nDVCS with tagged spectator proton with BONuS12

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Analysis : neutron DVCS with tagged proton

Analysis :

- Neutron DVCS: electroproduction of a high-energy real photon on a neutron.
- Here, the target is deuterium: quasi-free neutron
- The measurements on a neutron target will contribute to extracting the GPD E.
- Three types of measurement :
  - *Only the neutron* (RG-B analysis form A. Hobart)
  - *Only the spectator proton* (this work)
  - *Both of them* (ongoing analysis at JLAB by M. Hattawy)

- Missing high energy neutron → more uncertainty in exclusivity cuts.

- **Observable of this analysis: beam spin asymmetry (BSA/ALU).**
  - N+ : number of events with a electron with a positive helicity.
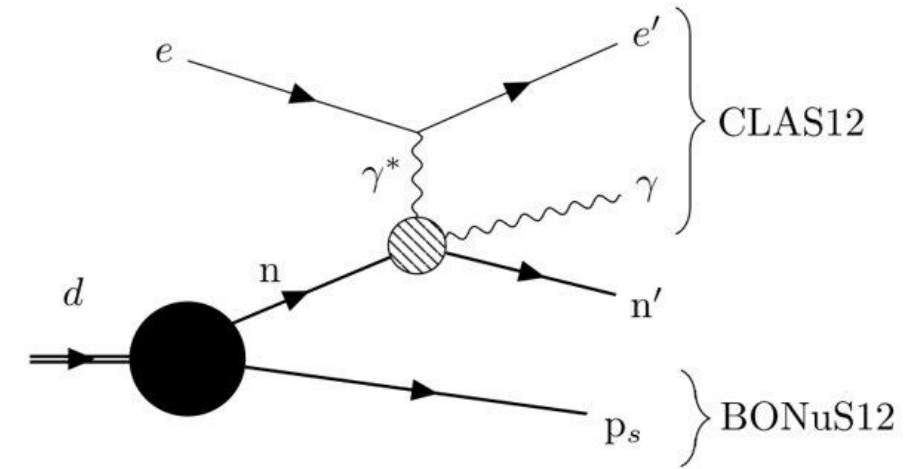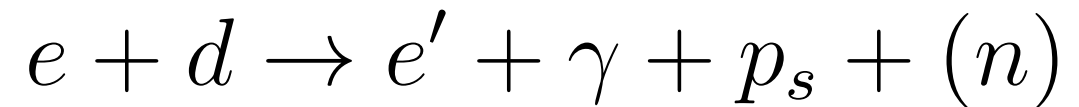 - N- : same of negative helicity

Figure 1.4: Proton-tagged neutron DVCS diagram in deuterium.

$$e + d \rightarrow e' + \gamma + p_s + (n)$$

$$A_{LU} = \frac{N^+ - N^-}{N^+ + N^-}$$

The BONuS12 experiment

- **Detector :**
  - The Radial Time Projection Chamber.
  - Built to detect low momentum proton (0.05 to 0.1 GeV/c)
  - BONuS12 replaced the central silicon tracker and micromegas.
- Three targets: deuterium, hydrogen, helium 4

- Data taken during the summer of 2020
- Gaseous deuterium target at 5.6 atm
- Torus field: full-field inbending electrons
- FT Off
- Beam energy : 10.38 GeV
- Overall polarization: 83.66%
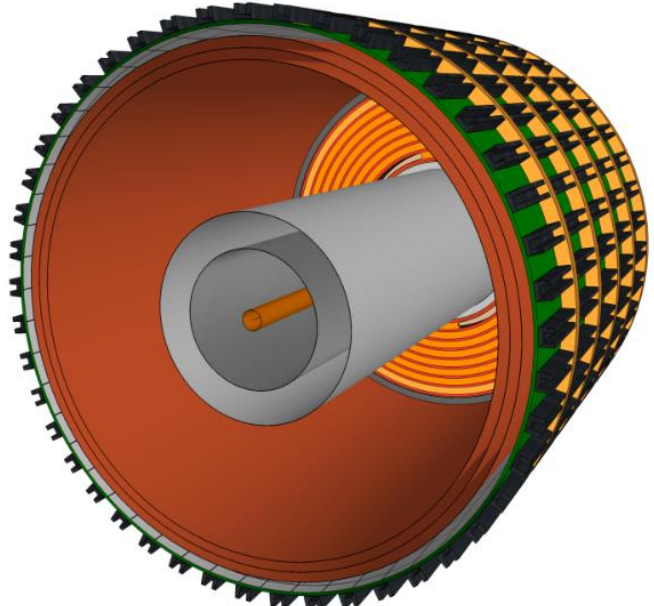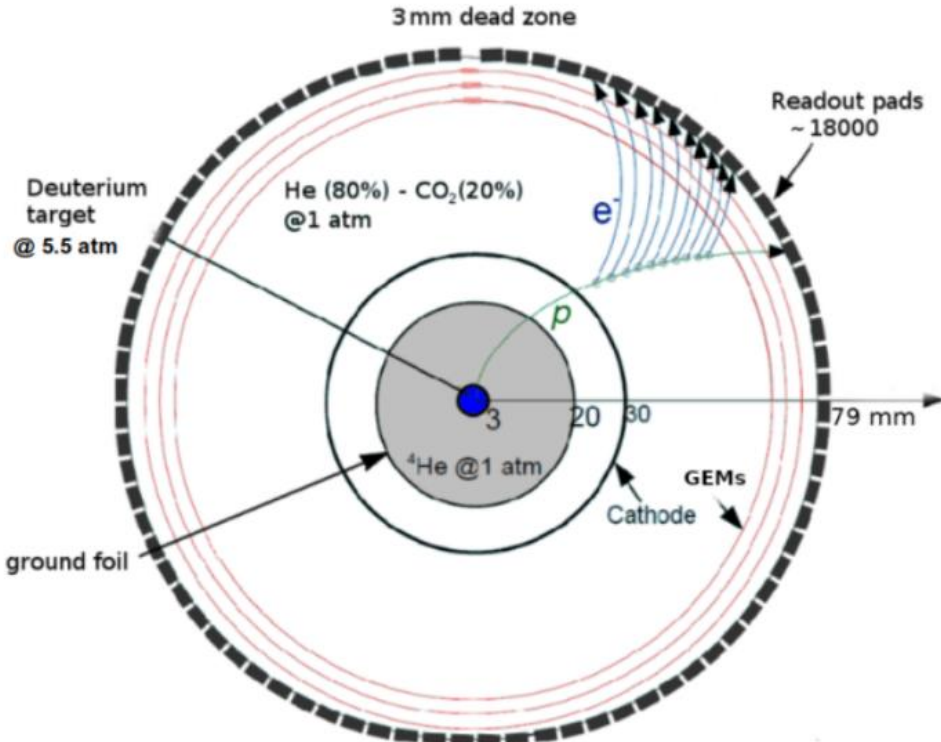
Electron and photon selection

Black: No cuts apply
Blue: All cuts expect the one shown

Electron pid cuts :

