Probing the sea quark Sivers function with the E1039 polarized Drell-Yan experiment

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For the E1039 Collaboration

Outline

- Motivation
- E1039 experiment introduction
  - Spectrometer
  - Polarized target
- Spin physics program at the E1039 experiment:
  - Study the sea quark Sivers function and flavor asymmetries with the Drell-Yan A_N measurements.
  - Probe the gluon Sivers function with the J/ψ A_N measurements.
  - Study the deuteron spin tensor function with the ND_3 target
- Summary and Outlook

Spin structure of the proton

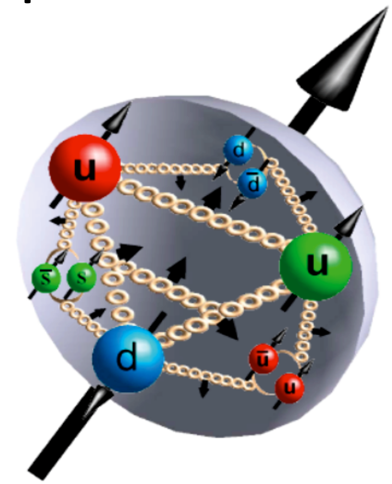
- Proton spin is carried by it components (quarks and gluons).

RHIC measured ~20%

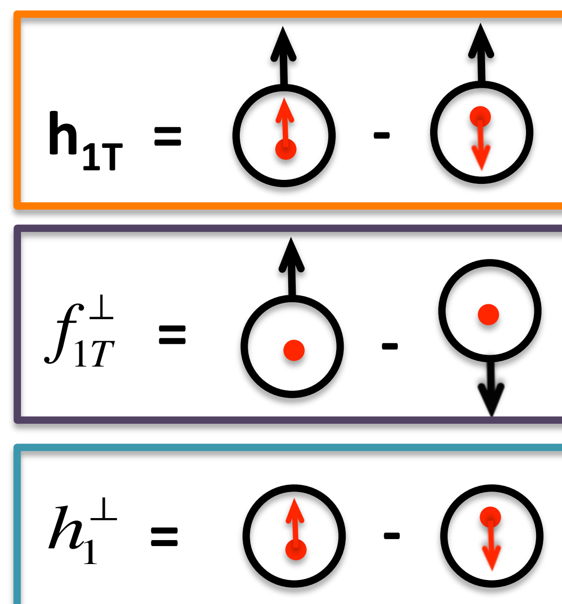
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

DIS measured ~30%

Little known



- Contributions to the orbital angular momentum component of the proton spin.
  - Transversity h_{1T}
  - Sivers function $f_{1T}^{\perp}$
  - Boer-Mulders function $h_1^{\perp}$

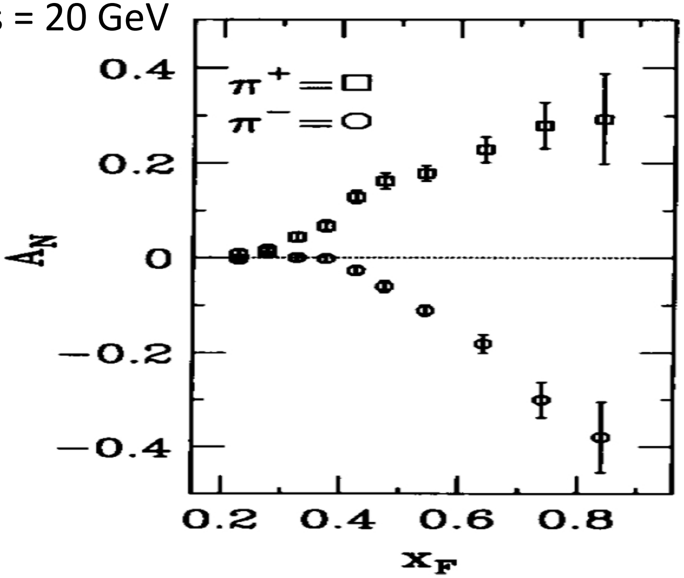


The quark Sivers function

- The quark Sivers function $f_{1T}^{\perp}$ is the distribution of unpolarized quarks in a transversely polarized nucleon.

E704, PLB 264 (1991) 462

√s = 20 GeV



- First observation of large transverse single spin asymmetry (A_N) of charged pions has been achieved by the E704 experiment.

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \propto f_{1T}^{\perp} \neq 0 \quad \Rightarrow \quad L_q \neq 0$$

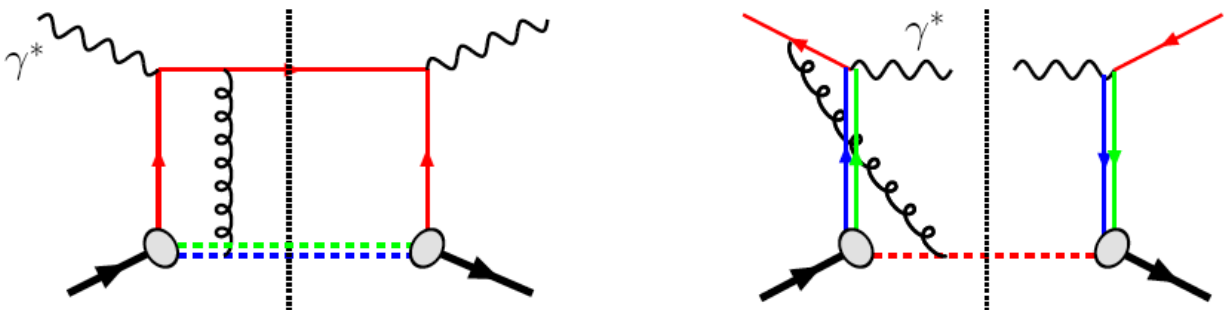
- In factorization framework with the assumption of universal PDF, transverse spin asymmetries of final states are proportional to the initial quarks or gluons polarization contributions.

Sivers function is process dependent

- In QCD:
  - Sign change of the quark Sivers function between DIS and Drell-Yan process.

DIS: attractive

Drell-Yan: repulsive



As a result:

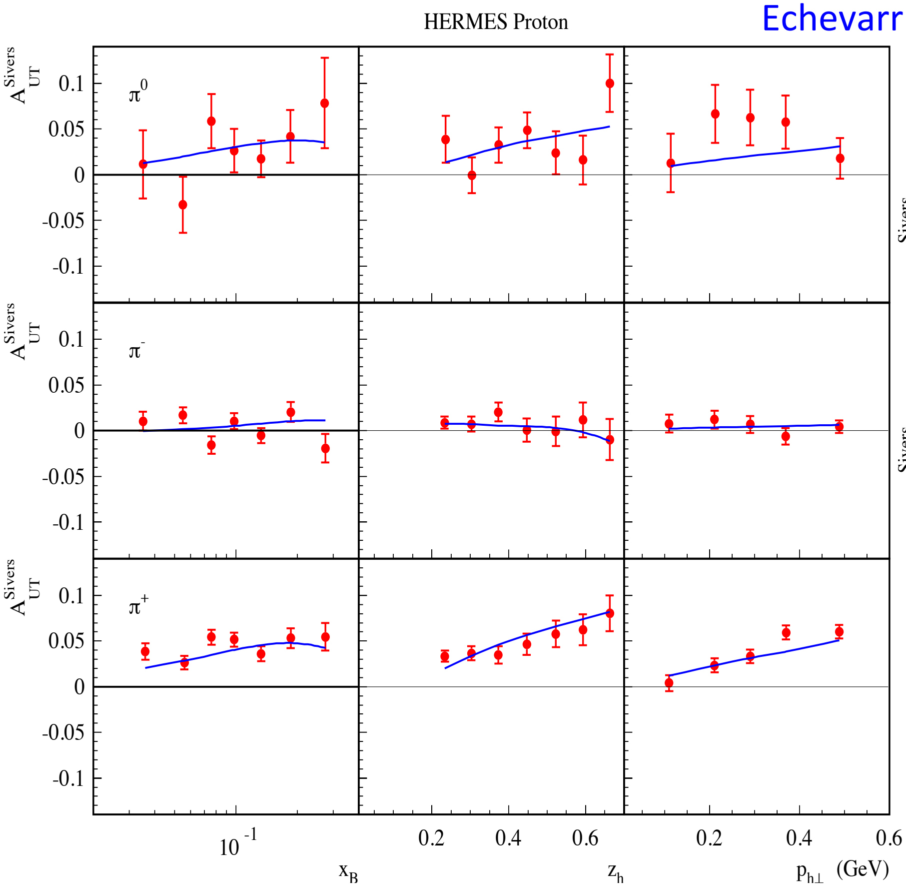
$$\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$$

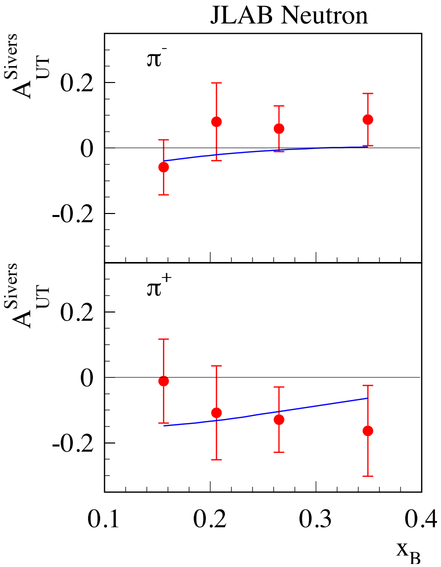
- Urgent need to achieve these milestone measurements!
- Determine the Sivers function from global QCD analysis.

