The First Polarized-Target DVCS Experiment with CLAS12 at Jefferson Lab

14th International Workshop on the Physics of Excited Nucleons - York

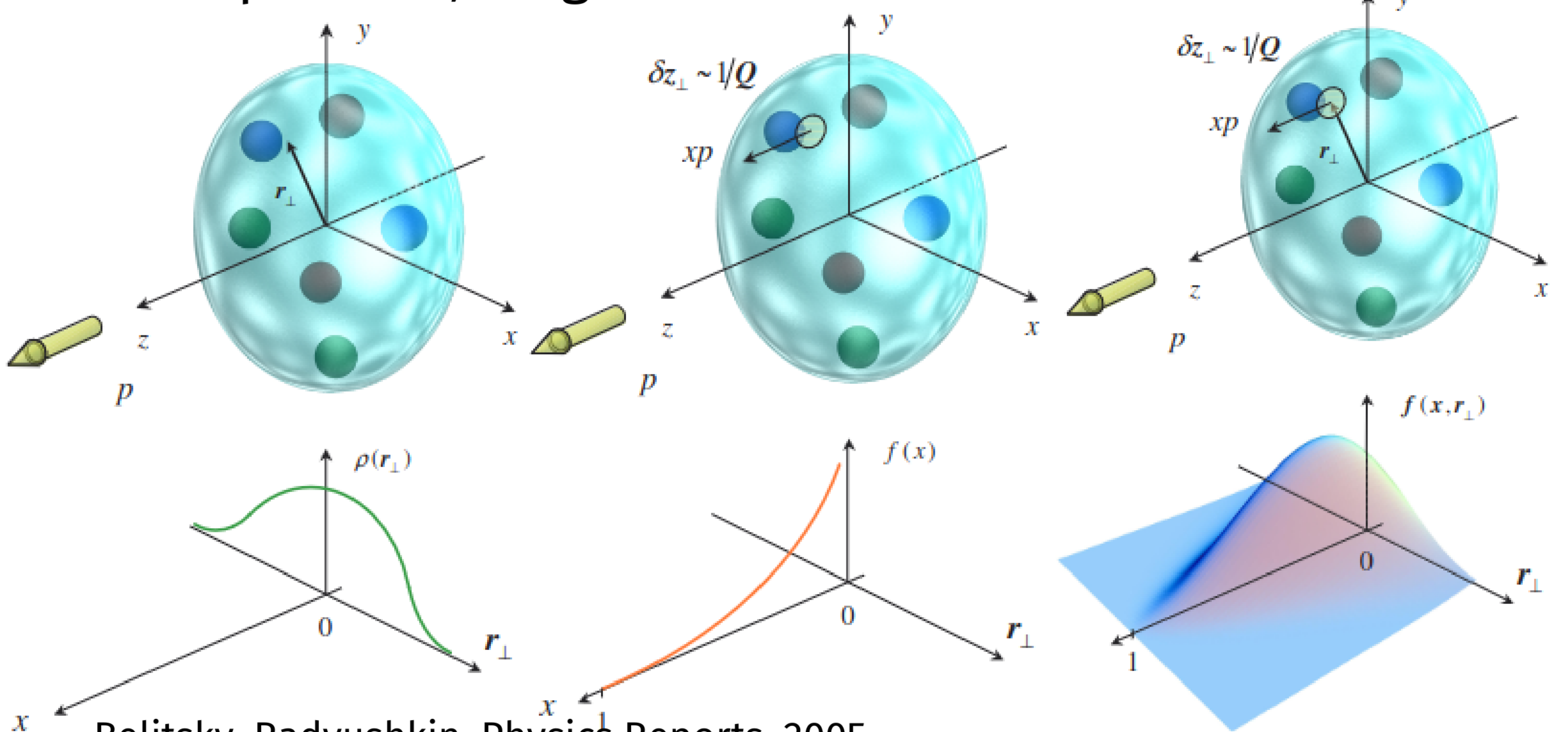
Pilleux Noémie - IJCLab, Paris Saclay University, France

17th June 2024

Understanding the Structure and Properties of Nucleons

- Generalized Parton Distributions (GPDs)

Transverse position, longitudinal momentum and their correlations

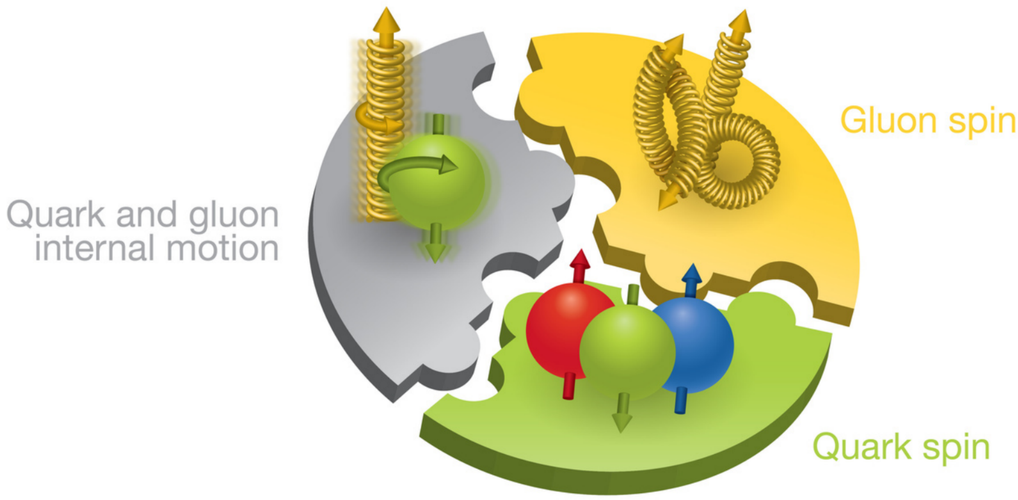


Belitsky, Radyushkin, Physics Reports, 2005

- Proton spin decomposition

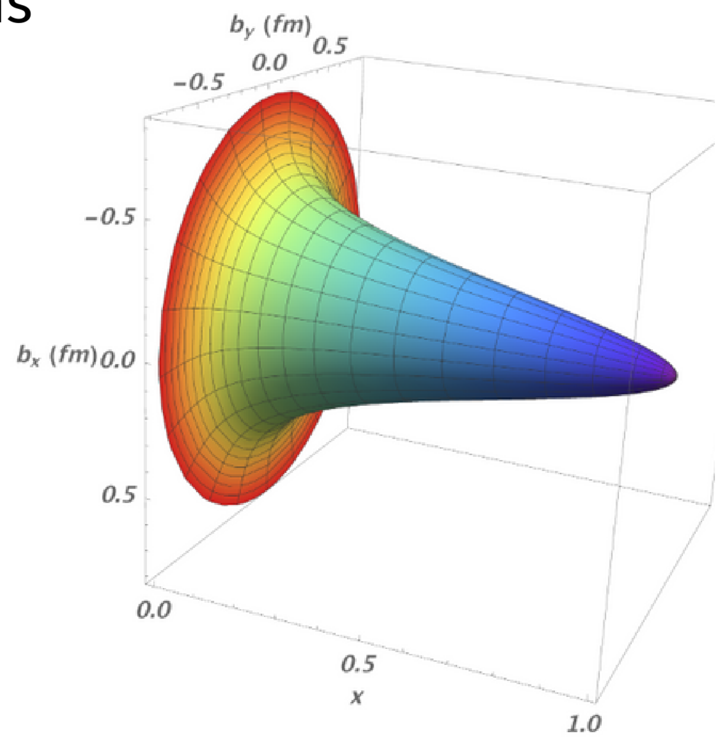
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

$$\frac{1}{2}\int_{-1}^{1} x dx (H(x,\xi,t=0) + E(x,\xi,t=0)) = \frac{1}{2}\Delta\Sigma + \Delta L$$

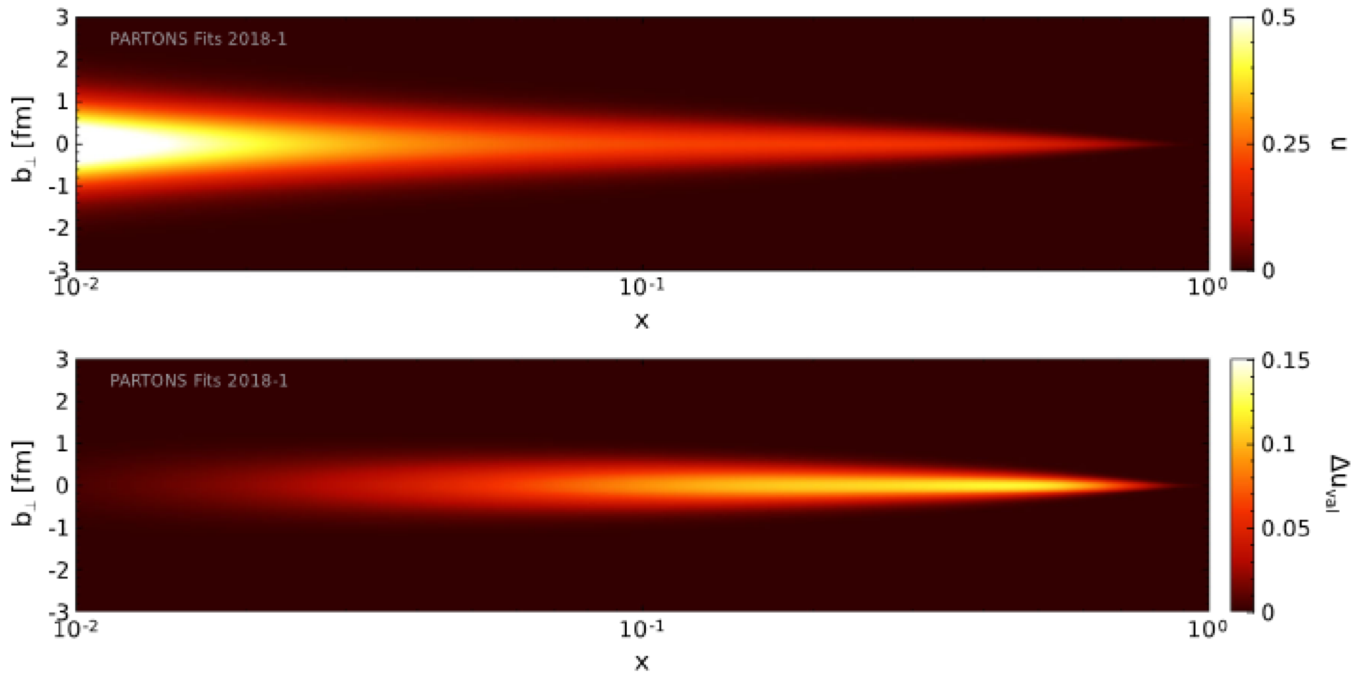


- Towards 3D imaging of nucleons

Dupré, Guidal, Vanderhaeghen, PRD95, 2017

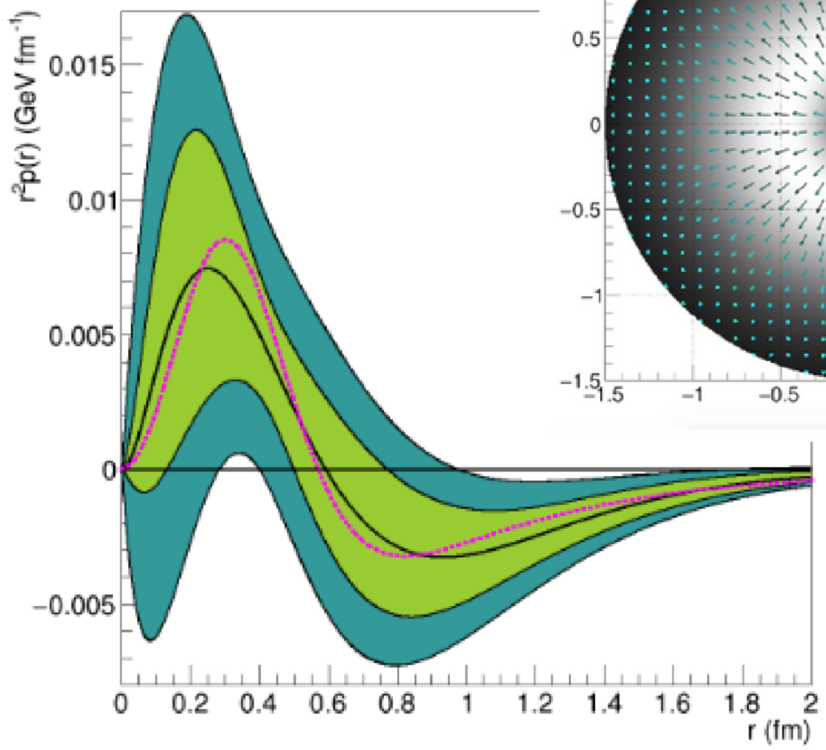


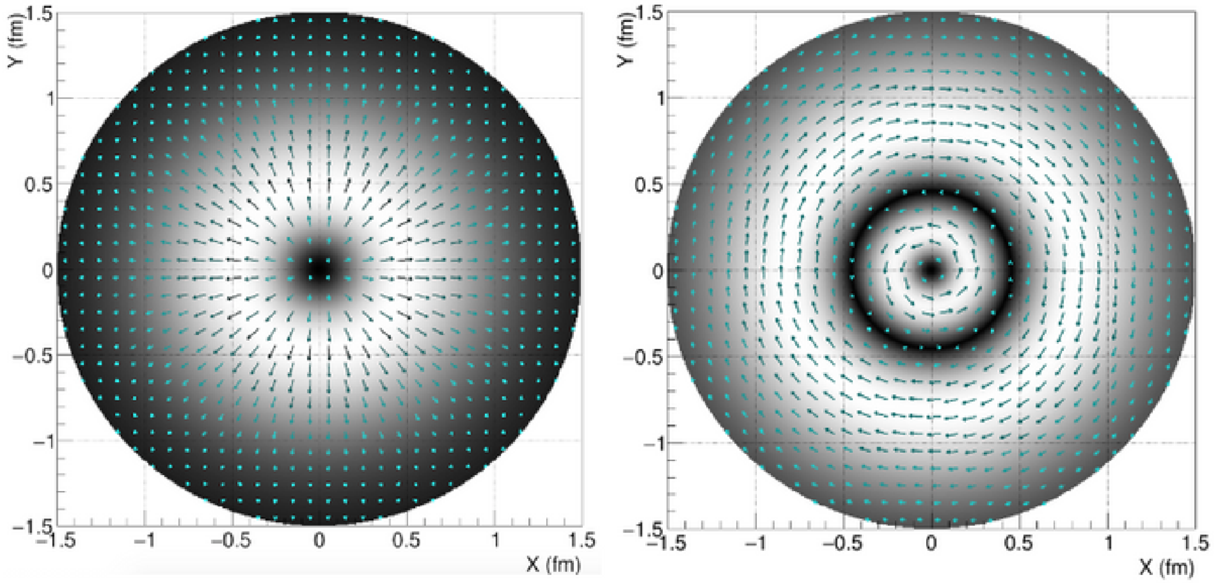
Moutarde, Sznajder, Wagner, EPJC 2018



- Forces and pressure inside nucleons

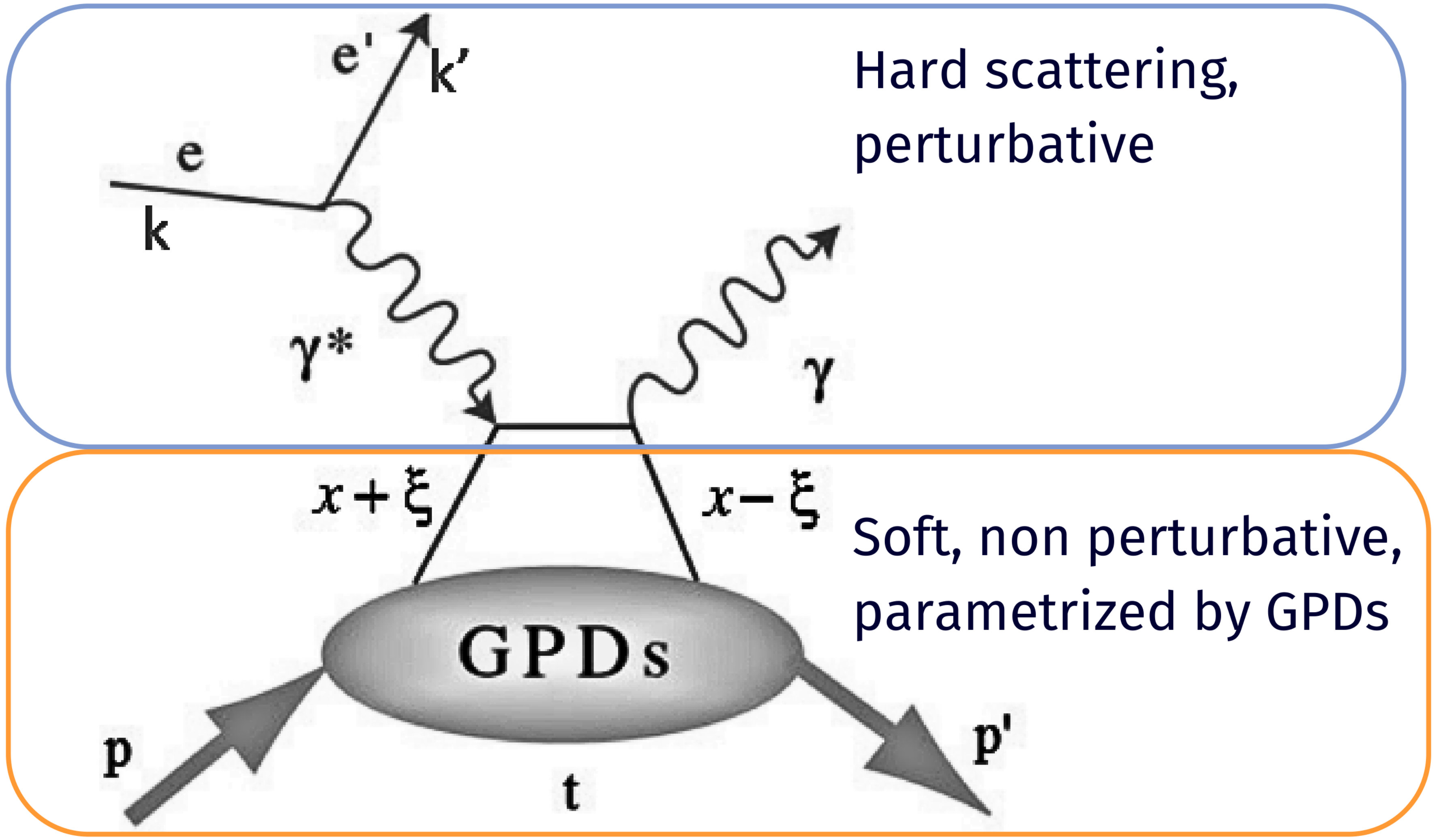
Burkert et al. 2018





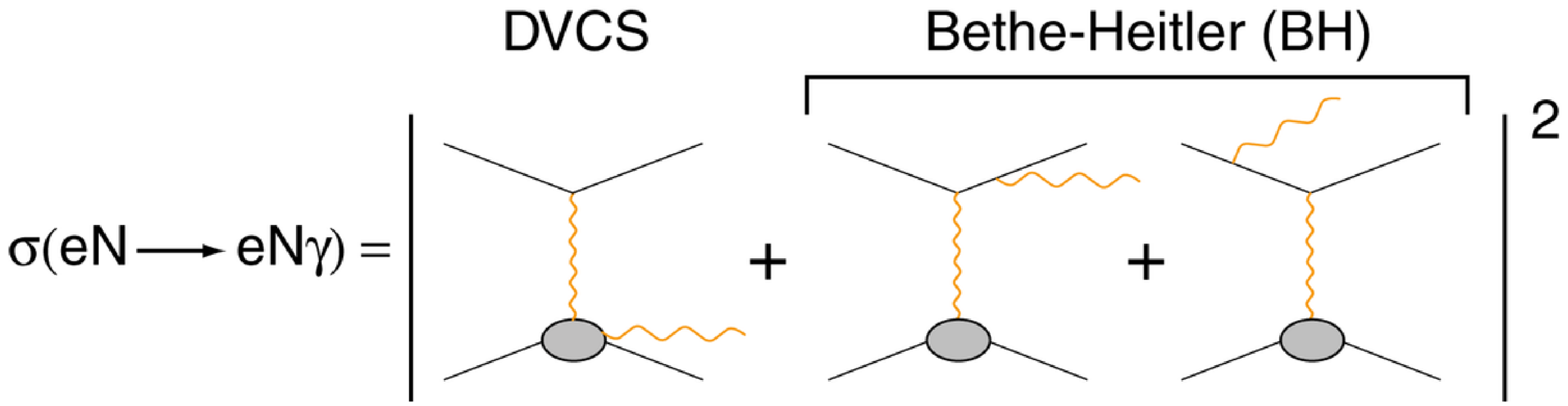
Burkert et al. 2021b

Deeply Virtual Compton Scattering (DVCS)



