Los Alamos NATIONAL LABORATORY

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Forward silicon vertex/tracking detector design and R&D for the future Electron-Ion Collider

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on behalf of the Los Alamos National Laboratory EIC team

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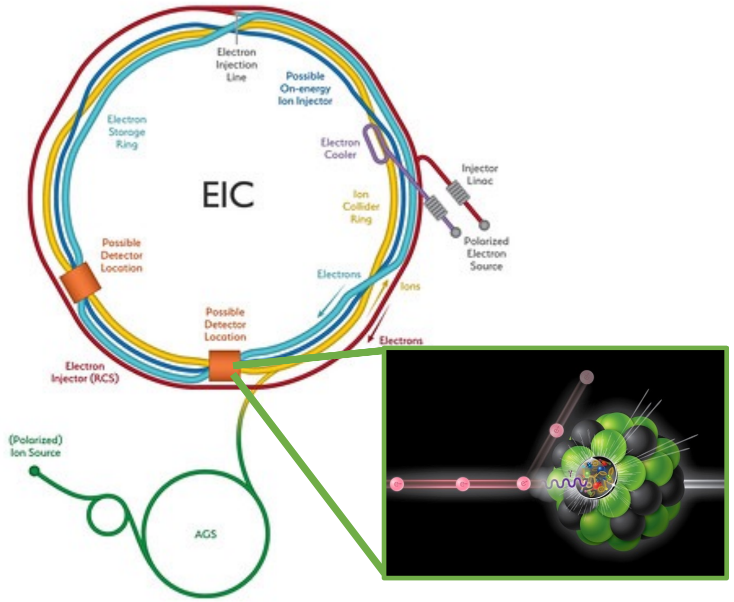
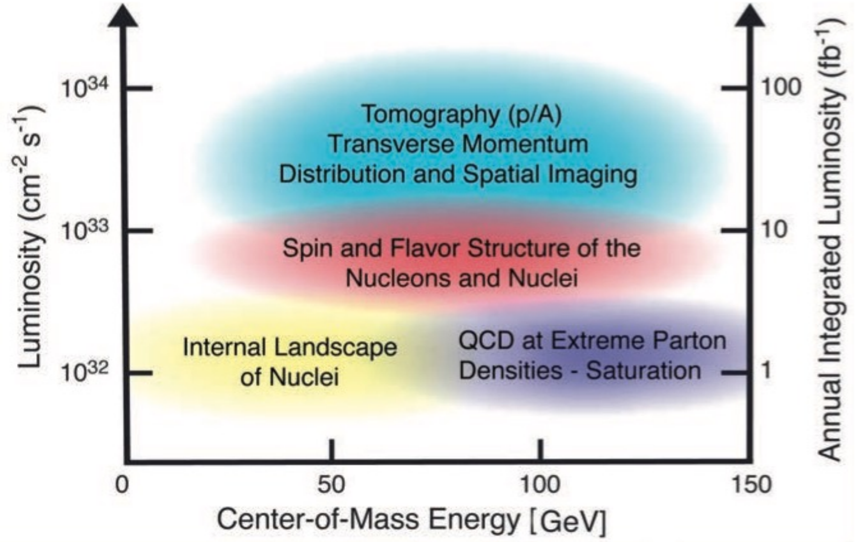
Introduction to the future Electron-Ion Collider (EIC)

- The future Electron-Ion Collider (EIC) to be built at BNL, will utilize high-luminosity high-energy e+p and e+A collisions to solve several fundamental questions in the nuclear physics field. It will operate:
  - (Polarized) p and nucleus beams at 41-275 GeV.
  - (Polarized) e beam at 5-18 GeV.
  - Instant luminosity $L_{int} \sim 10^{33\text{-}34}\ cm^{-2}sec^{-1}$. A factor of ~1000 higher than HERA.
  - Bunch crossing rate: ~10 ns.
- Heavy flavor hadrons and jets are good probes to explore the EIC science portfolio.
- A high granularity and precise silicon vertex/tracking detector is required to realize precise heavy flavor measurements.

