Sivers Asymmetries in Polarized Drell-Yan Production of Muon Pairs at COMPASS

IhnJea Choi
University of Illinois at Urbana-Champaign
For the COMPASS collaboration

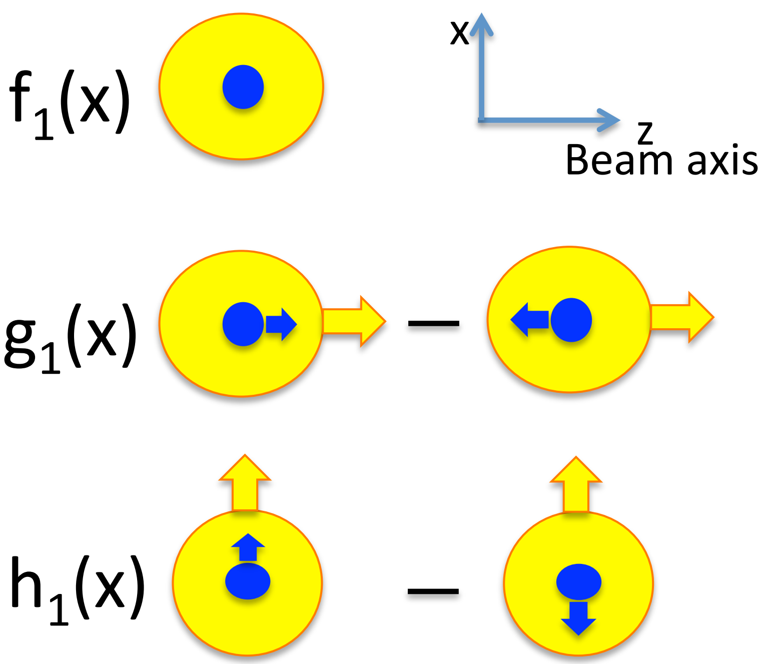
Forward Physics at RHIC (2012)

Outline

- TMD PDFs
- Transverse Polarized Drell-Yan process
- Sivers, Boer Mulders functions from DIS and SIDIS
- DY at COMPASS- acceptance
- DY at COMPASS- feasibility
- Sensitivity projections
- Summary

Quark Structure of Nucleon

At leading twist, spin structure of the nucleon is completely described by 3 independent structure functions

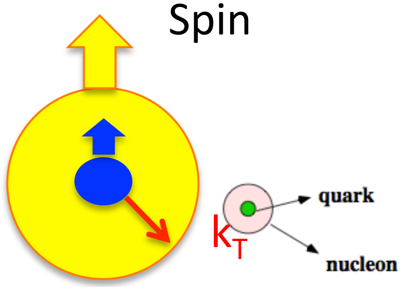


Unpolarized structure function

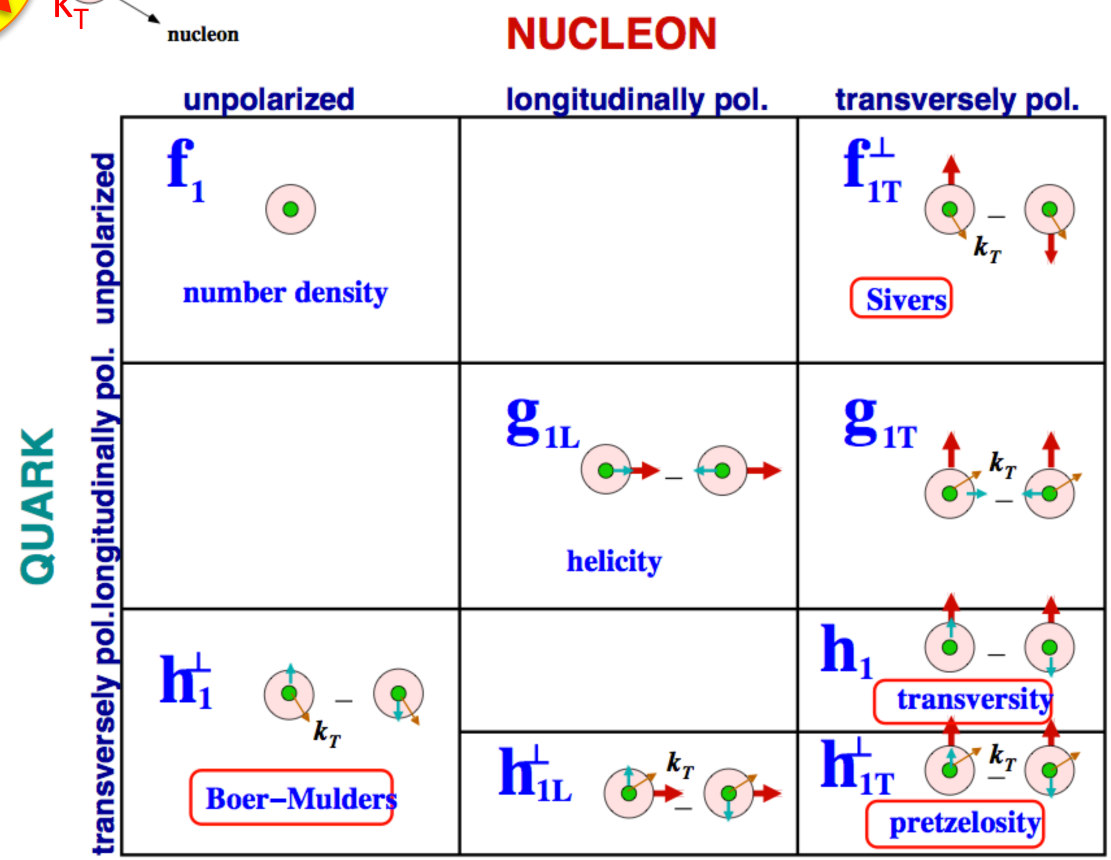
Helicity structure function

Transversity distribution function

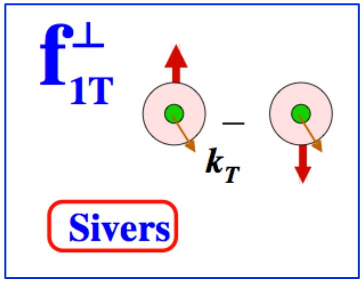
Transvers Momentum Dependent (TMD) PDFs



Non-zero quark transvers momentum k_T,
3 independent PDFs(x) ➔ **8 independent PDFs(x,k_T)**

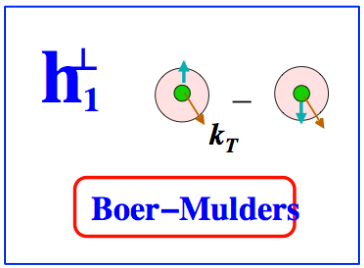


Sivers, Boer-Mulders, Transversity Distributions



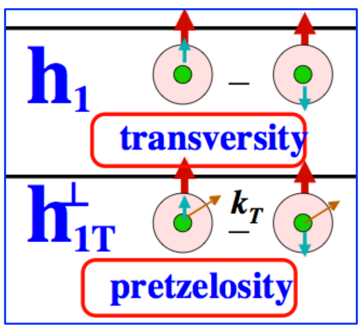
Sivers Function

Influence of the transverse spin of hadron onto their quark transverse momentum distribution



Boer-Mulders Function

Correlation between transverse spin and transverse momentum of the quark in unpolarized nucleon



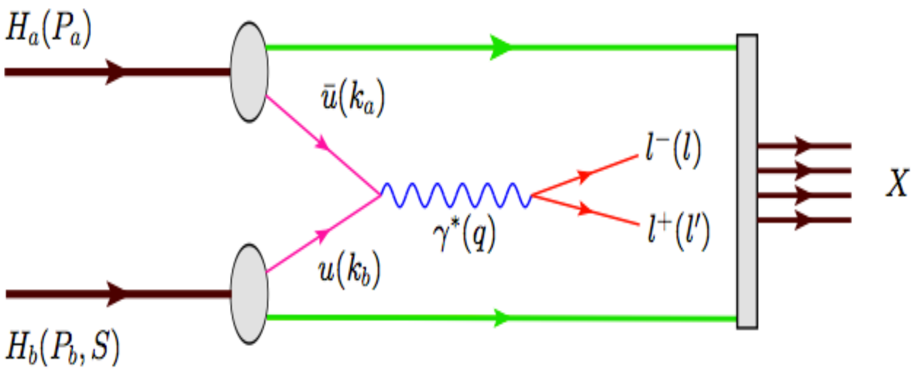
Pretzelosity

Probability to find a quark with Momentum x, k_T and transverse spin s_q in a proton with transverse spin S

Determination of Sivers-, Boer-Mulders-, and Transversity-distributions is very important to understand the partonic spin structure of hadron !

Drell-Yan Process

Drell-Yan process is an excellent tool to study tansversity and k_T-dependent PDFs
Quark and antiquark annihilation process. No fragmentation function
-> Clean signal to access initial parton structure



Arnold, Metz and sion Phys. Rev. D79 (2009) 034005

$$H_a(P_a) + H_b(P_b) \rightarrow \gamma^*(q) + X \rightarrow l^-(l) + l^+(l^-)$$

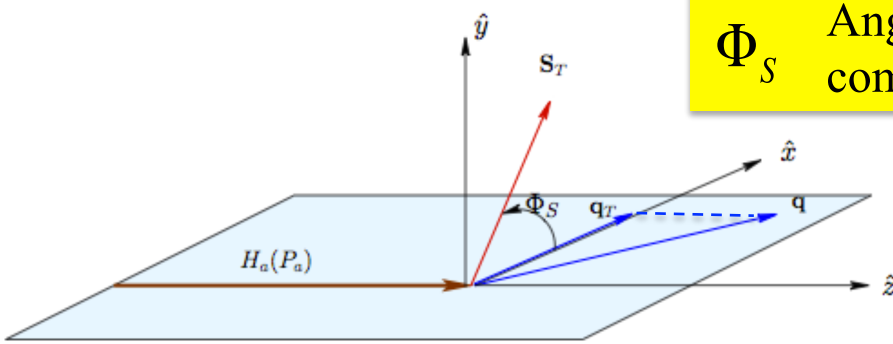
P_a Hadron Beam momentum
P_b = 0, (fixed target)
ι Lepton momenta
S target polarization

If the quarks intrinsic transverse momentum ≠ 0,
The dilepton has also $q_T = k_{Ta} + k_{Tb}$

s	$= (P_a + P_b)^2,$	the total centre-of-mass energy squared,
$x_{a(b)}$	$= q^2/(2P_{a(b)} \cdot q),$	the momentum fraction carried by a parton from $H_{a(b)}$,
x_F	$= x_a - x_b,$	the Feynman variable,
$M^2_{\mu\mu}$	$= Q^2 = q^2 = s\ x_a\ x_b,$	the invariant mass squared of the dimuon.

