Drell-Yan physics at COMPASS

C. Quintans, LIP-Lisbon

on behalf of the COMPASS Collaboration

DIS 2014, 1st May 2014
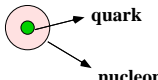
Co-financed by:

Outline

- Polarized Drell-Yan in COMPASS

- Unpolarized Drell-Yan

- Experimental set-up

- Beam test results

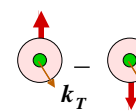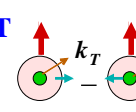- Expected event rates and asymmetries statistical errors

- Summary
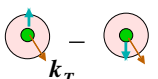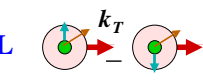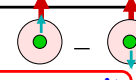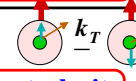
TMD PDFs

Beyond the collinear approximation:

If the intrinsic k_T of partons is taken into account, at leading twist 8 quark transverse momentum dependent PDFs are needed to describe the nucleon:

Effects arising from the correlations between the transverse momentum and the spin of quarks/nucleons are not necessarily small.

In fact, large azimuthal modulations were measured in unpolarized Drell-Yan 30 years ago (NA10, E615).

$\hookrightarrow$ Boer-Mulders effect.

TMD studies in COMPASS

In COMPASS @ CERN transverse momentum dependent PDFs (TMDs) can be accessed either from semi-inclusive DIS (SIDIS), or from Drell-Yan processes, using a transversely polarized target:

SIDIS

DY
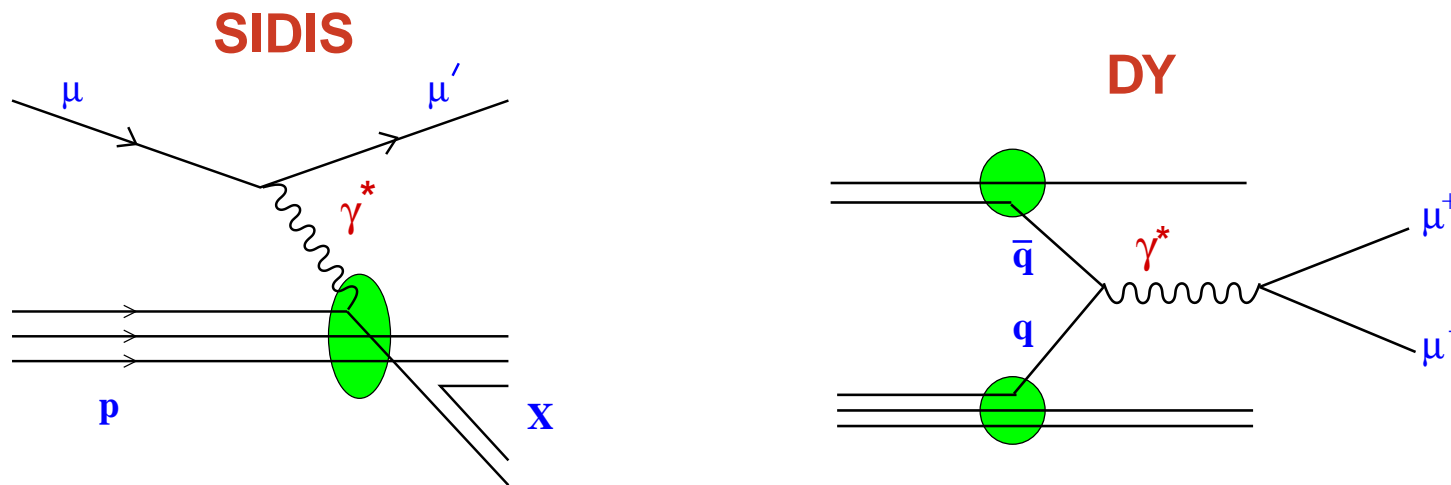
By measuring the Transverse Single Spin Asymmetries (TSSA) in these processes one can access the correlations between the parton k_T and the nucleon spin.

SIDIS: spin asymmetry proportional to TMD(quark) $\otimes$ FF(quark $\to$ hadron)

DY: spin asymmetry proportional to TMD(quark) $\otimes$ TMD(antiquark)

Polarized Drell-Yan

The single transversely polarized Drell-Yan cross-section can be written in a form evidencing the azimuthal asymmetries:

$$\frac{d\sigma}{d^4 q d\Omega} = \frac{\alpha^2}{Fq^2} \hat{\sigma}_U \left\{ (1 + D_{[\sin^2 \theta]} A_U^{\cos 2\phi} \cos 2\phi) \right.$$

$$+ |\vec{S}_T| \left(A_T^{\sin \phi_S} \sin \phi_S + D_{[\sin^2 \theta]} \left(A_T^{\sin(2\phi+\phi_S)} \sin(2\phi + \phi_S) \right. \right.$$

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

- A: azimuthal asymmetries
- D: depolarization factors
- S: target spin component

- $F = 4\sqrt{(P_a \cdot P_b)^2 - M_a^2 M_b^2}$
- $\hat{\sigma}_U$: cross-section surviving integration over ϕ and ϕ_S.

All these asymmetries are expected to be sizeable in the valence quark region (where COMPASS will measure). They contain a convolution of 2 TMDs:

- $A_U^{\cos 2\phi}$: $h_1^\perp(\pi) \otimes h_1^\perp(p)$
- $A_T^{\sin \phi_S}$: $f_1(\pi) \otimes f_{1T}^\perp(p)$

- $A_T^{\sin(2\phi+\phi_S)}$: $h_1^\perp(\pi) \otimes h_{1T}^\perp(p)$
- $A_T^{\sin(2\phi-\phi_S)}$: $h_1^\perp(\pi) \otimes h_1(p)$

(Non-)universality of TMD PDFs

SIDIS

DY
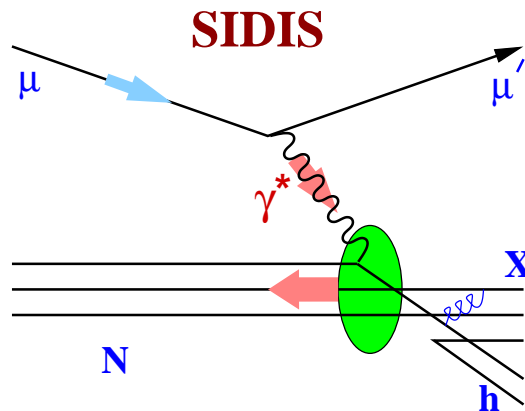
Final State Interactions
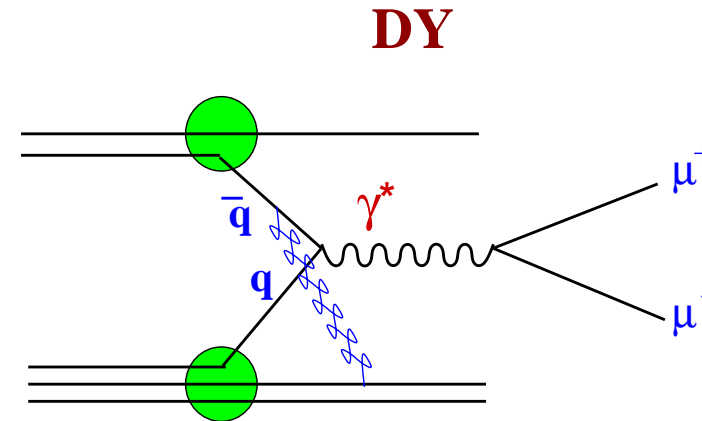
Initial State Interactions

Sivers and Boer-Mulders TMDs are T-odd, thus the prediction:

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

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

- The T-odd effect is a manifestation of non-zero quark orbital angular momentum.

