nDVCS with tagged spectator proton with BONuS12

Mathieu Ouillon
IJCLab / CLAS Workshop

- **Generalized Parton Distributions (GPDs) :**
  - *Non perturbative functions.*
  - *Three dimensions (longitudinal momentum + transverse position).*
  - *Impact parameter space, interpreted as a distribution in the transverse plane of partons carrying a given longitudinal momentum.*
  - *4 GPDs for spin ½ particle* $\rightarrow\ H, E, \widetilde{H}, \widetilde{E}$
  - *Link to FFs, PDFs and Ji sum rule.*

- **The measurements on a neutron target will provide, an important contribution to the extraction of the GPD E :**

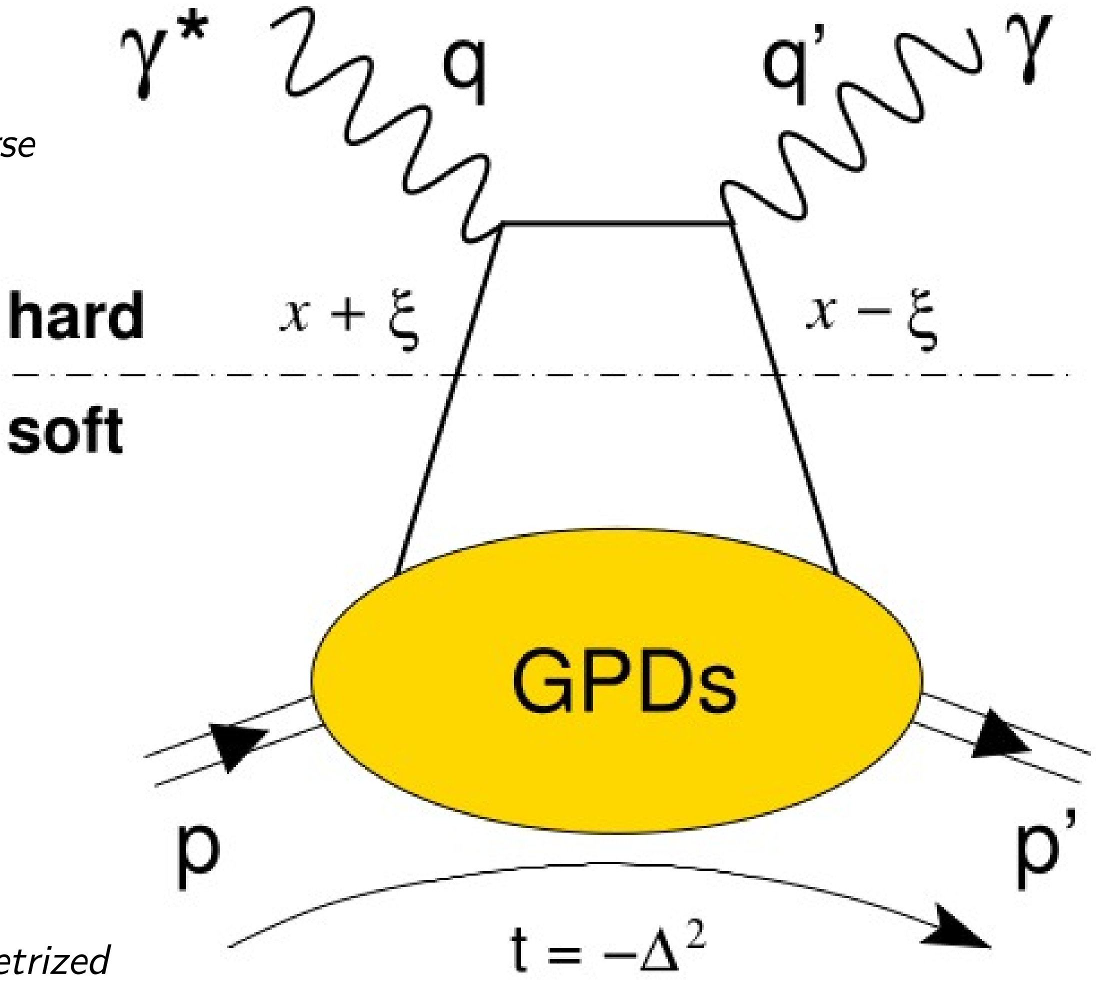
$$A_{LU}^{\sin\phi} \propto \Im m \left[F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E} \right],$$

F1 small → 0

u, d cancel → 0

  - *Flavor separation, baseline for studies of nuclear modifications.*

- **Access through DVCS/DVMP :**
  - *Two parts: the "hard" perturbative QCD, and the "soft" part parametrized by the GPDs.*



Neutron DVCS

- **Goal : Tagged neutron DVCS on the valance region.**

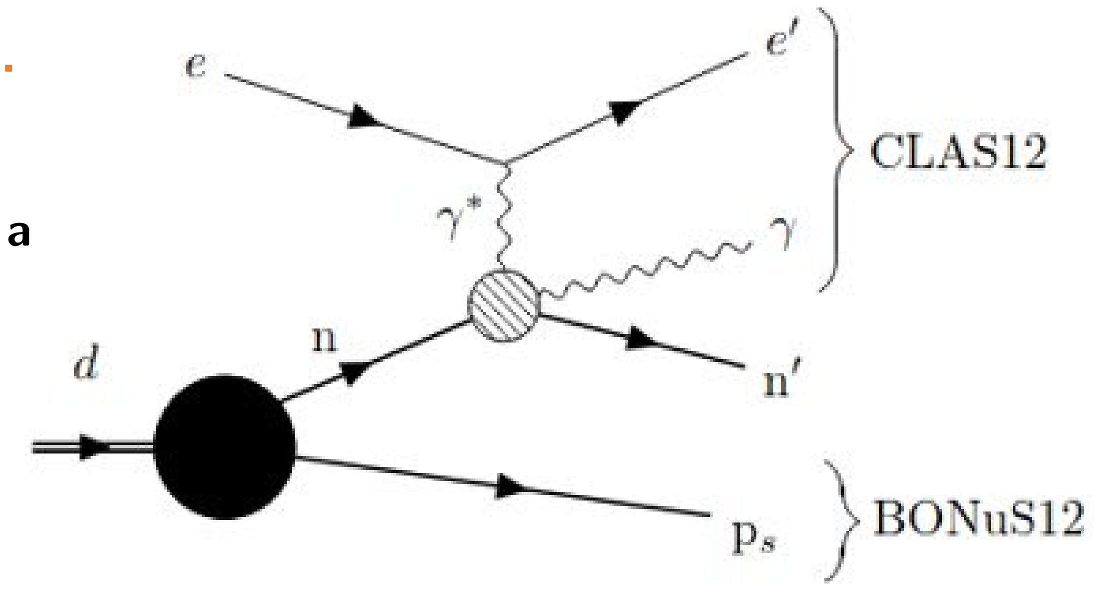
$$e + d \rightarrow e' + \gamma + p_s + (n)$$

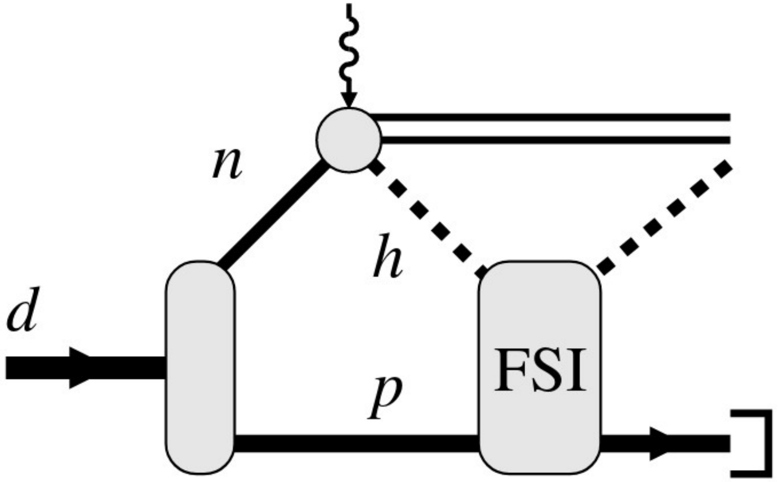
- **DVCS is exclusive electroproduction of a real photon from a quark of the nucleon.**

- **Three type 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 $\rightarrow$ more uncertainty in exclusivity cuts.**

- **What makes the free neutron structure hard to measure?**
  - *Can only access neutrons in a nucleus: Nuclear binding effects, Fermi motion, FSI, etc...*
  - *Final-state interactions: Where the struck nucleon interacts with the spectator. Hard to compute.*

