Study of hadron structure using Drell-Yan scattering

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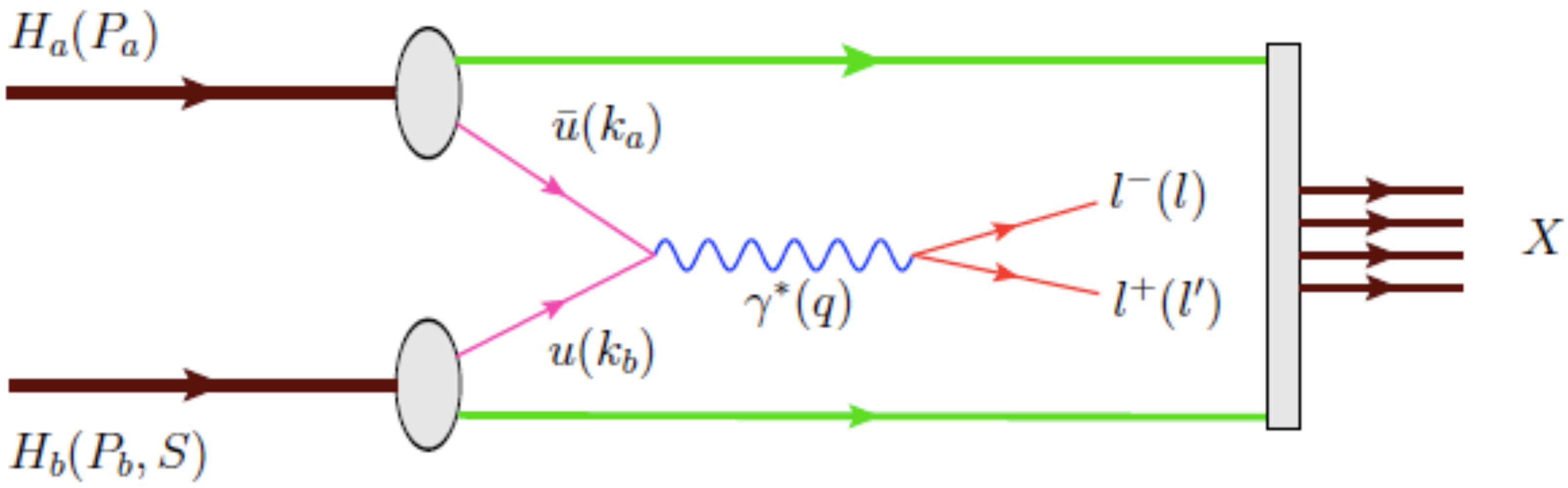
Outline

- Drell-Yan process, status of the theory
- Drell-Yan, polarised case
- Transversity & TMD PDFs:
  - Proton description at LO
  - TMDs factorisation and universality – crucial test of modern QCD
- Unpolarised pion Drell-Yan:
  - Pion PDFs
  - EMC effect in DY
  - Sea quark distributions
- TMDs study – choice of kinematic domain
- Upcoming/started DY experiments:
  - E906 @ FermiLab
    - Unpolarised proton induced DY
    - Future polarised DY experiment
  - Polarised DY@COMPASS
    - Set-up
    - Kinematics & Projections
  - RHIC?
- Some conclusions

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

Direct extraction of transversity and its accompanying T-odd distribution from the unpolarized and single-polarized Drell-Yan processes

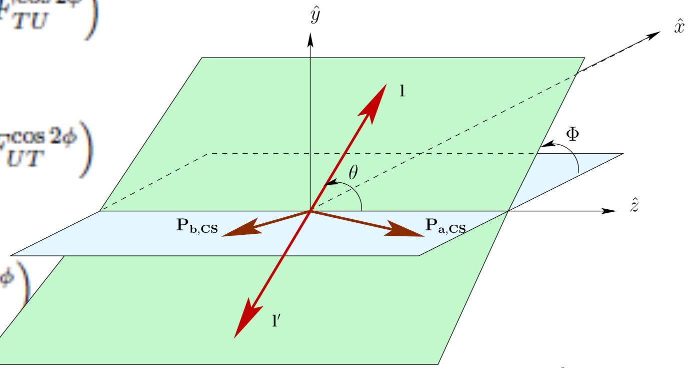
A.N. Sissakian,* O.Yu. Shevchenko,† A.P. Nagaytsev,‡ and O.N. Ivanov§
Joint Institute for Nuclear Research, 141980 Dubna, Russia

Phys. Rev. D72 (2005) 054027

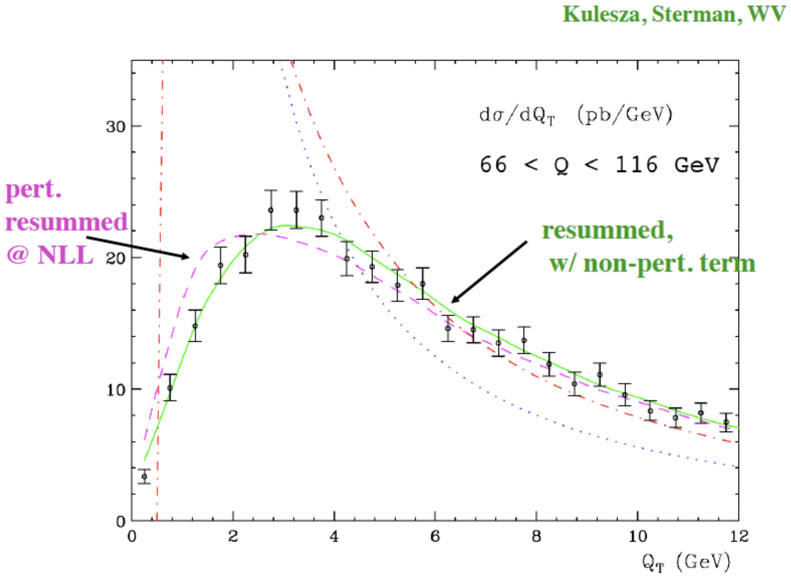
$$\frac{d\sigma^{(1)}(H_1 H_2^{\uparrow} \to l\bar{l}X)}{d\Omega d\phi_{S_2} dx_1 dx_2 d^2\mathbf{q}_T} = \frac{\alpha^2}{12Q^2}\sum_q e_q^2$$
$$\times\Big\{(1+\cos^2\theta)\mathcal{F}[\bar{f}_{1q} f_{1q}] + \sin^2\theta\cos(2\phi)$$
$$\times\mathcal{F}\left[(2\hat{\mathbf{h}}\cdot\mathbf{k}_{1T}\,\hat{\mathbf{h}}\cdot\mathbf{k}_{2T} - \mathbf{k}_{1T}\cdot\mathbf{k}_{2T})\frac{\bar{h}_{1q}^{\perp} h_{1q}^{\perp}}{M_1 M_2}\right]$$
$$+(1+\cos^2\theta)\sin(\phi-\phi_{S_2})\mathcal{F}\left[\hat{\mathbf{h}}\cdot\mathbf{k}_{2T}\frac{\bar{f}_1^q f_{1T}^{\perp q}}{M_2}\right]$$
$$-\sin^2\theta\sin(\phi+\phi_{S_2})\mathcal{F}\left[\hat{\mathbf{h}}\cdot\mathbf{k}_{1T}\frac{\bar{h}_{1q}^{\perp} h_{1q}}{M_1}\right]\Big\}.$$

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

$$\frac{d\sigma}{d^4q\, d\Omega} = \frac{\alpha_{em}^2}{F\, q^2}\times$$
$$\Big\{\Big((1+\cos^2\theta)\,F_{UU}^1 + (1-\cos^2\theta)\,F_{UU}^2 + \sin 2\theta\cos\phi\,F_{UU}^{\cos\phi} + \sin^2\theta\cos 2\phi\,F_{UU}^{\cos 2\phi}\Big)$$
$$+\ S_{aL}\Big(\sin 2\theta\sin\phi\,F_{LU}^{\sin\phi} + \sin^2\theta\sin 2\phi\,F_{LU}^{\sin 2\phi}\Big)$$
$$+\ S_{bL}\Big(\sin 2\theta\sin\phi\,F_{UL}^{\sin\phi} + \sin^2\theta\sin 2\phi\,F_{UL}^{\sin 2\phi}\Big)$$
$$+\ |\vec{S}_{aT}|\Big[\sin\phi_a\Big((1+\cos^2\theta)\,F_{TU}^1 + (1-\cos^2\theta)\,F_{TU}^2 + \sin 2\theta\cos\phi\,F_{TU}^{\cos\phi} + \sin^2\theta\cos 2\phi\,F_{TU}^{\cos 2\phi}\Big)$$
$$+\cos\phi_a\Big(\sin 2\theta\sin\phi\,F_{TU}^{\sin\phi} + \sin^2\theta\sin 2\phi\,F_{TU}^{\sin 2\phi}\Big)\Big]$$
$$+\ |\vec{S}_{bT}|\Big[\sin\phi_b\Big((1+\cos^2\theta)\,F_{UT}^1 + (1-\cos^2\theta)\,F_{UT}^2 + \sin 2\theta\cos\phi\,F_{UT}^{\cos\phi} + \sin^2\theta\cos 2\phi\,F_{UT}^{\cos 2\phi}\Big)$$
$$+\cos\phi_b\Big(\sin 2\theta\sin\phi\,F_{UT}^{\sin\phi} + \sin^2\theta\sin 2\phi\,F_{UT}^{\sin 2\phi}\Big)\Big]$$
$$+\ S_{aL}\,S_{bL}\Big((1+\cos^2\theta)\,F_{LL}^1 + (1-\cos^2\theta)\,F_{LL}^2 + \sin 2\theta\cos\phi\,F_{LL}^{\cos\phi} + \sin^2\theta\cos 2\phi\,F_{LL}^{\cos 2\phi}\Big)$$

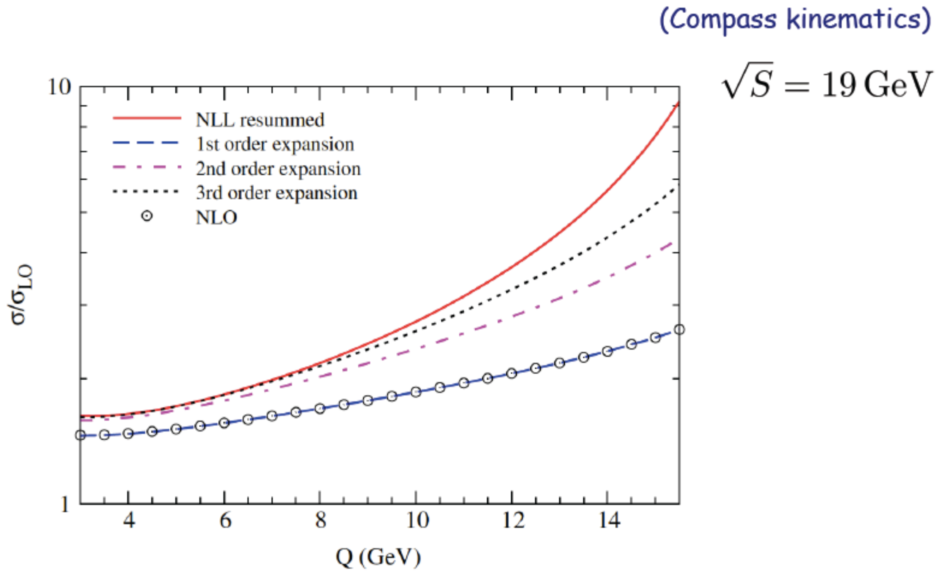


Pion-induced DY, DY Cross section calculations theoretical calculations - COMPASS



Aicher et al. (PRL 105, 252003 (2010))

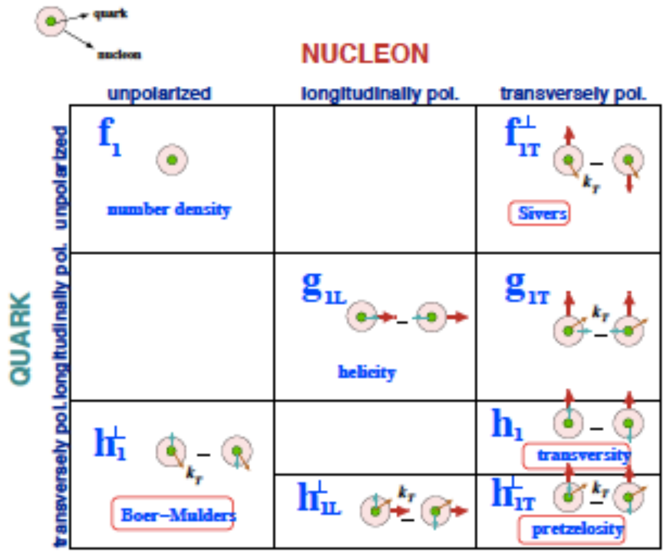
Very big progress recently achieved: NLO threshold re-summation mechanism with non - perturbative term (Vogelsang and collaborators) - good experimental data description – K-factor issue is not there anymore



Aicher, Schäfer, WV
(earlier studies: Shimizu, Sterman, WV, Yokoya)

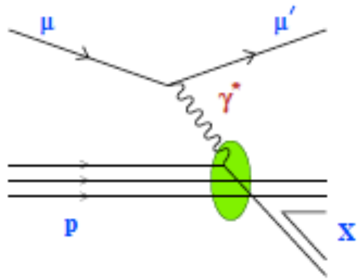
Leading Order PDFs

In LO, 8 Transverse Momentum Dependent PDFs (TMDs) are needed to describe the nucleon structure when the intrinsic transverse momentum is taken into account:

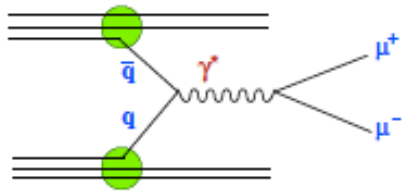


The highlighted TMDs can be studied using an un-polarized or a transversely polarized target

- From semi-inclusive DIS



- From Drell-Yan



By measuring the Single Transverse Spin Asymmetries (SSA) in these processes one can access the correlations between the partons $\mathbf{k}_T$ and the nucleon **spin**.

Were we studying TMD PDFs?

So far we were doing SIDIS thinking that we are studying the structure of the nucleon, no proof so far (artefact of our analysis tools or some different physics: higher twist or so)….

In order to obtain an important and convincing proof we have to change the “probe” ➔ the physics process we are using to access the nucleon structure. We have to go to Drell-Yan and see whether we see the similar effects and we can describe them in the framework of the TMD formalism and if the TMDs as we see them in DY are the same as in SIDIS.

Actually it was explicitly written in a very first version of the COMPASS DY proposal which was written by O.Teryaev and myself in the very beginning of 2005.

