Polarised Drell-Yan measurement in the COMPASS experiment at CERN

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on behalf of the COMPASS Collaboration

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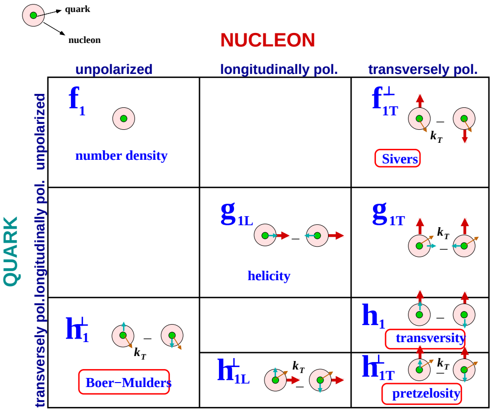
COMPASS @ CERN

COmmon Muon Proton Apparatus for Structure and Spectroscopy

- Fixed target experiment at the end of M2 SPS beam line
- Around 240 collaborators from 13 countries and 23 institutes

Transverse momentum dependent parton distribution functions - TMD PDFs



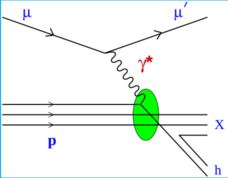
Sivers, Boer-Mulders, transversity and pretzelosity are accessible via either the single transversely polarised Drell-Yan measurement or the transversely polarised Semi-Inclusive DIS. The latter already measured in COMPASS and with published results.

The nucleon structure in leading order QCD, taking into account k_T, is described by 8 PDFs for each quark flavor.

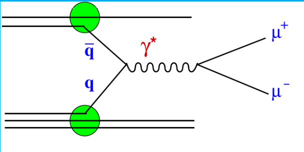
TMD PDFs in DY case

DY and SIDIS cross-sections are written in terms of angular modulations.

The amplitude of each angular modulation contains:



SIDIS: PDF ⊗ FF

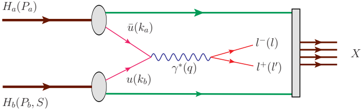


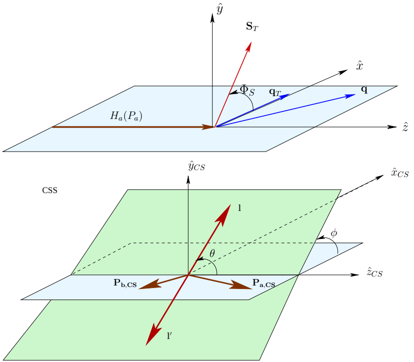
DY: PDF ⊗ PDF

DY is an excellent tool to access TMD PDFs:

- No fragmentation functions involved, but the convolution of 2 PDFs.
- All the TMD PDFs are expected to be sizable in the valence quark region - dominant region when π^- is used as beam.
- The QCD TMD approach is valid in the region Q ($M_{\mu\mu} > 4$ GeV/c^2) $\gg$ $\langle p_T \rangle \sim 1$ GeV/c.

Single polarised DY process





- $s = (P_a + P_b)^2$
- $x_{a(b)} = q^2/(2P_{a(b)} \cdot q)$
- $x_F = x_a - x_b$
- $Q^2 = q^2 = {M_{\mu\mu}}^2 = s x_a x_b$
- $q_T = k_{T\,a(b)}$

$$\frac{d\sigma}{d^4q d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U\{(1 + D_{[\sin^2\theta]}A_U^{\cos 2\phi}\cos 2\phi) + |\vec{S}_T|[A_T^{\sin\phi_S}\sin\phi_S$$
$$+ D_{[sin^2\theta]}(A_T^{sin(2\phi+\phi_S)}sin(2\phi + \phi_S) + A_T^{sin(2\phi-\phi_S)}sin(2\phi - \phi_S))]\}$$

- D depolarization factor
- $F = 4\sqrt{(P_a \cdot P_b)^2 - {M_a}^2{M_b}^2}$
- $\hat{\sigma}_U$ ϕ and ϕ_S integrated cross-section

