Sullivan DVCS with a proton beam

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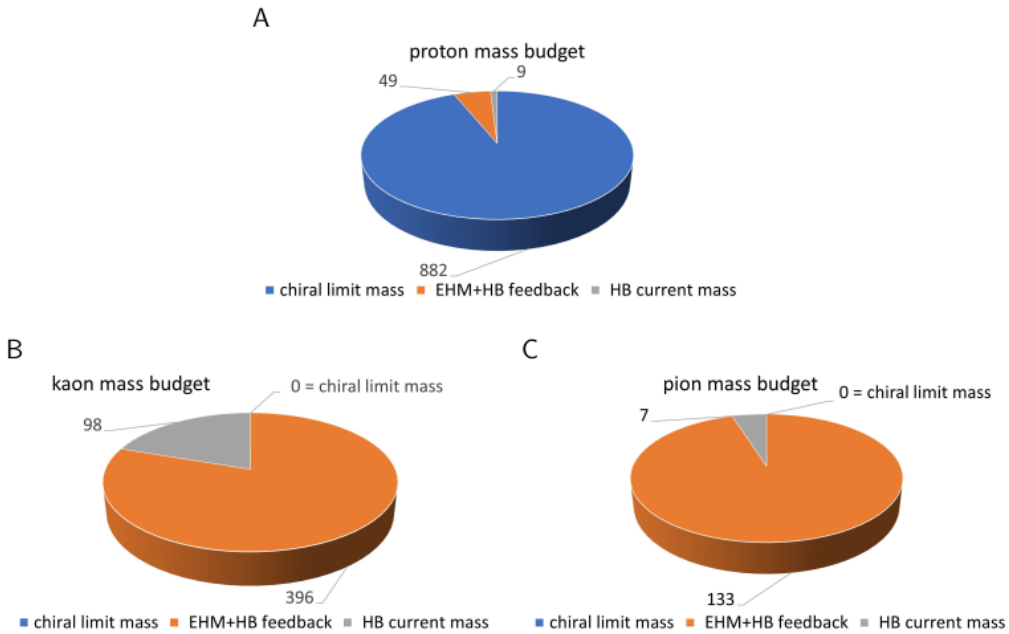
The pion

- Simplest QCD bound state, $\pi+$: (ud), mass: 140 MeV.
- A Nambu-Goldstone boson with spin 0.
- Parameterized by just one (complex) GPD: H_π

Pion questions

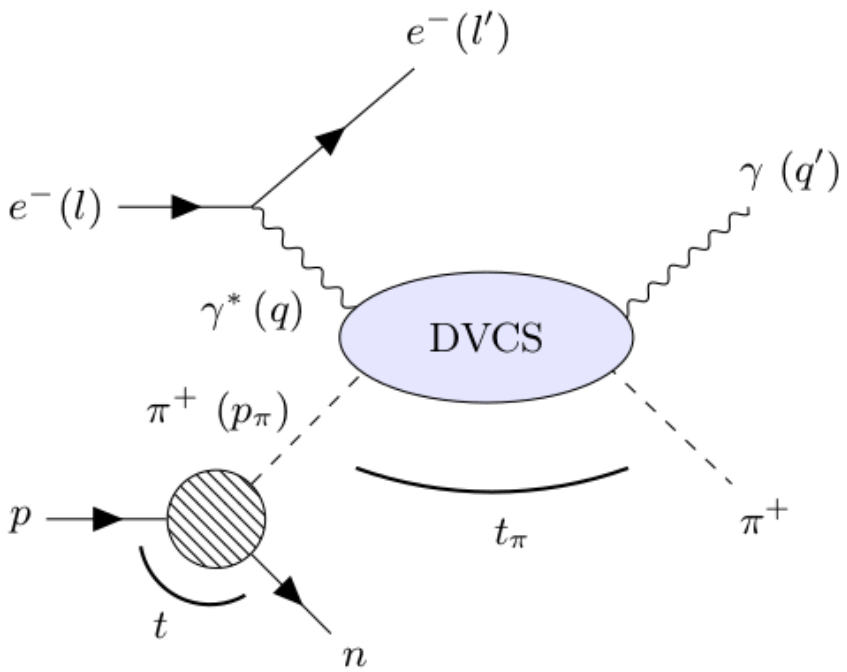
- Internal structure
- Difference in mass budget of pions, kaons and protons
- Effects of Nambu-Goldstone nature?



J. Phys. G: Nucl. Part. Phys. 48 075106

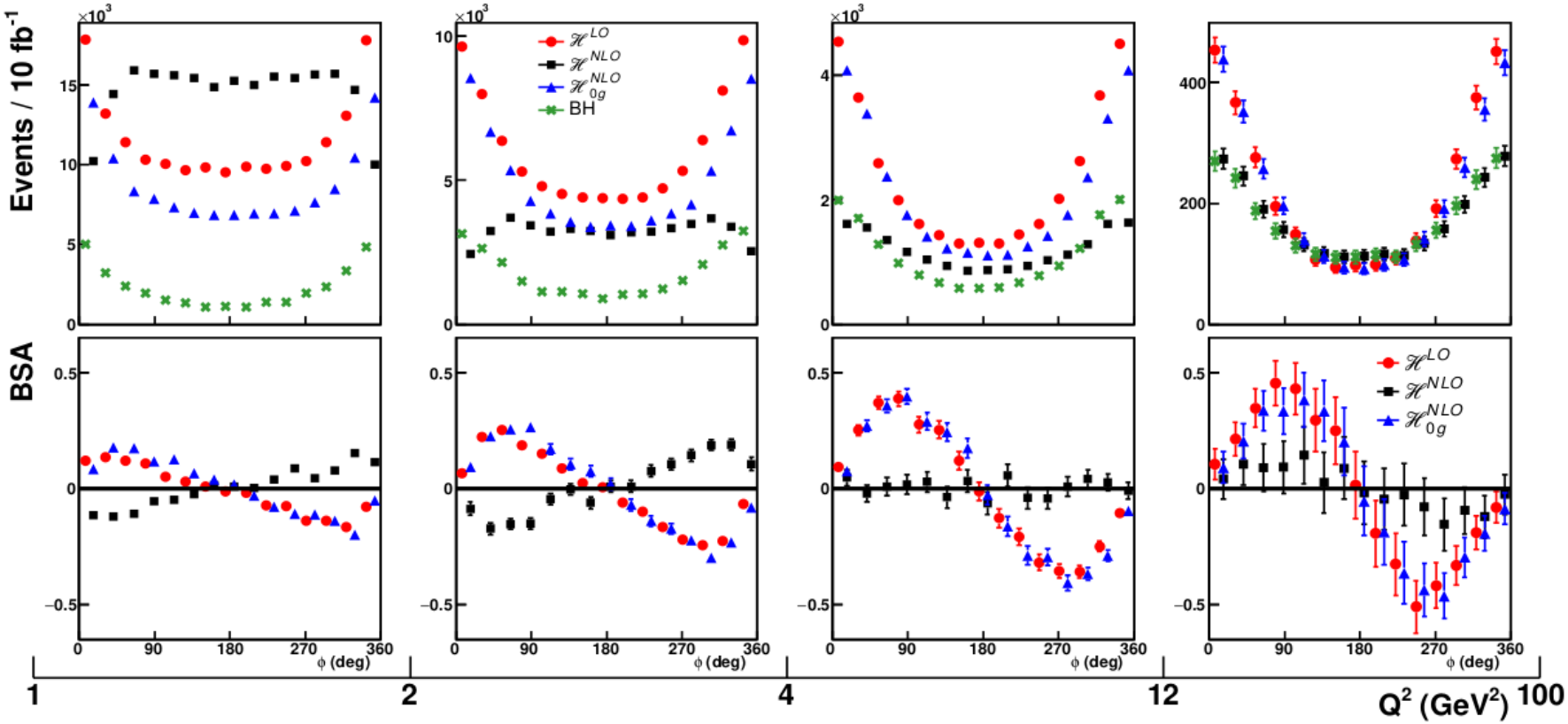
Sullivan DVCS

- Instead of a pion beam, protons can provide a source of pions via the virtual meson cloud around the proton.
- Such pions are off-shell, but results can be extrapolated to on-shell pions for low momentum transfers.
- Golden channel for GPDs: Deeply Virtual Compton Scattering
- DVCS on the pion, with e, γ, π^+ and n in the final state



