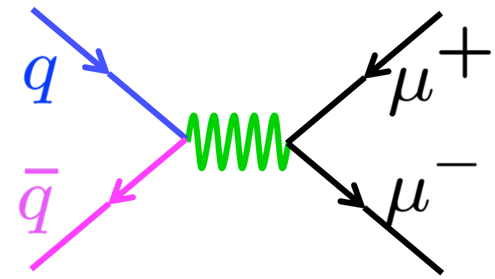
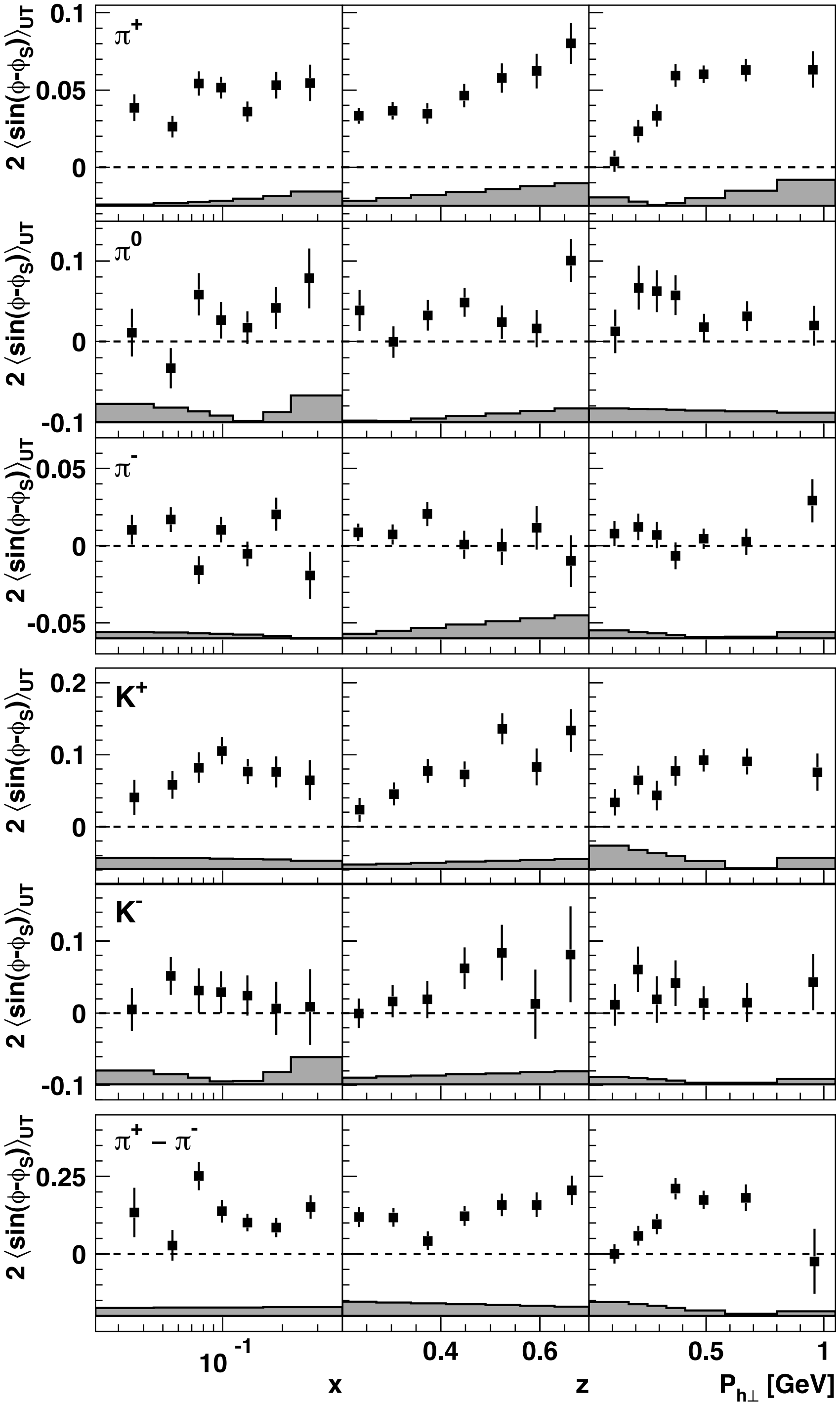


Polarized Target Drell-Yan at FNAL as E906 Follow-Up?

Xiaodong Jiang

Los Alamos National Laboratory

Los Alamos NATIONAL LABORATORY EST. 1943

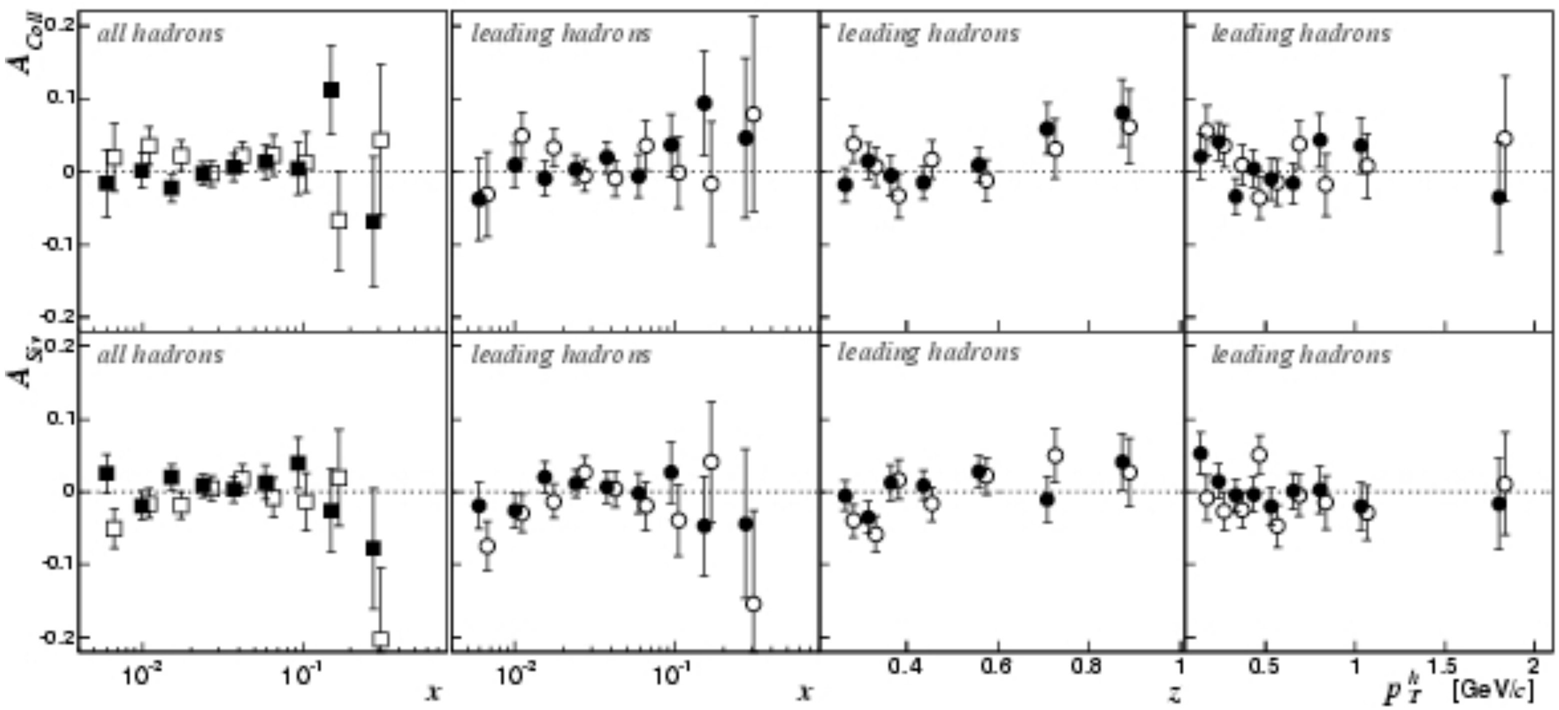


Hermes Proton: Sivers Asymmetry

$$\sigma(\phi,\phi_S) = \sigma_{UU}\{1 + 2\langle\cos\phi\rangle_{UU}\cos\phi + 2\langle\cos 2\phi\rangle_{UU}\cos 2\phi$$
$$+|S_T|[2\langle\sin(\phi-\phi_S)\rangle_{UT}\sin(\phi-\phi_S) + 2\langle\sin(\phi+\phi_S)\rangle_{UT}\sin(\phi+\phi_S) + \ldots]\}$$