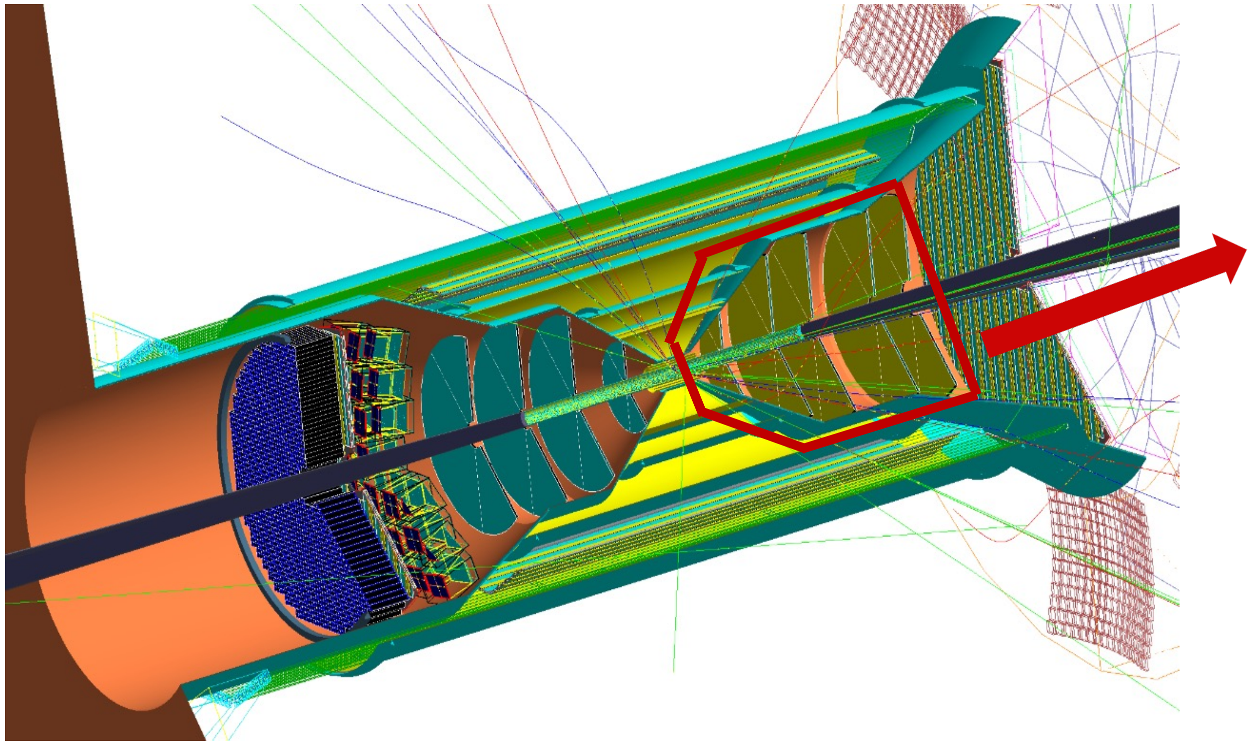


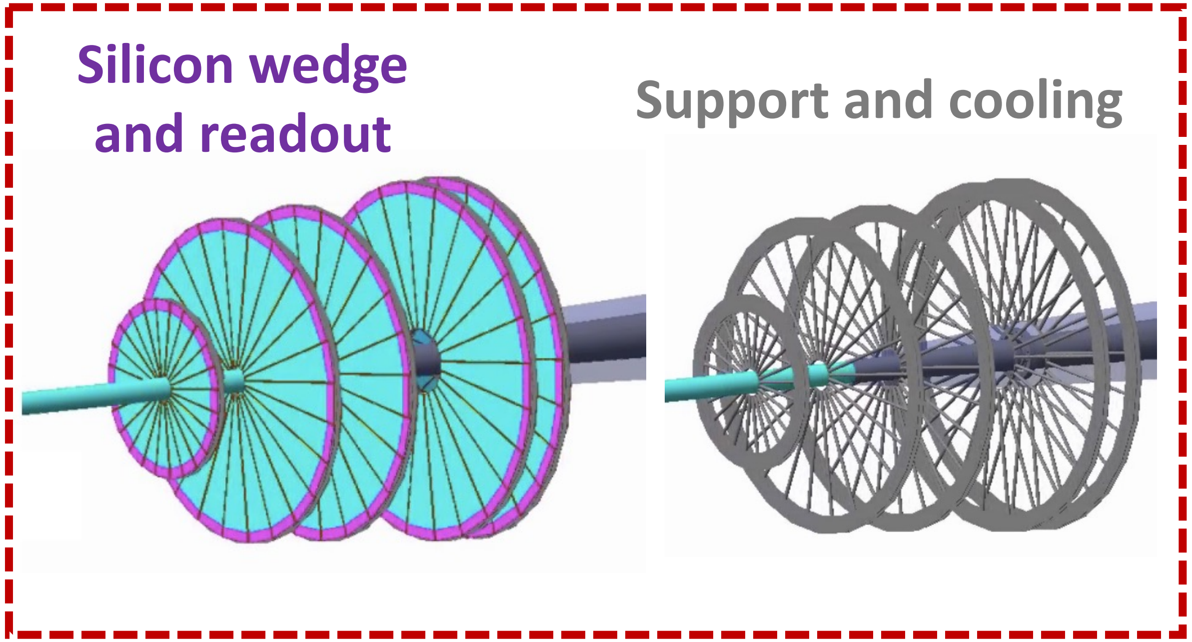


Forward Silicon Tracker design implemented in the ECCE detector

- The Monolithic Active Pixel Sensor based Forward Silicon Tracker (FST) design consists of 5 disks with the pseudorapidity coverage from 1.2 to 3.5, ~10B pixels and ~2.2m^2 active area.

LANL led FST detector design implemented in the selected EIC detector: ECCE

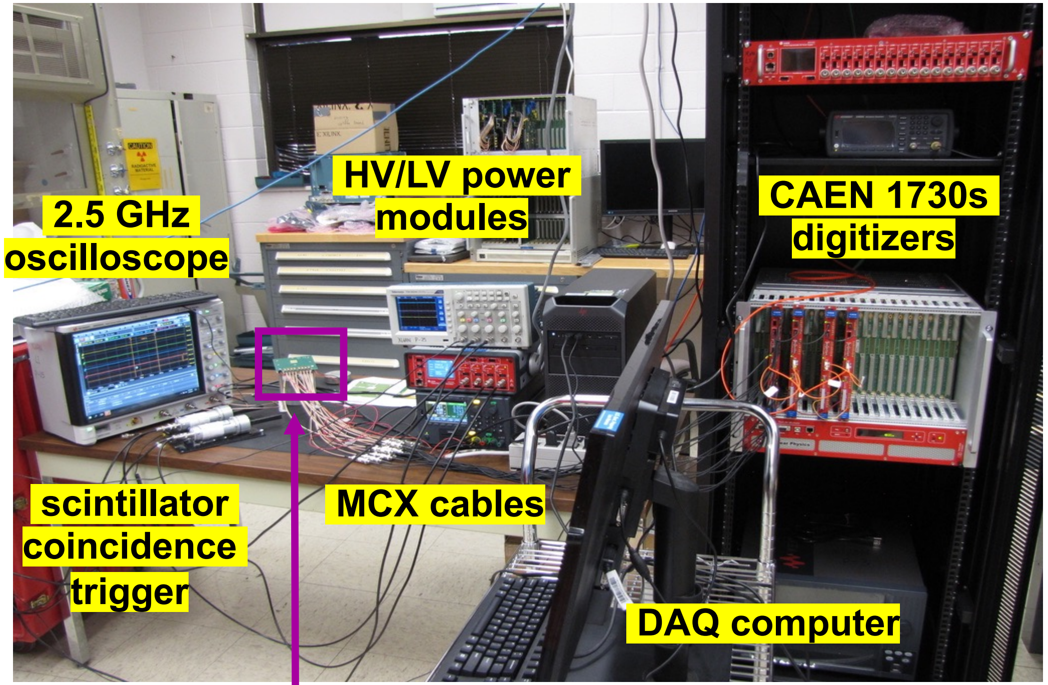


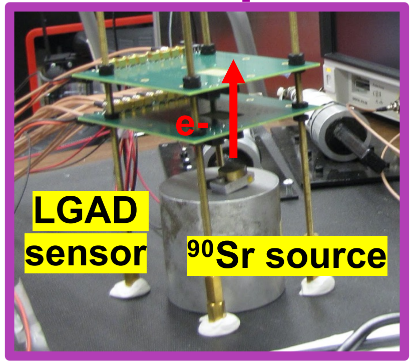


- Detailed detector layout (segmentations, readout units, cooling and support structures) has been implemented in GEANT4 simulation. Tracking performances are in the backup.

