Jefferson lab Hall A DIS program at 12 GeV

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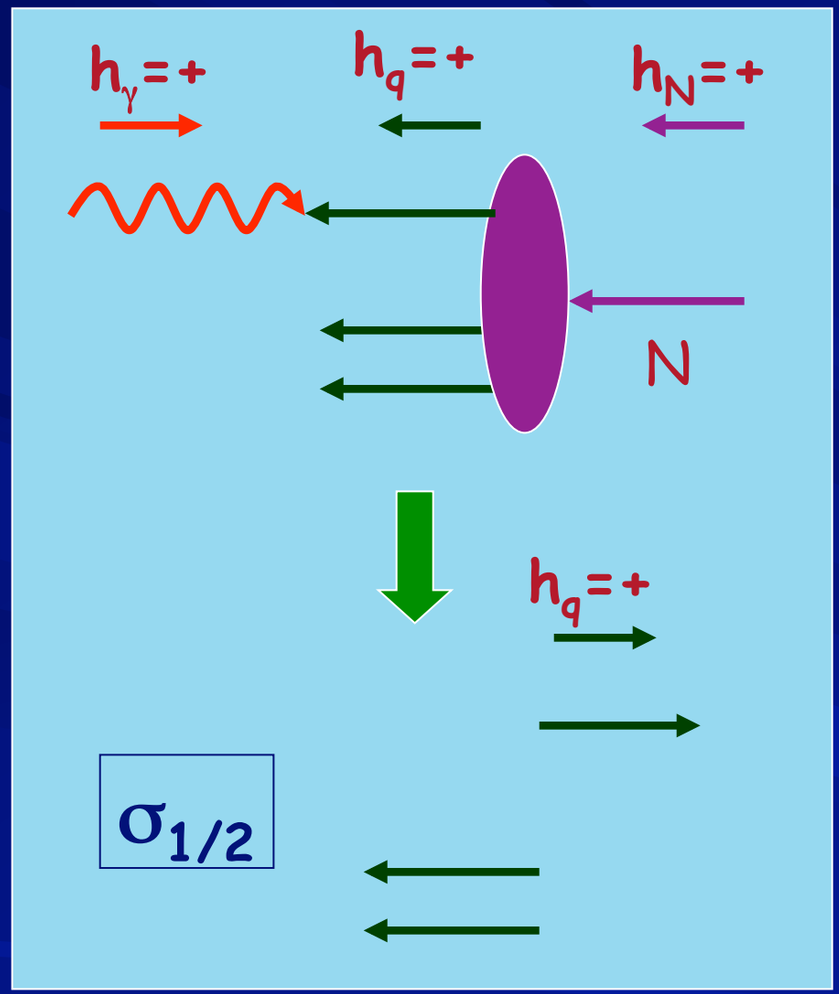
Outline

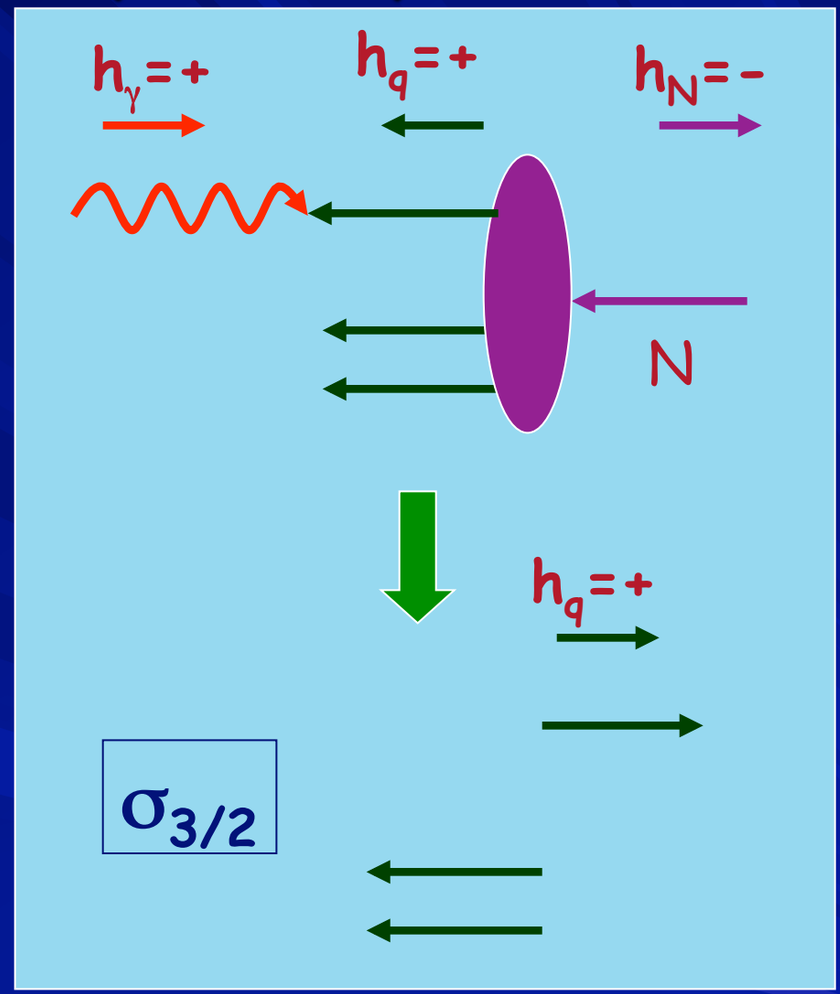
- Physics:
  - Neutron spin structure at high x; A^1_n
  - Parity violating DIS (PVDIS)
  - Semi Inclusive DIS (SIDIS)
- Instrumentation:
  - Hall A provides very high luminosities both unpolarized (1.4 x 10^{37} $cm^{-2}s^{-1}$) and polarized neutron (5 x 10^{38} $cm^{-2}s^{-1}$)
  - Hall A has been set aside as the "special installation" hall for 12 GeV: opportunity for creative instrumentation solutions to meet very demanding experimental requirements
  - Super-Bigbite spectrometer
  - Hall A solinoid spectrometer

Neutron spin structure at high x: A^1_n

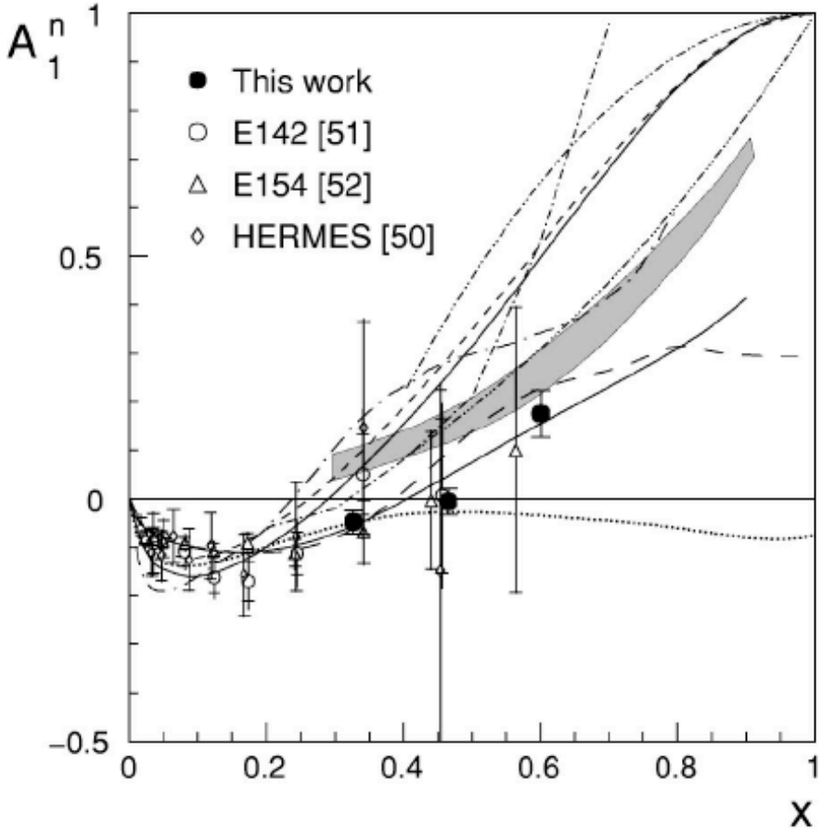
- test fundamental predictions of nucleon structure.
- flavor decomposition of polarized pdfs
  - One of the highlighted experiments in the 12 GeV plan

