P-1039:

Polarized Target Drell-Yan Single-Spin Asymmetry Measurement to Access Sea Quarks' Angular Momentum

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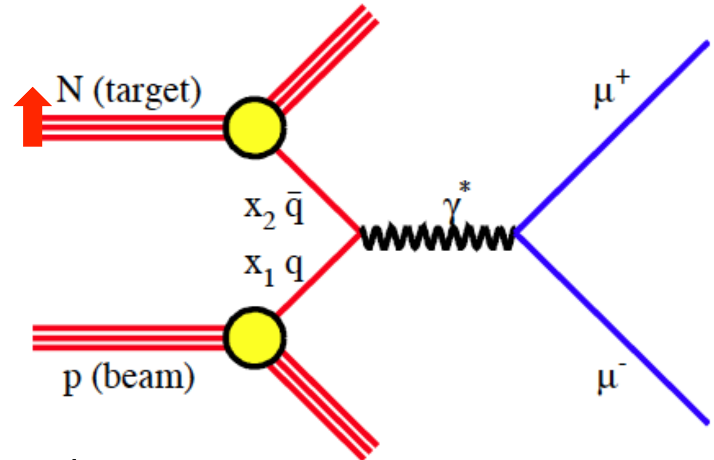
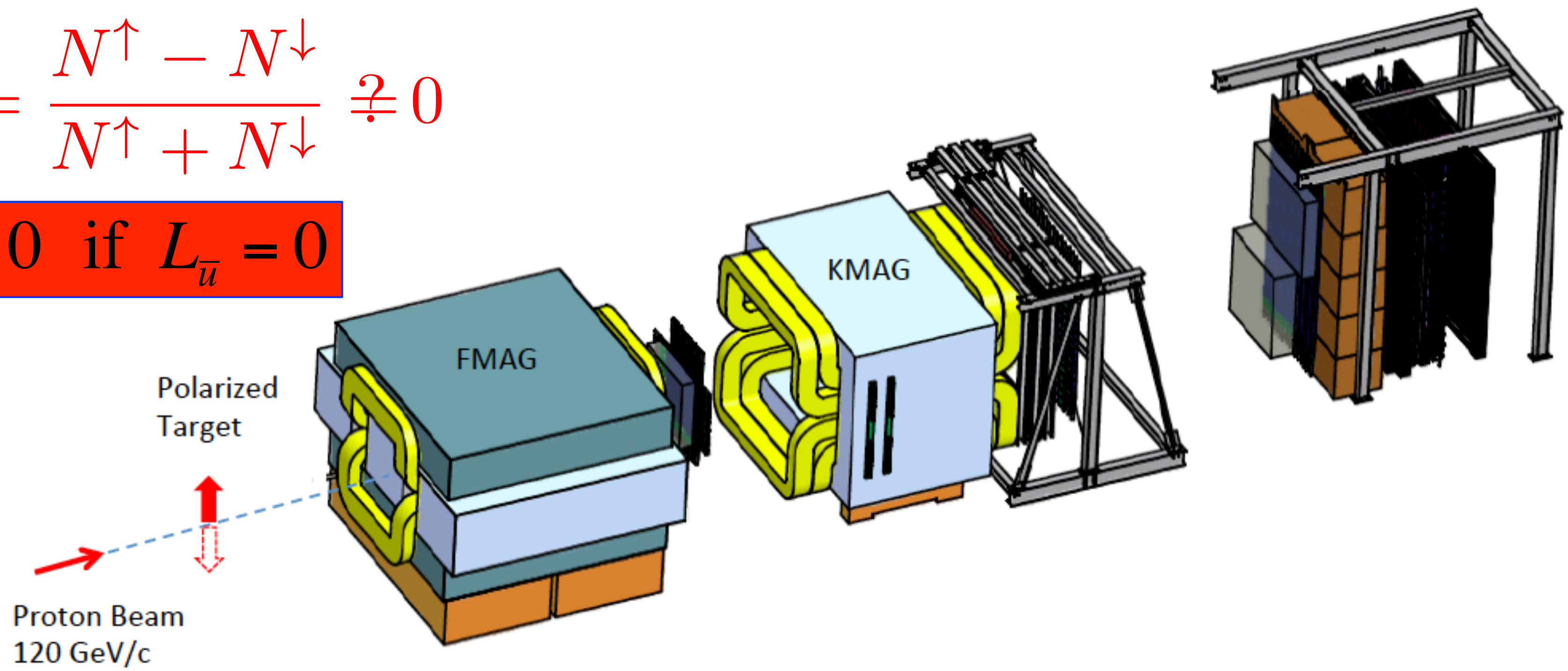
June 5th, 2013 @ Fermilab PAC.



- Measure Drell-Yan yield dependence on the target's spin direction.
- Strong constraints on sea quarks' angular momentum.
- Add a polarized proton (NH_3) target to SeaQuest (E906) setup.

$$A_N = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow} \stackrel{?}{=} 0$$

$$A_N \equiv 0 \quad \text{if} \quad L_{\bar{u}} = 0$$



Outline:

- **Nucleon spin puzzle: ~50% of proton spin is not accounted for. Sea quarks' orbital angular momentum could be a major part of the "missing spin".**
- **Quark orbital angular momentum leads to transverse momentum dependent distributions: Sivers distribution.**
- **Polarized target Drell-Yan asymmetry at SeaQuest (E906) provides a clean access to sea quark Sivers distribution.**
- **Experimental setup, polarized target and resources needed.**

Drell-Yan yields depend on target's spin direction?

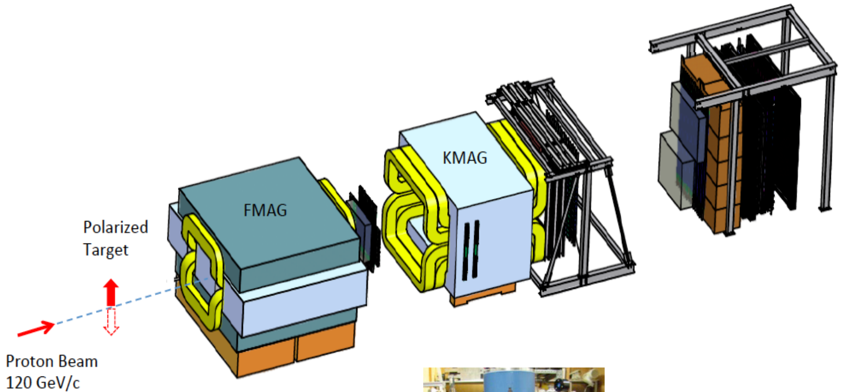
$$A_N = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \stackrel{?}{\neq} 0$$

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

$$A_N \equiv 0 \;\; \text{if} \;\; L_{\bar{u}} = 0$$

P-1039 Collaboration:

Co-Spokespersons: A. Klein, X. Jiang
Los Alamos National Laboratory



✚

Collaboration includes experts on

- Drell-Yan: E772, E866, E906
- Polarized target: BNL, SLAC, JLab
- Spin experiments: JLab, HERMES, RHIC

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Nucleon Spin Puzzle: ~50% of spin is missing

The need for a major breakthrough in understanding the origin of the nucleon spin

Nucleon's ½ spin:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma_q + L_q + \Delta g + L_g$$

Many years of spin experiments since 1988:

Quark polarization from all flavor:

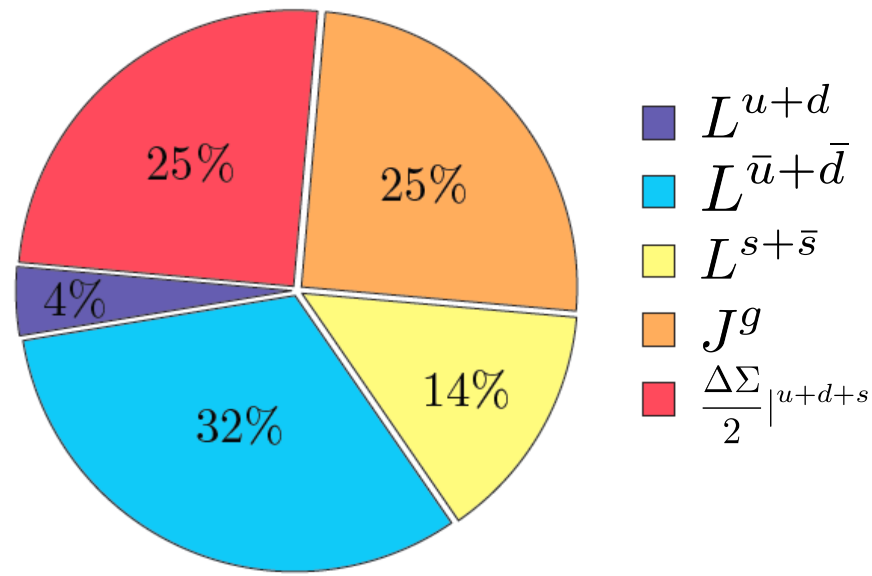
$$\Delta\Sigma_q \approx 0.25 \pm \ldots$$

Gluon polarization (RHIC):

$$\int_{0.05}^{0.2} dx \Delta g(x) = 0.1 \pm 0.06$$

about half of the nucleon's spin is not accounted for

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



$\Delta\Sigma_q \approx 25\%$

$2\ L_q \approx 46\%$ (0%(valence)+46%(sea))

$L_u \approx - L_d$

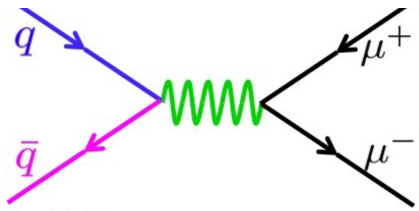
$2\ J_g \approx 25\%$

Orbital angular momentum ? Sea quarks' angular momentum could be a major part of the "missing spin".

Drell-Yan at SeaQuest (E906): a Clean Access to Sea Quark

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

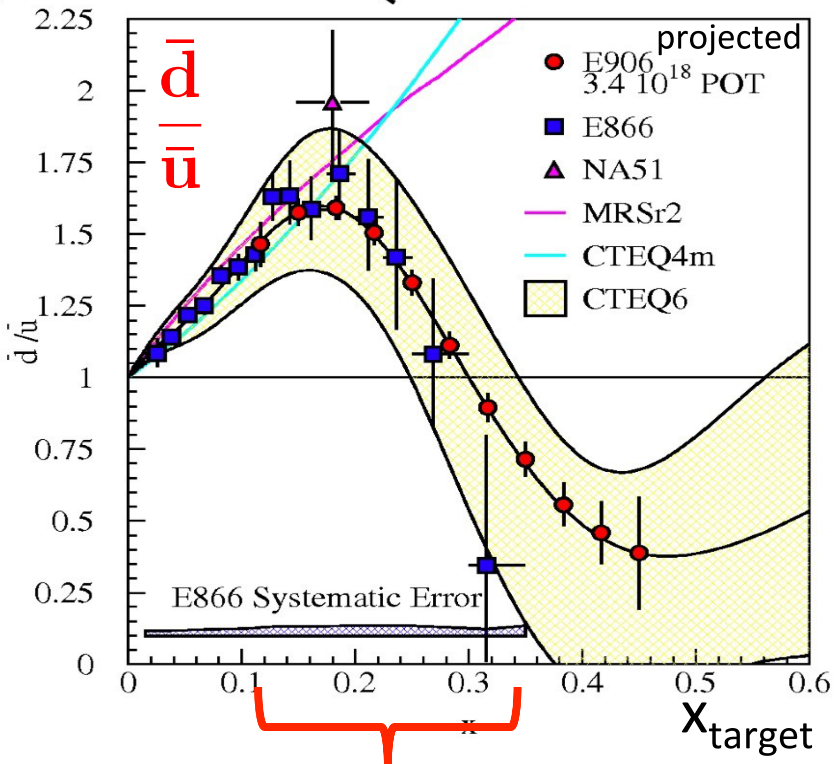
small

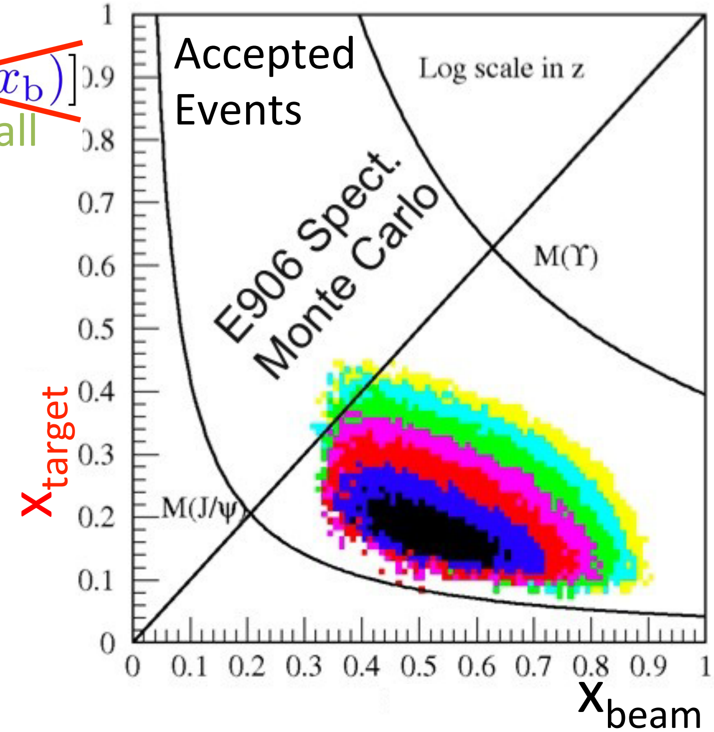


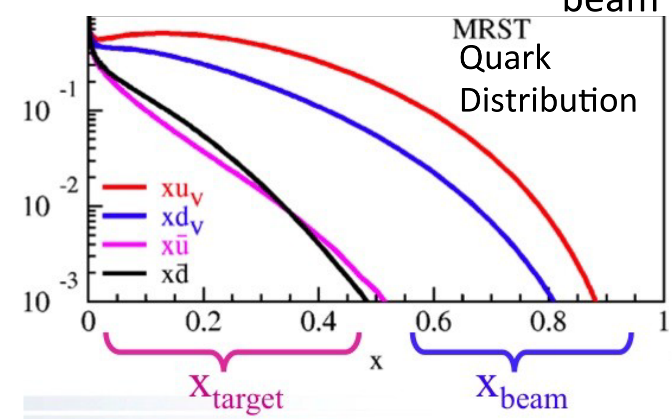
target sea quark

beam valence quark

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







Strong flavor asymmetry in the sea.