Azimuthal asymmetries

$$\frac{d\sigma}{d^4 q d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U\{(1 + D_{[\sin^2\theta]} A_U^{\cos 2\phi} \cos 2\phi) + |\vec{S}_T|[A_T^{\sin\phi_S} \sin\phi_S$$
$$+ D_{[sin^2\theta]}(A_T^{sin(2\phi+\phi_S)} sin(2\phi + \phi_S) + A_T^{sin(2\phi-\phi_S)} sin(2\phi - \phi_S))]\}$$

The amplitudes present in the DY cross-section are accessed via the measurement of the angular azimuthal asymmetries between the two oppositely transversely polarised target cells.

Each asymmetry relates to:

- $A_U^{\cos 2\phi}$: Boer-Mulders $h_1^{\perp}(\pi) \otimes$ Boer-Mulders $h_1^{\perp}(p)$
- $A_T^{\sin\phi_S}$: unpolarised PDF $f_1(\pi) \otimes$ Sivers $f_{1T}^{\perp}(p)$
- $A_T^{sin(2\phi+\phi_S)}$: Boer-Mulders $h_1^{\perp}(\pi) \otimes$ pretzelosity $h_{1T}^{\perp}(p)$
- $A_T^{sin(2\phi-\phi_S)}$: Boer-Mulders $h_1^{\perp}(\pi) \otimes$ transversity $h_1(p)$

DY <> SIDIS

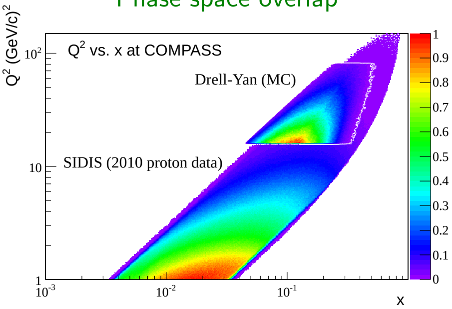
Theoretical prediction of the Sivers and the Boer-Mulders sign change:

$$f_{1T}^{\perp}(x, k_T)|_{DY} = -f_{1T}^{\perp}(x, k_T)|_{SIDIS}$$

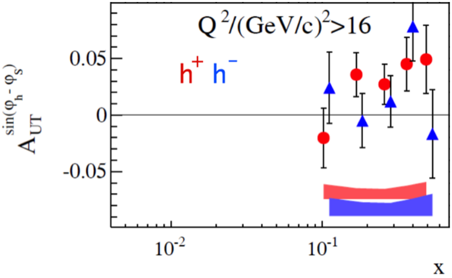
$$h_1^{\perp}(x, k_T)|_{DY} = -h_1^{\perp}(x, k_T)|_{SIDIS}$$

Experimental confirmation: crucial test of the QCD TMD approach.

Phase space overlap



Sivers asymmetry from SIDIS



$\delta A_{UT}^{\sin(\phi_h - \phi_S)} \approx 0.01$ for both h^+ and h^- in SIDIS for $Q^2 > 16\ (\mathrm{GeV}/c)^2$,
same statistical error as expected for Sivers from DY.

Flavor dependent EMC effect

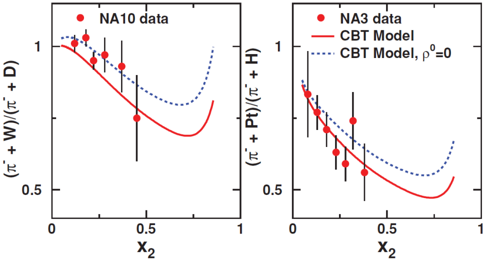
Several studies beyond the polarised DY measurement are possible regarding the use of nuclear targets such as the flavor dependent EMC effect:

- EMC effect ⇒ modification of the quark distributions in nuclei.
- Some models try to explain this effect considering a flavor dependence.

