SuperKEKB, BEAST, and Belle II

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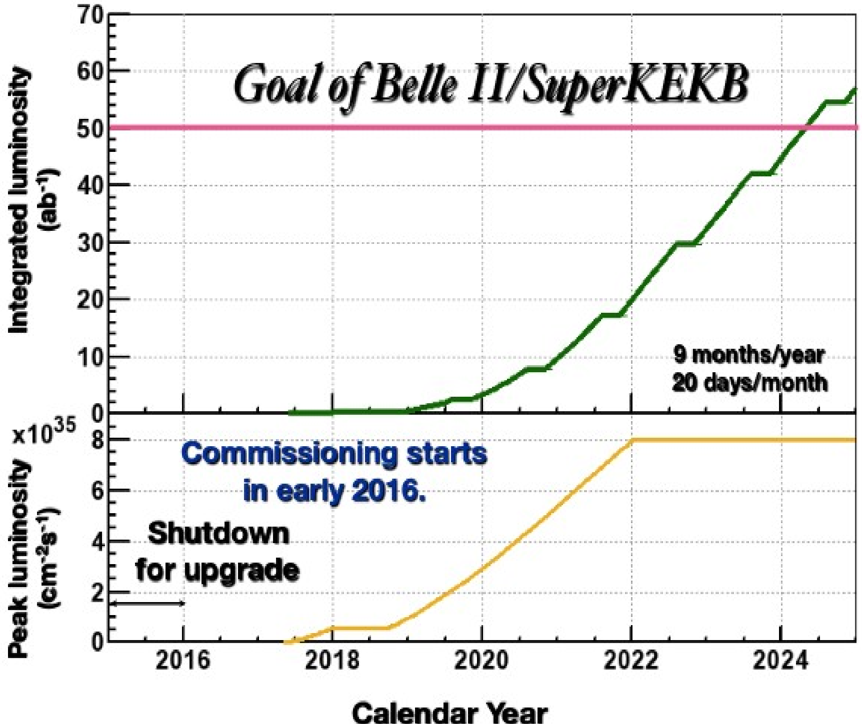
On behalf of the Belle II collaboration

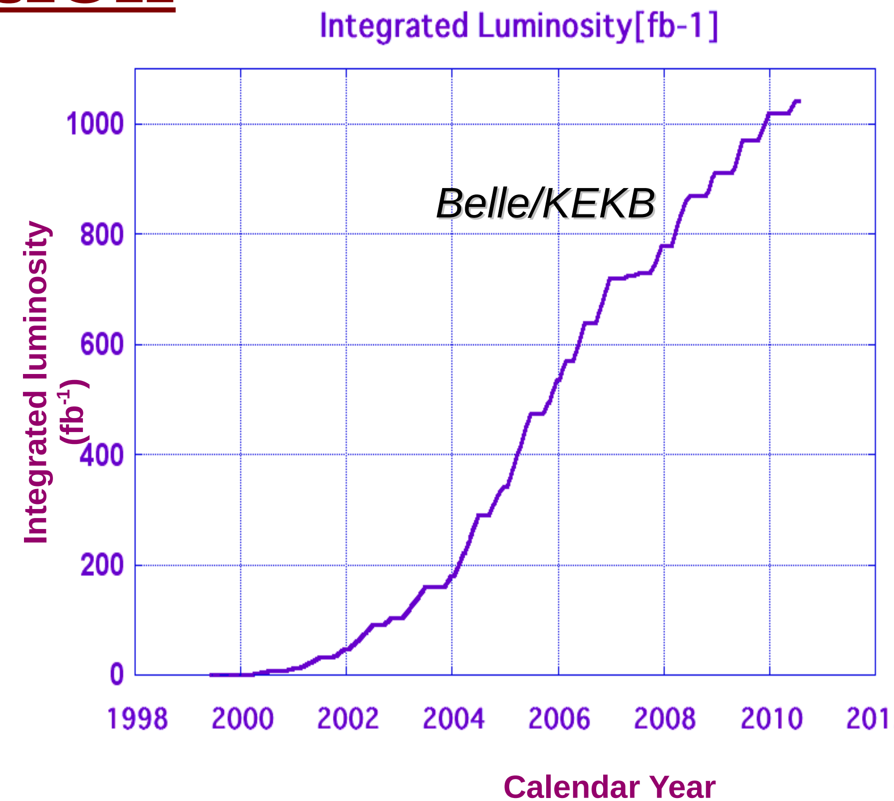
BEAUTY 2016, Marseille, France
May 2016

Talk outline

- Motivation
- SuperKEKB (description, operation)
- Commissioning (BEAST II)
- Belle II (VXD, CDC, TOP, ECL,ARICH, KLM)
- Conclusion

Motivation





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

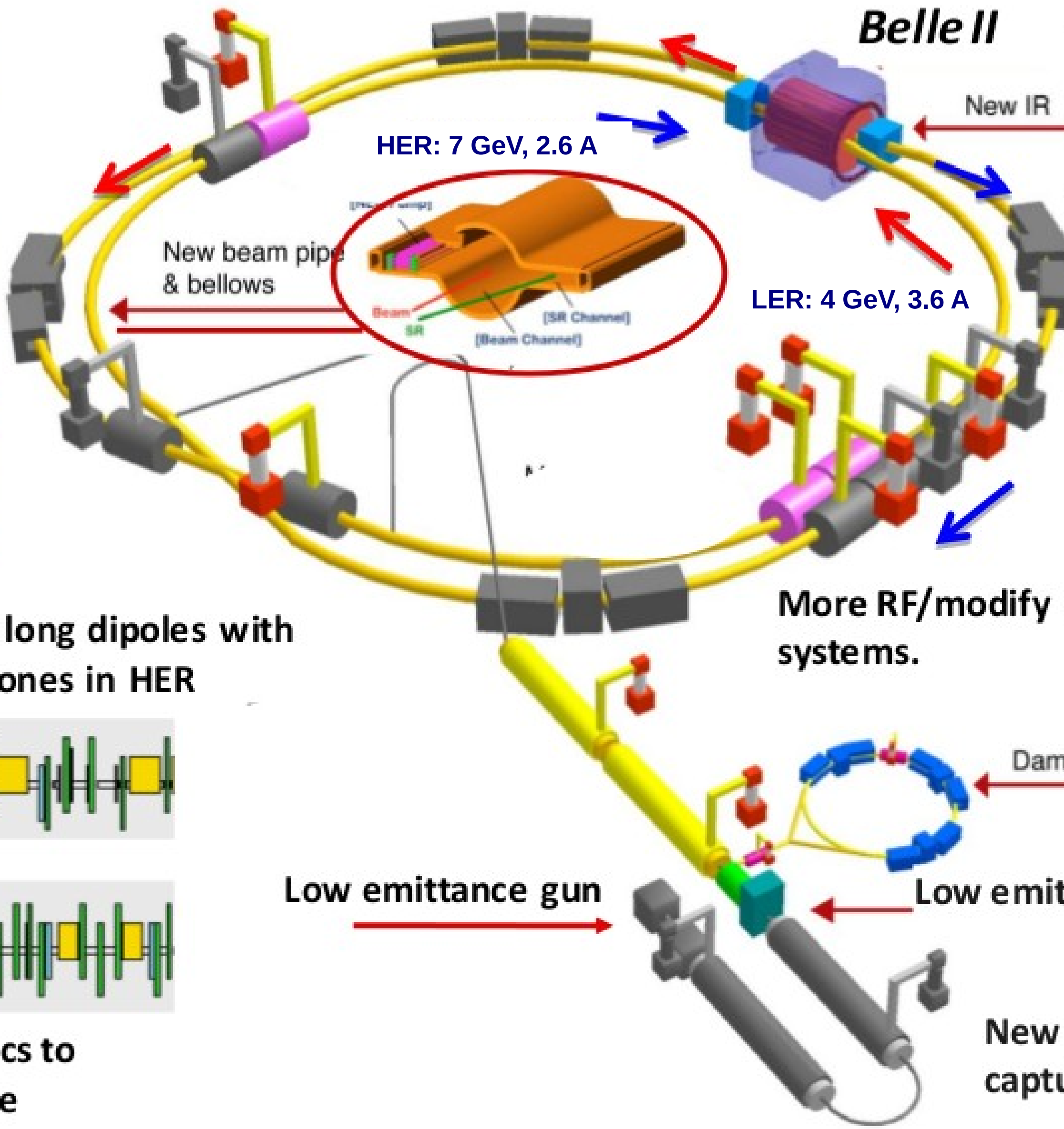
L_{peak} = 8 x 10^{35}cm^{-2}s^{-1} (40 x KEKB)

New physics opportunities:

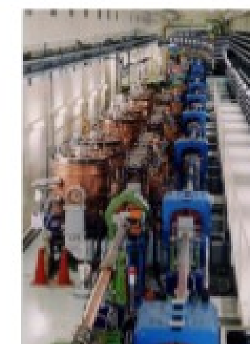
- Precise measurement of UT parameters
- Search for charged Higgs
- New sources of CP violation
- Lepton Flavour Violation in B and τ decays
- New physics search in missing energy modes of B decays
- Search for Dark matter, etc..

