Work on the Interplay among h^+, h^- and 2h Transverse Spin Asymmetries in SIDIS

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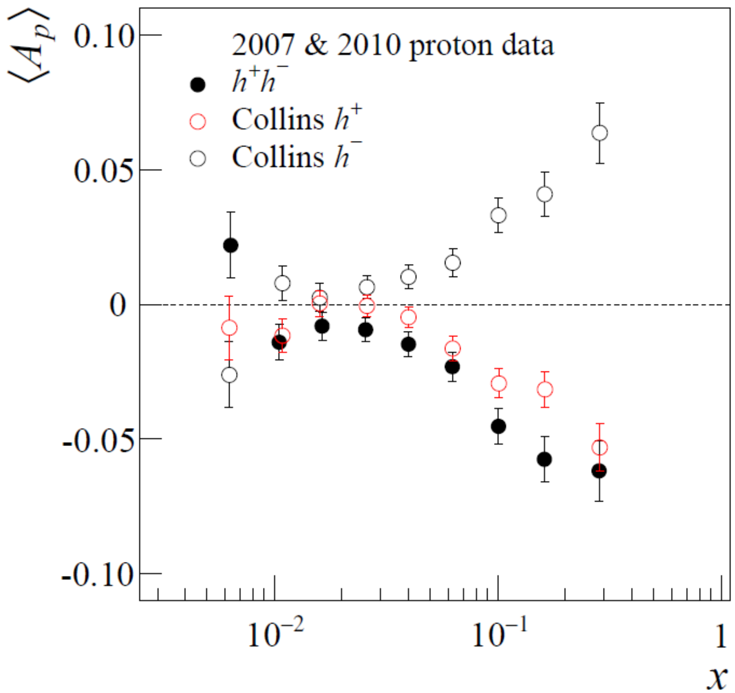
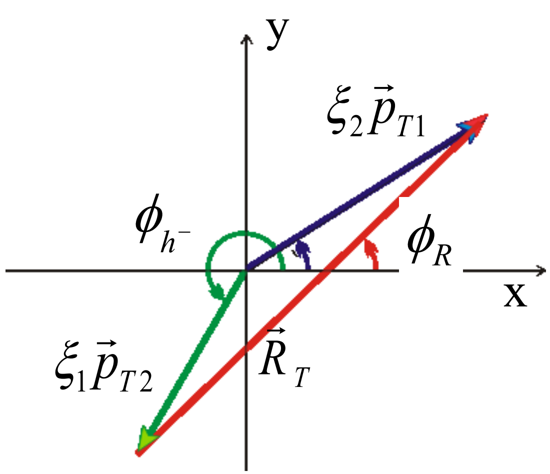
on behalf of the

COMPASS Collaboration

starting point

published COMPASS results





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

this motivated the study of the correlations between the relevant azimuthal angles and the corresponding asymmetries

1. strong correlation between

$$\phi_R \quad \text{and} \quad \phi_{2h} = \frac{1}{2}\left[\phi_{h^+} + (\phi_{h^-} - \pi) \right]$$

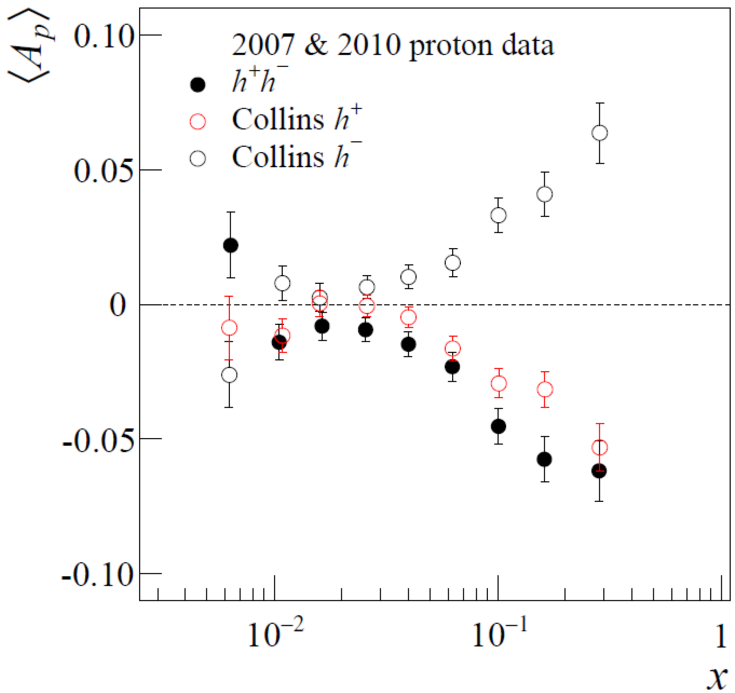
2. dihadron asymmetries evaluated using

$$\phi_{2hS} = \phi_{2h} + \phi_S - \pi \quad \text{or}$$

$$\phi_{RS} = \phi_R + \phi_S - \pi \quad \text{essentially the same}$$

starting point

published COMPASS results



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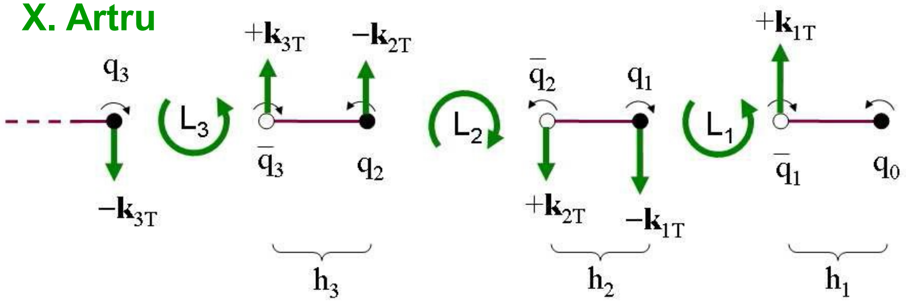


conclusion:

hints for a common physical origin for the Collins mechanism and the polarised dihadron FF

