Polarised Drell-Yan measurements at COMPASS-II

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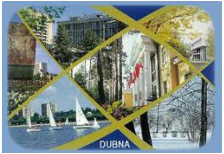
on behalf of the COMPASS/CERN Collaboration



21^{st} September 2012

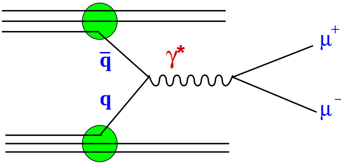
The 20th INTERNATIONAL SYMPOSIUM on Spin Physics (SPIN2012)

Co-financed by: FCT Fundação para a Ciência e a Tecnologia, QREN Quadro de Referência Estratégico Nacional, COMPETE

Outline

- The Drell-Yan process
- Polarised Drell-Yan @ COMPASS
- Goals of the DY measurement @ COMPASS
- COMPASS Experiment – Spectrometer description
- Feasibility of the measurement
- Acceptances, event rates and statistical errors

Annihilation of a $q\bar{q}$ pair from a 2 hadrons collision, producing a lepton pair



The angular distribution of the DY events can be written as:

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi]$$

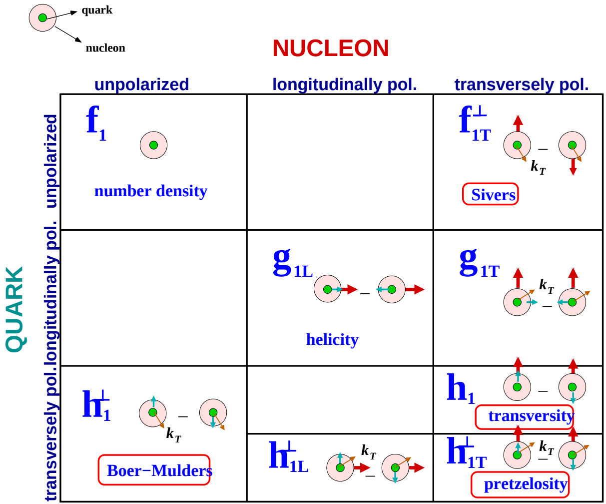
If quarks do not have transverse momentum (collinear hypothesis): $\boxed{\lambda = 1,\ \mu = 0,\ \nu = 0}$.

NA10 (CERN) and E615 (Fermilab) experiments measured a modulation of $\cos 2\phi$ up to 30%.

$\Rightarrow$ we cannot neglect the intrinsic transverse momentum k_T of quarks inside hadrons.

The nucleon structure in first order QCD is described by:

- 3 PDFs in the collinear approximation
- 8 PDFs taking into account the quark intrinsic transverse momentum, k_T

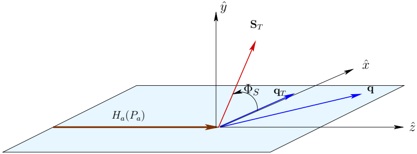


In the DY COMPASS program we will access 4 of them:

- **Transversity** h_1
- **Boer-Mulders** $h_1^{\perp}$
- **Sivers** $f_{1T}^{\perp}$
- **Pretzelosity** $h_{1T}^{\perp}$

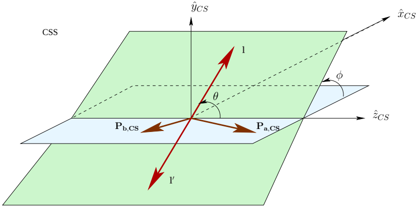
Several frames are commonly used in description of Drell-Yan process, the asymmetries depend on the frames used.

Target rest frame



- $\hat{z}$ is chosen along beam momentum
- $\hat{x}$ along virtual photon transverse momentum
- $\hat{y} = \hat{z} \times \hat{x}$

Collins-Soper frame



Collins-Soper can be reached from target rest frame by two subsequent Lorentz boosts.

