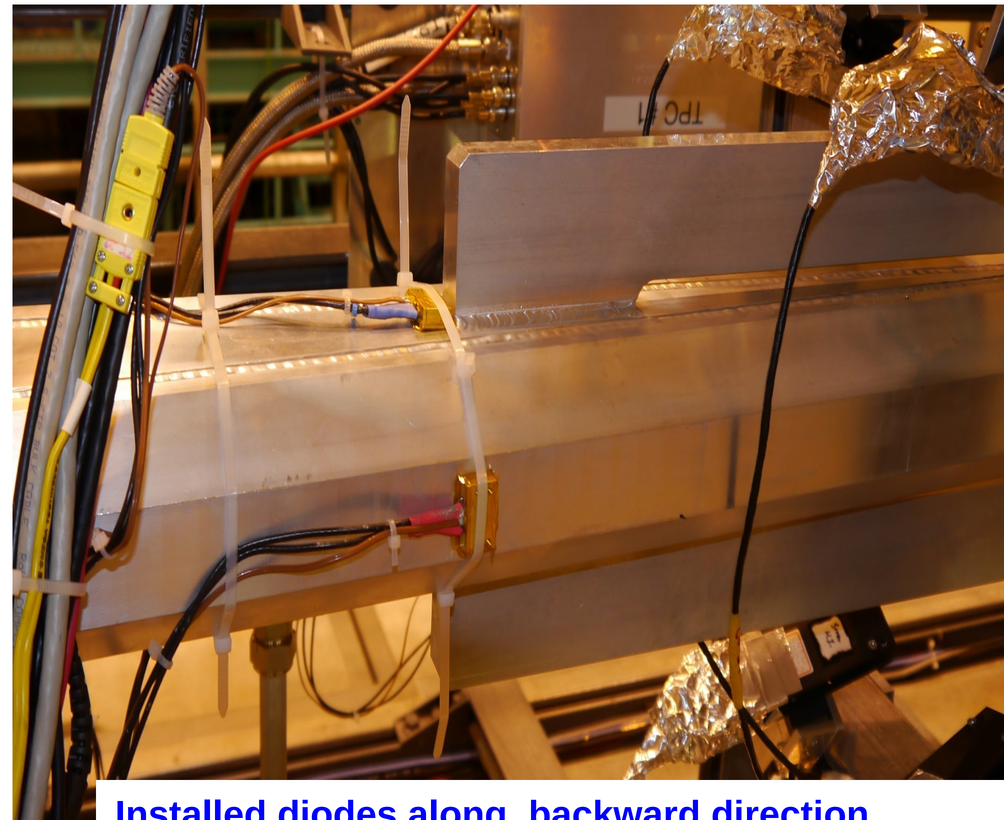




Installed diodes along IP

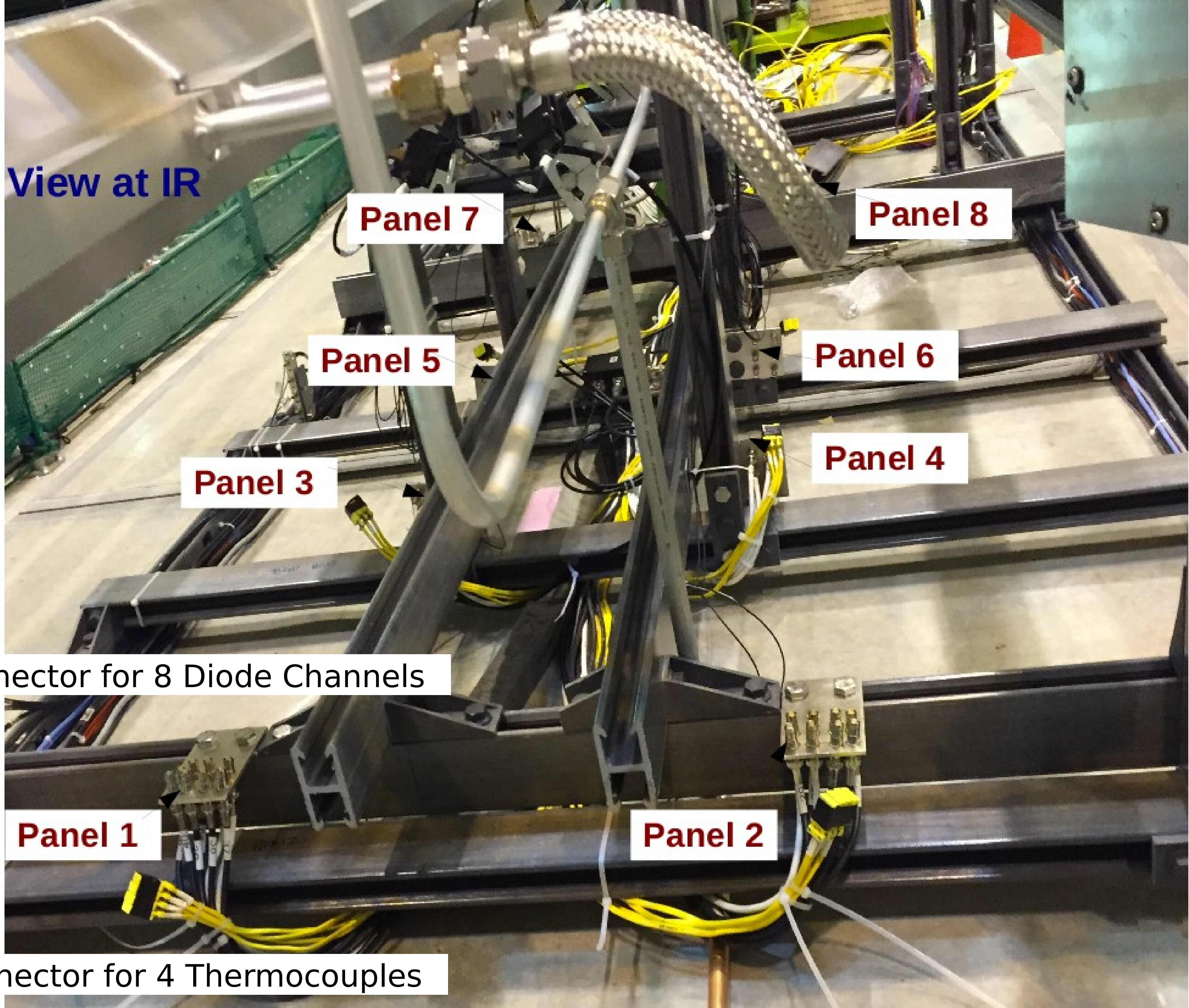


Installed diodes along forward direction



Installed diodes along backward direction

Front View at IR



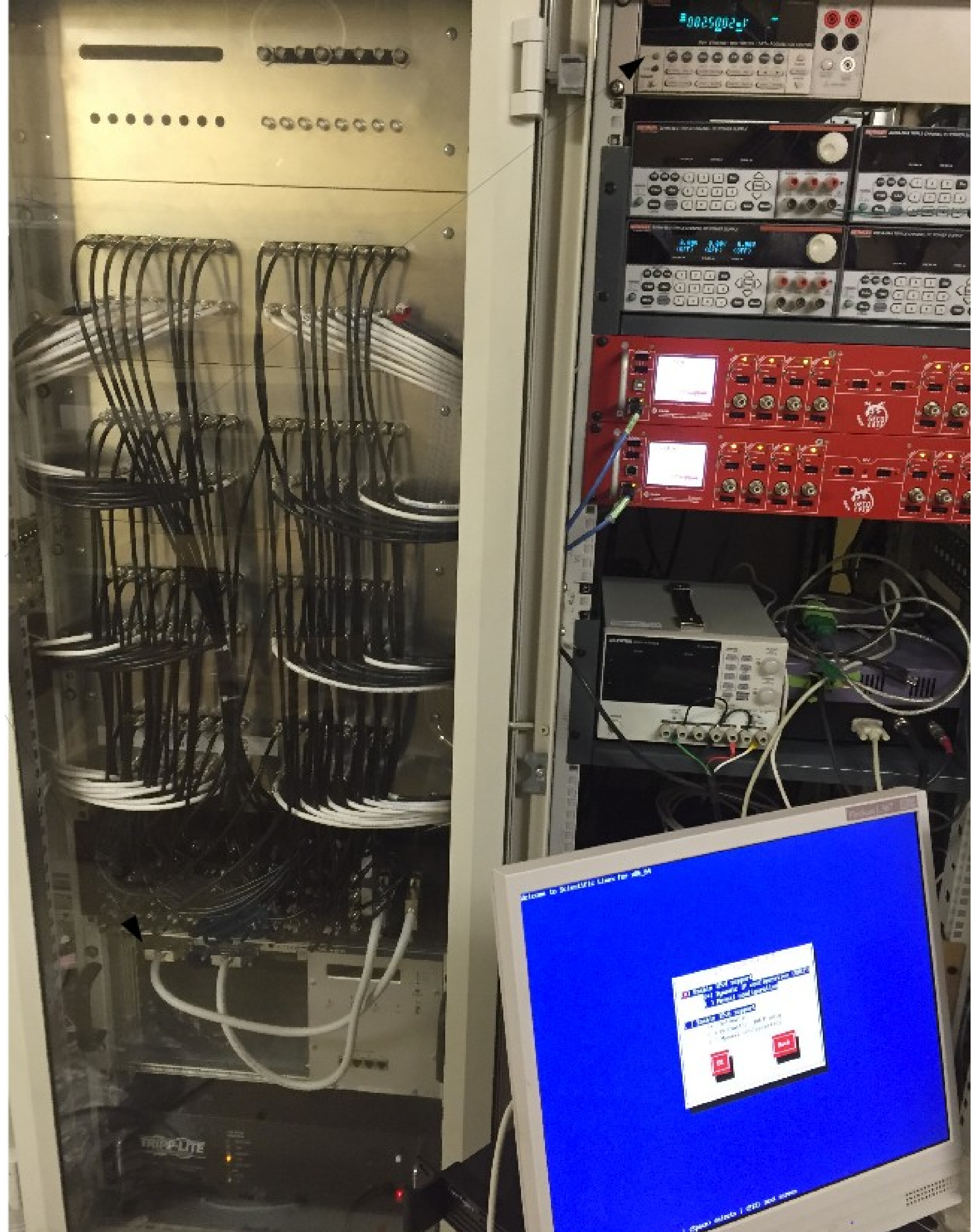
BEAST II Counting House

8 Channel Spare Amplifier Box

16 Channel Amplifier Boxes x 4

64 Channel Patch Panel

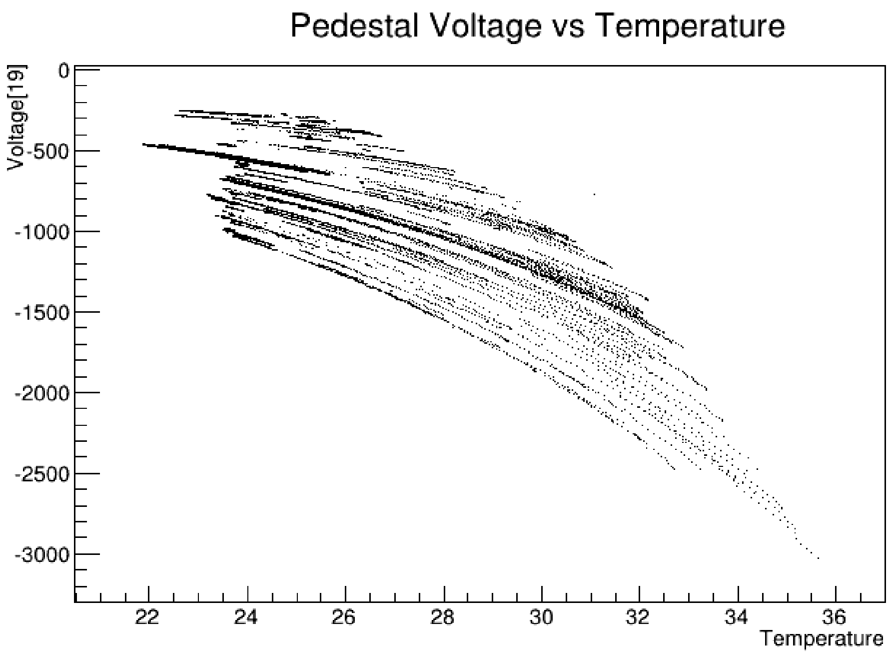
Digital Readout



PIN diode pedestal calibration

PINs sitting over beam pipe measure 2-3 hundreds krads of bkg.
Since background level is high, so calibration is difficult
Reason: Radiation damage, strong temperature dependence

