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Ferrara, Spin18

Interpretation of the unpolarized azimuthal asymmetries in SIDIS

Albi Kerbizi,

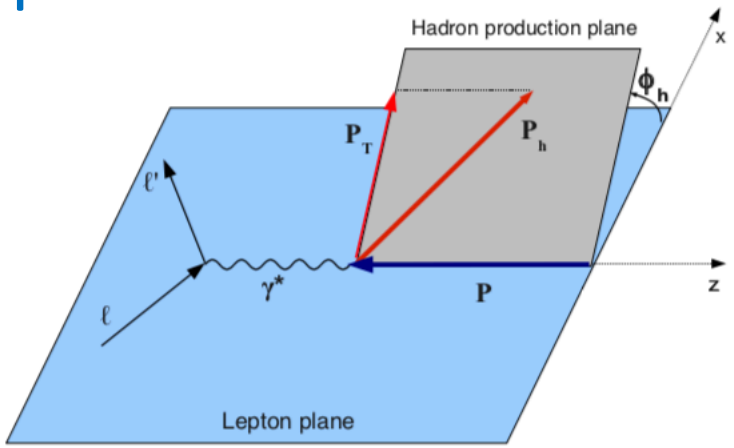
Trieste University and INFN

On behalf of the

COMPASS Collaboration

Asymmetries in unpolarized SIDIS

In the one photon exchange approximation, the unpolarized SIDIS cross section for an unpolarized beam is



$$\frac{d\sigma}{dx_B dz dy dP_T^2 d\phi_h} = \sigma_0[1 + \epsilon_1 A^{UU}_{\cos\phi_h} \cos\phi_h + \epsilon_2 A^{UU}_{\cos 2\phi_h} \cos 2\phi_h]$$

$$\epsilon_1(y) = \frac{2(2-y)\sqrt{1-y}}{1+(1-y)^2}, \qquad \epsilon_2(y) = \frac{2(1-y)}{1+(1-y)^2}$$

The **unpolarized azimuthal asymmetries** $A^{UU}_{\cos\phi_h}$ and $A^{UU}_{\cos 2\phi_h}$ receive contributions from

1. **Cahn effect** (mostly $A^{UU}_{\cos\phi_h}$) → kinematics of non-coplanar hard scattering
2. **Boer-Mulders effect** (mostly $A^{UU}_{\cos 2\phi_h}$) → quarks inside an unpolarized nucleon may have transverse polarization

→ they give access to the quark intrinsic transverse momentum and to the Boer-Mulders function

Existing data

- The $A_{\cos\phi_h}^{UU}$ and $A_{\cos 2\phi_h}^{UU}$ asymmetries in unpolarized SIDIS have been measured by several experiments, most recently by
  - HERMES: d, p [Phys.Rev. D87 (2013) no.1, 012010]
  - COMPASS: d (NPB 886 (2014) 1046), **(p → see A. Moretti talk)**

  → Strong kinematic dependence

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  → Strong kinematic dependence

- Difficulties in the interpretation of the asymmetries

  → phenomenological fits not conclusive

  → problems in extracting $\langle k_T^2 \rangle$ from $A_{\cos\phi_h}^{UU}$

  → BM function not yet extracted

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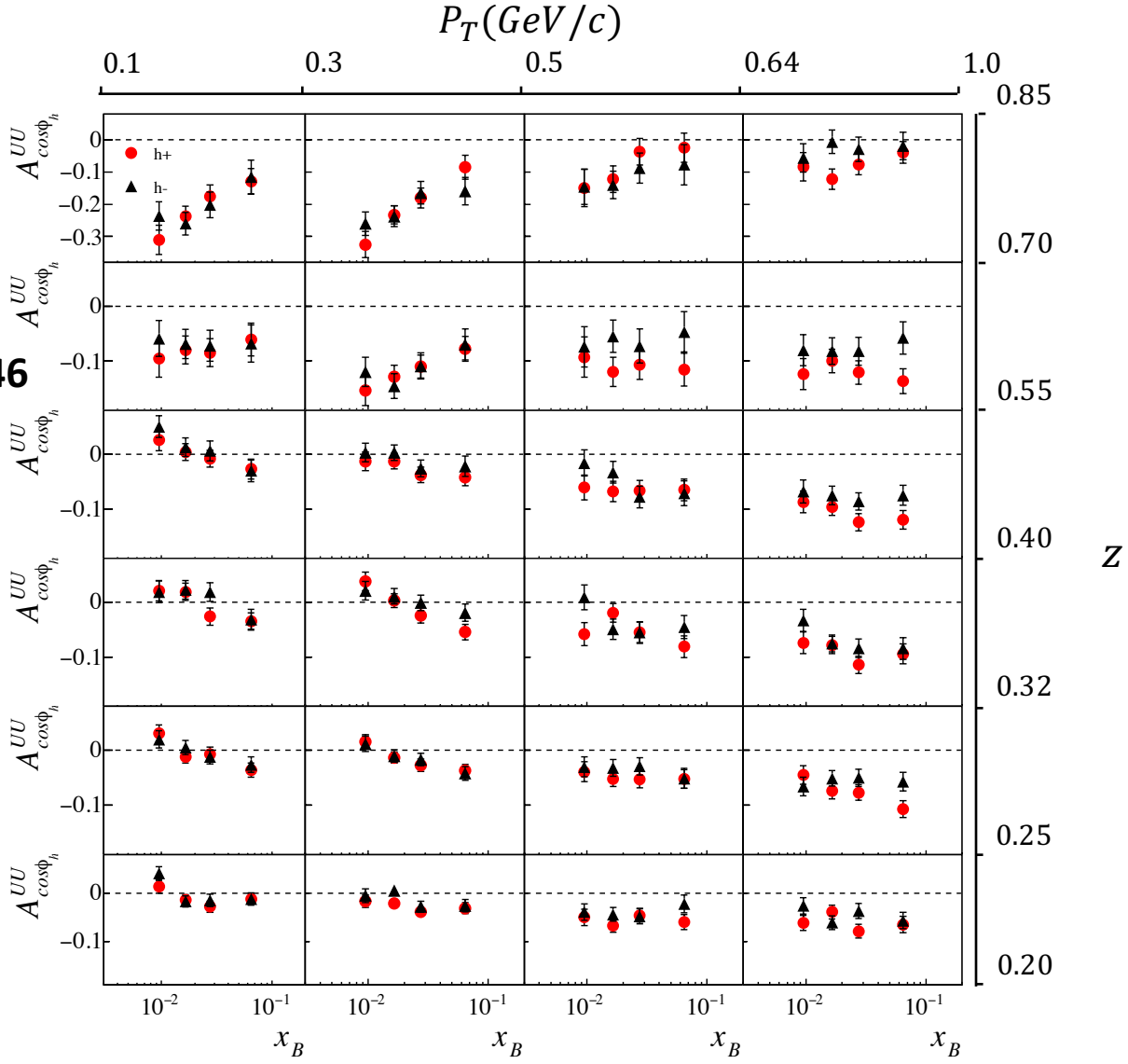
We tried to interpret COMPASS d $A_{\cos\phi_h}^{UU}$ asymmetry using a MC based on the $^3P_0$+string model (*) for polarized quark jets where we implemented the Cahn effect

(*) A. Kerbizi et al, **Phys.Rev. D97 (2018) no.7, 074010**

$A^{UU}_{\cos\phi_h}$ asymmetry from COMPASS

2004 d data

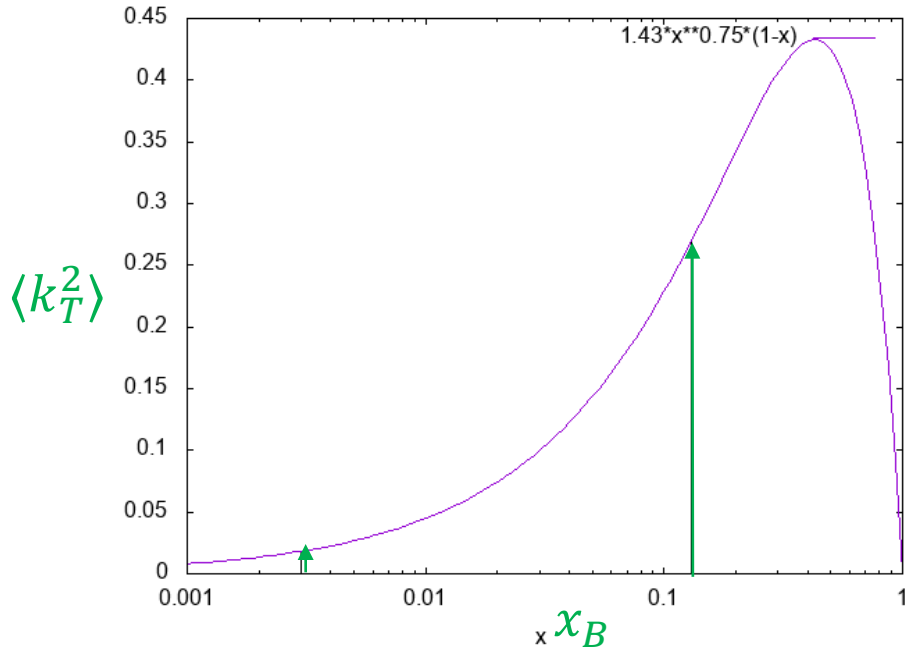
NPB 886 (2014) 1046



Intrinsic quark transverse momentum

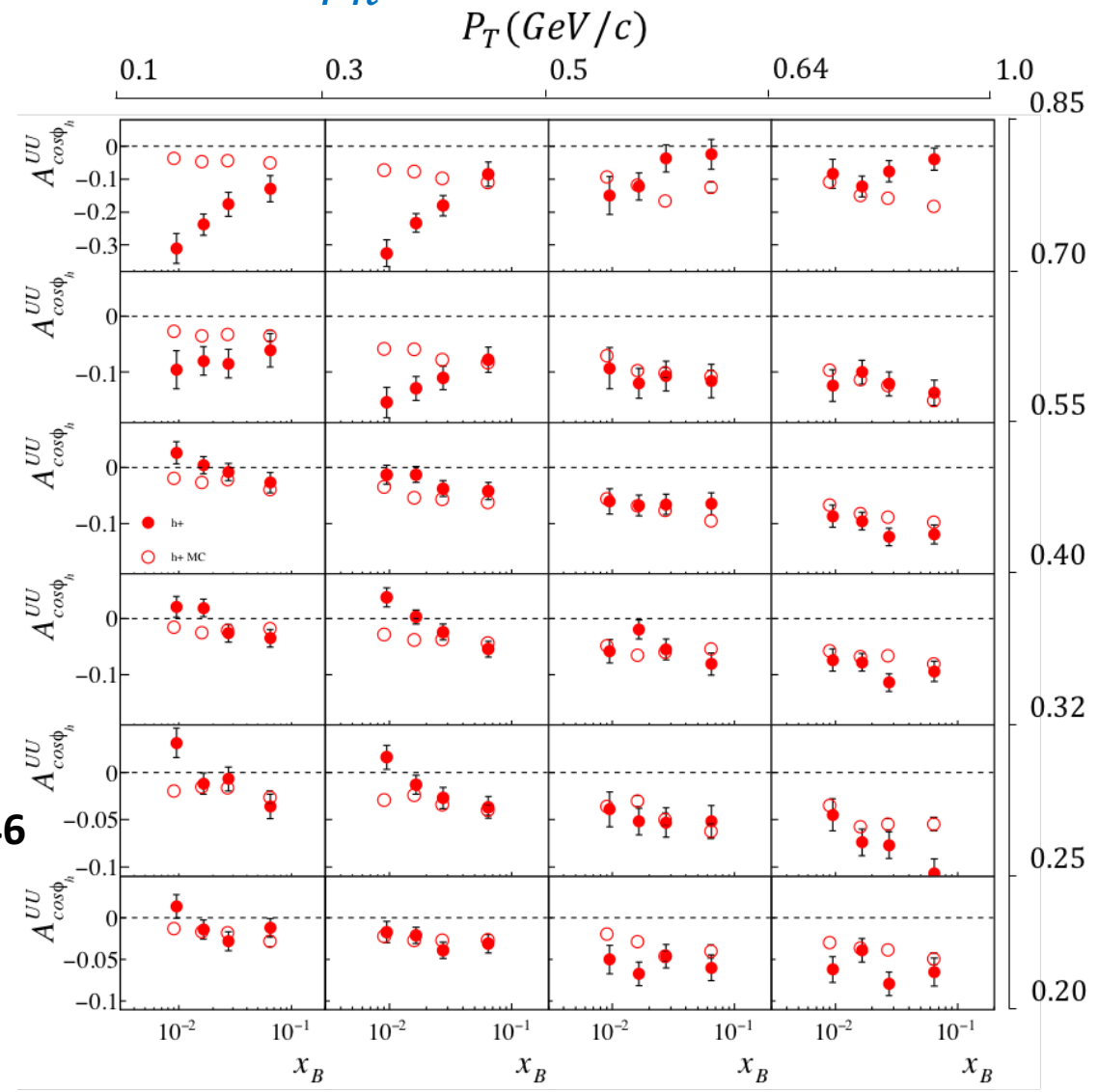
To describe the $A_{\cos\phi_h}^{UU}$ asymmetry with the MC in a limited kinematical region (up to $z \sim 0.5$) it is necessary to require