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

Sivers, Boer-Mulders functions SIDIS ←→ DY

QCD

$\sigma_h \cong \sigma_p \times$ 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

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

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

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

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

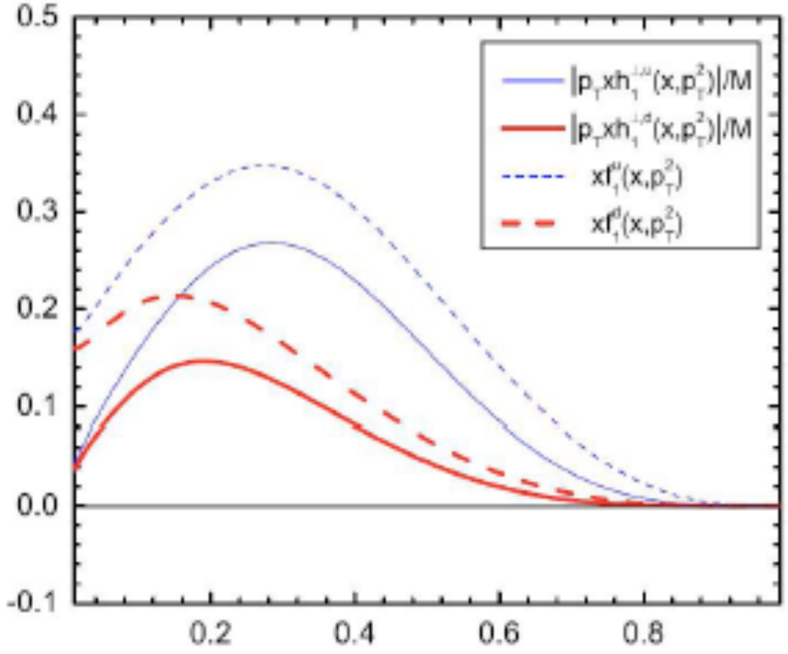
    → CSS resummation in Drell-Yan (Collins, Soper, Sterman, 1985); resum logarithms of the type

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

→ Has also implications for Fermilab and LHC physics

Some indications for the future Drell-Yan experiments

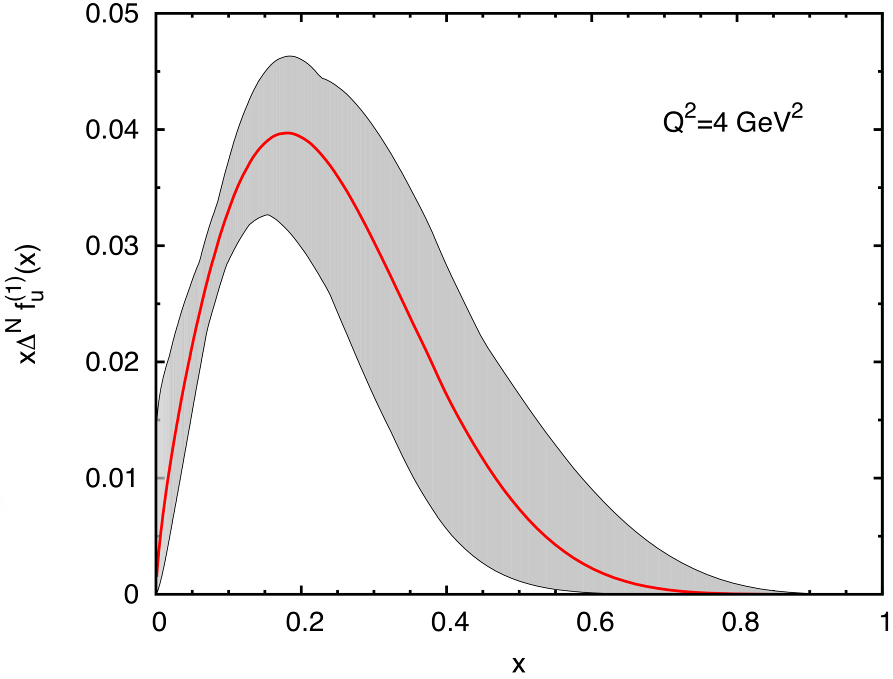
1. TMD PDFs – ALL are sizable in the valence quark region



► Boer-Mulder function for u and d quarks

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.

Pion-induced unpolarised DY, Pion structure functions I

The only way to access pion PDFs

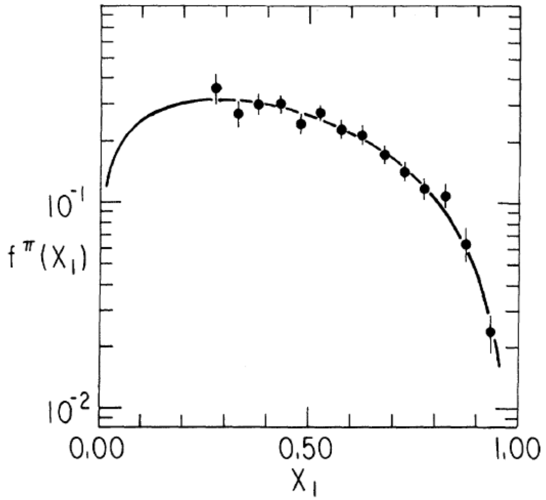
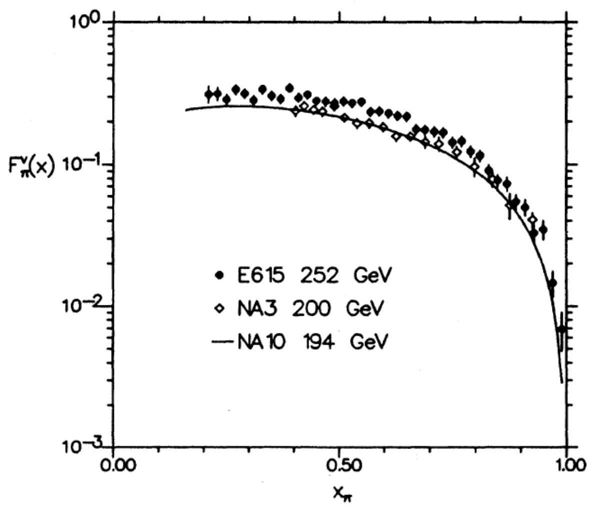


FIG. 3. The pion structure function $f^{\pi}(x_1) = x_1 \bar{u}^{\pi^-}(x_1)$.

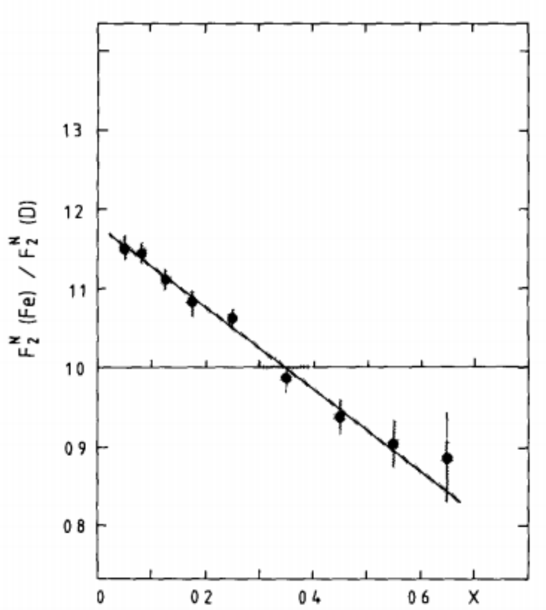
CIP (PRL 42, 951, (1979))



E615 (PRD 39, 92 (1989)):

Pion-induced unpolarised DY, flavour-dependent EMC effect I

EMC effect - experiment



Cloet et. al (PRL 102, 252301, 2009):
Flavor dependence of the EMC effects ?

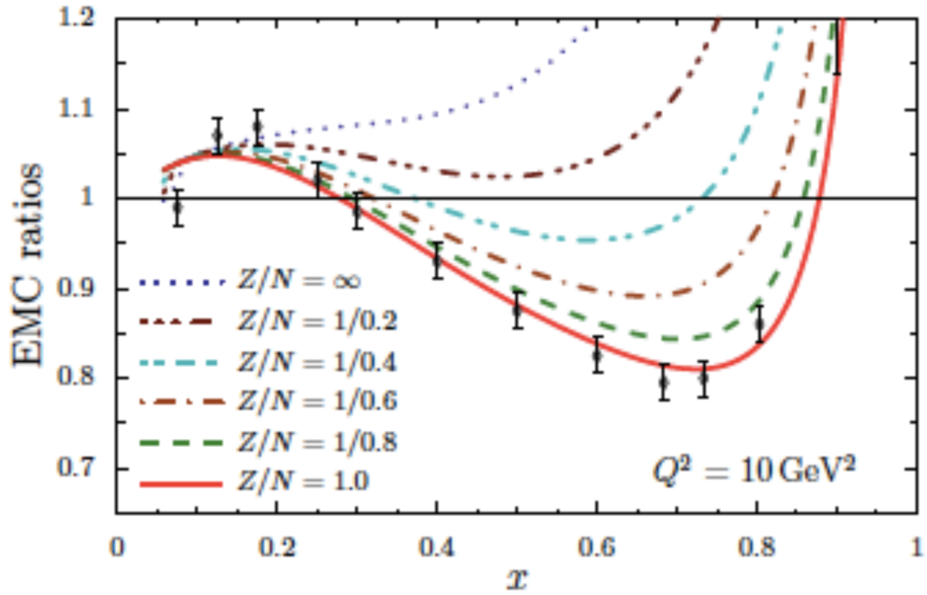
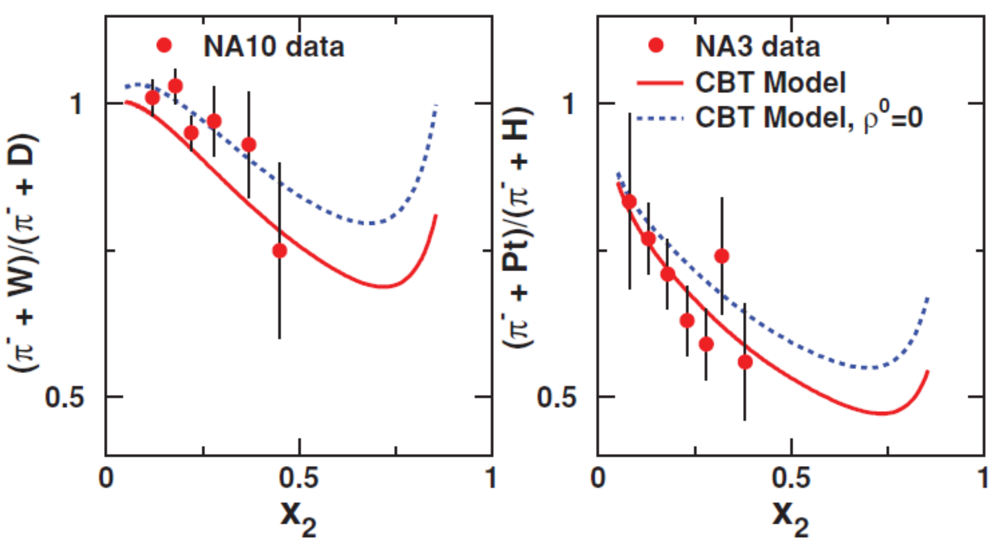


FIG. 1: Isospin dependence of the EMC effect for proton-neutron ratios greater than one. The data is from Ref. [24] and corresponds to $N = Z$ nuclear matter.

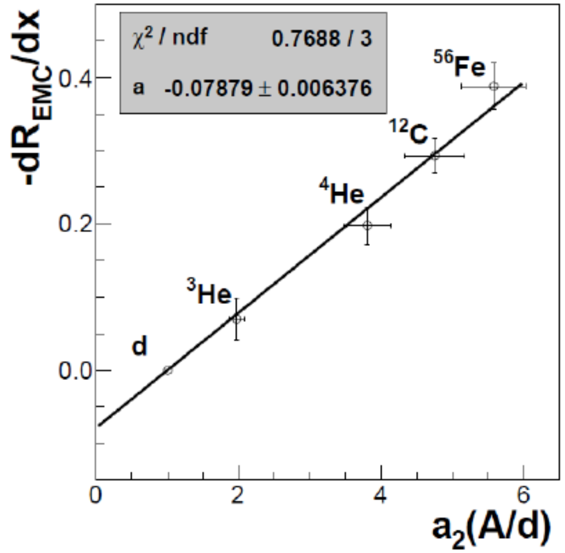
The isovector ρ^0 mean-field generated in Z≠N nuclei can modify nucleon's *u* and *d* PDFs in nuclei.

Pion-induced unpolarised DY, flavour-dependent EMC effect II

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



Dutta et al. (PRC 83, 042201, 2011):
Pion-induced Drell-Yan and the flavor-dependent EMC effect



SRC is related with isoscalar p-n interaction.
→ NO flavor-dependence of EMC effect

Weinstein et al. (PRL 106 , 052301 (2011)):
EMC & Short Range Correlation (SRC)

Sea quarks contribution study

Light Antiquark Flavor Asymmetry: Brief History

- NMC (Gottfried Sum Rule)

$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$

- NA51 (Drell-Yan)

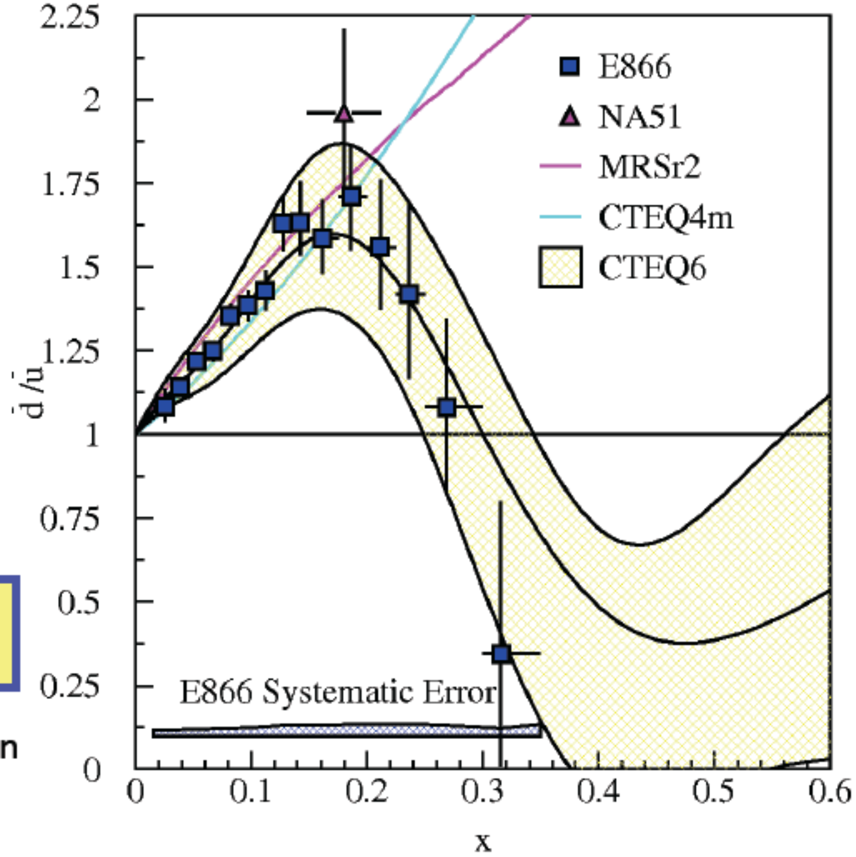
$\bar{d} > \bar{u}$ at $x = 0.18$

- E866/NuSea (Drell-Yan)