- pid $= 11$ and status < 0
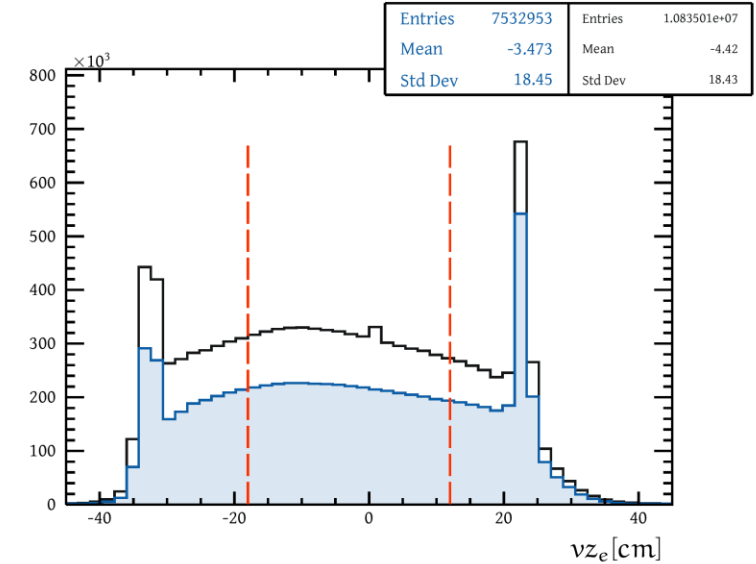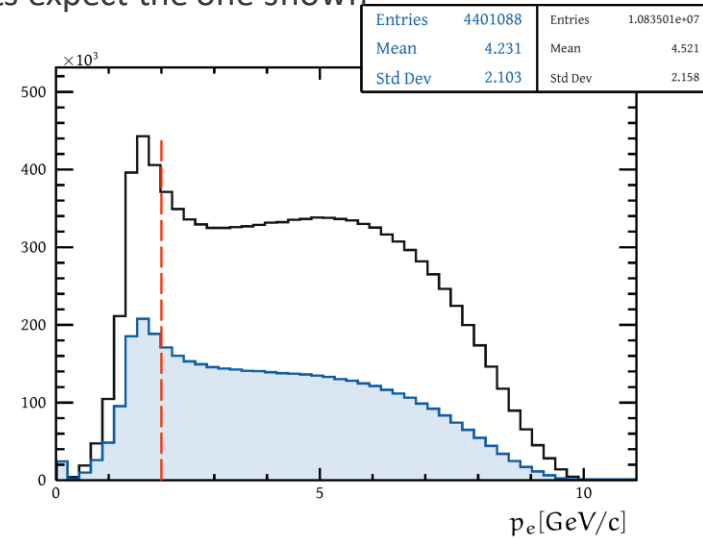- $p > 2$ GeV
- $-3 < \chi^2_{pid} < 3$
- $-18 < v_z < 12$ cm

Electron fiducial cuts :

- $E_{PCal} > 70$ MeV
- $9 < v, w$ cm
- for $p > 4.5 \rightarrow E_{dep,In}/p < 0.2 - E_{dep,PCal}/p$
- cuts on DC (Stefan Diehl 18 Apr 2020)

Entries	4401088	Entries	1.083501e+07
Mean	4.231	Mean	4.521
Std Dev	2.103	Std Dev	2.158

p_e[GeV/c]

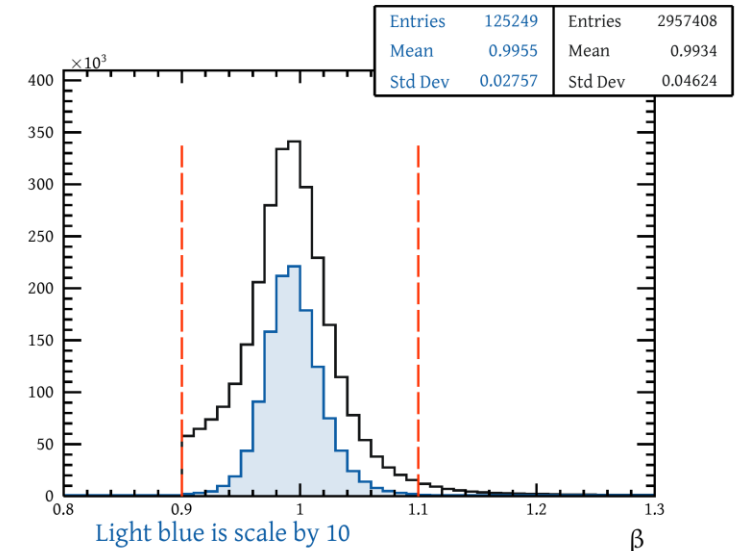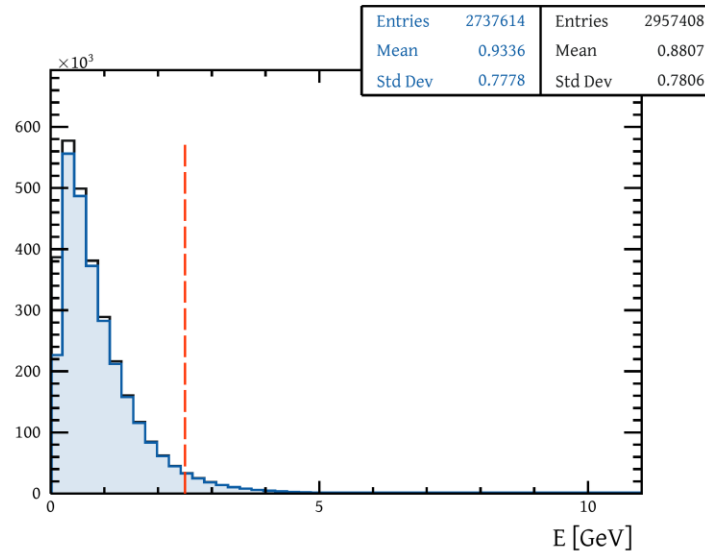| Entries	7532953	Entries	1.083501e+07
Mean	-3.473	Mean	-4.42
Std Dev	18.45	Std Dev	18.43

vz_e[cm]

Photon pid cuts :

- pid $= 22$
- $0.9 < \beta < 1.1$
- $E > 2.5$ GeV

Photon fiducial cuts :

- $9 < v, w$ cm

Black: Only electron cuts are applied
Blue: All cuts expect the one shown

Entries	2737614	Entries	2957408
Mean	0.9336	Mean	0.8807
Std Dev	0.7778	Std Dev	0.7806

E [GeV]

Entries	125249	Entries	2957408
Mean	0.9955	Mean	0.9934
Std Dev	0.02757	Std Dev	0.04624

Light blue is scale by 10
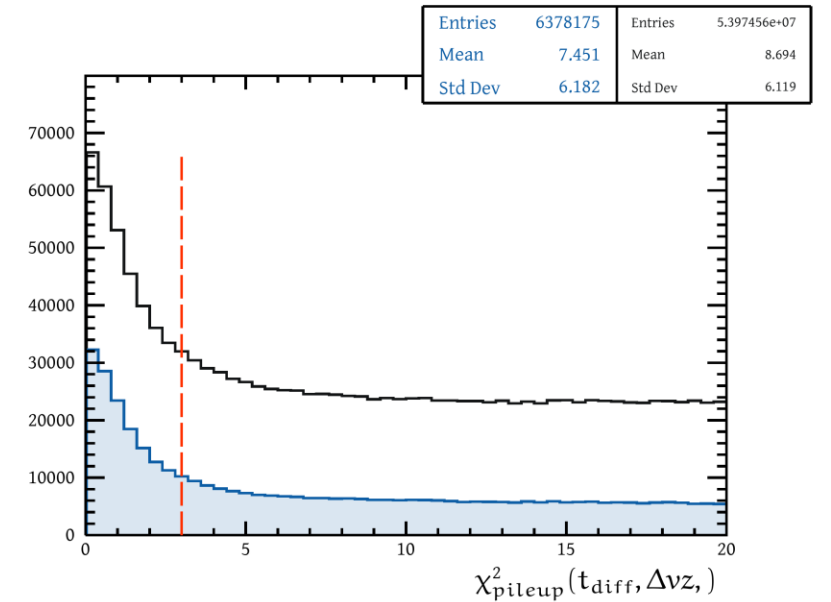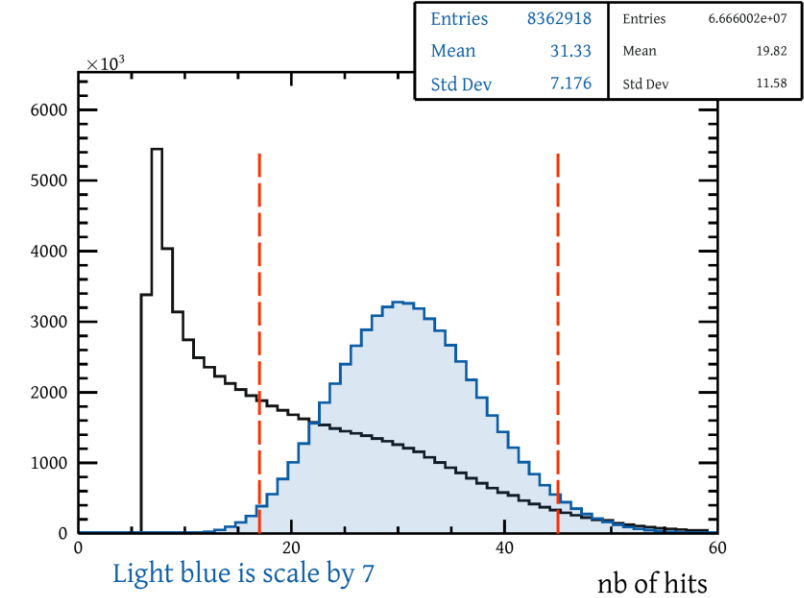
β

