Status of the neutron-DVCS/BH simulation at CLAS12

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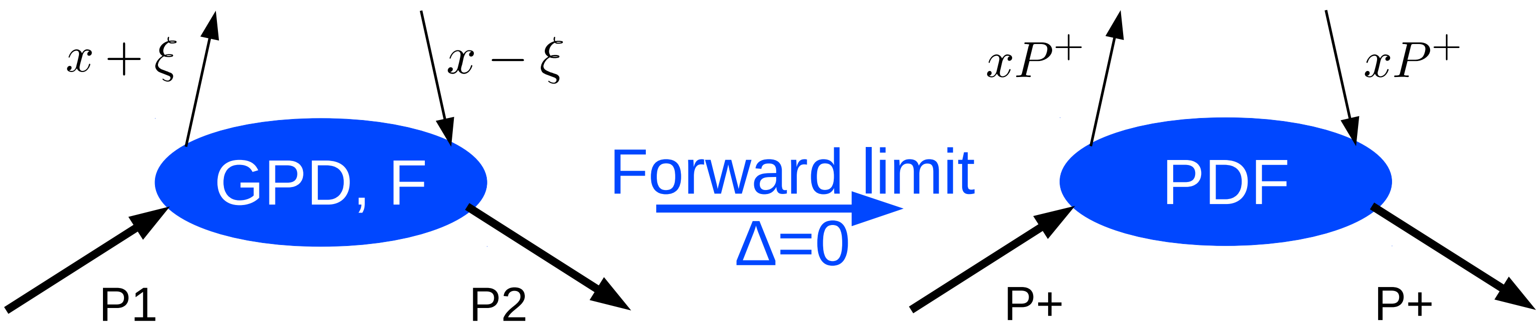
n-DVCS physics
Central neutron detector
Neutron reconstruction
Realistic simulation
Acceptance
Next step

Nucleon structure: GPD

- Generalized Parton Distribution (GPD) is the advanced description of nucleon structure beyond parton distribution function.

$$F^q(x,\xi,t=\Delta^2) = \int \frac{dz^-}{2\pi} e^{ixP^+z^-} < P_2|\bar{q}(-z)\gamma^+ q(z)|P_1 > |_{z^+=0,z_\perp=0}$$



$$\Delta = P_2 - P_1,\ \bar{M}^2 = M^2 - \Delta^2/4,\ \xi = (-\bar{P}\cdot q + \sqrt{(\bar{P}\cdot q)^2 + Q^2\bar{M}^2})/\bar{M}^2$$

GPDs are the useful information to know the transverse spatial position of partons, nucleon spin, the correlated q-qbar components...

DVCS is one of the popular reactions which access the GPDs.

Why neutron DVCS?

- Measuring neutron DVCS is highly complementary to measuring proton DVCS.

1) measuring both GPDs allows us to carry out a flavor separation (F=H, E, ...),

$$F^u(\xi,\xi,t) = \frac{9}{15}[4F^p(\xi,\xi,t) - F^n(\xi,\xi,t)]$$

$$F^d(\xi,\xi,t) = \frac{9}{15}[4F^n(\xi,\xi,t) - F^p(\xi,\xi,t)]$$

2) the beam spin asymmetry of n-DVCS is mainly governed by the GPD E, which is the least known GPD. To obtain the GPD E is important to understand the total angular momentum of the quark.

$$\frac{1}{2} = J_q + J_g, \quad J_q = \frac{1}{2}\int_{-1}^{1} dxx[H^q(x,\xi,t=0) + \underline{E^q(x,\xi,t=0)}]$$

E12-11-003 on CLAS12!

Experimental setup

- Polarized electron beam at 11 GeV and liquid deuterium target
- Final state particles: electron, neutron and gamma.

electron and gamma are detected at forward detectors & FTC, neutron is detected at central detectors.

Current simulation

- The full simulation is implemented to study the efficiency to detect neutron, acceptance, counting rate, run conditions…
- Softwares:

  genepi (event generator based on VGG model)

  + gemc (4a.2.2)

  + coatjava (5a.0.19)

GENEPI: GENerator for Electro-production of Photons Incoherently

- The incoherent scattering is chosen with the unpolarized deuteron target.
- The kinematic cuts for DVCS event generation are shown below.

$$0.001 < x_{bj} < 1 \tag{1}$$

$$1GeV^2 < Q^2 < 20GeV^2 \tag{2}$$

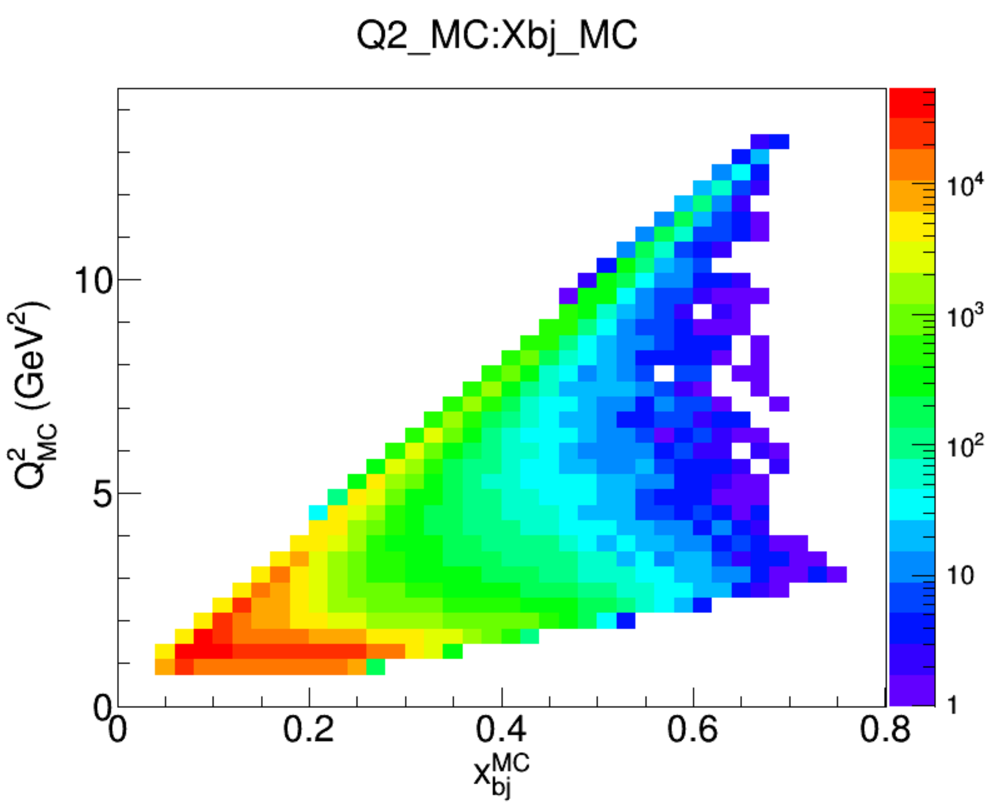
$$-1.2GeV^2 < t < 0GeV^2 \tag{3}$$

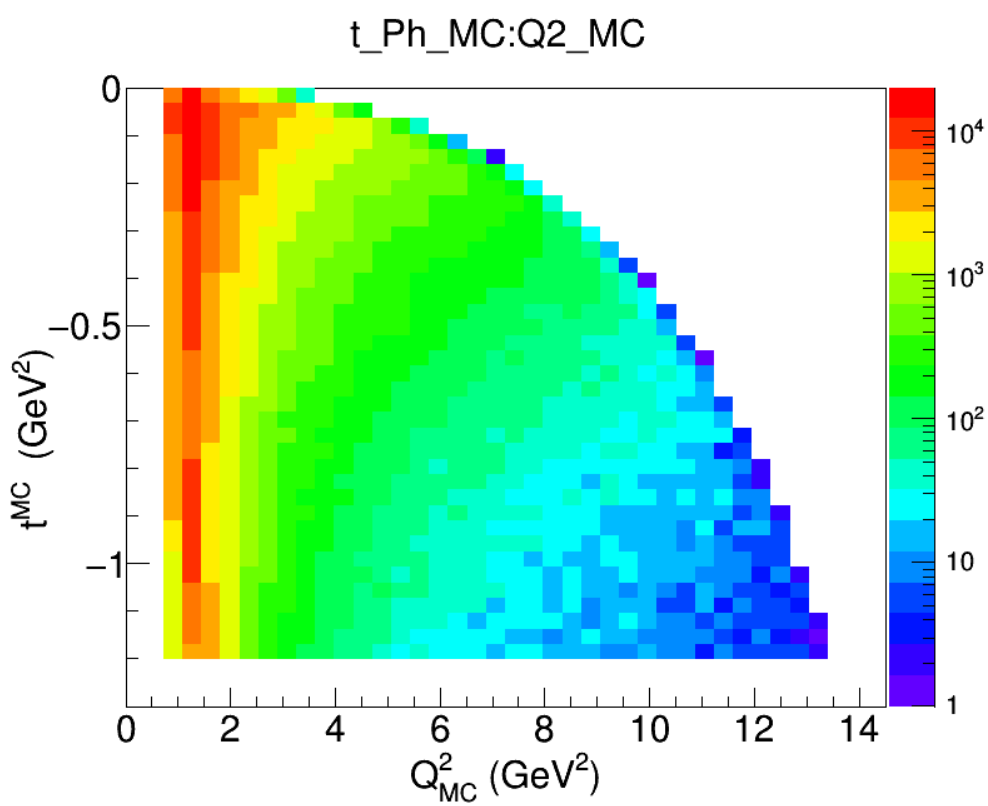
$$4GeV^2 < W^2 < 50GeV^2 \tag{4}$$

$$0.3GeV < \nu < 11GeV \tag{5}$$

We are more interested in events of high Q2, low t, and away from nucleon resonances.

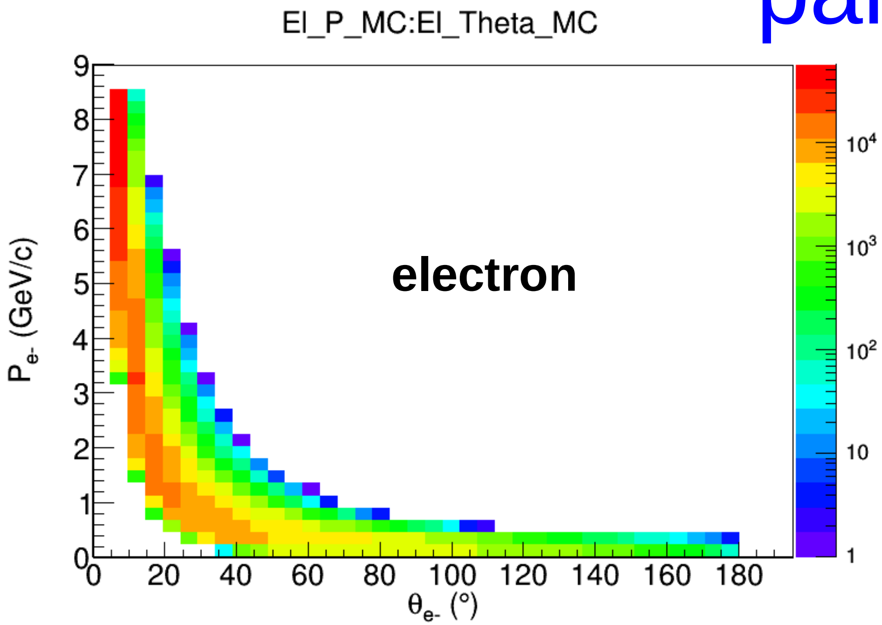
Invariant kinematic variable distributions at electron energy of 11 GeV

