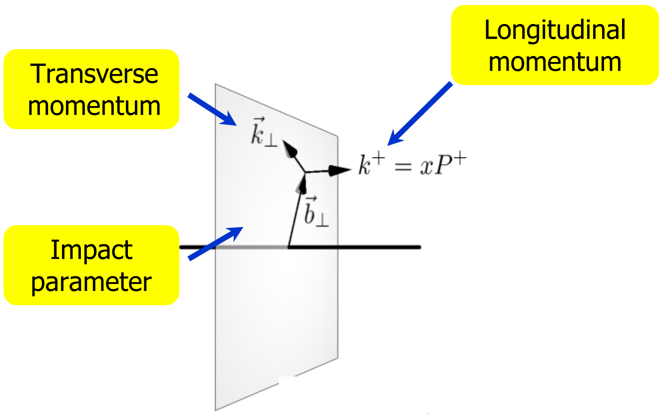
CLAS12 Run Group B

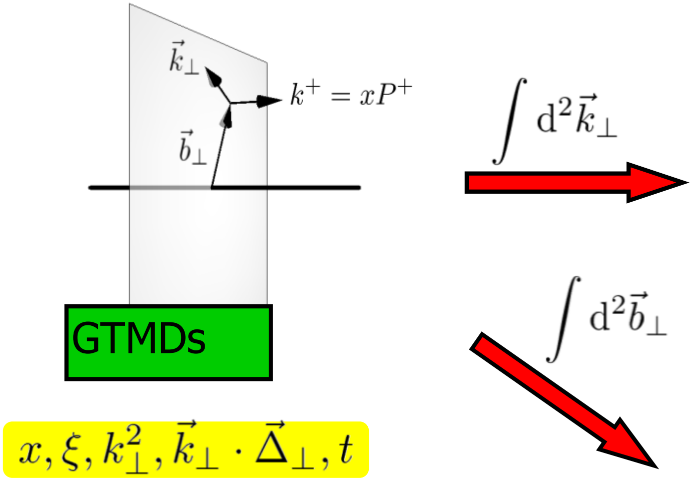
Electroproduction on deuterium with CLAS12

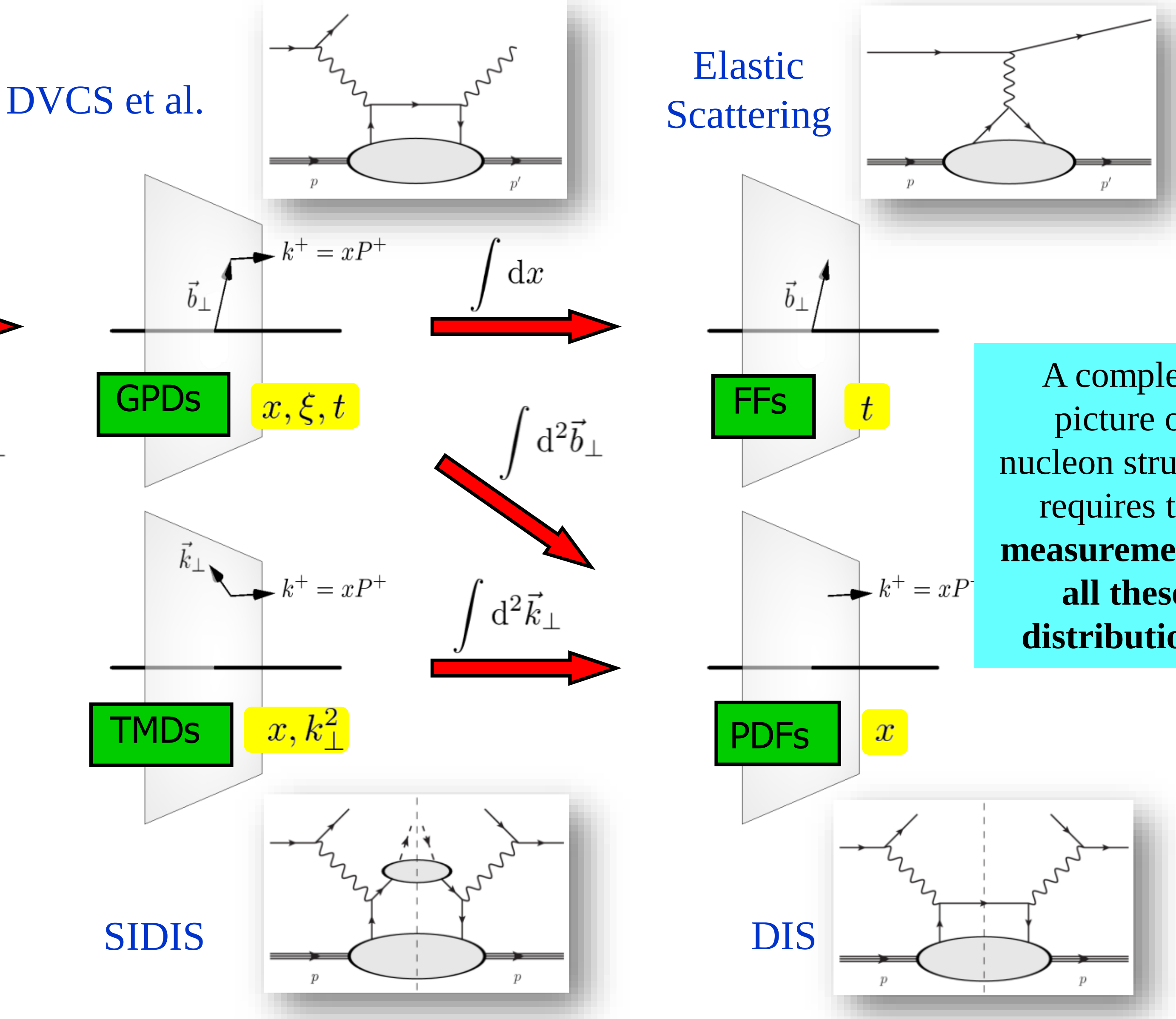
- Physics goals
- Run Group B experiments
- Overview of the data taking
- Results and analysis updates
- Beam time request

Silvia Niccolai, IJCLab Orsay (France)
PAC52, 7/10/2024

Multi-dimensional mapping of the nucleon





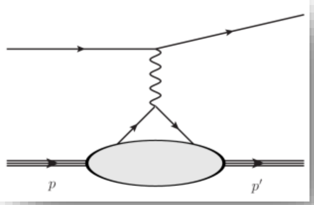


A complete picture of nucleon structure requires the **measurement of all these distributions**.

CLAS12 Run Group B aims to measure all these distributions, using **deuteron** as a **neutron target**
→ Quark-flavor separation, combining with proton results

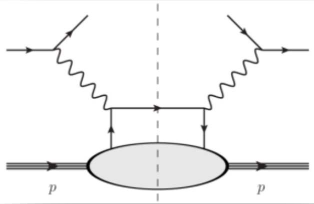
+ EMC effect, SRC
+ J/ψ photoproduction on deuteron

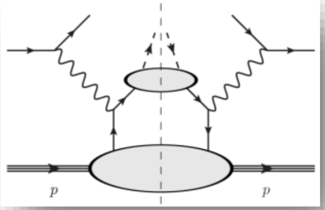
CLAS12 Run Group B: experiments



Elastic Scattering (G^n_M)

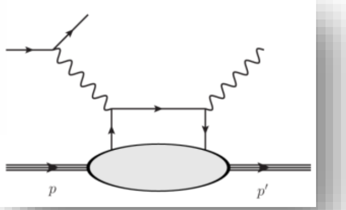
DIS (for SRC and EMC effect)

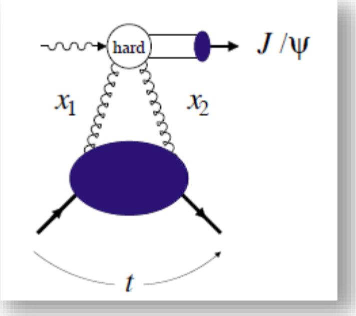




SIDIS (for PDFs and TMDs

nDVCS





J/ψ photoproduction

Experiment number	Title	Contact person	PAC days (rating)
E12-07-104	Neutron magnetic form factor	G. Gilfoyle	30 (A-)
E12-09-007a	Study of parton distributions in K SIDIS	W. Armstrong	56 (A-)
E12-09-008	Boer-Mulders asymmetry in K SIDIS	M. Contalbrigo	56 (A-)
E12-11-003	Deeply virtual Compton scattering on the neutron	S. Niccolai	90 (A High Impact)
E12-09-008b	Collinear nucleon structure at twist-3 in dihadron SIDIS	M. Mirazita	RG
E12-11-003a	In medium structure functions, SRC, and the EMC effect	O. Hen	RG
E12-11-003b	Study of J/ψ photoproduction off the deuteron	Y. Ilieva	RG
E12-11-003c/E12-07-104a	Quasi-real photoproduction on deuterium	F. Hauenstein	RG

Common features to all experiments of Run Group B:

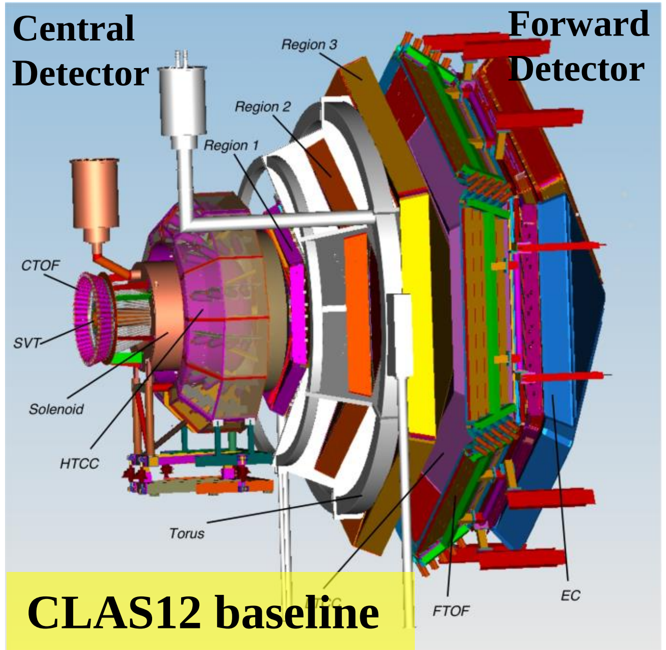
- **Liquid deuterium target**
- **Beam energy: « 11 » GeV**

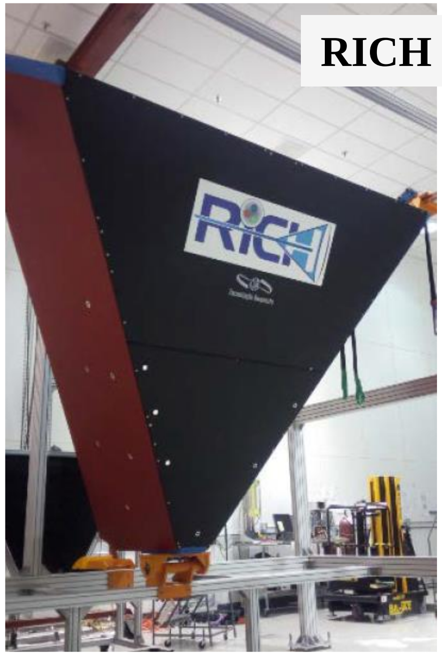
CLAS12 Run Group B: setup and run summary

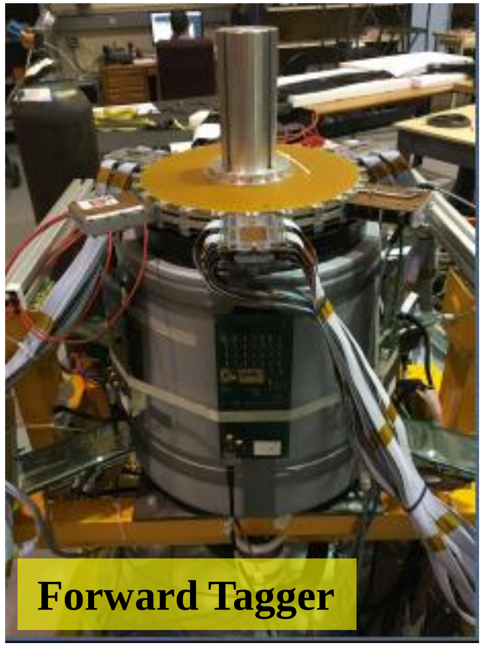
Scheduled beam time:
Spring19: February 6th - March 25th 2019
Fall19: December 3rd –20th 2019
Spring20: January 6th – 30th 2020

43.3 B triggers collected at 3 different beam energies:

- 10.6 GeV (9.7 B inbending) Spring19
- 10.2 GeV (11.7 B inbending) Spring19
- 10.4 GeV (9 B outbending) Fall19, (12.9 B inbending) Spring20



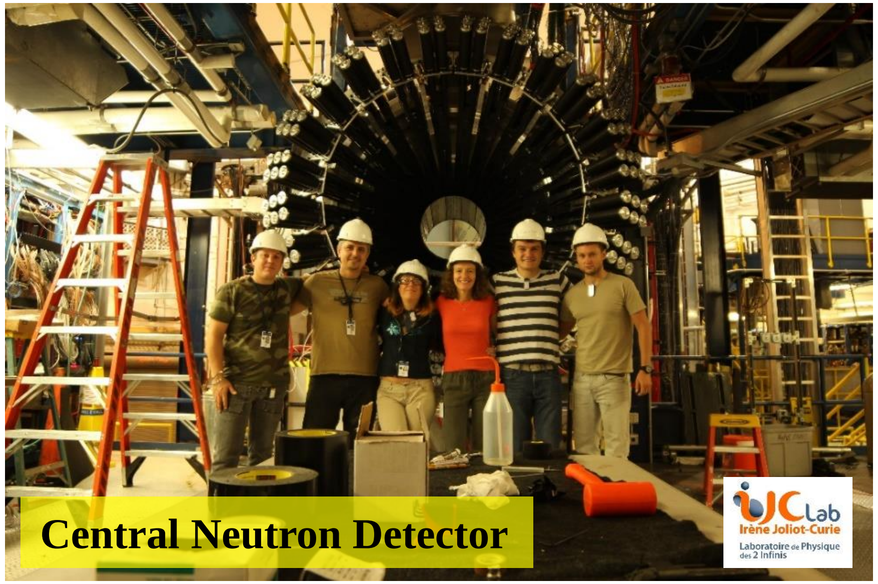




- Average beam polarization ~86%
- Liquid deuterium target, 5 cm long
- L = ~1.3 10^{35} $cm^{-2}s^{-1}$ per nucleon

38.9 total PAC days according to ABUs
→ **43.2% of the approved 90 PAC days**
51 PAC days left to run

The data have been calibrated and reconstructed in 2 passes. The results shown in the following come mainly from Pass1. Pass2 has higher yields and better resolutions.



Interest of DVCS on the neutron

A combined analysis of DVCS observables for proton and neutron targets
is necessary for the flavor separation of GPDs

$$(H,E)_u(\xi,\xi,t) = 9/15\left[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)\right]$$
$$(H,E)_d(\xi,\xi,t) = 9/15\left[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)\right]$$

Moreover, the beam-spin asymmetry for nDVCS is the most sensitive observable to the GPD E
→ Ji's sum rule for Quarks Angular Momentum

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

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi\,\mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} + kF_2\mathcal{E}\}d\phi \quad\Rightarrow\quad \mathrm{Im}\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \boldsymbol{\mathcal{E}_n}\}$$

Unpolarized beam, **transversely polarized target**:

$$\Delta\sigma_{UT} \sim \cos\phi\,\mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\phi \quad\Rightarrow\quad \mathrm{Im}\{\mathcal{H}_p, \mathcal{E}_p\}$$

Neutron
Proton

The BSA for nDVCS:

- is complementary to the TSA for pDVCS on transverse target, aiming at *E*
- depends strongly on the kinematics → wide coverage needed
- is smaller than for pDVCS → more beam time needed to achieve reasonable statistics

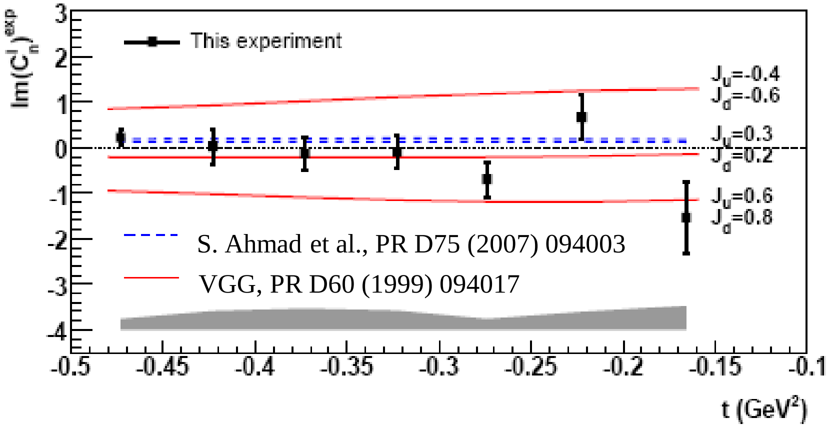
DVCS on the neutron in Hall A at 6 GeV

$\vec{e}d \to e\gamma(np)$

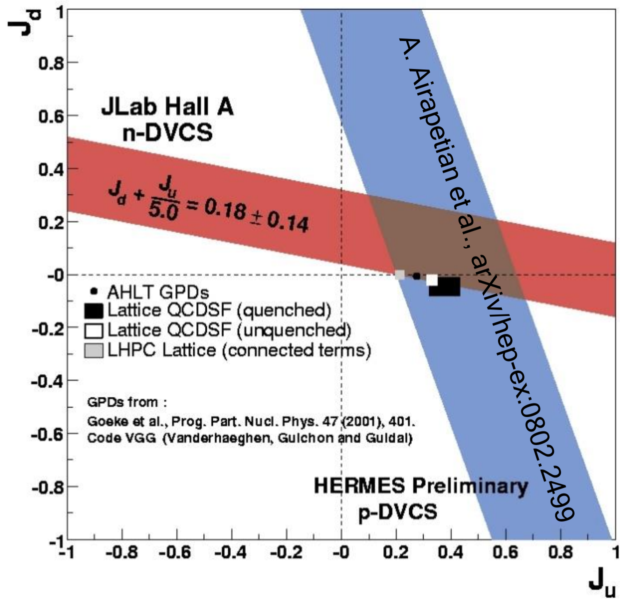
$$D(e,e'\gamma)X - H(e,e'\gamma)X = n(e,e'\gamma)n + d(e,e'\gamma)d + \ldots$$

$$\Delta\sigma_{LU} \sim \sin\phi \; \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}$$

