# EMC effect in the Drell-Yan process at COMPASS

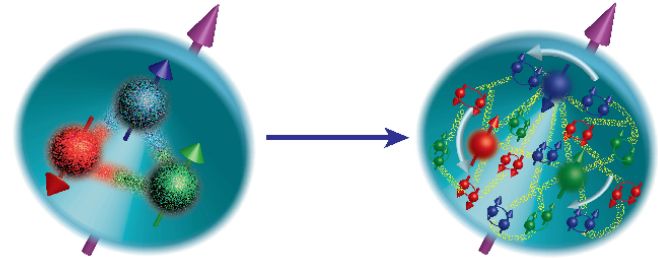
Evgenii Mitrofanov
(JINR DLNP, Dubna)

*On behalf of the COMPASS Collaboration*

June 6, 2018

The XXX Rencontres de Blois

# TMD PDFs



In the leading order QCD parton model nucleon spin-structure can be parametrized in terms of 8 quark transverse momentum (kT) dependent TMD PDFs.

| | | Nucleon Polarization | | |
|---|---|---|---|---|
| | | **U** | **L** | **T** |
| Quark Polarization | **U** | $f_1^q(x, \mathbf{k_T^2})$ Number Density | | $f_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Sivers |
| | **L** | | $g_1^q(x, \mathbf{k_T^2})$ Helicity | $g_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear T |
| | **T** | $h_1^{q\perp}(x, \mathbf{k_T^2})$ Boer-Mulders | $h_{1L}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear L | $h_{1T}^q(x, \mathbf{k_T^2})$ Transversity; $h_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Pretzelosity |

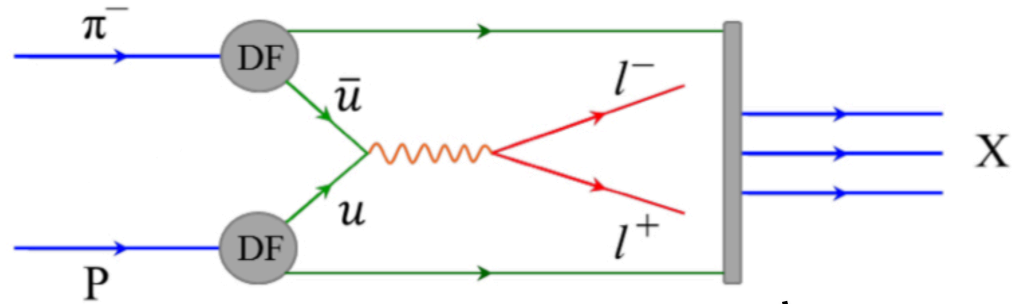
Nucleon — Nucleon spin — quark — quark spin — $\mathbf{k_T}$

TMD PDFs can be accessed through measurement of target spin (in)dependent azimuthal asymmetries both in SIDIS and Drell-Yan

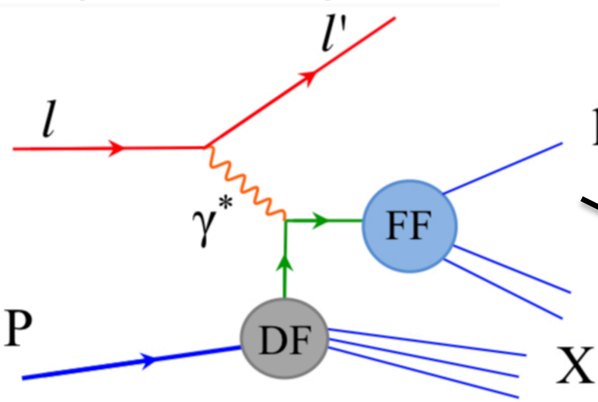
# TMD PDFs

| Quark Polarization | Nucleon Polarization: U | Nucleon Polarization: L | Nucleon Polarization: T |
|---|---|---|---|
| U | $f_1^q(x, \mathbf{k_T^2})$ Number Density | | $f_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Sivers |
| L | | $g_1^q(x, \mathbf{k_T^2})$ Helicity | $g_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear T |
| T | $h_1^{q\perp}(x, \mathbf{k_T^2})$ Boer-Mulders | $h_{1L}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear L | $h_{1T}^q(x, \mathbf{k_T^2})$ Transversity; $h_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Pretzelosity |

Nucleon — Nucleon spin — quark — quark spin — $\mathbf{k_T}$




Universality in the TMD-QCD parton model approach. Sign change between SIDIS and DY




$$h_1^{\perp q}|_{SIDIS} = -h_1^{\perp q}|_{DY}$$

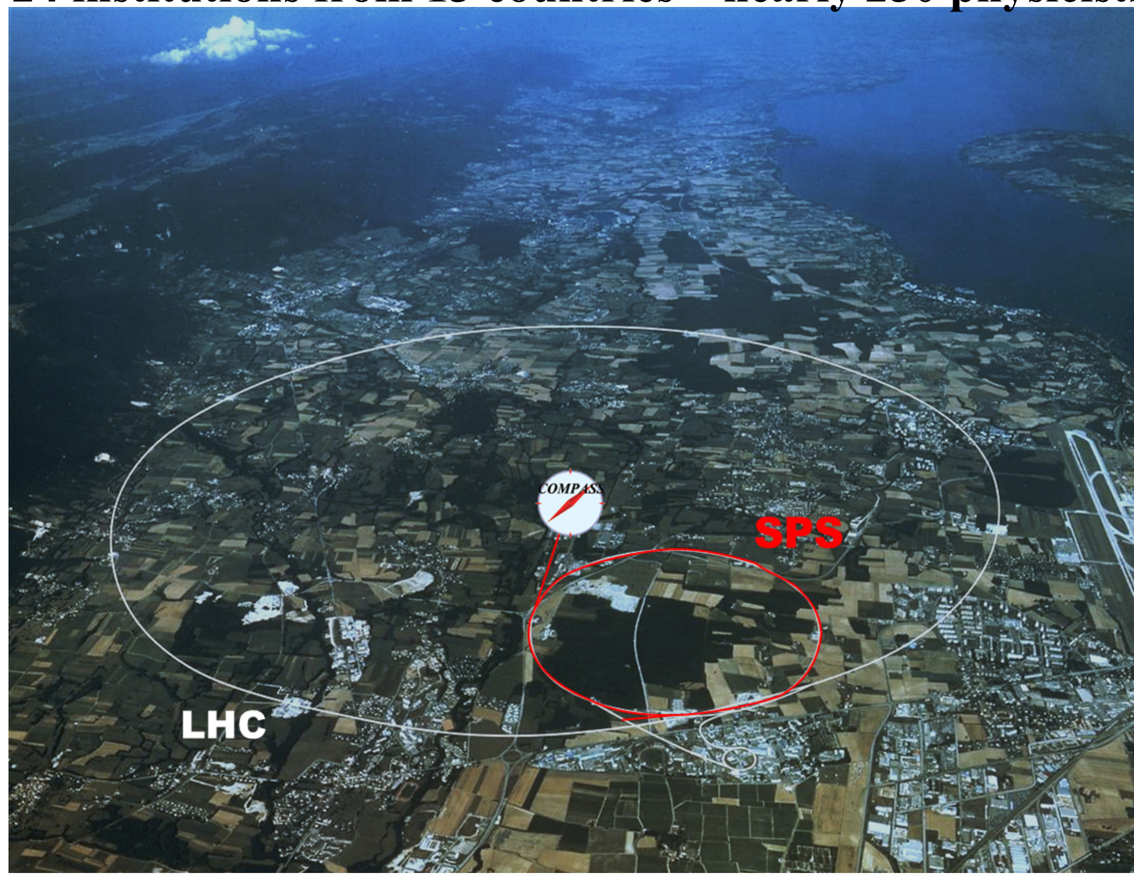
$$f_{1T}^{\perp q}|_{SIDIS} = -f_{1T}^{\perp q}|_{DY}$$

**The experimental test of this prediction is a major challenge in hadron pysics**

# COMPASS Collaboration

Fixed target high-energy experiment at CERN SPS
Wide physics programme

**24 institutions from 13 countries – nearly 250 physicists**




## COMPASS-I

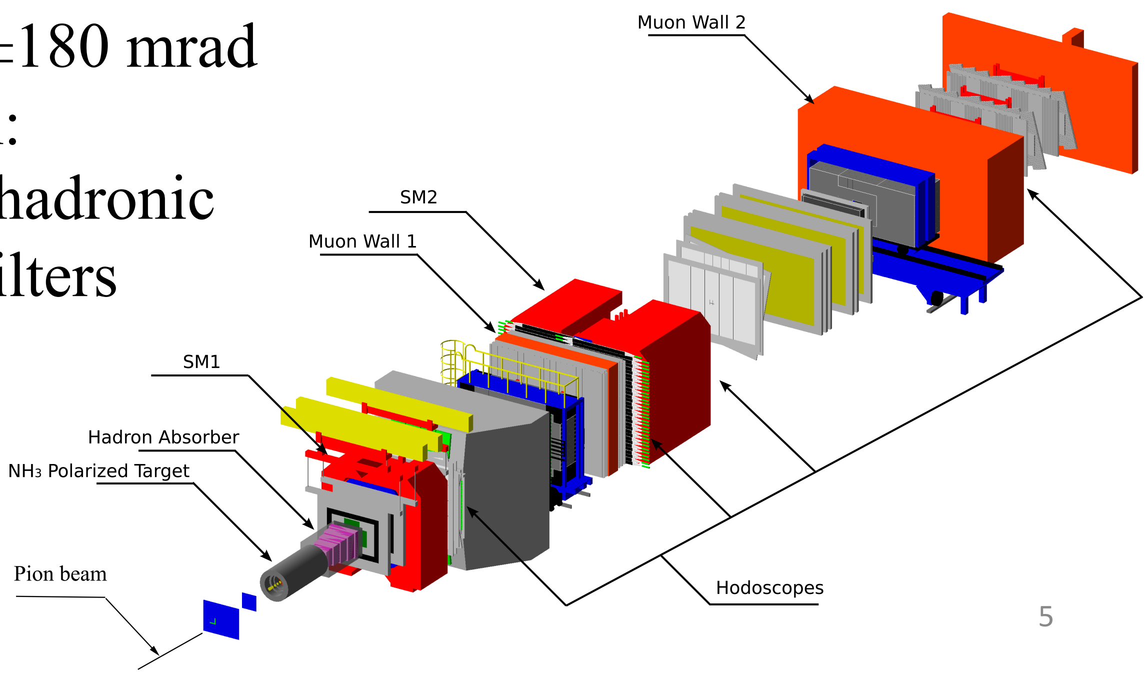
- Data taking: 2002-2011
- Muon and hadron beams
- Nucleon spin structure
- Spectroscopy

## COMPASS-II

- Data taking: 2012-2018
- Primakoff
- DVCS (GPD+SIDIS)
- Polarised Drell-Yan

# COMPASS spectrometer

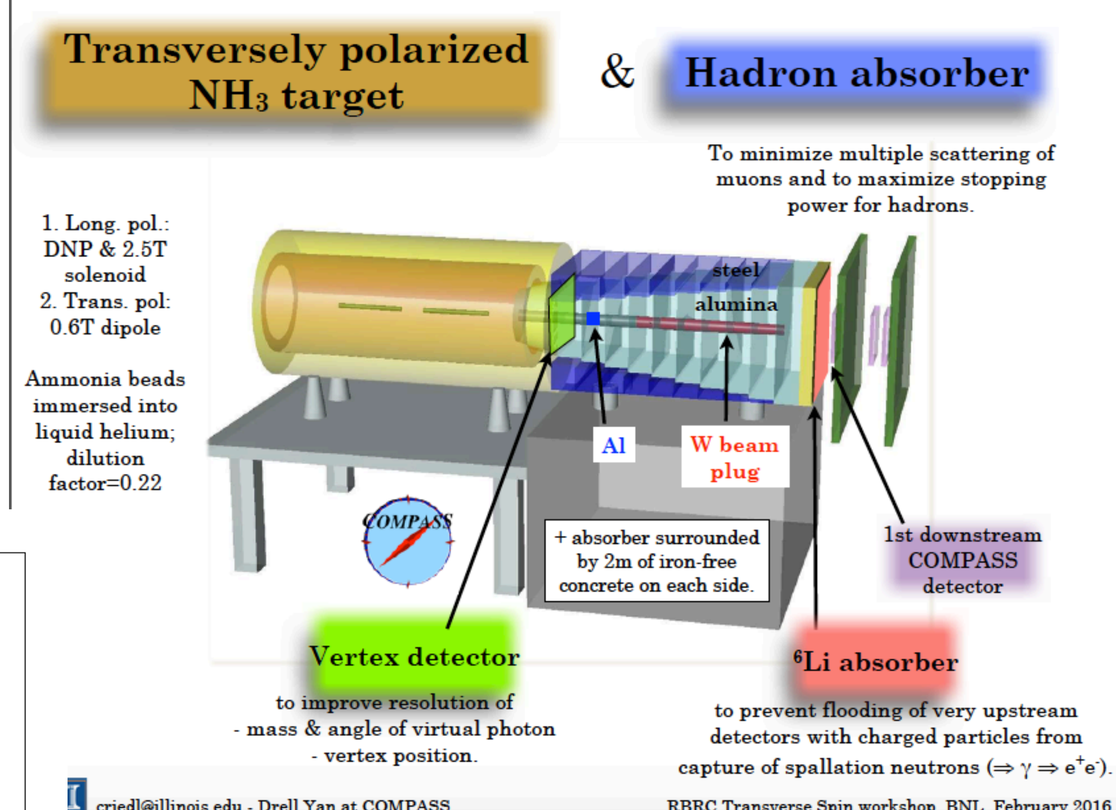
- **Target:** polarised $NH_3$ (two cells of 55 cm each), Al and W (2014, 2015)
- **Beam:** $\pi^-$ at 190 GeV/$c$
- **Features:**
  - Two-stage spectrometer
  - About 350 detector planes
  - Angular acceptance: ±180 mrad
  - Particle identification: electromagnetic and hadronic calorimeters, muon filters and RICH detector.

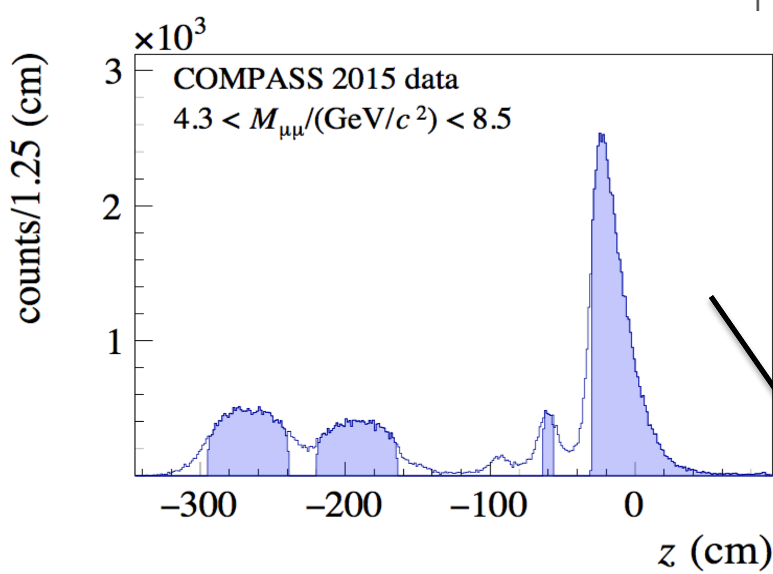


# COMPASS targets

- In 2014 and 2015 Drell-Yan process studied with negative pion beam of 190 GeV/*c*

- $NH_3$ target, W beam plug of hadron absorber and an additional Al target were used.

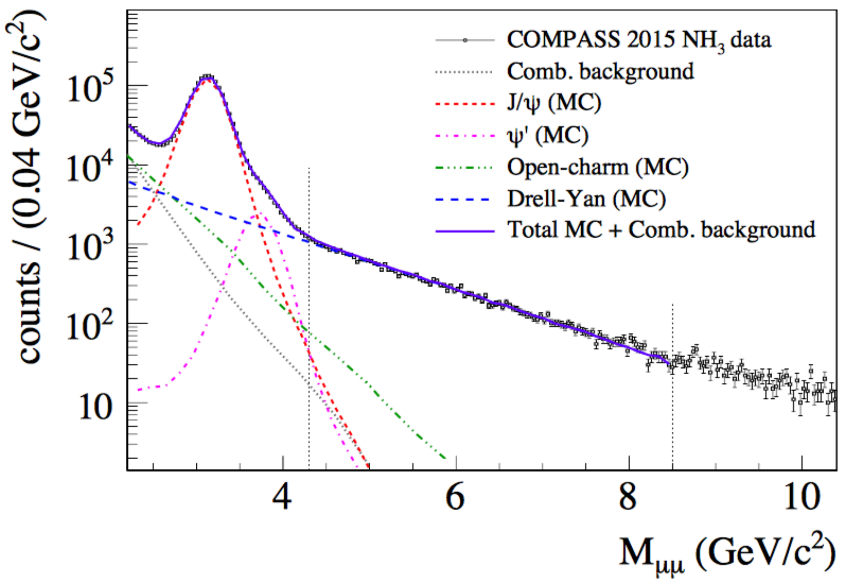


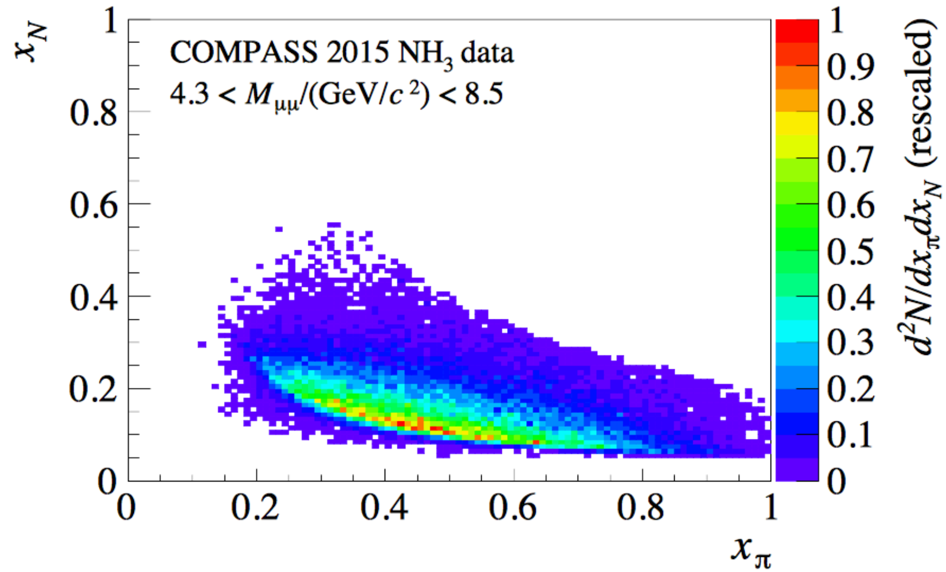




**Position of the interaction point along the beam.**

# COMPASS results for the $\pi^- + p \to \mu^+ + \mu^- + X$ reaction

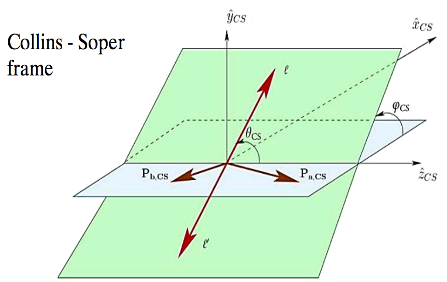
**Phys. Rev. Lett. 119, 112002 (2017)**

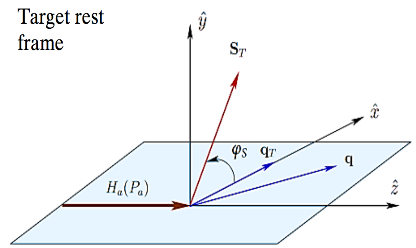



- Dimuon mass resolution for J/ψ peak is about 0.2 GeV/$c^2$ for the ammonia while for the tungsten plug it is 0.33 GeV/$c^2$.

# COMPASS results for the $\pi^- + p \to \mu^+ + \mu^- + X$ reaction



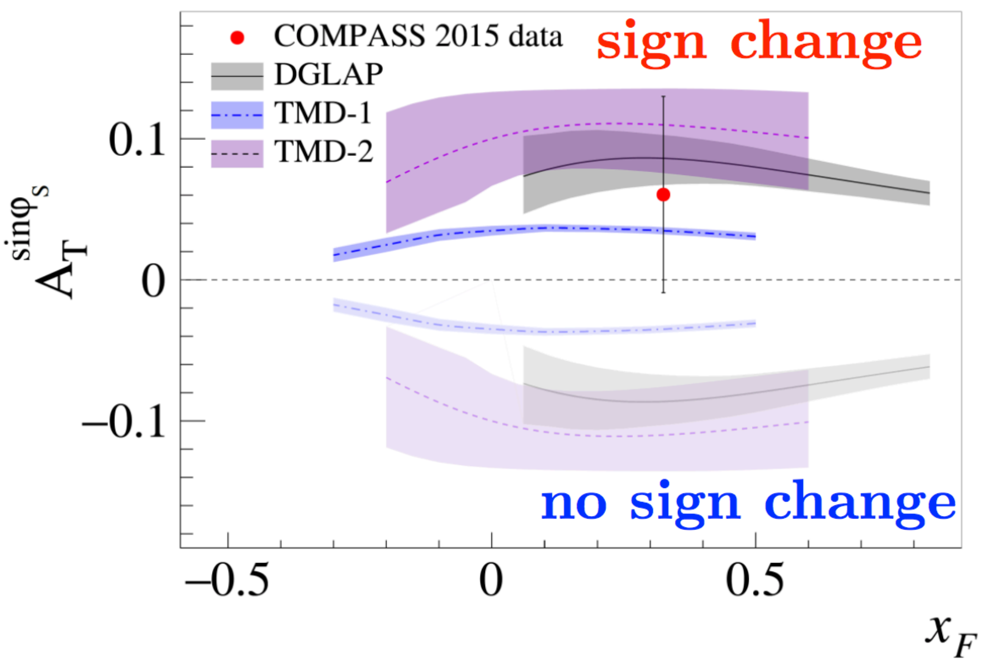




**Sivers** → $A_T^{\sin\varphi_S} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$

**Pretzelosity** → $A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp q}$

**Transversity** → $A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$

**Phys. Rev. Lett. 119, 112002 (2017)**

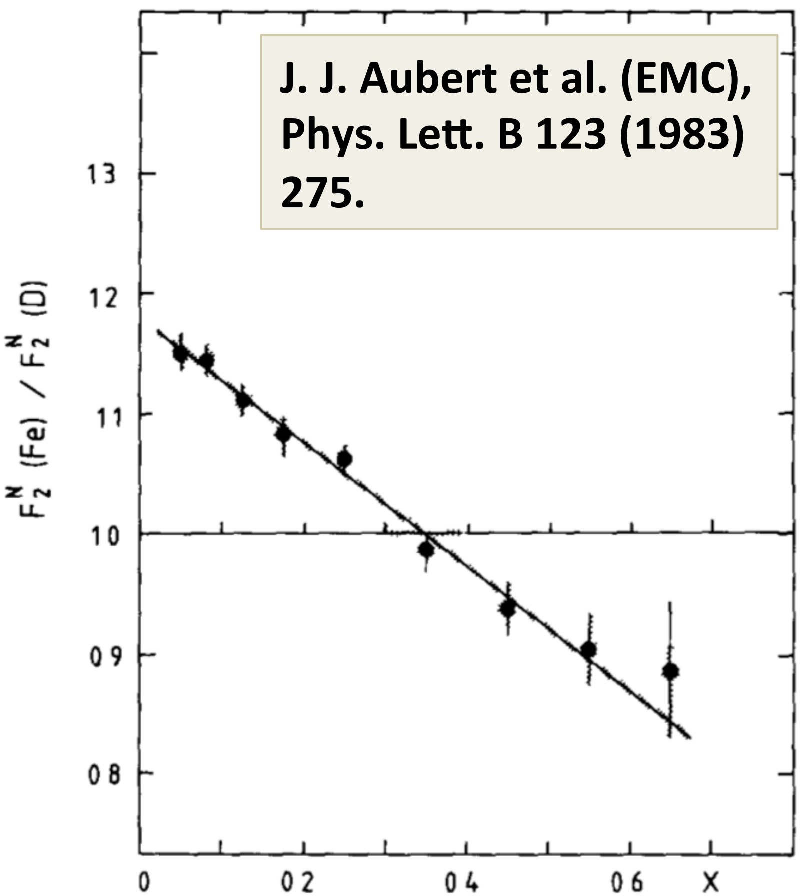



**DGLAP** (2016) M. Anselmino et al., **JHEP 1704 (2017) 046**
**TMD-1** (2014) M.G. Echevarria et al., **PRD 89 074013**
**TMD-2** (2013) P. Sun, F. Yuan, **PRD88, 114012**

**The first measurement of the DY Sivers assymetry is consistent with the predicted sign change for Sivers function**

# EMC effect

The EMC effect – a modification of quark and gluon distributions (PDFs) in bound nucleons by the nuclear environment was discovered by the European Muon Collaboration in 1983 in the deep inelastic scattering (DIS) of muons.

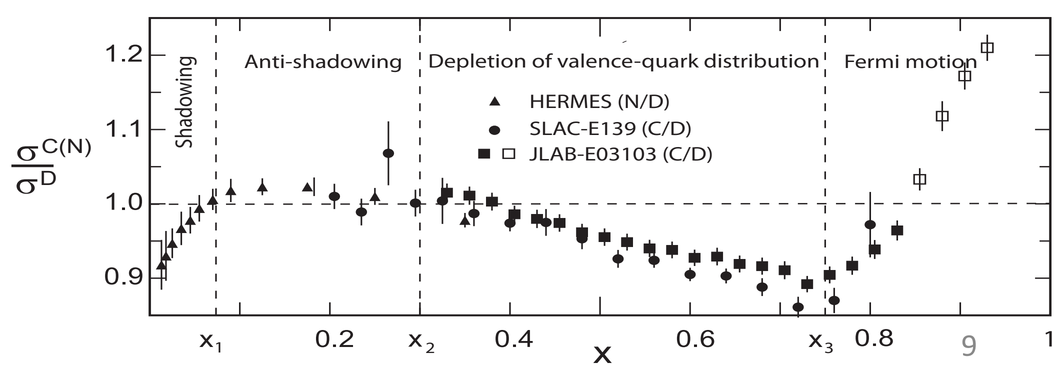



**J. J. Aubert et al. (EMC), Phys. Lett. B 123 (1983) 275.**

$$F_2(x, Q^2) = \sum_{q=u,d,s\ldots} x e_q^2 \left[ q(x, Q^2) + \bar{q}(x, Q^2) \right]$$

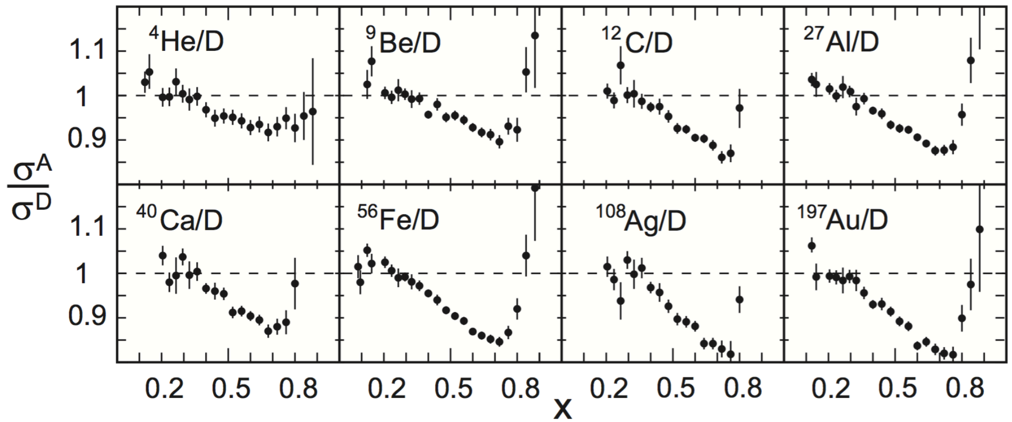
**Properties:**

1. **Universal shape;**
2. **"weak or no" $Q^2$ dependence**
3. **Size of the effect as well as «shadowing» increases with A of the nucleus**



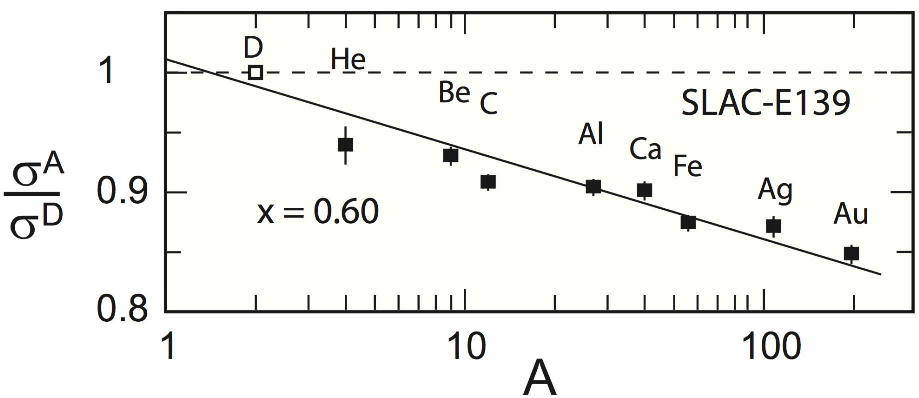
# EMC effect

R. G. Arnold et al. (SLAC-E139), PR L 52, 727 (1984)

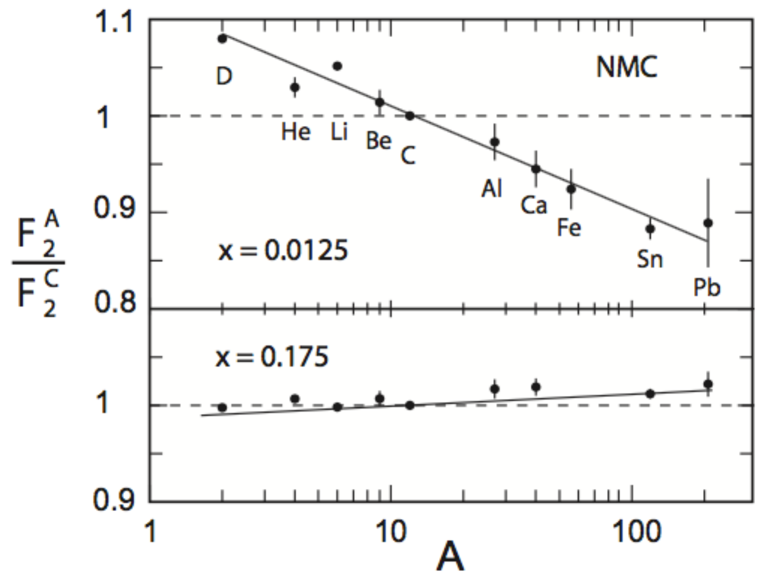



**Properties:**

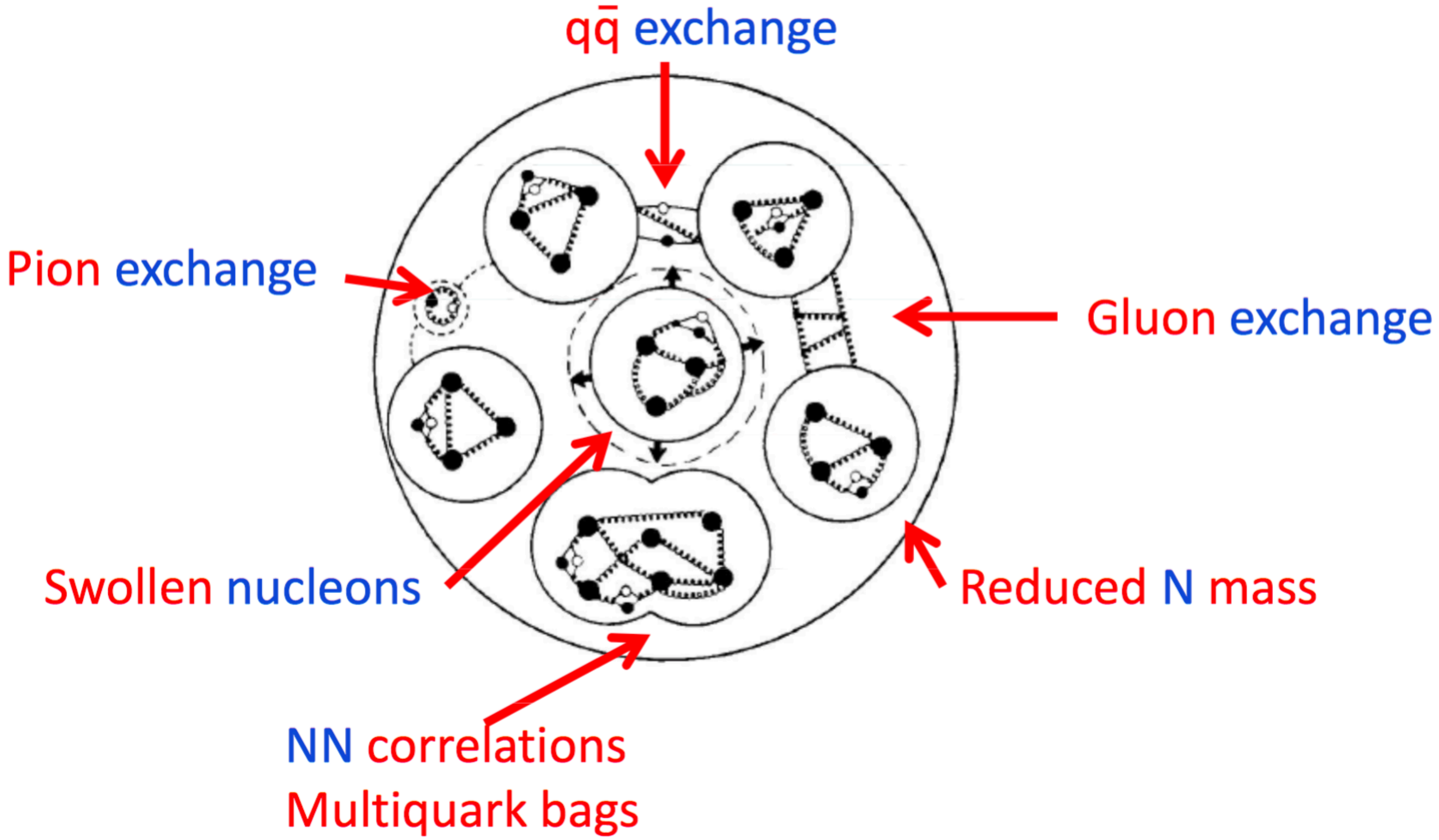
1. Universal shape;
2. "weak or no" $Q^2$ dependence
3. Size of the effect as well as «shadowing» increases with A of the nucleus




M. Arneodo et al. (NMC), Nucl. Phys. B 481 (1996) 3.



# EMC effect: possible explanations



# EMC effect (experiments)

| Laboratory, experiment | Beam | Energy (GeV) | Targets | Year of publication |
|---|---|---|---|---|
| NA3 | $\pi^-$ | 150 | Pt, H | 1981 |
| NA10 | $\pi^-$ | 140, 286 | D, W | 1987 |
| SLAC/E139 | e | 8-24.5 | D, $^4$He, Be, C, Ca, Fe, Ag, Au | 1984, 1994 |
| SLAC/E140 | e | 3.75-19.5 | D, Fe, Au | 1988, 1994 |
| CERN/EMC | $\mu$ | 100-280 | D, C, Ca, Cu, Fe, Sn | 1983-1993 |
| CERN/BCDMS | $\mu$ | 200, 280 | D, N, Fe | 1985-1987 |
| CERN/NMC | $\mu$ | 90, 200 | D, $^4$He, $^6$Li, Be, C, Al, Ca, Fe, Sn, Pb | 1991-1996 |
| FNAL/E772 | p | 800 | D, C, Ca, Fe, W | 1990 |
| FNAL/E866 | p | 800 | Be, Fe, W | 1999 |
| FNAL/E665 | $\mu$ | 490 | D, C, Ca, Xe, Pb | 1992-1995 |
| DESY/HERMES | e | 27.6 | D, $^3$He, N, Kr | 2000-2003 |
| JLAB/E03103 | e | 6 | D, $^3$He, $^4$He, Be, Cu, Au | 2009 |

**CERN/NMC measured the ratio of the structure functions**

***Drell-Yan process: NA3, NA10, FNAL/E772, FNAL/E866, FNAL/E665***

D. Higinbotham, G. Miller, O. Hen and K. Rith, CERN courier, 2013:

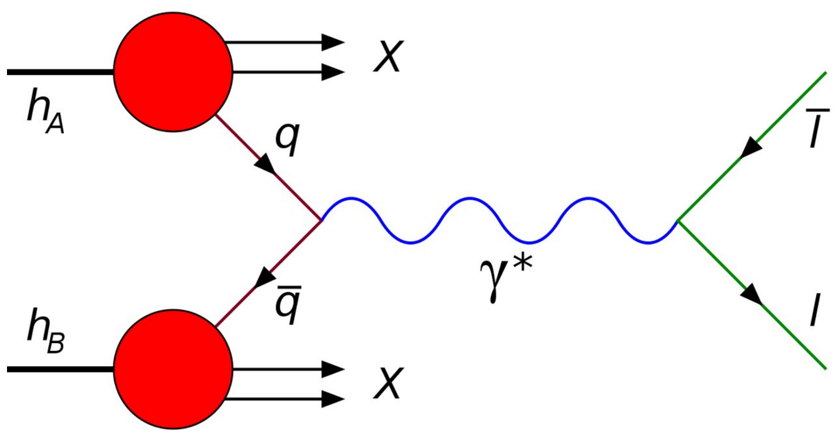
***"Thirty years on, CERN's EMC effect still puzzles experimentalists and theorists."***

# Drell-Yan process $(h_A + h_B \rightarrow l + \bar{l})$

$h_{A,B}$ - hadrons, $l$ - leptons

$x_1, x_2$ - part of hadron (A,B) momentum carrying by quark

$$\frac{d^2\sigma}{dx_1 dx_2} = K \frac{4\pi\alpha^2}{9 x_1 x_2} \frac{1}{s} \sum_{q=u,d,s\ldots} e_q^2 \left[ q(x_1)\bar{q}(x_2) + \bar{q}(x_1) q(x_2) \right]$$



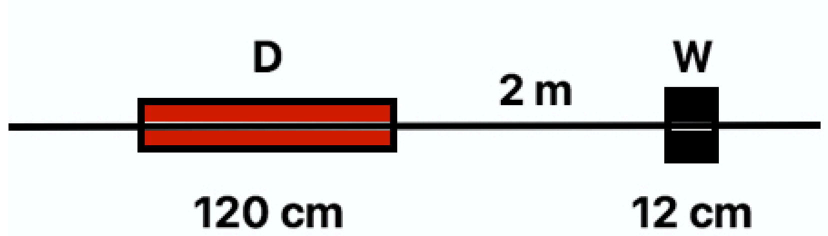

With pion beam on target with atomic mass A and D target, keeping only the dominant terms in the cross section

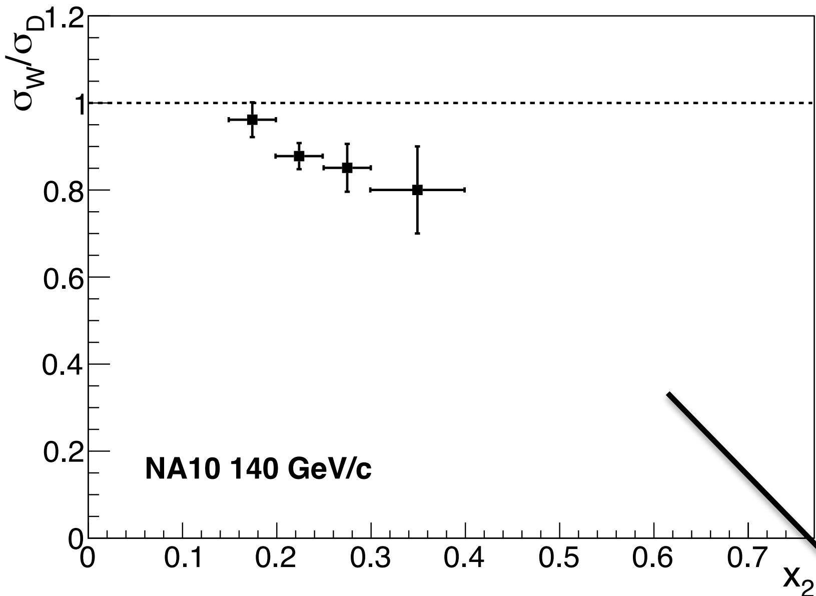
$$\frac{\sigma_{DY}^{\pi^- A}}{\sigma_{DY}^{\pi^- D}} \approx \frac{u_A(x_2)}{u_D(x_2)}$$

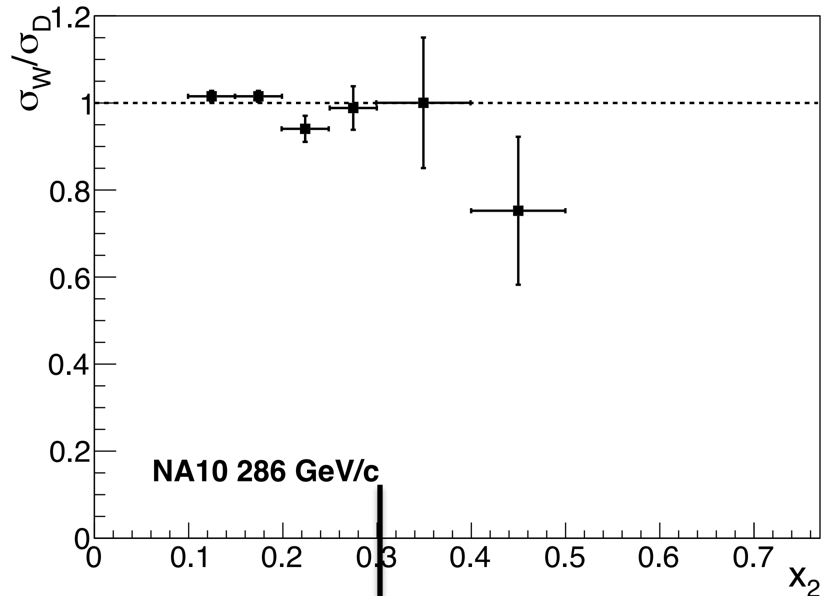
where $u_A(x_2)$ and $u_D(x_2)$ are PDFs for u-quark in a nucleus with a mass A and deuteron, respectively

***It is possible to distinguish contributions of pion valence quarks:***
***For $\pi^-$ beam: u-quark, for $\pi^+$ beam: d-quark***

# NA10 results




**Ref: NIM 223, 26 (1984)**

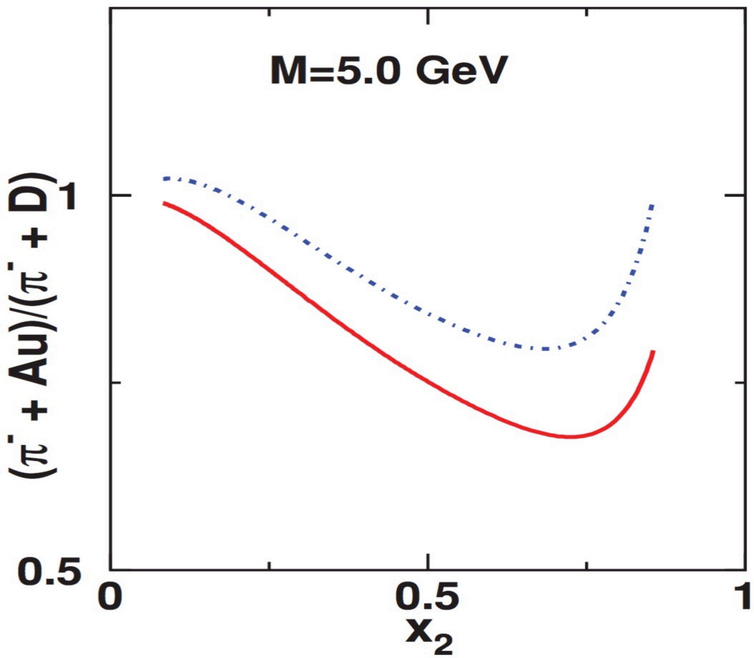
*«The $x_2$ distribution indicates an effect (slope) quite similar in shape and magnitude to that reported by DIS experiment»*

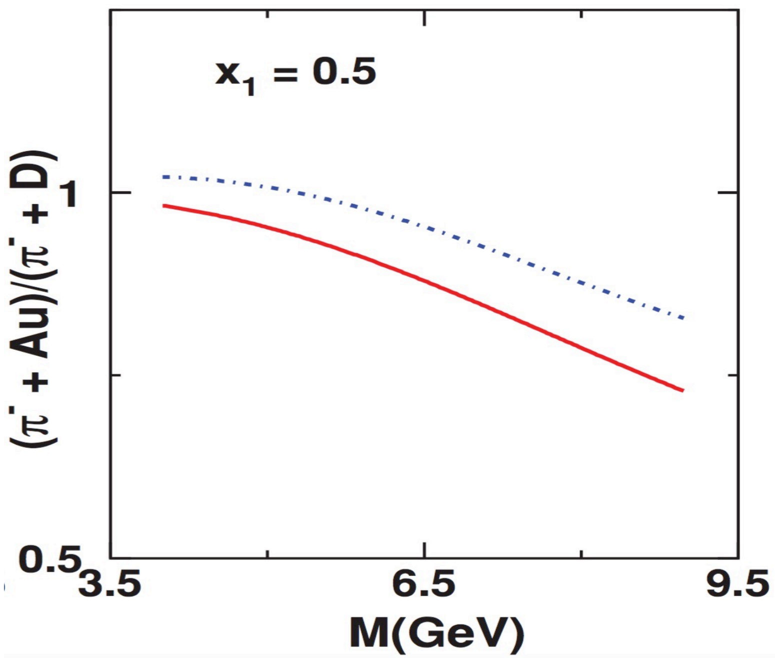
Ratio of the Drell-Yan cross sections for W and D using a π− beam of 140 GeV/*c* (left) and 286 GeV/*c* (right)

***Accuracy in this experiment is sufficient to confirm the observation of the EMC effect, but it is too low for detailed tests of various theoretical models.***

# EMC effect: predictions for COMPASS

Phys. Rev. C 83, 042201 (2011); Phys. Rev. Lett. 102, 252301 (2009)

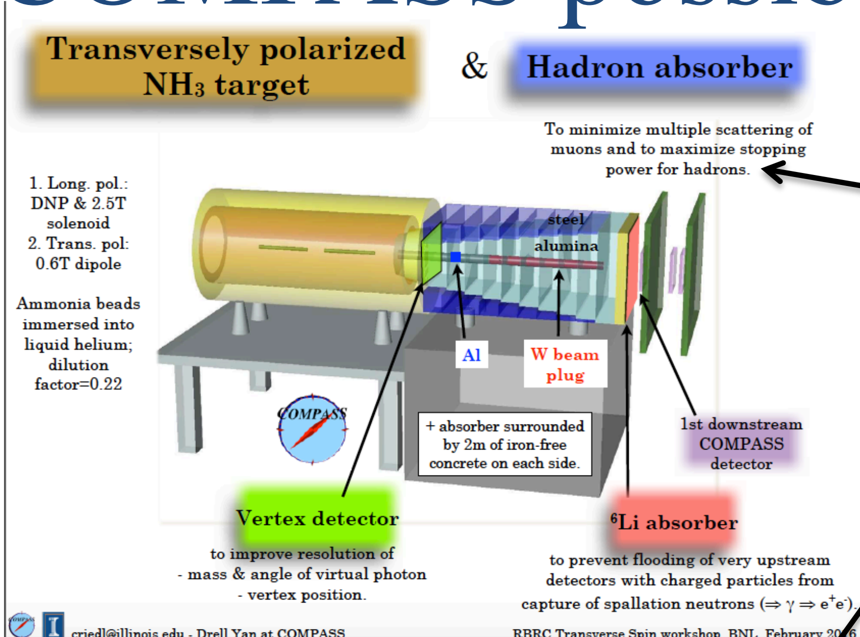


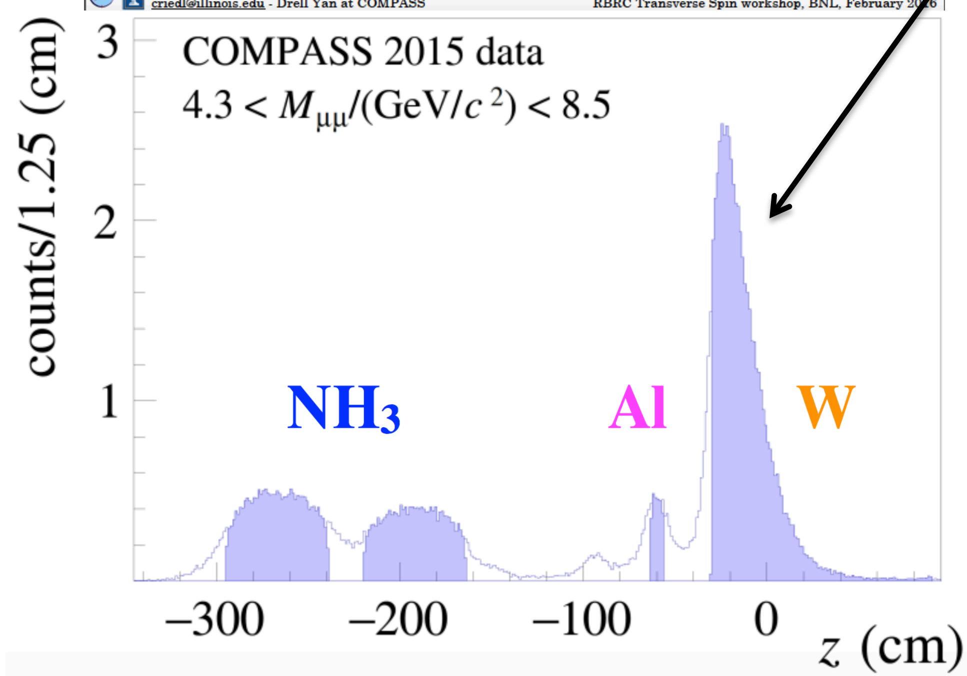




The ratio of Drell-Yan cross section for deuterium and gold calculated using Cloet, Bentz, Thomas model.

Here M is effective mass of lepton pair and negative pion beam of 160 GeV/*c* was used.

# COMPASS possibilities

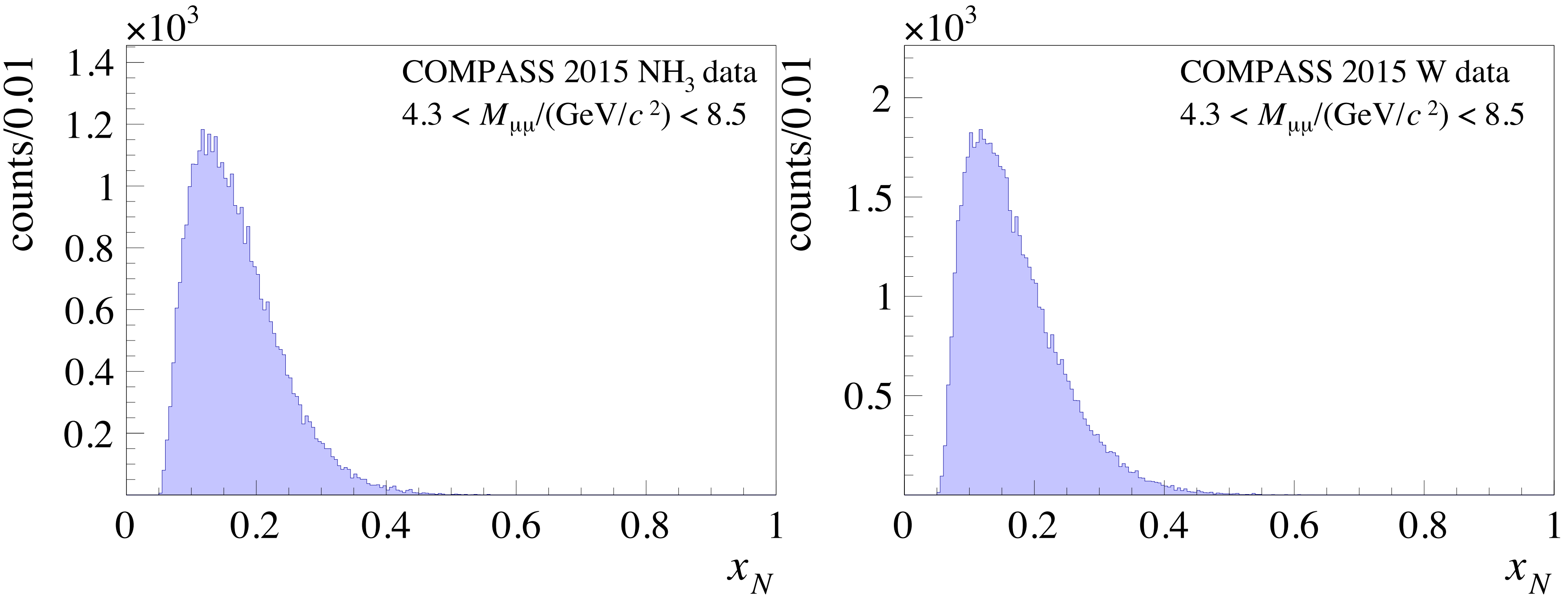



Hadron absorber can be used as the second nuclear target

COMPASS DY 2015 data can be used for studies on nuclear effects: dependence of PDFs on atomic number of the target– **EMC effect.**

# COMPASS results for the $\pi^- + p \rightarrow \mu^+ + \mu^- + X$ reaction




- For the EMC effect study the mass range above 5 GeV/$c^2$ can be used, which defines a lower limit of $x_2$ range accessible by COMPASS to be 0.07.

# Summary

**1. COMPASS collected DY data for the study of spin-dependent PDFs and published an important result. And on the other hand <u>this data can be used for the EMC-effect studies.</u>**

**2. After 30 years the origin of the EMC effect is still not fully understood. And there is no no model which describes the whole range of *x*.**

**3. The pion-induced Drell-Yan process allows to measure EMC effect separetly for u and d – quarks.**

**4. The COMPASS experiment at CERN in 2018 will provide new results on the EMC effect originating from the Drell-Yan process $(\pi^- + A \rightarrow \mu^+ + \mu^- + X)$ (where A is proton, tungsten and aluminium) covering range of *x* bigger 0.07: wider than other experiments.**

# Thanks for your attention

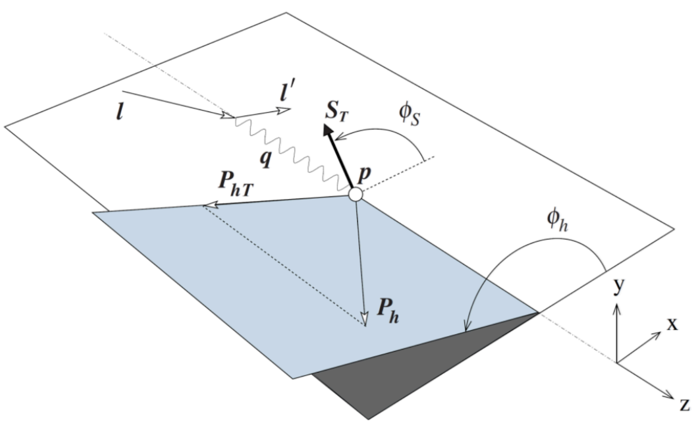
# Backup

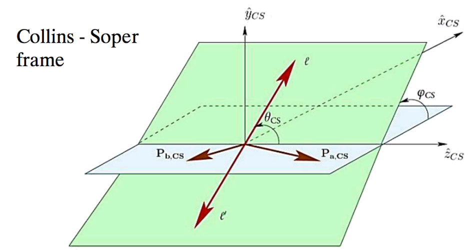
# SIDIS and DY cross-section

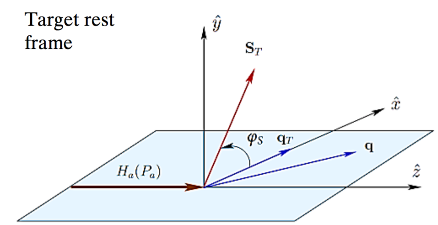
$$D_{f(\theta)} = \frac{f(\theta)}{1+\cos^2(\theta)}$$

$$\frac{d\sigma^{LO}}{dx\,dy\,dz\,dp_T^2\,d\varphi_h\,d\psi} \propto \left\{ \begin{array}{l} 1+\cos(2\phi_h)\varepsilon A_{UU}^{\cos(2\phi_h)} \\ +S_T \left[ \begin{array}{l} \sin(\phi_h-\phi_S)A_{UT}^{\sin(\phi_h-\phi_s)} \\ +\sin(\phi_h+\phi_S)\varepsilon A_{UT}^{\sin(\phi_h+\phi_s)} \\ +\sin(3\phi_h-\phi_S)\varepsilon A_{UT}^{\sin(3\phi_h-\phi_s)} \end{array} \right] \end{array} \right\}$$

$$\frac{d\sigma^{LO}}{d\Omega d^4q} \propto \left\{ \begin{array}{l} 1+D_{[\sin^2\theta]}\cos(2\varphi_{CS})A_U^{\cos 2\varphi_{CS}} \\ +S_T \left[ \begin{array}{l} \sin\varphi_S A_T^{\sin\varphi_S} \\ +D_{[\sin^2\theta]} \left( \begin{array}{l} \sin(2\varphi_{CS}+\varphi_S)A_T^{\sin(2\varphi_{CS}+\varphi_S)} \\ \sin(2\varphi_{CS}-\varphi_S)A_T^{\sin(2\varphi_{CS}-\varphi_S)} \end{array} \right) \end{array} \right] \end{array} \right\}$$




$A_{UU}^{\cos(2\phi_h)} \propto h_{1,p}^{\perp q} \otimes H_{1q}^{\perp h}$ ⟷ **Boer-Mulders** ⟷ $A_U^{\cos(2\varphi_{CS})} \propto h_{1,\pi}^{\perp,q} \otimes h_{1,p}^{\perp q}$

$A_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T,p}^{\perp q} \otimes D_{1q}^{h}$ ⟷ **Sivers** ⟷ $A_T^{\sin\varphi_S} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$

$A_{UT}^{\sin(\phi_h+\phi_S)} \propto h_{1,p}^{q} \otimes H_{1q}^{\perp h}$ ⟷ **Pretzelosity** ⟷ $A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp q}$

$A_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T,p}^{\perp q} \otimes H_{1q}^{\perp h}$ ⟷ **Transversity** ⟷ $A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$