Simulation and instrumentation for the future Electron-Ion Collider

WANG, Pu-Kai 2nd year PHD student of IJCLAB

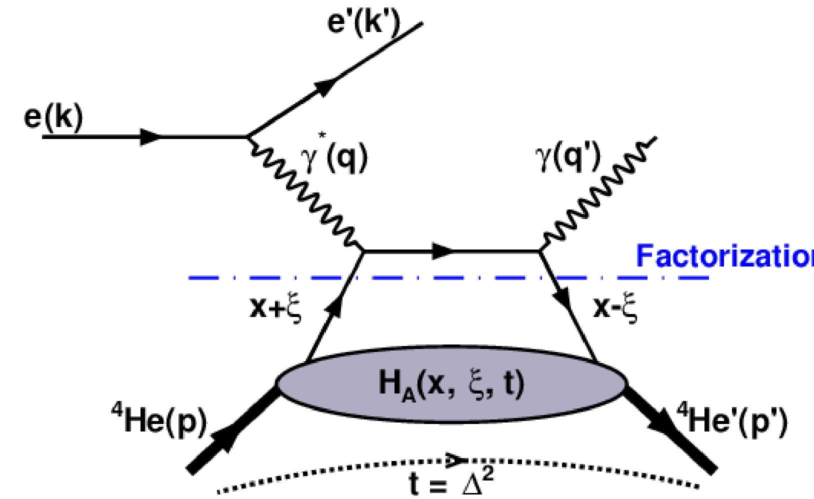
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

24/05/2022

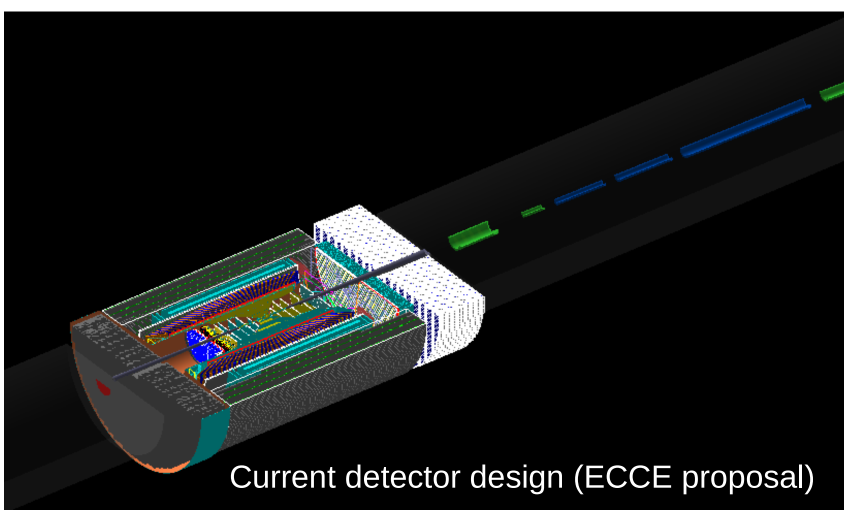
Exclusive process in future EIC

- The Generalized Parton Distribution (GPD) framework is a recent approach to understand the nucleon structure in further detail. It can also be used to study the spin structure of the proton.

- Deep Virtual Compton Scattering (DVCS) is a exclusive process that can provide access to the GPDs of the proton
  $e^- + p \to e^- + \gamma + p$

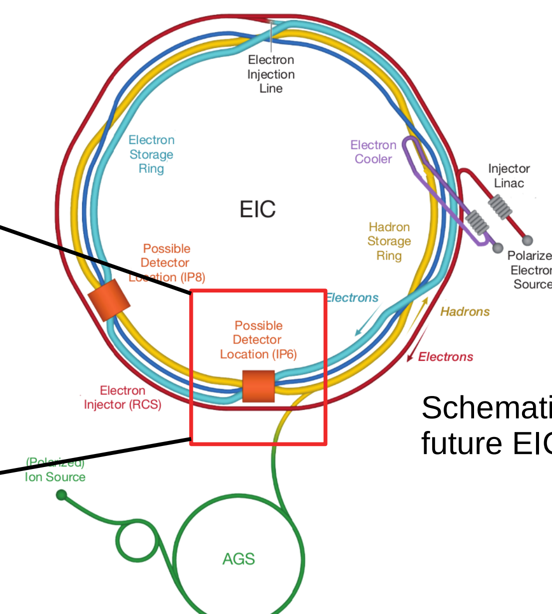


- A new electron ring will be added to Relativistic Heavy Ion Collider (RHIC) and the requirements:
  - highly polarized e- beam(~70%) and proton beam(~70%)
  - ion beam from deuteron to gold, lead or uranium
  - high luminosity: 10^{33}~10^{34} $cm^{-2}s^{-1}$
  - e^-+proton center of mass energy up to 140 GeV



Current detector design (ECCE proposal)

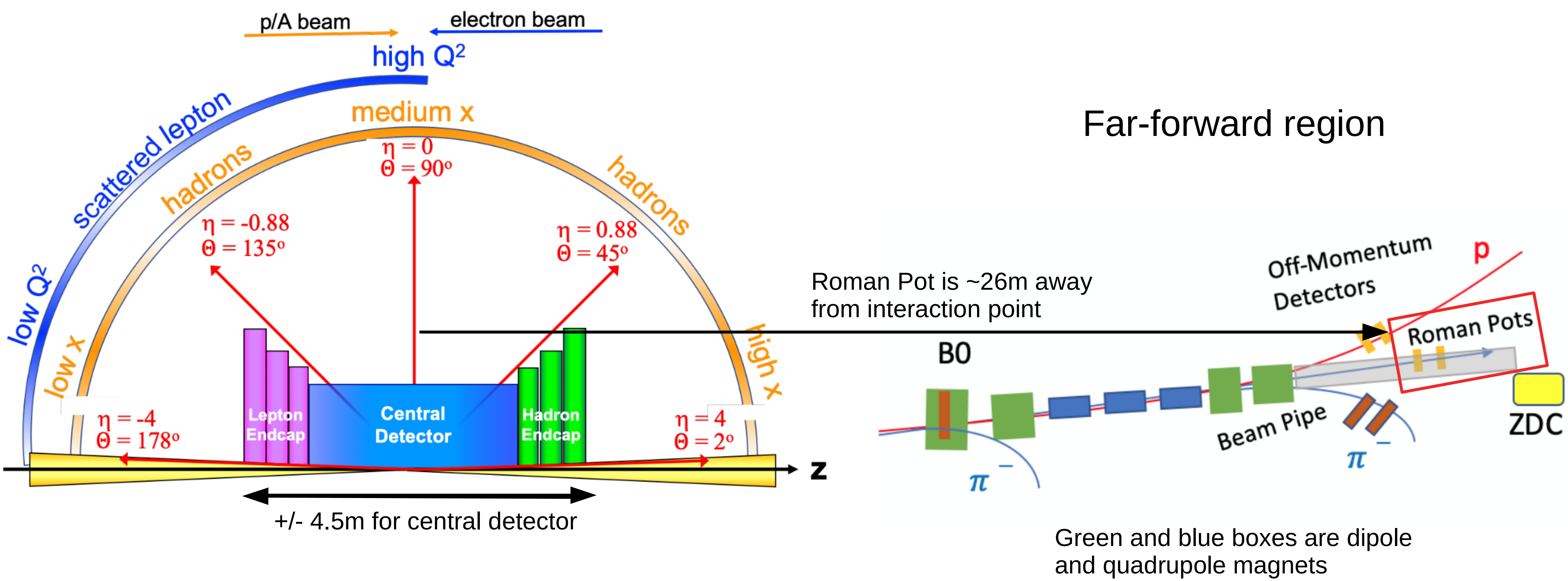
The first data taking will be in 2030



Schematic view of future EIC at BNL

Exclusive process in future EIC

- In the DVCS process, $e^- + p \rightarrow e^- + \gamma + p$
  - most scattered e- and photons go to the lepton Endcap and some toward the barrel detector.
  - The recoil protons go to the far-forward region and will be detected by the Roman Pots



