RGH ASYMMETRY STUDY FOR THE RGH PROPOSAL

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Comparison of the Multi-dimensional Sivers and Collins extraction in SIDIS process with the RGH simulaton.

RGH - DATA ANALIZED

This analysis uses data generated from a **MC simulation setup** build up by **Duke University** (provided by Matthew McEneaney).
It will consider **Semi-Inclusive DIS** processes with a **single** π^+ in the final state, from collision among e^- and a **transverse polarized target** of NH_3.

The objective is to **highlight the performance in asymmetries extraction** (Sivers and Collins) with the future **RGH** experiment, with comparison to previous experiment.

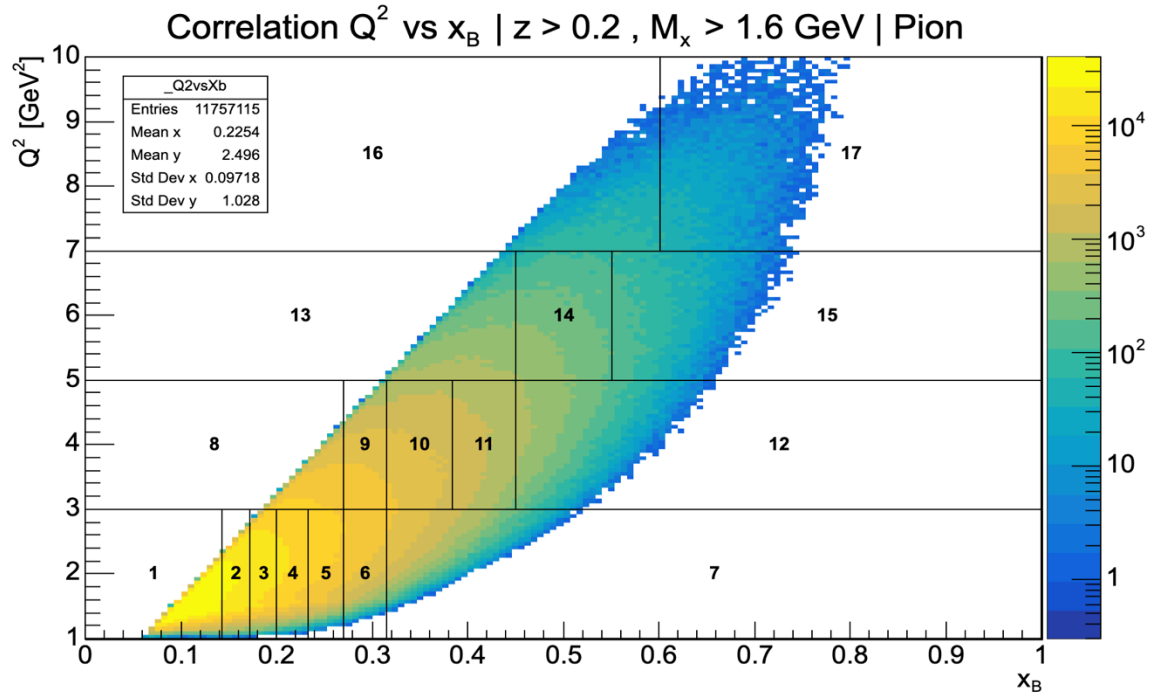
The data production is about **20 million** of SIDIS event, which will drop to around **12 million** due to the **removal of sector 4** (~38% data removed).

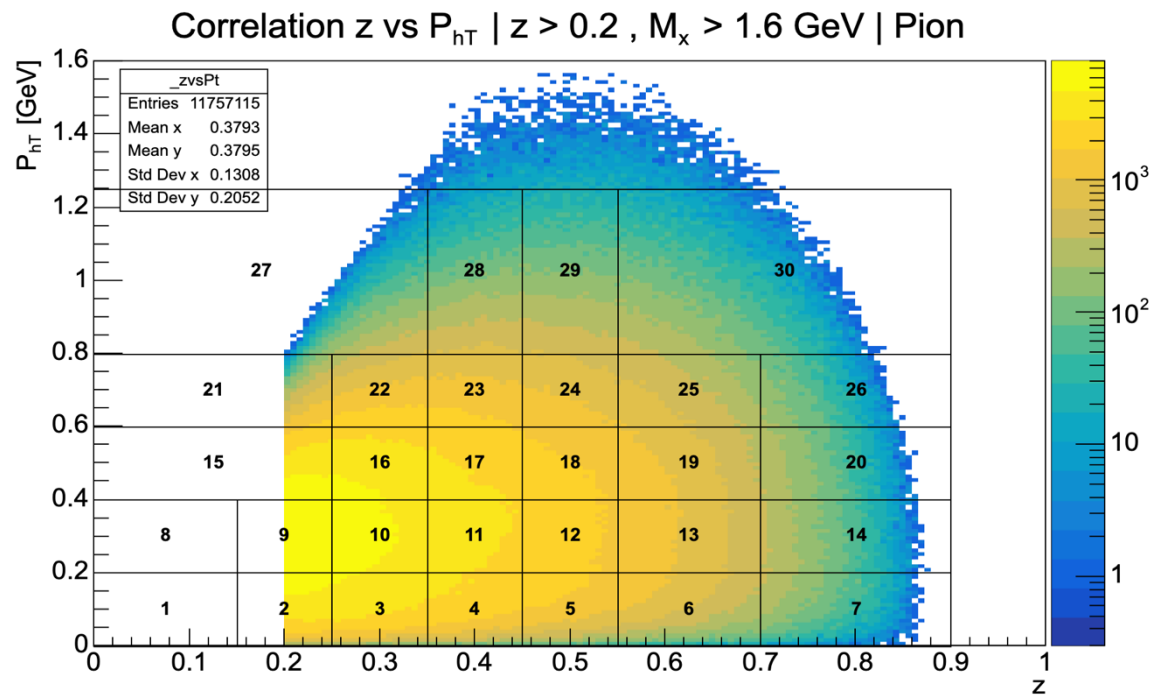
Data location: /volatile/clas12/lpolizzi/rgh_simulation/analysis/..._gen_pipkp

RGH MEASUREMENT

Binning grid of the phase space (same bin definition of Duke, to have comparison).

$$z > 0.2 \quad \& \quad M_X > 1.6\,GeV \quad \& \quad P_h > 1.0\,GeV \quad \& \quad y < 0.9 \quad \& \quad x_F > 0 \quad \& \quad No\ sect\ 4$$

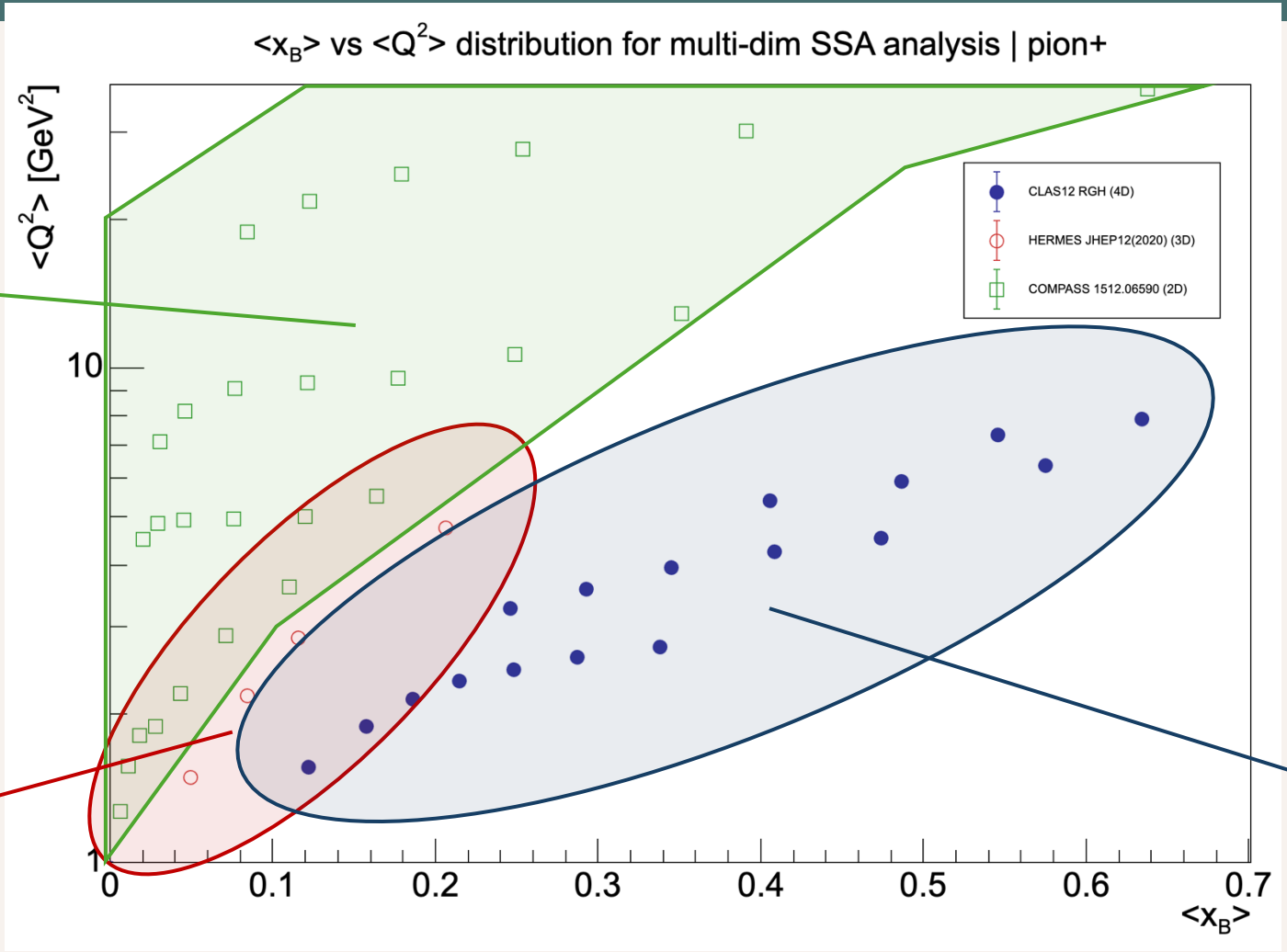




REGION COVERED - x_B vs Q^2

COMPASS: 2D measurement as a function of Q^2, x_B.