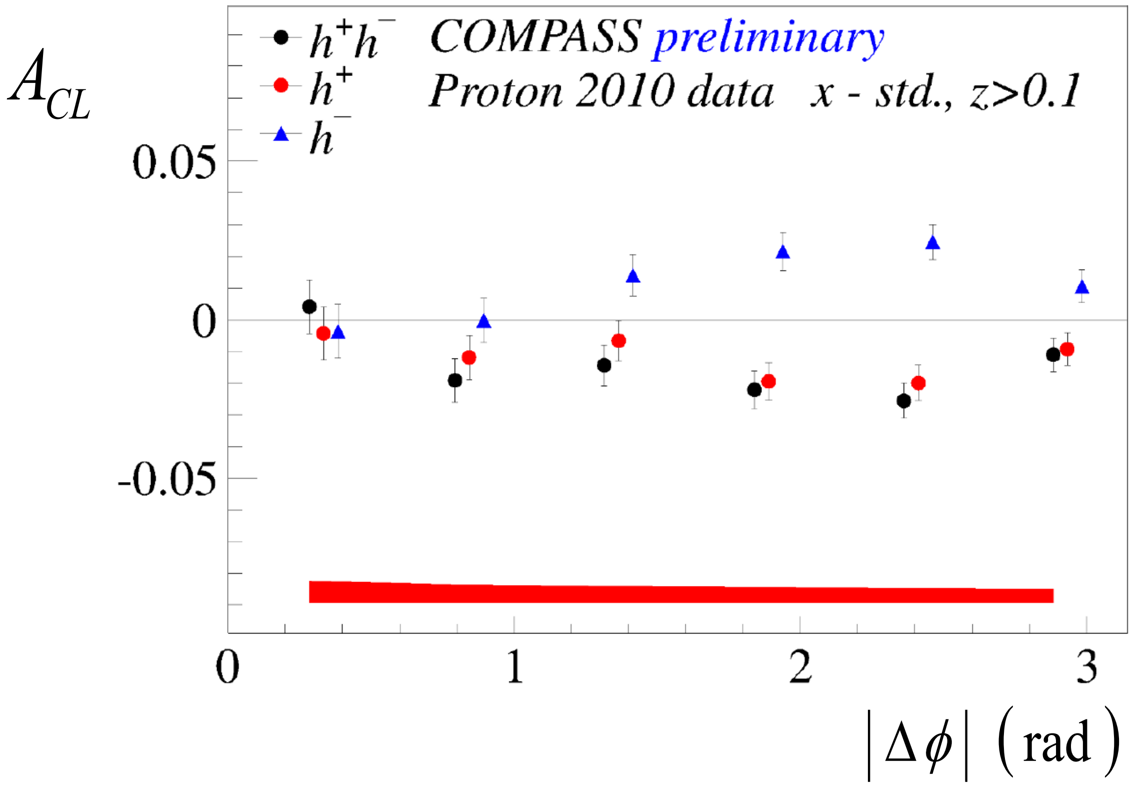
F. Bradamante [COMPASS Collaboration], Como 2013, D-SPIN 2013
C. Adolph et al. [COMPASS Collaboration], Phys. Lett. B 736 (2014) 124

further investigations

dependence of the Collins asymmetry for h+ and h- in the "2h sample"

and of the dihadron asymmetry on $\Delta\phi = \phi_1 - \phi_2 \quad (1 = h^+,\ 2 = h^-)$

C. Braun [COMPASS Collaboration], Transversity2014



data set and analysis

- data collected in 2010 (p↑)
- "2h sample"
  - standard COMPASS SIDIS requirements for event and hadron selection
  - only events with at least one h+ and one h-
    → "Collins-like" asymmetries
- 6 kinematical regions:

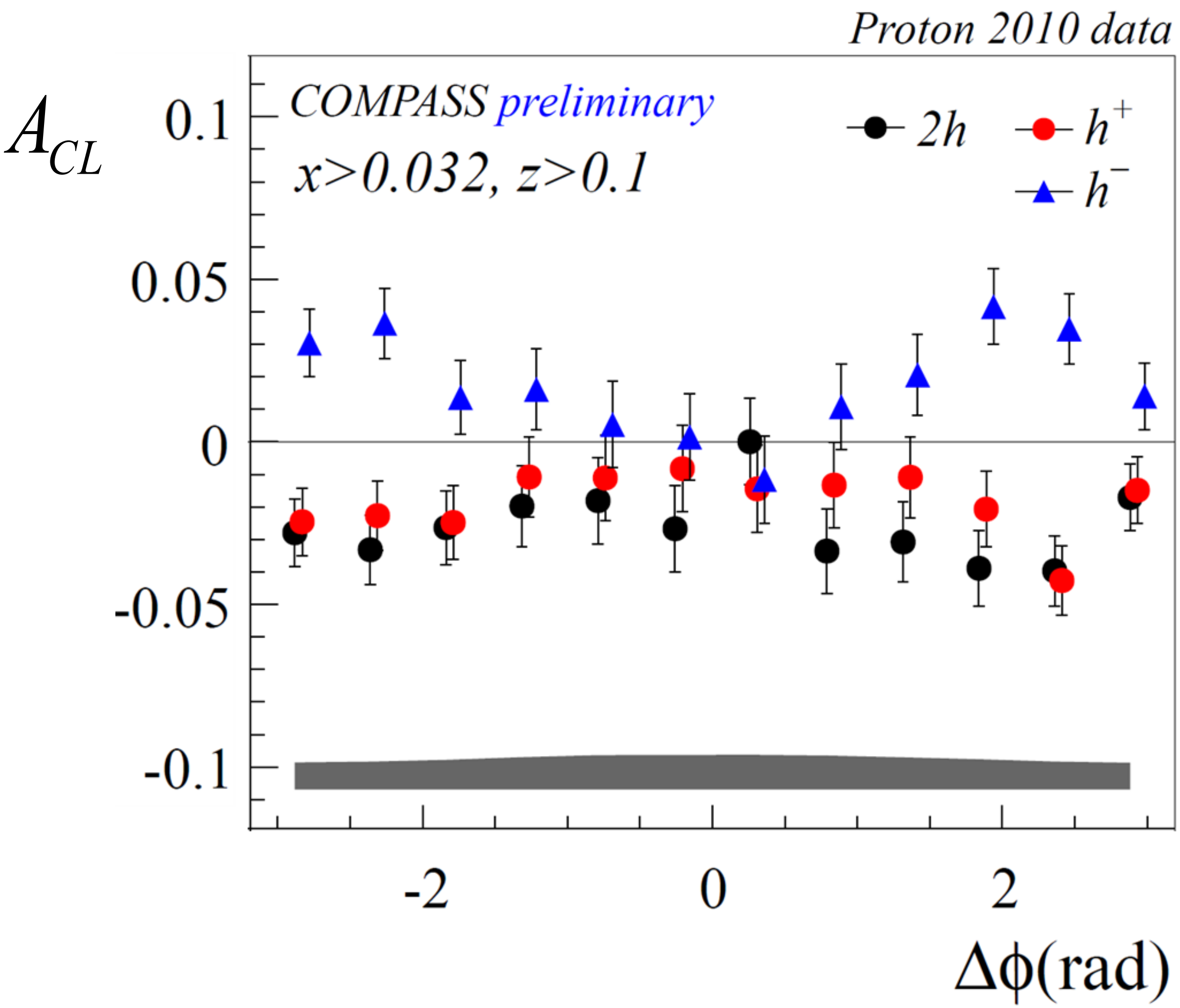
all x $z > 0.1$	$x < 0.032$ $z > 0.1$	$\boxed{x > 0.032}$ $\boxed{z > 0.1}$
all x $z > 0.2$	$x < 0.032$ $z > 0.2$	$x > 0.032$ $z > 0.2$

results will be shown only for x>0.032 and z>0.1

- $\phi_{1,2} + \phi_S - \pi$, $\phi_{2h,S}$ asymmetries measured in 12 bins of $\Delta\phi$

$$-\pi, -5\pi/6, -2\pi/3, -\pi/2, -\pi/3, -\pi/6, 0, +\pi/6, +\pi/3, +\pi/2, +2\pi/3, +5\pi/6, +\pi$$

