Collins and Sivers asymmetries in inclusive ρ^0 production from COMPASS

BAKUR PARSAMYAN

CERN, INFN section of Turin

on behalf of the COMPASS Collaboration

"XXIX International Workshop on Deep Inelastic Scattering and Related Subjects"

Santiago de Compostela, Spain

2-6 May 2022

Motivation

Transverse Spin Asymmetries (TSA) in Semi-Inclusive DIS (SIDIS)

are being measured since 2005:

***Collins** asymmetries - **Sivers** asymmetries – **Di-hadron** asymmetries*

measured at
- HERMES (p target, 27.5 GeV e^+/e^- beam)
- COMPASS (p, d target, 160 GeV μ beam)
- CLAS (^{3}He target, 6 GeV e^- beam)

for unidentified charged hadrons and for $\pi^+, \pi^-, \pi^0, K^+, K^-, K^0, p$

well known results, used to extract transversity and Sivers functions…

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{1 + \ldots + S_T\, A_{UT}^{\sin(\phi_h-\phi_S)} \sin\left(\phi_h - \phi_S\right) + S_T\, \varepsilon\, A_{UT}^{\sin(\phi_h+\phi_S)} \sin\left(\phi_h + \phi_S\right)\ldots\right\}$$

$$F_{UT,T}^{\sin(\phi_h-\phi_S)} = C\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k_T}}{M} f_{1T}^{\perp q} D_{1q}^{h}\right], F_{UT,L}^{\sin(\phi_h-\phi_S)} = 0$$

$$F_{UT}^{\sin(\phi_h+\phi_S)} = C\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p_T}}{M_h} h_1^q H_{1q}^{\perp h}\right]$$

TSAs for vector mesons: never measured so far

low statistics, high background

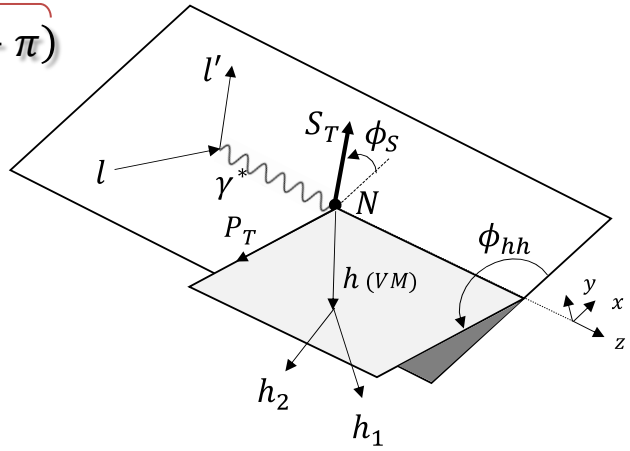
important insight on the quark fragmentation process into spin-1 particles

Cross-section and model predictions

SIDIS cross-section for VM production in the one-photon exchange approximation

[A. Bacchetta & P. Mulders, *Phys.Rev.D* 62 (2000) 114004]

$$\frac{\mathrm{d}^5\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\mathrm{d}z\,\mathrm{d}\varphi_{hh}\mathrm{d}P_T^2} \propto 1 - \boldsymbol{A_{UT}^{\sin(\phi_{hh}+\phi_S-\pi)}} D_{NN}|\boldsymbol{S_T}|\sin(\overbrace{\phi_{hh}+\phi_S-\pi}^{\phi_{Coll}}) + \boldsymbol{A_{UT}^{\sin(\phi_{hh}-\phi_S)}}|\boldsymbol{S_T}|\sin(\underbrace{\phi_{hh}-\phi_S}_{\phi_{Siv}}) + \cdots$$



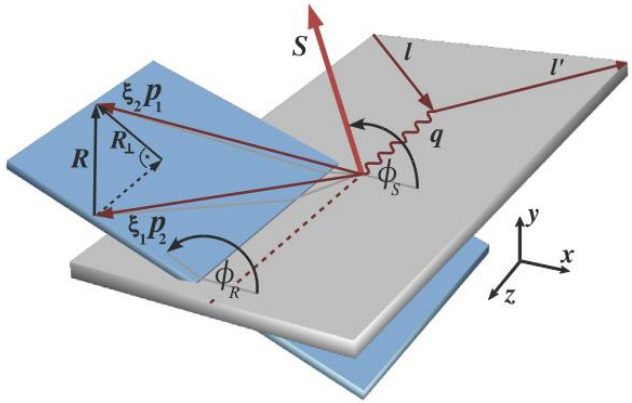
Collins asymmetry $A_{UT}^{sin(\phi_{hh}+\phi_S-\pi)} \sim h_1^q \otimes FF_{Collins}$

Sivers asymmetry $A_{UT}^{\sin(\phi_{hh}-\phi_S)} \sim f_{1T}^{\perp} \otimes FF_{unpolarized}$

Not to be confused with the dihadron asymmetries!

In that case, instead of ϕ_{hh} one uses ϕ_R :

that is, the azimuthal angle of the vector $\boldsymbol{R} = \frac{z_2\,\boldsymbol{p_1} - z_1\boldsymbol{p_2}}{z_1+z_2}$



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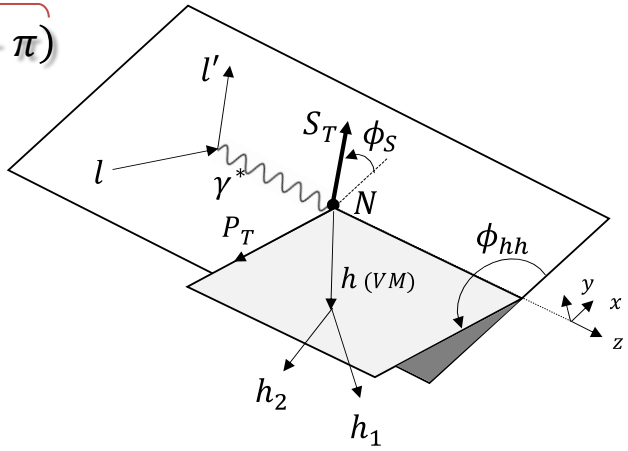

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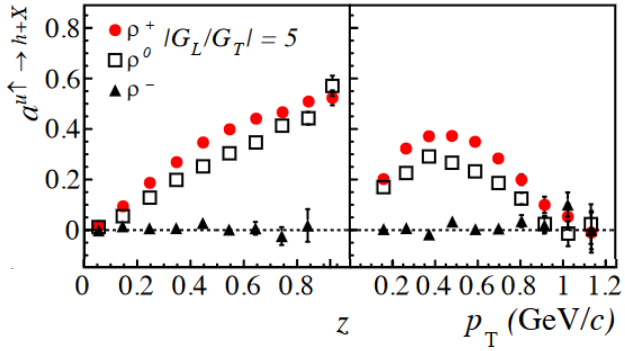
Sivers asymmetry $A_{UT}^{\sin(\phi_{hh}-\phi_S)} \sim f_{1T}^{\perp} \otimes FF_{unpolarized}$

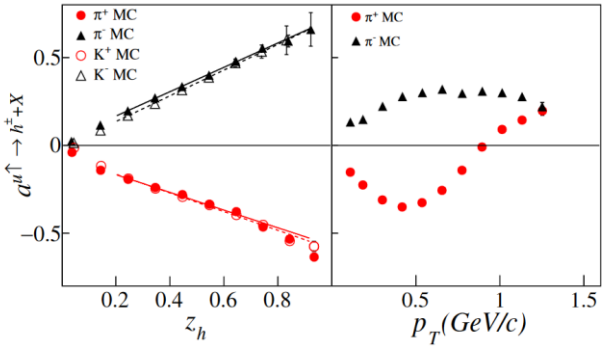
VMs are expected to exhibit an opposite sign and smaller Collins asymmetry compared to π^+

[J. Czyzewski, *Acta Phys.Polon. 27* (1996) 1759-1766; X. Artru, *Proc. DSPIN2009* ; string+3P0 model]

[A. Kerbizi et al., *hep-ph*: 2109.06124]