More detail:
May 4, 12:10 – 12:30
(by Jing-Ge Shiu)

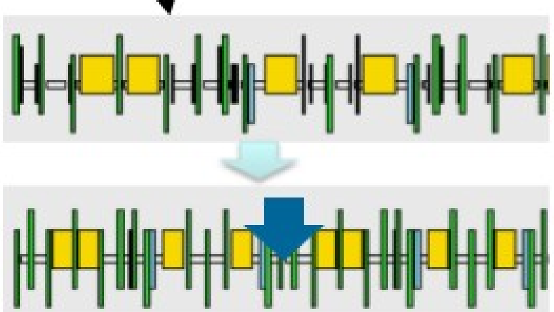
KEKB upgrade → SuperKEKB(nano-beam)



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



Replace long dipoles with shorter ones in HER



Redesign the HER arcs to reduce the emittance

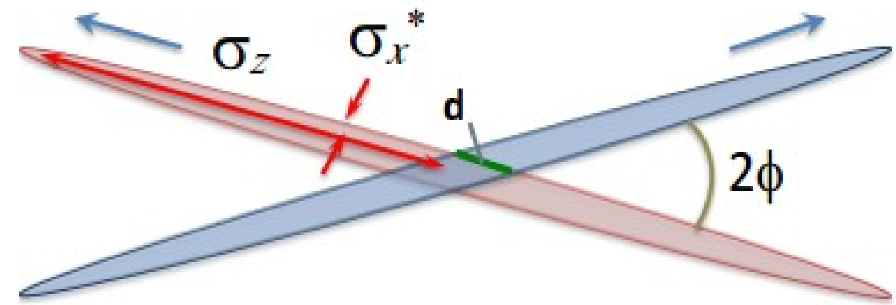
New positron target / capture section

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

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

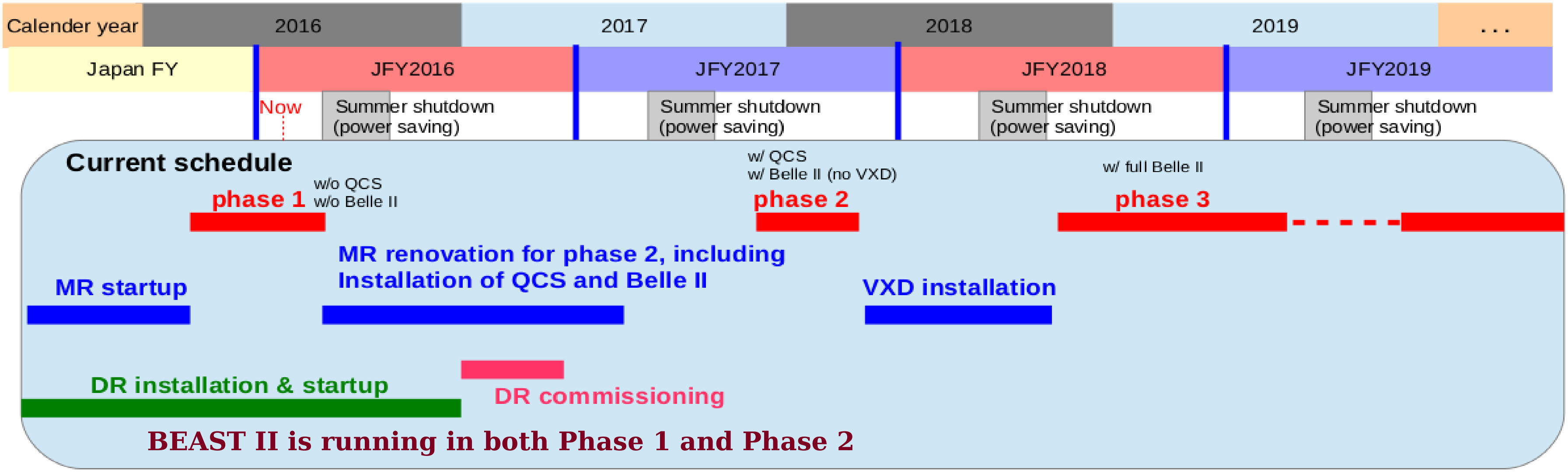
Beam current

Beam-Beam parameter

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!

Current status:

- Vacuum scrubbing
- Optics study
- BEAST dedicated machine study in mid May
- Other study and tuning
- 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 Experimen**T 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 – 30thJune

Sources of background:

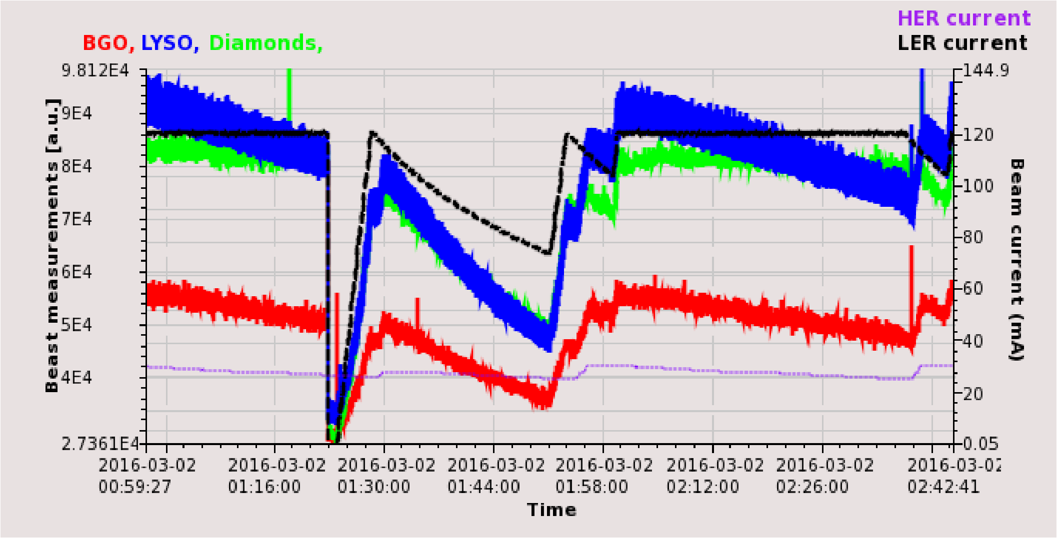
- Touschek scattering
- Beam gas scattering
- Synchrotron radiation
- Radiative Bhabha event
- 2 – photon process event

Fake hits, pile-up etc.

BEAST II cage at IR

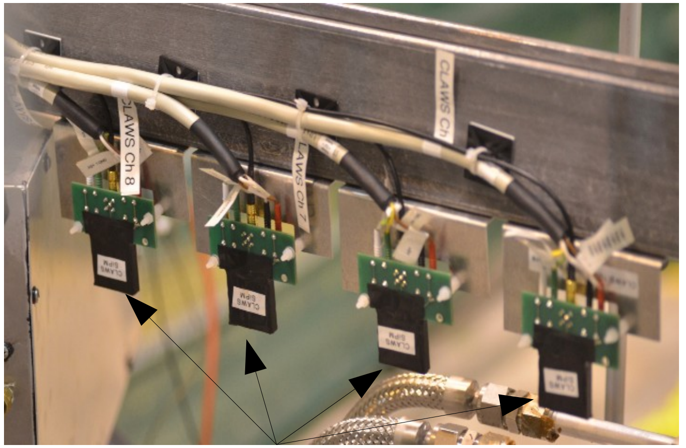
BEAST II Online monitor display

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.
- Current status: LER:0.6 A, HER: 0.5 A
- Phase1 Goal: 1 Amp (LER/HER)

First signal from SuperKEKB

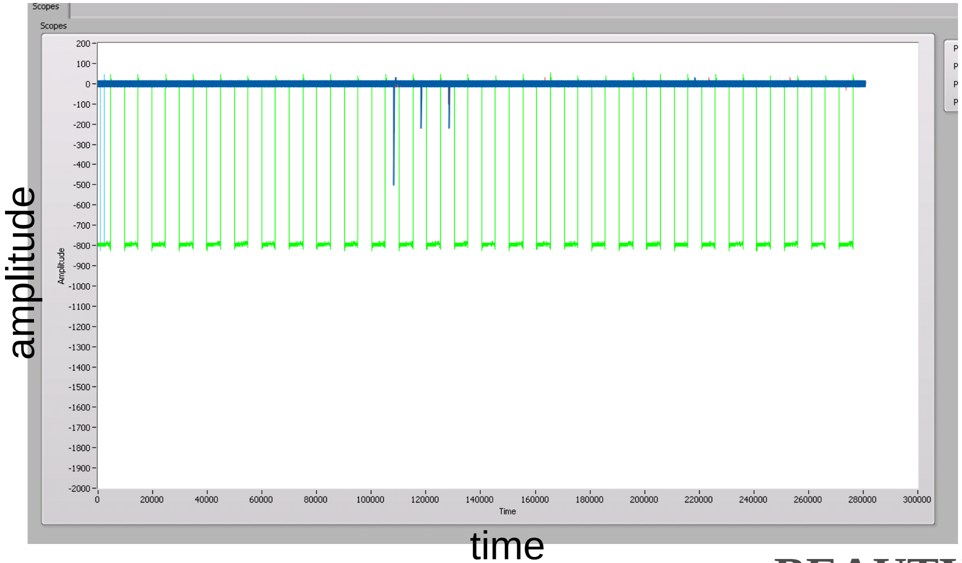


CLAWS around IR

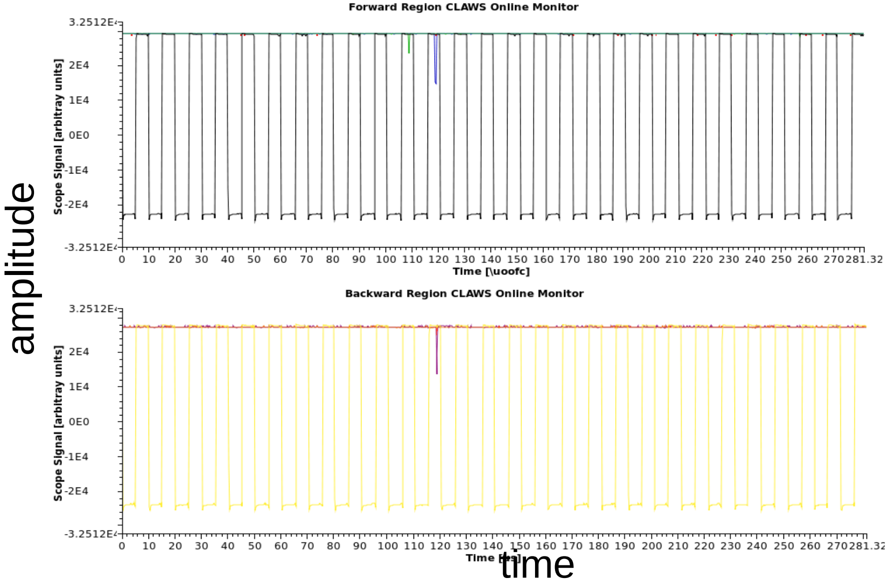
CLAWS (sCintillation Light And Waveform Sensors)

- CLAWS saw 1st SuperKEKB injection signal on 8th Feb.
- Measure the time evolution of the injection background at the IR
- 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



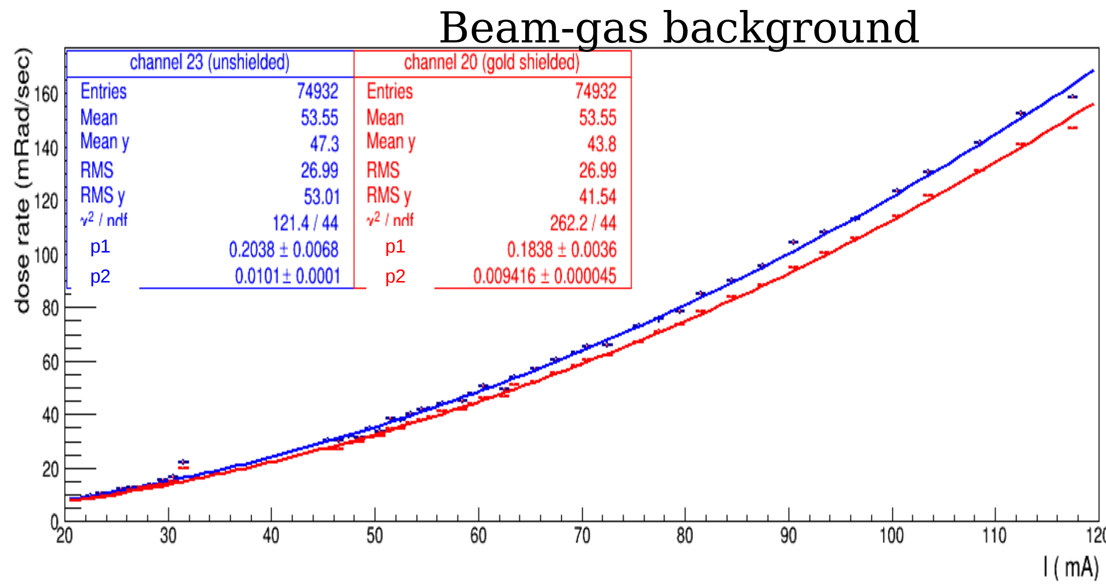
HER first turns



Beam background results from BEAST II

- **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 one sub detector is shown here.