Gives access to Compton Form Factors

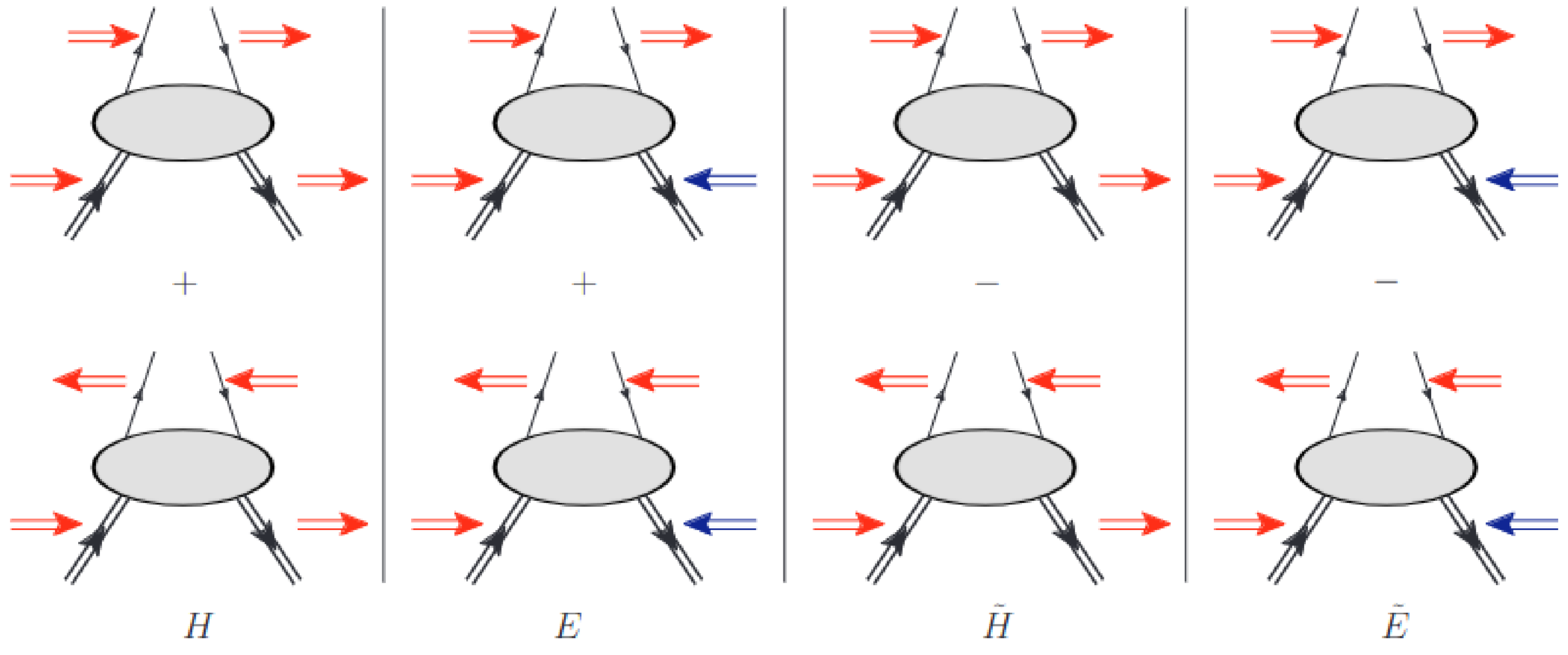
$$\mathcal{F}(\xi,t) = \int_{-1}^{1} dx F(\mp x,\xi,t)\left[\frac{1}{x-\xi+i\epsilon} \pm \frac{1}{x+\xi-i\epsilon}\right]$$



Access to linear combinations of CFFs and Form Factors thanks to the interference of BH and DVCS.

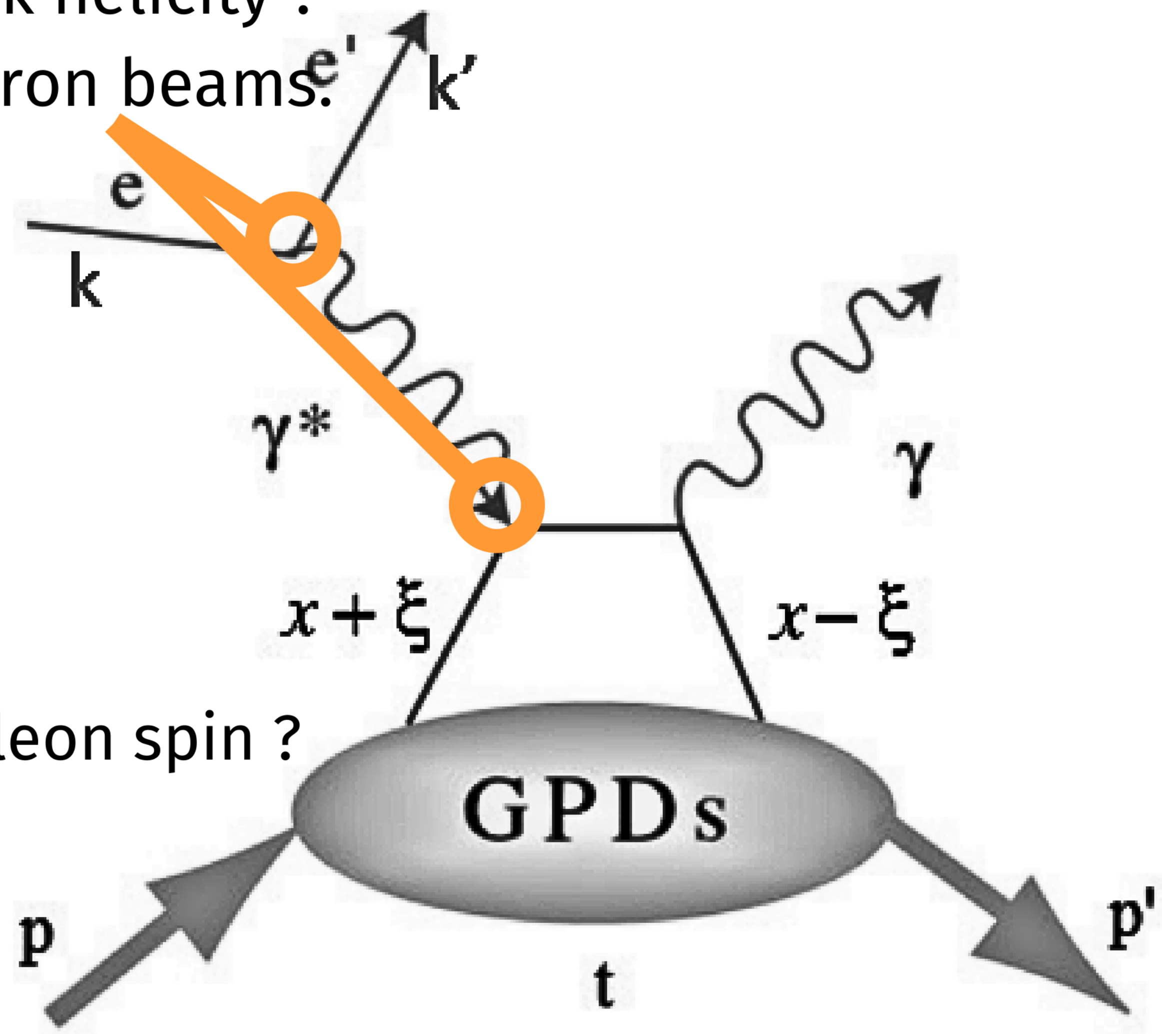
Accessing GPDs through DVCS

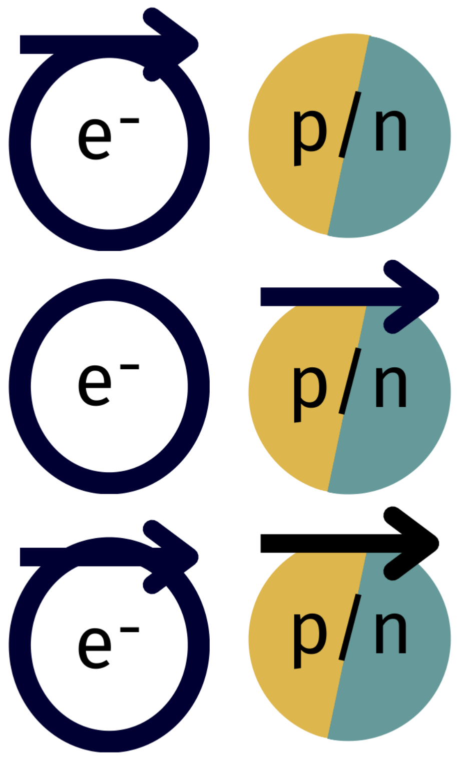
4 types of GPDs can be accessed depending on the quark and nucleon helicity.



Fixing the quark helicity ?
Polarized electron beams.

Controlling the nucleon spin ?
Polarized targets.

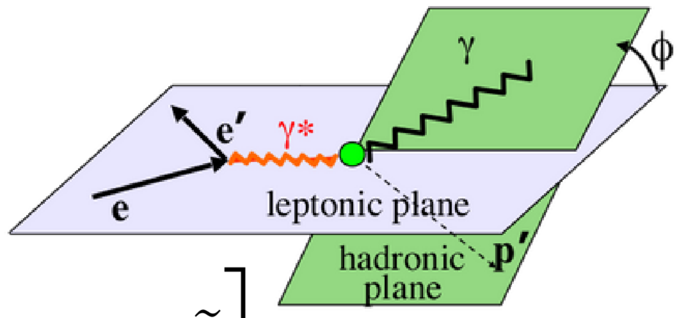




$$\Delta\sigma_{LU} \simeq sin(\phi)\Im\left[F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \xi\frac{t}{4M^2}F_2\mathcal{E}\right]$$

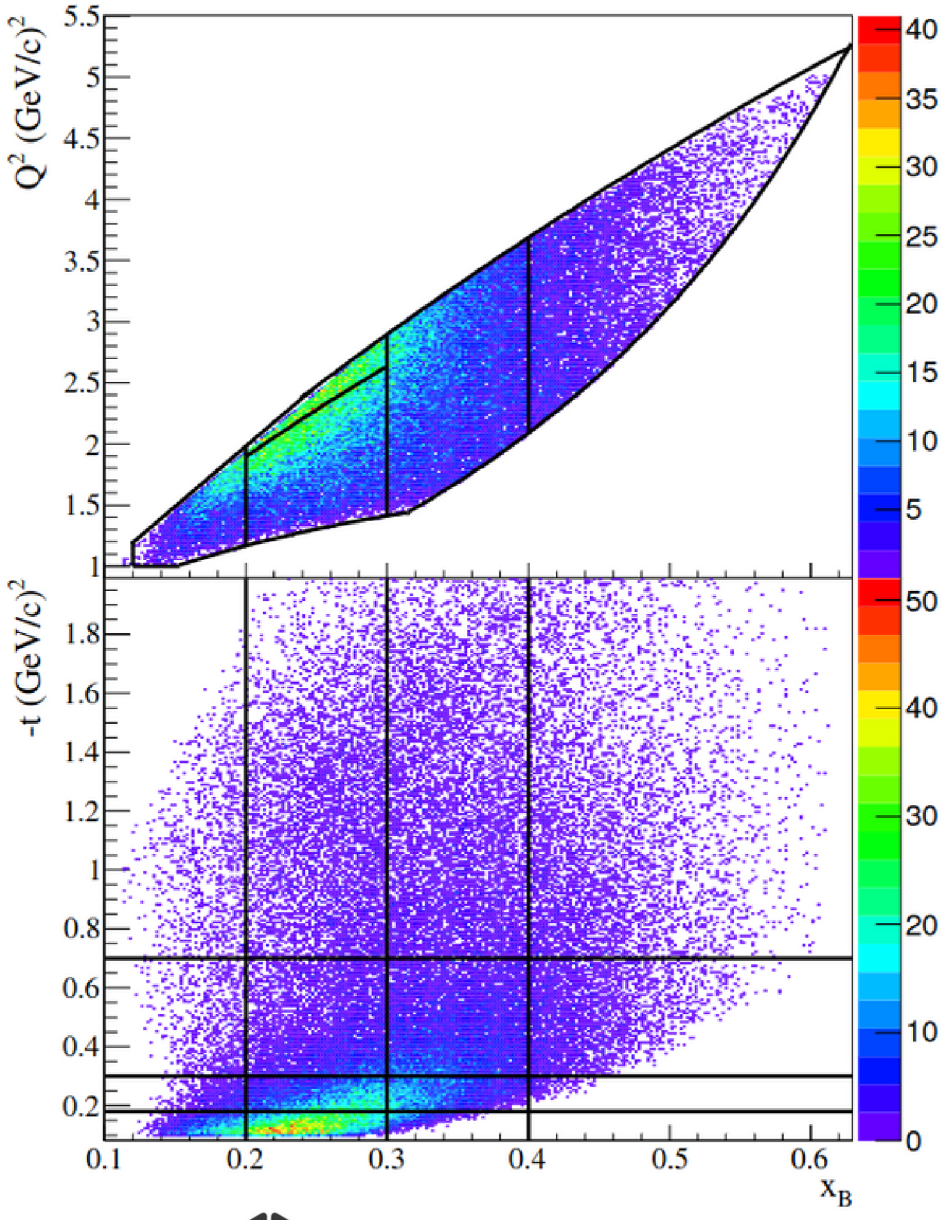
$$\Delta\sigma_{UL} \simeq \sin(\phi)\Im\left[F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H}+\frac{x_{bj}}{2}\mathcal{E}) - \xi(\frac{x_{bj}}{2}F_1+\frac{t}{4M^2}F_2)\tilde{\mathcal{E}}\right]$$

$$\Delta\sigma_{LL} \simeq (A+B\cos(\phi))\Re[F_1\tilde{\mathcal{H}}+\xi(F_1+F_2)(\mathcal{H}+\frac{x_{bj}}{2}\mathcal{E})-\xi(\frac{x_{bj}}{2}F_1+\frac{t}{4M^2}F_2)\tilde{\mathcal{E}}]$$



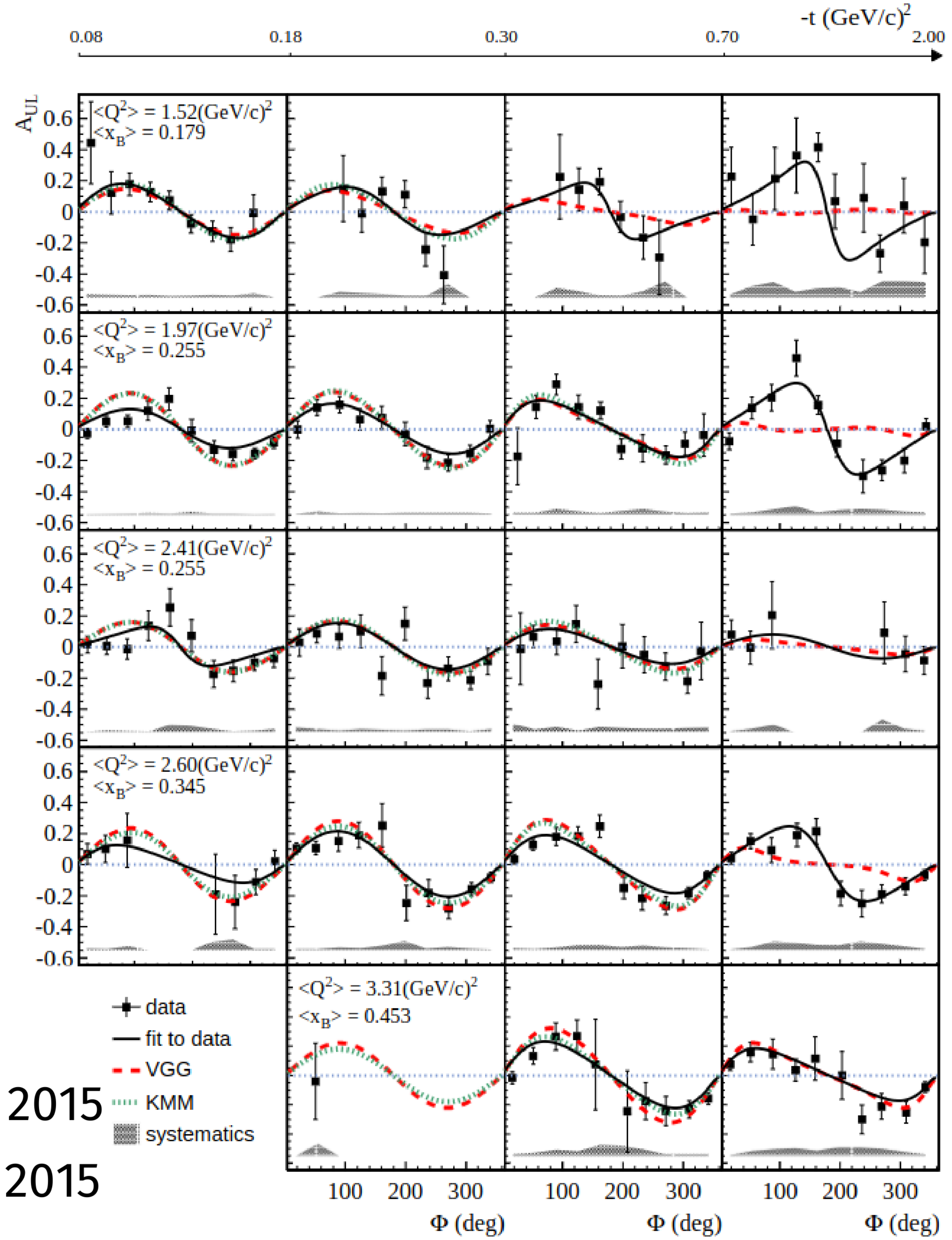
Existing CLAS Measurement of DVCS on Polarized Protons

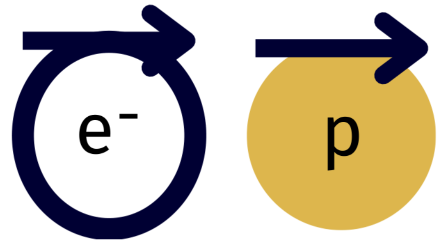
- First measurement in 2006 with the CLAS detector (JLab) at 6 GeV (S.Chen et al. PRL97, 2006)
- Few years later, dedicated CLAS measurement at 6 GeV with an upgraded detector