- $\hat{z}_{cs}$ is chosen along the bissector of the initial hadrons
- $\hat{x}_{cs}$ is chosen in the plane of the initial hadrons
- $\hat{y}_{cs} = \hat{z} \times \hat{x}$

Arnold *et al.*[1] derived the full expression of the σ_{DY}, for arbitrarily polarised beam and target.

Having an unpolarised beam and a transversely polarised target the σ_{DY} in LO can be written as:

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

$$+ D_{[sin^2\theta]}(\boxed{A_T^{sin(2\phi+\phi_S)}}sin(2\phi+\phi_S) + \boxed{A_T^{sin(2\phi-\phi_S)}}sin(2\phi-\phi_S))]\}$$

where:

- θ and ϕ are the polar and azimuthal angles of μ^- in the Collins-Soper reference frame
- ϕ_S is the angle between the transverse spin of the target nucleon and the transverse momentum of the γ^*
- F is given by $F = 4\sqrt{(P_\pi \cdot P_p)^2 - M_\pi^2 M_p^2}$
- q is the γ^* four-momentum
- $\hat{\sigma}_U$ is the part of the cross-section surviving the integration over the angles ϕ and ϕ_S
- $|\vec{S}_T|$ is the target polarisation value
- $D_{[sin^2\theta]}$ is the virtual photon depolarisation factor

[1] S. Arnold et al, Phys.Rev. D79 (2009)034005

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

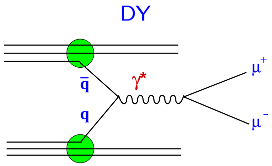
The azimuthal asymmetries A contain a convolution of 2 PDFs of the target and beam hadrons:

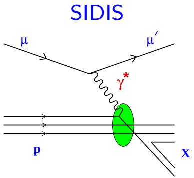
- $\boxed{A_U^{\cos 2\phi}}$ gives access to the Boer-Mulders functions of both hadrons.
- $\boxed{A_T^{\sin\phi_S}}$ gives access to the unpolarised PDF of beam hadron and the Sivers function of the target nucleon.
- $\boxed{A_T^{sin(2\phi+\phi_S)}}$ gives access to the Boer-Mulders function of the beam hadron and to the pretzelosity function of the target nucleon.
- $\boxed{A_T^{sin(2\phi-\phi_S)}}$ gives access to the Boer-Mulders function of the beam hadron and to the transversity function of the target nucleon.

We need to disentangle the PDFs in each of these asymmetries $\Rightarrow$ it requires some input.

TMDs universality test – DY <> SIDIS

The Sivers ($f_{1T}^{\perp}$) and the Boer-Mulders ($h_1^{\perp}$) functions are naïve time-reversal odd functions. This leads to the prediction that they must change sign when accessed from DY or SIDIS[2].





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

$$h_1^{\perp}{}_{DY} = -h_1^{\perp}{}_{SIDIS}$$

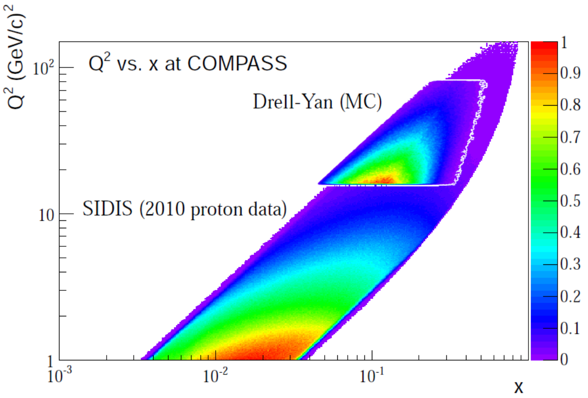
The experimental confirmation of this sign change is considered a crucial test of non-perturbative QCD. This TMDs universality check is the main goal of COMPASS 2014 run.

Joining the two years of the DY program, it will be possible also to compare the amplitude and the shape of the Sivers function between DY and SIDIS.