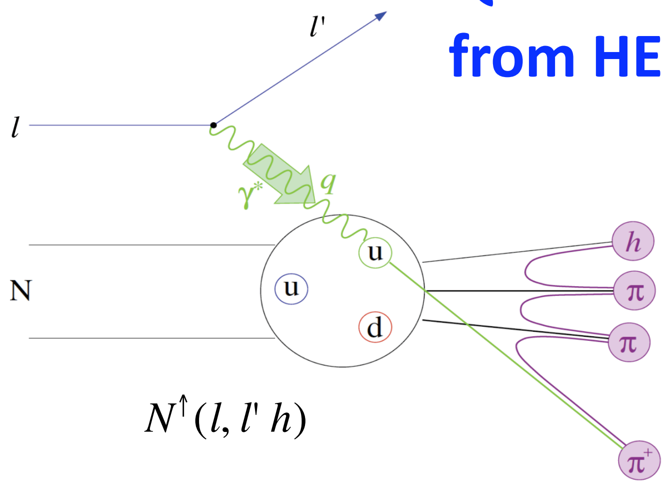
$$2\langle\sin(\phi-\phi_S)\rangle_{UT} = -\frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x,p_T^2)\otimes D_1^q(z,k_T^2)}{\sum_q e_q^2 f^q(x)\otimes D_1^q(z)}$$

COMPASS-2006: small A_{UT} on deuteron (p+n)



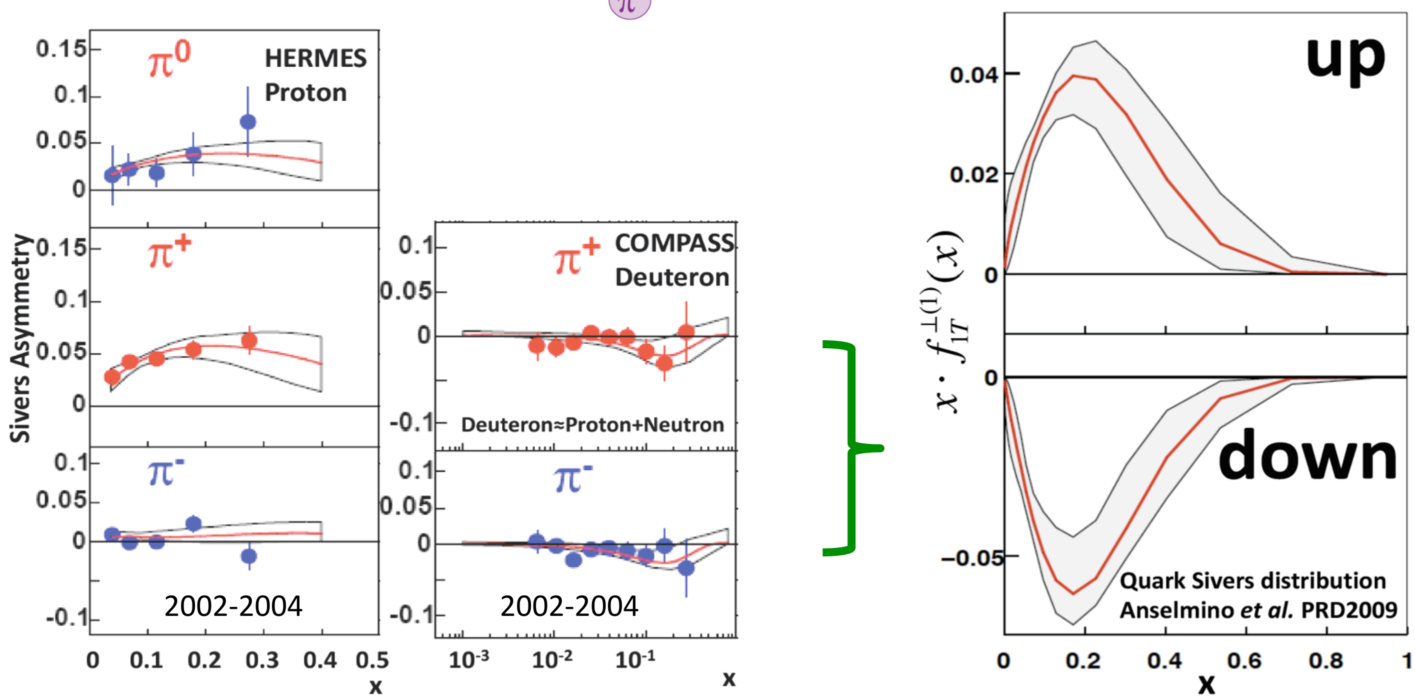
- Neutron SSA must have strong flavor dependence, in both Collins and Sivers.
- d-quark makes a large and opposite contribution compared to u-quark.

Quark Sivers distributions
from HERMES Proton and COMPASS Deutron data



Forbidden before 2002 quark Sivers distribution $f_{1T}^{\perp q}(x, k_T)$

- Naive T-odd, not allowed for collinear quarks. Transverse Mom. Dep. parton distributions (TMDs).
- Imaginary piece of interference L_q=0 ✖ L_q=1 quark wave functions.
- Gauge invariance of QCD requires Sivers function to flip sign between semi-inclusive DIS and Drell-Yan.



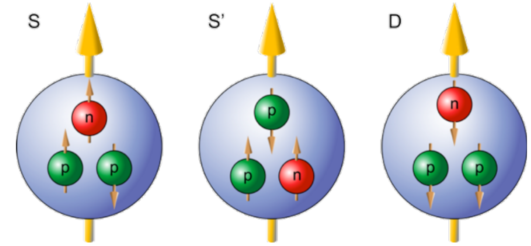
up-quarks favor left (L_u>0),

down-quarks favor right (L_d<0).