Collins like asymmetries



Collins like asymmetries

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

$$\frac{d\sigma^{h_1 h_2}}{d\phi_1 d\phi_2 d\phi_S} = \sigma_U^{h_1 h_2} + S_T \left[\sigma_{1C}^{h_1 h_2} \sin(\phi_1 + \phi_S - \pi) + \sigma_{1C}^{h_1 h_2} \sin(\phi_2 + \phi_S - \pi)\right]$$

A. Kotzinian, arXiv:1408.6674

the structure functions can depend on $\Delta\phi$

changing variables $(\phi_1, \phi_2) \rightarrow (\phi_1, \Delta\phi)$ $(\phi_1, \phi_2) \rightarrow (\phi_2, \Delta\phi)$

h^+

$$\begin{aligned}\frac{d\sigma^{h_1 h_2}}{d\phi_1 d\Delta\phi d\phi_S} \;=\; \sigma_U^{h_1 h_2} + S_T \Big[\Big(\sigma_{1C}^{h_1 h_2} + \sigma_{2C}^{h_1 h_2} \cos\Delta\phi\Big) \sin(\phi_1 + \phi_S - \pi) \\ - \sigma_{2C}^{h_1 h_2} \sin\Delta\phi \cos(\phi_1 + \phi_S - \pi)\Big]\end{aligned}$$

h^-

$$\begin{aligned}\frac{d\sigma^{h_1 h_2}}{d\phi_2 d\Delta\phi d\phi_S} \;=\; \sigma_U^{h_1 h_2} + S_T \Big[\Big(\sigma_{2C}^{h_1 h_2} + \sigma_{1C}^{h_1 h_2} \cos\Delta\phi\Big) \sin(\phi_2 + \phi_S - \pi) \\ + \sigma_{1C}^{h_1 h_2} \sin\Delta\phi \cos(\phi_2 + \phi_S - \pi)\Big]\end{aligned}$$

Collins like asymmetries

asymmetries

h^+

$$A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{1C}^{\sin(\phi_1+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{\sigma_{1C}^{h_1h_2}(\Delta\phi) + \sigma_{2C}^{h_1h_2}(\Delta\phi)\cos\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

$$A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{1C}^{\cos(\phi_1+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{-\sigma_{2C}^{h_1h_2}(\Delta\phi)\sin\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

h^-

$$A_{2CL}^{\sin(\phi_2+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{2C}^{\sin(\phi_2+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{\sigma_{2C}^{h_1h_2}(\Delta\phi) + \sigma_{1C}^{h_1h_2}(\Delta\phi)\cos\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

$$A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{2C}^{\cos(\phi_2+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{\sigma_{1C}^{h_1h_2}(\Delta\phi)\sin\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

Collins like asymmetries

asymmetries

h^+

$$A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{1C}^{\sin(\phi_1+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{\sigma_{1C}^{h_1h_2}(\Delta\phi) + \sigma_{2C}^{h_1h_2}(\Delta\phi)\cos\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

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h^-

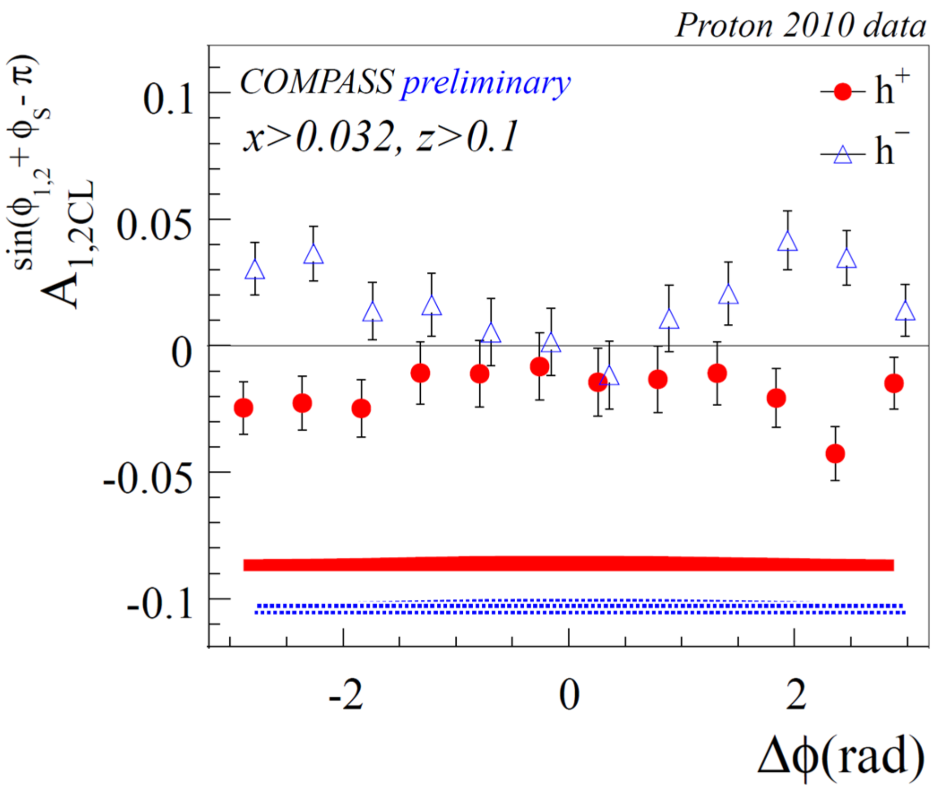
$$A_{2CL}^{\sin(\phi_2+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{2C}^{\sin(\phi_2+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{\sigma_{2C}^{h_1h_2}(\Delta\phi) + \sigma_{1C}^{h_1h_2}(\Delta\phi)\cos\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

