Polarized Drell-Yan studies at COMPASS

C. Quintans, LIP-Lisbon

on behalf of the COMPASS Collaboration

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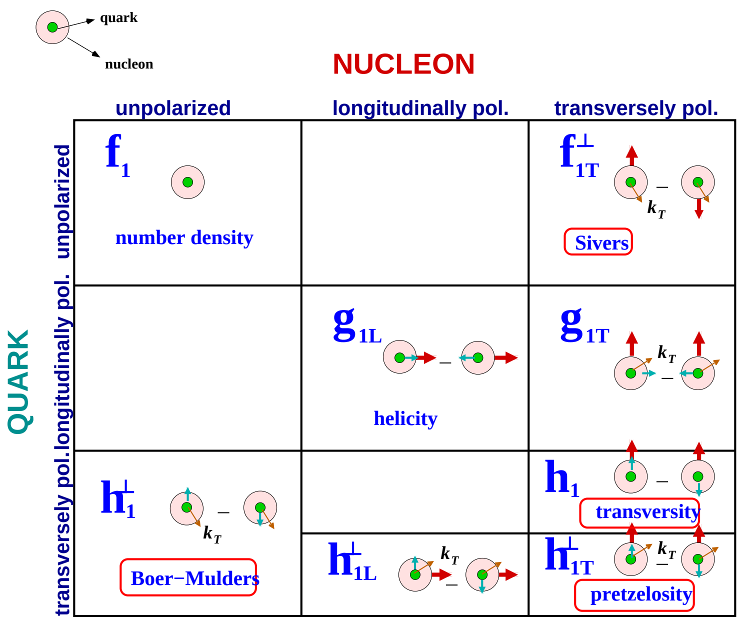
Co-financed by:

Overview

- Brief introduction on TMD PDFs
- The Drell-Yan process
- Polarized Drell-Yan in COMPASS
- The COMPASS experiment
- Acceptance, resolution and event rates
- Beam test results
- Summary

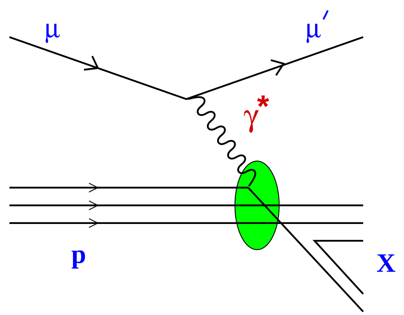
TMD PDFs

In LO, 8 Transverse Momentum Dependent PDFs (TMDs) are needed to describe the nucleon structure when the intrinsic transverse momentum is taken into account:

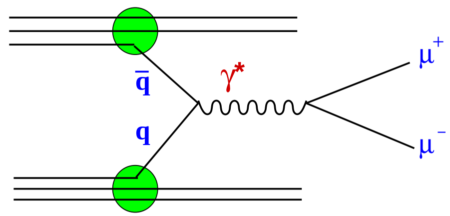


The highlighted TMDs can be studied using an un-polarized or a transversely polarized target

- From semi-inclusive DIS

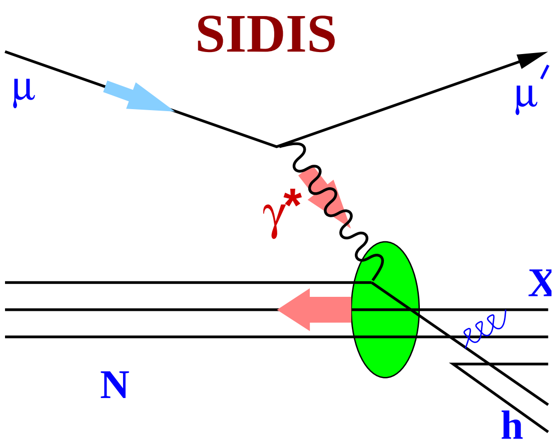


- From Drell-Yan

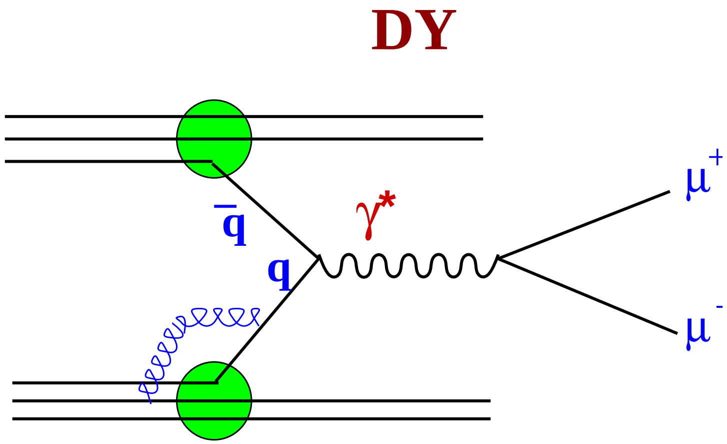


By measuring the Transverse Single Spin Asymmetries (TSSA) in these processes one can access the correlations between the partons $\mathbf{k}_T$ and the nucleon **spin**.

