Di-hadron asymmetries and interplay between transversity induced asymmetries in hadron leptoproduction at COMPASS

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DSPIN2015

8-12 September 2015 JINR, DUBNA

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

Collaboration
~ 250 physicists
28 institutions
12 countries

fixed target experiment at the CERN SPS

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

wide physics program carried on using both **muon** and hadron beam

luminosity: ~5 · 10^{32} cm^{-2} s^{-1}

beam intensity: 2·10^8 μ^+/spill (4.8s/16.2s)

beam momentum: 160 GeV/*c*

longitudinally polarized muon beam	**deuteron (^{6}LID)** polarized target	2002	L/T	hadron beam	nuclear targets	2004
		2003				
		2004				
		2006	L		LH target	2008
	proton (NH_3) polarized target	2007	L/T			2009
		2010	T			2012
		2011	L			2014
	H_2 target	2012			polarised DY	2015

the COMPASS spectrometer

- high energy beams
- large angular acceptance
- broad kinematical range

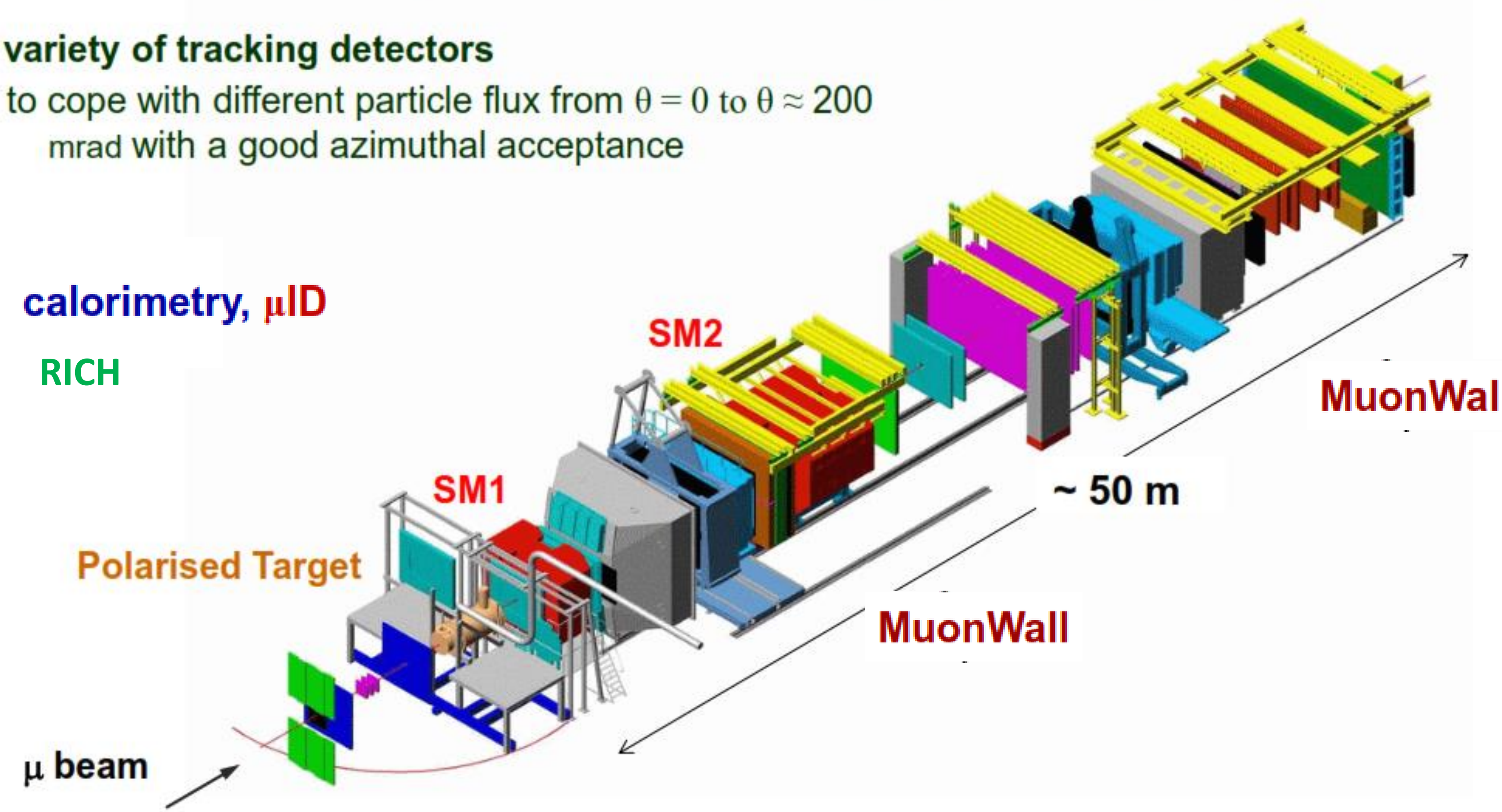
two stages spectrometer

Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors

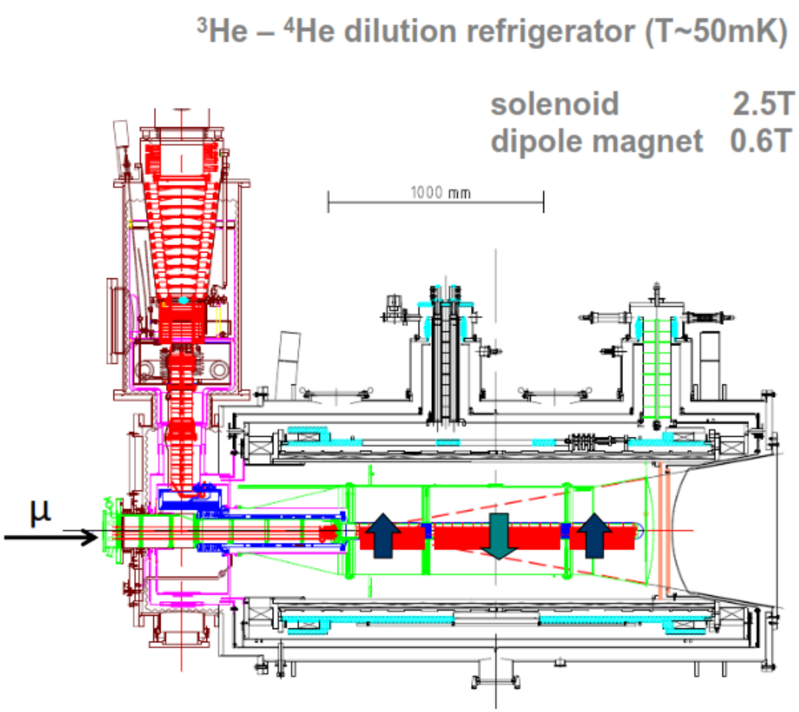
to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance



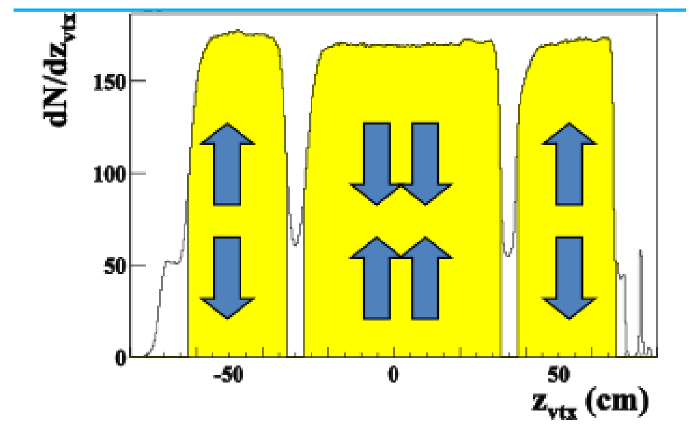
polarized target system (>2005)

solid state target operating in frozen spin mode

	d (^{6}LiD)	p (NH_3)
polarization	**50%**	**90%**
diliution factor	**40%**	**16%**



3 cells target with opposite polarizations



2 configurations:
polarisation reversed each week
to minimize possible systematic errors

the results shown in these slides are obtained from:

- **analysis performed on charged hadrons (unidentified)**
- **data taken during 2010**
- **on a transversely polarised proton target (NH_3)**
  and using a 160 GeV positive muon beam

SIDIS: *a key process to* ***investigate*** *the* ***structure of the nucleon***

lepton interacts with a **single constituent** of the nucleon (Q^2>1GeV^2/c^2)