Phenomenology

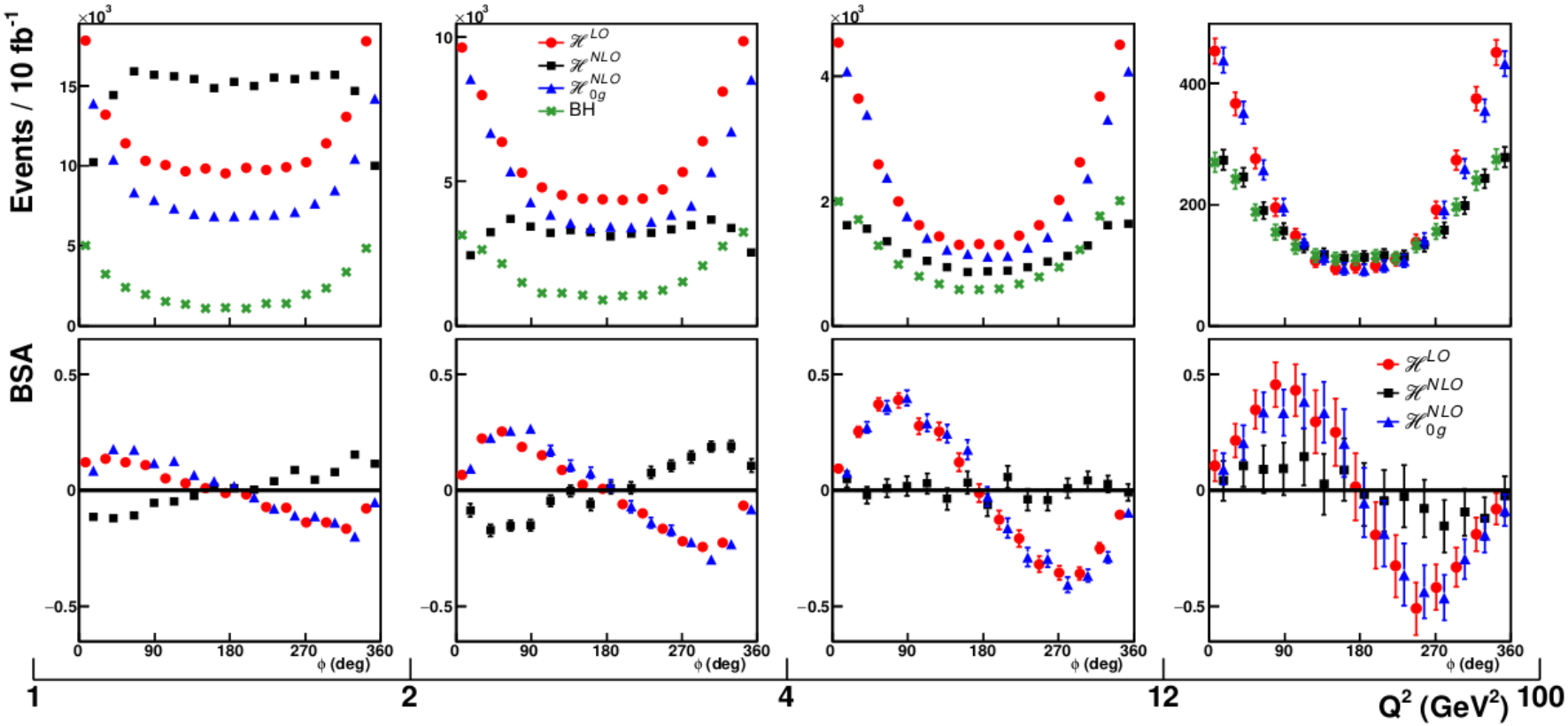
- Beam configuration: 275 GeV (p) x 18 GeV (e), luminosity: 10 fb^{-1}
- Plot the angle ϕ between the leptonic (γ^*, π^*) and hadronic (γ, π) planes: event yield and beam spin asymmetry



Theory: Phys. Rev. D 105, 094012

Follow-up: arXiv:2110.09462

Phenomenology conclusions



- The process should be measurable at the EIC
- Destructive interference between quark and gluon GPDs at NLO. Important to include both contributions.
- Looking at the BSA, there is a difference in behaviour between low and high Q^2.

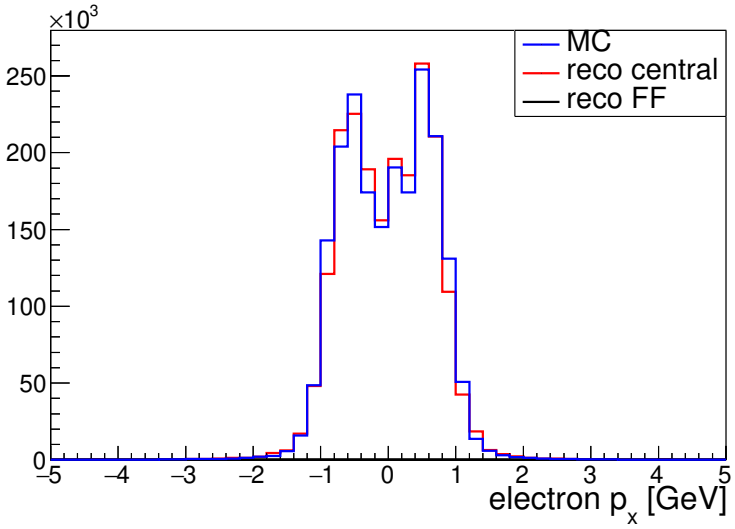
My simulation setup

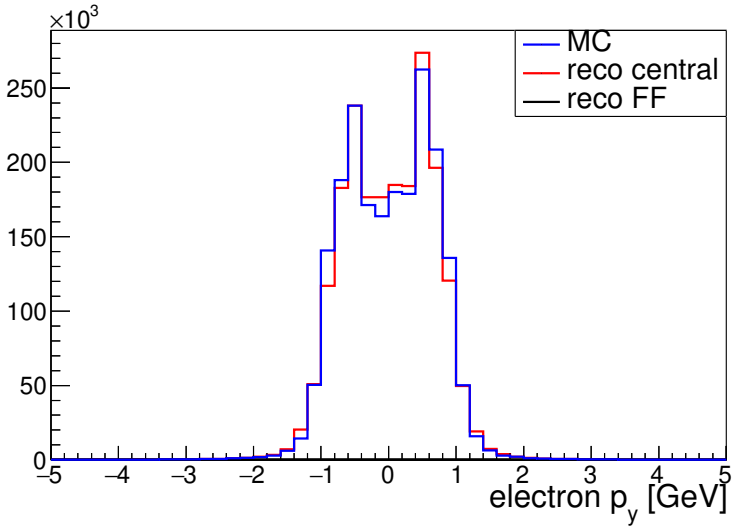
- Event generation code provided by Maxime Defurne, based on calculation by Belitsky and Muller.
- GPD model computed with DSE equations by Chavez et al.
- Conversion of ROOT output to a hepmc file.
- Applying the afterburner to rotate proton beam by 25 mrad + smearing.
- Simulation in 23.01.0 with Arches setup
- Reconstruction with Jana2/EICrecon
- 100k Sullivan DVCS events with 275x18 GeV beam configuration.

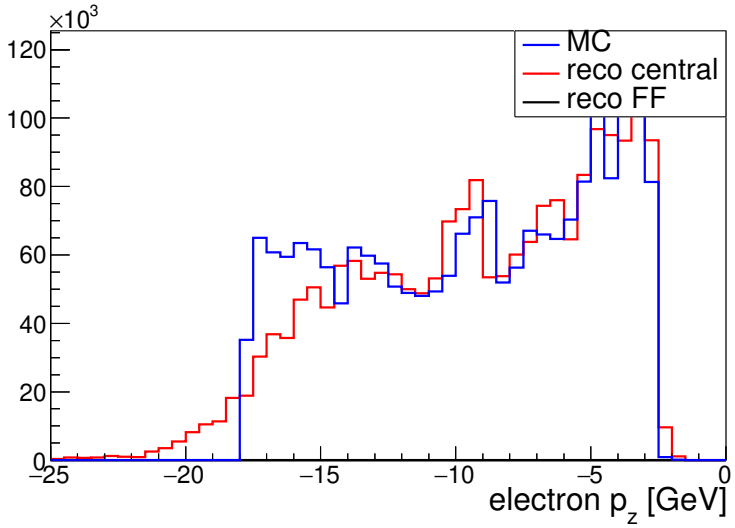
Some simulation/reconstruction details

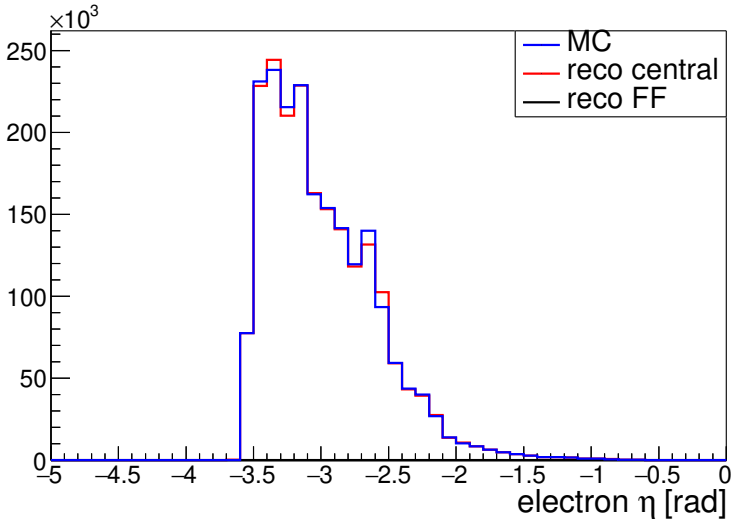
- I am currently using a hack to store the cross section event by event.
- Photons are not present as reconstructed particles - applying my own scale factors to clusters in the barrel and endcap calorimeters.
- In the ϕ plots, a cut on the invariant mass of the neutron-pion system $M(n, \pi) > 2$ GeV is applied to reduce backgrounds.
  - In the generation this cut is relaxed to 1.8 GeV to account for some migration post-simulation.

