Measurement of the azimuthal modulations of hadrons in unpolarized SIDIS

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On behalf of the COMPASS Collaboration

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Outline

1. Introduction
2. COMPASS
3. Measurement on ^{6}LiD target
4. Contribution of diffractive vector mesons
5. Measurement on H target
6. Conclusion

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Introduction

The SIDIS cross section in the one-photon exchange approximation:

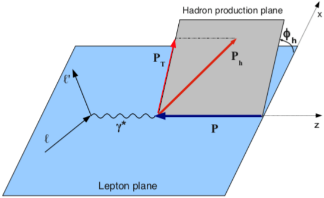
$$\frac{\mathrm{d}\sigma}{P_{h\mathrm{T}}\mathrm{d}P_{h\mathrm{T}}\mathrm{d}x\mathrm{d}y\mathrm{d}z\mathrm{d}\phi_h} = \sigma_0 \left(1 + \epsilon_1 A_{UU}^{\cos\phi_h}\cos\phi_h + \epsilon_2 A_{UU}^{\cos 2\phi_h}\cos 2\phi_h + \lambda\epsilon_3 A_{LU}^{\sin\phi_h}\sin\phi_h\right)$$

- where λ is the beam polarization and

$$\epsilon_1 = \frac{2(2-y)\sqrt{(1-y)}}{1+(1-y)^2}, \qquad \epsilon_2 = \frac{2(1-y)}{1+(1-y)^2},$$

$$\epsilon_3 = \frac{2y\sqrt{1-y}}{1+(1-y)^2}$$

- The amplitudes $A_{XU}^{f(\phi_h)}$ are commonly referred to as azimuthal asymmetries.

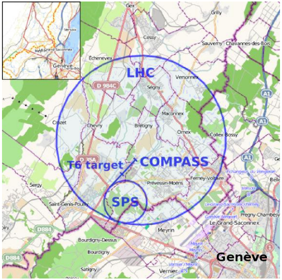


They receive contributions from:

- Cahn effect – mostly $A_{\mathrm{UU}}^{\cos\phi_h}$ – kinematics of the non-coplanar hard scattering.
- Boer–Mulders effect – mostly $A_{\mathrm{UU}}^{\cos 2\phi_h}$ – transverse polarisation of quarks inside unpolarised nucleon.
- Higher twist effects – $A_{\mathrm{UU}}^{\sin\phi_h}$.

Outline

- COMPASS Collaboration: 24 institutions from 13 countries (≈ 220 physicists).
- Experimental area: CERN Super Proton Synchrotron (SPS) North Area.
- Multi-purpose apparatus:
  - SIDIS with 160 GeV/c $\mu^{\pm}$ beam and large solid-state ^{6}LiD and NH_3 polarised target,
  - hadron spectroscopy with hadron beam (π^{-}, K^{-}, $\bar{p}$) and nuclear targets,
  - Drell–Yan with 190 GeV/c π^{-} beam and large solid-state NH_3 polarised target,
  - Two-stage spectrometer, about 350 detector planes, μ identification, RICH, calorimetry.



Location of the site at CERN's SPS

[Wikimedia Commons]

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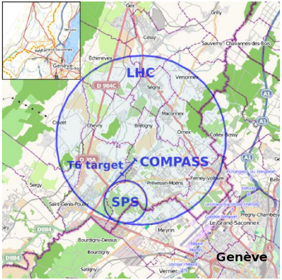

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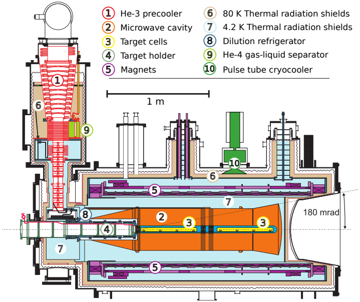

Polarised target cryostat.

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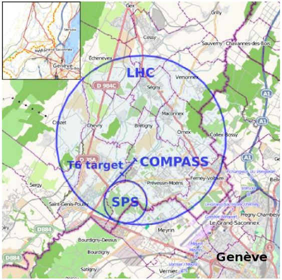

