# POLARISED DRELL-YAN MEASUREMENTS AT COMPASS-II

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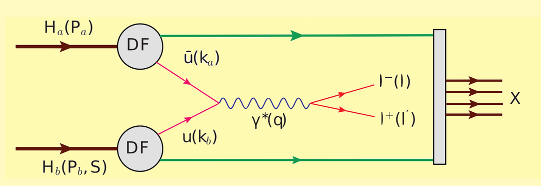
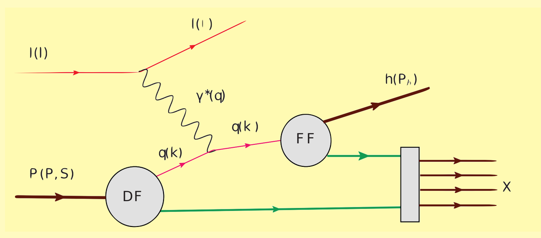
## What do we need to access spin dependent parton distribution functions through Drell-Yan?

**DY:**



**SIDIS:**



In single polarised Drell-Yan (DY), with transversely polarised target nucleons, the expression of the cross-section at leading order is [S. Arnold, *et al*, Phys.Rev. D79 (2009) 034004]:

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

$D$: depolarisation factor; $S_T$: transverse target spin; $F$: flux of incoming hadrons; $\sigma_U$: part of the cross-sec. surviving integration over $\phi$ and $\phi_S$; $\phi_S$: azimuthal angle of $S_T$ in the target rest frame; $\phi$: azimuthal angle of the lepton momentum in the Collins-Soper frame

$A_U^{\cos 2\phi}$ gives access to the Boer-Mulders functions of both incoming hadron and target nucleon

$A_T^{\sin(2\phi+\phi_S)}$ to the Boer-Mulders function of the beam hadron and to the prezelosity function

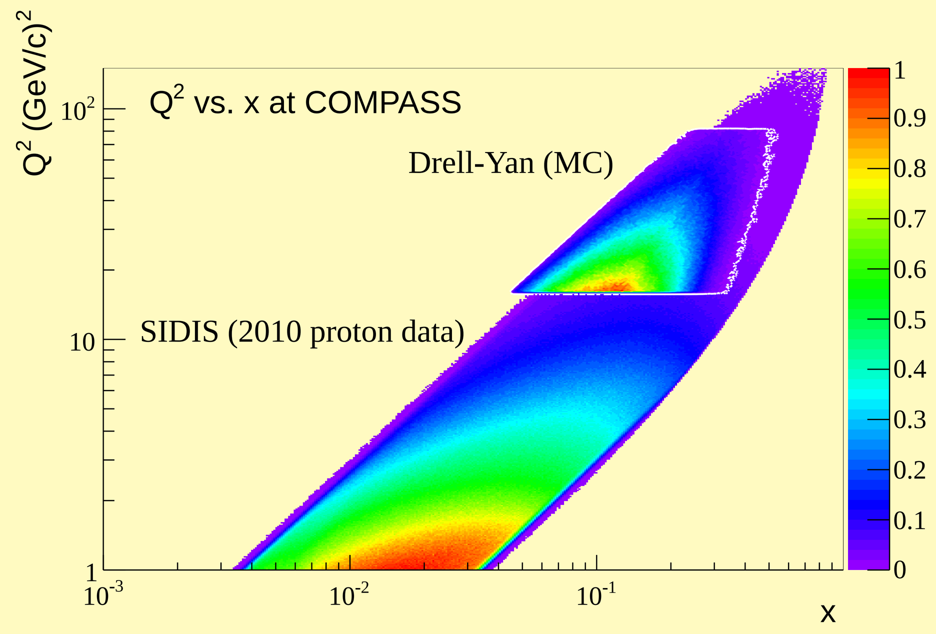
$A_T^{\sin\phi_S}$ to the Sivers function of the target nucleon

