

September 27<sup>th</sup>, 2023  
Durham

25<sup>th</sup> International Spin Symposium  
SPIN-2023

**The role of vector mesons in the interpretation of  
single spin asymmetries and opportunities  
with future studies**

Albi Kerbizi

Trieste University and INFN Trieste Section



POLFRAG



# Introduction to the tools used

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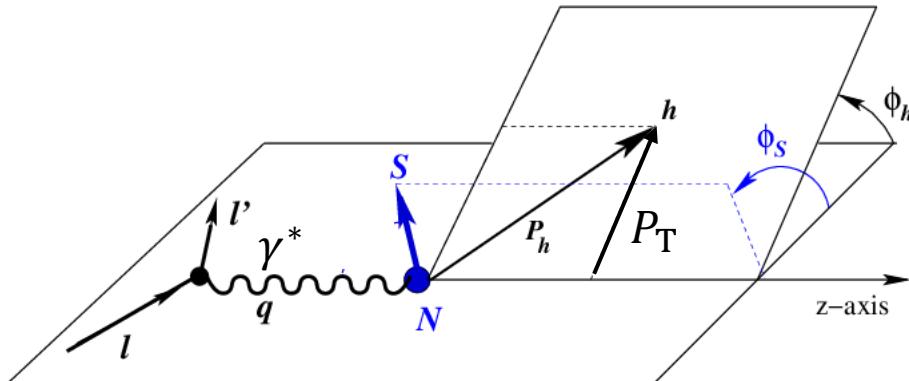
The presentation is based on

- i. the Collins (transverse spin) asymmetry in SIDIS

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amplitude of the  
 $\sin \phi_{\text{Coll}} = \sin(\phi_h + \phi_s - \pi)$   
modulation

$$A_{\text{UT}}^{\sin \phi_h + \phi_s - \pi} = \frac{\sum_q e_q^2 h_1^q \otimes H_{1q}^{\perp h}}{\sum_q e_q^2 f_1^q \otimes D_{1q}^h} \quad \begin{array}{l} \text{transversity } \text{Collins FF} \\ \text{Collins, NPB 396, 161 (1993).} \end{array}$$

relevant variables

$x_B$ ,

$z_h = P \cdot P_h / P \cdot q,$   
 $P_T$

$h_1^q$

transverse polarization of quarks in a transversely polarized nucleon

$H_{1q}^{\perp h}$

fragmentation of a transversely polarized quark in hadrons

Measured at HERMES, COMPASS, JLAB and used together with  $e^+e^-$  data by different groups for the extraction of  $h_1^q$  and  $H_{1q}^{\perp h}$

talk of A. Martin  
today, TMD session

# Introduction to the tools used

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The presentation is based on

i. the Collins (transverse spin) asymmetry in SIDIS

ii. The StringSpinner package [AK, L. Lönnblad, CPC **272** (2022) 108234; CPC **292** (2023) 108886]

implements the quark spin effects for SIDIS (Collins FF, di-hadron FF,  $G_1^\perp$ , ...) in the Pythia Monte Carlo event generator

uses the string+ ${}^3P_0$  model of polarized hadronization

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

can be used for the description and interpretation of data

public, available in [GitLab](#)

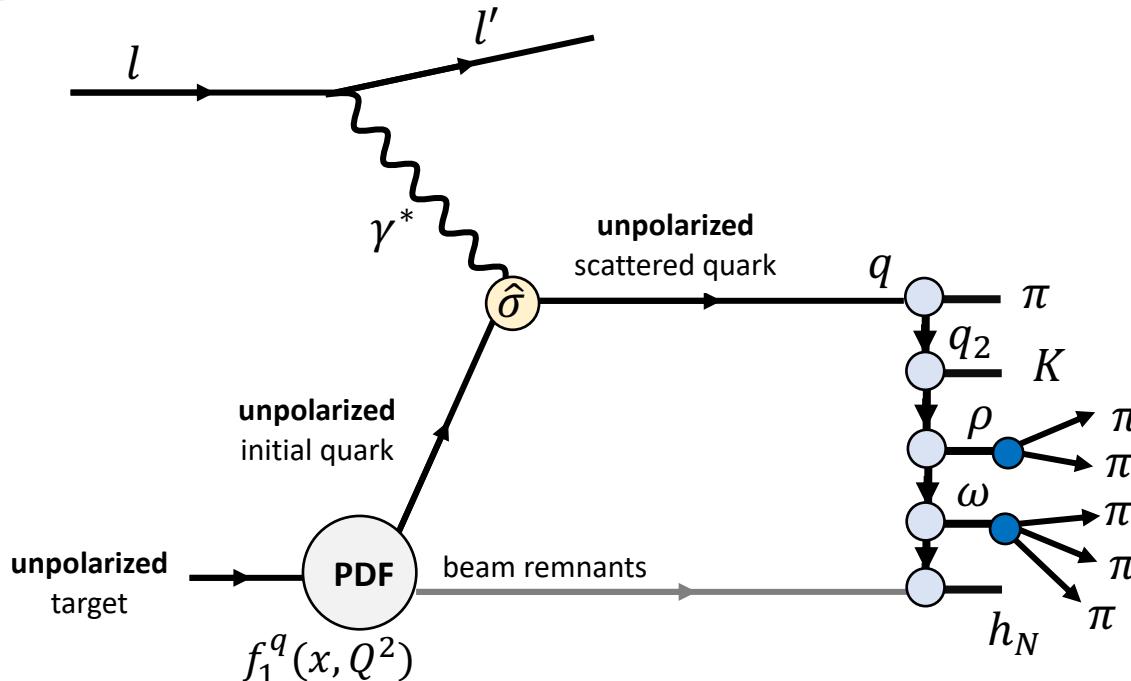
# The Monte Carlo generator: PYTHIA 8 + StringSpinner

PYTHIA 8 is used to simulate the DIS process  
unpolarized beam and target, no parton showers

Spin effects enabled by StringSpinner  
includes production of PS and VM

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

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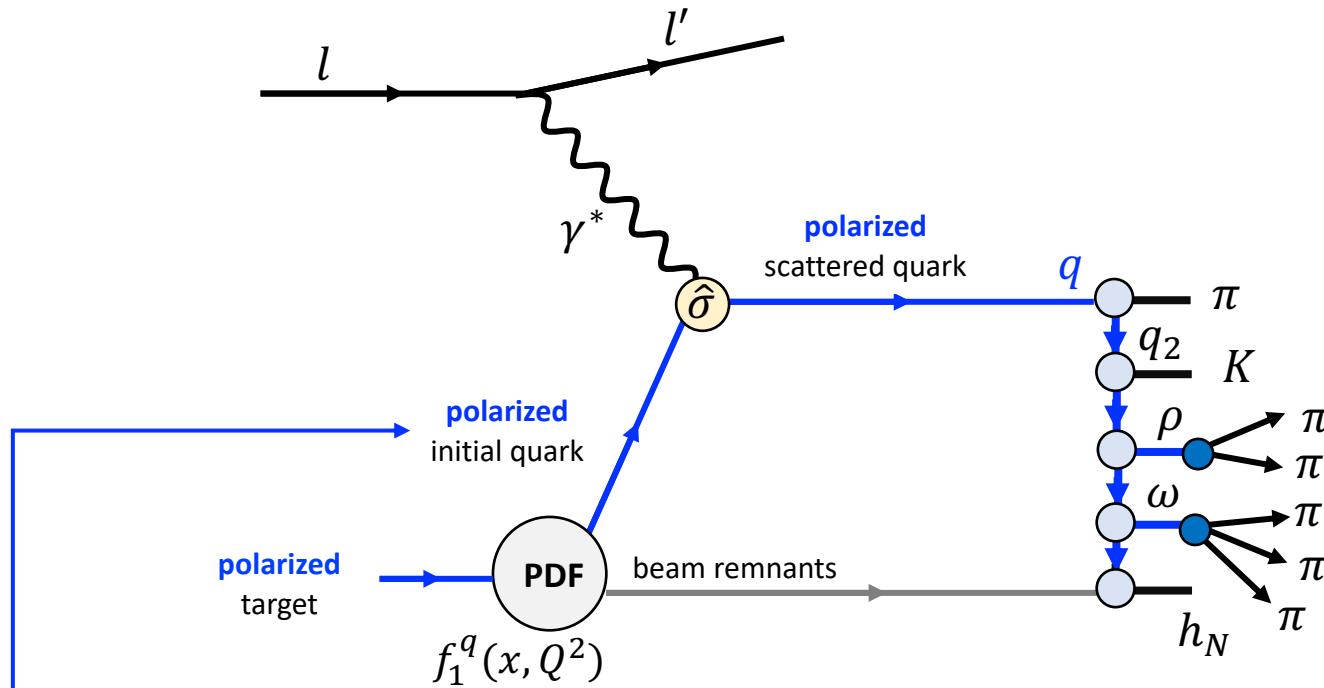