(Non-)Universality of TMDs



Final State Interactions



Initial State Interactions

From the interference between S- and P-states a (pseudo) T-odd effect arises for the Sivers and the Boer-Mulders TMDs, which come with opposite signs for SIDIS and for DY. Thus the prediction:

$$f_{1T}^{\perp}(DY) = -f_{1T}^{\perp}(SIDIS)$$

$$h_1^{\perp}(DY) = -h_1^{\perp}(SIDIS)$$

- The T-odd effect is a manifestation of non-zero quarks orbital angular momentum.
- The sign change observation is considered a crucial test of non-perturbative QCD and the TMDs approach.

Sivers from SIDIS

COMPASS has accessed the Sivers TMD in SIDIS using a proton target, observing:

- a positive asymmetry for h^+;
- an asymmetry compatible with zero for h^-.

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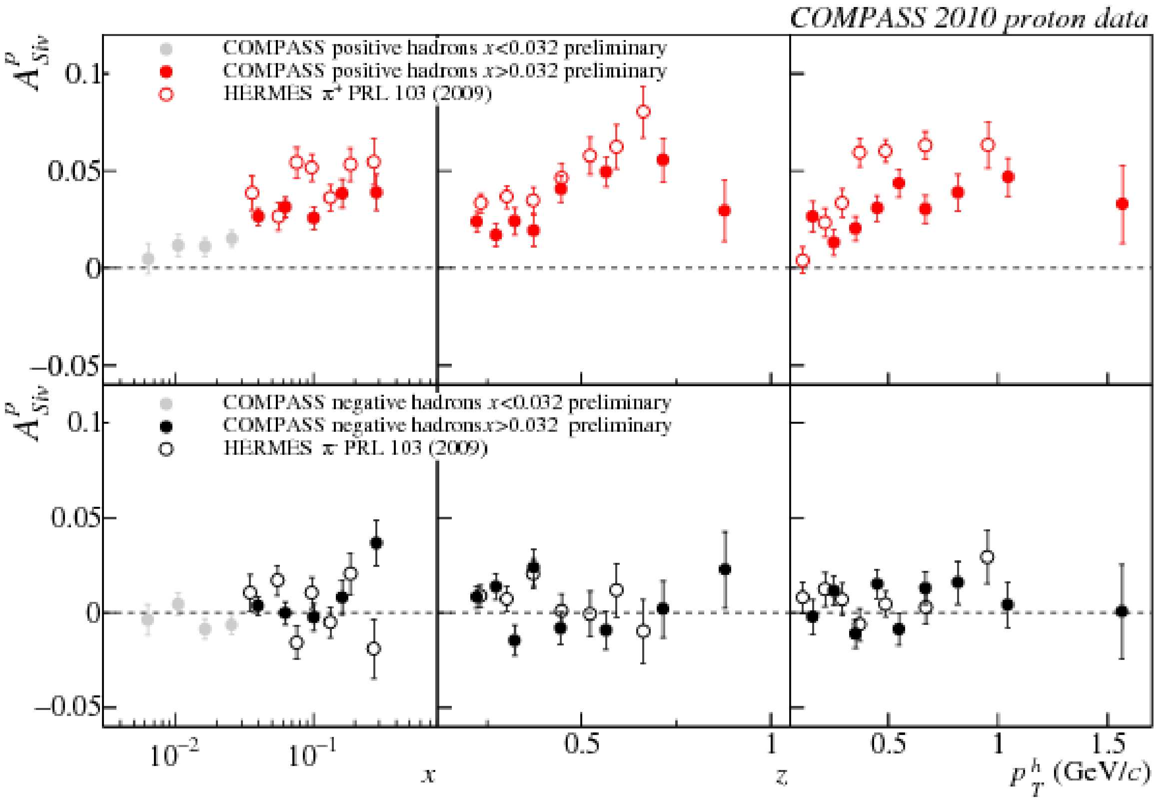


