**Science at the Luminosity Frontier:
Jefferson Lab at 22 GeV Workshop**

January 24, 2023

The role of vector mesons on transverse-spin asymmetries in SIDIS

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The Monte Carlo generator: PYTHIA 8 + StringSpinner

PYTHIA 8 is used to simulate the DIS process

- unpolarized beam and target
- parton showers off (LO)

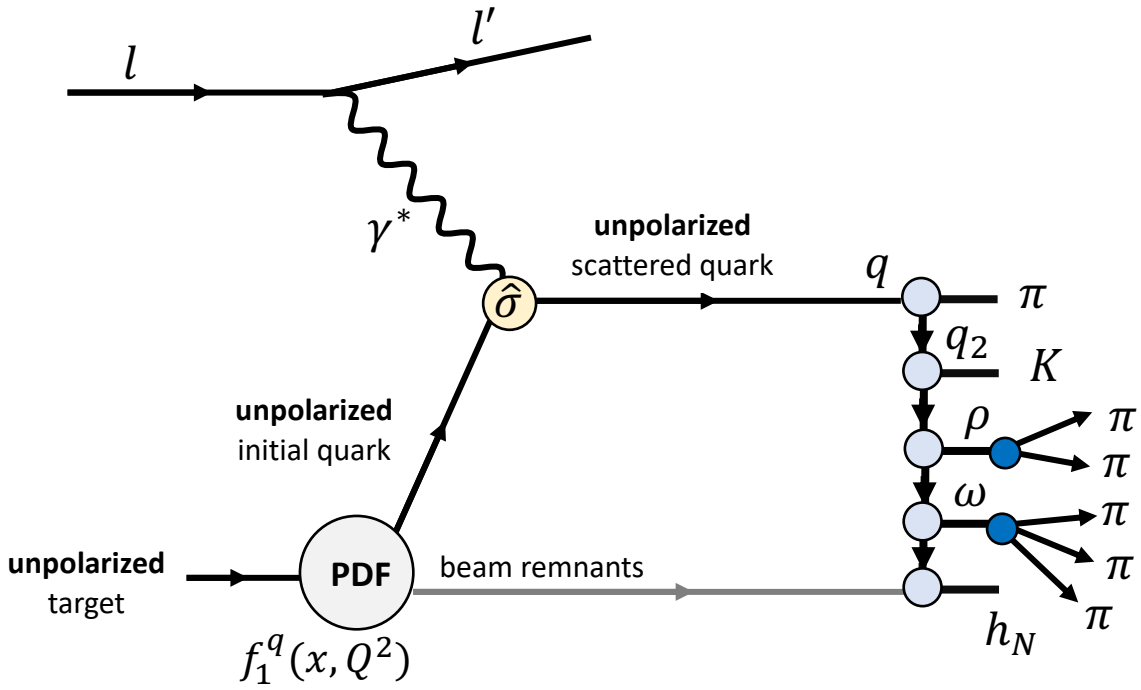
(see backup for details)

To enable spin effects → **StringSpinner**

- includes production of PS and VM

AK, L. Lönnblad, CPC **272** (2022) 108234

AK, L. Lönnblad, *PoS* ICHEP2022 (2022) 831



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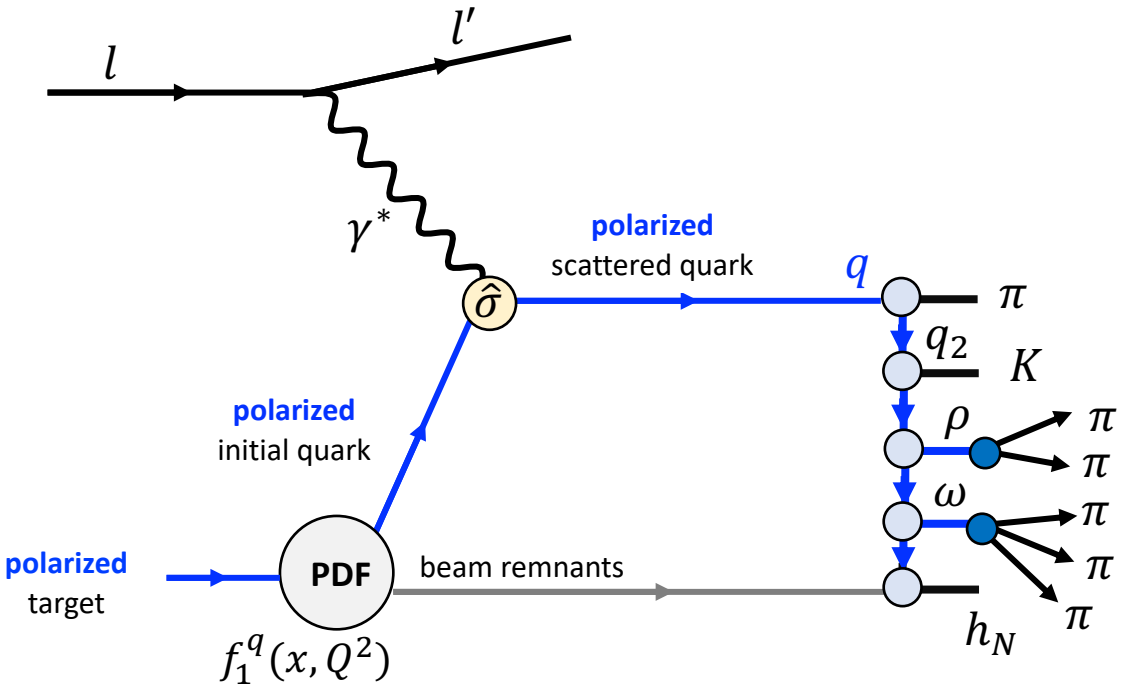