Advanced silicon technology R&D setup for EIC silicon tracker

LGAD (AC-LGAD) characterization with the ^{90}Sr source test





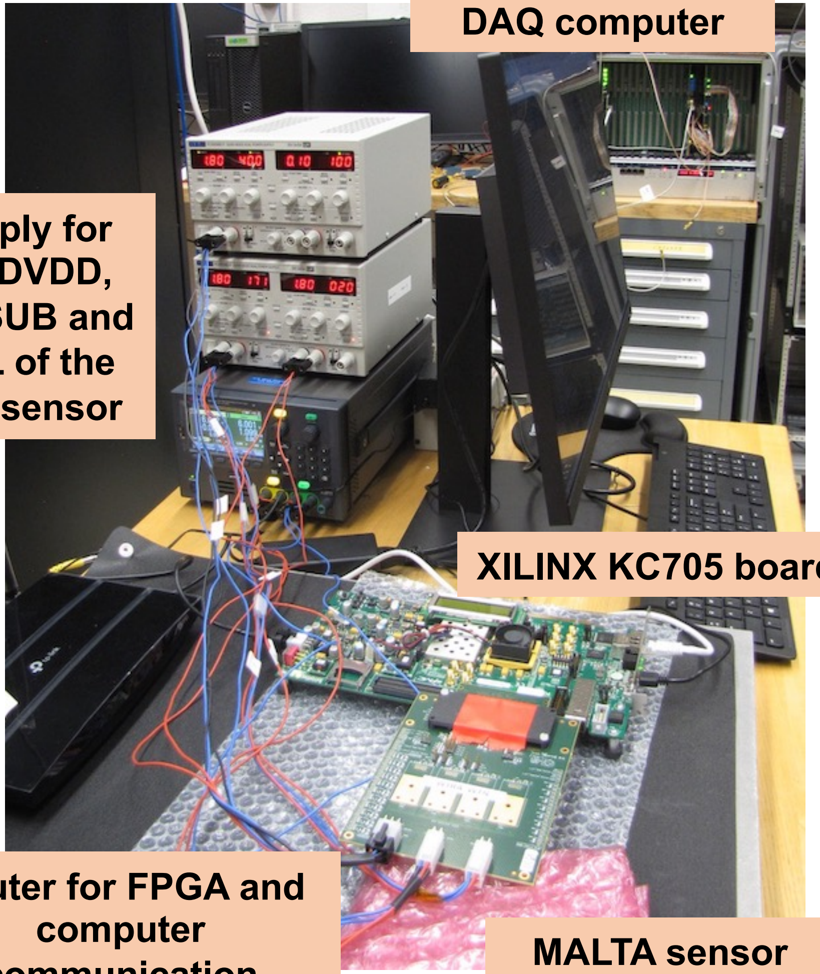
2-layer LGAD telescope

AC-LGAD:
Pixel size: 0.5-1.3 mm
Spatial res.: ~30 μm
Time res.: <30 ps

MALTA sensor characterization test bench

in collaboration with BNL, UCSC, CERN, FNAL, Rice Univ., UM, UNM, ANL, KIT, JLab, LGAD Consortium, UC Consortium

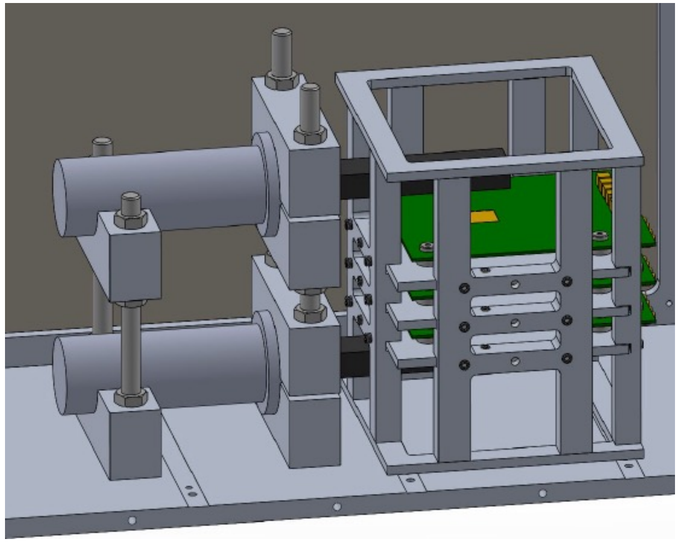
MALTA:
Pixel size: 36.4 μm
Spatial res.: ~7 μm
Time res.: ~2 ns



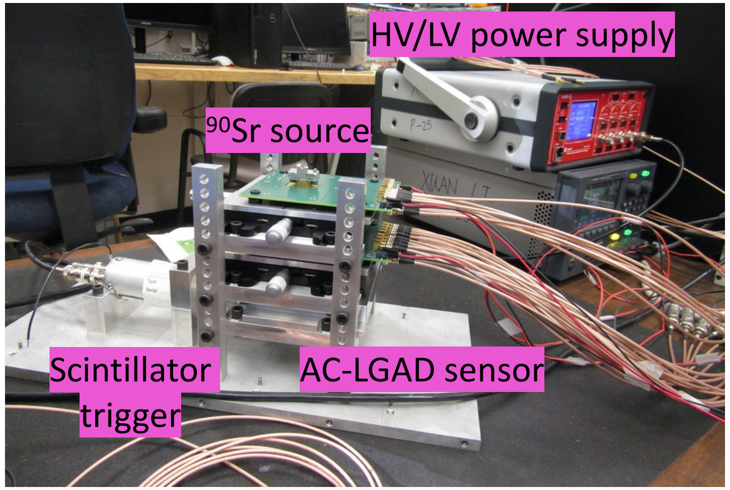
R&D test result example: LGAD and AC-LGAD

- Feasibility tests of a two-layer AC-LGAD telescope using a ^{90}Sr source.