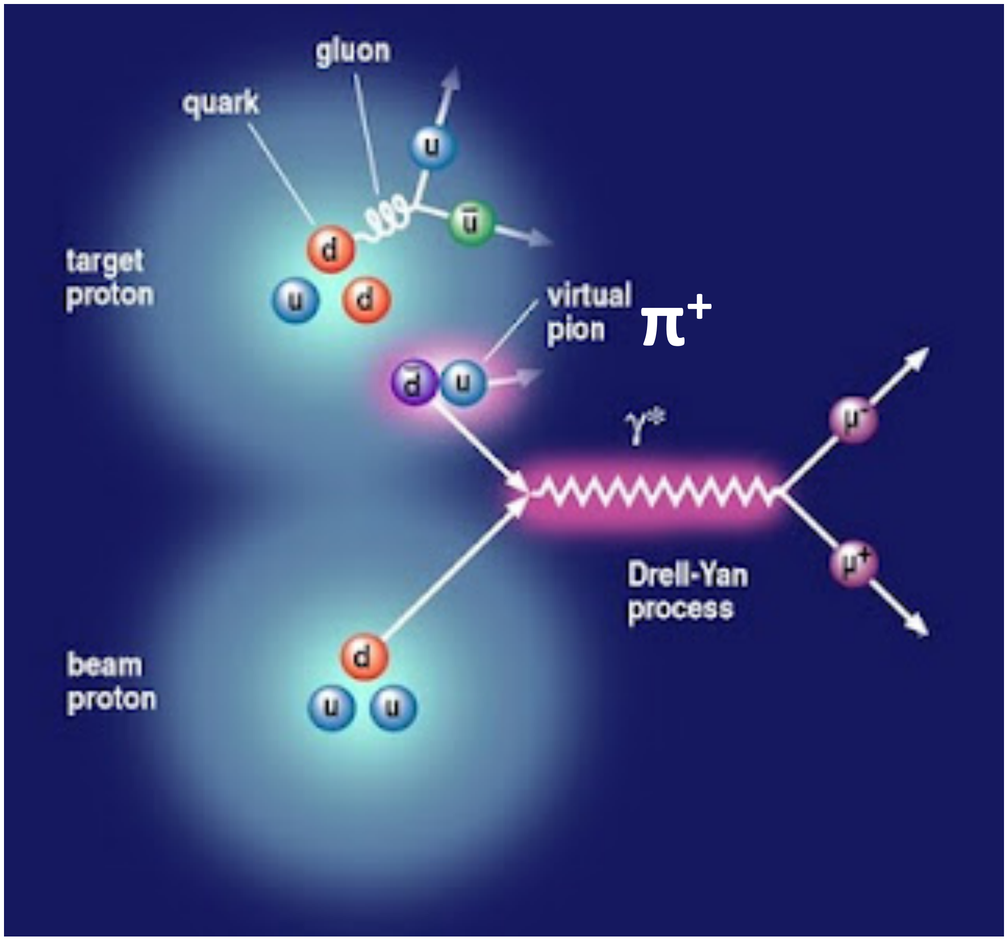
Could sea quarks carry a significant amount of angular momentum ?

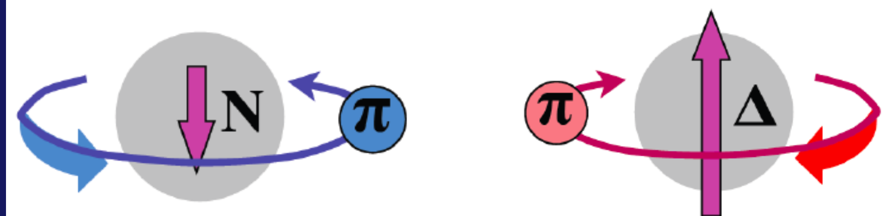
The meson cloud model explains the flavor asymmetry in the sea, and requires quarks to carry angular momentum.

$|p\rangle = p + N\pi + \Delta\pi + \ldots$

Pions $J^p=0^-$ Negative Parity

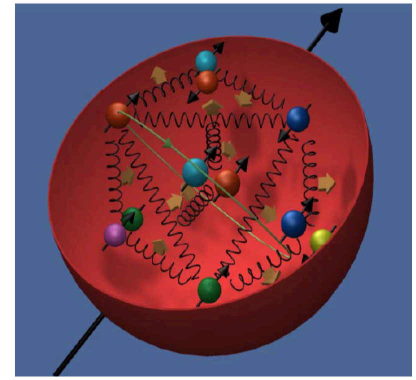
Need **L=1** to get proton's $J^p=½^+$





Sea quarks should carry orbital angular momentum.

Quark Orbital Momentum and the Sivers Function

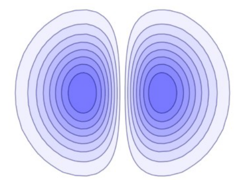


The Sivers function is the distribution of unpolarized quarks in a transversely polarized proton

$$\vec{L} = \vec{b} \times \vec{k}$$

$$f_{q/P^{\uparrow}}(x, \mathbf{k}_{\perp}, S) = f_1(x, \mathbf{k}_{\perp}^{2}) - \frac{\mathbf{S} \cdot (\hat{\mathbf{P}} \times \mathbf{k}_{\perp})}{M} f_{1T}^{\perp}(x, \mathbf{k}_{\perp}^{2})$$

quark density 

 Sivers distribution

Sivers distribution was believed to vanish until 2002!

- Naive T-odd, not allowed for collinear quarks. Transverse Mom. Dep. parton distributions (TMD).
- Imaginary piece of interference L_q=0 ✖ L_q=1 quark wave functions.

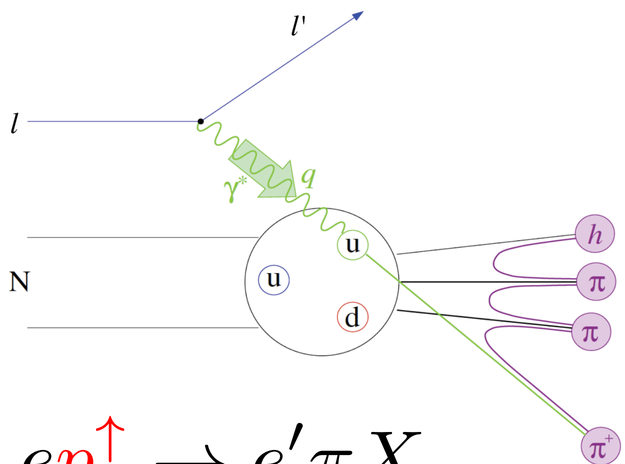
Sivers function = 0 ←→ L_q=0

Sea quark Sivers function =0 ?

Accessing the quark Sivers distribution

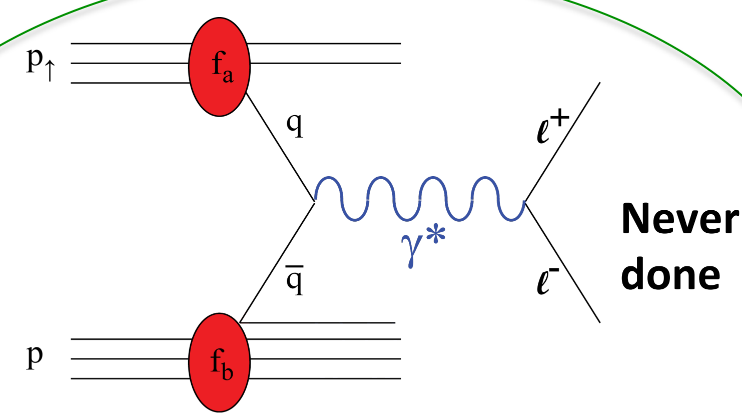
Polarized target experiments

Left-right asymmetry in Semi-Inclusive Deep Inelastic Scattering (SIDIS) on a polarized nucleon



$$ep^{\uparrow} \rightarrow e'\pi X$$

Left-right asymmetry in Drell-Yan di-muon production (DY) on a polarized nucleon



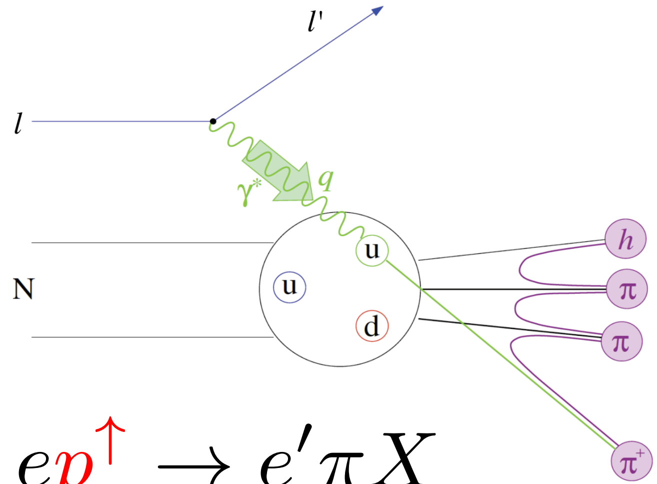
$$pp^{\uparrow} \rightarrow \mu^+\mu^- X$$

Cornerstone prediction of QCD

The same quark Sivers distribution in both processes, but with opposite sign

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

Asymmetry in Semi-Inclusive DIS



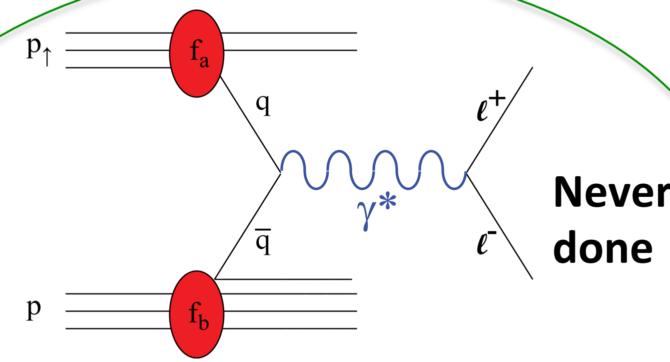
$$e p^{\uparrow} \rightarrow e' \pi X$$

$$d\sigma^{\uparrow\downarrow} = d\sigma_0 \pm \sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)$$

- Involves quark to hadron frag. func.
- Valence and sea quarks are mixed.

$$A_N = \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

Asymmetry in Drell-Yan



$$p p^{\uparrow} \rightarrow \mu^+ \mu^- X$$

$$d\sigma^{\uparrow\downarrow} = d\sigma_0 \pm \sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]$$

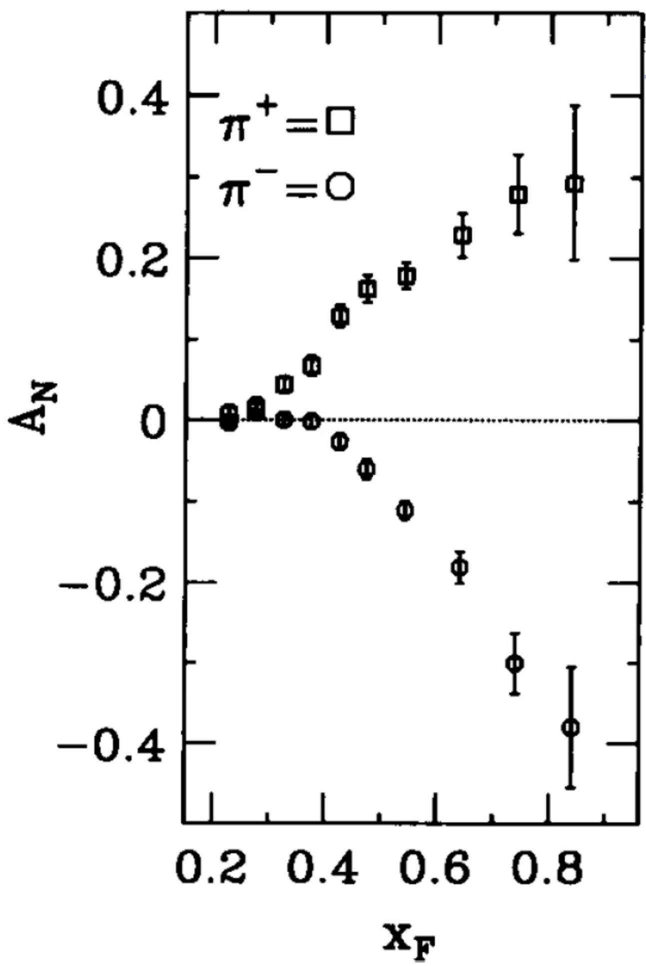
- No quark frag. func. involved.
- Valence and sea quarks can be isolated
  - Pol. Beam ➔ valence quark (P-1027)
  - Pol. Target ➔ sea quark (P-1039)

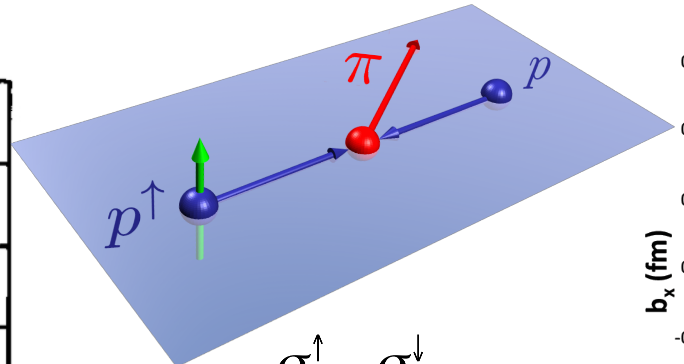
$$A_N = \frac{\sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]}{\sum_q e_q^2 [f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2]}$$

Quark Sivers Distribution Leads to Left-Right Bias

$p\, p^{\uparrow} \rightarrow \pi X$

E704 √s =20 GeV. PLB 264 (1991) 462.





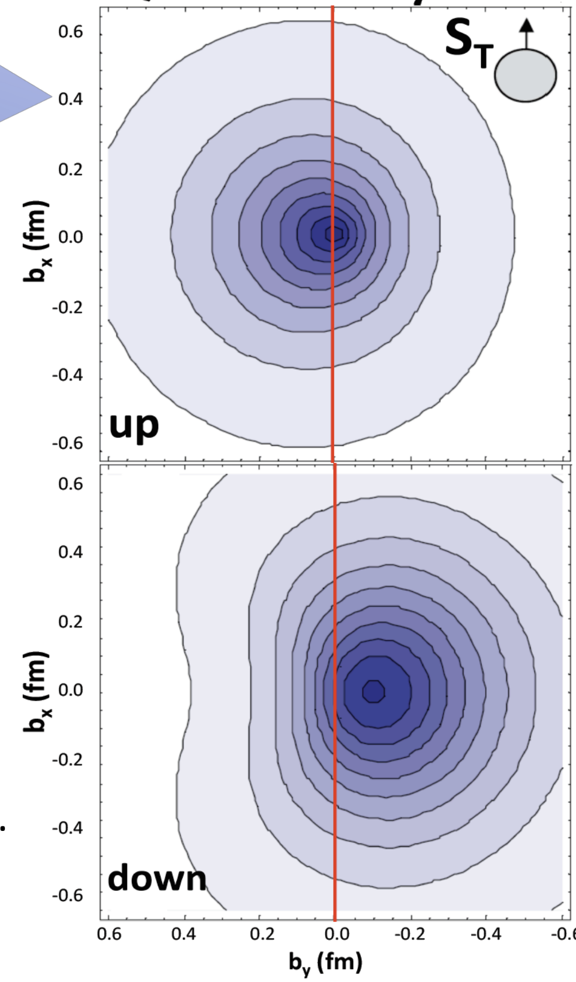
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$\pi^+ \, (u\bar{d})$ favors left

$\pi^- \, (d\bar{u})$ favors right

Sivers effect: quark's transverse motion generates a left-right bias. up-quarks favor the left, down-quarks favor the right ($L_u \approx - L_d$)

