

# Run Group B status update

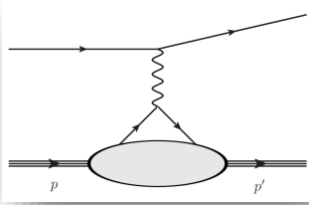
- RGB experiments
- Overview of the data taking
- Status of data processing and calibrations
- Analysis updates



Silvia Niccolai, IJCLab  
CLAS Collaboration meeting, 7/21/2020

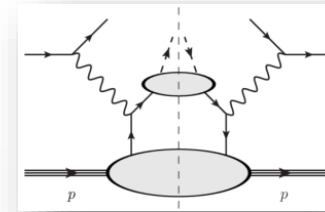
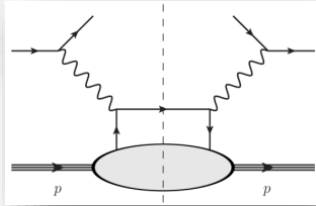


# CLAS12 Run Group B: experiments



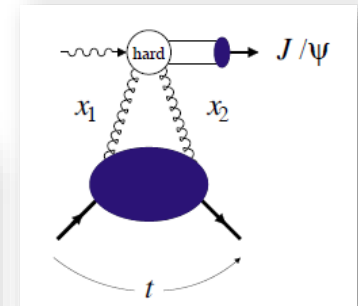
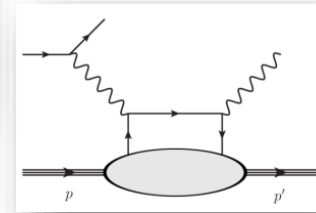
**Elastic Scattering**  
( $G_M^n$ )

**DIS (for SRC and EMC effect)**



**SIDIS (for PDFs and TMDs)**

**nDVCS**



**J/ $\psi$  photoproduction**

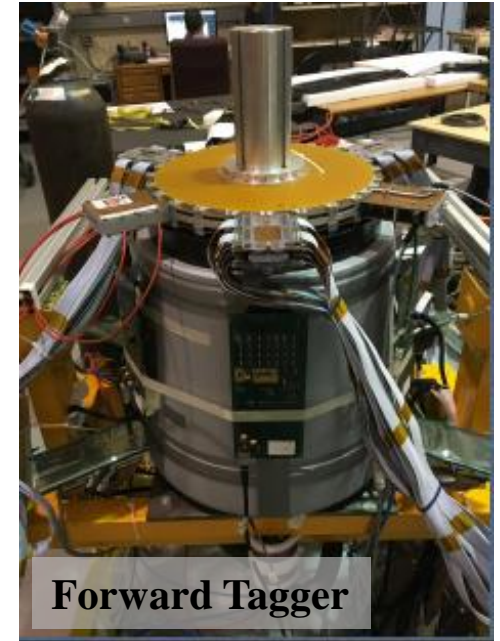
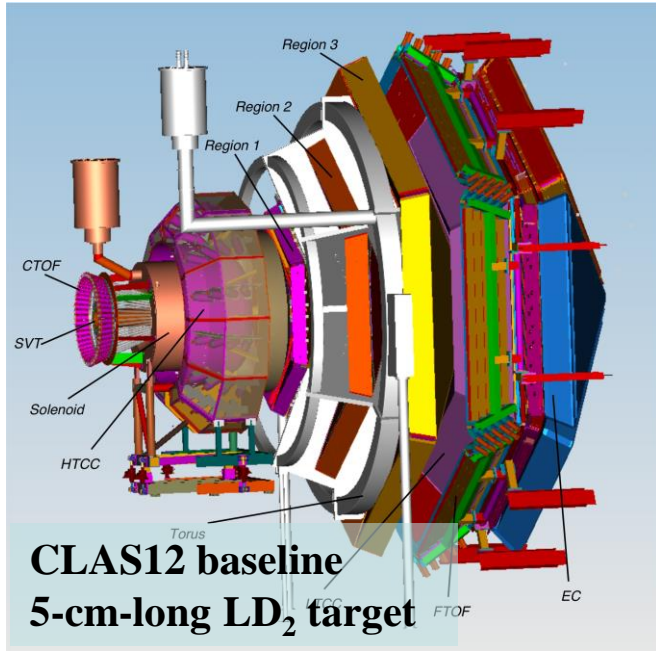
E12-07-104	Neutron magnetic form factor	G. Gilfoyle	A-	30
E12-09-007a	Study of parton distributions in K SIDIS	W. Armstrong	A-	56
E12-09-008	Boer-Mulders asymmetry in K SIDIS	M. Contalbrigo	A-	56
E12-11-003	Deeply virtual Compton scattering on the neutron	S. Niccolai	A (HI)	90
E12-09-008b	Collinear nucleon structure at twist-3 in 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/ $\psi$ photoproduction off the deuteron	Y. Ilieva	RG	
E12-11-003c	Quasi-real photoproduction on deuterium	F. Hauenstein	RG (*)	

Common features to all experiments of RG-B:

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

(\*) Joined RGB from fall run onwards

# Experimental setup (common to the 3 run periods)



# Run Group B overall statistics

## 2019 schedule:

Spring: February 6th - March 25th 2019

Fall: December 3 –20 2019

Winter: January 6 – 30 2020

38.9 total PAC days according to ABUs  
→ 43.2% of the approved 90 PAC days  
51 days requested for Jeopardy PAC

## 43.3 B triggers collected at 3 different beam energies:

10.6 GeV (9.7 B),

10.2 GeV (11.7 B),

10.4 GeV (21.9 B – 9 B outbending)

## Special runs (all run periods):

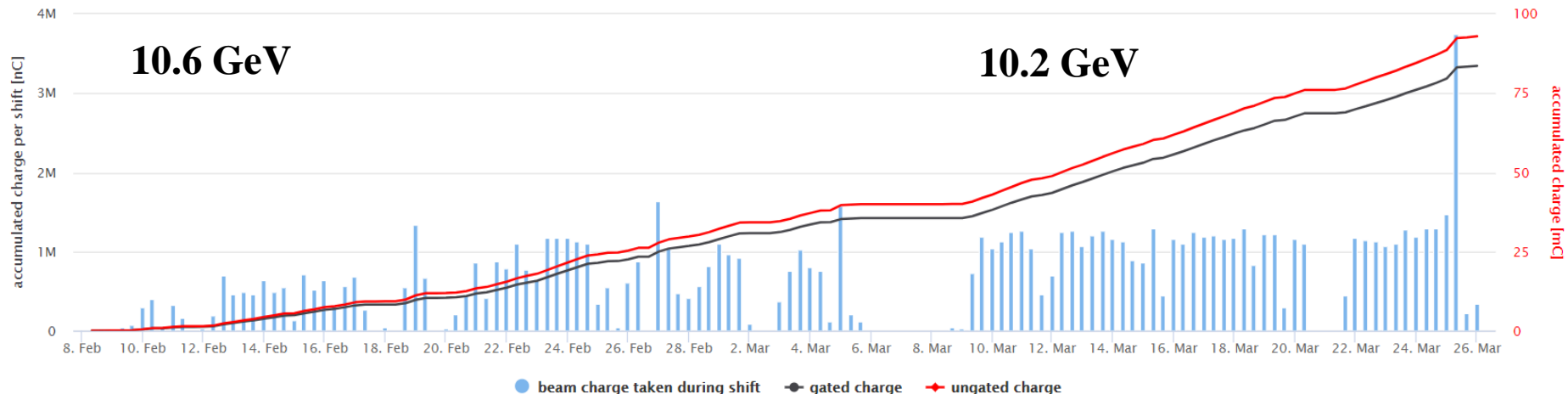
- 27 low-luminosity runs
- 9 empty target runs
- Several random trigger runs
- 3 zero-field alignment runs

Average beam polarization ~86% (22 Moeller runs)

start date: 02/08/2019

end date: 03/25/2019

Accumulated beam charge [IPM2C21A]