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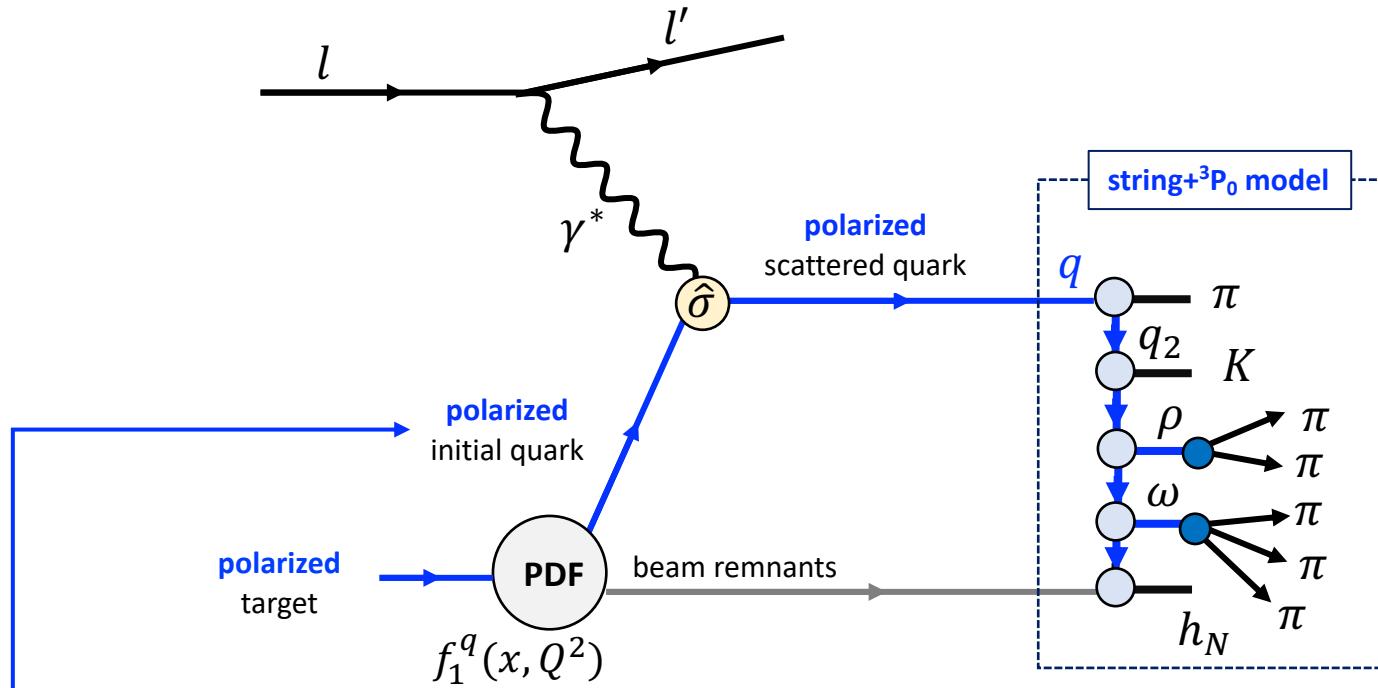
Transversity PDF  $h_1^q(x)$   
parametrization  
valence (sea) quarks polarized (unpolarized)

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Transversity PDF  $h_1^q(x)$   
parametrization  
valence (sea) quarks polarized (unpolarized)

string stretched between q and the beam  
remnants  
fragmented using the string+ ${}^3P_0$  model

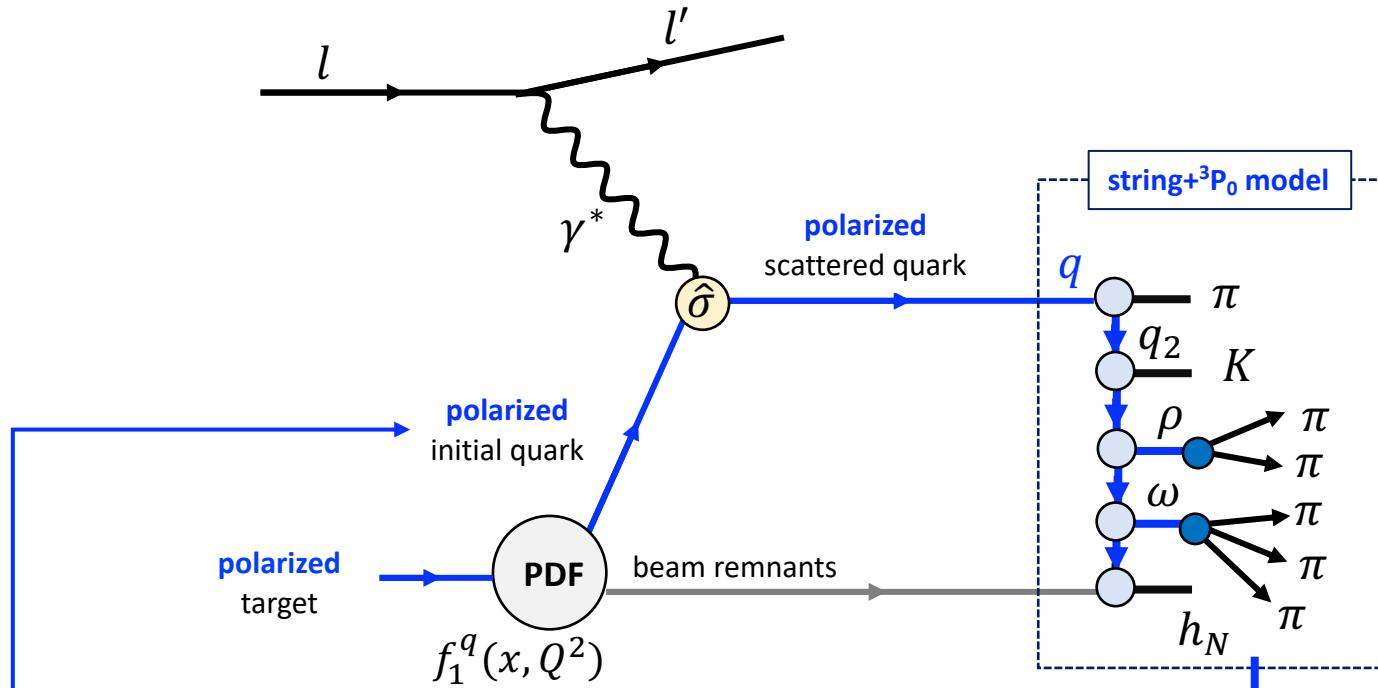
AK, Artru, Martin, PRD 104 (2021) 11, 114038

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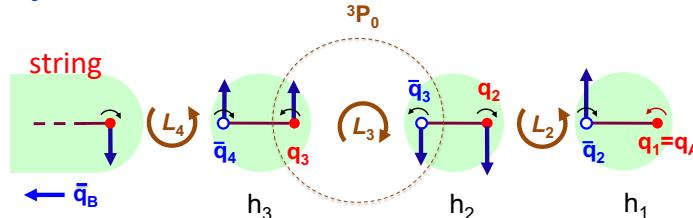
Collins asymmetry  
dihadron asymmetry  
etc

# 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

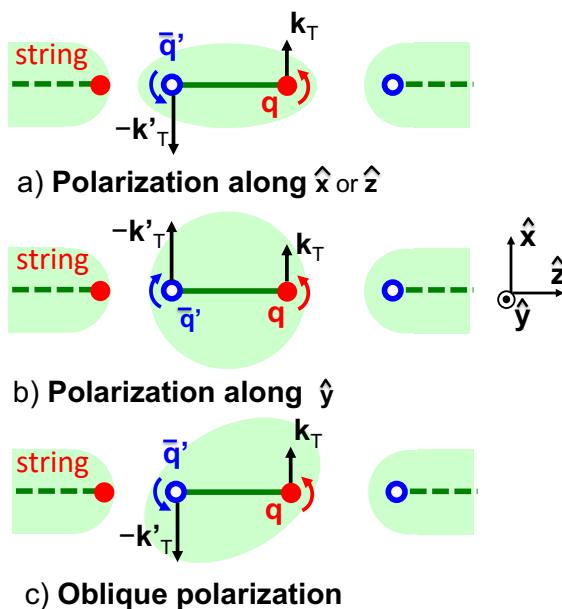
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PRD 104 (2021) 11, 114038

