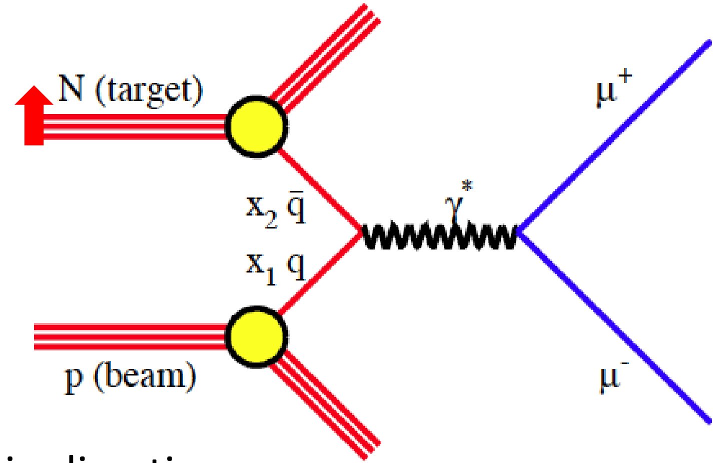
Fermilab P-1039

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

Xiaodong Jiang, Los Alamos National Laboratory

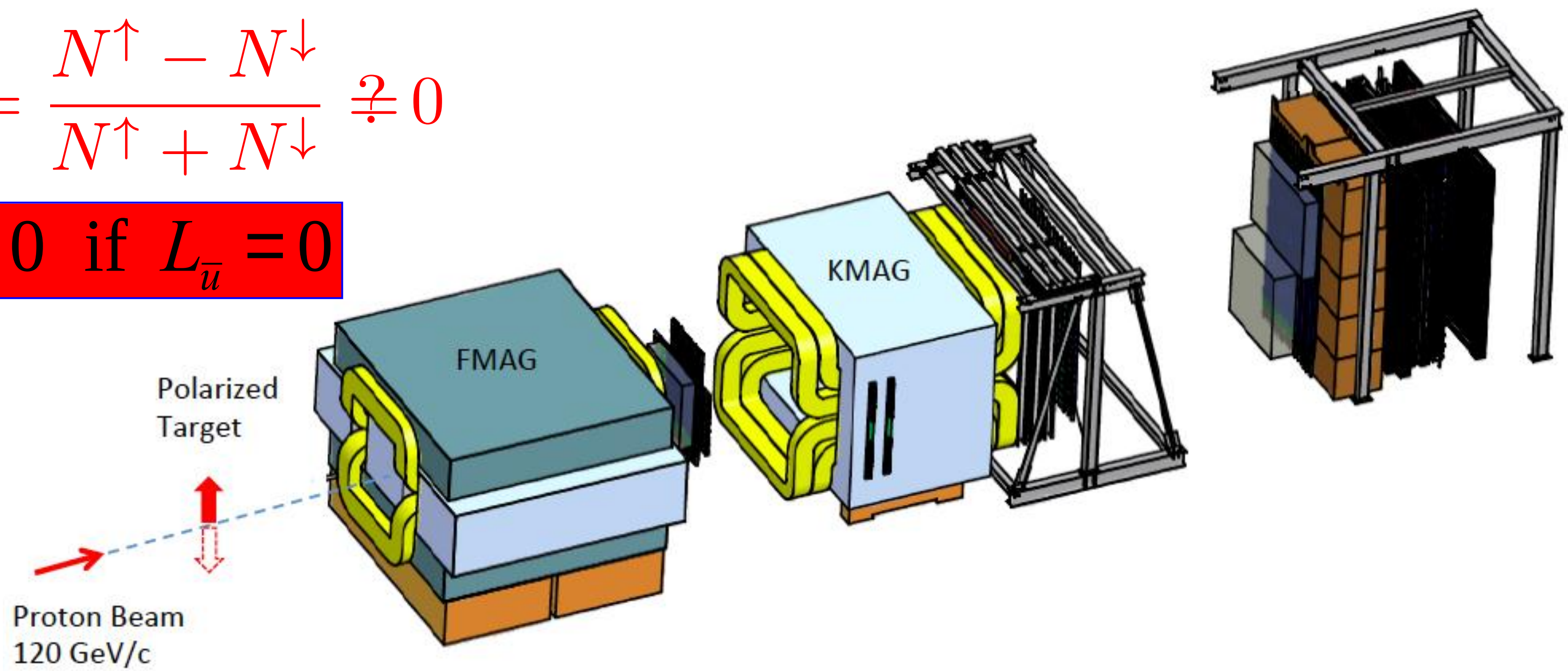
July 3rd, 2013 @ Hadronic Physics Workshop. Huangshan, China.



- 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.

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

$$\boxed{A_N \ ^{\circ}\ 0 \ \ \text{if} \ \ L_{\bar{u}} = 0}$$



FNAL Director Granted P-1039 Stage-I Approval

As you can see, the PAC recommends Stage-1 approval for P-1039, contingent on the funding from the DOE Office of Nuclear Physics (NP) for the project and continued minimal impact on the high-priority core program. I accept the PAC recommendation, and grant Stage-1 approval contingent upon funding from the DOE Office of Nuclear Physics. The laboratory management looks forward to discussing with you plans and prospects for obtaining this funding.

....

The PAC also appreciates the opportunity offered by this proposal to continue the partnership between Fermilab and the nuclear physics community.

Sincerely,

Piermaria Oddone

Letter-Of-Intent (P-1039): submitted May 6th, 2013.
FNAL PAC presentation: June 6th, 2013.
Stage-I approval: June 26th, 2013.

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.**

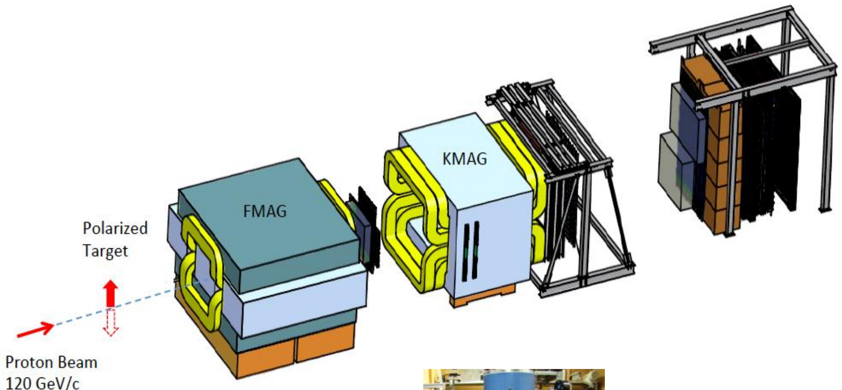
Drell-Yan yields depend on target's spin direction?

$$A_N = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \stackrel{?}{=} 0 \qquad\qquad A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

$$\boxed{A_N \;^{\circ}\; 0 \;\; \text{if} \;\; L_{\bar{u}} = 0}$$

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:

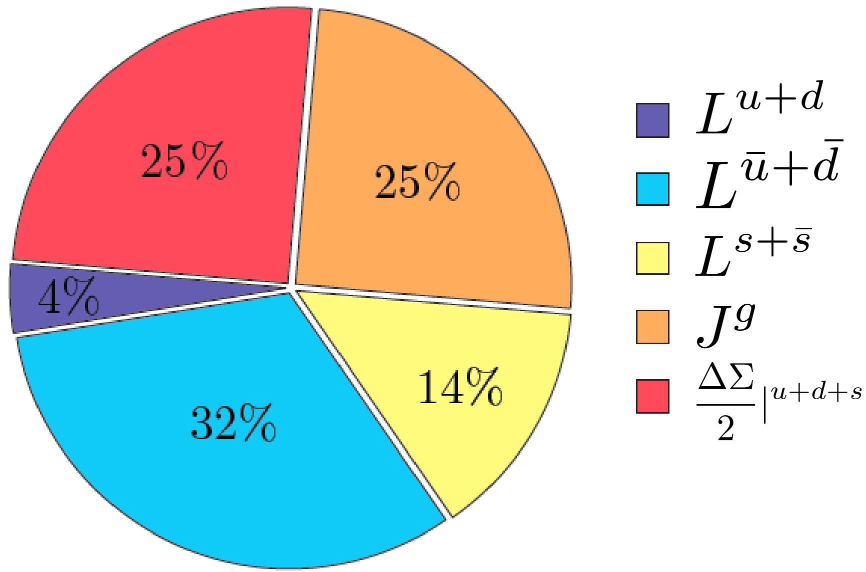
$$\Delta\Sigma_q \approx 0.25 \pm \ldots$$

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".

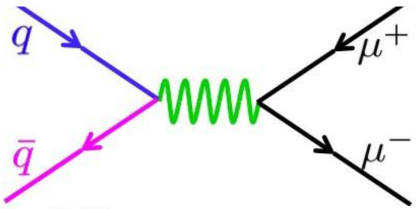
Drell-Yan at SeaQuest (E906): a Clean Access to Sea Quark