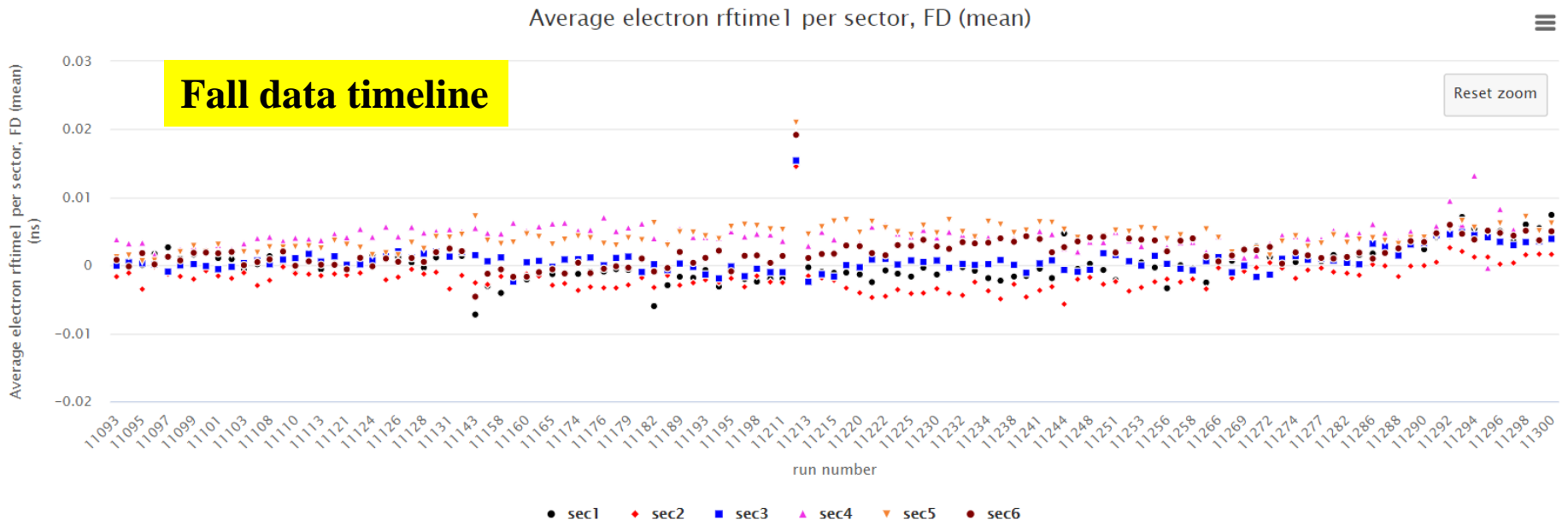
# Data processing and calibrations

## Spring19 data:

- Pass1 review on May 8th
- Work done on improved calibrations, updates to reconstruction (CD veto, neutral PID), understanding data features
- Replies given on June 6th, review completed
- Pass1 cooking started on June 13
- ~60% cooked at today, with one week of interruption due to farm problems
- RGK starts today parallel running with RGB for one week, then we'll pause RGB to give priority to RGK
- We'll resume RGB when RGK will be at 50%.

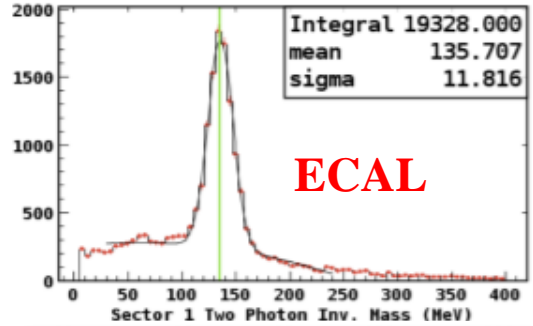
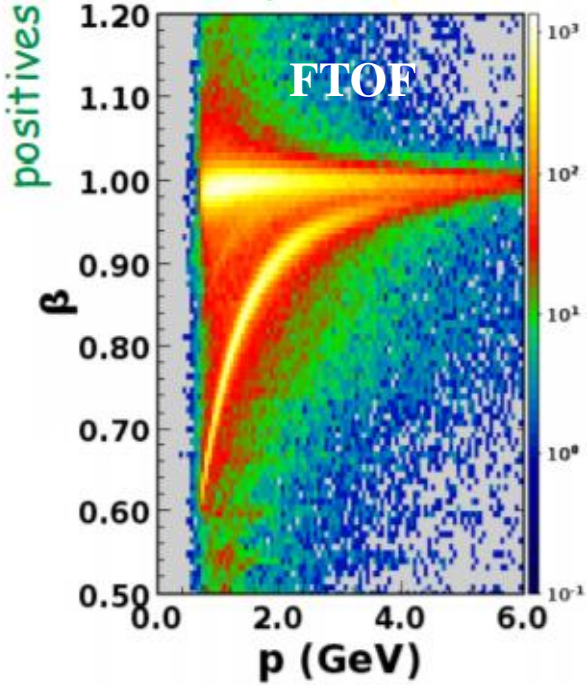
## Fall19 and Winter20 data:

- Cooking of first runs (11093 - 11328), calibration done for FTOF
- RF calibrated for all runs
- First runs calibrated for FTOF, CTOF, FTCal, HTCC, CND
- **Monitoring pass and analysis of timelines recently redone for *Fall* data, with latest COATJAVA**
- **Established runs to calibrate for *Fall* data**

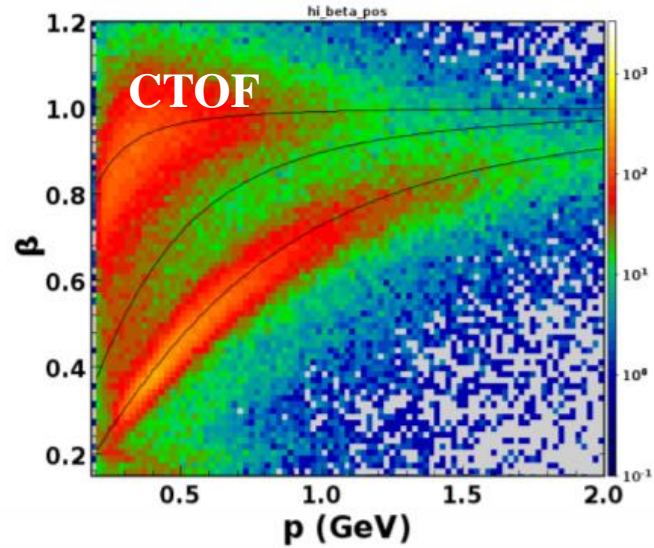
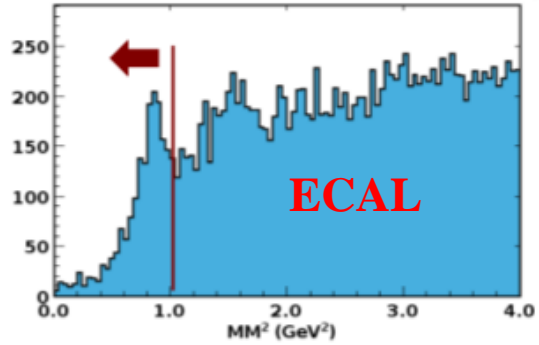