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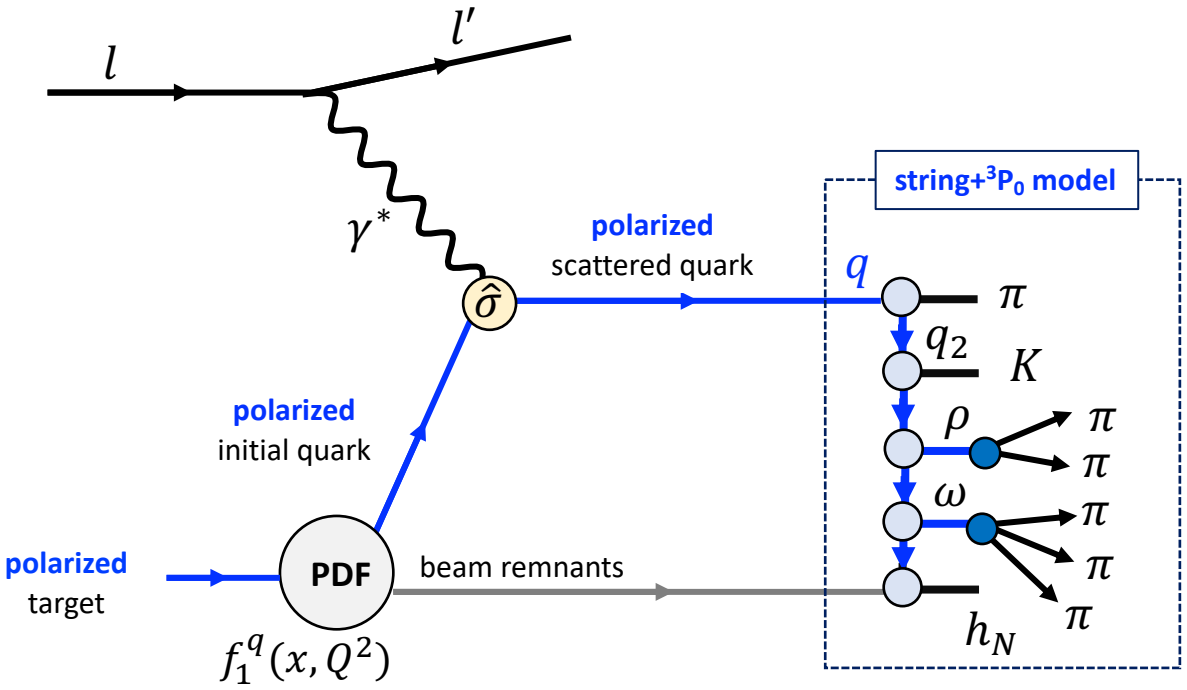

AK, ARTRU, MARTIN, ***PRD 104*** *(2021) 11, 114038*

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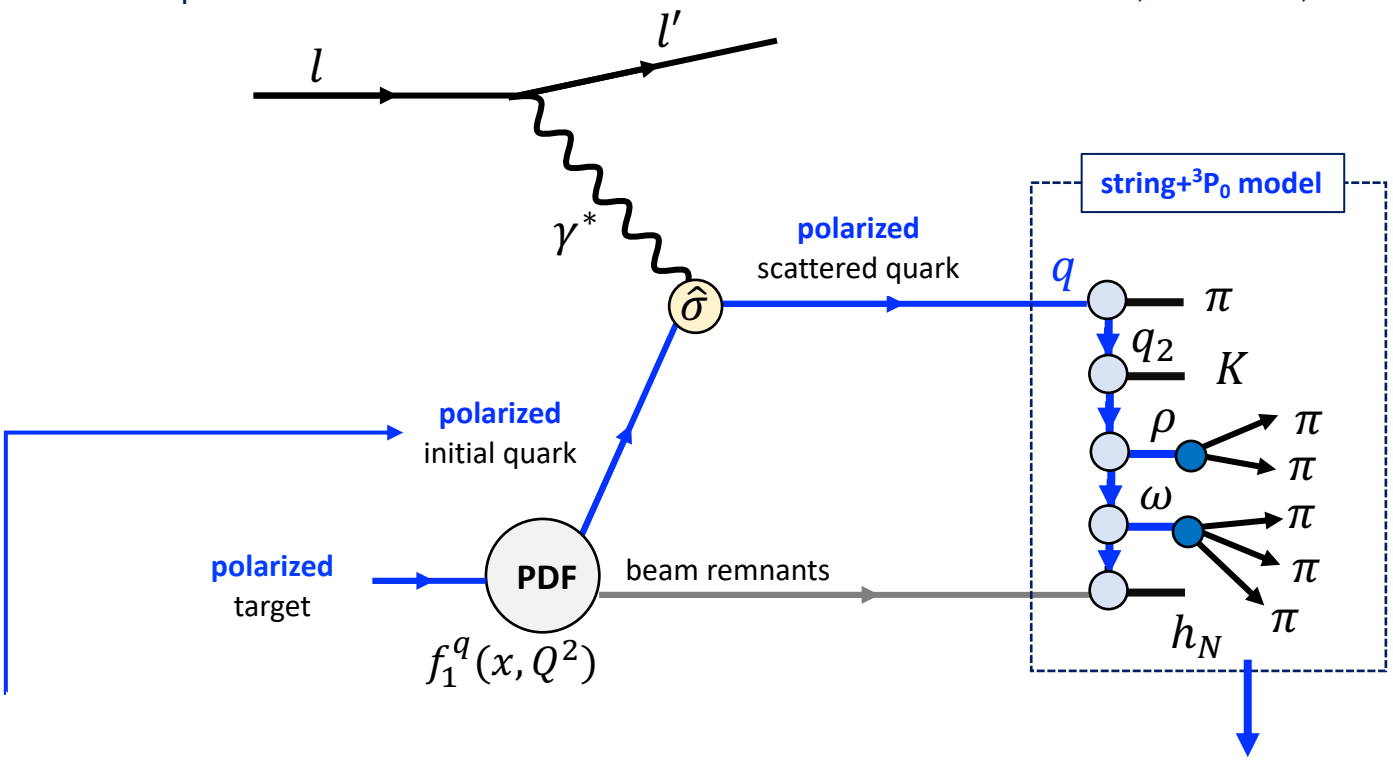


