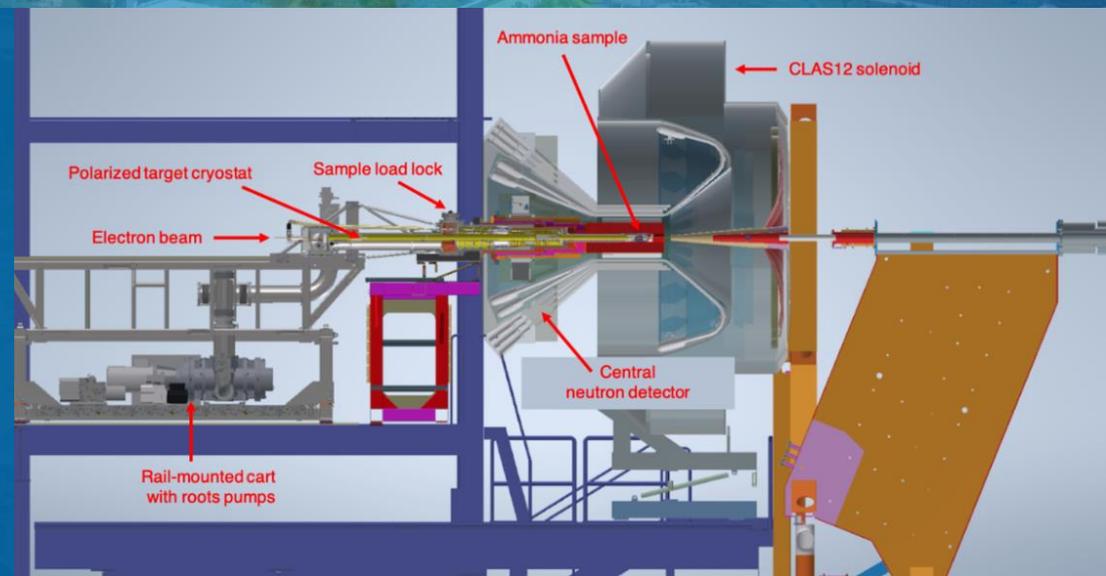


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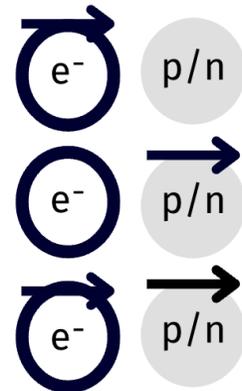
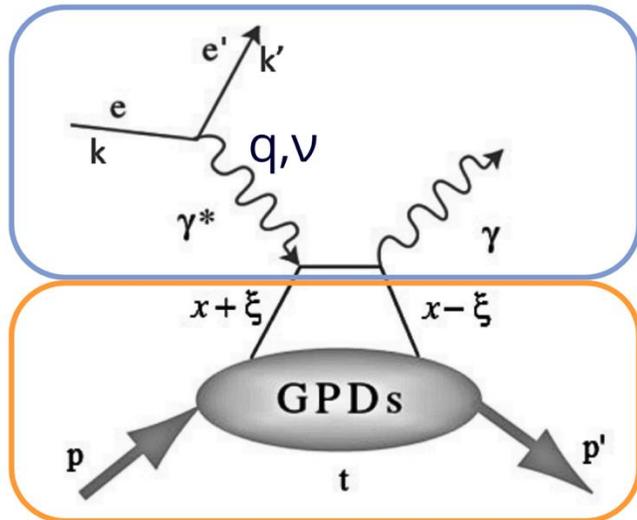
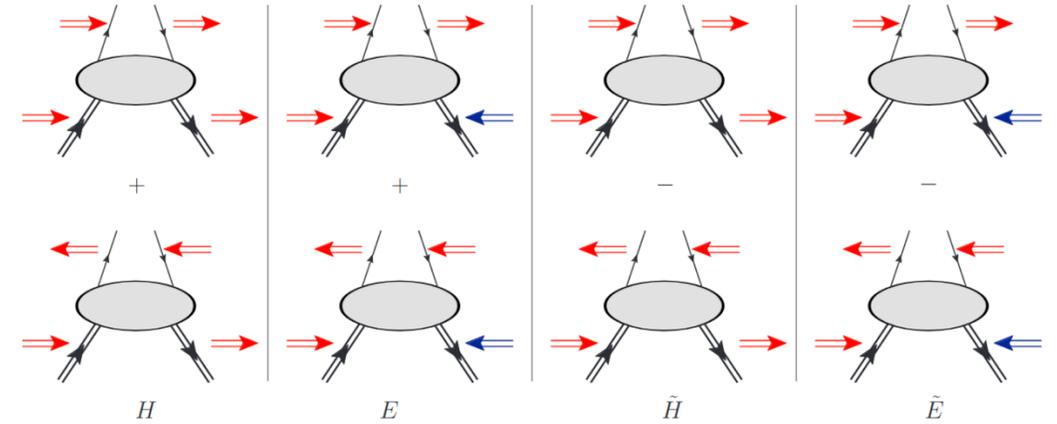
DVCS ON POLARIZED PROTONS IN DEUTERIUM WITH RGC



NOÉMIE PILLEUX

GENERALIZED PARTON DISTRIBUTIONS WITH LONGITUDINALLY POLARIZED TARGETS

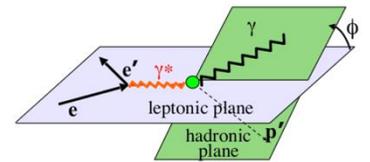
- Relative orientation of the probed quark helicity and nucleon spin: 4 helicity-conserving quark GPDs for nucleons
- Polarized electron beams and targets in the DVCS reaction give access to the associated Compton Form Factors



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

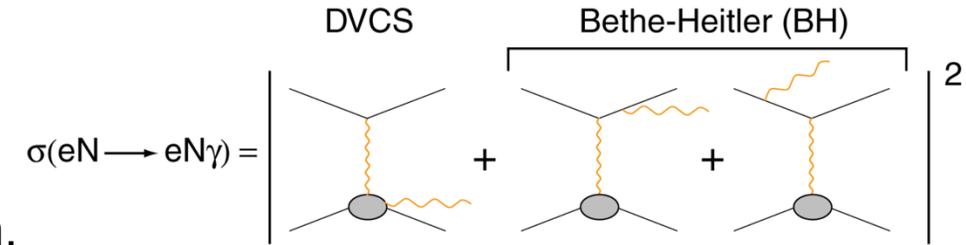
$$\Delta\sigma_{UL} \propto \sin(\phi) \Im \left[F_1 \tilde{\mathcal{H}} + \xi(F_1 + F_2) \left(\mathcal{H} + \frac{x_{bj}}{2} \mathcal{E} \right) - \xi \left(\frac{x_{bj}}{2} F_1 + \frac{t}{4M^2} F_2 \right) \tilde{\mathcal{E}} \right]$$

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



PROTON AND NEUTRON DVCS

- Interference with the Bethe-Heitler process involves form factors
→ protons and neutrons are sensitive to different CFFs
- Data on both protons and neutrons allow for flavor-decomposition.



$$\begin{aligned}
 \text{e}^- \text{ p/n} \quad \Delta\sigma_{LU} &\propto \sin(\phi) \Im \left[F_1 \mathcal{H} + \xi(F_1 + F_2) \tilde{\mathcal{H}} - \xi \frac{t}{4M^2} F_2 \mathcal{E} \right] \\
 \text{e}^- \text{ p/n} \quad \Delta\sigma_{UL} &\propto \sin(\phi) \Im \left[F_1 \tilde{\mathcal{H}} + \xi(F_1 + F_2) \left(\mathcal{H} + \frac{x_{bj}}{2} \mathcal{E} \right) - \xi \left(\frac{x_{bj}}{2} F_1 + \frac{t}{4M^2} F_2 \right) \tilde{\mathcal{E}} \right] \\
 \text{e}^- \text{ p/n} \quad \Delta\sigma_{LL} &\propto (A + B \cos(\phi)) \Re \left[F_1 \tilde{\mathcal{H}} + \xi(F_1 + F_2) \left(\mathcal{H} + \frac{x_{bj}}{2} \mathcal{E} \right) - \xi \left(\frac{x_{bj}}{2} F_1 + \frac{t}{4M^2} F_2 \right) \tilde{\mathcal{E}} \right]
 \end{aligned}$$

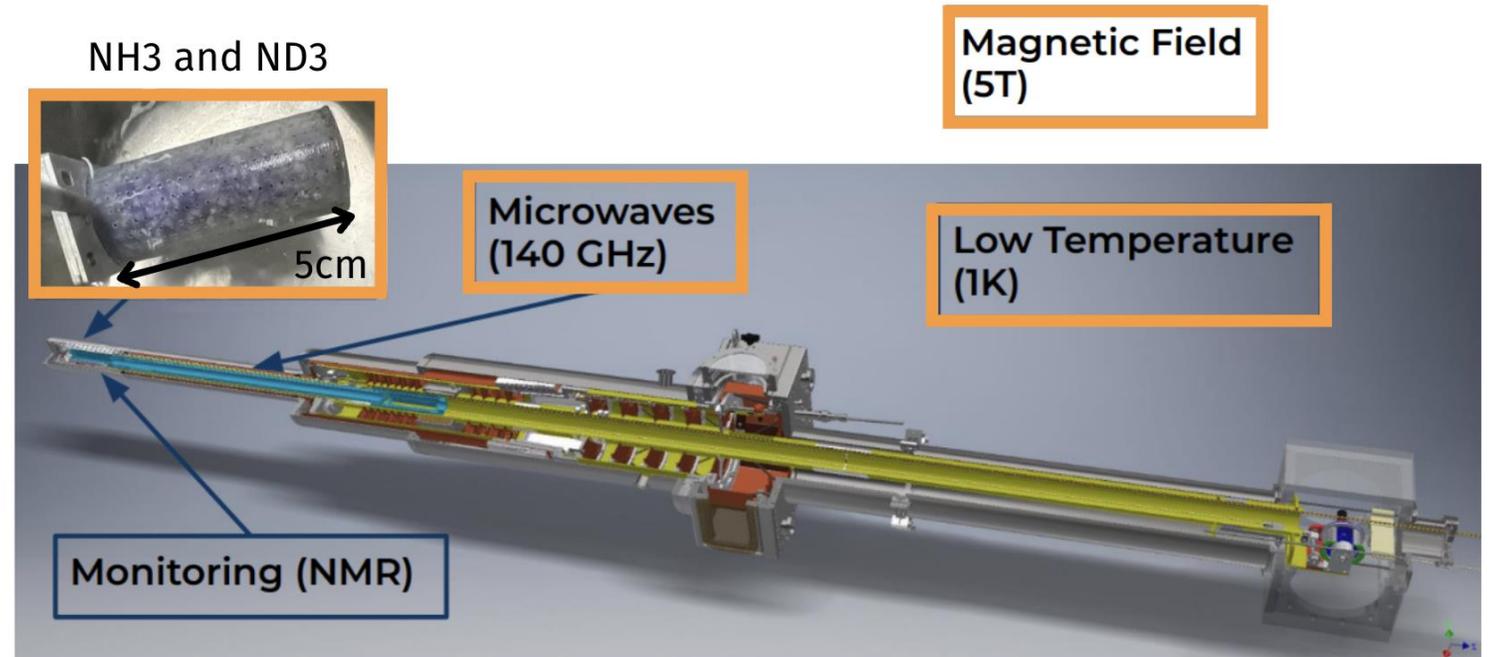
$$\mathcal{F}^u(\xi, t) = \frac{9}{15} (4\mathcal{F}_p(\xi, t) - \mathcal{F}_n(\xi, t))$$

$$\mathcal{F}^d(\xi, t) = \frac{9}{15} (4\mathcal{F}_n(\xi, t) - \mathcal{F}_p(\xi, t))$$

- No free neutron target: measurement in light nuclei, deuterium.
- Binding effects? Data on free protons in H and bound protons in D.