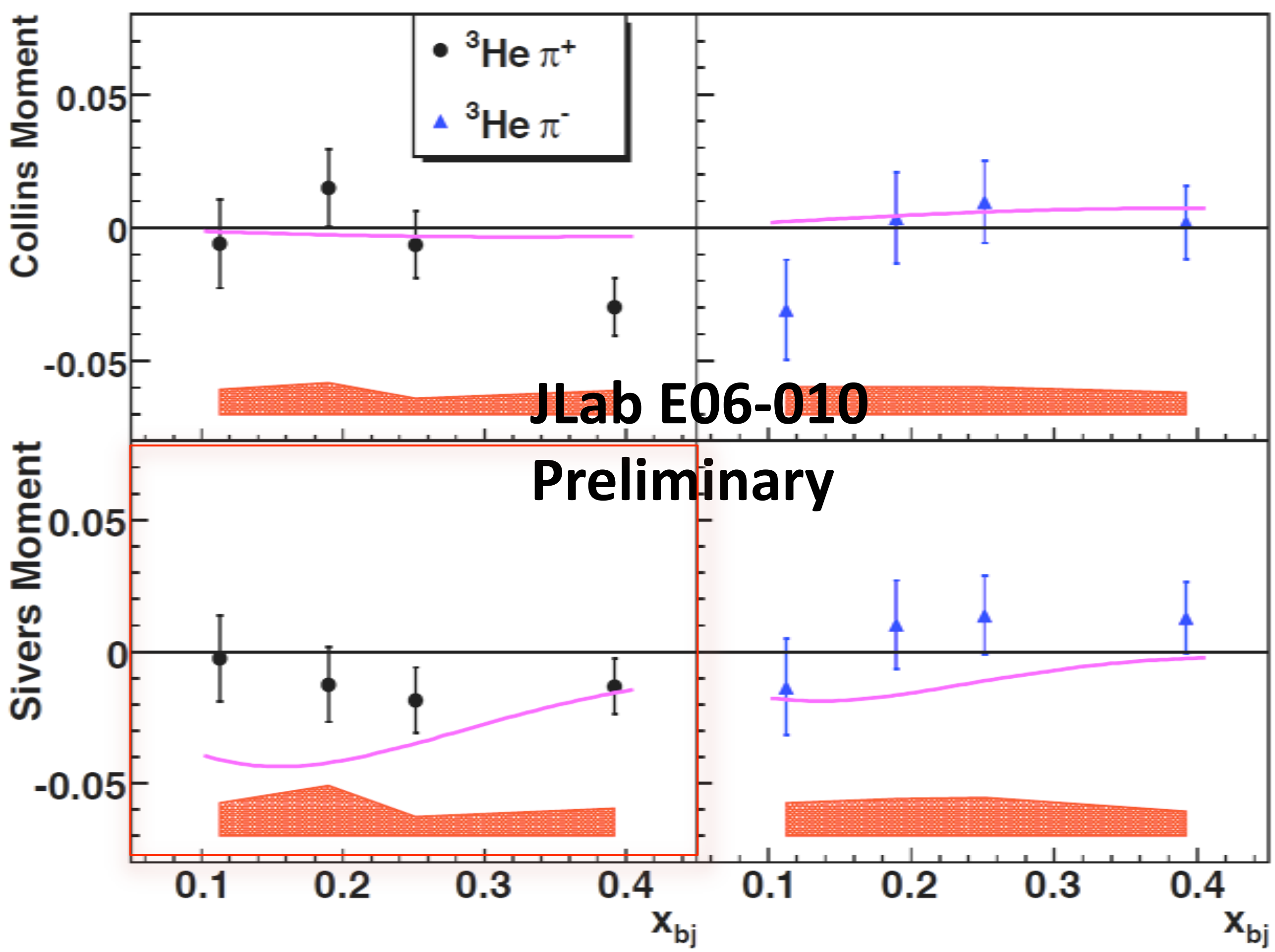
^{3}He Target Single-Spin Asymmetry

$$^3\mathrm{He}^{\uparrow}(e, e'h)$$

$$h = \pi^{+/-}, K^{+/-}$$



~87% ~8% ~1.5%



To extract information on neutron, one would assume:

$$^3\mathrm{He}^{\uparrow} = 0.865 \cdot \mathrm{n}^{\uparrow} - 2 \times 0.028 \cdot \mathrm{p}^{\uparrow}$$

^{3}He Collins SSA are not large.

^{3}He Sivers SSA are smaller than expected.
(d-quark Sivers ~1/2 that of u-quark.)

Could Sea-quark Sivers functions be none-zero?

- Transverse momentum sum rule:

$$\sum_{q=u,d,\bar{u},\bar{d}} f_{1T}^{\perp(1)q}(x) + f_{1T}^{\perp(1)g}(x) = 0$$

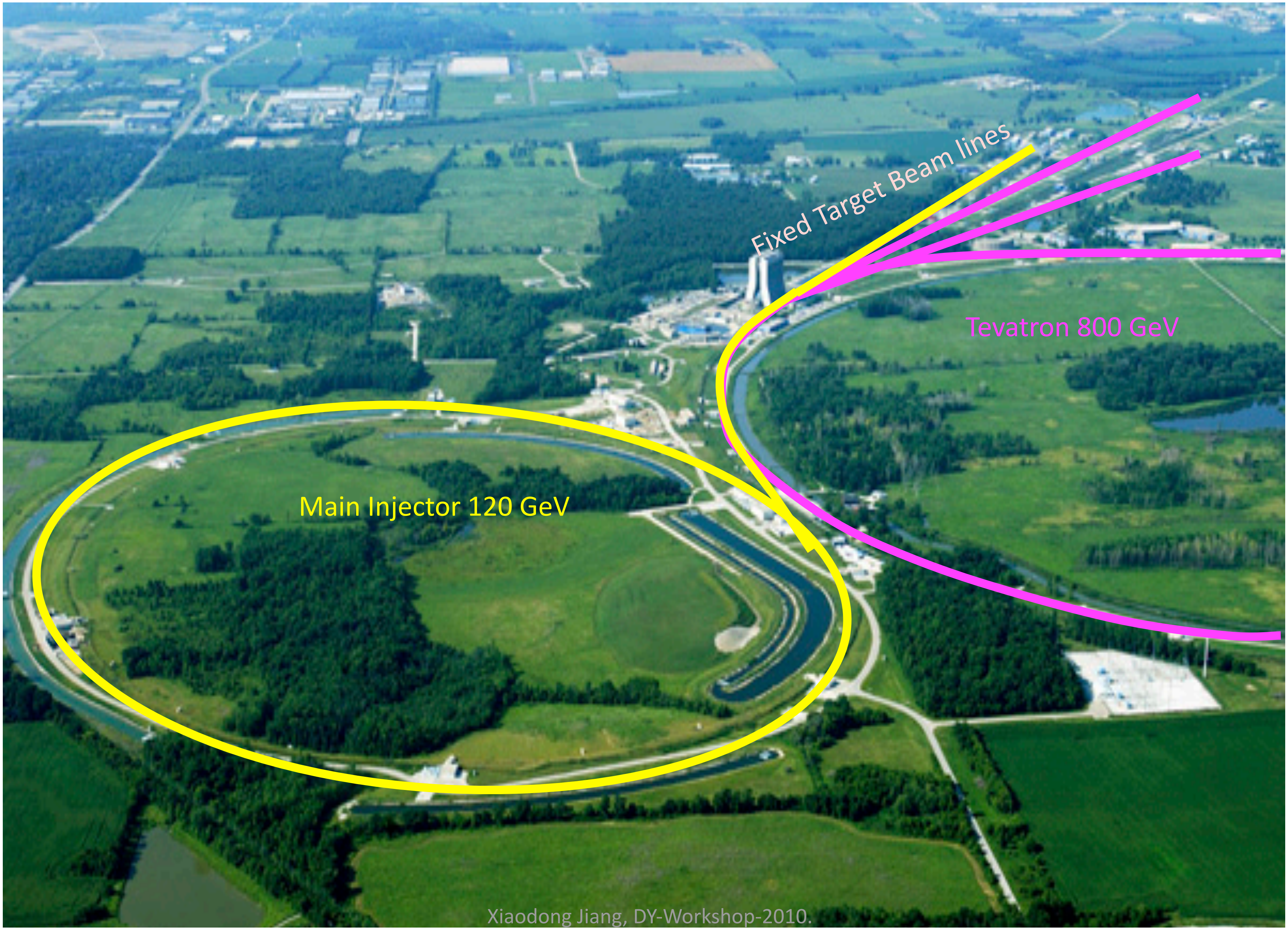
- Now that u-quark and d-quark Sivers functions are not canceling each other, there's room for considerable size sea quark and gluon Sivers functions.
- From Lattice-QCD. Sea quark's angular momentum could be not small (Keh-Fei Liu, 2010).