Pisano, et al., PRD91, 2015

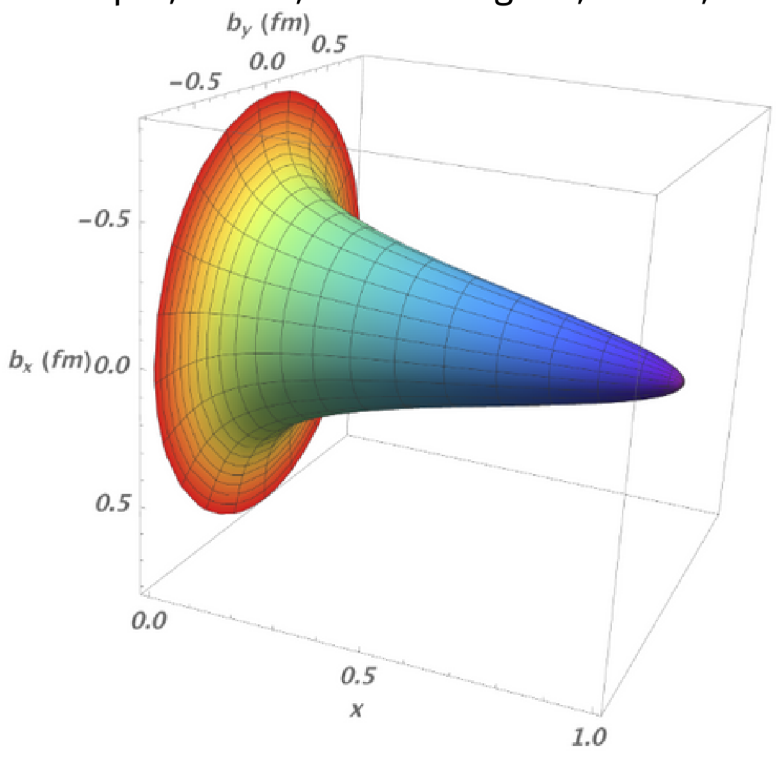
Seder, et al., PRL114, 2015

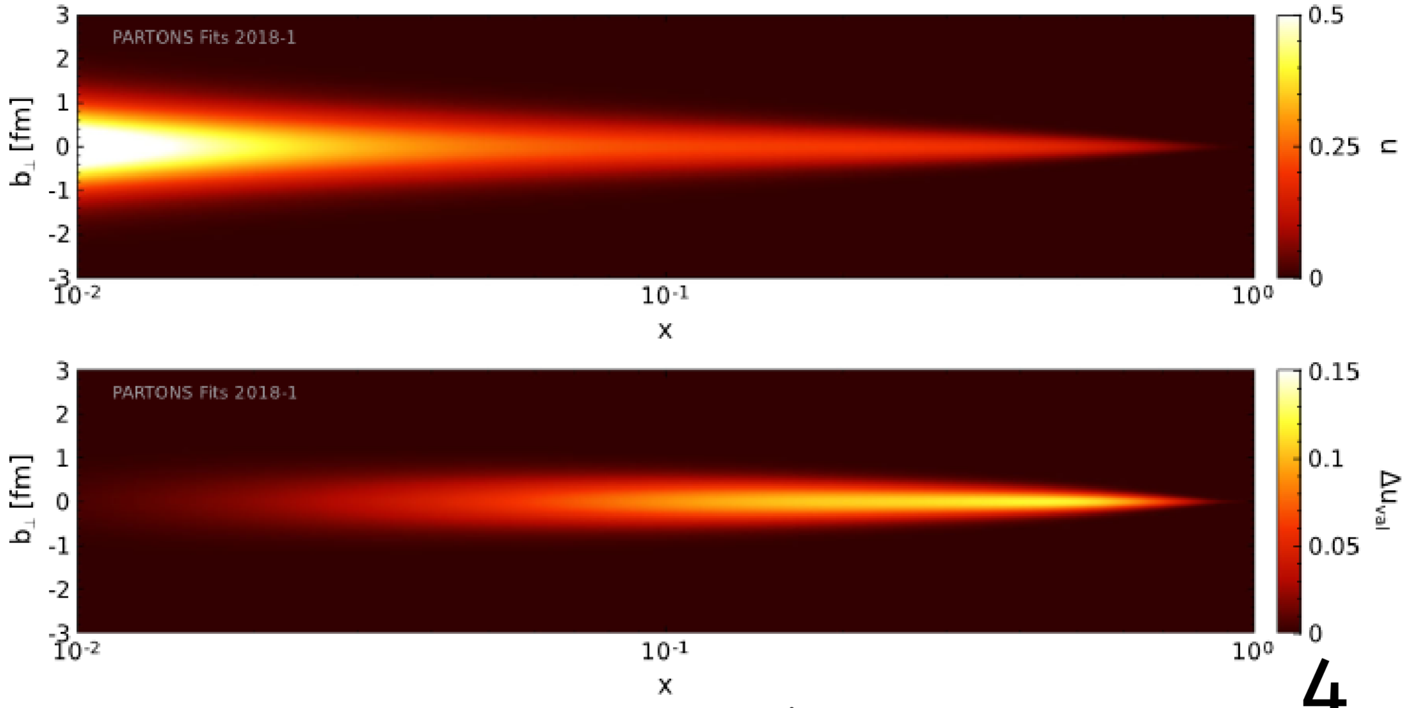




$H, \tilde{H}$

Dupré, Guidal, Vanderhaeghen, PRD95, 2017



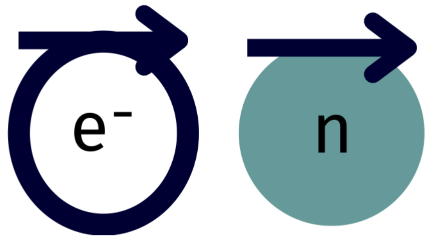


Moutarde, Sznajder, Wagner, EPJC 2018

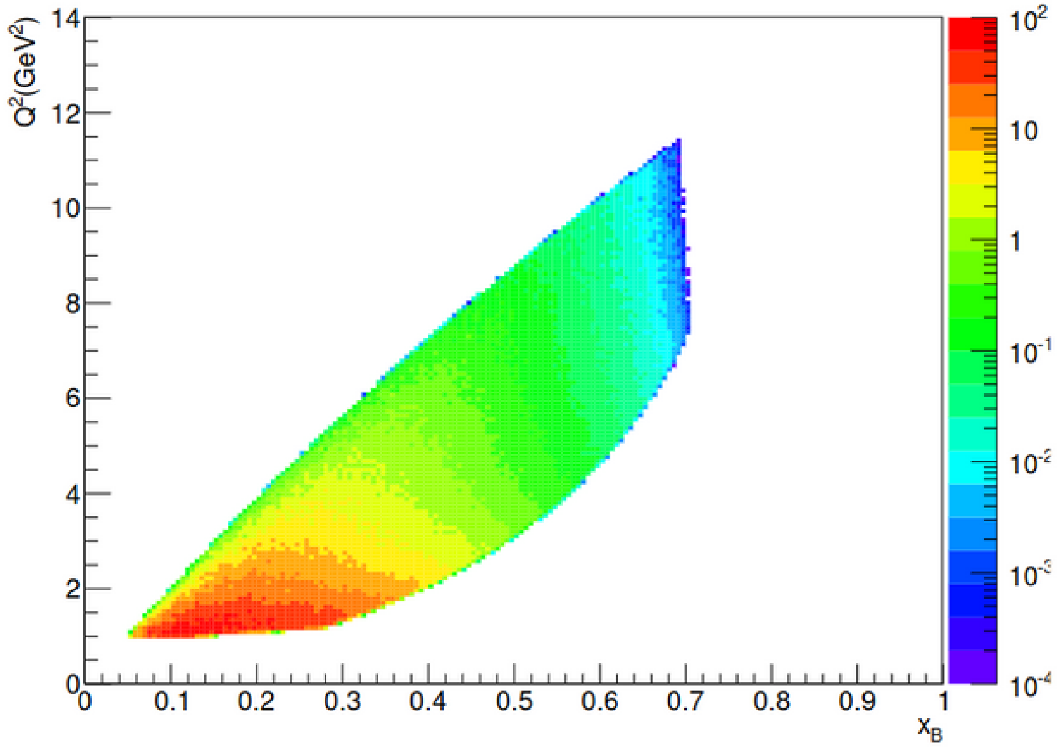
The CLAS12 Program for Polarized DVCS

DVCS measurement with **polarized H/D** at CLAS12

- First-time measurement for the neutron: new observables to access poorly-known H(n)
- Flavor decomposition of CFFs
- Comparison for protons in H and D to understand in-medium effects



$$H, E$$



Projected kinematics for ndvcs

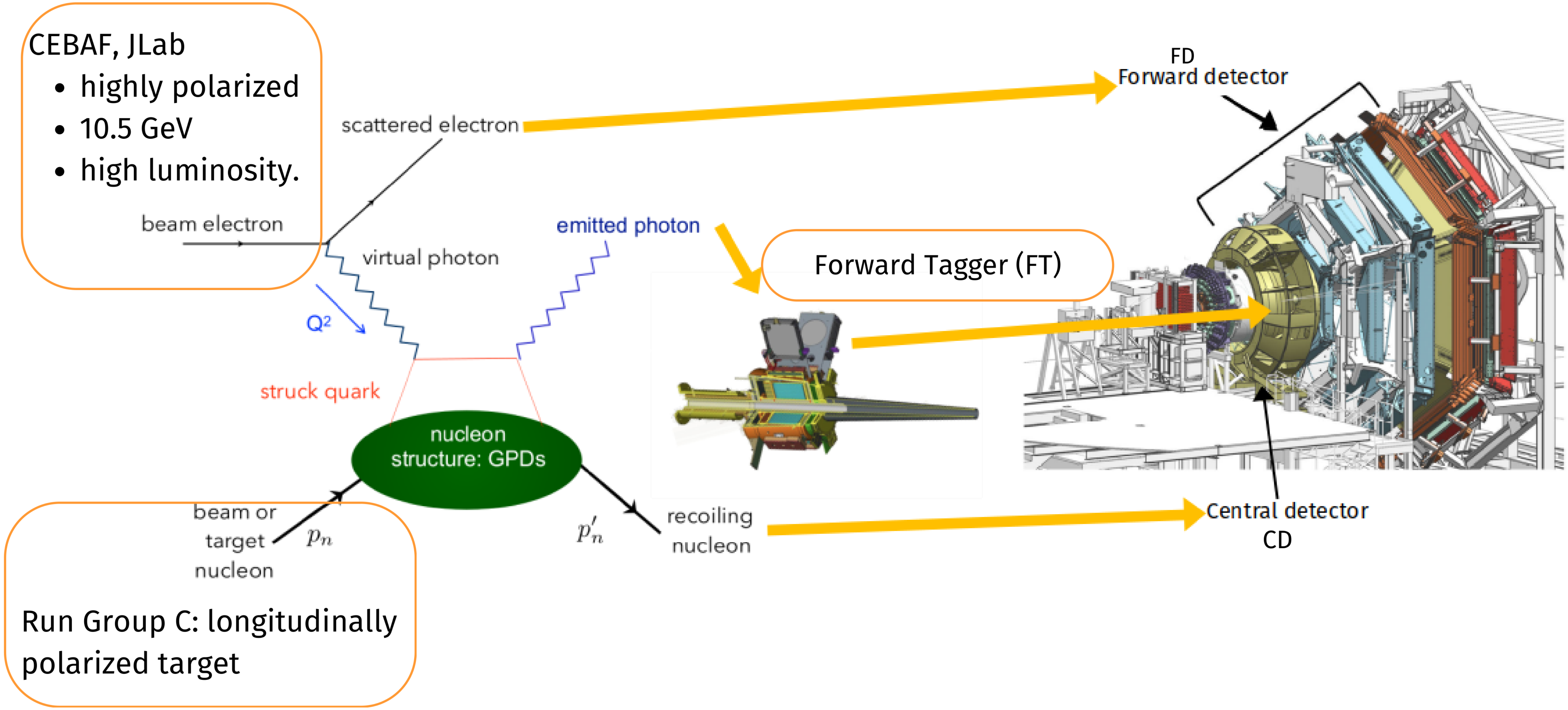
→ Run Group C (RGC) Experiment:

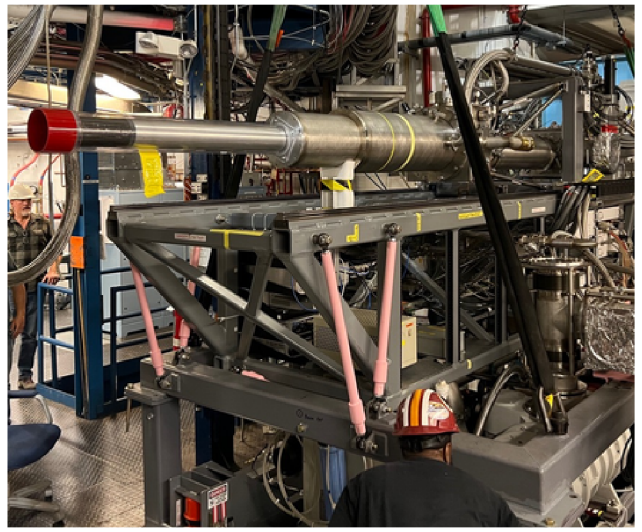
- June 2022 - March 2023
- A third of the dataset recently became available!
- Today: preliminary analysis for pDVCS in D and preparation of the nDVCS analysis.

Experimental Setup

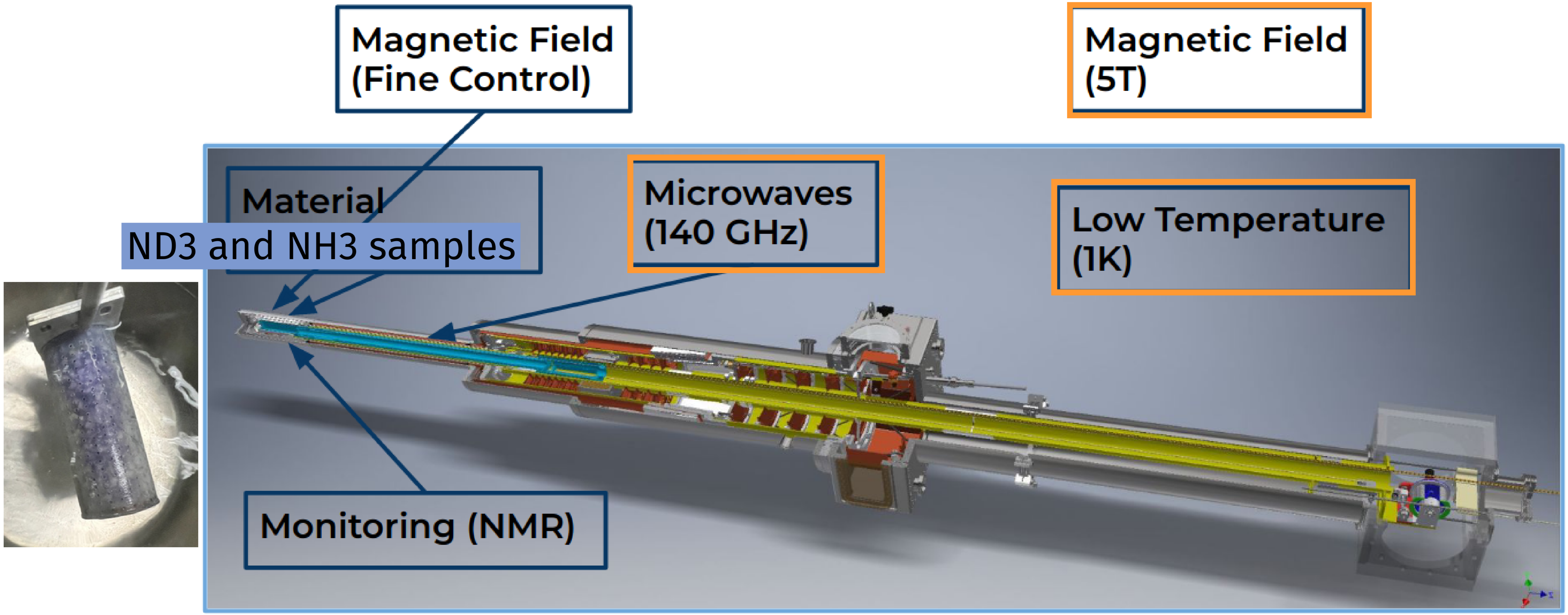
Measuring Polarized DVCS with CLAS12

- Polarized beams (CEBAF)
- DVCS measurement (CLAS12, Hall B)
- Polarized targets → Run Group C (RGC)



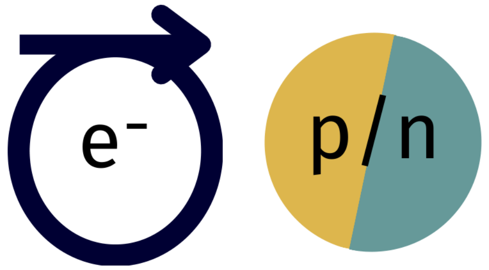


The RGC Polarized Target

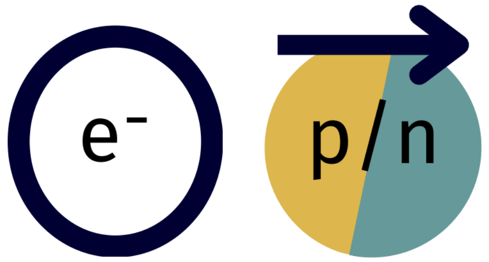


- 9 months of data taking!
- Data on NH3, ND3 and a variety of background targets (C, CH2, CD2…).
- An experimental success thanks to the expertise of the JLab target group.

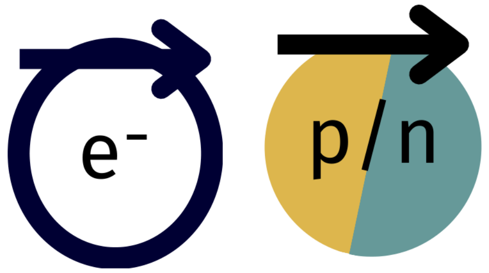
Experimental Definition of the DVCS Asymetries



$$A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{Pb \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$



$$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$



$$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_b \times Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$N^{b,t}$$

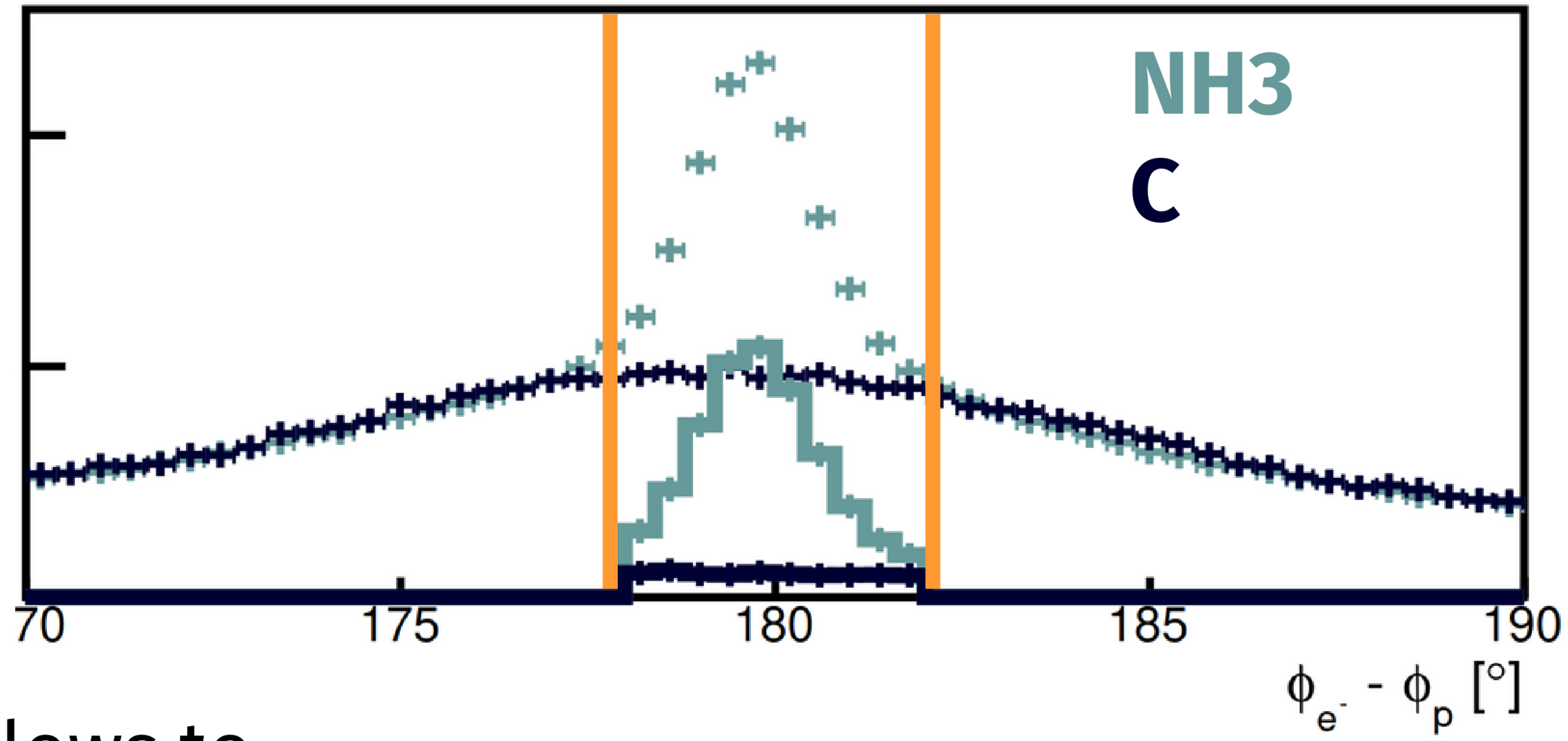
- Dilution factor (Df) for the unpolarized N background: measured using background targets.
- Beam polarization (Pb): Moller scattering measurements during the experiment (~83%).
- Target Polarization Pt: assessed with analysis of elastic events.