# Data quality of RGB data

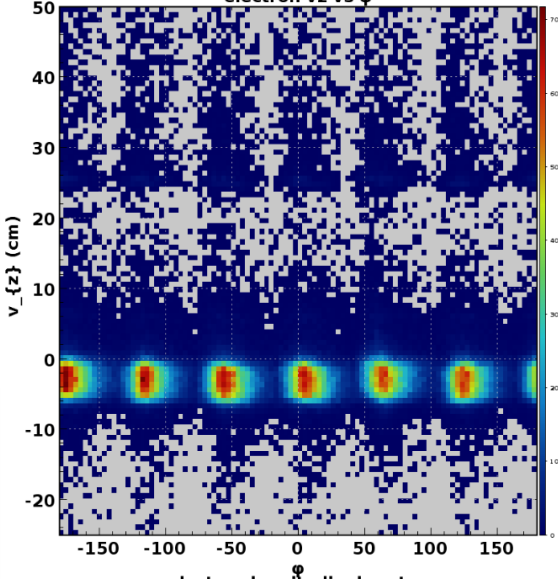
panel-1a



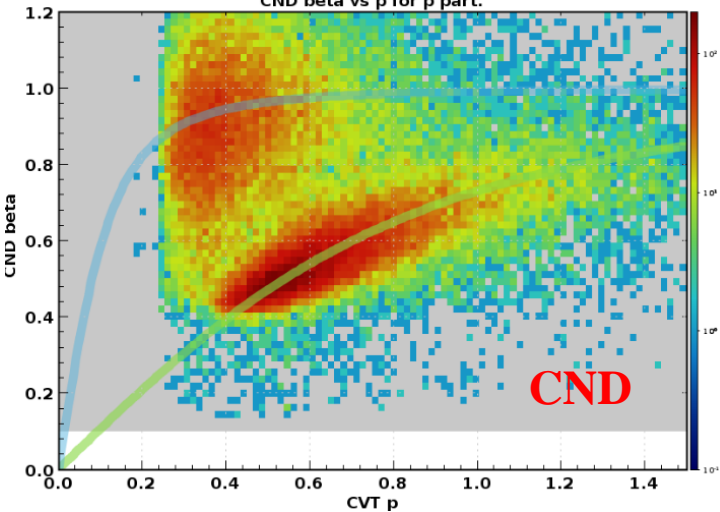
tagged neutrons  $d(e, e'\pi^+)nn$



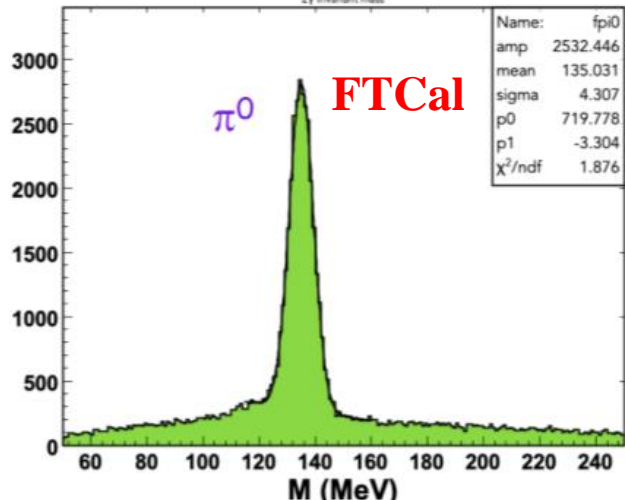
electron vz vs phi



CND beta vs p for p part.



Zy invariant mass



# CND: performances with CLAS12 data

**Purpose:** detect the **recoiling neutron in nDVCS**

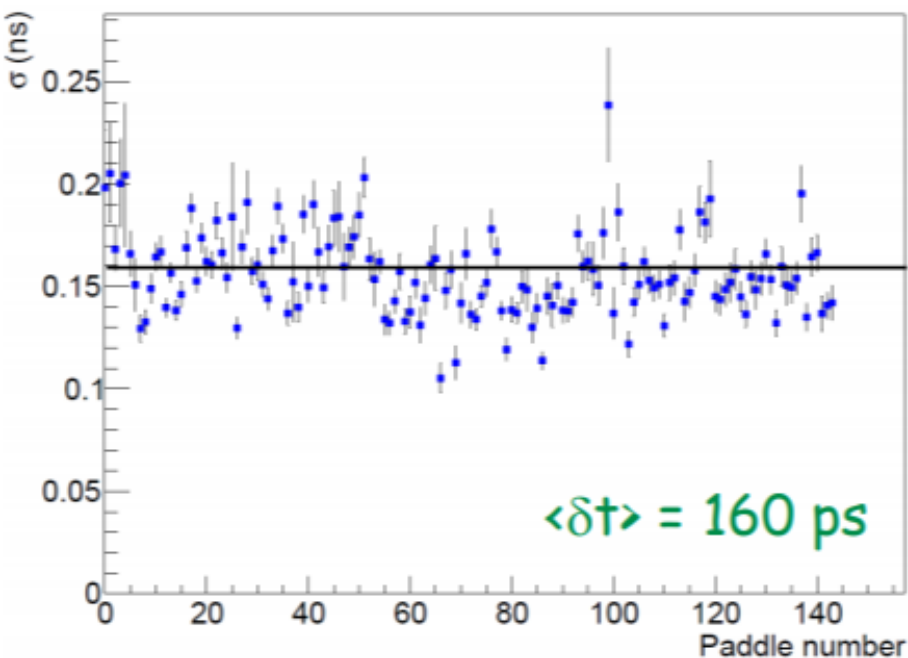
Requirements/performances:

- good neutron/photon separation for  $0.2 < p_n < 1$  GeV/c  
→  $\sim 150$  ps time resolution ✓ ( $\sim 160$  ps)
- momentum resolution  $\delta p/p < 10\%$  ✓
- neutron detection efficiency  $\sim 10\%$  ✓

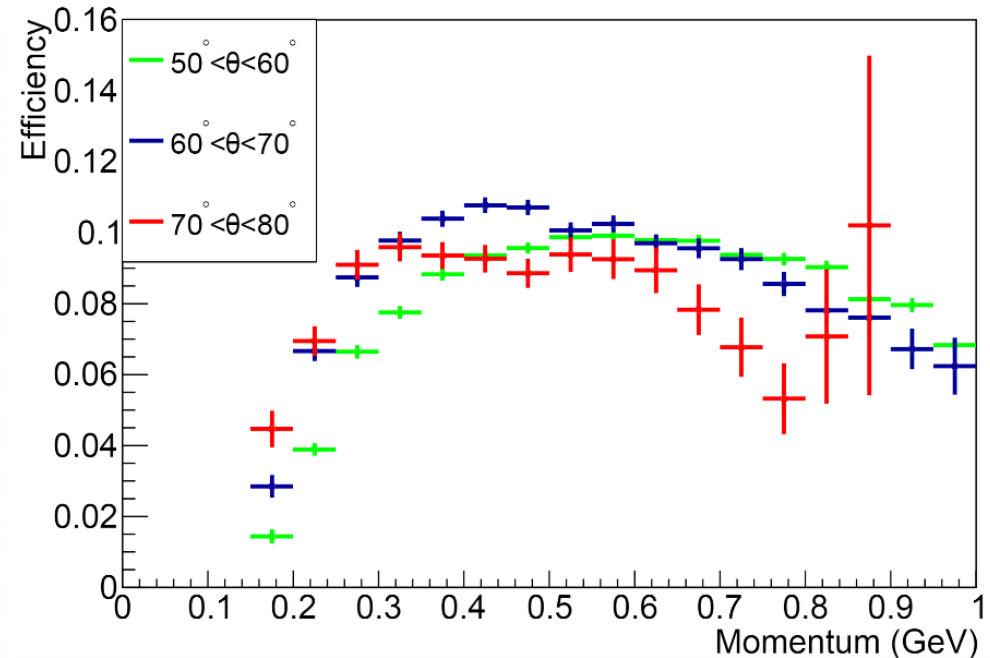
**CND design:** **scintillator barrel** - 3 radial layers, 48 bars per layer **coupled two-by-two** downstream by a **“u-turn” lightguide**, 144 long light guides with **PMTs** upstream

**S.N. et al., NIM A 904, 81 (2018)**

Timing resolution per paddle (RGB data)



Neutron efficiency from  $ep \rightarrow e' n \pi^+$  (RGA data)