HERMES: 3D measurement as a function of x_B, z, P_{hT}.



Only the x_B (or $x_B Q^2$) bins are presented here, that's why HERMES has only four points.

CLAS RGH: 4D measurement as a function of Q^2, x_B, z, P_{hT}.

RGH - ASYMMETRY

The asymmetry is injected as:

$$A = \frac{1}{2}\left[1 + P_t D\left(A_{UT}^{col} \sin(\phi_h + \phi_s) + A_{UT}^{siv} \sin(\phi_h - \phi_s)\right)\right]$$

Where the parameter is taken from HERMES:

$$A_{UT}^{col} = 0.05 + a_0 + a_1 x_B + a_2 Q^2 + a_3 z + a_4 P_{hT} + a_5 x_B^2 + a_6 z^2 + a_7 P_{hT}^2 + a_8 x_B z + a_9 x_B P_{hT} + a_{10} z P_{hT}$$
$$A_{UT}^{siv} = 0.05 + b_0 + b_1 x_B + b_2 Q^2 + b_3 z + b_4 P_{hT} + b_5 x_B^2 + b_6 z^2 + b_7 P_{hT}^2 + b_8 x_B z + b_9 x_B P_{hT} + b_{10} z P_{hT}$$

Taking a randon numer $\rho \in (0,1)$, if $\rho < A \;\rightarrow\; Spin = +1$ else $Spin = -1$.

RGH - ASYMMETRY

The asymmetry is calculated in both two-dimension (x_B, Q^2) and (z, P_{hT}), and four-dimension (x_B, Q^2, z, P_{hT}) with the maximum log-likelihood method:

$$\ln(\mathcal{L}) = \sum_{i=0}^{N} \ln[1 + P_t D^i (A_{UT}^{col} \sin(\phi_h^i + \phi_s^i) + A_{UT}^{siv} \sin(\phi_h^i - \phi_s^i)]$$

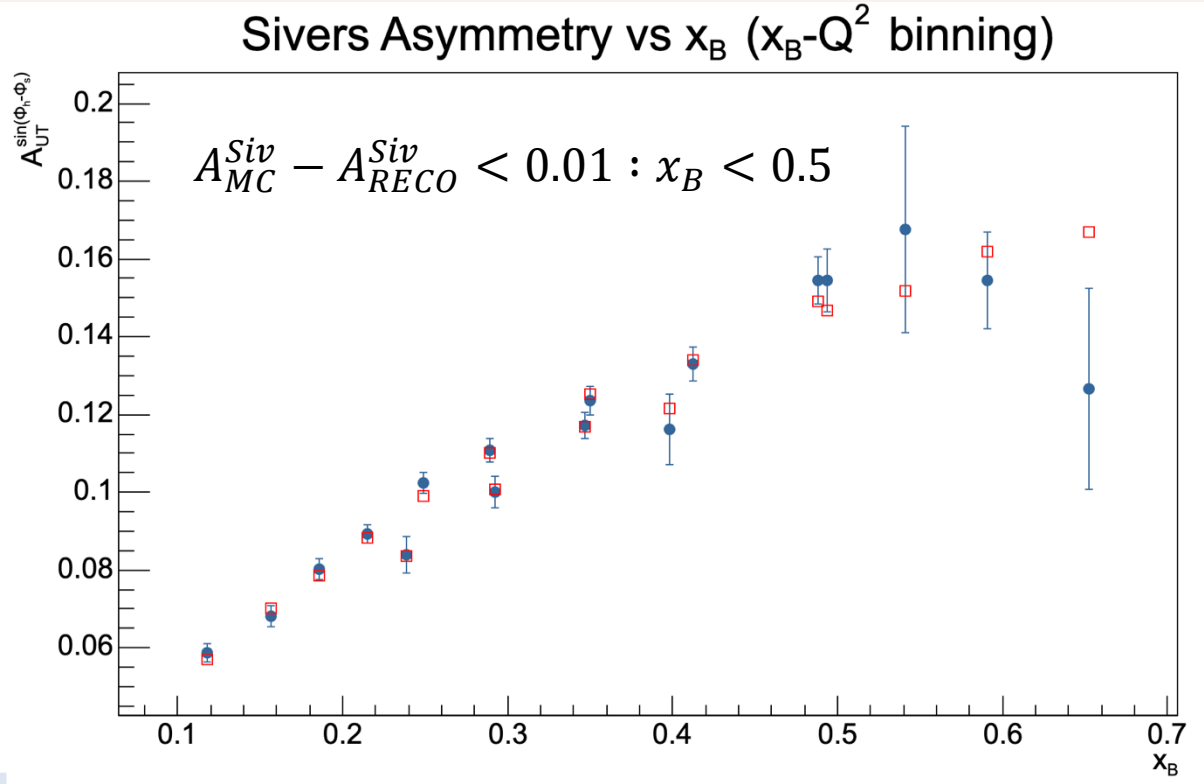
Throught Minuit2 from ROOT we minimize $-\ln(\mathcal{L})$ in order to perform the fit.

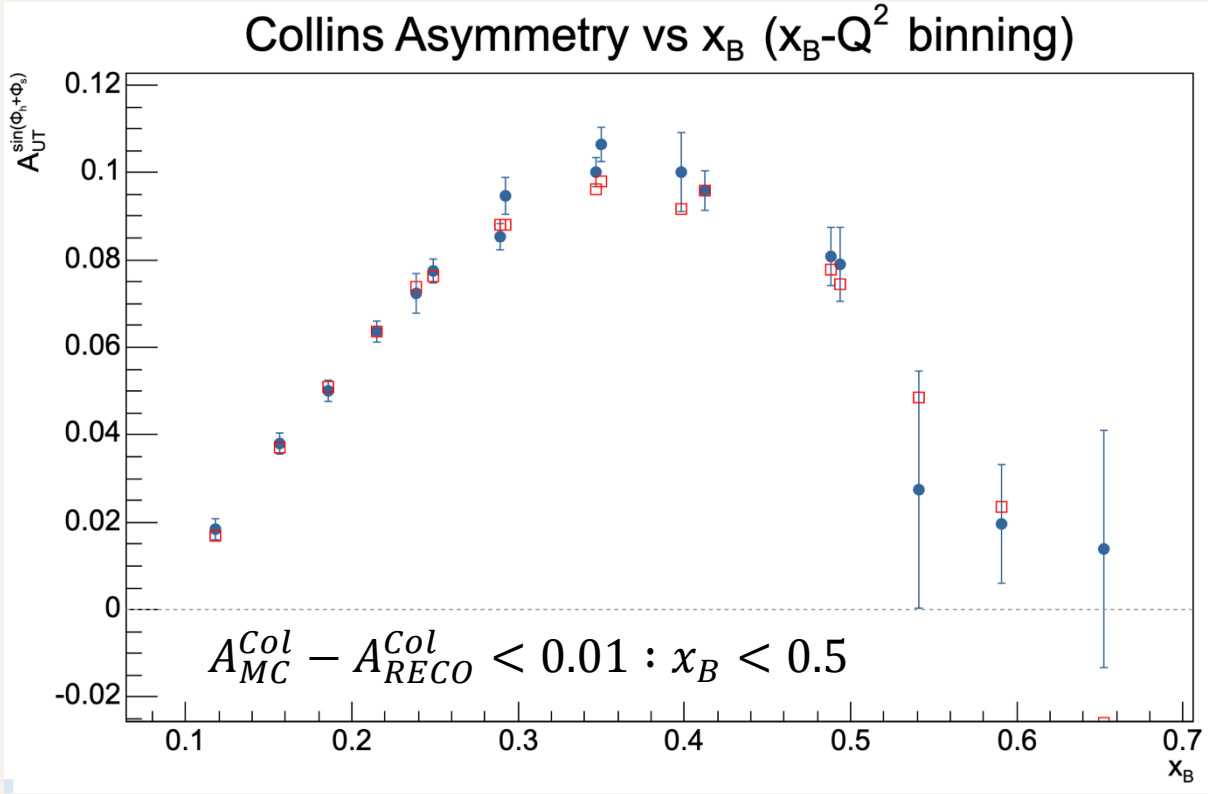
I assumed $P_t = 0.85$ and $D = \frac{1-y-\frac{1}{4}\gamma^2 y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2 y^2}$ as depolarization factor.

