Λ Beam Spin Asymmetry Studies using RGA Pass-2 Fall-18 Data

CLAS12 Collaboration Meeting

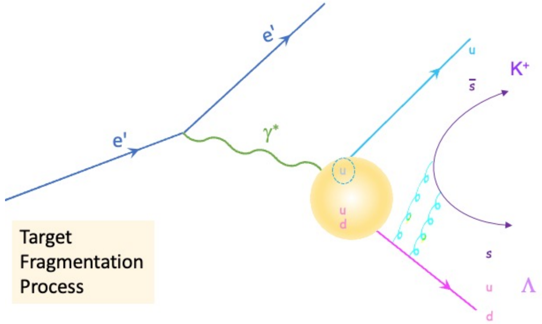
November 14, 2024

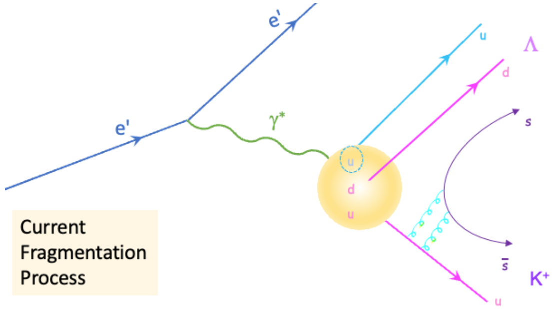
Veronique Ziegler

Motivation

- Beam Spin Asymmetry is a tool to understand hadronization.

  - Exclusive and semi-exclusive processes ep → e’ Λ X (X=$K^{(*)+}$, $K^0\pi^+$, …) to separate:
    - kinematical regions (Target and Current Fragmentation Regions)
    - dynamical contributions





  - Results for various exclusive channels such as ep→e’p(n, Δ)π (S.Diehl) and ep → e’ $\Lambda(\Sigma)$ K^+ (D.Carman) and semi-inclusive ep→e’p X (F.Benmokhtar*)

    *https://indico.jlab.org/event/910/contributions/15545/attachments/11958/18774/Benmokhtar-epX-Analysis-Collaboration-Nov-24.pdf

    - Comparison of these results with BSA for ep → e’ Λ X can add another piece to the puzzle of production mechanism off a polarized quark inside an unpolarized proton

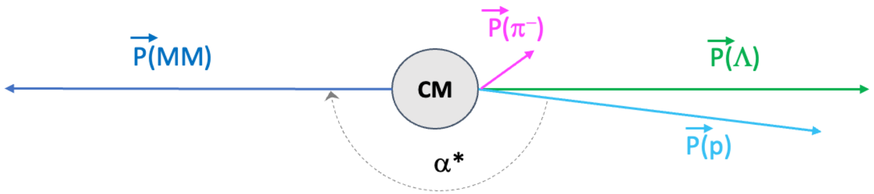
TFR: struck quark in X
CFR: struck quark in Λ

  - Exclusive Λ→ $p\pi^-$ reconstruction advantages:
    - More accurate reconstruction of the azimuthal angle
    - Less background than using missing mass method, narrower Λ signal
    - Allows to study contributions above ground-state K production

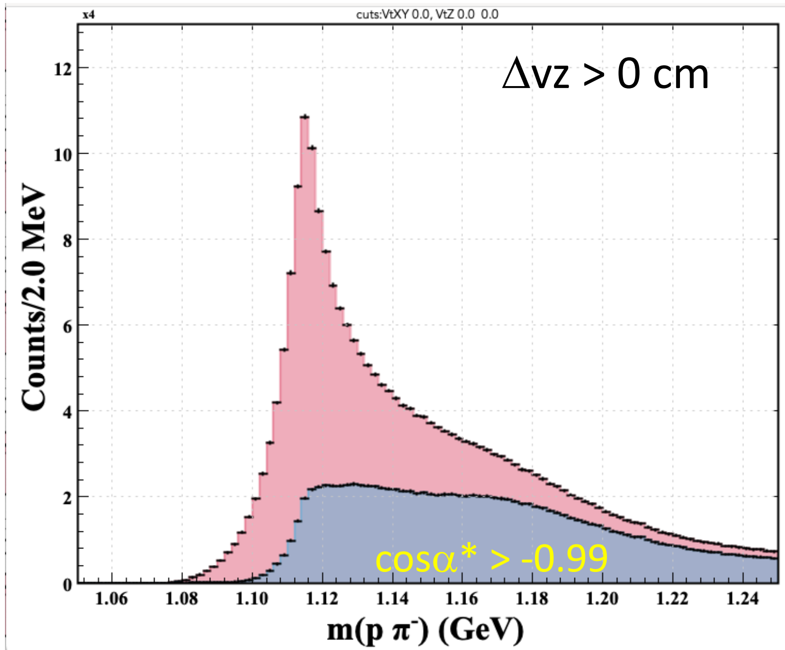
Λ Candidate Selection

- Selection of ep→ e ($p\pi^-$) X events using Fall18 (in- and out-bending) Pass-2 RGA data
- Skim these events using detached vertex reconstruction algorithm
  - Creates analysis bank with vertex and momenta of each track and track pair candidate at the reconstructed detached vertex
  - Topology: p & π^- in FD: improved resolution and signal-to-background ratio (study documented in Λ skim CLAS note)
  - PID ($|\chi^2_{PID}|$<15) selection criteria for p and π^-
  - Require the vertex between p and π^- to be reconstructed with doca<5 cm
  - Require Λ vertex to be downstream of the e- vertex
  - Require the cosine of the angle between the proton and pion computed assuming the Λ PDG mass between +/- 1
  - Subsequent vertex displacement (wrt e- vtx) optimization

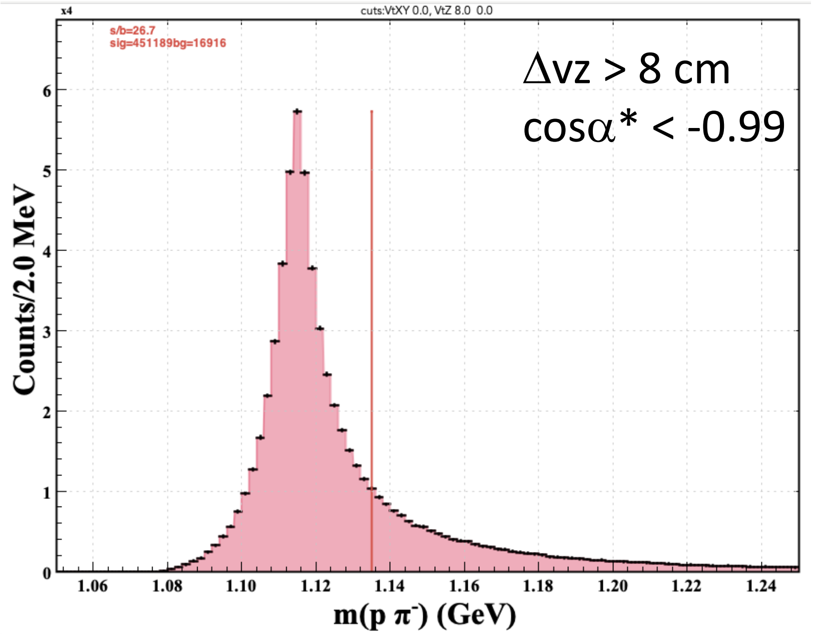
- Angular cut: cosα* = angle between P(p) and P(MM) in CM-frame



- Require cosα* < -0.99

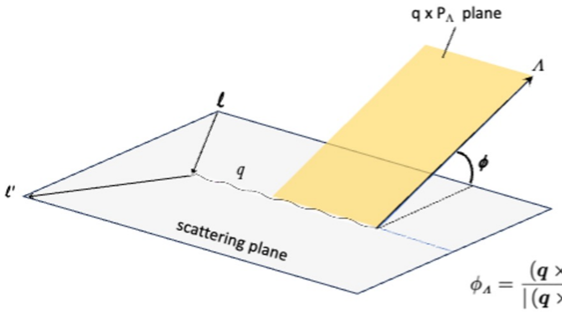


After vertex displacement (wrt e- vtx) selection:

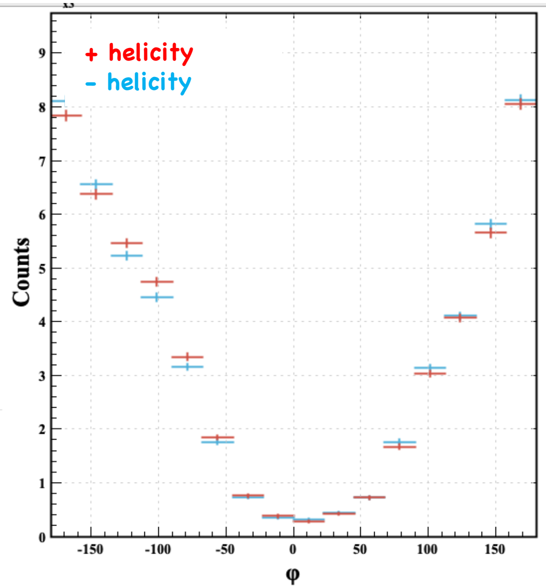


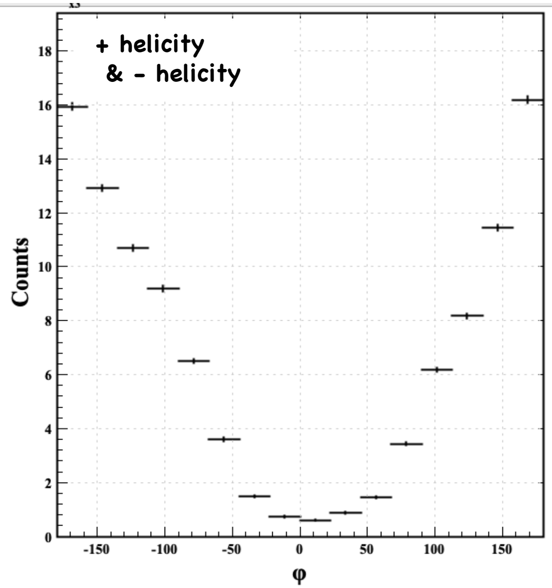
*c,f. My talk on Λ skim in Hadron Spectroscopy session

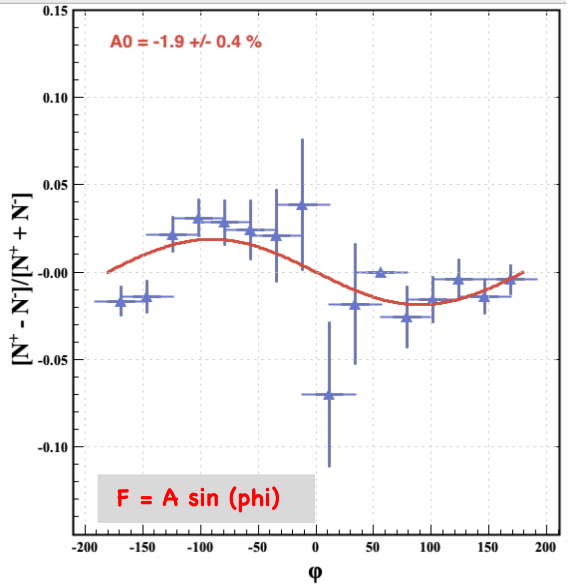
BSA for $1<Q^2<10$ GeV^2, $2<W<4.5$ GeV



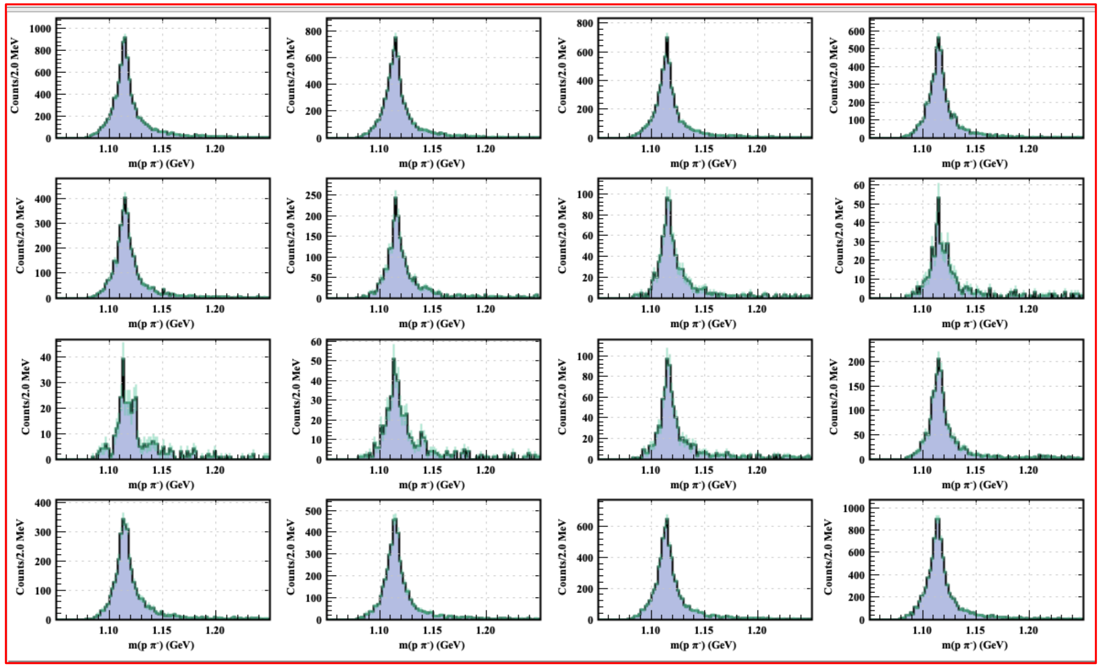
$$\phi_\Lambda = \frac{(\boldsymbol{q}\times\boldsymbol{l})\cdot\boldsymbol{P}_\Lambda}{|(\boldsymbol{q}\times\boldsymbol{l})\cdot\boldsymbol{P}_\Lambda|}\arccos\frac{(\boldsymbol{q}\times\boldsymbol{l})\cdot(\boldsymbol{q}\times\boldsymbol{P}_\Lambda)}{|\boldsymbol{q}\times\boldsymbol{l}|\,|\boldsymbol{q}\times\boldsymbol{P}_\Lambda|}$$



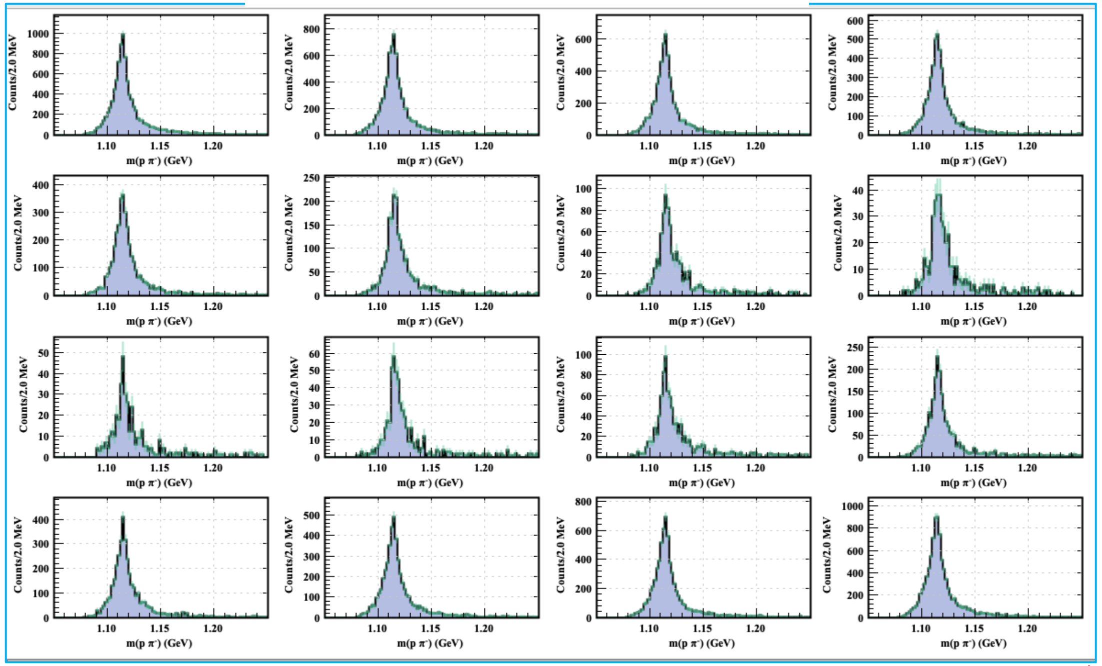




+ helicity $m(p\pi^-)$ spectra for each ϕ bin



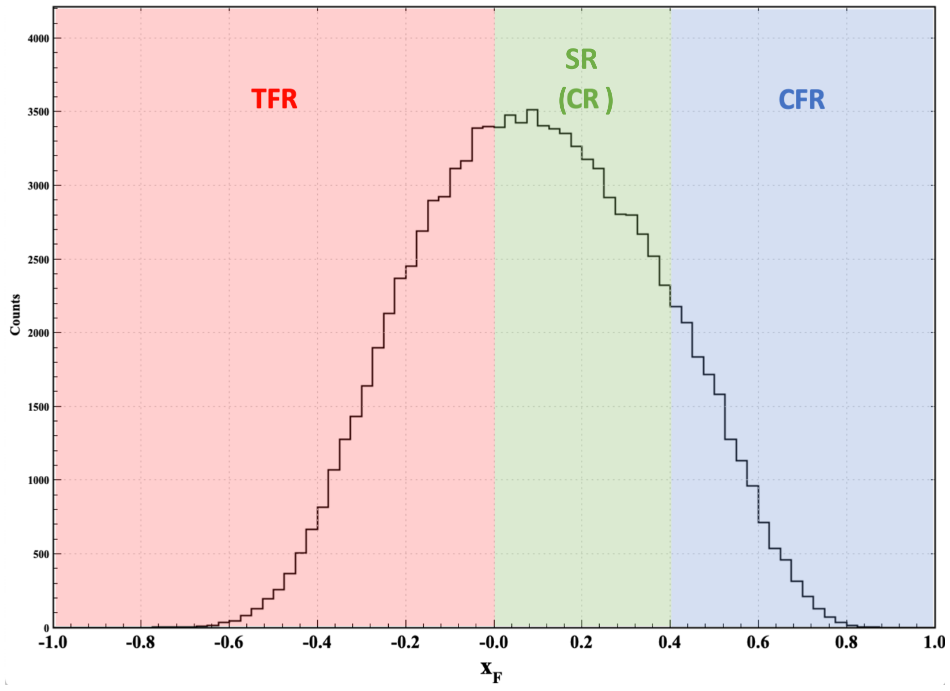
- helicity $m(p\pi^-)$ spectra for each ϕ bin



