

The Drell-Yan measurement at COMPASS-II

Stefano Takekawa
on behalf of the COMPASS Collaboration

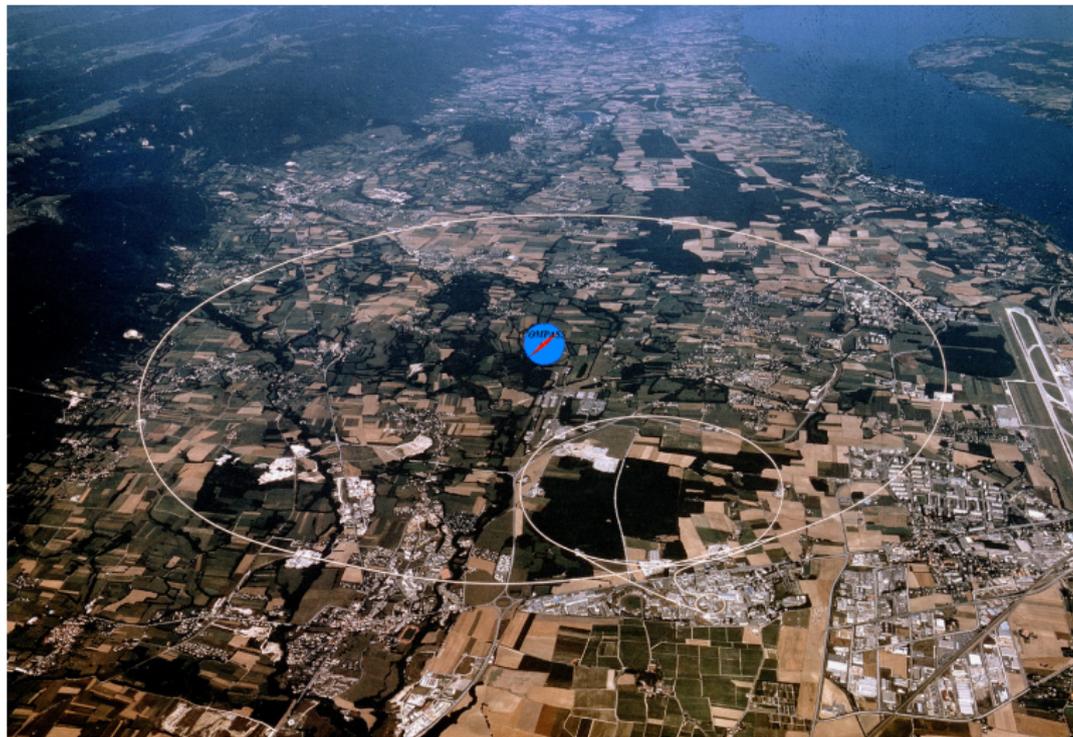
INFN

25/06/2013
Baryons 2013 - Glasgow



- ▶ Introduction
- ▶ TMD PDFs and Drell-Yan
- ▶ DY@COMPASS
- ▶ COMPASS spectrometer upgrades

COmmon Muon Proton Apparatus for Structure and Spectroscopy



The structure of the nucleon at LO

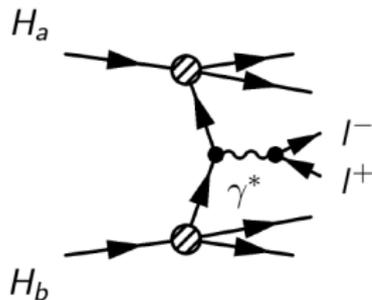
The structure of the nucleon can be described by three parton distribution functions (PDF) at leading order in collinear approximation. When the k_T dependence is taken into account, eight transverse momentum dependent (TMD) parton distribution functions are used to describe it

		nucleon		
		unpol.	long. pol.	transv. pol.
quark	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^\perp transv. h_{1T}^\perp Pretzl.

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

The Drell-Yan process

The Drell-Yan process can be used to access the TMD PDFs of the proton



The Drell-Yan process is the annihilation of a quark-antiquark pair coming from two hadrons

It is a simple process, it is well understood, but it has a very small cross-section

The single polarised Drell-Yan cross-section is (at LO):

$$\begin{aligned} \frac{d\sigma}{d^4q d\Omega} &= \frac{\alpha_{em}^2}{Fq^2} \hat{\sigma}_U \left\{ \left(1 + D_{[\sin^2 \theta]} A_U^{\cos 2\phi} \cos 2\phi \right) \right. \\ &+ |S_T| \left[A_T^{\sin \phi_S} \sin \phi_S + D_{[\sin^2 \theta]} \left(A_T^{\sin(2\phi + \phi_S)} \sin(2\phi + \phi_S) \right. \right. \\ &+ \left. \left. A_T^{\sin(2\phi - \phi_S)} \sin(2\phi - \phi_S) \right) \right] \left. \right\} \end{aligned}$$

