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Fragmentation of polarized quarks within the string+³P₀ model

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QCD structure of the nucleon

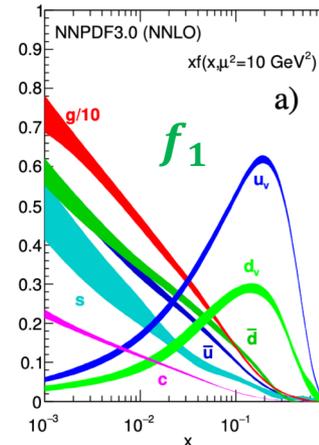
neglecting the quark transverse motions, the QCD structure of the nucleon is completely characterized by three **parton distribution functions (PDFs)**:

		nucleon		
quark		U	L	T
U		$f_1(x, k_T^2)$ <i>(unpolarized)</i>		$f_{1T}(x, k_T^2)$ <i>(Sivers)</i>
L			$g_1(x, k_T^2)$ <i>(helicity)</i>	$g_{1T}(x, k_T^2)$ <i>(worm-gear)</i>
T		$h_1^\perp(x, k_T^2)$ <i>(Boer-Mulders)</i>	$h_{1L}^\perp(x, k_T^2)$ <i>(worm-gear)</i>	$h_1(x, k_T^2)$ <i>(transversity)</i>
				$h_{1T}^\perp(x, k_T^2)$ <i>(pretzelosity)</i>

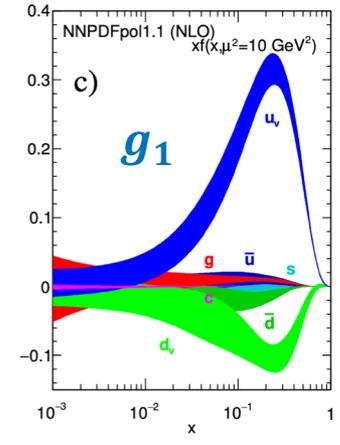
adding quark transverse momentum
other 5 TMD PDF's appear
~ *basically unknown*

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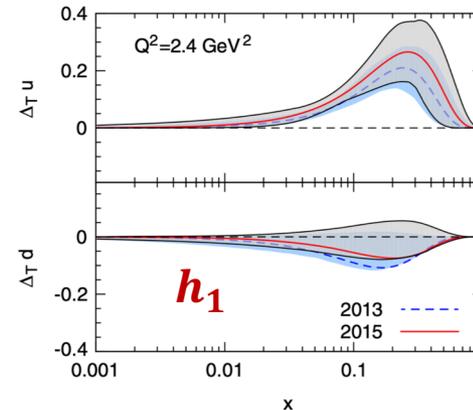
from PDG (2019)



known



fairly known



Anselmino et al.,
PRD 92, 114023
(2015)

the less known

accessing transversity: the Collins effect

transversity is necessary for the complete characterization of the nucleon at leading order but difficult to measure

*chiral odd object, therefore can only be measured coupled with an other chiral odd function, behaving as **a polarimeter for the quark transverse polarisation***

currently the most used polarimeter is the **Collins effect** (*J. Collins, 93'*):

left/right asymmetry in the azimuthal distribution of hadrons produced in the fragmentation of a transversely polarized quarks

described by the **Collins analysing power**

$$a^{q\uparrow \rightarrow h+X}(z_h, p_T) = \frac{p_T}{z_h M_h} \frac{H_{1q}^{h\perp}}{D_{1q}^h}$$

Collins Fragmentation Function (FF) (arrow pointing to $H_{1q}^{h\perp}$)

$z \simeq E_h / E_{quark}$ (arrow pointing to z_h)

transverse momentum of h (arrow pointing to p_T)

