Near Future COMPASS Program: Spin physics with Drell-Yan

Márcia Quaresma

LIP - Lisbon

April 22, 2012
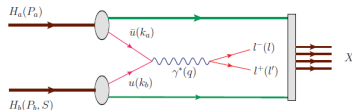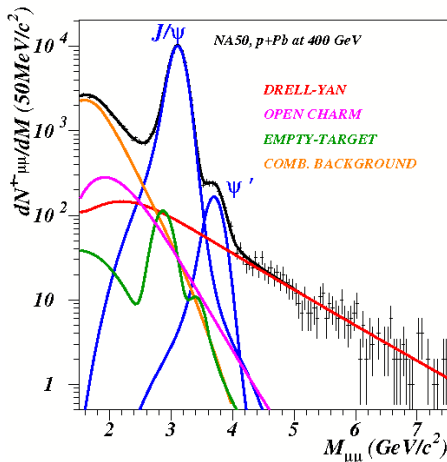
- Introduction to the Drell-Yan (DY) process

- Goals of its measurement @ COMPASS

- COMPASS Experiment – Spectrometer description

- Feasibility of the measurement

- Acceptances, event rates and statistical errors

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

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

- Strong DY cross section decreases with the dimuon mass ($\sigma \propto M^{-4}$).
- The Drell-Yan signal is very clean above 4 GeV/c^2 dimuon mass. It is the region where we are interested in.

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

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

The Lam-Tung sum rule $\boxed{1 - \lambda - 2\nu = 0}$ relates the modulation amplitudes of the DY process.

The collinear hypothesis implies: $\boxed{\lambda = 1,\ \mu = 0,\ \nu = 0}$.

This hypothesis was shown to be violated by the NA10 (CERN) and E615 (Fermilab) experiments.
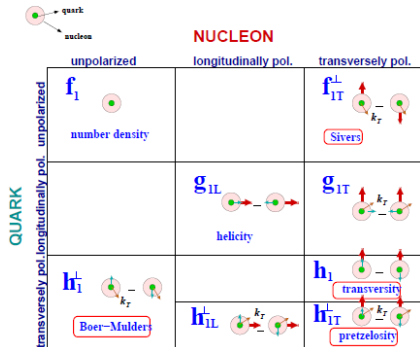
They measured a modulation of $\cos 2\phi$ up to 30%

This means 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 collinear approximation
- 8 PDFs taking into account the quark intrinsic transverse momentum, k_T

COMPASS will access 4 of them:

- **Transversity h_1**: describes the difference between the density number of quarks with parallel and anti-parallel spin w.r.t. the transversely polarised, relatively to the beam direction, father hadron
- **Boer-Mulders $h_1^\perp$**: describes the correlation between the transverse spin and the transverse momentum of a quark in an unpolarised nucleon
- **Sivers $f_{1T}^\perp$**: describes the influence of the nucleon transverse spin in the transverse momentum distribution of the quark
- **Pretzelosity $h_{1T}^\perp$**: describes the transverse polarization of a quark, along its intrinsic transverse momentum direction

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

Having an unpolarized beam and a transversely polarized 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 polarization value
- $D_{[\sin^2\theta]}$ is the virtual photon depolarization factor

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

---

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

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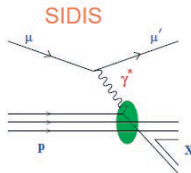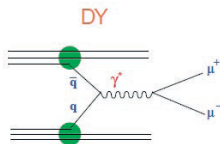
$$f_{1T}^{\perp}{}_{DY} = -f_{1T}^{\perp}{}_{SIDIS}$$

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

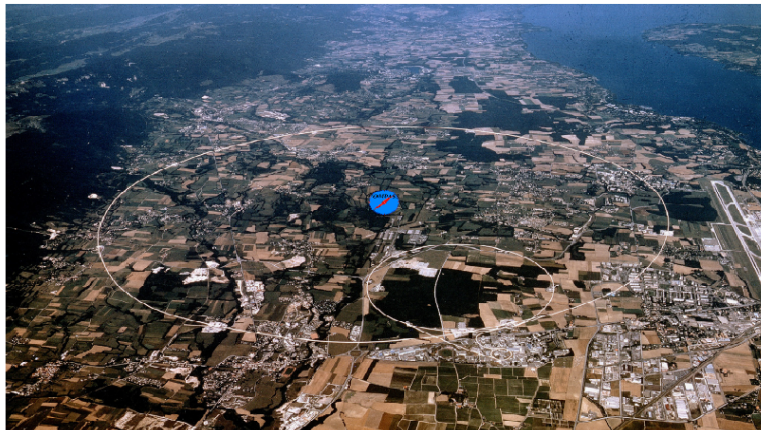The experimental confirmation of this sign change is considered a crucial test of non-perturbative QCD.