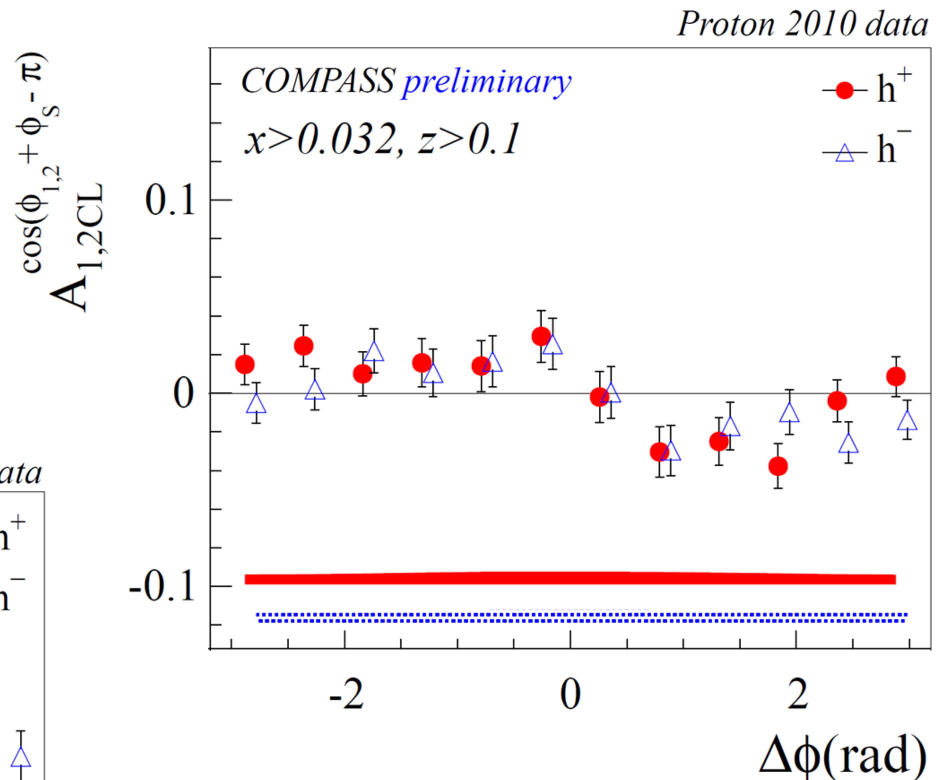
$$A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi) = \frac{\sigma_{2C}^{\cos(\phi_2+\phi_S-\pi)}}{\sigma_U^{h_1h_2}} = \frac{\sigma_{1C}^{h_1h_2}(\Delta\phi)\sin\Delta\phi}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

two new asymmetries expected

(go to zero when integrated on $\Delta\phi$!)

Collins like asymmetries





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Entanglement of the h⁺ and h⁻ Collins like asymmetries

the **sine and cosine asymmetries of the positive hadron**
can be written as linear functions of
the **sine and cosine asymmetries of the negative hadrons**,
and vice-versa

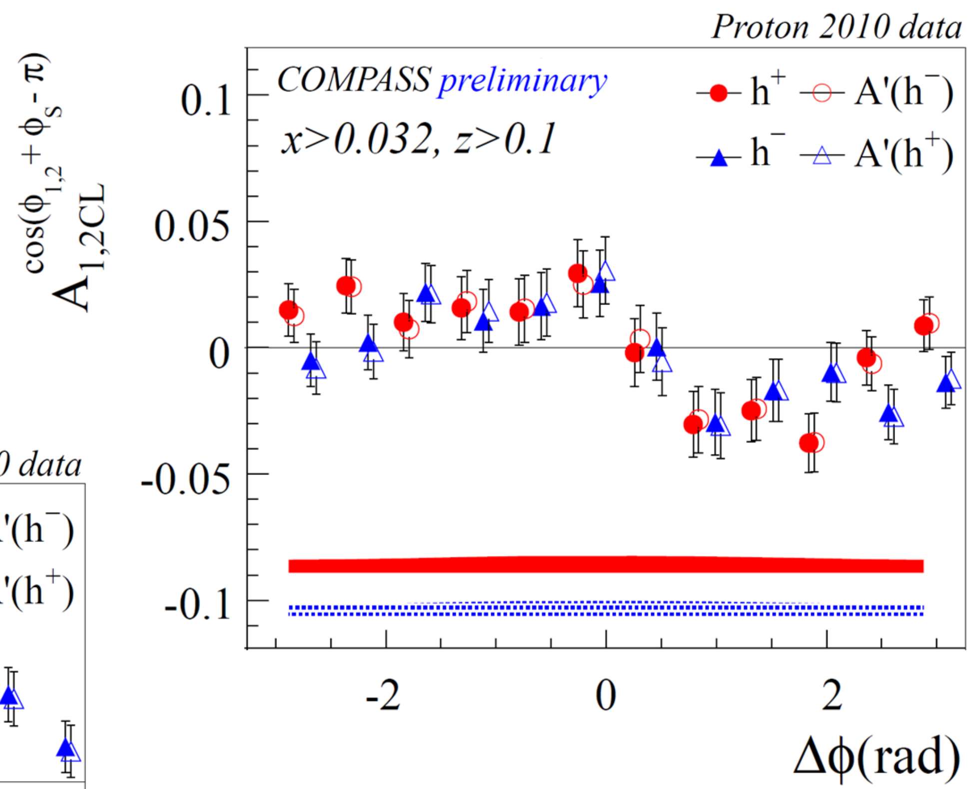
h^-

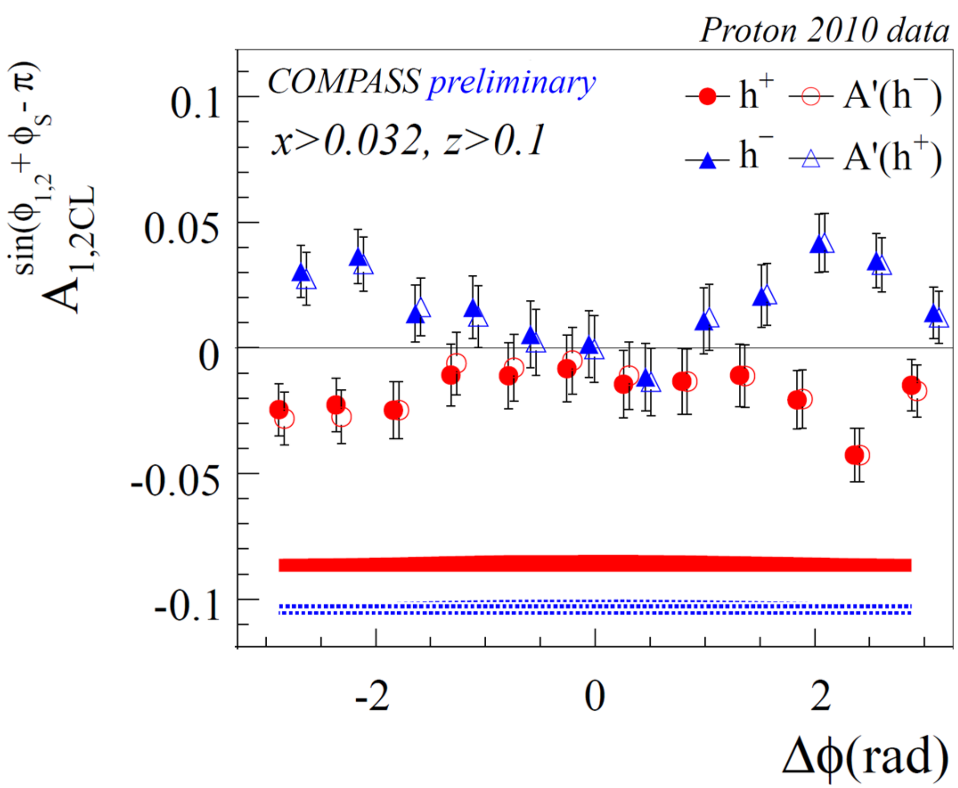
$$\begin{aligned} A_{2CL}^{\sin(\phi_2+\phi_S-\pi)}(\Delta\phi) &= A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi)\cos\Delta\phi - A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi)\sin\Delta\phi \\ A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi) &= A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi)\sin\Delta\phi + A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi)\cos\Delta\phi \end{aligned}$$