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

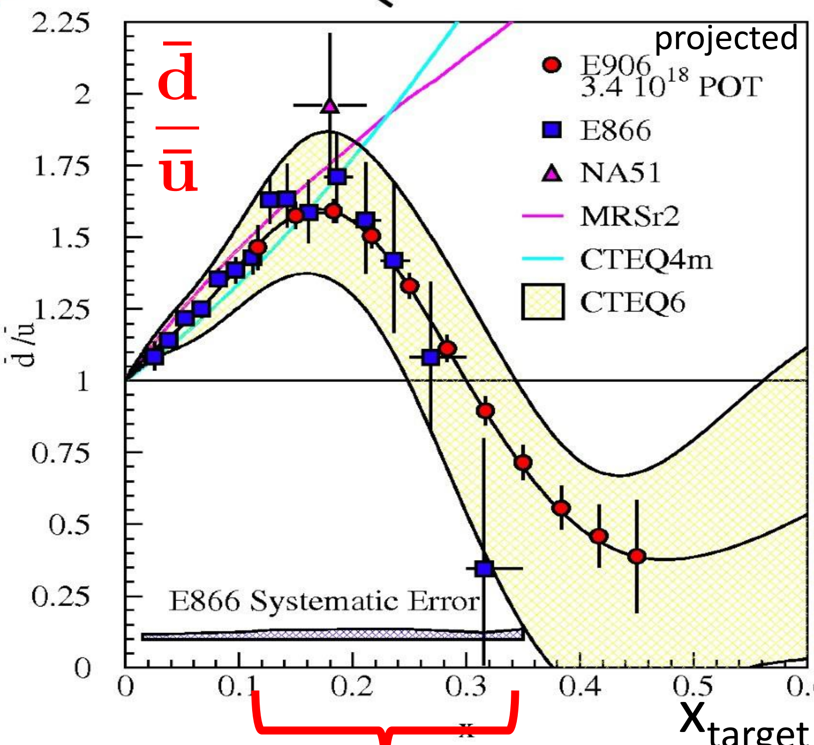
small

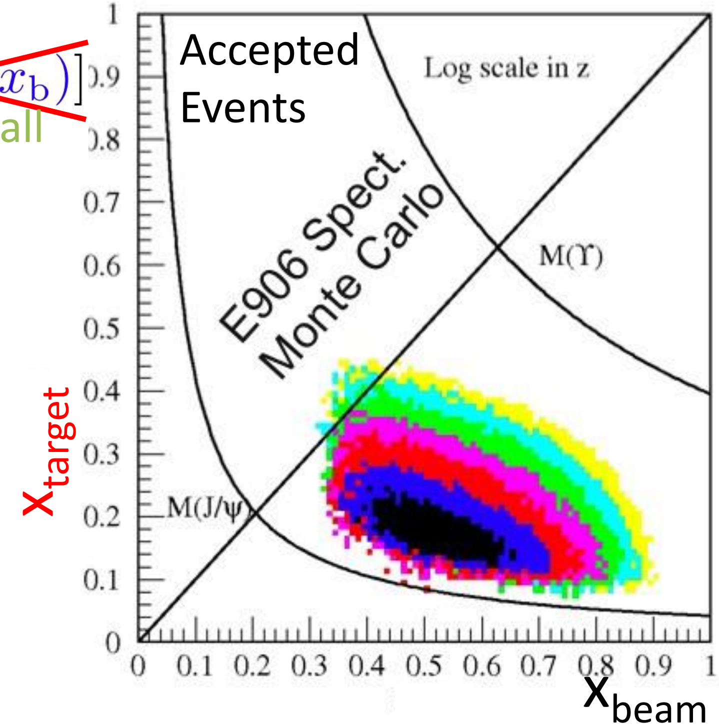
target sea quark

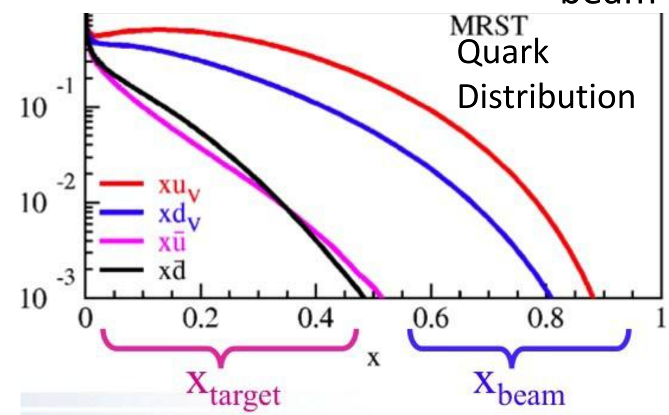
beam valence quark



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





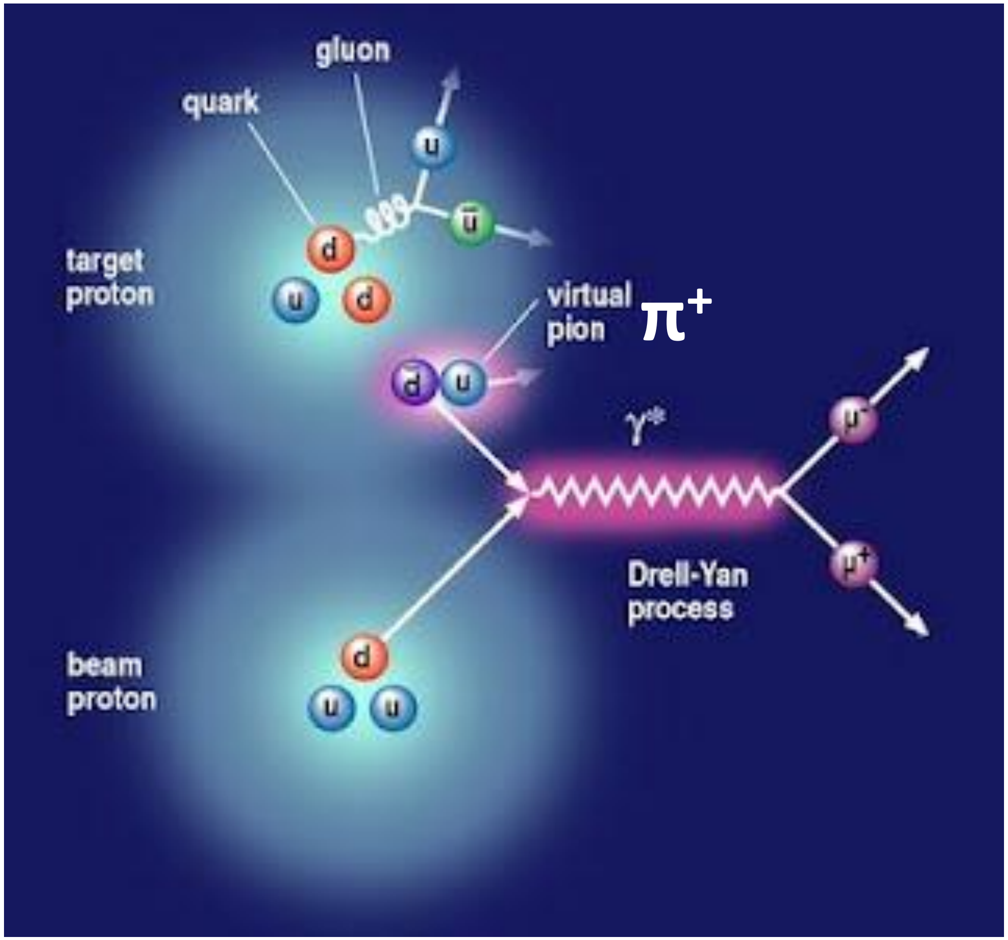


Strong flavor asymmetry in the sea.

Could sea quarks carry a significant amount of angular momentum ?

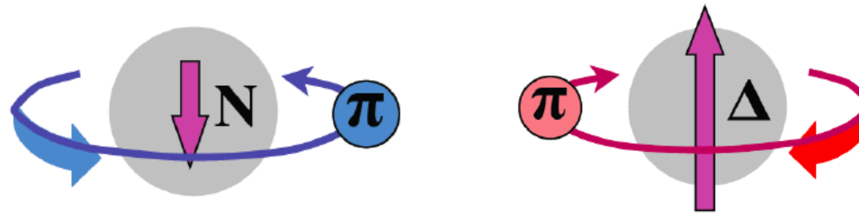
The meson cloud model explains the flavor asymmetry in the sea, and requires quarks to carry angular momentum.

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



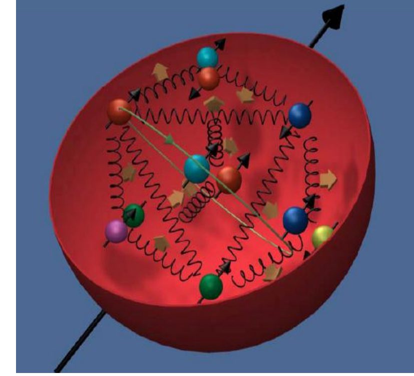
Pions $J^p=0^-$ Negative Parity

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



Sea quarks should carry orbital angular momentum.

Quark Orbital Momentum and the Sivers Function

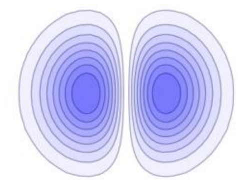


The Sivers function is the distribution of unpolarized quarks in a transversely polarized proton

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

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

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.

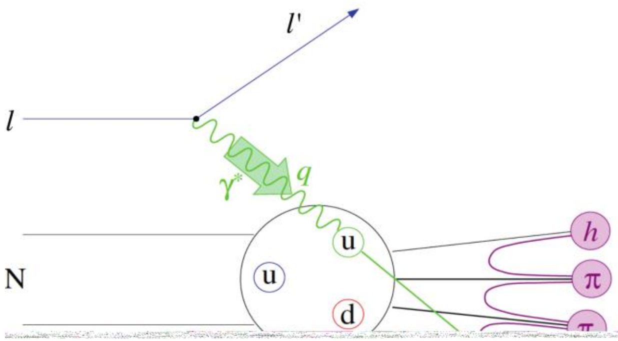
Sivers function = 0 ⇔ L_q=0

Sea quark Sivers function =0 ?

Accessing the quark Sivers distribution

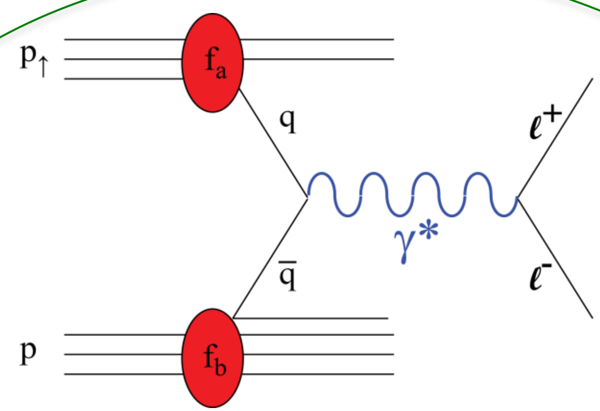
Polarized target experiments

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



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

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



Never done

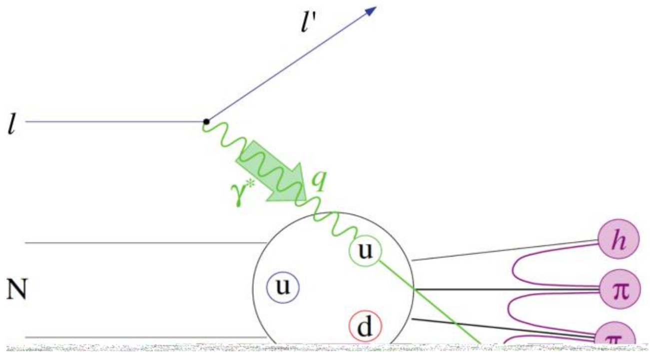
$$p p^{\uparrow} \to \mu^+ \mu^- X$$

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



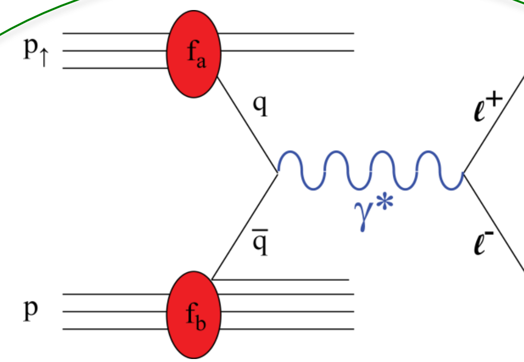
$$ep^{\uparrow} \rightarrow e'\pi X$$

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

- 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



Never done

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

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

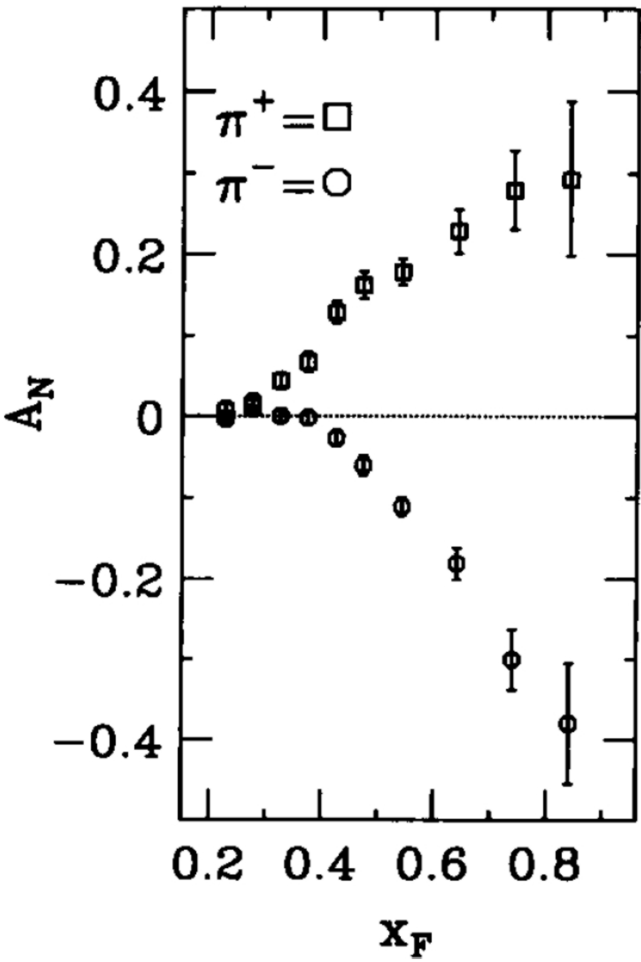
- No quark frag. func. involved.
- Valence and sea quarks can be isolated
  - Pol. Beam ➔ valence quark (P-1027)
  - Pol. Target ➔ sea quark (P-1039)

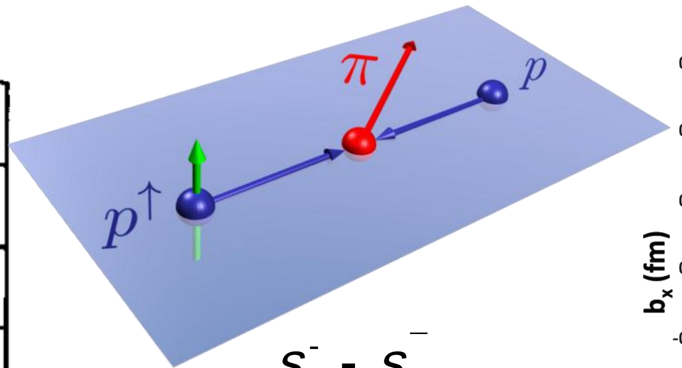
$$A_N = \frac{\sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]}{\sum_q e_q^2 [f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2]}$$

Quark Sivers Distribution Leads to Left-Right Bias

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

E704 √s =20 GeV. PLB 264 (1991) 462.