Outline

- Backward endcap EM calorimeter and Roman pot play an important role in DVCS process measurement $e^- + p \to e^- + \gamma + p$

- Our Work on backward endcap EM calorimeter:
  - crystal property measurements
  - construct the EEMC configuration in simulation

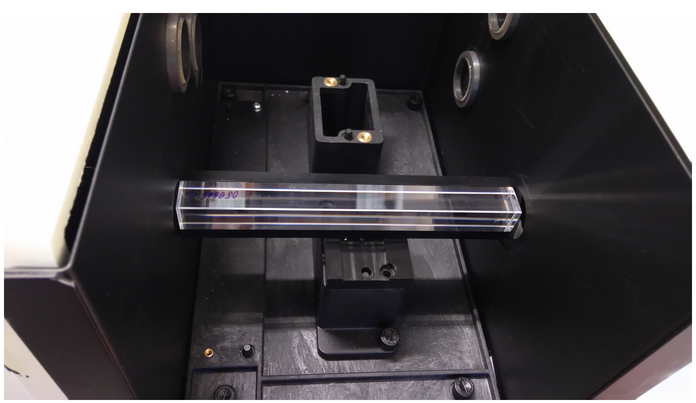
- Our work on Roman pot:
  - silicon sensor characteristic measurements
  - simulation study regarding the position resolution

Calorimeter - crystal radiation hardness

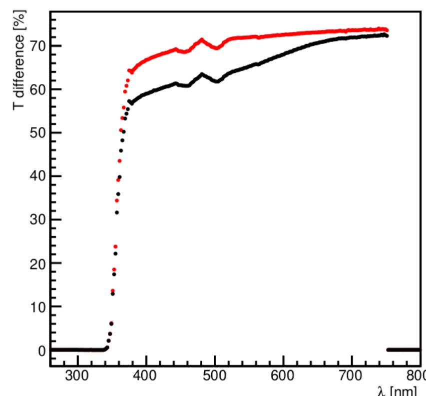
- Goal: determine crystals radiation hardness (30gy/year in end cap Calorimeter)
- Crystal: lead tungsten, manufacturer: Crytur
- Requirement: <20% transmittance loss after 30 Gy of radiation dose

Crystal property

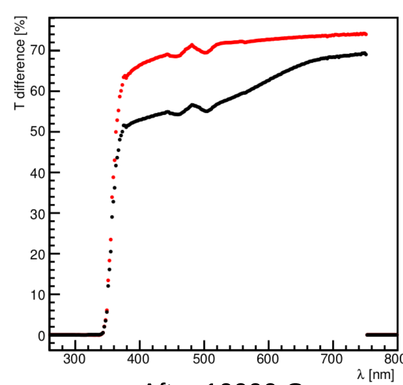
Parameter	PbWO4
Density	**8.28 g/cm^3**
Radiation length	**0.9 cm**
Emission peak[nm]	**420 nm**
Light yield	**15 p.e. / MeV**
Decay constant	**25 ns**



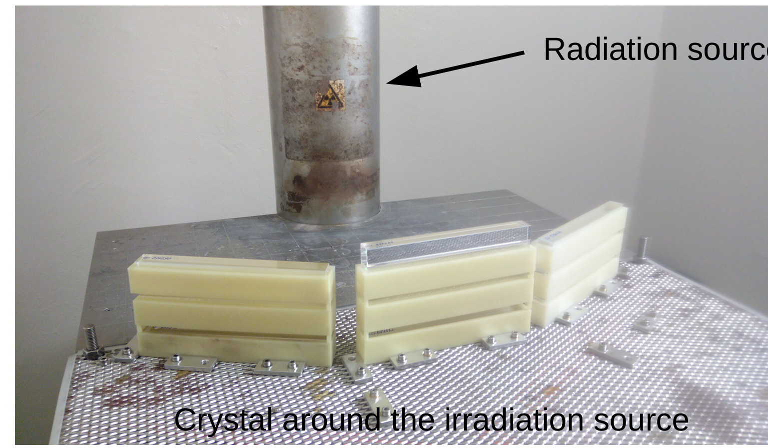
Crystal in the spectrometer

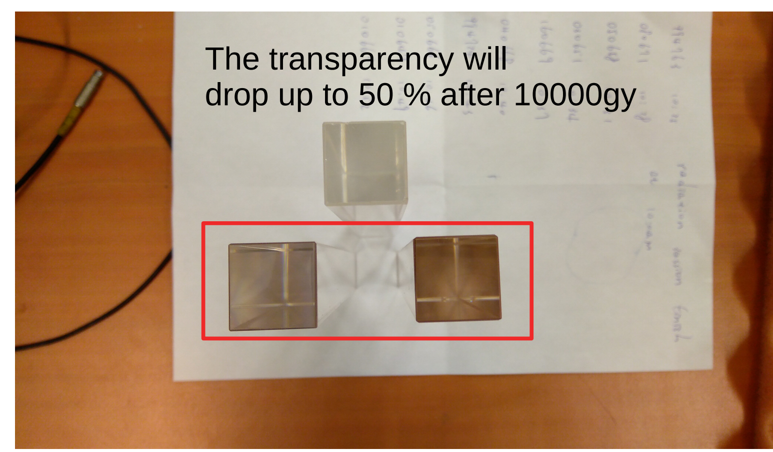


After 30 Gy dose
Loss of 10% transparency



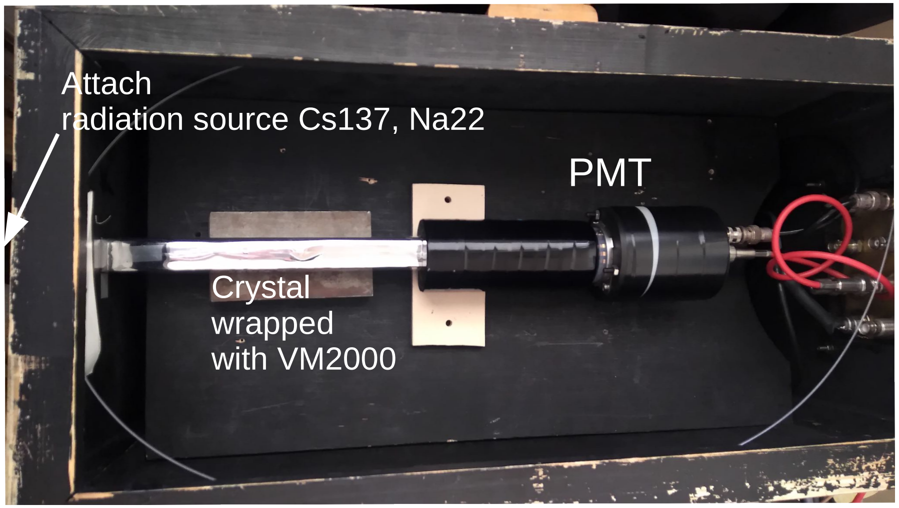
After 10000 Gy
Loss of transparency 20~50%

