Polarised Drell-Yan Process in the COMPASS Experiment

Márcia Quaresma, LIP - Lisbon
on behalf of the COMPASS collaboration

12th April 2016, DIS 2016 Hamburg

CERN/FIS-NUC/0017/2015

COMPASS experiment at CERN

COmmon Muon Proton Apparatus for Structure and Spectroscopy

- Fixed target experiment at the end of M2 SPS beam line
- Around 240 collaborators from 13 countries and 22 institutes
- Data taking since 2002 and approved up to 2018

Nucleon structure - TMD PDFs

The nucleon structure in leading order QCD, taking into account k_T, is described by 8 TMD PDFs for each quark flavour.

Quark \ Nucleon	unpolarised	longitudinally polarised	transversely polarised
unpolarised	f_1 unpolarised PDF		$f_{1T}^{\perp}$ Sivers
longitudinally polarised		g_1 helicity	$g_{1T}^{\perp}$ worm-gear T
transversely polarised	$h_1^{\perp}$ Boer-Mulders	$h_{1L}^{\perp}$ worm-gear L	h_1 transversity; $h_{1T}^{\perp}$ pretzelosity

COMPASS contribution:

- Studying TMD PDFs dependence on several kinematic variables
- Accessing them through two different processes, SIDIS and DY

Theoretical prediction of the Sivers and Boer-Mulders sign change when extracted from SIDIS or from DY

⇓

Crucial test of the QCD TMD approach

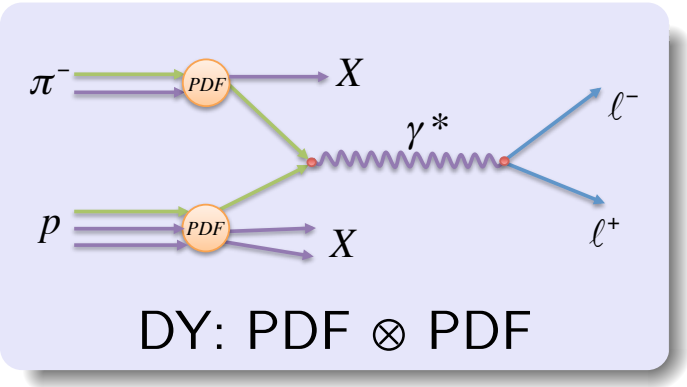
DY is an excellent tool to access TMD PDFs at COMPASS:

- All the TMD PDFs are expected to be sizeable in the valence quark region - dominant region when π^- is used as beam
- QCD TMD approach valid for Q ($M_{\mu\mu} > 4$ GeV/c^2) $\gg \langle p_T \rangle \sim 1$ GeV/c

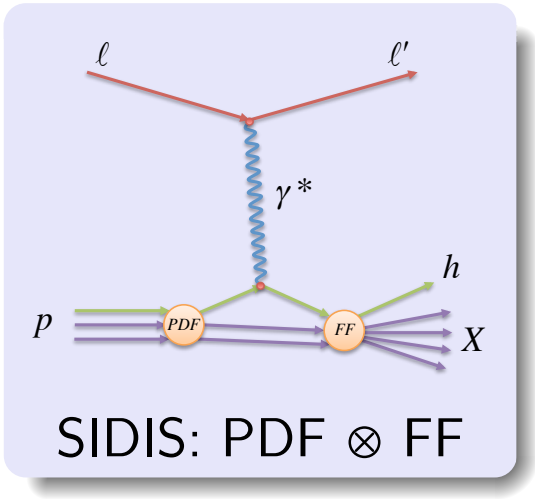
DY and SIDIS processes

DY and SIDIS cross-sections are written in terms of angular modulations.

The amplitude of each angular modulation contains:



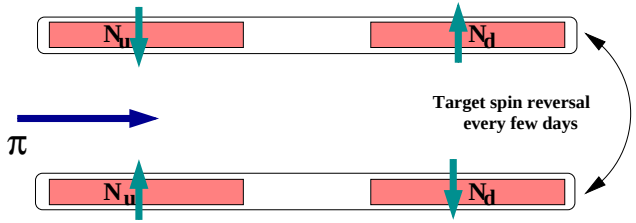
DY: PDF $\otimes$ PDF



SIDIS: PDF $\otimes$ FF

Experimental extraction of the amplitudes:

Two transversely and oppositely polarised target cells:



polarisation reversal each 2 weeks to cancel possible systematics

Measurement of the azimuthal asymmetries:

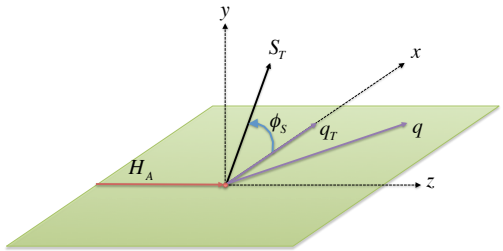
$$\frac{N_u(\phi_S,\phi_h)^{\downarrow} N_d(\phi_S,\phi_h)^{\downarrow}}{N_d(\phi_S,\phi_h)^{\uparrow} N_u(\phi_S,\phi_h)^{\uparrow}}$$

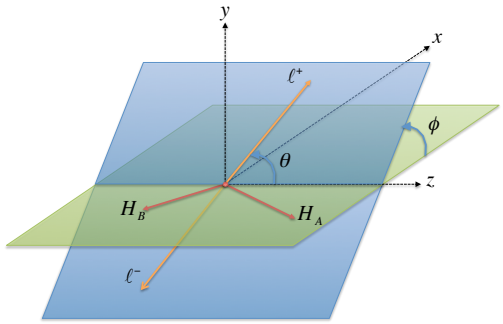
DY and SIDIS cross sections in terms of LO asymmetries

DY:

$$\frac{d\sigma}{d^4q d\Omega} = \frac{\alpha^2}{\Phi q^2}\hat{\sigma}_U \left\{\left(1+\cos^2(\theta)+\sin^2(\theta)A_{UU}^{\cos(2\phi)}\cos(2\phi)\right)\right.$$
$$+S_T\left[(1+\cos(\theta))A_{UT}^{\sin(\phi_S)}\sin(\phi_S)\right.$$
$$\left.\left.+\sin^2(\theta)\left(A_{UT}^{\sin(2\phi+\phi_S)}\sin(2\phi+\phi_S)+A_{UT}^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S)\right)\right]\right\}$$

$$\Phi = 4\sqrt{(P_a\cdot P_b)^2 - M_a^2 M_b^2},\ \hat{\sigma}_U = F_{UU}^1$$

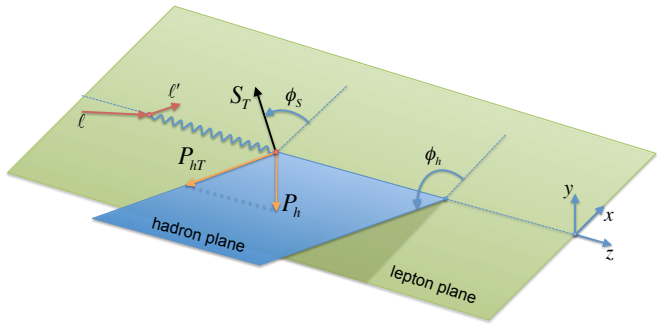




SIDIS:

$$\frac{d\sigma}{dx dy dz d\psi d\phi_h dP_{hT}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\sigma_U\left\{1+\varepsilon\cos(2\phi_h)A_{UU}^{\cos(2\phi_h)}\right.$$
$$+S_T\left[\sin(\phi_h-\phi_S)A_{UT}^{\sin(\phi_h-\phi_S)}+\varepsilon\sin(\phi_h+\phi_S)A_{UT}^{\sin(\phi_h+\phi_S)}\right.$$
$$\left.+\varepsilon\sin(3\phi_h-\phi_S)A_{UT}^{\sin(3\phi_h-\phi_S)}\right]$$
$$\left.+S_T P_l\left[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)A_{LT}^{\cos(\phi_h-\phi_S)}\right]\right\}$$

$$\varepsilon = \left(1-y-\frac{1}{4}\gamma^2y^2\right)/\left(1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2\right),\ \gamma = \frac{2Mx}{Q},\ \sigma_U = F_{UU,T}$$



All the asymmetries are extracted together using the Unbinned Maximum Likelihood Method.

LO asymmetries in DY and SIDIS and TMD PDFs

DY:

$$A_{UU}^{\cos(2\phi_{CS})} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{\perp q}$$ Boer-Mulders

$$A_{UT}^{\sin(\phi_S)} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$$ Sivers

$$A_{UT}^{\sin(2\phi_{CS}-\phi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$$ Transversity

$$A_{UT}^{\sin(2\phi_{CS}+\phi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp q}$$ pretzelosity

SIDIS:

$$A_{UU}^{\cos(2\phi_h)} \propto h_1^{\perp q} \otimes H_{1q}^{\perp h}$$

$$A_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$$

$$A_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1^{q} \otimes H_{1q}^{\perp h}$$

