CLAS collaboration meeting, JLAB

April 29, 2020, Newport News, VA

SIDIS π^+ Beam Spin Asymmetry Measurements with CLAS 12

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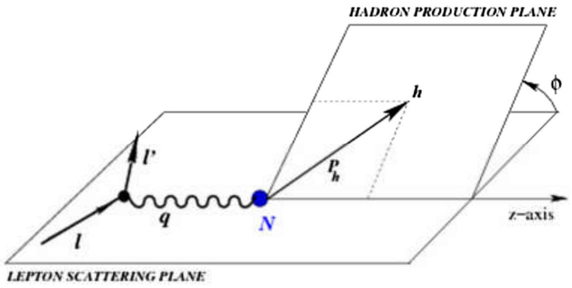
Physics Motivation

- The 3D nucleon structure in momentum space can be described by TMDs
- A way to acess these properties is the semi inclusive deep inelastic scattering



SIDIS cross section for an unpolarized target:

→ Contains model independent structure functions

$$\frac{d\sigma}{dx_B\,dQ^2\,dz\,d\phi_h\,dp_{h\perp}^2} = K(x,y,Q^2)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\sin\phi_h \underline{F_{LU}^{\sin\phi_h}}\Big\}$$

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\mathcal{C}\left(-\frac{\hat{\mathbf{h}}\cdot\mathbf{k_T}}{M_h}\left(xeH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{\mathbf{h}}\cdot\mathbf{p_T}}{M}\left(xg^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{E}}{z}\right)\right)$$

twist-3 pdf

Collins FF

unpolarized dist. function

twist-3 FF

twist-3 t-odd dist. funcion

Boer-Mulders

twist-3 FF

Physics Motivation

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\mathcal{C}\left(-\frac{\hat{\mathbf{h}}\cdot\mathbf{k_T}}{M_h}\left(x\underset{\text{twist-3 pdf}}{e}\underset{\text{Collins FF}}{H_1^{\perp}} + \frac{M_h}{M}\underset{\text{unpolarized dist. function}}{f_1}\frac{\underset{\text{twist-3 FF}}{\tilde{G}^{\perp}}}{z}\right) + \frac{\hat{\mathbf{h}}\cdot\mathbf{p_T}}{M}\left(x\underset{\text{twist-3 t-odd dist. funcion}}{g^{\perp}}D_1 + \frac{M_h}{M}\underset{\text{Boer-Mulders}}{h_1^{\perp}}\frac{\underset{\text{twist-3 FF}}{\tilde{E}}}{z}\right)\right)$$

- ➔ A convolution of 4 TMDs and 4 fragmentation functions
- ➔ Each term contains a twist 3 component
- ➔ The results can be used in a global fit to constrain the TMDs and FF

Additional constraints: i.e. from unpolarized structure functions

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left[-\frac{\hat{\mathbf{h}}\cdot\mathbf{p}_T}{M_h}\left(xhH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\mathbf{h}}\cdot\mathbf{k}_T}{M}\left(xf^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{H}}{z}\right)\right]$$

$$F_{UU}^{\cos 2\phi_h} = \mathcal{C}\left[-\frac{2(\hat{\mathbf{h}}\cdot\mathbf{p}_T)(\hat{\mathbf{h}}\cdot\mathbf{k}_T) - \mathbf{p}_T\cdot\mathbf{k}_T}{MM_h}h_1^{\perp}H_1^{\perp}\right].$$

+ di-hadron SIDIS: $F_{LU}^{\sin\phi_R} = -x\frac{|\vec{R}|\sin\theta}{Q}\left[\frac{M}{M_{\pi\pi}}xe^q(x)H_1^{\sphericalangle q}(z, cos\theta, M_{\pi\pi}) + \frac{1}{z}f_1^q(x)\tilde{G}(z, \cos\theta, M_{\pi\pi})\right]$

Bacchetta,Radici, PRD69,074026 (2004), Aurore Courtoy, arXiv:1405.7659

+ constraints from other experiments (SIDIS + Drell-Yan)

Physics Motivation

Goal of this study: Extract $F_{LU}^{\sin\phi} / F_{UU}$ from single π⁺ beam spin asymmetries

$$d\sigma = d\sigma_0 (1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi + \lambda_e A_{LU}^{\sin\phi} \sin\phi)$$

$$BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{\sin\phi} \sin\phi}{1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos(2\phi)} \cos(2\phi)}$$

$$A_{LU}^{\sin\phi} = \sqrt{2\varepsilon(1-\varepsilon)} \frac{F_{LU}^{\sin\phi}}{F_{UU}}$$

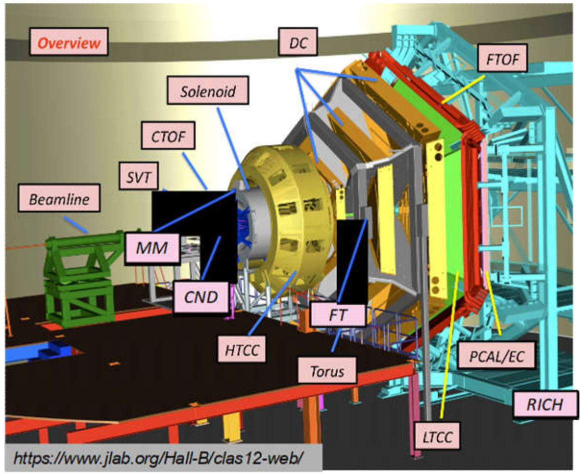
Past: Measurements have been performed with CLAS, HERMES and COMPASS

Advantages of CLAS12 → Significantly higher statistics

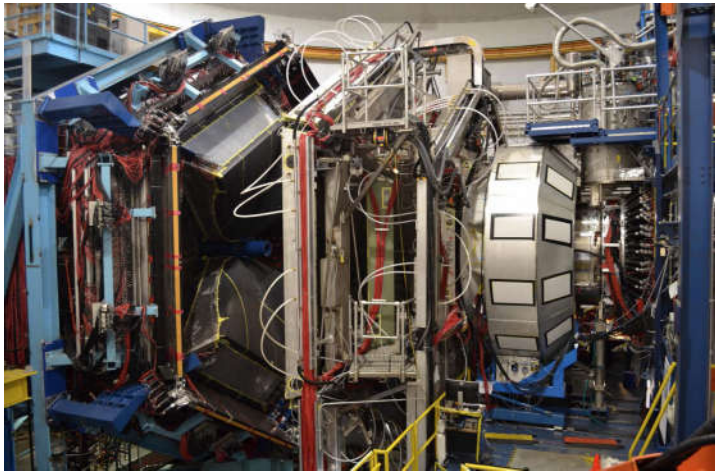
Advantages of CLAS12 → Extended kinematic coverage (Q^2, P_T)

Goal for a first CLAS12 publication: A multidimensional study in Q^2, x_B, z and P_T

Experimental setup and available dataset



https://www.jlab.org/Hall-B/clas12-web/



RG-A data from fall 2018 (pass 1 cooking):

➔ 10.6 GeV electron beam ➔ 85.9 / 89.2 % average polarization

➔ liquid H_2 target

➔ Available SIDIS $e\pi^+X$ events with inbending field configuration:

	pass 1 (~170 runs)	**DNP (64 runs)**
eventbuilder:	$1.01 \cdot 10^8$	$1.64 \cdot 10^7$
after fid. cuts and PID ref:	$5.67 \cdot 10^7$	$6.96 \cdot 10^6$

➔ Cooking of the outbending data is in progress

Electron ID

1. PCAL fiducial cuts
(v, w > 9 cm)

2. DC fiducial cuts for
the 3 regions
(χ^2 /NDF based method)

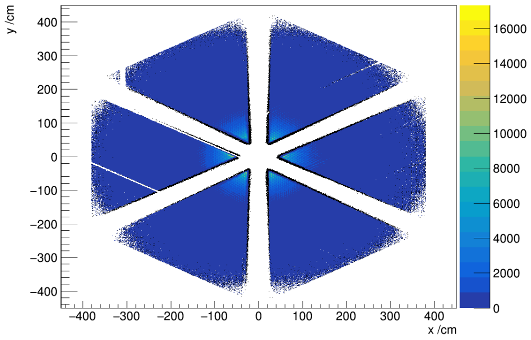
3. PCAL energy
deposition > 0.07 GeV
eventbuilder: > 0.06 GeV

4. Calorimeter sampling
fraction: 3-4 sigma region

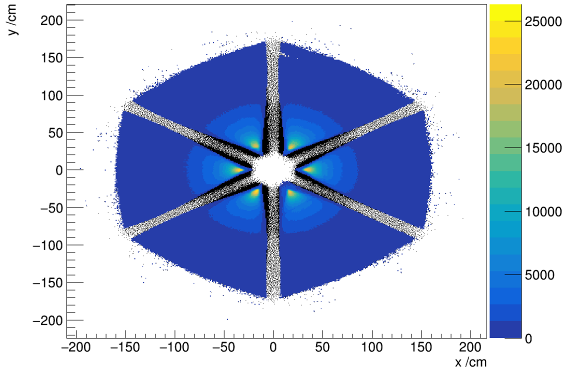
5. $p_e > 2.0$ GeV

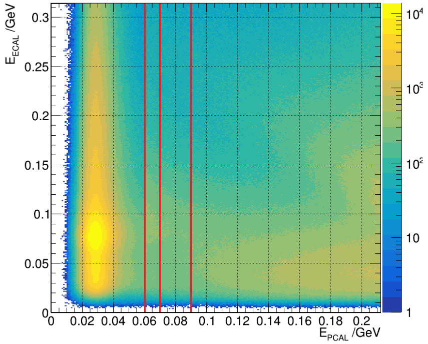
6. z-vertex cut [-13, +12]
➔ Widening caused by θ dependence
of the vertex resolution