AK, ARTRU, MARTIN, ***PRD 104*** *(2021) 11, 114038*

Transversity PDF $h_1^q(x)$

parametrization to reproduce COMPASS data

valence quarks polarized, sea quarks unpolarized

no explicit Q^2 dependence

Collins/dihadron asymmetry

The string+$^3P_0$ model of hadronization

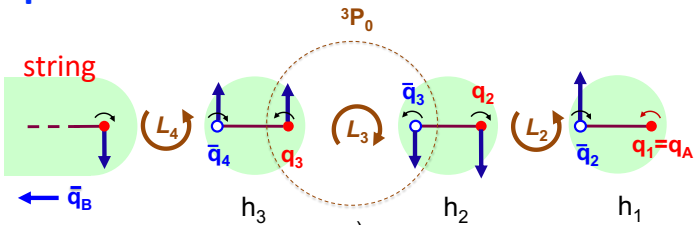
- Extension of the Lund string model

  string decays via tunnelling of $q\bar{q}$ pairs in relative $^3P_0$ state

- Quantum mechanical model, based on amplitudes

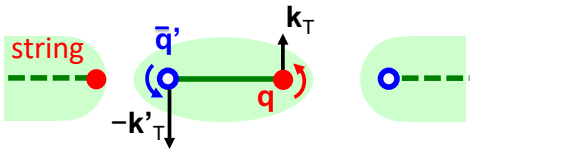
AK, X. Artru, A. Martin,
***PRD 104** (2021) 11, 114038*

pseudoscalar meson emission

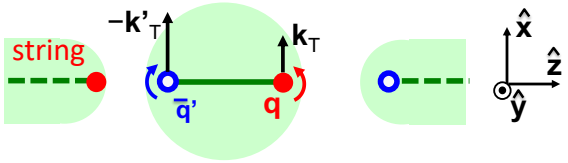


described by free parameter
μ (complex mass) for the $^3P_0$ w.f.
$\mathrm{Im}(\mu) \propto$ size of Collins effect for PS/VM

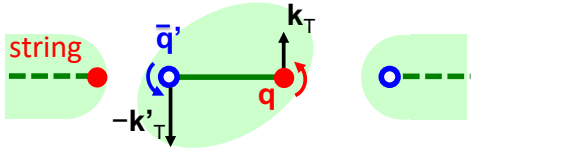
(polarized) **vector meson** emission



a) **Polarization along $\hat{x}$ or $\hat{z}$**



b) **Polarization along $\hat{y}$**



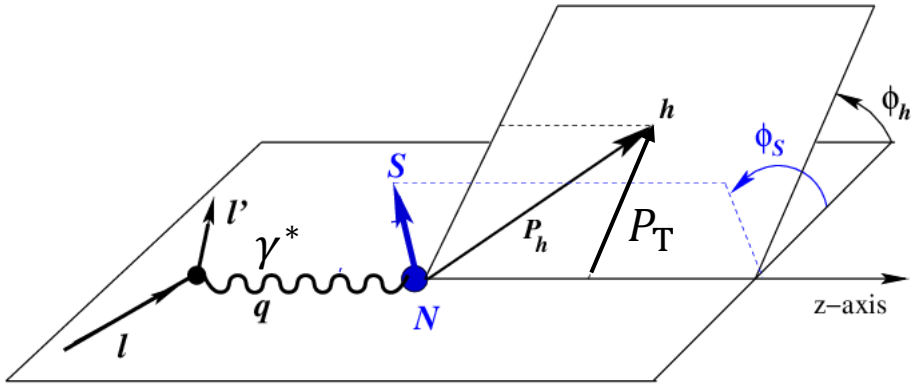
c) **Oblique polarization**

a) + b) described by the free parameter
f_L = fraction of L polarized VMs
$f_L \propto$ size of Collins effect for VM

c) described by the (phase) parameter
θ_{LT} gives oblique (LT) polarization
$\sin\theta_{LT} \propto$ size of Collins effect for decay mesons

the parameters have to be fixed from data

Results from simulations of T polarized SIDIS off protons
COMPASS and HERMES kinematics