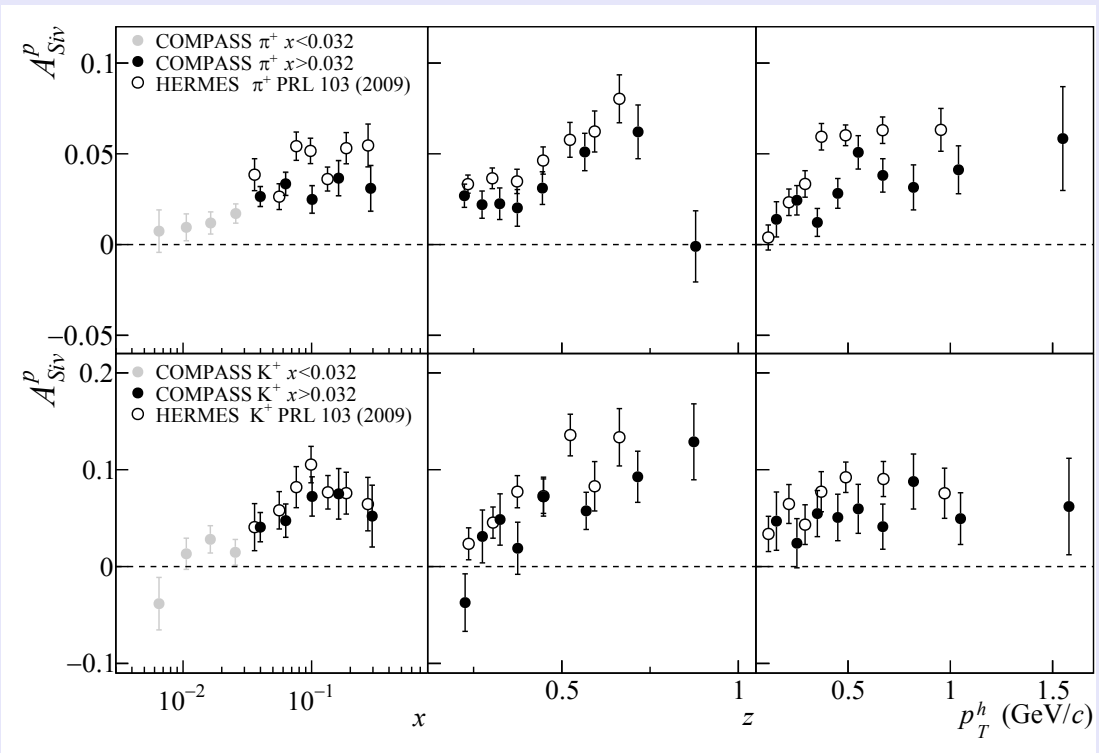
$$A_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$$

$$A_{LT}^{\cos(\phi_h-\phi_S)} \propto g_{1T}^{q} \otimes D_{1q}^{h}$$

Quark \ Nucleon	unpolarised	longitudinally polarised	transversely polarised
unpolarised	f_1 unpolarised PDF		$f_{1T}^{\perp}$ Sivers
longitudinally polarised		g_1 helicity	$g_{1T}^{\perp}$ worm-gear T
transversely polarised	$h_1^{\perp}$ Boer-Mulders	$h_{1L}^{\perp}$ worm-gear L	h_1 transversity; $h_{1T}^{\perp}$ pretzelosity

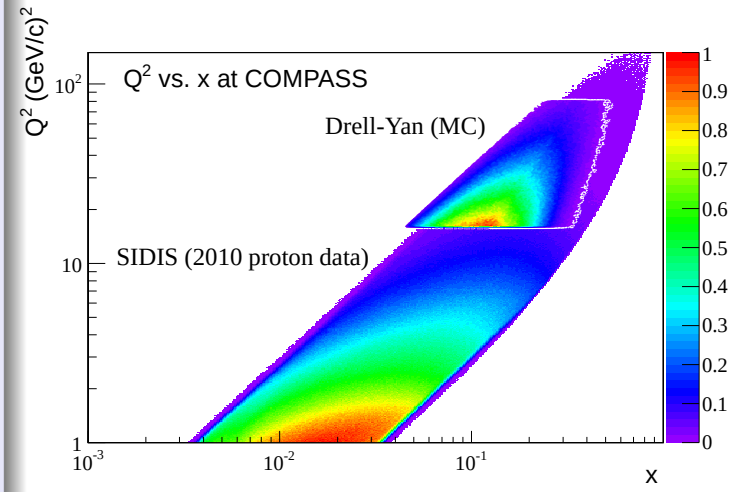
COMPASS results on Sivers asymmetry

COMPASS SIDIS proton data from 2007 and 2010
(*PLB 744 (2015) 250*)