[A. Kerbizi et al., *PRD* 97 (2018) 7, 074010]



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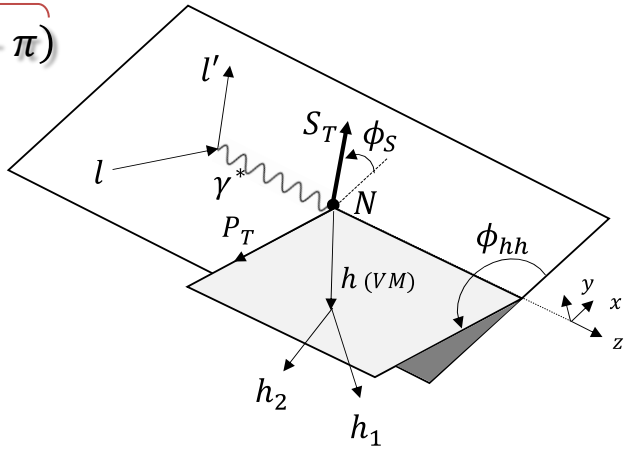

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COMPASS performed first ever measurements
of Collins and Sivers asymmetries for inclusive ρ^0 vector mesons

in this talk: preliminary results

COMPASS collaboration

Common **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

25 institutions from 13 countries
– nearly 200 physicists

- **CERN SPS north area**
- **Fixed target experiment**
- **Approved in 1997**
- **Taking data since 2002**

Wide physics program

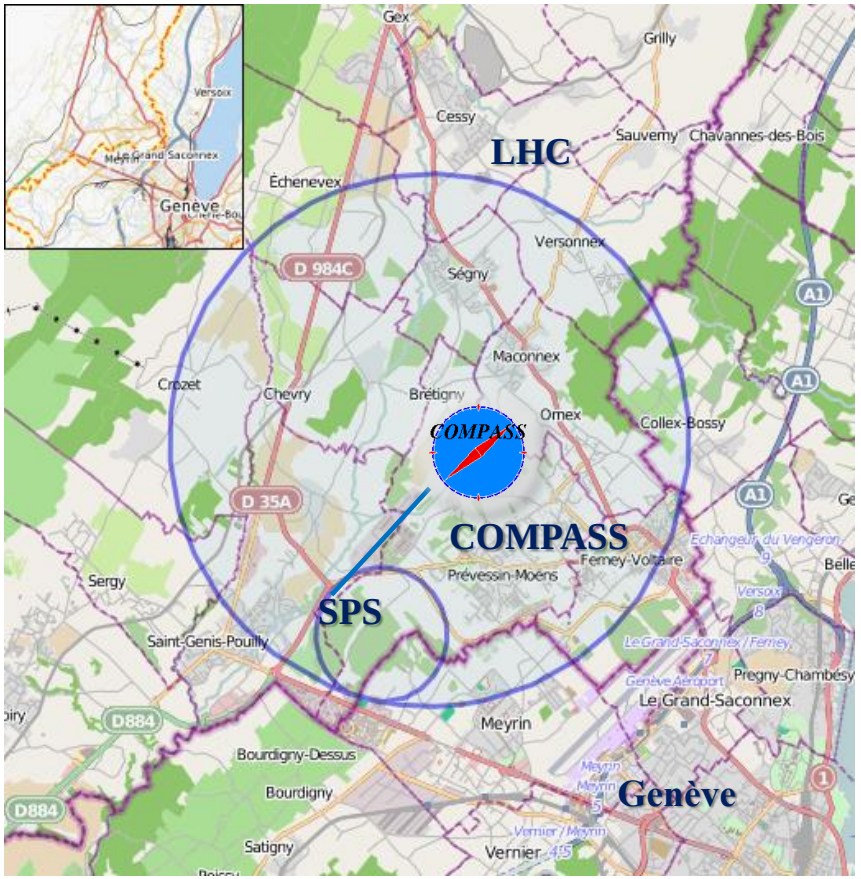
COMPASS-I

- **Data taking 2002-2011**
- **Muon and hadron beams**
- **Nucleon spin structure**
- **Spectroscopy**

COMPASS-II

- **Data taking 2012-2022**
- **Primakoff**
- **DVCS (GPD+SIDIS)**
- **Polarized Drell-Yan**
- **Transverse deuteron SIDIS**

See also COMPASS talks by J.Giarra (DVCS) and J.Matousek (SIDIS)



COMPASS web page: http://wwwcompass.cern.ch

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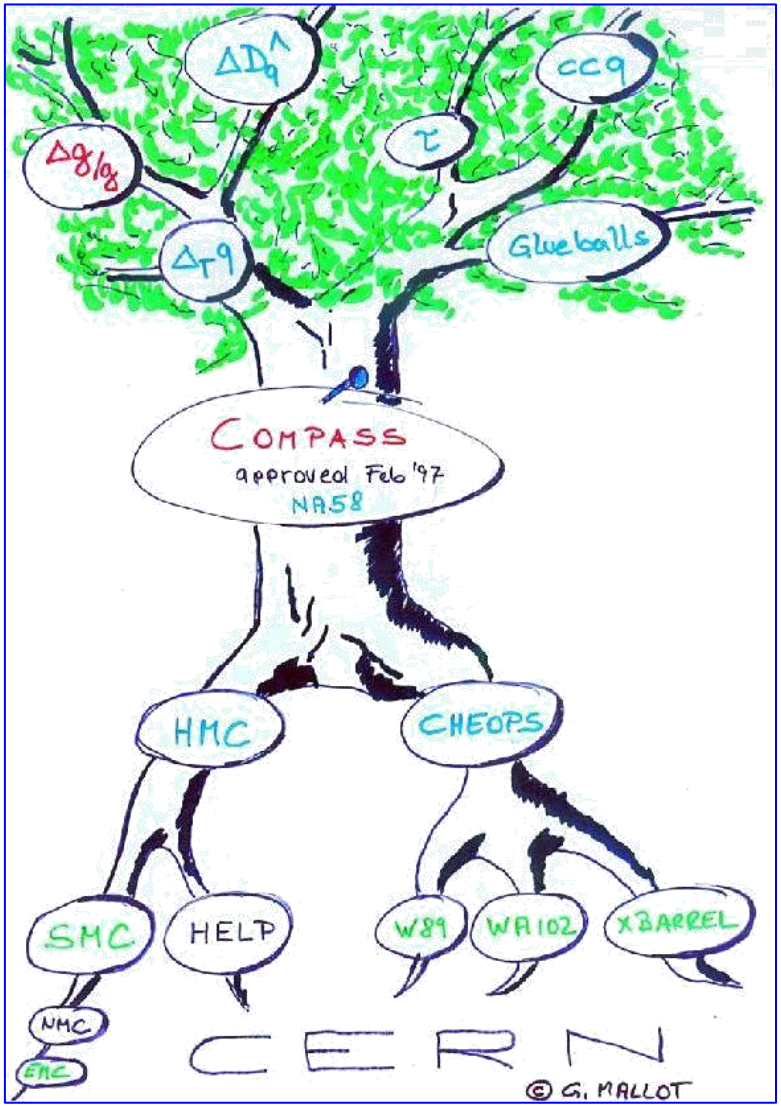
IWHSS-2022 workshop (anniversary edition)