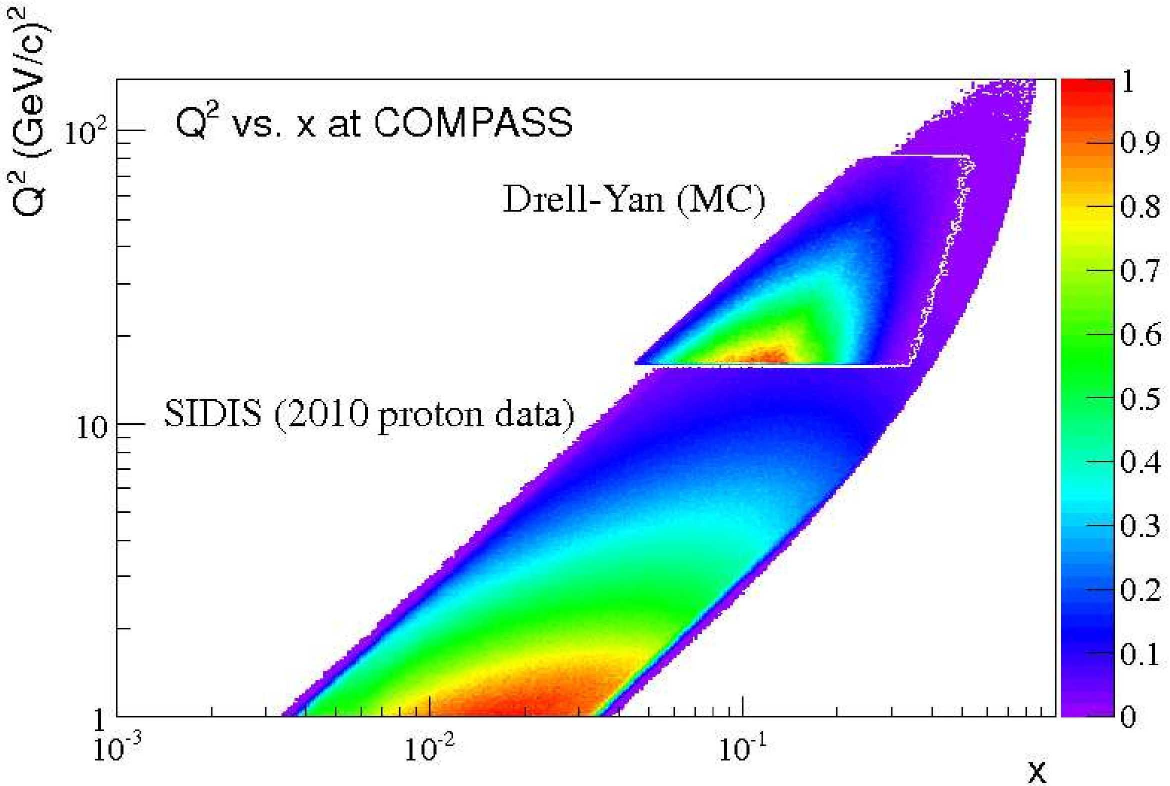
Qualitative agreement with HERMES PRL 103 (2009).
Difference may be due to TMD evolution (M. Aybat (2011)).

More in Federica Sozzi's talk.

SIDIS and DY in COMPASS

COMPASS has the unique opportunity to perform, using the same spectrometer and transversely polarized target, both the SIDIS and the Drell-Yan measurement.

DY from π^- beam at 190 GeV/c colliding on a NH_3 target: $4 \leq M_{\mu\mu} < 9$ GeV/c^2



SIDIS and DY measurements have an overlapping region.
Nevertheless, when comparing, TMD evolution must be taken into account.

Polarized Drell-Yan

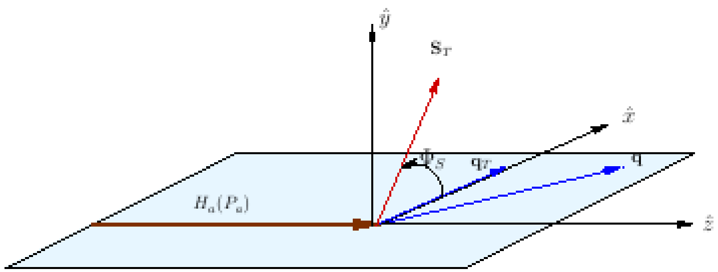
For a transversely polarized target, one can calculate the cross-section asymmetry between the 2 possible spin configurations.

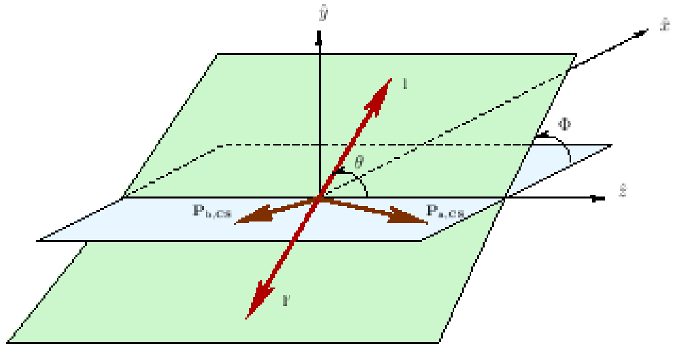
The Drell-Yan cross-section (LO) can be written as:

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

- A: azimuthal asymmetries
- D: depolarization factor
- S: target spin components

- $F = 4\sqrt{(P_a \cdot P_b)^2 - M_a^2 M_b^2}$
- $\hat{\sigma}_U$: cross-section surviving integration over ϕ and ϕ_S.