- COMPASS: $\langle Q^2 \rangle = 8.7$ GeV/c^2
- HERMES: $\langle Q^2 \rangle = 2.4$ GeV/c^2

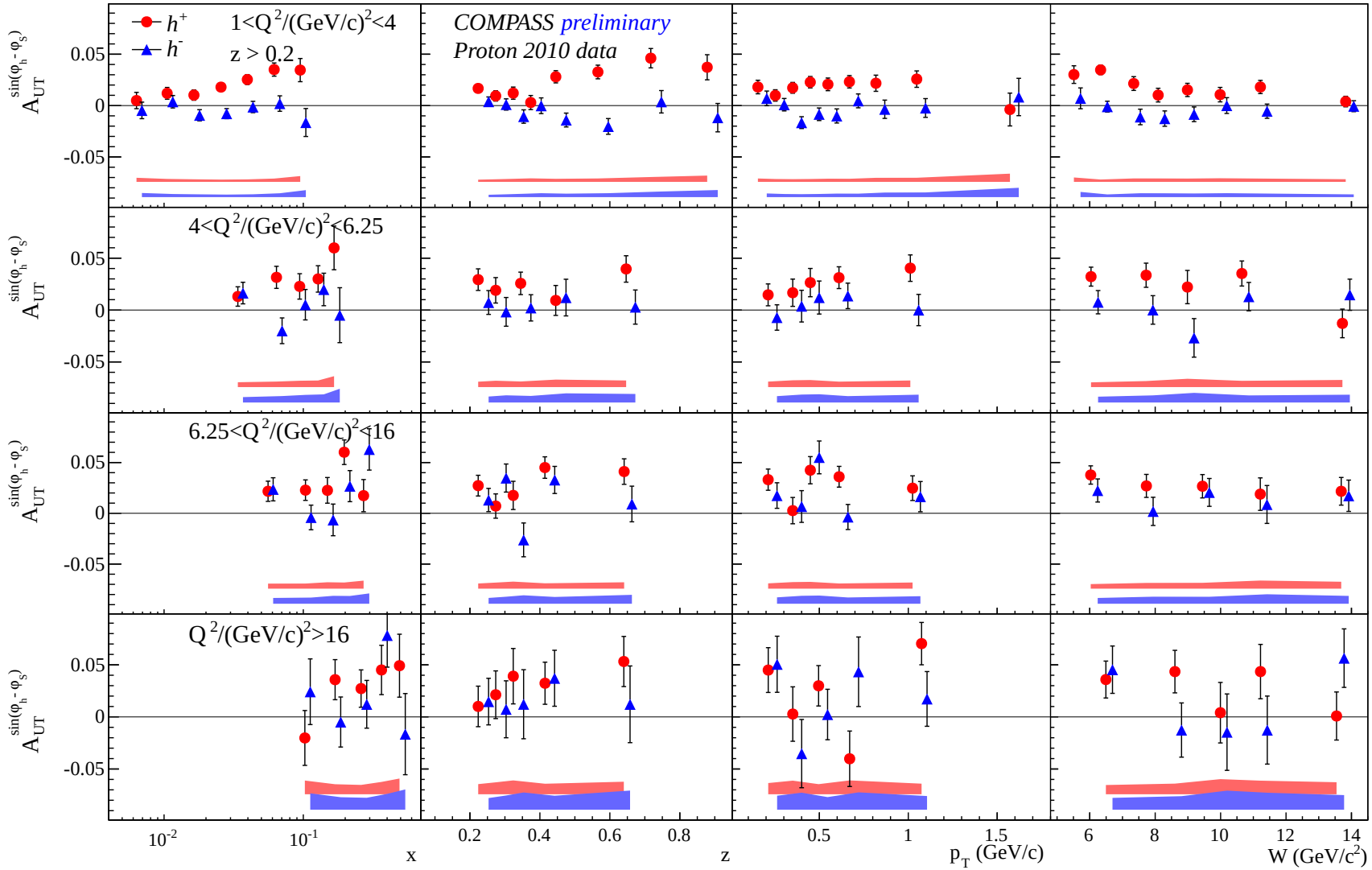
DY and SIDIS phase-space overlap at large Q^2