$\bar{d}(x)/\bar{u}(x)$ for $0.015 \leq x \leq 0.35$

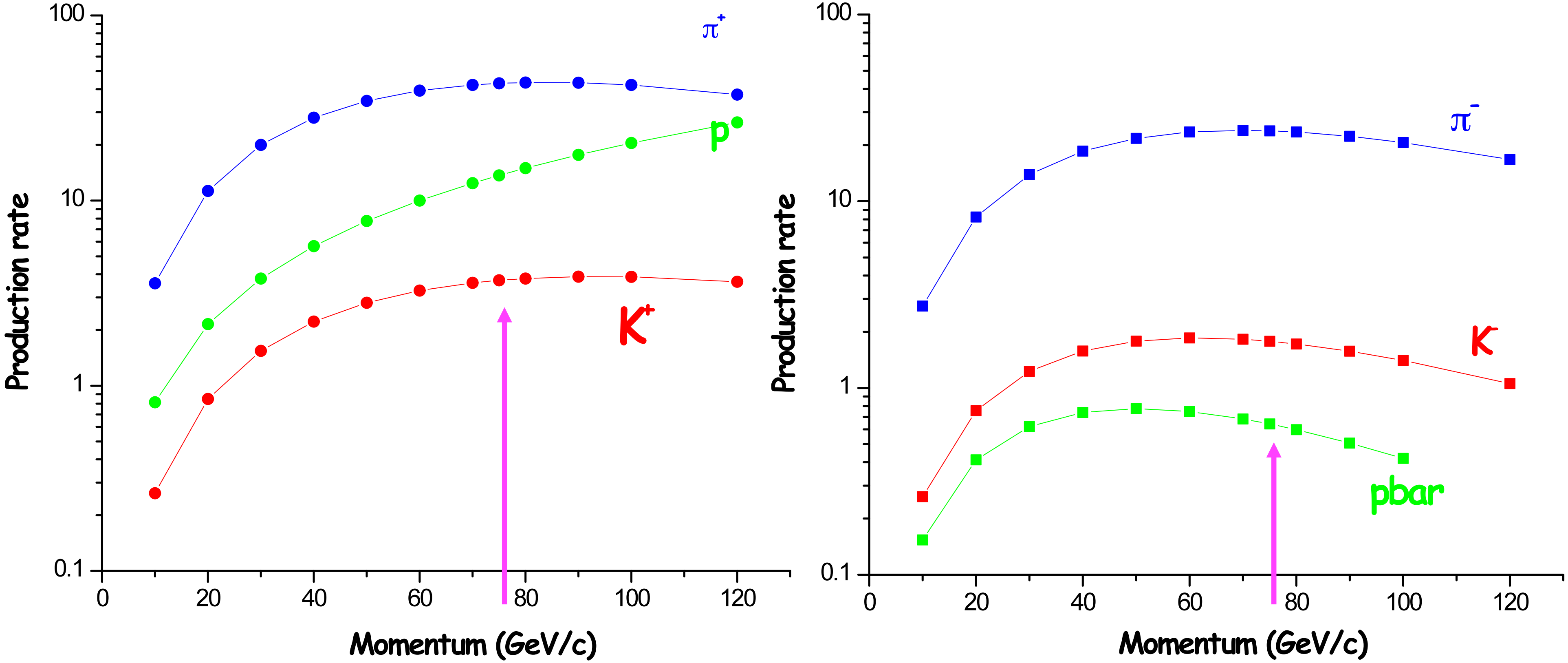
- **Knowledge of sea dist. are data driven**
  - Sea quark distributions are difficult for Lattice QCD

- Non perturbative QCD models can explain excess d-bar quarks, but not return to symmetry or deficit of d-bar quarks



Kaon and Antiproton induced Drell-Yan I,
Case of secondary SPS hadron beams

Particle production at 0 mrad



E906 Drell-Yan experiment at FermiLab (materials by Paul E. Reimer)

Advantages of 120 GeV Main Injector

The (very successful) past:

Fermilab E866/NuSea

- Data in 1996-1997
- ^1H, ^2H, and nuclear targets
- 800 GeV proton beam

The future:

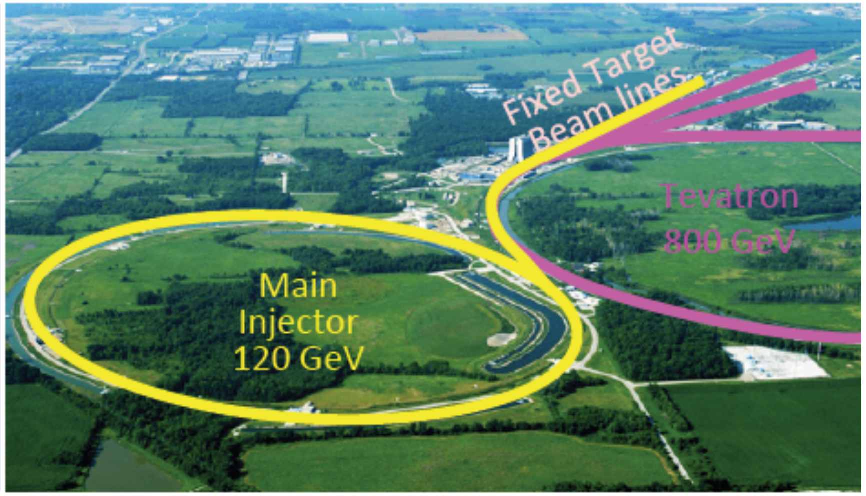
Fermilab E906

- First test run in 2011
- ^1H, ^2H, and nuclear targets
- 120 GeV proton Beam

$$\frac{d^2\sigma}{dx_t dx_b} = \frac{4\pi\alpha^2}{9x_t x_b}\frac{1}{s}\sum e^2\left[\bar{q}_t(x_t)\,q_b(x_b) + q_t(x_t)\,\bar{q}_b(x_b)\right]$$

- Cross section scales as 1/s
  - *7× that of 800 GeV beam*
- Backgrounds, primarily from J/ψ decays scale as s
  - *7× Luminosity for same detector rate as 800 GeV beam*

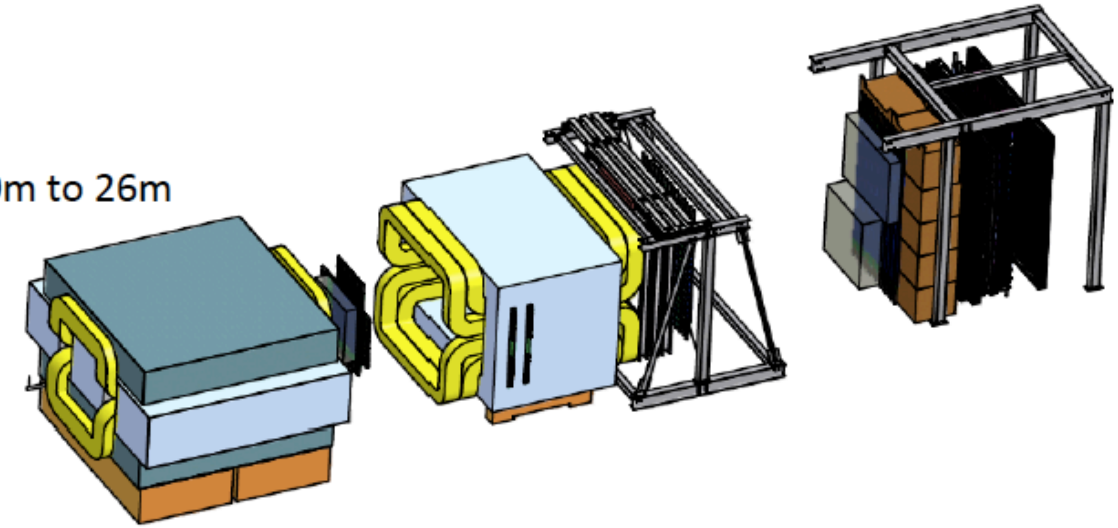
50× statistics!!



E906 Drell-Yan experiment at Fermilab

Drell-Yan Spectrometer Guiding Principles

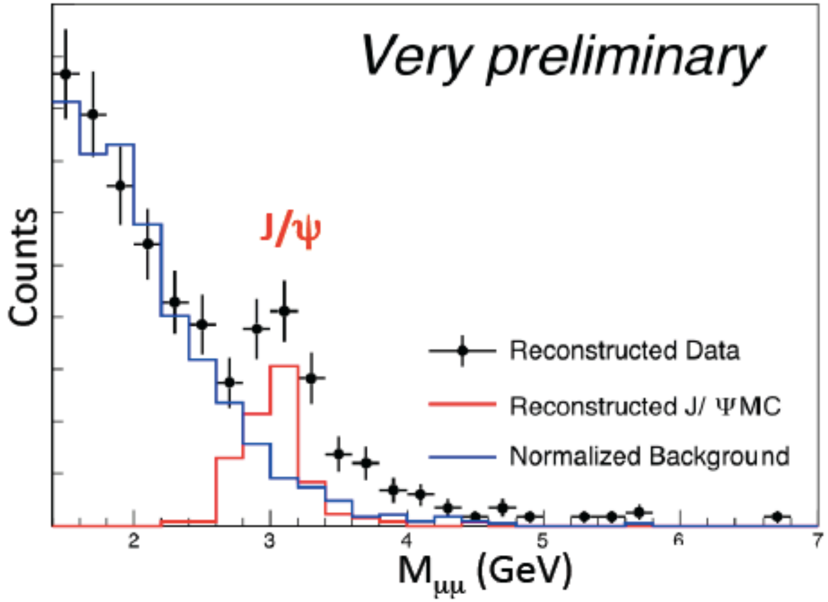
- Follow basic design of MEast spectrometer (don't reinvent the wheel):
  - Two magnet spectrometer
  - Beam dump within first magnet
  - Hadron absorber within first magnet
  - Muon-ID wall before final elements
- Where possible and practical, reuse elements of the E866 spectrometer.
  - Tracking chamber electronics
  - Hadron absorber, beam dump, muon ID walls
  - Station 2 tracking chambers
  - Hodoscope array PMT's
  - SM3 Magnet
- New Elements
  - 1st magnet (different boost)
    Experiment shrinks from 60m to 26m
  - Sta. 1 tracking (rates)
  - Scintillator (age)
  - Trigger (flexibility)
  - St. 3 tracking (acceptance)

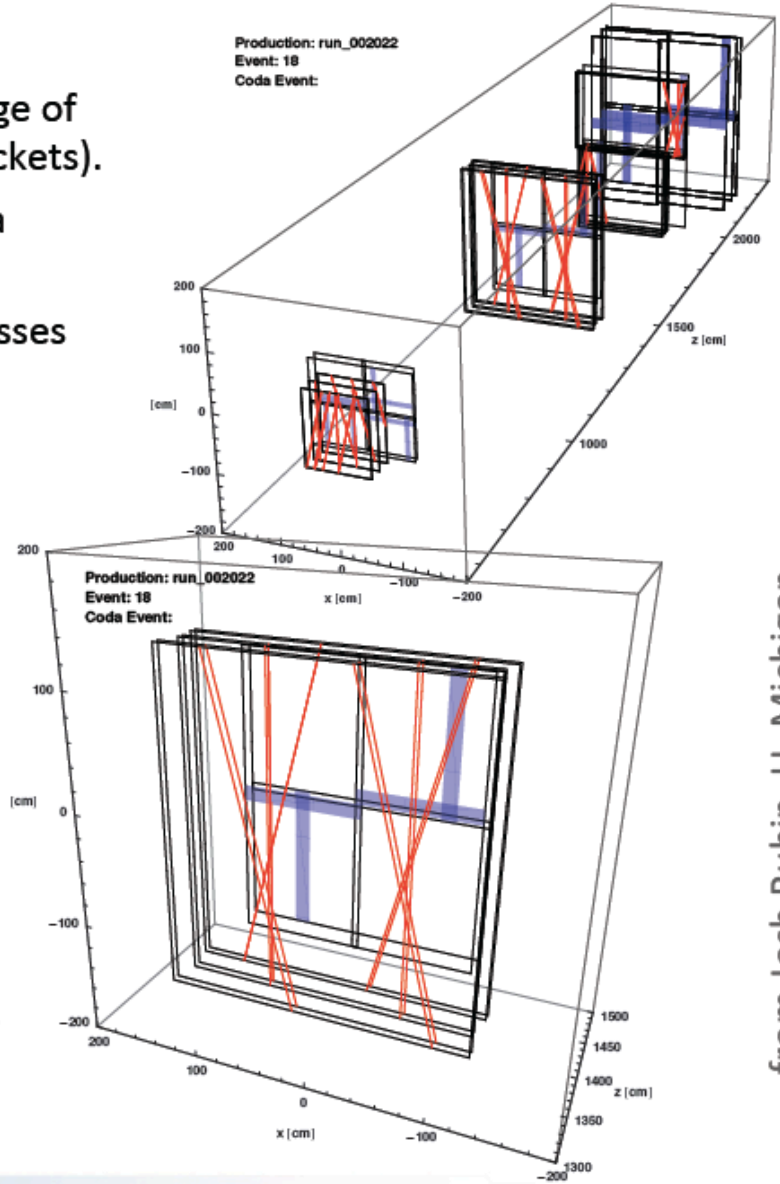


E906 Drell-Yan experiment at Fermilab

The Splat-Block Card

- A card was developed to keep a running average of the multiplicity over a 160 ns window (8 RF buckets).
- If average multiplicity above threshold, raises a trigger veto
- Luminosity greatly reduced, but trigger suppresses windows of time with large beam intensities.
  - capabilities



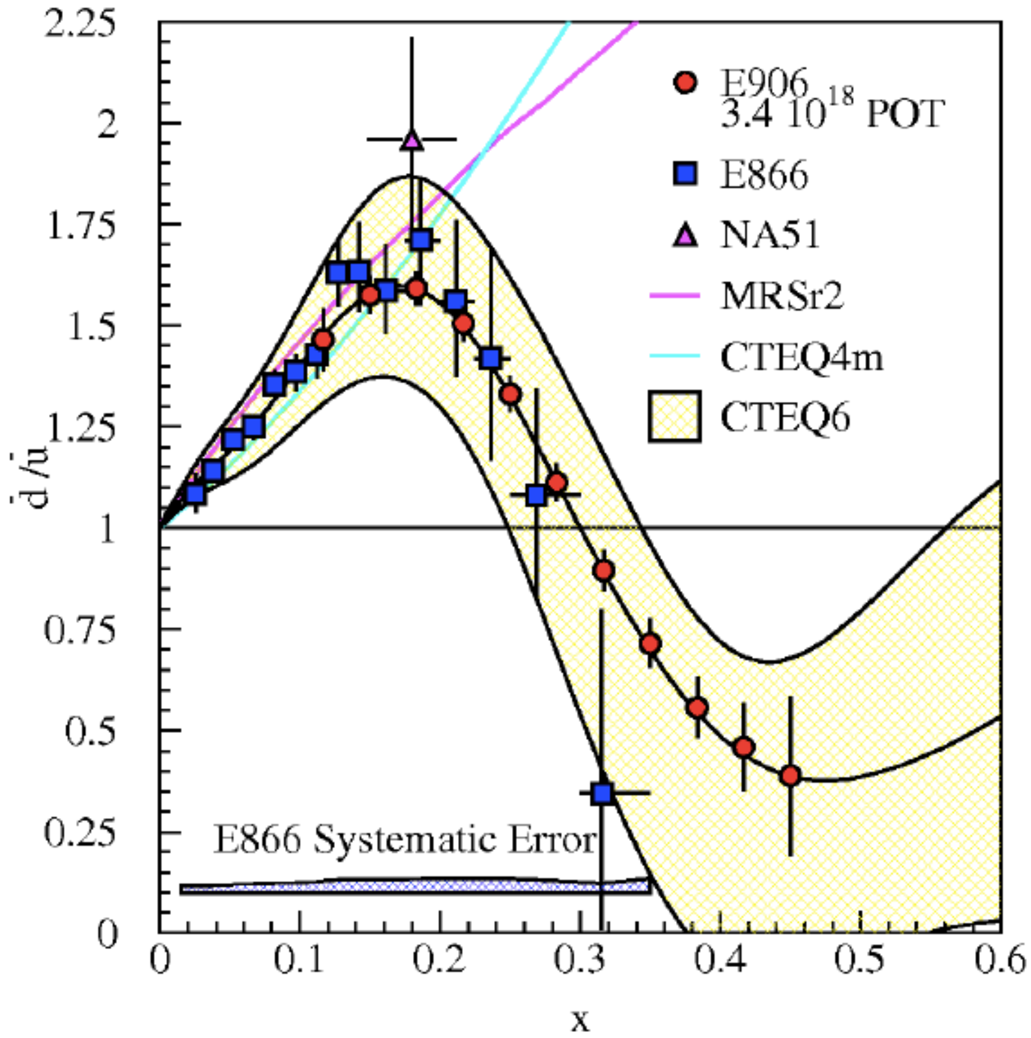


from Josh Rubin, U. Michigan

E906 Drell-Yan experiment at Fermilab

Extracting d-bar/-ubar From Drell-Yan Scattering

- E906/Drell-Yan will extend these measurements and reduce statistical uncertainty.
- E906 expects systematic uncertainty to remain at approx. 1% in cross section ratio.