RUN GROUP C

- Dynamically polarized nucleons in deuterium with ND₃ target
- Dynamically polarized target monitored with NMR
- Rastered beam
- ND₃, NH₃, C, CH₂, CD₂, ET targets



V. Lagerquist and the JLab Target Group

Dataset:

- "Summer2022": FT on, lower current, smaller target and raster radius
- "Fall2022": FT off, higher current, larger target and raster radius
- "Spring2023": back to the FT on configuration

MEASURING THE TARGET POLARIZATION

- Comparison between calculable and measured elastic double spin asymmetry → beam and target polarizations PbPt

$$A_{th} = \frac{2\tau G \left[\frac{M_p}{E_b} + G \left(\tau \frac{M_p}{E_b} + (1+\tau) \tan^2\left(\frac{\theta}{2}\right) \right) \right]}{1 + G^2 \frac{\tau}{\epsilon}} \quad G = \frac{G_M}{G_E} \quad P_b P_t = \frac{A_{meas}}{A_{th}}$$

- Q²-binned max likelihood estimation

dilution factor yields with positive/negative beam helicity

$$P_b P_t = \frac{\sum_{i=0}^{N_{bins}} f_i A_{th,i} (N_i^+ - N_i^-)}{\sum_{i=0}^{N_{bins}} f_i^2 A_{th,i}^2 (N_i^+ + N_i^-)} \quad f = \frac{N_D}{N_{ND_3}}$$

- Measurement is done on each orientation of the target polarization
- Need to account for the dilution from the unpolarized material in the target (N, liquid helium, aluminum foils)

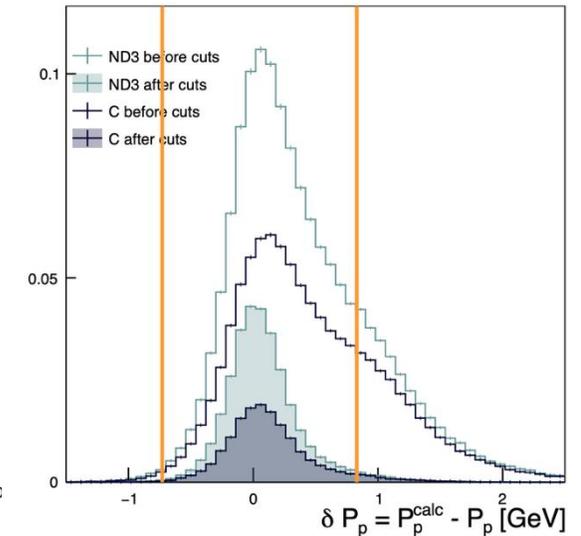
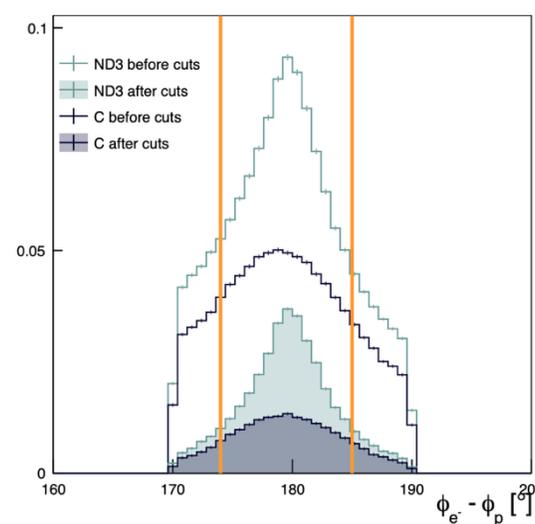
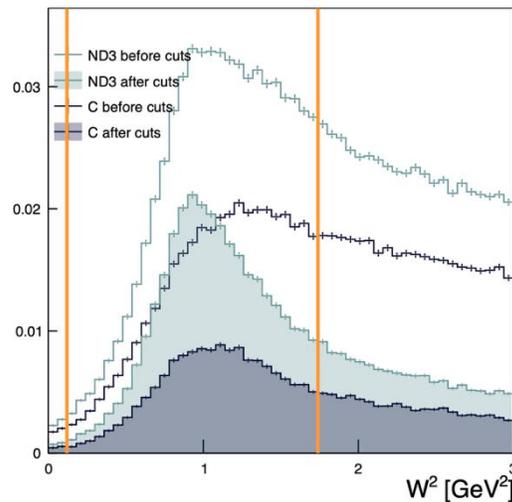
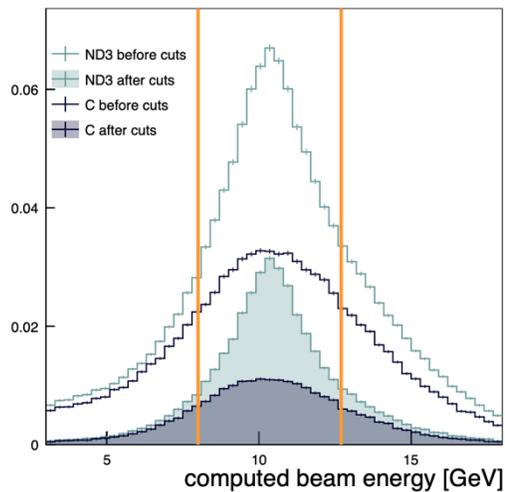
ELASTIC EVENTS

- Exclusive measurement of the elastic channel $ep \rightarrow e'p'$
- Protons are detected in the CD
- Very preliminary fiducial/PID cuts are applied

Variable	Min	max
$\Delta\phi$ [°]	174	185
$\Delta P(\text{proton})$ [GeV]	-0.73	0.83
Beam energy [GeV]	8.0	12.7
W^2 [GeV ²]	0.12	1.74

$$E_{\text{beam}}^{\text{calc}} = M \left(\frac{1}{\tan(\theta_{e^-}/2) \tan(\theta_p)} - 1 \right)$$

$$P_p^{\text{expected}} = \frac{E_{\text{beam}}}{1 + \frac{E_{\text{beam}}}{m_p} (1 - \cos(\theta_{e^-}))} \times \sqrt{\left(1 + \frac{E_{\text{beam}}}{m_p}\right)^2 (1 - \cos(\theta_{e^-}))^2 + \sin(\theta_{e^-})^2}$$



DILUTION FACTOR

- Data on auxiliary targets are used to estimate the dilution:
 - Carbon as a proxy for nitrogen
 - CH₂, CD₂
 - Empty targets with or without liquid helium and aluminum foils
- Nitrogen contribution dominates.
- Exclusive, lower-statistics channels: dilution factor from carbon alone may be enough
 - “Complete”: full expression using all contributions
 - “Simplified”: $D_f = 1 - c \frac{N_c}{N_{ND3}}$
 - c = ratio of the luminosities, involves packing fraction PF = volume occupied by the ammonia beads in the target cell

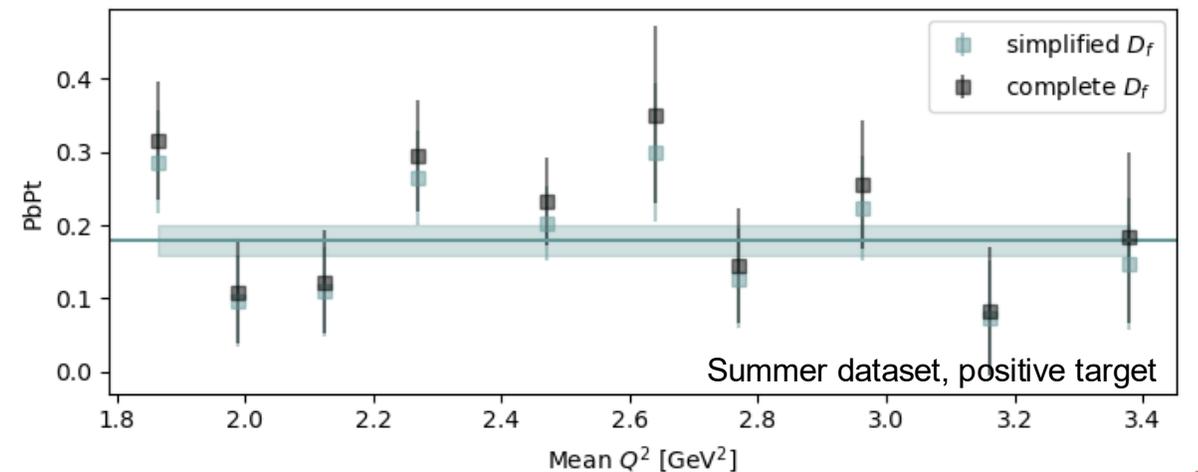
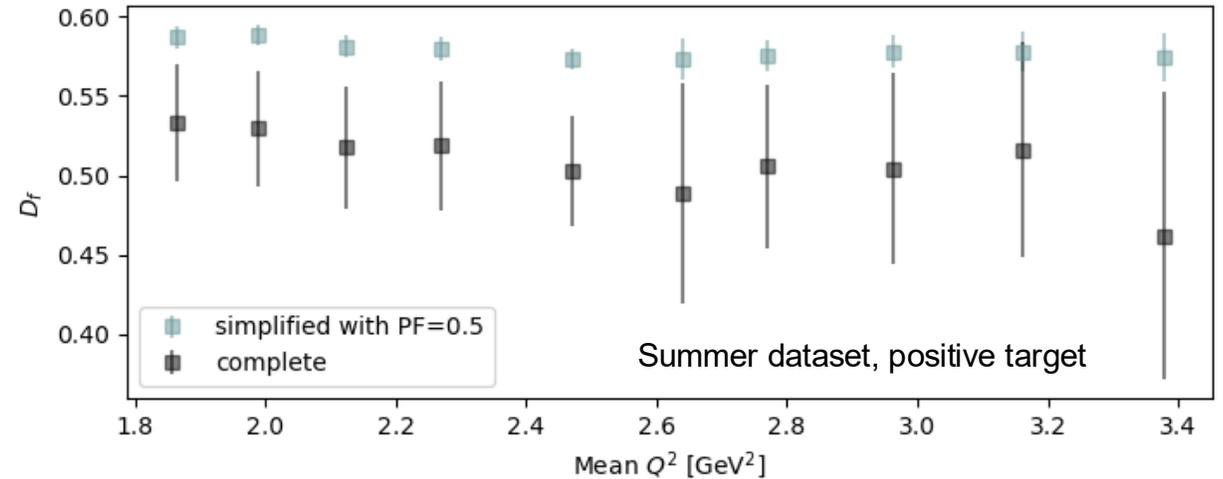
Dilution Factor Determination for RG-C

S.E. Kuhn¹ and D. Holmberg²

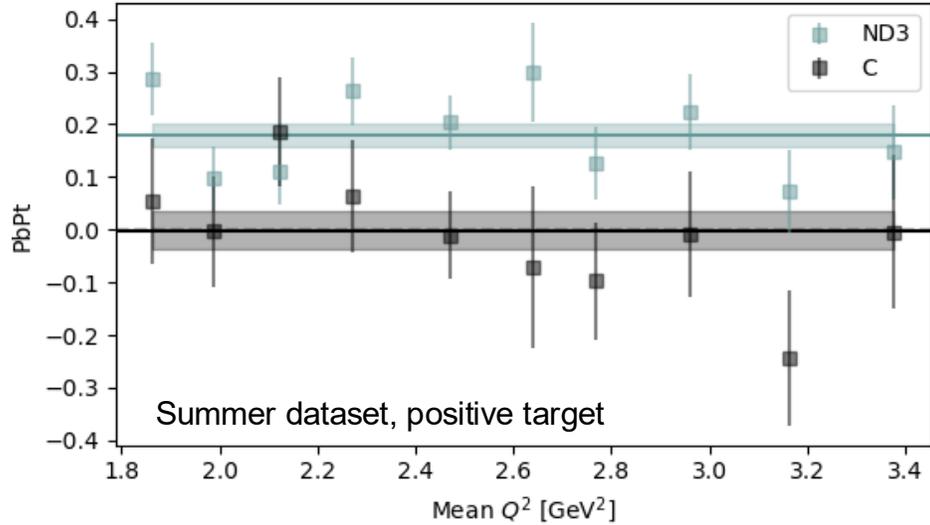
¹Old Dominion University, Norfolk, Virginia 23529