CERN Globe, August 29-31, 2022

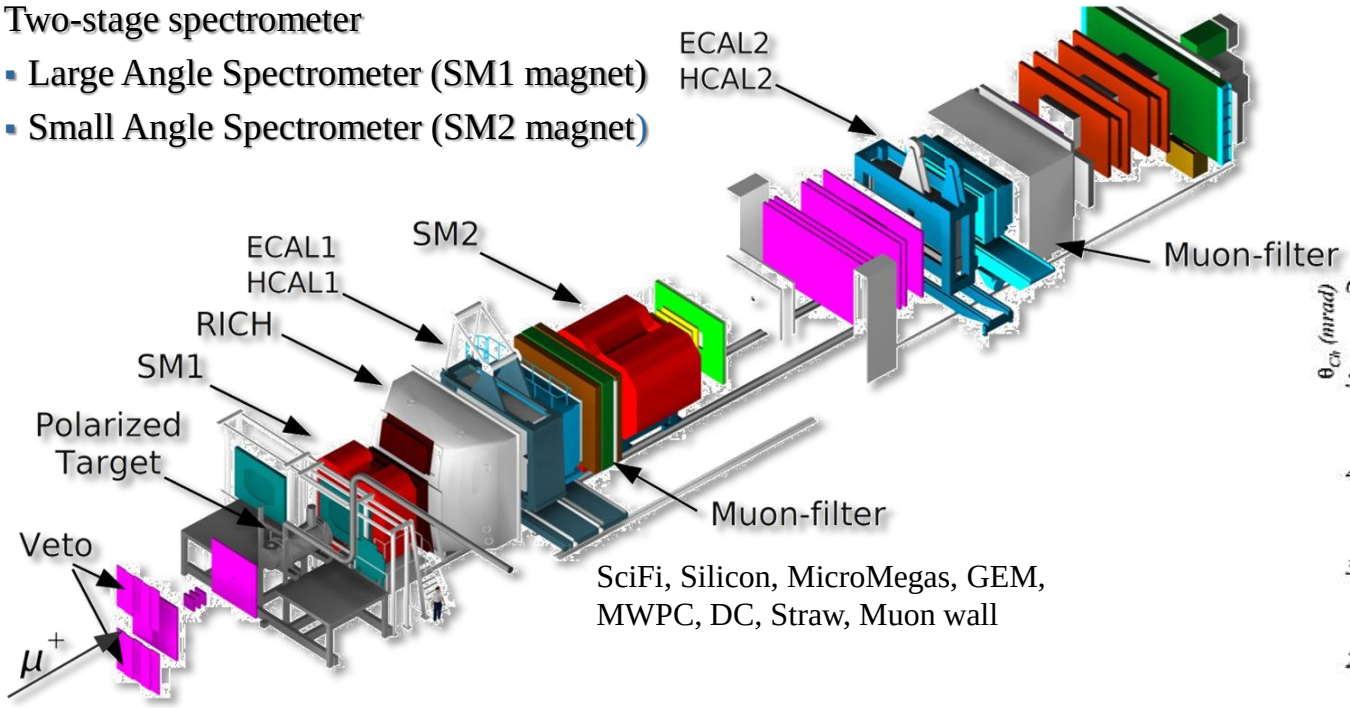
https://indico.cern.ch/e/IWHSS-2022



COMPASS experimental setup: Phase I (muon program)

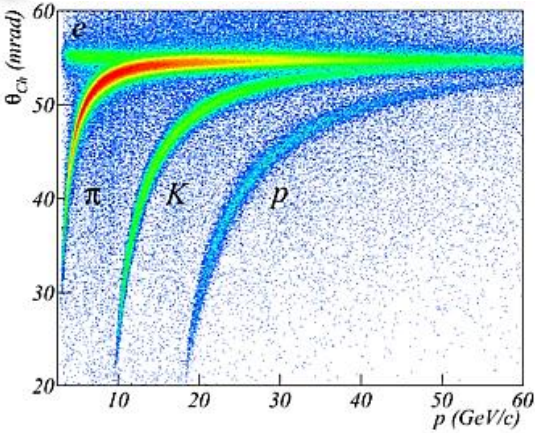
Two-stage spectrometer

- Large Angle Spectrometer (SM1 magnet)
- Small Angle Spectrometer (SM2 magnet)



SciFi, Silicon, MicroMegas, GEM, MWPC, DC, Straw, Muon wall

- High energy beam
- Large angular acceptance
- Broad kinematical range
- Momentum, tracking and calorimetric measurements, PID



This analysis: Data-taking year 2010

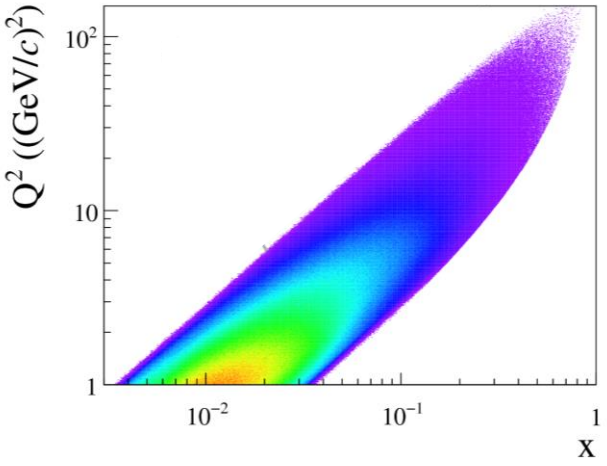
Longitudinally polarized (80%) μ^+ beam

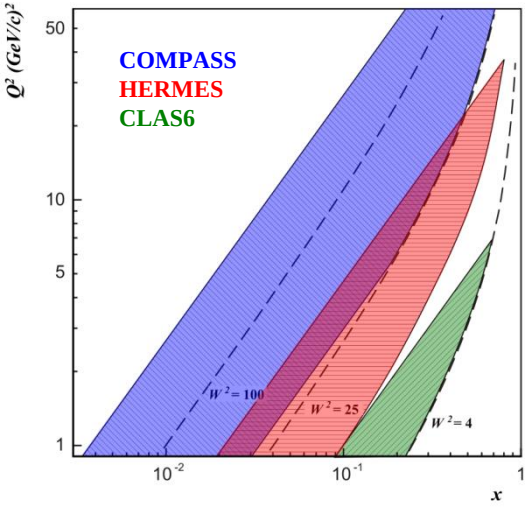
Energy: 160/200 GeV/c

Intensity: $2 \cdot 10^8$ μ^+/spill (4.8s)

Target: Solid state *(NH_3)*

- NH_3 3-cell configuration
- Polarization T ~ 80%, f ~ 0.14





Selection of ρ^0 events

Data sample: data collected in 2010 with a transversely polarized NH_3 (proton) target

DIS events selection

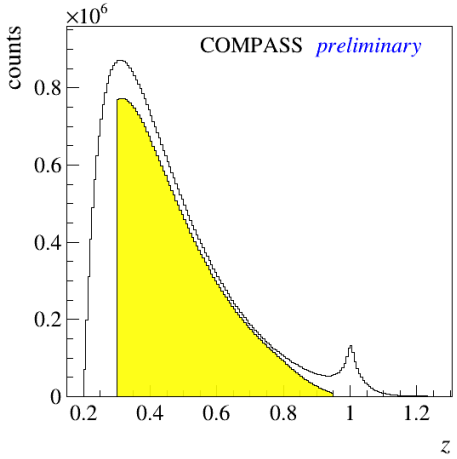
$$Q^2 > 1\ (\mathrm{GeV}/c)^2, \qquad W > 5\ \mathrm{GeV}/c^2, \qquad 0.003 < x < 0.700, \qquad 0.1 < y < 0.9$$

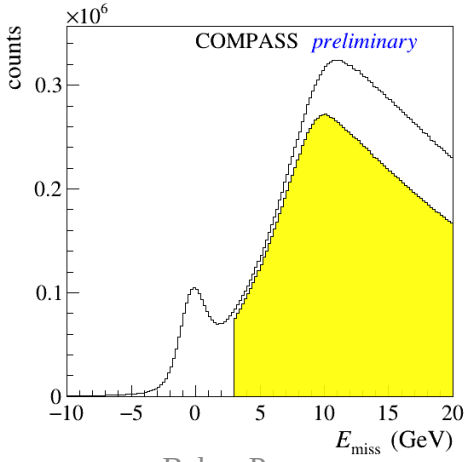
Two oppositely-charged hadrons selection