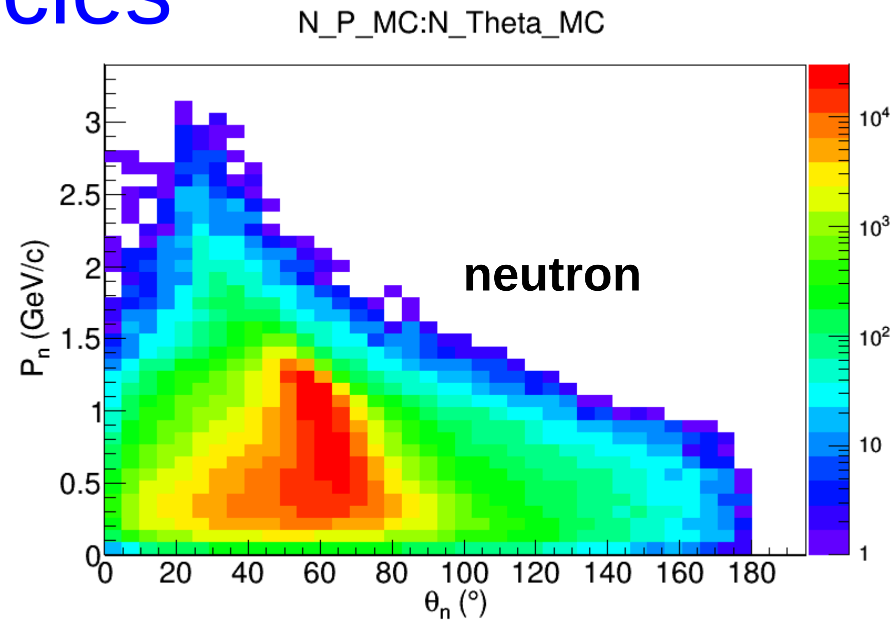


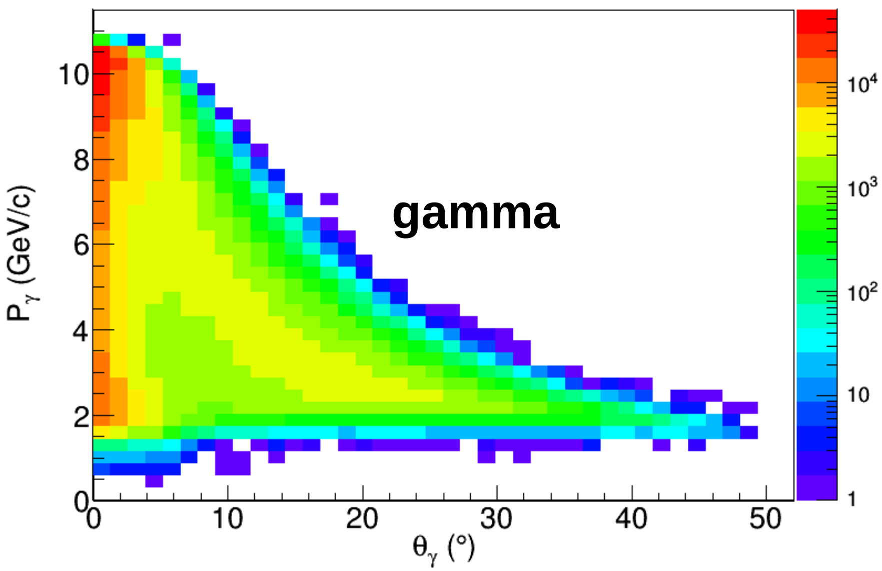


x, t, and Q2 invariant variables cover a large space.

Angular and momentum distributions of final particles



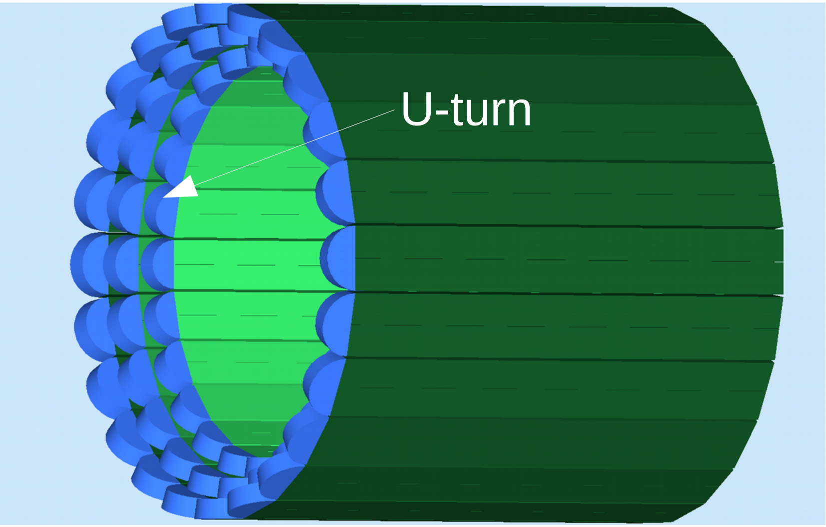


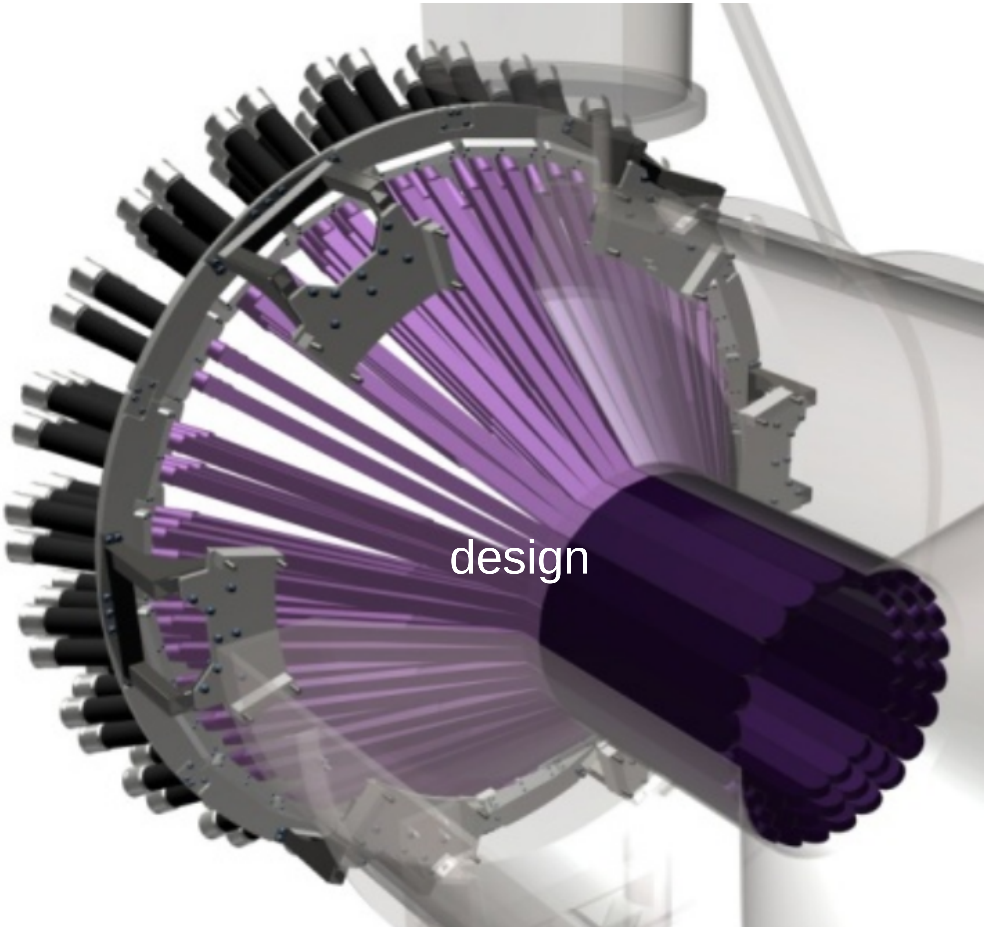


The electron and gamma particles are mainly at forward region. The neutron is mainly at the center region of 60 deg in the lab frame. The momentum of neutron is around 0.7 GeV/c. A capable neutron detector in the center region is needed.

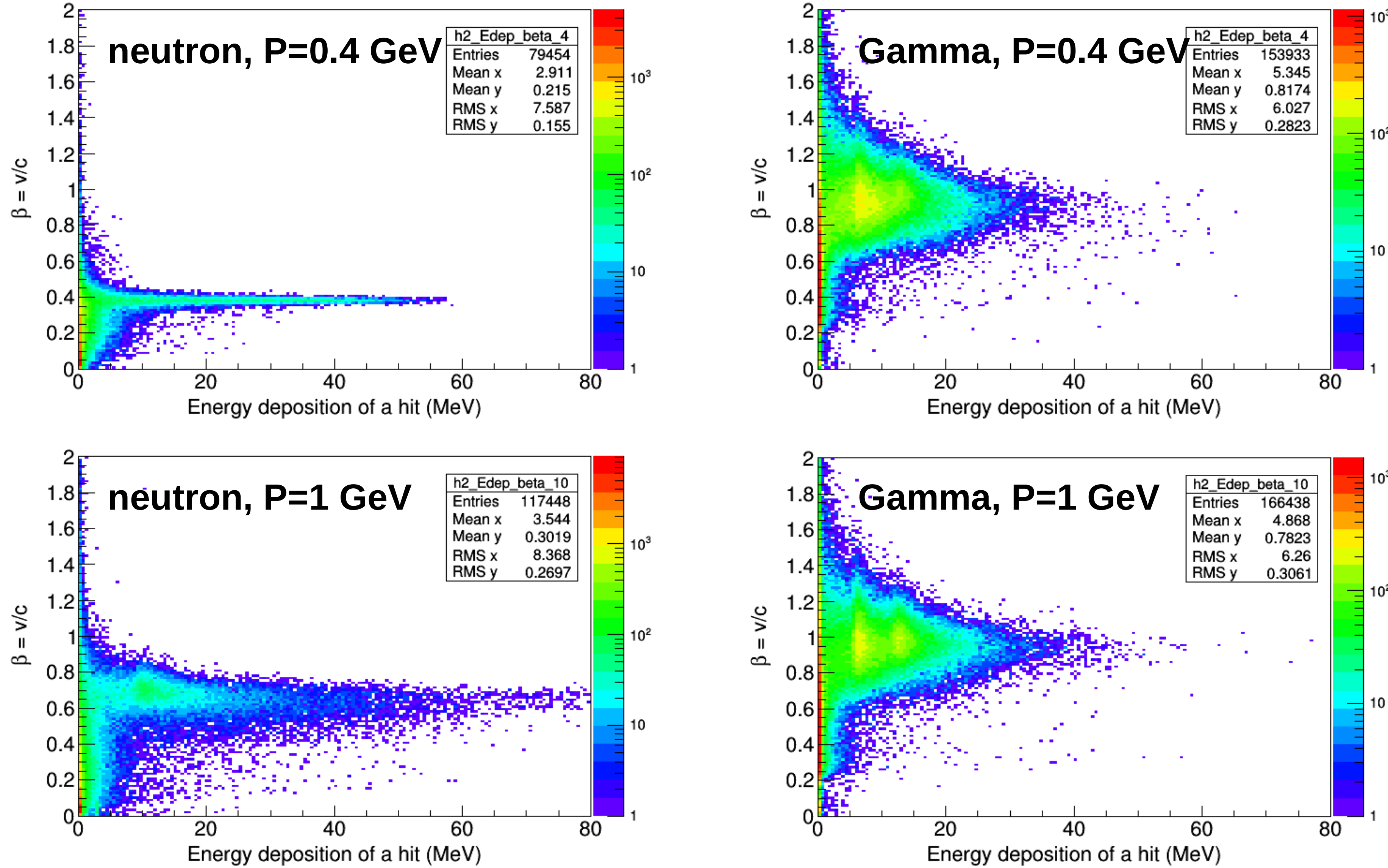
Central neutron detector (CND)

CND is made of three layer plastic scintillators (144 bars in total). Each layer is of 3 cm thick. Light is collected at only one end for each bar. Light at the other end goes to U-turn entering the neighboring bar.