## pseudoscalar meson emission



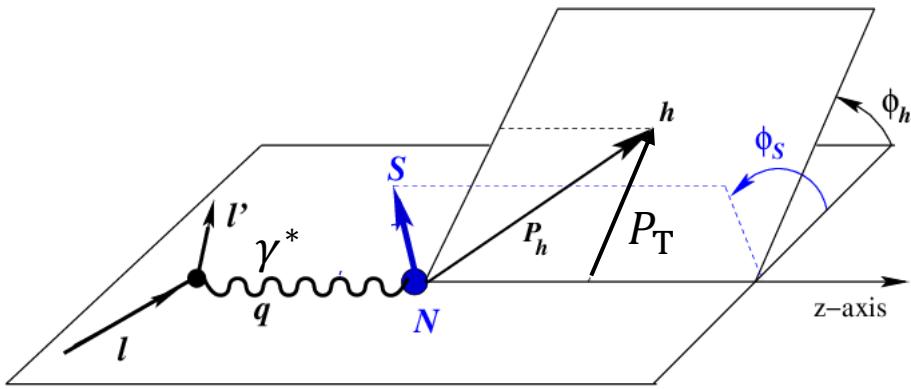
described by free parameter  
 **$\mu$  (complex mass) for the  $^3P_0$  w.f.**  
 $\text{Im}(\mu) \propto$  size of Collins effect for PS/VM

## (polarized) vector meson emission



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

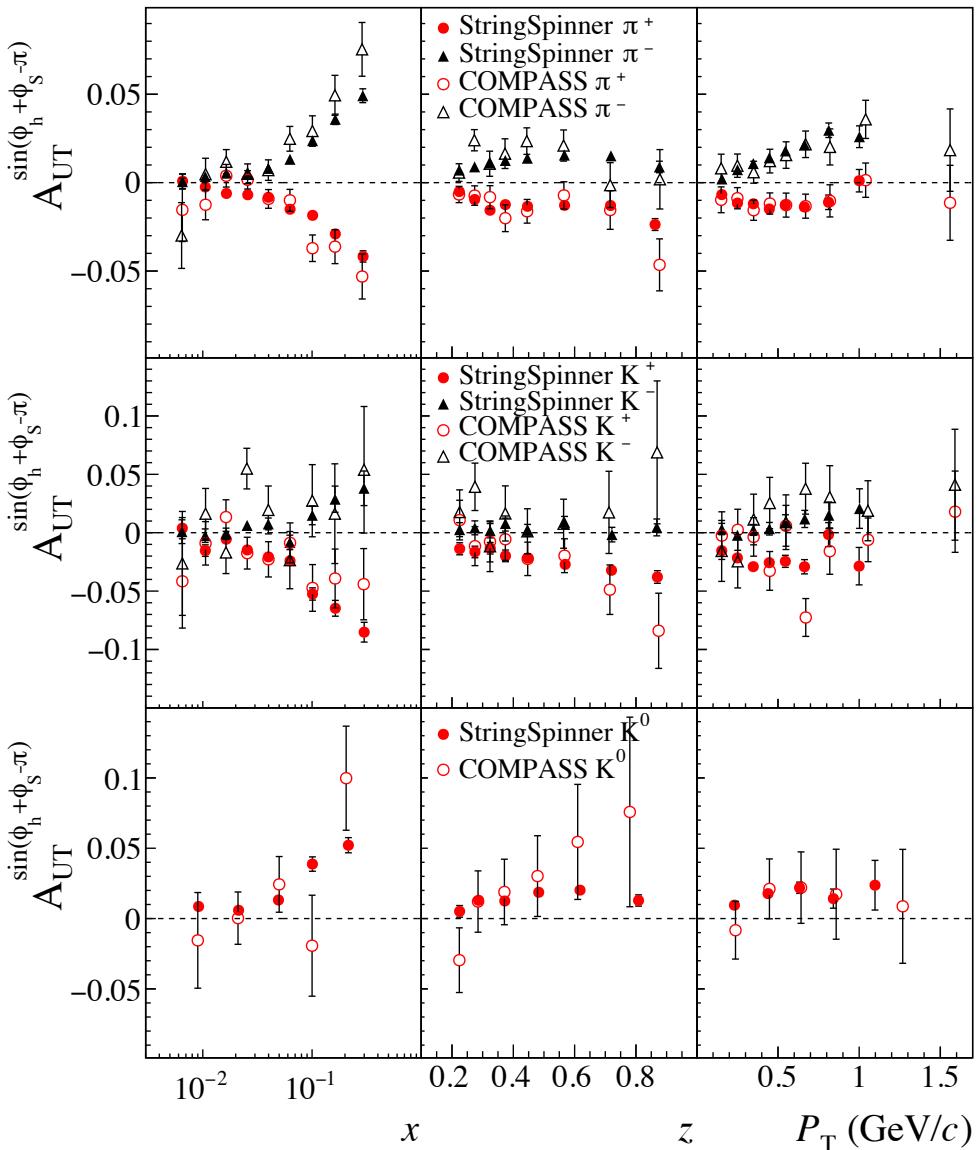
c) described by the parameter  
 **$\theta_{LT}$  gives oblique (LT) polarization**  
 $\sin\theta_{LT} \propto$  size of Collins effect for decay mesons



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

simulation settings in the backup slides

# Collins asymmetries for $\pi$ and K

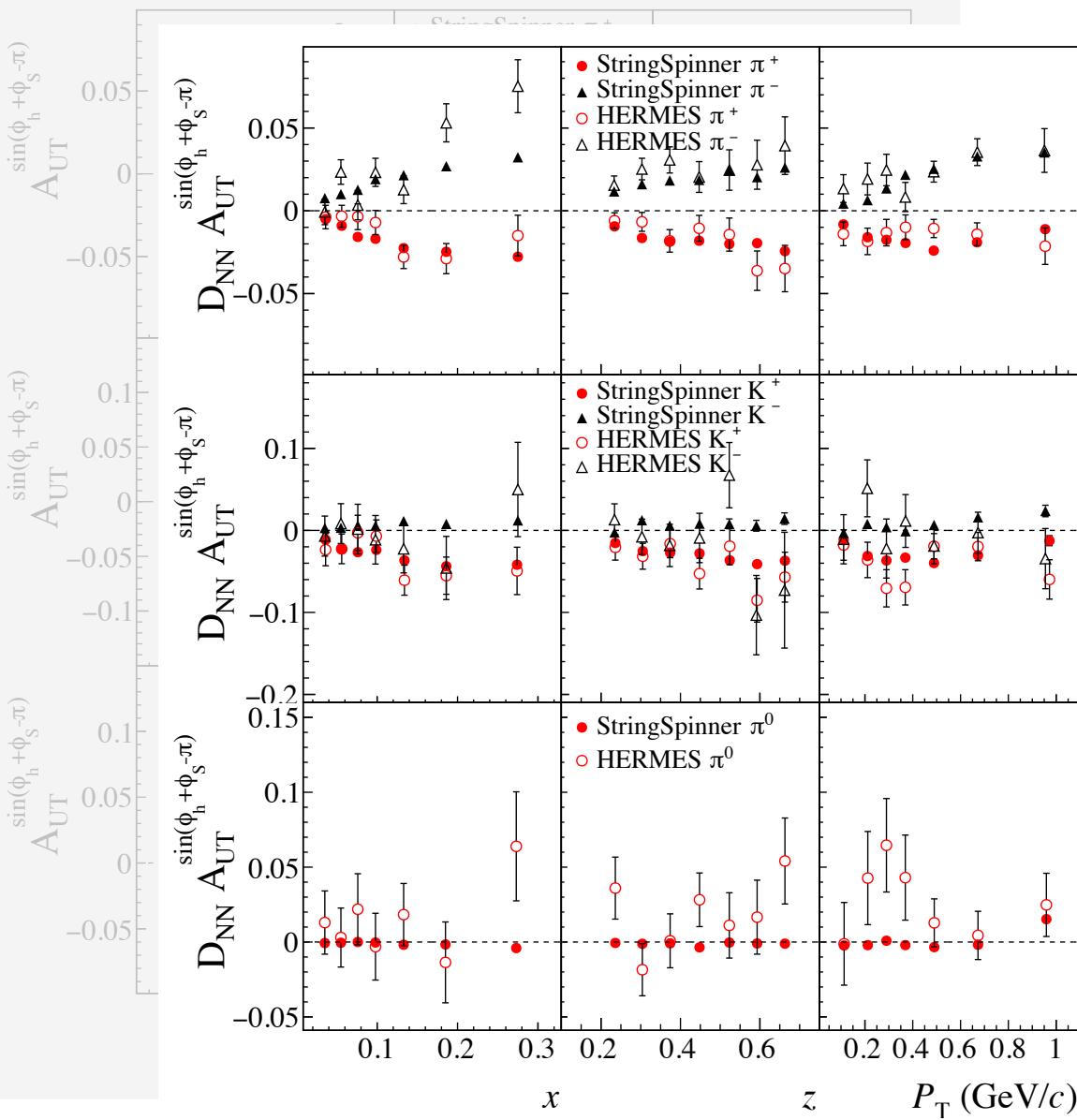


PLB 717 (2012) 376

## Comparison with COMPASS

- Satisfactory description
- Collins asymmetry for kaons reproduced  
NEW!