- The sign change observation is considered a crucial test of the TMD approach (valid when $p_T << Q$).

Sivers from SIDIS @ COMPASS

COMPASS has accessed the Sivers TMD in SIDIS using a proton target, observing:

- positive asymmetry for h^+;
- asymmetry compatible with zero for h^-.

COMPASS, Phys.Lett.B 717 (2012)
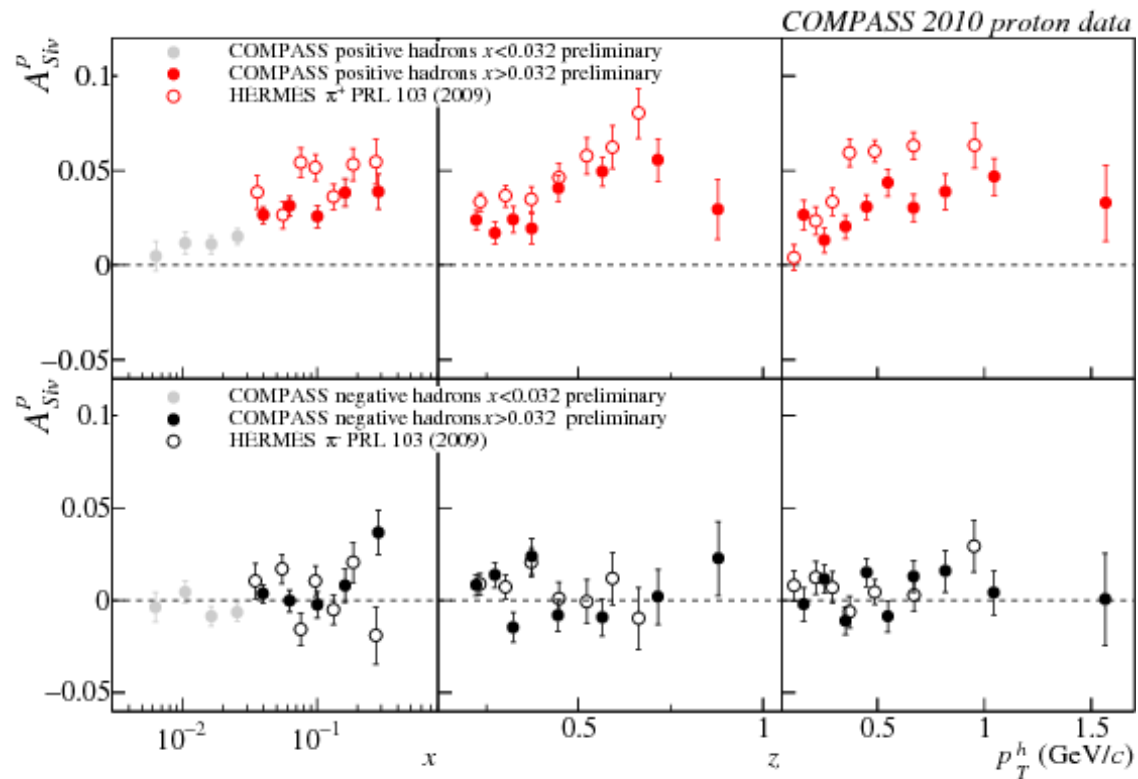
Qualitative agreement with HERMES (Phys.Rev.Lett. 103 (2009)).

Boer-Mulders from SIDIS @ COMPASS

The Boer-Mulders TMD is accessed convoluted with the Collins FF, via $A^{UU}_{\cos 2\phi_h}$ – in this asymmetry also the Cahn effect contributes.

Measured in SIDIS with unpolarized deuteron target:

COMPASS, hep-ex:1401.6284
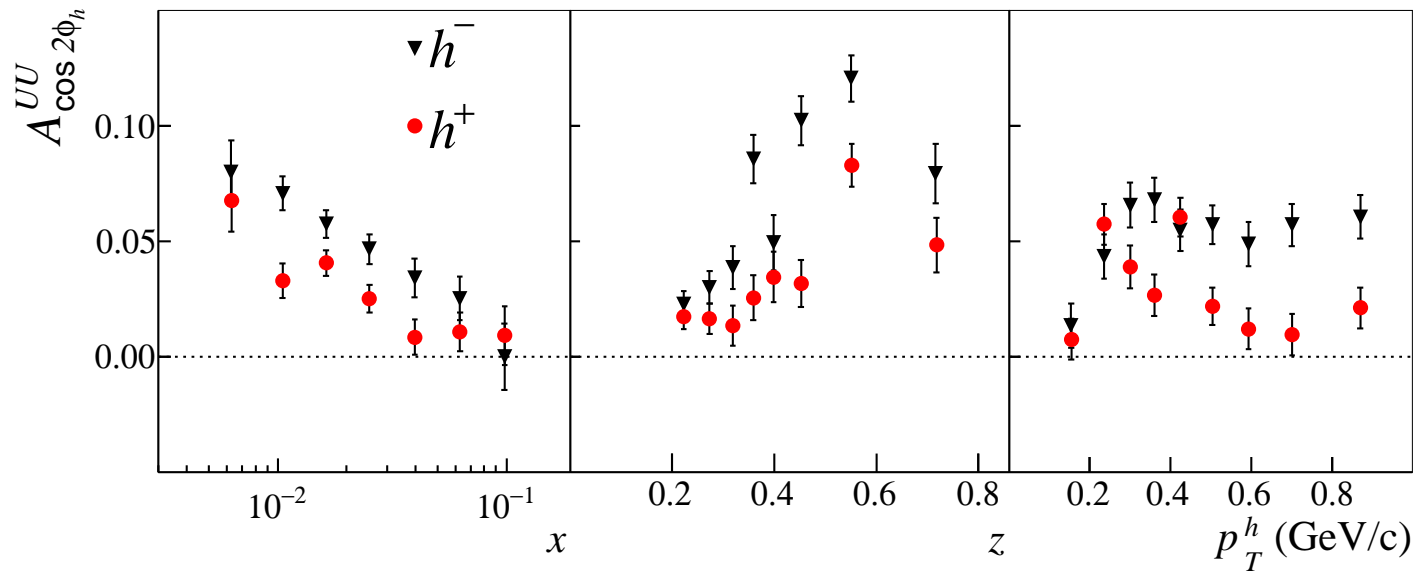
Strong effect with z, mainly at low x and p_T.