- the intrinsic $\langle k_T^2 \rangle$ of quarks to depend on x_B



- the dependence of the hadrons p_T in fragmentation to depend on z: in our case this is built-in in the model due to the underling string fragmentation framework.

$A_{\cos\phi_h}^{UU}$ compared to MC



h+

- ○ **MC**
- • Published

NPB 886 (2014) 1046

Same for h-

$A_{\cos\phi_h}^{UU}$ compared to MC

- Difference increasing when z increases and P_T decreases
- Contributions from other processes ??

h+

- ○ **MC**
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NPB 886 (2014) 1046

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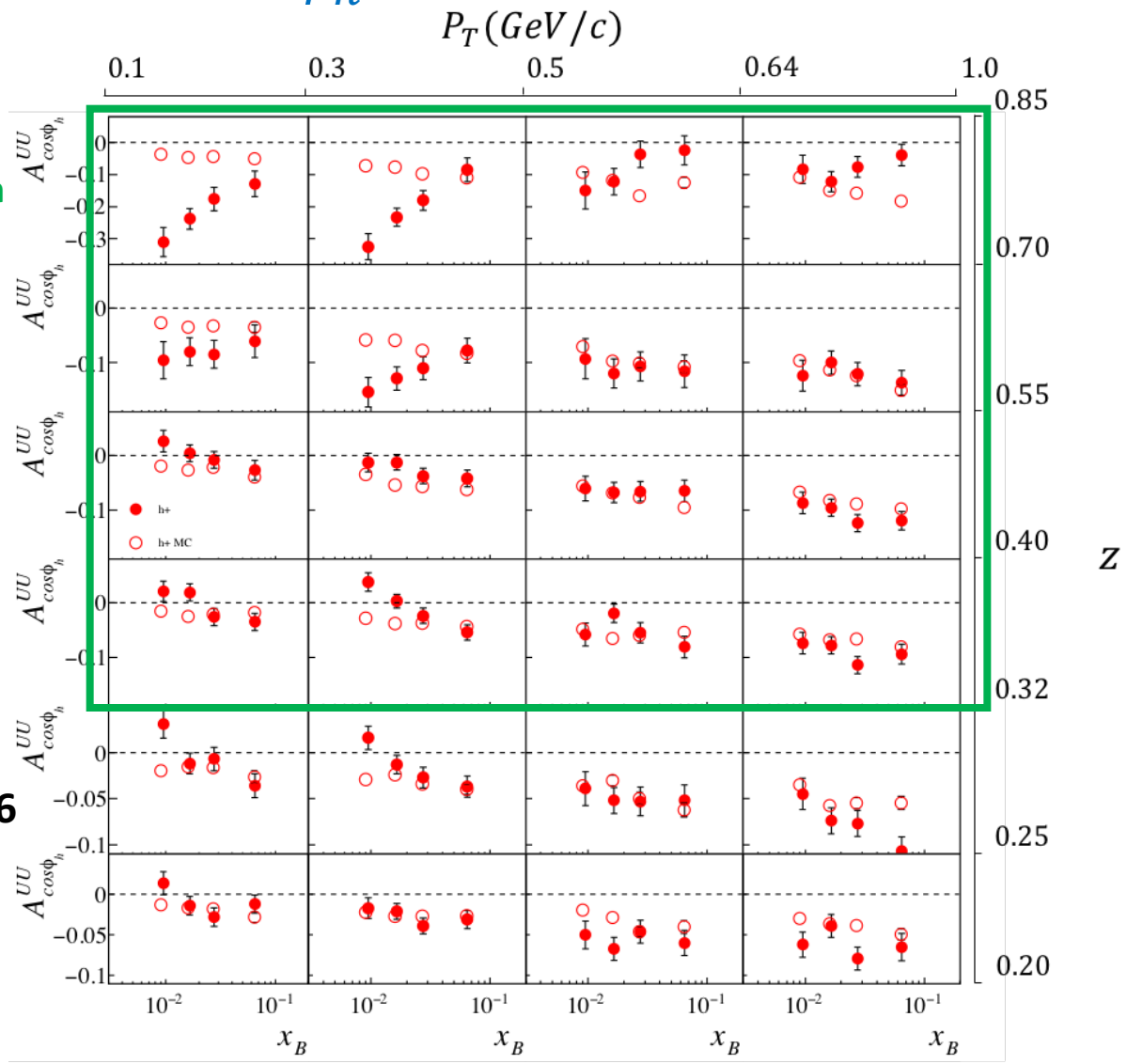
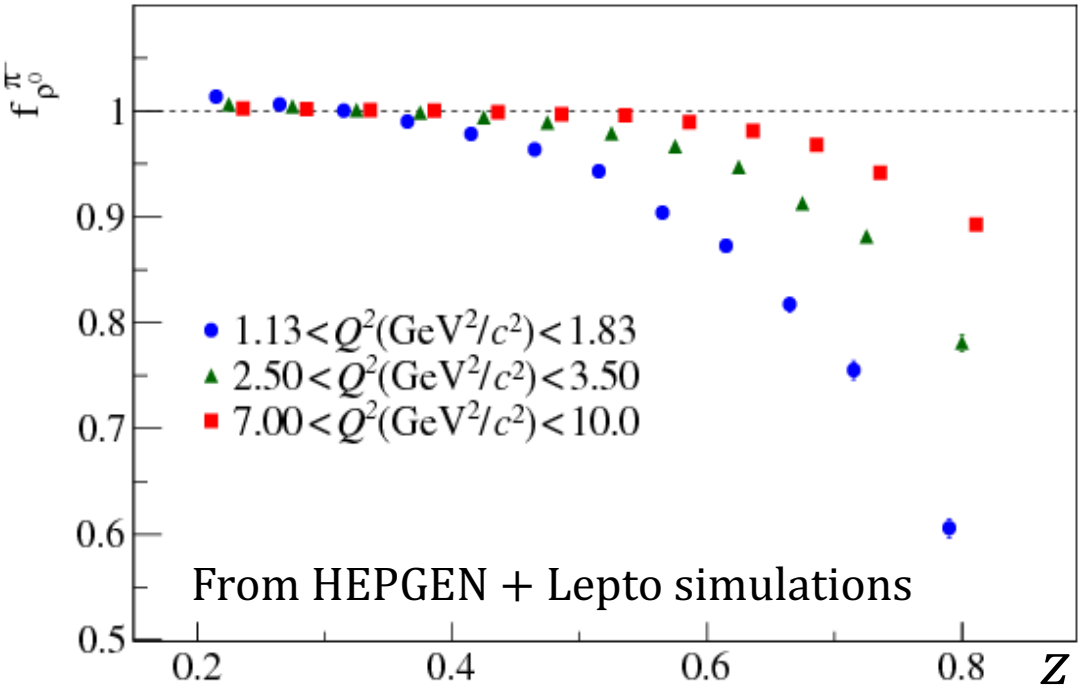


Diffractive VM contribution in COMPASS SIDIS sample (LiD)



π^- from diffractive ρ^0 → **important at large z and small Q^2**

PLB 764 (2017) 1

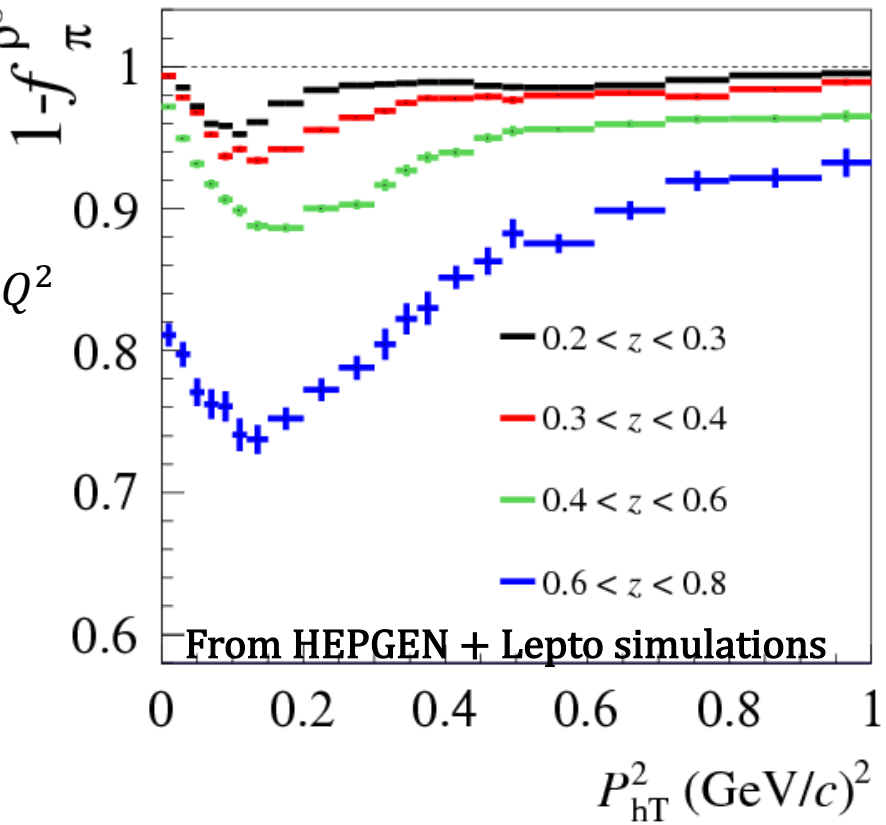
- COMPASS has estimated the contribution of hadrons produced in the decay of diffractive vector mesons (VM)

→ **ρ^0 contamination is not negligible at small Q^2 and at large z**

→ **ϕ mesons** contribute less and mostly at $z \sim 0.5$

Diffractive VM contribution in COMPASS SIDIS sample (LiD)