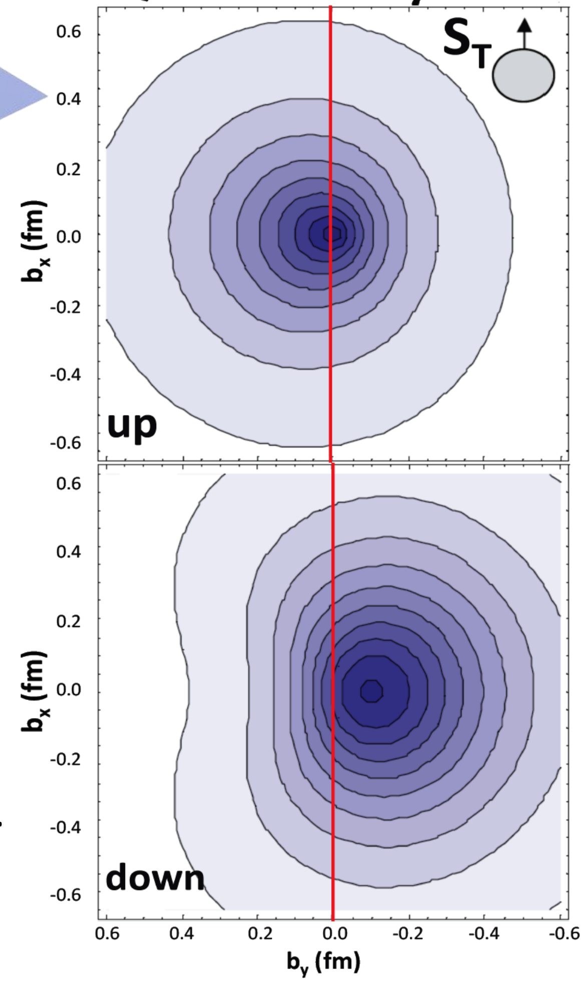
$$A_N = \frac{s^{-} - s^{-}}{s^{-} + s^{-}}$$

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

p^- $(d\bar{u})$ 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

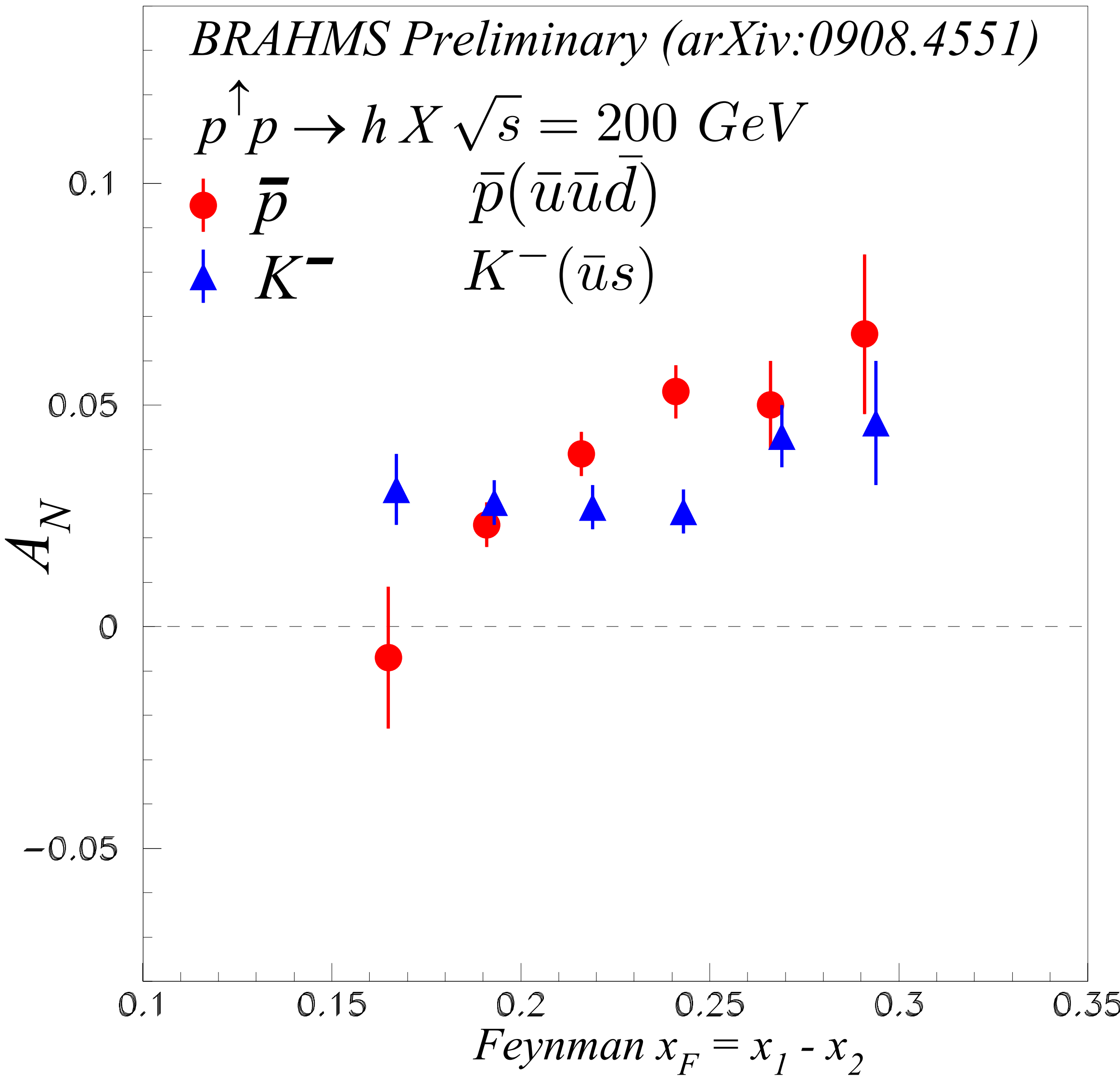


Lattice QCD PRL98:222001,2007.

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 ?



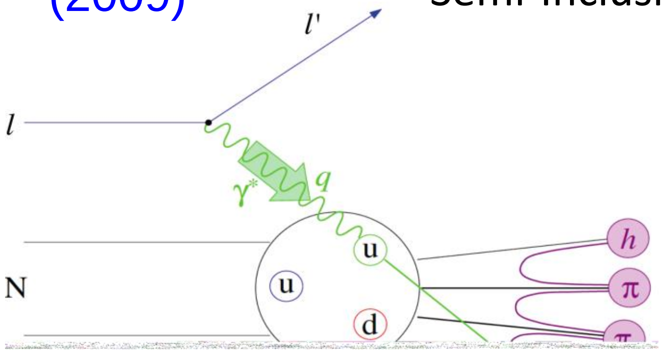
Sea quark generates left-right bias ?

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

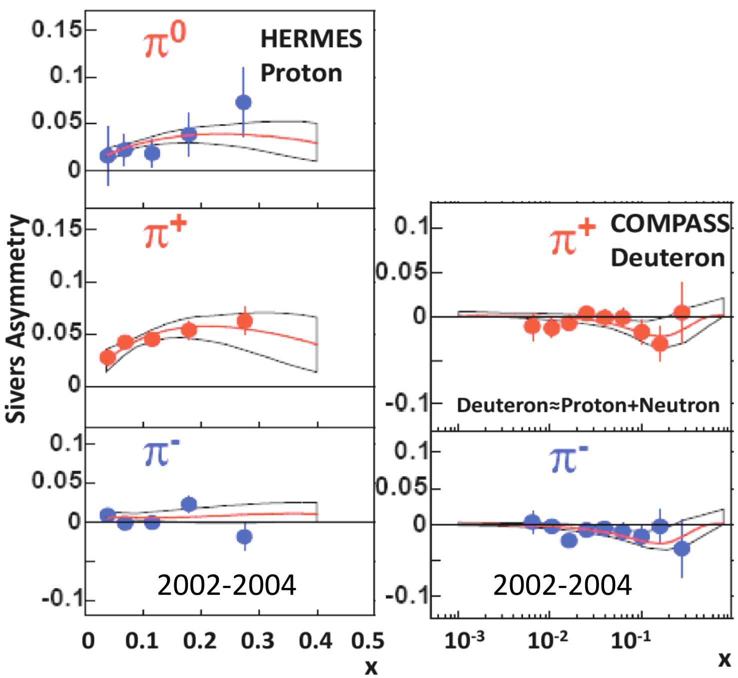


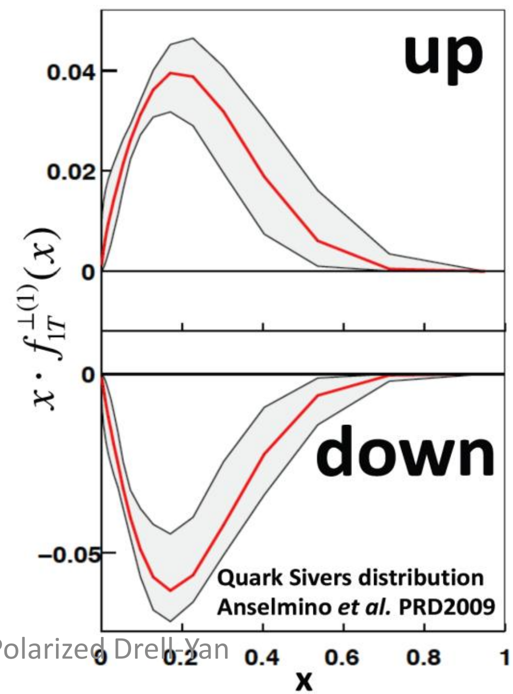
$$A_N \equiv \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

