Pion-induced Drell-Yan cross-section measurements at COMPASS

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on behalf of the COMPASS Collaboration

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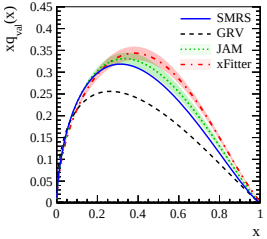
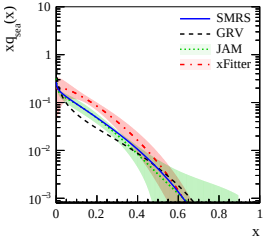
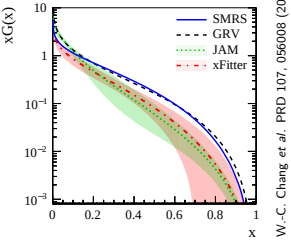
Pion structure

In principle the simplest hadron and yet still pretty unknown structure

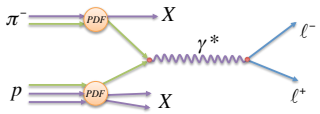




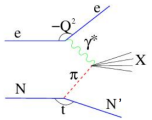


W.-C. Chang *et al.* PRD 107, 056008 (2023)

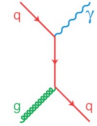
Drell-Yan



Sullivan process



Prompt photon



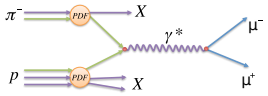
$\rightsquigarrow$ valence contribution

$\rightsquigarrow$ sea contribution

$\rightsquigarrow$ gluon contribution

Current experimental results are too scarce or not accurate enough to constrain phenomenological approaches

Landscape of π^--induced Drell-Yan



Variable definition:

- $M^2 = (p_{\mu^+} + p_{\mu^-})^2$
- q_T: Photon transverse momentum
- q_L^*: Photon long. momentum in π-N rest frame
- $x_F = \frac{2q_L^*}{\sqrt{s}}$
- $x_{\pi/N} = \frac{1}{2}\left(\sqrt{x_F^2 + 4\frac{M^2}{s}} \pm x_F\right)$

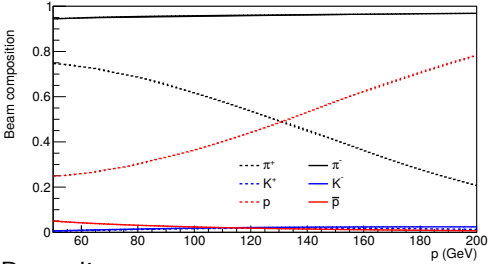
W.J. Stirling and M.R. Whalley 1993 J. Phys. G: Nucl. Part. Phys. 19 D1

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%

COMPASS can already contribute

COMPASS Collaboration at CERN

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

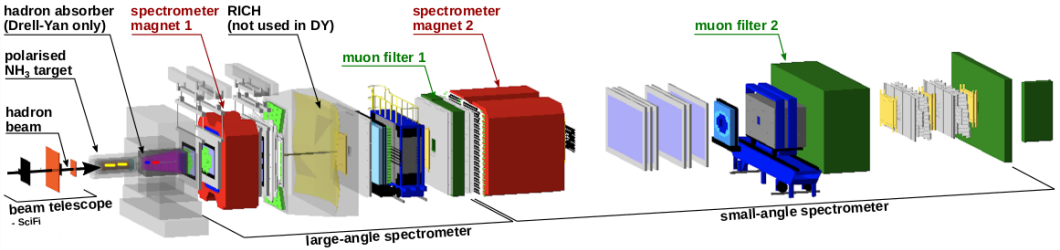


Beam line:

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

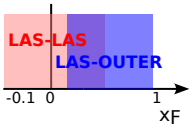
Apparatus: Two-stage spectrometer

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



Key elements:

- Versatile target area configuration
- 2 spectrometers in 1 for a wide coverage: 8mrad$<\theta_\mu<$160mrad
- **2 triggering system:**
  - LAS-LAS
  - LAS-OUTER
- 2 Muon filters
- $\sim$ 350 tracking planes



Approximate resolutions:

Target	δx_F	δq_T (MeV/c)	$\delta M/M$
Pol. targ.	0.03	150	3.5%
Al	0.03	245	4.5%
W	0.03	340	6.5%

Zoom on the target region

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

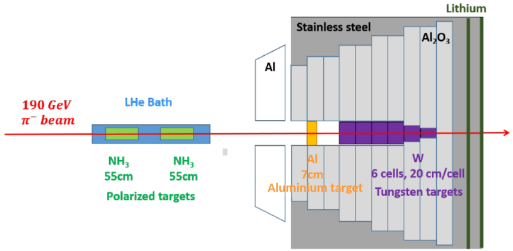
molar fraction of nucleons:

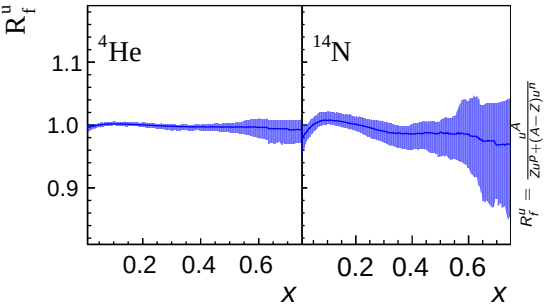
H	He	N
15.7%	11.1%	73.2%

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

Target will be denoted NH_3-He in the following

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



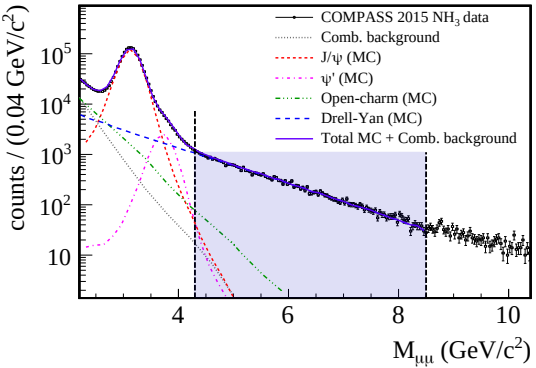


Nuclear modification PDF for u-quark from nNNPDF3.0

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

Evaluation of Drell-Yan process purity

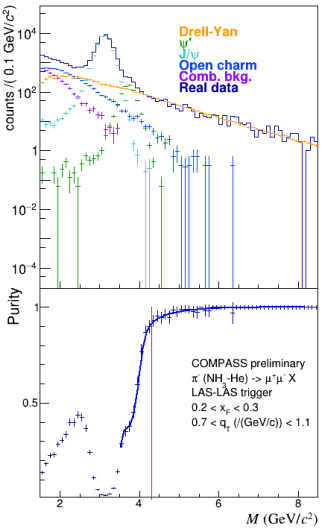
"Cocktail fit" from $M = 2.4$ (GeV/c^2) for each kinematic bins of cross-section

Process purity is assessed from the ratio of Drell-Yan component to the total and accounted for in the analysis

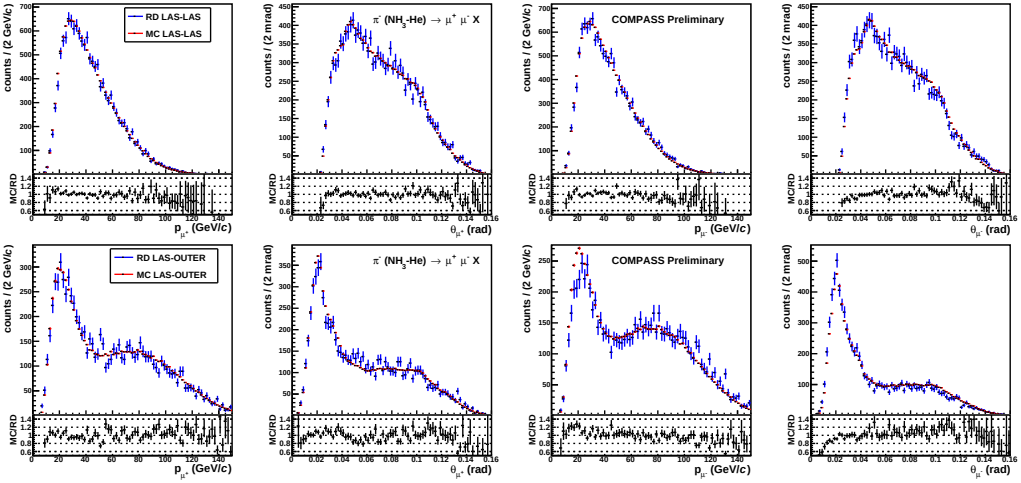
Purity is above 90% for

- $M > 4.3$ (GeV/c^2) for NH_3-He
- $M > 4.7$ (GeV/c^2) for Al
- $M > 5.5$ (GeV/c^2) for W

with mild ↗ with x_F & ↘ with q_T



Compare real data with Monte-Carlo for the first cell of NH_3-He target

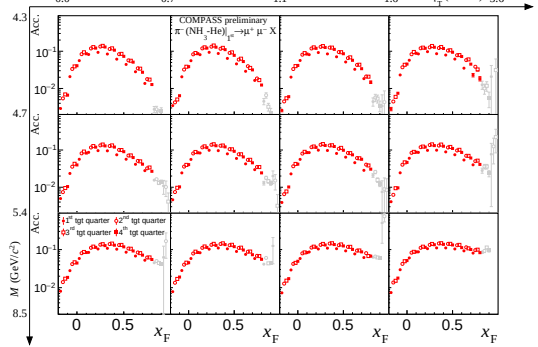


Good description of lab variables with weighted MC sample for $M > 4.3$ (GeV/c^2)
Similar level of agreement for other targets, except for W which shows larger variations