Azimuthal asymmetries

Each one of these asymmetries contains a convolution of 2 TMDs:

- $A_U^{\cos 2\phi}$: $h_1^\perp(\pi) \otimes h_1^\perp(p)$;
- $A_T^{\sin \phi_S}$: $f_1(\pi) \otimes f_{1T}^\perp(p)$;
- $A_T^{\sin(2\phi+\phi_S)}$: $h_1^\perp(\pi) \otimes h_{1T}^\perp(p)$;
- $A_T^{\sin(2\phi-\phi_S)}$: $h_1^\perp(\pi) \otimes h_1(p)$.

All expected to be sizeable in the valence quark region.

$\hookrightarrow$COMPASS: $x_p > 0.1$

A study of the asymmetries/TMDs as a function of x_F (or x_p) and p_T, not only for the sign check, but also their **shape** and **amplitude**.

J/ψ studies

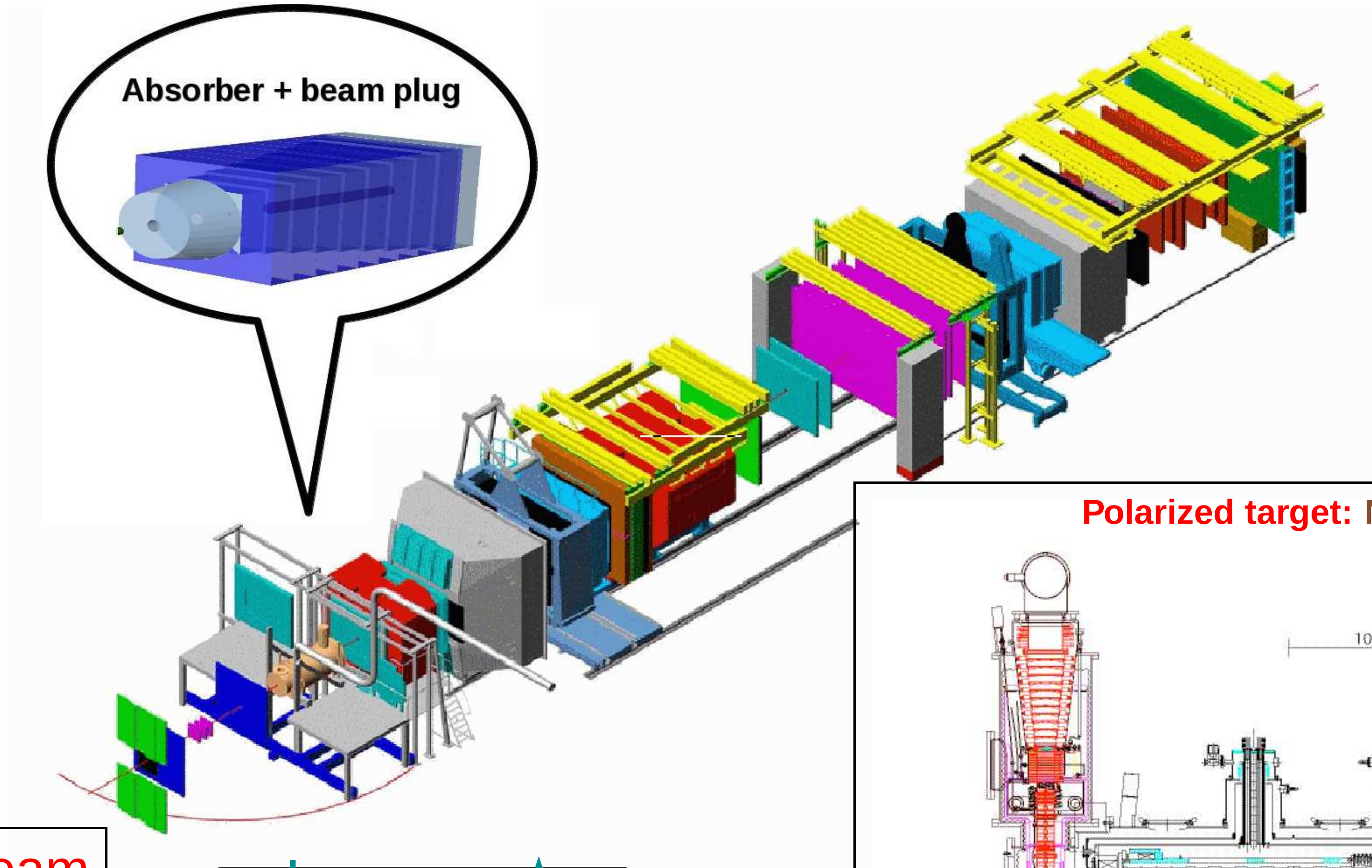
$$\pi^- p \rightarrow \text{J}/\psi \text{ X} \rightarrow \mu^+\mu^- X$$