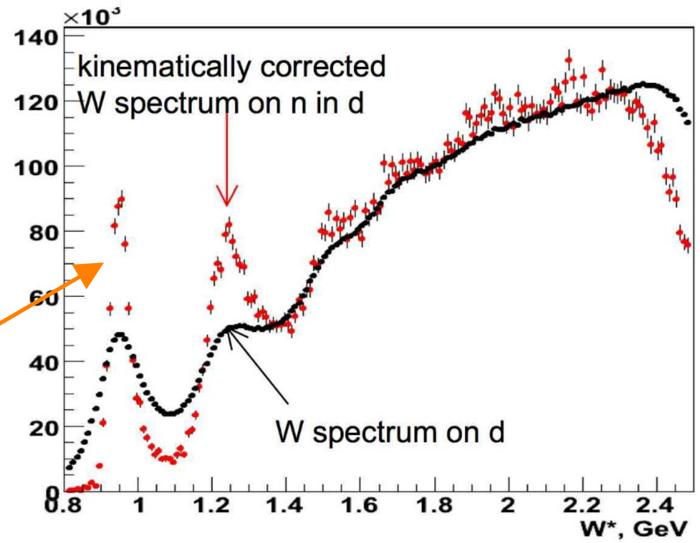


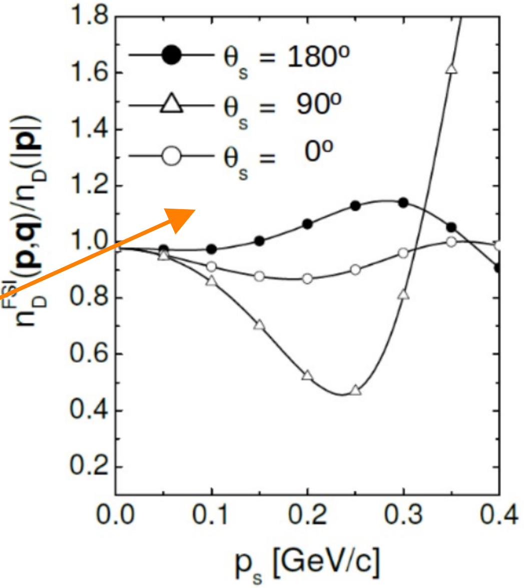


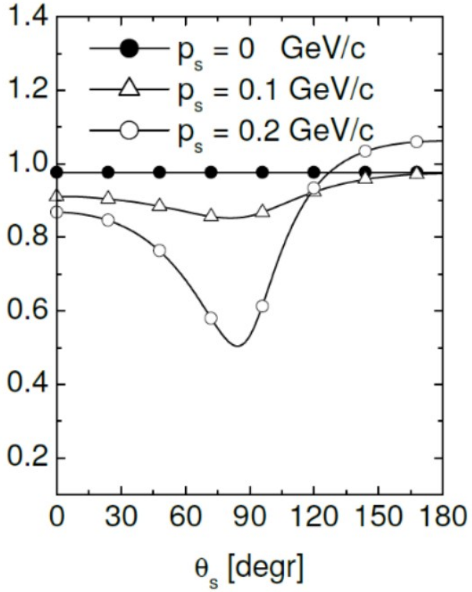
- **"Tag" means we measure the non-interacting part (the spectator).**

- **Detection of the spectator proton :**
  - *Detect low energy proton.*
  - *Initial neutron momentum can be inferred from the kinematic of the spectator proton.*
  - *Uncorrected W vs corrected W* with the initial momentum of the neutron.*

- **Tagged measurements → Select nuclear configuration via spectator kinematics, allowing differential study.**
  - *Spectator kinematics allows the selection of different regions of interest for study.*
  - *On-shell extrapolation enables access to free nucleon structure.*
  - *At low recoil momentum and backward spectator angle, the FSIs are negligible.*
  - *This kind of measurement help in the understanding of the nuclear effects.*

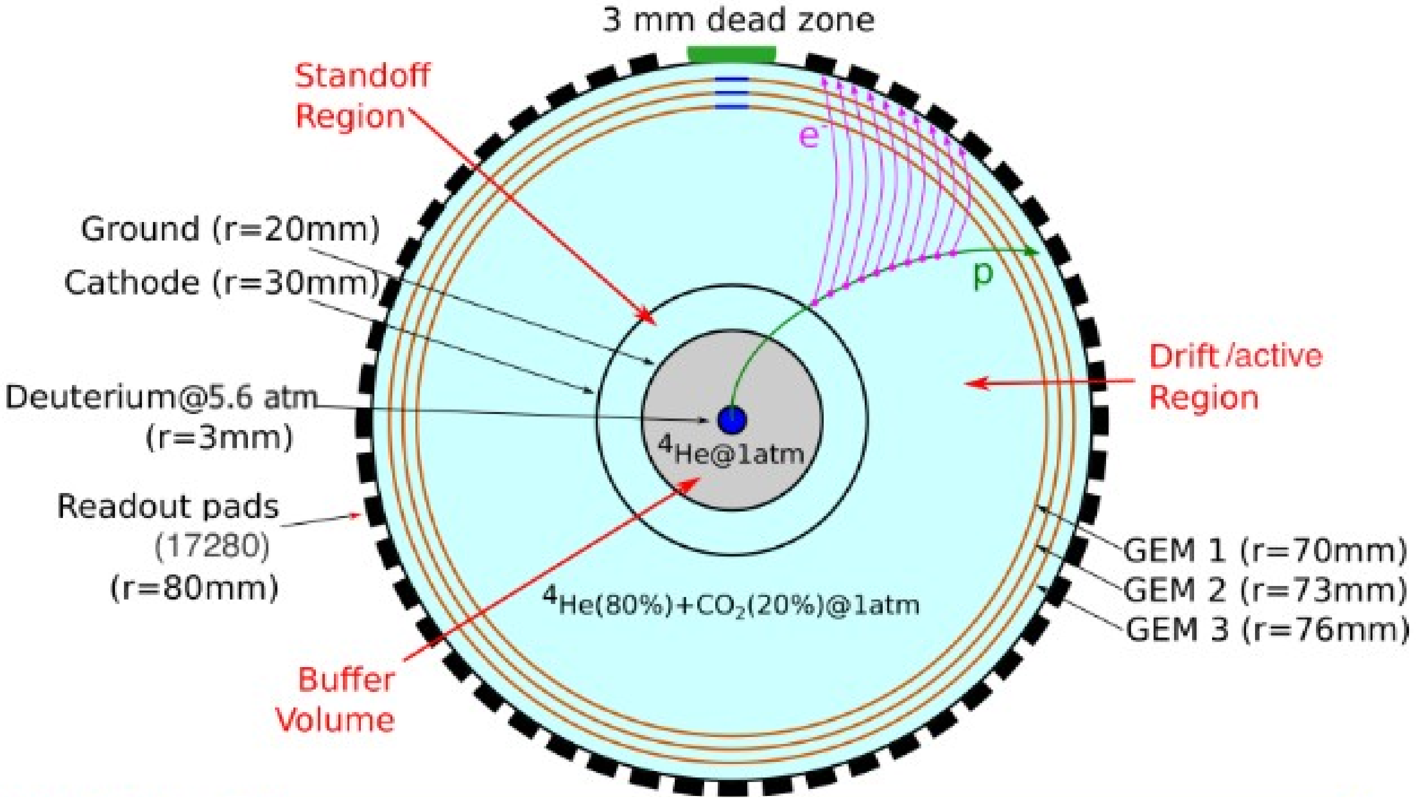






The BONuS12 experiment

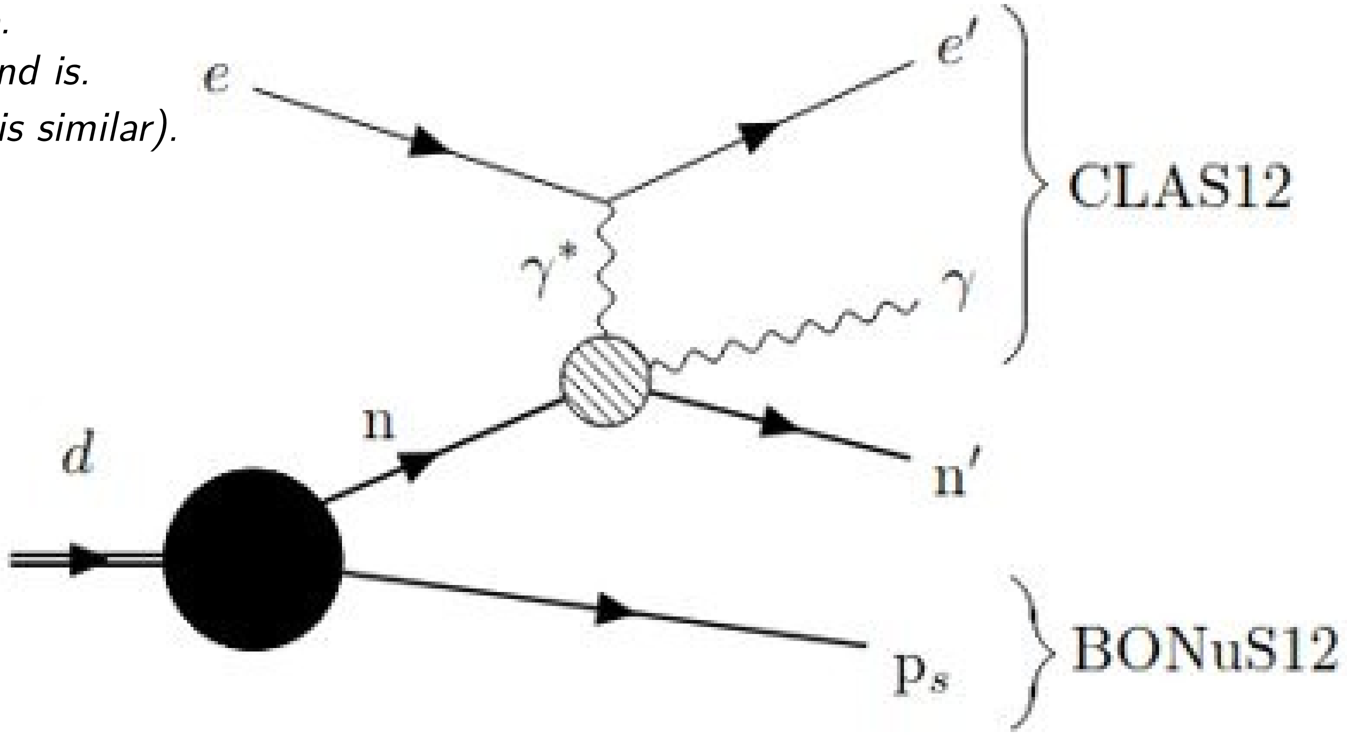
- **Detector :**
  - *The Radial Time Projection Chamber.*
  - *Built to detect low momentum proton*
    - *(0.05 to 0.1 GeV/c)*
  - *BONuS12 replaced the central silicon tracker and micromegas.*