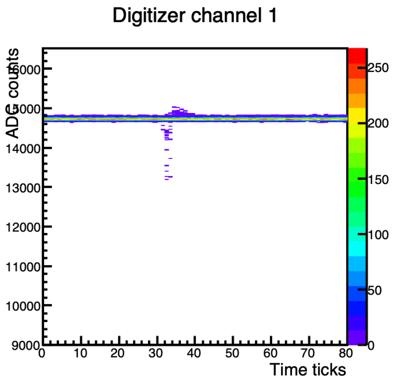
Mechanical design of 3-layer LGAD (AC-LGAD) telescope



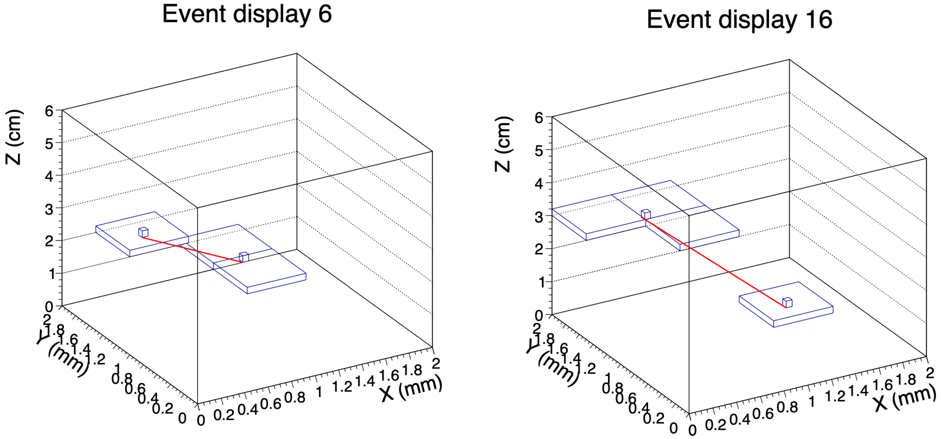
2-layer AC-LGAD telescope ^{90}Sr tests



Digitized pulse shape VS time tick (2ns) for individual pixel from the ^{90}Sr source tests.



Event display of reconstructed electron tracks

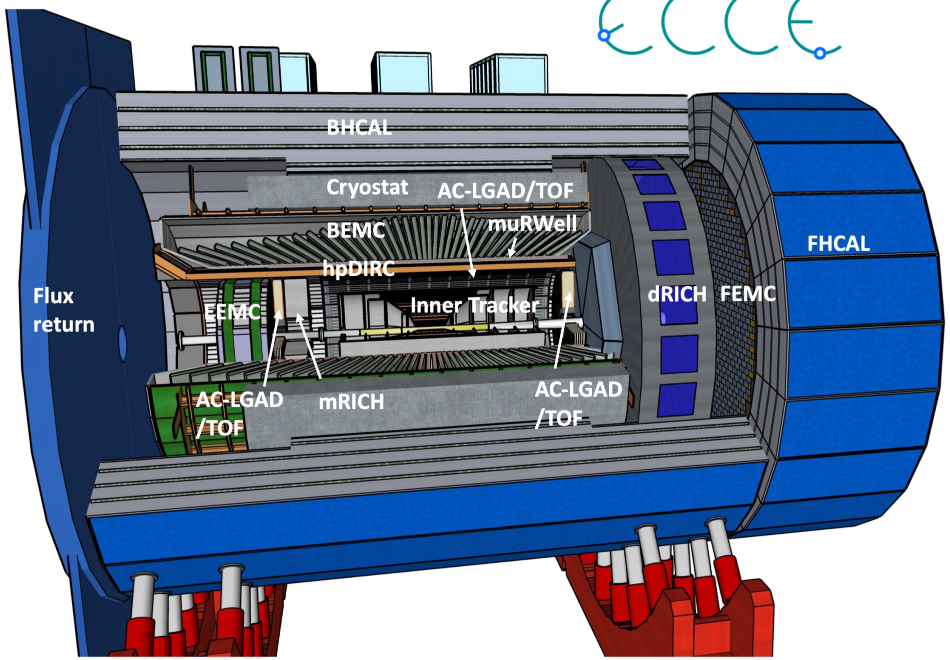


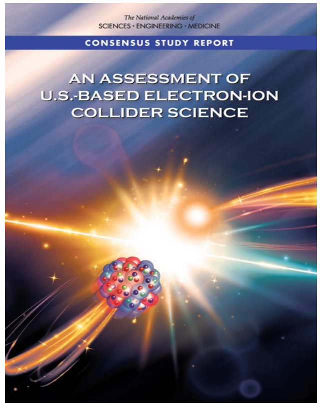
- **Irradiation tests will be performed at LANL LANSCE.**
- **MALTA R&D results are shown in the backup.**

- Tracking performances such as efficiency, spatial and temporal resolutions are under study with the 3-layer telescope configuration.

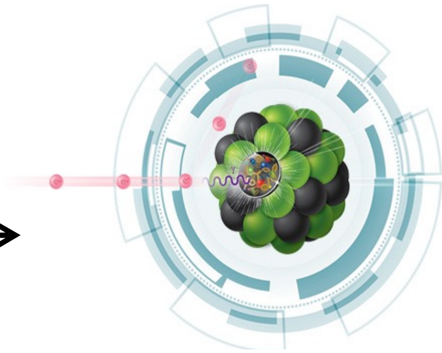
Summary and Outlook

- Great progresses have been achieved for the EIC silicon detector R&D, design and associated physics developments.
- The FST has been integrated into the EIC selected detector: ECCE.
- we look forward to work with more collaborators for the EIC detector/experiment realization.