h^+

$$\begin{aligned} A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi) &= A_{2CL}^{\sin(\phi_2+\phi_S-\pi)}(\Delta\phi)\cos\Delta\phi + A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi)\sin\Delta\phi \\ A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi) &= A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi)\cos\Delta\phi - A_{2CL}^{\sin(\phi_2+\phi_S-\pi)}(\Delta\phi)\sin\Delta\phi \end{aligned}$$

Entanglement of the h⁺ and h⁻ Collins like asymmetries





Mirror symmetry in Collins like asymmetries

ratio of structure functions

from the measured asymmetries one can extract

the structure function ratios

h^+

$$\frac{\sigma_{1C}^{h_1h_2}(\Delta\phi)}{\sigma_U^{h_1h_2}(\Delta\phi)} = A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi)\frac{1}{\sin\Delta\phi}$$

$$= A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi) + A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi)\cot\Delta\phi$$

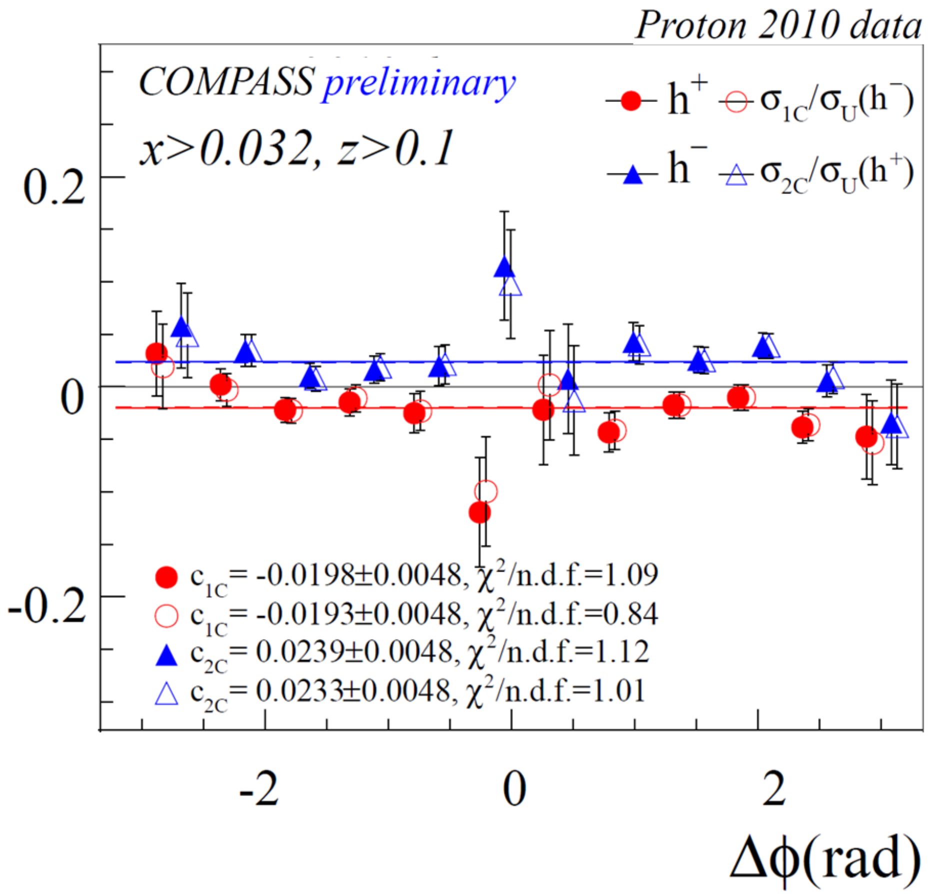
h^-

$$\frac{\sigma_{2C}^{h_1h_2}(\Delta\phi)}{\sigma_U^{h_1h_2}(\Delta\phi)} = -A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi)\frac{1}{\sin\Delta\phi}$$

$$= A_{2CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi) - A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi)\cot\Delta\phi$$

Mirror symmetry in Collins like asymmetries

$$\frac{\sigma_{1,2C}^{h1h2}(\Delta\phi)}{\sigma_U^{h1h2}(\Delta\phi)}$$



structure functions

- **either constant or**
- **with the same $\Delta\phi$ dependence**
  - **mirror symmetry**