Electron momentum



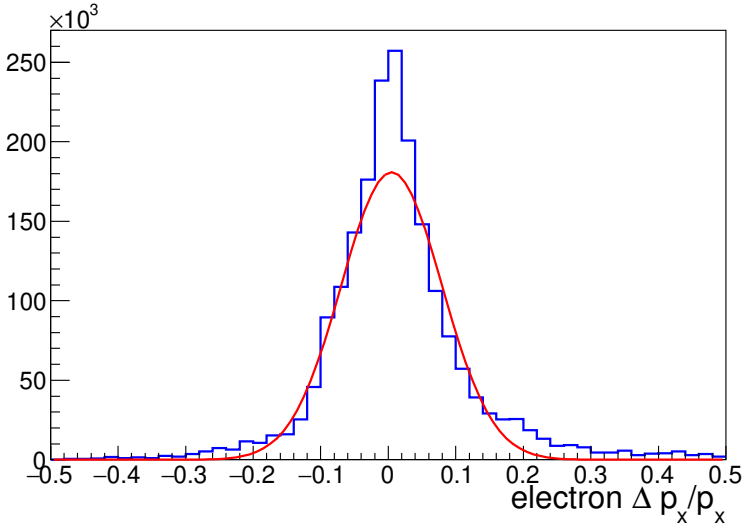


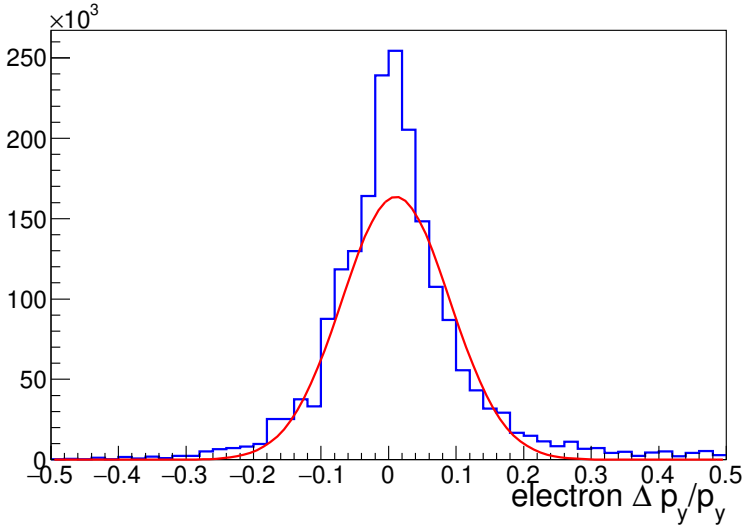


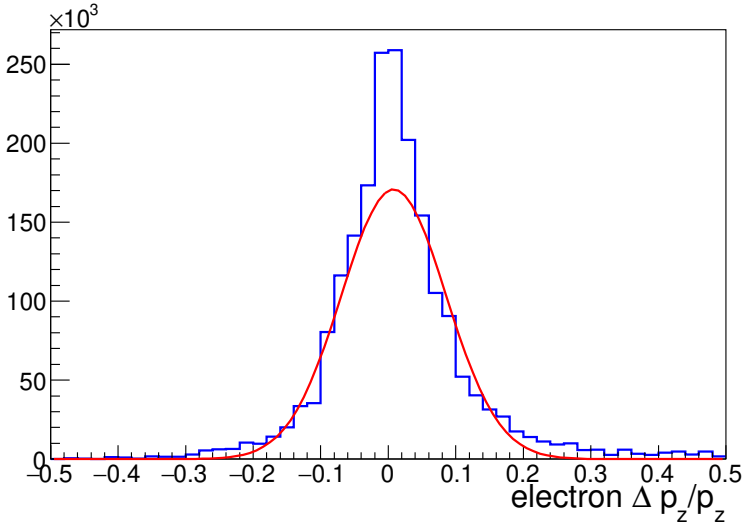


Good overall agreement. Efficiency: 1.0.

Electron momentum resolution



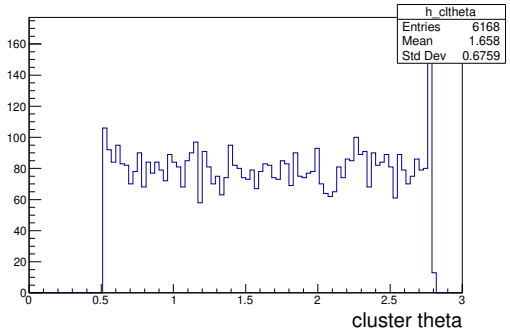




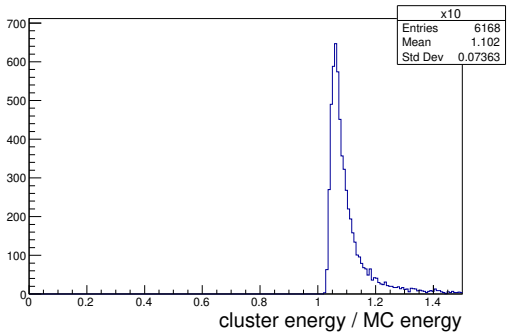
Resolution from gaussian fit: 7-8%

Obtaining photon energy from clusters

Barrel SciGlassclusters

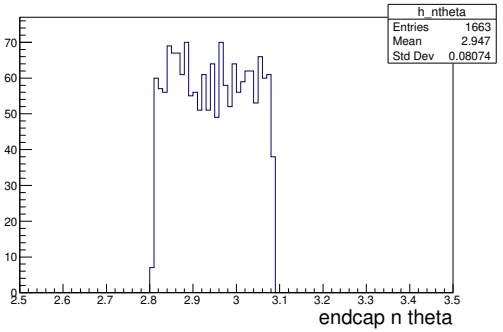


$\eta \sim$ [-1.8, 1.4]

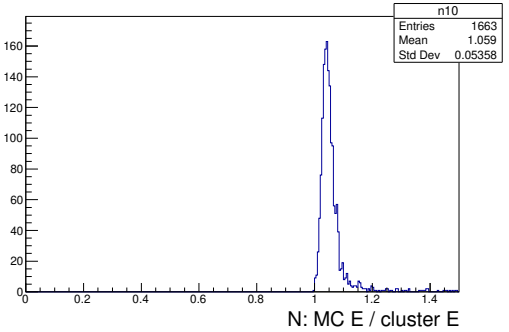


Scaling factor: 1.075

Endcap N

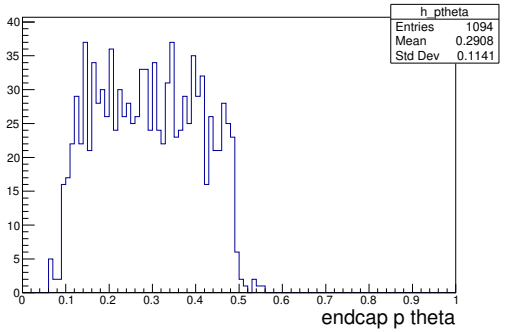


$\eta \sim$ [-3.9, -1.8]

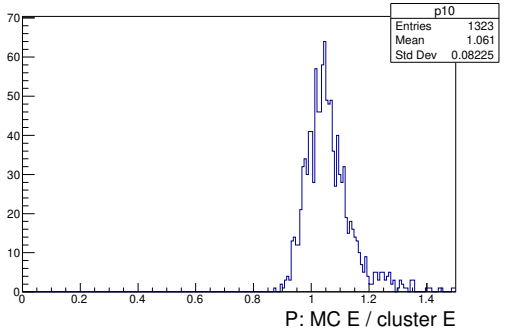


Scaling factor: 1.046

Endcap P



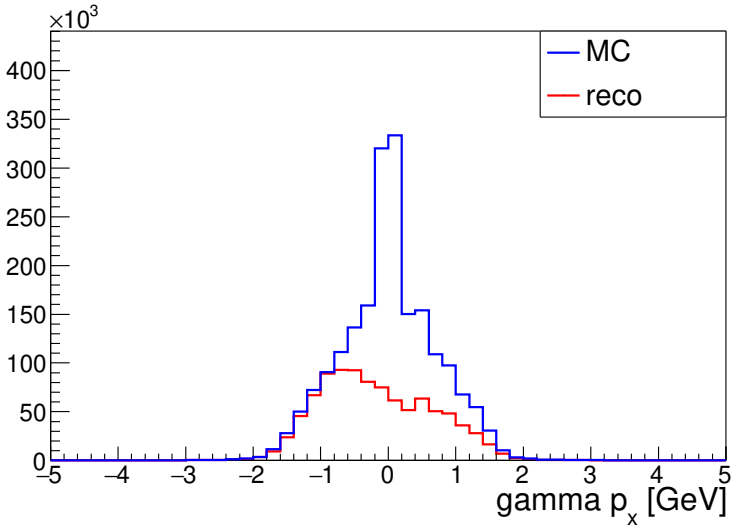
$\eta \sim$ [1.2, 3.5]