M. Mazouz et al., PRL 99 (2007) 242501



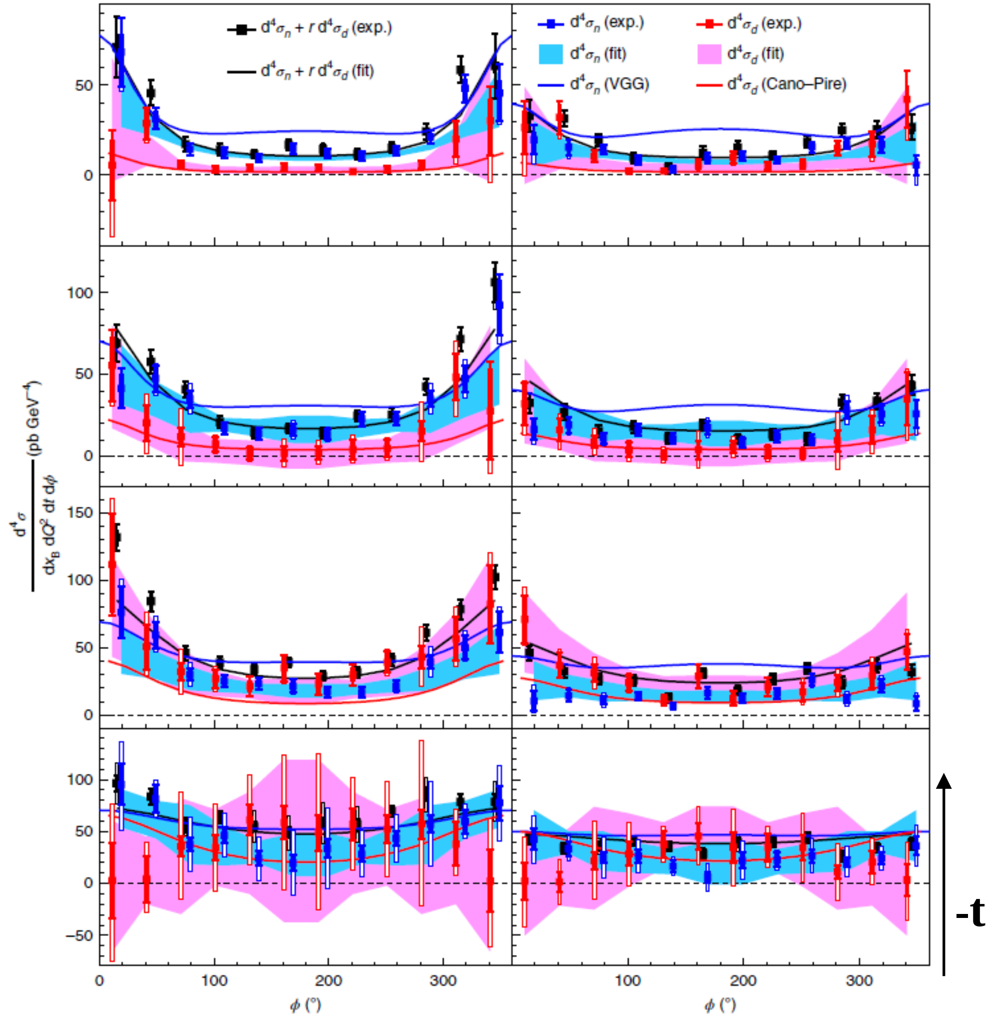
Q^2=1.9 GeV^2 and x_B=0.36



- **E03-106: First-time measurement of $\Delta\sigma_{LU}$ for nDVCS, model-dependent extraction of J_u, J_d**

nDVCS and coherent dDVCS separated through MM^2_X shift:

- large correlations at low –t
- good separation at larger -t

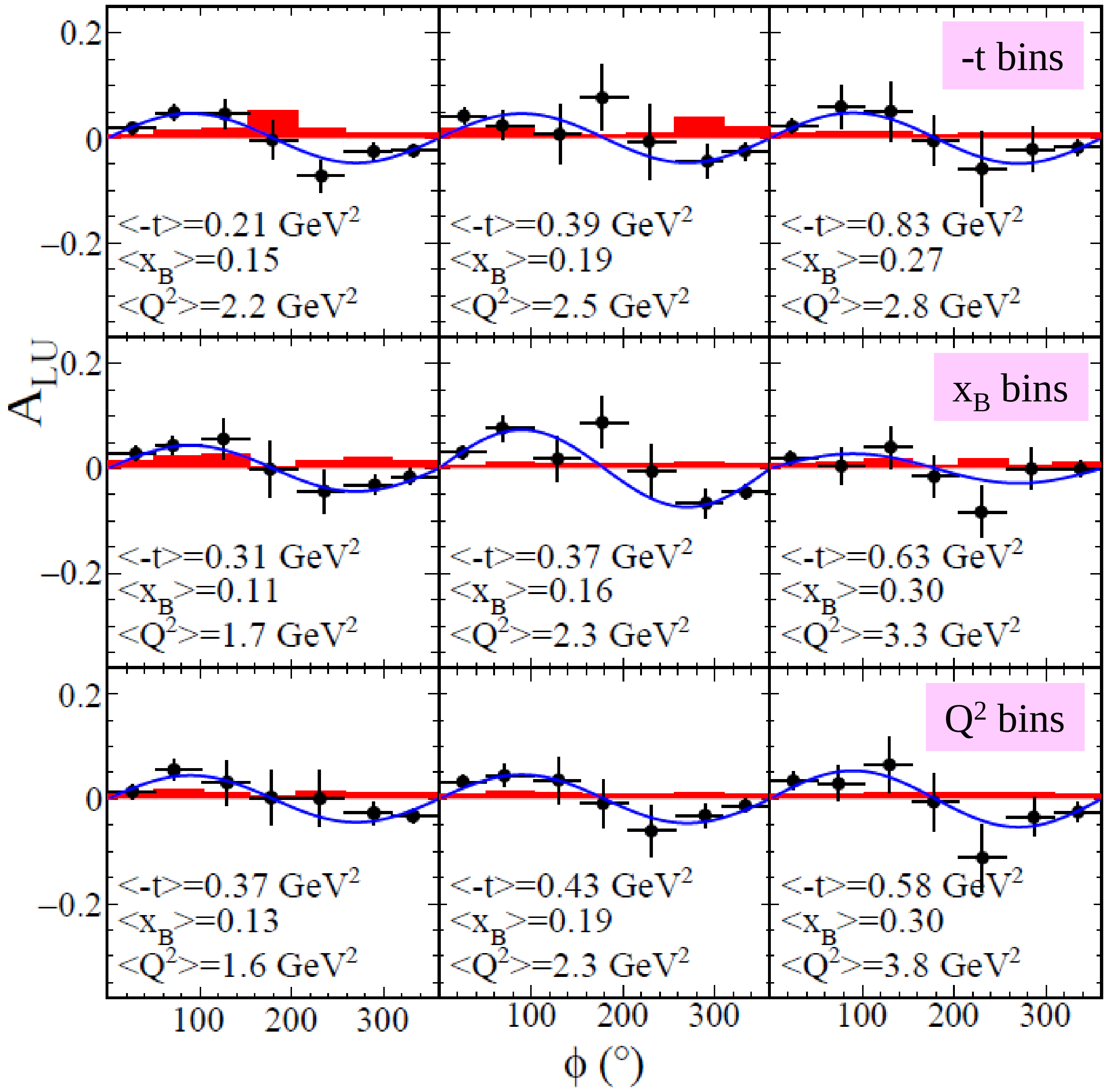


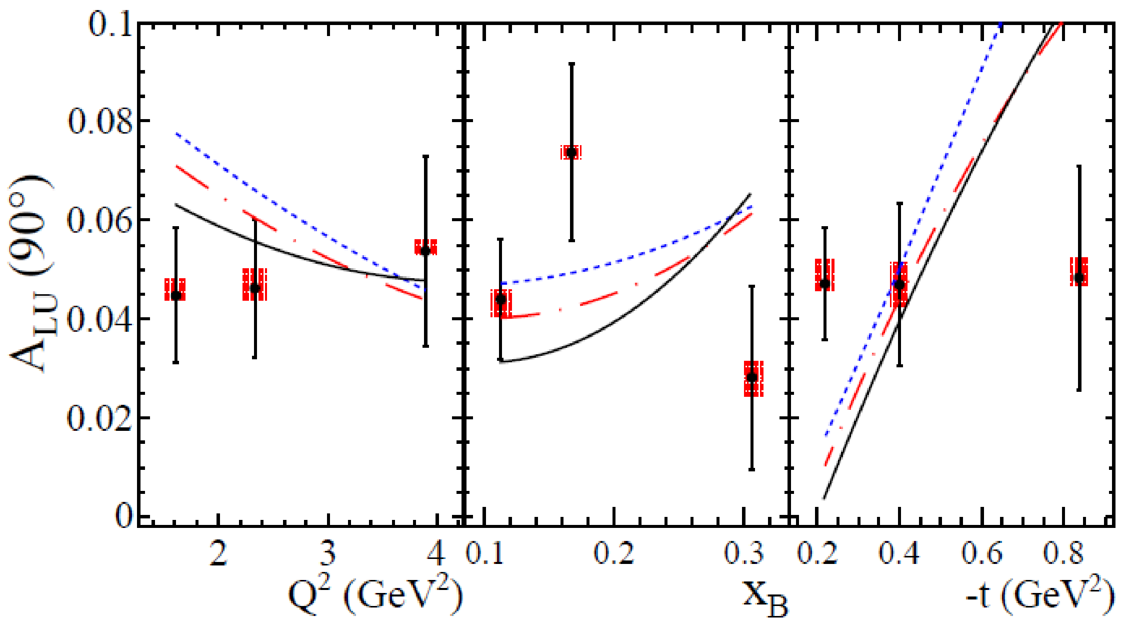
Hall-A experiment E08-025 (2010)

- Beam-energy « Rosenbluth » separation of nDVCS CS using an LD2 target and two different beam energies
- First observation of non-zero nDVCS CS
- **M. Benali et al., Nature 16 (2020)**

RGB data: first-time measurement of BSA for nDVCS with detection of the active neutron

$\vec{e}d \rightarrow en\gamma(p)$





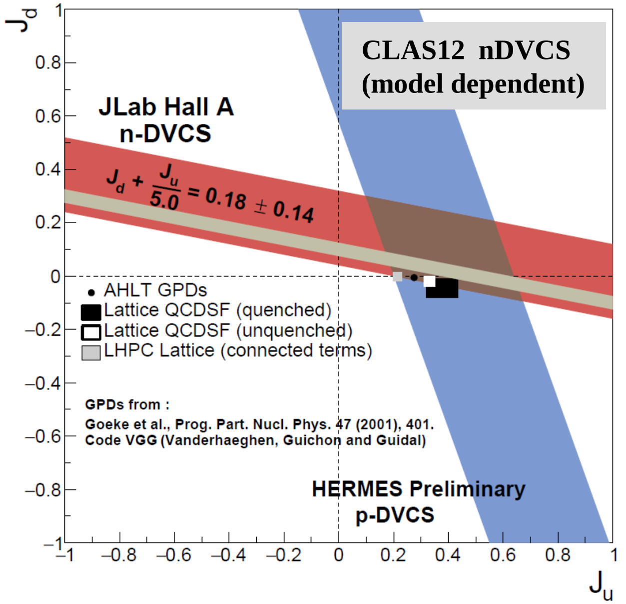
J_u = 0.35 J_d = 0.05

J_u = −0.2 J_d = 0.15

J_u = −0.45 J_d = 0.2

VGG model predictions giving the smallest χ^2

« VGG »: M. Vanderhaeghen, P.A.M. Guichon, and M. Guidal, PRD 60, 094017 (1999)



A. Hobart, S.N, et al. (CLAS) arXiv:2406.15539 [hep-ex] - Submitted to PRL

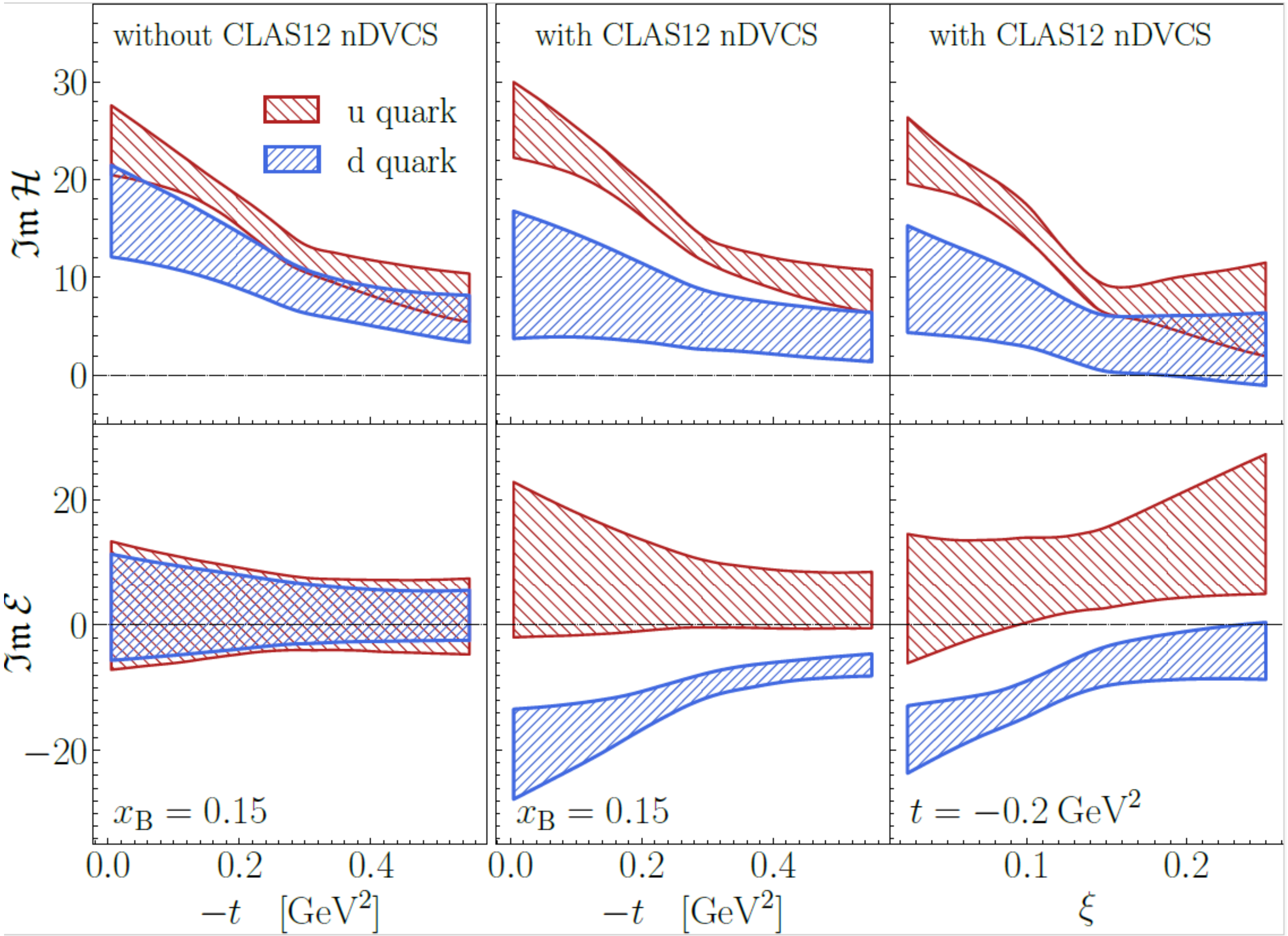
Impact on flavor separation of CFFs of RGB nDVCS data

$\vec{e}d \to en\gamma(p)$

- **Global fits of CFF** using **neural networks** (**K. Kumericki et al., JHEP 07, 073531 (2011); M. Cuic, K. Kumericki, et al., Phys. Rev. Lett. 533 125, 232005 (2020)**).