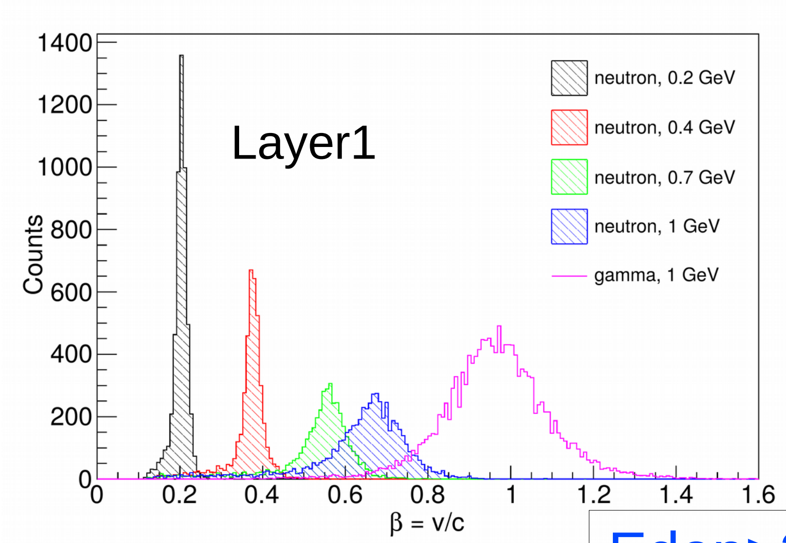


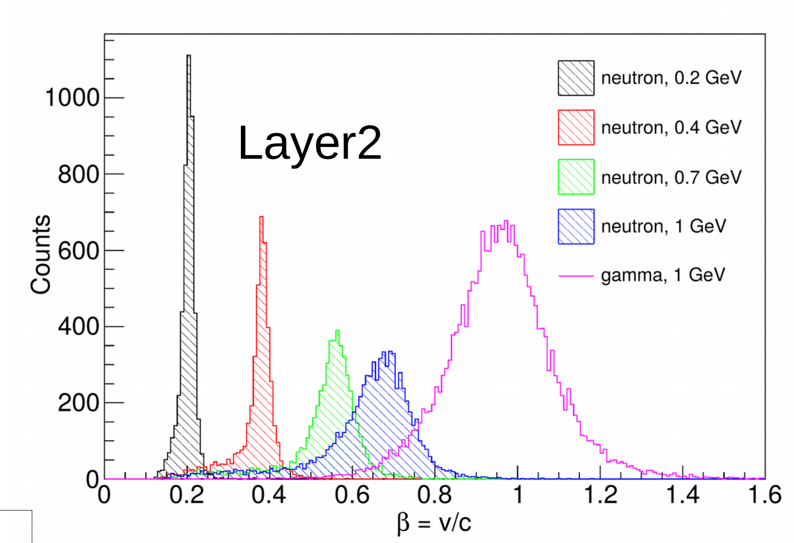


CND hits: deposited energy-β distributions

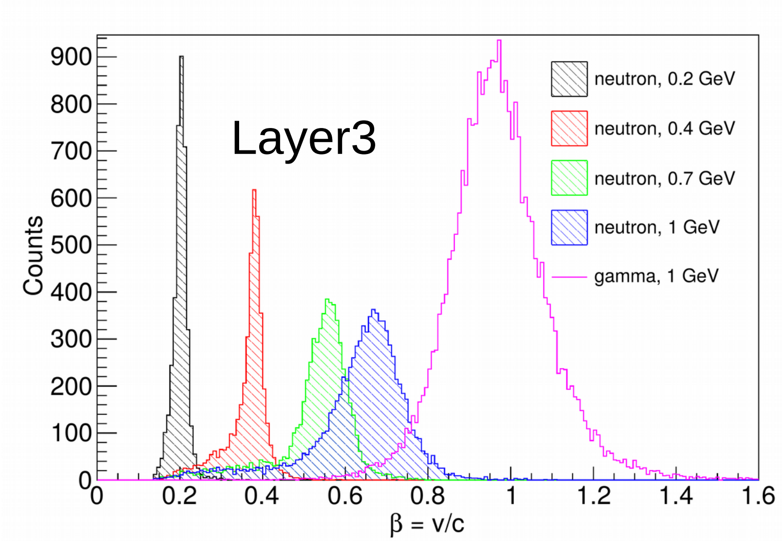


CND hits: beta distributions of neutral particles





Edep>2MeV



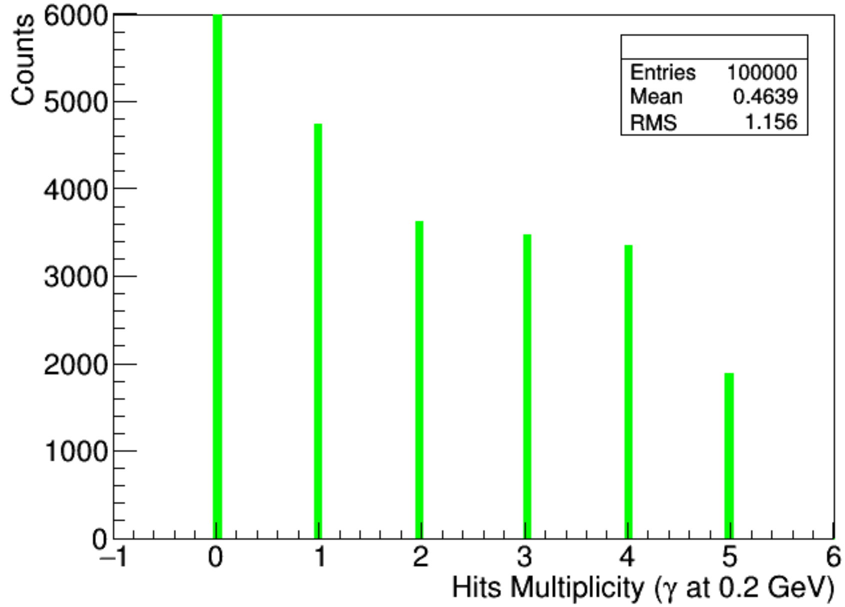
For gamma particle, the outer layer has more hits compared to inner layers. Electromagnetic showers happens at CTOF, CND and solenoid for Gammas.

Judged by the resolution of CND hit here, around 10% of the detected gamma are mixed with neutrons.

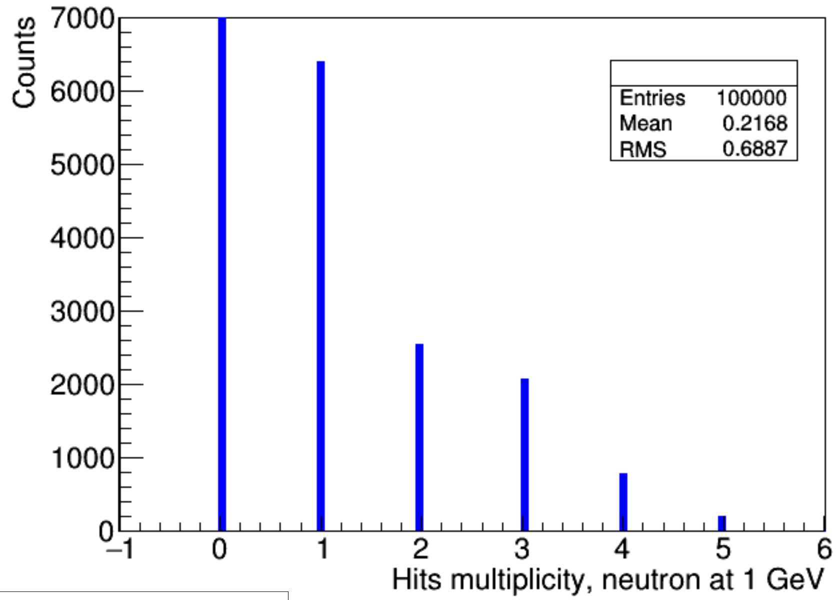
CND hits: multiplicity of neutral hits

- But, most of the detected gamma particles generate more than one hit (hits through all layers, and the hits in the neighbors). Electromagnetic showers happens at CTOF, CND and solenoid for Gammas.