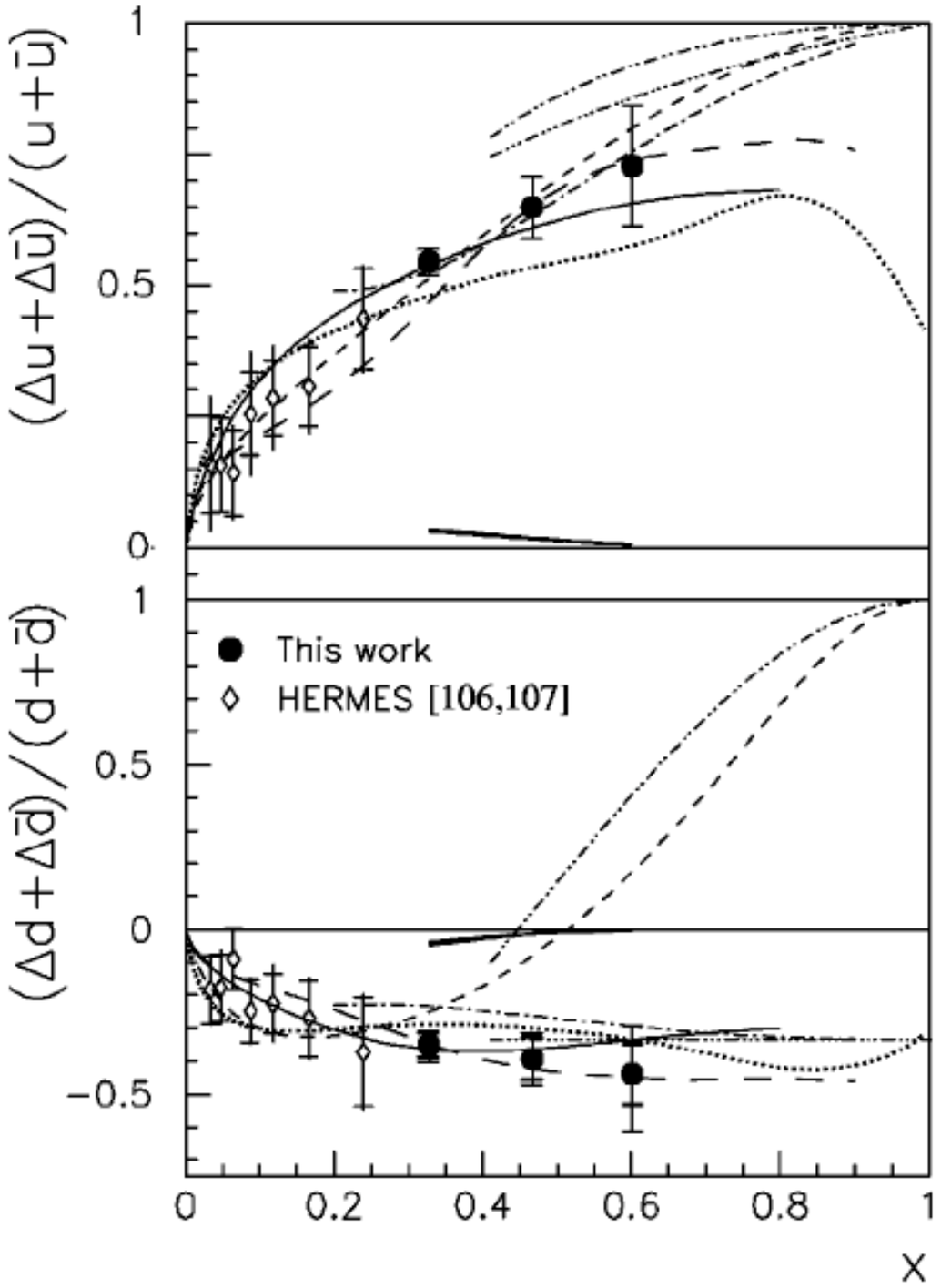
Virtual Photon Asymmetry



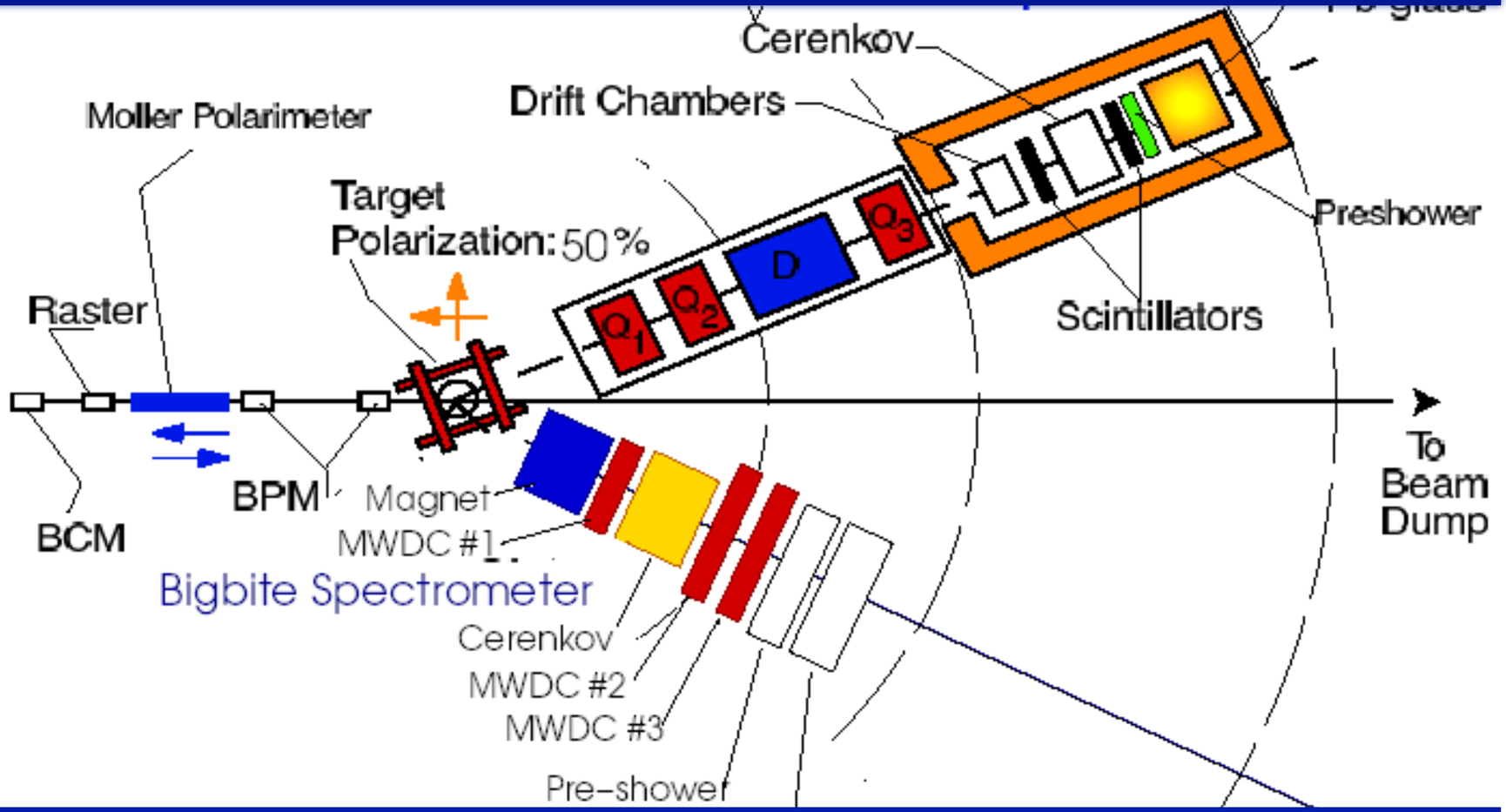


$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{g_1}{F_1}$$


A_1^n
This work
E142 [51]
E154 [52]
HERMES [50]
1
0.5
0
−0.5
0
0.2
0.4
0.6
0.8
1
x

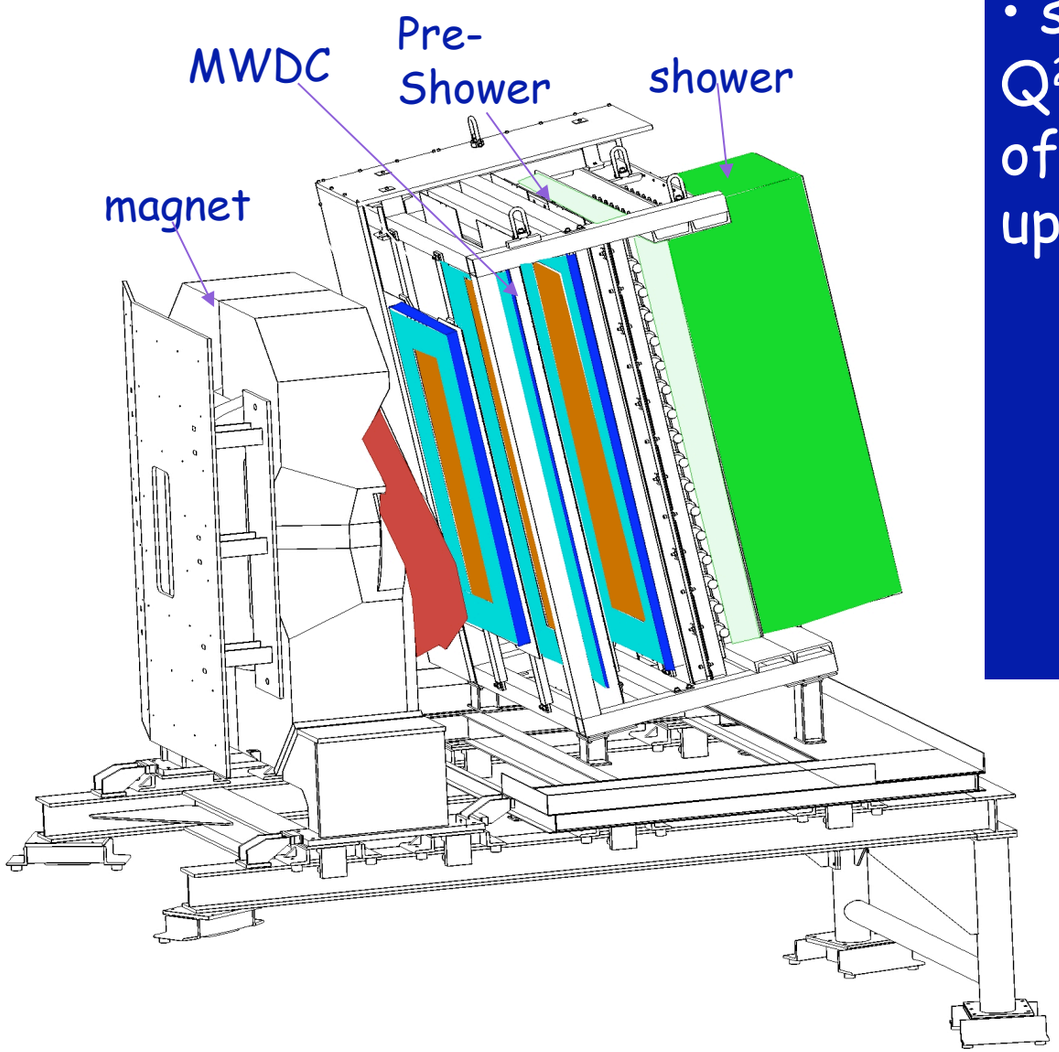

$(\Delta u+\Delta\bar{u})/(u+\bar{u})$
$(\Delta d+\Delta\bar{d})/(d+\bar{d})$
This work
HERMES [106,107]
1
0.5
0
−0.5
0
0.2
0.4
0.6
0.8
1
x

Already possible with existing equipment



- 6.6 GeV, 8.8 GeV polarized electron beams: 10 μA, Pe = 0.8
- Hall A polarized ^{3}He target: 30 cm of useful length.
- Bigbite Spectrometer @ 30°
- HRS-L @ 30°

Bigbite Spectrometer in Gen

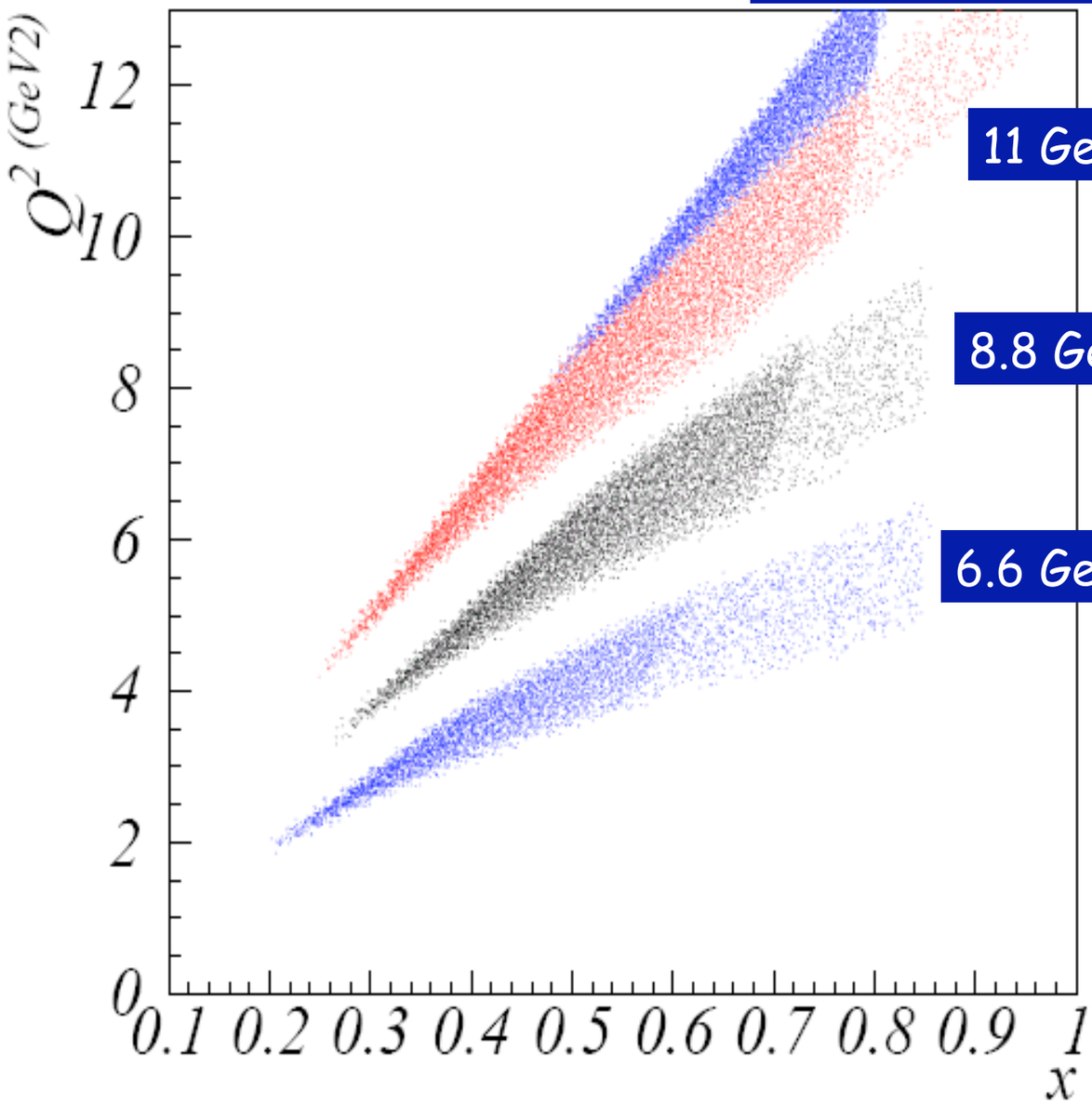


- successfully used for hall A high Q^2 Gen exp.: powerful combination of BigBite + Polarized ^{3}He target; up to L~ 4.5 x 10^{36} $cm^{-2}s^{-1}$.

