

Adding quark spin effects to PYTHIA string fragmentation

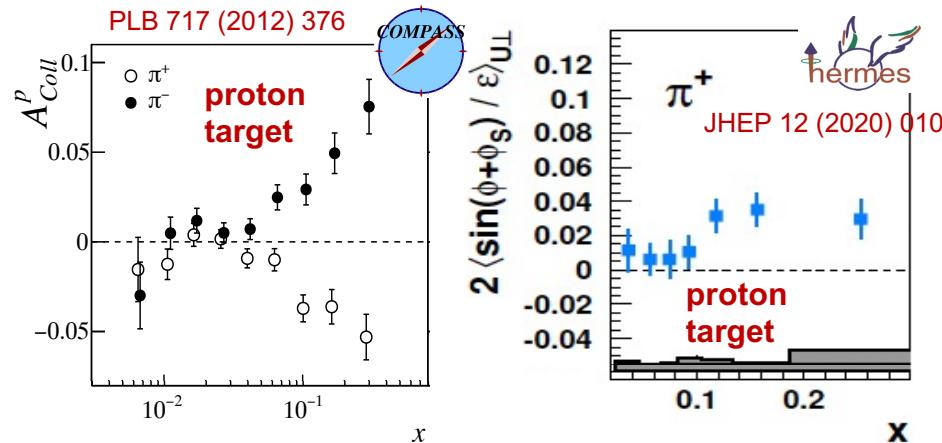
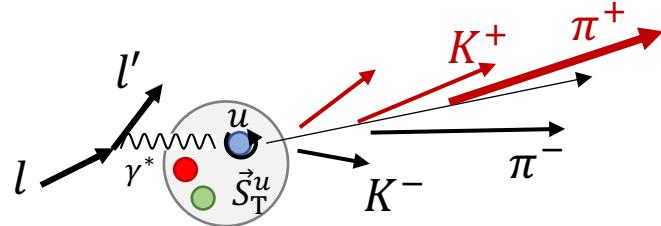
Albi Kerbizi

in collaboration with Leif Lönnblad

Motivation for spin effects in hadronization

The Collins effect in the fragmentation of transversely polarized quarks

Collins, NPB 396, 161 (1993).



Shows up e.g. as the **Collins asymmetry** in SIDIS

$$d\sigma^h \propto 1 + D_{NN} |\vec{S}_T| A_{Coll} \sin \phi_{Coll} + \dots$$

Transversity PDF

Transverse polarisation of quarks
in a transversely polarized nucleon

Collins FF

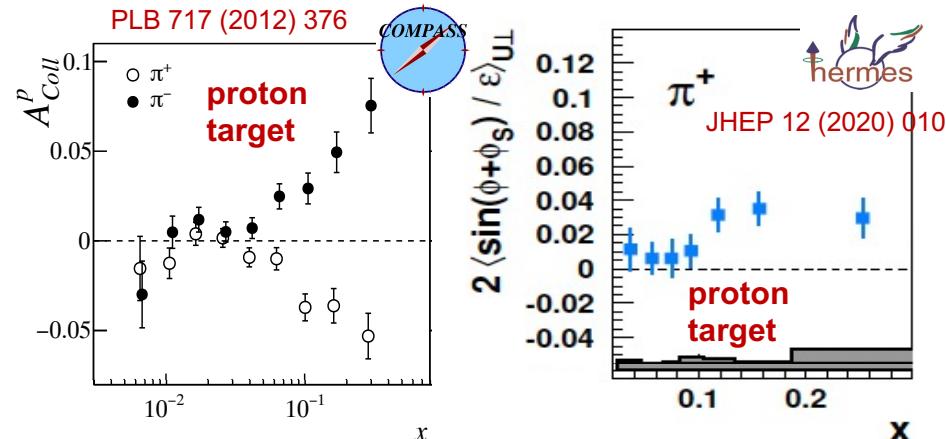
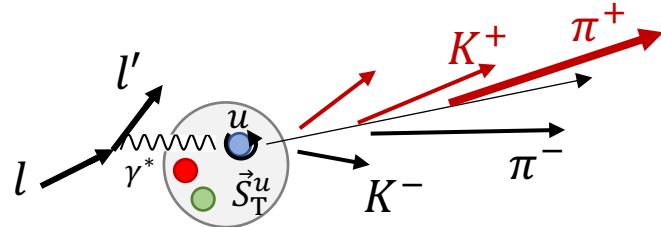
Fragmentation of a
transversely polarized quark
in an unpolarized hadron

$$A_{Coll} \simeq \frac{\sum_q e_q^2 h_1^q \times H_{1q}^{\perp h}}{\sum_q e_q^2 f_1^q \times D_{1q}^h}$$

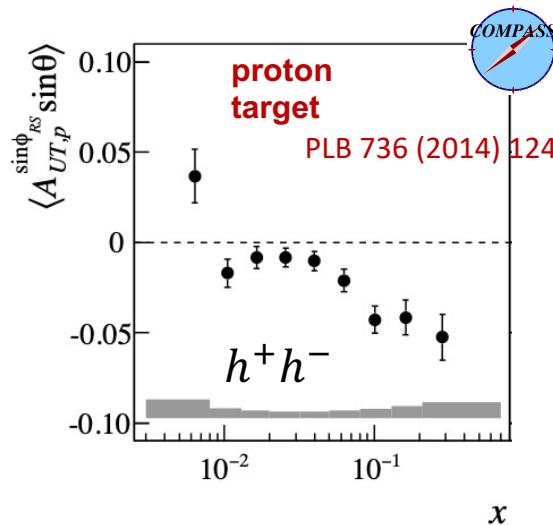
Motivation for spin effects in hadronization