The calibration takes into account:
1) Integrated beam dose
2) Temperature dependancy



Strong correlation between fit parameters → Everyday pedestal calibration separately for all 64 diodes

This worked pretty well!

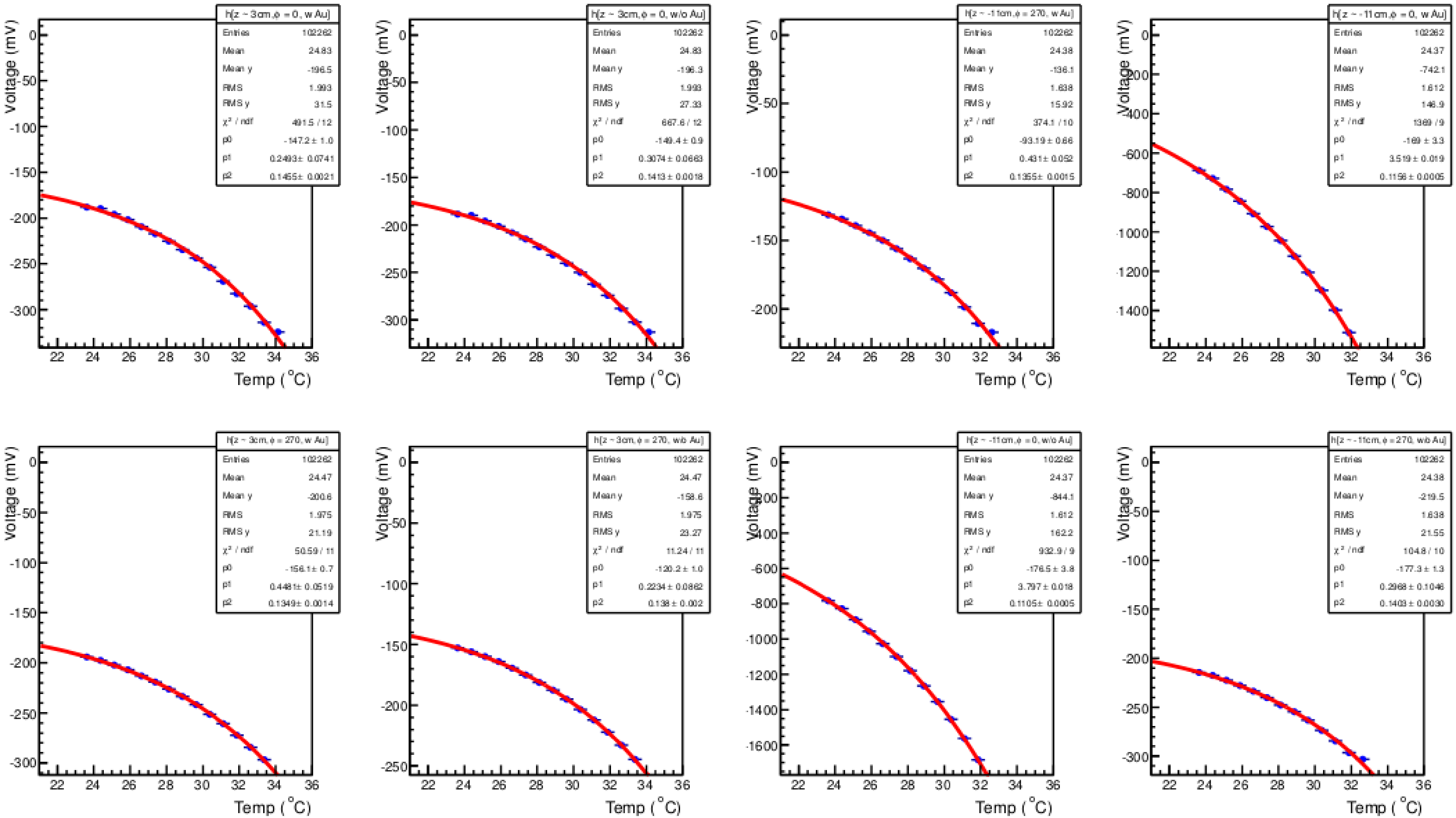
Everyday Pedestal Subtraction to get rid of pedestal bias

Functional form to fit pedestal : $p0 - e^{(p1+p2T)}$

p0 fits pedestal due to radiation damage.

p1, p2: fit temperature dependant part

Fit to Pedestal vs Temperature for eight different diodes



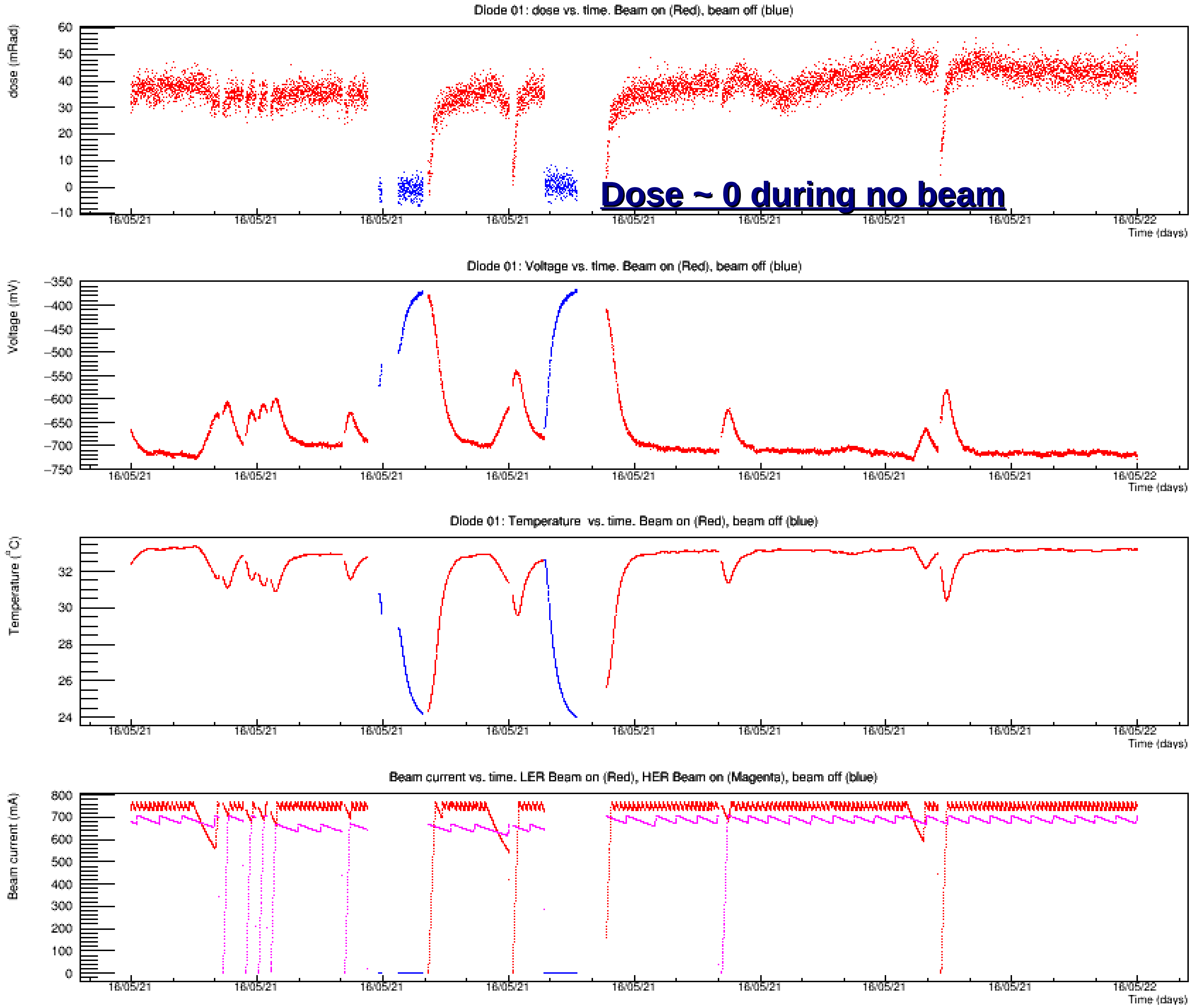
Pedestal substracted voltage (V) = V_{total} - (p0 – $e^{(p1+p2T))}$)