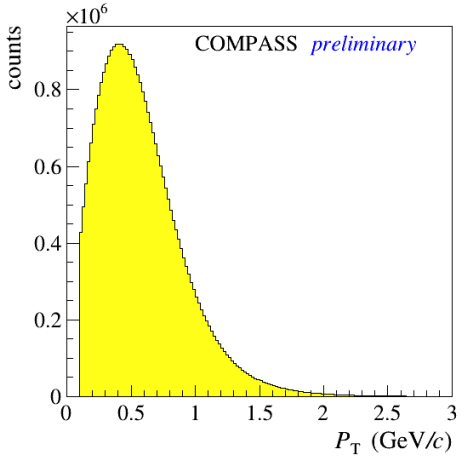
$$z_{h_{1(2)}} > 0.1, \qquad P_{h_{1(2)}T} > 0.1\ \mathrm{GeV}/c$$

Further cuts

$0.30 < z = z_{h_1} + z_{h_2} < 0.95$	fractional energy of the pair (reduce background)
$E_{miss} = (M_X^2 - M_p^2)/(2M_p) > 3$ GeV	missing energy (remove exclusive events)
$0.1 < P_T\ /\ (\mathrm{GeV}/c) < 4.0$	transverse momentum cuts (angular resolution)
$0.35 < M_{hh}\ /\ (\mathrm{GeV}/c^2) < 3.00$	invariant mass range







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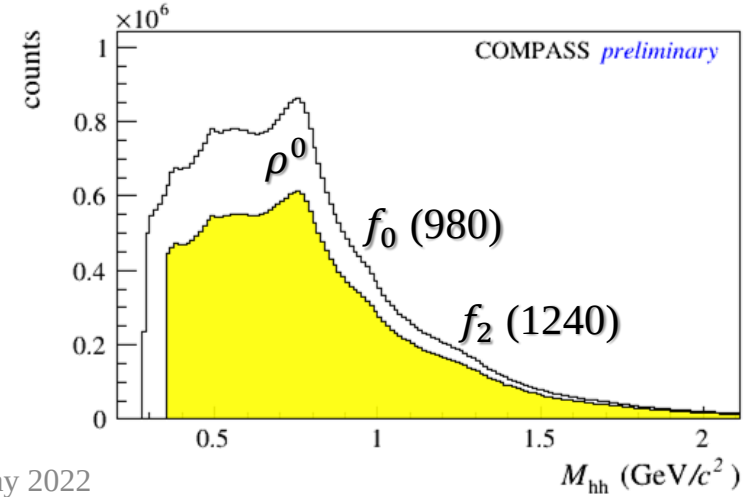


Large combinational background under the ρ^0 peak

Procedure for the extraction of the asymmetries

The Collins and Sivers TSAs for inclusive ρ^0 are extracted **in 4 steps**

1. Extraction of the uncorrected TSA for h^+h^- pairs $\boldsymbol{a_{UT}^{\sin\phi_X}}$
2. Estimation of the ρ^0-signal fraction $\boldsymbol{f_s}$
3. Extraction of background (side-band) TSA $\boldsymbol{A_{UT,bg}^{\sin\phi_X}}$
4. Extraction of ρ^0 TSA (subtracting the bacground TSA)

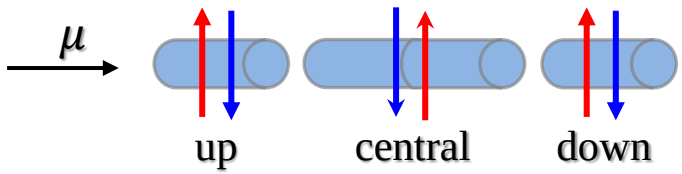
$$A_{UT}^{\sin\phi_X} = \frac{1}{f_s}\left[a_{UT}^{\sin\phi_X} - (1 - f_s)A_{UT,bg}^{\sin\phi_X}\right]$$

where $\phi_X = \phi_{Coll}, \phi_{Siv}$

Extraction of the asymmetries

Standard COMPASS methods applied for the extraction of the asymmetries
[COMPASS, *Nucl. Phys. B765* (2007) 31–70]

- Data-taking is organized in **(sub)periods – coupled weeks**
  - polarization reversal (in all 3 cells) once per week
  - Data from two sub-periods before/after reversal are combined into a period
  - minimization of systematic effects
- Asymmetries extracted for each period of data are then combined
- Six one-dimensional bins in x, z and P_T