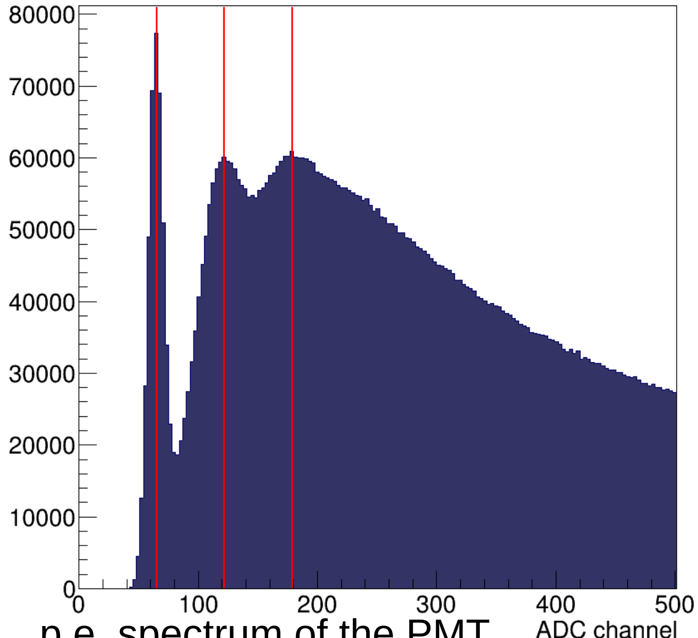




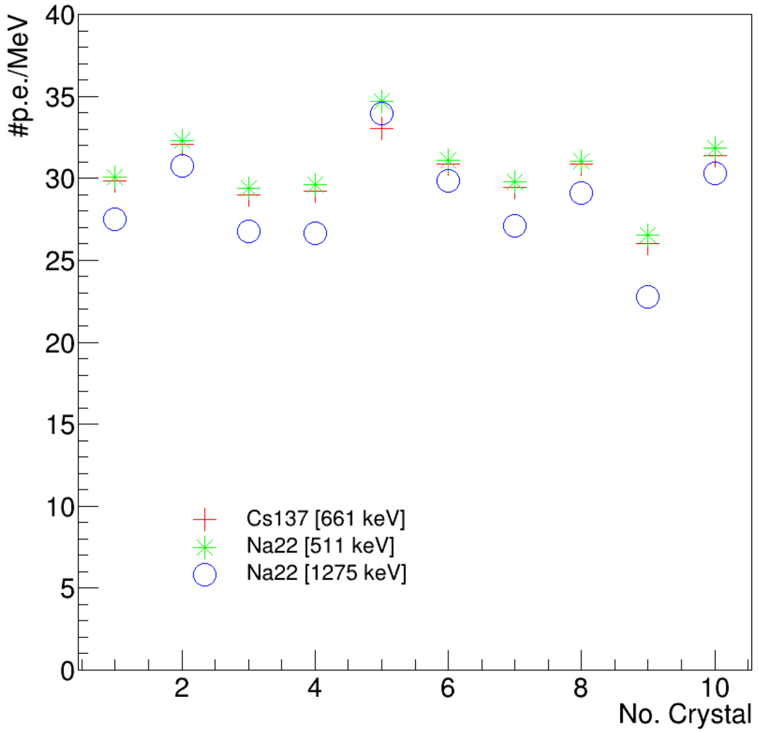
Calorimeter - crystal light yield

- Goal: use a Photo Multiplier Tube (PMT) to determine the crystal light yield.
- The crystal is wrapped with high reflective film
- The averaged light yield of 10 crystals: 30 photo-electrons (p.e.)





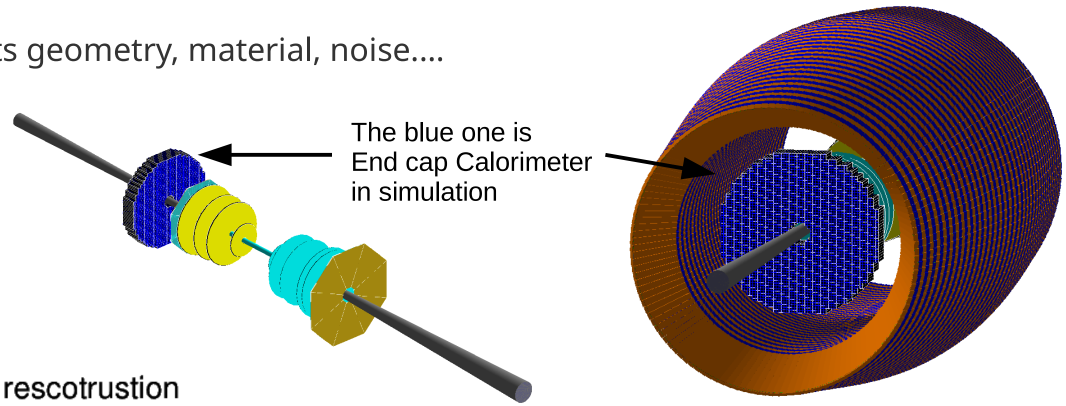
p.e. spectrum of the PMT

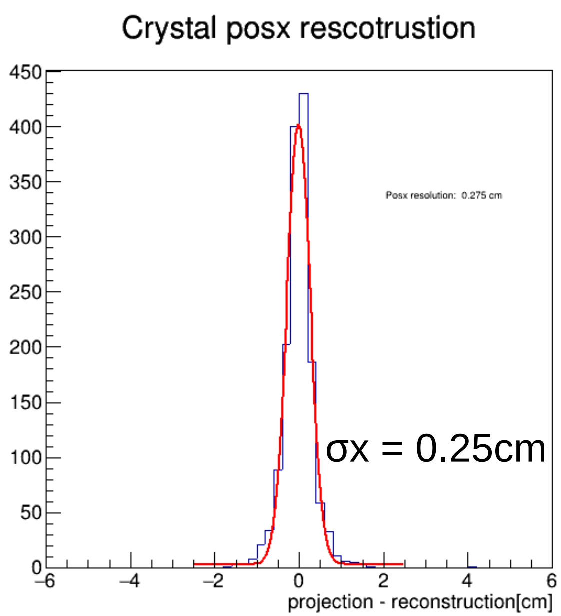


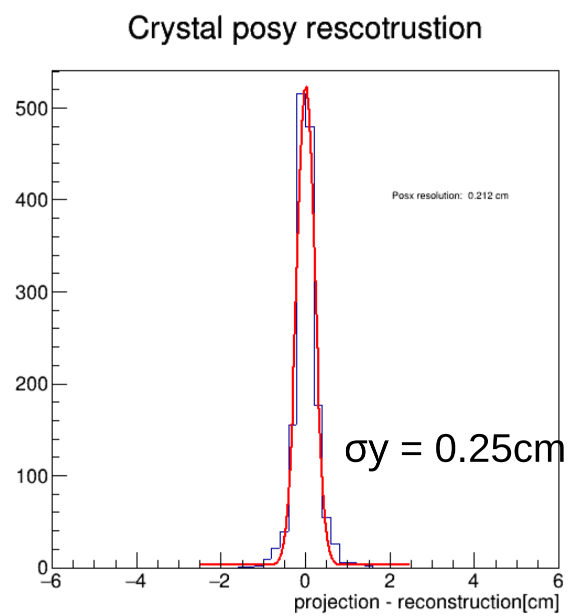
The light yield of 10 crystals with different radiation sources

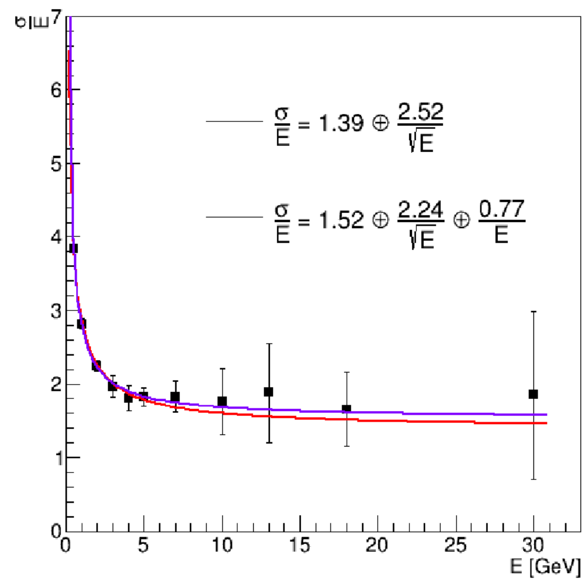
Calorimeter resolution study

- The backward End cap EM Calorimeter (EEMC) is placed at -1.75m from the interaction point and is composed of ~2000 crystals
- The position and energy resolution of the EEMC is related to its geometry, material, noise....
- The position resolution of the EEMC is ~10% of crystal size
- The energy resolution of the EEMC is good and consistent with the physics requirements