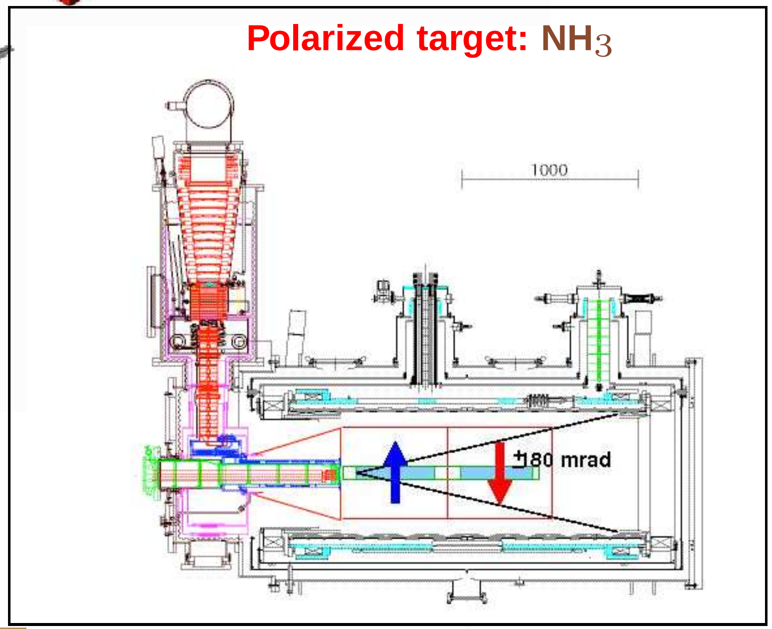
The valence region is also the most promising to study SSA using charmonia:

- Verify the duality hypothesis DY $\leftrightarrow$ J/ψ
  $\hookrightarrow$ J/ψ from $q\bar{q}$ annihilation
- Study J/ψ production mechanisms by varying the beam energy
  $\hookrightarrow$ $q\bar{q}$ annihilation versus gg fusion
- Access the gluon Sivers TMD
  $\hookrightarrow$ related to the gluons orbital angular momentum

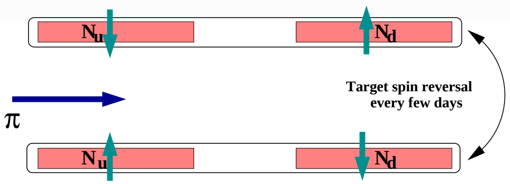
COMPASS set-up

The COMPASS experiment at CERN uses a secondary beam produced from the SPS extracted protons in a production target.