  - 76 msr over 40 cm of target.
  - ~1% momentum resolution
  - ~5 mm y_tg resolution

Kinematic Coverage

11 Gev beam @ 40 °



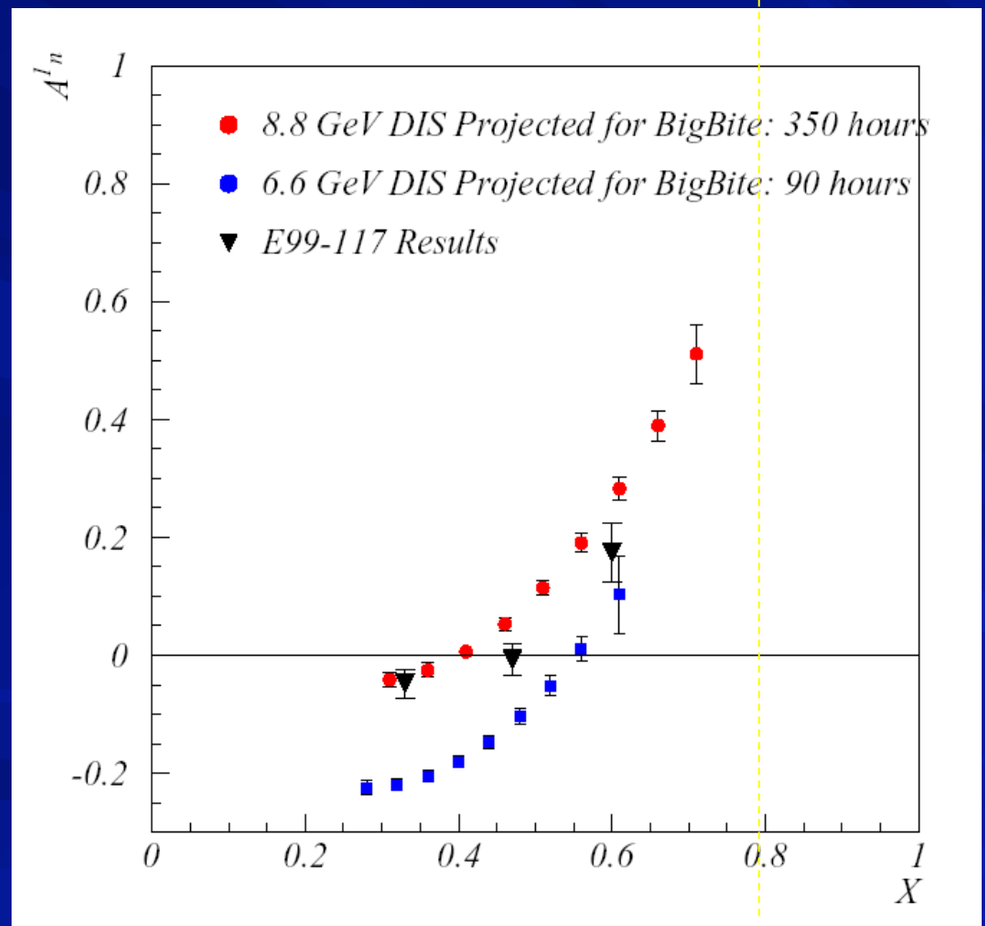
11 Gev beam @ 30 °

8.8 Gev beam @ 30 °

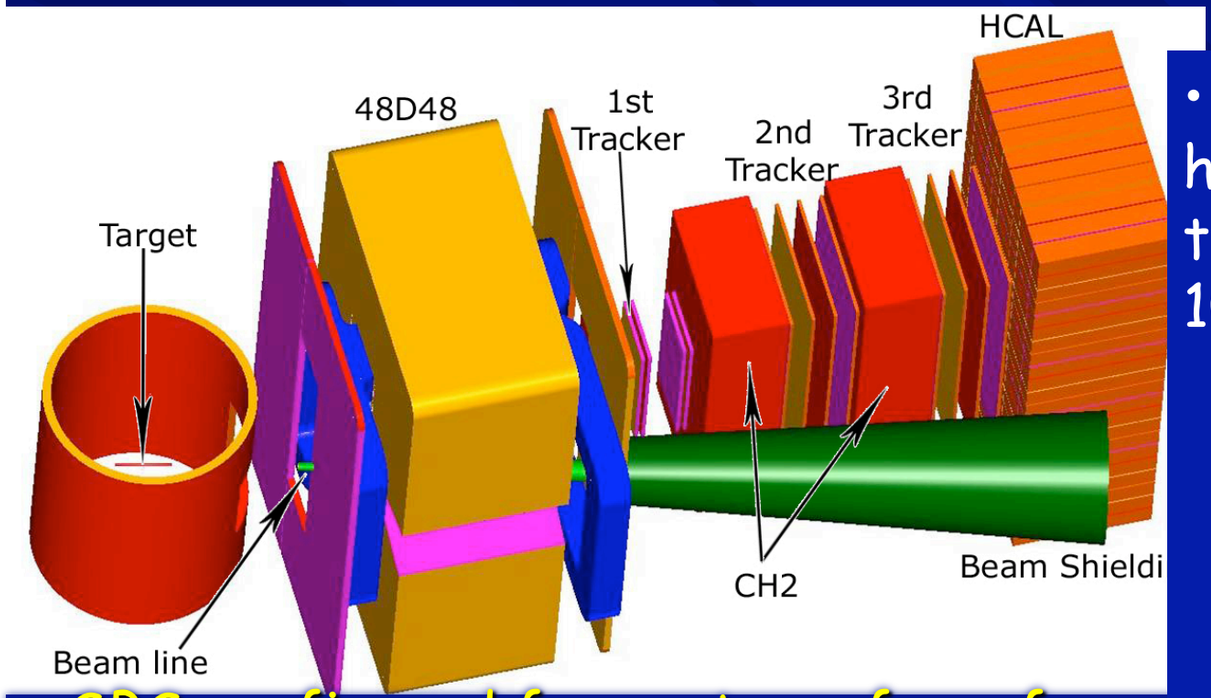
6.6 Gev beam @ 30 °

With Bigbite alone

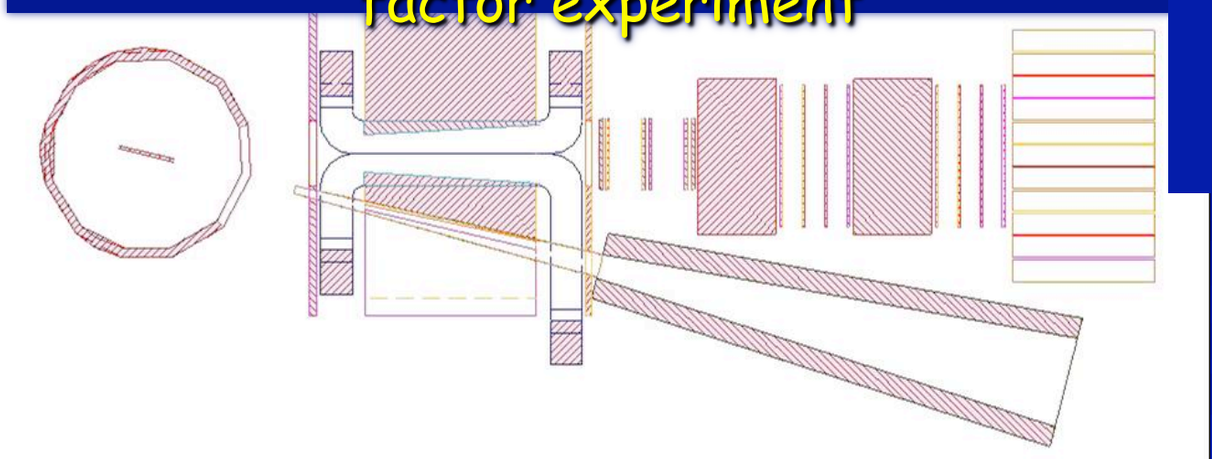
Using Bigbite with 6.6 GeV
and 8.8 GeV beam ~ 500 h



Super-Bigbite spectrometer

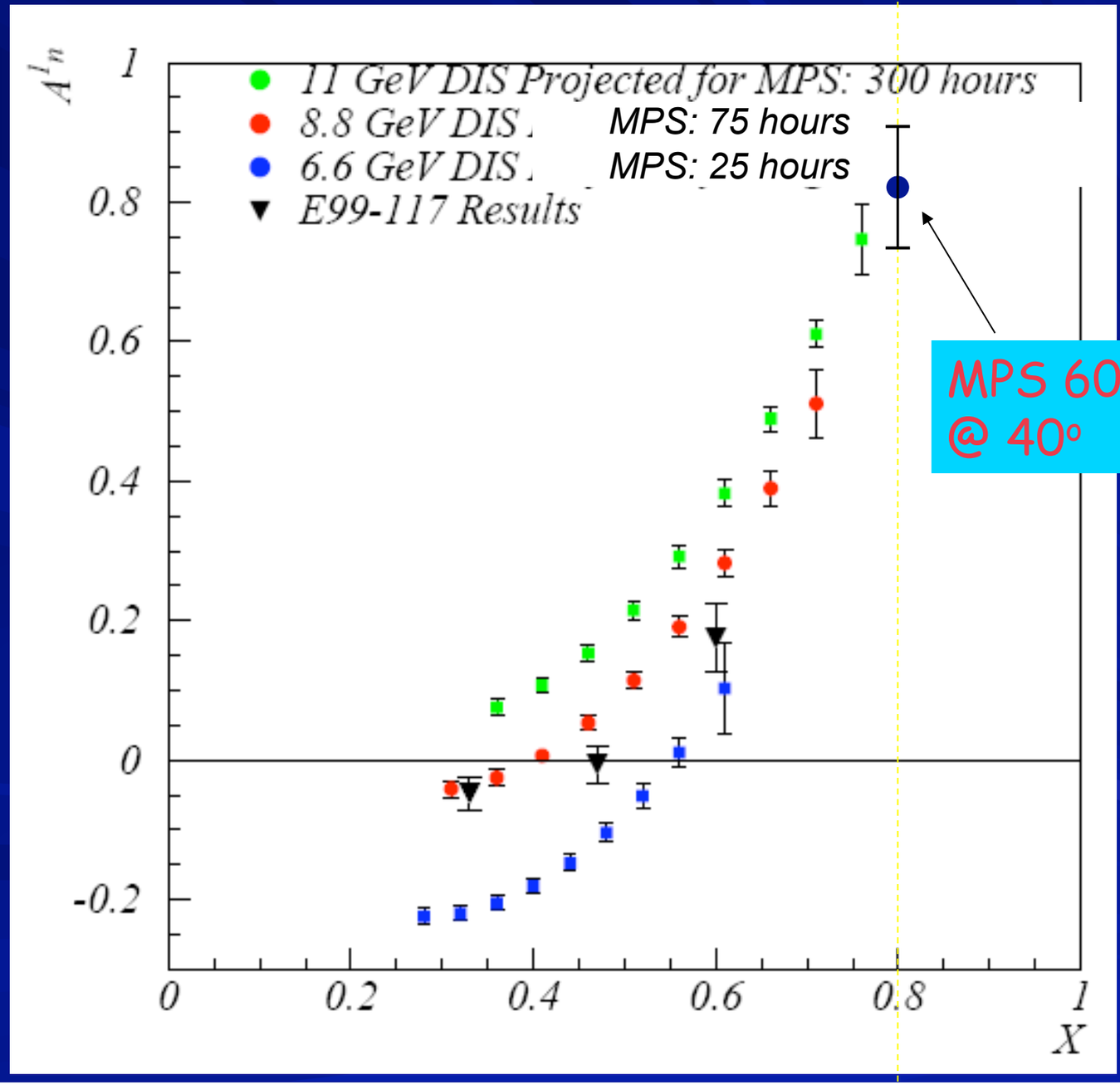


SBS configured for protons for a form factor experiment

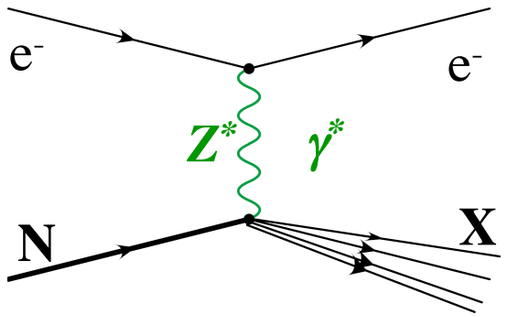


- GEM trackers – much higher luminosity compared to Bigbite; up to L~ 5 x 10^{38} $cm^{-2}s^{-1}$.
  - 40 msr over 40 cm of target.
  - ~0.5% momentum resolution for 4 GeV electrons.
  - ~5 mm y_tg resolution