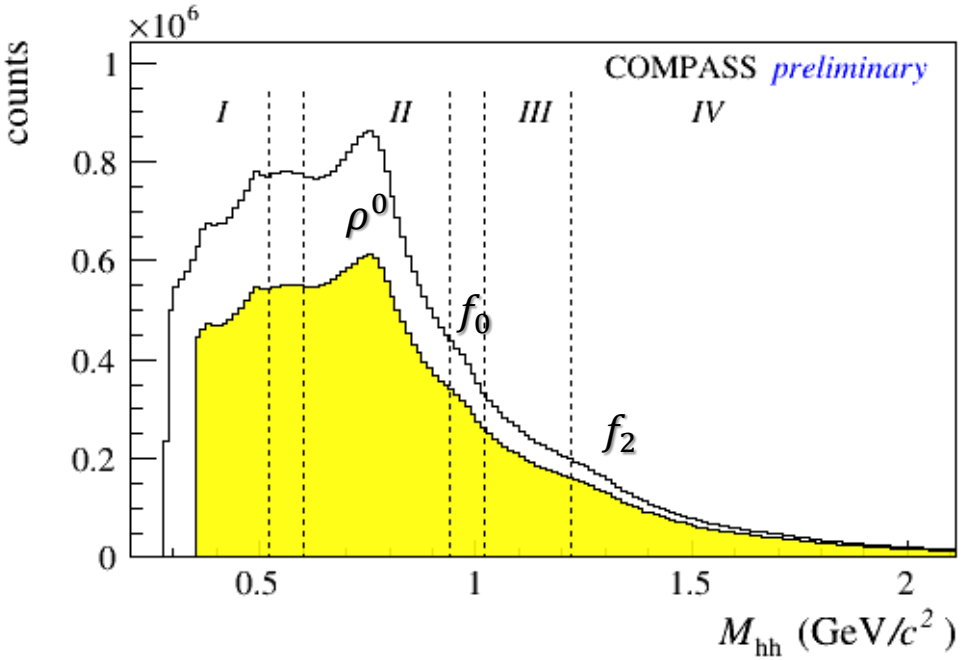
- **Four invariant mass regions**

$I \quad 0.35 < M_{hh}/(\mathrm{GeV}/c^2) < 0.52$

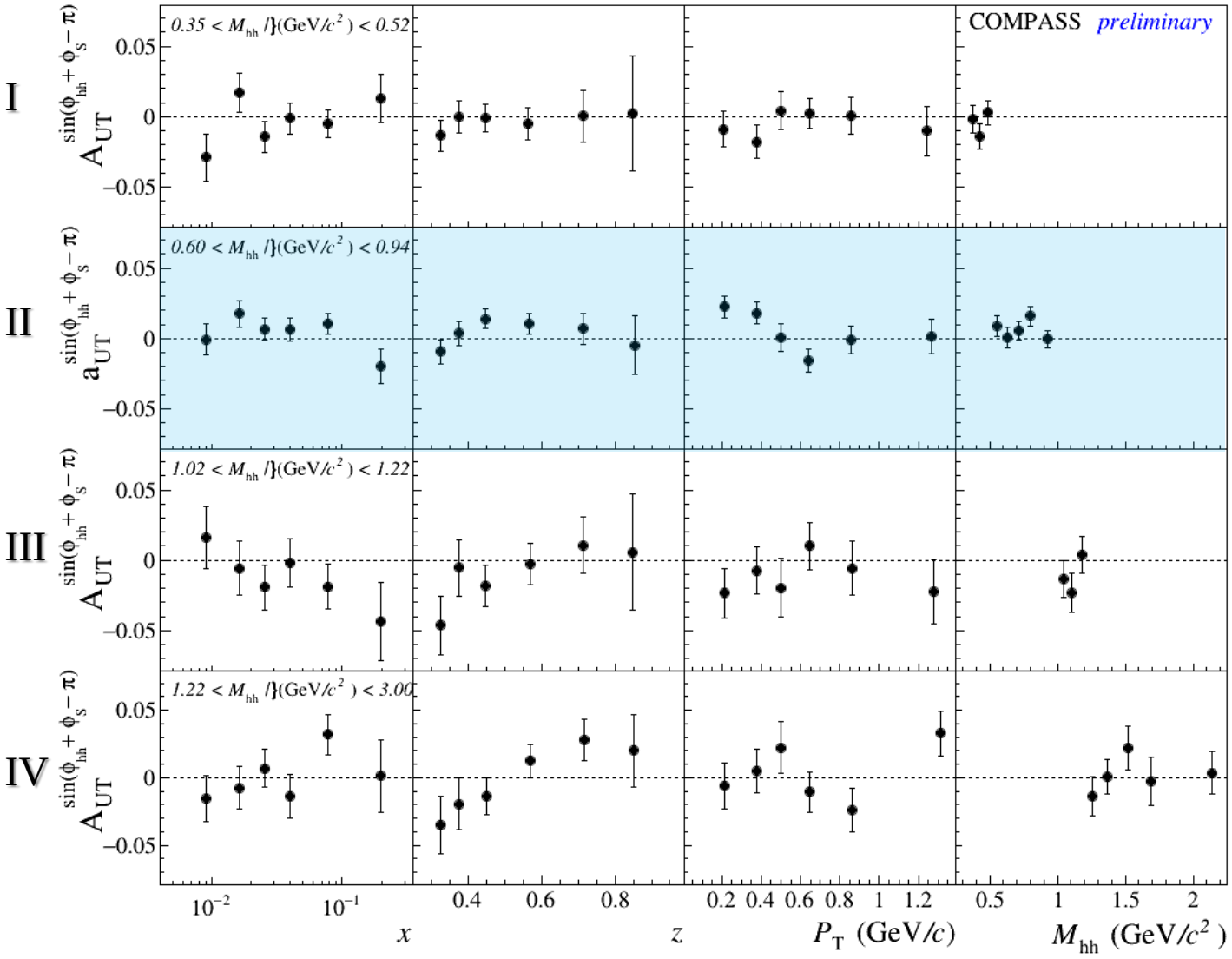
$\mathbf{II \quad 0.60 < M_{hh}/(GeV/c^2) < 0.94}$

$III \quad 1.02 < M_{hh}/(\mathrm{GeV}/c^2) < 1.22$

$IV \quad 1.22 < M_{hh}/(\mathrm{GeV}/c^2) < 3.00$



Collins asymmetries in four mass regions



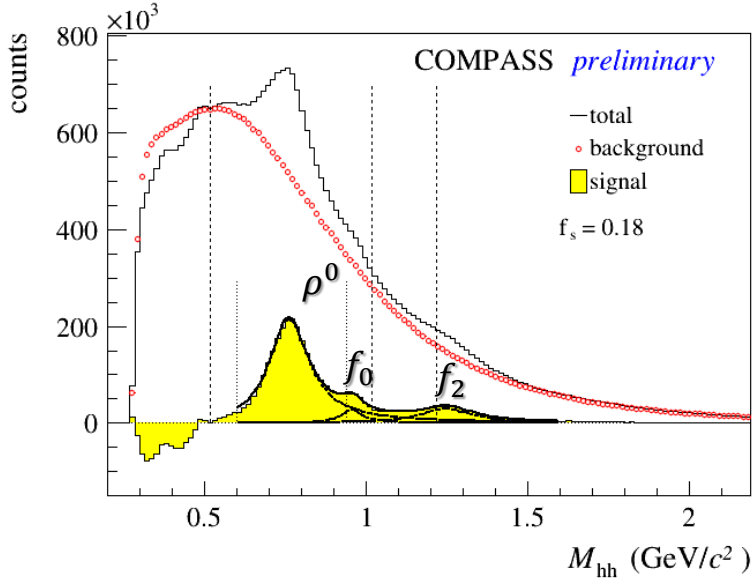
ρ^0 region

indication for a positive Collins asymmetry at intermediate z and small P_T

side-band asymmetries: compatible with zero in all 3 three regions

Signal fraction estimation

The background shape is modeled using the M_{hh} distribution from $h^+h^+ + h^-h^-$ sample



- $h^+h^+ + h^-h^-$ distribution normalized at $M_{hh} \sim 0.50 \frac{\text{GeV}}{c^2}$
- scaled $h^+h^+ + h^-h^-$ distribution subtracted from the h^+h^- one
- The signal distribution can be a fitted with the sum of three Breit-Wigner functions for ρ^0, f_0, f_2
- Signal fraction calculated by counting the signal yields in ρ^0 region as:

$$f_s = \frac{n_{\rho^0}}{n_{h^+h^-}}$$

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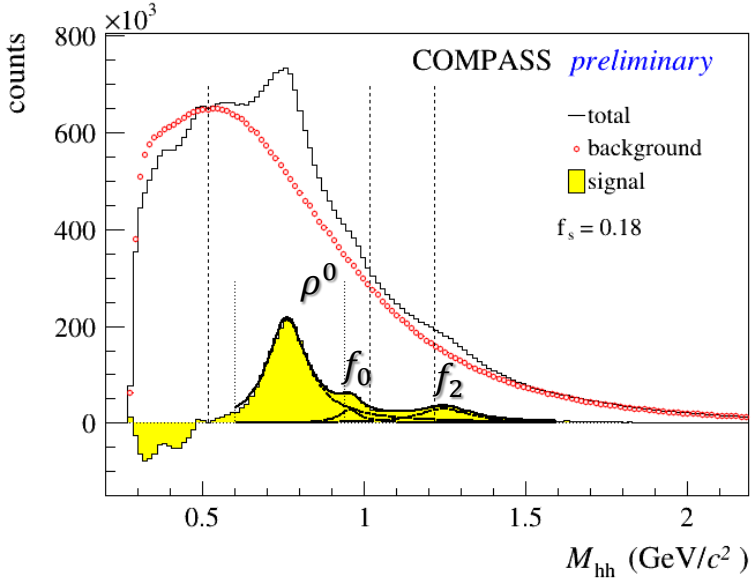

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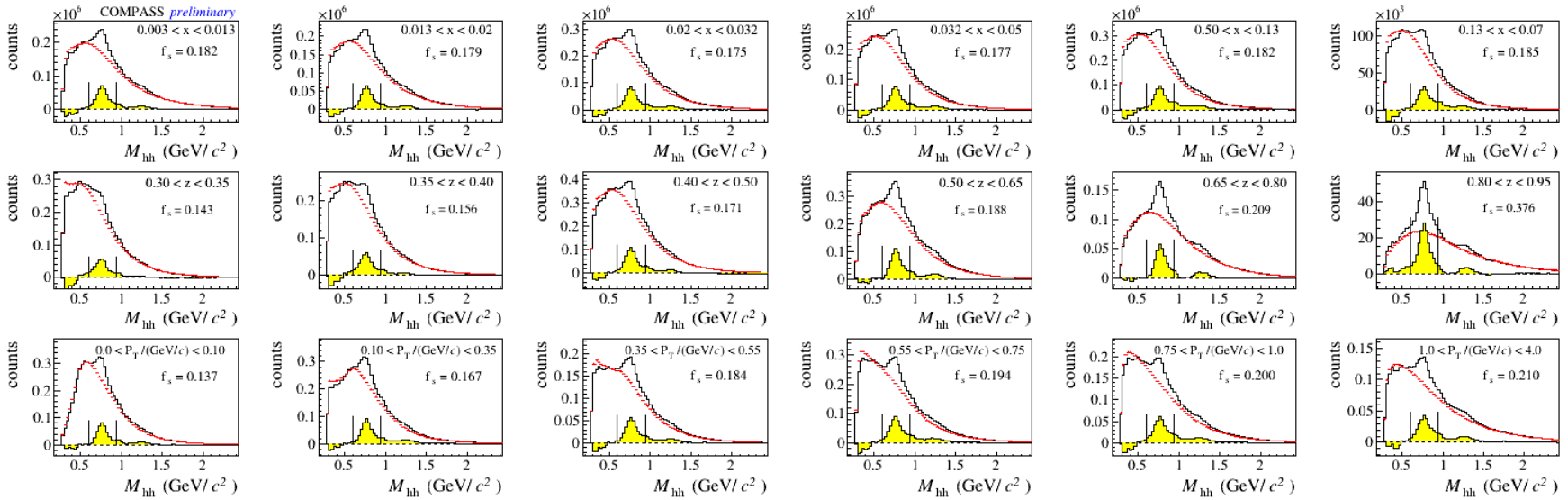
Same procedure is applied for each x, z, P_T bin