Definition of azimuthal angles in DY

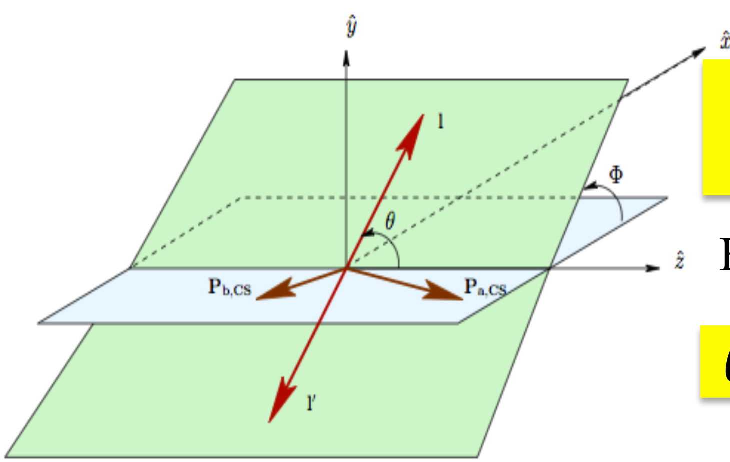
1) Target rest frame (TF)



Φ_S Angle between target spin(S_T) and transverse component of outgoing lepton pair momentum

Beam hadron

2) Rest frame of the virtual photon (CF : Collins-Soper frame)



Φ Angle between planes defined by hadron and lepton momenta

Beam hadron

θ Polar angle of lepton pair in the CF frame

Pol. Drell-Yan cross section

DY cross section for transversely polarized nucleon target

$$\frac{d\sigma}{d^4q\,d\Omega} = \frac{\alpha_{em}^2}{F\,q^2}\hat{\sigma}_U\Big\{\Big(1 + D_{[\sin 2\theta]}\,A_U^{\cos\phi}\cos\phi + D_{[\sin^2\theta]}\,A_U^{\cos 2\phi}\cos 2\phi\Big)$$
$$+\; S_L\Big(D_{[\sin 2\theta]}\,A_L^{\sin\phi}\sin\phi + D_{[\sin^2\theta]}\,A_L^{\sin 2\phi}\sin 2\phi\Big)$$
$$+\; |\boldsymbol{S}_T|\Big[\Big(D_{[1]}\,A_T^{\sin\phi_S} + D_{[\cos^2\theta]}\,\tilde{A}_T^{\sin\phi_S}\Big)\sin\phi_S$$
$$+\; D_{[\sin 2\theta]}\Big(A_T^{\sin(\phi+\phi_S)}\sin(\phi+\phi_S) + A_T^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S)\Big)$$
$$+\; D_{[\sin^2\theta]}\Big(A_T^{\sin(2\phi+\phi_S)}\sin(2\phi+\phi_S) + A_T^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S)\Big)\Big]\Big\}$$

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

A. Kotzinian,
COMPASS Note 2010-2,
February 10, 2010,

F: Flux of incoming hadrons, $D_{[]}$ depolarisation factor

At LO QCD

$$\frac{d\sigma}{d^4q\,d\Omega} \overset{\text{LO}}{=} \frac{\alpha_{em}^2}{F\,q^2}\hat{\sigma}_U\Big\{\Big(1 + D_{[\sin^2\theta]}\,\boxed{A_U^{\cos 2\phi}}\cos 2\phi\Big)$$
$$+\; |\mathbf{S}_T|\Big[\boxed{A_T^{\sin\phi_S}}\sin\phi_S + D_{[\sin^2\theta]}\Big(\boxed{A_T^{\sin(2\phi+\phi_S)}}\sin(2\phi+\phi_S)$$
$$+\; \boxed{A_T^{\sin(2\phi-\phi_S)}}\sin(2\phi-\phi_S)\Big)\Big]\Big\},$$

DY Asymmetries

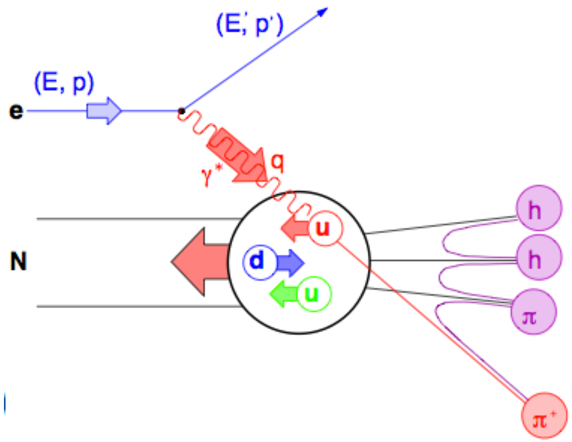
DY cross section

$$\frac{d\sigma}{d^4q\, d\Omega} \stackrel{\text{LO}}{=} \frac{\alpha_{em}^2}{F\, q^2} \hat{\sigma}_U \Big\{ \Big(1 + D_{[\sin^2\theta]} A_U^{\cos 2\phi} \cos 2\phi \Big) + |\mathbf{S}_T| \Big[A_T^{\sin\phi_S} \sin\phi_S + D_{[\sin^2\theta]} \Big(A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) + A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S) \Big) \Big] \Big\},$$

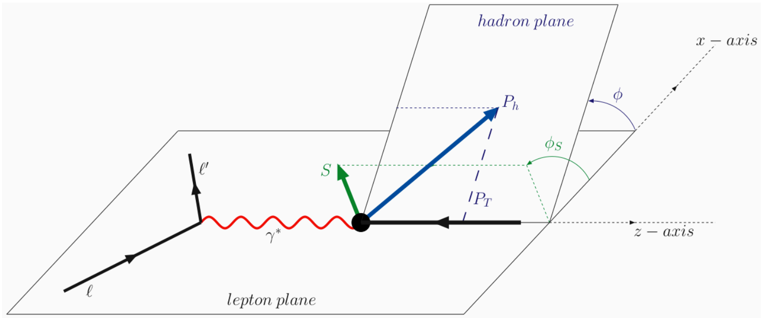
- $A_U^{\cos 2\phi}$ gives access to the Boer–Mulders functions of the incoming hadrons,
- $A_T^{\sin\phi_S}$ to the Sivers function of the target nucleon,
- $A_T^{\sin(2\phi+\phi_S)}$ to the Boer–Mulders function of the beam hadron and to $h_{1T}^{\perp}$, the pretzelosity function of the target nucleon,
- $A_T^{\sin(2\phi-\phi_S)}$ to the Boer–Mulders function of the beam hadron and h_1, the transversity function of the target nucleon.

All these asymmetries(modulations) are expected to be sizable in the valence quark range and can be measured at COMPASS !

Sivers in SIDIS



SIDIS Process



Definition of azimuthal angles
In SIDIS

Sivers from SIDIS $A_{UT}\sin(\phi - \phi_s)$

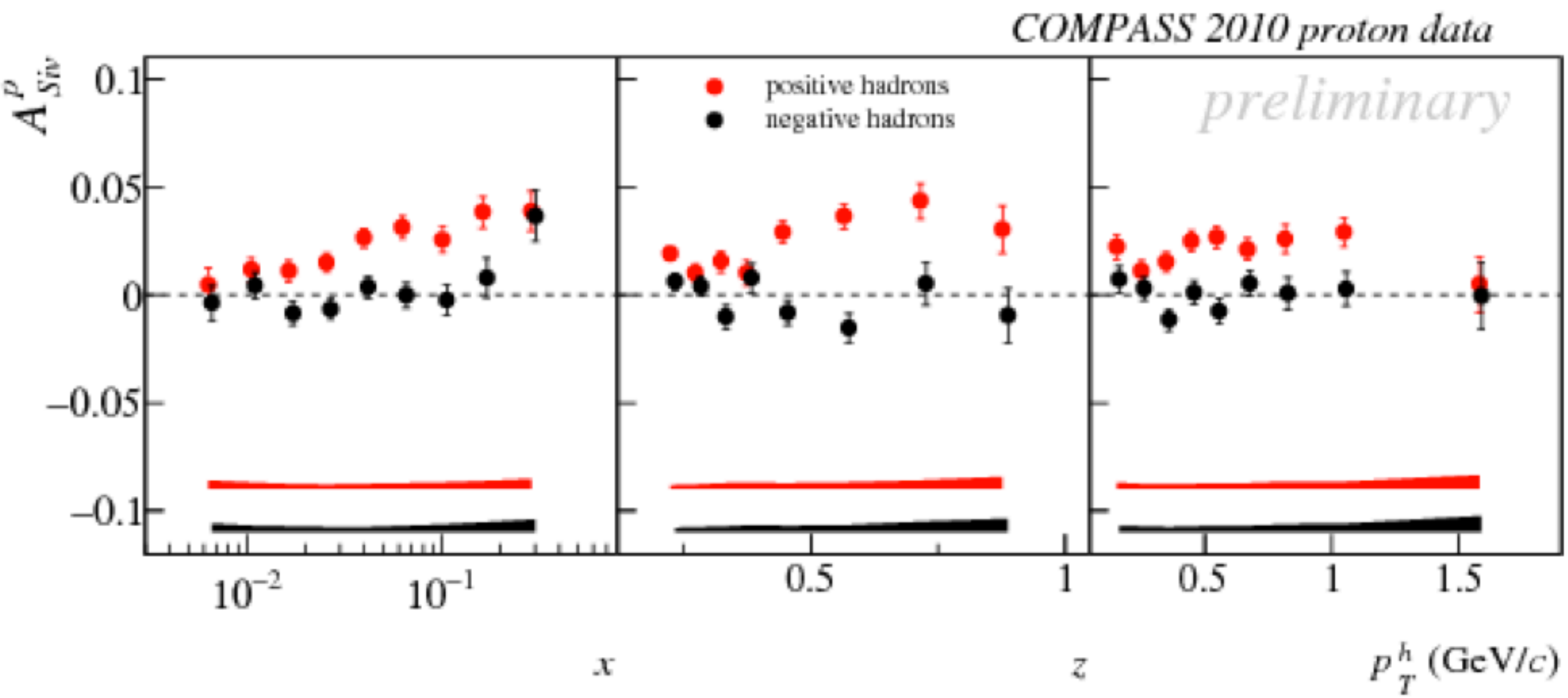
Lepton and produced hadron used a probe

access to quark k_T and transverse polarization

Convolution of PDFs and fragmentation function(FFs)

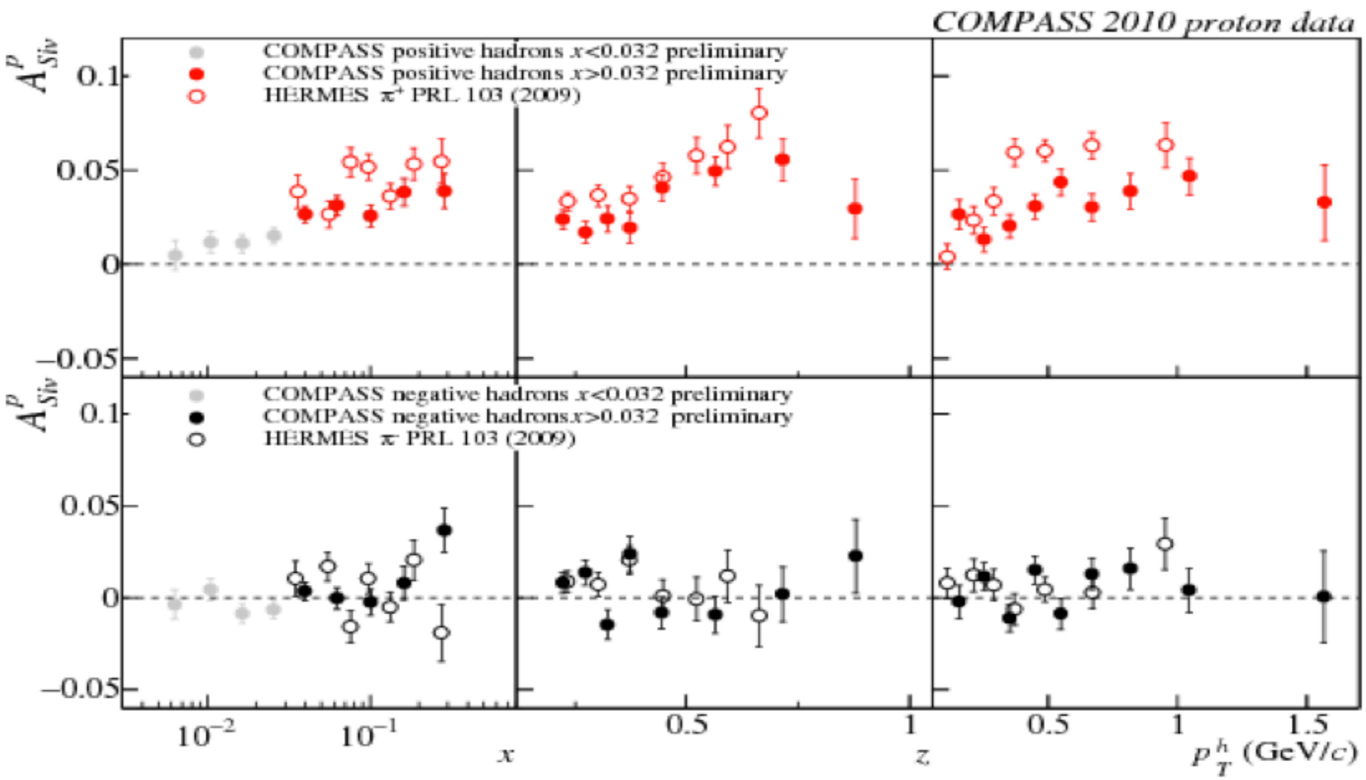
Sivers Asymmetries from SIDIS at COMPASS