²College of William and Mary, Williamsburg, Virginia 23187-8795, USA

(Dated: February 11, 2026)

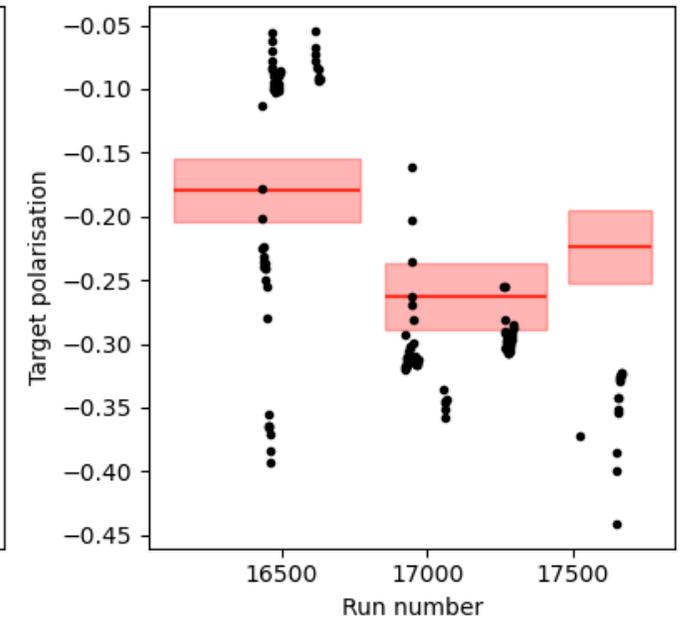
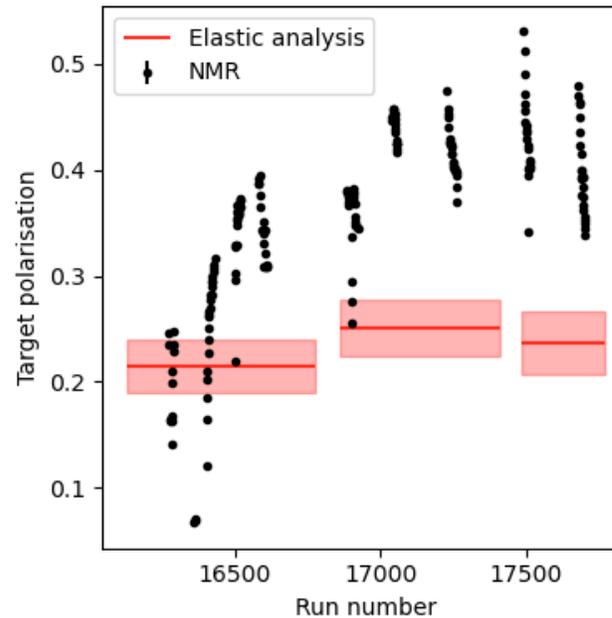


PbPt EXTRACTION



- Checked against carbon for which PbPt is 0 as expected.
- NMR system probes the polarization at the surface of the target, while the beam is depolarizing its center

Period	PbPt -	PbPt +
Fall 2022	-0.22 ± 0.02	0.21 ± 0.02
Summer2022	-0.15 ± 0.02	0.18 ± 0.02
Spring2023	-0.18 ± 0.03	0.19 ± 0.02

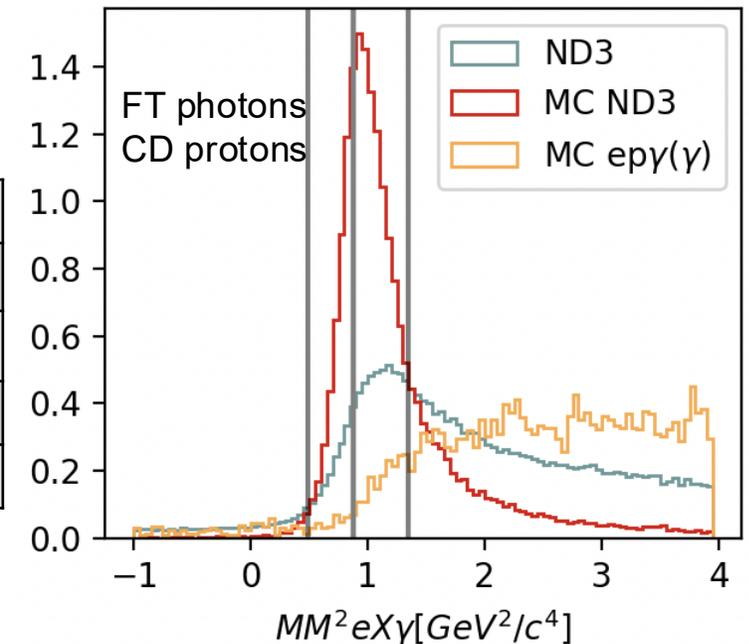
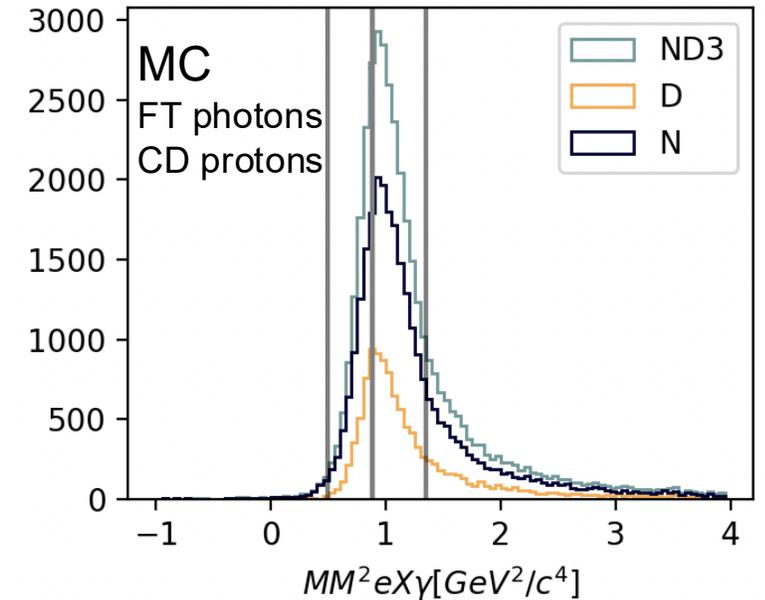


pDVCS EVENTS SELECTION

- Events with at least an electron, a proton and a photon
- Exclusivity cuts are derived as 3σ cuts from MC simulations:
 - genepi with Fermi motion and ND₃ distributions
 - $ep \rightarrow e'p'\gamma$ and $ep \rightarrow e'p'\pi^0$
- MC-data resolution matching remains to be studied
- Low statistics, a figure of merit should be defined to optimize signal and background:
 - unpolarized N
 - contamination from $ep \rightarrow e'p'\pi^0 \rightarrow e'p'\gamma(\gamma)$

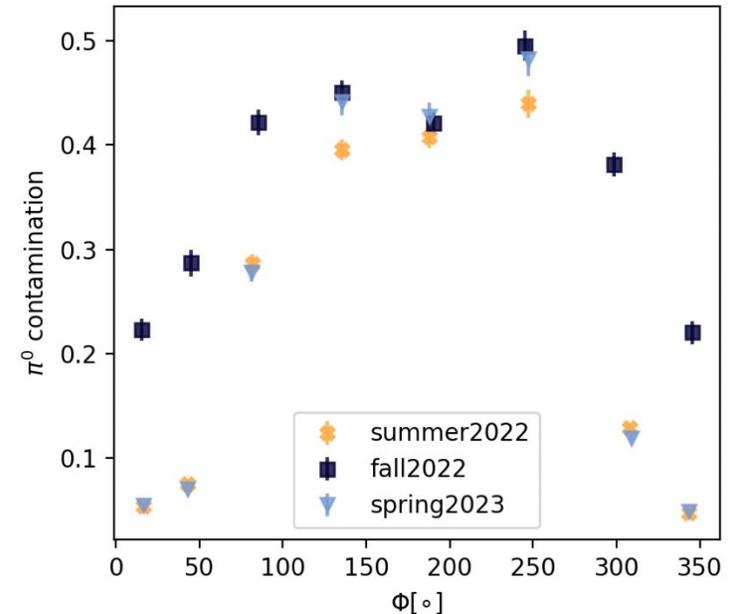
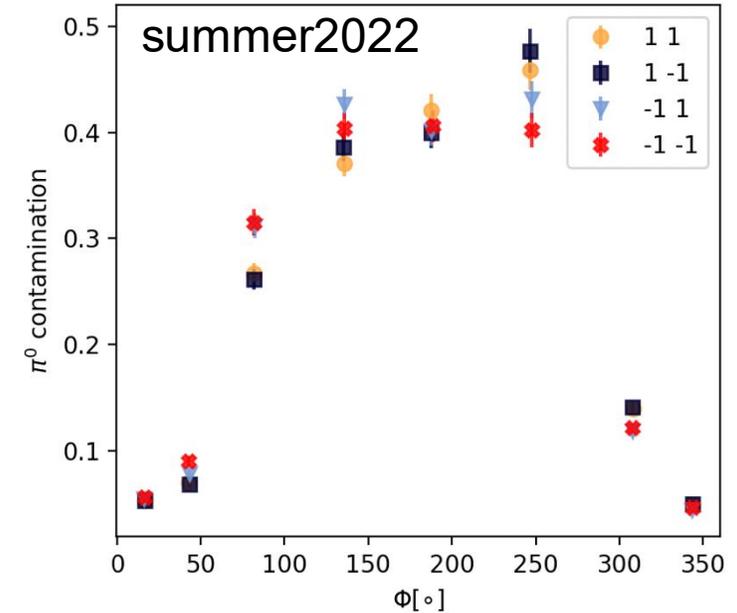
Proton in	Photon in	Fraction of events
CD	FT	~ 45%
CD	FD	~ 30%
FD	FD	~ 20%
FD	FT	~ 5%

Variable	Min	Max
$MM_{e\pi\gamma}^2$ [GeV ²]	-0.032	0.022
$MM_{eX\gamma}^2$ [GeV ²]	0.49	1.35
$\Delta\phi$ [°]	-0.52	0.53
Δt [GeV]	-0.22	0.22



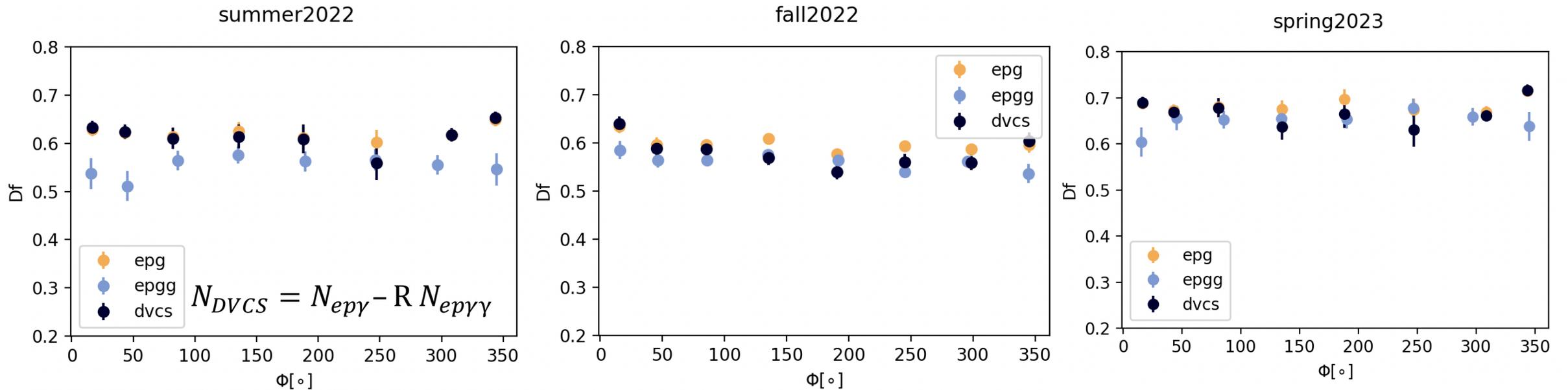
π^0 CONTAMINATION

- MC simulation for $ep \rightarrow e'p'\pi^0$:
 - $N_{ep\gamma\gamma}^{MC}$ are simulated DVMP events passing the $ep\gamma\gamma$ selection for DVMP
 - $N_{ep\gamma}^{MC}$ are DVMP events passing the $ep\gamma$ selection for DVCS
 - $R = \frac{N_{ep\gamma}^{MC}}{N_{ep\gamma\gamma}^{MC}}$
- $N_{DVCS} = N_{ep\gamma} - R N_{ep\gamma\gamma}$
- DVMP has a non-zero asymmetry, the subtraction is done for each orientation of the beam and target polarizations
- Larger contamination when the photon is detected in the FD \leftrightarrow central ϕ :
 - DVMP cross-section dominates
 - Looser exclusivity cuts in the FD compared to FT