- ✓ Clean Λ distributions for all ϕ bins ➔ no background subtraction needed

BSA as a Function of x_F

- Obtain BSA as a function of x_F to study Λ polarization behavior in the Target, Center, and Current Fragmentation Regions

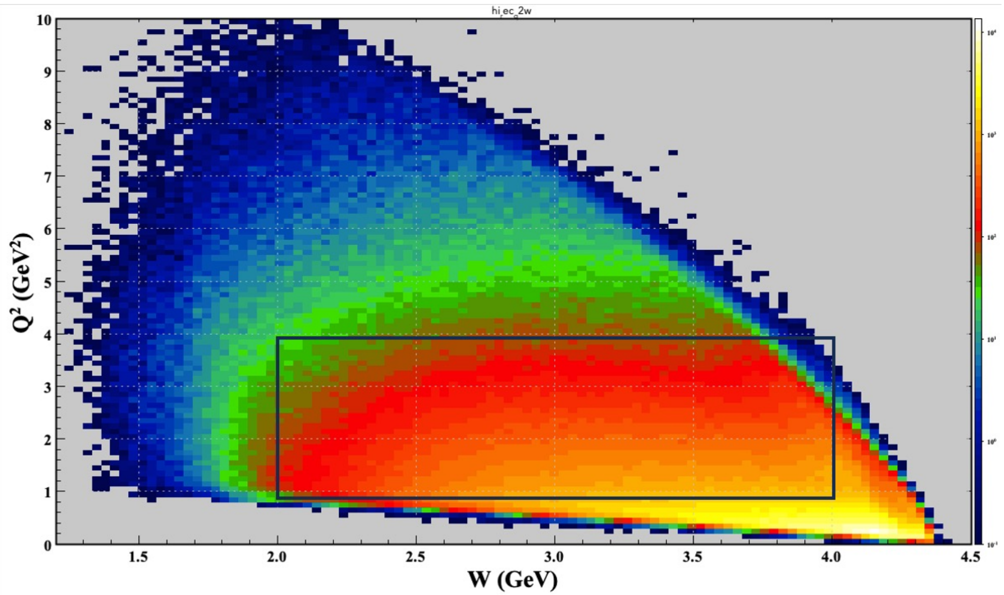


SR = Soft Region

$$x_{F_\Lambda} = 2P^*_{\parallel\Lambda} / W$$

- Selected range: $1 < Q^2 < 4$ GeV^2;
  $2 < W < 4$ GeV

~uniform Q^2,W bins

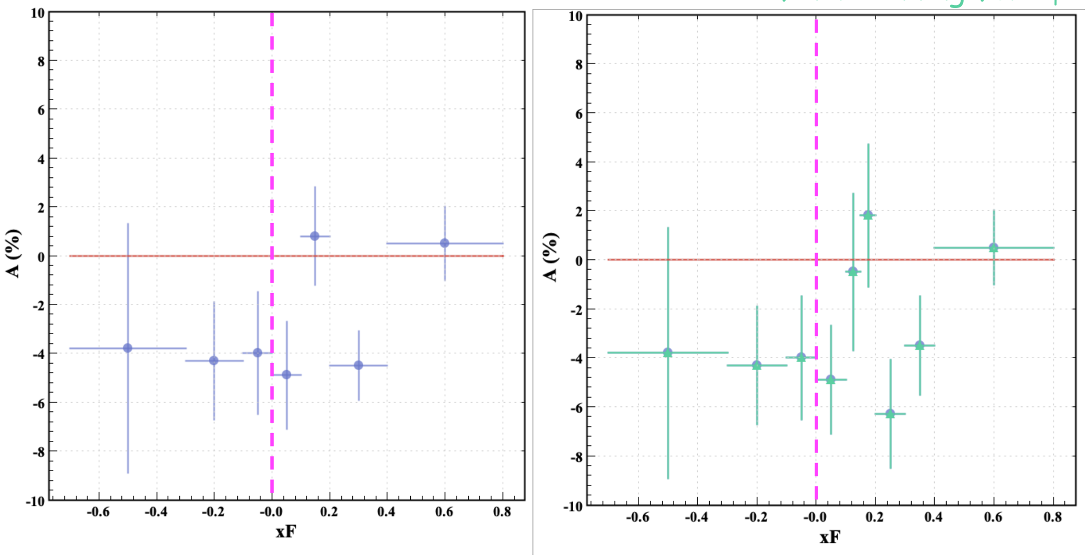


BSA as a Function of x_F

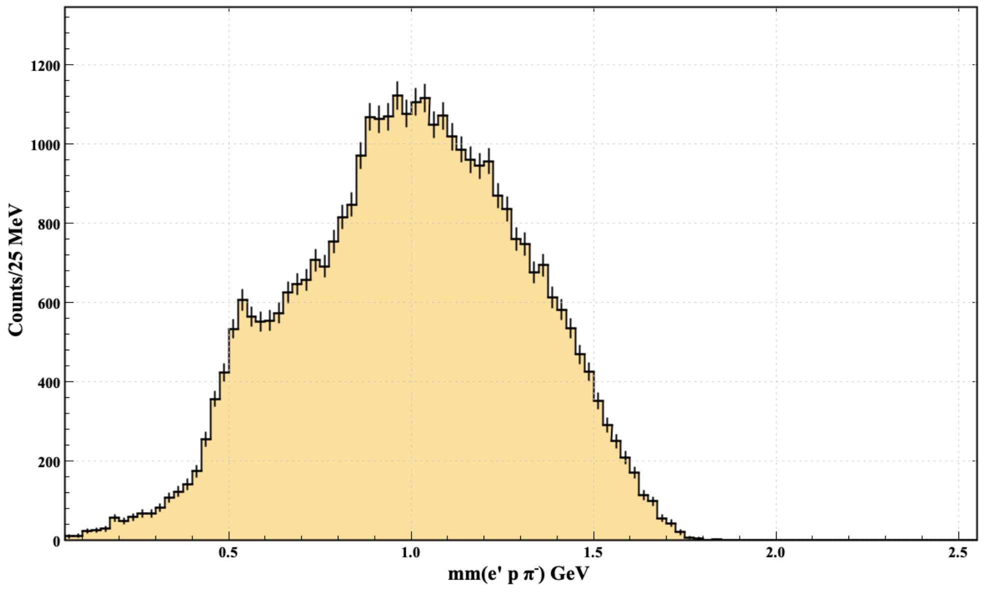
$1 < Q^2 < 4\ GeV^2$

2<W<3 GeV

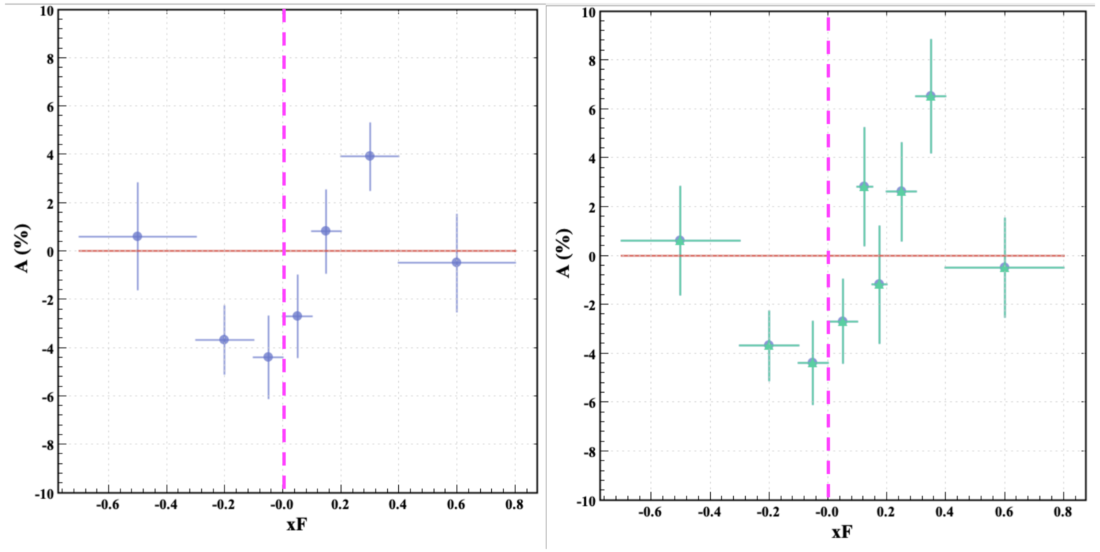
finer binning for x_F>0

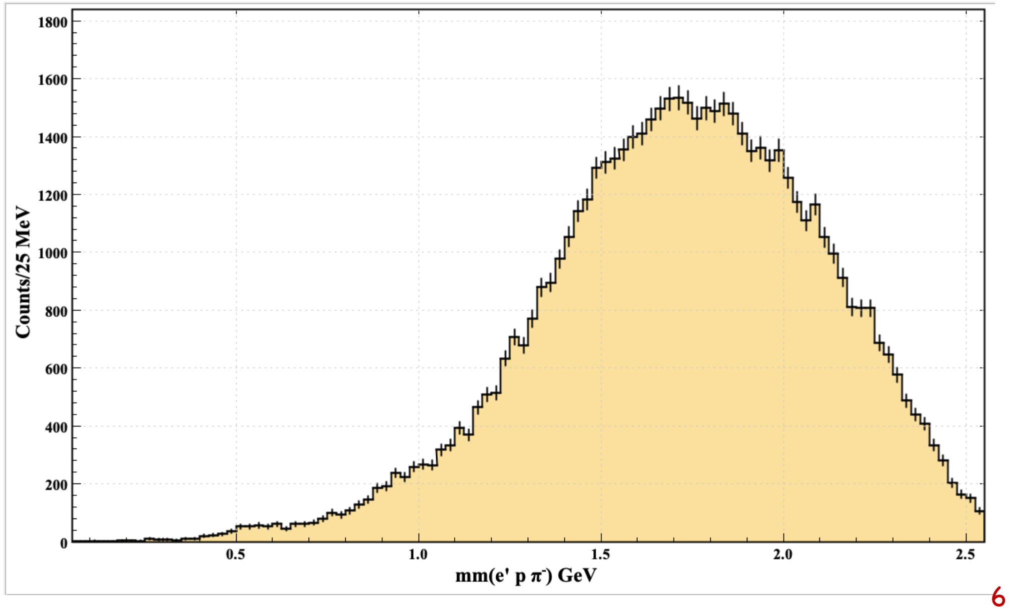


MM(e'Λ) (integrated over x_F)



3<W<4 GeV





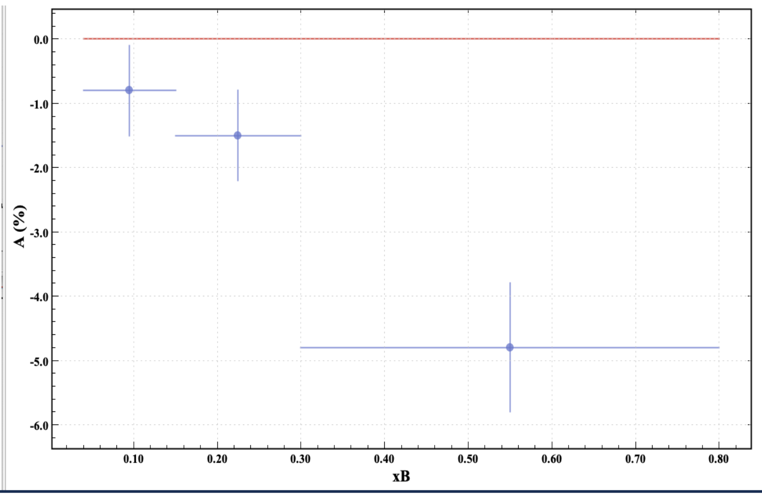
- Different behavior in the CFR (x_F>0) for W>3 GeV where the K^+ contribution is suppressed

BSA as a Function of x_F and x_B

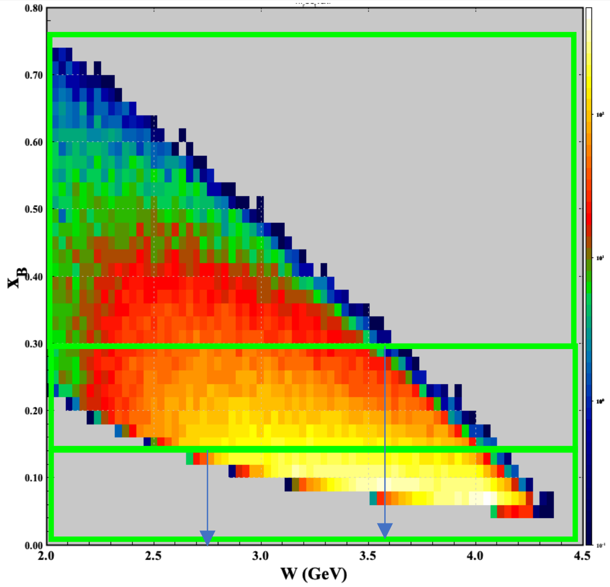
- $x_B = Q^2 / 2M_p \nu$ ~ fraction of the target proton's momentum carried by the struck quark

> At low x_B: low momentum parton representation of nucleon & gluon dominance ➔ insight into Λ production mechanics off the proton

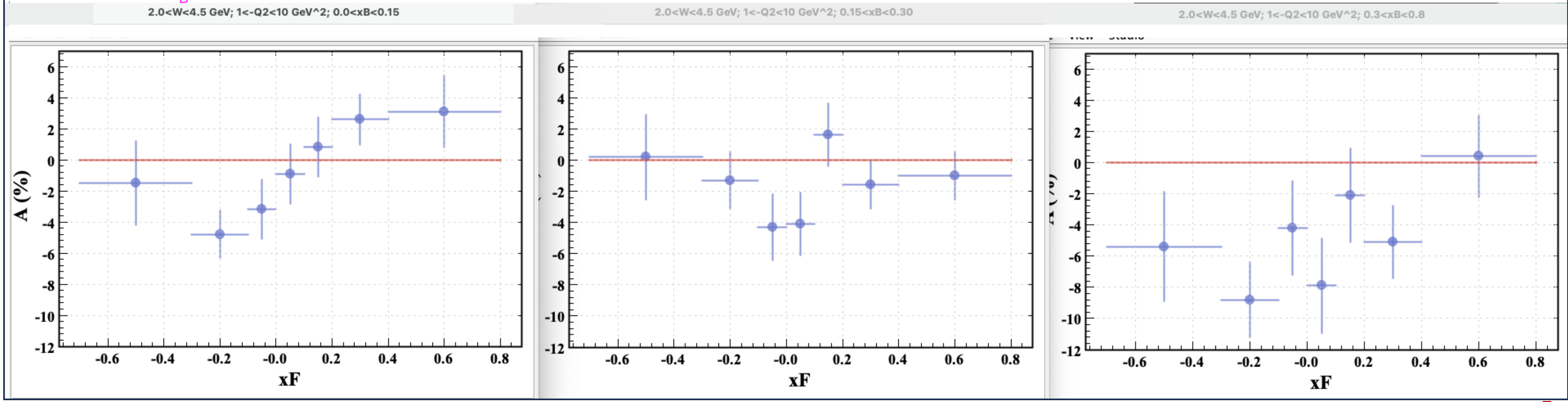
- For each bin in x_B obtain BSA as a function of x_F