Measuring the Target Polarization

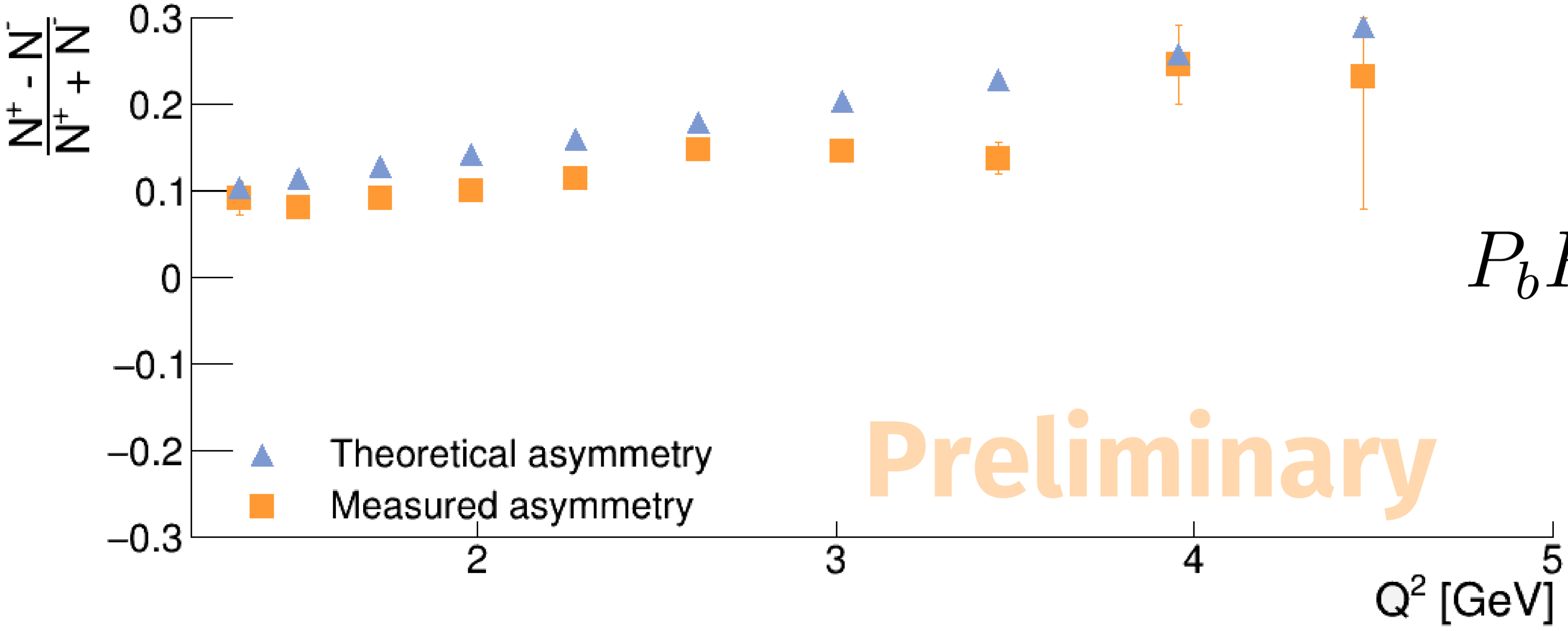
Target Polarization Measurement

- Using elastic events ep → e'p'
- The double-spin asymmetry is well known

$$A_{th} = \frac{2\tau G[\frac{M_p}{E_b} + G(\tau \frac{M_p}{E_b} + (1+\tau)\tan(\frac{\theta}{2})^2)]}{1 + G^2 \frac{\tau}{\epsilon}}$$



- Comparing with the measured asymmetry allows to assess the fraction of polarized electrons and protons.



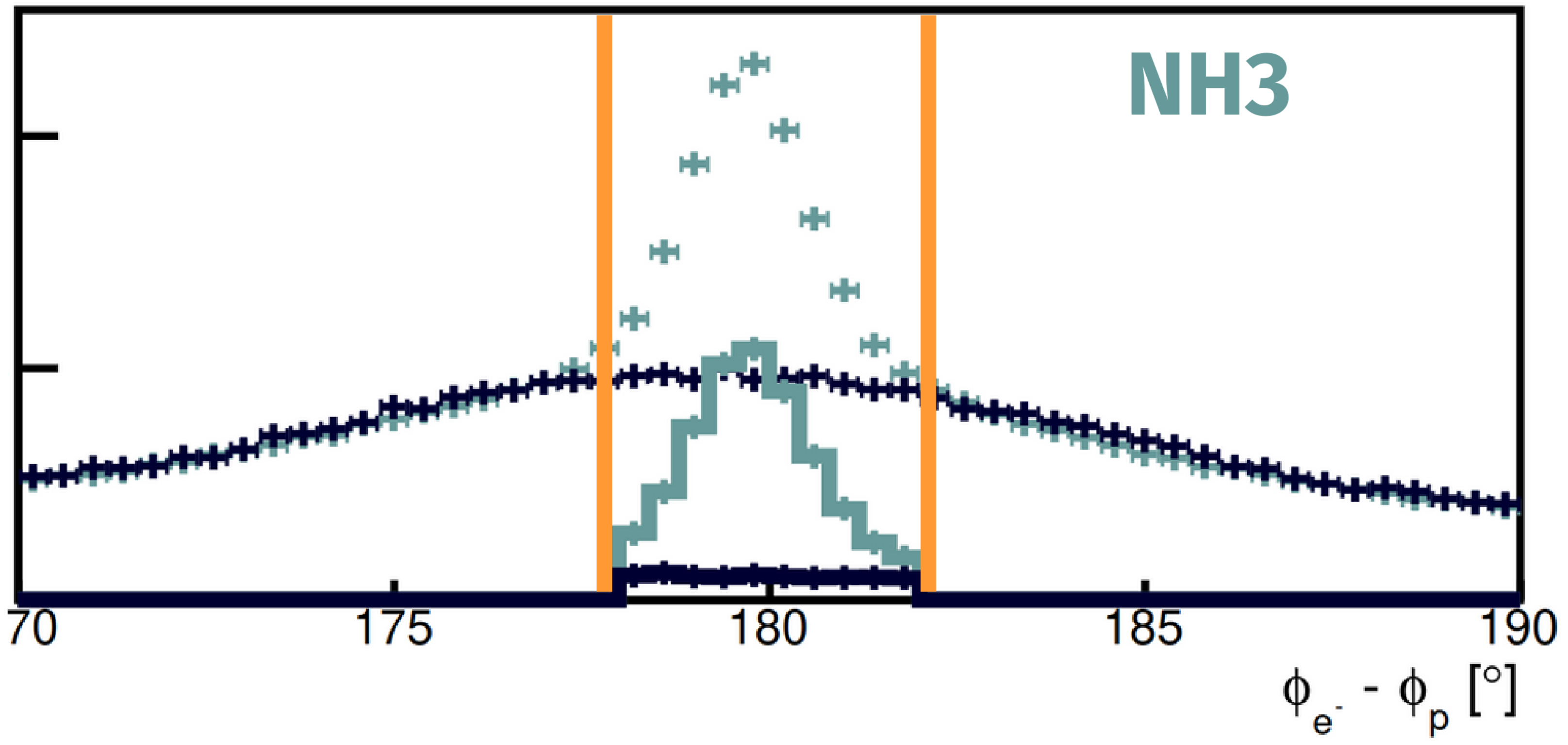
dilution factor

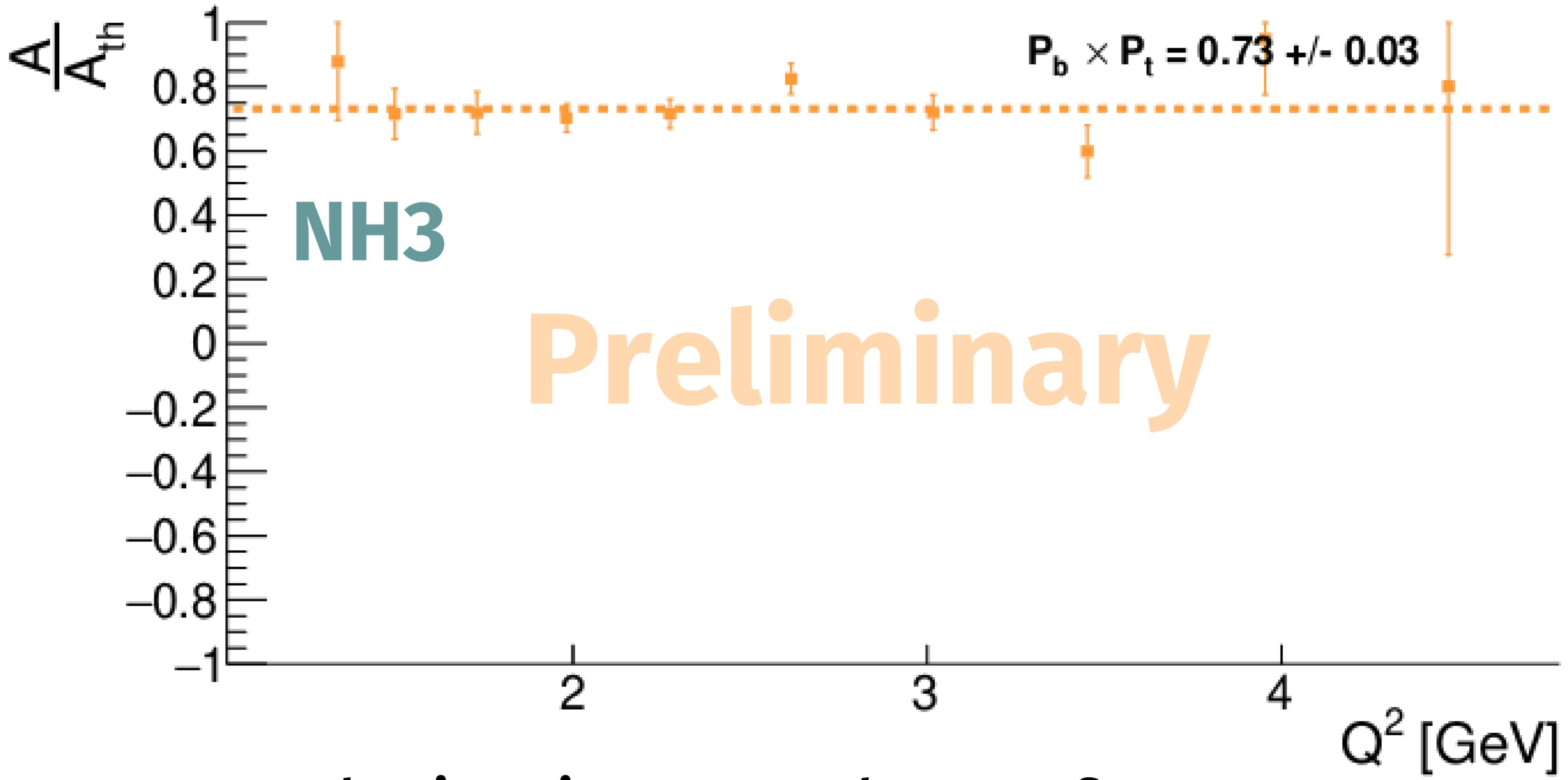
$$P_b P_t = \frac{\sum_{i=0}^{N_{bins}} f_i A_{th,i}(N_i^+ - N_i^-)}{\sum_{i=0}^{N_{bins}} f_i^2 A_{th,i}^2 (N_i^+ + N_i^-)}$$

yields with positive/negative beam helicity

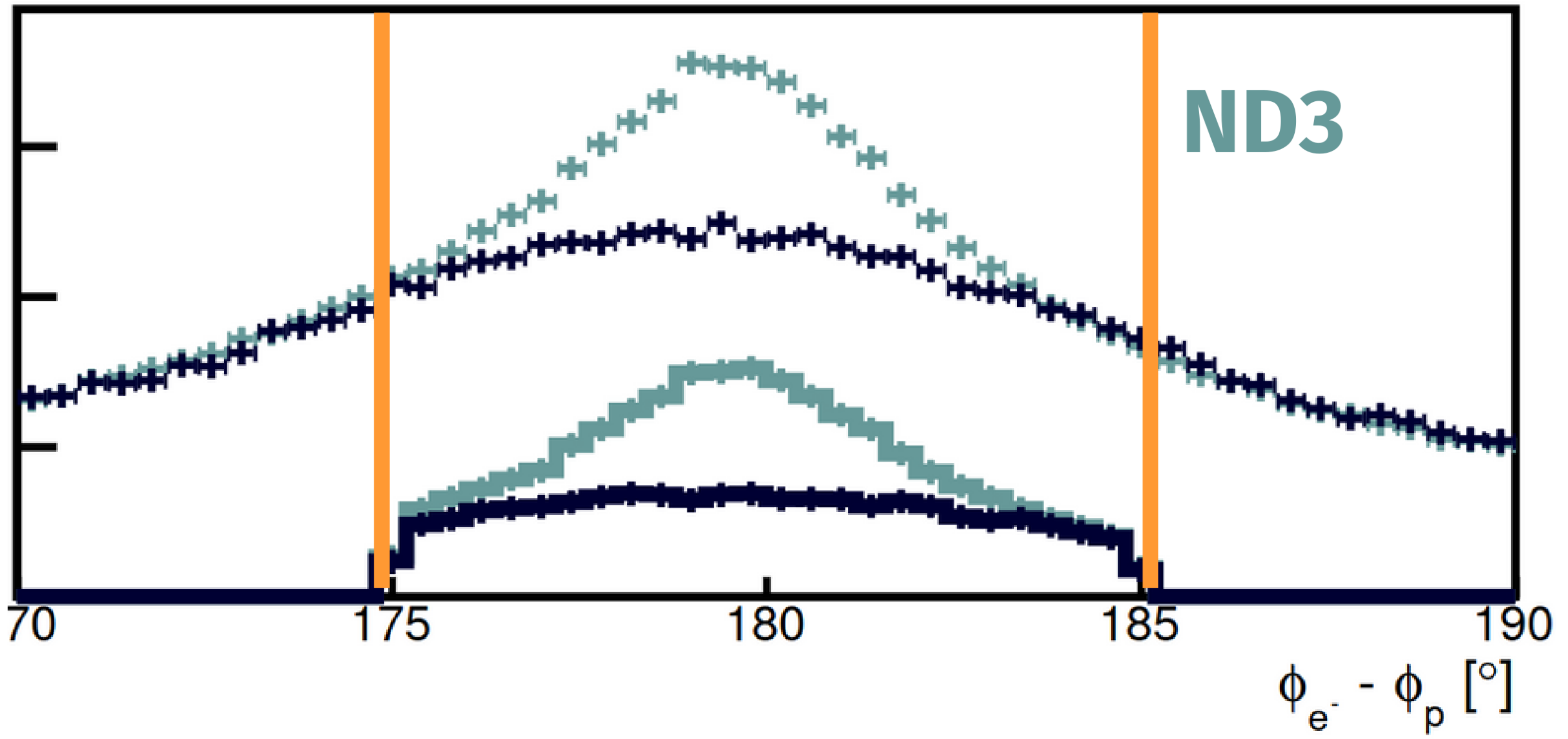
Challenges with Deuterium Data

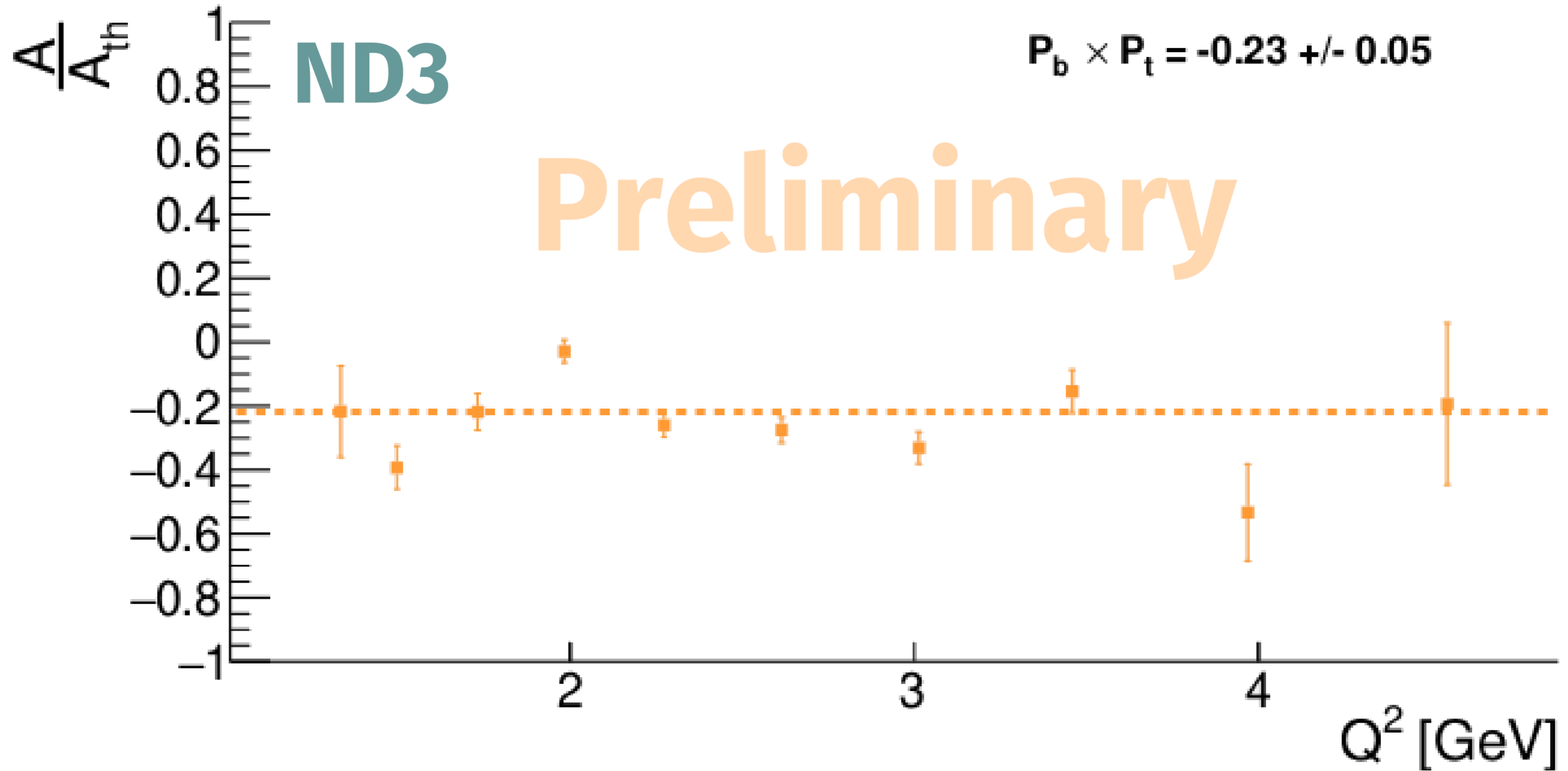
Ongoing analysis concerns p and n <u>in D</u>.
Fermi Motion affects resolutions.