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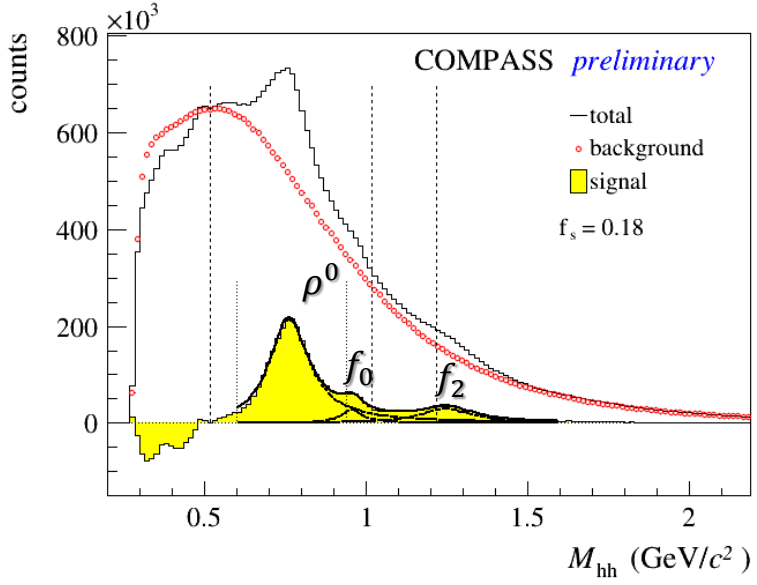

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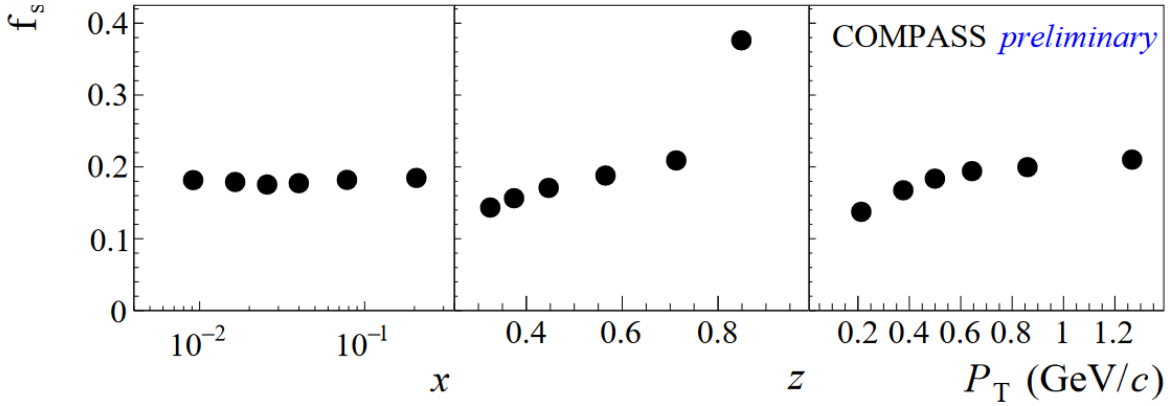
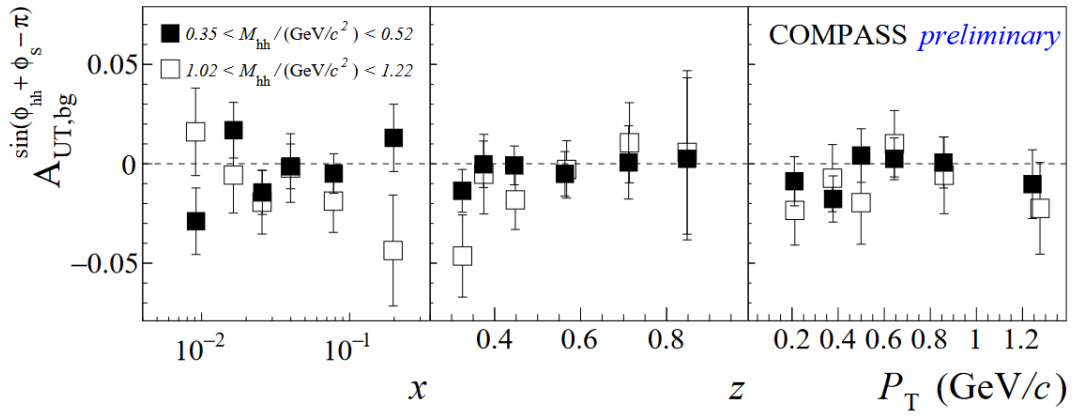


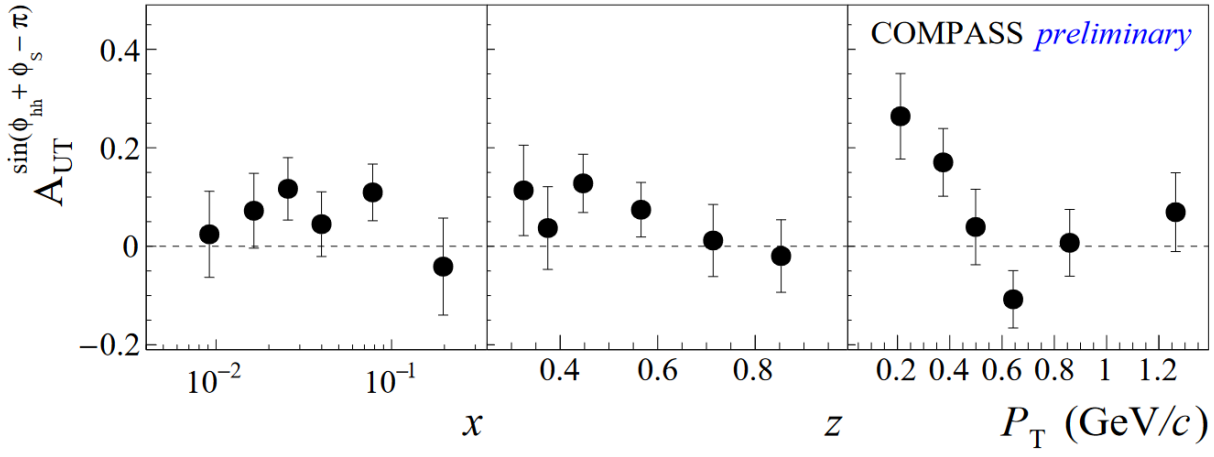
Signal fraction is ~ 18%

- increases with z up to 38%
- as expected e.g. in the string fragmentation model

Background- and corrected Collins asymmetries



The background asymmetry
$A_{UT,bg}^{sin\,\phi_{hh}+\phi_S-\pi}$
is the arithmetic mean of asymmetries in regions I and III



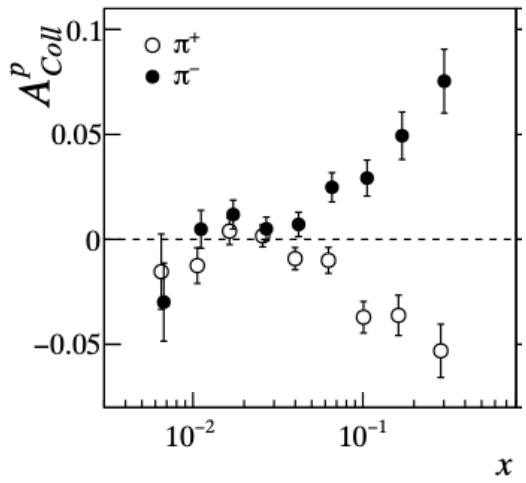
COLLINS ASYMMETRY FOR ρ^0

- indication for a positive asymmetry
- Large effect at small P_T
- only statistical uncertainties are shown