$A_T^{\sin(2\phi-\phi_S)}$ to the Boer-Mulders function of the beam hadron and to the transversity function of the target nucleon

### Change of sign of Sivers and Boer - Mulders functions?

$$f_{1T}^{\perp}|_{DY} = -f_{1T}^{\perp}|_{SIDIS} \quad \text{and} \quad h_1^{\perp}|_{DY} = -h_1^{\perp}|_{SIDIS}$$

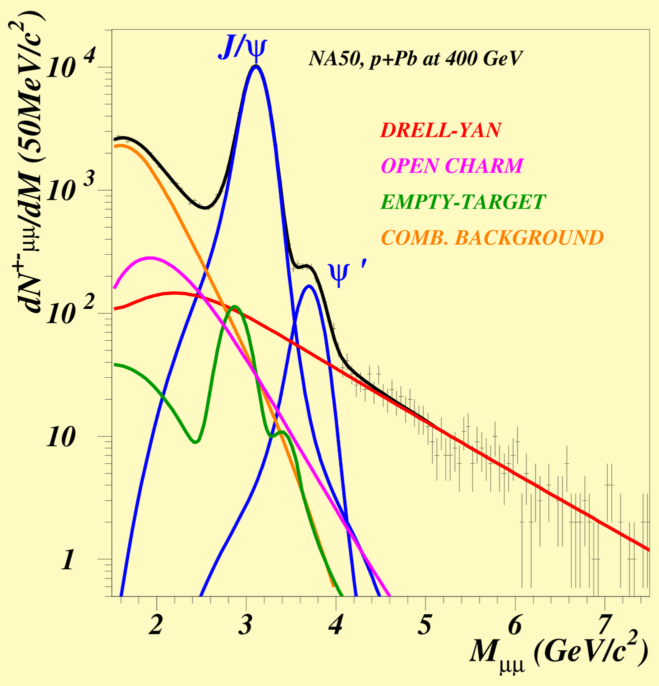
Critical test of universality of transverse momentum dependent (TMD) factorisation approach for the description of single spin asymmetry. In COMPASS, we have the opportunity to test the Sivers function sign change using the same spectrometer and a transversery polarised target in overlapping range of $x$ and $Q^2$ for SIDIS and DY.




The phace spaces of the two processes overlap at COMPASS

### Polarised Drell-Yan experiments:

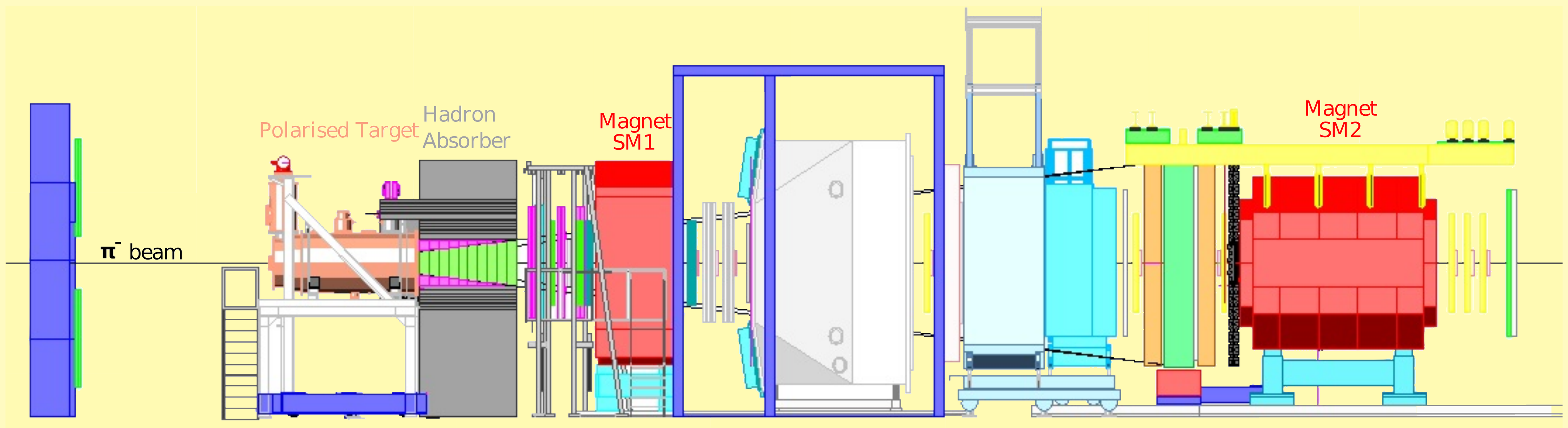
- High luminosity (DY cross section is a fraction nanobarns) and large angular acceptance
- Sufficiently high energy to access 'safe' background free $M$ range ($4 < M_{\mu\mu} < 9$ GeV/$c^2$)
- Good acceptance in the valence quark range
- Good figure of merit, which can be represented as a product of the luminosity, target polarisation and dilution factor