4

Proton selection in the RTPC

Tracks selection procedure :

- Select good quality tracks.
- Select tracks that come from the same interaction.
- PID cuts.

Good track cuts :

- $\chi^2_{helix} < 2.5 \rightarrow$ have a good fit quality
- $17 < nhits < 45 \rightarrow$ enought hits to fit but remove merged tracks
- $R_{helix} < 0 \rightarrow$ positive tracks
- $-18 < v_z < 12$ cm $\rightarrow$ tight fiducial cut inside the detector region

- Tracks from the same interaction :
  - Want to construct a chi2like variable to merge t_{diff} and Δv_z to reduce the background.
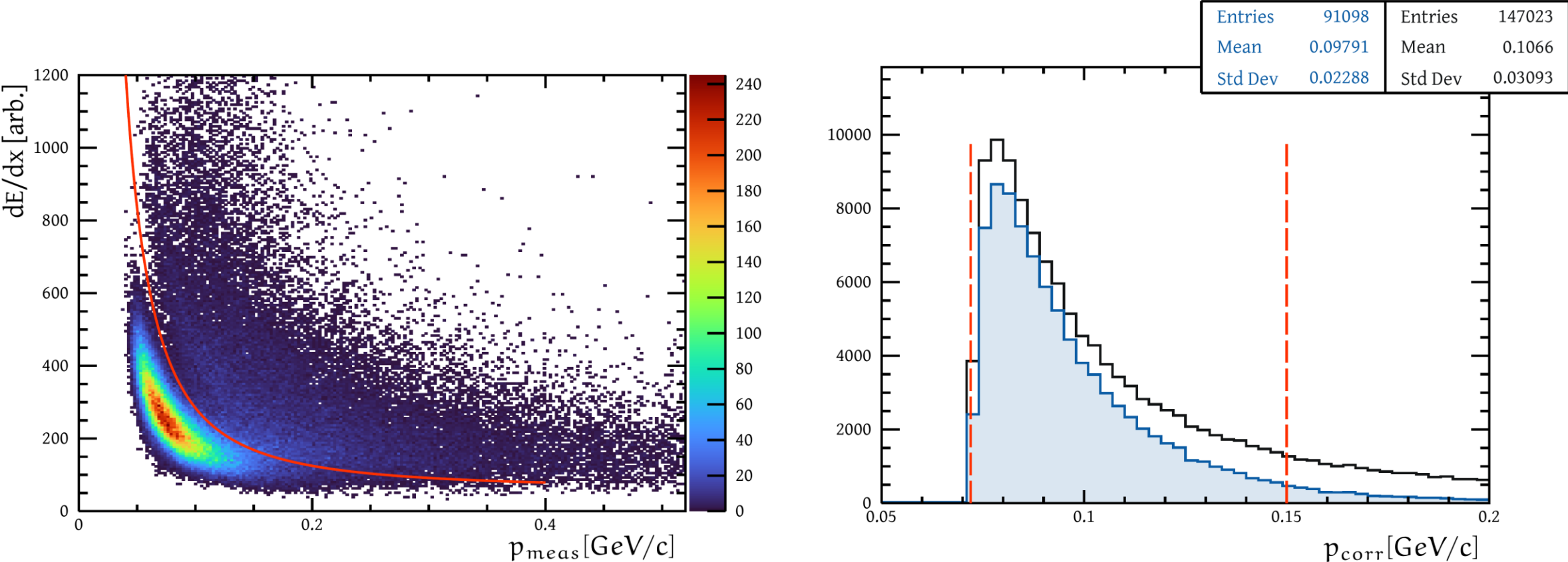 - This cut removes pile-up: it means removing good tracks from another event.

$$\chi^2_{pileup} = \left(\frac{t_{diff} - \mu_{t_{diff}}}{\sigma_{t_{diff}}}\right)^2 + \left(\frac{\Delta vz - \mu_{\Delta vz}}{\sigma_{\Delta vz}}\right)^2$$

Entries	8362918	Entries	6.666002e+07
Mean	31.33	Mean	19.82
Std Dev	7.176	Std Dev	11.58

Light blue is scale by 7   nb of hits

Entries	6378175	Entries	5.397456e+07
Mean	7.451	Mean	8.694
Std Dev	6.182	Std Dev	6.119

$\chi^2_{pileup}(t_{diff}, \Delta vz,)$

- The black line is before any cuts on the RTPC.

- The blue is after good track cuts.

Spectator proton identification : Select proton

- We select proton in all the goods tracks in the RTPC by cutting on :
    - $0.072 < p_{corr} < 0.15$ (correction function developed by M. Pokhrel)
    - $dE/dx < 60.15 + 4.63 \, p^{-1.773}$ (developed by M. Pokhrel)
        - Remove possible helium or nuclear fragment contamination