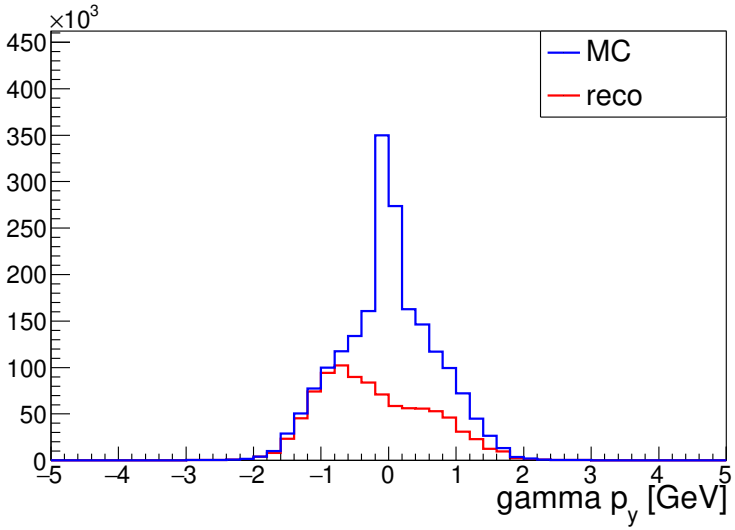


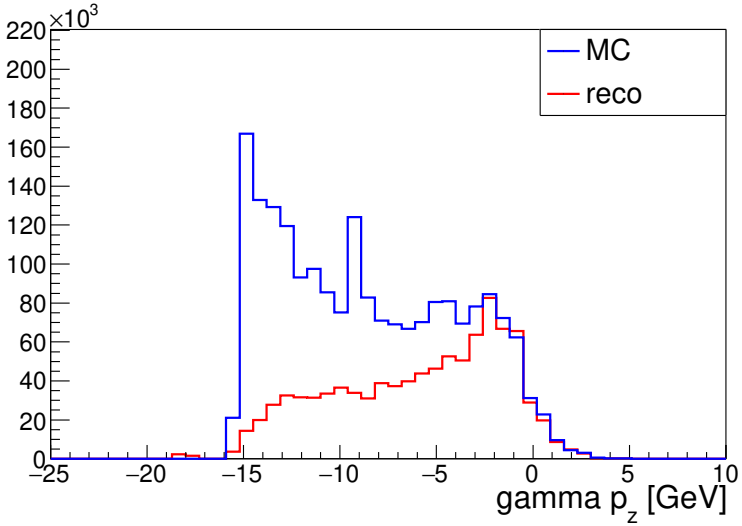
Scaling factor: 1.049

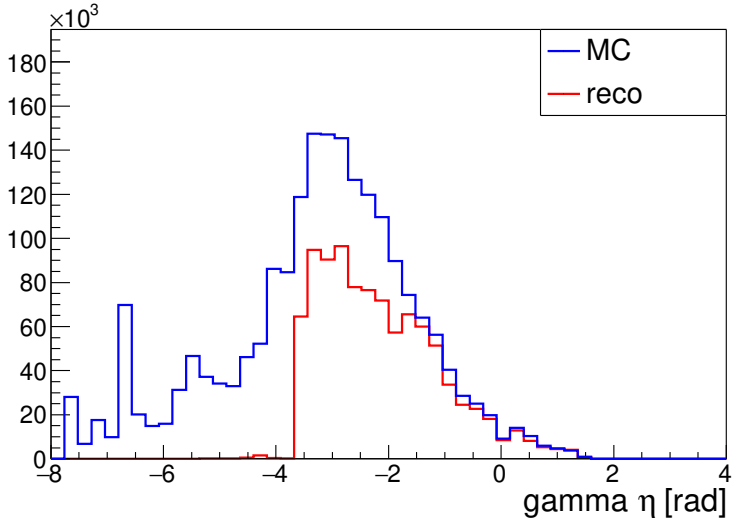
Doing a Gaussian fit and correcting the cluster energy by the fitted μ.

Photon momentum



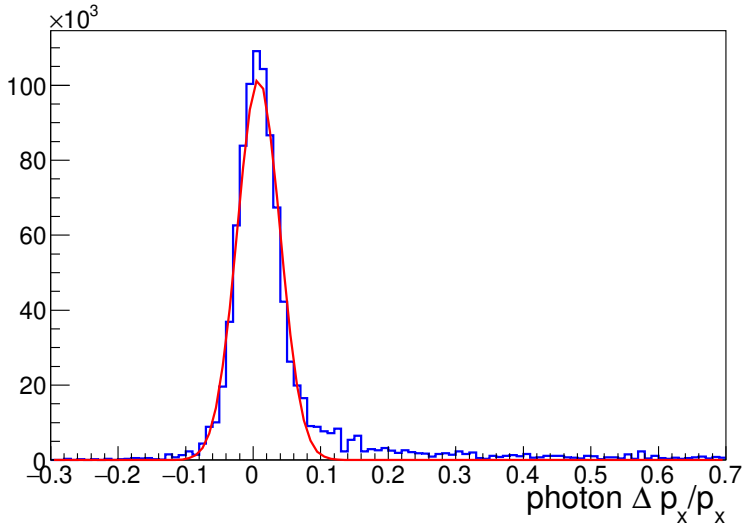


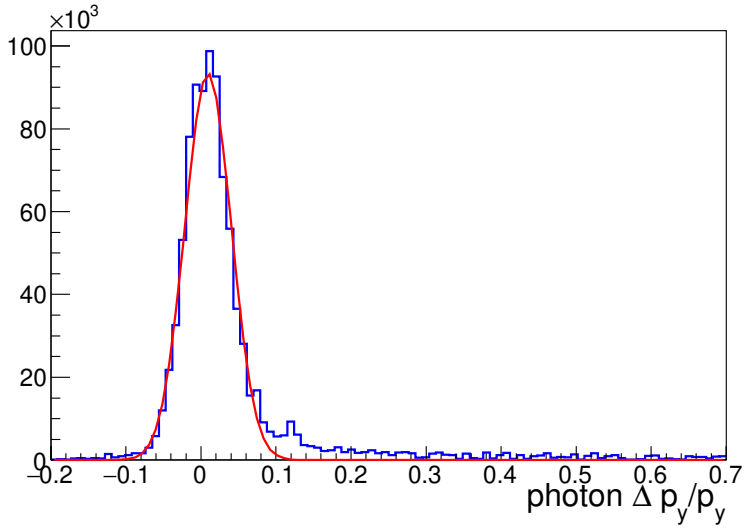


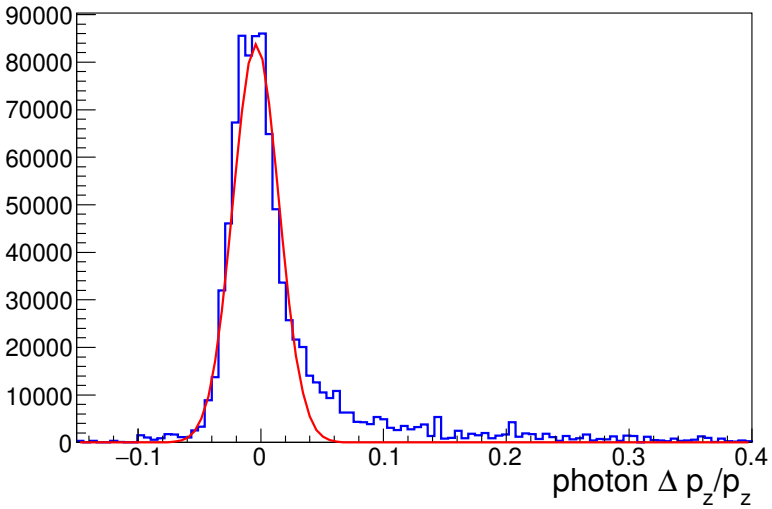


I am requiring $|p_\gamma| > 1\,\mathrm{GeV}$. Efficiency: 0.48.