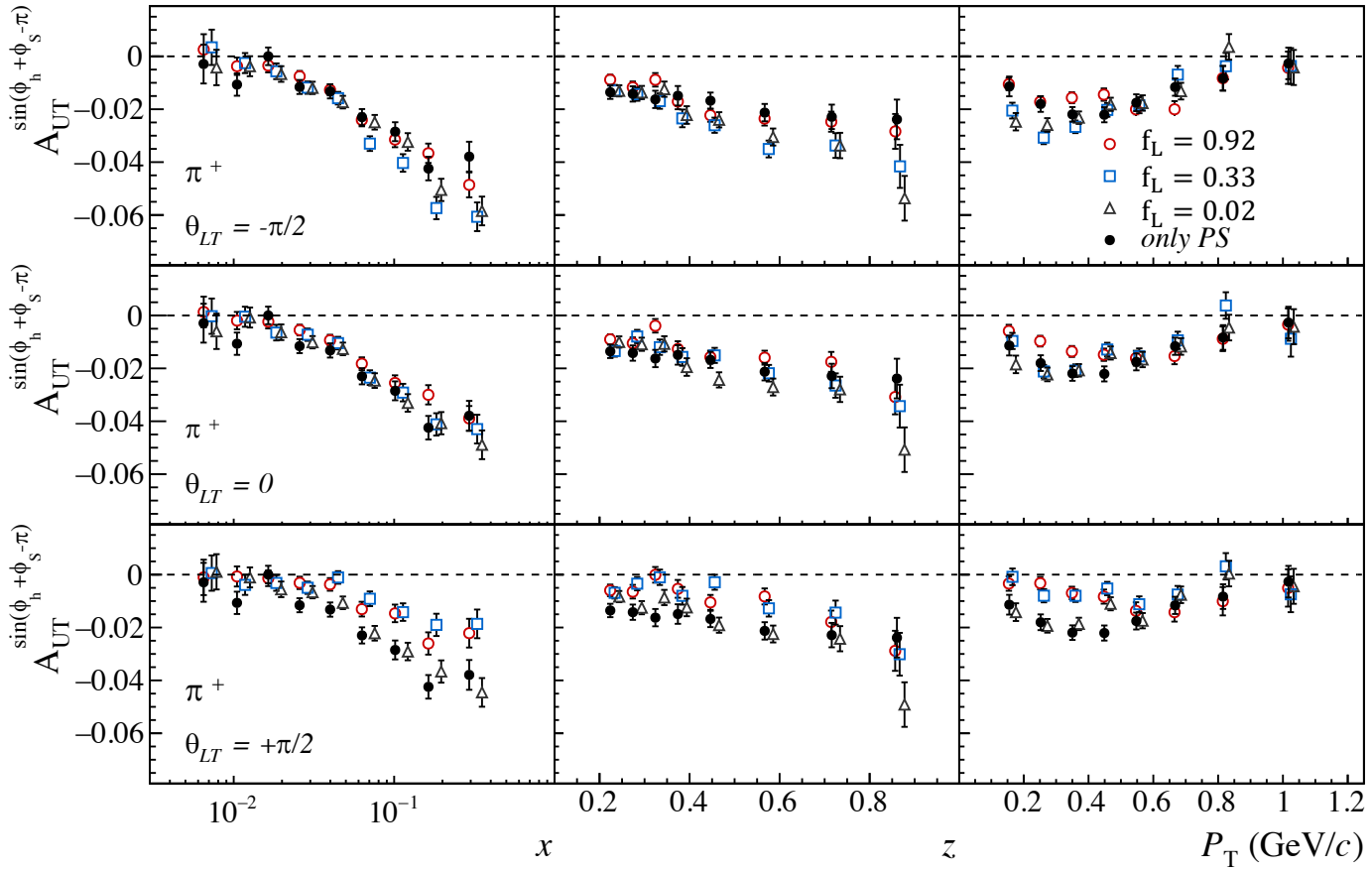


concentrate mostly on Collins asymmetries $A_{UT}^{\sin(\phi_h+\phi_S-\pi)}$
amplitude of the $\sin\phi_{Coll} = \sin(\phi_h + \phi_S - \pi)$ modulation

relevant variables: x_B, $z_h = P \cdot P_h / P \cdot q$, P_T

simulation settings → backup slides

Collins asymmetries for π^+ @ COMPASS kin.