Gamma, P = 0.2 GeV/c

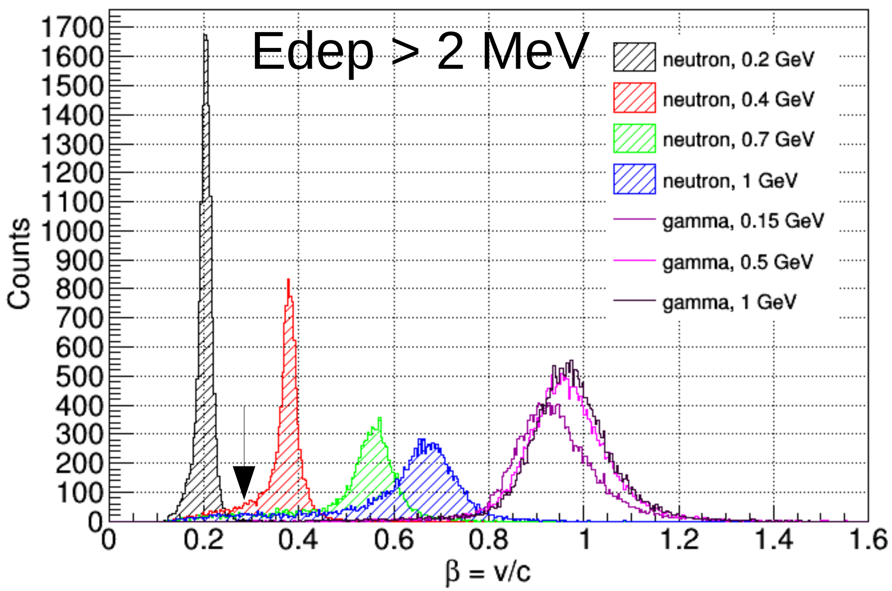


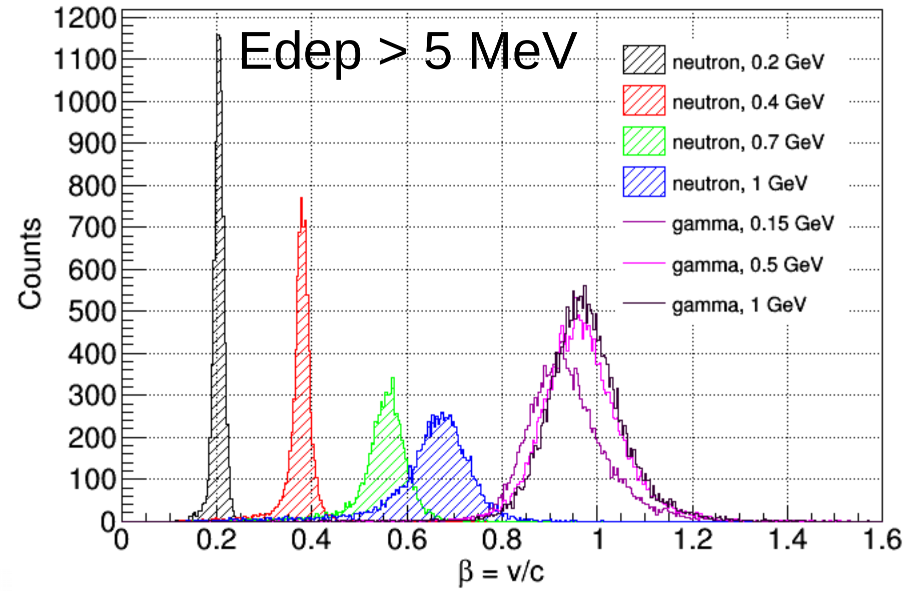
Neutron, P = 1 GeV/c

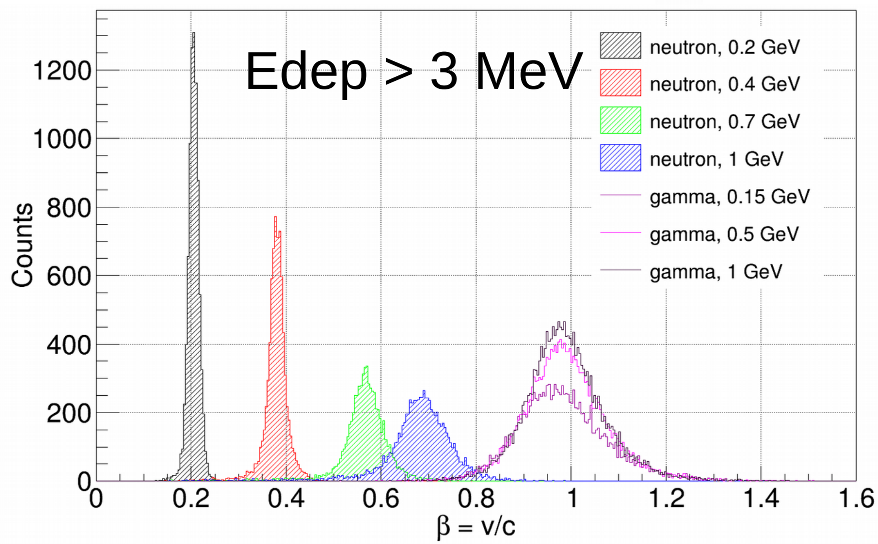


Edep>2MeV

CND hits: average beta of the hits of the event



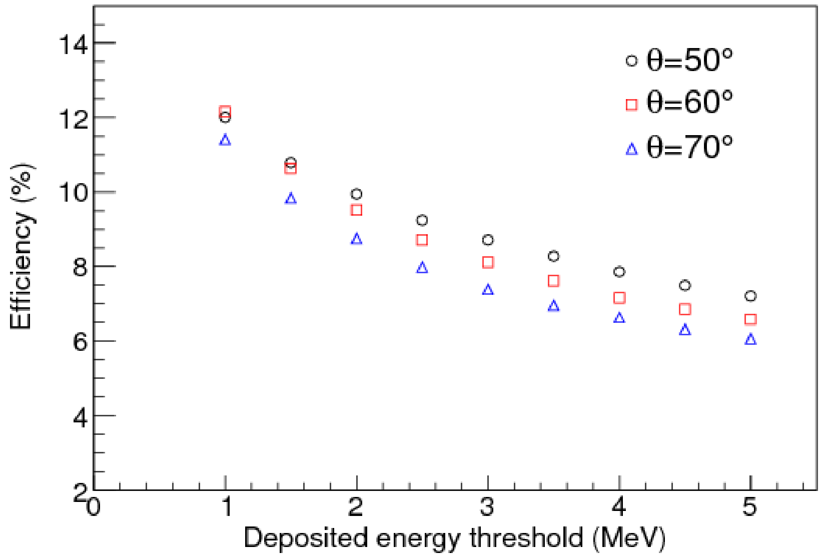


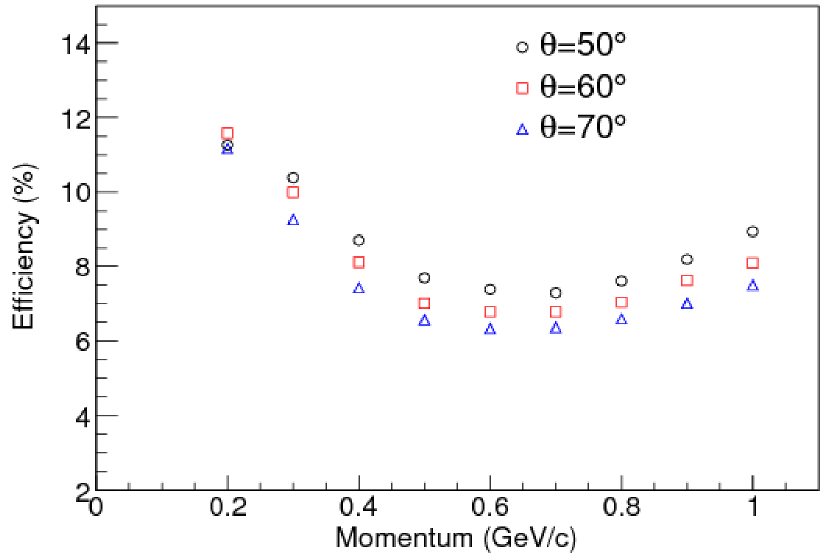


Using the average beta over all layers, CND classifies the neutron and the gamma with high purity.

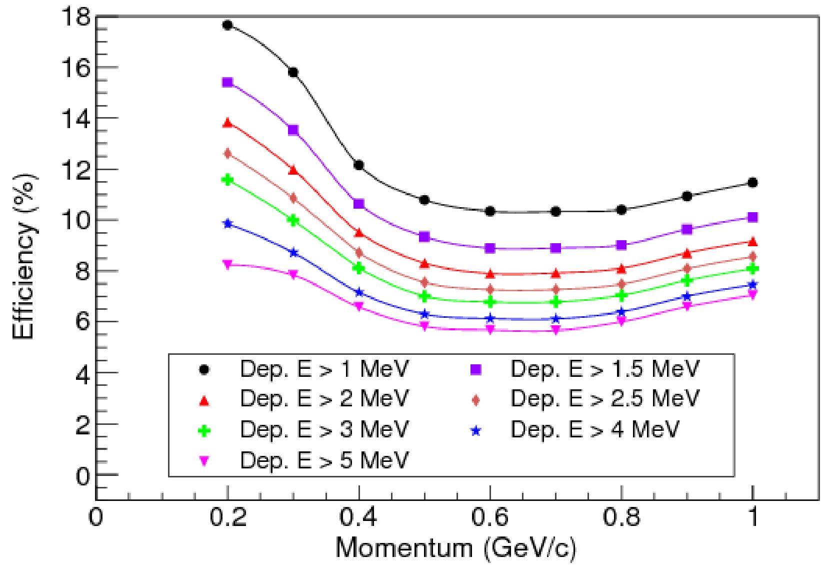
With higher threshold, the tail of the distribution at small beta side goes down slightly, and the counts of low momentum neutrons go down a little bit.

CND: neutron efficiency at different momenta, angles, and with different thresholds

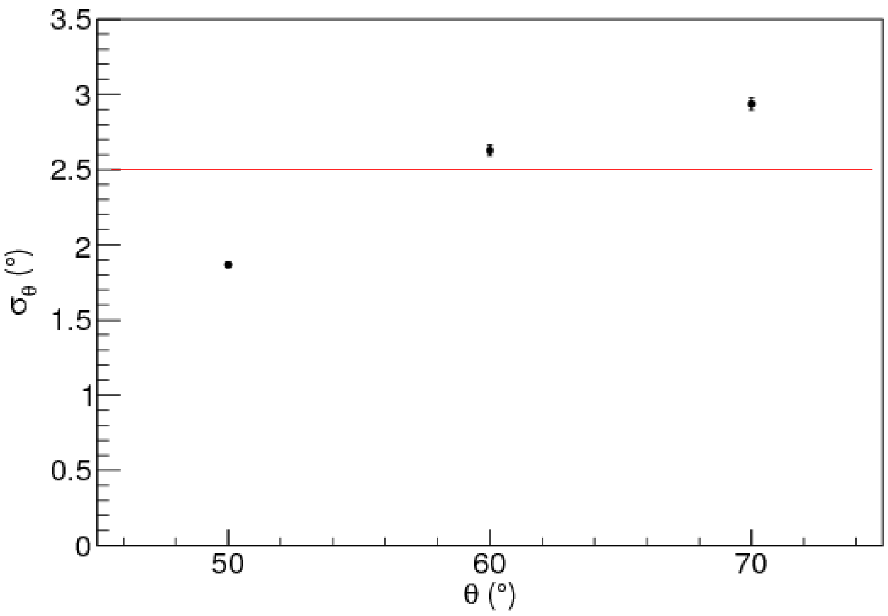


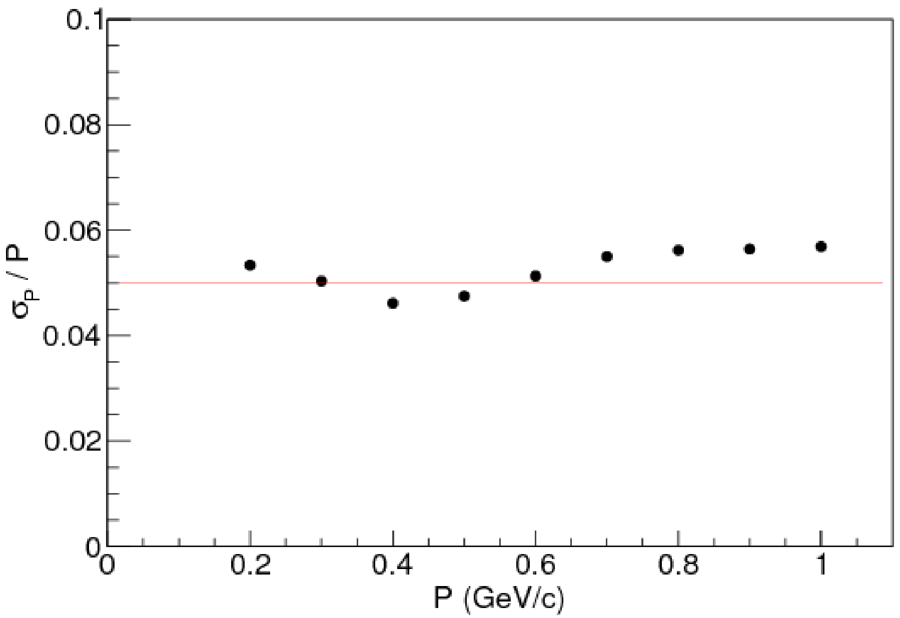


For n-DVCS events, the efficiency to get the neutron is around 7.5% with the deposited energy threshold at 3 MeV.



CND: angular and momentum resolutions





Angular resolution σ_θ is around 2.5 deg.

The relative uncertainty of momentum σ_P/P is around 5%.

Neutron reconstruction with CND

- Selection of neutron hits

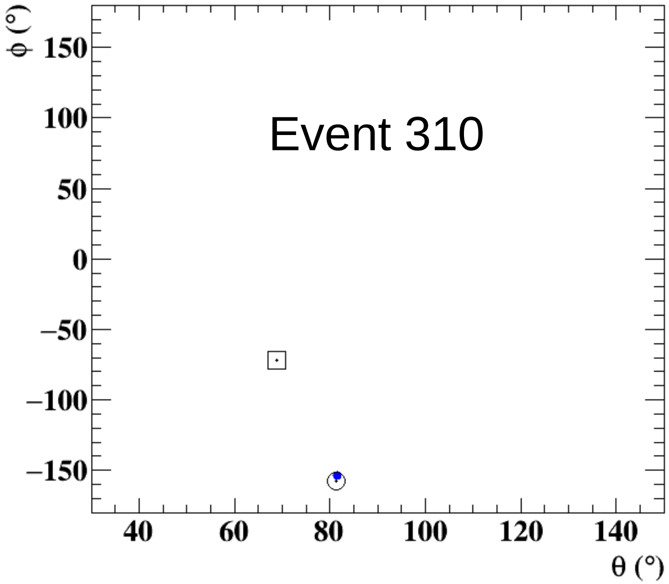
  1) energy deposition of the hit > 3 MeV

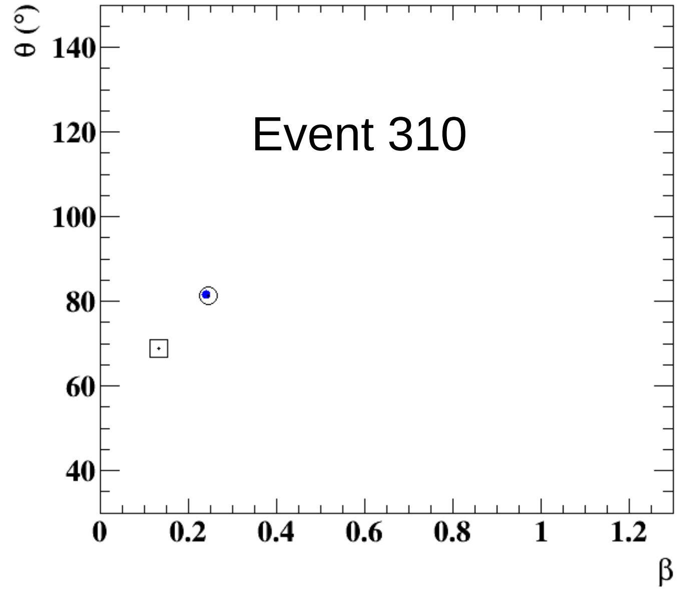
  2) veto of charged particle: no matched center track for the hit

