Drell-Yan cross-section measurement at COMPASS

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on behalf of the COMPASS Collaboration

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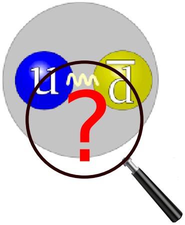
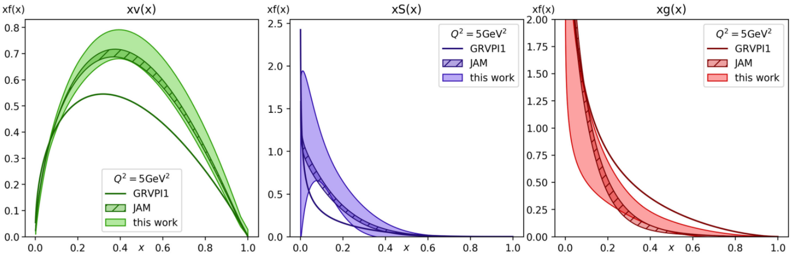
Pion structure

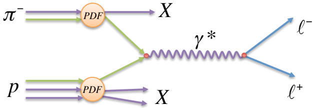
In principle the simplest hadron and yet still pretty unknown structure





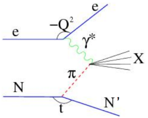
I. Novikov *et al.* PRD 102 014040 (2020)

Drell-Yan



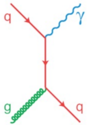
$\rightsquigarrow$ valence contribution

Sullivan process



$\rightsquigarrow$ sea contribution

Prompt photon



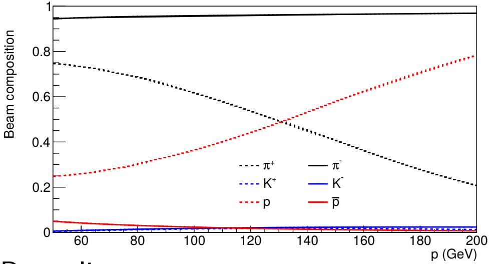
$\rightsquigarrow$ gluon contribution

Renew of interest with foreseen measurements at AMBER, JLab and EIC ...

COMPASS can already contribute

COMPASS Collaboration at CERN

$\sim$ 200 physicists from 25 institutions from 13 countries

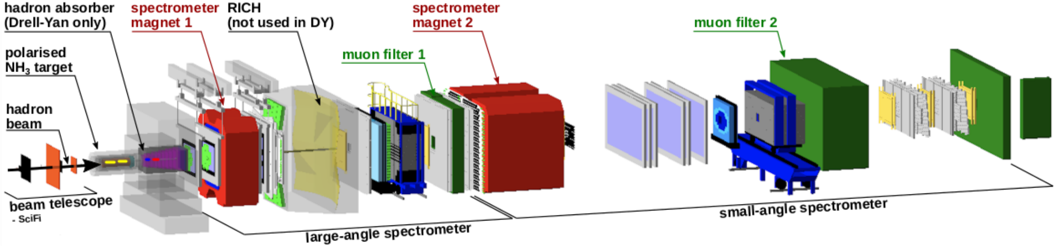


Beam line:

- High intensity hadron beam: $\sim$70 MHz
- High energy: 190 GeV
- Negative hadron beam composition:
    - **97% pions**
    - 2% kaons
    - 1% anti proton

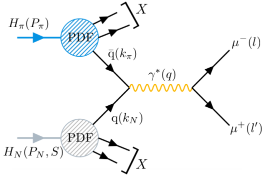
Apparatus: Two-stage spectrometer

NIMA 577 (2007) 455, NIMA 779 (2015) 69, NIMA 1025 (2022) 166069



Key elements:

- Versatile target area configuration
- **2 triggering systems**
- 2 spectrometers in 1 for a wide coverage:
  8mrad$<\theta_\mu<$160mrad $\rightarrow$ -0.2$<x_F<$0.9
- 2 Muon filters
- $\sim$ 400 tracking planes



Variable definitions:

$M^2 = (p_{\mu^+} + p_{\mu^-})^2$

q^*_L: Photon long. momentum in π-N rest frame

$$x_F = \frac{2q^*_L}{\sqrt{s}}$$

$$x_{\pi/N} = \frac{1}{2}\left(\sqrt{x_F^2 + 4\frac{M^2}{s}} \pm x_F\right)$$

Zoom on the target region

Light nuclei from spin average polarised target:
mixture of **NH_3** & **LHe**:

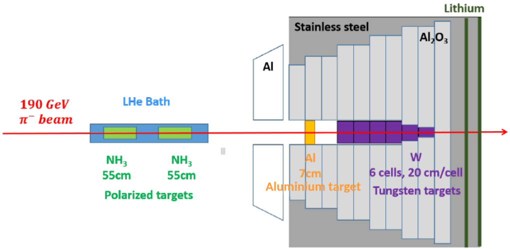
molar fraction of nucleons:

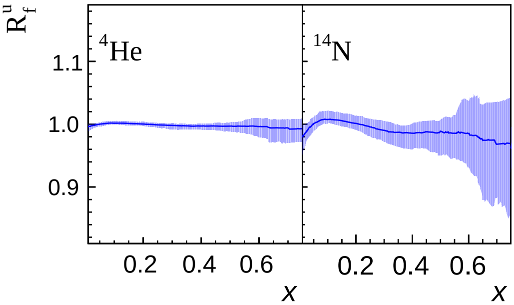
H	He	N
15.7%	11.1%	73.2%

$\sim \pm 2\%$ in the accessible region

Target will be denoted NH_3-He in the following

Two nuclear targets:
intermediate and large A: **Al** & **W**



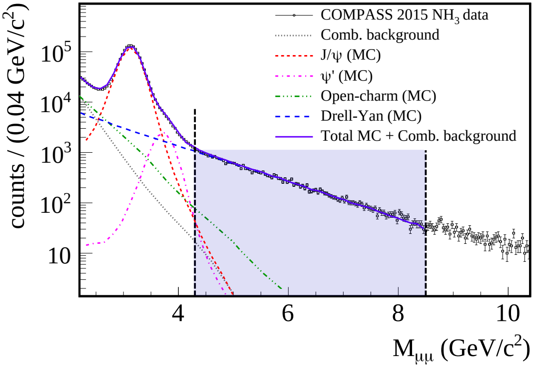


Nuclear modification PDF for *u*-quark from nNNPDF3.0

Mass spectra and region of interest

Several channels contribute to inclusive dimuon final state production:

- Combinatorial background
- Open-Charm production in low mass
- Resonances: J/ψ and ψ'
- Drell-Yan in high mass

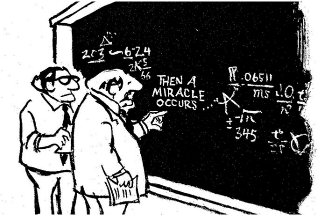


Statistical separation based on the different kinematic dependence with various Monte-Carlo samples and the combinatorial background distribution assessed from like-sign pairs in real data ($2\sqrt{N^{++}N^{--}}$): "Cocktail fit"

Collected pairs in the region of interest 4.3 GeV/c^2 to 8.5 GeV/c^2:
NH_3-He: 36 000 Al: 6 000 W: 43 000

Long way to cross-section measurement

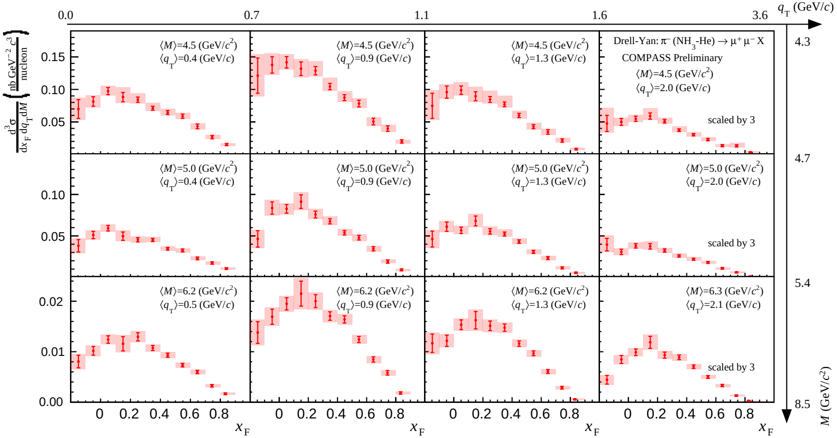
Recorded number of dimuons



Drell-Yan cross section

1. Process purity $> 90\%$ for $M/(\mathrm{GeV}/c^2) > 4.3$, 4.9 and 5.5 in NH_3-He, Al and W
2. Acceptance: between 1 and 20 %
3. Luminosity
4. Trigger system normalisation
5. . . .