VM production → sizeable dilution of the average asymmetry

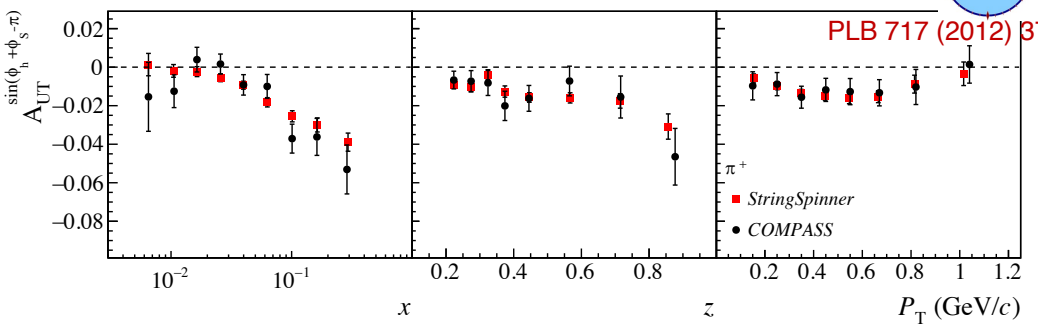
the result with only PS mesons scaled by ~ 0.5 to compare the shapes

VM polarization → variations in the trend of the asymmetries

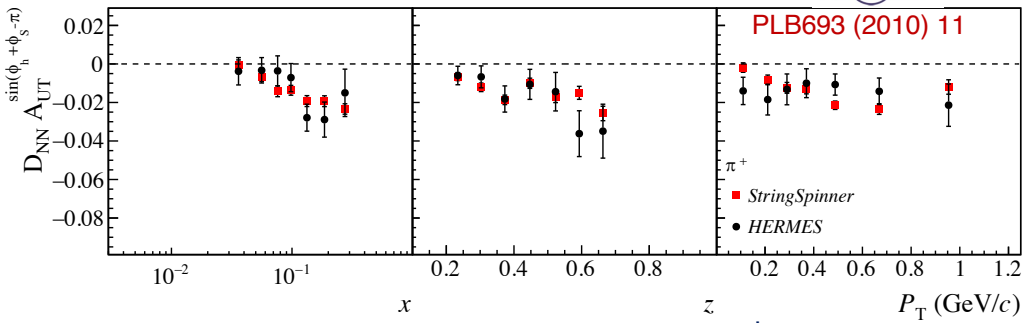
mainly at small P_T and large z_h

Comparison of simulated TSA with data

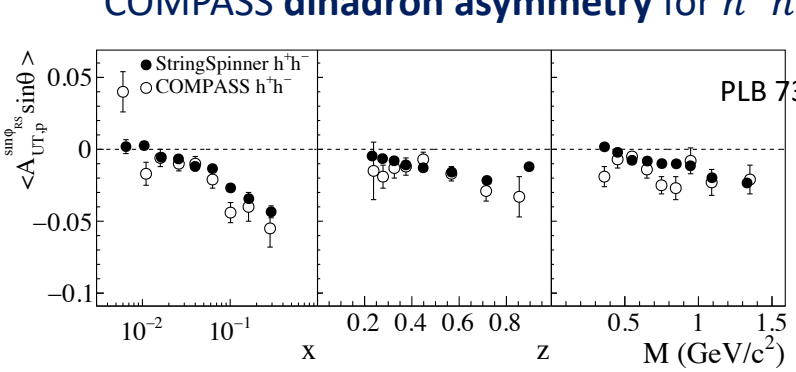
COMPASS **Collins asymmetry** for π^+



HERMES **Collins asymmetry** for π^+



COMPASS **dihadron asymmetry** for h^+h^-



parameters for spin effects in VM production set to

$f_L = 0.93 \rightarrow$ mainly L pol. VMs

$\theta_{LT} = 0 \rightarrow$ no oblique pol.

satisfactory description of TSA in SIDIS

also for π^- (see backup)

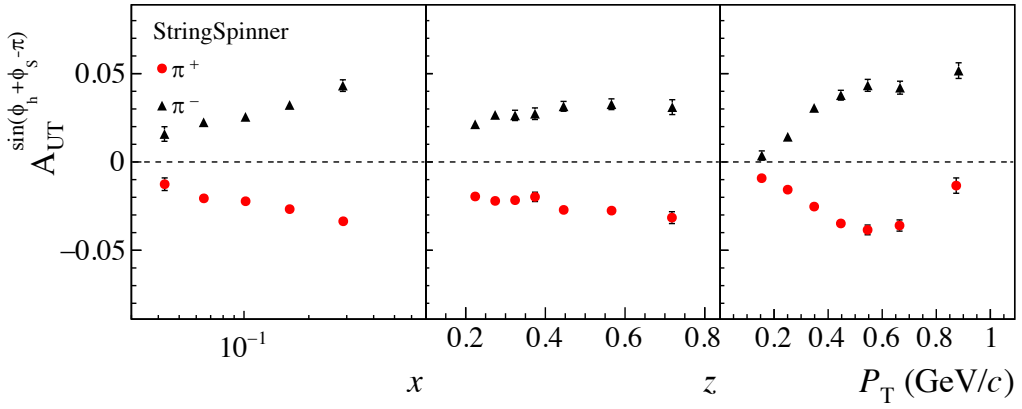
results in the following slides only with $f_L = 0.93$, $\theta_{LT} = 0$