Photon momentum resolution

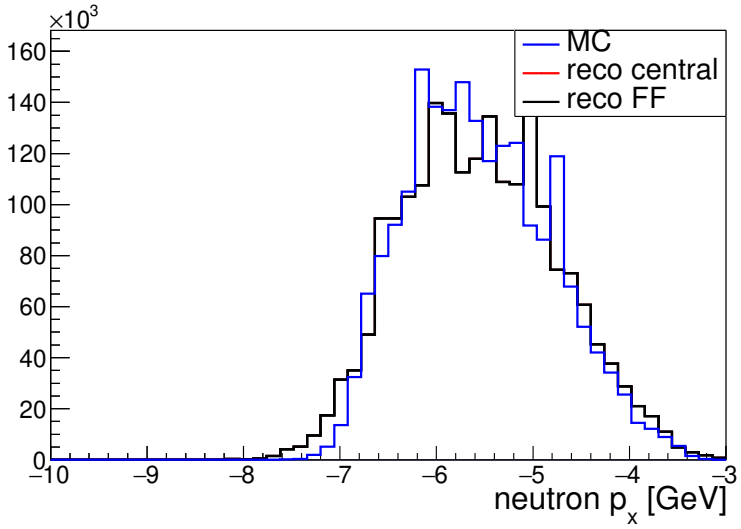


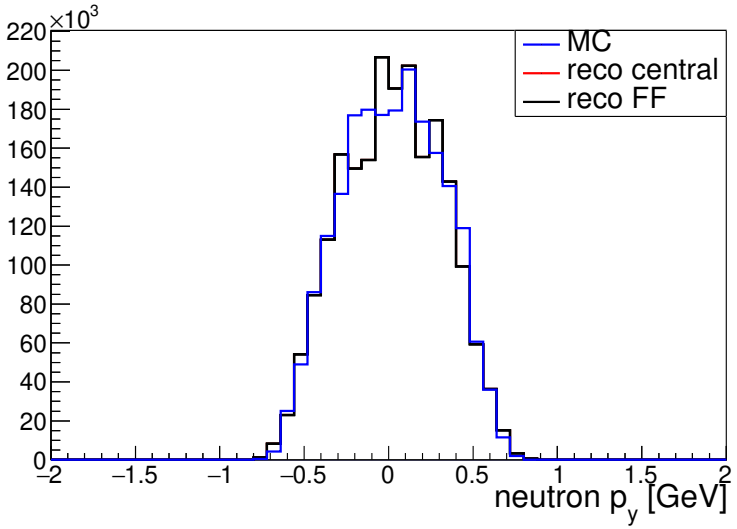


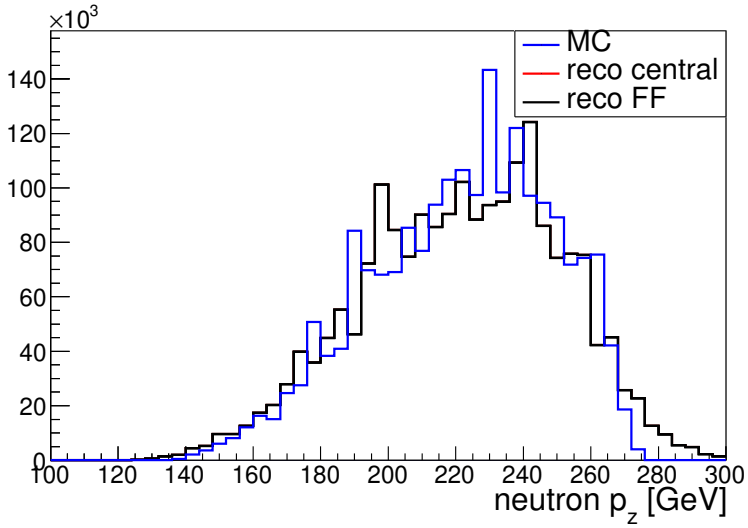


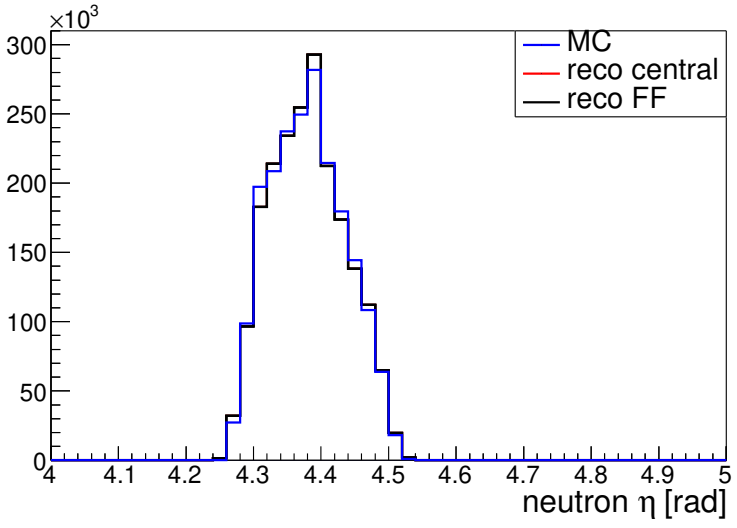
Resolution from Gaussian fit: 2-3%.