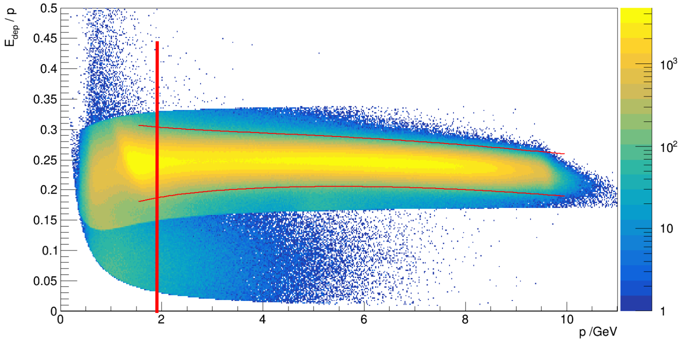
PCAL

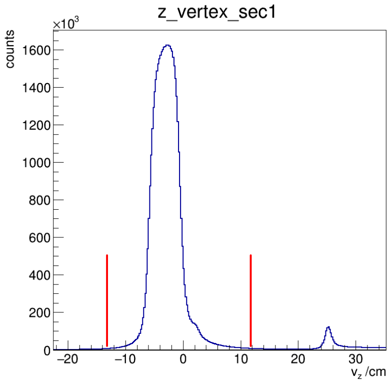


DC region 1

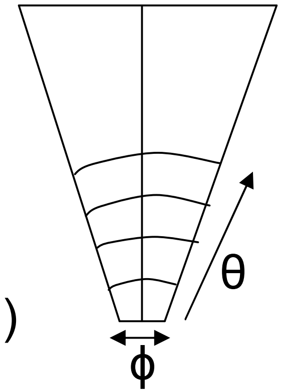








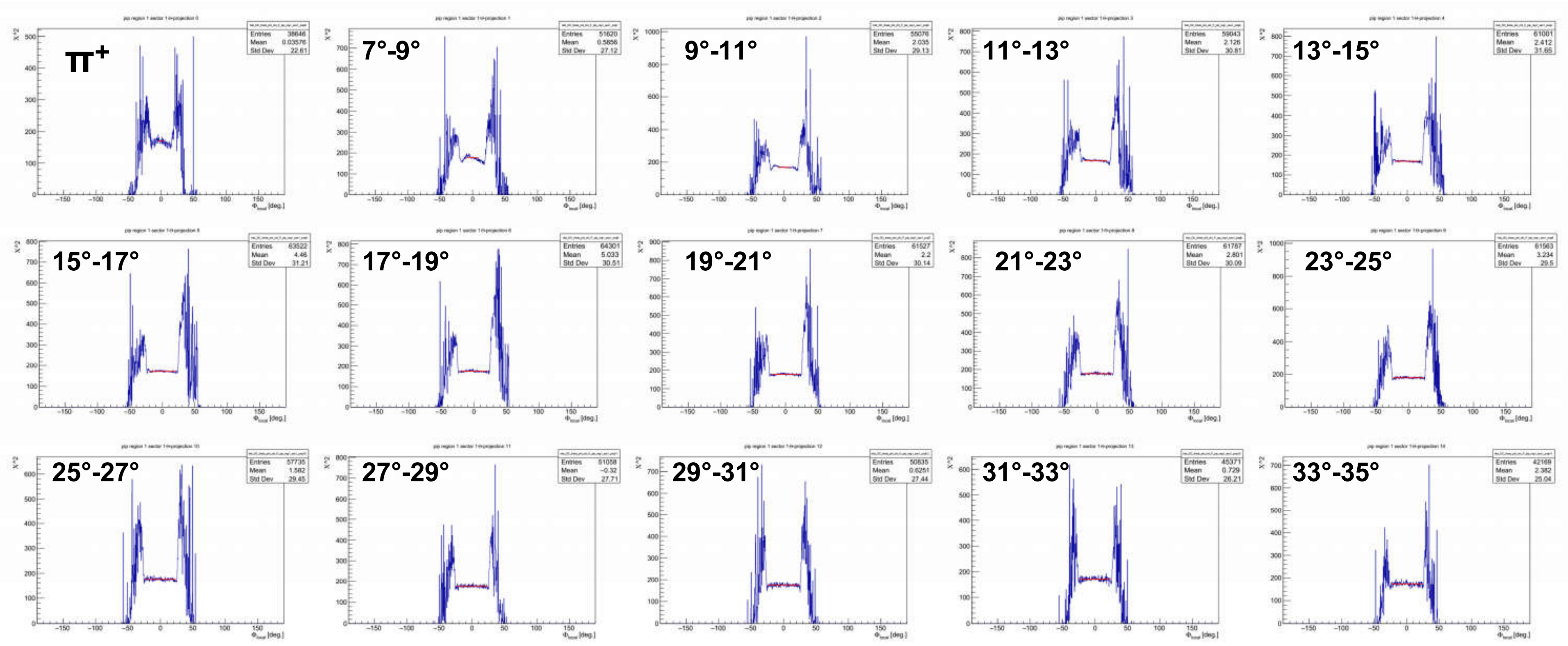
Hadron ID



1. DC fiducial cuts for the 3 regions

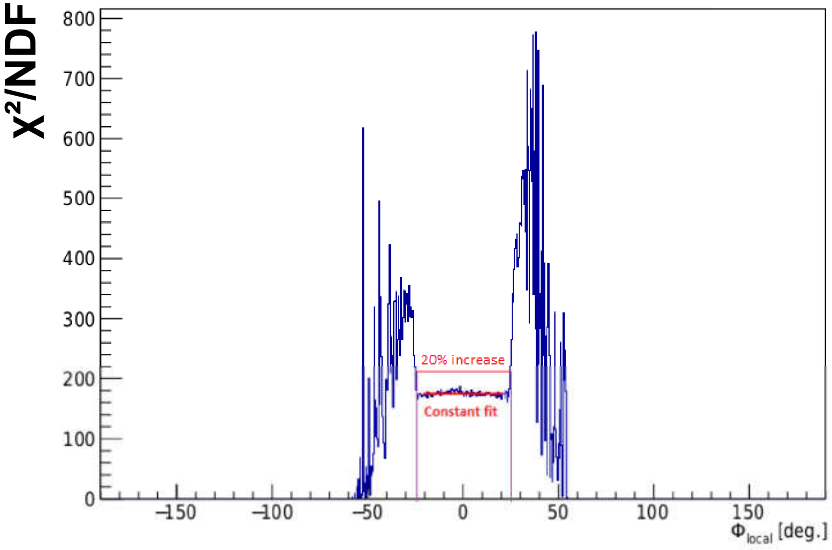
➔ Based on the local θ and Φ coordinates (from x, y, z hit positions)

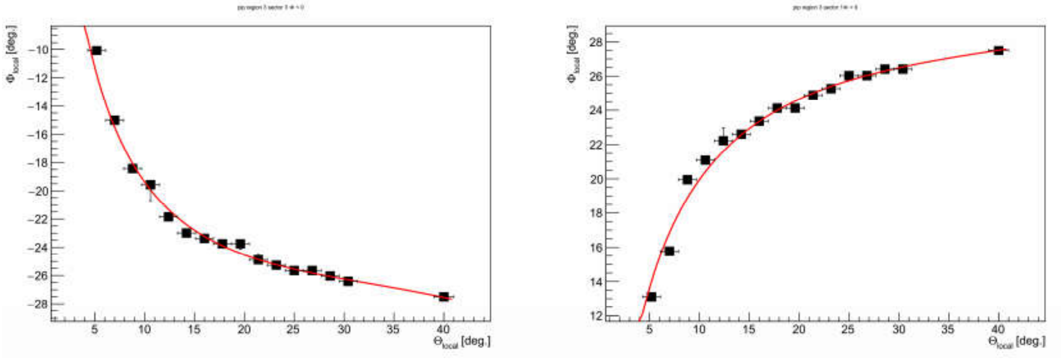
Average χ^2/NDF as a function of Φ_{local} for different bins in θ_{local} (sector 1, region1):



plots by A. Kripko (Giessen)

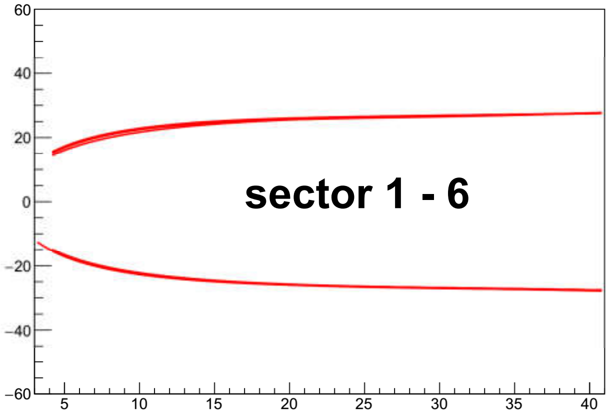
Hadron ID



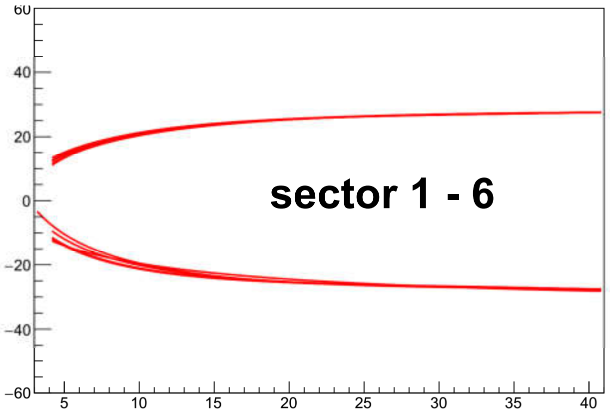


$$a + b * log(\Theta) + c * \Theta + d * \Theta^2$$

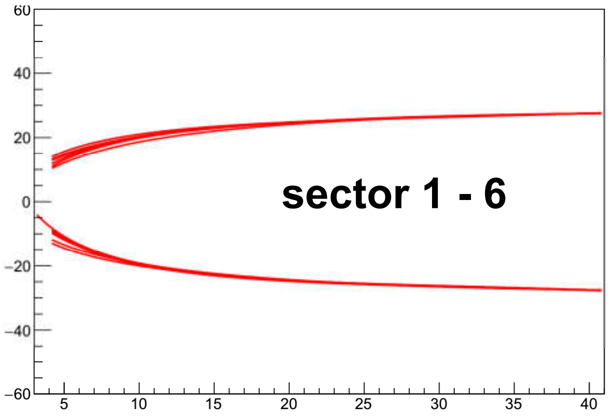
π^+ region 1



π^+ region 2



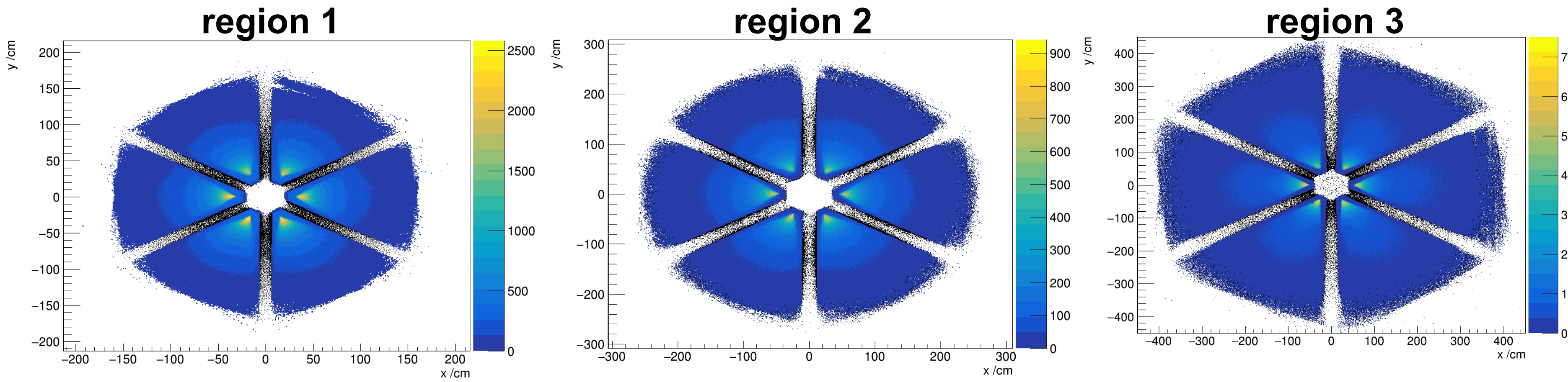
π^+ region 3



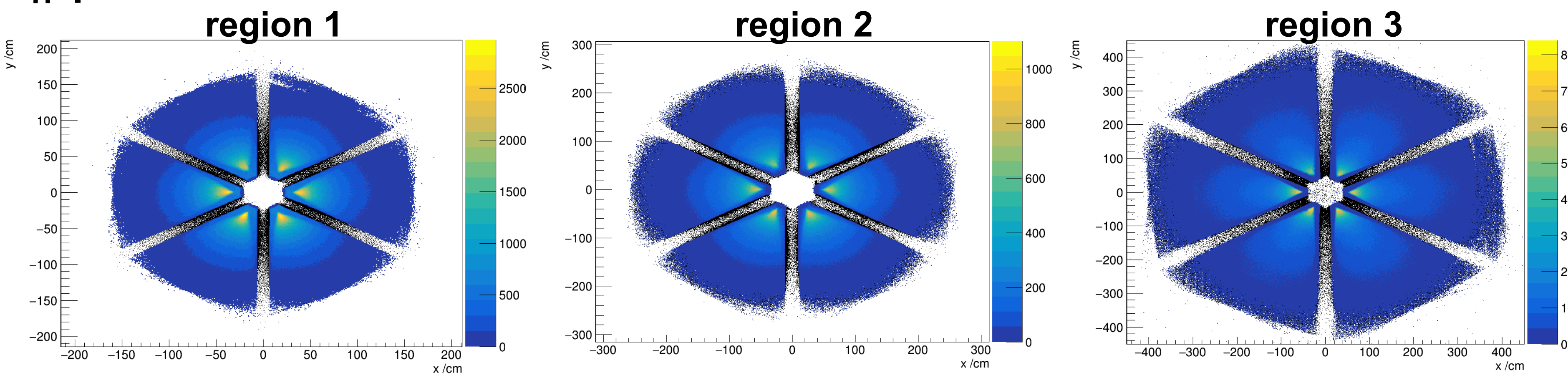
plots by A. Kripko (Giessen)