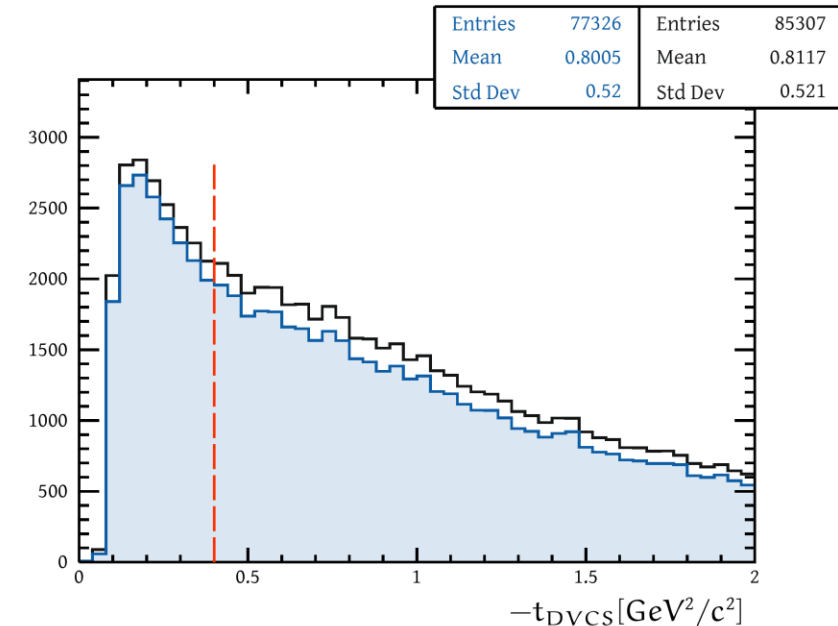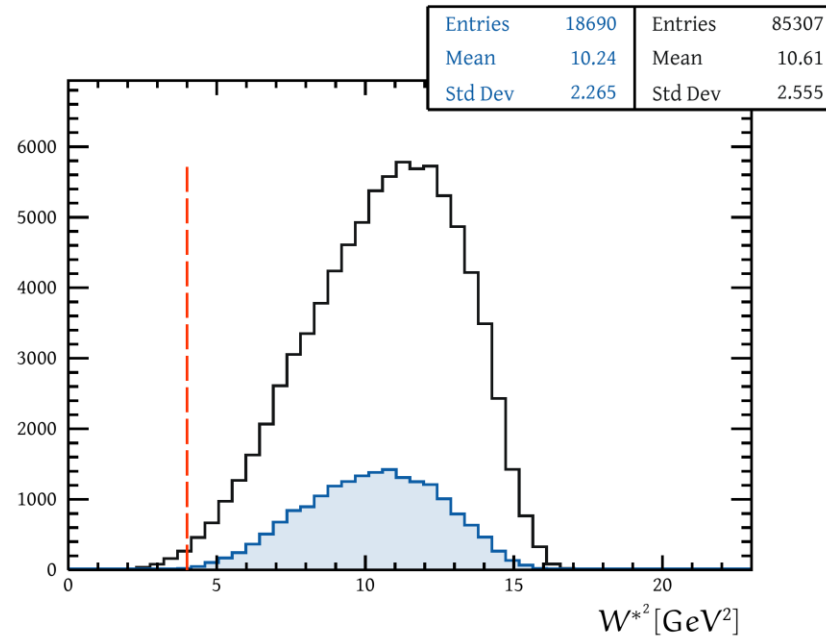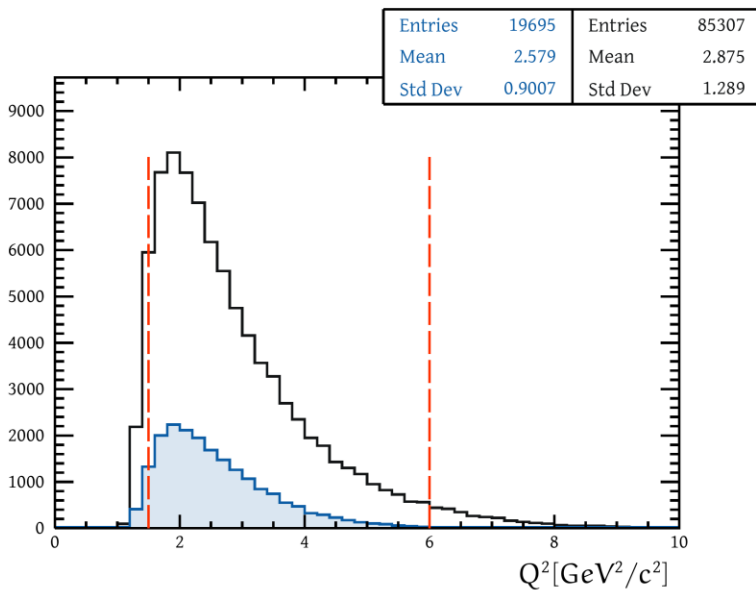|				
Entries	91098	Entries	147023
Mean	0.09791	Mean	0.1066
Std Dev	0.02288	Std Dev	0.03093

DVCS event selection

- DVCS events, so we cut on :

- $1.5 < Q^2 < 6$ GeV^2/c^2 → to have deeply virtual events

- $W^{*2} > 4$ GeV^2 → avoid the resonance region

- $t_{DVCS} < 0.4$ GeV^2/c^2

- To improve resolution on t, we compute the outgoing photon energy from 4-momentum conservation, and t with the outgoing photon direction, assuming an exclusive event

$$E_{\gamma_{calc}} = \frac{s + m_\gamma - m_n}{2\sqrt{s}}$$

$$t_{DVCS} = (E_{\gamma^*} - E_{\gamma_{calc}})^2 - E^2_{\gamma_{calc}} - p^2_{\gamma^*} + 2p_{\gamma^*} * E_{\gamma_{calc}} \cos\theta_{\gamma^*\gamma}$$

Entries	19695	Entries	85307
Mean	2.579	Mean	2.875
Std Dev	0.9007	Std Dev	1.289

Entries	18690	Entries	85307
Mean	10.24	Mean	10.61
Std Dev	2.265	Std Dev	2.555

Entries	77326	Entries	85307
Mean	0.8005	Mean	0.8117
Std Dev	0.52	Std Dev	0.521

Accidentals Correction

$$\chi 2_{\Delta v_z} = min(\frac{\Delta v z - 15}{\sigma_{\Delta v_z}}, \frac{\Delta v z + 15}{\sigma_{\Delta v_z}})$$

- Select a spectator proton that comes from another interaction. Done by modifying the delta vz term in chi2build :

- We can cut on chi2square at a higher value to have more statistics.
- Accidental contamination is sensitive to the helicity; most of our background is pDVCS.
- Need to correct the accidental contamination at the helicity level. We will compute a plus ratio and a minus one.
- The accidental contamination is around 20%. It will have a significant impact on the error bar for the asymmetry.
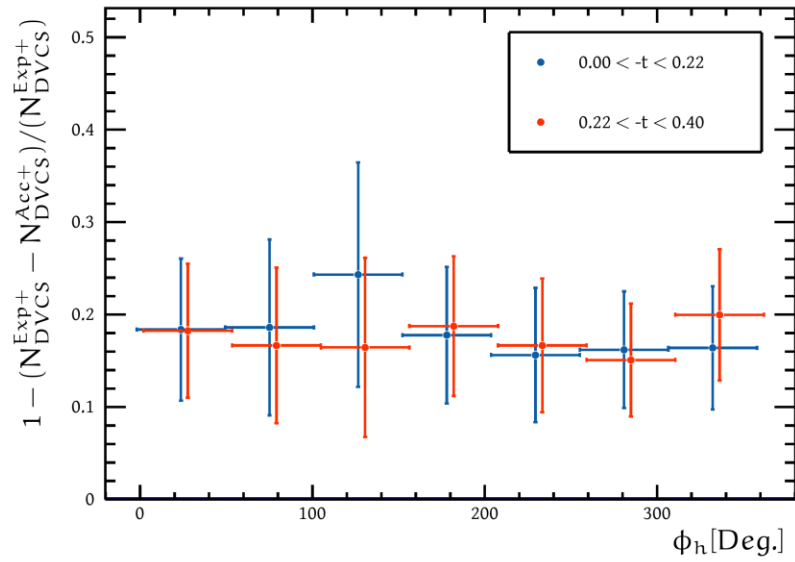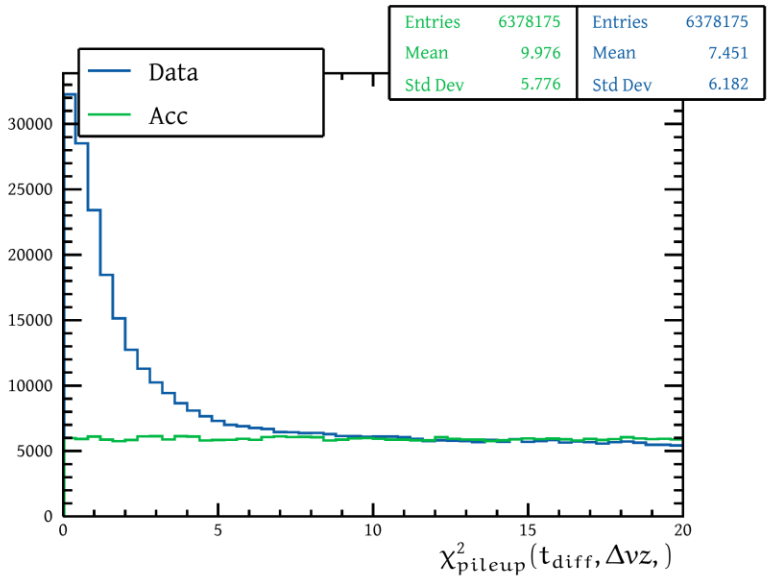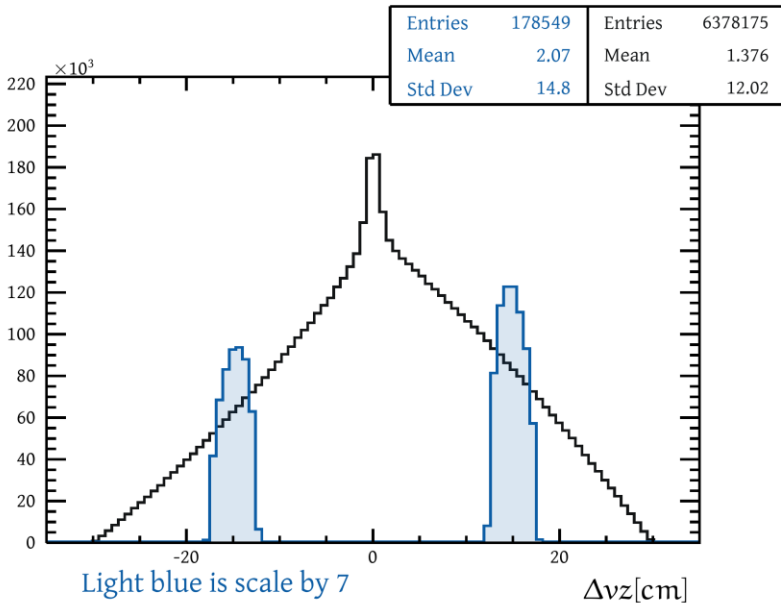
π^0 Correction

