COMPASS

INFN
Istituto Nazionale di Fisica Nucleare Sezione di Torino

TRANSVERSITY 2011

Third International Workshop on
TRANSVERSE POLARIZATION PHENOMENA IN HARD SCATTERING

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Veli Lošinj, Croatia

ECSAC
EUROPEAN CENTRE FOR SCIENCE ARTS AND CULTURE

Polarised (and not only) Drell-Yan at COMPASS-II

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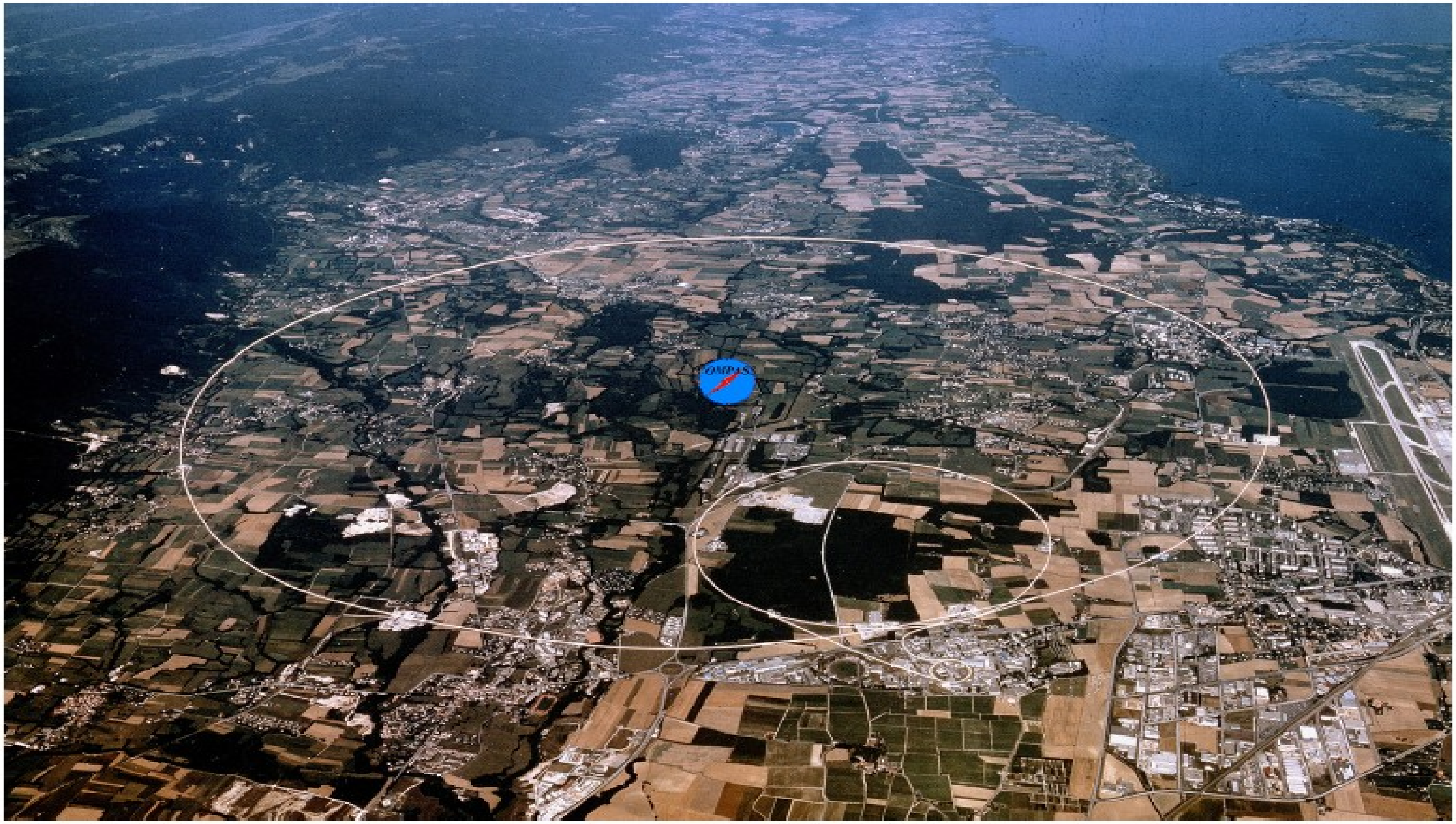
Outline

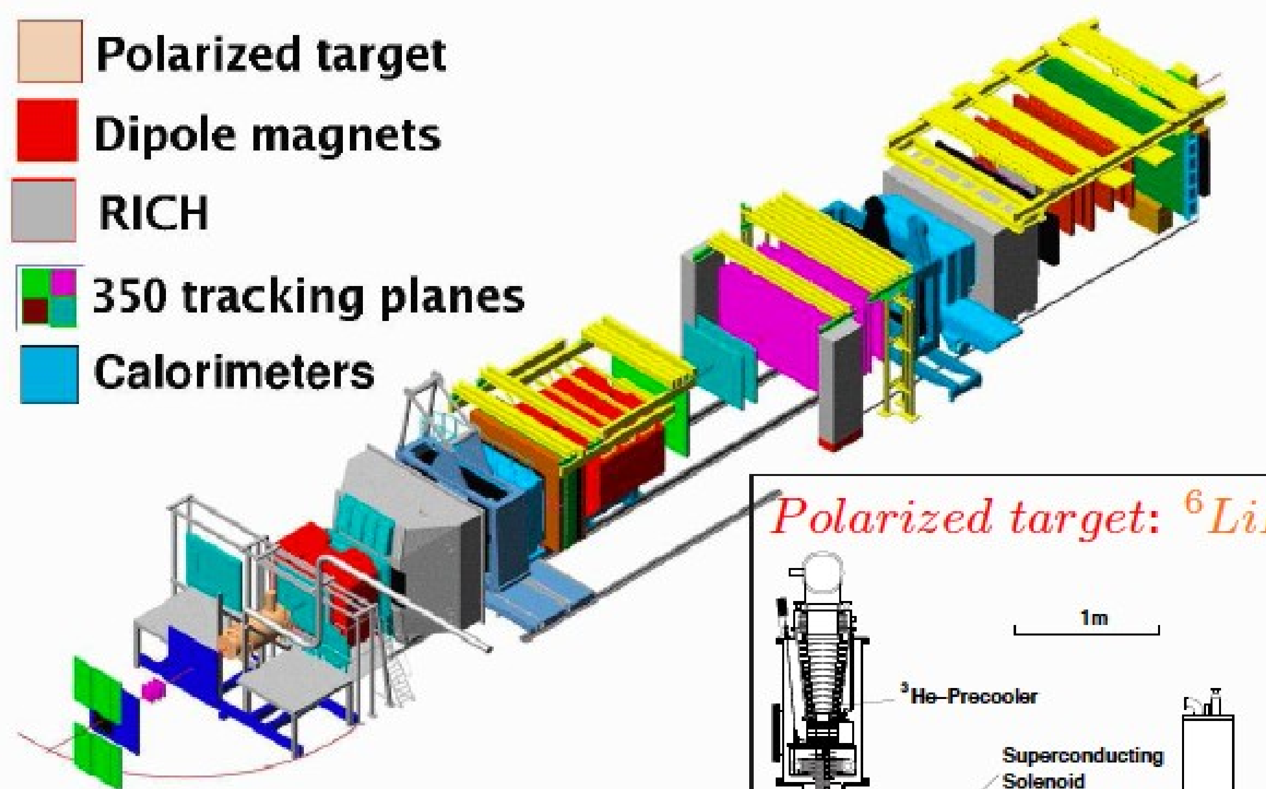
- COMPASS I → COMPASS-II
- Drell-Yan, polarised case
- Transversity & TMD PDFs:
  - Proton description at LO
  - TMDs factorisation and universality – crucial test of modern QCD
- Unpolarised pion Drell-Yan:
  - "Classical" Drell-Yan physics
  - Semi-exclusive case (access to the GPDs)
- TMDs study – choice of kinematic domain
- Polarised DY@COMPASS
  - Set-up
  - Kinematics & Projections
  - Beam test results
  - Timelines
- COMPASS ←→ AnDY – competition and complementarities
- Some conclusions

COMPASS facility at CERN (SPS)

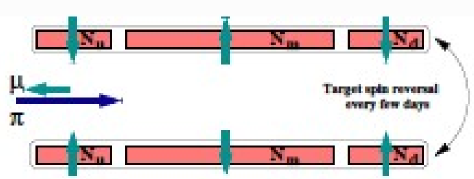
COmmon Muon Proton Apparatus for Structure and Spectroscopy



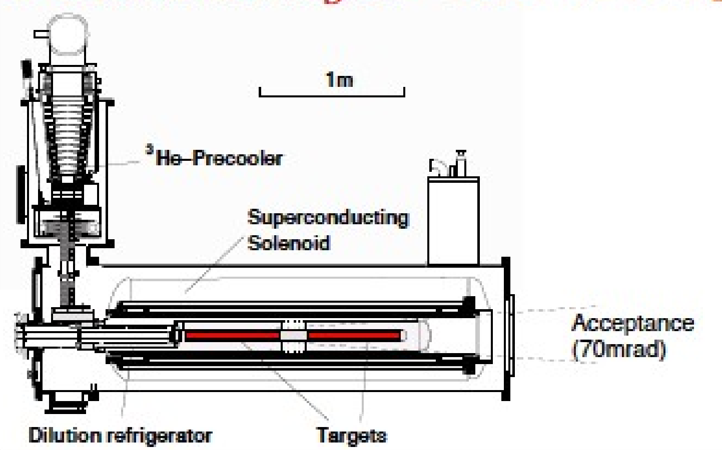
COMPASS facility at CERN



μ or π beam



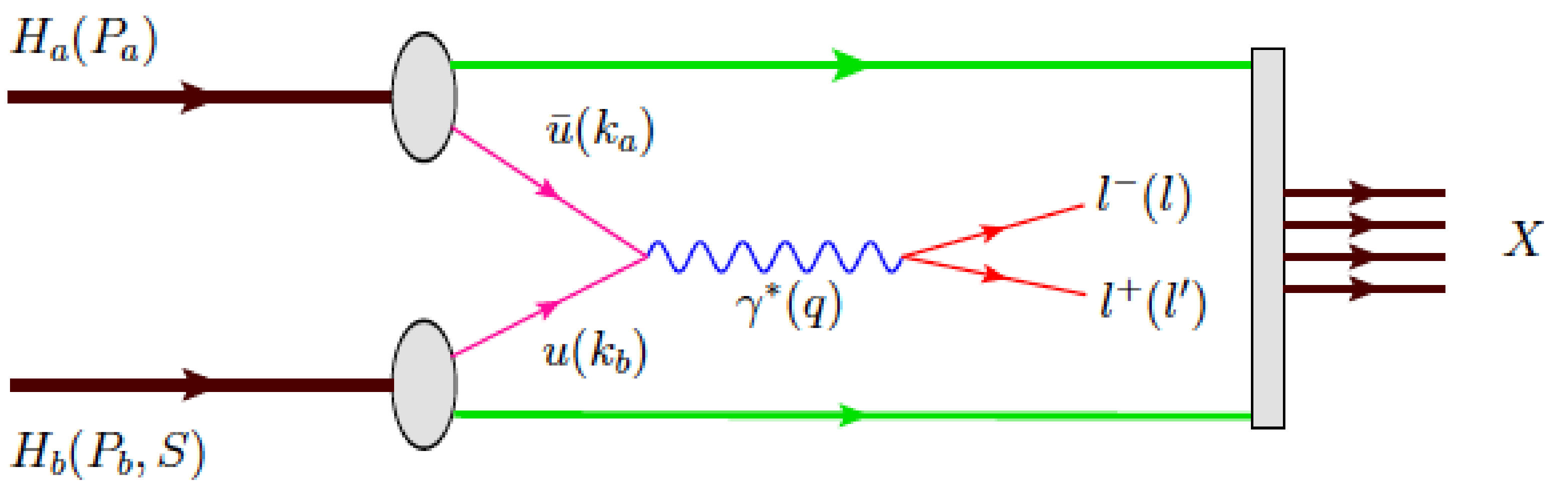
Polarized target: ^{6}LiD or NH_3



COMPASS-II (New Physics) a piece of history

- COMPASS is very sophisticated, universal and flexible facility ➔ Physics beyong SIDIS and hadron spectroscopy is possible:
  - Unique COMPASS Polarised Target
  - Both hadron and lepton beams
  - Flexible spectrometer structure ➔ easy-accessible spectrometer components
- All together that has generated new physics proposals with COMPASS – DVCS(GPDs) and polarised DY (here I will stick naturally to DY):
  - For the first time the idea of the polarised $\pi^- p$ DY were reported at the Villars SPSC meeting in September 2004, DY was basically considered as the alternative method (wrt SiDIS) to access transversity and TMD PDFs (rethinking of the original idea by R.Bertini (supported by Mauro) of ppbar doubly-polarised DY – as model-independent way to access transversity, ASSIA proposal at GSI, and PAX as well)
  - Beginning of 2005 – A.V.Efremov brought an attention to the issue of the sign-change of the Sivers function from SIDIS to DY (Brodsky, Collins), since then it became the flagship measurement
  - The first version of the polarised $\pi^- p$ DY Letter of Intent was written in 2005 (Oleg Teryaev has contributed as well)
  - Since then 3 International Workshops (Torino, Dubna, CERN), > 40 COMPASS DY subgroup meetings, 3 Beam Tests, > 20 presentations at the international Conferences…. In the end we succeed to convince ourselves that we can do it.
- The COMPASS-II proposal was submitted to the CERN SPSC on May 17th 2010
- Approved by the CERN research board on December 1st 2010, 1 year for Drell-Yan and 2 years for GPDs in the time interval between two LHC shutdowns.