The Collins effect in the fragmentation of transversely polarized quarks

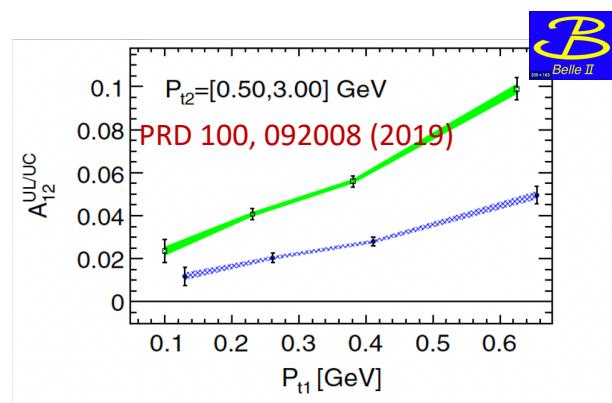
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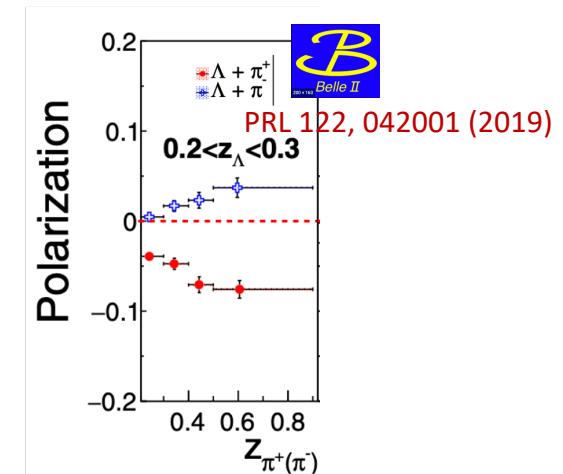
Shows up e.g. as the **Collins asymmetry** in SIDIS, .. but spin effects also in other processes



Dihadron production asymmetry
in SIDIS



Collins asymmetry for back-to-back $\pi^+\pi^-$ prod. in e^+e^- annih.



Λ transv. pol. in back-to-back
 $\Lambda\pi$ production in e^+e^- annih.

Spin effects are large and have been/are being explored by different experiments

- *they can not be studied with current event generators* see talk by S. F. Ravasio
- *recent work on introduction of spin effects in parton showers* Richardson, Webster, EPJ, C (2020) 80:83
still, complete collision events with spin effects can not be treated..

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still, complete collision events with spin effects can not be treated..

To build a MCEG with spin effects, a model for polarized hadronization is needed

*we use the **string+ 3P_0 model** to introduce spin effects in PYTHIA string fragmentation
for a DIS event with PS and VM production*

for now parton showers switched off

The string+ 3P_0 model of hadronization

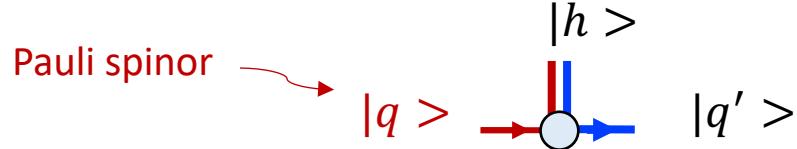
- Deeply studied by stand alone MC simulations

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

AK, X. Artru, Z. Belghobsi, A. Martin, PRD 100 (2019) 1, 014003

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- The building block of the model is the elementary splitting



The string+ 3P_0 model of hadronization

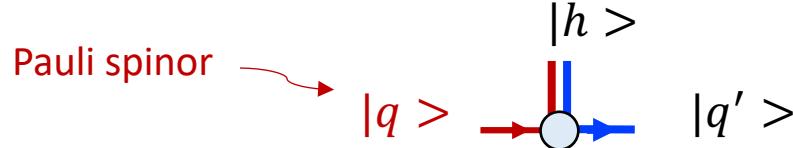
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- The building block of the model is the elementary splitting



described by the 2×2 quantum mechanical splitting amplitude T

$$T = (\text{Lund Splitting Function})^{1/2} \times$$

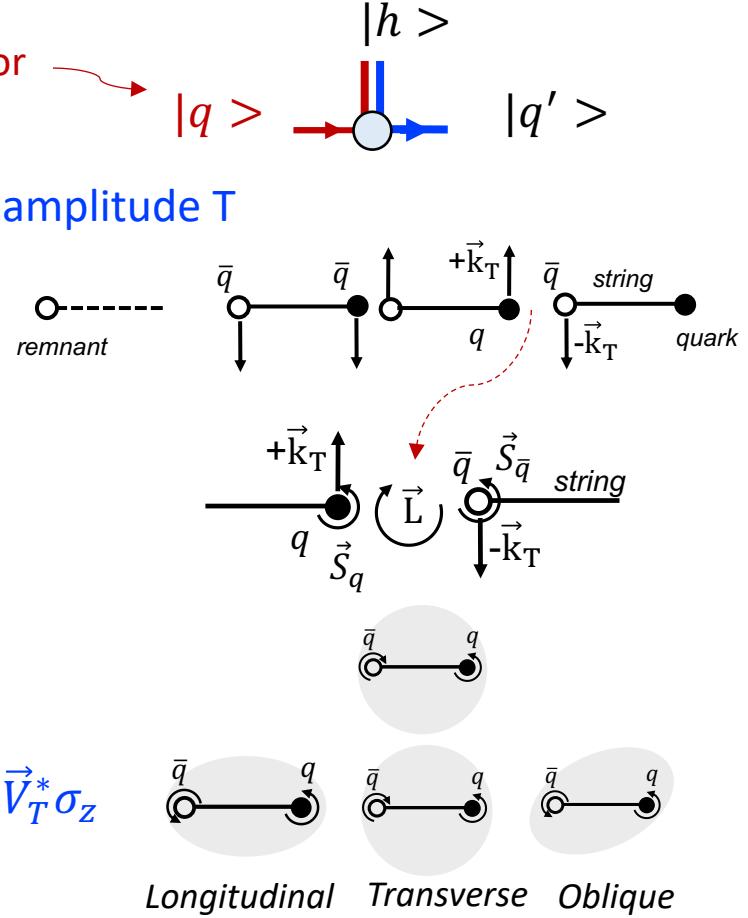
$\times {}^3P_0$ mechanism

$$\mu + \sigma_z \vec{\sigma}_T \cdot \vec{k}'_T$$

\times coupling $\left[\begin{array}{l} \text{PS meson: } \\ \text{VM with pol. } \vec{V} \end{array} \right]$