  3) tof cuts: tof < 8 ns, beta < 0.8

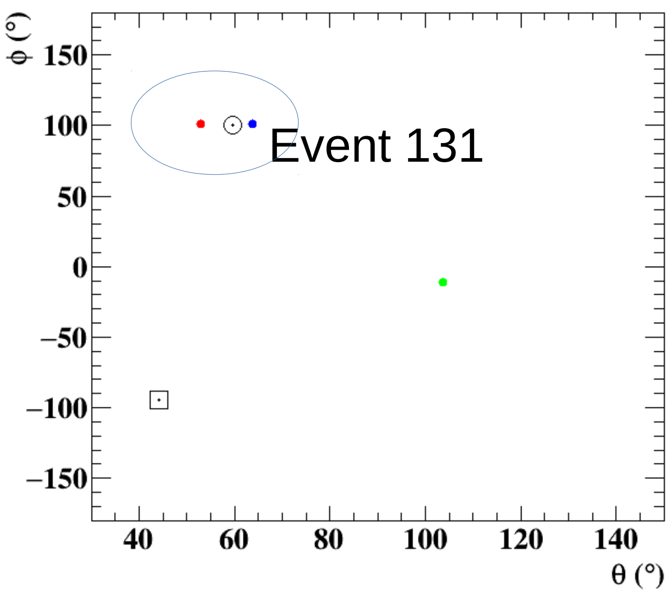
- Clustering of the neutron hits
- Provide the theta, phi, and momentum information of the neutrons

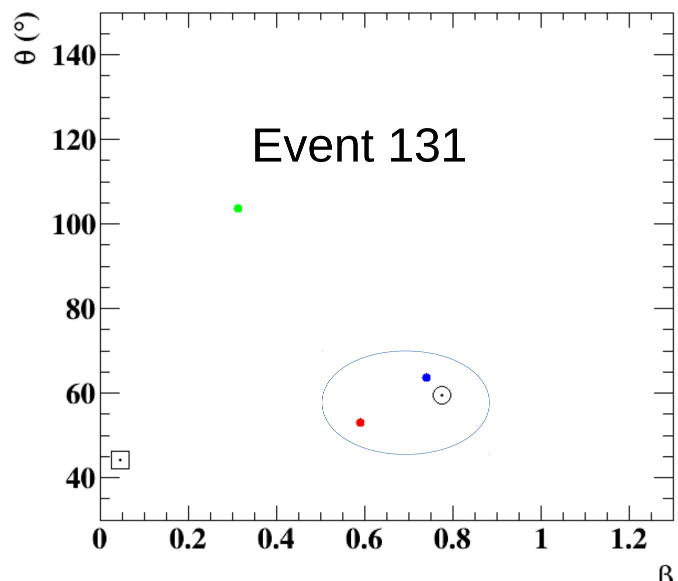
CND hits after the cuts





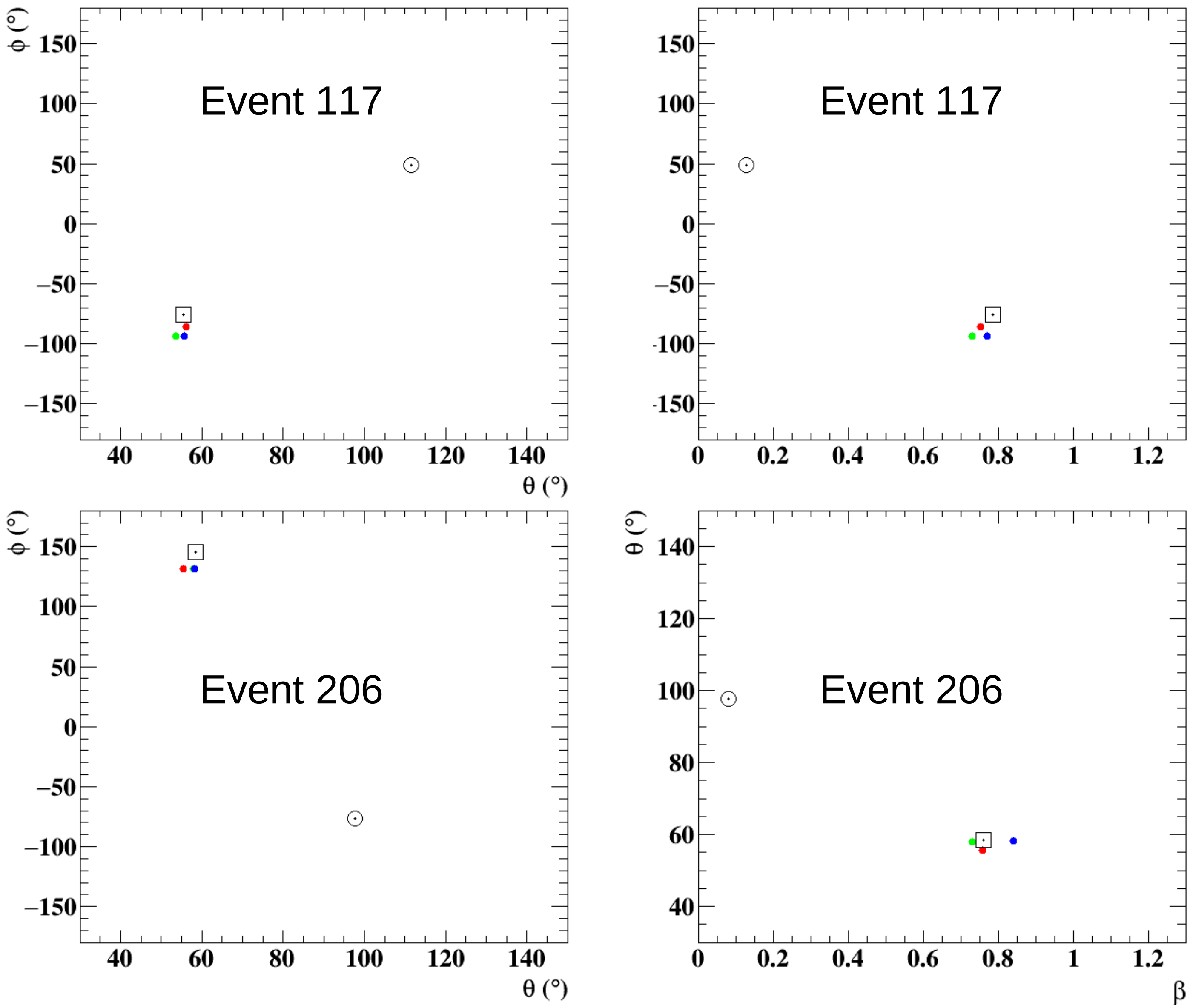
Red: layer-1
Green: layer-2
Blue: layer-3
Open circle: neutron MC
Open square: proton MC





Clustering: check whether or not the hits belong to one particle

CND hits after the cuts



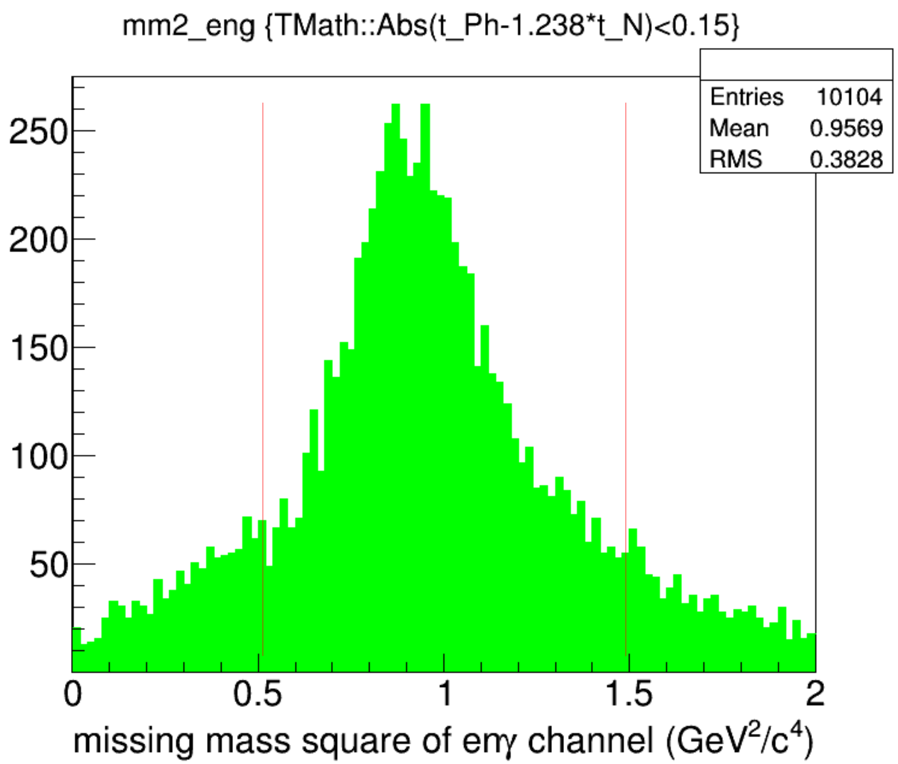
Red: layer-1
Green: layer-2
Blue: layer-3
Open circle: neutron MC
Open square: proton MC

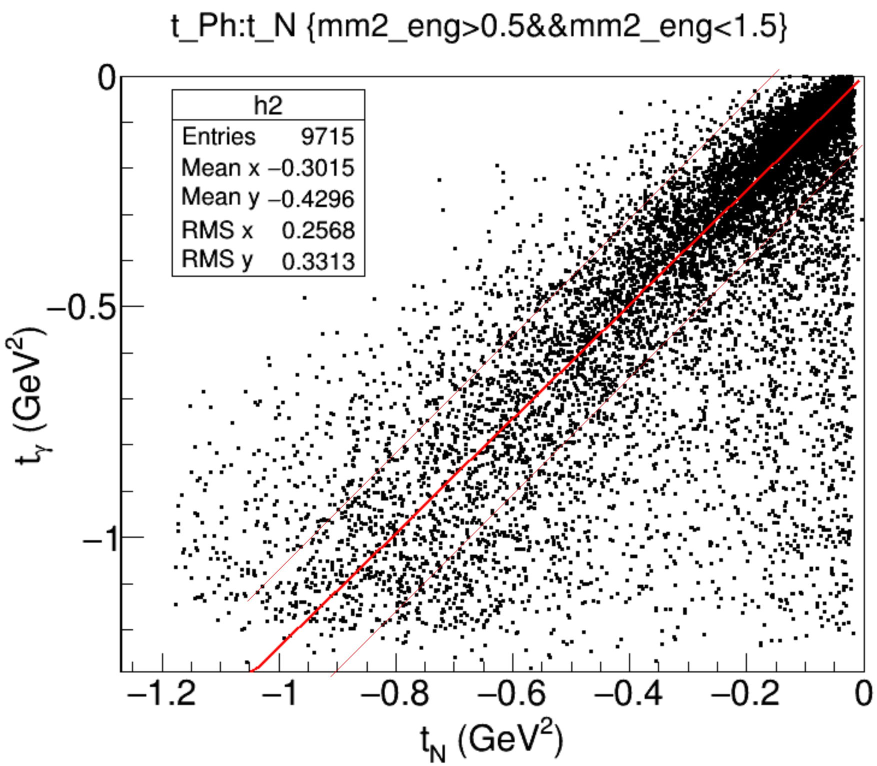
In the simulation, 10% of the proton of p-DVCS which go to the central detectors do NOT have tracks. Therefore these protons are misidentified as neutrons.
Central track reconstruction by coatjava5a.0.19 is not compatible for gemc4a.2.2 ???

Effectiveness of the veto depends on the coatjava released.