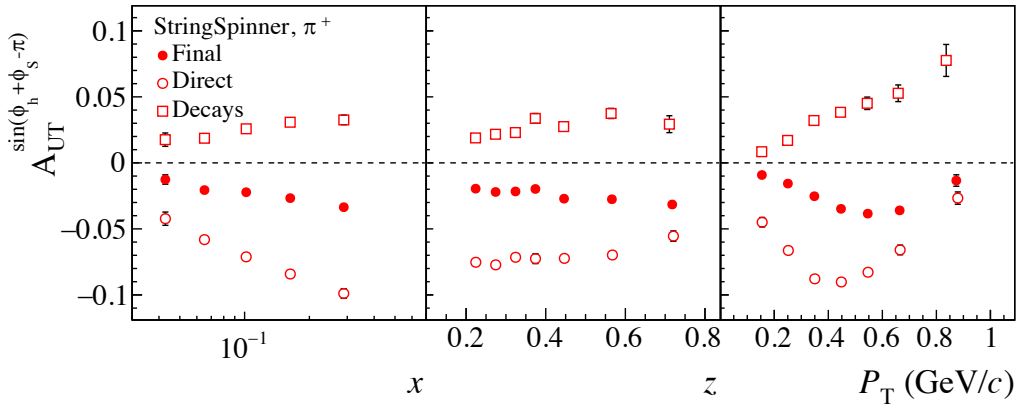
Results from simulations of T polarized SIDIS off protons

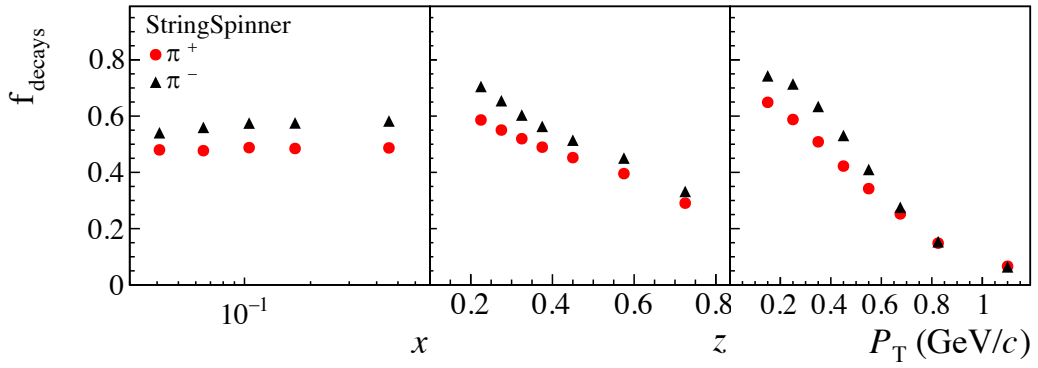
$\mathbf{e\,P \rightarrow e\,h\,X}$ @ 22 GeV

kinematic selections similar to the HERMES analysis (see backup)

Collins asymmetries for pions @ JLab 22 GeV







Collins TSA for π

slow decay as function of x_B

main contribution from valence quarks

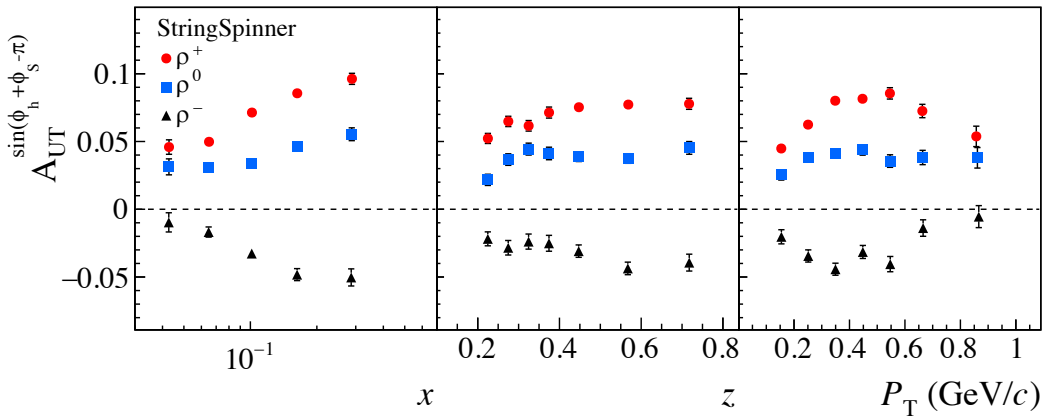
Decomposition of TSA for π^+

strong competition between primary and secondary mesons in the construction of the final asymmetry

Fraction of secondary π

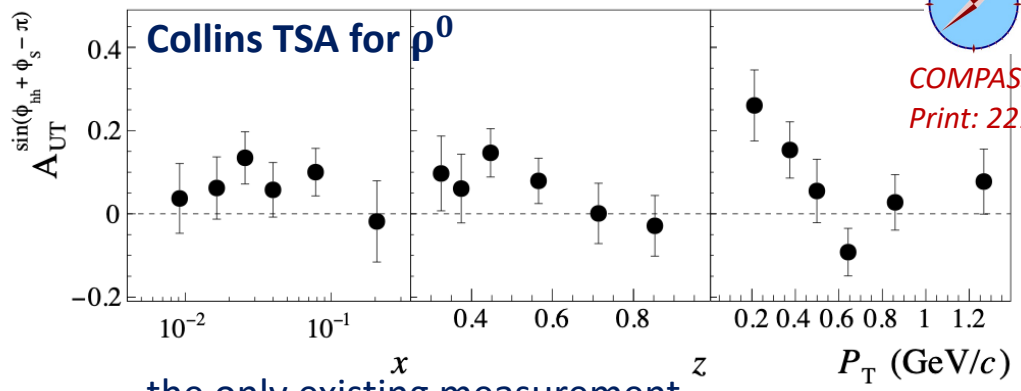
Large contribution of decay mesons at small P_T and small z_h!