- Drell-Yan@COMPASS: high intensity (up to $10^8$ particles/second) 190 GeV/$c$ $\pi^-$ beam and a transversely polarized NH3 target;
- The combinatorial background is kept under control by the presence of a hadron absorber downstream of the target.
- In spite of low cross-section the range $4 < M_{\mu\mu} < 9$ GeV/$c^2$ is ideal to study azimuthal asymmetries in DY due to negligible background contamination.
  - The combinatorial background in this range is 100 times lower than in the low mass range (50% of total yield for $2 < M_{\mu\mu} < 2.5$ GeV/$c^2$)
  - open charm contributes only at 15%

## COMPASS-II experimental layout

- Large angular acceptance spectrometer
- $\pi^-$ beam at 190 GeV/$c$ with intensity up to $1 \cdot 10^8$ particles/second
- Large acceptance COMPASS Superconducting Solenoid Magnet
- Transversely polarised $NH_3$ target working in frozen spin mode with long relaxation time
- Hadron absorber downstream of the target
- A detection system designed to stand relatively high particle fluxes
- A Data Acquisition System (DAQ) that can handle large amounts of data at large trigger rates
- New muon trigger in the first stage of the spectrometer
- Vertex detector to improve the cell separation of events



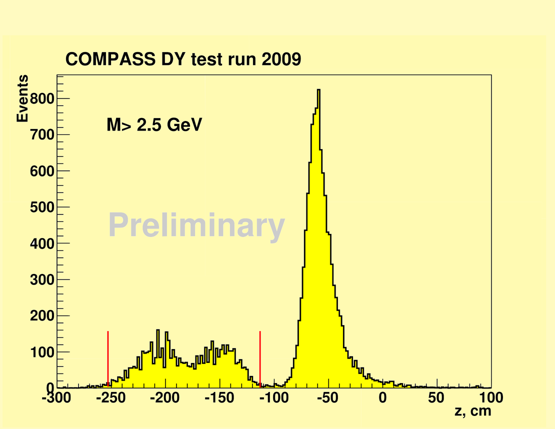

only part of the spectrometer is shown

## Feasibility

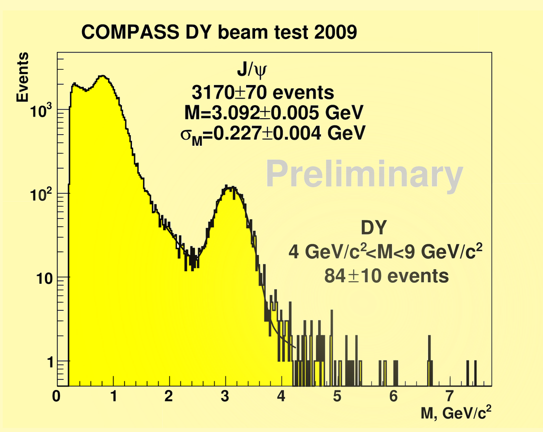
- In 2007, 2008 and 2009 short Drell-Yan beam tests were performed, to check the feasibility of the measurement
- In 2007, with a $\pi^-$ beam of 160 GeV/$c$ on a $NH_3$ target, and without hadron absorber: ≈ 90000 dimuon events (< 12 hours of data taking)
- In 2008 a second beam test was performed, also with an open configuration of the spectrometer, a $\pi^-$ beam of 190 GeV/$c$, and polyethylene target
- The target temperature does not seem to increase significantly with the hadron beam, long. polarisation relaxation times measured (2007 beam test)
- Reasonable occupancies in the detectors closer to the target can only be achieved if a hadron absorber and beam plug is used (2008 beam test)
- Physics simulation were validated, within statistical errors ($J/\psi$ peak and combinatorial background, in 2007 and 2009 beam tests)