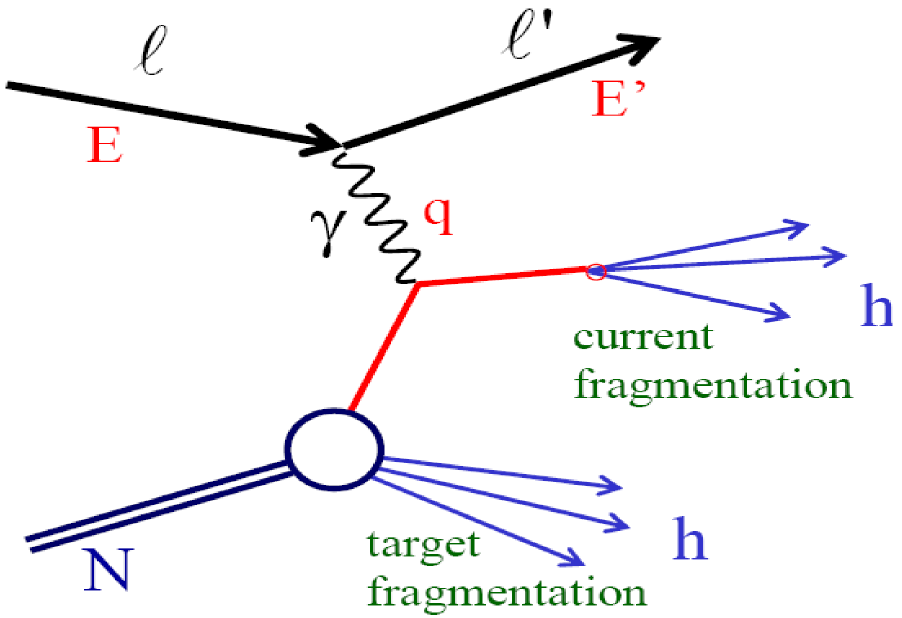
$$q = \ell - \ell'$$

$$Q^2 = -q^2 \qquad W^2 = (P+q)^2$$

$$x = \frac{Q^2}{2P\cdot q}$$ *Bjorken scaling variable*

$$y = \frac{P\cdot q}{P\cdot \ell} = \frac{E-E'}{E}$$

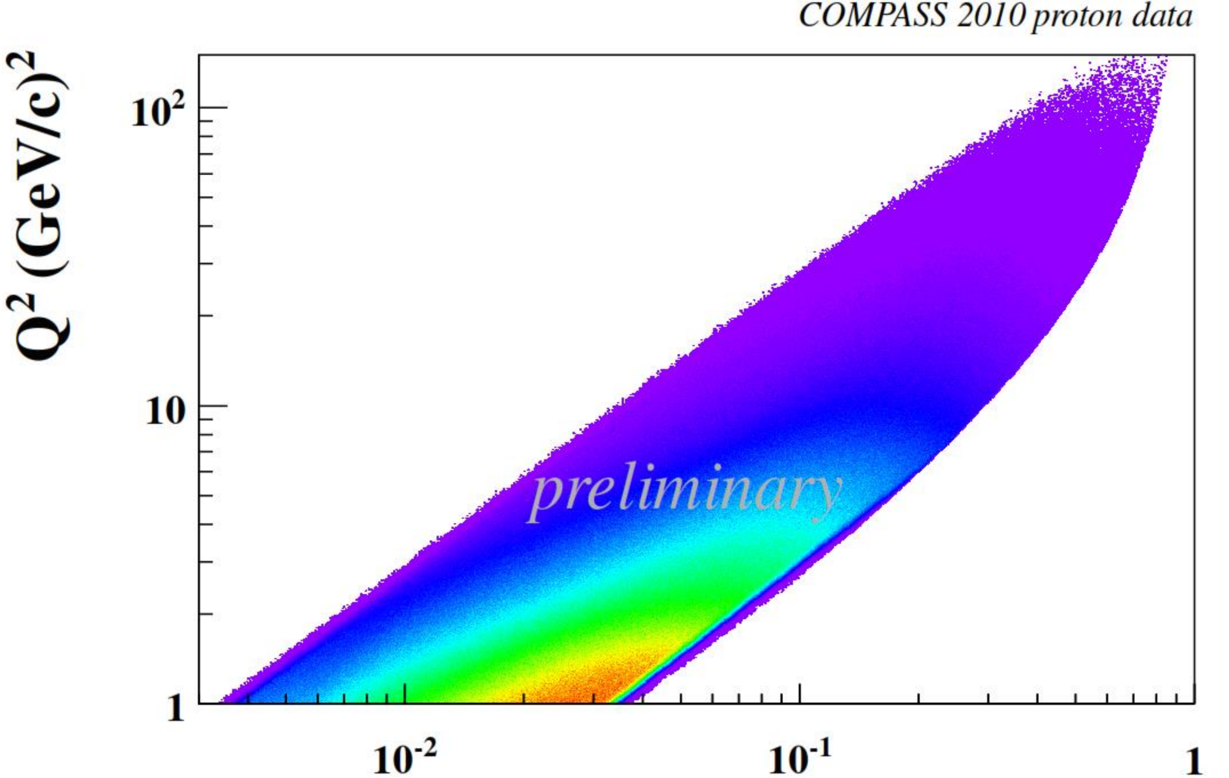
$$z = \frac{P\cdot P_h}{P\cdot q} = \frac{E_h}{E-E'}$$

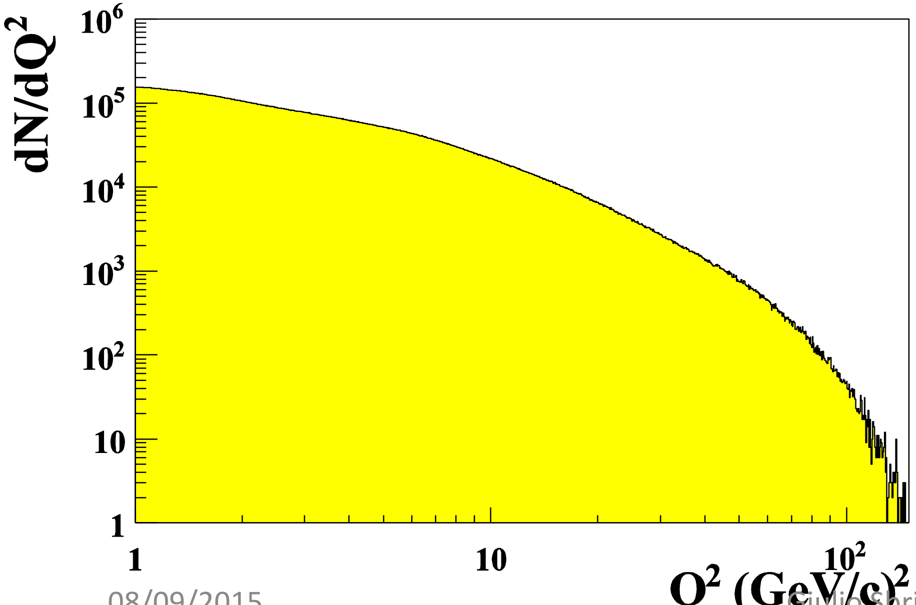


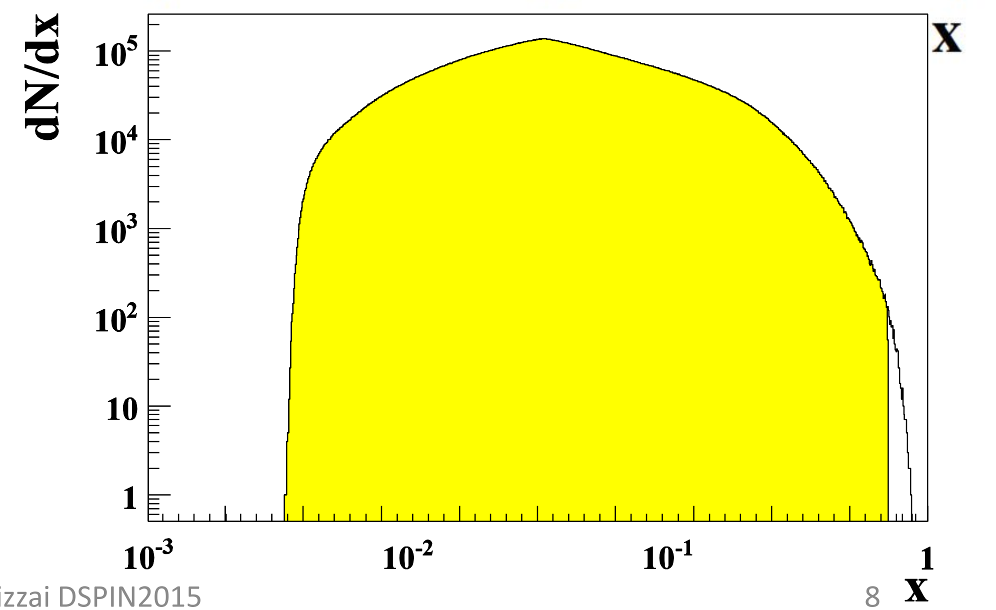
at least one hadron is detected in the final state
(information on the struck quark)