[2] J.C. Collins, Phys. Lett. B536 (2002) 43, J.C. Collins, talk at LIGHT CONE 2008

Q^2 vs x domain in COMPASS

In COMPASS we have the opportunity to access these TMD PDFs from both DY and SIDIS processes.



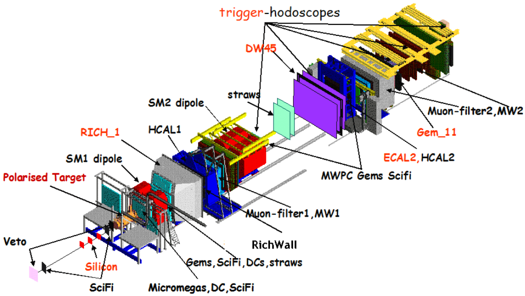
There is a phase space overlap between the two measurements.

COmmon Muon Proton Apparatus for Structure and Spectroscopy

Experimental setup

Two stages spectrometer

1. Large Angle Spectrometer (LAS)
2. Small Angle Spectrometer (SAS)



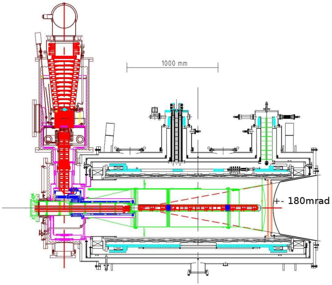
Beam

π^- @ 190 GeV/c

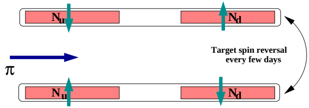
Polarised target, NH_3

dilution factor 22%

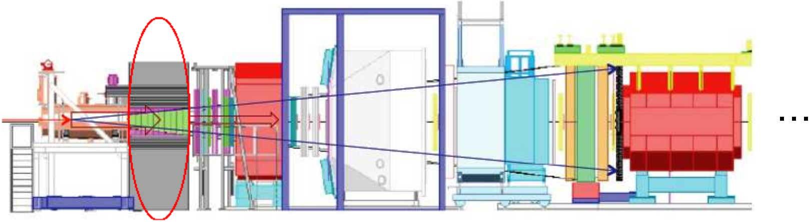
polarisation up to 90%



- Large angular acceptance ($\pm$180 mrad)
- Two target cells (NH_3) with opposite polarisations transverse to the beam



Hadron absorber and beam plug



- The main goal of the hadron absorber is to stop the produced hadrons in the primary interaction.
- The task of the beam plug is to stop the non-interacting beam.

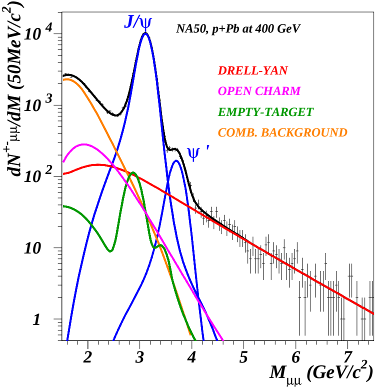
The hadron absorber also introduces multiple scattering in muons

⇒ It is important to minimise the number of radiation lengths crossed by the muons in the absorber, while maximising the number of pion interaction lengths.

Signal/Background

- Strong decrease of DY cross-section with the dimuon mass ($\sigma_{DY} \propto M_{\mu\mu}^{-4}$).
- The Drell-Yan signal is very clean for $M_{\mu\mu} > 4$ GeV/c^2. It is the region where we are interested in (the High Mass Region, HMR).

Dimuon mass distribution for *p* @ 400 GeV/*c* in a *Pb* target (NA50 Collaboration)



- $I_{beam} \leq 10^8\ \pi^-$/s $\sim$ 10 times lower than the NA50 beam intensity.

$\Rightarrow$ The combinatorial background ($\propto I_{beam}^2$) $\sim$ 100 lower than in NA50.

