The Belle II / SuperKEKB commissioning Time Projection Chambers characterization, simulation, and results

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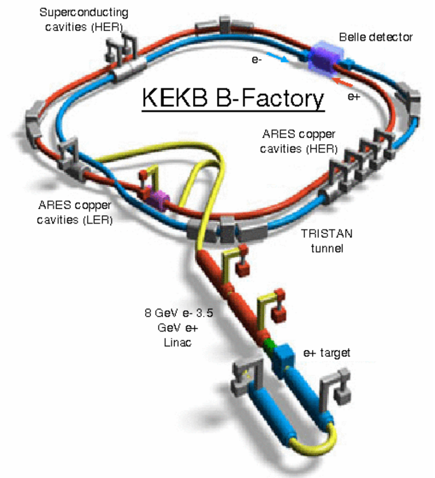
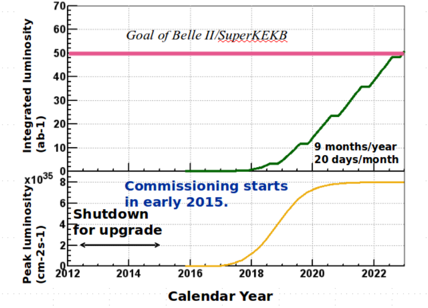
SuperKEKB, the intensity frontier

- Belle/Belle II experiment at KEK/superKEK B-factory in Tsukuba, Japan
- 1999 - 2010 Belle@KEKB $\mathcal{L} \sim 1$ ab^{-1} at $\Upsilon(1S, 2S, 3S, 4S, 5S)$ and continua
- 2018 - 202? Belle II@superKEKB $\mathcal{L}_{projected} = 40$ ab^{-1} at $\Upsilon(1S, 2S, 3S, 4S, 5S, 6S)$ and continua





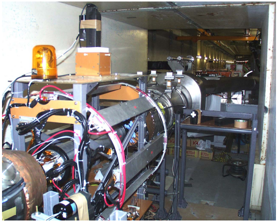
- Electron-positron collider
- New nano-beam scheme
- $\mathcal{L}_{peak} = 8 \times 10^{35} cm^{-2} s^{-1}$
- Commissioning started in 2016

High SuperKEKB record luminosity will generate very challenging beam-induced backgrounds

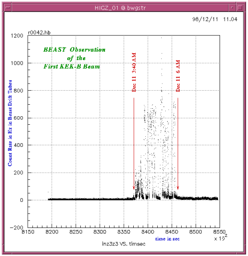
Beam Exorcism for A STable experiment, some history

aka BEAST was used in 1998 to monitor radiation level and particle rates during KEKB commissioning

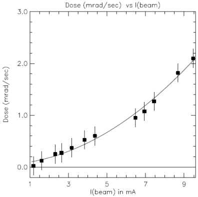
- BEAST in the cave



- First beam



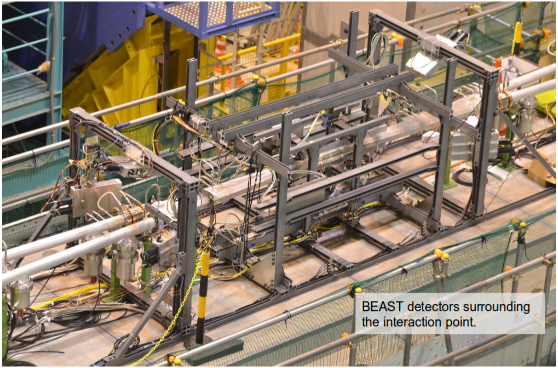
- rate



- Provided important feedback to accelerator group during commissioning, and ensured background levels acceptable before Belle roll-in
- Located at Interaction Region composed of PIN diodes, MOSFETs, Drift tubes, CsI and two Silicon Strip Ladders
- But did not prevent synchrotron radiation from damaging first beam-pipe
- Neutron backgrounds was not measured and reduced (KLM) efficiency

