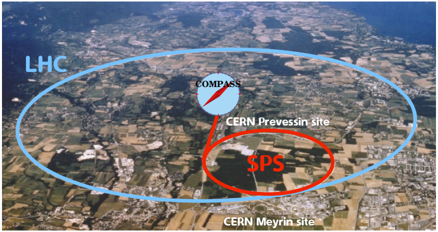
COMPASS Drell–Yan programme: recent results

Jan Matoušek
on behalf of the COMPASS collaboration
CERN, Geneva, Switzerland,
Faculty of Mathematics and Physics
Charles University, Prague, Czechia

International Workshop on Hadron Structure and Spectroscopy 2022
30. 8. 2022, CERN

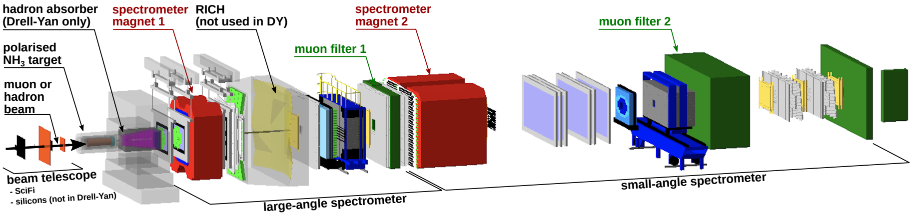
CHARLES UNIVERSITY
Faculty of mathematics
and physics

COMPASS



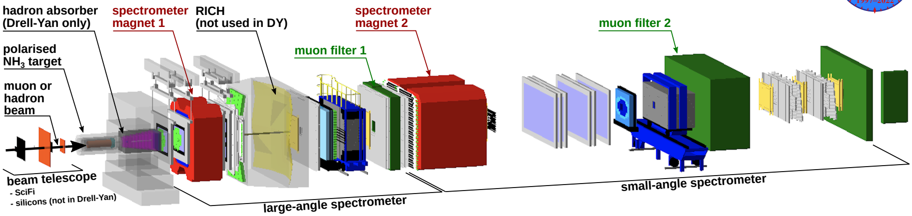
It is located at M2 beamline of CERN's SPS.

- Collaboration: 24 institutes, 13 countries.
- SIDIS with 160 GeV (200 GeV) μ^+ beam and longitudinally/transversely-polarised proton (NH_3) or deuteron (^{6}LiD) target
  Talks: G. Mallot, F. Bradamante, A. Bressan.
- Hadron spectroscopy with hadron beams and nuclear targets. Talks: S. Paul, D. Ecker.
- Drell–Yan with 190 GeV π^- beam and $p^\uparrow$ (NH_3), Al, W targets. This talk, A. Khatun.
- Hard exclusive processes and SIDIS with 160 GeV/c $\mu^\pm$ beam and liquid H_2 target.
  Talks: N. d'Hose, M. Pešková, A. Moretti.

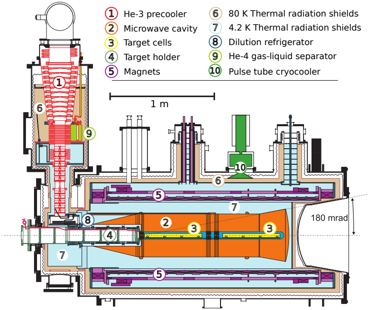


Drell–Yan setup (2015 and 2018).

Drell–Yan programme



Drell–Yan setup (2015 and 2018).



Polarised target

- Data taking 2015 + 2018 ($\approx 2 \times 200$ days).
- 190 GeV π^- beam.
- COMPASS spectrometer.
  - Muon identification.
  - Di-muon triggers: LAST–LAST: lower x_F,
    LAST–Outer: higher x_F.
- Transversely polarised NH_3 target ($p^\uparrow$).
  - Super-conducting 2.5 T solenoid, 0.6 T dipole.
  - MW system for dynamic nuclear polarisation.
  - Dilution refrigerator → 70 mK (‘frozen spin’).
- Al target and W target (‘beam plug’).
- Hadron absorber.

TMDs

Parton polarisation	Parent hadron polarization: Unpolarised	Longitudinal	Transverse
U	$f_1(x, k_T^2)$ (number density)		$f_{1T}^{\perp}(x, k_T^2)$ (Sivers)
L/C		$g_1(x, k_T^2)$ (helicity)	$g_{1T}(x, k_T^2)$ (Kotzinian–Mulders)
T/L	$h_1^{\perp}(x, k_T^2)$ (Boer–Mulders)	$h_{1L}^{\perp}(x, k_T^2)$ (worm-gear)	$h_1(x, k_T^2)$ (transversity) $h_{1T}^{\perp}(x, k_T^2)$ (pretzelosity)

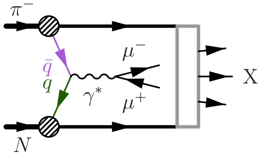
Parton polarisation:

L/C – longitudinal (quarks) or circular (gluons)

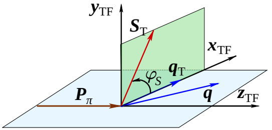
T/L – transverse (quarks) or linear (gluons)

8 leading twist TMD PDFs, 5 of them are relevant for $\pi^- p^{\uparrow}$ Drell–Yan reaction.

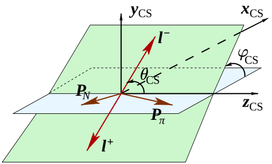
Drell–Yan process in pion–nucleon scattering



Drell–Yan process at LO.



Target frame.



Collins–Soper frame.