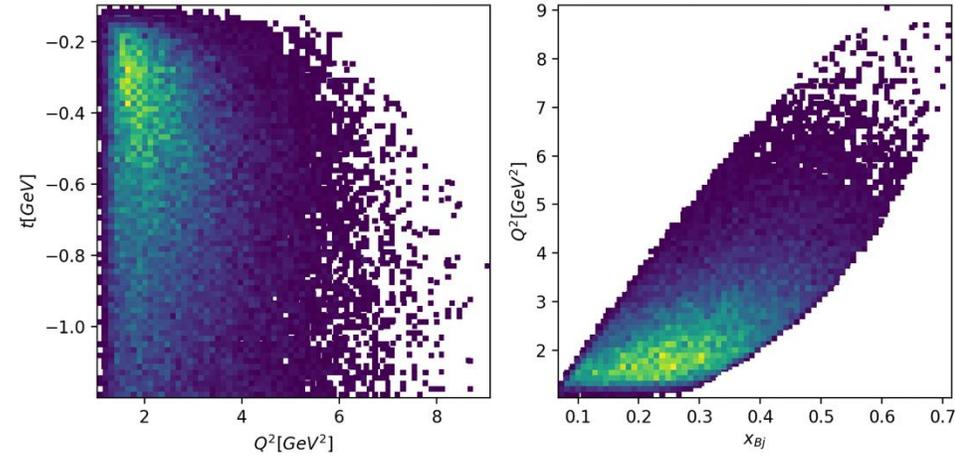
DILUTION FACTOR

- $Df = 1 - c \frac{N_c}{N_{ND3}}$
- Derived for each kinematic bin
- Statistics on carbon target and for $e'p'\pi^0$ events are limited
→ Their kinematic dependence and the possibilities for integration will be studied



ASYMMETRIES

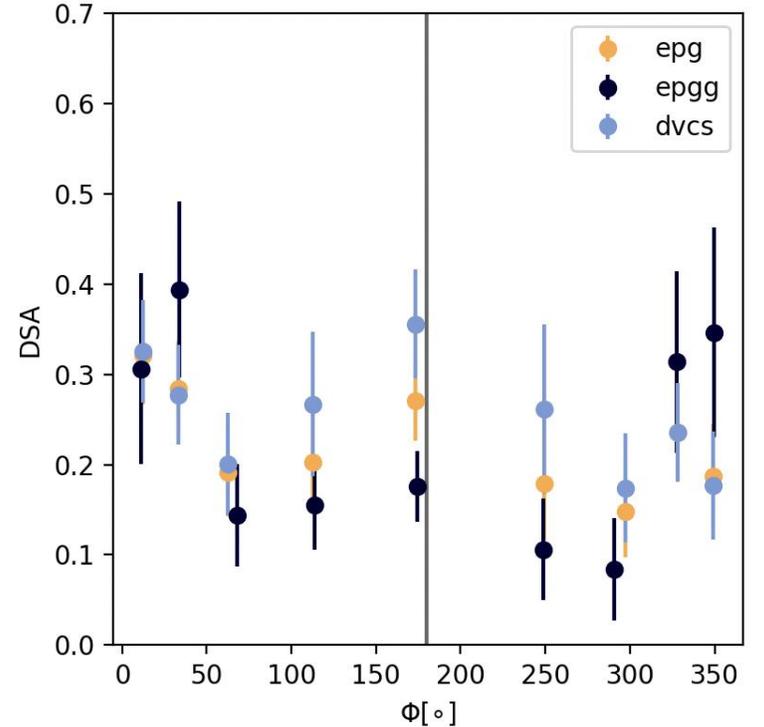
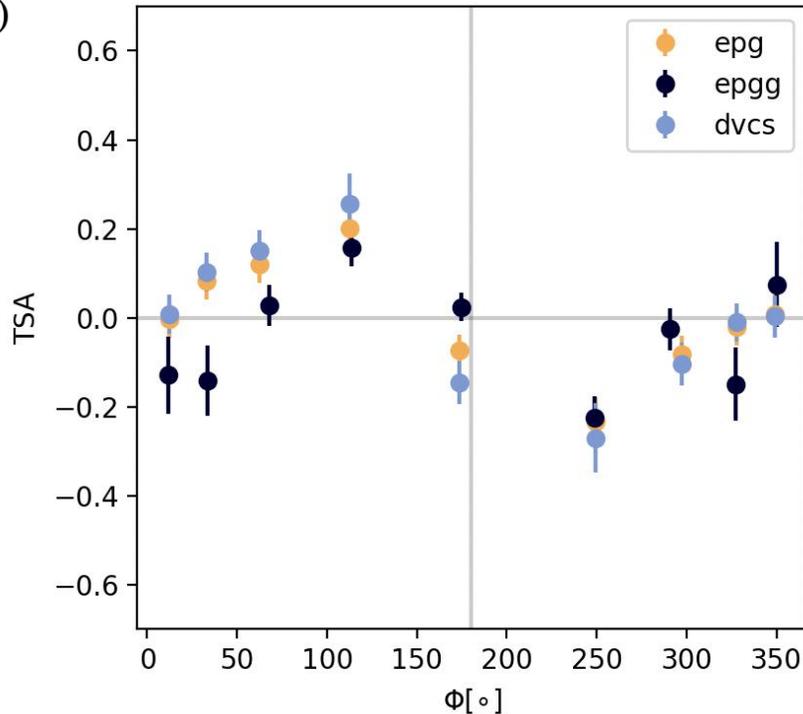
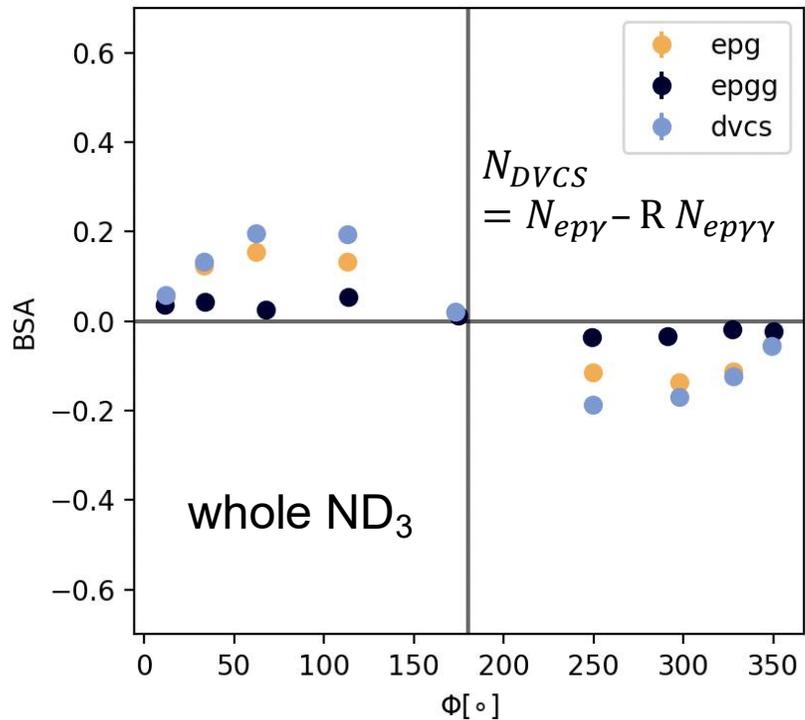
- N^{BT} - FC-normalized yields
- Beam polarization 80-83%
 - Target polarization ~ 25%
 - Dilution factor ~ 60%



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

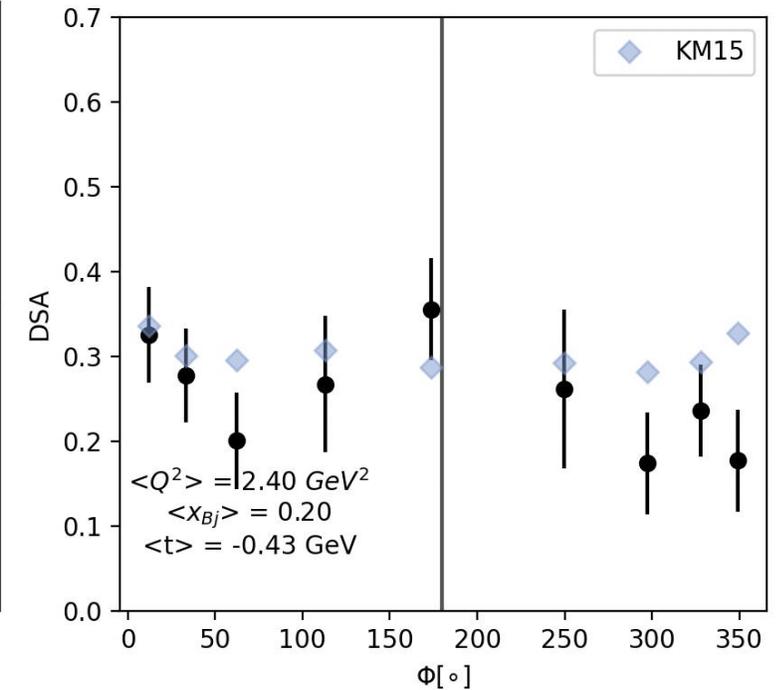
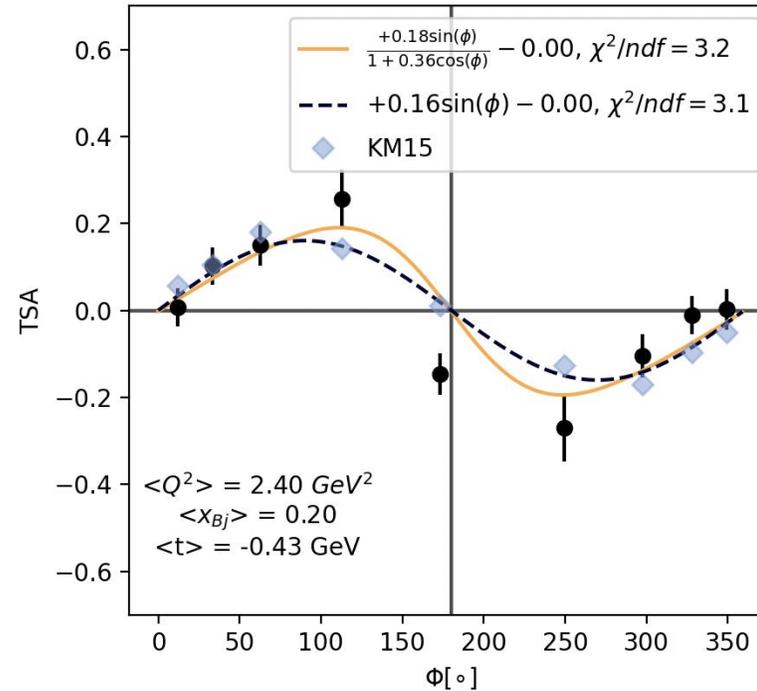
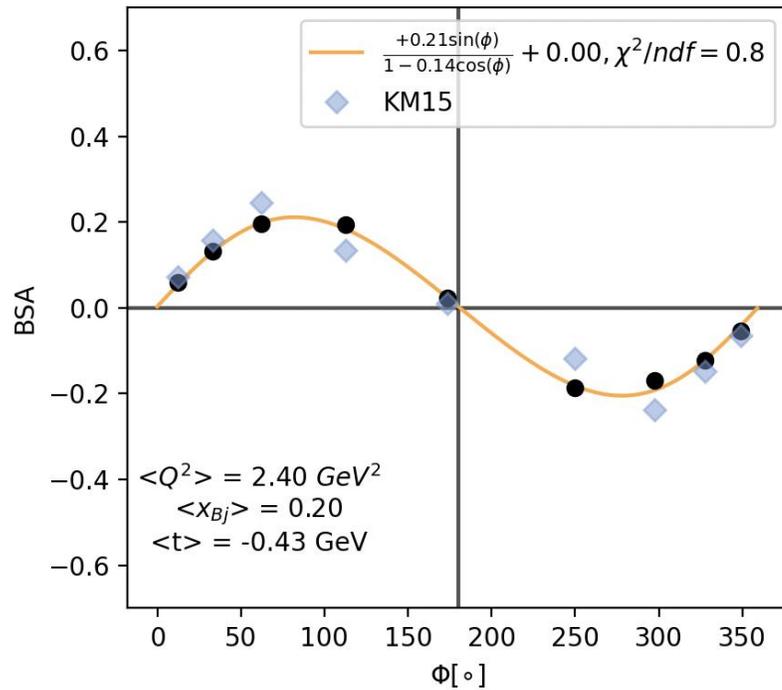
$$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{D_f \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