BEAST II in 2016, the Commissioning Detector

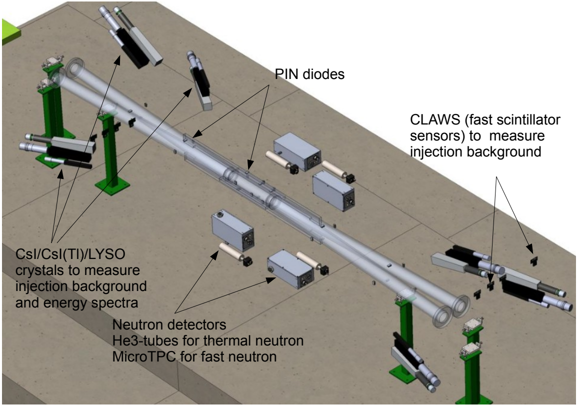
- Measure instantaneous and integrated radiation dose at position of Belle II sub-detectors
- Measurements of luminosity and background levels during beam commissioning
  - Beam-gas (Bremsstrahlung and Coulomb) $\propto Z^2.I.P$
  - Touschek $\propto N_{bunch}.I^2_{bunch}/\sigma_y$
  - Injection
  - Synchrotron Radiation $\propto E_e^2$ and B^2
  - Radiative Bhabha $\propto N_{bunch}.I_{bunch}$ (if collision)
  - 2-ph $\propto N_{bunch}.I_{bunch}$ (if collision)



Before the Physics run starts in late 2019, two commissioning phases are taking place:

- Last year, phase 1: beams commissioning (no collisions) without Belle II, only BEAST at the Interaction Region
- 2018, phase 2: nano-beams collision commissioning with Belle II, and BEAST placed at the heart of Belle II

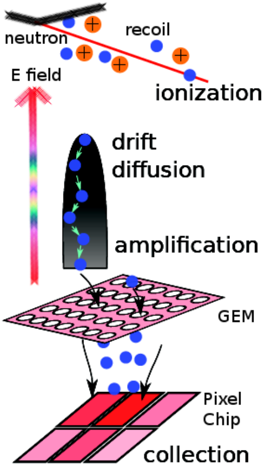
Phase 1 BEAST II



- Phase 1 BEAST II CAD drawing. BGO, diamond sensors, and QCS fast scintillator prototypes are not shown, 4 TPCs installed but only two operational TPCs
- Summary talk on BEAST II: M. Gabriel / R2-Experimental detector system(5) - 25.05.2017
- Dedicated talk on CLAWS: W. Hendrik / R1-Interface and beam instrumentation - 25.05.2017
- Dedicated talk on diamond sensors: C. La Licata / R4-Semiconductor detectors(3) - 23.05.2017

Directional Neutron Detection with TPCs

Time Projection Chamber (TPC) filled with $^{4}He:CO_2$:70:30 gas mixture at 1 atm



as fast neutron detector

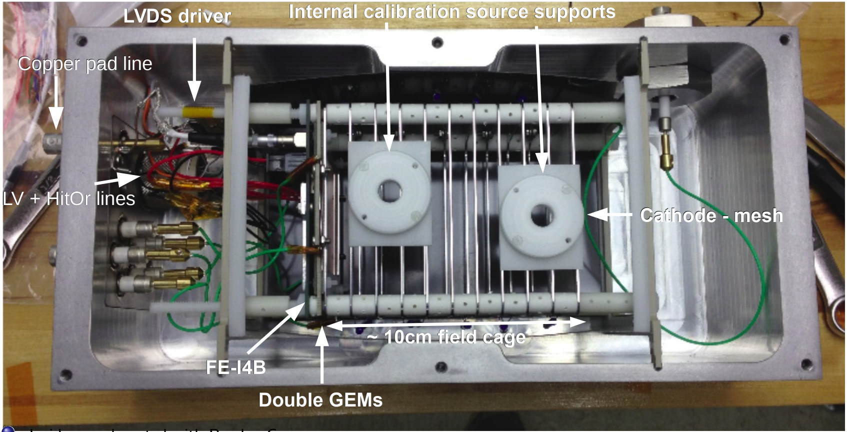
- Fast neutrons not detected directly
- But through their scattering product with
- The gas-nucleus by elastic scattering
  $n + A_{rest} \rightarrow n' + A_{recoil}$
- Nuclear recoil ionizes gas along track
- Electric field, produced by a Field Cage (FC), moves charges
- Amplification by 2 Gas Electron Multipliers (GEMs)
- Readout with ATLAS FE-I4B pixel chip
  - 2D charge distribution
  - $+$ timing information
  - $+$ known drift velocity
    $=>$ 3D hit information and track length
  - 3D fit gives the track direction $=> \theta, \phi$
  - $+$ known GEMs gain and Quenching Factor (QF)
    $=>$ energy, E