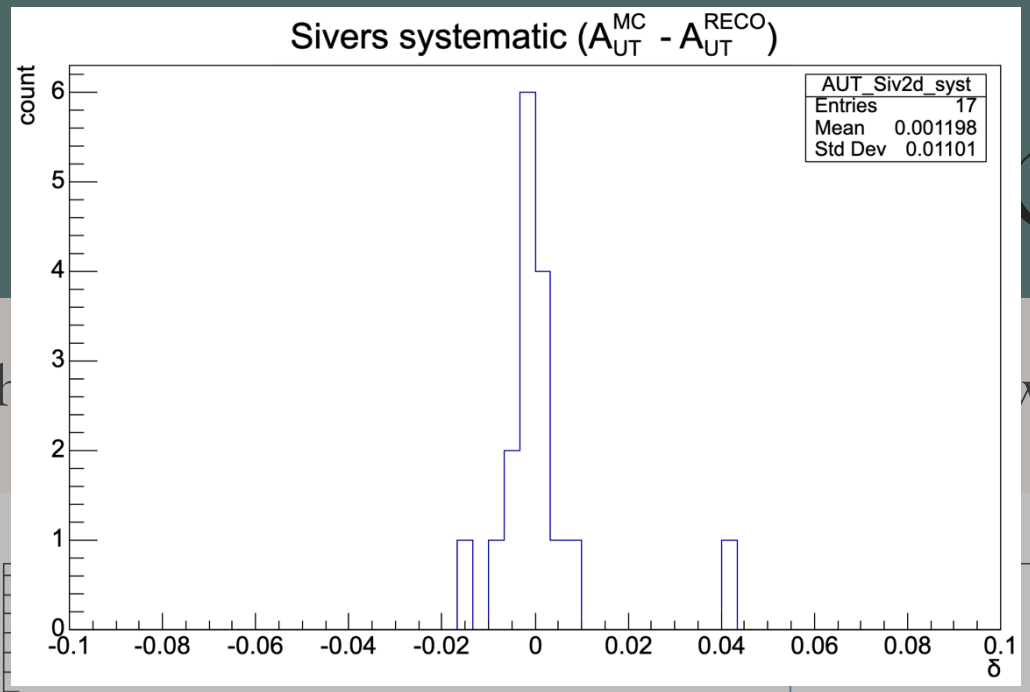
The relative extraction systematics were calculated from $A_{UT}^{inj} - A_{UT}^{reco}$. It was performed also a first estimation of the lepton-photon correction (with $\frac{A_{UL}}{A_{UT}} = 0.8$).

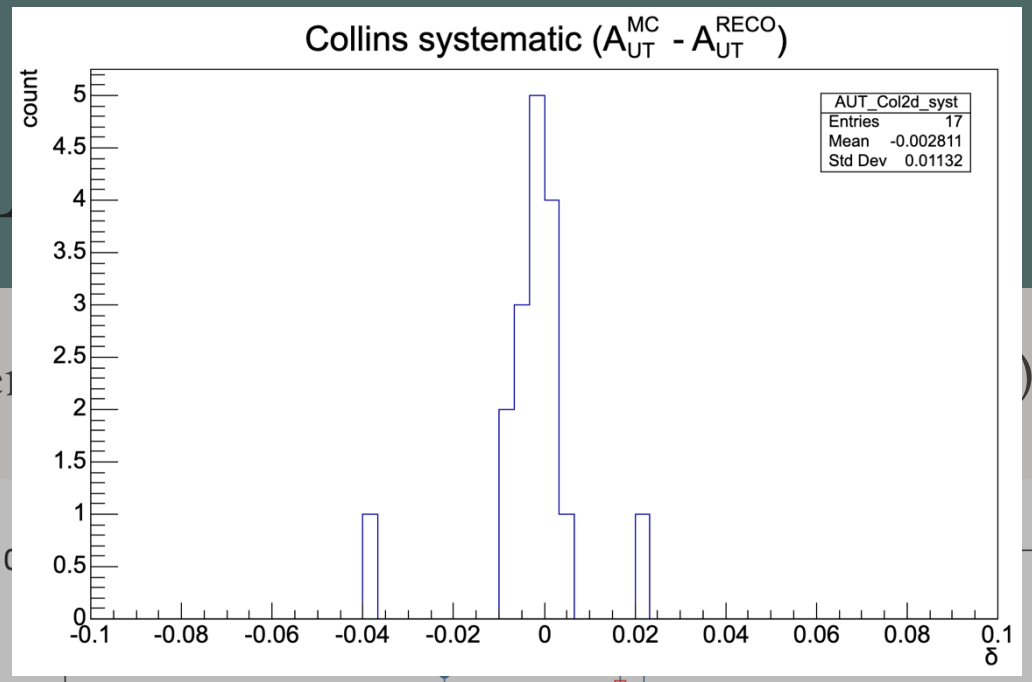
RGH – SIVERS & COLLINS 2D

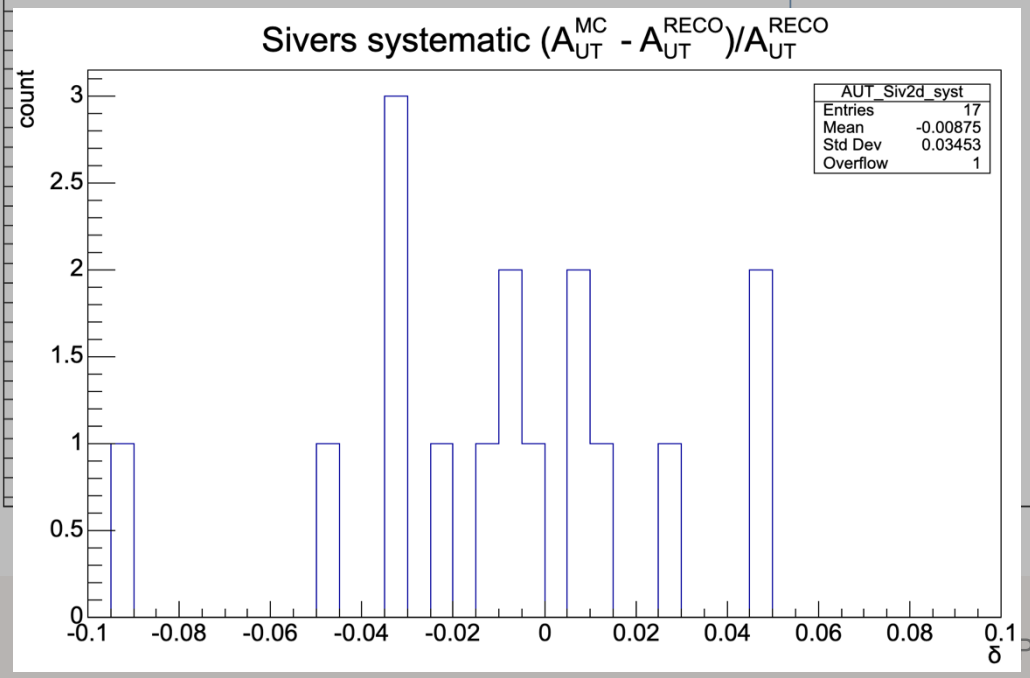
The first extraction for Sivers and Collins in two-dimension are (extracted and injected asymmetry):

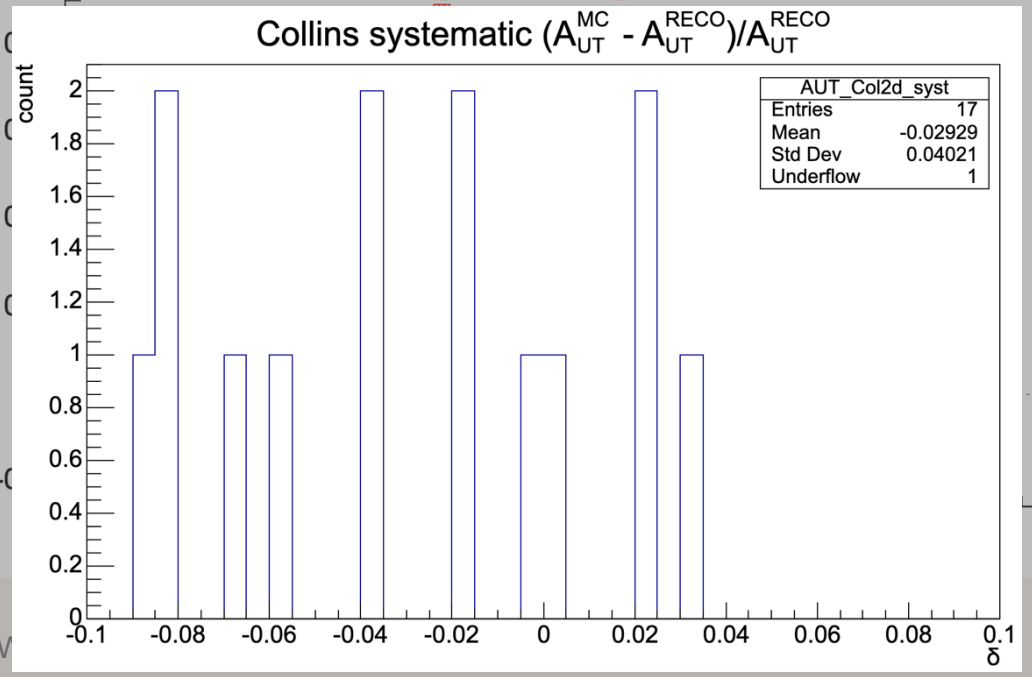





Sivers systematic ($A_{UT}^{MC} - A_{UT}^{RECO}$)
AUT_Siv2d_syst
Entries 17
Mean 0.001198
Std Dev 0.01101
count
δ