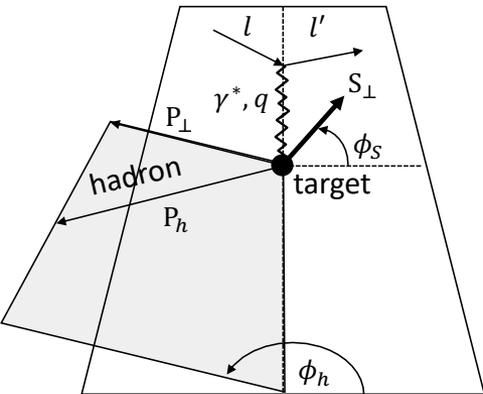
unpolarized fragmentation function (arrow pointing to D_{1q}^h)

however, **the Collins effect is not just a polarimeter**

It's study allows to shed light on the non perturbative spin dependence of the fragmentation process, still not understood

quark polarimetry

a powerful tool to access transversity and other TMD PDFs is semi-inclusive deep inelastic scattering (**SIDIS**)

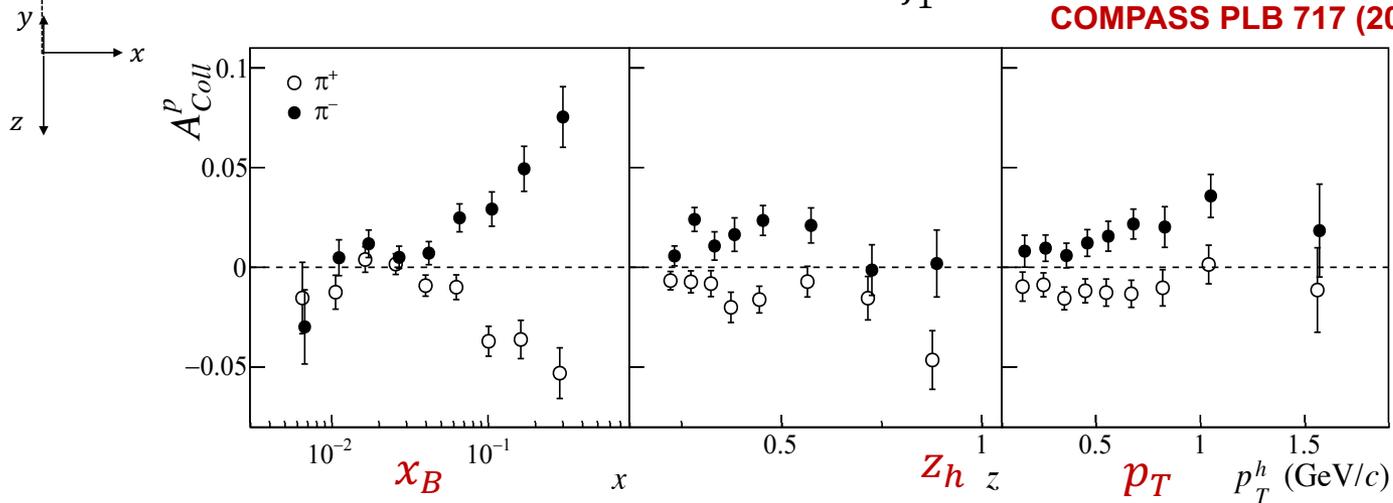


if only one hadron is observed in the final state
in the cross section transversity appears coupled with the Collins FF
*producing an azimuthal modulation known as the **Collins asymmetry***

$$A_{Coll}(x_B, z_h, p_T) = \frac{\sum_q e_q^2 h_1^q \otimes H_{1q}^{\perp h}}{\sum_q e_q^2 f_1^q \otimes D_{1q}^h}$$

for a proton target $A_{Coll} \simeq \frac{h_1^u}{f_1^u} \times a^{u \uparrow \rightarrow h+X}$

COMPASS PLB 717 (2012) 376



to improve the extraction of transversity and of the other TMD PDFs a good model and reliable MC simulations are needed