$D_{\{f(\theta)\}}$ = depolarisation factors, S = spin target components, F = flux of incoming hadrons and A = the azimuthal asymmetries, $\hat{\sigma}_U$ = cross section surviving the integration of ϕ and ϕ_S , θ and ϕ are the polar and azimuthal angle of the lepton in the CS frame, ϕ_S is the spin angle on the nucleon in the TF

What can be measured at COMPASS

At COMPASS, it will be possible to measure the asymmetries in single polarised Drell-Yan with the process $\pi^- + p^\uparrow \rightarrow \mu^+ \mu^- + X$

Each asymmetry term in the cross section gives access to two TMD PDFs:

- ▶ $A_U^{\cos 2\phi}$: access to the **Boer-Mulders** functions of both incoming hadron and target nucleon
- ▶ $A_T^{\sin \phi_S}$: access to the **Sivers** function of the target nucleon and unpolarised pdf of beam particle
- ▶ $A_T^{\sin(2\phi+\phi_S)}$: access to the Boer-Mulders function of the beam hadron and to the **pretzelosity** function of the target nucleon
- ▶ $A_T^{\sin(2\phi-\phi_S)}$: access to the Boer-Mulders function of the beam hadron and the **transversity** function of the target nucleon



SIDIS vs DY: a crucial test of TMDs factorization

SIDIS and DY are complementary ways to access the TMD PDFs
 → it is possible to perform a test of QCD

⇒ QCD expectation is:

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

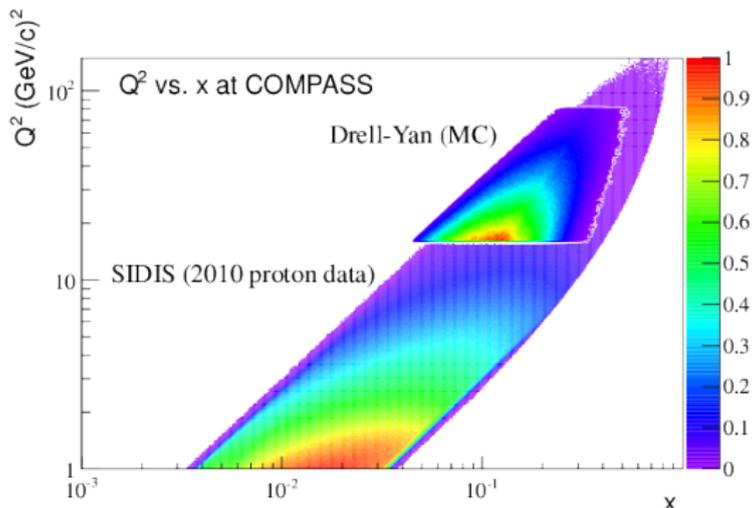
$$h_1^\perp(DY) = -h_1^\perp(SIDIS)$$

This happens because gauge links are present in the cross sections of SIDIS and Drell-Yan processes to provide the gauge invariance. The gauge link provides the possibility of existence of non-zero T-odd TMD PDFs. The Sivers and Boer-Mulders functions are T-odd and they change sign to provide the gauge invariance. This test includes not only the sign change but also the comparisons of the amplitude and the shape of the corresponding TMD PDFs.



Q^2 vs x phase space at COMPASS

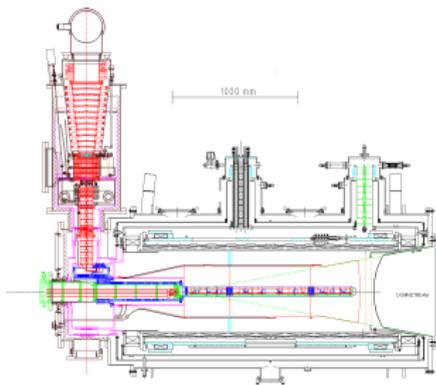
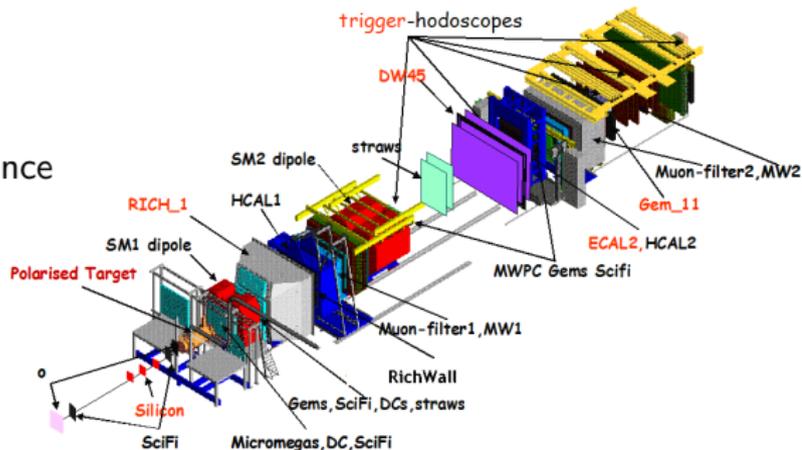
Both the Semi-Inclusive DIS and the Drell-Yan measurements allow to extract TMD PDFs



The phase spaces of the two processes overlap at COMPASS → consistent extraction of TMD PDFs in the same region!

