Spin physics in polarised Drell-Yan processes at COMPASS

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on behalf of the COMPASS Collaboration

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Introduction

A new measurement of transverse momentum dependent distribution functions (**TMD PDFs**) is presented. The **Drell-Yan process** allows to extract TMDs like the Sivers function and the Boer-Mulders function.
The **COMPASS** collaboration already expressed this interest in a Letter of Intent sent to the SPSC on January 2009

Jumping into PDFs land...

When k_T dependence is taken into account, eight parton distribution functions are used to describe the nucleon at LO

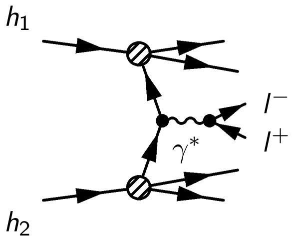
quark \ nucleon	unpol.	long. pol.	transv. pol.
unpol.	f_1		$f_{1T}^{\perp}$ Sivers
long. pol.		g_{1L}	g_{1T}
transv. pol.	$h_1^{\perp}$ B-M	$h_{1L}^{\perp}$	h_1 transv. $h_{1T}^{\perp}$ Pretzl.

TMD PDFs

The three TMD PDSs below describe important properties of spin dynamics of nucleon

- $f_{1T}^{\perp}\left(x, k_T^2\right)$: the Sivers effect is related to an azimuthal asymmetry in the parton intrinsic transverse momentum distribution induced by the nucleon spin
- $h_1^{\perp}\left(x, k_T^2\right)$: the Boer-Mulders function describes the correlation between the transverse spin and the transvere momentum of a quark inside the the unpolarised hadron
- $h_{1T}^{\perp}\left(x, k_T^2\right)$: the so-called Pretzelosity function describe the polarisation of a quark along its intrisic k_T direction making accessible the orbital angular momentum information

The Drell-Yan process



Being an electromagnetic process, at Born level in collinear approximation, the Drell-Yan cross section can be calculated

$$\sigma_{DY} = \sum_q \int \mathrm{d}x_1 \int \mathrm{d}x_2 f_1(x_1)\, f_2(x_2)\ \ \hat{\sigma}_0$$

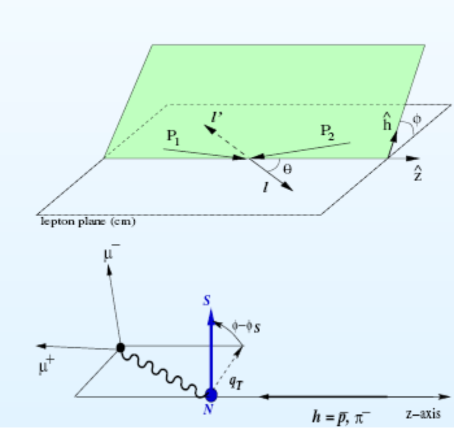
Good regions:

- $s > 100$ GeV^2
- $Q^2 = M^2_{\gamma^*} > 1$ GeV^2

and the phase space is defined by the variables

$$x_F = \frac{p_L}{\sqrt{s}} = x_1 - x_2$$
$$\tau = \frac{M^2}{\sqrt{s}} = x_1 \cdot x_2$$

The Drell-Yan process



In the Collins-Soper frame:

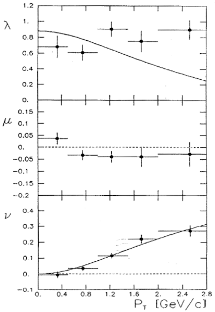
- θ and ϕ are the angles defined by the lepton pair w. r. t. the hadrons plane
- ϕ_{S_2} is the azimuthal angle of the target spin vector w. r. t. the lepton plane (if target is transversely polarised)

Drell-Yan angular distribution

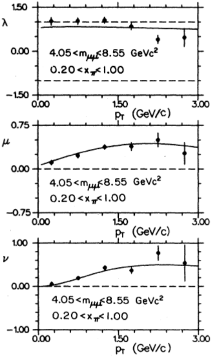
The unpolarised Drell-Yan angular distribution is:

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}\left(1 + \lambda\cos^2\theta + \mu\sin^2\theta\cos\phi + \frac{\nu}{2}\sin^2\theta\cos 2\phi\right)$$