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

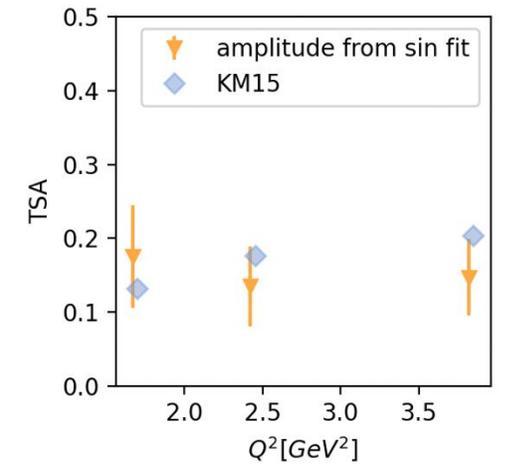
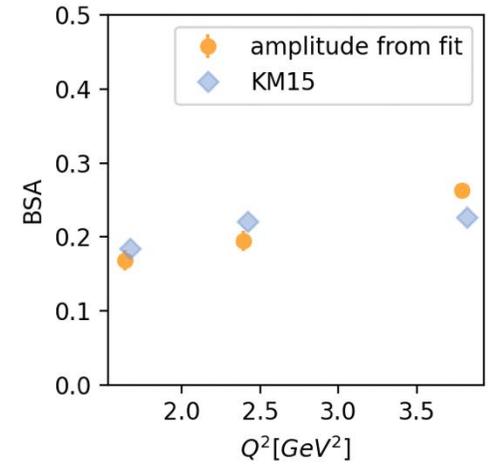
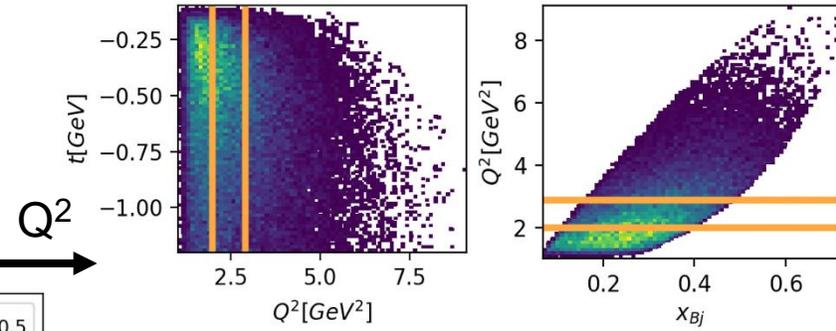
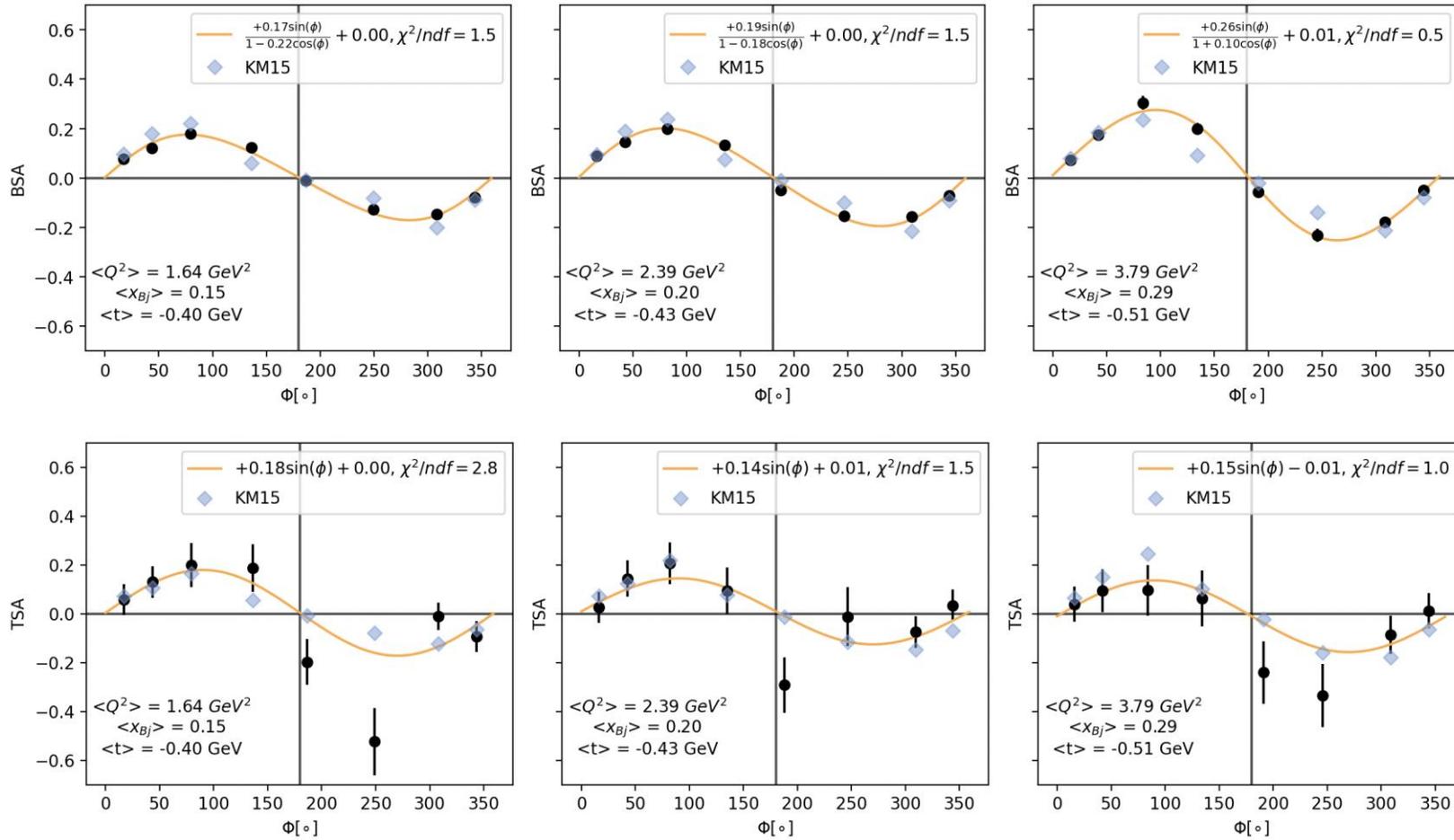