Sea quark Sivers function

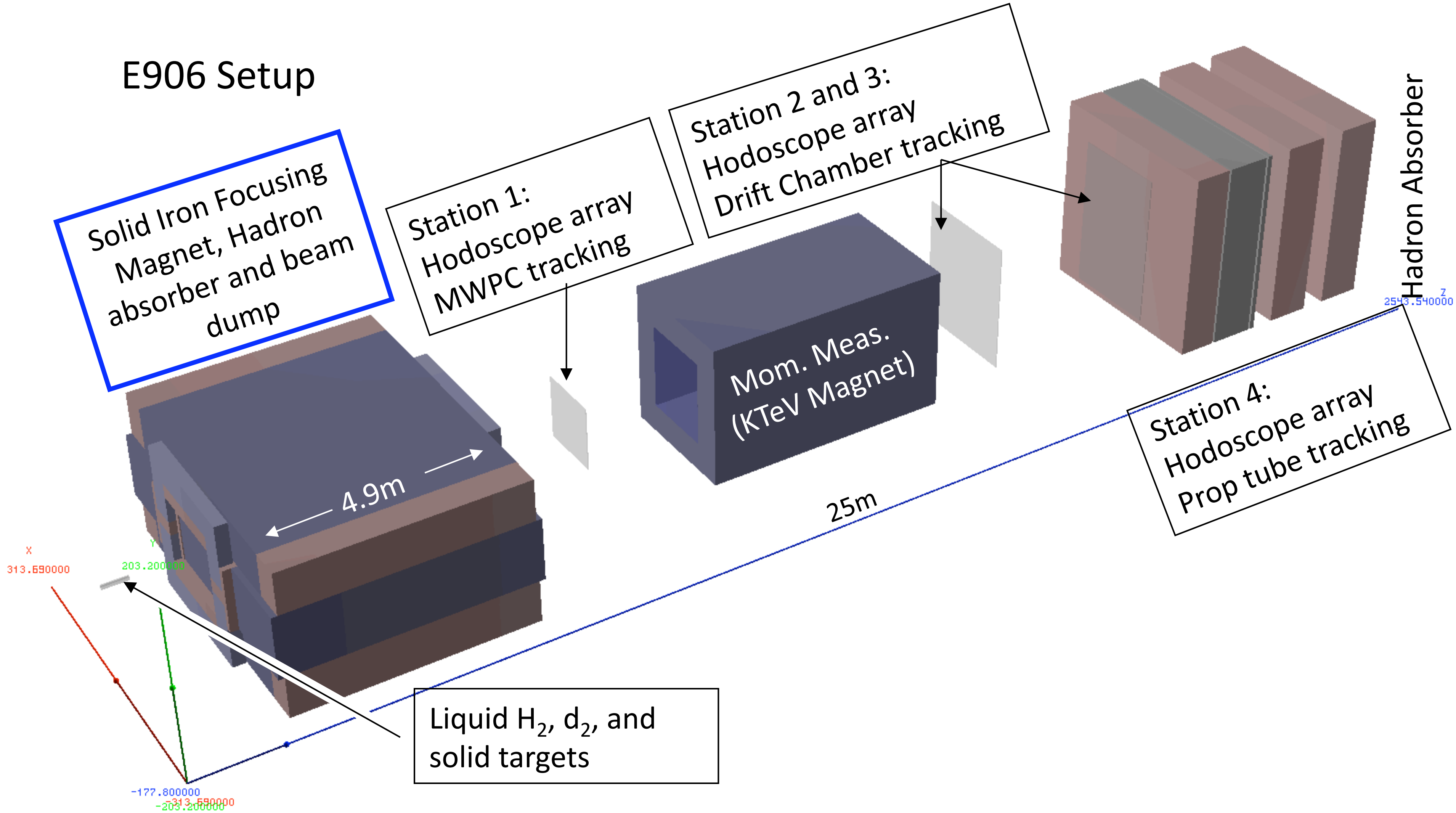
- Existing SIDIS data do not constrain sea quark Sivers function.
- Polarized Drell-Yan single spin asymmetry provides access to ratio of quark Sivers function to quark density, i.e. in the high x_F region, target DY-SSA:

$$in\ pp^{\uparrow} \rightarrow \mu^{+}\mu^{-}X, \quad A_N^{DY}(x_F) \propto \frac{f_{1T}^{\perp\bar{u}}(x_t)}{f_1^{\bar{u}}(x_t)}, \quad when\, x_b > x_t.\ (x_F = x_{beam} - x_{target}).$$

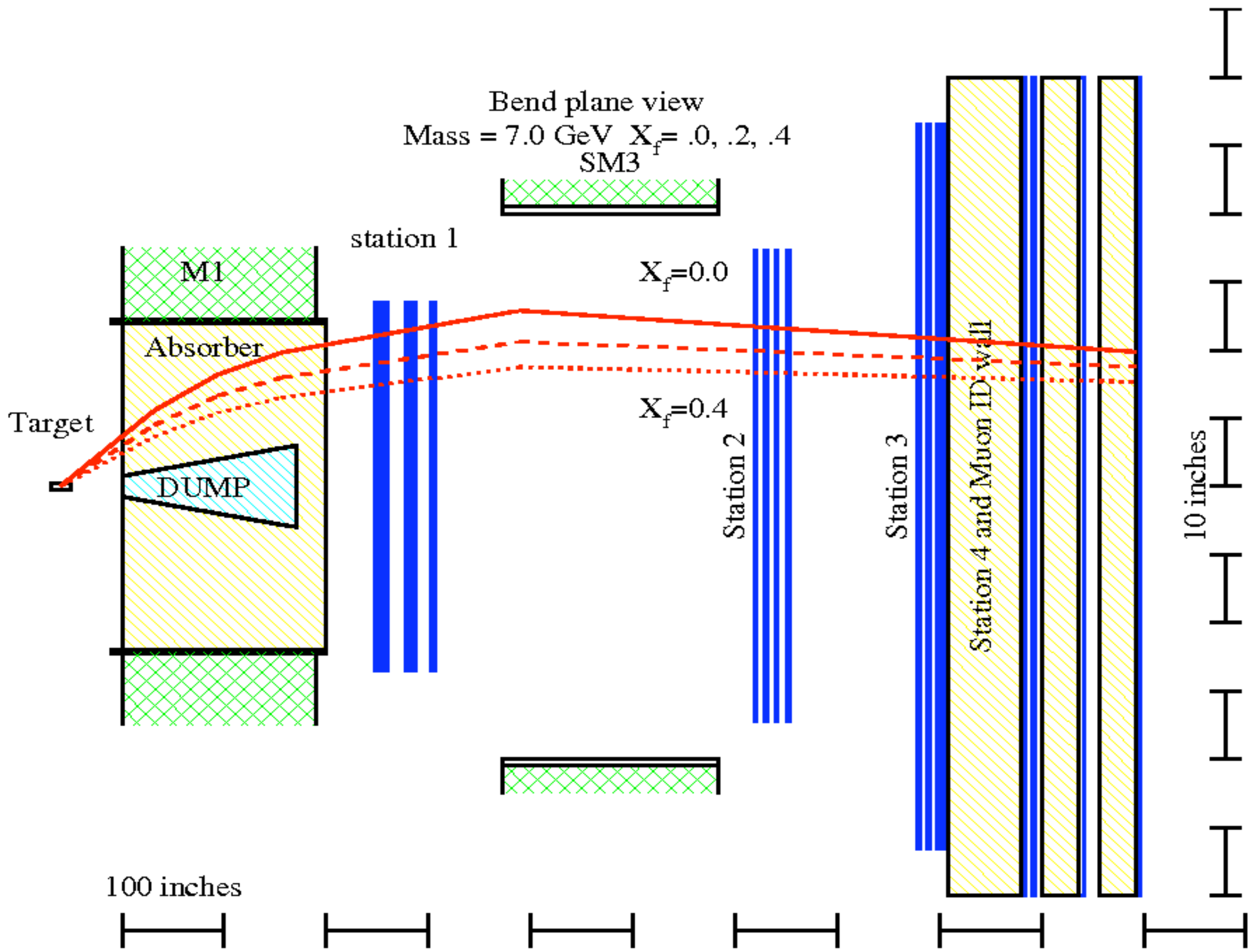
A preliminary feasibility study of a polarized target Drell-Yan measurement as a follow-up of FNAL-E906.
(Ming Liu and Xiaodong Jiang, 2010).