### Beam test 2009

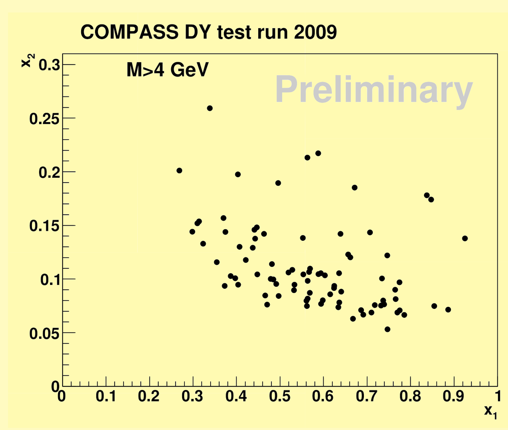
$\pi^-$ beam of 160 GeV/$c$ on 2-cells polyethylene target.
Setup including hadron absorber and a beam plug (3 days of data taking)



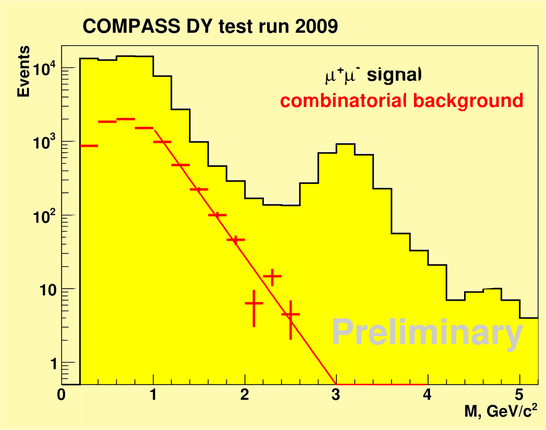

*Reasonable Z-vertex separation, allowing to distinguish the 2 target cells and the absorber.*




*from Monte-Carlo*
*expected $J/\psi$: 3600 ± 600*
*expected DY: 110 ± 22*




*Both annihilating quarks belong to the valence quark range.*




*Clean DY signal with $M > 4$, GeV/$c$*

## Event rates and statistical precision

### Expected event rates

- 280 days of data taking
- a beam intensity of $I_{beam} = 6 \times 10^7$ particles/second
- a luminosity of $L = 1.2 \times 10^{32} cm^{-2}s^{-1}$

$2.5 \times 10^5$ DY events with $4 < M_{\mu\mu} < 9$ GeV/$c^2$.
$1.4 \times 10^6$ DY events with $2 < M_{\mu\mu} < 2.5$ GeV/$c^2$