Integrated over Q^2



- About the same shape in different z bins

PLB 764 (2017) 1

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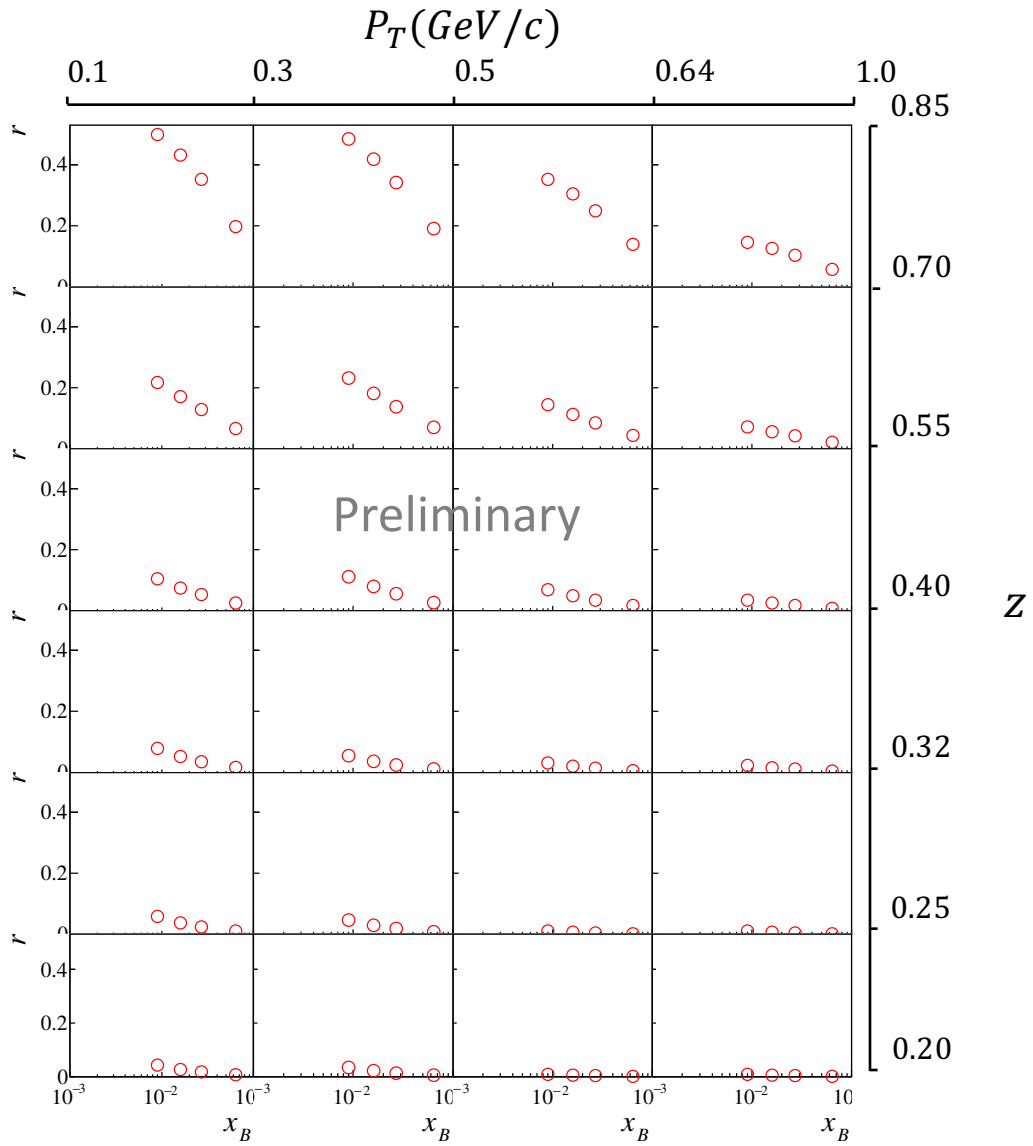
Fraction of pions from exclusive ρ^0

- From previous results we evaluated the fraction

$$r = \frac{N_h^{excl}}{N_h^{excl} + N_h^{SIDIS}}$$

- Same binning as for the published unpolarized azimuthal asymmetries
- **Up to 50% contamination in the highest z bin and at small P_T**



Do hadrons from exclusive VMs also contribute to $A_{cos\,\phi_h}^{UU}$ and $A_{cos\,2\phi_h}^{UU}$ asymmetries?

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We have studied this possible contribution for the first time.

Selection of the exclusive events

- We have used 2006 SIDIS data →
  - similar conditions to the 2004 data, same LiD target, same μ^+ beam energy
  - used for the study of the P_T^2 multiplicities

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- $Q^2 > 1(\mathrm{GeV}/c)^2$
- $W > 5(\mathrm{GeV}/c^2)$
- $0.2 < y < 0.9$
- $\theta_{\gamma^*}^{lab} < 60\mathrm{mrad}$
- $0.003 < x_B < 0.13$
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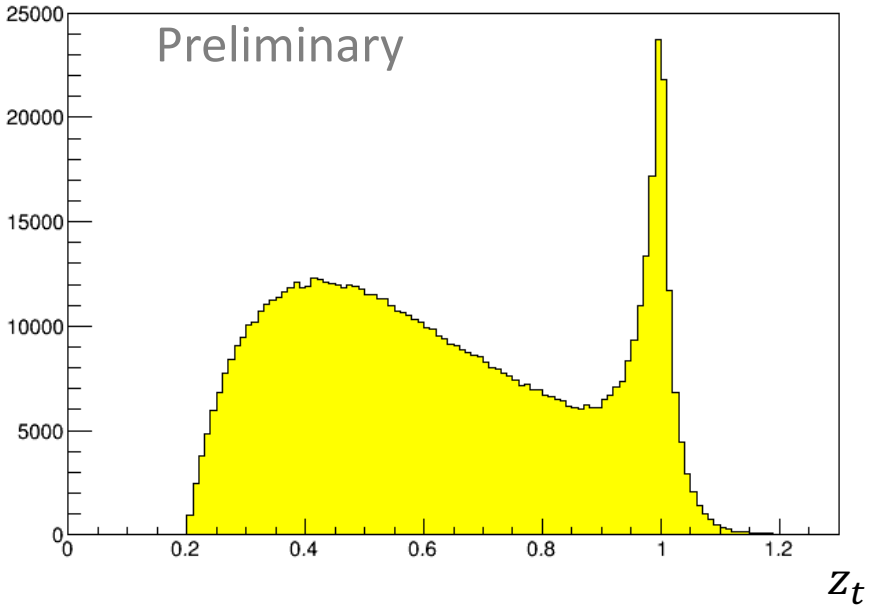

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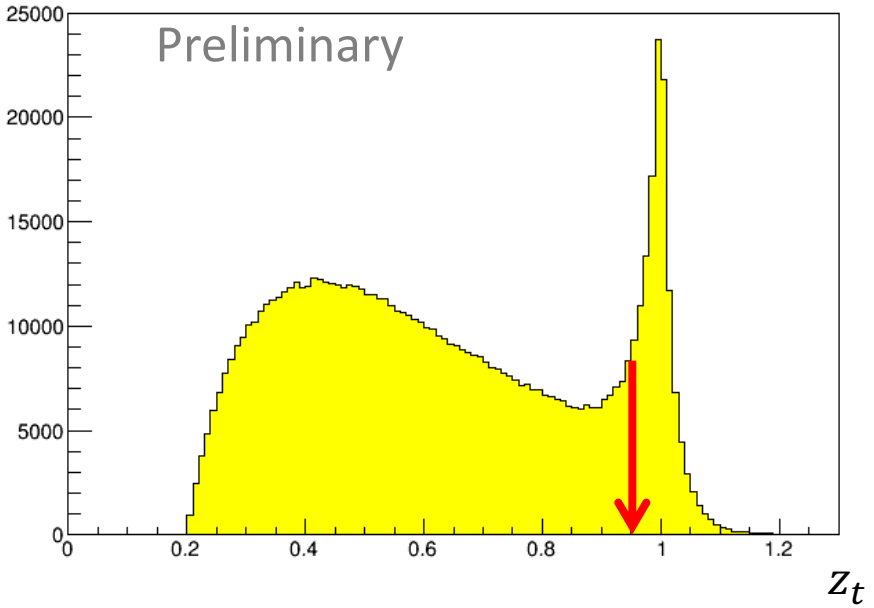

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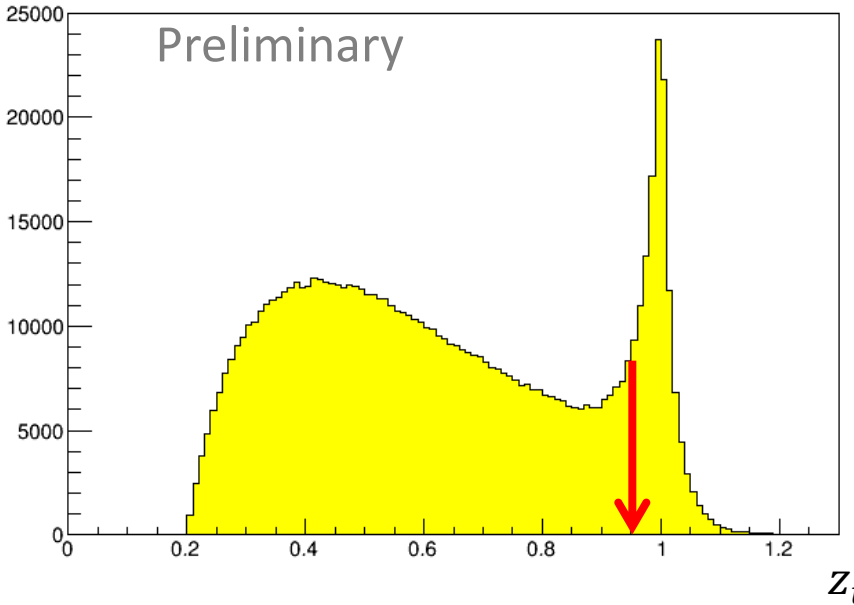