Fixed Target Beam lines
Tevatron 800 GeV
Main Injector 120 GeV
Xiaodong Jiang, DY-Workshop-2010.

E906 Setup

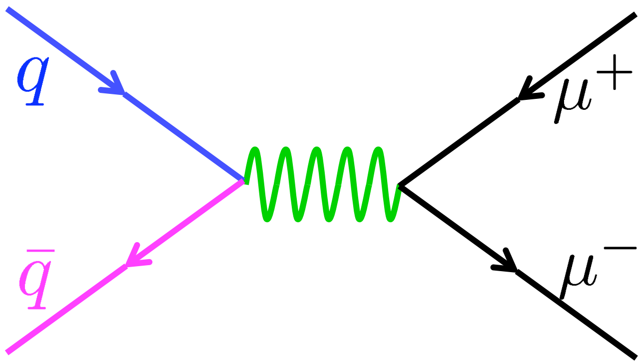


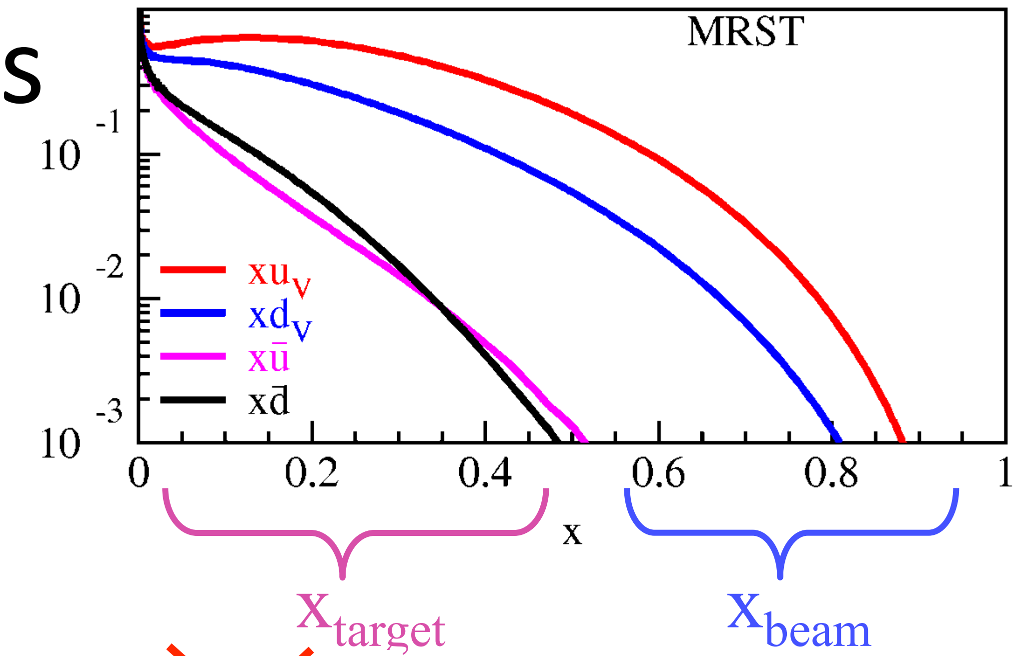
Xiaodong Jiang, DY-Workshop-2010.



Xiaodong Jiang, DY-Workshop-2010.

E906 Kinematics

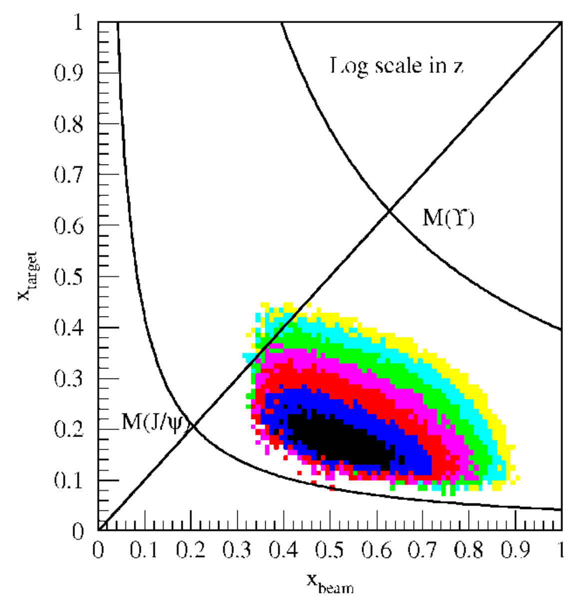




$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\sum e^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

Detector acceptance chooses x_{target} and x_{beam}.

- Fixed target → high $x_F = x_{beam} - x_{target}$
- *Beam nucleon provides valence quarks at high-x.*
- *Target nucleon provides sea anti-quarks at low/intermediate-x.*