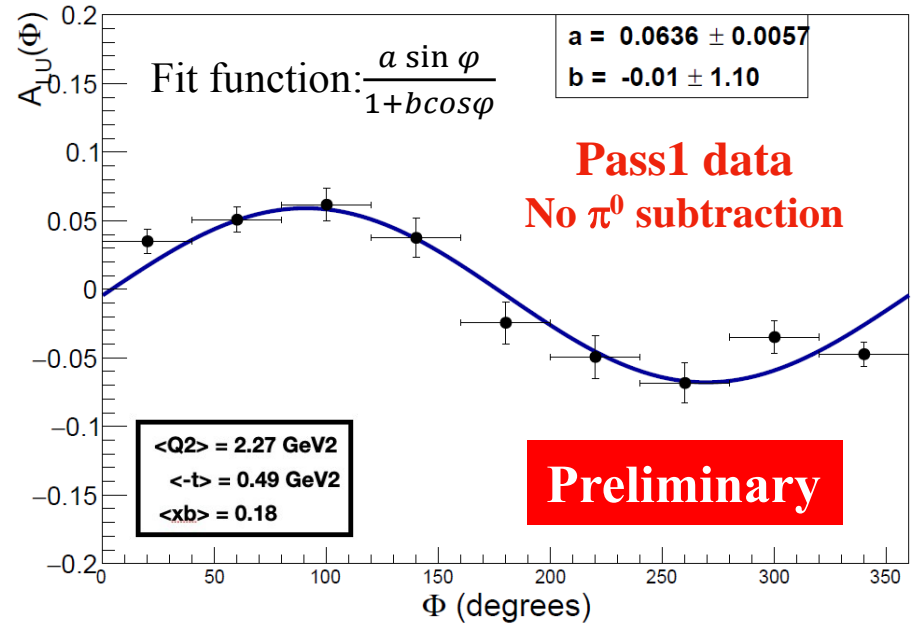
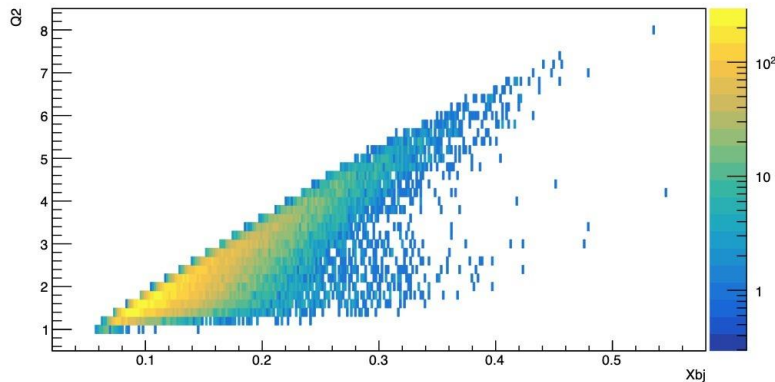
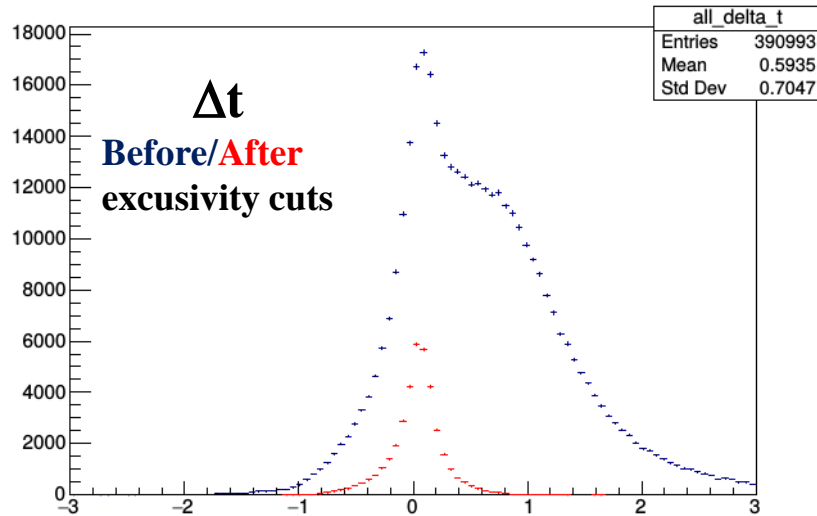


# Analysis updates: nDVCS

ed → en $\gamma$ (p)

- Events with at least one electron, neutron, photon are selected (EB PID + kinematic cuts)
- The chosen combination in each event is the one satisfying at best the exclusivity criteria on:

$M_X, p_X, E_X$  (ed → en $\gamma$ X),  $\Delta t, \Delta\phi, \theta_{\gamma X}$



- 28298 nDVCS event candidates
- Raw BSA integrated over all kinematics, **CD/FT detection topology**
- Includes **a charged particle veto** based on CND and CTOF information: remove proton contamination, due to CVT inefficiencies, from neutrals sample (tests and improvements are ongoing)
- Work ongoing on  $\pi^0$  subtraction, fiducial cuts, etc...

See A. Hobart's talk Wednesday at 12:15

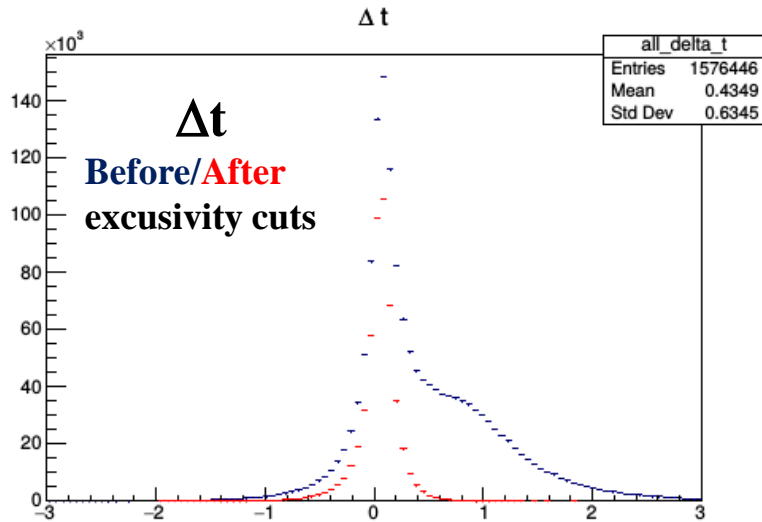


# Incoherent pDVCS on deuterium

ed → e p γ (n)

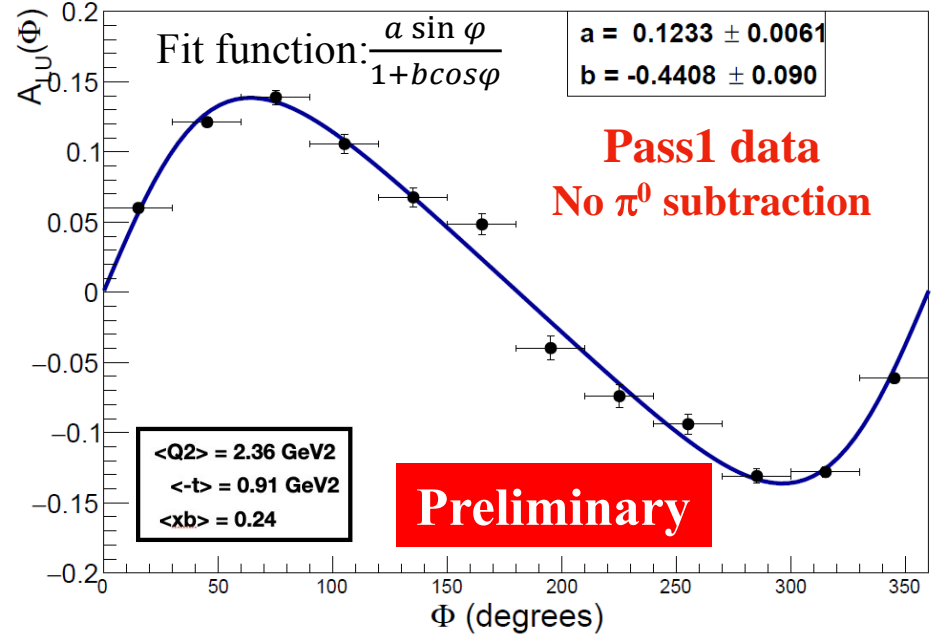
- Events with at least one electron, proton, photon are selected (EB PID + kinematic cuts)
- The chosen combination in each event is the one satisfying at best the exclusivity criteria:

$M_X, p_X, E_X$  (ed → e p γ X),  $\Delta t, \Delta\phi, \theta_{\gamma X}$



Interest of pDVCS on deuterium:

- In itself: nuclear medium effects on proton structure
- To evaluate FSI for nDVCS, comparing to free pDVCS