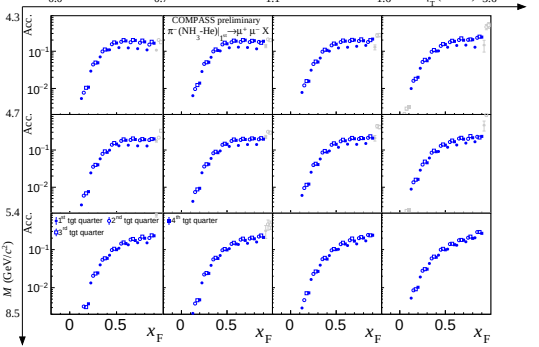
Acceptance example for the first cell of NH_3-He target

Determined from pure Drell-Yan Monte-Carlo sample in 4 dimensions: x_F, M, q_T, Z_{vertex}

LAS-LAS trigger

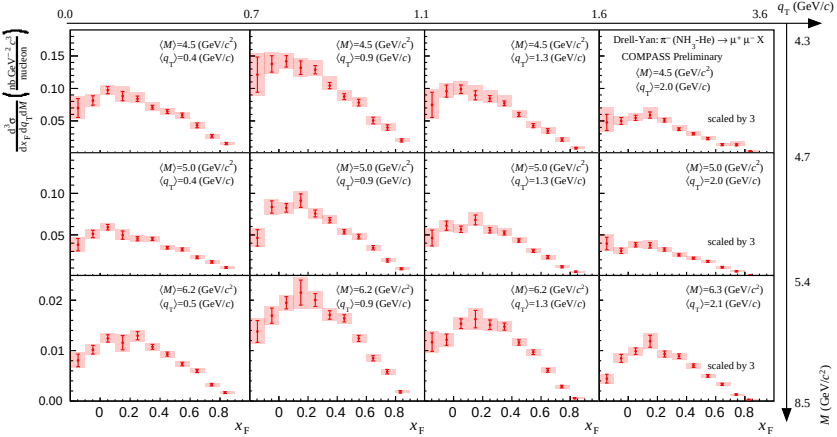


LAS-OUTER trigger



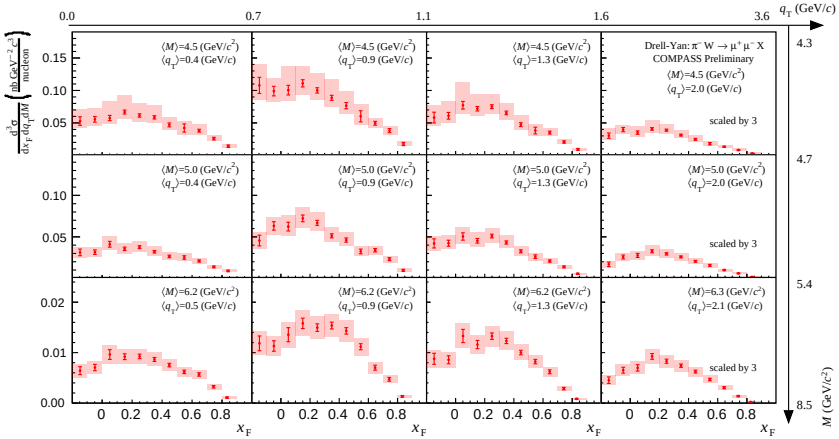
Acceptance restricted to domain where statistical accuracy is better than 10%
it varies between $\sim$1 to $\sim$20% with largest dependence on x_F

3 dimensional Drell-Yan cross section on NH_3-He



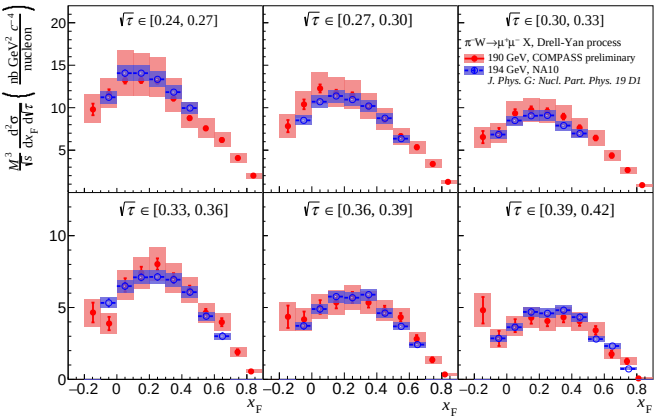
- **First high statistics measurement with light material**
- Red line/shaded area: statistical / total (stat. and syst.) uncertainties
- Dominated by statistical uncertainty