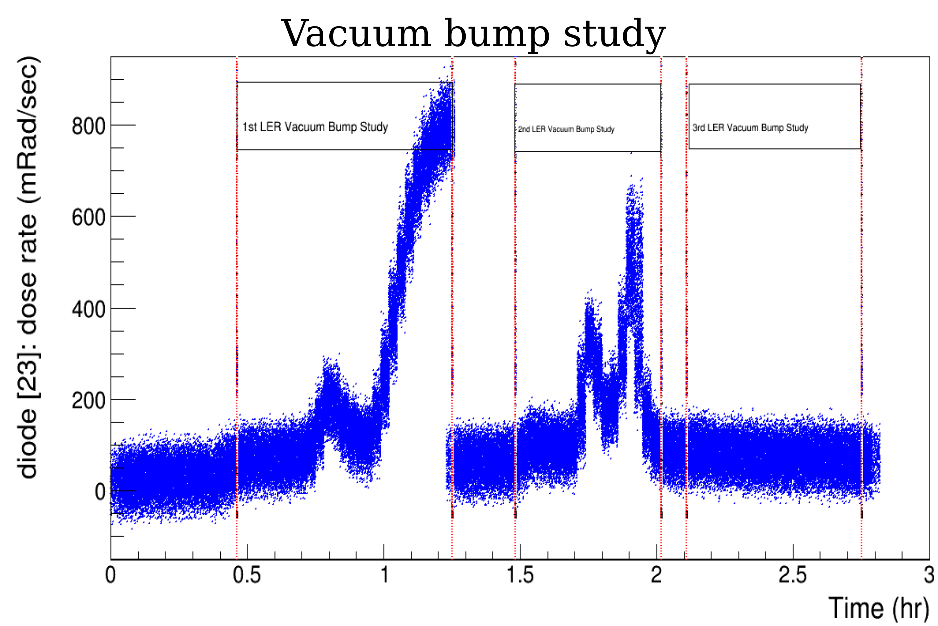


PIN dose vs beam current(I): $P[1] \times I + P[2] \times I^2$

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

- **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.

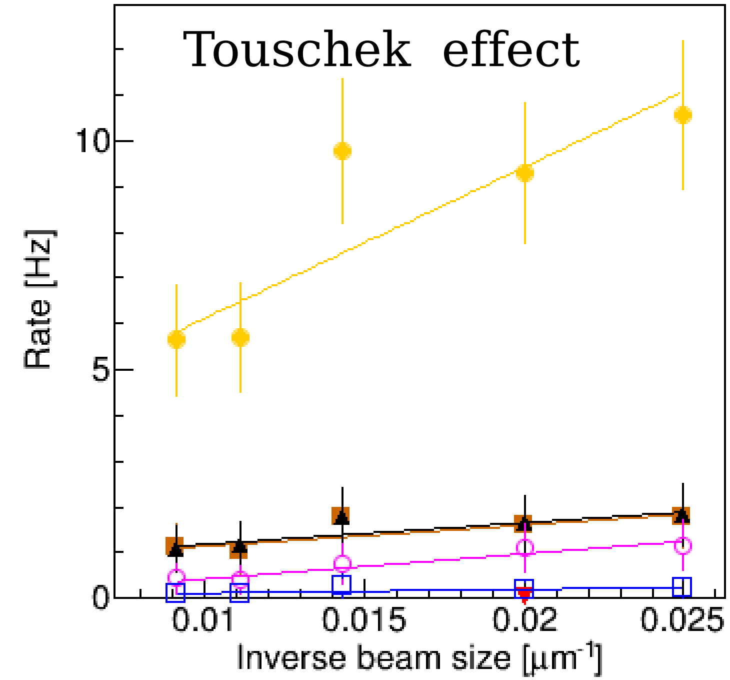


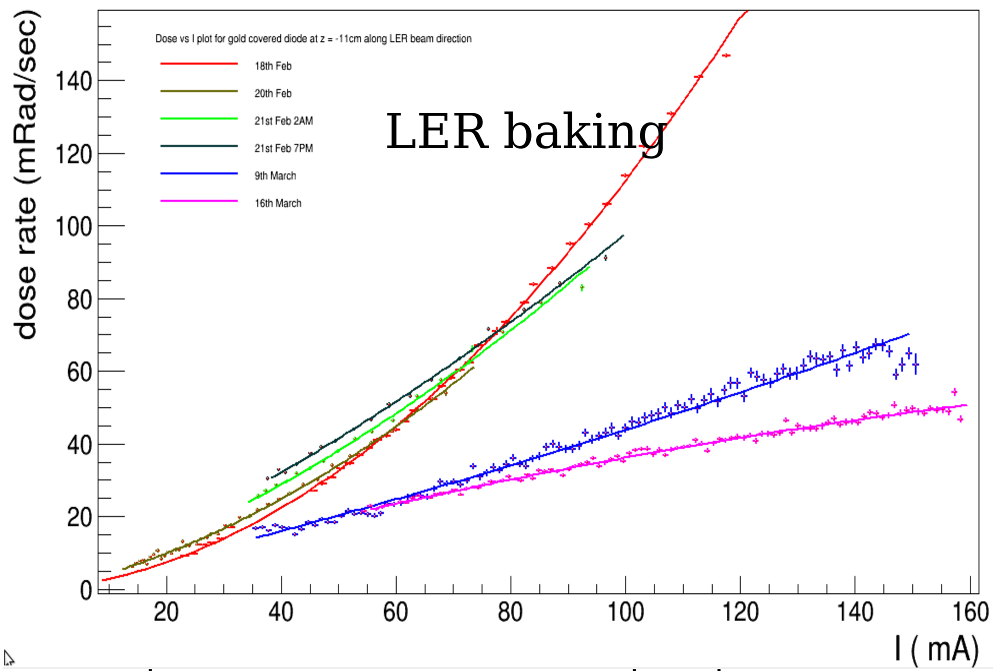
Some more beam background results from BEAST II

- **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".

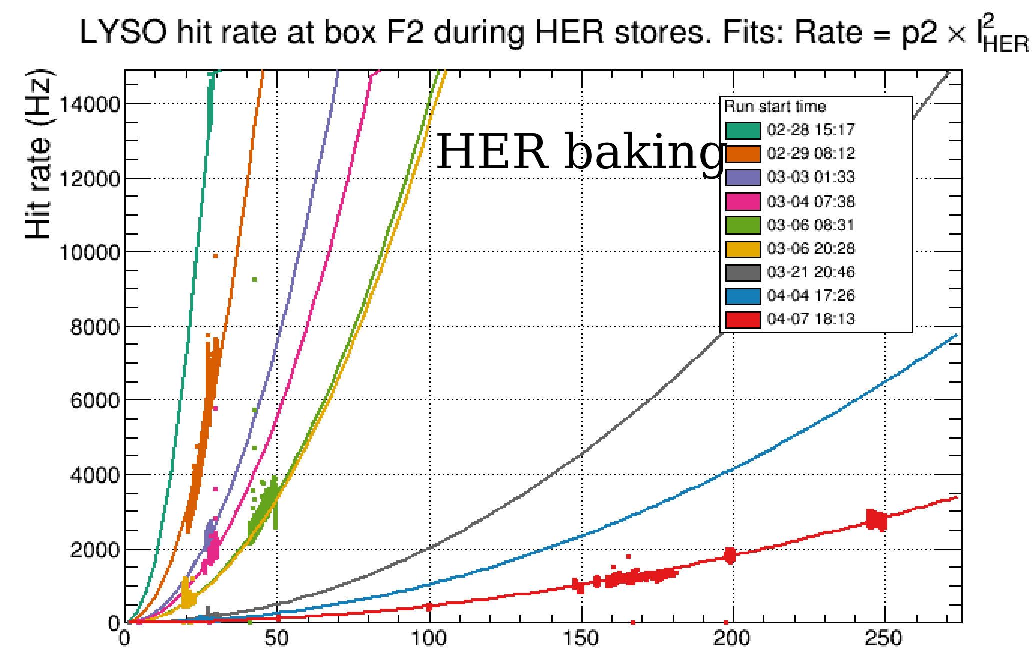
- **Touschek background**: proportional to inverse of beam size. occurs mainly due to intra e^+/e^- bunch scattering that changes momenta of beam particles. Very large beam background produced as off-energy particles hit inner walls of beam pipe.