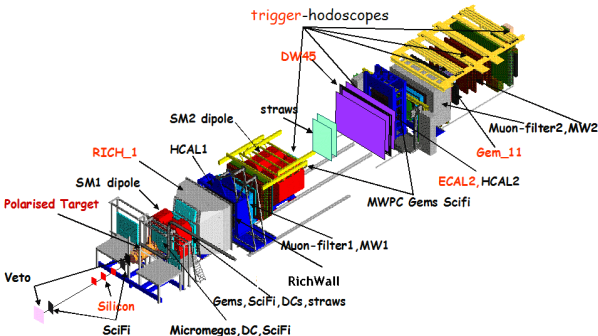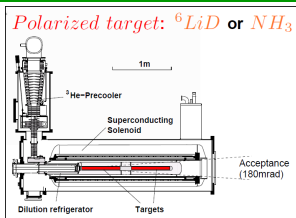[2]J.C. Collins, Phys. Lett. B536 (2002) 43, J.C. Collins, talk at LIGHT CONE 2008

COmmon Muon Proton Apparatus for Structure and Spectroscopy

- Beam telescope:
  - SciFis
- Large Angle Spectrometer (LAS):
  - SM1 magnet
  - Tracking detectors
  - RICH
  - ECAL1
  - HCAL1
  - Muons Filter 1
- Small Angle Spectrometer (SAS):
  - SM2 magnet
  - Tracking detectors
  - ECAL2
  - HCAL2
  - Muons Filter 2

In 2007, 2008 and 2009 short Drell-Yan beam tests were performed, to check the feasibility of the measurement, 2009 test was done using:

- π^- beam @ 190 GeV/c
- Two target cells (polyethylene) with 40 cm length and 5 cm diameter, spaced by 20 cm
- A prototype of an absorber:
  - Two blocks, of concrete and stainless steel, 100 cm length each, and 80×80 cm^2 in transverse dimensions each
  - A beam plug, inside the central part of absorber, made of W and steel disks.

Radiation and interaction lengths:
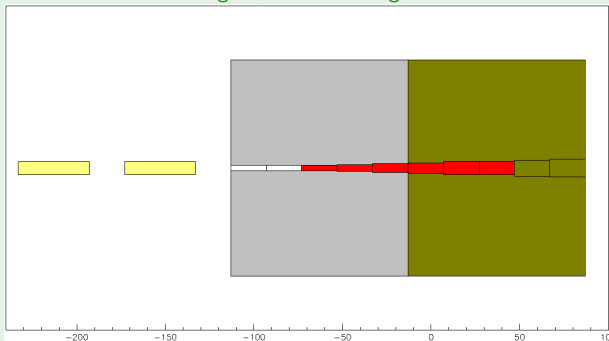
For muons:

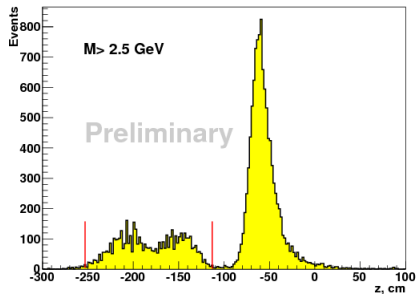(multiple scattering)

$x/X_0 = 66.17$

For pions:

(stopping power)

$x/\lambda_{int} = 6.69$

Target + Absorber region
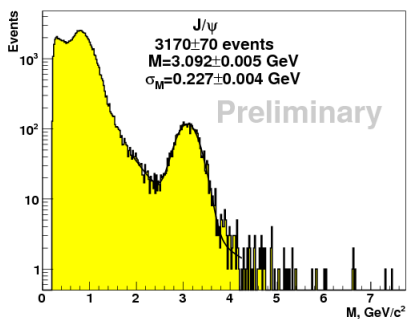
COMPASS DY test run 2009