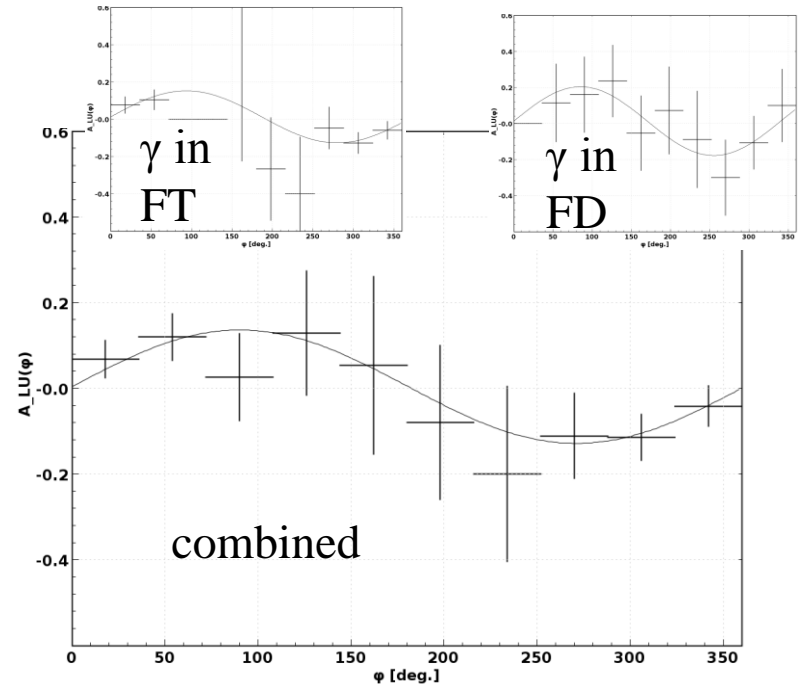
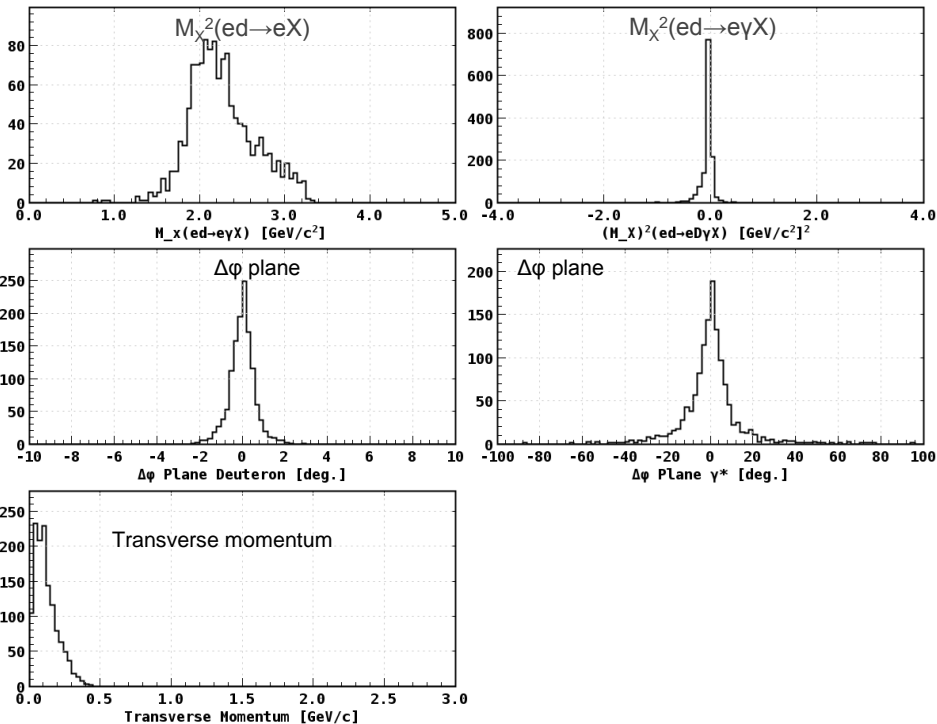
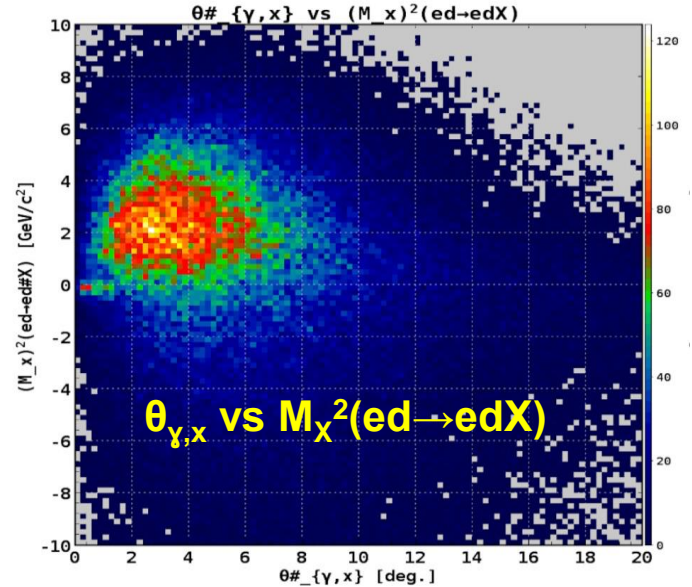
- 777111 identified pDVCS candidates
- Raw BSA integrated over all kinematics and detection topologies
- **Compatible with raw BSA from pDVCS in RGA**
- **nDVCS and pDVCS yields scale as expected (CS, efficiency)**
- Work ongoing on  $\pi^0$  subtraction, fiducial cuts, etc...

See A. Hobart's talk Wednesday at 12:15

# Coherent Deuteron DVCS

- 35 runs - pass0v16 (DNP cooking)
- $e + D \rightarrow e + D + \gamma$
- Exclusivity cuts for events with  $\gamma$  in FT:
  - $E_X(\text{ed} \rightarrow \text{ed}\gamma X) < 2 \text{ GeV}$
  - $p_t < 0.5 \text{ GeV}/c$
  - 2-dimensional cut on  $\theta_{\gamma,x}$  vs  $M_X^2(\text{ed} \rightarrow \text{ed}X)$
- Similar cuts for FD