Hadron ID

proton:



π^+:

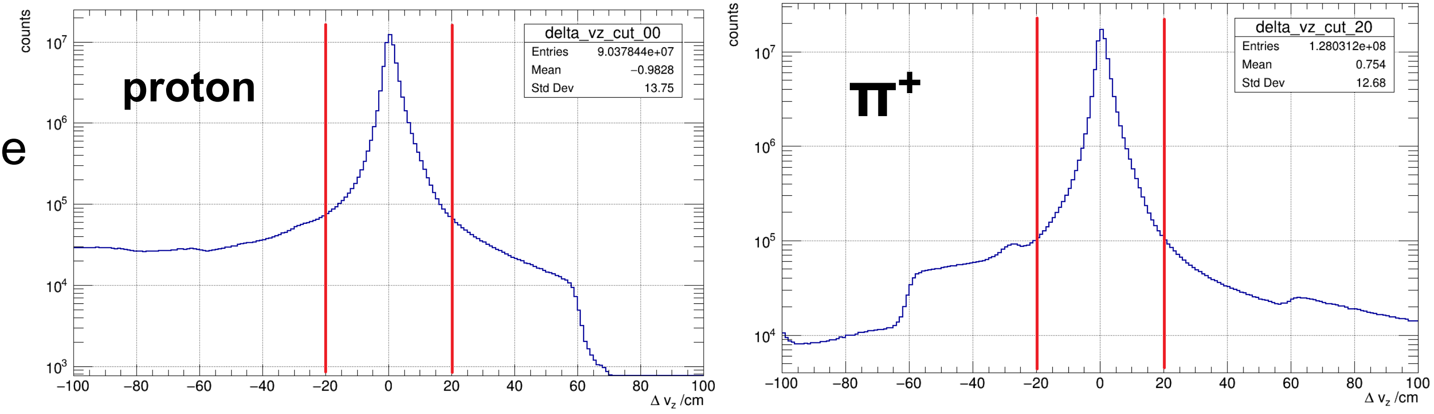


➔ Cuts individually adjusted for all hadron types

Hadron ID

2. Cut on the z-vertex diference

The hadron vertex should not be outside the target region

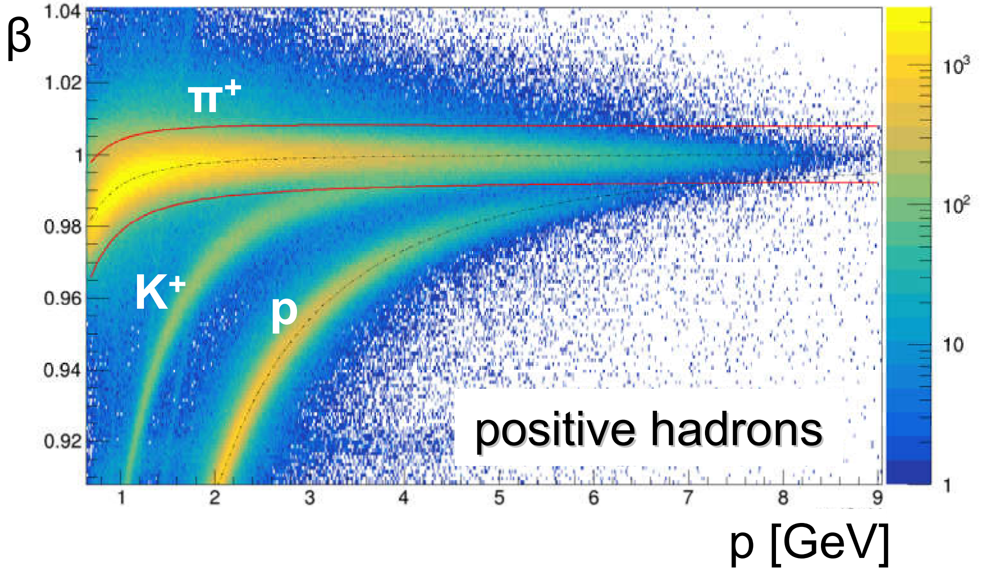


$|v_z(\text{ele}) – v_z(\text{had})| < 20$ cm

3. Final selection based on TOF

→ Maximum likelyhood PID from eventbuilder with

$\chi^2_{PID} > -2.0$ && $\chi^2_{PID} < +3.0$



Kinematic cuts

$P_{min}(e^-)$ = 2.0 GeV ($y < 0.8$) $P_{min}(\pi^+)$ = 1.25 GeV

DIS cut: $Q^2 > 1$ GeV² $W > 2$ GeV

Classical SIDIS regime: Cut on the final state hadron momentum fraction z

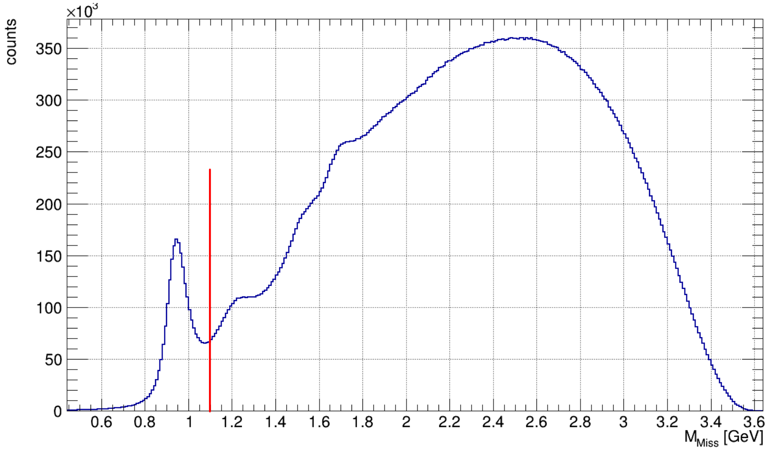
$$0.3 < z < 0.7$$

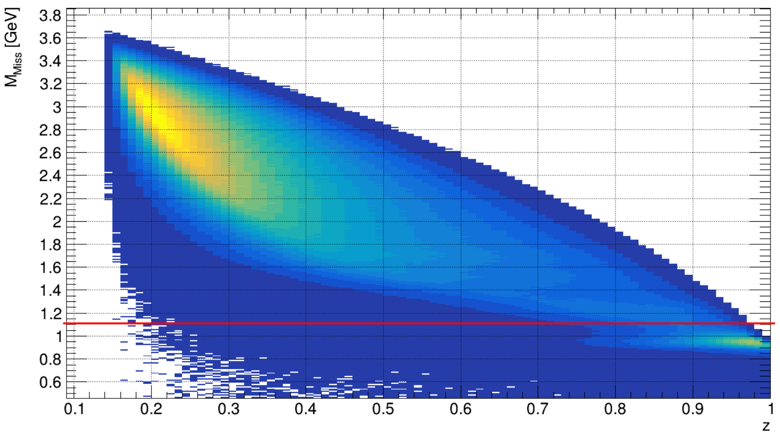
→ $z > 0.3$ removes the "target fragmentation region"