Mirror symmetry in Collins like asymmetries

constant ratio of structure functions plus

mirror symmetry imply

h^+

$$A_{1CL}^{\sin(\phi_1+\phi_S-\pi)}(\Delta\phi) = a\ (1-\cos\Delta\phi)$$

$$A_{1CL}^{\cos(\phi_1+\phi_S-\pi)}(\Delta\phi) = a\ \sin\Delta\phi$$

h^-

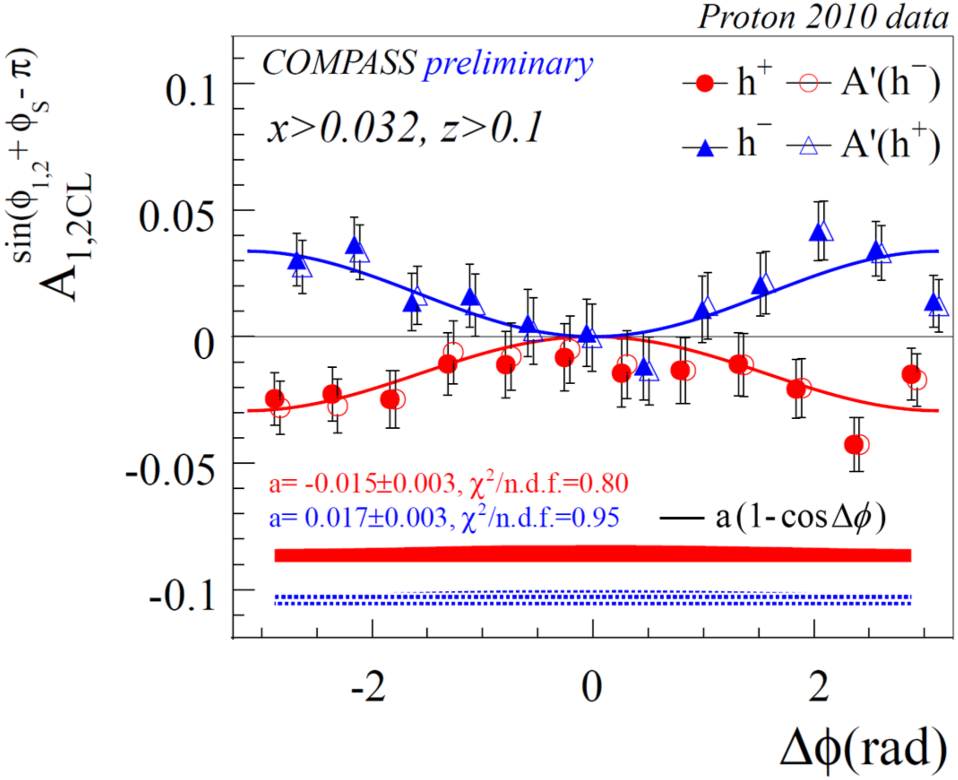
$$A_{2CL}^{\sin(\phi_2+\phi_S-\pi)}(\Delta\phi) = -\ a\ (1-\cos\Delta\phi)$$

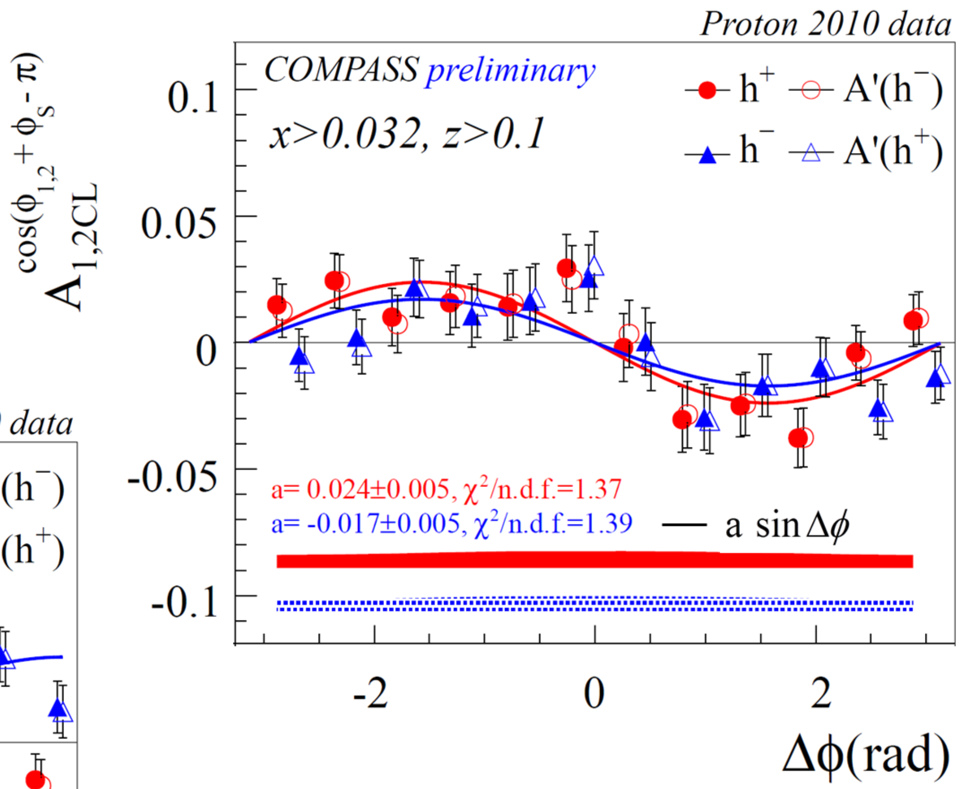
$$A_{2CL}^{\cos(\phi_2+\phi_S-\pi)}(\Delta\phi) = a\ \sin\Delta\phi$$

$$a = \frac{\sigma_{1C}^{h_1h_2}(\Delta\phi)}{\sigma_U^{h_1h_2}(\Delta\phi)} = -\frac{\sigma_{2C}^{h_1h_2}(\Delta\phi)}{\sigma_U^{h_1h_2}(\Delta\phi)}$$

Mirror symmetry in Collins like asymmetries

mirror symmetry





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Di-hadron asymmetries

since from our data

$$\frac{\sigma_{1C}^{h_1 h_2}(\Delta\phi)}{\sigma_U^{h_1 h_2}(\Delta\phi)} = - \frac{\sigma_{2C}^{h_1 h_2}(\Delta\phi)}{\sigma_U^{h_1 h_2}(\Delta\phi)} = \mathrm{a}$$

from the general expression of the cross-section, changing variables from (ϕ_1, ϕ_2) to $(\phi_{2h}, \Delta\phi)$, one gets