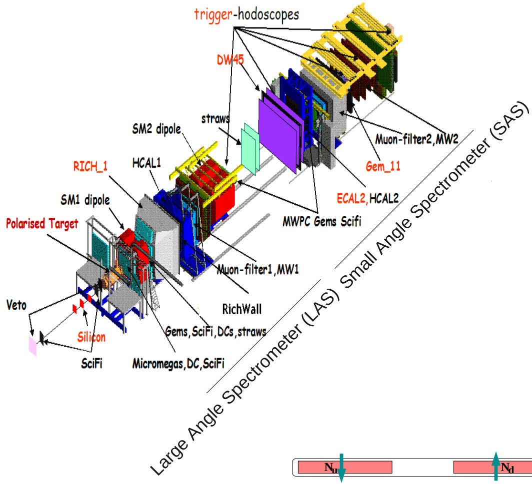
protons ≠ # neutrons ⇒ u and d quarks different nuclear effects

- Study the flavor dependence → dependence with **A**, where the ratios proton/neutron and so u/d are different.

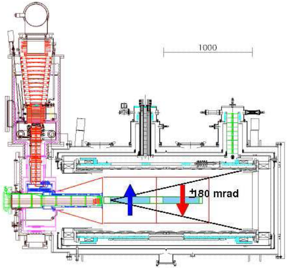
The existing data are not sufficiently accurate to draw any firm conclusion (PHYSICAL REVIEW C 83,042201 (R) (2011)).

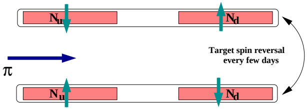


Experimental setup

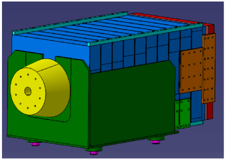


Polarised target, NH_3
dilution factor 22%
polarisation up to 90%





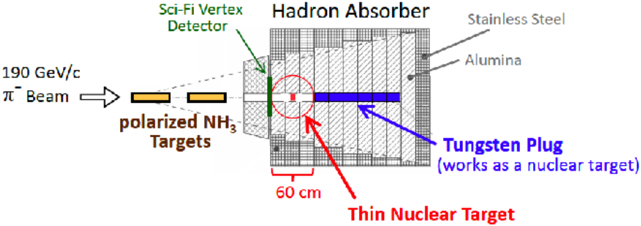
Experimental setup - Hadron absorber and beam plug



- A hadron absorber is placed downstream of the target to stop the hadrons and with a beam plug in the center to stop the non-interacting beam.

- The hadron absorber will introduce multiple scattering on muons and there will be a degradation of the resolutions. To partially solve this problem a vertex detector is introduced in the first part of the absorber.

An Al nuclear target is assembled before the tungsten beam plug, also used as nuclear target.

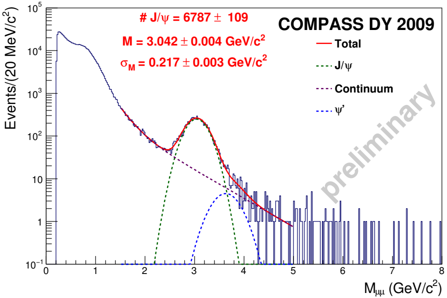


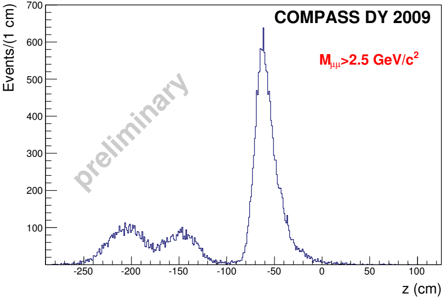
Feasibility of the experiment

In 2009 a 3 days data taking beam test was done using:

- a hadron absorber prototype.
- a π^- beam at 190 GeV/c with an intensity of $1.5 \times 10^7 \pi/s$.
- a double trigger based on calorimeter signals was also used.

$\hookrightarrow$ This year trigger will be based on hodoscopes with a high efficiency, purity and target pointing capability





- J/ψ yealds confirmed, $M_{J/\psi}$ and σ_M in agreement with the MC simulation.
- target cells and beam plug distinguishable, better Z_{vtx} resolution with the new absorber and the vertex detector.