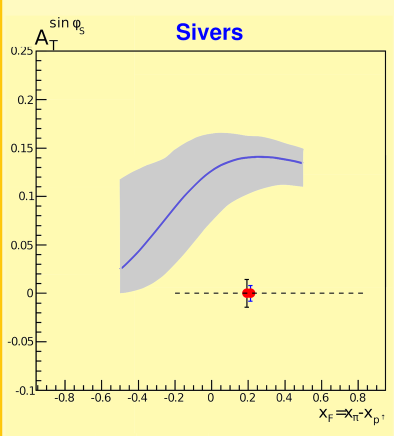
### The expected statistical error in the asymmetries

| Asymmetry | Dimuon mass (GeV/$c^2$) | | |
|---|---|---|---|
| | $2 < M_{\mu\mu} < 2.5$ | $J/\psi$ region | $4 < M_{\mu\mu} < 9$ |
| $\delta A_U^{\cos 2\phi}$ | 0.0020 | 0.0013 | 0.0045 |
| $\delta A_U^{\sin\phi_S}$ | 0.0062 | 0.0040 | 0.0142 |
| $\delta A_U^{\sin(2\phi+\phi_S)}$ | 0.0123 | 0.0080 | 0.0285 |
| $\delta A_U^{\sin(2\phi-\phi_S)}$ | 0.0123 | 0.0080 | 0.0285 |

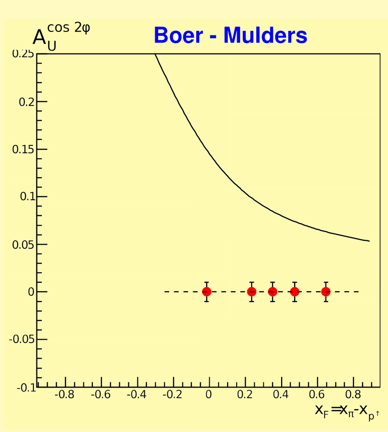
↪ Possibility to study the asymmetries in $x_F$ or $p_T$ bins.

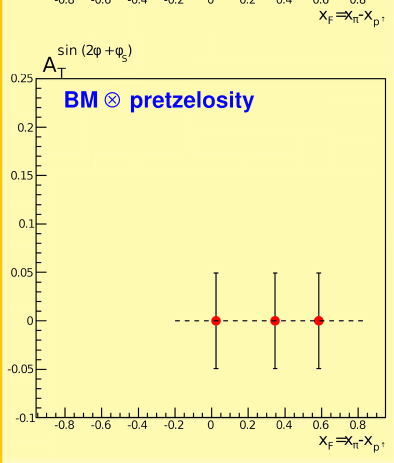
### Asymmetries: comparing with theory prediction

2 years of data taking DY with $4 < M_{\mu\mu} < 9$ GeV/$c^2$

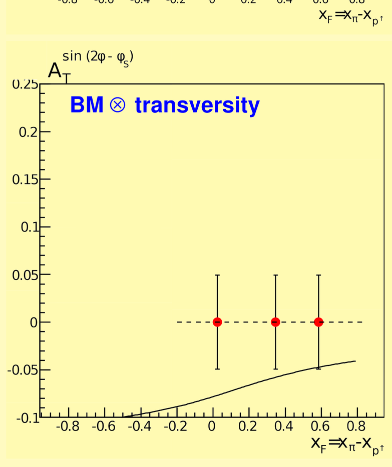



↩ M.Anselmino et al., Phys. Rev. D79, 054010 (2009)
D.Boer, Phys. Rev. D60 (1999) 014012; B.Zhang et al., Phys. Rev. D77 (2008) 054011 ↪




V.Barone et al., Phys. Rept. 359 (2002) 1; Phys. Rev. D56 (1997) 527




## Summary & Plans

- COMPASS has the possibility to access TMD PDFs with SIDIS and Drell-Yan processes
- COMPASS experimental conditions probe the valence quark region, where TMD effects are expected to be sizeable.
- The feasibility of Drell-Yan measurement was proven in a series of beam tests.

The COMPASS-II Proposal has been recommended by SPSC and is approved by the Research Board for a first period of 3 years including 1 year for Drell-Yan.
2015 Single polarised Drell-Yan with $\pi^-$ beam ⇒ TMDs (Sivers and Boer-Mulders) sign change.
Second year of Drell-Yan data taking?
...beyond 2017 ⇒ TMDs (Sivers, Boer-Mulders, and Pretzelosity), transversity PDF