- **BONuS12 experiment :**
  - *Data were taken in the summer of 2020.*
  - *3 beam energies : 10.4/10.3/10.2 GeV.*
  - *Beam polarization: 85%.*
  - *Four targets: Mainly deuterium, hydrogen, helium 4, and empty.*
  - *For more information: see M.Pokhrel talk on Friday*

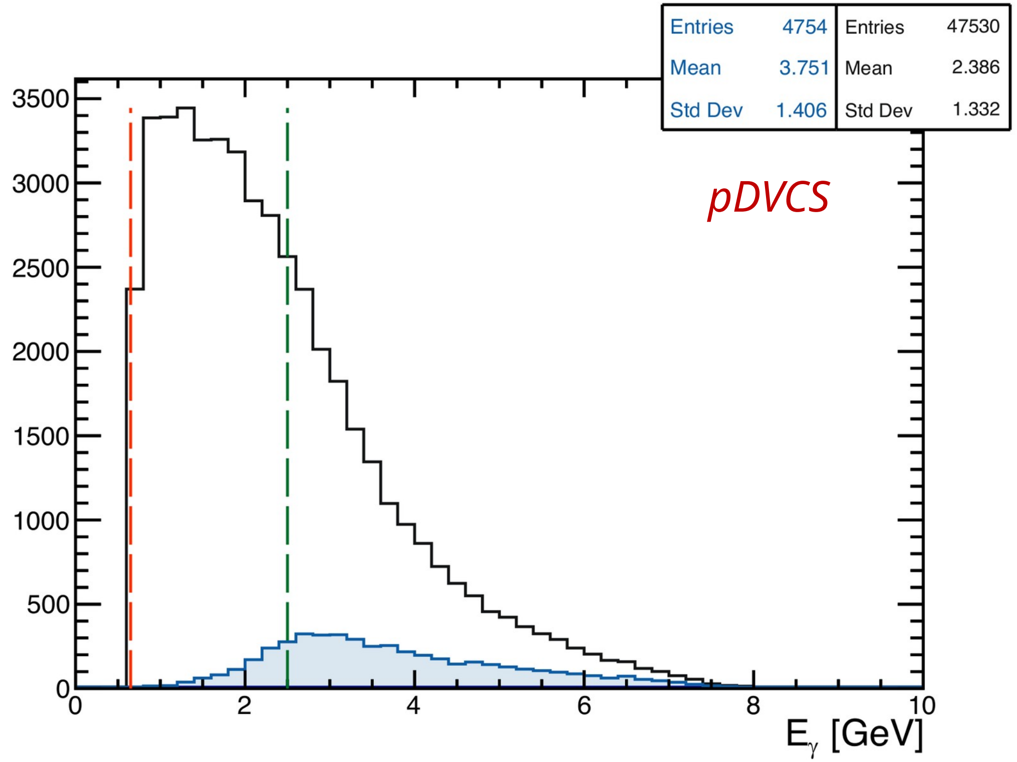
- **Neutron DVCS :**
  - *Detecting the spectator proton and not the struck neutron.*
  - *Only one exclusivity variable is available in nDVCS (miss mass of electron-photon system).*
  - *Cannot use exclusivity variables to reduce phase space (separate DVCS event from the background).*
  - *We need to do that before.*

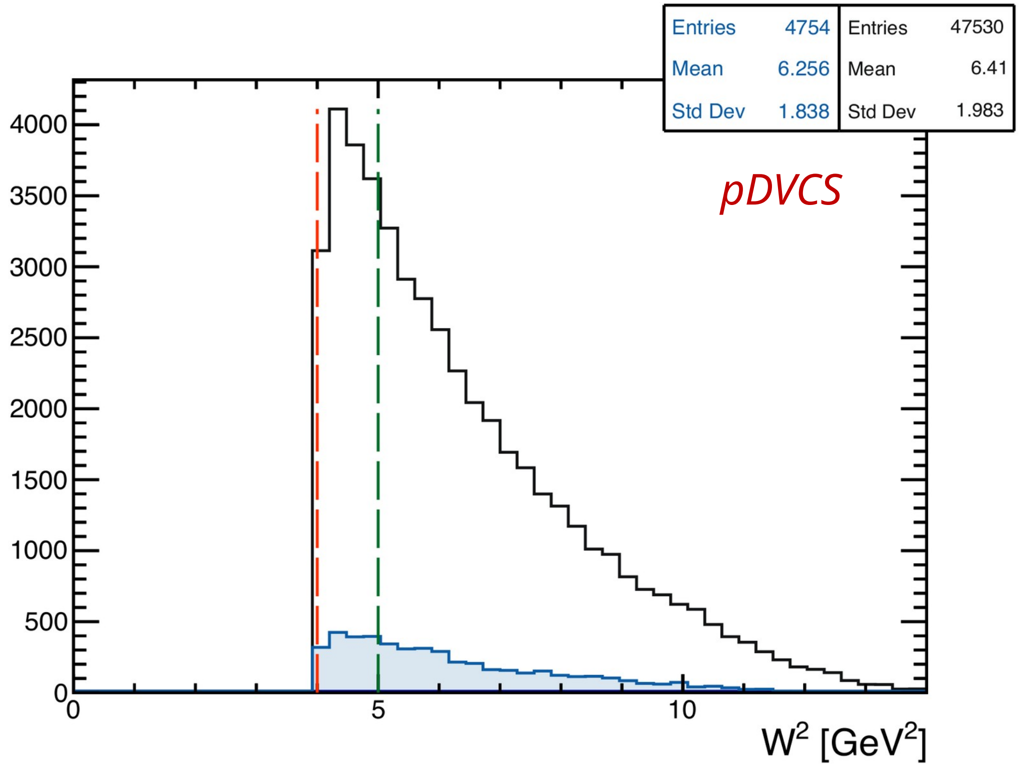
- **To know how to do that, we use a proton DVCS analysis :**
  - *Know six exclusivity variables to reduce the phase space.*
  - *Look after applying exclusivity cuts where the background is.*
  - *(We suppose that the background for the neutron case is similar).*



Proton DVCS analysis

- **Proton DVCS based on the RG-A analysis note :**
  - *On hydrogen target with BONuS12 data (calibration data).*
  - *The results conform with the analysis note.*
  - *Note from G. Christiaens, M. Defurne, D. Sokhan.*
- **Comparison between proton DVCS and neutron DVCS :**
  - *In the pDVCS analysis, identify zones where the ratio signal over the background is small.*
  - *We choose to cut these zones + narrow some PID cuts on the electron and photon.*





On the nDVCS analysis :

- **Target : Deuterium**
- **Beam energy : 10.4/10.3/10.2 GeV**

1.1.1 Electron kinematics

- $2.10 < p_e[GeV/c] < 8.00$
- $-28.00 < vz_e[cm] < 20.00$
- $-1.80 < \chi^2_e < 1.80$