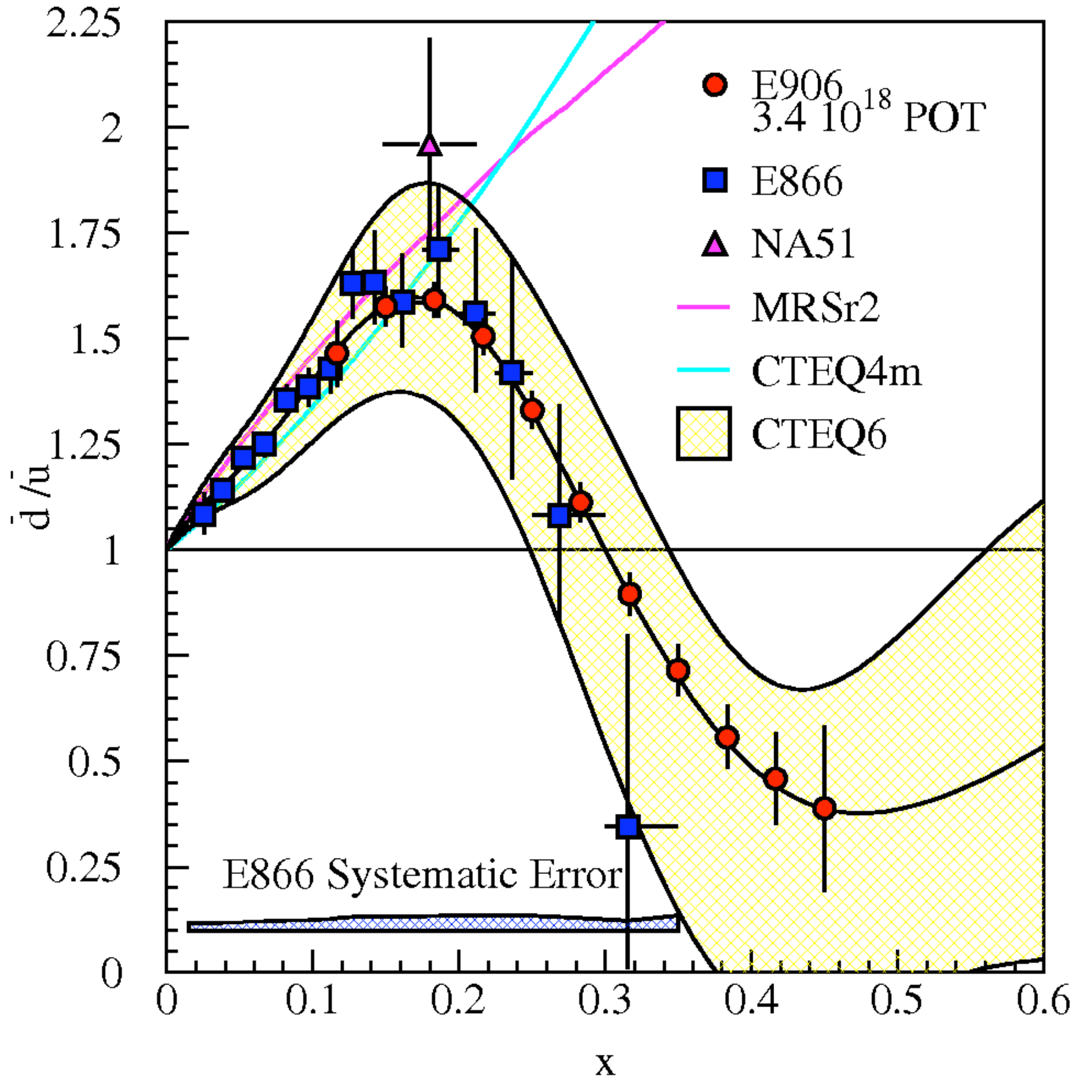
$$\frac{\sigma^{pd}}{2\sigma^{pp}}\Big|_{x1 >> x2} = \frac{1}{2}\left[\frac{1+\frac{d(x1)}{4u(x1)}}{1+\frac{d(x1)}{4u(x1)}\frac{\bar{d}(x2)}{\bar{u}(x2)}}\right]\left[1+\frac{\bar{d}(x2)}{\bar{u}(x2)}\right] \approx \frac{1}{2}\left[1+\frac{\bar{d}(x2)}{\bar{u}(x2)}\right]$$

Xiaodong Jiang, DY-Workshop-2010.

E906 measures ratio of Drell-Yan cross sections

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

On un-polarized proton and deuteron targets.



NH_3 target, assuming luminosity:

- Beam: 10^{19} proton (4 runs, 6 months each), 2×E906 total.
  (10^{13} proton/minute, 5 sec slow extraction. Average current ≈27 nA)
- Pol. target: 10cm NH_3, 3×JLab-Hall-C. Packing factor:0.7.
  (ρ*t≈9.2 g/cm^2). Dilution factor ≈0.2. Target polarization: 80%.
- Beam heating power: 0.5 watt (≈2×JLab-Hall-C).
- Instantaneous rates ≈ 2.5×E906 pp.
  (E906 LH_2 target ρ*t=3.54 g/cm^2)

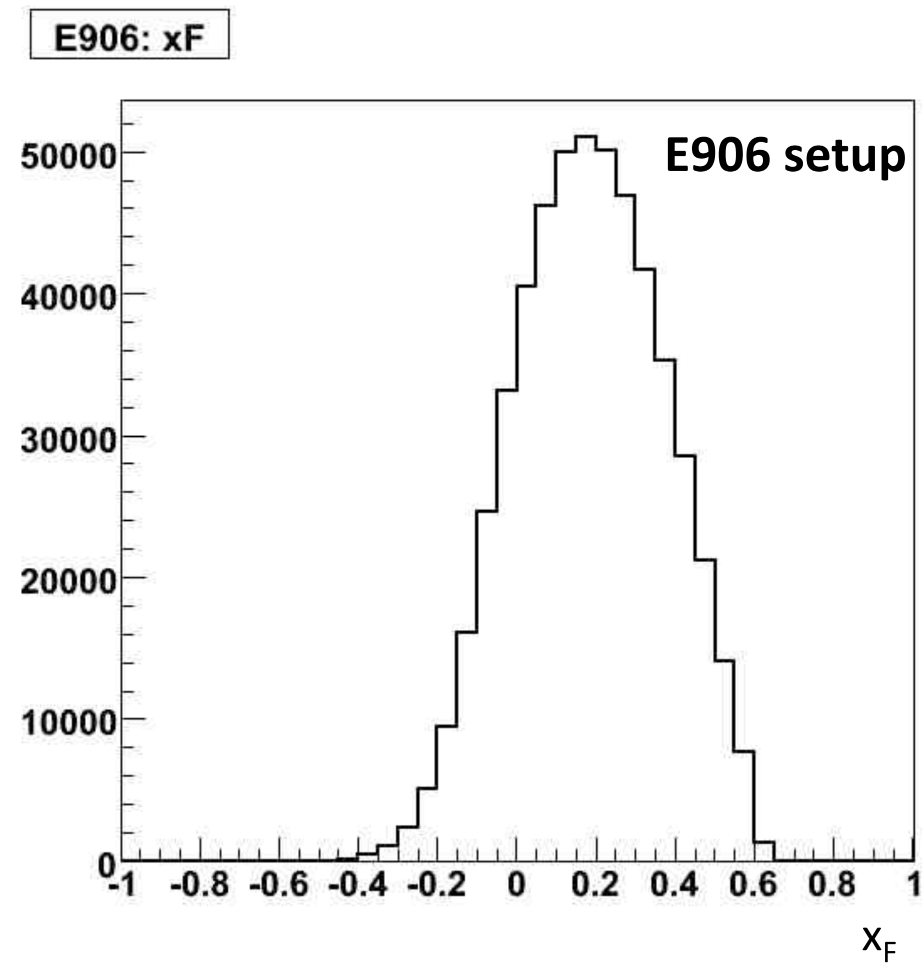
$$\int L \cdot dt = 4 \times 10^{43}\ cm^{-2},\ \ 4 \times 10^{10}\, pb^{-1}\ \ all\ \ nucleon, or\, 1.6 \times 10^{9}\, pb^{-1}\ \ pol.\ pp.$$

$$or\ \ \langle L \rangle_{total} = 3.3 \times 10^{35}\ cm^{-2} s^{-1}.$$

For the same spectrometer and detector set up as in E906,
number of DY events ≈ 8×E906-pp.