# Collins asymmetries for $\pi$ and K



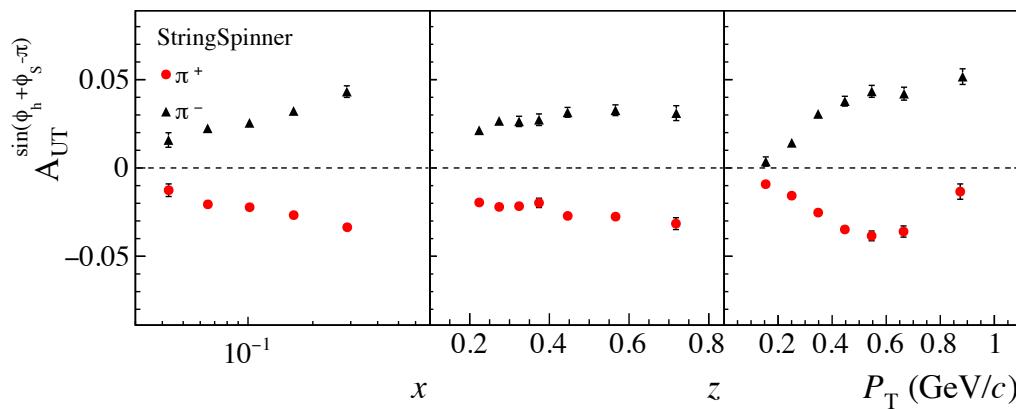
PLB693 (2010) 11

## Comparison with HERMES

- Satisfactory description  
 $\pi^0$  in simulations as expected by isospin
- Description of 2h asymmetries  
also OK (not shown)

Role of VMs in the Collins asymmetry  
as an example, 22 GeV e on a T polarized P target  
foreseen for the upgrade of JLAB at 22 GeV

# Collins asymmetries for pions

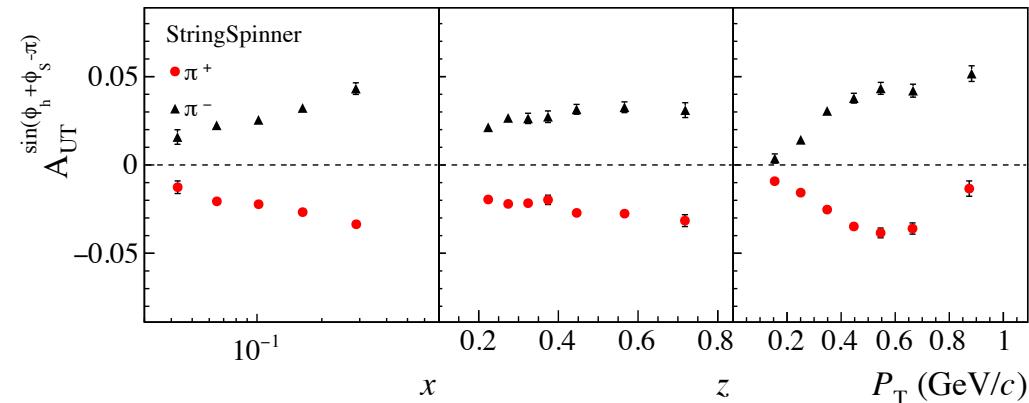


## Collins TSA for $\pi$

slow decay as function of  $x_B$

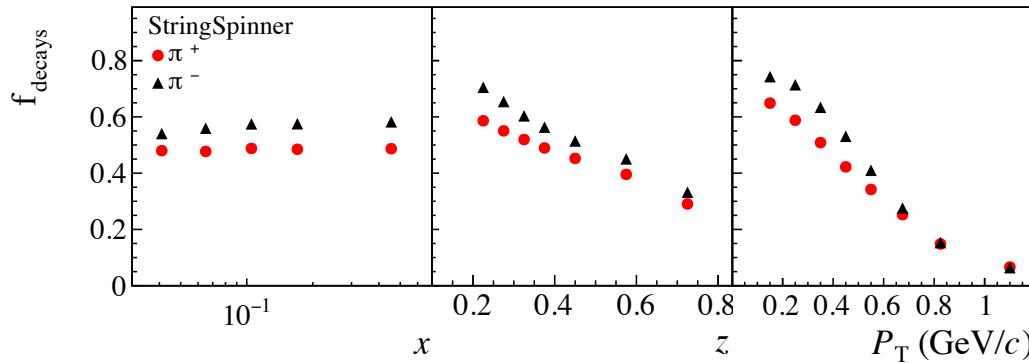
*main contribution from valence quarks*

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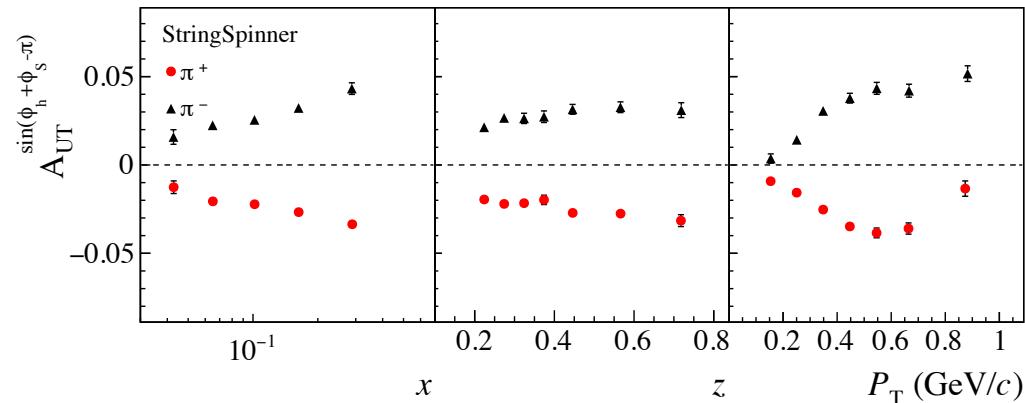
slow decay as function of  $x_B$   
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## Fraction of secondary $\pi$

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

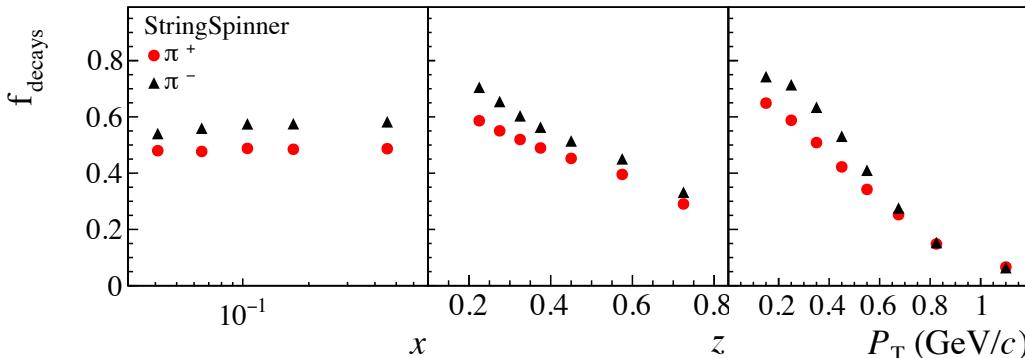
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## Collins TSA for $\pi$