3 dimensional Drell-Yan cross section on NH_3-He

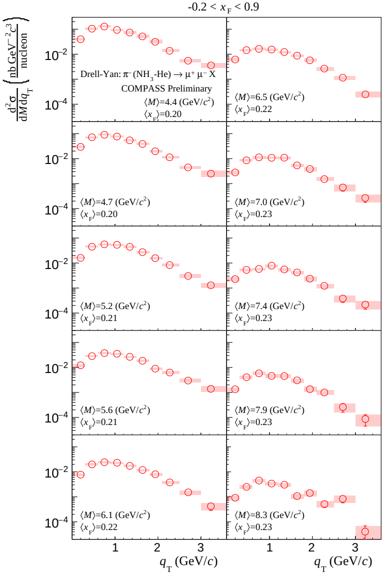


- **First high statistics measurement with light material**
- Red line/shaded area: statistical / total (stat. and syst.) uncertainties
- Dominated by statistical uncertainty

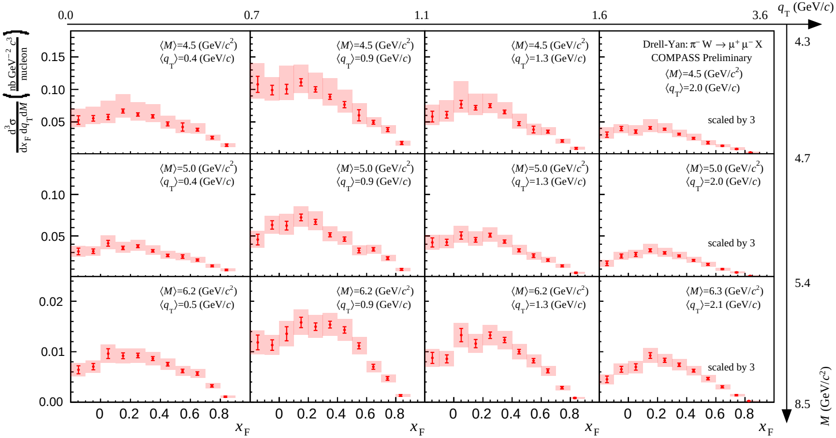
q_T dependence of Drell-Yan cross section on NH_3-He

Unique inputs to extract π TMD PDF with minimum nuclear effects

Systematics uncertainty at the level of statistical precision

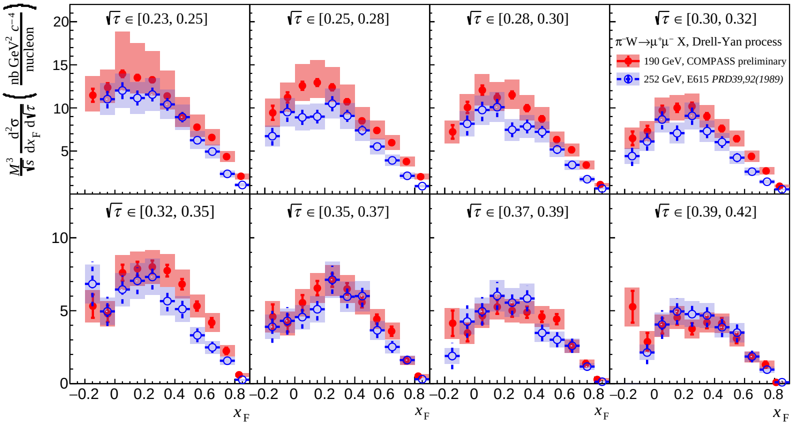


3 dimensional Drell-Yan cross section on W



- Wide kinematic coverage
- Red line/shaded area: statistical / total (stat. and syst.) uncertainties
- Dominated by systematic uncertainty

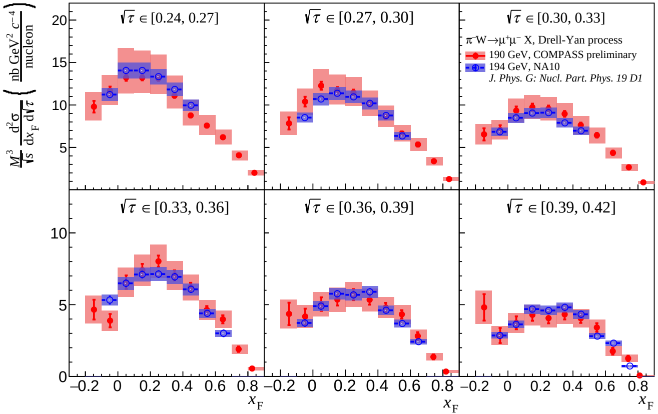
Drell-Yan cross section on W and comparison to E615



$$\sqrt{\tau} = M/\sqrt{s}$$

- **New results since 30 years**
- Similar kinematic coverage as E615
- Better statistics, similar total systematics except for the low mass region