NAS review	EIC CD0	EIC CD1	EIC CD2	EIC CD3	EIC CD-4a	EIC CD-4
2018	2020	2021	2023	2024	2030	2033

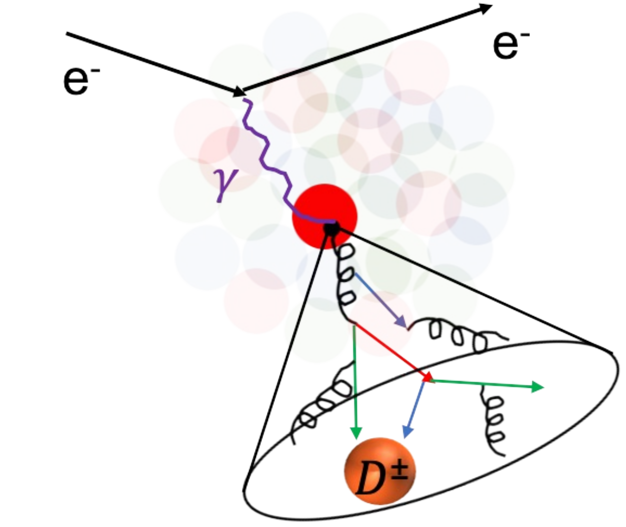


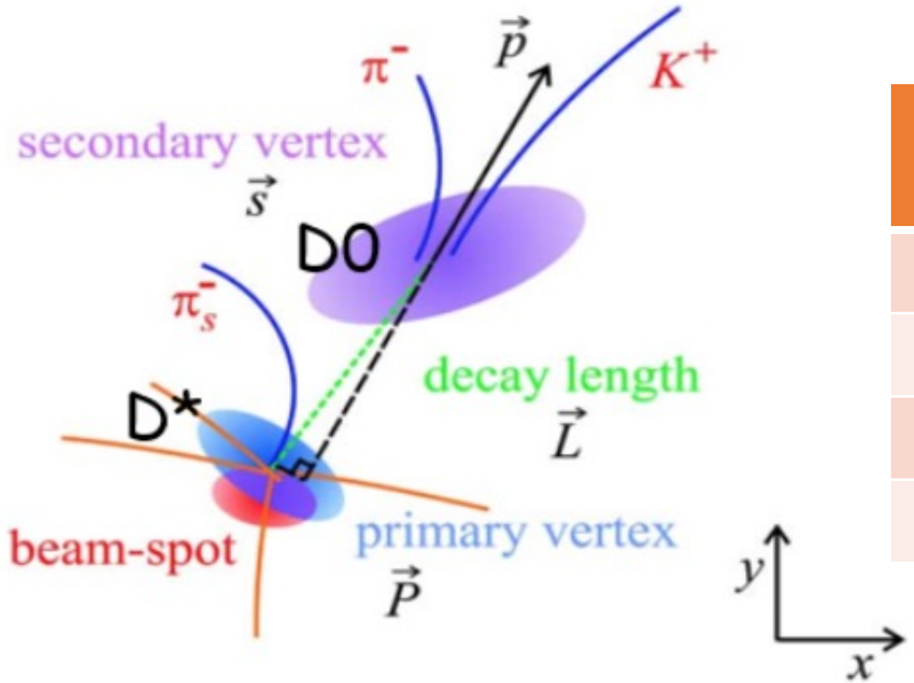
Backup

How to measure heavy flavor products?

- Hadrons containing heavy quarks (charm/bottom quarks) usually have a short lifetime compared to light flavor hadrons. They can be identified by detectors using their unique lifetime and masses.