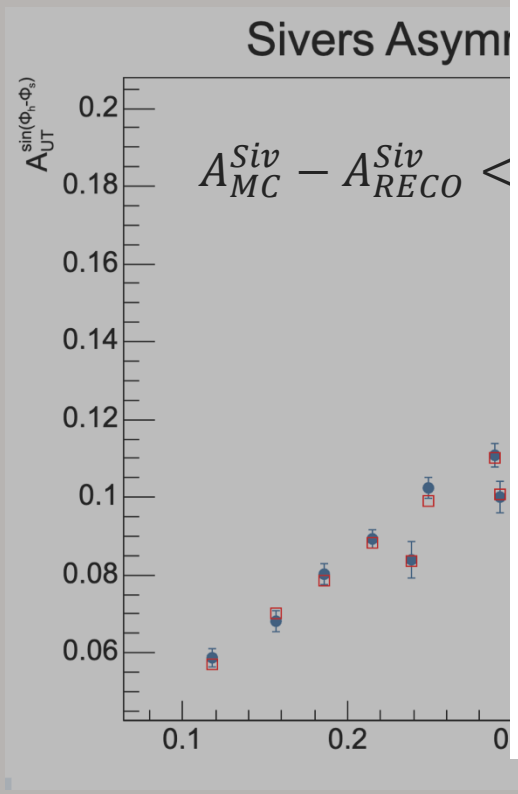

Collins systematic ($A_{UT}^{MC} - A_{UT}^{RECO}$)
AUT_Col2d_syst
Entries 17
Mean -0.002811
Std Dev 0.01132
count
δ

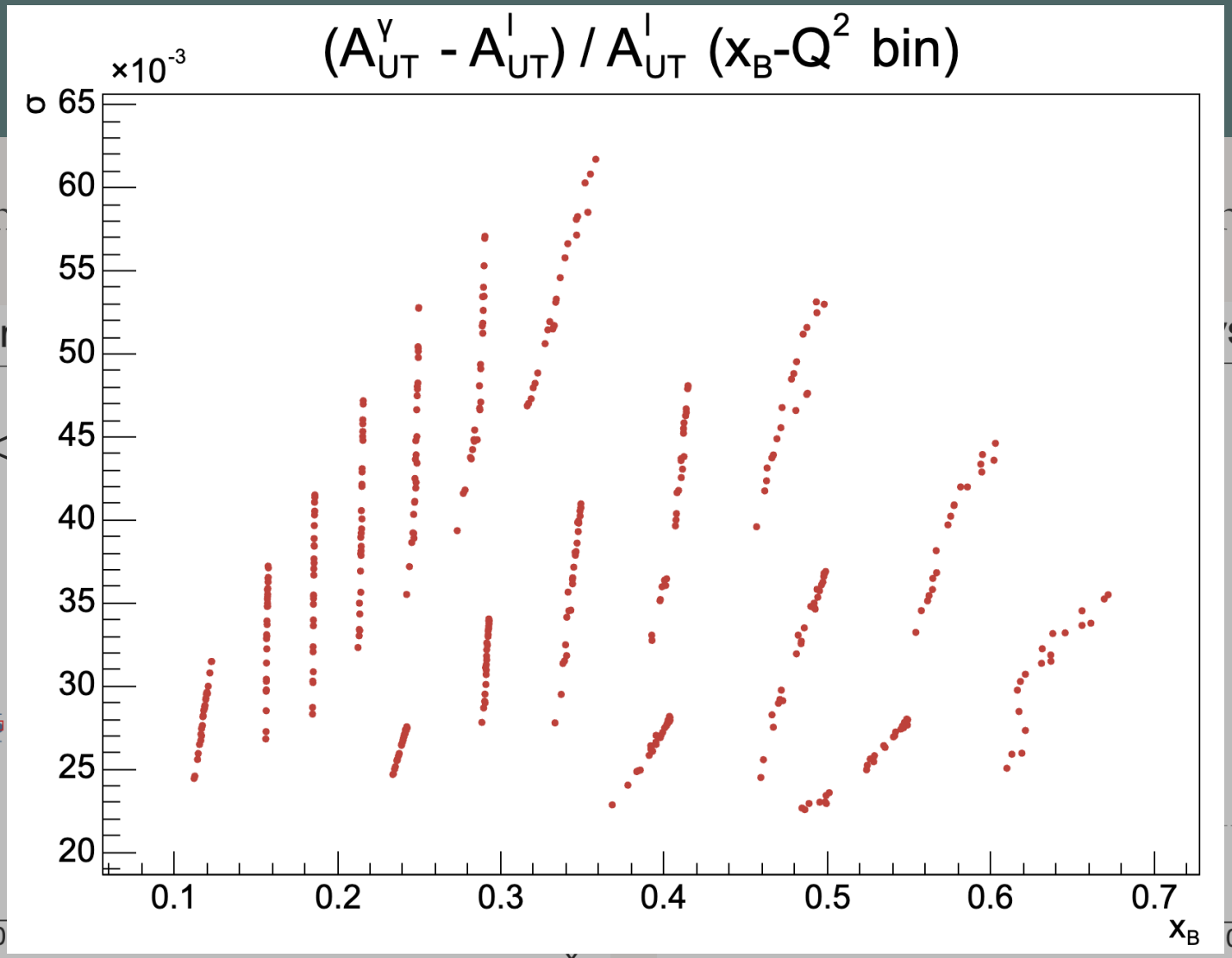

Sivers systematic ($A_{UT}^{MC} - A_{UT}^{RECO}$)/$A_{UT}^{RECO}$
AUT_Siv2d_syst
Entries 17
Mean -0.00875
Std Dev 0.03453
Overflow 1
count
δ

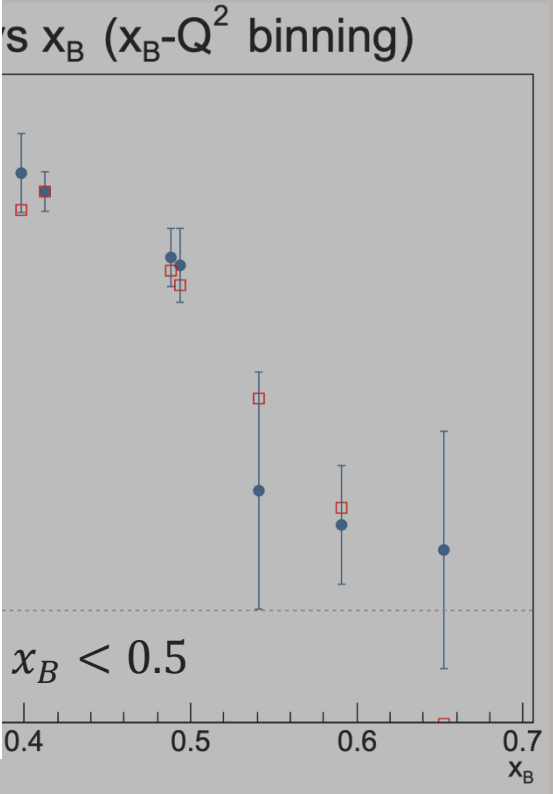

Collins systematic ($A_{UT}^{MC} - A_{UT}^{RECO}$)/$A_{UT}^{RECO}$
AUT_Col2d_syst
Entries 17
Mean -0.02929
Std Dev 0.04021
Underflow 1
count
δ

RGH –

The first extraction … injected asymmetry):