$=>$ We reconstruct the nuclear recoil track length and (θ,ϕ,E)

NIMA 788 (2015) 81-85 / PP 00 (2012) 1-8

TPCs designed and build by and at University of Hawaii

Time Projection Chamber: inside view



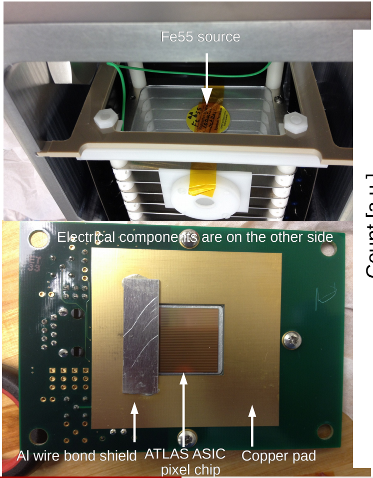
- Inside vessel coated with Parylen C
- Sensitive volume: $\sim$ 2 x 1.68 x 10 cm^3
- 2 internal 5.3 MeV alphas PO210 calibration sources at 2.79 cm and 8.56 cm from the top GEM2
- 2 GEMs => operating gain $\sim$ 1500
- 1 ATLAS ASIC pixel chip FE-I4B => 3D tracks + energy (few keVs to MeV)

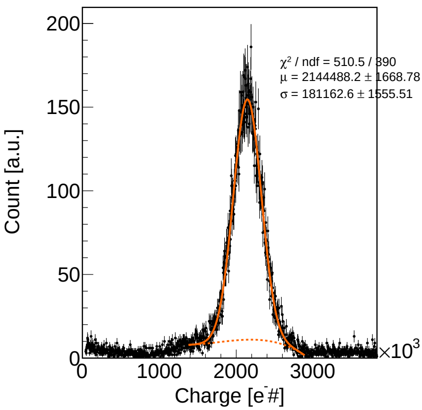
Effective gain measurements with Fe55 source in HI

Two independent measurements of the 168 primary electrons produced by the Fe55 source:

- PHA connected to copper pad
- ATLAS ASIC pixel chip (below bottom right: typical Fe55 spectra in 1atm HeCO2)

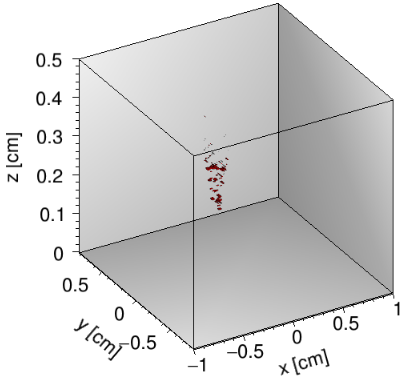
Preliminary, ATLAS ASIC pixel chip energy resolution: 8.4 % for 5.9 keV X-rays

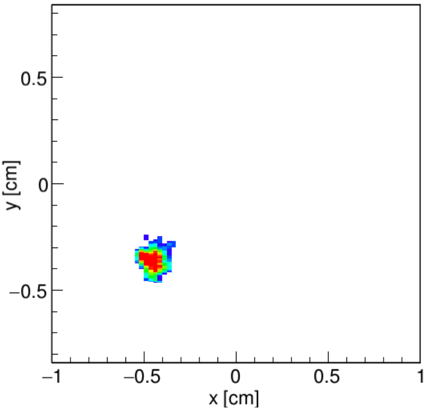




5.9 keV X-ray Fe55 3D and 2D views

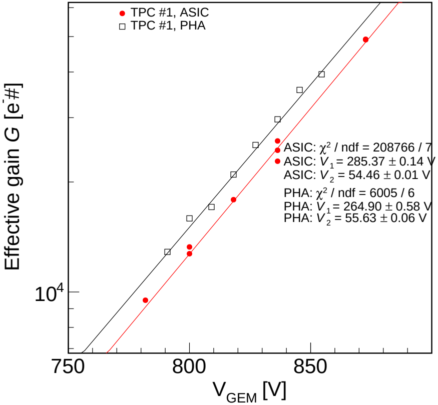
- Effective gain set to 50000
- 3D electron cloud with charge information preliminary