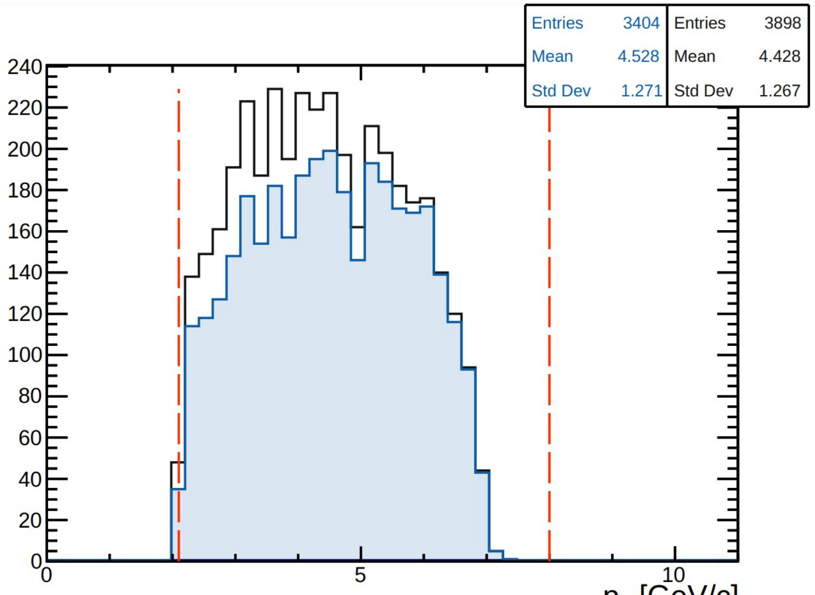
1.1.2 Electron fiducials

- $u[cm] > 14.00$
- $v[cm] > 14.00$
- $w[cm] > 14.00$
- $E_{pcal}[GeV] > 0.06$

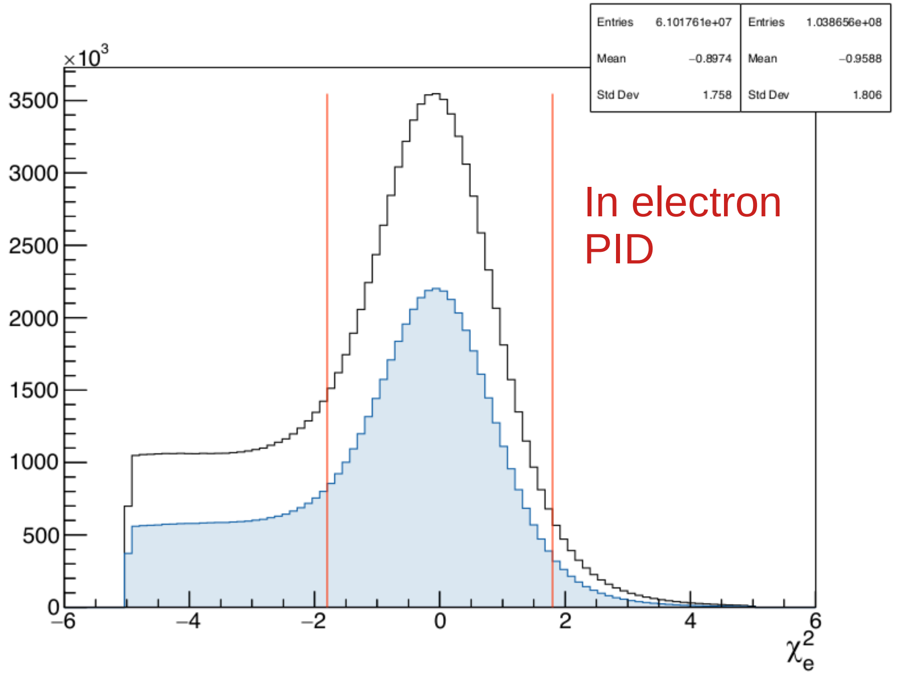
- **We choose events with :**
  - *An electron which is the trigger.*
  - *At least one photon, the most energetic is taken.*

- **Apply standard cuts (from the note) with some slight modifications.**

- **Compare to the standard pDVCS:**
  - *More strict cut on chi-square for electron.*
  - *Exclusivity cut shows the higher cut on p is not needed or at least needs to be lower.*

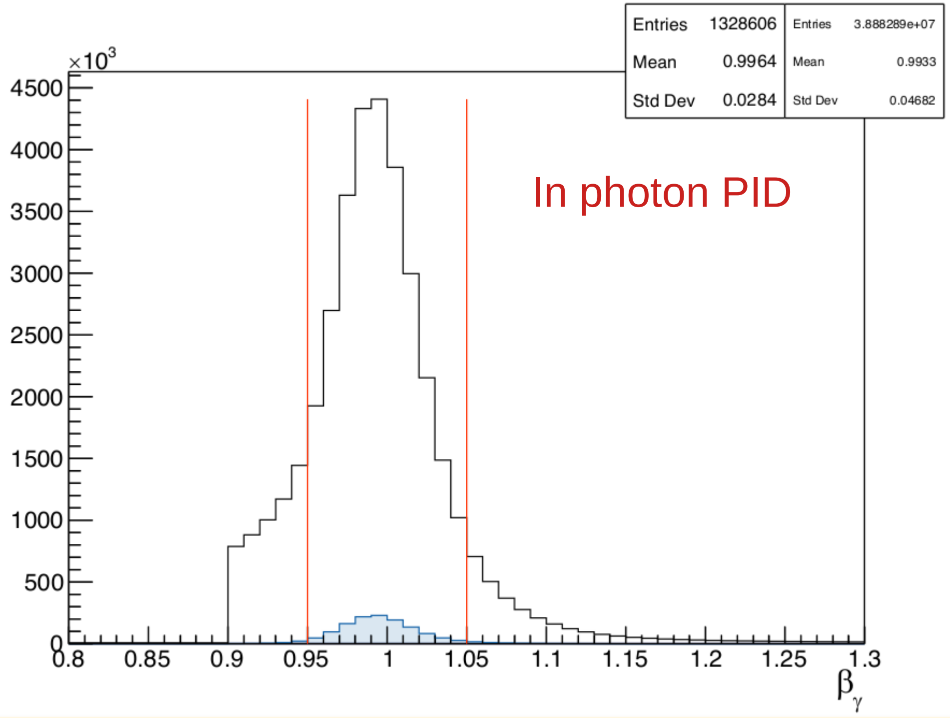


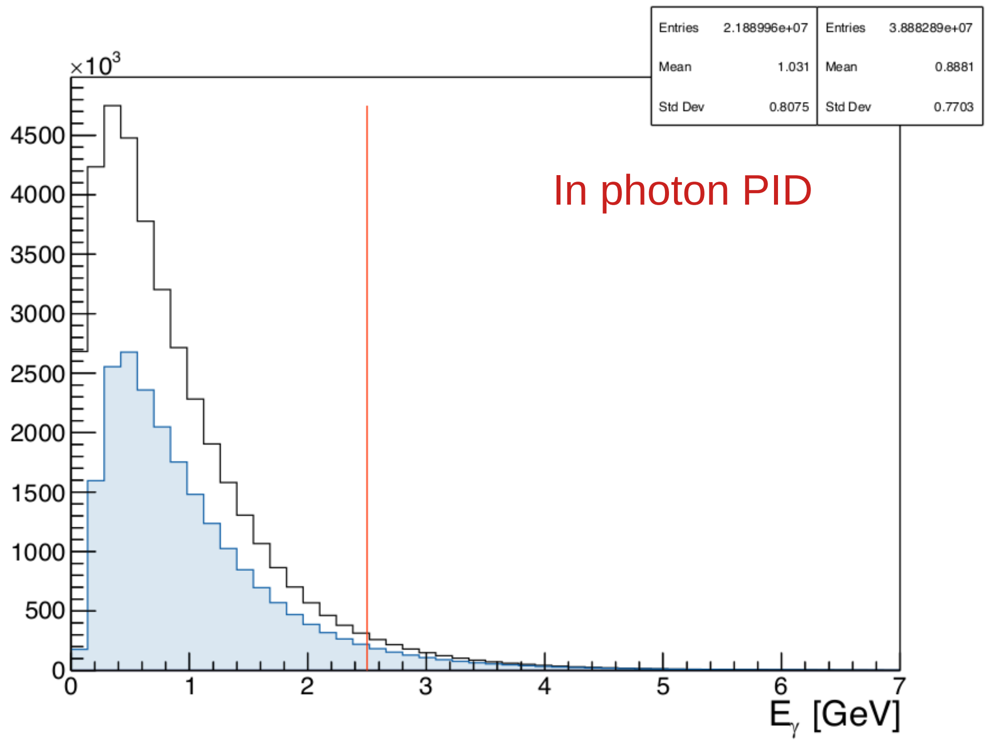
After exclusivity cuts



- **Select the high-energy photon for DVCS/BH process.**

- **Compare to the standard pDVCS :**
  - *A stricter cut on the photon's energy compared to the standard analysis.*
  - *Cut a part of our signal.*
  - *But, low energy $\rightarrow$ bad signal/background ratio as shown by the pDVCS analysis.*
  - *Little more narrow cut on beta.*





1.1.3 Photon kinematics

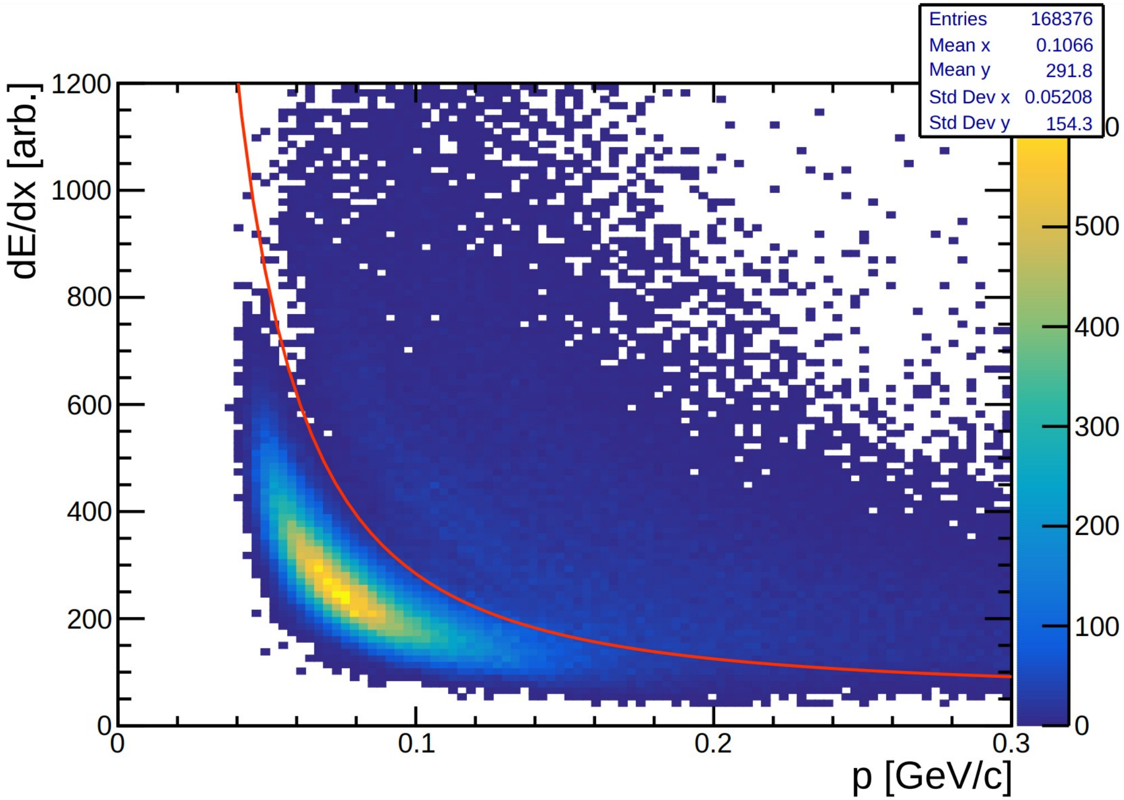
- $E_\gamma[GeV] > 2.50$
- $0.95 < \beta_\gamma < 1.05$