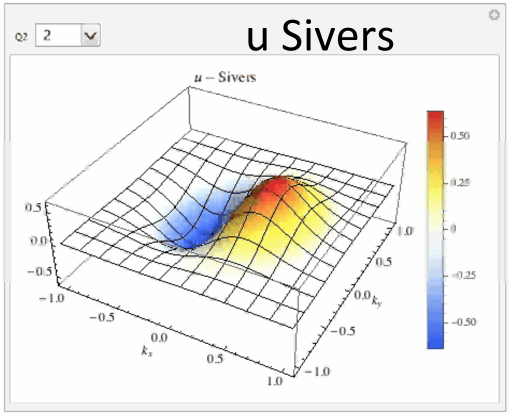
Sivers function determined in DIS

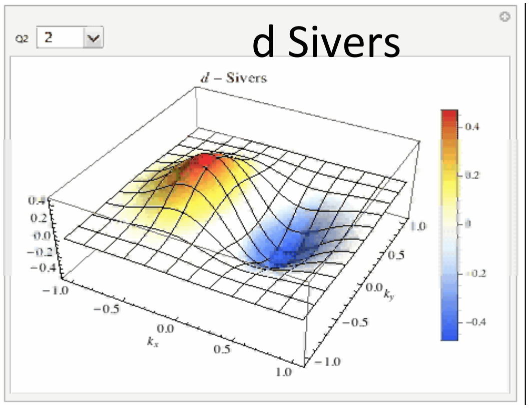
- Measurements in JLab, HERMES, COMPASS.
  - Involves quark to hadron fragmentation function.
  - Mix the valence and sea quark contribution.

Echevarria, Idilbi, Kang, Vitev, 14





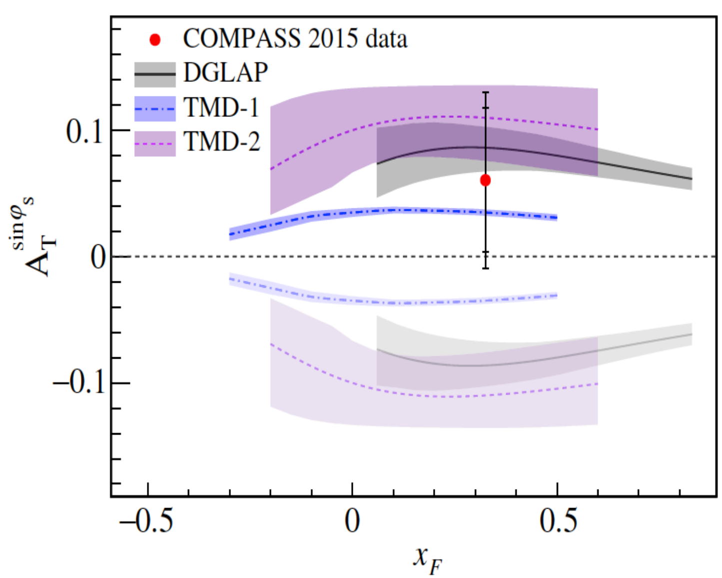




Sivers function determined in DY/W production

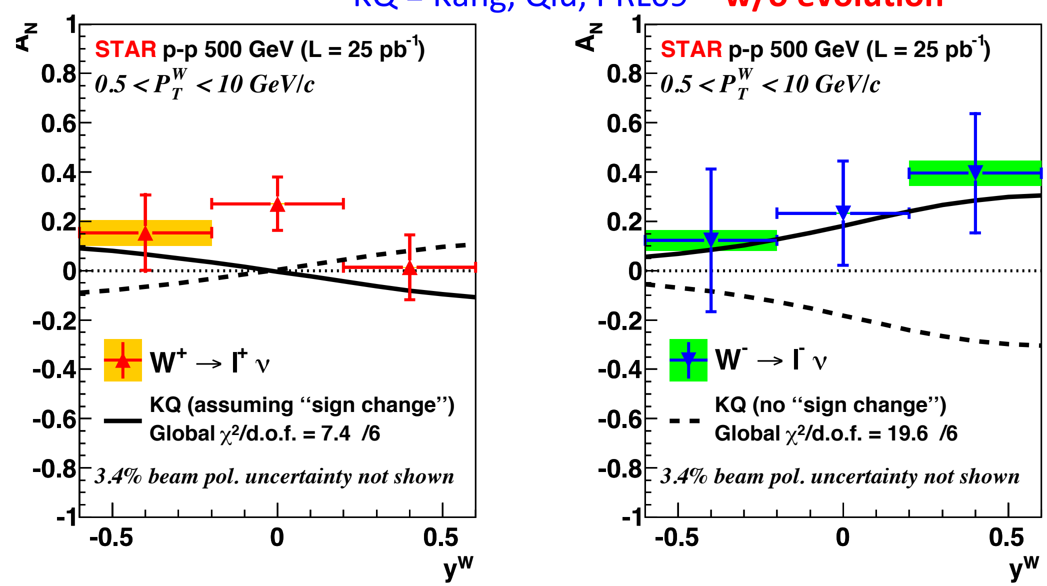
- Measurements of DY at COMPASS and W at RHIC
  - Provide evidence of Sivers function sign change.
  - Need include Q^2 evolution to interpret.
  - Large uncertainty require more statistics to constrain the quark Sivers function.
- **How about the sea quark Sivers function?**

COMPASS, PRL 119, 112002



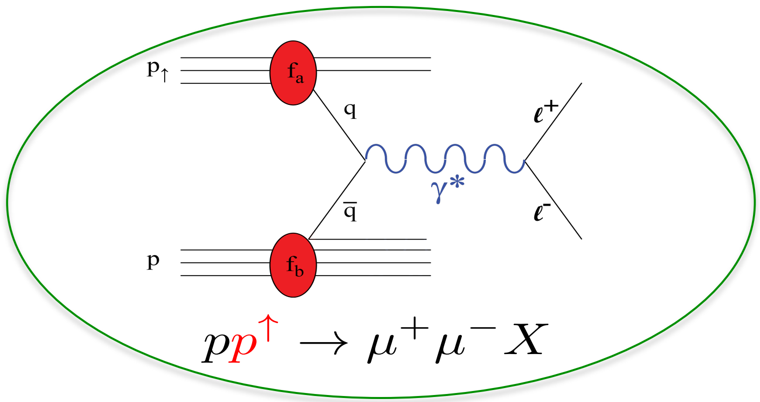
STAR, PRL.116.132301

KQ = Kang, Qiu, PRL09 – **w/o evolution**



Sea quark Sivers function

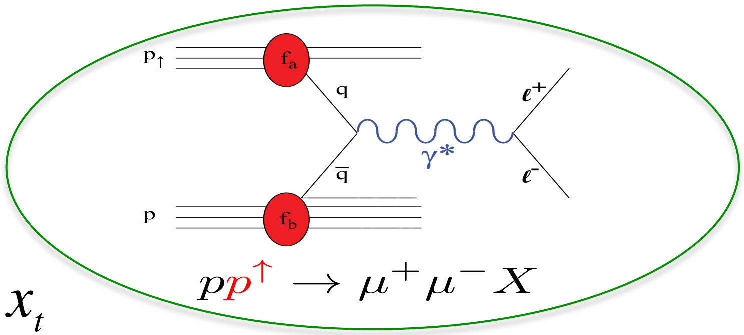
- Never measured and no information.
- Can we measure?
- The polarized target experiment: E1039.



- Even the E1039 experiment can not access the quark Sivers function sign change kinematic region, results from E1039 together with other measurements could provide constrains on the valence quark Sivers function.

How to access the sea quark Sivers function?

- E1039 experiment with the polarized target.



$x_F = x_b - x_t$

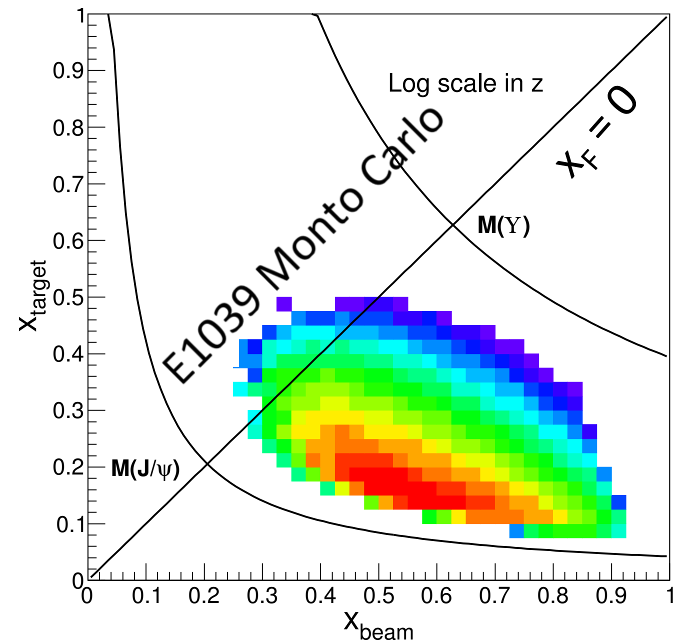
$$\frac{d^2\sigma}{dx_b\, dx_t} = \frac{4\pi\alpha^2}{9x_b\, x_t}\frac{1}{s}\sum_q e_q^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