Quark Density in 2D

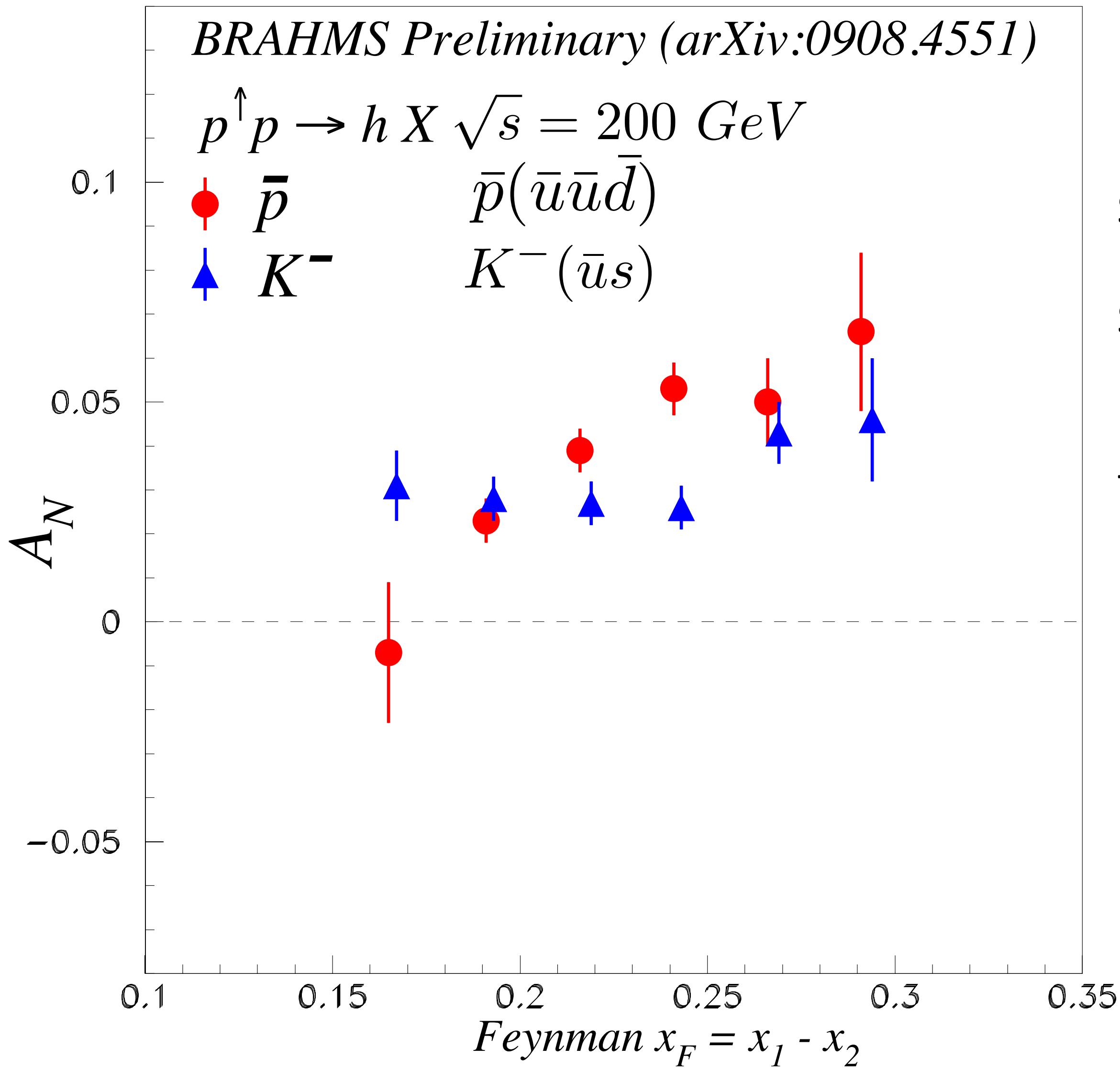


Lattice QCD PRL98:222001,2007.

Valence quarks have a clear left-right bias due to orbital angular momentum.

Sea quark Sivers distribution =0 ?

Hints of Non-Vanishing Sea Quark Sivers Distribution ?



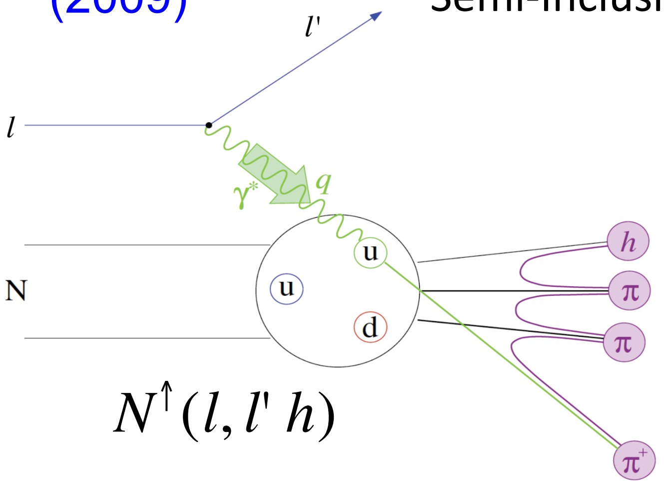
Sea quark generates left-right bias ?

Secondary string-breaking ?

Left-right bias generated through fragmentation process ?

Quark Sivers Distributions: fit to HERMES and COMPASS data (2009)

Semi-Inclusive Deep-Inelastic Scattering on transversely polarized targets

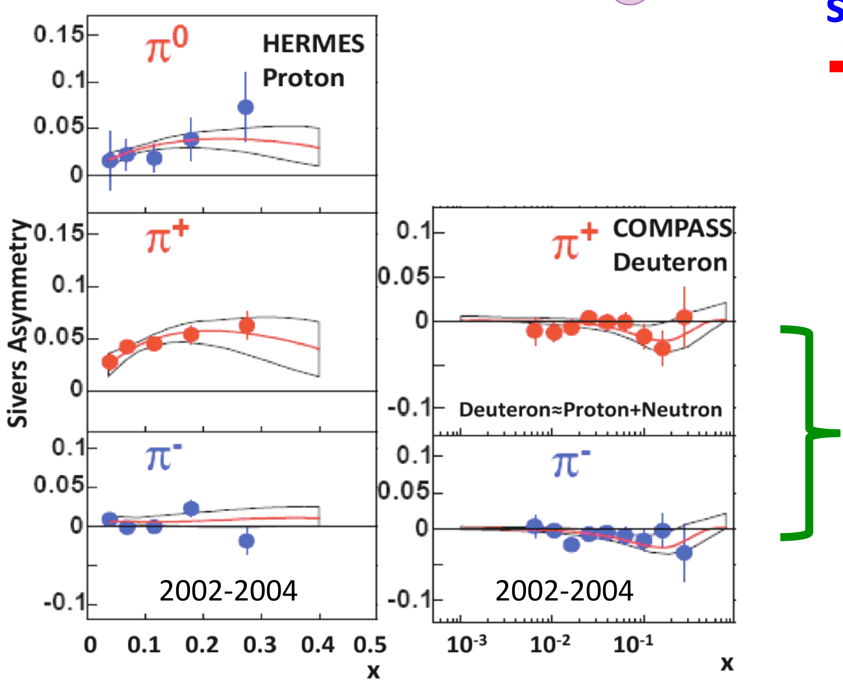


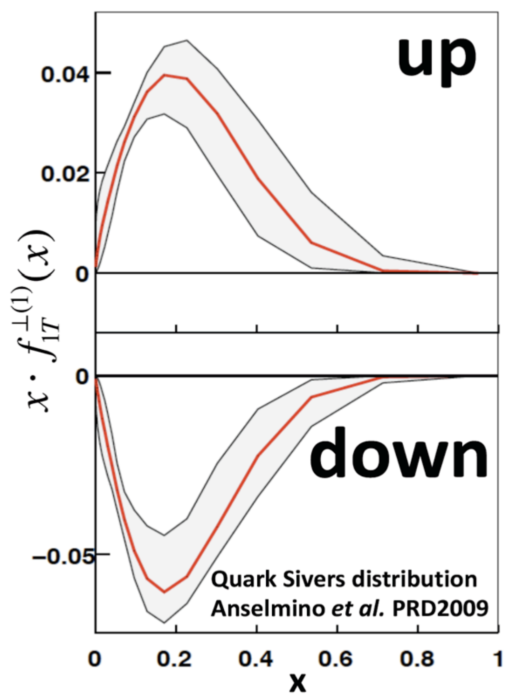
$N^{\uparrow}(l, l'\,h)$

$$A_N = \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

- **Involves quark fragmentation functions.**
- **Valence quark overwhelmingly dominate.**
- **Limited sensitivity to sea quark leads to zero sea quark Sivers distribution.**

➔ **large uncertainties in Sivers distribution**





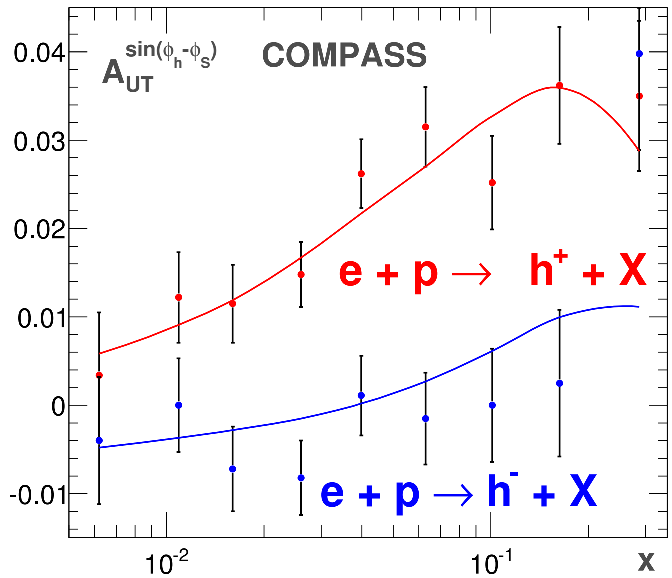
up-quark favors left (L_u>0),

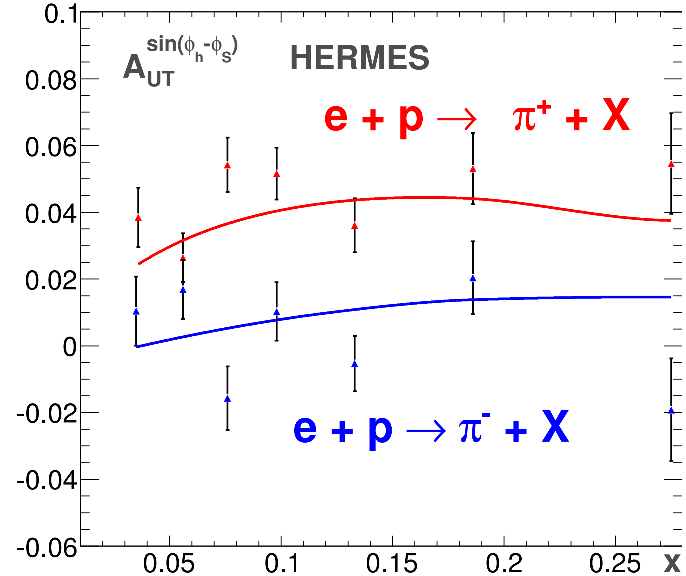
down-quark favors right (L_d<0).

$L_u \approx - L_d$

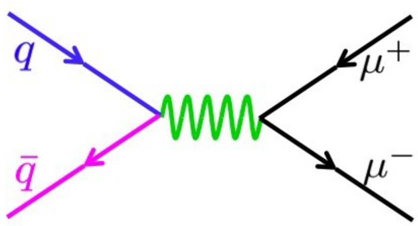
Quark Sivers Distributions: a new fit includes new data (2013)

Sun and Yuan:
arXiv:1304.5037



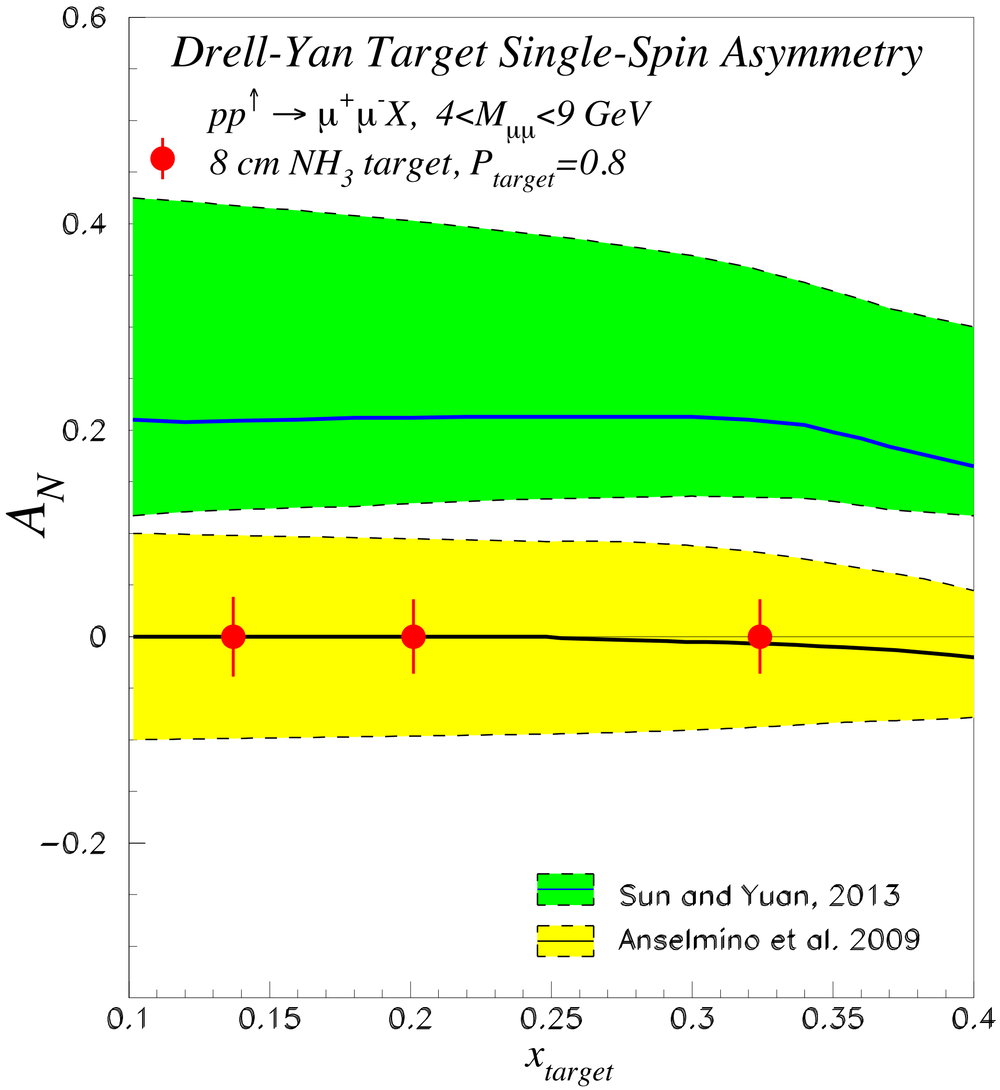


- Include new COMPASS proton target data (2010) and earlier transverse distribution data.
- Take Q^2-evolution effects into account.
- Allow contributions from sea quarks which lead to non-zero ubar Sivers distribution, however with large error bars.
- Predict Drell-Yan target single-spin asymmetry for SeaQuest.



$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

Projected Precision with a Polarized Target at SeaQuest



$$A_N^{DY} \propto \frac{u(x_b)\cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b)\cdot \bar{u}(x_t)}$$

Existing data do not put enough constraints on the sea quark Sivers distribution, neither in sign nor value.

If $A_N \neq 0$, major discovery:

- "Smoking Gun" evidence for $L_{ubar} \neq 0$
- Determine sign and value of ubar Sivers distribution
- Confirm Lattice QCD and Meson Cloud Model expectations
- Help shape physics direction at EIC

If $A_N = 0$:

- $L_{ubar}=0$, spin puzzle more dramatic ?
- Sea flavor asymmetry hard to explain.
- In contradiction to Lattice QCD and Meson Cloud Model.