- Touschek background estimation in phase1 is very important as SuperKEKB beam size is 20 times smaller than at KEKB



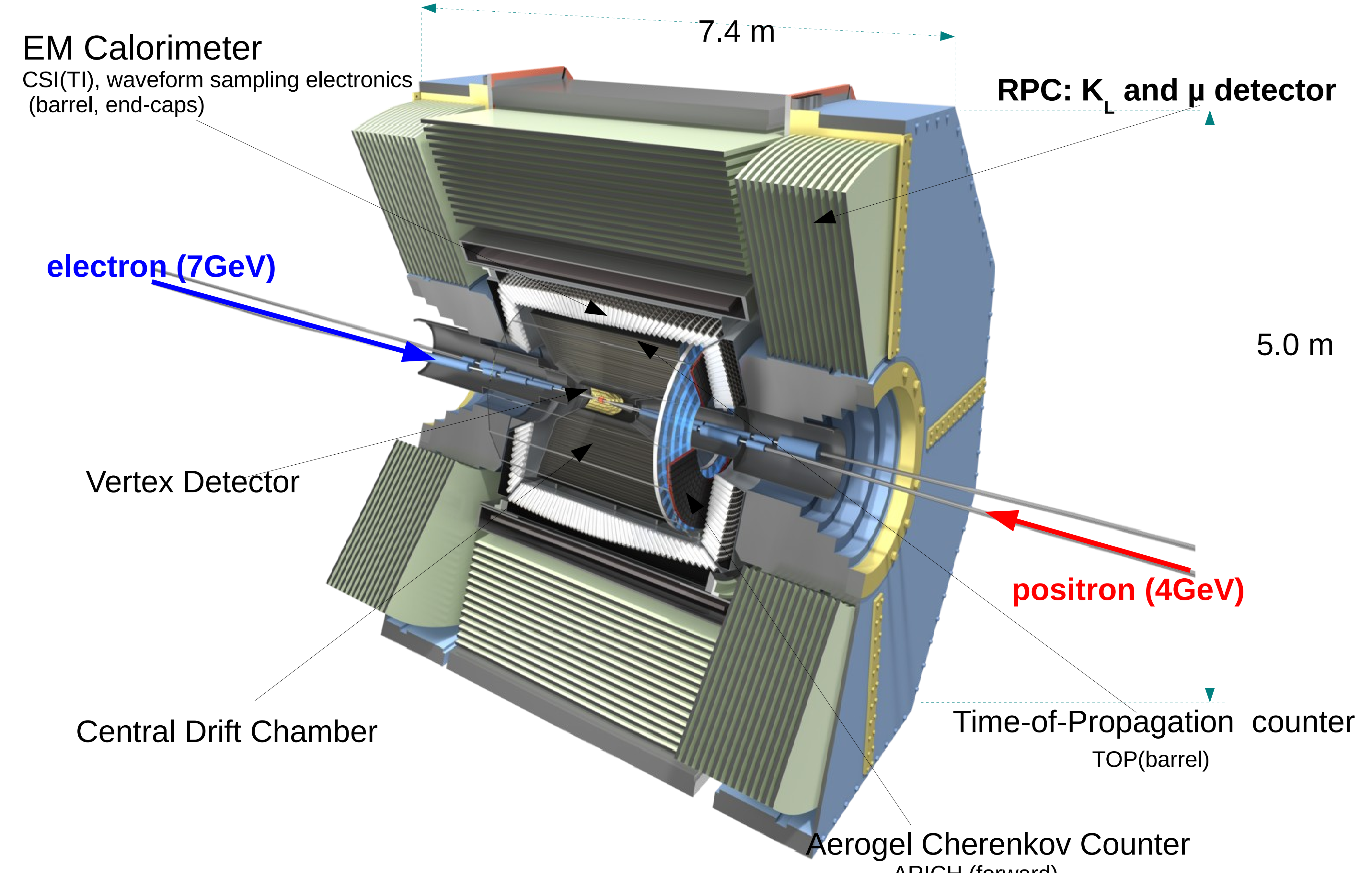


dose rate vs current seen on various days



Hit rate vs current seen on various days

Belle II Detector



Important improvements in Detector performance from Belle → BelleII

- Smaller beam pipe radius allows innermost PXD layer to sit closer to Interaction point (r = 1.4cm)
  Significantly improve the IP resolution along z direction

- Large tracker SVD and CDC:
  To increase Ks efficiency, improve IP and excellent timing resolution, better flavor tagging

- TOP and ARICH:
  Better K/pi separation covering whole range momentum along Barrel and Endcap region

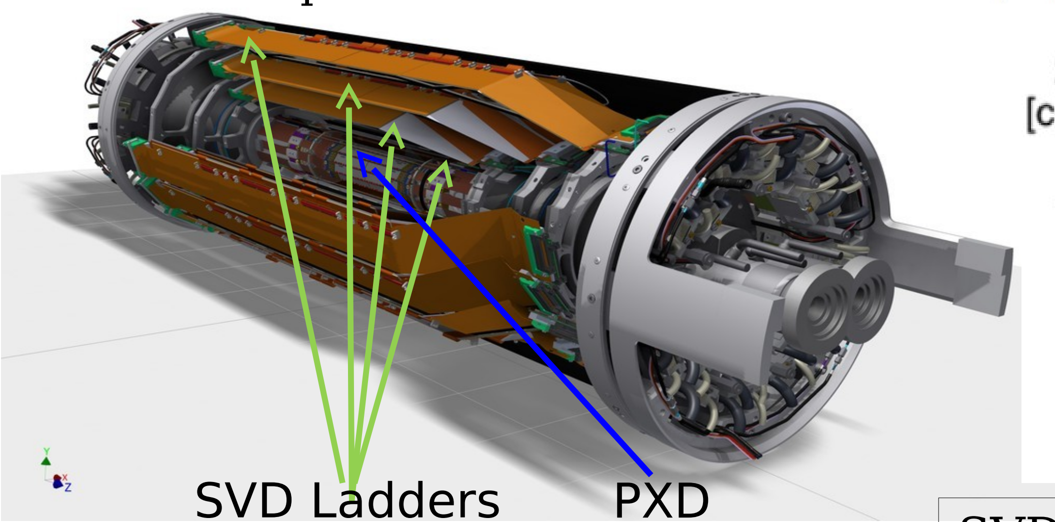
- ECL and KLM:
  Improvement in ECL and KLM to compensate larger beam background

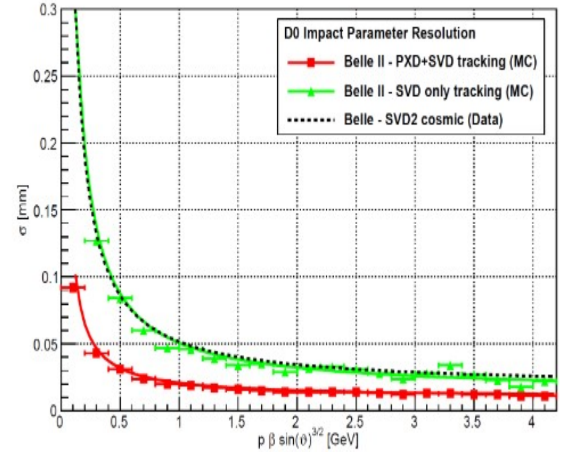
- Improve Hermeticity

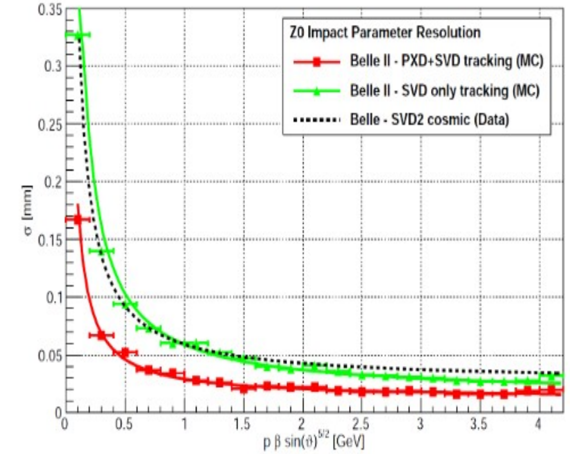
- Improved trigger and DAQ

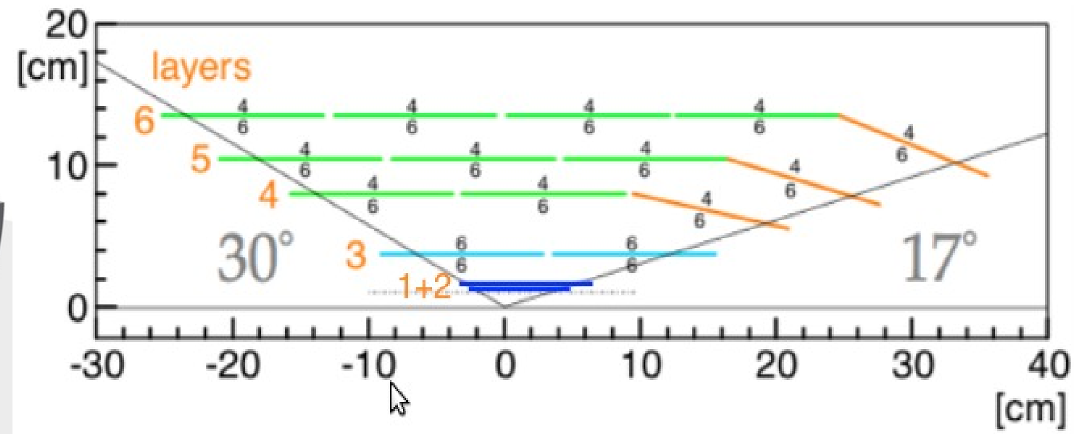
Belle II: Vertex detector (VXD)

- VXD = silicon vertex detector (SVD) + pixel detector (PXD)
- Provides precise measurement of the primary and secondary vertices of short-lived particles
- VXD under production









PXD:
- 2 layers of DEPFET pixels
- Very thin (50 μm) pixel sensor
- Inner most layer very close to IP (r = 1.4cm)
- Very low material budget
- Excellent spatial granularity (σ ≤15μm)

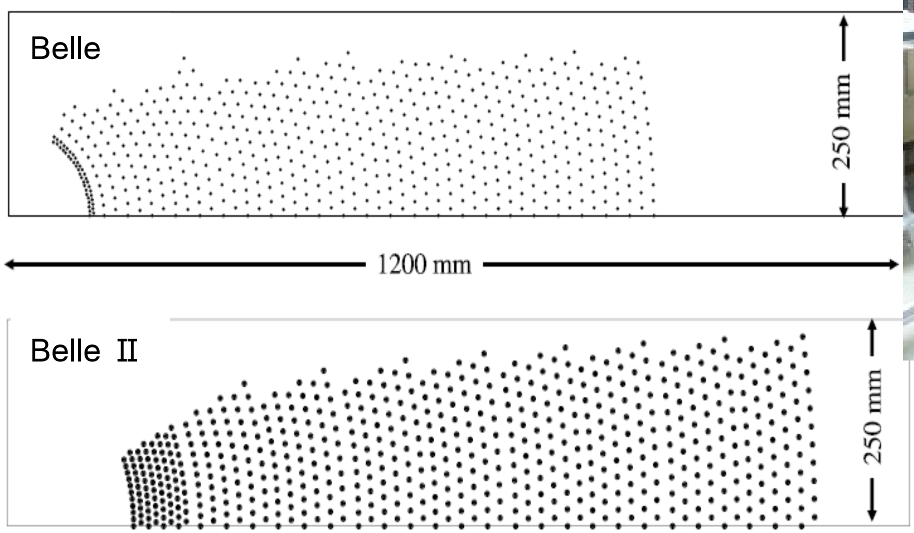
SVD:
- 4 layers of DSSD detectors
- Excellent timing resolution (σ ~ 2-3 ns)
- Low material budget
- Larger outer radius (6.05 cm → 14 cm)
- Inner radius: 3.8cm
- covers the full Belle II angular acceptance of $17^o < \theta < 150^o$