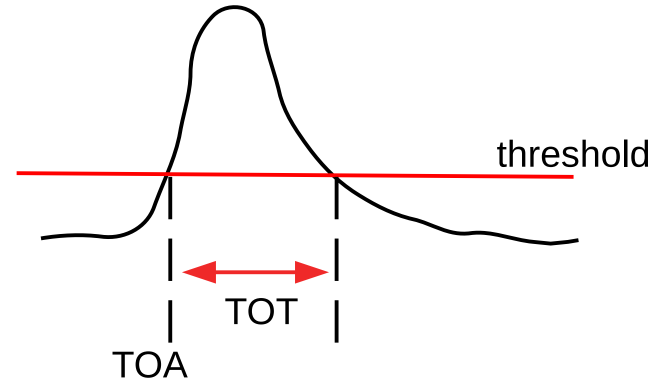




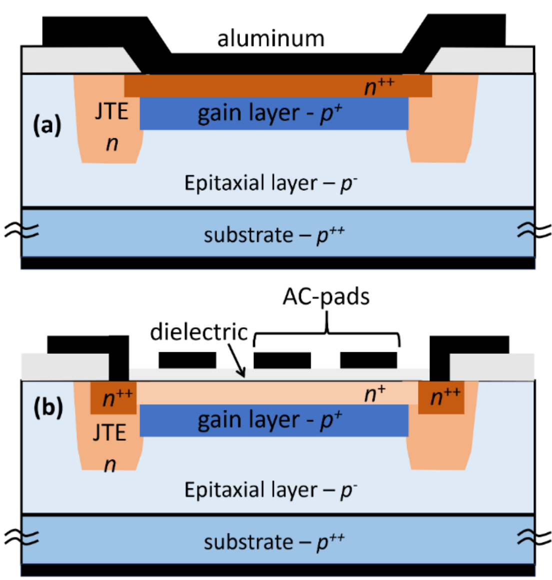




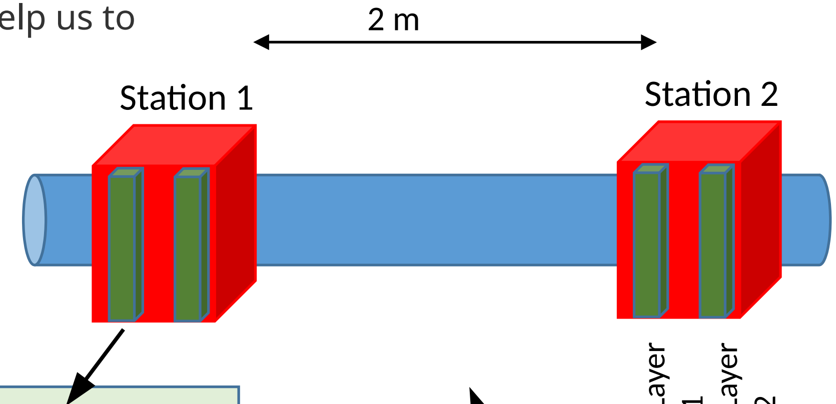
Roman Pots

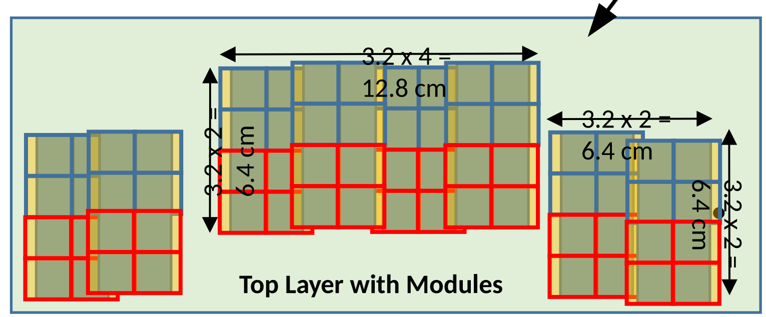


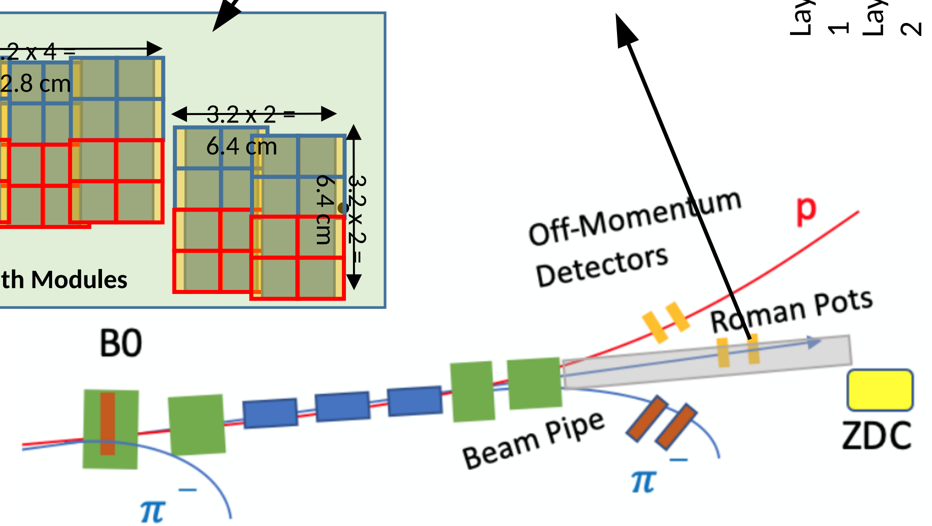
- AC couple-Low Gain Avalanche Diodes (AC-LGAD) are silicon sensors with:
  - good timing resolution
  - good position resolution (pixel size: 0.5x0.5 & 1.3x1.3 mm^2)
- Using the well developed ASIC, ALTIROC (2 TDC), as the readout to study the performance of AC-LGAD, sharing and the resolution
- Future EIC readout chip would be 1ADC + 1TDC. Simulation study would help us to know the which ADC resolution is optimized