*J. Dickovick,  
A. Biselli  
B. (Fairfield U.)*



# Hard Exclusive $\pi_0$ -Production

Paul Naidoo & Daria Sokhan – University of Glasgow

- Channels:**

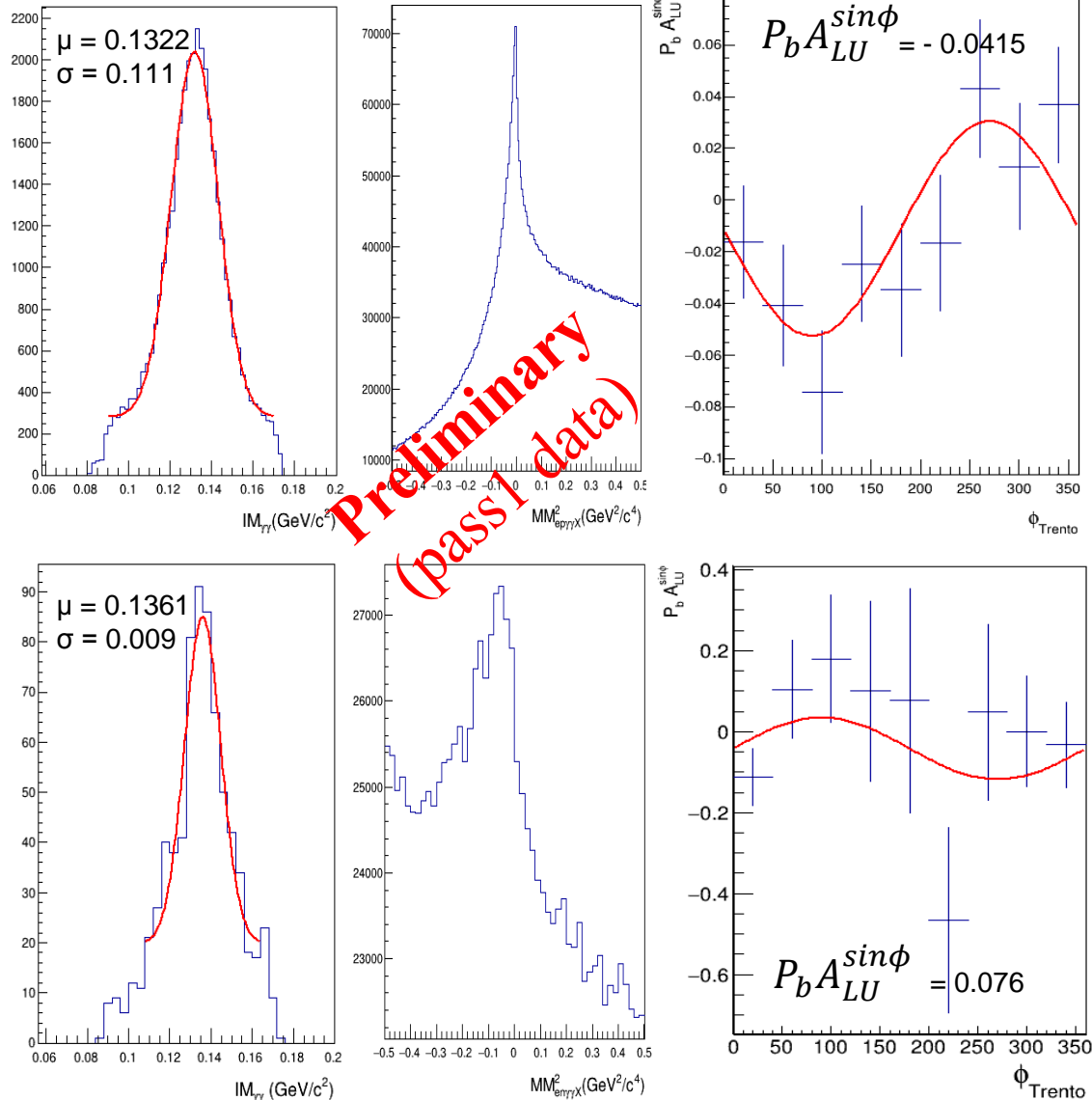
- $ed \rightarrow e'p'\pi_0(n_{\text{spect.}})$
- $ed \rightarrow e'n'\pi_0(p_{\text{spect.}})$

- Motivation:**

- DVCS and DVMP with proton and neutron targets needed for **flavour separation of GPDs**
- Exclusive  $\pi_0$  production is sensitive to **transversity GPDs**

- Cuts (work in progress):**

- $3\sigma$   $\pi_0$  mass
- $\pi_0$ -cone angle  $< 20^\circ$
- $|MM^2_{eN \rightarrow e'N'\gamma\gamma}| < 0.5 \text{ GeV}^2$
- $MP_{eD \rightarrow e'p'\gamma\gamma} < 0.7 \text{ GeV}$
- $Q^2 > 1 \text{ GeV}^2/c^4$
- $-t < 1 \text{ GeV}^2/c^4$



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

Work by L.Baashen (FIU), B.A. Raue (FIU), G. Gilfoyle (Richmond), L.C. Smith (UVA)

**Motivation :** Fundamental quantity related to the magnetization in the nucleon.

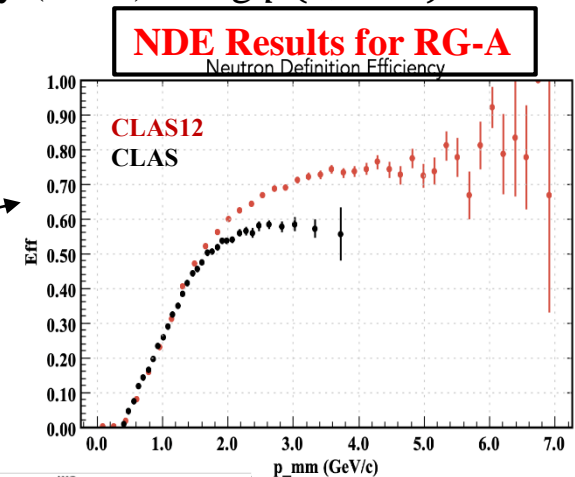
**Method :** Extract  $G_M^n$  using ratio technique:  $R = \frac{d(e,e'n)p}{d(e,e'p)n}$  in quasi-elastic (QE) kinematics.

**Required :** Precise determination of the neutron detection efficiency (NDE) using  $p(e,e'\pi^+)n$  reaction on hydrogen target in Run Group A.

**Analysis Status:**

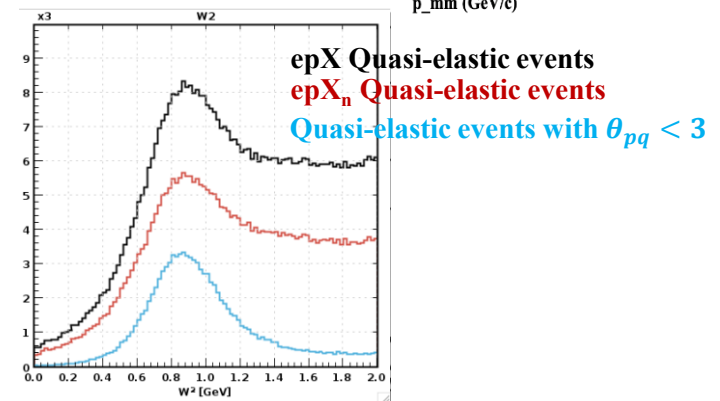
➤ **NDE Using RG-A:**

- NDE = 0.73 at the plateau ( $p_{mm} > 3.5$  GeV)
- Investigating the accuracy of both the numerator and denominator of the efficiency ratio to determine the right shape background using simulation.

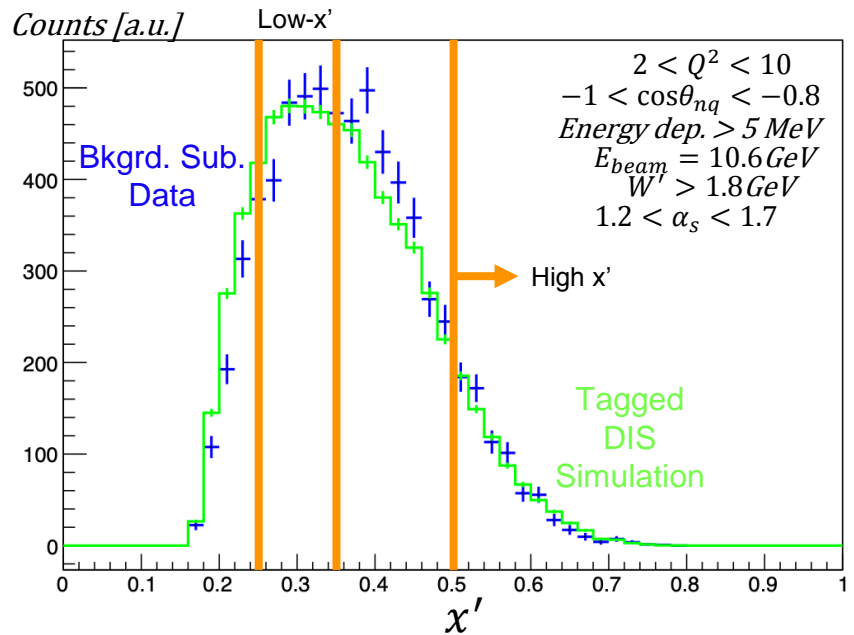
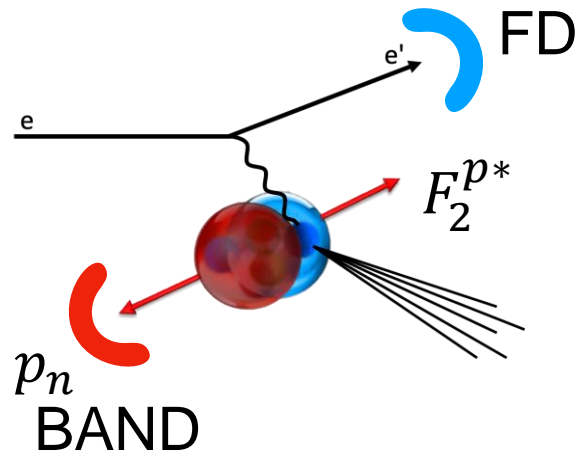