→ $z < 0.7$ removes contamination by pions from exclusive channels

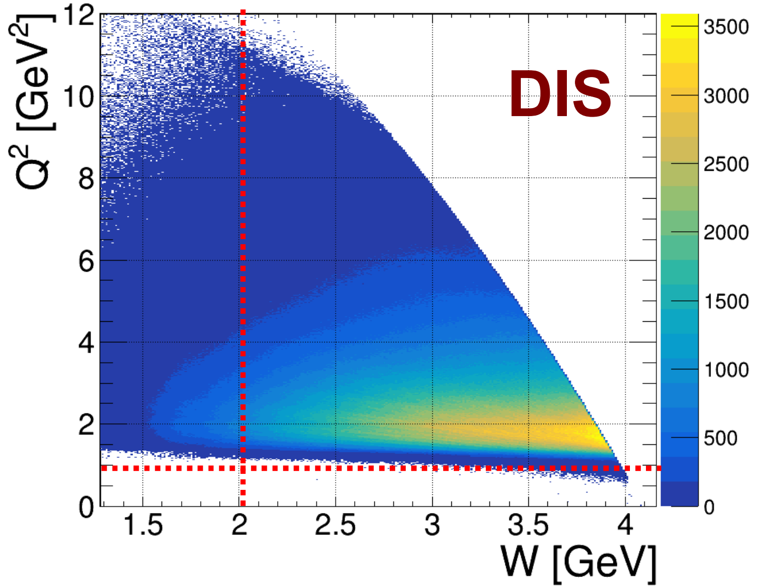
cut on the $e\pi^+X$ missing mass

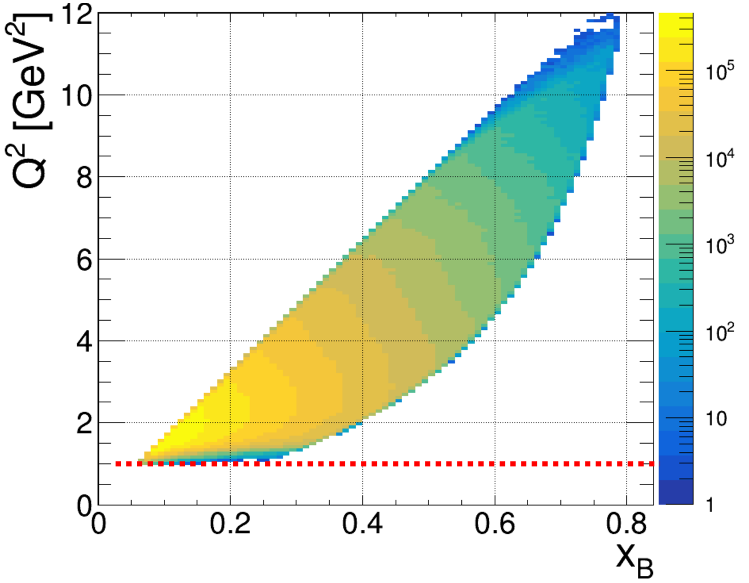
$M_{miss} > 1.1$ GeV

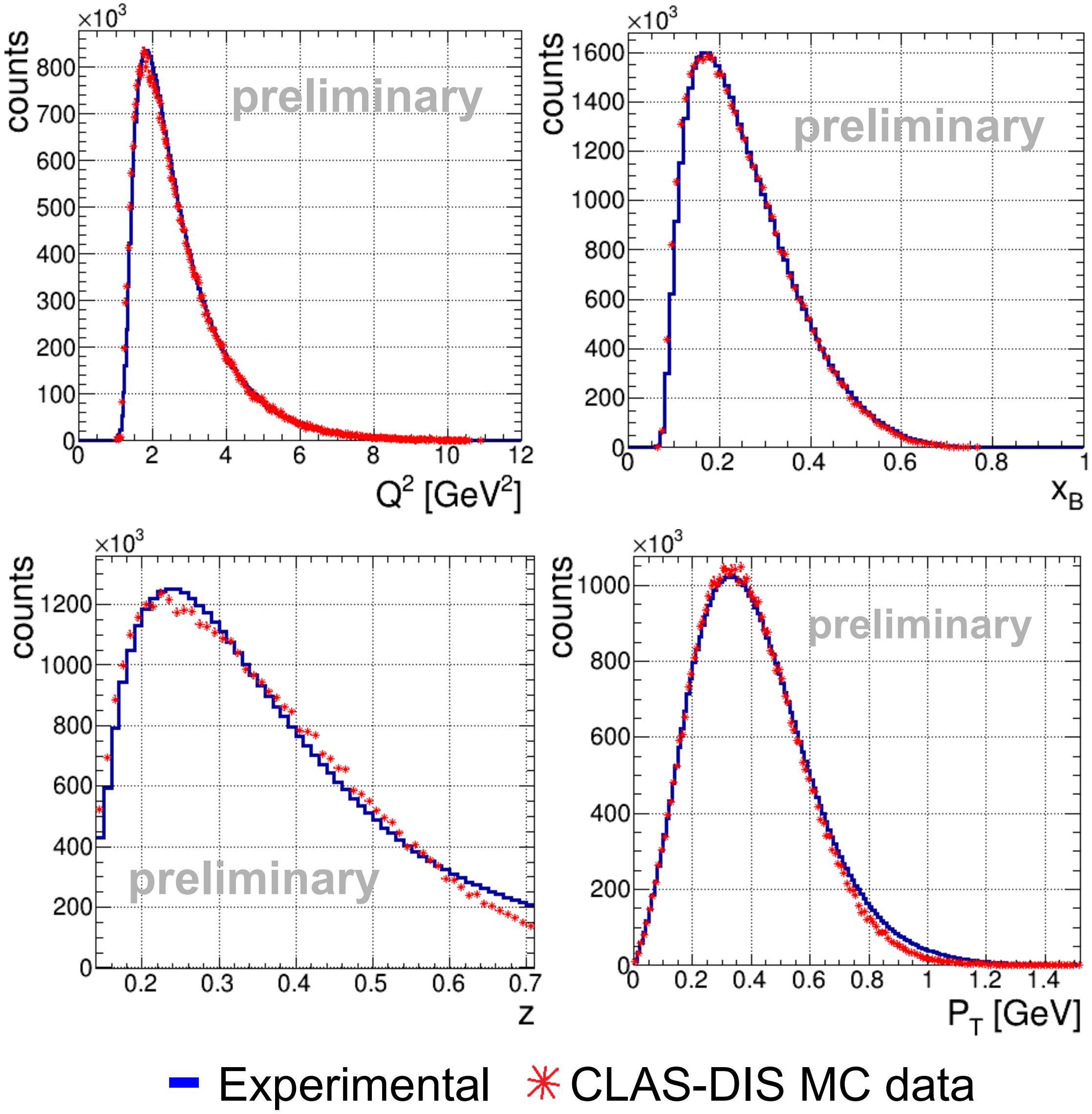




Kinematic coverage for π^+





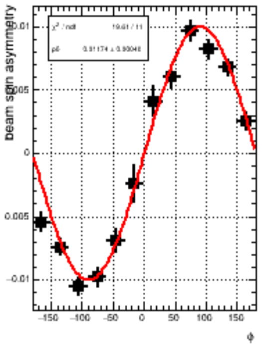


Beam spin asymmetry

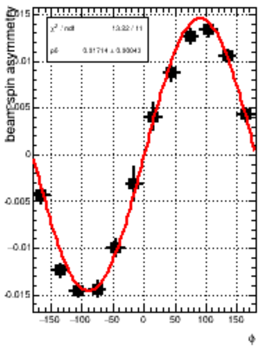
$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$$

$$P_e = \begin{cases} 85.9\ \% & \text{for run} <= 5328 \\ 89.2\ \% & \text{for run} >= 5331 \end{cases}$$