Drell-Yan Kinematics



$P_{a(b)}$	the momentum of the beam (target) hadron,
$s = (P_a + P_b)^2$,	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,
$\mathbf{k}_{Ta(b)}$	the transverse component of the quark momentum,
$\mathbf{q}_T = \mathbf{P}_T = \mathbf{k}_{Ta} + \mathbf{k}_{Tb}$	the transverse component of the momentum of the virtual photon.

Drell-Yan cross-section – general (full) angular distribution

2008: S. Arnold, (Ruhr U., Bochum) , A. Metz, (Temple U.) , M. Schlegel, (Jefferson Lab)
Phys.Rev.D79:034005,2009, e-Print: **arXiv:0809.2262**

$$\frac{d\sigma}{d^4q\, d\Omega} = \frac{\alpha_{em}^2}{F\, q^2} \times$$

$$\Big\{ \Big((1+\cos^2\theta)\, F_{UU}^1 + (1-\cos^2\theta)\, F_{UU}^2 + \sin 2\theta \cos\phi\, F_{UU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UU}^{\cos 2\phi} \Big)$$

$$+\ S_{aL} \Big(\sin 2\theta \sin\phi\, F_{LU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{LU}^{\sin 2\phi} \Big)$$

$$+\ S_{bL} \Big(\sin 2\theta \sin\phi\, F_{UL}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UL}^{\sin 2\phi} \Big)$$

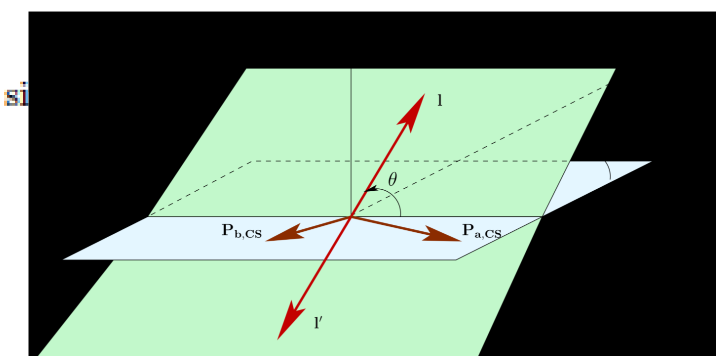
$$+\ |\vec{S}_{aT}| \Big[\sin\phi_a \Big((1+\cos^2\theta)\, F_{TU}^1 + (1-\cos^2\theta)\, F_{TU}^2 + \sin 2\theta \cos\phi\, F_{TU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TU}^{\cos 2\phi} \Big)$$

$$+ \cos\phi_a \Big(\sin 2\theta \sin\phi\, F_{TU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TU}^{\sin 2\phi} \Big) \Big]$$

$$+\ |\vec{S}_{bT}| \Big[\sin\phi_b \Big((1+\cos^2\theta)\, F_{UT}^1 + (1-\cos^2\theta)\, F_{UT}^2 + \sin 2\theta \cos\phi\, F_{UT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UT}^{\cos 2\phi} \Big)$$

$$+ \cos\phi_b \Big(\sin 2\theta \sin\phi\, F_{UT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UT}^{\sin 2\phi} \Big) \Big]$$

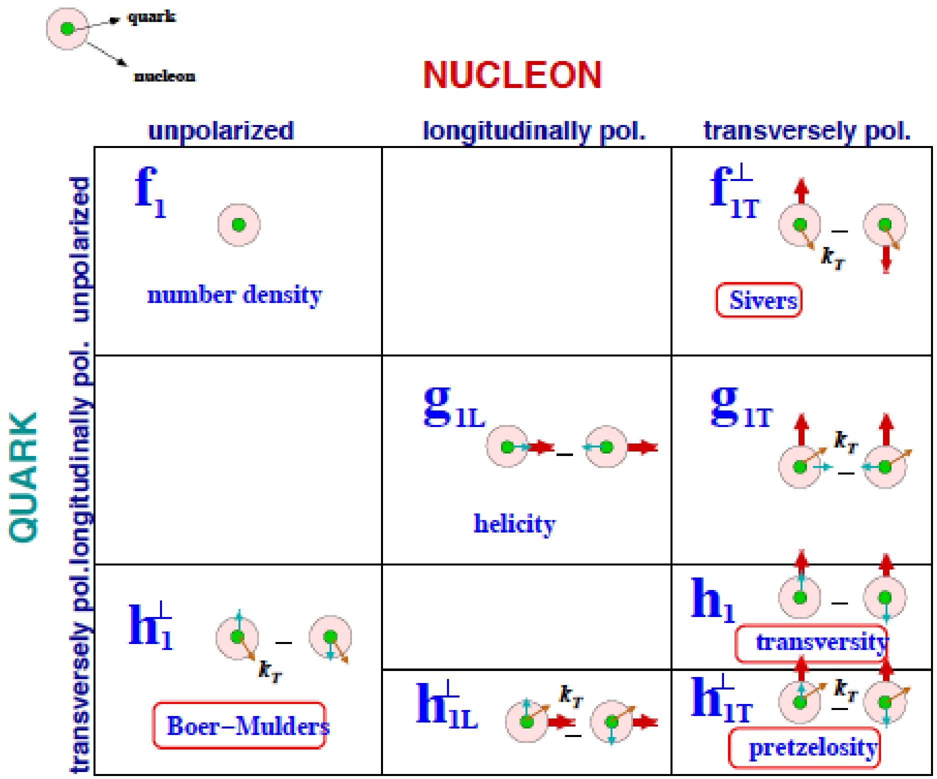
$$+\ S_{aL}\, S_{bL} \Big((1+\cos^2\theta)\, F_{LL}^1 + (1-\cos^2\theta)\, F_{LL}^2 + \sin 2\theta \cos\phi\, F_{LL}^{\cos\phi} + \mathrm{si}$$



Leading Order PDFs

At leading order, 3 PDFs are needed to describe the structure of the nucleon in the collinear approximation.

But if one takes into account also the quarks intrinsic transverse momentum k_T, 8 PDFs are needed:



TMD PDFs

TMD PDFs

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

- $f_{1T}^{\perp}(x, k_T^2)$: the Sivers effect is related to an 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 intrisic k_T direction making accessible the orbital angular momentum information

Single-polarised DY cross-section: Leading order QCD parton model

At LO the general expression of the DY cross-section simplifies to (Aram Kotzinian) :

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

Thus the measurement of 4 asymmetries (modulations in the DY cross-section):

- $A_U^{\cos 2\phi}$ 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 functions 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 functions of the beam hadron and h_1, the transversity function of the target nucleon.

TMDs universality SIDIS↔DY

The time-reversal odd character of the Sivers and Boer-Mulders PDFs lead to the prediction of a sign change when accessed from SIDIS or from Drell-Yan processes:

↪ Check the predictions:

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

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

Its experimental confirmation is considered a crucial test of non-perturbative QCD.

Universality test includes not only the sing-reversal character of the TMDs but also the comparison of the amplitude as well as the shape of the corresponding TMDs

SIDIS←→DY – QCD test

Andreas Metz (Trento-TMD'2010):

Sign reversal of the Sivers function

- Prediction based on operator definition (Collins, 2002)

$$f_{1T}^{\perp}\big|_{DY} = - f_{1T}^{\perp}\big|_{DIS}$$

- What if sign reversal of $f_{1T}^{\perp}$ is not confirmed by experiment ?
  - Would not imply that QCD is wrong
  - Would imply that SSAs not understood in QCD
  - Problem with TMD-factorization
  - Problem with resummation of large logarithms

    ⟶ Resummation relevant if more than one scale present

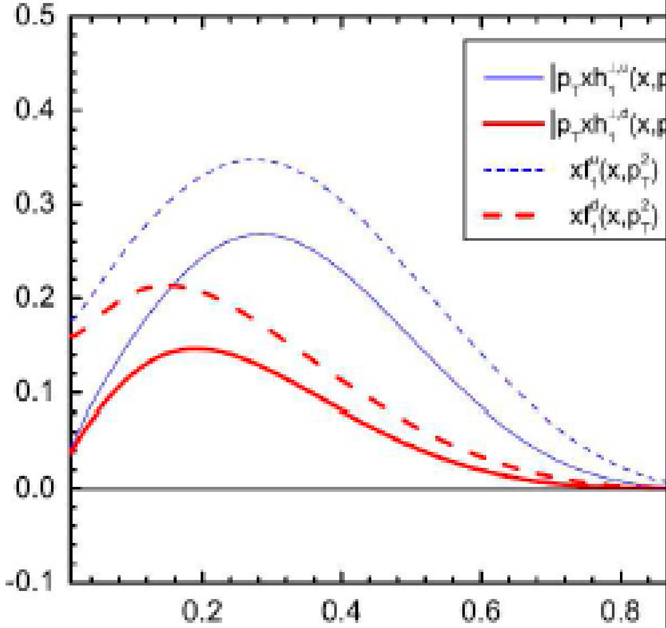
    ⟶ CSS resummation in Drell-Yan (Collins, Soper, Sterman, 1985); resum logarithms of the type

$$\alpha_s^k \ln^{2k} \frac{\vec{Q}_T^2}{Q^2}$$

⟶ Has also implications for Fermilab and LHC physics

Some indications for the future Drell-Yan experiments

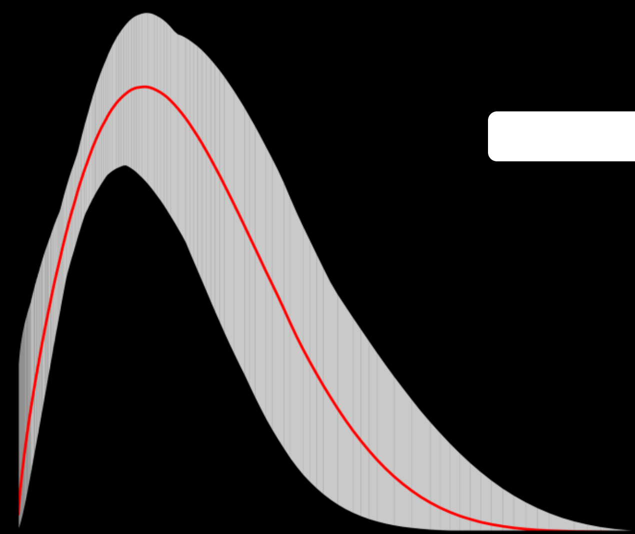
1. TMD PDFs – ALL are sizable in the valence quark region



► Boer-Mulder function for u and d qua

as extracted from $p + D$ data

from Zhang *et al Phys. Rev.* D77,0504011]



Sivers effect in Drell-Yan processes. M. Anselmino, M. Boglione U. D'Alesio, S. Melis, F. Murgia, A. Prokudin Published in Phys.Rev.D79:054010, 2009

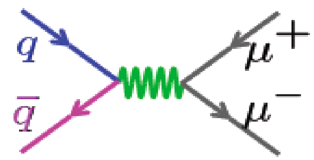
2. $\Lambda_{QCD} < p_T < Q$: - P_T should be small (~ 1 GeV), can be generated by intrinsic motion of quarks and/or by soft gluon emission. This is the region where TMD formalism applies.

Unpolarised Drell-Yan (parallel to the single polarised DY) ➔ Paul Reimer seminar at Torino 13/04/2011

What can we learn with unpolarized Drell-Yan?

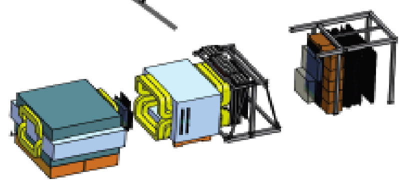
Argonne NATIONAL LABORATORY

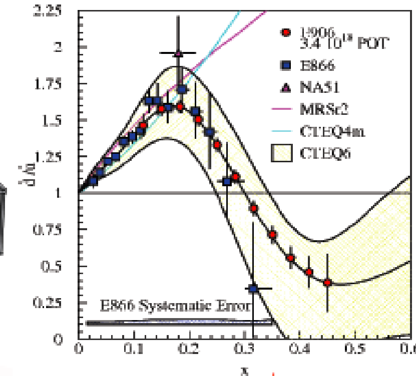
Paul E. Reimer
Physics Division
Argonne National Laboratory
13 April 2011

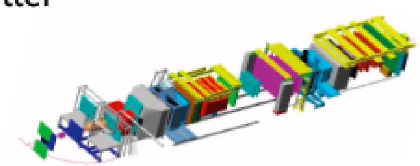


- **Proton** induced Drell-Yan
  - Sea of the proton and of nuclei
  - High-x valence distributions
  - Partonic energy loss in cold nuclear matter
- Pion (and Kaon) induced Drell-Yan
  - EMC effect
  - Valence structure of the pion and kaon
  - Transverse Structure & QCD via angular distributions
  - Sea of the pion?