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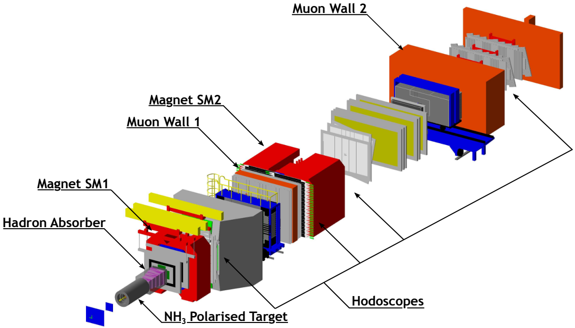
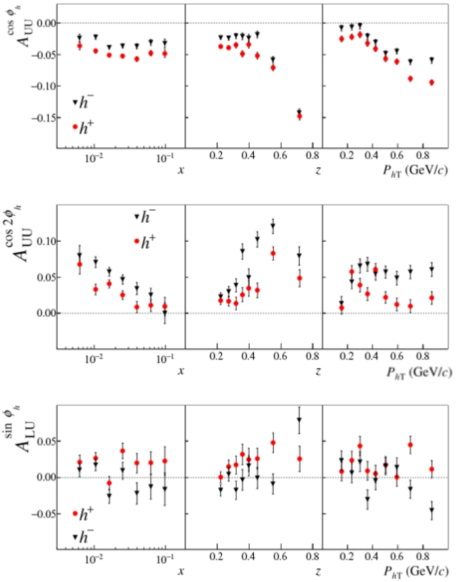


COMPASS Drell–Yan setup 2015 and 2018.

Outline

Measurement on ^{6}LiD target

- [COMPASS, Nucl.Phys.B 886 (2014) 1046]
- Isoscalar target, effectively deuteron.
- 1D analysis
  (bins in x, z and P_{hT} separately).
- 3D analysis (3D grid of bins).
- Strong kinematic dependence of the $\cos\phi_h$ and $\cos 2\phi_h$ asymmetries.
- The source of these are still not fully understood.
- Part of the explanation: background from diffracive vector meson production.



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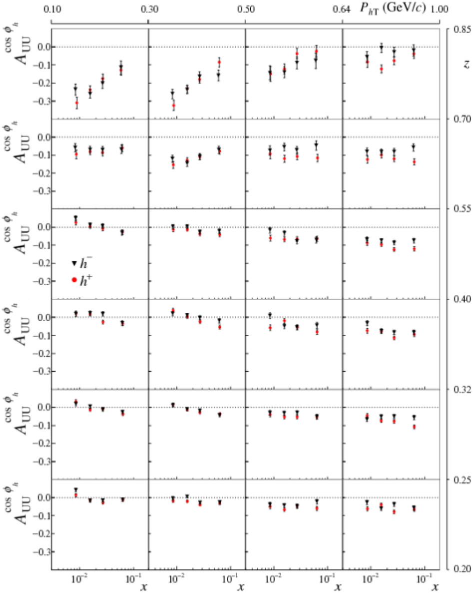
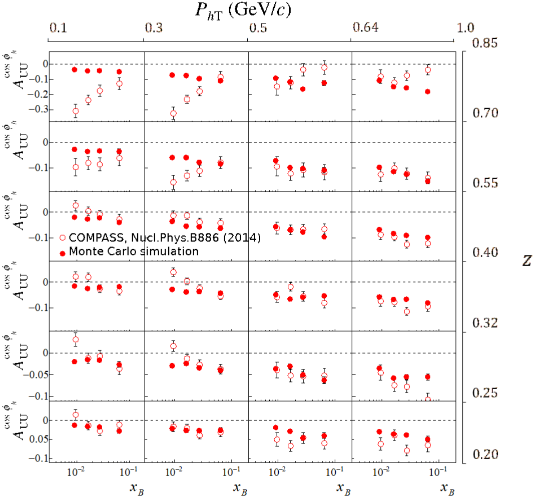


Outline

Contribution of diffractive vector mesons: Introduction

An attempt to simulate the Cahn and Boer–Mulders effects with Monte Carlo

- ${}^3\mathrm{P}_0$ $q\bar{q}$ creation,
- String fragmentation model.
- Model for intrinsic transverse momentum of quarks.
- [A.Kerbizi *et al.*, Phys.Rev.D97 (2018)]
- [A.Kerbizi (COMPASS), SPIN 2018]
- We can see different behaviour at small P_{hT} and large z.
- Contribution from a different process?



Positive hadrons (negative: similar).