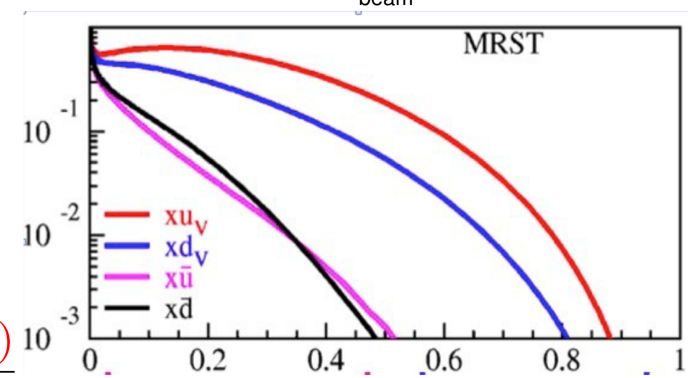
small

target sea quark

beam valence quark

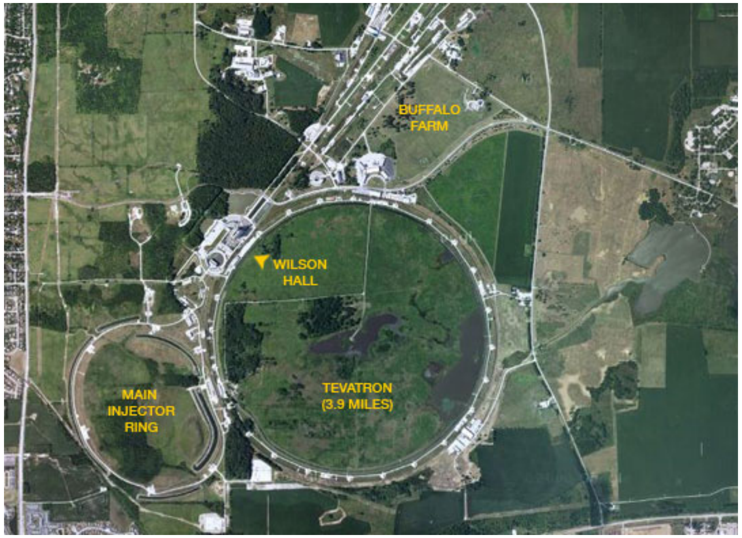
$\bar{u}_t(x_t) \cdot u_b(x_b)$ dominates





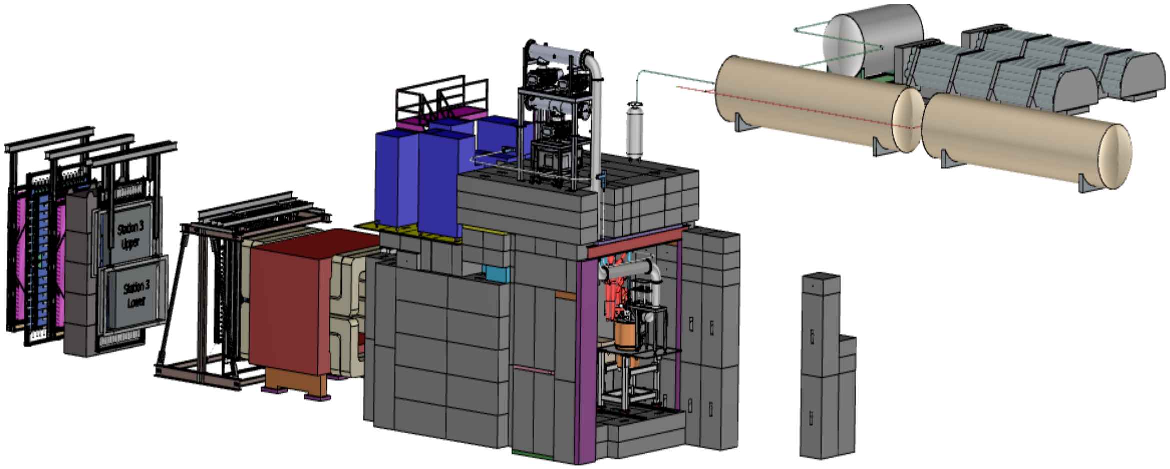
- Through kinematics selection, choose valence quark from the beam and the sea quark from the polarized target.
- E1039: ideal place to study the sea quark Sivers function. $A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$

E1039 at Fermi-lab



- 120 GeV proton beam.
- √s = 15 GeV.
- Instant luminosity : $4*10^{35}$ /cm^2/sec.
- Integrated luminosity per year: **L = 1.1 $*10^{43}/cm^2$.**
- Drell-Yan mass range 4<M<8 GeV/c^2.

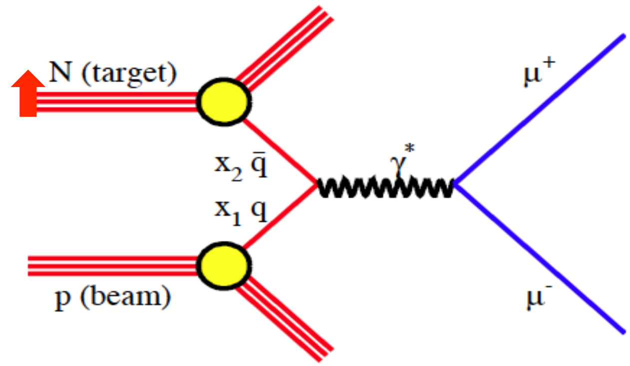
E1039 geometry



Upgrade based on E906:

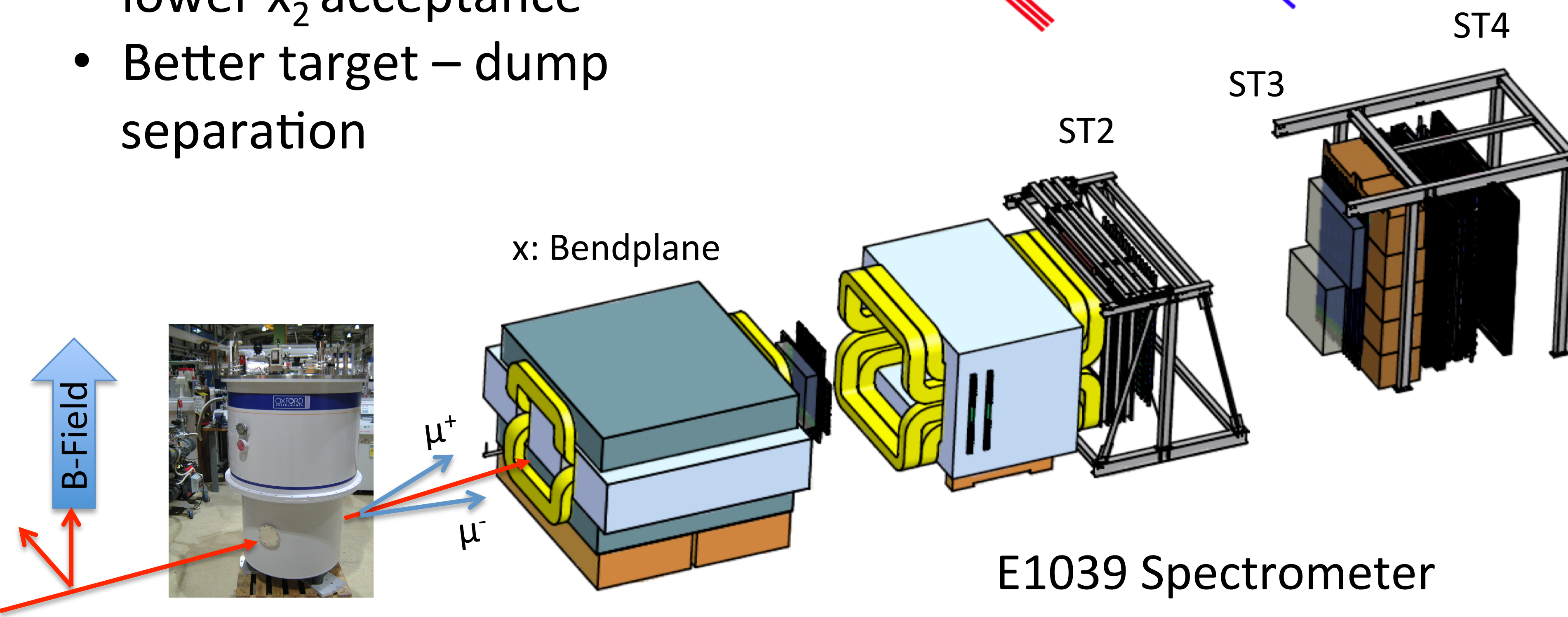
- **Rebuild shielding.**
- Collimators upstream.
- Closed Loop He system.
- 90 degree L/R monitors.

E1039 spectrometer



Target upstream by ~200cm from E906

- lower x_2 acceptance
- Better target – dump separation



How to get polarization

- At thermal equilibrium, polarization is $\propto \tanh(\frac{g\mu_B H}{2kT})$
- Requires low temperature T, large magnetic filed H.
- As $\mu_B = 9.3 \cdot 10^{-24} J/T$, $\mu_N = 5.05 \cdot 10^{-27} J/T$, it's hard to get nucleon polarized.
- How to solve this?
- Dynamic nuclear polarization (DNP).

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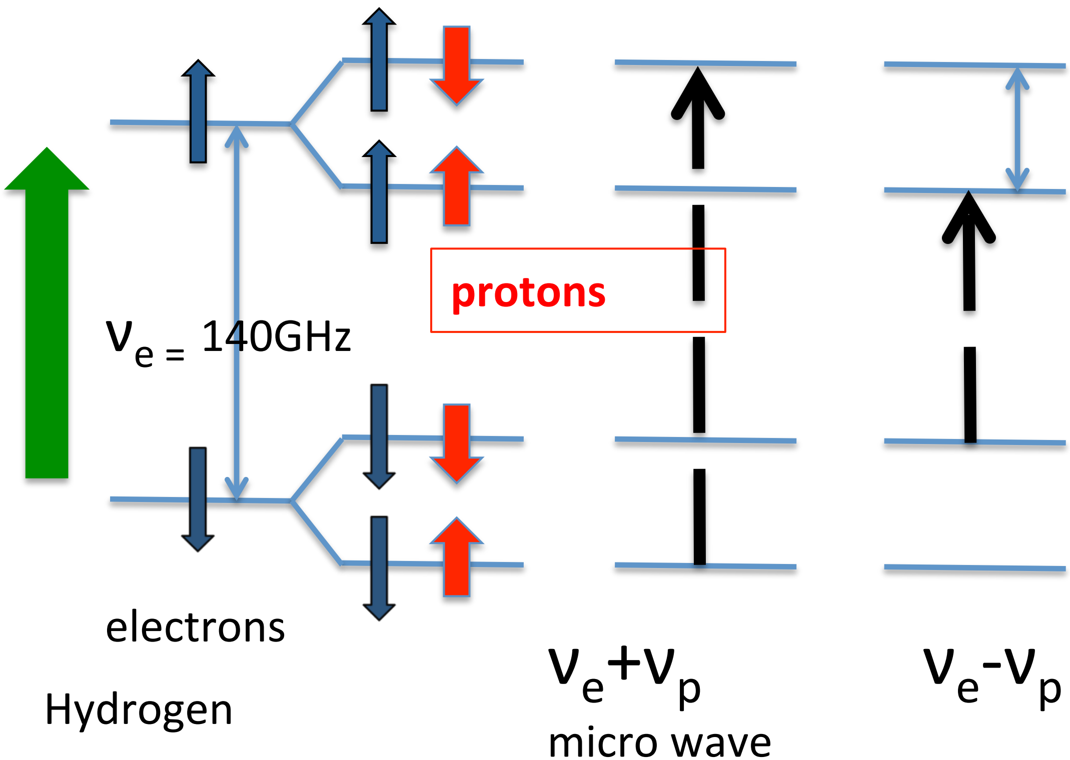
- Requires low temperature T, large magnetic filed H.
- As $\mu_B = 9.3 \cdot 10^{-24} J/T$, $\mu_N = 5.05 \cdot 10^{-27} J/T$, it's hard to get nucleon polarized.
- Use dipole interaction between p and e: **Hyperfine splitting**