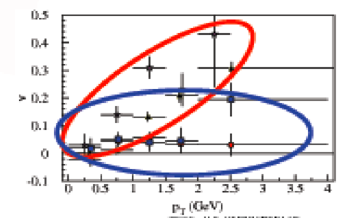
$$Q_\pi^{\mathrm{sea}} \equiv \int_0^1 x q_\pi^{\mathrm{sea}}(x)dx = 0.01$$







COMPASS



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Office of Nuclear Physics

U.S. DEPARTMENT OF ENERGY

+ Old Idea by Stan Brodsky – double J/Psi production and intrinsic nucleon strangeness

We need very much unpolarised DY data to run successful polarised DY experiment

Drell-Yan processes and access to GPDs

Very preliminary – feasibility is under discussion now, some indications:

- see talk by O.Teryaev (Friday, Sep. 2): Drell-Yan pair production in the pion-nucleon collisions for large x_F (the region whose exploration is favourable in COMPASS kinematics) is sensitive to such an important and hot ingredient of pion structure as its light-cone distribution amplitude (DA). In other words in this kinematic range pion participate in the interaction coherently (as a two-quark system) rather then by only one of its quark.

References:

A.Brandenburg, S.J.Brodsky, V.V.Khoze and D.Mueller, Phys.Rev.Lett. 73, 939 (1994)
A.Brandenburg, D.Mueller and O.V.Teryaev, Phys.Rev.D 53, 6180 (1996)
A.P. Bakulev, N.G. Stefanis, O.V.Teryaev, Phys.Rev.D76:074032,2007.

- B.Pire, O.Teryaev: Semi-exclusive DY – crucial test of the GPDs universality (time-like process contrary to the Deep Inelastic scattering)

Reference:

B.Pire, L. Szymanowski, arXiv:0905.1258v1 [hep-ph] 8 May 2009

Why Drell-Yan @ COMPASS

1. Large angular acceptance spectrometer
2. SPS M2 secondary beams with the intensity up to 10^8 particles per second
3. Transversely polarized solid state proton target with a large relaxation time and high polarization, when going to spin frozen mode;
4. a detection system designed to stand relatively high particle fluxes;
5. a Data Acquisition System (DAQ) that can handle large amounts of data at large trigger rates;
6. The dedicated muon trigger system

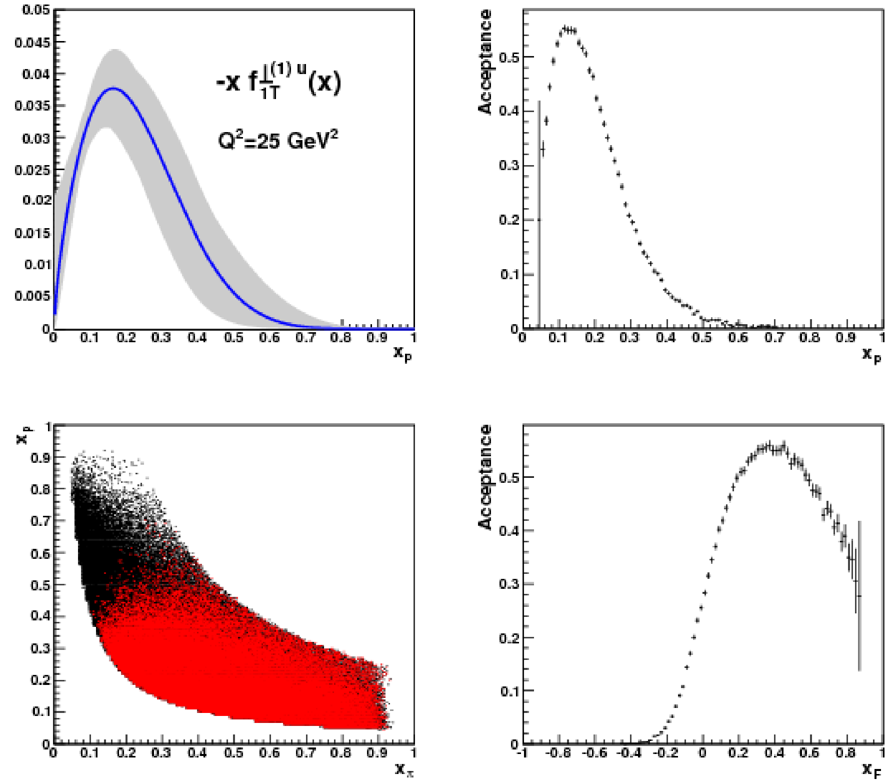
For the moment we consider two step DY program:

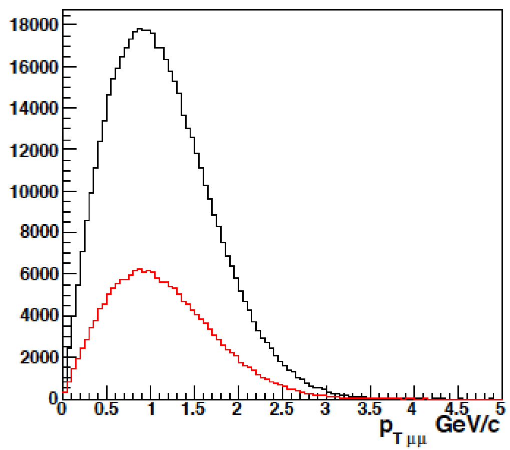
- The program with high intensity pion beam
- The program with Radio Frequency separated antiproton beam

DY@COMPASS – kinematics - valence quark range

$\pi^- p \rightarrow \mu^- \mu X$ (190 GeV pion beam)

- In our case ($\pi^- p \rightarrow \mu^- \mu X$) contribution from valence quarks is dominant
- In COMPASS kinematics u-ubar dominance
- $<P_T>$ ~ 1GeV – TMDs induced effects expected to be dominant with respect to the higher QCD corrections





(HMR): $4. \leq M_{\mu\mu} \leq 9.\ \mathrm{GeV/c^2}$

DY@COMPASS - set-up

$\pi^- p \rightarrow \mu^- \mu X$ (190 GeV)

The main characteristics of the future fixed-target Drell-Yan experiment:

1. Small cross section ➔ High intensity hadron beam (up to 10^9 pions per spill) on the COMPASS PT

2. High intensity hadron beam on thick target ➔
    1. Hadron absorber to stop secondary particles flux
    2. Beam plug to stop the non interacted beam
    3. Radioprotection shielding around to protect things and people
    4. High-rate-capable radiation hard beam telescope

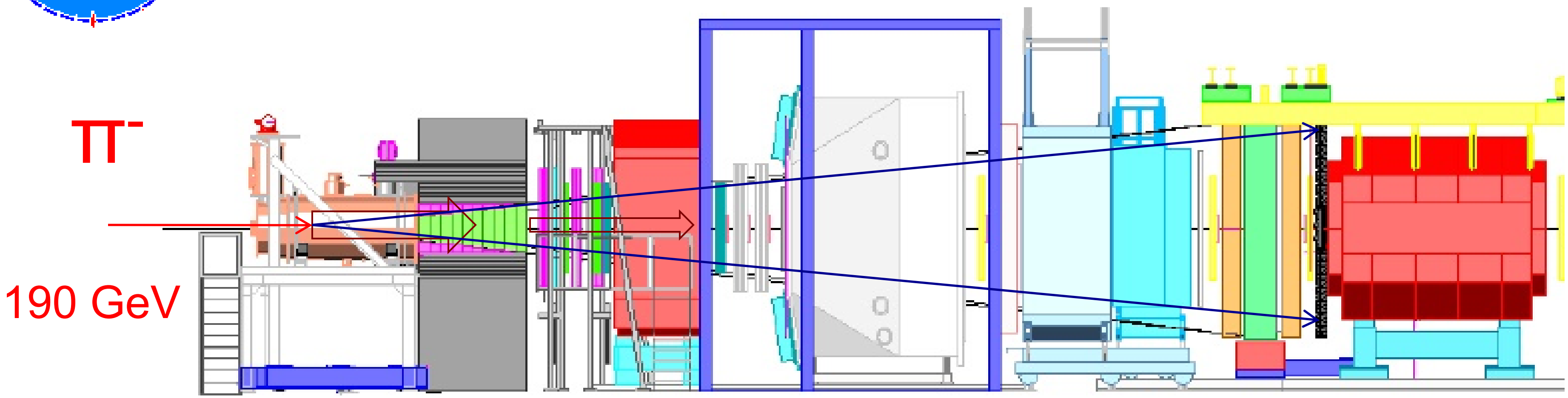
3. Hadron absorber + shielding ➔ PT has to be moved by 2.2 meters upstream

4. LAS dominates in the acceptance ➔The performance of the LAS tracking system must be improved and muon trigger in LAS has to be well tuned.

5. Hadron absorber ➔ vertex detector is very welcome to improve cell-to-cell separation

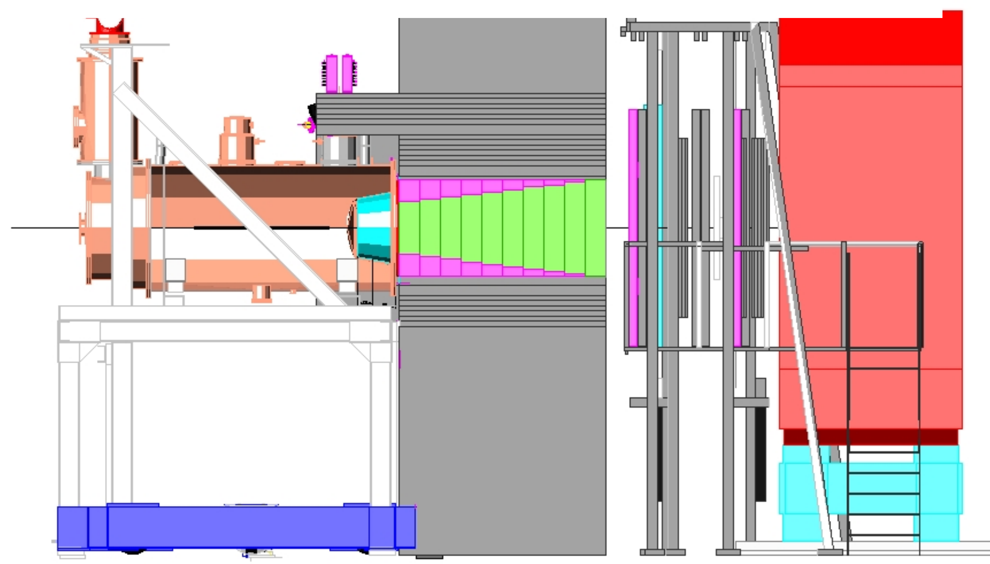
DY@COMPASS - set-up

$\pi^- p^\uparrow \rightarrow \mu^- \mu X$

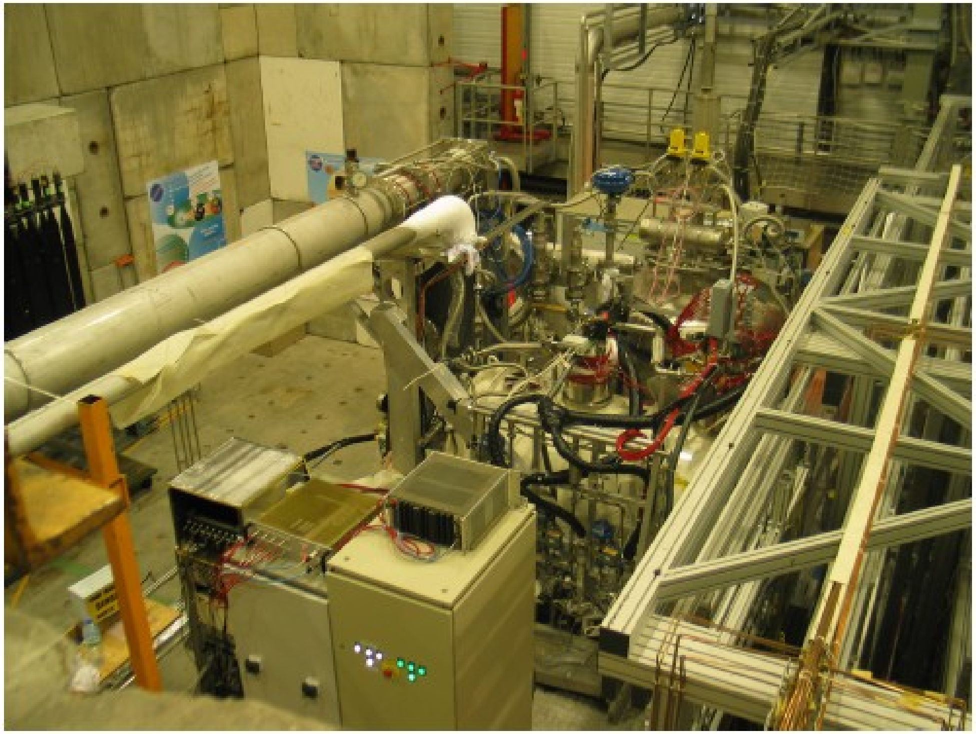


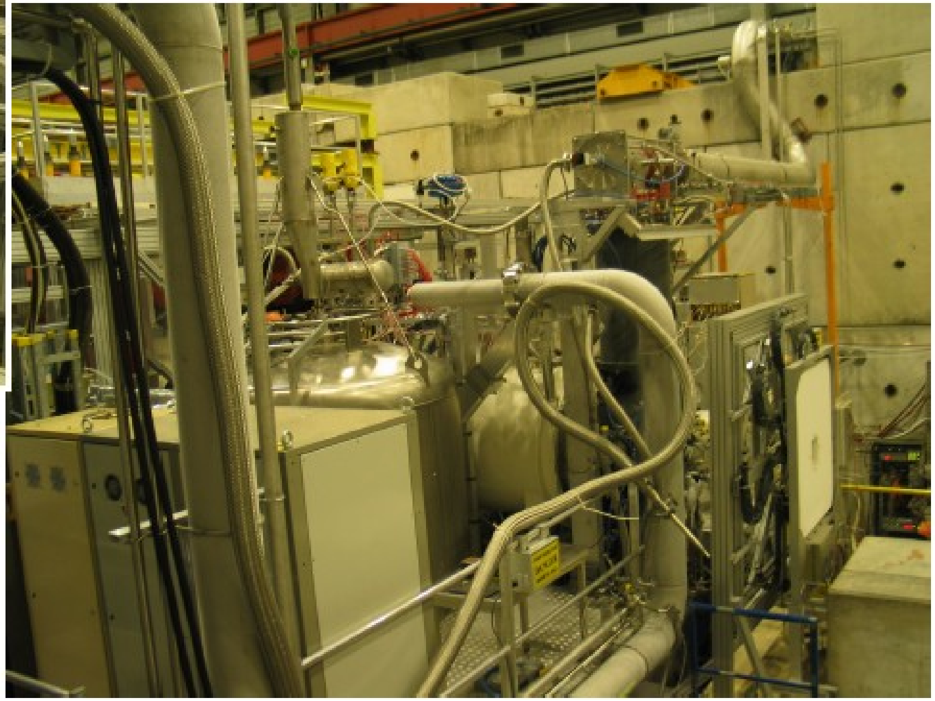
Key elements:

1. COMPASS PT
2. Tracking system (both LAS abs SAS) and beam telescope in front of PT
3. Muon trigger (in LAS is of particular importance - 60% of the DY acceptance)
4. RICH1, Calorimetry – also important to reduce the background (the hadron flux downstream of the hadron absorber ~ 10 higher then muon flux)

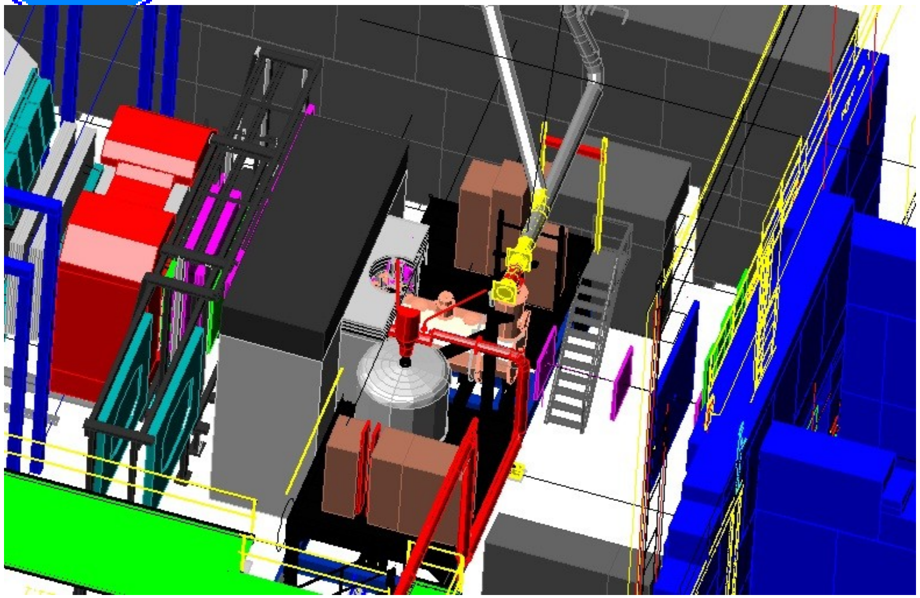


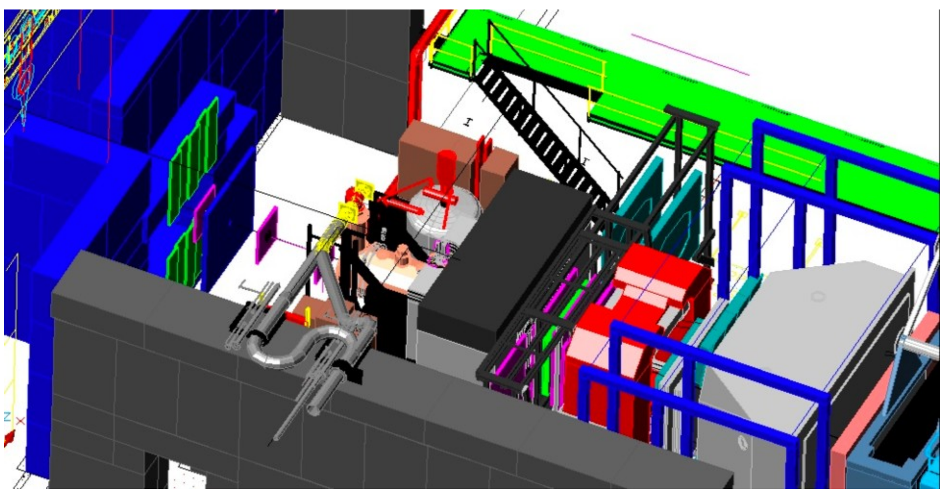
PT movement

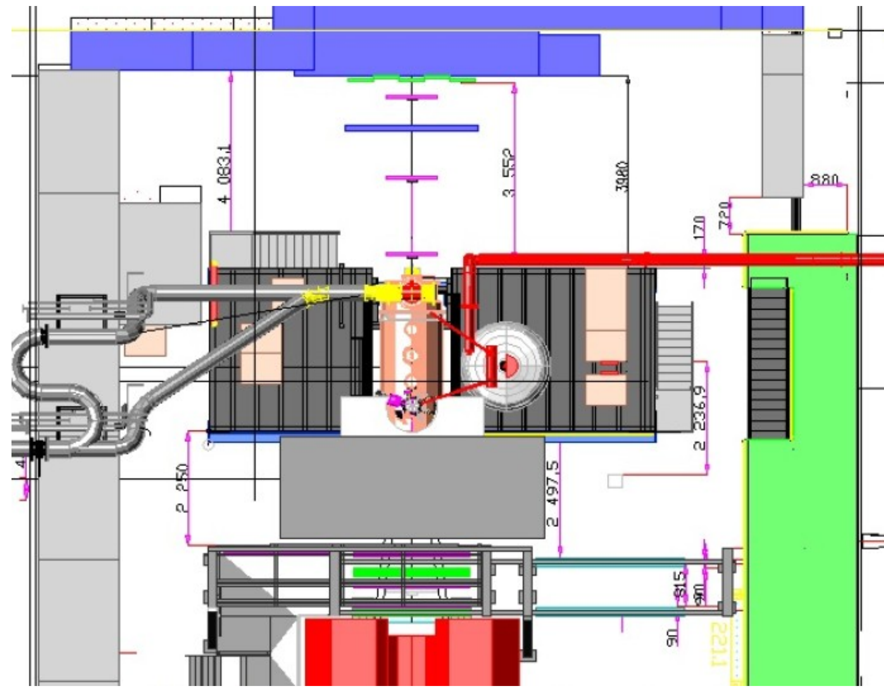




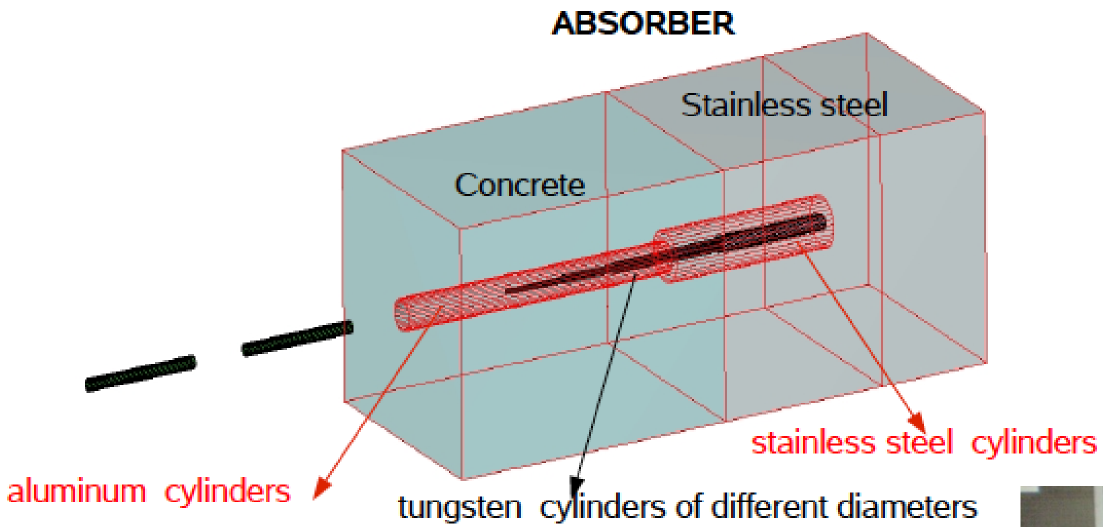
Drell-Yan experiment lay-out
Hadron absorber&R.P.shieldings and Polarised Target







DY Feasibility@COMPASS: Beam Test 2009 – the most important in a row of three beam tests 2007-2009



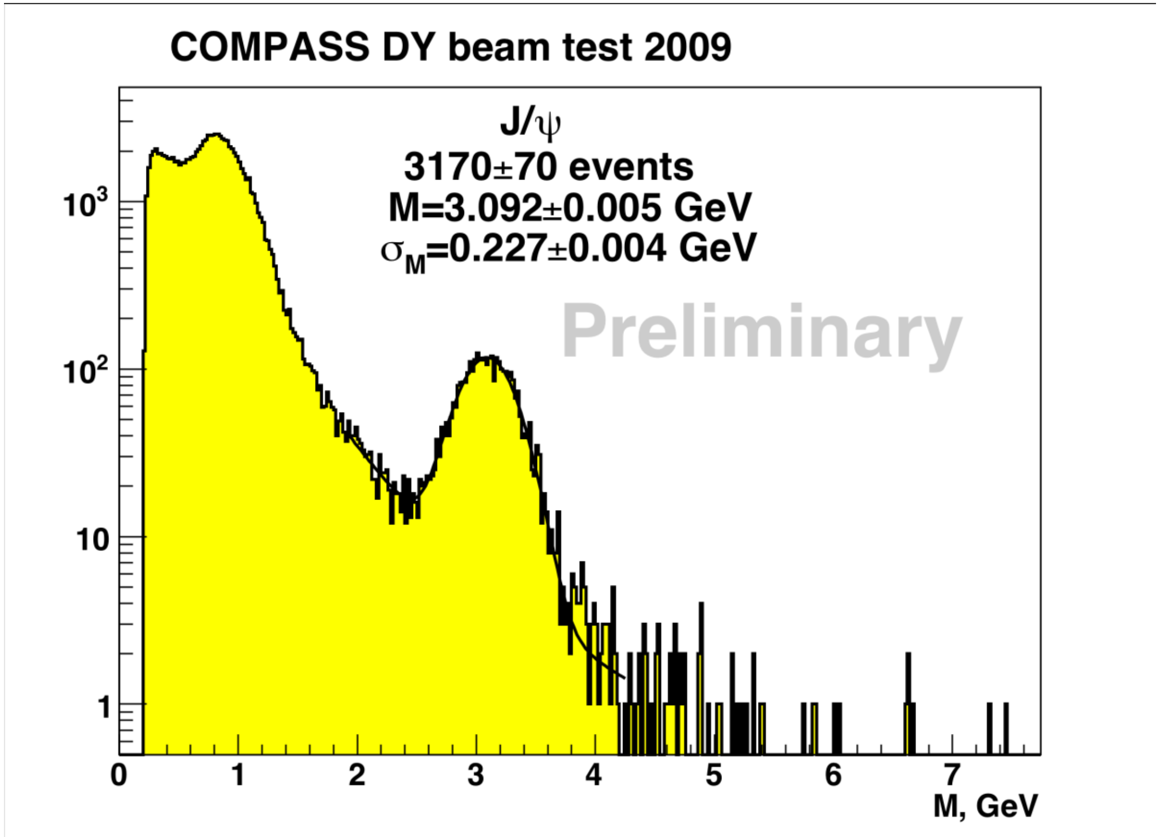
DY Feasibility@COMPASS
Beam Test 2009 (with hadron absorber III)

Radiation in the experimental area, detector occupancies and J/Psi yield:

Everything as expected

DY@COMPASS - feasibility - Signal

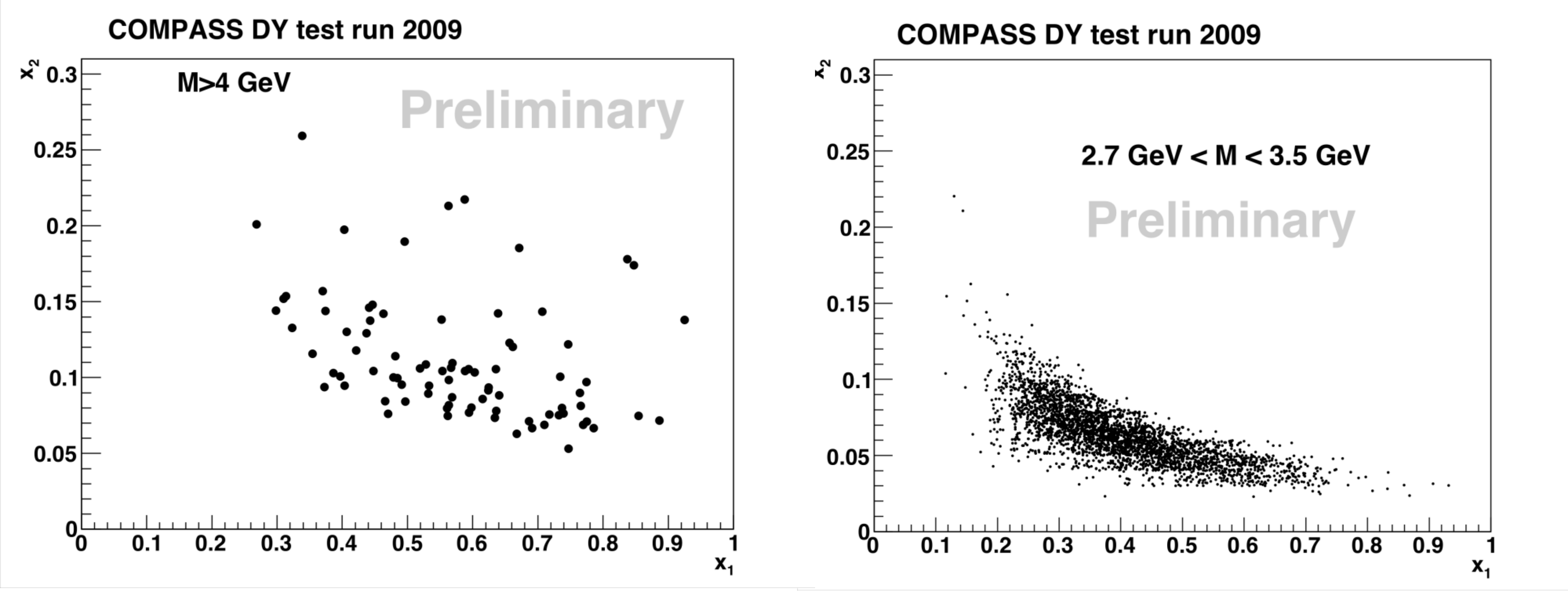
- Expected according to the proposal J/Psi and Drell-Yan yields: 3600±600 and 110±22 (normalized to 2009 beam flux ~3.7 x 10^{11})
- Measured in 2009 beam test J/Psi yield is 3170±70, and DY yield is 84±10



DY@COMPASS - feasibility – Kinematics I

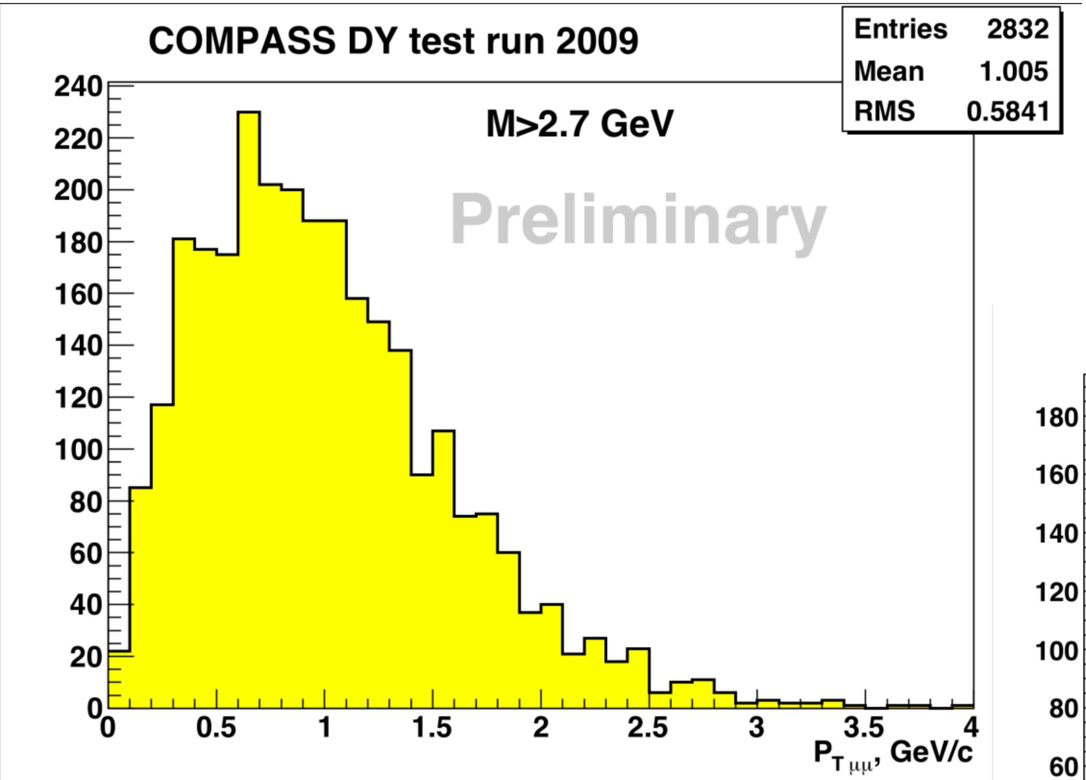
- Valence quark range for both J/Psi and DY

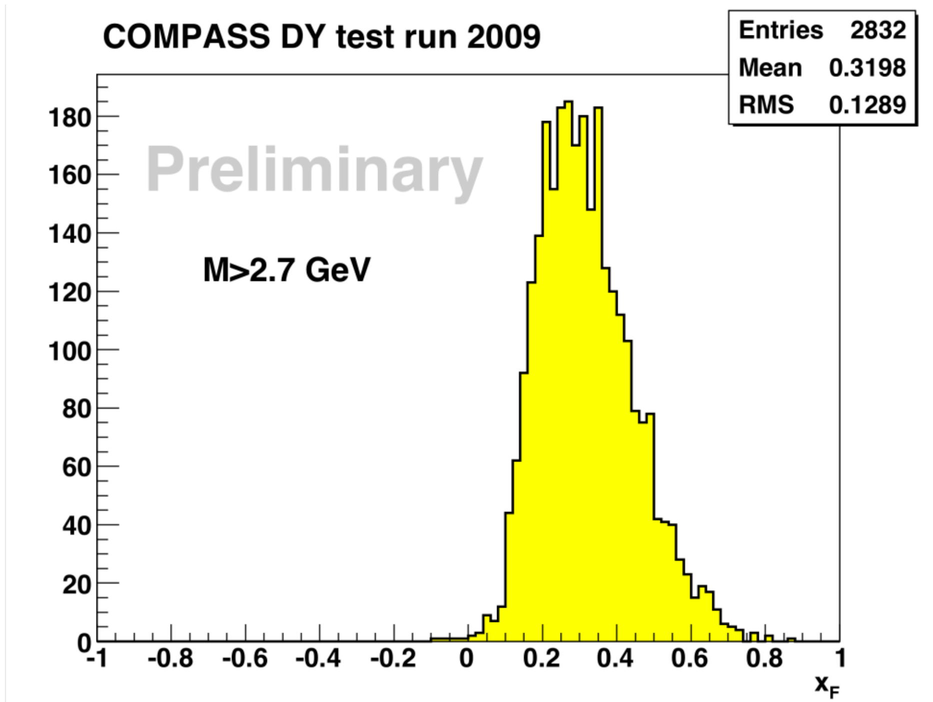
$$x_1 = \frac{Q^2}{P_1 q},$$
$$x_2 = \frac{Q^2}{P_2 q},$$
$$x_f = x_1 - x_2,$$



DY@COMPASS - feasibility – Kinematics II

q_T and x_F ranges





DY@COMPASS projections I

With a beam intensity $I_{beam} = 6 \times 10^7$ particles/second,
a luminosity of $L = 1.7 \times 10^{33}\ cm^{-2}s^{-1}$ can be obtained.

$\hookrightarrow$ Assuming 2 years of data-taking, one can collect > 200000 DY events in the region $4 < M_{\mu\mu} < 9.$ GeV/c^2.

Predictions for the Sivers asymmetry in the COMPASS phase-space, for the mass region $4. < M < 9.$ GeV/c^2, compared to the expected statistical errors of the measurement:

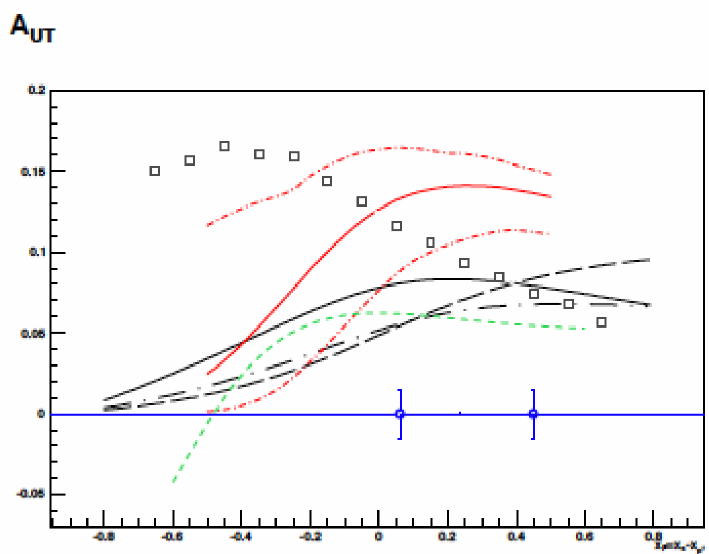
– solid and dashed: Efremov et al, PLB612(2005)233;

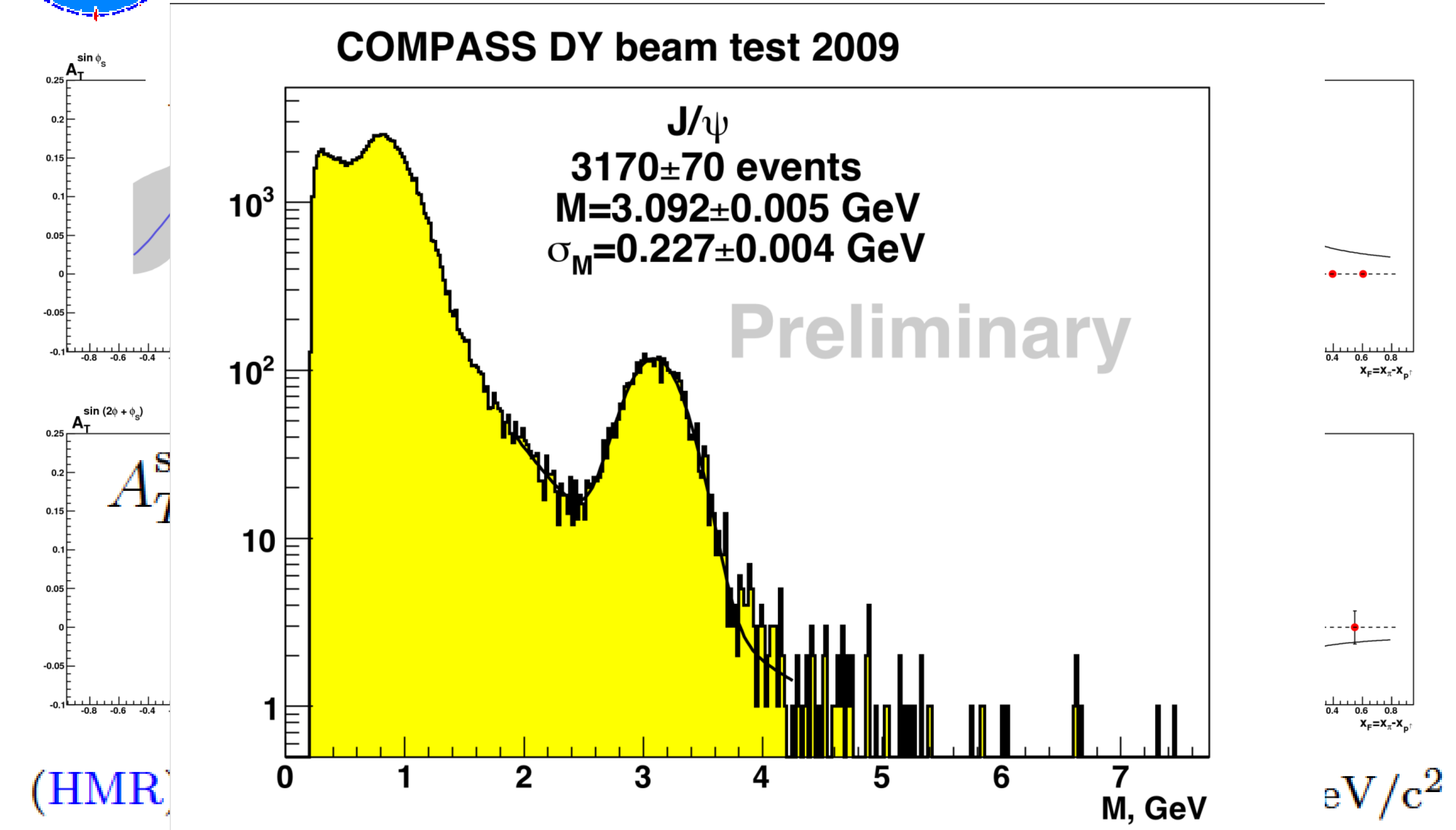
– dot-dashed: Collins et al, PRD73(2006)014021;

– solid, dot-dashed: Anselmino et al, PRD79(2009)054010;

– boxes: Bianconi et al, PRD73(2006)114002;