LGAD used in HGTD detector of ATLAS





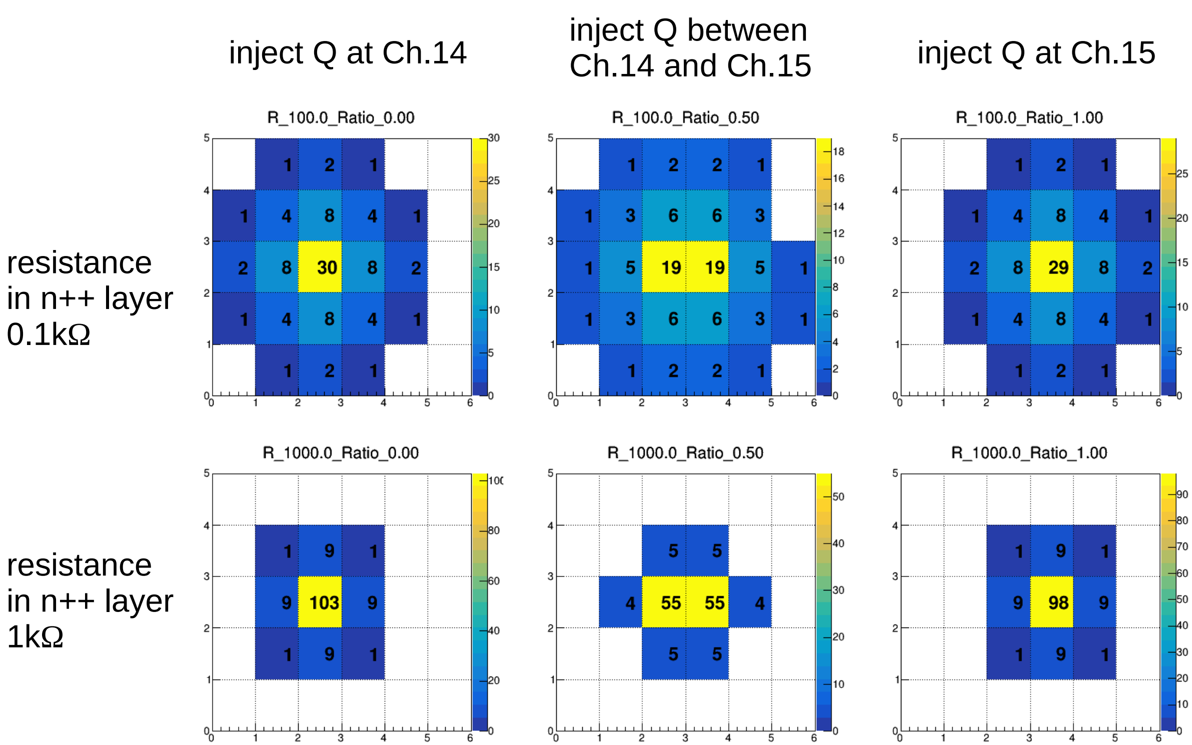


AC-LGAD is developed by BNL and the R&D is ongoing

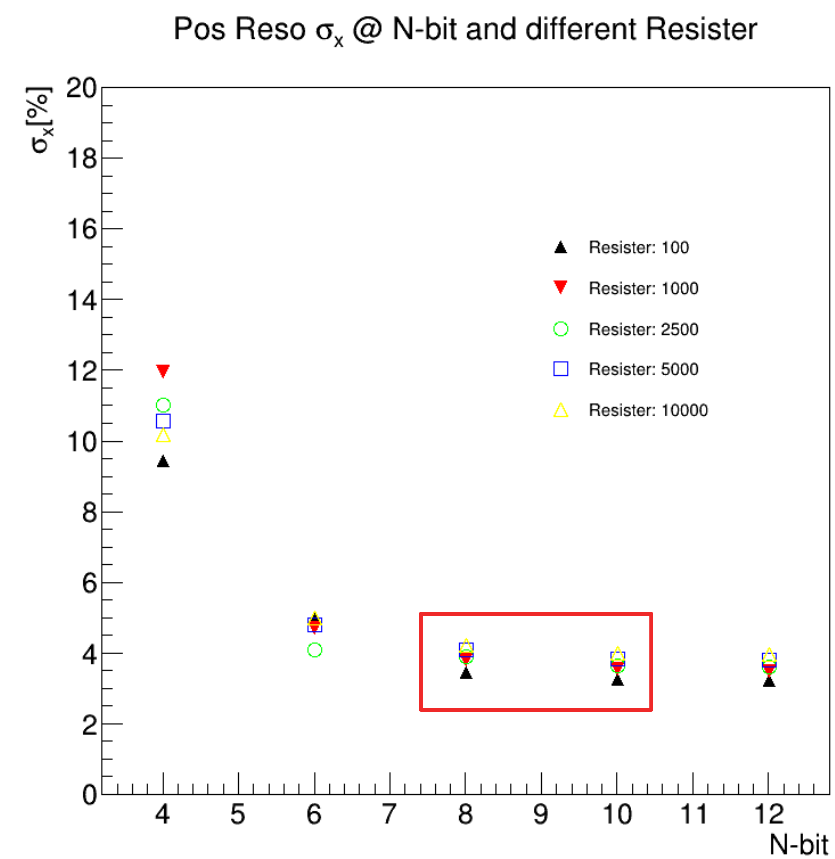
Simulation of signal sharing among neighboring pixels

- Different inject position, noise level and inject energy are simulated
- Implement the ADC algorithm
- Position resolution for different ADC resolution and resistor value
- We can reconstruct the injected position within 4% of the pixel size

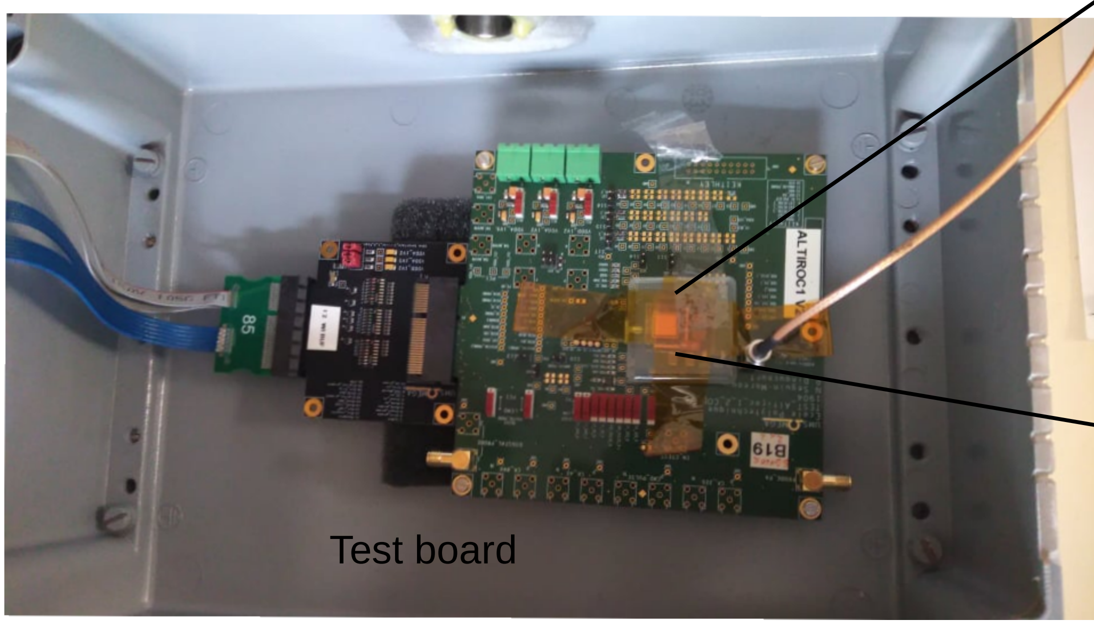
No significant σ_x difference between ADC-8 & 10 bit
And Due to the low power consumption and small size, **ADC-8bit is chosen**

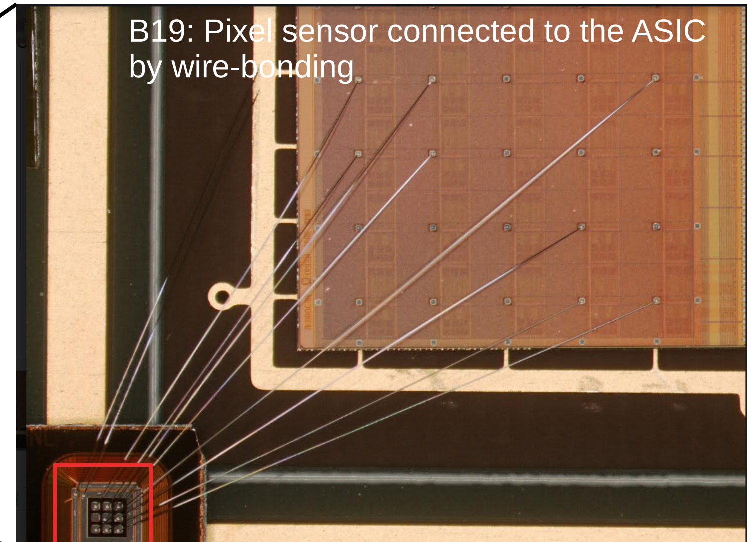


Simulation of charge sharing

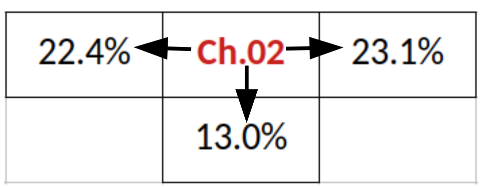


Sharing determination of AC-LGAD by charge injection

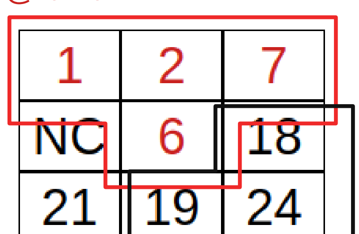




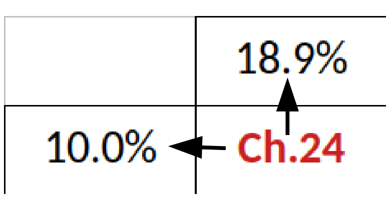
2 type of Preamp used here:
VPA: Voltage PreAmp
TZ: Transimpedence Preamplifier