Paul E. Reimer ECT* Workshop on the Flavor Structure of the Nucleon Sea

1 July 2013

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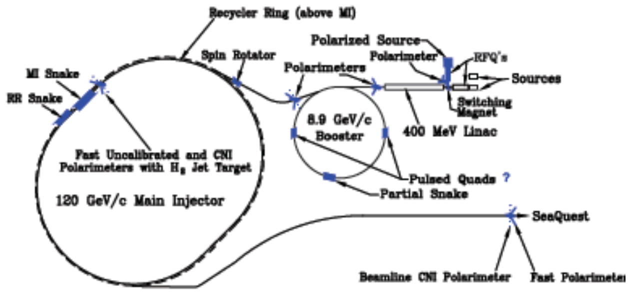
E906 Drell-Yan experiment at Fermilab

Polarized Drell-Yan at Fermilab



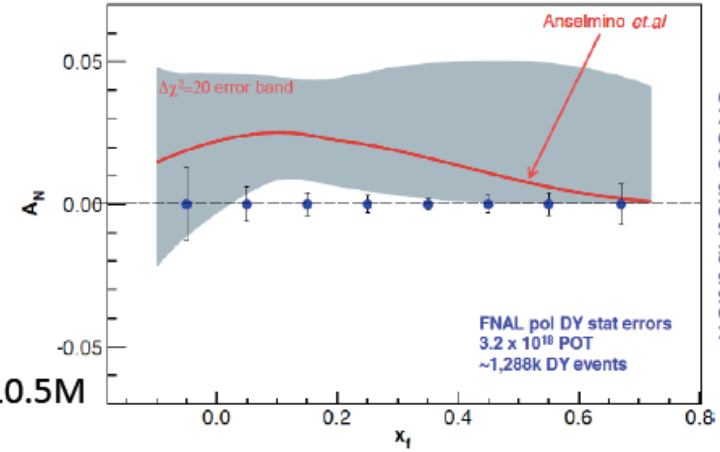
Test Fundamental Prediction of QCD Gauge formalism and factorization

$$f_{1T}^{\perp}(x,k_T)\big|_{\mathrm{SIDIS}} = - f_{1T}^{\perp}(x,k_T)\big|_{\mathrm{DY}}$$

Does the Sivers' function change sign?

Polarized beam

- Measure valence-quark distributions
  - Directly comparable to SIDIS measurements
  - Fits expect measureable asymmetry
- Stage-I Fermilab Approval
- Fermilab intensity frontier: Luminosity
- Cost: \$6.5M + 65%(cont. and manage.) = \$10.5M
- Argonne Spokesperson (PER)



Polarized beam Valence Sivers distribution

Polarized Target

- Measure Single Spin Asymmetry (SSA) in Sea Quarks
- Double Spin Asymmetry w/polarized beam
- LOI submitted Spring 2013

COMPASS facility at CERN (SPS)

COmmon Muon Proton Apparatus for Structure and Spectroscopy

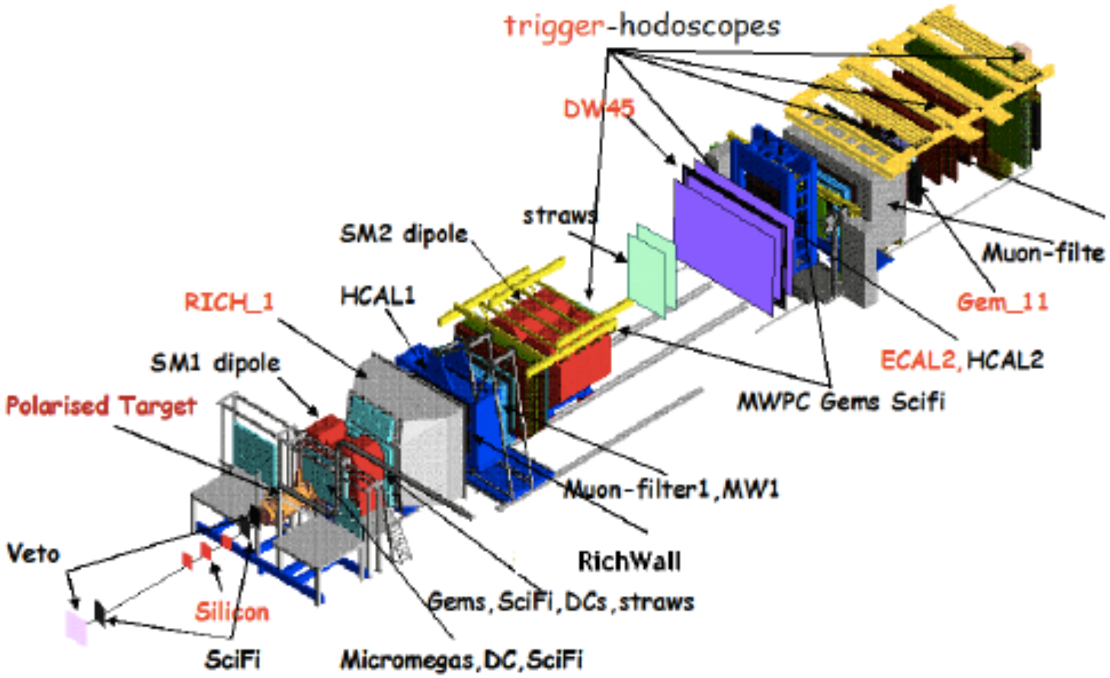
COMPASS facility at CERN

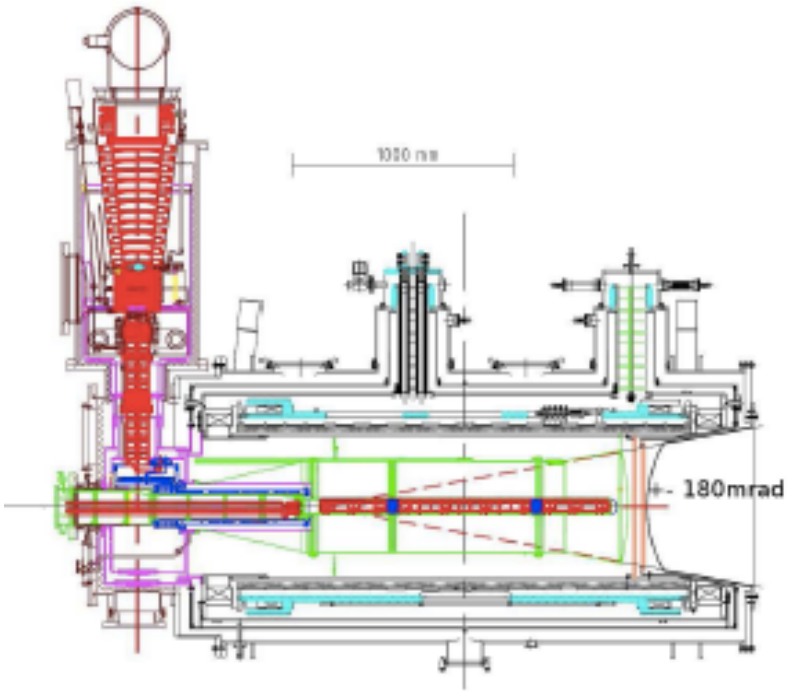
Two stages spectrometer

1. Large Angle Spectrometer (LAS)
2. Small Angle Spectrometer (SAS)

Most important features:

1. Muon, electron or hadron secondary beams
2. Solid state polarised targets (NH_3 or ^6LiD) as well as liquid hydrogen target and nuclear targets
3. Powerful tracking system – 350 planes
4. PiD – Muon Walls, Calorimeters, RICH





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
  - 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 5 International Workshops (Torino, Dubna, CERN, Trento), > 70 COMPASS DY subgroup meetings, 4 Beam Tests, > 50 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.

Why Drell-Yan @ COMPASS

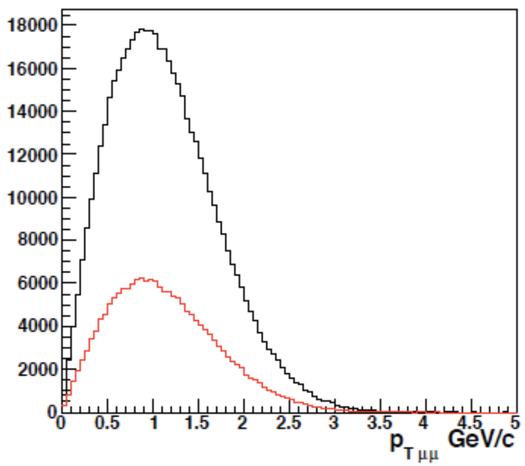
1. Large angular acceptance spectrometer
2. SPS M2 secondary beams with the intensity up to 10^8 particles per second
3. Transversely polarized solid state proton target with a large relaxation time and high polarization, when going to spin frozen mode;
4. a detection system designed to stand relatively 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

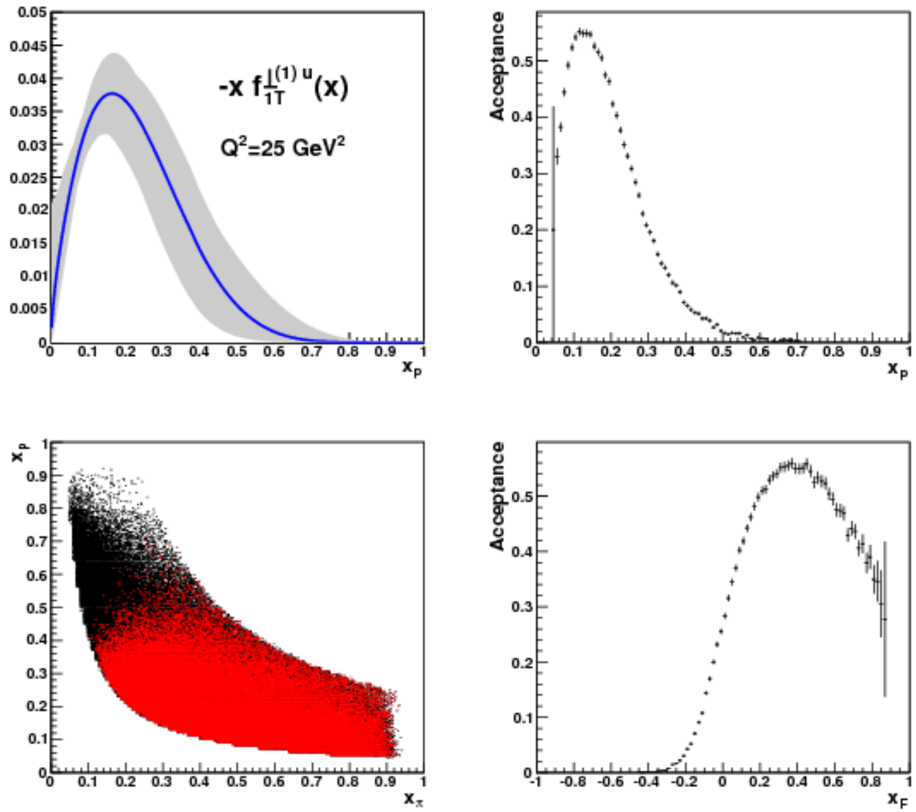
For the moment we consider two step DY program:

- 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
- $\langle P_T \rangle \sim$ 1GeV – TMDs induced effects expected to be dominant with respect to the higher QCD corrections





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

DY@COMPASS - set-up

$\pi^- p^{\uparrow} \rightarrow \mu^- \mu X$ (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.

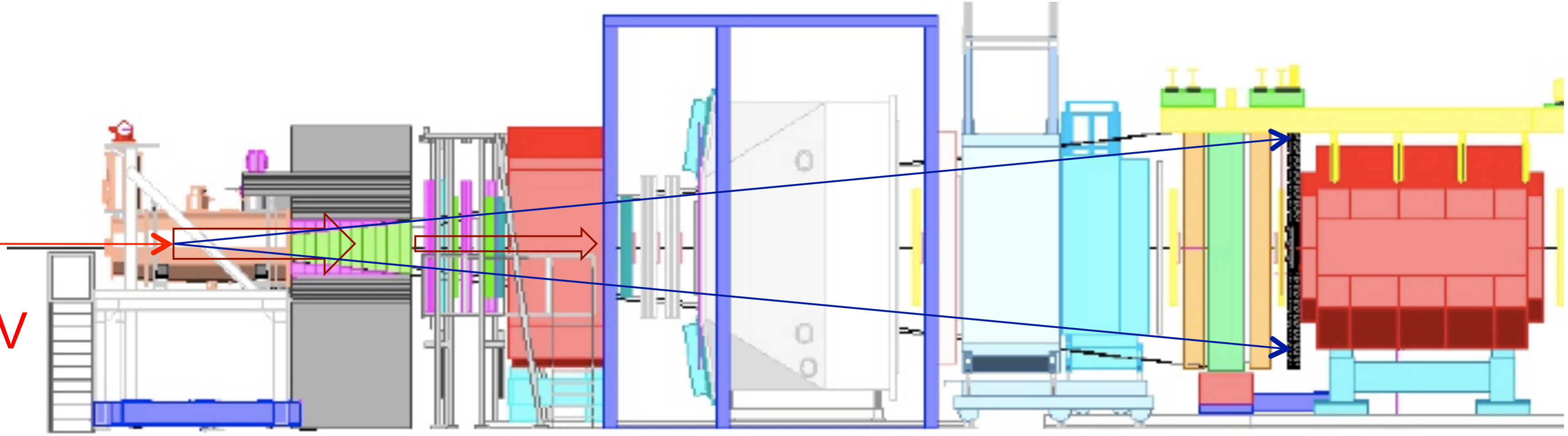
5. Hadron absorber ➔ vertex detector is very welcome to improve cell-to-cell separation