Target polarizations are lower for D.

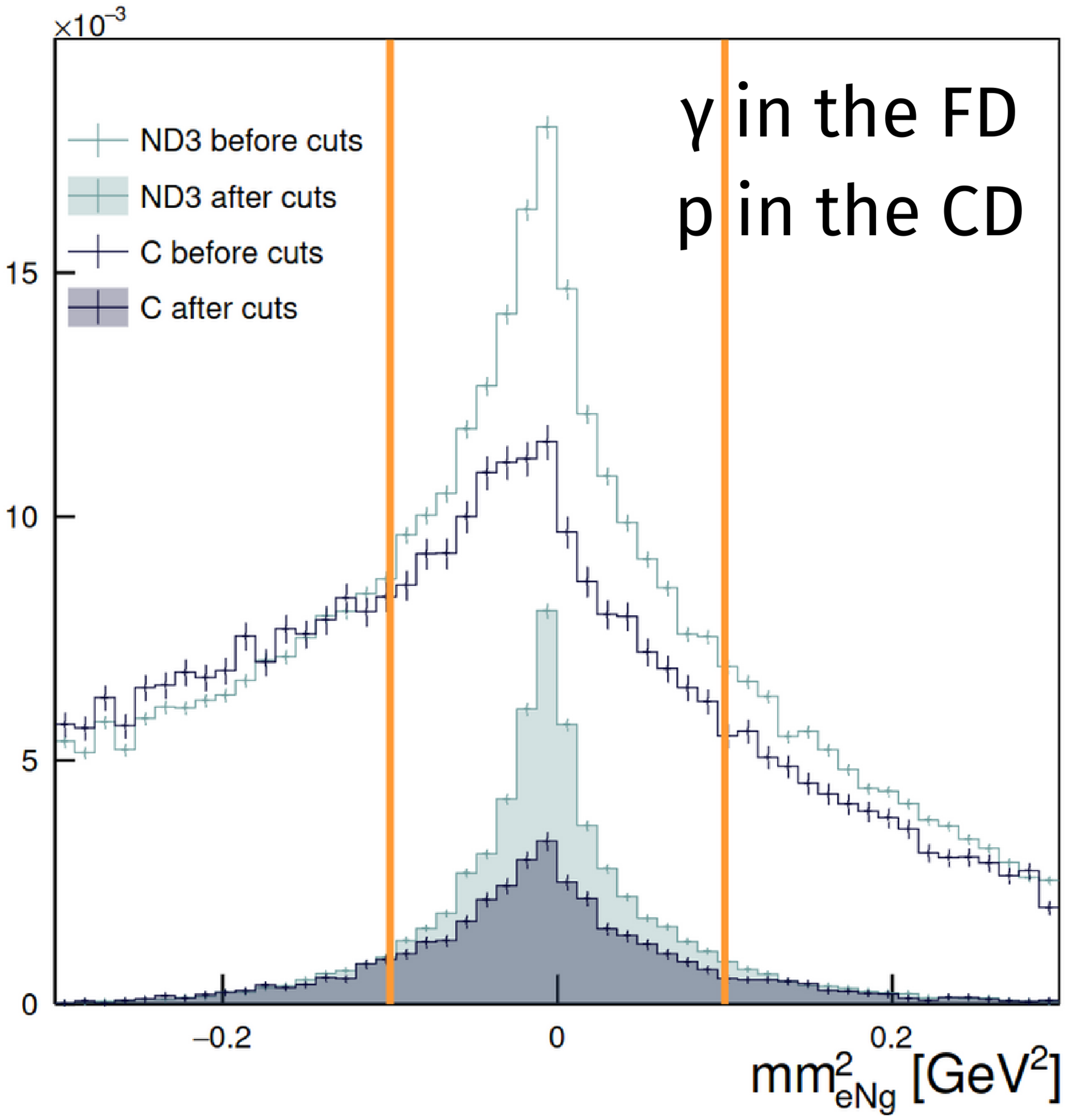


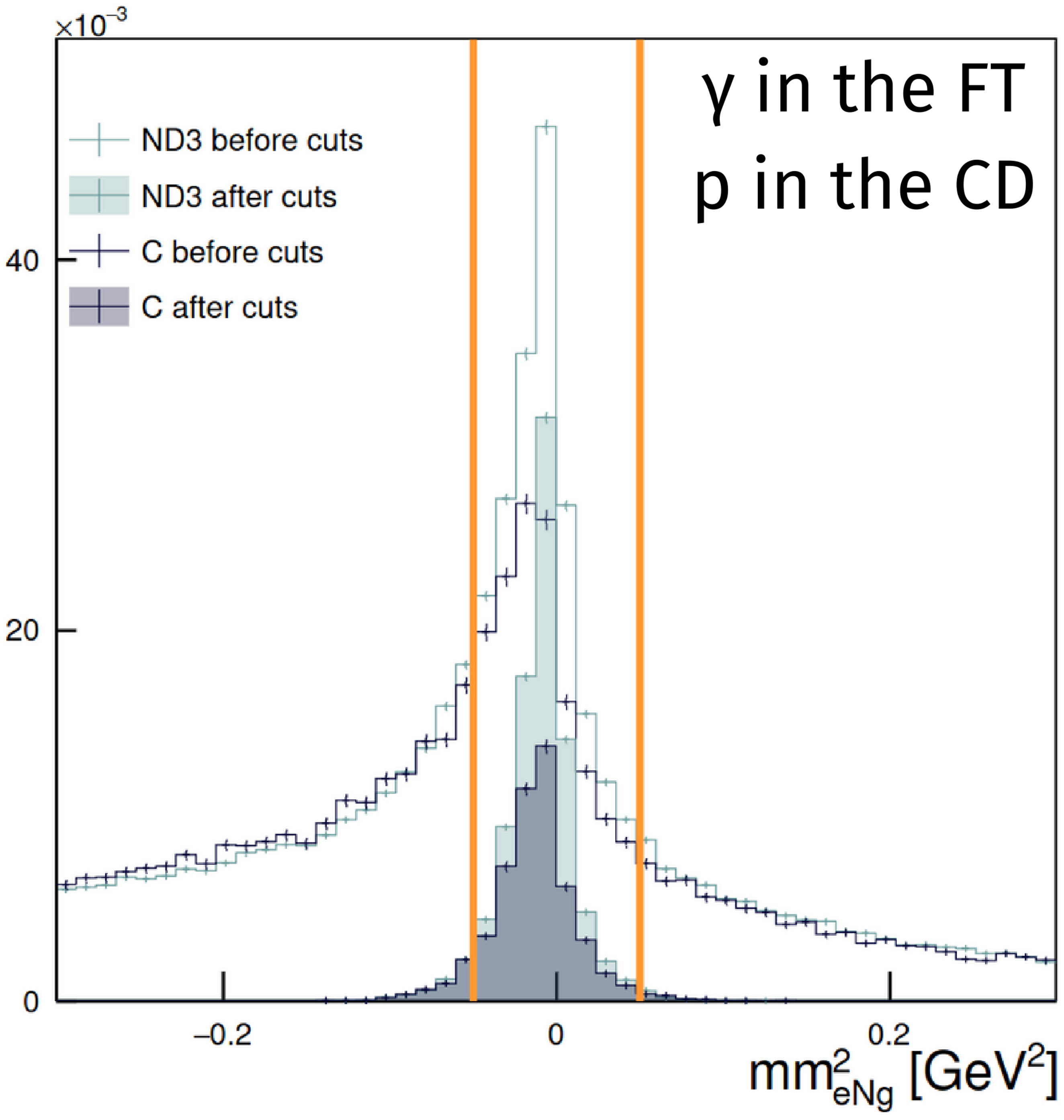


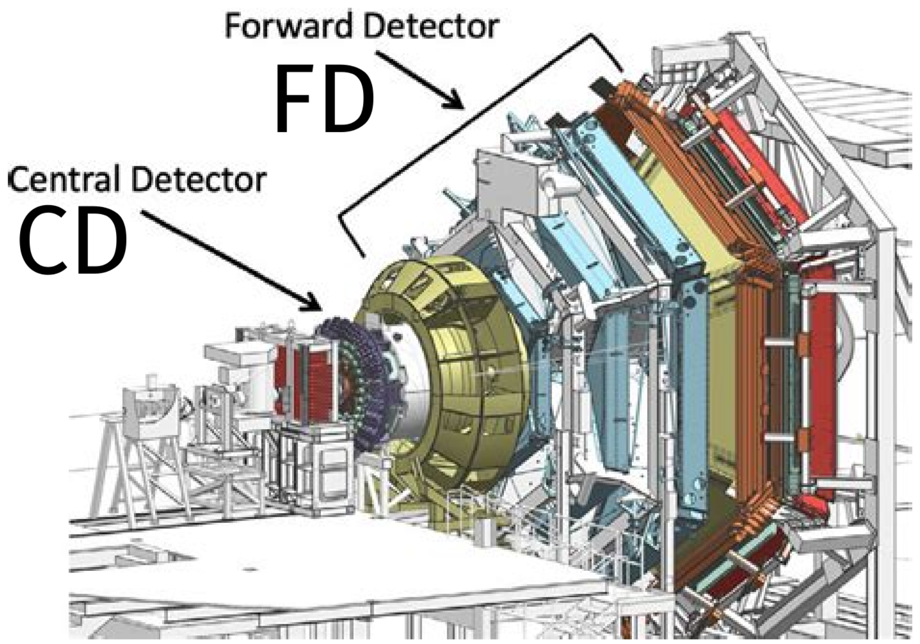
Measuring DVCS

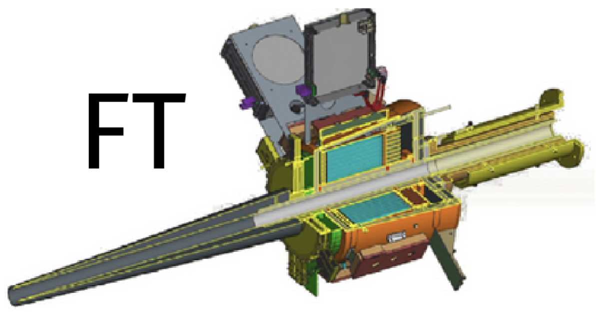
DVCS Event Selection

- Selecting ep → e'p'γ events.
- Building exclusivity variables to select DVCS.
- A compromise has to be made between statistics and purity excluding the N background.









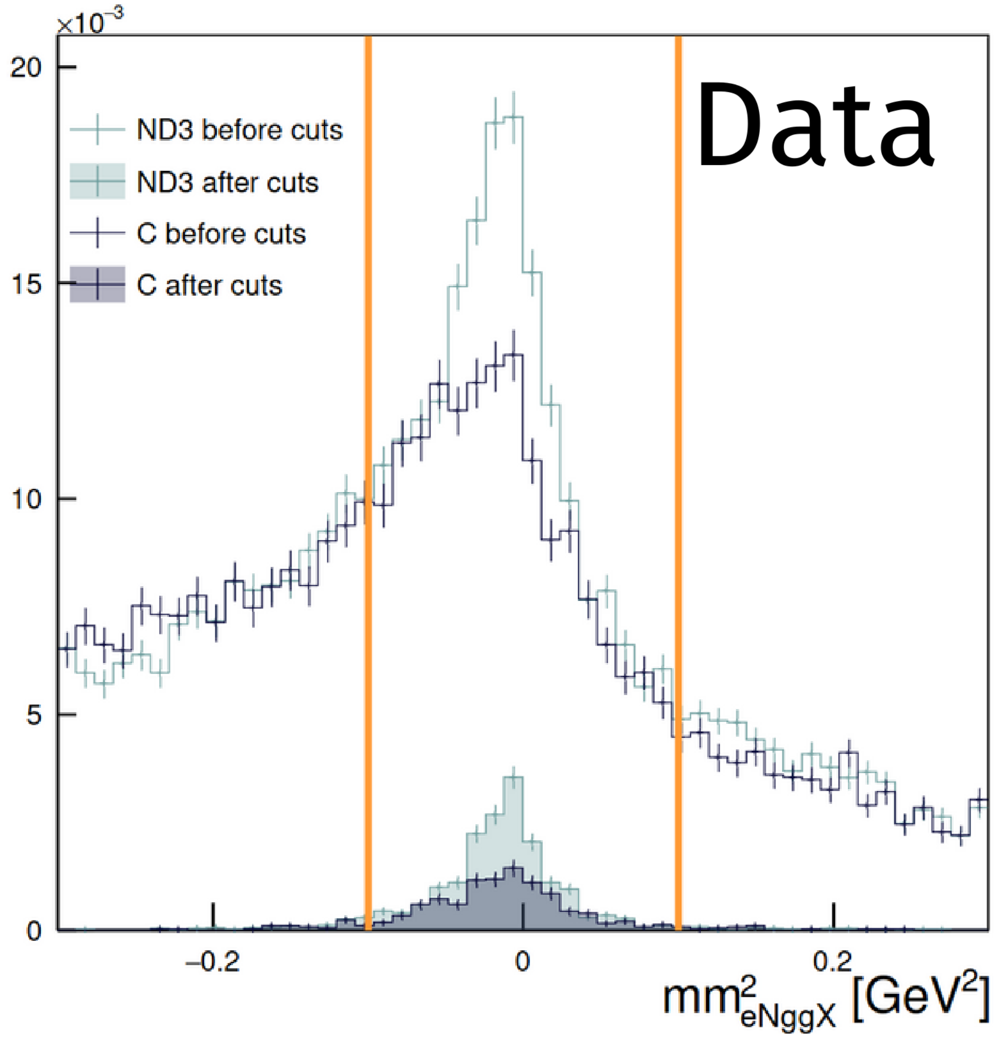
π^0 Contamination

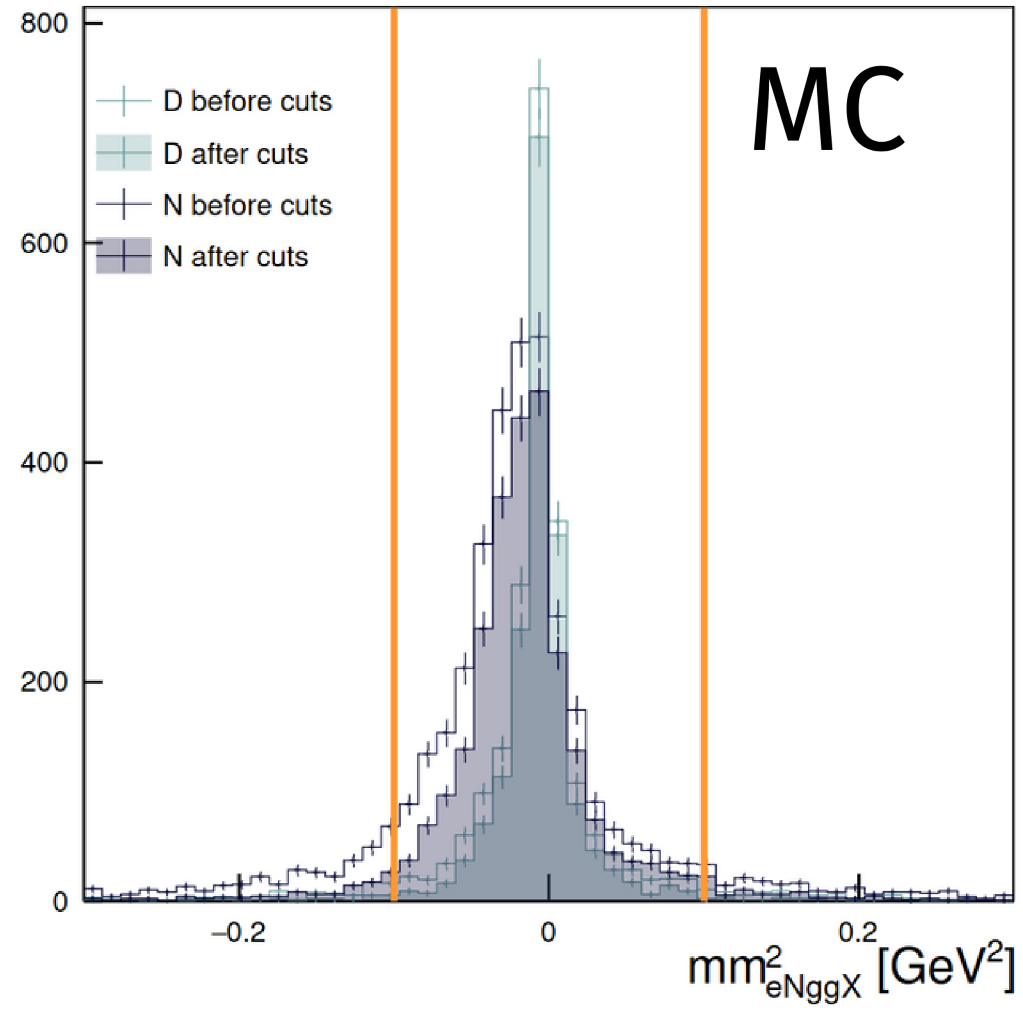
- An important source of background comes from π^0 production

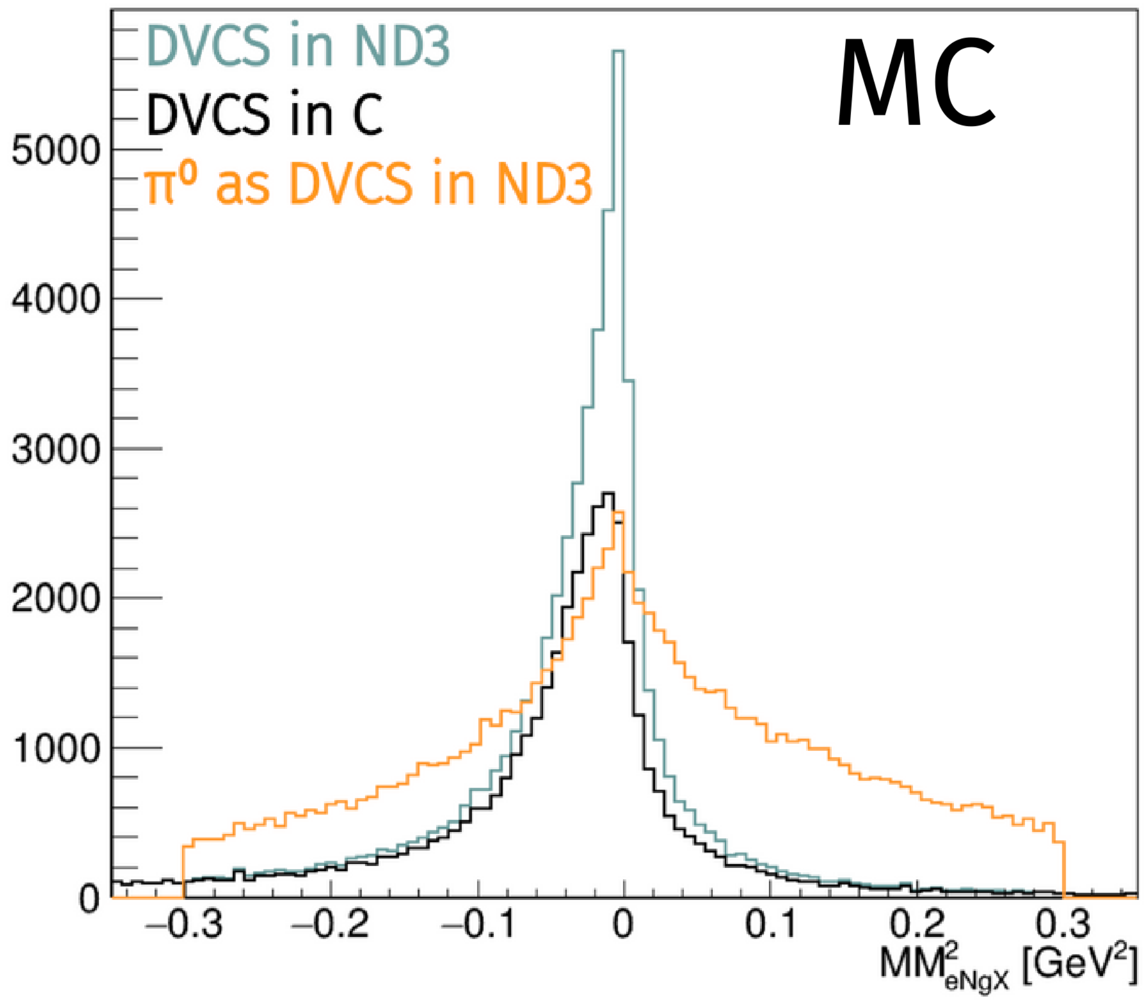
$$eN \rightarrow e'N'\pi^0 \rightarrow e'N'\gamma(\gamma)$$

