Pion TMDs analysis at COMPASS and AMBER

an impact study through MAP framework

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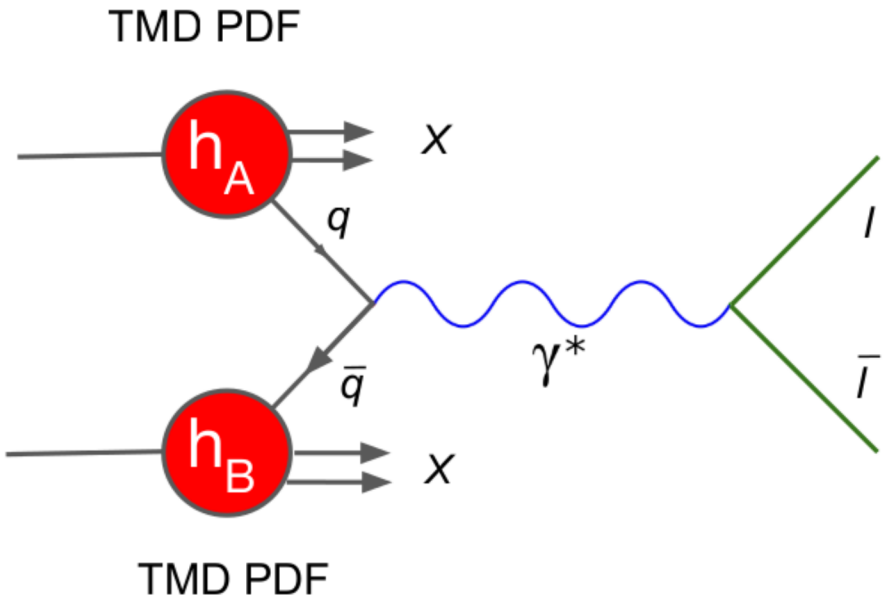
AMBER
Apparatus for Meson and Baryon Experimental Research

REF 2023
Madrid UCM - 27th October

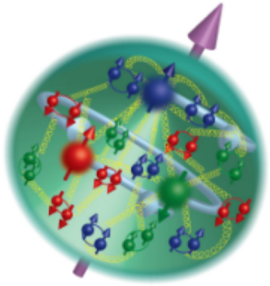
[Outline]

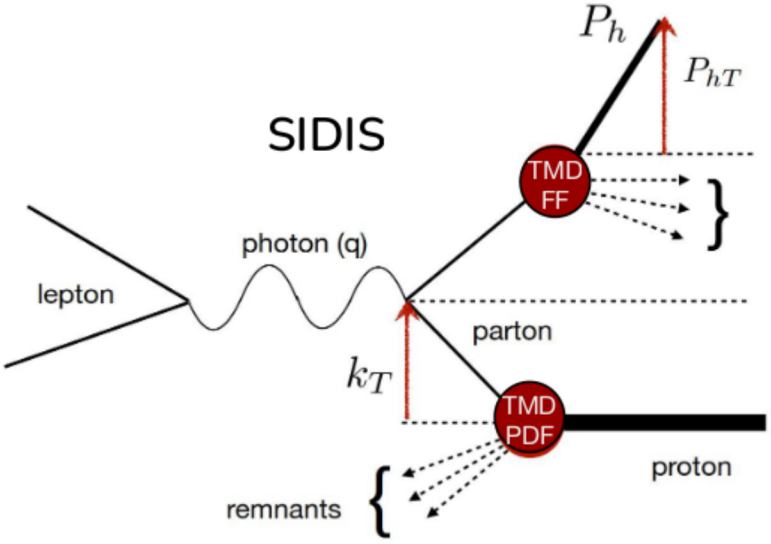
- COMPASS DY program
- impact study for pion TMDs on COMPASS pseudodata using MAP framework
- Future possibilities for meson structure at AMBER

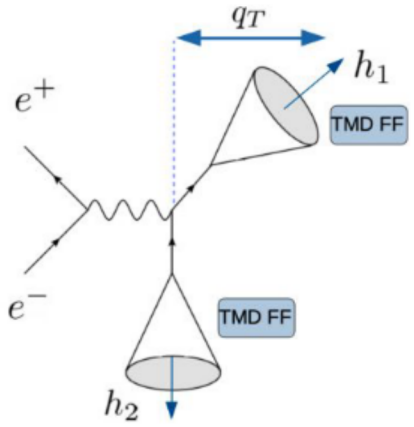
[TMDs in nucleons]



Drell-Yan

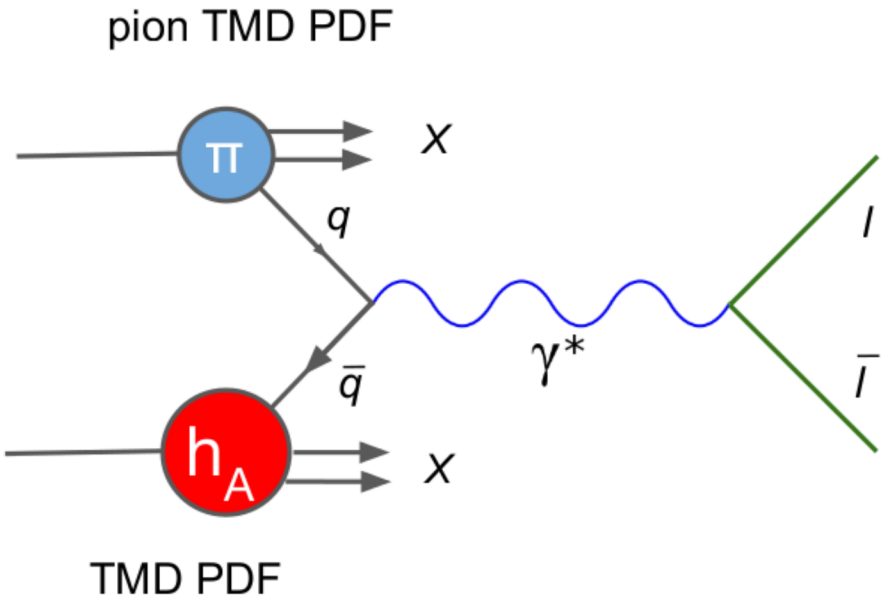


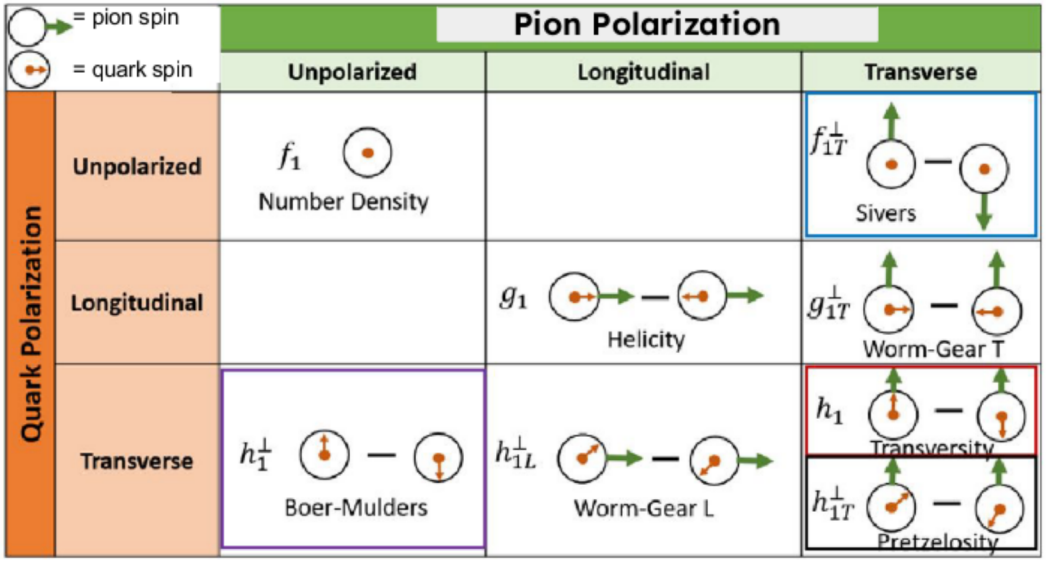




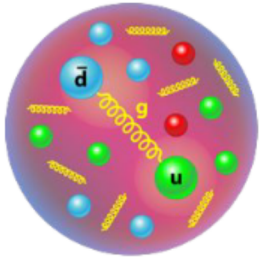
e^+e^- annihilation

[pion TMDs]



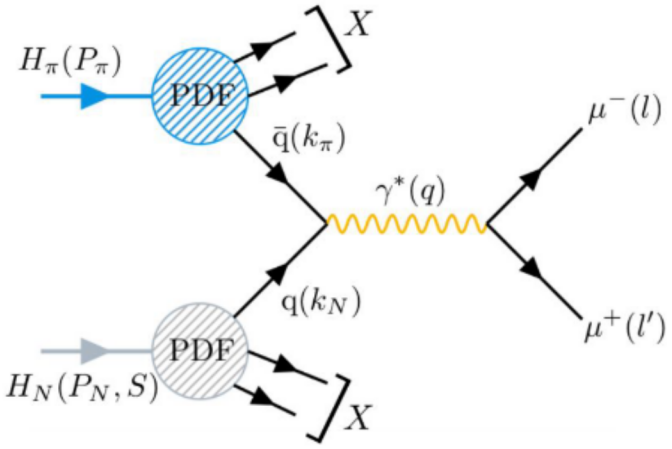


Drell-Yan



[COMPASS setup for DY]

Measured process:

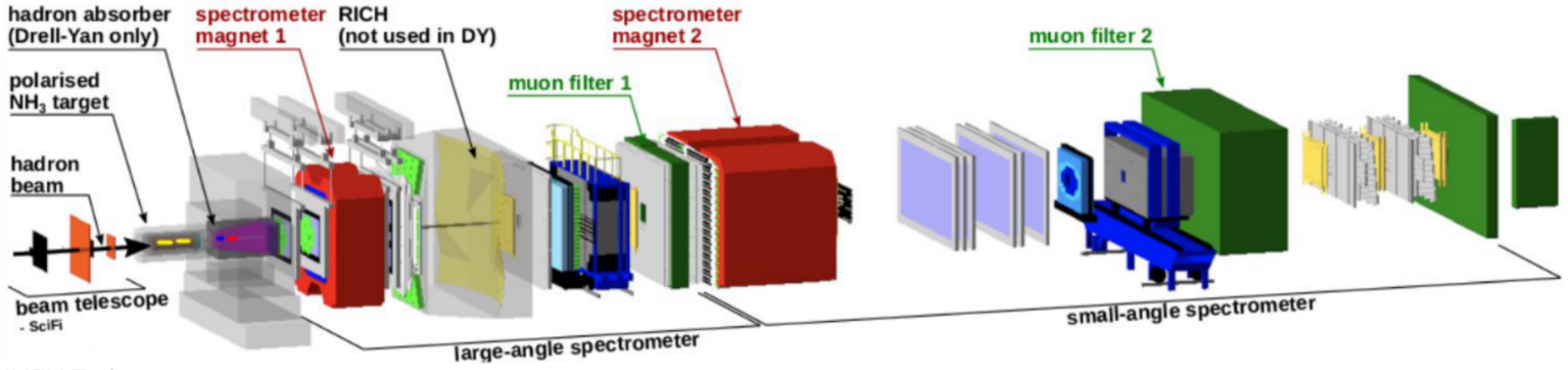


Beam:

- 190 GeV h^- beam
- purity 97% π^-
- intensity ~70 MHz

Key elements:

- 2 x 55cm NH_3 polarised target
- Al and W target (beam plug)
- 2.4m long h absorber
- ~300 tracking planes

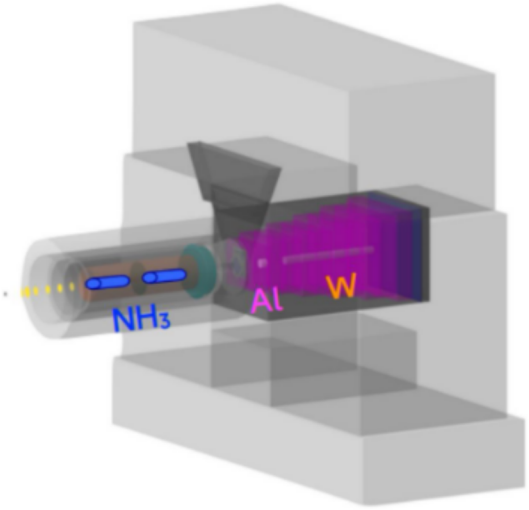


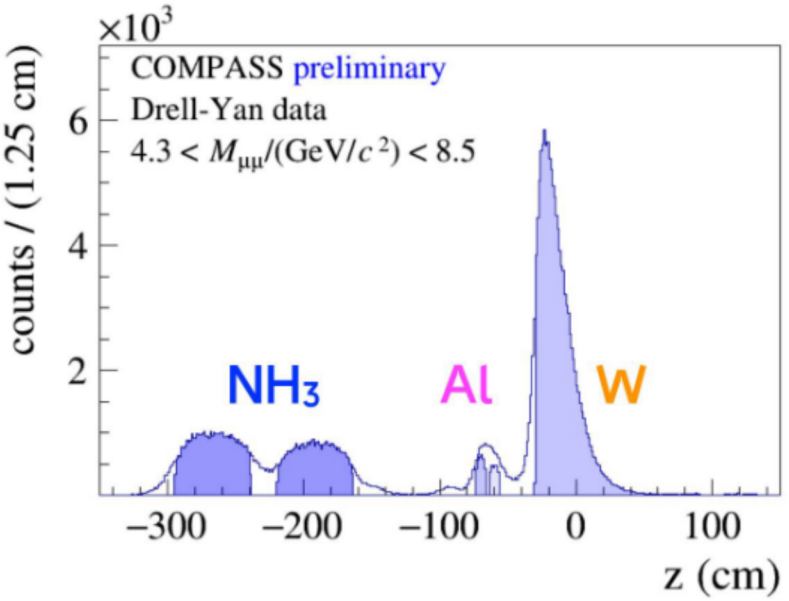
[COMPASS setup for DY]

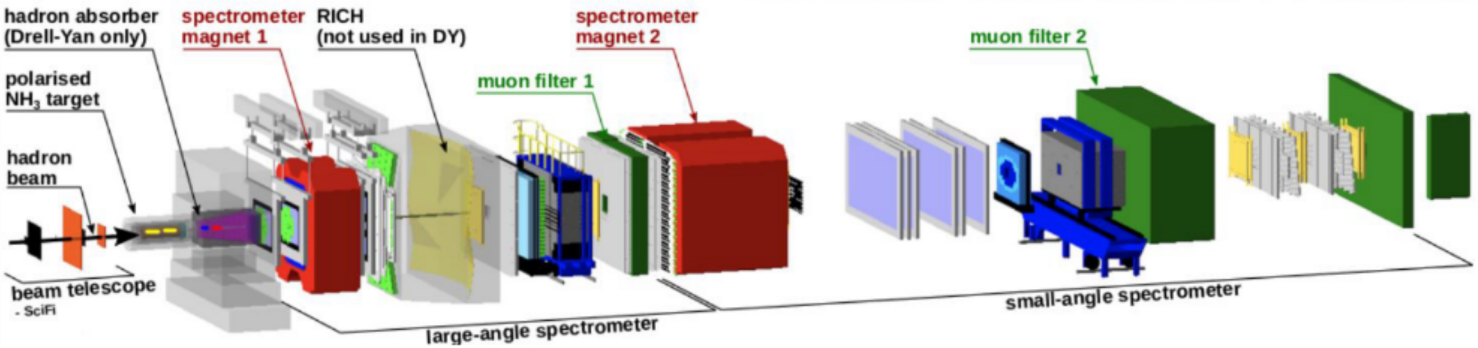
190 GeV h^- beam

Target

W Al NH_3



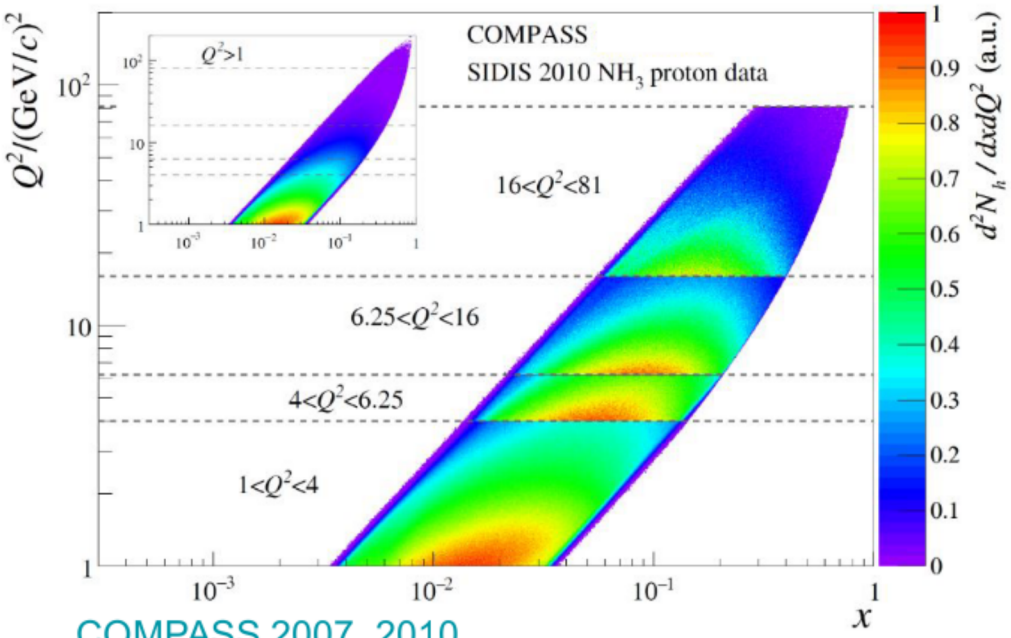




[Kinematic coverage]

SIDIS on transv. pol. proton $\mu + p^{\uparrow} \rightarrow \mu' + h + X$

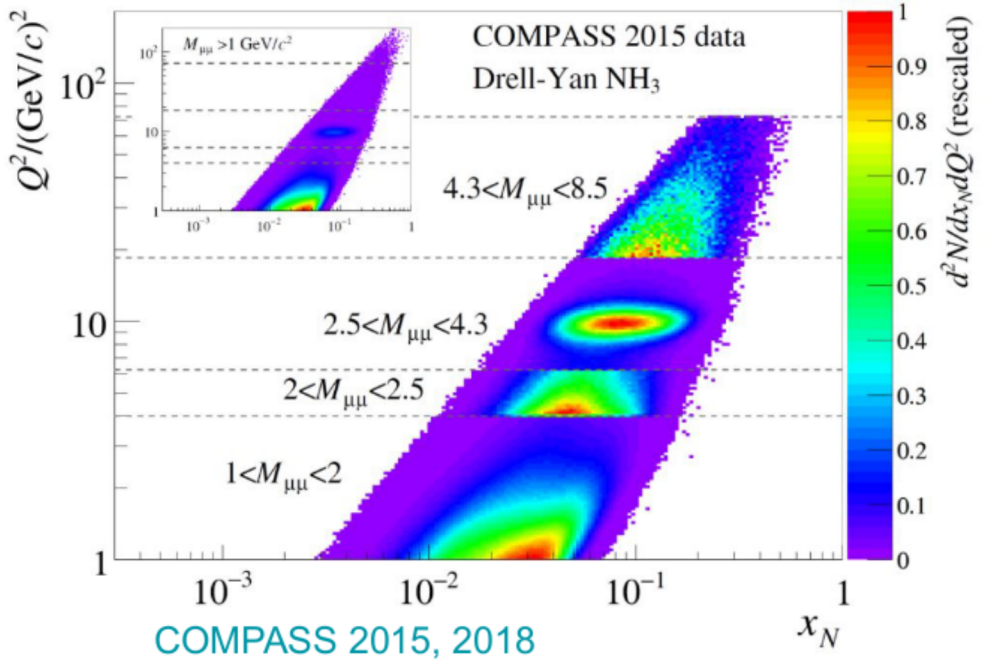
PLB 770 (2017) 138



COMPASS 2007, 2010

Pion-induced transv. pol.Drell-Yan $\pi^- + p^{\uparrow} \rightarrow \mu^+\mu^- + X$

PRL 119 (2017) 112002



COMPASS 2015, 2018

Similar x and Q^2 range → minimisation of Q^2 evolution effects between the two processes

Unique conditions to test **TMD universality**

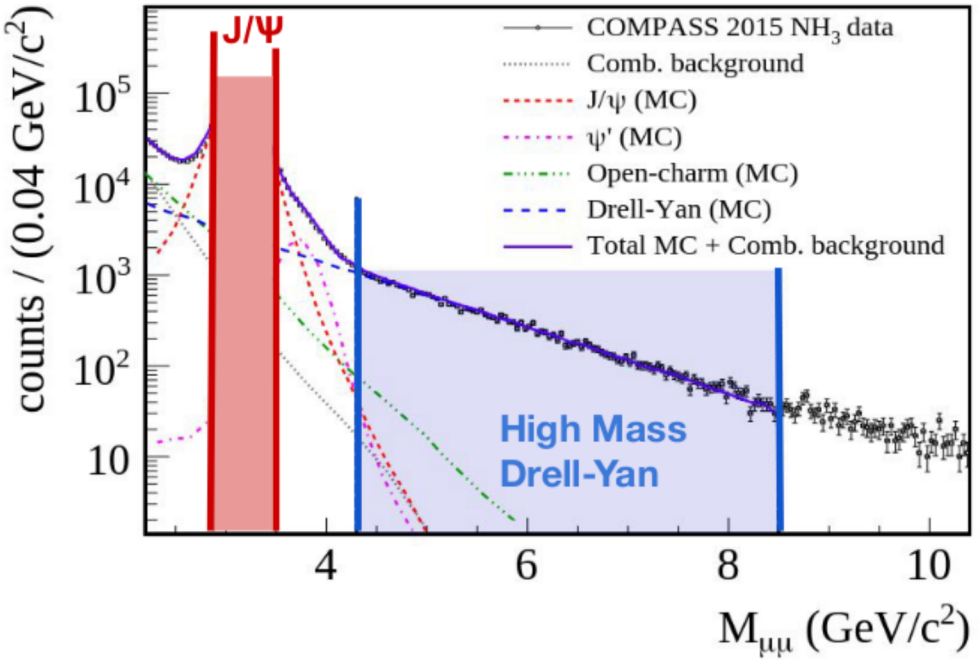
[DY COMPASS measurements: kinematics]

I. $1 < M_{\mu\mu} < 2$ GeV/c^2 Low Mass
large background contamination

II. $2 < M_{\mu\mu} < 2.5$ GeV/c^2 Intermediate Mass
High DY cross section
low DY signal/background ratio

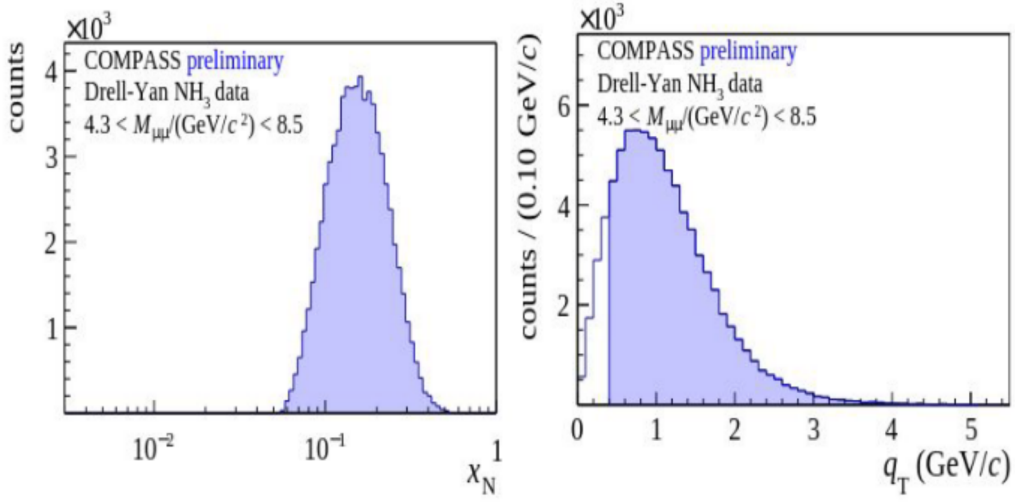
III. $2.5 < M_{\mu\mu} < 4.3$ GeV/c^2 Charmonia Mass
J/ψ physics

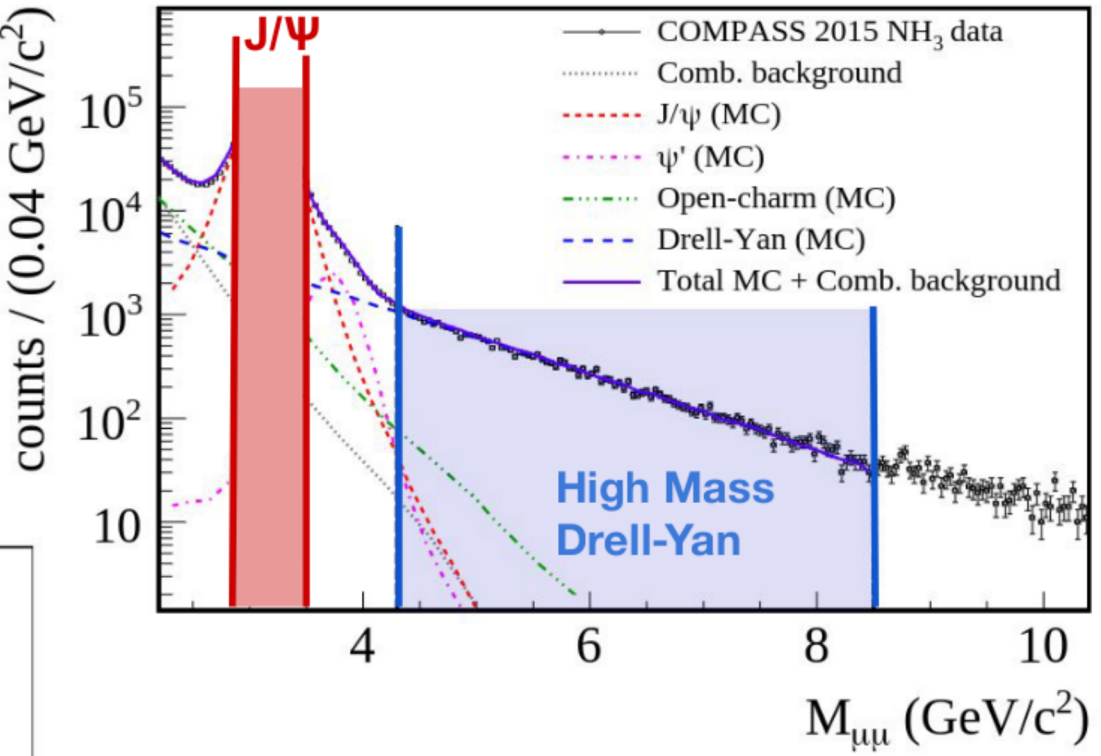
IV. $4.3 < M_{\mu\mu} < 8.5$ GeV/c^2 High Mass
beyond J/ψ and ψ' peak valence
quark region but…low DY
cross-section



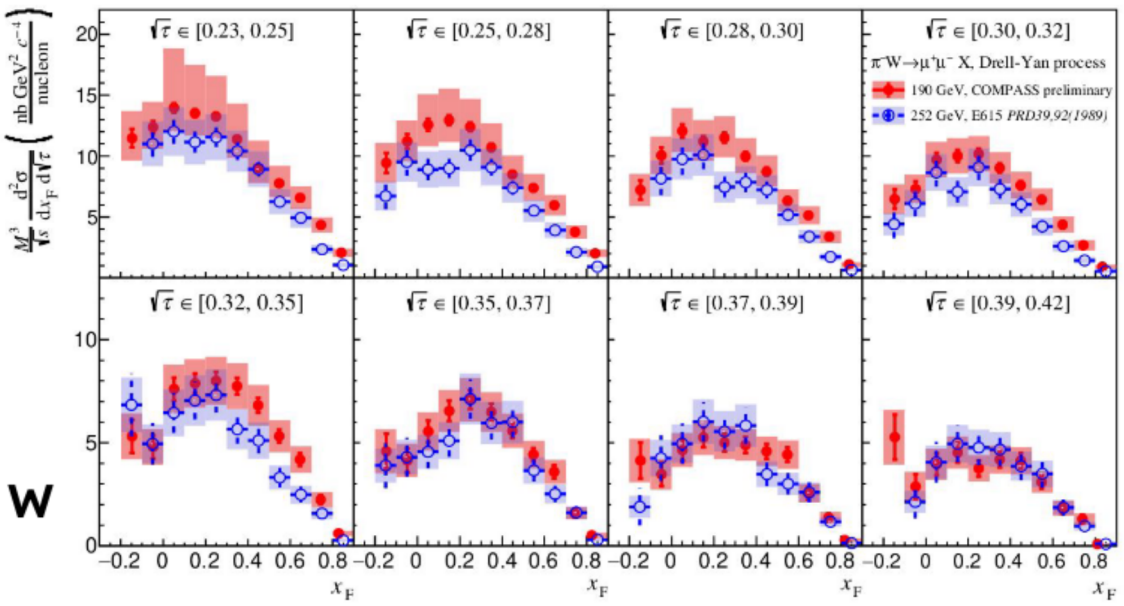
[DY analysis cuts]

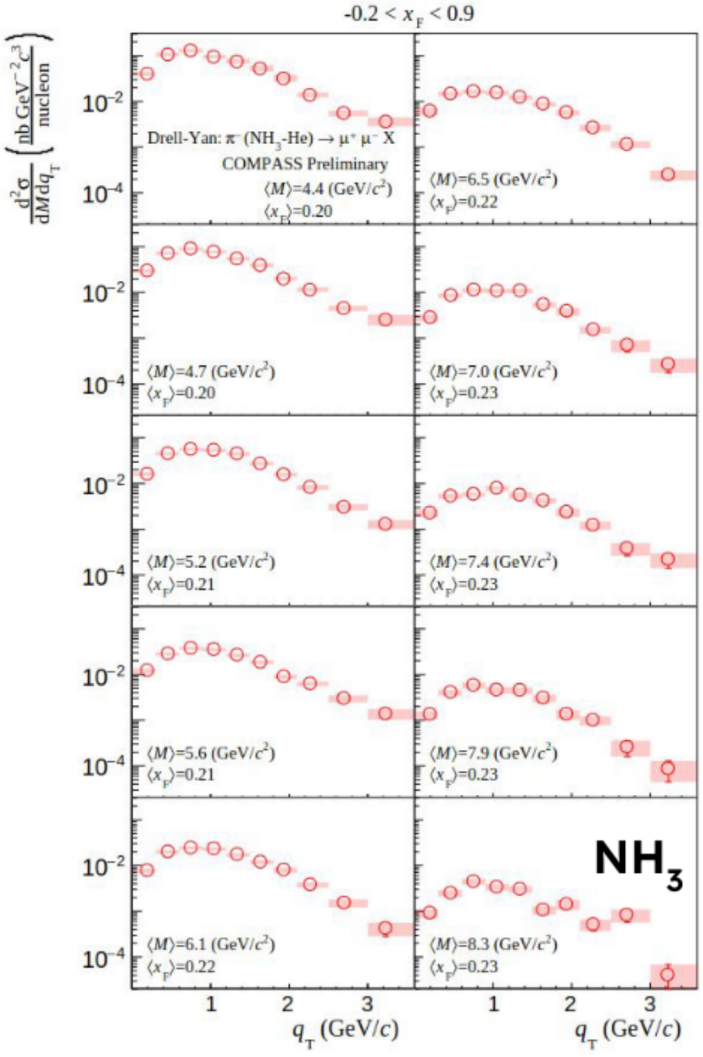
- $4.3 < M\mu\mu < 8.5$ GeV/c^2
- Drell-Yan purity: **96%**
- Probing $x_N \sim 0.17$: up quark dominance
- $qT > 0.4$ GeV for angular resolution,
- but low cross-section





[DY cross section at COMPASS]



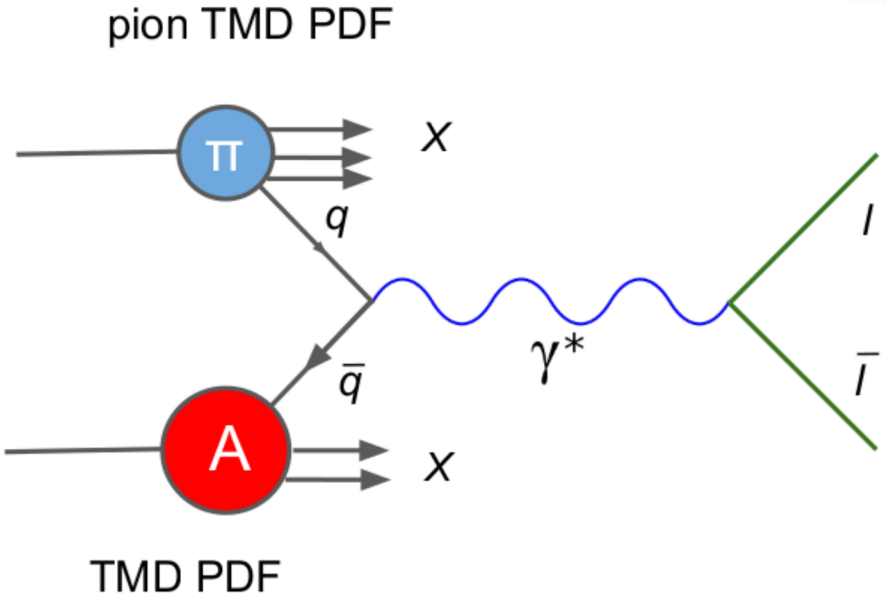


First new results in the last 30 years

Similar kinematic coverage as E615, better statistics, similar systematics

(V. Andrieux, SPIN 2023)

[pion TMDs from Drell-Yan]



DY PROCESS

$$h_A(P_A) + h_B(P_B) \to \gamma^*(q) + X \to \ell^+(l) + \ell^-(l') + X$$

unpolarized cross section

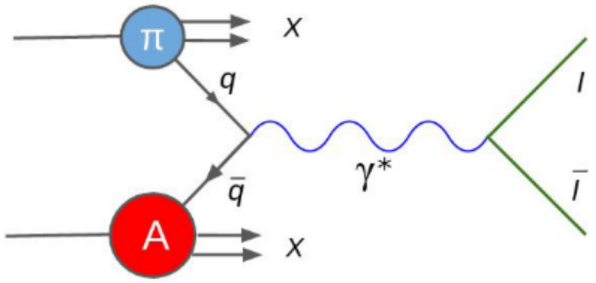
STRUCTURE FUNCTIONS

$$F^1_{UU}, F^2_{UU}$$

CROSS SECTION

$$\frac{d\sigma^{DY}}{d|\boldsymbol{q}_T|dydQ} \simeq \frac{16\pi^2\alpha^2}{9Q^3}|\boldsymbol{q}_T|F^1_{UU}(x_A, x_B, \boldsymbol{q}_T, Q)$$

[pion TMDs from Drell-Yan]



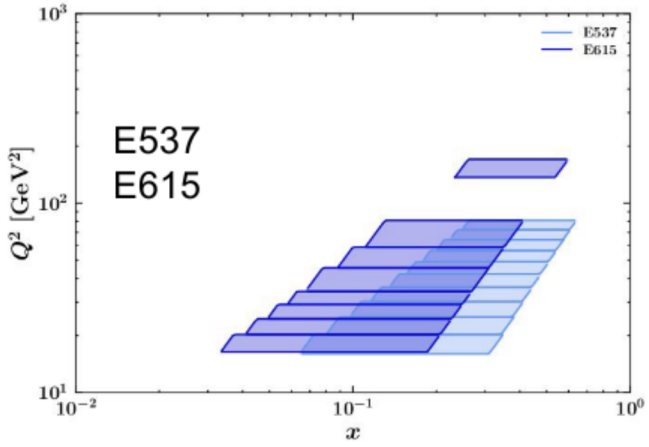
$$\frac{d\sigma^{DY}}{d|\boldsymbol{q}_T|dydQ} \propto \int d|\boldsymbol{b}_T||\boldsymbol{b}_T|J_0(|\boldsymbol{q}_T||\boldsymbol{b}_T|)\hat{f}^{\,a}_{1\pi}\left(x_A, \boldsymbol{b}_T^2; \mu, \zeta_A\right)\hat{f}^{\,\bar{a}}_{1p}\left(x_B, \boldsymbol{b}_T^2; \mu, \zeta_B\right)$$

$\hat{f}^{\,\bar{a}}_{1p}\left(x_B, \boldsymbol{b}_T^2; \mu, \zeta_B\right)$ taken from MAP collaboration global extraction at N^{3}LL

MAP22Pion [2206.07598]

[Pion TMD framework: MAP]

data



accuracy

N^{3}LL

Non-perturbative part

$$f_{1NP}^{\pi}(x, \boldsymbol{b}_T^2; \zeta) = e^{-g_{1\pi}(x)\frac{b_T^2}{4}} \left[\frac{\zeta}{Q_0}\right]^{g_K(\boldsymbol{b}_T^2)/2}$$

$$= e^{-g_{1\pi}(x)\frac{b_T^2}{4}} \left[\frac{\zeta}{Q_0}\right]^{-g_2^2\frac{b_T^2}{4}}$$

evolution kernel

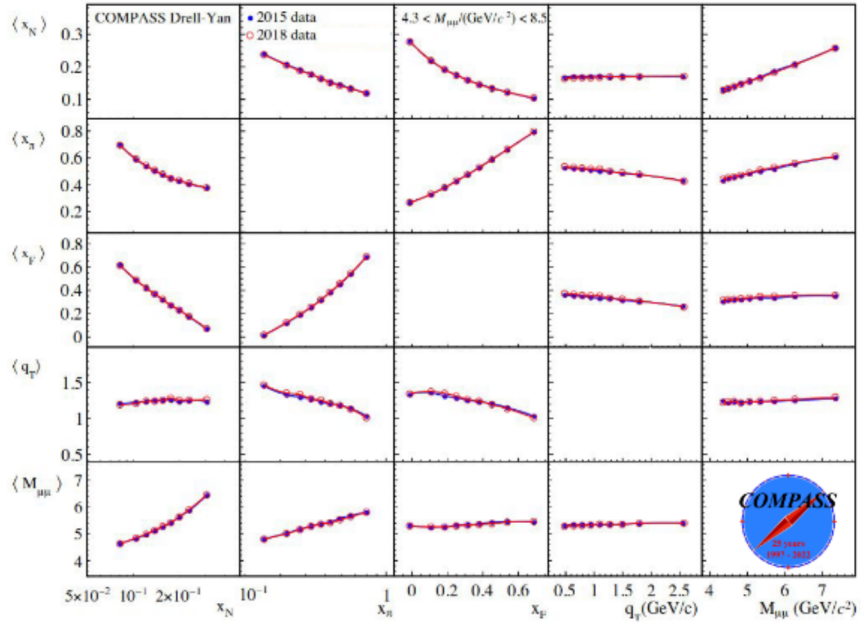
$$b_*(|\boldsymbol{b}_T|, b_{\min}, b_{\max}) = b_{\max}\left(\frac{1-e^{-|\boldsymbol{b}_T|^4/b_{\max}^4}}{1-e^{-|\boldsymbol{b}_T|^4/b_{\min}^4}}\right)^{1/4}$$

$$b_{\min} = 2e^{-\gamma_E}/\mu_f \qquad b_{\max} = 2e^{-\gamma_E}\mathrm{GeV}^{-1}$$

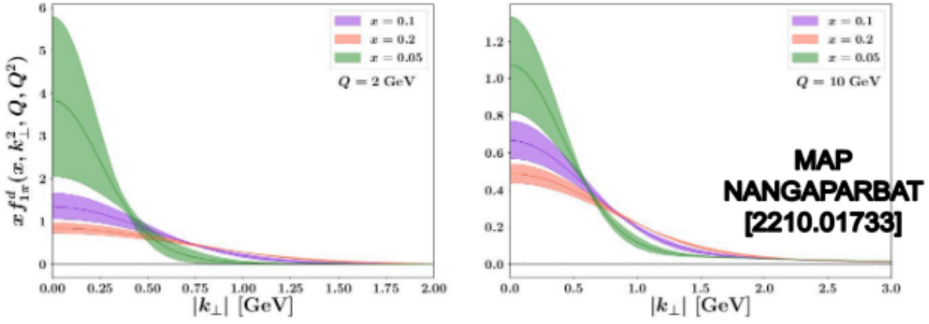
MAP
NANGAPARBAT
[2210.01733]

[Impact study: DY predictions on COMPASS space]

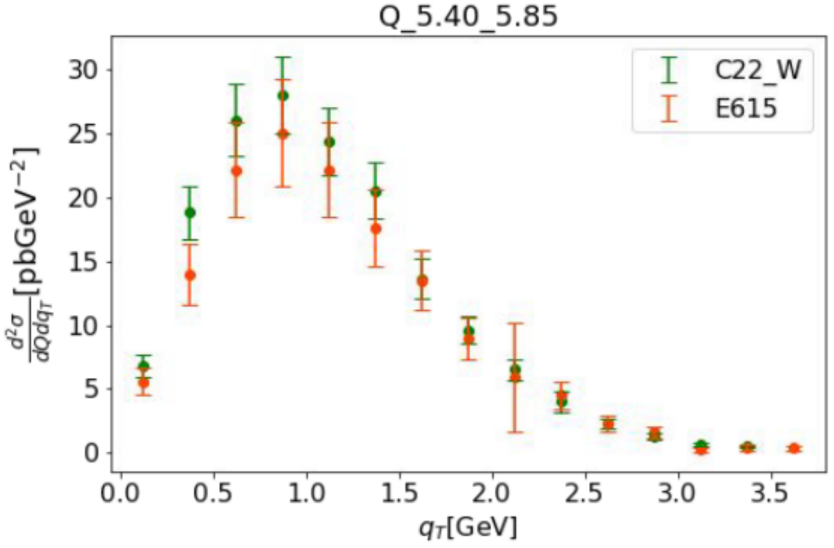
COMPASS kinematics



MAP22 pion TMDs



CMP predictions (used as pseudodata)



Uncertainties

stat. from experimental analysis

syst:

W 15% **Al** 10%

NH^3 10%

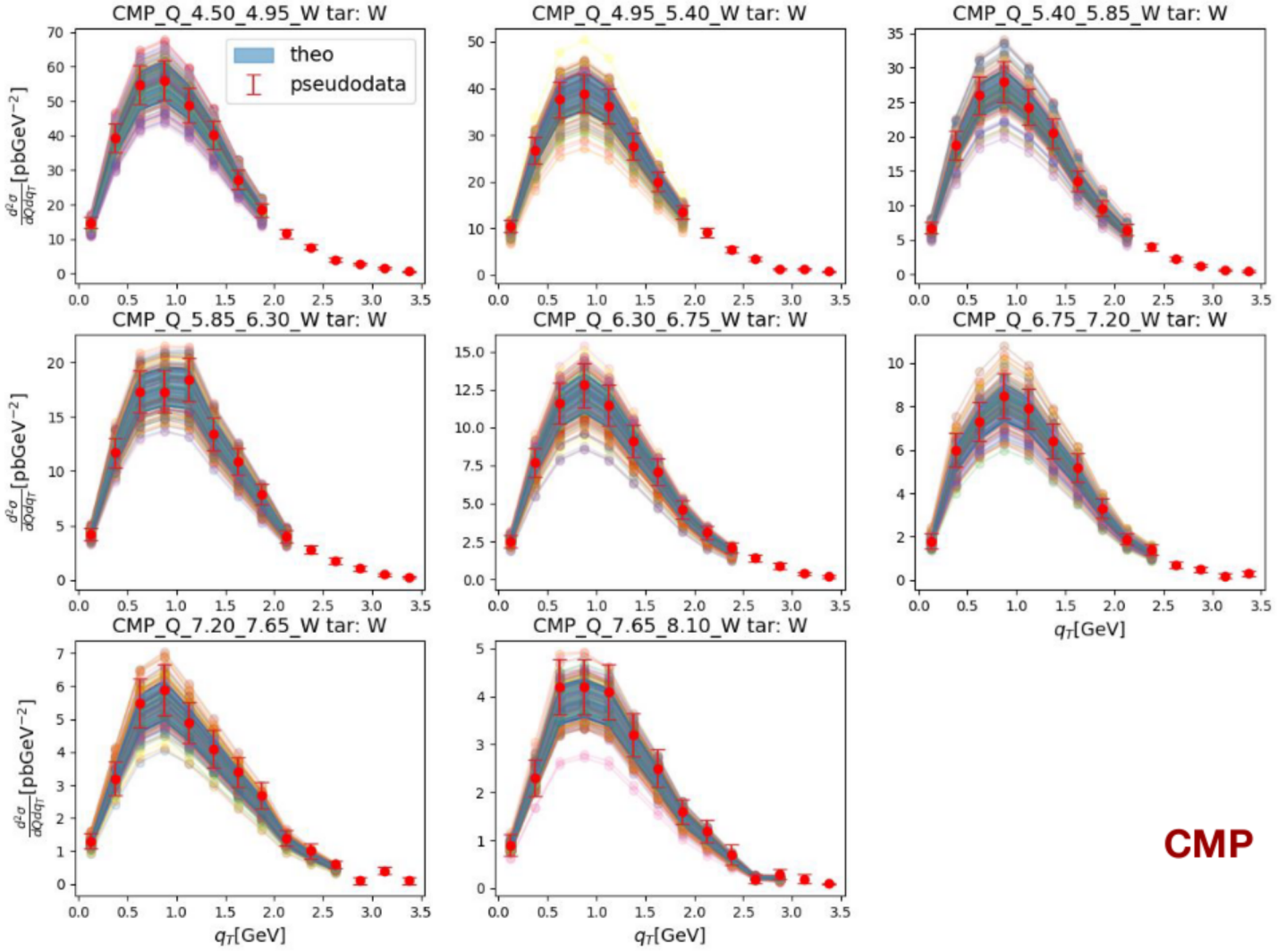
[Impact study: exploratory fit of pion TMDs]

IMPACT STUDY

MAP NANGAPARBAT [2210.01733]

200 replicas

$\frac{d^2\sigma}{dQdq_T}[\text{pbGeV}^{-2}]$



CMP

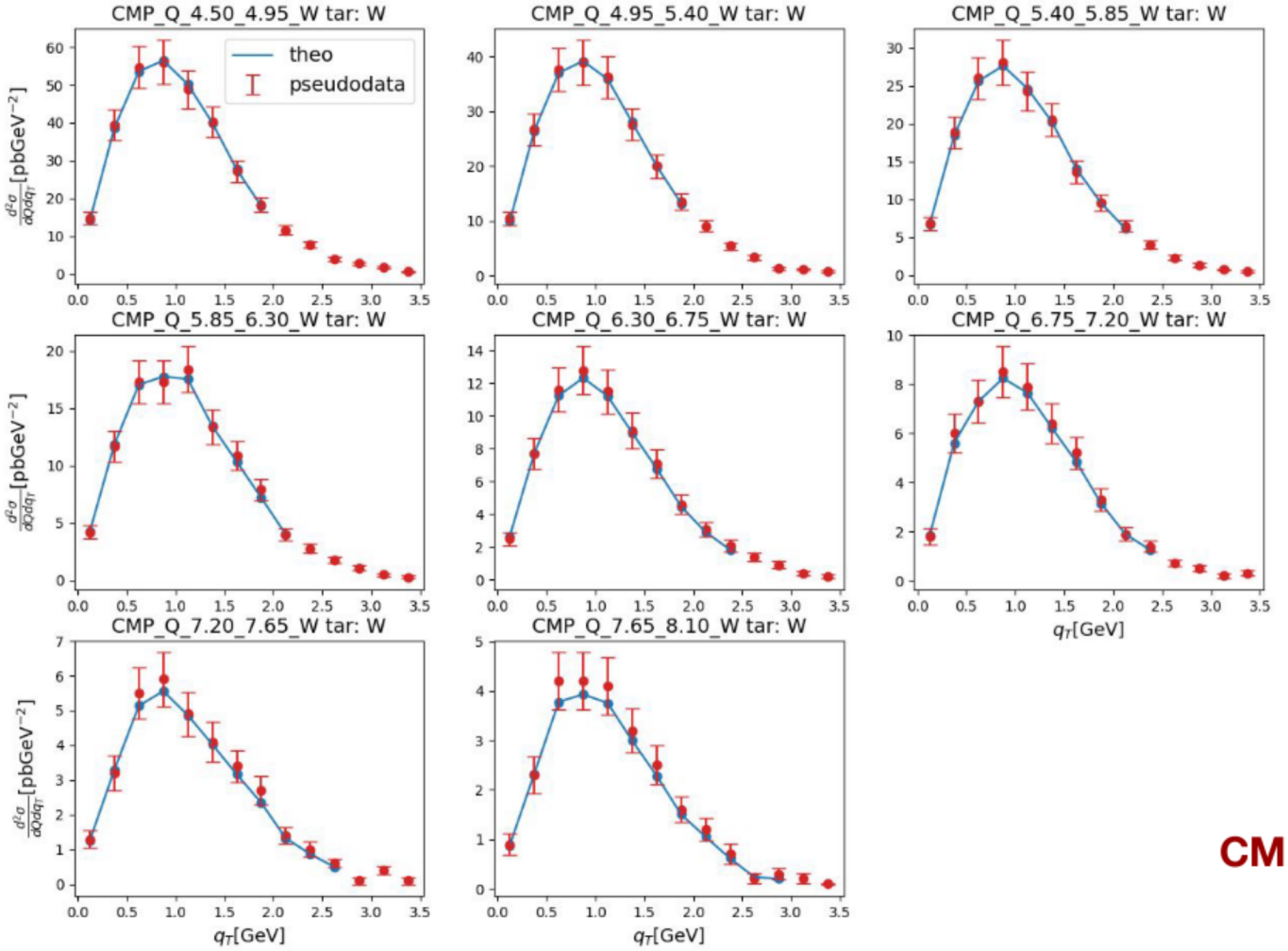
[Impact study: exploratory fit of pion TMDs]

IMPACT STUDY

MAP NANGAPARBAT [2210.01733]

NO replicas

$\frac{d^2\sigma}{dQdq_T}[\text{pbGeV}^{-2}]$



CMP

[Impact study: exploratory fit of pion TMDs]

IMPACT STUDY

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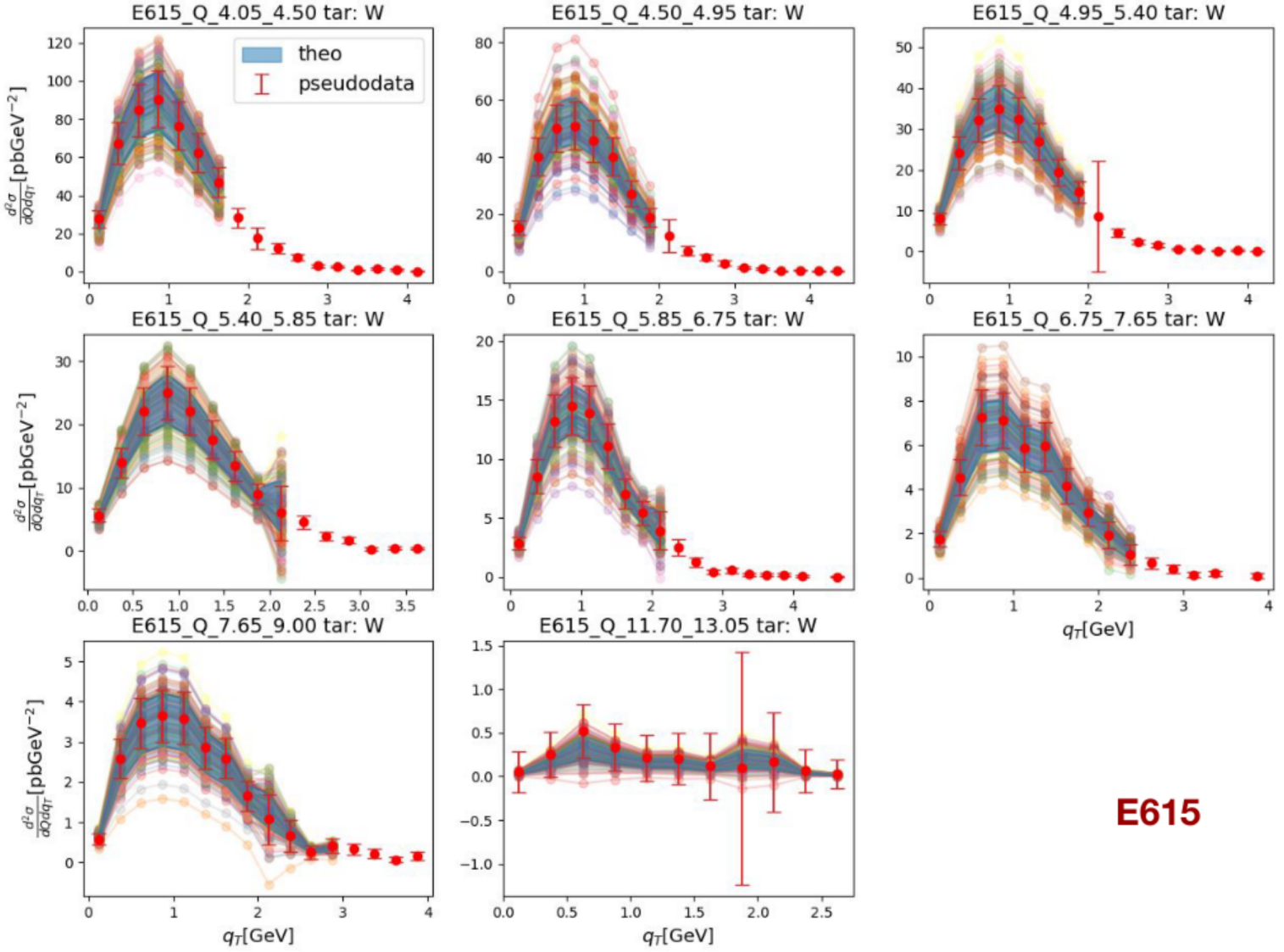


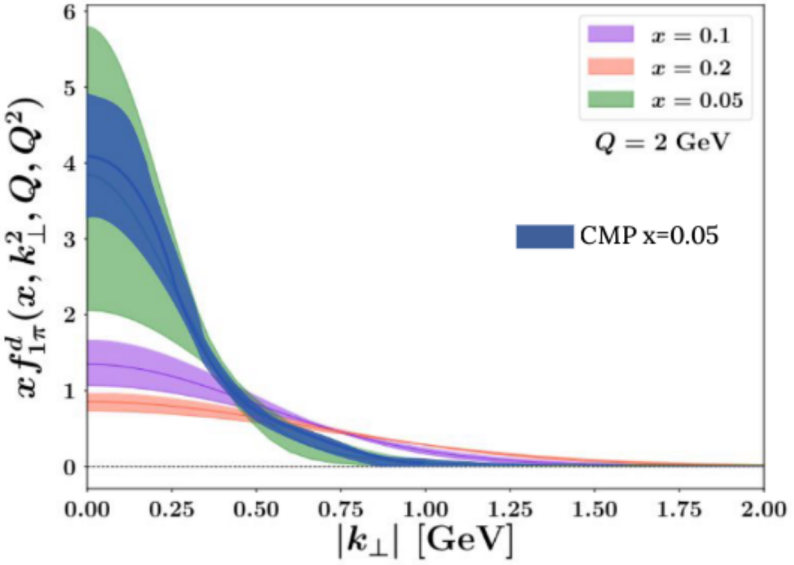
E615

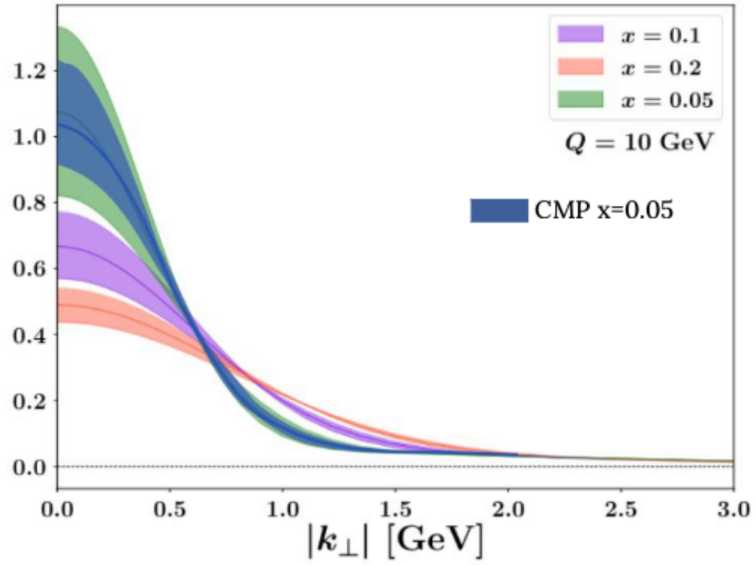
[Exploratory fit of pion TMDs: results]

E615+E537 χ_0^2: 1.55
...+ **C22** χ_0^2 W: 1.62
...+ **C22** χ_0^2 Al: 1.75

209 data points

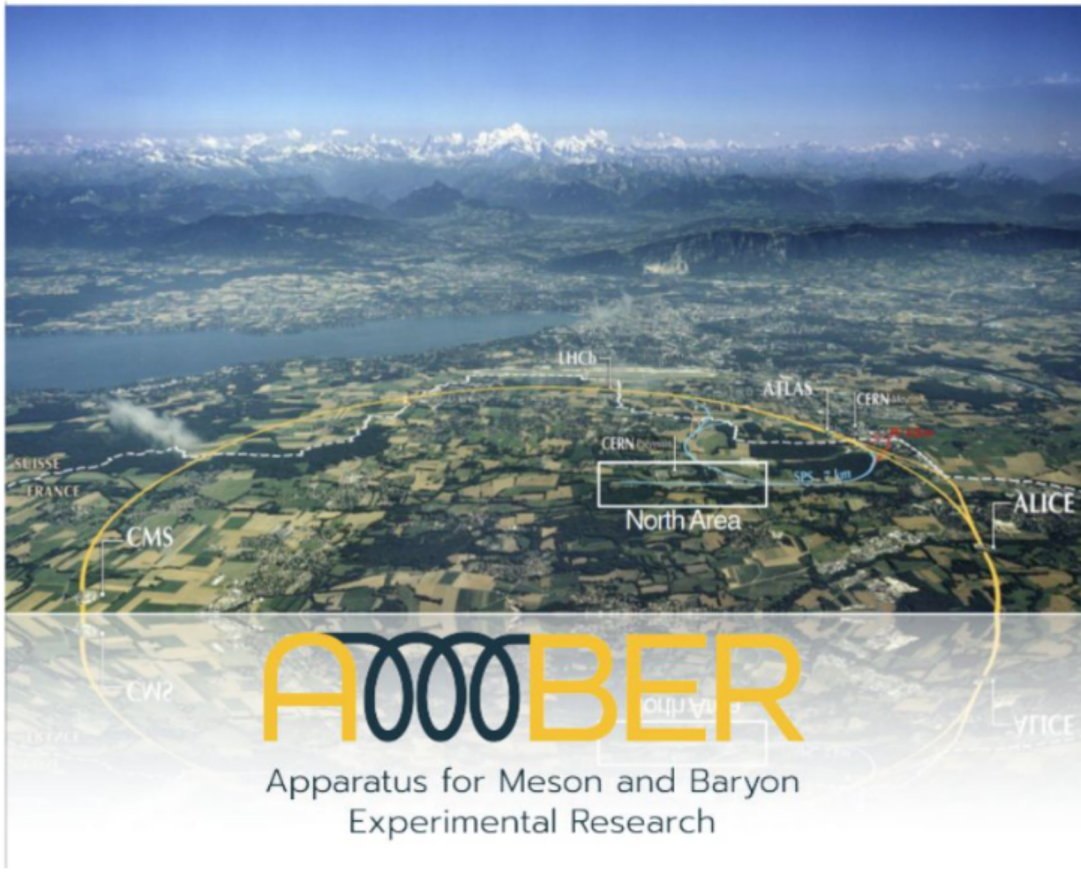
Hint of smaller uncertainties in pion TMD PDF with the inclusion of COMPASS results





Future of meson structure: AMBER physics program

- In EHN2 (former COMPASS) experimental hall
- Availability of both **hadron and muon beams**
- Positive and negative beam available, and in **wide range** of energies (~ 60 - 250 GeV/c)
- Re-use of large aperture dipole magnets and some of the most recent COMPASS detectors
- Improved particle identification and tracking through implementations of new detectors and update of existing ones



[AMBER planned physics program]

	Beam	Target	Additional hardware
Proton radius measurement	100 GeV muons	high pressure H	active target TPC, tracking stations
pbar production cross section	50, 280 GeV protons	liquid H_2, He	LHe target
DY measurement with pions/kaons	charged kaons and pions	C,W	vertex detectors, active adsorber
prompt photon measurements	>100 GeV charged pi/K	LH_2, Ni	hodoscopes
K-induced spectroscopy	50, 100 GeV charged kaons	LH_2	recoil TOF, forward PID
Meson radius	50 : 280 GeV charged pi/K		

Phase I
2023 -> 2029

Phase II
Beyond 2029

[AMBER planned physics program]

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Phase I
2023 -> 2029

Phase II
Beyond 2029

MESON STRUCTURE AT AMBER

[knowledge of pion structure]

Current limits:

- Mostly heavy target
  - nuclear effects
- Some did not publish cross-sections
- Some did not measure with both beam charges
  - no sea/valence separation

E615 / NA3 / NA10 / COMPASS15

AMBER improvements

➤ High energy and intensity pion beams
Example @ 190 GeV/c^2
$I\,\pi^- \sim I_{beam} = 7.0\text{x}10^7$/s
$I\,\pi^+ \sim 25\%\ I_{beam} = 1.7\text{x}10^7$/s

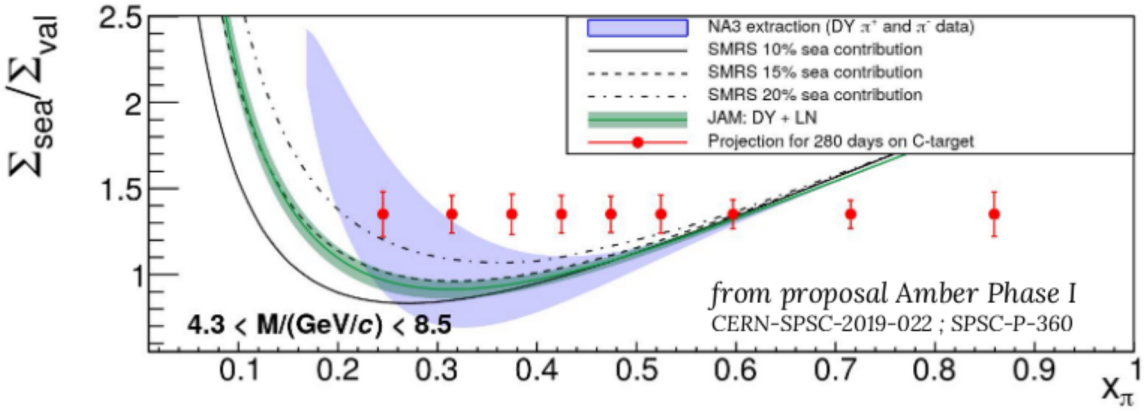
➤ COMPASS-like apparatus

➤ Segmented Carbon target

⇒ π^+ and π^- beam on C and W target

Improved PDF **flavour separation**

➤ Aim at the first precise direct measurement of the **pion sea** contribution



[Summary]

COMPASS is a unique framework to study TMD PDFs universality and evolution

Pion TMDs extractions are now based on a limited number of data, COMPASS new dataset could help to better understand them

AMBER planned physics program will give us new tools to look at meson structure through pions and kaons processes