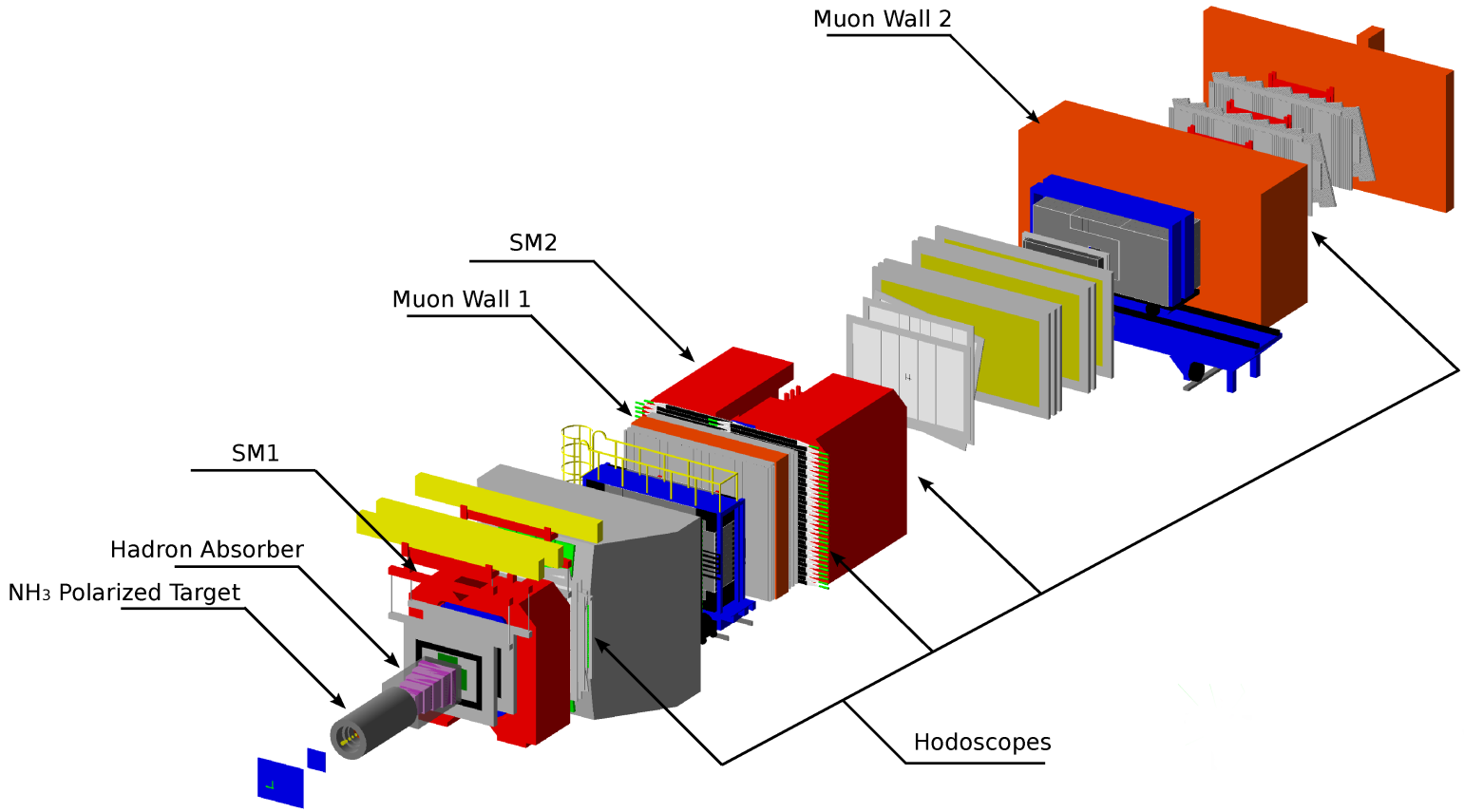
The Q^2 evolution has to be studied

SIDIS Data MultiDimensional Analysis – Sivers asymmetry

2D analysis: 4 Q^2, each divided in bins of x, z, p_{Th}, W
(also a 3D analysis was performed)