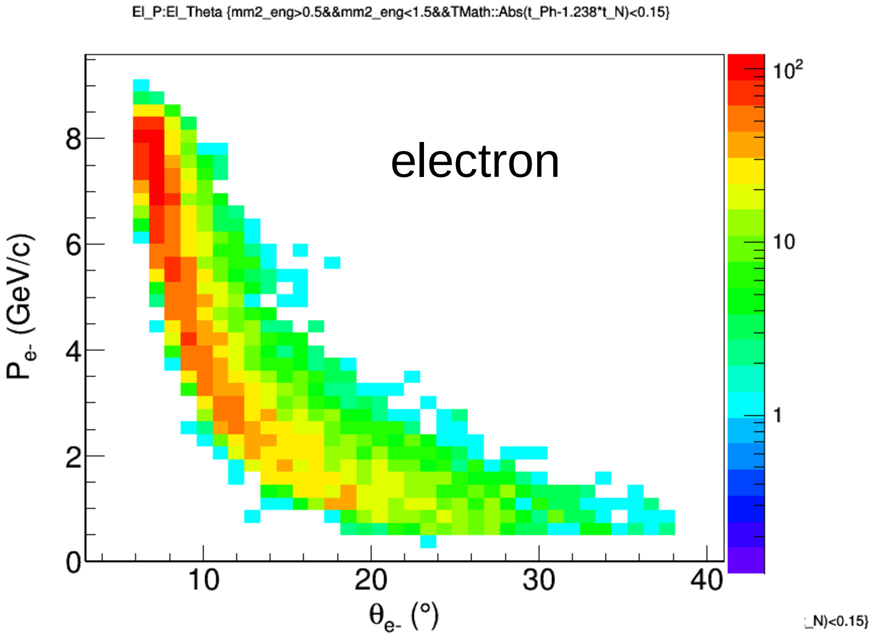
n-DVCS: selections of good events

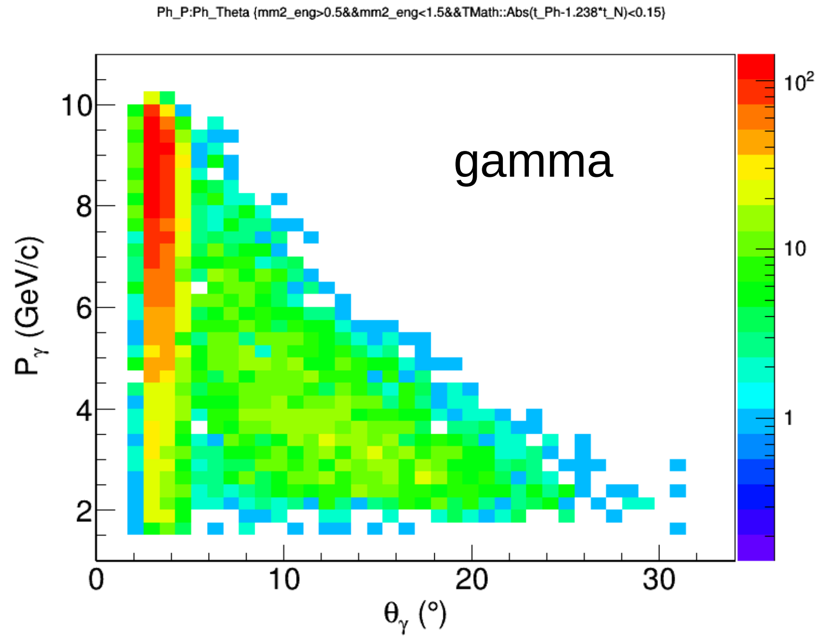
- missing mass cut, and t correlation cut are applied.
- Only one electron, one neutron and one photon.

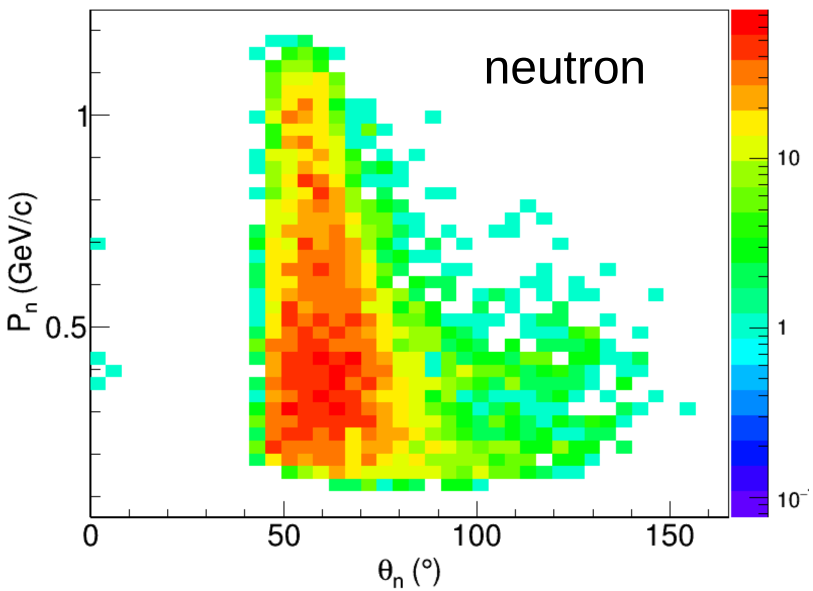




n-DVCS: reconstructed final state particles

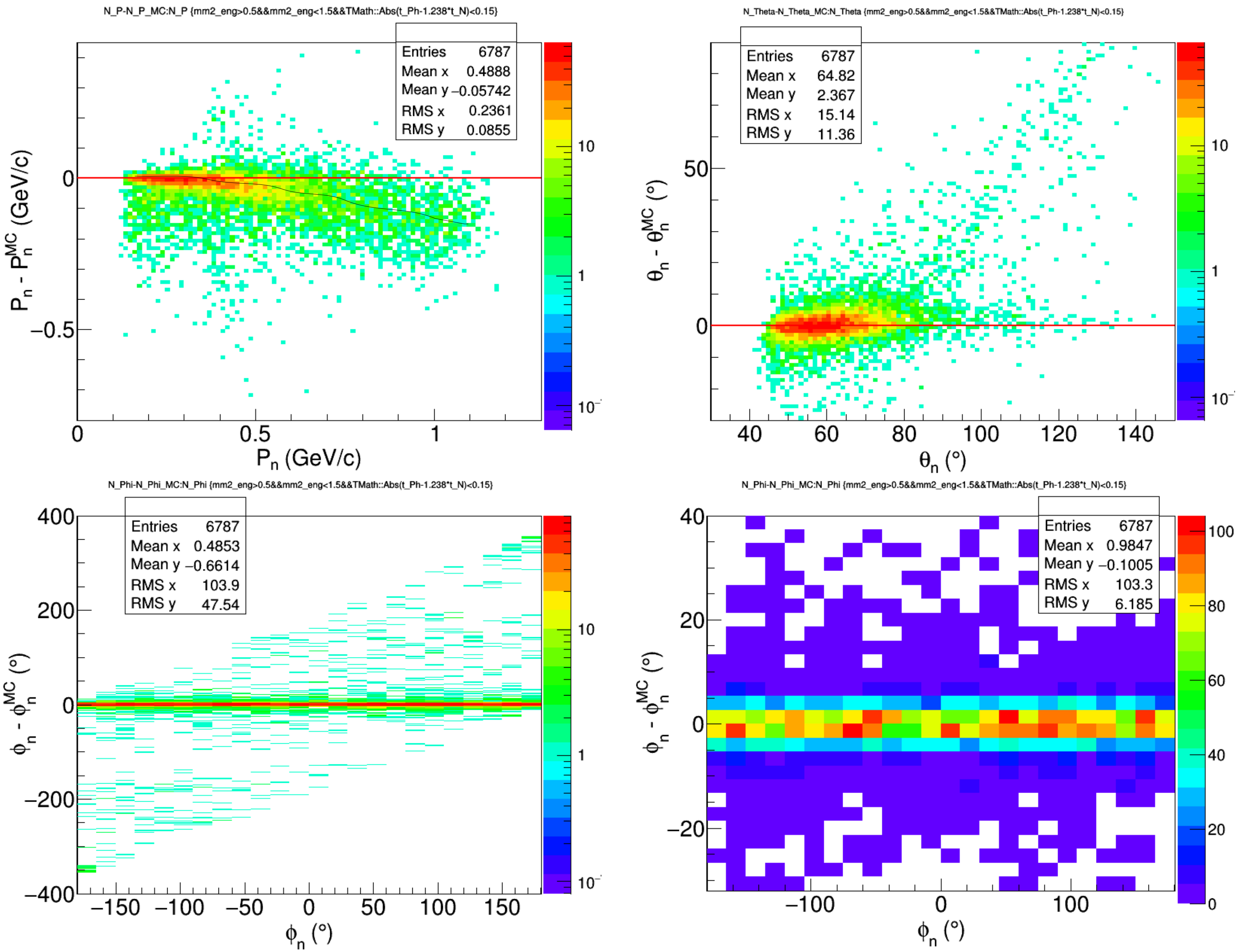






Gammas are detected in FEC and FT, while so far neutrons are only coming from the CND. Larger acceptance will come from including neutrons detected in the CTOF, FTOF, and FEC.

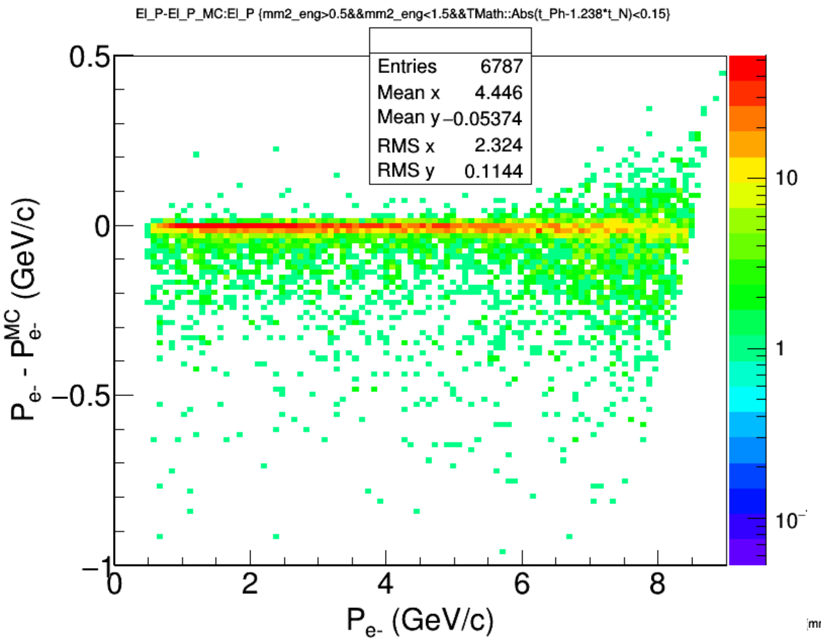
n-DVCS: resolutions of selected neutrons

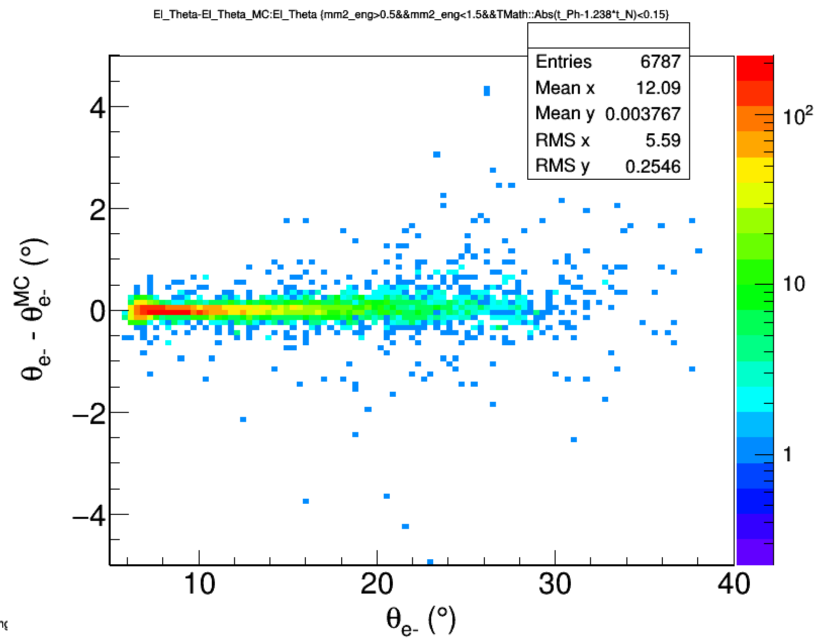


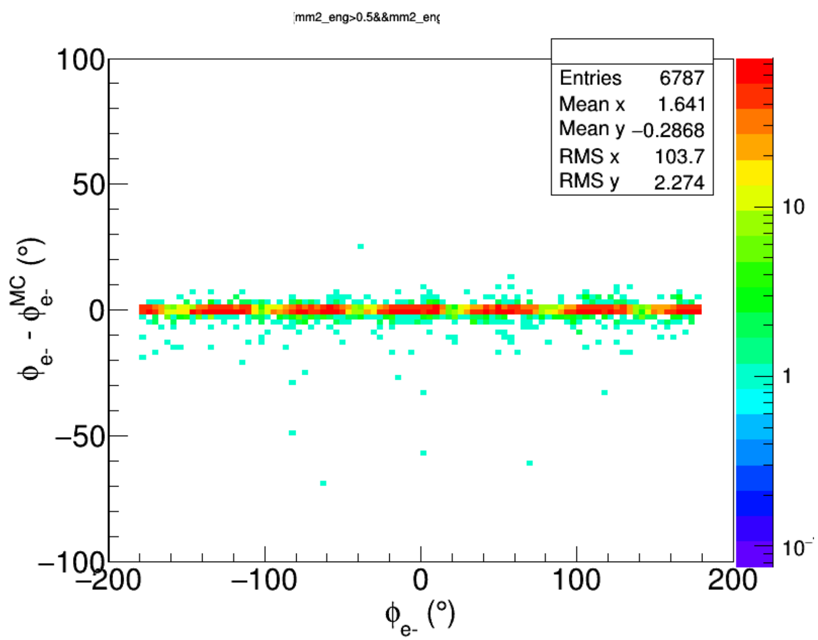
There is energy loss for high momentum neutron.