M> 2.5 GeV

Preliminary

COMPASS DY beam test 2009
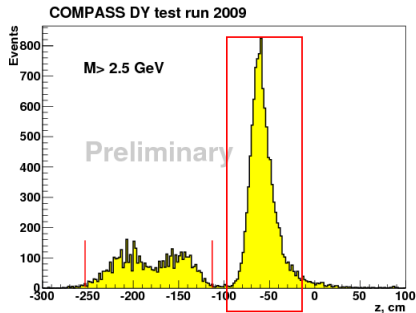
J/ψ
3170±70 events
M=3.092±0.005 GeV
σ_M=0.227±0.004 GeV

Preliminary

Huge number of events due to the fact we didn't have a dimuon trigger.
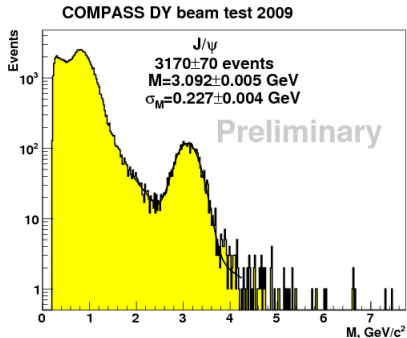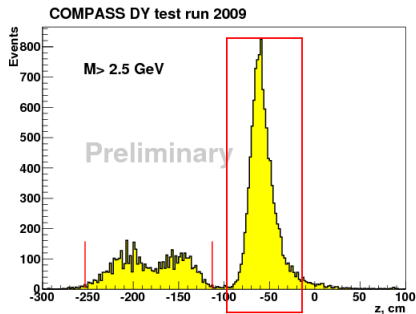
Huge number of events due to the fact we didn't have a dimuon trigger.

Large mass resolution due to problems in reconstruction program.

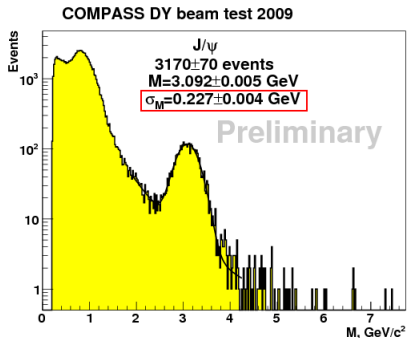The proposal setup was in the meanwhile optimized. The newer version is:

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

Radiation and interaction lengths:

For muons:

(multiple scattering)

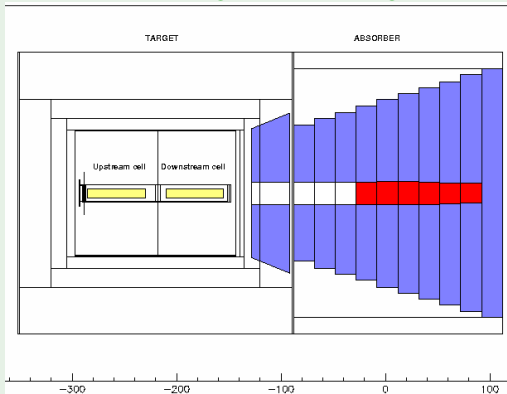$x/X_0 = 33.53$
(66.17 for 2009 absorber)

For pions:

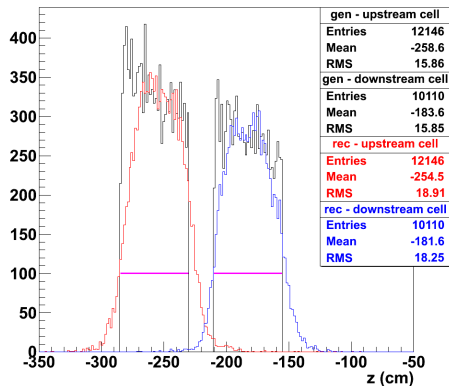(stopping power)

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

Polarised Target + Absorber region

z vertex distribution

gen - upstream cell	
Entries	12146
Mean	-258.6
RMS	15.86
gen - downstream cell	
Entries	10110
Mean	-183.6
RMS	15.85
rec - upstream cell	
Entries	12146
Mean	-254.5
RMS	18.91
rec - downstream cell	
Entries	10110
Mean	-181.6
RMS	18.25

⇓

$\Delta z = 6$ cm in HMR

Dimuon mass resolution

Entries	14610
Mean	0.05287
RMS	0.2295
χ^2 / ndf	20.89 / 23
Prob	0.588
Constant	765.1 ± 9.2
Mean	0.04886 ± 0.00190
Sigma	0.1779 ± 0.0020

⇓
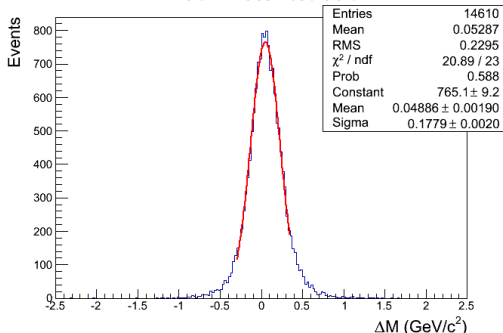
$\Delta M = 178$ MeV/c^2 in HMR

The dimuons acceptance in the High Mass Region (HMR) is 39%.