DIS event selection

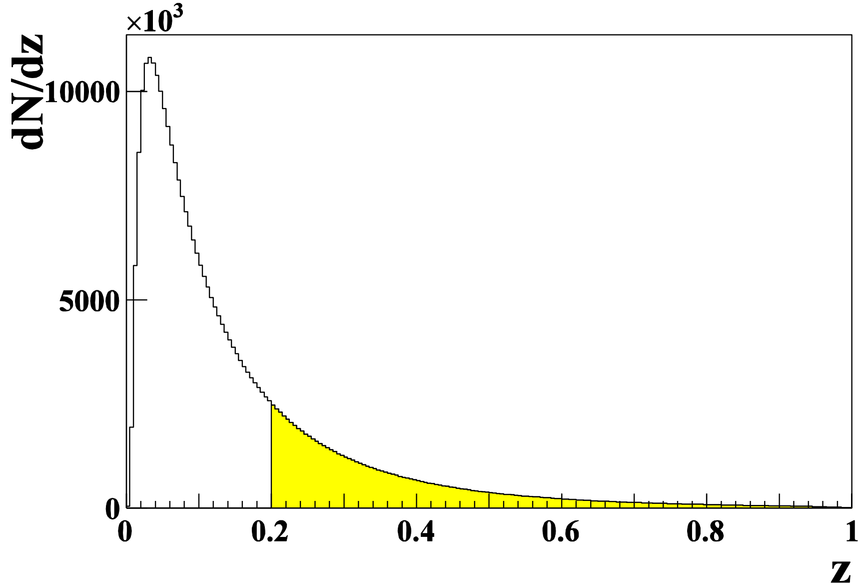
$Q2 > 1\ (GeV/c)^2$
$0.1 < y < 0.9$
$W > 5\ GeV/c^2$

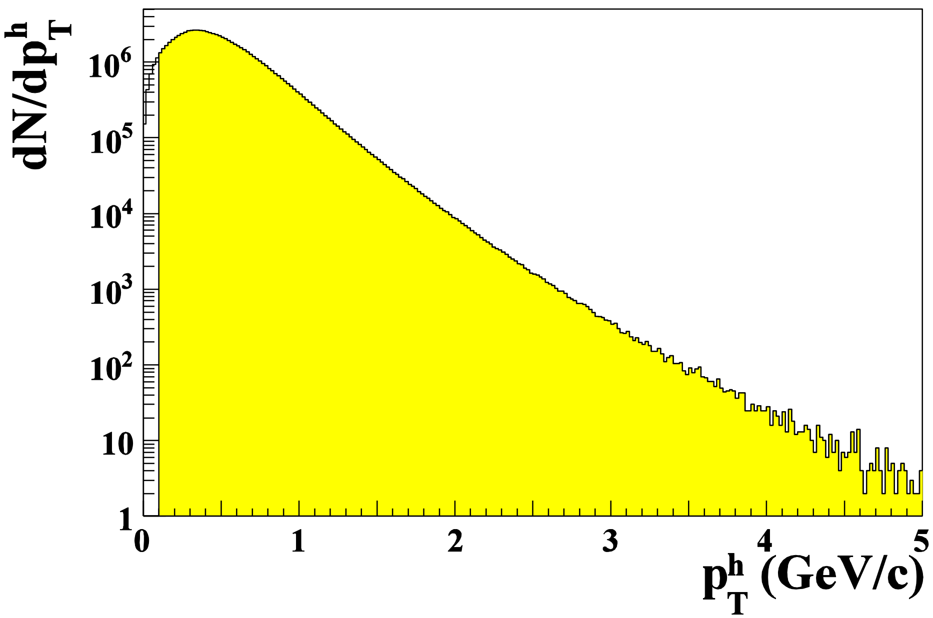






SIDIS event selection





charged hadron selection

z>0.2

p_T^h > 0.1 GeV/c ← transverse momentum w.r.t. the virtual photon direction

Collins Asymmetries

Collins asymmetries $l\ N \rightarrow l' h X$

direction of the polarization

kinematical factors $D_{NN} = \frac{1-y}{1-y-\frac{y^2}{2}}$

$$N_h^{\pm} = N_h^0 \left[1 \pm f P_T D_{NN} A_{Coll} \sin(\phi_h + \phi_S + \pi)\right]$$

Collins angle

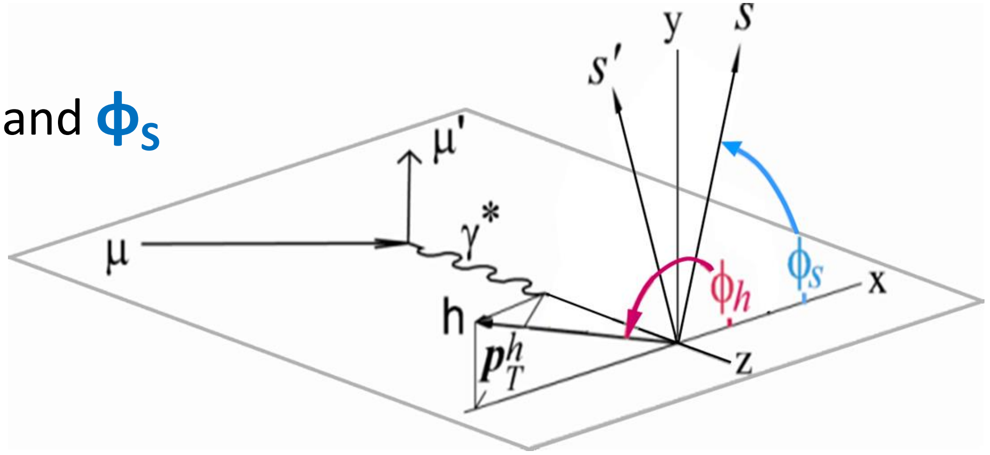
target polarisation P_T
dilution factor f

transversity PDF — Collins FF

convolution over the transverse momenta of the quarks in the nucleon $k_\perp$ and in the fragmentation $p_\perp$

$$A_{Coll} \approx \frac{\sum_q e_q^2 \cdot h_1^q(k_\perp^2, x) \otimes H_{1q}^{\perp h}(p_\perp^2, z)}{\sum_q e_q^2 \cdot f_1^q(k_\perp^2, x) \otimes D_{1q}^{2h}(p_\perp^2, z)}$$

definition of the produced hadron and target polarisation azimuthal angles ϕ_h and ϕ_S



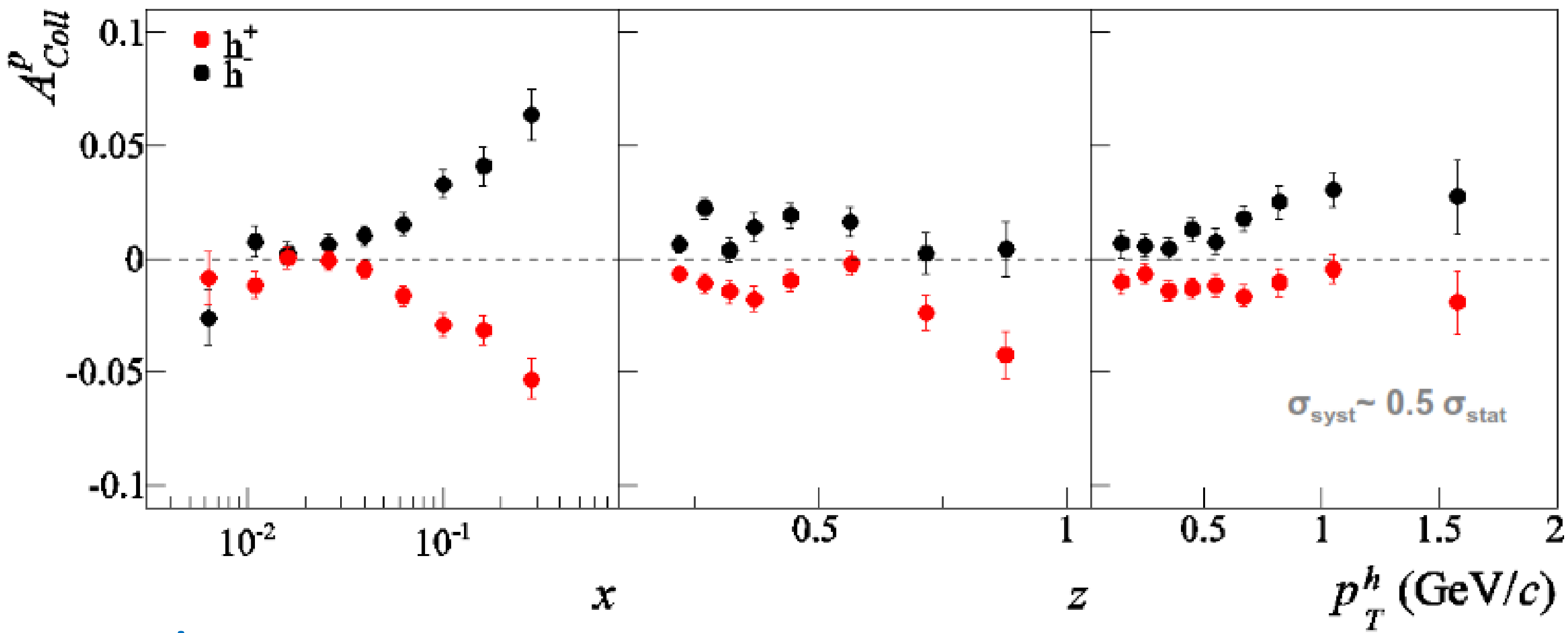
The Collins asymmetry *charged hadrons*

azimuthal distributions calculated in the different bins of ***x***, ***z*** and p_T^h