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

- **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





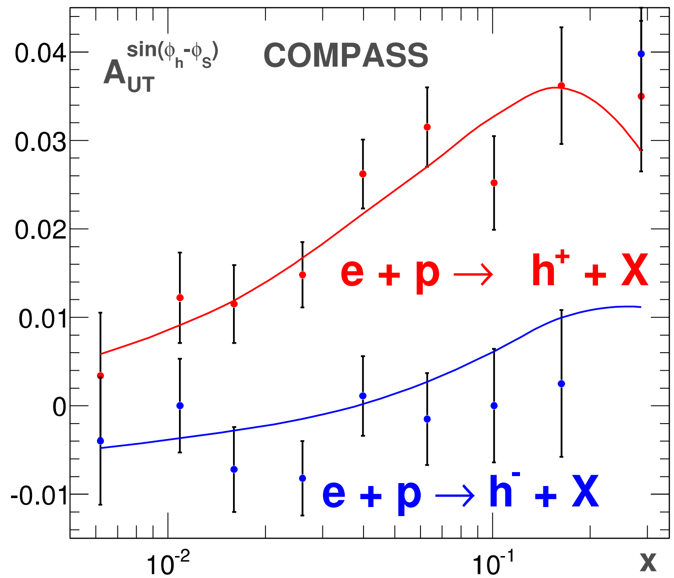
up-quark favors left (L_u>0),

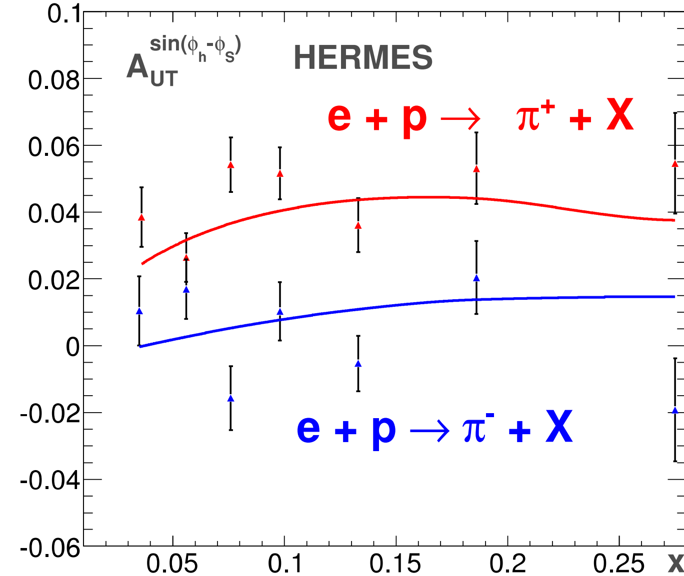
down-quark favors right (L_d<0).

$L_u \approx - L_d$

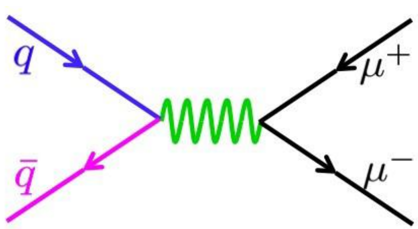
Quark Sivers Distributions: a new fit includes new data (2013)

Sun and Yuan:
arXiv:1304.5037



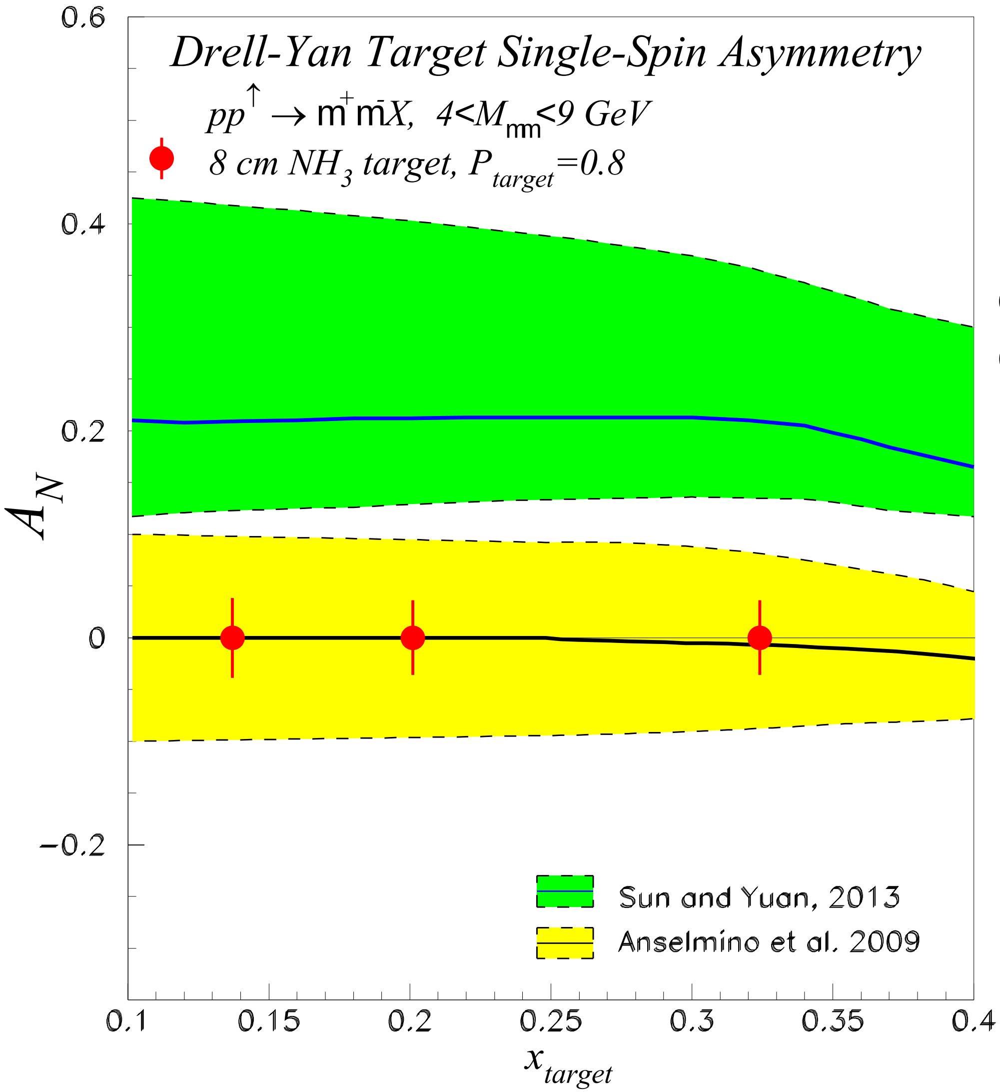


- Include new COMPASS proton target data (2010) and earlier transverse distribution data.
- Take Q^2-evolution effects into account.
- Allow contributions from sea quarks which lead to non-zero ubar Sivers distribution, however with large error bars.
- Predict Drell-Yan target single-spin asymmetry for 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 :
$L = 1.4 \times 10^{43}$ /cm^2 ⇔ POT = 2.1×10^{18}

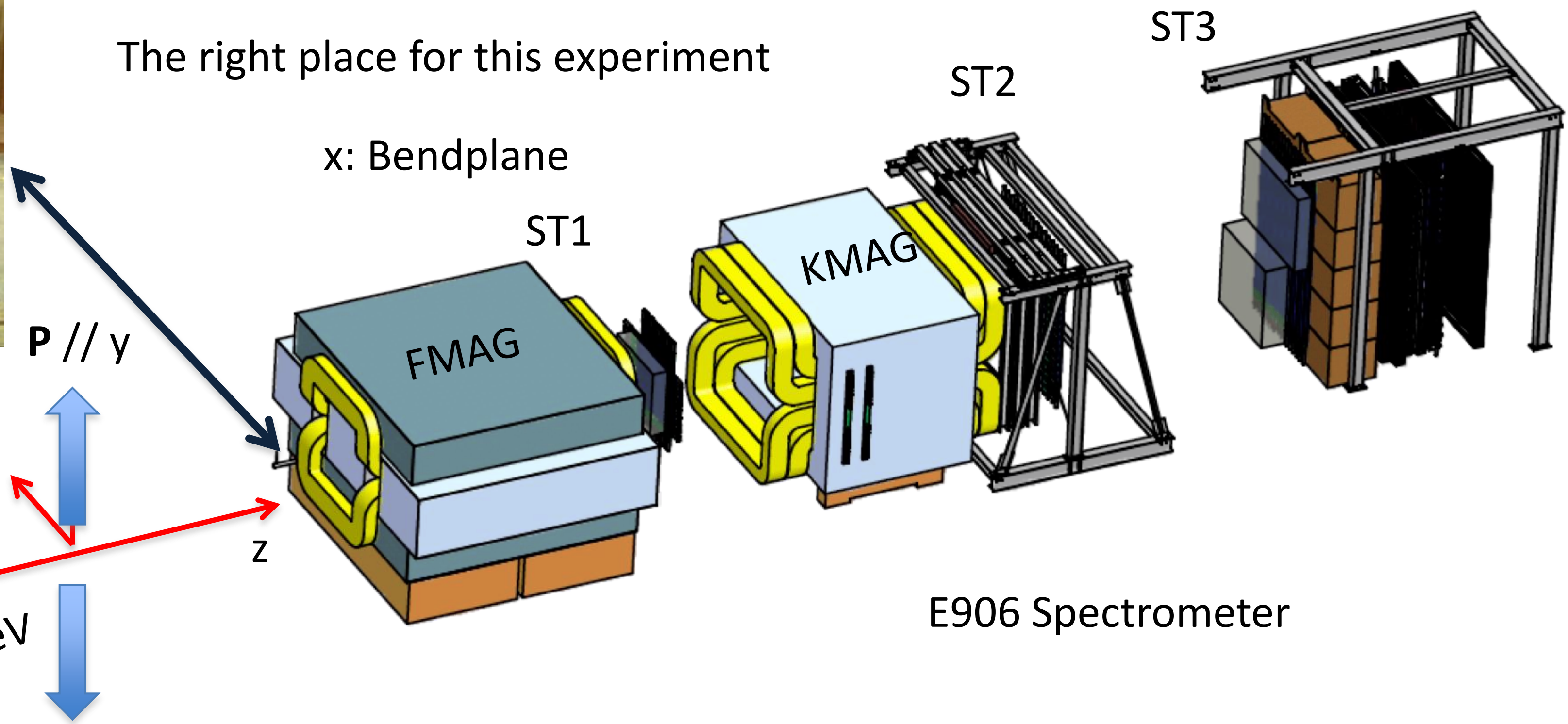
Request for two calendar years of beam time

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 $A_N \neq 0$.