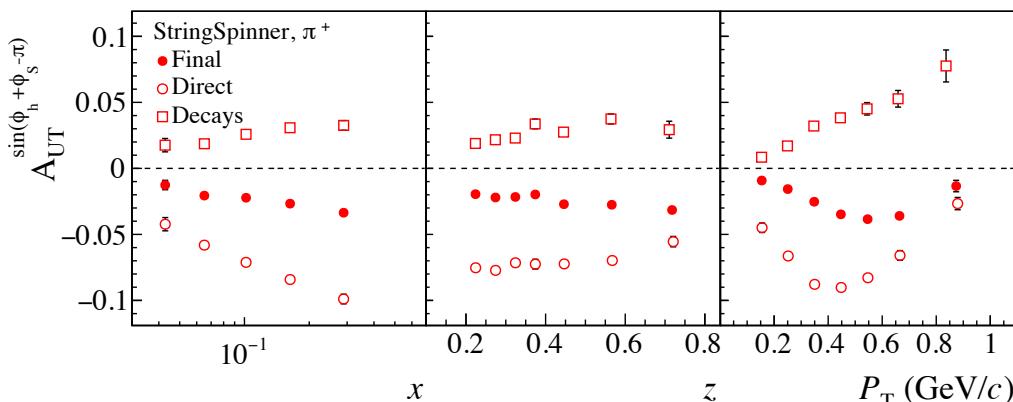
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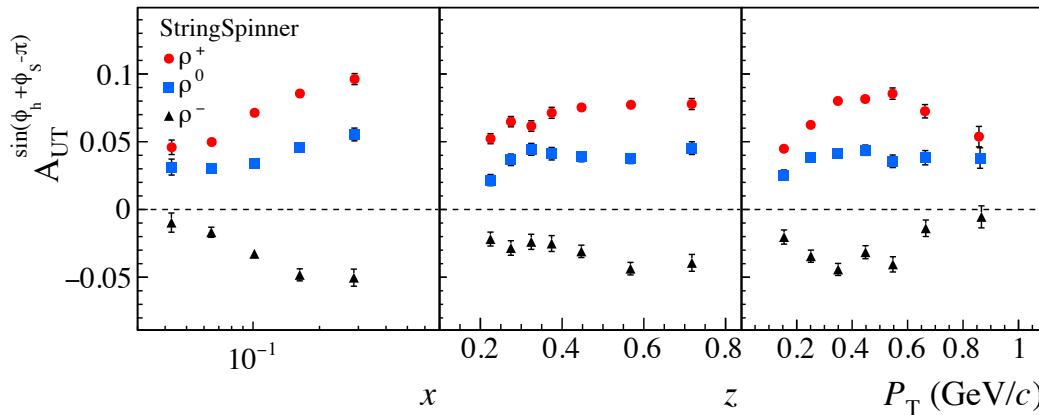
Large contribution of decay mesons at small  $P_T$  and small  $z_h$ !



## Decomposition of TSA for $\pi^+$

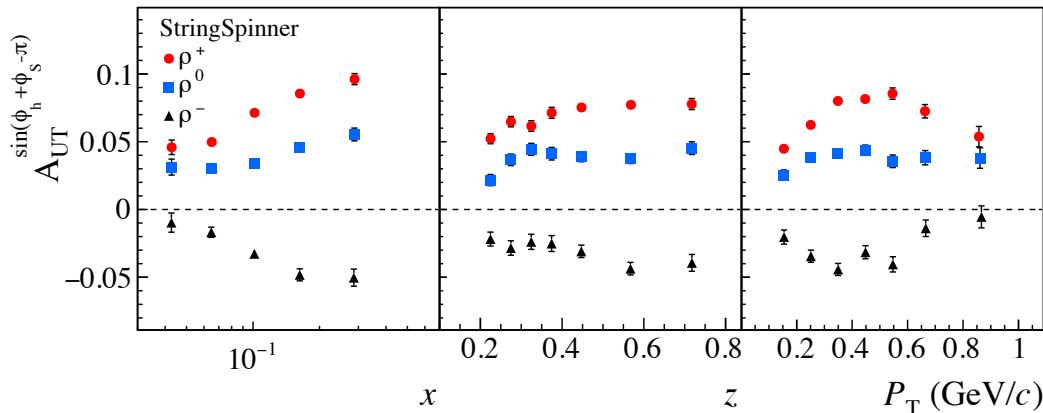
strong competition between primary and secondary mesons in the construction of the final asymmetry

# Collins asymmetries for $\rho$ - mesons



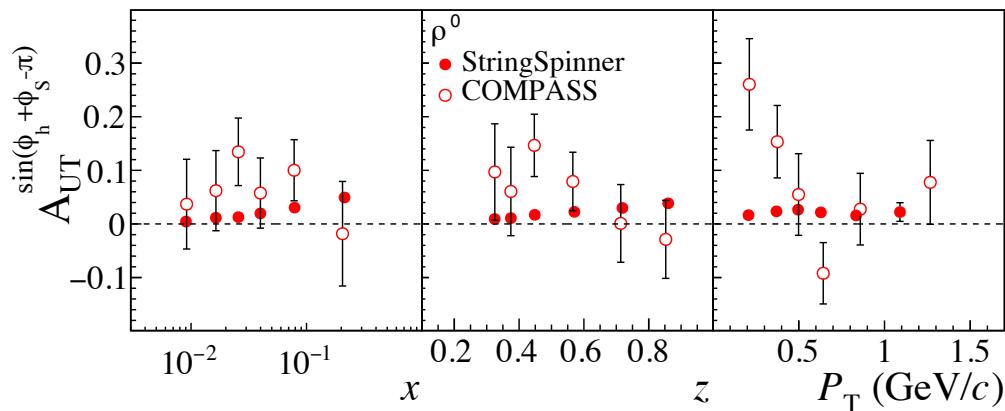
- ❑ sizeable asymmetries  
*negligible contamination from decays*
- ❑ opposite Collins effect w.r.t pions
- ❑ spin-dependence of fragmentation into VMs still largely unknown  
**an opportunity for future experiments**

# Collins asymmetries for $\rho$ - mesons



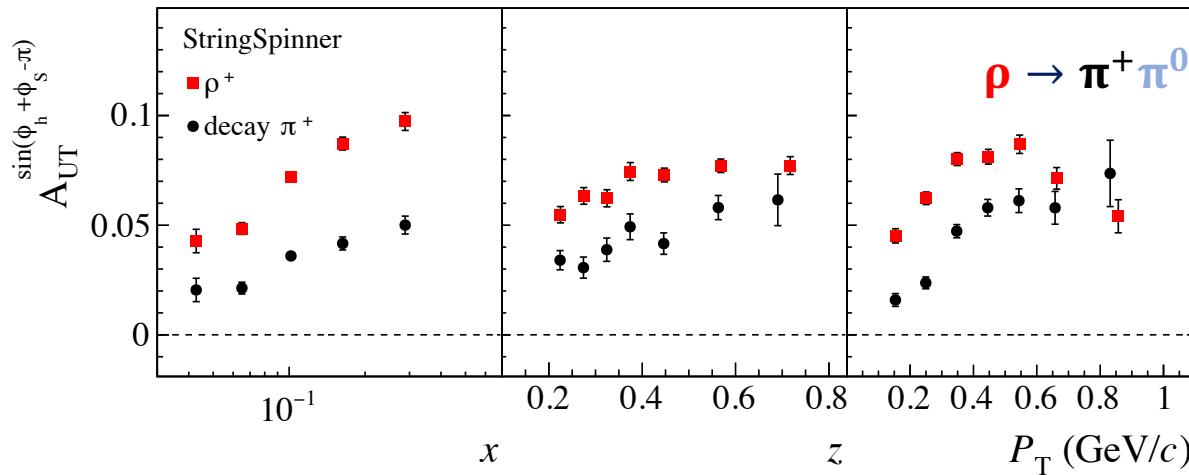
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**Collins TSA for  $\rho^0$  @ COMPASS** PLB 843 (2023) 137950



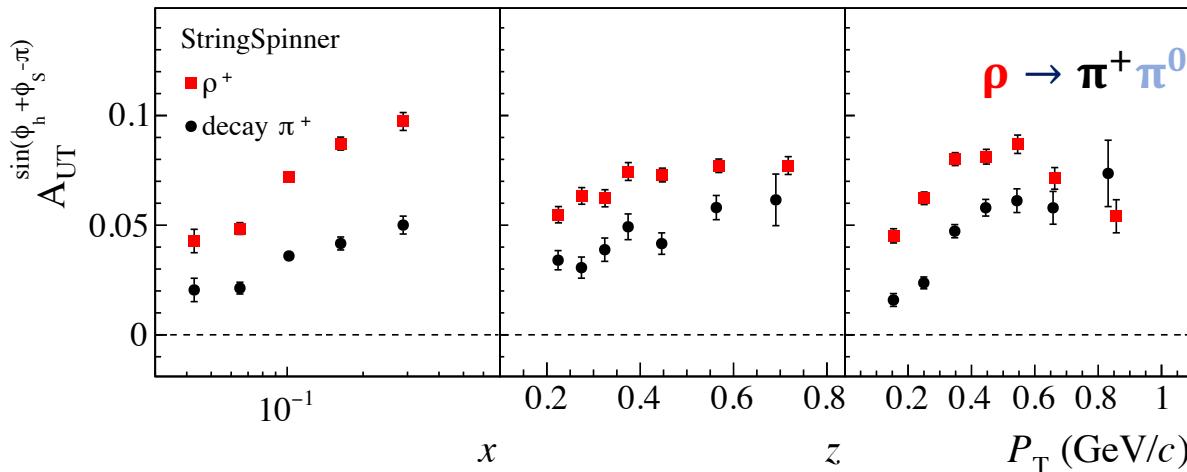
- ❑ the only existing measurement by COMPASS  
not negligible uncertainties