SIDIS and DY @ COMPASS

The COMPASS polarized Drell-Yan measurement ($4 < M_{\mu\mu} < 9$ GeV/c^2) has an overlapping region with the SIDIS measurement.

$\hookrightarrow$ Unique opportunity to access TMDs also via DY, with the same spectrometer.

Flavor dependent EMC effect

EMC effect: modification of the quark distributions in nuclei.

Different models try to explain it, some predict a flavor dependence.
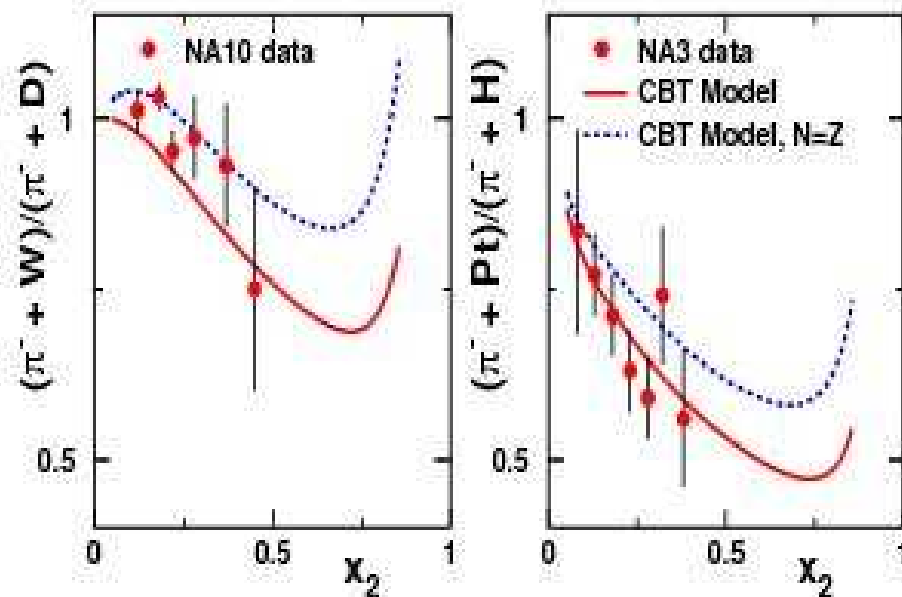
D. Dutta, Phys.Rev.C 83, 042201 (2011)

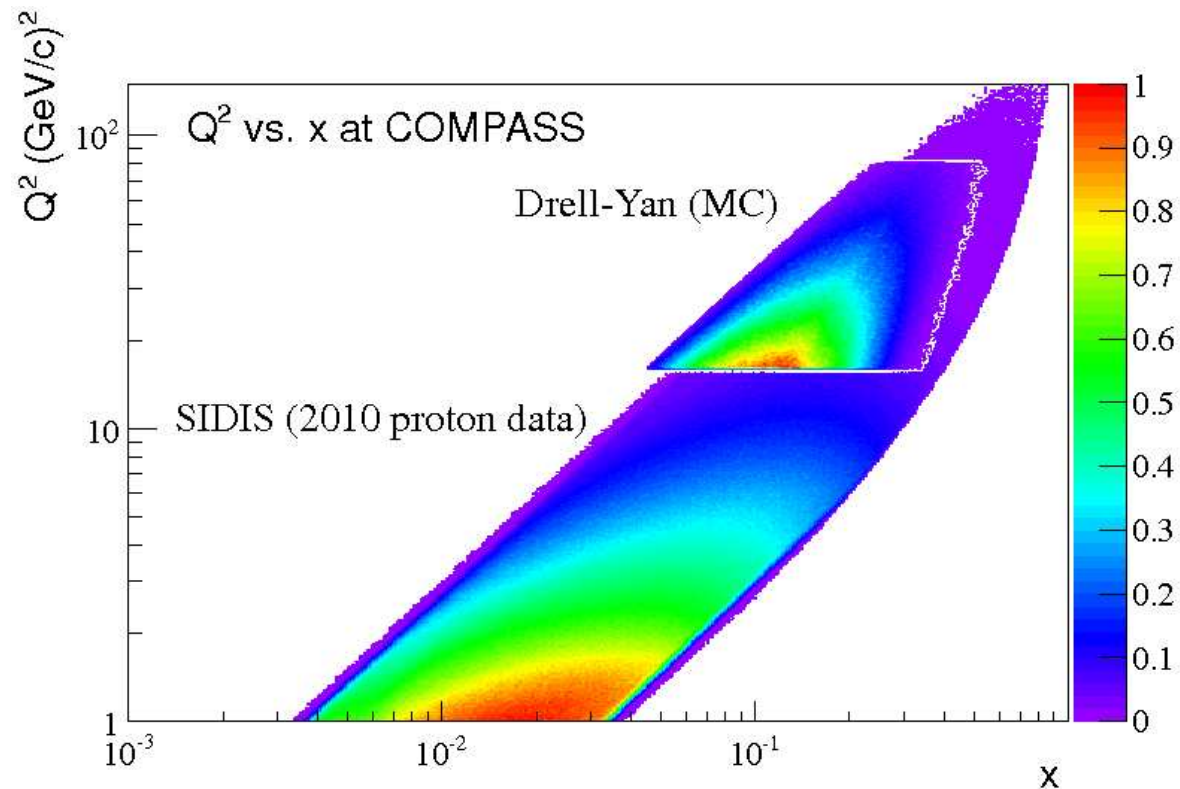Past experiment results could not clarify the preference or not for flavor dependent nuclear PDFs (here, CBT model).

COMPASS can measure the pion-induced unpolarized Drell-Yan cross-section ratios:

$$\frac{\sigma^{DY}(\pi^- + A)}{\sigma^{DY}(\pi^- + D)} \approx \frac{u_A}{u_D} \qquad \frac{\sigma^{DY}(\pi^- + A)}{\sigma^{DY}(\pi^- + p)} \approx \frac{u_A}{u_p}$$

$\hookrightarrow$ Sensitive to the EMC effect and its flavor dependence.