DY@COMPASS - set-up

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

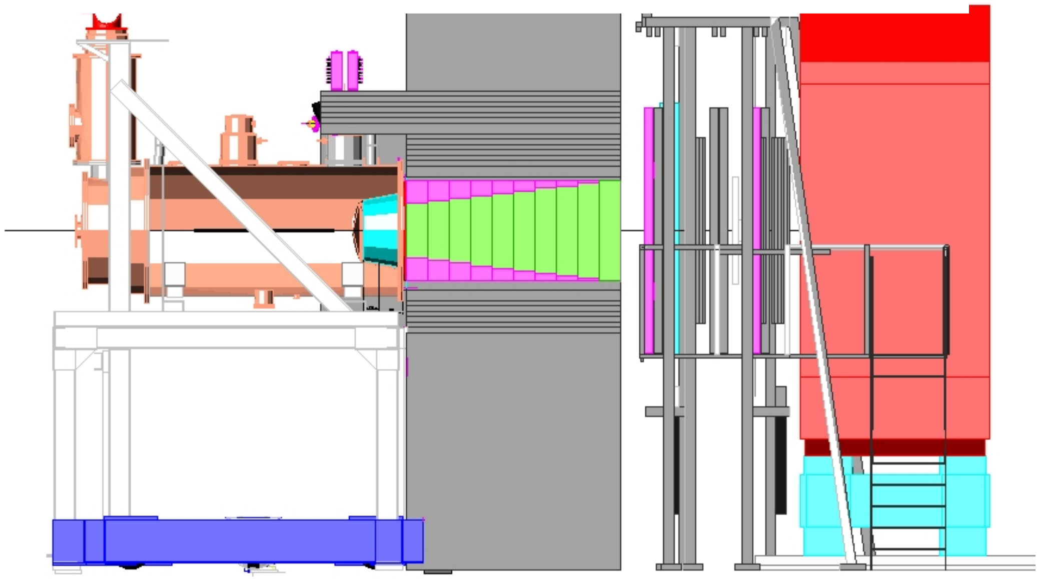
π^-

190 GeV

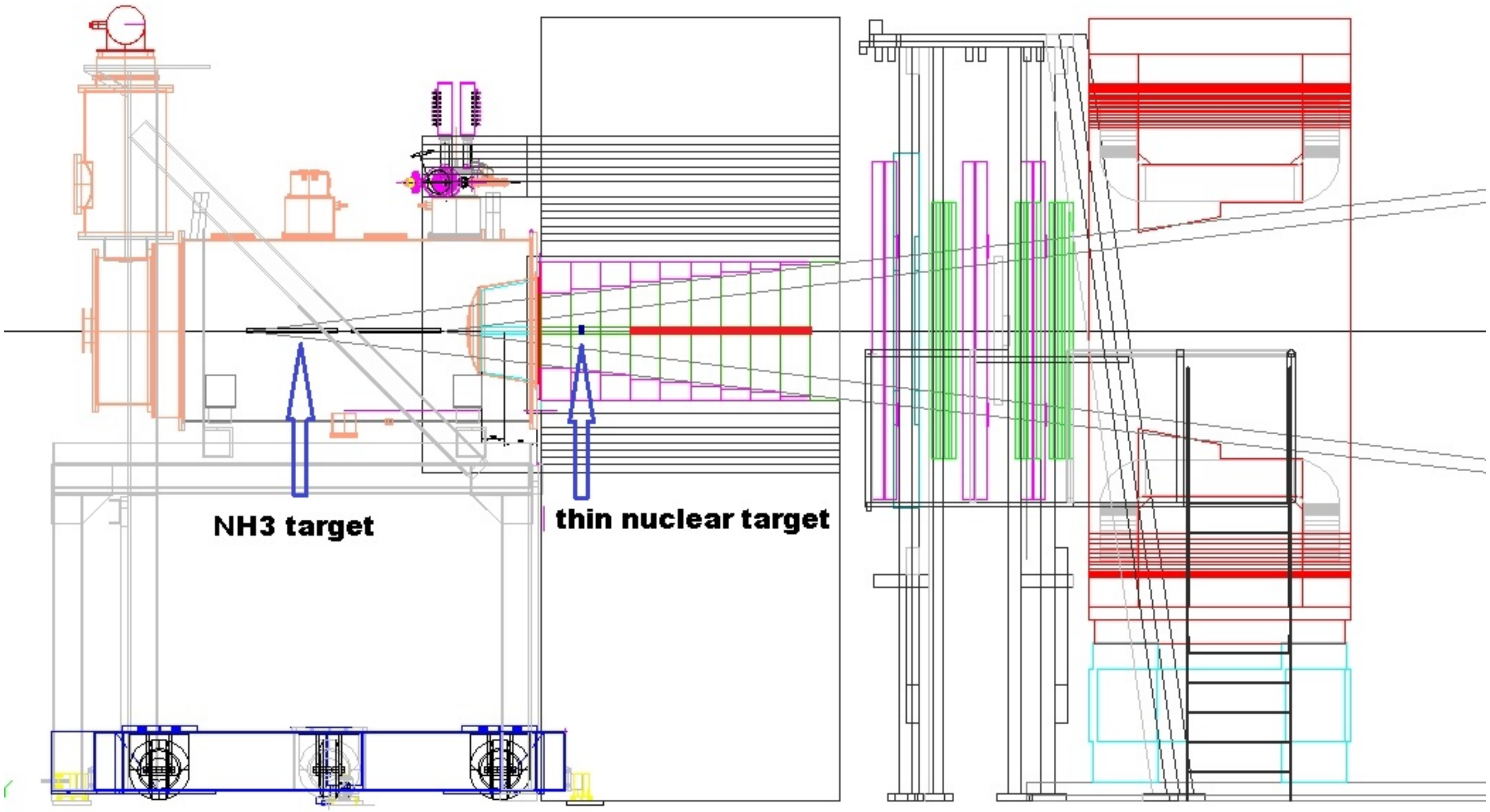


Key elements:

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)

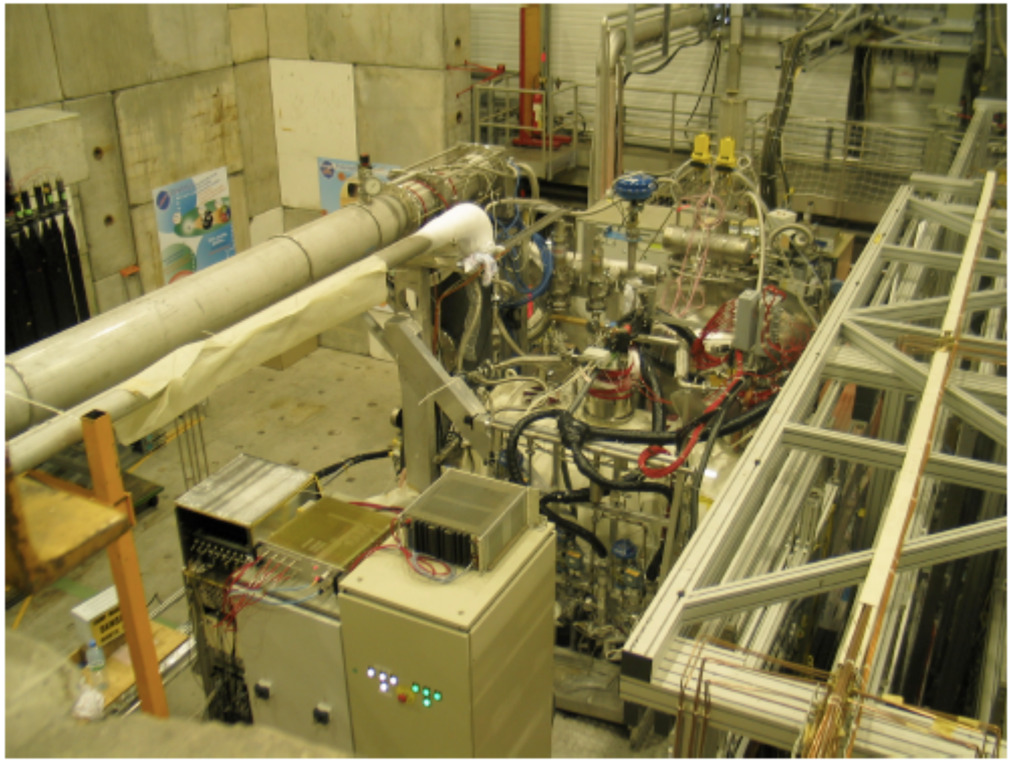


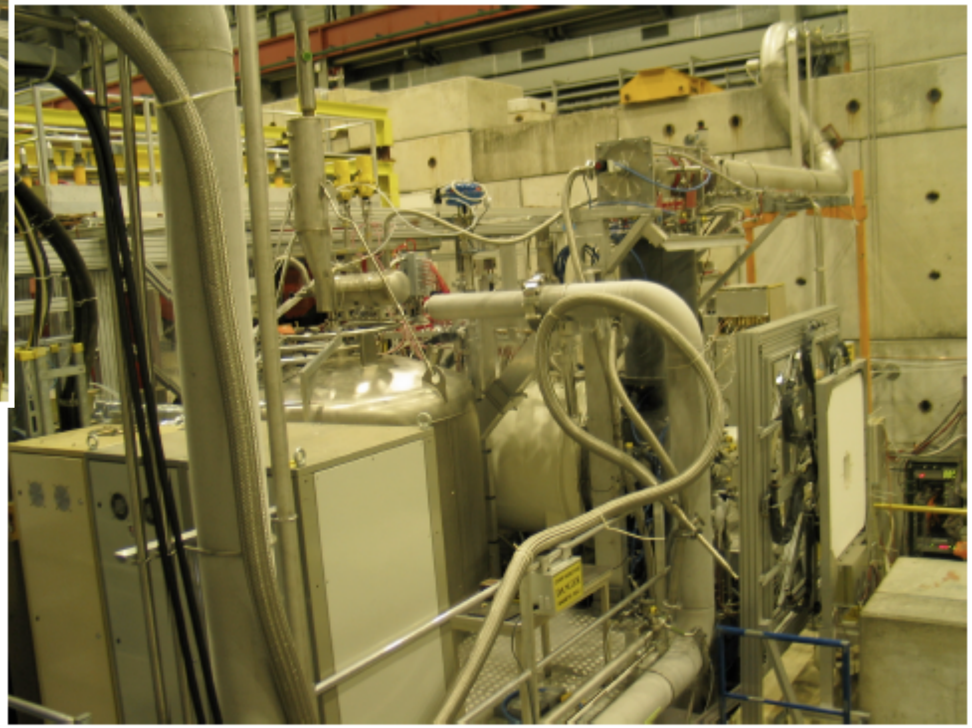
Flavour-dependent EMC effect study, possible set-up



Feasibility and set-up optimization still has to be completed

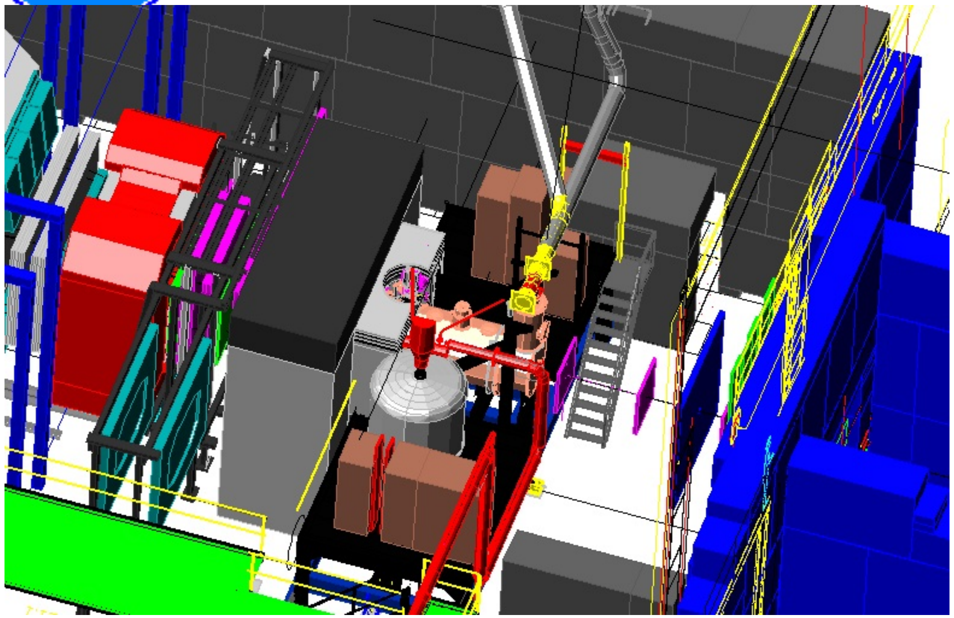
PT movement

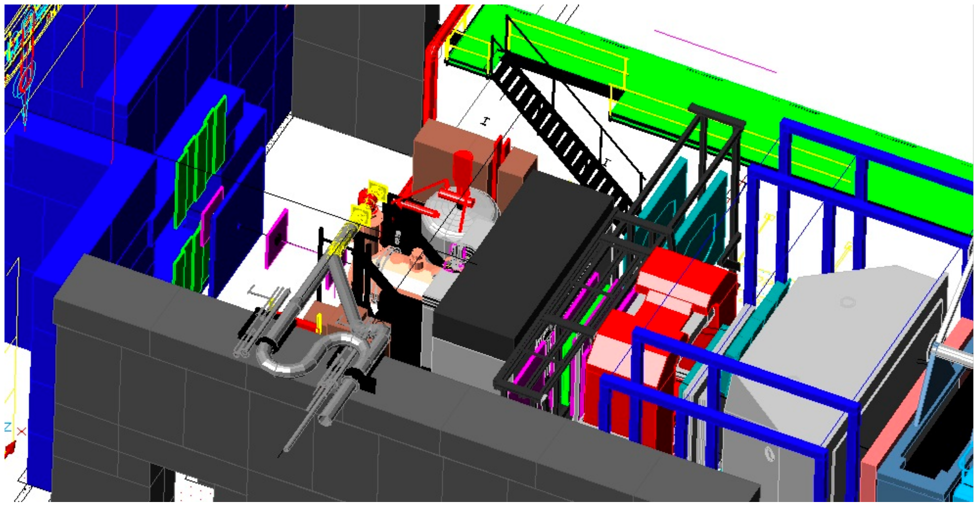


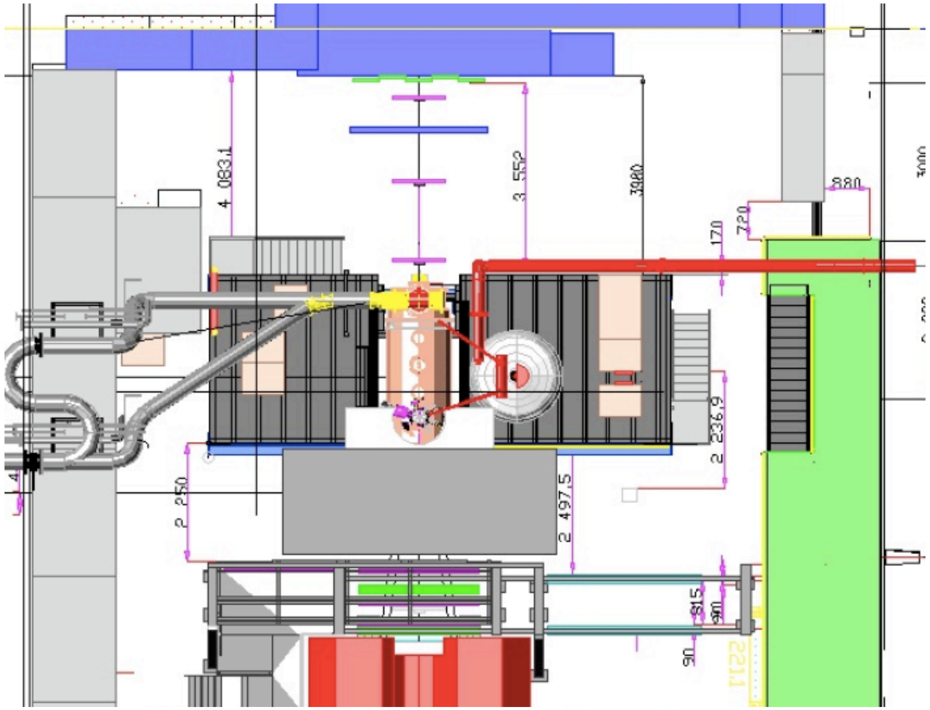


Drell-Yan experiment lay-out

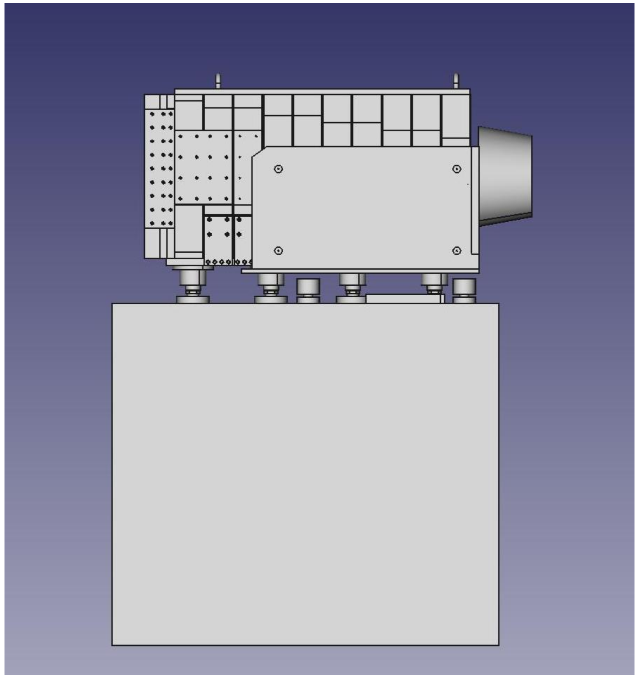
Hadron absorber&R.P.shieldings and Polarised Target