Collins asymmetries for ρ - mesons @ JLab 22 GeV



- opposite Collins w.r.t pions
- sizeable asymmetries

negligible contamination from decays

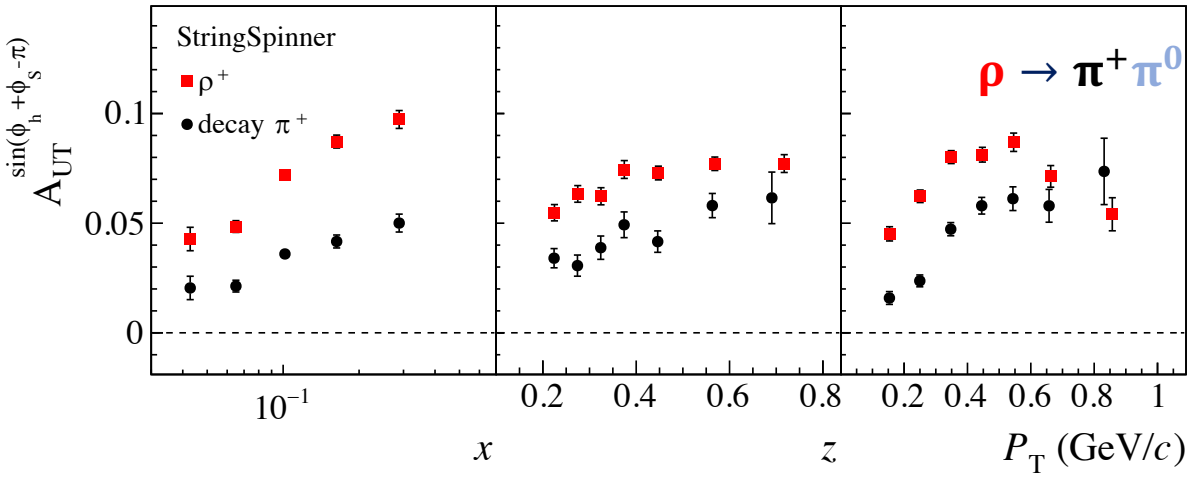


COMPASS, CERN-EP-2022-234, e-Print: 2211.00093

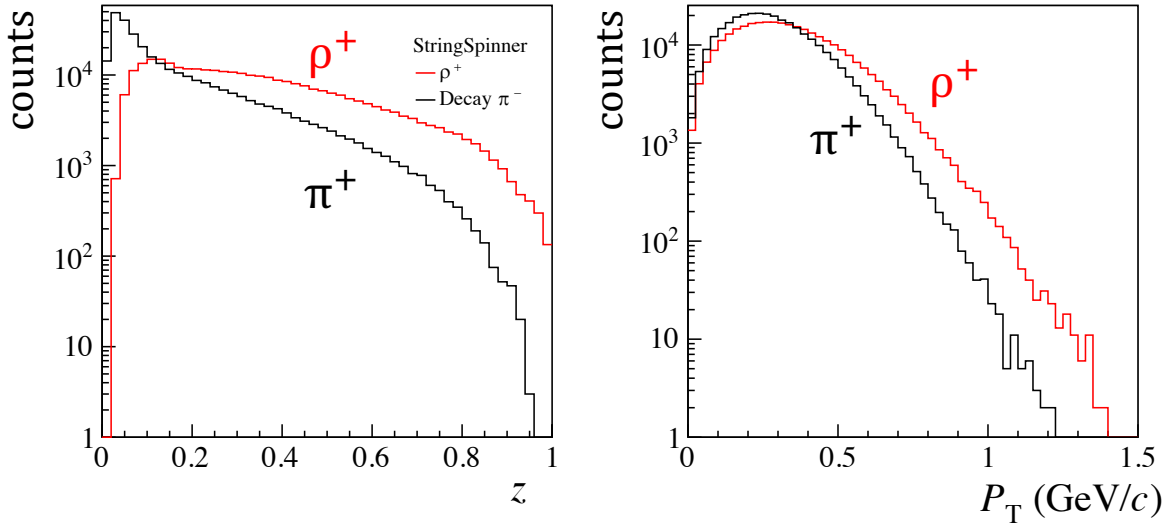
the only existing measurement

- sign and average value agrees with the string+$^3P_0$ model for $f_L = 0.92$
- large uncertainties

Collins asymmetries for decay pions @ JLab 22 GeV



- Asymmetry of decay pions same sign as the parent VM and diluted *still sizeable!*



decay mesons contribute mostly at (relatively) small z_h and small P_T

Conclusions

• Using the string+$^3P_0$ model in Pythia via StringSpinner, we can simulate (transverse)-spin effects in SIDIS

• Transverse-spin effects in SIDIS @ Jlab 22 GeV are expected to be sizeable

• The observed transverse-spin effects strongly depend on vector meson production and their polarization