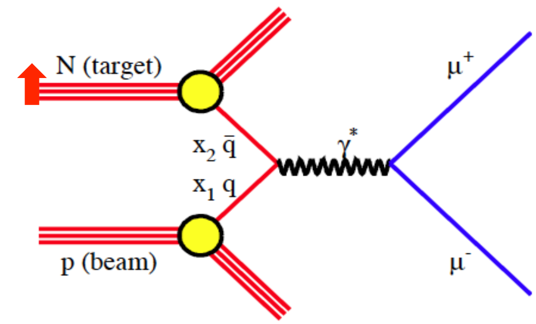
Statistics shown for one calendar year of running :
$\mathcal{L} = 1.4 * 10^{43}$ /cm^2 ⇐⇒ POT = $2.1*10^{18}$

Request for two calendar years of beam time

COMPASS, P-1027 and P-1039

	Beam Pol.	Target Pol.	Favored Quarks	Physics Goal
COMPASS $\pi^- p^\uparrow \to \mu^+\mu^- X$	✗	✔	Valence quark	Sign change and size of Sivers distribution for valence quark
P-1027 $p^\uparrow p \to \mu^+\mu^- X$	✔	✗	Valence quark	Sign change and size of Sivers distribution for valence quark
P-1039 $p p^\uparrow \to \mu^+\mu^- X$	✗	✔	Sea quark	Size and sign of Sivers distribution for Sea quarks, if DY $A_N \neq 0$.

Physics Summary



- **We know almost nothing about sea quarks angular momentum.**
- **Quark orbital angular momentum leads to quark Sivers distribution.**
- **Identifying a non-vanishing sea quark Sivers distribution could lead to a major breakthrough in nucleon structure.**
- **Polarized target D-Y at Fermilab's SeaQuest provides an unique opportunity to pin down sea quark's angular momentum.**
- **Dedicated group of theorists at LANL to support this effort: I. Vitev, Z. Kang, C Lee, R. Gupta, B. Yoon**

Does Drell-Yan yield depend on target's spin direction?

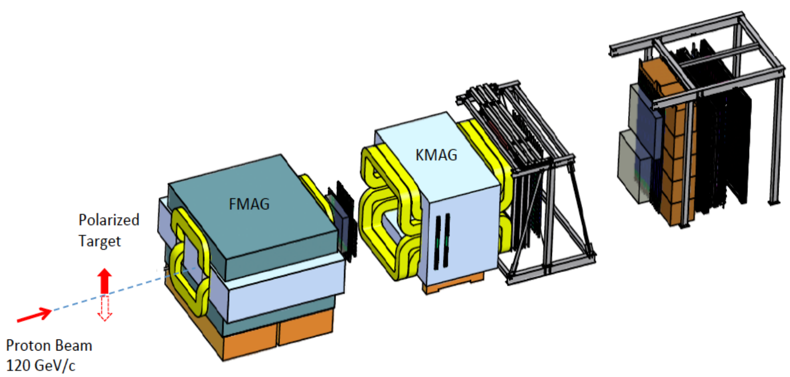
$$A_N = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \stackrel{?}{=} 0$$

$(A_N \equiv 0 \text{ if } L_{\bar{u}} = 0)$

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

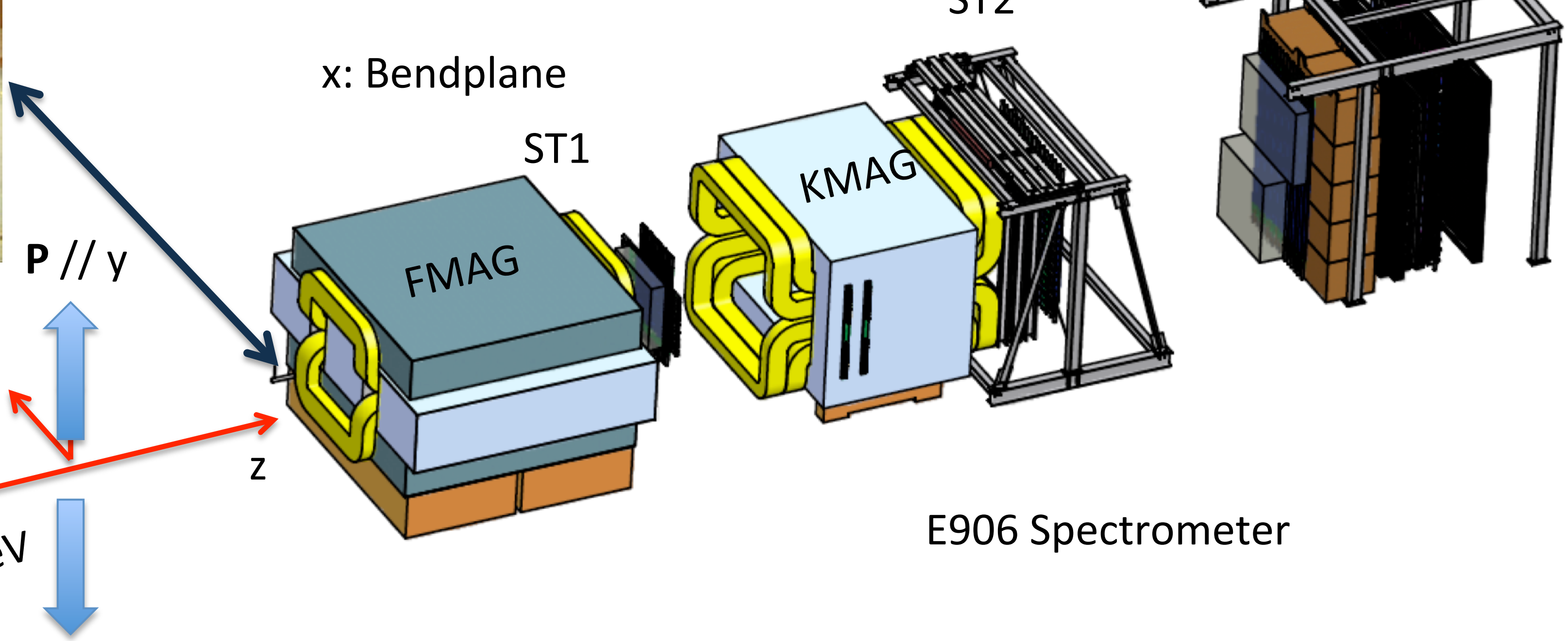
The Polarized Target Installation and Support Needed

- Why here at FNAL
- Current spectrometer and Integration
- Polarized Target Overview
- Special Requirements for Polarized Target Experiments
- Yield and Precision
- Support needed
- Time Line
- Summary



New LANL polarized target & E906 Spectrometer

The right place for this experiment



- 4 scintillator hodoscope stations (x and y)
- 4 tracking stations (x and stereos)
- Setup close to E906 (see later)
- $1*10^{13}$ p/spill
- Kinematic Range 4 < M <8 GeV

Why at FNAL and why now

- **Can perform world's highest luminosity polarized target Drell-Yan measurement at Fermilab's 120 GeV proton beam**
- Perfect spectrometer for study of sea quarks
- Only small modifications required
- Pol target work aligns well with schedule

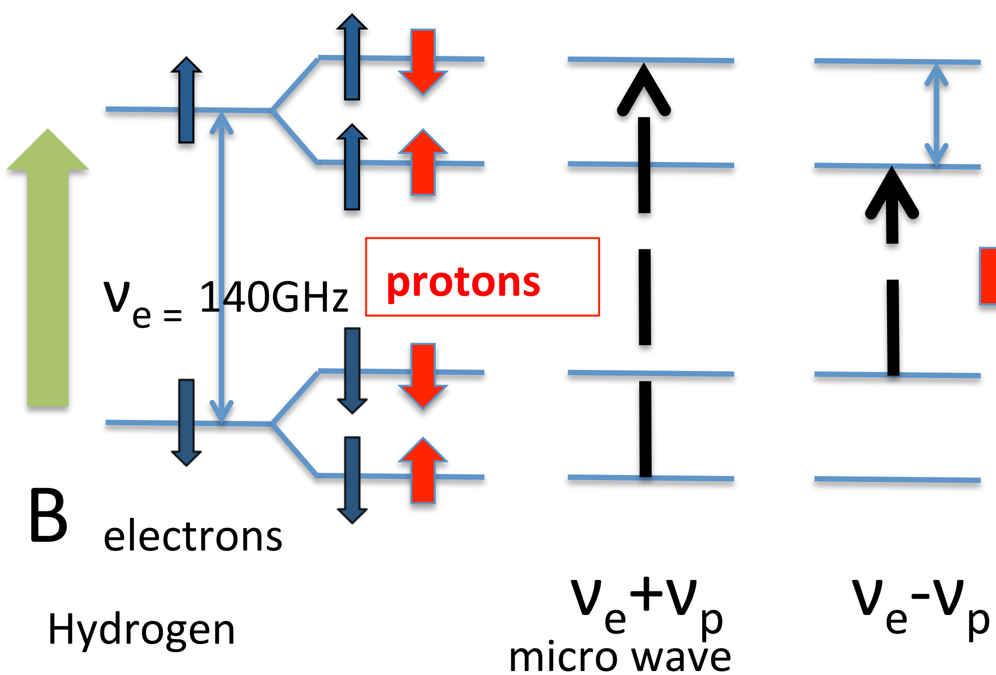
Principle of Dynamic Nuclear Polarization:

Polarization *P*

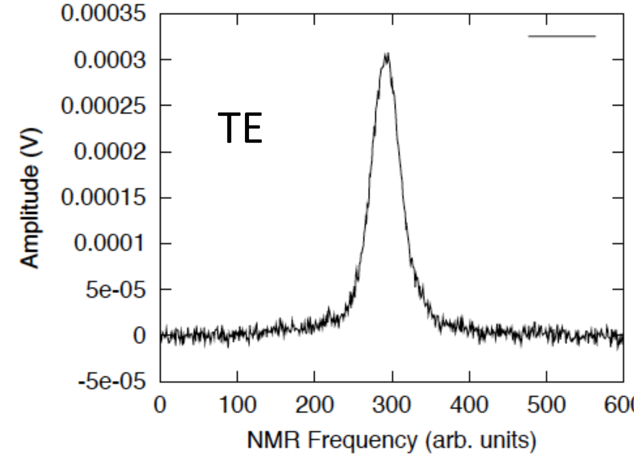
$$P_i = \left[\frac{\mu_i g_i H}{2k_B T}\right]$$

Thermal Equilibrium TE
TE: T=1K, H=5T
$P_e = .998$
$P_p = .005$

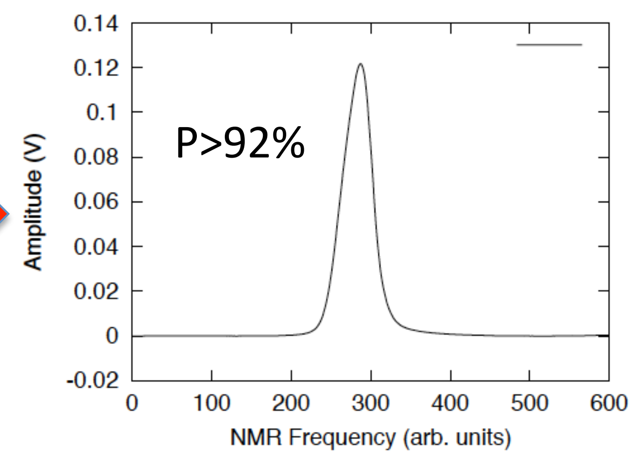
1. Create paramagnetic centers through irradiation
2. Use dipole-dipole interaction=> Hyperfine Splitting
3. Pump on electrons with 140 GHz
4. $\tau_e << \tau_p$ => Large Polarization (τ Relaxation times)



TE measurement



Polarization Measurement



Keith et al. NIM A 501 (2003), 327 JLAB
Well established technology: SLAC, JLAB, PSI …

The Polarized Target System

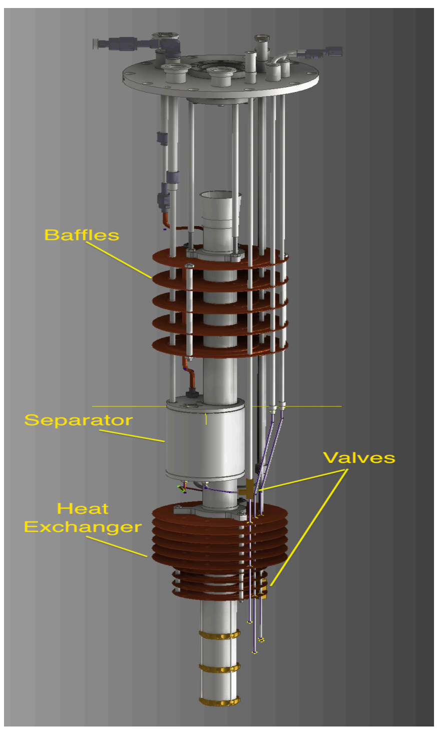
Magnet from LANL

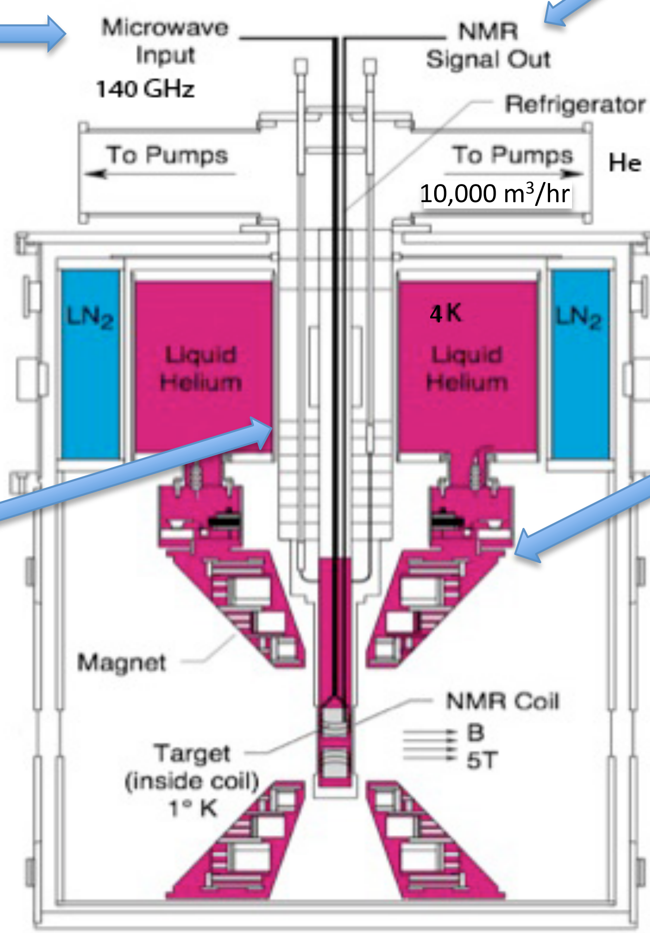
Measure polarization

Microwave: Induces electron spin flips

- Tube + Power equip:

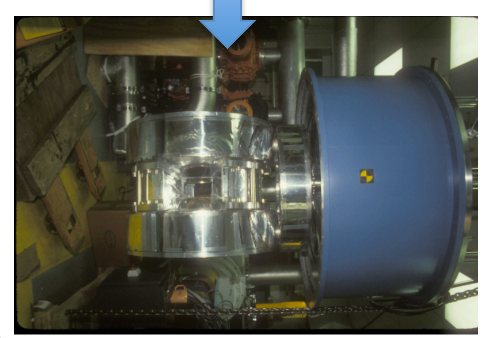
Cryostat: UVa





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

Superconducting Coils for Magnet: 5T
Rotation needed



Target material: frozen NH_3
Irradiation @ NIST

JLAB target

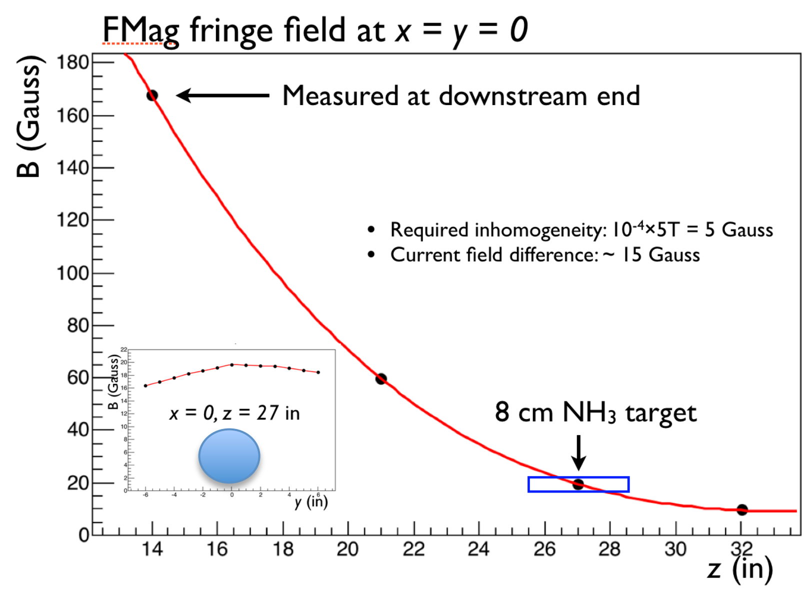
NH_3 Target Parameters:

- Cylinder Φ : 4cm (x,y), length 8cm (z)
- ρ= .91 g/cm^3 frozen NH_3
- Packing Fraction = .6
- Dilution Factor = 3/17 NH_3
- 5.1 g/cm^2 (NH_3) + .44 g/cm^2 He
- 3 * 10^{24} nucleons/cm^2

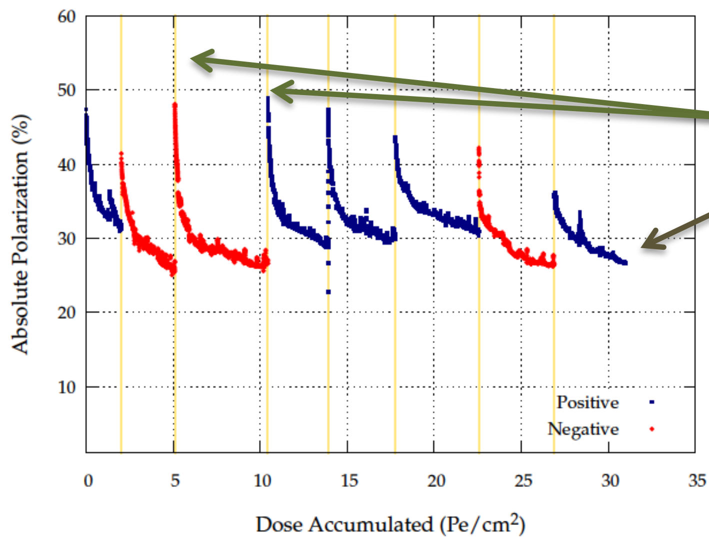
Soft Iron Plate to clamp field from 15G to 5 G

Requirements and Running conditions:

- $\frac{d\vec{B}}{\vec{B}} < 10^{-4}$ field uniformity over cell
- μ- wave: 2.2 W +beam: 370mW
- Total heat load **2.6 W**
- 100 liter liquid He/day
- Requires **10,000 m^3/hr** pumping capacity



Beam effects on polarized Target



Polarization as a function of accumulated beam dose 2.5T target (D. Crab private communication)

- Anneal every 24 hours ~ 1hr at 80K (yellow line)
- Replace target material every 10 days (two active targets) , will take one shift
    - Replace target stick
    - Cool down
    - perform TE measurement
    - Turn on microwave, measure again

Systematics control:

- Reverse Polarization Direction once a day
- Reverse magnet field of Fmag and Kmag every two days
- Reverse magnetic field of target magnet every target replacement
- Background measurements every shift with target out

Systematic errors:

- Absolute: 1% (Luminosity precision on different pol directions)
- ΔA/A ~ 4% (Dominant effect polarization measurement)

Yield and Beam Time Request

Yield Calculation

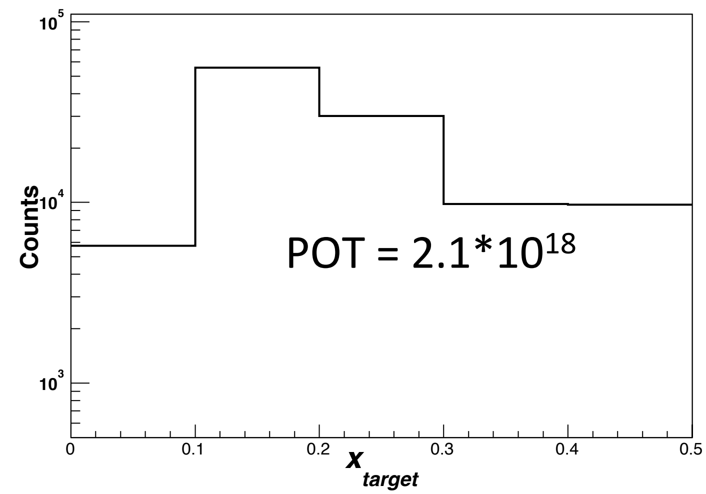
- beam: 1 $*10^{13}$ p/spill
- Target : 3.1 $*10^{24}$ N/cm^2
- One year $\mathcal{L}$ = 1.4 $*10^{43}$ /cm^2
- POT = 2.1$*10^{18}$
- 4<M<8 GeV

Assumed Efficiencies:

- Beam and Experiment availability from E906 = .5
- Additional efficiency due to pol target =.8 (conservative)

Cuts	Efficiency	Yield/ calendar year
All DY in the kinematic range	100%	1.34E+08
$\mu^+\mu^-$ accepted by all detectors	2%	2.78E+06
Accepted by trigger	50%	1.39E+06
$\mu^+\mu^-$ pair reconstructed (with target/dump separation cut)	8%	1.11E+05

Bin	x_t_min	x_t_max	$\langle x_{target} \rangle$	N_{evt}	σ_A
1	0.00	0.17	0.137	34761	0.039
2	0.17	0.24	0.201	37472	0.036
3	0.24	0.50	0.324	38853	0.036



measuring time for given ΔA

$$t^{-1} \propto \rho (f \bullet P)^2$$

- f = .6
- P = .8

Request for two calendar years of beam time

Changes to E906 Target Cave and Support

Changes and Support needed

- lift roof of cave (36") .2M$
- new hoist in cave (2 ton)
- He and LN fill lines .5M$
- He lines installation 1M$
- beam collimator to prevent magnet quenches
- beam position monitors
- Safety infrastructure for Oxygen deficiency
- Liquid Helium needs for 2 years:

A) Helium liquefier system/recovery

- running and maintaining system
- According to A. Klebaner too expensive

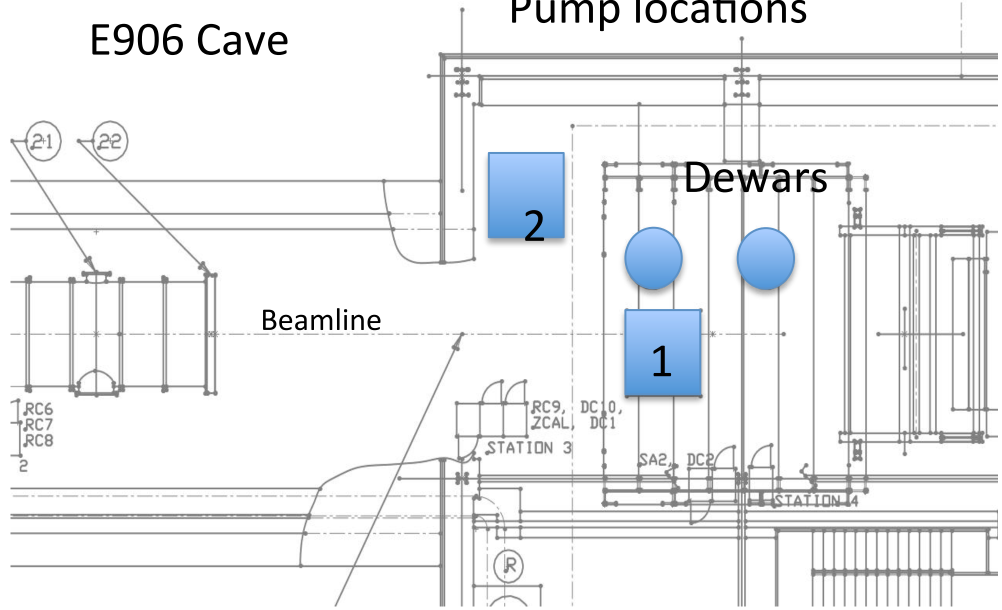
B) Buying liquid Helium

- storage system for exhaust
- 100 lt *600 = 60,000 lt gas = 420K$
- Might be able to sell back to vendor

TOTAL : ~2.1 M$ (including labor) (very preliminary)

Negotiation: FNAL, DOE and collaboration

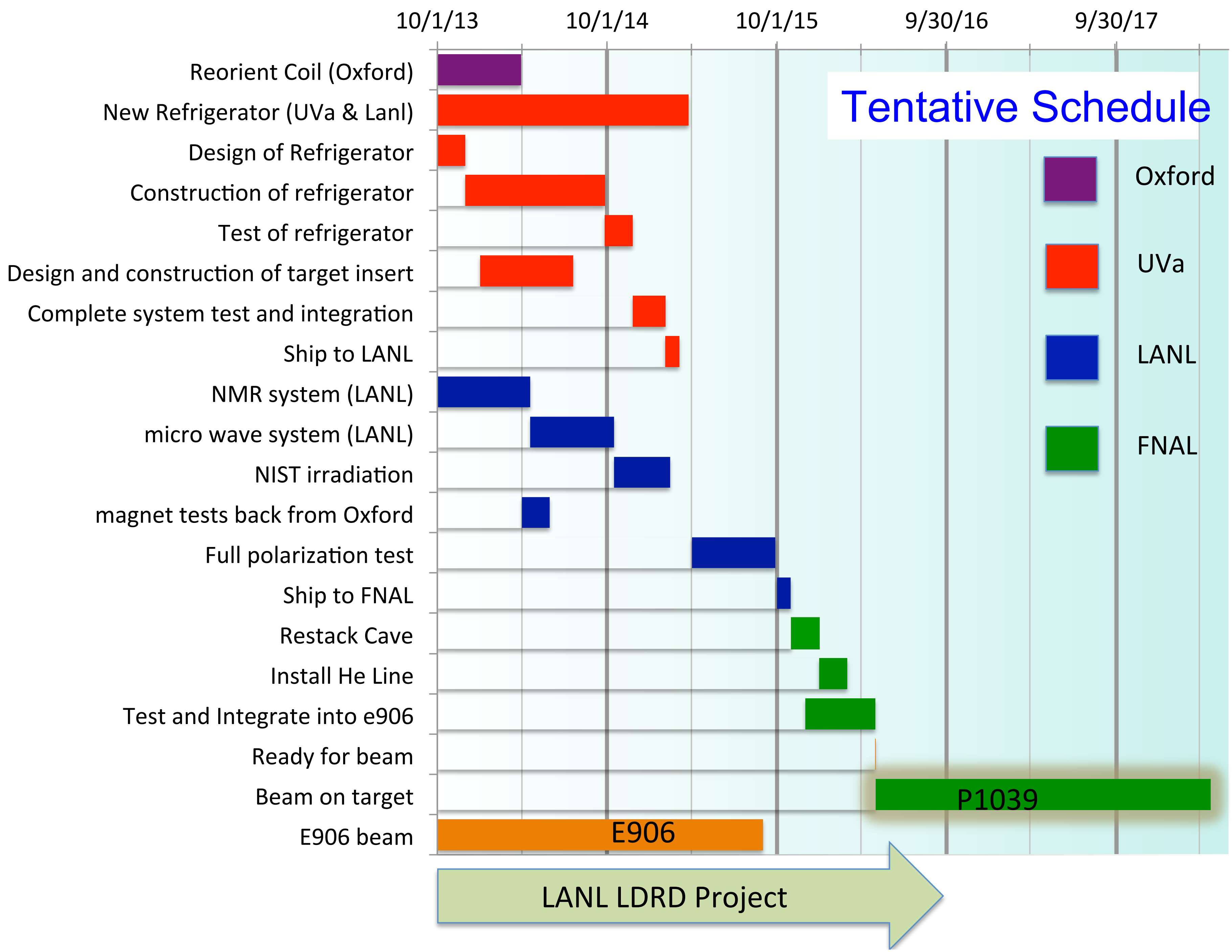
1,2: possible Roots Pump locations



LANL contribution through LDRD:

1. Refrigerator + Instrumentation 240K
2. Pumps 250K (ROOTS and Compressor)
3. µ-wave 200K (already have tube)
4. NMR 120K
5. Transferlines and plumbing 90K
6. NIST irradiation 80K
7. Oxford changes 80K
8. Magnet + power supplies 1.2 M$

TOTAL: 5.2 M$ (including labor)

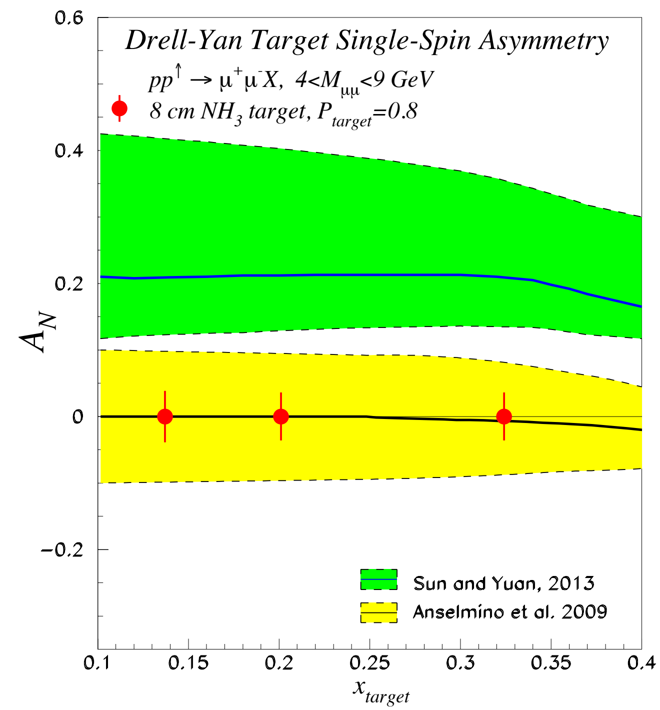

10/1/13
10/1/14
10/1/15
9/30/16
9/30/17
Tentative Schedule
Reorient Coil (Oxford)
New Refrigerator (UVa & Lanl)
Design of Refrigerator
Construction of refrigerator
Test of refrigerator
Design and construction of target insert
Complete system test and integration
Ship to LANL
NMR system (LANL)
micro wave system (LANL)
NIST irradiation
magnet tests back from Oxford
Full polarization test
Ship to FNAL
Restack Cave
Install He Line
Test and Integrate into e906
Ready for beam
Beam on target
E906 beam
P1039
E906
Oxford
UVa
LANL
FNAL
LANL LDRD Project