Cross-section with transversely polarised target:

$$\frac{d\sigma}{d\Omega} \propto \left(F_U^1 + F_U^2\right)\left(1 + A_U^1 \cos^2\theta_{CS}\right)$$

$$\times \left\{ \begin{array}{l} 1 + D_{[\sin^2\theta_{CS}]} A_U^{\cos 2\varphi_{CS}} \cos 2\varphi_{CS} + D_{[\sin 2\theta_{CS}]} A_U^{\cos\varphi_{CS}} \cos\varphi_{CS} \\ + S_{\mathrm{T}} \left[\begin{array}{l} A_T^{\sin\varphi_S} \sin\varphi_S \\ + D_{[\sin 2\theta_{CS}]} \left(\begin{array}{l} A_T^{\sin(\varphi_{CS}-\varphi_S)} \sin(\varphi_{CS}-\varphi_S) \\ + A_T^{\sin(\varphi_{CS}+\varphi_S)} \sin(\varphi_{CS}+\varphi_S) \end{array} \right) \\ + D_{[\sin^2\theta_{CS}]} \left(\begin{array}{l} A_T^{\sin(2\varphi_{CS}-\varphi_S)} \sin(2\varphi_{CS}-\varphi_S) \\ + A_T^{\sin(2\varphi_{CS}+\varphi_S)} \sin(2\varphi_{CS}+\varphi_S) \end{array} \right) \end{array} \right] \end{array} \right\}$$

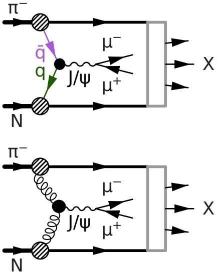
$$D_{[f(\theta_{CS})]} = f(\theta_{CS}) / \left(1 + A_U^1 \cos^2\theta_{CS}\right)$$

Cross-section with unpolarised target:

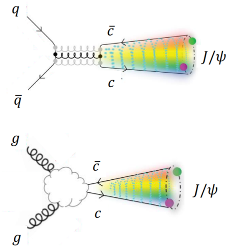
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+1}\left(1 \begin{array}{l} + \lambda \cos^2\theta_{\mathrm{CS}} \\ + \mu \sin 2\theta \cos\varphi_{\mathrm{CS}} \\ + \frac{\nu}{2} \sin^2\theta \cos 2\varphi_{\mathrm{CS}} \end{array}\right).$$

$\lambda = A_{\mathrm{U}}^1$, $\mu = A_{\mathrm{U}}^{\cos\varphi_{\mathrm{CS}}}$ and $\nu = 2A_{\mathrm{U}}^{\cos 2\varphi_{\mathrm{CS}}}$

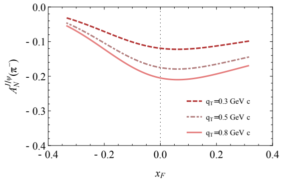
J/ψ production in pion–nucleon scattering



J/ψ production in πp.



The parton level sub-processes[1]

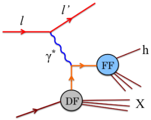


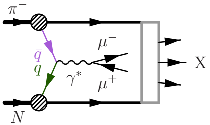
[Anselmino *et al.*. Phys.Lett.B770 (2017)]

- $q\bar{q}$ annihilation: access to quark TMD PDFs.
  - A large Sivers asymmetry at COMPASS was predicted, assuming only $q\bar{q}$.
- gg fusion: access to gluon TMD PDFs.
  - For example, to the d-type Sivers function of gluons.
  - Suggested dominant at COMPASS [Chang *et al.*, Phys.Rev.D102 (2020)]
- Feed-down: dilution of the information on nucleon structure.

[1] Diagrams: courtesy of Pietro Faccioli. The rainbow area = soft interactions (CEM/COM). The cloud = several perturbative contributions.

COMPASS 25 years 1997–2022





SIDIS on transversely polarised nucleons

- Structure functions F:
  $F = \mathrm{PDF}_{q,\mathrm{p}} \otimes \mathrm{FF}_{q\to h}$.
- In particular:
  - $F_{\mathrm{UU}}^{\cos\varphi_\mathrm{h}}$ and $F_{\mathrm{UU}}^{\cos 2\varphi_\mathrm{h}}$ linked to $h_{1,\mathrm{p}}^{\perp}$,
  - $F_{\mathrm{UT,T}}^{\sin(\varphi_\mathrm{h}-\varphi_\mathrm{S})} = f_{1\mathrm{T,p}}^{\perp} \otimes D_1$.
  - $F_{\mathrm{UT}}^{\sin(\varphi_\mathrm{h}+\varphi_\mathrm{S})} = h_{1,\mathrm{p}} \otimes H_1^{\perp}$,
  - $F_{\mathrm{UT}}^{\sin(3\varphi_\mathrm{h}-\varphi_\mathrm{S})} = h_{1\mathrm{T,p}}^{\perp} \otimes H_1^{\perp}$

Drell–Yan on transversely polarised nucleons

- Structure functions F:
  $F = \mathrm{PDF}_{q,\mathrm{p}} \otimes \mathrm{PDF}_{\bar{q},\pi^-}$.
- In particular:
  - $F_{\mathrm{U}}^{\cos 2\varphi_{\mathrm{CS}}} = h_{1,\pi}^{\perp} \otimes h_{1,\mathrm{p}}^{\perp}$,
  - $F_{\mathrm{T}}^{\sin\varphi_\mathrm{S}} = f_{1,\pi} \otimes f_{1\mathrm{T,p}}^{\perp}$,
  - $F_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}-\varphi_\mathrm{S})} = h_{1,\pi}^{\perp} \otimes h_{1,\mathrm{p}}$.
  - $F_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}+\varphi_\mathrm{S})} = h_{1,\pi}^{\perp} \otimes h_{1\mathrm{T,p}}^{\perp}$

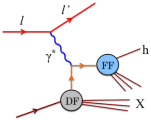
A sign change predicted for Sivers and Boer–Mulders functions:

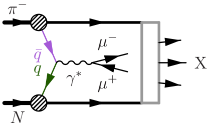
$$f_{1\mathrm{T}}^{\perp q}\big|_{\mathrm{SIDIS}} = -f_{1\mathrm{T}}^{\perp q}\big|_{\mathrm{DY}}$$

$$h_{1}^{\perp q}\big|_{\mathrm{SIDIS}} = -h_{1}^{\perp q}\big|_{\mathrm{DY}}$$

[J. Collins, Phys.Lett. B536 (2002) 43]