amplitudes of the azimuthal modulations **extracted**

fitting the azimuthal distribution in ϕ_h and ϕ_S *using extended maximum likelihood estimator*

combined **2007** - PLB 692 (2010) 240 - and **2010** - PLB 717 (2012) 376 -



- **precise measurements**
- **clear signal at x > 0.03, with opposite sign for h+ and h-**

dihadron asymmetries

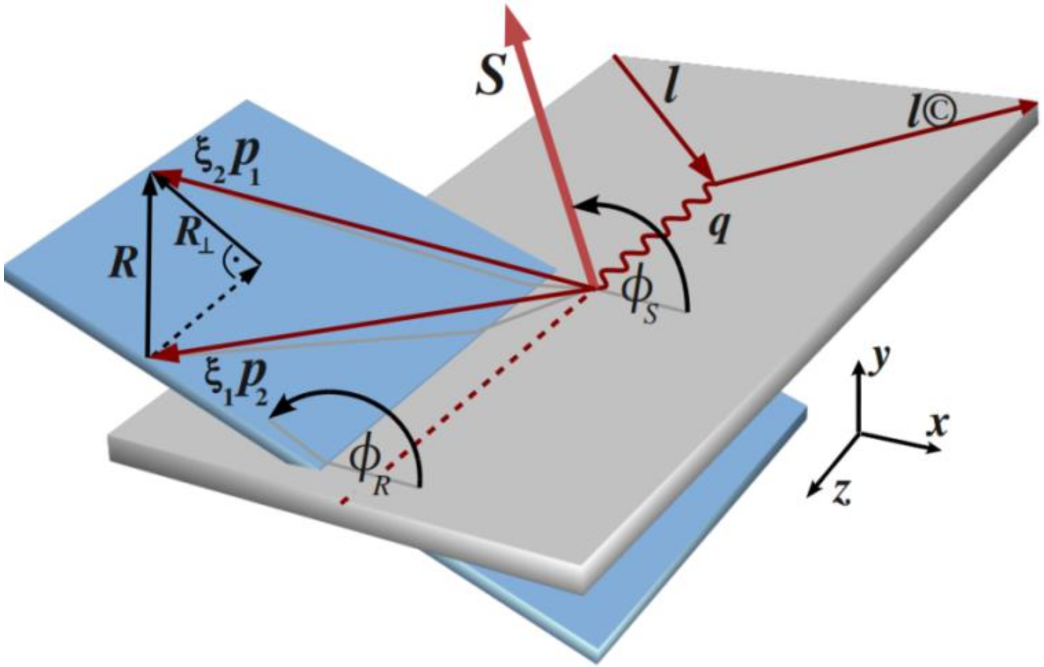
dihadron asymmetries

$$lN \rightarrow l' h^+ h^- X$$

we measure $A_{UT}^{\sin\phi_{RS}}$

from $N_{h^+h^-} = N_h^0 \left[1 \pm f P_T D_{NN} A_{UT}^{\sin\phi_{RS}} \sin(\phi_{RS})\right]$

all possible ***oppositely charged hadrons pairs***



the azimuthal distribution of the hadrons pairs shows a modulation in the **azimuthal angle**:

$$\phi_{RS} = \phi_R + \phi_S - \pi$$

$$R = \xi_1 p_1 - \xi_2 p_2$$

$$\xi_1 = \frac{z_2}{z_1 + z_2} \qquad \xi_2 = \frac{z_1}{z_1 + z_2}$$

Artru definition arXiv:0207309v2
equivalent to Radici et al arXiv:1212.3568v1
as seen from data

dihadron asymmetries

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all possible ***oppositely charged hadrons pairs***

transversity PDF

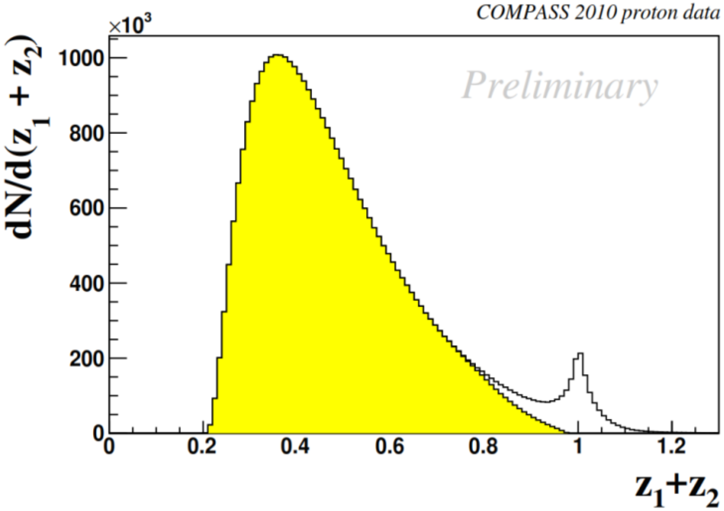
dihadron interference FF

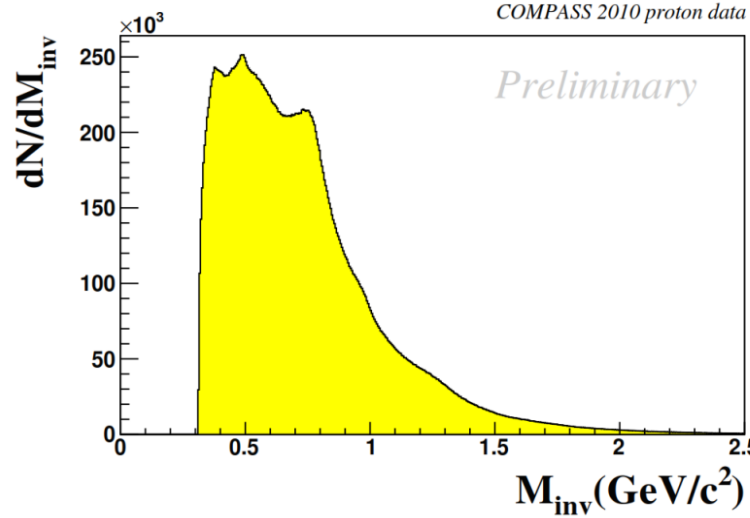
$$A_{UT}^{\sin\phi_{RS}} \approx \frac{\sum_q e_q^2 \cdot h_1^q(x) \cdot H_{1q}^{\angle}(z, M_{hh}^2)}{\sum_q e_q^2 \cdot f_1^q(x) \cdot D_{1q}^h(z, M_{hh}^2)}$$

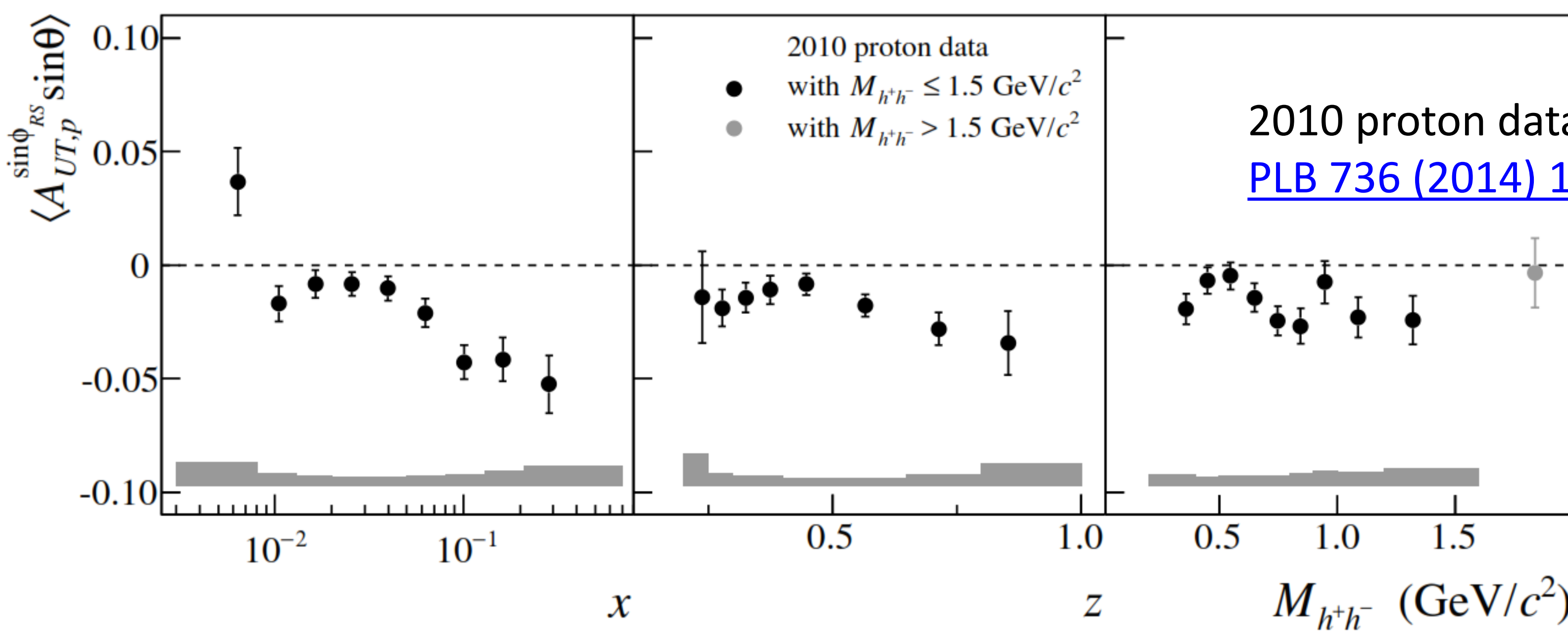
no convolution on the intrinsic transverse momenta

collinear !