Summary

- **First Measurement of p-p Drell Yan with a polarized target.**
- **Measure Single Spin Asymmetry for Sea Quarks**
- **Access Quark Angular momentum through Sivers Distribution.**
- **Help solve the nucleon spin puzzle**
- **Establish sign of Sivers Distribution, if nonzero**

$$A_N \equiv 0 \quad \text{if} \quad L_{\bar{u}} = 0$$

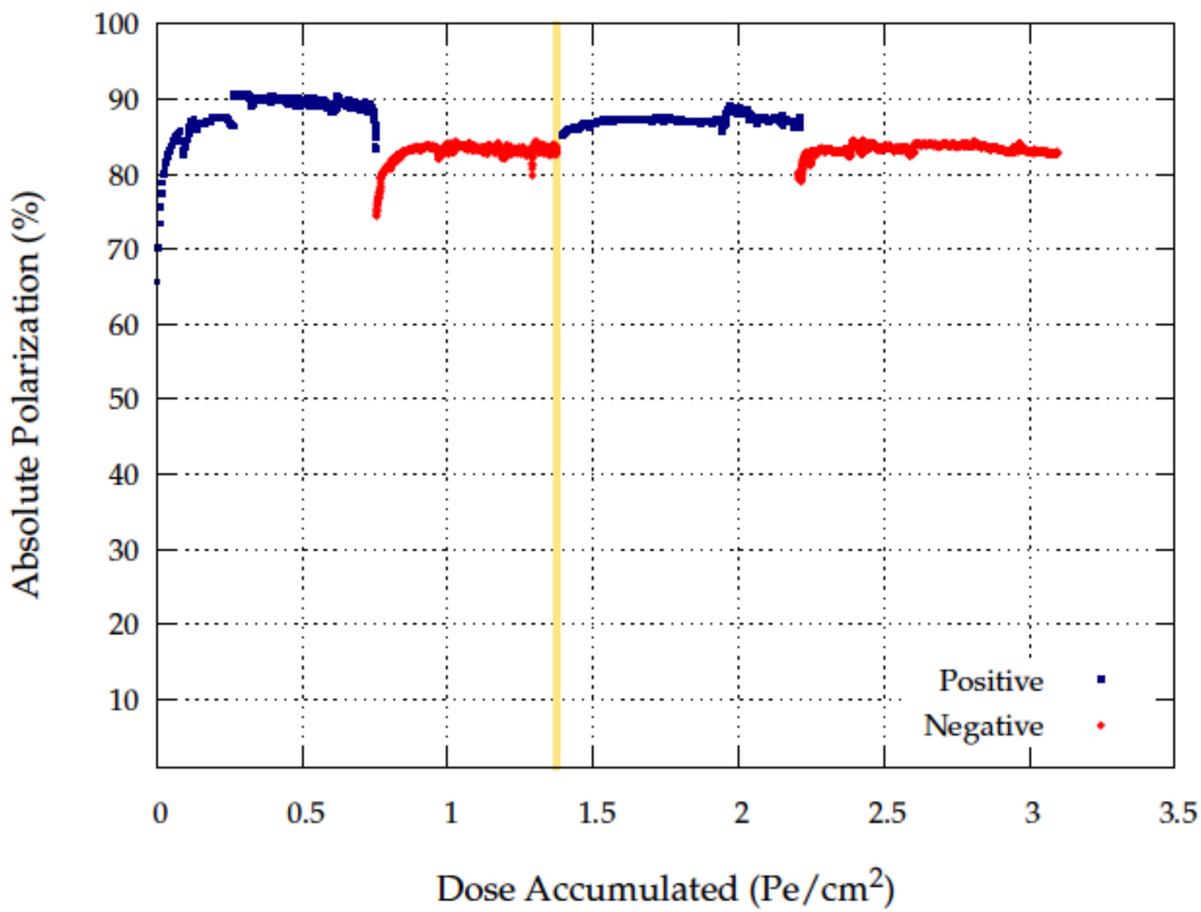
- **Request 2 calendar years of beam time**
- FNAL and E906 ideally situated for this experiment
- Aligns well with current E906 beam time
- Spectrometer already in place, largely unchanged
- Replace cryogenic targets with polarized target
- Provide new facility for FNAL nuclear spin physics
- Requires only modest support from FNAL



Backup slides

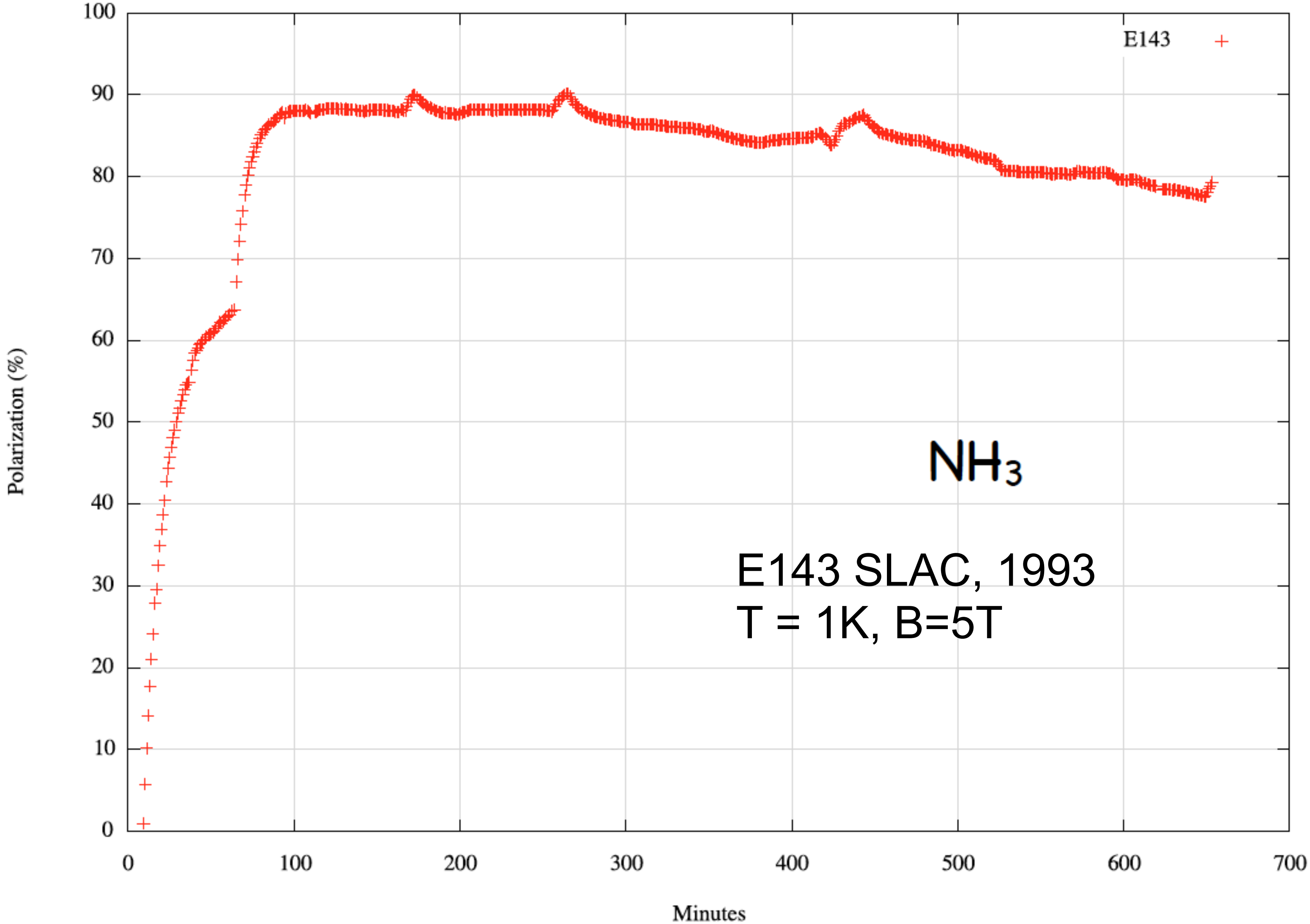
PAC Questions at the Meeting and Our Brief Answers

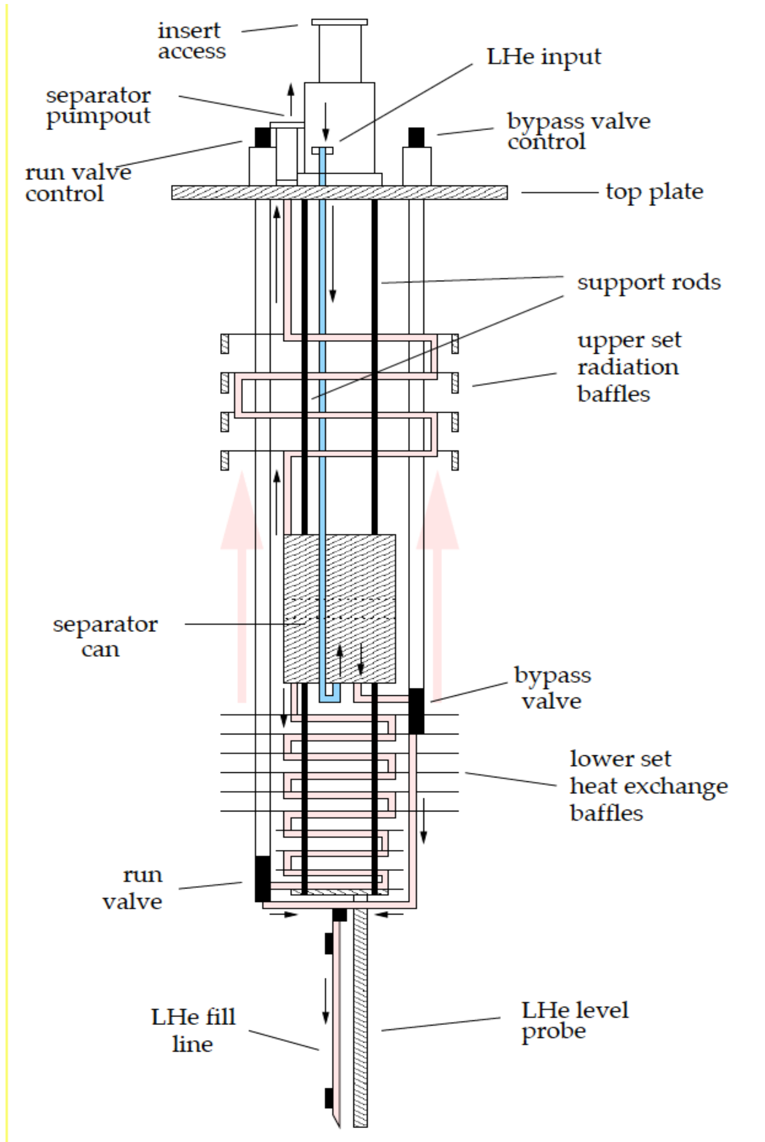
PAC Final Question and Our Answer



Hall A G2p target draft arXiv:1305.3295

Figure 8: Polarization vs. dose for the material which accounted for over half the total dose accumulated during G_E^p, taken with a 5 T magnet field and 10 nA beam current. The vertical line represents removal and storage at 77 K.


E143
NH3
E143 SLAC, 1993
T = 1K, B=5T
Polarization (%)
Minutes
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700

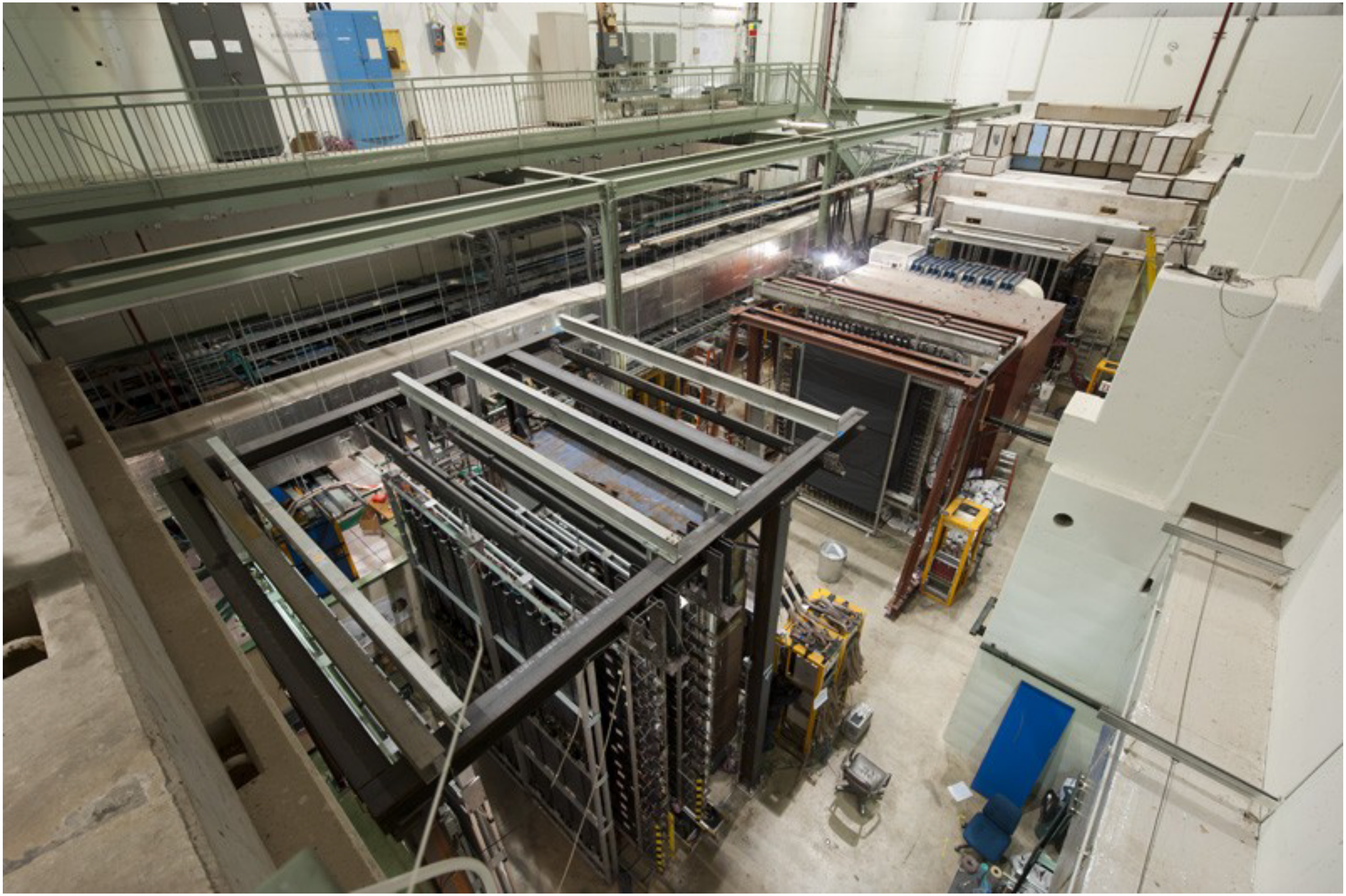

insert access
separator pumpout
run valve control
LHe input
bypass valve control
top plate
support rods
upper set radiation baffles
separator can
bypass valve
lower set heat exchange baffles
run valve
LHe fill line
LHe level probe

SeaQuest(E906), P-1027 and P-1039 using a Similar Setup

	Beam Pol.	Target Pol.	Favored Quarks	Physics Goal
SeaQuest $pN \rightarrow \mu^+\mu^- X$	✗	✗	-	Unploarized sea quark flavor asymmetry dbar/ubar.
P-1027 $p^{\uparrow}p \rightarrow \mu^+\mu^- X$	✔	✗	Valence quark	Sign change and size of Sivers distribution for valence quark
P-1039 $pp^{\uparrow} \rightarrow \mu^+\mu^- X$	✗	✔	Sea quark	Size and sign of Sivers distribution for Sea quarks, if DY $A_N \neq 0$.

Possible improvements in near future.

A high rate front tracking station (GEM) to improve vertex and momentum resolution.
Adiabatic passage for spin reversal.
Target material, 7LiH, improve dilution factor.
Magnetic field reconfiguration, change acceptance to focus on lower x2.
New tracking stations with larger detectors.



