Polarized Drell-Yan at COMPASS

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on behalf of the COMPASS Collaboration
INFN section of Turin and University of Turin

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Outline

- Introduction
  - TMD PDFs
  - The Drell-Yan process
  - The SIDIS process
  - Drell-Yan SIDIS bridge
- The COMPASS experiment
  - Selected SIDIS results from Phase I
- The COMPASS Polarized DY program
  - Four COMPASS – Drell-Yan mass-ranges
  - COMPASS DY Experimental setup
  - COMPASS Polarized DY Run 2015
- Conclusions

Transverse Momentum Dependent Parton Distribution Functions, TMD PDFs

In the **leading order QCD parton model** nucleon spin-structure can be parametrized in terms of in total 8 twist-2 intrinsic transverse momentum ($\mathbf{k_T}$) dependent TMD PDFs.

Quark \ Nucleon	U	L	T
U	$f_1^q(x,\boldsymbol{k}_T^2)$ Number density		$f_{1T}^{q\perp}(x,\boldsymbol{k}_T^2)$ Sivers
L		$g_1^q(x,\boldsymbol{k}_T^2)$ Helicity	$g_{1T}^{q\perp}(x,\boldsymbol{k}_T^2)$ Kotzinian-Mulders or Worm-gear T
T	$h_1^{q\perp}(x,\boldsymbol{k}_T^2)$ Boer-Mulders	$h_{1L}^{q\perp}(x,\boldsymbol{k}_T^2)$ Worm-gear L	$h_1^q(x,\boldsymbol{k}_T^2)$ Transversity $h_{1T}^{q\perp}(x,\boldsymbol{k}_T^2)$ Pretzelosity

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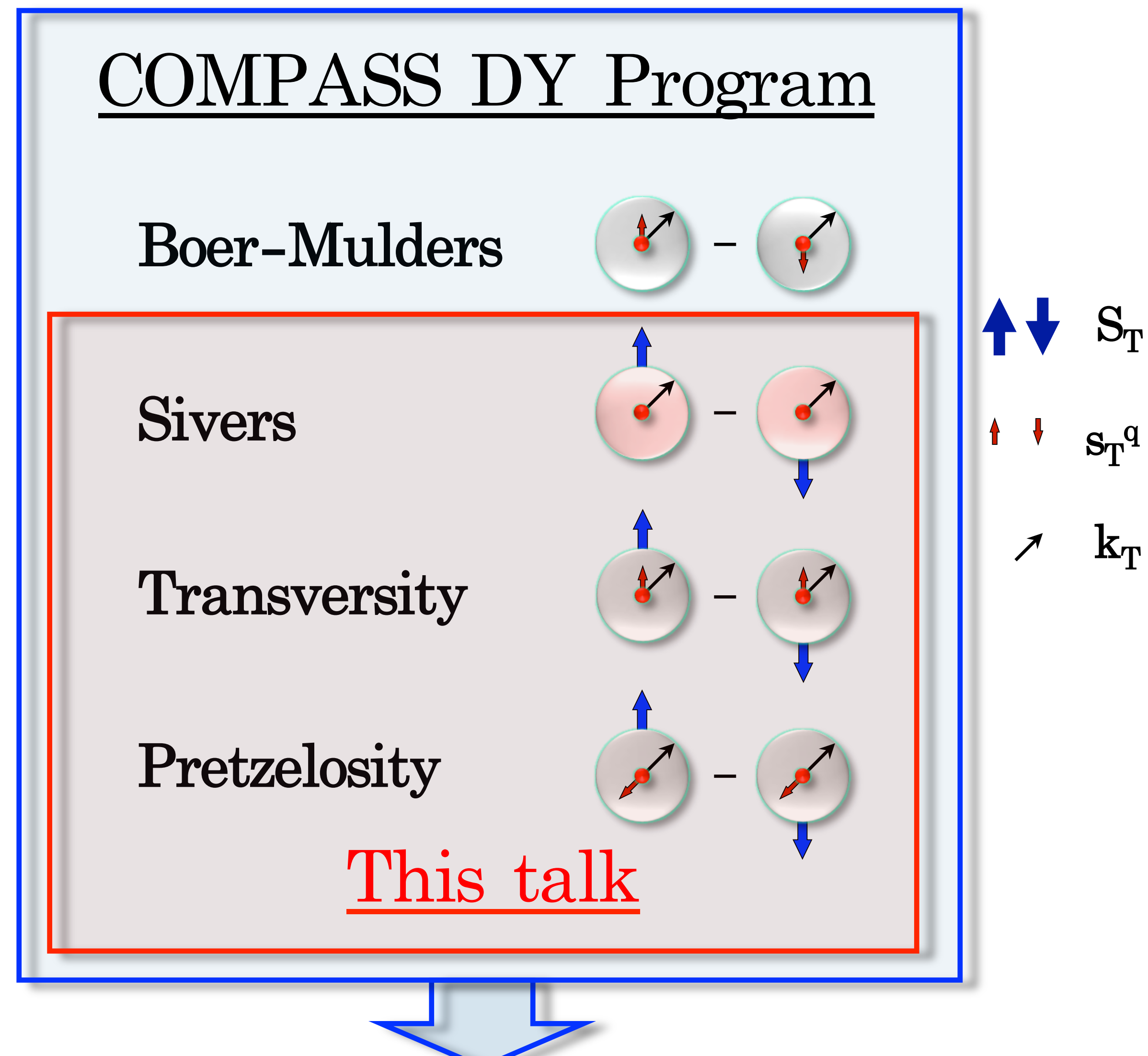
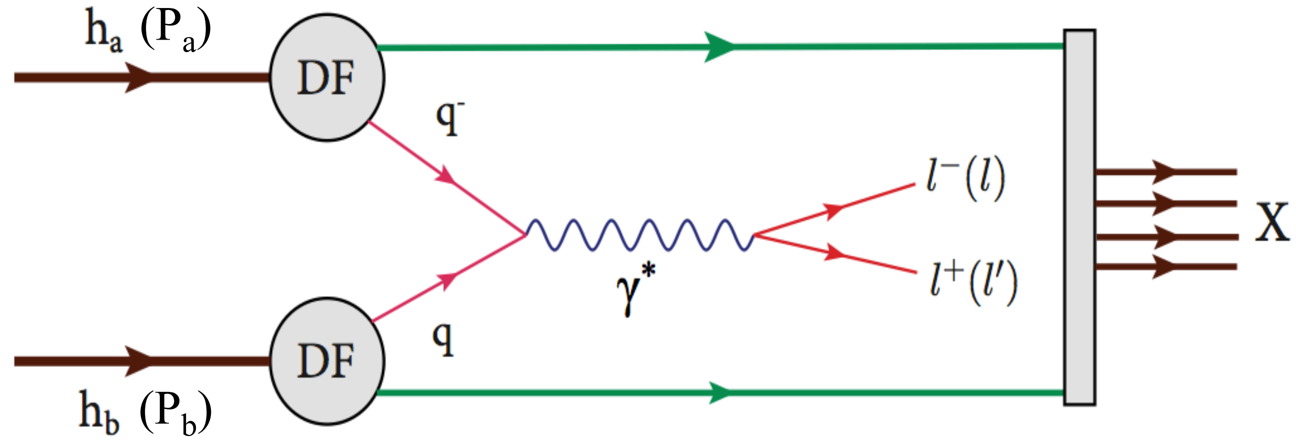


TMD PDFs can be accessed through measurement of target spin (in)dependent azimuthal asymmetries both in **SIDIS** and **Drell-Yan**

Single Polarized Drell-Yan



General **leading order** QCD parton model expression of the SP DY **cross-section**

$$D^{LO}_{[f(\theta)]} = \frac{f(\theta)}{1+\cos^2\theta}$$

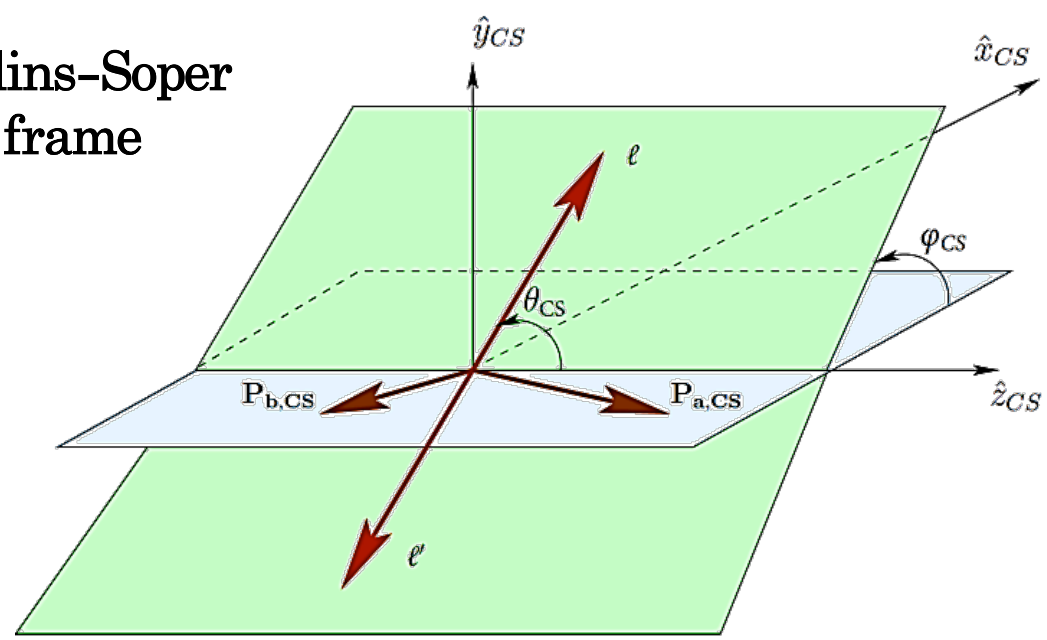
D-factors

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

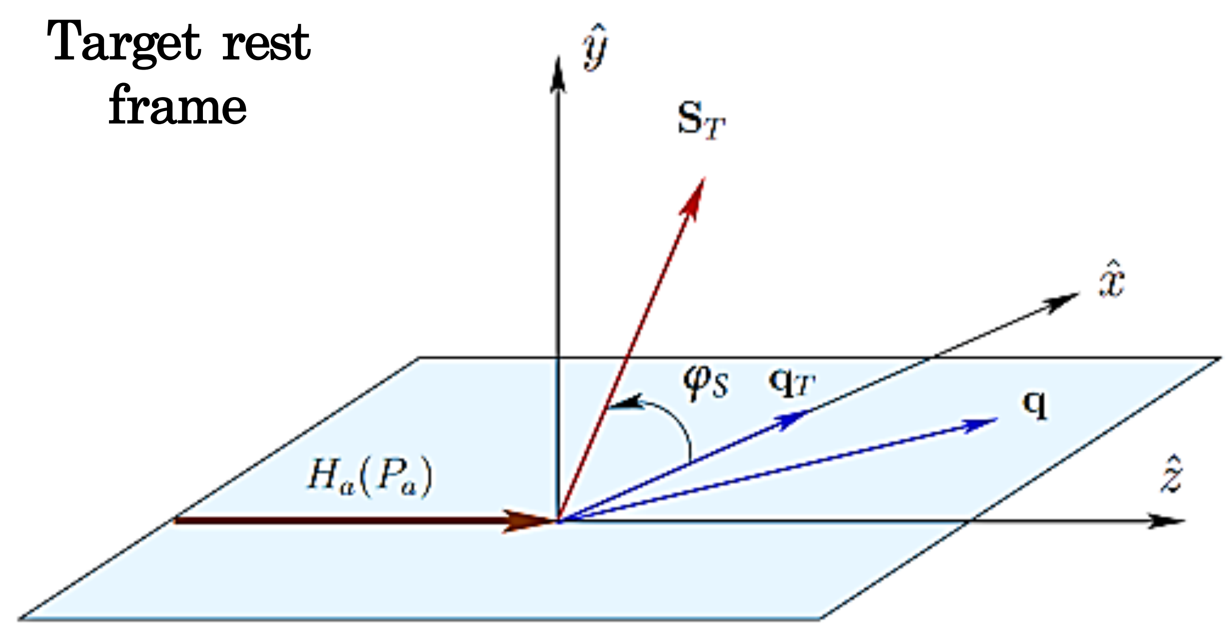
$$A_{U,T}^{w(\varphi_{CS},\varphi_S)} = \frac{F_{U,T}^{w(\varphi_{CS},\varphi_S)}}{F_U^1+F_U^2}$$

Azimuthal asymmetries

Collins-Soper frame

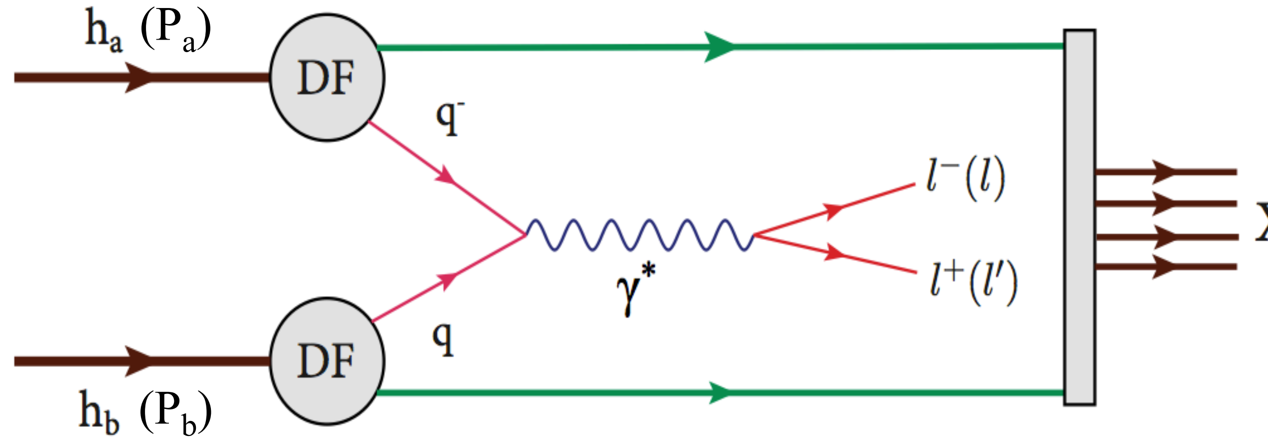


Target rest frame



Single Polarized Drell-Yan

General **leading order** QCD parton model expression of the SP DY **cross-section**



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

$$D^{LO}_{[f(\theta)]} = \frac{f(\theta)}{1+\cos^2\theta}$$

D-factors

$$A_{U,T}^{w(\varphi_{CS},\varphi_S)} = \frac{F_{U,T}^{w(\varphi_{CS},\varphi_S)}}{F_U^1 + F_U^2}$$

Azimuthal asymmetries

@COMPASS: $h_a = \pi^-$ (190 GeV/c) $\quad h_b = p^{\uparrow}$

$$A_U^{\cos 2\varphi_{CS}} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{\perp q}$$

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

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

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

- At LO
  - 1 *Unpolarized* Asymmetry
  - 3 Single Spin Asymmetries
- Measurements of these azimuthal asymmetries provide an access to specific convolutions of TMD PDFs of h_a and h_b

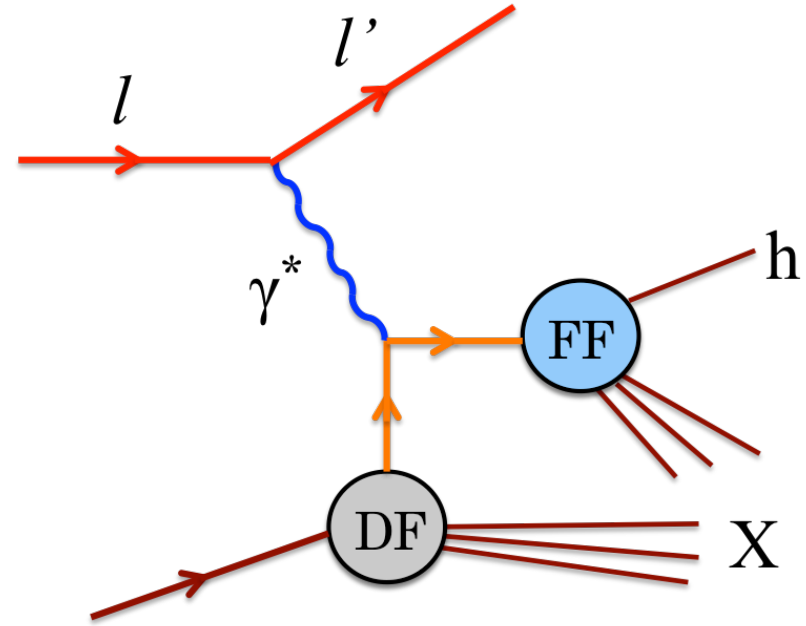
The SIDIS process

$$\frac{d\sigma^{LO}_{SIDIS}}{dx\,dy\,dz\,dp_T^2\,d\varphi_h\,d\psi} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]$$

$$\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\left\{\ 1+\cos 2\phi_h\left(\varepsilon A_{UU}^{\cos 2\phi_h}\right)\right.$$

$$+\ S_T\begin{bmatrix}\sin(\phi_h-\phi_S)\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right)\\+\ \sin(\phi_h+\phi_S)\left(\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\right)\\+\ \sin(3\phi_h-\phi_S)\left(\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\right)\end{bmatrix}$$

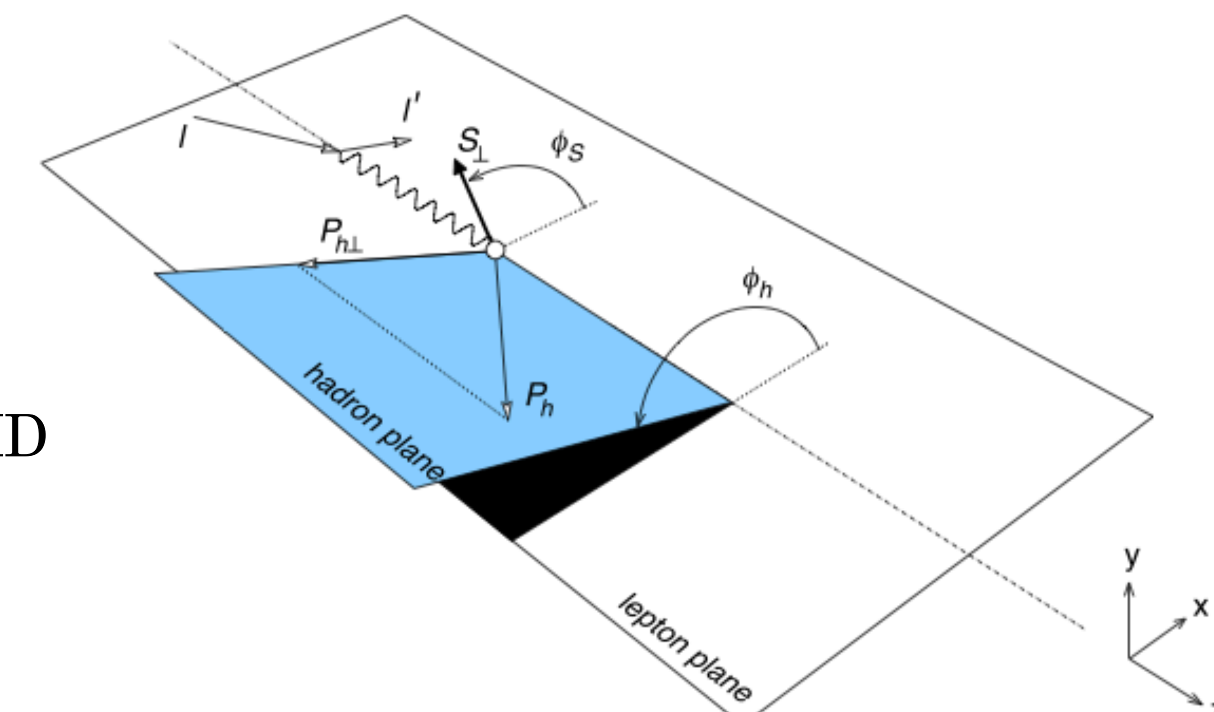
$$\left.+\ S_T\lambda\left[\cos(\phi_h-\phi_S)\left(\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\right)\right]\ \right\}$$



$$A_{U(L),T}^{w(\phi_h,\phi_S)}=\frac{F_{U(L),T}^{w(\phi_h,\phi_S)}}{F_{UU,T}+\varepsilon F_{UU,L}};\quad \gamma=\frac{2Mx}{Q};$$

$$\varepsilon=\frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2};$$

- **At LO, 1 Unpolarized, 3 Single Spin and 1 Double Spin Asymmetries.**
- Measurement of SIDIS azimuthal asymmetries provides an access to specific convolutions of TMD and Fragmentation functions (FFs).



The SIDIS process

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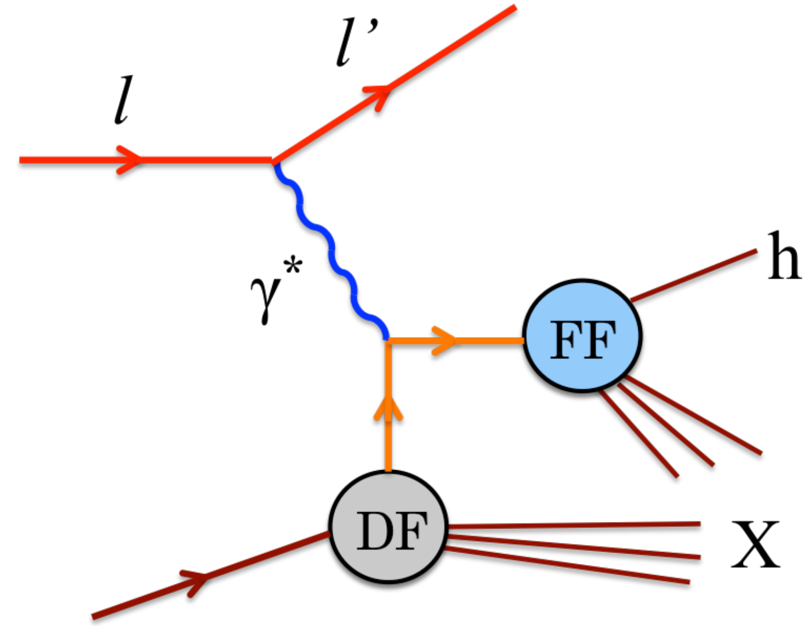


$$\frac{d\sigma^{LO}_{SIDIS}}{dx\,dy\,dz\,dp_T^2\,d\varphi_h\,d\psi} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]$$

$$\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\Big\{ 1+\cos 2\phi_h\left(\varepsilon A_{UU}^{\cos 2\phi_h}\right)$$

$$+\ S_T\left[\begin{array}{l}\sin(\phi_h-\phi_S)\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right)\\ +\ \sin(\phi_h+\phi_S)\left(\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\right)\\ +\ \sin(3\phi_h-\phi_S)\left(\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\right)\end{array}\right]$$

$$+\ S_T\lambda\left[\cos(\phi_h-\phi_S)\left(\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\right)\right]\Big\}$$

$$A^{w(\phi_h,\phi_S)}_{U(L),T} = \frac{F^{w(\phi_h,\phi_S)}_{U(L),T}}{F_{UU,T}+\varepsilon F_{UU,L}};\quad \gamma=\frac{2Mx}{Q};$$

$$\varepsilon = \frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2};$$

$$A_{UU}^{\cos 2\phi_h} \propto h_1^{\perp q}\otimes H_{1q}^{\perp h}$$

$$A_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp q}\otimes D_{1q}^{h}$$

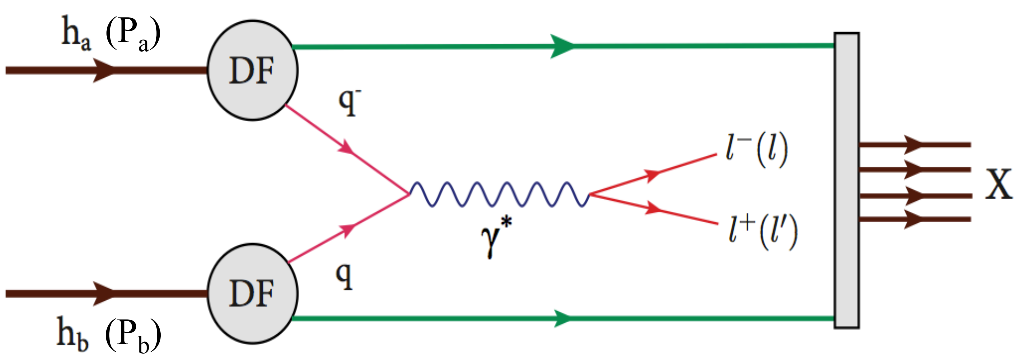
$$A_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1^{q}\otimes H_{1q}^{\perp h}$$

$$A_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T}^{\perp q}\otimes H_{1q}^{\perp h}$$

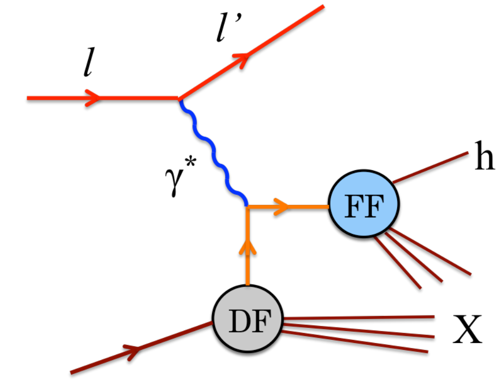
$$A_{LT}^{\cos(\phi_h-\phi_S)} \propto g_{1T}^{q}\otimes D_{1q}^{h}$$

- **At LO, 1 Unpolarized, 3 Single Spin and 1 Double Spin Asymmetries.**
- Measurement of SIDIS azimuthal asymmetries provides an access to specific convolutions of TMD and Fragmentation functions (FFs).

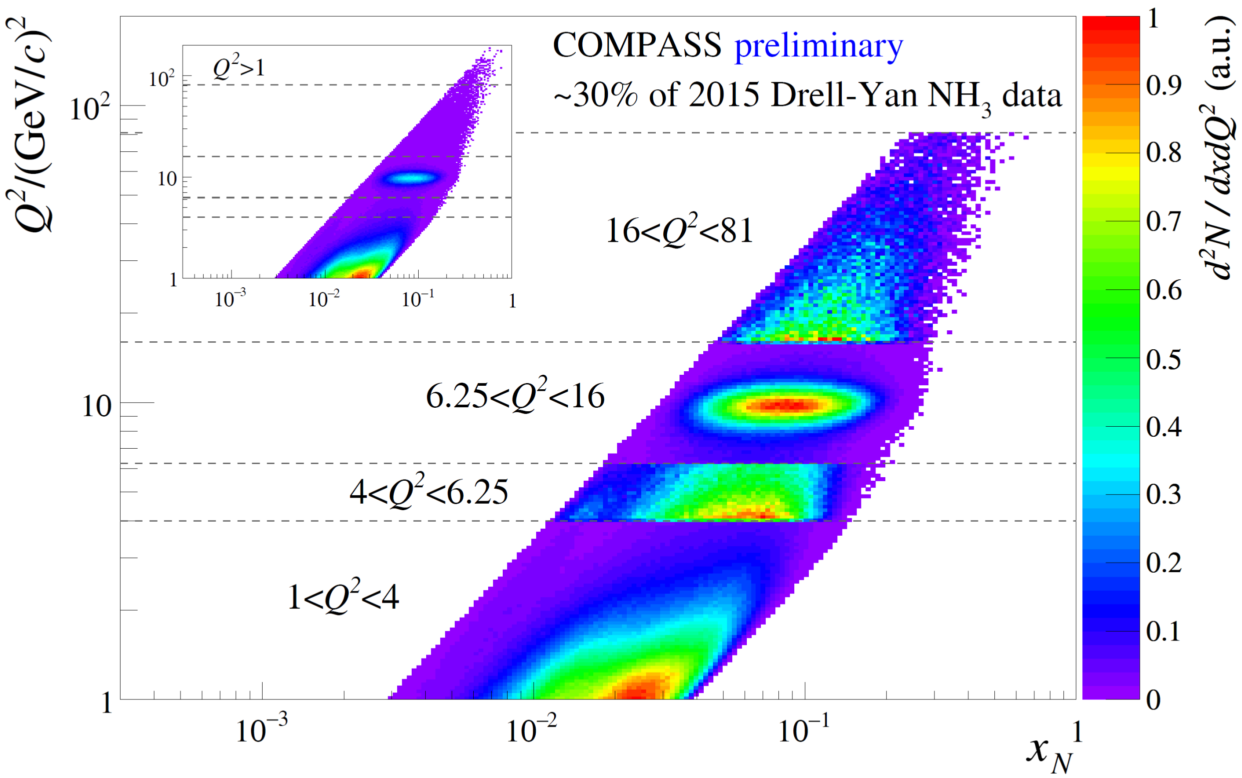
DY-SIDIS Bridge

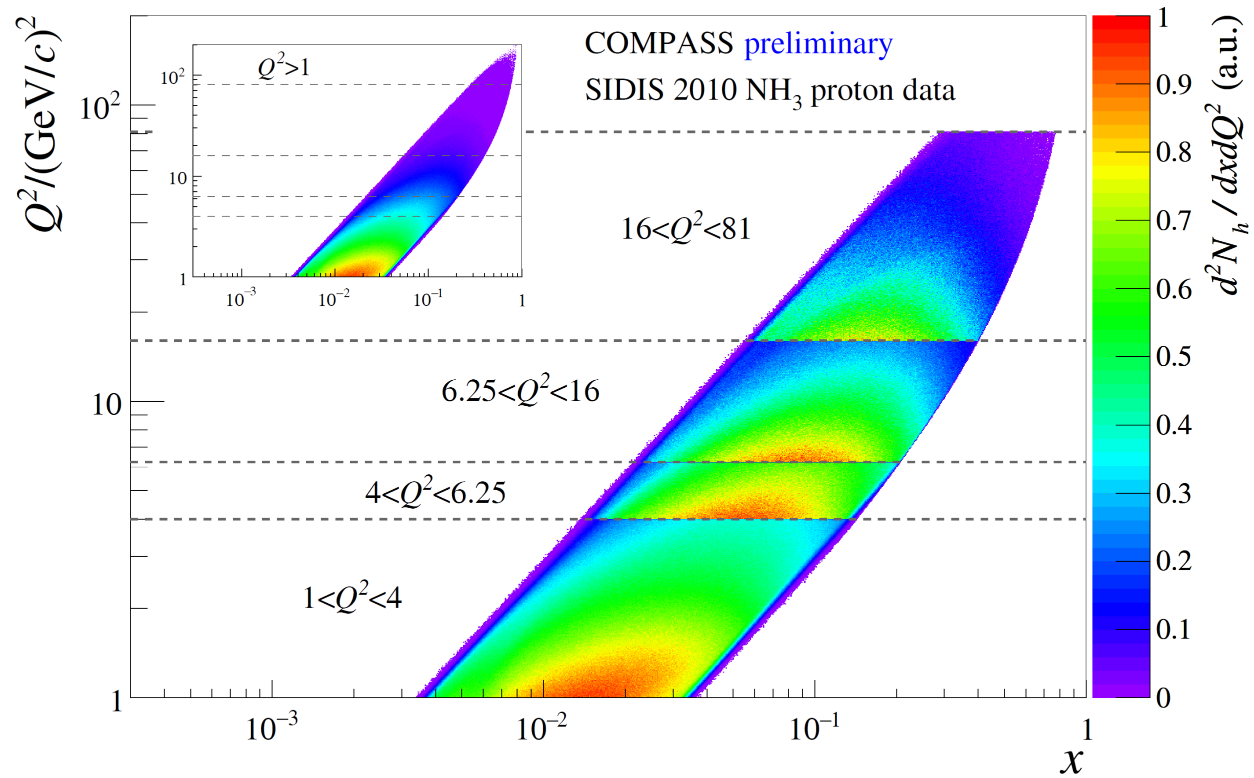


Single Polarized DY (LO)



Transversely polarized SIDIS (LO)





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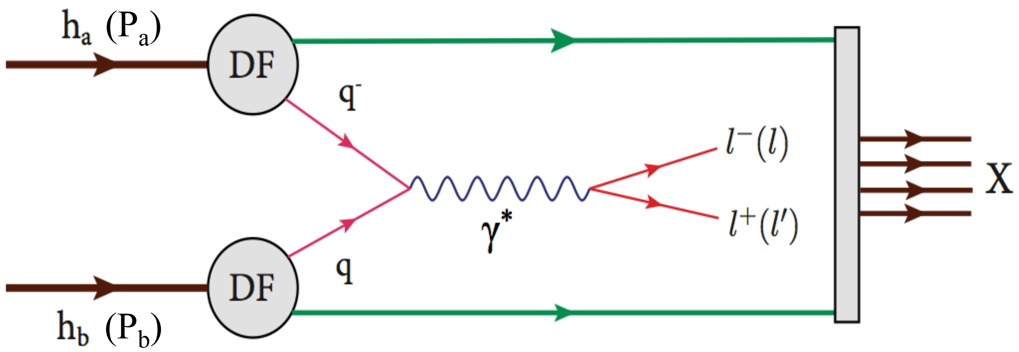
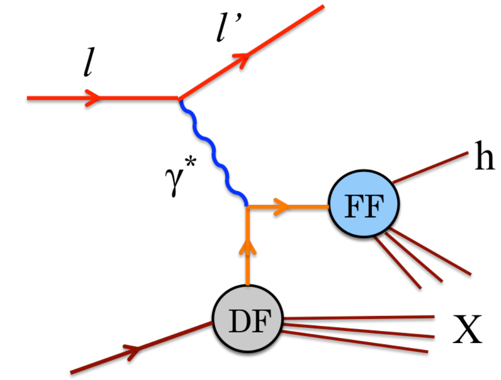


Single Polarized DY (LO)

$$\frac{d\sigma^{LO}}{d\Omega} = \frac{\alpha_{em}^2}{Fq^2} F_U^1 \left\{ 1+\cos^2\theta + \sin^2\theta \cos 2\varphi_{CS} A_U^{\cos 2\varphi_{CS}} + S_T \left[\begin{array}{l} (1+\cos^2\theta)\sin\varphi_S A_T^{\sin\varphi_S} \\ + \sin^2\theta \left(\begin{array}{l} \sin(2\varphi_{CS}+\varphi_S) A_T^{\sin(2\varphi_{CS}+\varphi_S)} \\ + \sin(2\varphi_{CS}-\varphi_S) A_T^{\sin(2\varphi_{CS}-\varphi_S)} \end{array} \right) \end{array} \right] \right\}$$



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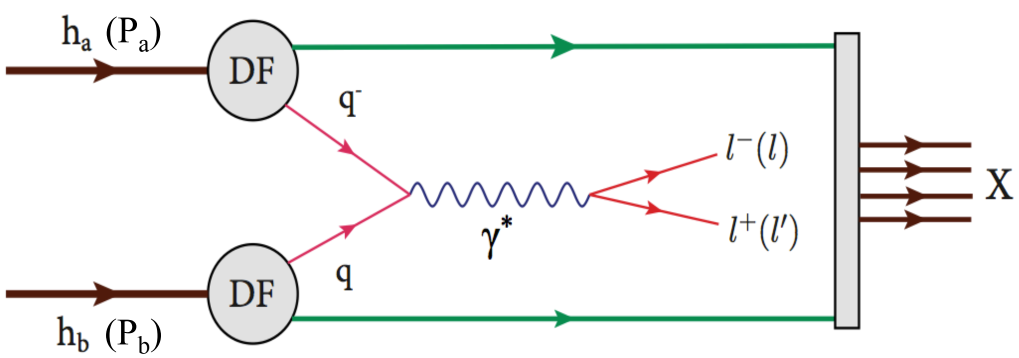
Transversely polarized SIDIS (LO)

$$\frac{d\sigma_{SIDIS}^{LO}}{dxdydzdp_T^2 d\varphi_h d\psi} = \left[\frac{\alpha}{xyQ^2} \frac{y^2}{2(1-\varepsilon)} \left(1+\frac{\gamma^2}{2x}\right) \right] \times \left(F_{UU,T} + \varepsilon F_{UU,L}\right) \left\{ 1 + \cos 2\phi_h \left(\varepsilon A_{UU}^{\cos 2\phi_h}\right) + S_T \left[\begin{array}{l} \sin(\phi_h-\phi_S)\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right) \\ + \sin(\phi_h+\phi_S)\left(\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\right) \\ + \sin(3\phi_h-\phi_S)\left(\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\right) \end{array} \right] + S_T\lambda \left[\cos(\phi_h-\phi_S)\left(\sqrt{(1-\varepsilon^2)} A_{LT}^{\cos(\phi_h-\phi_S)}\right) \right] \right\}$$

DY-SIDIS Bridge



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$$\frac{d\sigma^{LO}}{d\Omega} = \frac{\alpha_{em}^2}{Fq^2} F_U^1 \Big\{ 1+\cos^2\theta + \sin^2\theta \cos 2\varphi_{CS} A_U^{\cos 2\varphi_{CS}}$$

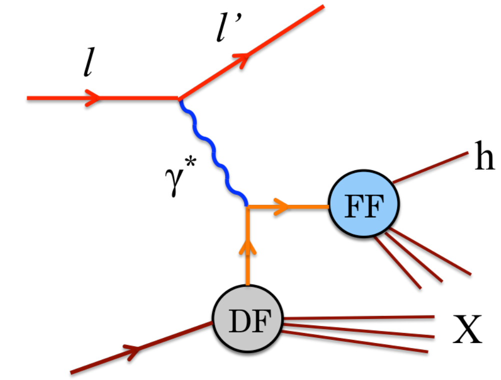
$$+ S_T \left[\left(1+\cos^2\theta\right)\sin\varphi_S A_T^{\sin\varphi_S} + \sin^2\theta \left(\sin\left(2\varphi_{CS}+\varphi_S\right) A_T^{\sin(2\varphi_{CS}+\varphi_S)} + \sin\left(2\varphi_{CS}-\varphi_S\right) A_T^{\sin(2\varphi_{CS}-\varphi_S)} \right) \right] \Big\}$$

$h_{1,\pi}^{\perp q} \otimes h_1^{\perp q}$

$f_{1,\pi}^{q} \otimes f_{1T}^{\perp q}$

$h_{1,\pi}^{\perp q} \otimes h_1^{q}$

$h_{1,\pi}^{\perp q} \otimes h_{1T}^{\perp q}$



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$$\times\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\Big\{ 1+\cos 2\phi_h\left(\varepsilon A_{UU}^{\cos 2\phi_h}\right)$$

$$+ S_T \left[\sin\left(\phi_h-\phi_S\right)\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right) + \sin\left(\phi_h+\phi_S\right)\left(\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\right) + \sin\left(3\phi_h-\phi_S\right)\left(\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\right) \right]$$

$$+ S_T\lambda\left[\cos\left(\phi_h-\phi_S\right)\left(\sqrt{\left(1-\varepsilon^2\right)}A_{LT}^{\cos(\phi_h-\phi_S)}\right)\right] \Big\}$$

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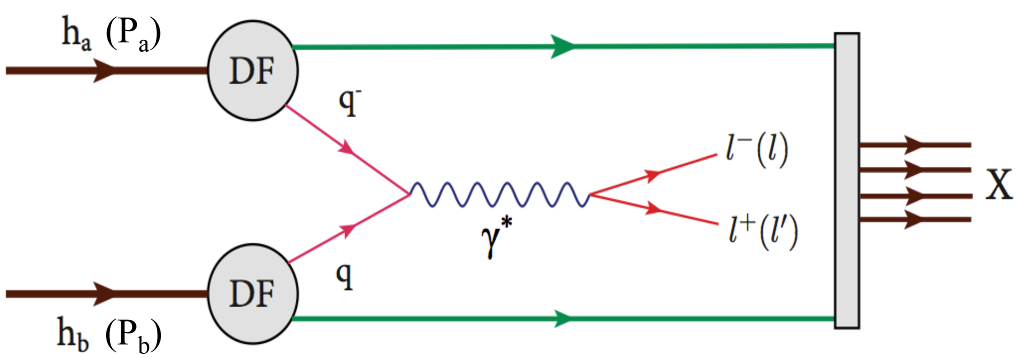

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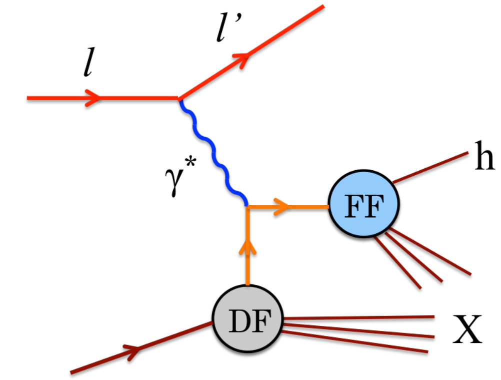

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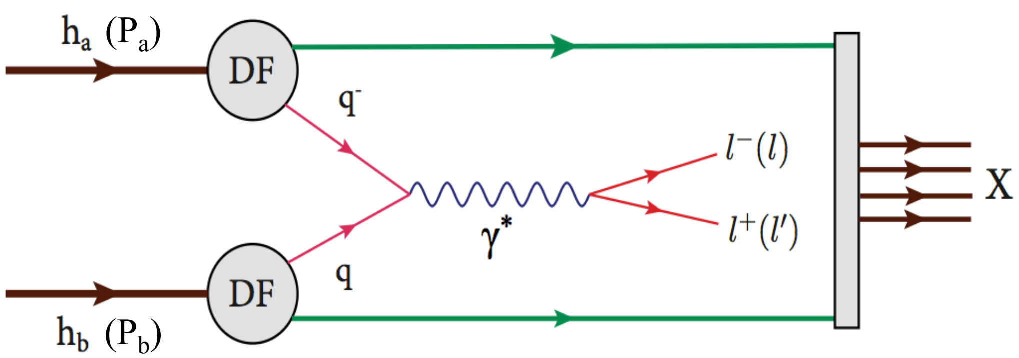
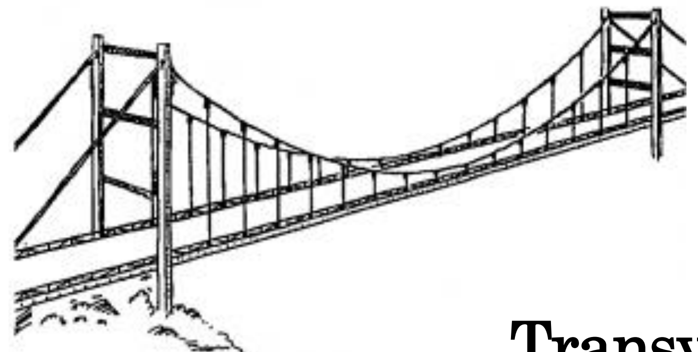
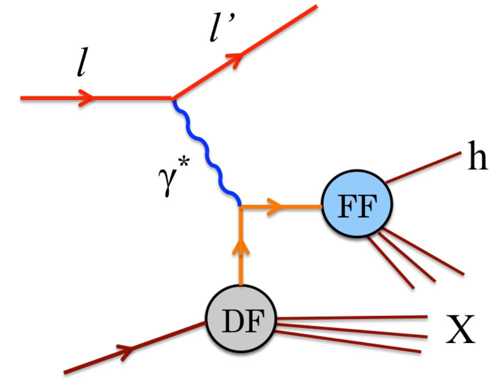
$$+ S_T\lambda\left[\cos(\phi_h-\phi_S)\left(\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\right)\right]\Big\}$$

- $h_1^{\perp q} \otimes H_{1q}^{\perp h}$ ← $\cos 2\phi_h$
- $f_{1T}^{\perp q} \otimes D_{1q}^{h}$ ← $\sin(\phi_h-\phi_S)$
- $h_1^{q} \otimes H_{1q}^{\perp h}$ ← $\sin(\phi_h+\phi_S)$
- $h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$ ← $\sin(3\phi_h-\phi_S)$
- $g_{1T}^{q} \otimes D_{1q}^{h}$ ← $\cos(\phi_h-\phi_S)$

DY-SIDIS Bridge







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Transversely polarized SIDIS (LO)

$$\frac{d\sigma_{SIDIS}^{LO}}{dx\,dy\,dz\,dp_T^2\,d\varphi_h\,d\psi} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right] \times \left(F_{UU,T}+\varepsilon F_{UU,L}\right) \Big\{ 1+\cos 2\phi_h \left(\varepsilon A_{UU}^{\cos 2\phi_h}\right) + S_T \Big[\sin\left(\phi_h-\phi_S\right)\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right) + \sin\left(\phi_h+\phi_S\right)\left(\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\right) + \sin\left(3\phi_h-\phi_S\right)\left(\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\right) \Big] + S_T\lambda \Big[\cos\left(\phi_h-\phi_S\right)\left(\sqrt{\left(1-\varepsilon^2\right)} A_{LT}^{\cos(\phi_h-\phi_S)}\right) \Big] \Big\}$$

$h_1^{\perp q}$

$f_{1T}^{\perp q}$

h_1^q

$h_{1T}^{\perp q}$

DP – DY only g_{1T}^q

Within the concept of generalized universality (time-reversal modified process-independence) of TMD PDFs it appears that same parton distribution functions can be accessed both in SIDIS and Drell-Yan

TMD Universality

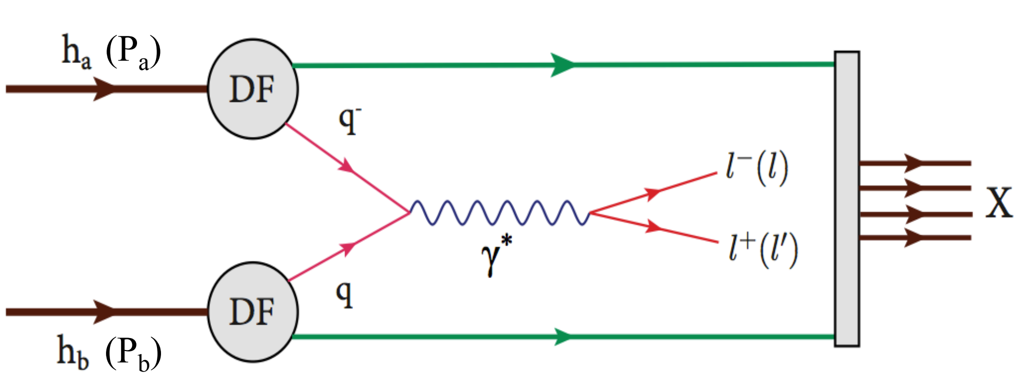
Sivers and BM sign change

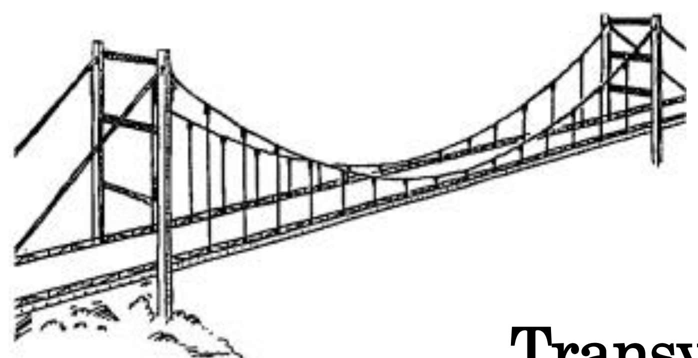
$$f_{1T}^{\perp q}\big|_{DY} = - f_{1T}^{\perp q}\big|_{SIDIS}$$

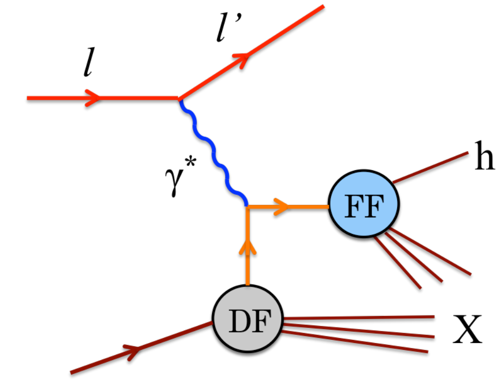
$$h_1^q\big|_{DY} = - h_1^q\big|_{SIDIS}$$

h_1^q $\quad$ $h_{1T}^{\perp q}$

DY-SIDIS Bridge







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Single Polarized DY (LO)

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$$+ S_T \left[\left(1+\cos^2\theta\right)\sin\varphi_S A_T^{\sin\varphi_S} + \sin^2\theta \left(\sin\left(2\varphi_{CS}+\varphi_S\right) A_T^{\sin(2\varphi_{CS}+\varphi_S)} + \sin\left(2\varphi_{CS}-\varphi_S\right) A_T^{\sin(2\varphi_{CS}-\varphi_S)} \right) \right] \Big\}$$

Transversely polarized SIDIS (LO)

$$\frac{d\sigma_{SIDIS}^{LO}}{dxdydzdp_T^2 d\varphi_h d\psi} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right] \times \left(F_{UU,T} + \varepsilon F_{UU,L}\right) \Big\{ 1 + \cos 2\phi_h \left(\varepsilon A_{UU}^{\cos 2\phi_h}\right)$$

$$+ S_T \left[\sin\left(\phi_h-\phi_S\right)\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right) + \sin\left(\phi_h+\phi_S\right)\left(\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\right) + \sin\left(3\phi_h-\phi_S\right)\left(\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\right) \right]$$

$$+ S_T\lambda \left[\cos\left(\phi_h-\phi_S\right)\left(\sqrt{\left(1-\varepsilon^2\right)} A_{LT}^{\cos(\phi_h-\phi_S)}\right) \right] \Big\}$$

$h_1^{\perp q}$

$f_{1T}^{\perp q}$

h_1^q

$h_{1T}^{\perp q}$

DP – DY only g_{1T}^q

Within the concept of generalized universality (time-reversal modified process-independence) of TMD PDFs it appears that same parton distribution functions can be accessed both in SIDIS and Drell-Yan

Polarized DY data are needed for the verification!

TMD Universality

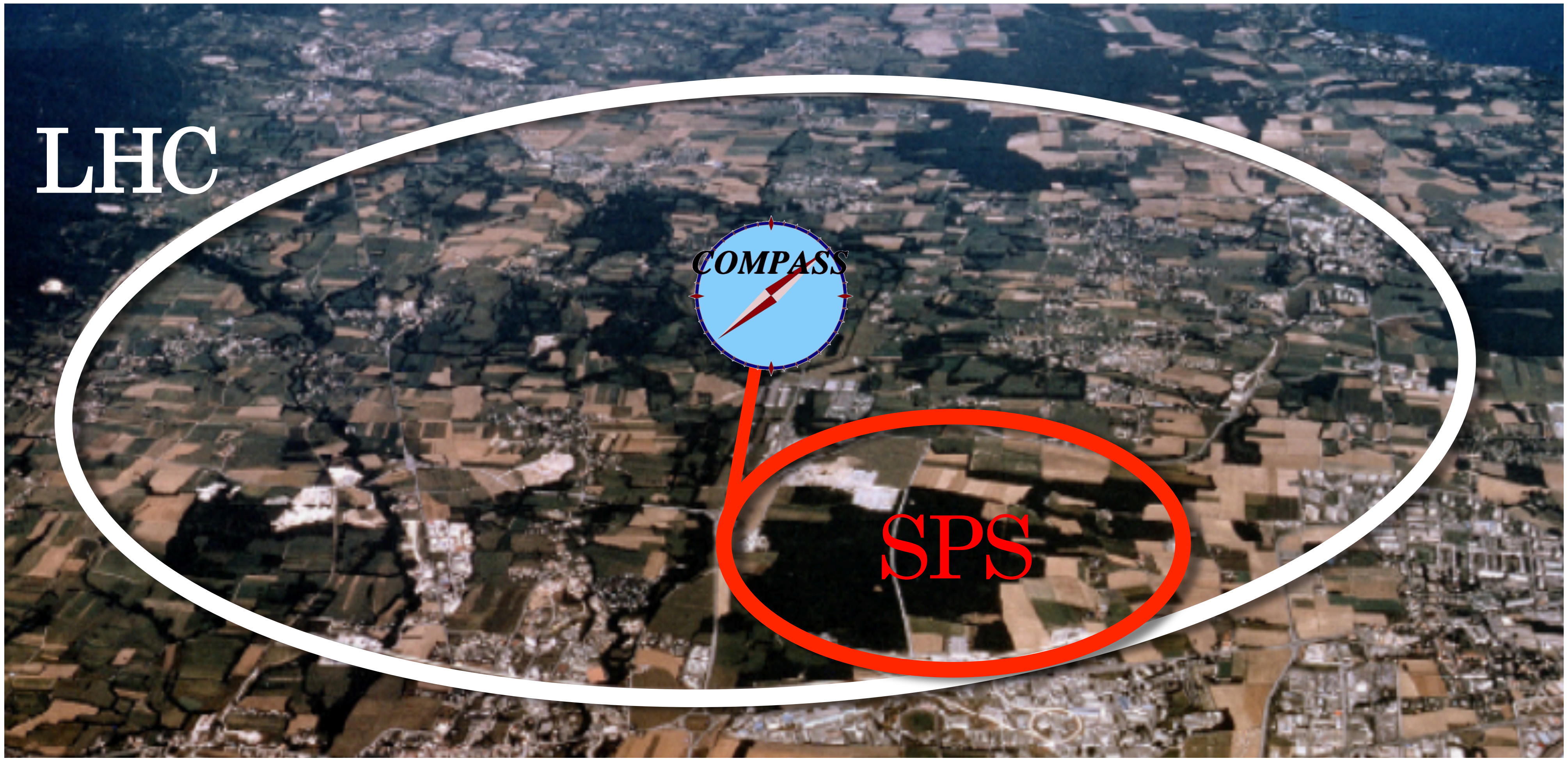
Sivers and BM sign change

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

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

h_1^q $h_{1T}^{\perp q}$

The COMPASS collaboration



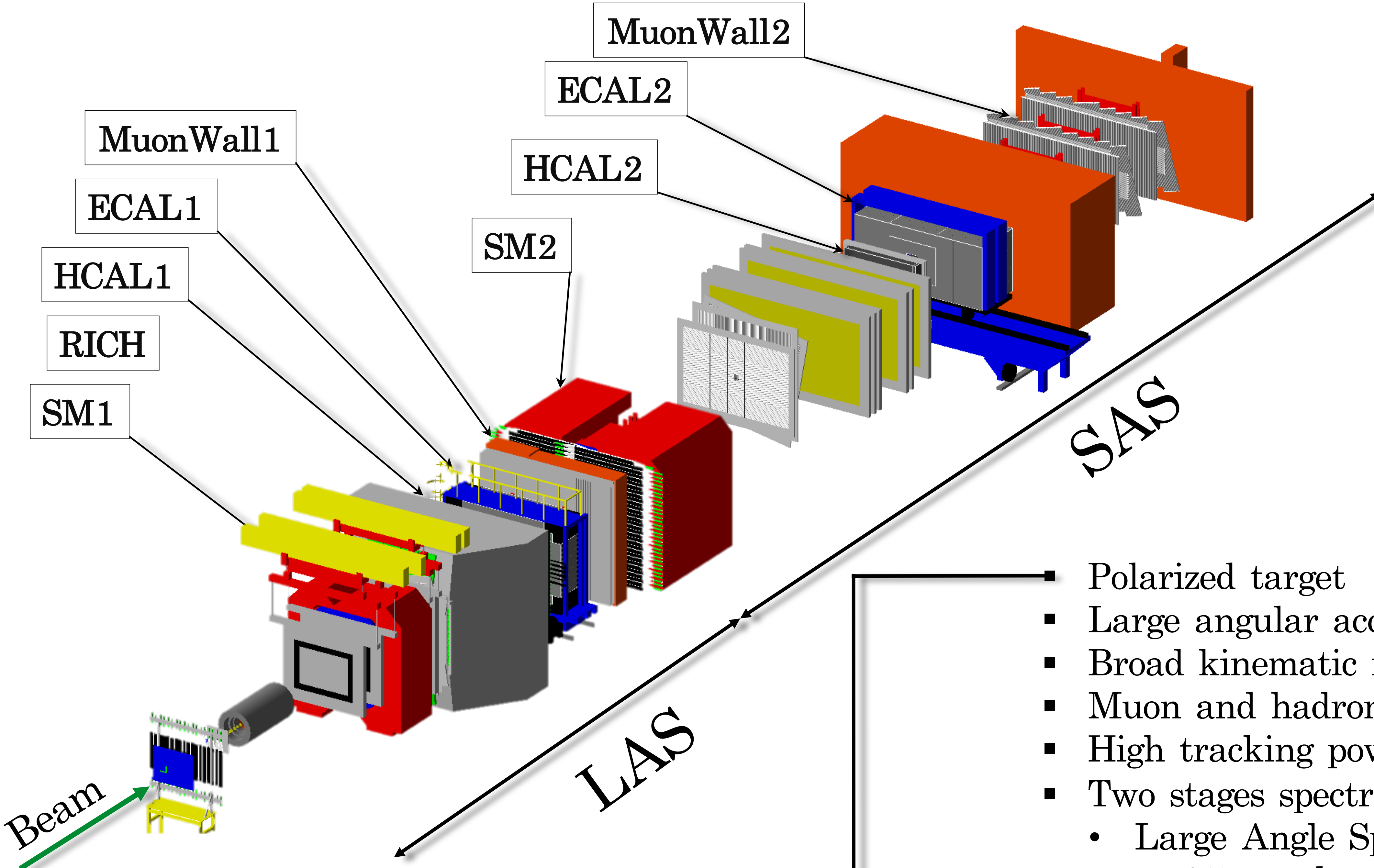
- SPS North Area
- Fixed target experiment
- First data taking in 2002

Phase I
- 2002 – 2011
- Hadron spectroscopy
- Nucleon spin structure studies

G.K. Mallot → Tuesday
M.Mikhasenko → Thursday

Phase II
- 2012 – 2018
- Primakoff + DVCS pilot run (2012)
- Drell-Yan (2015, 2018)
- DVCS + Unpolarized SIDIS(2016-2017)

COMPASS SIDIS experimental setup



- Polarized target
- Large angular acceptance
- Broad kinematic range covered
- Muon and hadron beam
- High tracking power (~350 planes)
- Two stages spectrometer
  - Large Angle Spectrometer (LAS)
    - 35 mrad < θ < 180 mrad
    - SM1 magnet (1 T · m)
  - Small Angle Spectrometer (SAS)
    - 18 mrad < θ < 35 mrad
    - SM2 magnet (4.4 T · m)

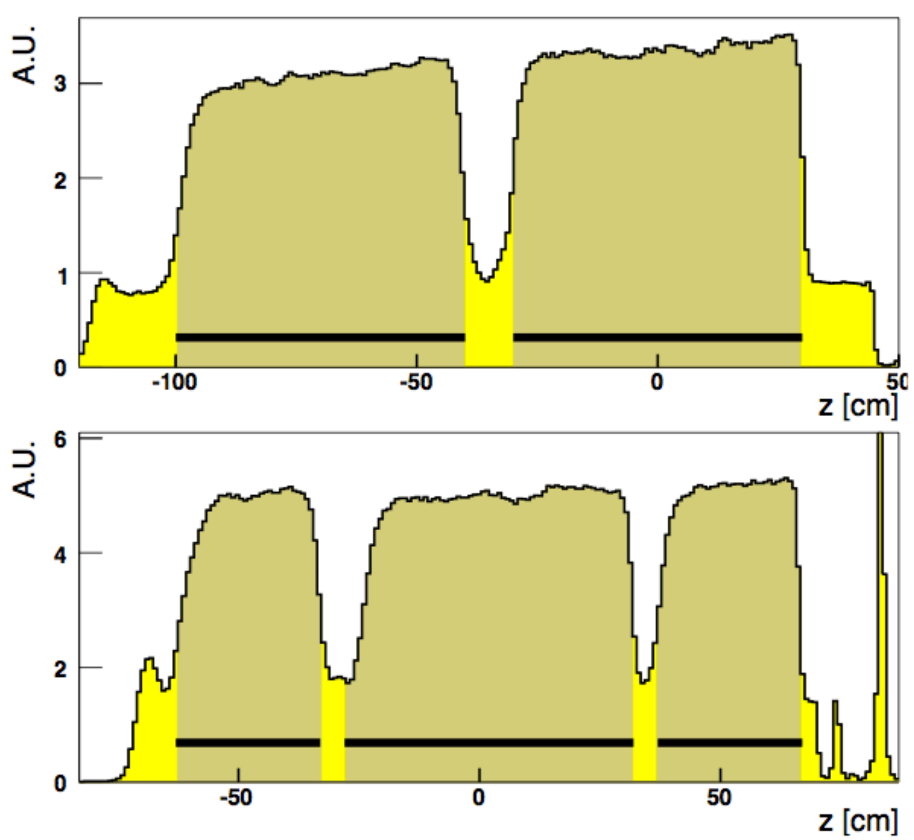
Target	# of cells	Polarization
NH_3	3	L&T, ~80-90 %
^{6}LiD	2,3	L&T, ~50 %

COMPASS SIDIS data taking

Year	Beam	Target	# cells	Polarization
2002	μ^+ @ 160 GeV/c	Deuteron, ^{6}LiD	2	L & T, ~ 50%
2003	μ^+ @ 160 GeV/c	Deuteron, ^{6}LiD	2	L & T, ~ 50%
2004	μ^+ @ 160 GeV/c	Deuteron, ^{6}LiD	2	L & T, ~ 50%
2006	μ^+ @ 160 GeV/c	Deuteron, ^{6}LiD	3	L ~ 50%
2007	μ^+ @ 160 GeV/c	Proton, NH_3	3	L & T, ~ 90%
2010	μ^+ @ 160 GeV/c	Proton, NH_3	3	T, ~ 90%
2011	μ^+ @ 200 GeV/c	Proton, NH_3	3	L, ~ 90%

- During Phase I, the COMPASS collaboration collected a considerable amount of **SIDIS data**, using L&T polarized proton and deuteron targets.
- Many interesting and important **results** and still more to come from several ongoing analysis…

G.K. Mallot → Tuesday



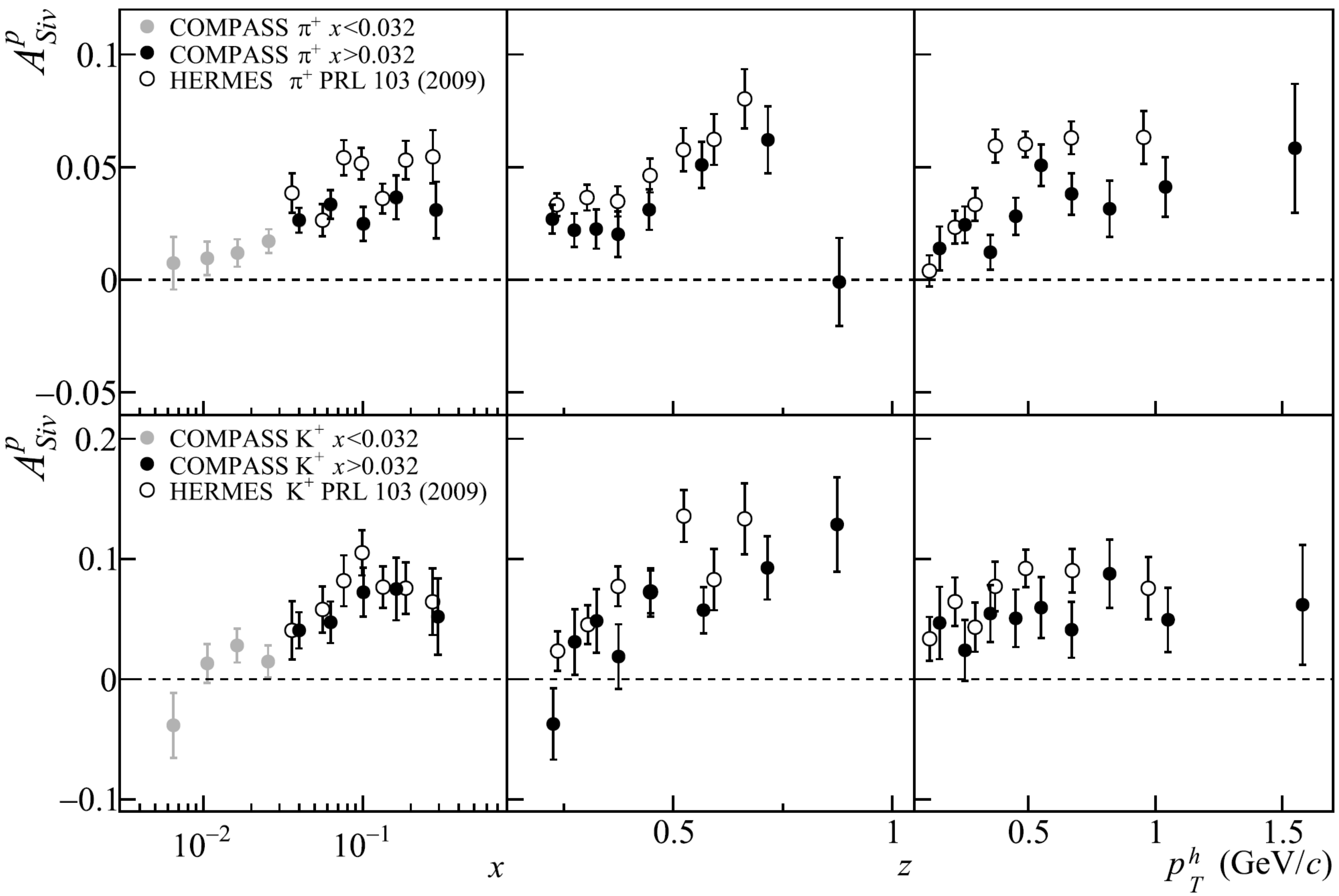
2002 - 2004

2006 - 2011

COMPASS SIDIS results: Sivers

PLB 744 (2015) 250

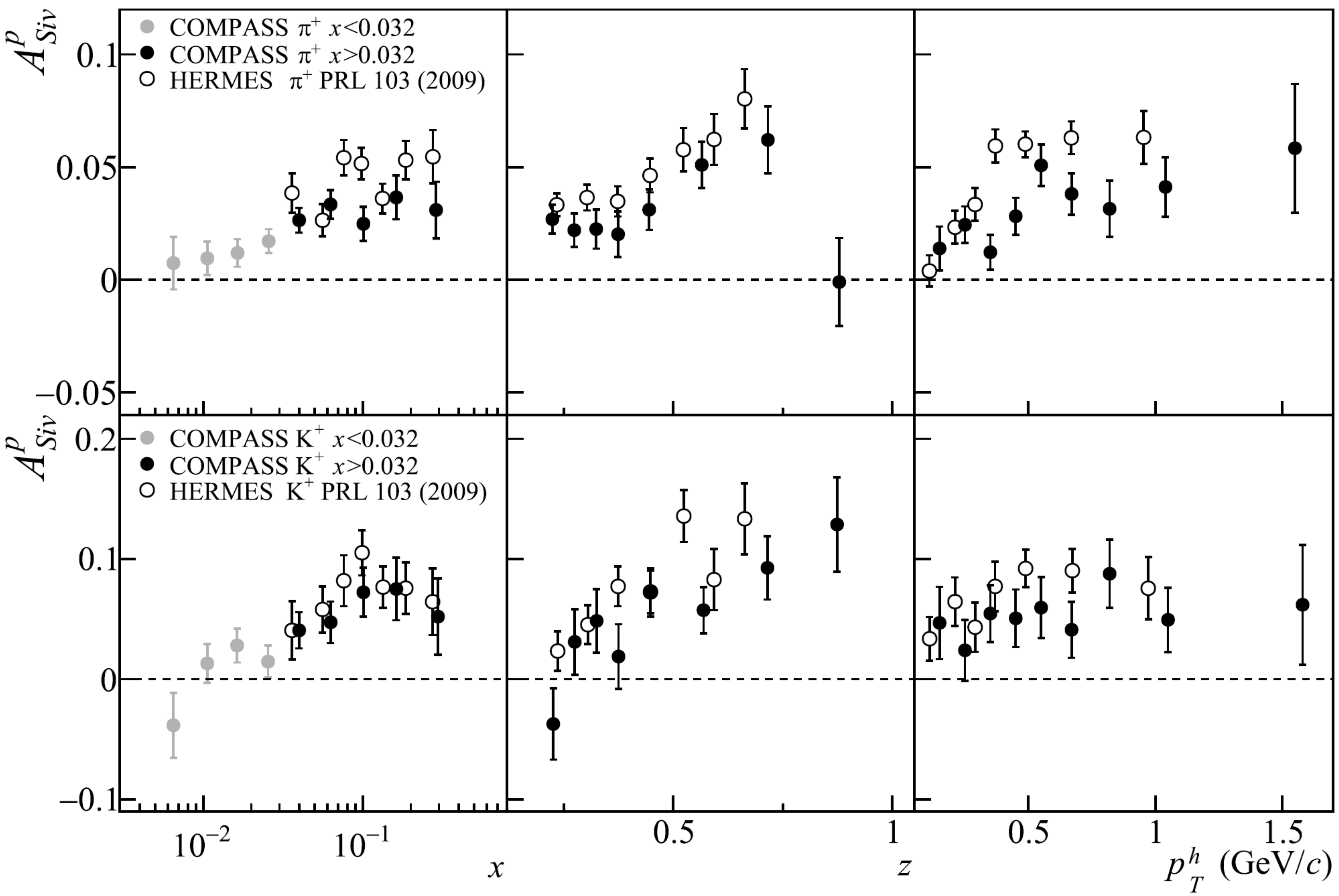
$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$



- Sivers asymmetry for π^+ and K^+ : COMPASS proton 2010 vs Hermes proton 2002-2005.
- Sivers asymmetry measured in COMPASS is lower than the one from HERMES, for both π^+ and K^+.

COMPASS SIDIS results: Sivers

PLB 744 (2015) 250



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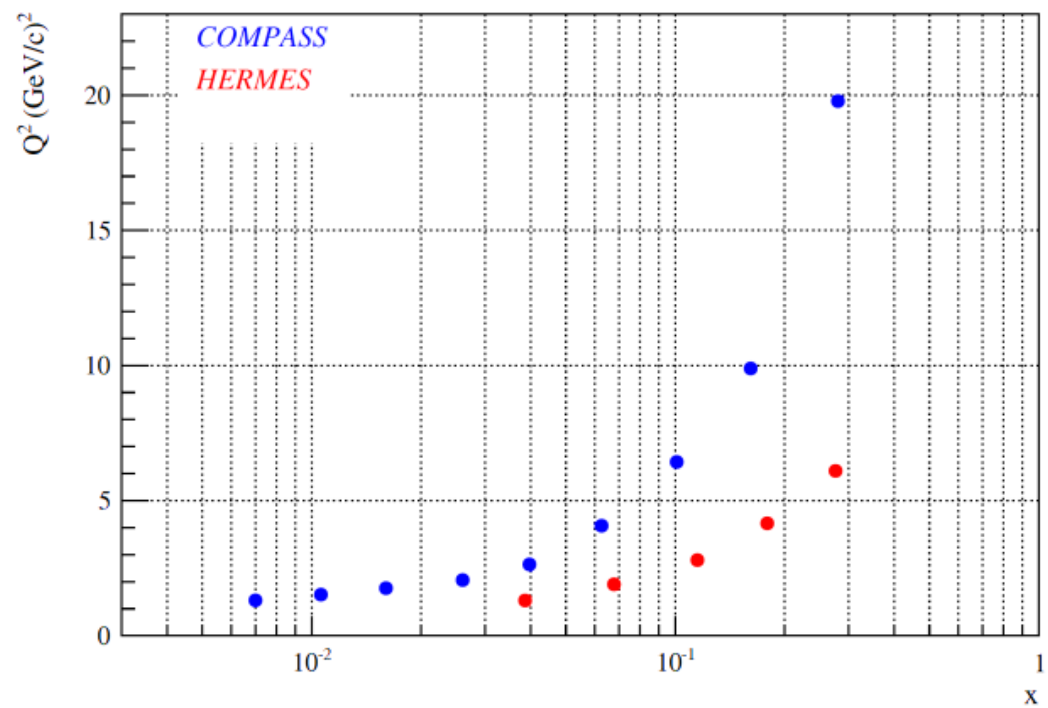
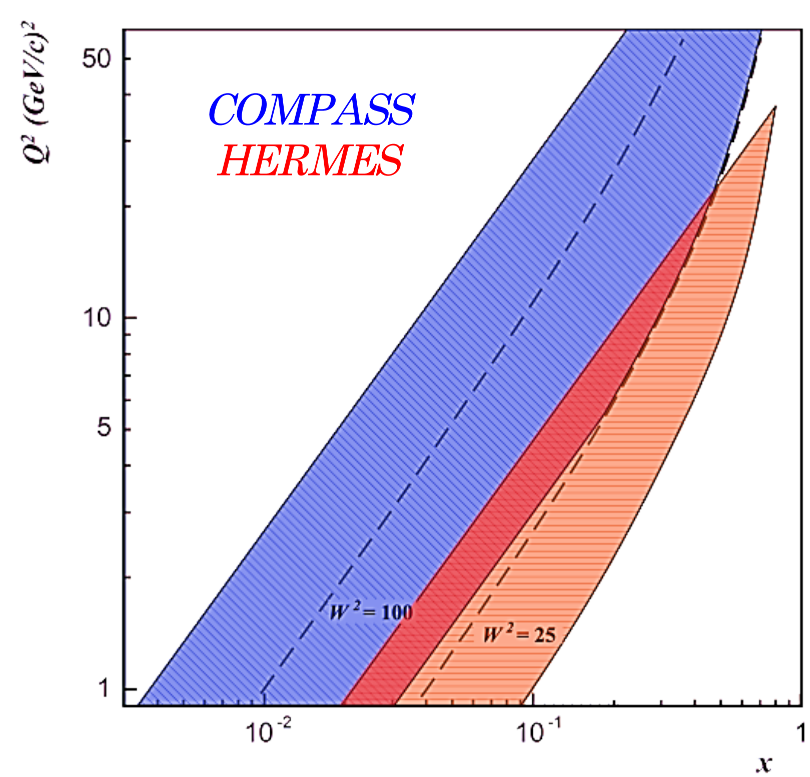




- Sivers asymmetry for π^+ and K$^+$: COMPASS proton 2010 vs Hermes proton 2002-2005.
- Sivers asymmetry measured in COMPASS is lower than the one from HERMES, for both π^+ and K$^+$.
- Different x:Q^2 phase spaces.
- For given x COMPASS operates with larger mean Q^2 values (factor 2-3).
- Can the differences in the Sivers amplitude be an evidence of **TMD evolution effects?**

COMPASS DY ranges

Four Q^2 (or mass) ranges

I. $1 < Q^2/(GeV/c^2) < 4$, "Low mass"

- Large combinatorial background:
  - Pion and Kaon decays.
  - Open charm (bottom) semi-leptonic decays $D\bar{D}$, $B\bar{B}$
- Smaller Asymmetries.

II. $4 < Q^2/(GeV/c^2) < 6.25$, "Intermediate"

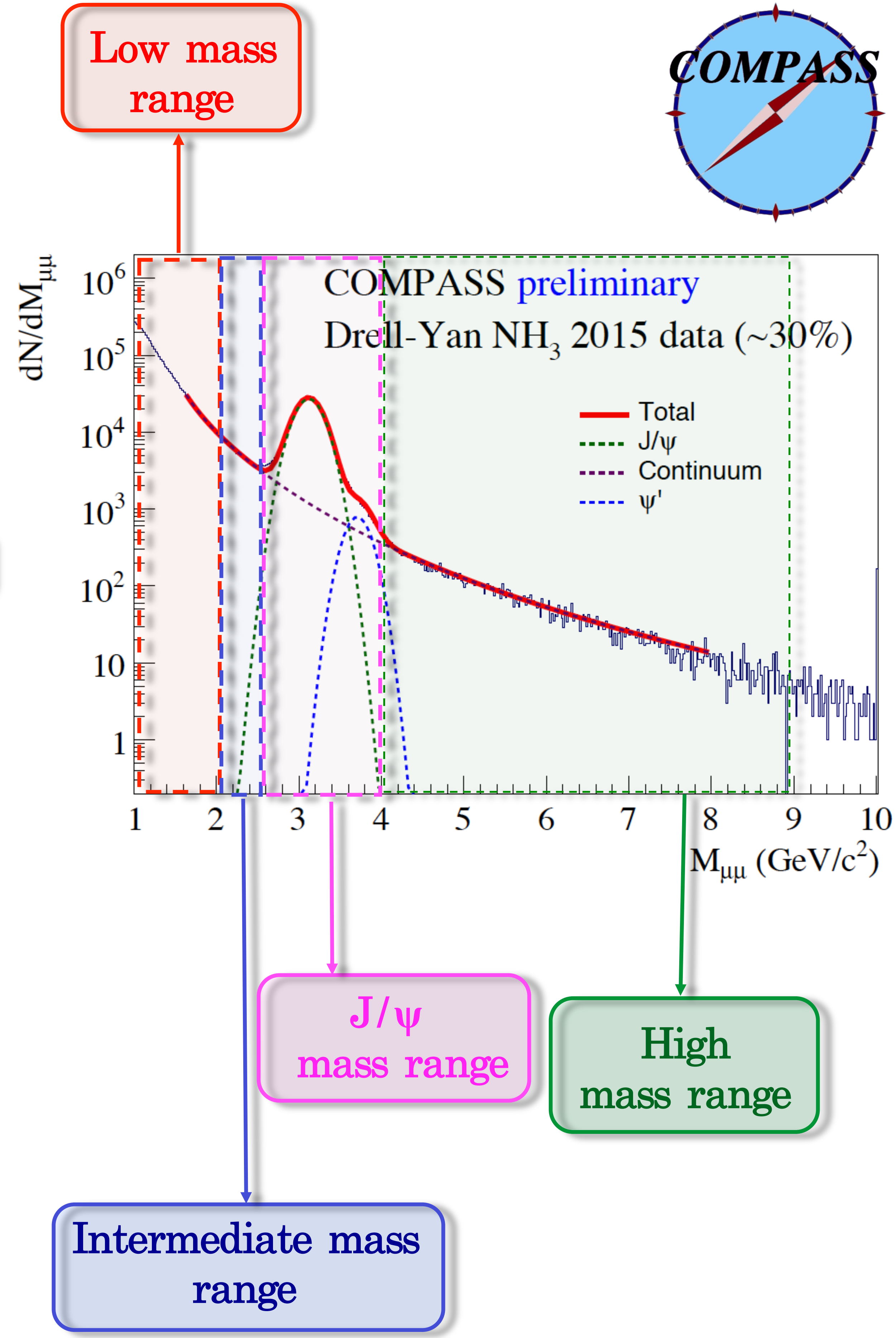
- High DY cross section.
- Still low signal/background

III. $6.25 < Q^2/(GeV/c^2) < 16$, "$J/\psi$"

- Strong J/ψ signal ➔ Studies of J/ψ physics.
- Lower background
- Difficult to disentangle DY

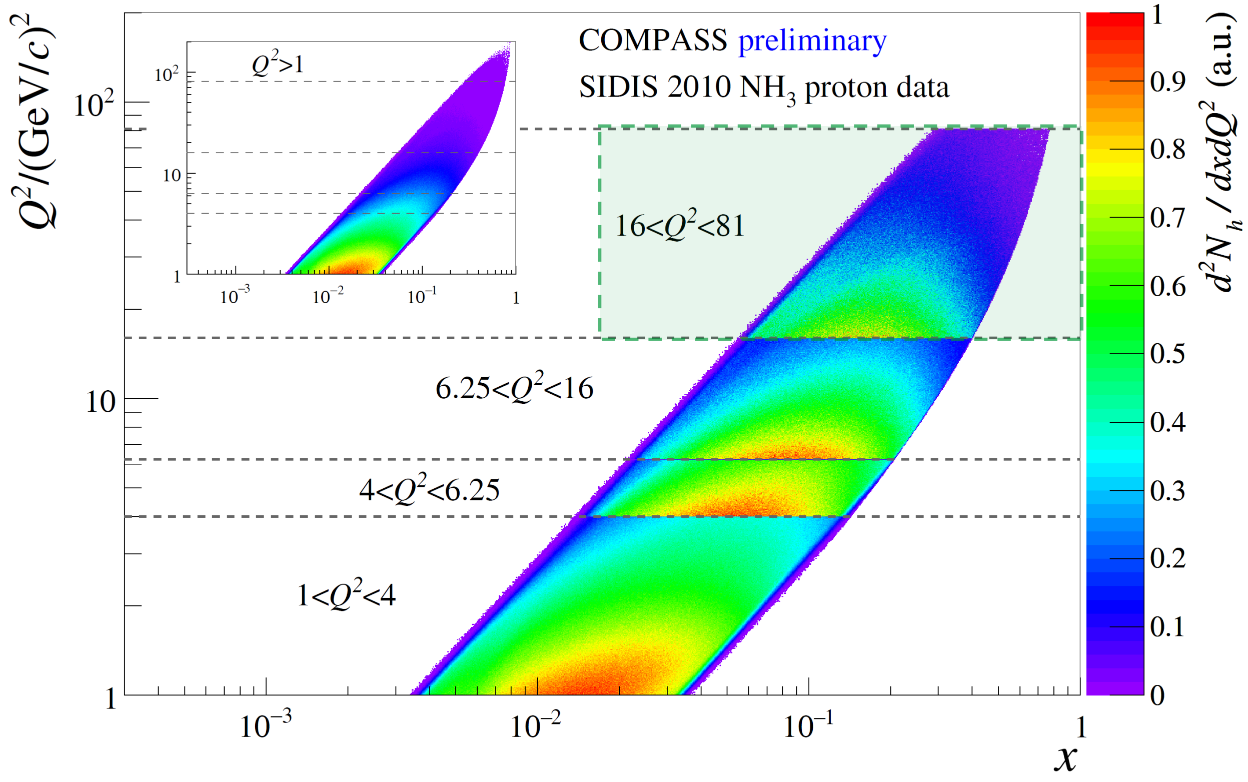
IV. $16 < Q^2/(GeV/c^2) < 81$, "High Mass"

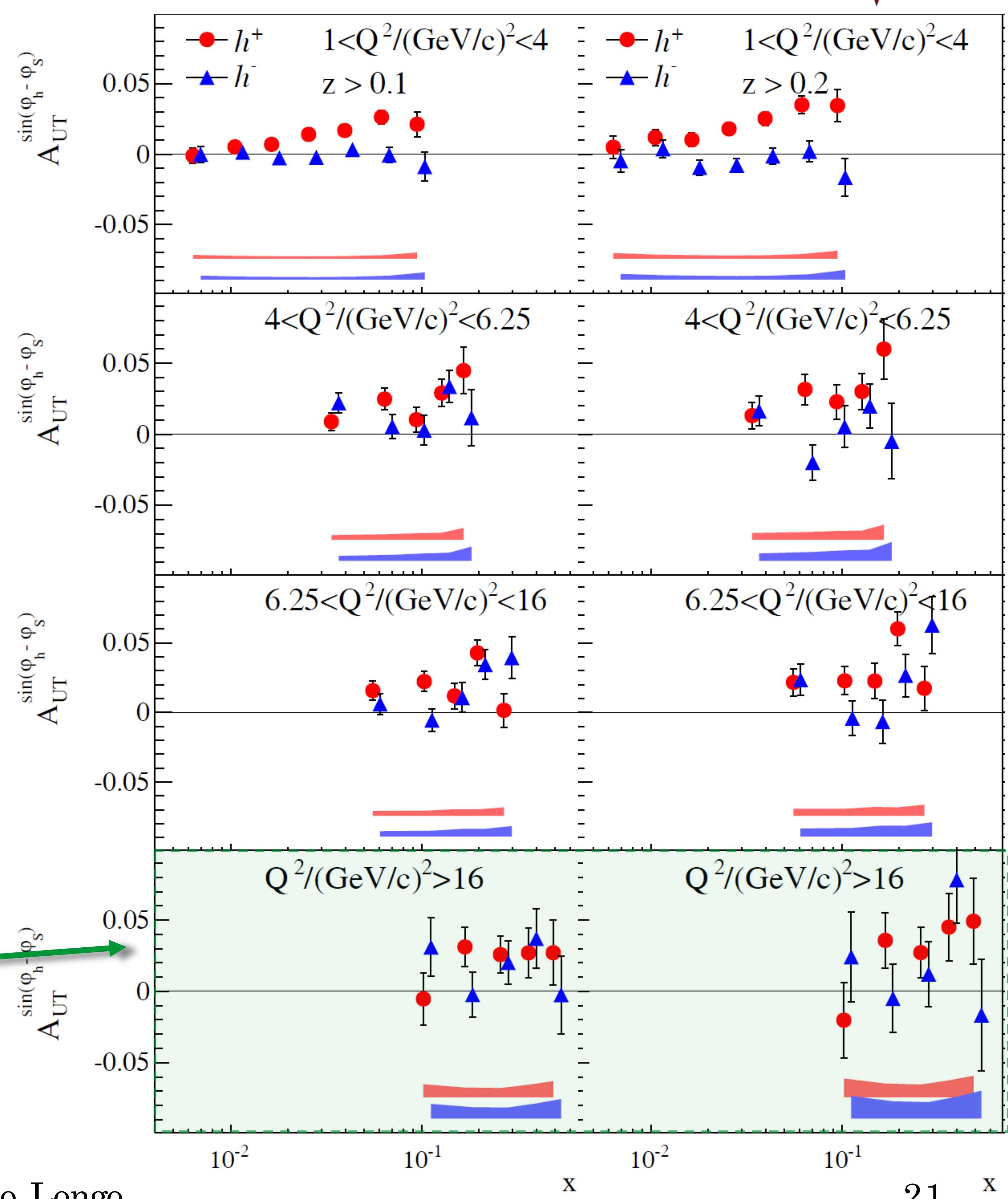
- Beyond J/ψ and ψ' peak.
- Low background and just in the region $16 < Q^2/(GeV/c^2) < 25$
- Valence quark region ➔ Larger asymmetries! But …
- Low cross-section



SIDIS results in DY ranges

B.Parsamyan (OBO COMPASS), Transversity-2014 conference, arXiv:1411.1568 [hep-ex]





- COMPASS Proton 2010 data sample divided into the 4 Q^2 DY ranges.
- Sivers asymmetry extracted for each Q^2 range, using two different z-ranges
- Results for the Sivers asymmetry in DY High mass range in SIDIS are already available!
- Only DY part of the puzzle is missing.

SIDIS results in DY ranges

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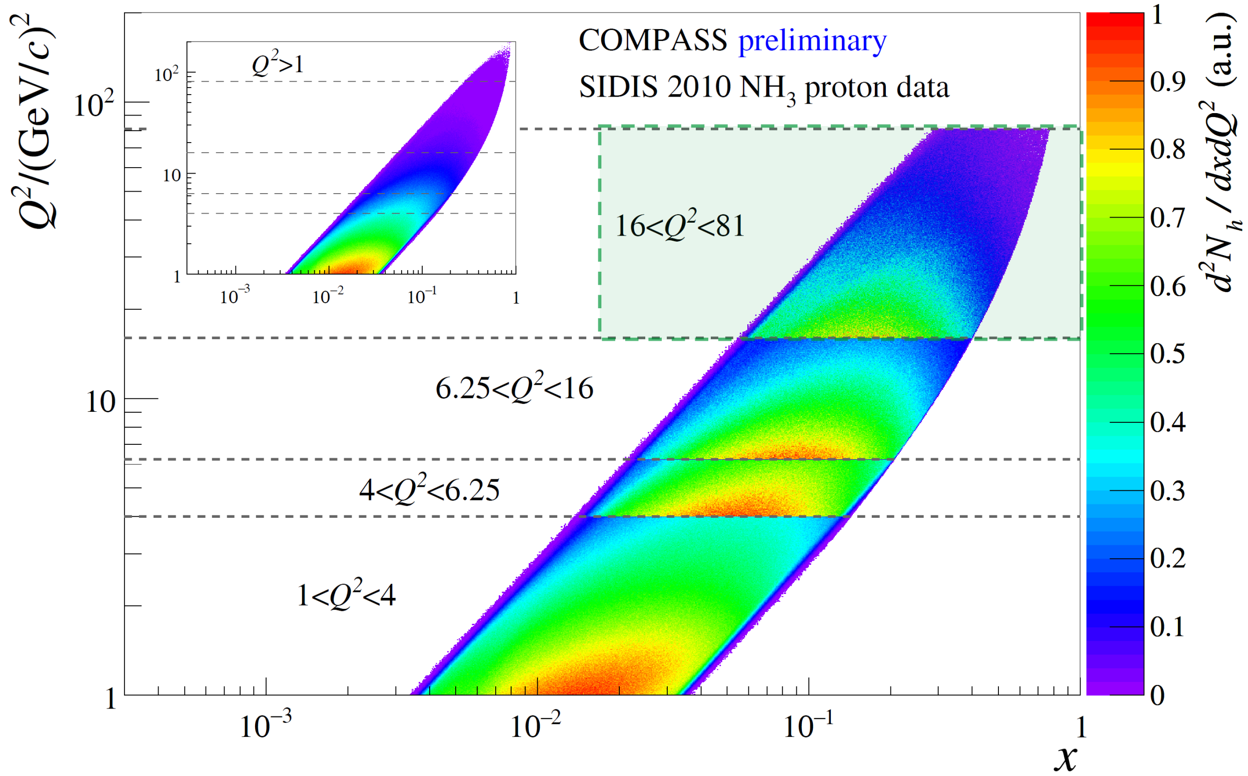

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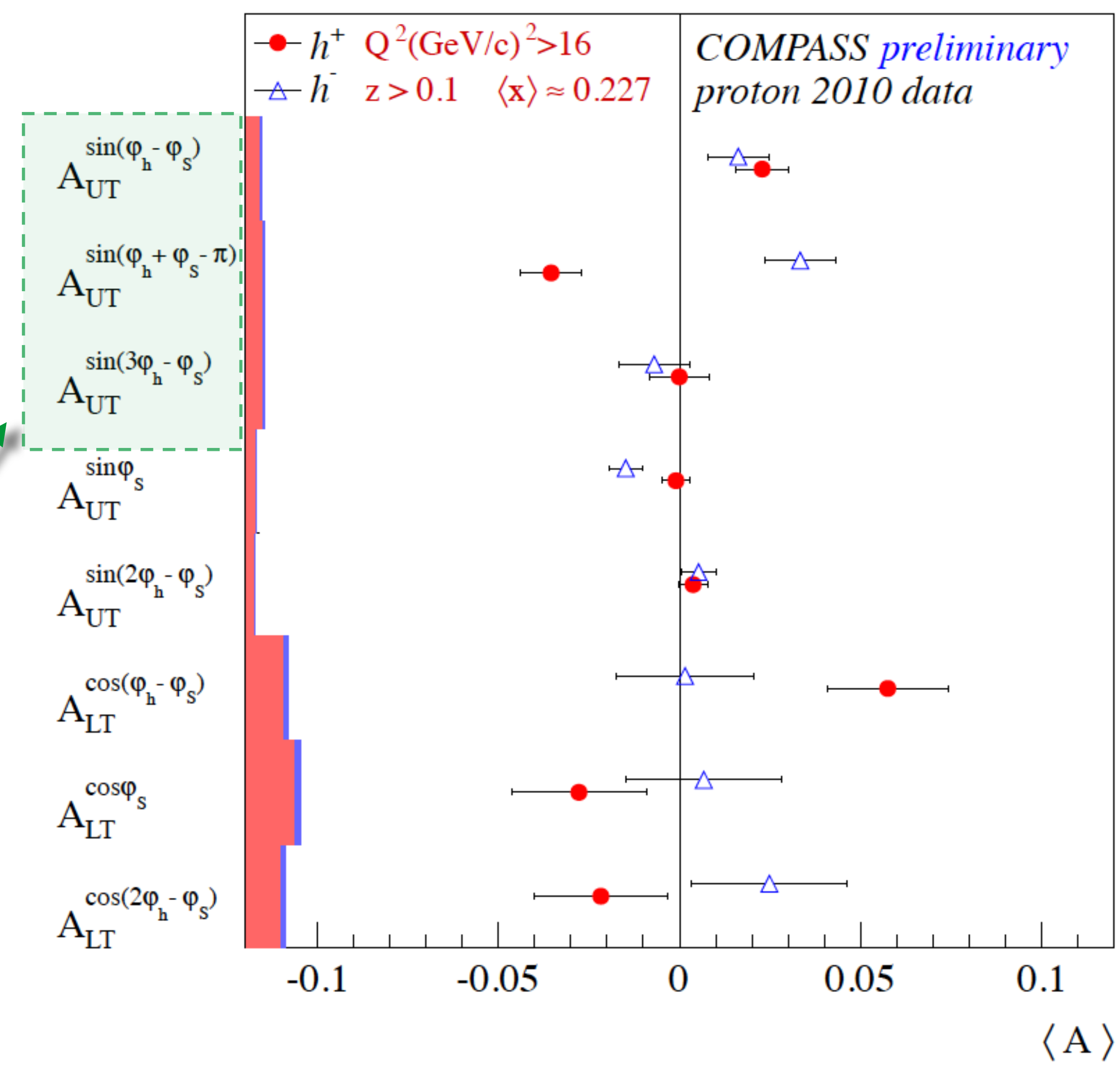
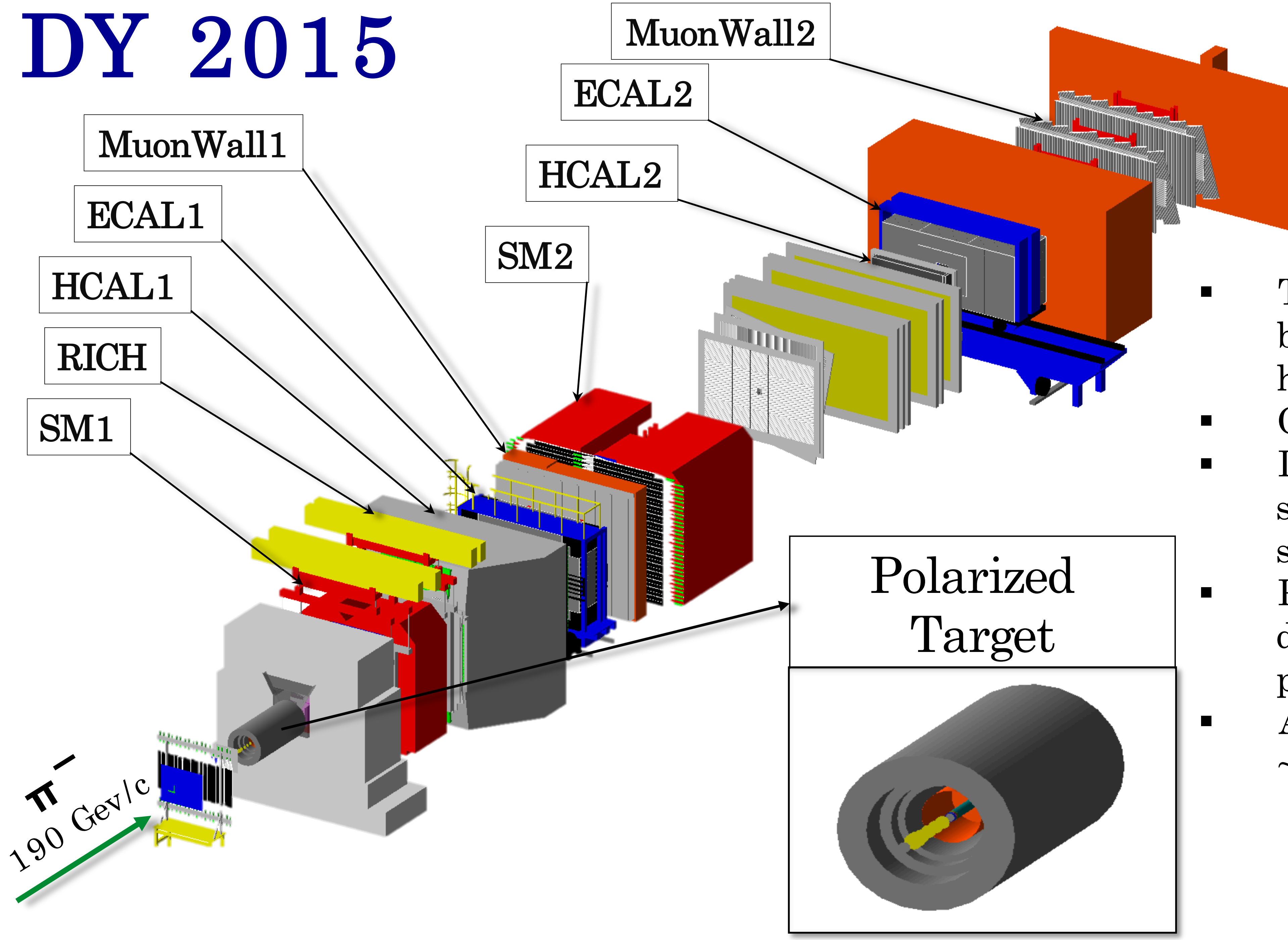


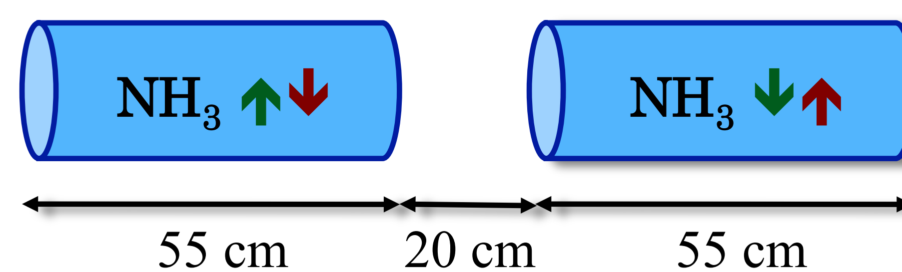
COMPASS experimental setup: DY 2015



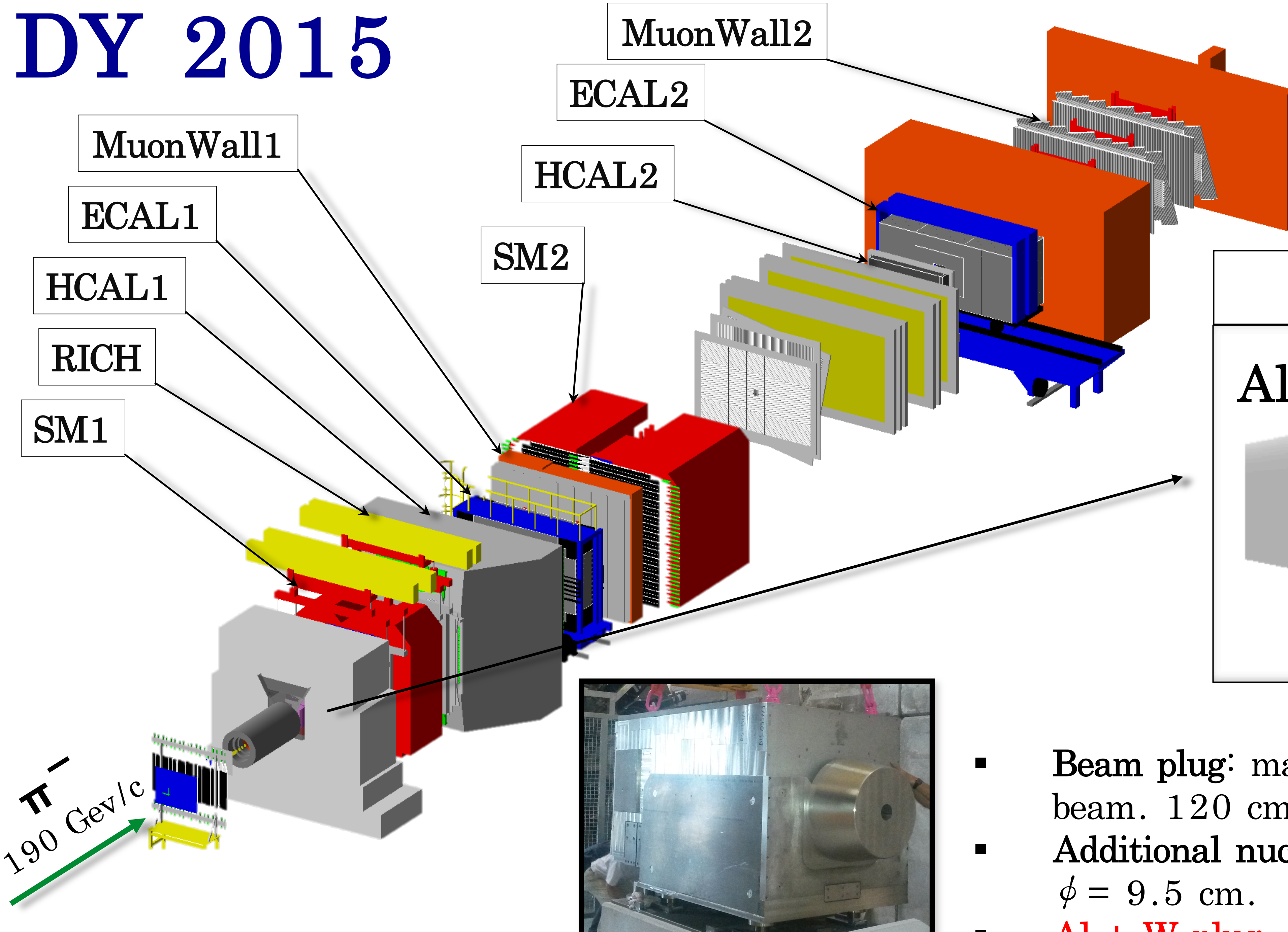
- Target material: ammonia beads immersed into liquid helium.
- Oppositely polarized cells.
- Data are collected simultaneously for both target spin orientation.
- Polarization reversal each 7 days, which allows to reduce possible systematics.
- Average polarization per cell ~ 80 %.

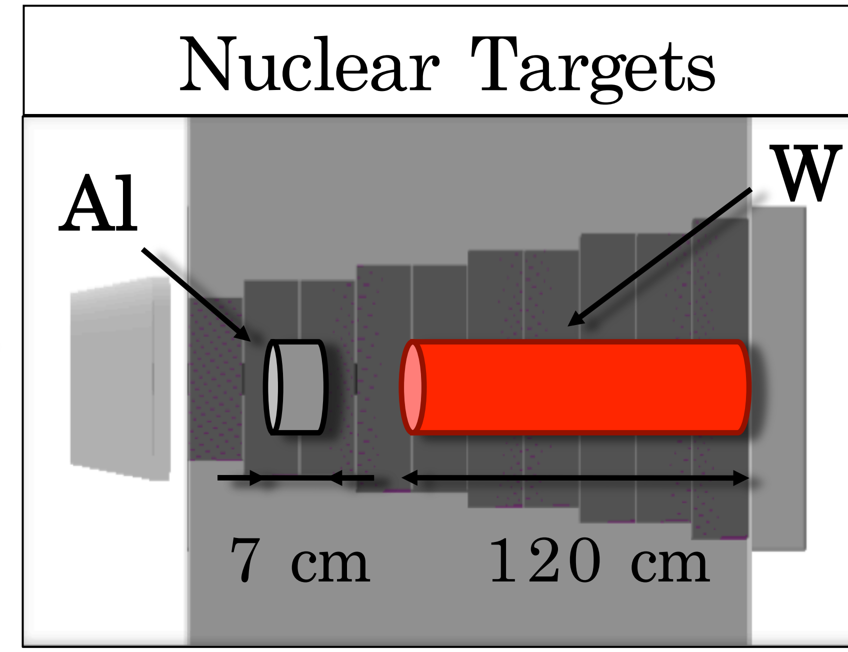
Setup for DY, $\pi^- + p^\uparrow \longrightarrow \mu^+\mu^- + X$

- Polarized Target



COMPASS experimental setup: DY 2015



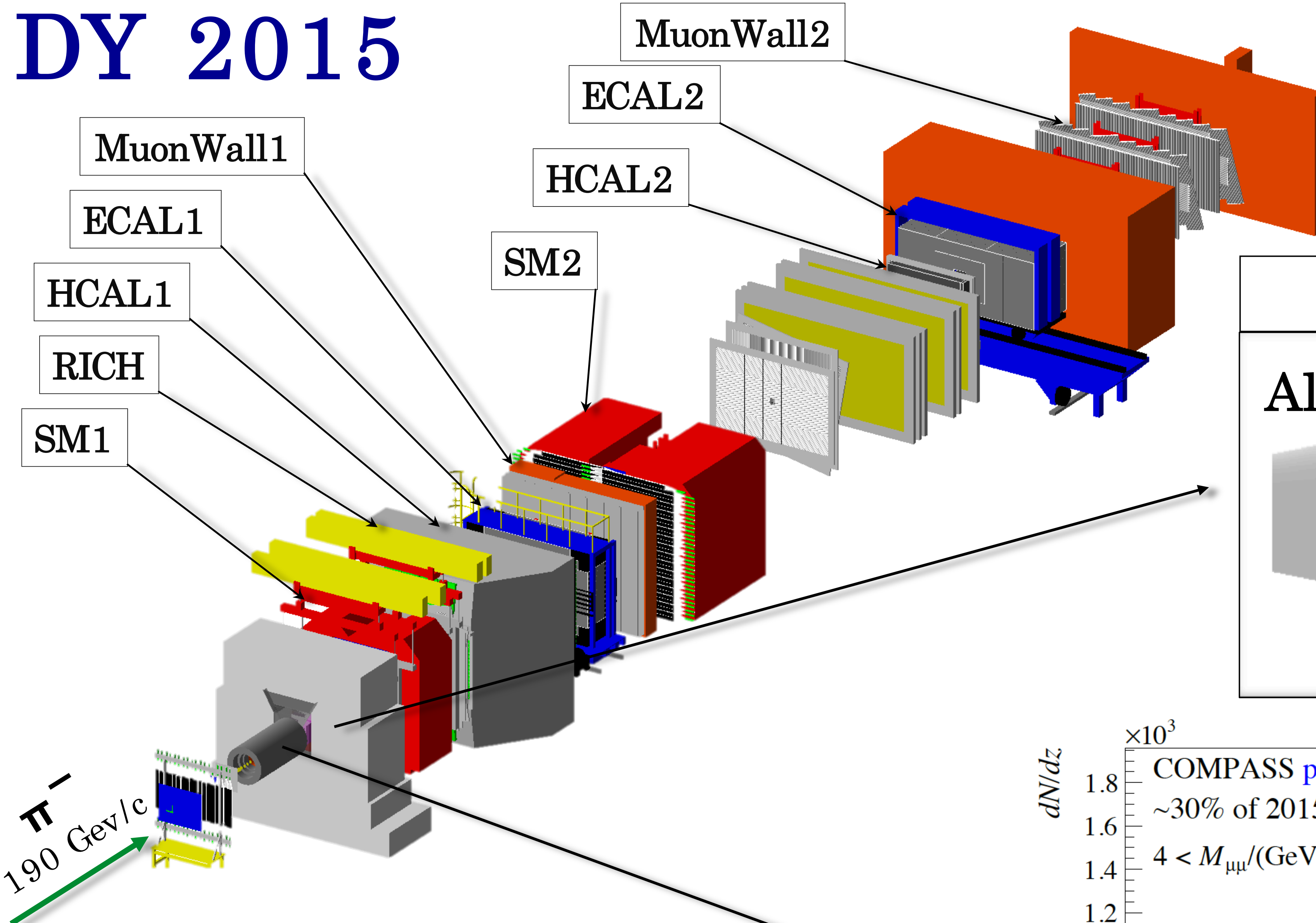


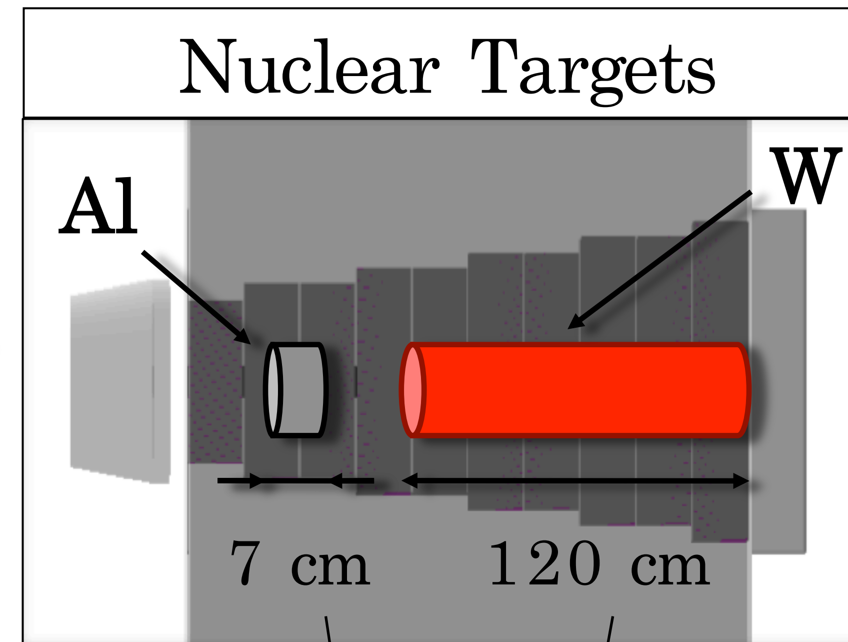
Setup for DY, $\pi^- + p^\uparrow \longrightarrow \mu^+\mu^- + X$

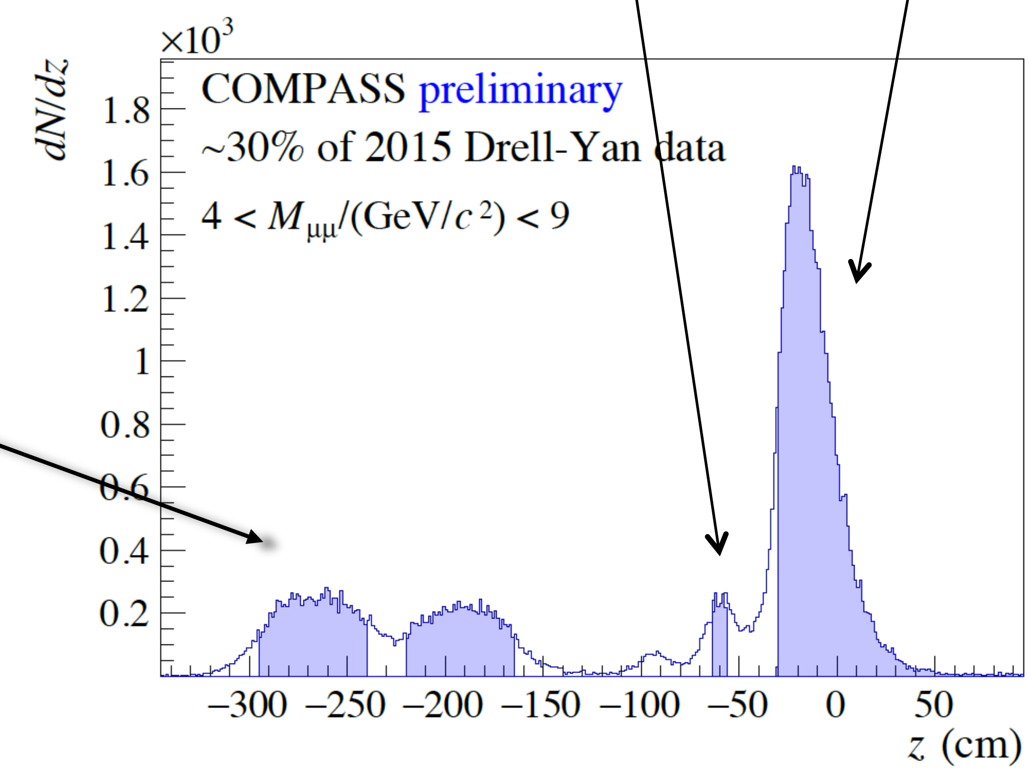
- Polarized Target
- Hadron Absorber
- Nuclear Targets

- **Beam plug**: made of tungsten, to stop the beam. 120 cm long, $\phi = 9.5 - 8.5$ cm.
- **Additional nuclear target**: Al, 7 cm long, $\phi = 9.5$ cm.
- Al + W plug → along with NH_3 are another source for unpolarized DY data.
- Higher yield due to density of the materials.
- Lower reconstruction and vertex resolution with respect to NH_3

COMPASS experimental setup: DY 2015



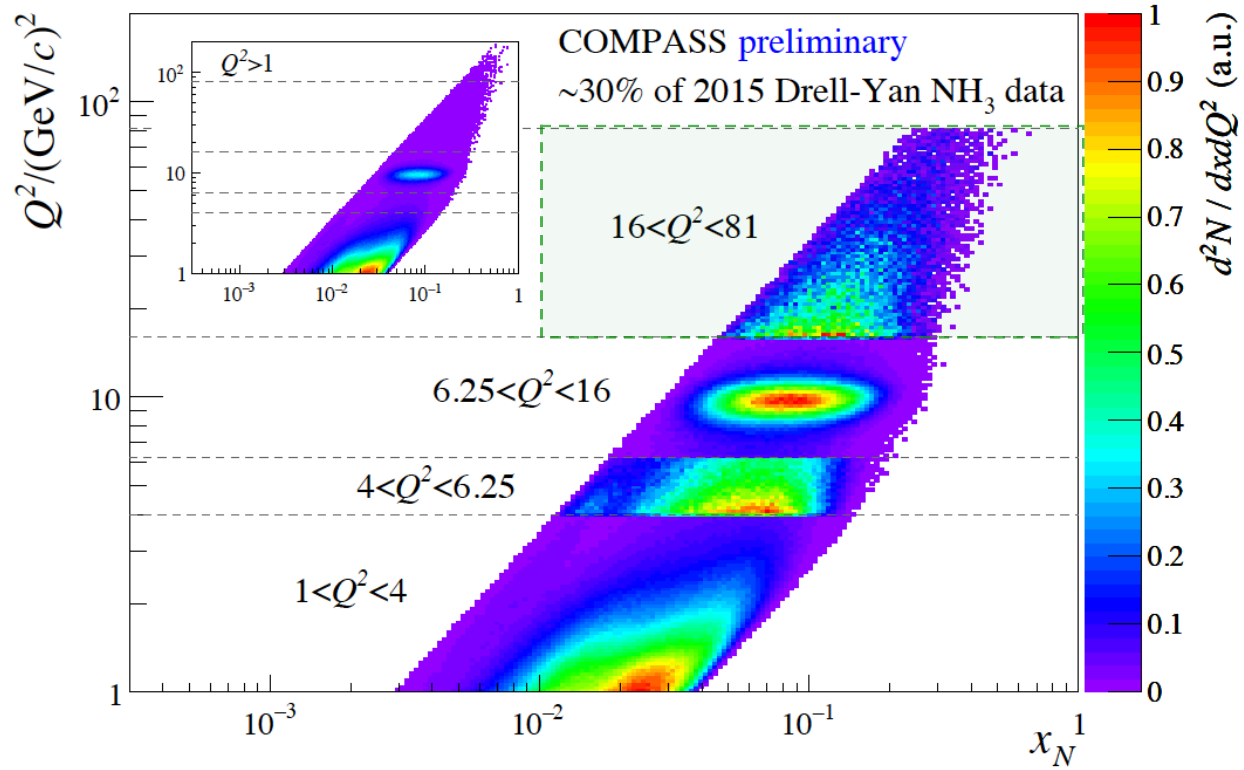


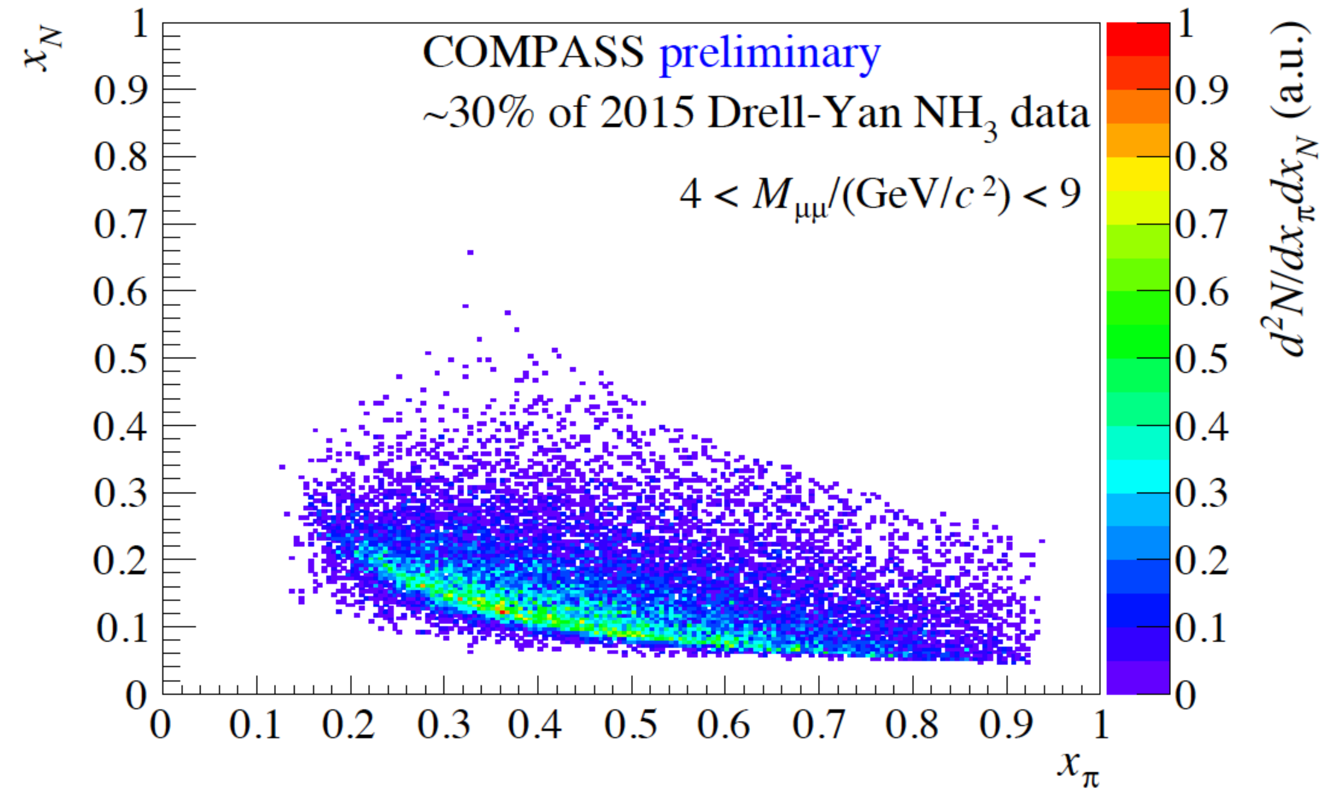


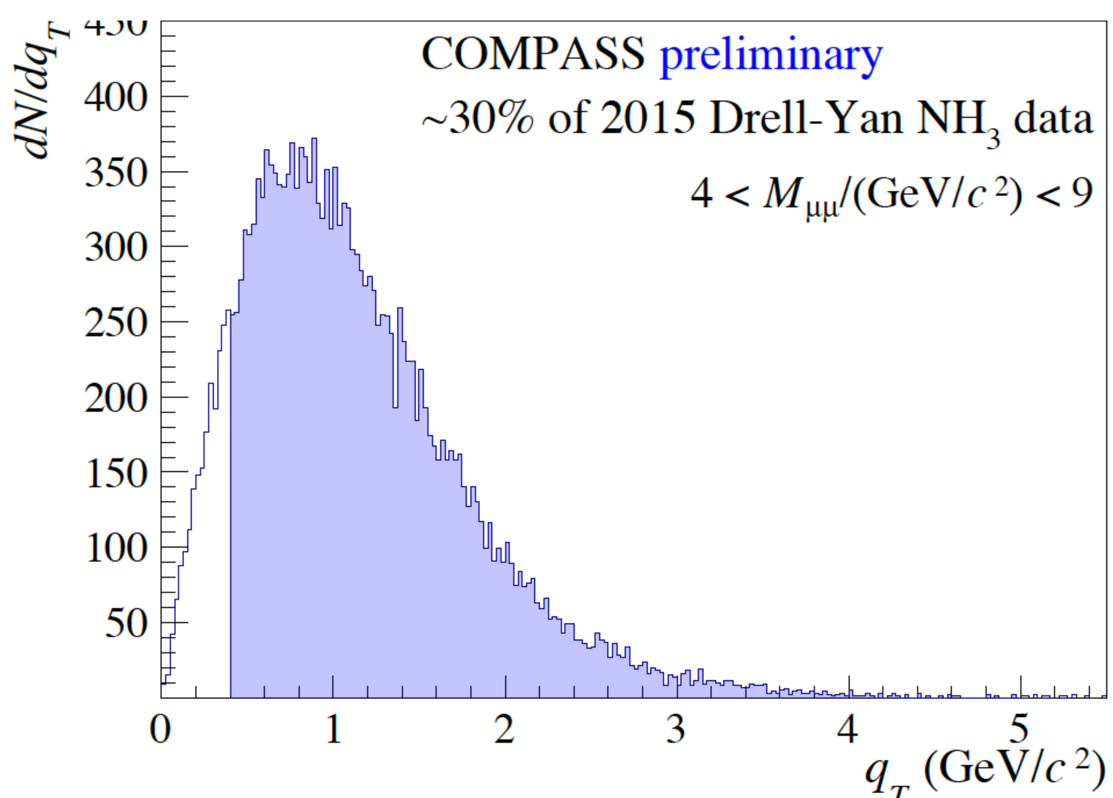
Setup for DY, $\pi^- + p^{\uparrow} \longrightarrow \mu^+\mu^- + X$

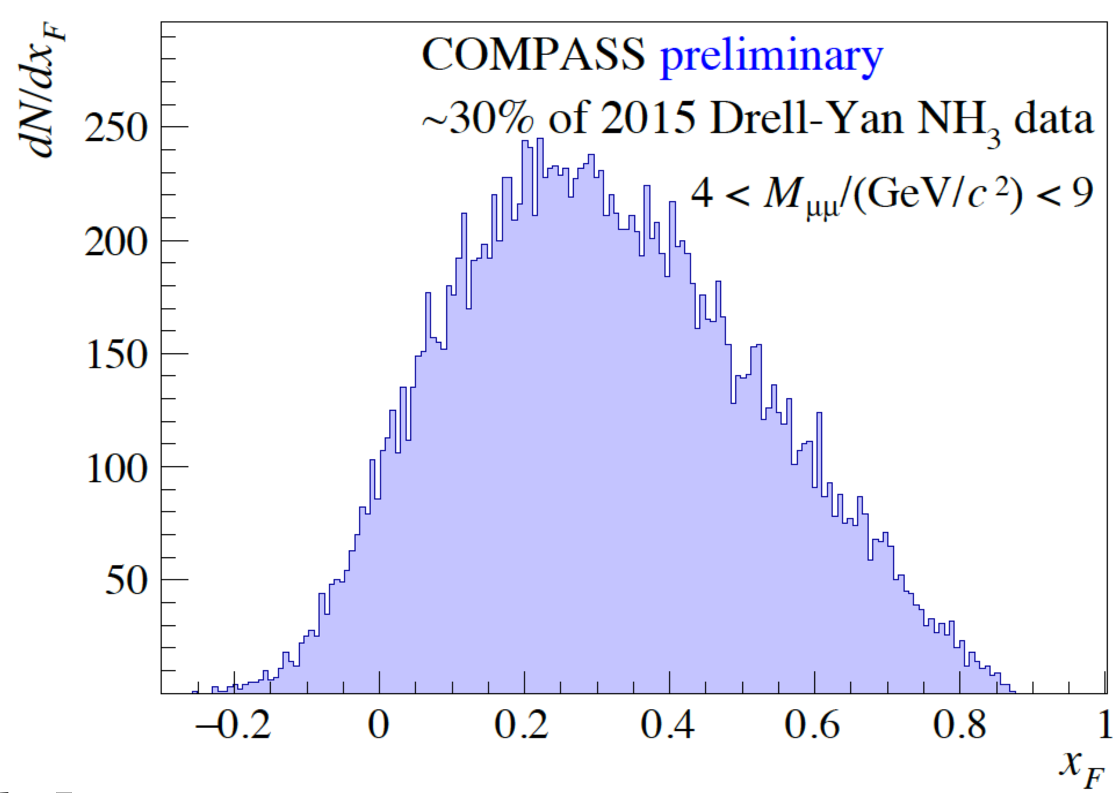
- Polarized Target
- Hadron Absorber
- Nuclear Targets

COMPASS DY run 2015 kinematics: x_π , x_N, x_F and q_T



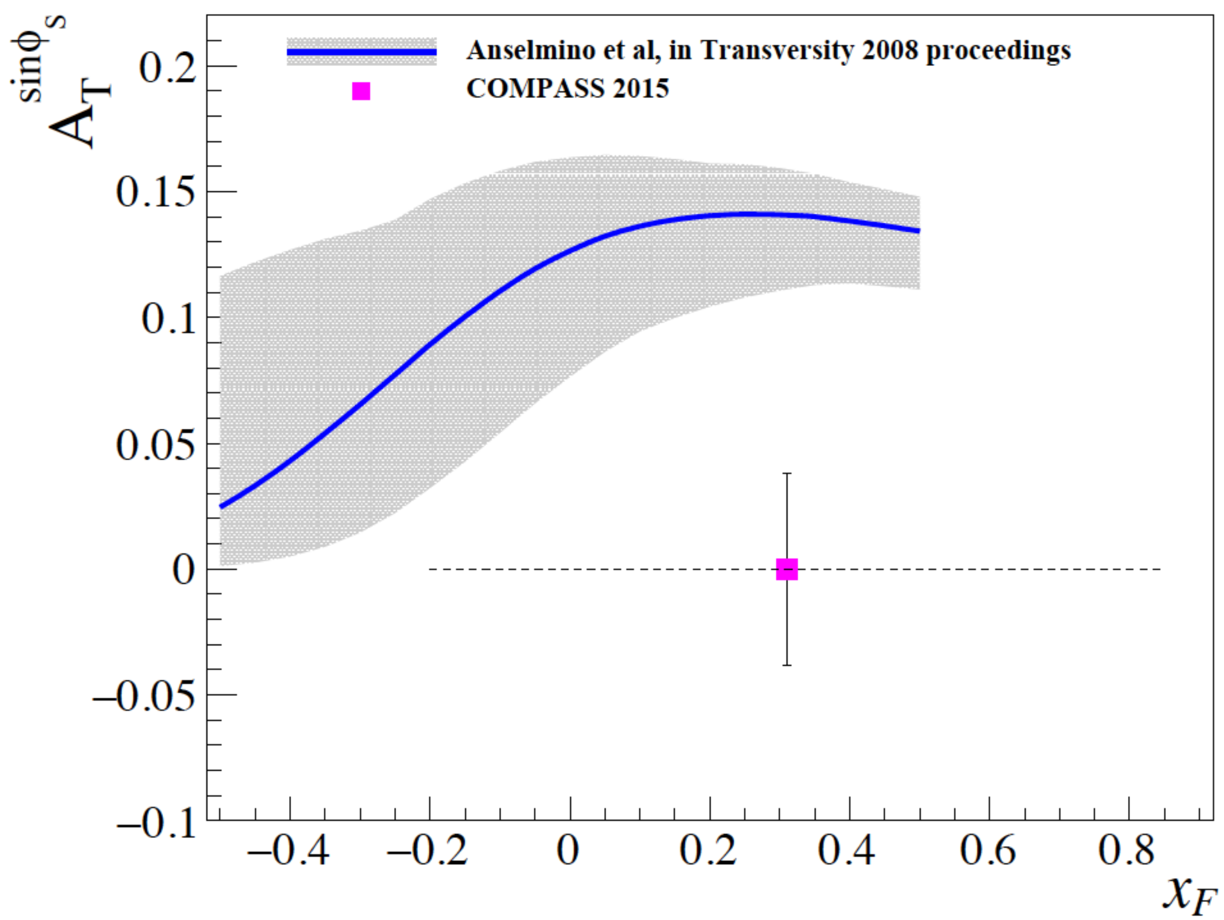




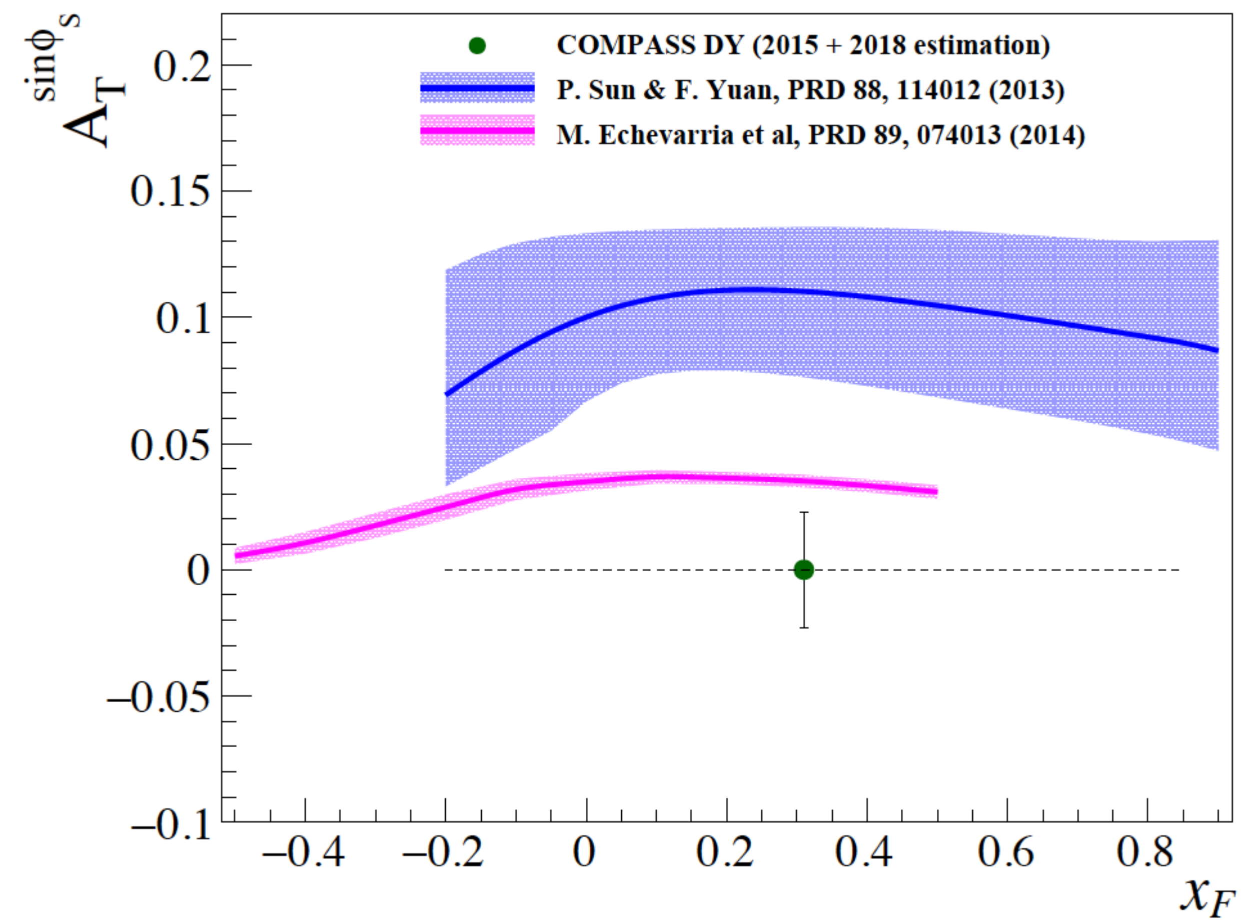


Expected accuracy

- After 2015 DY run, COMPASS expected accuracy for Sivers asymmetry was updated;



Estimated accuracy for COMPASS DY-Run of 2015



Estimated accuracy for COMPASS DY-Run of 2015+2018

- There is a variety of models giving largely spread theoretical predictions.
- Experimental data are the necessary input to constrain the models

Conclusions

- The DY and SIDIS process are complementary ways to access TMD PDFs.
- The COMPASS Collaboration took a considerable amount of SIDIS data during the Phase I.
- The experiment has taken the first ever polarized DY data in 2015.
- **COMPASS is the first experiment that has measured both SIDIS and polarized DY using essentially the same spectrometer!**
    - Cross SIDIS-DY studies are already available.
    - Exploration of the same x:Q^2 phase space both in SIDIS and DY.
    - **First opportunity to test TMD universality and the sign change between SIDIS and DY for Sivers and Boer-Mulders PDFs.**
- **Analysises are running, new results will be available soon!**

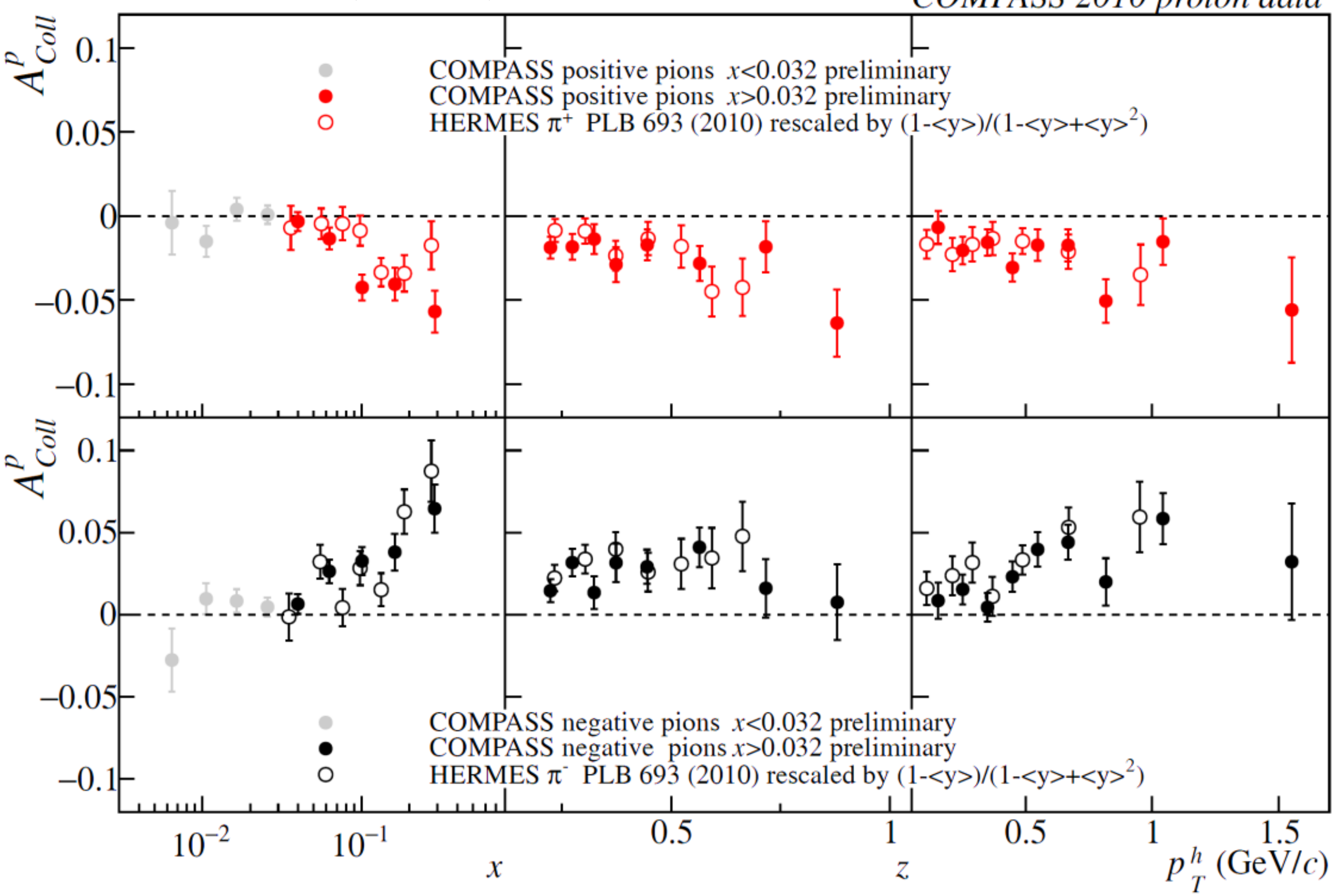
Thank you!

ευχαριστίες!

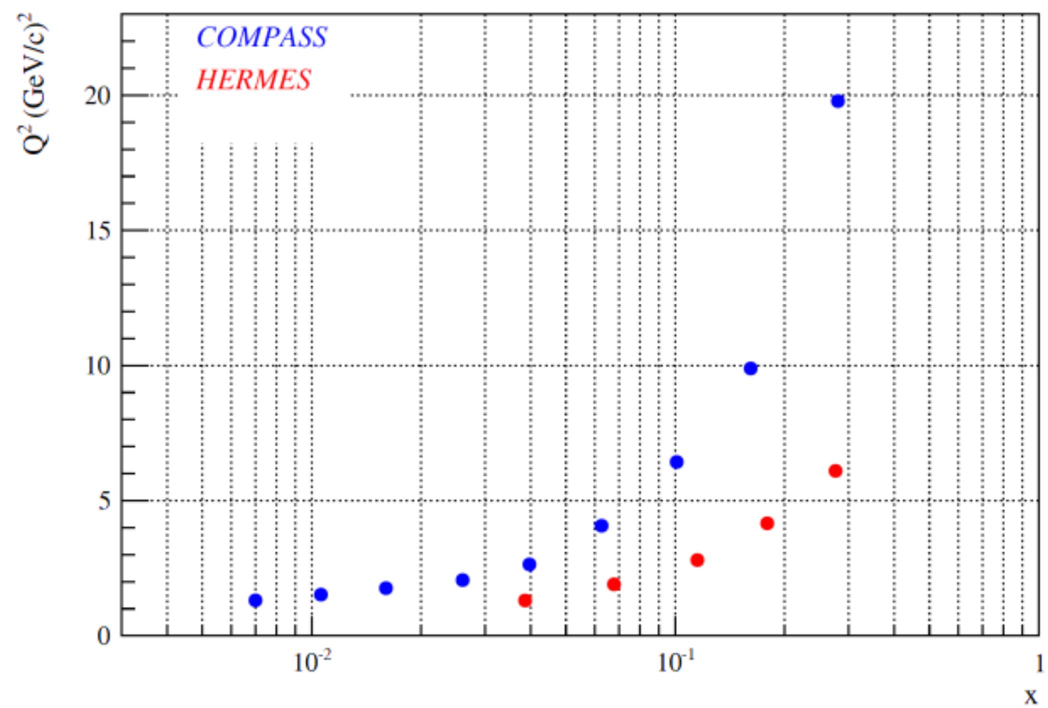
Spare Slides

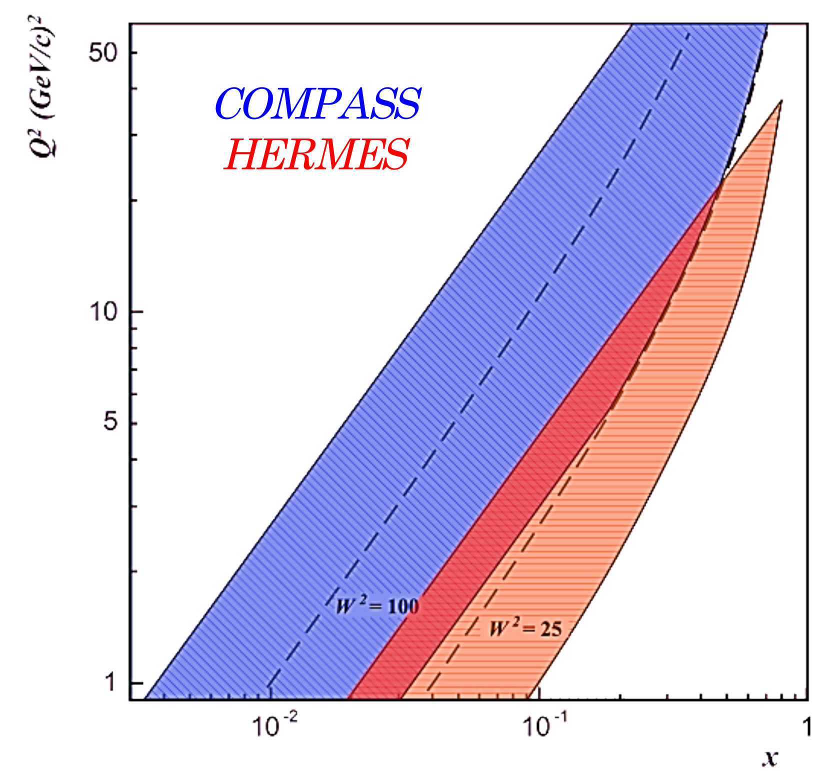
COMPASS SIDIS results: Collins

PLB 744 (2015) 250



$$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$$



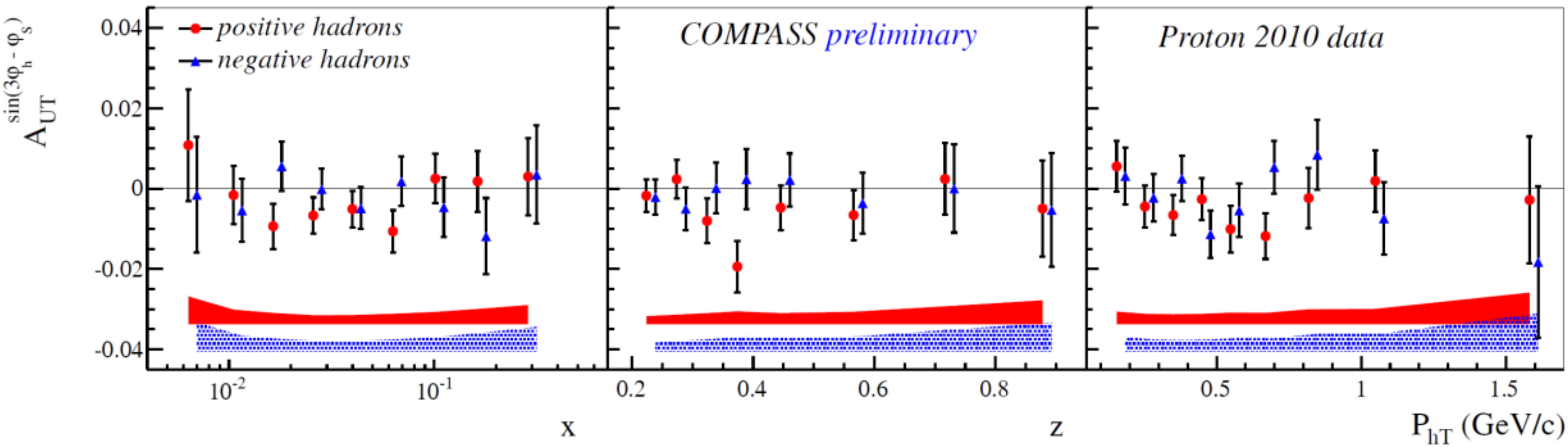


- Collins asymmetry : COMPASS proton vs Hermes proton.
- Clear effect at large x.
- Collins amplitudes for π^+ and π^- are mirror symmetric (favoured unfavoured Collins FF).
- Even taking into account **different Q² coverage** of the experiments, asymmetries appeared to be **compatible**.

COMPASS SIDIS results: Pretzelosity

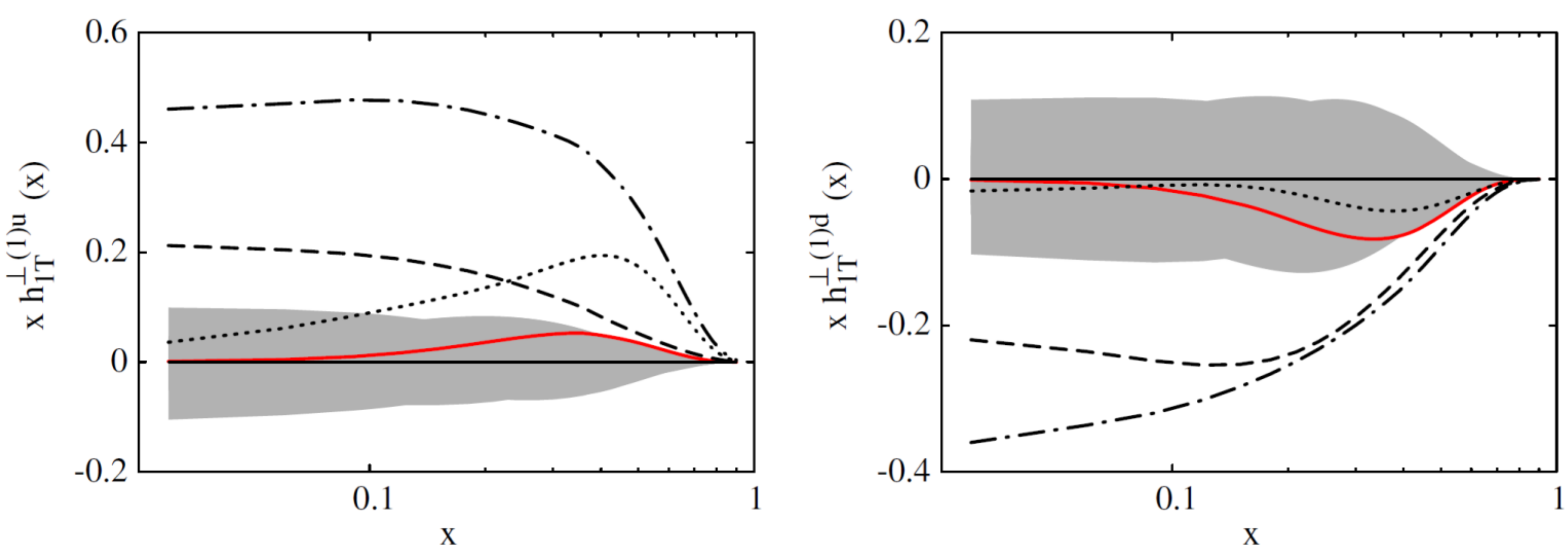
B.Parsamyan, PoS DIS2013 (2013), 2013

$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$



- Asymmetry is small and compatible with zero within statistical accuracy;
- It still can provide some information about the PDF;

Ch. Lefky, A. Prokudin Phys.Rev. D91 (2015) 034010



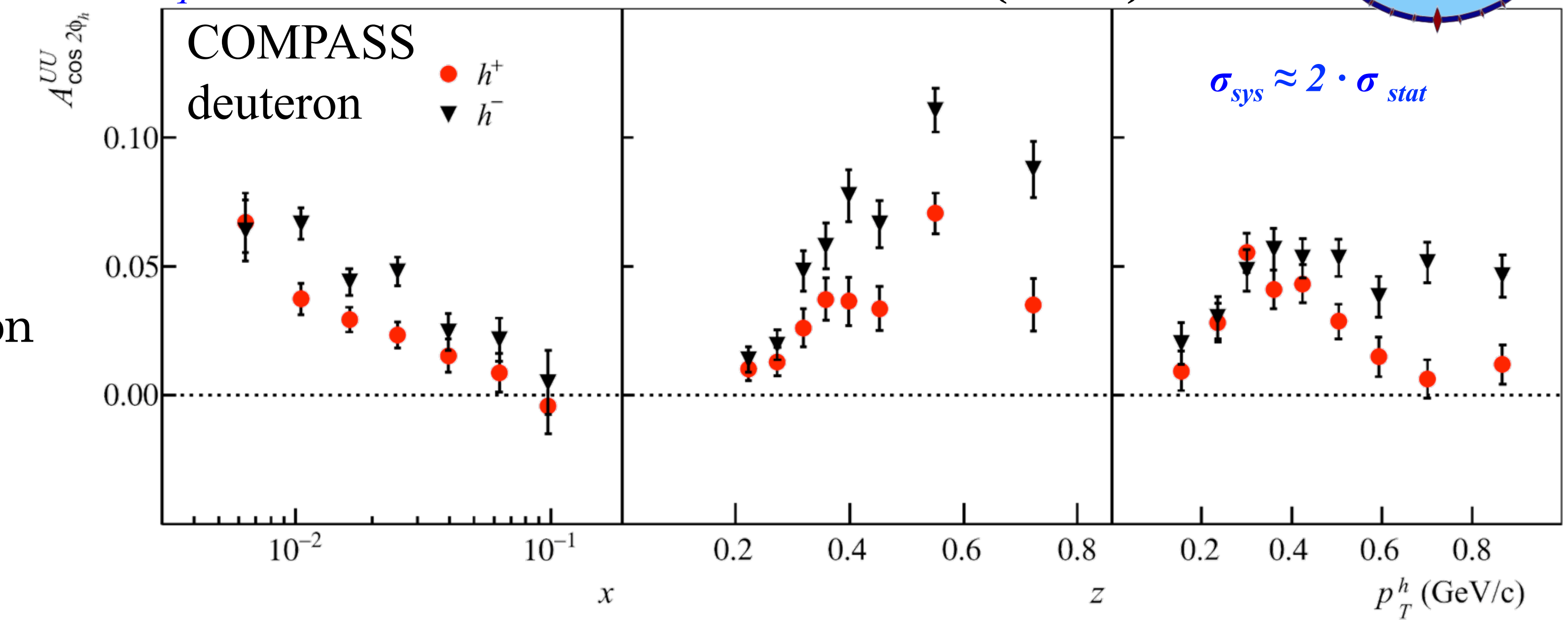
COMPASS SIDIS results: BM

Boer-Mulders effect + "twist-4" Cahn effect

$$A_{UU}^{\cos 2\phi_h} \propto -h_1^{\perp q} \otimes H_{1q}^{\perp h} + \left(\frac{M}{Q}\right)^2 f_1^q \otimes D_{1q}^h + ...$$

NPB 886 (2014) 1046

- Large positive amplitudes decreasing with x for both h^+/h^-.
- Clear differences between h^+/h^-
- Slightly larger amplitude for h^-
- Similarity between proton and deuteron results for $A_{UU}^{\cos 2\phi_h}$ has been previously observed at HERMES collaboration.



COMPASS SIDIS results: BM

Boer-Mulders effect + 2"twist-4" Cahn effect

$$A_{UU}^{\cos 2\phi_h} \propto -h_1^{\perp q} \otimes H_{1q}^{\perp h} + \left(\frac{M}{Q}\right)^2 f_1^q \otimes D_{1q}^h + \ldots$$

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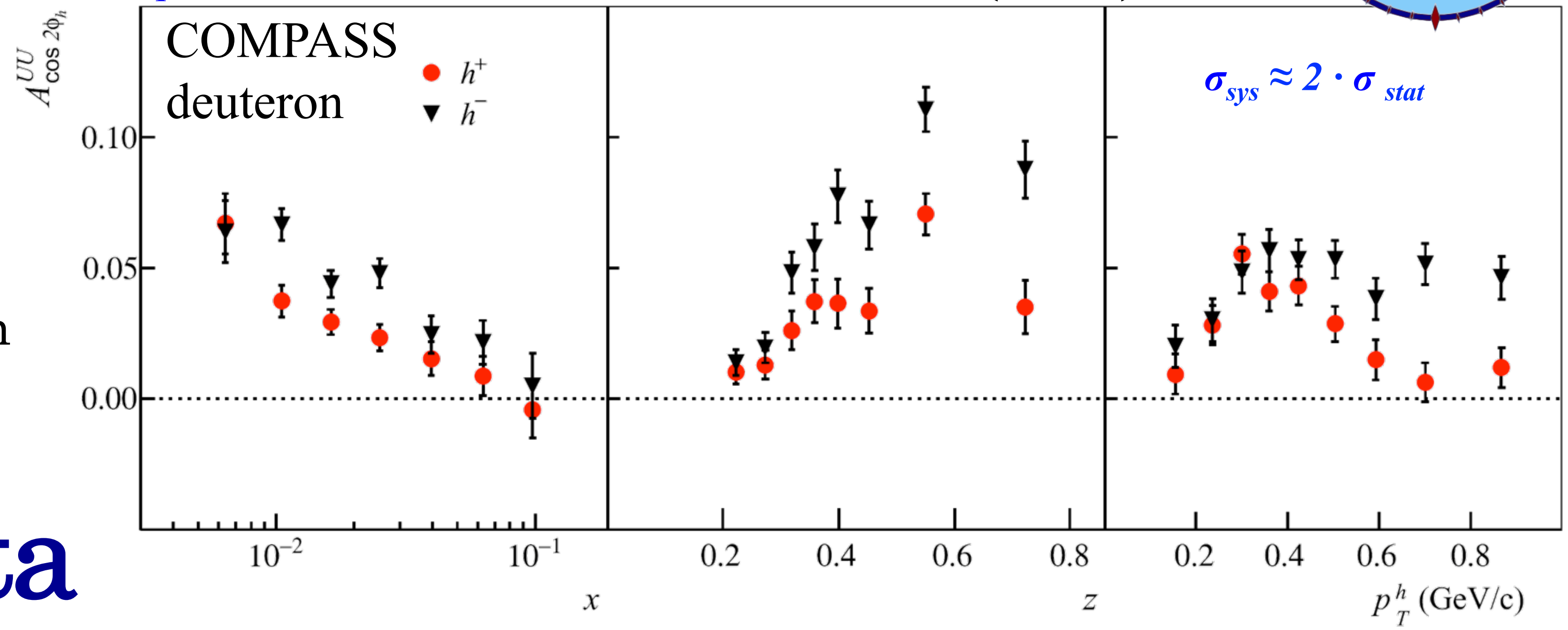
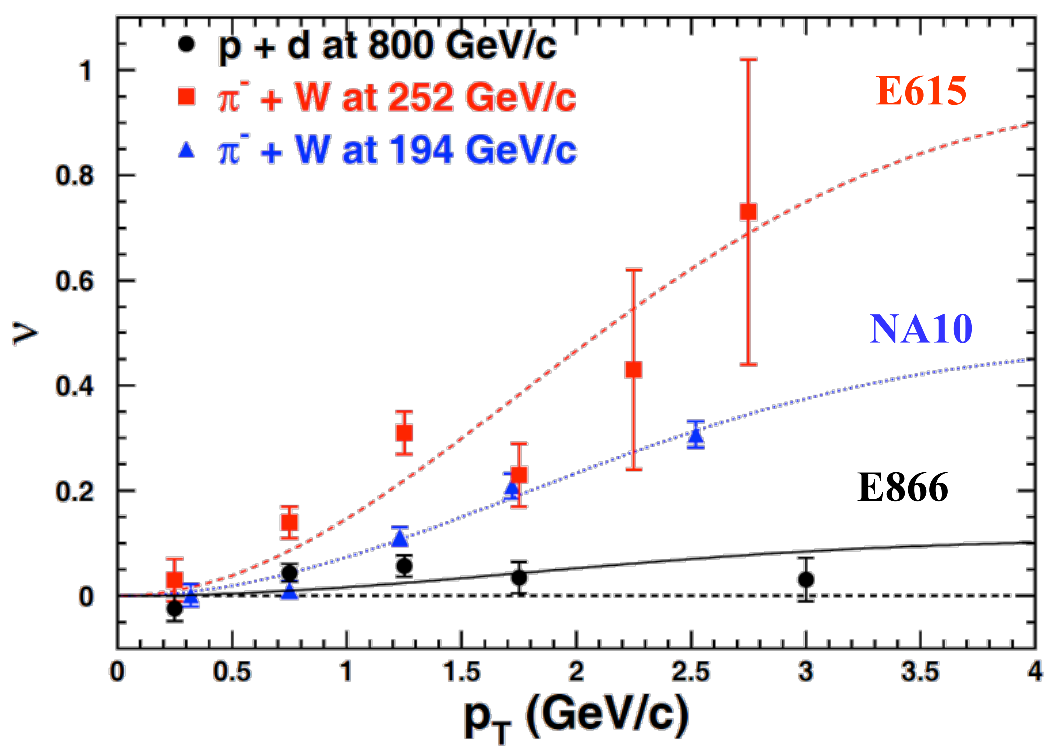


Available DY data

$$\nu = 2A_U^{\cos 2\varphi} \propto h_{1q}^{\perp} \otimes h_{1\bar{q}}^{\perp}$$



- Clear effect in Drell-Yan
- Energy and quark flavour dependence
  - Smaller effect for sea quarks

E866, PRL99, 082301 (2007)

COMPASS SIDIS results: BM

Boer-Mulders effect + 2"twist-4" Cahn effect

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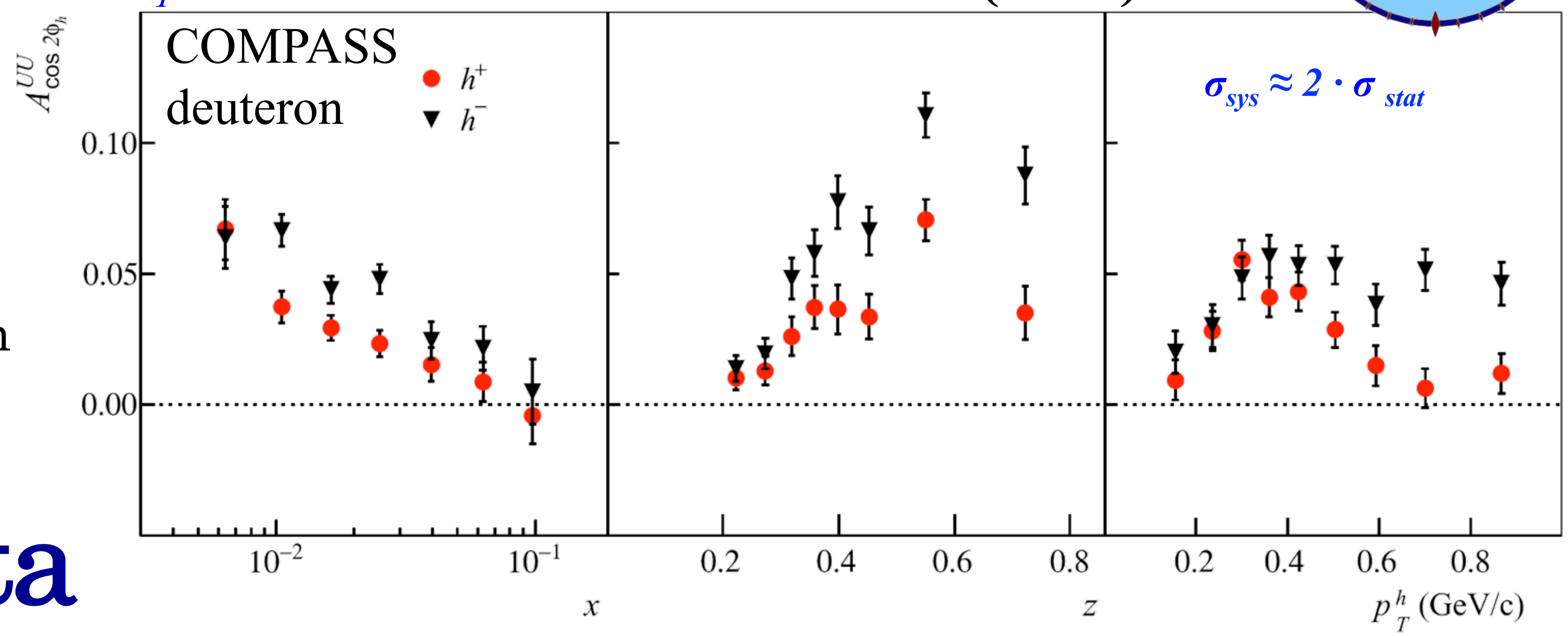
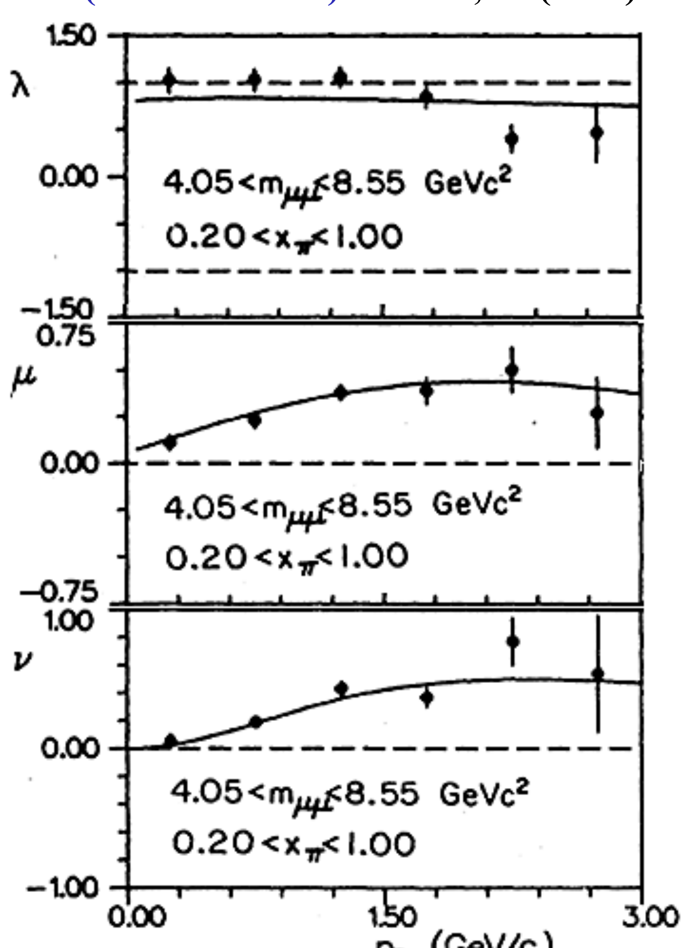
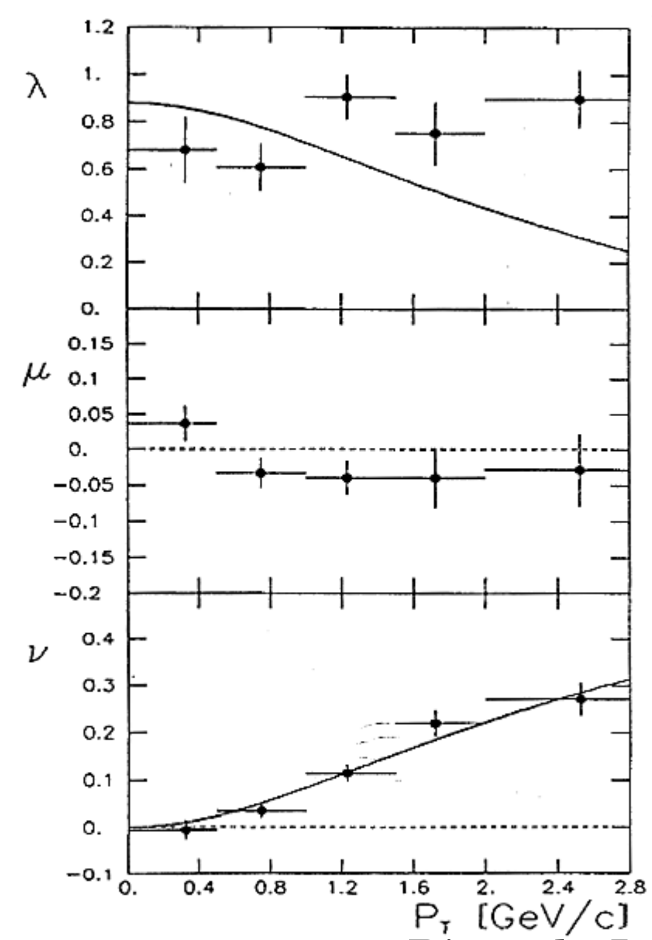


Available DY data

E615 (π^-W 252 GeV) PRD 39, 92 (1989)



NA10 (π^-W 194 GeV) Z.Phys.C 31, 513 (1986)



$$\frac{d\sigma}{d\Omega} \propto \left(1 + \lambda \cos^2\theta + \mu \sin 2\theta \cos\varphi_{CS} + \frac{\nu}{2} \sin^2\theta \cos 2\varphi_{CS}\right)$$

Lam Tung relation (collinear LO pQCD)

$1-\lambda-2\nu = 0 \longrightarrow \lambda=1, \mu=0, \nu=0$

Violation of L-T relation:
Data from E615 (FNAL) and NA10 (CERN) experiments.

COMPASS is collecting higher precision π^-NH_3, π^-W, π^-Al data

COMPASS SIDIS results: BM

Boer-Mulders effect + 2"twist-4" Cahn effect

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NPB 886 (2014) 1046

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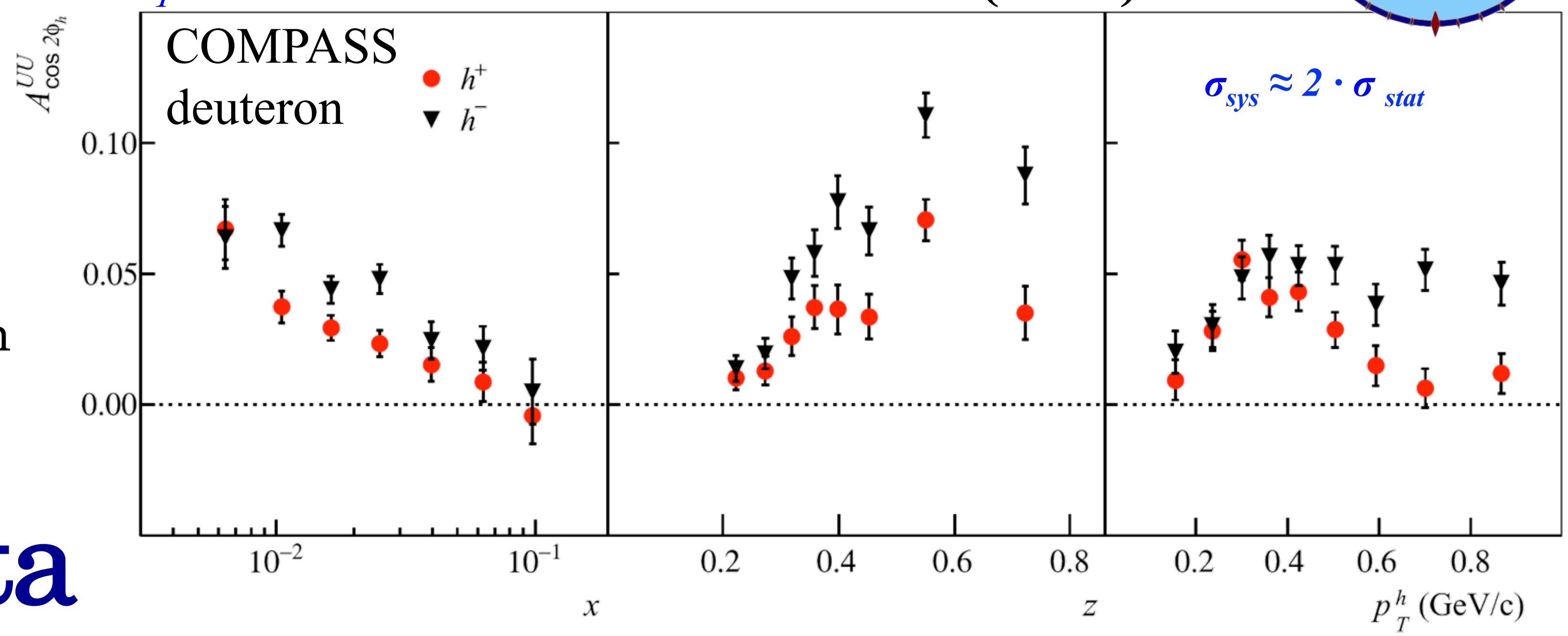

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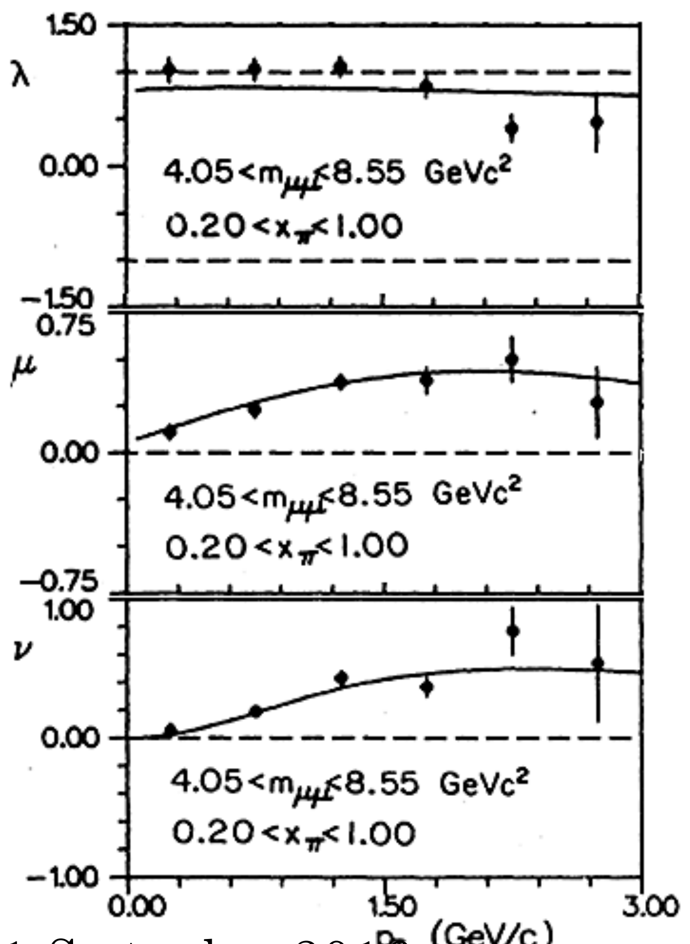

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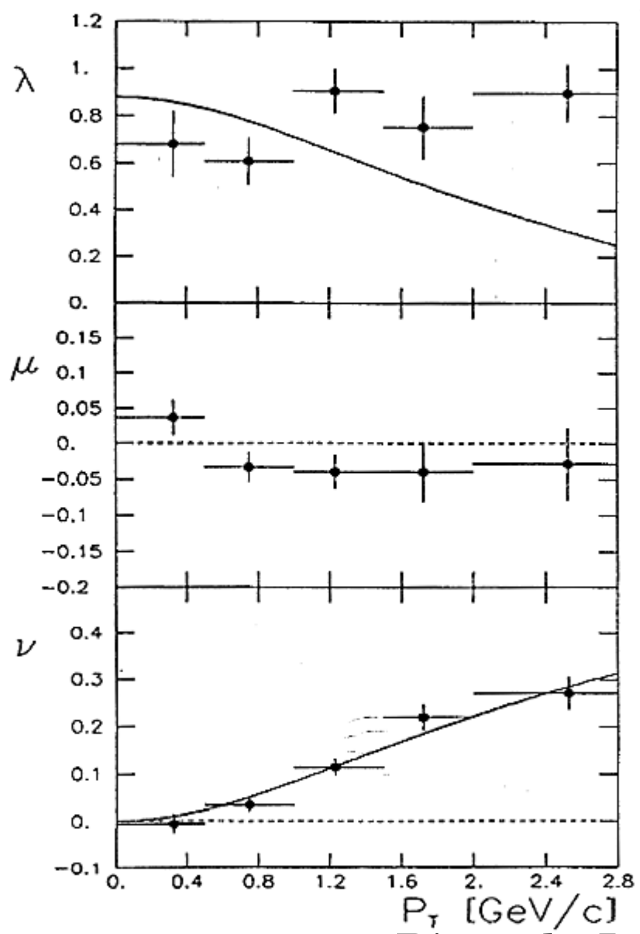

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Lam Tung relation (collinear LO pQCD)

$1 - \lambda - 2\nu = 0 \longrightarrow \lambda = 1, \ \mu = 0, \ \nu = 0$

Boer-Mulders PDF's sign-change between SIDIS and Drell-Yan and deep analysis of the LT-relation violation are one of the main issues addressed by COMPASS.