Drell–Yan vs. SIDIS



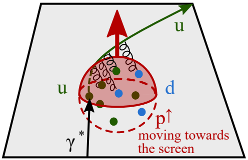


SIDIS on transversely polarised nucleons

- Structure functions F:
  $F = \mathrm{PDF}_{q,\mathrm{p}} \otimes \mathrm{FF}_{q\to h}$.
- In particular:
  - $F_{\mathrm{UU}}^{\cos\varphi_\mathrm{h}}$ and $F_{\mathrm{UU}}^{\cos 2\varphi_\mathrm{h}}$ linked to $h_{1,\mathrm{p}}^{\perp}$,
  - $F_{\mathrm{UT,T}}^{\sin(\varphi_\mathrm{h}-\varphi_\mathrm{S})} = f_{1\mathrm{T,p}}^{\perp} \otimes D_1$.
  - $F_{\mathrm{UT}}^{\sin(\varphi_\mathrm{h}+\varphi_\mathrm{S})} = h_{1,\mathrm{p}} \otimes H_1^{\perp}$,
  - $F_{\mathrm{UT}}^{\sin(3\varphi_\mathrm{h}-\varphi_\mathrm{S})} = h_{1\mathrm{T,p}}^{\perp} \otimes H_1^{\perp}$

Drell–Yan on transversely polarised nucleons

- Structure functions F:
  $F = \mathrm{PDF}_{q,\mathrm{p}} \otimes \mathrm{PDF}_{\bar{q},\pi^-}$.
- In particular:
  - $F_{\mathrm{U}}^{\cos 2\varphi_{\mathrm{CS}}} = h_{1,\pi}^{\perp} \otimes h_{1,\mathrm{p}}^{\perp}$,
  - $F_{\mathrm{T}}^{\sin\varphi_\mathrm{S}} = f_{1,\pi} \otimes f_{1\mathrm{T,p}}^{\perp}$,
  - $F_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}-\varphi_\mathrm{S})} = h_{1,\pi}^{\perp} \otimes h_{1,\mathrm{p}}$.
  - $F_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}+\varphi_\mathrm{S})} = h_{1,\pi}^{\perp} \otimes h_{1\mathrm{T,p}}^{\perp}$



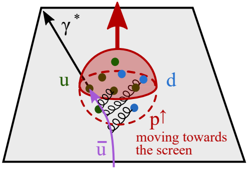
Sivers effect in SIDIS
(as described by [M. Burkardt, Nucl.Phys. A735 (2004) 185].

A sign change predicted for Sivers and Boer–Mulders functions:

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

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

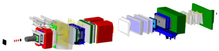
[J. Collins, Phys.Lett. B536 (2002) 43]

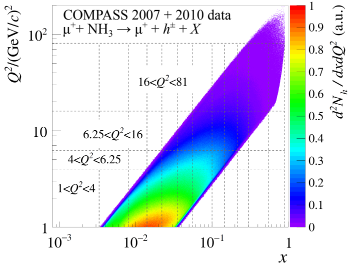


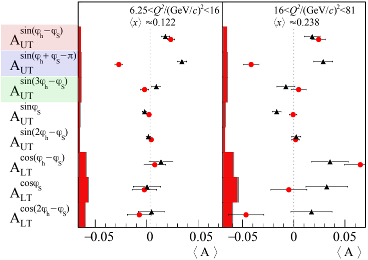
Sivers effect in Drell–Yan drawn in the same manner.

SIDIS results in DY range

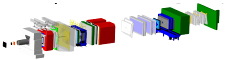
COMPASS SIDIS (2007 + 2010)

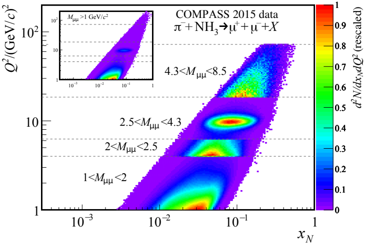




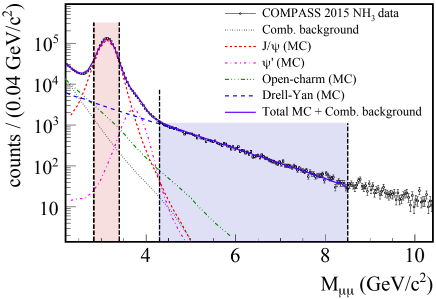


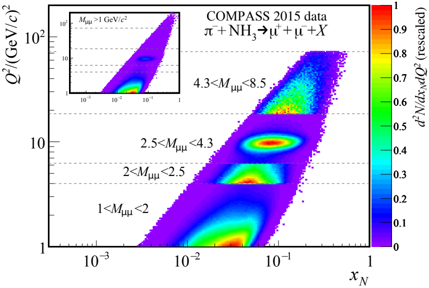
COMPASS Drell–Yan (2015 + 2018)





- Q^2 range corresponding to the Drell–Yan measurement in COMPASS SIDIS data.
- TSAs extracted at this hard scale $\to$ minimizing evolution effects.
- Clear signal for Sivers and transversity.
- [Phys.Lett.B770 (2017) 138]





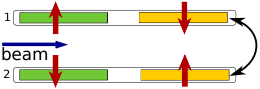
Low mass
- $1 < M_{\mu\mu}/(\mathrm{GeV}/c^2) < 2.5$
- Large background (combinatorial, open charm)

J/ψ mass
- $2.5 < M_{\mu\mu}/(\mathrm{GeV}/c^2) < 4.3$
- Dominated by charmonia.
- $2.85 < M_{\mu\mu}/(\mathrm{GeV}/c^2) < 3.4$ → 92% pure J/ψ production.

High mass
- $4.3 < M_{\mu\mu}/(\mathrm{GeV}/c^2) < 8.5$
- 96% pure Drell–Yan.
- Low cross-section.

- Re-analysis of 2015 and 2018 data:
  - High mass Drell–Yan: spring 2022,
  - J/ψ range: summer 2022.
- Final results for TSAs.

Transverse spin asymmetries measurement

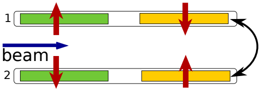


Data taken with 2 cells simultaneously, polarisation reversed every few days.