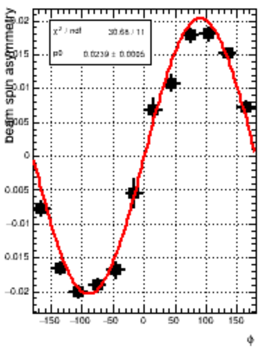
z = 0.25



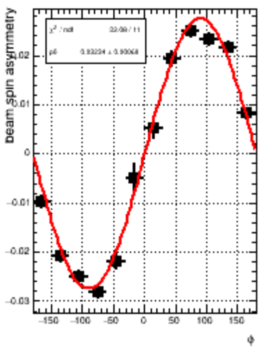
z = 0.35



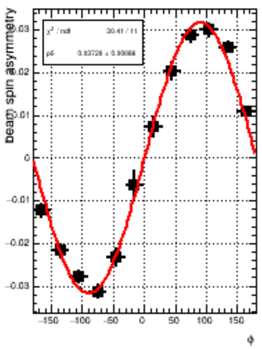
z = 0.45



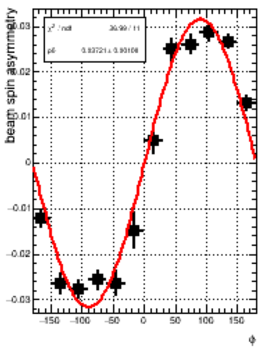
z = 0.55



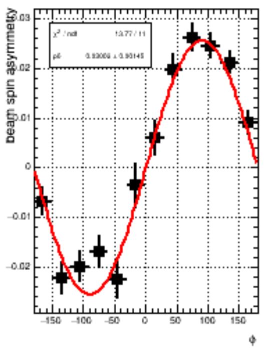
z = 0.65



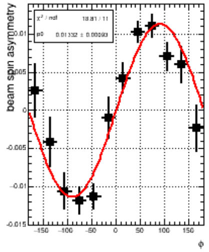
z = 0.75



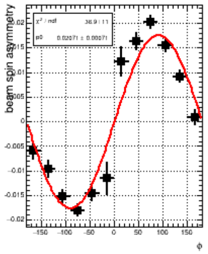
z = 0.85



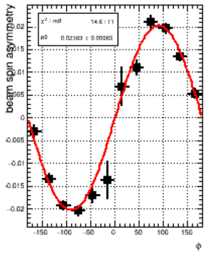
P_T = 0.15 GeV



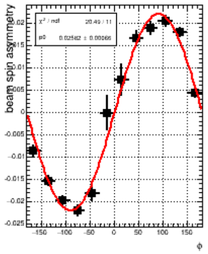
P_T= 0.25 GeV



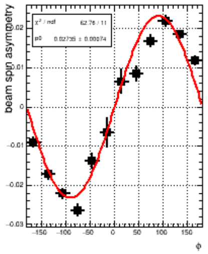
P_T = 0.35 GeV



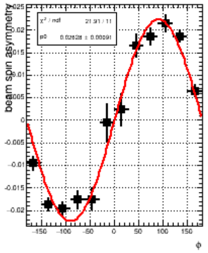
P_T = 0.45 GeV



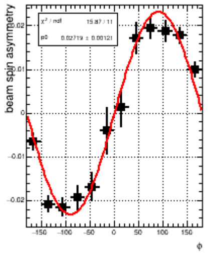
P_T = 0.55 GeV



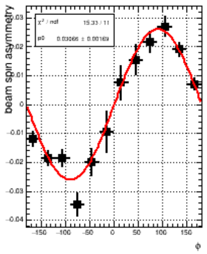
P_T = 0.65 GeV



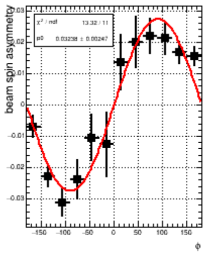
P_T = 0.75 GeV



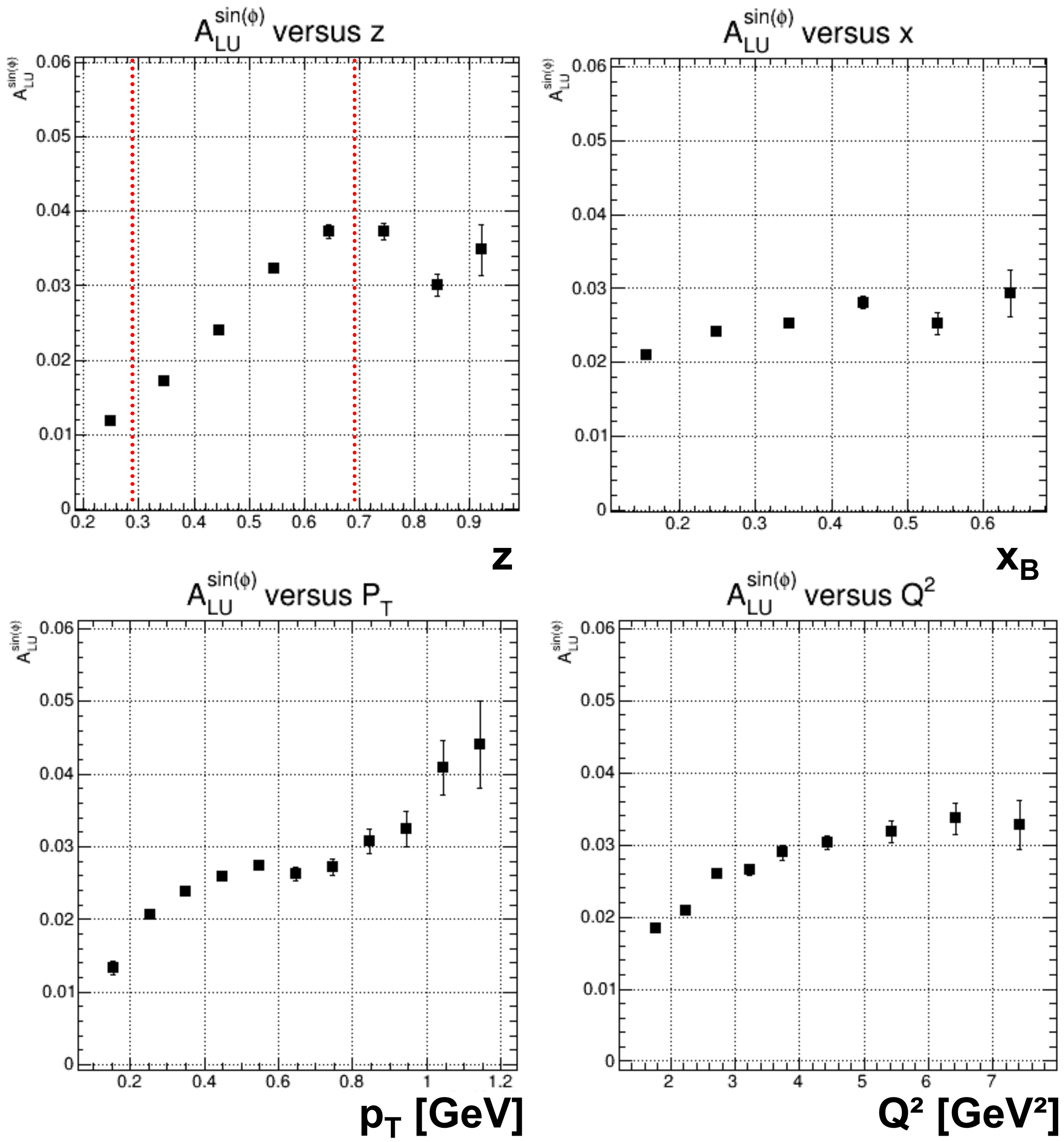
P_T = 0.85 GeV



P_T = 0.95 GeV



1D binning for z, x_B, P_T and Q^2

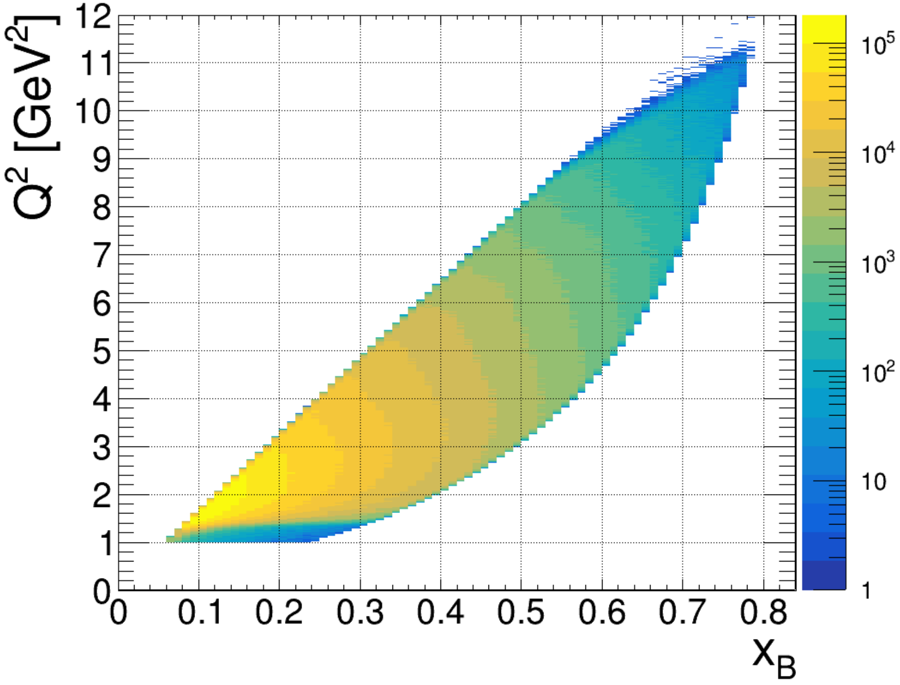


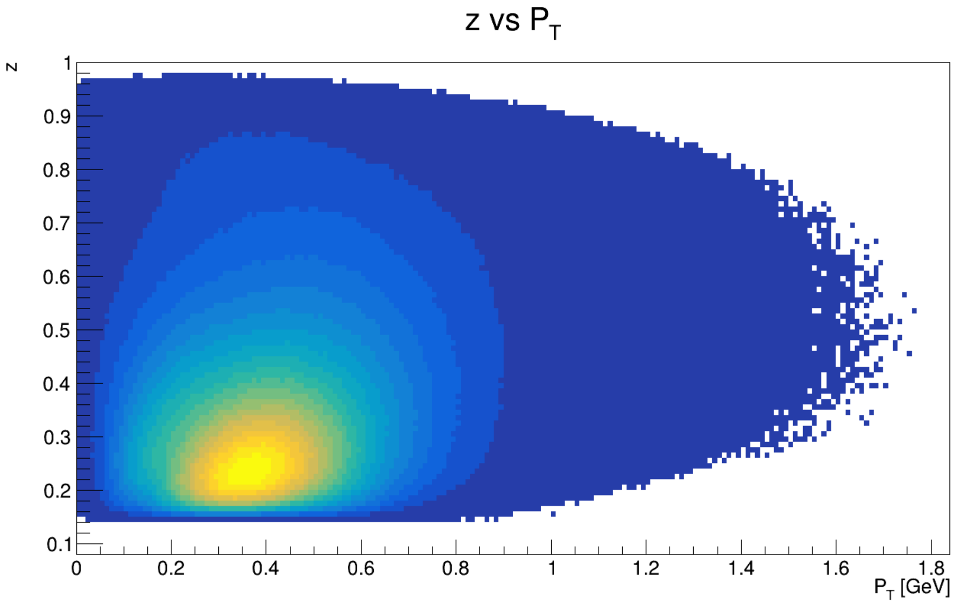
In 1 dimension:

→ **statistical uncertainty is very small !**

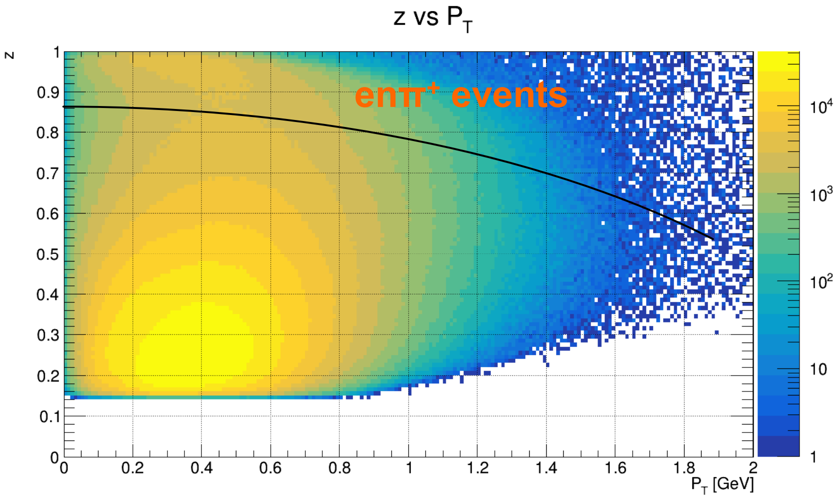
But: Uncertainty of the integrated kinematics is very large and hard to modell in theory

A multidimensional binning

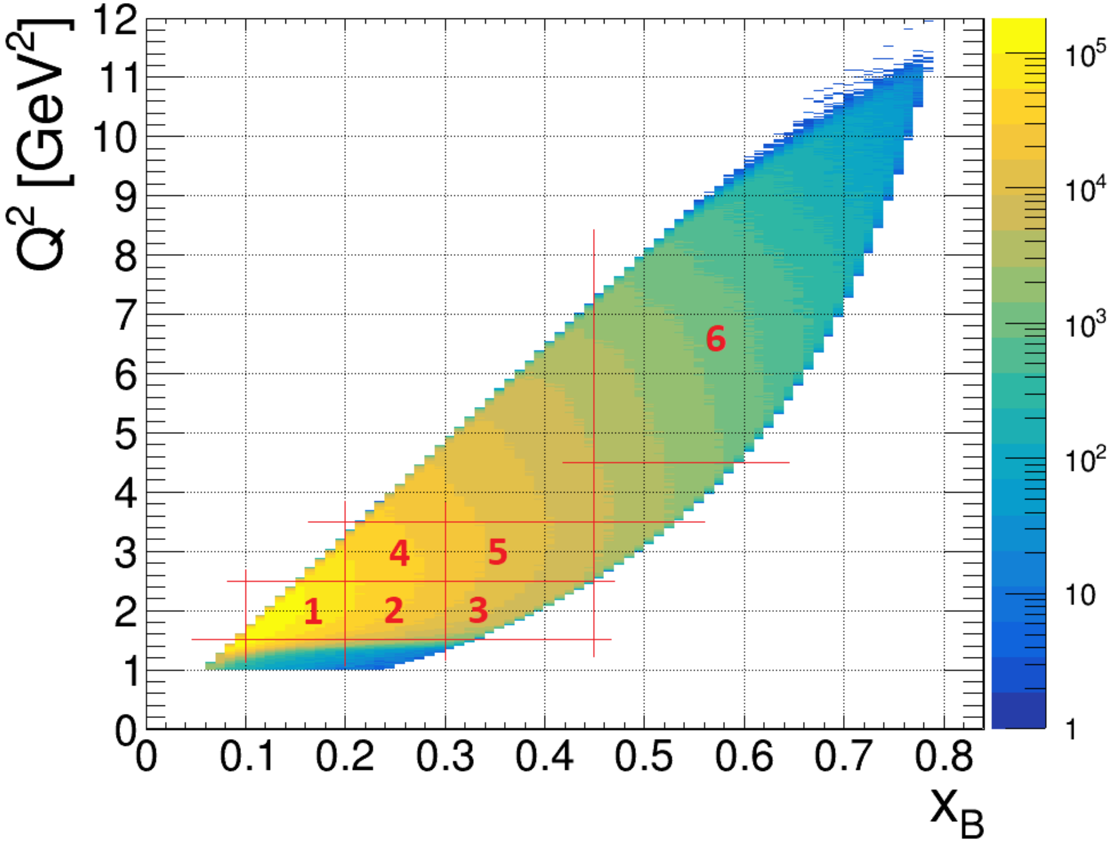




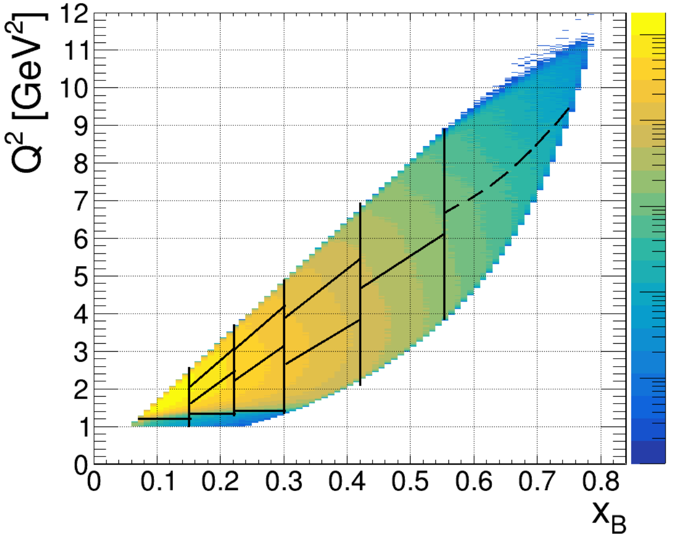
without a cut on M_{miss} > 1.1 GeV:



A multidimensional binning



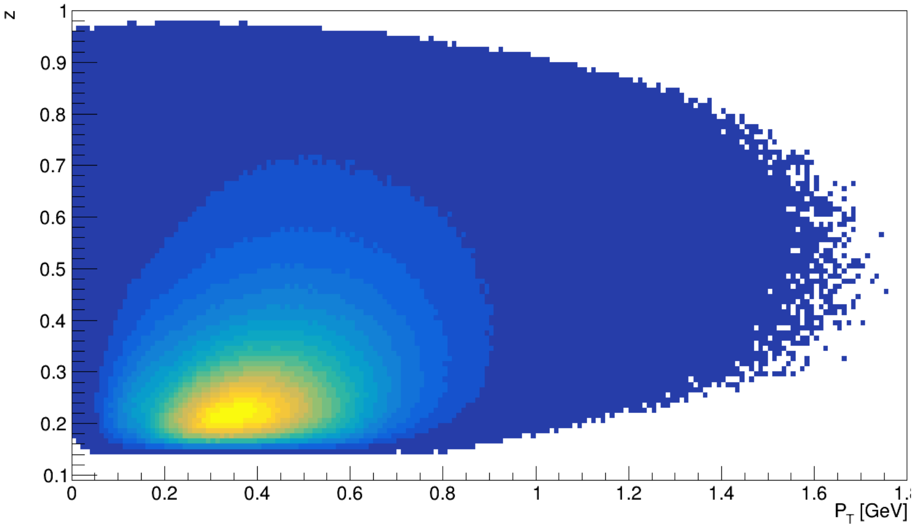
example for the planed binning:



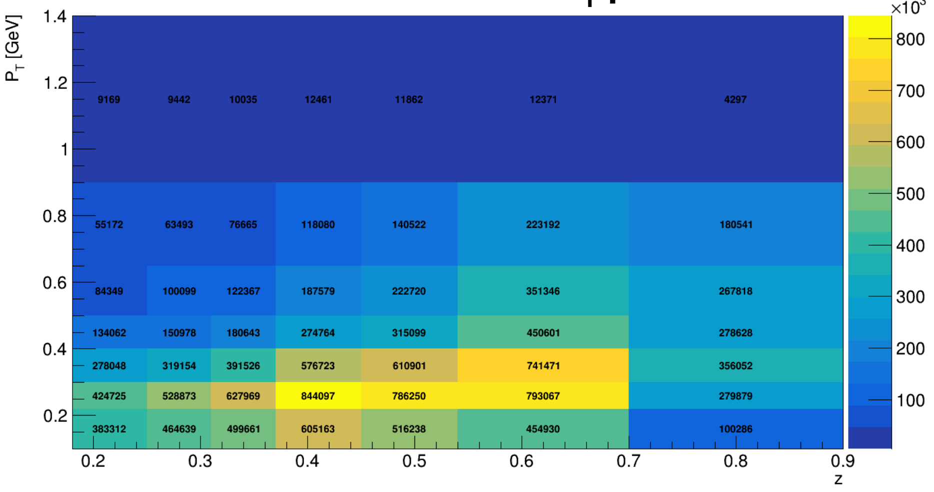
➔ **The adjustment of the final binning scheme is in progress**