Event rates and statistical accuracy

Considering:

- $I_{beam} = 10^8 \pi/s$
- $\mathcal{L} = 2.3 \times 10^{33}\ cm^{-2}\ s^{-1}$
- geometrical acceptance of 39%
- $4 < M_{\mu\mu} < 9$ GeV/c^2
- beam spill=9.6 s
- SPS super cycle=34 s

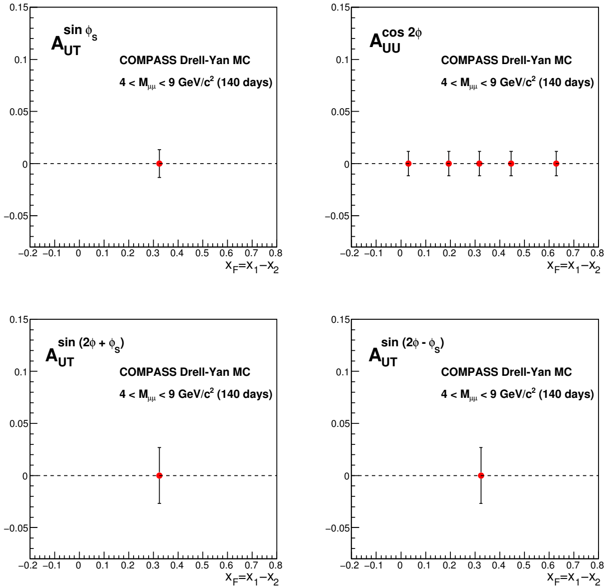
DY event rate:

- 2000 events/day
- 285000 events/year ($\approx$ 140 days)

The expected statistical errors of the asymmetries, considering 285000 events, are:

Asymmetry	Statistical error ($4 < M_{\mu\mu} < 9$ GeV/c^2)
$\delta\, A_{UU}^{\cos 2\phi}$	0.005
$\delta\, A_{UT}^{\sin \phi_S}$	0.013
$\delta\, A_{UT}^{\sin(2\phi+\phi_S)}$	0.027
$\delta\, A_{UT}^{\sin(2\phi-\phi_S)}$	0.027

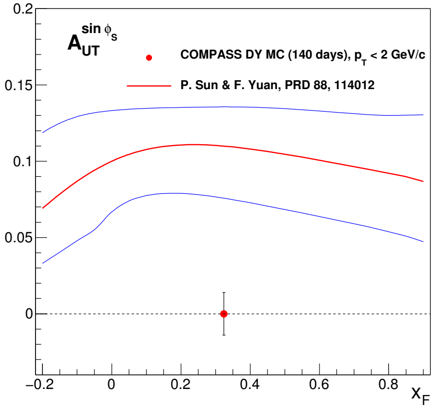
Asymmetries precision projections

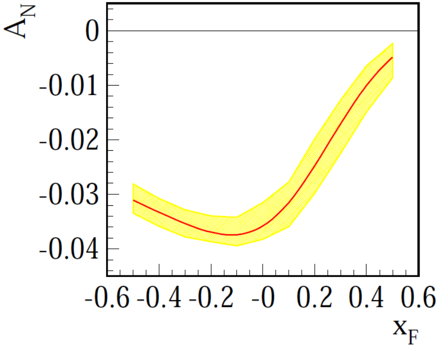


Asymmetries theoretical predictions

Different theory predictions for the spin asymmetries in COMPASS are available.

Two predictions for the Sivers asymmetry are shown:





Echevarria *et al*, arXiv: 1401.5078

$x_F = x_p - x_\pi$

Final remarks

- The Pilot Drell-Yan run will start next month and will last for two months.
- This pilot run will be the opportunity to test the whole concept and work out data taking strategy for the next year data taking.
- The Sivers function sign change is expected to be checked based on the COMPASS SIDIS and DY results.
- The nuclear targets will give the opportunity to perform some unpolarised DY studies such as the flavor dependence EMC effect.
- The possibility to have a 2nd year of DY data taking before LS2 (2019) will be discussed soon.

We are looking forward to have the first ever DY polarised data.