- x_B bin 1 ~ W > 2.7 GeV → K^+ suppressed
- x_B bin 3 ~ W < 3.5 GeV → K^+ not suppressed

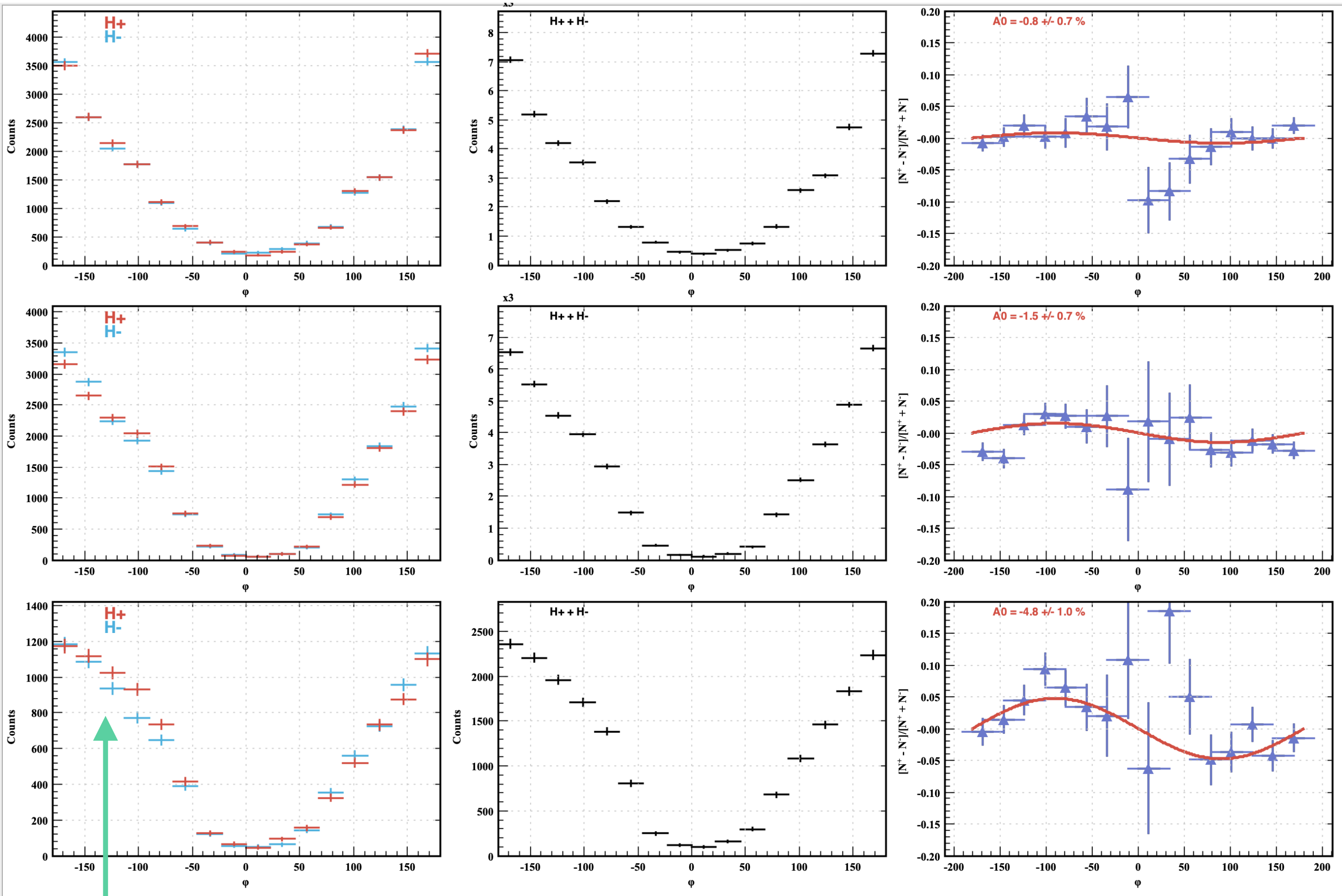


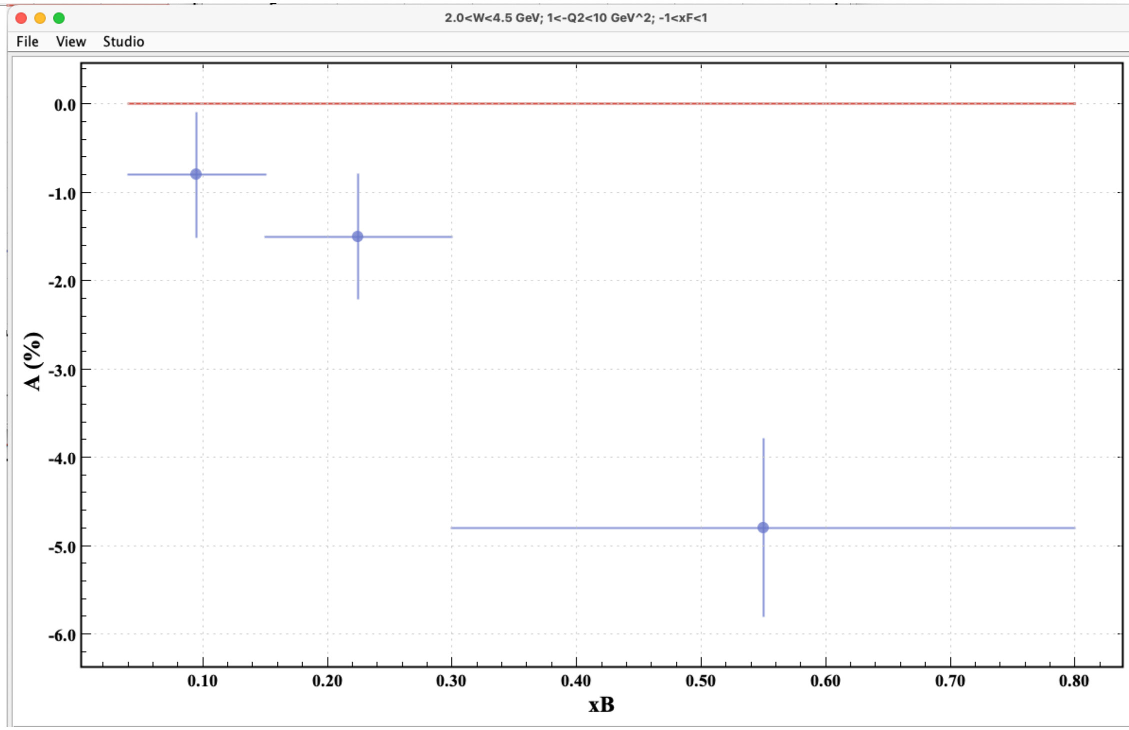
x_B bin 1 | 2 | 3



BSA as a Function of x_B

Selected range : $1 < Q^2 < 10$ GeV^2; $2 < W < 4.5$ GeV

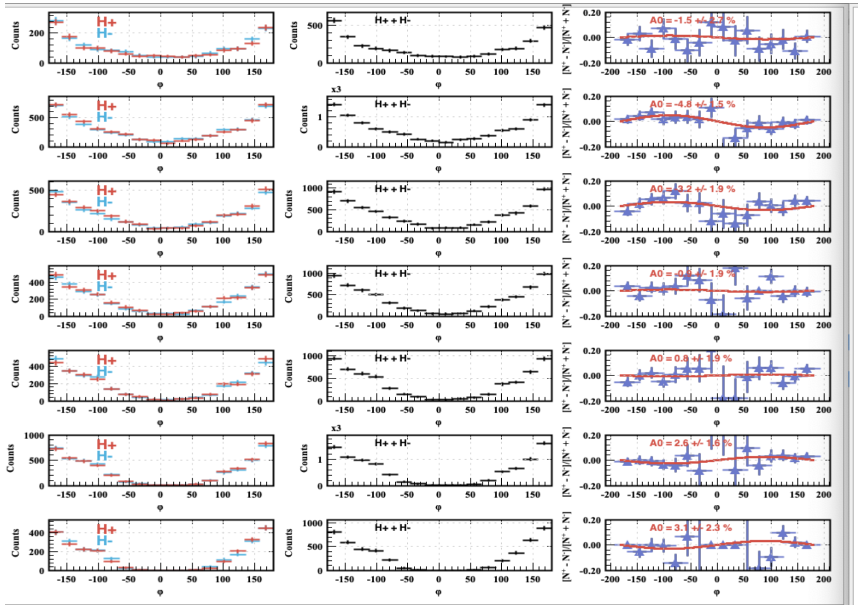


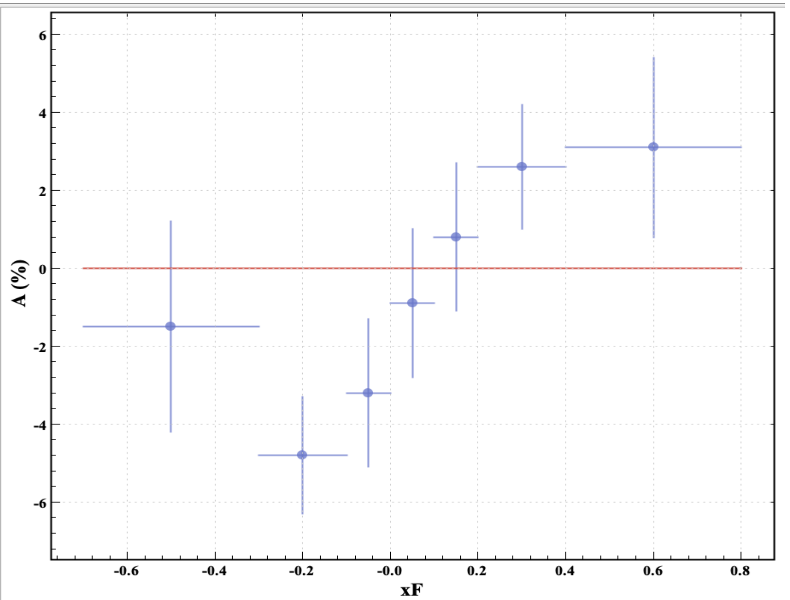


- Larger BSA at large x_B
  - Integrated over x_F

Likely effect from ep→e'ΛK⁺ where angular distribution has dips near +/-180 deg. due to cosϕ, cos2ϕ interference convoluted with acceptance

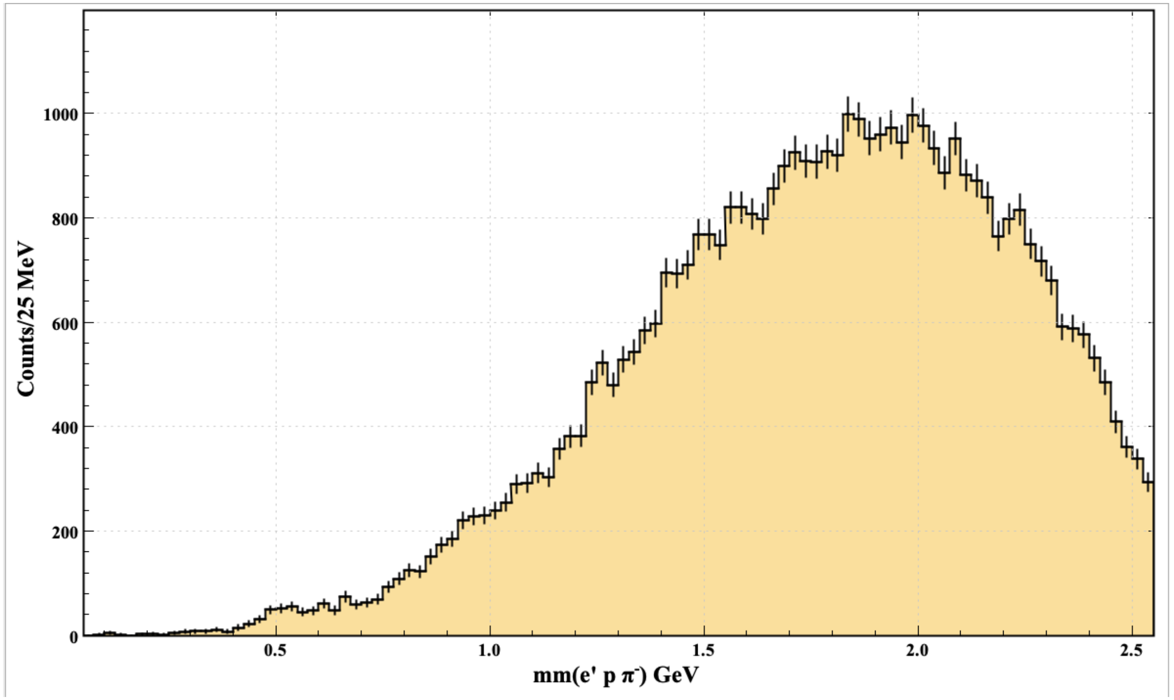
BSA as a Function of x_F for $x_B < 0.15$





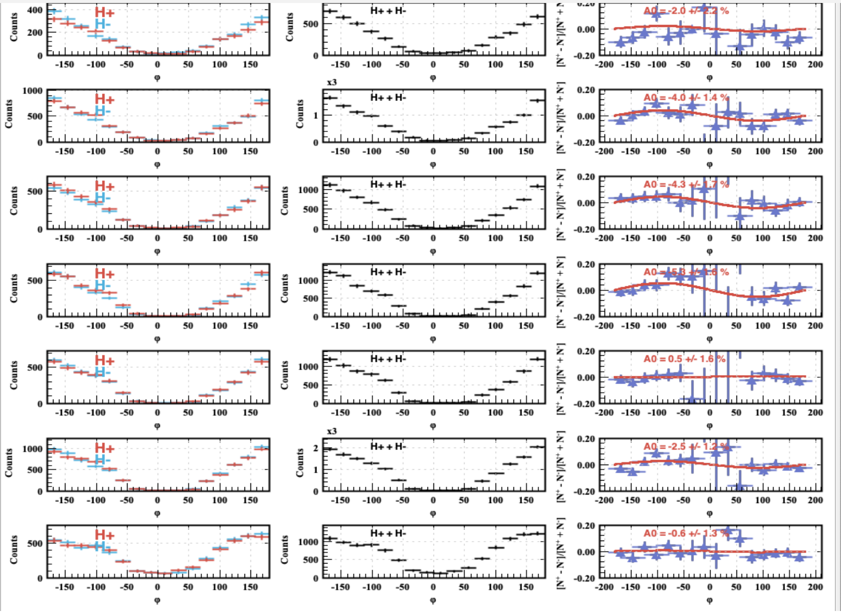
$1 < Q^2 < 10\ GeV^2$; $2 < W < 4.5$ GeV

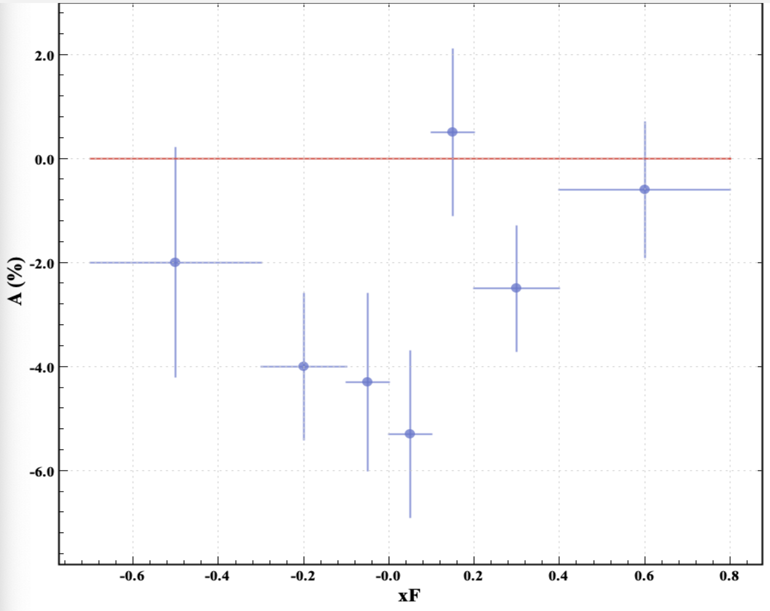
MM(e'Λ) (GeV)