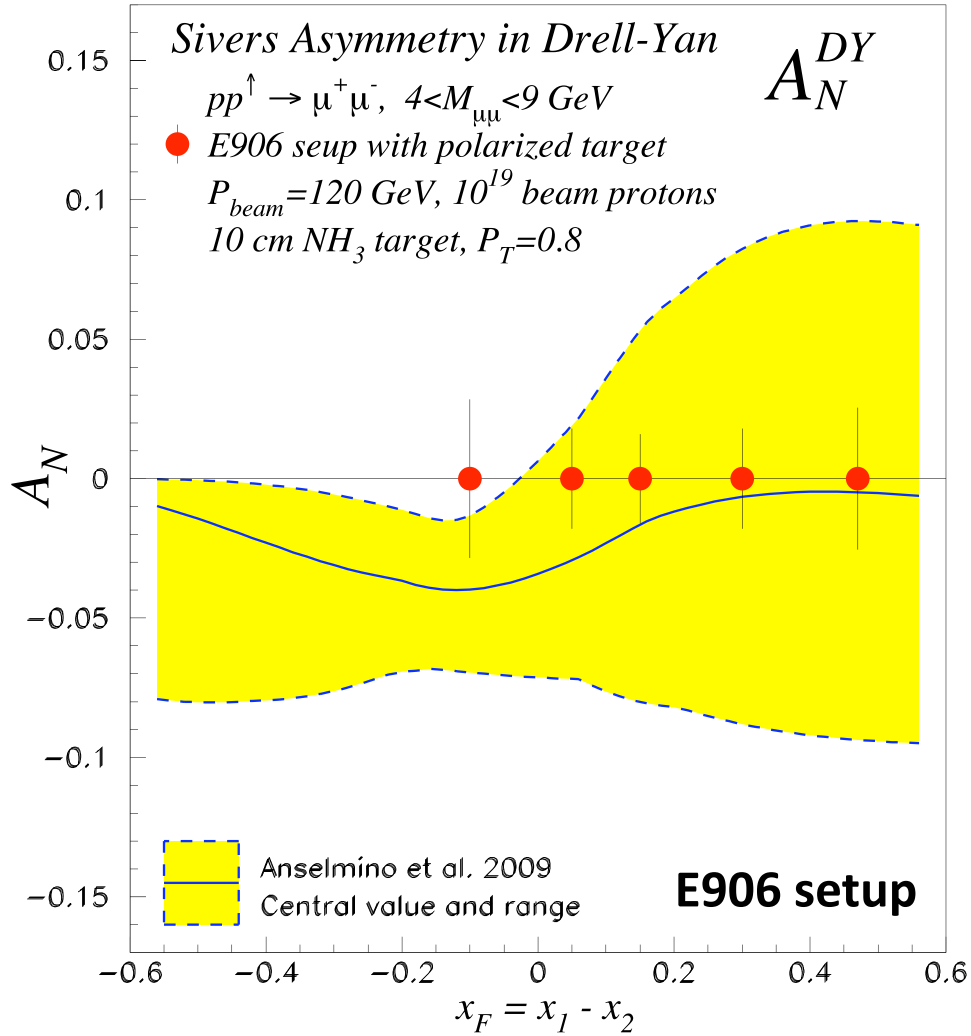
Pythia simulation, E906 setup

p_{z1}>15 GeV/c, p_{z2}>15 GeV/c.
$M_{\mu\mu}$>4.2 GeV



Split into 5 x_F bins.
Account for target polarization 0.8,
dilution factor 0.2.

Constrain f_{1T}/f_1 to ±2% for u-bar.

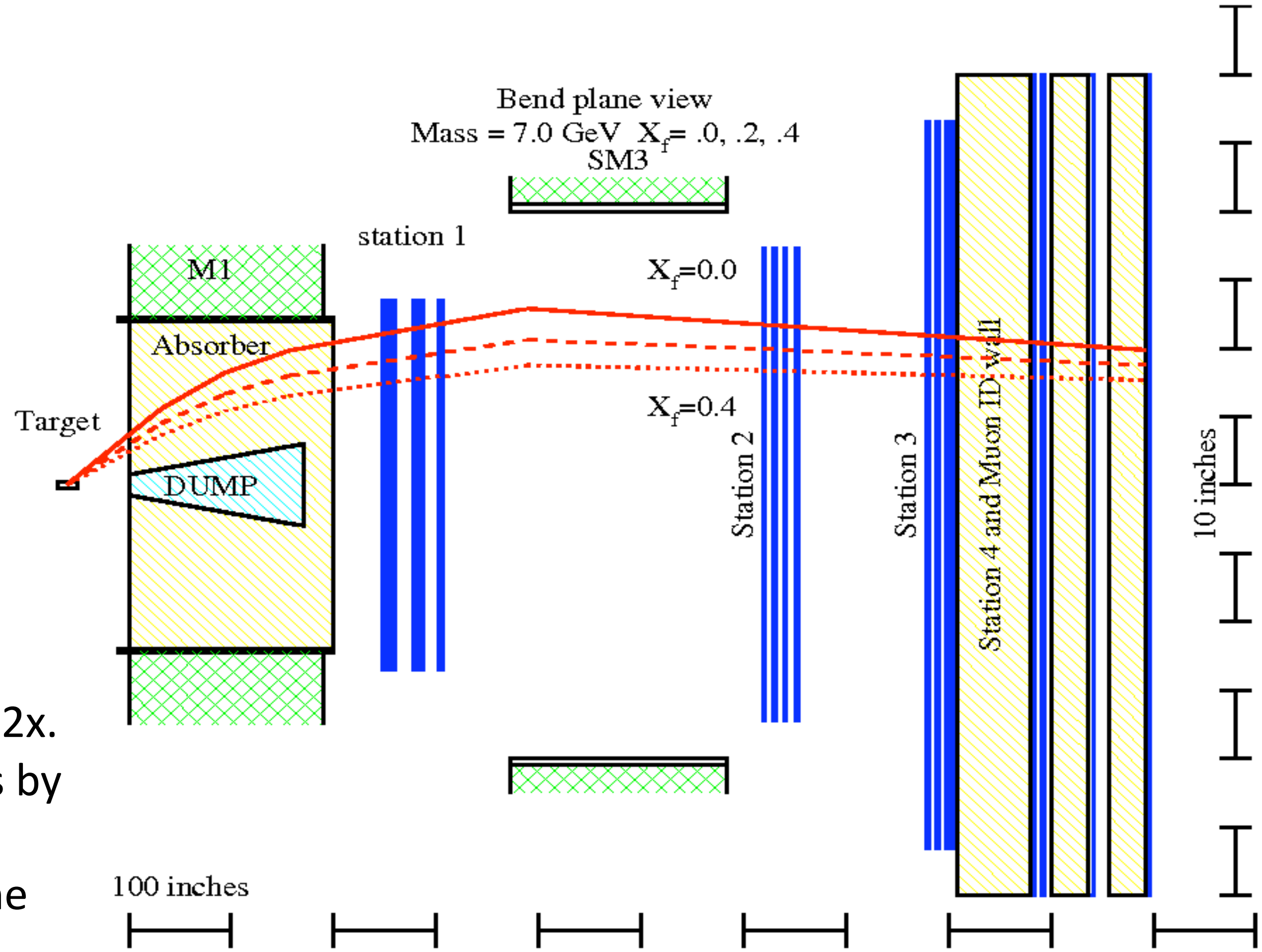


E906 was designed to strongly favor high x_F in order to access d-bar/u-bar at high-x.

To access low x_F region:

To detect muons at a larger angle (~20°) and a lower momentum (p_{zi}>7.5 GeV/c).