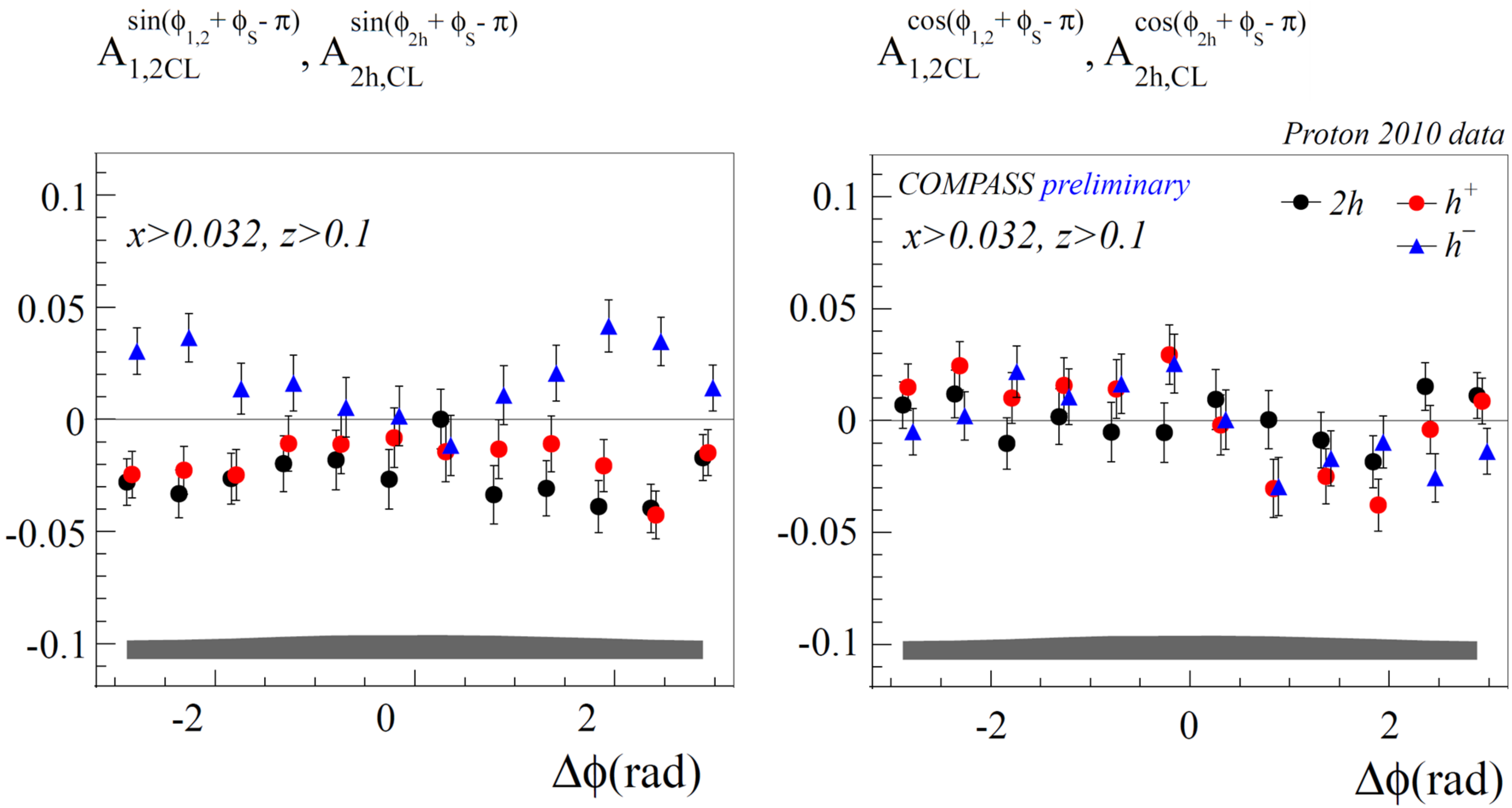
$$\boxed{\sigma^{h1h2} = \sigma_U^{h1h2} + S_T \cdot \sigma_{1C}^{h1h2} \cdot \sqrt{2(1-\cos\Delta\phi)} \cdot \sin(\phi_{2h} + \phi_S - \pi)}$$

NB: no $\cos(\phi_{2h} + \phi_S - \pi)$ modulation

and the di-hadron asymmetry is

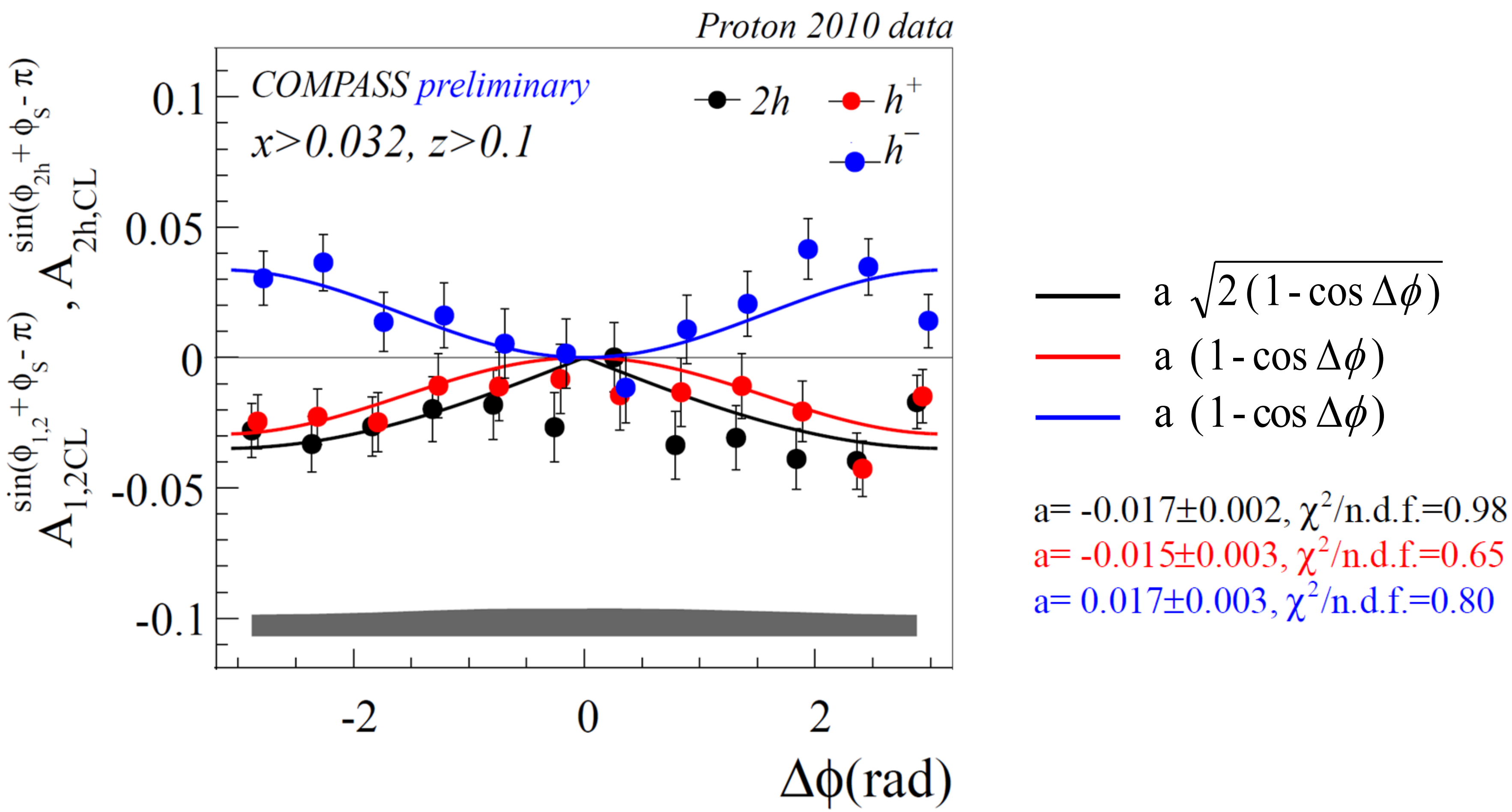
$$\boxed{A_{2h,CL}^{\sin(\phi_{2h}+\phi_S-\pi)} = \frac{\sigma_1^{h1h2}(\Delta\phi)}{\sigma_U^{h1h2}(\Delta\phi)} \cdot \sqrt{2(1-\cos\Delta\phi)} = \mathrm{a}\ \sqrt{2(1-\cos\Delta\phi)}}$$