$A_{UT}^{\sin\phi_{RS}}$ **asymmetries** measured as function of x, $z=z_1+z_2$, M_{inv}

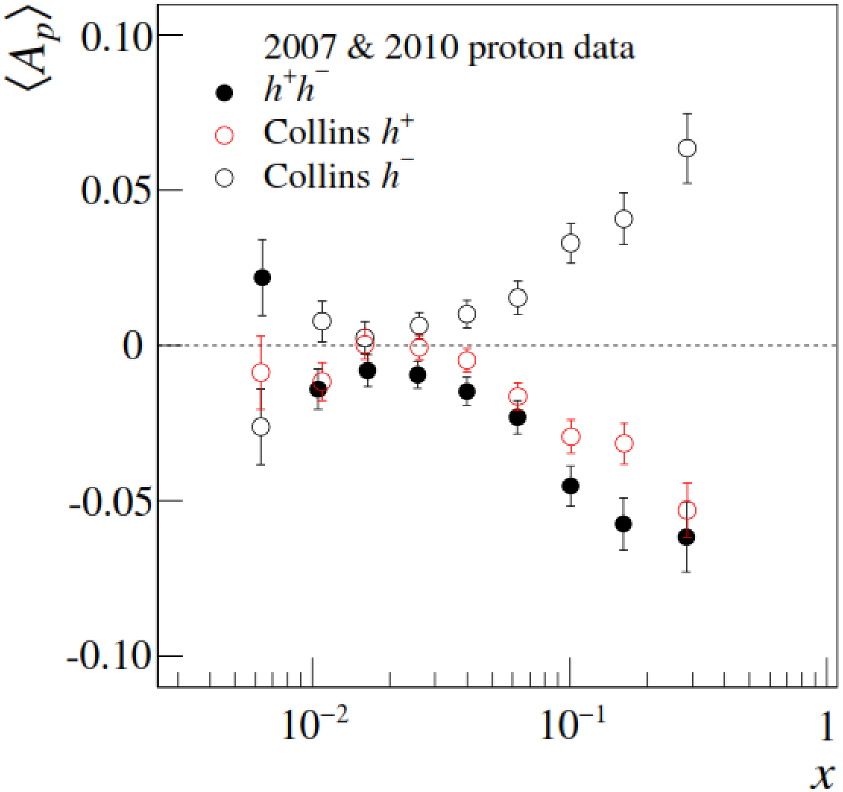






2010 proton data
PLB 736 (2014) 124

interplay between dihadron and Collins asymmetries



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- Collins asymmetry for h+ and for h- :
  "mirror symmetry"
- dihadron asymmetry vs Collins asymmetry:
  only somewhat larger

motivated further studies on the interplay between the transversity induced asymmetries analysis of the single hadron and dihadron **transversity induced asymmetries** performed ***on a common data sample*** *(2010 transversely polarised proton)*

standard COMPASS SIDIS sample
but with h^+ h^- at least detected (each hadron with z >0.1)

essentially the same as the sample used to measure the dihadron asymmetries

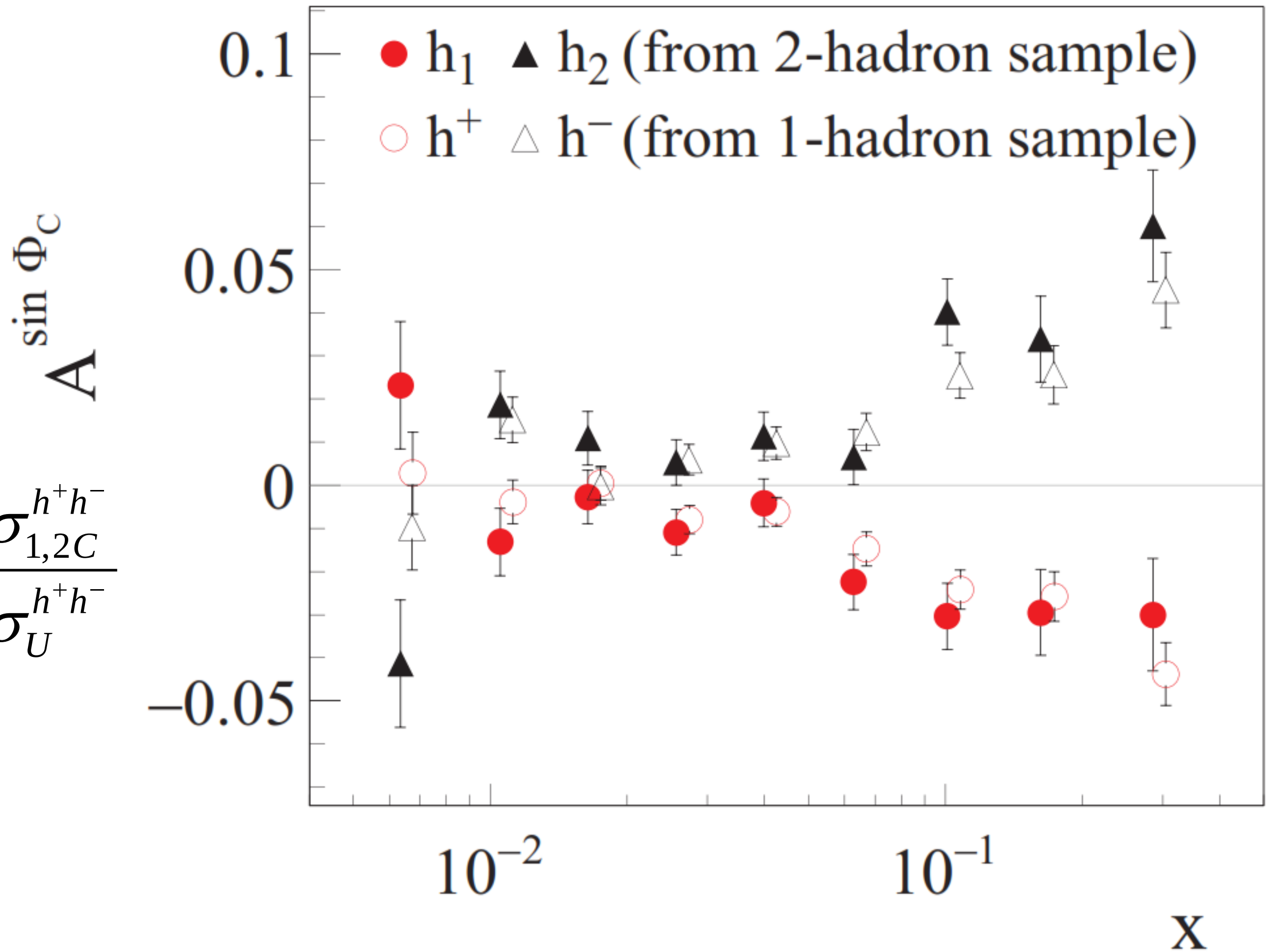
the general expression for the $lN \rightarrow l' h^+ h^- X$ cross section

$$\frac{d\sigma^{h^+h^-}}{d\phi_{h^+} d\phi_{h^-} d\phi_S} = \sigma_U^{h^+h^-} + S_T \cdot \left[\sigma_{1C}^{h^+h^-} \sin(\phi_{h^+} + \phi_S - \pi) + \sigma_{2C}^{h^+h^-} \sin(\phi_{h^-} + \phi_S - \pi)\right]$$

A.Kotzininan PRD91 (2015) 054001

single hadron asymmetries from the **common sample** are **very similar** to the Collins asymmetries calculated from the **1 hadron sample** (which are the usual Collins asymmetries)