The COMPASS spectrometer

- ▶ μ , p , π , K beam
- ▶ 50-270 GeV/c momentum
- ▶ ± 180 mrad angular acceptance



- ▶ NH_3 target polarisation $\sim 90\%$
- ▶ dilution factor 0.22 (Drell-Yan)
- ▶ three cells target

The main characteristics of the Drell-Yan experiment:

- ▶ $\pi^- + p^\uparrow \rightarrow \mu^+ \mu^- + X$
- ▶ the low Drell-Yan cross section requires a high intensity pion beam in order to obtain a good statistics
- ↔ beam intensity up to $10^8 \pi^-$ per second on the thick target (~ 1 interaction length)
- ↔ a hadron absorber is needed to stop secondary particles flux and a beam plug to stop the non-interacted beam
- ↔ rearrangement of the target area to place the absorber
 - ▶ new muon trigger in the first stage of the spectrometer
 - ▶ vertex detector to improve the cell separation of events



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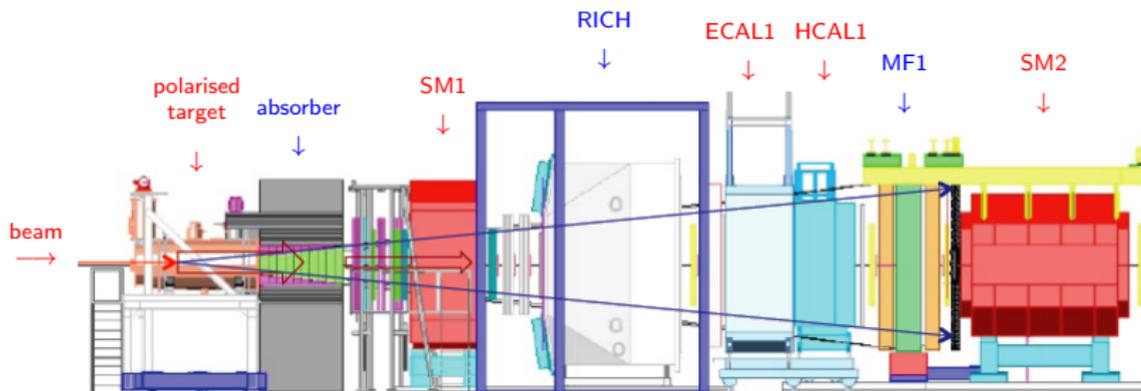
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Design of the spectrometer

The first stage of the spectrometer has key importance because the main fraction of muons from Drell-Yan process is in its acceptance



View of the COMPASS Large Angle Spectrometer from CAD design

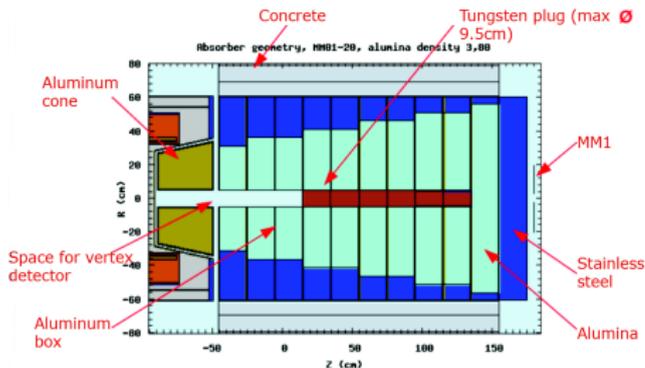
Upgrades

- ▶ target area
- ▶ hadron absorber
- ▶ vertex detector



Upgrades

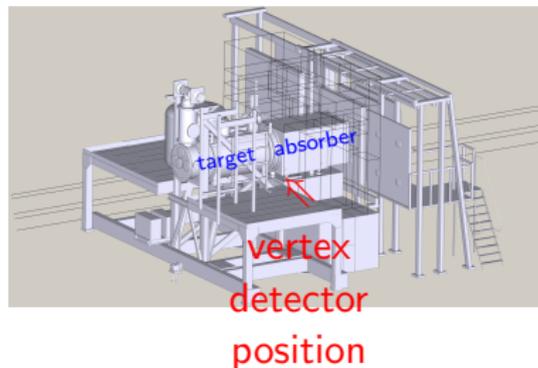
- ▶ target area
- ▶ hadron absorber
- ▶ vertex detector