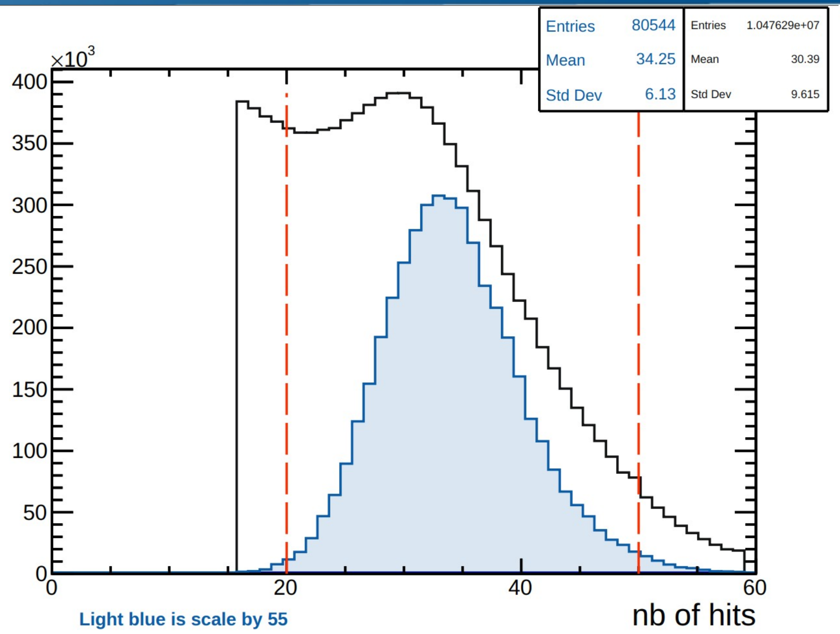
1.1.4 Photon fiducials

- $u[cm] > 14.00$
- $v[cm] > 14.00$
- $w[cm] > 14.00$
- $E_{pcal}[GeV] > 0.06$

- **Identify the spectator proton track in BONuS12 detector :**
  - *Low momentum proton (0.05 to 0.1 GeV/c)*
  - *In the RTPC every low momentum particle can leave a track, and the acquisition window is large, four µs.*
  - *We apply two types of cuts, the quality and the kinematics cuts.*

- $0.05 < p[GeV/c] < 0.10$
- $-18.00 < vz[cm] < 12.00$
- $\chi^2 < 2.50$
- $20.00 < nbofhits < 50.00$
- $r_{helix}[cm] < 0.00$
- $\chi^2(t_{diff}, \Delta vz, \epsilon) < 6.00$
- $dE/dx[arb.] < f(p)$





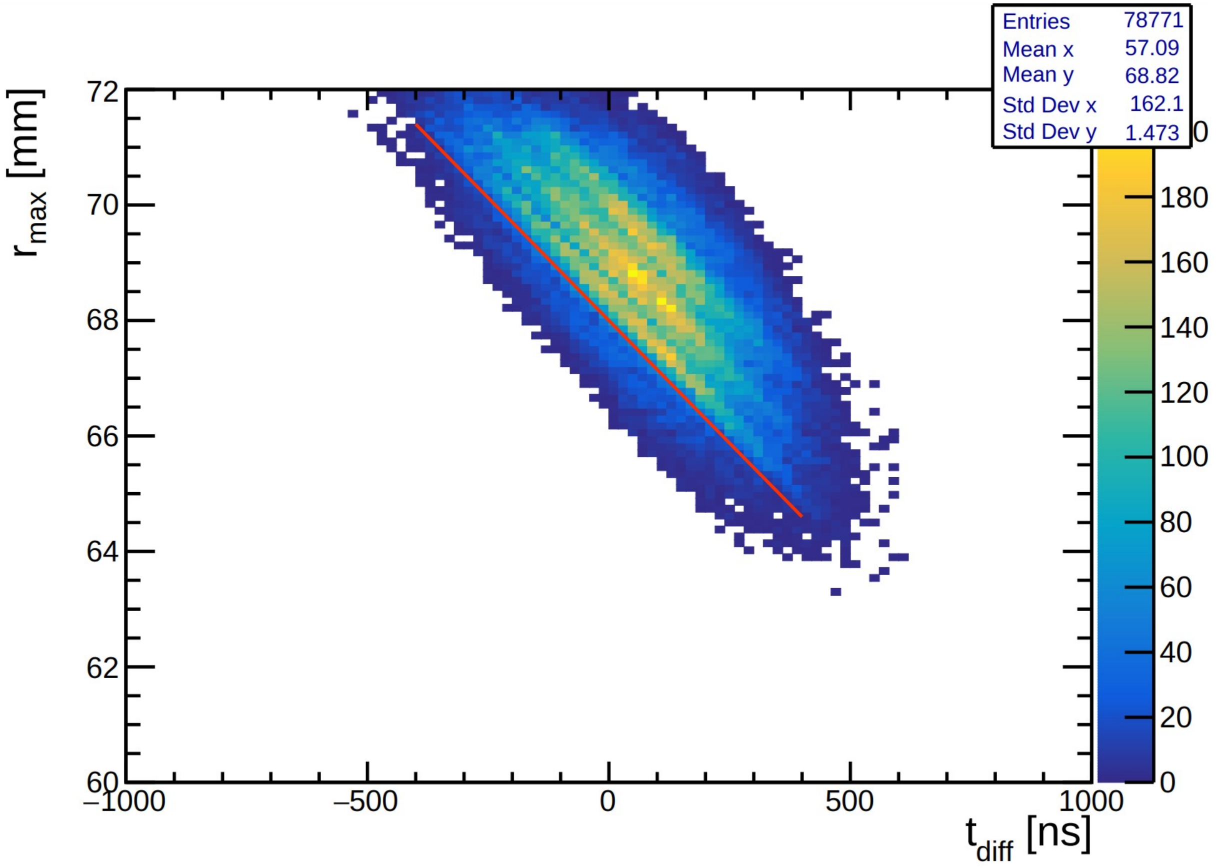
- **We only have good tracks now, but we must remove the accidentals.**

- **We need to find in coincidence (in time and space) track with the electron.**

- **For that, we cut on t_{diff}, Δvz and ϵ :**
  - *t_{diff} is the time to subtract from the trajectory to put the first hit of the track at the cathode.*
  - *Δvz = electron vertex - RTPC vertex.*
  - *Correlation between the max radius of the track and t_{diff}.*
  - *Fit the correlation (red line) and build a new variable called epsilon :*

$$\epsilon = at_{diff} + b - r_{max}$$

  - *But instead of 1D cutting on each variable, build a new variable to do a multidimensional cut.*

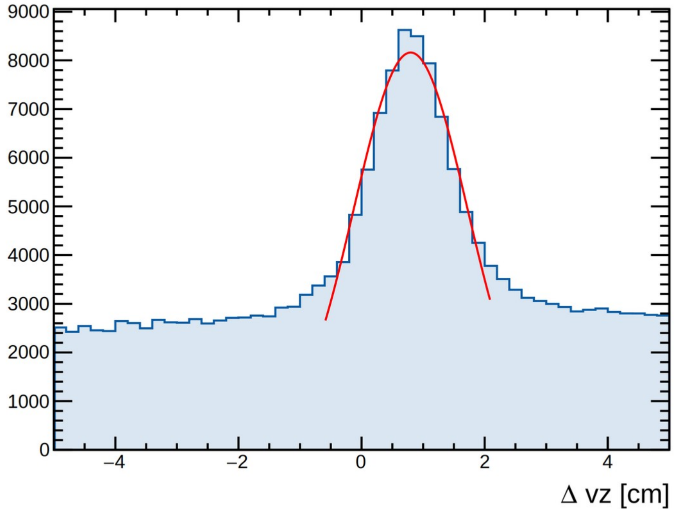


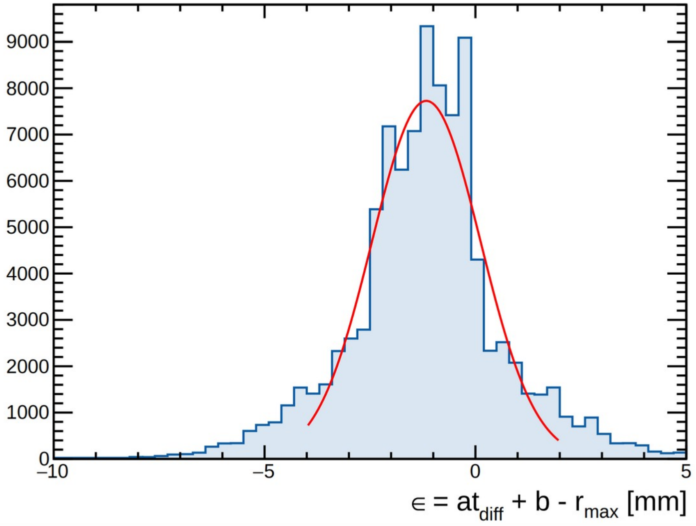
nDVCS with spectator proton : Particle identification - Proton in RTPC