COMPASS Drell-Yan setup

Absorber + beam plug

Polarized target: NH$_3$

π^- beam @190 GeV/c

Target spin reversal every few days

1000

±180 mrad
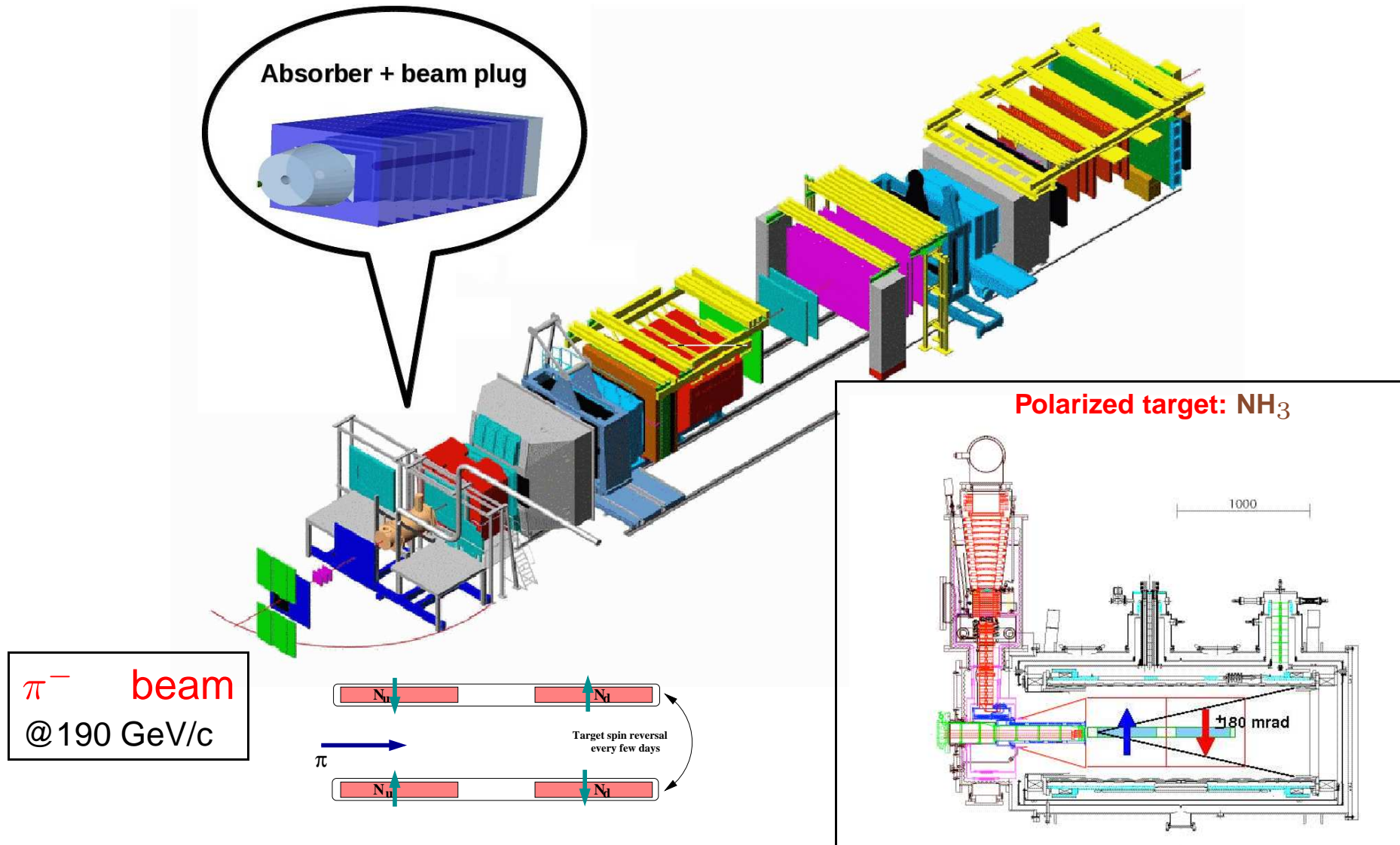
Feasibility of the measurement

In 2009, a 3 days beam test was performed using a π^- beam with 190 GeV/c on a polyethylene target. A hadron absorber (concrete $+$ steel) and W beam plug were placed downstream of target. A dimuon trigger based on calorimeter signals was used.

J/ψ = 6787 $\pm$ 109

M = 3.042 $\pm$ 0.004 GeV/c^2

σ_M = 0.217 $\pm$ 0.003 GeV/c^2
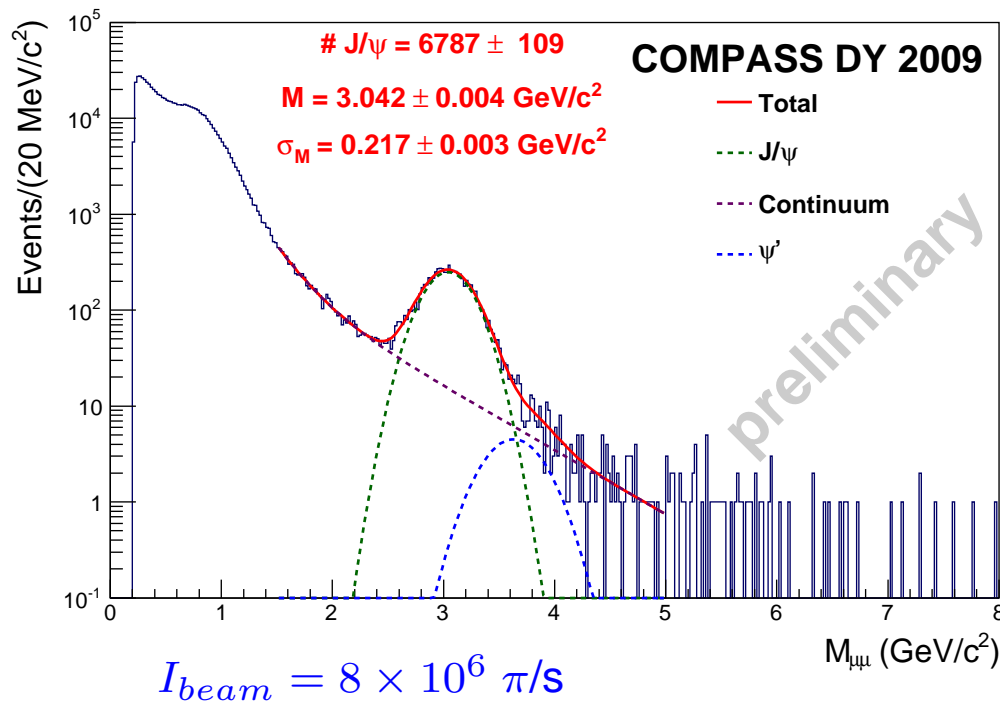
COMPASS DY 2009

— Total
---- J/ψ
---- Continuum
---- ψ'

preliminary

$I_{beam} = 8 \times 10^6 \ \pi$/s

- #J/ψ in agreement with expected (low trigger efficiency, non-optimal reconstruction efficiency).