INTEGRATED ASYMMETRIES

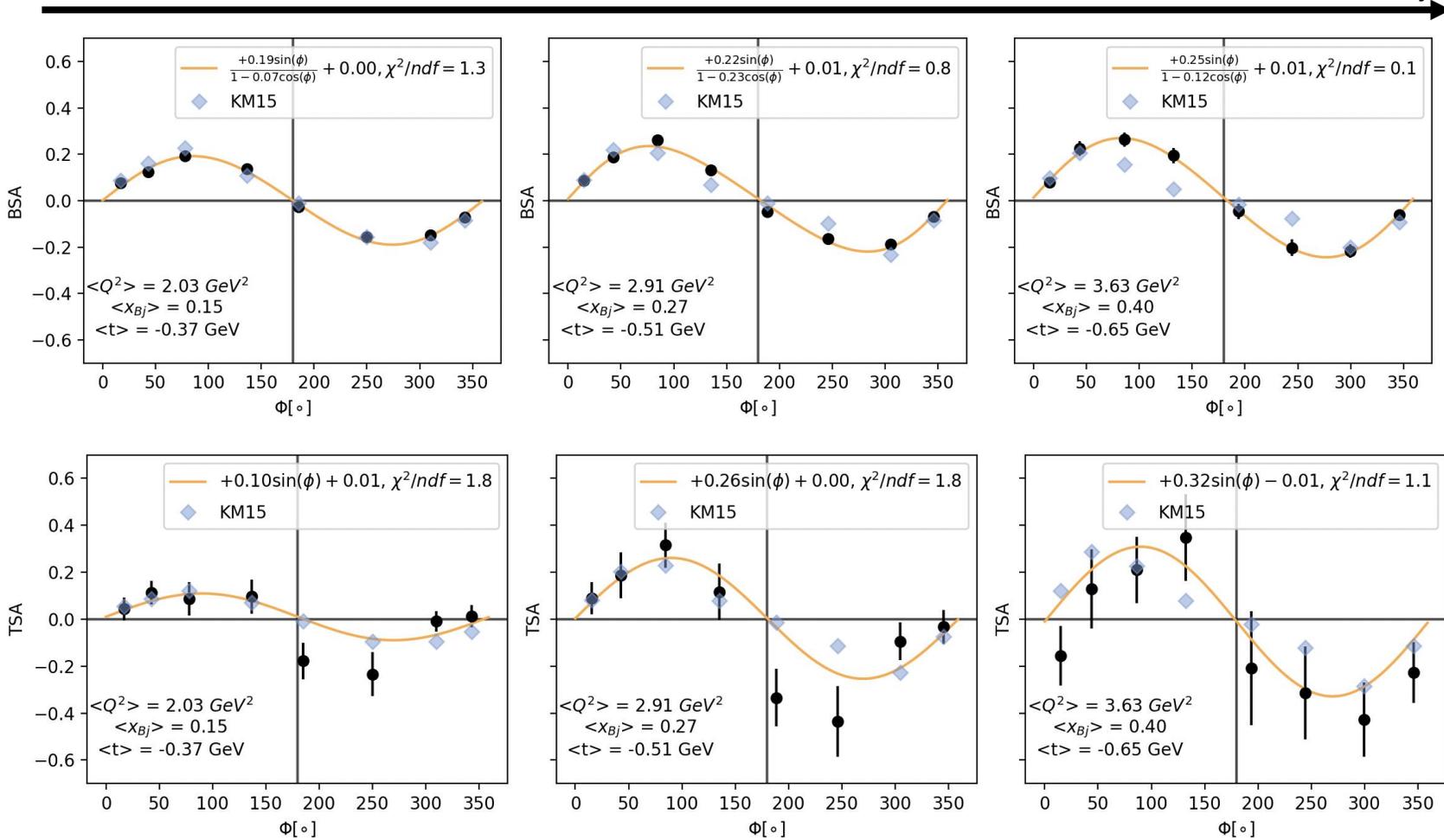
BSA measured on ND₃
KM15: free protons



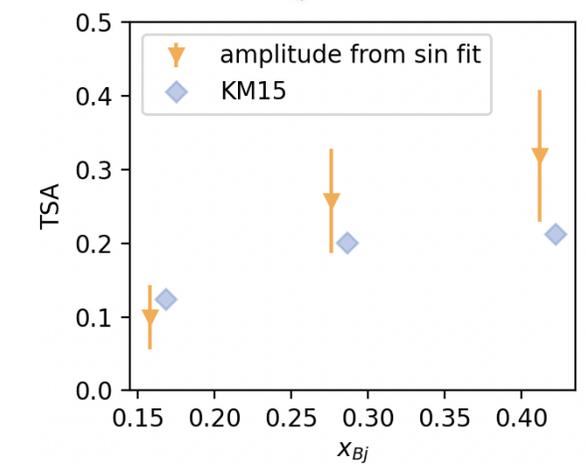
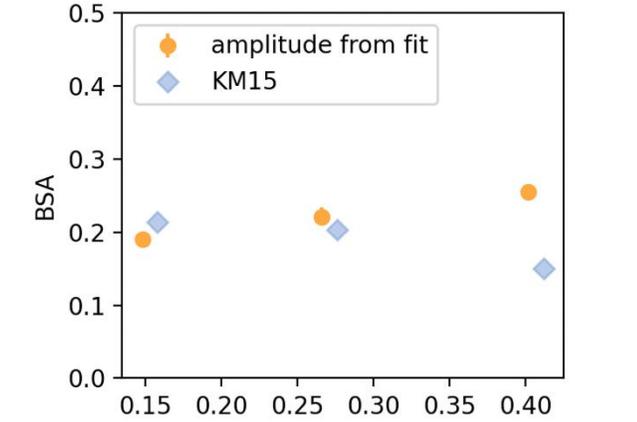
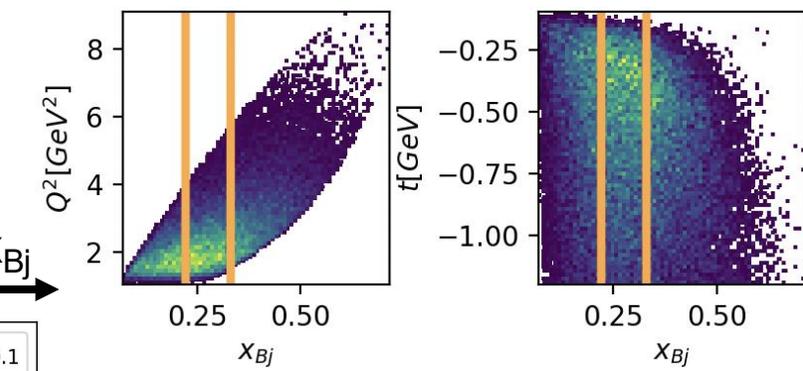
SOME 2D BINNING - Q^2



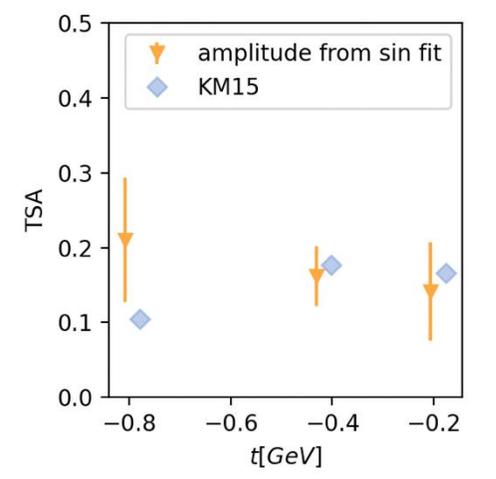
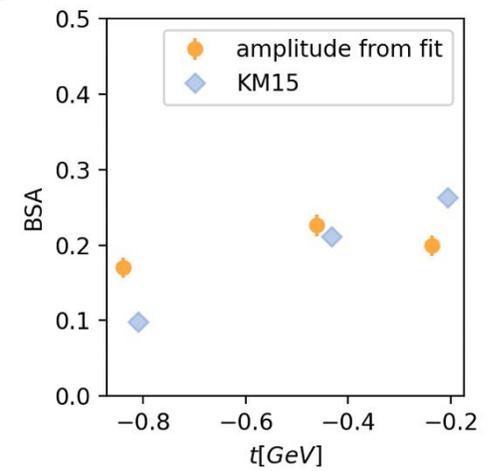
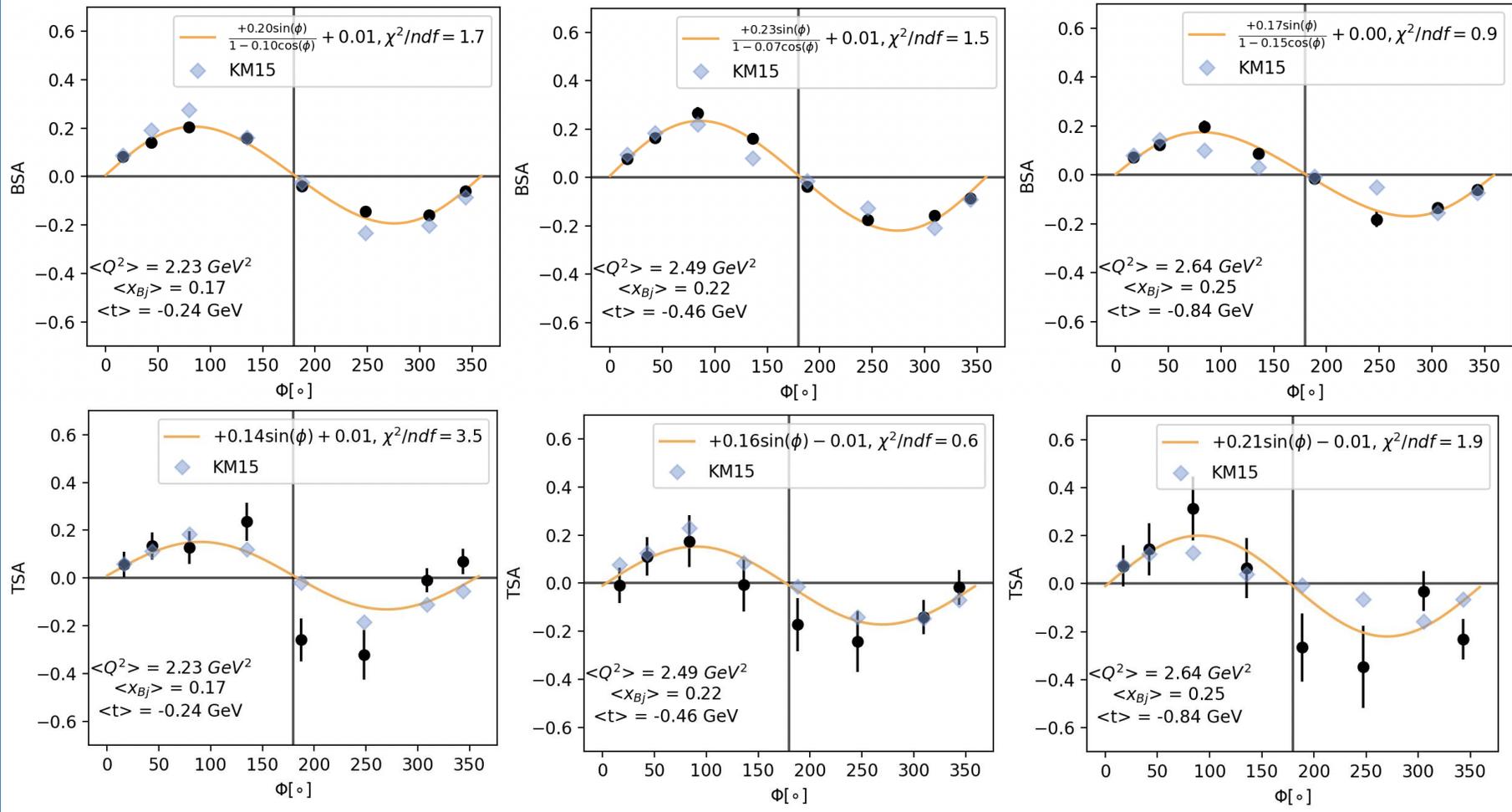
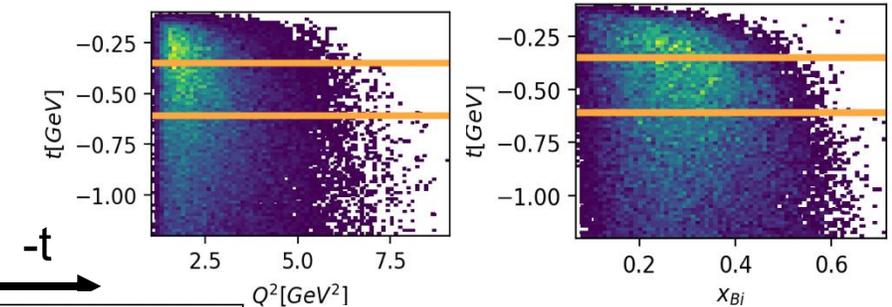
SOME 2D BINNING – X_{Bj}



X_{Bj}



SOME 2D BINNING - t



SUMMARY AND MORE

- Longitudinally polarized DVCS for bound protons in deuterium
- Towards a measurement for the neutron
- Statistics are low but some binning is possible, a good start for a first-time measurement
- RGC is an exciting experiment and we're starting to tame our dataset, very active efforts for first physics results

(non exhaustive) TO DO:

- Signal/Background optimization
- Data-MC matching
- Systematic studies

Perspectives:

- Comparison to free protons. From RGC NH_3 ?
- Neutron dvcs
 - Statistics will be a big challenge
 - Additional challenge with protons misidentified as neutrons in the CD → see Grace's talk
- RGC should resume running in 2028 for 40 PAC days, current dataset is 95 PAC days
 - DVCS analyses would benefit from FTO configuration
 - Deuterium data would really benefit neutron studies!

BACKUP



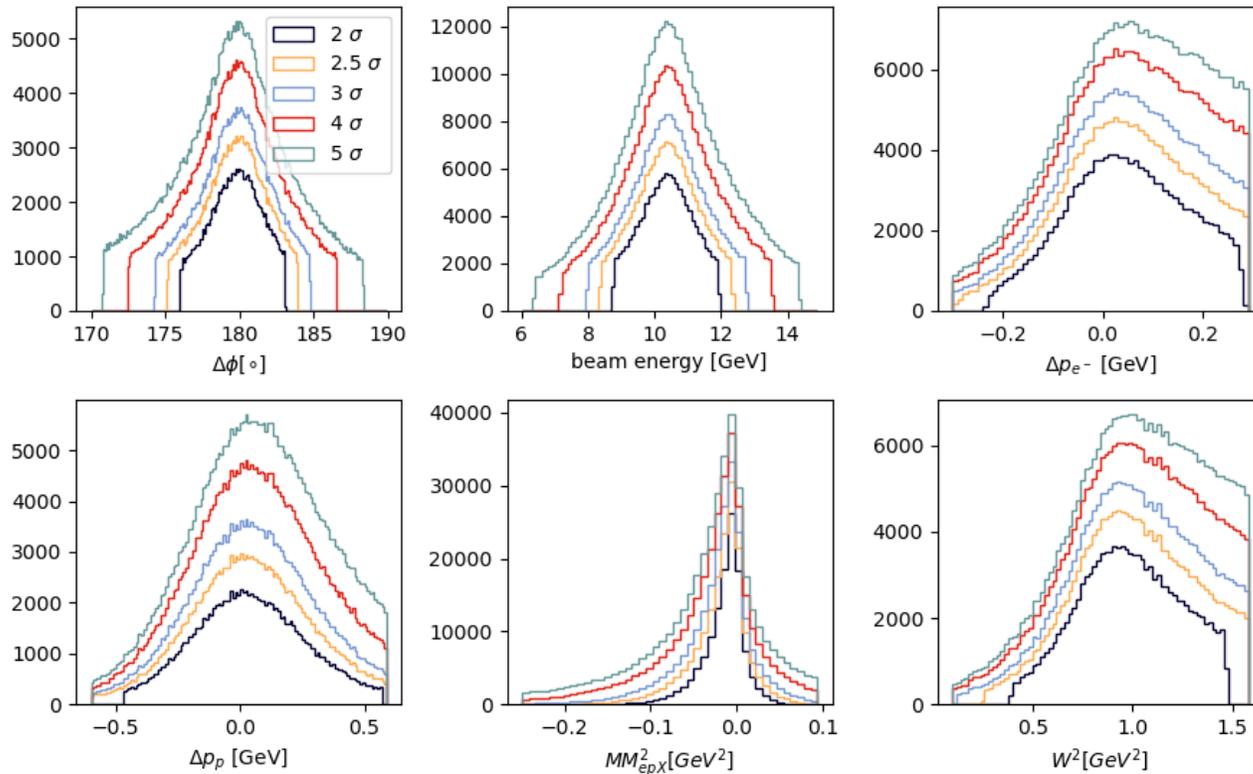
Argonne National Laboratory is a
U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC.