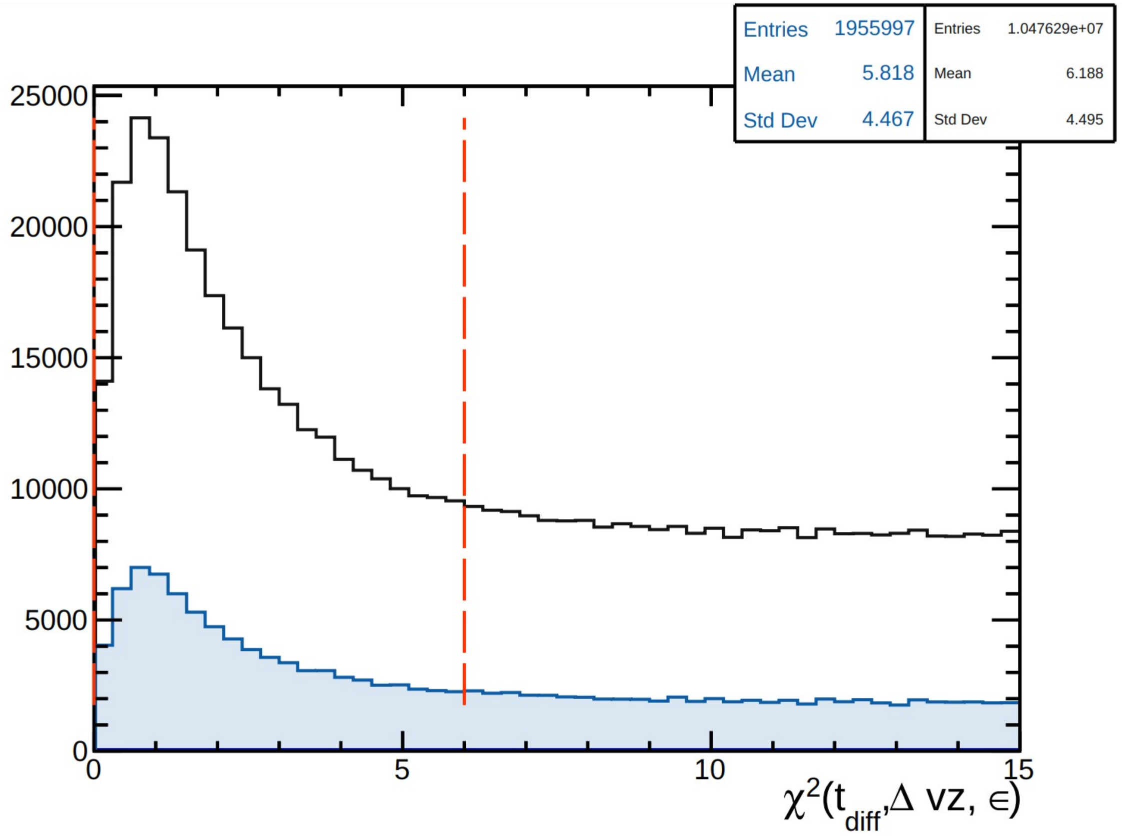
- **Compute a new variable, a chi-square like, based on t_{diff}, Δvz and ϵ :**
  - *The mean and sigma of t_{diff} is file based.*
  - *The mean and sigma of Δvz is fitted by applied all cuts plus ϵ and t_{diff} cuts.*
  - *The mean and sigma of epsilon is fitted by applied all cuts plus Δvz and t_{diff} cuts.*

$$\chi^2(t_{diff}, \Delta vz, \epsilon) = \left(\frac{t_{diff} - \bar{t_{diff}}}{\sigma_{t_{diff}}}\right)^2 + \left(\frac{\Delta vz - \bar{\Delta vz}}{\sigma_{\Delta vz}}\right)^2 + \left(\frac{\epsilon - \bar{\epsilon}}{\sigma_\epsilon}\right)^2$$

- **Use to reduce the background by multidimensional cut (spherical cut instead of square)**

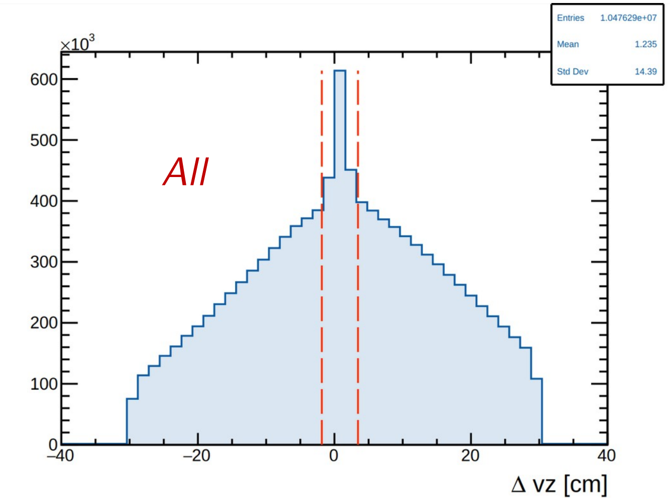


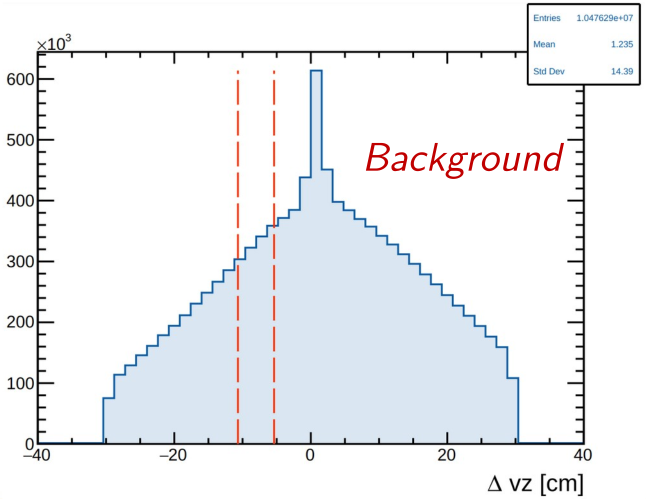


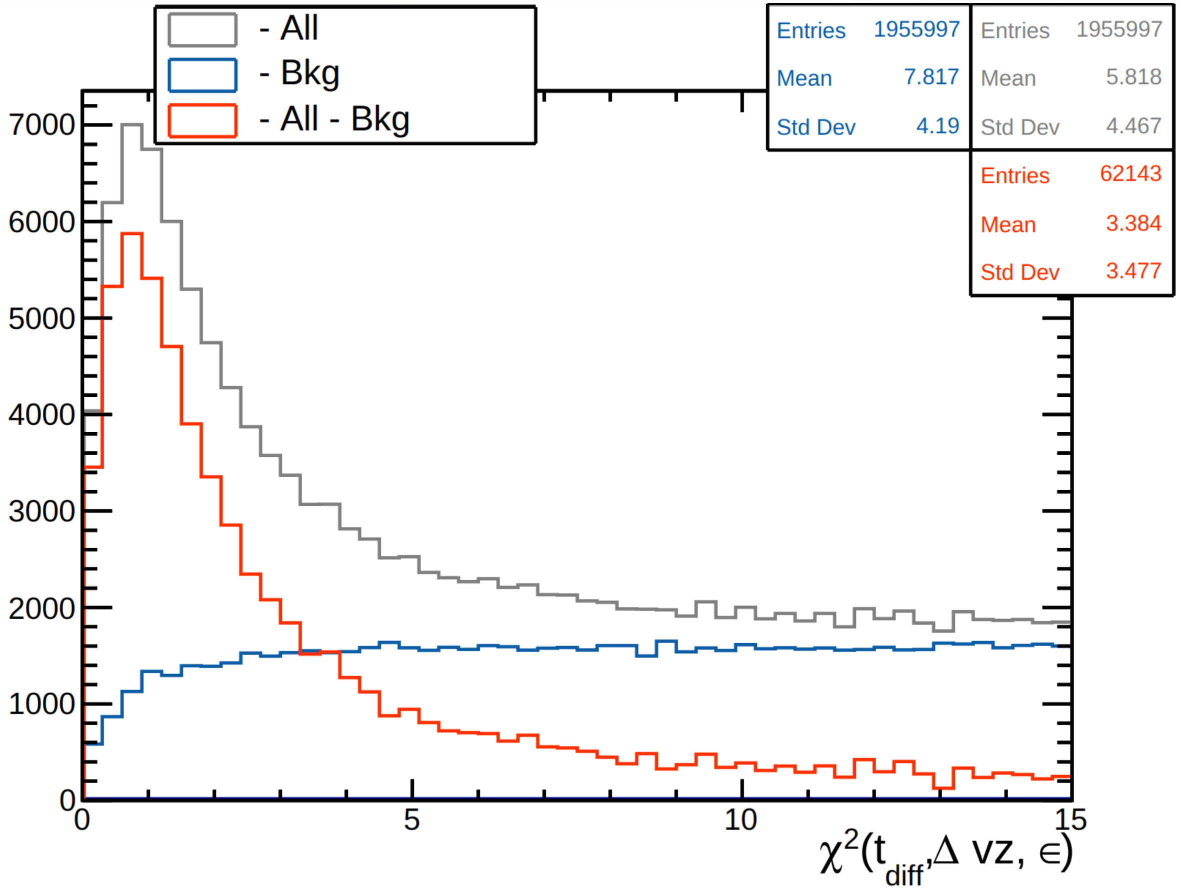


- **To estimate the accidental background :**
  - *Use chi-square build from t_{diff}, Δvz and ϵ.*
  - *Change the mean of Δvz by adding 10 sigma Δvz.*