- Mass resolution and pole of J/ψ in agreement with expectation – validation of MC.

- Hadron absorber keeps combinatorial background under control (at beam intensity lower than nominal by factor 10).

The future measurement will use a very different dimuon trigger, based on hodoscope signals: much faster, with target-pointing capability, and much better purity.

Feasibility of the measurement

COMPASS DY 2009

$M_{\mu\mu} > 2.5$ GeV/c^2

preliminary
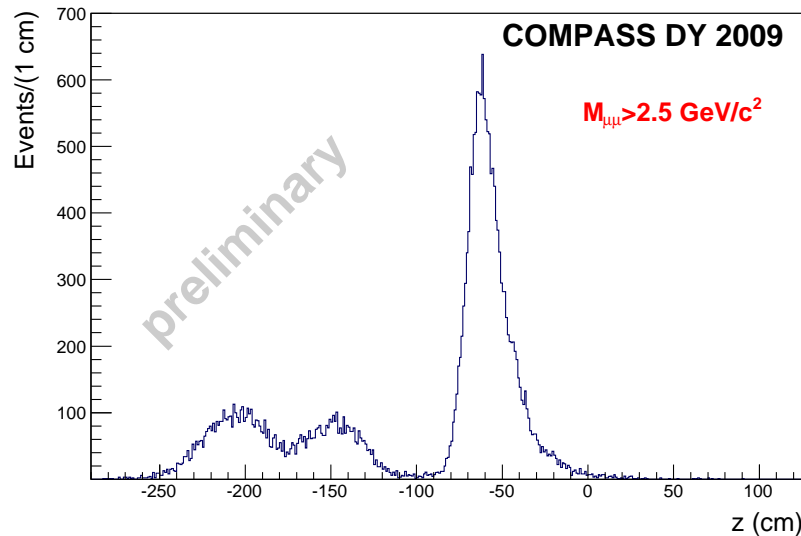
The vertex distribution from 2009 clearly shows the dimuon events originated in each of the target cells, as well as those produced in the tungsten beam plug.

The separation between the target cells which are oppositely polarized is very important.

↪ This year an optimized hadron absorber (Al_2O_3) will be used.

↪ A vertex detector will be placed in the middle.
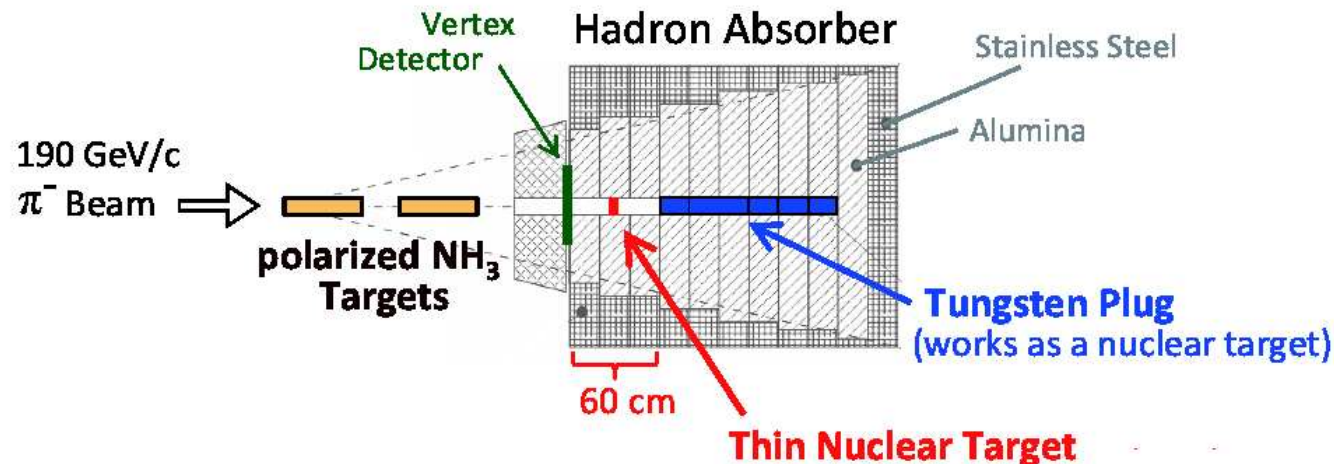
Timeline

The COMPASS Drell-Yan measurement will start in October this year, and continue during the whole 2015 Run.

- Hadron absorber and beam plug installation.

- NH_3 polarized target: transverse polarization, spin rotation every few days/hours.

- Possibility to use a thin nuclear target, in addition to the tungsten plug (unpolarized targets downstream of the polarized one, will intercept 60% of the pion beam).

- scintillating fibers vertex detector, placed in the middle of hadron absorber.

- Hodoscope based dimuon trigger system.
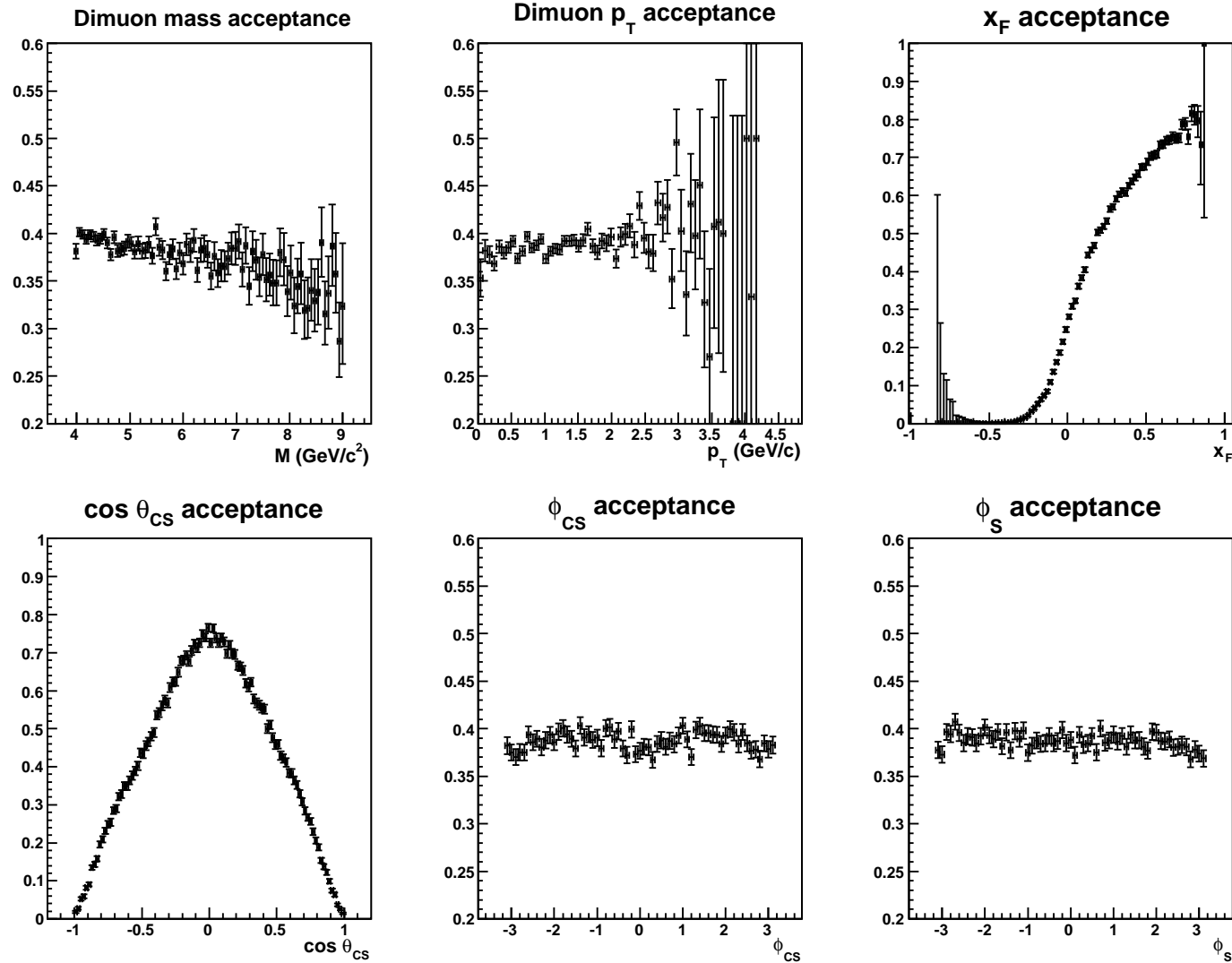
COMPASS may continue the Drell-Yan program, by making