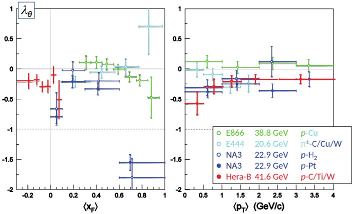
- Acceptance in polarisation-dependent azimuthal angles is cancelled in combinations of target cells and data taking periods.
- Not all nuclei in the target are polarised
  - Dilution of the signal by fP_N.
  - P_N: polarisation of the polarisable nuclei in NH_3 (measured by NMR)

$$\langle P_{\mathrm{p}} \rangle_{2015+2018} = 0.72.$$

  - f: dilution factor – fraction of the cross-sections on polarisable nuclei.
    $\rightarrow$ depends on the process and kinematic range.
    $\rightarrow$ requires a calculation.
- Event migration between cells
  due to finite Z_{vertex} resolution – modelled in MC.
- Depolarization factor $D_{[f(\theta_{\mathrm{CS}})]} = \frac{f(\theta_{\mathrm{CS}})}{1+A_{\mathrm{U}}^1 \cos^2\theta_{\mathrm{CS}}}$
  $\rightarrow$ requires the knowledge of $A_{\mathrm{U}}^1 = \lambda$. We assume:
  Drell–Yan: $\lambda = 1$.
  J/ψ: $\lambda = 0$.
- Unbinned maximum likelihood fit of all the modulations in 2 cells and 2 sub-periods.



Data taken with 2 cells simultaneously, polarisation reversed every few days.



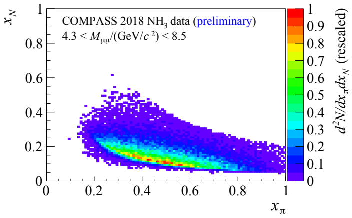
Measurements of λ in J/ψ production at different $\sqrt{s}$.
The closest to COMPASS is NA3 (200 GeV/c π^- on Pt and H).

- Acceptance in polarisation-dependent azimuthal angles is cancelled in combinations of target cells and data taking periods.
- Not all nuclei in the target are polarised
  - Dilution of the signal by $f P_N$.
  - P_N: polarisation of the polarisable nuclei in NH_3 (measured by NMR)

$$\langle P_\mathrm{p} \rangle_{2015+2018} = 0.72.$$

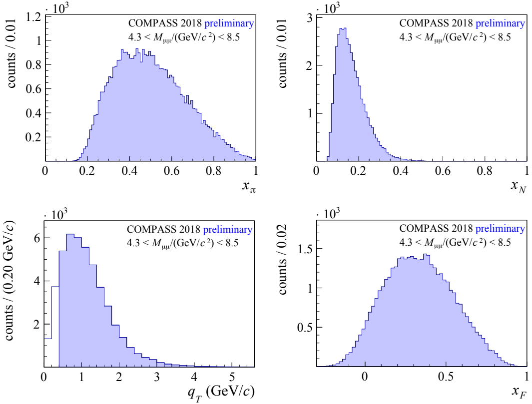
  - f: dilution factor – fraction of the cross-sections on polarisable nuclei.
    → depends on the process and kinematic range.
    → requires a calculation.
- Event migration between cells due to finite Z_vertex resolution – modelled in MC.
- Depolarization factor $D_{[f(\theta_\mathrm{CS})]} = \frac{f(\theta_\mathrm{CS})}{1+A_\mathrm{U}^1 \cos^2\theta_\mathrm{CS}}$
  → requires the knowledge of $A_\mathrm{U}^1 = \lambda$. We assume:
  Drell–Yan: $\lambda = 1$.
  J/ψ: $\lambda = 0$.
- Unbinned maximum likelihood fit of all the modulations in 2 cells and 2 sub-periods.

High mass Drell–Yan region: Kinematic coverage

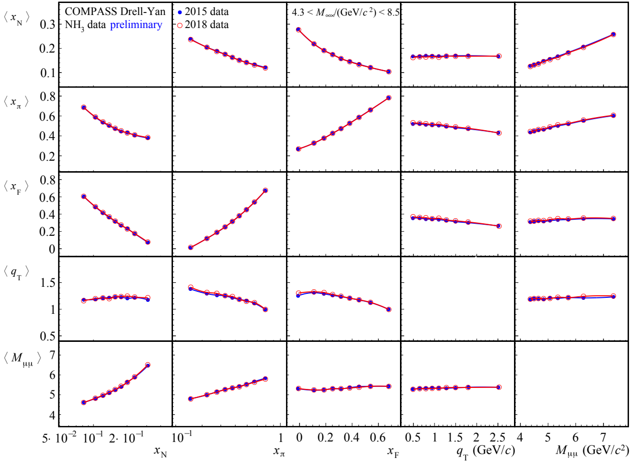


$$\langle x_\pi \rangle = 0.5, \quad \langle x_N \rangle = 0.17.$$

- Valence region (uū annihilation).
- $\langle M_{\mu\mu} \rangle = 5.3$ GeV/c^2.
- $q_T > 0.4$ GeV/c required.
- $\langle q_T \rangle = 1.17$ GeV/c.



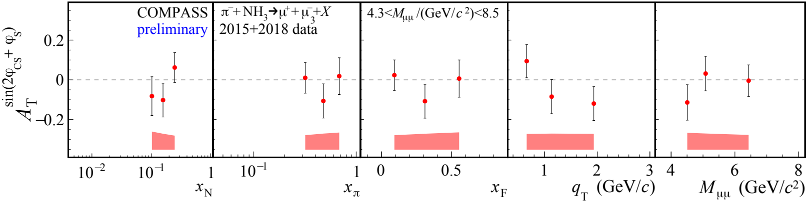
High mass Drell–Yan region: Kinematic coverage



Correlations between mean values of the kinematic variables.
2015 and 2018 data cover the same phase space.

High mass Drell–Yan region: TSA results

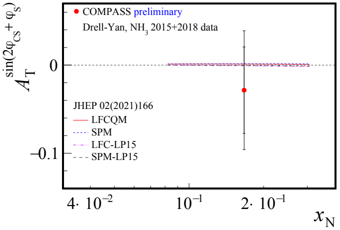
$A_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}+\varphi_{\mathrm{S}})} \propto h_{1,\pi}^{\perp q} \otimes h_{1\mathrm{T,p}}^{\perp q}$ (Boer–Mulders ⊗ pretzelosity)



Compatible with zero, no significant kinematic dependence visible.

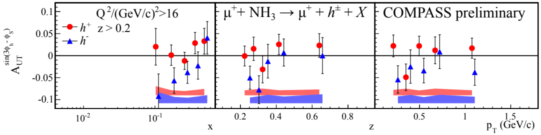
The error bars are statistical, the color bands show systematic uncertainty.