λ, μ and ν as a function of virtual photon transverse momentum p_T



CS frame.
Falciano et al, Z. Phy. C 31, (1986) 513



GJ frame.
Conway et al, Phys. Rev. D 39, (1989) 92

The Lam-Tung sum rule[1] holds

$1-\lambda = 2\nu$

At LO, in collinear approssimation:

$\lambda = 1$ and $\mu = \nu = 0$

but

NA10 and E615 showed a $\cos 2\phi$ modulation

[1] C. S. Lam and W. K. Tung, Phys. Rev. D 21, (1980) 2712

Boer-Mulders function (unpolarised Drell-Yan)

NA10 and E615 show that λ, μ and ν clearly deviate from LO values but Lam-Tung rule is expected to be followed: this is explained by QCD corrections and Lam-Tung sum rule still holds. But at higher orders this is not true any more: most suspected is the Boer-Mulders function

The $\cos 2\phi$ modulation can be explained by the product of two Boer-Mulders functions

$$\begin{aligned} \sigma_{DY} &\propto \bar{h}_1^{\perp}\left(x_1, k_{1T}^2\right) \otimes h_1^{\perp}\left(x_2, k_{2T}^2\right) \cos 2\phi \\ &+ \sum (pdf_1 \otimes pdf_2) \end{aligned}$$

Sivers function (single polarised Drell-Yan)

When the target is transversely polarised the Sivers function becomes accessible

$$\begin{aligned}\sigma_{DY} \quad \propto \quad & \bar{f}_1\left(x_1, k_{1T}^2\right) \otimes f_{1T}^{\perp}\left(x_2, k_{2T}^2\right)\ \sin\left(\phi - \phi_{S_2}\right) \\ + \quad & \bar{h}_1^{\perp}\left(x_1, k_{1T}^2\right) \otimes h_1\left(x_2, k_{2T}^2\right)\ \sin\left(\phi + \phi_{S_2}\right) \\ + \quad & \bar{h}_1^{\perp}\left(x_1, k_{1T}^2\right) \otimes h_{1T}^{\perp}\left(x_2, k_{2T}^2\right)\ \sin\left(3\phi - \phi_{S_2}\right) \\ + \quad & \sum(pdf_1 \otimes pdf_2)\end{aligned}$$

The Sivers effect produces a single spin asymmetry (SSA) $A^{\sin\left(\phi - \phi_{S_2}\right)}$

Test of QCD

It's possible to perform a test of QCD by comparing the results from SIDIS and DY.

QCD expectation is:

$$
\begin{aligned}
f_{1T}^{\perp}(DY) &= -f_{1T}^{\perp}(SIDIS) \\
h_{1}^{\perp}(DY) &= -h_{1}^{\perp}(SIDIS)
\end{aligned}
$$

J/ψ-DY duality[1]

Since the J/ψ is a vector particle like the photon and the helicity structure of $\bar{q}q\,(J/\psi)$ and $(\bar{q}q)\,\gamma^*$ couplings is the same, it is possible to establish an analogy between the two processes $h_1 h_2 \rightarrow J/\psi X \rightarrow l^+ l^- X$ and $h_1 h_2 \rightarrow \gamma^* X \rightarrow l^+ l^- X$

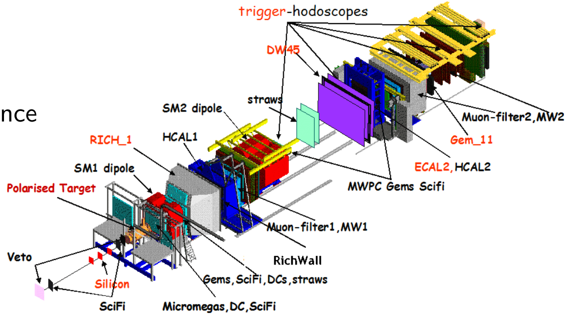
Studying the J/ψ production will be possible:

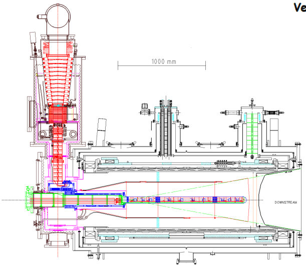
- check the duality hypothesis
- dramatically enlarge statistics (for region of mass around J/ψ mass)

[1] N. Anselmino, V. Barone, A. Drago and N. Nikolaev, Phys. Lett. B 594, (2004) 97
A. Sissakian, O. Shevchenko and O. Ivanov, JETP Lett. 86 (2007) 751

The COMPASS spectrometer

- μ, p, π, K, $\bar{p}$ beam
- 50-270 GeV/c momentum
- ±180 mrad angular acceptance





- NH_3 target polarisation ∼90%
- dilution factor 0.14
- three cells target

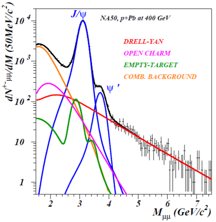
What there is and what is needed

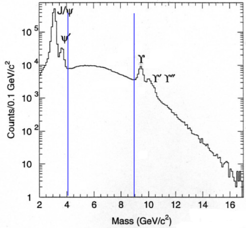
At COMPASS will be study: $\pi^- p^{(\Uparrow)} \rightarrow \mu^+\mu^- + X$

- COMPASS is a running experiment
- the collaboration has experience with TMD PDFs
- unique polarised target
- wide angular acceptance
- muon tracking system
- presence of know-how on Drell-Yan physics

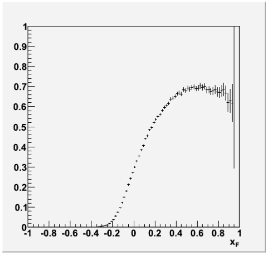
- an hadron absorber is needed
- the muon trigger has to be upgraded
- as high as possible luminosity which unluckily is limited by radioprotection safety rules

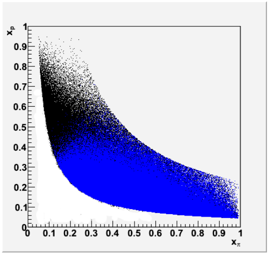
DY acceptances





The COMPASS acceptance covers the valence quark region ($x > 0.1$)



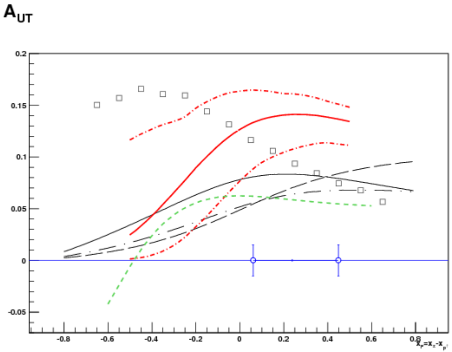


The safe mass interval is between 4 and 9 GeV/c^2

Asymmetries are expected to be significant in valence quark region, up to 10%

Asymmetry error and theory predictions

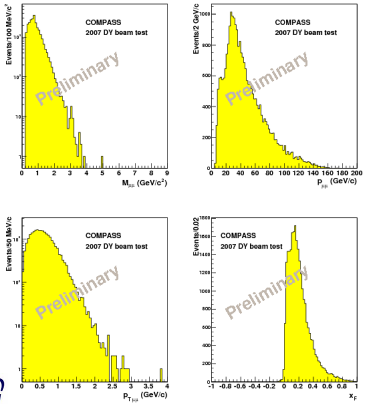
$\delta A^{\sin(\phi_{S_2}-\phi)}$ is expected to be $\approx 1-2\%$, assuming two years of data taking and depending of the number of bins

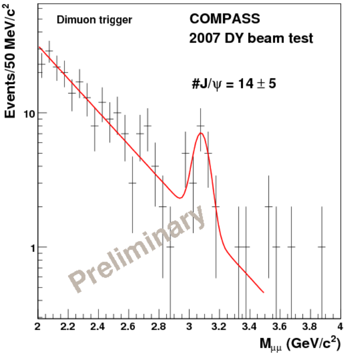


- Efremov et al, PLB612 (2005) 233 (solid and dashed)
- Collins et al, PRD73 (2006) 014021 (dot-dashed)
- Anselmino et al, PRD79 (2009) 054010 (red solid, red dot-dashed)
- Bianconi et al, PRD73 (2006) 114002 (boxes)
- Bacchetta et al, PRD78 (2008) 074010 (green short-dashed)

2007 DY beam test

160 Gev/c π^- beam on NH_3 target; no absorber; moun trigger; less than 12 hours of data taking $\rightarrow$ collected $\approx$ 90000 dimuons events





Effectiveness of DY trigger.
J/ψ expected were 20 $\pm$ 8

2008 and 2009 DY beam test

In 2008 a second short beam test was performed, still without an hadron absorber, to test detectors performance but at 1/4 of possible beam intensity the detector occupancy was too high $\rightarrow$ need of an absorber

Late in this year, at the end of the 2009 run, a beam test is foreseen: an absorber will be inserted in the spectrometer as well as small trigger test hodoscope to help developing a new large angle dimuon trigger

Time scale

Facility	Type		s (GeV^2)	Timeline
RHIC (STAR)	collider,	$p^{\Uparrow}p$	200^2	>2013
E906 (Fermilab)	fixed target,	pp,	250	>2011
J-PARC	fixed target,	$pp^{\Uparrow}$, $\pi p^{\Uparrow}$	$60 \div 100$	>2015
GSI (PAX)	collider,	$\bar{p}^{\Uparrow}p^{\Uparrow}$	200	>2017
GSI (Panda)	fixed target,	$\bar{p}p$	30	>2016
NICA	collider,	$p^{\Uparrow}p^{\Uparrow}$, $d^{\Uparrow}d^{\Uparrow}$	676	>2014
COMPASS	fixed target,	$\pi^{\mp}p^{\Uparrow}$	$300 \div 400$	>2010

Conclusions

The Drell-Yan program at COMPASS will allow to study:

- the intrinsic partonic transverse momentum (unpolarized cross section)
- the Boer-Mulders function (unpolarized angular distribution)
- the Sivers function and its sign (transverse polarized DY)
- the transversity function
- J/ψ-DY duality

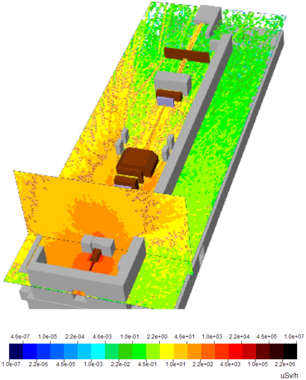
A **Letter of Intent** has already been sent to SPSC.

Thank you!

Backup

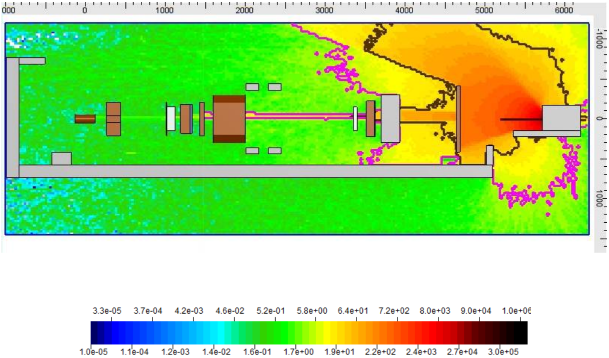
Looking deep in one issue: radioprotection

COMPASS is a ground experiment: that means that radioprotection rules define limits to beam intensity (then to luminosity). Moreover an absorber in the middle of the experimental hall completely changes the dose rate w. r. t. experienced muon or hadron conditions



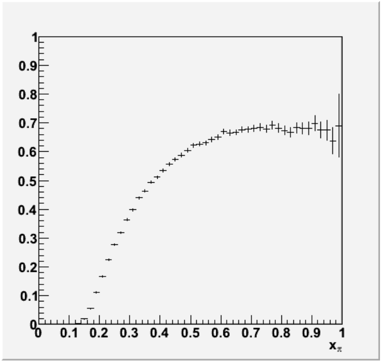
Fluka simulations by H. Vincke, CERN

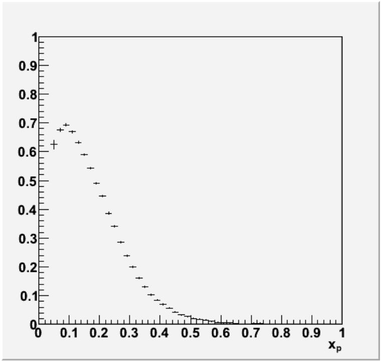
More on looking deep in one issue: radioprotection



Fluka simulations by H. Vincke, CERN

More on acceptances





Past DY experiments

Exp.	Beam (GeV/c)	Target	Physics
NA3	$\pi^{\pm}$ 150/200/280	H_2, Pt	π, K PDFs
NA10	π^{-} 140/194/284	D, W	π PDFs, Boer-Mulders
NA51	p 450	H_2,D	$\bar{d}/\bar{u}$ asymmetry in proton
E615	π^{-} 252	W	π, K PDFs, Boer-Mulders
E866	p 800	H_2,D	$\bar{d}/\bar{u}$ asymmetry in proton
COMPASS	π 160/190	pol NH_3	Sivers, Transversity, ...