Projected data: DIS



Parity Violating Deep Inelastic Scattering (PVDIS)



$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[\mathbf{a}(x) + Y(y)\,\mathbf{b}(x)\right]$$

a(x) and **b**(x) contain quark distribution functions $f_i(x)$

$x \equiv x_{Bjorken}$

$y \equiv 1 - E'/E$

$f_i^{\pm} \equiv f_i \pm \overline{f}_i$

$$a(x) = \frac{\sum_i C_{1i} Q_i f_i^+(x)}{\sum_i Q_i^2 f_i^+(x)} \qquad b(x) = \frac{\sum_i C_{2i} Q_i f_i^-(x)}{\sum_i Q_i^2 f_i^+(x)}$$

For an isoscalar target like ^2H, structure functions largely cancel in the ratio at high x

at high x

$$a(x) = \frac{3}{10}(2C_{1u} - C_{1d})\left(1 + \frac{0.6\,s^+}{u^+ + d^+}\right) \to \mathbf{0}$$

$$b(x) = \frac{3}{10}(2C_{2u} - C_{2d})\left(\frac{u_v + d_v}{u^+ + d^+}\right) + \cdots \to \mathbf{1}$$

At high x, A_{PV} becomes independent of x, W, with well-defined SM prediction for Q^2 and y

New combination of:
Vector quark couplings C_{1q}
Also axial quark couplings C_{2q}

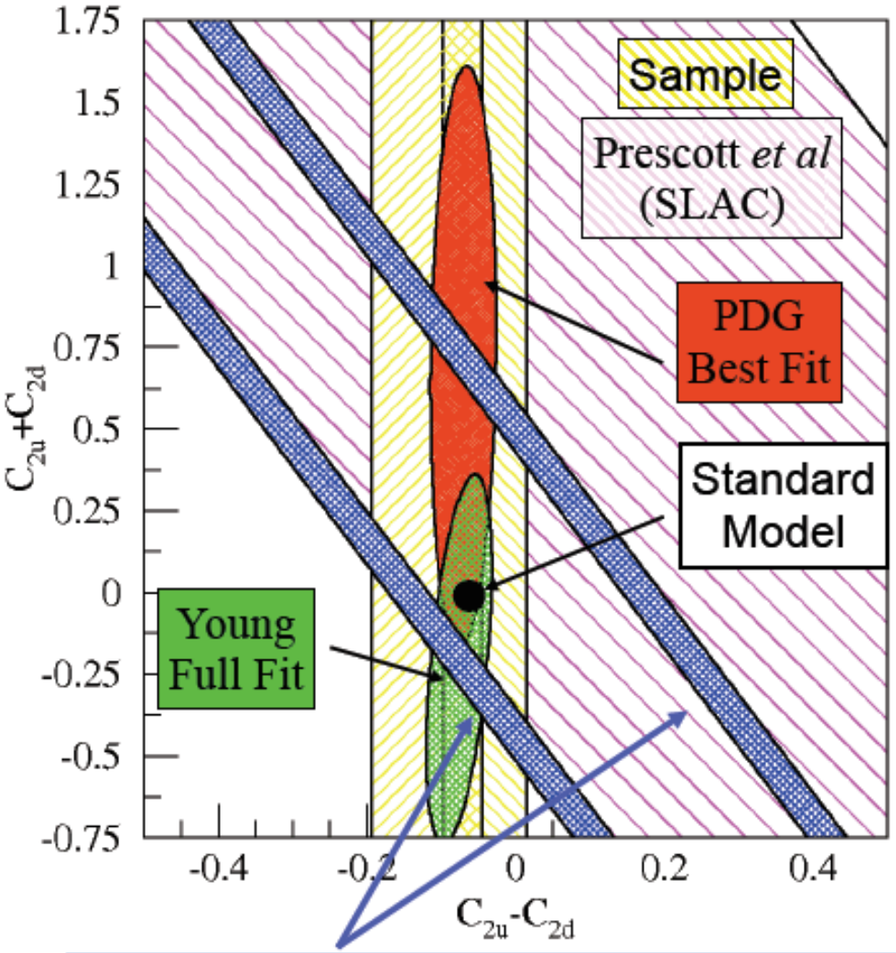
Sensitive to new physics at the TeV scale

C_{2q} inaccessible in elastic scattering

- Physics potential
  - Excellent sensitivity to C_{2u} and C_{2d}.
  - Standard Model Test
  - Charge Symmetry Violation (CSV)
  - Higher Twist
  - d/u for the Proton

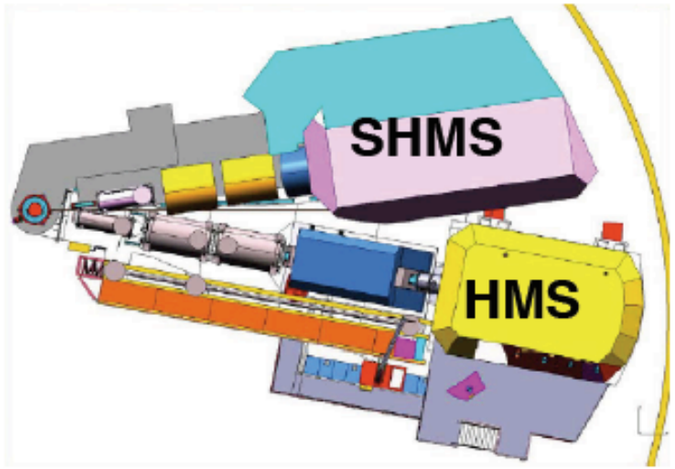
PVDIS w/ Base Equipment

E08-011: PVDIS off ^{2}H at 6 GeV



6 GeV PVDIS 3% A_d measurement:
Bands correspond to central values of either PDG best fit or Young et al.'s best fit.

Proposal approved for 11 GeV: Factor of ~ 2 to 3 improvement

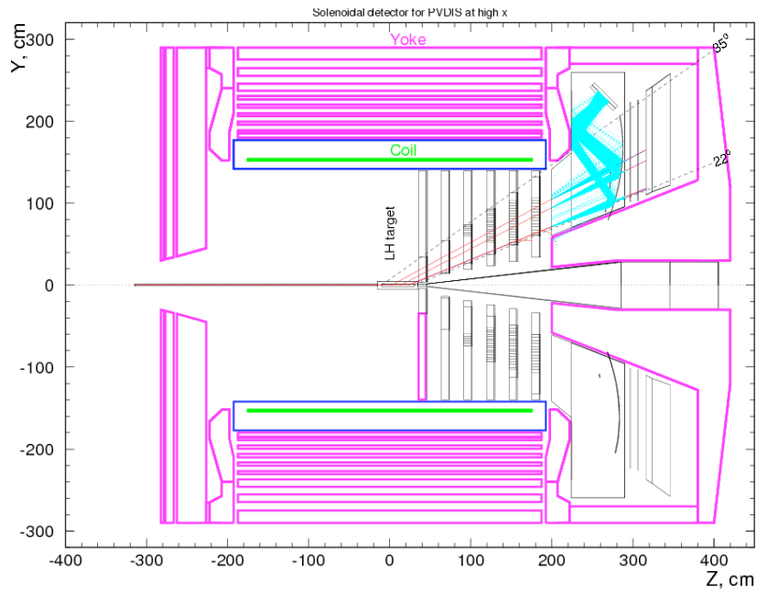


- 08-011 provides first look, at x~0.25-0.3
- Insensitive to CSV, HT, but possibly sensitive to the quark sea?

- 11 GeV, allows greater precision at higher x, but doesn't provide lever arm to fully separate QCD effects