p0, p1, p2 values taken from pedestal fit

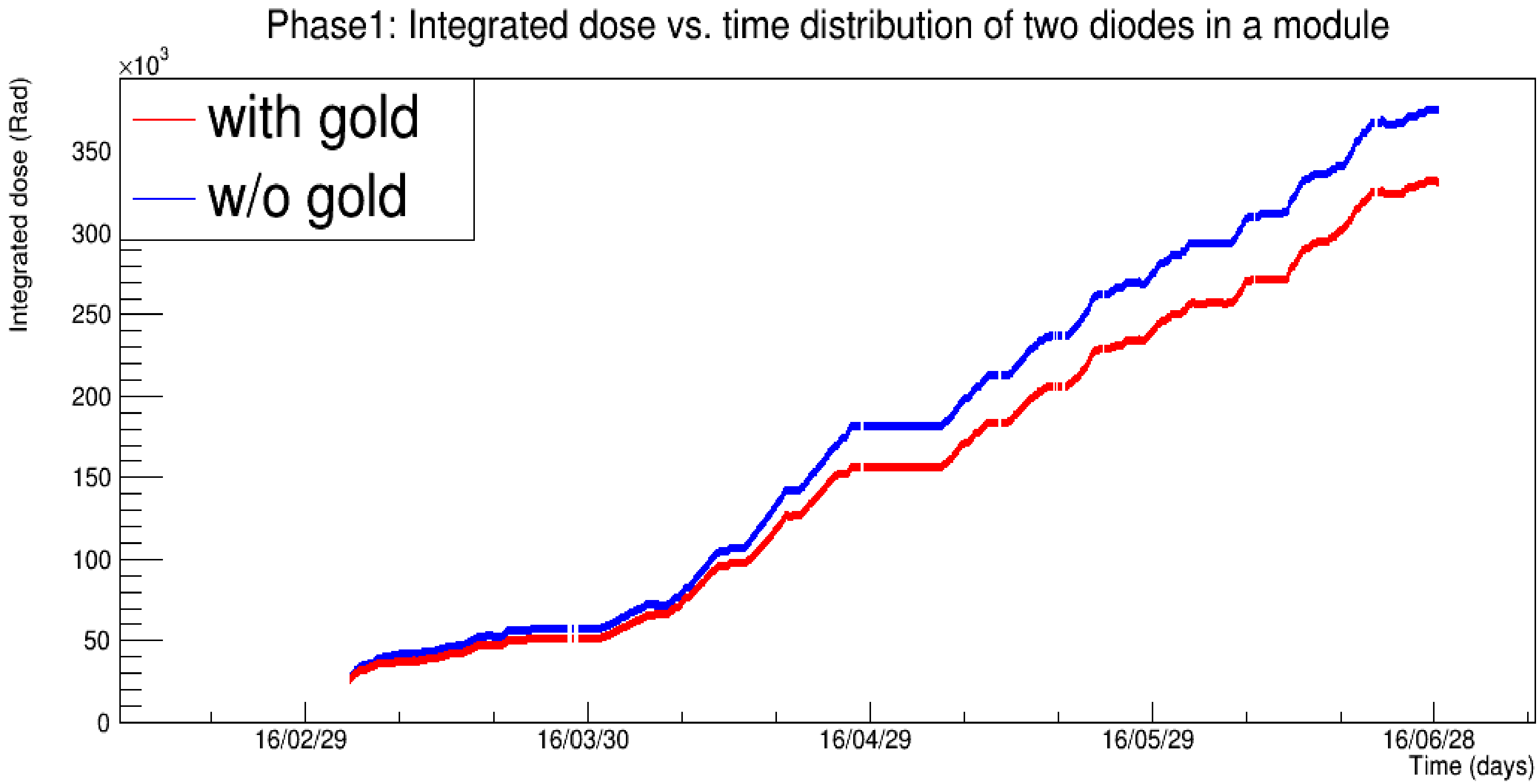
Conversion of voltage to dose rate (V/E) = 0.67 V/Rad Sec^{-1}
(considering total volume of diode = 0.01 cm x 0.07 cm^2)

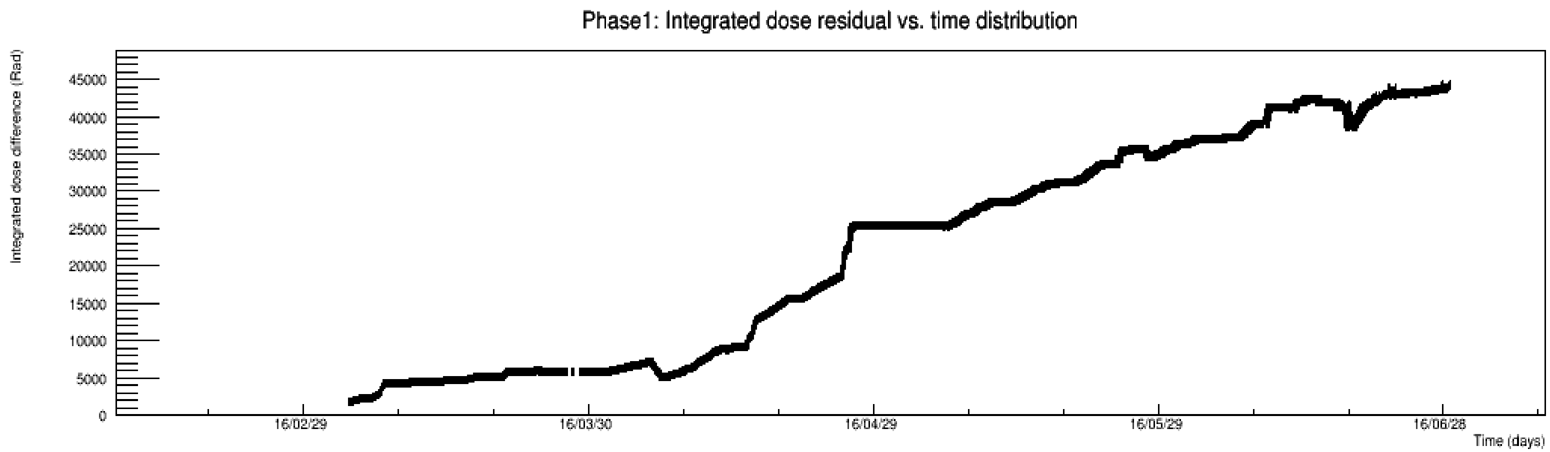
Pedestal subtracted voltage (expressed in dose) vs time distribution at different locations are in next slide

Channel 1 result from 21st May data

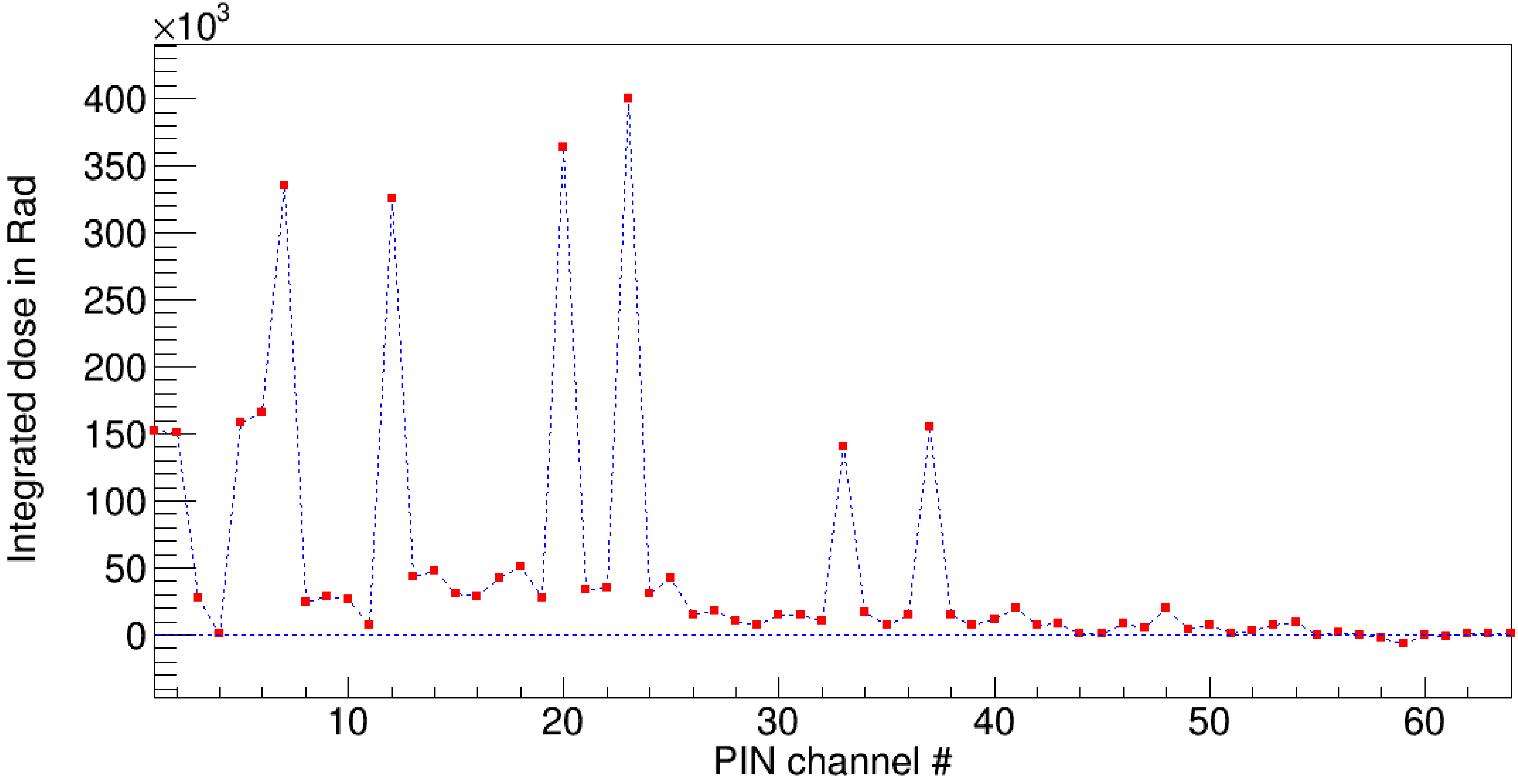


phase1 PIN dose now ready to look to phase1 results


Phase1: Integrated dose vs. time distribution of two diodes in a module
×10^3
Integrated dose (Rad)
with gold
w/o gold
0
50
100
150
200
250
300
350
16/02/29
16/03/30
16/04/29
16/05/29
16/06/28
Time (days)


Phase1: Integrated dose residual vs. time distribution
Integrated dose difference (Rad)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
16/02/29
16/03/30
16/04/29
16/05/29
16/06/28
Time (days)

Data: Phase1 Integrated dose vs PIN channel



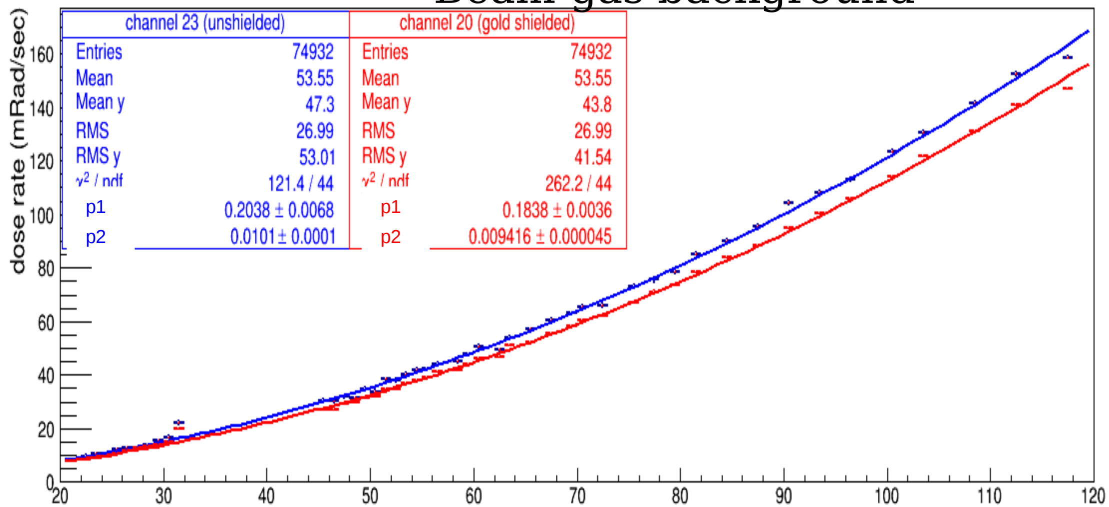
data integrated dose is 3 to 5 times larger than simulation result

Different Beam background results

- **Beam-gas background**:

Produced due to scattering of beam-gas with the residual gas atoms.
All BEAST sub-detectors clearly see beam-gas background. Result from PIN diode detector is shown here.