- **The background is better reproduced by shifting Δvz.**
- **The background is almost constant over the entire range of chi-square.**
- **So even under the signal peak, we have about a quarter of background.**



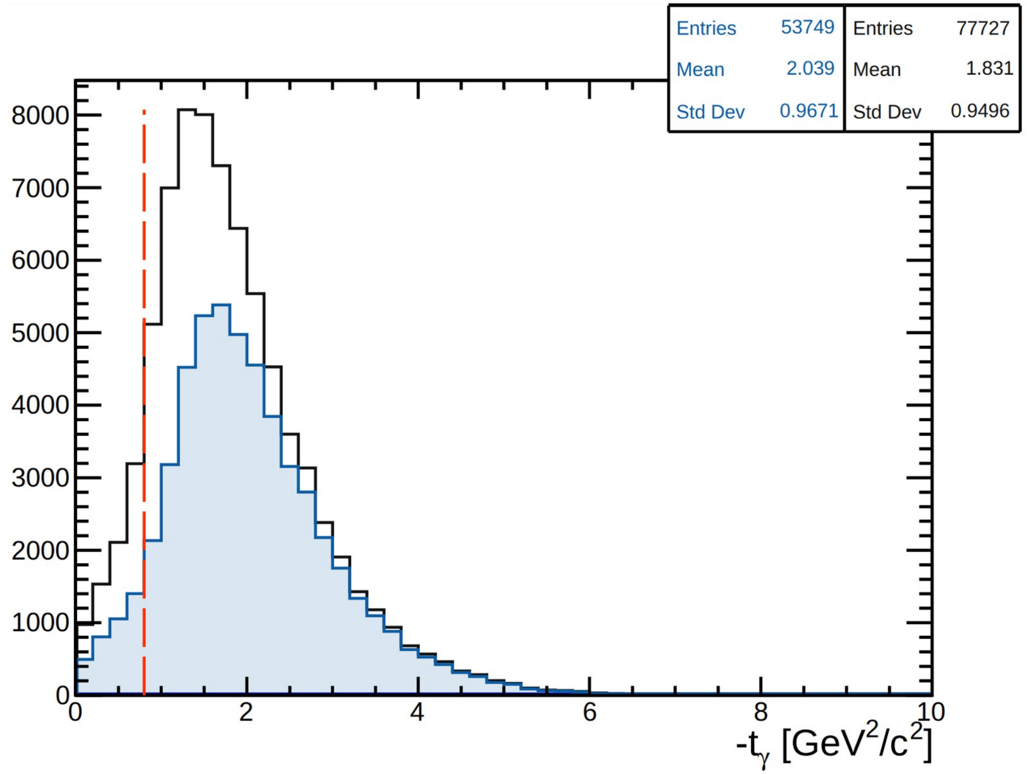


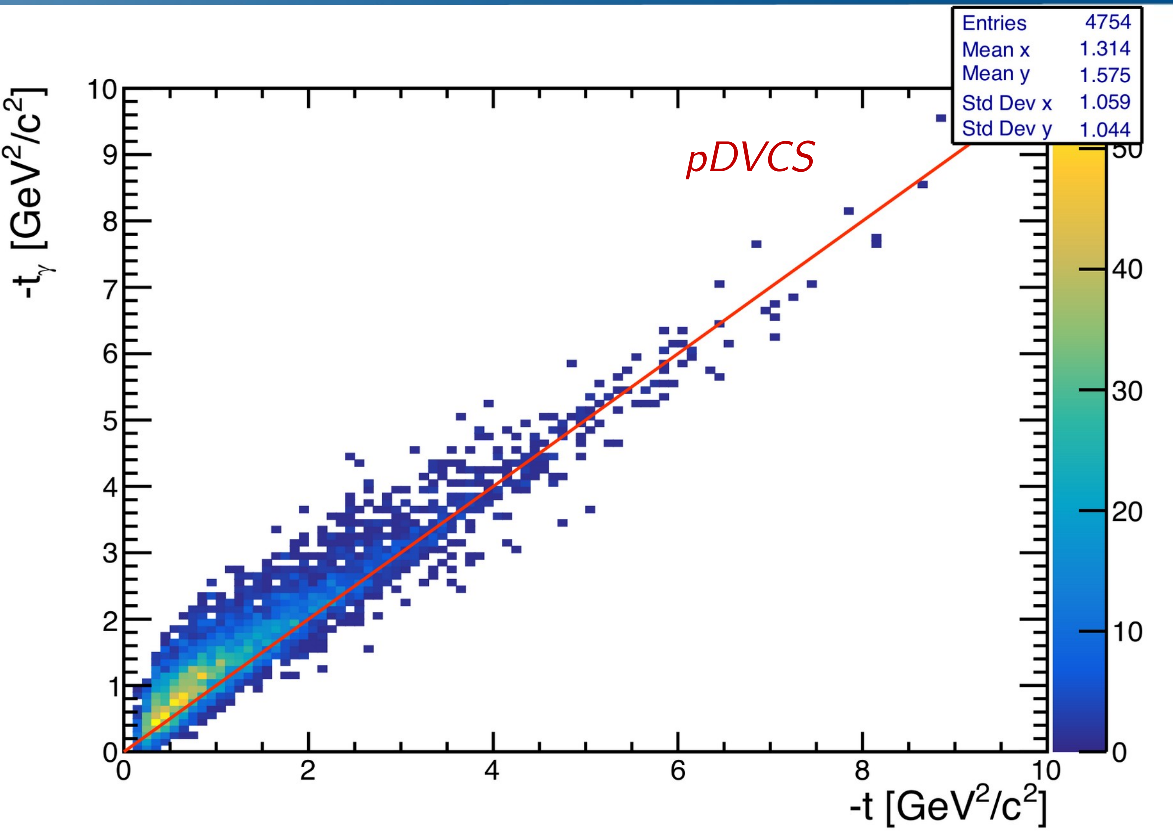


nDVCS with spectator proton : Kinematics

- **Without detecting the struck nucleon, t should be computed with the (virtual and real) photon.**
- **Theoretically equal, in real data, the photon reconstruction is worse than the nucleon one.**

- **Cut on nDVCS at small t to remove the background.**





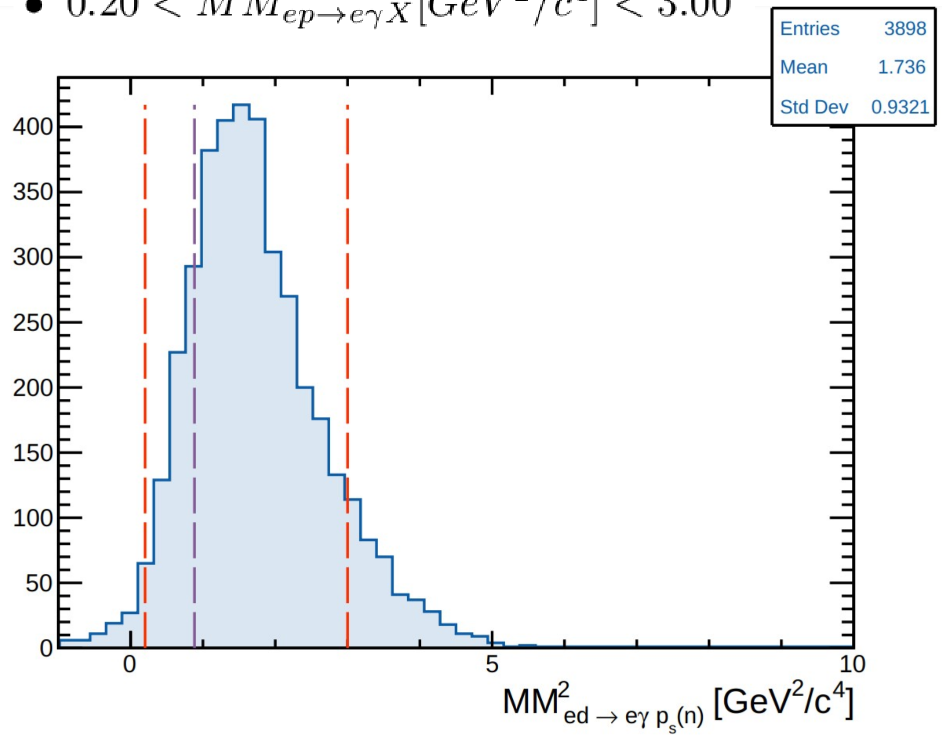
- $Q^2[GeV^2/c^2] > 2.00$
- $W*^2\ [GeV^2] > 5.00$
- $t_\gamma[GeV^2/c^2] < 0.80$

We should apply a correction (derived from simulation) to have a good value of t.
Could come from π^0.