A positive Sivers asymmetry for positive hadrons
An asymmetry compatible with zero for negative hadrons



Sivers measurement from SIDIS

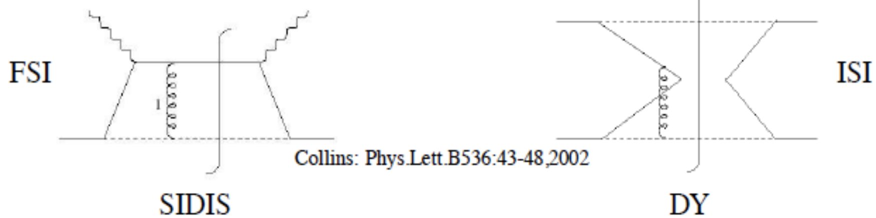
Sivers asymmetry measurement from HERMES and COMPSS experiments



Recent suggestions that difference may be due to TMD evolution: M. Aybat (2011), T. Rogers, A. Prokudin

Sign change of Sivers- and Boer-Mulders Functions between SIDIS and DY

SIDIS   DY



J.C. Collins, Phys. Lett. B536 (2002) 43

Direction of the gauge-link of k_T dependent PDFs is process-dependent and changes its sign between SIDIS and DY

Sivers $$f_{1T}^{\perp}(x, \mathbf{k}_T)\Big|_{SIDIS} = -f_{1T}^{\perp}(x, \mathbf{k}_T)\Big|_{DY}$$

Boer-Mulders $$h_1^{\perp}(x, \mathbf{k}_T)\Big|_{SIDIS} = -h_1^{\perp}(x, \mathbf{k}_T)\Big|_{DY}$$

Unknown !

Need to confirm sign reversal In Pol DY process !

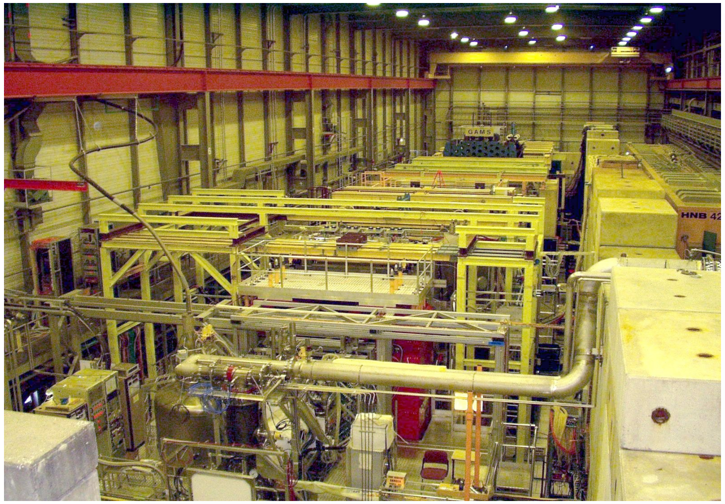
TEST universality of TMD and QCD in non-perturbative regime !

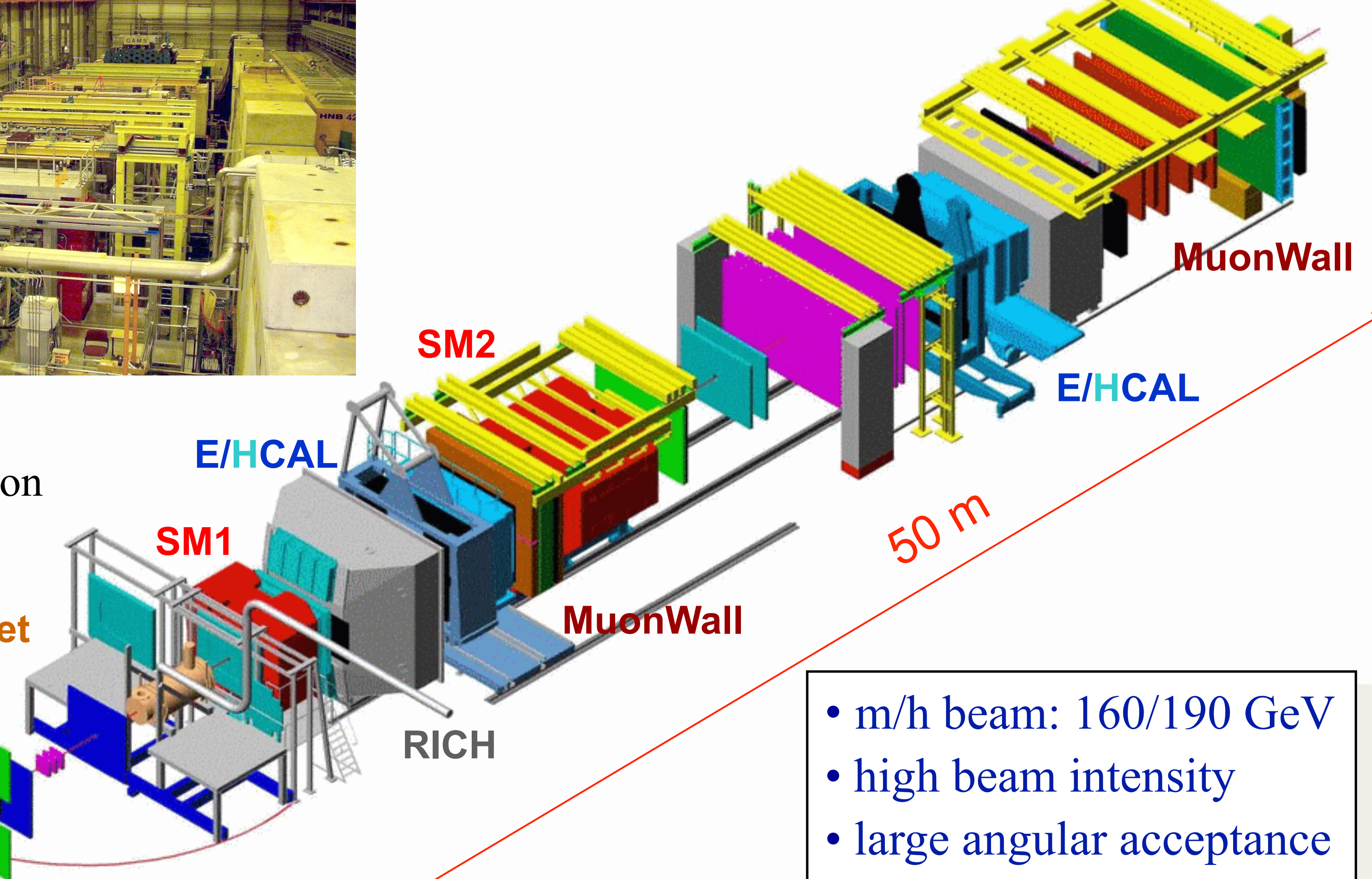
COMPASS

COmmon Muon Proton Apparatus for Structure and Spectroscopy

Fixed target experiment at CERN SPS beam line
Data taking since 2002
Muon and Baryon spectroscopy with high energy muon and hadron beam

The COMPASS Spectrometer



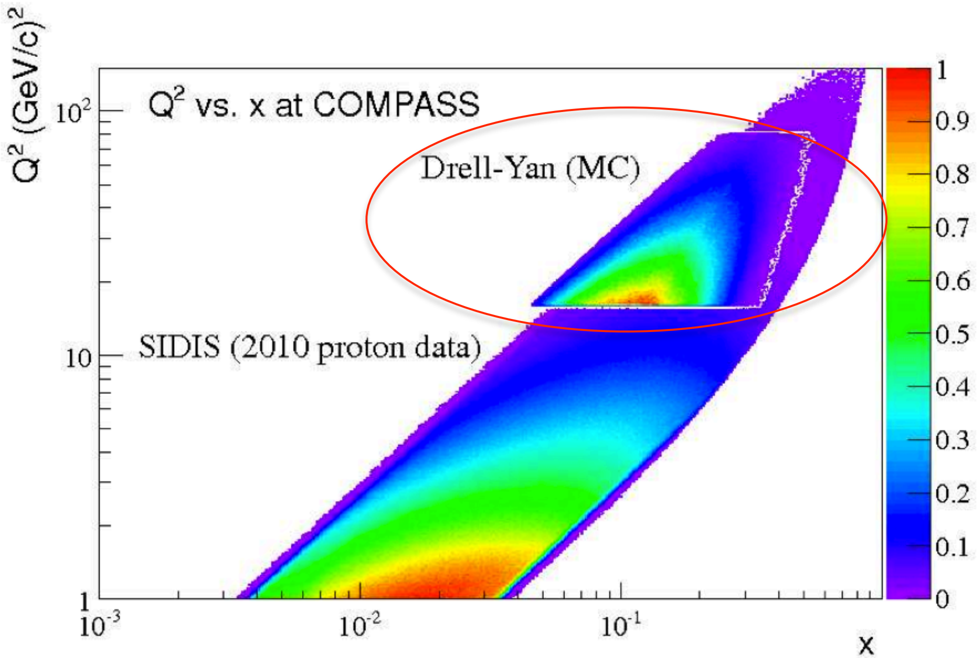


Secondary hadron beam from SPS

- m/h beam: 160/190 GeV
- high beam intensity
- large angular acceptance
- broad kinematical range

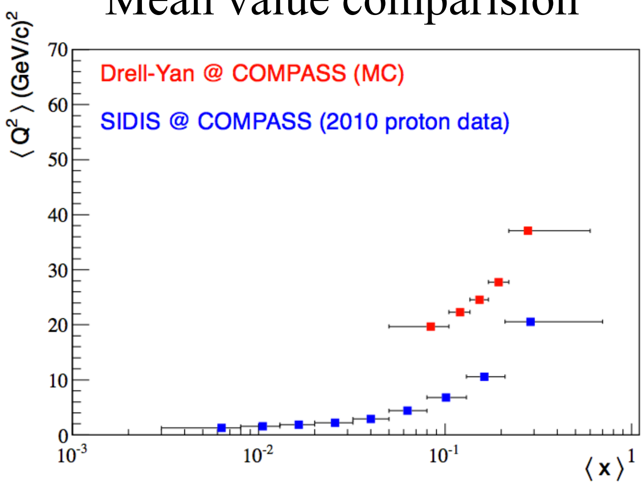
Two stage spectrometer in order to cover a large Kinematic range

SIDIS and DY kinematic



The COMPASS SIDIS and DY experimental measurements have an overlapping kinematic region.