- Data used: CLAS6 and HERMES pDVCS observables, CLAS12 pDVCS BSA and nDVCS BSA

- Same extraction method applied to nDVCS Hall-A data, only separation for Im$\mathcal{H}$



The CLAS12 nDVCS data allow the quark-flavor separation of both Im$\mathcal{H}$ and Im$\mathcal{E}$

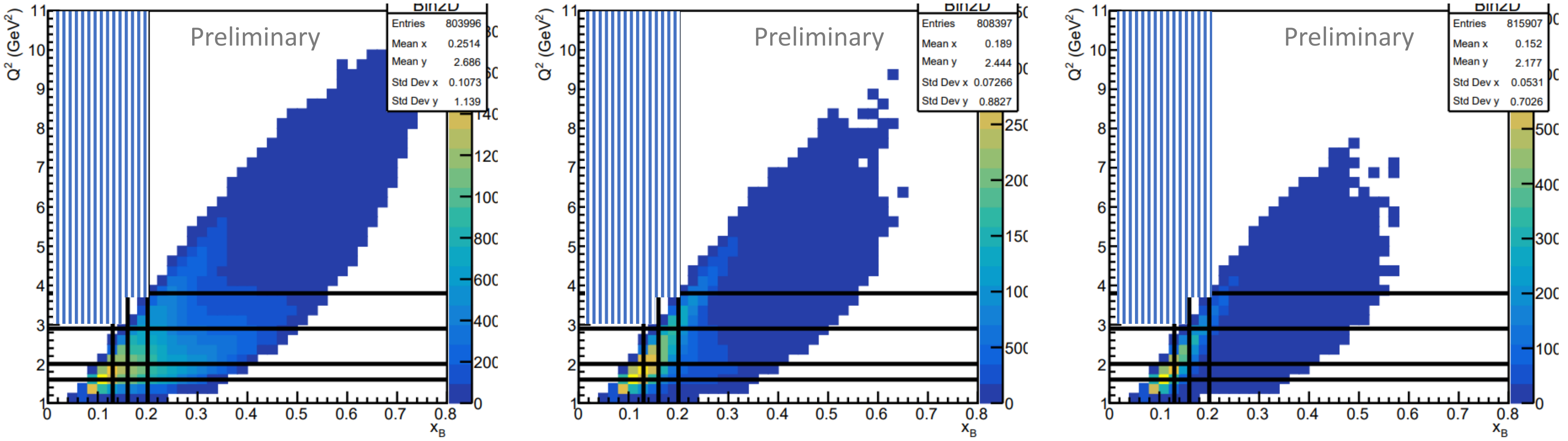
A. Hobart, S.N, et al. (CLAS) arXiv:2406.15539 [hep-ex] - Submitted to PRL

A. Hobart (IJCLab)

Incoherent pDVCS on a deuterium target

$\vec{e}d \rightarrow ep\gamma(n)$

First-time measurement of incoherent pDVCS on deuteron



Bin numbering starts from left to right and from bottom up

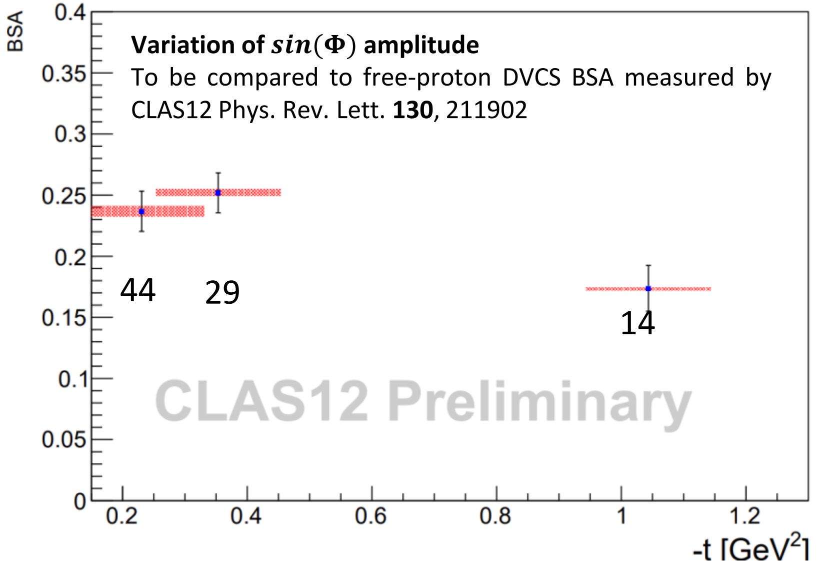
bin number	$< Q^2 >$ GeV²	$< x_b >$	$< -t >$ GeV²
1	1.43794	0.10069	0.767361
2	1.48186	0.144366	0.844629
3	1.4914	0.178824	0.87073
4	1.50756	0.2373	0.851789
5	1.76792	0.114657	0.777427
6	1.8051	0.144373	0.825599
7	1.80447	0.179402	0.863781
8	1.81536	0.258406	0.923301
9	2.0849	0.124705	0.764681
10	2.26532	0.146577	0.793068
11	2.4122	0.179697	0.827414
12	2.43479	0.287563	1.00085
13	3.0799	0.188297	0.790217
14	3.31486	0.30929	1.04349
15	4.83889	0.380624	1.228
16	1.43915	0.100179	0.356721
17	1.49262	0.142616	0.362959
18	1.4954	0.176071	0.350067
19	1.50509	0.249393	0.309281
20	1.77057	0.114679	0.34701
21	1.81394	0.143668	0.348841
22	1.82669	0.175209	0.355866
23	1.81383	0.263491	0.318227
24	2.08646	0.124711	0.342502
25	2.26728	0.146758	0.340636
26	2.46209	0.17752	0.348786
27	2.45997	0.26518	0.340427
28	3.08043	0.188274	0.334151
29	3.34394	0.248423	0.35341
30	4.46623	0.295696	0.370628
31	1.43626	0.0986234	0.200339
32	1.50515	0.13983	0.218898
33	1.49559	0.17749	0.195675
34	1.50618	0.241843	0.211988
35	1.77032	0.114665	0.198266
36	1.83854	0.140417	0.212787
37	1.82375	0.176723	0.20719
38	1.81611	0.248591	0.216637
39	2.08516	0.124803	0.198108
40	2.27128	0.145977	0.203877
41	2.55103	0.174046	0.21458
42	2.44112	0.256179	0.228055
43	3.07532	0.187944	0.210093
44	3.37468	0.230834	0.230575
45	4.30035	0.274016	0.247191

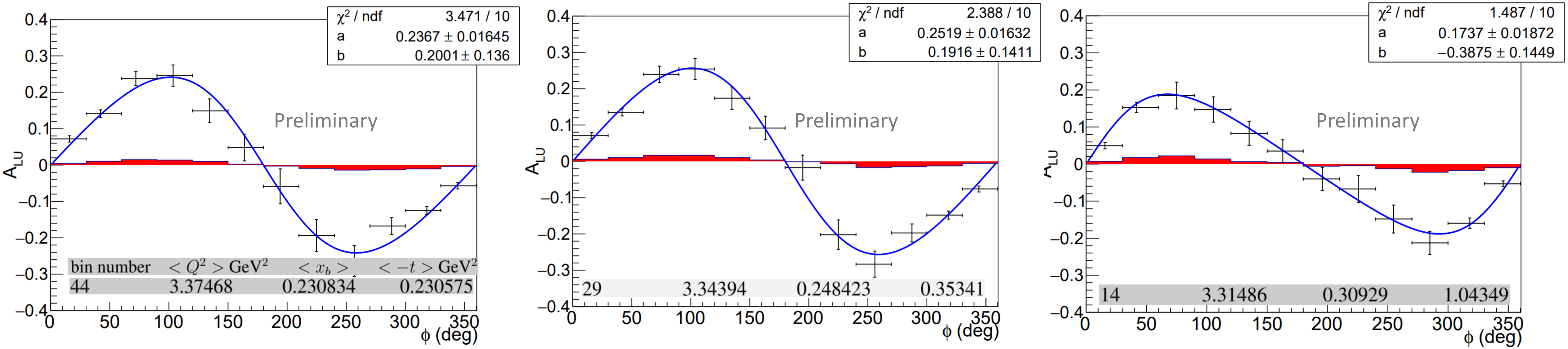
- Useful for the nDVCS measurement
  - Estimate the free-neutron DVCS from comparison of free/bound pDVCS
- Complementary to existing measurements of incohrent DVCS in light nuclei
  - Quantify medium effects on GPDs

Incoherent pDVCS on a deuterium target

$\vec{e}d \rightarrow ep\gamma(n)$

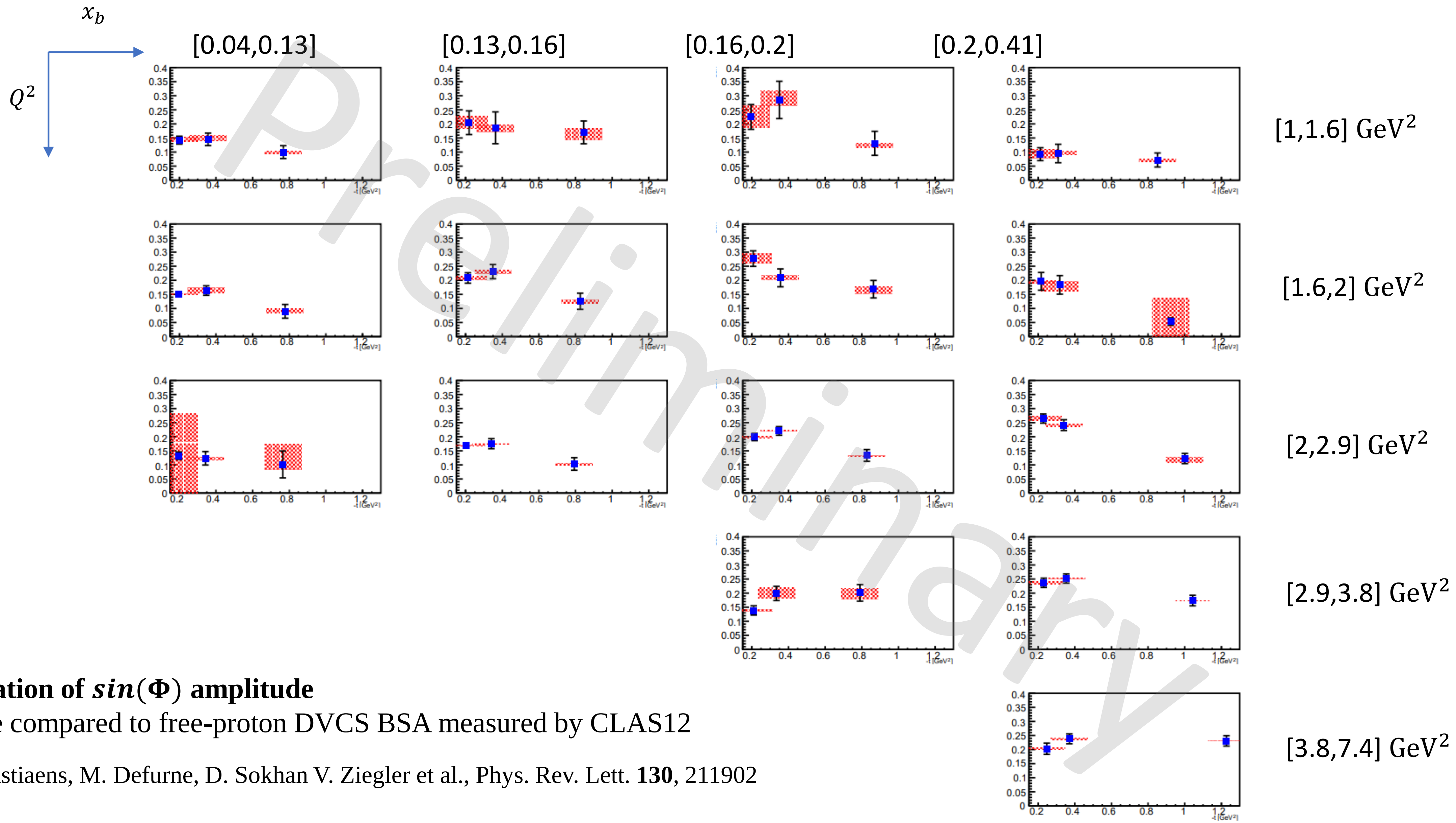
- Systematic errors include:
  - Error due to beam polarization
  - Error due to selection cuts
  - Error due to merging of data sets with different energies
- Statistics is expected to triple with remaining scheduled beam time and improvements with reconstruction software





Incoherent pDVCS on a deuterium target

$\vec{e}d \rightarrow ep\gamma(n)$



Variation of $sin(\Phi)$ amplitude

To be compared to free-proton DVCS BSA measured by CLAS12

G. Christiaens, M. Defurne, D. Sokhan V. Ziegler et al., Phys. Rev. Lett. **130**, 211902

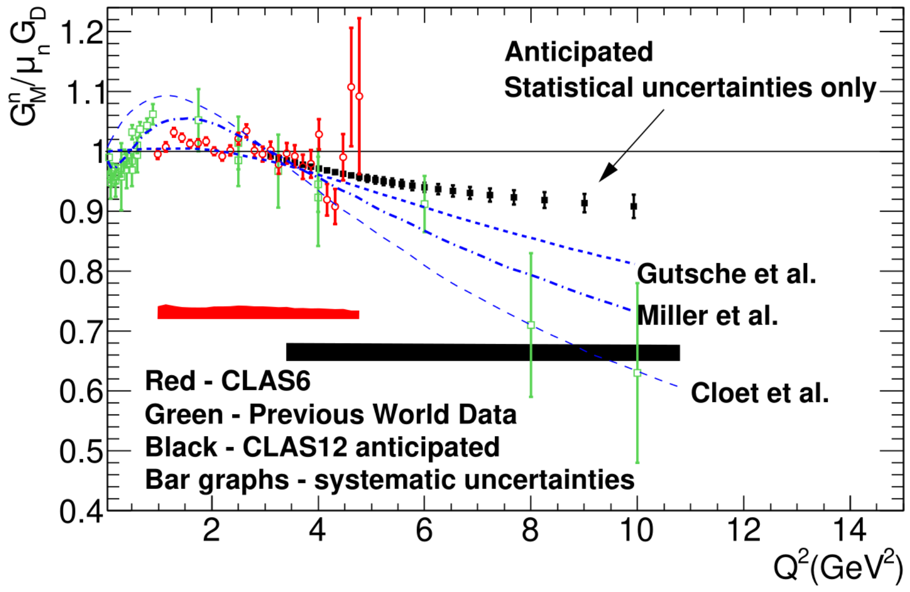
Measurement of the Neutron Magnetic Form Factor G_M^n at High Q^2 Using the Ratio Method on Deuterium

ed→en(p)

ed→ep(n)

L.Baashen (KSU), B.A.Raue (FIU), G.P.Gilfoyle (Richmond)

Goal: Extract G_M^n at high Q^2 using the ratio of quasi-elastic e-n and quasi-elastic e-p events on deuterium: $R = \frac{d(e,e'n)p}{d(e,e'p)n}$



- The neutron magnetic form factor is a fundamental observable related to the distribution of magnetization in the neutron.
- The figure shows world's data for G_M^n including anticipated results.
- Curves show recent theoretical calculations from Gutsche et al. (PRD 97, 054011, 2018)) and Miller et al. (arXiv 1912.07797 [nucl-th], 2020).
- Considerable progress has been made. The Pass1 extraction of G_M^n is complete and was the topic of L.Baashen's doctoral thesis at Florida International University.
- The group is now analyzing the Pass2 data which has increased statistics and improved resolution.
- Completing the RGB run time will extend the reach in Q^2 and improve the statistical precision.

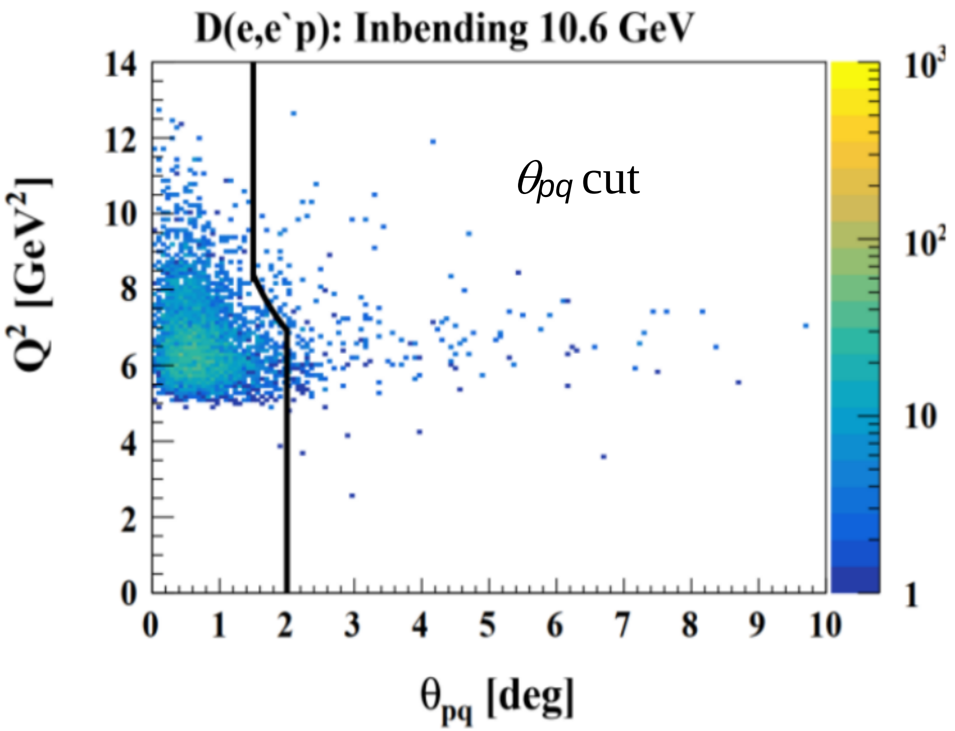
Measurement of the Neutron Magnetic Form Factor G_M^n at High Q^2 Using the Ratio Method on Deuterium: Analysis strategy

ed→en(p)

ed→ep(n)

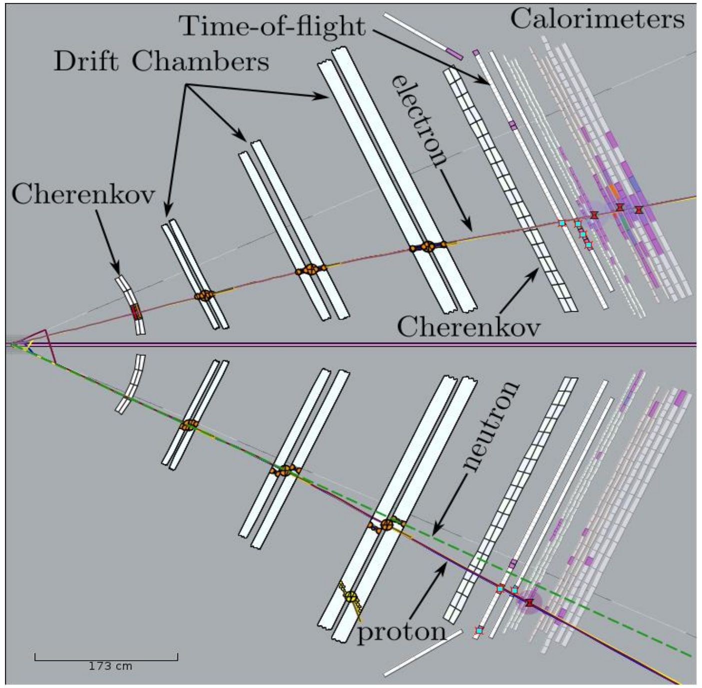
Quasi-Elastic e-n and e-p Event Selection

- Use *e-n* and *e-p* scattering angles for electron and nucleon to calculate beam energy. Require 1σ cut on result.
- Require reaction products to lie in the same plane: $|\Delta\phi| < 1.7°$.
- Require $\theta_{pq} < 2$-$3°$ where θ_{pq} is the angle of the nucleon relative to the 3-momentum transfer.