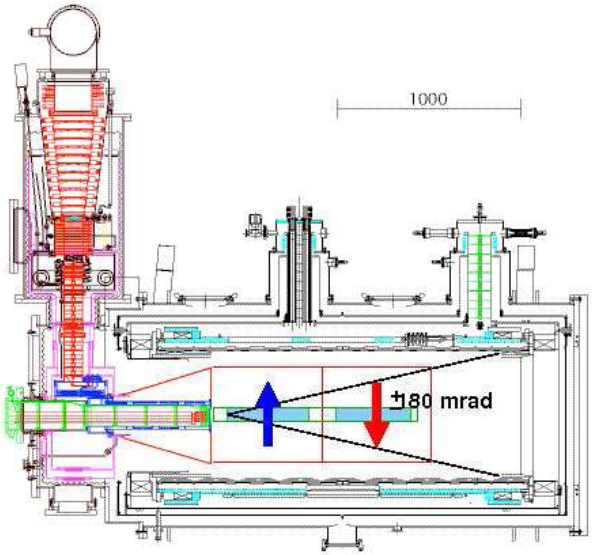
COMPASS general purpose spectrometer



- Two stages spectrometer, wide angular acceptance, ±180 mrad
- Muon and hadron beams
- Polarised target (longitudinally and transversely polarised NH_3 and ^6LiD)
- About 350 detector planes
- Particles identification: calorimeters, RICH and μ Filters

Polarised DY programme

Polarised target

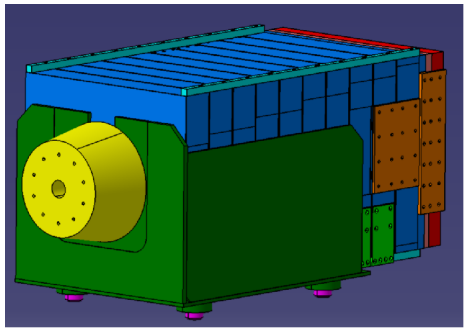


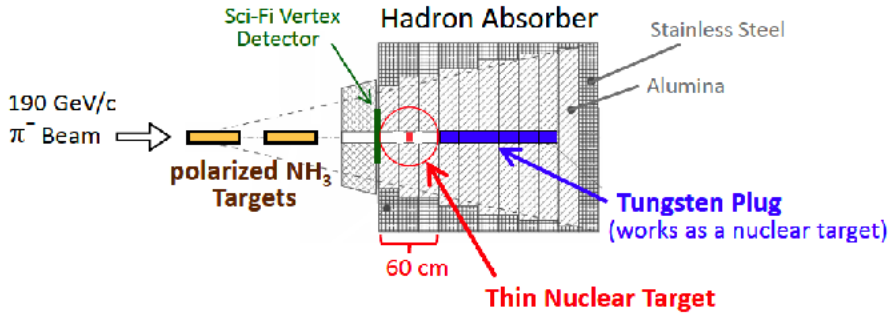
- Two cells of NH_3
- Polarisation $\sim 80\%$
- Dilution factor $\sim 22\%$

Hadron beam

190 GeV/c π beam (small contamination of K and $\bar{p}$)

Hadron absorber

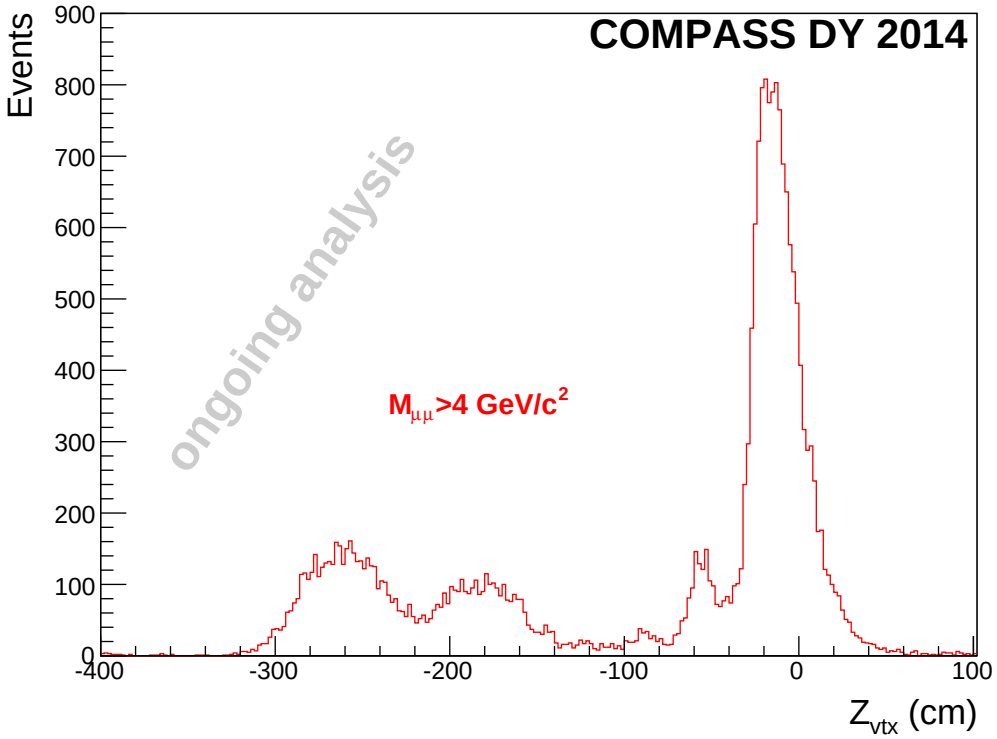




- Due to small cross-section, measurement requires high luminosity
- Hadron absorber downstream of target
  - Stops hadrons and non interacting beam
  - Degrade resolutions, two target cells, vertex detector
- Nuclear targets: Al and W $\Rightarrow$ unpolarised DY studies