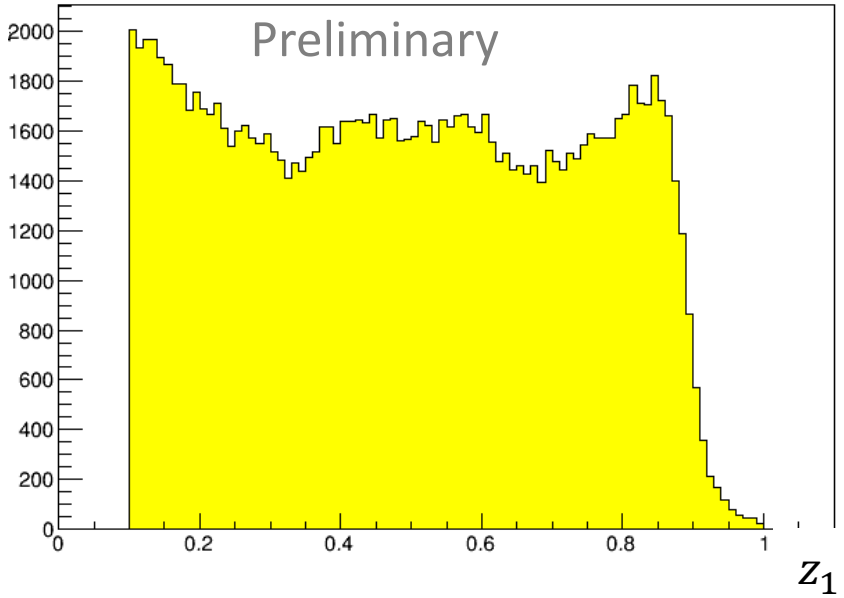

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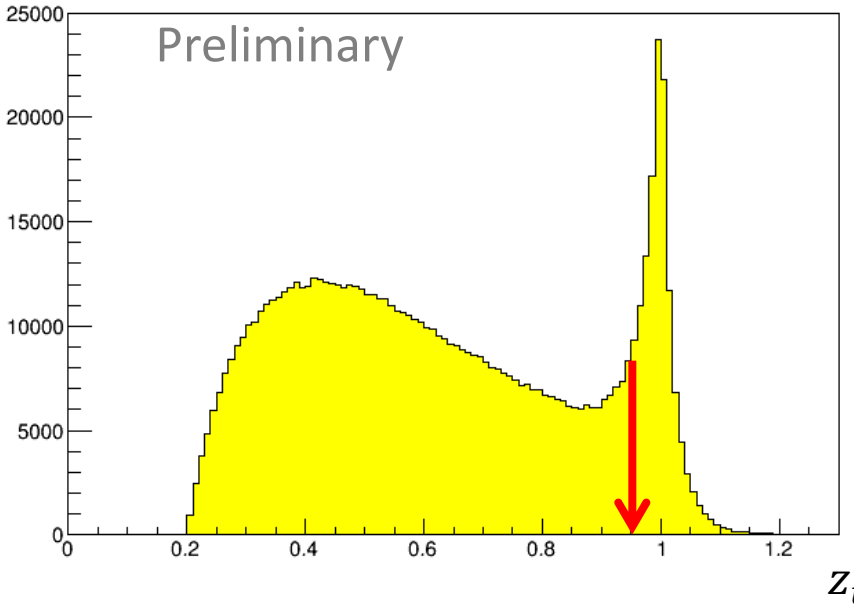
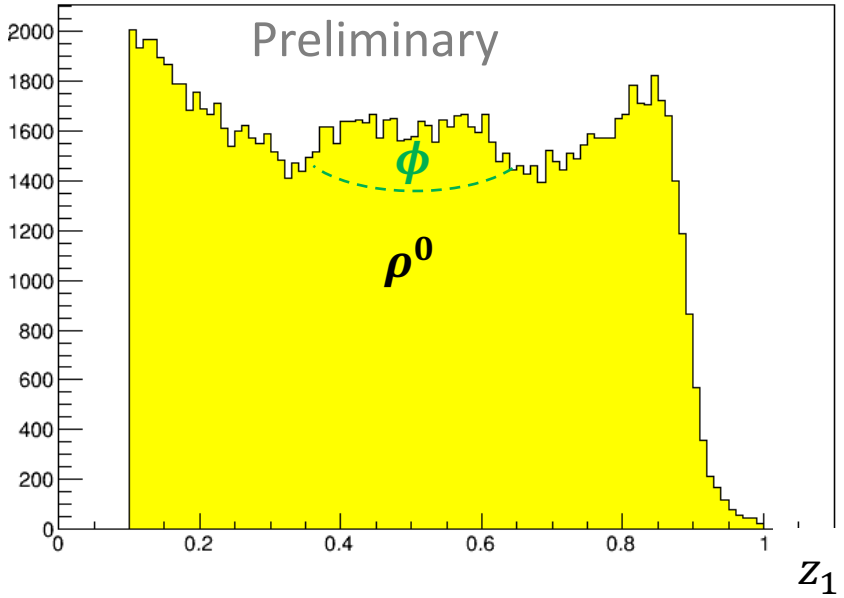
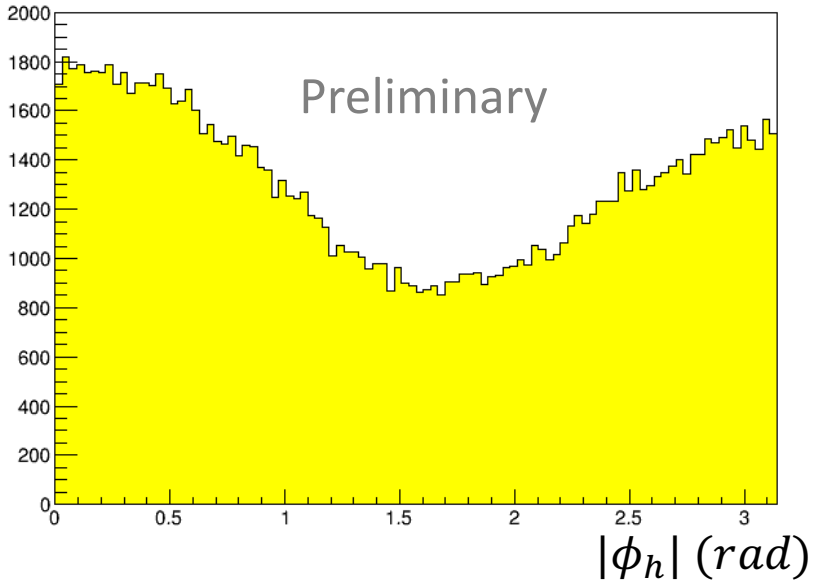
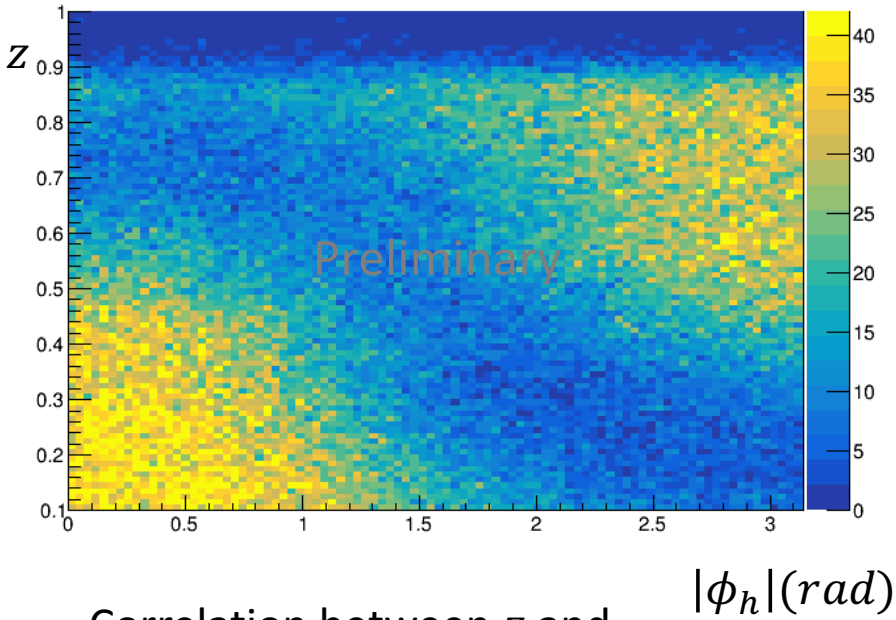




Azimuthal distributions in exclusive events



$|\phi_h|$ distribution for h+ in exclusive events



Correlation between z and $|\phi_h|$ for h+ in exclusive events

- **$|\phi_h|$ distributions show very large modulations**
- **Strong correlation between z and $|\phi_h|$**

Modulations in the azimuthal distributions

- The acceptance corrected azimuthal distributions in exclusive events have been fitted using the function

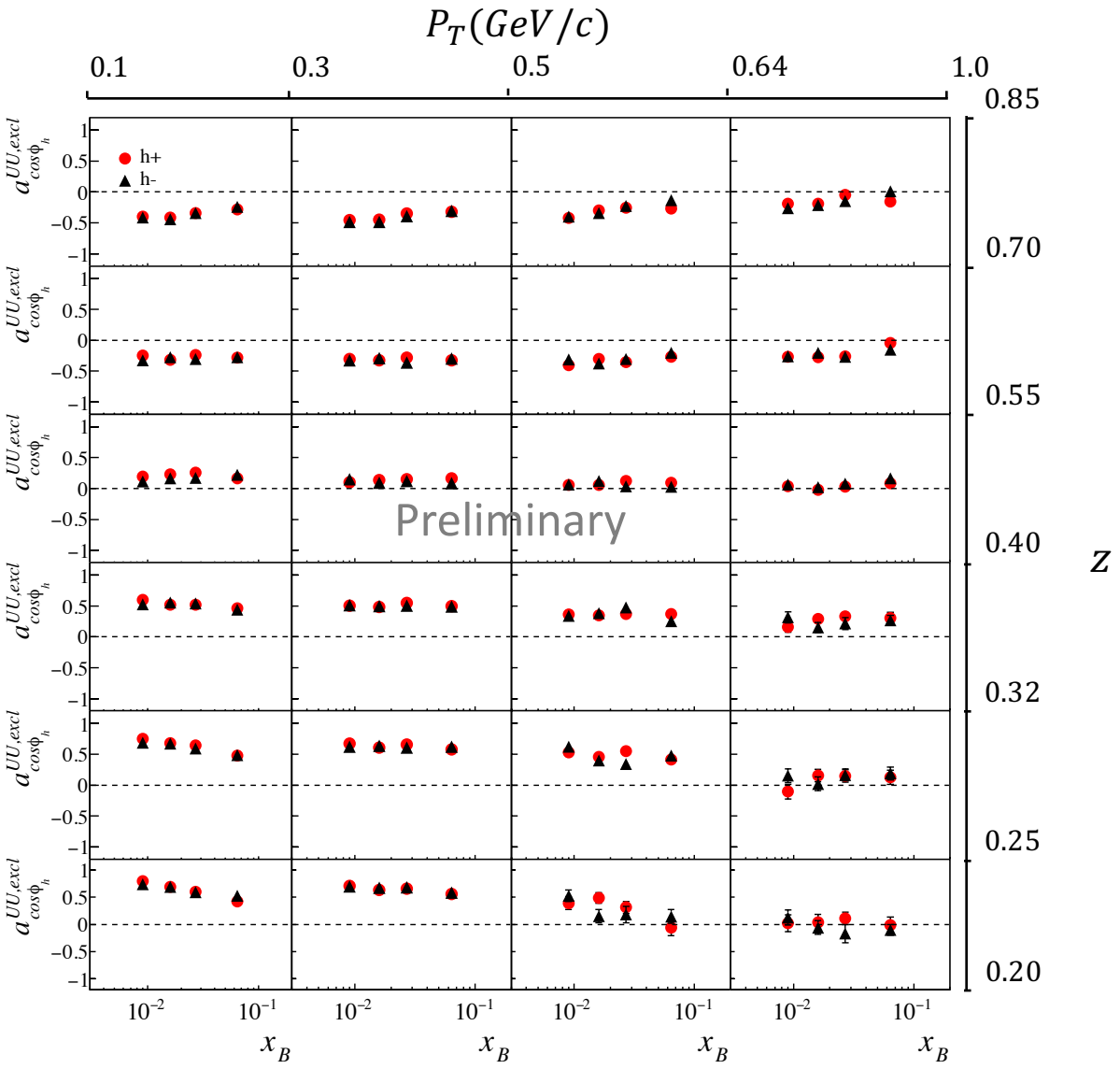
$$N_{excl}(\phi_h; \boldsymbol{v}) = N_0[1 + \epsilon_1(y) a^{UU,excl}_{\cos\phi_h}(\boldsymbol{v}) \cos\phi_h + \epsilon_2(y) a^{UU,excl}_{\cos 2\phi_h}(\boldsymbol{v}) \cos 2\phi_h]$$