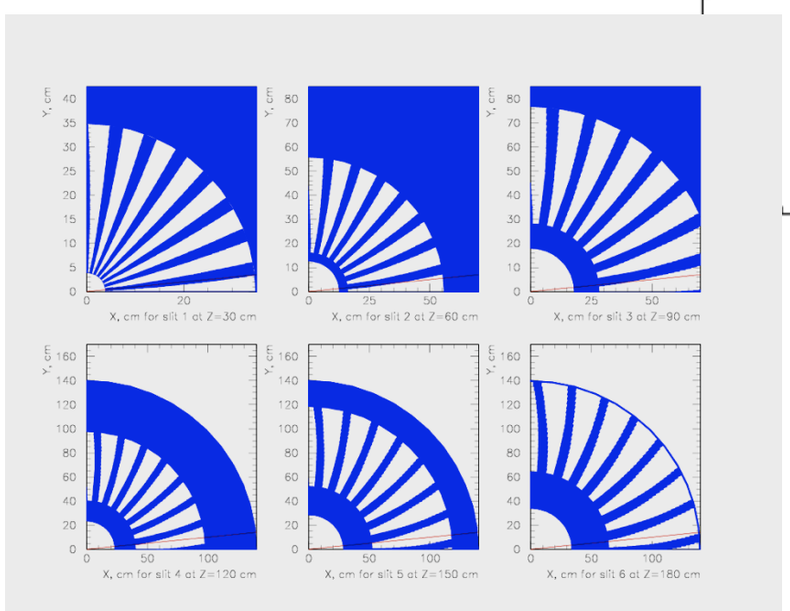
A Design for Precision PV DIS Physics

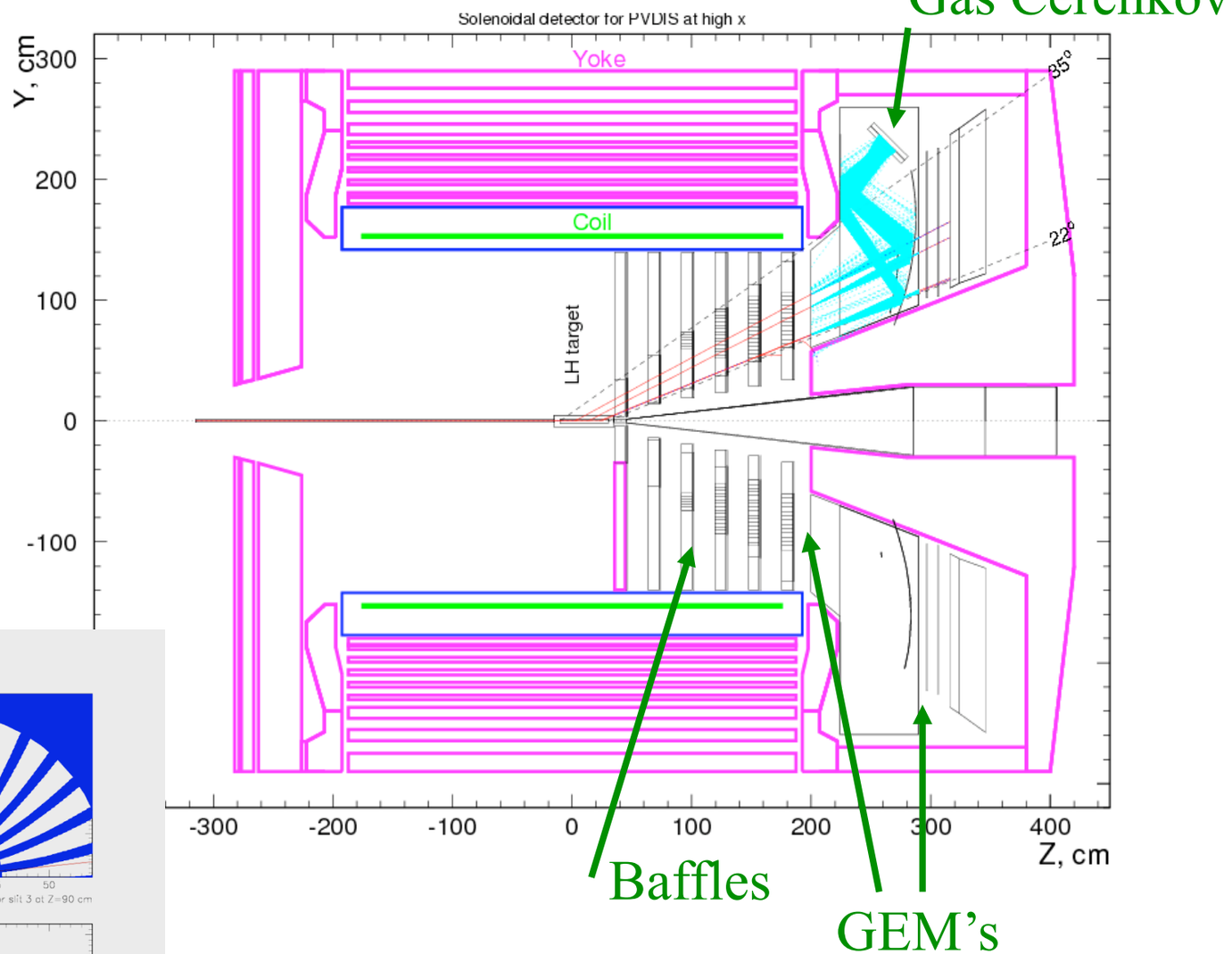
- ***High Luminosity on LH_2 & LD_2***
- ***Better than 1% errors for small bins***
- ***x-range 0.25-0.75***
- ***W^2 > 4 GeV^2***
- ***Q^2 range a factor of 2 for each x***
  - (Except x~0.75)
- ***Moderate running times***



- ***Solenoid (from BaBar, CDF or CLEOII)***
  contains low energy backgrounds (Moller, pions, etc)
  trajectories measured after baffles
- ***Fast tracking, particle ID, calorimetry, and pipeline electronics***
- ***Precision polarimetry (0.4%)***

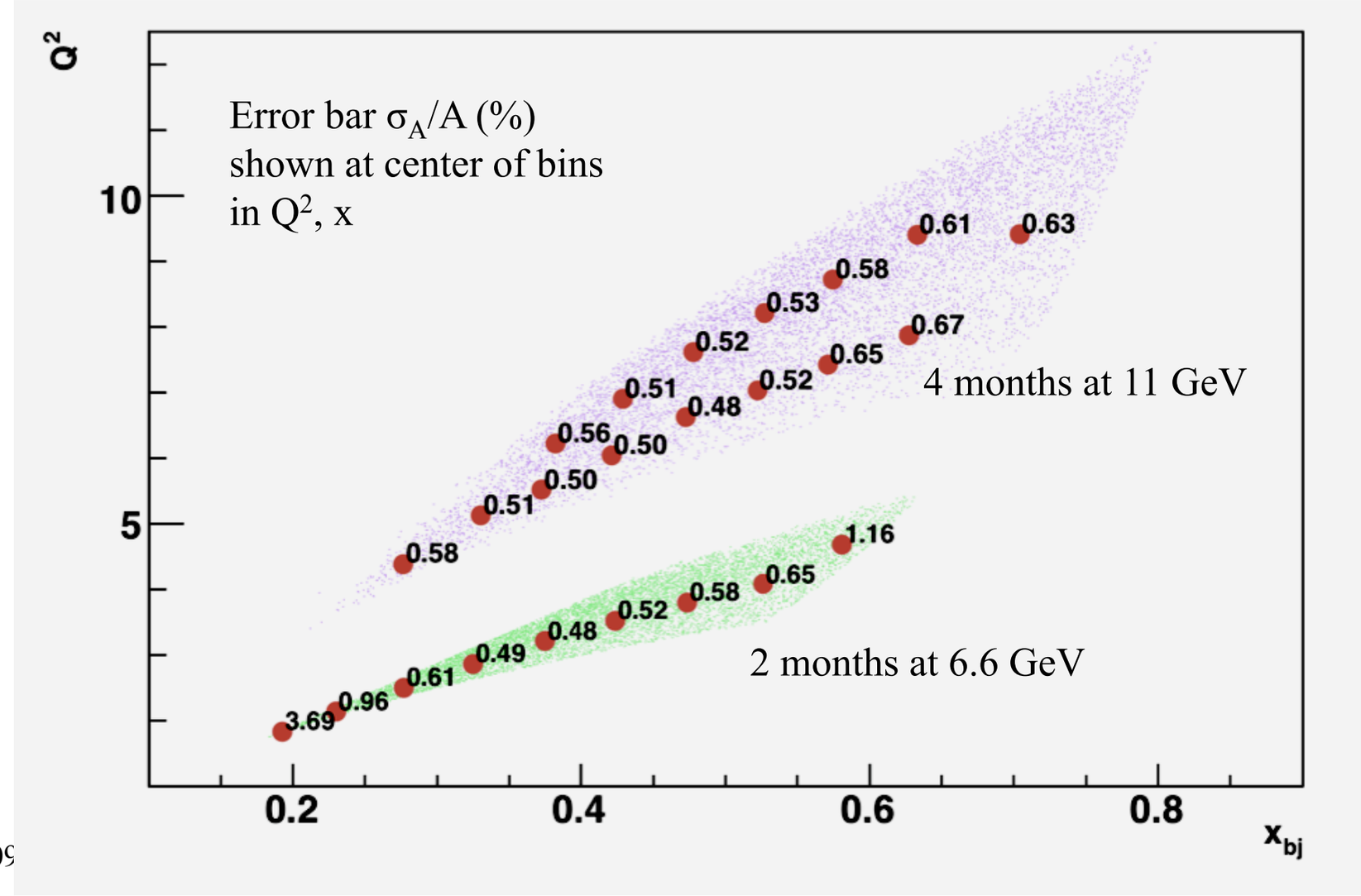
SoLID Spectrometer





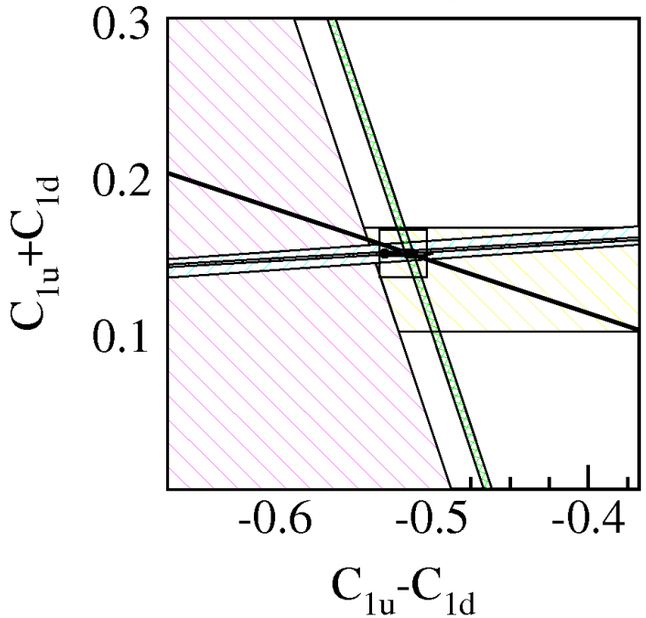
Statistical Errors (%) vs Kinematics

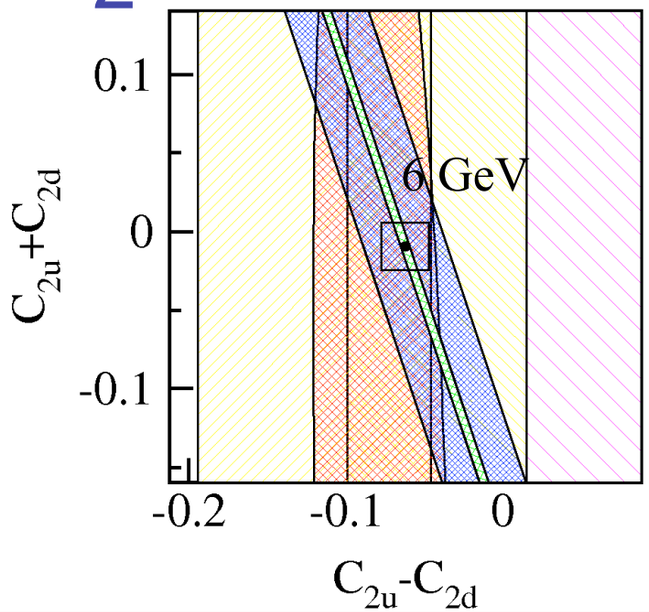
Strategy: sub-1% precision over broad kinematic range for **sensitive Standard Model test** *and* **detailed study of hadronic structure contributions**