- Main background for this analysis : π^0 .

- Use simulation to **subtract** them:

$$N_{\pi^0(1\gamma)}^{Exp} = \frac{N_{\pi^0(1\gamma)}^{Sim}}{N_{\pi^0(2\gamma)}^{Sim}} N_{\pi^0(2\gamma)}^{Exp}$$

- Cuts on the π^0 :
  - $0.08 < M_{\gamma\gamma} < 0.18$
 - $E_{\pi 0} > 0.1$

- Same cuts for all other particles.

- Want to see the amount of π^0 event inside the exp events.
- Fit the contamination to reduce statistical error (add systematics).

- The π^0 contamination is around 5%. Except for the high t bin where it is a 20%. We can see that the π^0 contamination increases rapidly with t.
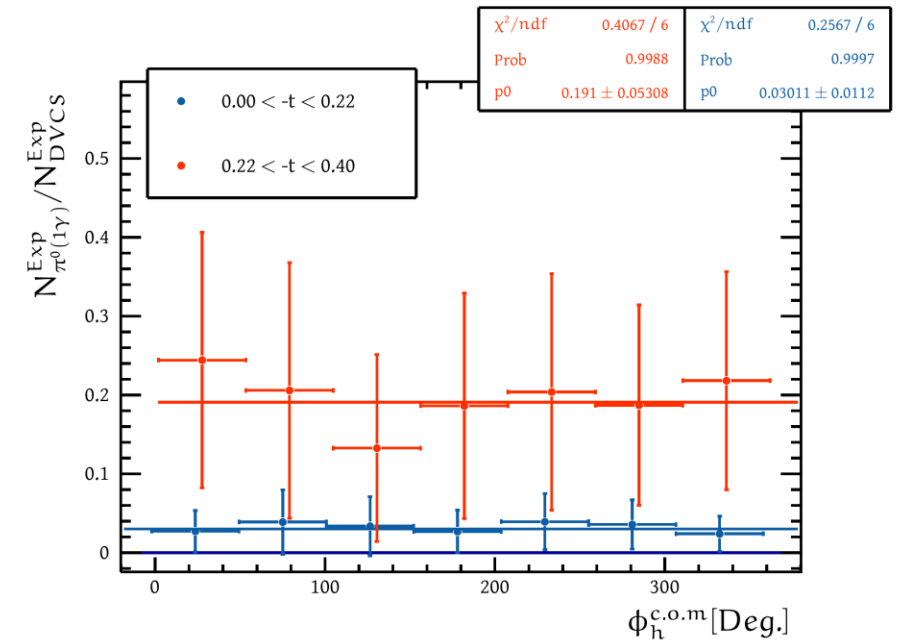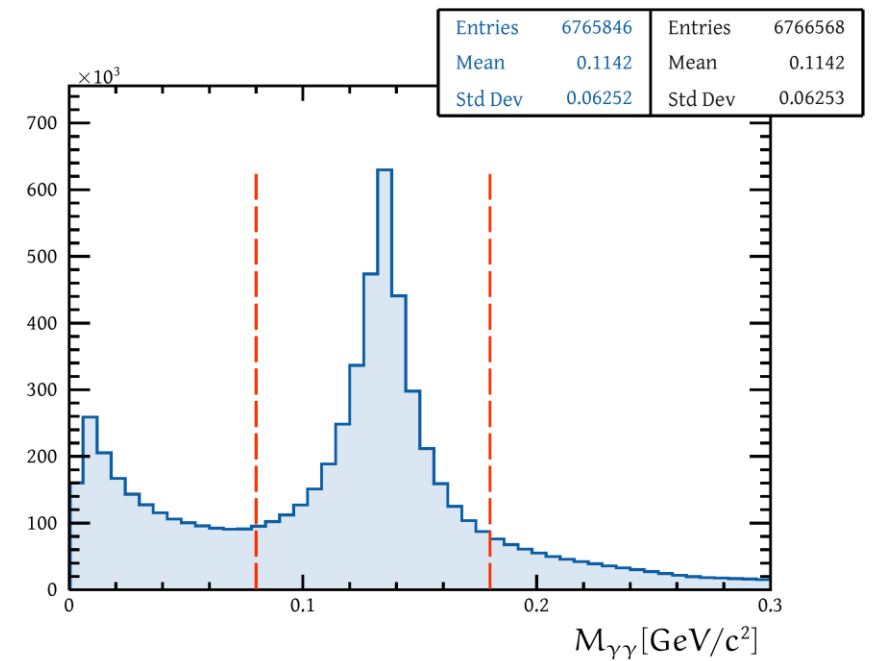
DVCS event selection

- We select event with the missing mass of the ed → eγp$_s$X system : it should be equal to the square of mass of neutron.

- The missing mass for accidents is nearly the same as for DVCS. So we cannot remove some accidentals by cutting on this. This is due to the low momentum proton compared to the missing neutron.

- there are additional (minor) backgrounds after the pi0 and accidental subtraction which will be taken care of later (e.g., contamination with A > 2 target gases, PID backgrounds etc.).