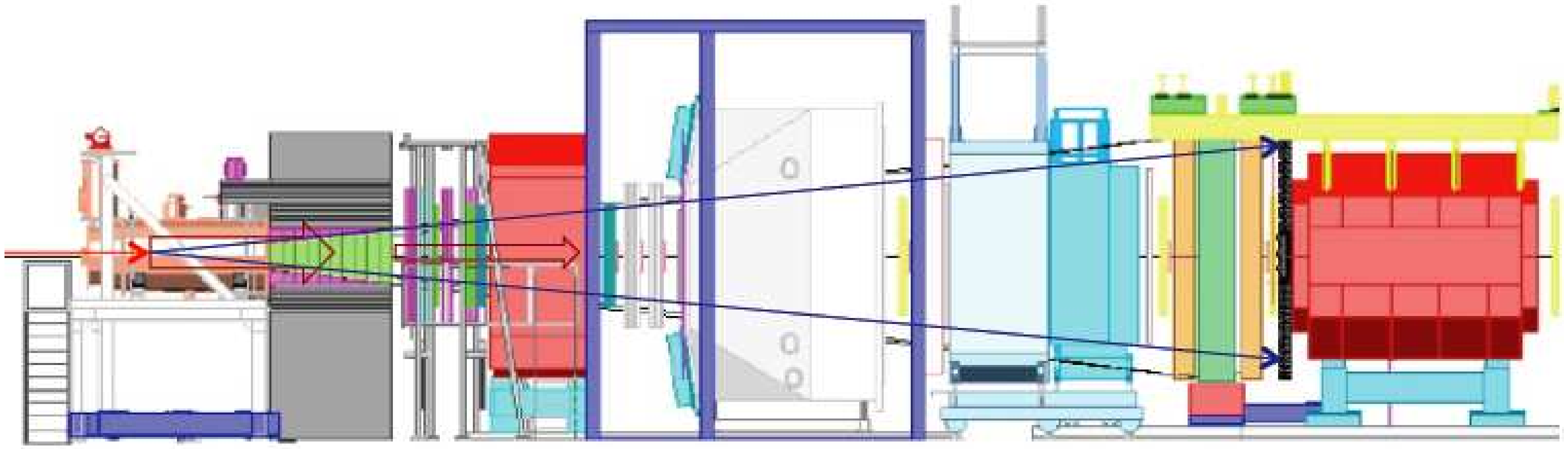




π^- beam
@190 GeV/c



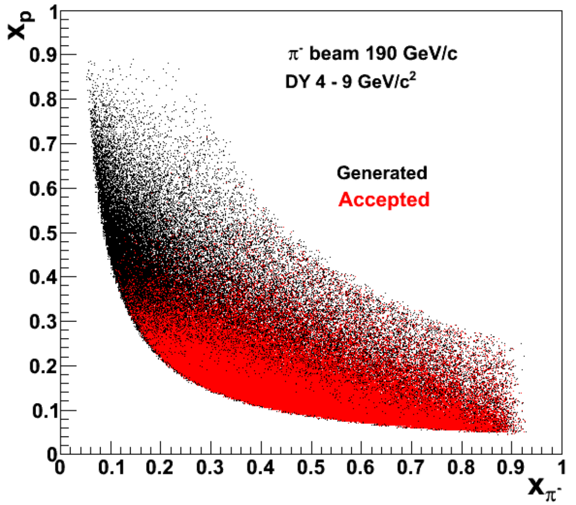
Drell-Yan at COMPASS



- π^- beam @190 GeV/c, I_{beam} up to 1×10^8 particles/second.
- A transversely polarized target of NH_3, with dipole field 0.6 T.
- Hadron absorber 240 cm long; and tungsten beam plug of 120 cm.
- Vertex detector in the middle of the hadrons absorber, to improve on resolutions.
- A beam telescope with very good time resolution.
- Dimuon trigger based on hodoscope signals coincidence, homothetic and pointing to the target.
- Long relaxation time of target polarization guaranteed by larger beam spot ($\sigma \approx$ 1cm) $\Rightarrow$ lose very small angle muons.

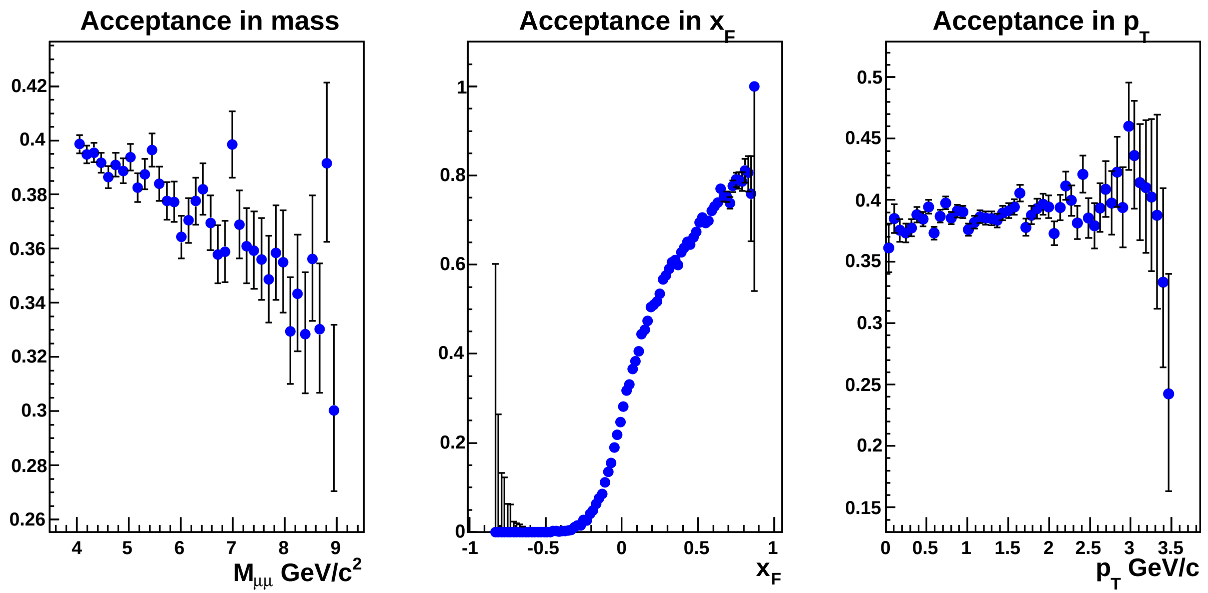
DY COMPASS acceptance

Drell-Yan with π^- beam on fixed target: u-quark dominance, with valence x_p.