# Collins asymmetries for decay pions

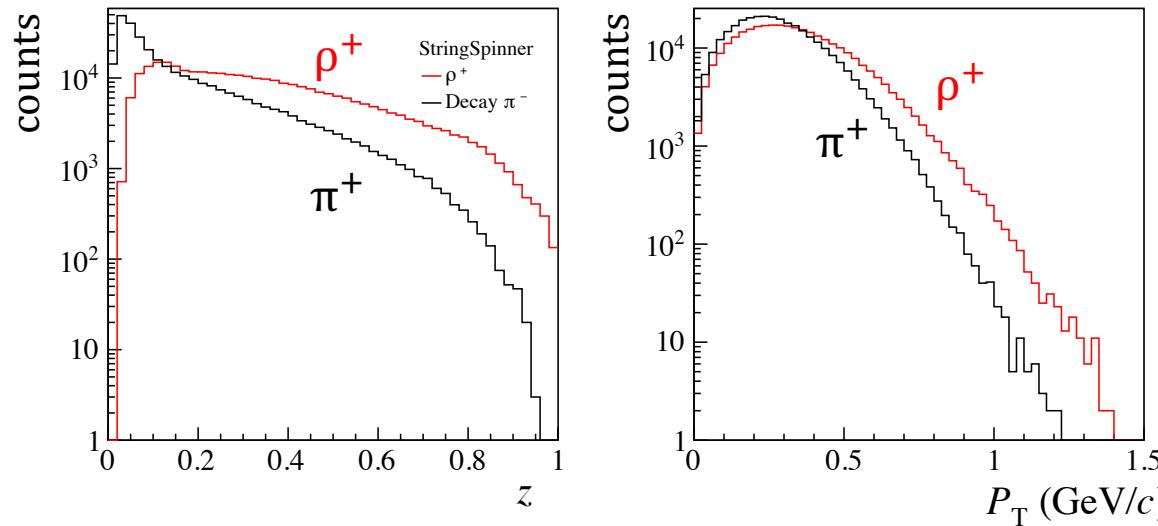


- Asymmetry of decay pions same sign as the parent VM and diluted  
*still sizeable!*

# Collins asymmetries for decay pions

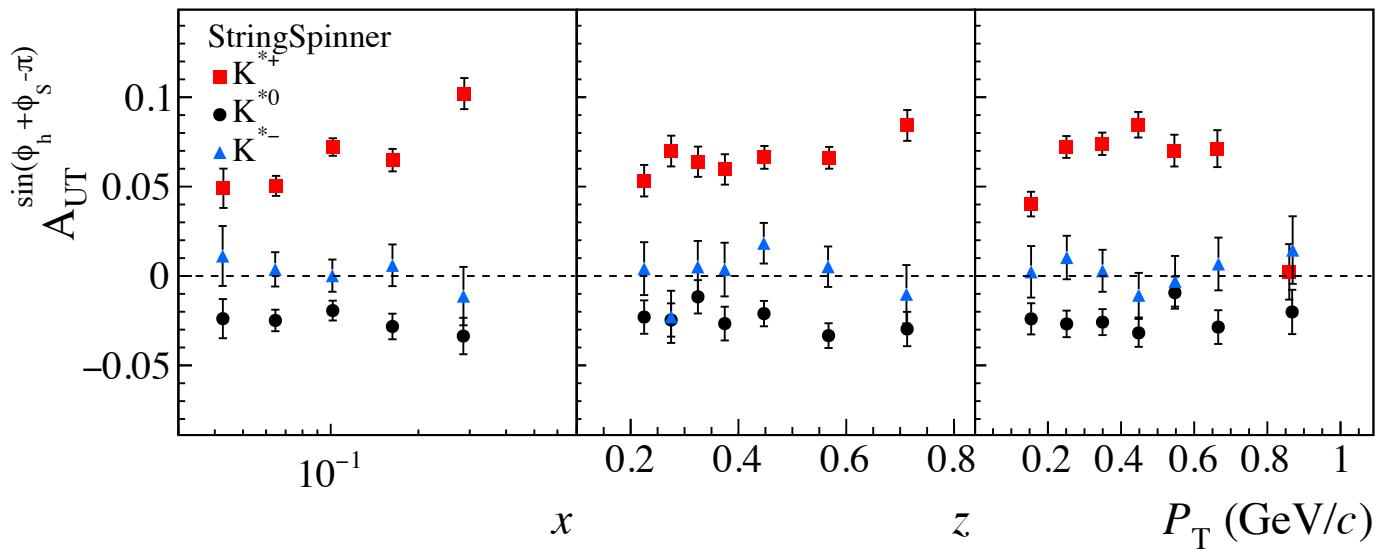


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decay mesons contribute mostly at (relatively) small  $z_h$  and small  $P_T$