Systematic error

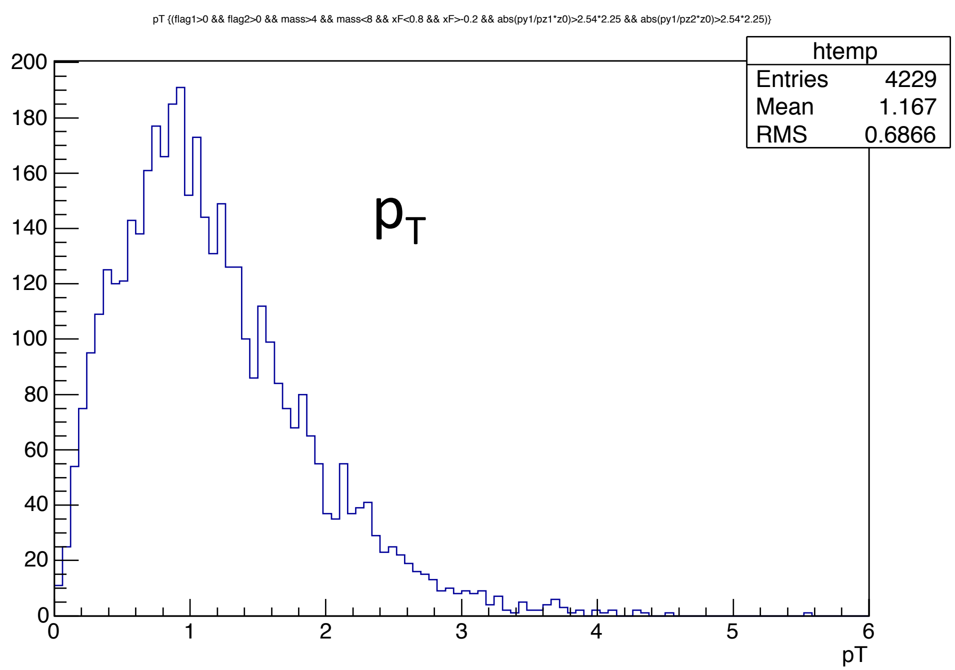
$$A_{meas} = \frac{N_+ - N_- \frac{L_+}{L_-}}{N_+ + N_- \frac{L_+}{L_-}}$$

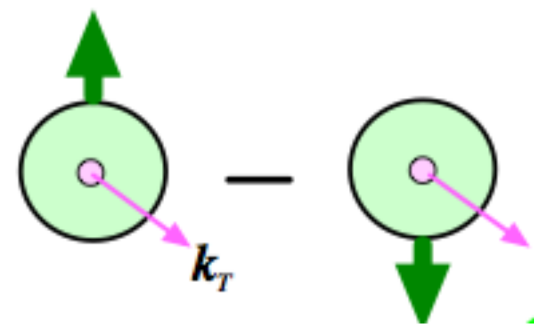
$$(\delta A_{meas})_{sys} = \frac{N_- \bullet \delta(\frac{L_+}{L_-})}{N_+ + N_- \bullet \frac{L_+}{L_-}} \bullet (1 + A_{meas})$$

for small Asymmetry $\frac{N_+}{L_+} \approx \frac{N_-}{L_-}$

$$(\delta A_{meas})_{sys} \approx \frac{1}{2}(1 + A_{meas}) * \frac{\delta\left(\frac{L_+}{L_-}\right)}{\frac{L_+}{L_-}}$$

- Geant 4 MC from E906
- DY cross section from pythia using CETQ5M PDF
- added simple field from pol target
- E906 life time: .75, beam .66 = .5 overall





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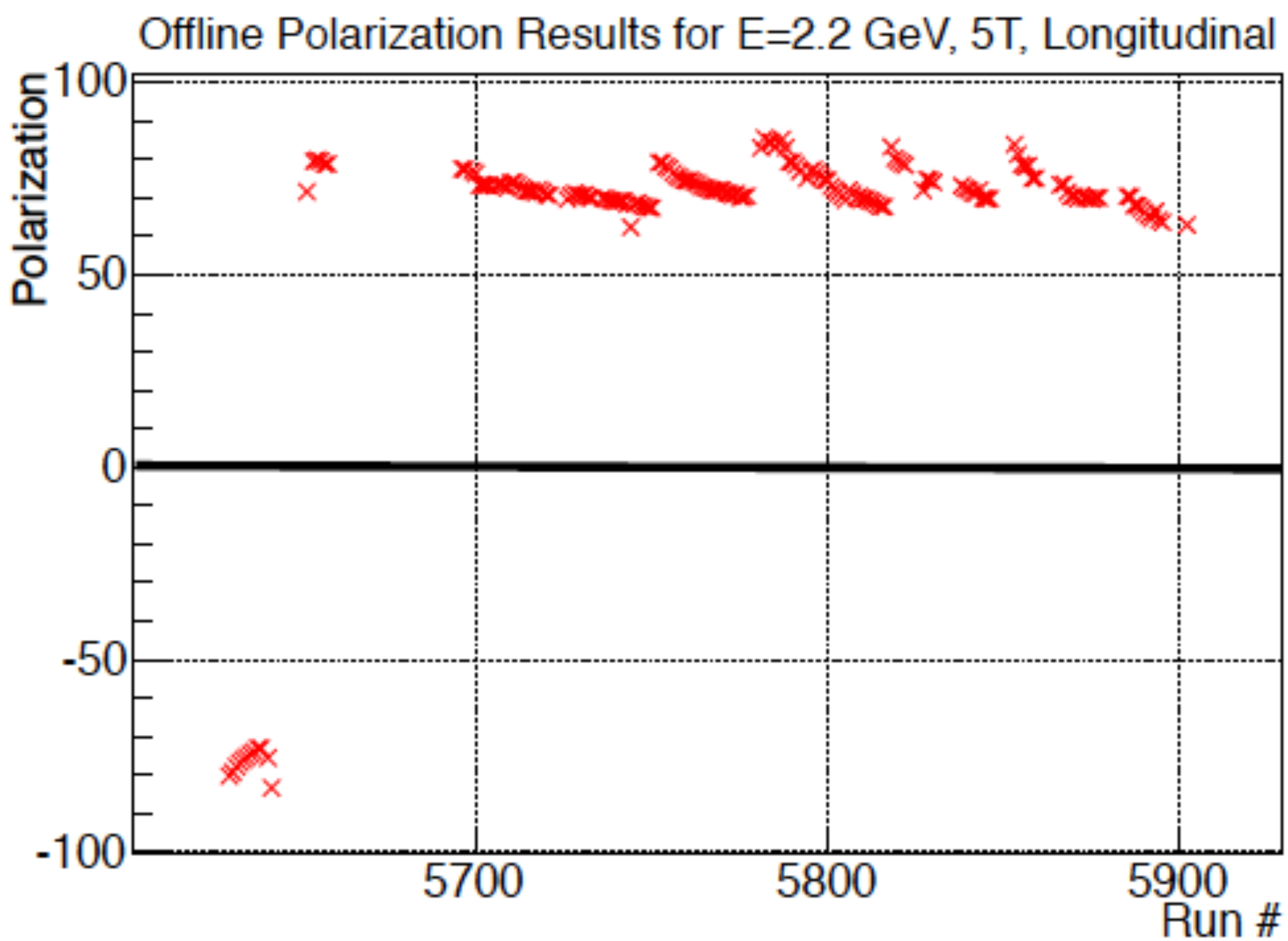


PAC Question1:

1. What is the explicit link of quark Sivers function to quark orbital angular momentum ?

A. Sivers function is related to the imaginary piece of quark L=0 (s-wave) and L=1 (p-wave) wave-function interference, within a particular model, for example quarl-diquark model, the amount of L=1 wave function introduced is translated to Sivers function, and result in specific value of quark angular momentum. The link between Sivers function and quark angular momentum would be model dependent. But if ubar carries zero orbital angular momentum, the ubar Sivers function should be zero. The correlation between transverse momentum kt and transverse polarization of the nucleon is only possible for the case of non-vanishing angular momentum of the quarks.
(Zhongbo Kang)
At the moment, there is no first-principle/rigorous relation between Sivers function and OAM from QCD theory. Thus even though our Lattice QCD could calculate OAM and Sivers function, separately, still one doesn't have the exact quantitative relation between them ... (except the qualitative relation, i.e., if ubar carries zero orbital angular momentum, then ubar Sivers function should be zero).
One example of model dependent link,there is some study already -- from Sivers asymmetry to get the OAM can be done:
Constraining quark angular momentum through semi-inclusive measurements
Alessandro Bacchetta, Marco Radici **Phys.Rev.Lett. 107 (2011) 212001 arXiv:1107.5755**

$$f_{1T}^{\perp(0)a}(x;Q_L^2) = -L(x)\, E^a(x,0,0;Q_L^2),$$

$$J^u = 0.229 \pm 0.002^{+0.008}_{-0.012}, \qquad J^{\bar{u}} = 0.015 \pm 0.003^{+0.001}_{-0.000},$$

$$J^d = -0.007 \pm 0.003^{+0.020}_{-0.005}, \qquad J^{\bar{d}} = 0.022 \pm 0.005^{+0.001}_{-0.000},$$

$$J^s = 0.006^{+0.002}_{-0.006}, \qquad J^{\bar{s}} = 0.006^{+0.000}_{-0.005}.$$

Alessandro Bacchetta, Marco Radici **Phys.Rev.Lett. 107 (2011) 212001 arXiv:1107.5755**

PAC Question 2:

2. What if COMPASS do pi^+ beam on pol. Proton target, would they able to access u-bar Sivers as well ?

A. The Answer is no, the kinematic won't work. A pi+ beam at COMPASS will be mostly sensitive to target d-quark Sivers distribution. A pi^+ beam, which is (u d-bar), would pick up target d-quark (in d-bar d Drell-Yan) as well as the target u-bar in (u ubar DY). However, in COMPASS kinematics which covers x_target=0.1~0.3, d-quark density in target overwhelm u-bar density by a factor of 10. Target u-bar Sivers effect will be very much suppressed compared to that of target d-quark Sivers effect. In addition, COMPASS has no plan to do pi^+ beam Drell-Yan. There're are other approved COMPASS measurements in line for DVCS and Longitudinal polarized target run for 2015-2018, the only polarized target Drell-Yan run with COMPASS would happen only in 2014.

Anselmino PRD 2009

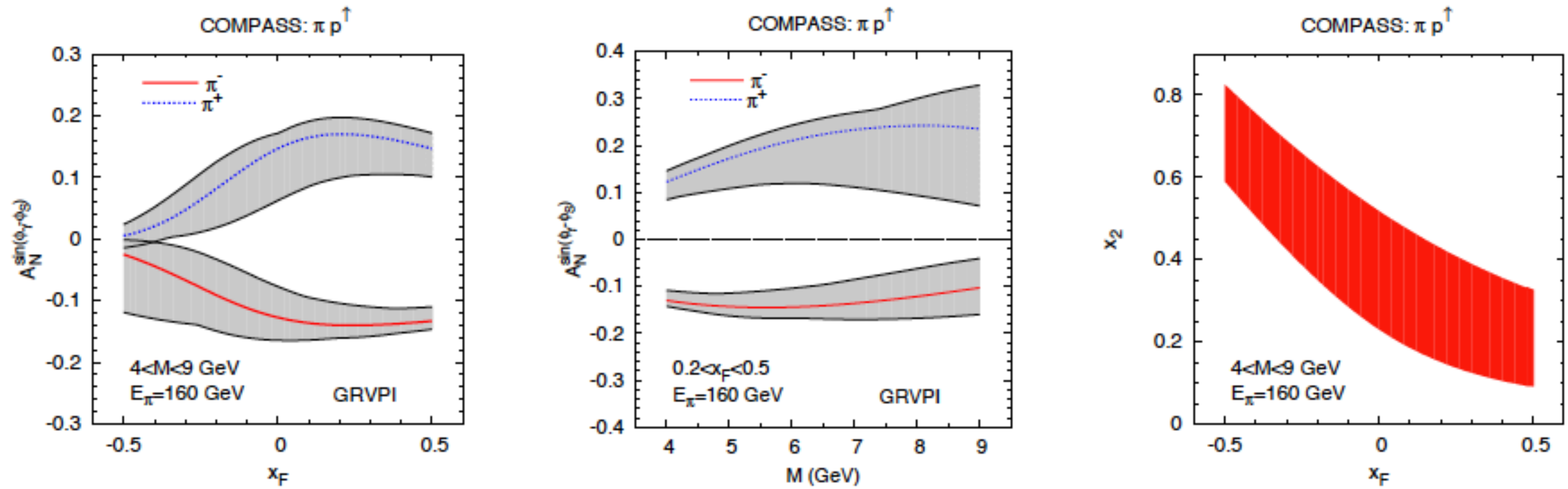
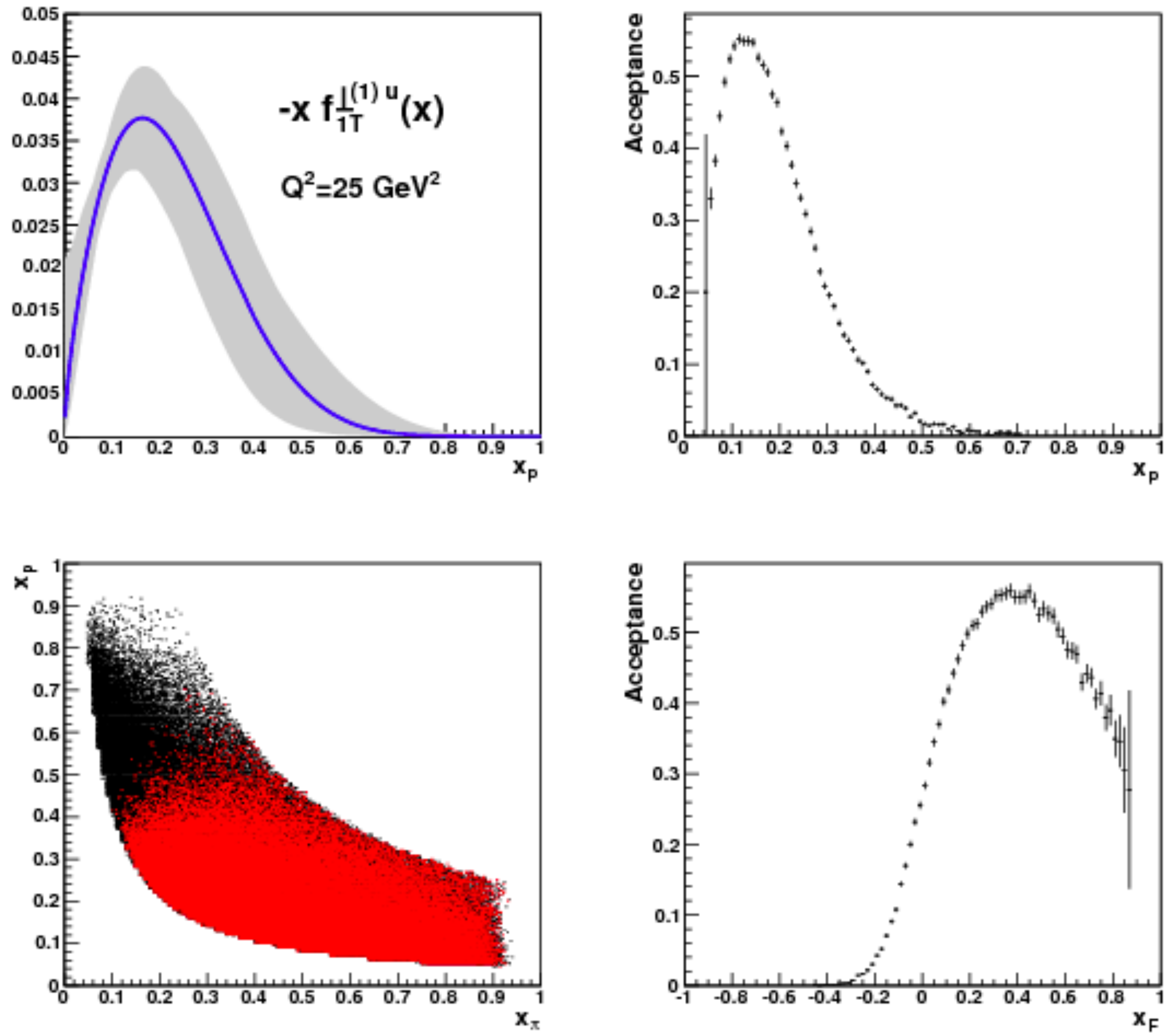
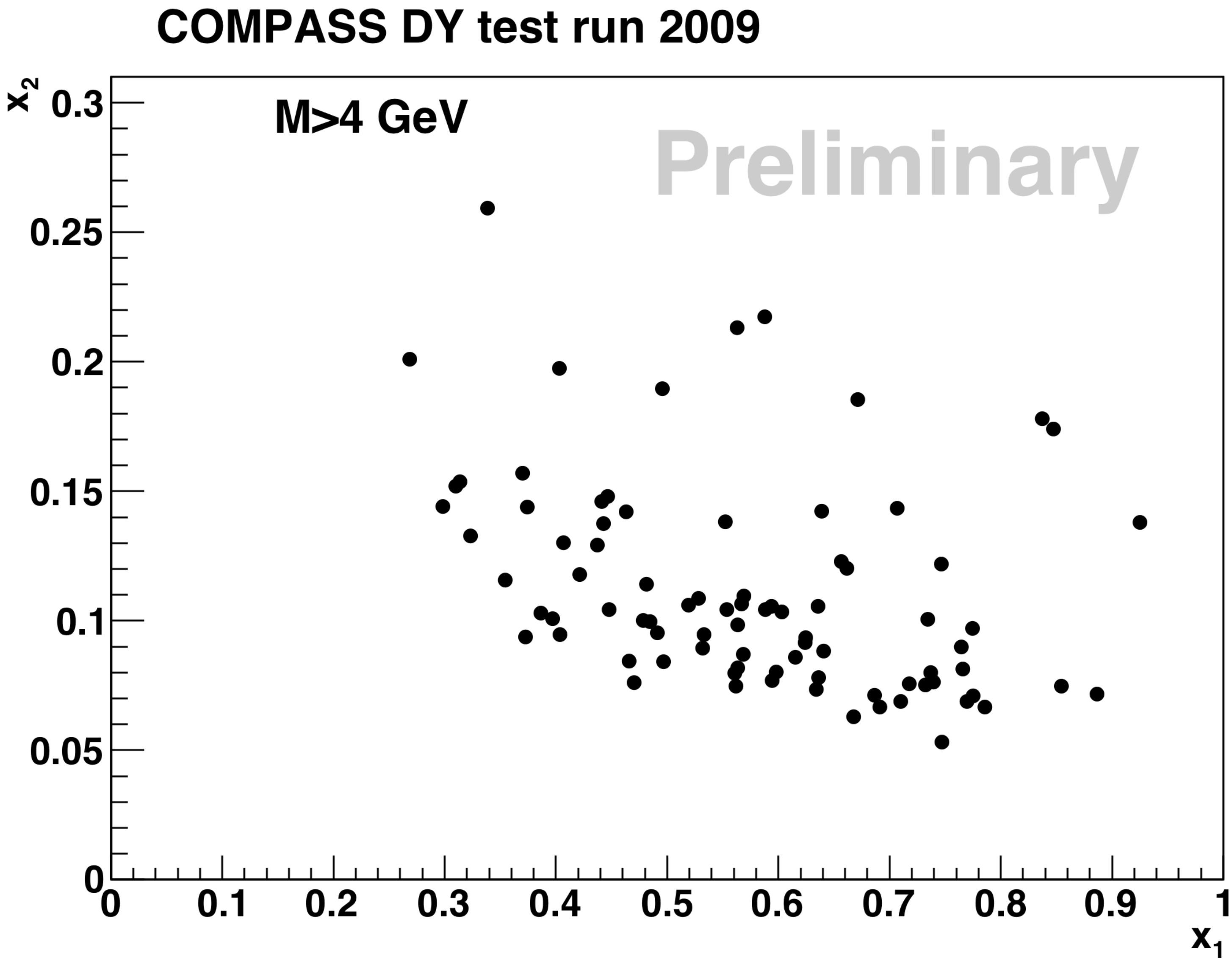