➤  **$G_M^n$  Using RG-B (DNP cooking):**

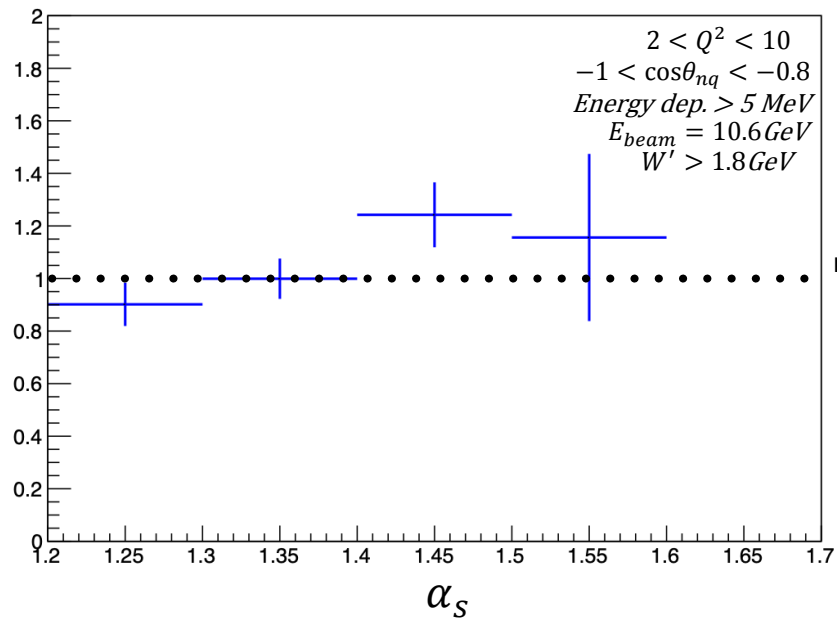
- Developed and tested codes to extract  $R$  on early DSTs and simulation.
- Plot shows effect of cuts on QE  $e'p$  selection.



# Study bound proton structure by tagging neutron



[High  $x'$  Data/High  $x'$  Sim]/[Low  $x'$  Data/Low  $x'$  Sim]



1 = No modification of proton structure

E. Segarra (MIT)

## Next steps:

- simulation (neutron smearing, radiative effects, etc..)
- Pass-1 validation
- double ratio systematics

## DNP Cook (10.6 GeV only)

$$\alpha_s = (E_s - p_s^z) / m_s$$

# Di-hadron Multiplicity

$$e N \rightarrow e' \pi^+ \pi^- X$$

Number of di-hadron pairs per DIS electron

$$M(z, pT, Q^2, x, M_{hh}) = \frac{d\sigma^{hh}/dx_B dQ^2 dz dM_{hh}}{d\sigma_e^{DIS}/dx_B dQ^2}$$

$$d\sigma^{dh} \propto \sum_q e_q^2 f_{1,q}(x_B) D_{1,q}(z, M_h)$$

Di-hadron unpolarized Fragmentation Function (FF)

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

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

$K_f \rightarrow$  kinematic factors

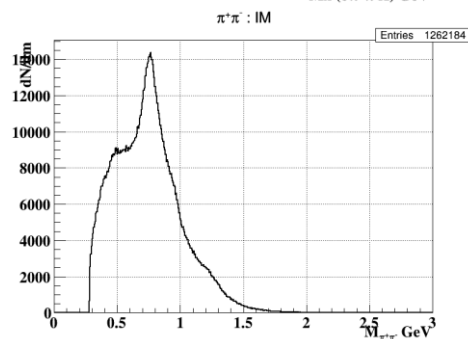
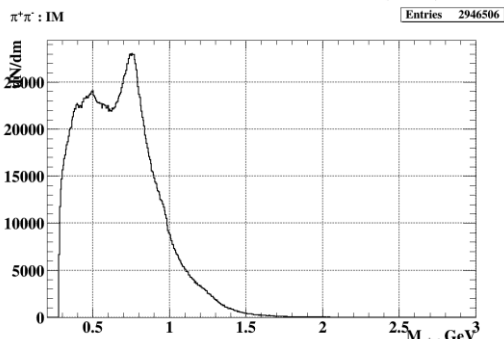
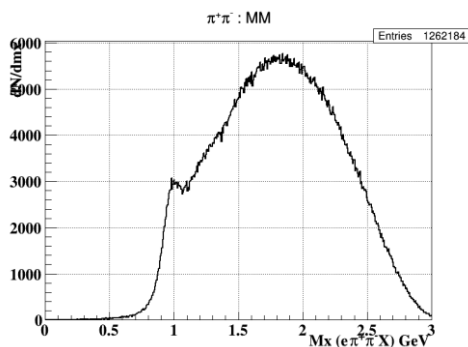
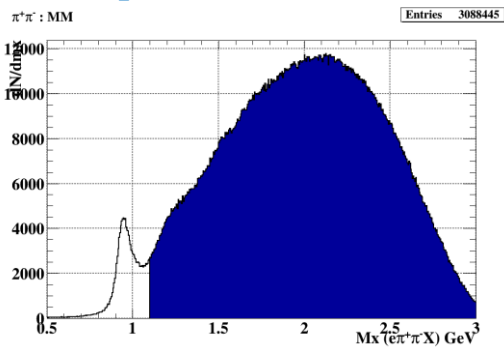
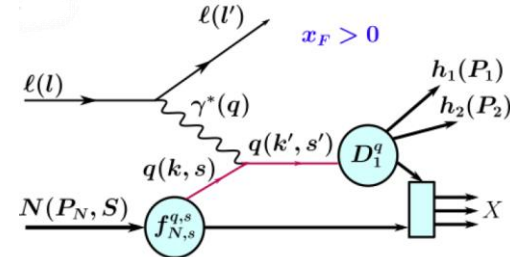
$$D_{1,d}^{dh} = 3 \frac{\frac{4}{9} M^d (f_{1,u} + f_{1,d}) - M^p \left( \frac{4}{9} f_{1,u} + \frac{1}{9} f_{1,d} \right)}{K_f f_{1,d}}$$