- DVCS yields are corrected using π^0 yields and MC

$$N^{b,t} = N^{b,t}_{raw} - N^{b,t}_{ep\gamma\gamma} R^{MC}_{Acc}$$







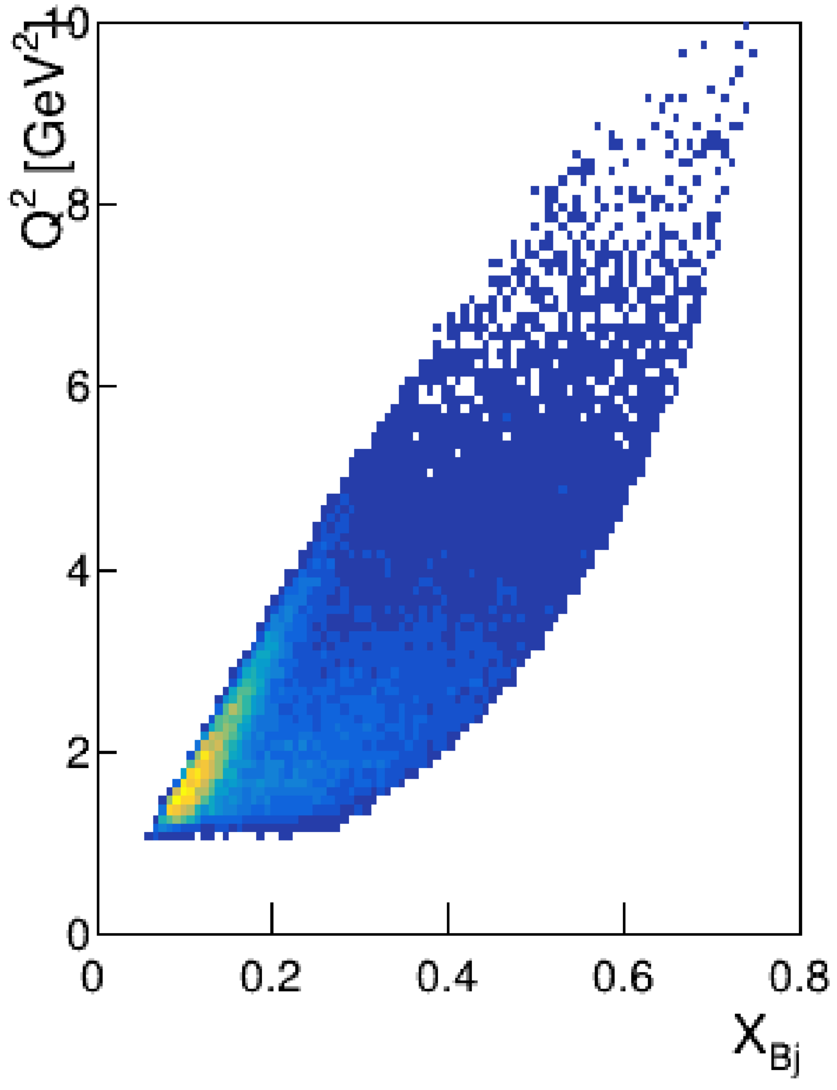
$$R^{MC}_{Acc} = \frac{N^{\pi^0,MC}_{1\gamma}}{N^{\pi^0,MC}_{2\gamma}}$$

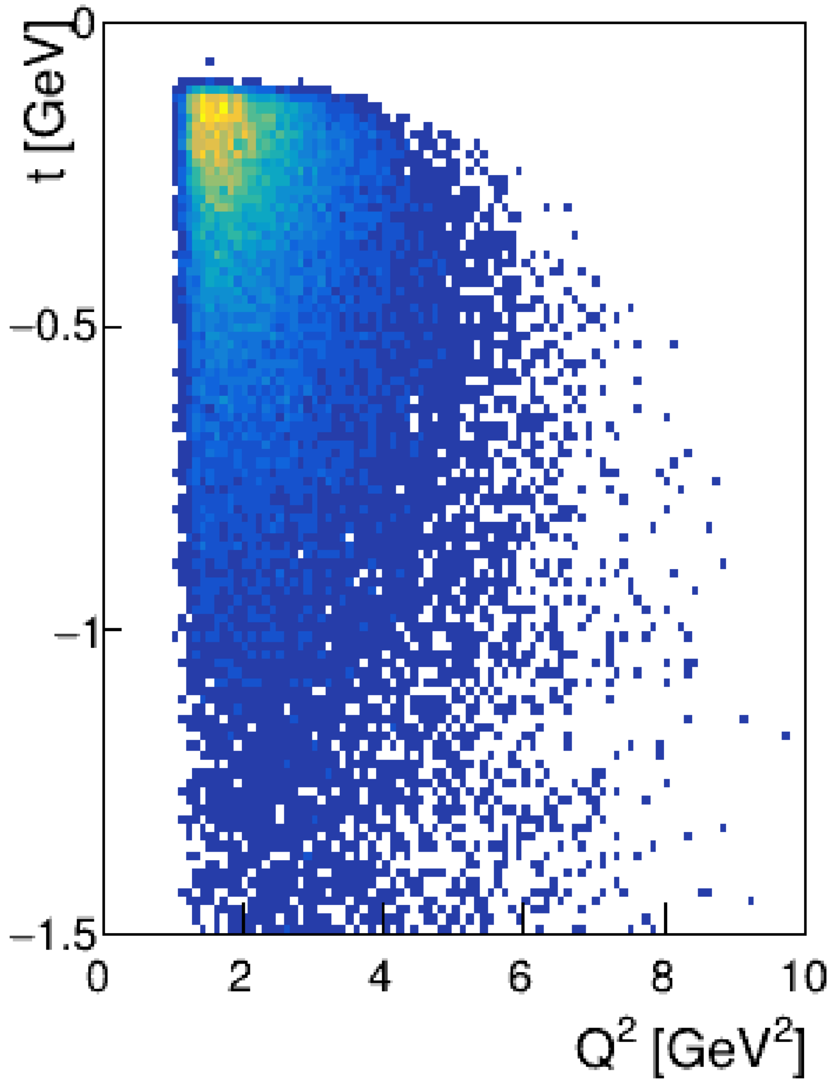
Preliminary Results

Beam Spin Asymmetry

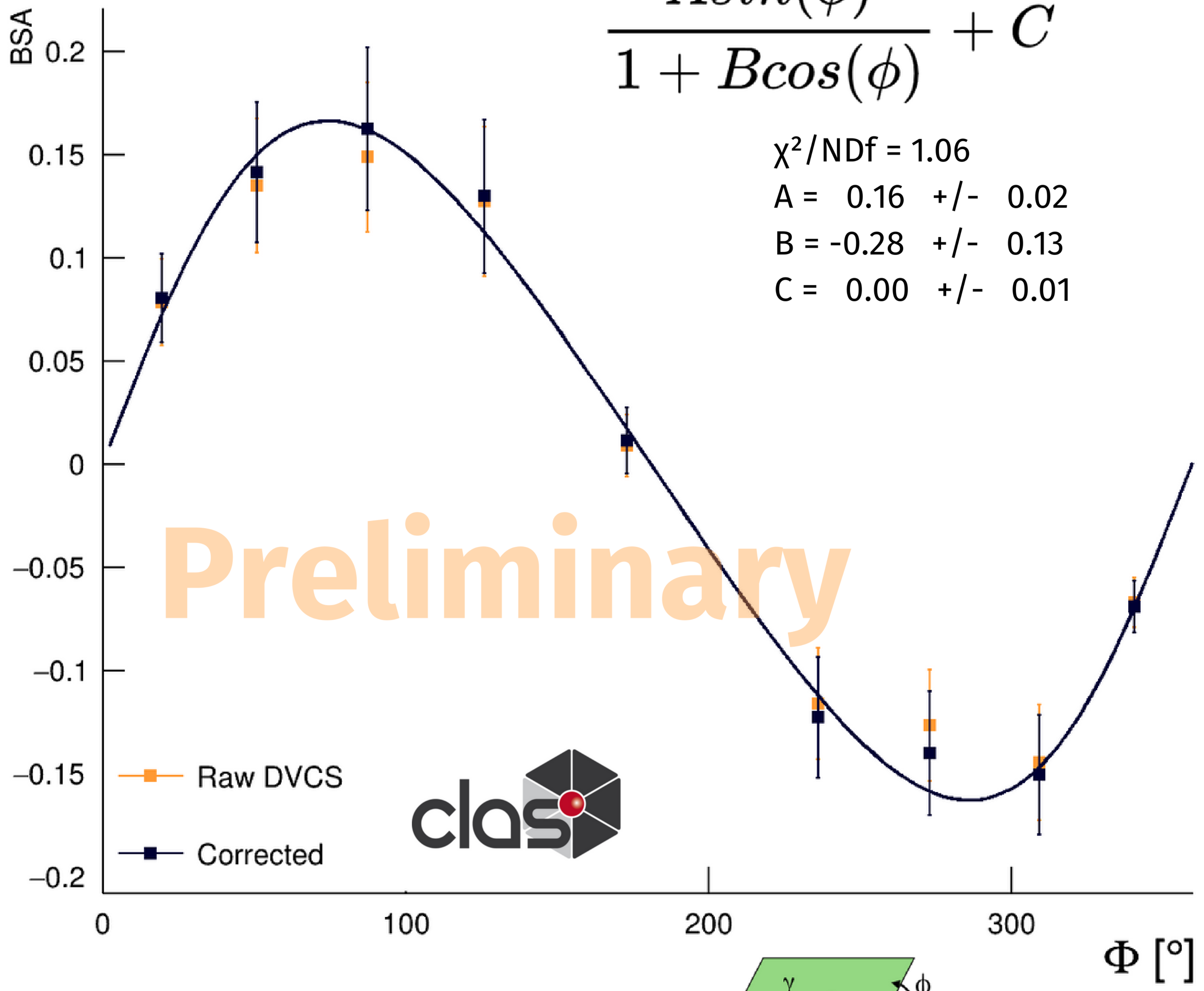
$$A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{P_b(P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

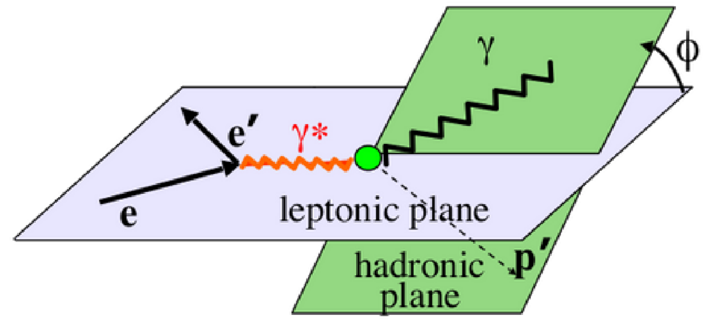
$$A_{LU}(\phi) \simeq \frac{s^I_{1,unp} sin(\phi)}{c^{BH}_{0,unp} + (c^{BH}_{1,unp} + c^I_{1,unp})cos(\phi)}$$



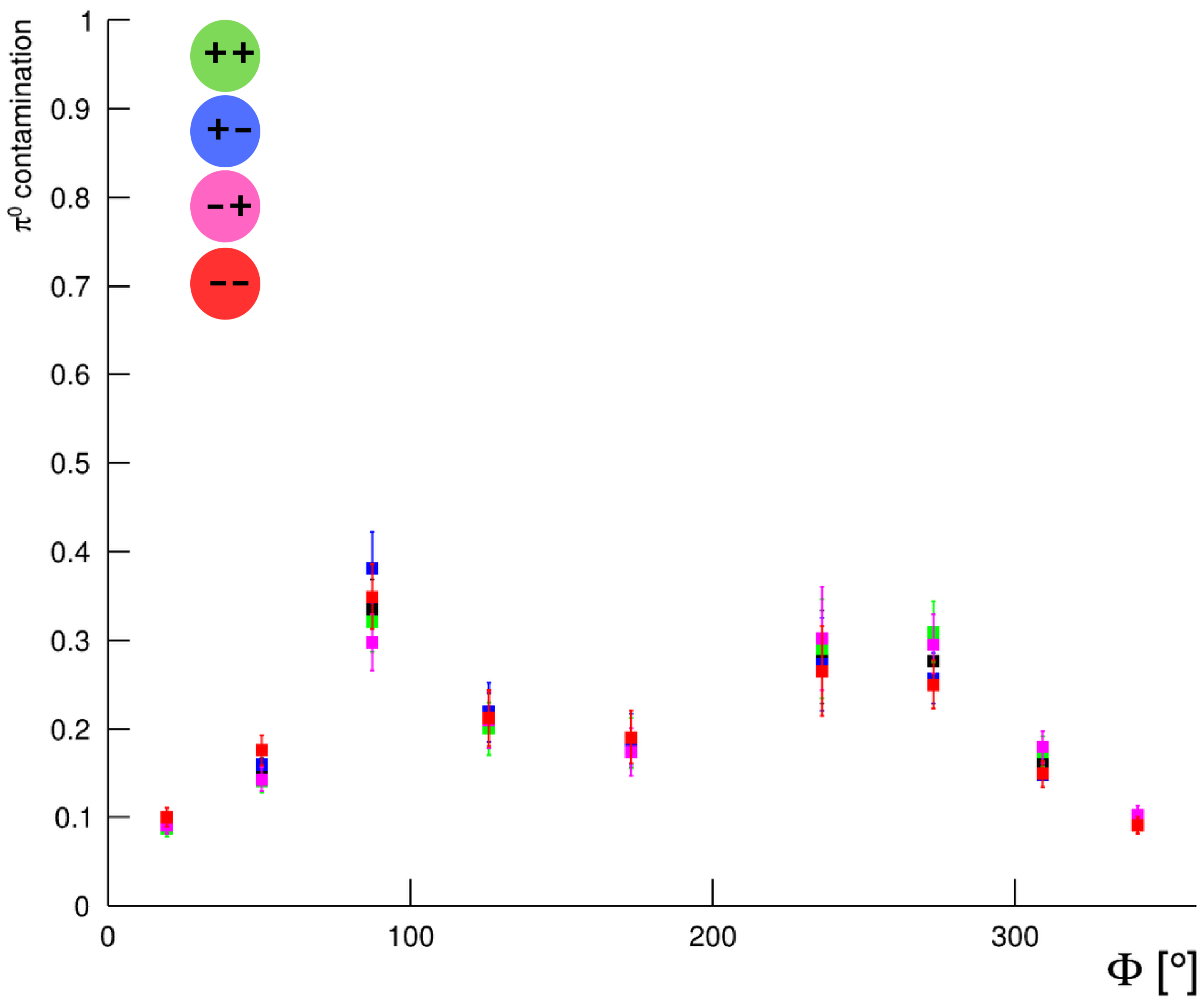


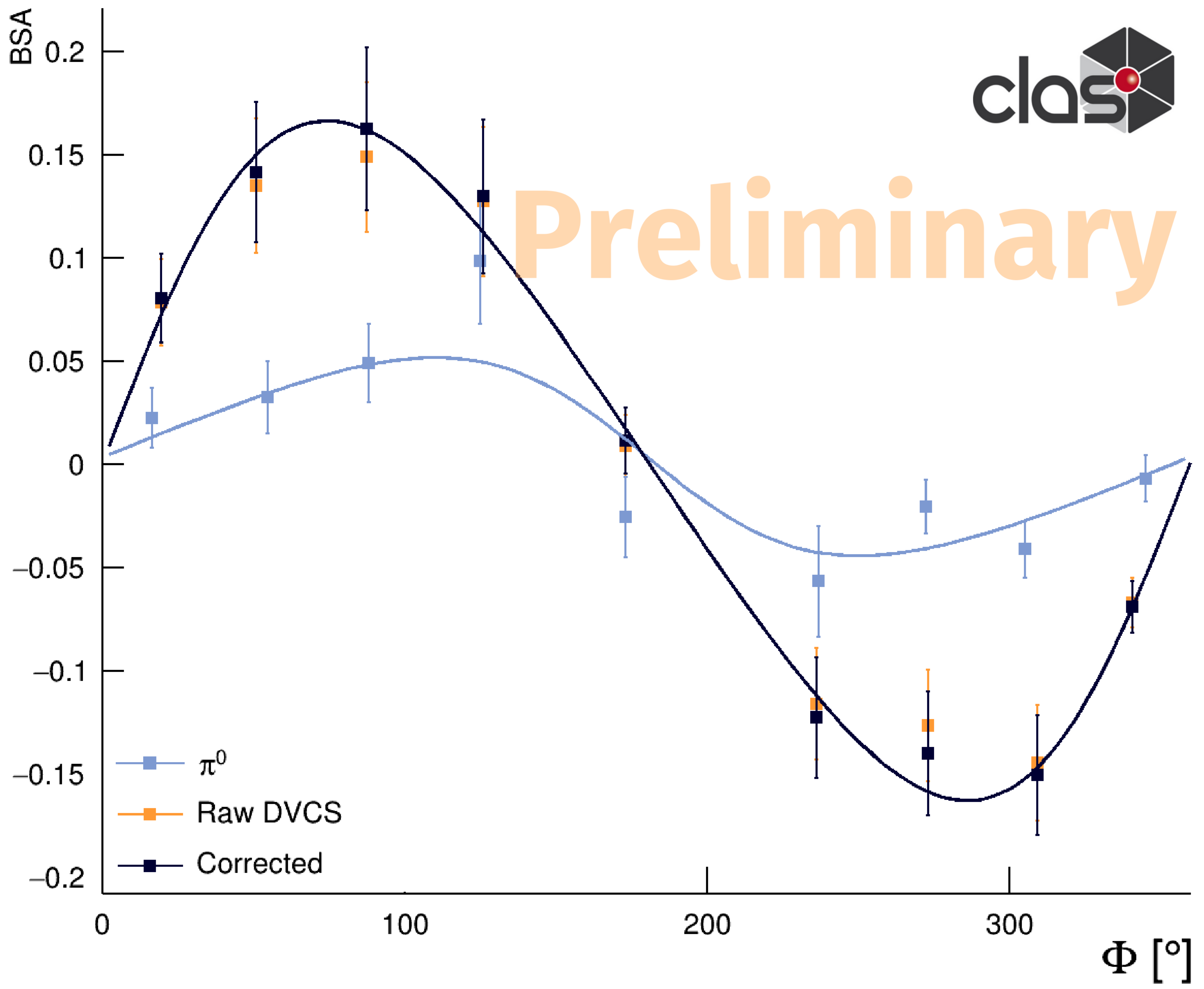
$$\frac{Asin(\phi)}{1 + Bcos(\phi)} + C$$