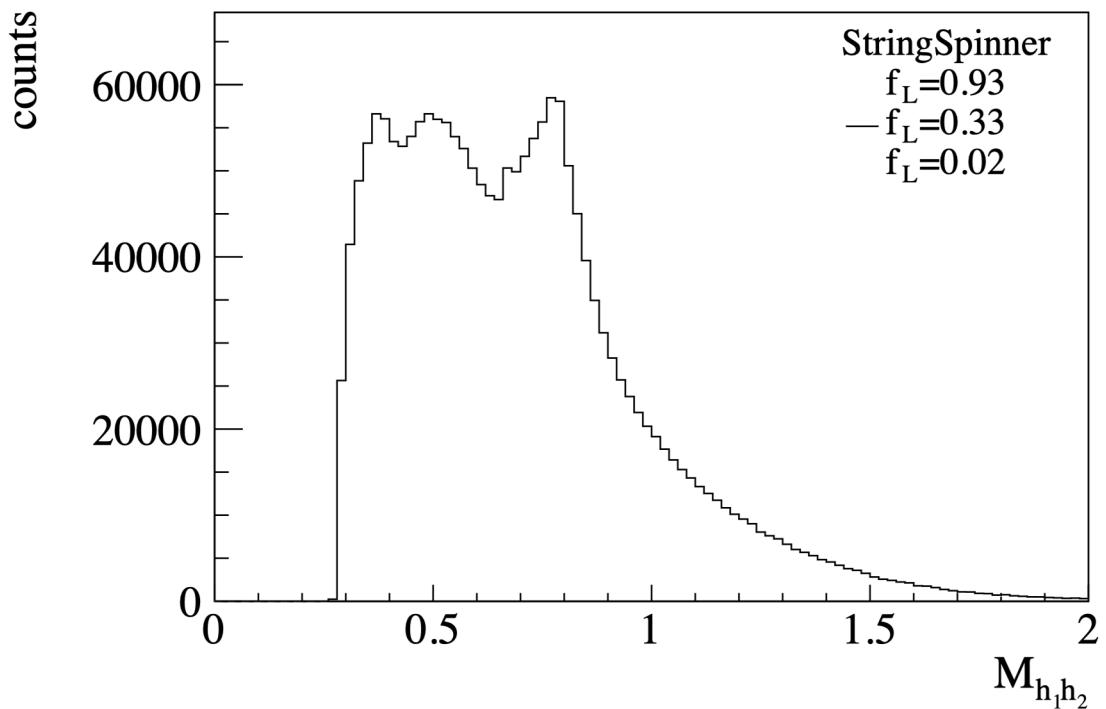
# Collins asymmetries for $K^*$



- Sizeable asymmetry for  $K^{*+}$
- Smaller for  $K^{*0}$  and  $K^{*-}$

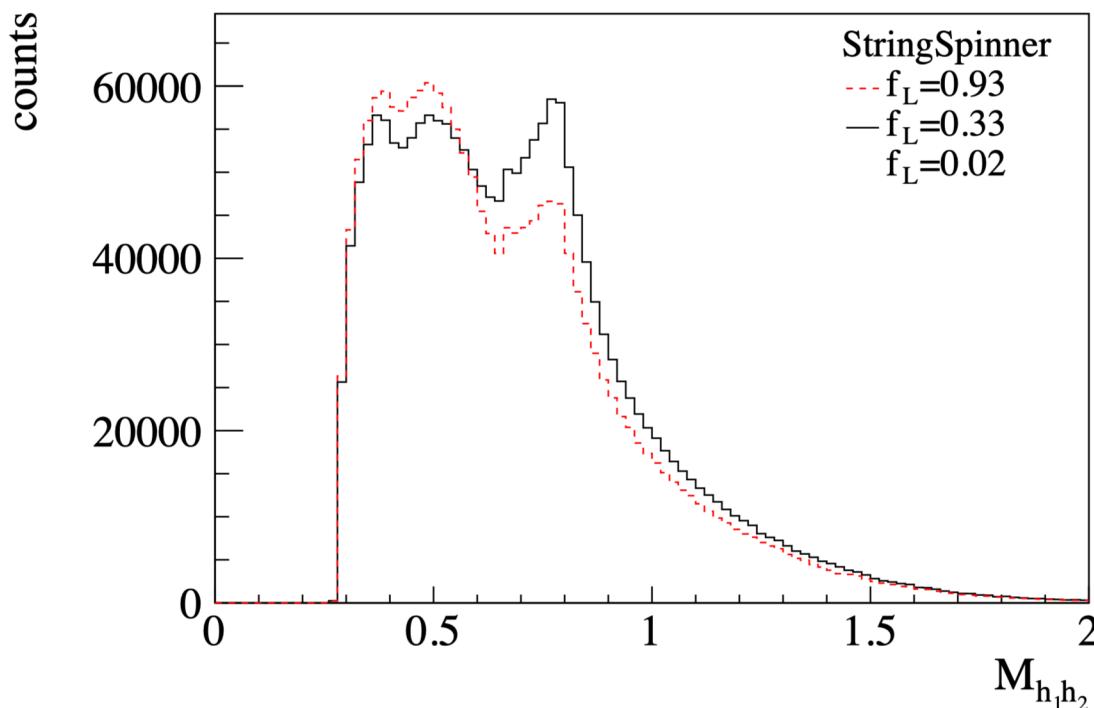
# Invariant mass distribution of $h^+h^-$ pairs

$h^+h^-$  pairs assuming  $\pi$  mass  
 $z_1 > 0.1, z_2 > 0.1$



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 $z_1 > 0.1, z_2 > 0.1$



VM with L pol.

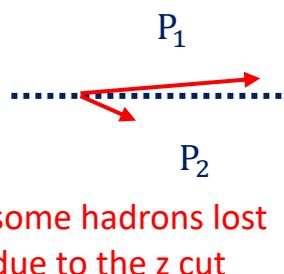
$P_1^*$

$P_2^*$

$M_{h_1h_2}$

string

boost

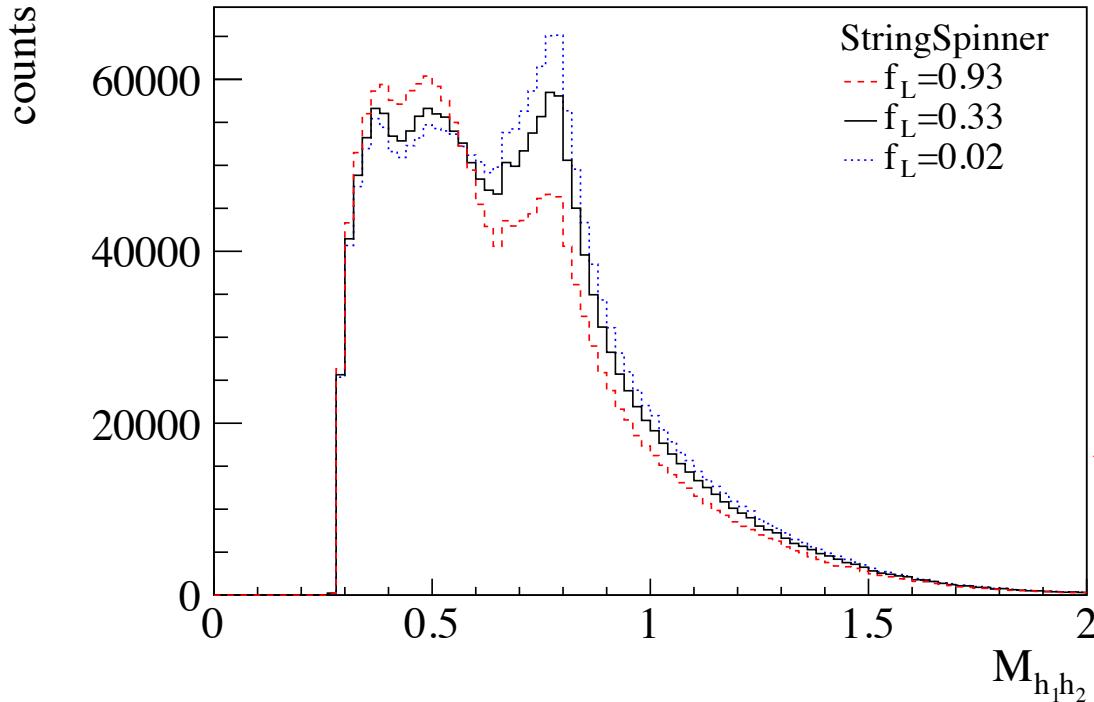


some hadrons lost  
due to the  $z$  cut

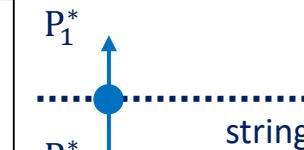
The shape of the invariant mass distributions depends on the VM polarization due to the kinamtic cuts

# Invariant mass distribution of $h^+h^-$ pairs

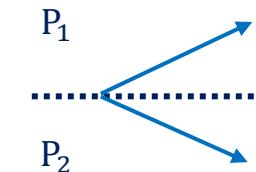
$h^+h^-$  pairs assuming  $\pi$  mass  
 $z_1 > 0.1, z_2 > 0.1$



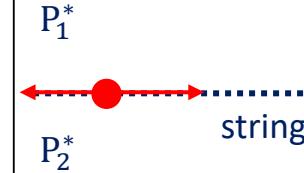
VM with T pol.



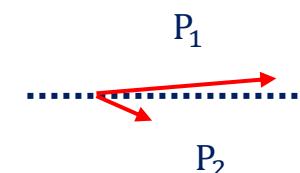
boost



VM with L pol.



boost



some hadrons lost  
due to the  $z$  cut

The shape of the invariant mass distributions depends on the VM polarization due to the kinamtic cuts  
 → sensitivity to the free parameter  $f_L$

Important observable for present and future experiments!