FIG. 2: The single spin asymmetries $A_N^{\sin(\phi_\gamma-\phi_S)}$ for the Drell-Yan process $\pi^\pm p^\uparrow \to \mu^+\mu^- X$ at COMPASS, as a function of $x_F = x_1 - x_2$ (left panel) and as a function of M (central panel). The integration ranges are $(0 \le q_T \le 1)$ GeV, $(4 \le M \le 9)$ GeV and $0.2 \le x_F \le 0.5$. The results are given for a pion beam energy of 160 GeV, corresponding to $\sqrt{s} = 17.4$ GeV. The right panel shows the allowed region of x_2 values as a function of x_F.

COMAPSS Acceptance



COMAPSS x1 vs x2 coverage



PAC Question-3

3. In order to complete the full loop on spin, do you need both valence quark Sivers and sea quark Sivers measured ? If there's one experiment you can run, which one you pick first, polarized target, or polarized beam.

A. Before a polarized beam is available, very soon like in 2015, I would certainly pick the polarized target experiment. When a polarized beam is available, certainly a polarized beam Drell-Yan to pin down valence quark Sivers is very important, at that point we (the polarized target LOI) are perfectly happy to be pushed back in the schedule.

XJ: For polarized proton beam SSA at E906 kinematics, I claim that with a nuclei target, P-1027 can reach the same physics goal, even if there's modification of sea density in nuclei. Since Asy=(beam-valence-u-Sivers function*target unpolarized u-bar-density \over beam-u-density*target u-bar-density, it won't matter if the u-bar density is modified in nuclei. I will need to confirm with theorists in the coming days.

P-1027 Target Density and Rates.

Table 1: Various relevant experimental factors used in the Monte Carlo simulation for the Drell -Yan rate estimation. Note that ε_r is the reconstruction efficiency, ε_t is the trigger efficiency, t_{spill} is the time of one spill and n_{spill} is the maximum number of spills per minute.

l_{H_2}	50.8 cm
ρ_{H_2}	0.0678 g/cm^3
I_p	9.5×10^{10} p/s = 15 nA
L	2×10^{35} cm^{-2}s^{-1}
Ω	0.02
ε_r	0.5
ε_t	0.8
t_{spill}	2 s
n_{spill}	3 /min
ε_{exp}	0.5

Table 2: The number of Drell-Yan events estimated per day for the dimuon invariant mass range $4.2 < M < 8.5$ GeV assuming an experimental efficiency (ε_{exp}) of 0.5.

Invariant Mass (GeV)	R (/day)
$4.2 < M < 8.5$	1,865

P-1027 Beam SSA. Prediction

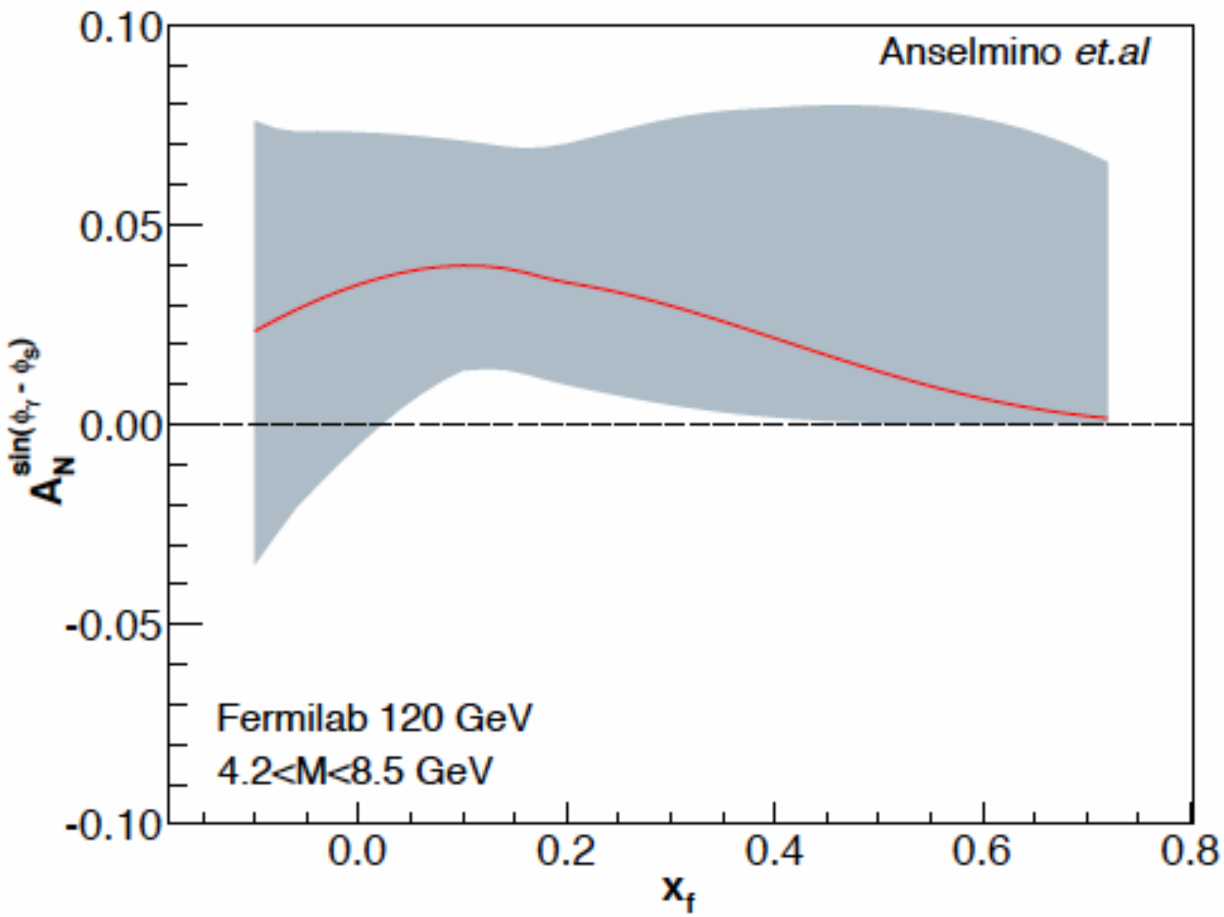


Figure 6: Sivers asymmetry, $A_N^{\sin(\phi_\gamma - \phi_S)}$, as a function of x_f for a polarized Drell-Yan experiment at the Fermilab Main Injector [46]. The red line indicates the prediction for the Sivers SSA, and the gray shaded area represents the $\sqrt{20}$-sigma error band.

P-1027 Beam SSA Statistical Precision

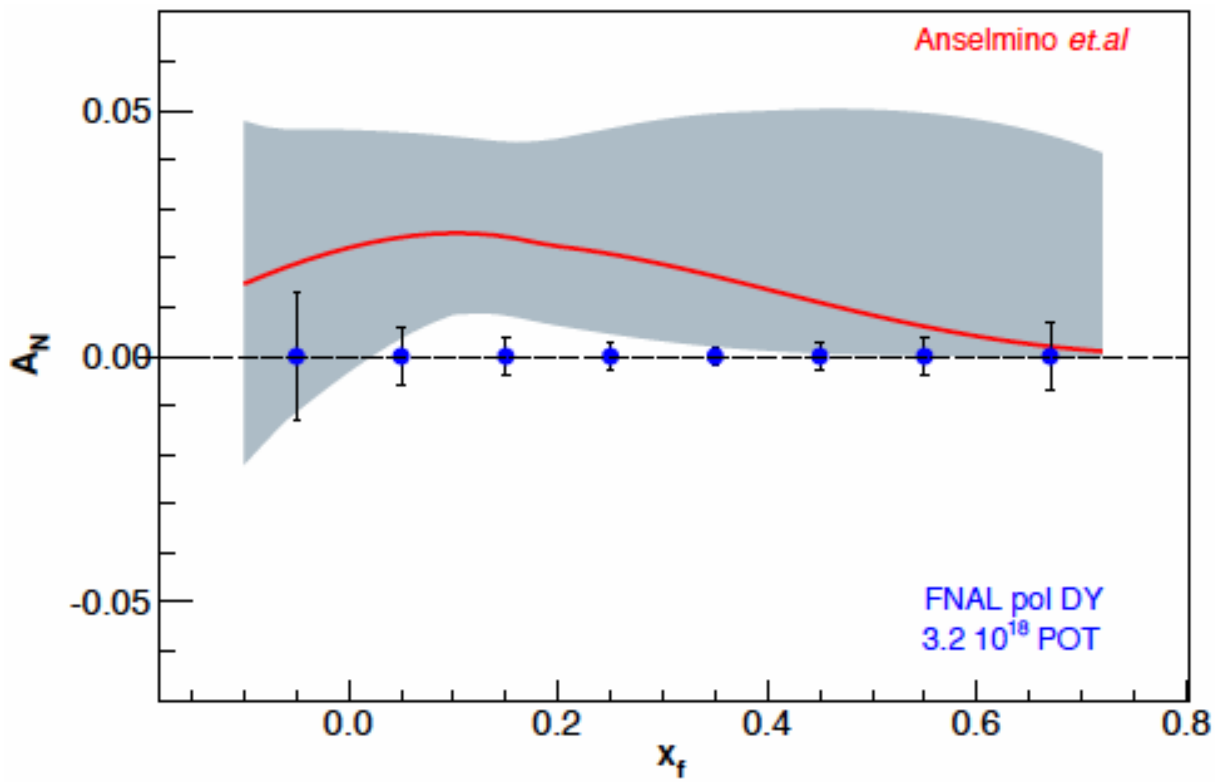


Figure 7: Single spin asymmetry A_N as a function of x_f. The SSA A_N (red line) is related to the Sivers SSA amplitude by $A_N = \frac{2}{\pi} A_{TU}^{\sin\phi_b}$. The expected statistical uncertainties (blue solid circles) for a 70% polarized beam on an unpolarized target and 3.2×10^{18} protons on target are (arbitrarily) plotted on the zeroline.

We double checked the error bars in this plot…

PAC Question-4: Where's the money Come from DOE Nuclear Physics ?

Andi's comments in an email 06/0513: We were basically asked to think along the lines of not getting anything from FNAL, and so where would the money come from. I told them that this is a LOI and once we have the support for the physics we can go back to DOE and ask for support. I completely agree with Pat, that we should not let them off the hook and I have no intention for that.
What I also said after having talked with Chuck is that the 1M$ for the installation seems high. two -three techs for 2 month is certainly not 1 M$, even in LANL dollars this is more like 500K and FNAL is still cheaper than we are.

PAC Question-5: proton budget, any impact to NOVA ?

A. Same impact as of E906 keep running. No accelerator shutdown/modification needed .

PAC Final Question regarding the Priority of P-1027 and P-1039

What is the physics priority of the collaboration, 1039 or 1027, and why? What is the order?

I*n terms of the physics priority we (the collaboration repersentatives) feel that P1027 should run first. Determining the change of sign of the Sivers asymmetry provides a rigorous test of QCD and is also one of the DOE milestones for nuclear physics. After a successful completion of P1027, we would then continue with P1039 and measure the sea quark Sivers asymmetry.*

In the case that the polarized beam will get delayed well beyond the end of E906, it would be preferable to install the polarized target and measure the sea quark Sivers asymmetry.
Experiment P1039 is also unique in that it is the only DY experiment foreseen to probe the angular momentum of the seaquarks. Furthermore, running the polarized target in such circumstances would guarantee a continuation of a successful physics program until the polarized beam is ready. The current plan for installing the polarized target is such that the p1027 cryogenic target could be easily swapped in again.