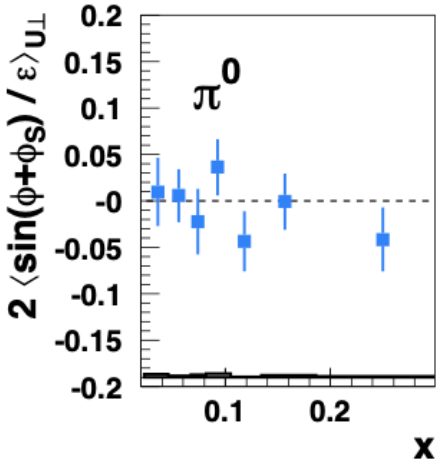
$$\sigma_{syst} \approx 0.3\sigma_{stat}$$

Background- and corrected Collins asymmetries

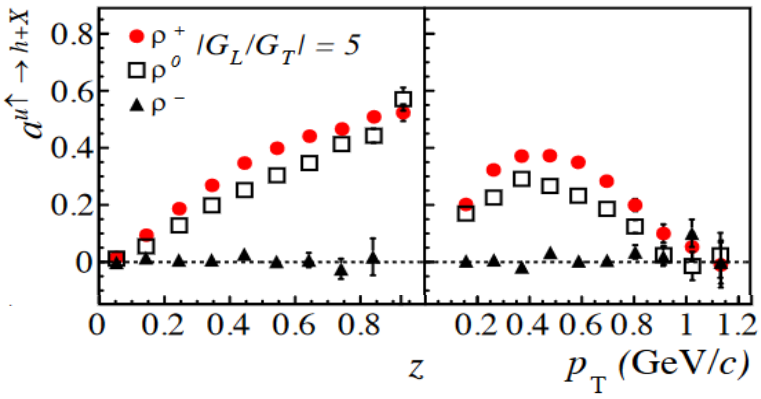
Collins asymmetry for π^+, π^-
[COMPASS, *PLB 744* (2015) 250]

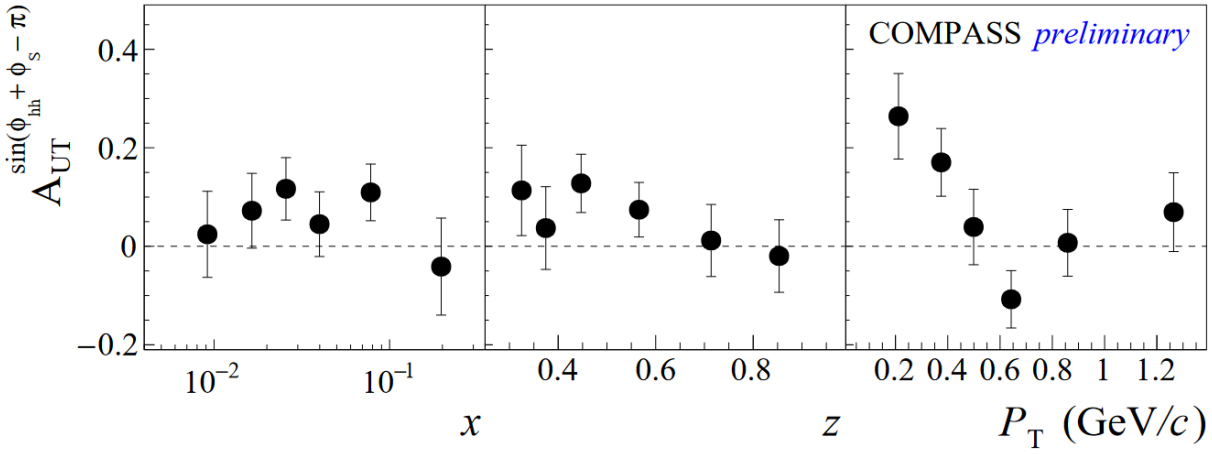


Collins asymmetry for π^0
[HERMES, *JHEP 12* (2020) 010]



[A. Kerbizi et al., *hep-ph*: 2109.06124]



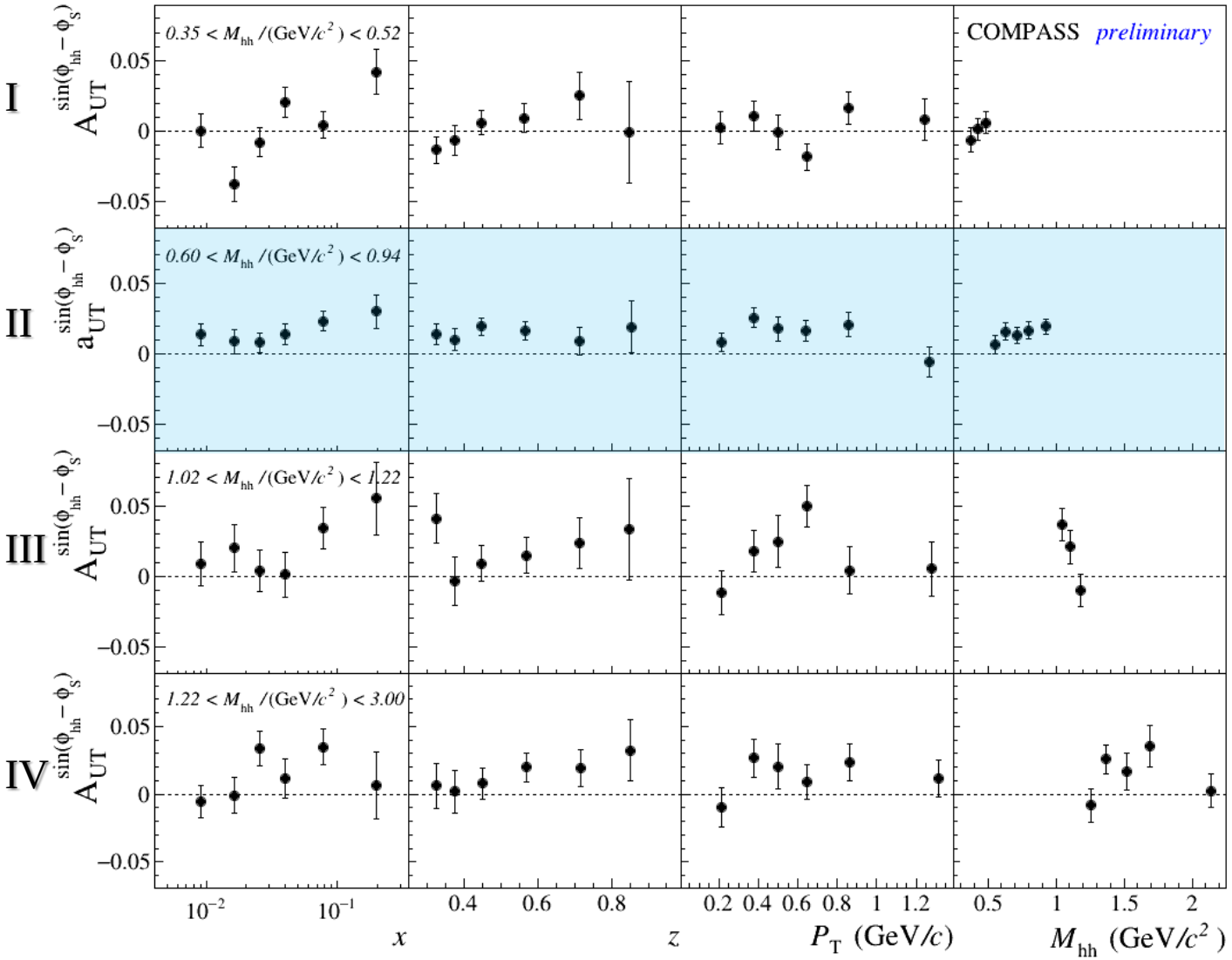


COLLINS ASYMMETRY FOR ρ^0

- indication for a positive asymmetry
- opposite to π^+ and π^0 as predicted by the models
- Large effect at small P_T
- only statistical uncertainties are shown