An additional scale uncertainty of 5% is not shown (dilution factor, λ, polarization).



Integrated, compared to predictions.

Curves: [Bastami *et al.*, JHEP 02 (2021) 166]



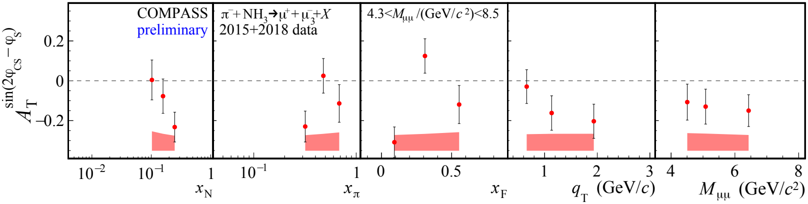
SIDIS in the corresponding Q^2 range.

$A_{\mathrm{UT}}^{\sin(3\varphi_{\mathrm{h}}-\varphi_{\mathrm{S}})} \propto h_{1\mathrm{T,p}}^{\perp q} \otimes H_{1,q}^{\perp h}$

(pretzelosity ⊗ Collins FF)

High mass Drell–Yan region: TSA results

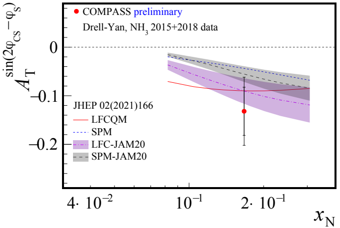
$A_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}-\varphi_{\mathrm{S}})} \propto h_{1,\pi}^{\perp q} \otimes h_{1,\mathrm{p}}^{q}$ (Boer–Mulders function $\otimes$ transversity)



Negative (about 1.5σ significance), kinematic dependence not really significant.

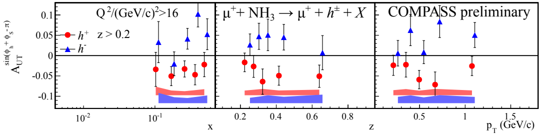
The error bars are statistical, the color bands show systematic uncertainty.

An additional scale uncertainty of 5% is not shown (dilution factor, λ, polarization).



Integrated, compared to predictions.

Curves: [Bastami *et al.*, JHEP 02 (2021) 166]

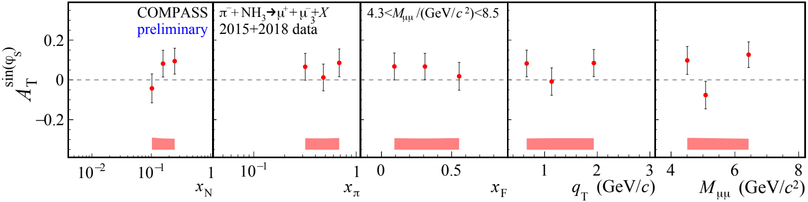


SIDIS in the corresponding Q^2 range.

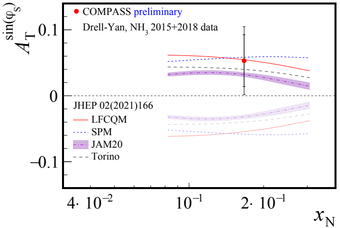
$A_{\mathrm{UT}}^{\sin(\varphi_{\mathrm{h}}+\varphi_{\mathrm{S}}-\pi)} \propto h_{1,\mathrm{p}}^{q} \otimes H_{1,q}^{\perp h}$

(transversity $\otimes$ Collins FF)

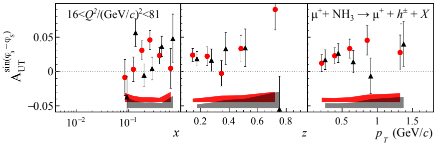
$A_{\mathrm{T}}^{\sin\varphi_{\mathrm{S}}} \propto f_{1,\pi}^{q} \otimes f_{1\mathrm{T,p}}^{\perp q}$ (number density ⊗ Sivers function)



Positive (1σ significance), kinematic dependence not really significant.
The error bars are statistical, the color bands show systematic uncertainty.
An additional scale uncertainty of 5% is not shown (dilution factor, λ, polarization).

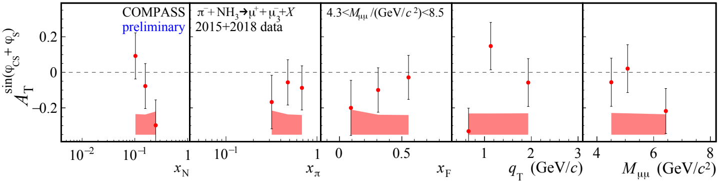


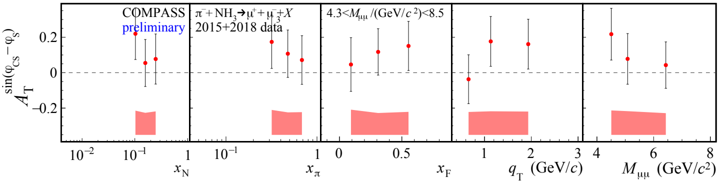
Integrated, compared to predictions.
Curves: [Bastami *et al.*, JHEP 02 (2021) 166]



SIDIS in the corresponding Q^2 range.
$A_{\mathrm{UT}}^{\sin(\varphi_{\mathrm{h}}-\varphi_{\mathrm{S}})} = f_{1\mathrm{T,p}}^{\perp q} \otimes D_{1,q}^{h}$
(Sivers ⊗ unpolarised FF)
[Phys.Lett.B770 (2017) 138]

Higher-twist





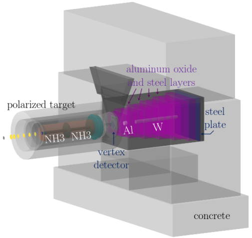
Both compatible with zero, no significant kinematic dependence visible.

The error bars are statistical, the color bands show systematic uncertainty.

