Probing Nucleon Structure in Drell-Yan and J/ψ Production at COMPASS

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Overview

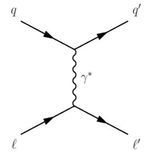
- COMPASS is a fixed target experiment at CERN studying in particular Transverse Momentum Dependent (TMD) Parton Distribution Functions (PDFs) that describe the 3D partonic nucleon structure in momentum space
- TMD PDFs can be accessed experimentally via measurements of nucleon spin-(in)dependent asymmetries in hard-scattering reactions, e.g. Semi-Inclusive Deep Inelastic Scattering (SIDIS) and the Drell-Yan (DY) process
- One of the key measurements: Sivers asymmetry in SIDIS and DY to test the theoretically predicted sign change of the Sivers TMD PDFs
- Spin-dependent asymmetries in COMPASS J/ψ events may give information about the gluon Sivers function and the J/ψ production mechanisms
- Parallel computing resources used to reconstruct and analyze real and Monte-Carlo data on a large scale

Probing Nucleon Substructure

Scattering experiments reveal substructure of nucleons

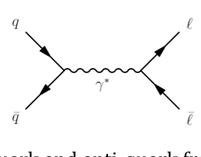
Non-inclusive processes must be used to probe transverse-momentum dependence

Semi-inclusive Deep Inelastic Scattering (SIDIS)



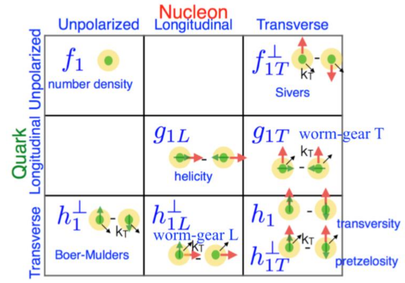
- Lepton scatters off quark by exchanging a virtual photon
- Outgoing lepton and one outgoing hadron measured

Drell-Yan Scattering (DY)

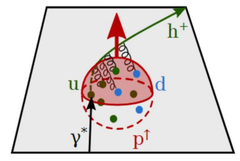


- Quark and anti-quark from two different nucleons annihilate into a virtual photon, which decays into a dilepton
- Outgoing dilepton measured

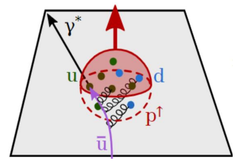
TMD PDFs describe correlations between the polarization and transverse momentum of quarks or gluons and the polarization of their parent nucleons



Sign of **Sivers function** is predicted to be dependent on when soft gluon exchange happens in the scattering process



In SIDIS, gluon exchange happens in final state interaction

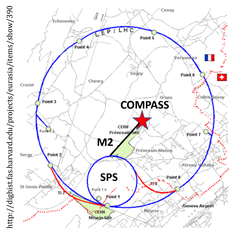


In DY, gluon exchange happens in initial state interaction

Thus, Sivers function should have opposite sign when measured in SIDIS vs DY

Verifying this experimentally is an important test of the TMD framework of QCD

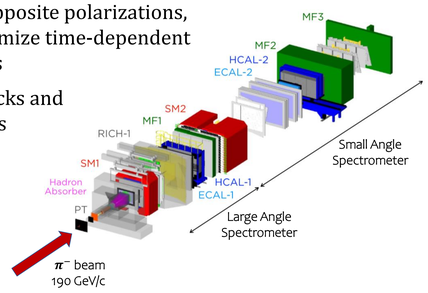
COMPASS Experiment



- Located in the North Area of CERN
- Beam from the SPS via the M2 beam line
- SIDIS data with polarized muon beam and polarized ^{6}LiD or NH_3 target taken in 2002-2007 and 2010-2011
- DY data with π^- beam and transversely polarized NH_3 target taken in 2015 and 2018

