Probing nucleon's spin structures with polarized Drell-Yan in the Fermilab E1039 experiment

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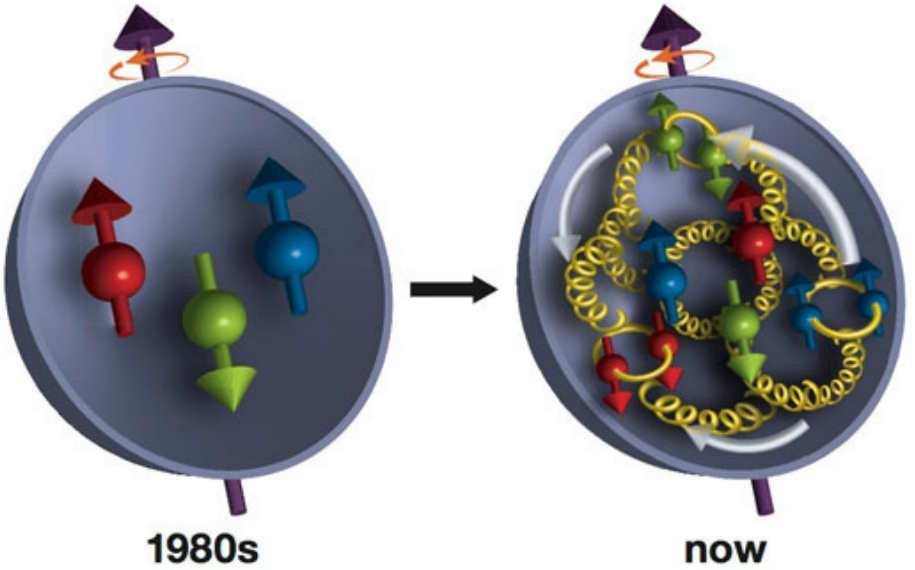
For the E1039 collaboration at Fermilab

Outline

- Introduction
- Physics goals
  - Sivers function
  - Tensor polarization
  - Tensor charge
  - ...
- The experiment
  - Status
  - Schedule

Introduction

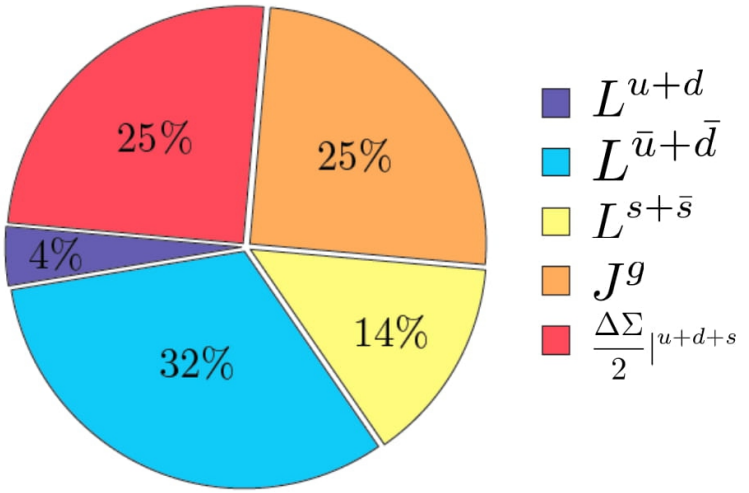
- Proton has been discovered for about 100 years and yet we haven't understood how its spin come to be?
- The sea quark Orbital Angular Momentum, O.A.M., can play important role!



Nucleon Spin: Large Sea Quark O.A.M. Contribution?

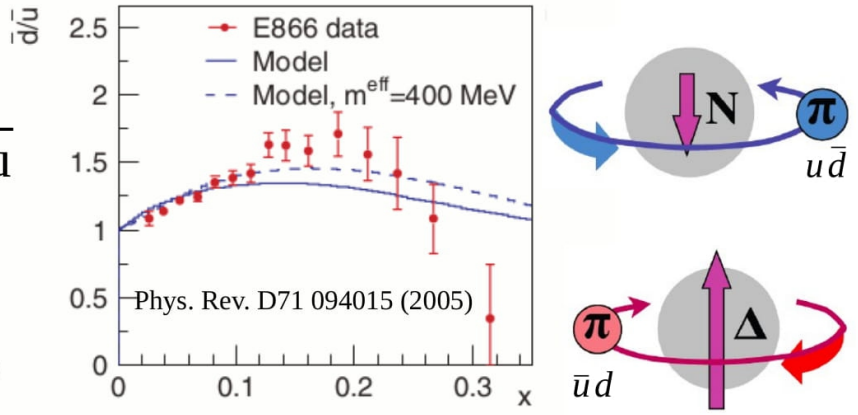
$$S_{proton} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + J_g + \langle L_q \rangle + \langle L_{\bar{q}} \rangle$$

Lattice QCD: K.-F. Liu *et al* arXiv:1203.6388



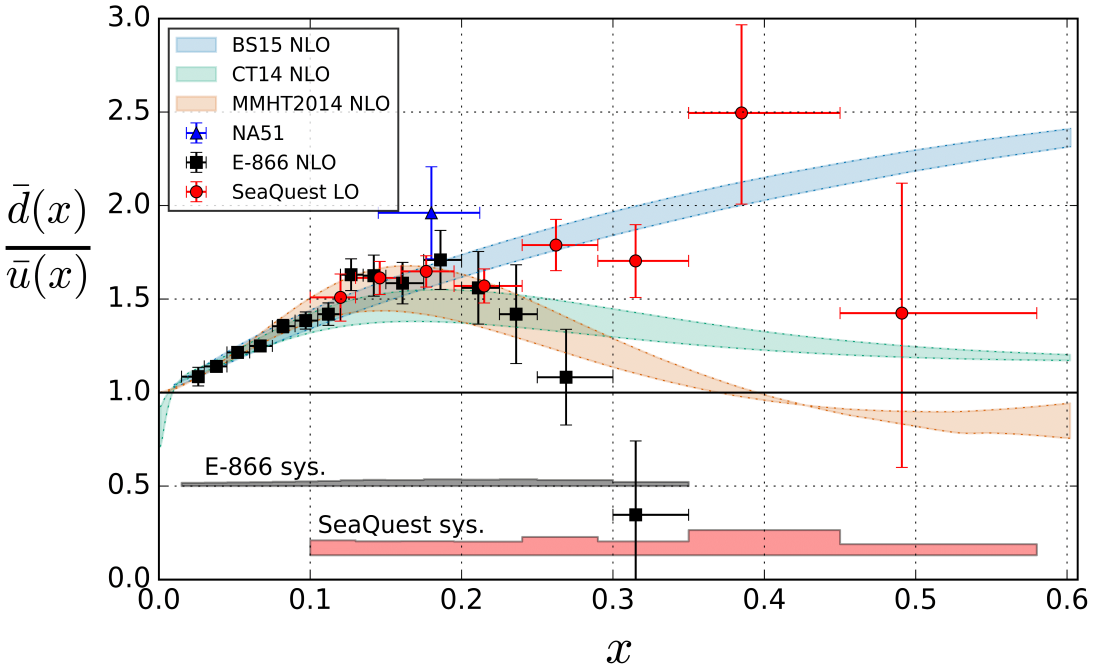
- Lattice QCD calculations indicate as much as 50% come from quark O.A.M.
- $\Delta L_{valence} \approx$ Small

- Hints of sea quark O.A.M already seen
  - Pion Cloud model interpretation of $\bar{d}/\bar{u}$ flavor asymmetry
- **Directly Accessible when measuring sea quark Sivers TMD**



The SeaQuest experiment

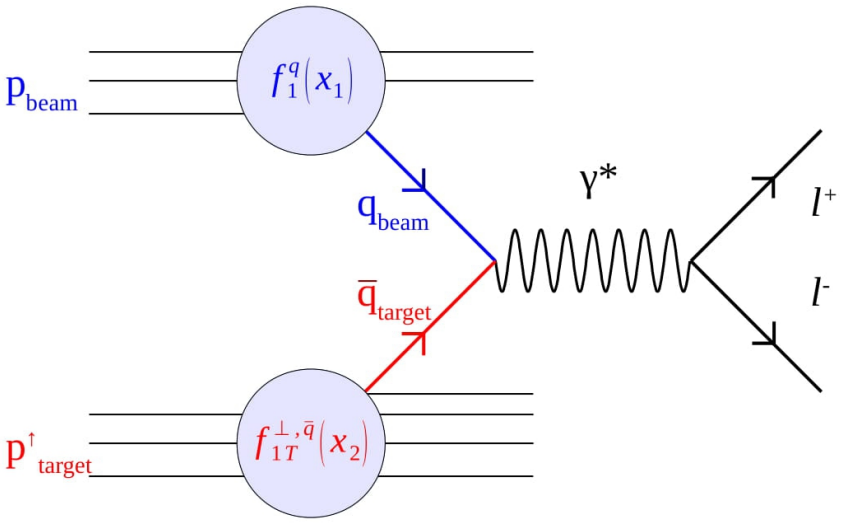
- Done taking data in 2017
- Analyzing data
- Preliminary result available
- Expect to update and publish soon



Accessing Sea Quark Sivers PDFs

- Quark Sivers TMD directly accessible using Polarized SIDIS, **Polarized Drell-Yan**

Polarized Drell-Yan



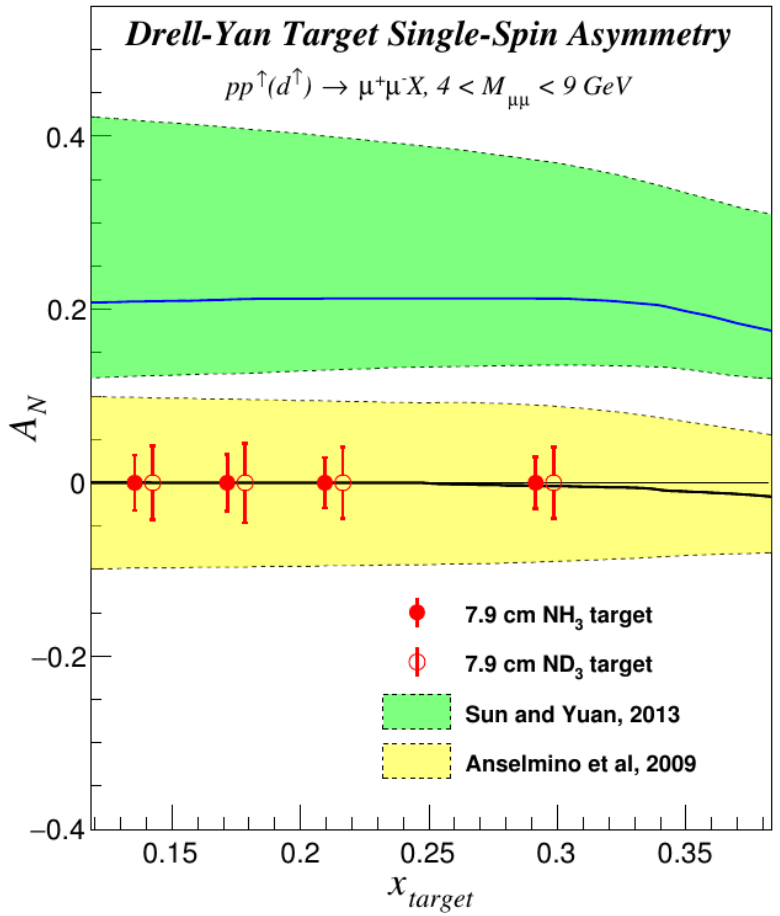
E1039 Seaquest Experiment

$$A_N^{DY} \propto \frac{\sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]}{\sum_q e_q^2 [f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2]}$$

- L-R single spin asymmetry in Drell-Yan production
- **No Quark Fragmention function**
- Valence-Sea quark **Isolated.**

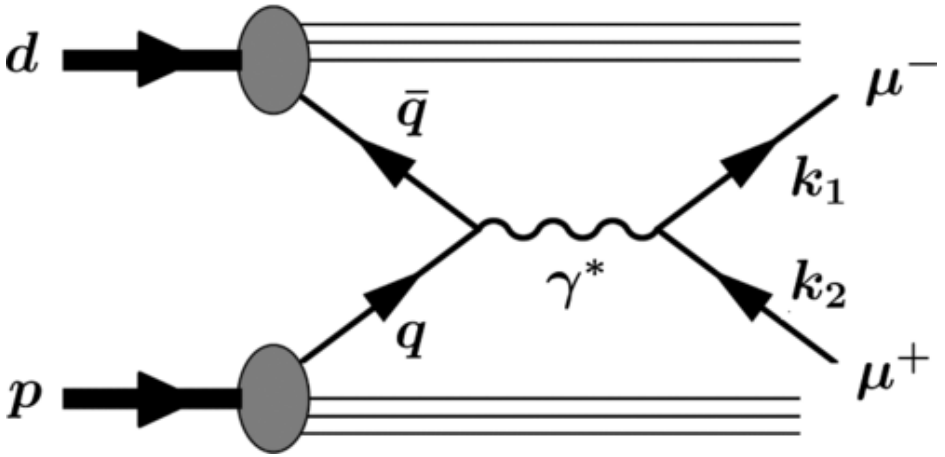
- **A fixed target Drell-Yan Experiment with polarized target isolates sea quark Sivers TMD to target!**

The sensitivity of asymmetry, A_N, in polarized SeaQuest



- Green band is an extrapolation of HERMES/COMPASS result.
- Yellow band assumes no Sivers function.

Tensor polarization



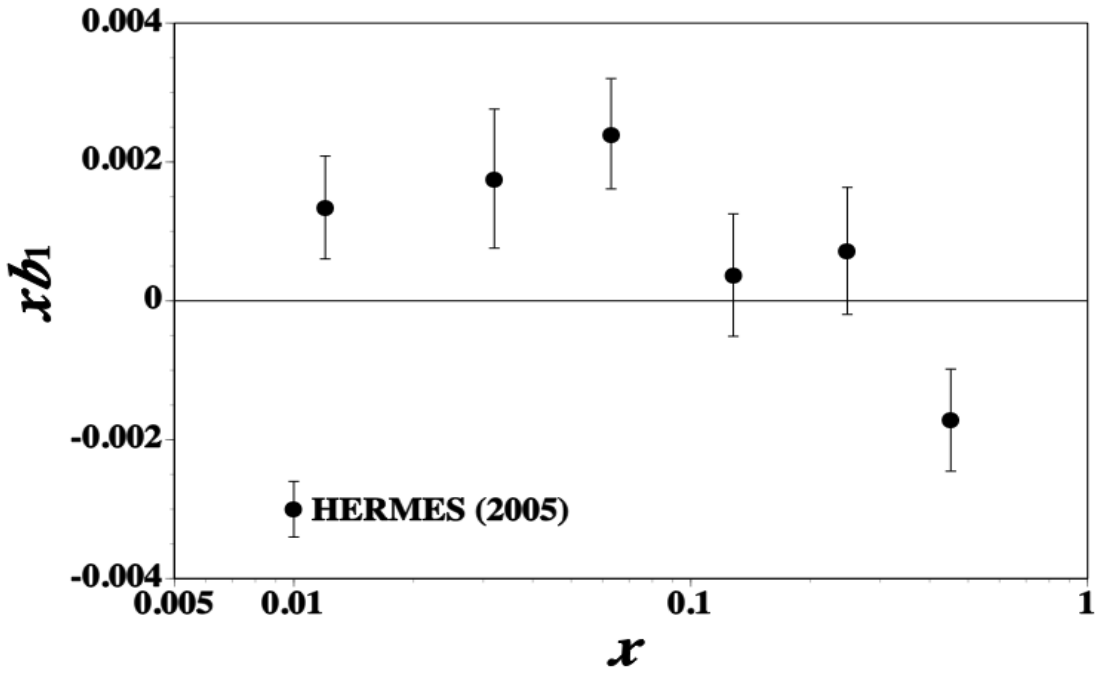
- Tensor polarization in Drell-Yan process of

  $p + d \rightarrow \mu^+ + \mu^-$

  where *d* is polarized
- Deutron is spin 1 thus has three magnetic substates:
  - m = +1, 0, -1
- Tensor polarization terms leads to new PDFs, b_1, b_2, b_3 and b_4.
- Where b_1 express the difference between |m| = 1 and |m| = 0.

Tensor polarization of antiquark

- Fitting HERMES data with
  - zero tensor-polarized antiquark distributions (set 1)
  - non-zero tensor-polarized antiquark distributions (set 2).
- The HERMES data better supports the case of non-zero tensor polarization PDFs of antiquarks.



S. Kumano and Qin-Tao Song, PhysRev.D 94, 054022

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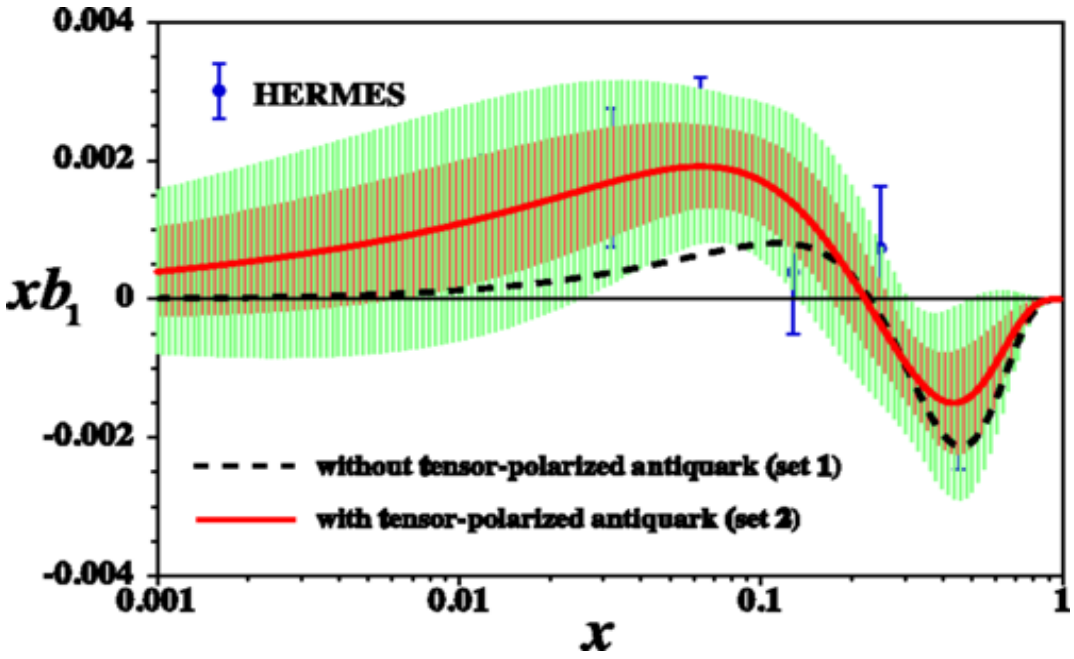
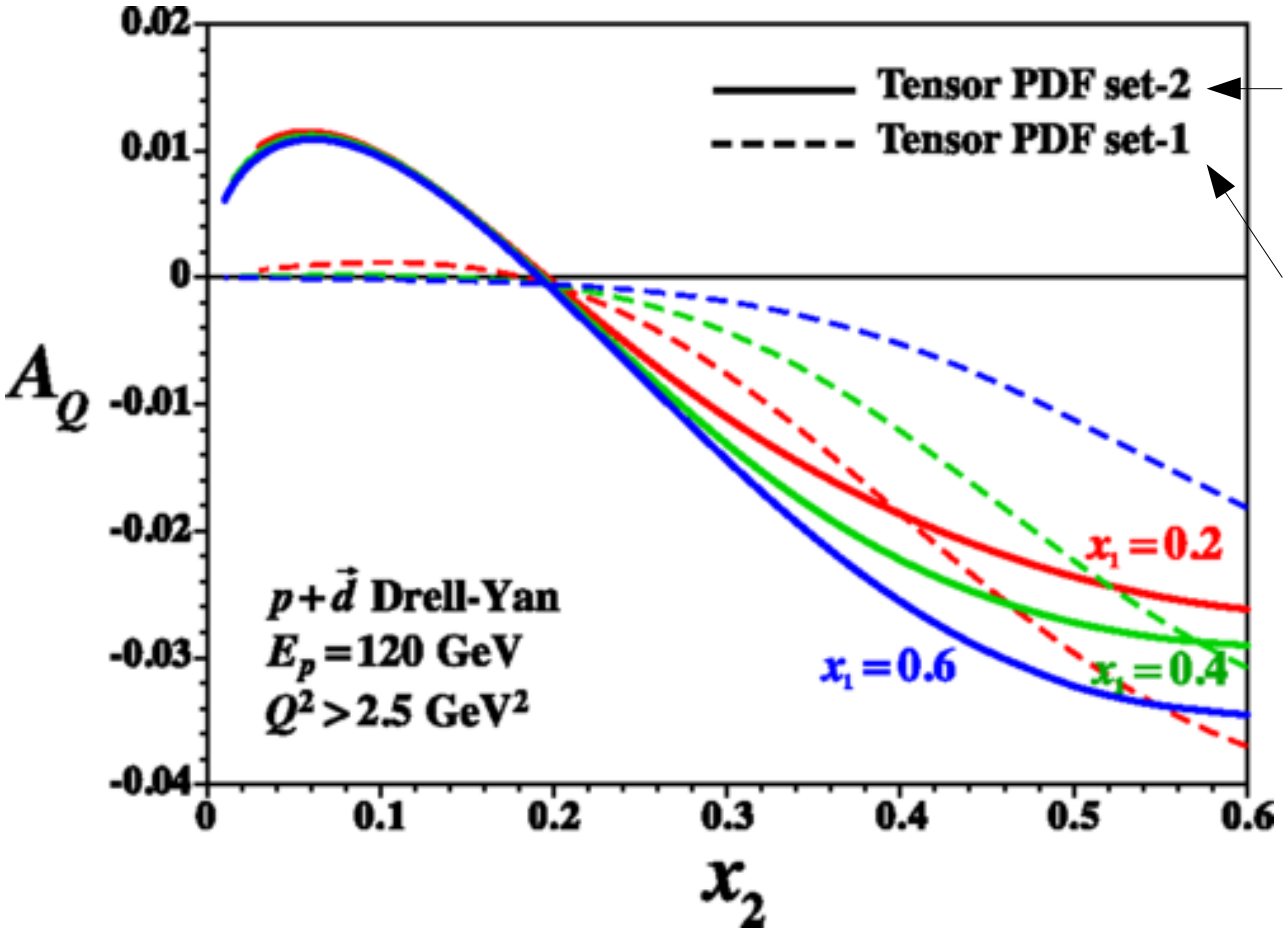


Tensor asymmetry with polarized deuteron, for E1039, predicted

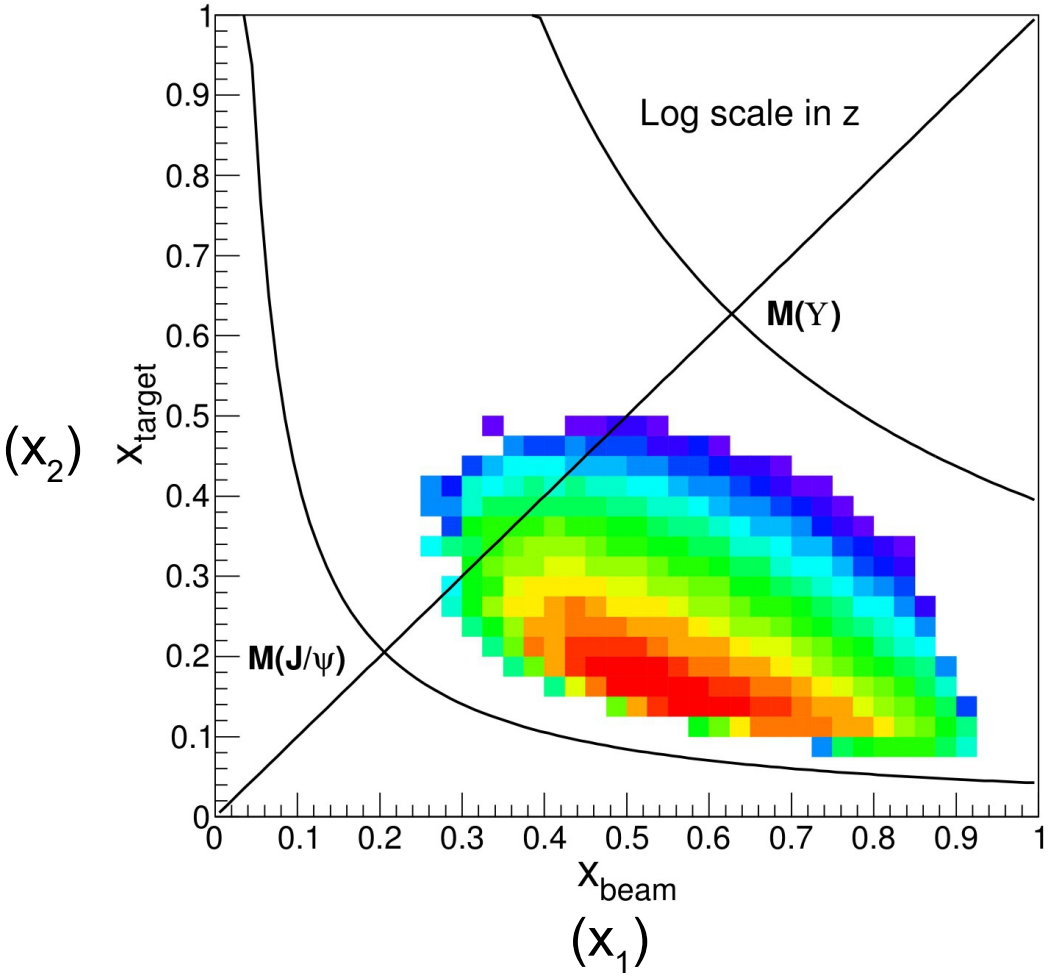


Non-zero tensor polarization PDFs

Zero tensor polarization PDFs

S. Kumano and Qin-Tao Song, PhysRev.D 94, 054022

X_1, X_2 distribution of E1039

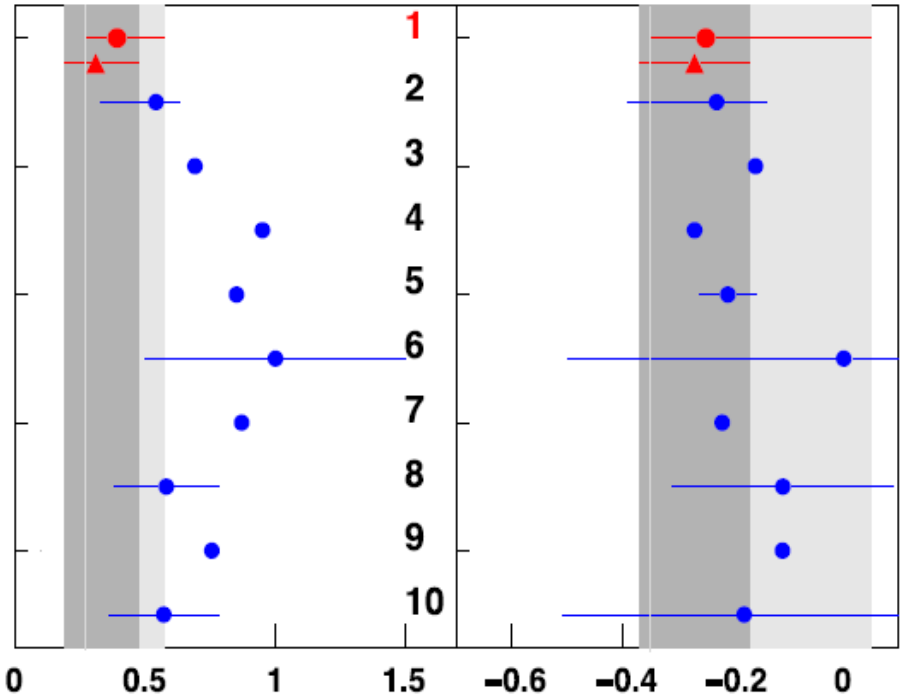


Tensor charge

$$\delta q = \int_0^1 [h_1^q(x) - h_1^{\bar{q}}(x)]dx$$

Where h_1 is the transversity of given quark.

- $\delta u = 0.39^{+0.18}_{-0.12}$ $\quad$ $\delta d = -0.25^{+0.30}_{-0.10}$
- $\delta u = 0.31^{+0.16}_{-0.12}$ $\quad$ $\delta d = -0.27^{+0.10}_{-0.10}$



- Global fit with two different Collins Fragmentation Functions.
  - This fit neglects the contributions from sea quarks also with limited x range.

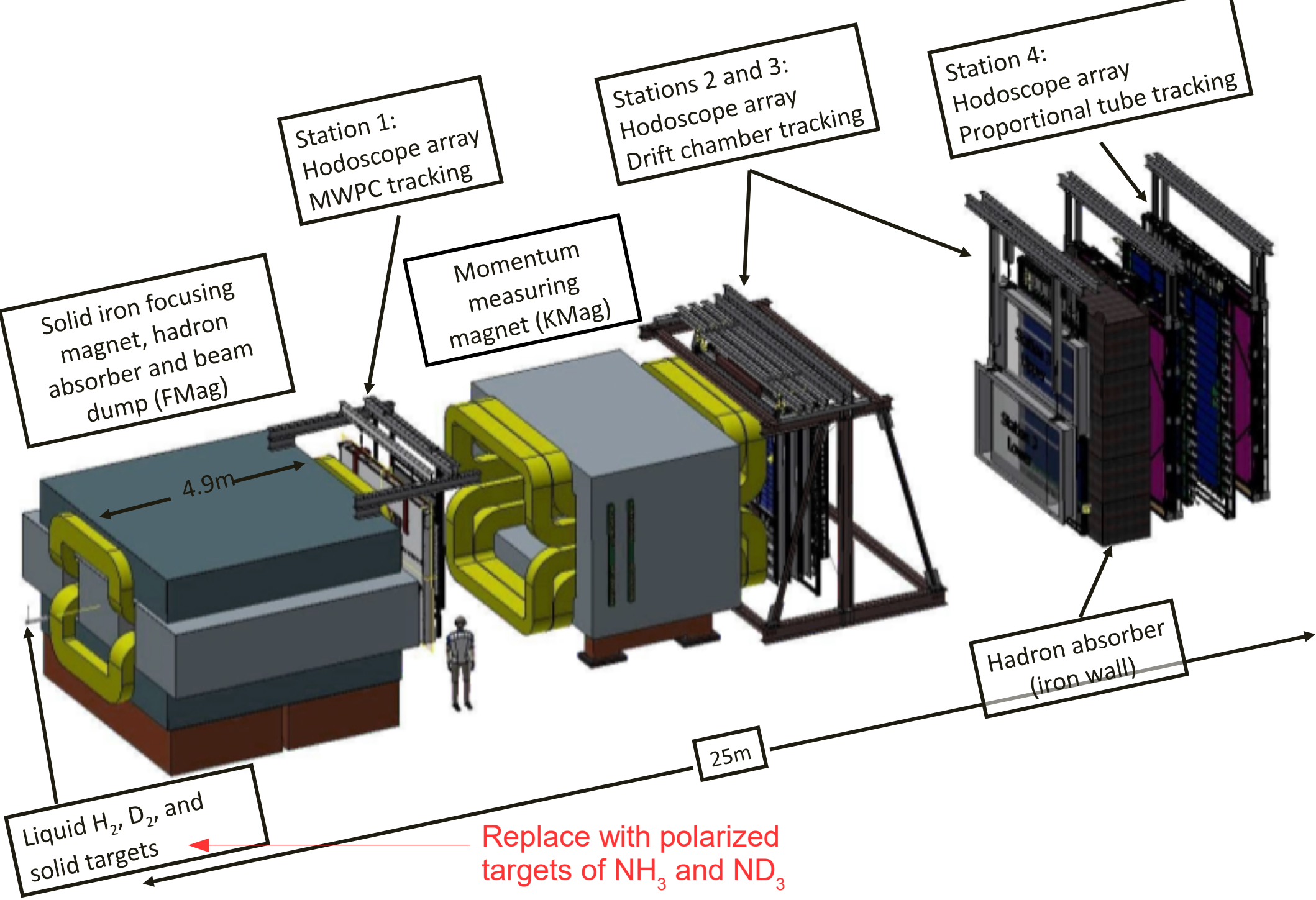
Predictions from various models.

E1039, polarized DY, can provide transversity without Fragmentation Functions!

M. Anselmino et. al. PhysRevD.87.094019,

The E1039 specterometer

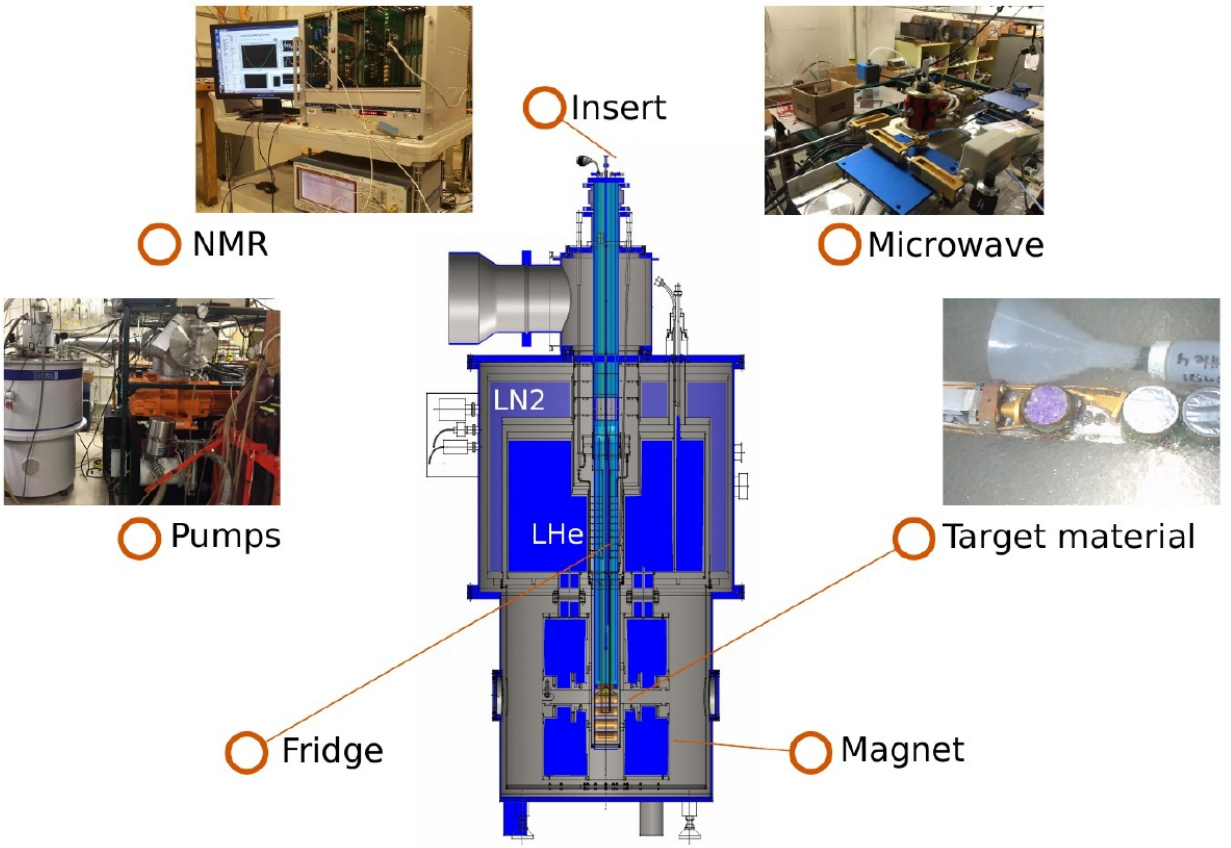
- The spectrometer is basically the same as the SeaQuest/E906 experiment.
- New fiber scintillators are added in the station 1 and 2.
  - These will be part of the trigger for better *z* resolution; which helps in rejecting background.
  - These can also be used to construct new trigger for Dark Photon search.

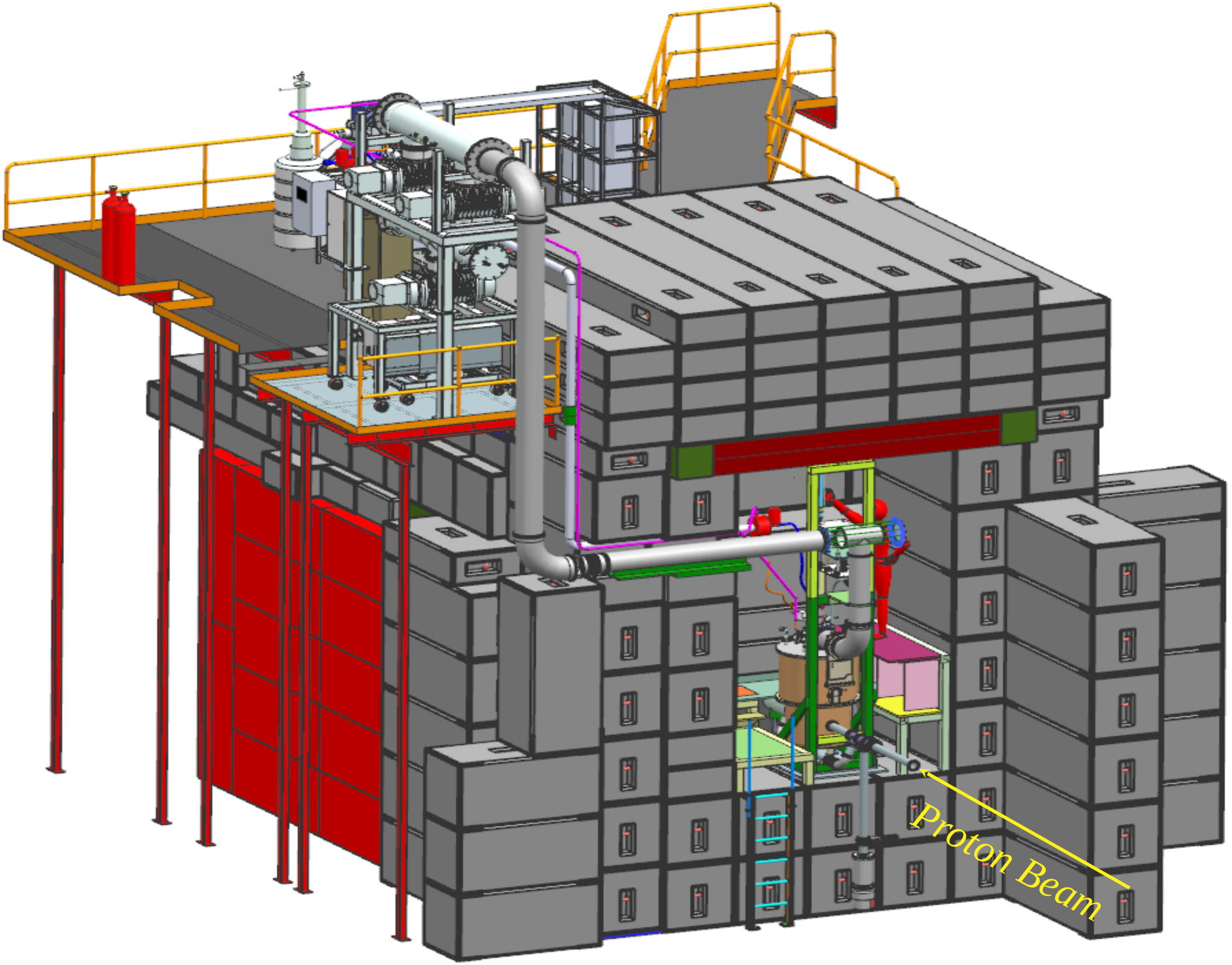

Station 1:
Hodoscope array
MWPC tracking
Stations 2 and 3:
Hodoscope array
Drift chamber tracking
Station 4:
Hodoscope array
Proportional tube tracking
Solid iron focusing magnet, hadron absorber and beam dump (FMag)
Momentum measuring magnet (KMag)
4.9m
Hadron absorber (iron wall)
25m
Liquid H_2, D_2, and solid targets
Replace with polarized targets of NH_3 and ND_3

The target

- The new target uses polarized NH_3 or ND_3.
- The target position is moved upstream along the beamline.
  - This is to better probe small x_2 region.
  - This also provides much better separation of tracks from dump and target, important for background rejection.
- The new target cave is now under construction.