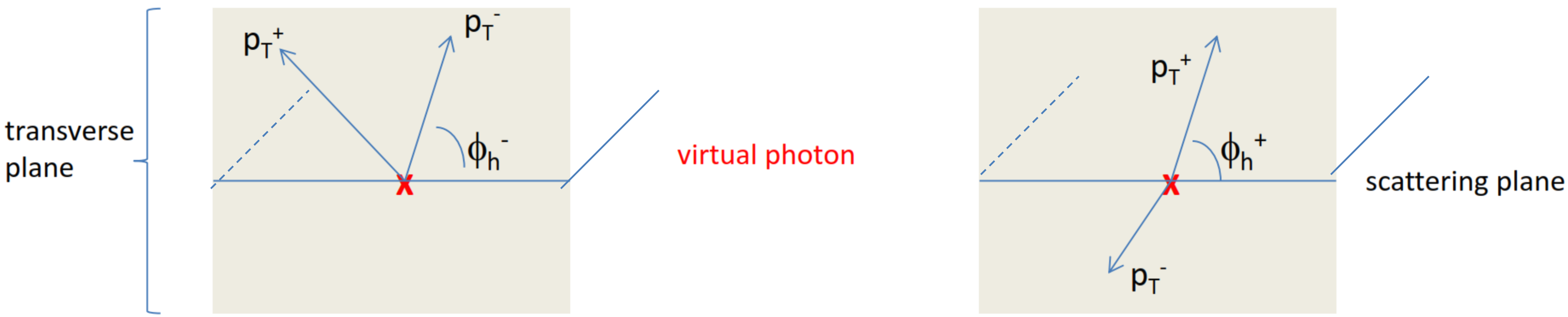
$$A^{\sin(\phi_C)} = \frac{\sigma_{1,2C}^{h^+h^-}}{\sigma_U^{h^+h^-}}$$



we studied the **azimuthal correlation** among the hadrons forming the pair

$$\Delta\phi = \phi_{h^+} - \phi_{h^-}$$

$\phi_h^+ - \phi_h^- \sim 0$ $\phi_h^+ - \phi_h^- \sim \pi$



we measured single hadron transversity induced as function of ΔΦ

the two hadron cross section can be written as function of **Δφ** and **φ** $_{+,-}$

dependencies σ(Δφ) omitted ....

$$\phi_{h^+}, \phi_{h^-} \rightarrow \phi_{h^+}, \Delta\phi$$

$$\frac{d\sigma^{h^+h^-}}{d\phi_{h^+}\, d\Delta\phi\, d\phi_S} = \sigma_U^{h^+h^-} + S_T \cdot \left[\left(\sigma_{1C}^{h^+h^-} + \sigma_{2C}^{h^+h^-} \cos\Delta\phi \right) \sin(\phi_{h^+} + \phi_S - \pi) + \ldots \right]$$

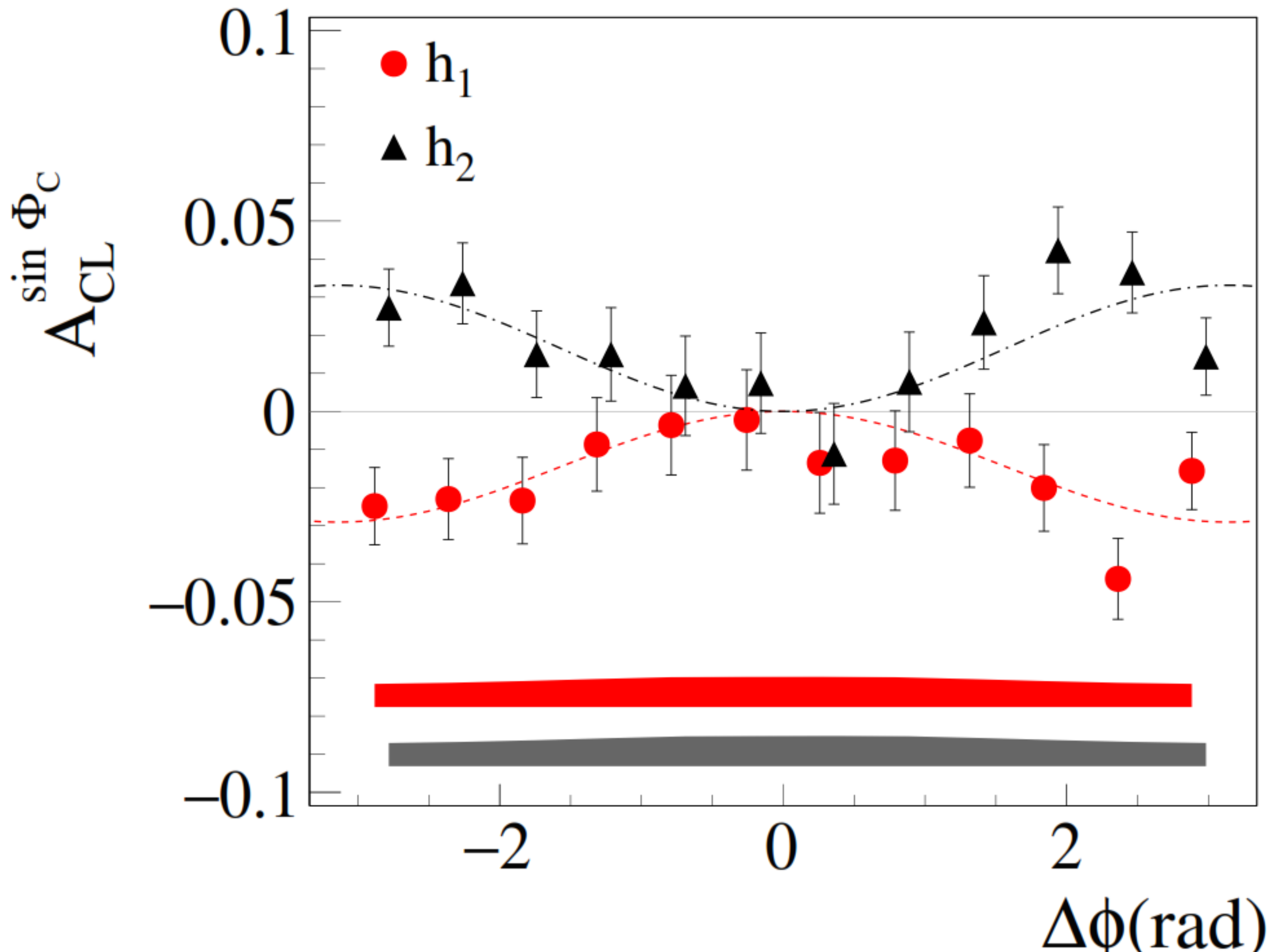
$$\phi_{h^+}, \phi_{h^-} \rightarrow \Delta\phi, \phi_{h^-}$$

$$\frac{d\sigma^{h^+h^-}}{d\phi_{h^-}\, d\Delta\phi\, d\phi_S} = \sigma_U^{h^+h^-} + S_T \cdot \left[\left(\sigma_{2C}^{h^+h^-} + \sigma_{1C}^{h^+h^-} \cos\Delta\phi \right) \sin(\phi_{h^-} + \phi_S - \pi) + \ldots \right]$$

we measured **single hadron** transversity induced asymmetries as function of **ΔΦ**

$$A_{1CL}^{\sin(\phi_{h^+}+\phi_S-\pi)} = \frac{\sigma_{1C}^{h^+h^-}(\Delta\phi) + \sigma_{2C}^{h^+h^-}(\Delta\phi)\cdot\cos\Delta\phi}{\sigma_U^{h^+h^-}(\Delta\phi)}$$

$$A_{2CL}^{\sin(\phi_{h^+}+\phi_S-\pi)} = \frac{\sigma_{2C}^{h^+h^-}(\Delta\phi) + \sigma_{1C}^{h^+h^-}(\Delta\phi)\cdot\cos\Delta\phi}{\sigma_U^{h^+h^-}(\Delta\phi)}$$