DNP:

T = 1K H = 5T

Use microwave

to provide RF transition

ν_e = 140 GHz

ν_p = 213 MHz

e: Electron Spin Resonance

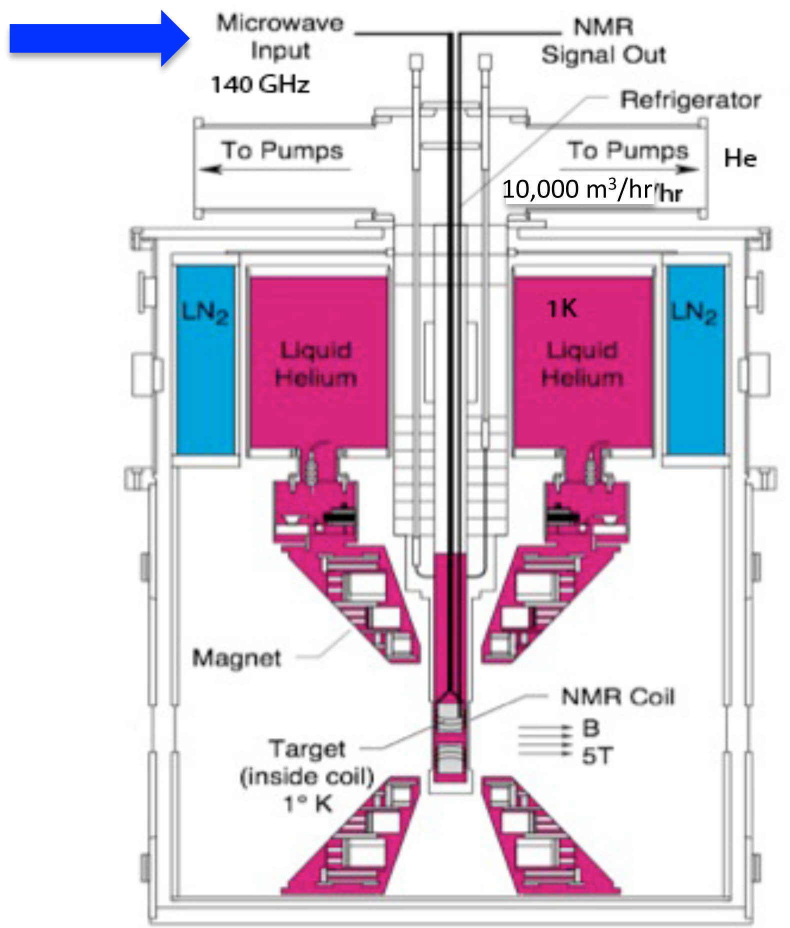
p: nuclear spin transitions

"Pump" the proton spin with microwave.

The Polarized Target System (longitudinal configuration)

Microwave: Induces electron spin flips

- EIO + Power equip:



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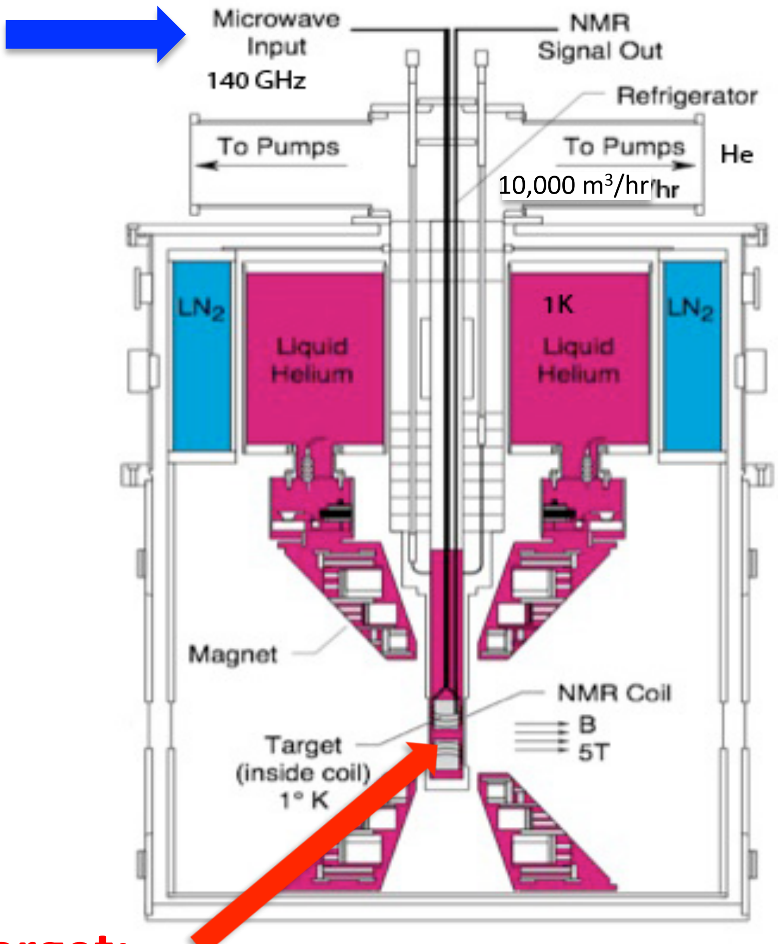


Target:

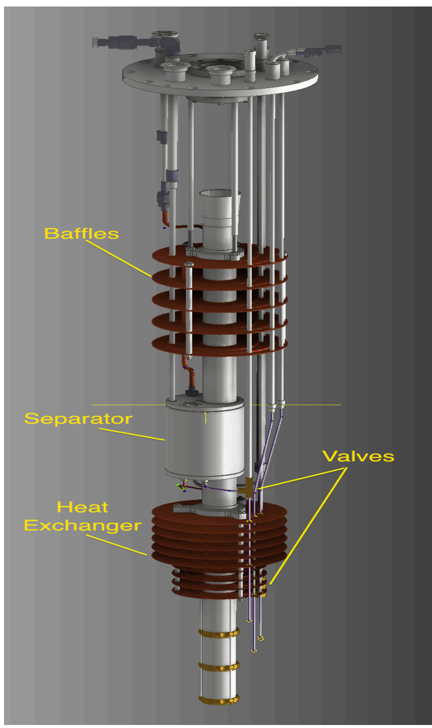
material: frozen NH3/ND3, Irradiation@ NIST

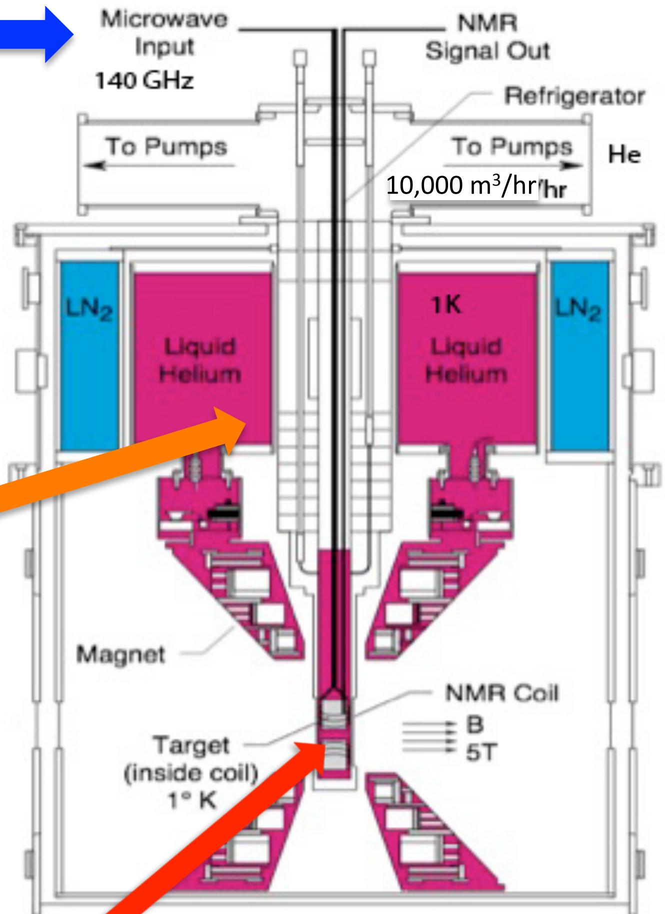
The Polarized Target System (longitudinal configuration)

Microwave: Induces electron spin flips

- EIO + Power equip:

Refrigerator:





Roots pump system used to pump on ^{4}He vapor to reach 1K

Target:

material: frozen NH3/ND3, Irradiation@ NIST

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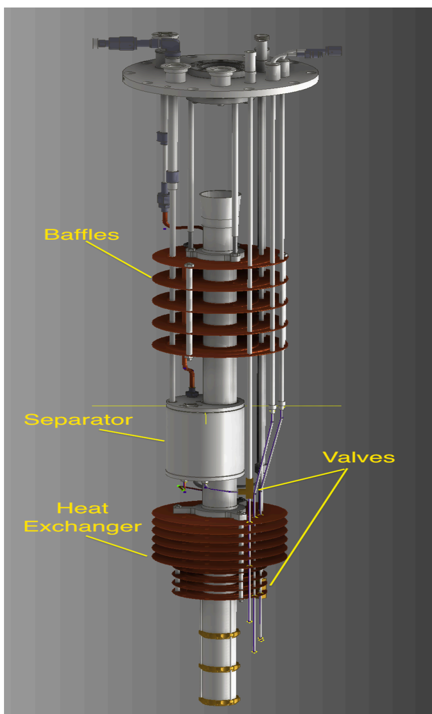
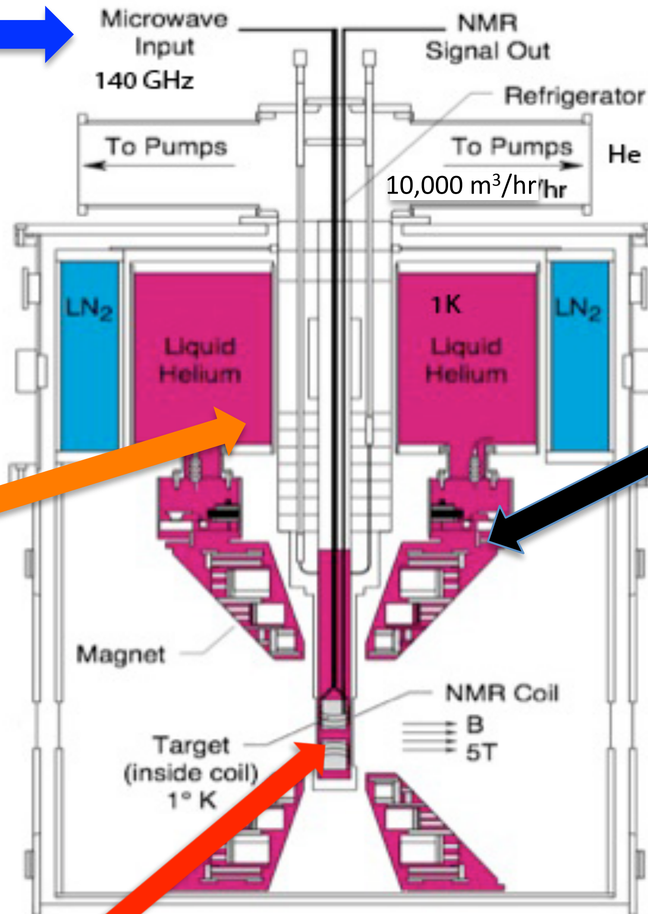
- EIO + Power equip:

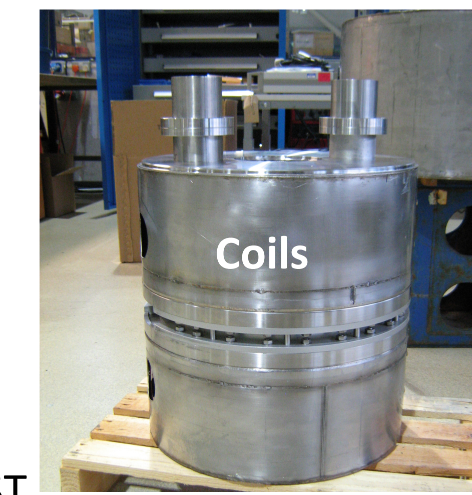
Refrigerator:





Roots pump system used to pump on ^{4}He vapor to reach 1K

Superconducting Coils for Magnet: 5T



Target:

material: frozen NH3/ND3, Irradiation@ NIST

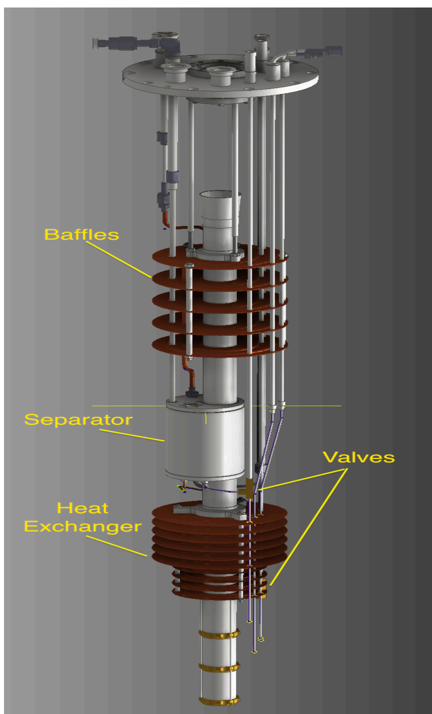
The Polarized Target System (longitudinal configuration)

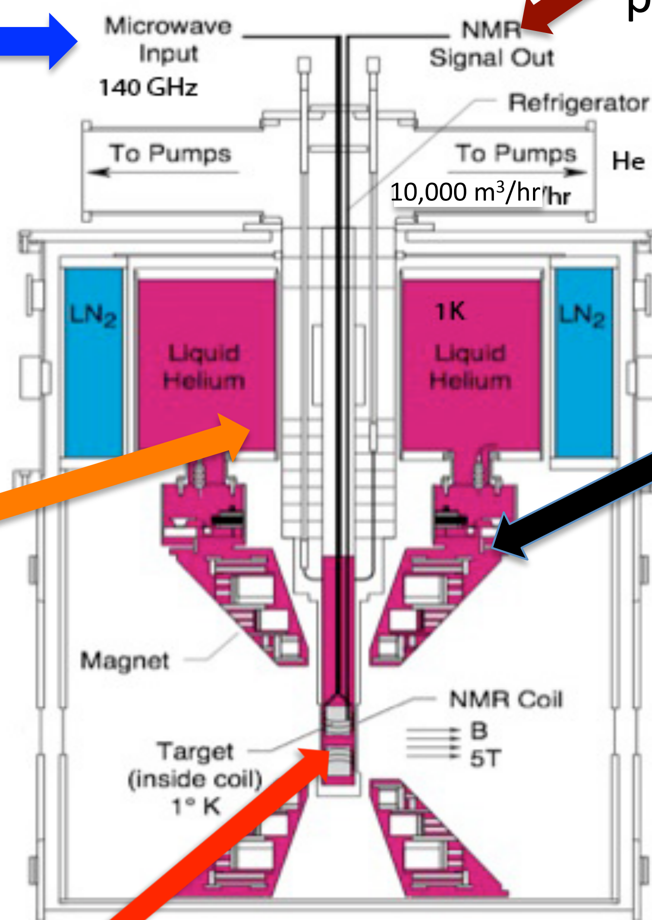
Microwave: Induces electron spin flips

- EIO + Power equip:

NMR system: to measure polarization

Refrigerator:





Roots pump system used to pump on ^{4}He vapor to reach 1K

Superconducting Coils for Magnet: 5T

Target:

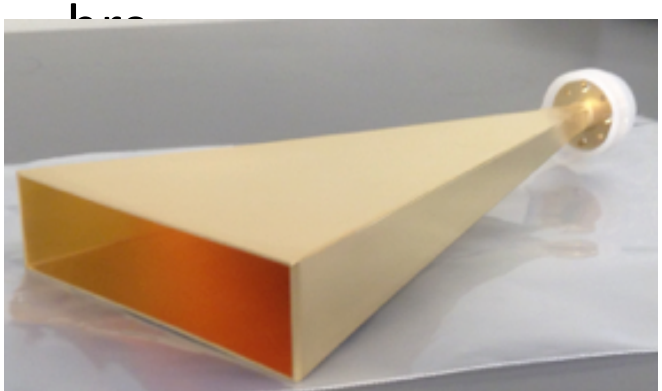
material: frozen NH3/ND3, Irradiation@ NIST

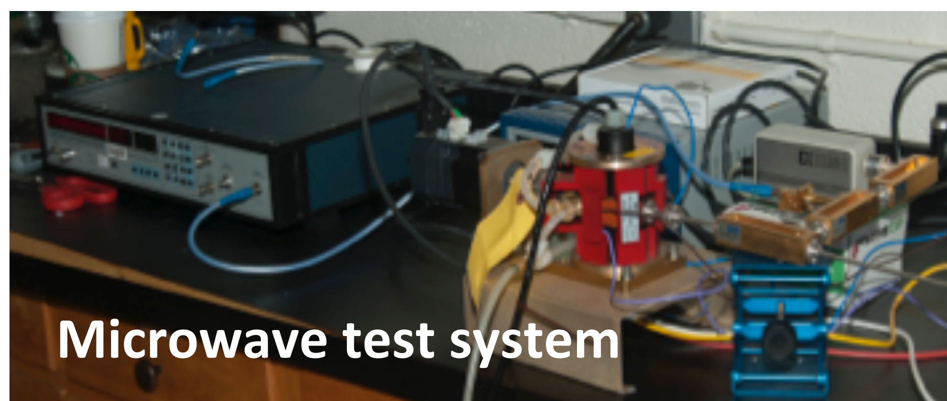
Polarized target system: target and microwave

- **Target:** consists of insert, holder and target material.