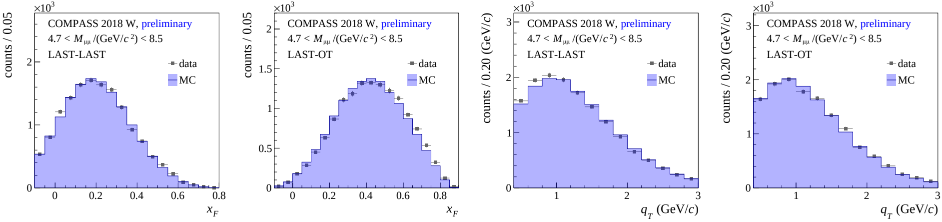
An additional scale uncertainty of 5% is not shown (dilution factor, λ, polarization).

Acceptance correction needed:

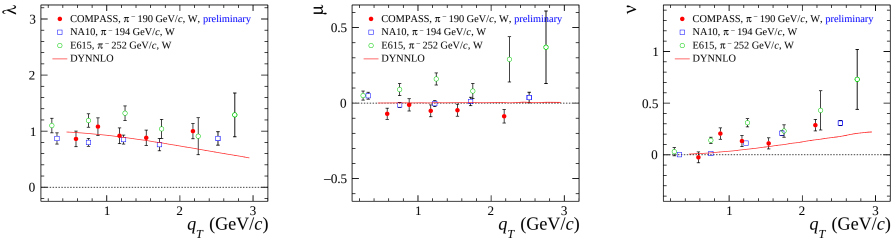
- Pythia 8 event generator.
- Geant 4-based model of the spectrometer (TGeant).
- Beam parameters and 2-dimensional detector efficiency extracted from the data.
- 2018 data only (better trigger description).



Target region with the hadron absorber in TGeant. [Courtesy of T. Szameitat]

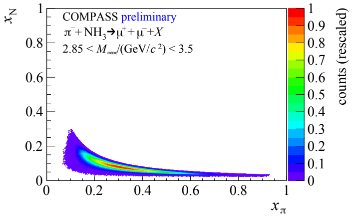


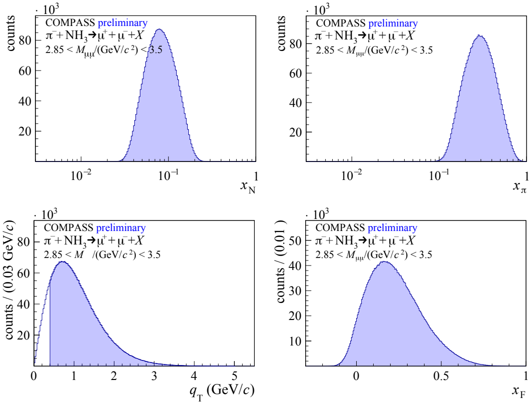
Data–MC comparison for W target and two trigger systems (note the different x_F coverage).



- Preliminary result from W target, analysis of NH_3 ongoing.
- Presented in 2021 [Lian (COMPASS), SciPost Phys.Proc. 8, 028 (2022)].
- Only the first 20 cm of W plug selected (to limit the effect of reinteraction).
- Restricted mass range $4.7 < M_{\mu\mu}/(\mathrm{GeV}/c^2) < 8.5$ due to worse mass resolution in W.
- Unpolarised asymmetries in line with previous πN experiments.
- Comparison with pQCD calculation using DYNNLO [Chang *et al.*, Phys.Rev.D 99 (2019)] leaves room for possible contribution from the Boer–Mulders function.

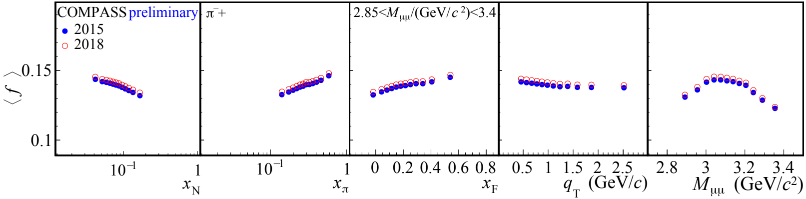
J/ψ mass region: Kinematic coverage



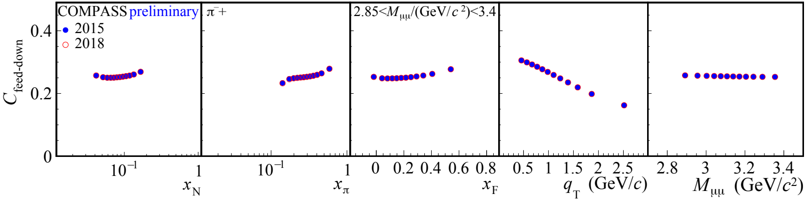


$$\langle x_\pi \rangle = 0.3, \quad \langle x_N \rangle = 0.09.$$

- Lower x_π and x_N with respect to high mass Drell–Yan.
- $q_T > 0.4$ GeV/c required.
- $\langle q_T \rangle = 1.05$ GeV/c.

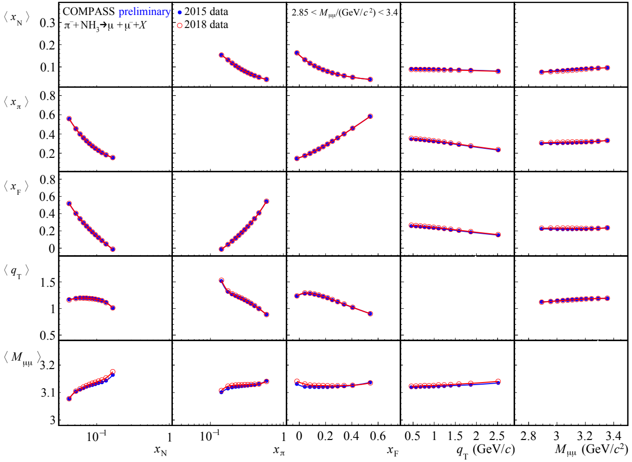


Dilution factor based on cross sections kindly provided by R. Vogt (ICEM model) and M. Nefedov (NRQCD framework). Event mixing effects are included.



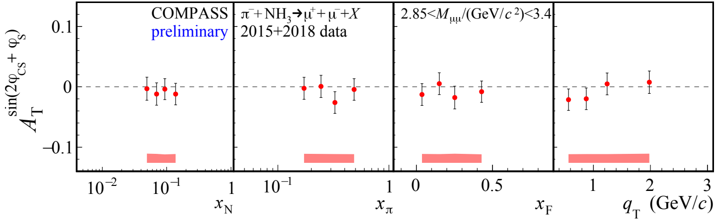
Estimate of the feed-down from heavier charmonia obtained in the framework of parton Reggeization approach. The asymmetries are not corrected for the feed-down.