Belle II: CDC

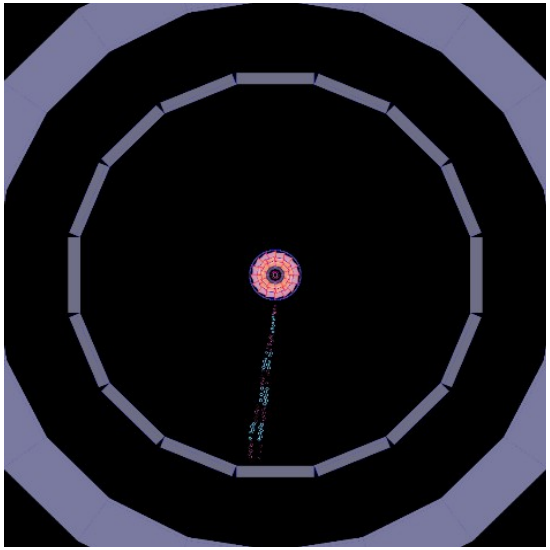
- Belle II CDC is larger than Belle CDC
- Smaller drift cells with sense wires and more layers allow better charged track reconstruction and dE/dx measurement compared to Belle
- Faster readout electronics
- Ready for Installation
- Cosmic ray test ongoing

	Belle	Belle II
Radius of inner boundary (mm)	88	168
Radius of outer boundary (mm)	863	1111
Number of layers	50	56
Number of total sense wires	8400	14336
Gas	$He-C_2H_6$	$He-C_2H_6$
Diameter of sense wire (μm)	30	30

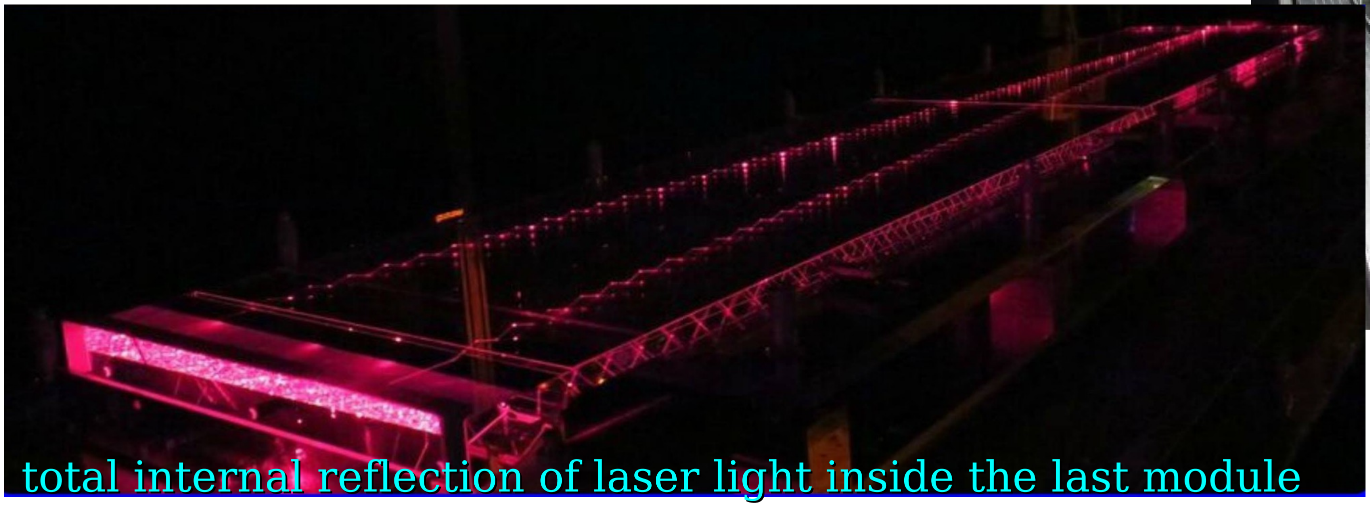
Wire Configuration



Event display



Particle ID: TOP (Barrel)



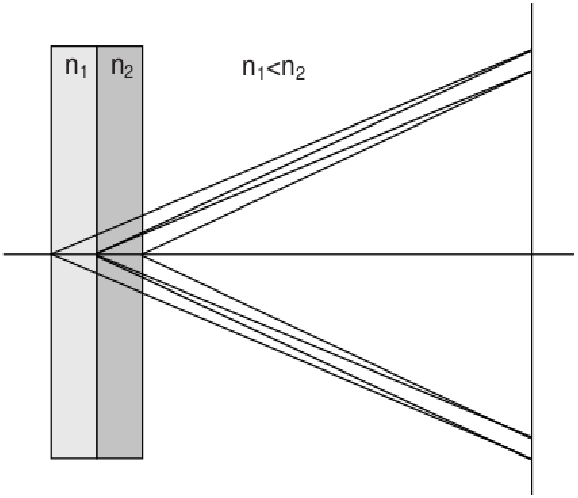
Modules of size: 20mm x 0.45 m x 2.7m

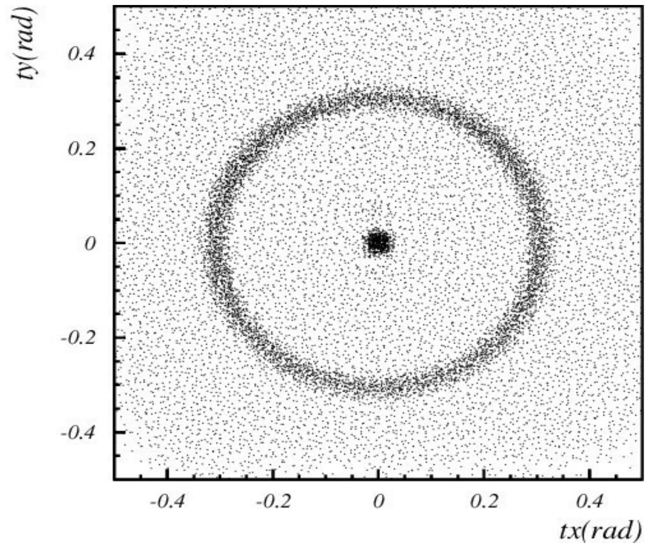
Comparison between Belle II PID (simulation) and Belle PID

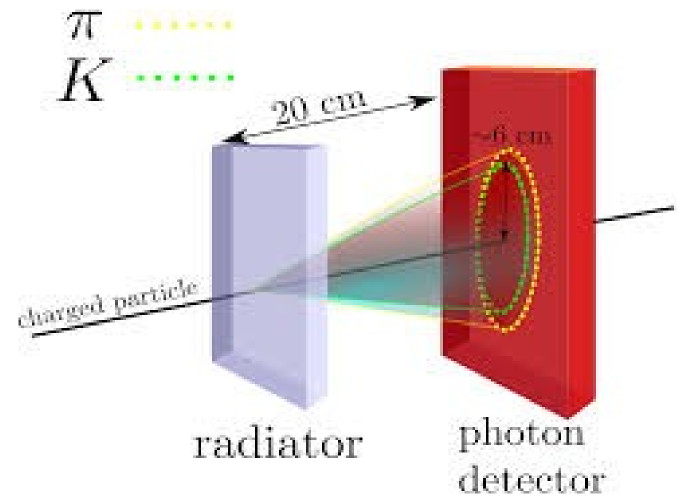
	Belle PID (%)	Belle II PID (%)
Ave. K efficiency	88	94
Π fake rate	9	4

- TOP used for particle identification in Barrel region covering whole range of momentum.
- Cherenkov photons internally reflected inside the quartz radiator were measured as Cherenkov image reconstructed from the 3-D information (x, y, time) by pixelated MCP-PMTs (Micro-Channel Plate Photo-Multiplier Tubes) having excellent time resolution.
- Each module consists of two quartz bars, array of photo detectors, focussing mirror and prism.
- 12/16 have been Installed in barrel region. All modules are glued. Complete Installation in May.
- Commissioning of all 16 modules ongoing.

Particle ID: Aerogel RICH (Forward Endcap)







Two 2cm thick aerogel layers with $n_1 = 1.045$, $n_2 = 1.055$

- ARICH Identifies particle covering full momentum in the forward endcap.
- Two layers of aerogel lead to better photon yield without affecting resolution.
- 420 Hybrid Avalanche Photo Detectors (HAPD), 144 channels each.
- The beam test results and simulations show excellent KID efficiency at a low π misID.
- Successful magnetic field test. Installation in Autumn.

Belle II: ECL

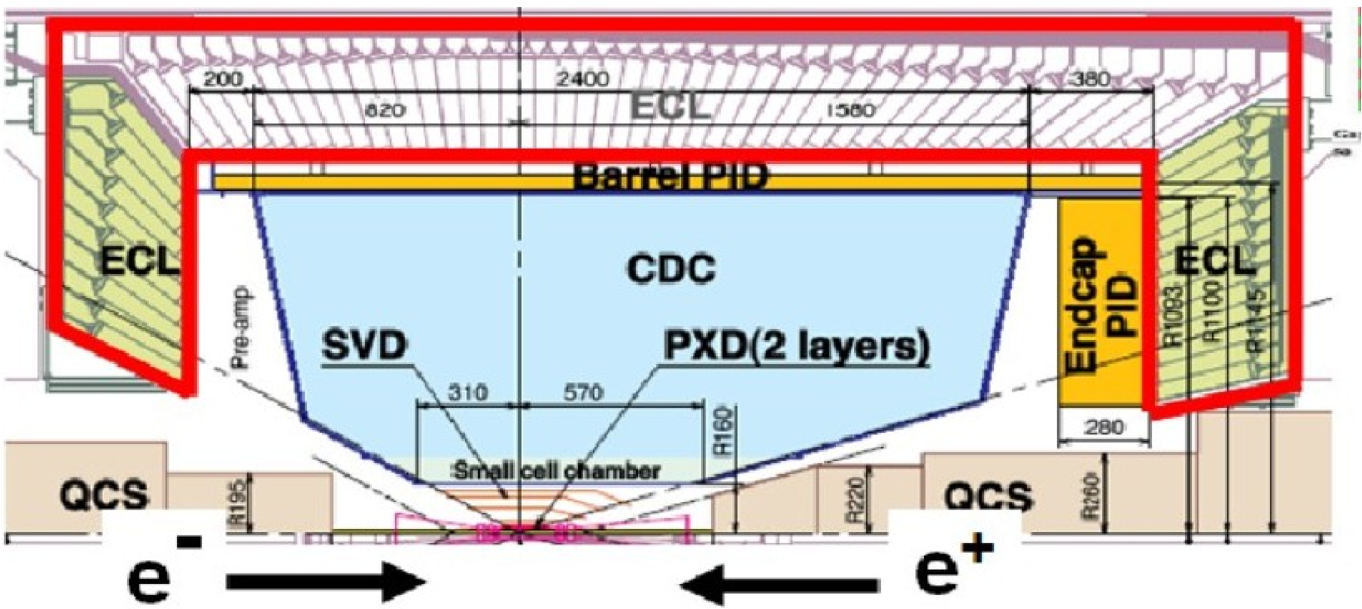
Upgrade from Belle → Belle II to compensate larger background in Belle II

- Barrel and Endcap ECL: Reusage of Belle CSI (TI) crystal calorimeter with improved back-end readout electronics having better waveform sampling to compensate larger beam related background.
- Barrel ECL already installed.
- Cosmic test on going.