Mean value comparision



There is overlap in the phase-space accessed by the 2 measurements.
when comparing the TMDs extracted,
the QCD evolution of the TMDs
must be properly taken into account.

π^- beam for Drell-Yan

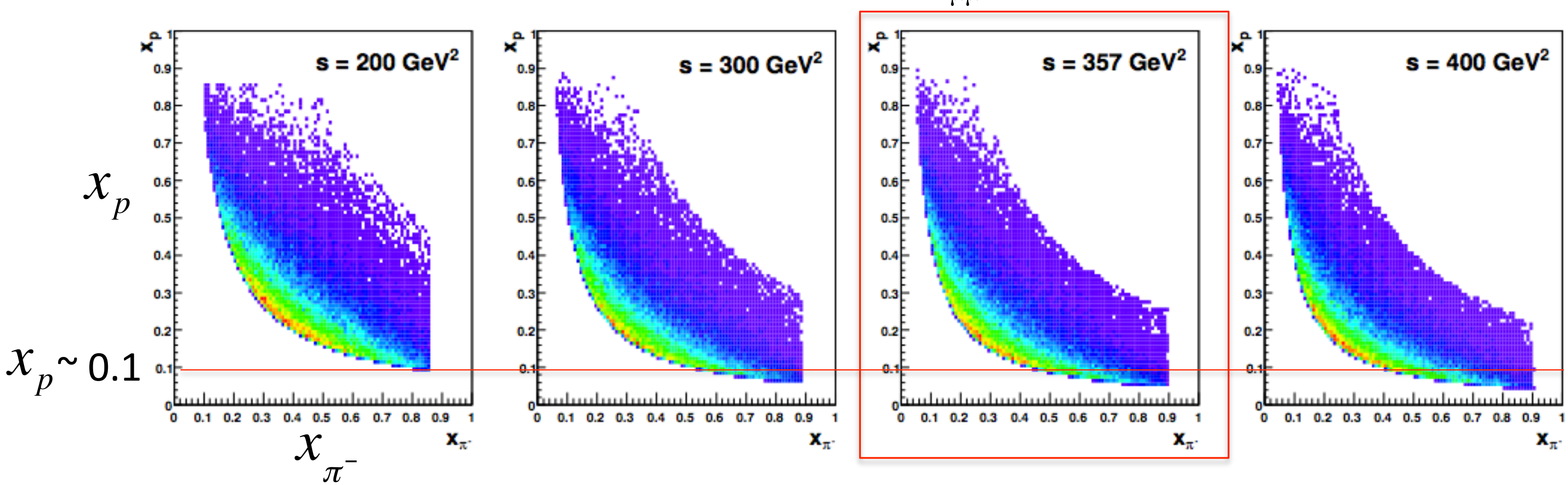
Choice of beam at COMPASS

$$\pi^-(\bar{u}d) + p\uparrow(uud) \rightarrow \ell^+\ell^- X$$

u-quark and anti-u quark dominant in Drell-Yan process

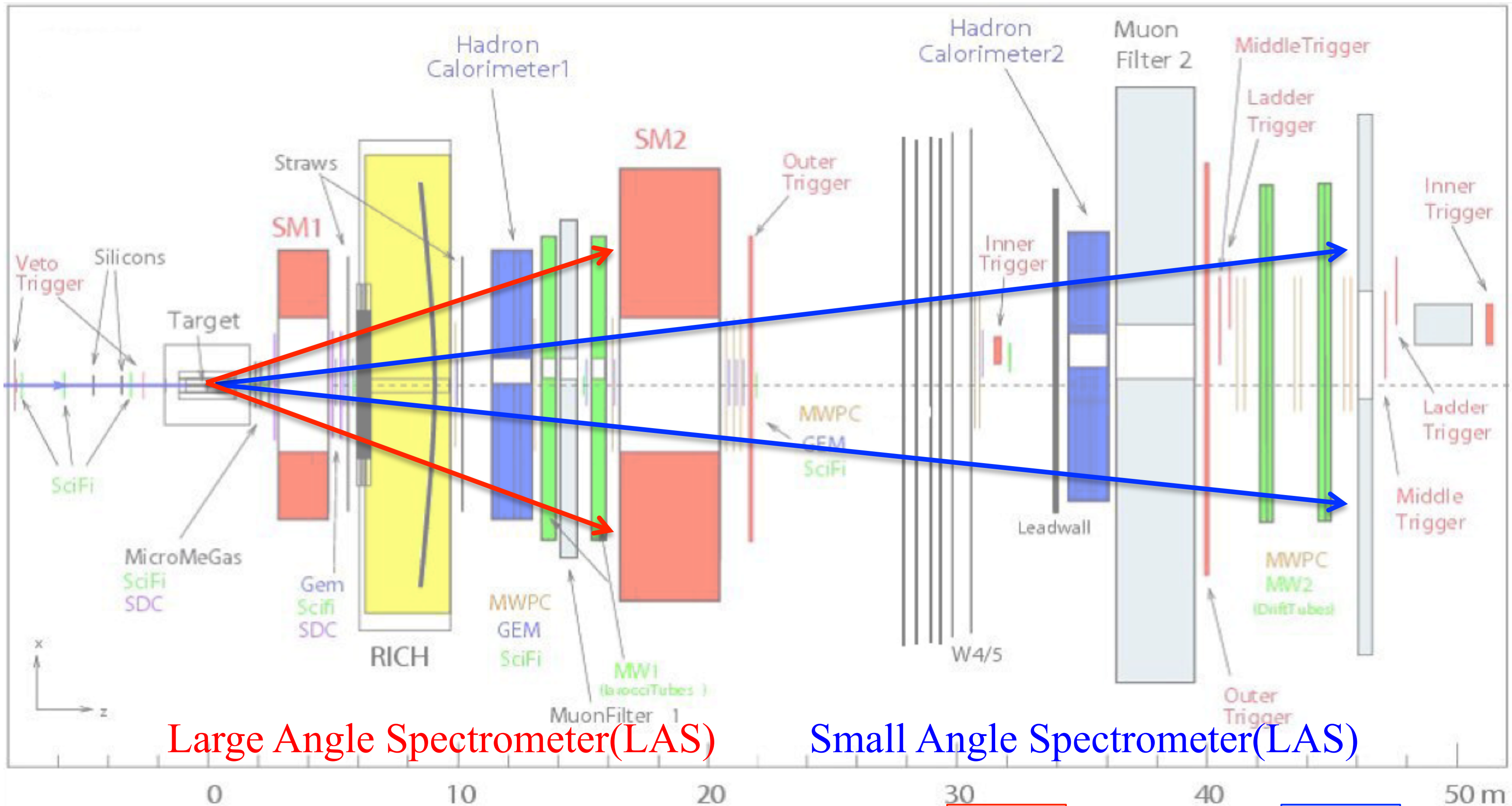
TMDs are sensitive at valence quark regime

Choice of beam energy PYTHIA, $4 < M_{\mu\mu} < 9$ GeV/c



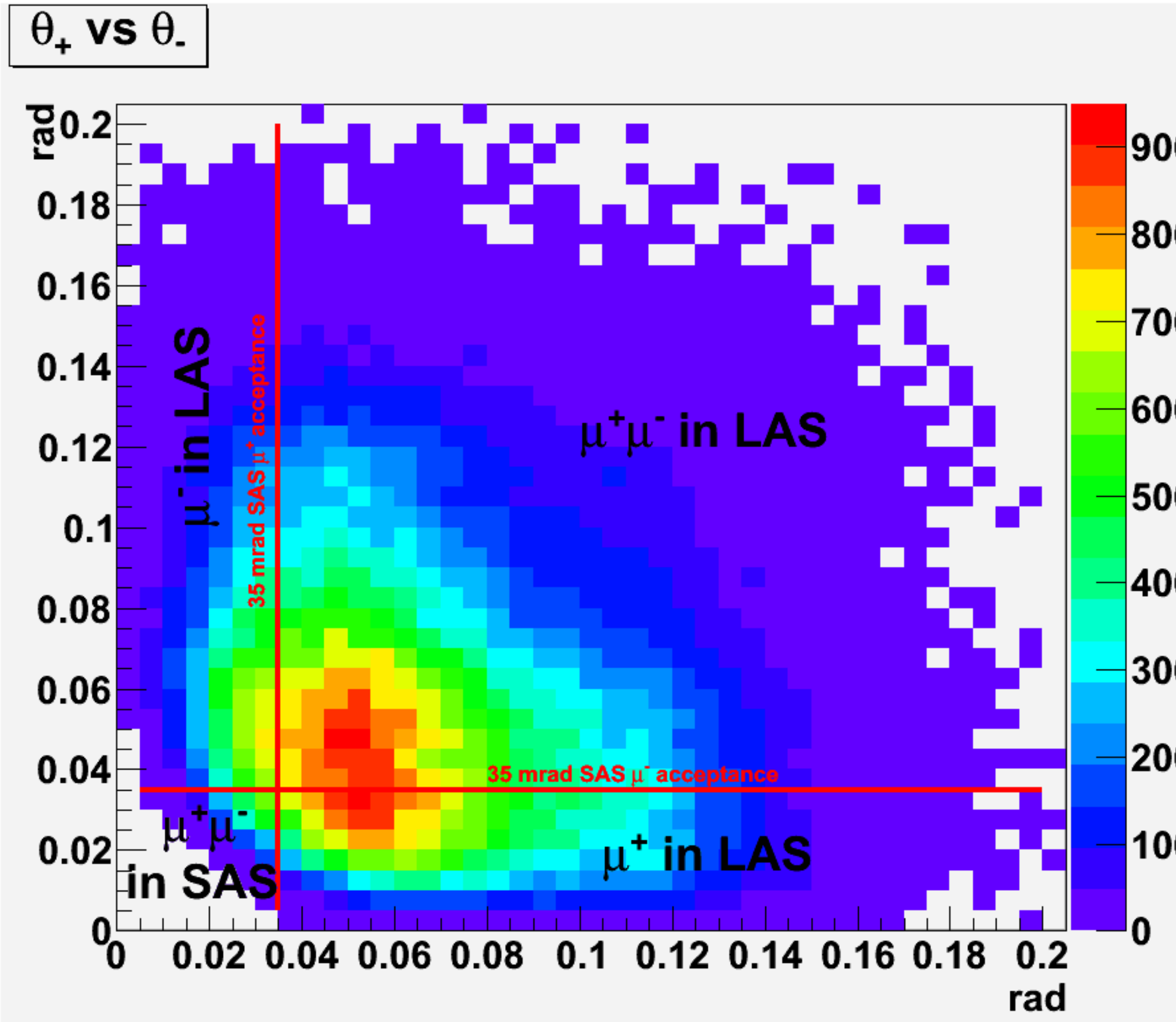
The value s = 357 GeV², corresponding to a pion beam momentum of 190 GeV/c, seems to be a good choice. -> As the energy increased, the phase space coverage extends to the low-x non-valence region

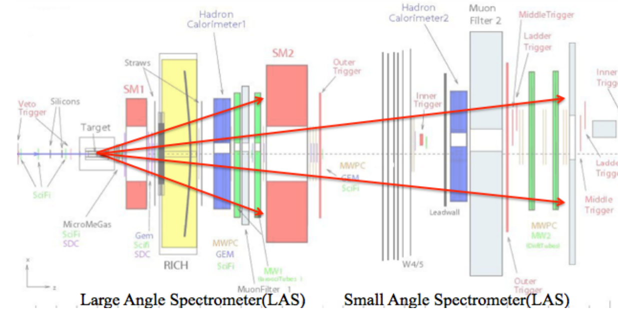
DY acceptance at COMPASS (I)