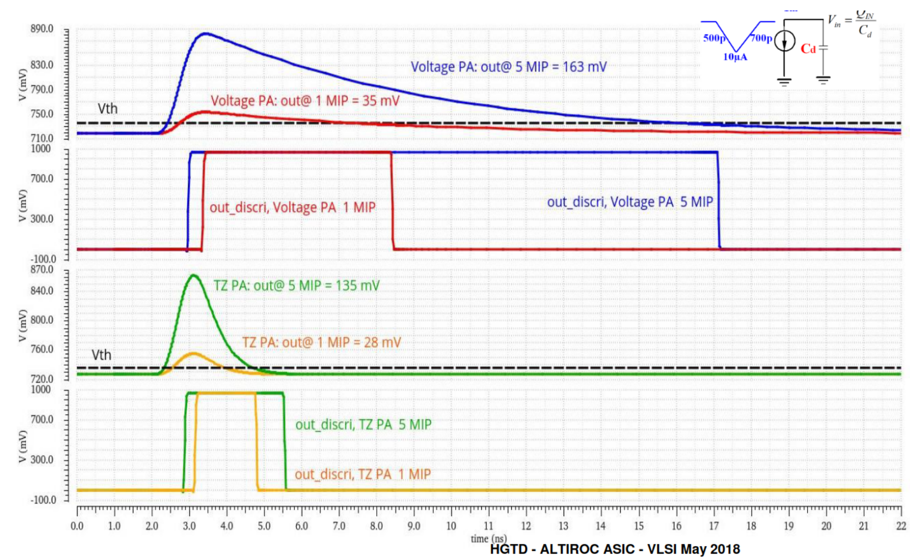
inject 8pF @ ch.02



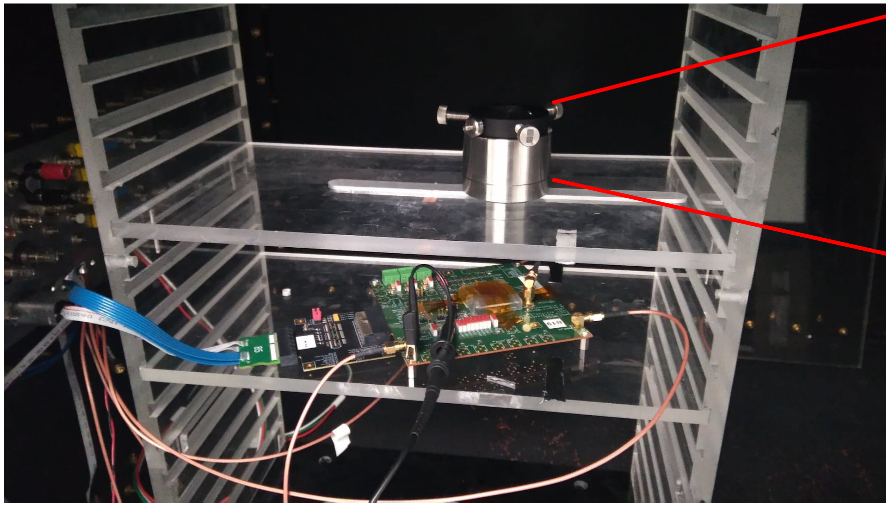
Sharing of charge injection

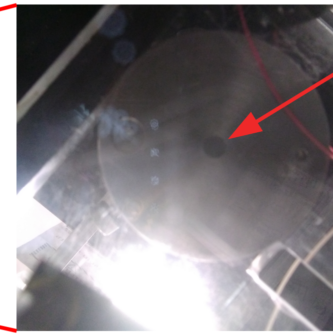


inject 8pF @ ch.24



Sharing determination of AC-LGAD by beta source

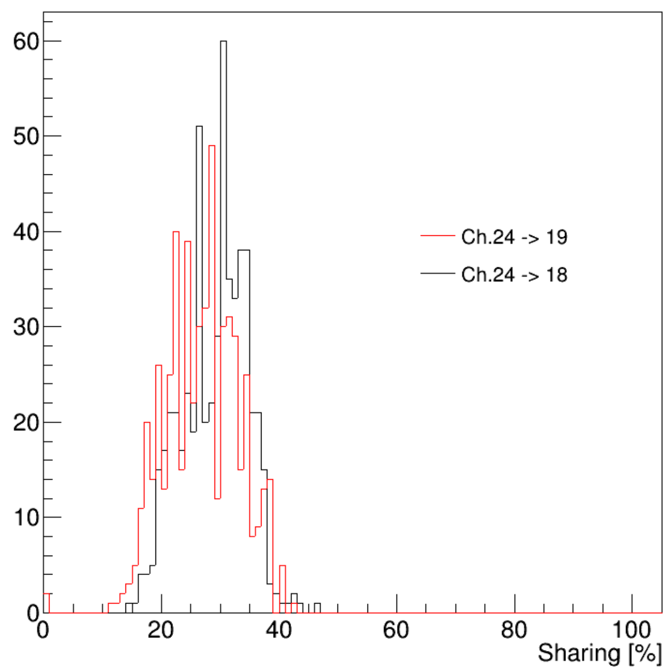




Beam hole for Sr-90 [37MBq]

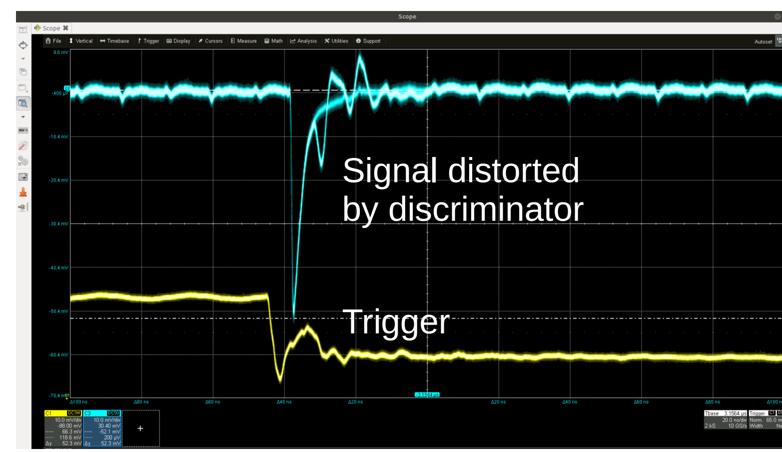
- The Beta source is placed right above sensor, 5~10 cm away.
- High voltage is -170V
- The whole setup put in black box

Sharing from Ch.24 to 18, 19



1	2	7
NC	6	18
21	19	24

24 share to 18 and 19
$TOT_{24} > TOT_{18}$ and $TOT_{24} > TOT_{19}$



- From the beta source measurement, we can get ~30% of sharing
- The discrepancy in inject charge and beta source measurements comes from the TDC distortion

Summary

- The radiation tests of 10 crystals proved their good radiation hardness
- The light yield of the 10 crystals measured are consistent and fulfill the criteria of the experiment
- The basic simulation construction of EEMC is completed and the performance is consistent with the requirements.
- The ADC-8bit will be adapted based on the chip position resolution study
- The sharing of AC-LGAD is determined by both charge injection(~15%) and beta source(~30%).