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

In a similar setup as in FNAL E906

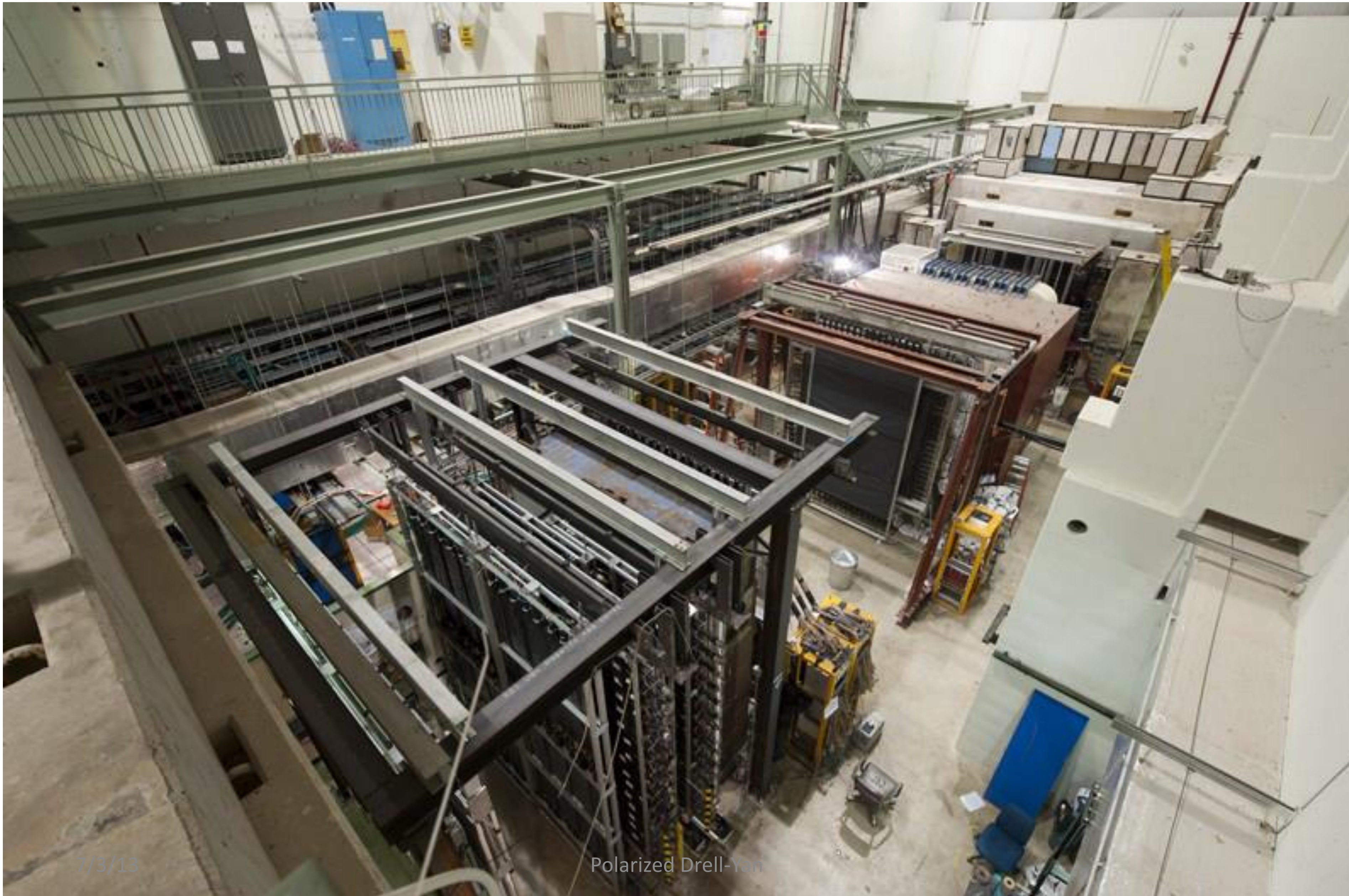
•Can perform world's highest luminosity polarized target Drell-Yan measurement at Fermilab's 120 GeV proton beam

•Perfect spectrometer for study of sea quarks

•Only small modifications required

•Pol target work aligns well with schedule

E906 Setup Now



Principle of Dynamic Nuclear Polarization:

Polarization P

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

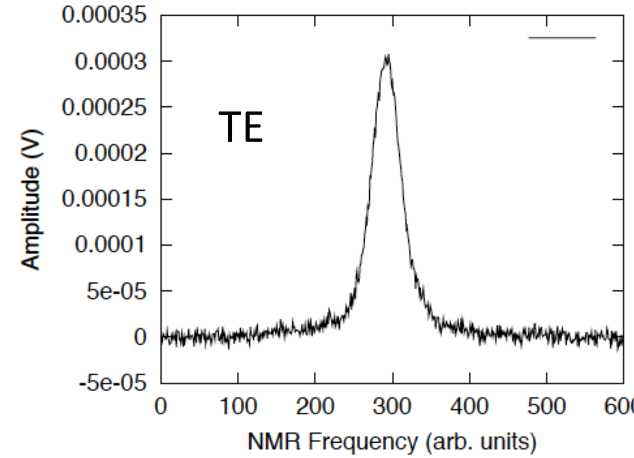
Thermal Equilibrium TE

TE: T=1K, H=5T

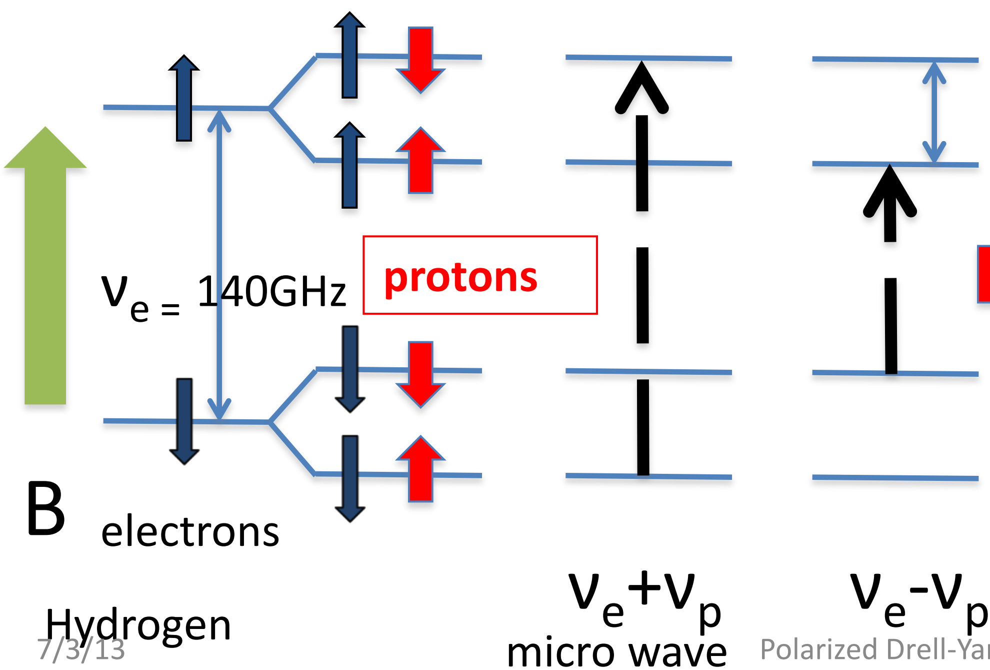
P_e = .998

P_p =.005

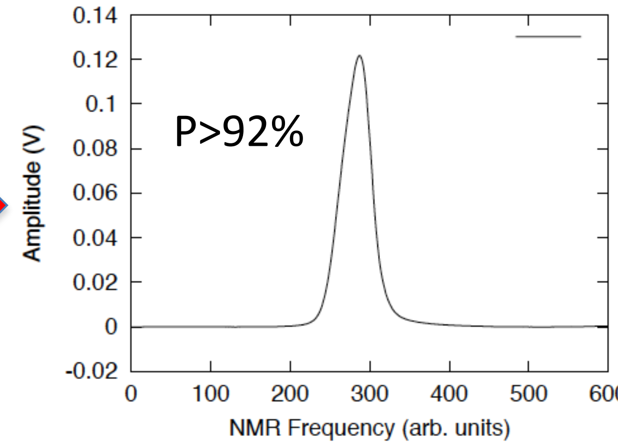
TE measurement



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)



Polarization Measurement



Keith et al. NIM A 501 (2003), 327 JLAB

Well established technology: SLAC, JLAB, PSI …

The Polarized Target System (UVa/SLAC/JLab)

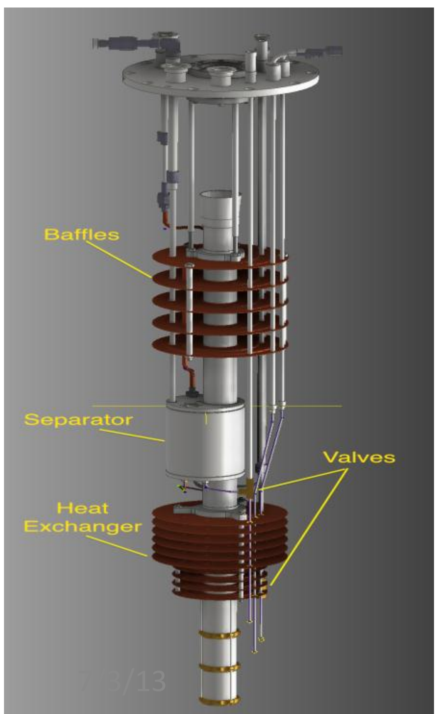
Magnet from LANL

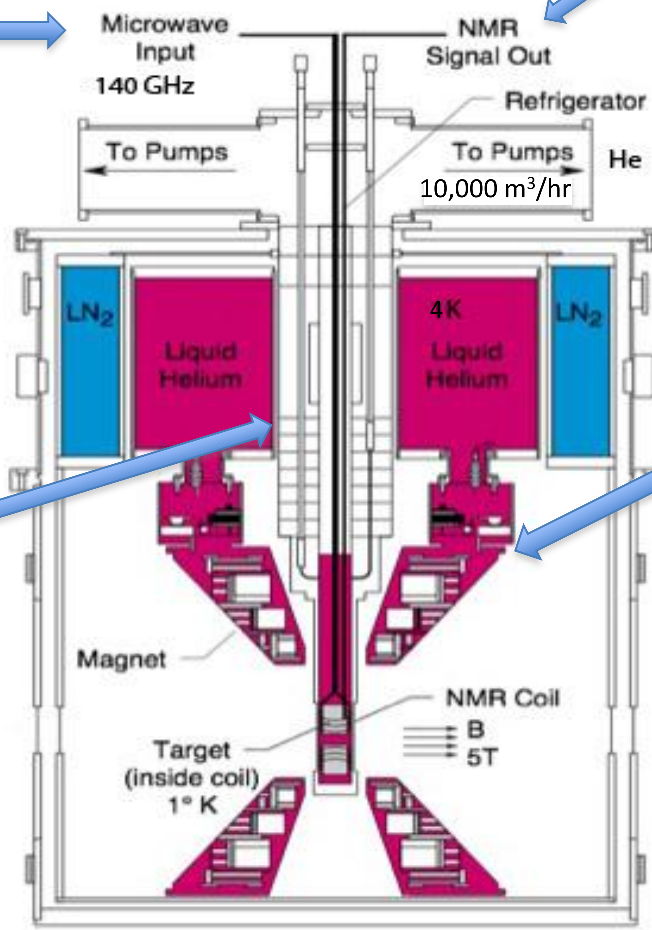
Measure polarization

Microwave: Induces electron spin flips

- Tube + Power equip:

Cryostat: UVa

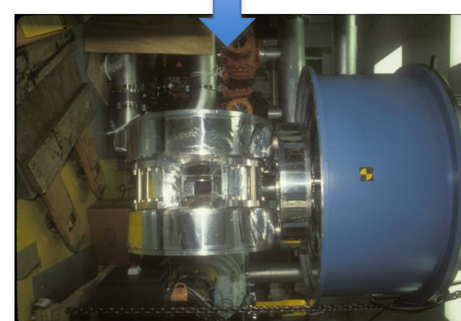




Roots pump system used to pump on ^{4}He vapor to reach 1K

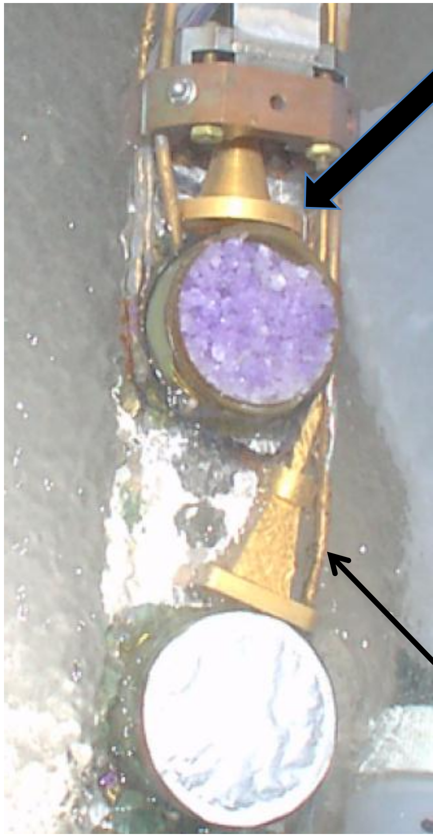
Superconducting Coils for Magnet: 5T

Rotation needed



Target material: frozen NH_3

Irradiation @ NIST



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

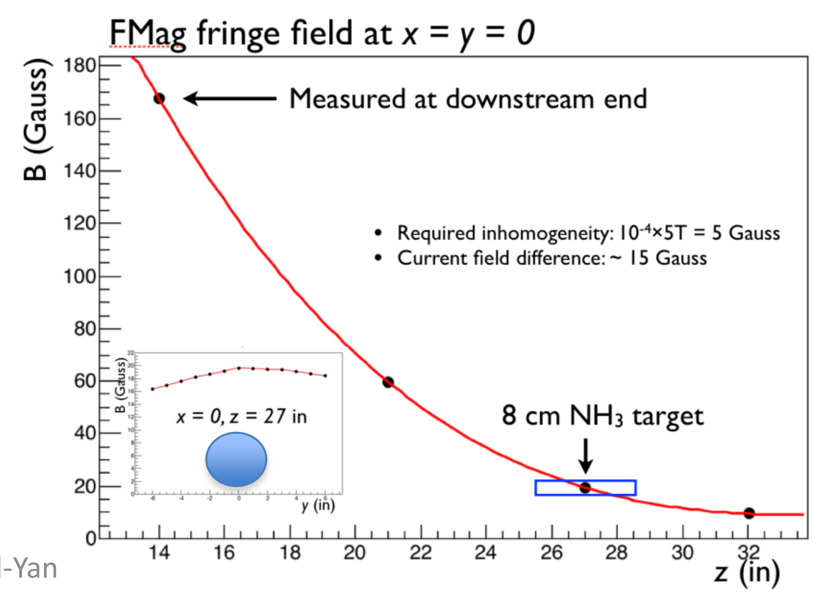
μ-wave horn

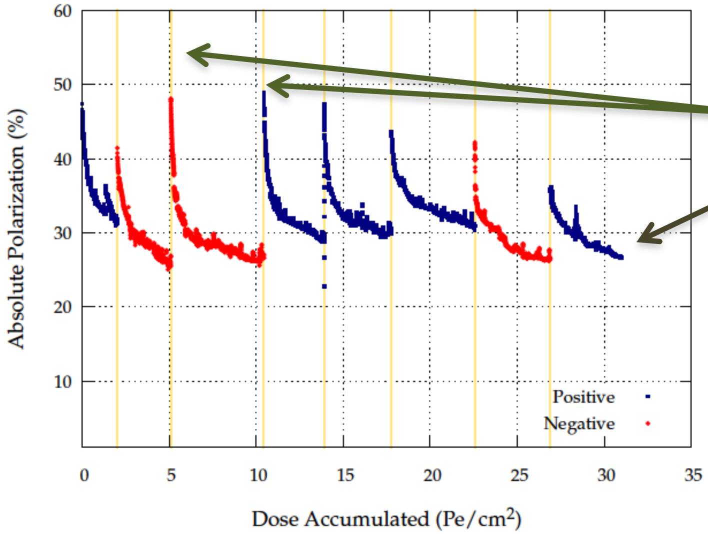
JLAB target

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

Requirements and Running conditions:

- $\frac{d\vec{B}}{B} \leqslant 10^{-4}$ 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 m³/hr** pumping capacity





Beam effects on polarized Target

- 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

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

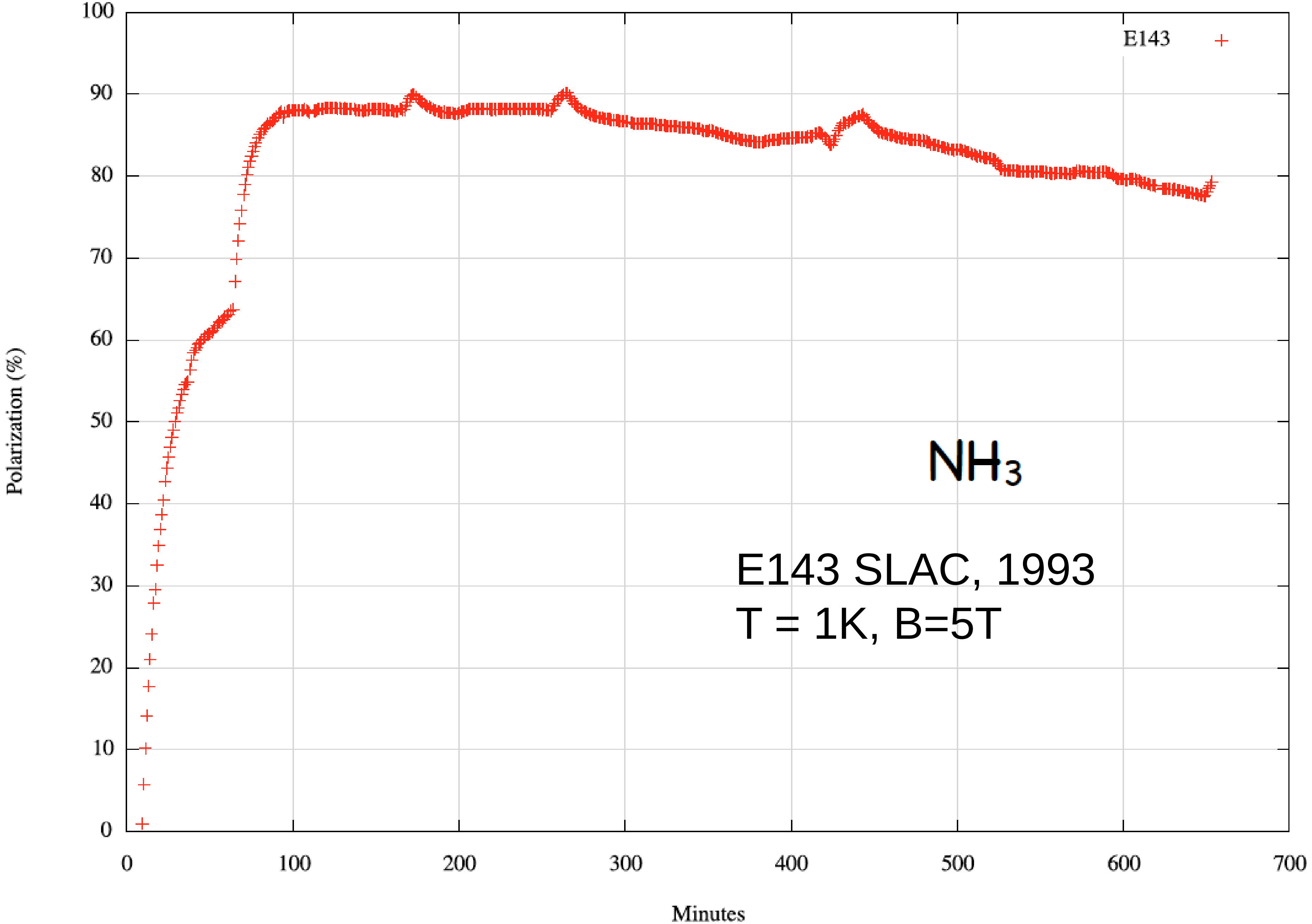
Systematics control:

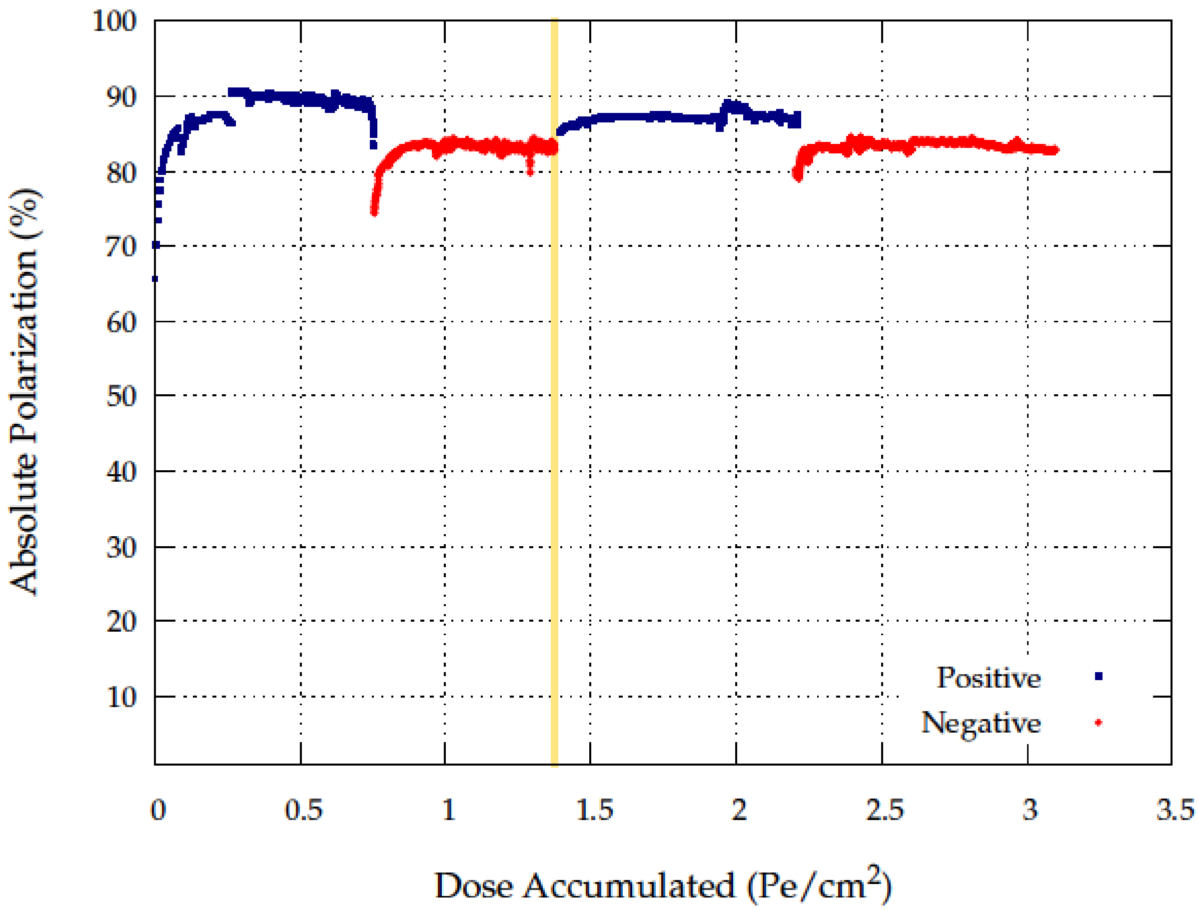
- Reverse Polarization Direction once a day
- Reverse magnet field of Fmag and Kmag every two days
- Reverse magnetic field of target magnet every target replacement
- Background measurements every shift with target out

Systematic errors:

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

•ΔA/A ~ 4% (Dominant effect polarization measurement)


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



Hall A G2p target NIM 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.