Purity of the reconstructed neutron is good.

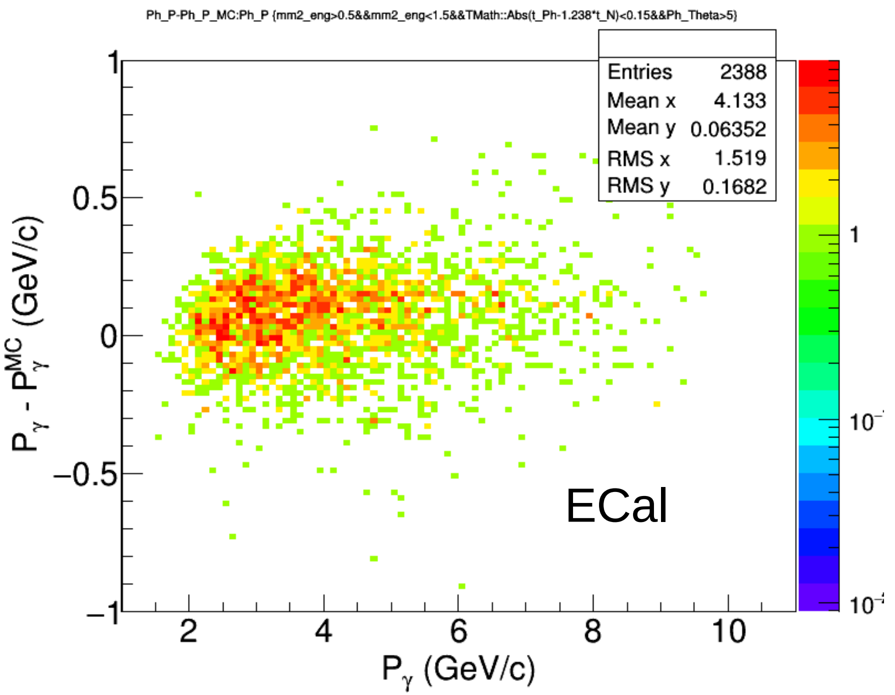
n-DVCS: resolutions of selected electrons

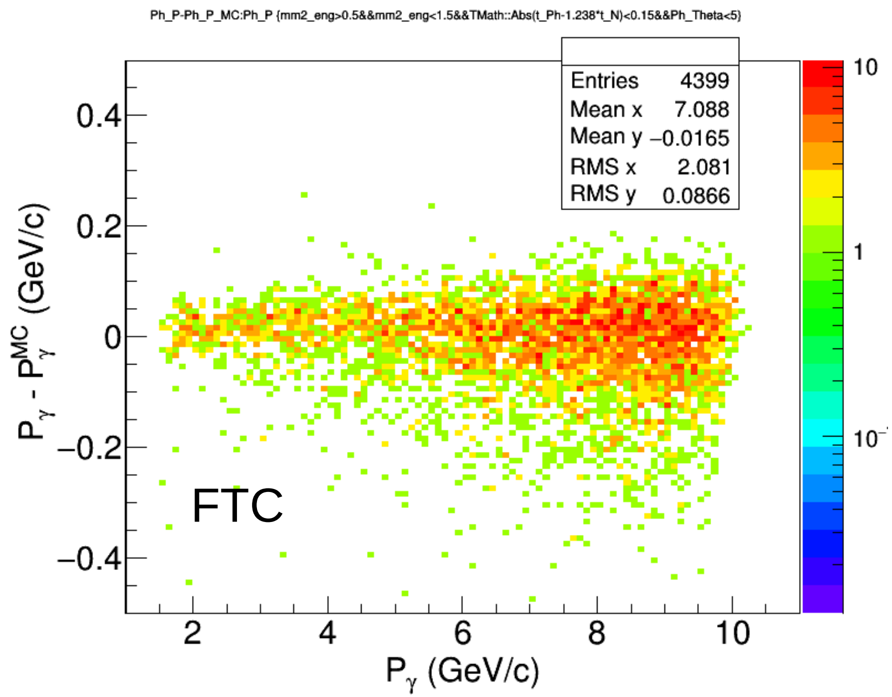






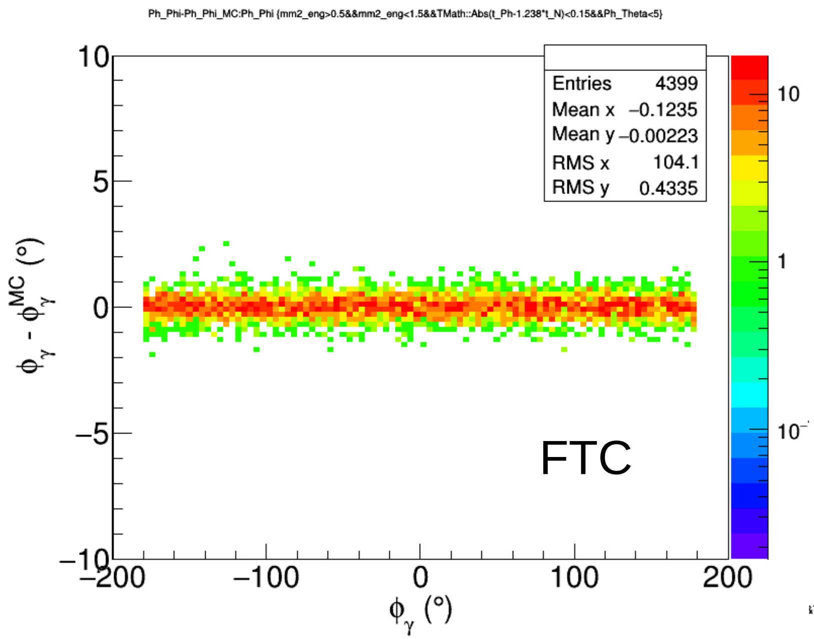
n-DVCS: resolutions of selected photons

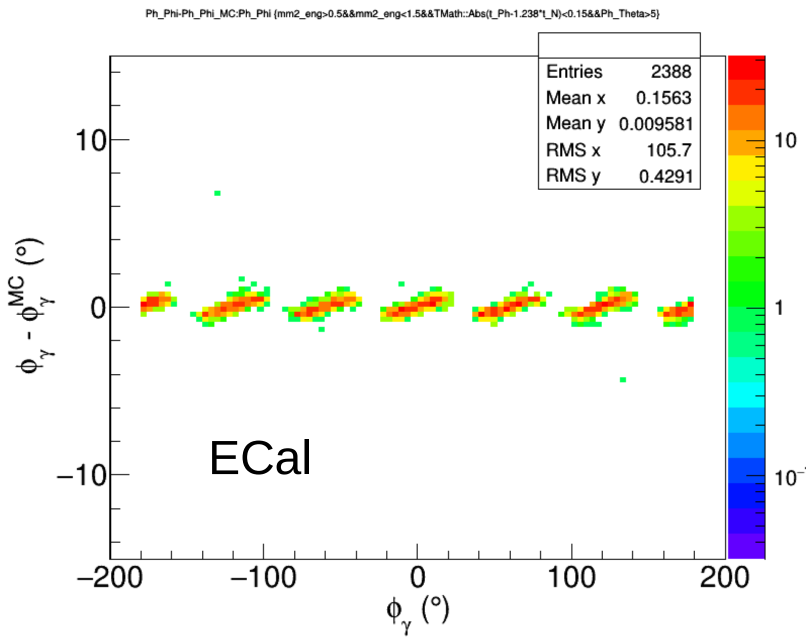


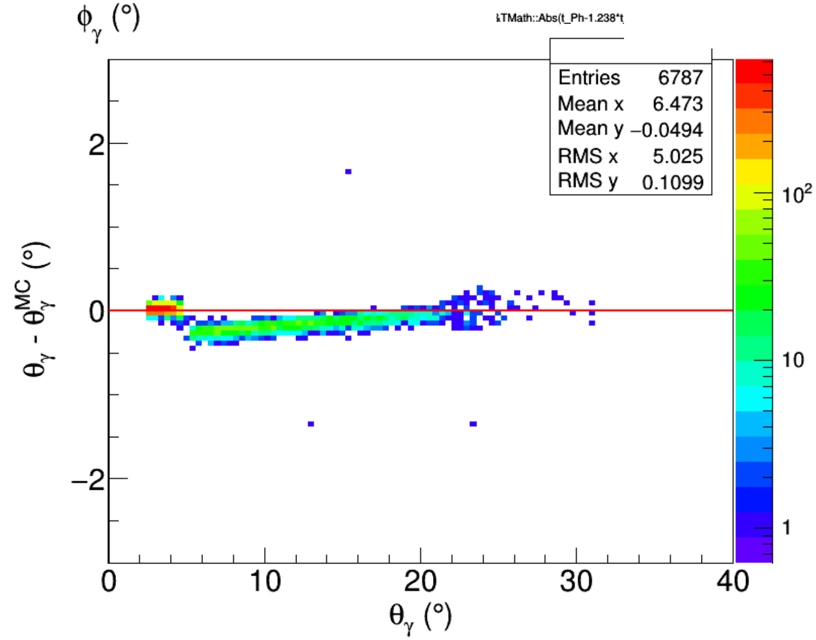


Energy resolution of Gammas is main source for the width of missing mass distribution.