J/ψ mass region: Kinematic coverage

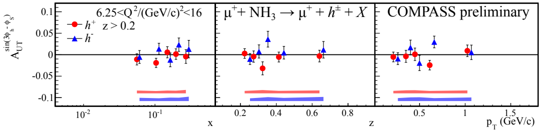


Correlations between mean values of the kinematic variables.
2015 and 2018 data cover the same phase space.

$A_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}+\varphi_{\mathrm{S}})} \propto h_{1,\pi}^{\perp q} \otimes h_{1\mathrm{T,p}}^{\perp q}$ (Boer–Mulders ⊗ pretzelosity, assuming $q\bar{q}$)



Compatible with zero, no significant kinematic dependence visible.
The error bars are statistical, the color bands show systematic uncertainty.
An additional scale uncertainty of 12% is not shown (dilution factor, λ, polarization).



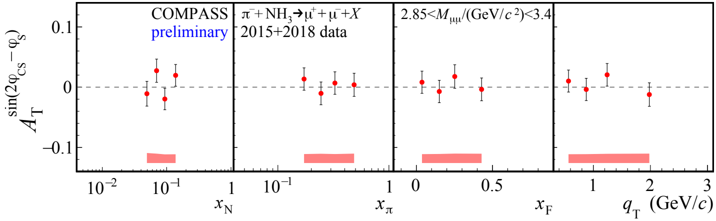
SIDIS in the corresponding Q^2 range.

$A_{\mathrm{UT}}^{\sin(3\varphi_{\mathrm{h}}-\varphi_{\mathrm{S}})} \propto h_{1\mathrm{T,p}}^{\perp q} \otimes H_{1,q}^{\perp h}$

(pretzelosity ⊗ Collins FF)

J/ψ mass region: TSA results

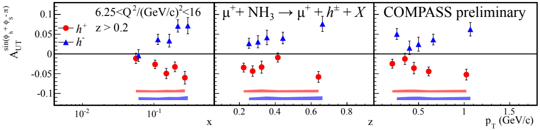
$A_{\mathrm{T}}^{\sin(2\varphi_{\mathrm{CS}}-\varphi_{\mathrm{S}})} \propto h_{1,\pi}^{\perp q} \otimes h_{1,\mathrm{p}}^{q}$ (Boer–Mulders function $\otimes$ transversity, assuming $q\bar{q}$)



Compatible with zero, no significant kinematic dependence visible.

The error bars are statistical, the color bands show systematic uncertainty.

An additional scale uncertainty of 12% is not shown (dilution factor, λ, polarization).



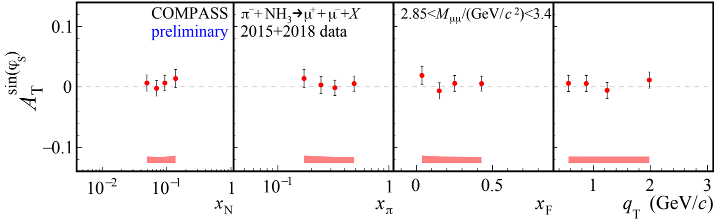
SIDIS in the corresponding Q^2 range.

$A_{\mathrm{UT}}^{\sin(\varphi_{\mathrm{h}}+\varphi_{\mathrm{S}}-\pi)} \propto h_{1,\mathrm{p}}^{q} \otimes H_{1,q}^{\perp h}$

(transversity $\otimes$ Collins FF)

J/ψ mass region: TSA results

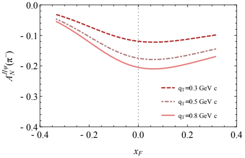
$A_{\mathrm{T}}^{\sin\varphi_{\mathrm{S}}} \propto f_{1,\pi}^{q} \otimes f_{1\mathrm{T,p}}^{\perp q}$ (number density ⊗ Sivers function, assuming $q\bar{q}$)



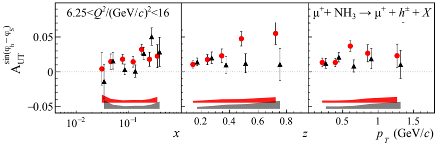
Compatible with zero, no significant kinematic dependence visible.

The error bars are statistical, the color bands show systematic uncertainty.

An additional scale uncertainty of 12% is not shown (dilution factor, λ, polarization).



Prediction assuming $q\bar{q}$ and no feed-down [Anselmino *et al.*. Phys.Lett.B770 (2017)]



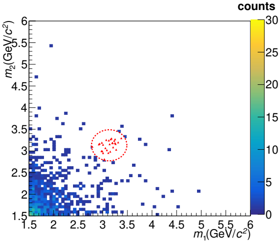
SIDIS in the corresponding Q^2 range.

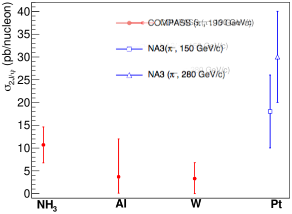
$A_{\mathrm{UT}}^{\sin(\varphi_{\mathrm{h}}-\varphi_{\mathrm{S}})} = f_{1\mathrm{T,p}}^{\perp q} \otimes D_{1,q}^{h}$

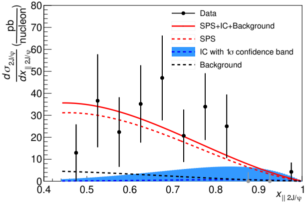
(Sivers ⊗ unpolarised FF)

[Phys.Lett.B770 (2017) 138]