$$\sigma_{syst} \approx 0.3\sigma_{stat}$$

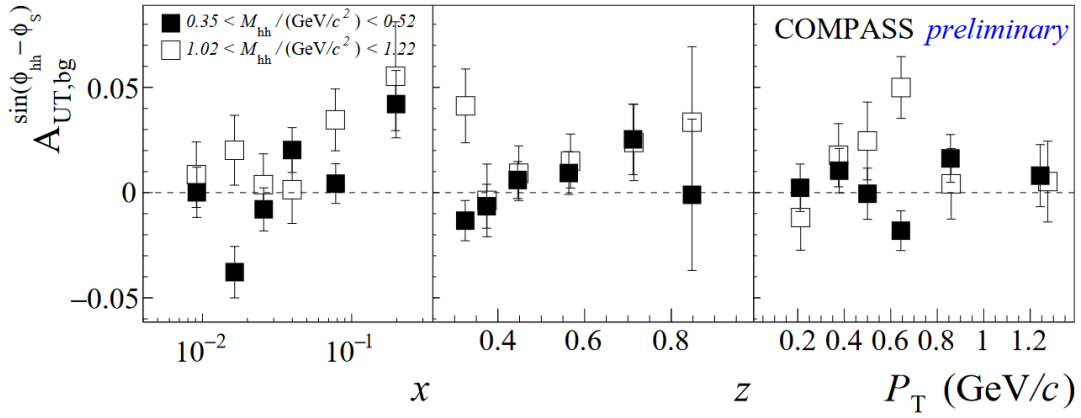
Sivers asymmetries in four mass regions



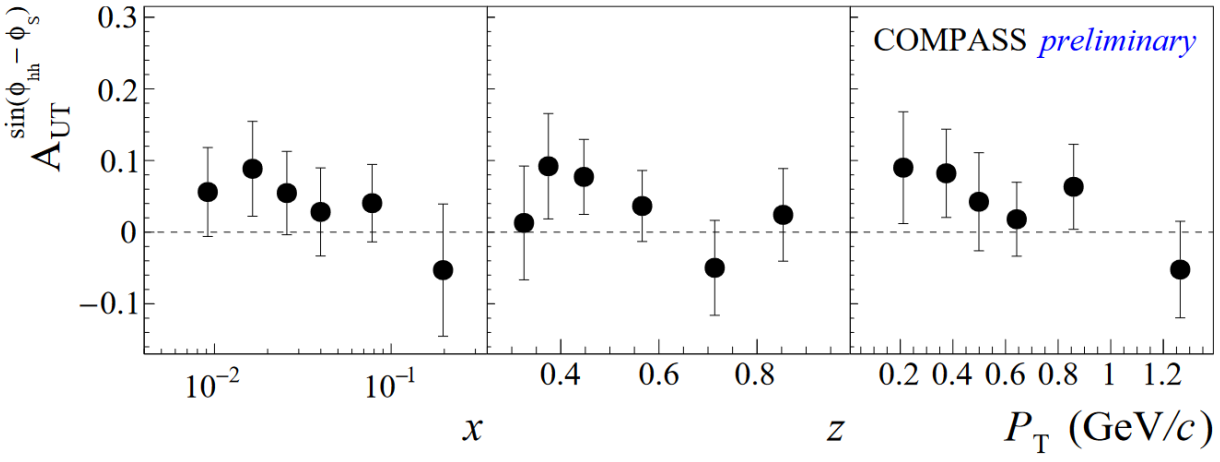
ρ^0 region: clear positive asymmetry

side-band asymmetries: tend to be positive

Background- and corrected Sivers asymmetries



The background asymmetry
$A_{UT,bg}^{sin\,\phi_{hh}-\phi_S}$
is the arithmetic mean of asymmetries in regions I and III



SIVERS ASYMMETRY FOR ρ^0

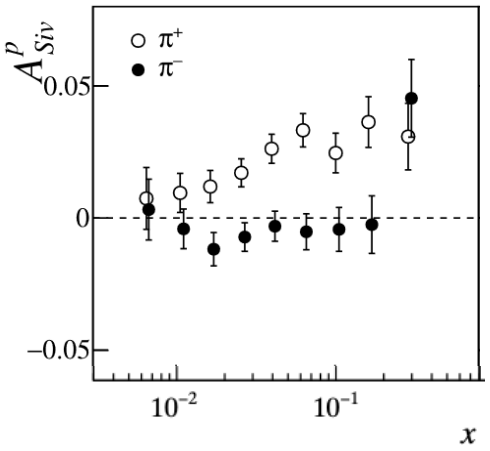
- indication for a positive asymmetry

- only statistical uncertainties are shown

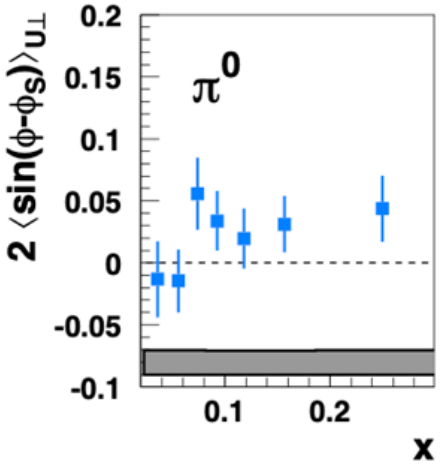
$$\sigma_{syst} \approx 0.3\sigma_{stat}$$

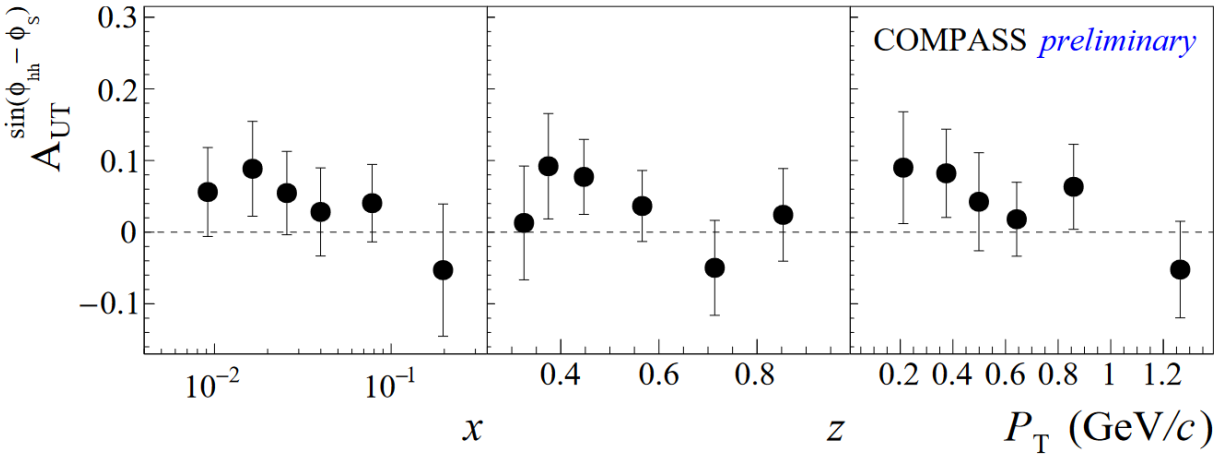
Background- and corrected Sivers asymmetries

Sivers asymmetry for π^+, π^-
[COMPASS, *PLB 744* (2015) 250]



Sivers asymmetry for π^0
[HERMES, *JHEP 12* (2020) 010]





SIVERS ASYMMETRY FOR ρ^0

- indication for a positive asymmetry
- similar to π^0 as expected from the models
- only statistical uncertainties are shown

$$\sigma_{syst} \approx 0.3\sigma_{stat}$$

Conclusions

- COMPASS measured the ***Collins and Sivers asymmetries for inclusively produced*** $\boldsymbol{\rho^0}$ *for the first time*
- Indication for a positive *Collins asymmetry* for ρ^0
  - opposite to the π^+ case, as expected from models
- Indication for a positive *Sivers asymmetry* for ρ^0
  - In agreement with model expectations

Original slides – a courtesy of A. Kerbizi and A. Moretti