Acceptance Matching

- Need to have the same solid angle W for *e-n* and *e-p* events.
- Start with a good electron. Assume elastic scattering and a stationary nucleon.
- Swim a proton and a neutron through CLAS12 and require both to hit the PCAL/ECAL.
- Complete the analysis of the event.



Corrections to the e-n/e-p Ratio

ed→en(p)

ed→ep(n)

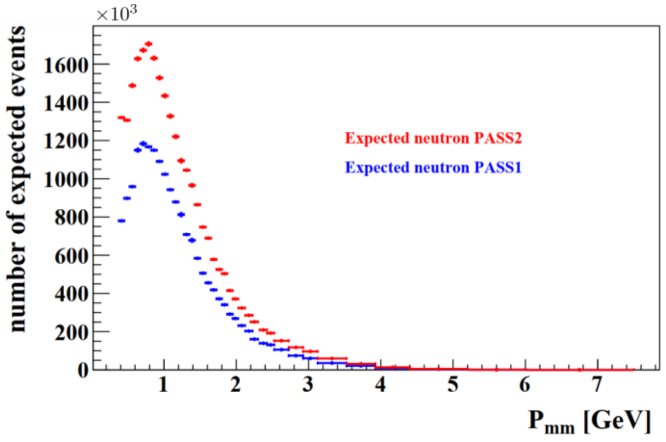
Measuring the neutron detection efficiency (NDE) for **quasi-elastic e-n**

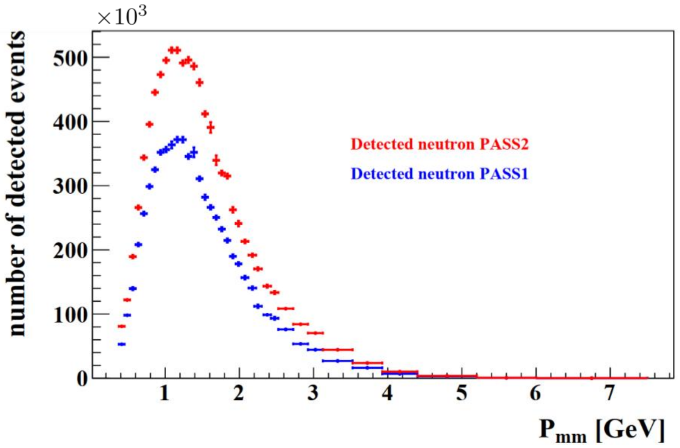
- Use ep→e'π^+n from Run Group A on LH_2 target to obtain tagged neutrons.
- Require a good electron and π^+ and then predict the neutron trajectory.
- If the trajectory intersects the PCAL/ECAL this is an expected event.
- Search for a neutral hit near the intersection. If found, this is a detected event.
- Note the increase in the number of Pass2 events below compared with Pass1.
- The NDE is the ratio of detected events to expected ones.

Other Corrections

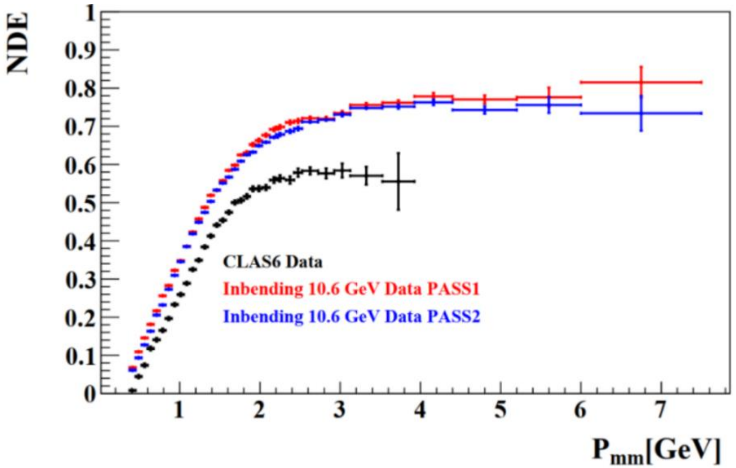
- Proton Detection Efficiency (PDE)
- Fermi Correction
- Radiative Correction
- Nuclear Correction

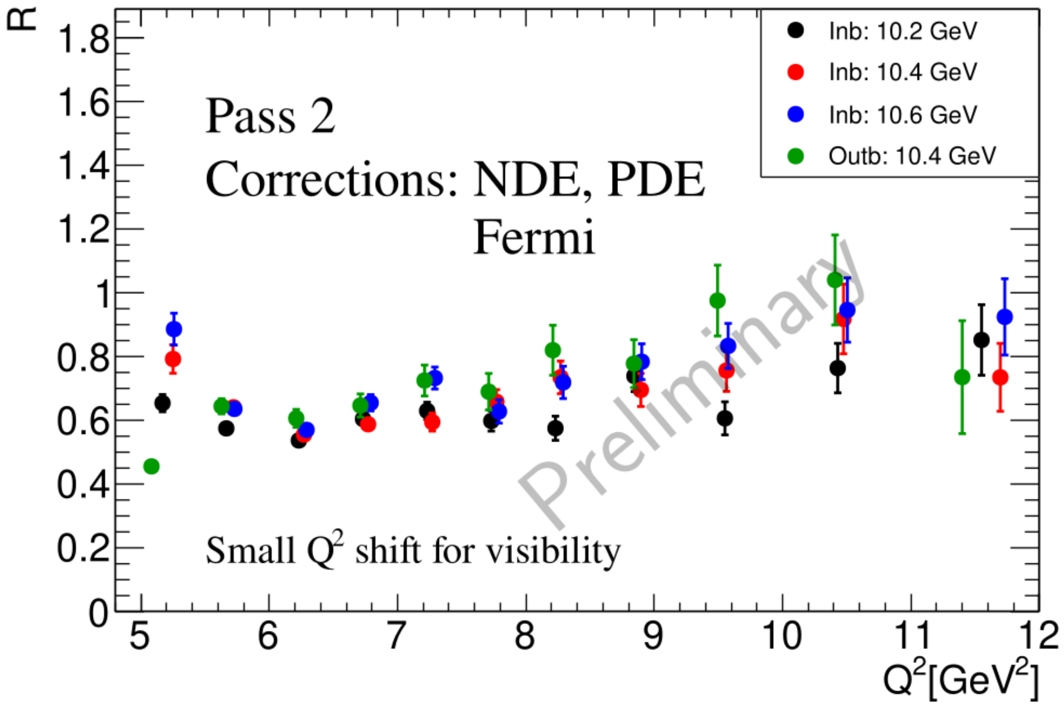
Corrections 1-3 above have been completed for Pass1 and are ongoing for Pass2. Radiative corrections are very close to one. We are working with two theorists on the nuclear correction.





Comparison of Pass 1 and Pass 2 NDE
They agree within 2-3%.
Plot shows the CLAS6 results too.

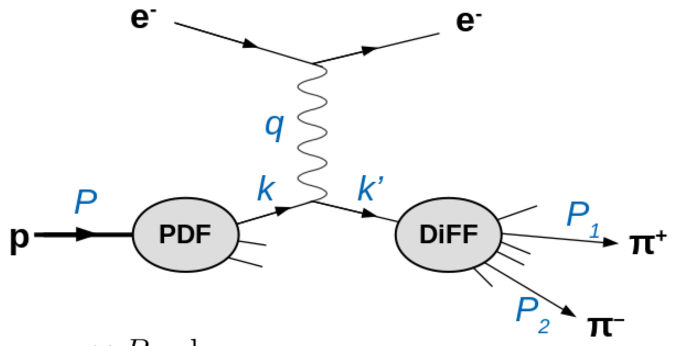




C. Dilks (JLab)
T. Hayward (UConn)

SIDIS: Current Fragmentation Dihadron Production

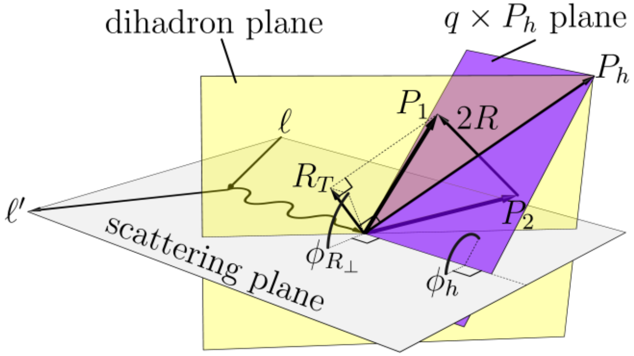
$\vec{e}d \rightarrow e\pi^+\pi^- X$



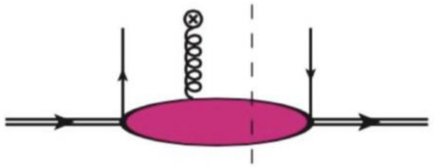
$$eN \rightarrow e + \pi^+(P_1) + \pi^-(P_2) + X$$

Beam spin asymmetry → collinear twist-3 PDF *e(x)* *(and more)*

$$A_{LU} = \frac{d\sigma_+ - d\sigma_-}{d\sigma_+ + d\sigma_-} = A_{LU}^{\sin\phi_R}\sin\phi_R + A_{LU}^{\sin\phi_h}\sin\phi_h + \ldots$$

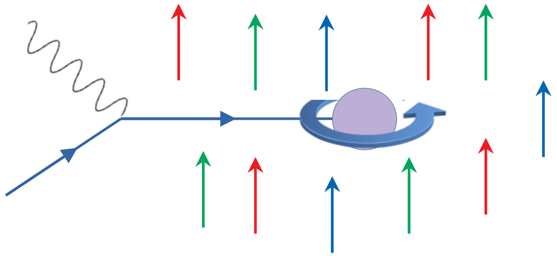


- Twist-3 PDFs: quark-gluon interactions



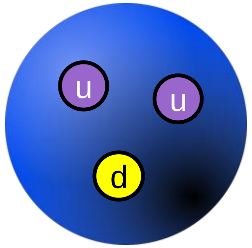
- **e(x) physical interpretation via *x* moments:**
  - 1st: Contribution of finite quark masses to nucleon mass: $m_q \rightarrow m_N$
  - 3rd: "Boer-Mulders Force": Transverse force exerted by color field on q↑ after scattering, in an unpolarized nucleon

Phys.Rev.D 88 (2013) 114502



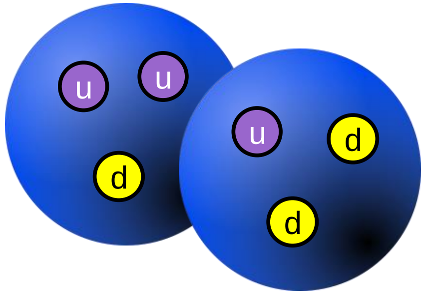
Different targets → e(x) flavor dependence

RG-A



vs.

RG-B



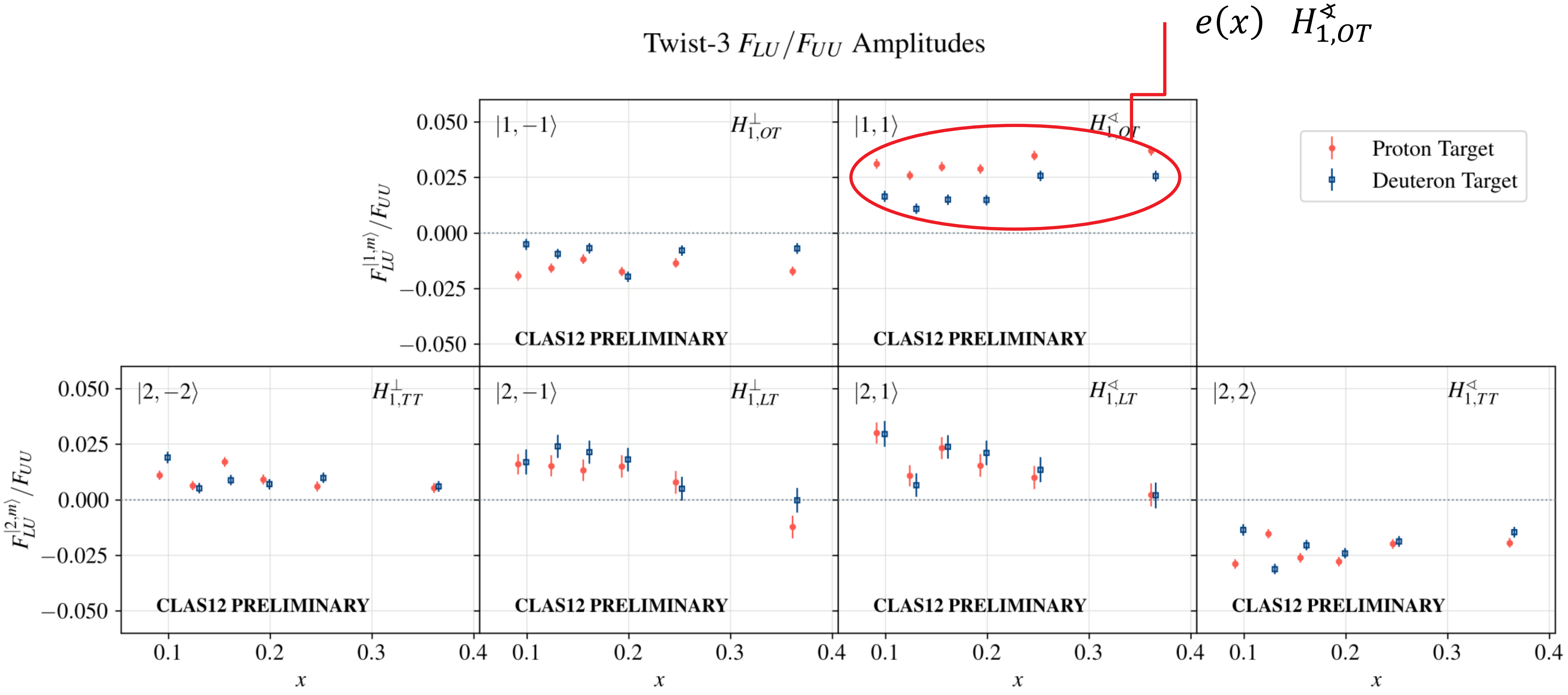
→ access decoupled valence distributions:

$$e^{u_v}(x) \text{ and } e^{d_v}(x)$$

SIDIS: Current Fragmentation Dihadron Production

$\vec{e}d \rightarrow e\pi^+\pi^- X$

- Significant difference between targets' $A_{LU}^{\sin\phi_R}$ → provides a path for flavor-dependent e(x) extraction
- Partial waves provide more insight into dihadron fragmentation angular momentum dependence



SIDIS: Correlating with the Target Fragmentation Region (TFR)

$\vec{e}d \to e\pi^{\pm}pX$

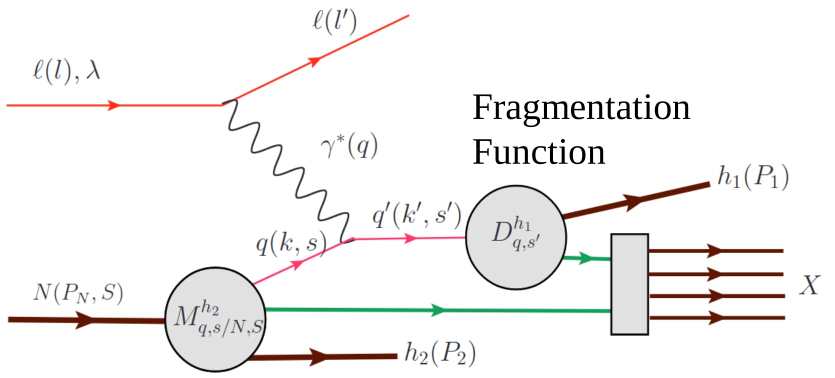
C. Dilks (JLab)
T. Hayward (UConn)