- (un-)polarized Drell-Yan measurements with ^{6}LiD target;

- unpolarized Drell-Yan measurements with liquid hydrogen long target

- ...

This could happen after the 2018 SPS/LHC shutdown at CERN.

$\longrightarrow$ not approved yet.

Acceptance

The global geometrical acceptance of DY dimuons with $4 < M < 9$ GeV/c^2 is 39%.

Event rates and asymmetry uncertainties

The COMPASS beam availability will be better than foreseen, thanks to a shorter SPS-supercycle. Also the increase in beam intensity contributes to higher event rates. The expected events rate for Drell-Yan with masses $4 < M_{\mu\mu} < 9$ GeV/c^2 is now:

- With a beam intensity of $I_{beam} = 10^8$ particles/second, and 9.6s of beam every 34 seconds, one expects 2000/day.
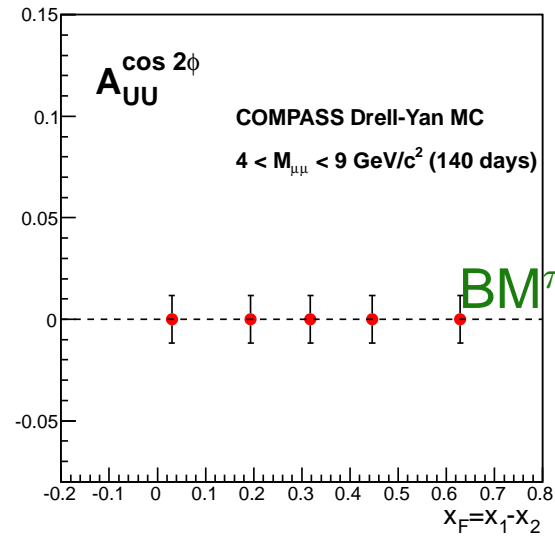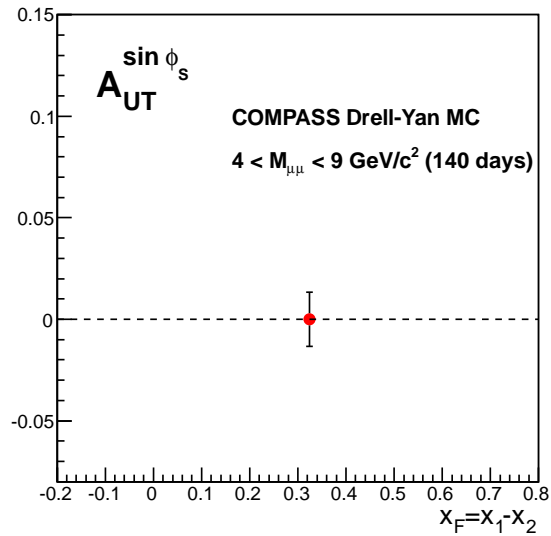
- In 140 days, 285 000 events.

The expected statistical errors in the asymmetries, with 140 days of data collection, are:

Asymmetry uncertainties	Dimuon mass (GeV/c^2) $4 < M_{\mu\mu} < 9$
$\delta A_U^{\cos 2\phi}$	0.005
$\delta A_T^{\sin \phi_S}$	0.013
$\delta A_T^{\sin(2\phi+\phi_S)}$	0.027
$\delta A_T^{\sin(2\phi-\phi_S)}$	0.027

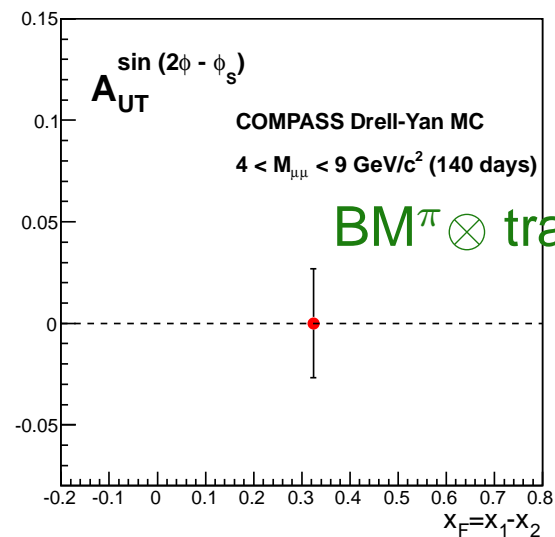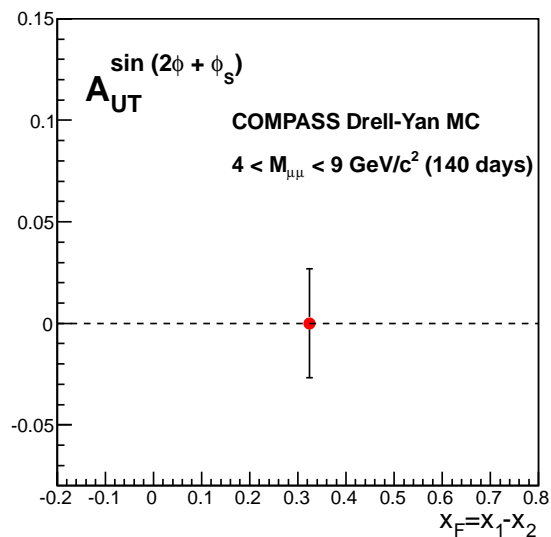$\hookrightarrow$ Possibility to study the asymmetries in several x_F or p_T bins.