Belle II ECL trigger efficiency (simulation) compared to Belle ECL efficiency

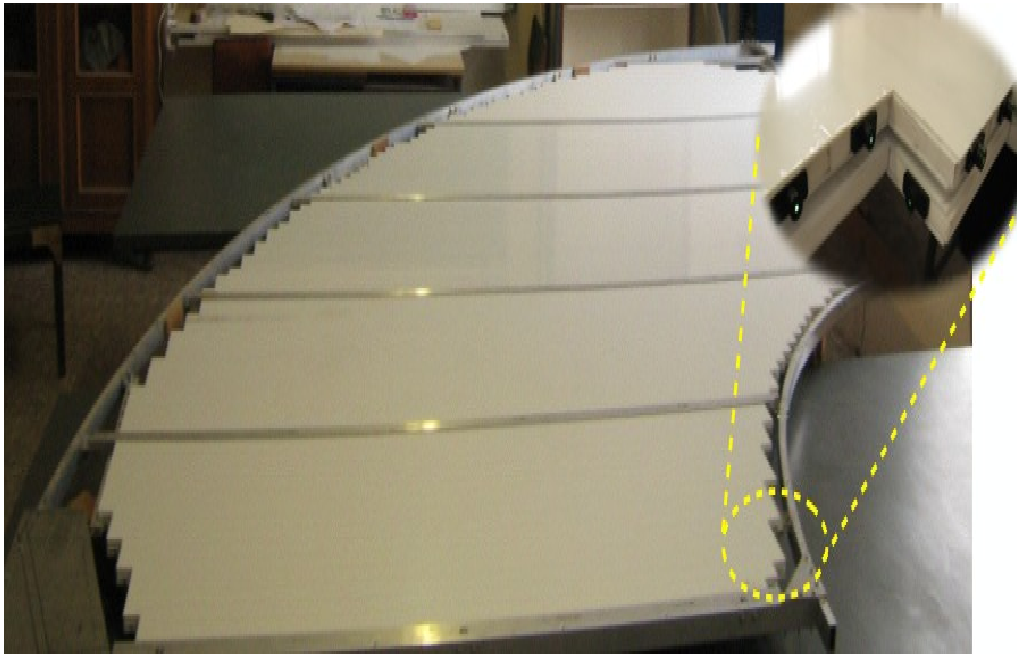
Physics trigger: $E_{tot} > 1$ GeV

	ε_{phys} (total)	ε_{signal}	ε_{bkg}
Belle	99.42 %	88.70 %	10.72 %
Belle II	99.90 %	99.12 %	0.78 %



Belle II: KLM

- Due to expected high neutron background and to keep KLM efficiency, Endcaps and two innermost barrel RPC layers of Belle were replaced with scintillators
- Absorptive Iron plates, where KL can shower hadronically
- Installation completed in 2013 (barrel KLM) and 2014 (endcap KLM)
- Commissioning in progress with cosmic rays

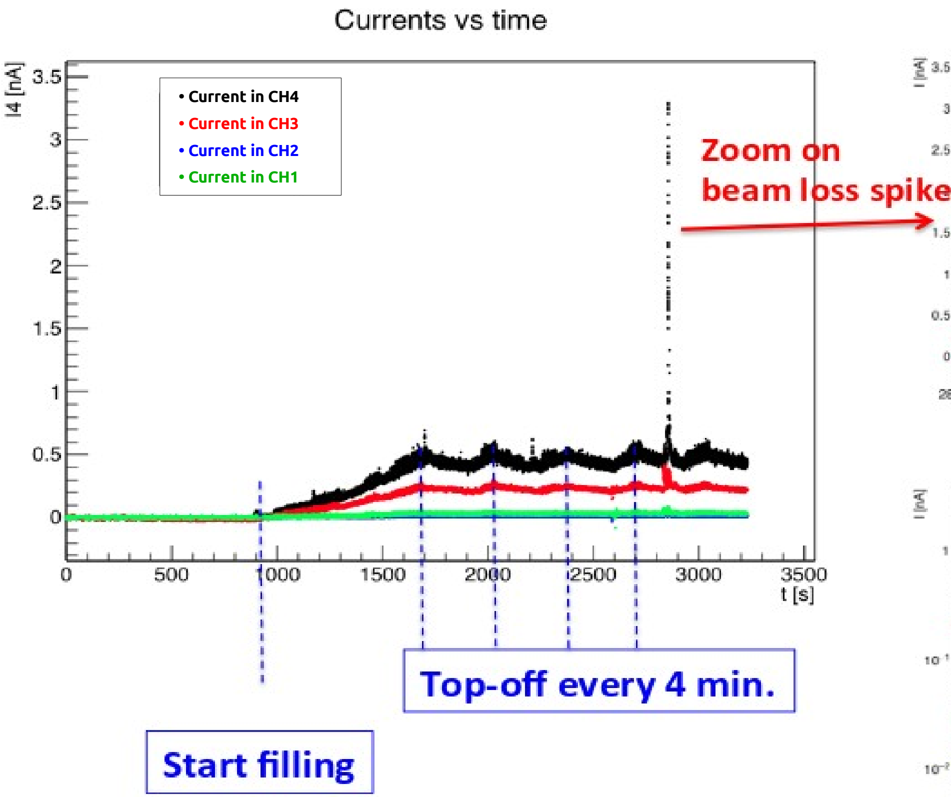


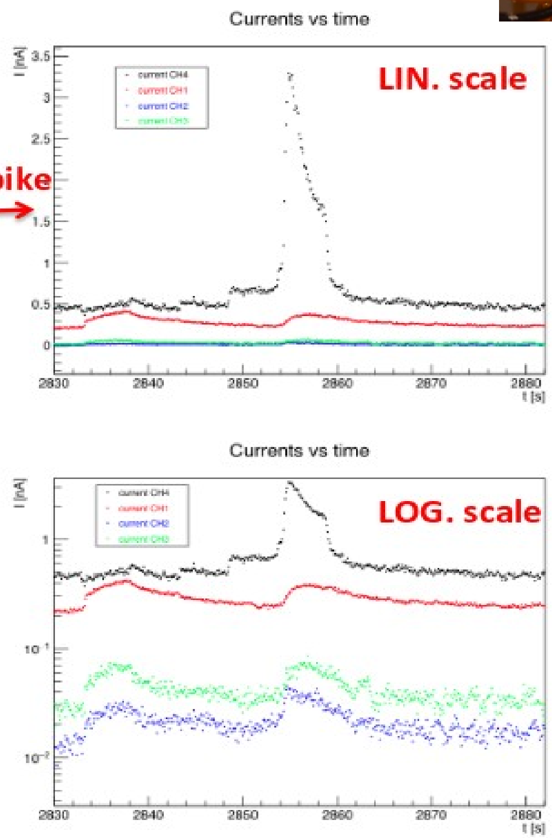
Summary

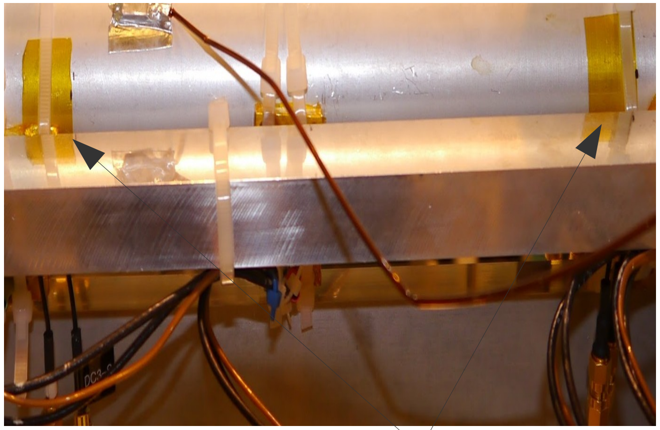
- SuperKEKB phase1 commissioning has started
- BEAST II phase 1 detectors are studying beam background very successfully
- BEAST II has seen charged particles, x-rays, thermal neutrons, and fast neutrons from beam-gas events clearly
- Belle II is moving on schedule with KLM, ECL, TOP installed
- Belle II will start operation in 2017 and start taking physics data in 2018.

Thank you!

Diamonds





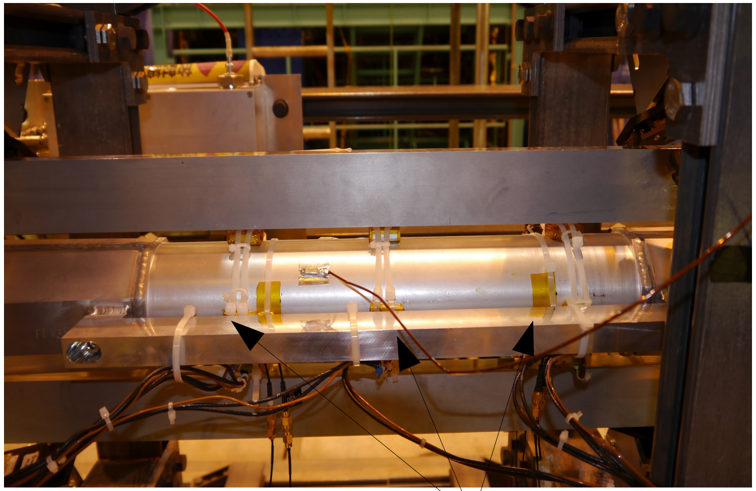


Diamond sensor around IR

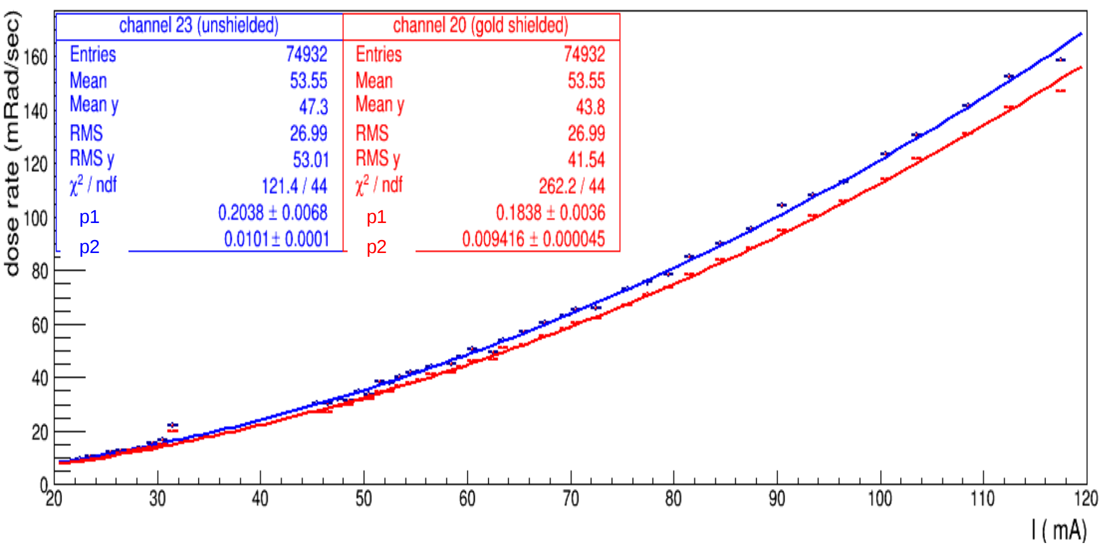
Ionizing current seen by diamond sensors at various locations during vacuum scrubbing