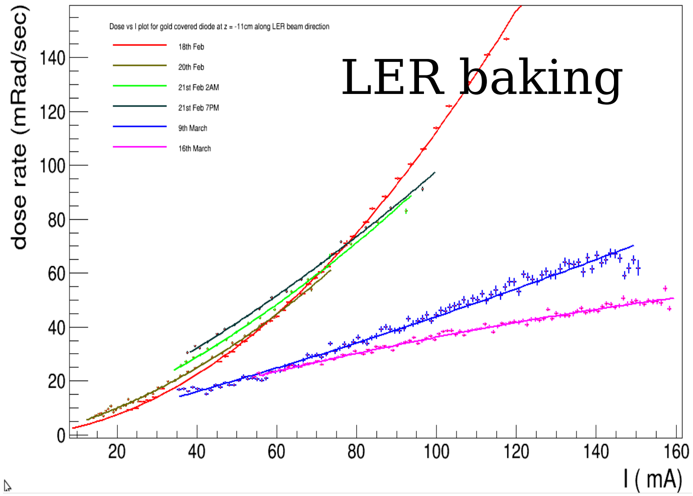
Beam-gas background

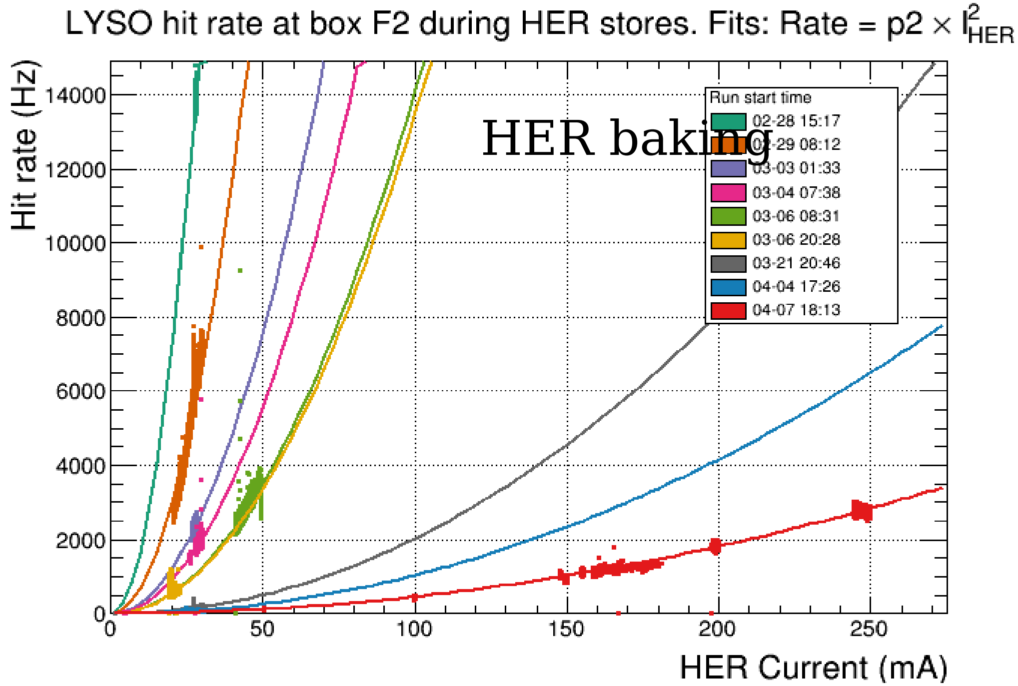


PIN dose vs beam current(I): $P[1] \times I + P[2] \times I^2$

P[1] (shielded) < P[1] (unshielded) is a sign of synchrotron background

- **LER/HER baking**: Beam-gas background produced due to scattering of beam with residual gas decreases with time as the integrated current increases. We call this effect "baking".





Different Beam background results cont...

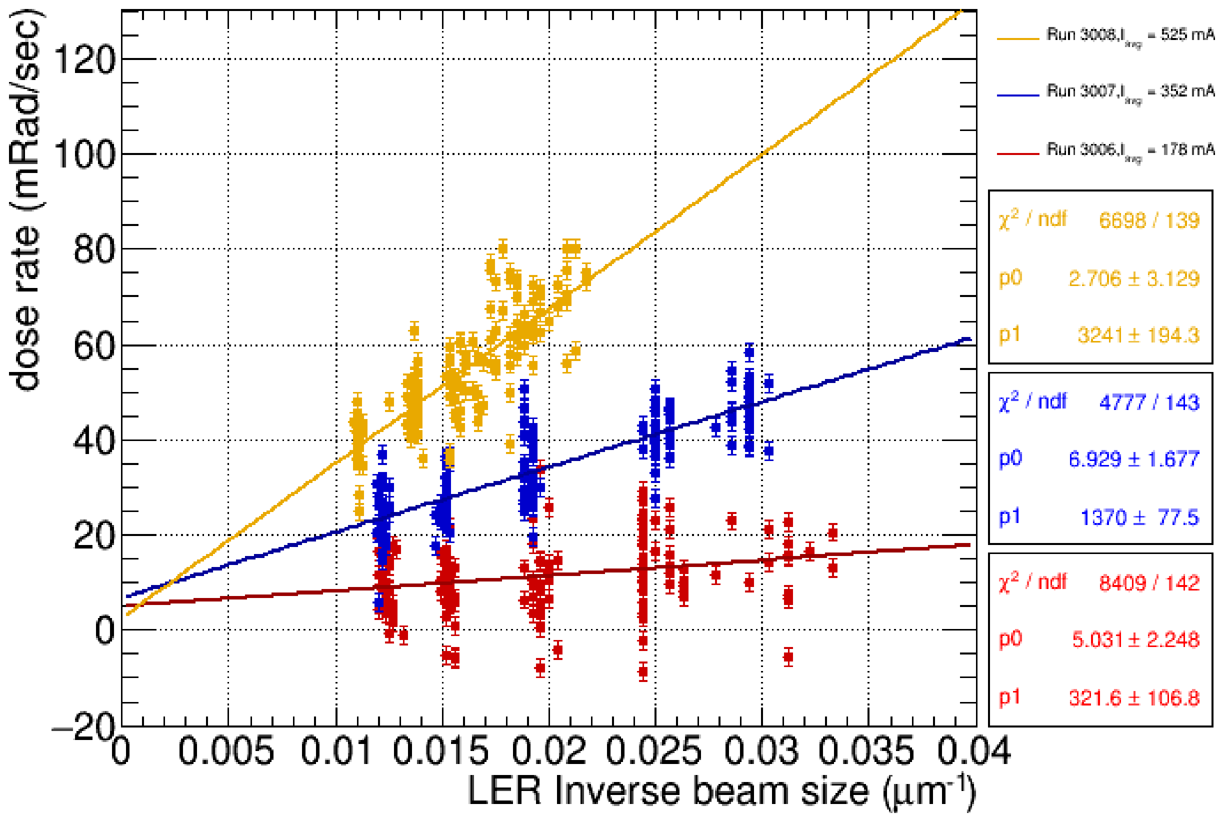
Touschek background:

- proportional to inverse of beam size, third power of the beam energy, number of bunches and second power of the bunch current.
- occurs mainly due to intra e^+/e^- bunch scattering that changes momenta of beam particles. Very large beam background produced as off-energy particles hit inner walls of beam pipe.
- Fake hits due to background shower particles deteriorate the detector's physics resolution and ultimately damage the silicon material used in the detector
- Touschek background estimation in phase1 is very important as SuperKEKB beam size is 20 times smaller than at KEKB.
- Measured background is much less than the estimated because we introduced several counter measures by installing horizontal and vertical movable collimators

LER Touschek Scan

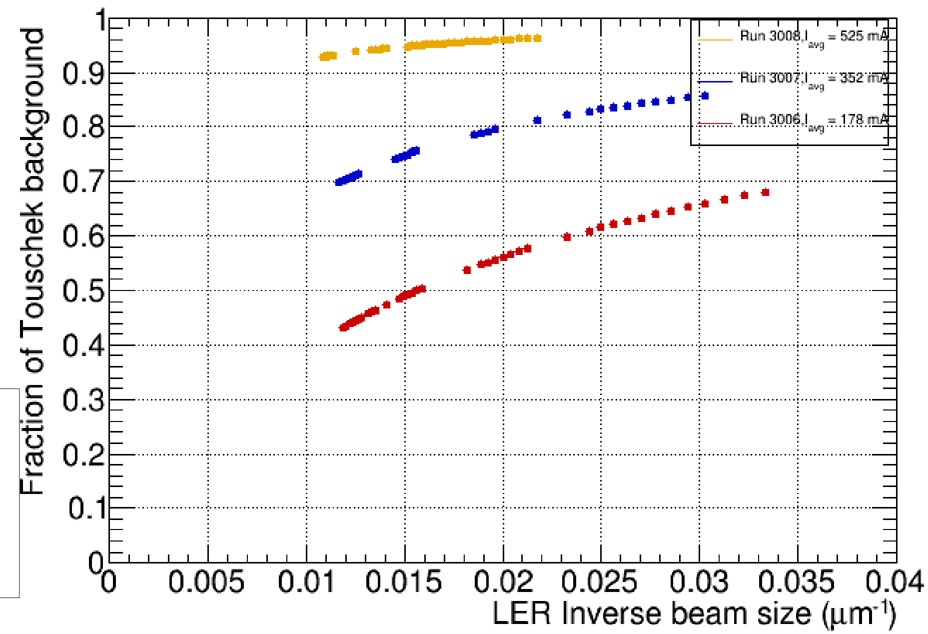
Run: 3006 - 3008

Channel 6, Position: φ =180, z = +15 cm (along LER direction)