$$\boldsymbol{v} = (x_B, z, P_T)$$

in the same bins of the 2004 COMPASS azimuthal asymmetries for h^+ and h^-

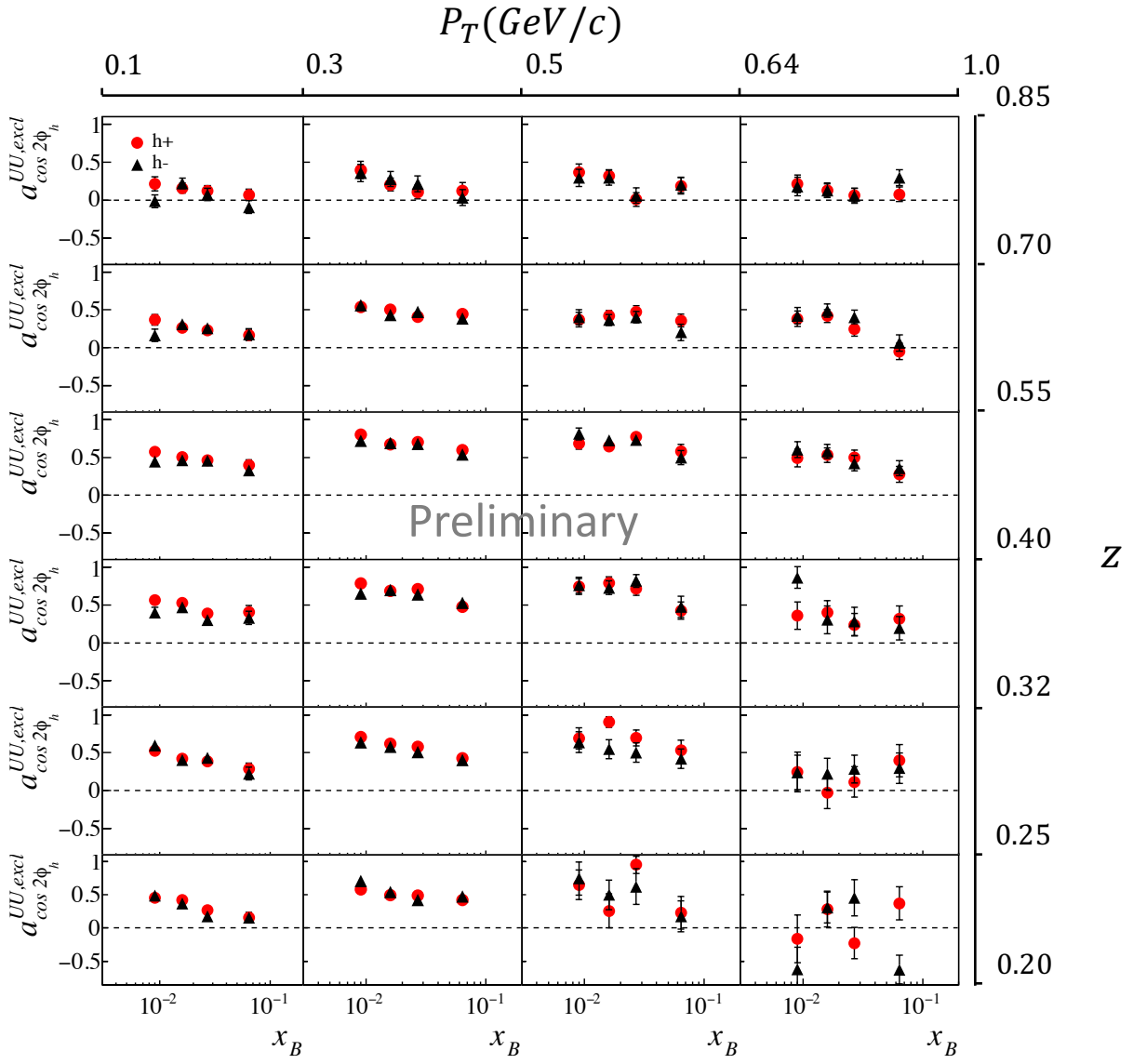
$a_{\cos\phi_h}^{UU,excl}$ amplitude

- Large amplitudes at small P_T and x_B
- Strong z dependence
- Change of sign with z
- Same for h^+ and h^-



$a_{\cos 2\phi_h}^{UU,excl}$ amplitude

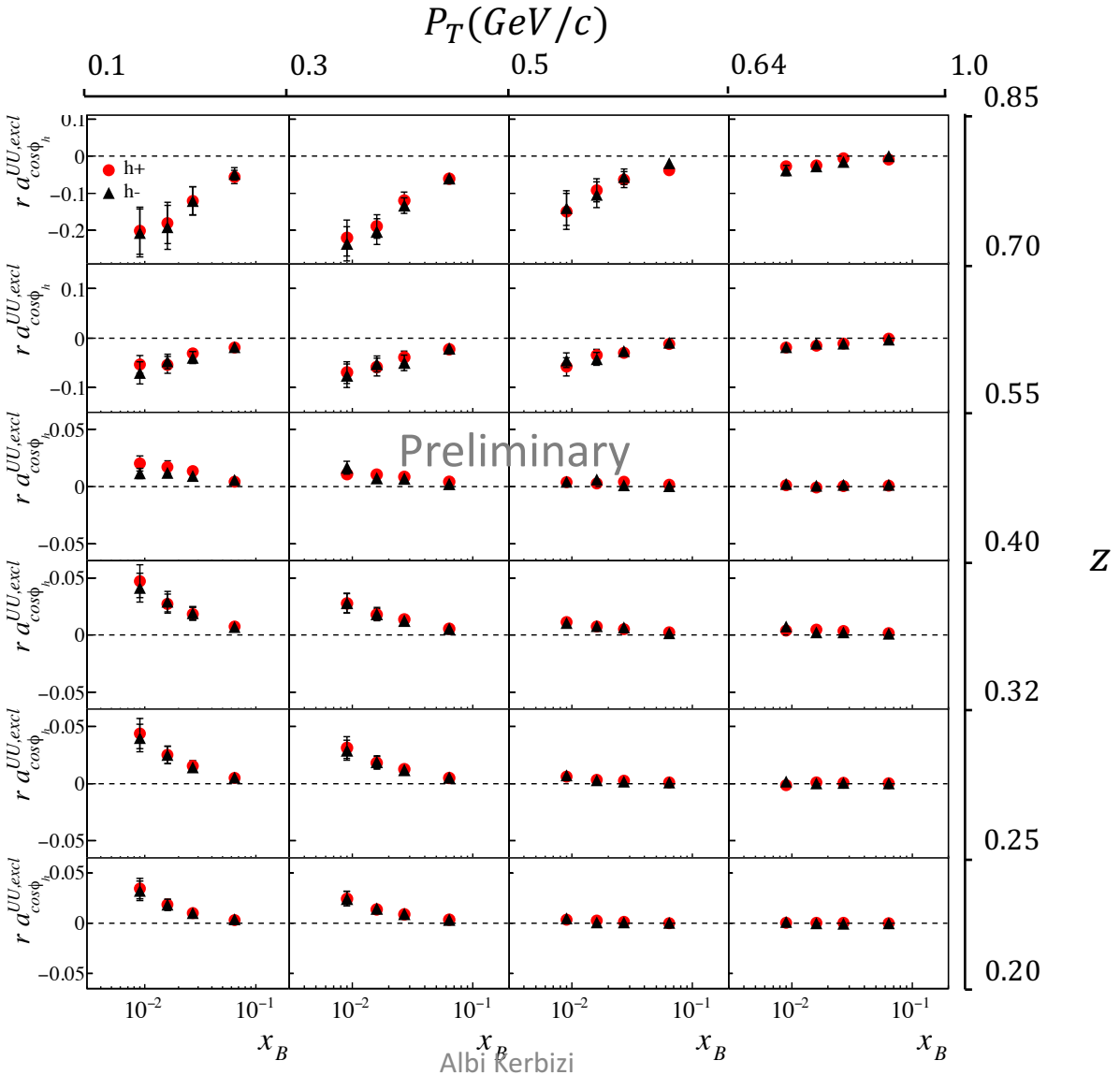
- Smaller but still not negligible
- Positive values
- Same for h^+ and h^-



Exclusive contribution to the SIDIS asymmetries

$r a^{UU,excl}_{\cos\phi_h}$

Clearly different from zero!



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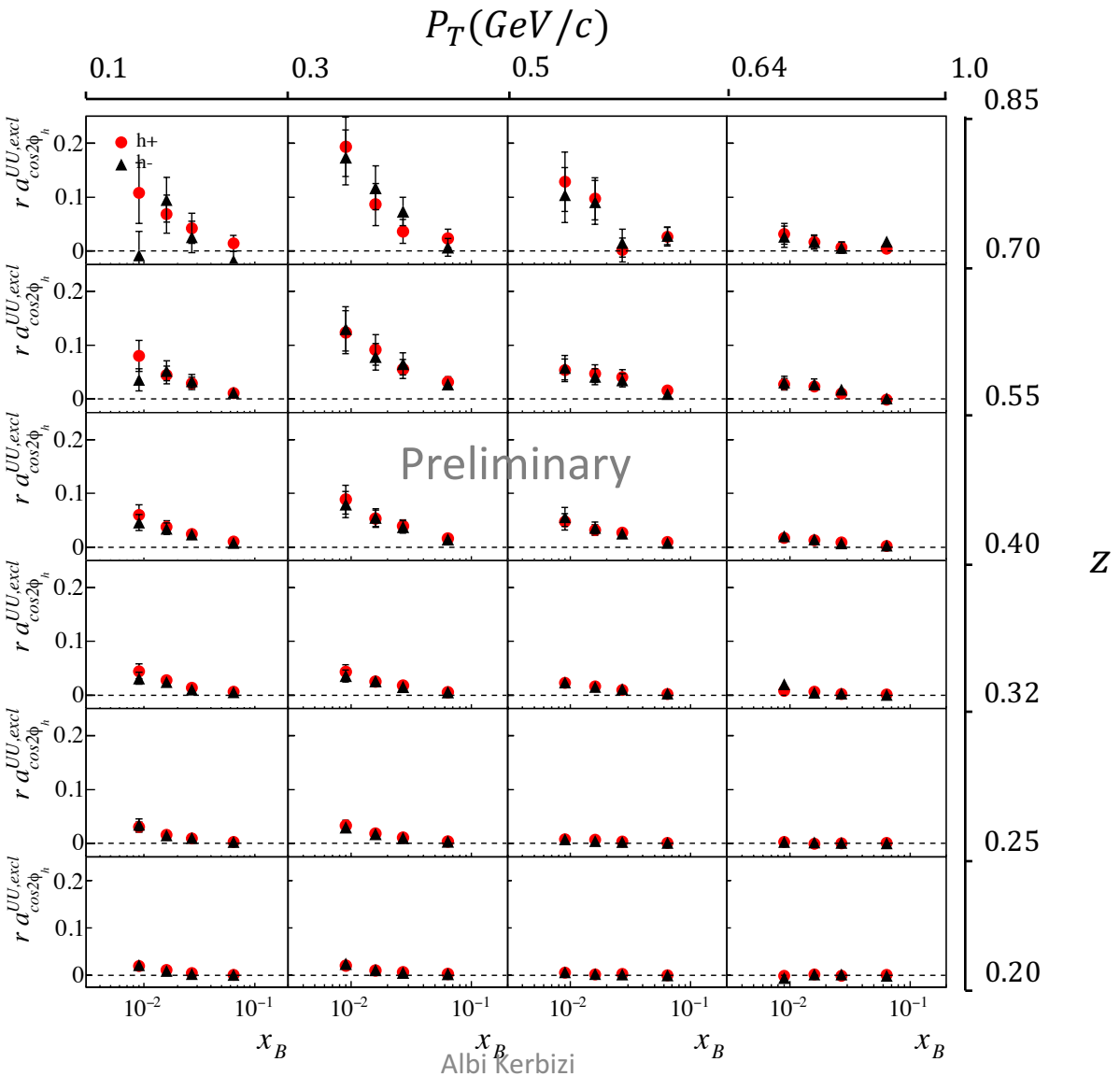