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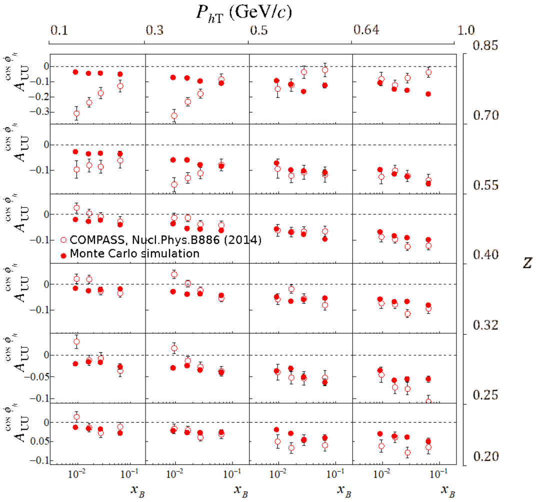
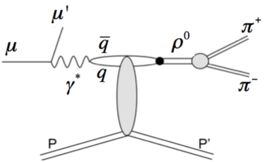


Positive hadrons (negative: similar).

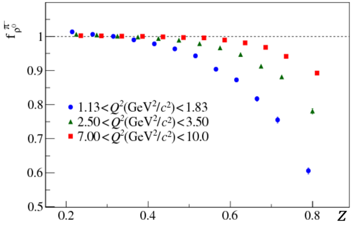
Contribution of diffractive vector mesons: Fraction

The fraction of diffractive vector mesons was estimated for the hadron multiplicity analysis

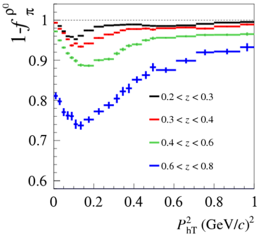
- [COMPASS, Phys.Rev.D97 (2018)].
- Determined from Monte Carlo samples of LEPTO (SIDIS) and HEPGEN (diffractive).
- The fraction goes up to 50 % in some kinematic bins.
- Mostly: low P_{hT}, high z, low Q^2.
- ϕ mesons give smaller contribution at $z \simeq 0.5$
- Do they contribute to the asymetries?



The diffractive ρ^0 production and decay.



The fraction of π^- from SIDIS (the rest is diffractive ρ.



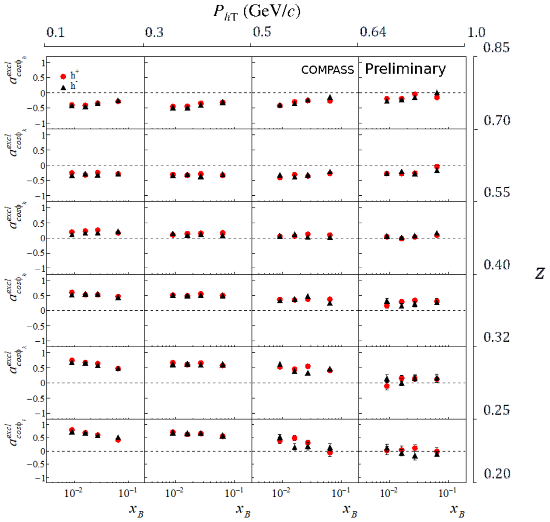
The fraction of π from SIDIS (the rest is diffractive ρ.

The azimuthal asymmetry of single hadrons coming from decaying diffractive ρ^0 and ϕ has been estimated for the first time

- [A.Kerbizi (COMPASS), SPIN 2018]
- Determined from the data – a subsample of $2h$ with

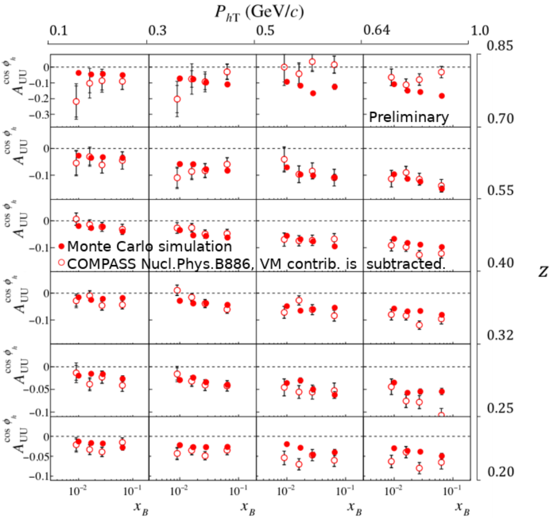
$$z_1 + z_2 > 0.95$$

- Strong positive signal at large z,
- strong negative at small z.
- $\cos 2\phi_h$: smaller, but non-negligible.