$$\sigma_z$$

$$G_L V_L^* \mathbf{1} + G_T \vec{\sigma}_T \cdot \vec{V}_T^* \sigma_z$$



The string+ 3P_0 model of hadronization: parameters

- Deeply studied by stand alone MC simulations

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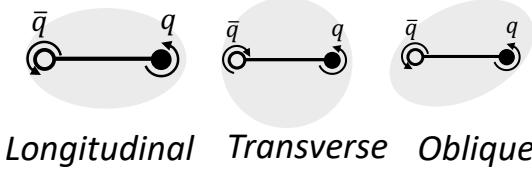
Complex mass μ :

$\text{Re } \mu \rightarrow$ longitudinal spin effects *(jet handedness)*

$\text{Im } \mu \rightarrow$ transverse spin effects *(Collins, dihadron)*

$$f_L = \frac{|G_L/G_T|^2}{2 + |G_L/G_T|^2} \rightarrow \text{relative fraction of L and T polarized VMs}$$

$$\theta_{LT} = \arg\left(\frac{G_L}{G_T}\right) \rightarrow \text{oblique polarization}$$

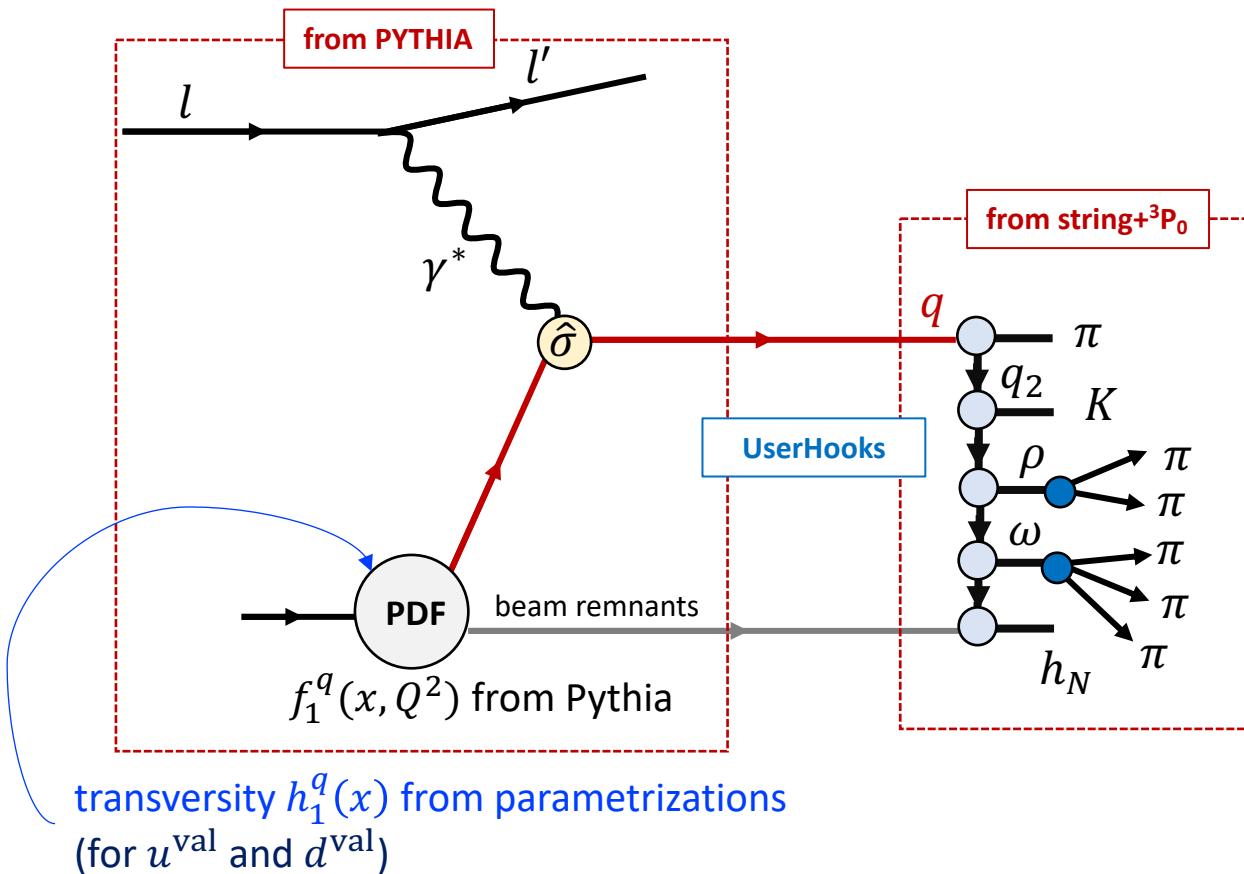


The interface with PYTHIA 8: StringSpinner

The string+ 3P_0 model has been interfaced to PYTHIA 8 for the DIS process as an external package

→ **StringSpinner**

[AK, L. Lönnblad, CPC 272 (2022) 108234] (only PS meson production)



Implementation of spin effects in PYTHIA

- Polarization \mathbf{S}_q of the struck quark calculated using h_1^q
- Polarization \mathbf{S}'_q of the scattered q transformed according to QED