Current **F**ragmentation **R**egion

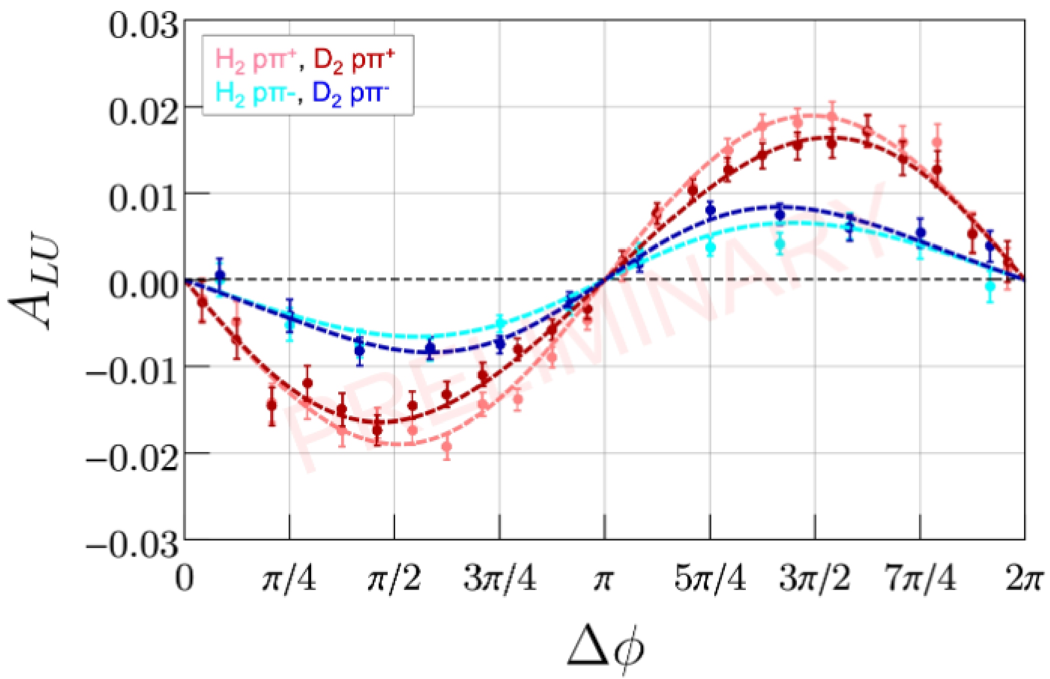
Target **F**ragmentation **R**egion

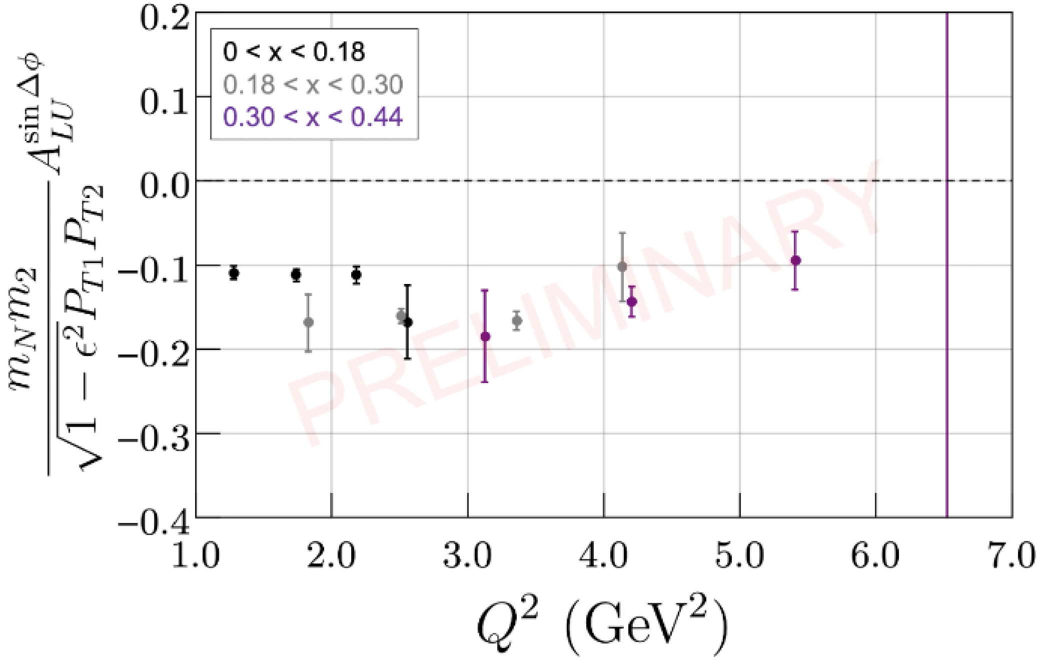
$$eN \to e + \pi^{\pm}(P_1) + p(P_2) + X$$

- **Fracture Function:** conditional probability to produce a TFR hadron
- Largely unexplored → Accessible in beam spin asymmetries in Back-to-Back proton-pion production
- Different targets → flavor-dependent fracture functions



A. Kotzinian, M. Anselmino, and V. Barone, Nuovo Cim. C 036, 127 (2013)





E. Segarra (MIT)
T. Kurtz (MIT)

BAND/CLAS12 tagged DIS analysis

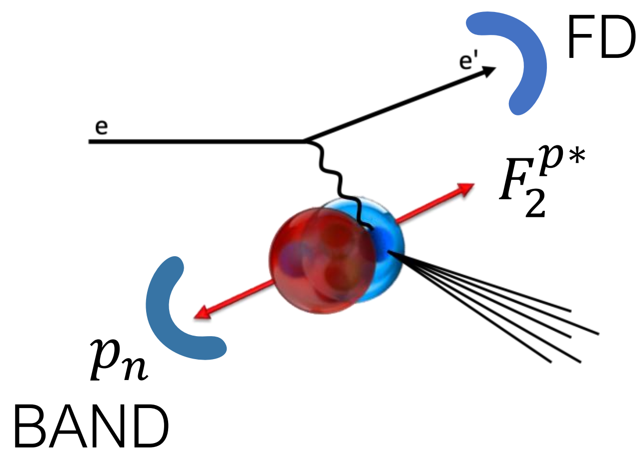
ed→enX

Observable (double ratio): $$\mathcal{R}(\alpha_{S,i}, x') = \frac{Y_{exp}(\alpha_{S,i}, x')/Y_{exp}(\alpha_{S,i}, x'_0)}{Y_{sim}(\alpha_{S,i}, x')/Y_{sim}(\alpha_{S,i}, x'_0)}$$

α_S: spectator neutron light-cone momentum fraction

x': Bjorken scaling variable for a moving nucleon

$x'_0 = 0.3$

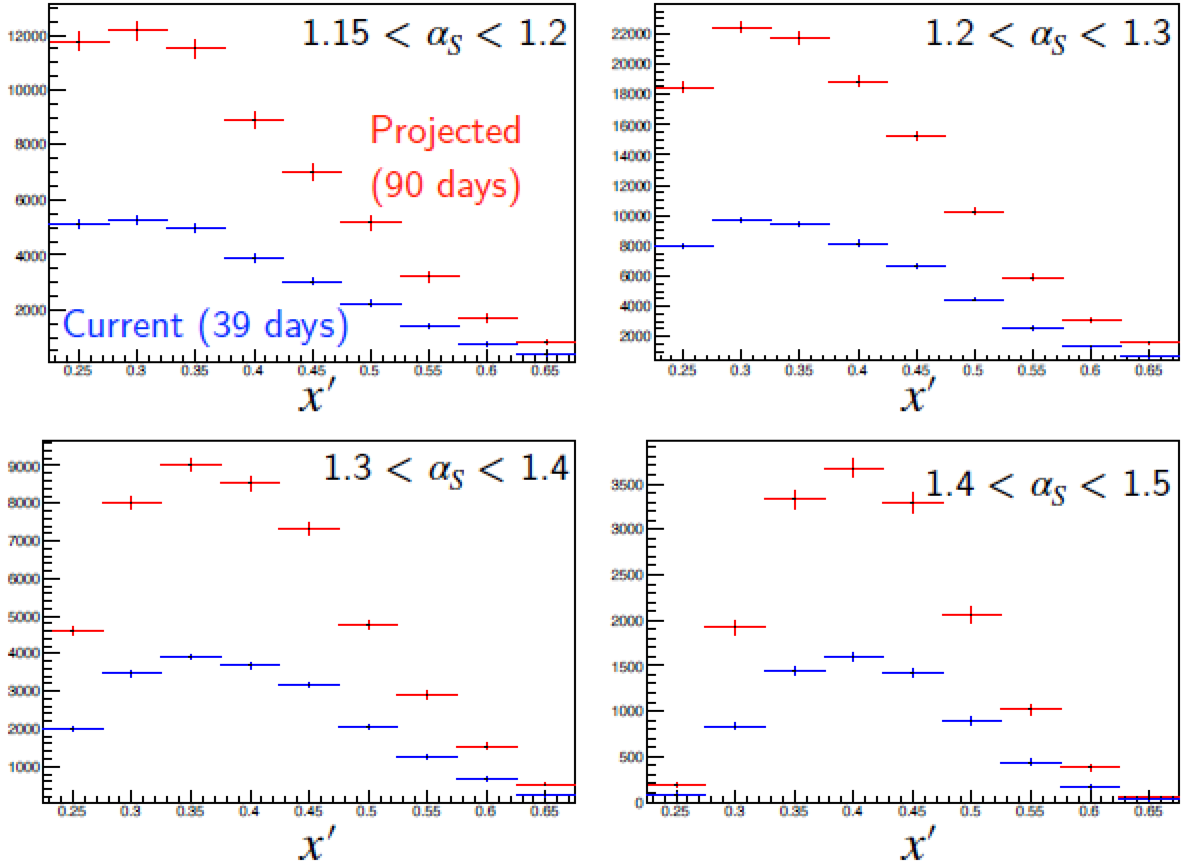


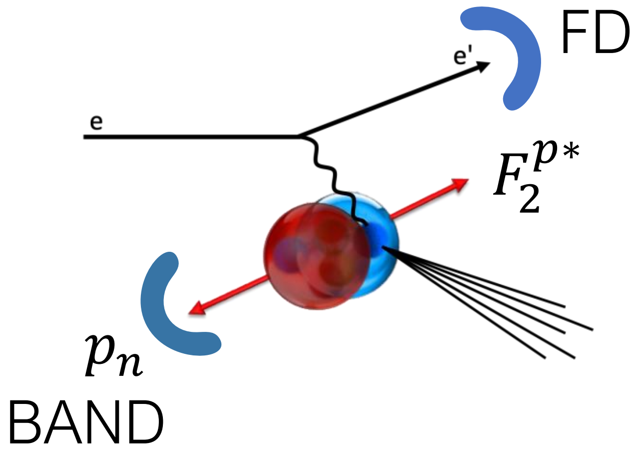
- Neutron-tagged DIS from deuterium, tagged by the detection of a **high-momentum spectator neutron**, allows the study of the **bound proton structure function F_2^{*p}** when the proton is in a high-momentum, highly-virtual state
- The experimental yield is proportional to the bound proton structure
- The simulated yield is proportional to the free proton structure (free used in event generator)
- The double ratio is sensitive to bound/free proton cross section
- Comparing the ratio with theoretical predictions allows one to disentangle the various effects (nucleon motion, short-range correlations, binding) contributing to the modification of the structure function.
- An analysis note based upon RGB data is in the final stages of internal review in the CLAS Collaboration

BAND/CLAS12 tagged DIS analysis

ed→enX

Observable (double ratio): $$\mathcal{R}(\alpha_{S,i}, x') = \frac{Y_{exp}(\alpha_{S,i}, x')/Y_{exp}(\alpha_{S,i}, x'_0)}{Y_{sim}(\alpha_{S,i}, x')/Y_{sim}(\alpha_{S,i}, x'_0)}$$

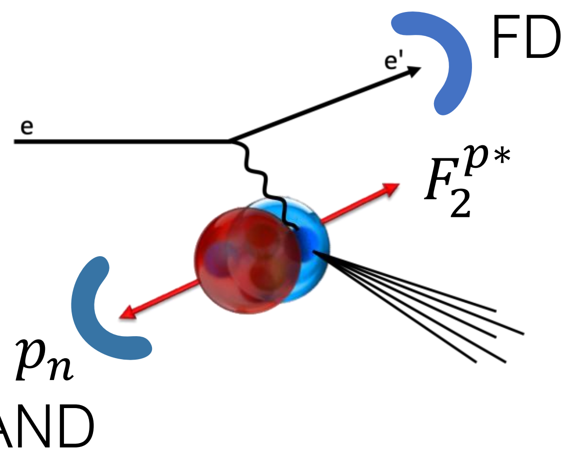


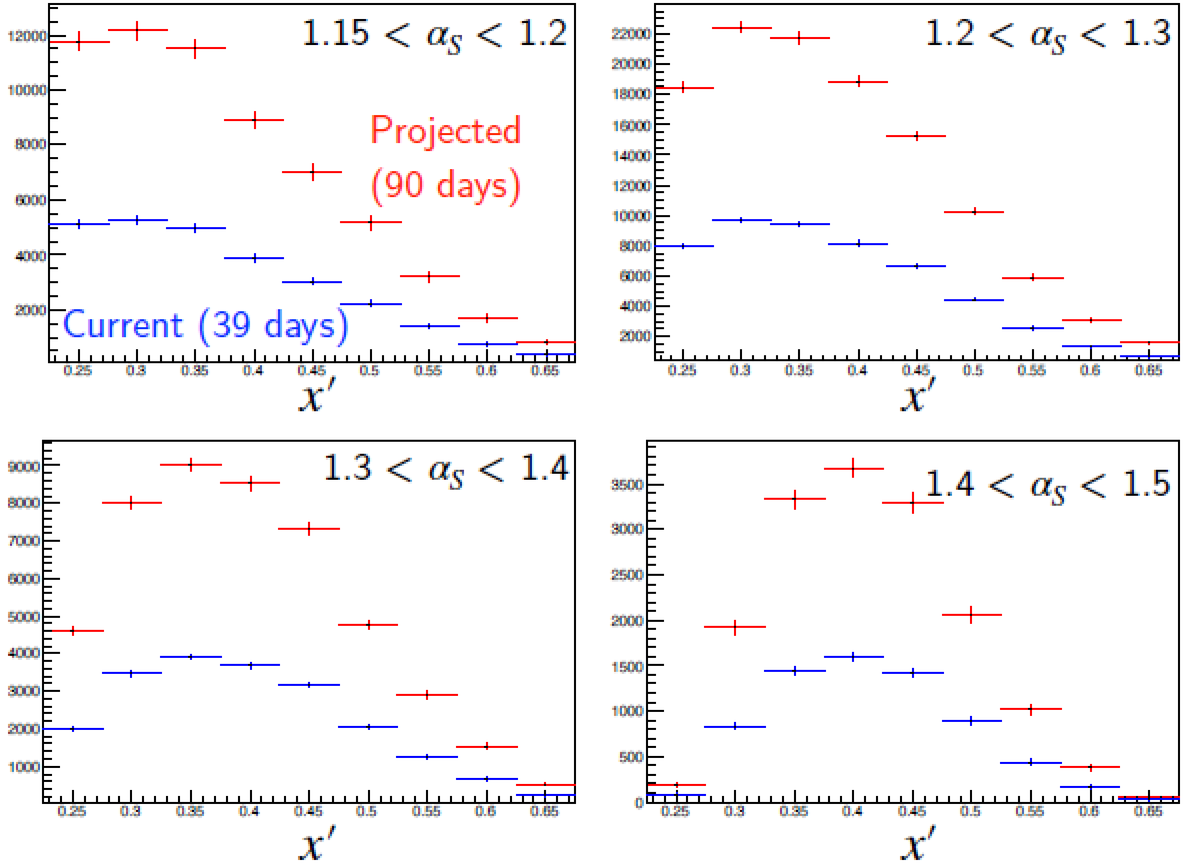


BAND/CLAS12 tagged DIS analysis

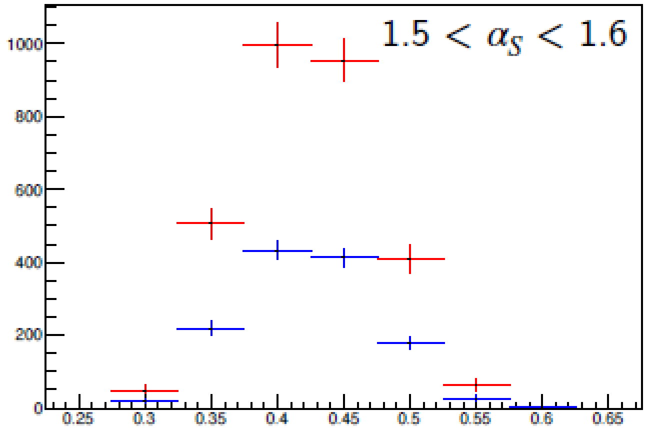
ed→enX

Observable (double ratio): $\mathcal{R}(\alpha_{S,i}, x') = \dfrac{Y_{exp}(\alpha_{S,i}, x')/Y_{exp}(\alpha_{S,i}, x'_0)}{Y_{sim}(\alpha_{S,i}, x')/Y_{sim}(\alpha_{S,i}, x'_0)}$





Could also extend analysis to higher α_S bin with approximately same stats as current highest bin



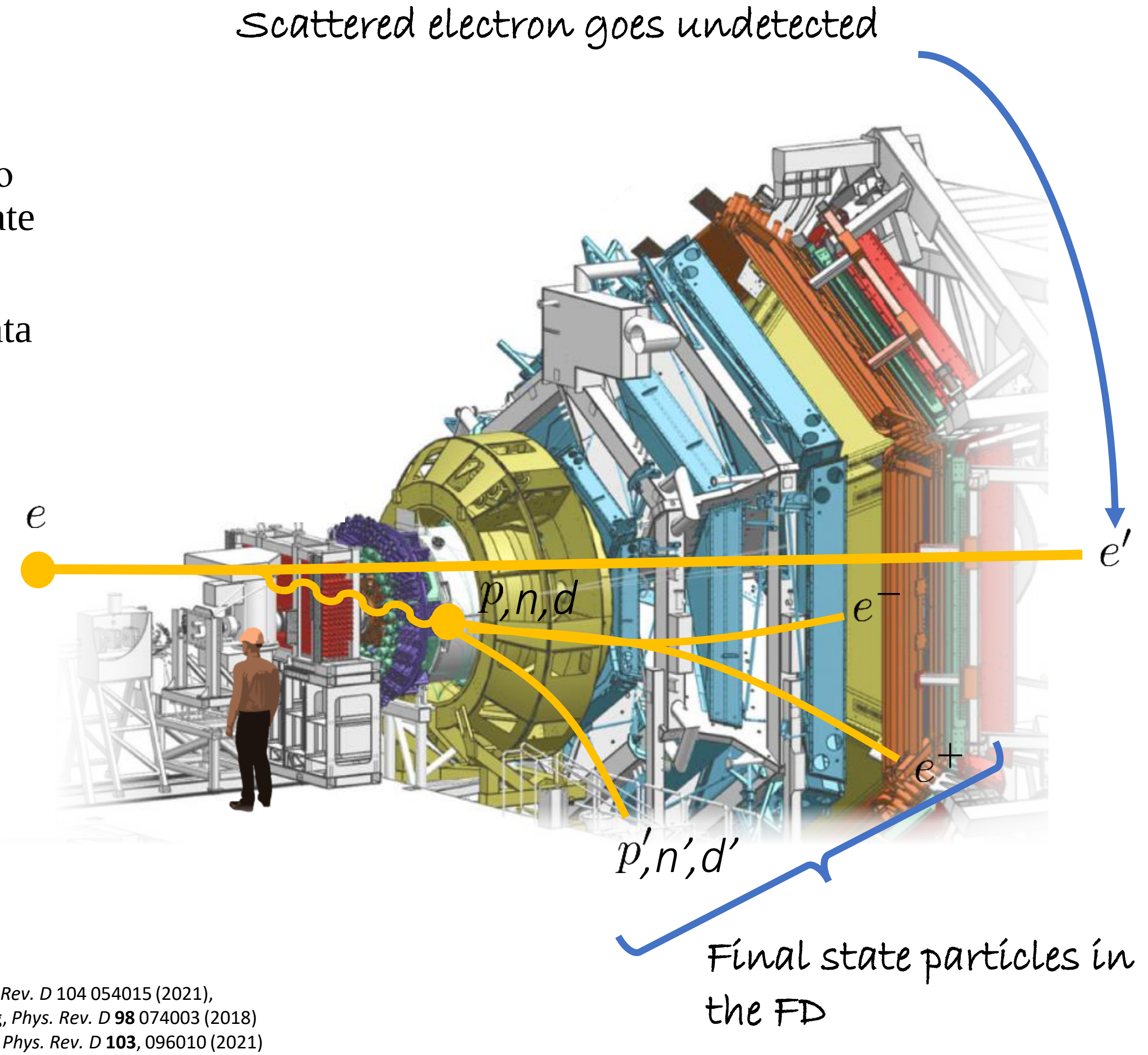
R. Tyson (Glasgow)

J/ψ Photoproduction (E12-11-003B)

$\gamma N \to (e') J/\psi \to (e) e^+ e^- N$

- Models based on VMD, holographic QCD and GPD frameworks relate J/ψ near-threshold photoproduction to the nucleon gluonic gravitational form factors (gGFFs) [1-3].
- There is some disagreement within the theoretical community on the validity of estimating the gGFFs from J/ψ photoproduction. There are also suggestions in GlueX data that other production mechanisms may dominate the near-threshold region [4-6].
- A first measurement of J/ψ photoproduction on the neutron with RG-B data can help establish the isospin invariance of the near-threshold production mechanism. This could also lead to estimates of the neutron gGFFs.
- Higher precision data is needed to clarify the validity of relating J/ψ photoproduction to the gGFFs [4-6].