Di-hadron asymmetries



no $\cos(\phi_{2h} + \phi_S - \pi)$ modulation

Di-hadron asymmetries



ratio of the integrals compatible with $4/\pi$

Sivers like asymmetries

general expression of the cross-section with Sivers effect

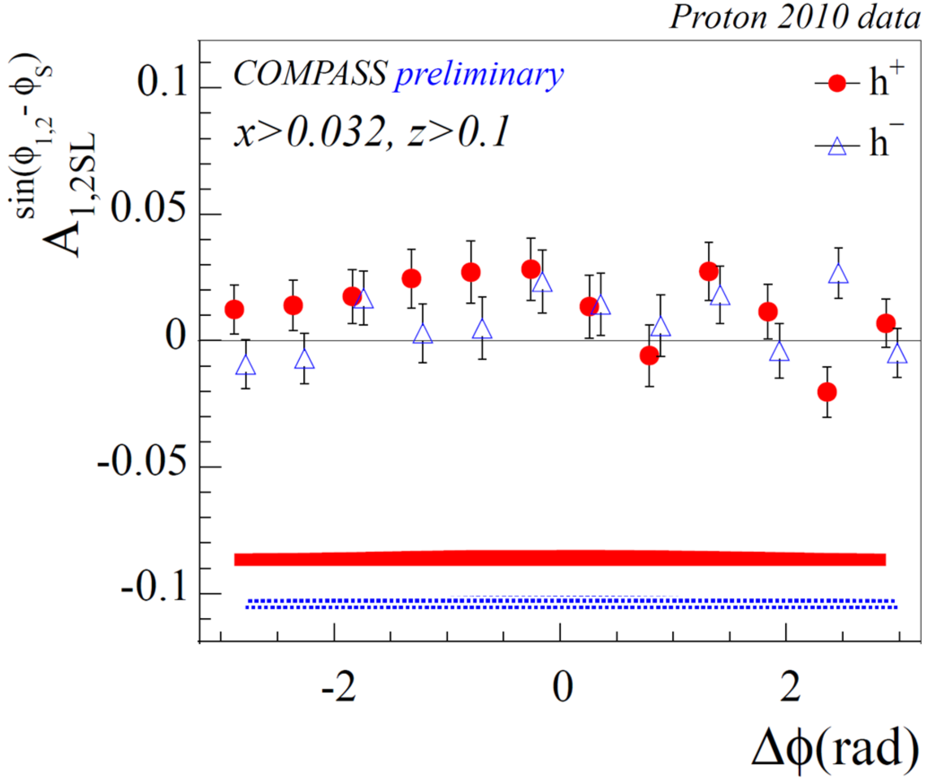
$$\sigma^{h_1 h_2}_{SivIncl}(\Delta\phi) = \sigma^{h_1 h_2}_{U}(\Delta\phi) +$$
$$+ S_T \left[\sigma^{h_1 h_2}_{1S}(\Delta\phi)\sin(\phi_1 - \phi_S) + \sigma^{h_1 h_2}_{2S}(\Delta\phi)\sin(\phi_2 - \phi_S)\right]$$

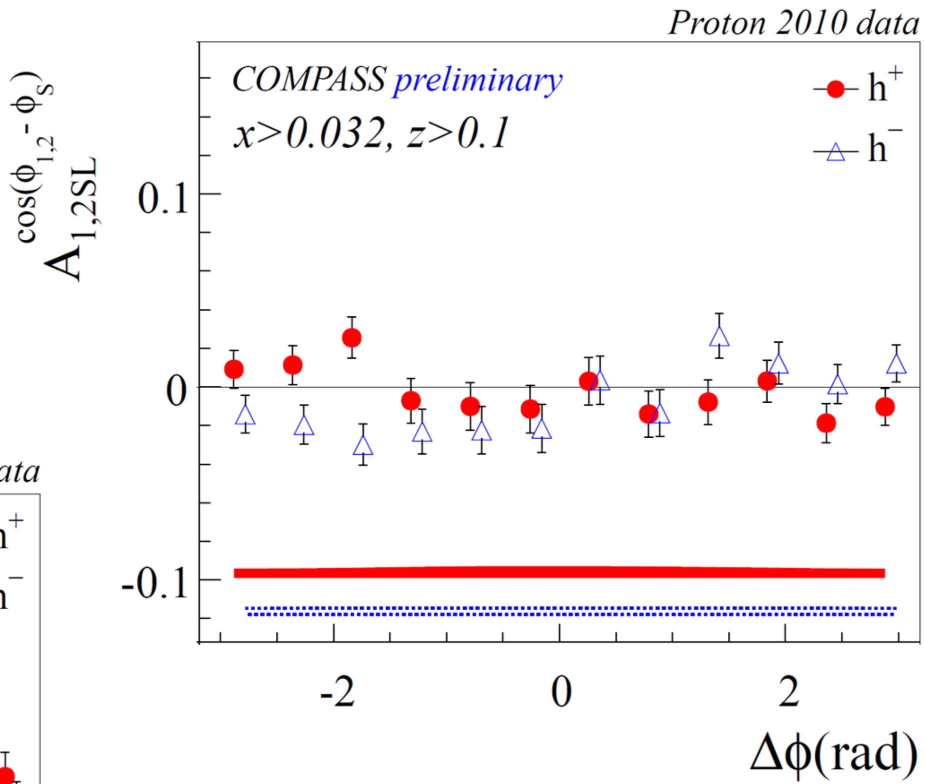
asymmetries

$$A^{\sin(\phi_1-\phi_S)}_{1SL}(\Delta\phi) = \frac{\sigma^{h_1 h_2}_{1S}(\Delta\phi) + \sigma^{h_1 h_2}_{2S}(\Delta\phi)\cos\Delta\phi}{\sigma^{h_1 h_2}_{U}(\Delta\phi)}$$
$$A^{\cos(\phi_1-\phi_S)}_{1SL}(\Delta\phi) = \frac{-\sigma^{h_1 h_2}_{2S}(\Delta\phi)\sin\Delta\phi}{\sigma^{h_1 h_2}_{U}(\Delta\phi)}.$$

and similar expressions for negative hadrons

Sivers like asymmetries





- **entanglement OK**
- **NO MIRROR SYMMETRY**

SUMMARY

- The h⁺ and h⁻ Collins asymmetries as function of $\Delta\phi$ are mirror symmetric and exhibit a $(1-\cos\Delta\phi)$ behavior in agreement with the general expression for the cross section $lN \rightarrow l' h^+ h^- X$
- Also $\cos(\phi_{1,2}+\phi_S-\pi)$ asymmetries are observed, as expected, and are mirror symmetric
- The h^+ and h^- asymmetries are entangled
- The 2h asymmetry can also be derived from the h^+ asymmetry, and has the expected $\Delta\phi$ dependence and the ratio of the integrals is compatible with the expected $4/\pi$ value
- Sivers-like asymmetry are also entangled but do not exhibit mirror symmetry

contributions from Belle and Babar

would be particularly useful