$f_{1q}$  of the proton are known

proton data

$K_f f_{1,d}$

deuteron data



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

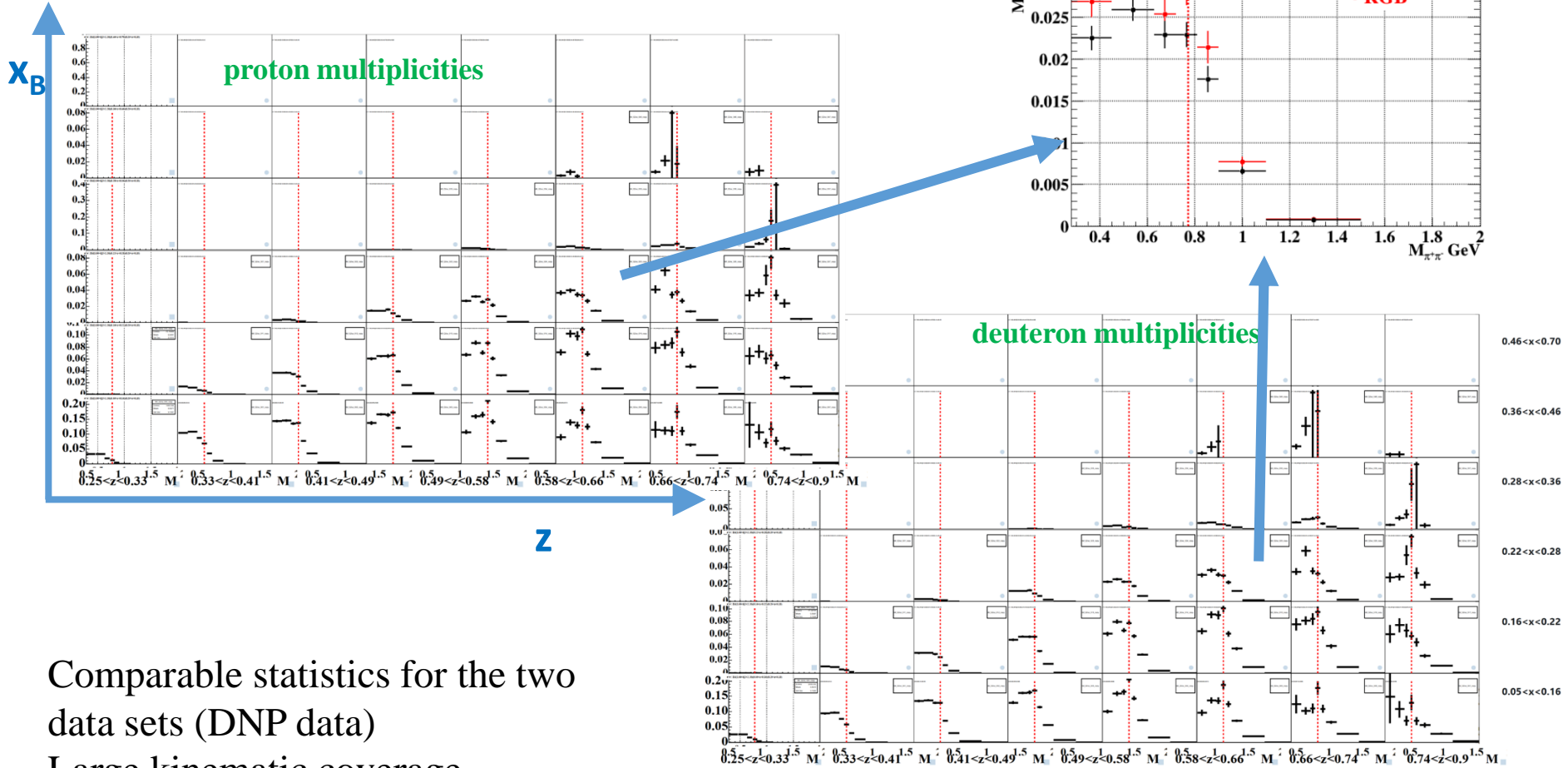
Monte-Carlo acceptance included

- proton target data available
- deuteron data in production
- rg-B data corrected with proton MC

Reasonable agreement between data and MC

# Multiplicities

$$1 < Q^2 < 2.2 \text{ GeV}^2$$



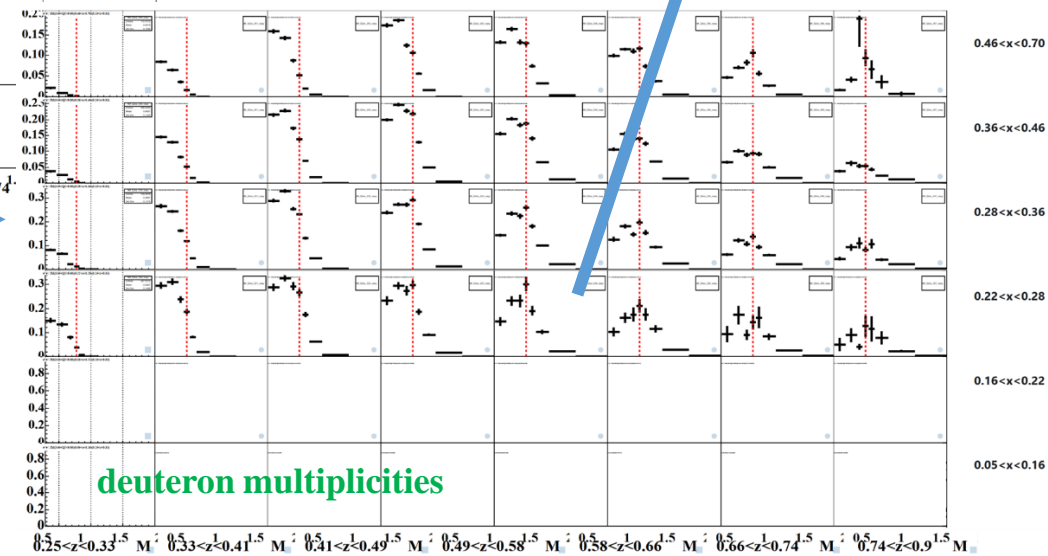
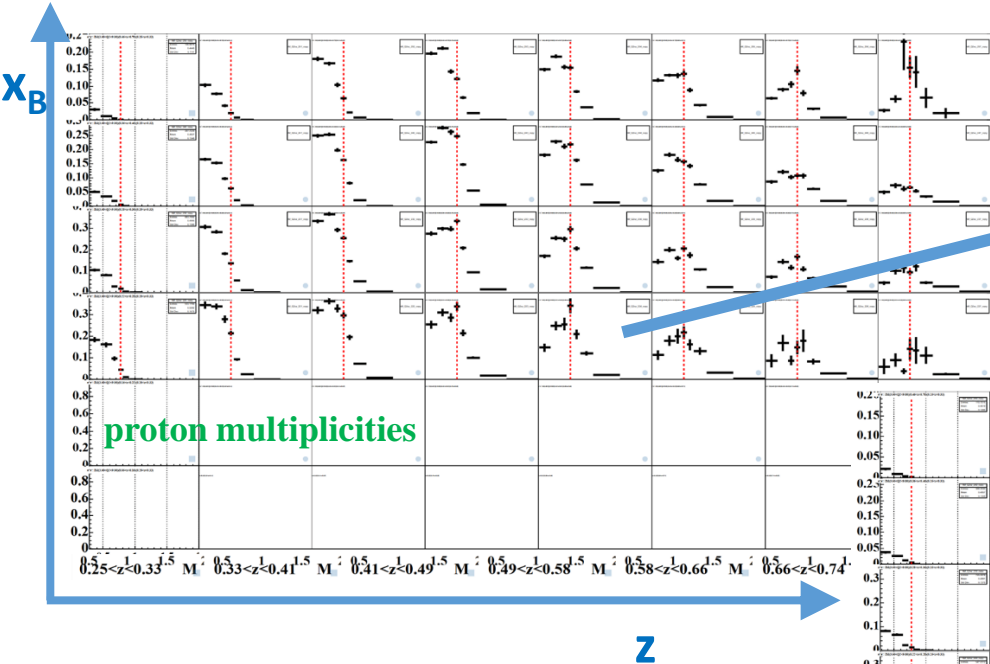
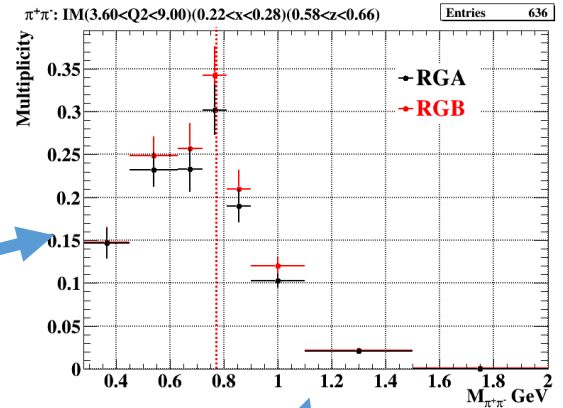
Comparable statistics for the two data sets (DNP data)

Large kinematic coverage

First-time measurement

# Multiplicities

$3.6 < Q^2 < 9.0 \text{ GeV}^2$



- Comparable statistics for the two data sets (DNP data)
- Large kinematic coverage
- First-time measurement



# Conclusions

- The first « half » of RG-B running ended on January 30
- ~38.9 PAC days collected out of 90 approved for nDVCS
- Three different beam energies for the 3 periods
- Cooking ~60% done for the Spring dataset (~50% of the collected statistics)
- Calibrations well advanced for Fall and Winter datasets
- Physics analyses in good progress: n/p/d-DVCS, n/p-DVMP( $\pi^0$ ),  $G_M^n$ , Tagged-DIS, Di-hadron SIDIS
- Jeopardy PAC on September 25, 51 PAC days requested

**All this is possible thanks to our great RG-B team**

Special thanks to:

**Chef:** Zhiwen Zhao

**Monitoring:** Yordanka Ilieva

**Timelines:** Sangbaek Lee

All **detector experts** and **calibrators**

All people involved in **data analysis**

***Weekly RGB meeting: Friday 8:30AM, BJ: 237353330***