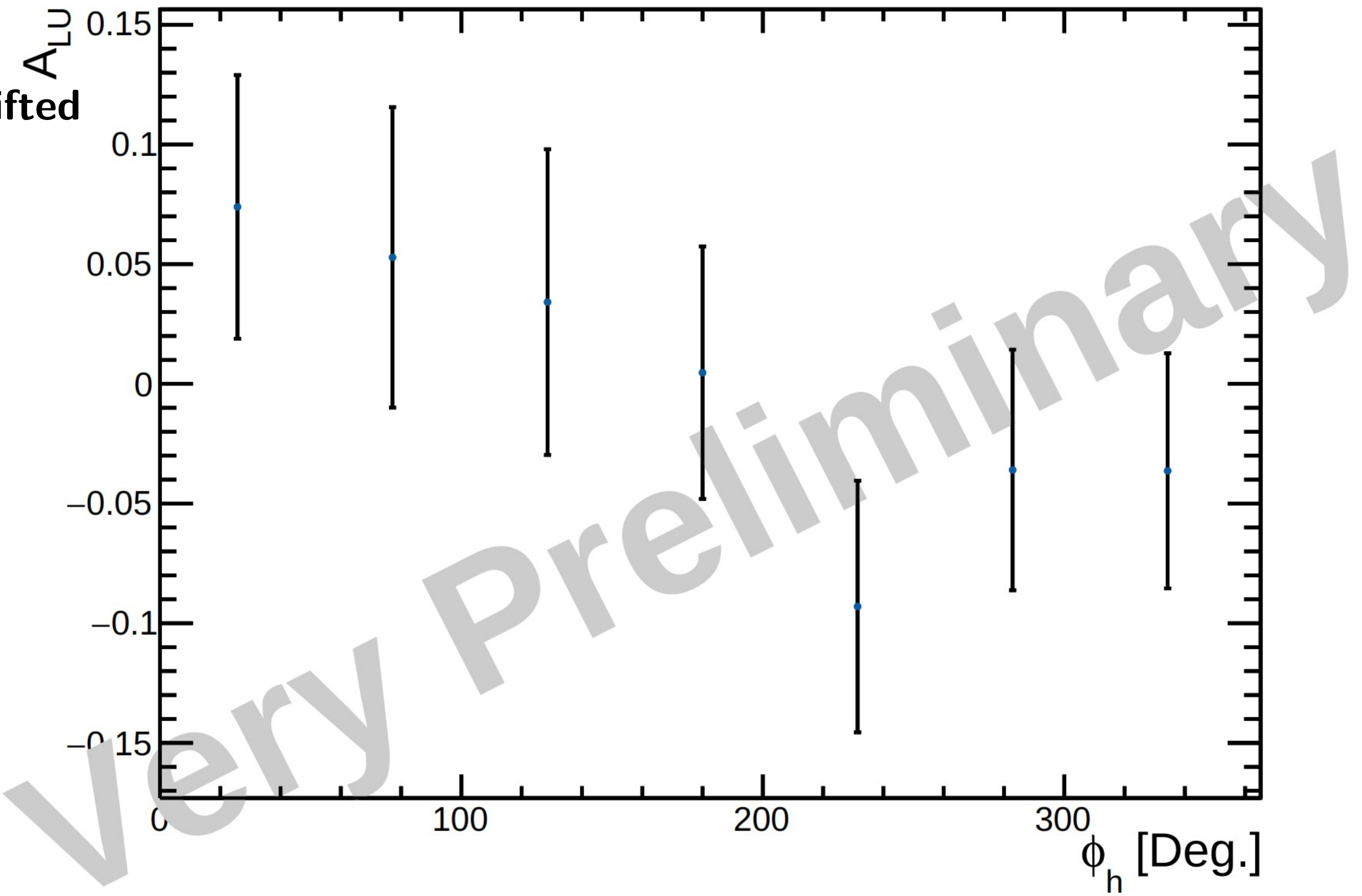
Without the struck nucleon, we have only one exclusivity variable, the missing mass of electron-photon.

See a clear peak in the distribution but shifted by 0.6 unit.

- $0.20 < MM_{ep\rightarrow e\gamma X}[GeV^2/c^4] < 3.00$



Raw integrated beam-spin asymmetry



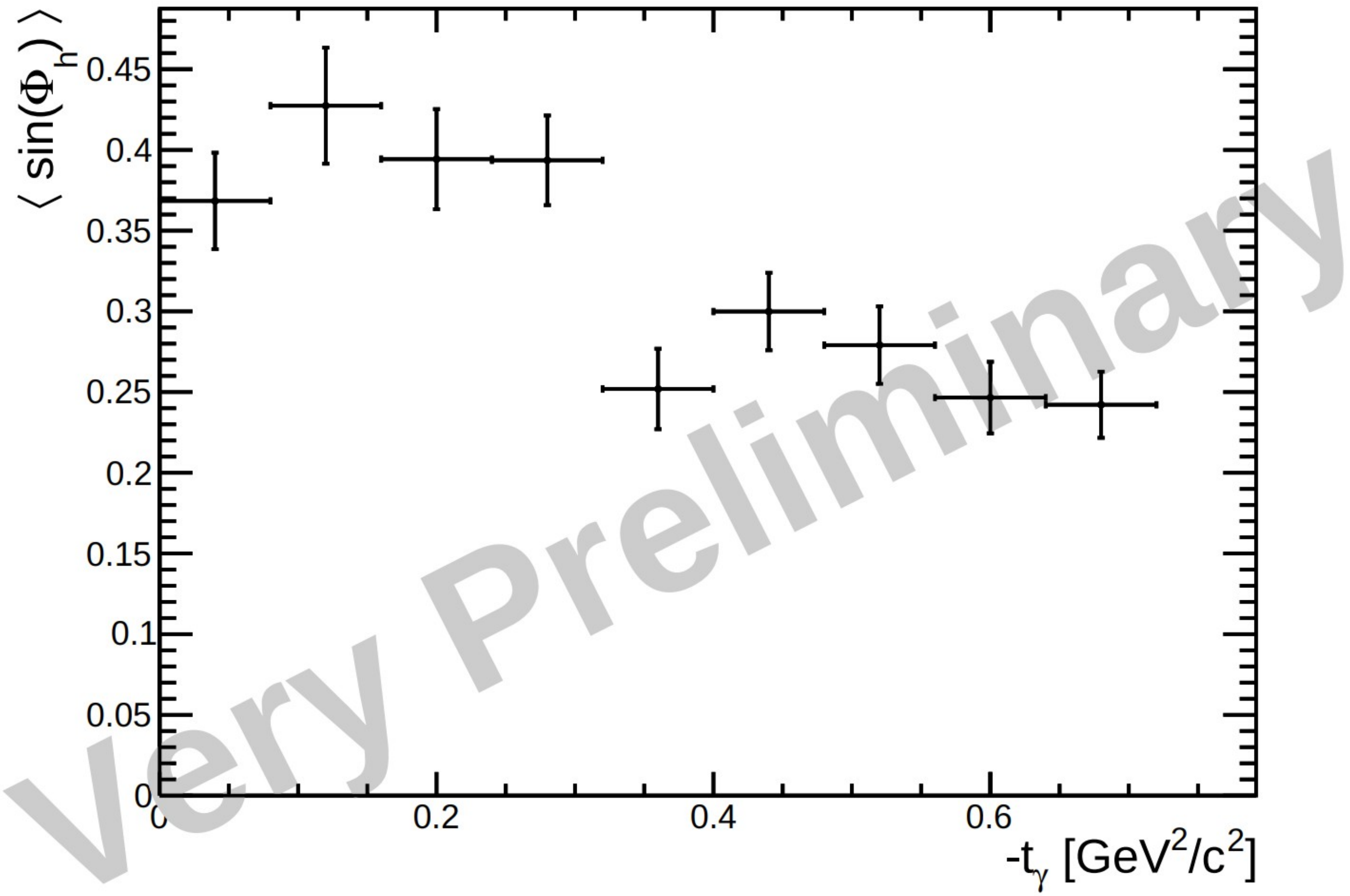
nDVCS with spectator proton : sin(ϕh) vs t

- **We can extract the beam spin asymmetry by fitting the asymmetry as a function of ϕ_h, or via direct calculation.**

- **Weighed moment method:**

$$A_{LU}^{sin(\phi_h)} = \frac{2}{P * N} \sum_{event=1}^{N} sin(\phi_h)$$

- **Can do a binning in t, Q^2, x_{Bj} …**
- **Useful if the static is low.**



Conclusion

- **Done :**
  - *Extract a raw beam spin asymmetry for nDVCS with a tagged proton.*
  - *Reduce the background with a multidimensional background.*

- **To do :**
  - *Use simulation to correct t from the photon, to correct asymmetry from the acceptance.*
  - *Compute the accidental combinatorial background.*
  - *The π^0 background substraction.*