$e^- + \text{Au} \rightarrow e^- + jet(D^{\pm}) + X$



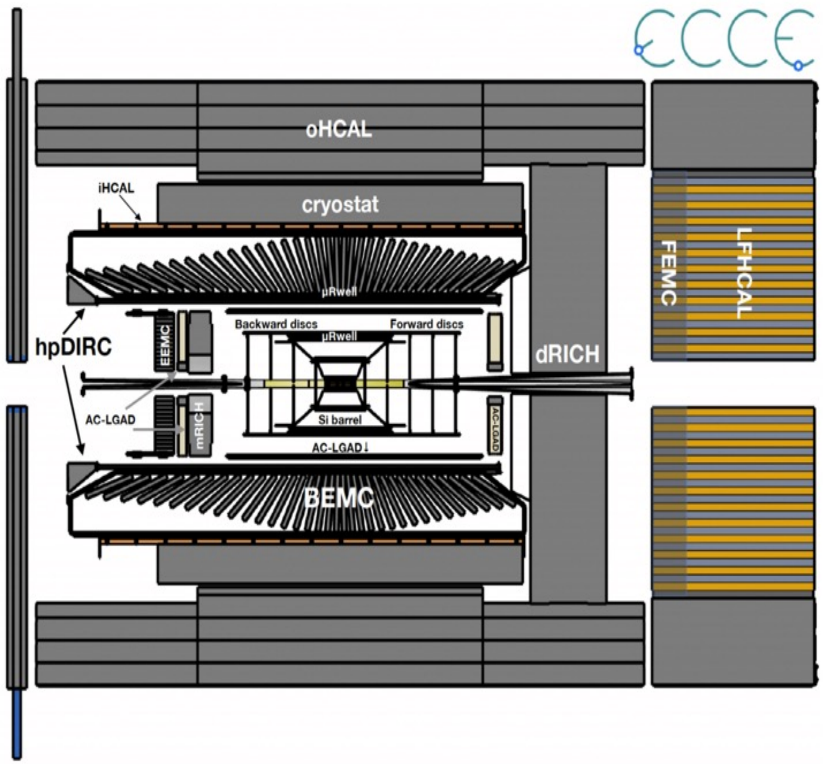


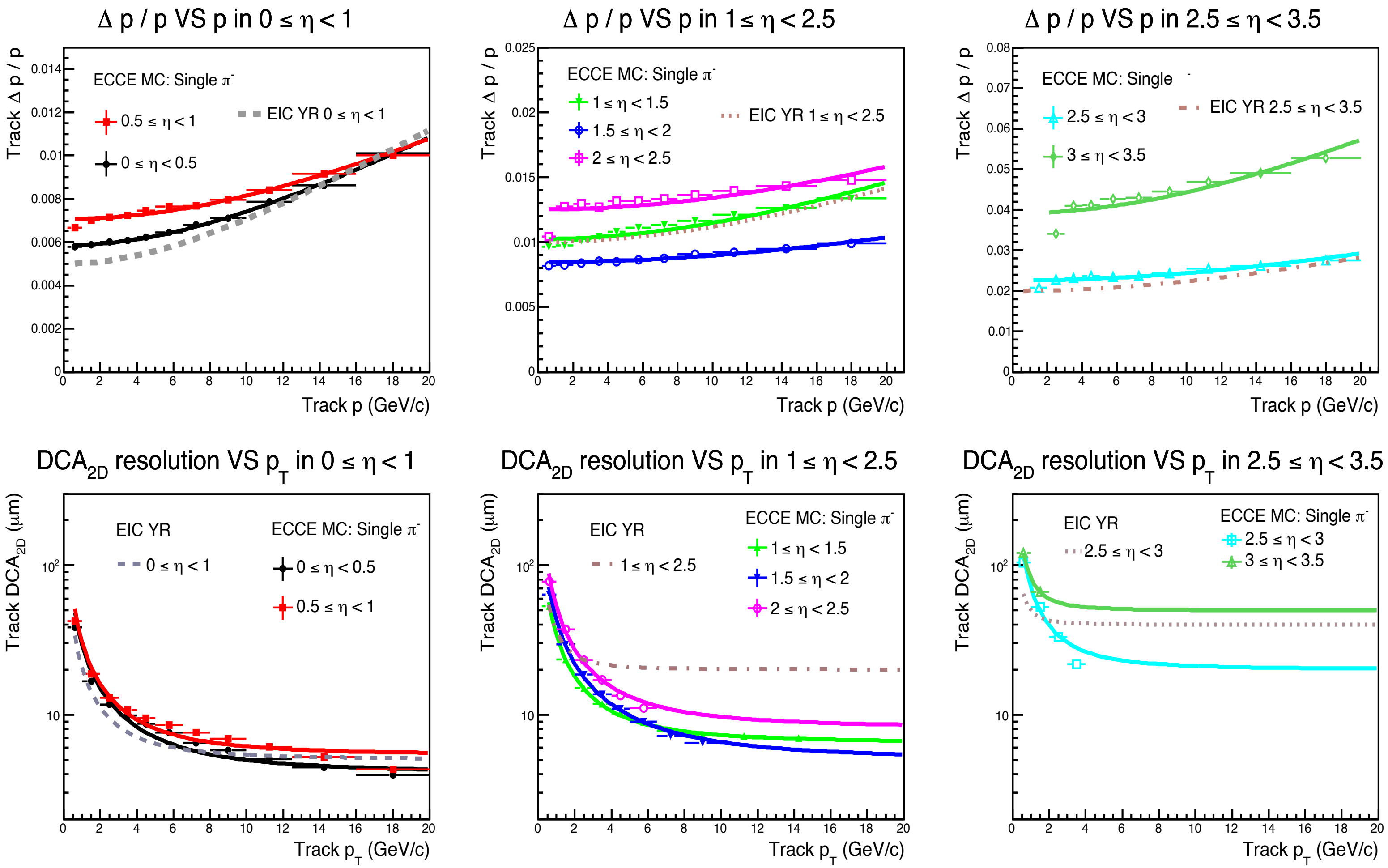
Particle	Mass (GeV/c^2)	Average decay length
$D^{\pm}$	1.869	312 micron
D^0	1.864	123 micron
$B^{\pm}$	5.279	491 micron
B^0	5.280	456 micron

- A high granularity and low material budget silicon vertex and tracking detector is required to identify heavy flavor particles.

Tracking performance evaluated in GEANT4 simulation

- Integrated MAPS, μRwell and AC-LGAD tracking detectors at ECCE provide precise momentum and transverse DCA_{2D} resolutions.