Feasibility of the measurement

The feasibility of the measurement was proved by several beam tests done so far.

- verification of the absorber effect and the spectrometer response ✓
- verification of the radiation doses ✓
- validation of the J/ψ yields projected ✓

The last one was performed in 2009, using:

- A hadron absorber prototype, made of concrete and stainless steel.
- A beam plug, inside the central part of absorber, made of W and steel discs.
- π^- beam @ 190 GeV/c up to $I_{beam} = 1.5 \times 10^7\ \pi/s$.
- Two unpolarised target cells (polyethylene) with 40 cm length and 5 cm diameter, spaced by 20 cm.

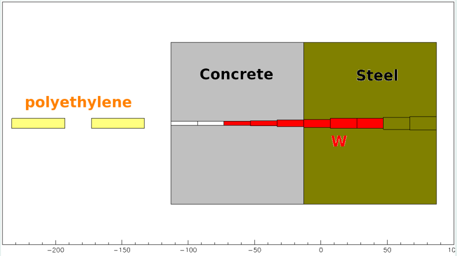
Number of radiation lengths (multiple scattering for muons):

$x/X_0 = 66.17$

Number of interaction lengths (stopping power for pions):

$x/\lambda_{int} = 6.69$

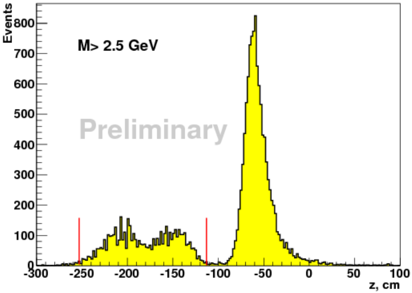
Target + Absorber region



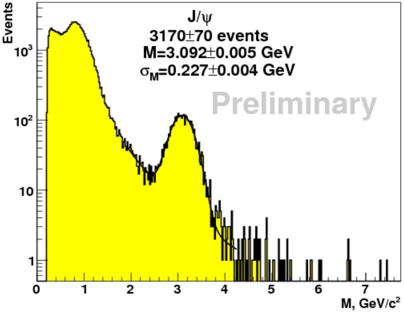
2009 DY beam test - results

- 3 days test

z vertex distribution

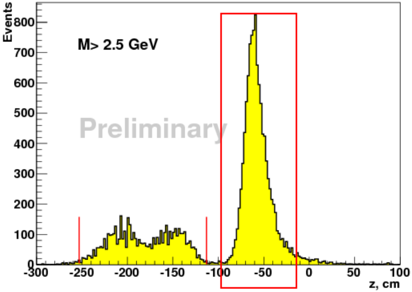


Dimuon mass distribution

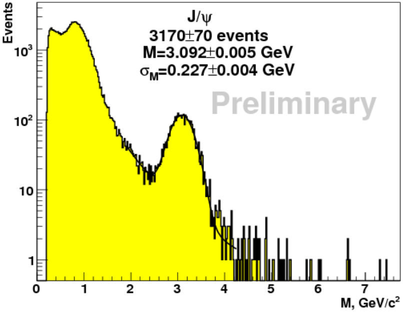


- 3 days test

z vertex distribution



Dimuon mass distribution

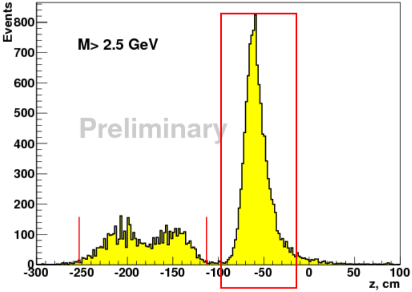


⇓

Huge number of events due to the fact that we didn't have an optimised dimuon trigger, with target pointing capability.