A multidimensional binning

1.5 GeV² < Q² < 2.5 GeV² z vs P_T bin 1 **$0.1 < x_B < 0.2$**

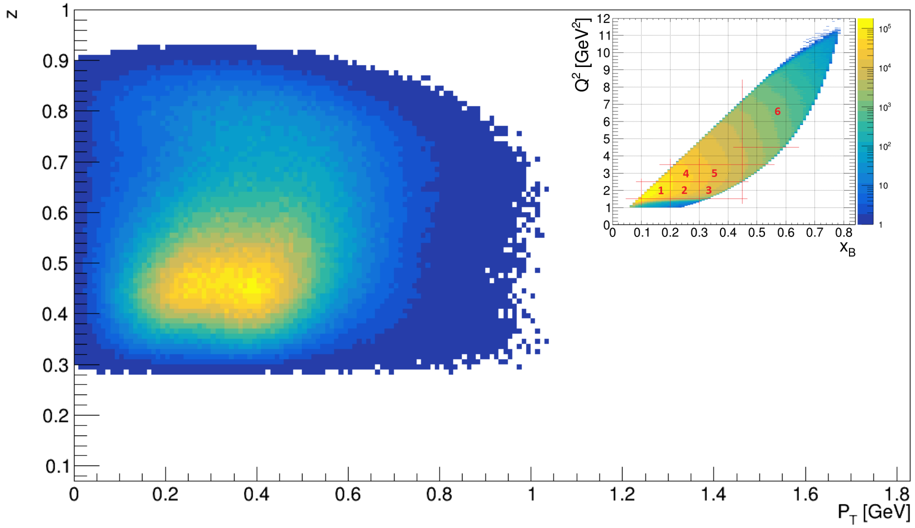


7 x 7 bins in the z – P_T plane

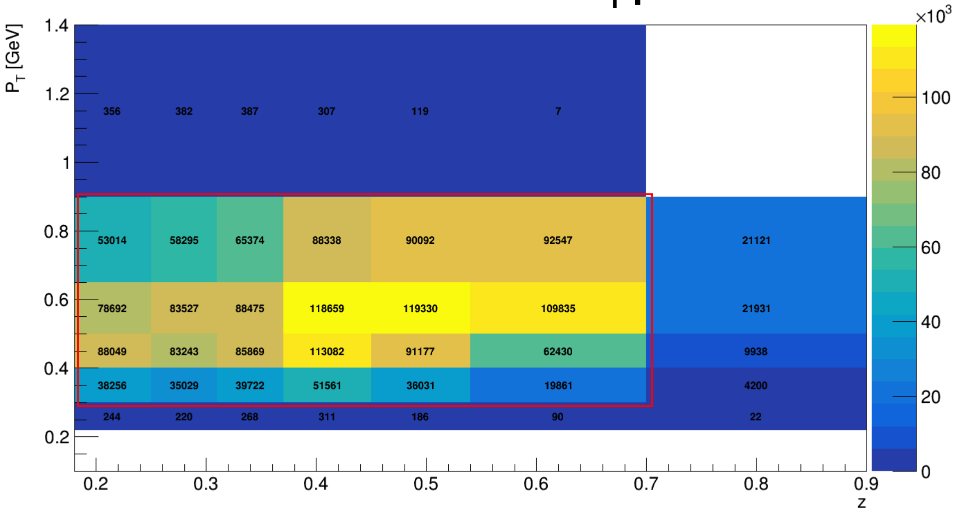


9169	9442	10035	12461	11862	12371	4297
55172	63493	76665	118080	140522	223192	180541
84349	100099	122367	187579	222720	351346	267818
134062	150978	180643	274764	315099	450601	278628
278048	319154	391526	576723	610901	741471	356052
424725	528873	627969	844097	786250	793067	279879
383312	464639	499661	605163	516238	454930	100286

1.5 GeV² < Q² < 2.5 GeV² z vs P_T bin 3 **$0.3 < x_B < 0.45$**

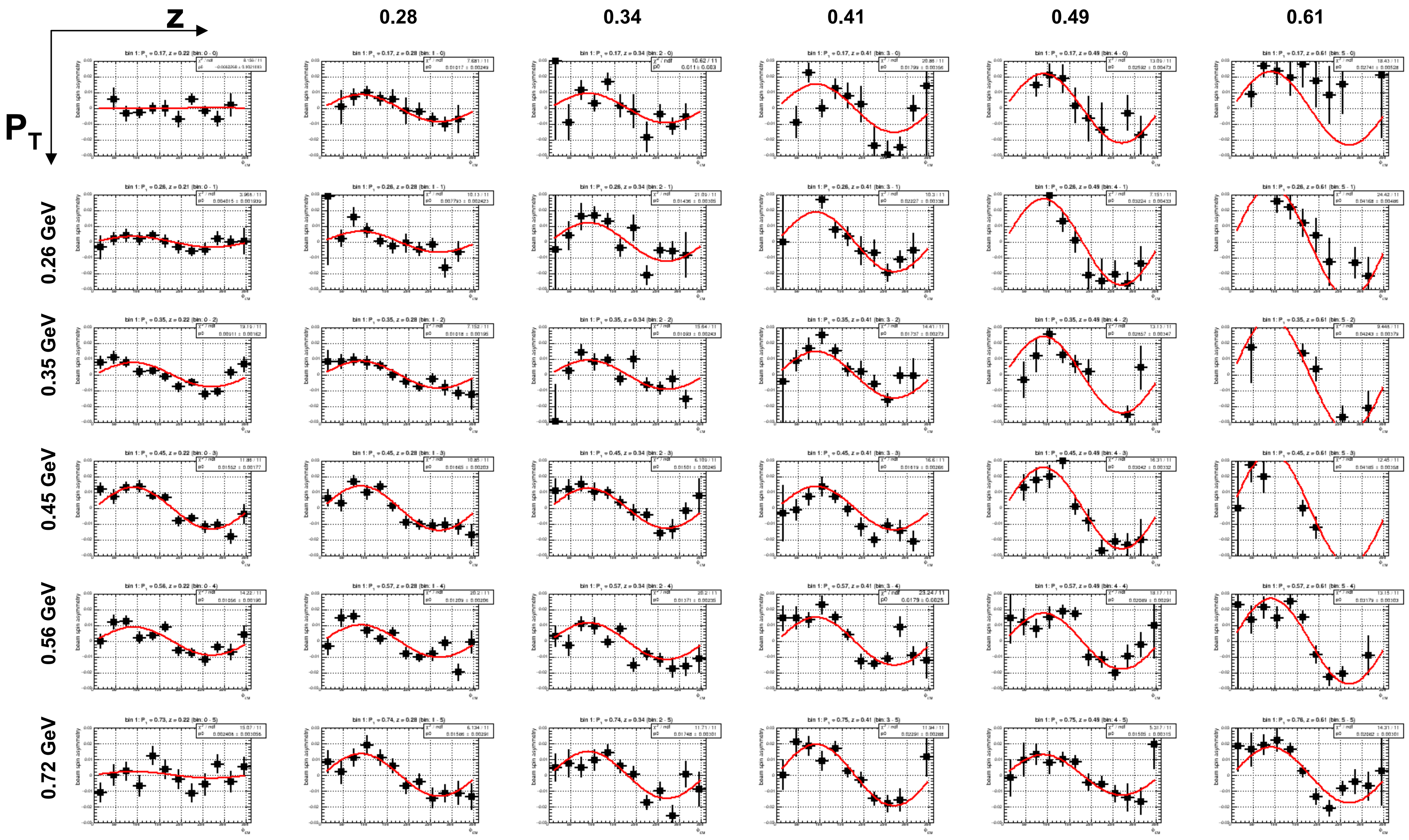


7 x 7 bins in the z – P_T plane

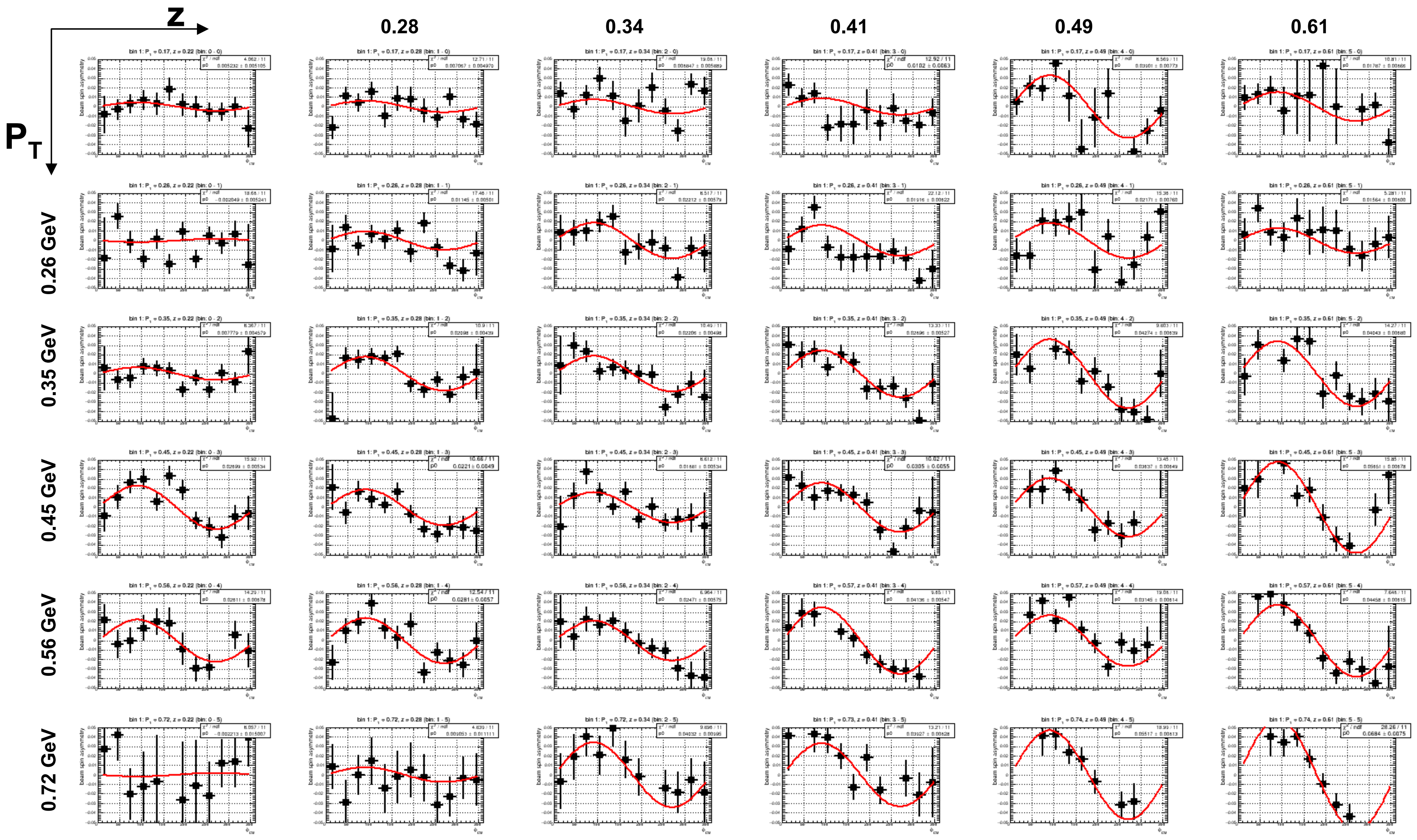


356	382	387	307	119	7	
53014	58295	65374	88338	90092	92547	21121
78692	83527	88475	118659	119330	109835	21931
88049	83243	85869	113082	91177	62430	9938
38256	35029	39722	51561	36031	19861	4200
244	220	268	311	186	90	22

