Probing the Strong Interaction at A Fixed Target ExpeRiment with the LHC beams

AFTER @ LHC

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Ecole de Physique des Houches

Europe/Paris timezone

Study of hadron structure using Drell-Yan scattering

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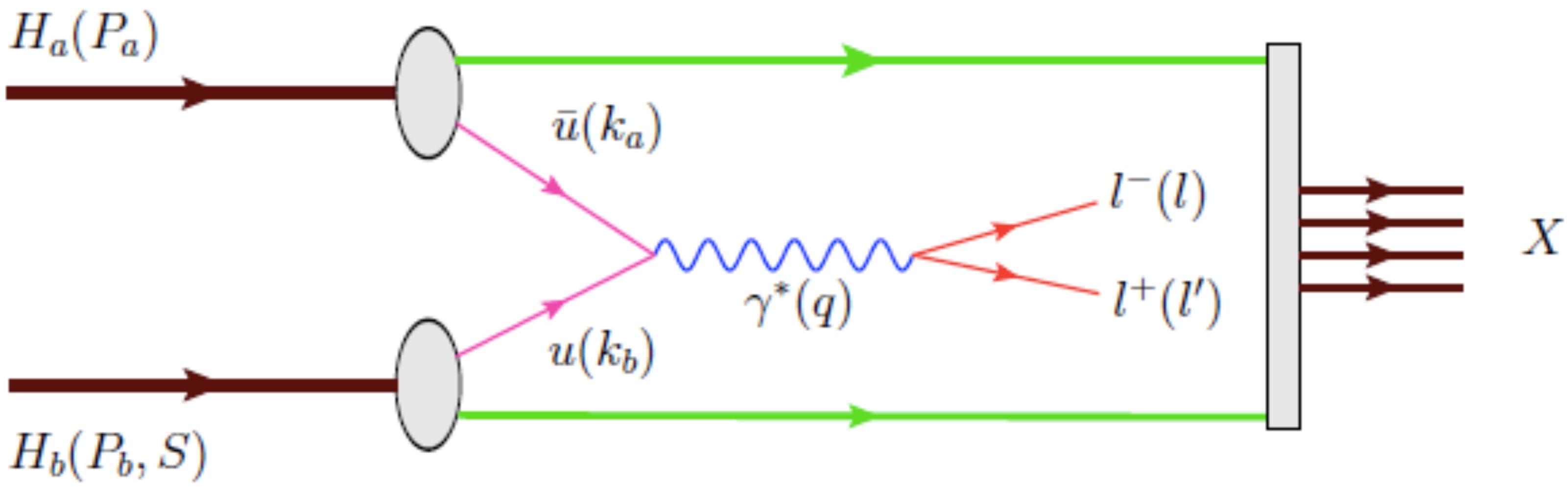
Outline

- 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
- TMDs study – choice of kinematic domain
- Polarised DY@COMPASS
  - Set-up
  - COMPASS Polarized Target
  - Kinematics & Projection
- Some input for DY with AFTER
  - Intensity/structure
  - Kinematics
  - Spectrometer
- Conclusions

Drell-Yan Process/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,
$M_{\mu\mu}^2 = Q^2 = q^2 = s\ x_a\ x_b,$	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.

General formula for all DY cross-section angular dependencies is available since 2010

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

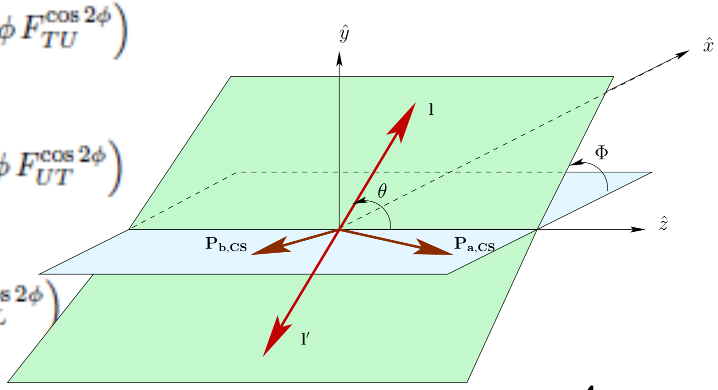
A.N. Sissakian,* O.Yu. Shevchenko,† A.P. Nagaytsev,‡ and O.N. Ivanov§
Joint Institute for Nuclear Research, 141980 Dubna, Russia

Phys. Rev. D72 (2005) 054027

$$\frac{d\sigma^{(1)}(H_1 H_2^{\uparrow} \to l\bar{l}X)}{d\Omega\, d\phi_{S_2}\, dx_1\, dx_2\, d^2\mathbf{q}_T} = \frac{\alpha^2}{12Q^2}\sum_q e_q^2 \times\Big\{(1+\cos^2\theta)\mathcal{F}[\bar f_{1q} f_{1q}] + \sin^2\theta\cos(2\phi) \times \mathcal{F}\Big[(2\hat{\mathbf h}\cdot\mathbf k_{1T}\,\hat{\mathbf h}\cdot\mathbf k_{2T} - \mathbf k_{1T}\cdot\mathbf k_{2T})\frac{\bar h_{1q}^\perp h_{1q}^\perp}{M_1M_2}\Big] + (1+\cos^2\theta)\sin(\phi-\phi_{S_2})\mathcal{F}\Big[\hat{\mathbf h}\cdot\mathbf k_{2T}\frac{\bar f_1^q f_{1T}^{\perp q}}{M_2}\Big] - \sin^2\theta\sin(\phi+\phi_{S_2})\mathcal{F}\Big[\hat{\mathbf h}\cdot\mathbf k_{1T}\frac{\bar h_{1q}^\perp h_{1q}}{M_1}\Big]\Big\}.$$

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

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



Status of the theory: Pion-induced DY, DY Cross section calculations theoretical calculations - COMPASS

Very big progress recently achieved: NLL threshold re-summation mechanism with non-perturbative term - good experimental data description – K-factors issue is not there anymore (M. Aicher, A. Sch¨afer and W. Vogelsang, Phys.Rev.Lett. 105 (2010) 252003)

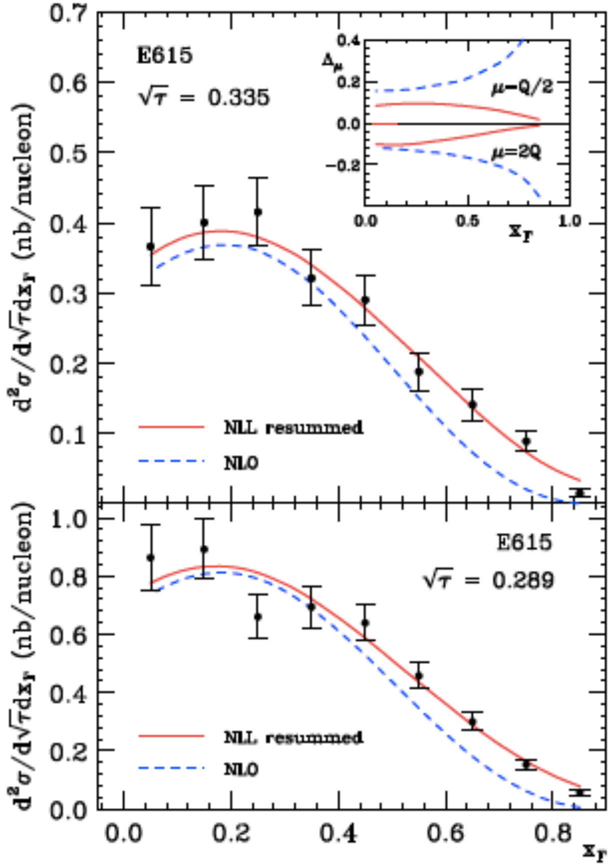


FIG. 2: Comparison of our NLL-resummed Drell-Yan cross section based on fit 3 to some of the E615 Drell-Yan data. The inset in the upper figure shows the scale variation of the resummed and the NLO cross sections (see the text).

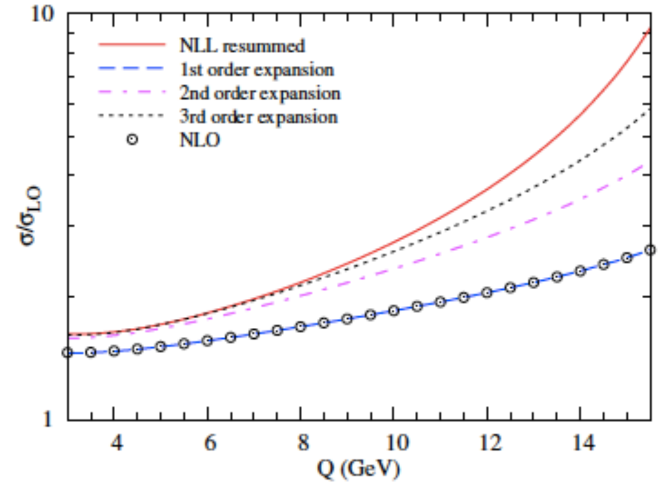
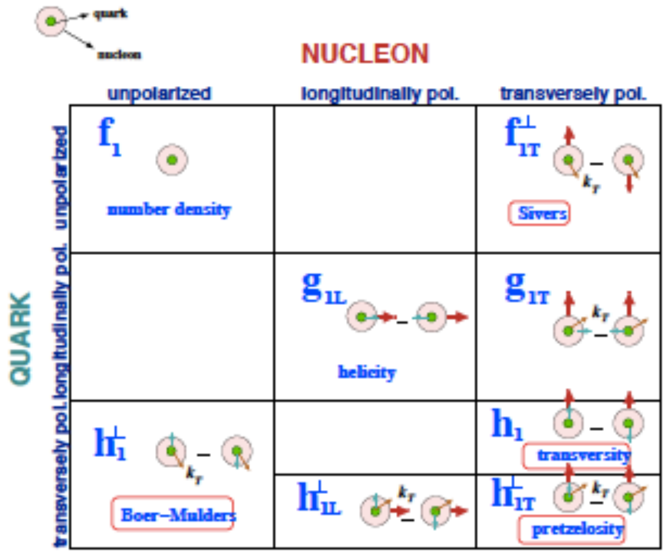


FIG. 2: "K-factors" as defined in Eq. (27) at $\sqrt{S} = 19$ GeV as functions of the lepton pair mass Q, at NLO (symbols) and for the NLL-resummed case. Also shown are the expansions of the resummed cross section to first, second and third order in the strong coupling.

The case of COMPASS (M. Aicher, A. Sch¨afer and . Vogelsang Phys.Rev. D83 (2011) 114023)

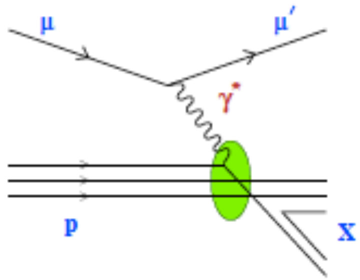
Leading Order PDFs

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

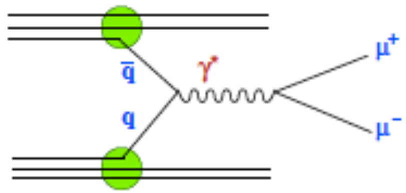


The highlighted TMDs can be studied using an un-polarized or a transversely polarized target

- 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**.

Why 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.

TMD PDFs

Nucleon polarization

Quark polarization	unpol.	long. pol.	transv. pol.
unpol.	f_1 Number Density		$f_{1T}^{\perp}$ Sivers
long. pol.		g_1 Helicity	g_{1T} Worm Gear
transv. pol.	$h_1^{\perp}$ Boer-Mulders	$h_{1L}^{\perp}$ Worm Gear	h_1 Transversity $h_{1T}^{\perp}$ Pretzelosity

$f_{1T}^{\perp}(x,k_T^2)$ Sivers function

the correlation between the transverse spin of the nucleon and the transverse momentum of the quark.

$h_1^{\perp}(x,k_T^2)$ Boer-Mulders function

the correlation between the transverse spin and the transverse momentum of a quark in unpolarized nucleon.

$h_{1T}^{\perp}(x,k_T^2)$ Pretzelosity function

the polarization of a quark along its k_T direction, making accessible to 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 :

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

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:

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

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

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

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

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

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

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

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

    $\longrightarrow$ Resummation relevant if more than one scale present

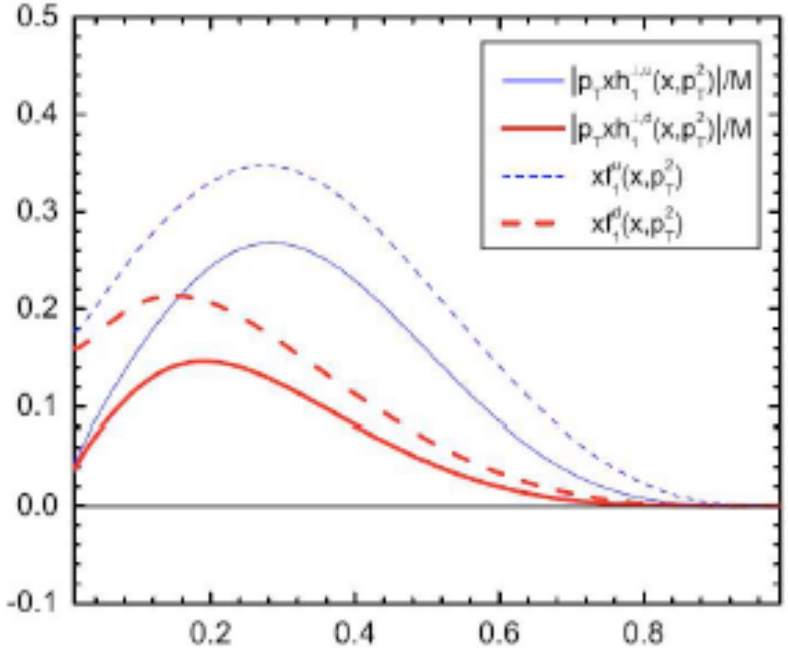
    $\longrightarrow$ CSS resummation in Drell-Yan (Collins, Soper, Sterman, 1985); resum logarithms of the type

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

$\longrightarrow$ Has also implications for Fermilab and LHC physics

Some indications for the future Drell-Yan experiments

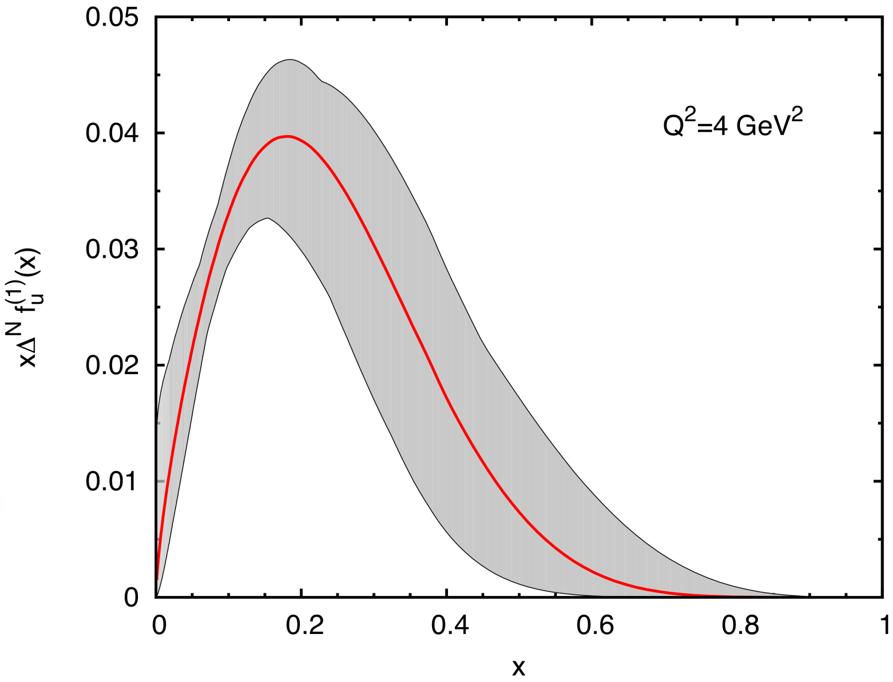
1. TMD PDFs – ALL are sizable in the valence quark region



► 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.

COMPASS facility at CERN (SPS)

COmmon Muon Proton Apparatus for Structure and Spectroscopy

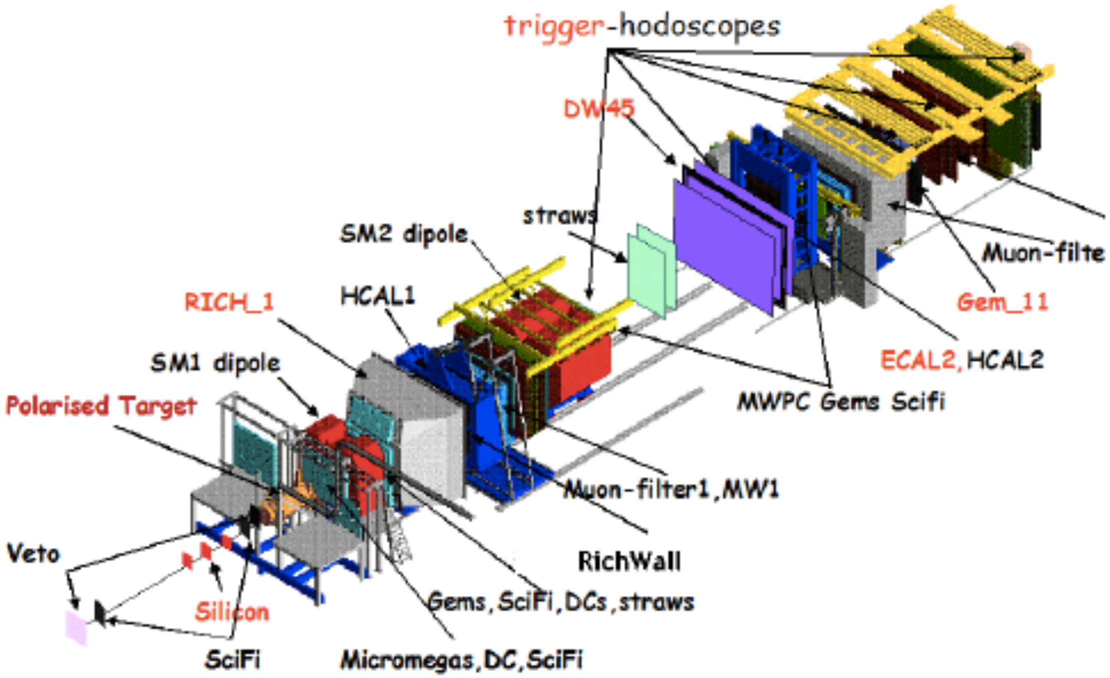
COMPASS facility at CERN

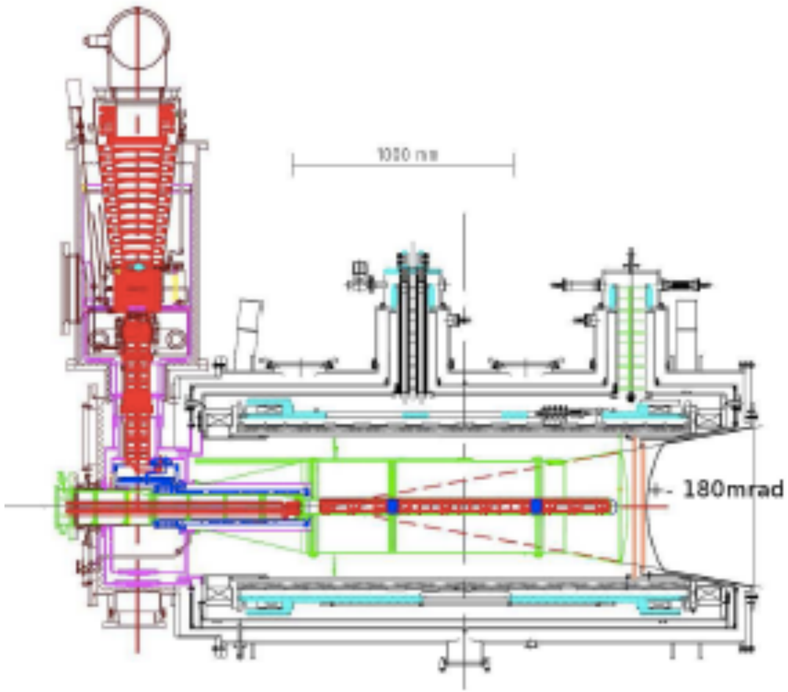
Two stages spectrometer

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

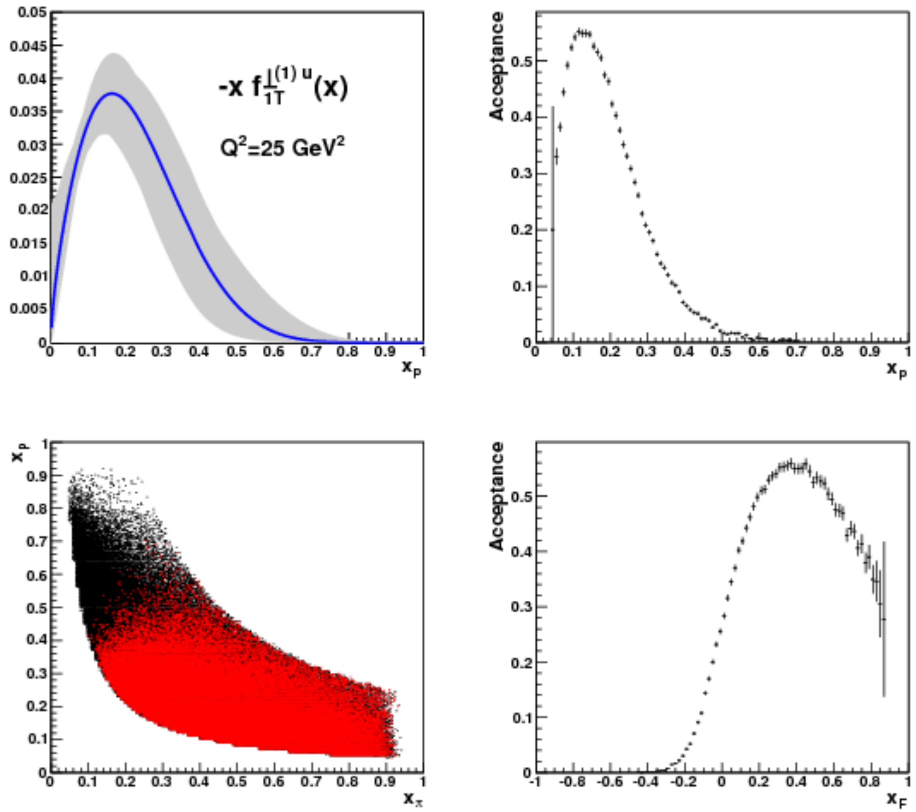
For the moment we consider two step DY program:

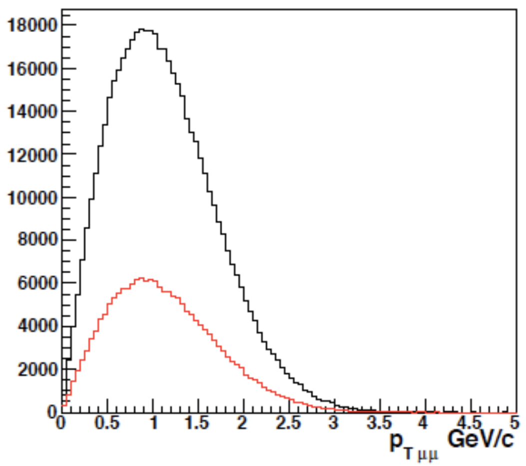
- The program with high intensity pion beam
- The program with Radio Frequency separated antiproton beam

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
- $<P_T>$ ~ 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

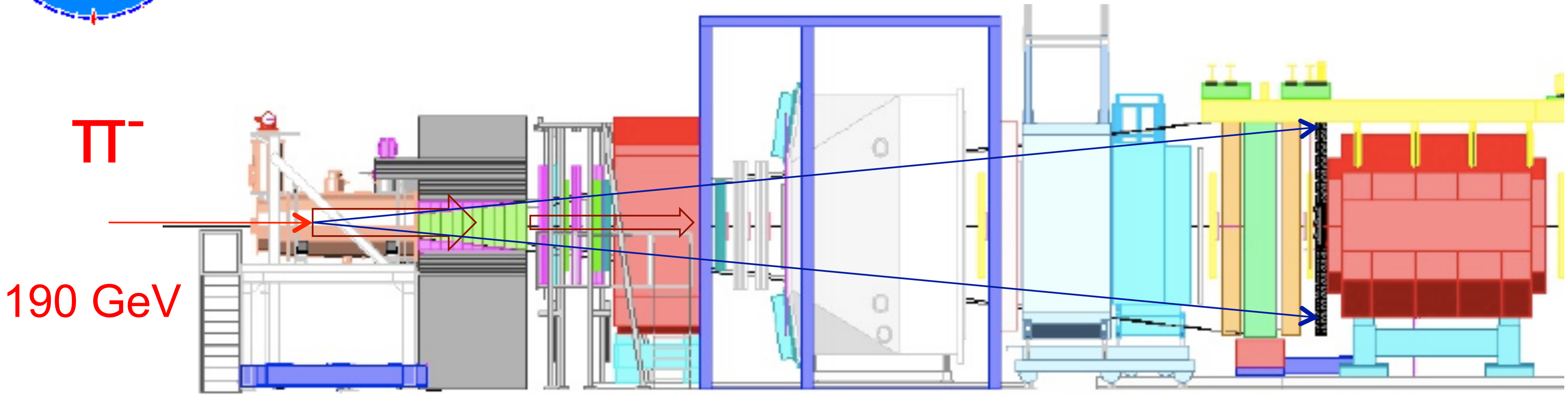
3. Hadron absorber + shielding ➔ PT has to be moved by 2.2 meters upstream

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

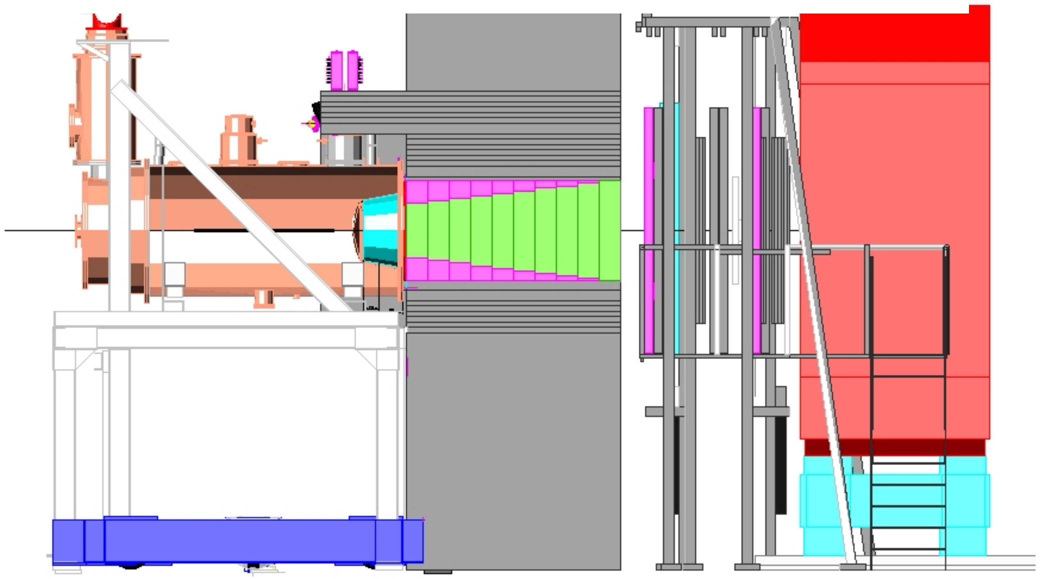
DY@COMPASS - set-up

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



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)



COMPASS PT

- Statistical accuracy: $\dfrac{\delta A^{exp}}{A^{exp}} = \dfrac{1}{\sqrt{2N}\; P_B P_T f\, A^{phys}}$

  ❶ ❷ ❸

  → 1. Large target
  2. High target polar.
  3. High dilution factor

- The challenge for COMPASS:

1. To run the largest solid polarized target = higher statistic
2. To achieve the highest polarization
3. To measure the polarization without disturbing the experiment
4. To reduce multiple scattering = minimizing non-target material
5. To have changes of the sign of polarization = against false asymmetries from acceptance changes

COMPASS PT
Fifure of merit

Choice of the material

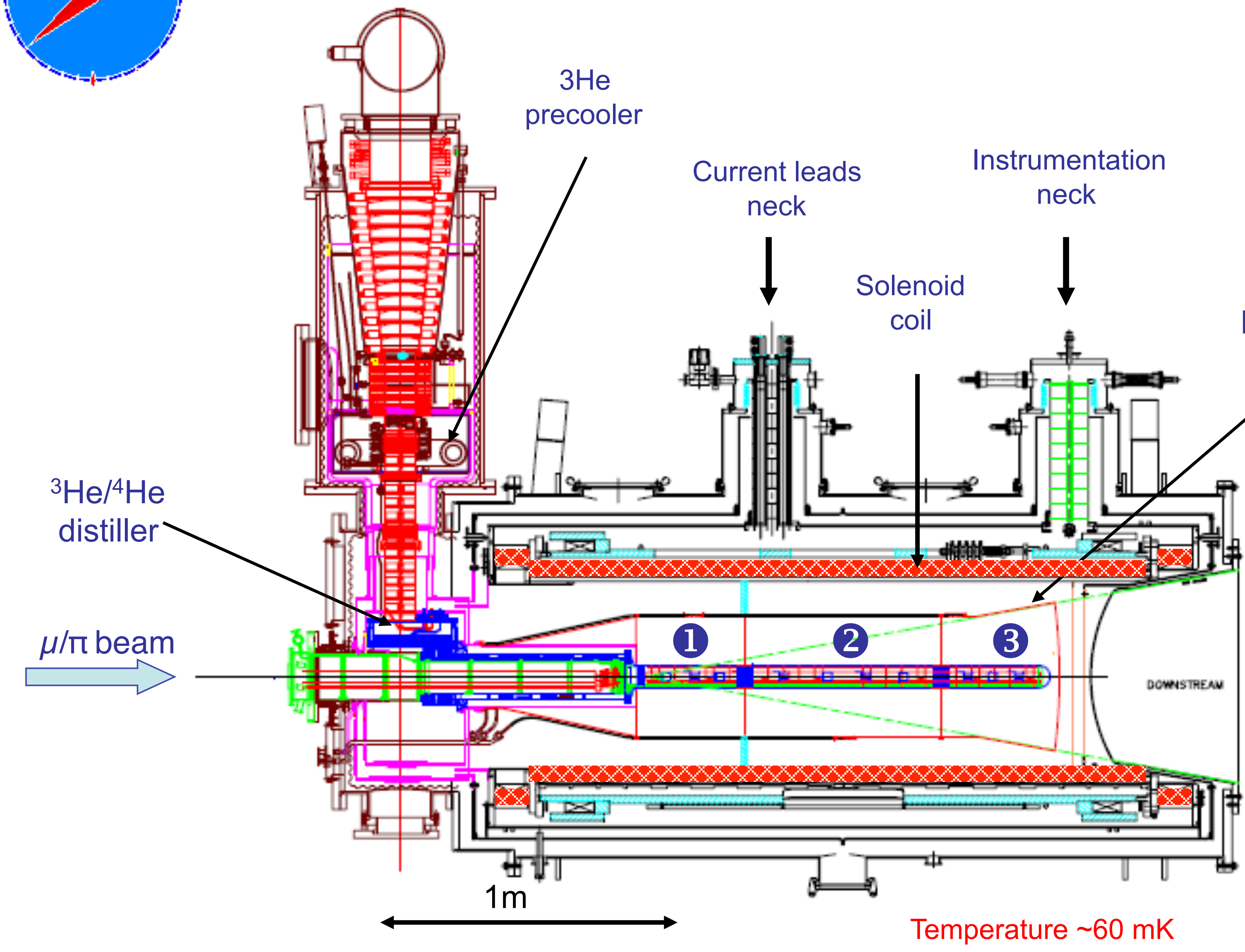
The beam time t to reach a certain statistical accuracy **DA** shows the dependency

$$t^{-1} \propto r\,(f\,P)^2$$

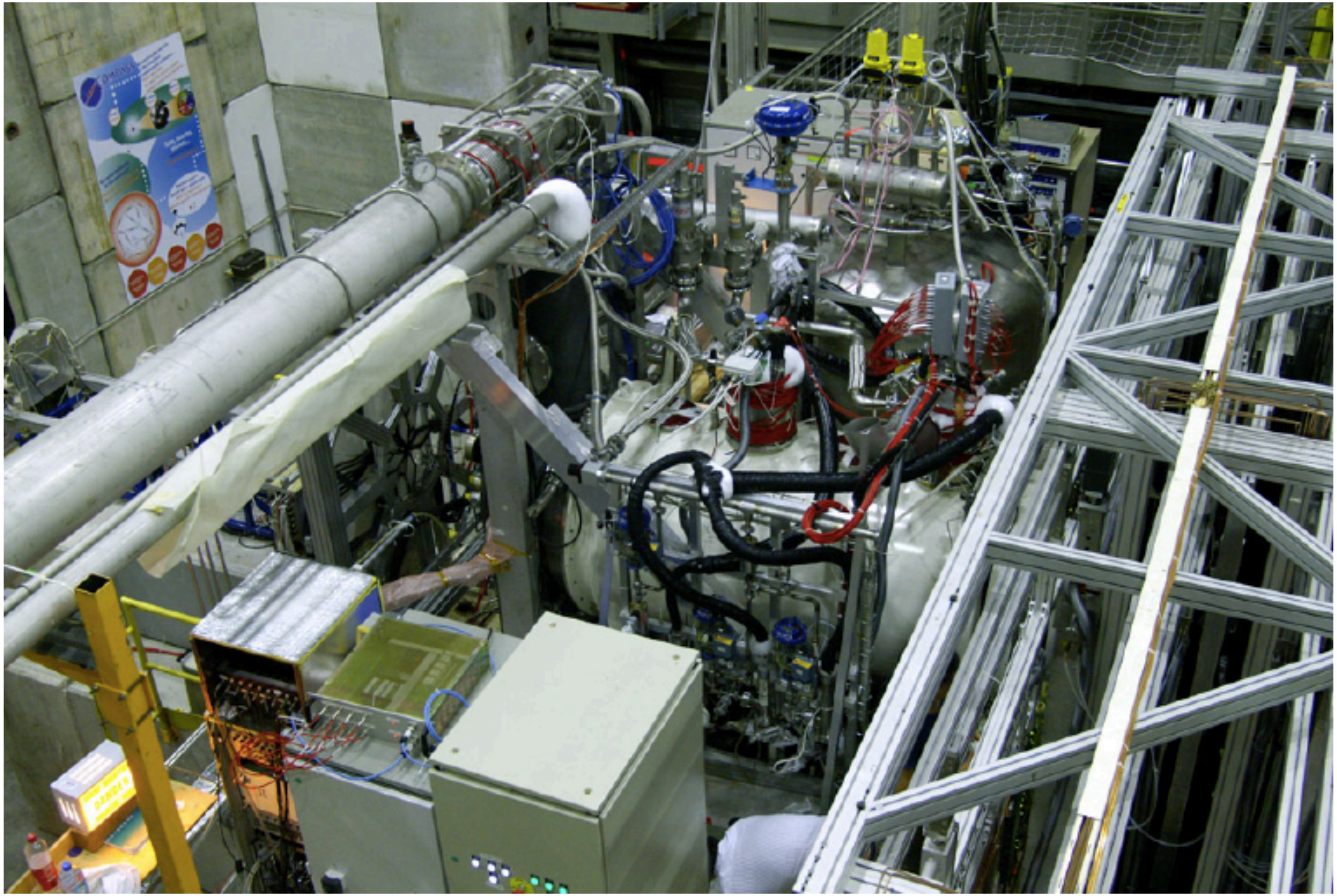
We define the Figure of Merit (FoM) $FoM = k\,r\,(f\,P_T)^2$

	SMC	SMC	COMPASS
Material	NH_3	D-butanol	^{6}LiD
Density	0.85	1.10	0.84
Polarization	H: ~0.90	D: ~0.50	D: ~0.50
Packing factor k	0.60	0.60	0.55
Dilution factor f	0.176	0.238	~0.50
FoM	10.3	6.7	16.0

Sketch of the new target set-up “COMPASS”:

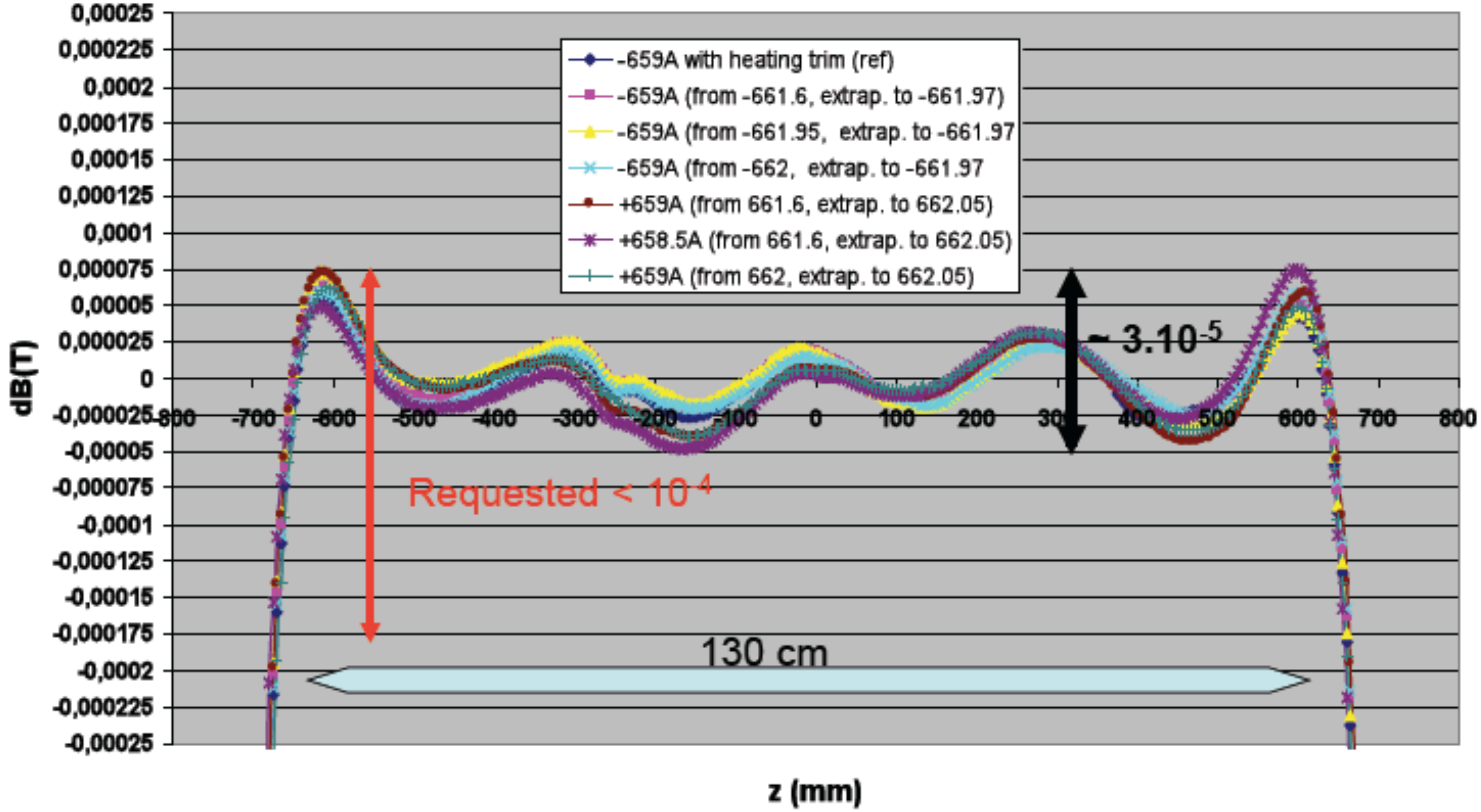


Old COMPASS PT



Old COMPASS PT

Field homogeneity achieved at Saclay



NEW COMPASS PT

After some accidents in 2011the decision was taken by the collaborator to refurbish the PT + PT super-conducting magnet system. This refurbishment was including:

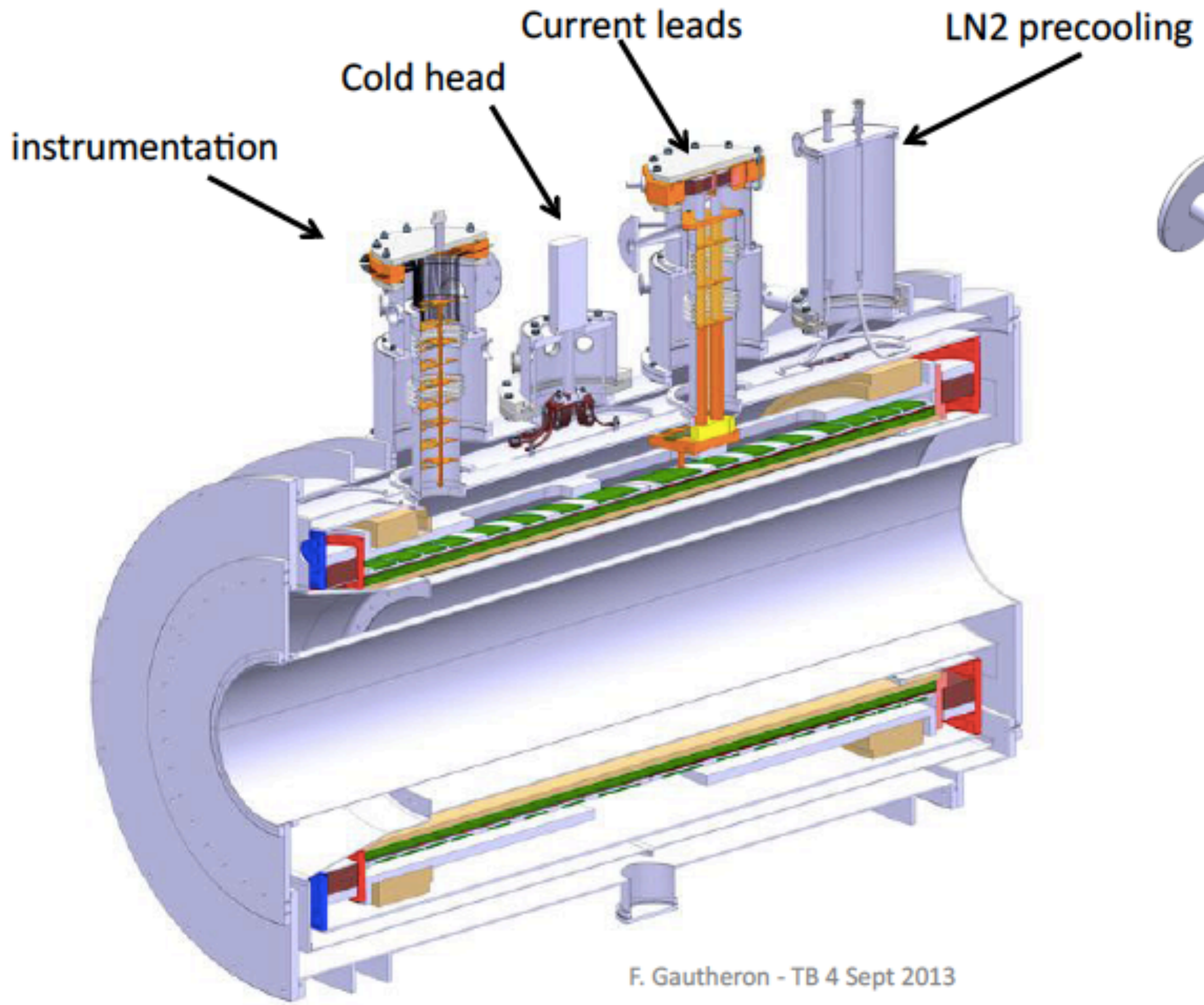
1. Complete magnet disassembly and burned trim coils repair
2. New Magnet Control System
3. New Magnet Safety System
4. New Power supplies

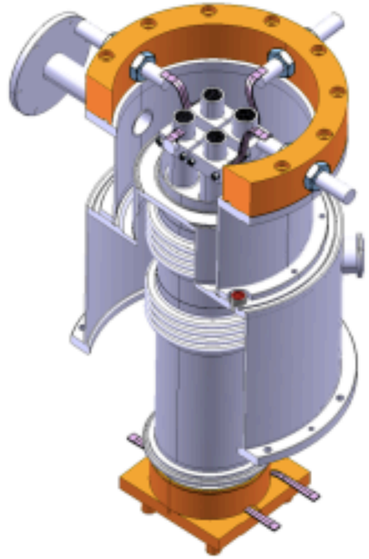
Etc.

NEW COMPASS PT
Reassembling in the vacuum cryostat

NEW COMPASS PT

Cut view of the set-up





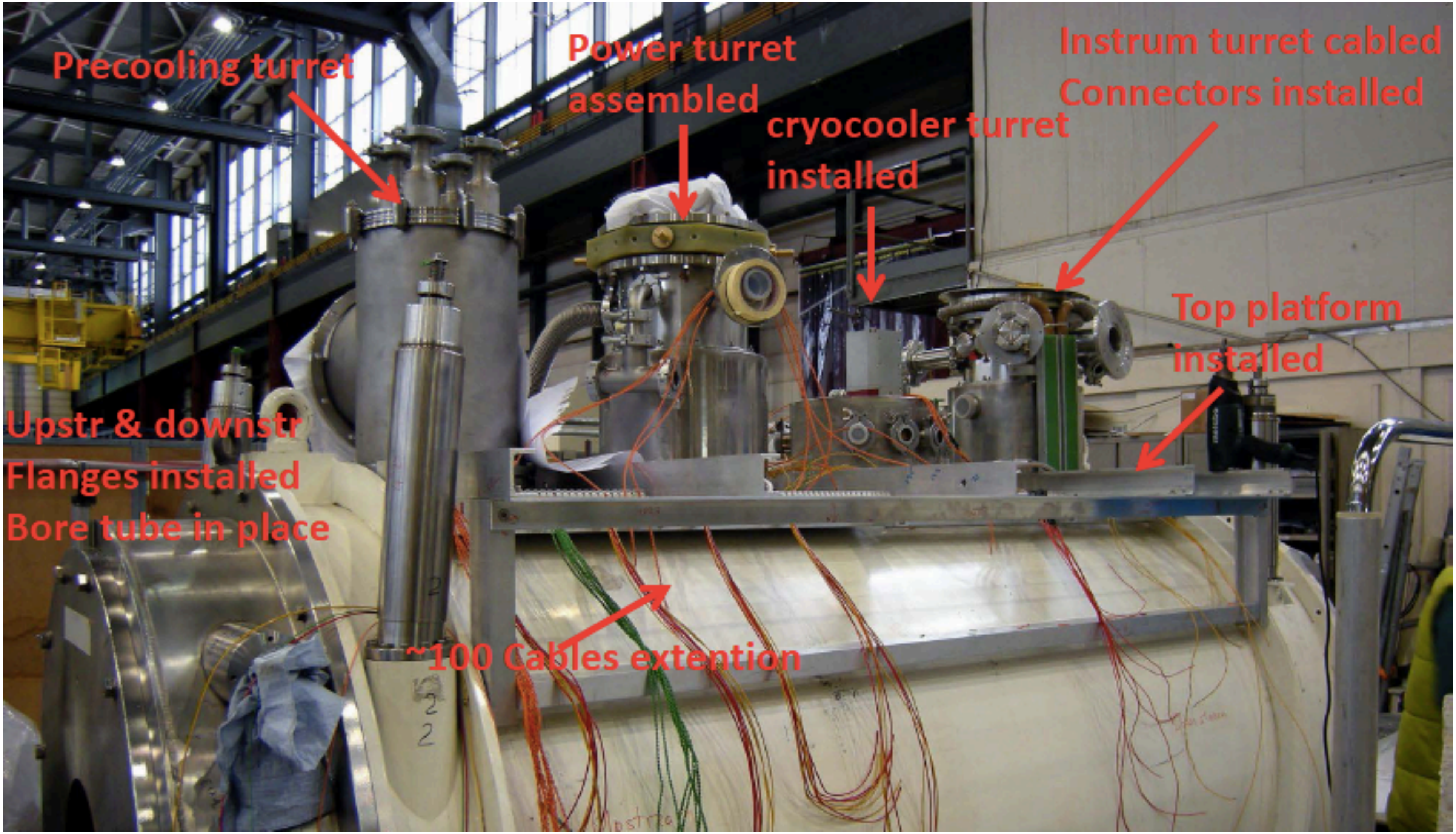
NEW COMPASS PT

Some new elements of MSS and MCS

Trim coils PSU rack

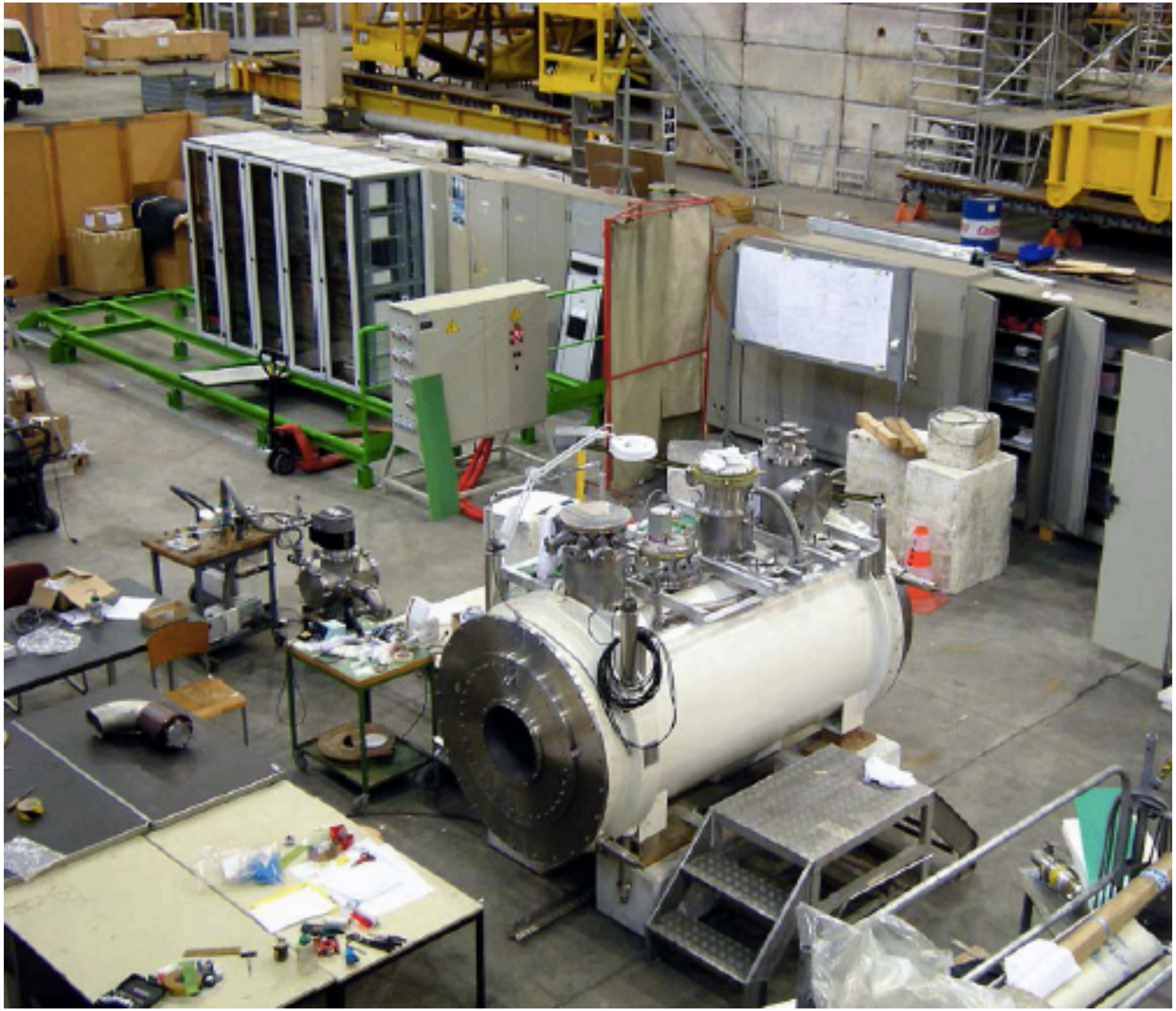
Magnet heaters PSU racks

NEW COMPASS PT
READY to be tested system

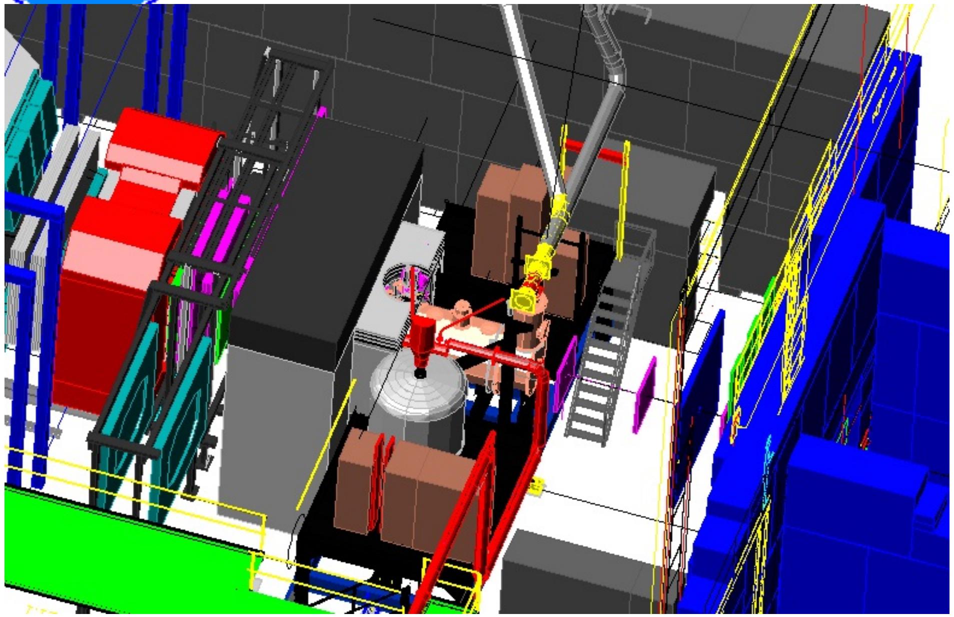


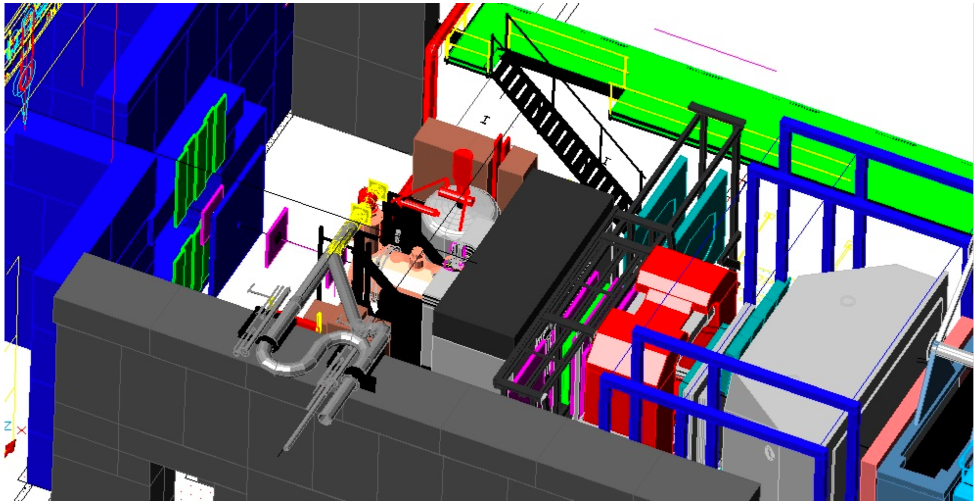
NEW COMPASS PT

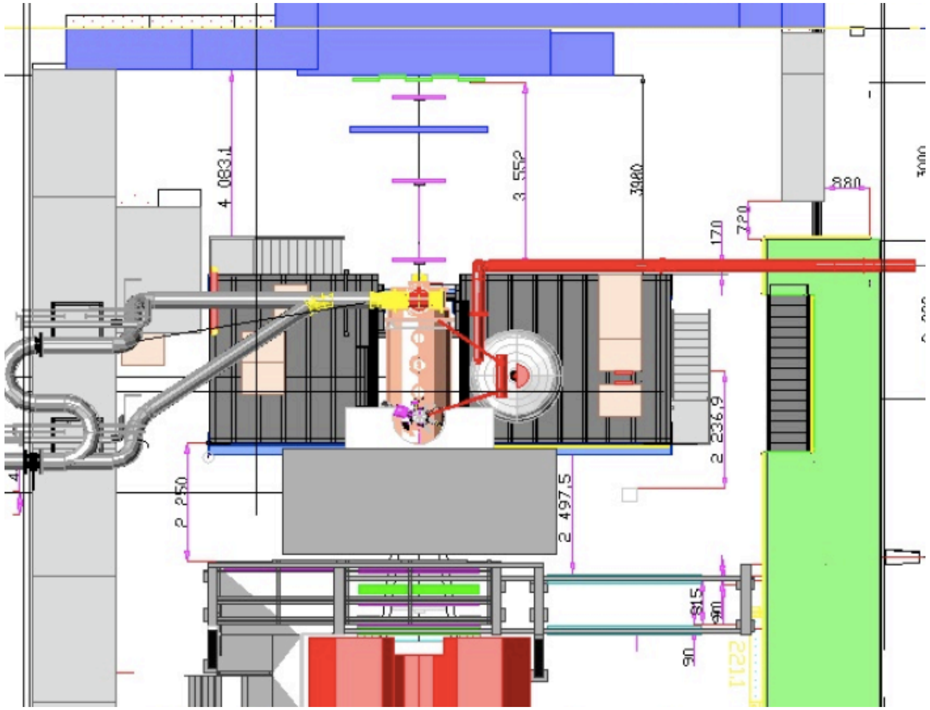
Test area, Magnet is expected to be back to COMPASS in February



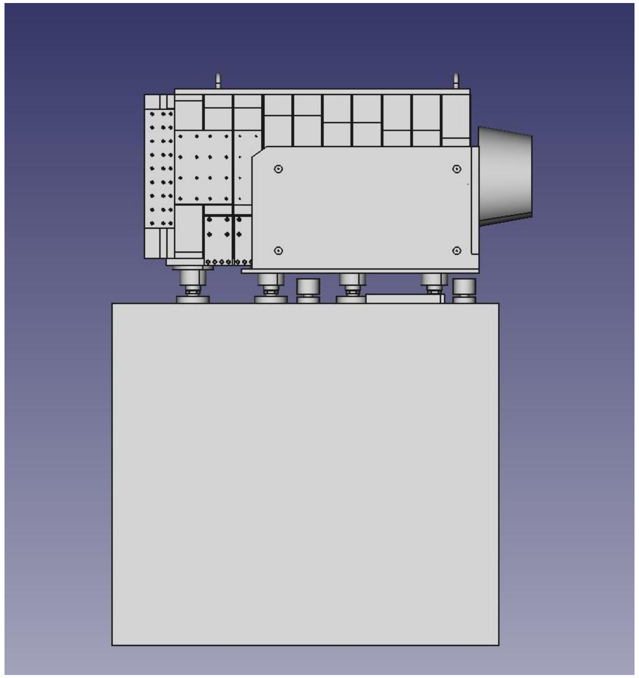
Drell-Yan experiment lay-out
Hadron absorber&R.P.shieldings and Polarised Target

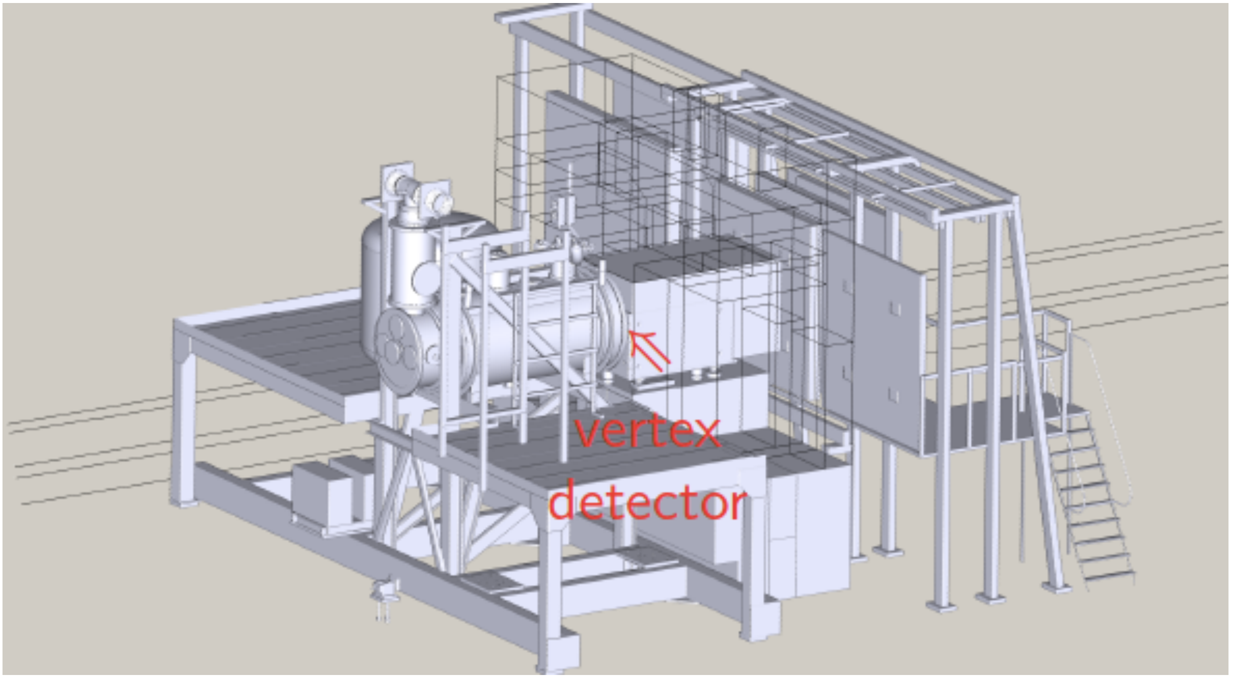


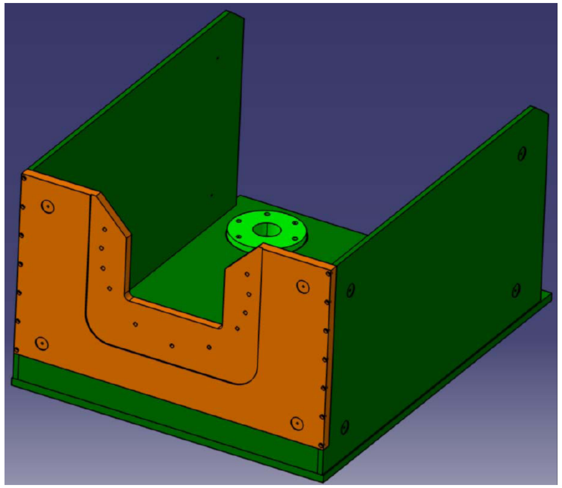


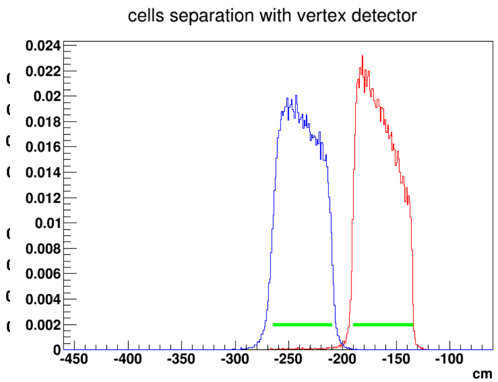


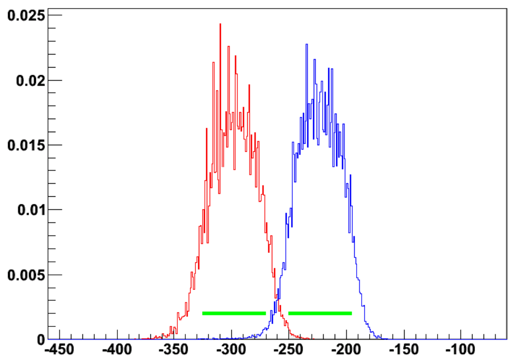
Drell-Yan experiment lay-out
Sci-Fi based Vertex detector





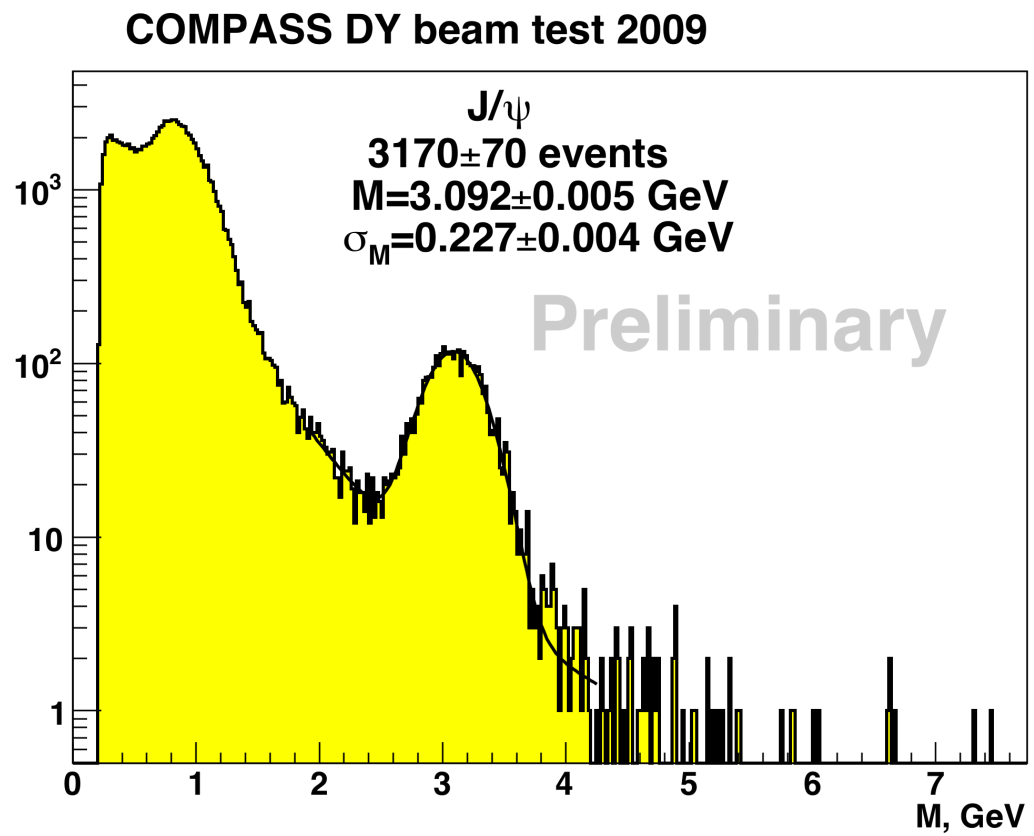






DY@COMPASS - feasibility - Signal

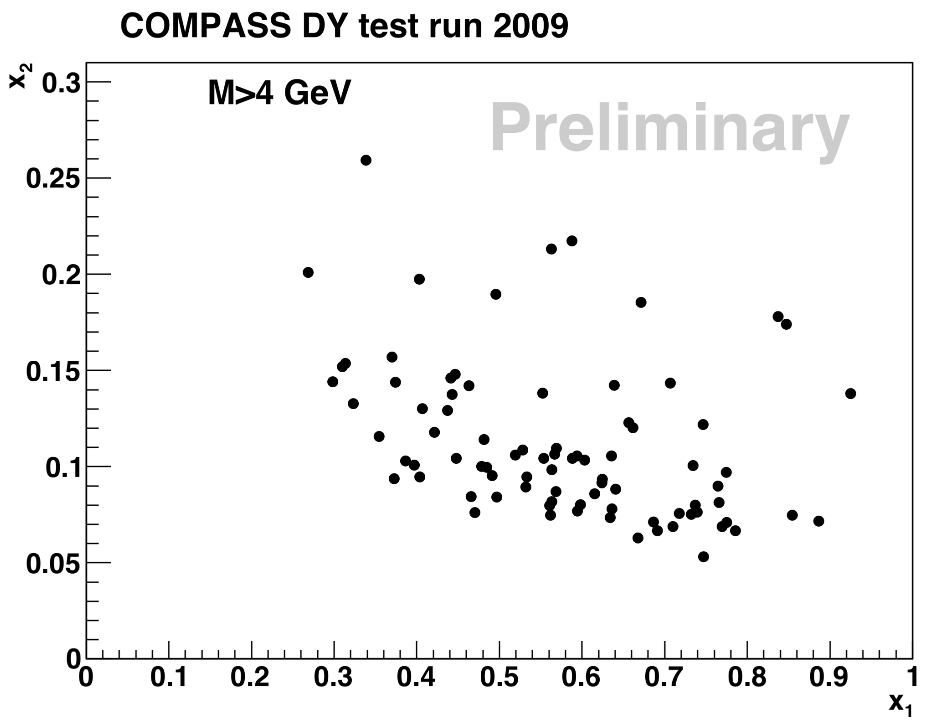
- Expected according to the proposal J/Psi and Drell-Yan yields: 3600±600 and 110±22 (normalized to 2009 beam flux ~3.7 x 10^{11})
- Measured in 2009 beam test J/Psi yield is 3170±70, and DY yield is 84±10

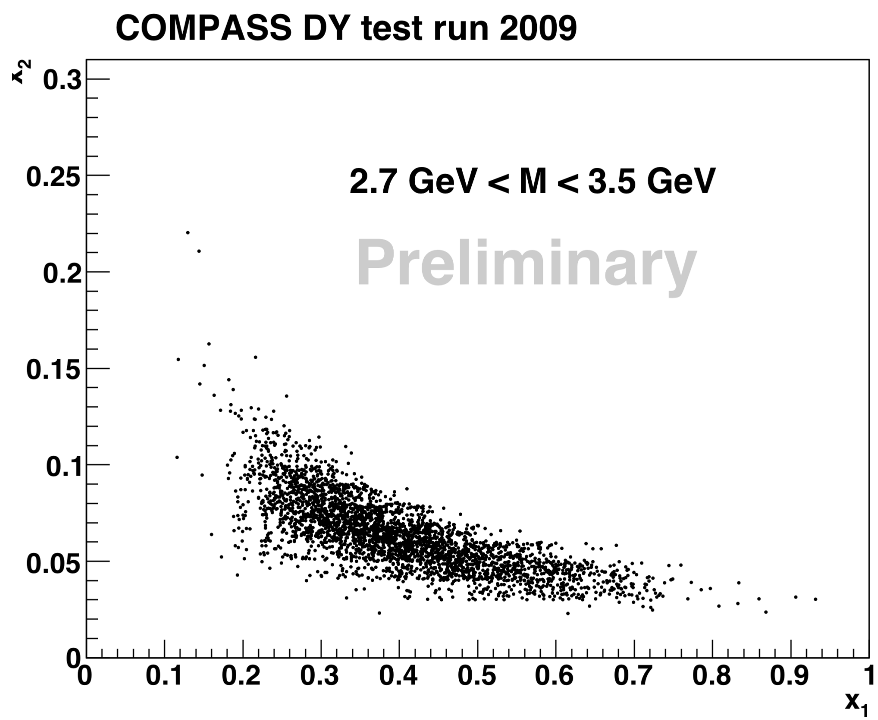


DY@COMPASS - feasibility – Kinematics I

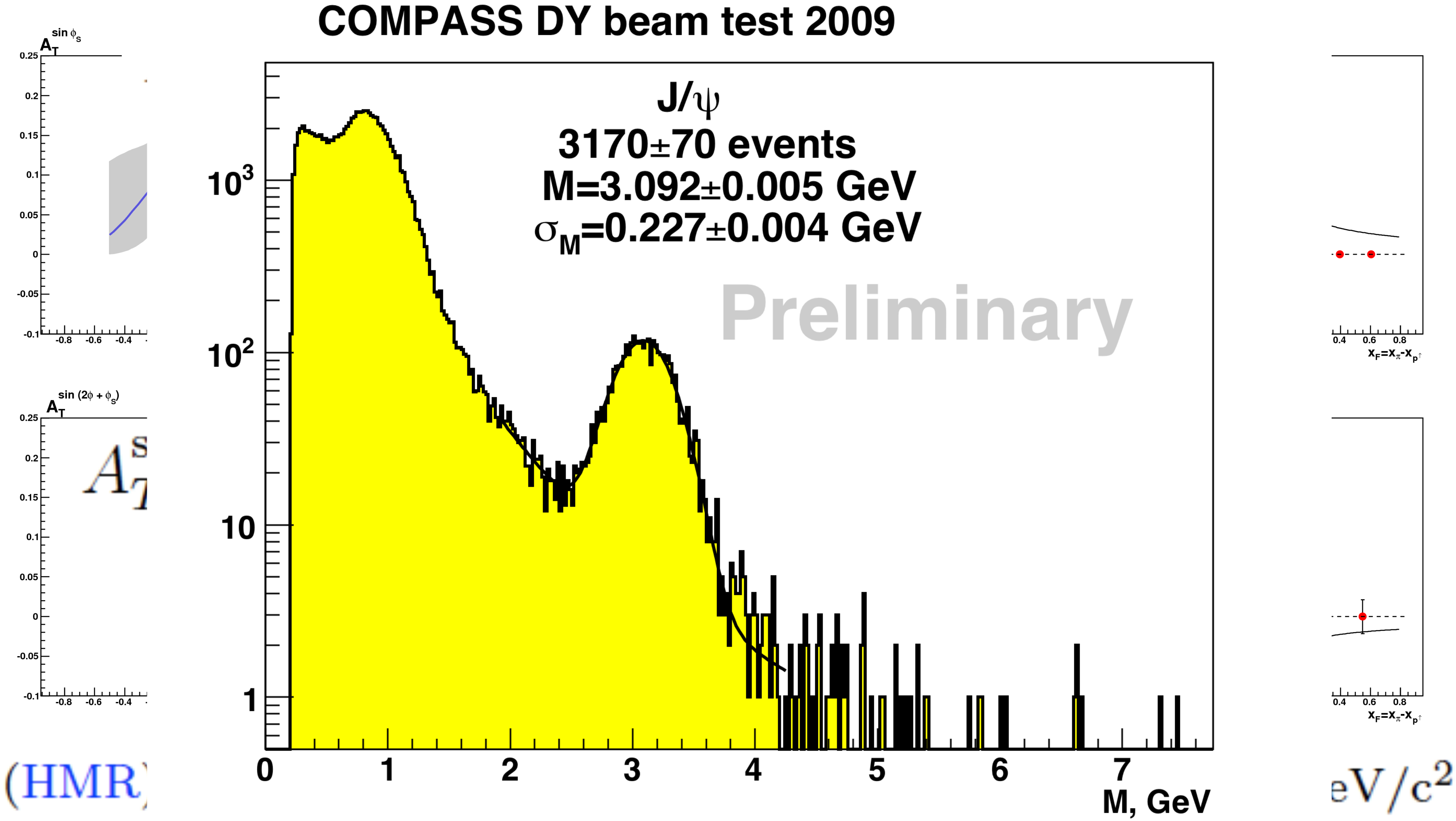
- Valence quark range for both J/Psi and DY

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



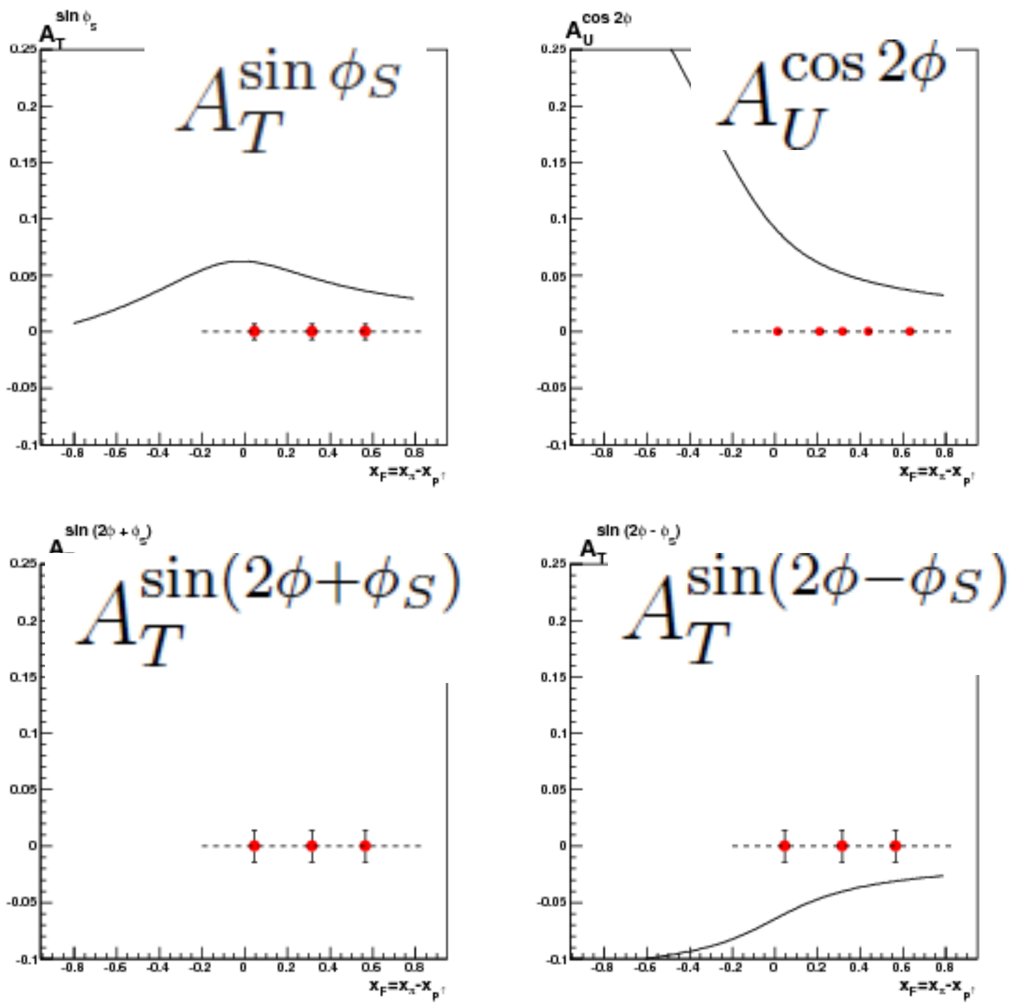


DY@COMPASS projections II



DY@COMPASS projections III

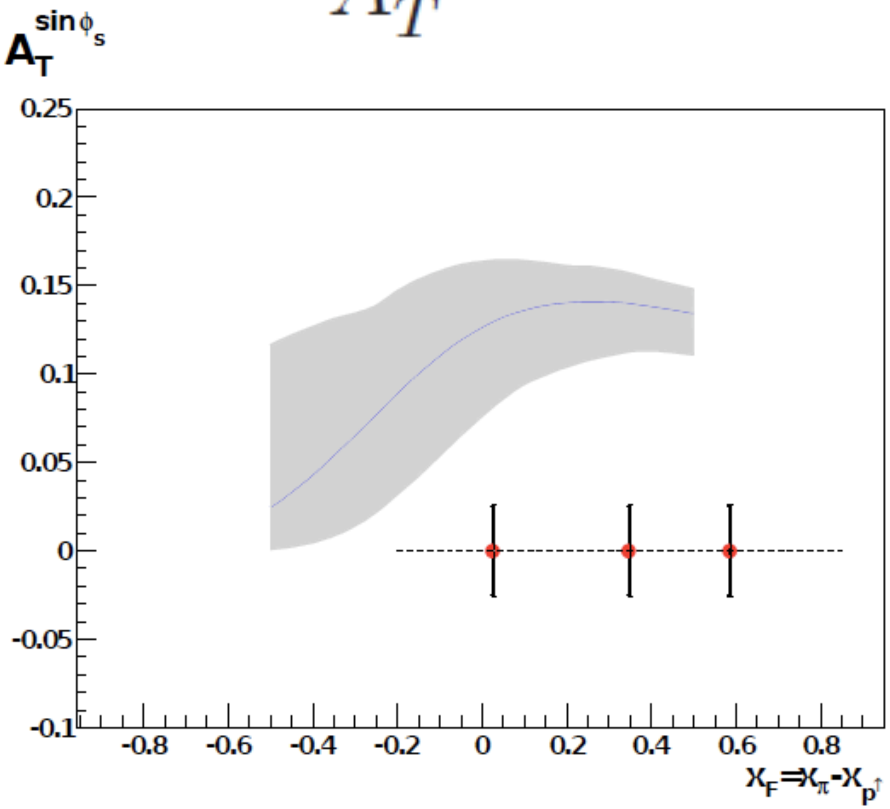
J/ψ region: $2.9 \leq M_{\mu\mu} \leq 3.2\ \mathrm{GeV/c^2}$



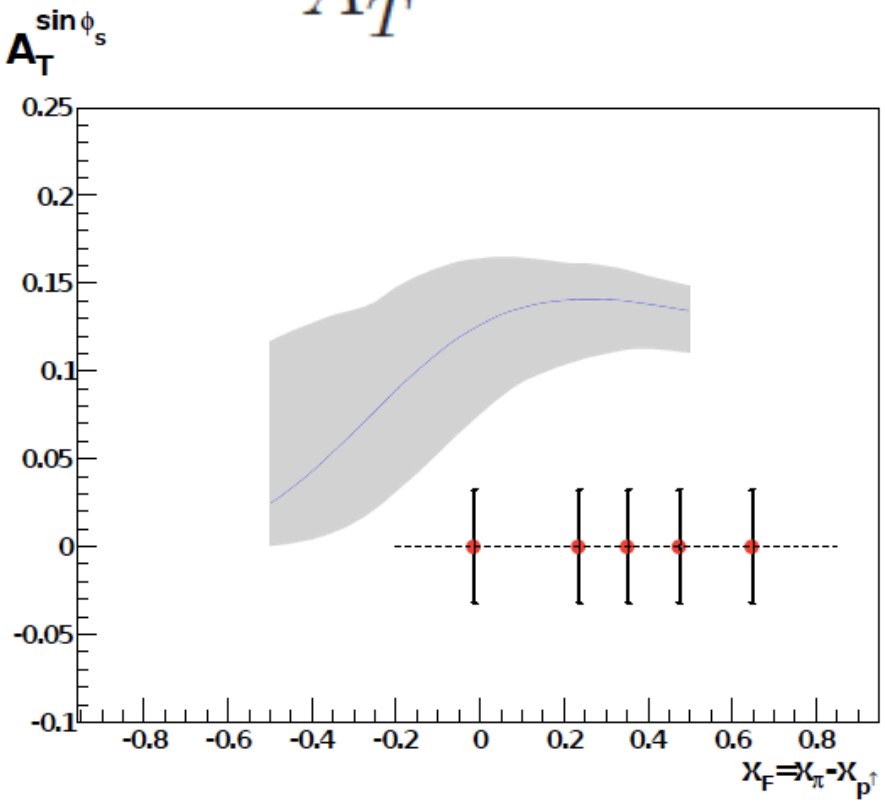
DY@COMPASS projections IV

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

$A_T^{\sin \phi_S}$



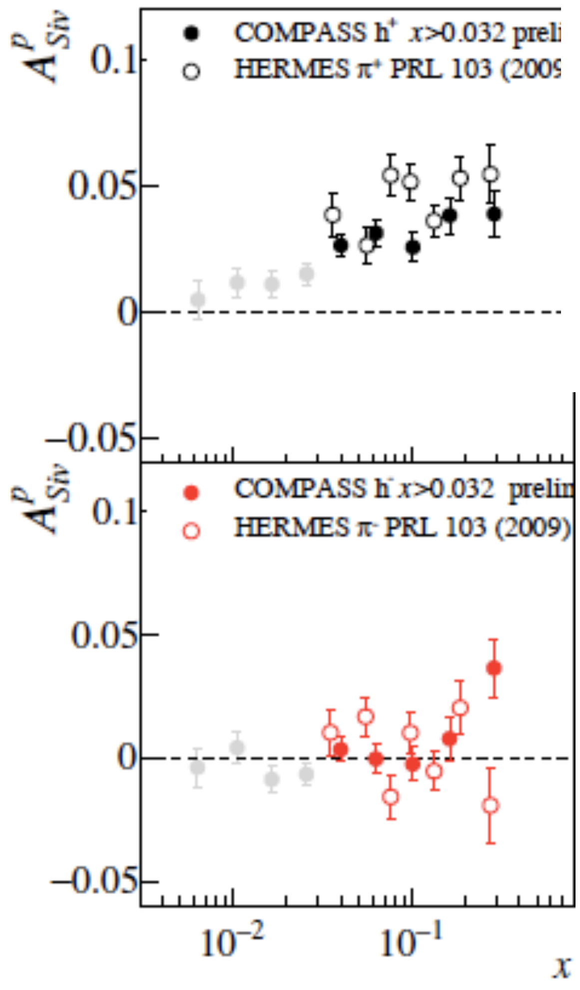
$A_T^{\sin \phi_S}$

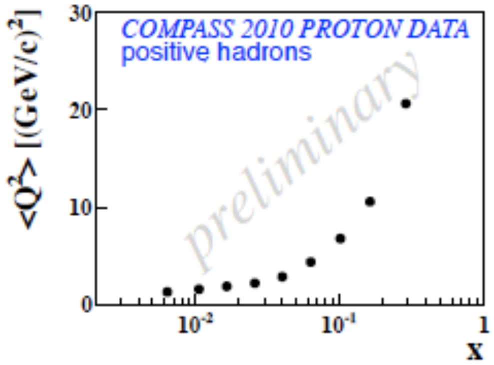


SIDIS←→DY – QCD test

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

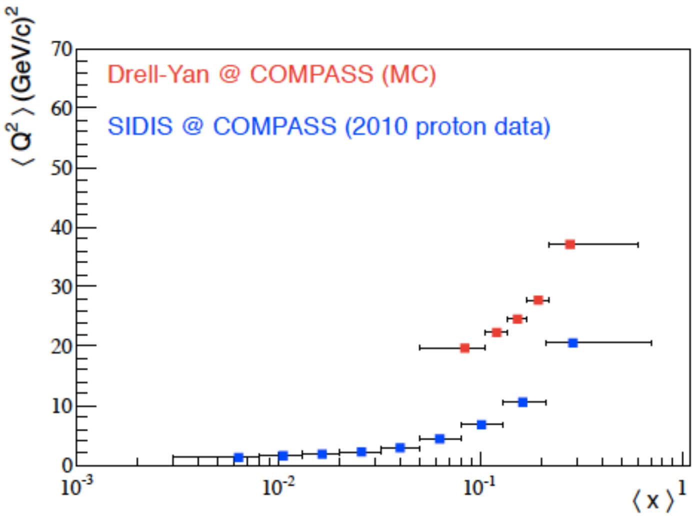


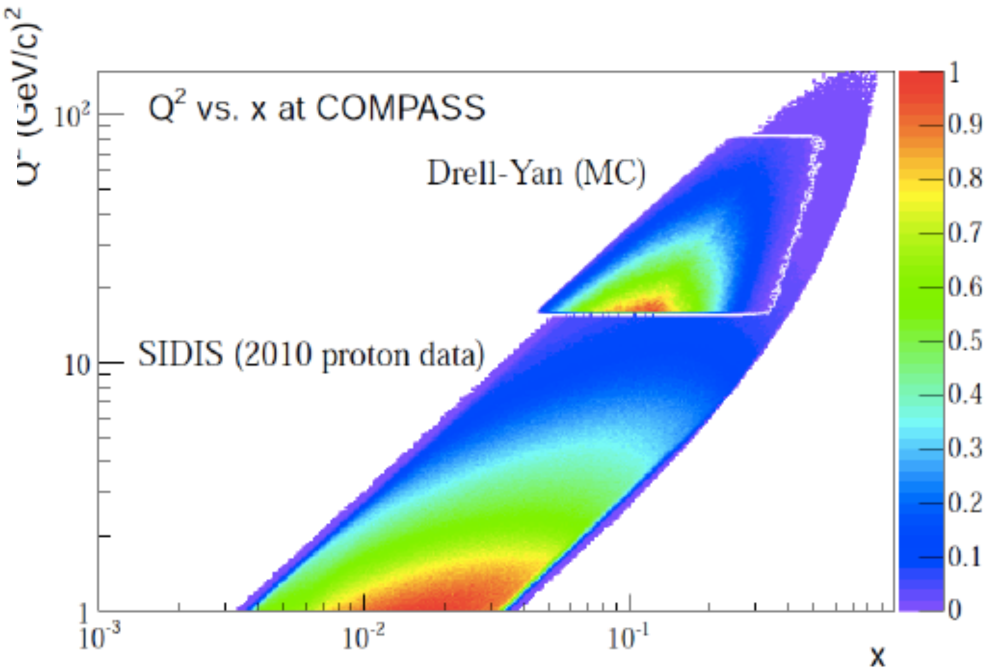


Drell-Yan COMPASS
<Q^2>~25 GeV^2,
0.05 < x_B <0.4

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.

What kind of recommendation can we give to the DY@AFTER interested people I
Beam

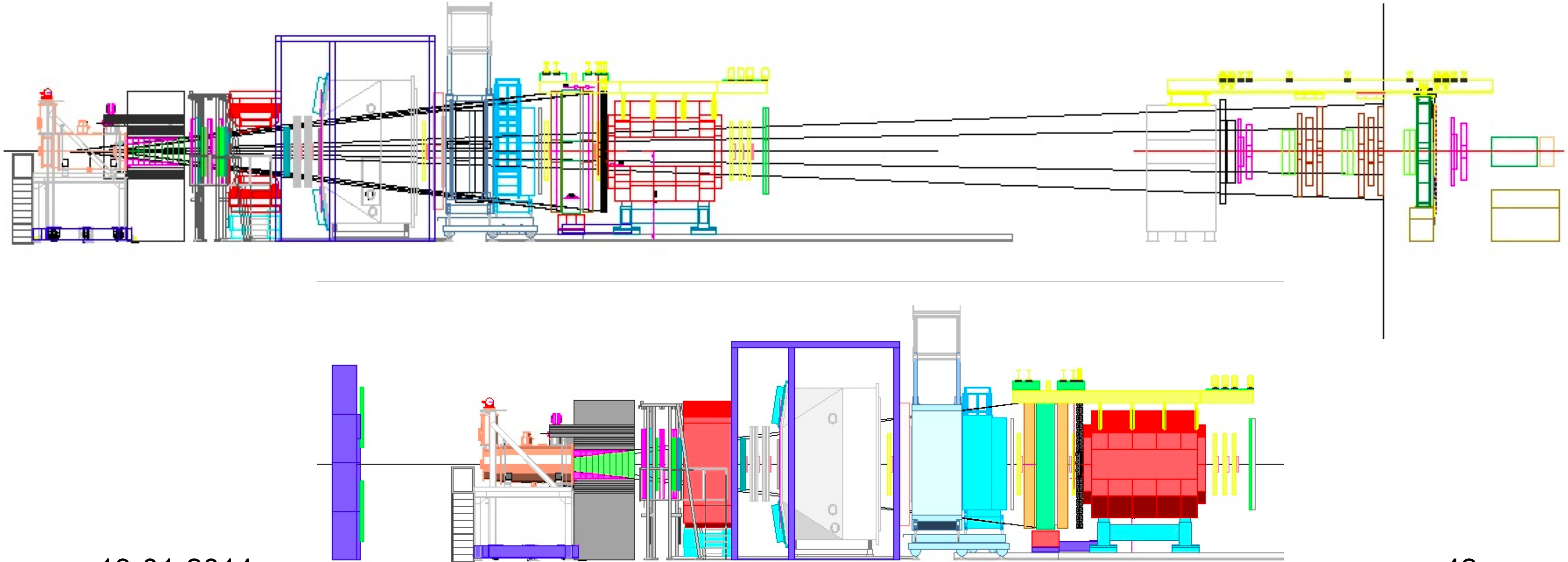
1. Moderate beam intensity in case of the solid state polarised target. Normally, for example NH_3 target can be operated with a proton beam intensity up to the 10^9 particles per second.

2. Large beam spot (defocused beam or beam wobbling) in case of the solid state PT. Target has to be illuminated uniformely (more or less) and not heated by the focused beam very locally. In case of the focused beam it will be much more difficult to control the polarisation of the target – it might bring to a very large uncertainties.

3. De-bunched slow extraction – 25 nsec structure of the LHC beam has to be smeared.

What kind of recommendation can we give to the DY@AFTER interested people II
Kinematics

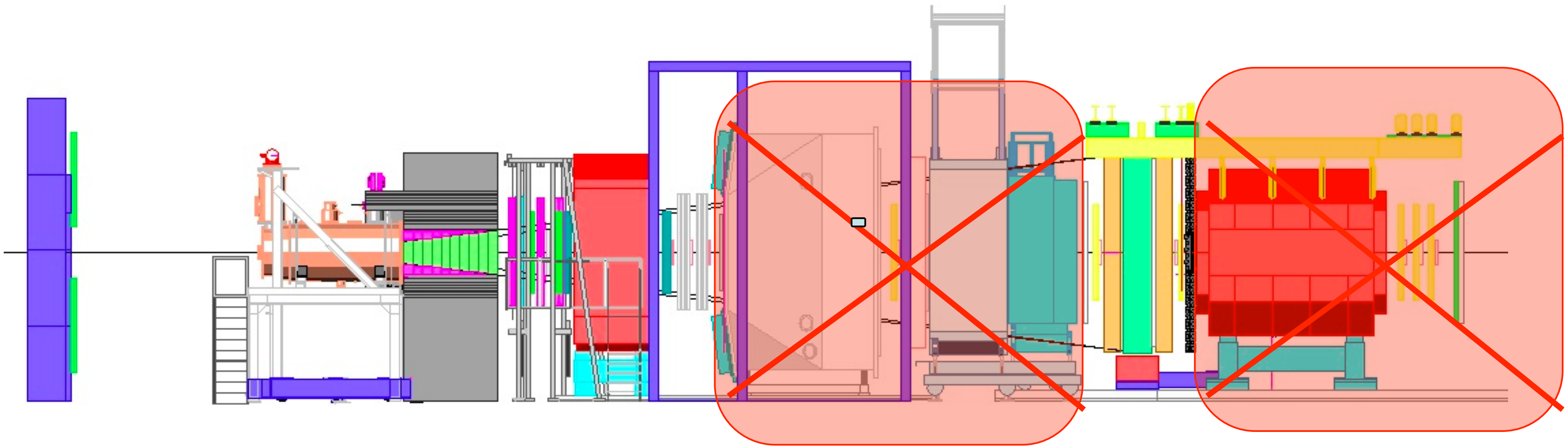
In order to be sensitive to spin effects one has to have a good acceptance coverage of the target fragmentation region (in case of the fixed polarised target experiment and unpolarised beam). In fixed target geometry experiment that would mean to have good acceptance coverage at “large” angles.



What kind of recommendation can we give to the DY@AFTER interested people III
Spectrometer

In case of DY physics the spectrometer can be rather simple, MUST elements:

- Beam telescope (depends on how beam is extracted)
- Polarised Target
- Hadron absorber
- Vertex detector
- 1 stage spectrometer (Dipole or Solenoid magnet + two groups of tracking stations- before and after)
- Muon detectors and dimuon trigger



Drell-Yan Experiments 5 years Running plan

1. Fermilab E-906: data taking resumed 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 ?

DY Experiments: Summary

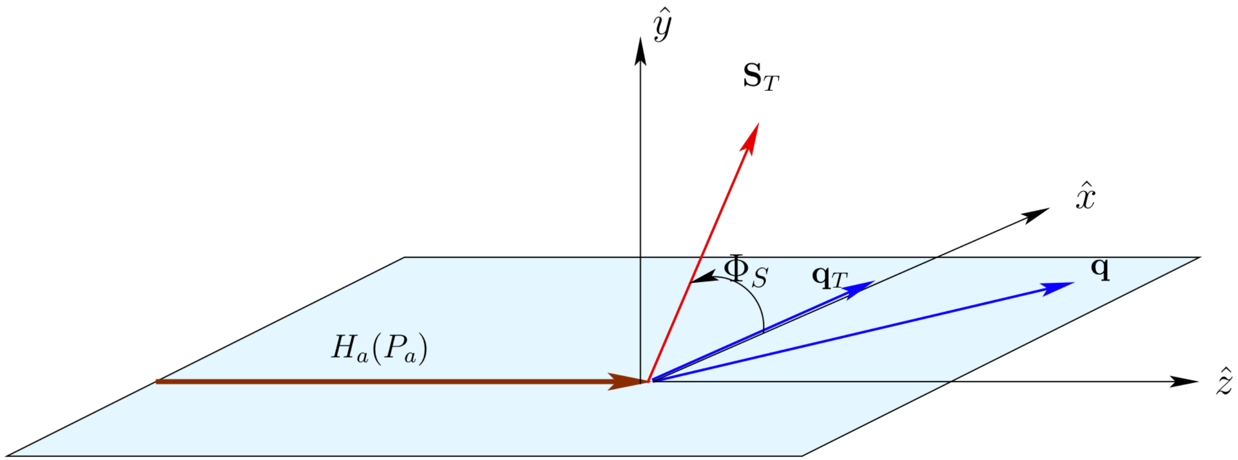
- Proton and pion induced DY – data are coming up in the next 2 years
- Some statistics with kaons and antiprotons will be available
- Statistical error on single spin asymmetries on the level of 1÷2% will be achieved by the of 2016
- A lots of new unique data is just behind the corner, AFTER can as well provide a valuable contribution to this business.

- Spares

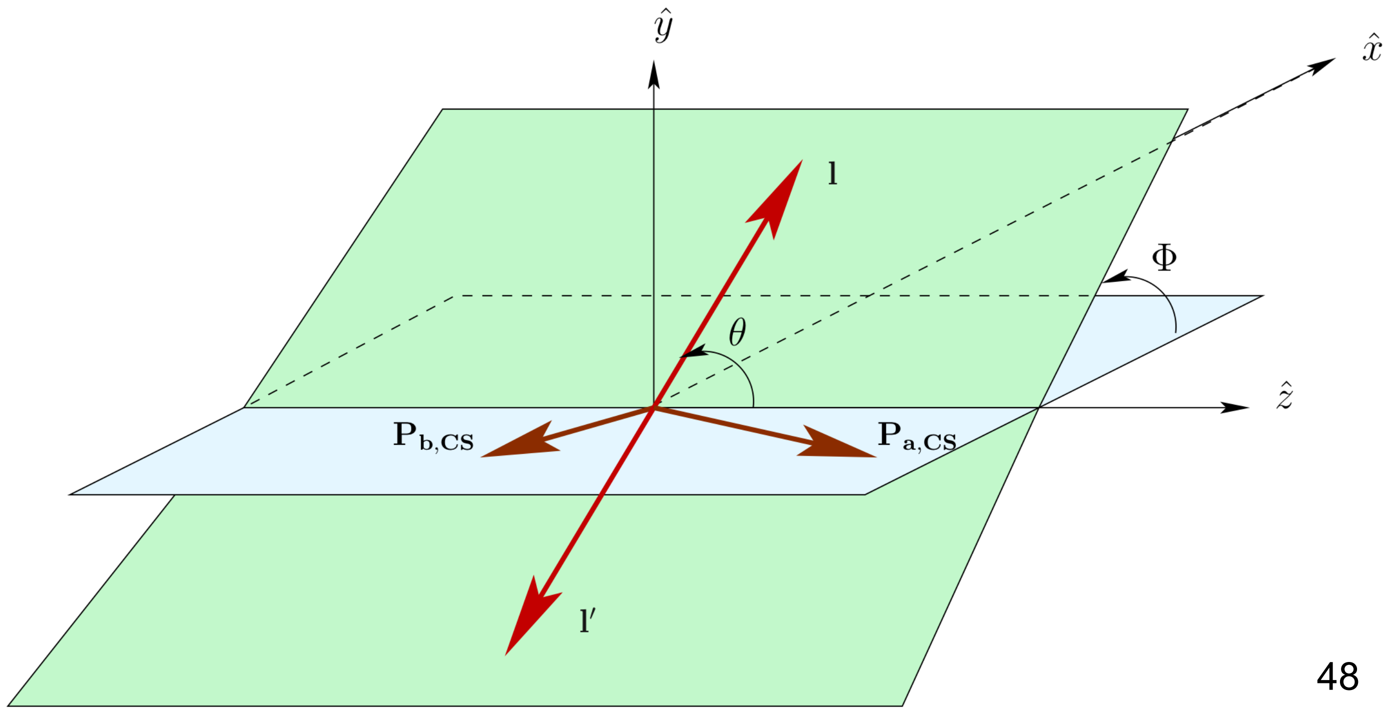
TMDs at Drell-Yan: road map

- 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

TF



Collins-Soper



Drell-Yan Workshop at CERN, April 26-27

Studying the hadron structure in Drell-Yan reactions

26-27 April 2010 *CERN*

Overview
Programme
Registration
Registration Form
List of registrants
Laptop and Wireless access
Access Cards
Accomodation
How to get to CERN

Support

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.

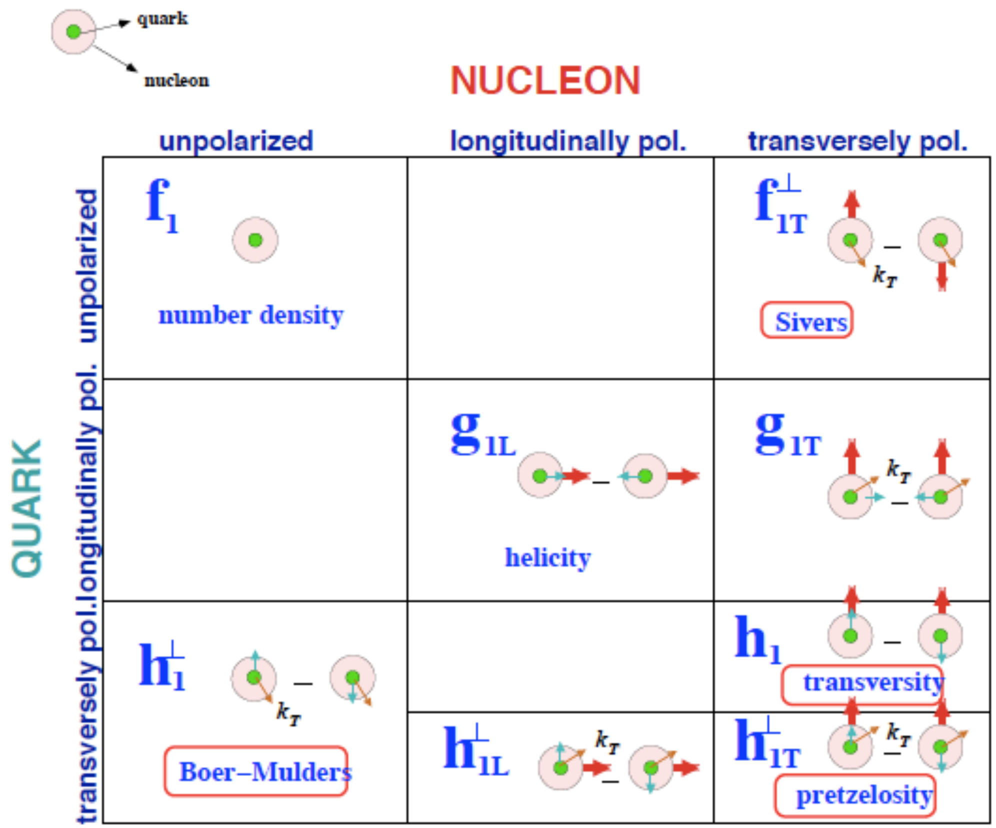
Organizers: Paula Bordalo (LIP-Lisbon and IST/UTL)
Oleg Denisov (CERN/INFN-Torino)
Eva-Maria Kabuss (Mainz)
Fabienne Kunne (CEA Saclay)
Alain Magnon (CEA Saclay)
Gerhard Mallot (CERN)
Anna Martin (Univ. Trieste and INFN-Trieste)
Wolf-Dieter Nowak (CERN)
Daniele Panzieri (Univ. Alessandria and INFN-Torino)

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:

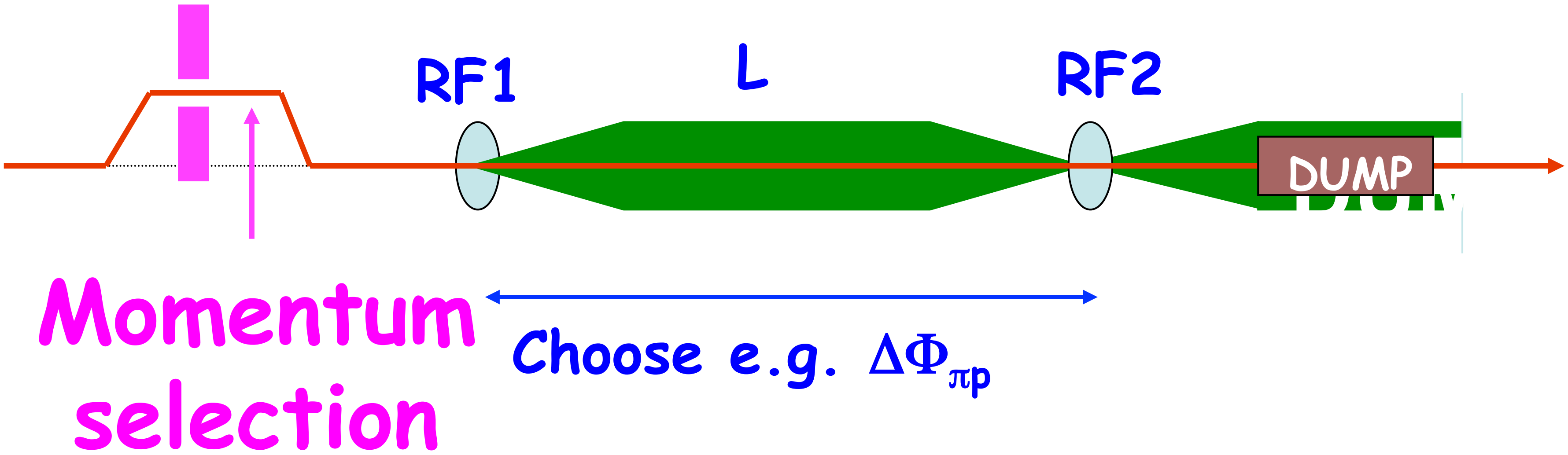


Polarized Drell-Yan measurements in COMPASS C. Quintans – p.2

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

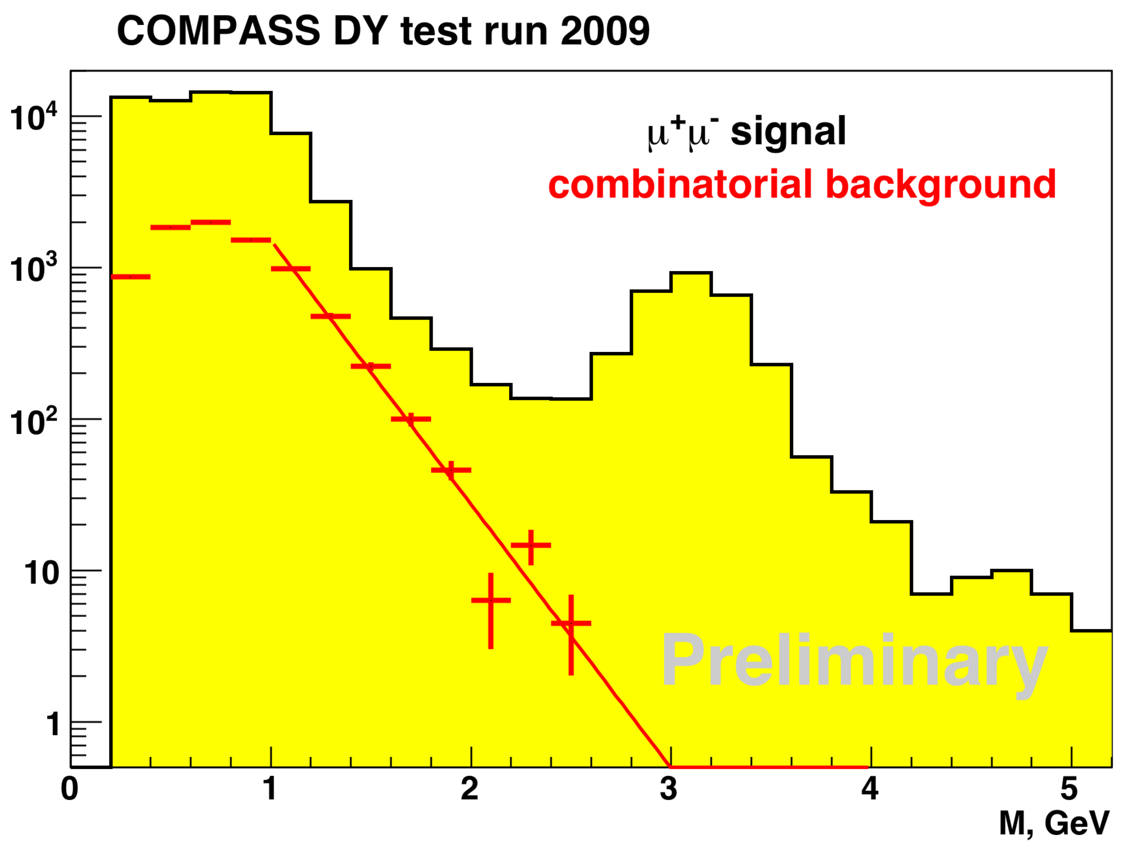
E.g. a system with two cavities:



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

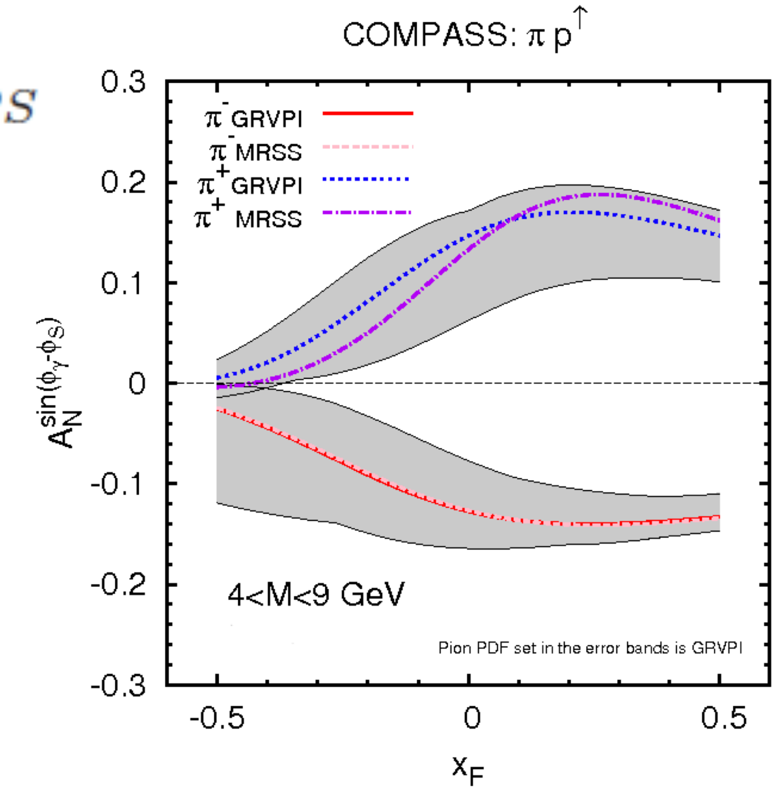
DY@COMPASS - feasibility – Background II – Combinatorial

- 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

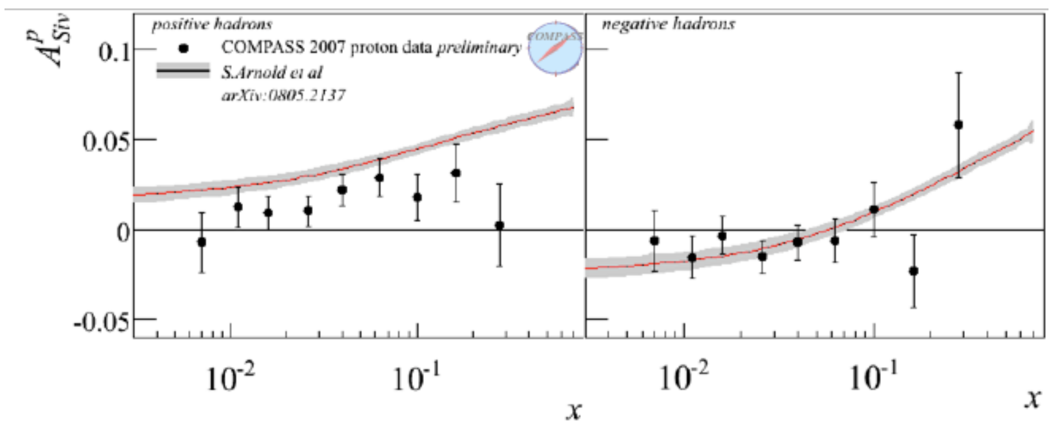
$A_T^{\sin\phi_S}$

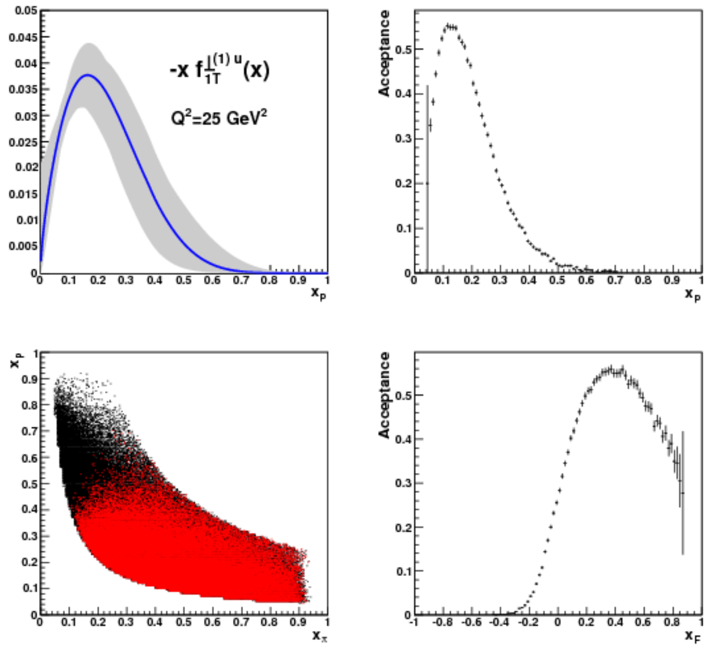


In case of $\pi^- p$ scattering the valence pion $\bar{u}$ unpolarised PDF is well known and there is no difference between two pdf sets. In case of $\pi^+ p$ scattering there is a little contamination coming from sea $\bar{u}$ of the pion, which annihilates with valence u quark of the proton, because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





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

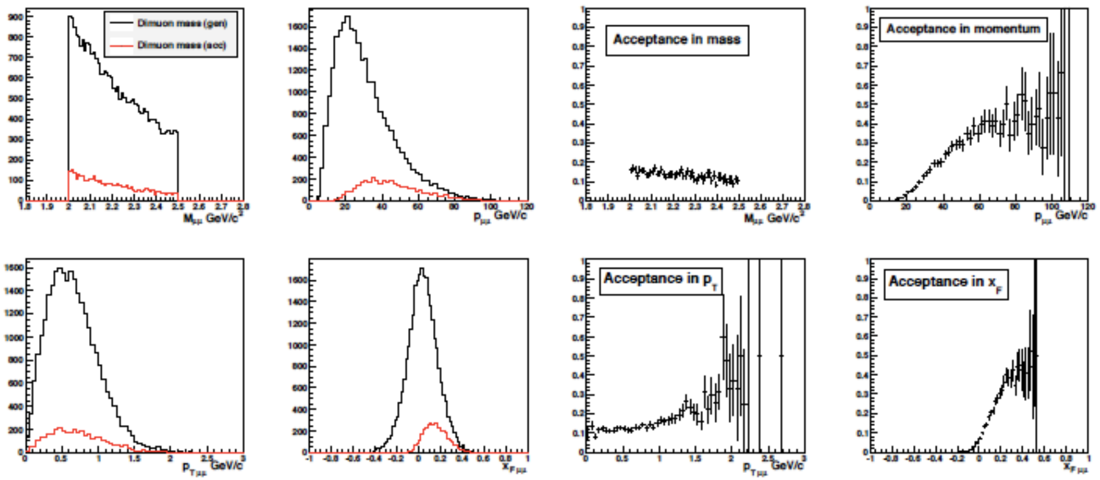
$$\tau = x_a x_b = M^2/s$$

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

Pion-induced unpolarised DY, Pion structure functions I

The only way to access pion PDFs

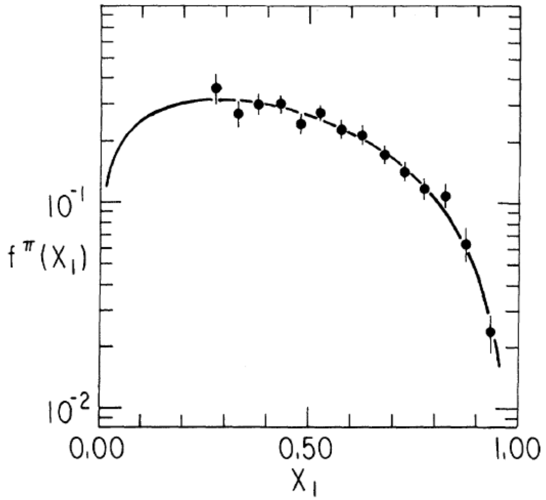
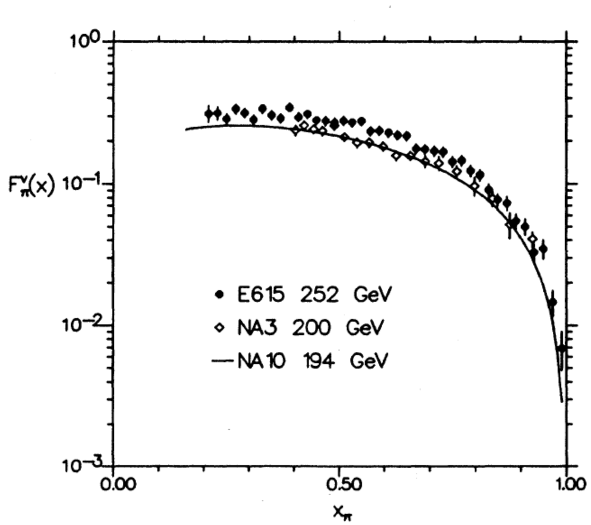


FIG. 3. The pion structure function $f^{\pi}(x_1) = x_1 \bar{u}^{\pi^-}(x_1)$.

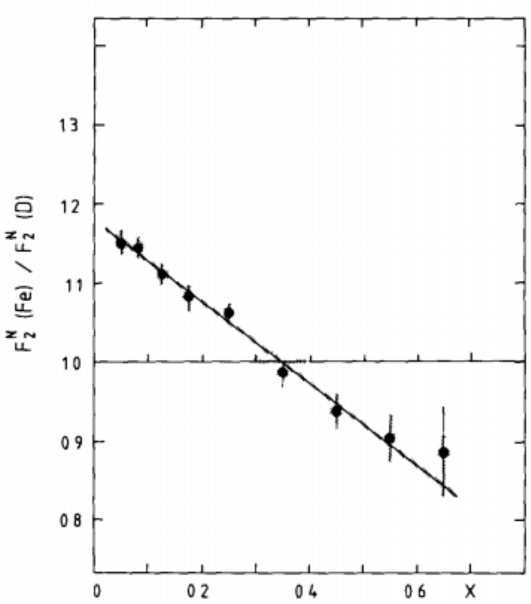


CIP (PRL 42, 951, (1979))

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 ?

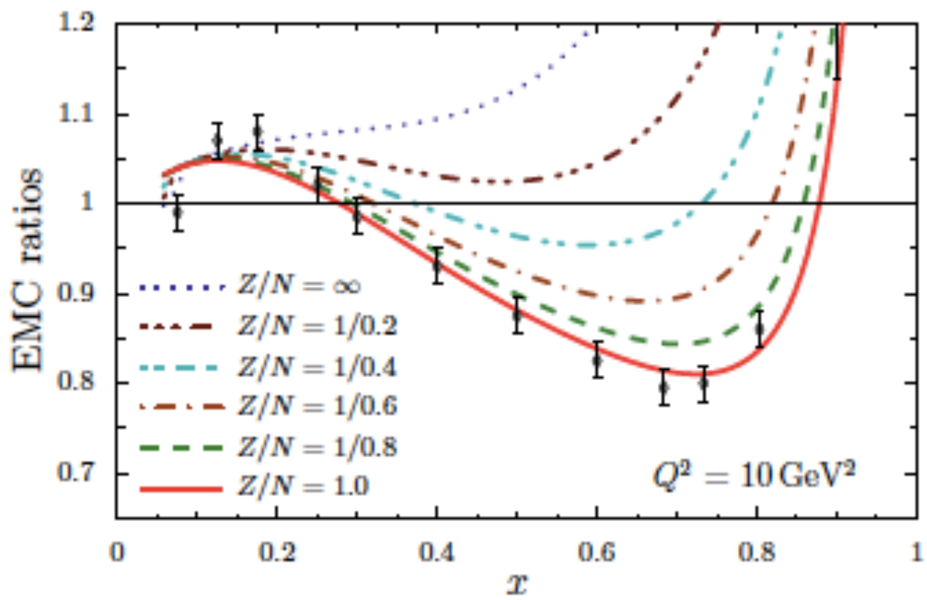
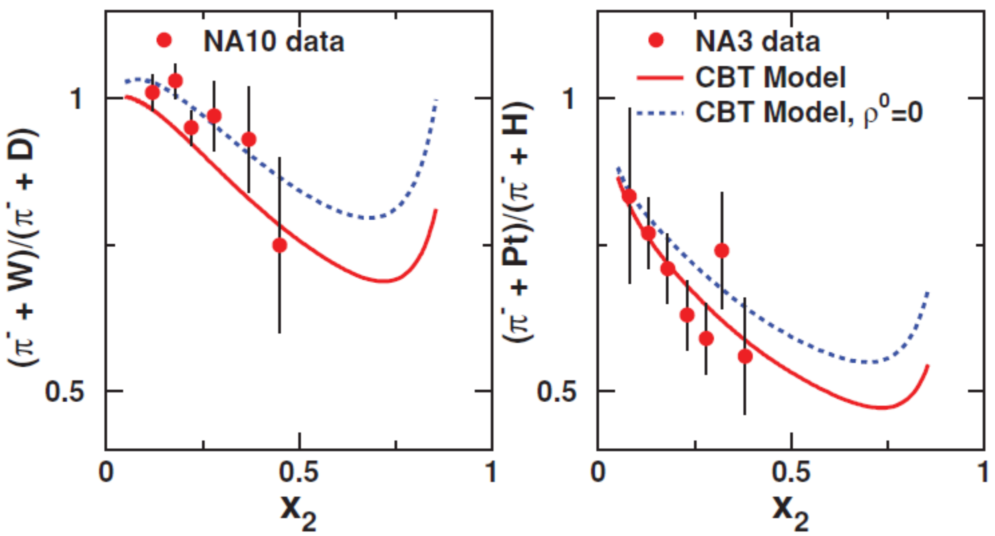


FIG. 1: Isospin dependence of the EMC effect for proton-neutron ratios greater than one. The data is from Ref. [24] and corresponds to $N = Z$ nuclear matter.

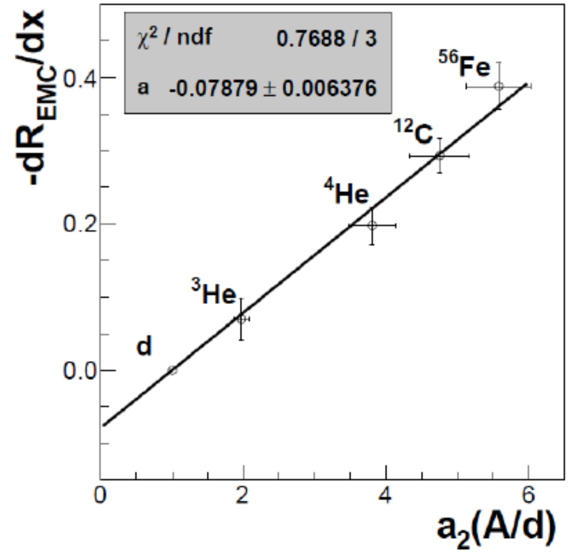
The isovector ρ^0 mean-field generated in Z≠N nuclei can modify nucleon's *u* and *d* PDFs in nuclei.

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



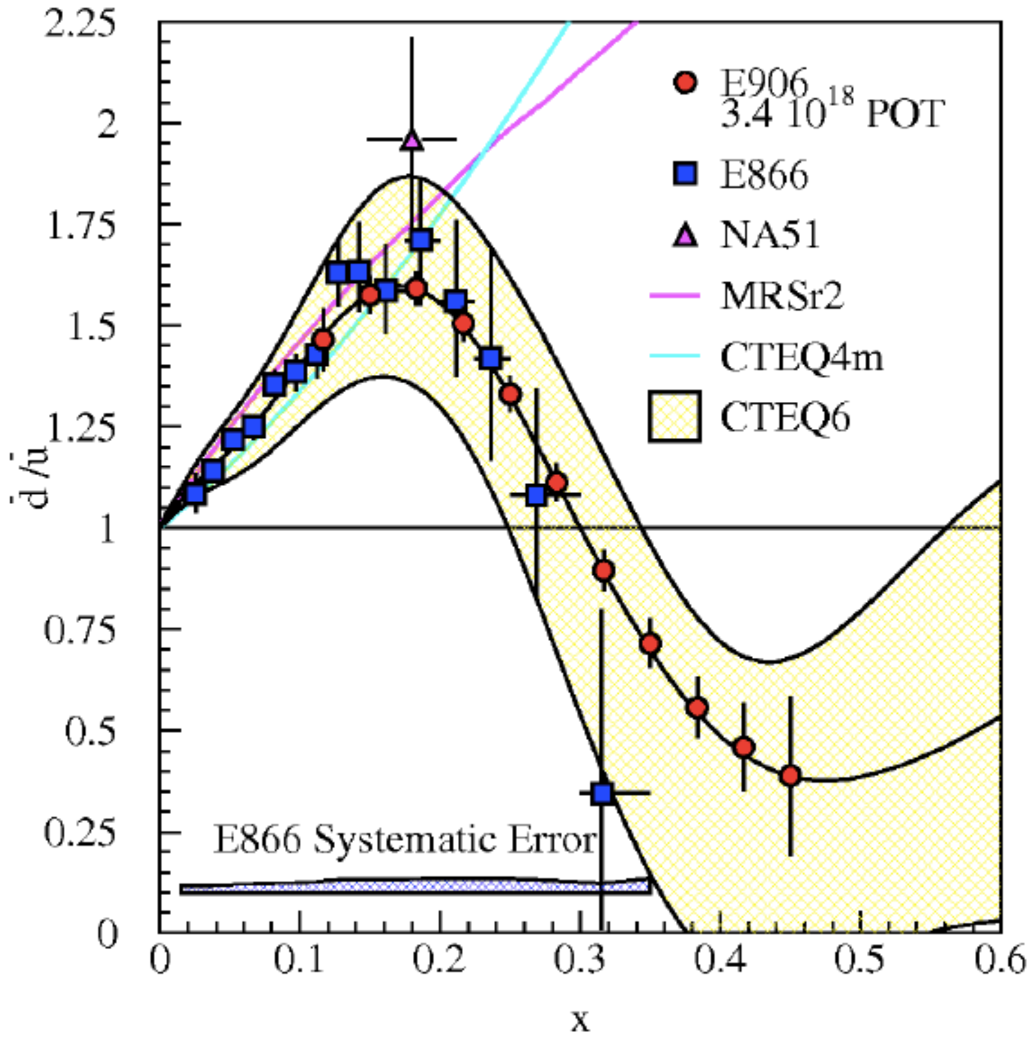
SRC is related with isoscalar p-n interaction.
→ NO flavor-dependence of EMC effect

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

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.



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)

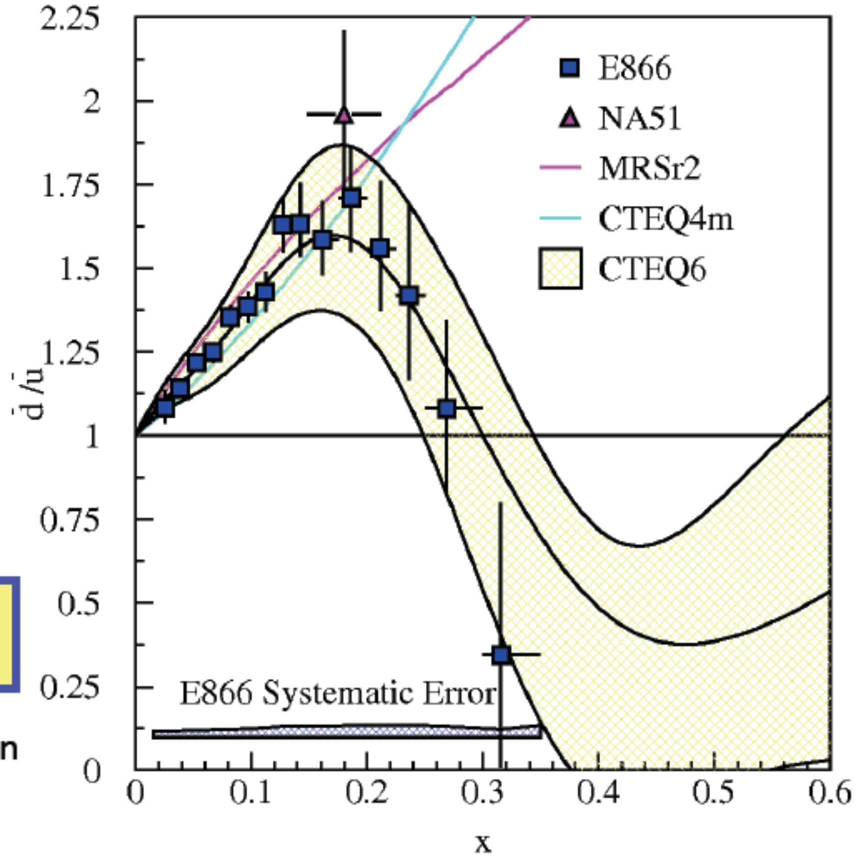
$$\bar{d} > \bar{u} \text{ at } x = 0.18$$

- E866/NuSea (Drell-Yan)

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

- **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



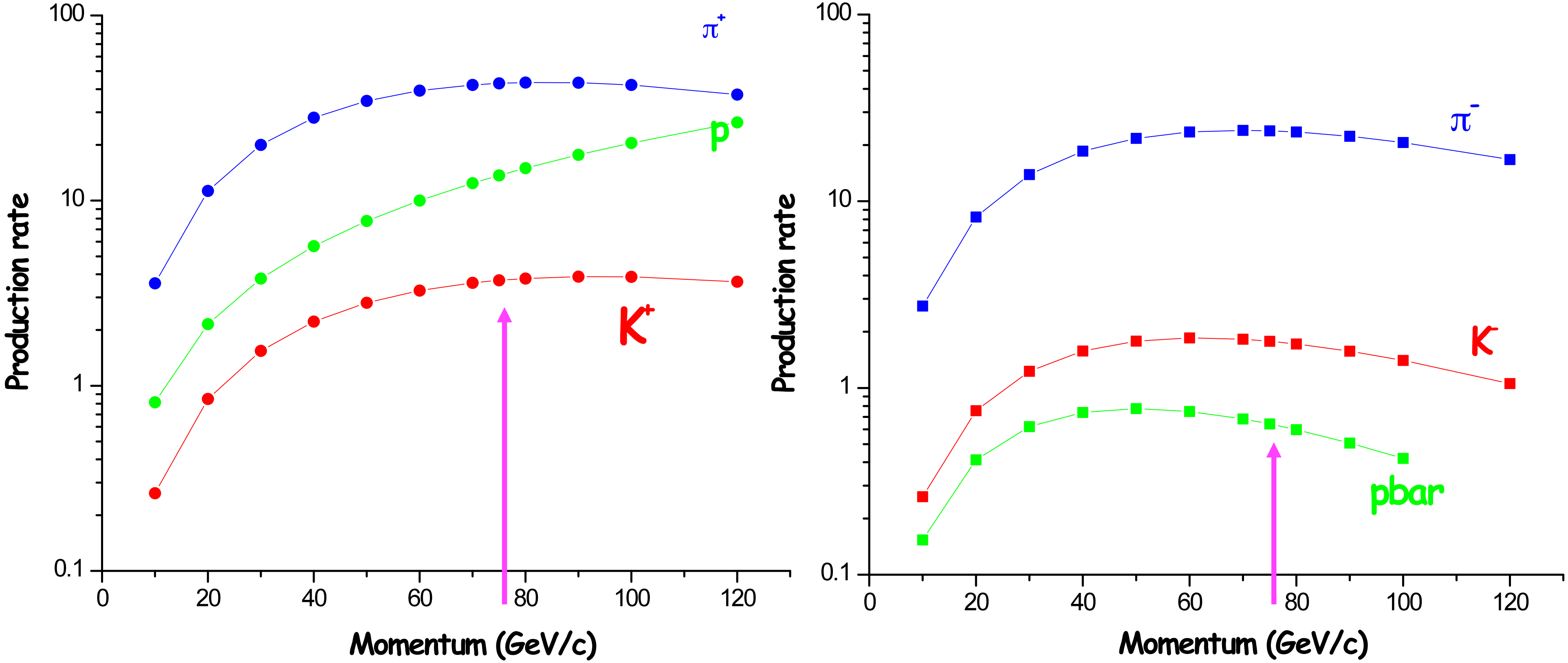
Paul E. Reimer ECT* Workshop on the Flavor Structure of the Nucleon Sea

1 July 2013

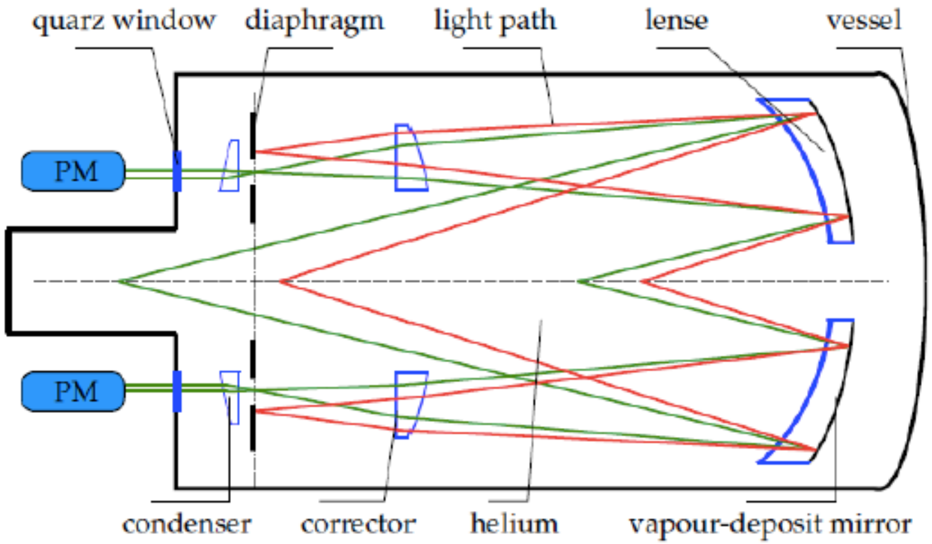
15

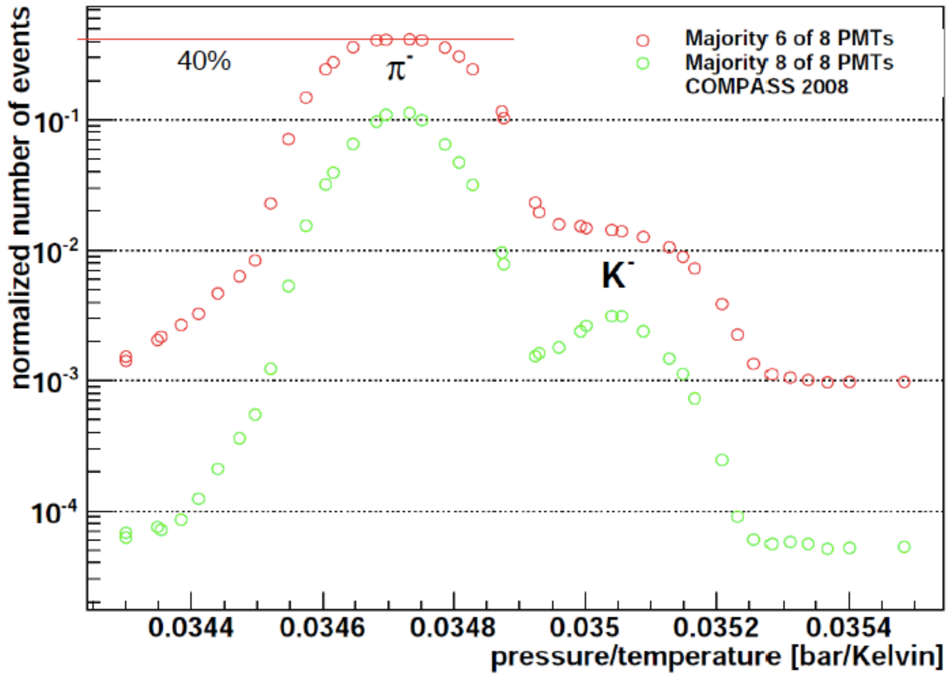
Kaon and Antiproton induced Drell-Yan I, Case of secondary hadron beams

Particle production at 0 mrad



Some statistical error projections, Kaon and Antiproton induced Drell-Yan III





If one assume 70% efficiency of the CEDARs 'kaon/antiproton' tagging We can expect up to 10.000 DY events induced by the K^- and pbar

E906 Drell-Yan experiment at Fermilab

Advantages of 120 GeV Main Injector

The (very successful) past:

Fermilab E866/NuSea

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

The future:

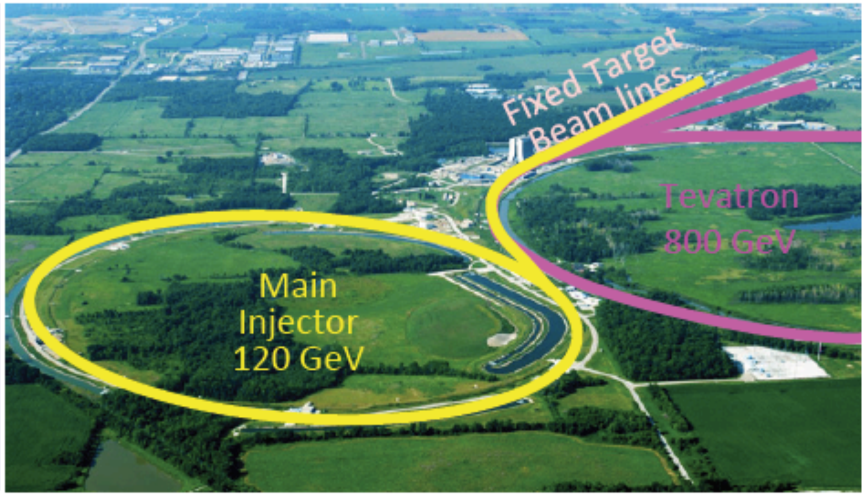
Fermilab E906

- First test run in 2011
- ^{1}H, ^{2}H, 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*

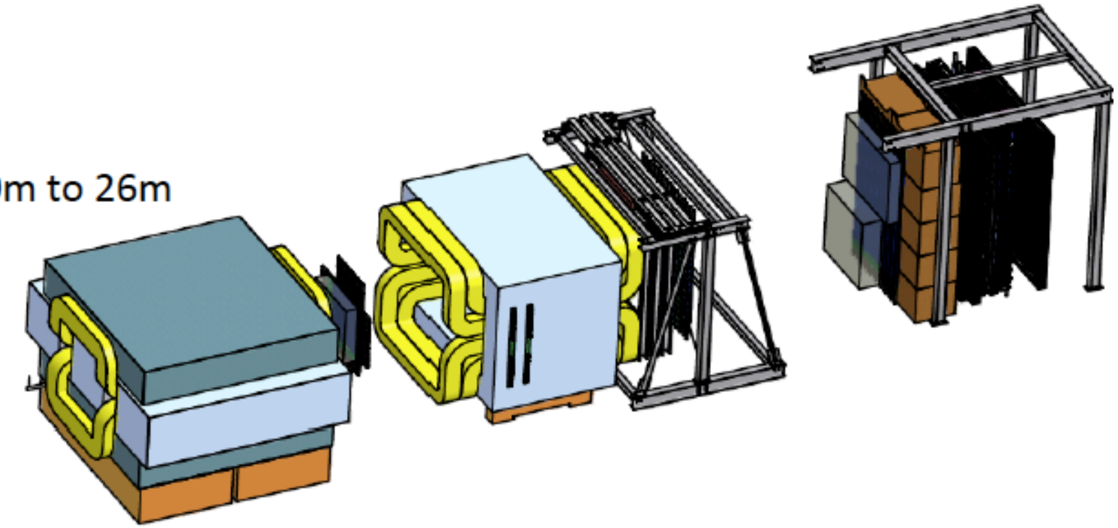
50× statistics!!



E906 Drell-Yan experiment at Fermilab

Drell-Yan Spectrometer Guiding Principles

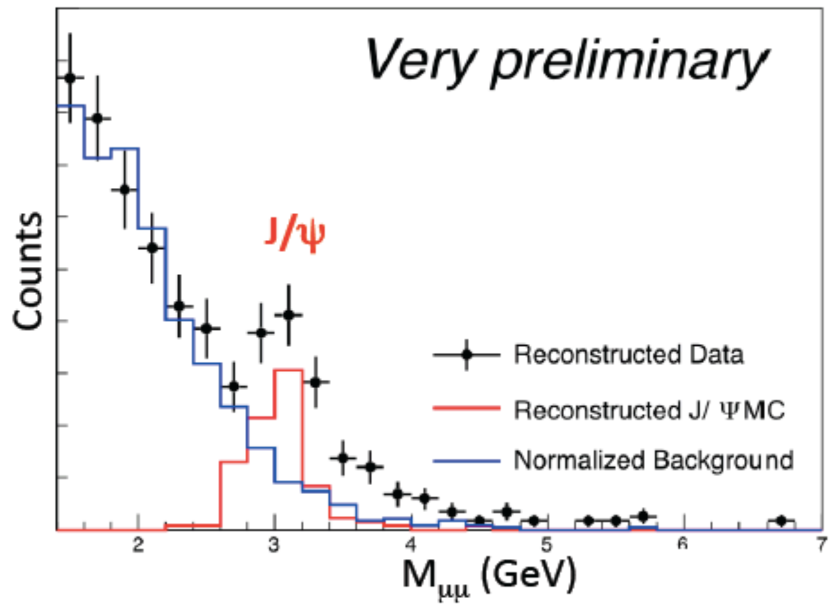
- Follow basic design of MEast spectrometer (don't reinvent the wheel):
  - Two magnet spectrometer
  - Beam dump within first magnet
  - Hadron absorber within first magnet
  - Muon-ID wall before final elements
- Where possible and practical, reuse elements of the E866 spectrometer.
  - Tracking chamber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

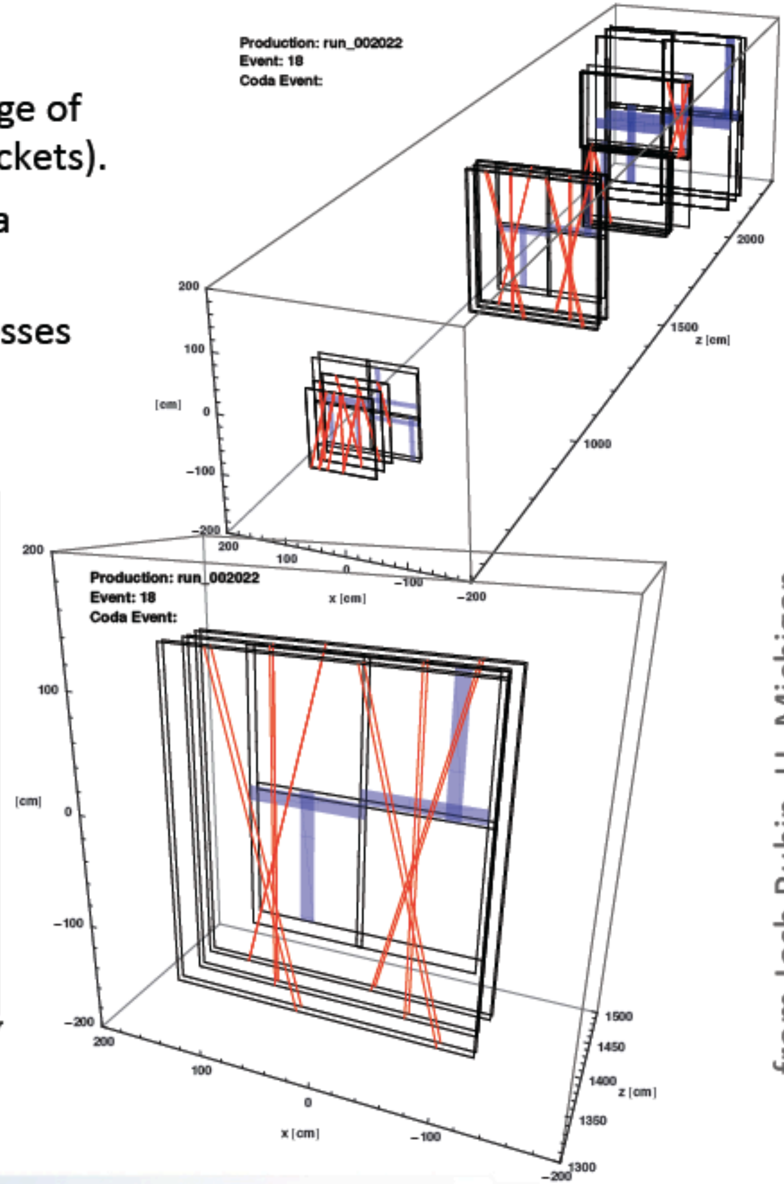


E906 Drell-Yan experiment at Fermilab

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

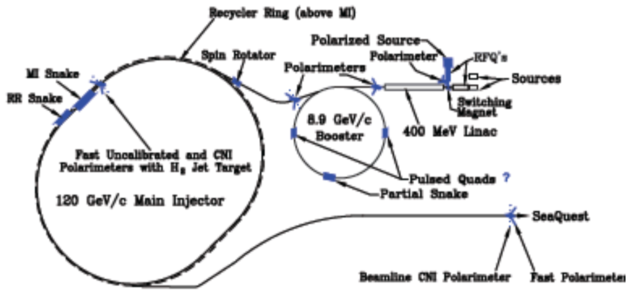




from Josh Rubin, U. Michigan

E906 Drell-Yan experiment at Fermilab

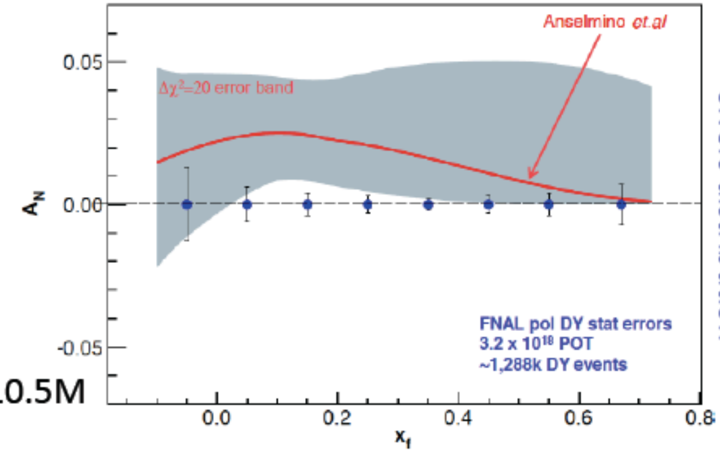
Polarized Drell-Yan at Fermilab



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 Valence Sivers distribution

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 Target

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

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

1 July 2013

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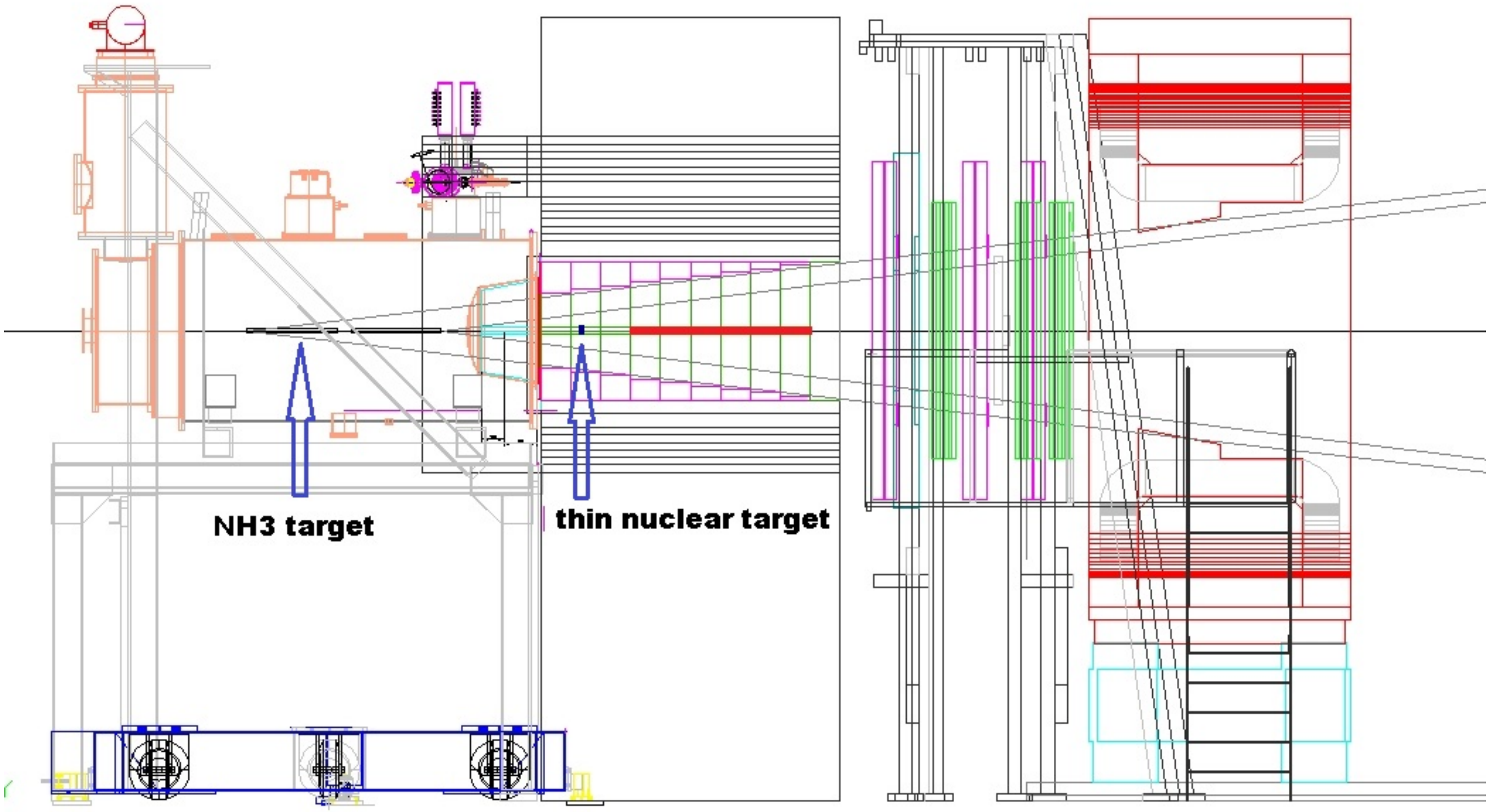
Flavour-dependent EMC effect study, possible set-up



Feasibility and set-up optimization still has to be completed

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