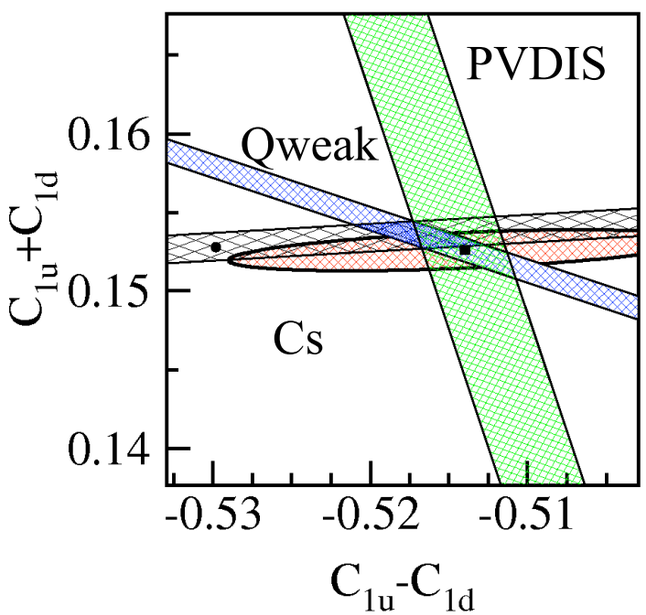
Sensitivity: C_1 and C_2 Plots

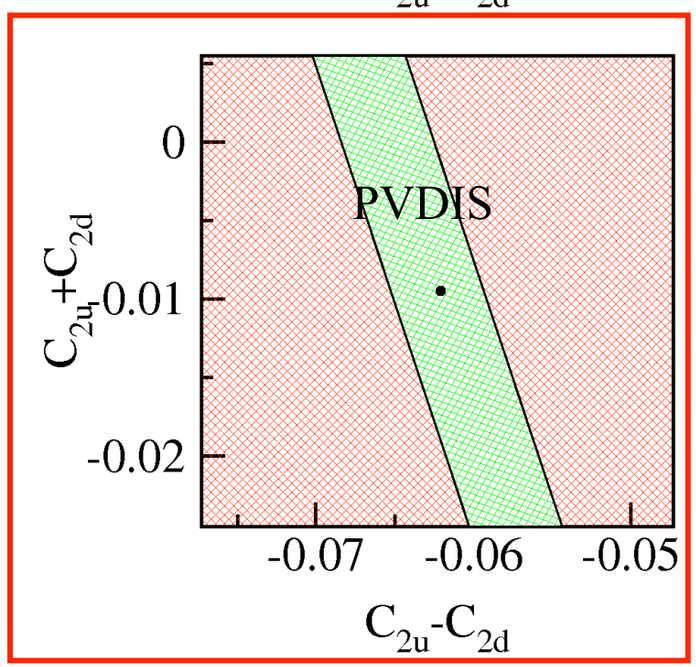
World's data





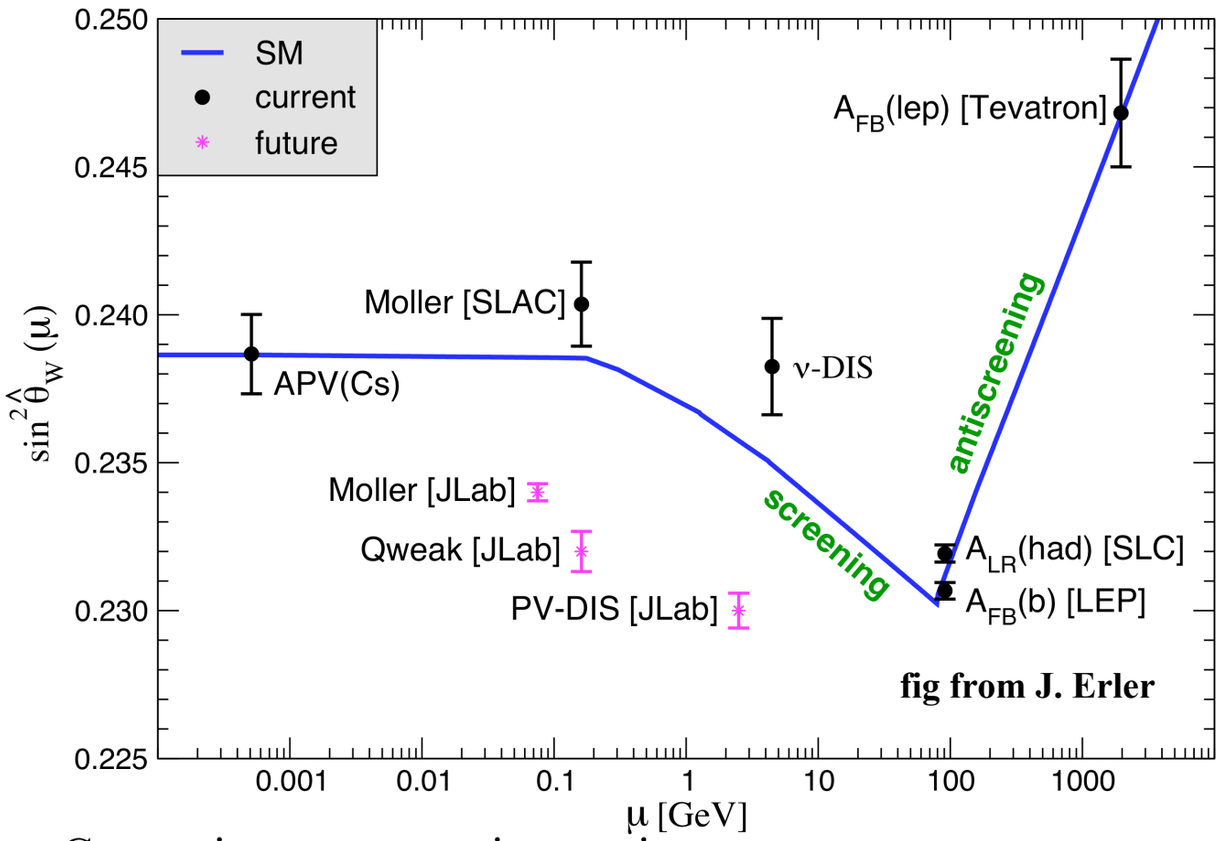
Precision Data





Precision on $\sin^2\theta_W$

Impressive precision on $\sin^2\theta_w$ (comparable to Qweak)
but real value is not sensitive to different combination of couplings



Constraint on contact interactions

$$\frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2 + g_{RL}^2 - g_{LR}^2|}} \approx 2.5 \text{ TeV}$$

CSV with PVDIS

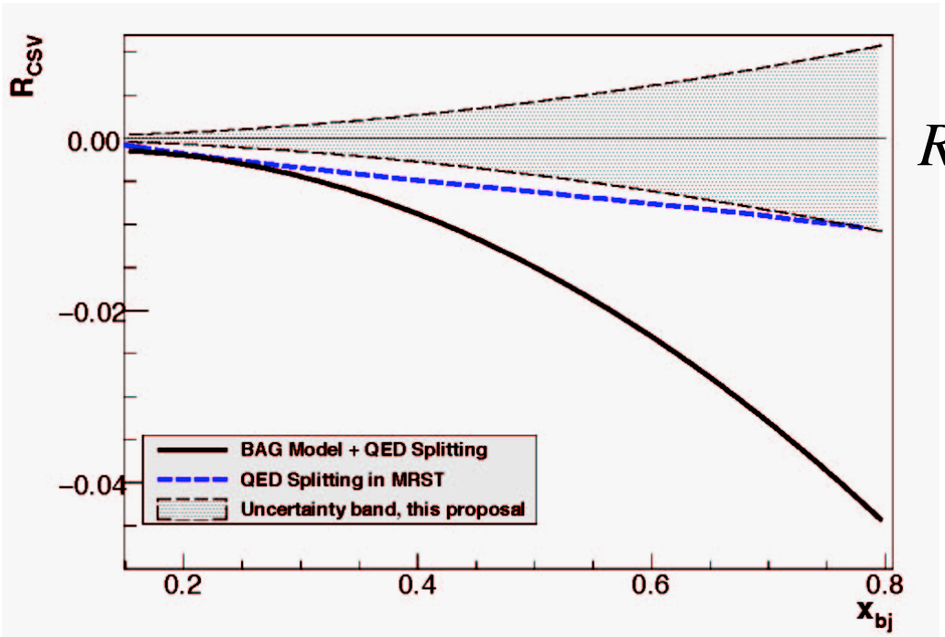
Parton-level charge symmetry assumed in deriving ^{2}H

A_{PV} **Charge Symmetry Violation**

$$\delta u(x) = u^p(x) - d^n(x)$$

$$\delta d(x) = d^p(x) - u^n(x)$$

- **u,d quark mass difference**
- **electromagnetic effects**

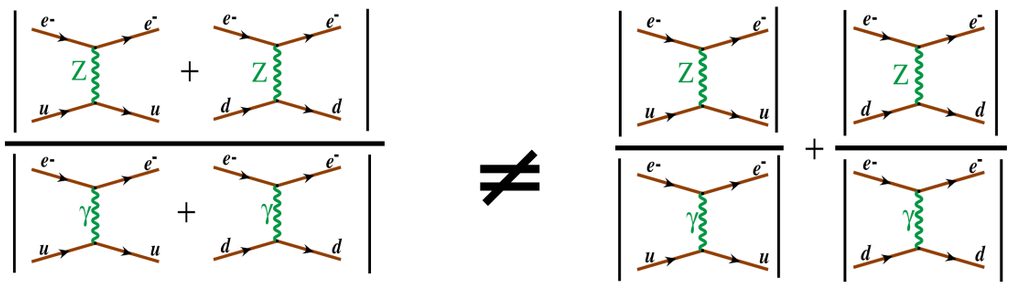


$$R_{CSV} = \frac{\delta A_{PV}(x)}{A_{PV}(x)} = 0.28\,\frac{\delta u(x) - \delta d(x)}{u(x) + d(x)}$$

- ***Direct observation of parton-level CSV would be very exciting!***
- ***Important implications for high energy collider pdfs***
- ***Could explain significant portion of the NuTeV anomaly***

Higher Twist

Does higher twist fully cancel from the asymmetry?

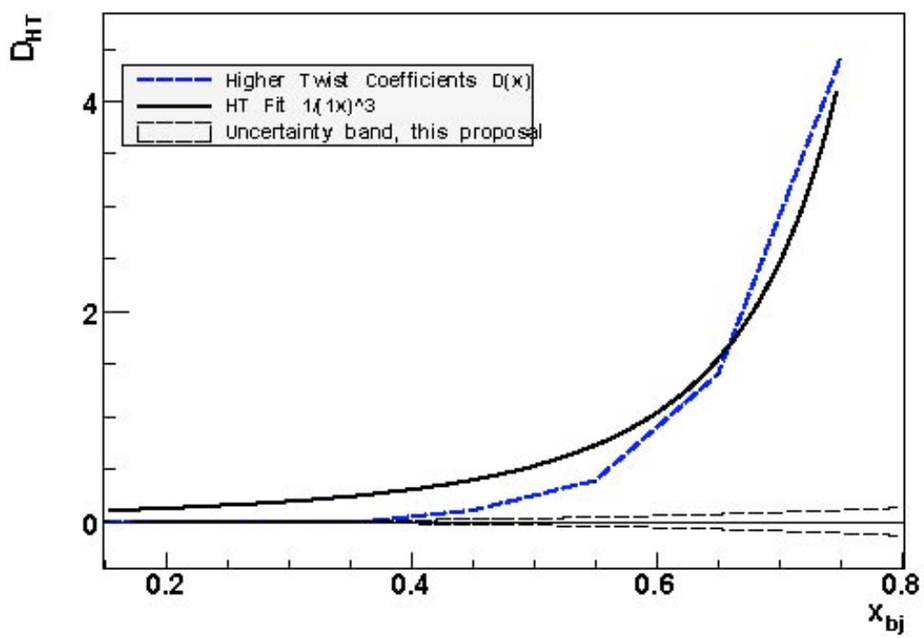


At higher x, a more interesting higher twist effect may be evident:

$$F_2(x,Q^2)=F_2(x)(1+D(x)/Q^2)$$

- A_{PV} sensitive to diquarks: ratio of weak to electromagnetic charge depends on amount coherence
- Do diquarks have twice the x of single quarks?

$$A_{PV}=A_{PV}(1+C_{HT}(x)/Q^2)$$

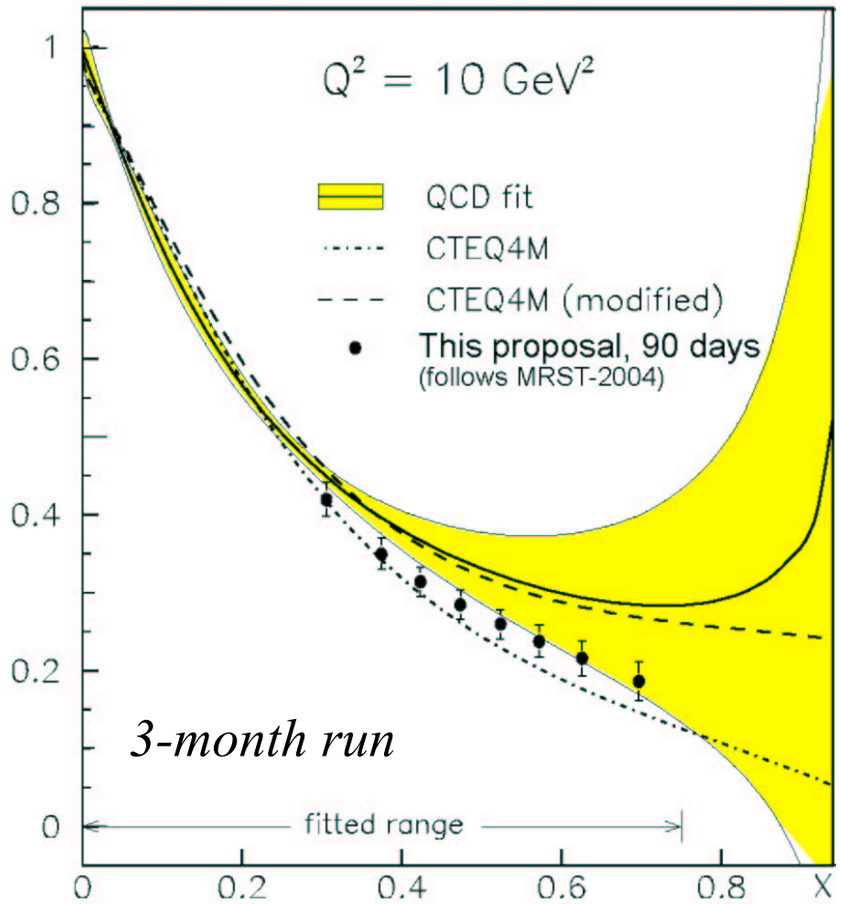


PVDIS on the Proton: d/u at High x

$$a^P(x) \approx \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)}$$

Deuteron analysis has large nuclear corrections (Yellow)