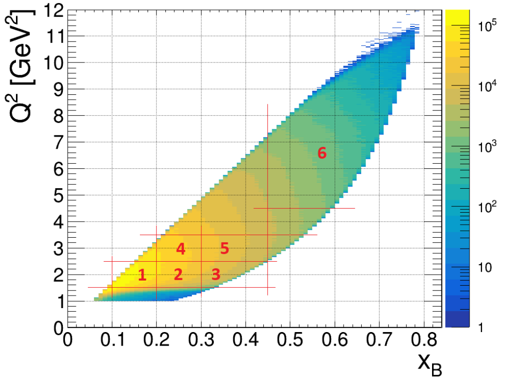
BSA for bin 1 (1.5 GeV < Q^2 < 2.5 GeV and 0.1 < x_B < 0.2)

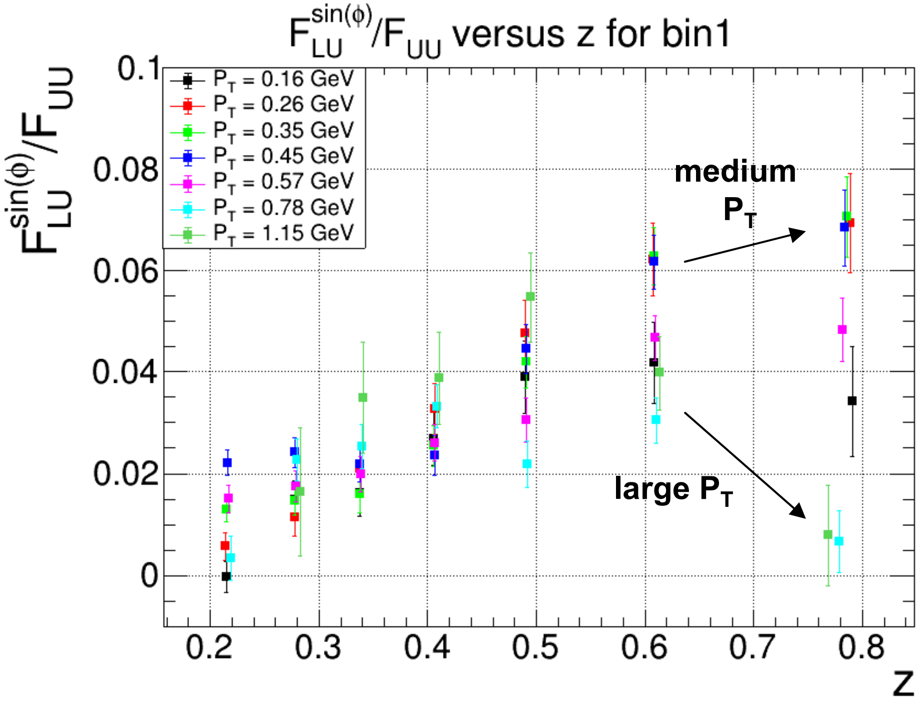


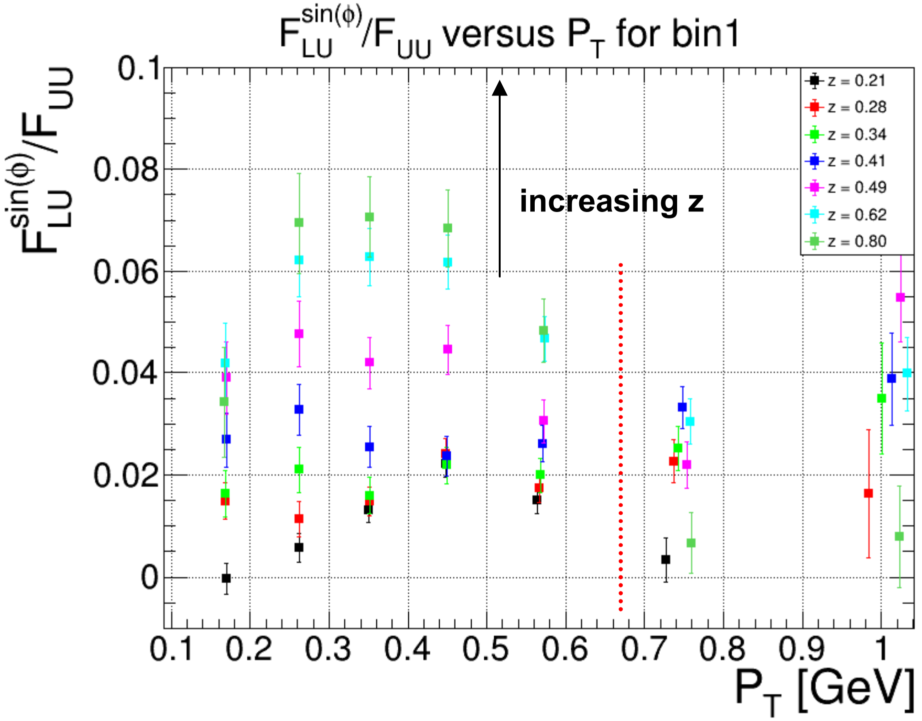
BSA for bin 6 ($Q^2 > 4.5$ GeV² and $x_B > 0.45$)



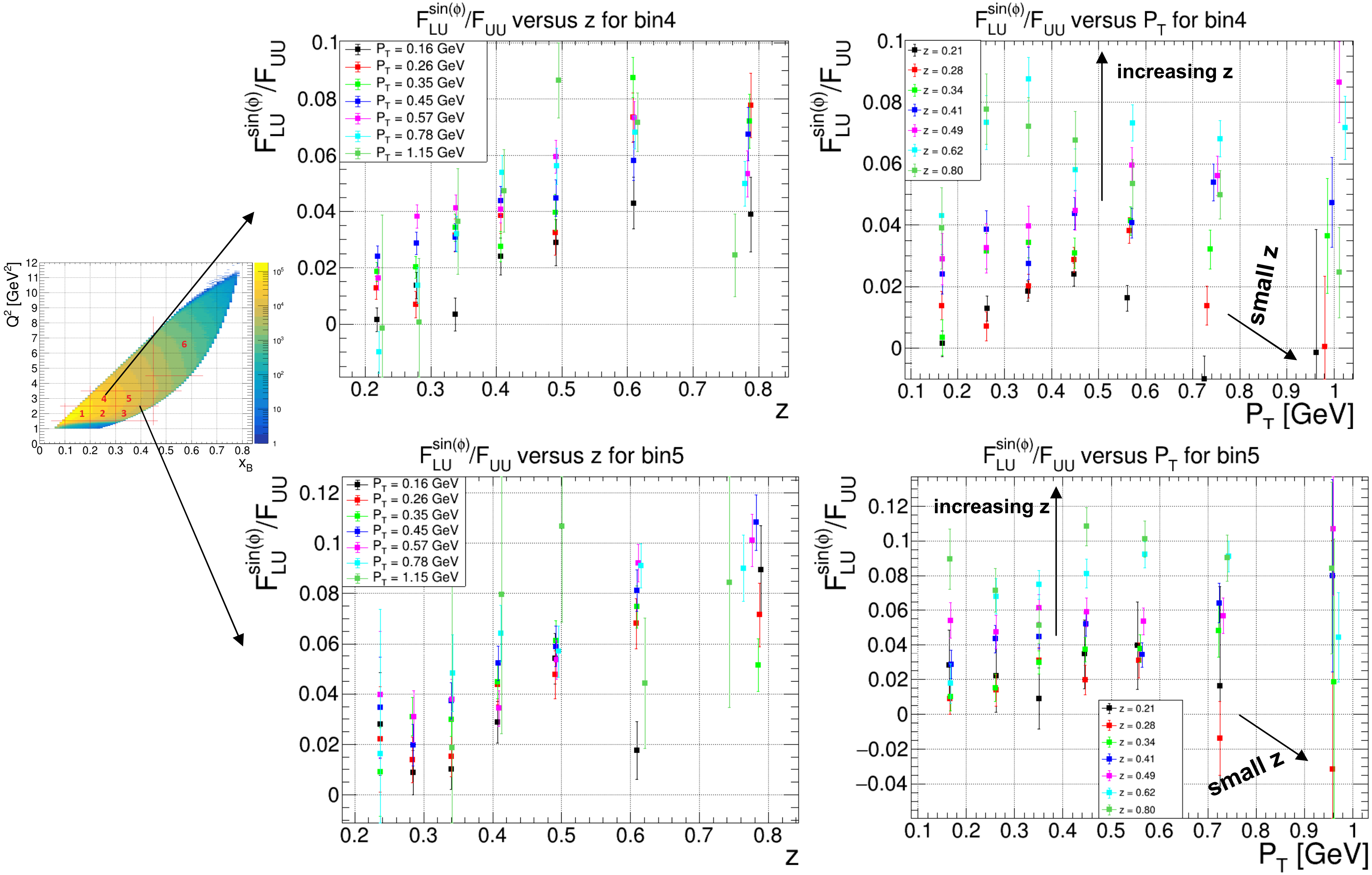
results for bin 1 (1.5 GeV < Q^2 < 2.5 GeV and 0.1 < x_B < 0.2)