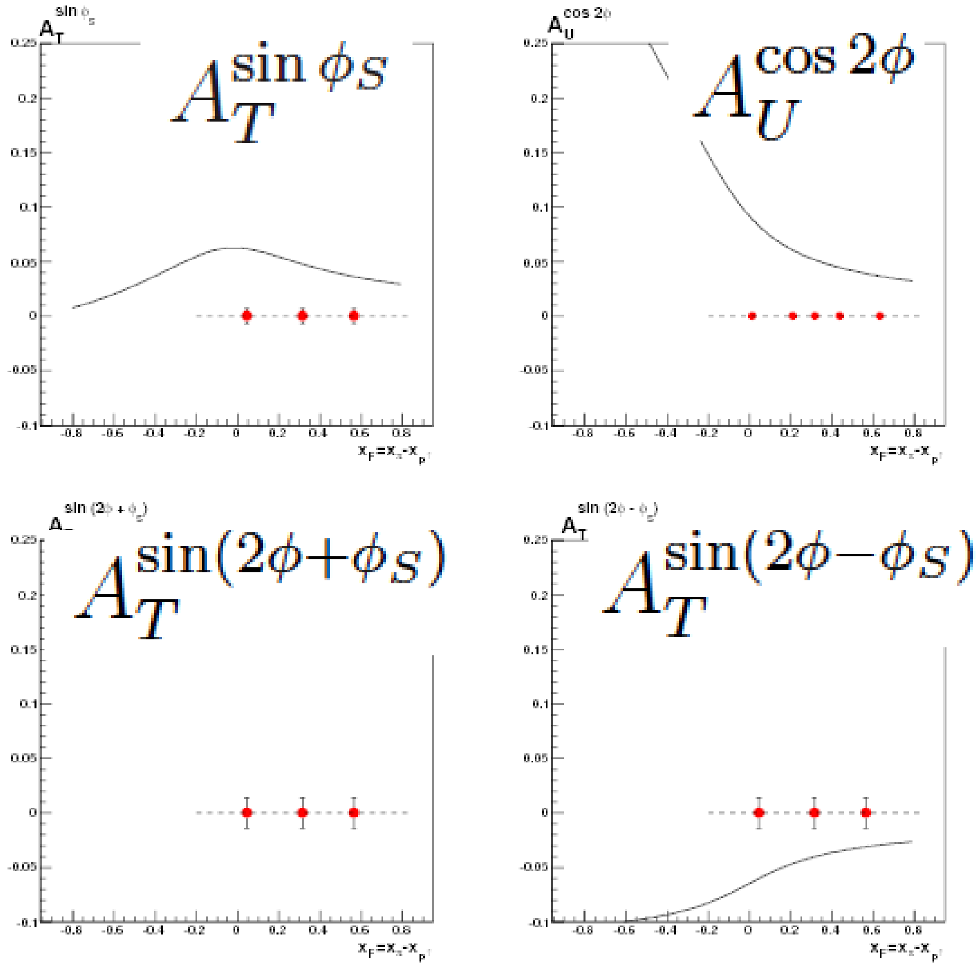
– short-dashed: Bacchetta et al, PRD78(2008)074010.




COMPASS DY beam test 2009
J/ψ
3170±70 events
M=3.092±0.005 GeV
σM=0.227±0.004 GeV
Preliminary
M, GeV
0
1
2
3
4
5
6
7
1
10
10^2
10^3
(HMR)
eV/c^2

DY@COMPASS projections III

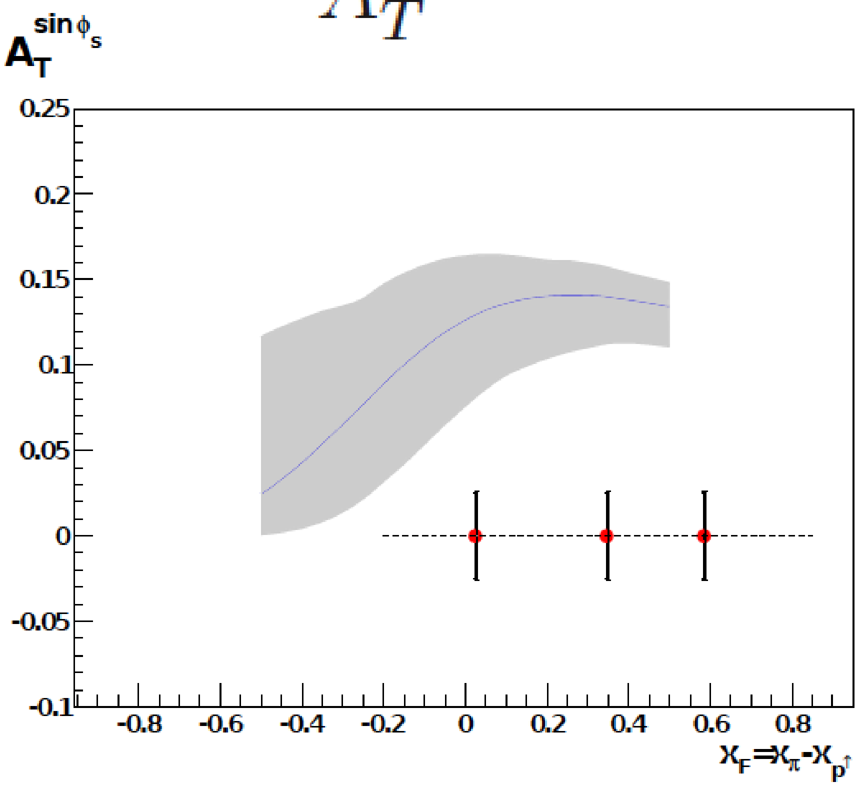
J/ψ region: $2.9 \leq M_{\mu\mu} \leq 3.2$ GeV/c^2



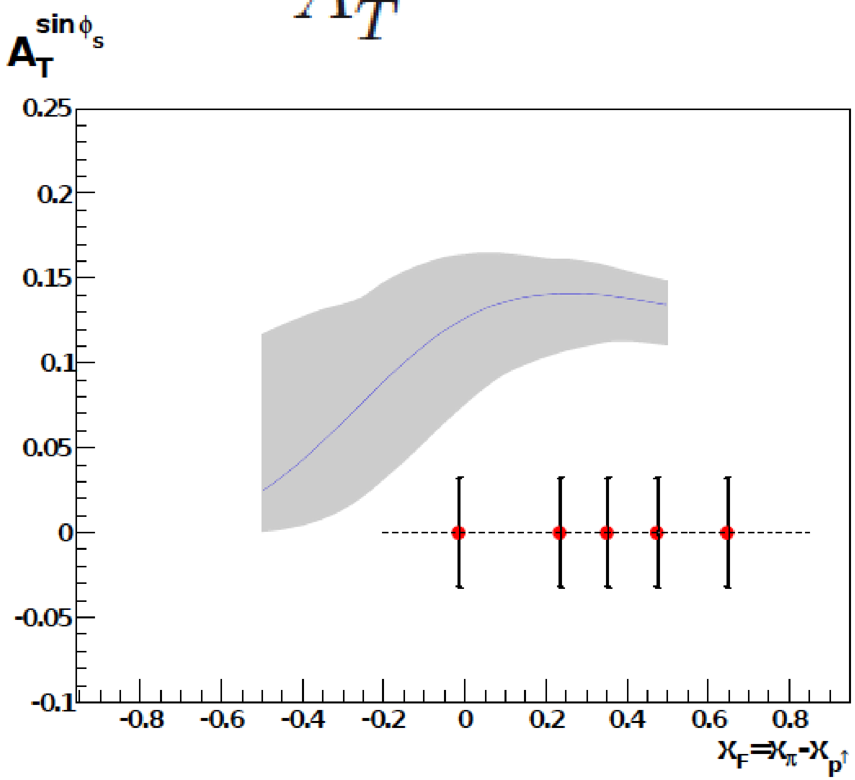
DY@COMPASS projections IV

$$(\text{HMR}): 4. \leq M_{\mu\mu} \leq 9.\ \text{GeV}/c^2$$

$A_T^{\sin\phi_S}$



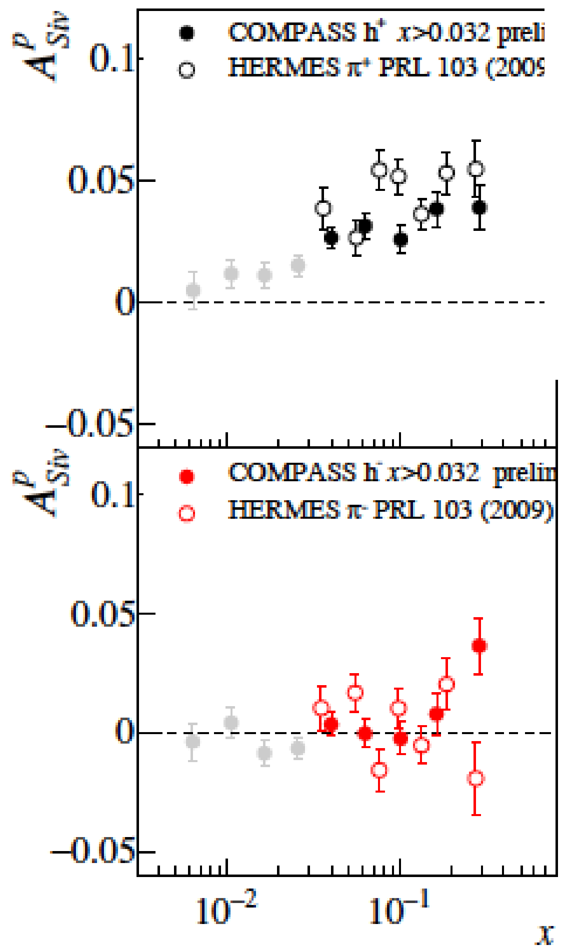
$A_T^{\sin\phi_S}$

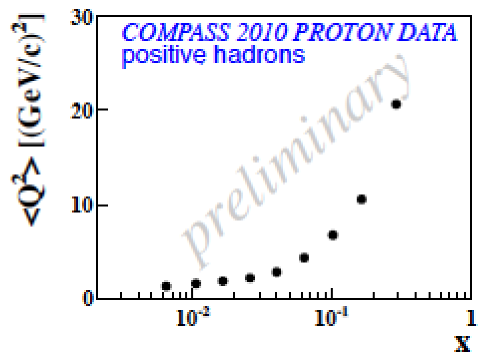


SIDIS←→DY – QCD test

VERY IMPORTANT – Kinematics compatibility SIDIS←→ DY

As it was stressed many times during the recent Drell-Yan workshop at BNL (May 11-13 2011) for the conclusive test of the Sivers function sign change from SIDIS to Drell-Yan one has to perform the measurement in the overlapping kinematical ranges (HERMES Q^2_{max}~3.5 GeV ^{2}, 0.032 < x_P <0.3, COMPASS Q^2_{max} ~20 GeV^2, 0.001 < x_P <0.3).
In this sense DY@COMPASS is the ideal case. Drell-Yan at COMPASS <Q^2>~25 GeV^2, 0.05 < x_P <0.4





Drell-Yan COMPASS <Q^2>~25 GeV^2, 0.05 < x_B <0.4

AT the next analysis meeting we will release DY <Q^2> values vs. $x_{B.Proton}$

COMPASS Running until 2016 III

Decision by the Collaboration on tentative running schedule (April, 2011):

2014-2016

Tentative schedule

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

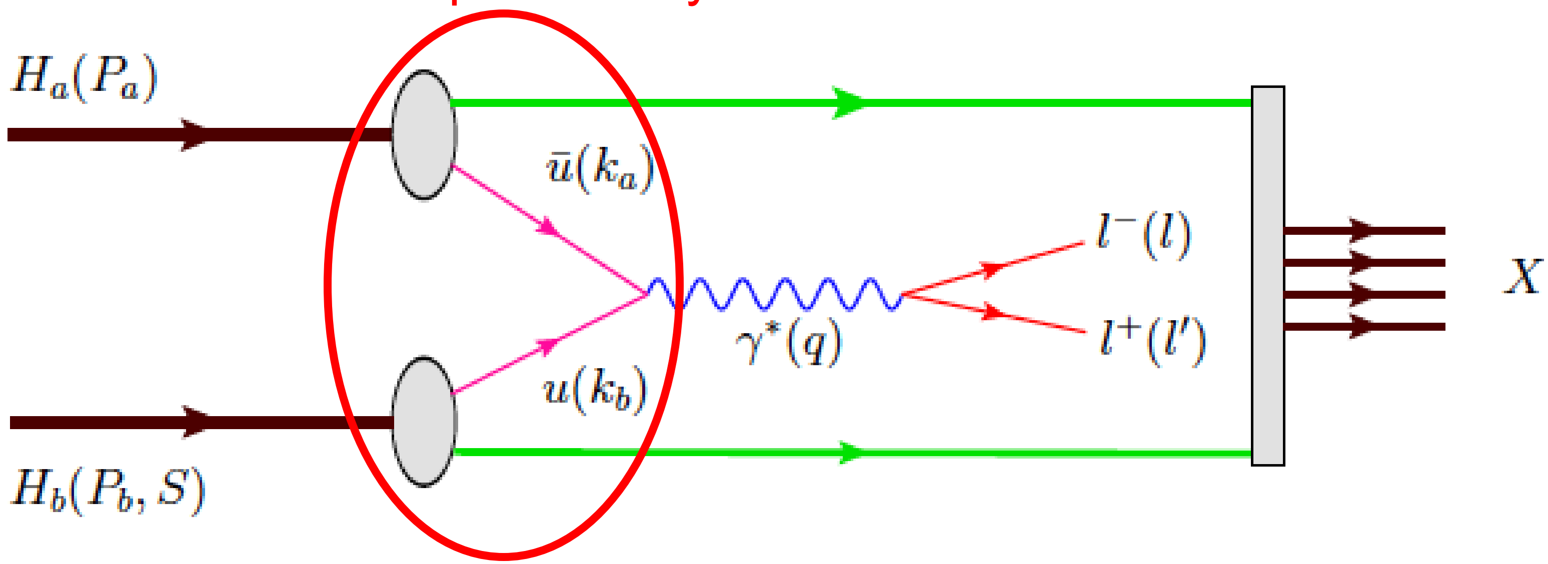
End of 2013 – short DY test very desirable