A_{PV} for the proton has no such corrections (complementary to BONUS)

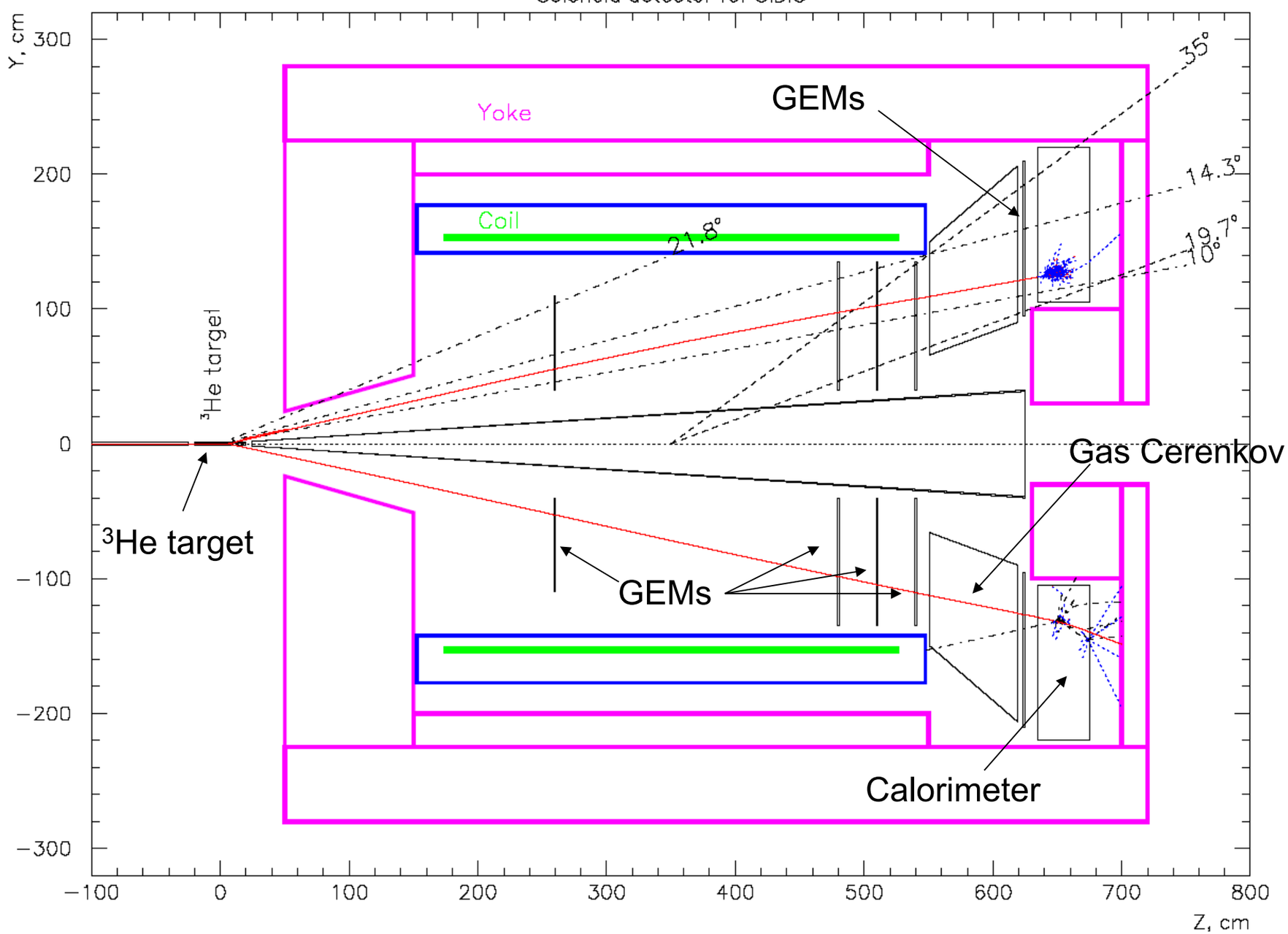


The challenge is to get statistical and systematic errors ~ 2%

Neutron Transversity

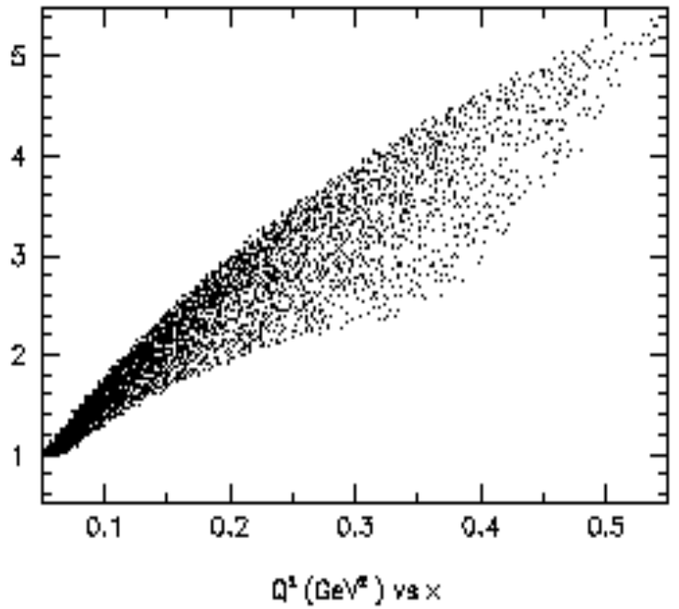
- Transversity and *TMD*s
  - From exploration to precision study
  - Transversity: fundamental PDFs, tensor charge
  - TMDs provide 3-d structure information of the nucleon
  - Laboratory to study QCD
  - Learn about quark orbital angular momentum
  - Multi-dimensional mapping of TMDs
  - 3-d ($x,z,P^{\perp}$)
  - Q2 dependence
  - multi facilities, global effort
- Demanding mesurement
  - ➢ Multi-dimension, small asymmetries, precision → very high statistics
  - ➢ High luminosity AND large acceptance needed
  - ➢ With the proposed spectrometers Hall A can do Transversity and *TMD*s: unprecedented precision

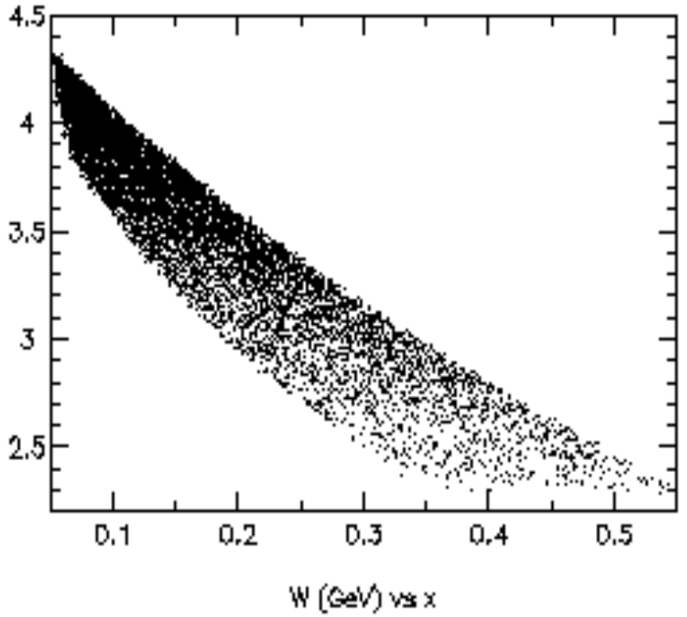
Solenoid detector for SIDIS



SIDIS Kinematical with the Solenoid (10º, 17º)