NH3 target irradiated with electrons

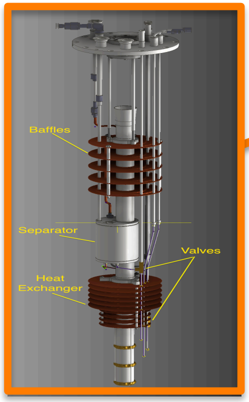
- **Microwave:** RF transition 140 GHz, preserve polarization ~ 8 hrs

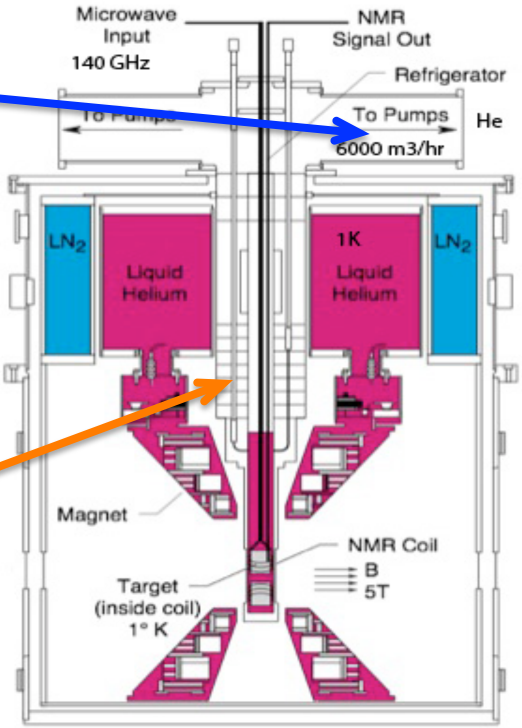




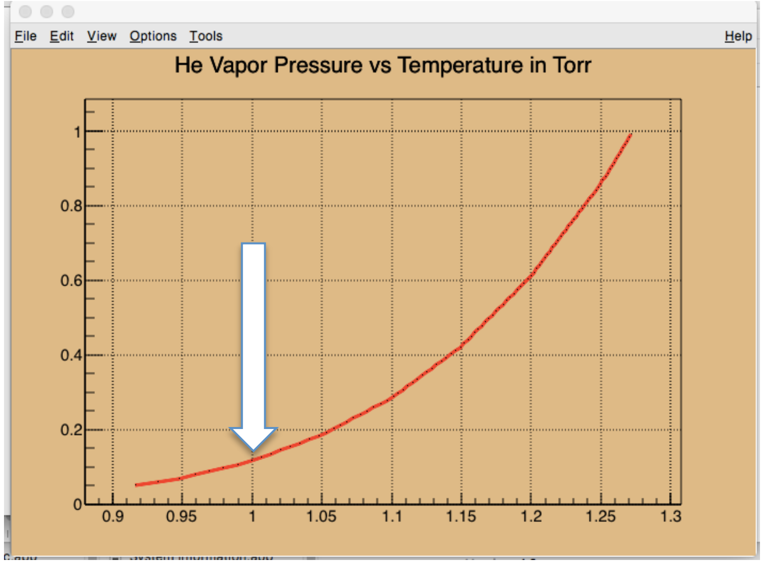
Maintain polarization: Low temperature ~ 1K

- To keep low temperature as low as 1K.
  - Pump on vapor pressure of liquid Helium.
  - Use refrigerator.



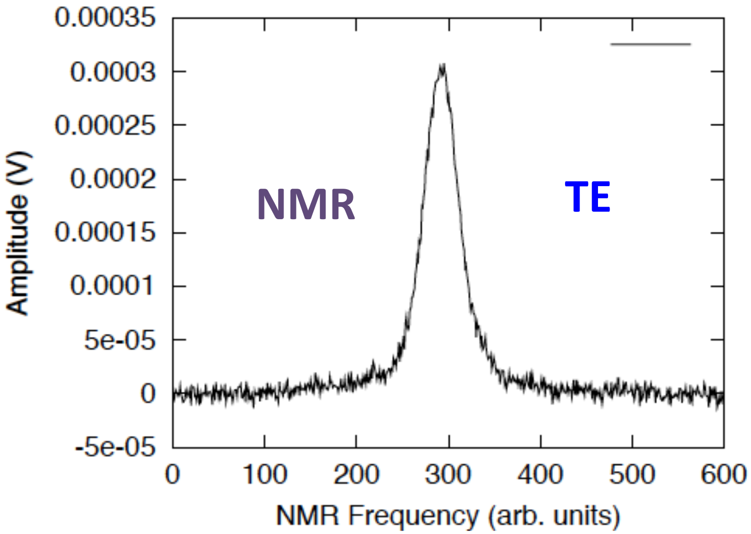


Cool down test:

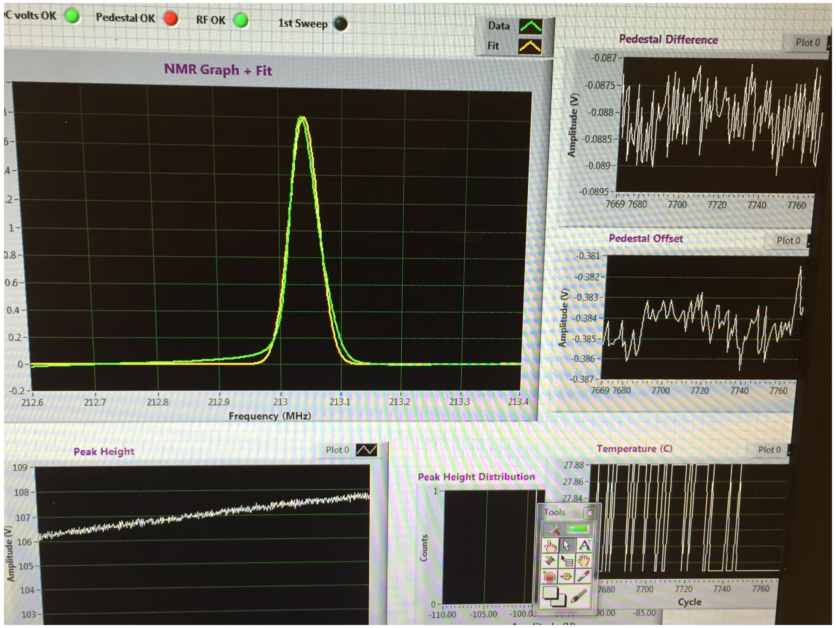


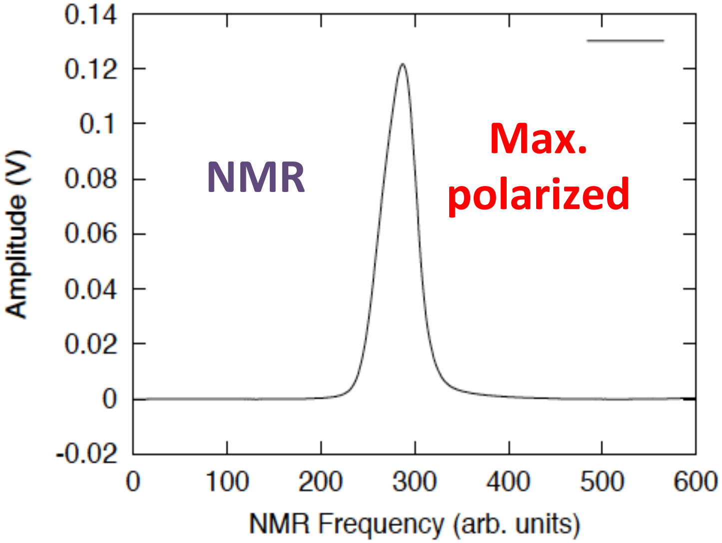
Polarization measurement: NMR system

- Thermal Equilibrium TE:
  - T=1K, H=5T
  - P_e = .998
  - Measure P_p =.005 since $\mu_N / \mu_B \sim 10^{-3}$



NMR system monitor view when the target is maximally polarized

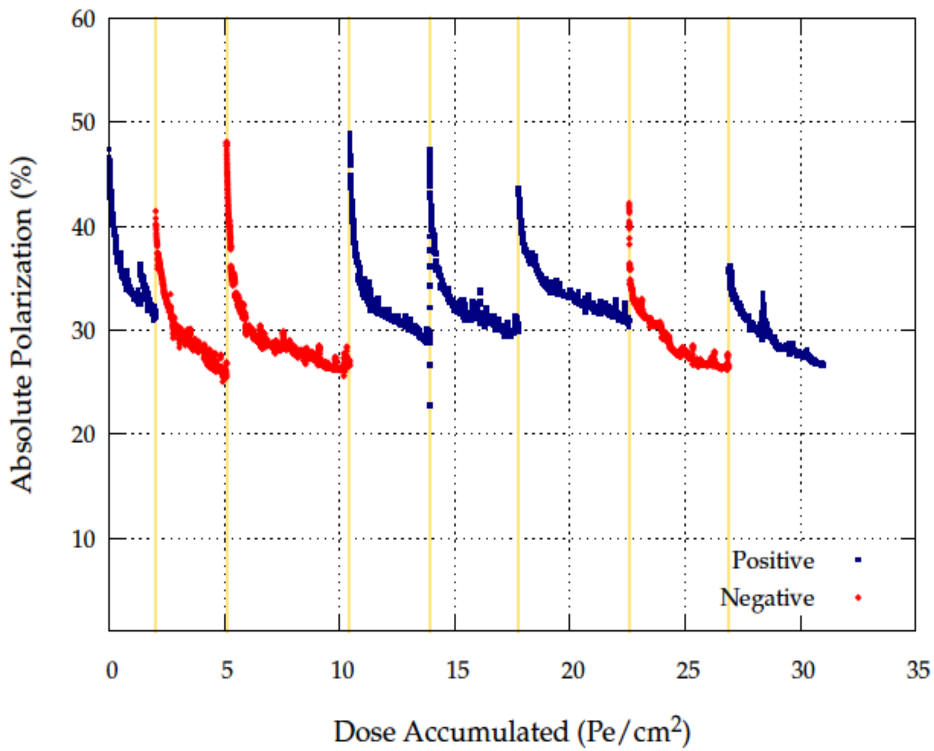




Polarization Measured P~92 %

Recover polarization from Beam effect

Test at 2.5T magnetic field

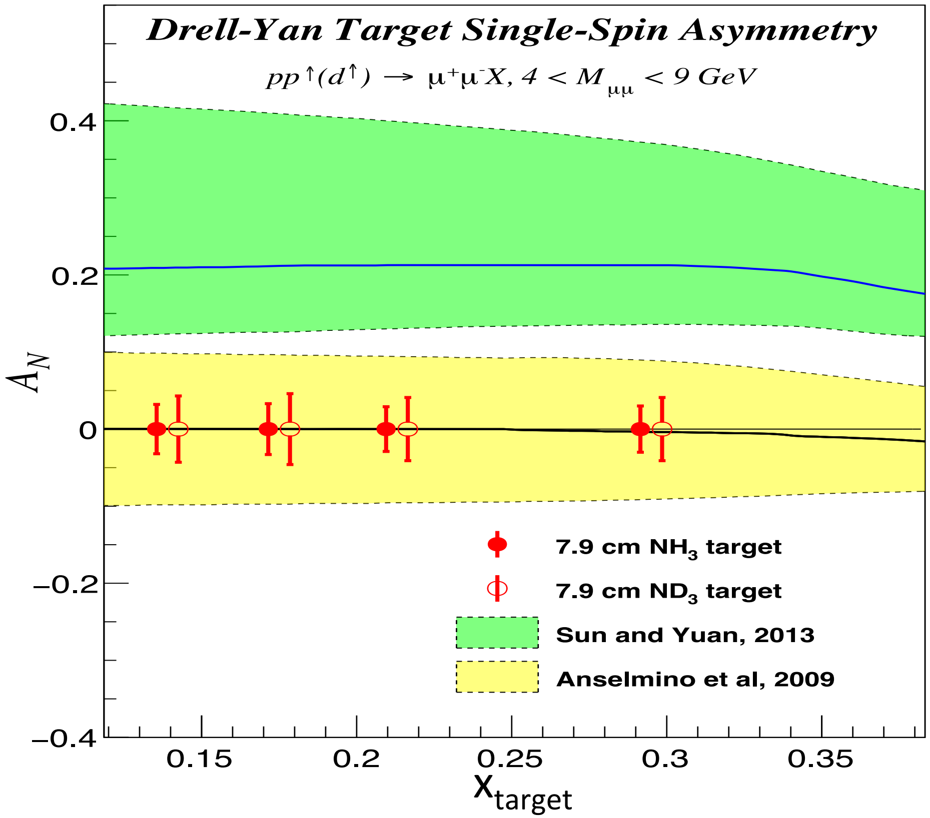


- Beam effect:
  - Polarization anneal every 24 hours.
- Systematics control:
  - Reverse polarization direction once a day.
  - Reverse magnetic field of target magnet every target replacement.
  - Background measurements.

Systematic errors:

- Absolute: 1% (Luminosity precision on different pol directions).

First direct sea quark Sivers measurement: Drell-Yan A_N



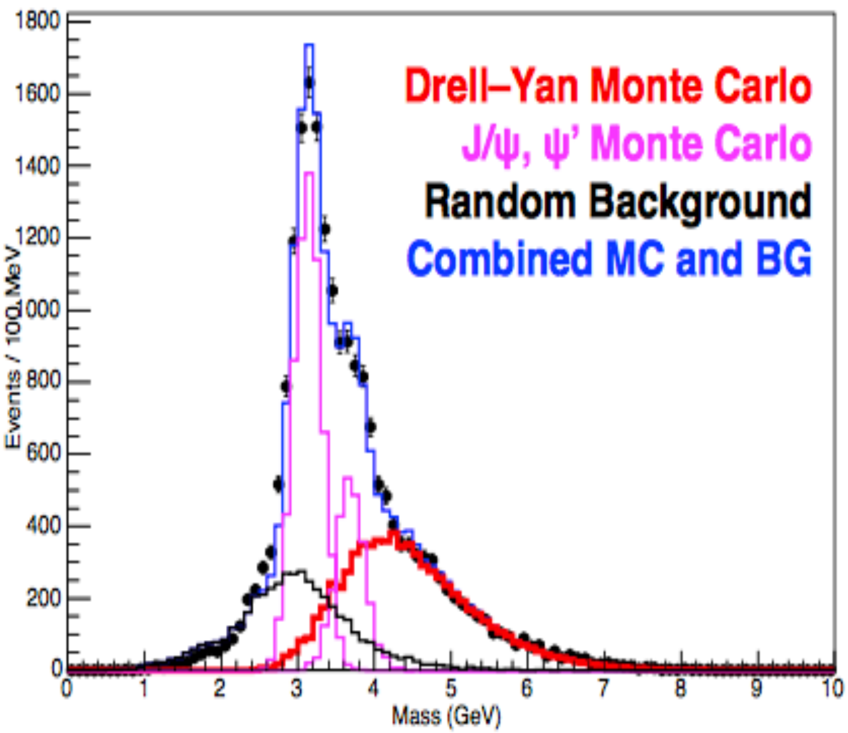
- Projection of DY A_N at E1039 with realistic efficiency and polarization.
- Provide direct constraint on the sea quark Sivers function and flavor asymmetries in the $0.14<x_2<0.30$ region.
- Provide inputs for theoretical interpretation.

Range x_2	Mean x_2	N events p	ΔA % p	N events n	ΔA % n
0.1-0.16	.139	5.0×10^4	3.2	5.8×10^4	5.4
0.16-0.19	0.175	4.5×10^4	3.3	5.2×10^4	5.7
0.19-0.24	0.213	5.7×10^4	2.0	6.6×10^4	5.0
0.24-0.6	0.295	5.5×10^4	3.0	6.4×10^4	5.1

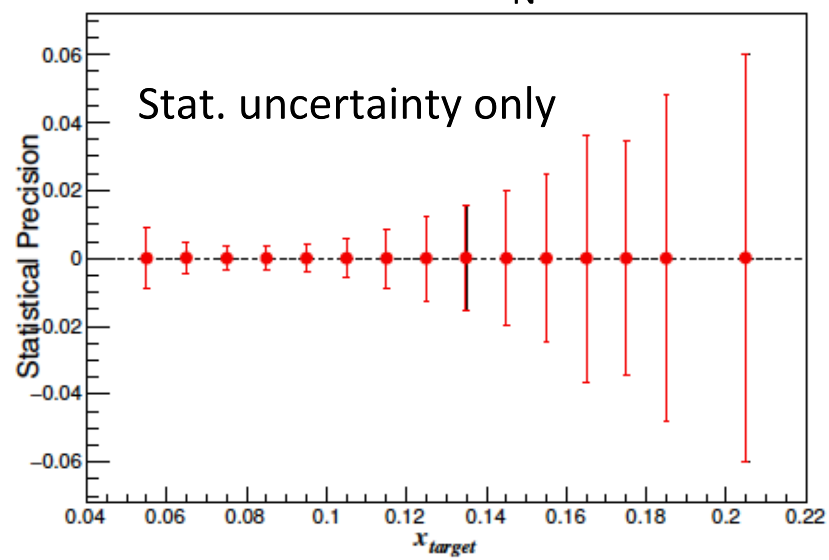
How about gluon Sivers function?

- Around 1 million J/ψ is expected to be recorded at the E1039 experiment with DAQ upgrade.

Di-muon mass from E906
Similar spectrum for E1039



Projected J/ψ A_N at E1039

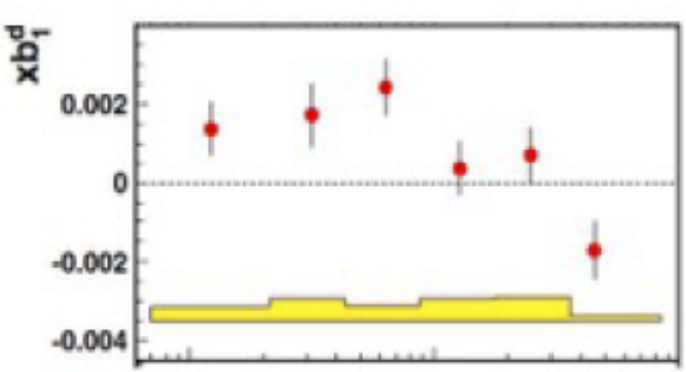


- Provide constraint on the gluon Sivers function with the J/ψ A_N measurements.

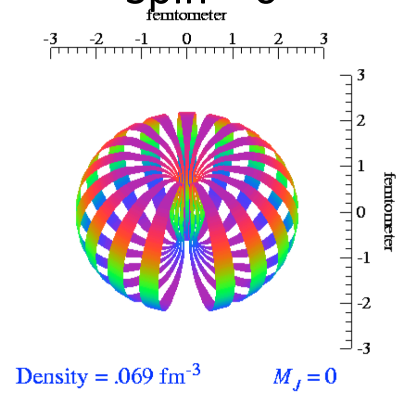
Deuteron spin structure?

- Use tensor polarized ND_3 target to
  - measure the deuteron tensor function b1 and study nuclear effects on quarks.
  - study the geometric aspects from the quark-gluon dynamic twist contributions to the nucleon spin (Delta-b4).