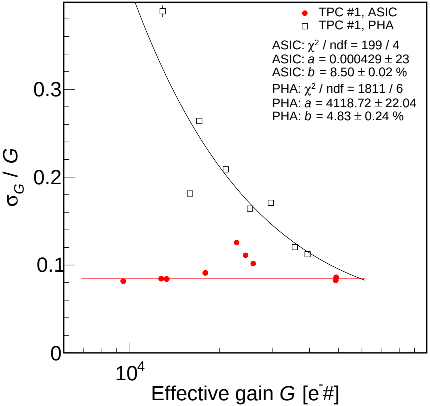




Effective gain measurements

- Effective gain vs GEM voltages: $G = 10^{\frac{V_{\mathrm{GEM}} - V_1}{V_2}}$ preliminary
- GEM resolution vs effective gain: $\sigma_G / G = \sqrt{(a/G)^2 + b^2}$ preliminary



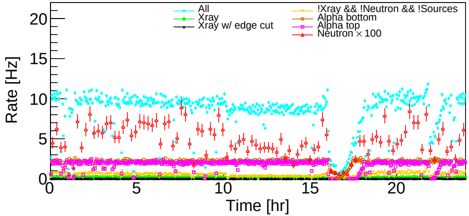


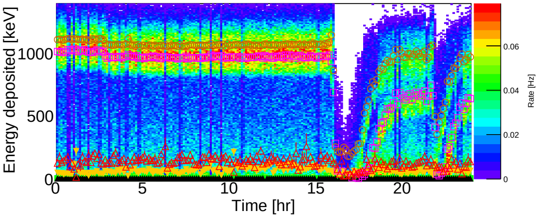
- Gain difference between PHA and ASIC chip explained by ASIC electronic-induced offset threshold NIMA 178 (2015) 49-53 and inefficiency due metalization, correctable and estimable
- Lower noise floor in ATLAS pixel ASIC than in PHA setup explained better ASIC gain resolution measurements

Gain stability during phase 1 operation under beams

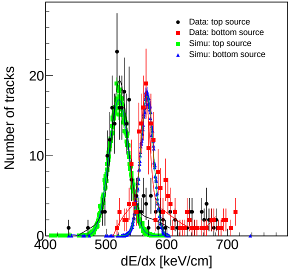
Monitored by measuring the energy deposited by two PO210 internal calibration sources

- Rate/Energy deposited vs time preliminary





- Calibration sources compared to simulation preliminary



- Data corrected by a single fudge factor to match simulation

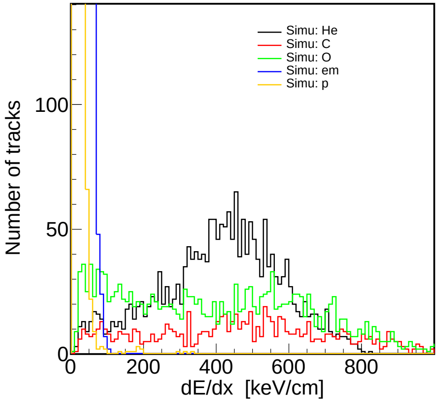
  TPC simulator developed by University of Florida

- Gas flow stopped after dedicated LER Touschek beam study

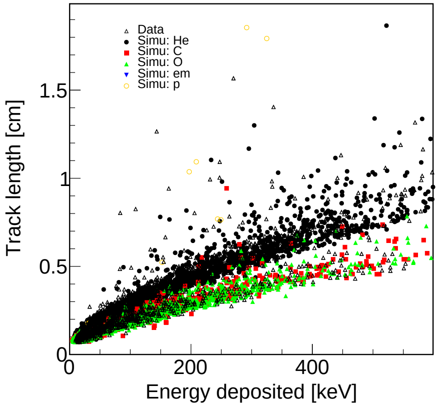
Particle ID

Determined by TPC simulator preliminary

- Simulated dE/dx for different particle species



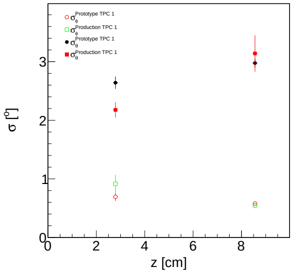
- Track length vs energy deposited compared to data after final selection criteria