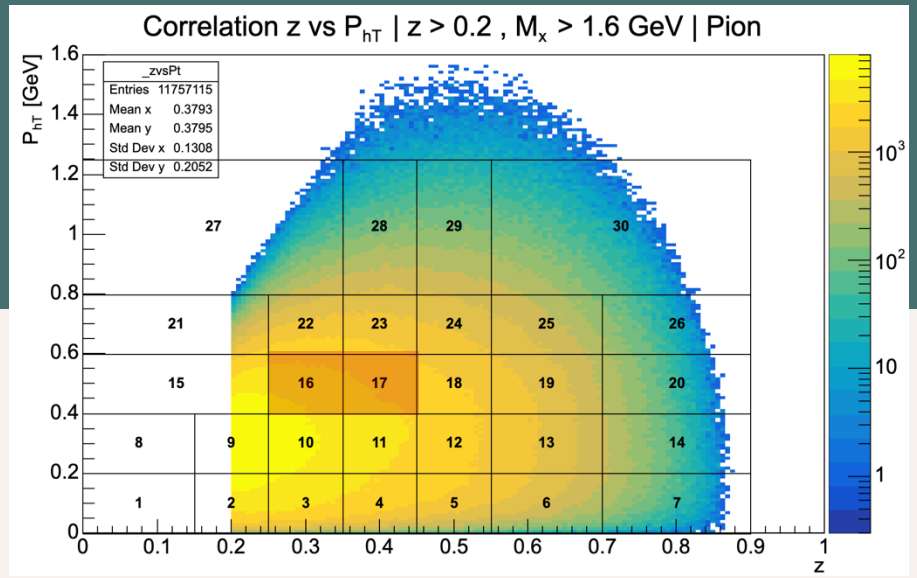


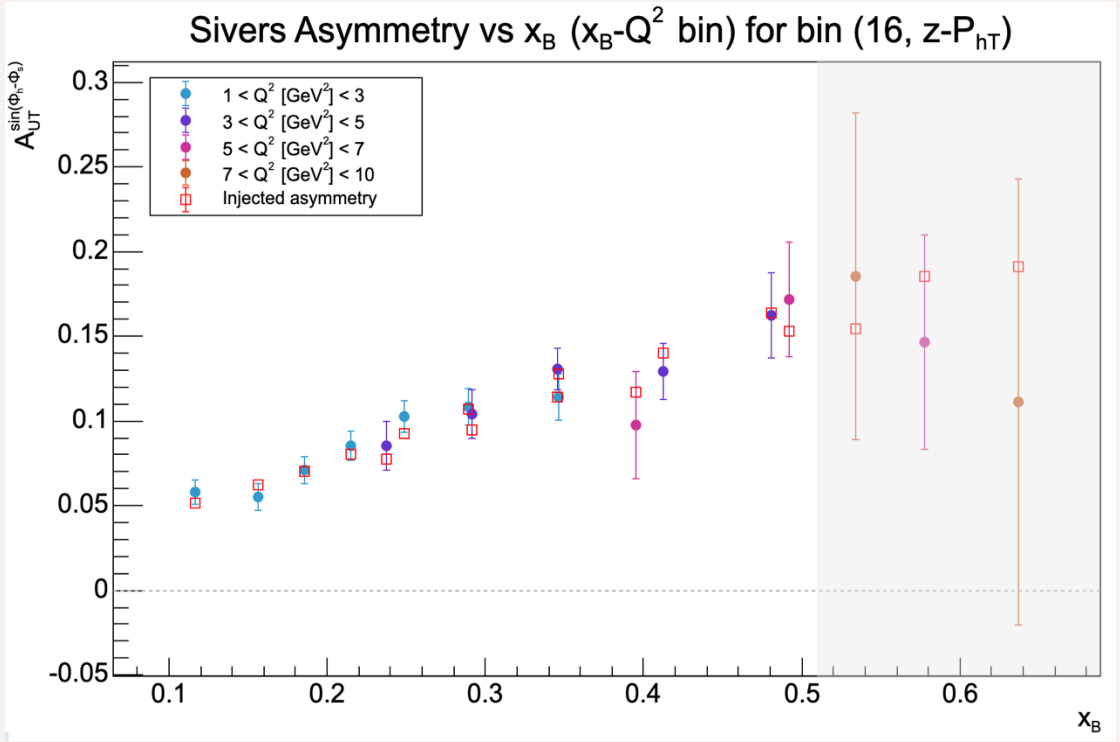


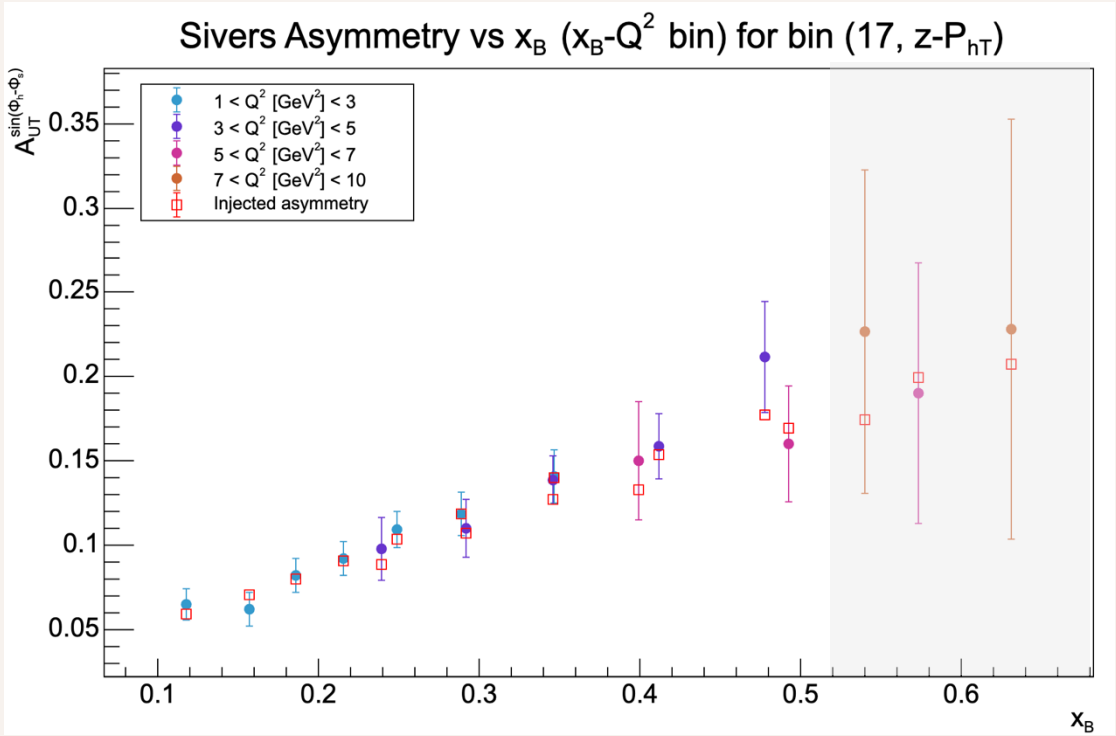
$\sigma_{UT}^{l\gamma} = (A_{UT}^{\gamma} - A_{UT}^{l})/A_{UT}^{l}$ between **2.2**% and **6.1**%.

RGH – SIVERS 4D

Quick observation of two central bin in the z, P_{hT} distribution. Grey area: high uncertainty.