- The aim is to study **coherent and incoherent J/ψ quasi-real photoproduction on the deuteron**:
- $\gamma N \to J/\psi\, N'$ (N=p,n incoherent production on p & n)
- $\gamma d \to J/\psi\, d'$ (coherent production on d)
- for J/ψ decaying to $l^- l^+ = e^-e^+$ or $\mu^-\mu^+$.

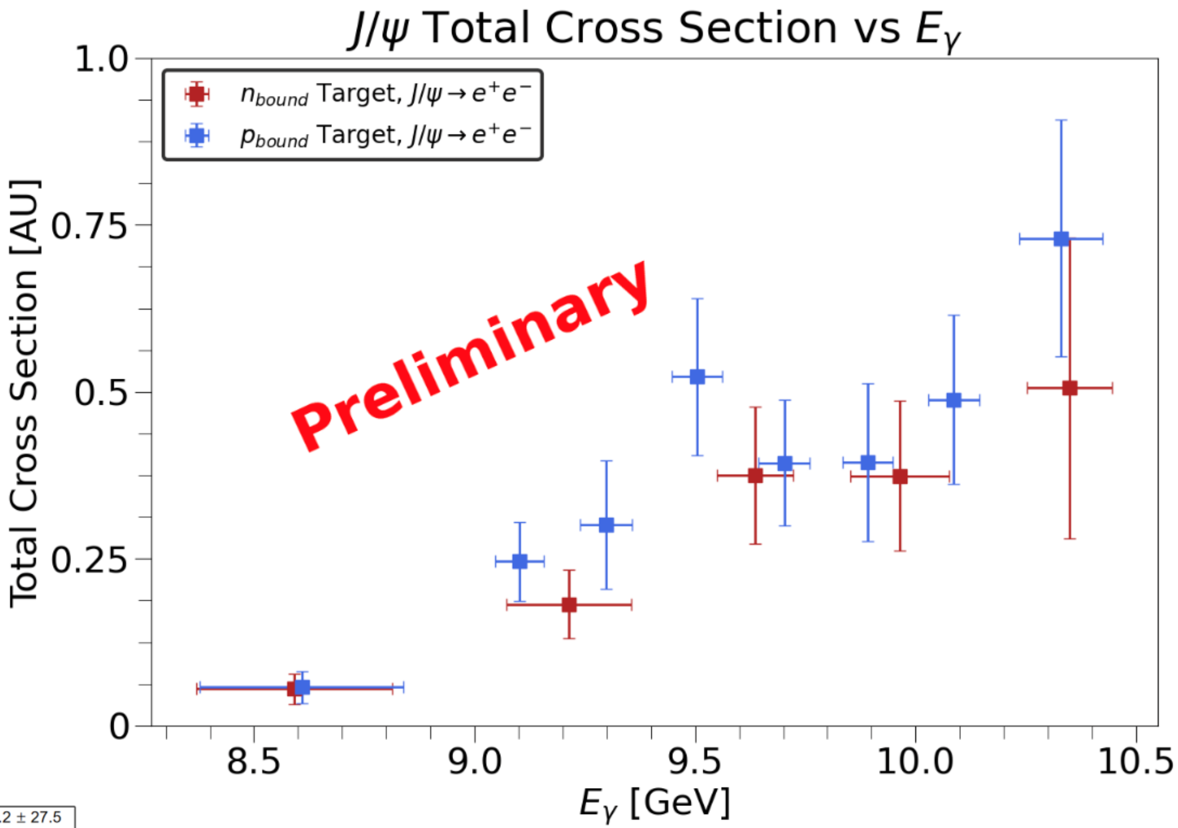


[1] D. Kharzeev, *Phys. Rev. D* 104 054015 (2021),
[2] Y. Hatta, D.-L. Yang, *Phys. Rev. D* **98** 074003 (2018)
[3] Y. Guo, X. Ji, Y. Liu, *Phys. Rev. D* **103**, 096010 (2021)
[4] L. Tang, Y.-X. Yang, Z.-F. Cui, C. D. Roberts *arXiv*:2405.17675
[5] M.-L. Du, *et. al.* , *Eur. Phys. J. C* 80 1053 (2020)
[6] D. Winney, *et. al.* (JPAC), *Phys. Rev. D* **108**, 054018 (2023)

J/ψ Photoproduction (E12-11-003B)

$\gamma N \rightarrow (e')J/\psi \rightarrow (e)e^{+}e^{-}N$

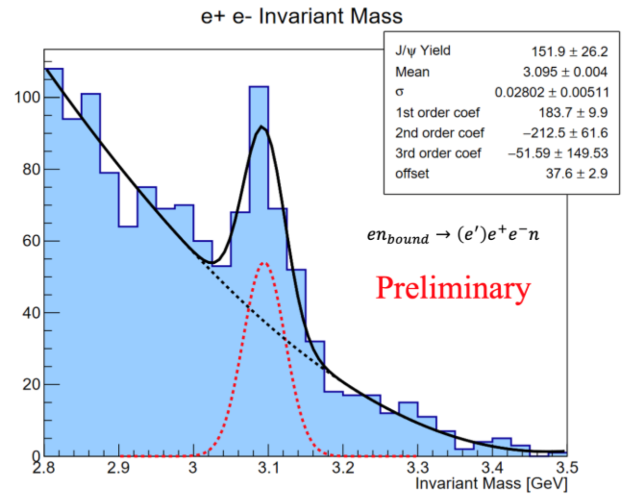
- Exclusivity is achieved through missing four momentum analysis of the scattered electron.
- Analysis of J/ψ photoproduction on proton and neutron is well advanced.
- One PhD Thesis on J/ψ photoproduction on proton and neutron (R. Tyson, Uni. Of Glasgow).

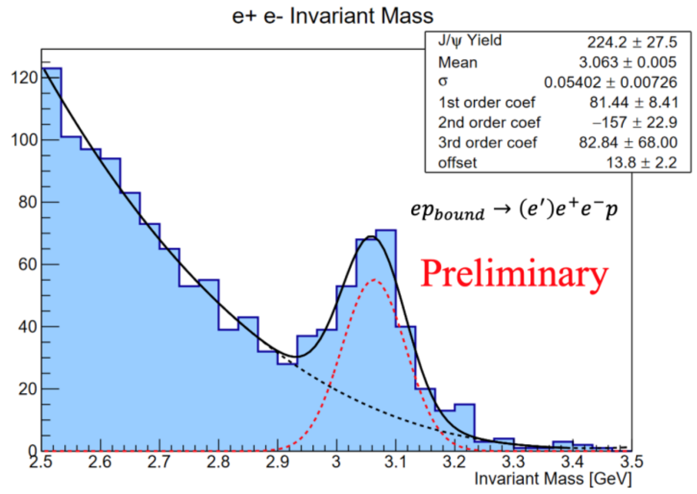


Results in AU as normalization is in progress.

Only using spring 2019 data (21.7 PAC days):

- ~ 56 % of collected data
- ~ 24% of allocated beam time





Conclusions and beam-time request

- Run Group B aims at mapping the **3D structure of the neutron** via electroproduction on deuterium
- **Quark-flavor separation** of the measured structure functions combining with proton data
- The first « half » of RG-B running ended on January 30
- **~38.9 PAC days collected out of the 90 PAC days approved for nDVCS**
- Three different beam energies for the 3 periods
- **Physics analyses finished or advanced**: n/p/(d)-DVCS, G^n_M, Di-hadron SIDIS, J/ψ, Tagged-DIS, (n/p-DVMP(π^0))
- Analysis of K-SIDIS in progress (RG-A being analyzed first)

We request the PAC to allow us to run the remainder 51 days of our approved beam time:

- ✓ ***We will measure the BSA for nDVCS in 4-D (Q^2, x_B, -t, ϕ) with improved statistical errors, exploiting the full available phase-space, and possibly at a constant beam energy, thus delivering the originally proposed physics output and providing unprecedented constraints on the CFFs of the GPD E***
- ✓ ***We will achieve high precision at high Q^2 for G^n_M, where no other data exist***
- ✓ ***We will triple the statistics for K-SIDIS, as the 51 more days will run with 2 RICH sectors***
- ✓ ***We will allow precise extraction of the Di-hadron FF for u and d quarks***
- ✓ ***We will provide a first-time measurement of J/ψ photoproduction on deuterium***
- ✓ ***We will perform a multi-dimensional study of SRC on a bound proton***
- ✓ ***We will provide first-time pioneering measurements for new channels (d-DVCS, n-DVMP(π^0))***
- ✓ ***The improved CLAS12 tracking and reconstruction, along with the high-luminosity upgrade of CLAS12 will further increase statistical precision for all our measurements***

Back-up slides

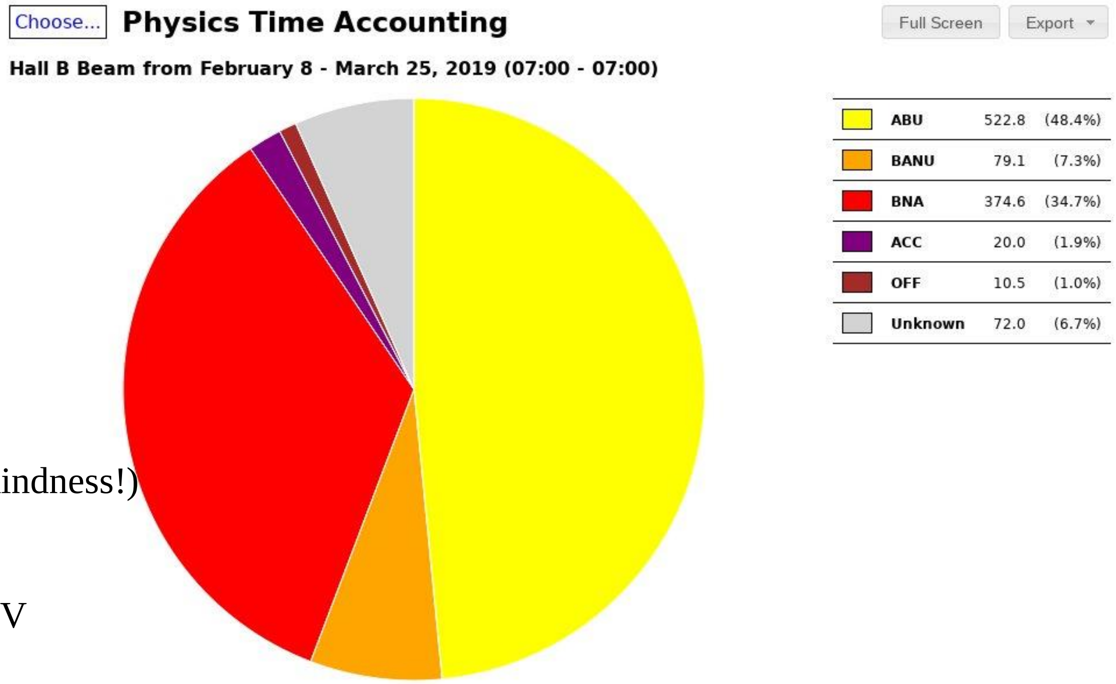
Run Group B spring 2019 run

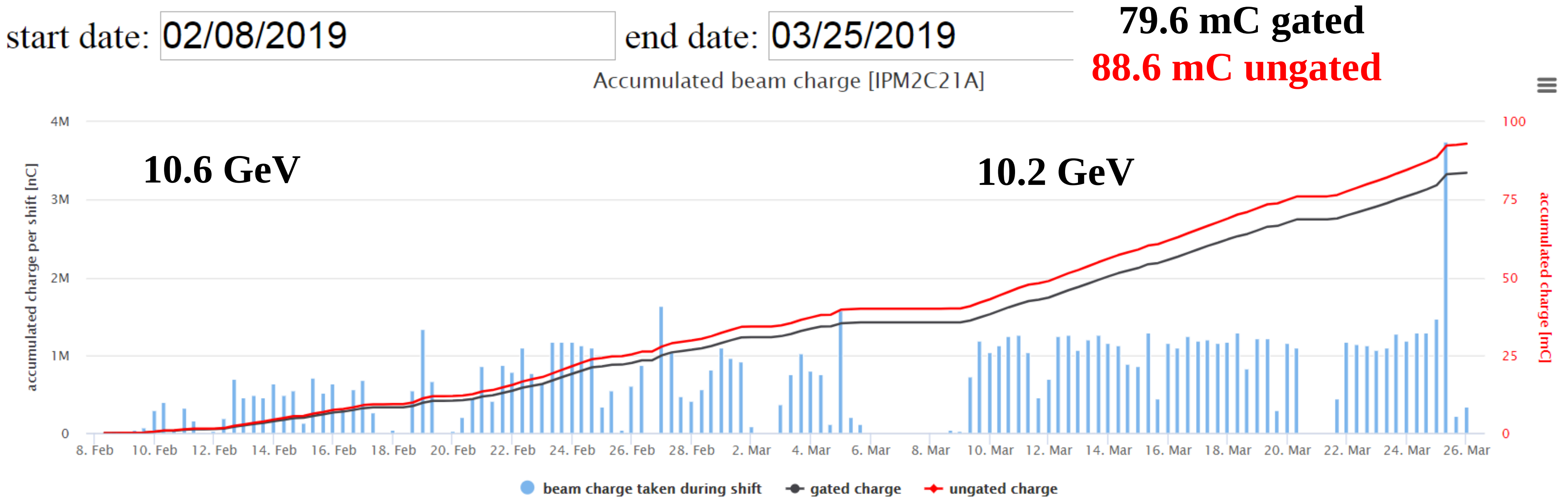
Running conditions:

- **10.6** – **10.2** GeV beam energy
- Torus ***inbending***
- Production current: 35 nA → 50 nA
- Event-weighed average current: 47.9 nA
- DAQ rate: ~14 kHz

Outcome:

- Original schedule: 1/30 – 3/10
- Final accelerator schedule: 2/8 – 3/17
- Actual days ran: 2/8 – 3/25 (thanks to RG-A's kindness!)
- 21.7 PAC days according to ABUs (48.4%)
- 237 good production runs
- ~9.7 B triggers at 10.6 GeV, ~11.7 B at 10.2 GeV





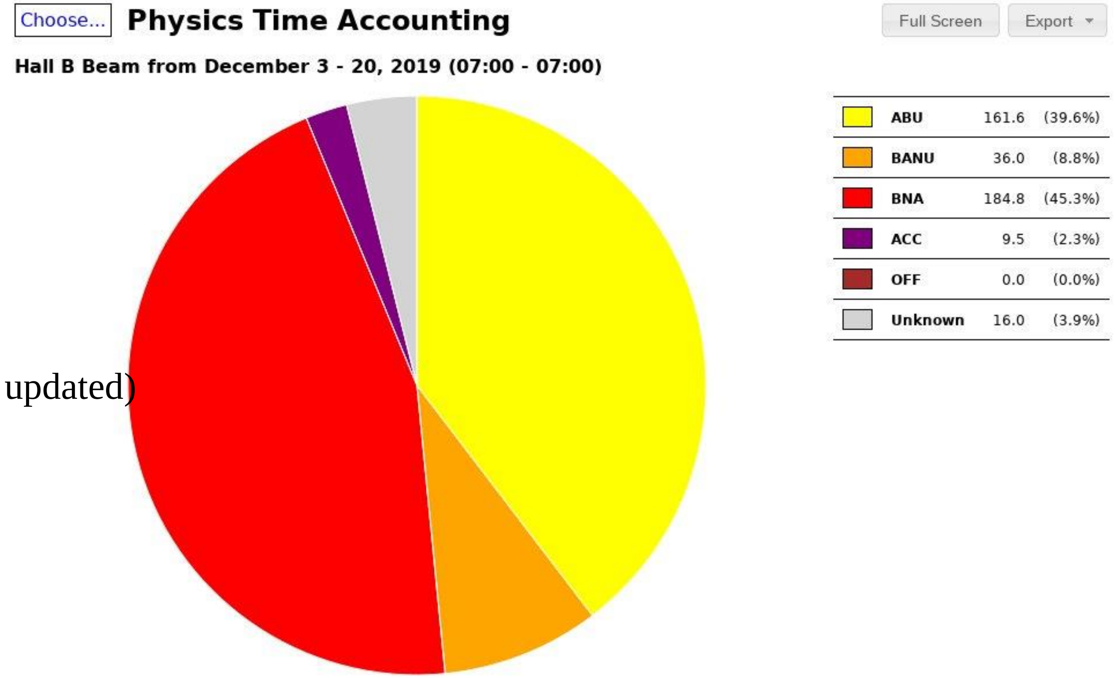
Run Group B fall 2019 run

Running conditions:

- **10.4** GeV beam energy
- Torus ***outbending***
- Production current: 40 nA
- Event-weighed average current: 38.8 nA
- DAQ rate: ~24 kHz
- ~1 day at 2-pass for BAND

Outcome:

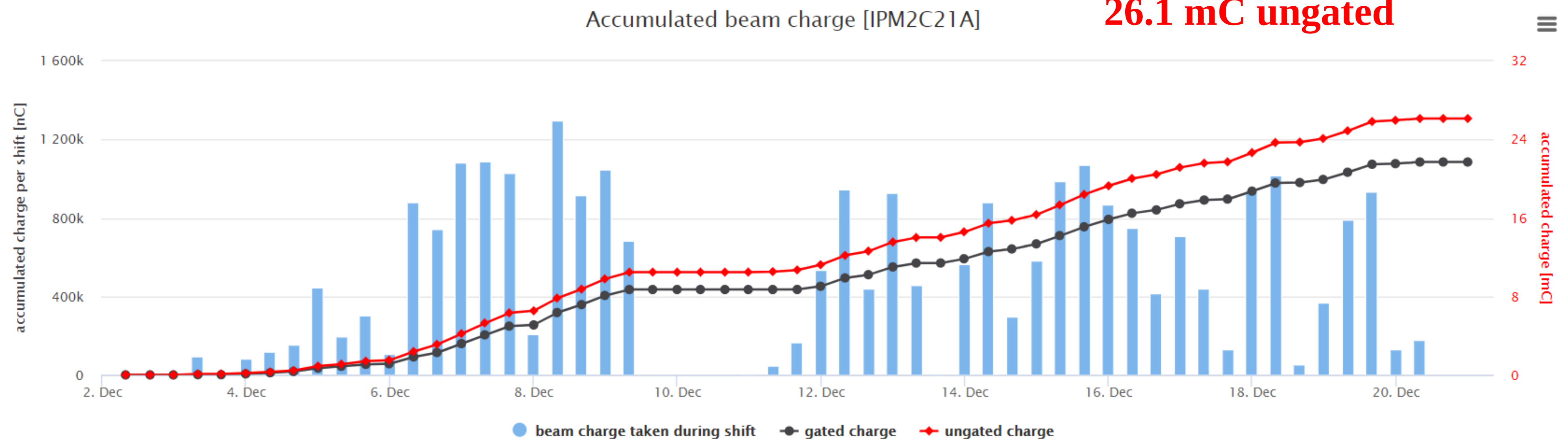
- Accelerator schedule: 11/25 – 12/19 (should be updated)
- Actual days ran: 12/3 – 12/20
- 6.7 PAC days according to ABUs (39.6%)
- 91 good production runs
- ~9. B triggers at 10.4 GeV



start date: 12/02/2019 end date: 12/20/2019

21.7 mC gated

26.1 mC ungated



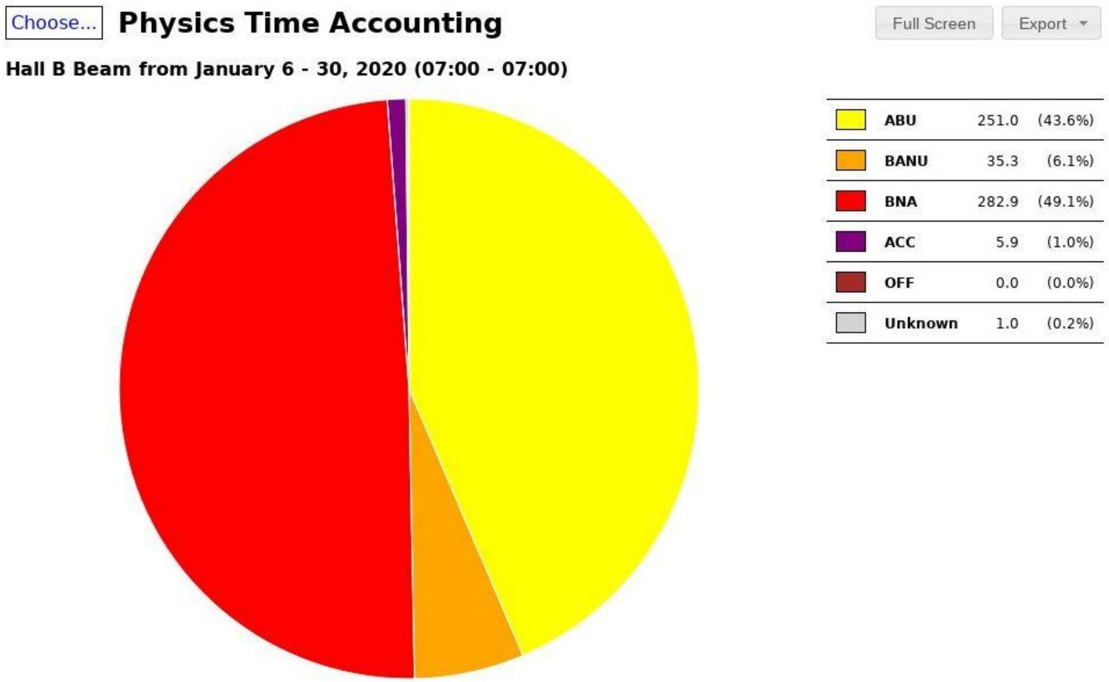
Run Group B winter 2020 run

Running conditions:

- **10.4** GeV beam energy
- Torus ***inbending***
- Production current: 40 → 50 nA
- Event-weighed average current: 45.1 nA
- DAQ rate: ~19 kHz

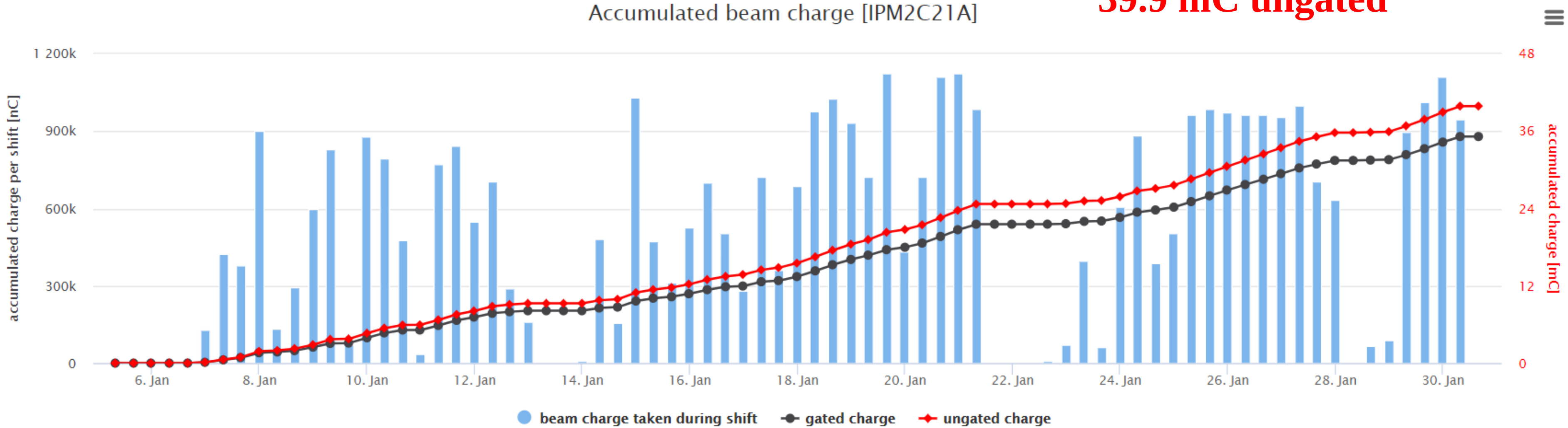
Outcome:

- Accelerator schedule: 1/10 – 1/29
- Actual days ran: 1/7 – 1/29
- 10.5 PAC days according to ABUs (43.6%)
- 181 good production runs
- 12.9 B triggers at 10.4 GeV



start date: 01/05/2020 end date: 01/30/2020

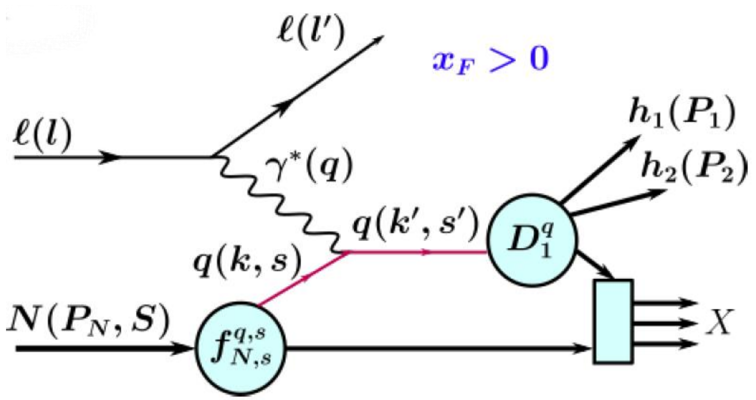
35.2 mC gated
39.9 mC ungated



Di-hadron Multiplicities

e N → e' $\pi^+ \pi^-$ X

Number of di-hadron pairs per DIS electron



$$M(x_B, z, M_{\pi\pi}; Q^2) = \frac{d\sigma^{dh} / dx_B dz dM_{\pi\pi} dQ^2}{d\sigma^{DIS} / dx_B dQ^2}$$

$$d\sigma^{dh} \propto \sum_q f_{1,q}(x_B) D_{1,q}^{dh}(z, M_{\pi\pi})$$

Di-hadron unpolarized Fragmentation Function (FF)
It enters in the denominator of every asymmetry

Assuming isospin symmetry, the analysis of hydrogen and deuterium data allows the extraction of u and d FF

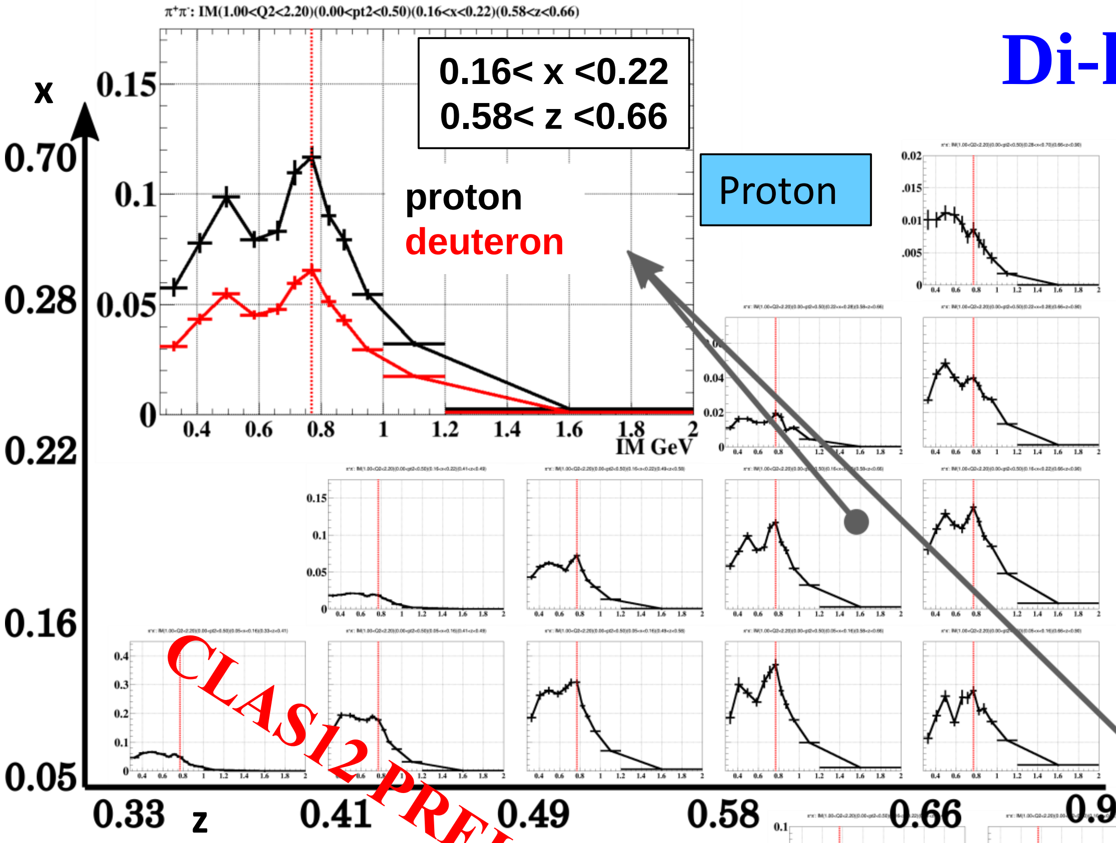
$$D_{1,u}^{dh} = 3\frac{M^p\left(\frac{4}{9}f_{1,u} + \frac{1}{9}f_{1,d}\right) - \frac{1}{9}M^d\left(f_{1,u} + f_{1,d}\right)}{K_f f_{1,u}}$$

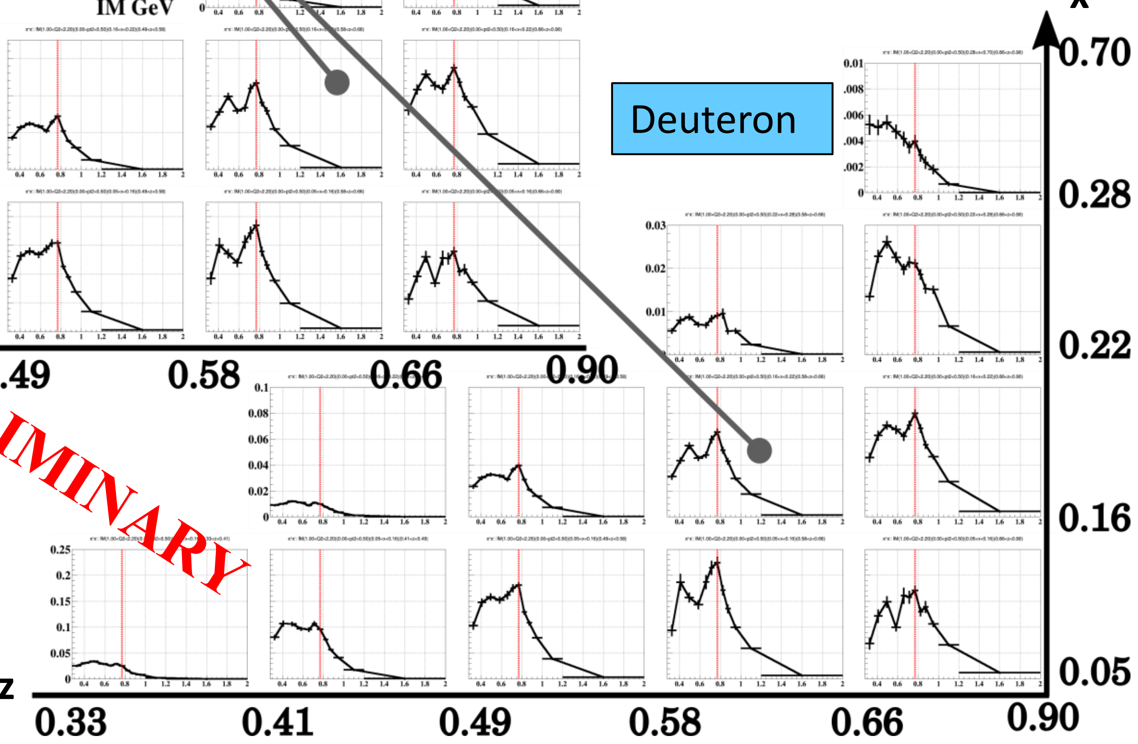
$$D_{1,d}^{dh} = 3\frac{\frac{4}{9}M^d\left(f_{1,u} + f_{1,d}\right) - M^p\left(\frac{4}{9}f_{1,u} + \frac{1}{9}f_{1,d}\right)}{K_f f_{1,d}}$$

K_f → kinematic factors

The PDF f_{1q} of the proton are known

Di-hadron Multiplicities





$1 < Q^2 < 2.2$ GeV^2

- 4D analysis in x_B, z, $M_{\pi\pi}$ and Q^2
- DIS cuts: $Q^2 > 1$, $W > 2$, $y<0.8$
- SIDIS cuts: $x_F^{+/-} > 0$, $0.1 < z < 0.95$, MM>1.1

O. Soto, M. Mirazita (INFN-LNF)

Completion of the run will provide about x5 more statistics, allowing:
- **improved sensitivity in the high x and high Q^2 region**
- **better precision in extracting D_1^d**
- **access to TMD adding p_T dependence (5D analysis)**

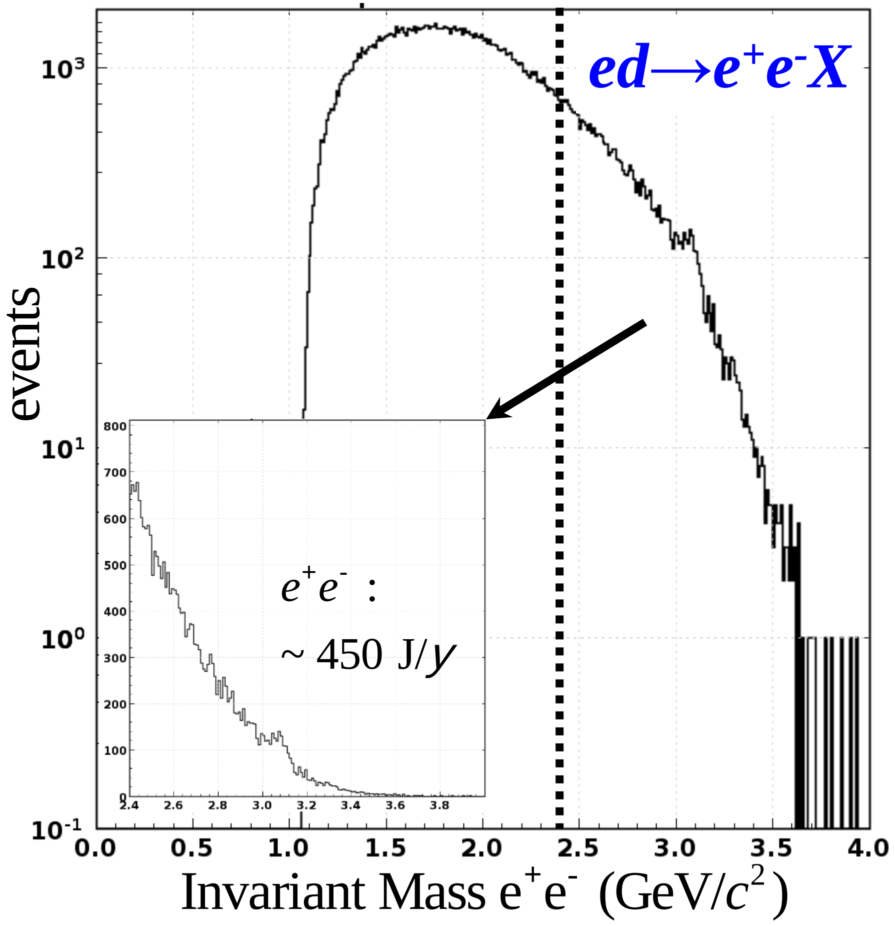
$$4M^p - M^d \rightarrow D_1^u$$

$$4M^d - M^p \rightarrow D_1^d$$

Study of J/ψ Photoproduction off Deuteron

M.D. Baker, A. Freese, L. Guo, Ch. Hyde, **Y. Ilieva**, **B. McKinnon**, **P. Nadel-Turonski**, M. Sargsian, **V. Kubarovsky**, **S. Stepanyan**, N. Zachariou, **Zh.W. Zhao**

All data from Spring 2019



Q1: Impact of experiment remains as high as in 2018 (originally proposed).