Drell-Yan cross section on W and comparison to NA10



$$\sqrt{\tau} = M/\sqrt{s}$$

- **Wider kinematic coverage**
- Worse accuracy in statistics as well as in systematics

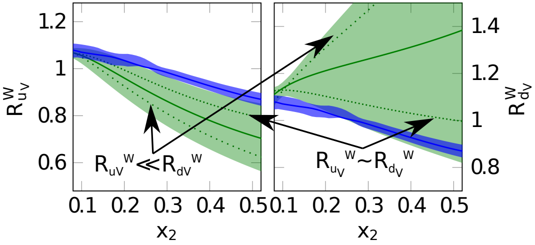
Nuclear dependence studies

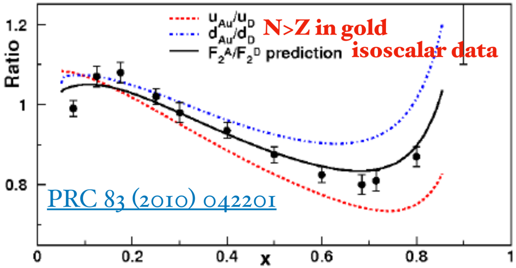
Flavour dependent EMC effect:

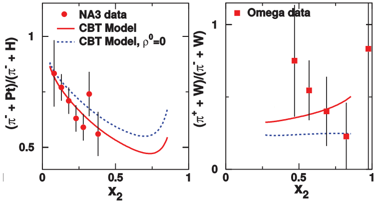
Unlike DIS, π-induced Drell-Yan process tags the quark flavour

nCTEQ15: unconstrained flavour dependence

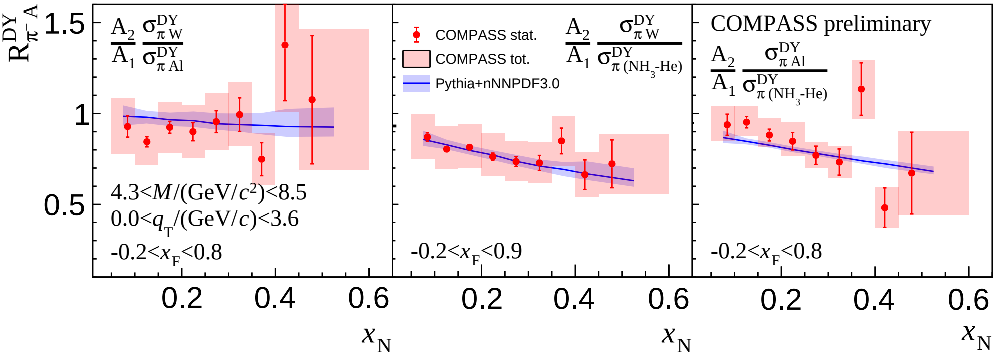
EPS09: no flavour dependence







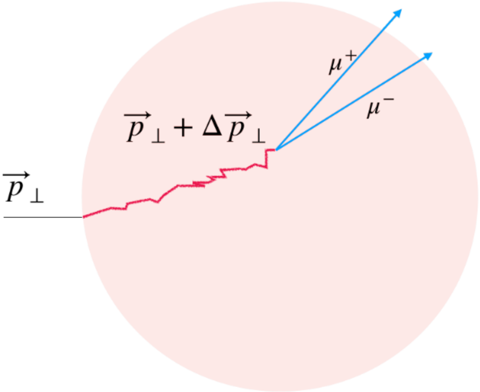
Flavour dependence of $R^{DY}_{\pi A}(x_N) = (A_2 d\sigma^{DY}_{\pi A_1})/(A_1 d\sigma^{DY}_{\pi A_2})$



- Ratio of integrated DY cross section per nucleon in all but x_N variable
- Covering the domain of EMC effect and end of anti-shadowing
- General trend as expected...
- ... Currently limited by systematics except possibly for Al/(NH_3-He)

Parton energy loss and Cronin effects

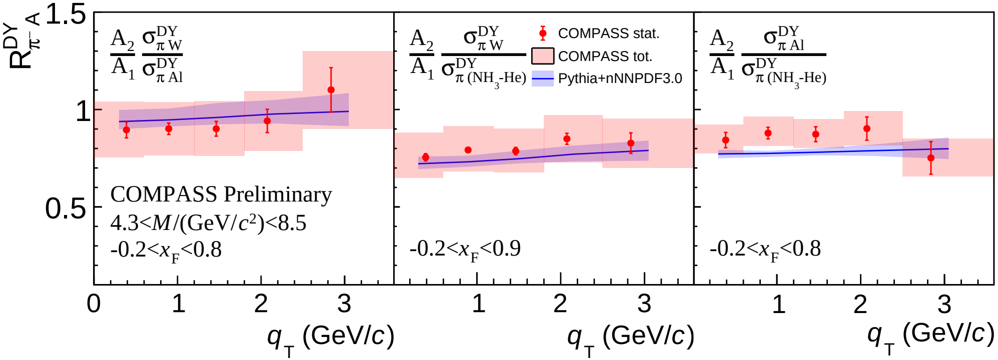
Parton crossing nuclear medium, looses energy due to multiple scattering and gluon emission