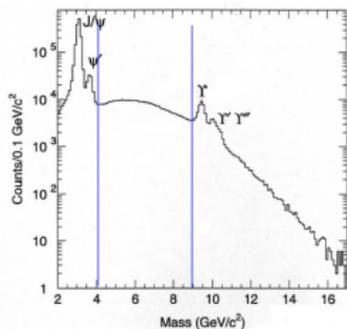
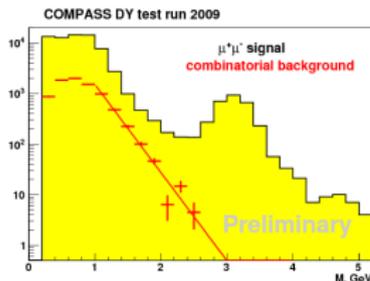
- ▶ 120 cm tungsten beam plug
- ▶ aluminium conical part
- ▶ 200 cm alumina (Al_2O_3)
- ▶ non-magnetic stainless steel peripheral part

Upgrades

- ▶ target area
 - ▶ hadron absorber
 - ▶ vertex detector
- A vertex detector has been proposed to:
- ▶ improve mass resolution of the virtual photon
 - ▶ improve resolution on the primary vertex position
 - better cell separation

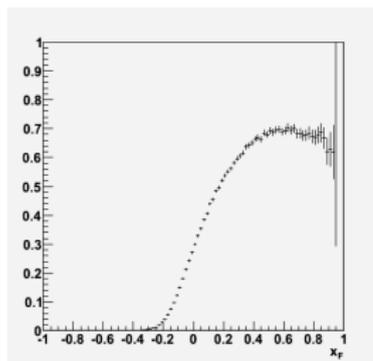


Acceptance to Drell-Yan events

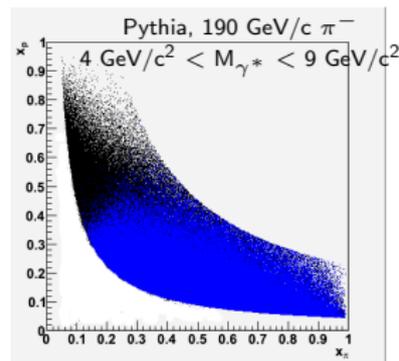


The safe mass interval is between 4 and 9 GeV/c²

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



x_F acceptance plot

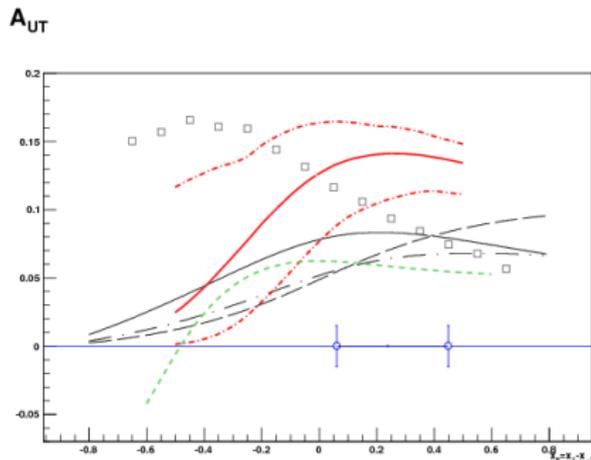


x_p vs x_π scatter plot: in black all generated events, in blue events in acceptance

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

Statistical errors and predictions

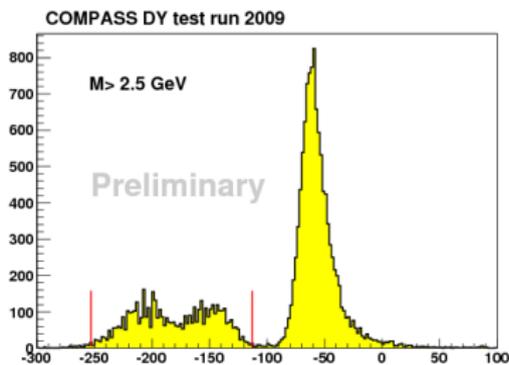
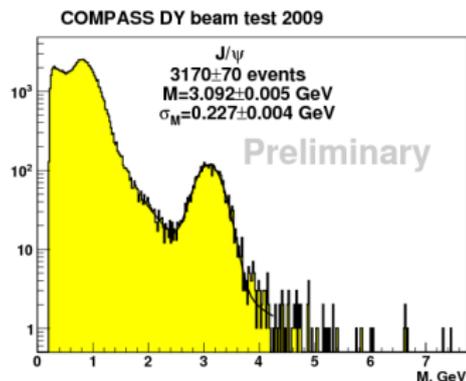
Predictions exist for the single spin asymmetry due to the Sivers effect, for the virtual photon mass range 4-9 GeV/c² and for the COMPASS kinematics. They are compared with the expected errors (1-2%) coming from a two bin analysis of two years of data taking. There is not TMD evolution in the predictions.



- ▶ 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)

Drell-Yan tests

In 2007, 2008, 2009 and 2012 important tests were performed at COMPASS. The most recent one was done in the **condition of the future measurement, with the hadron absorber**. During the short data taking, the **feasibility was proved**, the J/ψ peak and Drell-Yan events were observed as expected and the two cells were distinguished.



- target temperature ok!
- radioprotection limits respected!

- detector occupancies ok!
- agreement of simulations and reality!