J/ψ mass region: Double J/ψ cross section

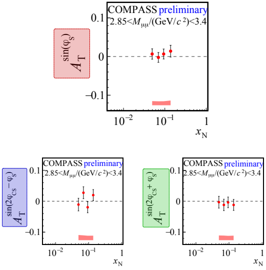




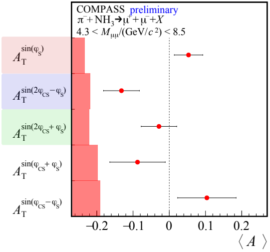


- Production of two quarkonia in COMPASS kinematics:
  - single-parton scattering (SPS): $q\bar{q}$ (2/3) or gg (1/3) in pQCD.
  - Intrinsic charm (IC) hypothesis [Vogt, Brodsky, Phys.Lett.B 349 (1995)].
- Previous fixed-target measurement by NA3 (no acceptance correction) [NA3, Phys.Lett.B 114 (1982)] [NA3, Phys.Lett.B 158 (1985)]
- COMPASS 2015 + 2018 data, NH_3 + Al + W target
- NH_3: 28 events, expected background 3 events, $\frac{\sigma_{2J/\psi}}{\sigma_{J/\psi}} = (1.02 \pm 0.22_{\text{stat}} \pm 0.27_{\text{syst}}) \times 10^{-4}$.
- Result in line with SPS expectation,
- $x_{\parallel 2J/\psi}$ distribution fitted to the sum of SPS and IC. Little room left for the IC.
- Paper submitted: [COMPASS, CERN-EP-2022-073]

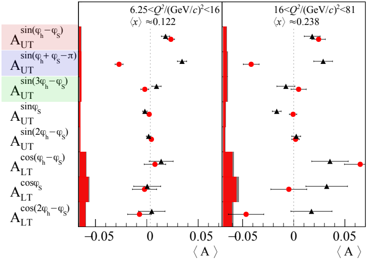
Transverse spin asymmetries



J/ψ

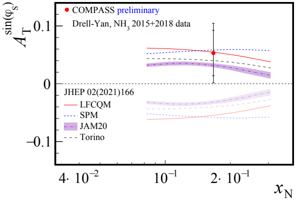


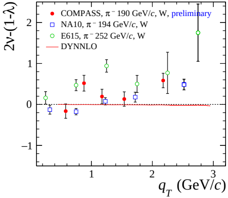
Drell–Yan



SIDIS at corresponding Q^2.

- Final results for 2015 + 2018 data.
- J/ψ and high-mass Drell–Yan ranges.
- Drell–Yan: Sivers – favours the sign change,
  transversity – 1.5σ from zero.
- J/ψ production: New results!
  All TSAs compatible with zero.





Unpolarised asymmetries

- Preliminary results for W target, analysis ongoing for NH_3.
- Results in line with previous πN experiments.
- They suggest Lam–Tung rule violation.

J/ψ cross section

- Ratio of cross sections on W and Al: New result, presented by A. Khatun tomorrow.

Double J/ψ cross section

- Final results, intrinsic charm disfavoured. [COMPASS, CERN-EP-2022-073]

Ongoing work and plans

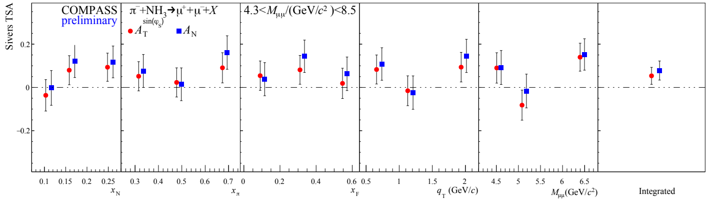
- TSAs weighted by q_T: interpretable without a k_T-ansatz for the TMDs.
- Drell–Yan cross section on nuclear targets – almost finished.
- Unpolarised asymmetries: Drell–Yan on NH_3, J/ψ.

Conclusions

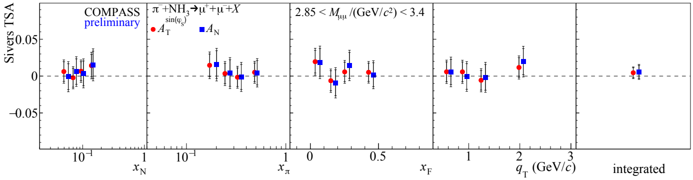
- COMPASS Drell–Yan data analysis is gradually concluding.
- The unique data lead to several interesting results recently.
- More results are expected soon.

Thank you for your attention!

Backup: A_N asymmetries

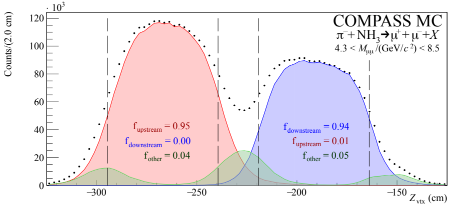


Comparison of A_N and Sivers asymmetry in the high-mass Drell–Yan range.

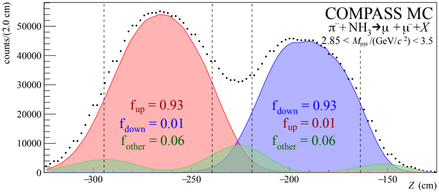


Comparison of A_N and Sivers asymmetry in the J/ψ mass range.

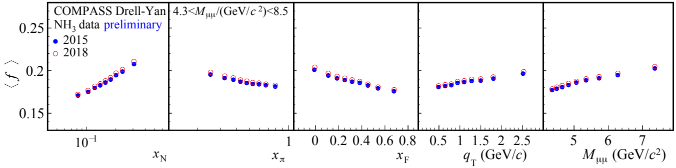
- A left-right asymmetry, expected to be similar to Sivers asymmetry.



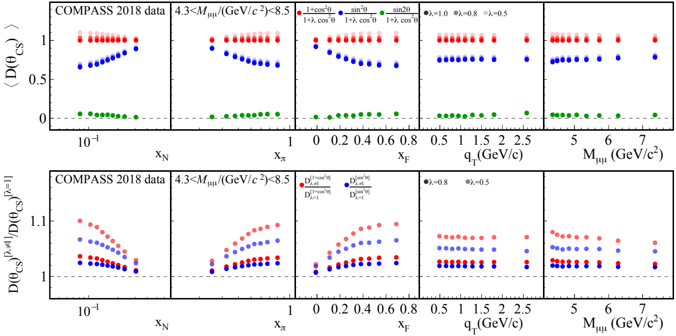
High mass Drell–Yan.



J/ψ



Dilution factor corrected for event mixing and its dependence on kinematic variables.



Depolarisation factors. We assume $\lambda = 1$.
The impact of $\lambda < 1$ is shown (top: comparison, bottom: ratio to the $\lambda = 1$ case).