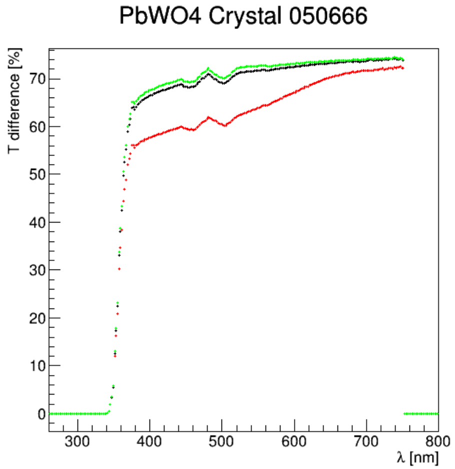
Outlook:

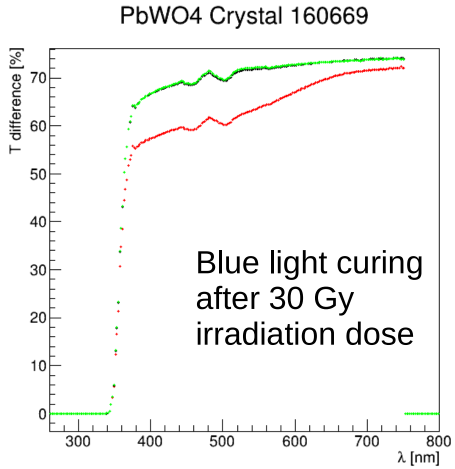
- More advanced simulations of the EEMC: mechanical structure, improved clustering, etc.
- Laser tests of the AC-LGAD sensors. Laser can offer desired charge injection and position

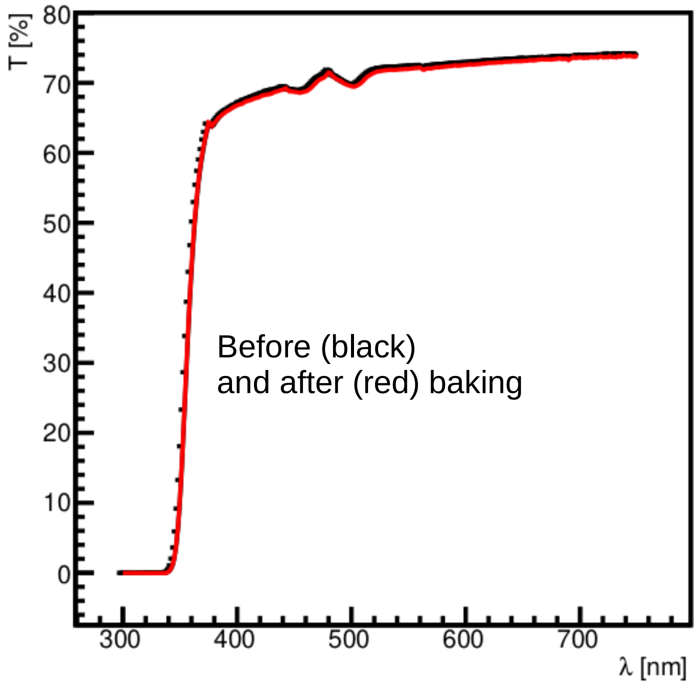
BACKUP

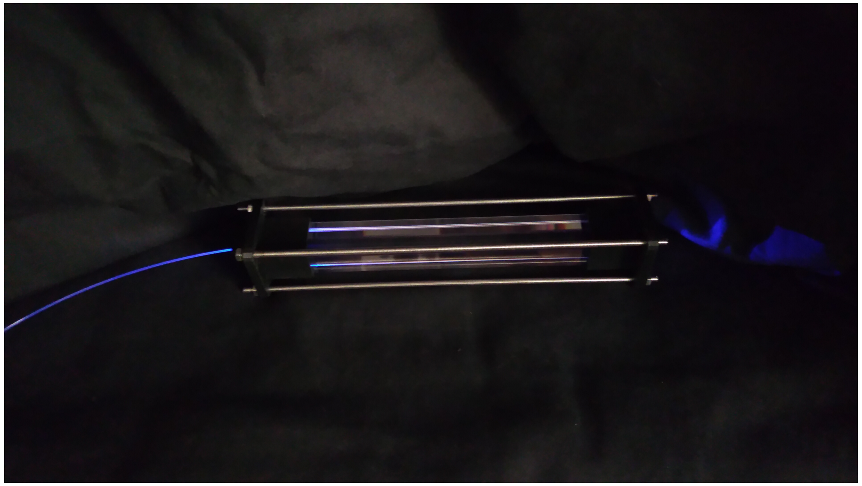
Backup
Calorimeter - crystal radiation hardness

- Goal: test the ability to recover the crystal transmittance
  - baking the crystal @250°C (works for both small and large damage)
  - expose the blue light (works only for small damage)



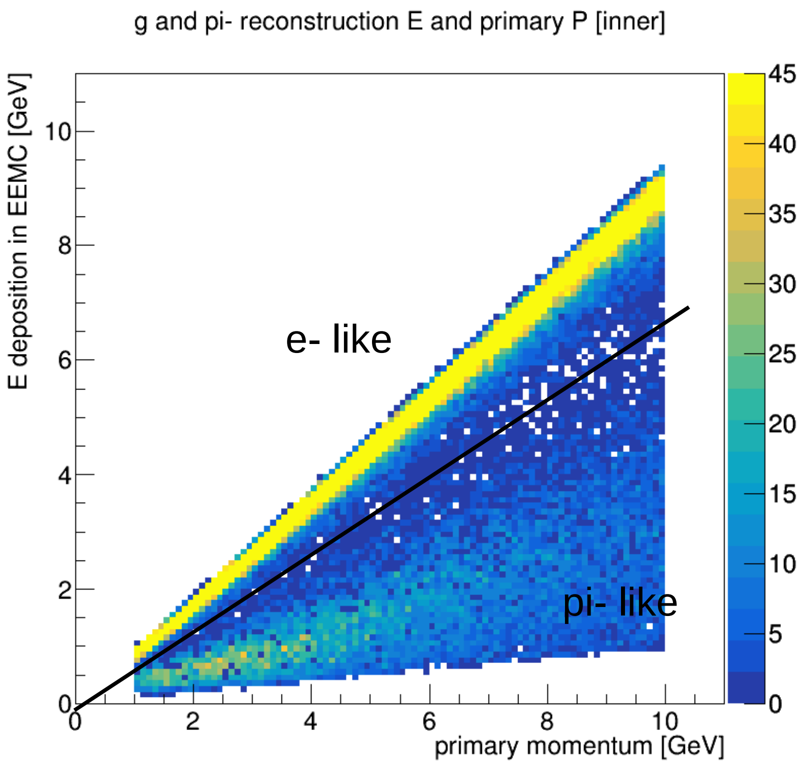


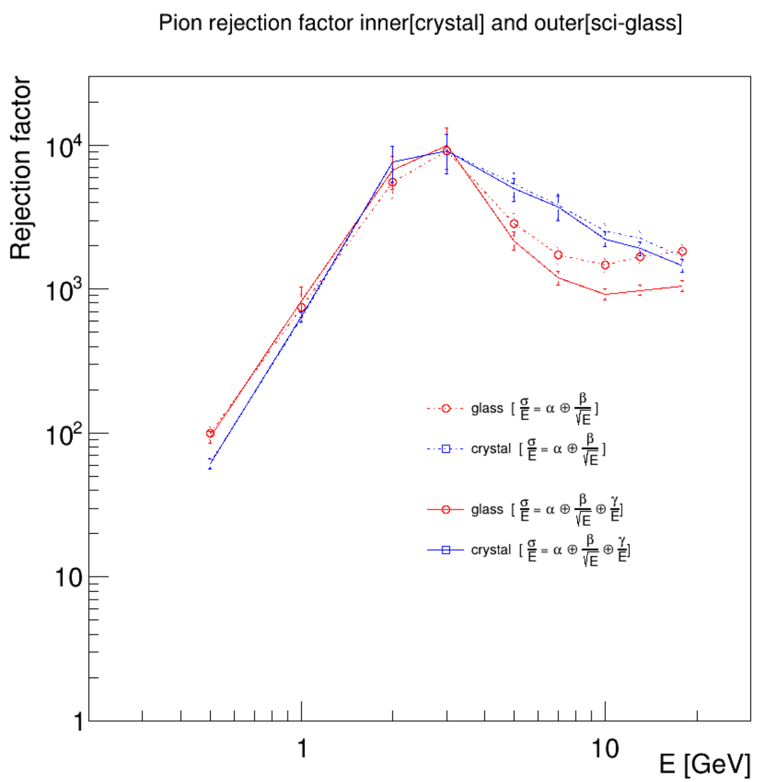




Backup
Calorimeter pion rejection

- EMCalorimeter can also be used for particle identification
- To separate e- and pi-, one can use the ratio of energy deposition (calorimeter) and momentum (tracker)