Time scale

There is much interest in measuring TMD PDFs with the Drell-Yan process

Facility	Type		s (GeV^2)	Timeline
COMPASS	fixed target	$\pi^\pm p^\uparrow$	357	2014
RHIC (STAR, PHENIX)	collider	$p^\uparrow p$	200^2	> 2016
Fermilab (SeaQuest)	fixed target	$p^\uparrow \Rightarrow H, pH^\uparrow \Rightarrow$	234	> 2015
J-PARC	fixed target	$pp^\uparrow, \pi p^\uparrow$	60 – 100	> 2018
Fair (PAX)	collider	$\bar{p}^\uparrow p^\uparrow$	200	> 2018
NICA	collider	$p^\uparrow p^\uparrow, d^\uparrow d^\uparrow$	144, 676	> 2018

COMPASS has the chance to be the first experiment
to collect single polarised Drell-Yan data

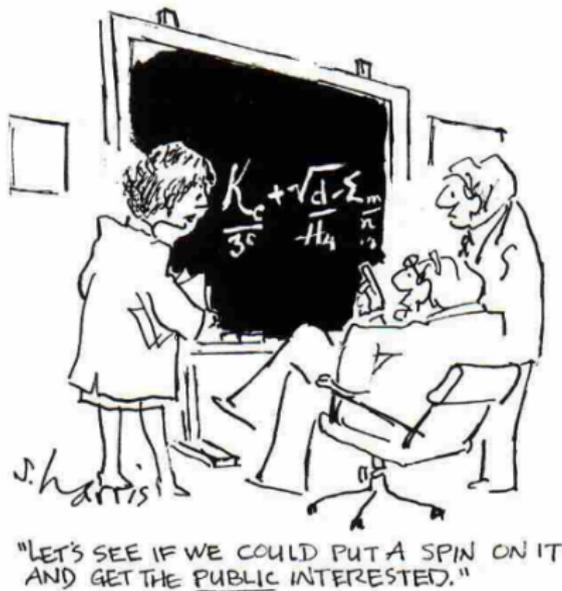


Summary

- ▶ the Drell-Yan measurement is part of the COMPASS-II Proposal
- ▶ the CERN Research board approved the COMPASS-II Proposal on 1st December 2010
- ▶ COMPASS will have **first data on single polarised Drell-Yan in 2014**
- ▶ COMPASS has the possibility to access TMD PDFs with SIDIS and Drell-Yan processes
- ▶ **a crucial test of TMD PDFs factorization** can be done by measuring the change of sign of the **Boer-Mulders** and the **Sivers** functions

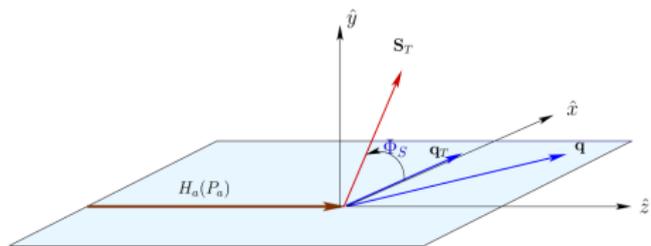
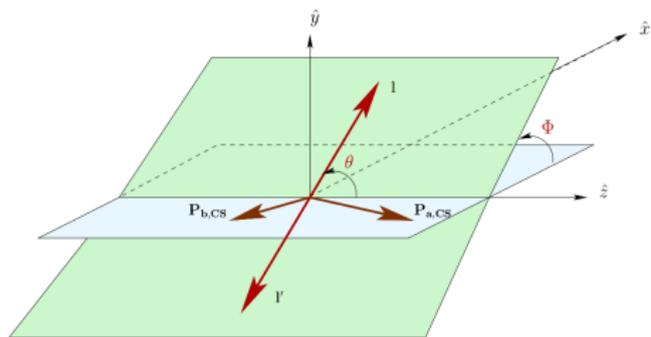


Thanks for your attention!



Backup

Definition of angles



The Collins-Soper frame: virtual photon rest frame, P_a and P_b lie in the x - z plane, z axis in the direction of $(P_a - P_b)$. The CS frame is usually chosen to study the Drell-Yan angular distribution

θ and ϕ are the angles defined by the lepton pair w. r. t. the hadrons plane

ϕ_S is the azimuthal angle of the target spin vector in the target rest frame (if target is polarised)

J/ψ -DY duality¹

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:

$$\begin{array}{c} H_a H_b \rightarrow J/\psi X \rightarrow I^+ I^- X \\ \updownarrow \\ H_a H_b \rightarrow \gamma^* X \rightarrow I^+ I^- X \end{array}$$

Studying the J/ψ production will be possible:

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

¹N. 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

Expression of asymmetries

$$F_U^1 \stackrel{\text{LO}}{=} \mathcal{C}[f_a \bar{f}_a]$$

$$A_U^{\cos 2\phi} \stackrel{\text{LO}}{=} \mathcal{C}\left[\left(2(\mathbf{h} \cdot \mathbf{k}_{aT})(\mathbf{h} \cdot \mathbf{k}_{bT}) - \mathbf{k}_{aT} \cdot \mathbf{k}_{bT}\right) h_1^\perp \bar{h}_1^\perp\right] / M_a M_b F_U^1$$

$$A_T^{\sin \phi_s} \stackrel{\text{LO}}{=} \tilde{A}_T^{\sin \phi_s}$$

$$\stackrel{\text{LO}}{=} \mathcal{C}\left[\mathbf{h} \cdot \mathbf{k}_{bT} f_1 \bar{f}_{1T}^\perp\right] / M_b F_U^1$$

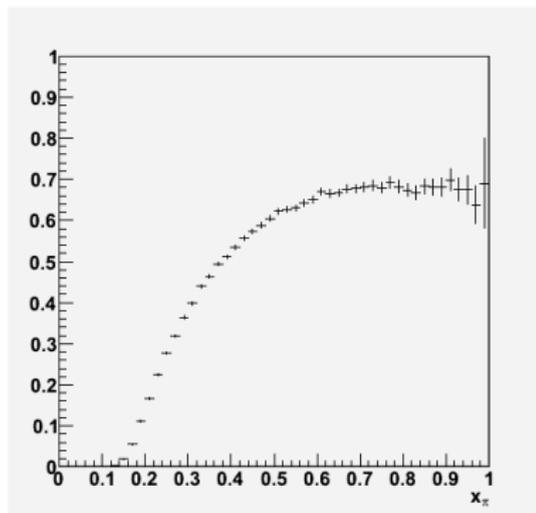
$$A_T^{\sin(2\phi + \phi_s)} \stackrel{\text{LO}}{=} -\mathcal{C}\left[\left(2(\mathbf{h} \cdot \mathbf{k}_{bT})\left[2(\mathbf{h} \cdot \mathbf{k}_{aT})(\mathbf{h} \cdot \mathbf{k}_{bT}) - \mathbf{k}_{aT} \cdot \mathbf{k}_{bT}\right] - \mathbf{k}_{bT}^2 (\mathbf{h} \cdot \mathbf{k}_{aT})\right) h_1^\perp \bar{h}_{1T}^\perp\right] / 4M_a M_b^2 F_U^1$$

$$A_T^{\sin(2\phi - \phi_s)} \stackrel{\text{LO}}{=} -\mathcal{C}\left[\mathbf{h} \cdot \mathbf{k}_{aT} h_1^\perp \bar{h}_1\right] / 2M_a F_U^1$$

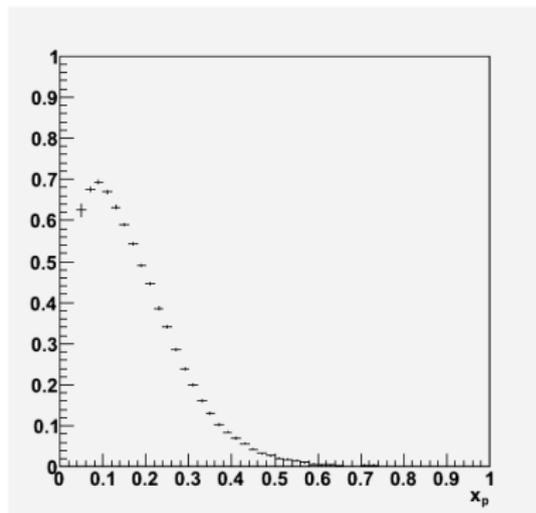
where $\mathbf{h} = \mathbf{q}_T / q_T$



More on acceptances



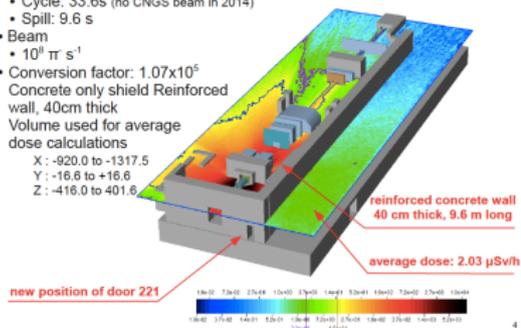
x_π acceptance plot



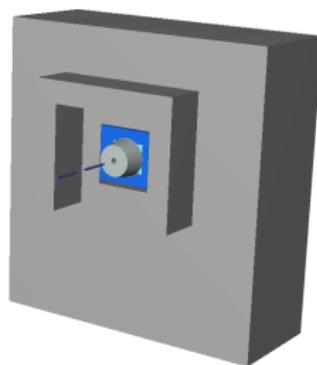
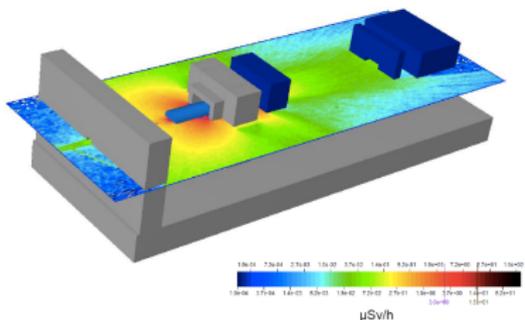
x_p acceptance plot

Hadron absorber: shielding

- SPS
 - Cycle: 33.6s (no CNGS beam in 2014)
 - Spill: 9.6 s
- Beam
 - $10^{11} \pi \text{ s}^{-1}$
- Conversion factor: 1.07×10^5
- Concrete only shield Reinforced wall, 40cm thick
- Volume used for average dose calculations
 - X : -920.0 to -1317.5
 - Y : -16.6 to +16.6
 - Z : -416.0 to 401.6



15 minutes after the end of the run



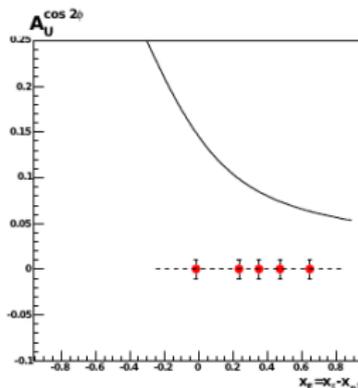
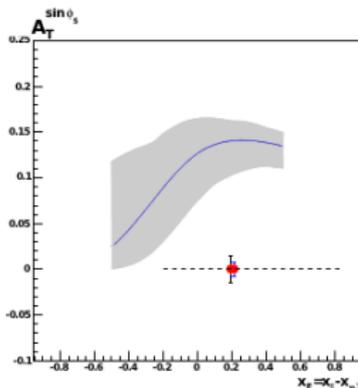
The absorber surrounded by the concrete shield

Also radioprotection rules were considered and they will be respected

Predictions for asymmetries: 4-9 GeV/c² @ COMPASS

Sivers

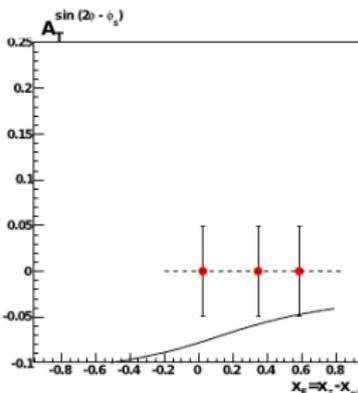
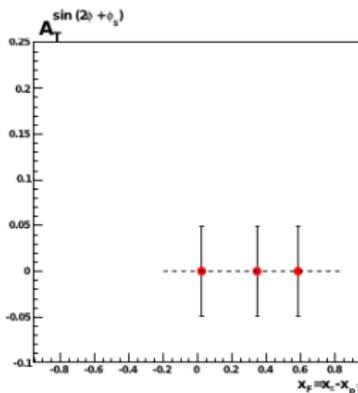
M. Anselmino
et al, Phys.
Rev. D 79,
054010 (2009)



Boer-
Mulders

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

BM ⊗
pretz.



BM ⊗

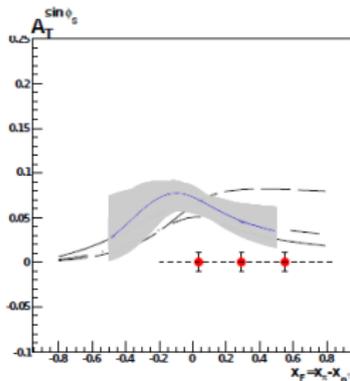
transv.

A. N. Sissakian,
Phys. Part.
Nucl. 41,
64-100 (2010)

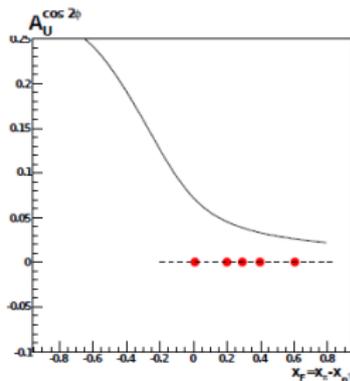


Predictions for asymmetries: 2-2.5 GeV/c² @ COMPASS

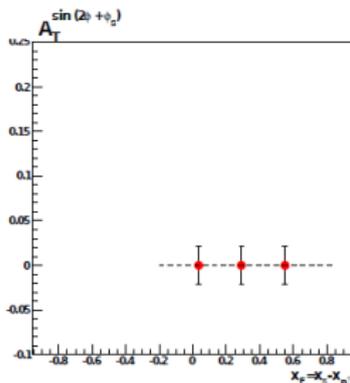
Sivers



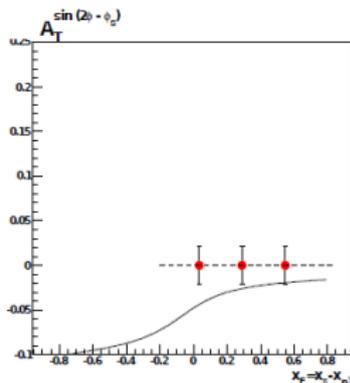
Boer-Mulders



BM ⊗
pretz.