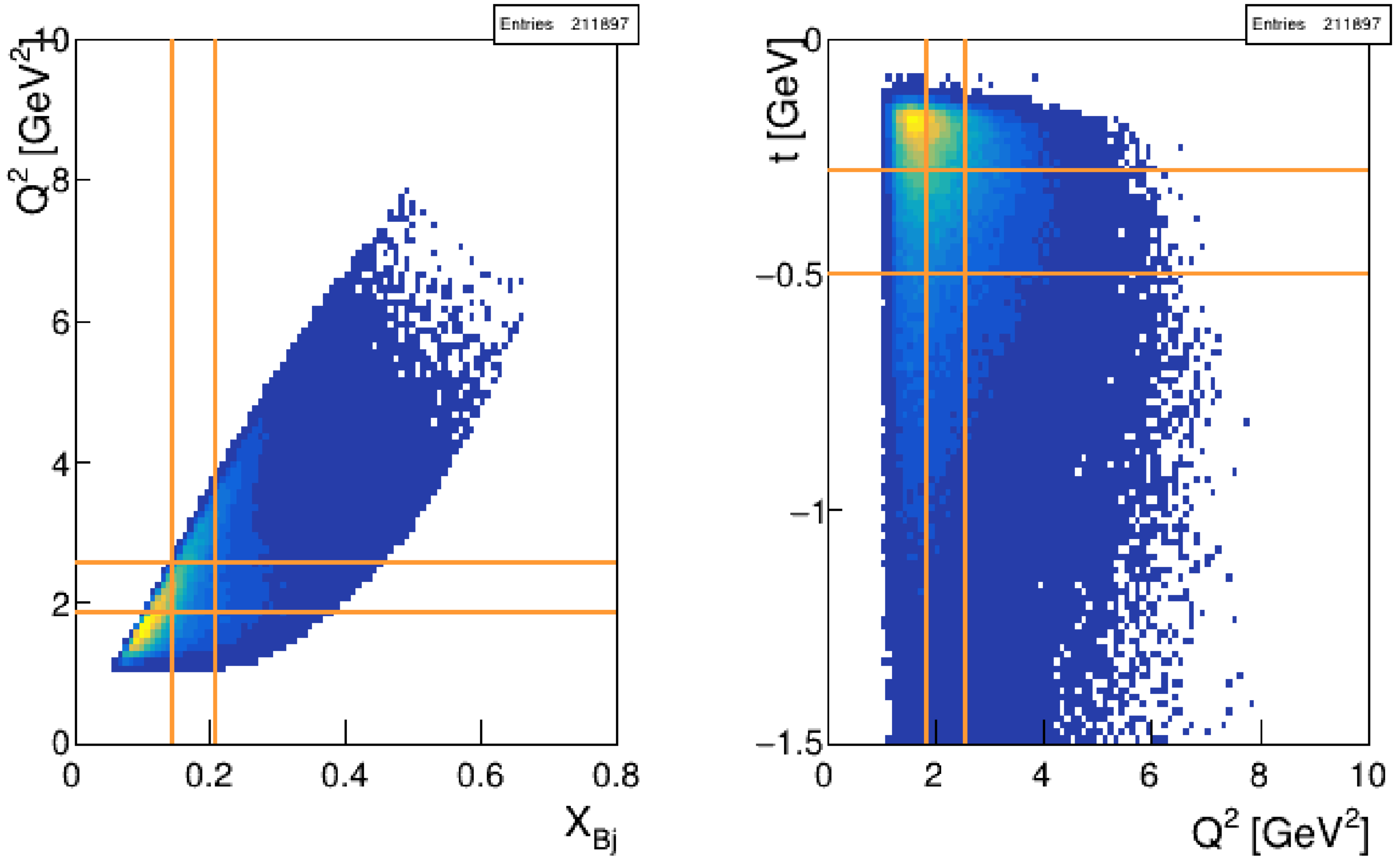


Beam Spin Asymmetry - π^0 Contamination

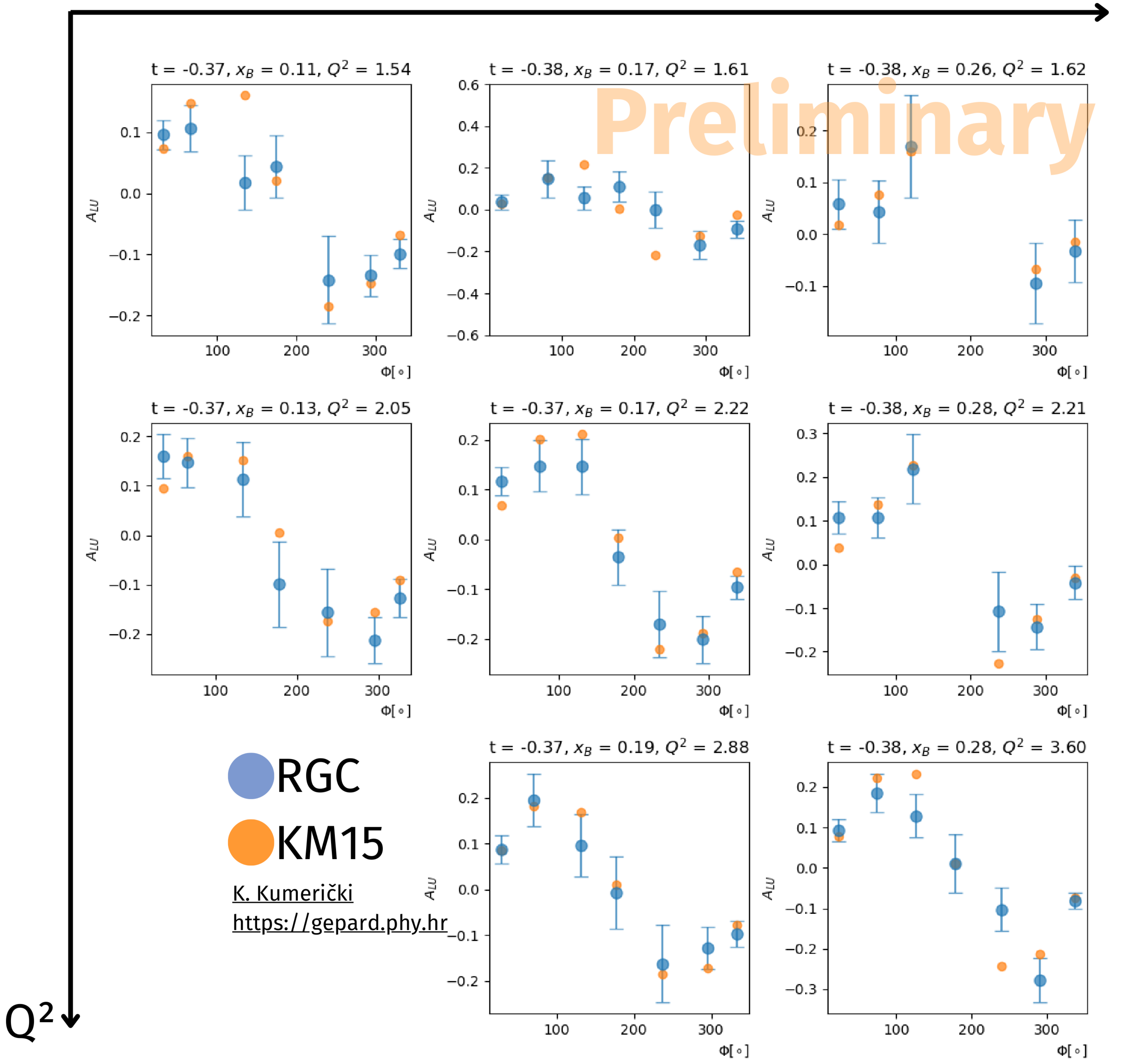




Beam Spin Asymmetry - 4D

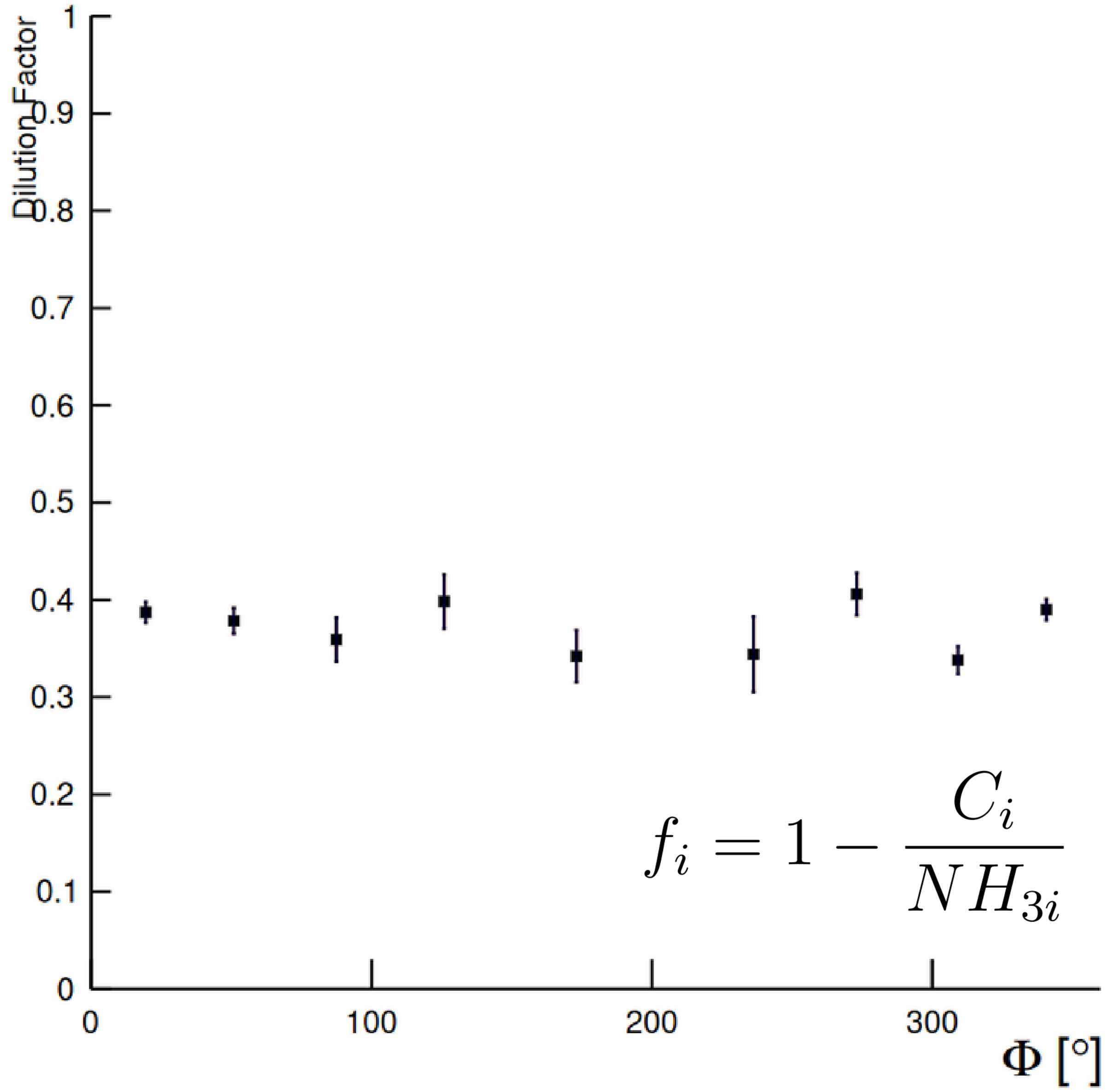


- Example for the intermediate t bin.
- Comparison is made with the KM15 model (free proton).
- Contribution from N background will be studied in future steps of the analysis.

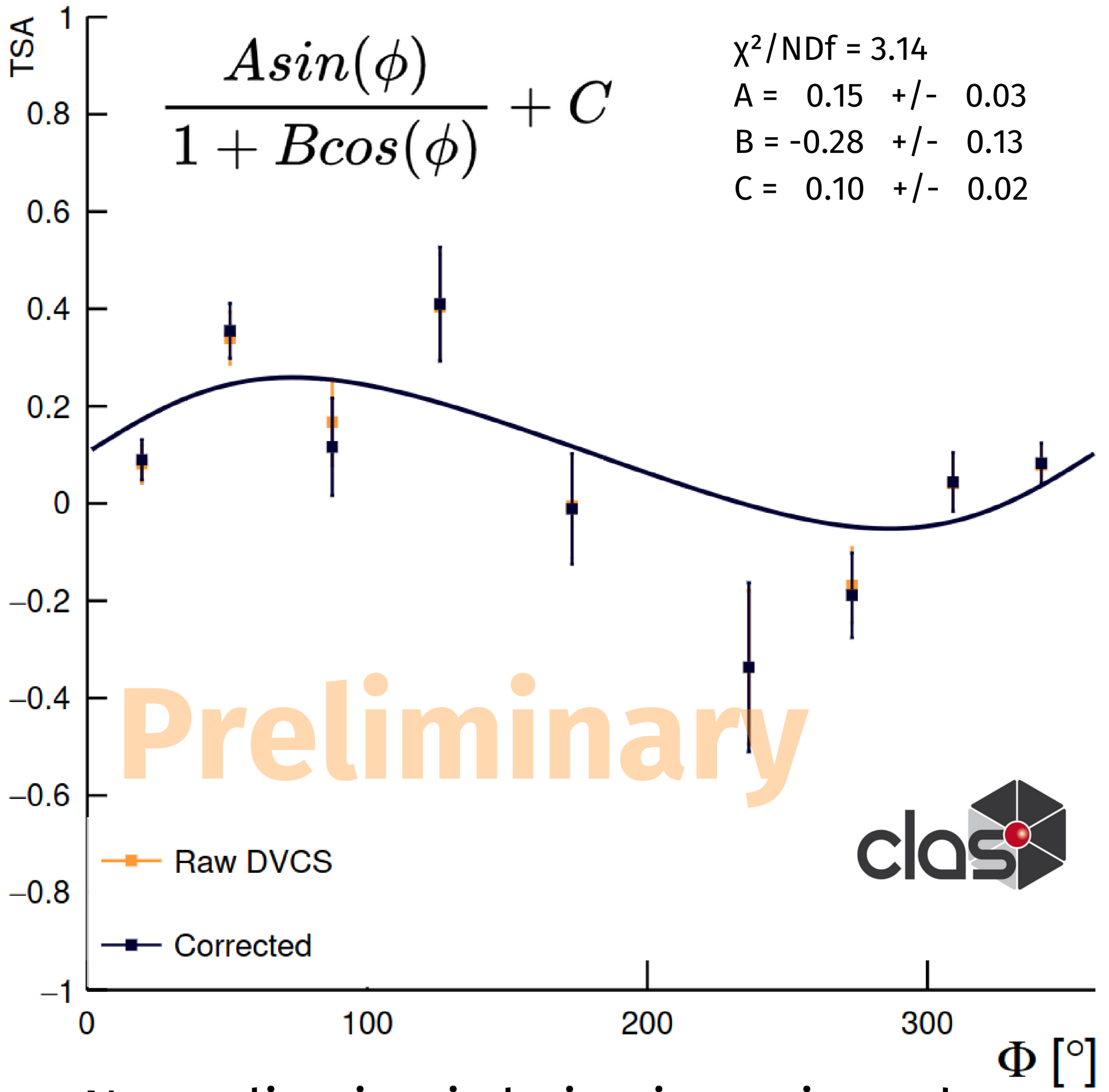


Target Spin Asymmetry

$$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{Df \times (P_t^{-}(N^{++} + N^{-+}) + P_t^{+}(N^{+-} + N^{--}))}$$

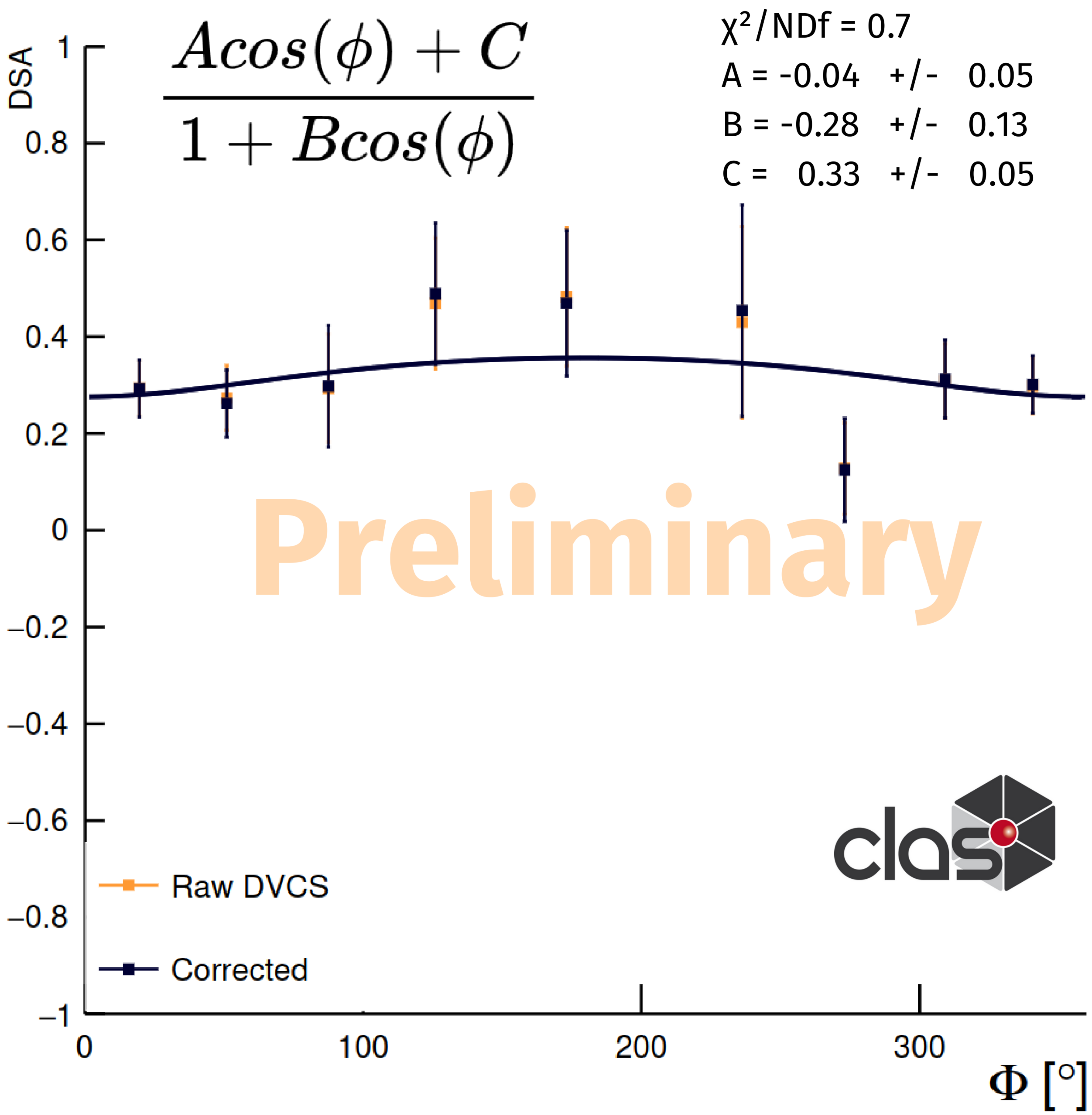


$$A_{UL}(\phi) \simeq \frac{s^{I}_{1,LP} sin(\phi)}{c^{BH}_{0,unp} + (c^{BH}_{1,unp} + c^{I}_{1,unp}) cos(\phi)}$$



Normalisation is being investigated.