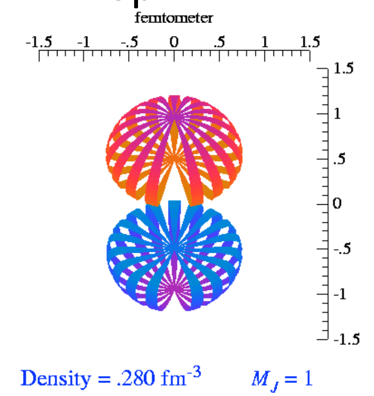
HERMES b1 result



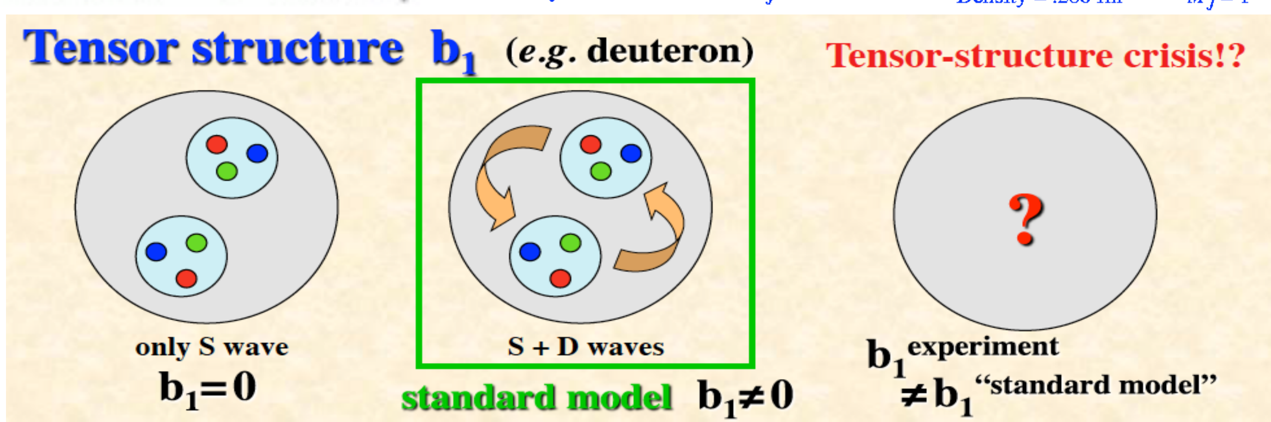
Spin = 0



Spin = 1



From S. Kumano, arXiv:1606.03149



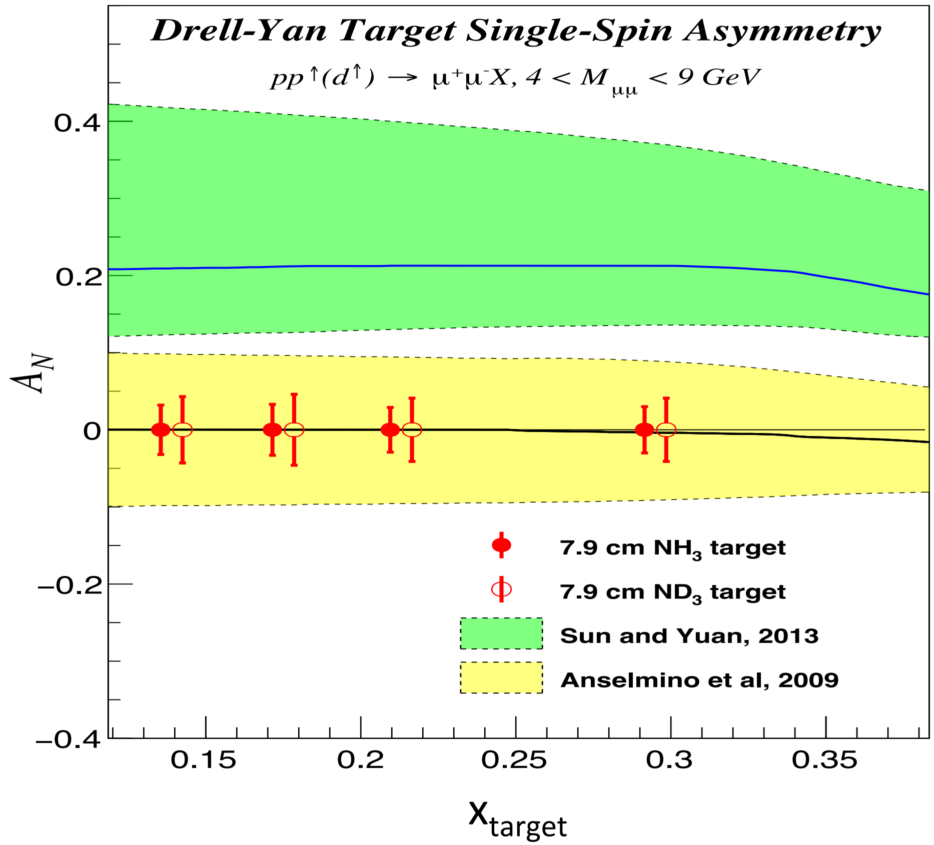
E1039 Status and Timeline

- **E1039 has been fully funded by DOE NP.**
- **Experiment Status**
  - magnet system is finished and working
  - refrigerator is finished and tested (at 1K)
  - NMR system is finished and working
  - mechanical design completed
  - full system cooldown/test with full extended 8cm long target
  - first time measure three coil NMR simultaneously
  - P_{max} ~92%
  - Working on cold NMR system
- **Schedule**
  - E906 decommissioning complete by June, 2018.
  - E1039 target installation, detector repairs and commissioning in summer 2018.
  - Start commissioning with first beam in fall 2018.

Summary

- First direct sea quark Siver asymmetry measurement will be realized at the E1039 experiment.
  - Provide new path to distinguish the quark orbital angular momentum contribution to the proton spin.
  - Determine the sign and magnitude of flavor dependent sea quark Sivers function.
- New measurements such as the J/ψ A_N and spin-1 tensor structure function can be done at E1039 as well.

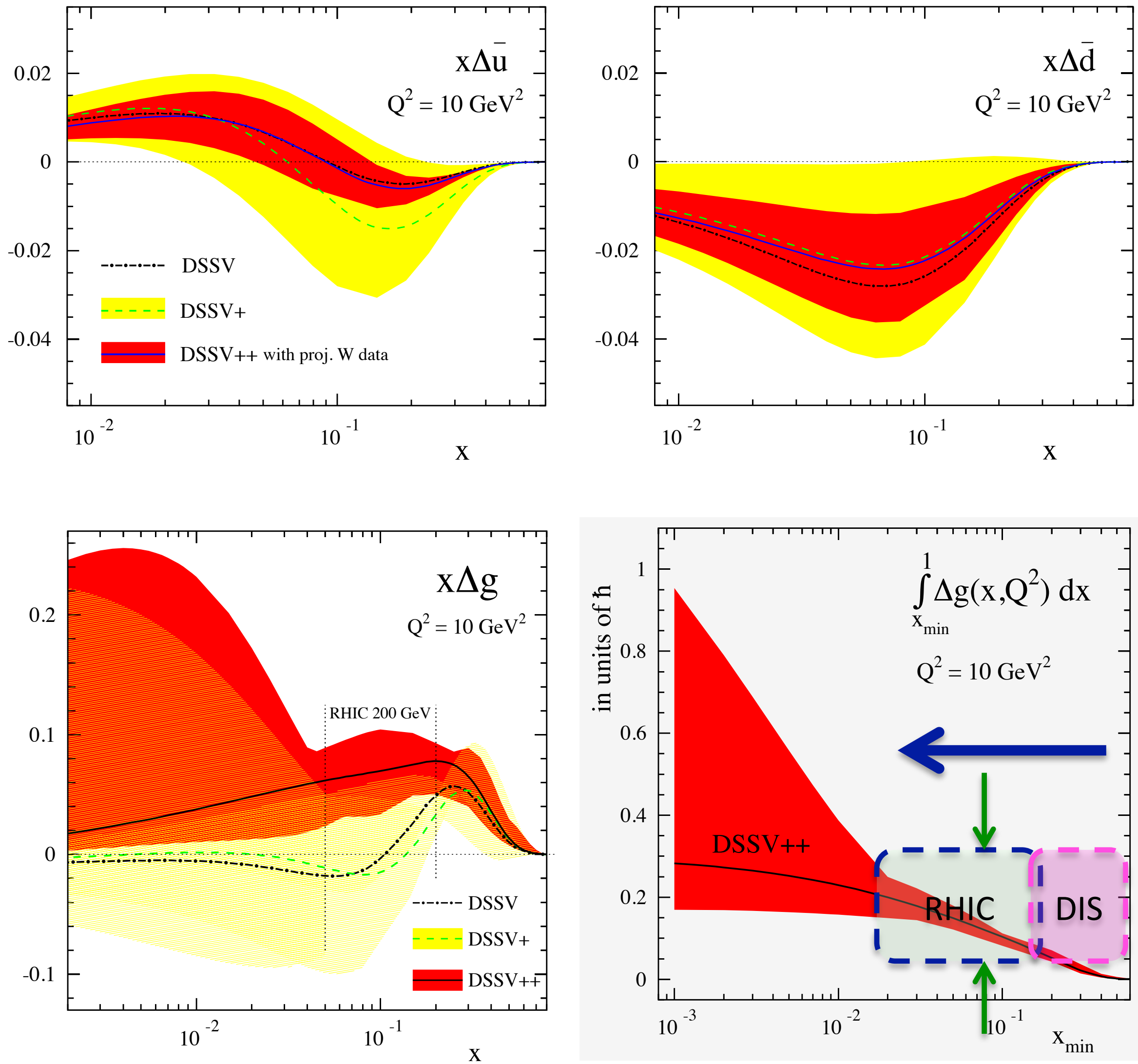
Outlook



- Welcome more collaborators to join the efforts.
- Look forward to a fruitful physics program at the E1039 experiment with 2 years of data taking.

Backup

Current knowledge of pPDF



arXiv:1304.0079

- Sea quark and gluon pPDF has large uncertainties.
- DIS can only access gluons via evolution. W production in SIDIS is complicated.
- Data from polarized p+p collisions at RHIC will improve the precision and measured different x region from the DIS experiments.

Yield and Asymmetry estimates

- f = .176 , .3
- P = .8 , .32

Range x_2	Mean x_2	N events p	ΔA % p	N events n	ΔA % n
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$$\Delta A = \frac{1}{f}\frac{1}{P}\frac{1}{\sqrt{N_{Total}}} \qquad t^{-1} \propto \rho\left(f \bullet P\right)^2$$

Target/Accelerator Effi: 50%
Spectrometer: 80%
Acceptance 2.2%
Trigger 90%
Reconstruction 60%
Beam: 2.67×10^{12} p/spill
Total integrated Luminosity: 1.82×10^{42} & 2.11×10^{42}