PIN diodes

- An important BEAST sub detector to measure integrated radiation dose during BEAST Phase1
- Separate the charged particles from X-rays



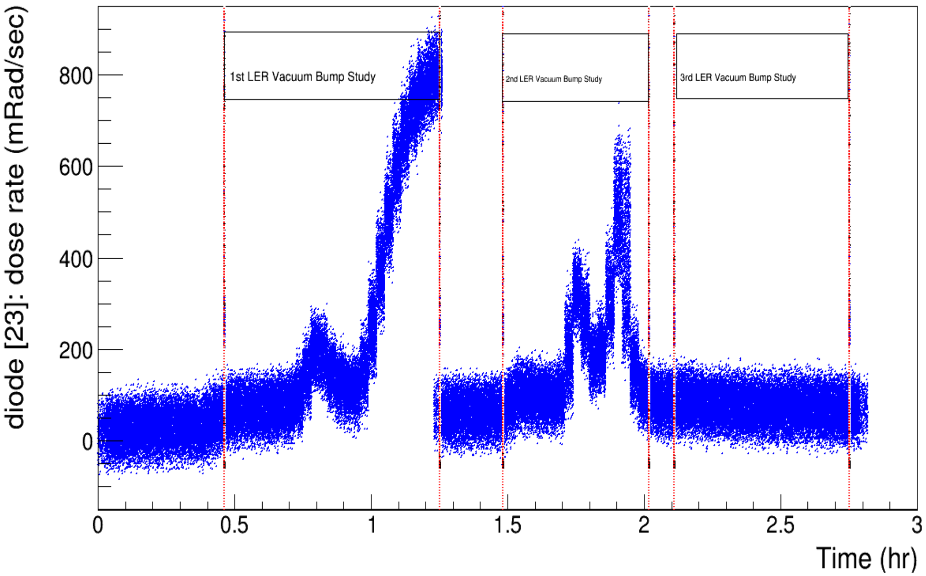
PIN diodes around IP



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

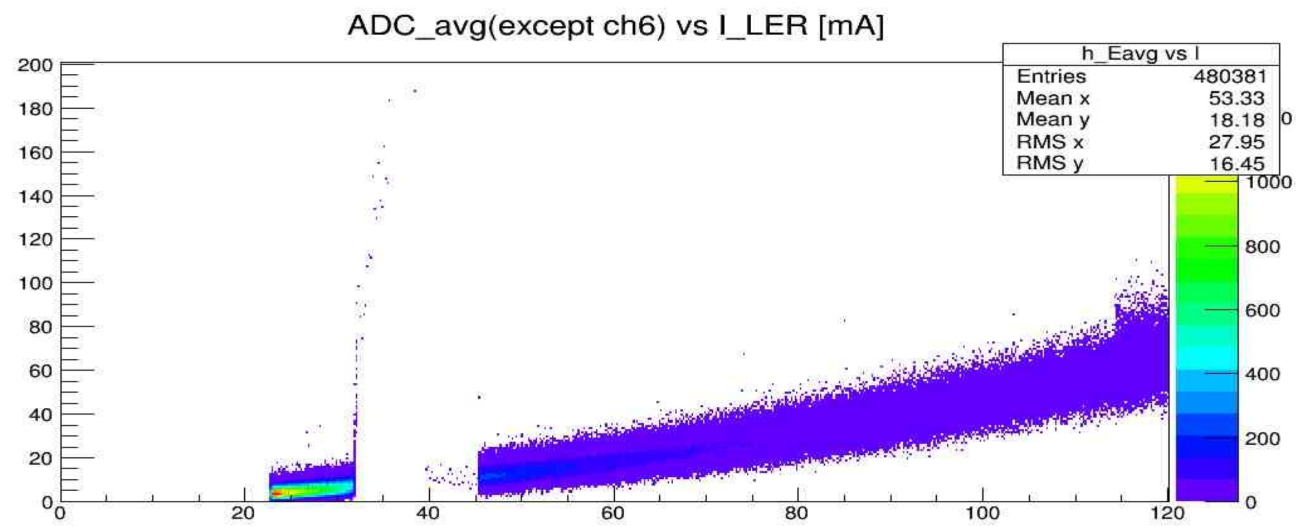
P[1] (shielded) < P[1] (unshielded) is a sign of synchrotron background

Diodes clearly see beam gas background



Recent Vacuum bump study. pressure bumps introduced at various locations in LER to see radiation at IR