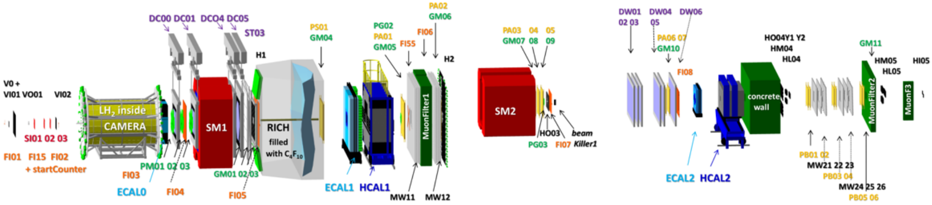


Azimuthal $\cos\phi_h$ modulation of the decay hadrons.

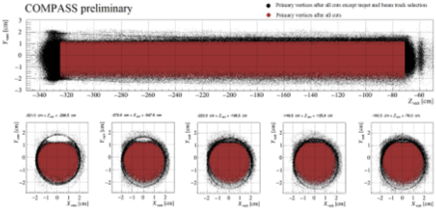
- Finally, knowing both the fraction and the azimuthal modulation of the hadrons from the decaying diffractive ρ^0 and ϕ, one can subtract the contribution from the SIDIS asymmetry.
- After the subtraction, the agreement with the $^3P_0$ + string fragmentation model is much better.



The subtracted $A_{UU}^{\cos\phi_h}$ asymmetry for h^+ compared with the Monte Carlo model.



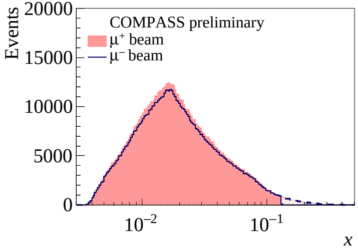
- Primar goal of the 2016 and 2017 runs: Deep virtual Compton scattering to access GPDs.
- 2.5 m long liquid H target with recoil p detector.
- Alternating μ^+ and μ^- beam (interesting for the $\sin\phi_h$ asymmetry).
- Great care for good electromagnetic calorimetry.
- Important for SIDIS: RICH.



Vertices reconstructed in the target region.

Part of data collected in 2016 and 2017

- Preliminary analysis.
- 1 period out of 12 + 9.
- About 4 % of the statistics.



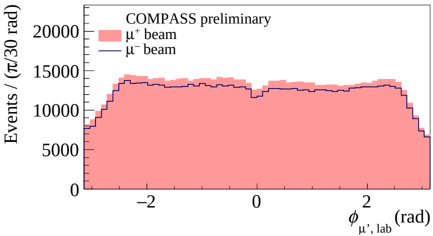
DIS event selection:

- $Q^2 > 1\ (\mathrm{GeV}/c)^2$
- $W > 5\ \mathrm{GeV}/c^2$
- $0.2 < y < 0.9$
- $0.003 < x < 0.13$ (7 bins)

Hadron selection:

- $0.2 < z < 0.85$ (8 bins)
- $0.1 < P_{hT} < 1\ \mathrm{GeV}/c$ (9 bins)

	μ^+ beam	μ^- beam
h^+	269 000	254 000
h^-	216 000	200 000



Measurement on H target: Event selection, kinematics

Part of data collected in 2016 and 2017

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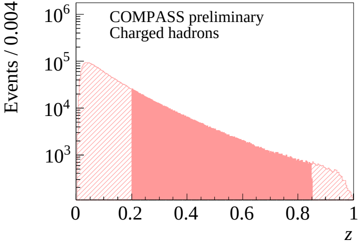
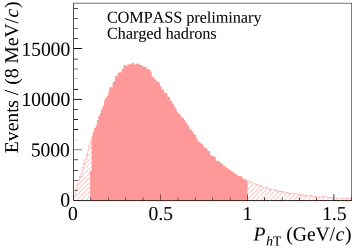
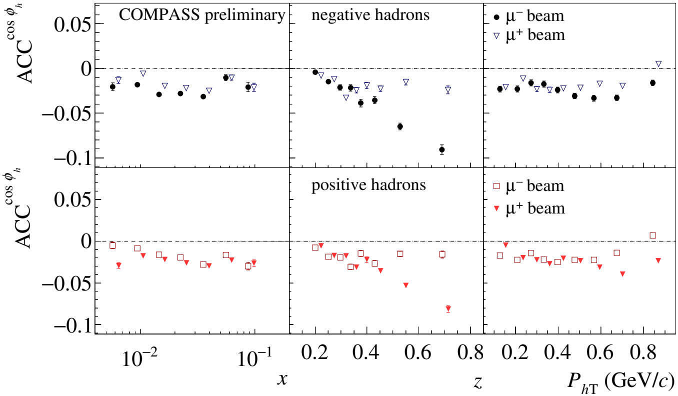