- PYTHIA starts hadronization and emits $h_1 = \text{PS}$
- Accept h_1 with the 3P_0 probability for PS

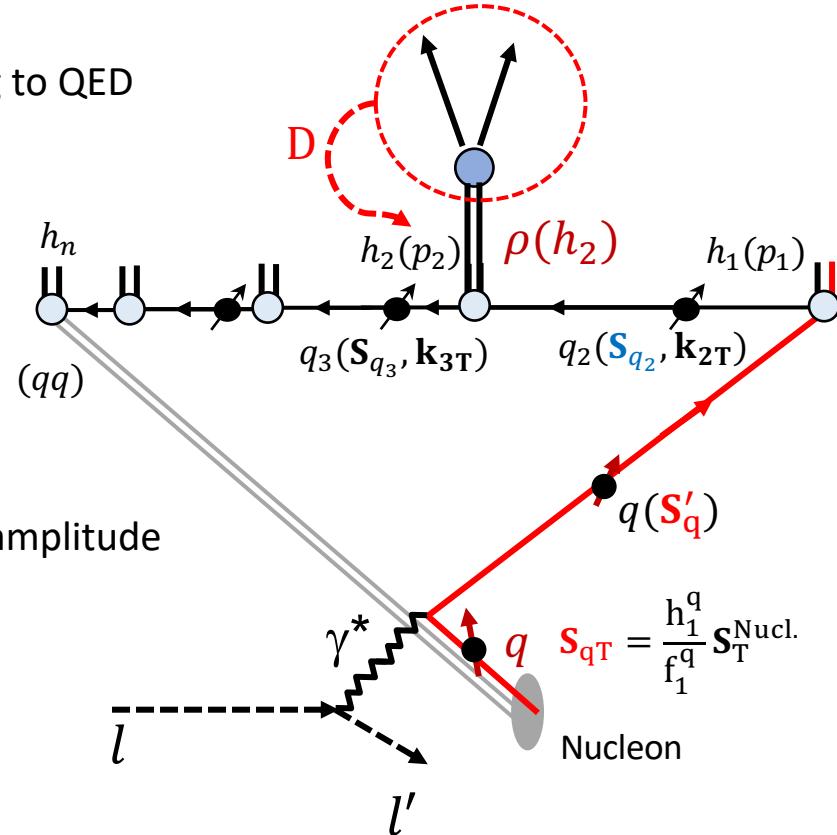
$$w_{\text{PS}} = [1 - \hat{\alpha} \mathbf{S}_q \cdot (\hat{z} \times \hat{\mathbf{k}}_{2T})]/2$$

$$\hat{\alpha} = \frac{2\text{Im}(\mu)k_{2T}}{|\mu|^2 + \mathbf{k}_{2T}^2}$$

- Decay of a PS meson handled by Pythia
- Calculate density matrix $\rho(q_2)$ of q_2 using the splitting amplitude

- PYTHIA emits $h_2 = \text{VM}$
 - Accept h_2 with the 3P_0 probability for VM
- $$w_{\text{VM}} = [1 + f_L \hat{\alpha} \mathbf{S}_{q_2} \cdot (\hat{z} \times \hat{\mathbf{k}}_{3T})]/2$$

- Decay the VM:**
 - calculate density matrix of VM
 - generate the polarized decay
 - Return a decay matrix \mathbf{D} to the VM production vertex [Collins '88, Knowles '88]
 - Store decay products and pass them to Pythia at a later stage
 - calculate density matrix of next quark



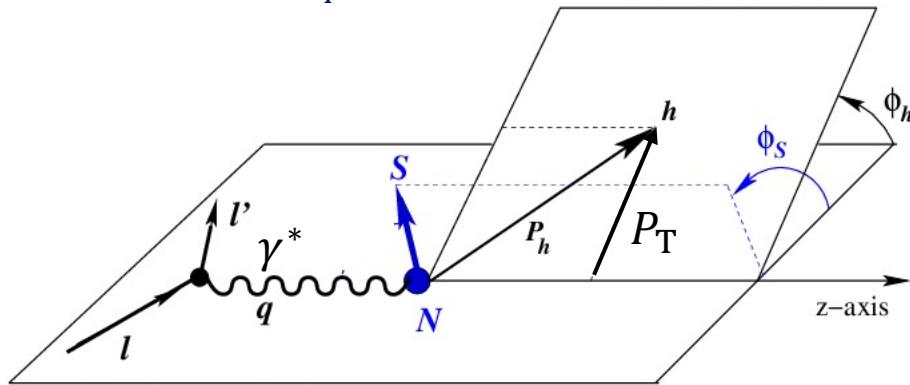
Recipe applied till end of string fragmentation

(selection of)

Results from simulations of T polarized SIDIS on protons

kinematics of COMPASS and HERMES experiments

no intrinsic \vec{k}_T



Relevant hadronic variables

Bjorken x

fractional energy $z = E_h/E_{\gamma^*}|_{TRF}$

transverse momentum P_T

Relevant free parameters for string fragmentation

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

Pythia parameters:

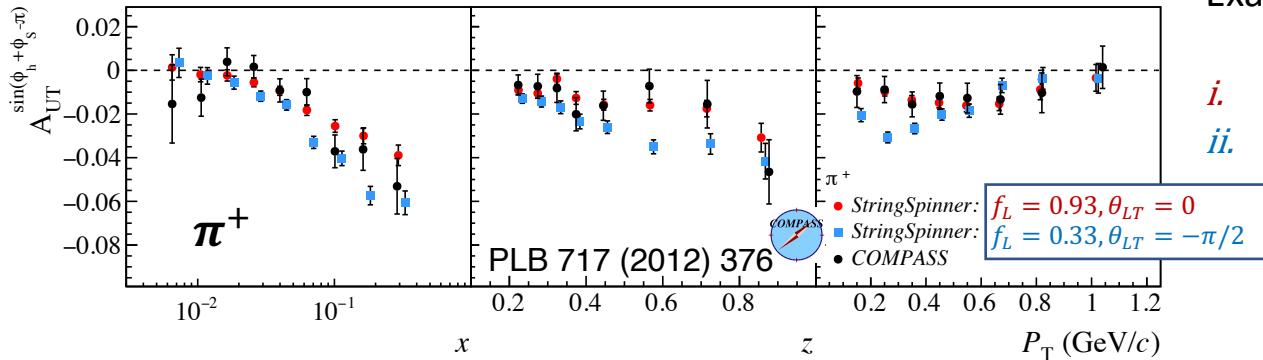
StringZ:aLund	0.9
StringZ:bLund	0.5 $(\text{GeV}/c^2)^{-2}$
StringPT:sigma	0.37 GeV/c
StringPT:enhancedFraction	0.0
StringPT:enhancedWidth	0.0 GeV/c

String+3P0 parameters

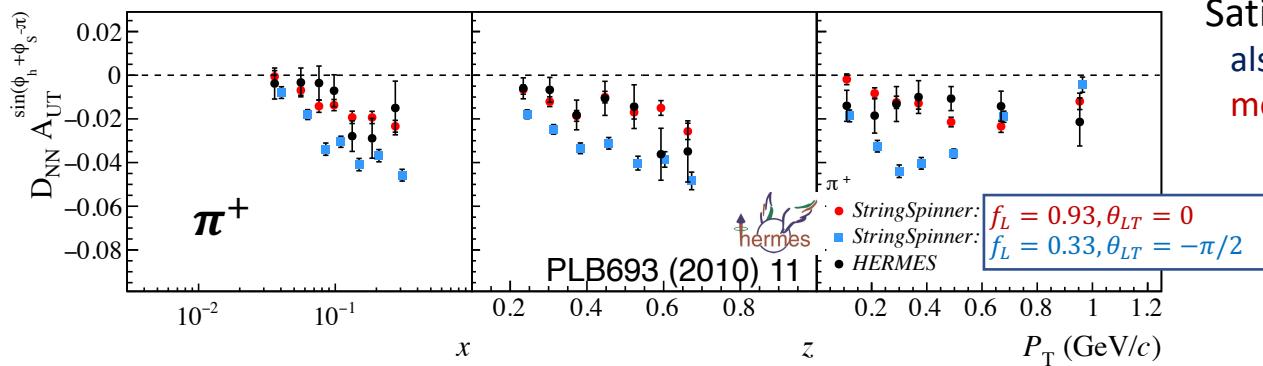
$\text{Re}(\mu)$	0.42 GeV/c^2
$\text{Im}(\mu)$	0.76 GeV/c^2
f_L	0.93, 0.33, 0.02
θ_{LT}	$-\pi/2, 0, +\pi/2$] No unique setting

Comparison with SIDIS data on TSA

COMPASS Collins asymmetry



HERMES Collins asymmetry



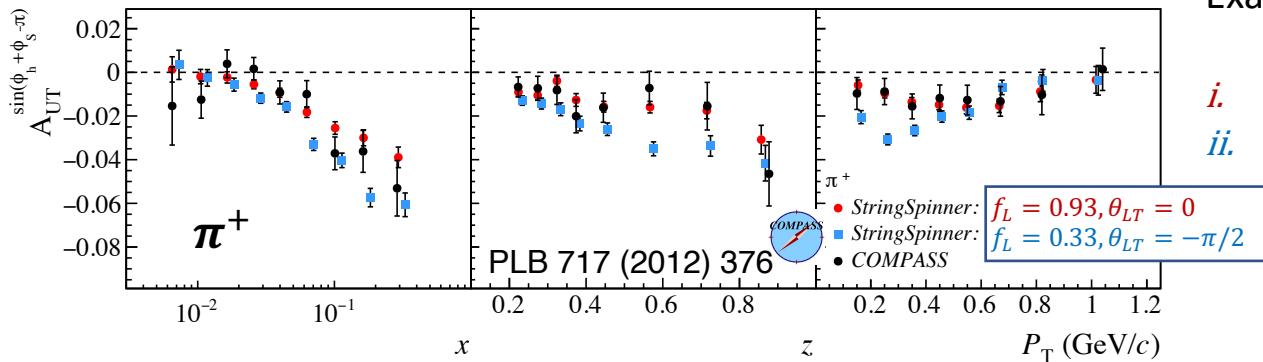
Example: two choices of parameters

- i. $f_L = 0.93, \theta_{LT} = 0$ good X^2
- ii. $f_L = 0.33, \theta_{LT} = -\frac{\pi}{2}$ bad X^2

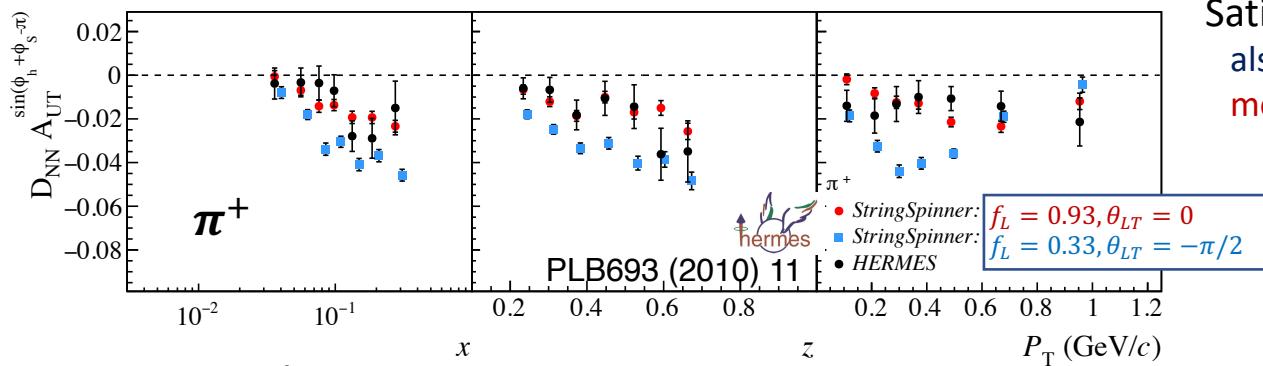
Satisfactory description of SIDIS data
also for other values of f_L and θ_{LT}
more precise SIDIS data needed to fix them