Neutron momentum



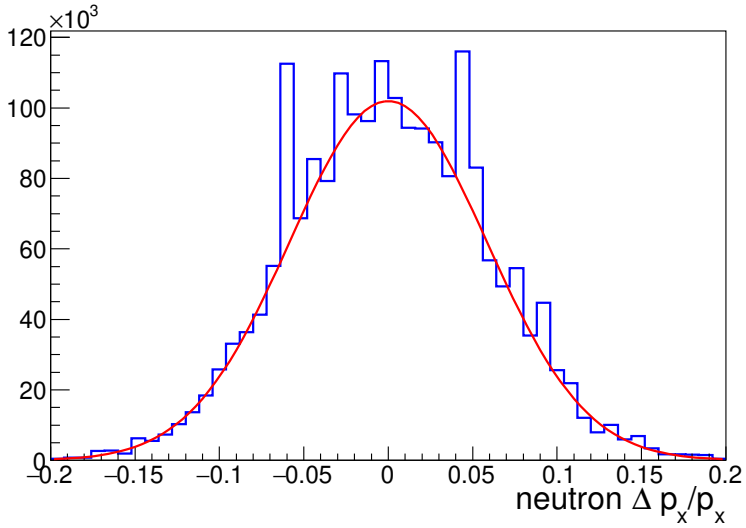


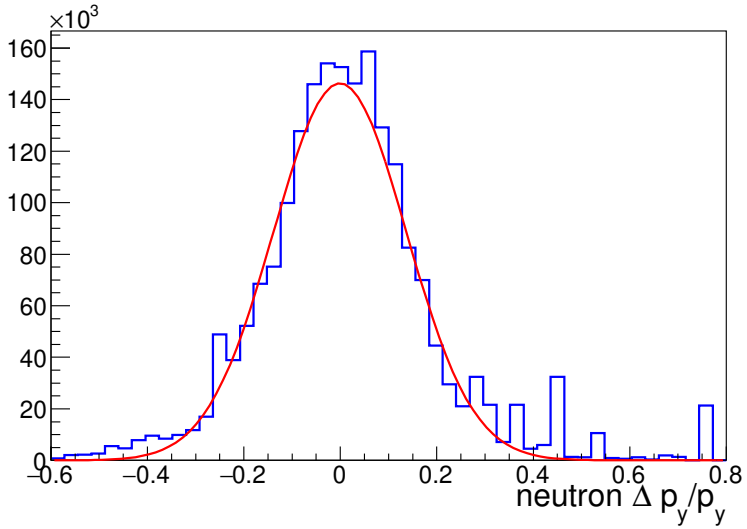


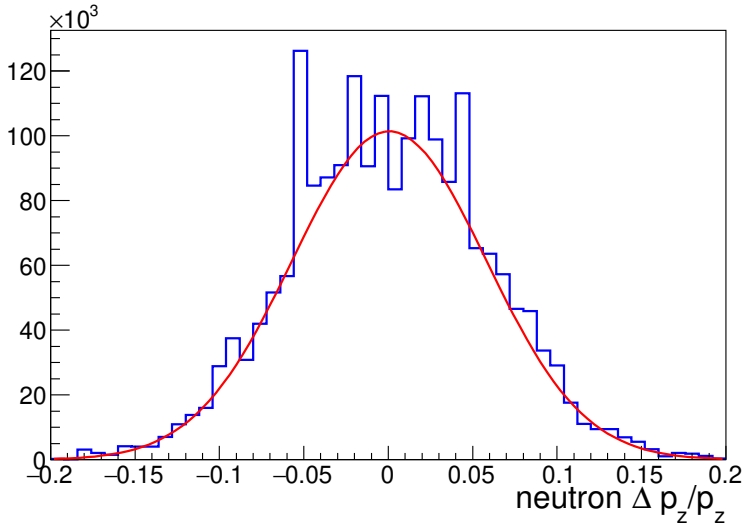


Neutrons are detected in by ZDC. Smeared collection. Efficiency: 1.0

Neutron momentum resolution

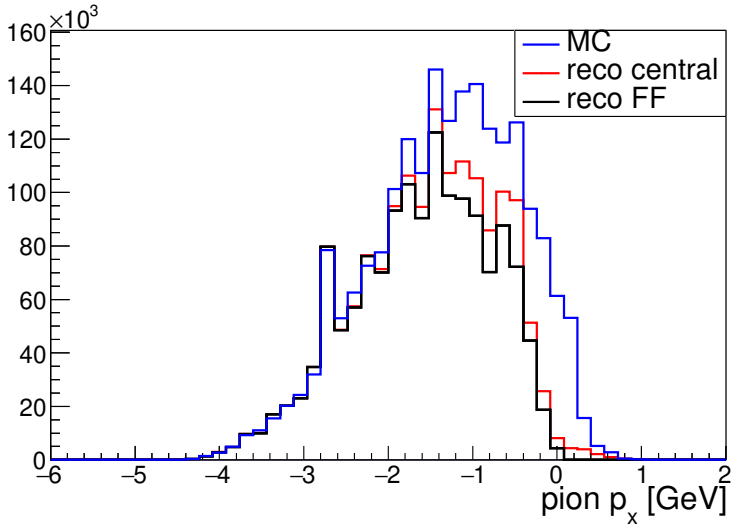


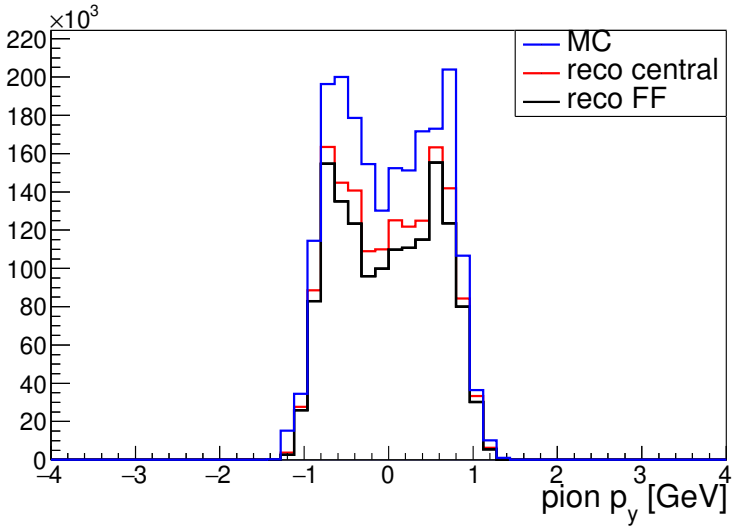


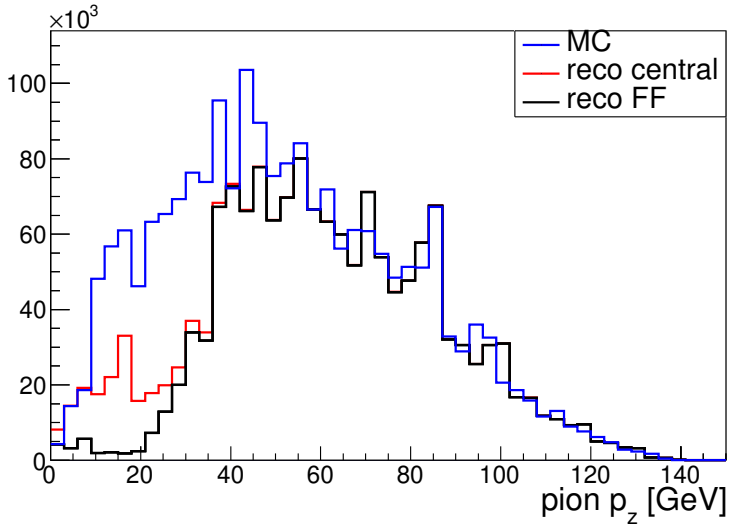


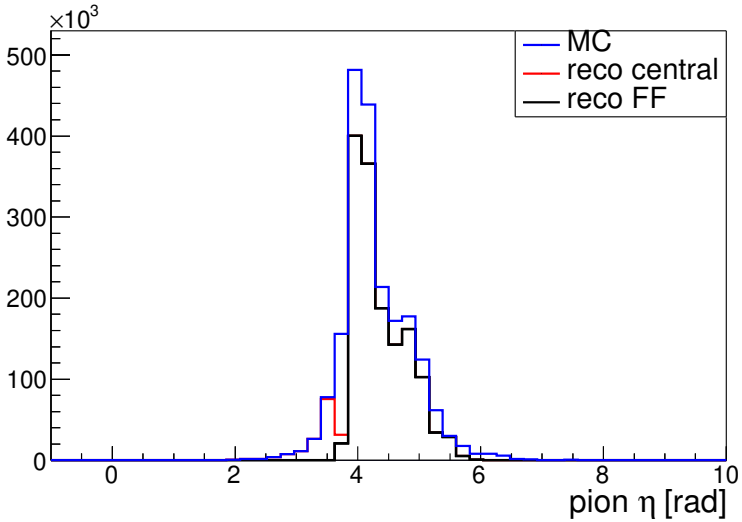
Resolution: 6-14% (larger for p_y).

Pions



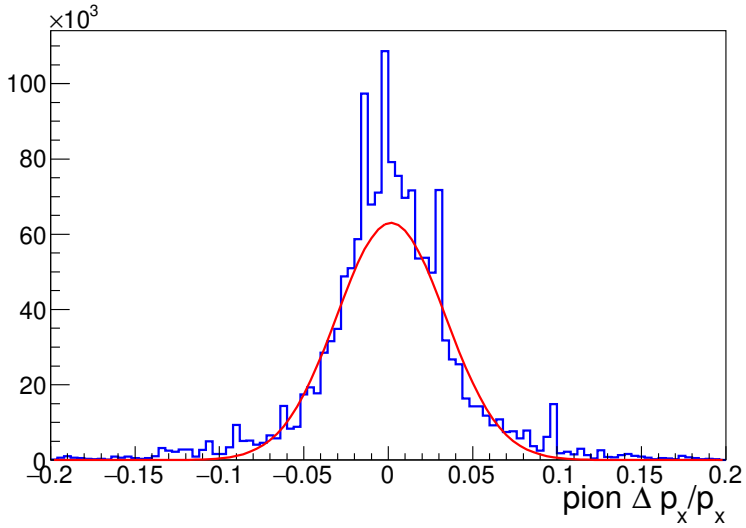


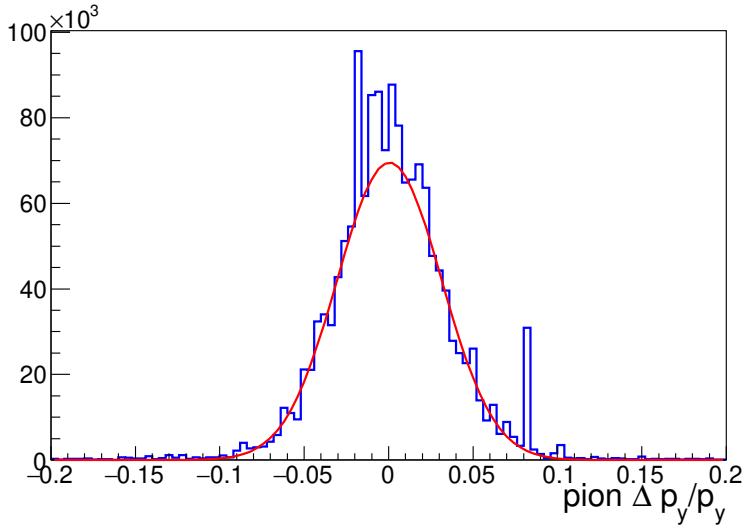


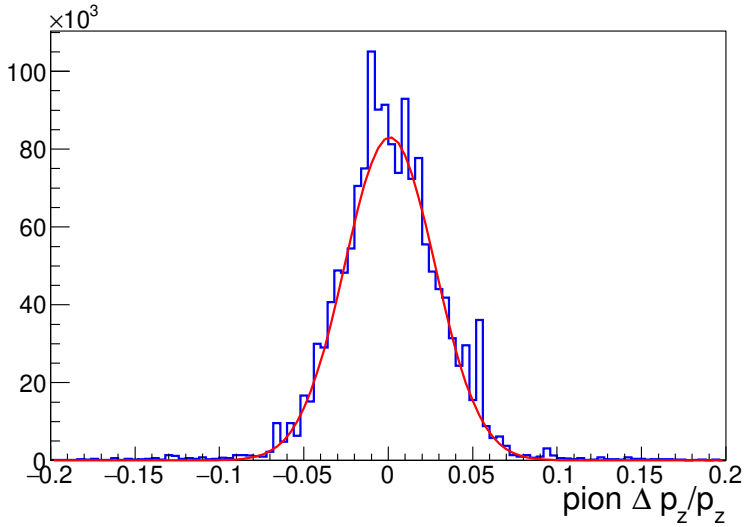


Most pions are in the FF part. Smeared collection. Efficiency: 0.78.

Pion momentum resolution

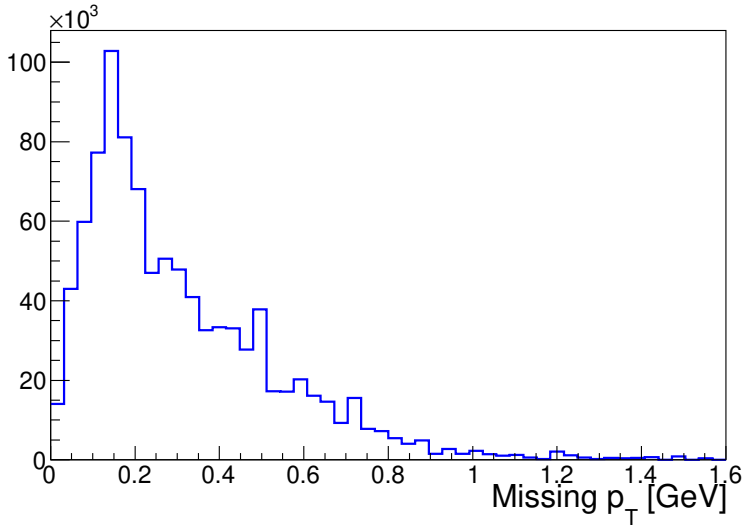


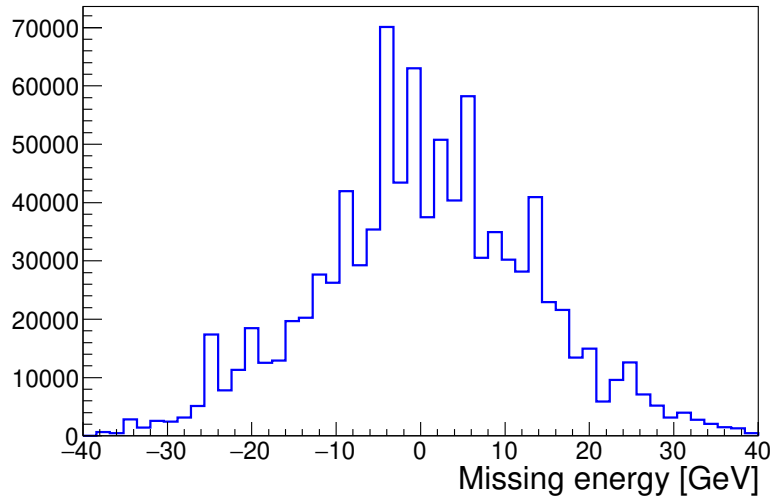




Resolution: 3%.