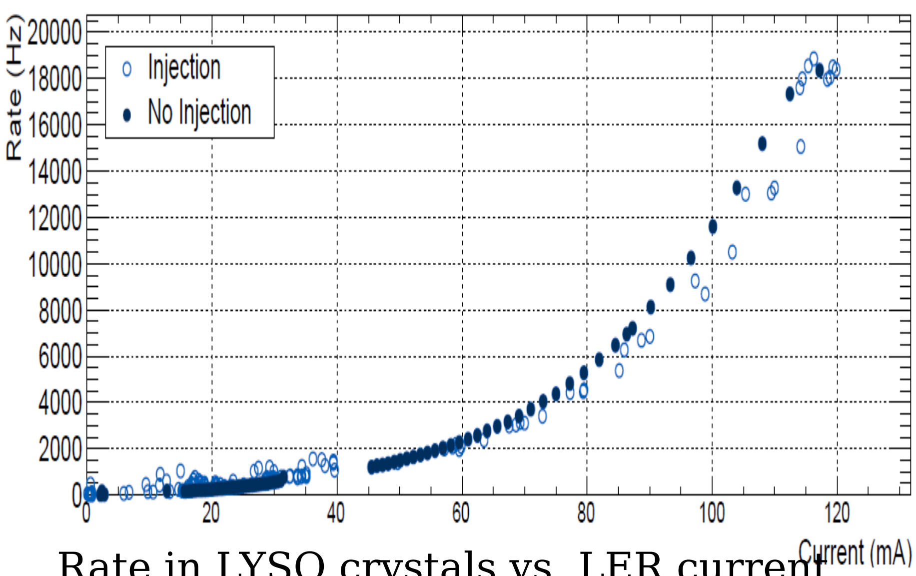
BGO



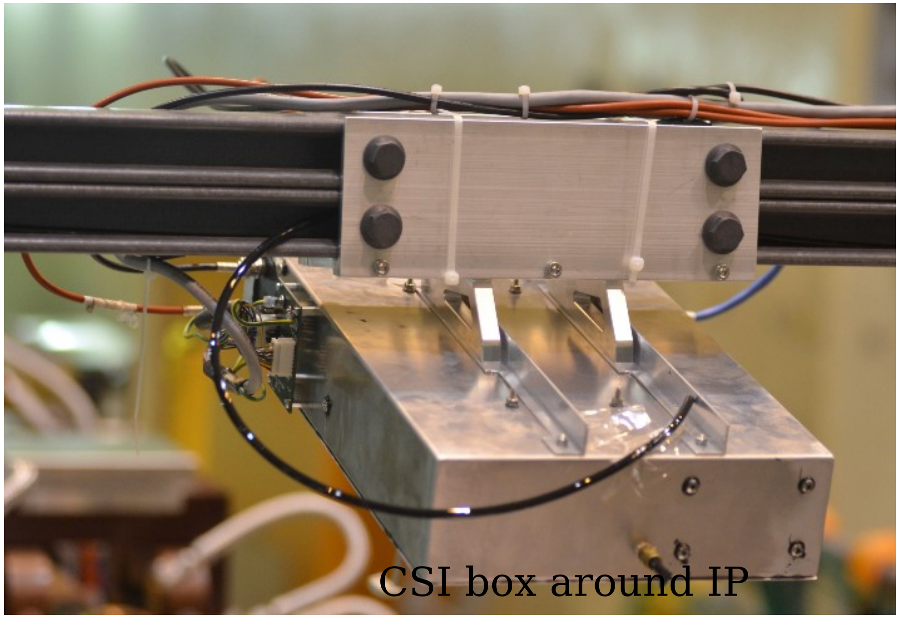
BGO see beam gas very clearly

BGO around IP

CSI crystal

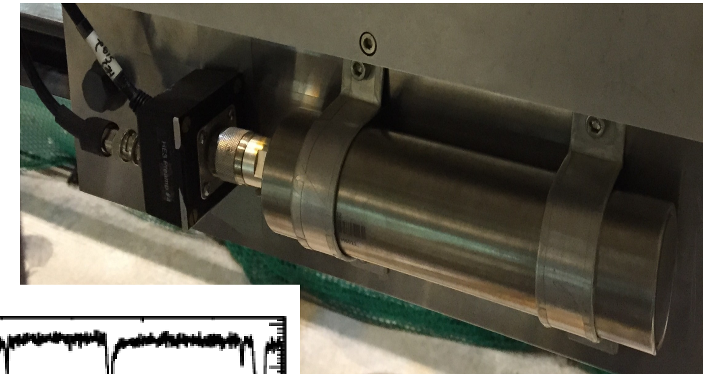


Rate in LYSO crystals vs. LER current

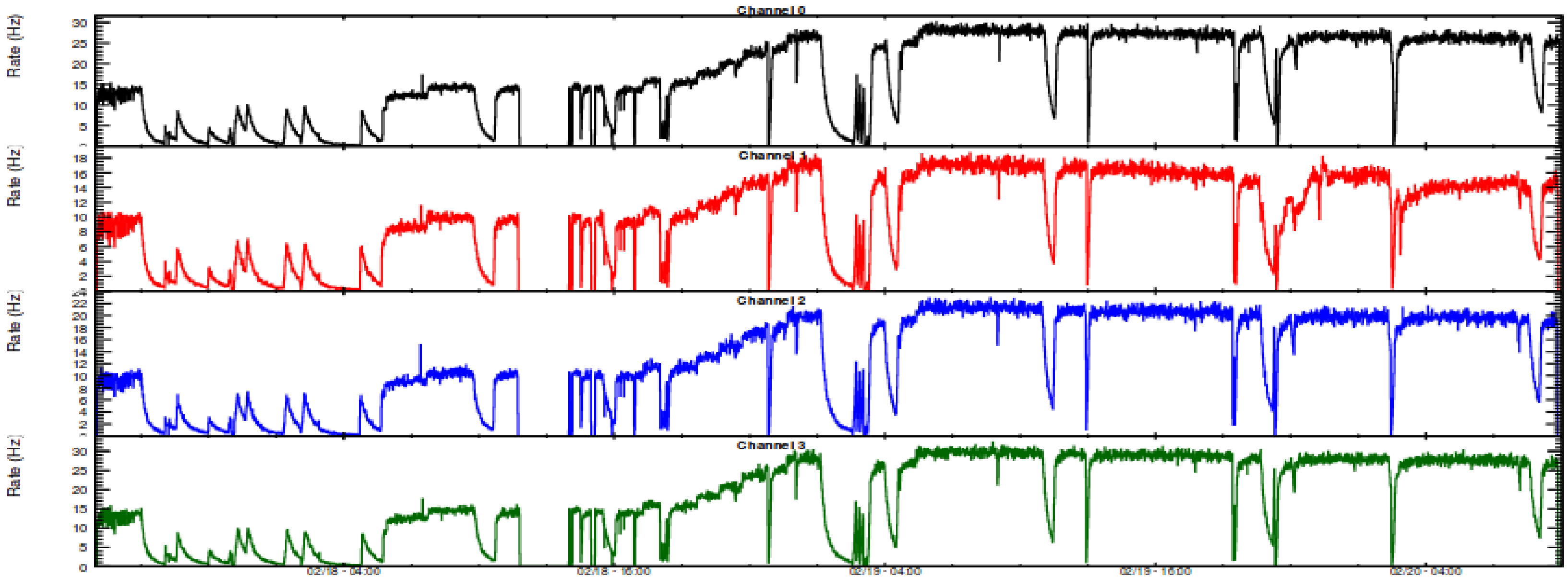


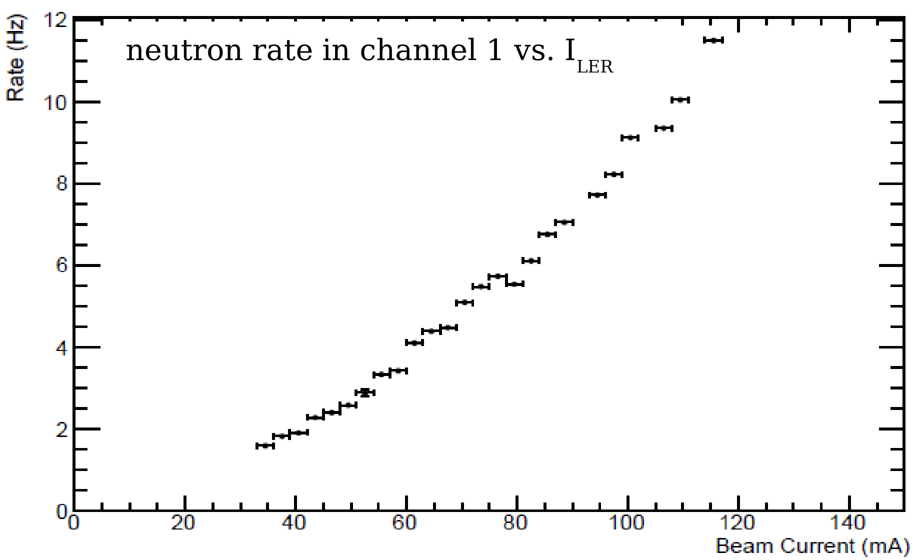
CSI box around IP

He3-tubes: thermal neutron



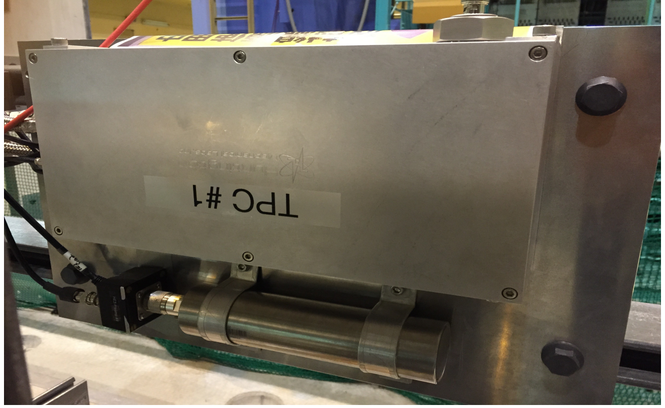
Thermal neutron rate vs. time by different channels



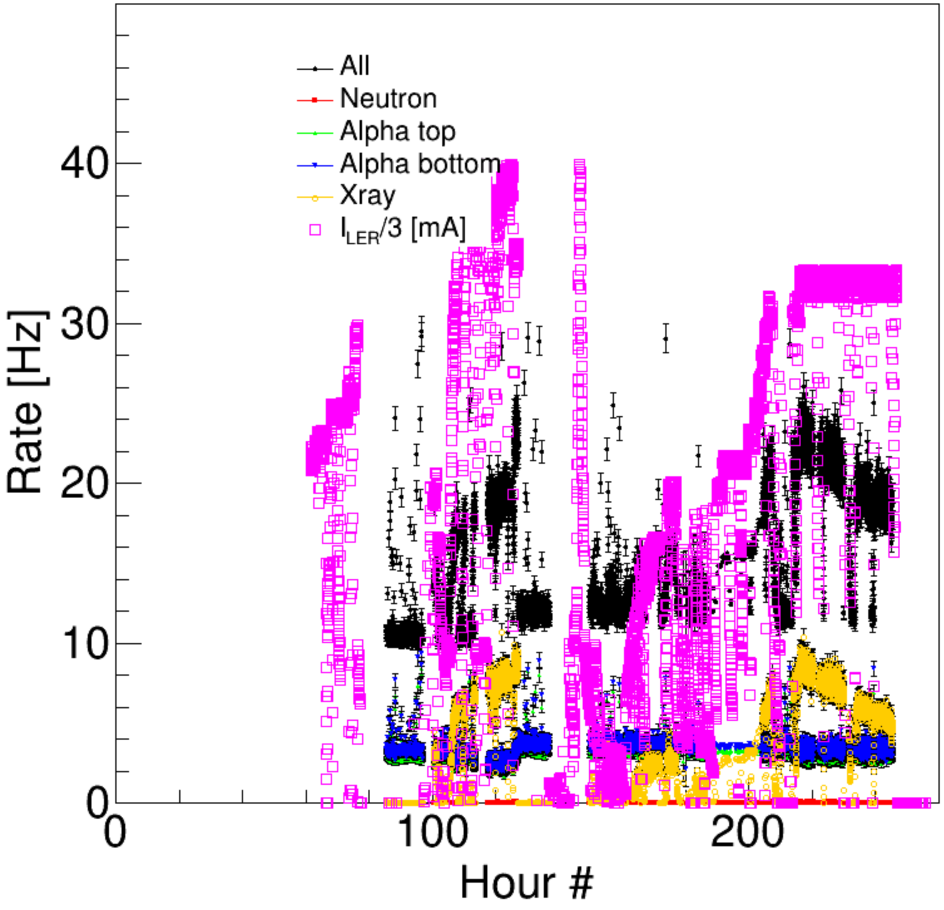


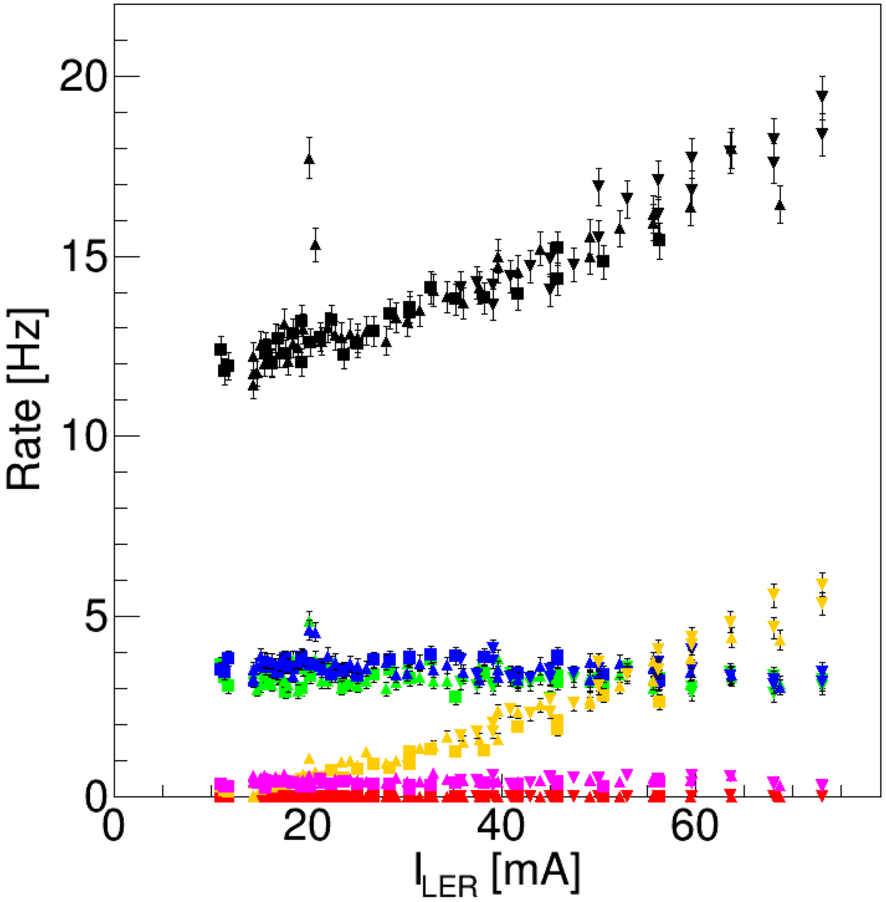
lot of thermal neutrons produced by beam-gas events

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