Mass range (GeV/c^2)	Average acceptance (%)	LAS	LAS+SAS	SAS
4–9	35	64	40	4
2–2.5	43	32	54	20

DY acceptance at Compass (II)

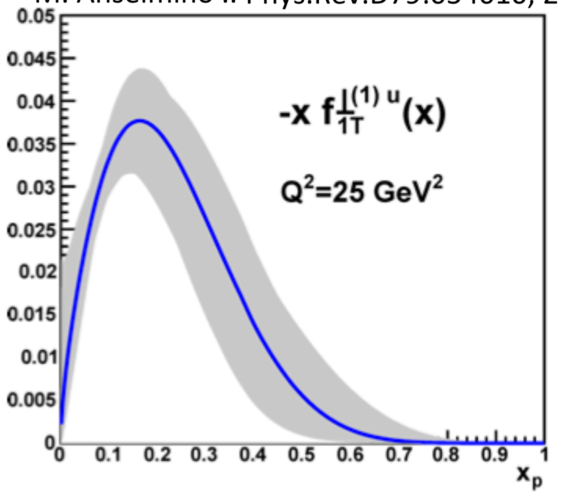


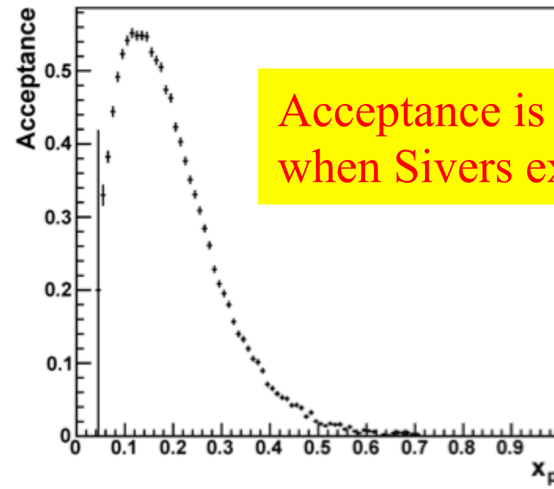


95% of all Drell-Yan muon pairs in the di-muon mass range $4<m<9$ GeV/c^2 have at least one muon in the LAS/LAT

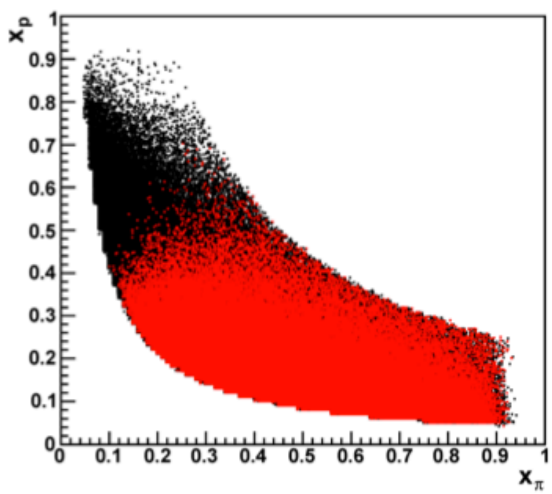
DY kinematics $4 < M_{uu} < 9$ GeV/c^2 at COMPASS

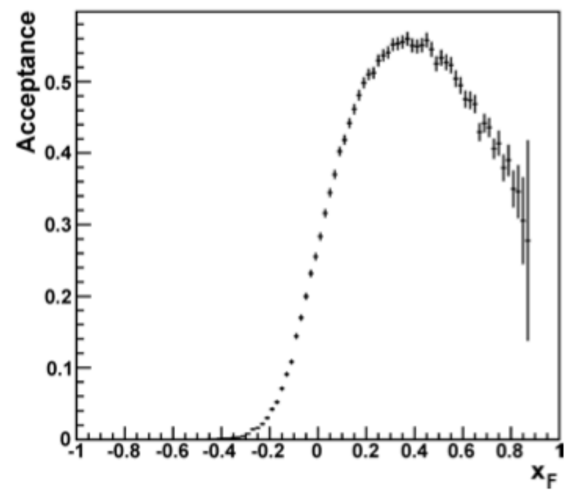
M. Anselmino .. Phys.Rev.D79:054010, 2009





Acceptance is largest
when Sivers expected to be largest

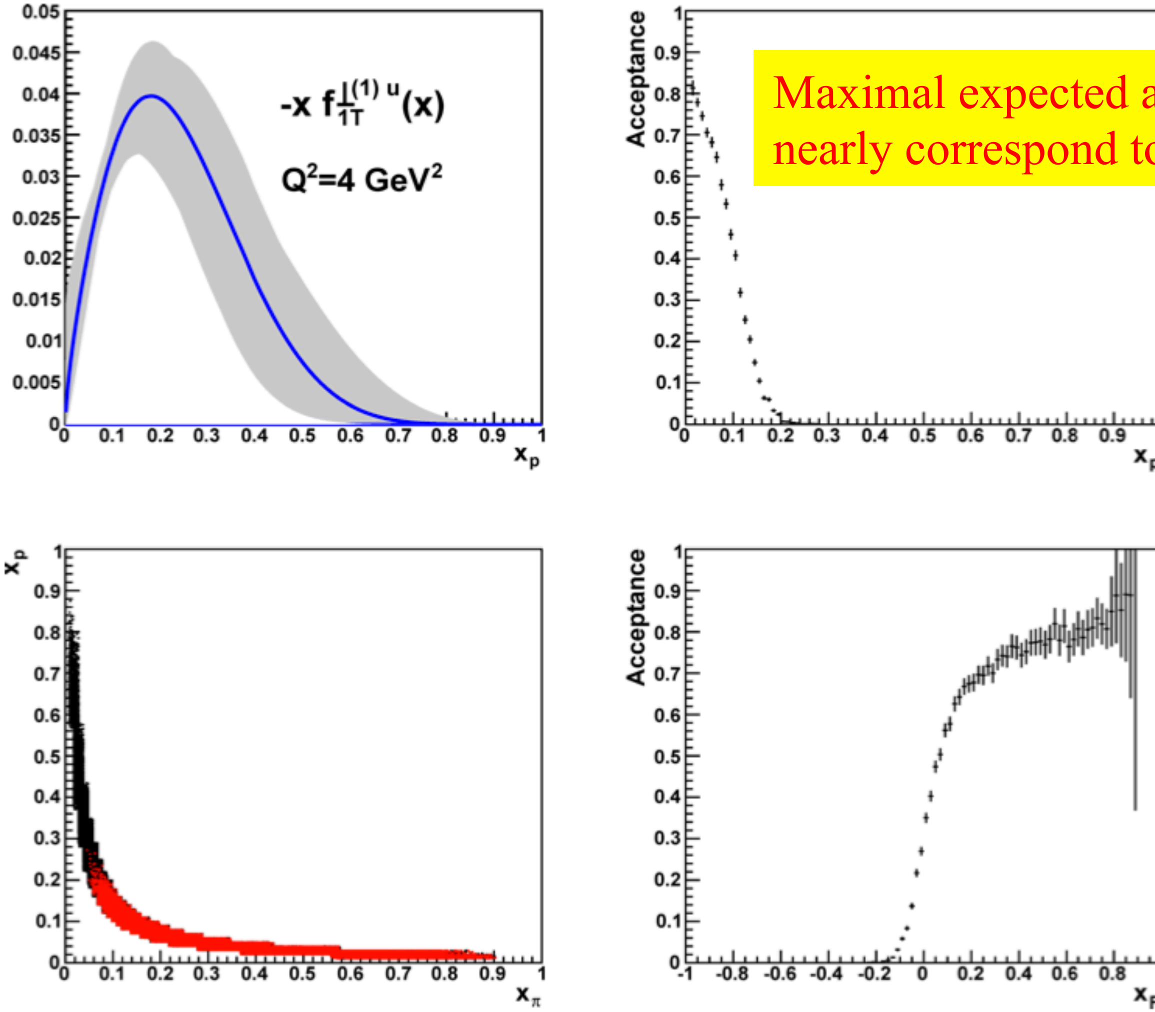




Valence range (x~> 0.1) for both quarks (pure u-ubar annihilation)
PT dimuon about 1GeV/c where TMD effects are dominant

DY kinematics $2 < M_{uu} < 2.5$ GeV/c^2 at COMPASS

M. Anselmino .. Phys.Rev.D79:054010, 2009



Maximal expected asymmetry value nearly correspond to the maximal acc.

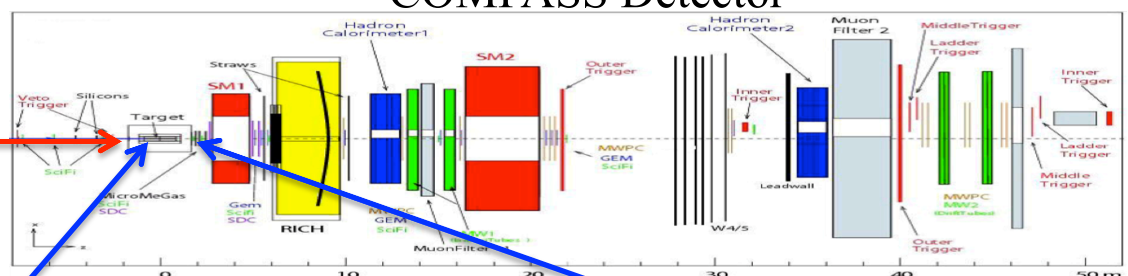
DY feasibility – test setup

Pion induced DY test run, Year 2007, 2008, 2009

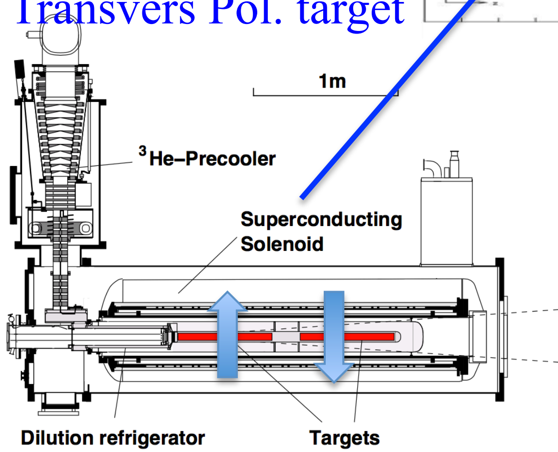
π^- 190 GeV/c beam -> u quark anti-uquark dominant DY process
Polarised target simulated by two cylinders of polyetylene (CH_2) -> NH_3
Hadron absorber installed
8 x10^7 pions/spill (spill length 9.6s)