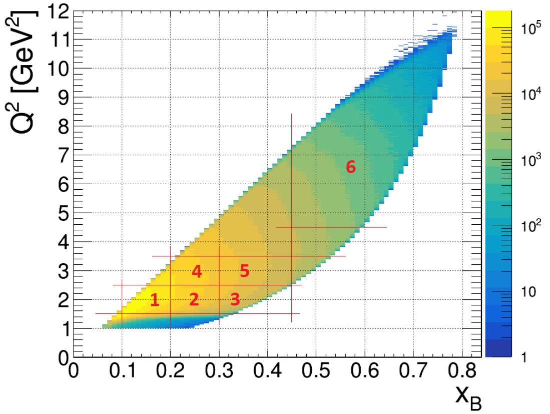


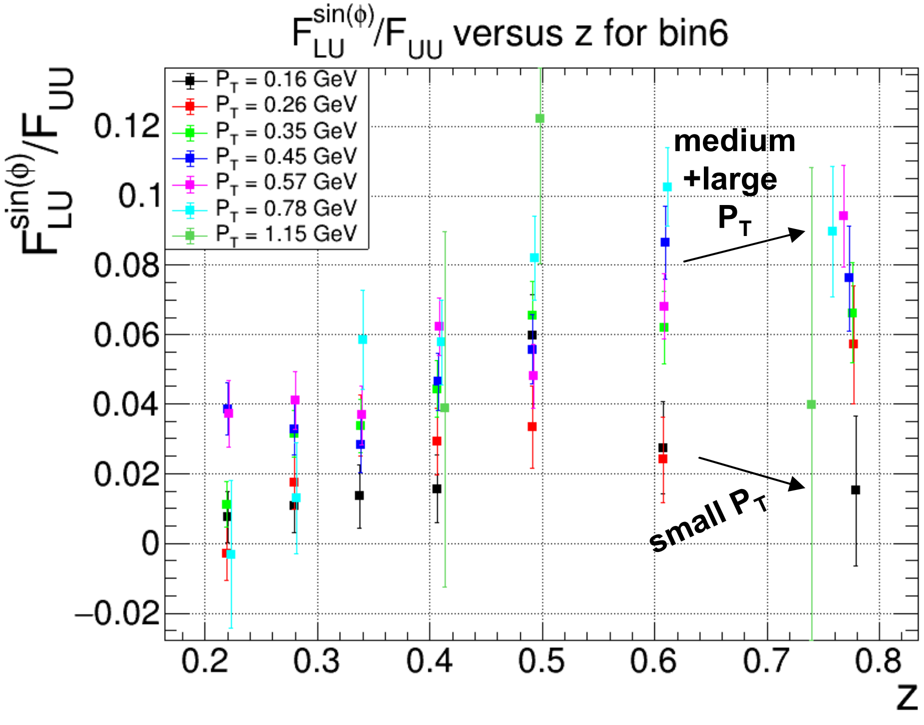


results for bin 4 and 5



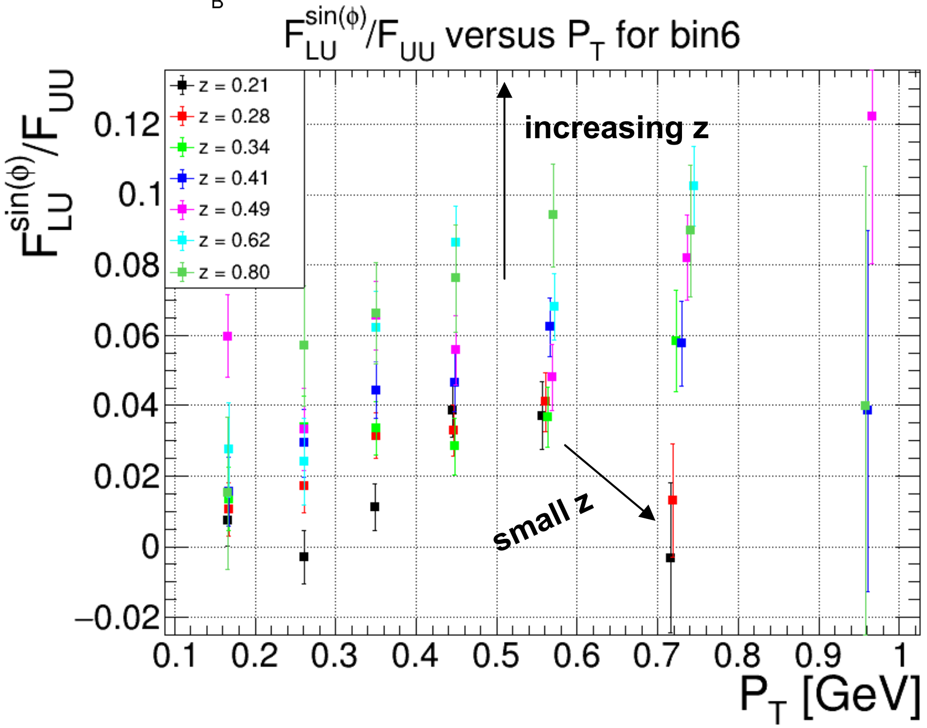
results for bin 6 ($Q^2 > 4.5$ GeV^2 and $x_B > 0.45$)





medium +large P_T

small P_T



increasing z

small z

Sources of systematic uncertainty

→ Uncertainty of the beam polarisation

→ Fiducial cuts and particle ID refinements
(strictness of the PID / contamination in the pion sample)

→ Acceptance Effects

→ Extraction method and higher order moments

→ Detector inefficiencies / sector dependence

→ Radiative effects

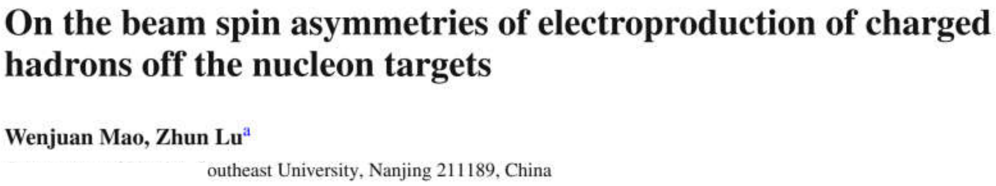
→ Binning / resolution effects

➔ See my talk at the last collaboration meeting

➔ Study is in progress based on the final inbending statistics

Comparison to theoretical predictions

theoretical predictions:



On the beam spin asymmetries of electroproduction of charged hadrons off the nucleon targets

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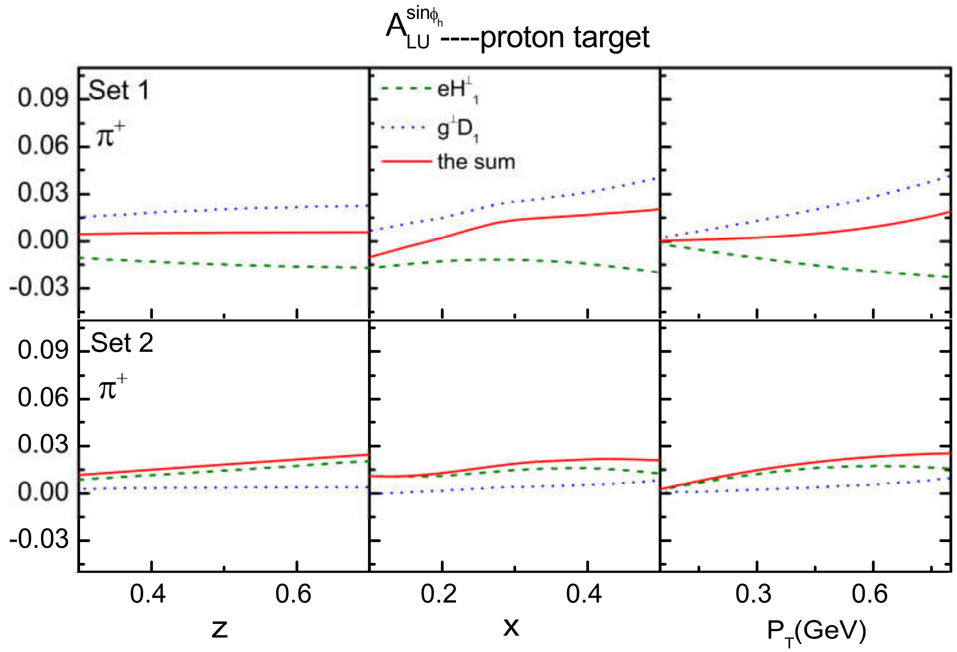
outheast University, Nanjing 211189, China



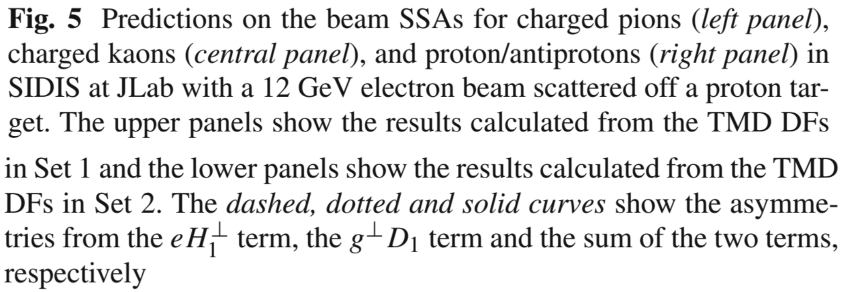
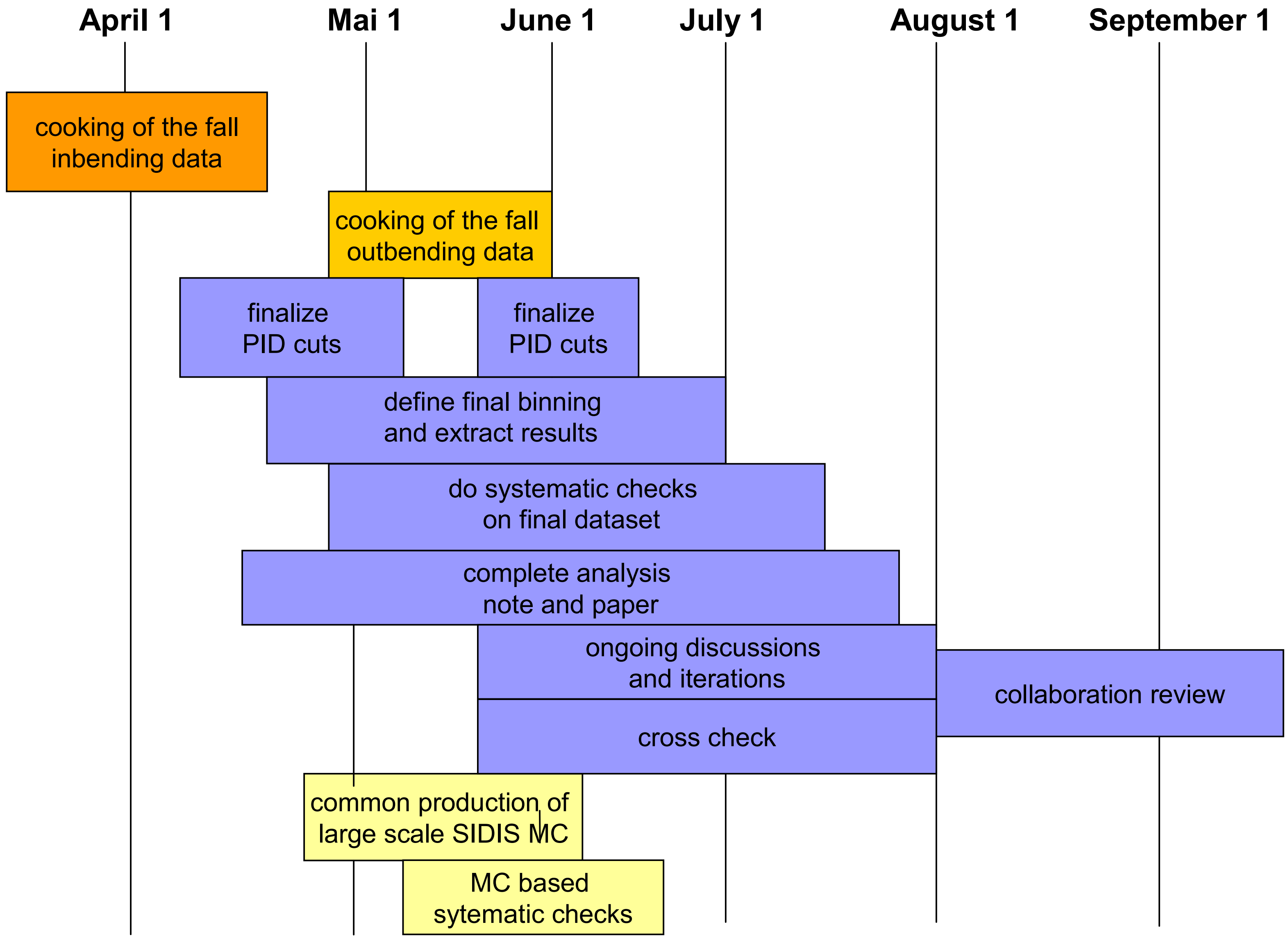


Fig. 5 Predictions on the beam SSAs for charged pions (*left panel*), charged kaons (*central panel*), and proton/antiprotons (*right panel*) in SIDIS at JLab with a 12 GeV electron beam scattered off a proton target. The upper panels show the results calculated from the TMD DFs in Set 1 and the lower panels show the results calculated from the TMD DFs in Set 2. The *dashed, dotted and solid curves* show the asymmetries from the $eH_1^\perp$ term, the $g^\perp D_1$ term and the sum of the two terms, respectively

➔ Theoretical predictions will be compared to the multidimensional data

➔ A multidimensional binning will enable a much better comparability with the calculations and a more reliable TMD extraction from global fits

Timelines and path towards a first publication



Conclusion and Outlook

- All analysis methods have been developed and tested on the DNP data
- Adjustment of cuts etc. for the pass 1 data is in progress / completed
- Common SIDIS MC production for pass 1 data is in progress
- The goal for the first publication is to show a multidimensional binning for π^+

  → A multidimensional binning will be available for the first time and is very importnant for global TMD fits.
- The final mutidimensional binning is under investigation

  → Statistics (~ 10 x more than DNP) is sufficient for a fully multidimensional binning (we expect up to 588 bins)
- The analysis note and the paper are under preparation in coordination with the common RG-A analysis note