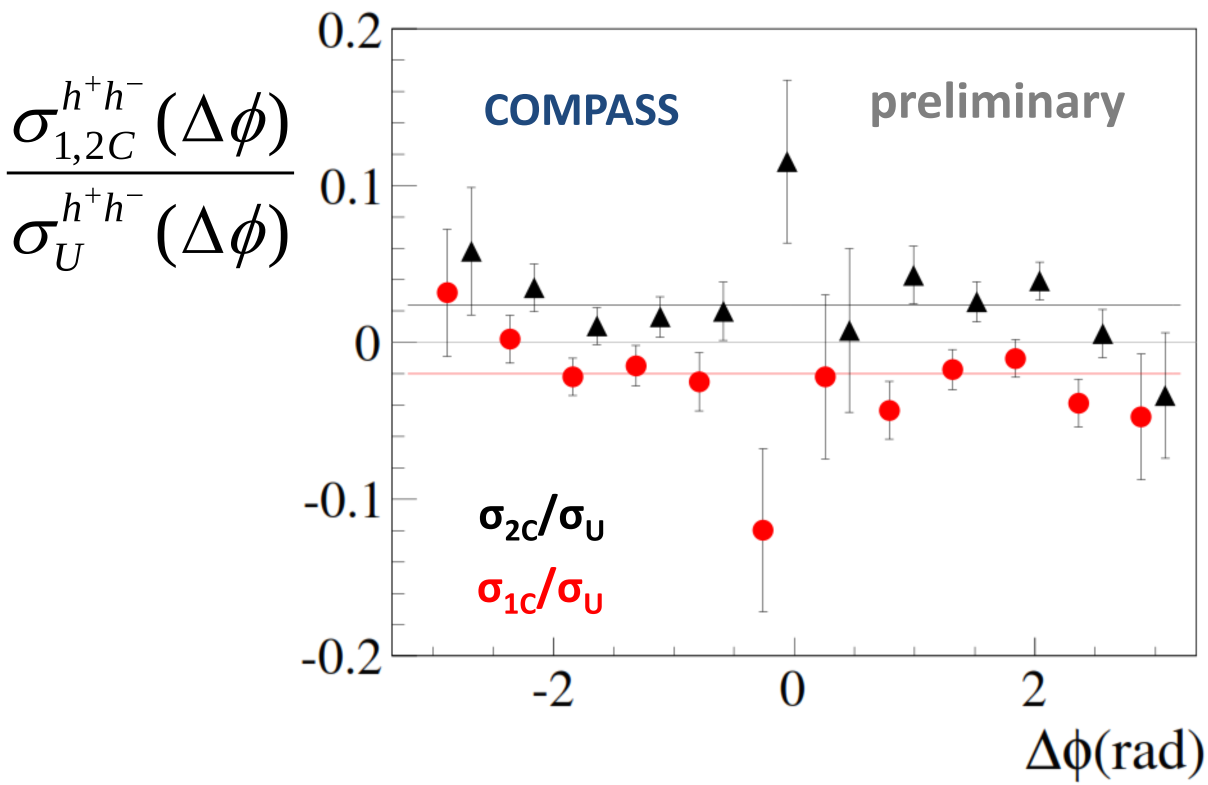


signal bigger when
h+ and h-
go in opposite direction

mirror asymmetries

$$\sigma_{1C}^{h^+h^-} = -\sigma_{2C}^{h^+h^-}$$

the dependence from **ΔΦ** in the
polarised part and ***unpolarised*** part of the cross section
has been found to be roughly the same



the ΔΦ dependence looks similar

and also
mirror symmetry

comparison between **dihadron** and **Collins** asymmetries

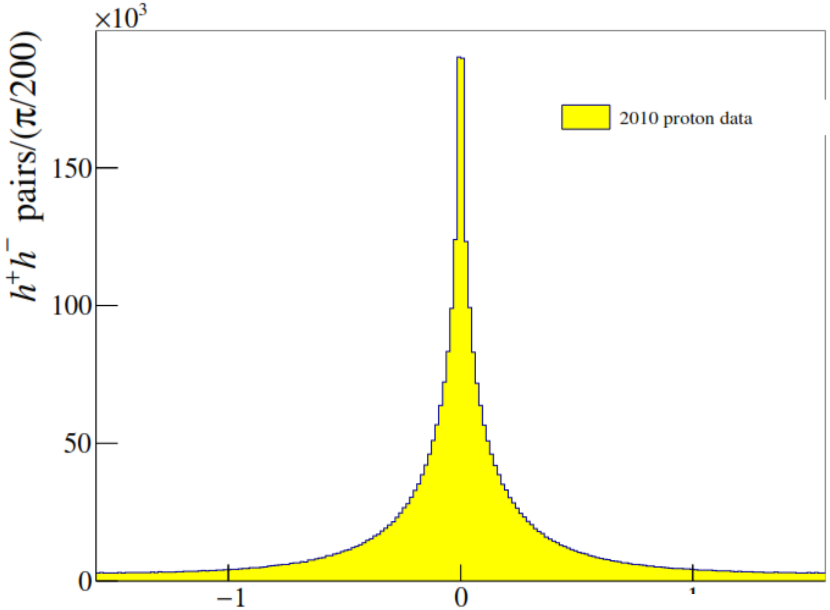
we defined another angle for the 2 hadrons pair *(more simple to use…)*

ϕ_{2h} which is the azimuthal angle of the vector $\hat{P}_T^{h^+} - \hat{P}_T^{h^-}$

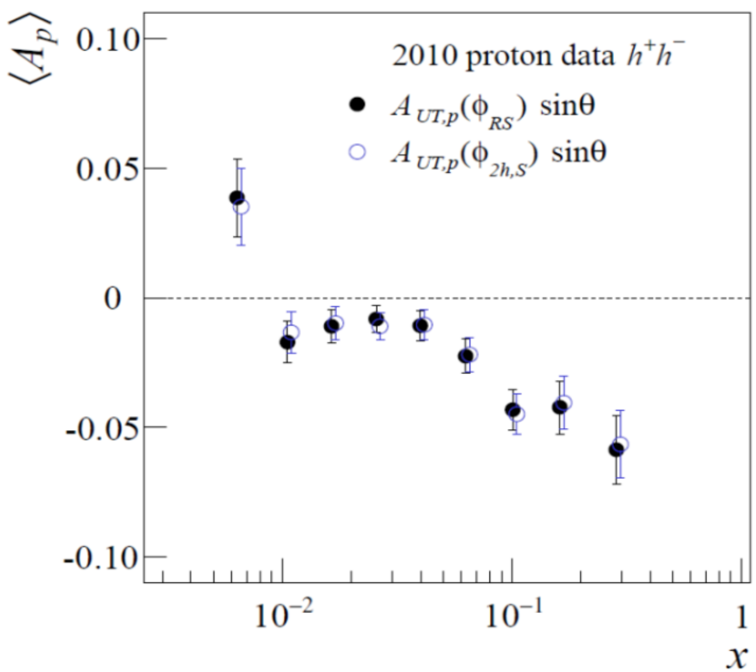
strongly correlated with

ϕ_R $\quad \dfrac{z^{h^-} \cdot \hat{P}_T^{h^+} - z^{h^+} \cdot \hat{P}_T^{h^-}}{z^{h^-} + z^{h^+}}$

used to extract the "standard" dihadron asymmetries



$\phi_R - \phi_{2h}$



azimuthal transverse spin asymmetries calculated using the 2 angles are the same

we defined another angle for the 2 hadrons pair *(more simple to use…)*

and by using the relation implied by the mirror asymmetries $\sigma_{1C}^{h^+h^-} = -\sigma_{2C}^{h^+h^-}$
the **cross section** becomes

$$\frac{d\sigma^{h^+h^-}}{d\phi_{2h}d\Delta\phi\, d\phi_S} = \sigma_U^{h^+h^-} + S_T \cdot \boxed{\sigma_{1C}^{h^+h^-} \cdot \sqrt{2(1-\cos\Delta\phi)}} \sin(\phi_{2h} + \phi_S - \pi)$$

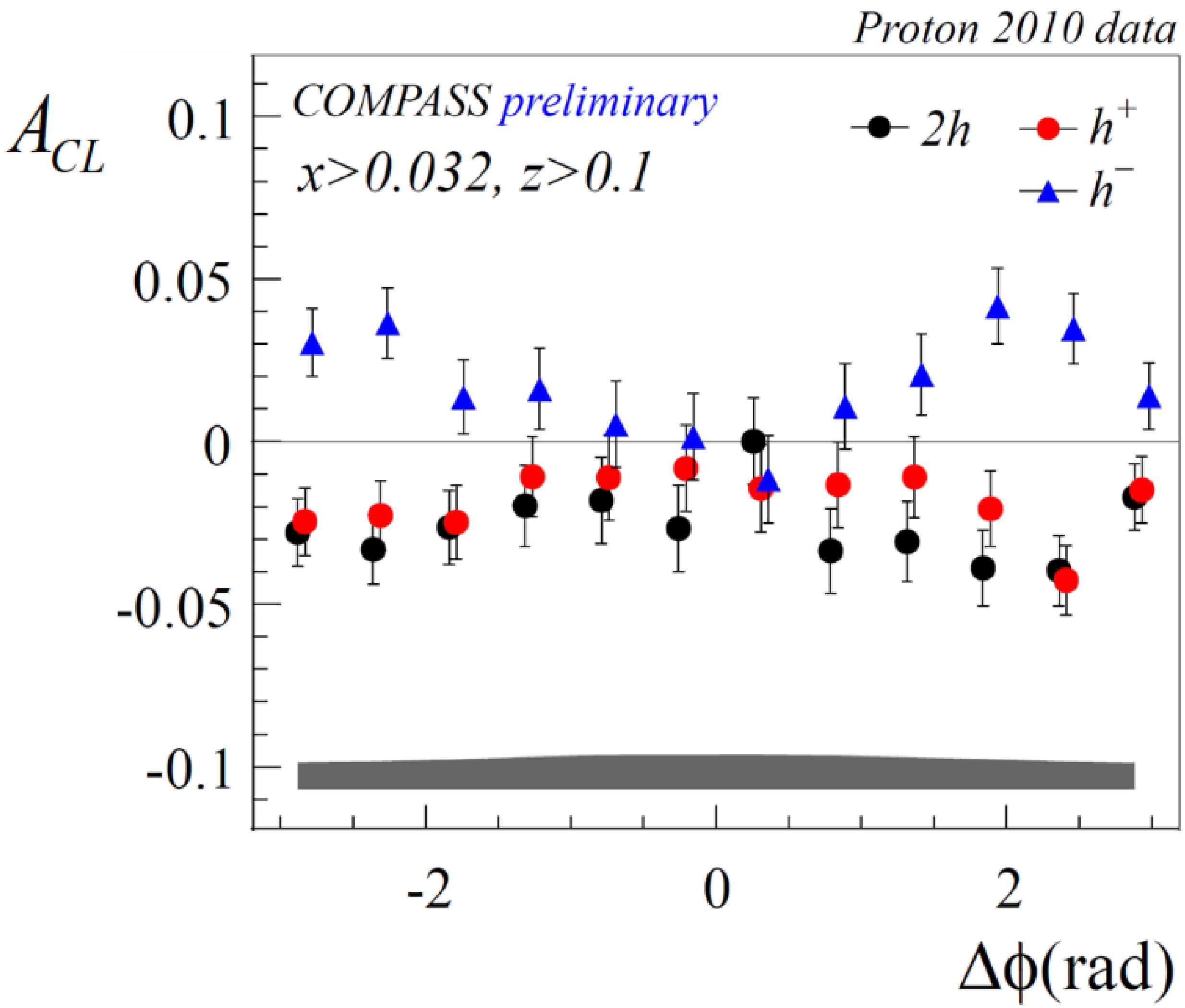
measure **di-hadron asymmetries** *(in φ_{2h})*
as function of **ΔΦ**
to compare with single hadron collins like asymmetries