COMPASS Detector

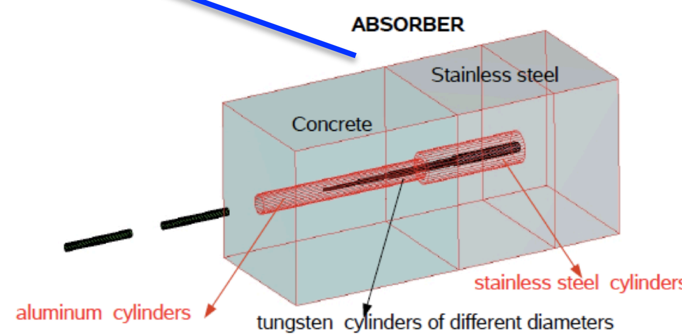
π^- beam



Transvers Pol. target



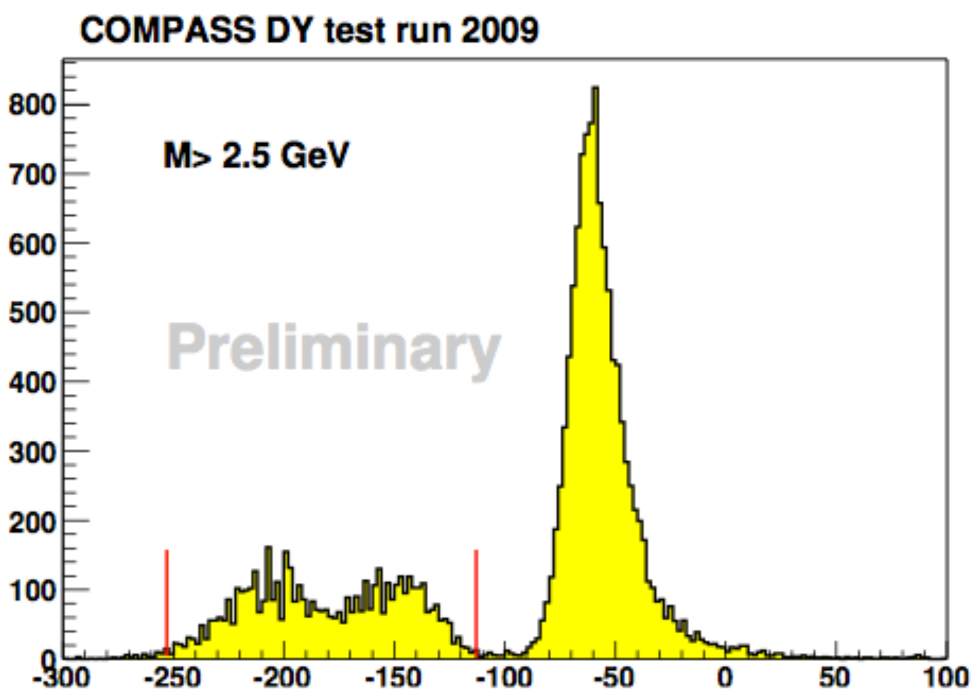
Two 40cm length of Polyethylene(CH_2) separated by 20cm



Hadron absorber
Beam plug (stop non-interacting beam)

Muon pairs z-vertex distribution

2009 beam test for DY

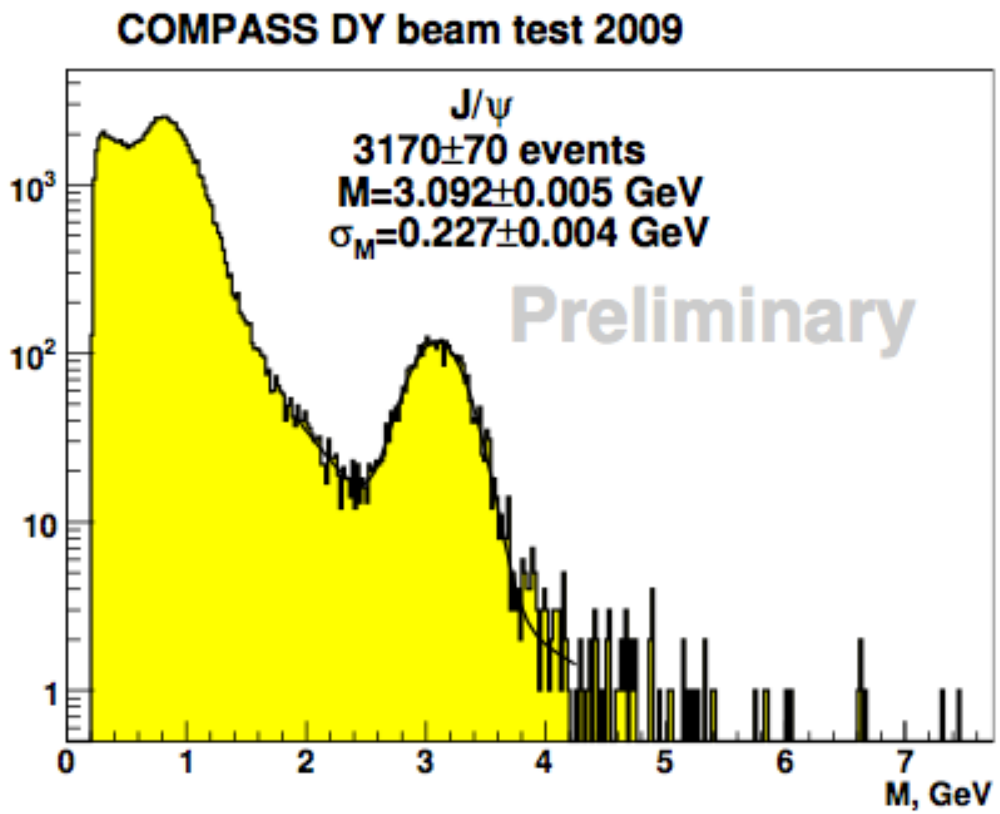


Two CH_2 target cells (40cm + 40cm)
Gap between cells 20cm

Reconstructed z-vertex position visible (Requires improved beam and vertex tracking)

Peak around -50cm is from hadron absorber

DY feasibility (2009 Beam test)

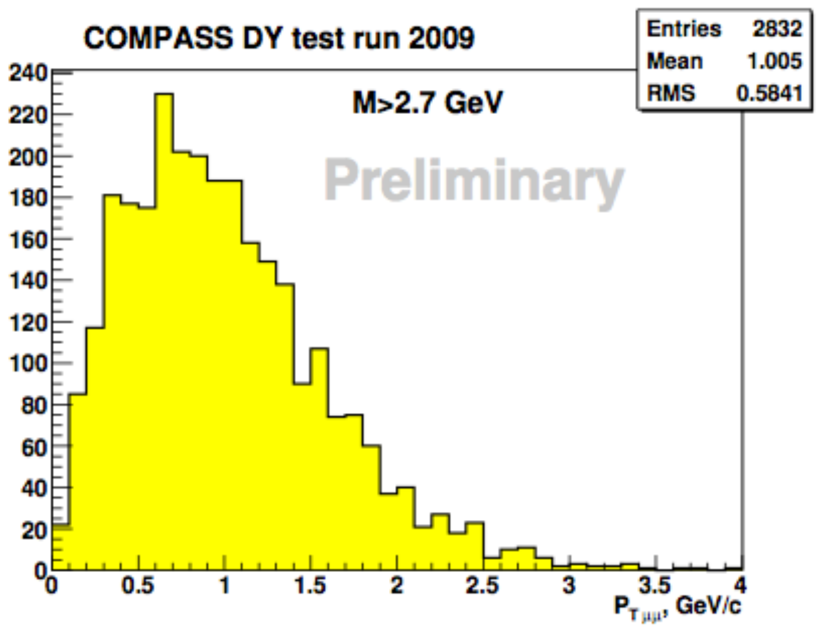


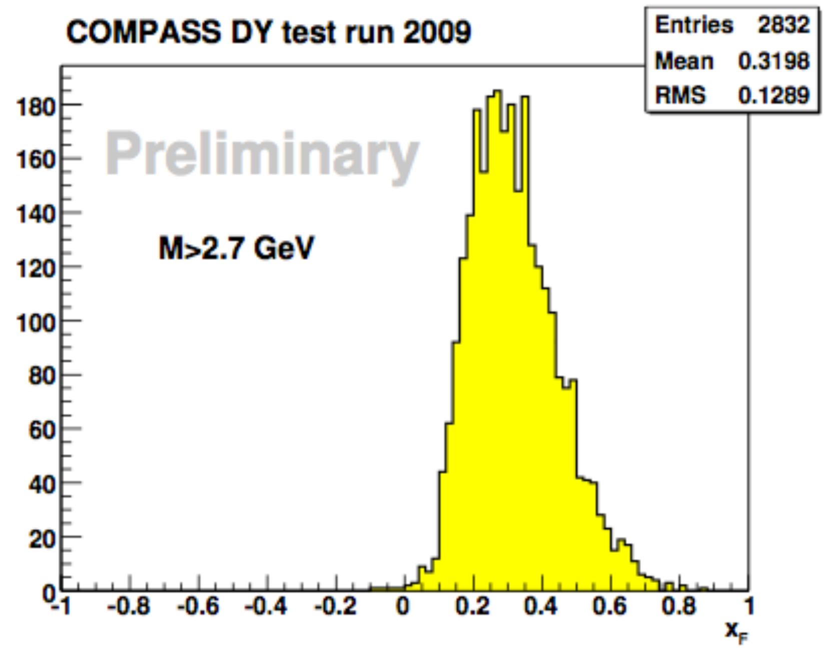
3 days data taking on 2009

	J/Psi	DY ($4<M_{uu}< 9$)
Expected	3600+- 600	110+-22
Data	**3170+-70**	**84+-10**

