Measurement of the azimuthal modulations of hadrons in unpolarized SIDIS

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On behalf of the COMPASS Collaboration

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1 Introduction

2 COMPASS

3 Measurement on $^6$LiD target

4 Contribution of diffractive vector mesons

5 Measurement on H target

6 Conclusion
Outline

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Introduction

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

$$\frac{d\sigma}{P_hT dP_hT dx dy dz d\phi_h} = \sigma_0 \left( 1 + \epsilon_1 A_{UU}^\cos \phi_h \cos \phi_h + \epsilon_2 A_{UU}^\cos 2\phi_h \cos 2\phi_h + \lambda \epsilon_3 A_{LU}^\sin \phi_h \sin \phi_h \right)$$

where $\lambda$ is the beam polarization and

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

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

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

They receive contributions from:

- **Cahn effect** – mostly $A_{UU}^\cos \phi_h$ – kinematics of the non-coplanar hard scattering.
- **Boer–Mulders effect** – mostly $A_{UU}^\cos 2\phi_h$ – transverse polarisation of quarks inside unpolarised nucleon.
- **Higher twist effects** – $A_{UU}^\sin \phi_h$. 
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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 ($\pi^-$, K$^-$, $\bar{p}$) and nuclear targets,
- Drell–Yan with 190 GeV/c $\pi^-$ beam and large solid-state NH$_3$ polarised target,
- Two-stage spectrometer, about 350 detector planes, $\mu$ identification, RICH, calorimetry.

Location of the site at CERN’s SPS

[Wikimedia Commons]
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Polarised target cryostat.
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Measurement on $^6\text{LiD}$ target

- 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 diffractive vector meson production.
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Contribution of diffractive vector mesons: Introduction

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

- $^3P_0 \ q\bar{q}$ creation,
- String fragmentation model.
- Model for intrinsic transverse momentum of quarks.

[ 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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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 $Q^2$.
- $\phi$ mesons give smaller contribution at $z \simeq 0.5$.
- Do they contribute to the asymmetries?

The diffractive $\rho^0$ production and decay.

The fraction of $\pi^-$ from SIDIS (the rest is diffractive $\rho$).

The fraction of $\pi$ from SIDIS (the rest is diffractive $\rho$).
Contribution of diffractive vector mesons: Asymmetry

The azimuthal asymmetry of single hadrons coming from decaying diffractive $\rho^0$ and $\phi$ 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 $\rho^0$ and $\phi$, 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.
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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 $\mu^+$ and $\mu^-$ beam (interesting for the $\sin \phi_h$ asymmetry).

Great care for good electromagnetic calorimetry.

Important for SIDIS: RICH.

Vertices reconstructed in the target region.
Measurement on H target: Event selection, kinematics

Part of data collected in 2016 and 2017
- Preliminary analysis.
- 1 period out of 12 + 9.
- About 4% of the statistics.

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

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

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Measurement on H target: Acceptance

Azimuthal modulation of the acceptance.

\[ ACC = ACC^0 (1 + ACC^{\cos \phi_h} \cos \phi_h + ACC^{\cos 2\phi_h} \cos 2\phi_h) + ACC^{\sin \phi_h} \sin \phi_h) \]

- 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 \(\mu^\pm\))
The results with $\mu^-$ and $\mu^+$ 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...
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- Large contribution from $\rho^0$ was measured on $^6\text{LiD}$, mostly at low $Q^2$ and $P_{hT}$ and at high $z$.
- Subtraction of this contribution will help with 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.
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Thank you for your attention!