Measurement on H target: Acceptance



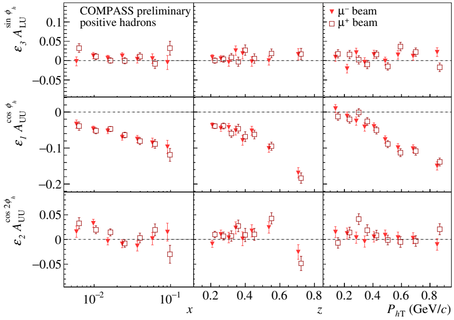
Azimuthal modulation of the acceptance.

$$\mathrm{ACC} = \mathrm{ACC}^0(1 + \mathrm{ACC}^{\cos\phi_h}\cos\phi_h + \mathrm{ACC}^{\cos 2\phi_h}\cos 2\phi_h) + \mathrm{ACC}^{\sin\phi_h}\sin\phi_h)$$

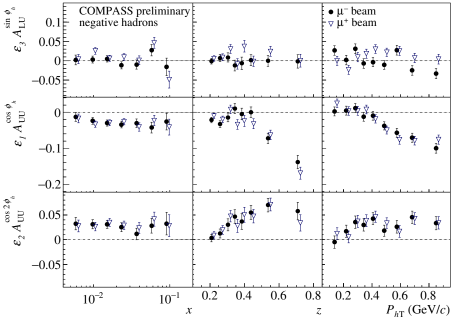
- Monte Carlo tailored for the given period.
- Generator: LEPTO.
- Geant4-based simulation of the apparatus.

- Acceptance modulations: about 2 %.
- Up to 10 % at high z (mirror symmetry for $h^\pm$ and $\mu^\pm$)

Measurement on H target: Results

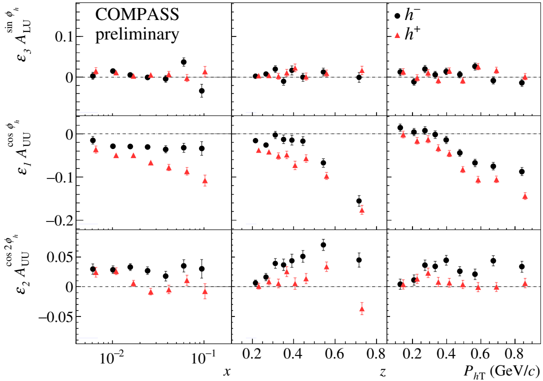


Positive hadrons



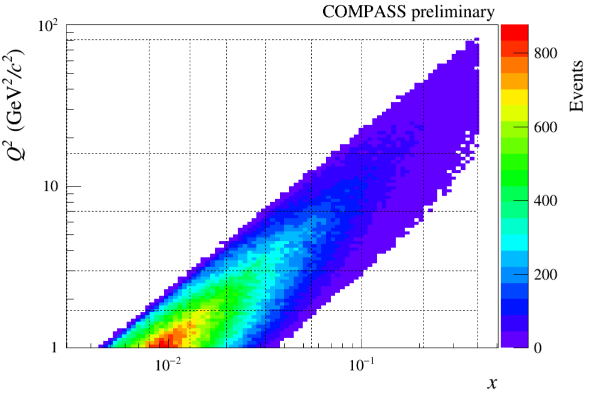
Negative hadrons

The results with μ^- and μ^+ beam are consistent.



Azimuthal asymmetries from 2016 data.

- The strong kinematic dependencies are observed on H as well.
- The result corresponds to about 4 % of the statistics.
- Considering 2016 + 2017 data: statistical uncertainty about 30 % of those from ^{6}LiD.
- Plan: 4D binning in x Q^2 z and P_{hT} (like for the multiplicities, see the next talk)
- Long term plans: particle identification with RICH, other variables...



Coverage in x and Q^2 with the binning shown.

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Conclusion

A contribution to the asymmetry from the decays of diffracively produced ρ^0 and ϕ.

- Large contribution from ρ^0 was measured on ^{6}LiD,
  mosly at low Q^2 and $P_{h\mathrm{T}}$ and at high z.
- Subtraction of this contribution will help wit the interpretations of the data.

New measurement of azimuthal asymmetries in unpolarised SIDIS on H target

- Only 4 % of the statistics of 2016 2017 data.
- The strong kinematic dependencies are observed on H as well.
- Plan: 4D binning in x Q^2 z and $P_{h\mathrm{T}}$,
  diffractive vector meson contribution subtraction.
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