amplitudes of the azimuthal modulations in the Collins angle

h^+

h^-

dihadron



same mechanism seems to give collins asymmetries and di-hadron asymmetries

there is a **quantitative relation** between **dihadron** and the **single hadron Collins-like asymmetries** that is derived using

$$\sigma_{1C}^{h^+h^-} = -\sigma_{2C}^{h^+h^-}$$

which comes from the ***mirror asymmetries*** *seen from data*

writing explicitly the measured asymmetries we have

h+

$$A_{1CL}^{\sin(\phi_{h^+}+\phi_S-\pi)} = \frac{\sigma_{1C}^{h^+h^-}}{\sigma_U^{h^+h^-}} \cdot (1-\cos\Delta\phi)$$

h-

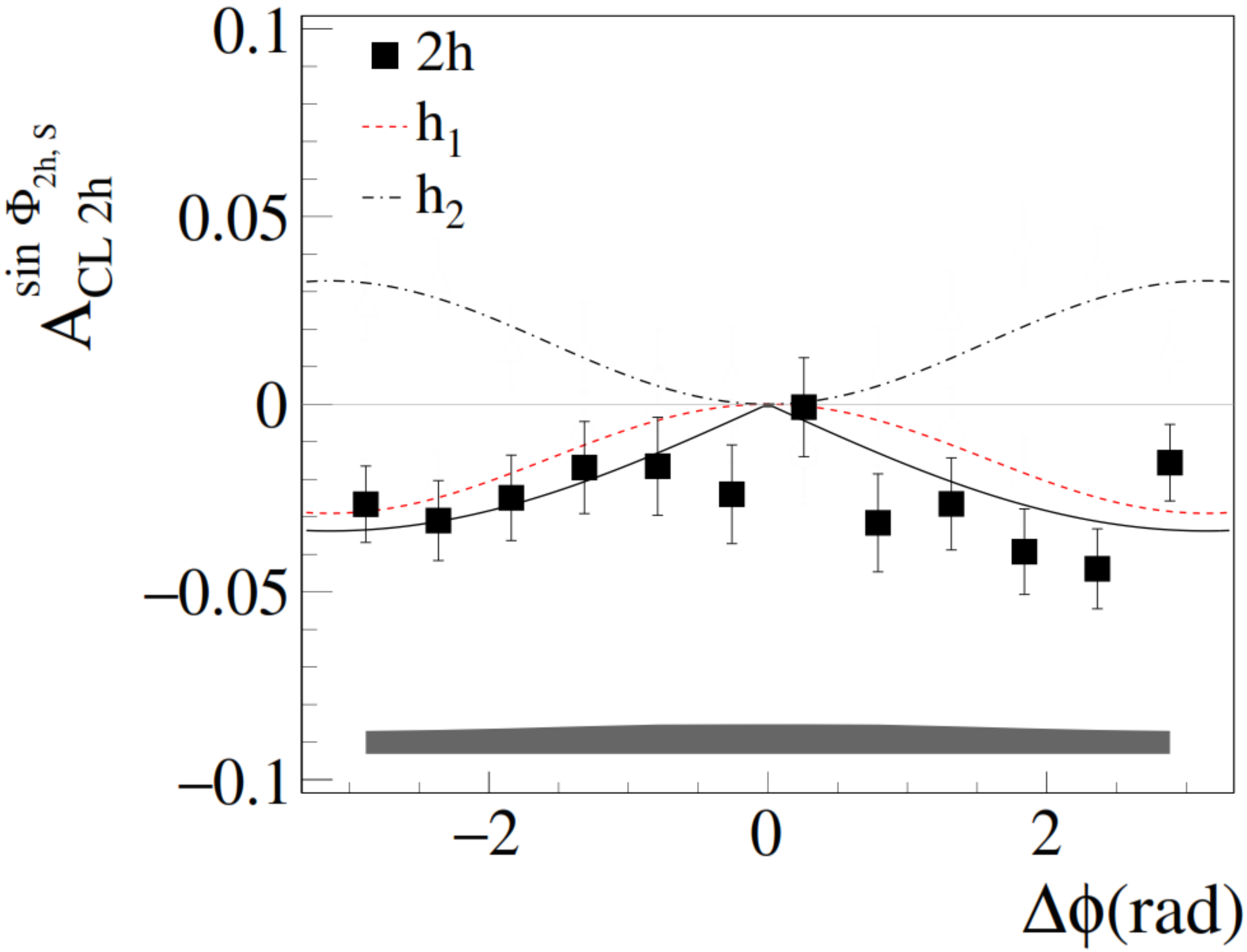
$$A_{2CL}^{\sin(\phi_{h^-}+\phi_S-\pi)} = -\frac{\sigma_{1C}^{h^+h^-}}{\sigma_U^{h^+h^-}} \cdot (1-\cos\Delta\phi)$$

dihadron

$$A_{2h,CL}^{\sin(\phi_{2h}+\phi_S-\pi)} = \frac{\sigma_{1C}^{h^+h^-}}{\sigma_U^{h^+h^-}} \cdot \sqrt{2\cdot(1-\cos\Delta\phi)}$$

⬇

same quantity !

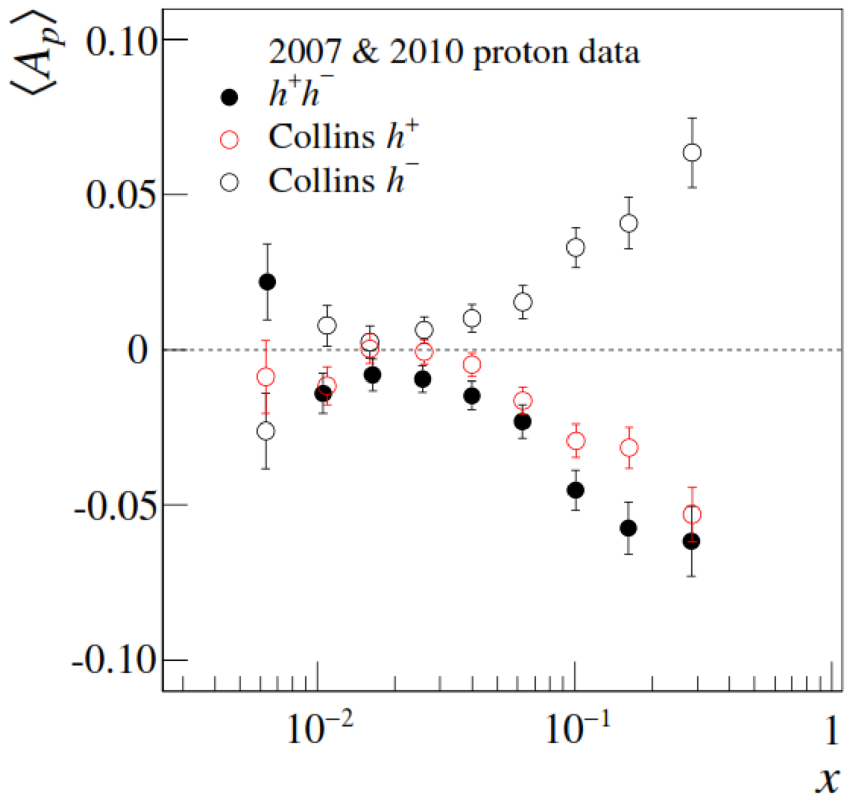


$$c \cdot (1 - \cos\Delta\phi)$$

$$-c \cdot (1 - \cos\Delta\phi)$$

$$c \cdot \sqrt{2 \cdot (1 - \cos\Delta\phi)}$$

integrating over Δφ the ratio between dihadron and positive hadron asymmetries is 4/π



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integrating over Δφ the ratio between dihadron and positive hadron asymmetries is 4/π

interesting results
the paper has been written

interplay among transversity induced asymmetries in hadron leptoproduction
arXiv:1507.07593v1
CERN-PH-EP-2015–199

submitted to Phys.Rev.Lett.