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 NA10

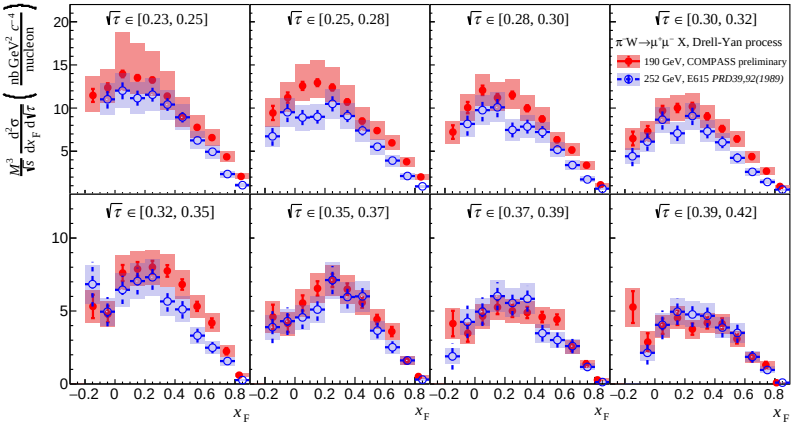


New results since 30 years

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

- **Wider kinematic coverage**
- Worse accuracy in statistics as well as in systematics
- Good agreement with NA10 results

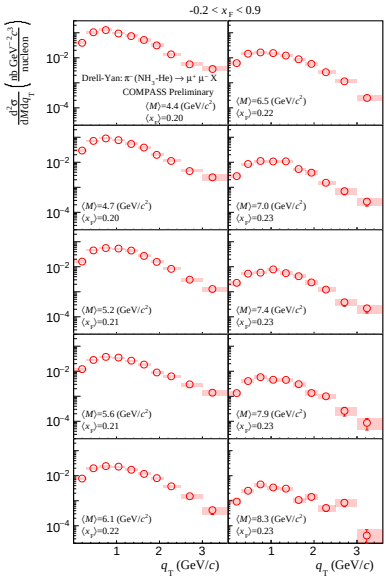
Drell-Yan cross section on W and comparison to E615



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

- Similar kinematic coverage as E615
- Better statistics, similar total systematics except for the low mass region
- Reasonable agreement at high masses, systematically above at low masses

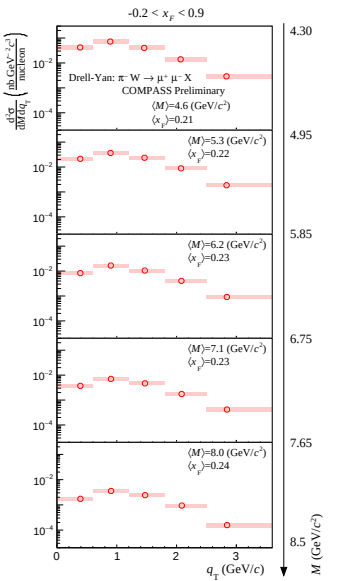
q_T dependence of Drell-Yan cross section



New inputs to extract π TMD PDF with minimum nuclear effects in $\Leftarrow$ NH_3-He

and W target $\rightarrow$
for comparison with past experiments (E615 and E532)

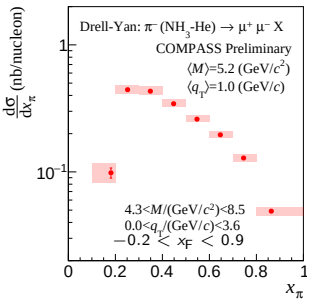
Systematics uncertainty at the level of statistical precision



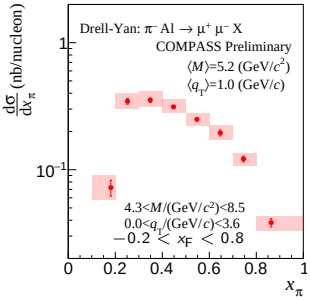
Drell-Yan cross section versus x_π

For completeness: cross-section results available for light, medium and heavy targets

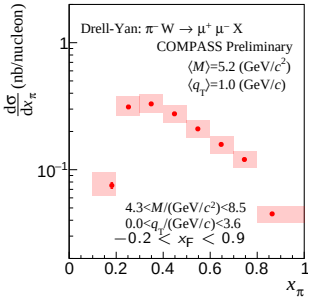
NH_3-He



Al



W



Inputs to study nuclear effects (not shown today):

- Parton energy loss
- Cronin effect
- EMC effect

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

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

Perspective:

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

Brand new inputs to constrain the Pion TMD-PDFs

BACKUP

Situation for the other experiments

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