The accepted dimuons are:

- μ_1 (1st spectrometer) & μ_2 (1st spectrometer) - 22%
- μ_1 (2nd spectrometer) & μ_2 (2nd spectrometer) - 2%
- μ_1 (1st spectrometer) & μ_2 (2nd spectrometer) - 18%

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 we expect the following statistical errors in azimuthal asymmetries:

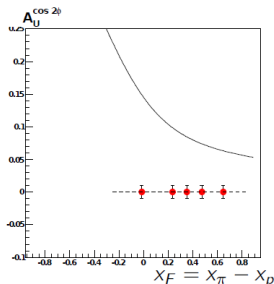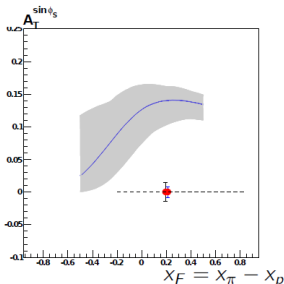| Asymmetry (%)	$4 < M_{\mu\mu} < 9$ GeV/c^2
$\delta A_U^{\cos 2\phi}$	0.43
$\delta A_T^{\sin \phi_S}$	1.34
$\delta A_T^{sin(2\phi+\phi_S)}$	2.70
$\delta A_T^{sin(2\phi-\phi_S)}$	2.70

Unpolarized PDF $\otimes$ Sivers

M. Anselmino *et al*, Phys. Rev. D 79 (2009) 054010
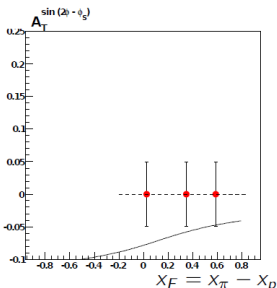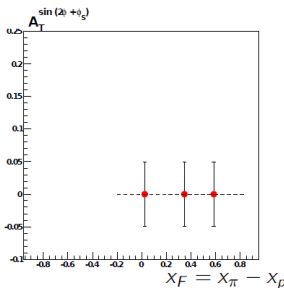
Boer-Mulders $\otimes$ Boer-Mulders

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

Boer-Mulders $\otimes$ Pretzelosity

Zhun Lu *et al*, arXiv:1101.2702v2

Boer-Mulders $\otimes$ Transversity

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

- The opportunity to study, with the same spectrometer, 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 proven after three successful beam tests.
- The COMPASS II Proposal was approved by CERN for a first period of 3 years including 1 year for Drell-Yan.
- Drell-Yan data taking will start in 2014.

BACKUP SLIDES

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

- $A_U^{\cos 2\phi}$ gives access to the Boer-Mulders functions of both incoming hadrons.

- $A_T^{\sin \phi_S}$ gives access to the unpolarised PDF of beam hadron and the Sivers function of the target nucleon.

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

- $A_T^{\sin(2\phi-\phi_S)}$ 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.

The J/ψ duality corresponds to consider a possible analogy in the production mechanisms of both J/ψ and γ^*.

Studying the charmonium mass region in the dilepton decay channel:

1. Check duality hypothesis - polarized J/ψ production cross-section
2. Access PDFs from J/ψ events - larger statistics available

In 2007, 2008 and 2009 short Drell-Yan beam tests were performed, to check the feasibility of the measurement.

2007 test:

- open spectrometer (without hadron absorber)
- π^- beam @ 160 GeV/c and an unpolarized NH_3 target
- we collected $\simeq 90000$ dimuons in $\lesssim 12$ hours
- validation of the J/ψ yields expected
- verification of the spectrometer response and radiation doses

2008 test:

- open spectrometer (without hadron absorber)
- increase of the beam intensity
- high occupancy of detectors closer to the target region $\Rightarrow$ proof that is mandatory the use of an absorber