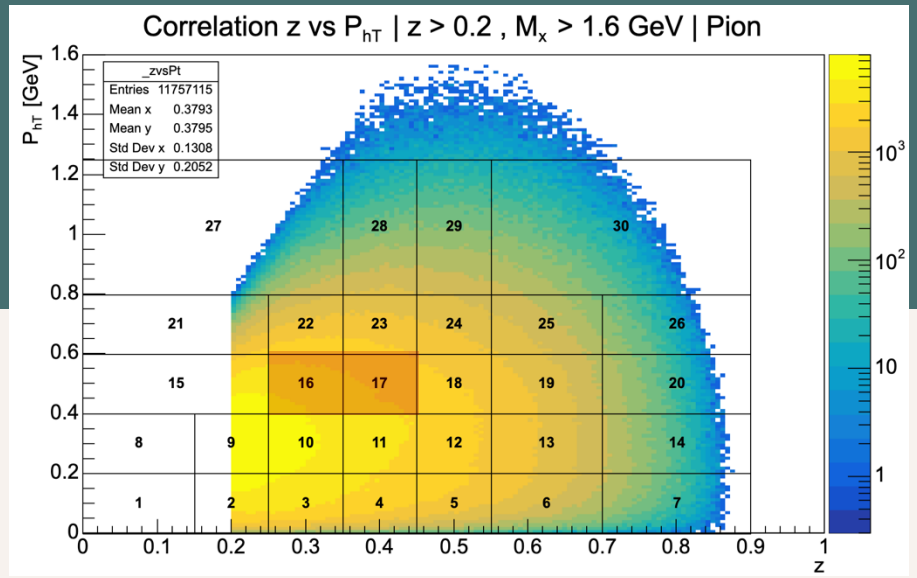


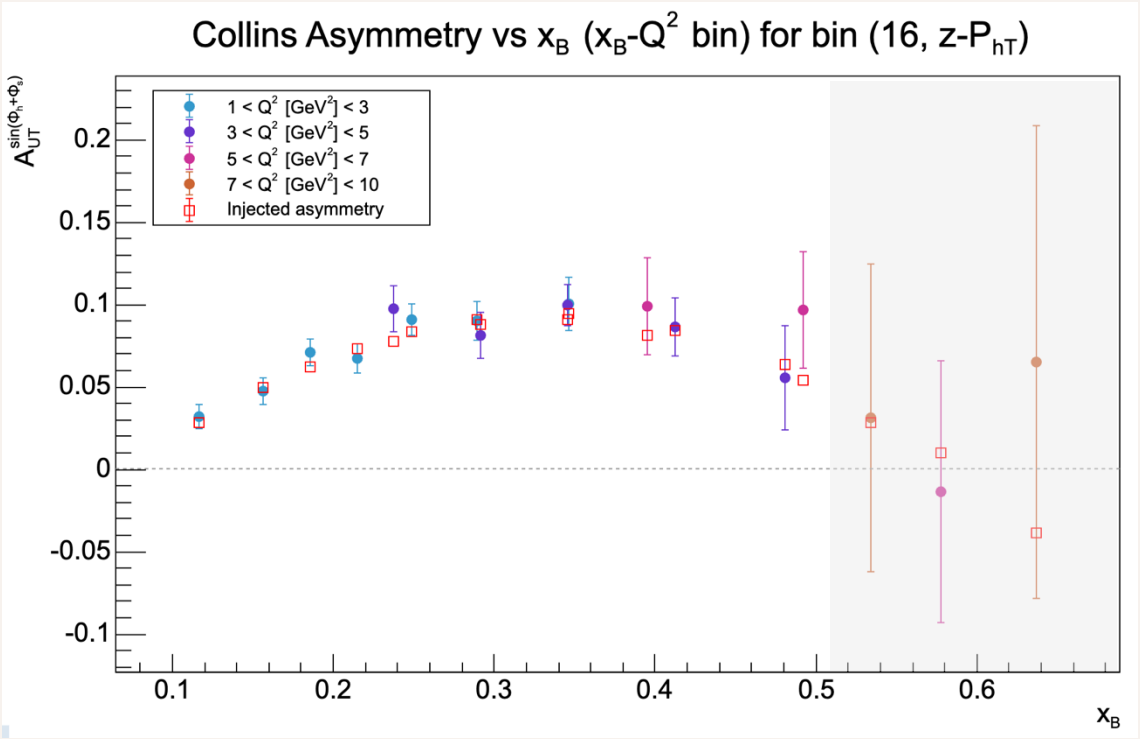


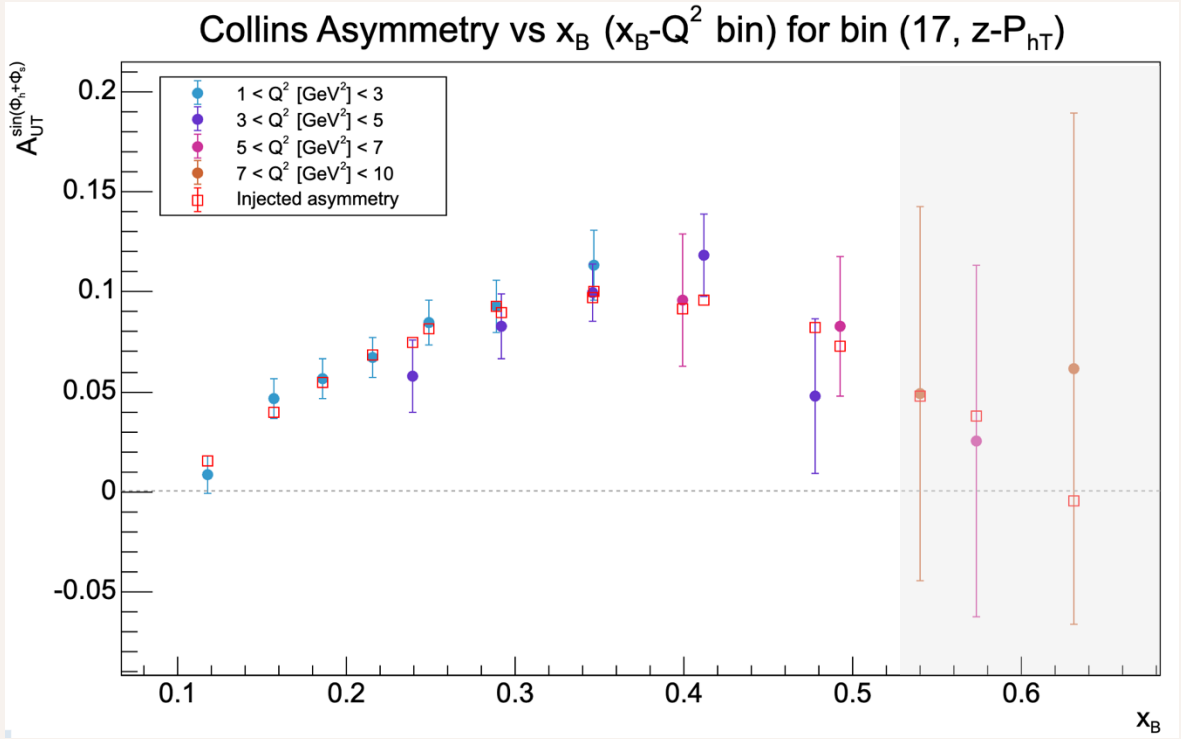


RGH – COLLINS 4D

Quick observation of two central bin in the z, P_{hT} distribution. Grey area: high uncertainty.

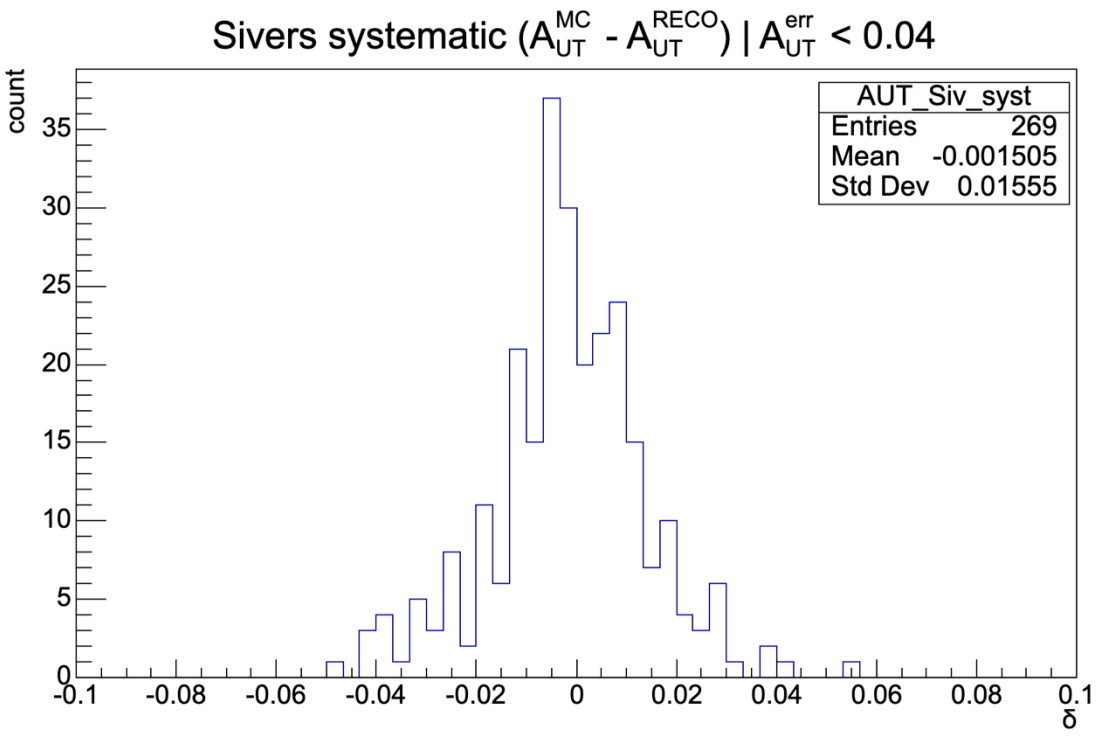


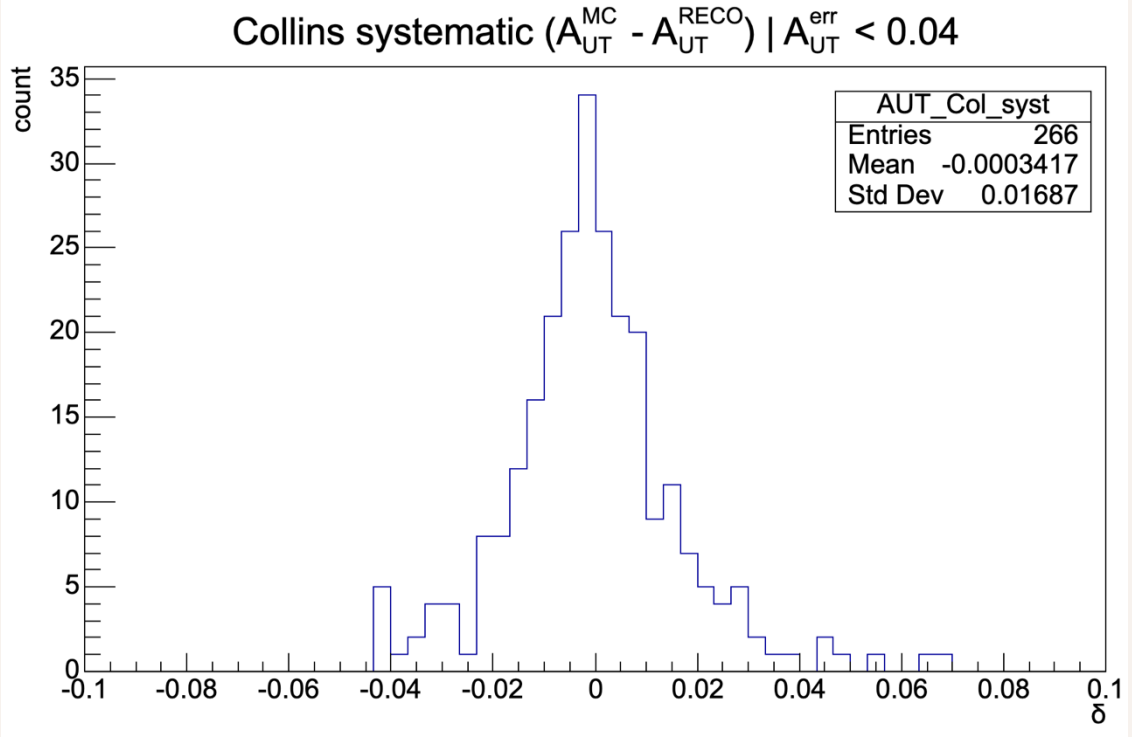




RGH – SYSTEMATIC ERROR

Considering the measures with a statistical uncertainty < 0.04 we can see that, usually, the difference between the injected and extracted asymmetry is smaller that our uncertainty.