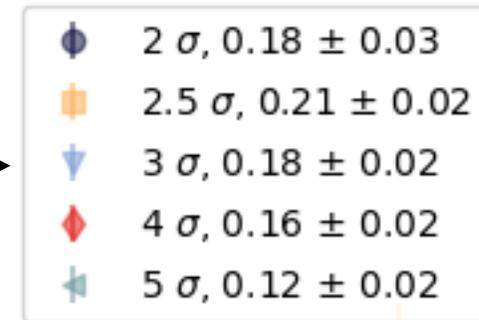
FIRST LOOK AT SYSTEMATICS

Summer dataset, positive target

ND3

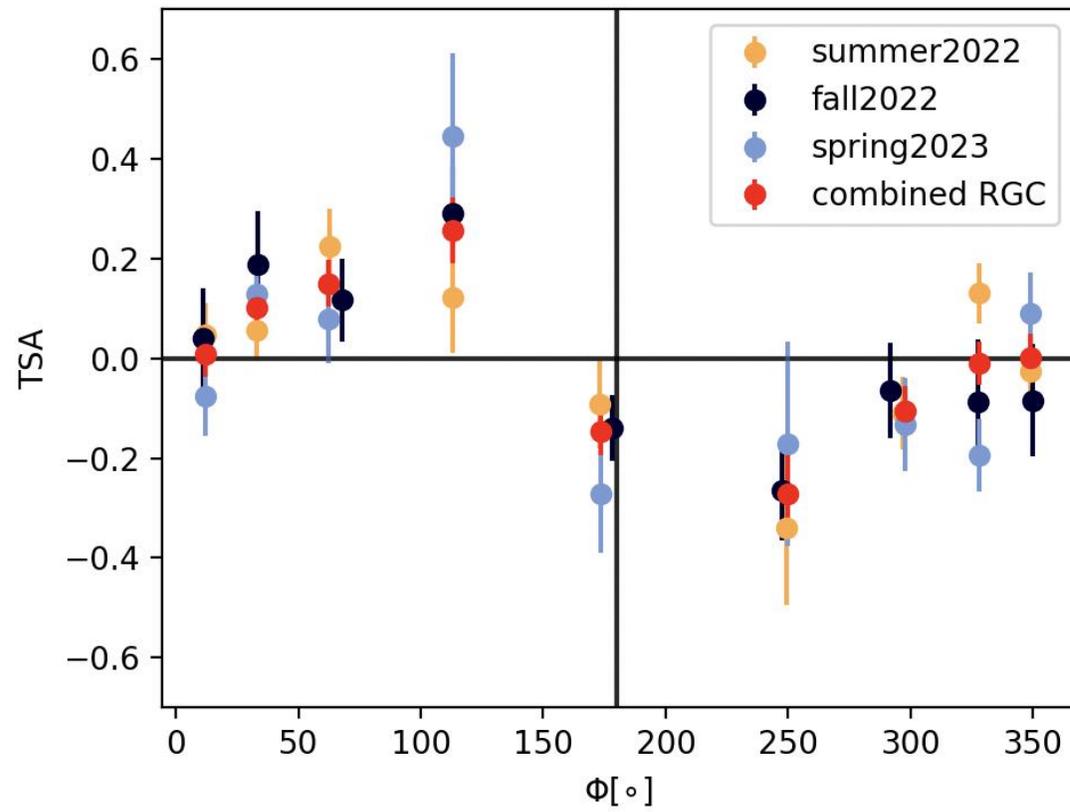
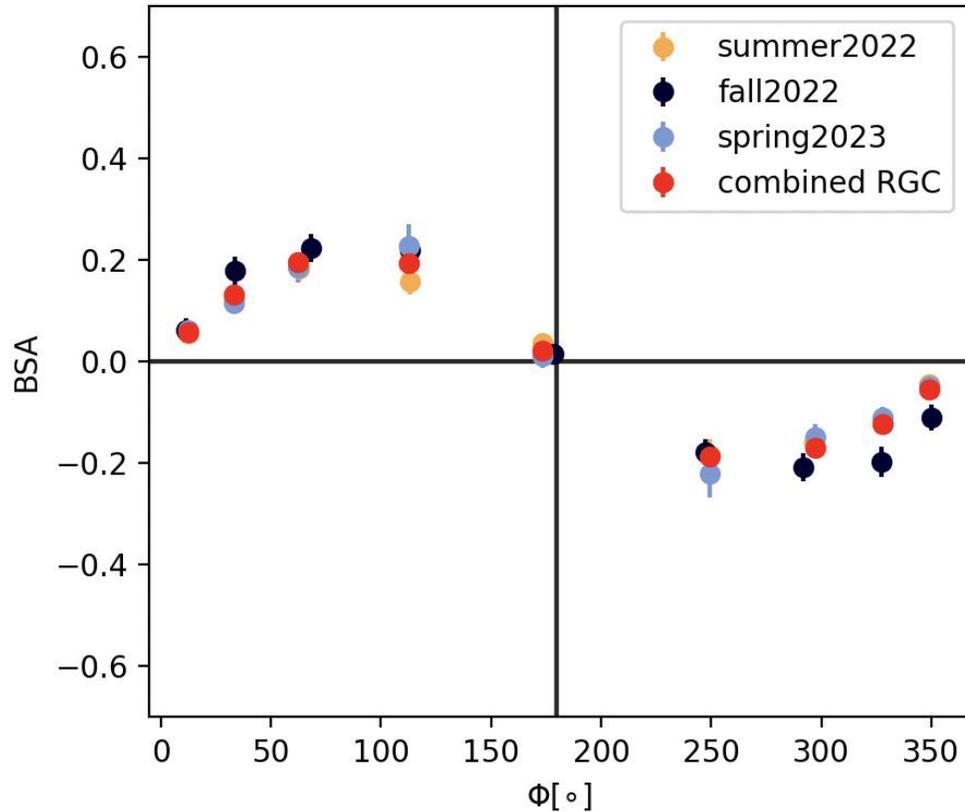


- PF determination has a small impact
- Varying exclusivity cuts

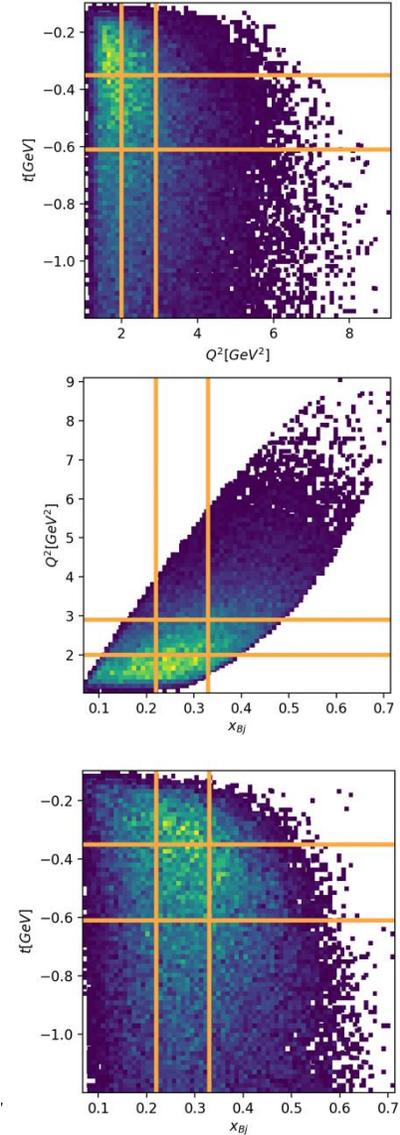
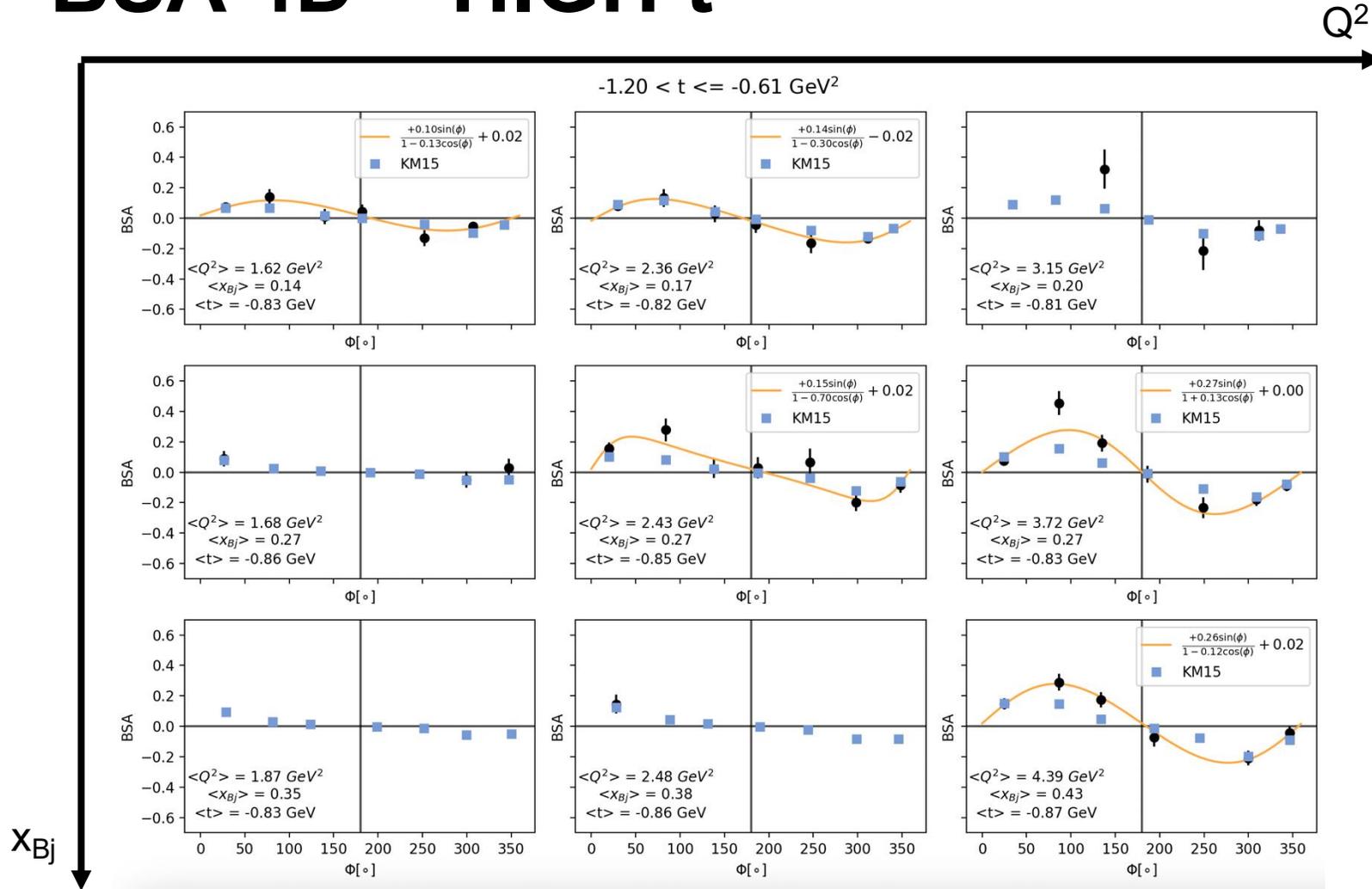


- More to be done:
 - Choice of G_E/G_M in the theoretical DSA $\sim 1\%$
 - Deuterium d-state?