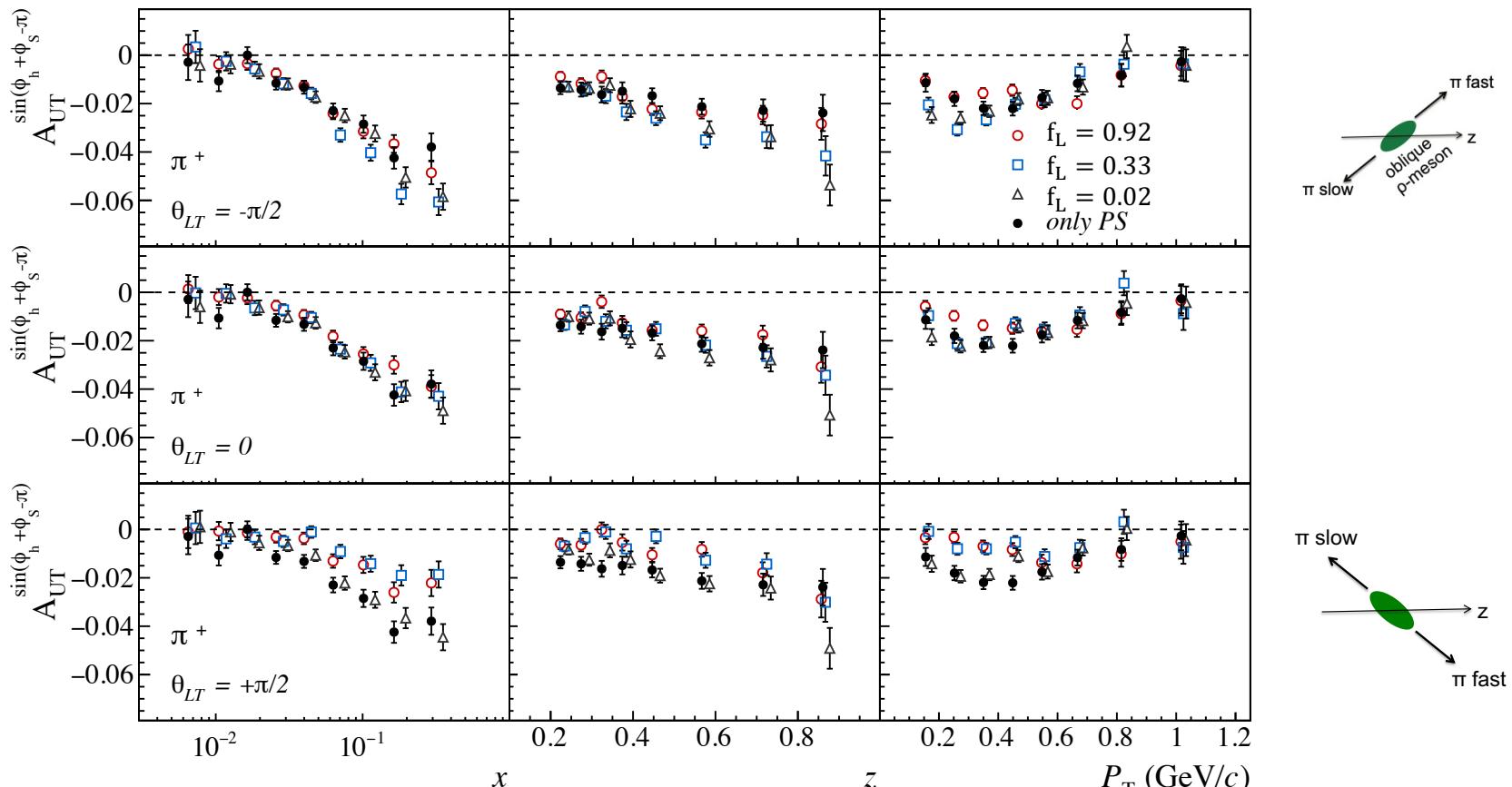
## Conclusions

- ❑ The string+ ${}^3P_0$  model of hadronization is a valuable tool for the simulation of polarized SIDIS  
implemented in Pythia via StringSpinner
- ❑ The observed transverse-spin effects strongly depend on vector meson production and polarization
- ❑ VMs are important 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... an opportunity for future experiments such as JLAB22 and EIC

## **Backup**

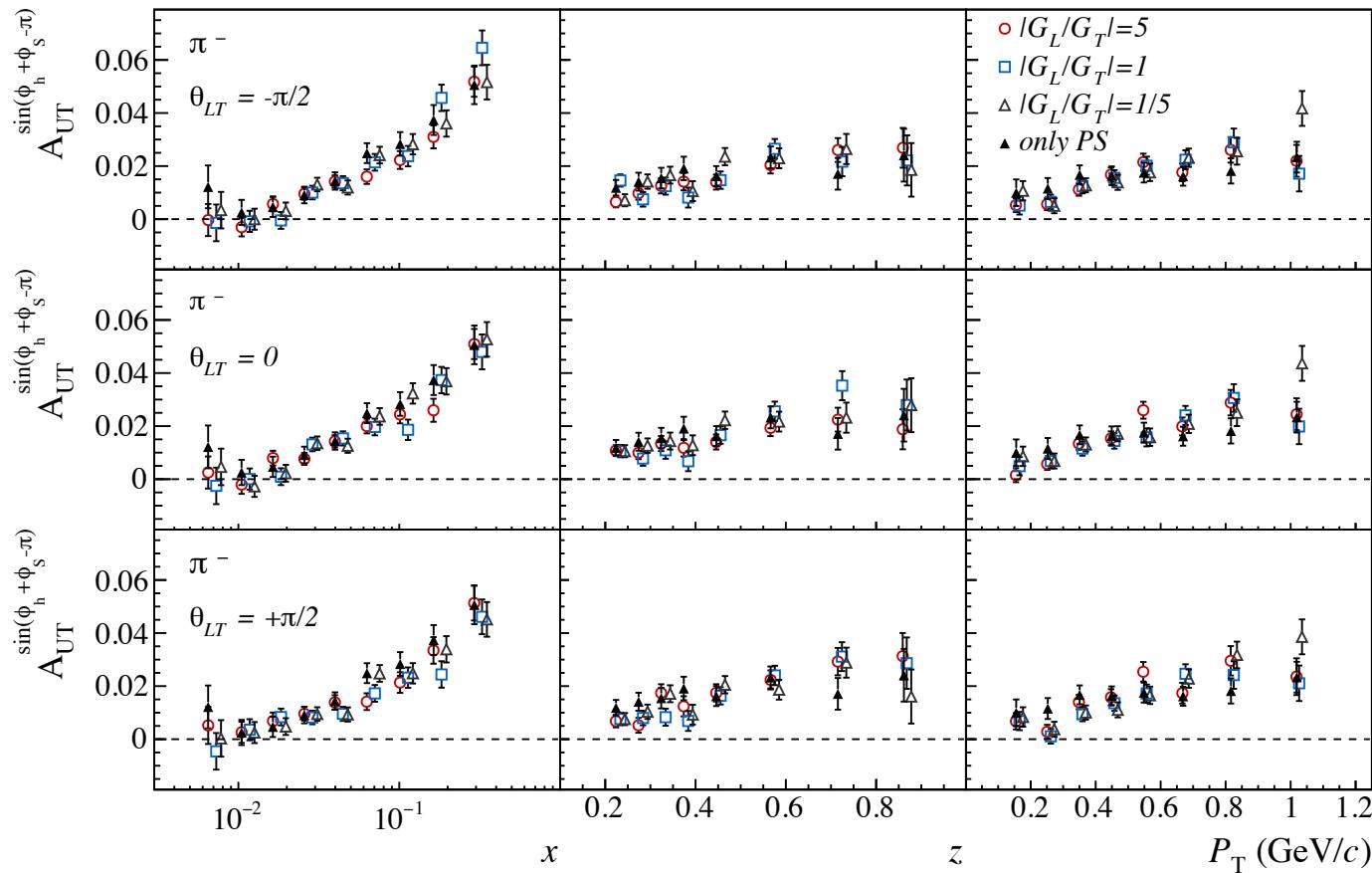
# Collins asymmetries for $\pi^+$ @ COMPASS kin.



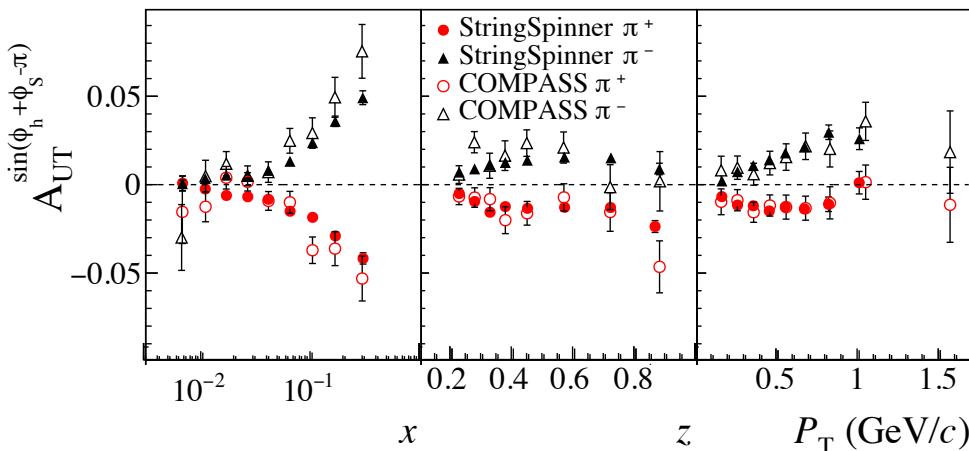
VM production → sizeable dilution of the average asymmetry  
*the result with only PS mesons scaled by ~ 0.5 to compare the shapes*

VM polarization → variations in the trend of the asymmetries  
*mainly at small  $P_T$  and large  $z_h$*

# Collins asymmetries for $\pi^-$ @ COMPASS kin.



# Collins asymmetries for $\pi$ and $K$ @ COMPASS



Satisfactory description as a function of the three kinematic variables