Double Spin Asymmetry



$$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_b \times Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

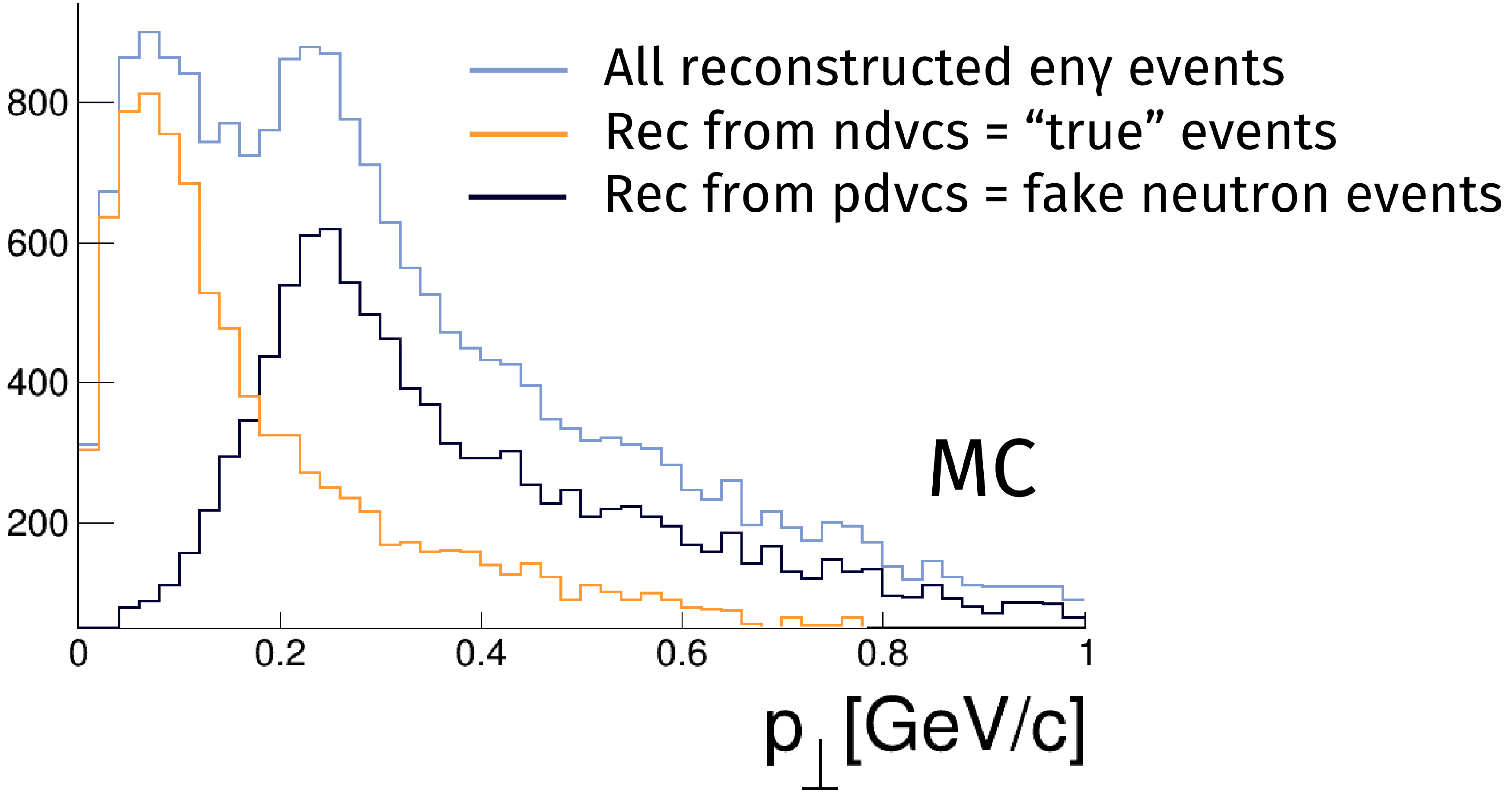
$$A_{LL}(\phi) \simeq \frac{c_{0,LP}^{BH} + c_{0,LP}^{I} + (c_{1,LP}^{BH} + c_{1,LP}^{I})\cos(\phi)}{c_{0,unp}^{BH} + (c_{1,unp}^{BH} + c_{1,unp}^{I})\cos(\phi)}$$

Challenges for nDVCS

Fake n Bakground

Additional source of background for ndvcs:

- Neutron PID are identified as particles with hits in scintillators not associated with tracks in the tracking system
- Tracking system is not 100% efficient: protons misidentified as neutrons.
- They are assigned a straight track, their momentum is not well reconstructed: they appear in exclusivity variables !

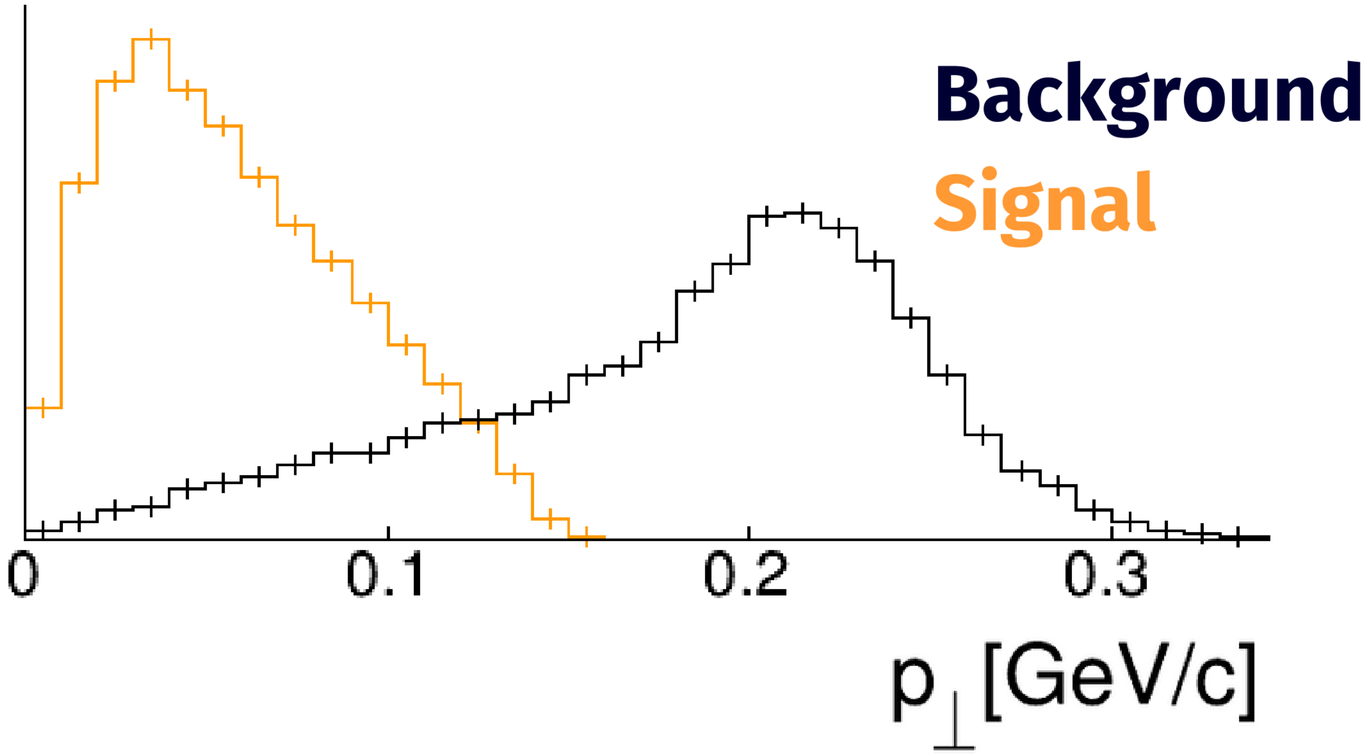


A Machine Learning Approach

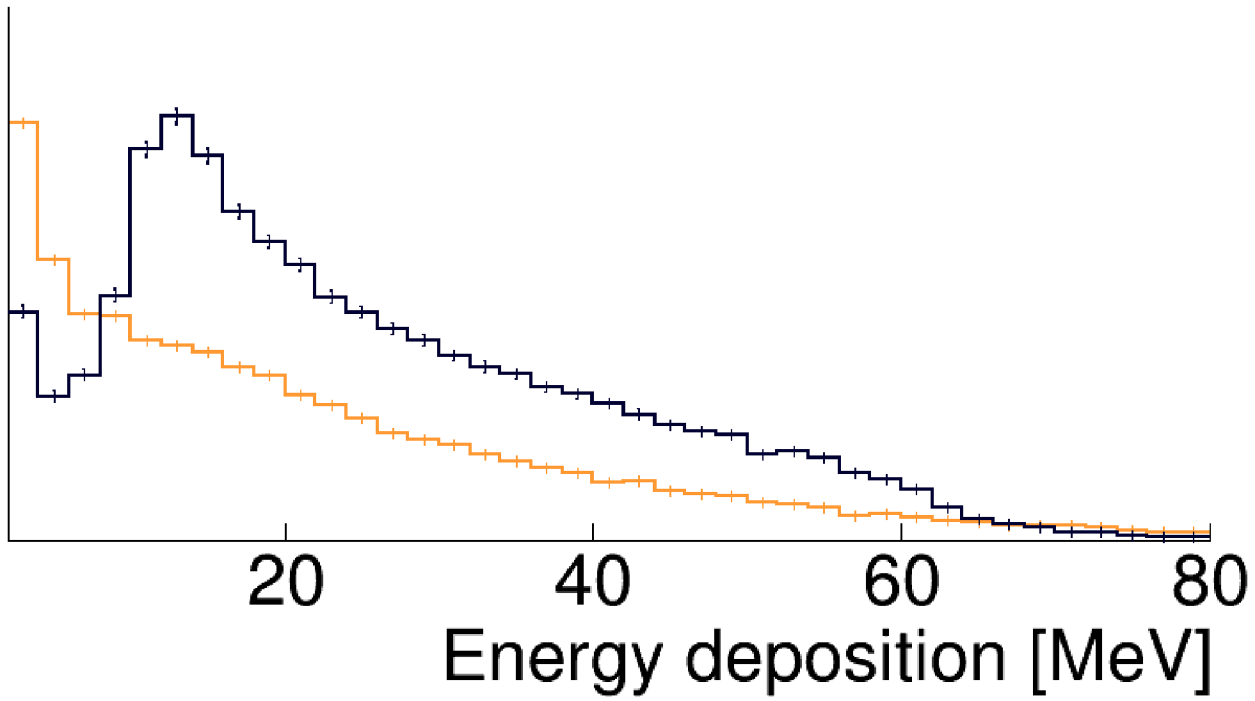
To try and reduce this source of background, a machine learning approach is tested.

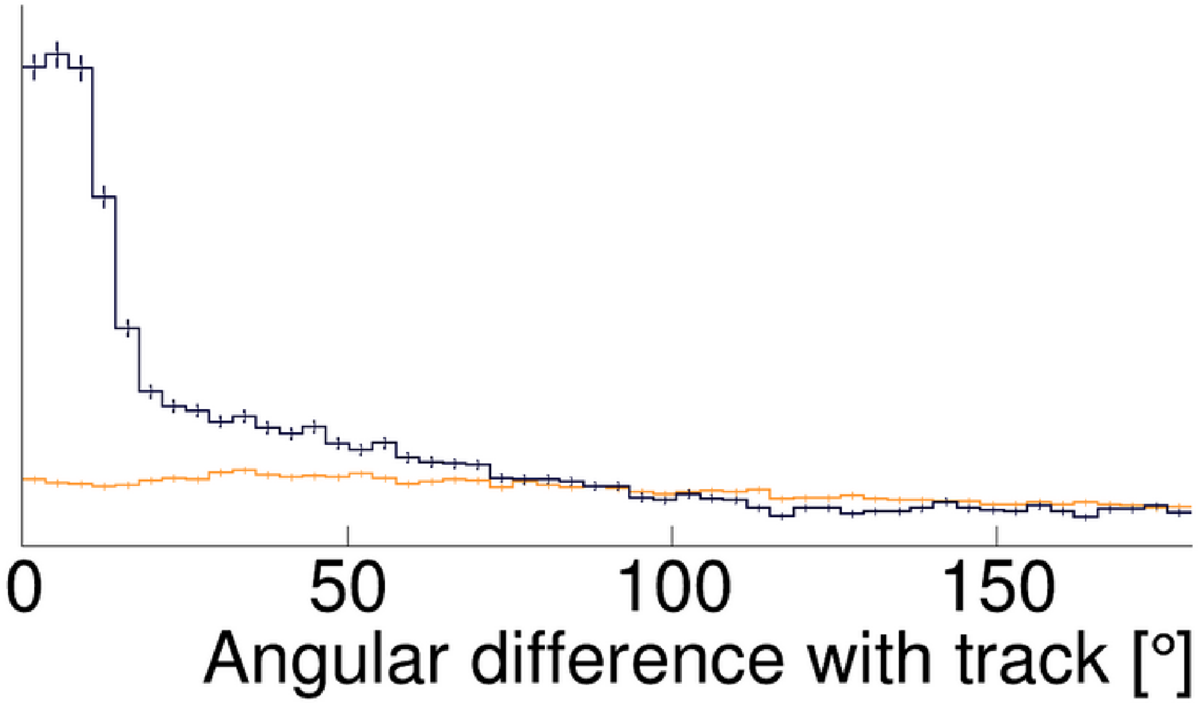
Using CLAS12 data on an H target.

- True neutrons sample: $ep \to en\pi^+$
- Fake neutrons sample: $ep \to en\gamma$



Ideal goal: improving PID at detector-level

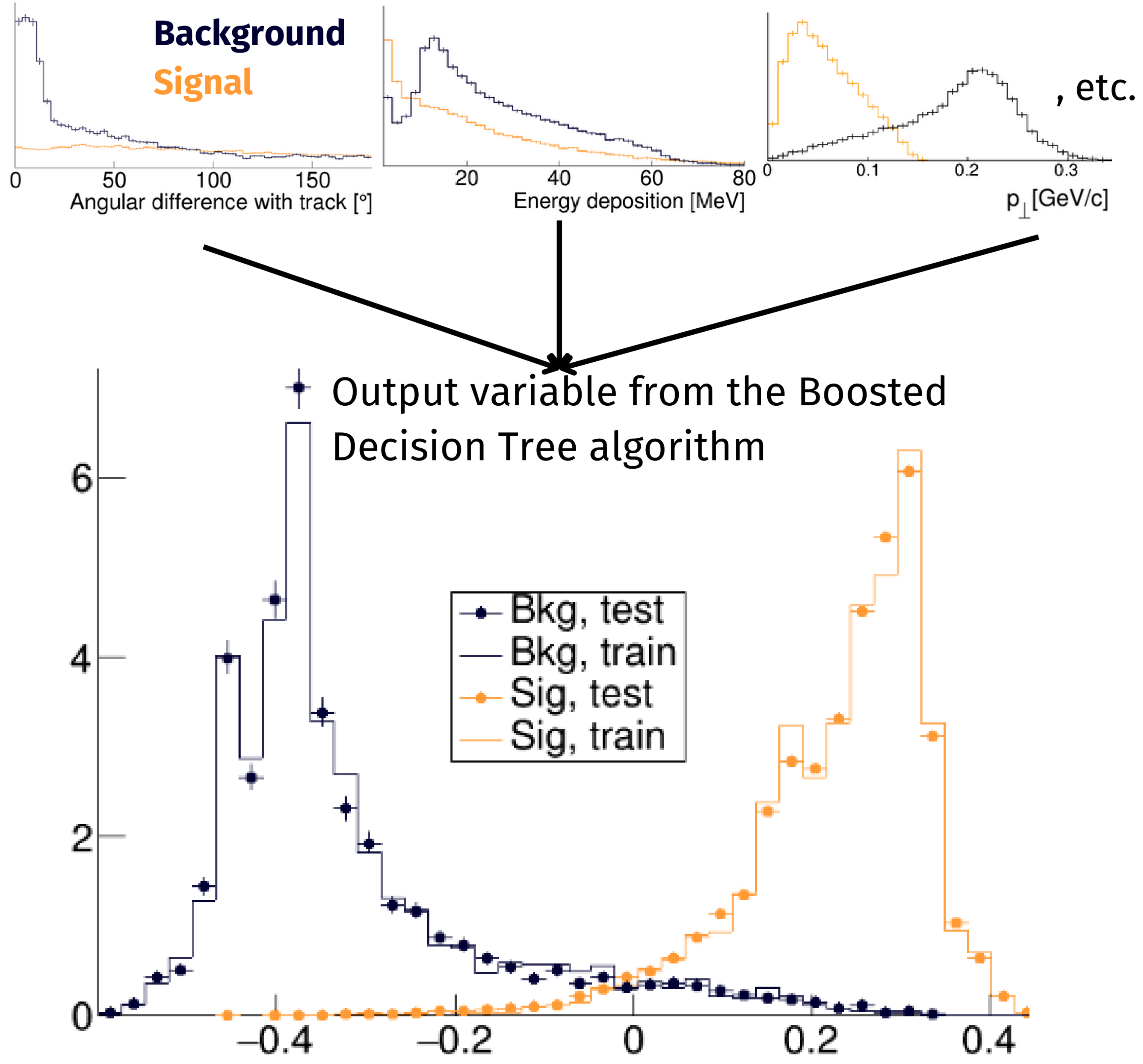




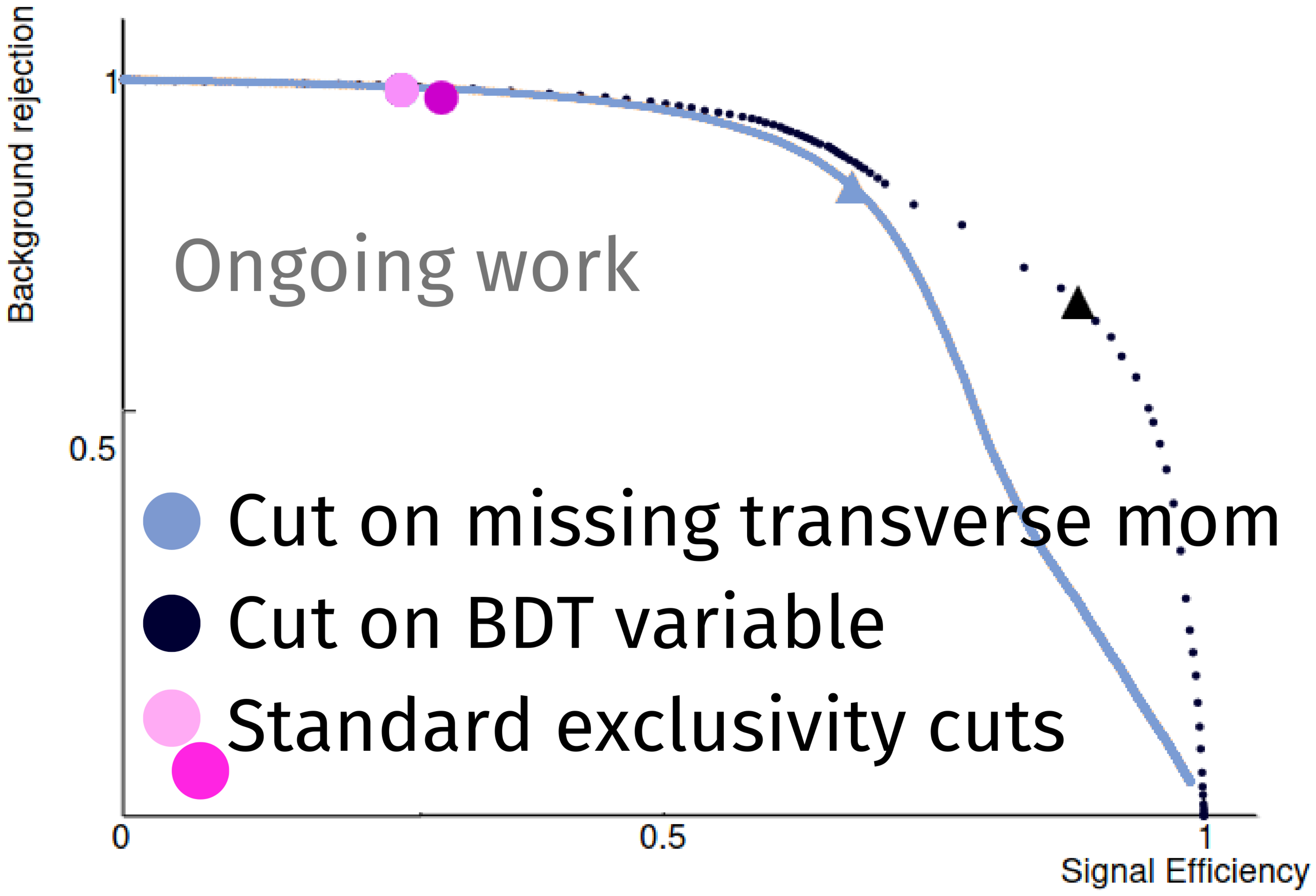
, etc.

A ML Approach

For now, we keep using an exclusivity variable.



Applied to RGC simulations



Conclusion

- The first polarized DVCS experiment with the CLAS12 detector will allow to access proton and neutron Compton Form Factors and extract their flavor dependency.
- Data taking took place between 2022 and 2023, the star of the show is the CLAS12 polarized target!
- Data analysis is ongoing, many challenges are associated with dealing with a polarized nuclear target, and with neutron detection in particular.
- First results for pDVCS in D have been extracted. They will be compared to results for pDVCS in H to understand medium effect.
- Analysis tools are in place, more results will be available soon as calibrations are being finalized for the rest of the dataset!