2013 Long shut down necessary for PT mouvement and installation

→ Agreed upon

What is common:
Willing to measure the Sivers asymmetry in a polarised Drell-Yan process
What is different:

- feasibility study level (COMPASS – mostly engineering challenge)
- Instrumentation
- $\sqrt{s}$ ~18 GeV ←→ 500 GeV
- Two complementary measurements



COMPASS: Summary

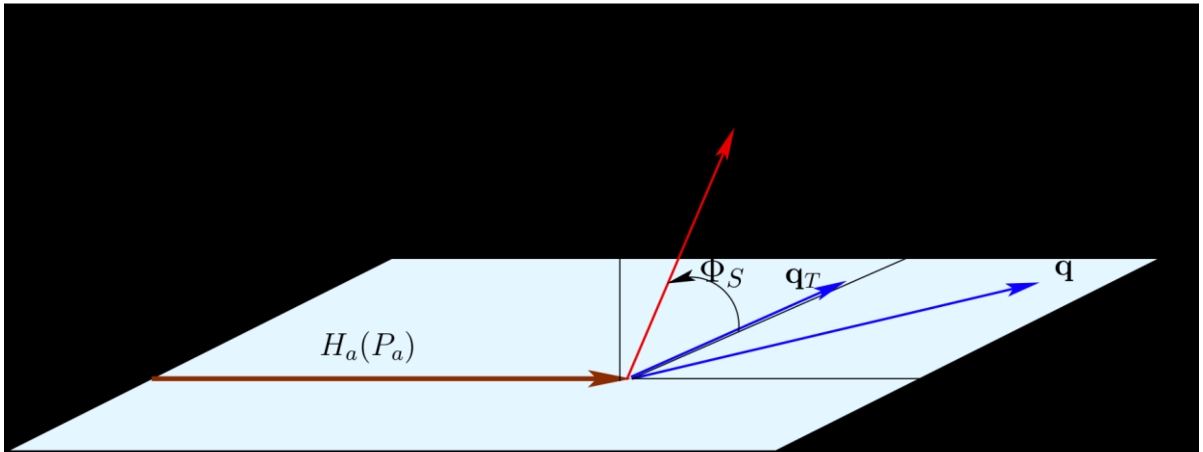
- Pion and, later probably antiproton beams (50-200 GeV)
- Drell-Yan process dominated by the contribution from the valence quarks (both beam and target), $\tau = x_1 x_2 = Q^2/s \cong 0.05 \div 0.4$
- Solid state polarised targets, NH_3 and ^6LD, in case of hydrogen target
- Statistical error on single spin asymmetries after one year of running is on the level 1÷2%
- At the Paris'11 Collaboration meeting the decision was taken to run Drell-Yan experiment at 2014
- Looking at the huge activity in the sector a lots of new DY data is just behind the corner

- Spares

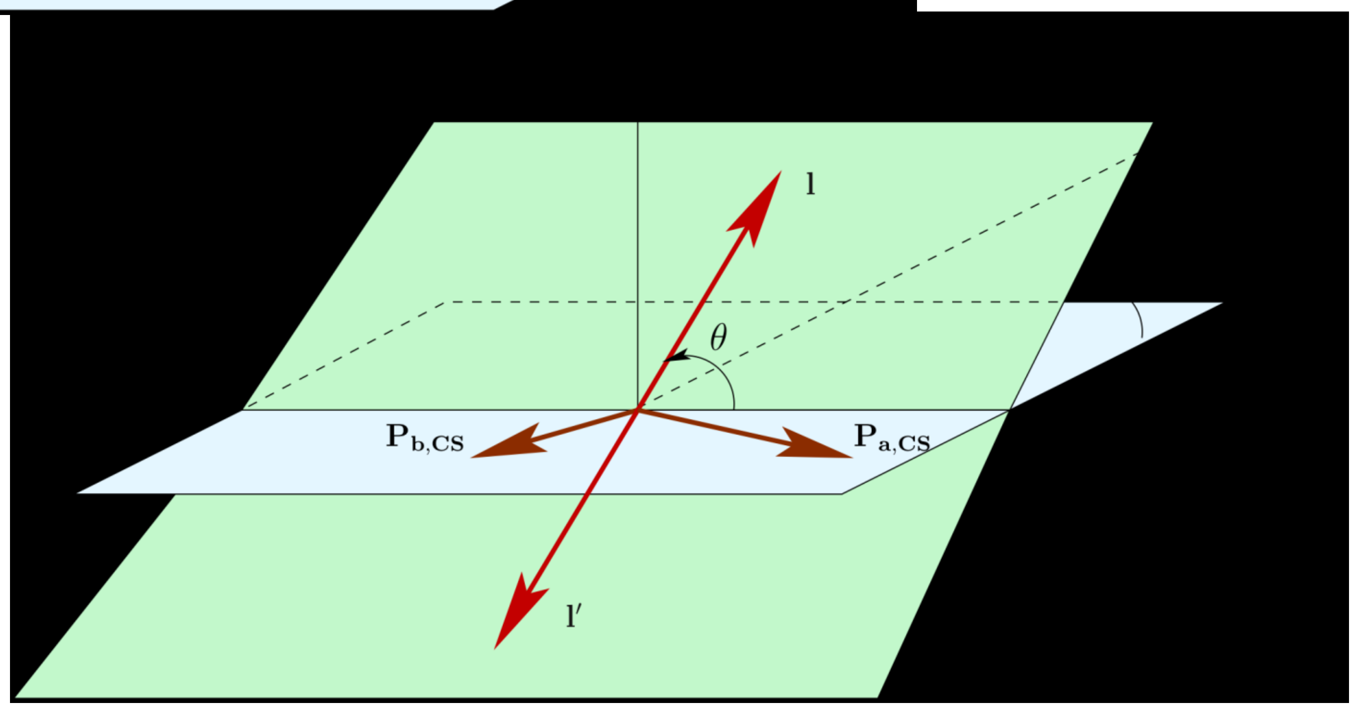
TMDs at Drell-Yan: road map

- 2010 – COMPASS polarised SIDIS data (Sivers, transversity via global data fit)
- 2010 – 2013? E906 (SeaQuest) – pp Drell-Yan – Boer-Mulders of the proton
- 2013 - 2016 COMPASS polarised Drell-Yan pi-p data – TMDs universality and T-odd TMDs sign change SIDIS←→DY (for Boer-Mulders funtion study the input from E906 as well as new transversity fit from the global data analysis is very welcome)
- 2015 → …… RHIC, NICA pp (un)polarised DY data – very welcome – complimentary to COMPASS
- 2017 → more COMPASS data, antiprotons?.....
- MANY NEW data - just behind the corner

Coordinate systems



TF



Collins-Soper

Drell-Yan Workshop at CERN, April 26-27

Studying the hadron structure in Drell-Yan reactions

26-27 April 2010 *CERN*

Since a long time the Drell-Yan (DY) process is considered to be a powerful tool to study hadron structure. In the past, several experiments were successfully carried out using unpolarised beams and targets. Nowadays, taking into account the much advanced understanding of the spin structure of the nucleon, we are discussing a new generation of DY measurements using polarised beams and/or targets.

The COMPASS collaboration is currently preparing a proposal for future studies of nucleon structure beyond 2011. One of the main aims is a first measurement of transverse-momentum-dependent parton distributions (TMDs) using the Drell-Yan process on a transversely polarised proton target hit by a pion beam. Among the distributions to be studied are Sivers, Boer-Mulders and pretzelosity TMDs as well as transversely polarised quark distributions.

The workshop will review ongoing theoretical and experimental efforts related to the Drell-Yan process. Detailed presentations and discussions of the theoretical aspects will be complemented by descriptions of planned fixed-target and collider experiments.

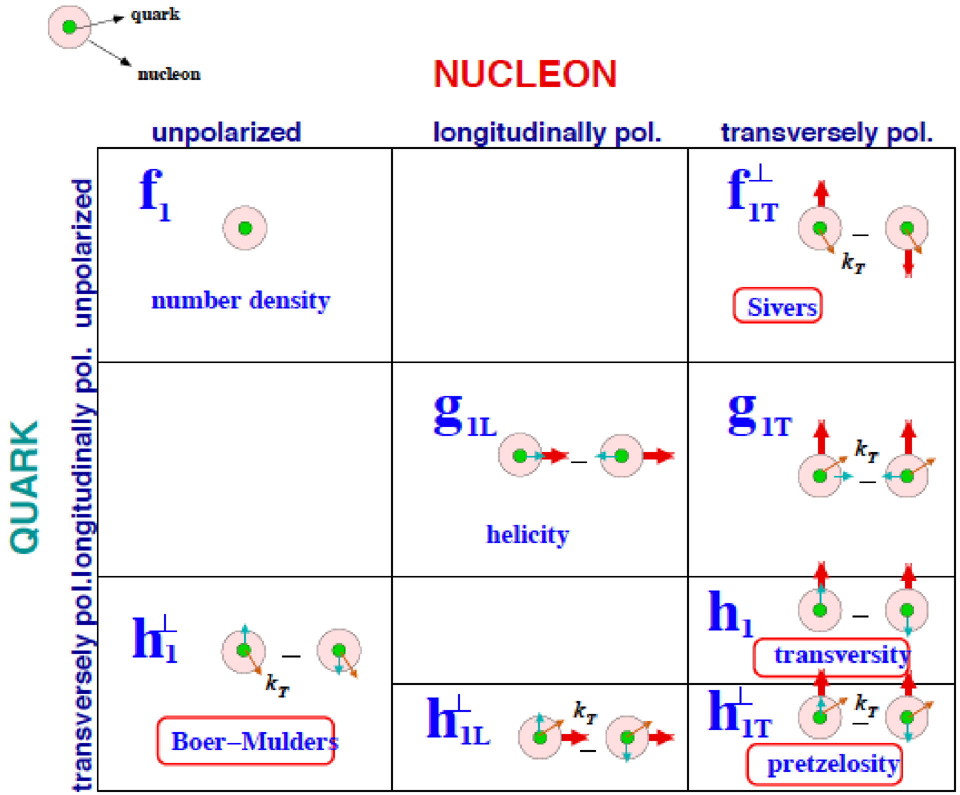
Organizers: Paula Bordalo (LIP-Lisbon and IST/UTL)
Oleg Denisov (CERN/INFN-Torino)
Eva-Maria Kabuss (Mainz)
Fabienne Kunne (CEA Saclay)
Alain Magnon (CEA Saclay)
Gerhard Mallot (CERN)
Anna Martin (Univ. Trieste and INFN-Trieste)
Wolf-Dieter Nowak (CERN)
Daniele Panzieri (Univ. Alessandria and INFN-Torino)

Dates: from 26 April 2010 09:00 to 27 April 2010 18:00

Location: *CERN*
Salle Andersson
Room: 40-S2-A01

Parton distribution functions

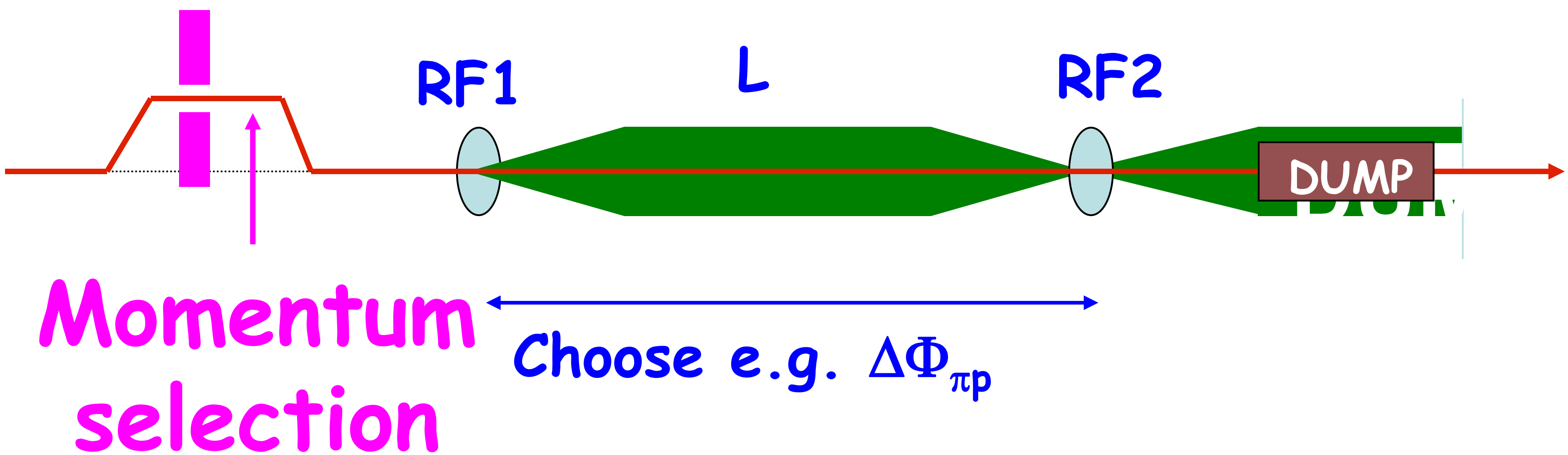
Taking into account the intrinsic transverse momentum k_T of quarks, at LO **8 PDFs** are needed for a full description of the nucleon:



WHAT ABOUT A RF SEPARATED $\bar{p}$ BEAM ???