- $0.2 < MM^2_{ed \to egp_sX} < 2.1$ GeV^2/c^4
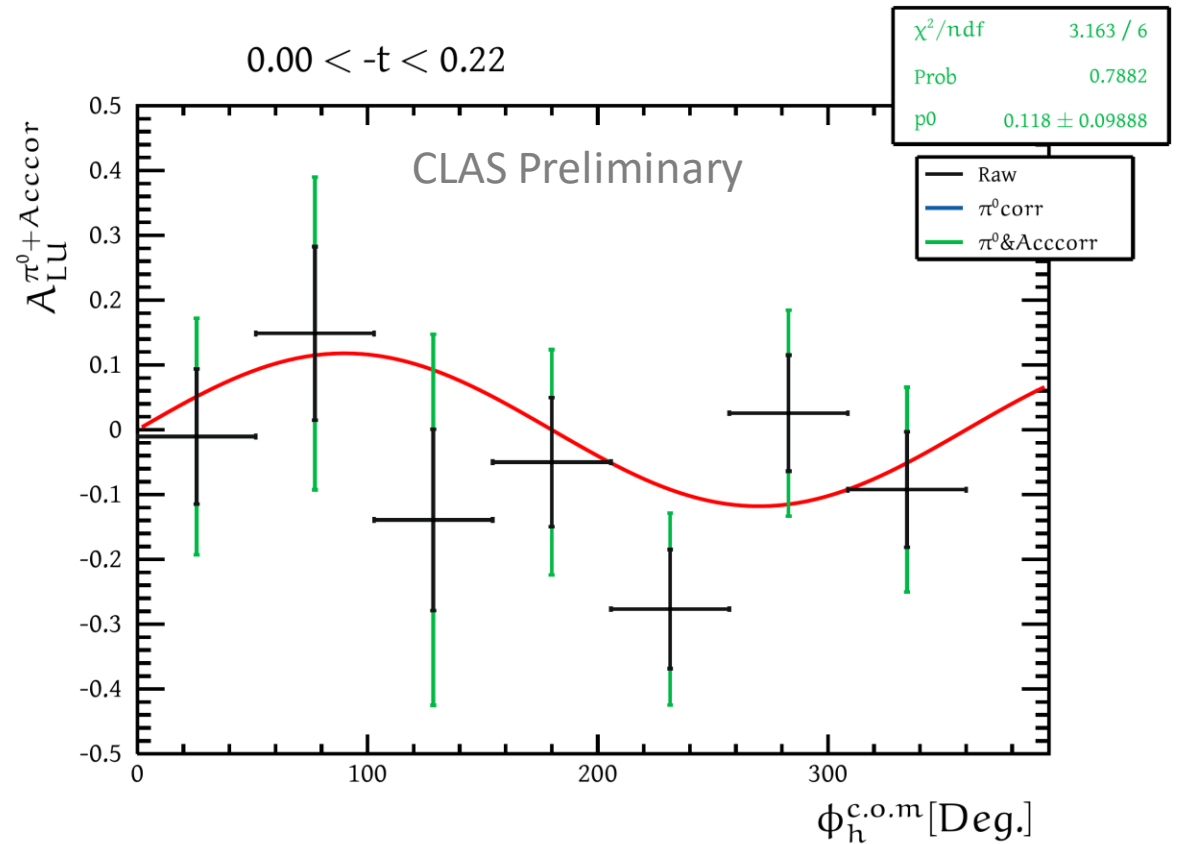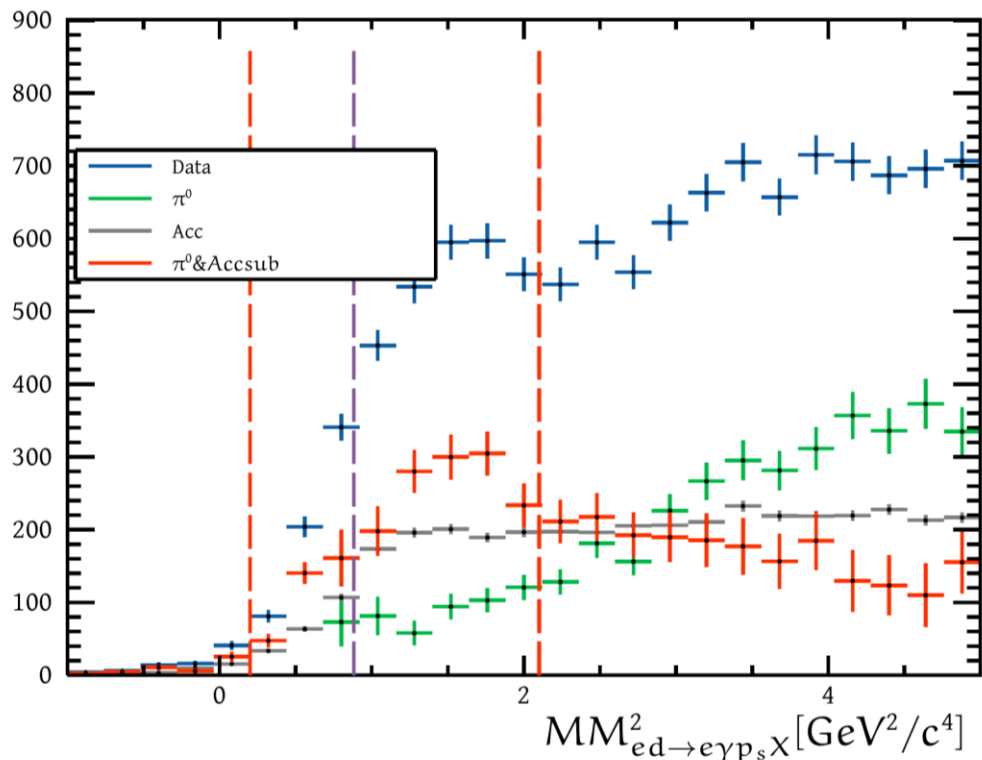
Another method to subtract the background (1/2)

Instead of the missing mass we can compute an equivaled varaible : ΔE/E.

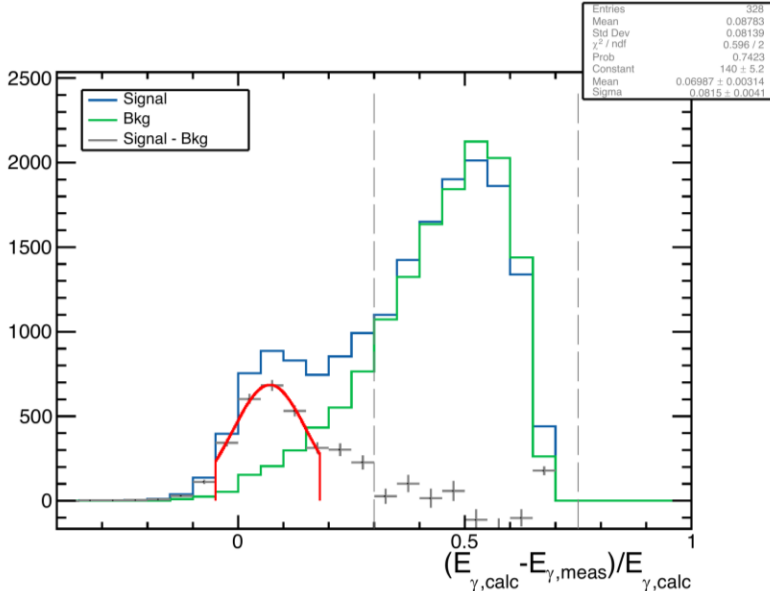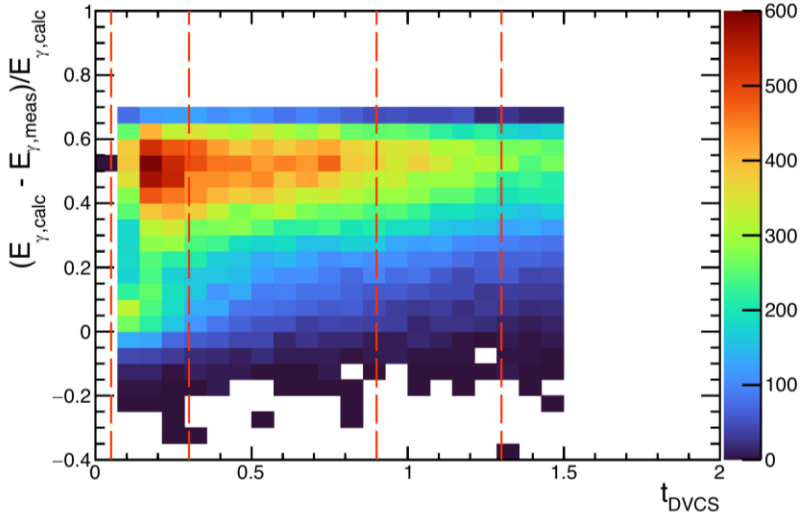Use the high t data as background.