n-DVCS: resolutions of selected photons

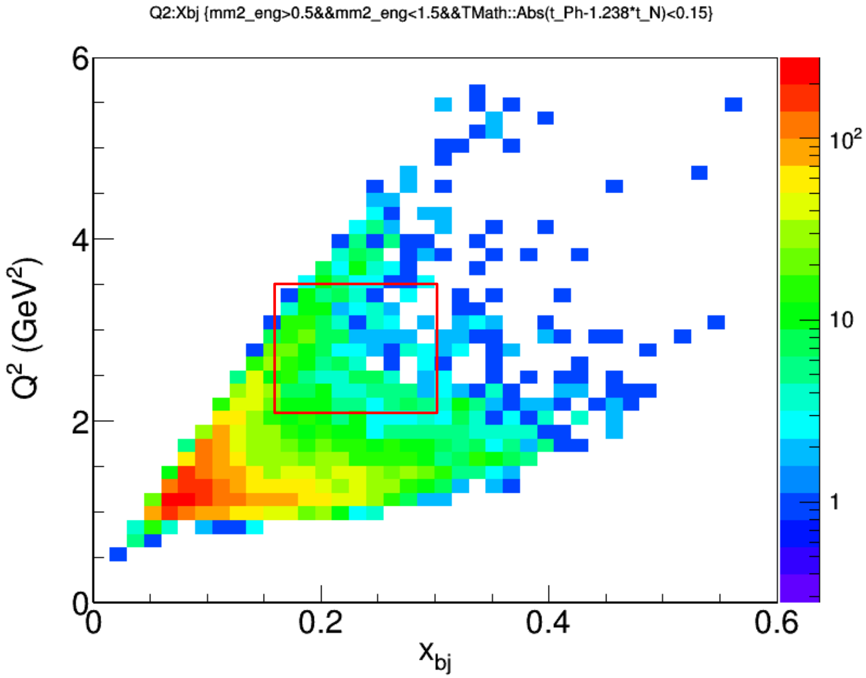


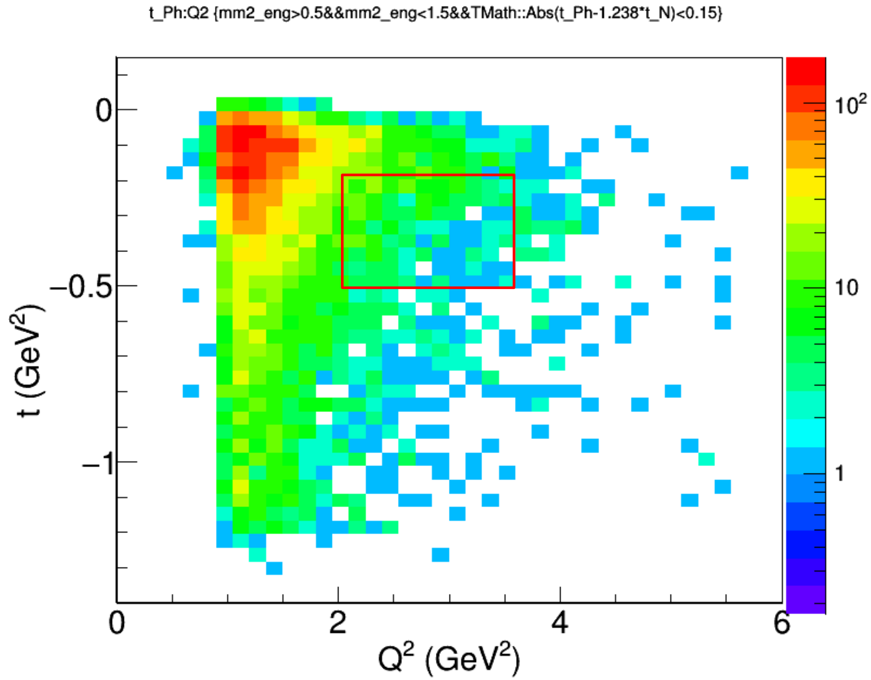




There is small bias for the angles of the reconstructed Gammas.

n-DVCS: kinematic region from reconstructed particles

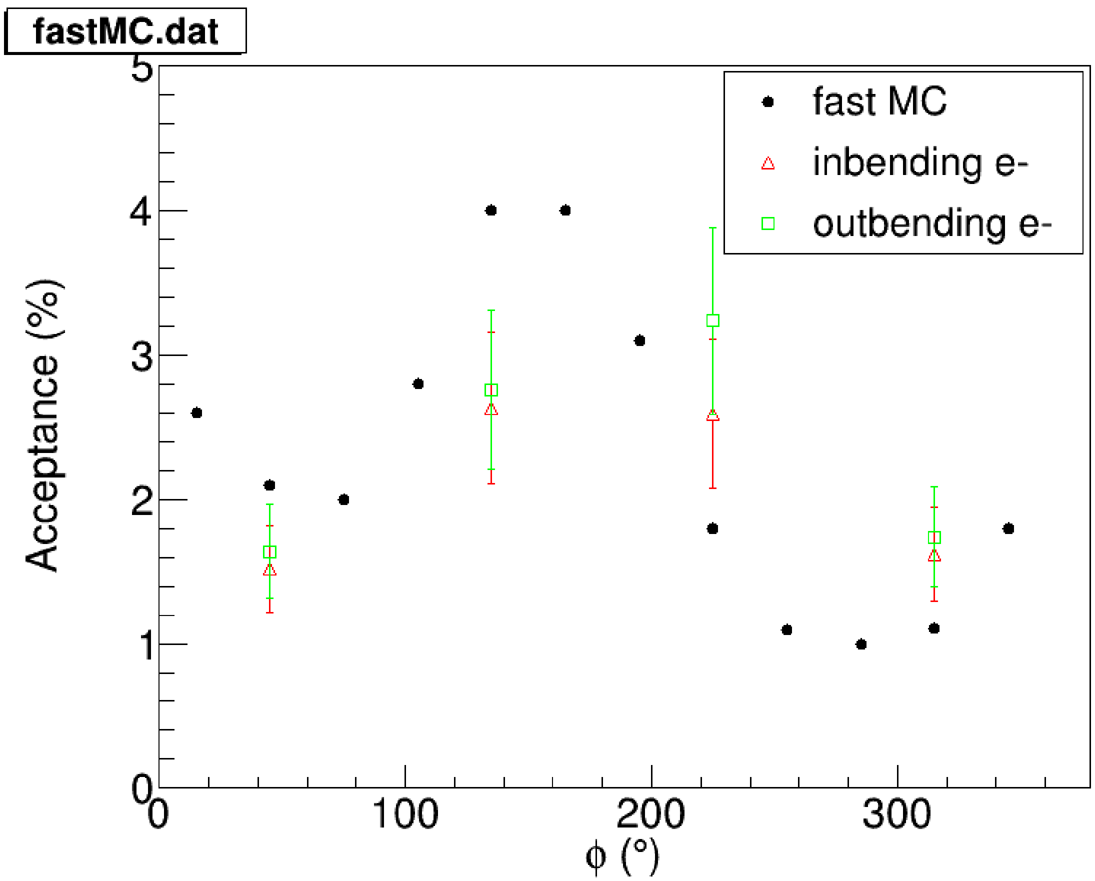




The red rectangle shows the bin of which the acceptance is studied in the following slides.

n-DVCS: acceptance

- The kinematic bin: 2 < Q2 < 3.5 GeV2, 0.15 < x < 0.3, and -0.5 < t < -0.2 GeV2



The acceptance is smaller than that from fast simulation, because of:
1) neutron efficiency is around 7.5%. fast MC simulation assumes 10%

2) electron and gamma efficiencies at Forward detectors < 100%. fast MC simulation assumes 100%

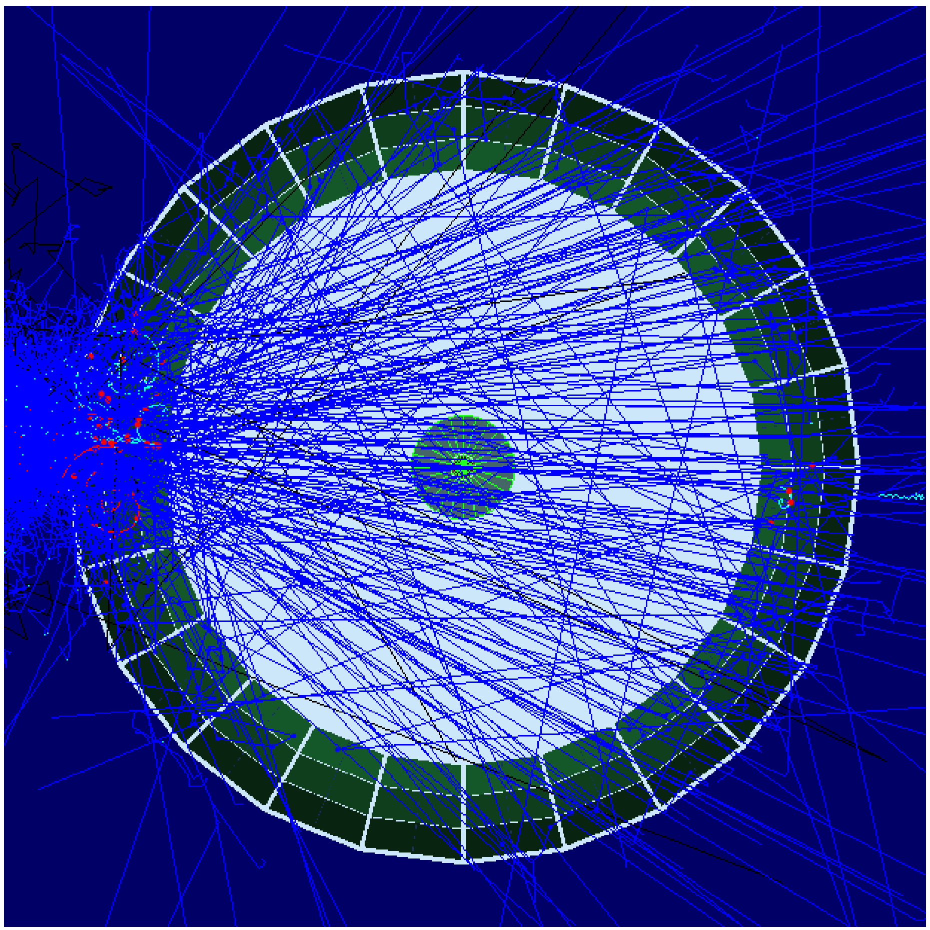
Next step

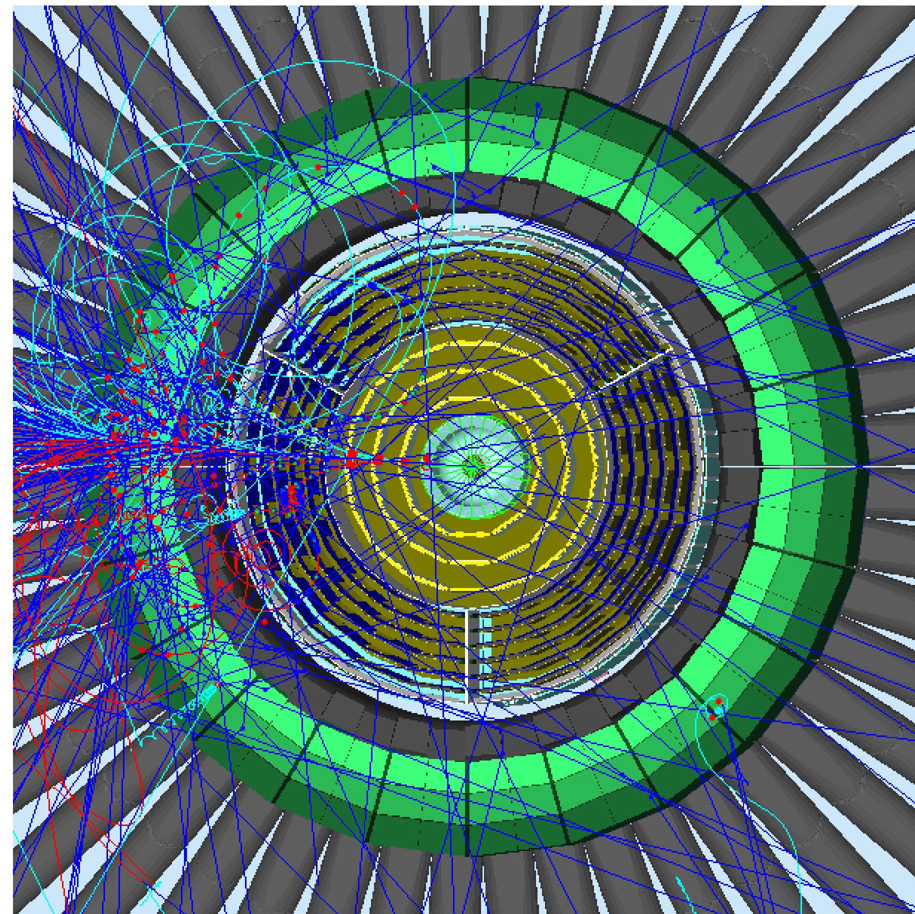
- Simulation with more statistic
- CTOF, FTOF, and FEC for neutron detection
- Veto of charged particles by central track information
- Analysis of real data from Run-Group A ($ep \rightarrow en\pi+$) to evaluate neutron efficiency in the CND
- Background simulation, exclusive $\pi 0$ production
- Energy loss correction for neutron

Backup-1

- Gamma particle interact with center detectors, multi-hits

100 gamma particles,
P = 0.5 GeV/c





Backup-2

1) hierarchical clustering algorithm is taken
2) the definition of the closeness between CND_hit A and CND_hit B:

$$s = \sqrt{\sum_i \frac{(x_i^A - x_i^B)^2}{\sigma_i^A \sigma_i^B}} \; (x_i = \theta, \phi, \beta;\; \sigma_i \; the \; resolution)$$

To determine whether or not the hits belong to the same cluster