The geometrical acceptance is 39%

- 2 muons at Large Angle (LAS): 22%
- 2 muons at Small Angle (SAS): 2%
- one muon in LAS and another in SAS: 18%

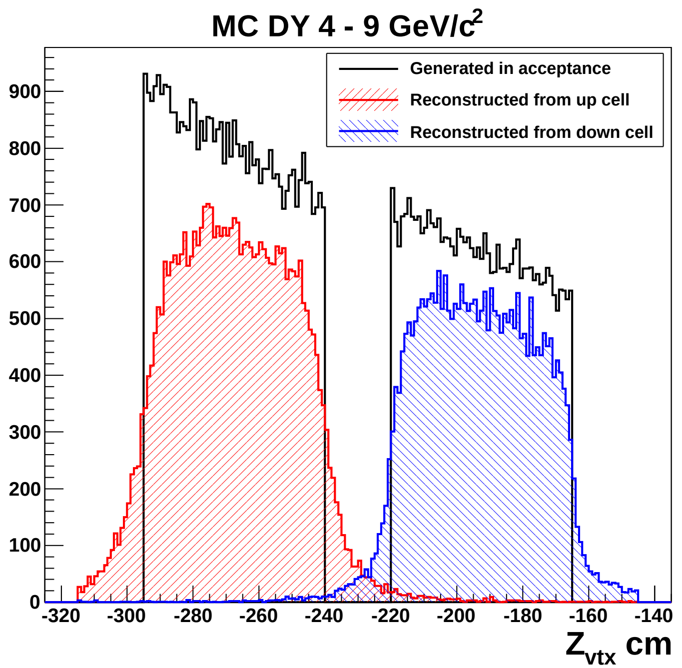


High mass Drell-Yan

- Drell-Yan has a very low cross-section (fractions of nanobarn).
- Cross-section decreases with the dimuon mass as M^{-4}.

Nevertheless we choose to study the DY in the high mass region: $4 \leq M_{\mu\mu} < 9$ GeV/c^2, since this region of the spectrum is background free.

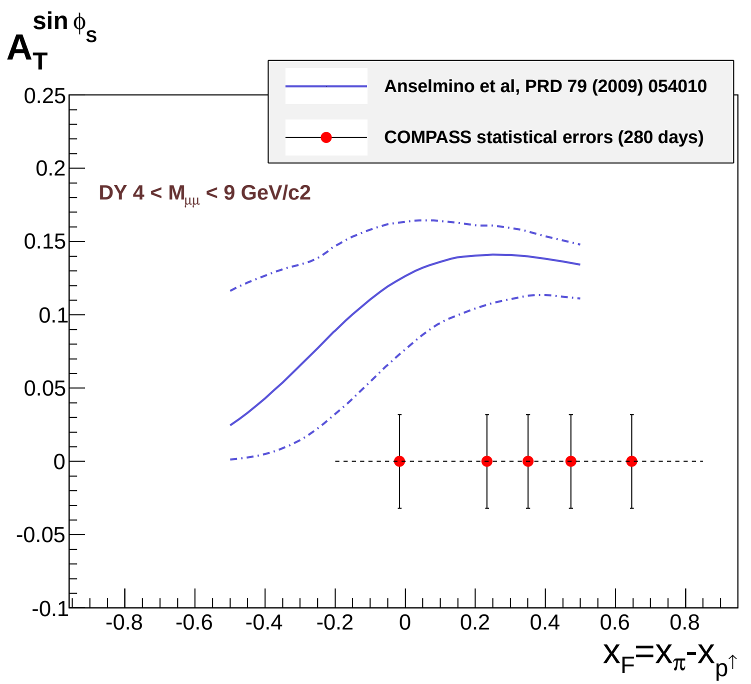
$\hookrightarrow$ To control the combinatorial background: a hadron absorber with a low Z material (Al_2O_3) – minimize the muons multiple scattering; maximize the hadrons stopping power.



Expected event rates

In order to have enough statistics, one needs high luminosity: With beam intensity $I_{beam} = 6 \times 10^7 \ s^{-1}$, a luminosity $L = 1.2 \times 10^{32} \ cm^{-2} s^{-1}$ can be obtained.