$$\gamma^* + n \rightarrow \gamma + n'$$

$$\begin{bmatrix} p_x \\ p_y \\ p_z \\ E \end{bmatrix} + \begin{bmatrix} p_x \\ p_y \\ p_z \\ E \end{bmatrix} \rightarrow \begin{bmatrix} p_x \\ p_y \\ p_z \\ \boxed{E} \end{bmatrix} + \begin{bmatrix} \cdot \\ \cdot \\ \cdot \\ \boxed{M} \end{bmatrix}$$

Missing mass: Use all the information from the initial state and the outgoing photon to compute the mass of the neutron. Compare it to the expected one.
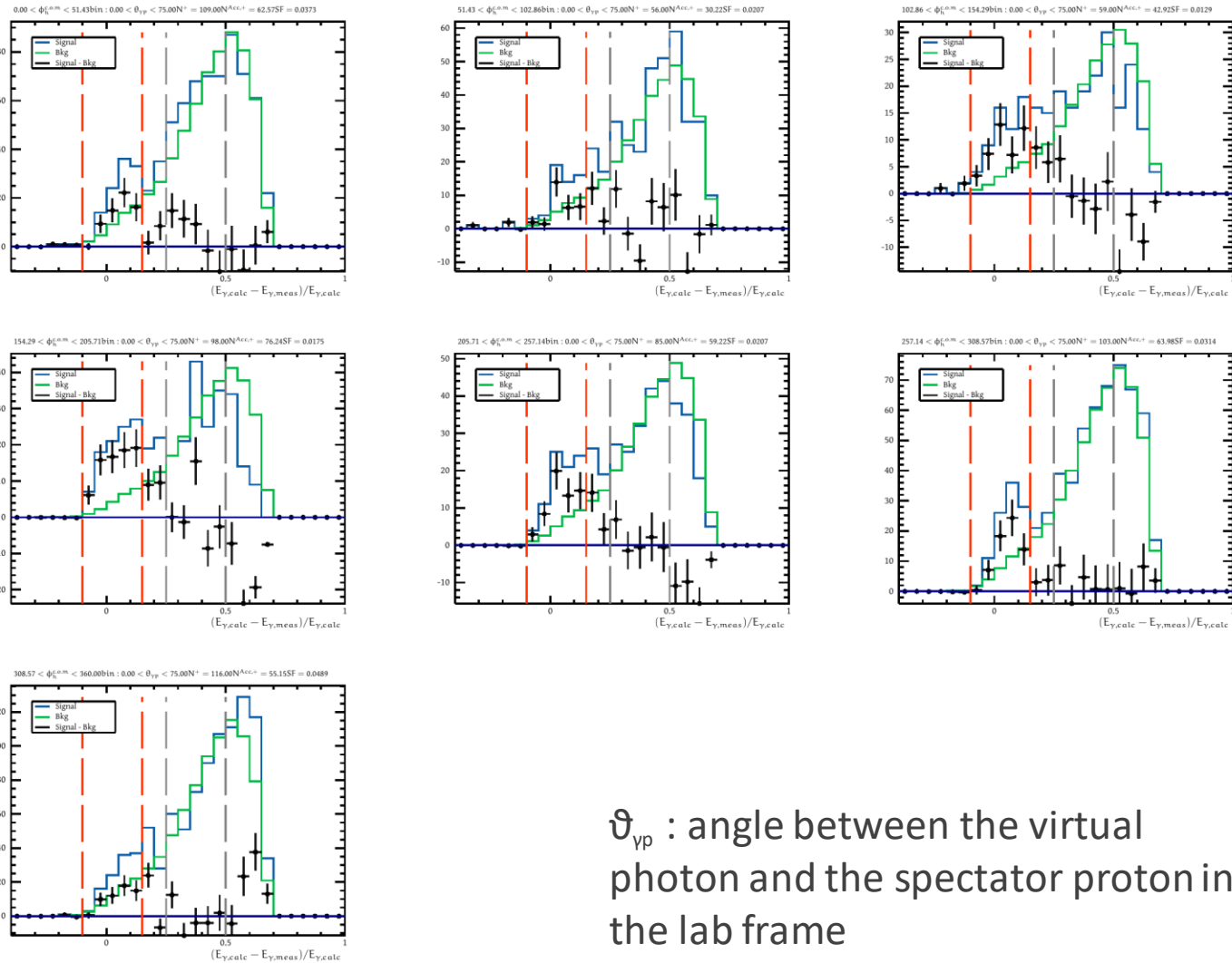
Energy of the outgoing photon: Use the expected mass of the neutron, the initial state, and the angle of the outgoing photon to compute the energy. Compare it to the measured.

Integrate over Φ_h

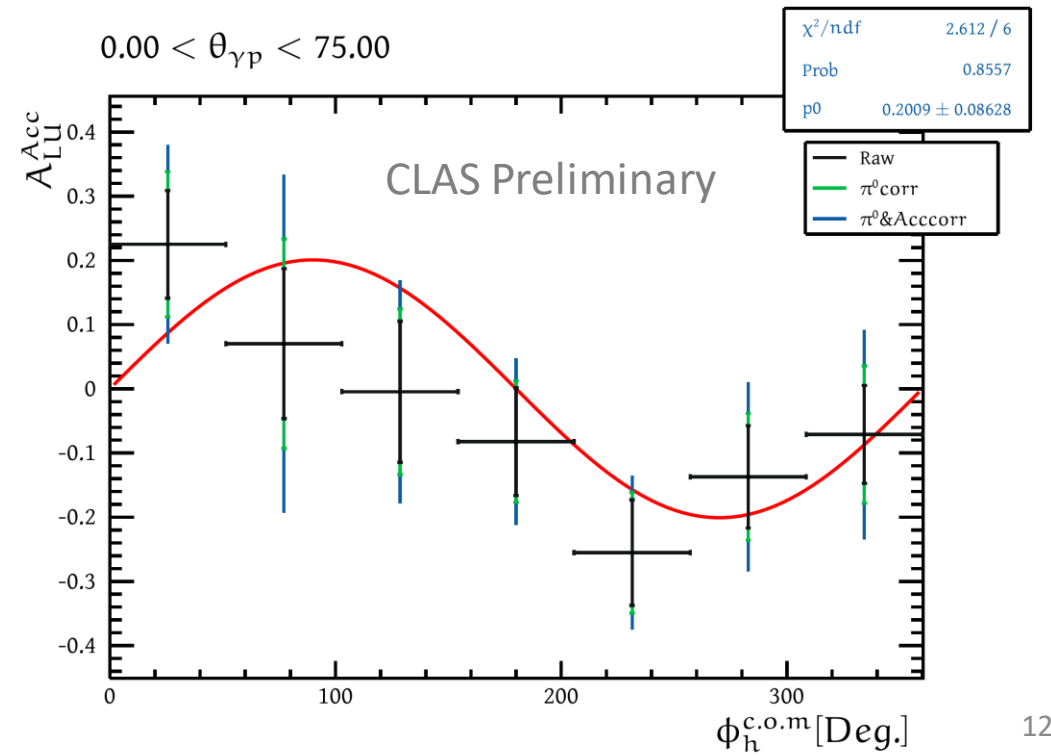# Other method to substract the background (2/2)

- Have a binning in Φ_h, helicity and the other variable (Q^2, x_B, …).
- Use the integrate background for all Φ_h bin.
- Scale the background to match the mean between the grey line.
- Count the number of event between the red lines for the beam spin asymmetry.