Agreed well with expectation

DY feasibility – p_T, x_F distributions



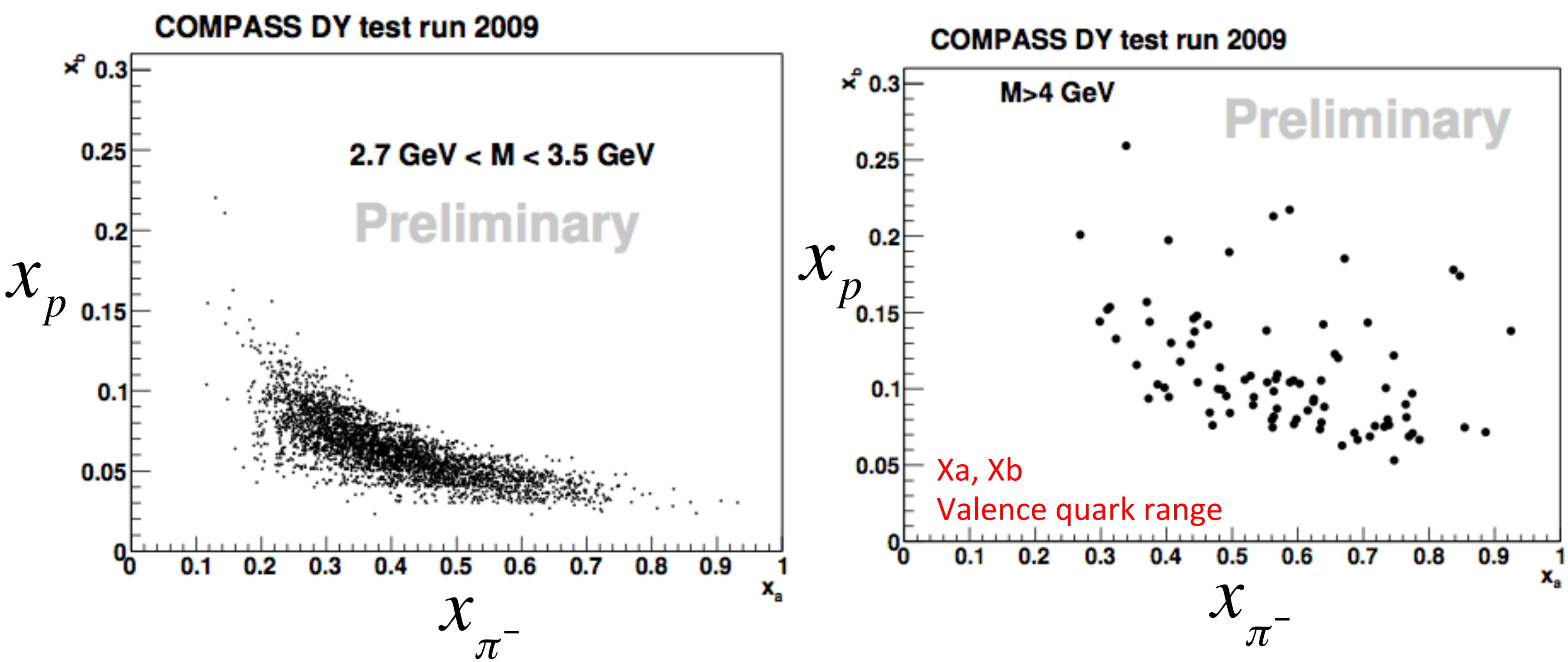


Mean pT ~ 1GeV/C

COMPASS sensitive to TMDs

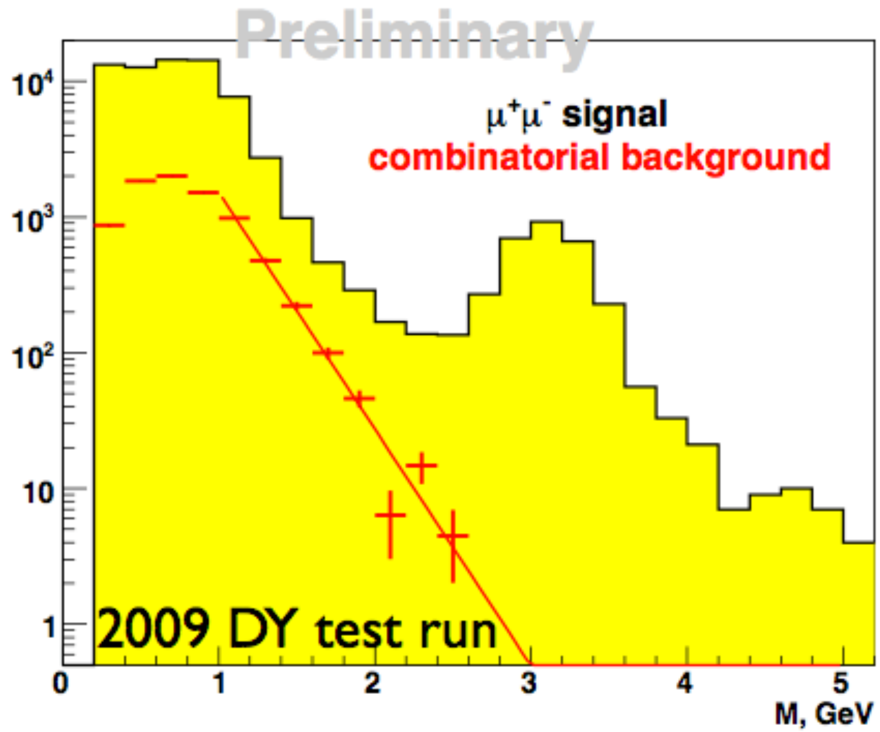
(TMDs expected to be accessible up to $P_T \sim 2$GeV/c)

x_p and x_π distributions



COMPASS Acceptance cover both DY and J/ψ

DY feasibility - Background



Background

1) Combinatorial muon BG originating from pion and kaon decays
   - controllable by optimizing hadron absorber and beam plug
2) Open-charm semi-leptonic drcays
   - Seen to negligible in simulation Muu>2GeV in PYTHIA
   - Improved by proper muon angular cut

Number of Expected DY events

$$\pi^-(\bar{u}d) + p\uparrow(uud) \rightarrow \ell^+\ell^- X$$

With a beam intensity of $I_{beam} = 6 \times 10^7$ particles/second, $L = 1.2 \times 10^{32}$ $cm^{-2}s^{-1}$

Expect 900/day DY events with $4 < M_{uu} < 9$ GeV/c^2
In 280 days(= 2 years), 250000 events in the DY high mass range
(~ 420000 events if $I_{beam} = 1 \times 10^8$ particles/second)

Expect 4300/day DY events with $2 < M_{uu} < 2.5$ GeV/c^2
In 280 days, 11900000 events in the DY low mass range

Expect 13700/day DY + J/Ψ events with $2.9 < M_{uu} < 3.2$ GeV/c^2
In 280 days, 3845000 events in the DY low mass range

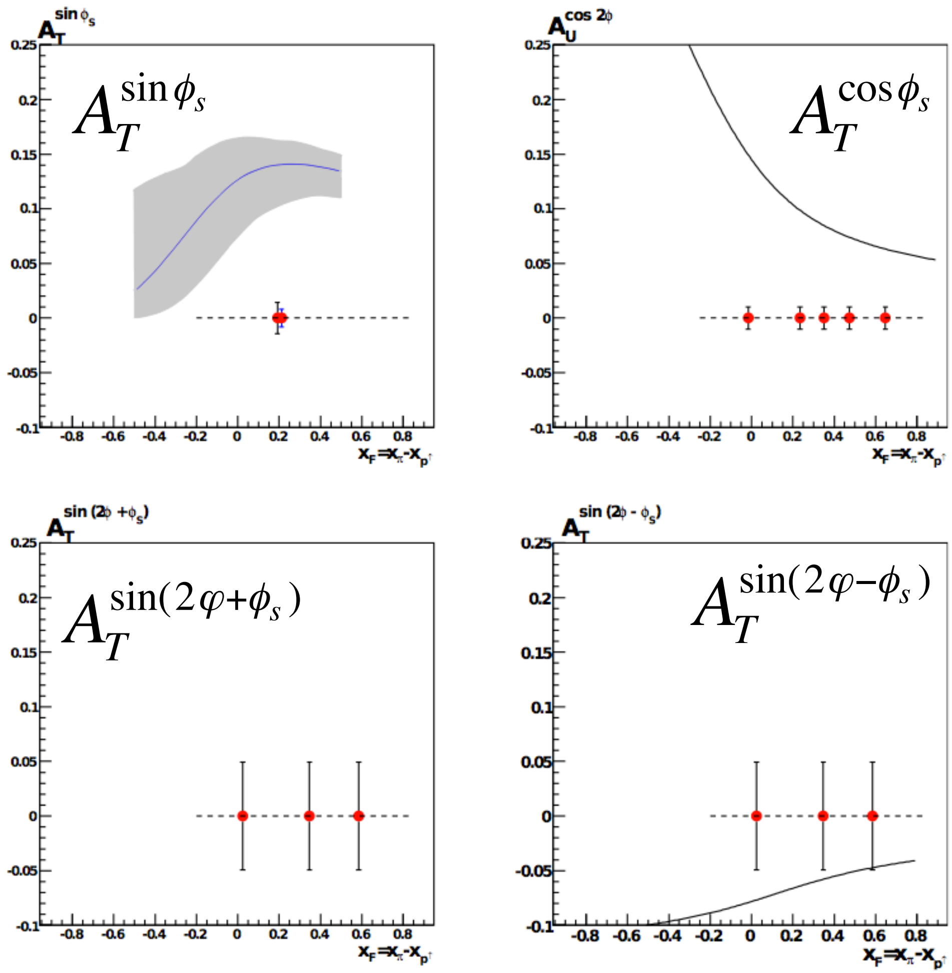
Statistical Error Estimates for Asymmetries

$$\delta A_U^{\cos 2\phi} = 2\sqrt{\frac{2}{N}}; \qquad \delta A_U^{\cos 2\phi} = \frac{1}{fS_T}\sqrt{\frac{2}{N}}; \qquad \delta A_U^{\sin(2\phi \pm \phi_S)} = \frac{2}{fS_T}\sqrt{\frac{2}{N}};$$

Asymmetry	Dimuon mass (GeV/c^2)		
	$2 < M_{\mu\mu} < 2.5$	J/ψ region	$4 < M_{\mu\mu} < 9$
$\delta A_U^{\cos 2\phi}$	0.0020	0.0013	0.0045
$\delta A_T^{\sin \phi_S}$	0.0062	0.0040	0.0142
$\delta A_T^{\sin(2\phi+\phi_S)}$	0.0123	0.008	0.0285
$\delta A_T^{\sin(2\phi-\phi_S)}$	0.0123	0.008	0.0285

DY Statistical Precision (I)