Comparison with SIDIS data on TSA

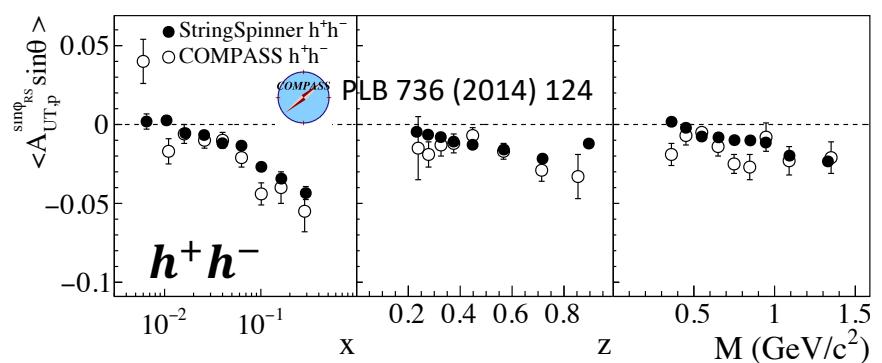
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HERMES Collins asymmetry



COMPASS 2h asymmetry



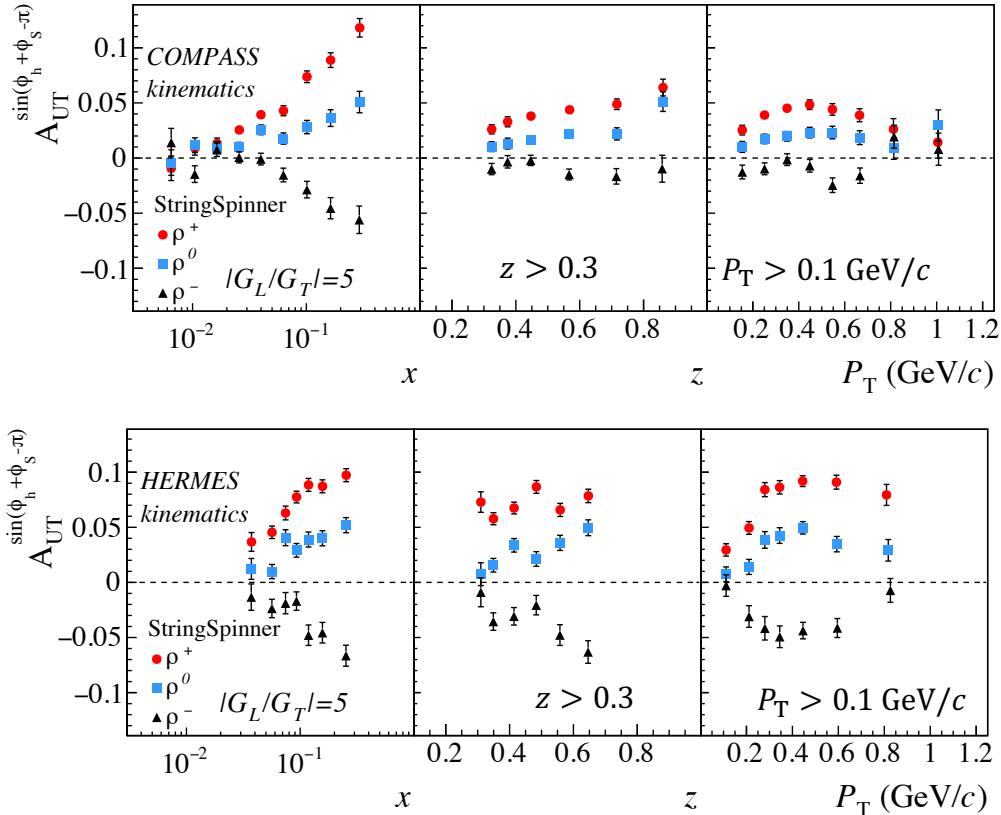
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Satisfactory description of SIDIS data
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Good description of 2h asymmetry
weak dependence on f_L and θ_{LT}