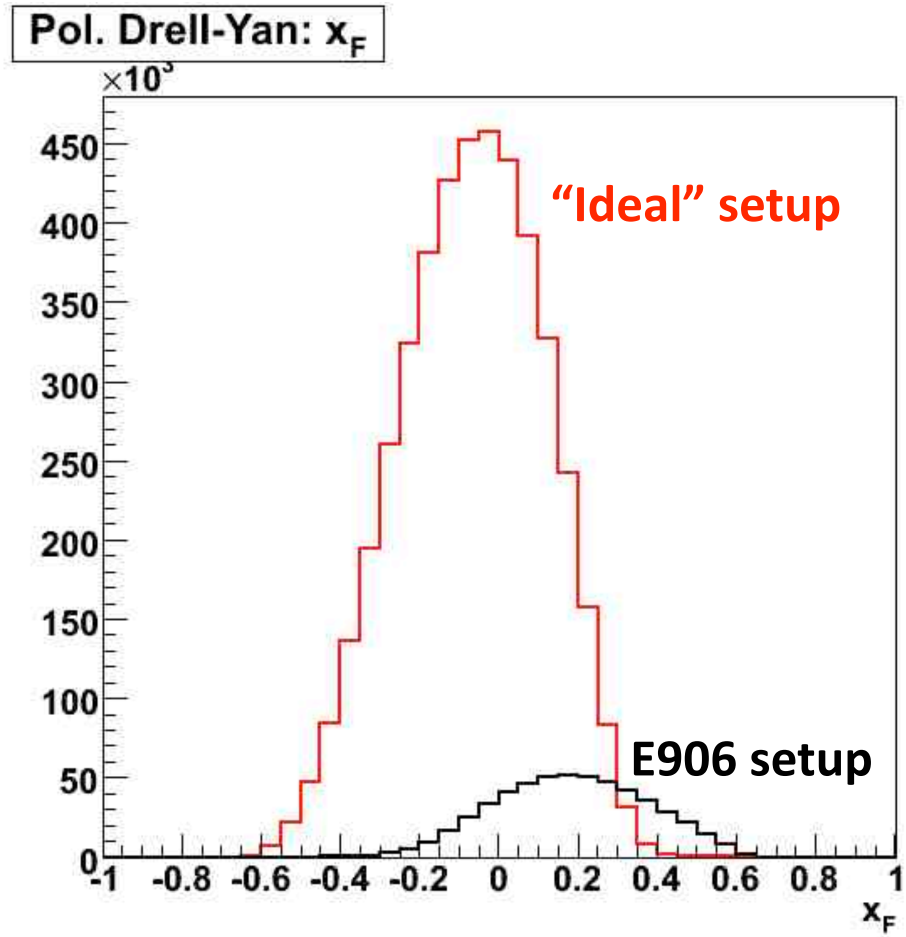
Increase 1st dipole opening by 2x. Cut hadron absorber thickness by one half. Assuming the "new" tracking stations can handle the increased background rates …



Pythia simulation: ideal setup

P_{z1}>7.5 GeV/c, p_{z2}>7.5 GeV/c.
$5^o<\theta_\mu<30^o$.
$M_{\mu\mu}$>4.2 GeV.
Same luminosity.

~8x DY events compared to E906 setup.

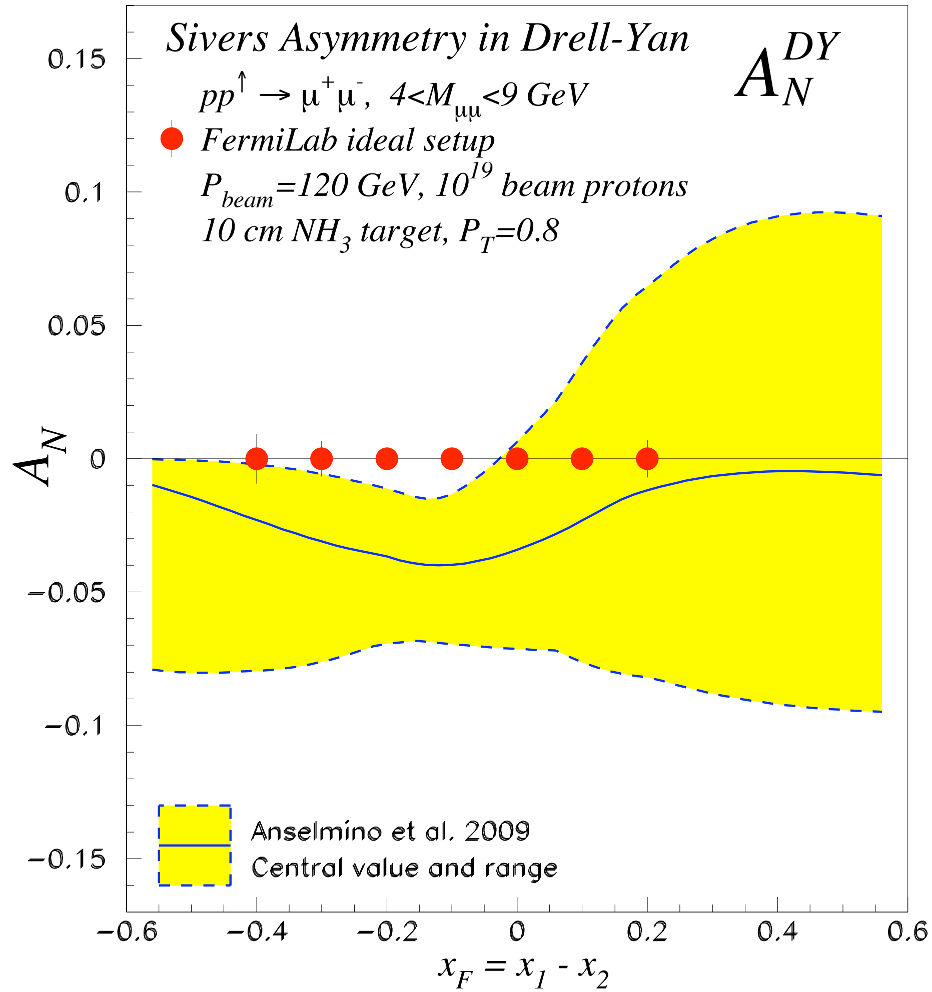


Although there're many detailed works to be done to realize the "ideal" setup …

“Ideal” Setup

Constrain f_{1T}/f_1 to ±0.5% for u-quark, test Sivers function sign change to 8σ level over a wide range of x_F.

Constrain f_{1T}/f_1 to ±0.5% for u-bar.



One-type of polarized NH_3 target could fit several experiments

- Polarized Drell-Yan @FNAL.
- Hall A proton SIDIS @JLab-12 GeV.
- Polarized Drell-Yan @JPARC-50 GeV.

Requirements for polarized target:

- 10 cm target length (or 6-8cm), can take 30-100 nA proton/electron beam.
- Prefer vertical polarization, for maximum SSA.

  (spectrometer acceptance is always expanded in the horizontal direction).
- Detect charge particles in the forward angle: $\pm 30^o$.
- Prefer frequent spin-flip to reduce detector and luminosity related systematics. At least one spin flip per 8-hour shift.

Could a JLab-type polarized ^{3}He target work at E906 ?

- Assuming the max. density*length as in JLab-12 GeV Hall A proposal (Super-BigBite). 60 cm * 10 atm. $\rho * t = 0.08$ g/cm^2.
- Cell diameter is large enough to avoid cell side wall contribution.
- End windows are thin enough to avoid a large dilution factor (E906 can not resolve vertex as in Hall A).

F.O.M=dilution^2*Polarization^2*ρ*t

$^3He/NH_3 \approx 0.013$

^{3}He gas target is too thin for Drell-Yan experiments.

Polarized Target Drell-Yan Experiments at Fermi Lab ?

Promising. Very attractive physics:

- To constrain u-quark Sivers function to ±0.5%. A clear test of Sivers function sign flip.
- To constrain u-bar Sivers function to ±0.5%.

Major technical requirements are:

- A 10 cm long pol. NH_3 target, with frequent spin-flip.
- A complete redesign of a large acceptance Drell-Yan spectrometer.
- New tracking detectors to match the higher rates and the large acceptance.

NM4/KTeV Hall