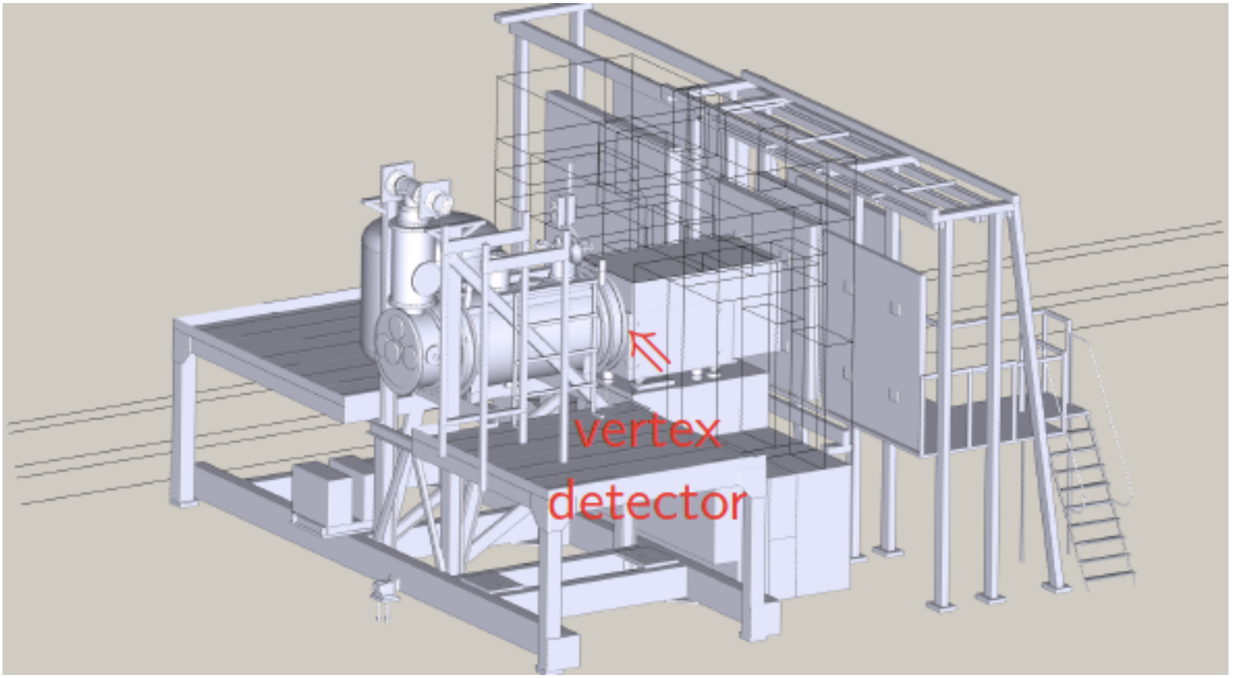


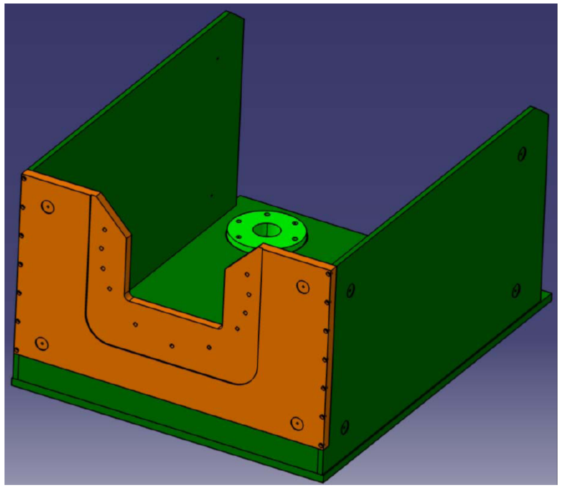


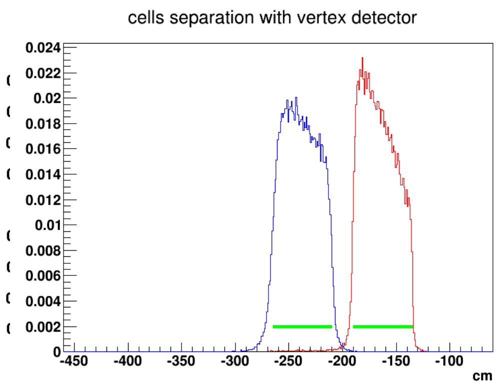


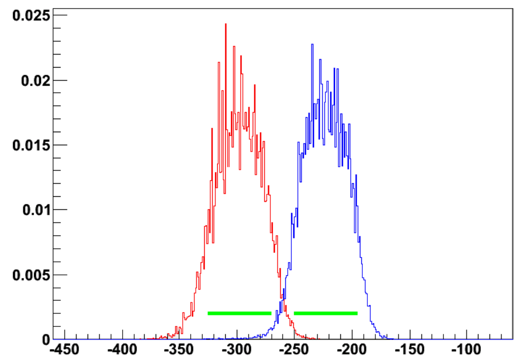
Drell-Yan experiment lay-out
Sci-Fi based Vertex detector







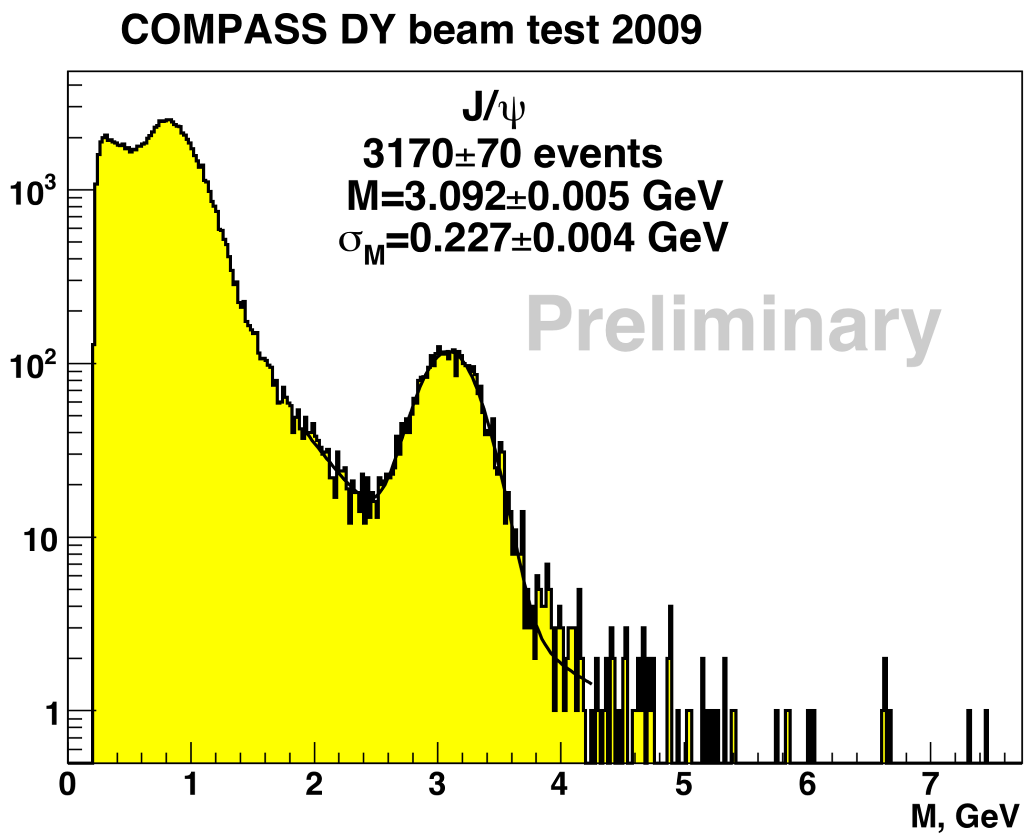




Oleg Denisov

DY@COMPASS - feasibility - Signal

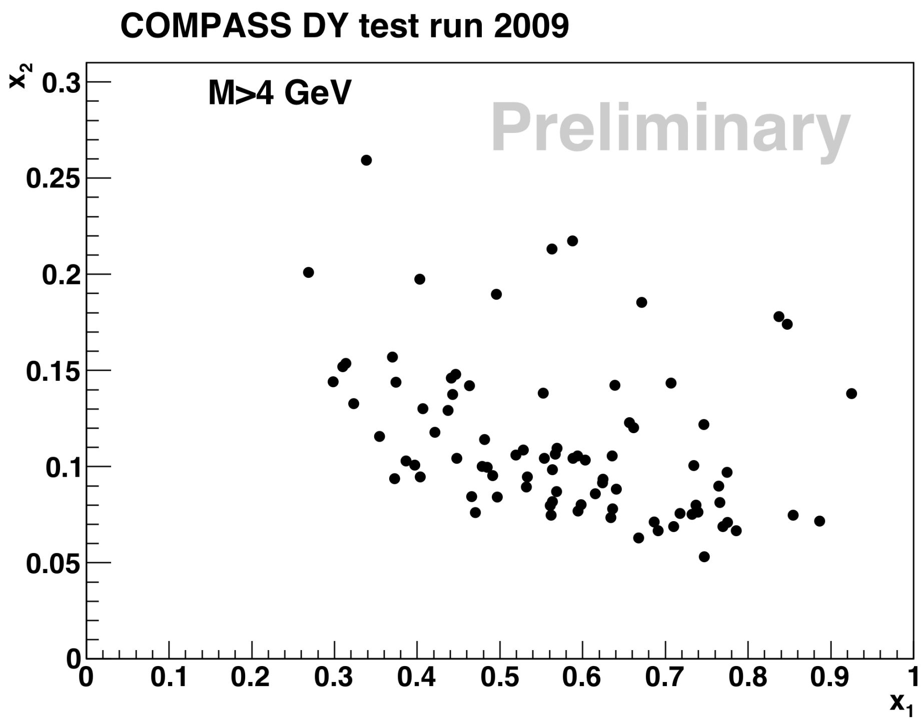
- Expected according to the proposal J/Psi and Drell-Yan yields: 3600±600 and 110±22 (normalized to 2009 beam flux ~3.7 x 10^{11})
- Measured in 2009 beam test J/Psi yield is 3170±70, and DY yield is 84±10

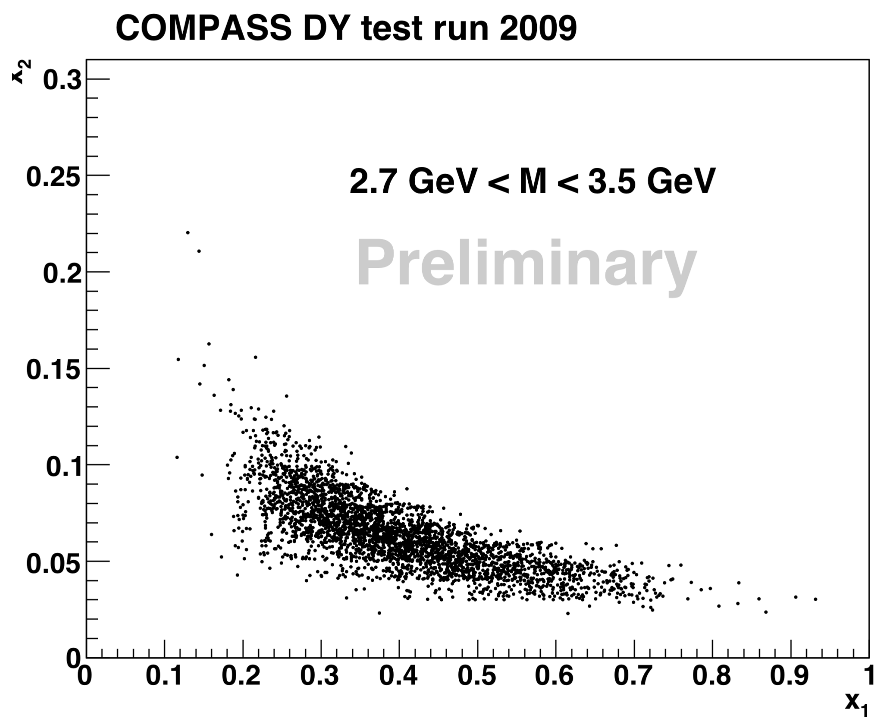


DY@COMPASS - feasibility – Kinematics I

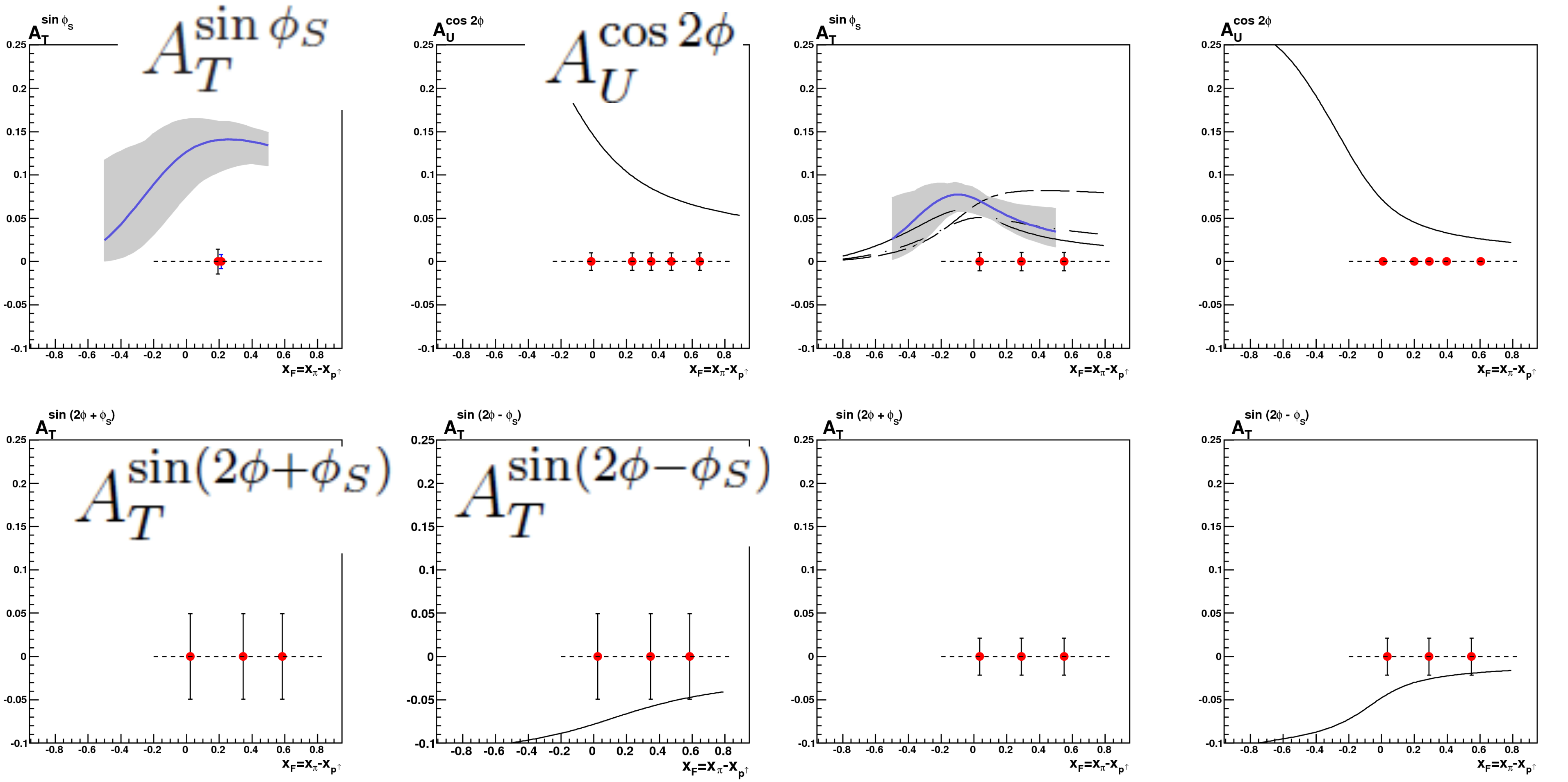
- Valence quark range for both J/Psi and DY