The polarized target

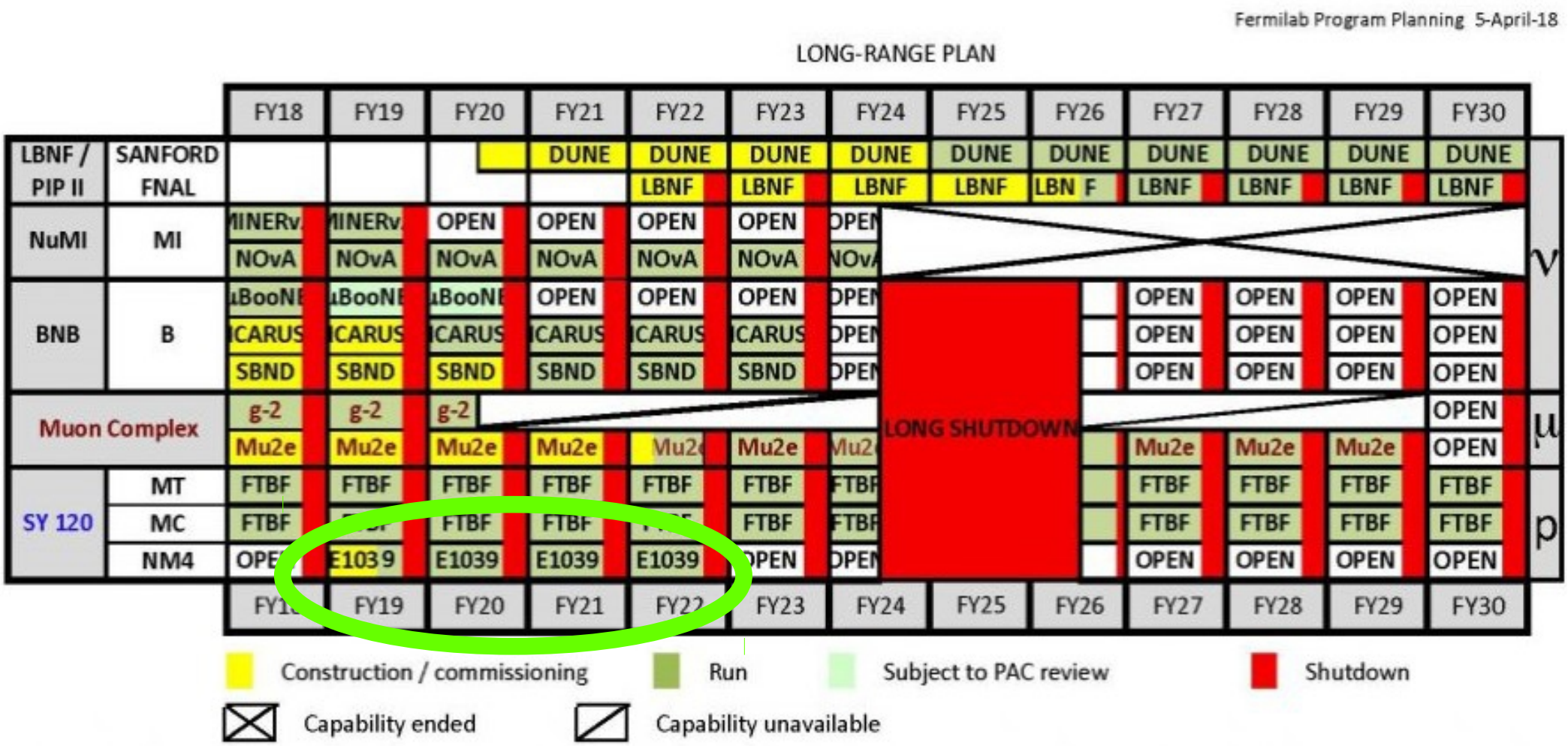



Proton Beam

Preparing the experiment

- Checking detectors
- Beam line and target cave reconstruction are well in progress
- Installation of polarized target will start soon
- DAQ upgrade
- Trigger upgrade
- Online monitoring
- Offline production
- ...

The schedule



Summary

- E1039 will measure the asymmetry induced by Sivers function of antiquark, zero or non-zero.
- With polarized ND_3, study tensor polarization
- Tensor charge
- Expect to take beam in Feb. 2019.
- Physics data taking starts in Sep. 2019, for two years.
- Invitation for new collaborators!

From *M. Anselmino et. al.*,

- *The coupling of two chiral-odd partonic distributions could occur in Drell-Yan processes (D-Y), but, so far, no data on polarized D-Y are available. (2013)*
- This is now changing!

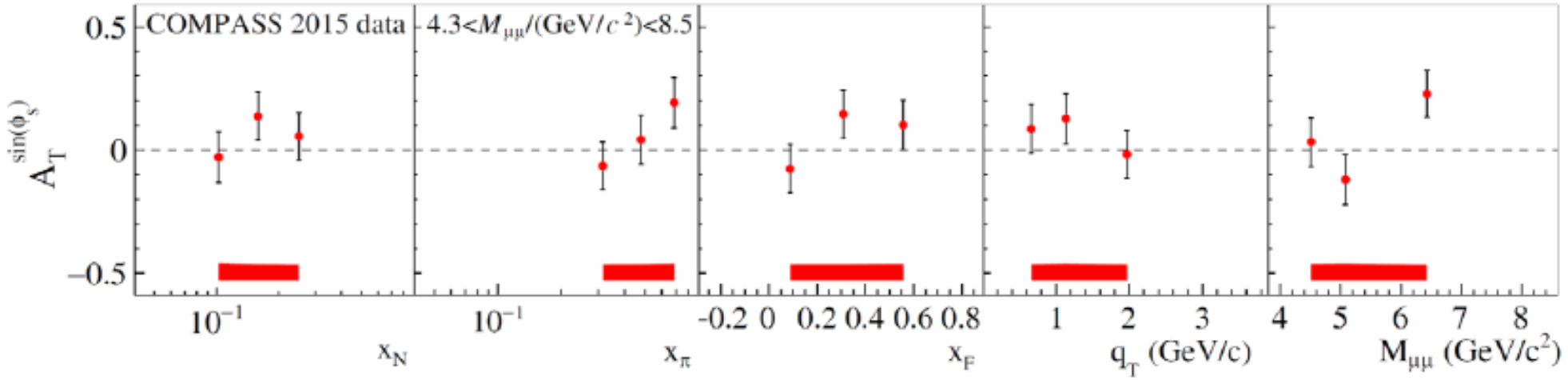
Stay tuned!

Transverse spin asymmetry in Transversely polarized D-Y

$$\frac{d\sigma^{LO}}{d^4q d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\tilde{\sigma}_U^{LO}$$

$$A_T^{\sin\phi_s} \propto \text{Density}\, f_1|_\pi \otimes \text{Sivers}\, f_{1T}^{\perp}|_p$$

$$\left\{\left(1 + D^{LO}_{[\sin^2\theta]} A_U^{\cos 2\varphi}\cos 2\varphi\right) + \left|\vec{S}_T\right|\left[A_T^{\sin\varphi_S}\sin\varphi_S + D^{LO}_{[\sin^2\theta]}\left(A_T^{\sin(2\varphi-\varphi_S)}\sin(2\varphi-\varphi_S) + A_T^{\sin(2\varphi+\varphi_S)}\sin(2\varphi+\varphi_S)\right)\right]\right\}$$

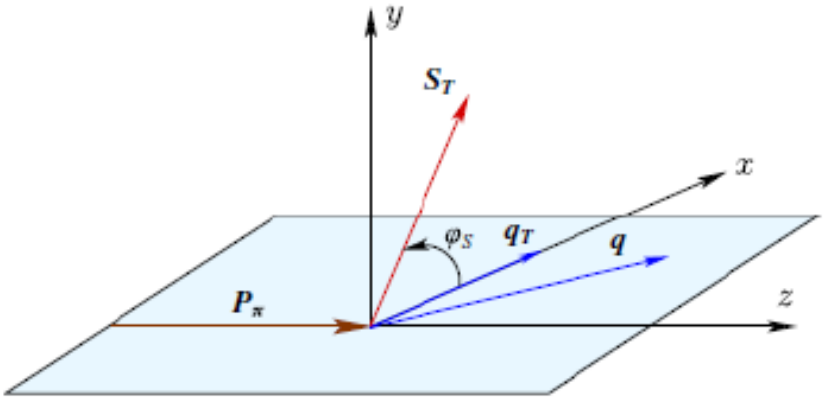


COMPASS, PRL 119 (2017) 112002

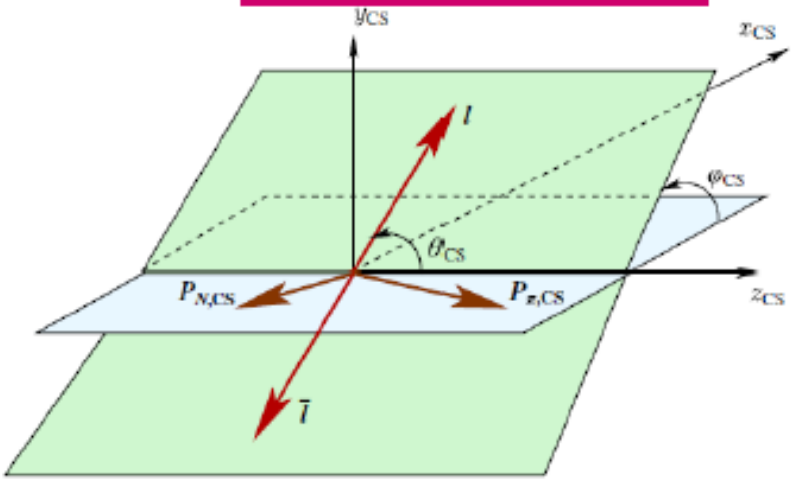
Measuring transversity in the Drell-Yan process