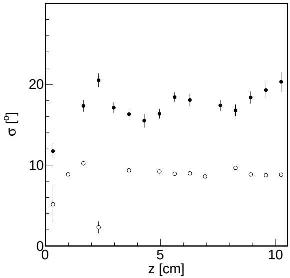
- Events fully contained in fiducial area of chip
- Selection criteria based on dE/dx and pixel number give clean neutron sample

Angular resolution

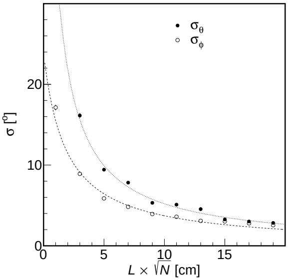
- Data calibration alphas resolution vs z preliminary



- Simulated neutron recoils resolution vs z preliminary



- Simulated neutron recoils resolution vs $L\sqrt{N}$ preliminary

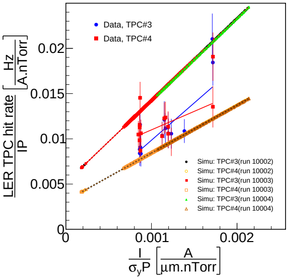


- Angular resolution depends of z and energy deposited
- Alphas' calibration have typically 1 MeV deposited energy
- Alpha recoils have typically 200 keV deposited energy

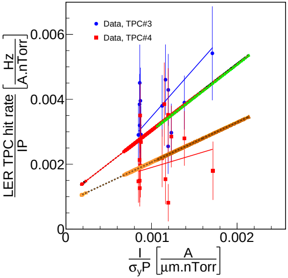
LER Touschek beam study

Single beam circulating, LER, to determine Beam Gas and Touschek contribution from neutrons and electromagnetic particles

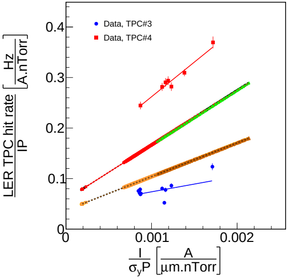
- Neutron radiation, He/C/O recoils preliminary



- Indirect neutron radiation, proton recoils preliminary



- Electromagnetic particles preliminary

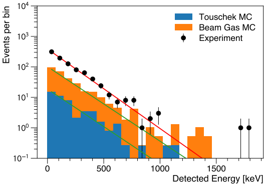


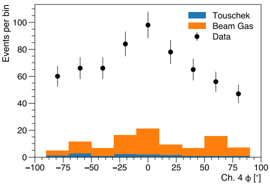
- Normalization of simulation scaled to data for comparison
- Beam-induced background simulation underestimates neutron radiation by 3 to one order of magnitude
- Beam-induced background simulation overestimates EM radiation by 3 to one order of magnitude

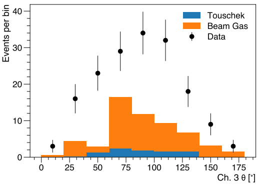
LER Touschek beam study

Neutron recoil energy and angular comparison between data and simulation

- Energy spectrum preliminary
- Azimuthal angle distribution preliminary
- Polar angle distribution preliminary







- Predicted and measured energy spectra agree 3 to one order of magnitude
- Beam-induced background simulation underestimates neutron radiation by 3 to one order of magnitude
- Neutrons from beam pipe can be identified by selecting recoils with $\phi = 90 \pm 10$ ^{o}
- Energy and angular distributions in data and MC are similar

Conclusion

- BEAST II Measured instantaneous and integrated radiation dose
- 10 direction sensitive TPC fast neutron detectors have been constructed by University of Hawaii
- Two TPCs were operated in commissioning phase 1
- TPC simulator has been developed by University of Florida:
  - Used to calibrate the data
  - Determined PID
  - Determined general expected TPC properties
- TPCs measured neutron rates, recoil energy distributions, and energy spectra
- A preliminary analysis shows that neutron backgrounds are underestimated by the simulation
- SuperKEKB beam loss simulations are being tuned based on the BEAST experience
- 8 TPCs to be deployed in commissioning phase 2
- Detailed papers on:
  - Phase 1 results
  - BEAST TPCs
  - TPC simulator

  are forthcoming

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Thanks for your attention