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





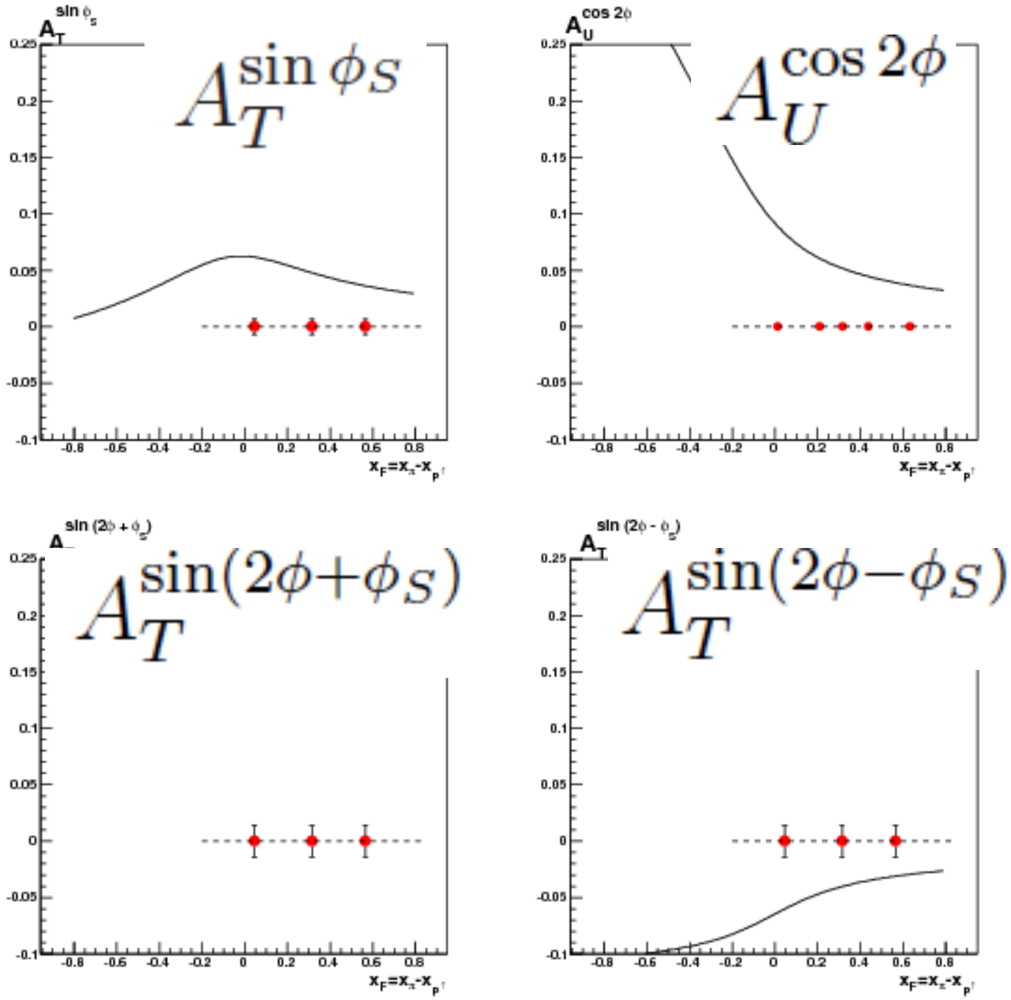
DY@COMPASS projections II



$(\text{HMR}): 4. \leq M_{\mu\mu} \leq 9.\ \text{GeV}/c^2$ $(\text{IMR}): 2.0 \leq M_{\mu\mu} \leq 2.5\ \text{GeV}/c^2$

DY@COMPASS projections III

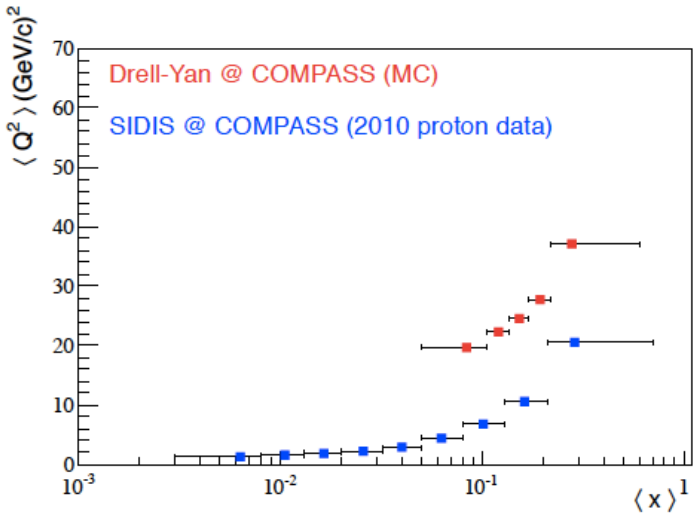
J/ψ region: $2.9 \le M_{\mu\mu} \le 3.2\ \mathrm{GeV}/c^2$

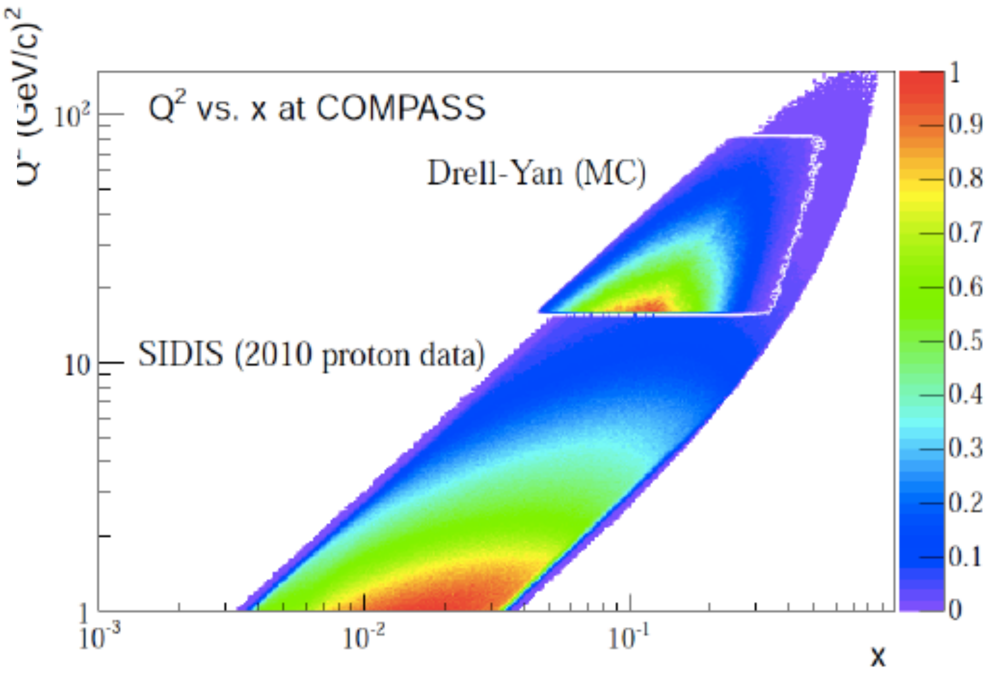


SIDIS←→DY – QCD test at COMPASS

VERY IMPORTANT – Kinematics compatibility SIDIS←→ DY

In COMPASS we have the opportunity to access these TMD PDFs from both DY and SIDIS processes.





There is a phase space overlap between the two measurements.

Drell-Yan Experiments 5 years Running plan

1. Fermilab E-906: data taking will resume in September 2013 and will last for at least 1 year (experiment is approved for 2 years running period)

2. Polarised DY at Fermilab – hopefully in a few years from now

3. COMPASS polarized Drell-Yan measurement will be started in the mid of October 2014, with a short beam test. Physics data taking will take place over the whole 2015.

4. A second year of DY data-taking is planned, in case of LS2 delay, in 2018.

5. RHIC ?

COMPASS Drell-Yan Running until 2019

1. Two (almost) running experiments for Drell-Yan physics after long no data period
2. 100% complementary experiments
3. What is missing – collider experiment, DY@NICA is very welcome:
   - 4π geometry – access to the exclusive channels (no absorber)
   - Collider mode – no dilution factor as in case of fixed target solid state PT experiments (factor ~5 in statistical error)
   - We are entered the era of the global fits and global data analysis ➔ NICA data will certainly contribute a lot

DY Experiments: Summary

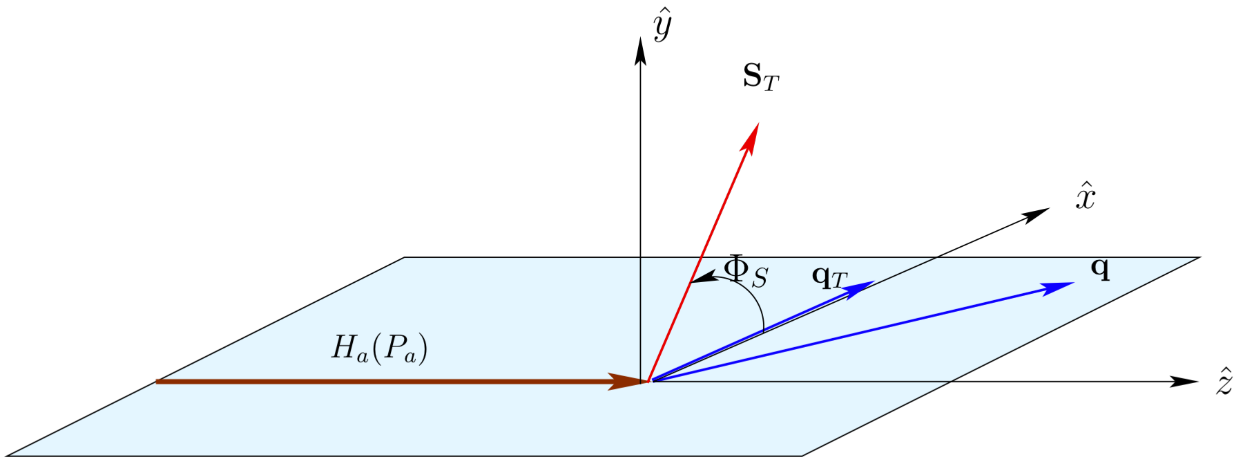
- Proton and pion induced DY – data are coming up in the next 2 years
- Some statistics with kaons and antiprotons will be available
- Statistical error on single spin asymmetries on the level of 1÷2% will be achieved by the 2016
- A lots of new unique data is just behind the corner

- Spares

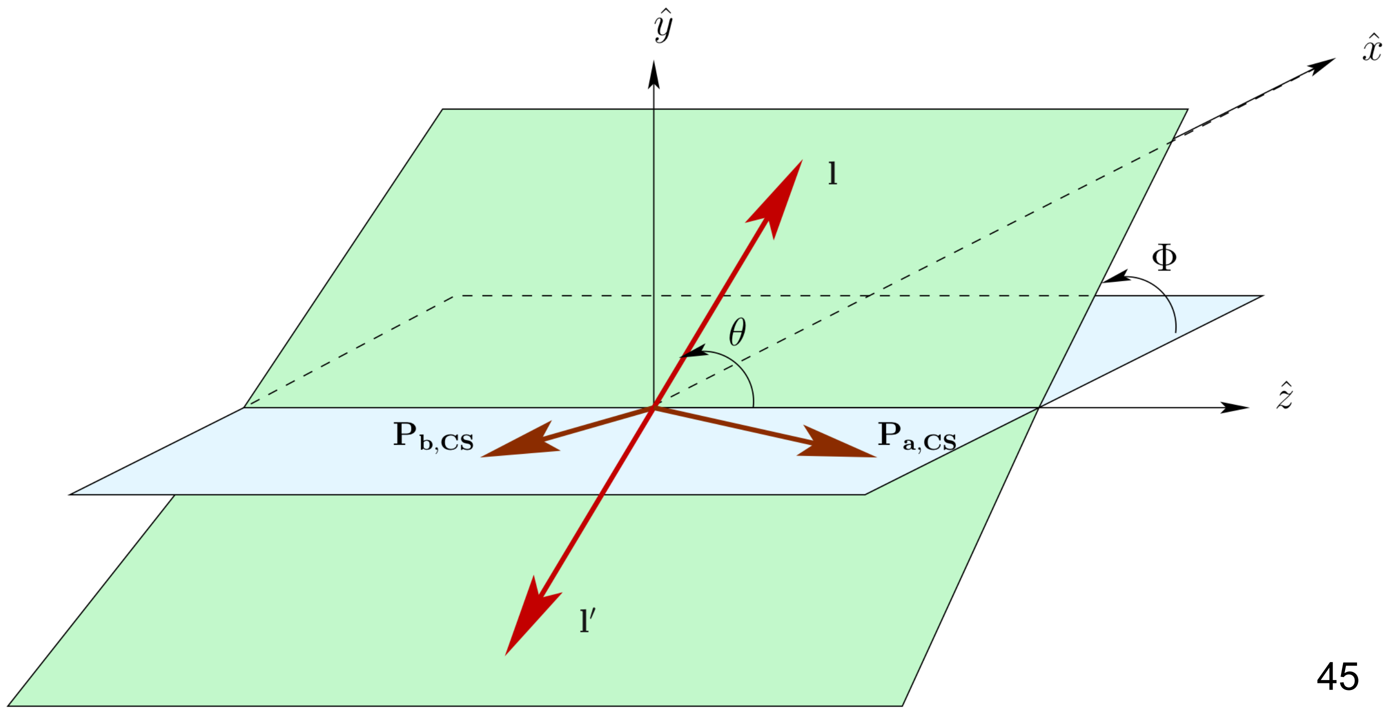
TMDs at Drell-Yan: road map

- 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.