$$\frac{d\sigma}{dq^4 d\Omega} \propto \hat{\sigma}_U \left(1 + S_T \left\{ D_1 A_T^{\sin\varphi_S} \sin\varphi_S + D_2 \left[A_T^{\sin(2\varphi_{CS}-\varphi_S)} \sin(2\varphi_{CS}-\varphi_S) + A_T^{\sin(2\varphi_{CS}+\varphi_S)} \sin(2\varphi_{CS}+\varphi_S) \right] \right\}\right).$$

Lab frame



Dilepton rest frame (CS)



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$$\frac{d\sigma}{dq^4 d\Omega} \propto \hat{\sigma}_U \left(1 + S_T \left\{ D_1 A_T^{\sin\varphi_S} \sin\varphi_S + D_2 \left[A_T^{\sin(2\varphi_{CS}-\varphi_S)} \sin(2\varphi_{CS}-\varphi_S) + A_T^{\sin(2\varphi_{CS}+\varphi_S)} \sin(2\varphi_{CS}+\varphi_S) \right] \right\}\right).$$

D_2 : depolarization factor

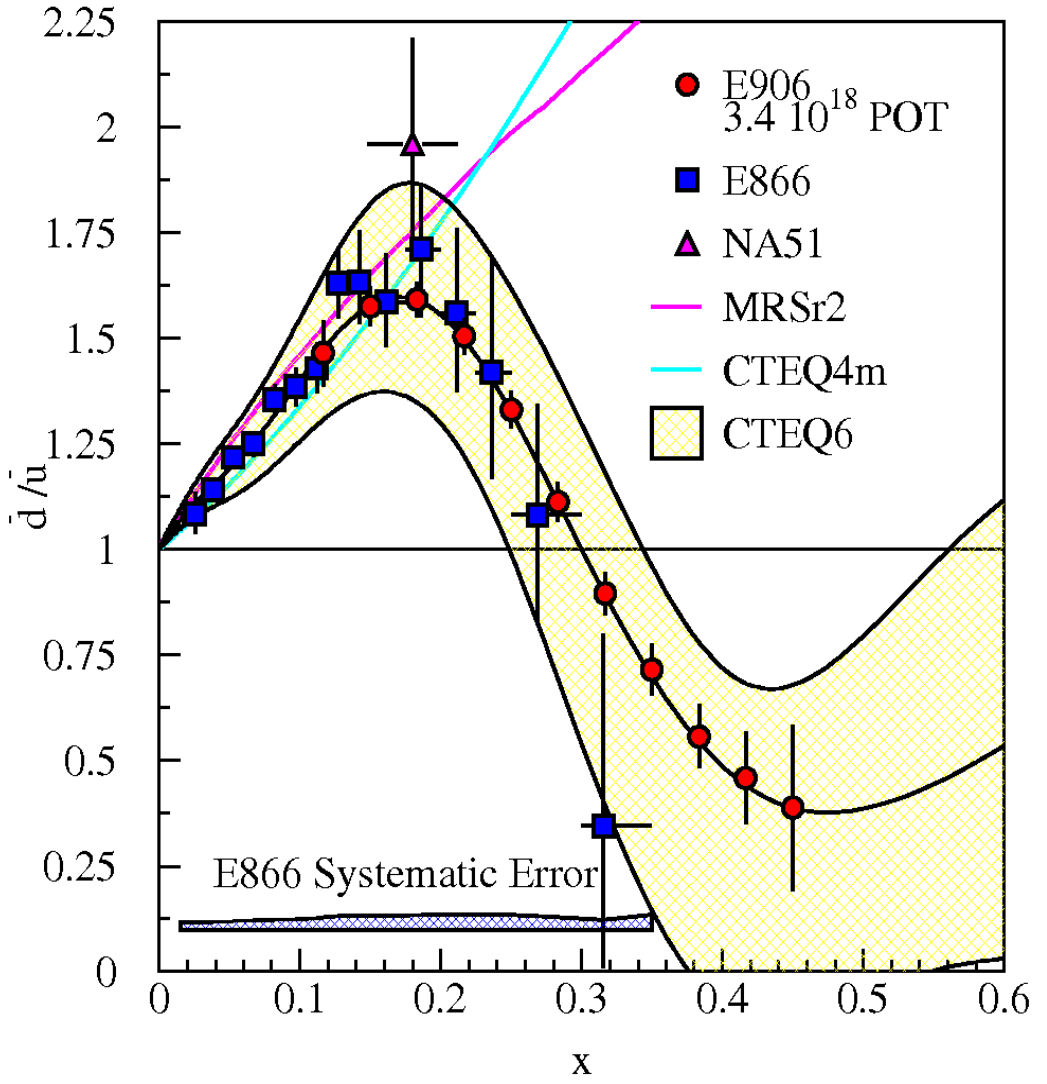
φ_S : azimuthal angle between $\vec{q}_T$ and $\vec{S}_T$

φ_{CS} : azimuthal angle of μ^- in the Collins-Soper frame

$A_T^{\sin(2\phi_s-\phi_S)} \propto$ BM $h_1^{\perp}|_p \otimes$ Transversity $h_1|_p$

The SeaQuest experiment

- Done taking data in 2017.
- Analyzing data.
- Expect to publish result soon.



Tensor polarization

- Tensor polarization is
  - available when the target particle
    - has spin = 1, such as deuteron and
    - is polarized.
- For a spin 1 particle in magnetic field,
  - Zeeman effects creats three levels, m=+1,0,-1; which have three population, p+, p0 and p-.
  - In this case there are
    - vector polarization = p+ - p-
    - tensor polarization = (p+ - p0) - (p0 - p-) = 1 – 3 p0.

Tensor polarization

- Additional tensor polarization terms lead to additional PDFs, namely $\boldsymbol{b}_1$, $\boldsymbol{b}_2$, $\boldsymbol{b}_3$ and $\boldsymbol{b}_4$.
- Where, in parton model, $\boldsymbol{b}_1$ describes the difference between |m| = 1 and m = 0 states.

DAQ and trigger upgrade

- Previously we read out all TDC's through the Readout Controler in each VME crate.
- The upgrade is to read out data through the ethernet port of the TDC's, which has ARM cpu on board. This significantly improves the data throughput.
- It is then important to reduce the junk events as much as we can to save the disk space and CPU power required in data handling.

Online monitoring and data production

- Computing resources in the control room is revisited to provide information in semi real time when data is being taken. This should include not only hit distributions but also high level physics events reconstructed such as J/Psi mass peak.
- Data production (decoding) should happen as soon as possible after data is taken. Quick turn around is important for the experiment to success.