PROJECTION RESULTS

Duke has produced the projection of the **asymmetry uncertainties** for RGH (both $\boldsymbol{\pi^+}$ and $\boldsymbol{\pi^+\pi^-}$) provided to the theorists, and we performed a cross-check to assert their outcome.

This work was setted up by Matthew McEneaney.

RGH Statistics Projections

- Estimate RGH statistics using known RGC statistics
- Let $R_{RG,MC} = N_{RG,Rec}/N_{RG,Gen}$:

$$N_{RGH,i} = N_{RGC,i} \cdot \frac{R_{RGH,MC,i}}{R_{RGC,MC,i}} \cdot \frac{\mathcal{L}_{RGH}}{\mathcal{L}_{RGC}}$$

- Generated simulation for RGH
- Use existing simulation and data for RGC
- Use bin counts and total XSs to find $R_{RGH,MC,i}/R_{RGC,MC,i}$

RGH Asymmetry Uncertainty Projections

- Plugging in values from the RGC inbending NH_3 Fall 2022 dataset and RGH proposal

$$N_{RGH,i} = N_{RGC,i} \cdot \frac{R_{RGH,MC,i}}{R_{RGC,MC,i}} \cdot \frac{\boldsymbol{100days \cdot 5\times10^{33}cm^{-2}s^{-1}}}{\boldsymbol{13.2days \cdot 4.0\times10^{34}cm^{-2}s^{-1}}}$$

- Projected uncertainties are computed assuming target polarization $P_t = 0.85$ and dilution $D_t = 3/17$ for both run groups

Only works for raw asymmetry, not modulations!

$$\sigma_{RGH,i} = \sigma_{RGC,i} \cdot \frac{P_{t,RGC} \cdot D_{t,RGC}}{P_{t,RGH} \cdot D_{t,RGH}} \cdot \sqrt{\frac{N_{RGC,i}}{N_{RGH,i}}}$$

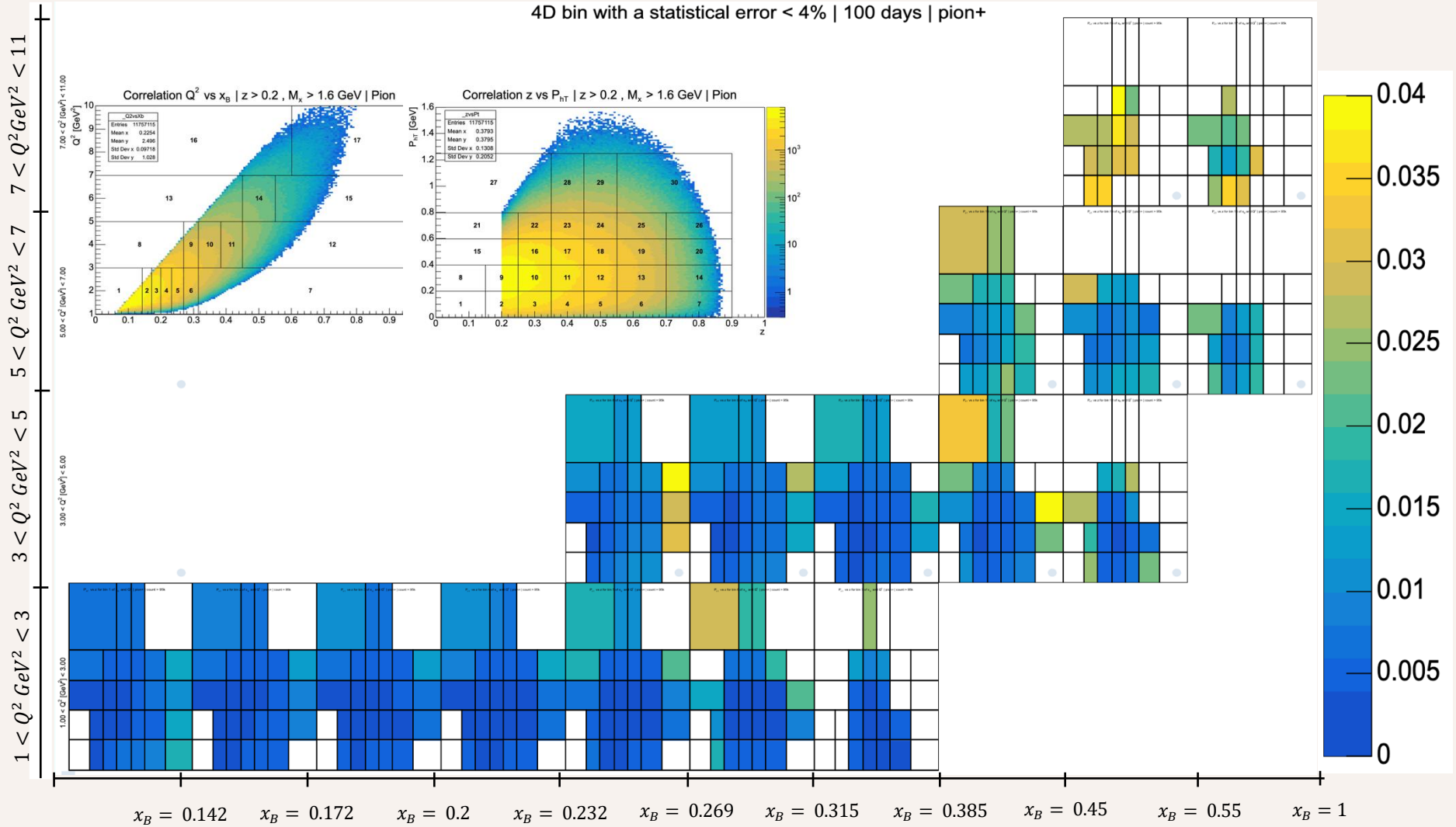
$$\delta A_{UT} \simeq \frac{1}{P_t \cdot D_t}\sqrt{1/N}$$

Scale uncertainty from $A_{UL}^{\sin\phi_{R_T}\sin\theta}$ modulation in RGC data