- No obvious K (K*) contribution to the reaction ep → e'ΛX

BSA as a Function of x_F for $x_B > 0.15$

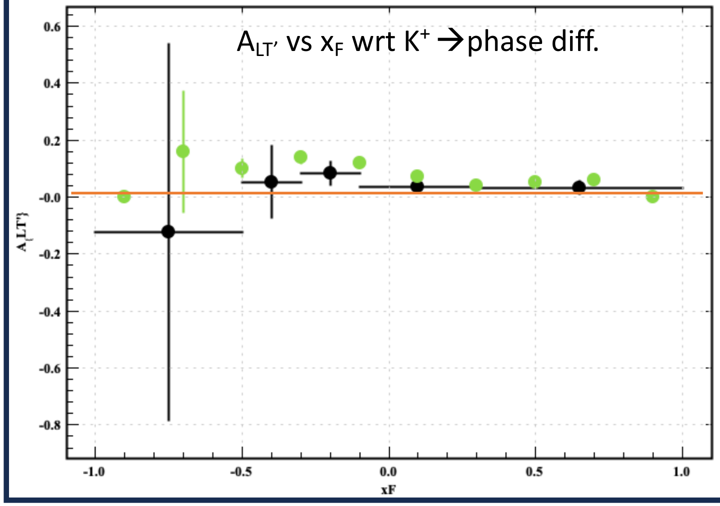




$1 < Q^2 < 10$ GeV^2; $2 < W < 4.5$ GeV

K contributions contribute to larger negative average $A_{LT'}$

- Analysis of $eK^+\Lambda$ events (ϕ_K) shows that the value of A_{LT}' does not change sign as a function of x_F

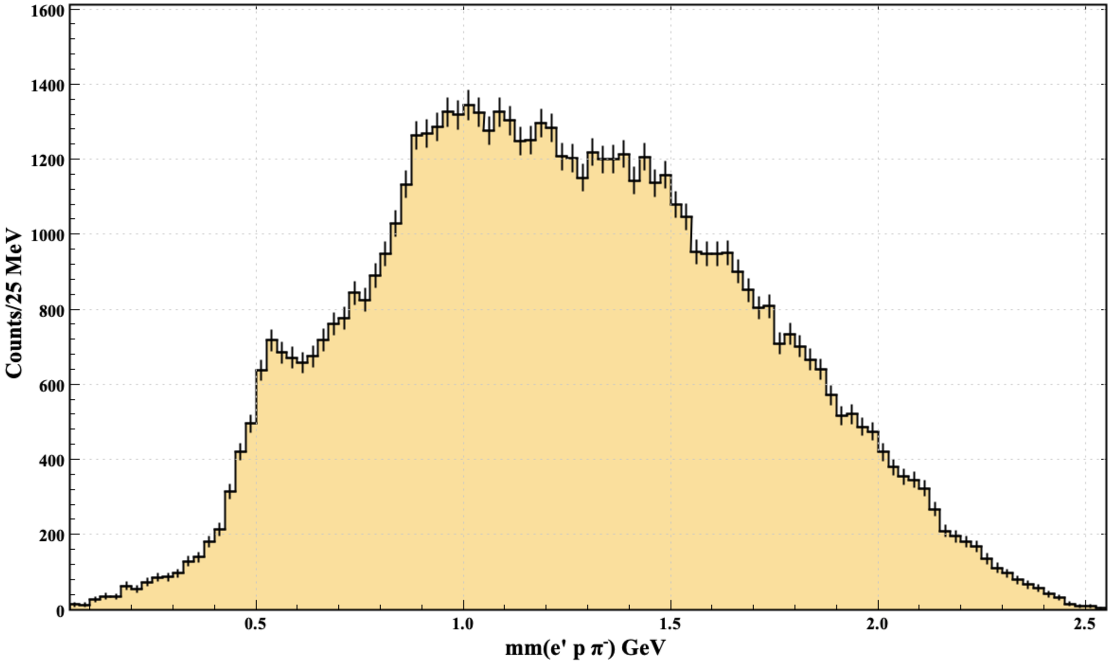


- BSA for $K^+\Lambda$ events from RGK data at 6.535 GeV vs x_F for Q^2 =1.0 - 4.5 GeV^2

(D.Carman's analysis)

- Obvious X=K^+ contribution to the reaction ep → e'Λ X

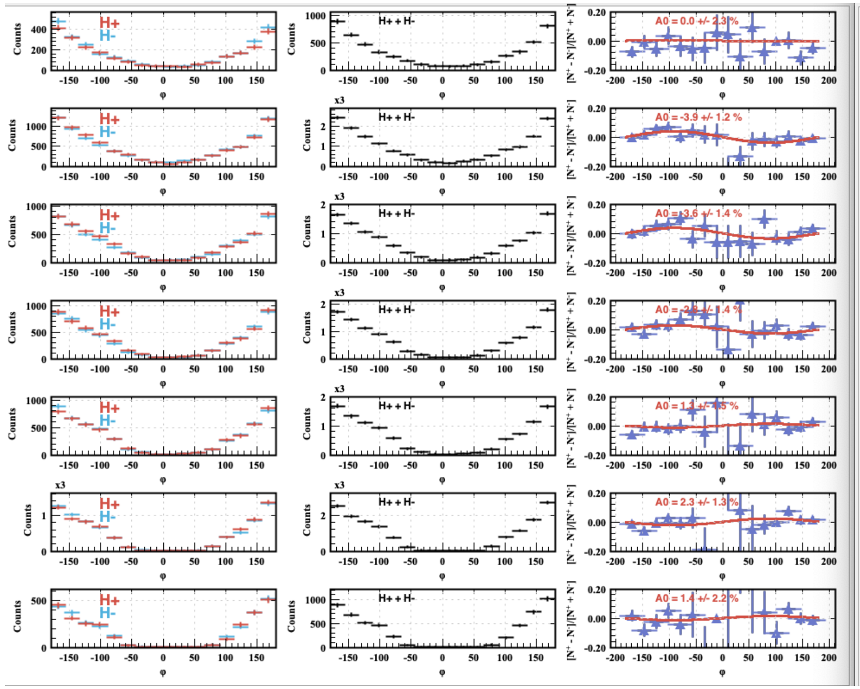
MM(e'Λ) (GeV)

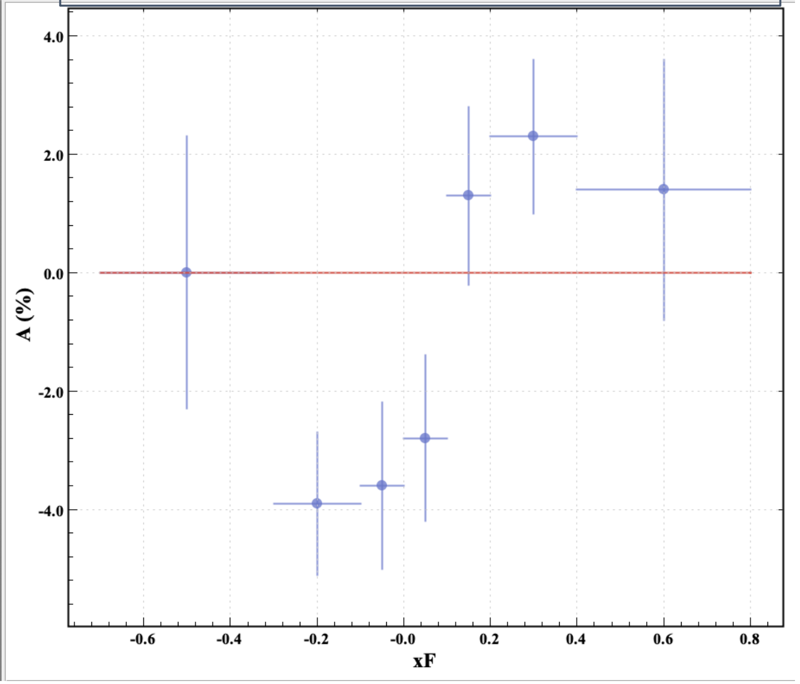


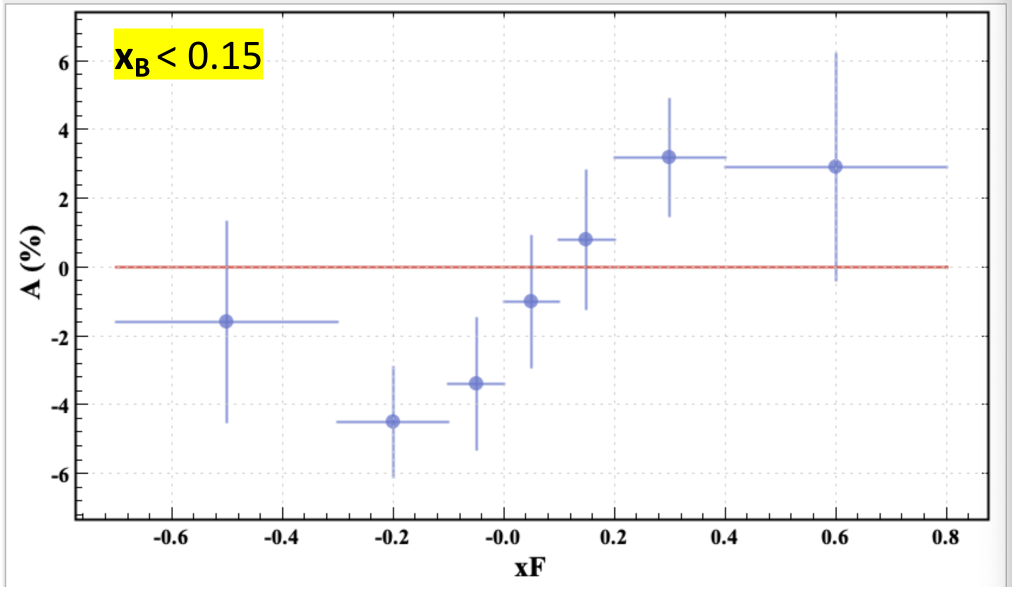
BSA as a Function of x_F for MM>1.2 GeV

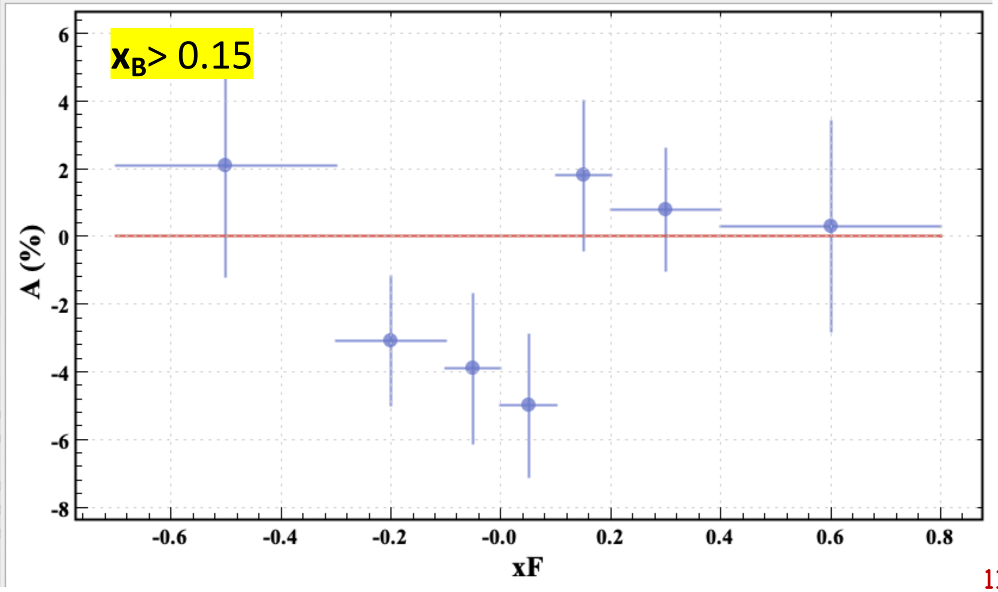
- Require MM(eΛ) >1.2 GeV to remove K (K*[892]) contributions
- Sign flip seen in both regions of x_B but position of minimum seems to shift depending on x_B

$1 < Q^2 < 10$ GeV^2; $2 < W < 4.5$ GeV









$A_{LT'}$ vs x_F for 2 regions of x_B

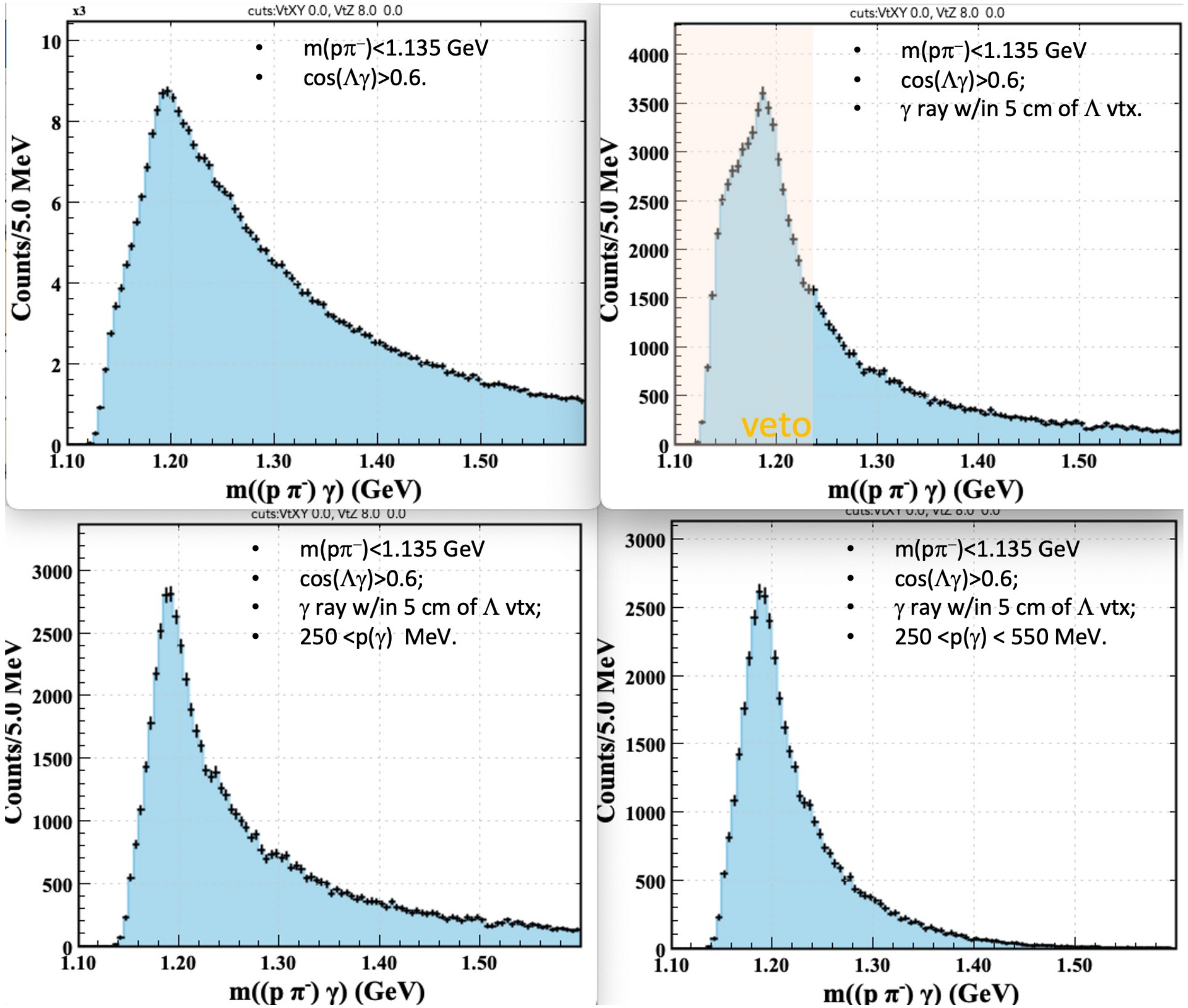
Contamination from e p→e' (Σ→Λ γ) X Events