Signatures:

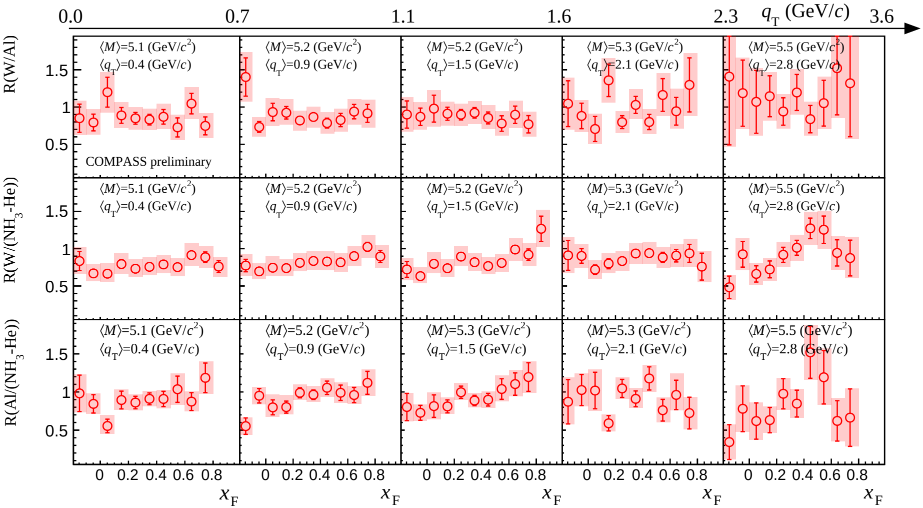
- Gain of transverse momentum:
  q_T Broadening
- Loss of longitudinal momentum:
  Suppression at large x_F

Drell-Yan nuclear modification factor $R^{DY}_{\pi A} = (A_2 d\sigma^{DY}_{\pi A_1})/(A_1 d\sigma^{DY}_{\pi A_2})$ vs q_T



- Ratio of integrated DY cross section per nucleon in all but q_T variable
- Measurements are in agreement with effective effects encoded in nPDF
- Currently limited by systematics except possibly for Al/(NH_3-He)

Drell-Yan nuclear modification factor $R(A_1/A_2)$ in x_F for various q_T bins



Steeper slope in x_F at large q_T mainly in W/(NH$_3$-He) and Al/(NH$_3$-He)

Soon in bins of x_N to disentangle from anti-shadowing and EMC effects

Conclusion and Outlook

$\Rightarrow$ COMPASS has released a wealth of preliminary Drell-Yan cross sections

$\Rightarrow$ High statistics measurement is available on a light target

$\Rightarrow$ Systematics uncertainties are at the same order of magnitude as E615

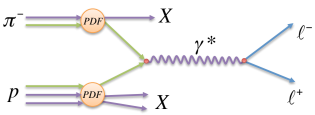
Perspective:

Finalisation of Drell-Yan cross-section measurements in the coming months expected

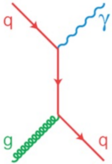
BACKUP

How to probe the meson structure?

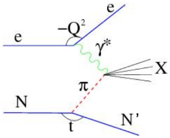
Drell-Yan



Prompt photon



Sullivan process



π^--induced Drell-Yan measurements:

W.J. Stirling and M.R. Whalley 1993 J. Phys. G: Nucl. Part. Phys. 19 D1

Experiment	Target type	Beam energy (GeV)	DY mass (GeV/c^2)	DY events	Systematics
NA3	30cm H_2	200	4.10 – 8.50	121	12.6%
	6cm Pt	200	4.20 – 8.50	4,961	
NA10	120cm D_2	286	4.2 – 8.5	7,800	6.5%
		140	4.35 – 8.5	3,200	
	12cm W	286	4.2 – 8.5	49,600	
		194	4.07–15.19	155,000 (inc. Υ)	
		140	4.35 – 8.5	29,300	
E615	20cm W	252	4.05 – 8.55	30,000	16%

Situation for the other experiments

- NA10: Estimated to be negligeable and no correction
- E615: Evaluation with MC technique and subtraction