First and very preliminary thoughts, guided by
- recent studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g. http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

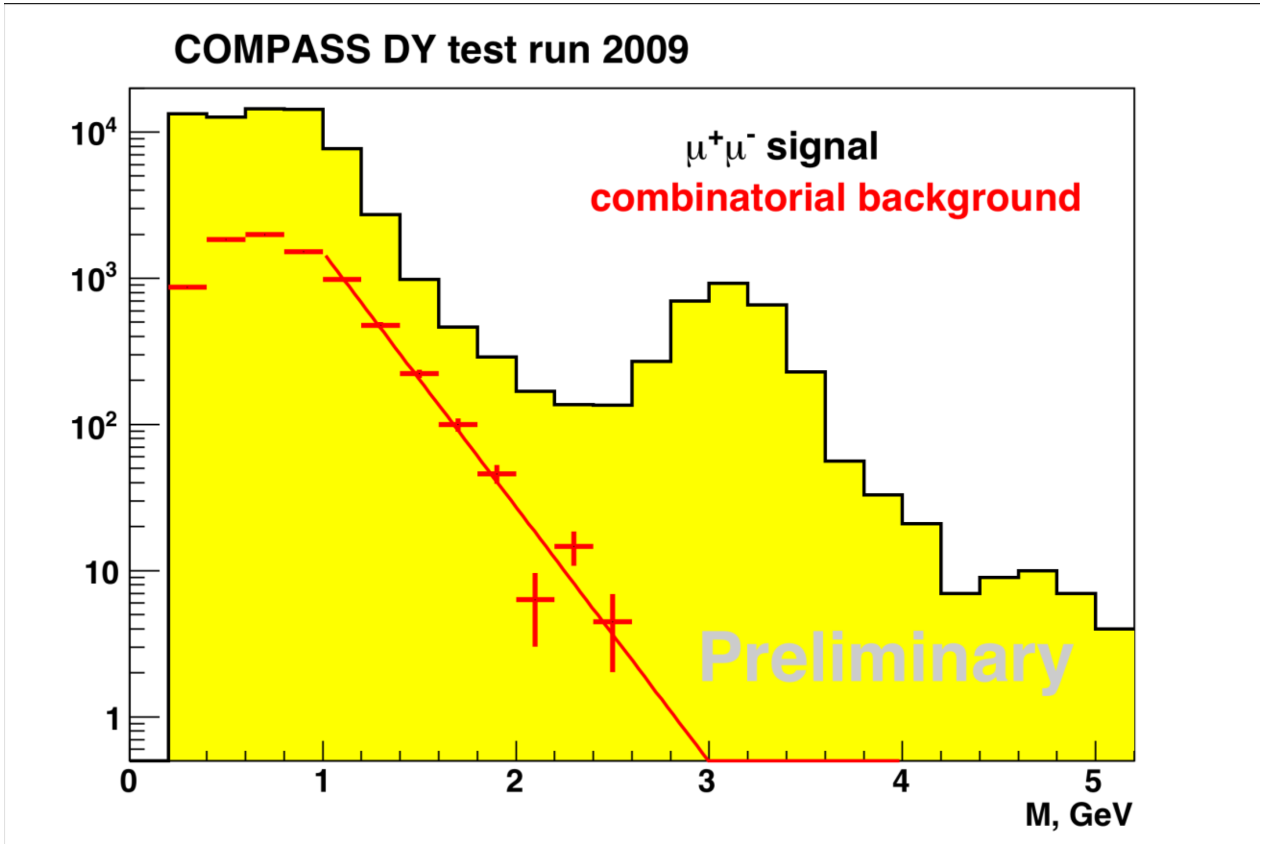
E.g. a system with two cavities:



$$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

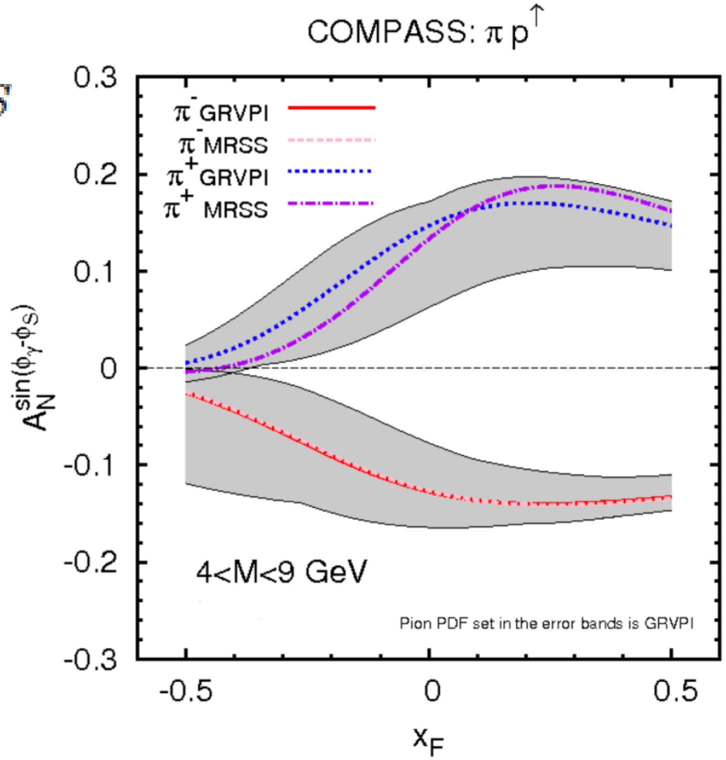
DY@COMPASS - feasibility – Background II – Combinatorial

- 2009 beam test id very important
- Combinatorial background suppressed by ~10 at 2.0 GeV/c dimuon invariant mass (beam intensity ~8 times lower wrt Proposal)



DY@COMPASS uncertainty coming from the pion PDFs

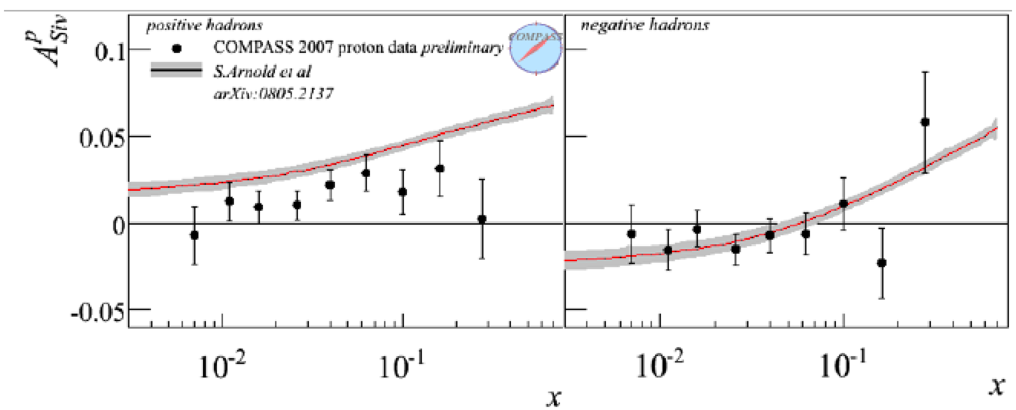
$A_T^{\sin \phi_S}$

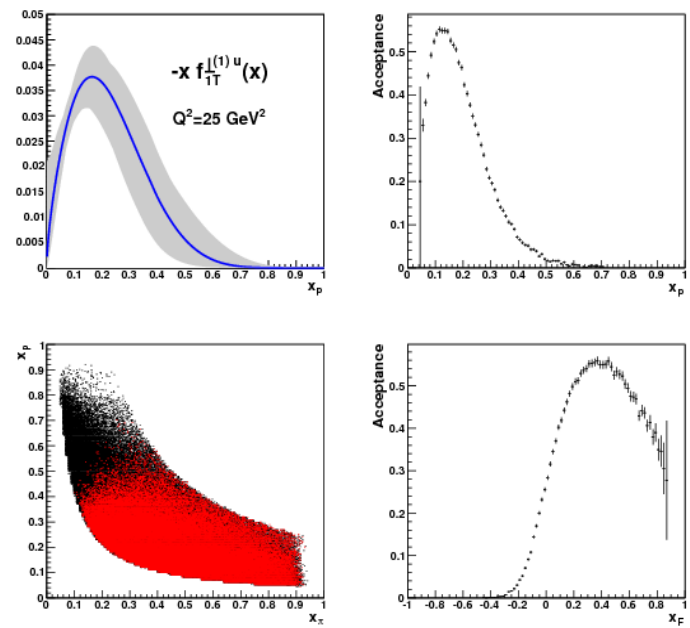


In case of $\pi^- p$ scattering the valence pion $\bar{u}$ unpolarised PDF is well known and there is no difference between two pdf sets. In case of $\pi^+ p$ scattering there is a little contamination coming from sea $\bar{u}$ of the pion, which annihilates with valence u quark of the proton, because the distribution functions are weighted in the cross section with e_q^2, and the $\bar{u}u$ contribution is multiplied by factor 4/9 while the $\bar{d}d$ by factor 1/9. Thus, the contribution from the sea $\bar{u}$ of the pion can not be neglected, it is less known with respect to valence PDFs and it explains the difference from one data set (GRVPI) to another (MRSS).

DY@COMPASS ➔ SIDIS complemenatrity

- TMD PDFs study in SIDIS is an important part of the COMPASS-I program
- COMPASS-II, TMDs study in Drell-Yan processes:
  - We change the probe (elementary process)
  - We upgrade the spectrometer and we change its lay-out
  - We change the kinematic range





Some indications for the future Drell-Yan experiments

$$\delta A = \frac{1}{P_b f} \frac{1}{\sqrt{N_{sig}}} \sqrt{1 + \frac{N_{sig}}{N_{backg}}}$$

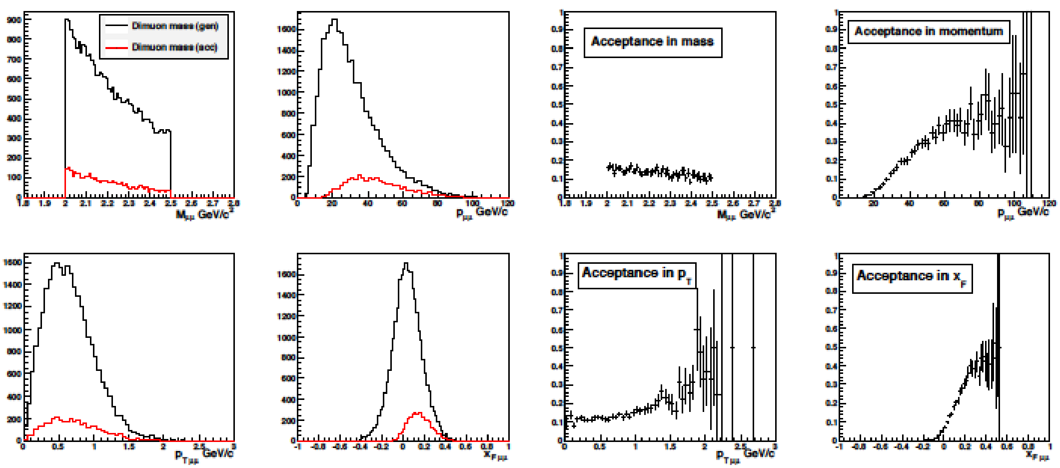
$$\tau = x_a x_b = M^2/s$$

1. Drell-Yan experiments:
   - High luminosity (DY Cross Section is a fractions of nanobarns) and large angular acceptance, better pion or antiproton beams (valence anti-quark)
   - Sufficiently high energy to access 'safe' of background free M_{ll} range (4 GeV/c < M_{ll} < 9 GeV/c)
   - Good acceptance in the valence quark range $x_B > 0.05$ and kinematic range: $\tau = x_A x_B = M^2/s > 0.1$
2. Polarised Drell-Yan:
   - Good factor of merit (F_m), which can be represented as a product of the luminosity and beam (target) polarisation (dilution factor) ($F_m \sim L \times P_{beam}\ (f)$)

DY@COMPASS - feasibility – Background I – D-Dbar

- Calculated by MC
- Negligible in both HM and IM ranges (~15% contribution in IM)

Acceptance for open-charm 2.0 - 2.5 GeV/c^2



As in the IMR the acceptances are 14% for open-charm and 43% for DY, the ratio of observable events in the dimuon mass spectra will be

$N_{DD}/N_{DY} = (5.47 \times 0.14)/(12.46 \times 0.43) = 0.14$.

Sivers, Boer-Mulders functions SIDIS ←→ DY

QCD

↓

$\sigma_h \cong \sigma_p \times \text{PDF}$

↓

Direction of the gauge-link of the k_T dependent PDF is process-dependent (gauge-link is resummation of all collinear soft gluons) and it changes to the opposite in SIDIS wrt DY

↓

QCD factorization, valid for hard processes only (Q, q_T are large)

Cross-sections are gauge-invariant objects, to provide the gauge invariance of the PDFs the gauge-link was introduced (intrinsic feature of PDF). The presence of gauge-link provides the possibility of existence of non-zero T-odd TMD PDFs

Sivers and Boer-Mulders functions are T-odd, and to provide the time-invariance they change the sign in SIDIS wrt DY due to the opposite direction of the gauge-link

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

J. Collins, talk at LIGHT CONE 2008