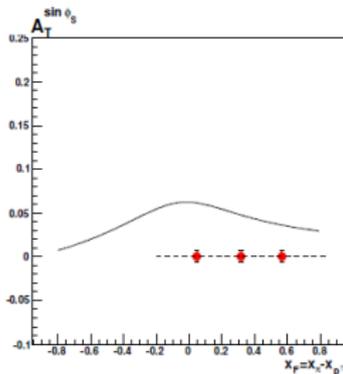


BM ⊗
transv.

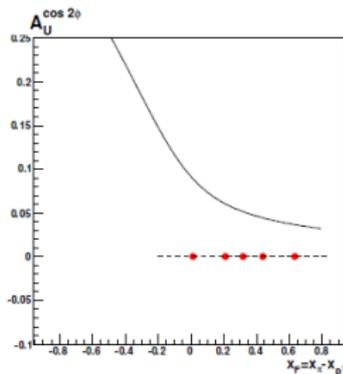


Predictions for asymmetries: 2.9-3.2 GeV/c² @ COMPASS

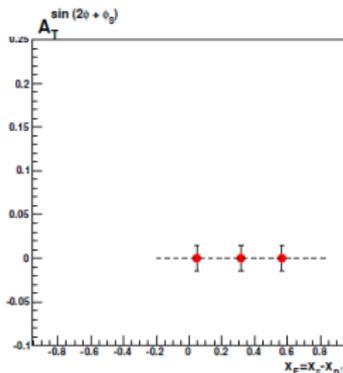
Sivers



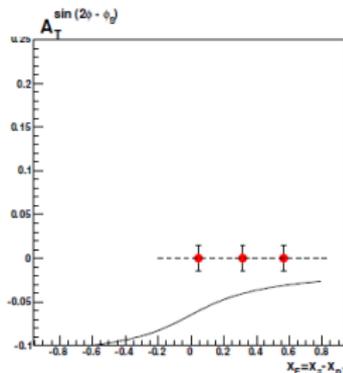
Boer-Mulders



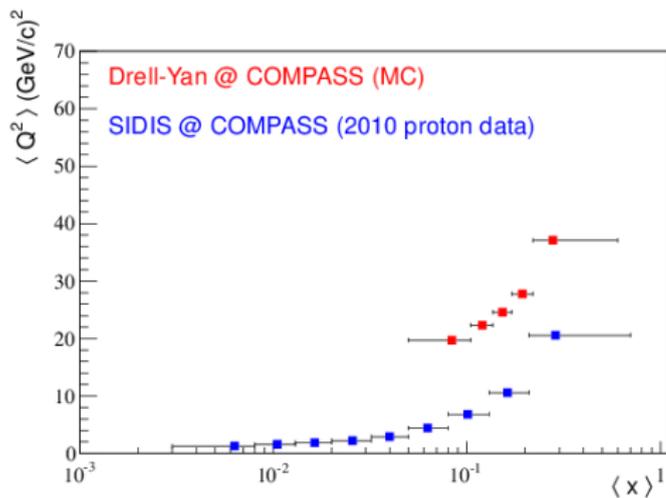
BM \otimes
pretz.



BM \otimes
transv.



Q^2 vs x mean values

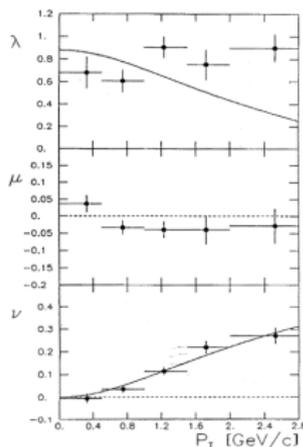


Drell-Yan angular distributions

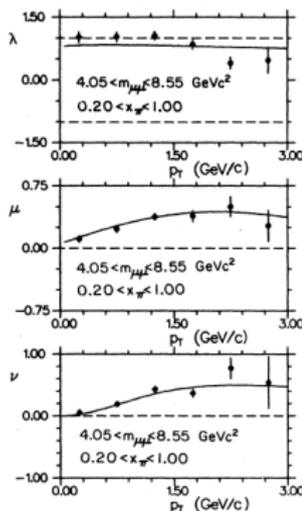
The unpolarised Drell-Yan angular distribution is:

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

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



λ , μ , ν in CS frame
Falciano et al, Z. Phys.
C 31, 513 (1986)



λ , μ , ν in GJ frame
Conway et al, Phys.
Rev. D 39, 92 (1989)

The parameters λ , μ and ν are related by the Lam-Tung sum rule¹:

$$1 - \lambda = 2\nu$$

At LO, in collinear approximation:

$$\lambda = 1 \text{ and } \mu = \nu = 0$$

but

NA10 and E615 showed **non-zero** values for λ , μ , ν and also a $\cos 2\phi$ modulation

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