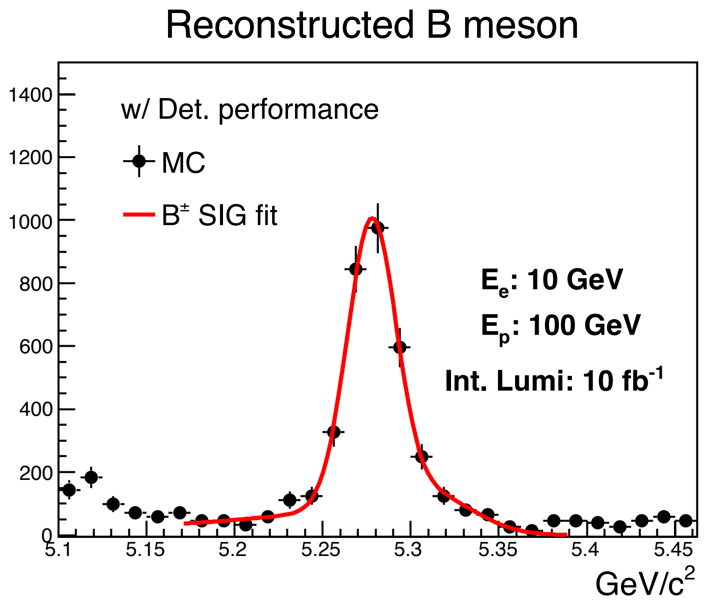


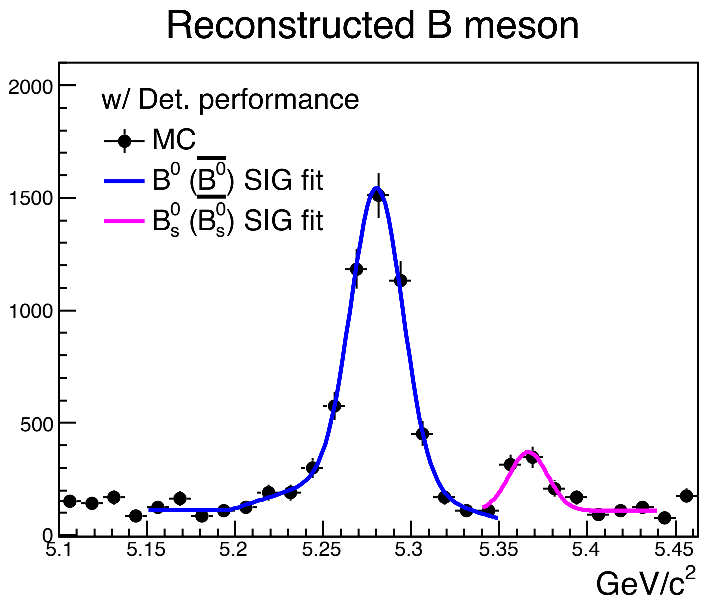


Reconstruction of heavy flavor hadron in e+p simulation

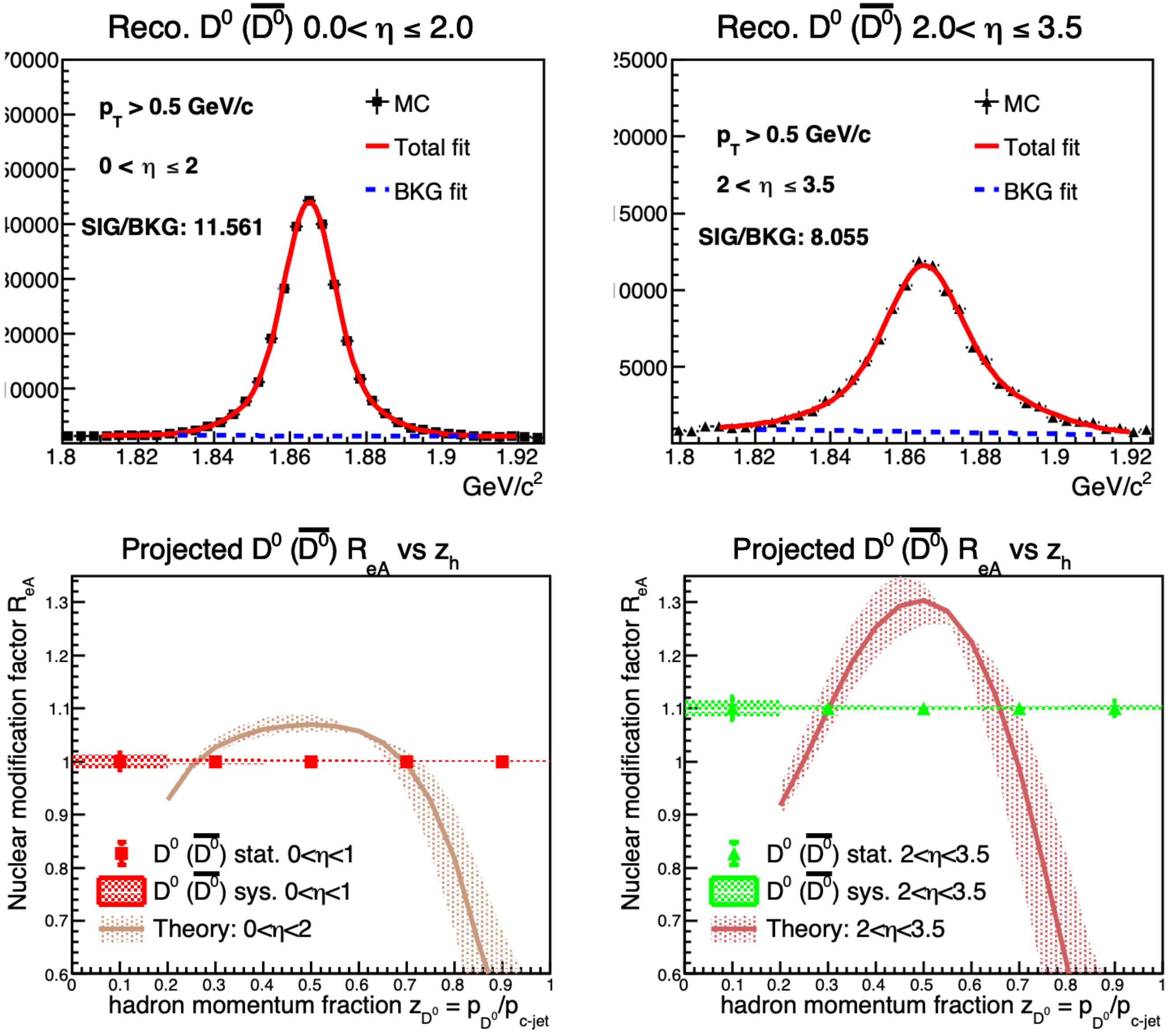
- The full analysis framework which includes the event generation (PYTHIA), detector response in GEANT4 simulation, beam remnant & QCD background, and hadron reconstruction algorithm have been setup.
- Mass distributions of reconstructed bottom hadrons using the proposed EIC tracking and PID detector performance inside the Beast magnet in 10 GeV electron and 100 GeV proton collisions with integrated luminosity: 10 fb^{-1}.

arXiv:2009.02888





Forward heavy Flavor signals enabled by the FST

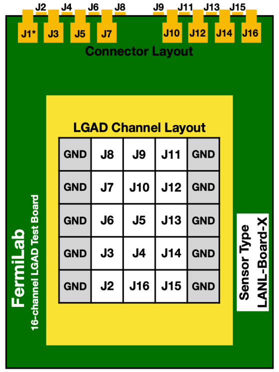


- Clear and pronounced $D^0(\overline{D^0})$ signals have been found in e+p simulation with the latest EIC accelerator and detector design.
- The associated reconstructed cross section ratios (R_{eA}) shed light on exploring the hadronization in vacuum and nuclear medium with better precisions than theoretical predications.

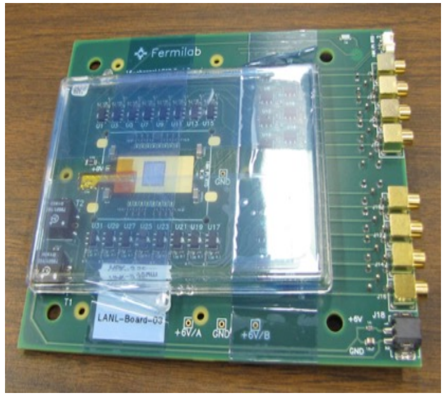
Advanced silicon technology candidates for EIC silicon tracker

- Several advanced silicon technologies are being tested at LANL.