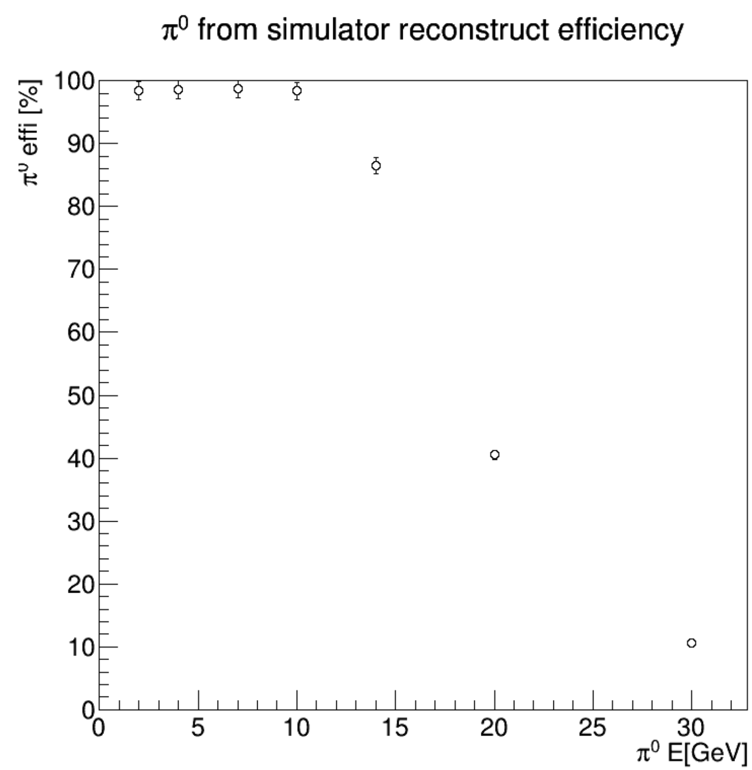




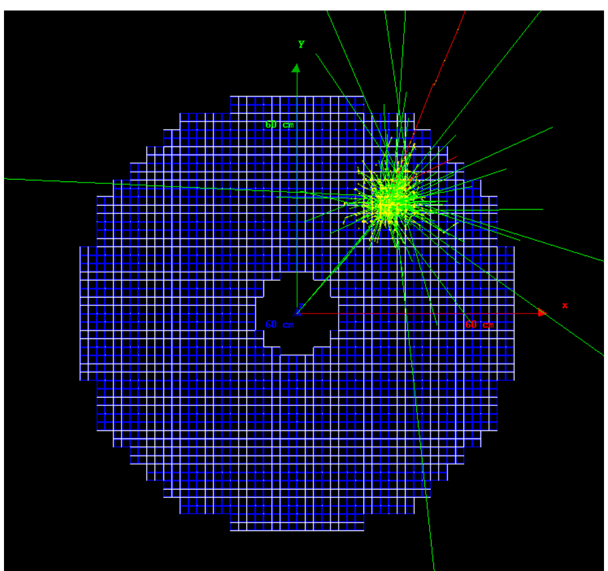
Pion rejection factor v.s. energy

Backup
Calorimeter Pi0 reconstruction

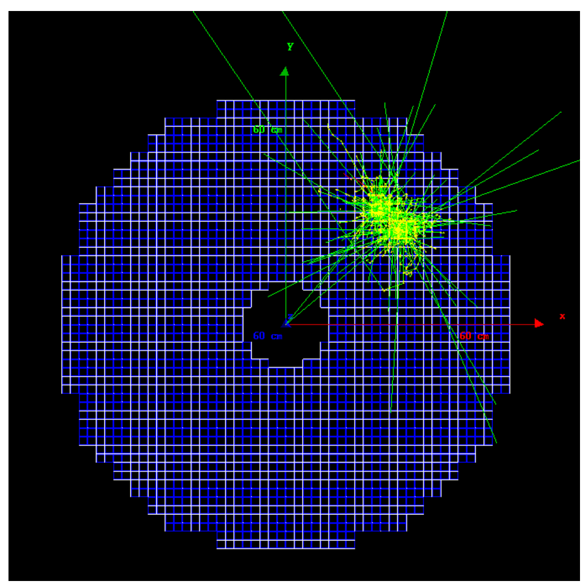
- DIS process -> pi^0 and photon in electron-going direction
- pi^0 -> 2g , br(0.988), pi^0 life time: 8.5x10-17s
- Calorimeter needs to separate two nearby photon
- The pi0 efficiency can be improved by the clustering algorithm (work in progress)



Single photon

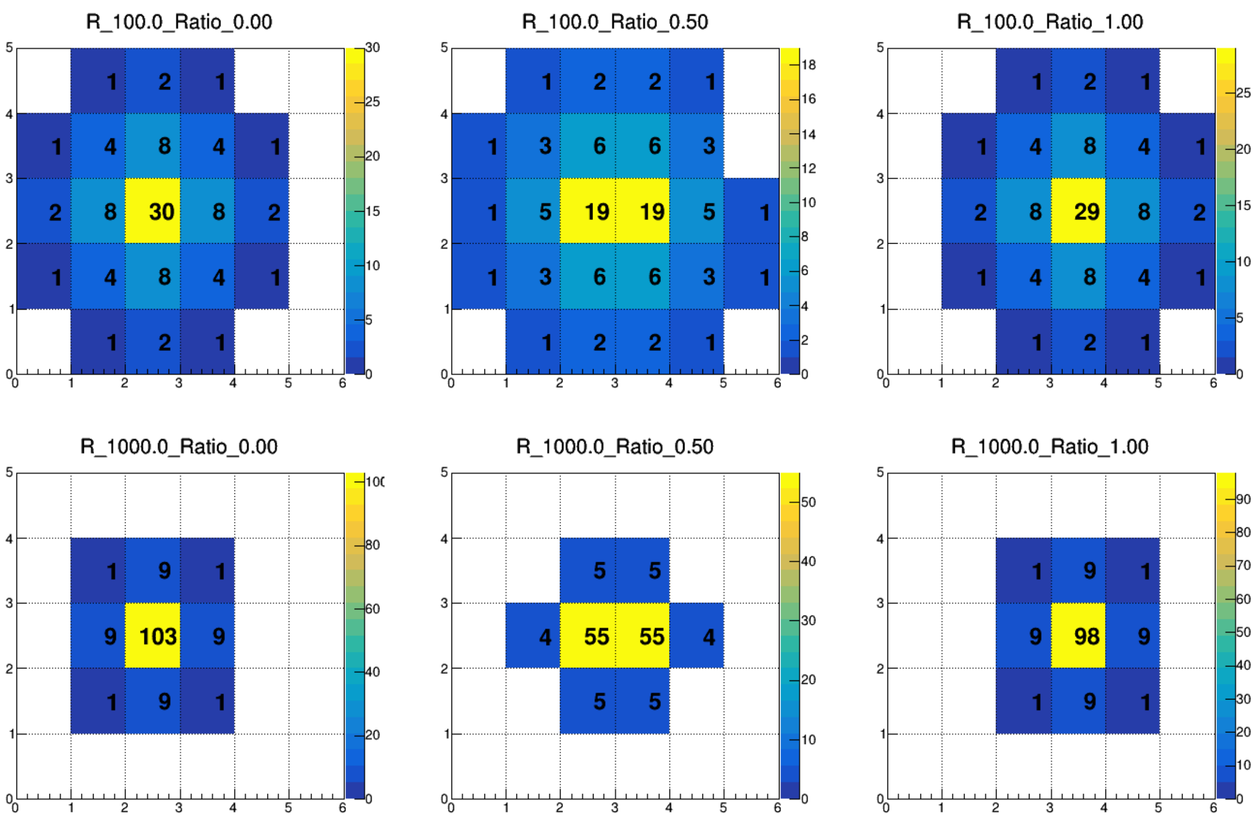


Two closed photon



Simulation of signal sharing among neighboring pixels

- The purpose is to know the difference in position resolution for ADC 8 or 10 bit
- The position of the injected charge can be calculated by: $\Sigma(Pos_i * V_i) / \Sigma V_i$
- The position resolution is the RMS of ΔD = (Reco Pos - Inject Pos)



the sharing map of different charge inject position and different resistor, unit[mV]