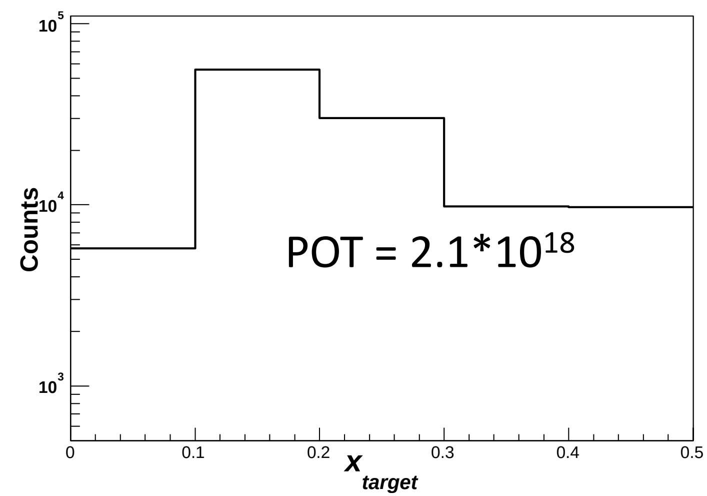
Yield and Beam Time Request

Yield Calculation
- beam: 1 *10^{13} p/spill
- Target : 3.1 *10^{24} N/cm^2
- One year 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	<x_{target}>	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

$$t^{-1}\ \mu\ r\,(f \cdot P)^2$$

- 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

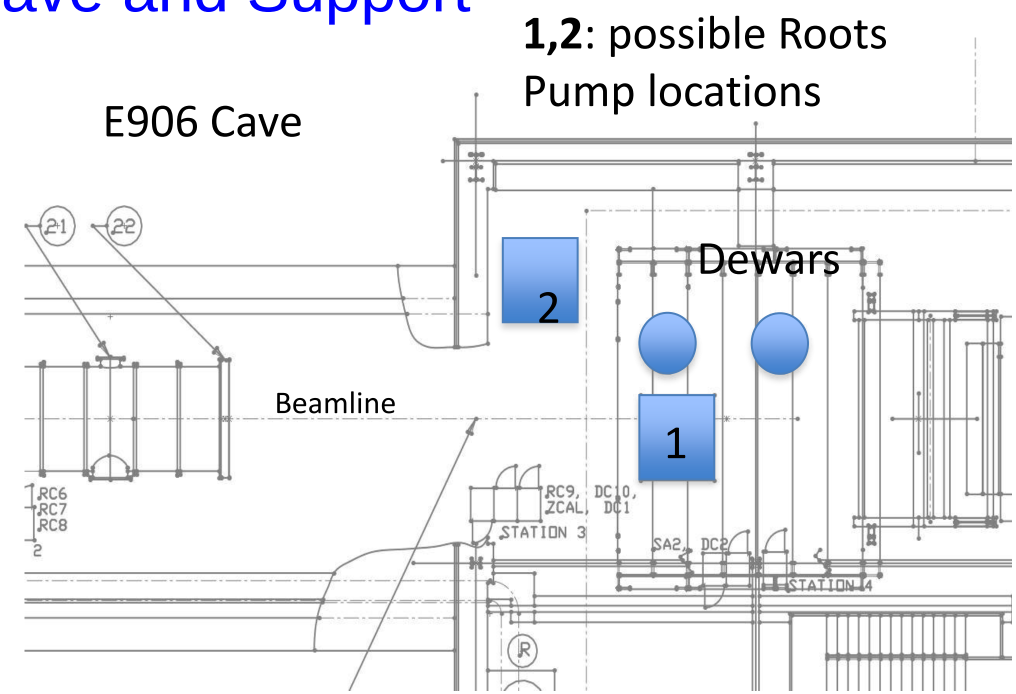
- running and maintaining system
- According to A. Klebaner too expensive

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



LANL contribution through LDRD:

1.Refrigerator + Instrumentation 240K

2.Pumps 250K (ROOTS and Compressor)

3.µ-wave 200K (already have tube)

4.NMR 120K

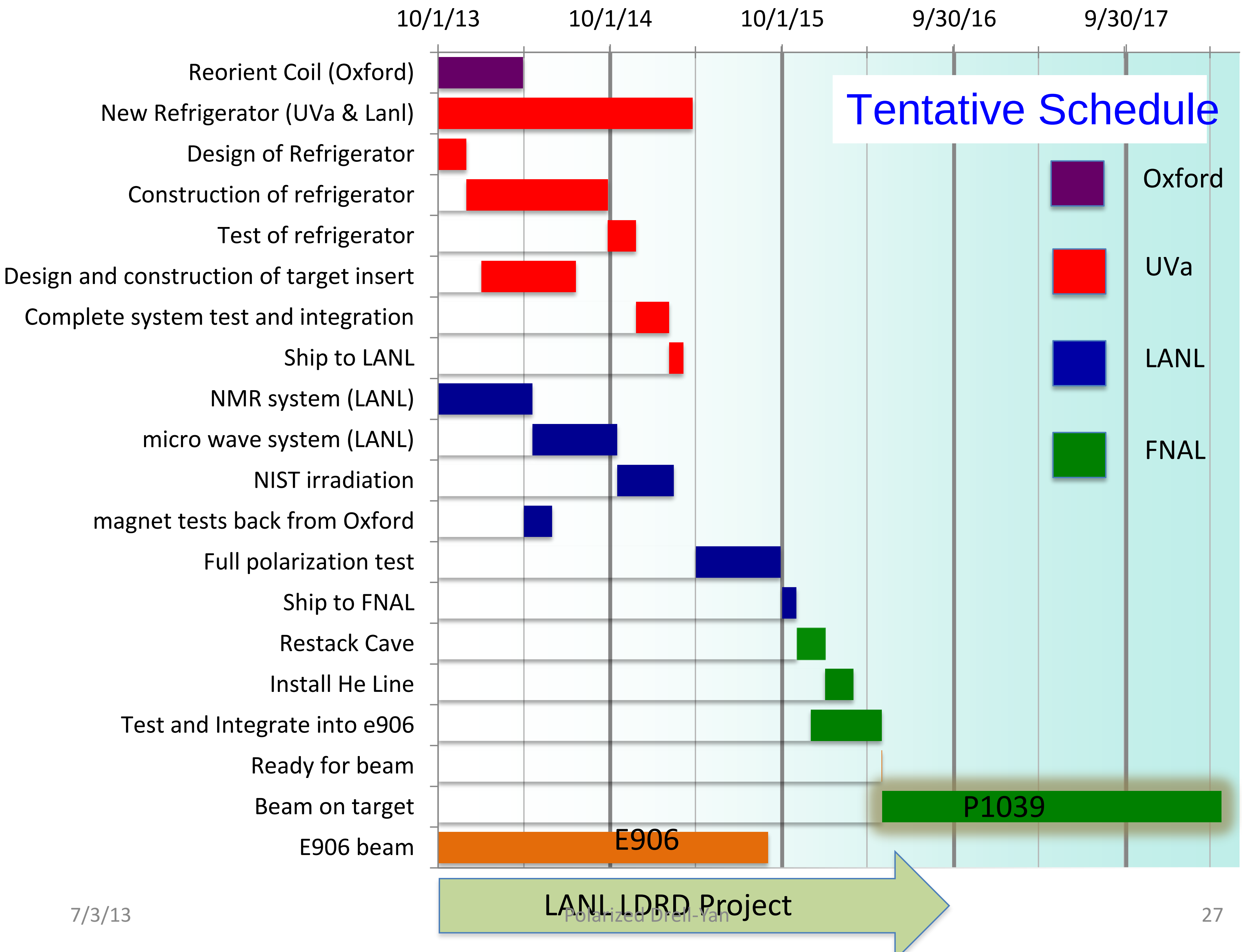
5.Transferlines and plumbing 90K

6.NIST irradiation 80K

7.Oxford changes 80K

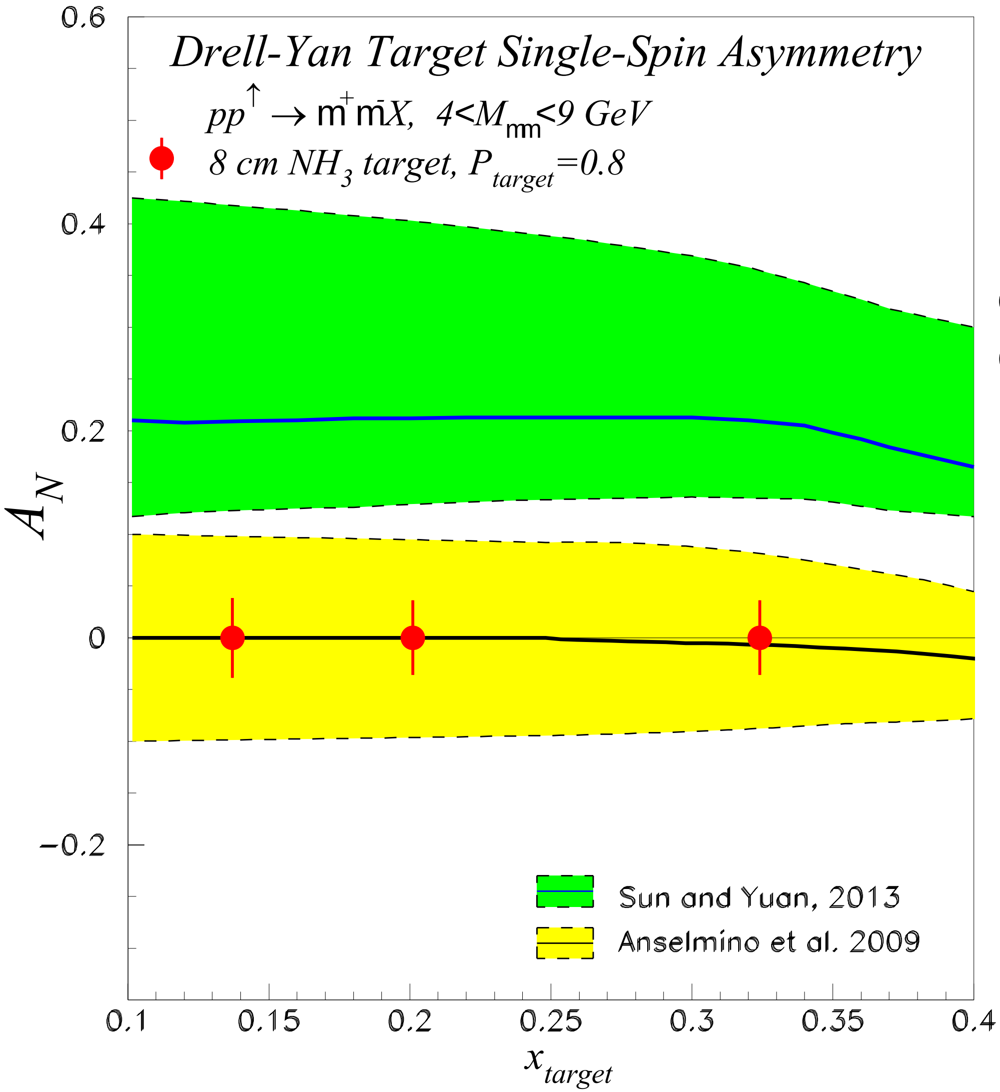
8.Magnet + power supplies 1.2 M$

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

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

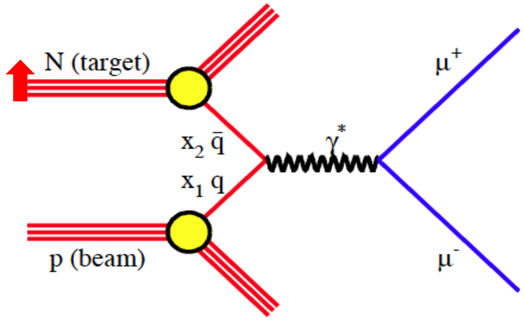
If $A_N = 0$:

- $L_{ubar}=0$, 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 :
L = 1.4 *10^{43} /cm^2 ⇔ POT = 2.1*10^{18}

Request for two calendar years of beam time

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.**

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

$$A_N = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \stackrel{?}{\neq} 0 \qquad A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

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

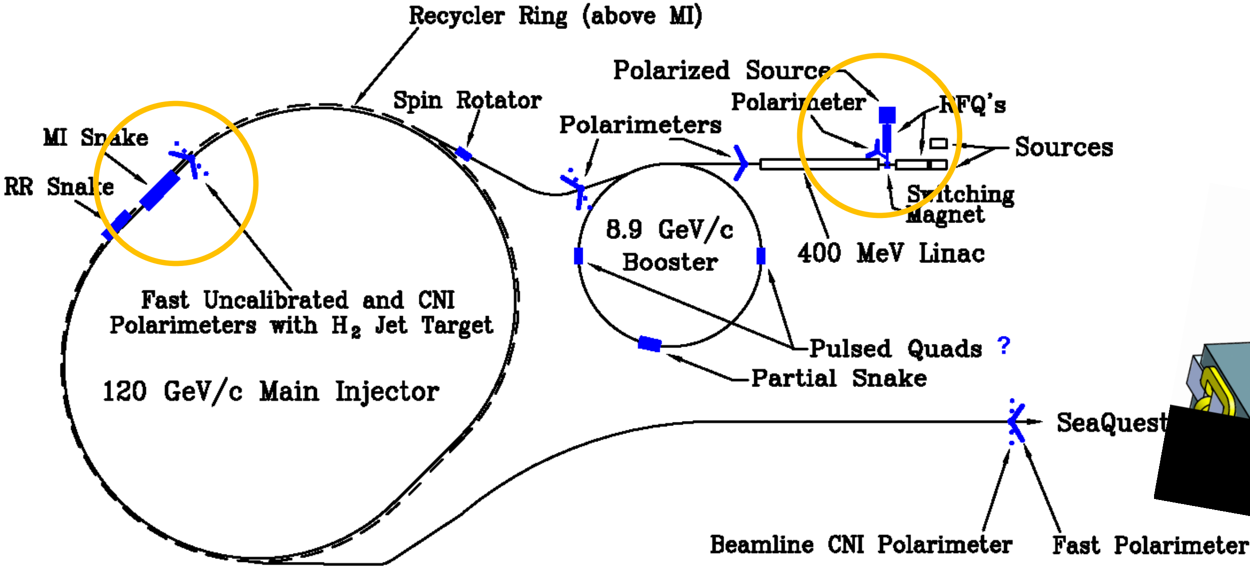
SeaQuest(E906), P-1027 and P-1039 using a Similar Setup

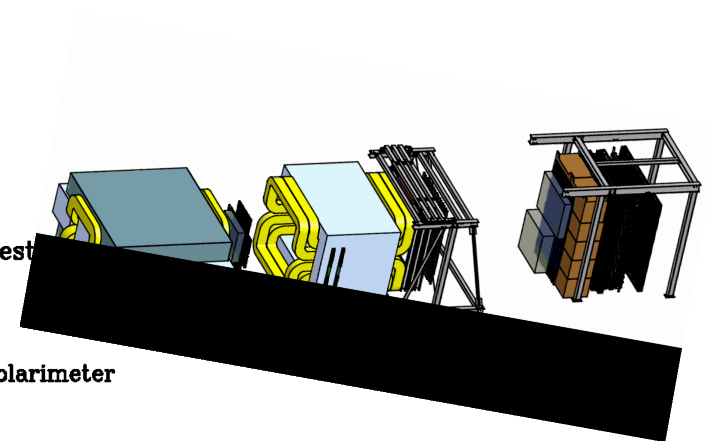
	Beam Pol.	Target Pol.	Favored Quarks	Physics Goal
SeaQuest $pN \to \mu^+\mu^- X$	✕	✕	-	Unploarized sea quark flavor asymmetry dbar/ubar.
P-1027 $p^\uparrow p \to \mu^+\mu^- X$	✔	✕	Valence quark	Sign change and size of Sivers distribution for valence quark
P-1039 $pp^\uparrow \to \mu^+\mu^- X$	✕	✔	Sea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

Polarized Beam Drell-Yan at Fermilab Main Injector

P-1027 Stage-I approved

- Polarize Beam in Main Injector & use SeaQuest di-muon spectrometer
  - measure Sivers asymmetry





- SeaQuest di-muon Spectrometer
  - fixed target experiment, optimized for Drell-Yan
  - luminosity: $L_{av} = 3.4 \times 10^{35}$ /cm²/s
    → $I_{av} = 1.6 \times 10^{11}$ p/s (=26 nA) / $N_p = 2.1 \times 10^{24}$ /cm²
  - approved for 2-3 years of running: 3.4×10^{18} pot
  - by 2015: fully understood, ready to take pol. beam

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Univ. of Michigan
May 2013.

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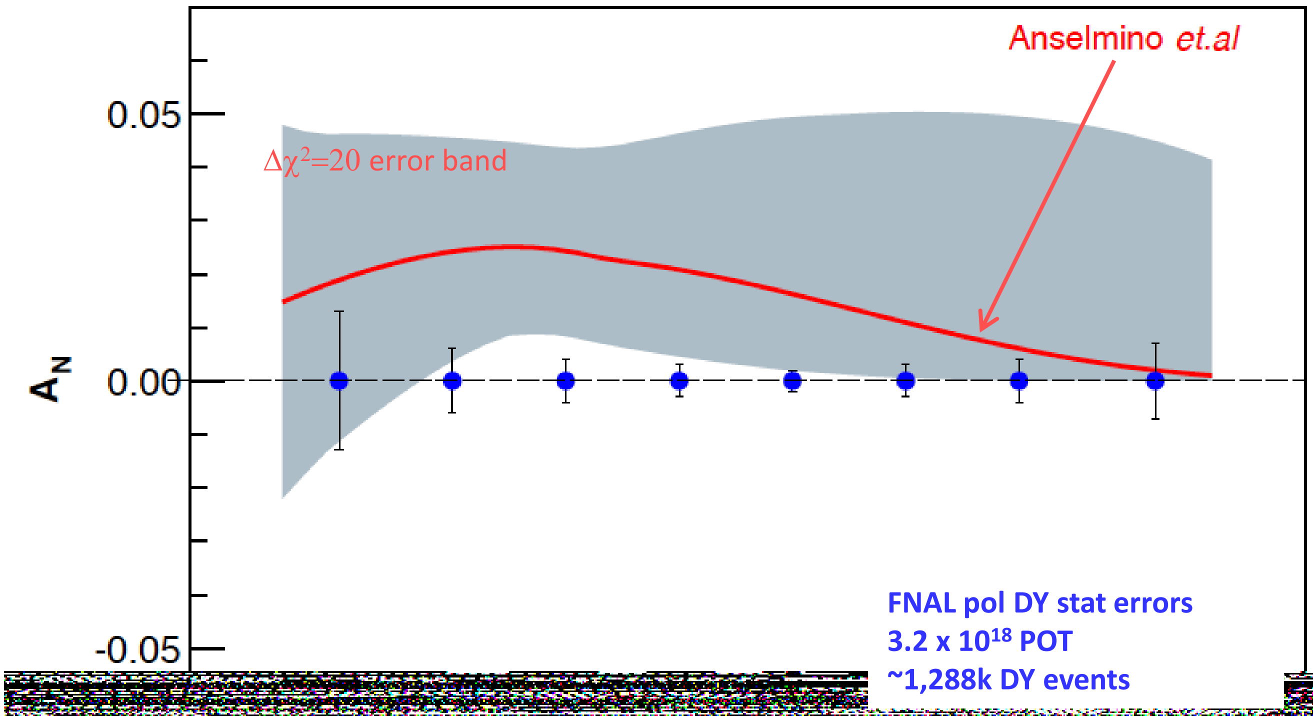
Univ. of Michigan
May 2013.

Experimental Sensitivity

- luminosity: $L_{av} = 2 \times 10^{35}$ (10% of available beam time: I_{av} = 15 nA)
- 3.2 x 10^{18} total protons for 5 x 10^5 min: (= 2 yrs at 50% efficiency) with P_b = 70%



Note:

$$A_N = \frac{2}{p} A_{TU}^{\sin f_b}$$

- Can measure not only sign, but also the size & maybe shape of the Sivers function !

The Path to a polarized Main Injector

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May 2013.

Stage 1 approval from Fermilab: 14-November-2012

- Detailed machine design and costing using 1 snake in MI
  - Spin@Fermi collaboration provide design
  - Fermilab (AD) does verification & costing

- Collaboration with A.S. Belov at INR and Dubna to develop polarized source

- Develop proposal to DoE NP/HEP to polarize the Main Injector
  - Cost to polarize Main Injector $10M
    - ⟶ includes 15% project management & 50% contingency
  - secure funding to
    - ⟶ do detailed design: $200k/yr (short-term)
    - ⟶ implement modifications to MI: $10M (longer-term)
    - ⟶ conversations with DoE NP & HEP, NSF NP have started

In the longer term future, if we have both polarized beam and polarized target, Drell-Yan double-spin asymmetry can provide accesses to sea quark's polarization (through A_{LL}) and transverse spin (transversity, through A_{TT})

We define Drell-Yan longitudinally polarized beam-target double-spin asymmetry A_{LL} as:

i.e, the ratio of the difference over the sum (or asymmetry) between the spin-aligned and spin-anti-aligned Drell-Yan cross sections, at the Leading Order, we have:

if anti-quarks carry no spin ➔

FNAL "prospected data" vs. theory predictions

NH_3 Target

^3He Target

if anti-quarks carry no spin ➔

Chiral Quark Soliton Model: Wakamatsu, 2010.

BBS statistical model: Soffer et al 2004.

Translate into Δubar/ubar, Δdbar/dbar - Fermilab kinematics

Chiral Quark Soliton Model: Wakamatsu, 2010.

BBS statistical model: Soffer et al 2004.

A_{TT} to Access Transversity

where θ is the polar angle of either lepton in the rest frame of the virtual photon, and ϕ is the azimuthal angle between the direction of the polarization and the normal to the plane of the di-lepton decay.

$\langle\cos(2\phi)\rangle \approx 2/\pi$, i.e. almost cover all DY azimuthal angles.

if cover all θ, peak at 1.0 for $\theta=90^o$.

Lacking knowledge on transversity, we took the Soffer (positivity) bounds for both quark and anti-quark, i.e:

We can also try Anselmino group's fits results of quark transversity, later.

A_{TT} FNAL "prospected data" vs. theory predictions

NH_3 Target

^3He Target

Backup slides

JLab Hall A E08-027

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

- *The spokespeople of E1027 and P1039 feel that E1027 should run first in terms of physics priority. Determining the change of sign of the Sivers function provides a rigorous test of QCD. This test is essential to interprete polarized Drell-Yan data in terms of orbital angular momentum. In addition it is one of the DOE milestones for hadronic physics. After a successful completion of E1027, we would then continue with P1039 and measure the sea quark Sivers asymmetry.*

  Should the project to polarize the proton beam in the Main Injector get delayed well beyond the end of E906, we would prefer to install the polarized target and measure the sea quark Sivers asymmetry first.
  P1039 is unique in that it is the only Drell-Yan experiment foreseen to probe the angular momentum of the sea quarks. 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 E1027 cryogenic target could be easily swapped in after P1039.

- **Wolfgan Lorenzon, Paul Reimer, Xiaodong Jiang, Andi Klein**