Drell-Yan measurement - 2014 pilot run

- NH_3 target **not polarised**, also Al and W targets
- $\mathbf{I_{beam} \sim 7 \times 10^7 \pi/s}$
- 17 days of stable data taking used for the analysis
- First COMPASS unpolarised high mass DY data

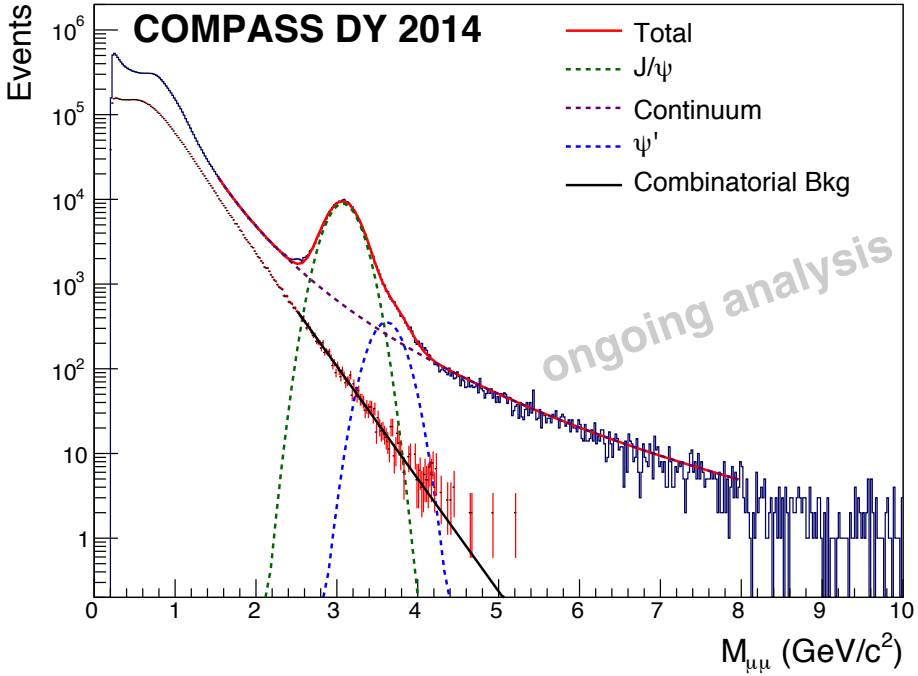


Clear signal from all targets:
NH_3, Al, W

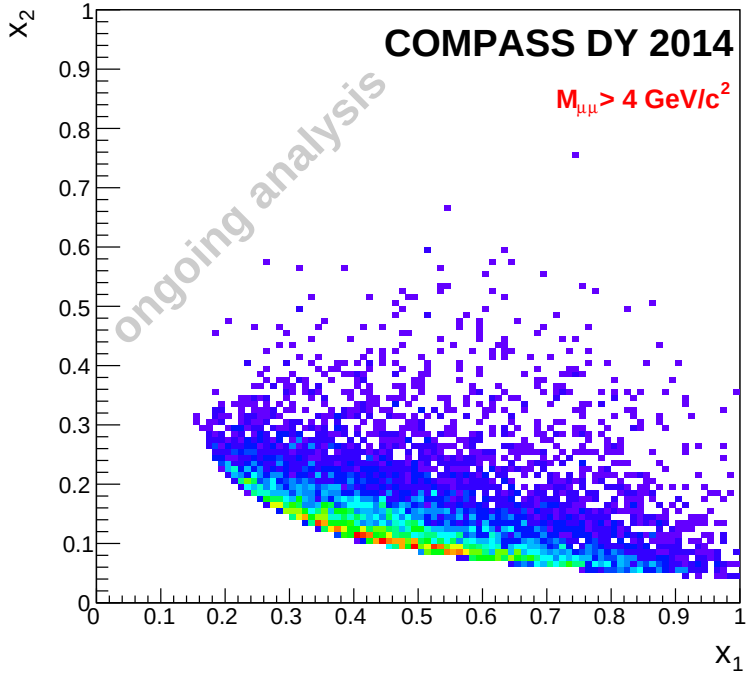
⇓

Reasonable Z_{vtx} resolution

DY 2014 pilot run - Results



Almost background free high mass DY events



Valence quarks region coverage

Unpolarised DY analysis is ongoing:

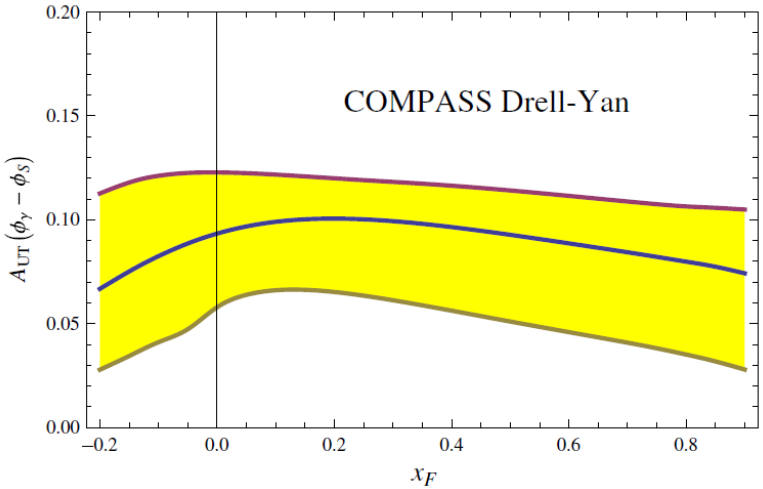
- Studies of the flavour dependent EMC effect (modification of quark distributions in nuclei) ⇒ available data from past experiments not enough accurate
- Dedicated studies on the Lam Tung sum rule violation ⇒ precision improvement w.r.t. past experiments

Polarised Drell-Yan measurement - 2015 run

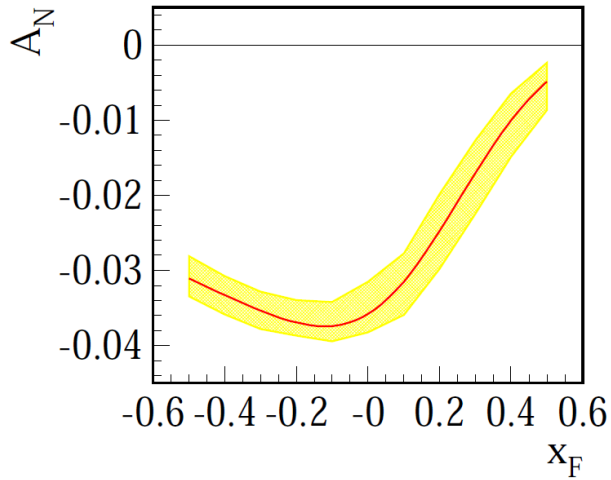
1st World Experiment

- NH_3 **polarised** target (plus Al and W targets)
- $I_{beam} \sim 10^8 \pi/s$ - very high intensity
- Four months of stable data taking are being analysed
  ↪ **One period already produced**
- $M_{\mu\mu} > 4$ GeV/c^2 ~ **80000** $\mu^+\mu^-$ **pairs** expected from polarised target
- $\delta A_{UT}^{\sin(\phi_S)} \sim 2.8\%$ ⇒ Models predict $A_{UT}^{\sin(\phi_S)}$ from 5% to 10%

Sivers asym: $A_{UT}^{\sin(\phi_S)} = A_{UT}(\phi_\gamma - \phi_S) = -A_N$, the same pion PDF is used (PRD 45 (1992) 2349)



P. Sun and F. Yuan, PRD 88 (2013) 114012,
$x_F = x_\pi - x_p$, $p_T < 2$ GeV/c



Echevarria *et al*, PRD 89 (2014) 074013,
$x_F = x_p - x_\pi$, $p_T < 1$ GeV/c

Final remarks

- The first ever polarised DY measurement using π^- beam and proton polarised target was done by COMPASS in 2015.
  $\hookrightarrow$ These data are being analysed.
- Unique opportunity to extract the TMD PDFs from both SIDIS and DY in the same experiment.
- DY results will have a key contribution in the test of the Sivers sign change theoretical prediction.
- Unpolarised DY data from nuclear targets is being analysed, statistical improvement w.r.t. past experiments.
- The possibility to have a second year of polarised DY data taking in 2018 is under consideration.

First COMPASS DY polarised data preliminary results should be ready soon ☺