- 3 days test

z vertex distribution



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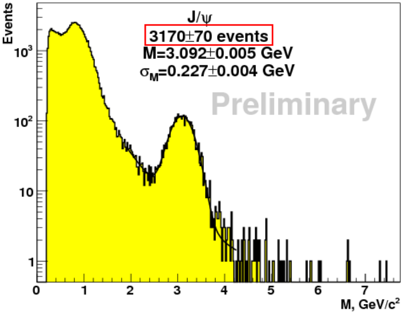
Dimuon mass distribution



⇓

The expected number of J/ψ was confirmed.

The setup for DY experiment is being optimised. The latest simulated version is:

- Two target cells (NH_3) inside the dipole (55 cm length, 4 cm diameter, spaced by 20 cm);
- The absorber is 236 cm long, made of Al_2O_3;
- The plug is made of 6 discs of W 20 cm long each and 20 cm of Alumina in the most downstream part (total of 140 cm).

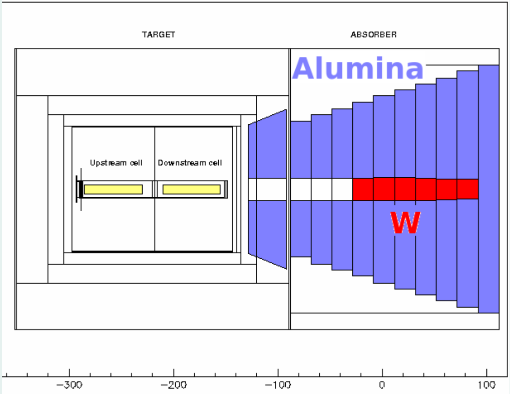
Number of radiation lengths (multiple scattering for muons):

$x/X_0 = 33.53$
(66.17 for 2009 beam test absorber)

Number of interaction lengths (stopping power for pions):

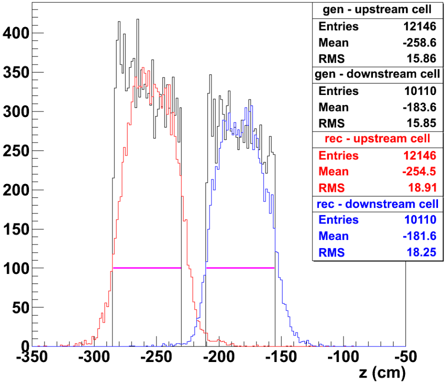
$x/\lambda_{int} = 7.25$
(6.69 for 2009 beam test absorber)

Polarised Target + Absorber region

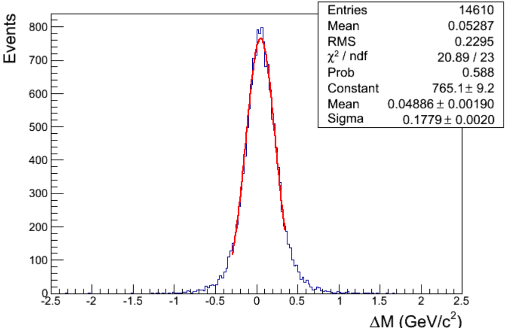


DY setup status - MC results

z vertex distribution



Dimuon mass resolution



$\Downarrow$

$\Delta z \simeq 6$ cm in HMR ($M_{\mu\mu} > 4$ GeV/c^2)

$\Downarrow$

$\Delta M \simeq 180$ MeV/c^2 in HMR ($M_{\mu\mu} > 4$ GeV/c^2)

Contamination:

Upstream cell — < 1 %

Downstream cell — $\simeq 1$ %

$\Rightarrow$ A very low level of contamination.

Acceptances, event rates and experimental accuracy

The dimuons acceptance in the HMR ($M_{\mu\mu} > 4$ GeV/c^2) is 39%.

The accepted dimuons are:

μ_1 (1^{st} spectrometer) & μ_2 (1^{st} spectrometer) – 22 %
μ_1 (2^{nd} spectrometer) & μ_2 (2^{nd} spectrometer) – 2 %
μ_1 (1^{st} spectrometer) & μ_2 (2^{nd} spectrometer) – 18 %

The trigger is being developed based in coincidences of hodoscopes with the target pointing capability.