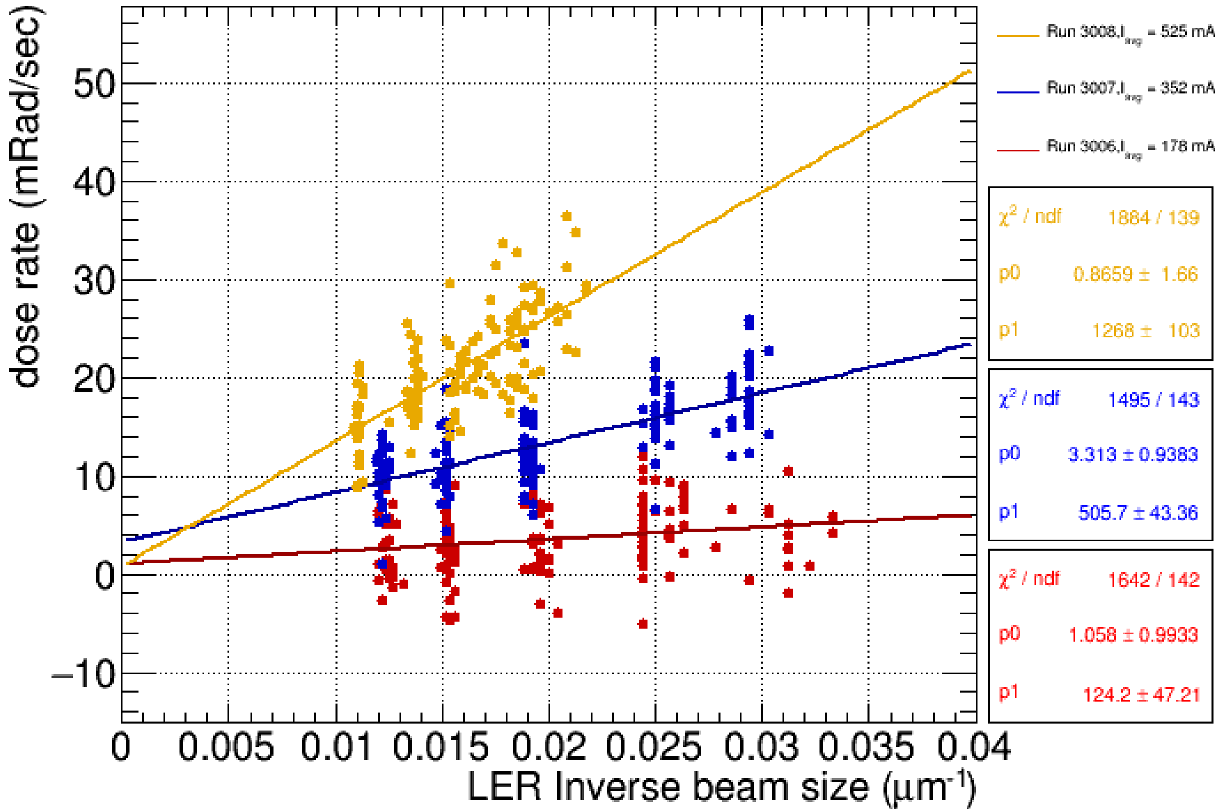
Touschek background fraction vs LER Inverse beam size

Touschek background fraction:
(p1 x beam size^{-1})/(p0 + p1 x beam size^{-1})

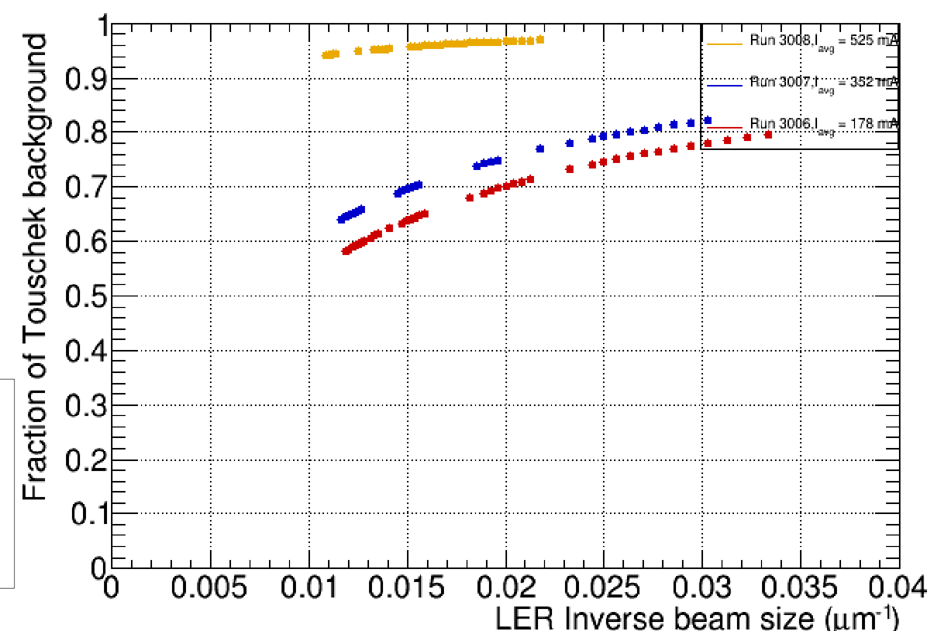


Conclusion (from right plot):
Very clear and very high Touschek background seen by PIN channel 6 at position: z = +15 cm, φ = 180

Channel 0, Position:φ = 180, z = +3 cm (along LER direction)

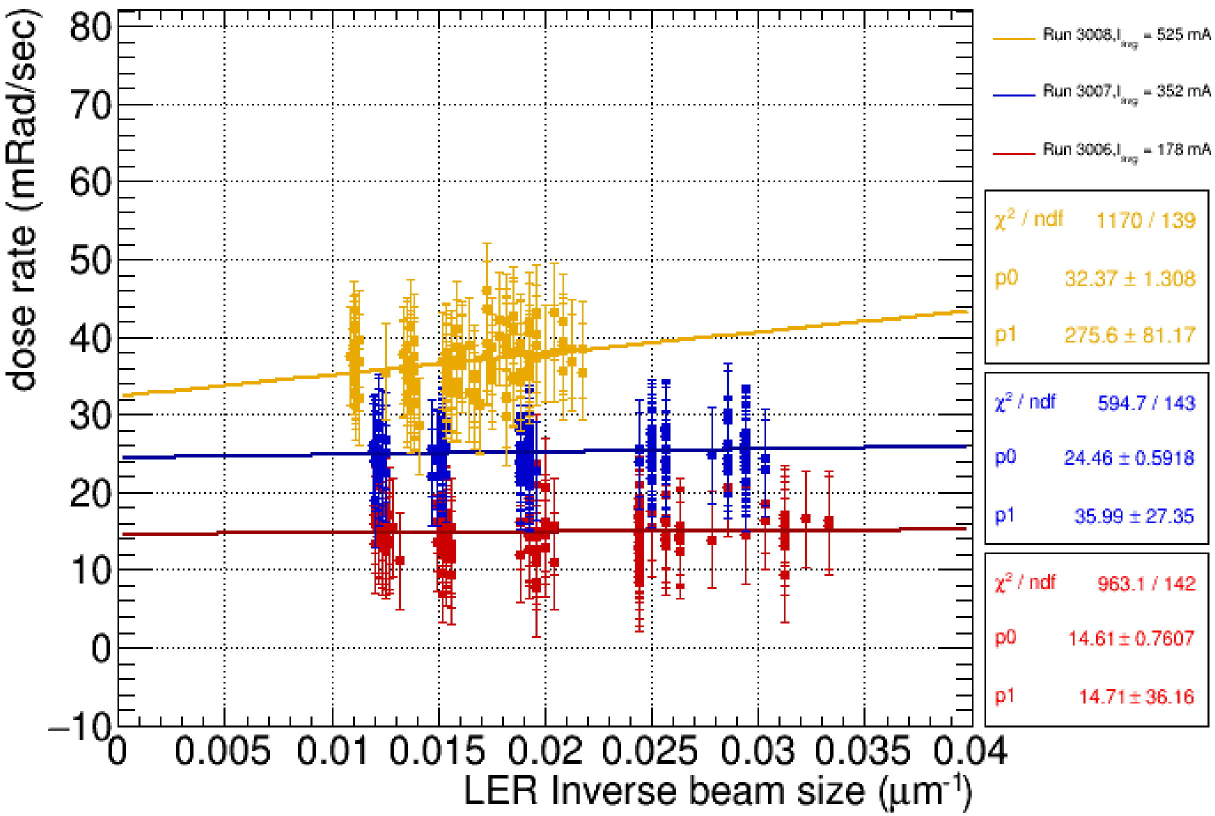


Touschek background fraction vs LER Inverse beam size

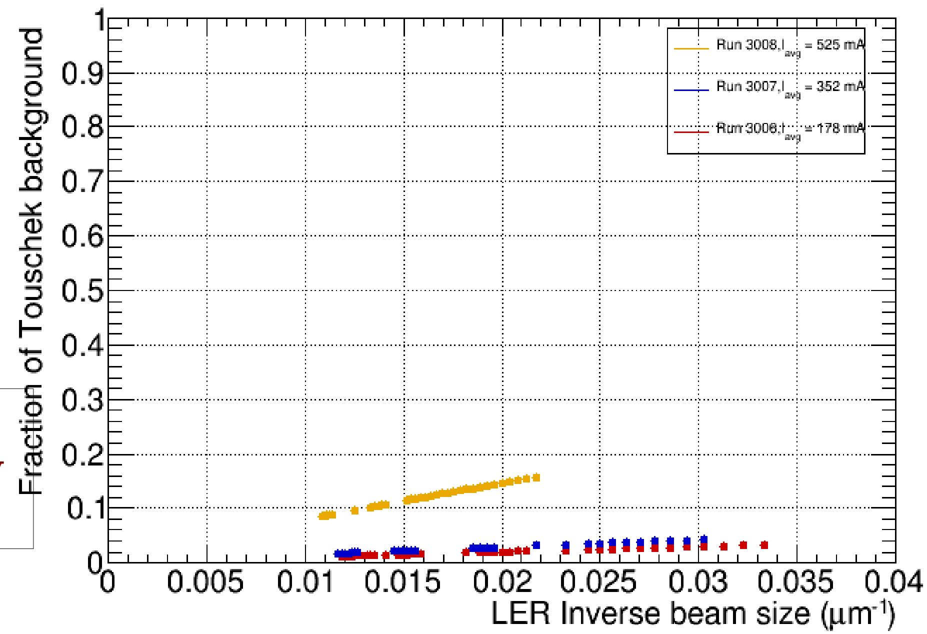


Conclusion (from right plot):
Very clear and very high Touschek background seen by PIN channel 0 at position: z = +3 cm, φ = 180

Channel 19, Position: φ =0, z = -11 cm (along LER direction)



Touschek background fraction vs LER Inverse beam size



Conclusion (from right plot):
Low contribution of Touschek background seen by PIN channel 19 at position: z = -11 cm, φ = 0