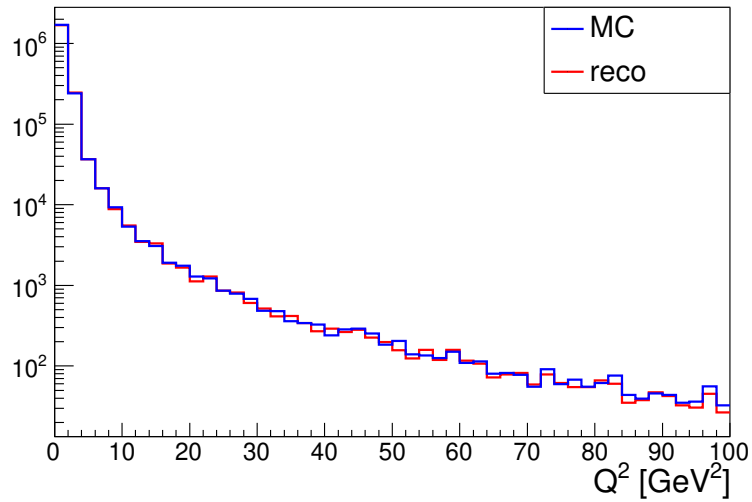
Missing energy and missing transverse momentum

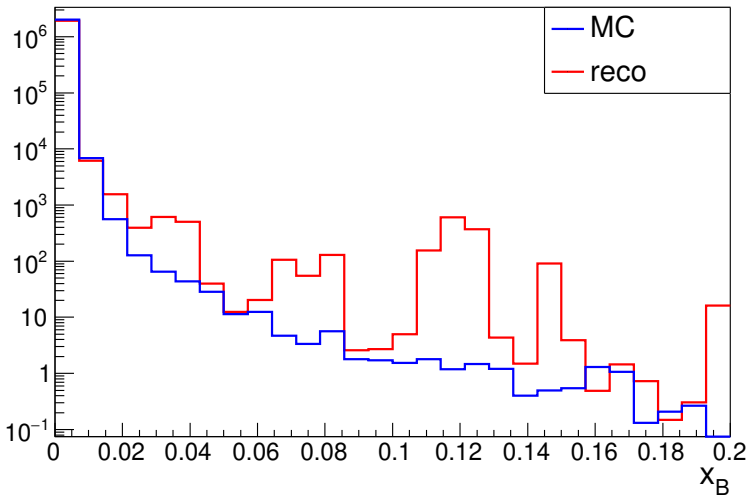


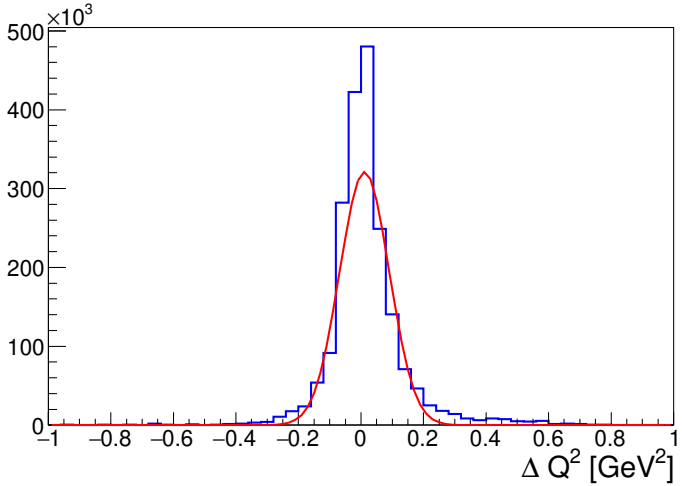


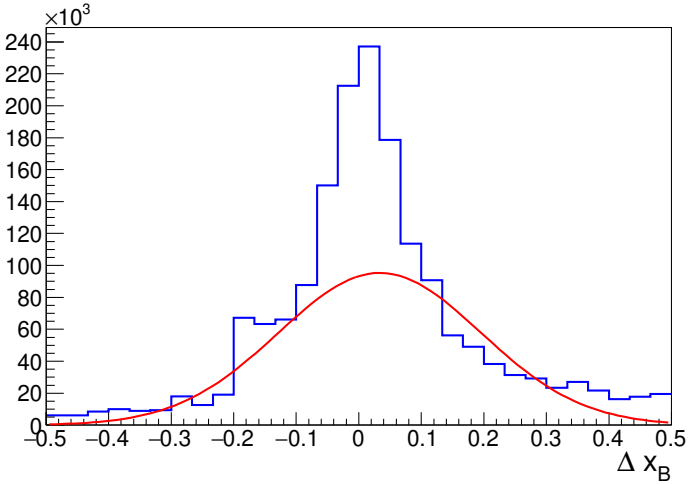
Exclusivity: I am requiring exactly 1 reconstructed electron, 1 photon >1 GeV, 1 neutron and 1 pion.

Q^2 and x_B





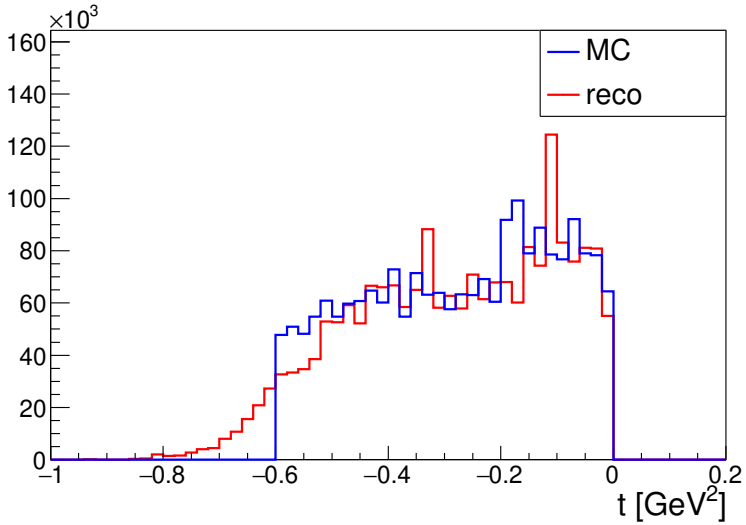


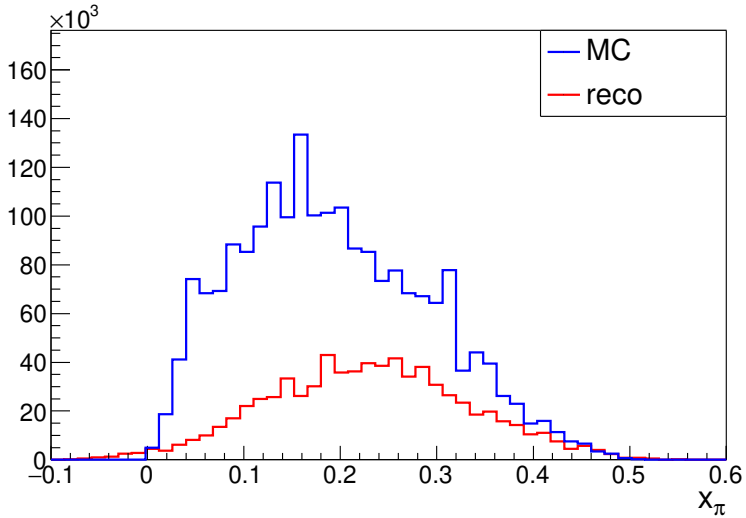


Virtuality of the photon

$$x_B = \frac{Q^2}{2p \cdot q}.$$

t and x^{π} (virtual pion emission)