$\vartheta_{\gamma p}$: angle between the virtual photon and the spectator proton in the lab frame

Asymmetry at 90°: Comparison
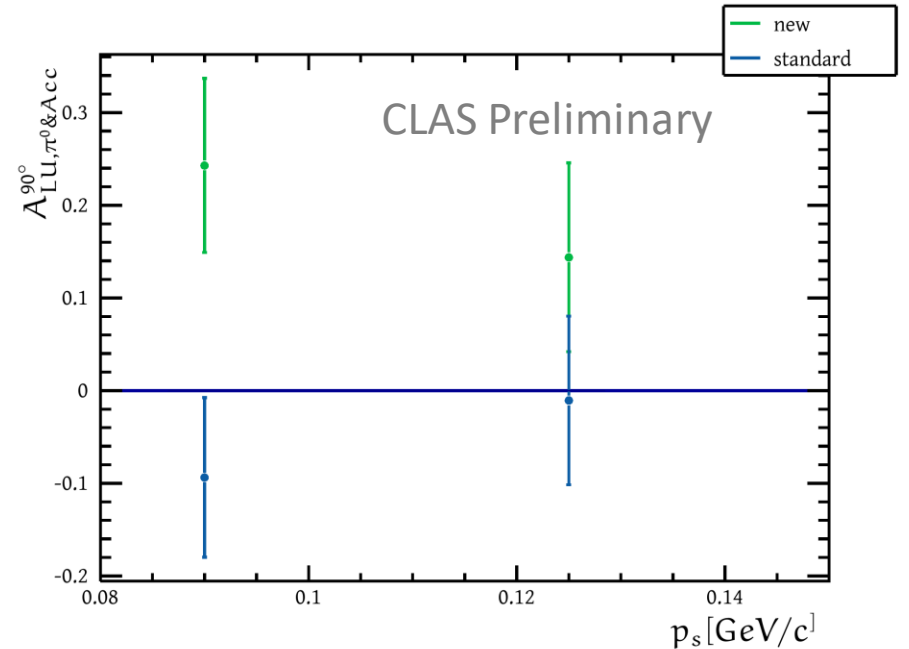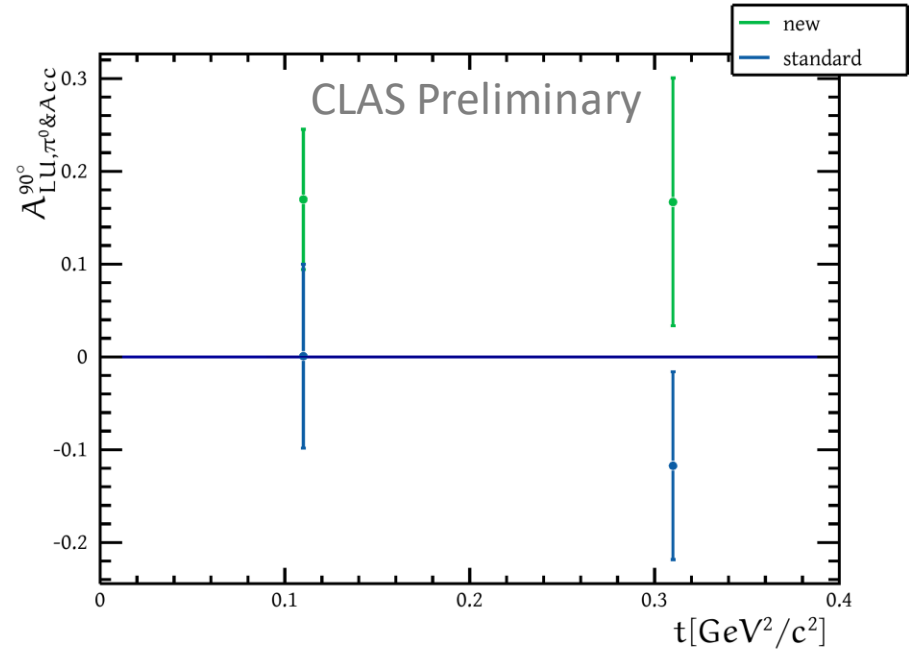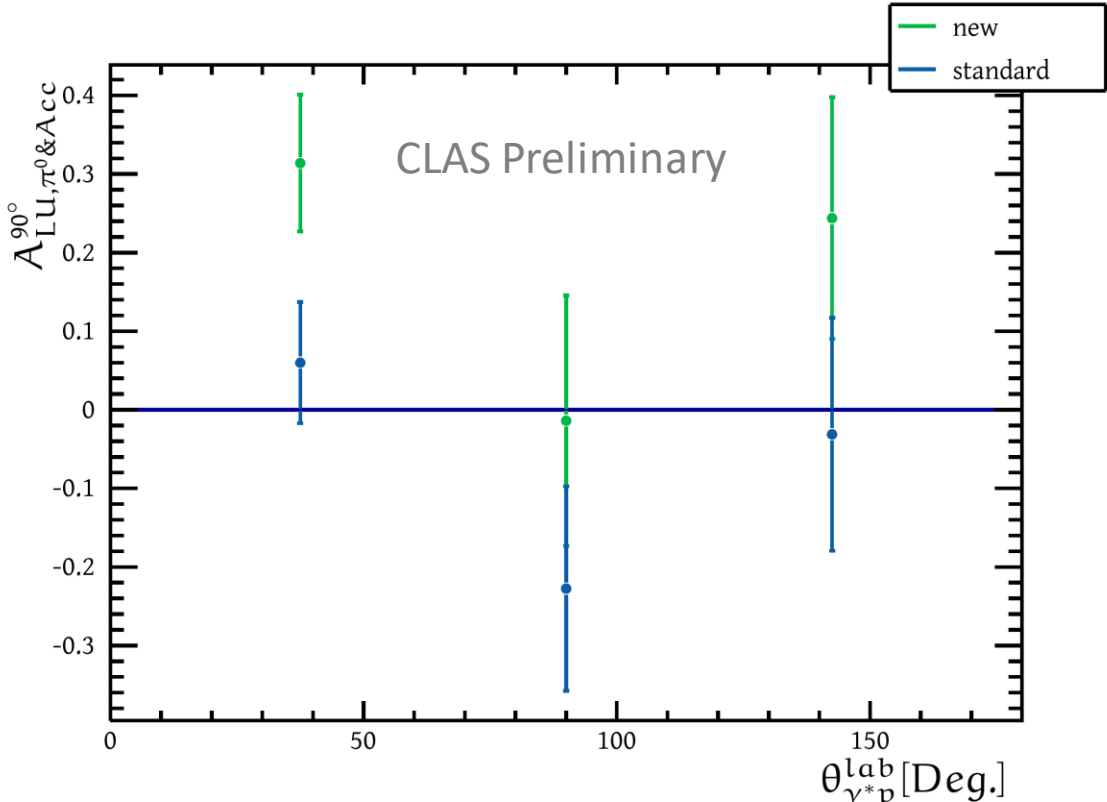
Conclusion

- First neutron DVCS with spectator proton analysis :
    - Extract the asymmetry at 90° for new variables : $\vartheta_{\gamma p}$ and p_s.
    - Correct the asymmetry for accidentals and π^0.
    - Hard to draw any conclusion due to the low statictics.
    - Some improvement in statistics could be achieved by refining all cuts and background subtraction
- Test a new method to correct for the background with data at high t.
    - Both methods mostly give similar results within the error range.
- Significant asymmetry for the small $\vartheta_{\gamma p}$: where we expect the most of FSI.
- With tagged spectator, we have more control on the reaction : FSI, inital state is fully known.
- Without detecting the active nucleon we loss a lot of power to select DVCS event.
- Other experiment can use tagging with more statics to have strong conclusion, or tag more spectator (i.e ALERT).