Setup in 2015 & 2018

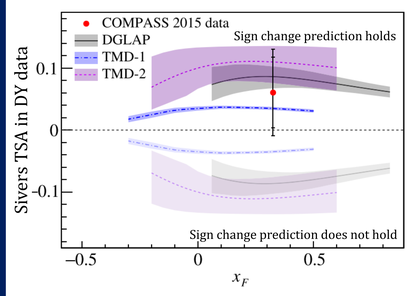
- Target has two cells with opposite polarizations, flipped periodically to minimize time-dependent acceptance variation effects
- Two-part spectrometer tracks and identifies outgoing particles
- Muon filters (MF) identify muons, the signature output of DY events
- Hadron absorber reduces spectrometer illumination without disturbing muons



COMPASS Sivers Results

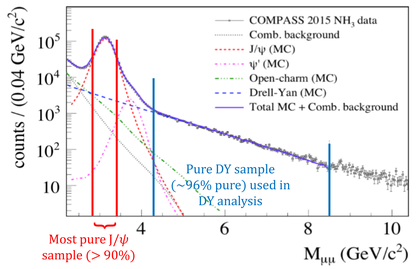
- **Transverse-spin-dependent azimuthal asymmetries (TSAs)** are experimental observables related to specific TMD PDFs
- TSAs represent the amplitude of angular modulations in the cross-section, and can often be extracted by forming ratios of event counts from oppositely polarized target cells
- TSAs related to Sivers function measured in COMPASS SIDIS and DY data

COMPASS results favor the Sivers sign change hypothesis



- Curves show predictions of Sivers asymmetry in COMPASS DY data based on SIDIS results and different QCD evolution theories
- Data already analyzed from 2018 gives a result compatible with 2015 while reducing the error bars
- Results with full 2015/2018 data will further shrink error bars – there is ~30% more data from 2018 compared to 2015

TSAs in COMPASS J/ψ Data



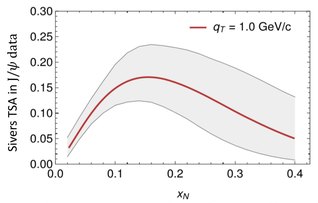
- Other processes besides DY can produce the signature dimuon, including the decay of the J/ψ meson
- DY and J/ψ event samples selected based on dimuon invariant mass
- J/ψ mesons can be produced via quark-antiquark annihilation or gluon-gluon fusion

J/ψ production via quark-antiquark annihilation:

- Sivers TSA gives information about quark Sivers function like regular DY data

J/ψ production via gluon-gluon fusion:

- Sivers TSA gives information about the poorly known gluon Sivers function



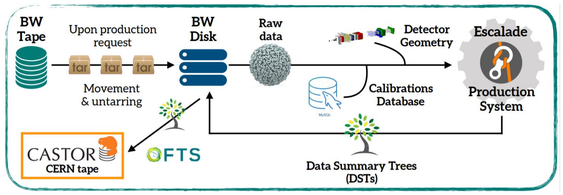
Sivers asymmetry in J/ψ events produced via quark-antiquark annihilation predicted to be large

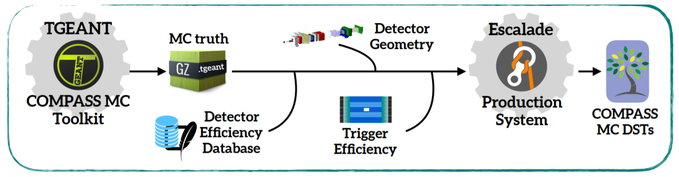
Verifying whether this prediction matches experiment will help to understand the J/ψ production mechanism at COMPASS kinematics

M. Anselmino, V. Barone, M. Boglione. *Phys. Lett. B*, **770**(2017), 302-306.

Data Production

- Digital information from spectrometer converted to physical quantities using COMPASS Reconstruction and Analysis Libraries (CORAL)
- Monte-Carlo (MC) simulations performed to study and predict spectrometer behavior
- MC raw data processed with CORAL like real data





- Large-scale real data and MC reconstruction requires high performance parallel computing resources
- COMPASS has utilized allocations on the Blue Waters supercomputer at NCSA and the Frontera supercomputer at TACC

BW allocation (2016-2019)

- ~14 million node hours, including large PRAC award
- 32 CPUs per node

Frontera allocation (2019-present)

- ~ 1.5 million node hours
- 56 CPUs per node
- Nodes are 3x faster than BW

Acknowledgements

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