Azimuthal asymmetry uncertainties

$f_1^\pi \otimes \text{Sivers}^p$

$A_{UT}^{\sin \phi_S}$

COMPASS Drell-Yan MC

$4 < M_{\mu\mu} < 9$ GeV/c^2 (140 days)

$x_F = x_1 - x_2$

$A_{UU}^{\cos 2\phi}$

COMPASS Drell-Yan MC

$4 < M_{\mu\mu} < 9$ GeV/c^2 (140 days)

$BM^\pi \otimes BM^p$

$x_F = x_1 - x_2$

$BM^\pi \otimes \text{pretzel.}^p$

$A_{UT}^{\sin (2\phi + \phi_S)}$

COMPASS Drell-Yan MC

$4 < M_{\mu\mu} < 9$ GeV/c^2 (140 days)

$x_F = x_1 - x_2$

$A_{UT}^{\sin (2\phi - \phi_S)}$

COMPASS Drell-Yan MC

$4 < M_{\mu\mu} < 9$ GeV/c^2 (140 days)

$BM^\pi \otimes \text{transv.}^p$

$x_F = x_1 - x_2$

To conclude

- COMPASS polarized Drell-Yan measurement will start in October 2014. Physics data taking will continue during 2015 (full beam time).

- Simultaneous extraction of all relevant azimuthal asymmetries from the polarized Drell-Yan data in the mass region $4 < M_{\mu\mu} < 9$ GeV/c^2.

- After 1 year of data-taking: expected statistical error in the Sivers asymmetry $\approx$1%.

- Unpolarized Drell-Yan on nuclear targets measured in parallel, for studies on the flavor dependence of EMC effect.

- A second year of DY data-taking is planned, possibly in 2018 – still to be approved.

The COMPASS measurements will contribute to the common effort of extracting the TMD PDFs, namely Sivers, Boer-Mulders, pretzelosity and transversity PDF.

SPARE: Boer-Mulders with flavor separation

Drell-Yan with π^- beam on proton target: u-quark dominance.

Drell-Yan with π^- beam on deuteron target: access to the quark Boer-Mulders functions in the neutron, that relate to those in the proton:

$$h_{1u/n}^{\perp} = h_{1d/p}^{\perp} \qquad\qquad h_{1d/n}^{\perp} = h_{1u/p}^{\perp}$$

$\hookrightarrow$ Comparing the $\cos 2\phi$ angular dependent unpolarized DY cross-sections from $\pi^- p$ and $\pi^- D$ collisions one can access the ratio:
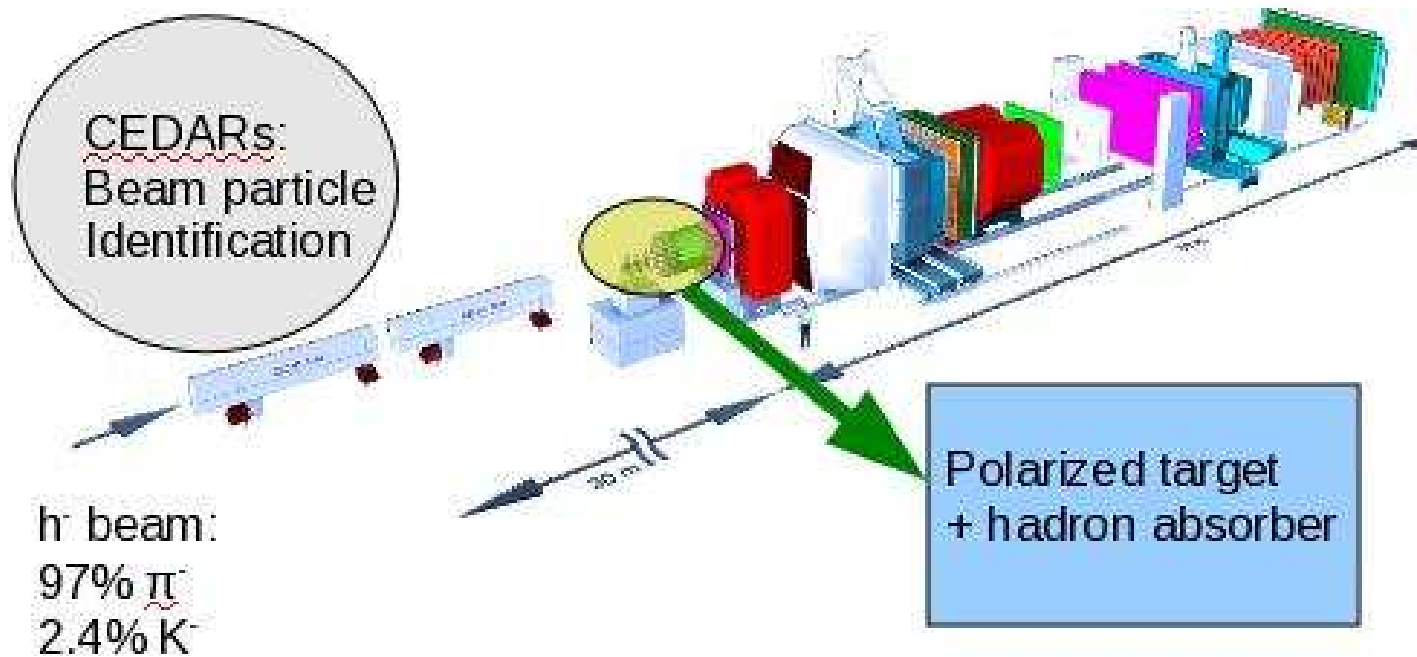
$$h_{1}^{\perp,d}/h_{1}^{\perp,u}$$

in the valence quark region.

SPARE: Kaon TMD PDFs

The COMPASS negative hadron beam contains a small percentage ($\approx 2.4\%$) of kaons mixed.

The use of 2 CEDAR detectors in the beamline allows to tag the kaon beam interactions.

CEDARs:
Beam particle
Identification

h⁻ beam:
97% π^-
2.4% K^-

Polarized target
+ hadron absorber

$\hookrightarrow$ COMPASS has the possibility to access for the first time the kaon TMD PDFs – done in parallel with the other measurements.

SPARE: J/ψ studies

Large statistics on J/ψ will be collected, since the cross-section is larger than the DY@4 - 9 GeV/c^2 by a factor $\approx$50.