We expect an DY event rate of 900 events/day in the HMR assuming:

- π^- beam with 190 GeV/c
- $I_{beam} = 6 \times 10^7$ particles/s
- $L = 1.2 \times 10^{32}$ cm^{-2}s^{-1}

Assuming two years of data taking (about 280 days) we expect the following statistical errors in azimuthal asymmetries:

Asymmetry	Uncertainty in HMR
$\delta A_U^{\cos 2\phi}$	0.0057
$\delta A_T^{\sin \phi_S}$	0.0143
$\delta A_T^{sin(2\phi+\phi_S)}$	0.0285
$\delta A_T^{sin(2\phi-\phi_S)}$	0.0285

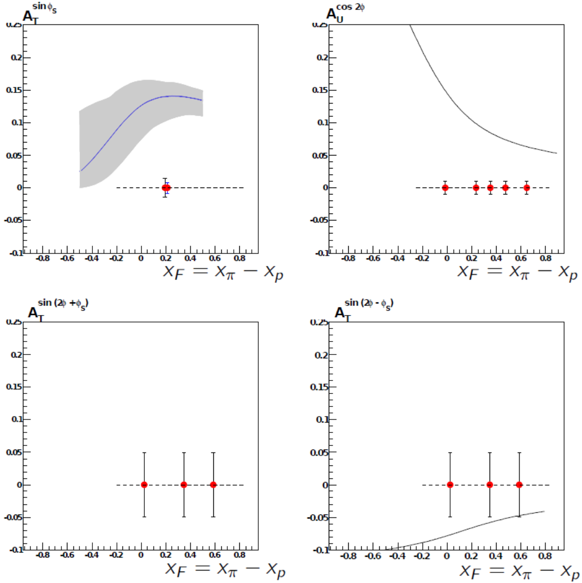
Azimuthal asymmetries and experimental accuracy

Unpolarised PDF
$\otimes$
Sivers

M. Anselmino *et al*, Phys. Rev. D 79 (2009) 054010

Boer-Mulders
$\otimes$
Boer-Mulders

B. Zhang *et al*, Phys. Rev. D 77 (2008) 054011



Boer-Mulders
$\otimes$
Pretzelosity

Boer-Mulders
$\otimes$
Transversity

A. N. Sissakian *et al*, Phys. Part. Nucl. 41: 64-100, 2010

Theory update is needed to take into account the Q^2 evolution.

Competition and complementarity

Facility	type	s (GeV^2)	timeline
COMPASS	fixed target, $\pi^{\pm} H^{\uparrow\rightarrow}$, $\pi^{\pm} D^{\uparrow\rightarrow}$	357	$2014 + \geq 2017$
Fermilab (SeaQuest)	fixed target, $p^{\uparrow\rightarrow} H$, $pH^{\uparrow\rightarrow}$	234	> 2015
RHIC (STAR, PHENIX)	collider, $p^{\uparrow} p$	200^2	> 2016
J-PARC	fixed target, $p^{\uparrow\rightarrow} D$	60 - 100	> 2018
FAIR (PAX)	collider, $\bar{p}^{\uparrow} p^{\uparrow}$	200	> 2018
NICA	collider, $p^{\uparrow} p^{\uparrow}, D^{\uparrow} D^{\uparrow}$	676, 144	> 2018

COMPASS aims to perform the first polarised DY experiment in the world.

Summary

- The opportunity to study, in the same experiment, the TMD PDFs from both SIDIS and the DY processes is unique.
- The sign change in Sivers and Boer-Mulders functions when accessed by DY and SIDIS will be checked.
- The feasibility of the measurement was proved after some beam tests were performed.
- The COMPASS II Proposal was approved by CERN for a first period of 3 years including 1 year for Drell-Yan.
- Polarised Drell-Yan data taking will start in 2014 and the second year of data taking with NH_3 is expected in 2017.