”true” SIDIS azimuthal asymmetries

- Finaly, the true SIDIS azimuthal asymmetries have been evaluated as

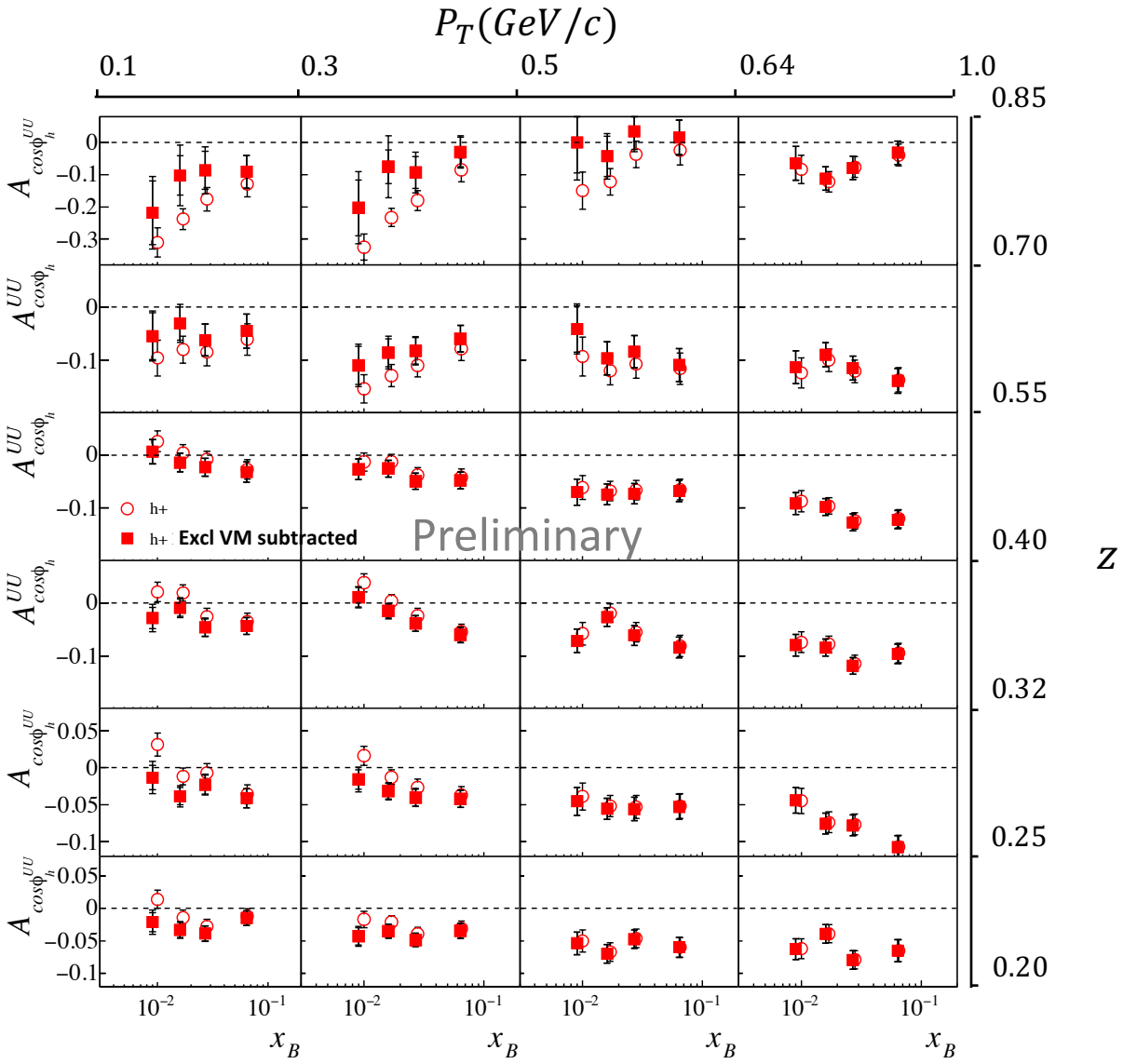
$$A_{\cos n\phi_h}^{UU} \rightarrow \frac{1}{1-r}\left(A_{\cos n\phi_h}^{UU} - r a_{\cos n\phi_h}^{UU,excl}\right), \qquad n = 1,2$$

- $A_{cos\ \phi_h}^{UU}$ and $A_{cos\ 2\phi_h}^{UU}$ are the **published values of the semi-inclusive azimuthal asymmetries**

Comparison between the subtracted and the published $A_{cos\ \phi_h}^{UU}$ asymmetry for h+

Empty points –>
○ $A_{\cos\ \phi_h}^{UU}$
published

Full points –>
■ $A_{\cos\ \phi_h}^{UU}$
after exclusive VM subtraction



Comparison between the subtracted and the published $A_{cos\,2\phi_h}^{UU}$ asymmetry for h+

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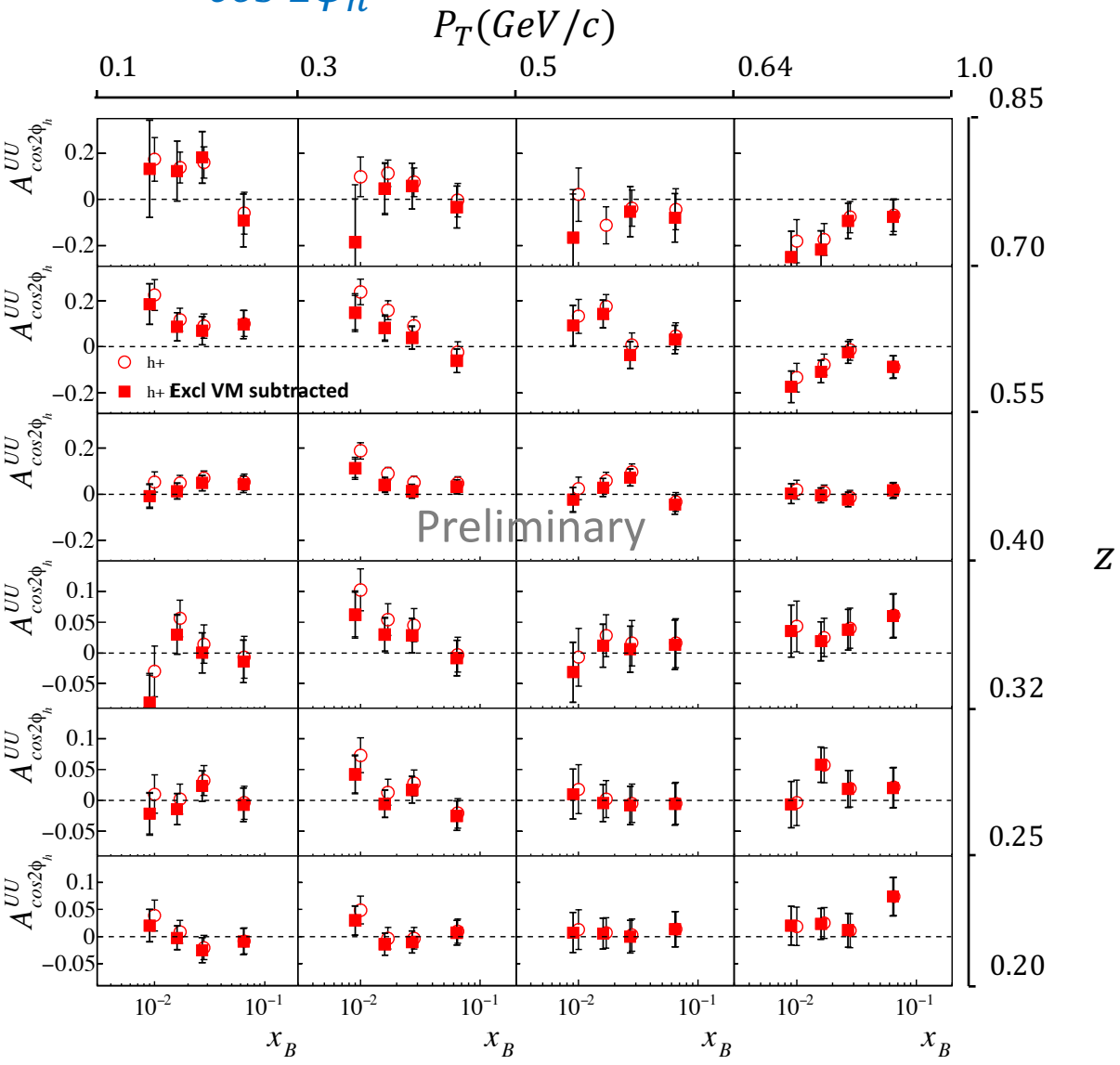
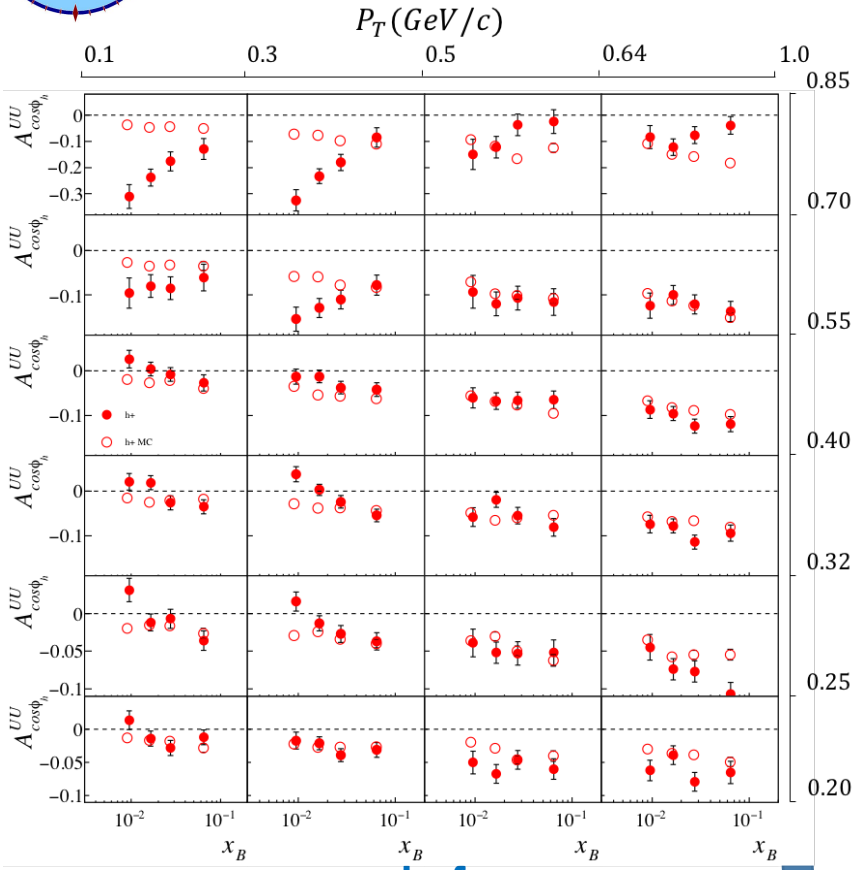
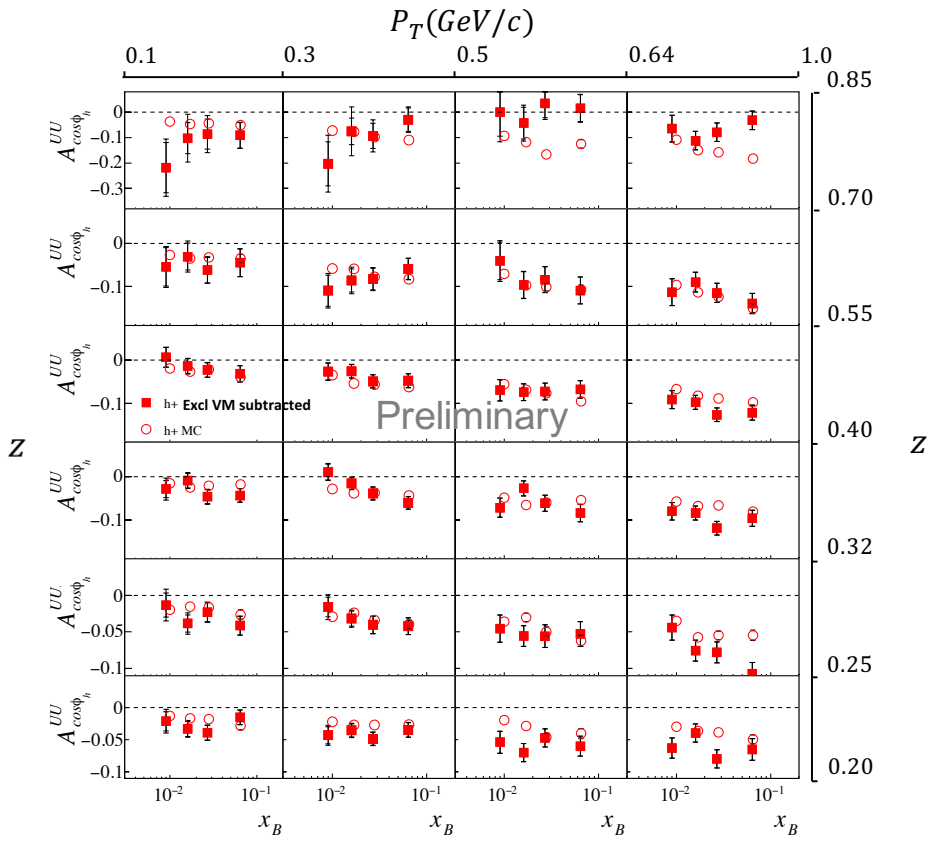