Collins asymmetries for ρ mesons



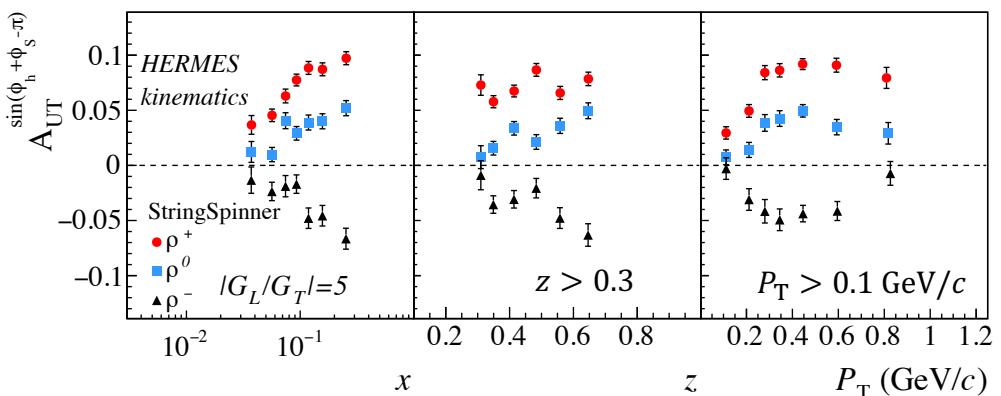
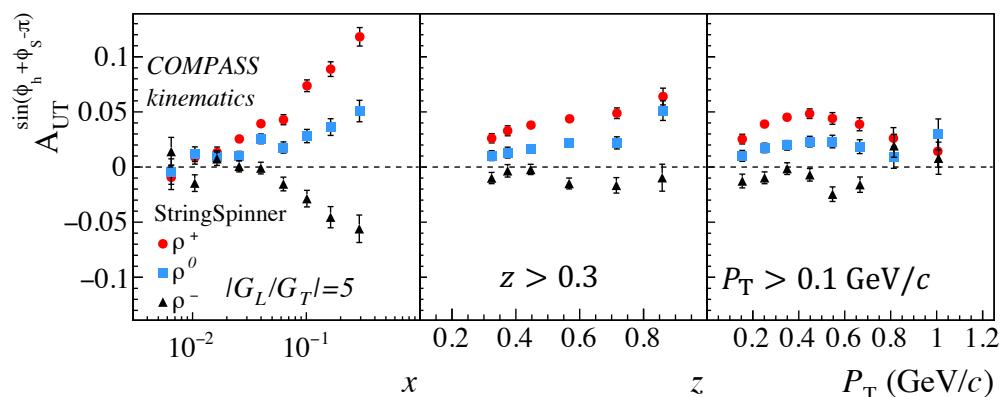
Large effects for large f_L

the asymmetry vanishes as $f_L \rightarrow 0$ (not shown here)

Strong dependence on f_L

a precise measurement of the asymmetry would help to fix the parameter

Collins asymmetries for ρ mesons

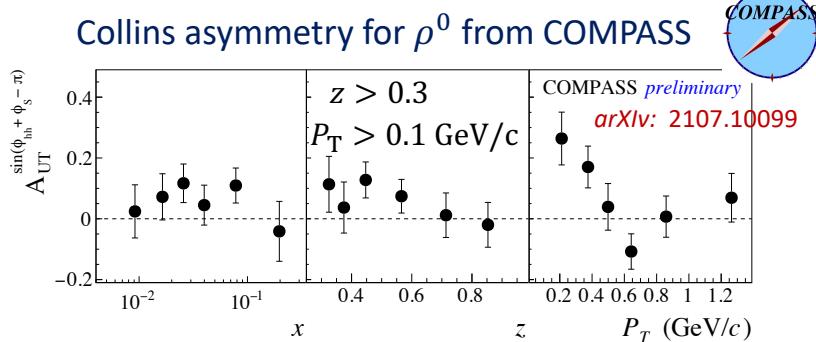


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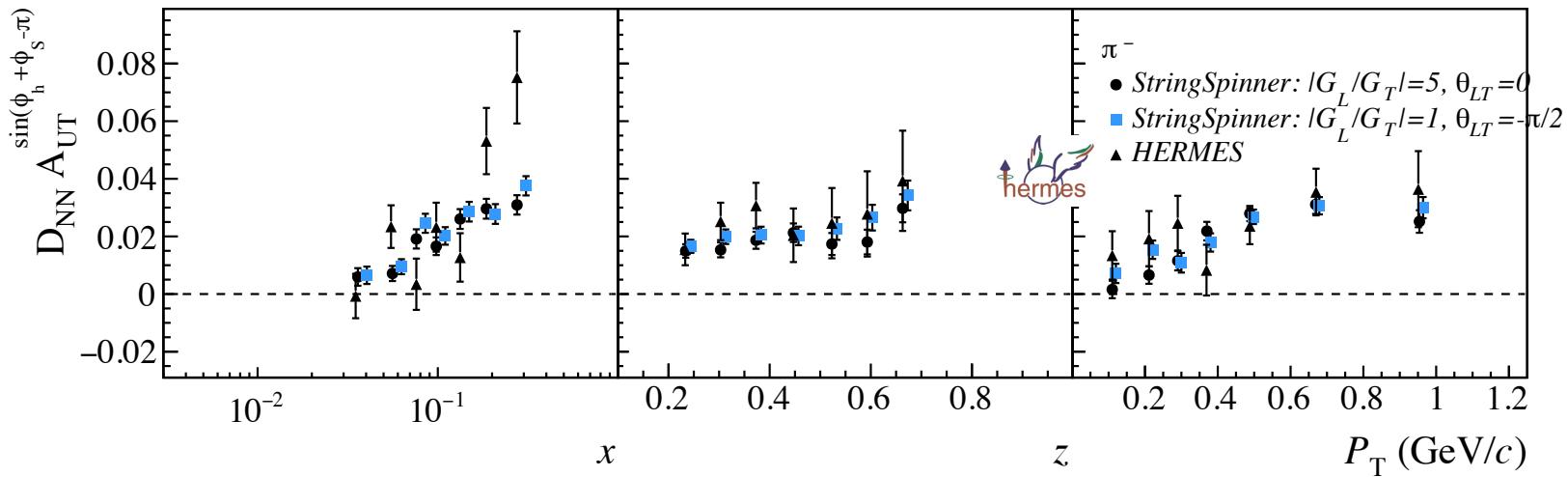
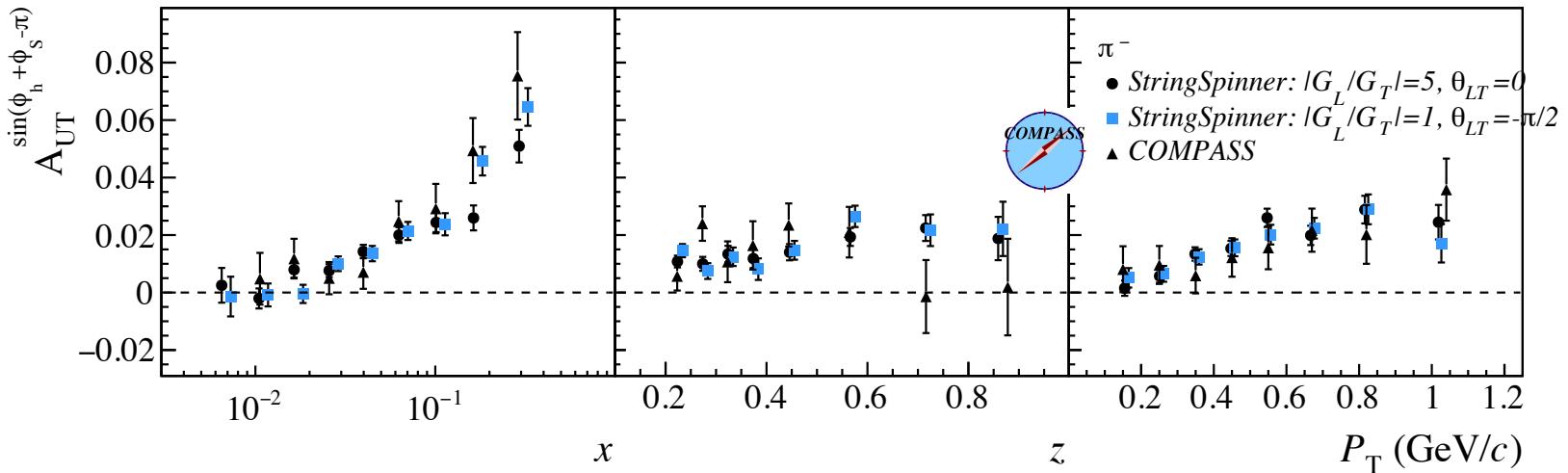
interesting result,
same sign as simulations and similar average value