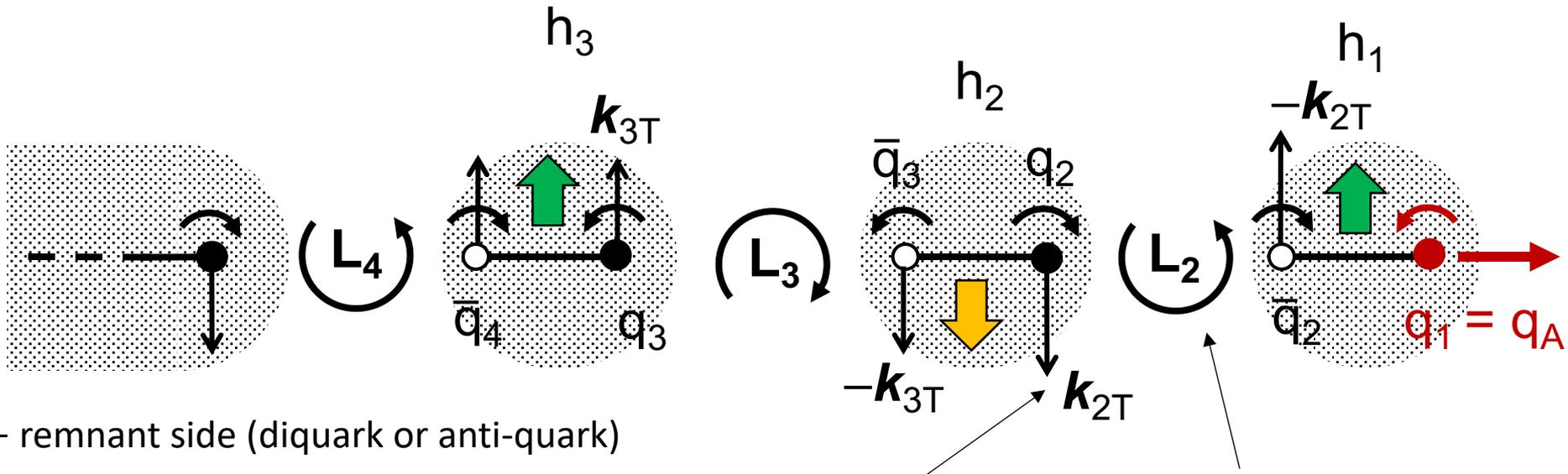
- phenomenological description of data
 - guide for data analysis
 - predictions for future experiments (JLab12, EIC, LHCspin, ..)
-
- presently commonly used event generators do not include spin effects in hadronization → **no Collins effect**

I tried to fill this lack by using a solid model
to this topic I dedicated my master thesis and my PhD

the string + 3P_0 model (X. Artru, 2009)

$q\bar{q}$ pairs in 3P_0 state: $S = 1, L = 1, \mathbf{L} = -\mathbf{S} \quad [J = 0]$

pseudo-scalar meson



left-right asymmetry → classical model for the Collins effect

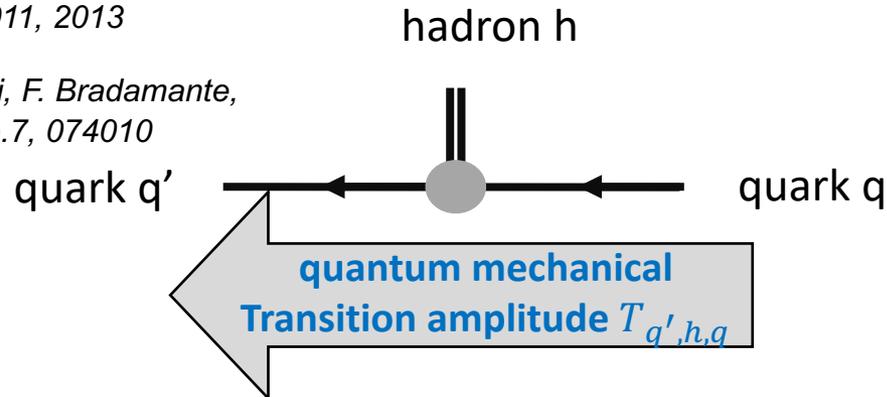
for a reliable model → quantum mechanical formulation needed

recursivity: the elementary splitting

string breaking can be viewed as the recursive repetition of the elementary splitting