• The question about P_C pentaquark signal in photoproduction remains unresolved. Neutron channel is critical given that no positive signal in the proton channel has been reported from Halls D and C.

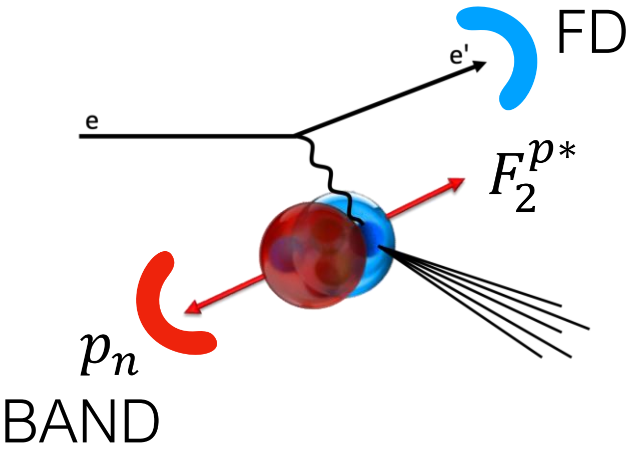
• This experiment remains the sole near-threshold exclusive study worldwide of re-scattering and coherent physics.

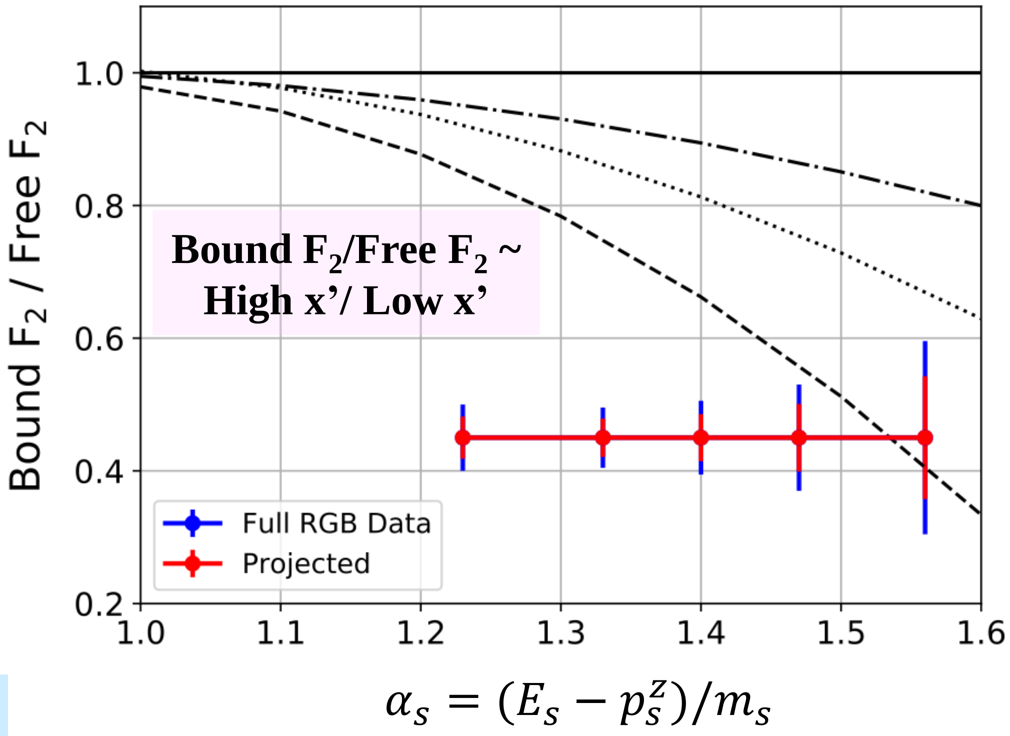
Q2: Data analysis and received data

- Inclusive yield (Spring 2019 data) ~450 J/ψ (e^+e^-). Analysis is in progress for the exclusive channels.
- Pentaquark study: received only 11% of requested 90 days due to energy drop.
- Coherent and incoherent study: received only 22% of requested 90 days due to energy drop.
- **$E_b \geqq 10.6$ GeV is crucial for all of the J/ψ research**.
- The complete data are essential for the extraction of differential cross sections needed to deliver the physics goals of experiment.

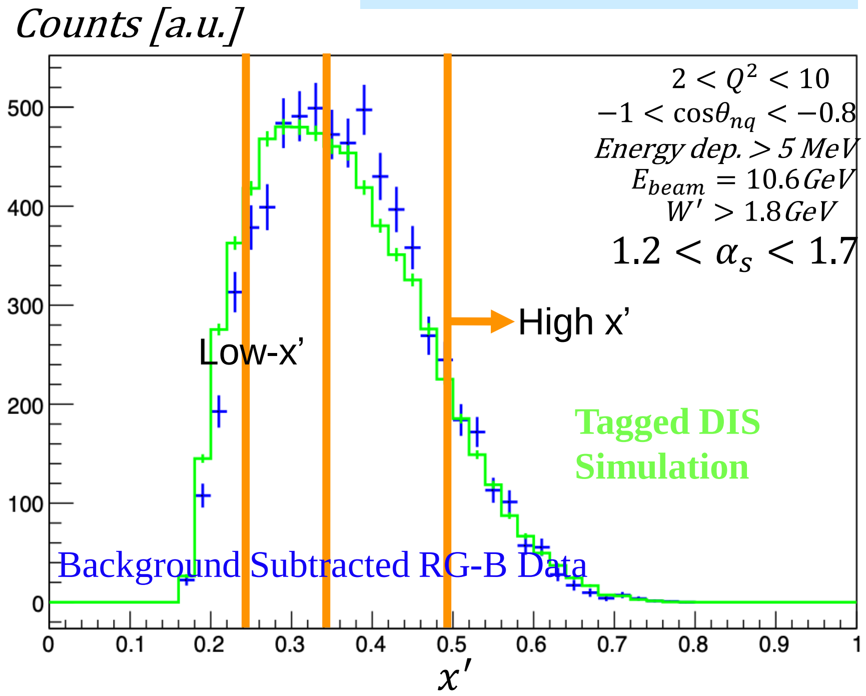
Q3: No request for reconsideration of allocated beam time or assigning scientific ranking (remains Run Group Proposal).

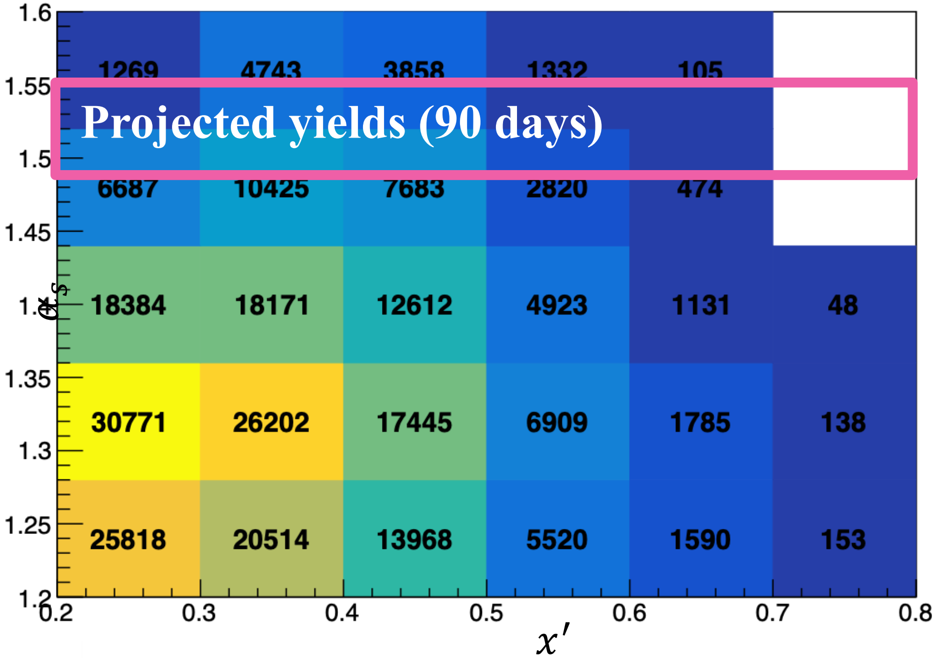
Study bound proton structure by tagging the neutron





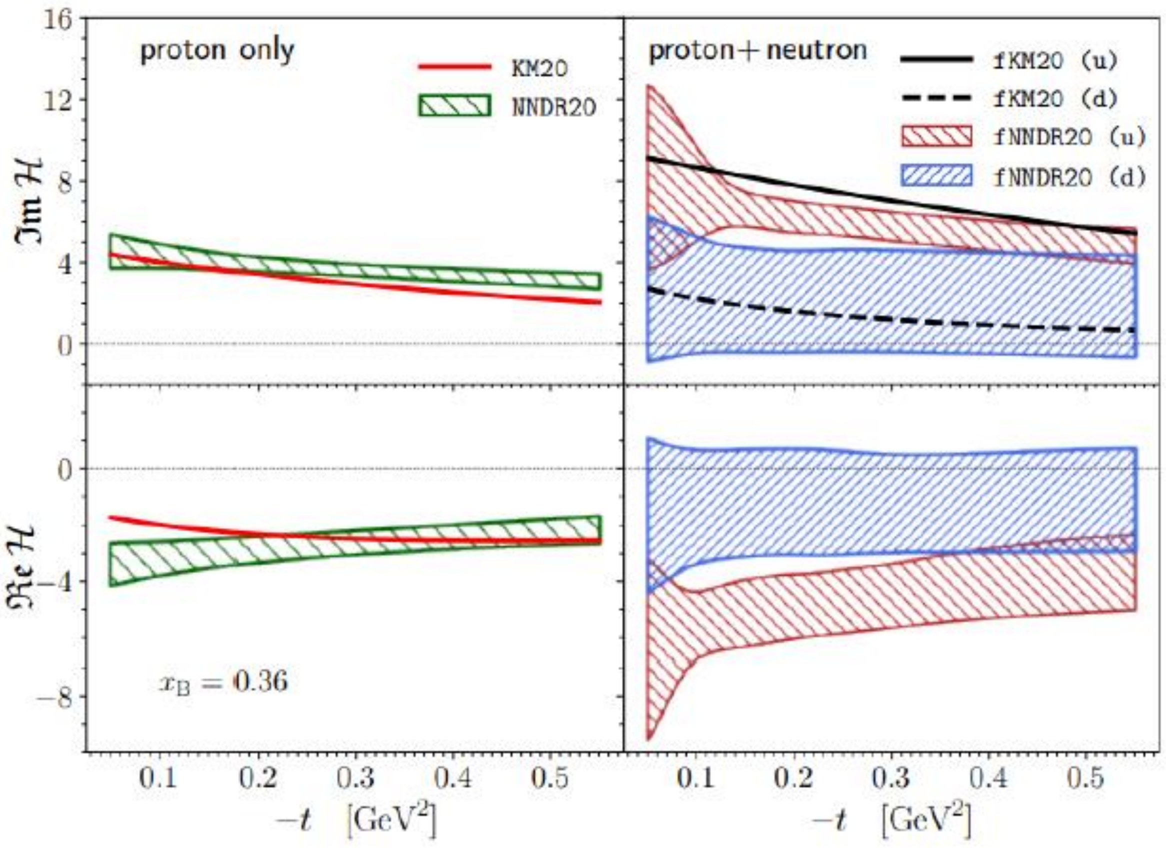
E. Segarra et al. (MIT, ODU)

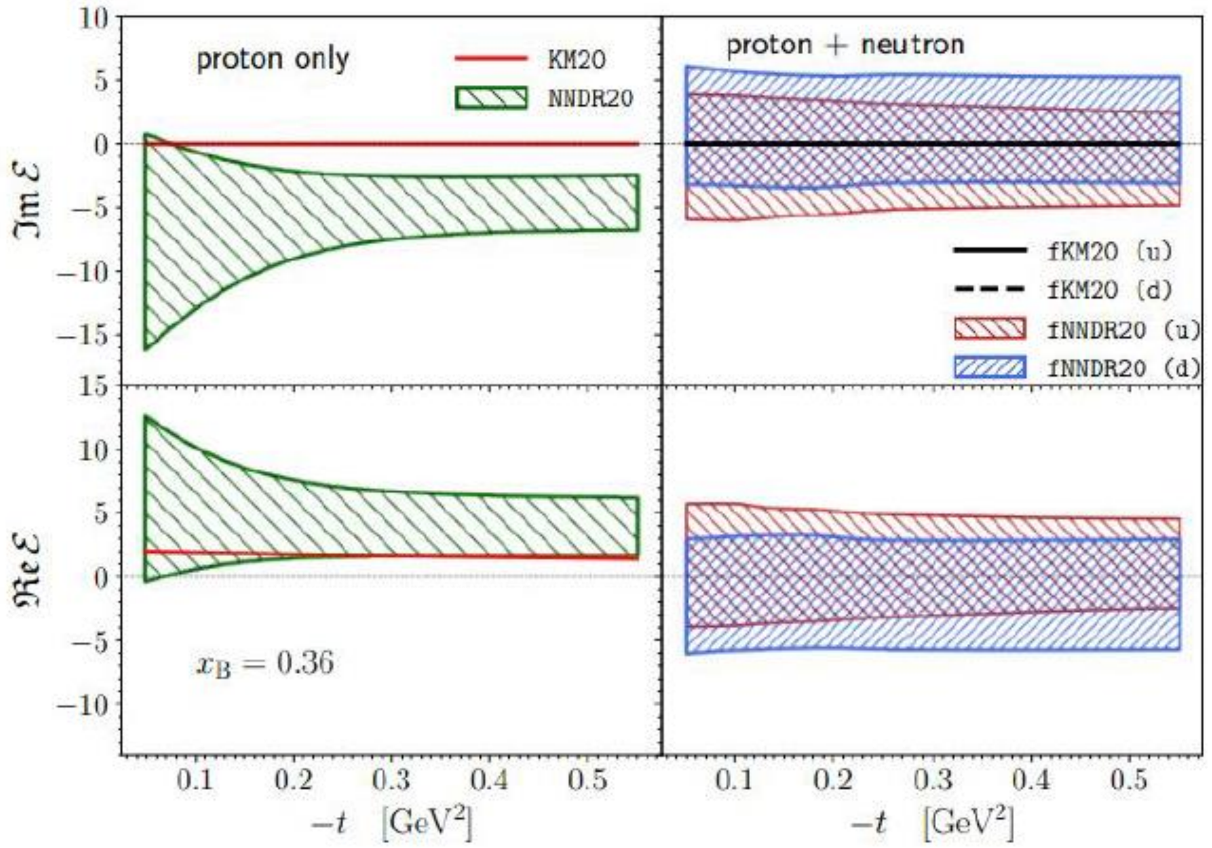




Extraction of CFFs and flavor separation using 6-GeV JLab data

M. Čuić, K. Kumericki et al. Phys. Rev. Lett.125.232005 (2020) and Arxiv 2007.00029 (2020)





- Proton- and neutron-DVCS data from JLab (CLAS6 and Hall A)
- Up and down contributions to the CFFs of H are separated
- The CFFs of E are not separated, a significant sign ambiguity remains

E12-07-104	Neutron magnetic form factor	G. Gilfoyle	A-	30
E12-09-007a	Study of parton distributions in K SIDIS	W. Armstrong	A-	56
E12-09-008	Boer-Mulders asymmetry in K SIDIS	M. Contalbrigo	A-	56
E12-11-003	Deeply virtual Compton scattering on the neutron	S. Niccolai	A **(HI)**	**90**
E12-09-008b	Collinear nucleon structure at twist-3 in di-hadron SIDIS	M. Mirazita	RG	
E12-11-003a	In medium structure functions, SRC, and the EMC effect	O. Hen	RG	
E12-11-003b	Study of J/ψ photoproduction off the deuteron	Y. Ilieva	RG	
E12-11-003c	Quasi-real photoproduction on deuterium	F. Hauenstein	RG	