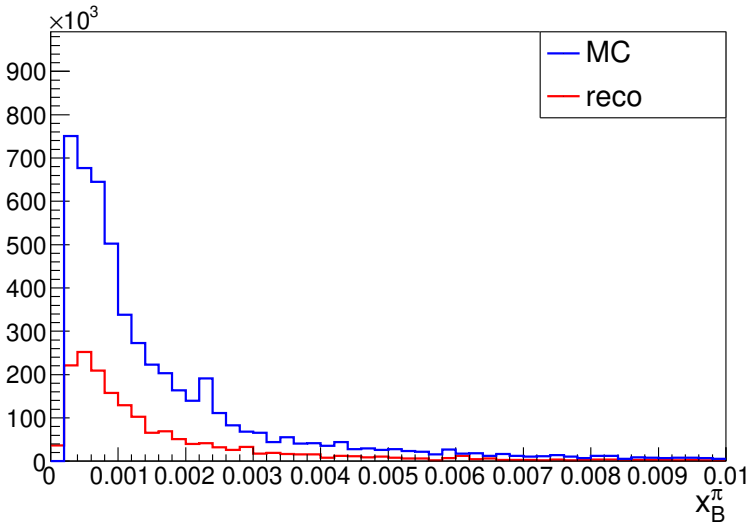
$t = (p - p')^2$

Momentum transfer to the neutron

$x_{\pi} = \frac{p_{\pi} \cdot l}{p \cdot l}$

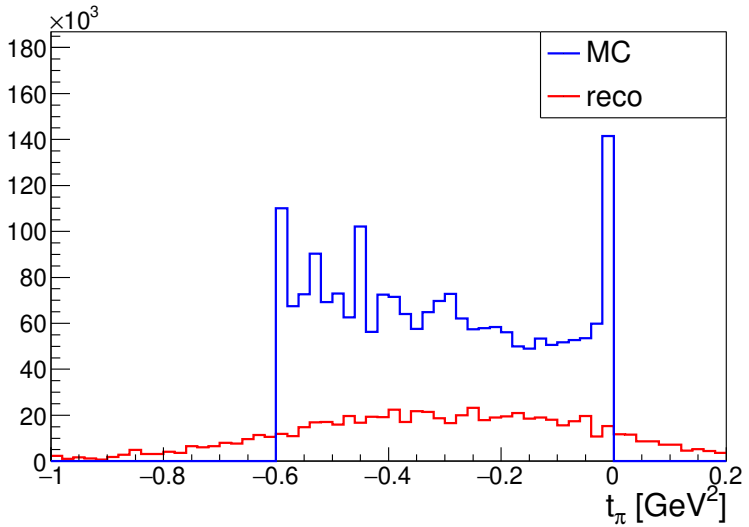
Fraction of proton energy carried by virtual pion in ep CoM

x_B^π, t^π



$$x_B^\pi = \frac{Q^2}{2p_\pi \cdot q}$$

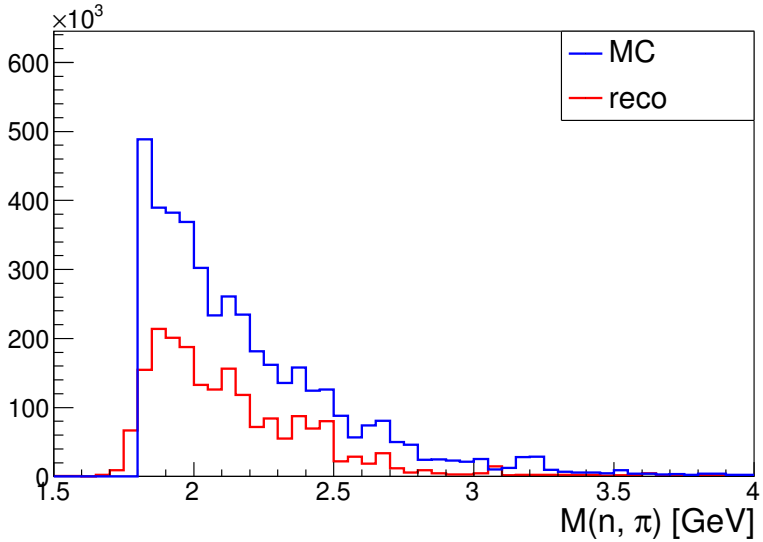
The cuts $10^{-3} < x_B^\pi < 10^{-2}$ are applied for ϕ plots.

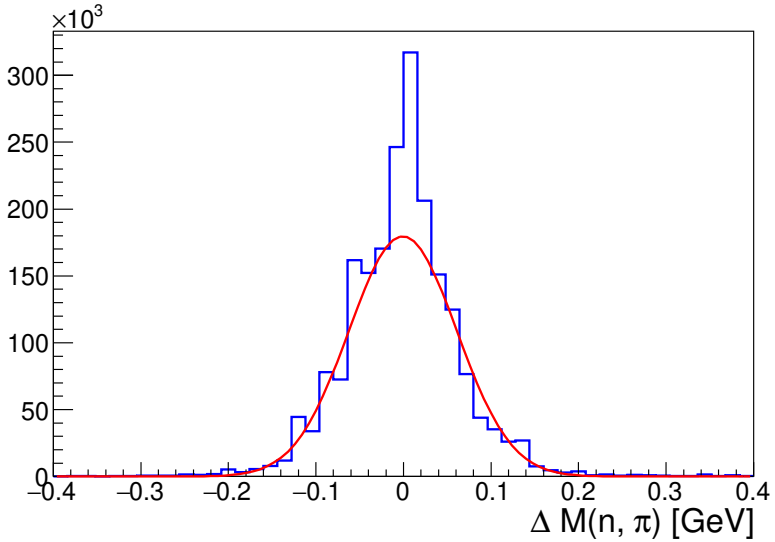


$$t^\pi = (p_\pi - p'_\pi)^2$$

Momentum transfer to the pion

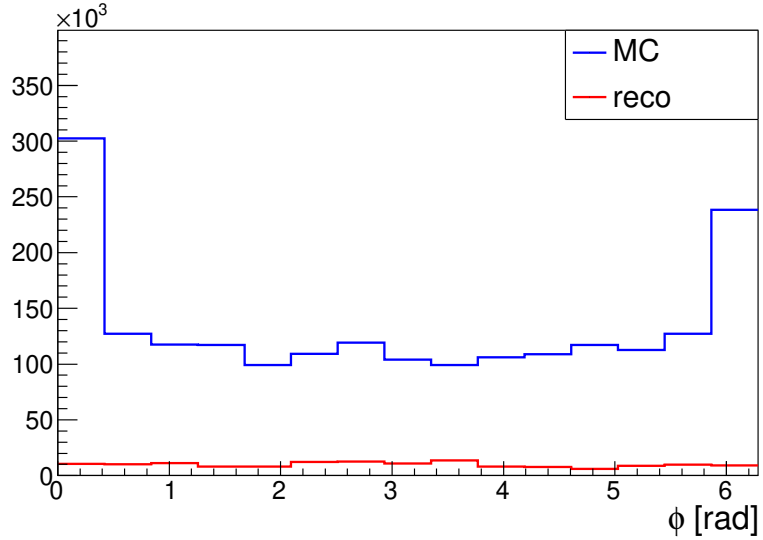
n, π invariant mass

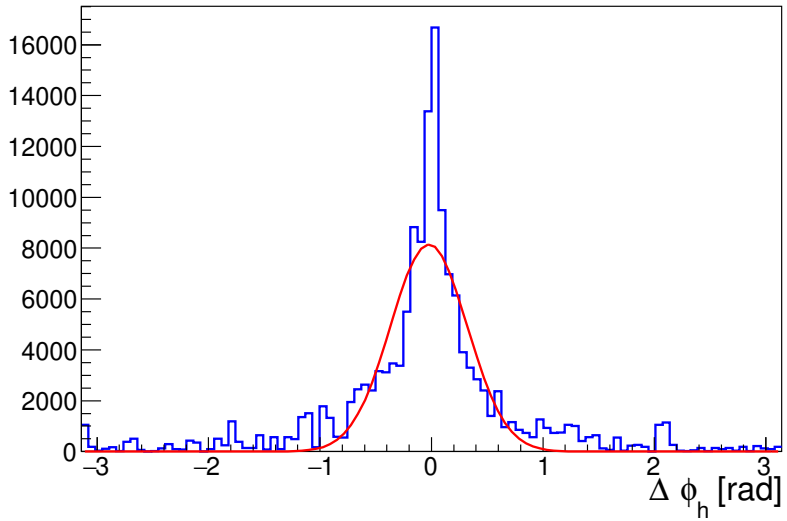




A cut of $M(n, \pi) > 2$ GeV is applied in the ϕ plots. I have generated events from 1.8 GeV to account for migration. With a resolution of 0.6 GeV this seems enough.

ϕ





ϕ: angle between leptonic and hadronic plane in the virtual photon-pion cloud CoM. Reconstruction efficiency $\epsilon = 0.07$. Resolution from Gaussian fit: 0.34 rad. 15 bins should be ok ($2\pi/15$=0.42). ϵ cutflow:

Exclusivity	0.37
$1 <= Q^2 < 100\text{GeV}^2$	0.32
ϕ! =nan	0.29
$M(N, \pi) > 2$ GeV	0.14
$10^{-3} < x_B^{\pi} < 10^{-2}$	0.07

Conclusions

- I have ran the Sullivan process through the ePIC framework, including afterburner, Geant4 simulation and Jana2 reconstruction.
- I have estimated the resolution of ϕ, 15 bins seems reasonable.
- Fewer events are expected compared to the article, particularly at low Q^2, but the order of magnitude agrees.
- I produced 100k events on a local cluster. Statistical fluctuations are large in the reconstructed ϕ distribution.
- It would be helpful if a larger sample ($\sim$3 million events) could be produced centrally.
- Once I have more statistics, I would look at the beam spin asymmetry.