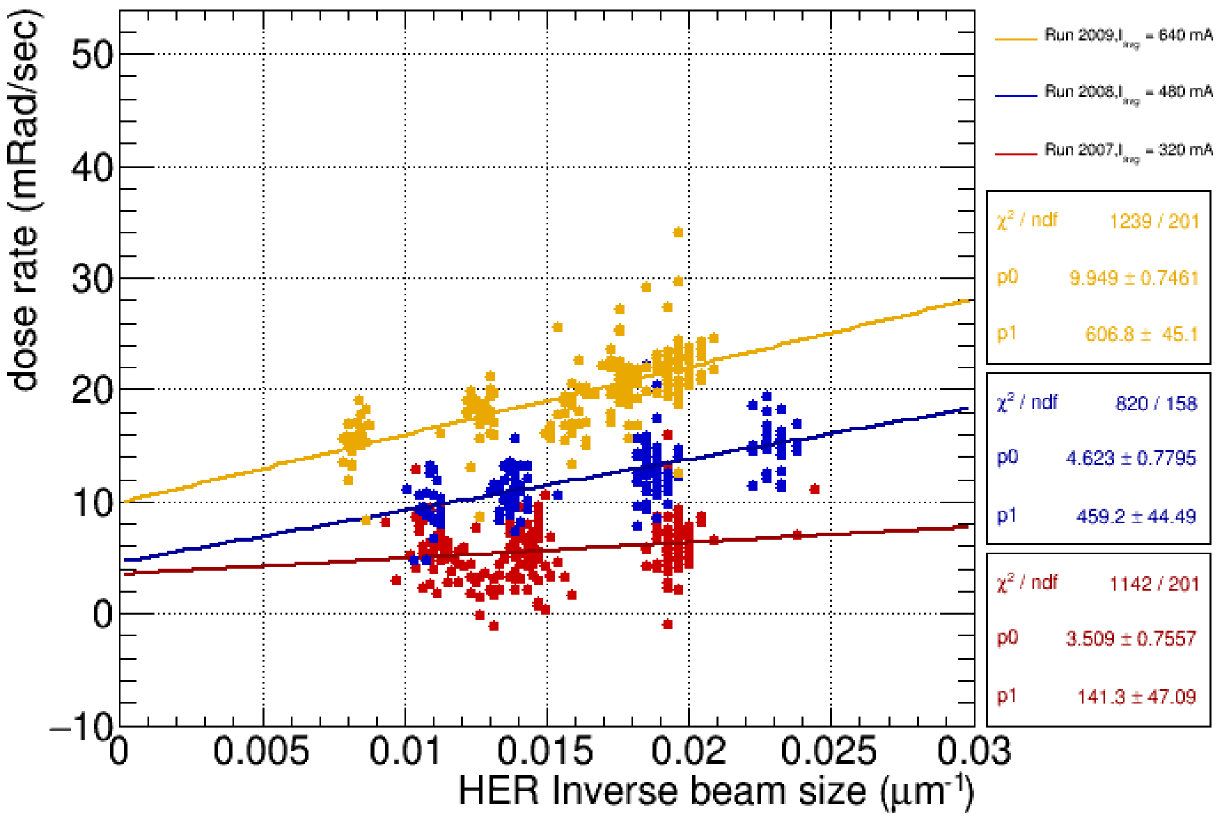
Conclusion:

Diodes along +z LER direction see very high Touschek background contribution

HER Touschek Scan

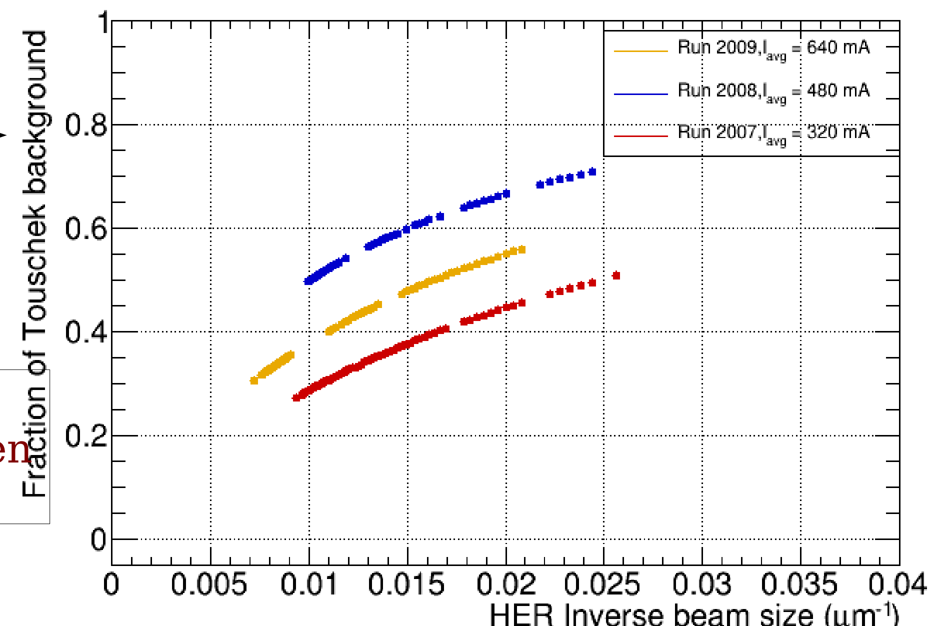
Run: 2007 - 2009

Channel 4, Position: φ =180, z = -11 cm (along HER direction)



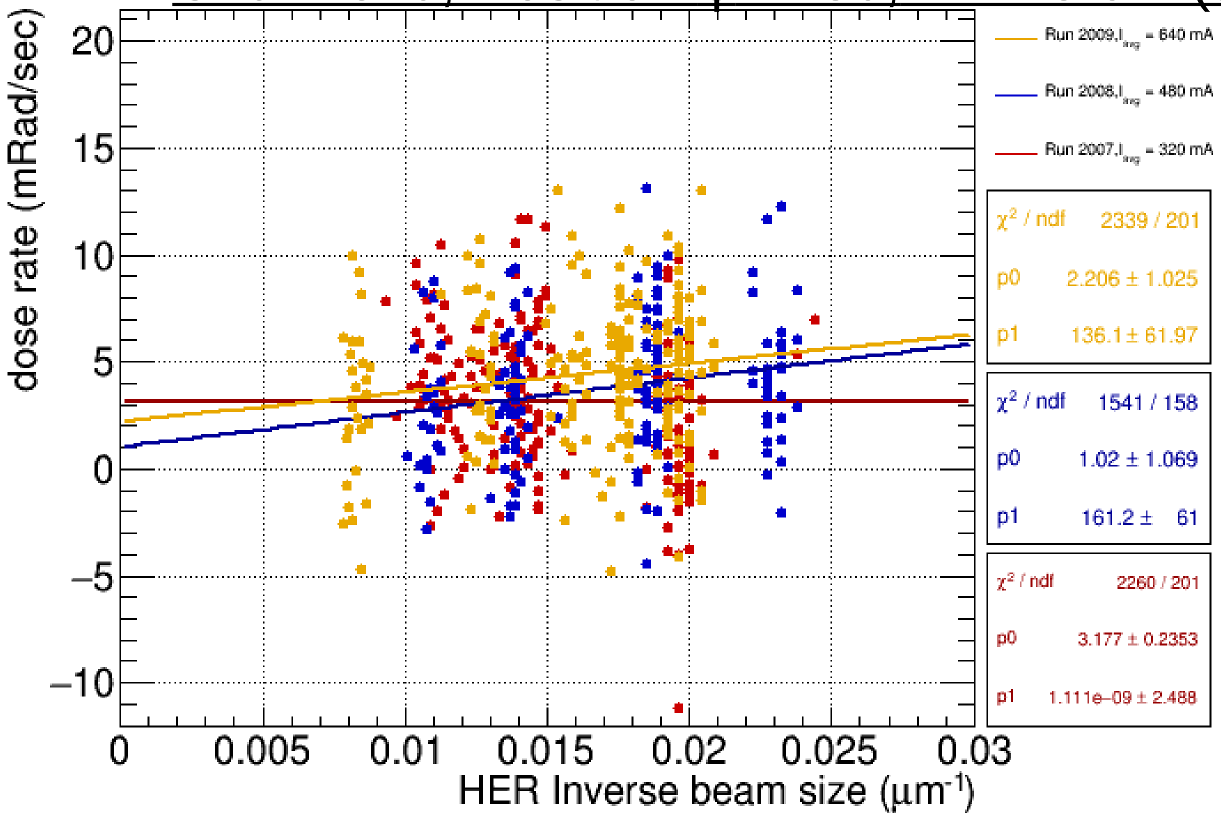
Touschek background fraction vs HER Inverse beam size

Touschek background fraction:
(p1 x beam size^{-1})/(p0 + p1 x beam size^{-1})

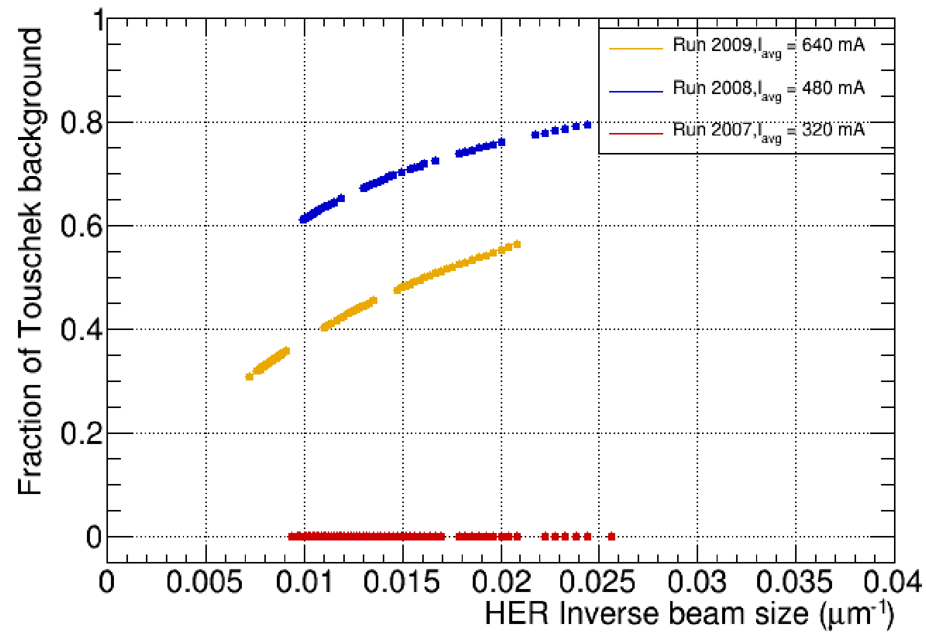


Conclusion (from right plot):
Very clear HER Touschek background contribution seen by PIN channel 4 at position: z = -11 cm, φ = 180

Channel 0, Position: φ =180, z = +3 cm (along HER direction)



Touschek background fraction vs HER Inverse beam size



Conclusion (from right plot):
Clear HER Touschek background contribution seen by PIN channel 0 at position: z = +3 cm, φ = 180

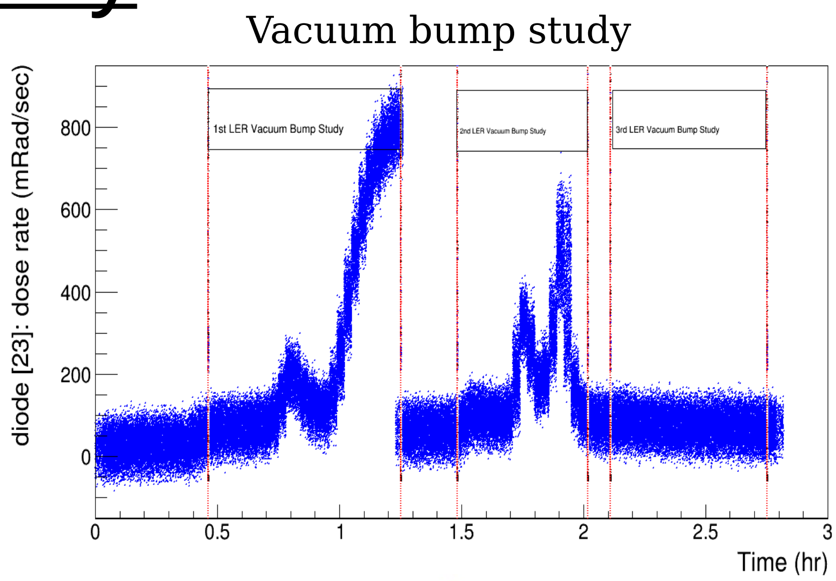
Conclusion:

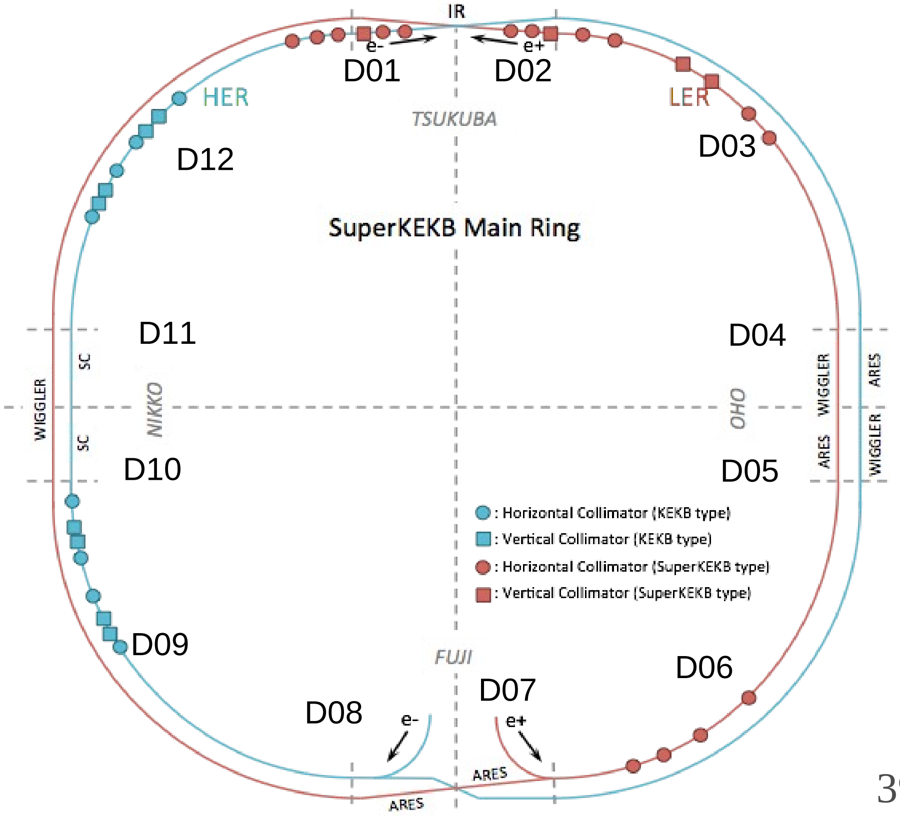
Diodes along -z HER direction see clear Touschek background contribution

Vacuum bump study

pressure bumps introduced at various locations in LER to see radiation at IR. All BEAST sub detectors were successful to see background produced due to pressure bumps. The results for the LER were in agreement with simulation (Large increase from the D1 bump but no change from the distant D4 bump).

Result of one sub-detector is shown here.





LER Vacuum bump study

Run 5001: Vacuum bump at D02_L25,26 (5~12m upstream from IP)
Run 5002: Vacuum bump at D02_L23,24 (12~35m upstream from IP)
Run 5003: Vacuum bump at D02_L20,21,22 (35~70m upstream from IP)
Run 5004: Vacuum bump at D02_L18,19,20 (70~85m upstream from IP)

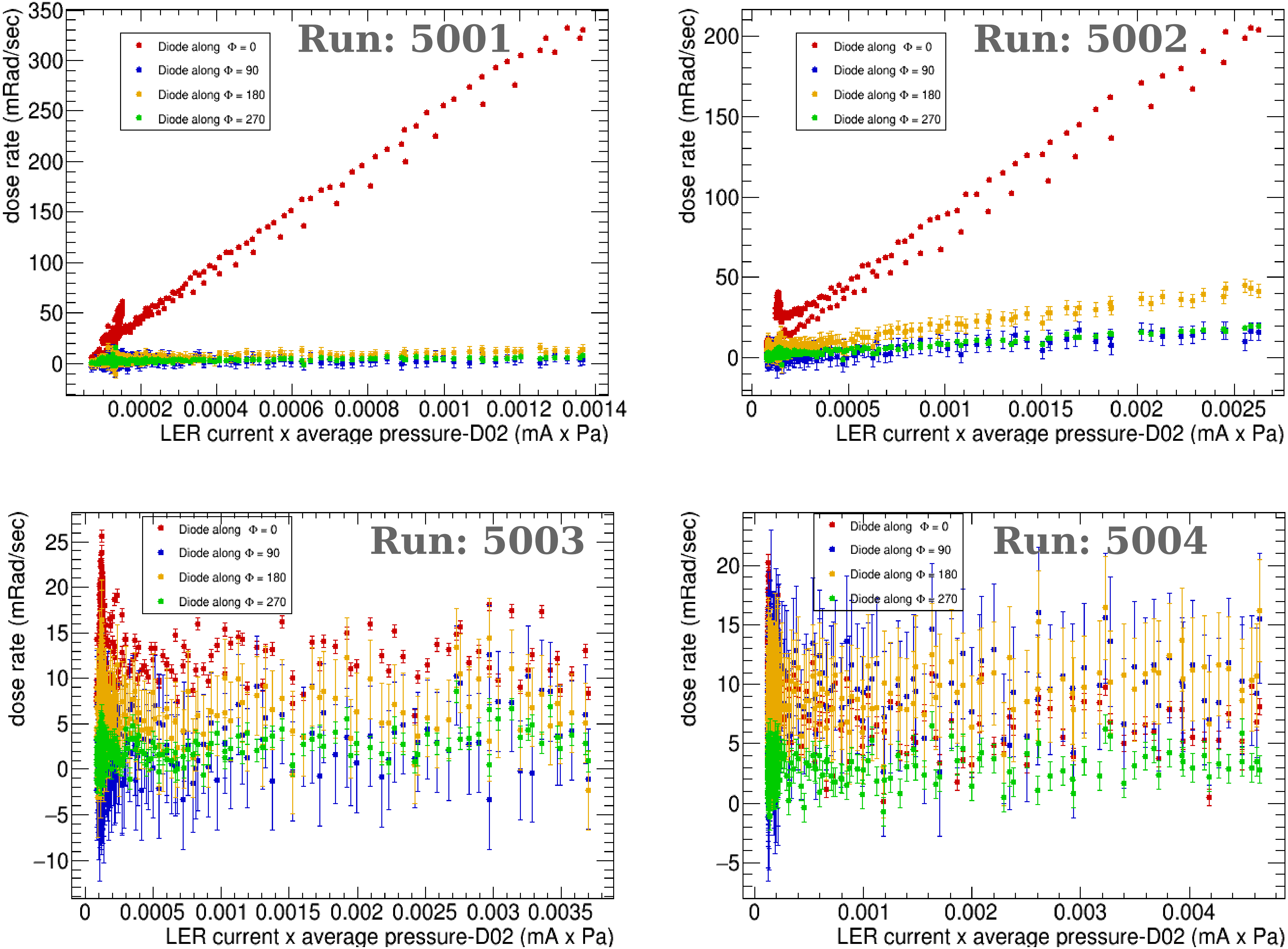
Sensor positions:

(Z = -11cm, φ = 0)

(Z = -11cm, φ = 90)

(Z = -11cm, φ = 180)

(Z = -11cm, φ = 270)


Run: 5001
Run: 5002
Run: 5003
Run: 5004
Diode along Φ = 0
Diode along Φ = 90
Diode along Φ = 180
Diode along Φ = 270
dose rate (mRad/sec)
LER current x average pressure-D02 (mA x Pa)

- Run 5001, 5002 have large impact on PIN diode
- Run 5003, 5004 have almost no impact
- Pressure bumps around D04, D05, D07, D10, D11 have very little or no impact to PIN diode
- Some φ dependence due to pressure bump at D02 L23-24

HER Vacuum bump study

HER vacuum bumps introduced at locations : D12 (Run 6001), D09 (Run 6002), D06 (Run 6003), D05 (Run 6004)

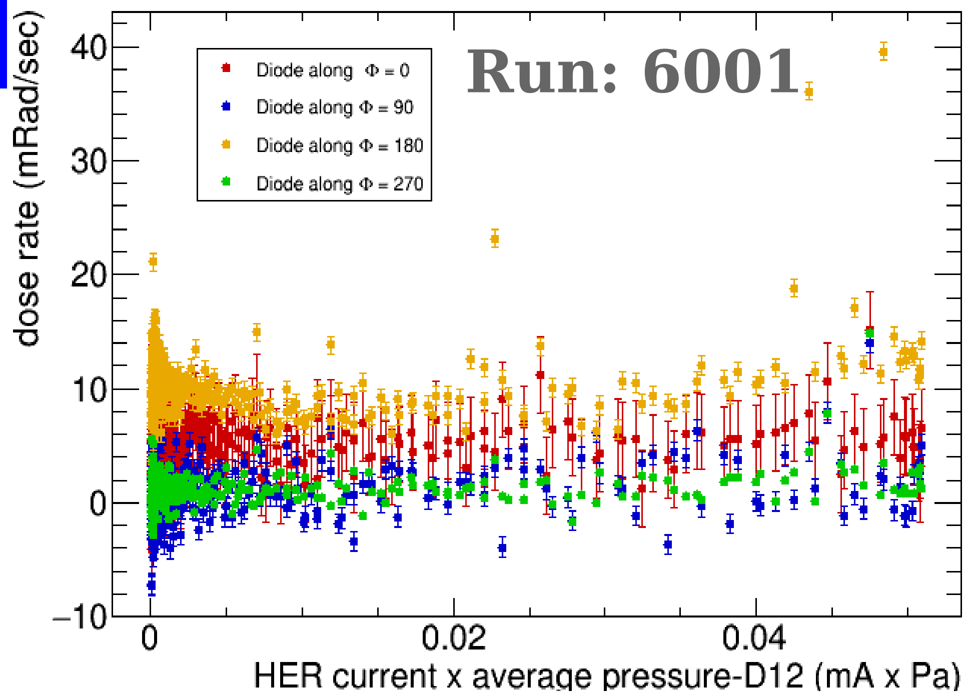
sensor positions:

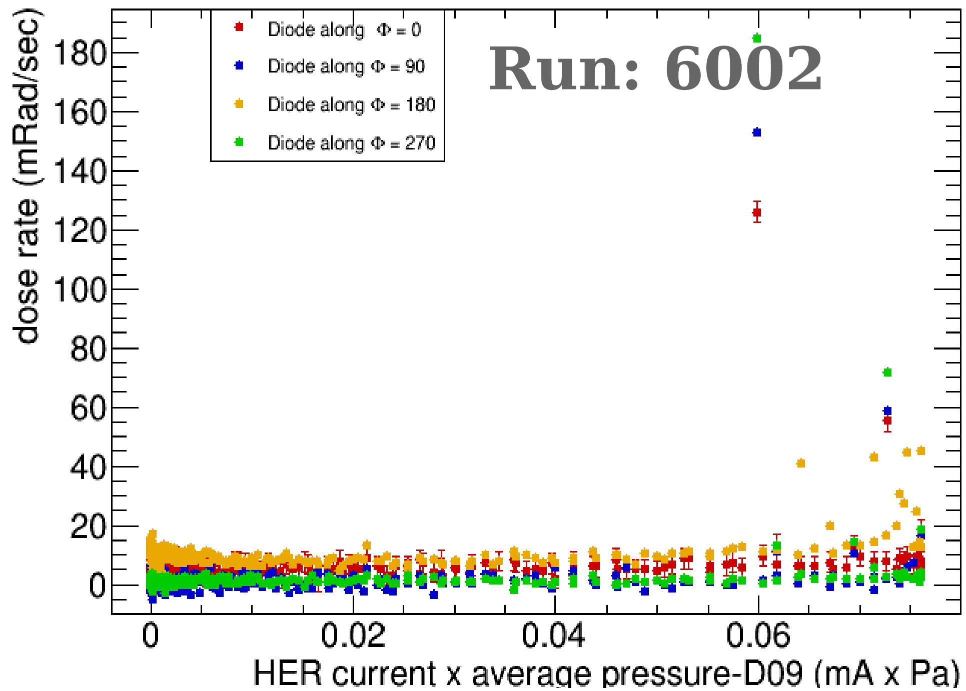
(Z = -11cm, φ = 0)

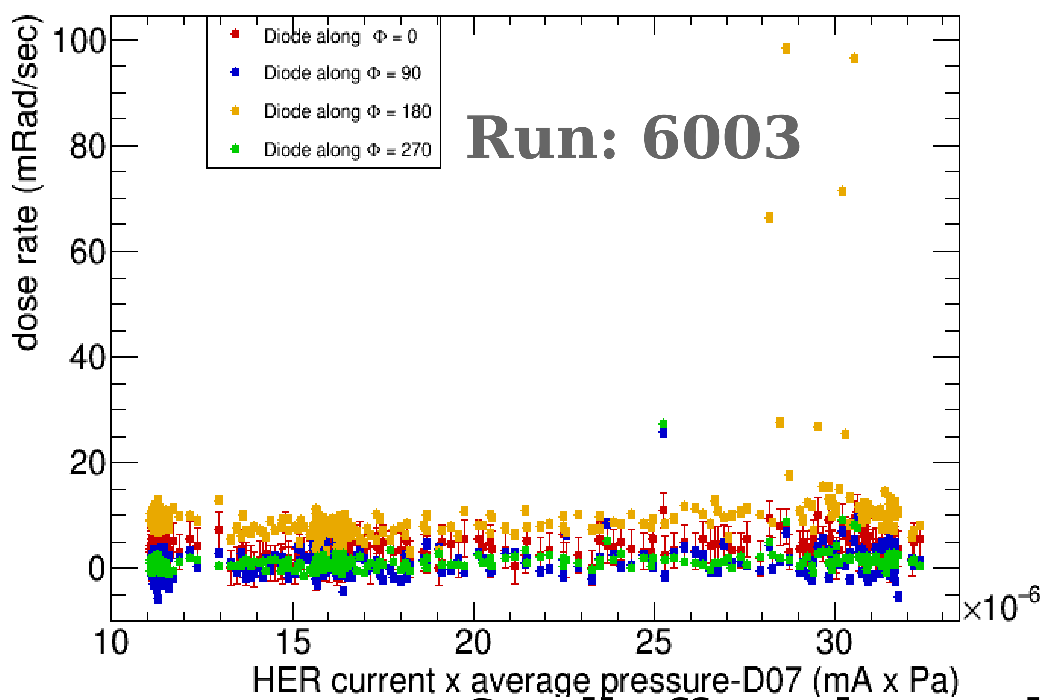
(Z = -11cm, φ = 90)

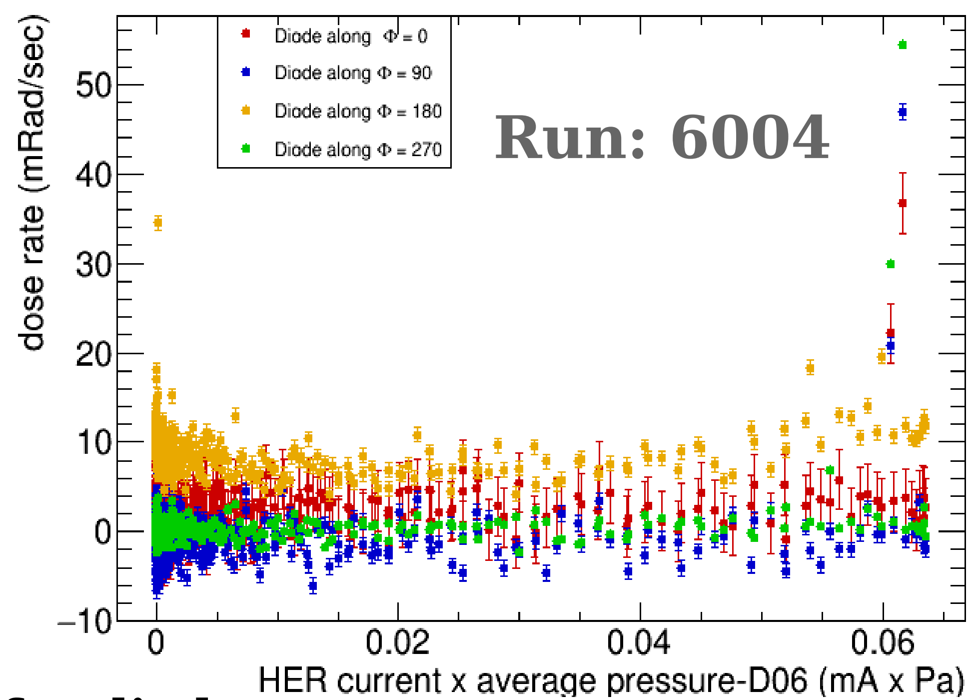
(Z = -11cm, φ = 180)

(Z = -11cm, φ = 270)



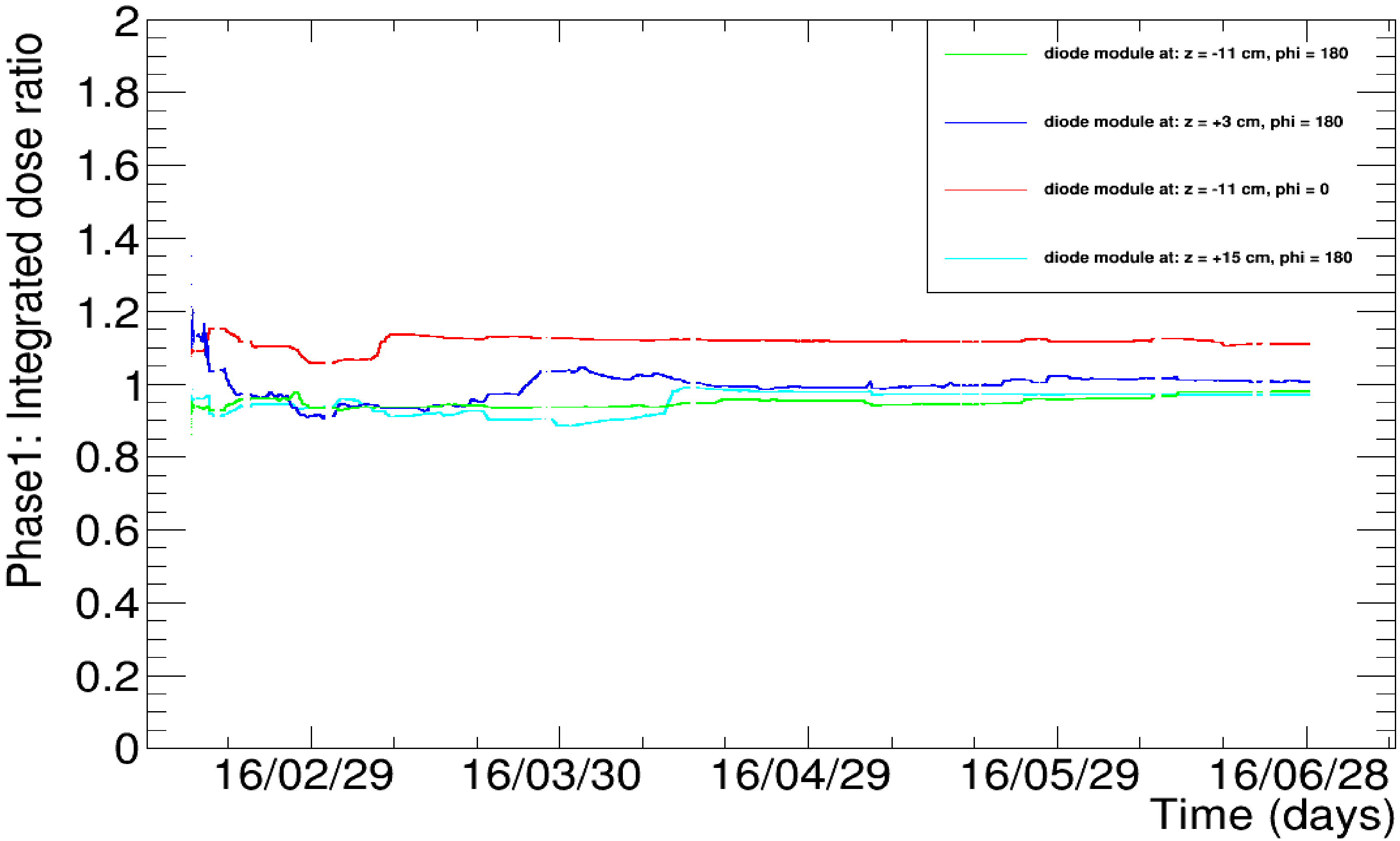






Small effect observed for diode at φ = 180

Synchrotron background search: Integrated dose ratio of diode w/o gold to diode w/ gold



Result consistent with one. Small deviation from one is due to position difference of diodes in a single module.

No hints of synchrotron background

Summary:

- Successful BEAST phase1 background study.
- LER Touschek background higher than HER.
- LER vacuum bump study: Run 5001, 5002 has large impact on PIN diode
- Phi dependence observed for Run 5002
- HER vacuum bump study: small effect observed for diode along HER
- No significant contribution to dose from Synchrotron Radiation.
- Hundreds kilorads of integrated background seen in phase1.
- BEAST II has seen clear charged particles, x-rays, thermal neutrons, and fast neutrons from beam-gas.
- Background study using various particles has been performed.
- Dependng uopn position, Results from all detectors agree to each other
- Background under control. we are safe to role-in BelleII.
- BEAST note and paper is getting finilazied. Aiming for publication in February

Thank you!