9 Feb. 2026 M. McEneaney, Duke University 2

Matthew presentation: link here

RGH – SIVERS 4D STATISTICAL ERROR



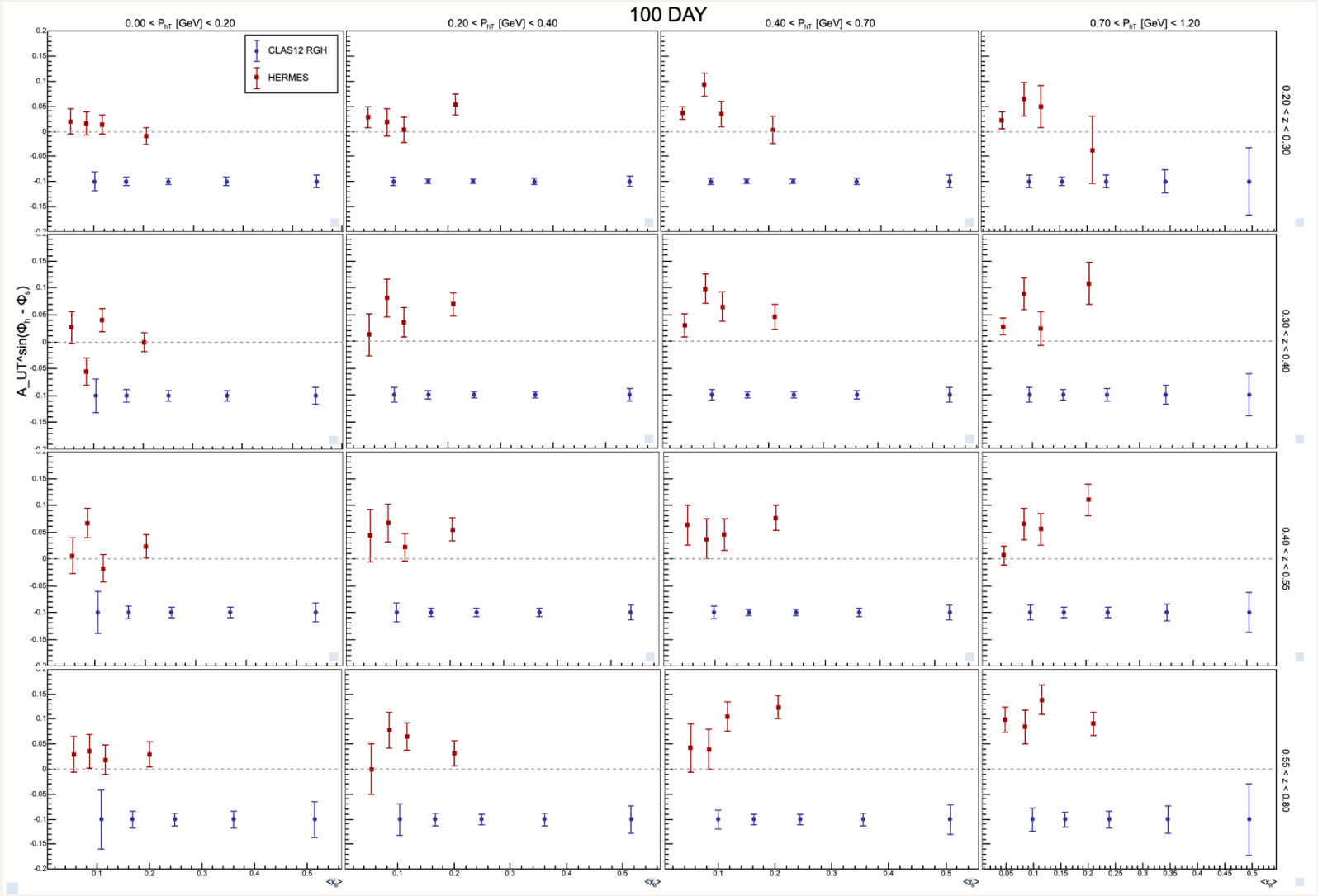
SIVERS UNCERTAINTY COMPARISON

In this plot the Q^2 regions were keep togheter to have a correct comparison with the measurement of HERMES JHEP12 in 2020.

The errors where calculated as:

$$\sigma_{UT} = \frac{1}{DP}\sqrt{\frac{1-(DP\cdot A)^2}{Y_{RGH}}}$$

With: $P = 0.85$ and $Y_{RGH} = evt \cdot \frac{5}{4}$ which represent the projection of the statistic over 20mln events taking into account the dilution.



CLOSE OUT

- **Explore the valence region:** RGH will enable multidimensional measurements of transverse-spin asymmetries in Semi-Inclusive DIS.
- **Complement HERMES and COMPASS:** CLAS covers a different kinematic region, helping build a more complete picture of nucleon structure.
- **Unlock precise 4D measurements:** High luminosity of CLAS will allow asymmetry extractions in up to four dimensions, with improved statistical precision.

THANKS

PROJECTION RESULTS

Cross-check of Matthew Projection on the 1D x_B distribution.

bin	mean_xB	RGH_projected	RGH_Matthew_proj	RGH_delta_Aut_scaled	RGH_Matthew_delta	RGC_delta_Aul	RGC_Matthew_delta
1	0.126643	1.82263e+06	1.94411e+06	0.00746916	0.007223	0.00231494	0.002377855
2	0.168839	1.83149e+06	1.98209e+06	0.00675547	0.006634	0.00234085	0.002563948
3	0.198273	1.86825e+06	1.94303e+06	0.00640806	0.006479	0.0025202	0.002750041
4	0.227279	2.07952e+06	2.03405e+06	0.00588349	0.00620	0.00260178	0.002770718
5	0.25914	2.16102e+06	2.05975e+06	0.00564531	0.006045	0.00278013	0.002853426
6	0.297588	2.33066e+06	2.16534e+06	0.00535037	0.005828	0.00286332	0.002832749
7	0.351671	2.57028e+06	2.35839e+06	0.00503987	0.005518	0.00304879	0.00289478
8	0.469767	2.93614e+06	2.84428e+06	0.00476469	0.004991	0.0033365	0.003039519

x_B : [0.0, 0.1362, 0.1615, 0.1839, 0.2059, 0.2332, 0.2703, 0.3273, 0.45, 1.0]

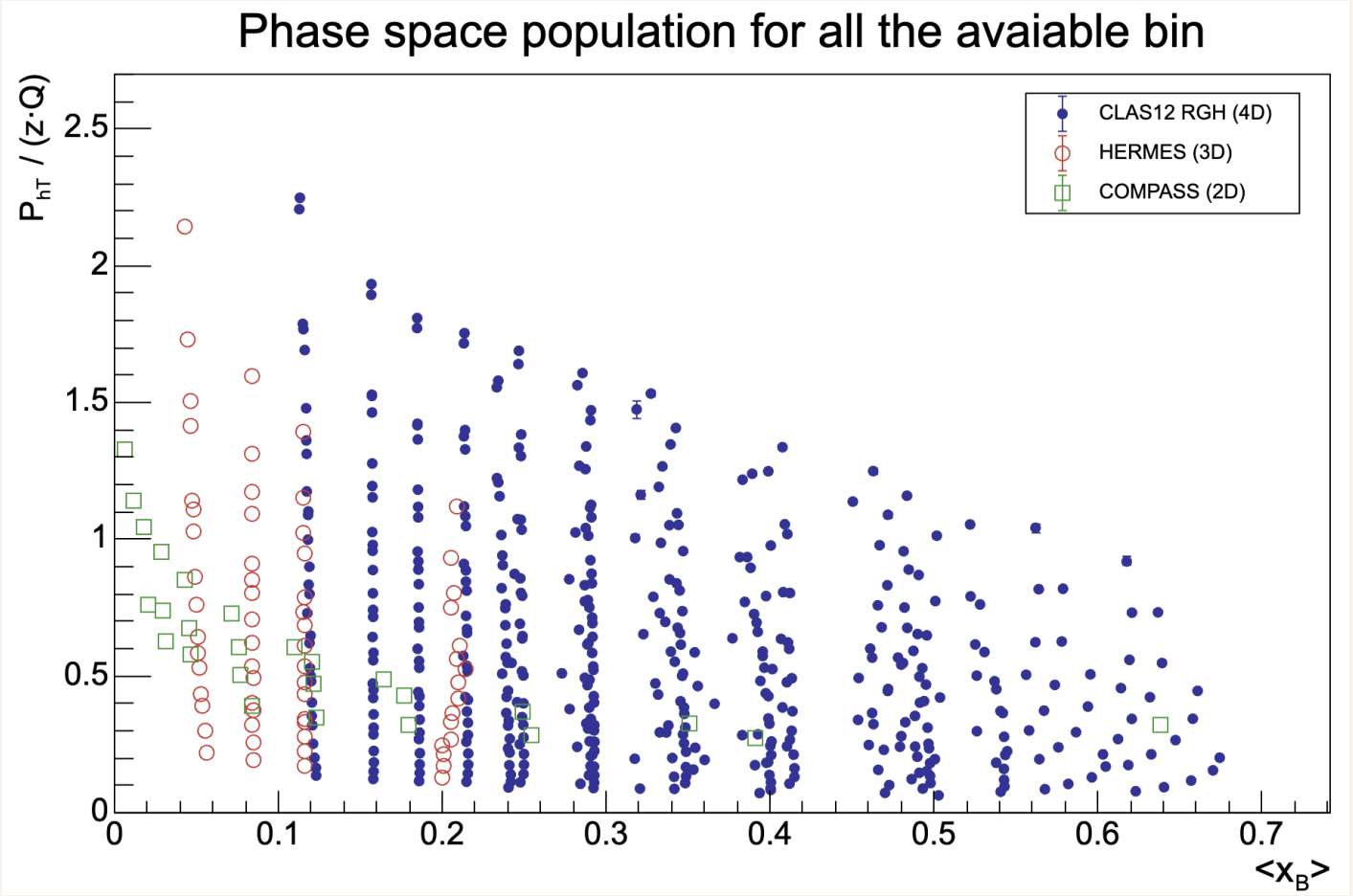
Column without the name are my estimation for the cross-check. Even with few discrepancies on selection cut we found good agreement.

TMD FACTORIZATION REGIME

The bin coverage of **RGH** compared to previous analyses such as **HERMES** and **COMPASS**.

Here they are represented in the scale of the **mean value** of the x_B compared to the **mean value** of P_{hT}/zQ in each bin.

This scale can be used to define the TMDs calculation regime (However, it **does not represent** a restrictive way of defining where TMDs can be applied).



TMD FACTORIZATION REGIME - HERMES

This plot display the **mean value** of the fraction $\frac{P_{hT}}{zQ}$ in each bin.

The upcoming **RGH** analysis will enable the exploration of a **higher** x_B region compared to that accessed by **HERMES**, remaining in a similar **TMD regime**.

Here the RGH bins are modified to imitate the ones from HERMES.

z **bins**	$P_{h\perp}$ **bins**
]0.20; 0.28]	]0.00 GeV; 0.23 GeV]
]0.28; 0.37]	]0.23 GeV; 0.36 GeV]
]0.37; 0.49]	]0.36 GeV; 0.54 GeV]
]0.49; 0.70]	]0.54 GeV; 2.00 GeV]

Hermes bin definition