- The selected Λ → pπ- can be produced in the reaction e p→e' (Σ→Λ γ) X
- This is a background to the reaction e p→e' Λ X
- To reduce the contribution from this background a veto on the γ is imposed :

rejecting events where there is a photon spanning an angular cone (cos ζ = 0.6) wrt Λ momentum vector

- Σ→Λ γ candidate selection
  - Missing mass against $e^- p\pi^-$ for selected Λ → $p\pi^-$ events
  - $m(p\pi^-)<1.135$ GeV

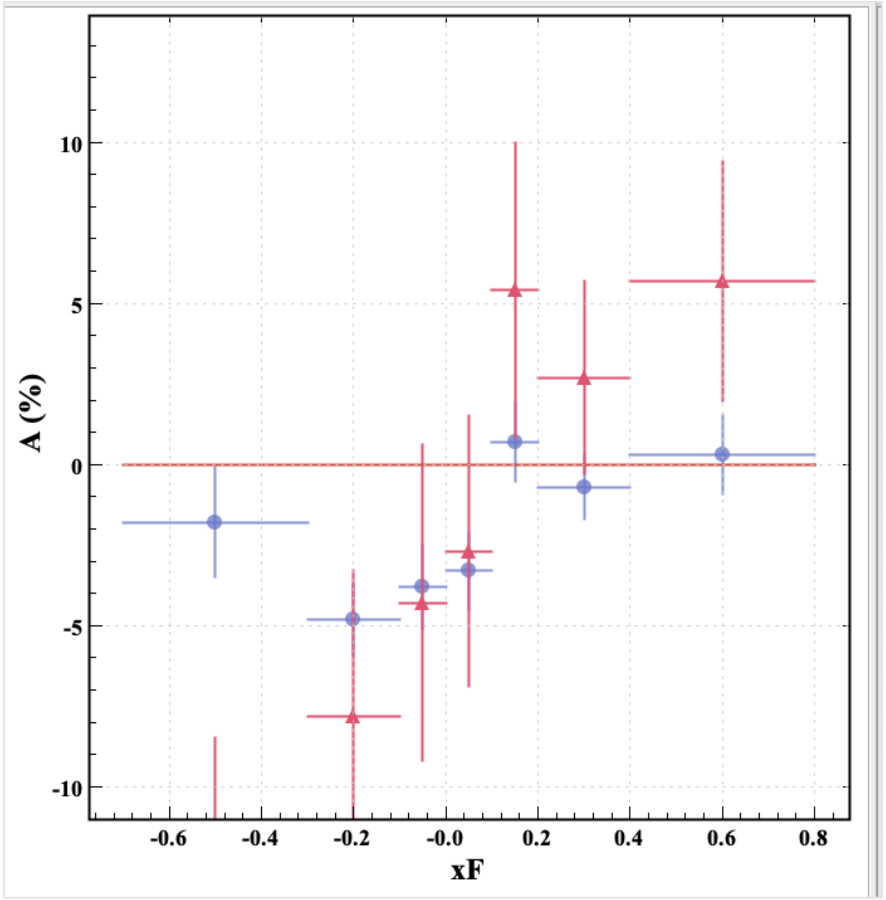
Observed Σ^0→Λ γ signal from 4-momentum addition of a γ with the selected Λ



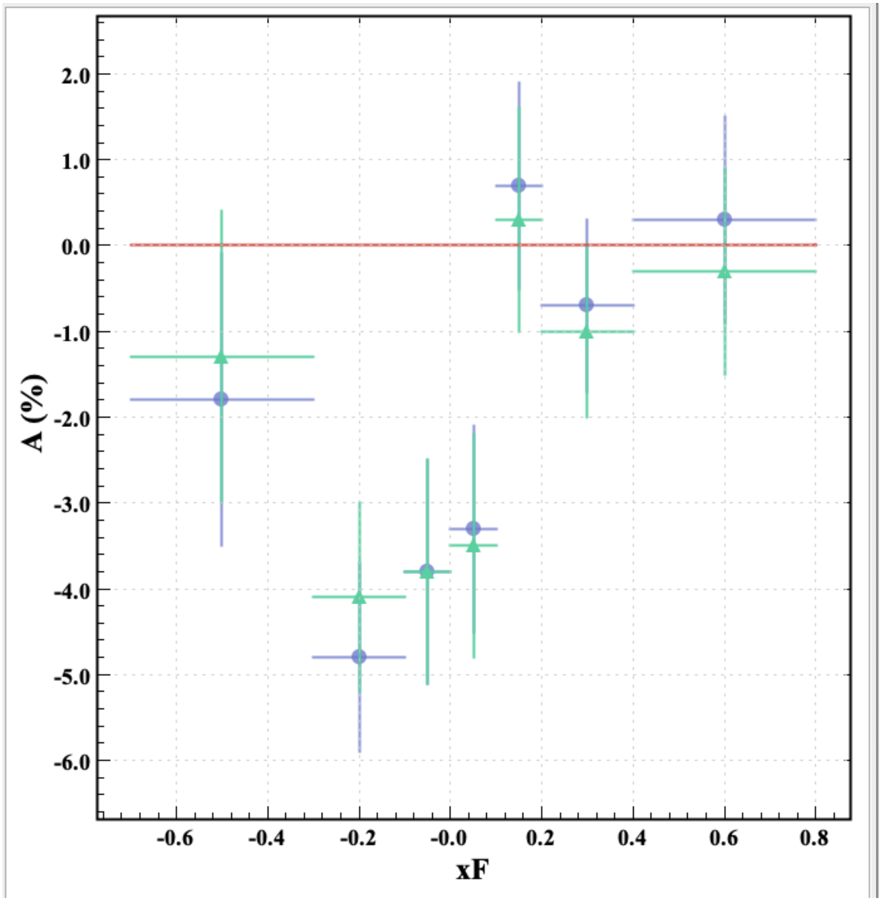
- Σ veto on photon and m(Λγ) from the reaction Σ→Λ γ

Study of Σ Contamination from e p→e' (Σ→Λ γ) X Events

△ Selected e p→e' (Σ→Λ γ) X Events
● Selected e p→e' Λ X Events



△ With Veto against e p→e' (Σ→Λ γ) X Events
● Selected e p→e' Λ X Events

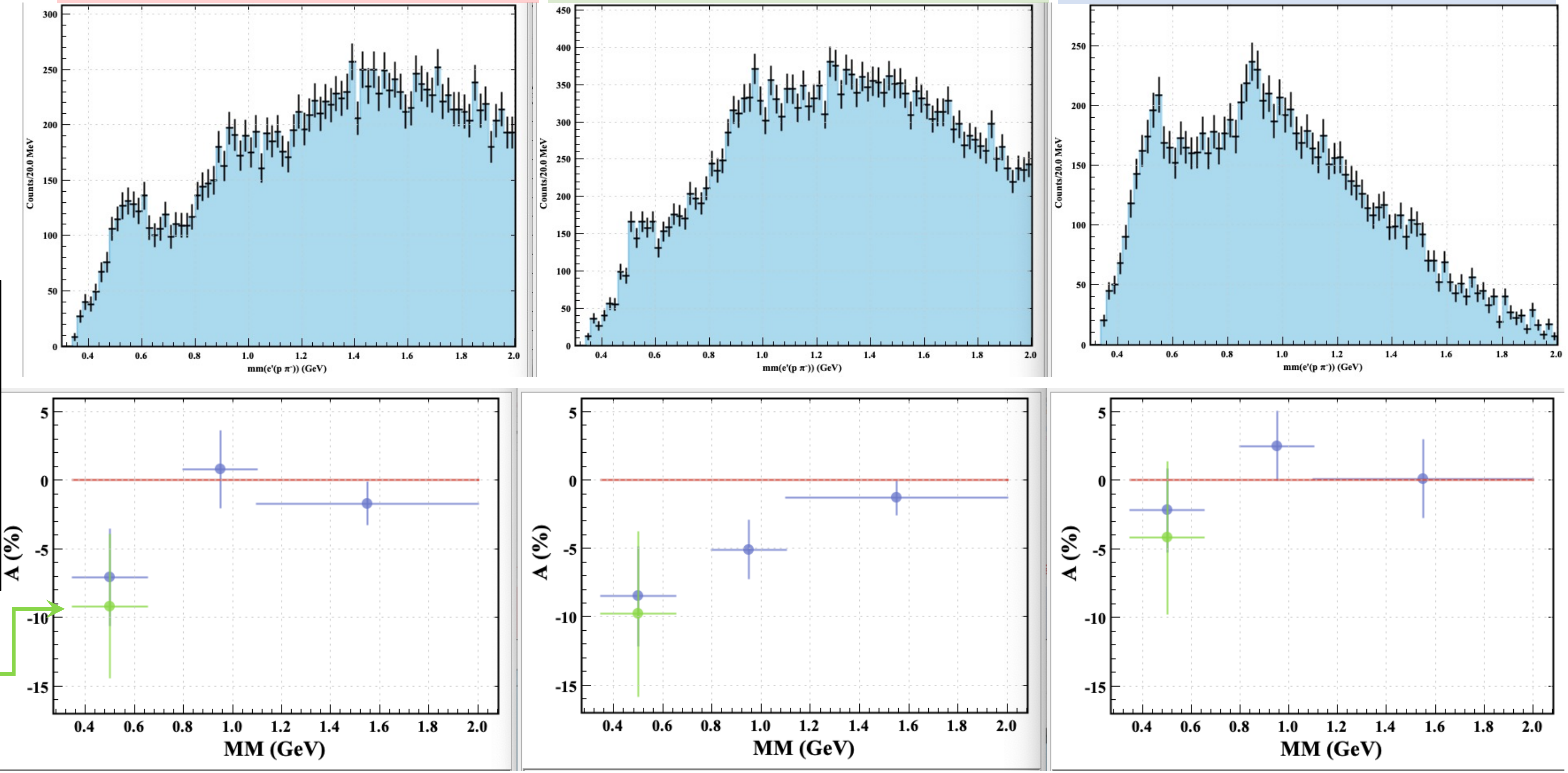


- Little effect of veto on BSA distribution

BSA as a Function of MM with γ Veto*

* Veto against $\cos(\Lambda\gamma)>0.6$

TFR	SR	CFR

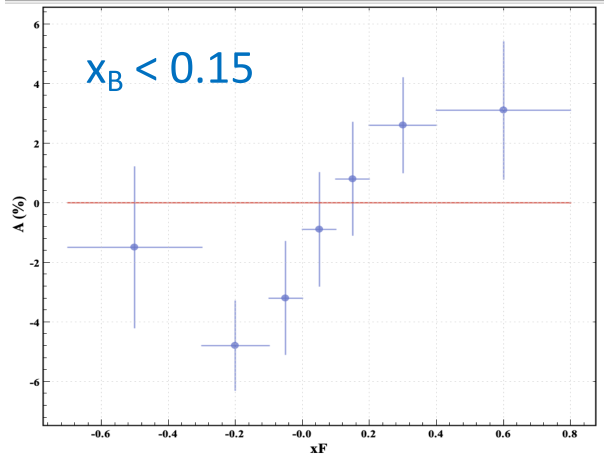


The difference between the blue and green data points gives an estimate of the contribution of the background under the K^+ peak

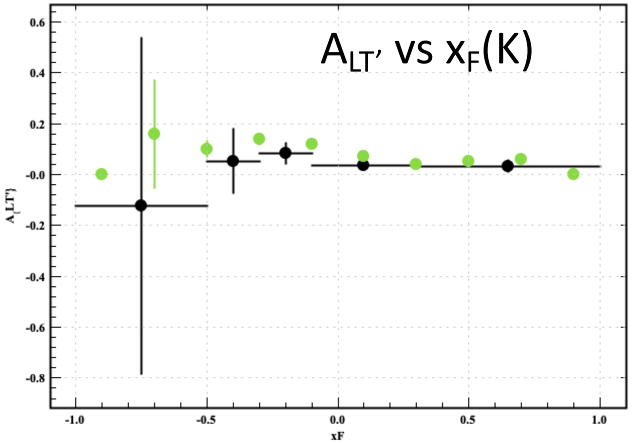
$K^+\Lambda$ events

Observations

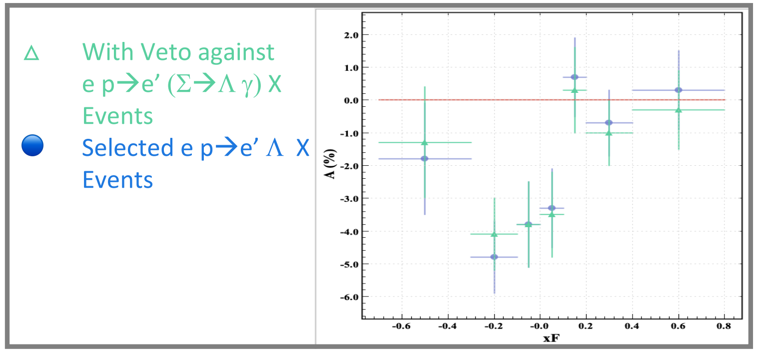
- A BSA (with ϕ computed wrt the Λ) sign flip is observed in the CFR when the contribution to ep → e' Λ X from the reaction ep → e' Λ K^+ is negligible:
  - Region MM > 1.2 GeV
  - Region $x_B < 0.15$
  - Region W > 3 GeV



- When the reaction ep → e' Λ K^+ is not negligible the BSA as a function of x_F is negative for all values of x_F.

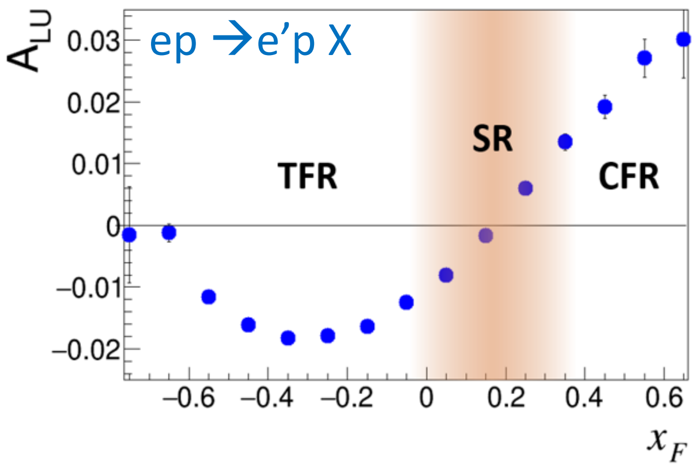


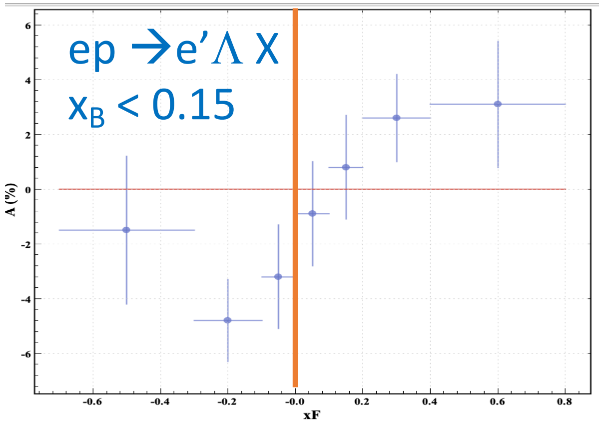
- The contamination from the reaction ep → e' $\Sigma(\rightarrow\Lambda\gamma)$ X has minimal impact on the BSA behavior as a function of x_F.



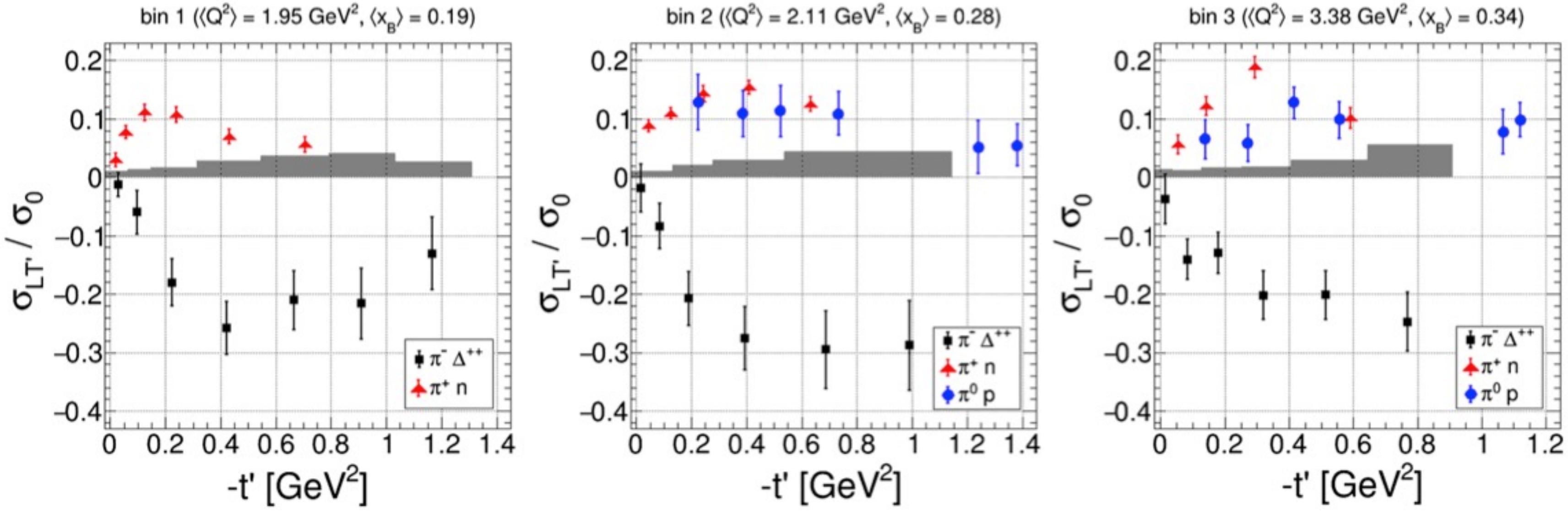
Interpretation

F. Benmokhtar





- Behavior (in region with minimal K^+ contribution) similar to what is observed for the reaction ep →e'p X
- Polarized u-quark kicked out likely responsible for sign of BSA in T- and C-FR
  - Quark dynamics govern s-quark spin orientation for $\Lambda\ K^{+(*)}$ final states
  - Polarization of struck quark in the proton shown to be responsible for sign of asymmetry



← γ* kicks out a longitudinally polarized u quark

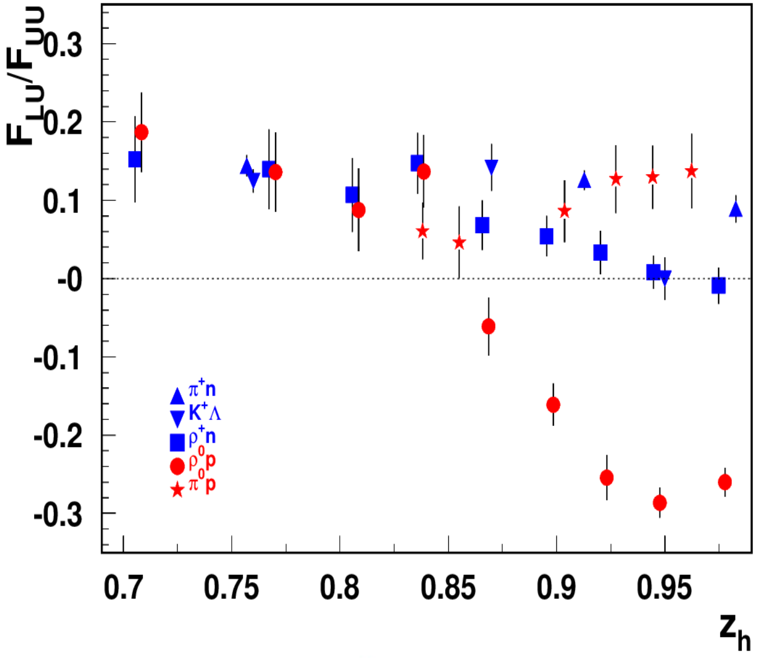
← γ* kicks out a longitudinally polarized d quark in reaction ep → e' $\pi^-\Delta^{++}$

S. Diehl et al. PRL 131, 021901 (2023)

Interpretation ~ "diffractive" kinematics separation

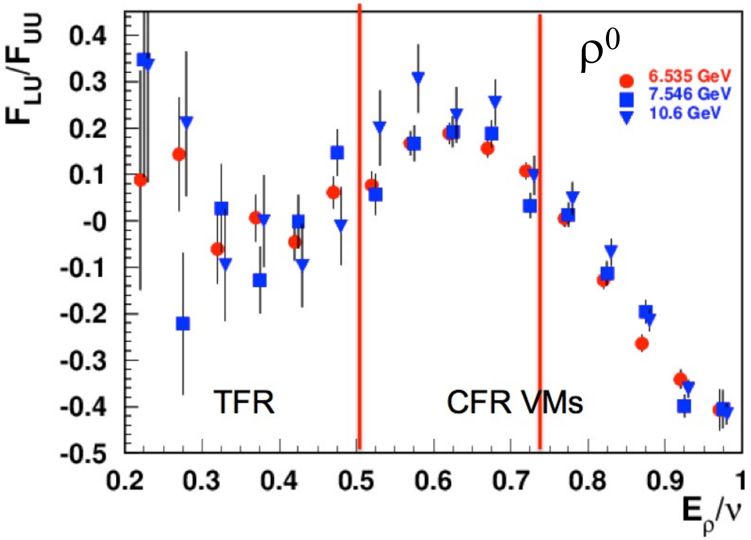
H. Avakian

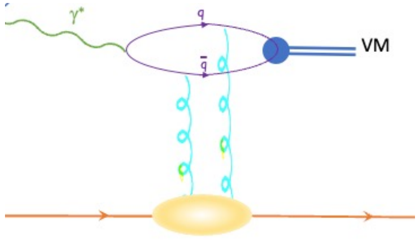
- Behavior for exclusive $\rho^0 p$ final state different from $\rho^+ p$ final state
- At high $z_h = E_h/\nu$, effect from "diffractive" ρ^0
- Difference between quark-exchange and gluon-exchange processes
  - BSA sign flip possibly resulting from gluon-exchange dynamics
  - $ep \rightarrow e'\Lambda K^+$ channel: non-diffractive channel
  - For Λ semi-exclusive channel, BSA sign flip in CFR could come from excited kaon
    - Production mechanism of the K-meson in the Target



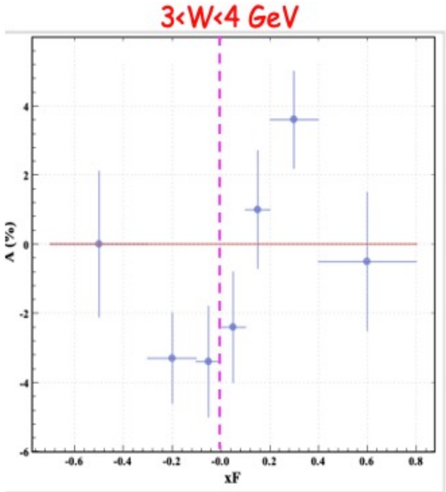
← non-"diffractive" channels

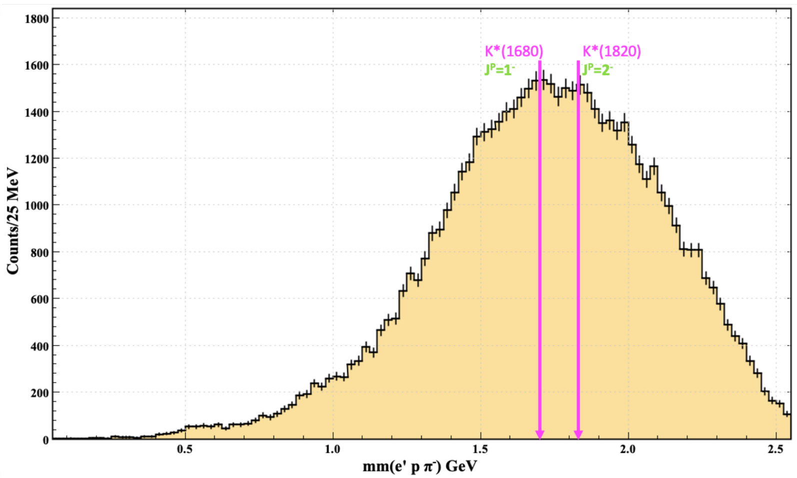
← "diffractive" ρ^0 (VM)





Diffractive vector meson electroproduction



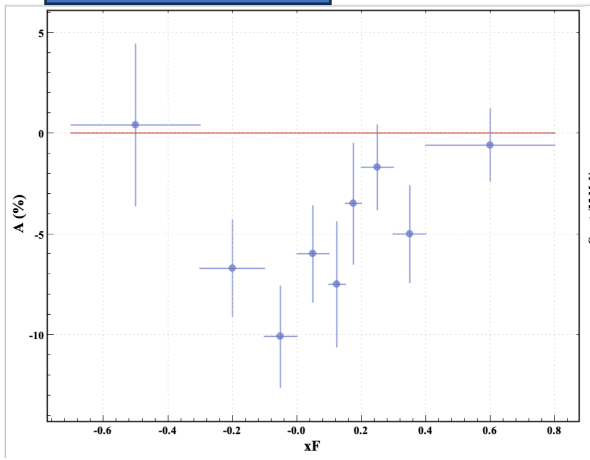


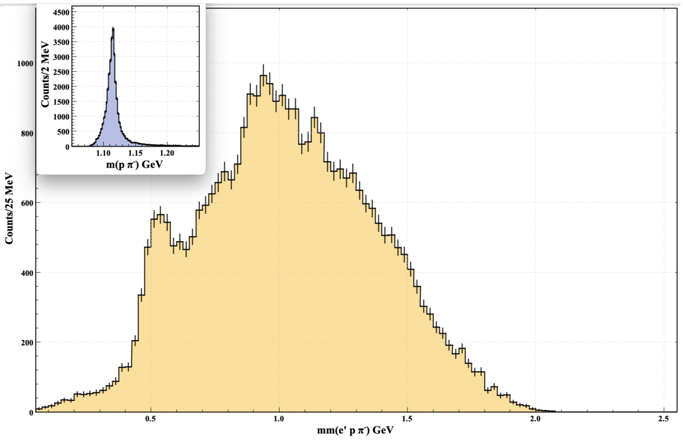
Outlook

- Try to identify which reaction is responsible for the BSA sign flip in the CFR
  - A lot more statistics needed
  - Use nuclear target data (RGC), deuteron target data (RGB)

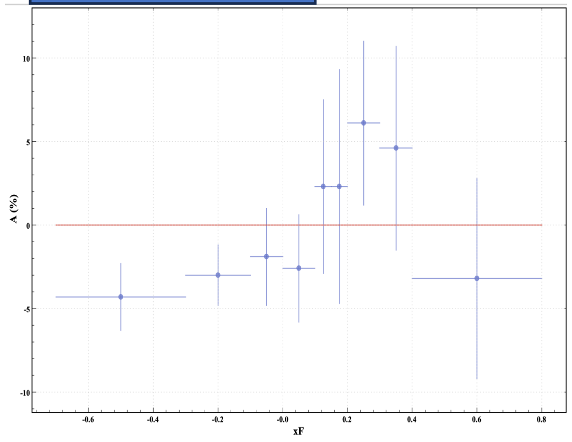
- Analysis combining different datasets
  - Different data sets with different beam energies → combining distributions to be taken into consideration
    → different targets possibly requiring different background rejection cuts, take Fermi motion* into account

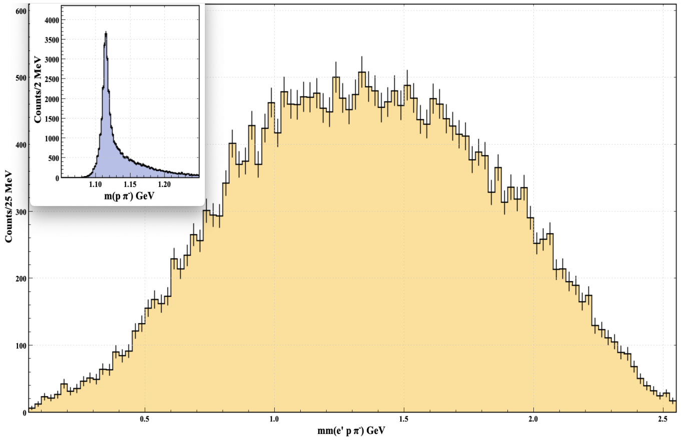
RGK 6.5+7.5 GeV
LH





RGC Fall+Summer22
NH_3





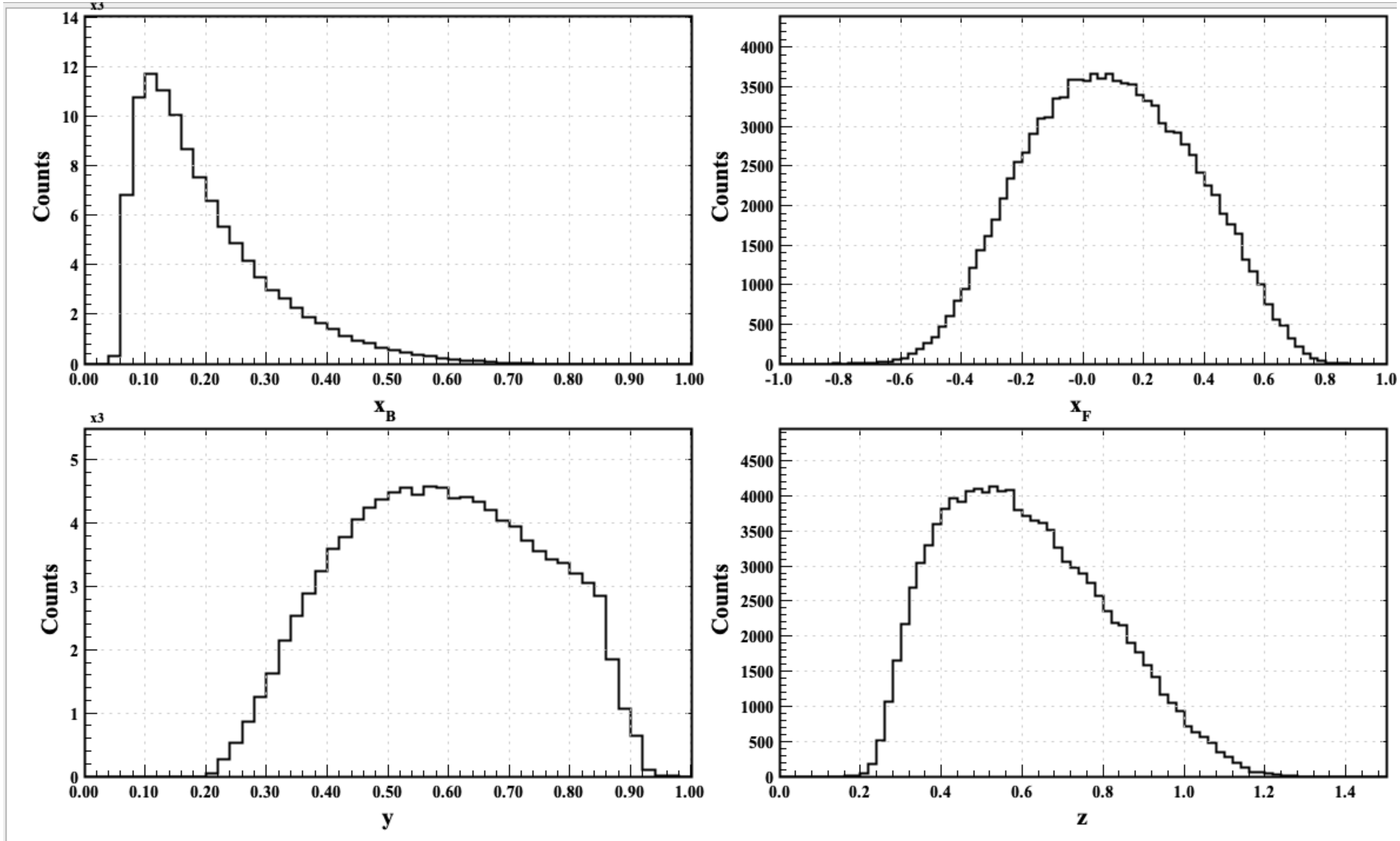
* Fermi motion (not taken into account) affects MM

- RGK analysis consistent with RGA ep→e'ΛK^+ results
  - Dominant kaon contribution

- RGC analysis indicative of possible sign flip evidenced in RGA analysis when kaon contribution is suppressed

BACKUP SLIDES

DIS Variables



Kinematics of Current Region Fragmentation in Semi-Inclusive Deeply Inelastic Scattering