Comparison between MC and $A_{cos\,\phi_h}^{UU}$ asymmetries for h+ with subtracted VM contribution

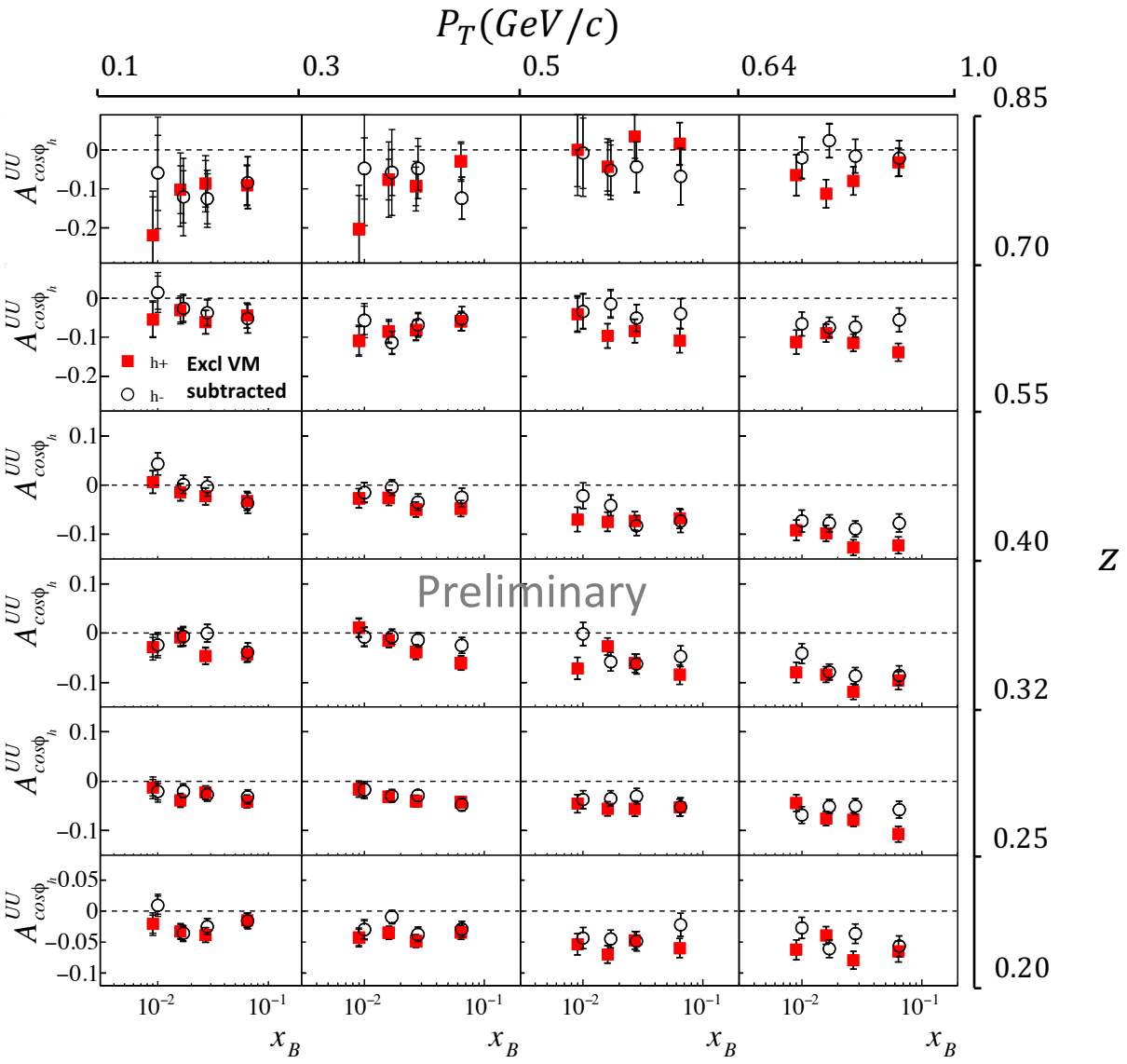


before

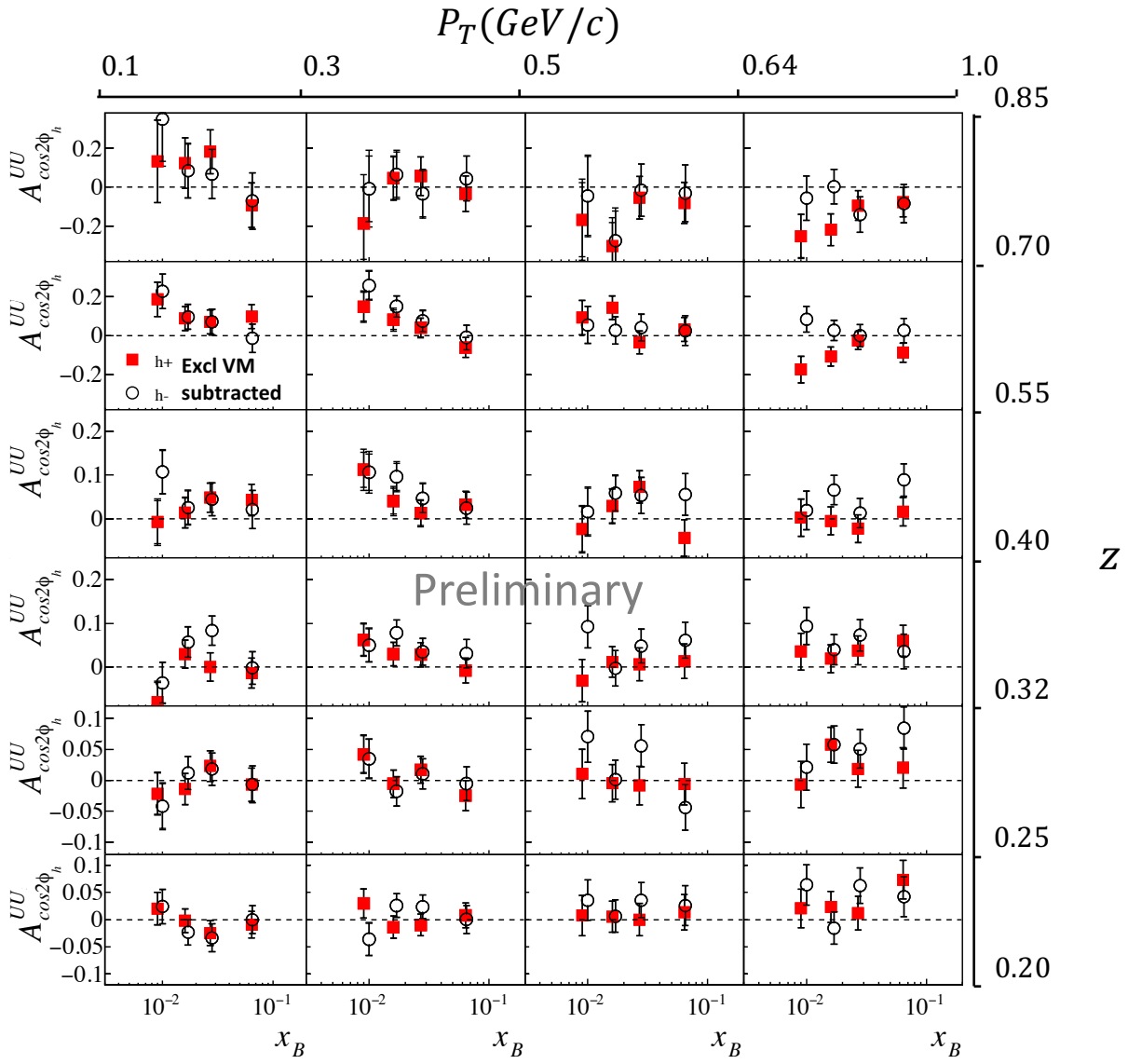


now!

$A_{\cos\phi_h}^{UU}$ asymmetry after subtracting exclusive VM contribution



$A^{UU}_{\cos 2\phi_h}$ asymmetry after subtracting exclusive VM contribution



Conclusions

- A large contribution from exclusive VM production is present at small Q^2, large z and small P_T
- For the first time we have measured the modulations in the azimuthal distributions of hadrons from the decay of exclusive VMs:
  - The amplitudes of $\cos\phi_h$ and $\cos 2\phi_h$ modulations are very large, clearly different from zero, with strong kinematical dependence
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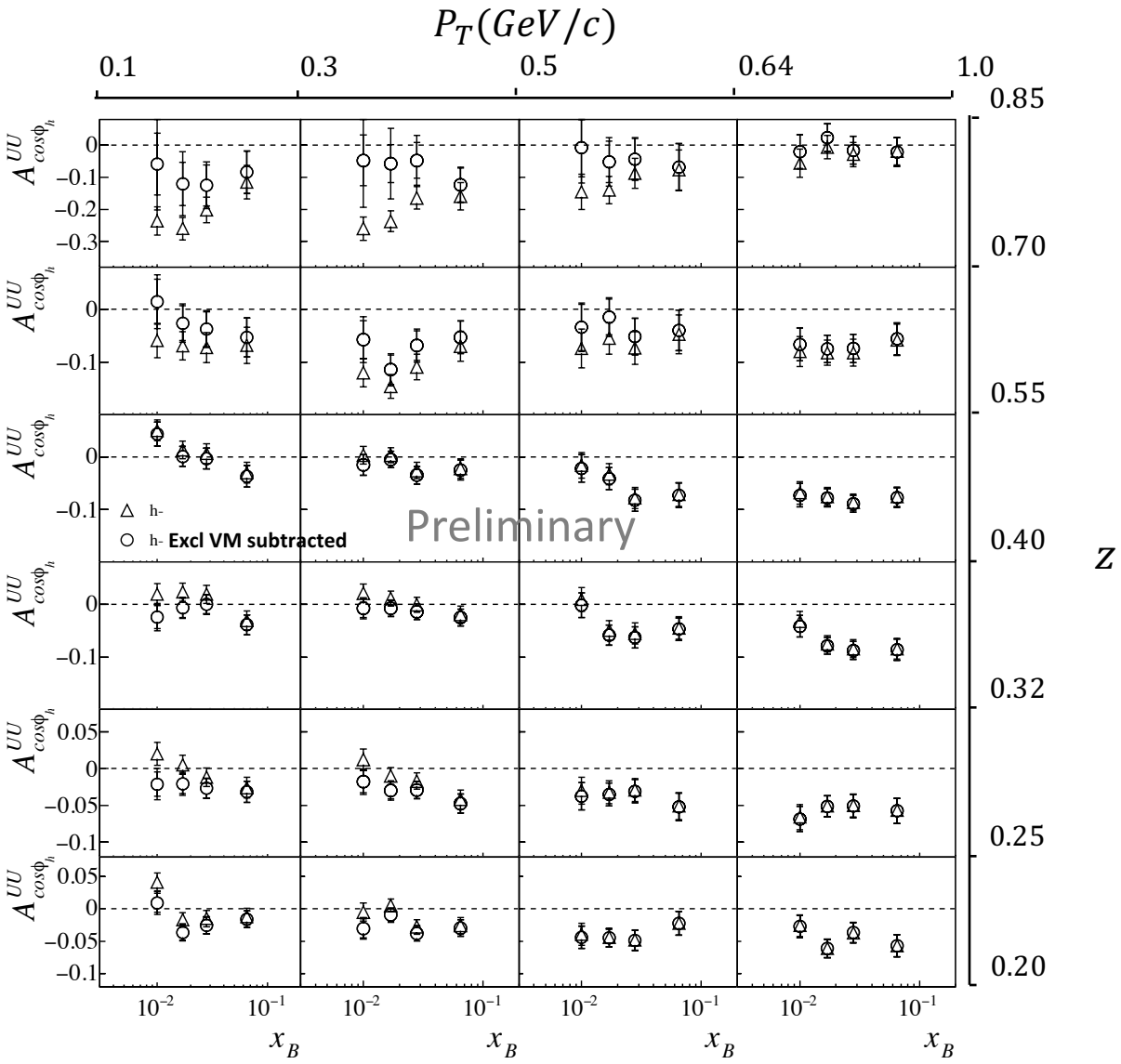
An important message for the past and future measurements...