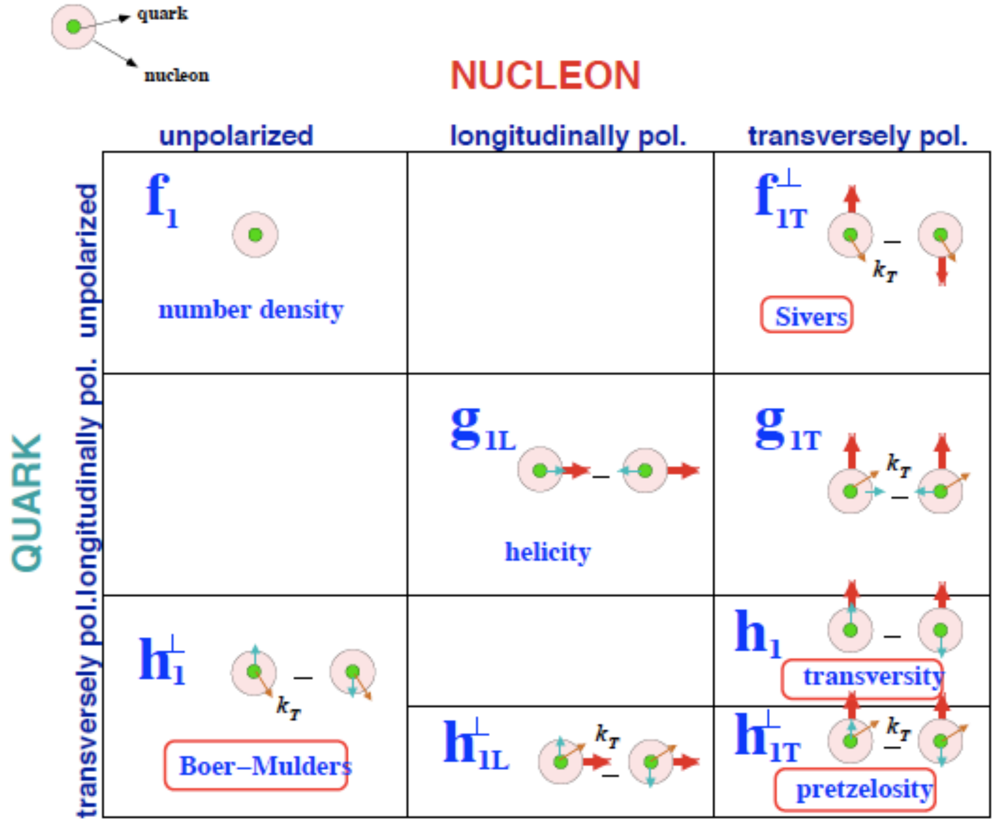
Organizers: Paula Bordalo (LIP-Lisbon and IST/UTL)
Oleg Denisov (CERN/INFN-Torino)
Eva-Maria Kabuss (Mainz)
Fabienne Kunne (CEA Saclay)
Alain Magnon (CEA Saclay)
Gerhard Mallot (CERN)
Anna Martin (Univ. Trieste and INFN-Trieste)
Wolf-Dieter Nowak (CERN)
Daniele Panzieri (Univ. Alessandria and INFN-Torino)

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

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

Parton distribution functions

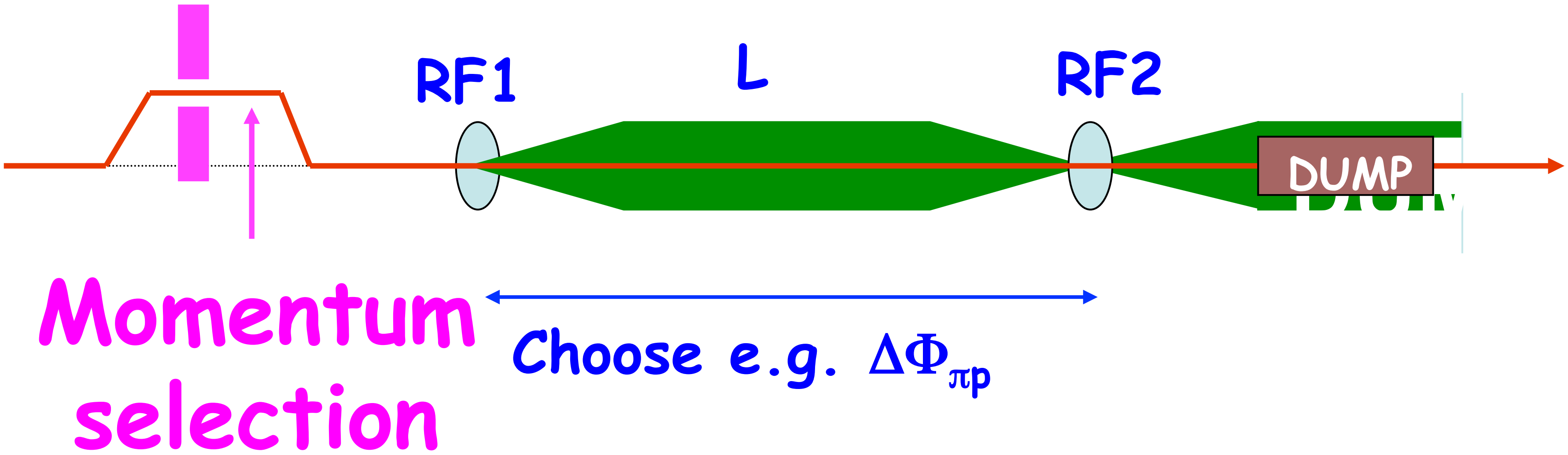
Taking into account the intrinsic transverse momentum k_T of quarks, at LO **8 PDFs** are needed for a full description of the nucleon:



WHAT ABOUT A RF SEPARATED⌧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

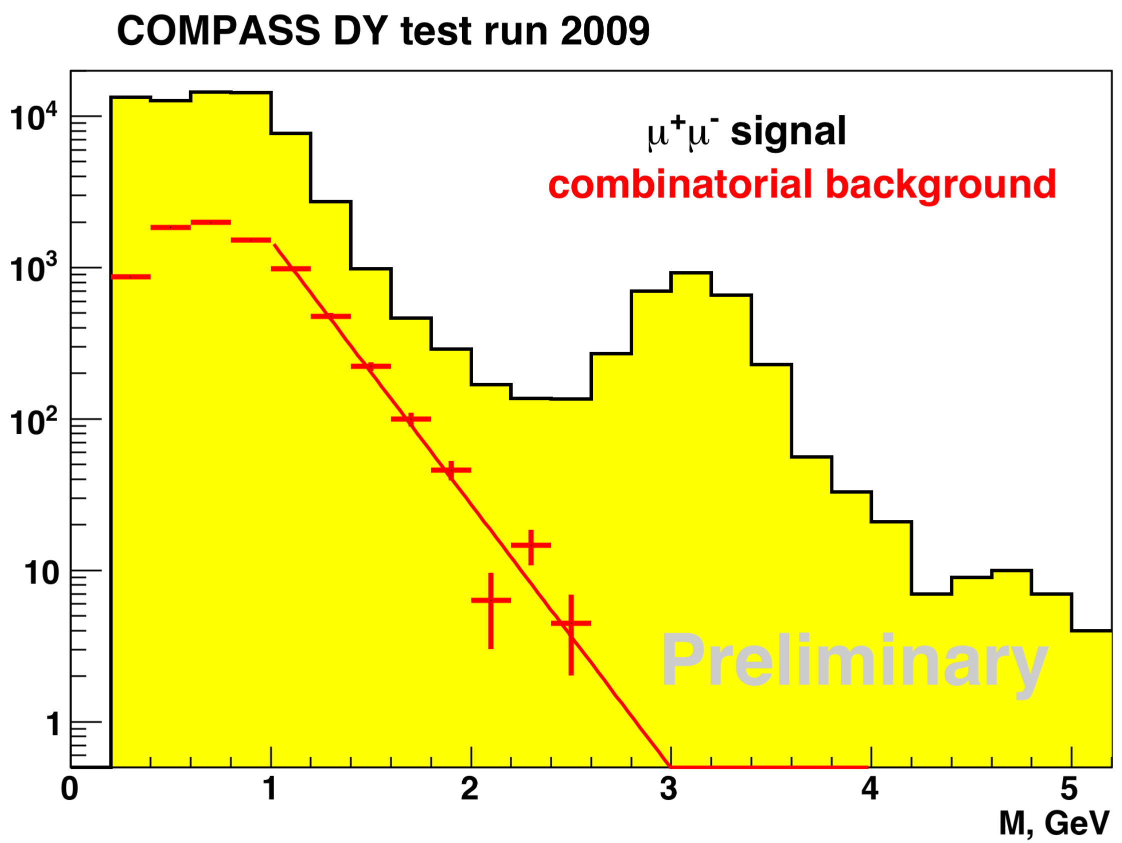
E.g. a system with two cavities:



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

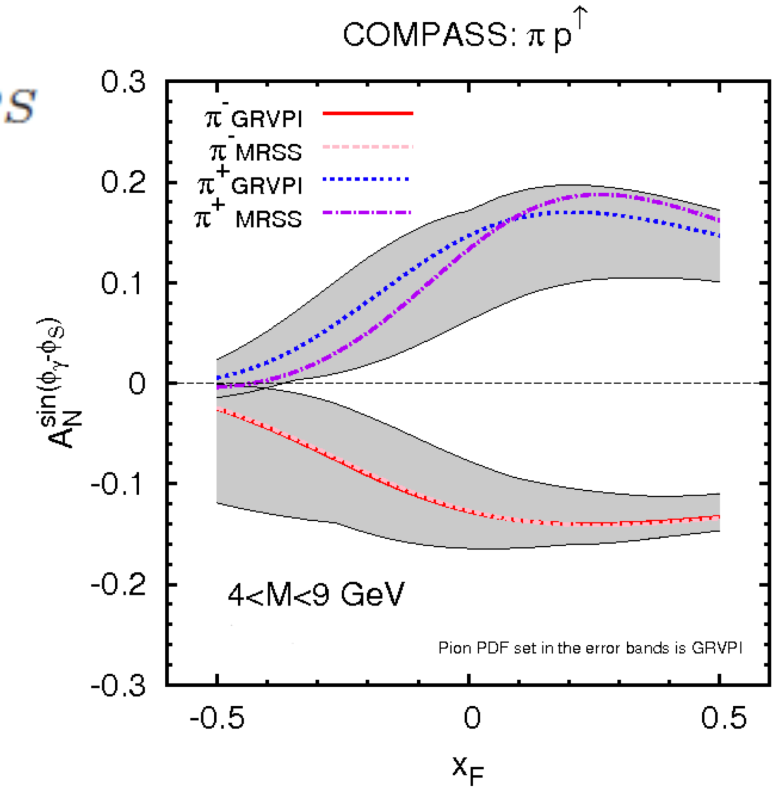
DY@COMPASS - feasibility – Background II – Combinatorial

- 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

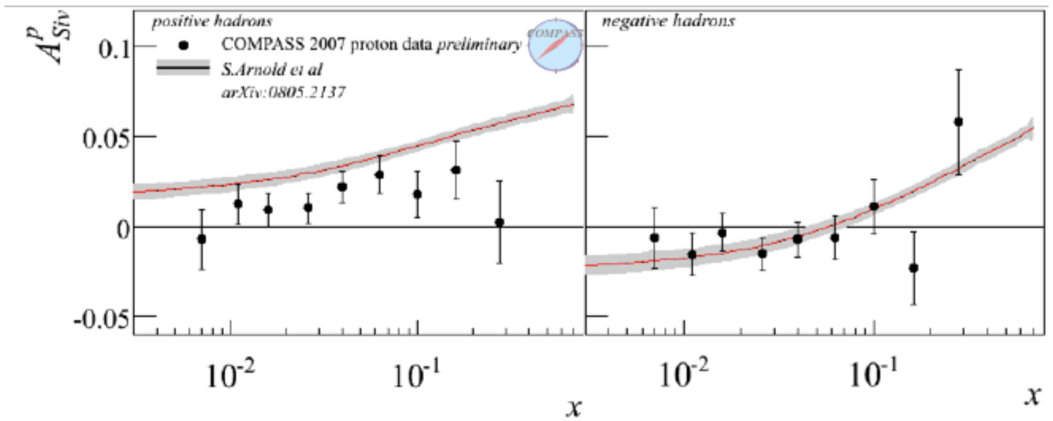
$A_T^{\sin\phi_S}$

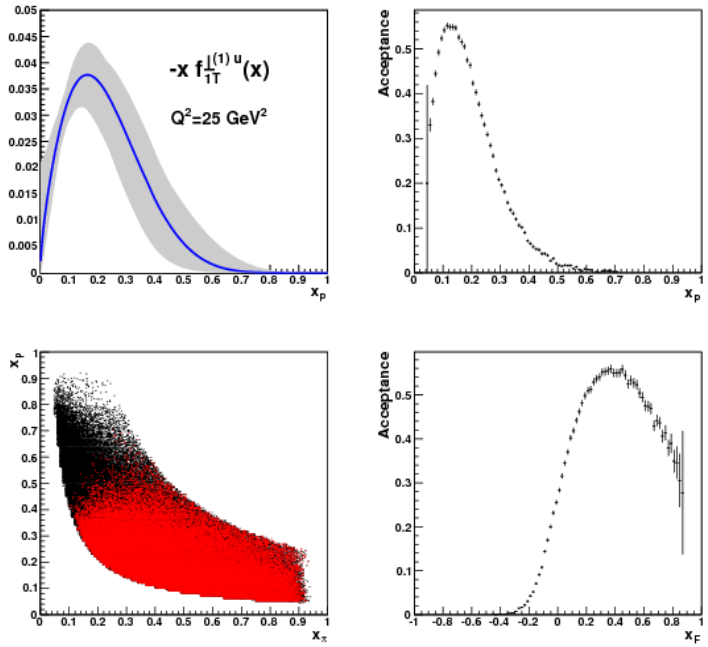


In case of $\pi^- p$ scattering the valence pion $\bar{u}$ unpolarised PDF is well known and there is no difference between two pdf sets. In case of $\pi^+ p$ scattering there is a little contamination coming from sea $\bar{u}$ of the pion, which annihilates with valence u quark of the proton, because 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 complementarity

- 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





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

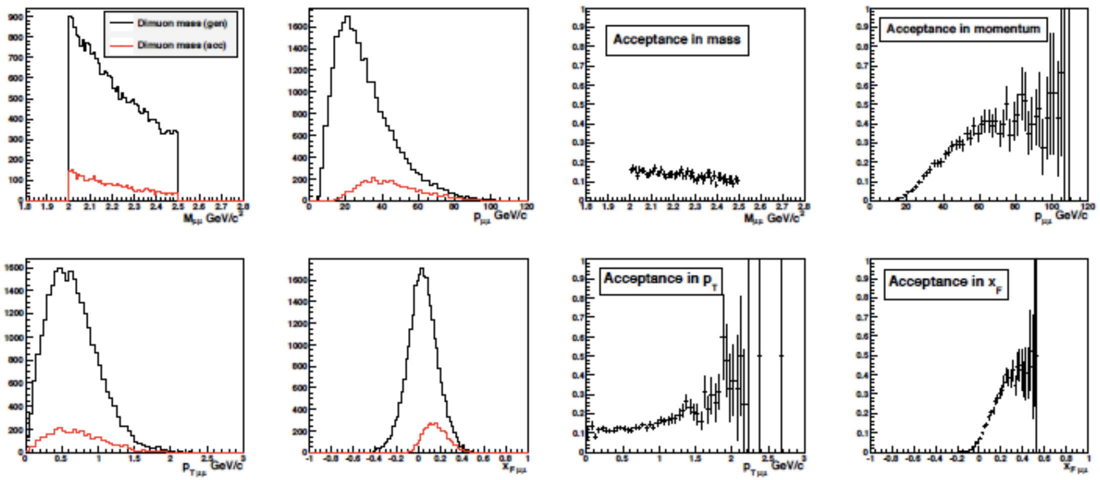
$$\tau = x_a x_b = M^2/s$$

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