M. Boglione[a], J. Collins[b], L. Gamberg[c], J. O. Gonzalez-Hernandez[d,e], T. C. Rogers[d,e], N. Sato[e]

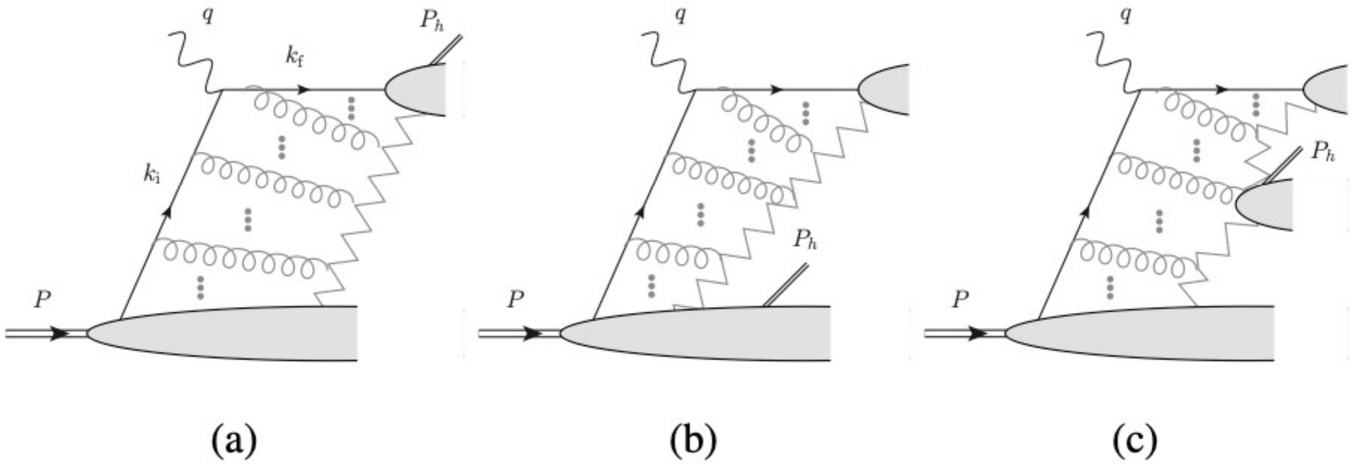
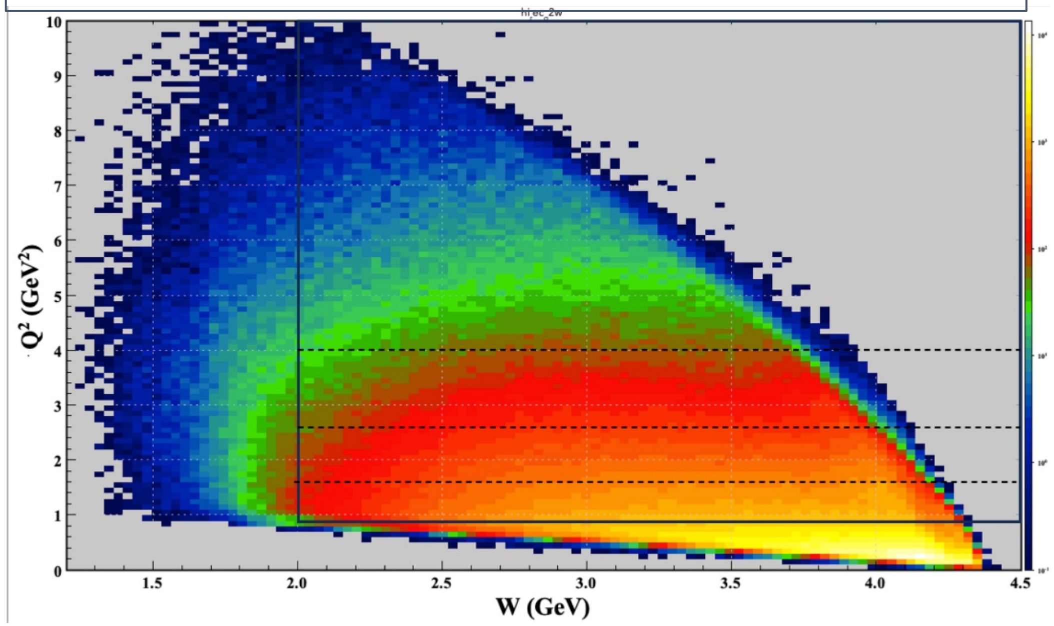
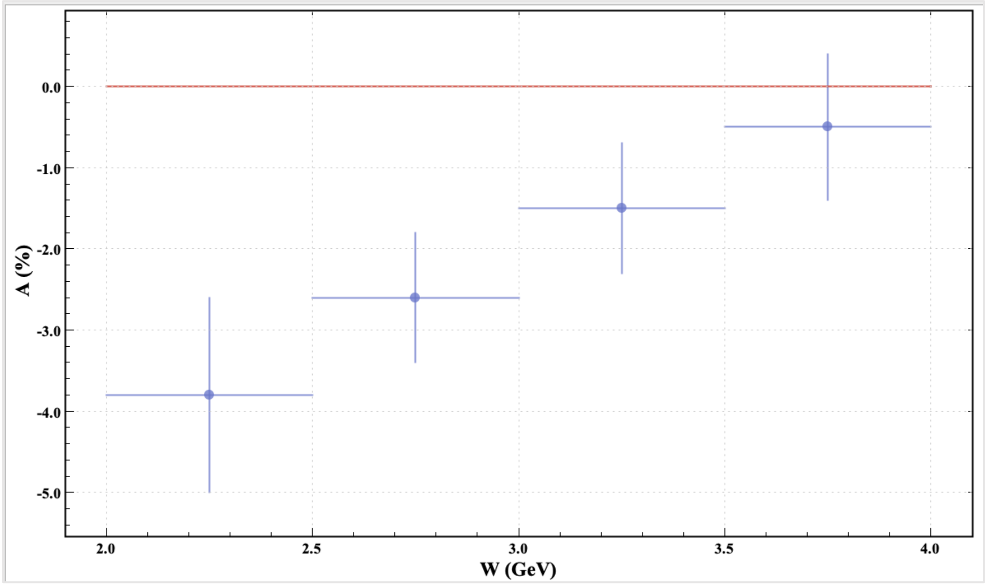


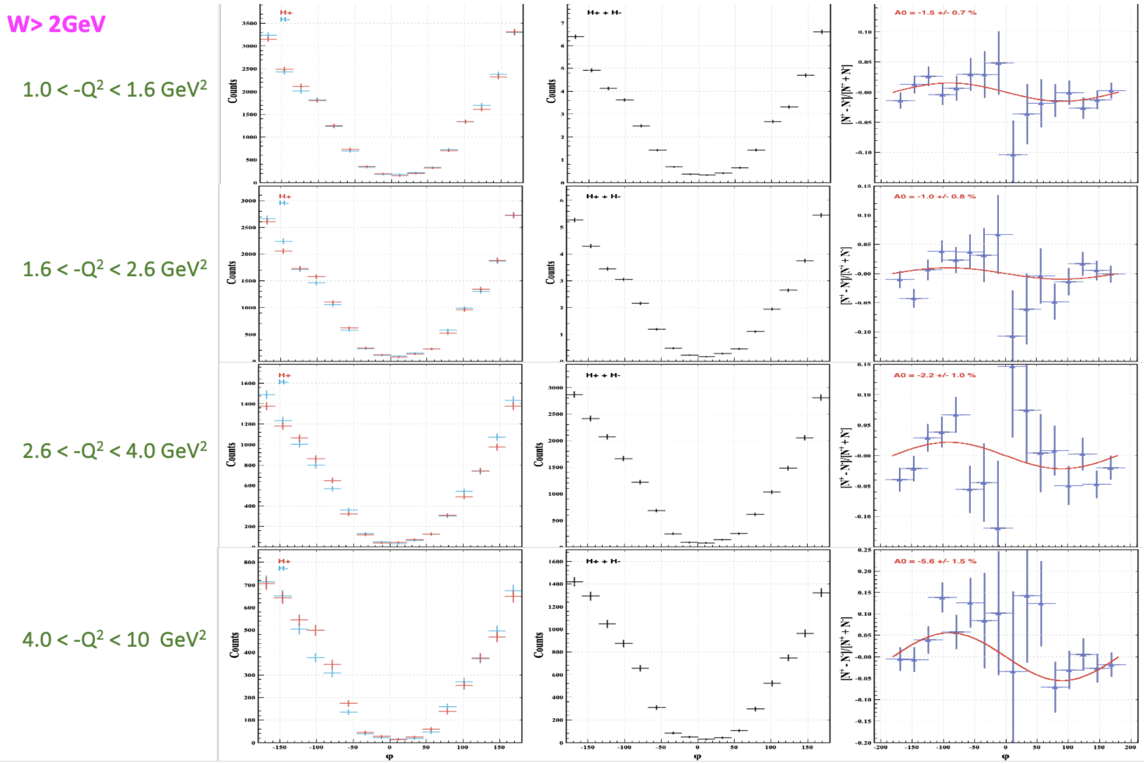
Figure 1: Lowest order SIDIS graphs corresponding to (a) the current region (b) the target region and (c) the central (soft) region. The faded zigzag lines represent non-perturbative and other interactions (e.g. hadronization) between the outgoing parton and the target jet.