M. Anselmino et all
PRD79(2009)054010

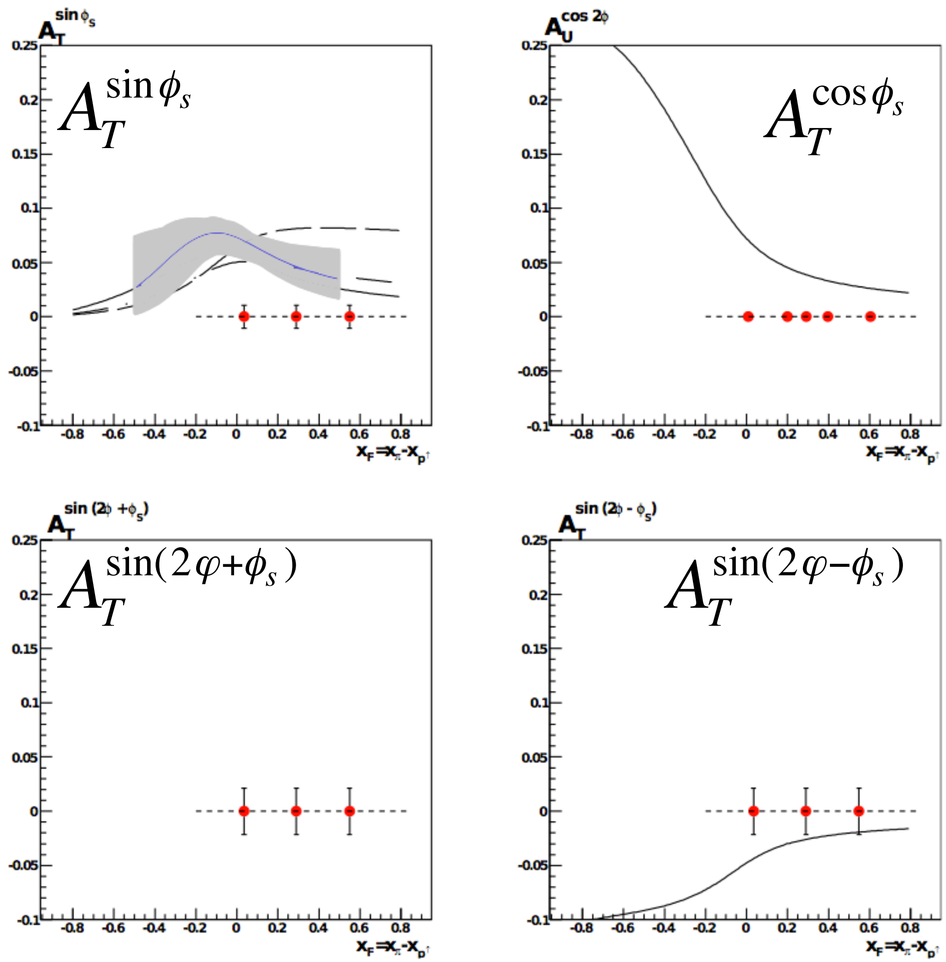


B. Zhang et all
PRD77(2008)054011

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

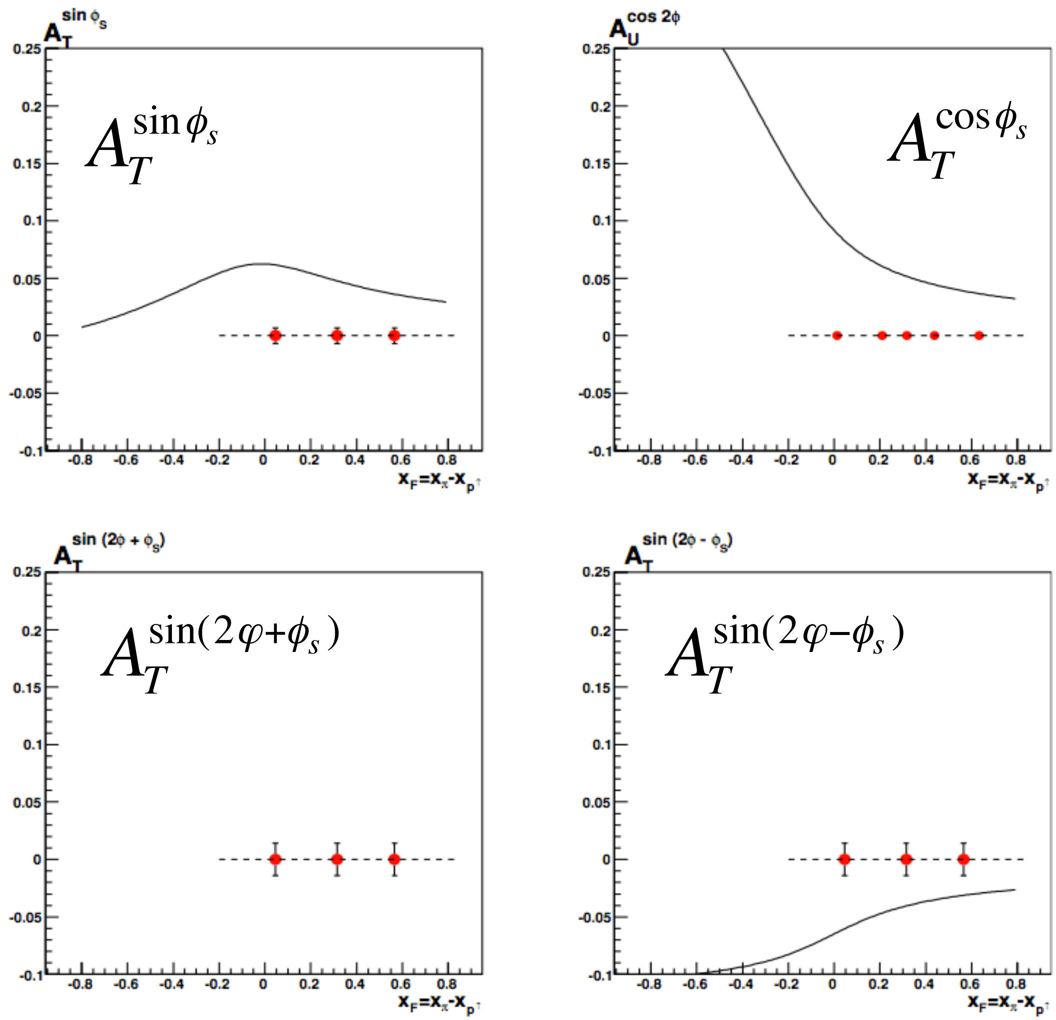
$4 < M_{\mu\mu} < 9$ GeV/c^2

DY Statistical Precision (II)



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

J/Ψ Statistical Precision (III)



$2.9 < M_{\mu\mu} < 3.2$ GeV/c^2

Detector Upgrades

- COMPASS Polarised target:
  - New target holder (2x55 cm, 20 cm gap)
  - Old/modified Micro-Wave cavity (2 cells target)
  - PT Pump system refurbishing
- COMPASS PT has to be moved by ~2.2 meters upstream in order to release a space for the Hadron Absorber
- Hadron absorber (Alumina Al_2O_3) and beam plug (tungsten)
- Radio-Protection screen (stainless steel & borated polyeth.)
- New SciFi-based beam telescope
- H1 trigger hodoscope modification (central hole size adjustment)
- New vertex detector (SciFi based)
- New Large Area tracking station in the LAS

COMPASS Running until 2016

2014-2016

Tentative schedule

2012	Primakoff	18 weeks
	GPDs	6 weeks
2014	Drell-Yan	
2015	GPDs	
2016	GPDs	

End of 2013 – short DY test very desirable

2013 Long shut down necessary for PT mouvement and installation

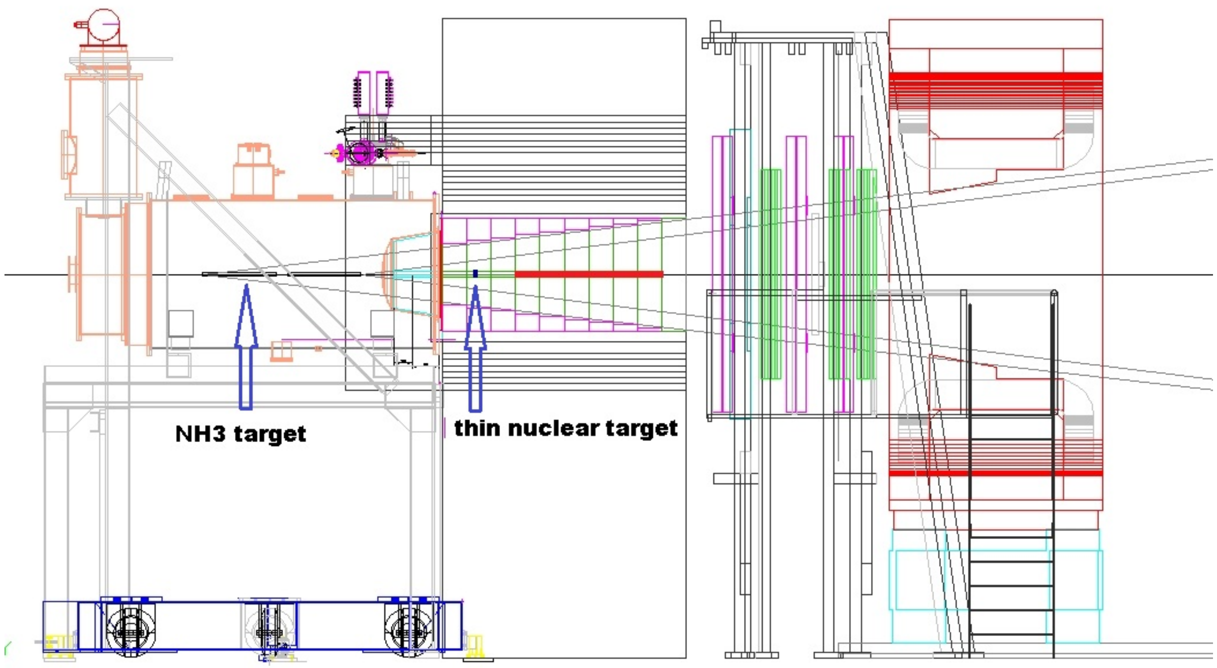
→ Agreed upon

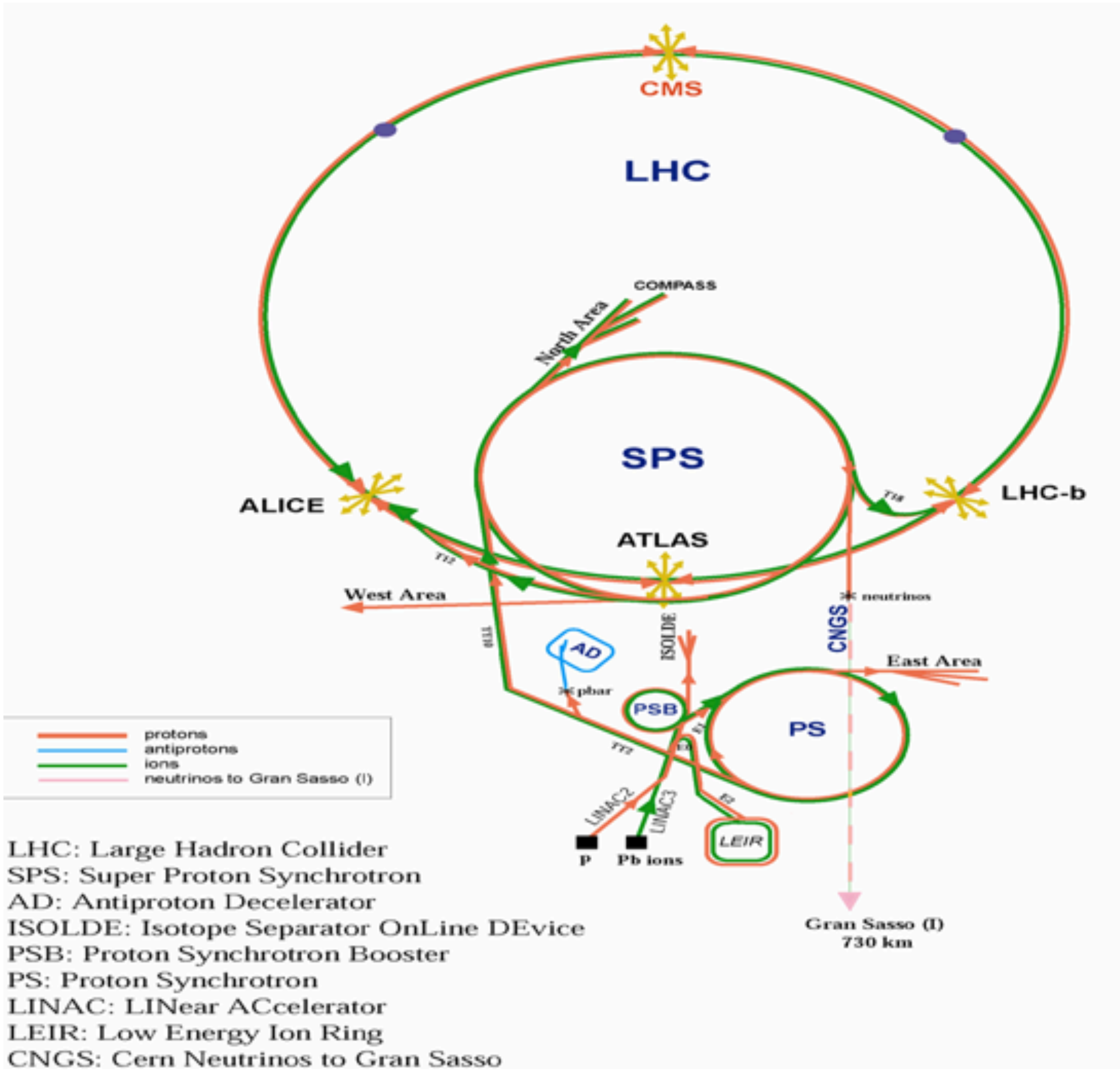
Summary

- Sivers asymmetry have been measured in SIDIS at COMPASS and at HERMES.
- COMPASS II will test expected sign change of Sivers and Boer-Mulders PDFs in DY
- Feasibility of Drell-Yan measurement was demonstrated with 2009 test beam
- Expected statistical precision of asymmetry measurement is 1~2%
- The pion induced transverse polarized Drell-Yan measurement will start in 2014

backup

NH_3 + Thin Nuclei Targets




CMS
LHC
COMPASS
North Area
SPS
ALICE
LHC-b
ATLAS
West Area
neutrinos
CNGS
ISOLDE
AD
pbar
East Area
PSB
PS
LINAC2
LINAC3
P
Pb ions
LEIR
Gran Sasso (I)
730 km
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso