Measurement of Pion-induced Drell-Yan Cross Section from COMPASS Data

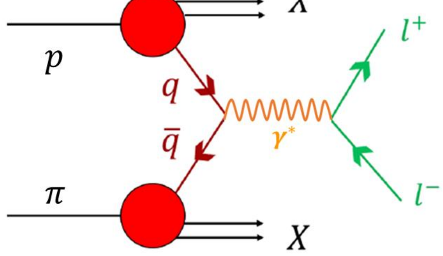
12th Workshop on Hadron Physics and Opportunities Worldwide, Dalian

Chia-Yu Hsieh
Institute of Physics, Academia Sinica, Taipei
on behalf of COMPASS collaboration

Introduction of Global Fit of Pion PDF

Pion − induced Drell − Yan

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

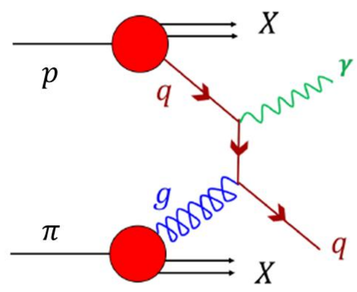


sensitive to valence

NA10, E615, COMPASS (new)

Pion − induced prompt − gamma

$\pi^- p \rightarrow \gamma X$

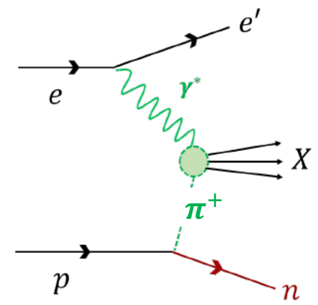


sensitive to gluon

WA70

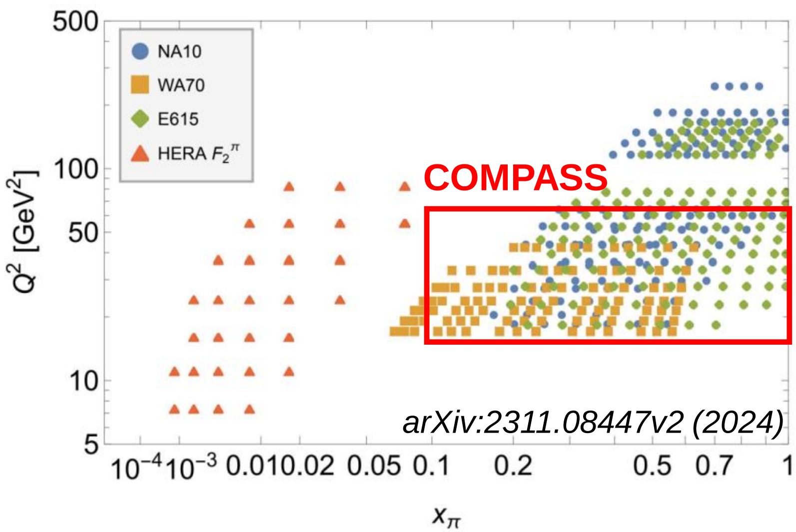
Sullivan process (leading-neutron DIS)

$p \rightarrow \pi^+ n$



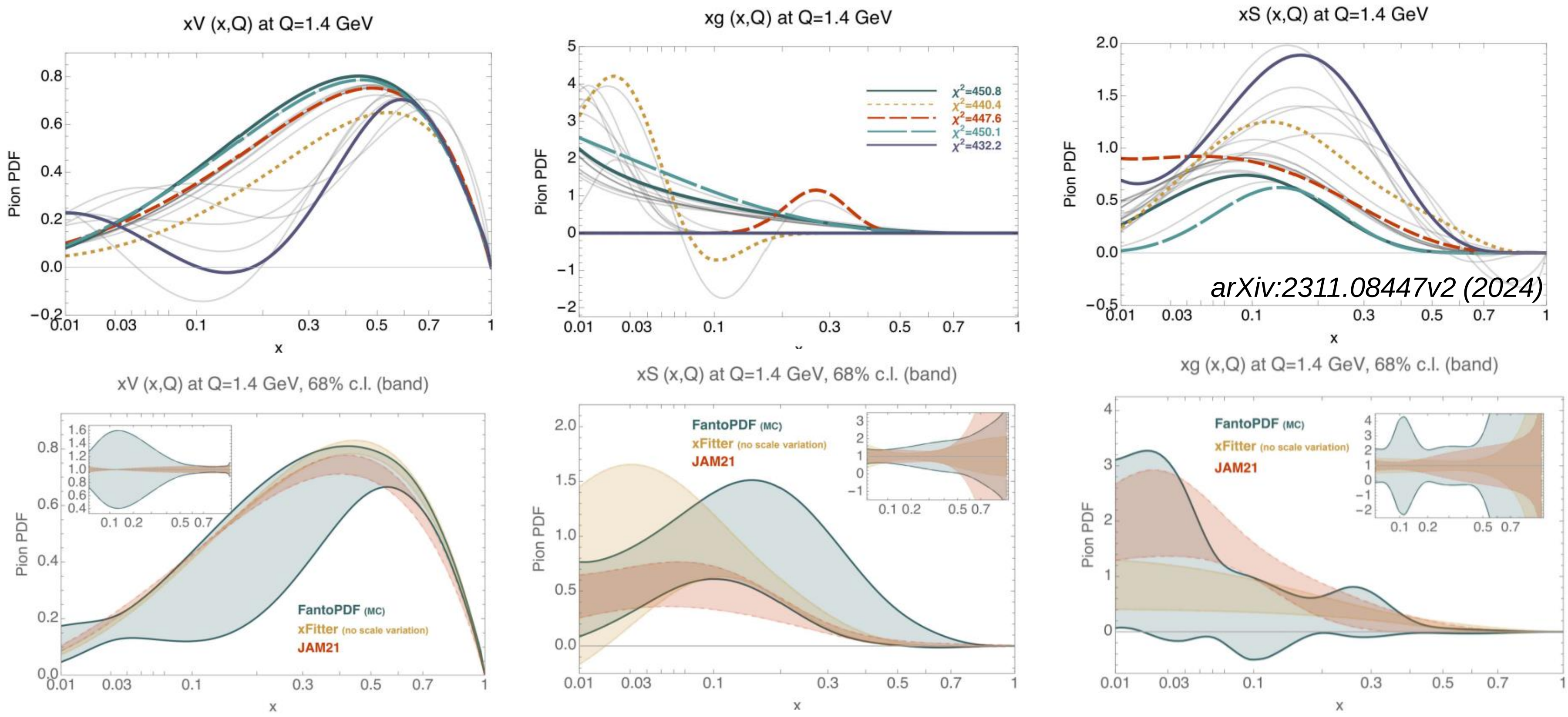
sensitive to quark and gluon

HERA



- Data for global fit of pion PDF is very limited. Each of them has their own difficalties.
- **Pion-induced Drell-Yan : A normalization issue occurs between E615 and NA10 data, by up to 20%. COMPASS data is a new data in 30 years and will be an independence check.**
- Pion-induced prompt-gamma : Data has large systematics due to the background γ signals from the secondary π^0 decay.
- The interest of using Sullivan process to study pion structure is increasing. The equivalence of pion cloud and pion beam data remains a subject to be studied.

Introduction of Global Fit of Pion PDF

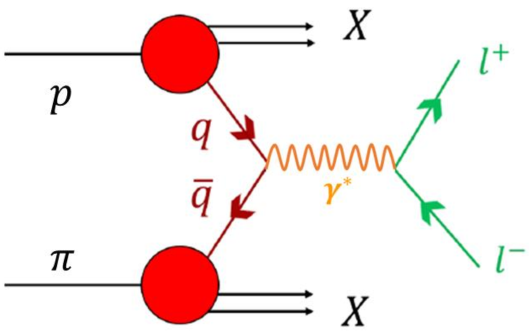


- From the previous published pion PDFs, GRV(1998), xFitter(2020) and JAM21(2021), one could conclude the valence distribution of pion PDF is already well constrained with the input of NA10 and E615. The remaining issue is the large uncertainty of sea distribution and gluon distribution.

- However, FantoPDF given by CTEQ group shows that the form of pion PDF is parameterization dependent. **The uncertainty of valence distribution is still large. COMPASS data could help to narrow down the uncertainty.**

Pion-induced Drell-Yan Process

$LO \quad : q\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^-$



- $Center\ of\ mass\ energy : s$
- $Dimuon\ mass : M^2 = (p_{\mu+} + p_{\mu-})^2$
- $Dimuon\ transverse\ momentum : q_T$
- $Dimuon\ longitutinal\ momentum : q_L$
- $Feynman - x : x_F = x_\pi - x_N$
- $Bjorken - x : x_{\pi/N} = \frac{1}{2}\left(\sqrt{x_F^2 + 4\frac{M^2}{s}} \pm x_F\right)$

PDF

S.D. Drell and T.M. Yan
PRL 25 (1970) 316

$$\frac{d^2\sigma}{dMdx_F} = \frac{2\pi\alpha^2}{9M_{ll'}^3}\left(\frac{x_\pi x_p}{x_\pi + x_p}\right)\sum Q_q^2\left[q(x_\pi)\bar{q}(x_p) + \bar{q}(x_\pi)q(x_p)\right]$$

TMD PDF

Journal of High Energy Physics
Article number: 90 (2019)

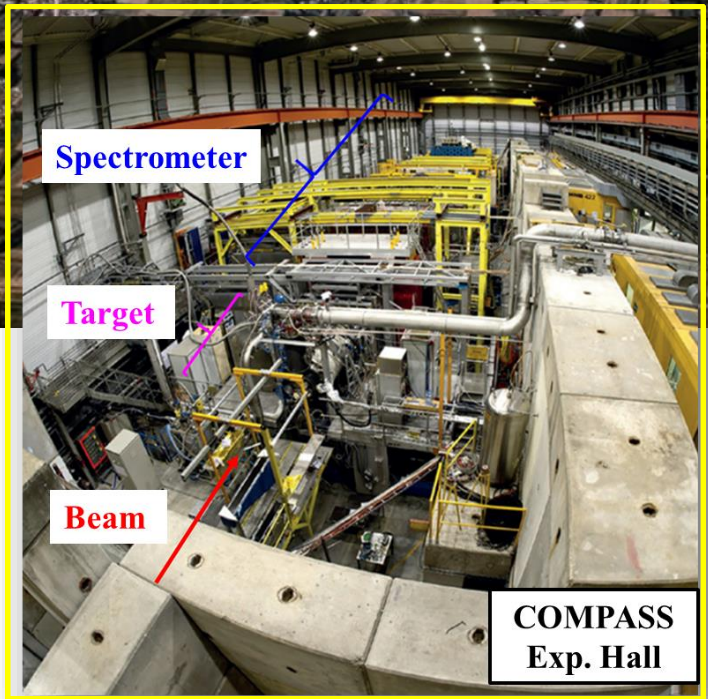
$$\frac{d^3\sigma}{dMdx_F dq_T} = \sigma_0 \sum_{f_\pi, f_p} H_{f\pi fp}(M,\mu) \int \frac{d^2\boldsymbol{b}}{4\pi} e^{i(\boldsymbol{b}.\boldsymbol{q_T})} F_{h\pi\rightarrow f\pi}(x_\pi, \boldsymbol{b}; \mu, \zeta_1) F_{hp\rightarrow fp}(x_p, \boldsymbol{b}; \mu, \zeta_1)$$

- With COMPASS data, we provides :
  - Differential cross section in $M, x_F, and\ q_T$ ➔ PDF, TMD PDF studies.
  - Differential cross section in x_F, q_T, x_N ➔ Nuclear effect (Multiple targets).

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

- Nucleon structure
- Hadron structure
- Hadron spectroscopy

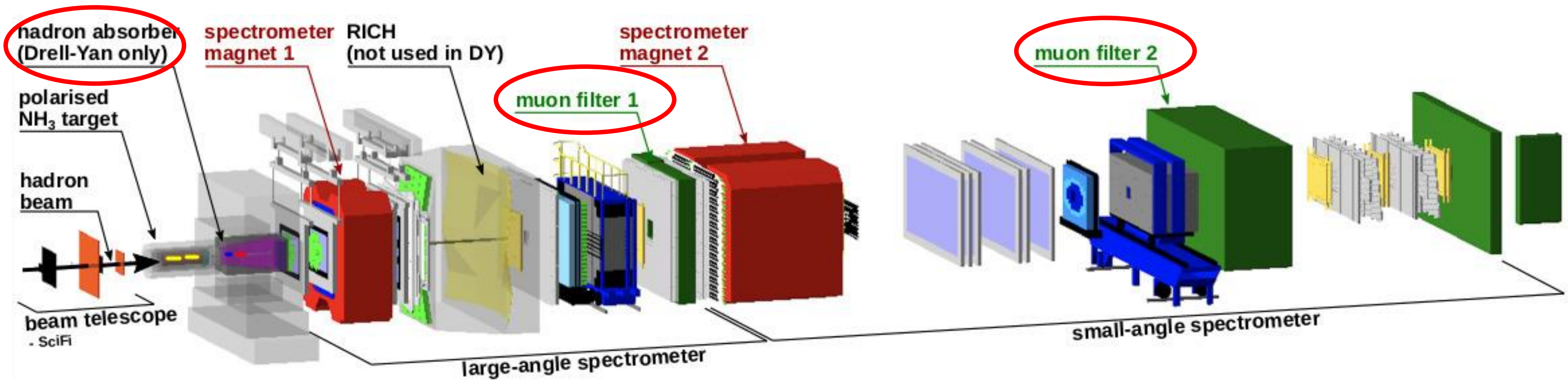
- Common spectrometer
- High intensity muon and hadron beams



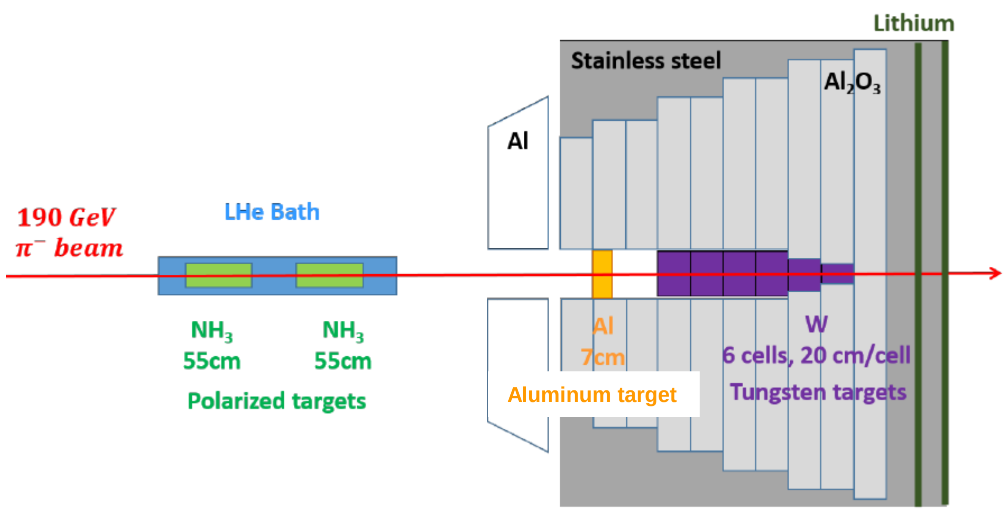
- **COMPASS**
  - fixed target experiment at CERN
  - 60m-long spectrometer
  - Multiple beam and target choices for different physics purposes

Drell-Yan Data Taking at COMPASS in 2015 and 2018

Spectrometer : ~350 tracking planes / two-stage spectrometer / dimuon triggers



Beam and Target region : 190 GeV π^- beam / three targets / hadron absorber

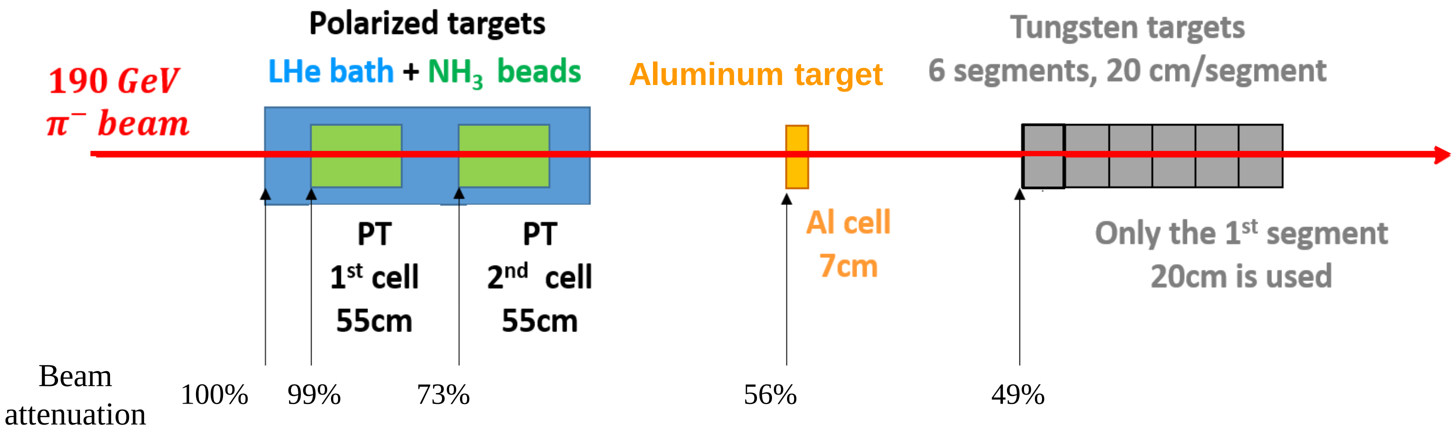


$$\pi^- + p \rightarrow \mu + \mu^- + X$$

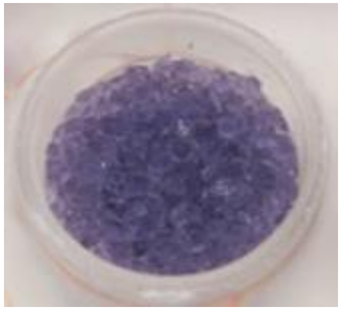
π^- Beam | NH_3-He, Al, W | Dimuon Events | Absorber

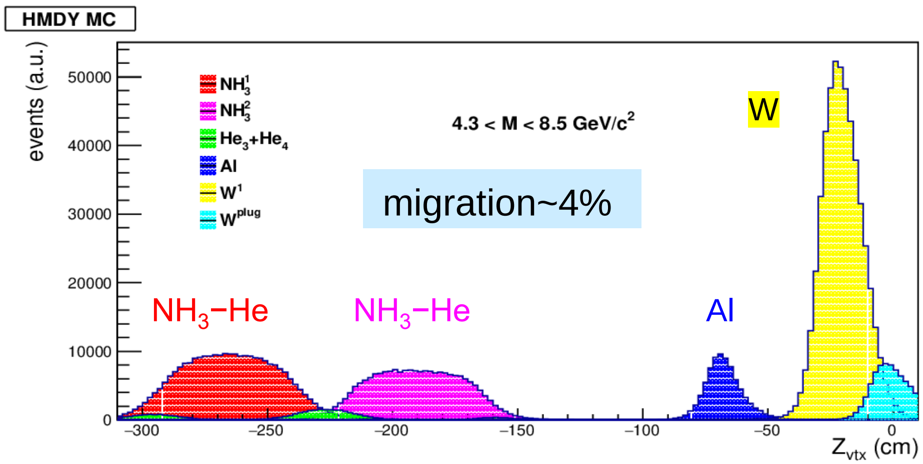
- Only 2018 data will be shown today.
- Data from light target is provided.

Target Composition



Solid NH_3 beads

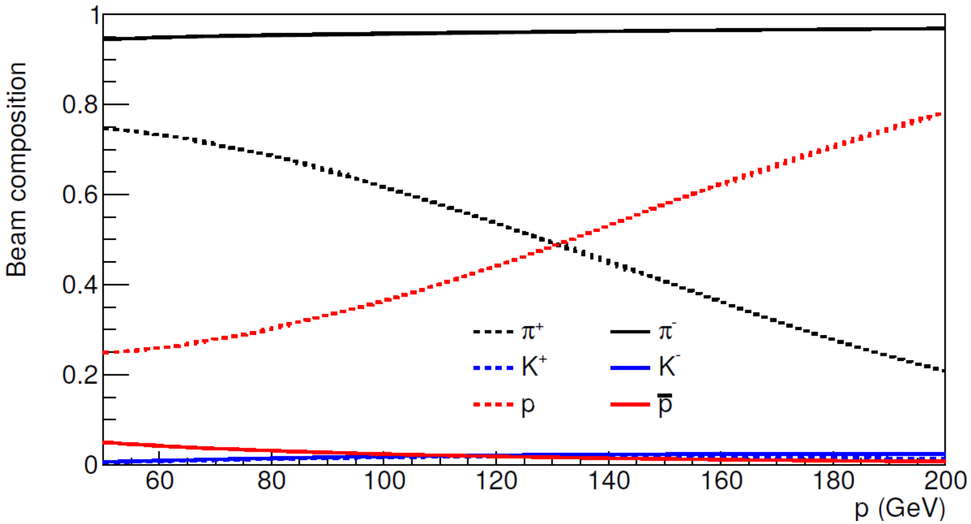


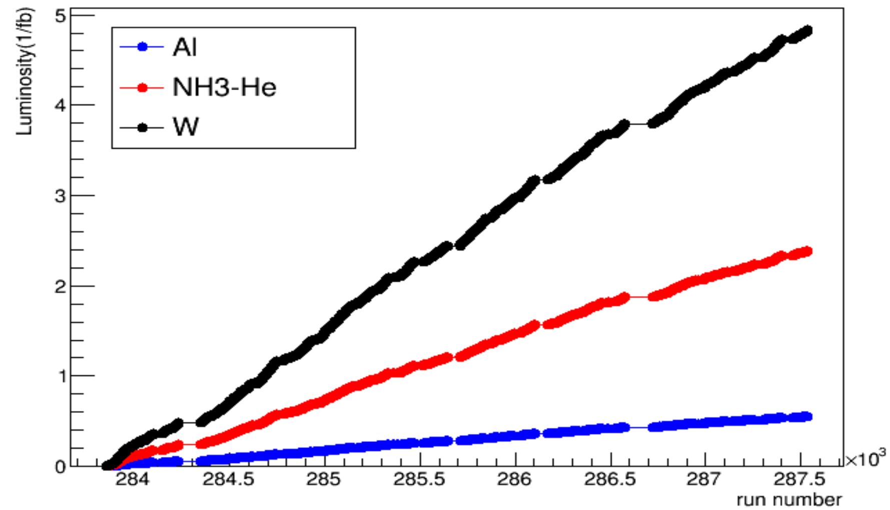


- **NH_3-He target**
- Solid NH_3 beads immersed in liquid He at low temperature for polarization purpose.
- Only “unpolarized” differential Drell-Yan cross section from NH_3-He target will be shown later.
- **Molar fraction of nucleon : 15.7 % ^{1}H, 11.1 % ^{2}He, 73.2 % ^{7}N.**

- **W target**
- Beam dump
- **Only events from the first 20 cm are selected to reduce secondary re-interactions.**

Beam Composition and Luminosity

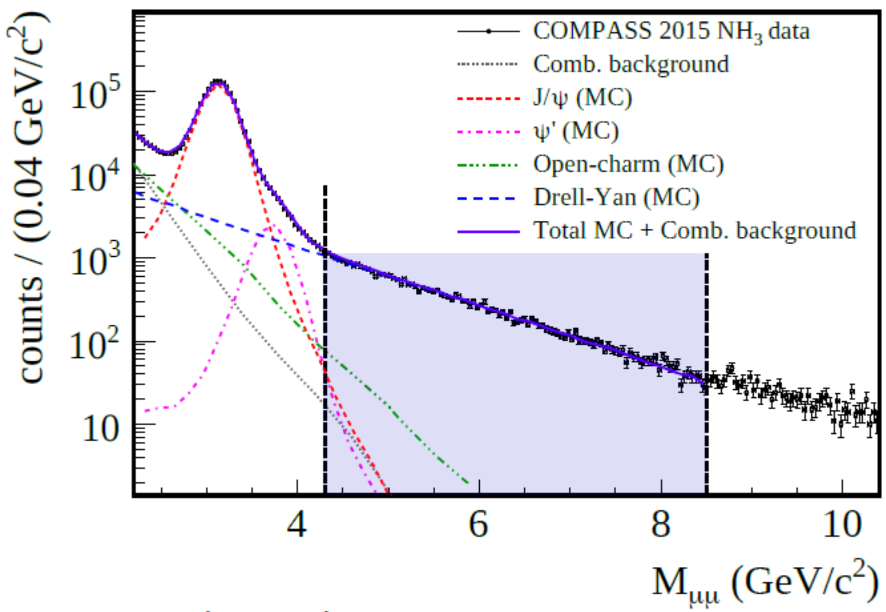




- **Beam condition**
- **190 GeV** beam momentum
- Average intensity 70 MHz
- Negative hadron beam composition: **97% pions, 2% kaons, 1% antiprotons. The beam composition is accounted for in the systematic uncertainties.**

- **Integrated luminosity**
- **W** : $\sim 5\ fb^{-1}$
- **NH_3-He** : $\sim 2\ fb^{-1}$
- **Al** : $\sim 0.5\ fb^{-1}$

High Mass Drell-Yan Sample



- Kinematic coverage

① $4.3\ \mathrm{GeV}/c^2 < \mathrm{M} < 8.5\ \mathrm{GeV}/c^2$

② $-0.2 < x_F < 0.9$

③ $0.0\ \mathrm{GeV}/c < q_T < 3.6\ \mathrm{GeV}/c$

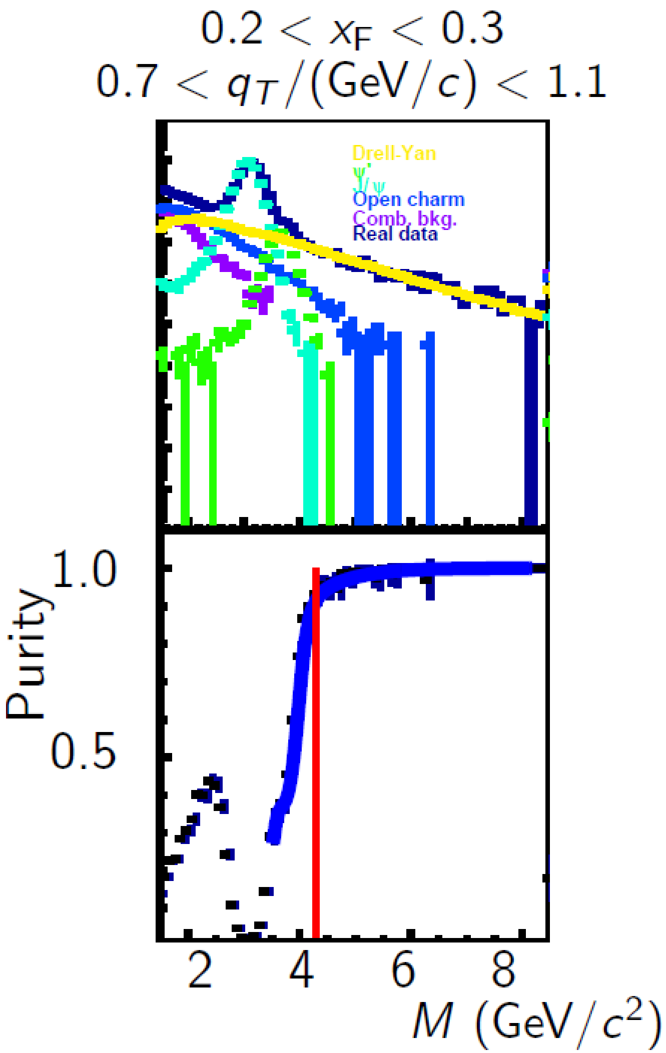
- **Background contribution**

  ➔ purity extraction

- Open charm production
- J/ψ and ψ' resonances
- Random $\mu^+\mu^-$ combination is estimated by random like-sign dimuons collected.

- **Number of dimuon pair selected :**
  - **W : 43k events**
  - **NH_3-He : 36k events**
  - **Al : 6k events**

Purity Extraction



- Purity extraction of DY sample is through **cocktail fit.** It is extracted in **multi-dimensional**.

① $4.3\ \mathrm{GeV}/c^2 < M < 8.5\ \mathrm{GeV}/c^2$: 4 bins
② $-0.2 < x_F < 0.9$: 11 bins
③ $0.0\ \mathrm{GeV}/c < q_T < 3.6\ \mathrm{GeV}/c$: 3 bins

- **Purity of DY sample is above 90% :**

① NH_3−He : $\mathbf{M > 4.3\ GeV/c^2}$
② Al : $\mathbf{M > 4.7\ GeV/c^2}$
③ W : $\mathbf{M > 5.5\ GeV/c^2}$

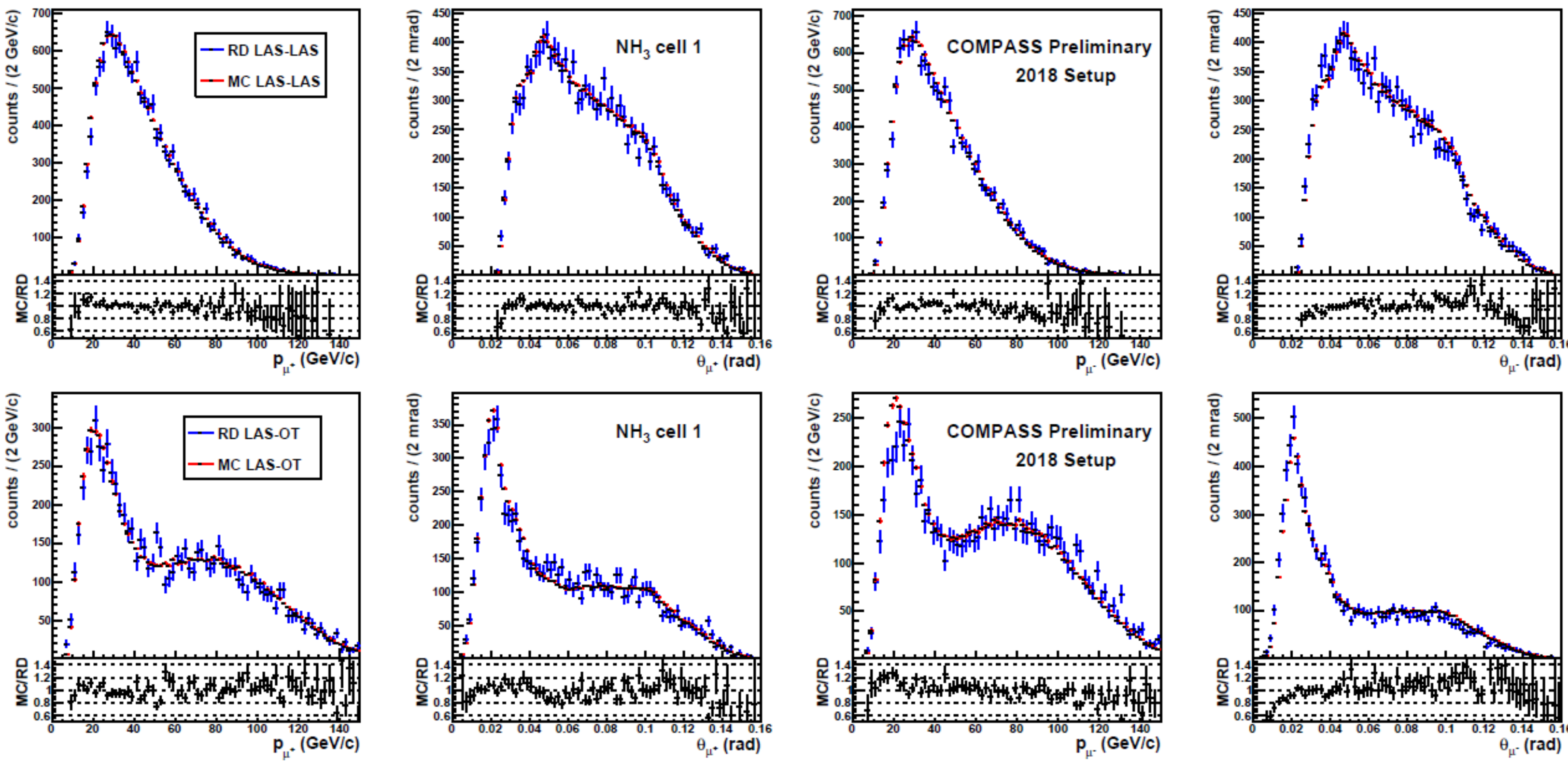
Worse purity for W due to the worse mass resolution and worse q_T resolution.

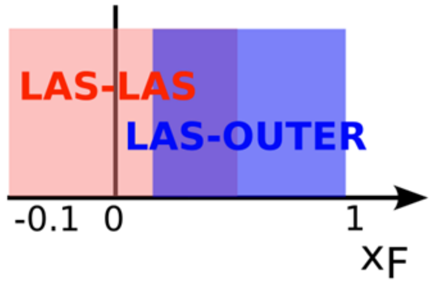
Target	Resolution		
	x_F	q_T(GeV/c)	M
NH_3−He	0.03	150	3.5%
Al	0.03	245	4.5%
W	0.03	340	6.5%

Data and MC Comparison

NH_3−He Cell#1 LASxLAS

NH_3−He Cell#1 LASxOUT

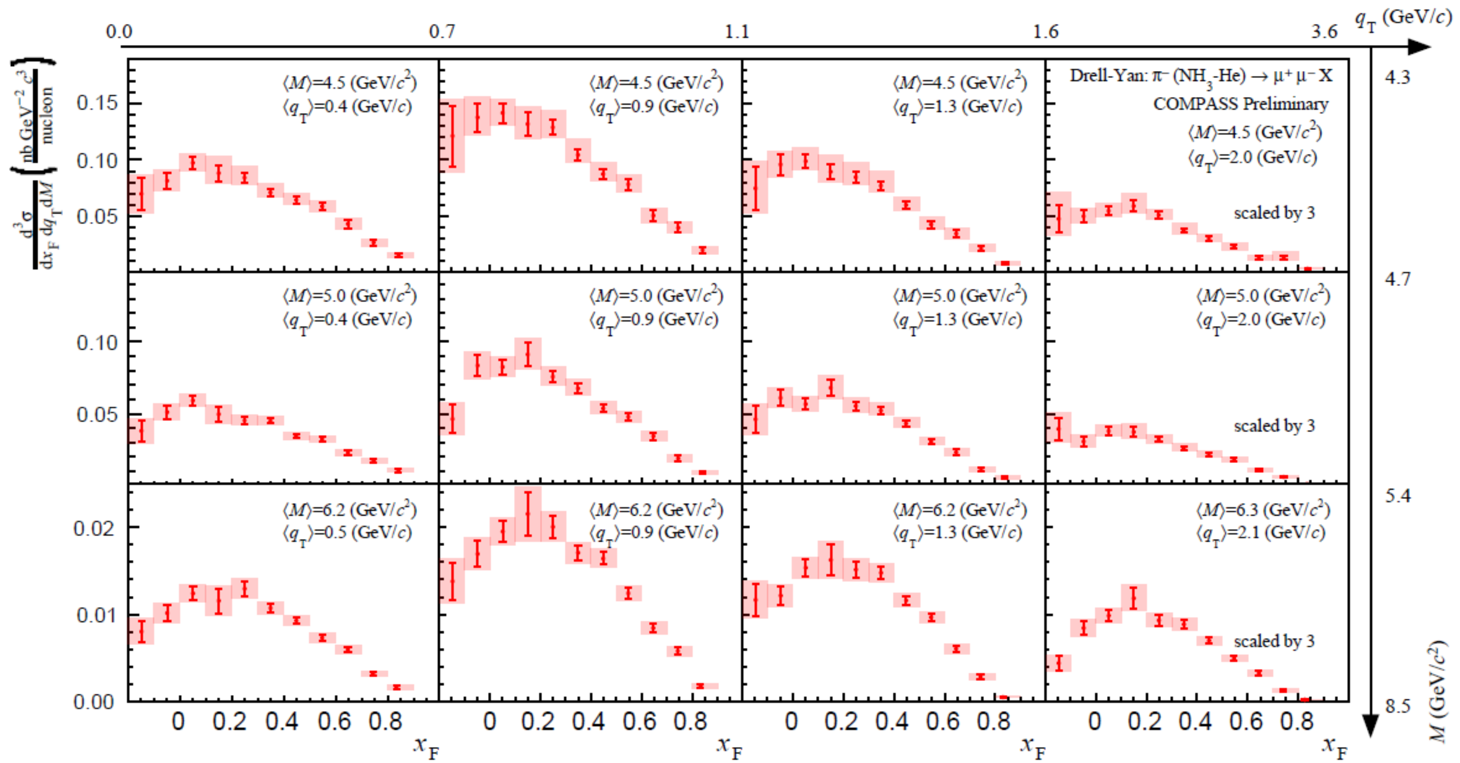




- **Nice agreement between data and MC for NH_3−Hecells.**
- Similar level agreement for the other targets.
- However, slightly worse for W cells.

3-Dimensional Drell-Yan Cross Sections NH_3−He Target

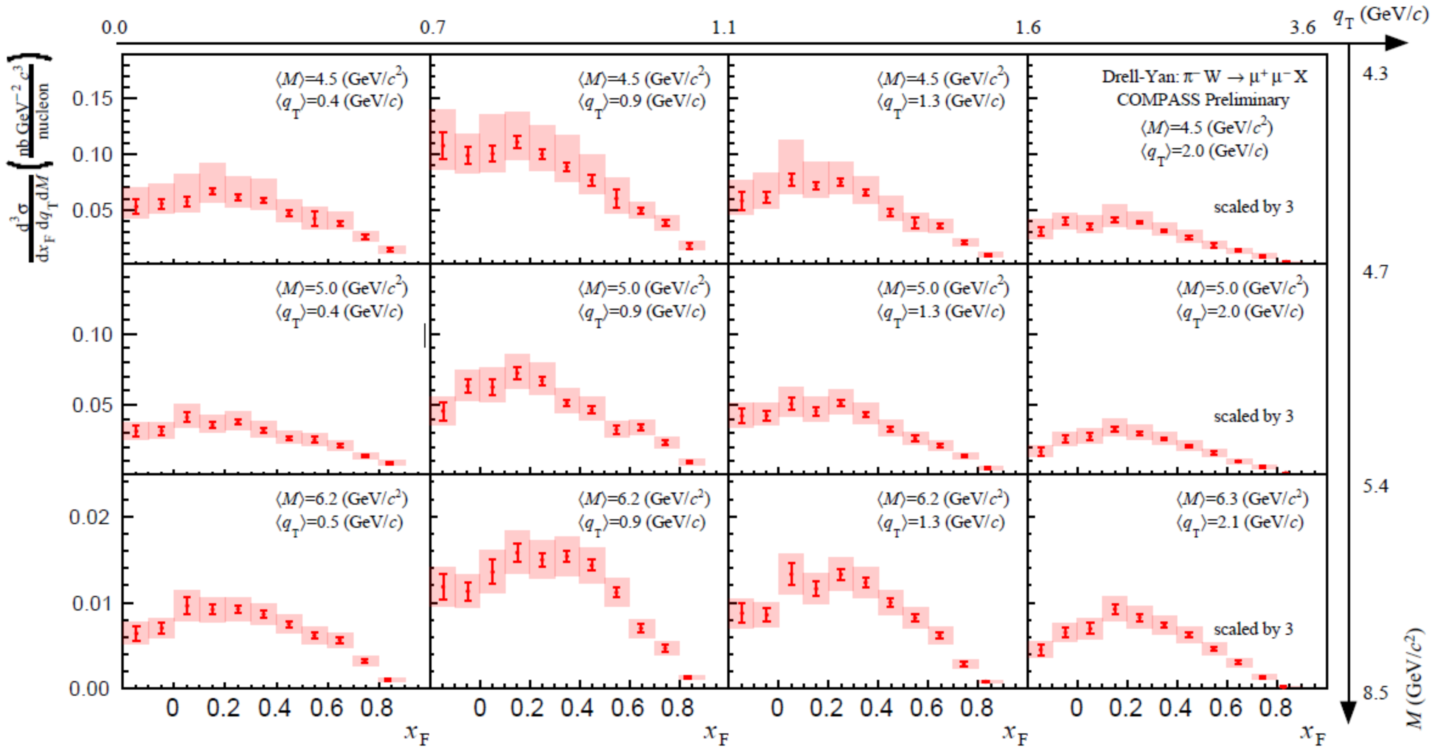
NH_3−He target



- COMPASS provides the **first three-dimensional cross sections** for pion-induced DY experiment.
- Systematics is extracted in three dimensional.
- Data from light target is provided with small systematics and statistical uncertainty.

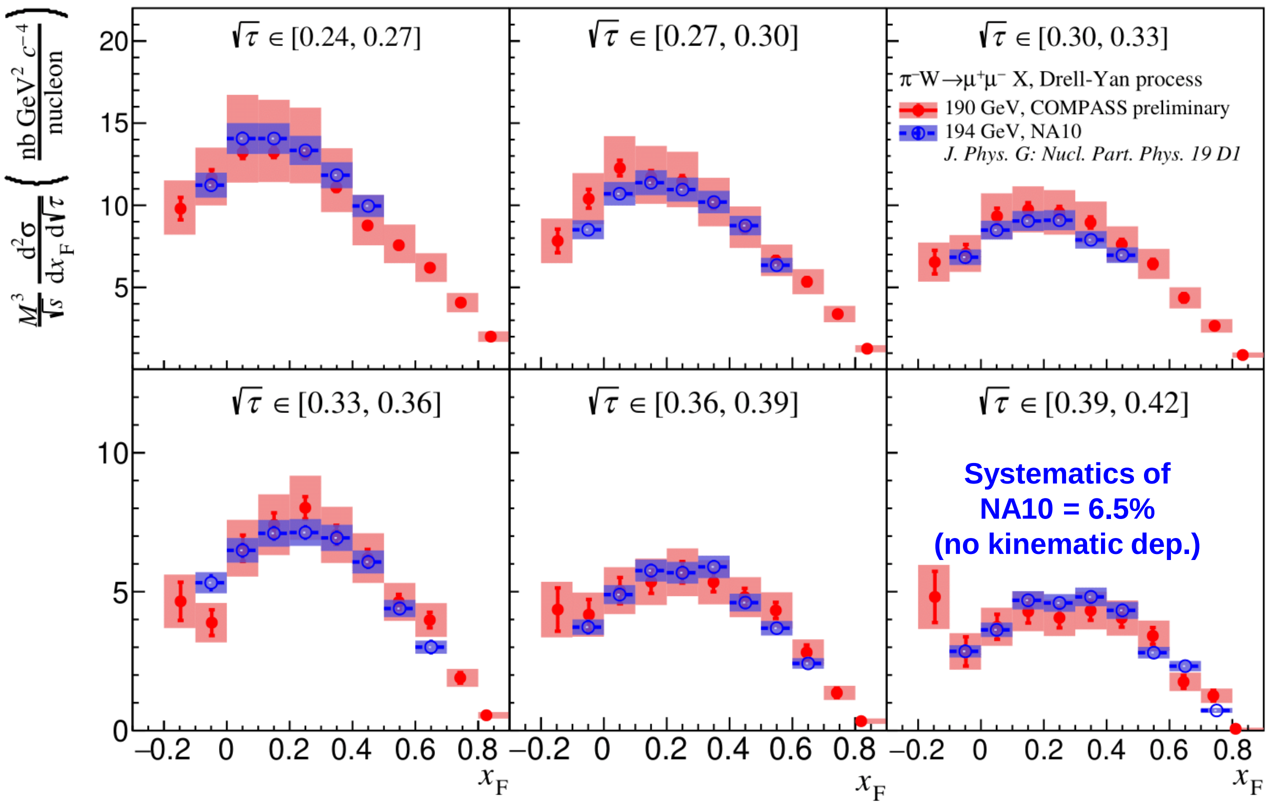
3-Dimensional Drell-Yan Cross Sections W Target

W target



The systematics of W target in low mass is large due to the purity extraction.

COMPASS Results Compare with NA10 Experiment with W Target

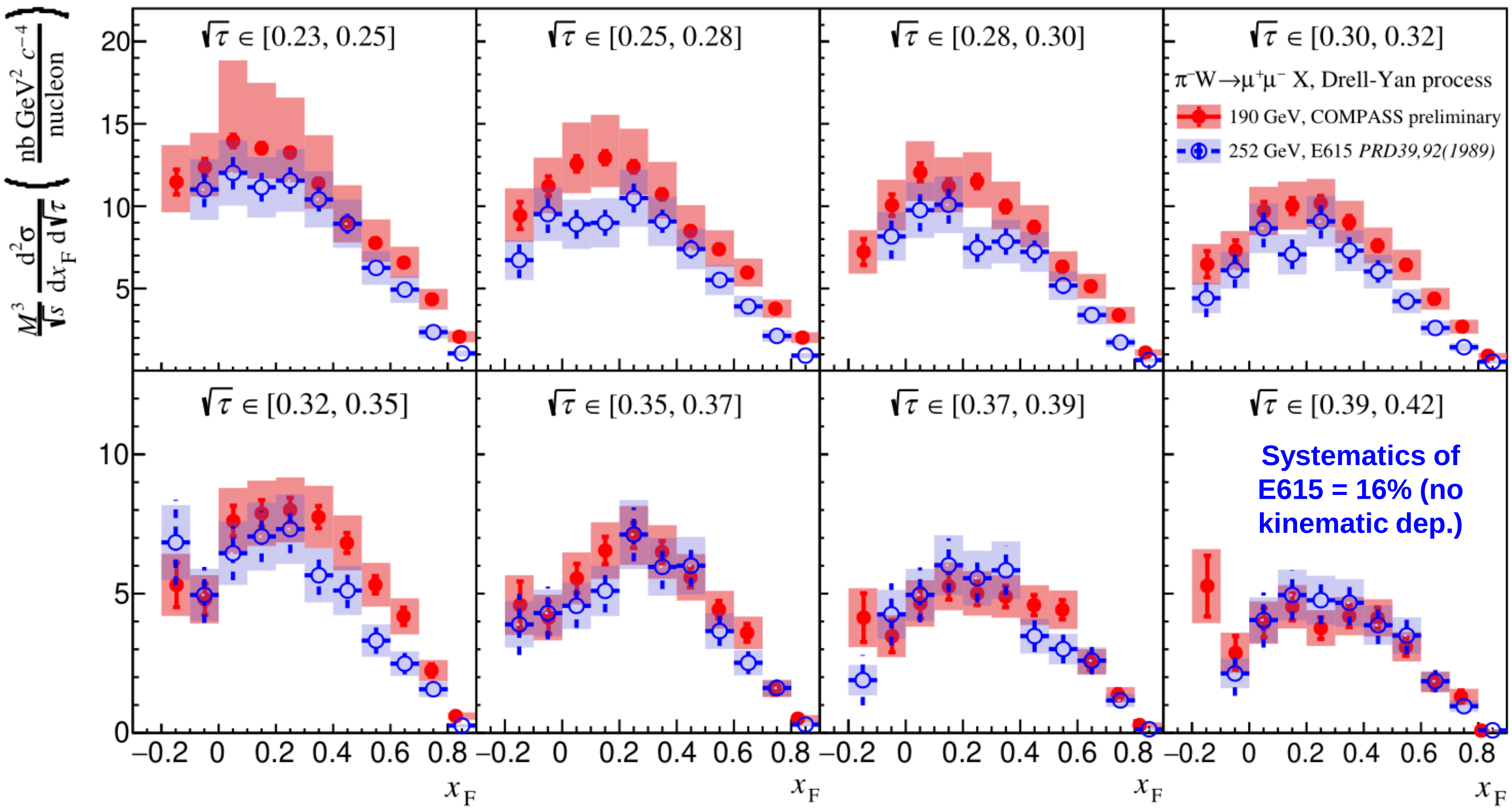


$$\tau = \frac{M^2}{s}$$

- Comparison with NA10 194 GeV data

① Good agreement
② COMPASS has larger kinematic coverage in x_F.
③ NA10 has smaller statistical and systematic uncertainties.

COMPASS Results Compare with E615 Experiment with W Target

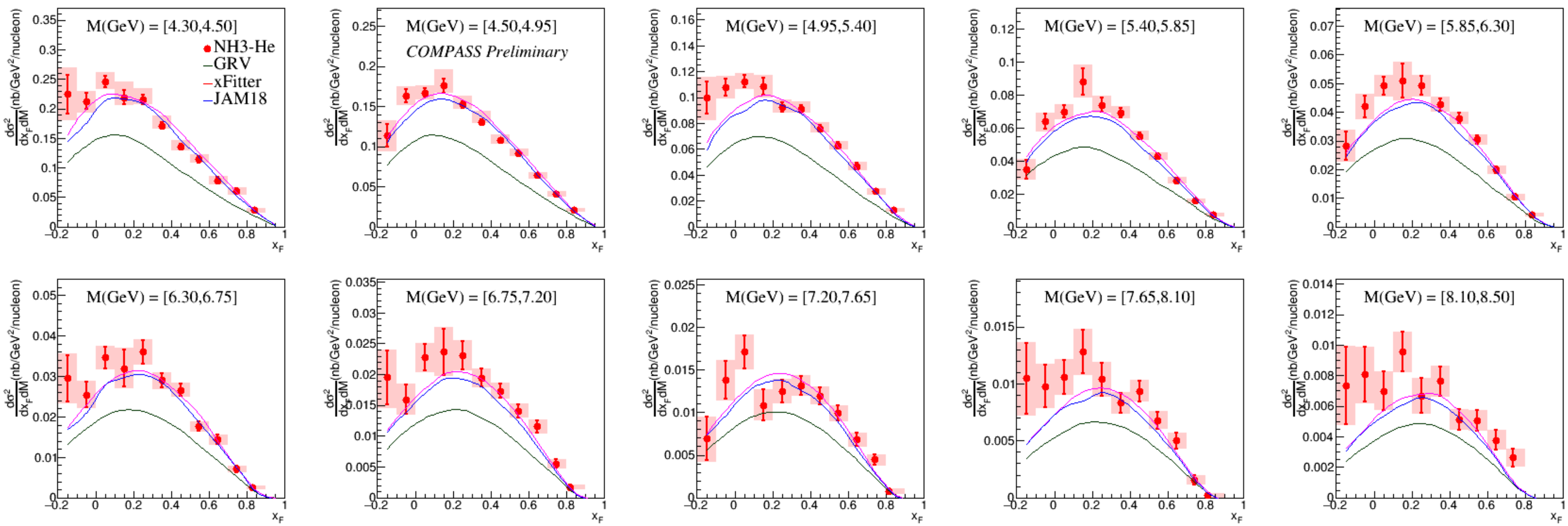


$$\tau = \frac{M^2}{s}$$

- Comparison with E615 252 GeV data

Reasonable agreement at high mass, systematics above at low mass.

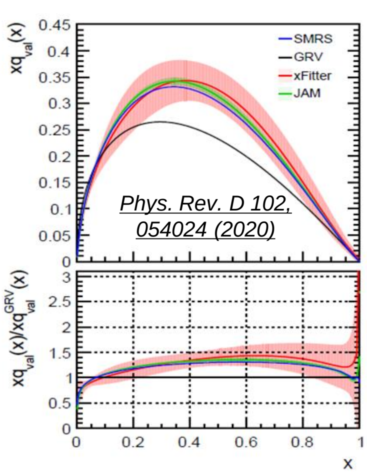
COMPASS Results Compare with DYNNLO Calculation



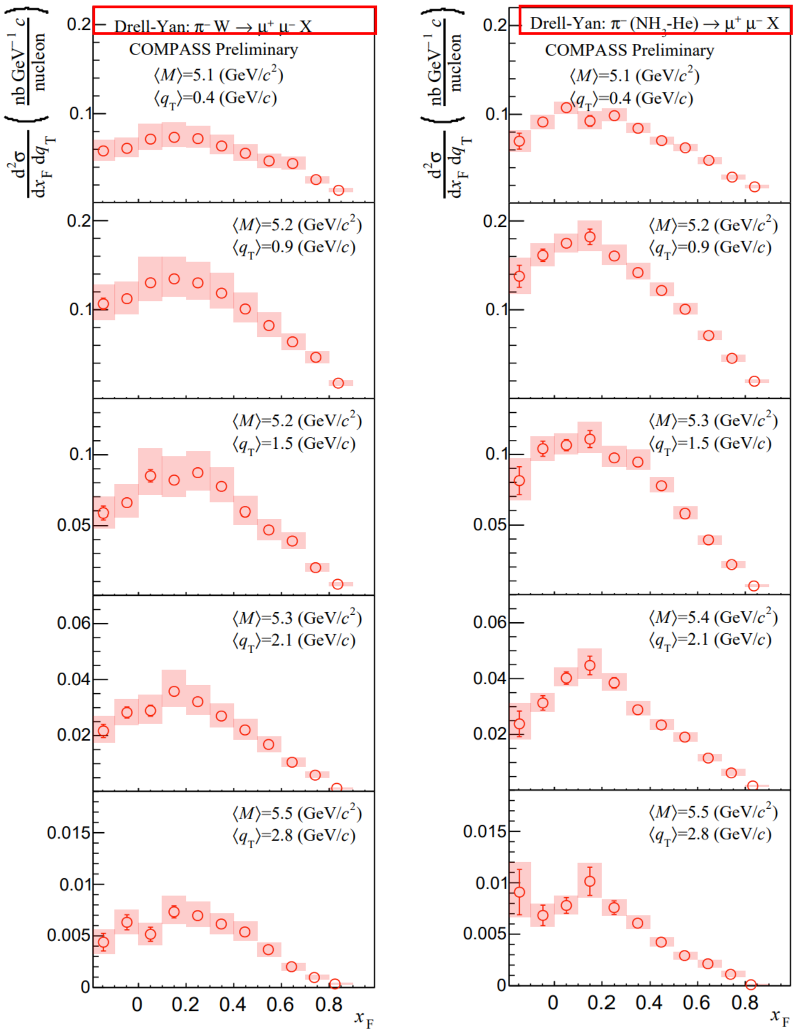
- DYNNLO Calculation (Phys.Rev.Lett.103:082001,2009)
- **NH_3−He PDF : molar fraction of nCTEQ PDF.**
- Calculations for the NH_3−He target are based on private communications with Wen-Chen Chang (Academia Sinica).

- **COMPASS data has nice agreement w/ DYNNLO calculation of xFitter and JAM. The normalization from GRV is low. The reason could be the low valence contribution from GRV.**

Valence @ Q^2 = 9.6 GeV^2

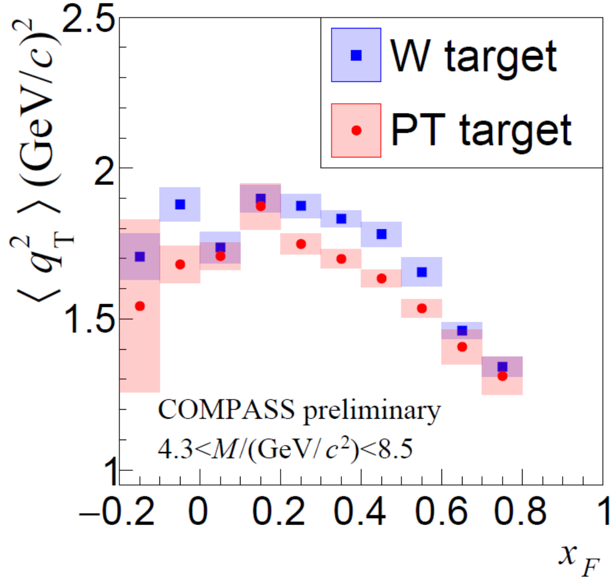


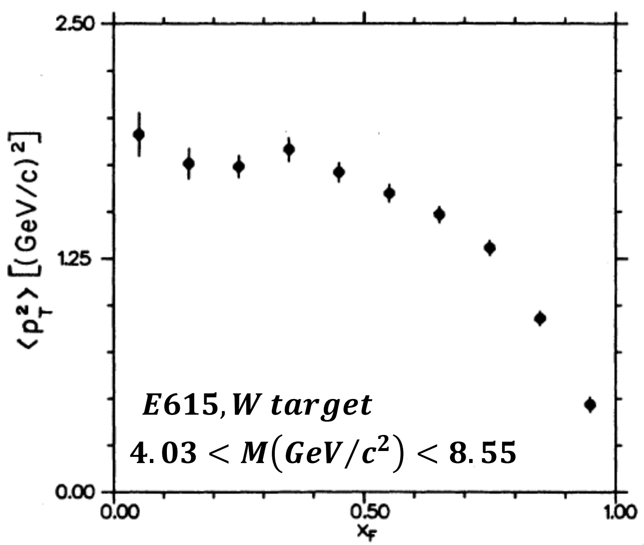
Differential Cross Sections in q_T



These q_T dependence data could provide further constraints on pion TMD PDF.

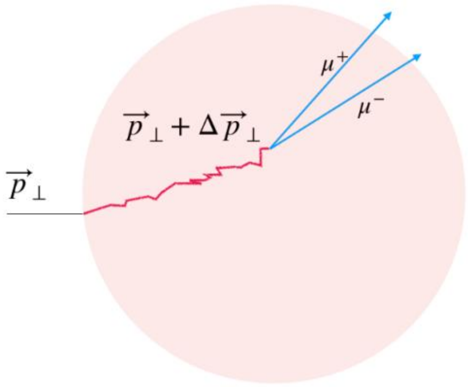
Mean $\langle q^2_T \rangle$ versus x_F for Two Targets



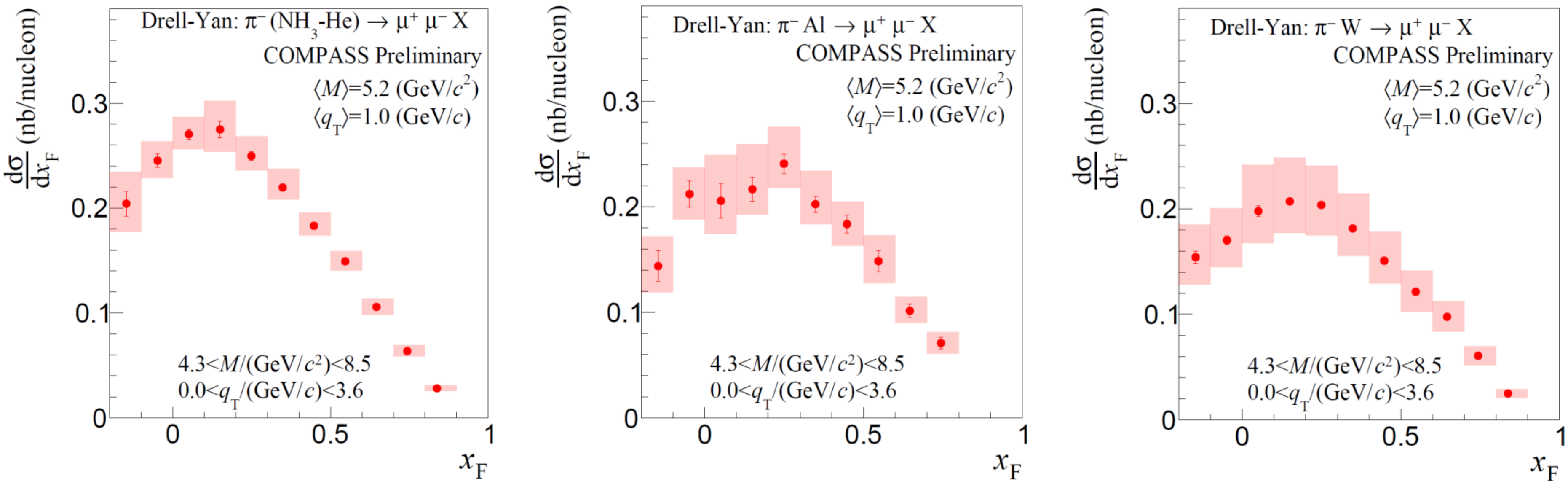


Phys.Rev.D 39 (1989) 92-122

- $\langle q^2_T \rangle$ is studied to observe q_T broadening effect which indicates the stronger quark multiple scattering in heavier target.
  - $\langle q^2_T \rangle$ increases for W target
  - $\langle q^2_T \rangle$ drops as x_F increases (for both targets).



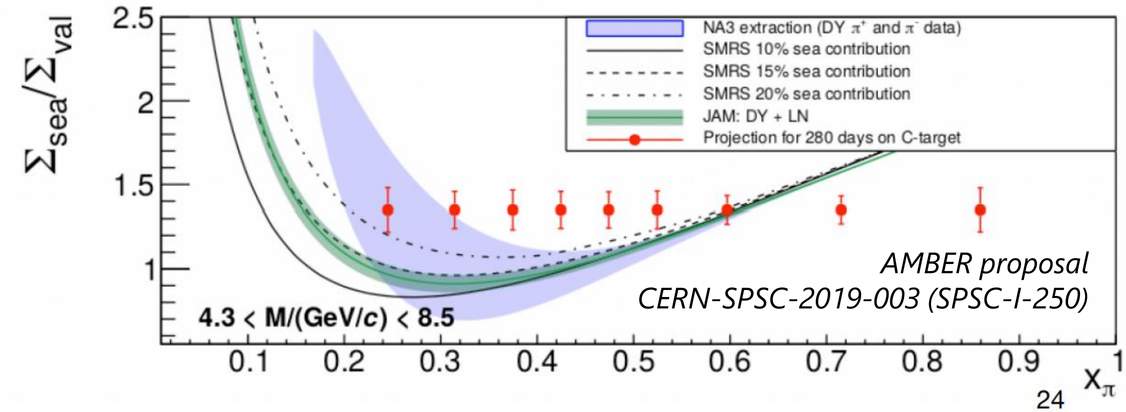
Differential Cross Sections for Various Targets versus x_F



The ratio of Drell-Yan cross sections between heavy and light nuclear targets provides an access to cold nuclear effects.

Future Projects for Pion PDF Study

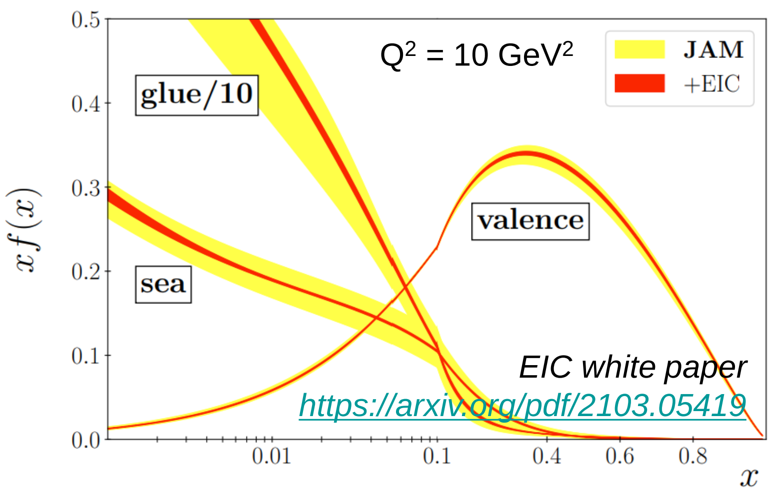
- **AMBER : Pion induced Drell-Yan process, p**ositive and negative pion beam on carbon and tungsten target.



$$\frac{\Sigma_{sea}}{\Sigma_{valence}} = \frac{4\sigma^{\pi^+C} - \sigma^{\pi^-C}}{-\sigma^{\pi^+C} + \sigma^{\pi^-C}}$$

To measure poorly known sea quarks.

- **EIC : Leading-neutron DIS process,** 10 GeV electron beam collides with 135 GeV proton.



Wide kinematic coverage to better constrain not only gluon but also valence.

Summary

- We report the new results from the pion-induced Drell-Yan cross sections measurements on several targets from COMPASS.
- These new data provide independent check of previous NA10 and E615 data. In terms of the normalization, COMPASS is better consistent with NA10 data.
- Multi-dimensional differential cross sections from these new COMPASS data would lead to improved extractions of pion PDFs as well as unpolarized pion TMD PDFs. Especially our data from light target (NH_3−He)could reduce the nuclear effect in the extraction.
- The new COMPASS data also provide new information on the nuclear effects of the Drell-Yan process, including the q_T broadening and the partonic energy-loss effects.
- Future measurements on the pion PDFs are anticipated for the upcoming AMBER, JLab, EIC, EicC.