- 900 events/day from DY in $4 \leq M_{\mu\mu} < 9$ GeV/c^2
- 4300 events/day from DY in $2 \leq M_{\mu\mu} < 2.5$ GeV/c^2
- ≈22500 events/day from DY+J/ψ in $2.9 \leq M_{\mu\mu} < 3.2$ GeV/c^2

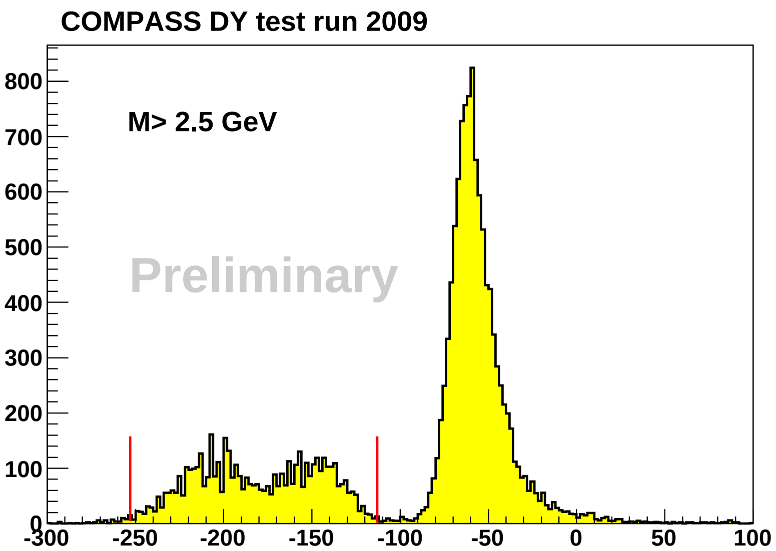


Asymmetry uncertainty	Dimuon mass (GeV/c^2)		
	$2 < M_{\mu\mu} < 2.5$	J/ψ region	$4 < M_{\mu\mu} < 9$
$\delta\ A_U^{\cos 2\phi}$	0.0026	0.0014	0.0056
$\delta\ A_T^{\sin\phi_S}$	0.0065	0.0036	0.0142
$\delta\ A_T^{\sin(2\phi+\phi_S)}$	0.0131	0.0073	0.0284
$\delta\ A_T^{\sin(2\phi-\phi_S)}$	0.0131	0.0073	0.0284

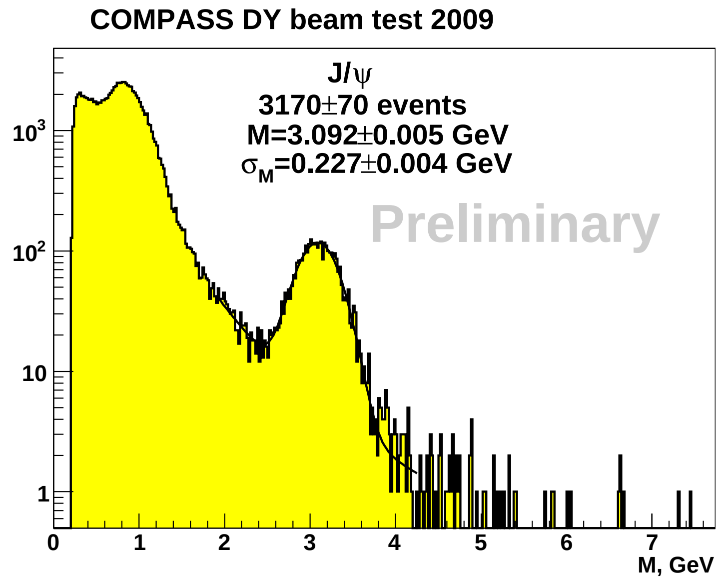
Feasibility studies

Several tests were already performed, showing the radiation conditions; the background reduction when using a hadron absorber; the concept of the dimuon trigger; detector occupancies and trigger rates.

2009: π^- beam 190 GeV/c on a 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.



Mass resolution as expected.

J/ψ events match the expected yield.

Summary

- COMPASS polarized Drell-Yan measurement to start by the end of 2014, with a short beam test. Physics data taking during 2015 (full year). A second year of DY data-taking is planned, possibly in 2018.
- Feasibility of the measurement was shown in the beam tests already performed.
- Sivers and Boer-Mulders PDFs sign change when measuring in Drell-Yan or in SIDIS will be checked.
- After 1 year of data-taking: expected statistical error in the Sivers asymmetry $\approx$2% (systematic errors will be smaller).
- With 2 years of data-taking: enough statistics for studies as function of x_F and p_T.

The COMPASS measurements will contribute to the common effort of extracting the TMDs, namely Sivers, Boer-Mulders and pretzelosity, as well as the transversity PDF.