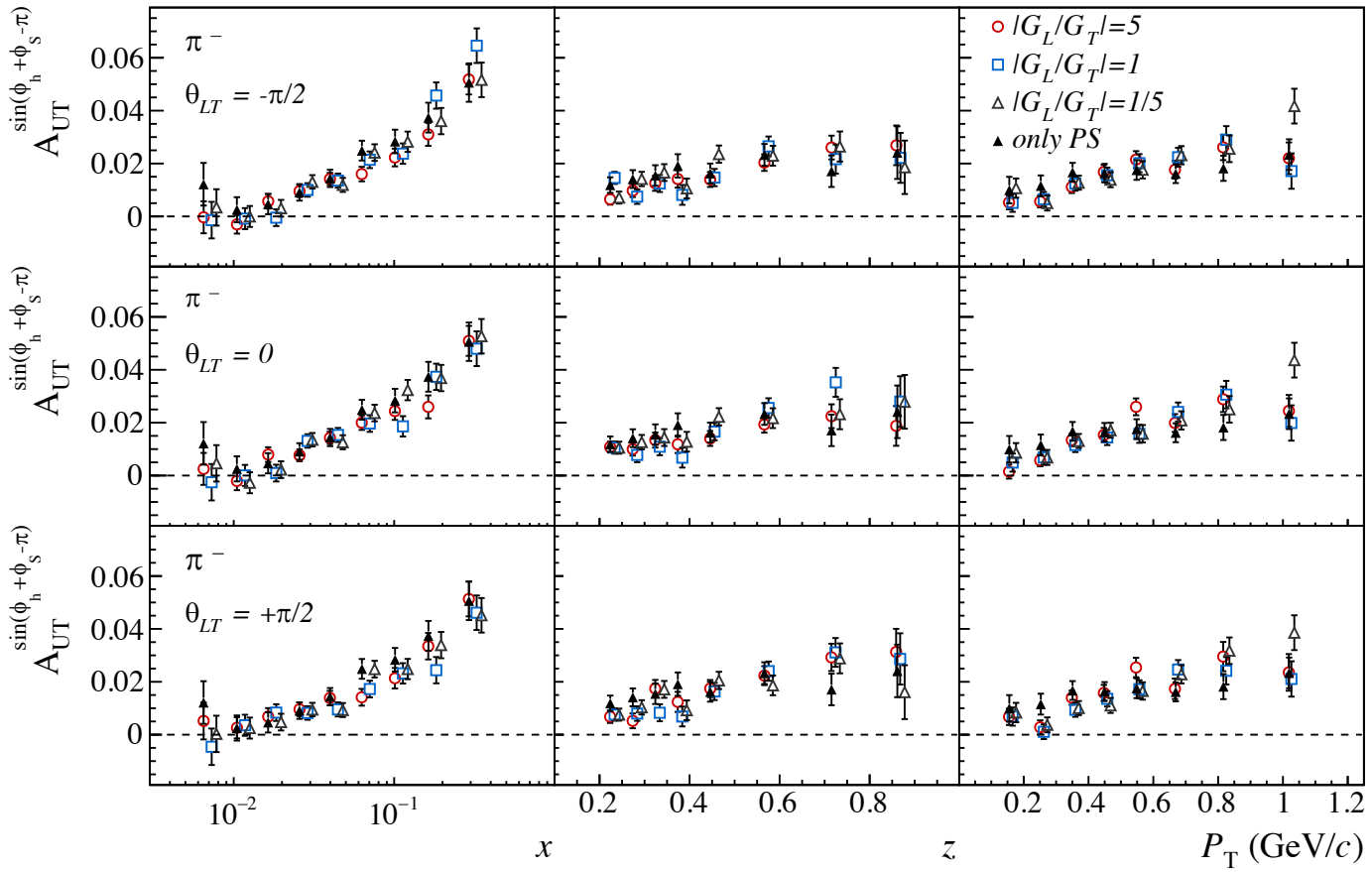
the contribution of VMs to the osberved hadron sample is large

VMs are essential to understand the physics of (polarized) hadronization, and for the interpretation of data

experimental information on inclusively produced VMs is however limited, more data is needed!

Backup

Collins asymmetries for π^- @ COMPASS kin.



Relevant free parameters for string fragmentation used in simulations

(see Kerbizi, Artru, Martin, PRD104 (2021) 11, 114038)

Pythia parameters

StringZ:aLund	0.9
StringZ:bLund	0.5 $(\mathrm{GeV}/c^2)^{-2}$
StringPT:sigma	0.37 GeV/c
StringPT:enhancedFraction	0.0
StringPT:enhancedWidth	0.0 GeV/c
BeamRemnants:primordialKT	off

String+$^3P_0$ parameters

$\mathrm{Re}(\mu)$	0.42 GeV/c^2
$\mathrm{Im}(\mu)$	0.76 GeV/c^2
f_L	0.93, 0.33, 0.02
θ_{LT}	$-\pi/2$, 0, $+\pi/2$

Phase space and kinematic selections for TSA @ Jlab 22 GeV

$$Q^2 > 1\left(\frac{\mathrm{GeV}}{c}\right)^2, \qquad W^2 > 10\left(\frac{\mathrm{GeV}}{c^2}\right)^2, \qquad 0.2 < y < 0.85, \qquad 0.032 < x_B < 0.7$$

$$0.2 < z_h < 0.8, \qquad 0.1\frac{\mathrm{GeV}}{c} < P_T < 1.3\frac{\mathrm{GeV}}{c}$$