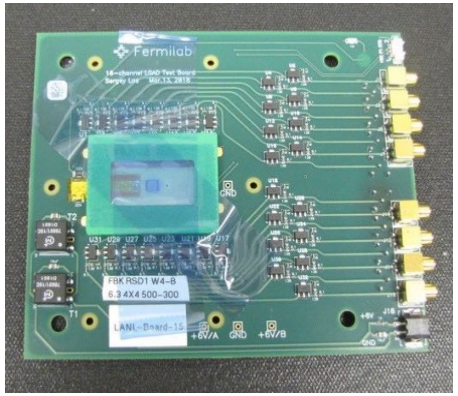
LGAD pixel map 3X5 Matrix



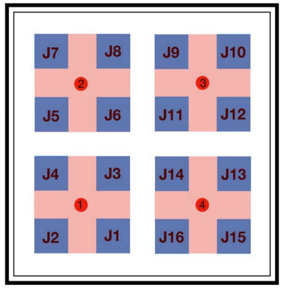
LGAD Carrier Board



AC-LGAD Carrier Board



AC-LGAD pixel map 4X4 Matrix



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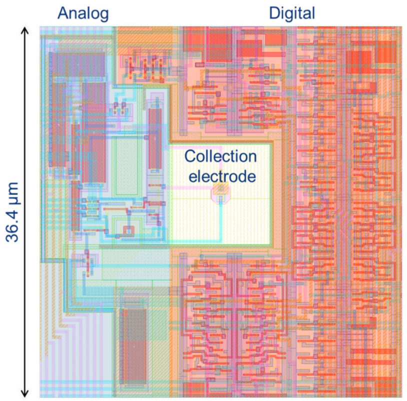
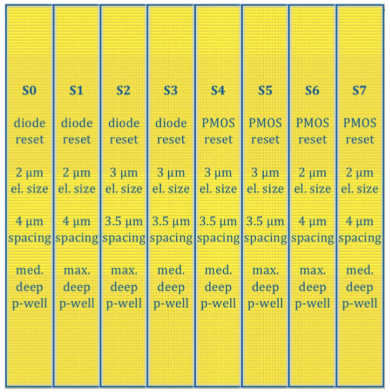
MALTA Carrier Board

MALTA Pixel diagram



MALTA sensor diagram 512X512 Matrix



Low Gain Avalanche Detector (LGAD) and AC-Coupled LGAD (AC-LGAD)

Pixel size: 0.5 to 1.3 mm

Spatial resolution: ~30 μm

Time resolution: <30 ps

Depleted Monolithic Active Pixel Sensor (e.g., MALTA)

Pixel size: 36.4 μm

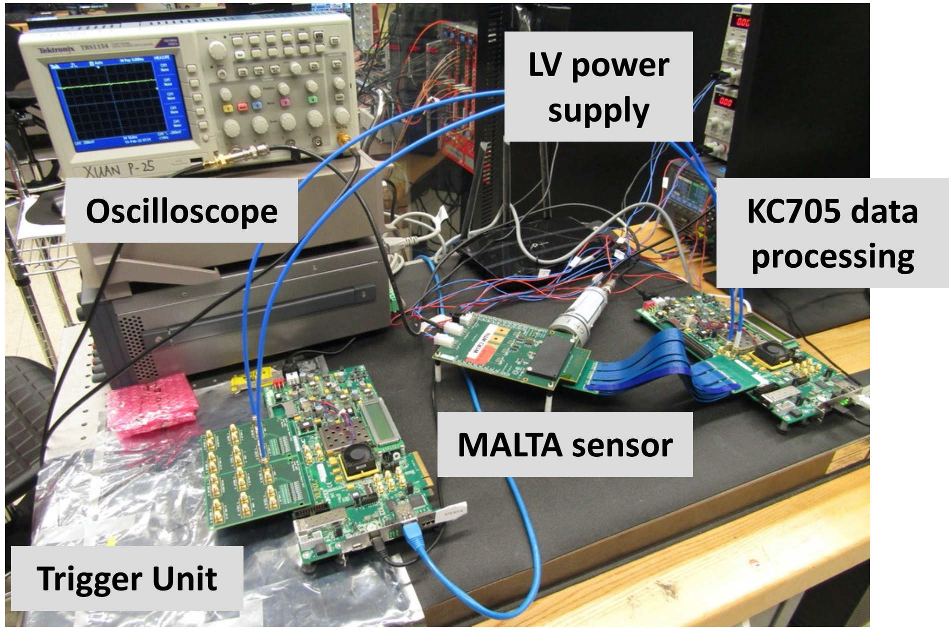
Spatial resolution: ~7 μm

Time resolution: ~2 ns

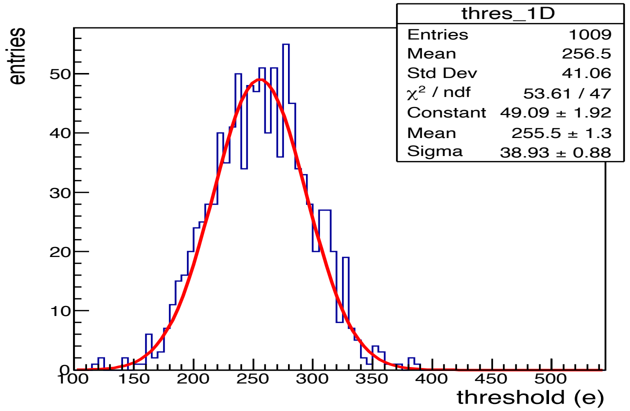
MALTA R&D test results

- Threshold and noise scan has been performed.
- Hit occupancy has been studied with the ^{90}Sr source.

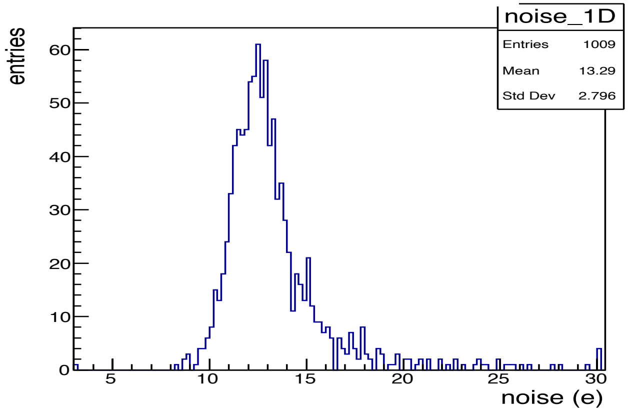
MALTA prototype sensor bench test



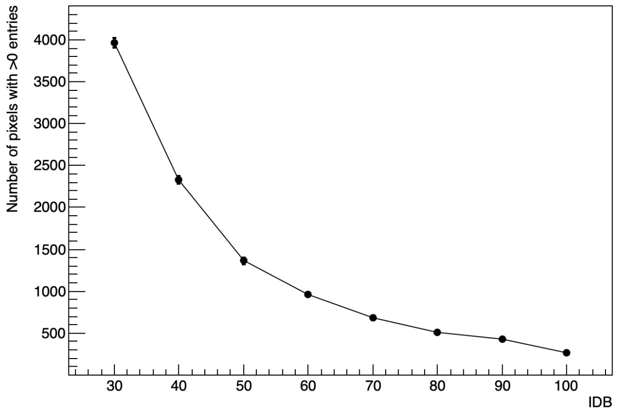
Threshold scan



Noise scan



Noisy pixel rate VS IDB value



^{90}Sr source hit occupancy