Interesting physics topic in itself:

- Cross-section measurement with accuracy better than 10%

- Production mechanism – expect both gluon-gluon and quark-antiquark annihilation
  $\hookrightarrow$ J/ψ from gluon-gluon fusion: valuable tool to access the gluon Sivers TMD;
  $\hookrightarrow$ J/ψ from quark-antiquark annihilation: duality with DY – access quark TMDs.

- J/ψ polarization – not much known, in this energy regime.

SPARE: Predictions for DY@COMPASS Sivers asymmetry

Some recent predictions for the COMPASS DY Sivers asymmetry:
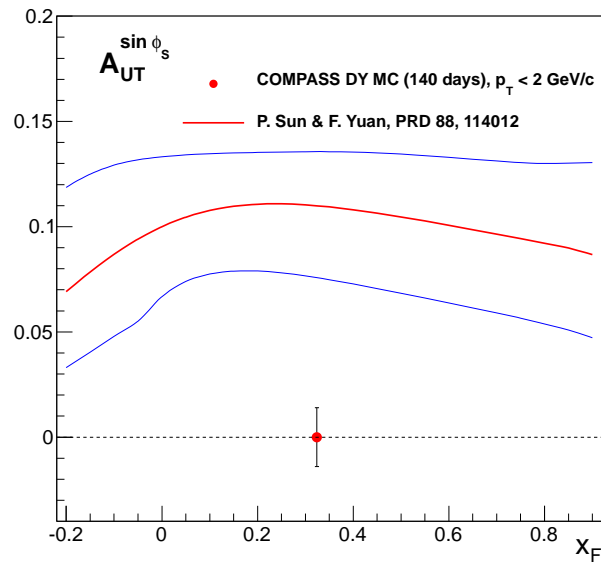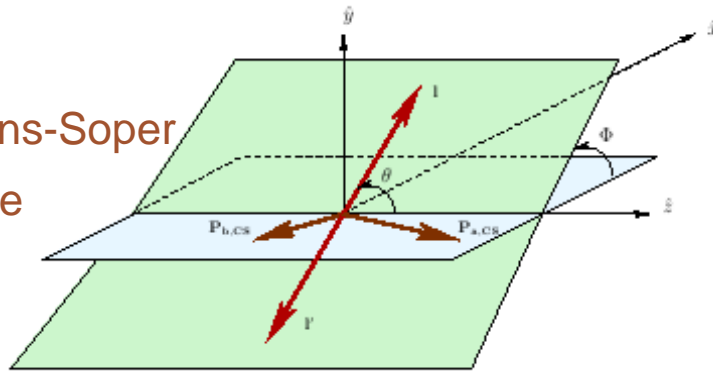

P. Sun and F. Yuan, PRD 88, 114012
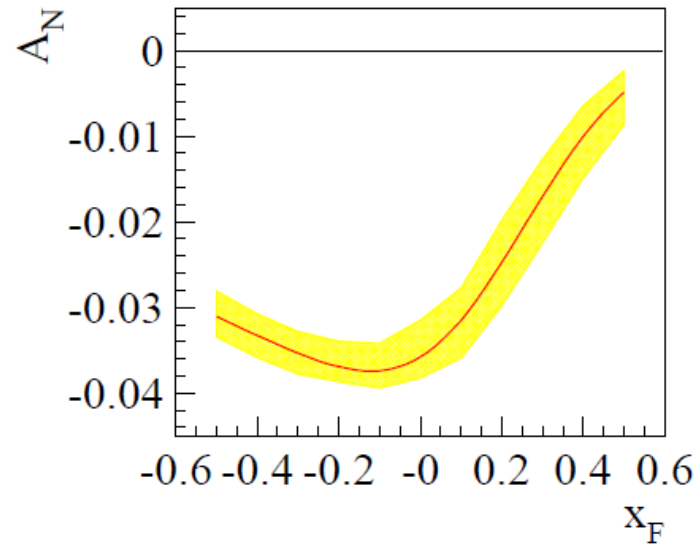
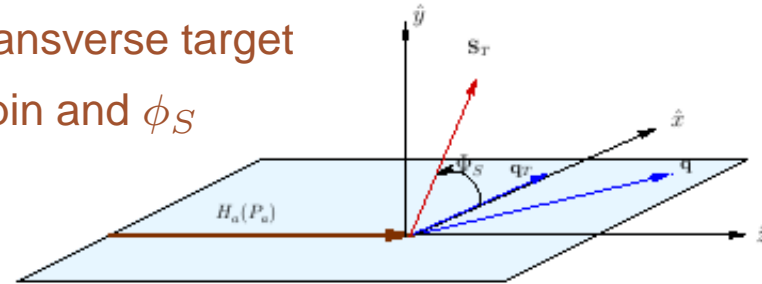Echevarria et al, arXiv: 1401.5078

Note: $x_F = x_p - x_\pi$
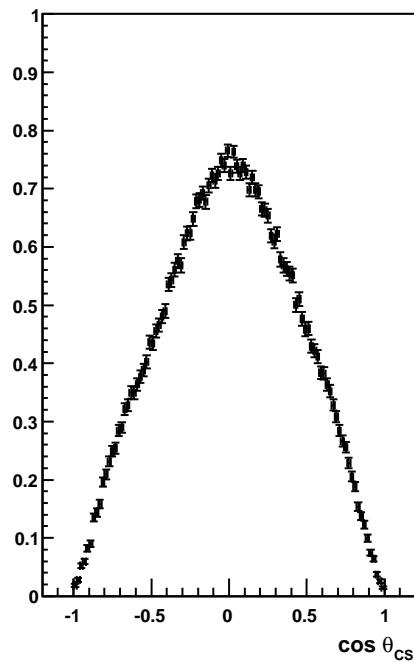negative asymmetry due to frame convention

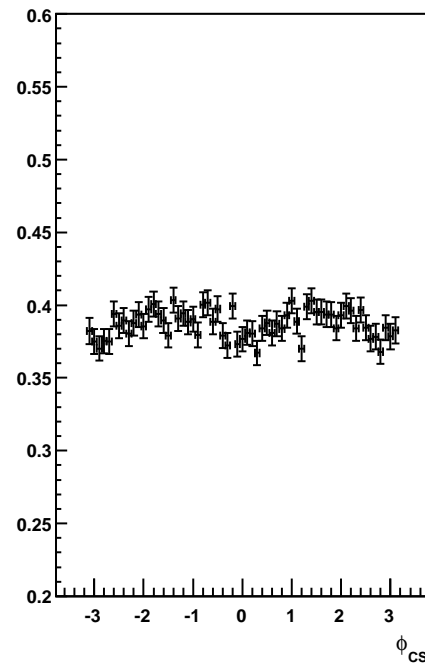# SPARE: DY Angular acceptances

Collins-Soper frame

Transverse target spin and ϕ_S

cos θ_{cs} acceptance

ϕ_{cs} acceptance

ϕ_S acceptance