X. Artru, Z. Belghobsi *DSPIN-2011*, 2013

A. Kerbizi, X. Artru, Z. Belghobsi, F. Bradamante,
and A. Martin, *PRD97* (2018) no.7, 074010



$T_{q',h,q} =$ string fragmentation dynamics \times spin matrices from $3P_0$ mechanism
~ Lund String Model
as in Pythia, Lepto, ..

- only one new complex free parameter for all spin effects

basis for MC simulations

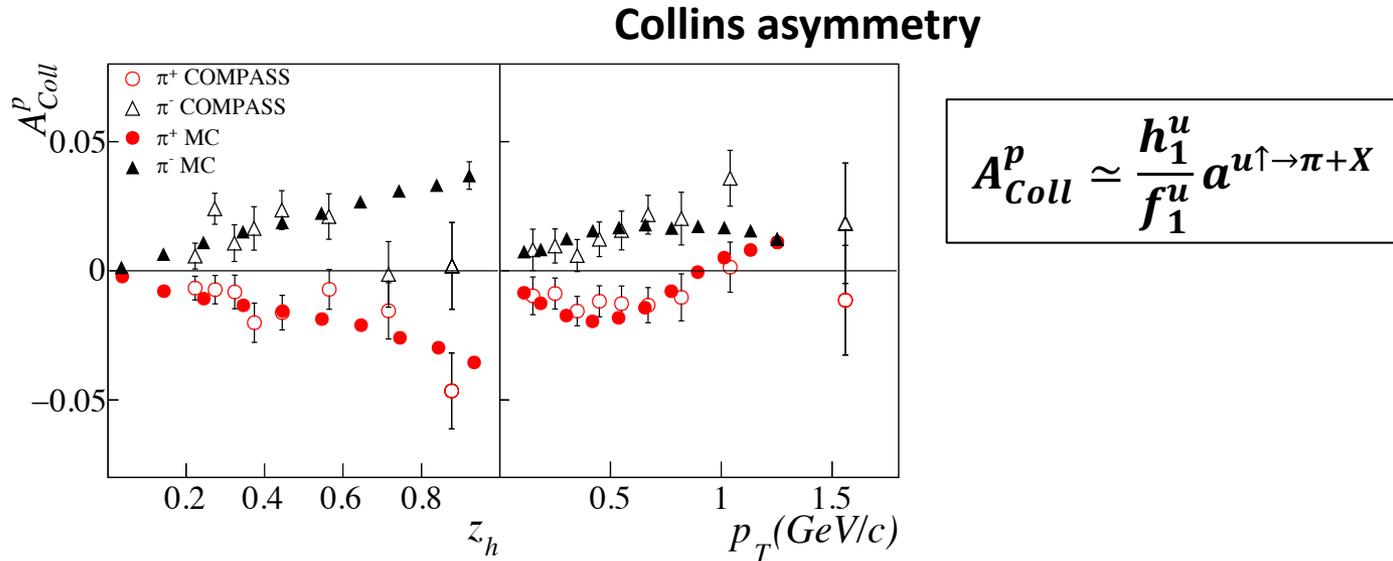
the model is implemented in a stand alone MC program

allowed to fix the free parameters by comparison with suitable observables

comparison with COMPASS proton data

A. Kerbizi, X. Artru, Z. Belghobsi, F. Bradamante and A. Martin, PRD97 (2018) no.7, 074010

COMPASS PLB 717 (2012) 376



- **in simulations only fragmentation of fully transversely polarized u quarks**
because in reality quarks are partially polarized, the MC is scaled by $\lambda \simeq h_1^u/f_1^u = 0.055 \pm 0.010$ estimated by a χ^2 minimization
- **the model reproduces the main features of the data**
→ **strong motivation to continue the work**

implementation of the 3P_0 model in PYTHIA 8

for more quantitative simulations:

- the 3P_0 model has been implemented in Pythia 8 **for the simulation of the transversely polarized SIDIS processes**
- parametrizations of the transversity PDFs are introduced for the calculation of the quark transverse polarization

Kerbizi, Lönnblad, PoS DIS2019 (2019) 179

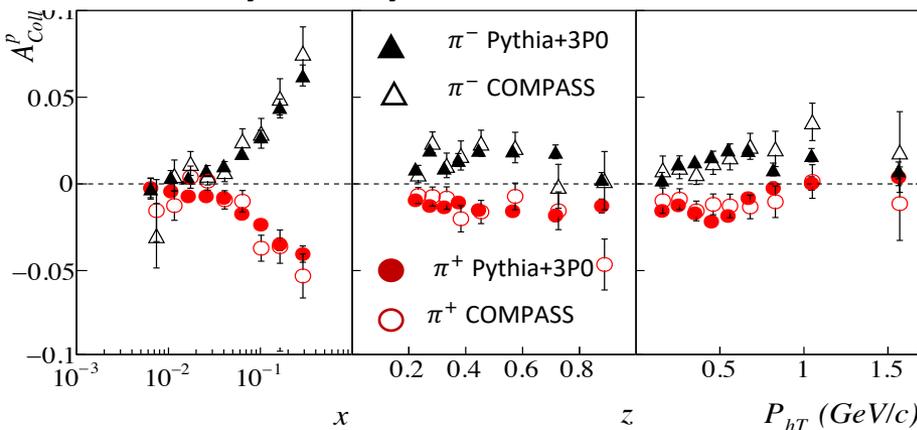
- **new development, done for the first time**

→ restrictions (only pseudoscalar mesons, no parton showers)

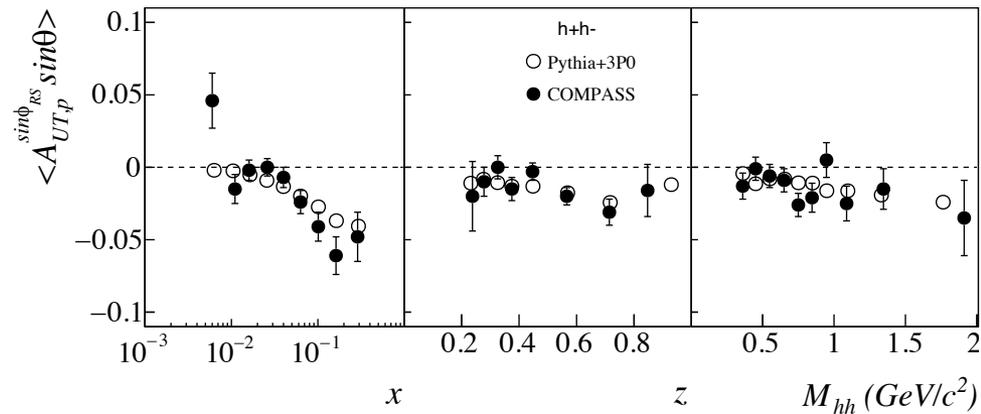
the same mechanism reproduces other effects: f.i. the dihadron asymmetry

Collins asymmetry

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COMPASS PLB 736 (2014) 124



nice description of data!!

conclusions

- in spite of being simple, the string+3P0 model provides a nice description of data and has predictive power
- for the first time spin effects in Pythia 8 hadronization
 - starting point for the systematic introduction of spin effects in the generator
- the model is being developed further
 - vector meson production is being studied
 - the description of other processes like the e^+e^- annihilation to hadrons which is the next step

Thank you!