Conclusions

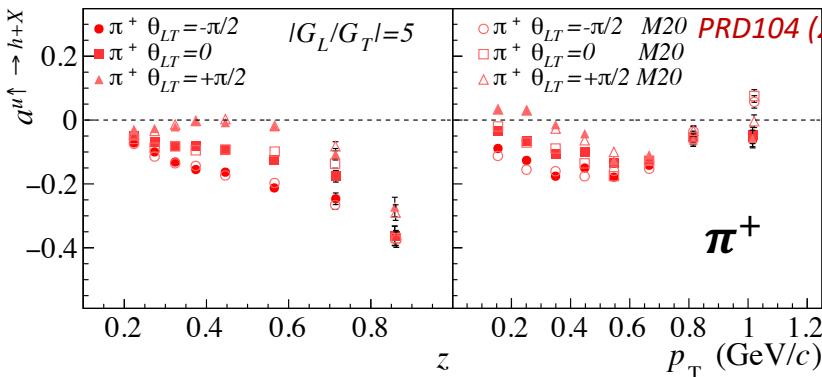
- Using the string+ 3P_0 model, we have started a systematic introduction of spin effects in Pythia 8 hadronization for DIS → the StringSpinner package
the most recent version with PS and VM production to be published soon
- Promising results, good description of available data
- The extention to other processes is important and foreseen
next step e^+e^- annihilation, important also to better tune the free parameters of the model

Backup

Comparison of Collins asymmetries for π^- with SIDIS data



Validation of transverse spin effects in StringSpinner



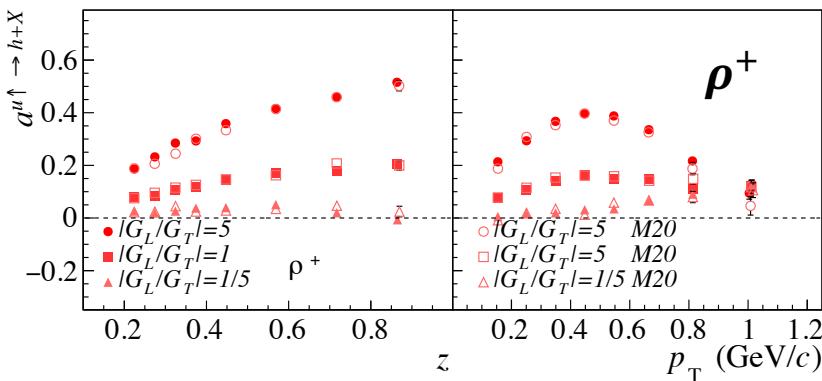
Collins analysing power for π^+

ok

same analysing power

same dependence on free parameters

ok also π^-

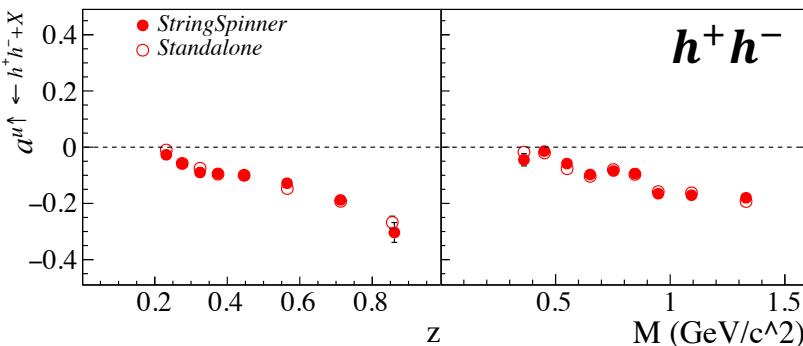


Collins analysing power for ρ^+

ok

same analysing power

ok also ρ^0, ρ^-



Dihadron analysing power for h^+h^-

ok

same analysing power

same spin effects as M20!

also same kinematic distributions
(not shown)