Backup

Comparison between the subtracted and the published $A^{UU}_{cos\,\phi_h}$ asymmetry for h-

Triangles
△ $A^{UU}_{\cos\,\phi_h}$
published

Circles
○ $A^{UU}_{\cos\,\phi_h}$
after exclusive VM subtraction



Comparison between the subtracted and the published $A_{cos\,2\phi_h}^{UU}$ asymmetry for h-

Triangles
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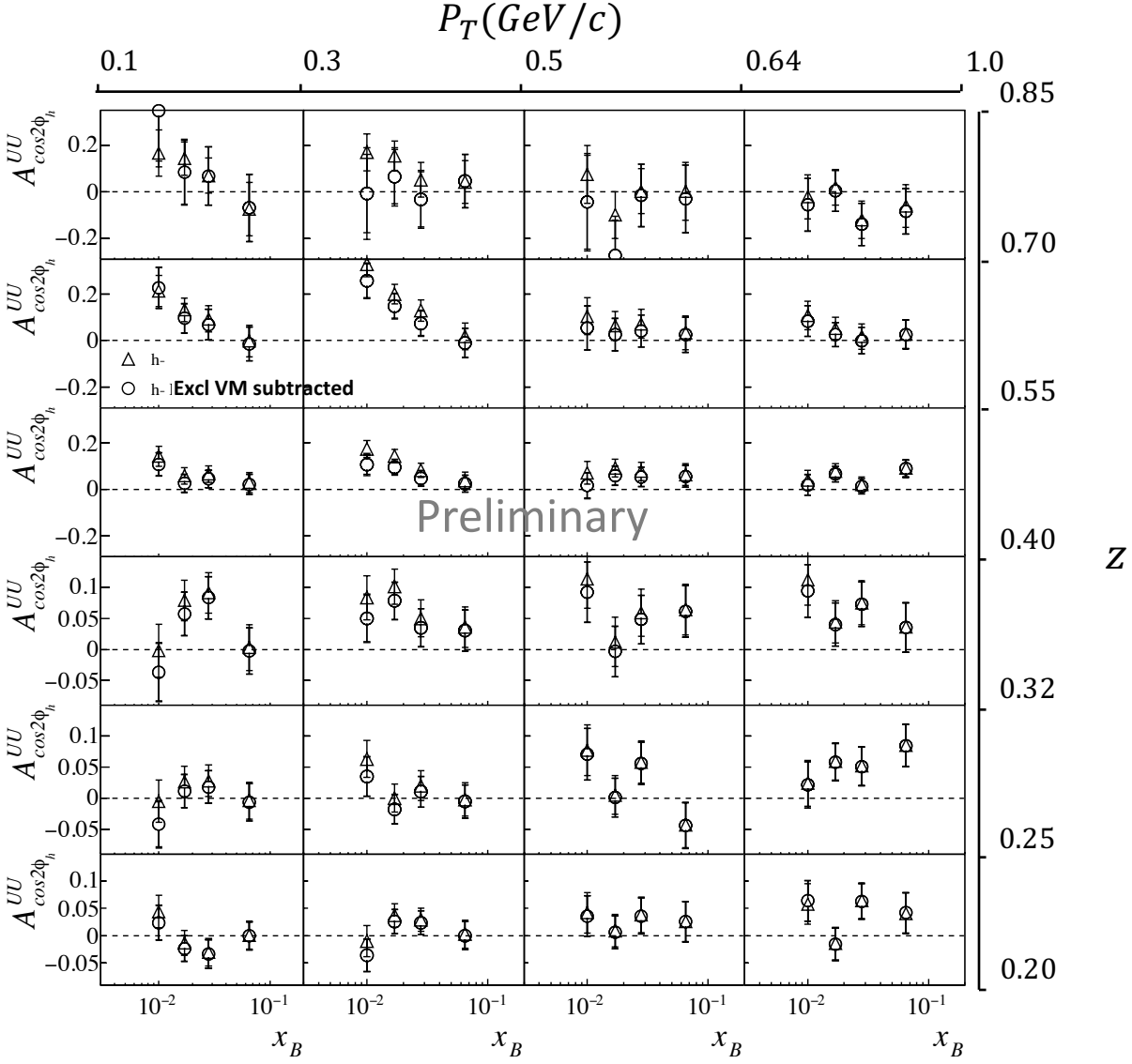
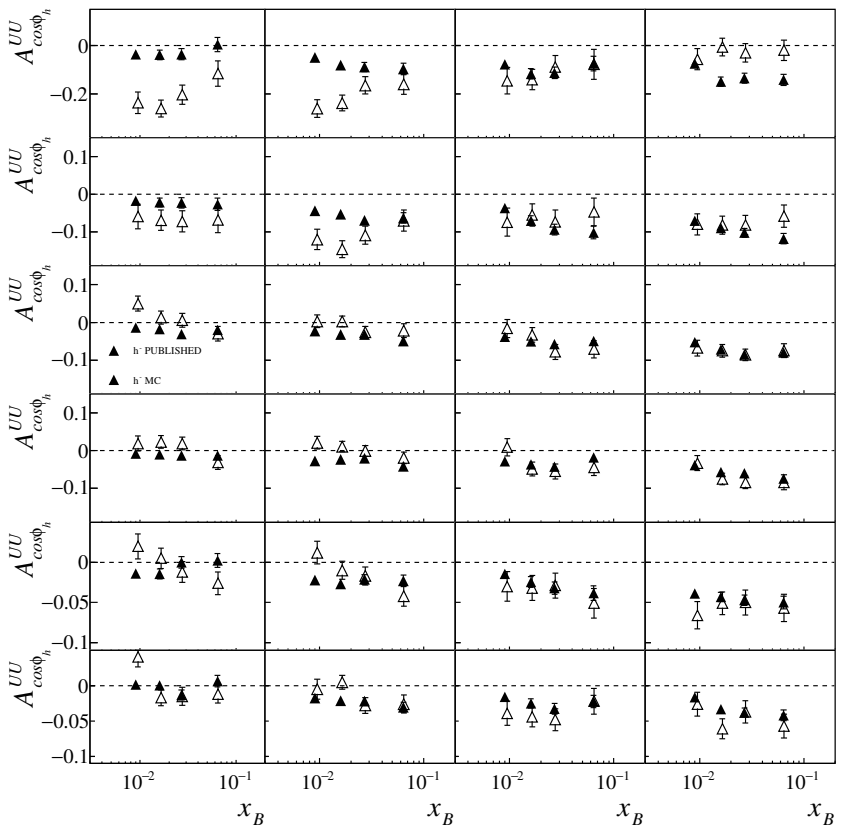


Comparison between MC and $A^{UU}_{cos\,\phi_h}$ asymmetry for h- after subtracting the exclusive VM contribution



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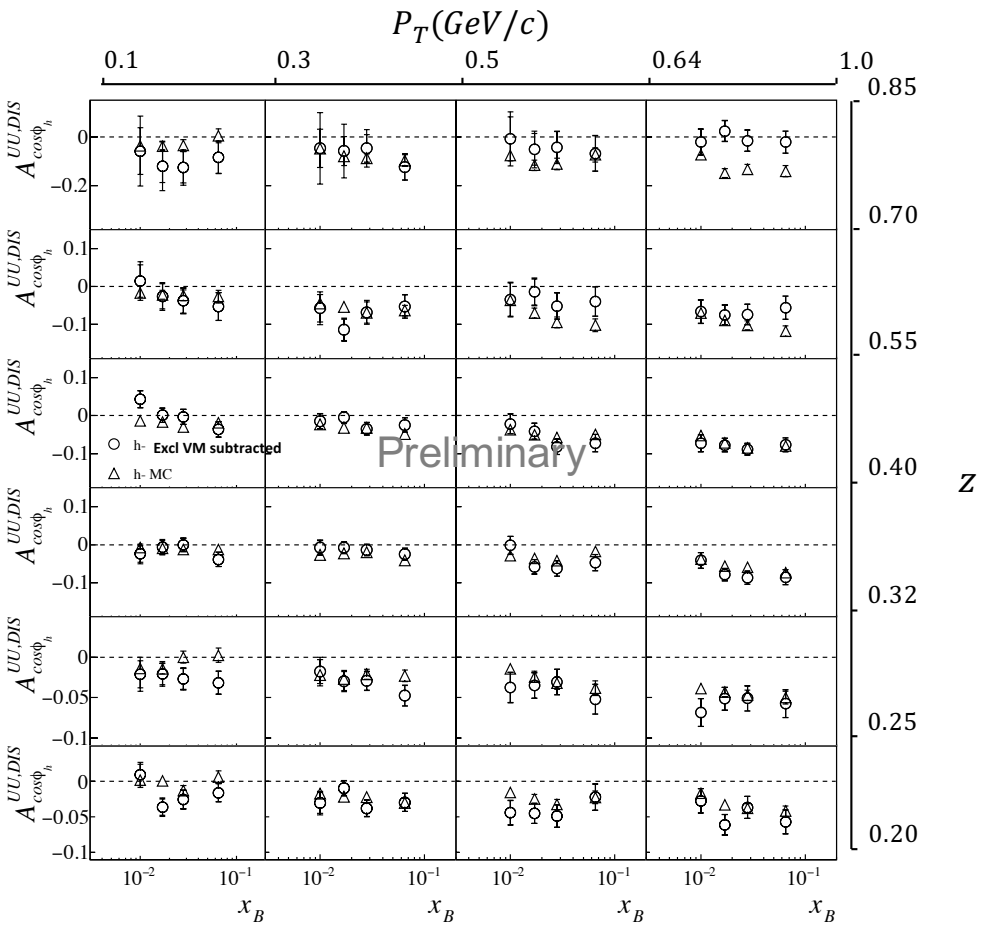

now!