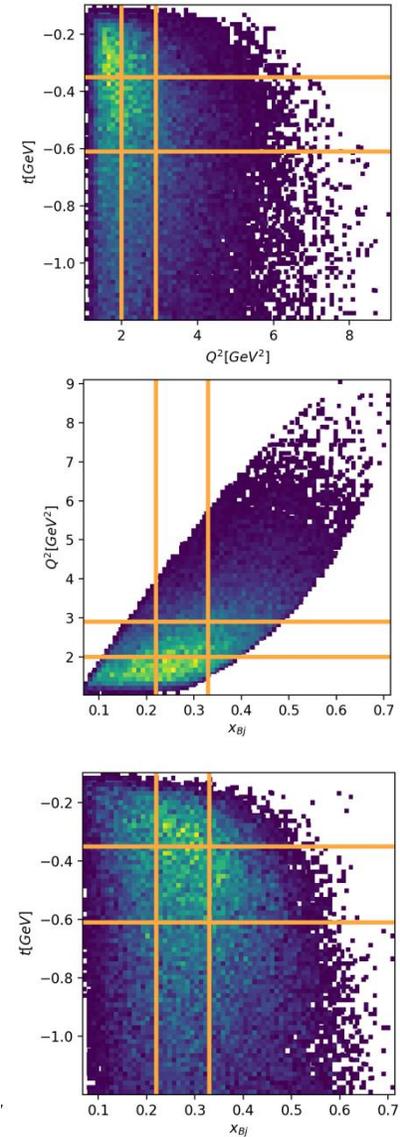
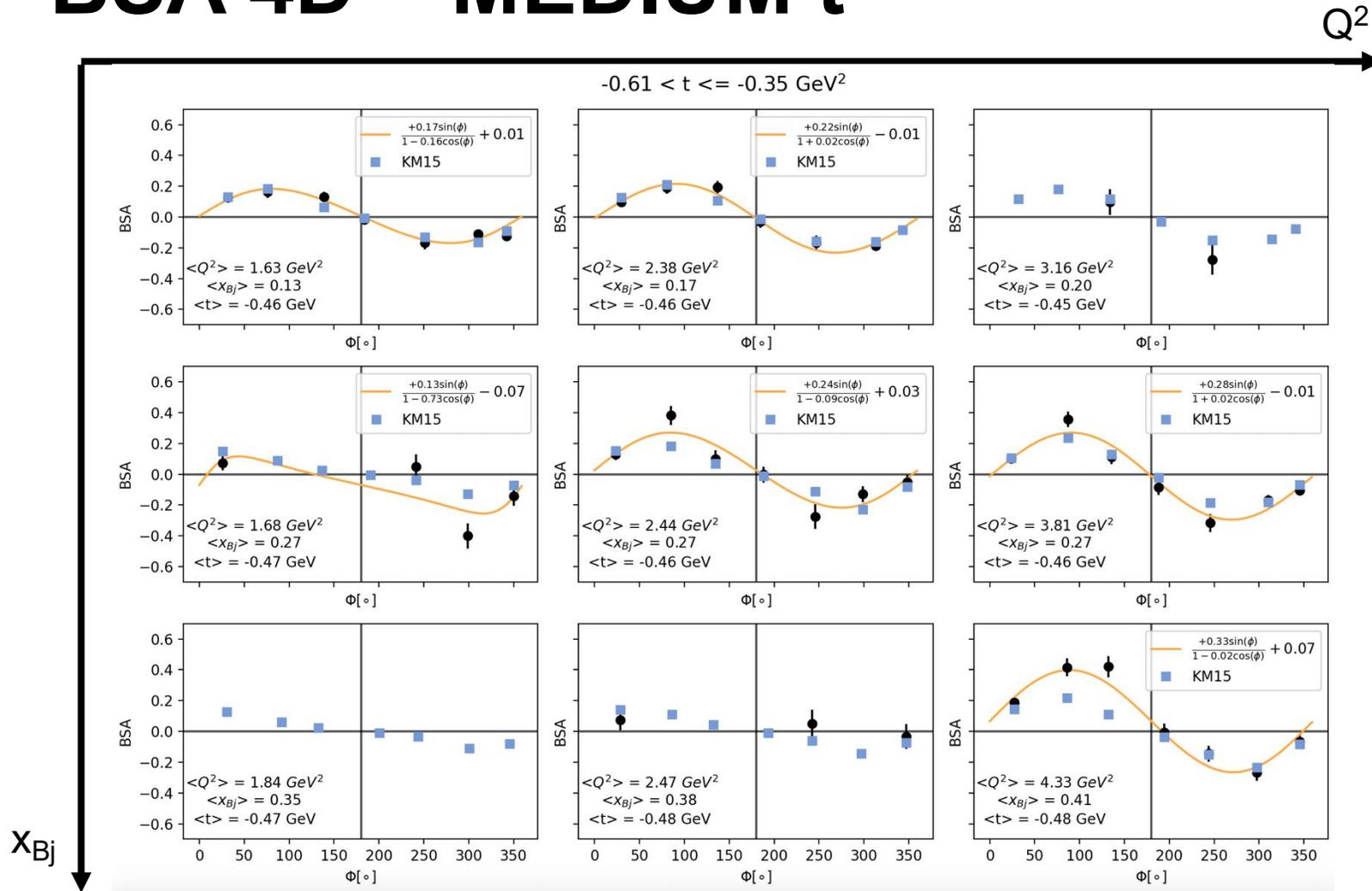
COMBINING RGC DATASETS



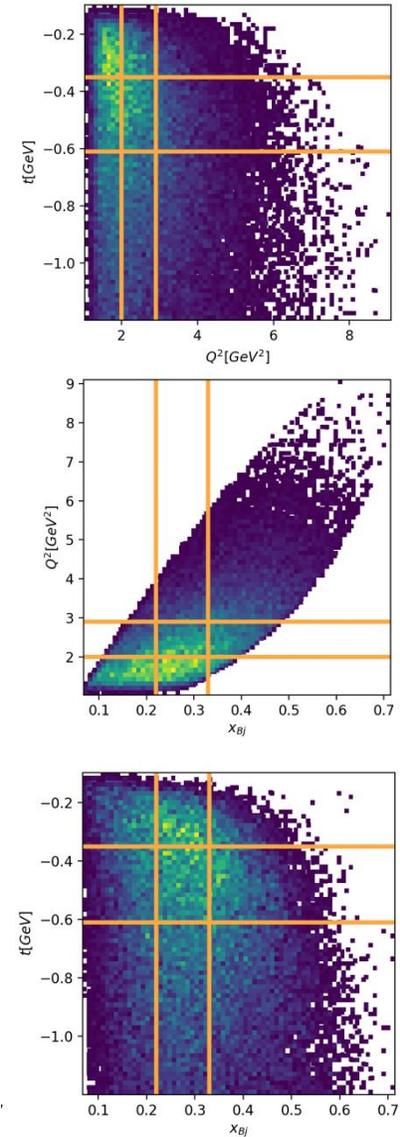
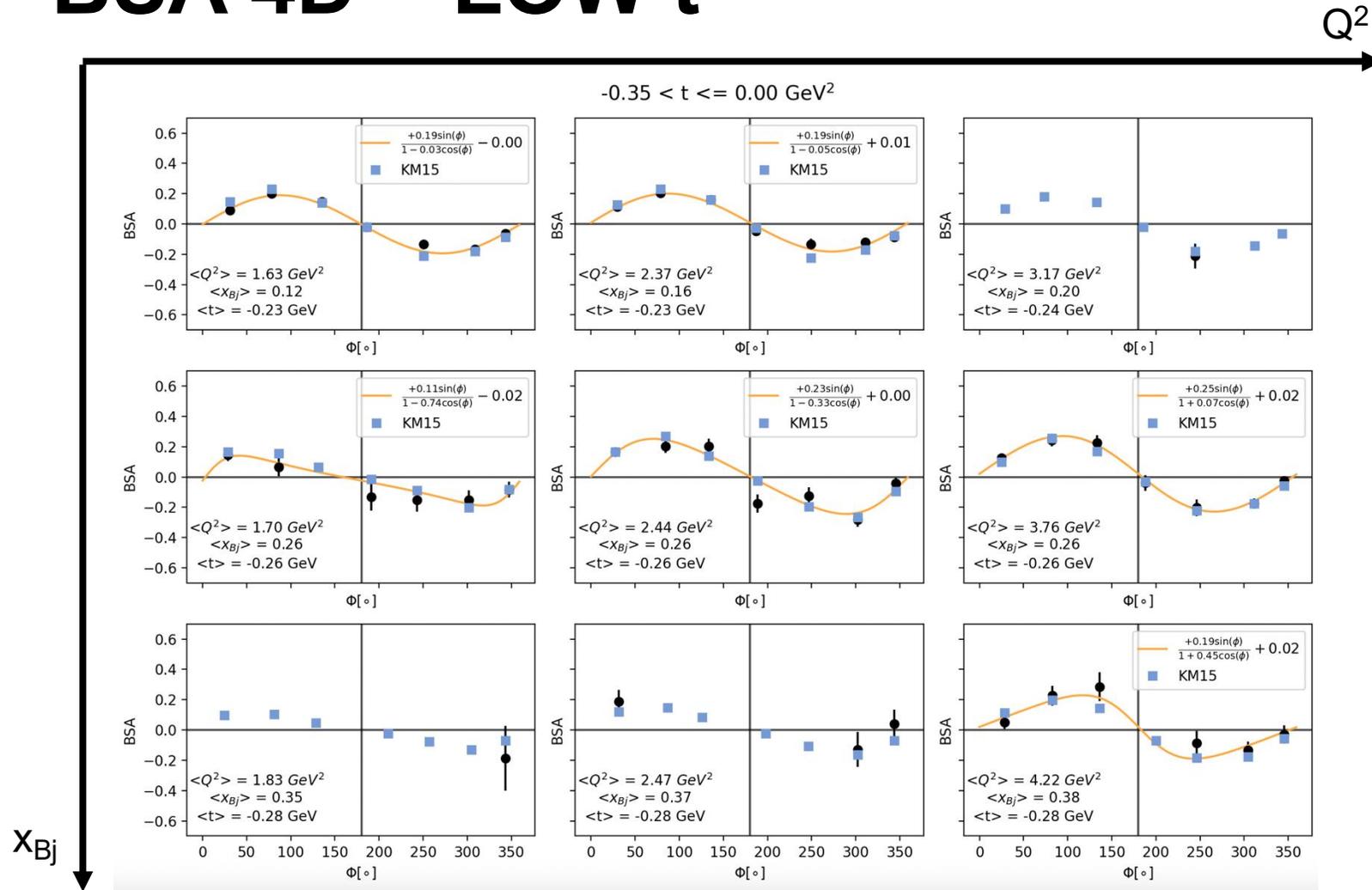
BSA 4D – HIGH t



BSA 4D – MEDIUM t



BSA 4D – LOW t



Fiducial and PID cuts

- Very preliminary fiducial/PID cuts
 - $-3 < \text{electron } \chi_{PID}^2 < 3$
 - $-2.6 < \text{electron } \chi_{PID}^2 < 3.4$ (asymmetric in the summer dataset and needs to be adapted for the rest)
 - DC edge region1 $> 5\text{cm}$, region 2 $> 5\text{cm}$, region 3 $> 10\text{cm}$
 - PCAL $lv > 8\text{cm}$, $lw > 8\text{cm}$
 - CVT edge layer 1 $> 0\text{cm}$, layer 3 $> 0\text{cm}$, layer 5 $> 0\text{cm}$, layer 7 $> -2\text{cm}$, layer 12 $> -5\text{cm}$