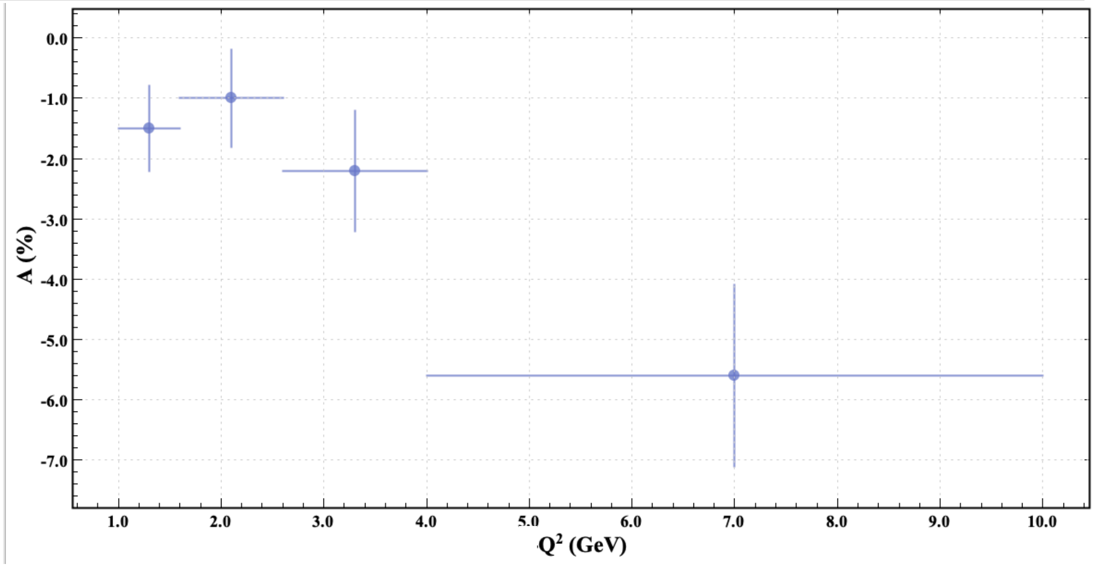
BSA as a Function of W and Q^2

Selected range: $1 < Q^2 < 10$ GeV^2; $2 < W < 4.5$ GeV





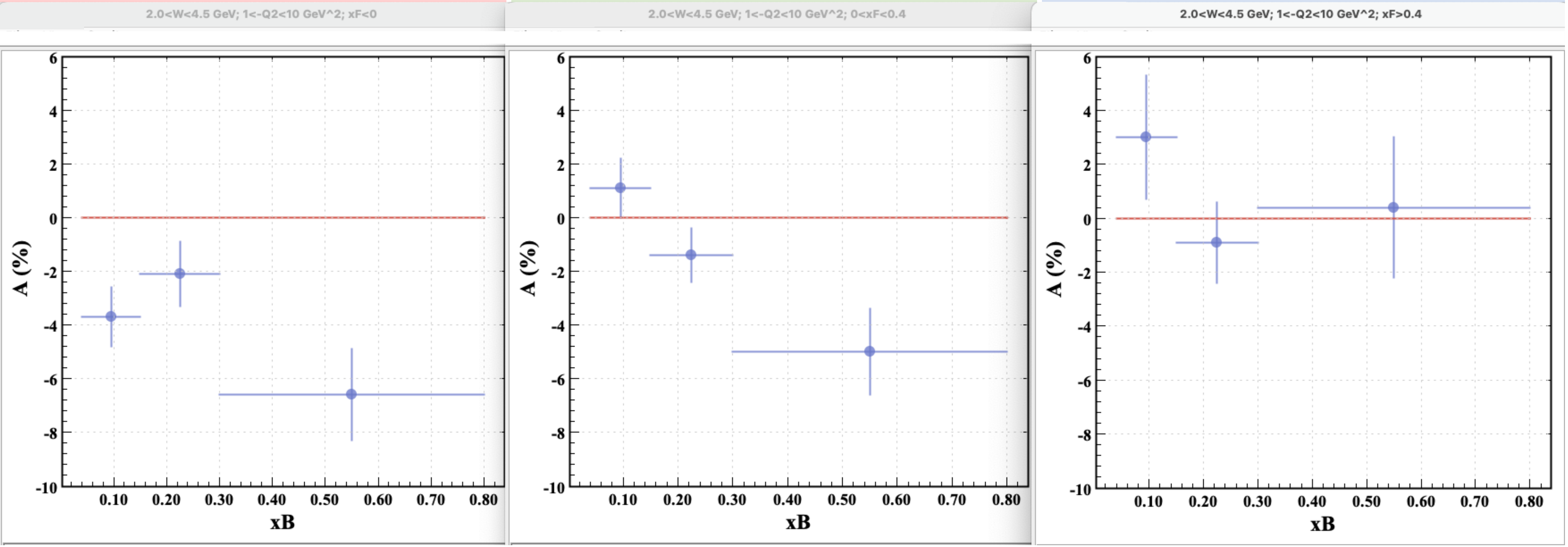




BSA as a Function of x_B

- BSA as a function of x_B in Target and Current regions

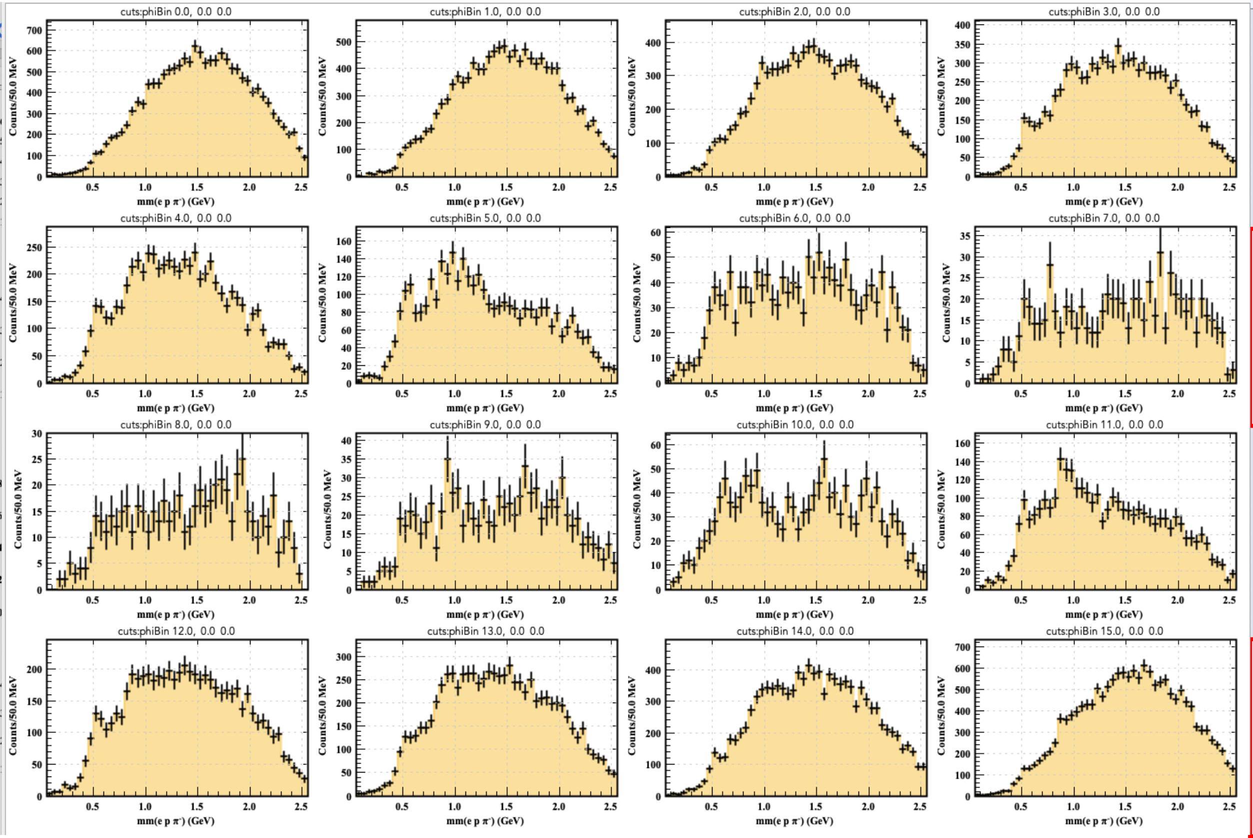
TFR | CR | CFR



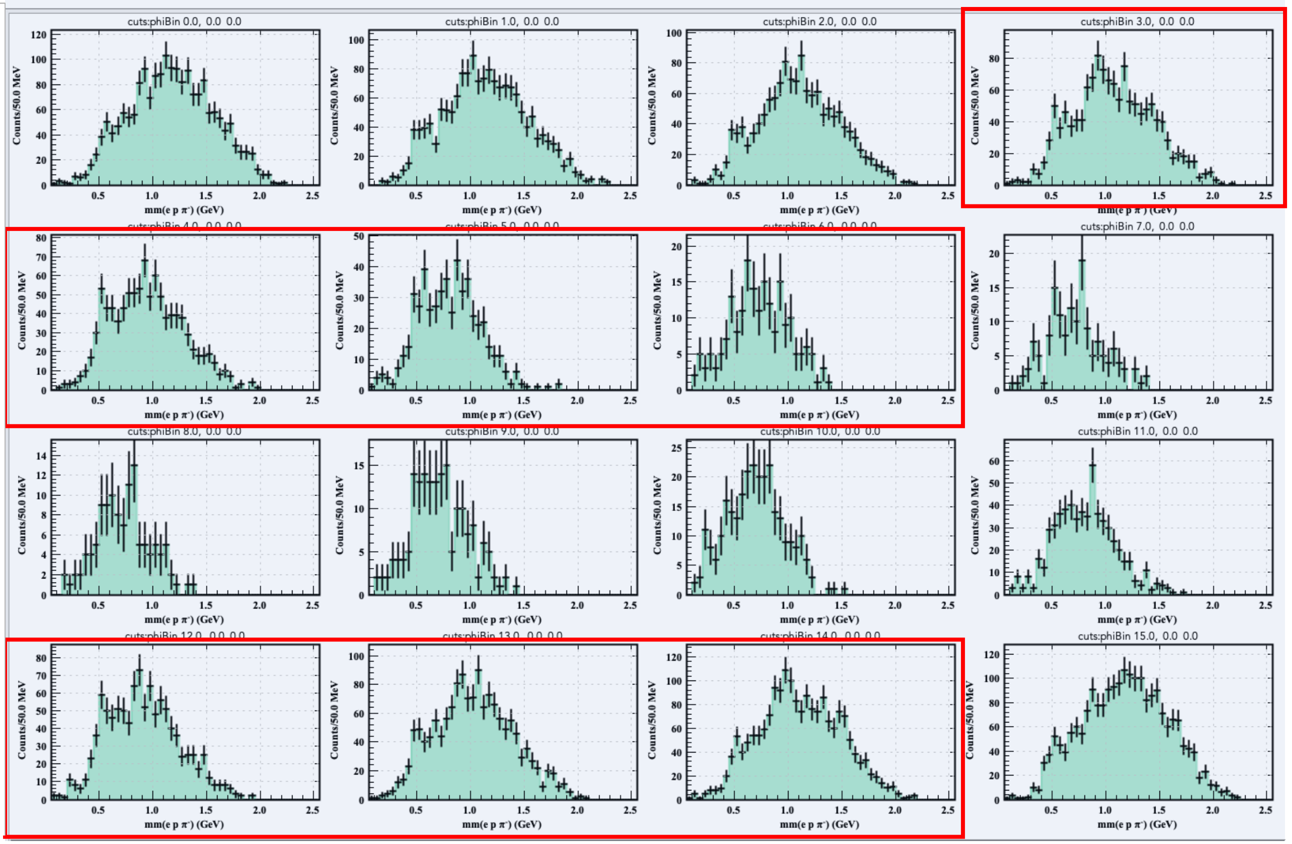
K(*)+ Contributions in the CFR

$1 < Q^2 < 10$ GeV^2; $2 < W < 4.5$ GeV; $0 < x_B < 1$

All Fragmentation Regions

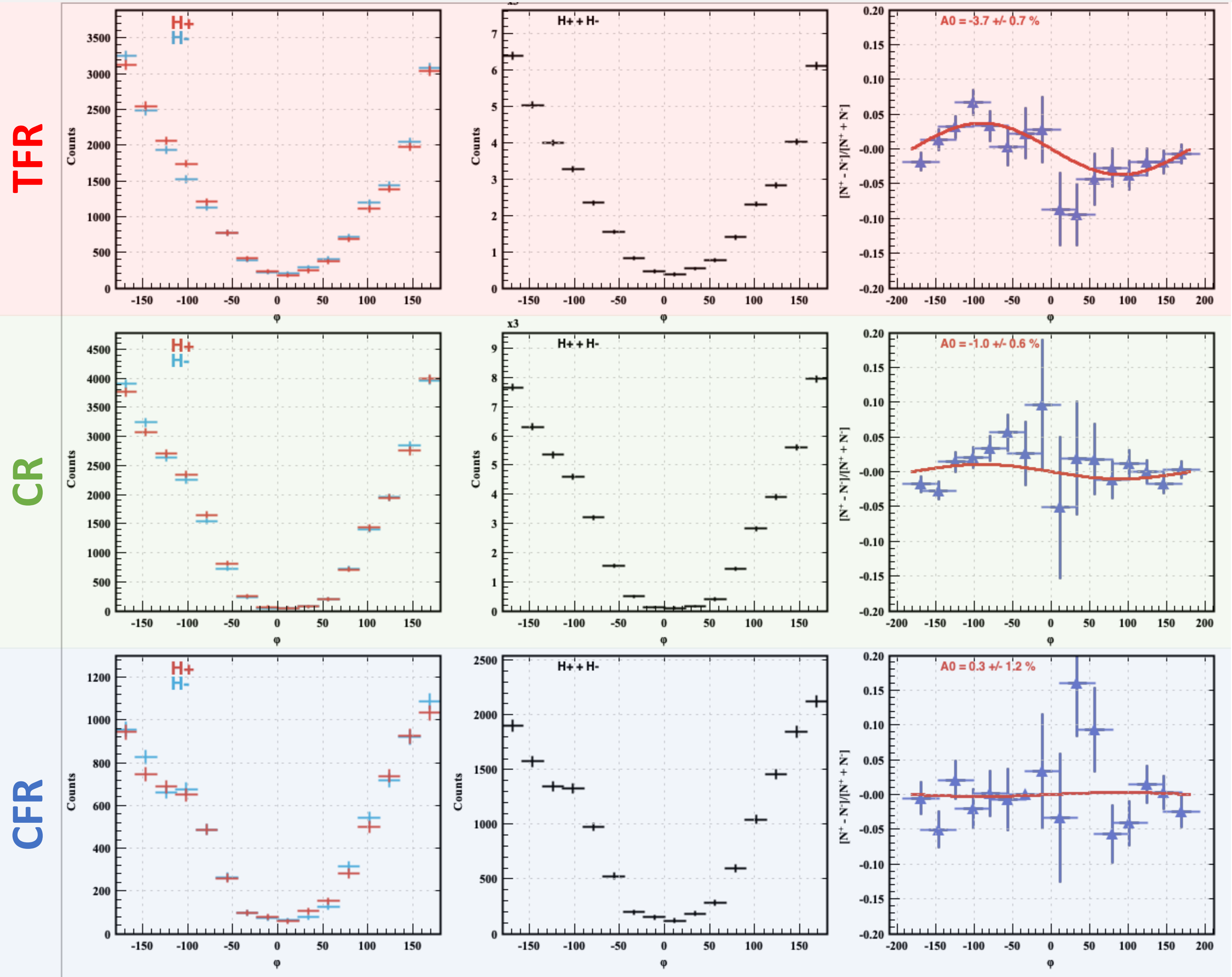


CFR



- Enhanced K* contributions

BSA as in 3 Fragmentation Regions

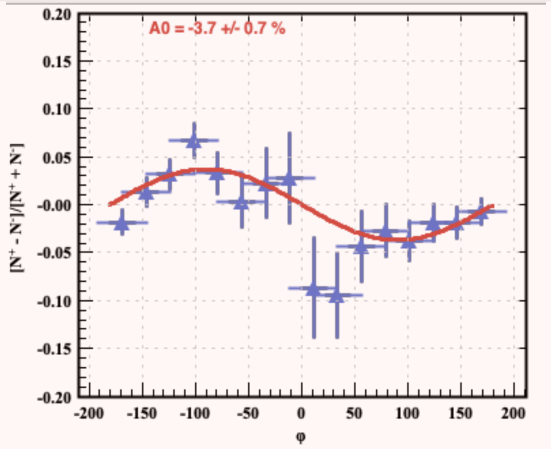


$1 < Q^2 < 10\ GeV^2$
$2 < W < 4.5\ GeV$

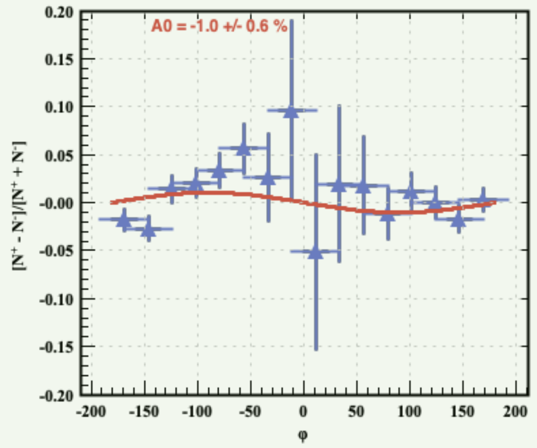
- ~ flat in CFR

BSA as in 3 Fragmentation Regions [over all x_B]

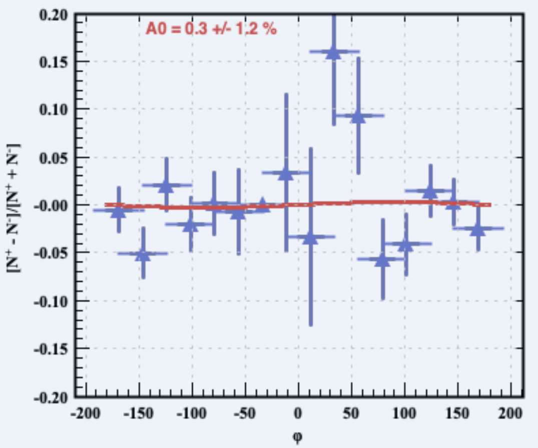
TFR



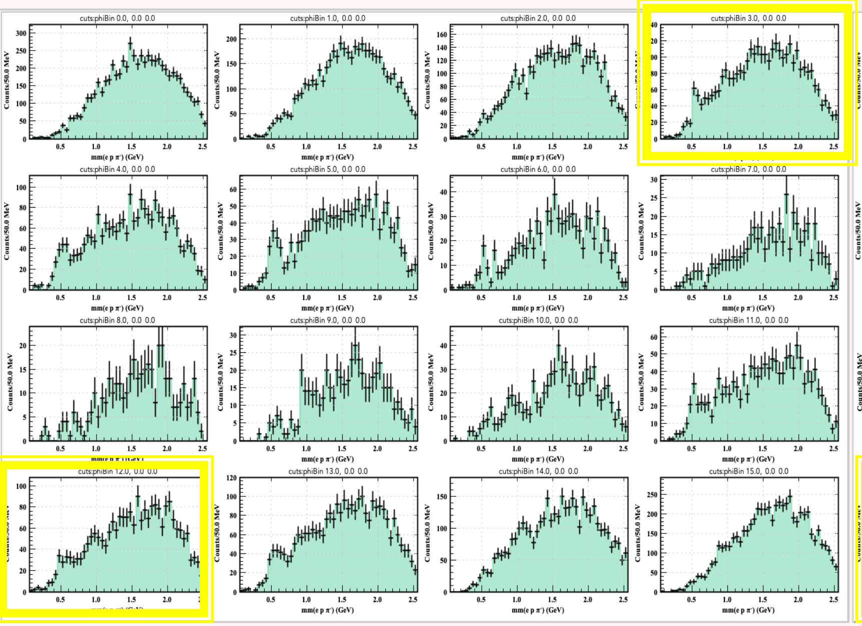
CR

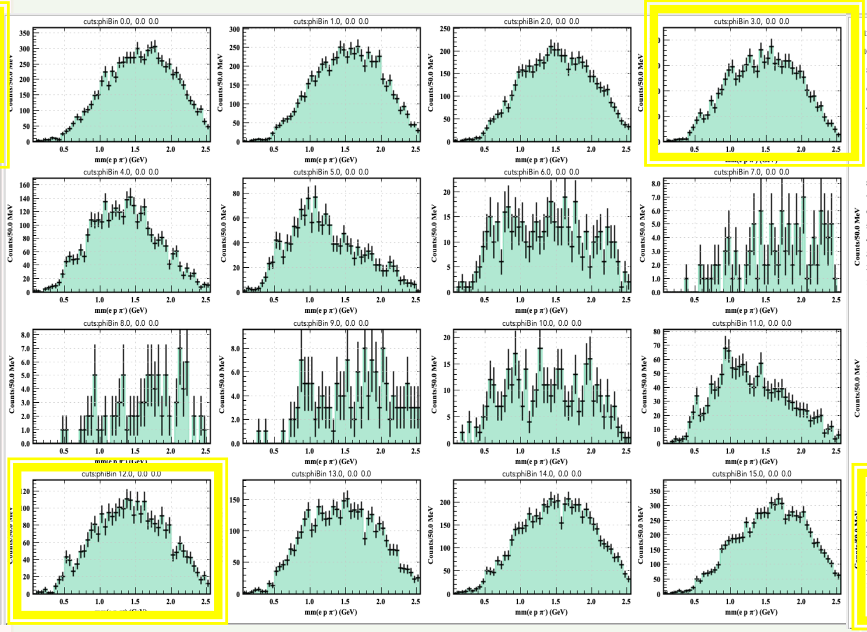


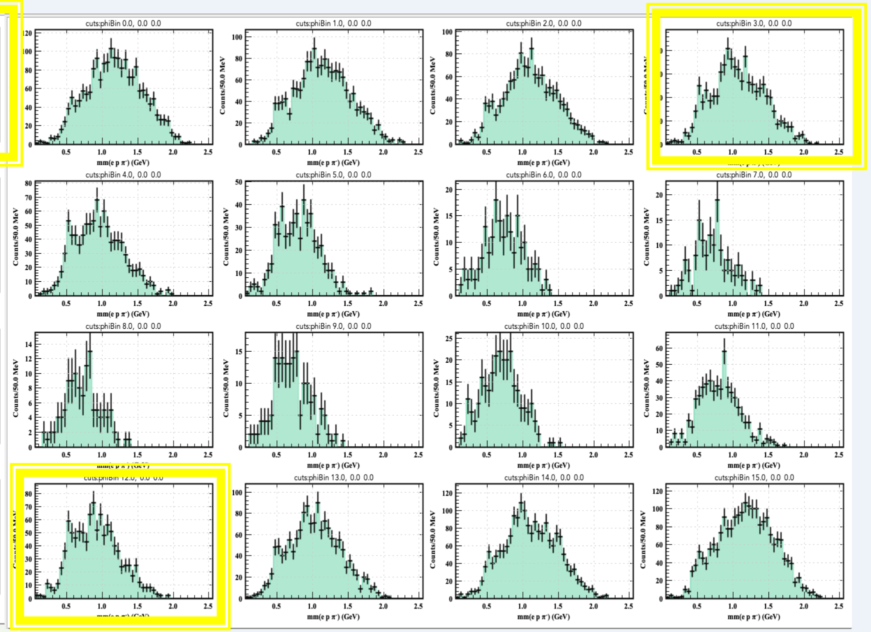
CFR



MM spectra in 3 fragmentation regions for each bin in ϕ_Λ of the BSA distributions







Bins corresponding to f = A sinϕ extrema