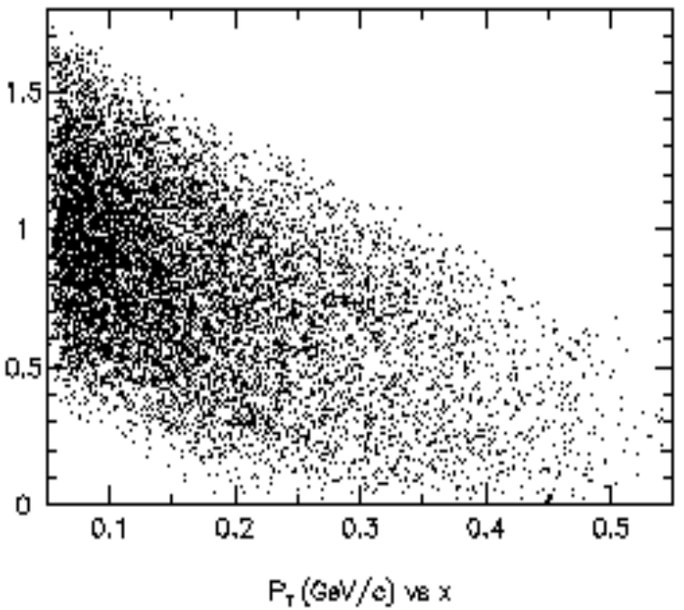
Q^2 vs x

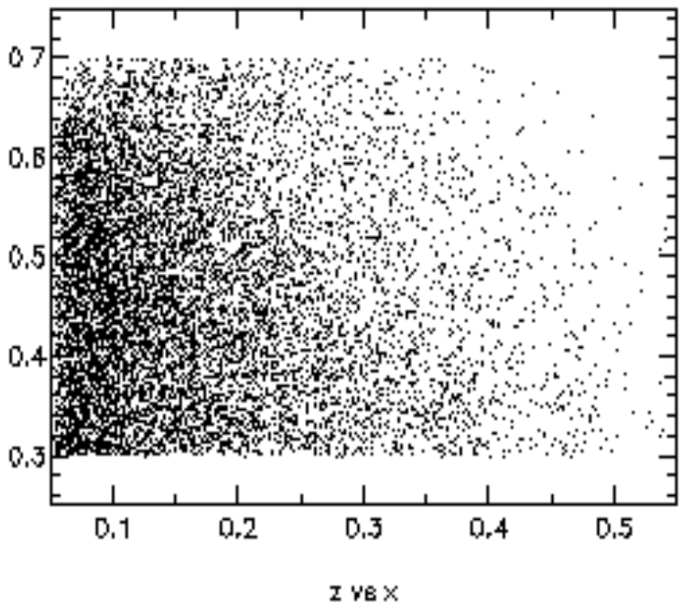




W vs x

P_T vs x

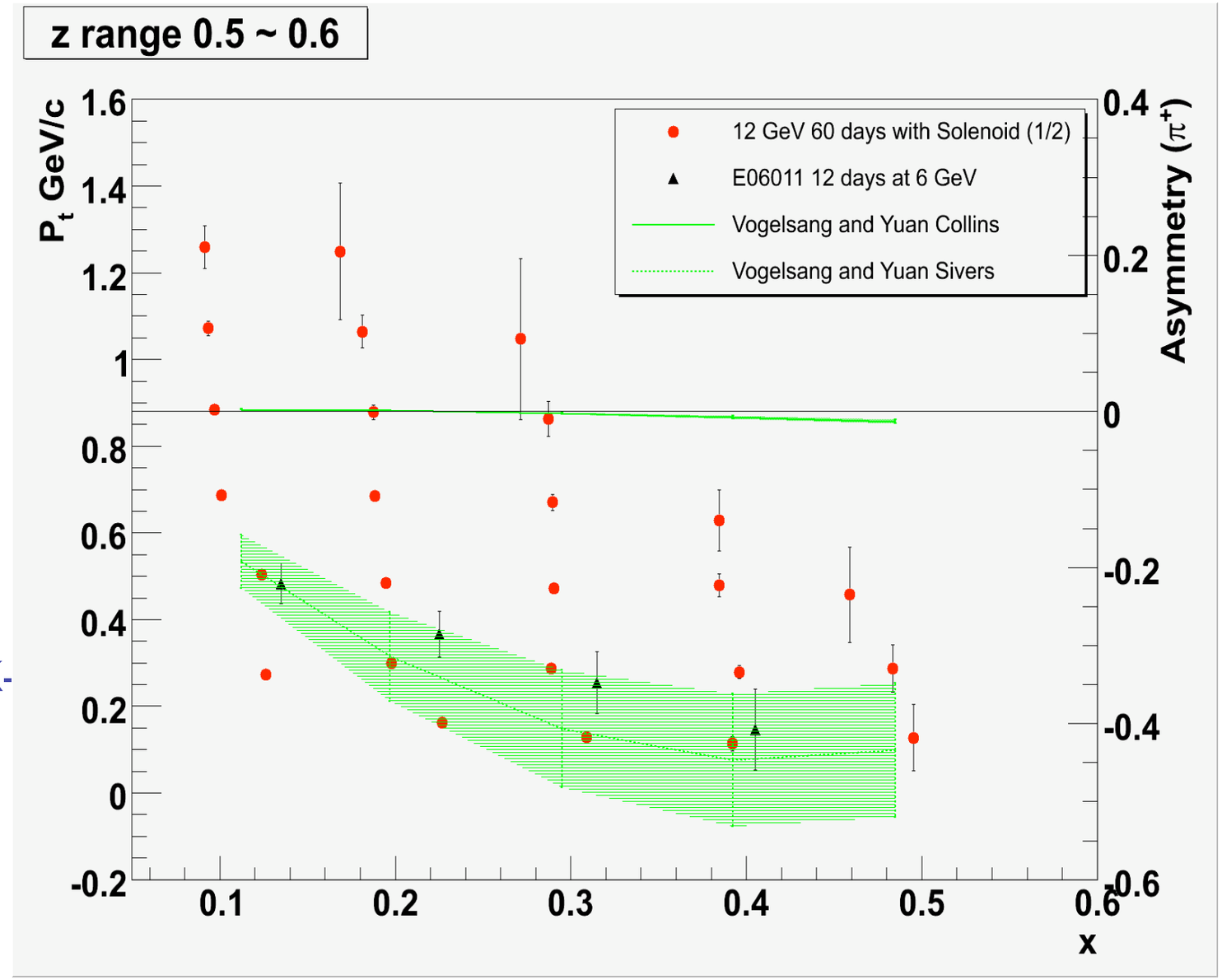




z vs x

Projection vs P_T and x for π+ (60 days)

- For one z bin (0.5-0.6)
- Will obtain 4 z bins (0.3-0.7)
- Also π- at same time
- With upgraded PID for K+ and K-



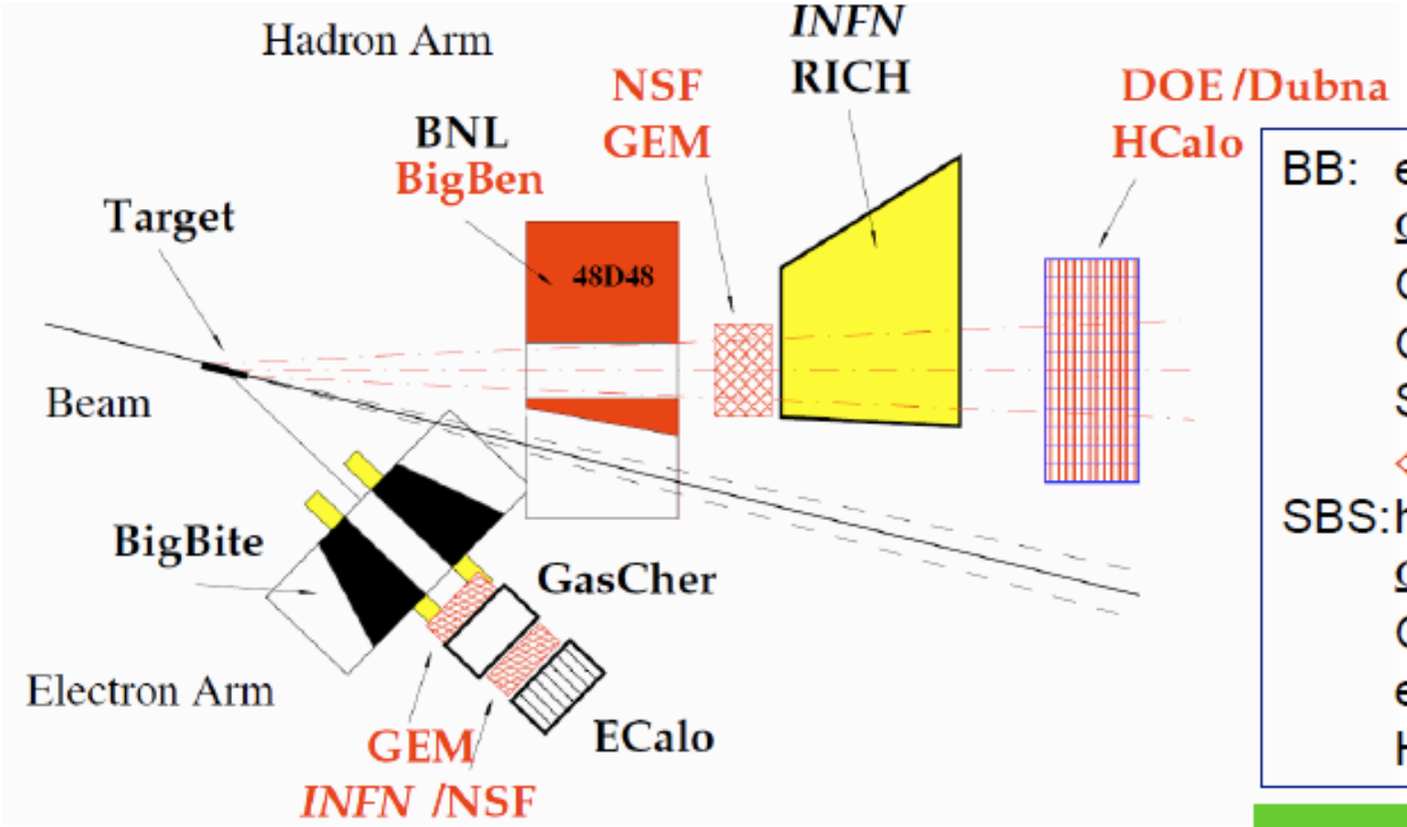
Measurement of the Semi-Inclusive π and K electro-production in DIS regime from transversely polarized ^{3}He target with the SBS & BB spectrometers in Hall A

G. Cates, E. Cisbani, G.B. Franklin, B. Wojtsekhowski
and the SBS Collaboration
http://hallaweb.jlab.org/12GeV/SuperBigBite

- Extract Sivers and Collins (and Pretzelosity) asymmetries on π and K with high statistics
- Provide 2D binning (at least) on the relevant variables: x, $P_\perp$ and z, for both hadrons
- Provide Q^2 dependence
- Explore for the first time the high x valence region (with overlap to HERMES, COMPASS, JLab6 data)

Experimental Setup and parameters

$$e + {}^3He^{\uparrow} \rightarrow e' + \pi(K)^{\pm} + X$$



BB: e-arm at 30°
Ω = 45 msr
GEM Tracker
Gas Cherenkov
Shower
⇐ GMn/PR-09-019

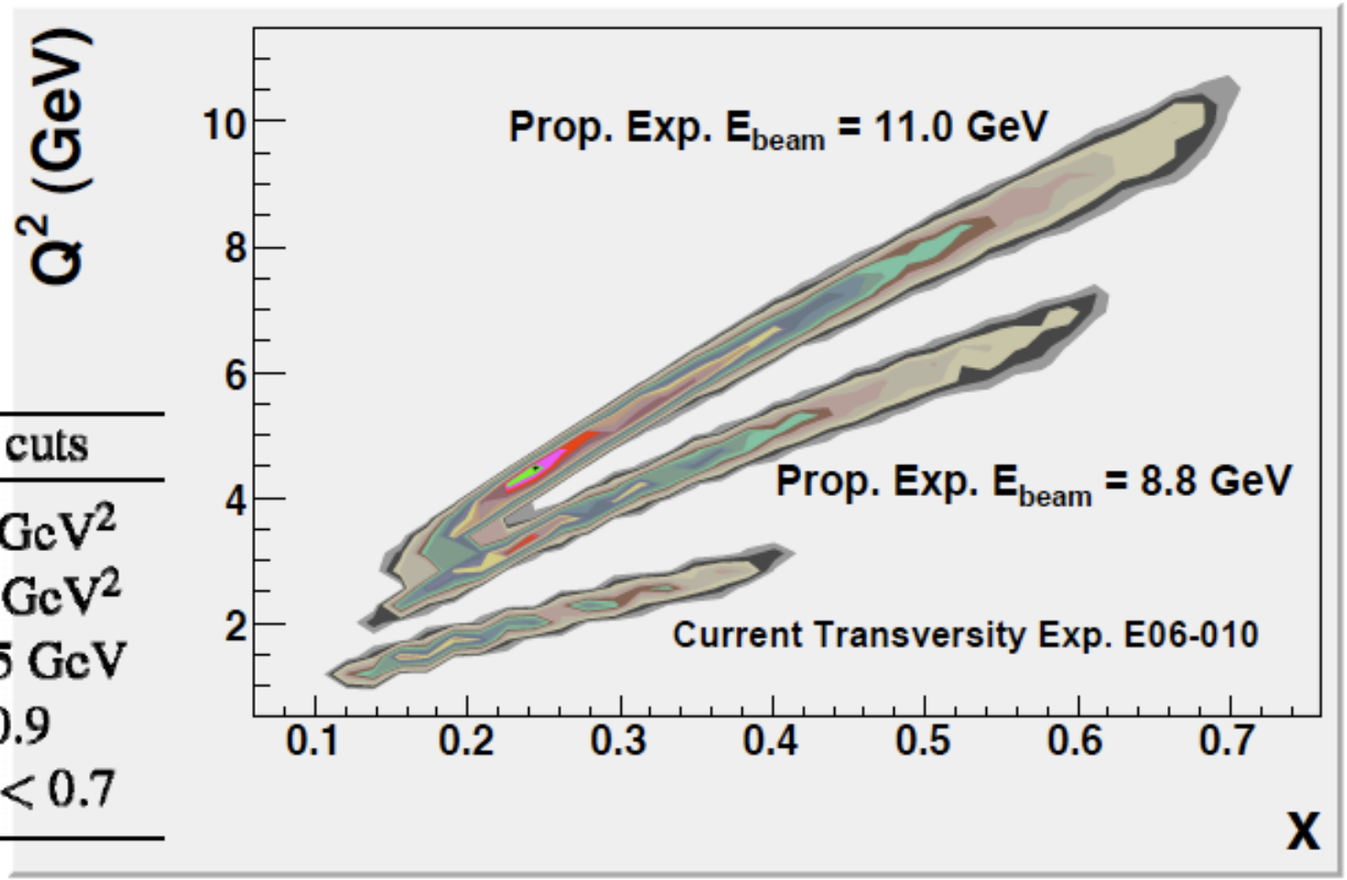
SBS: h-arm at 14°
Ω = 50 msr
GEM tracker
excellent PID / RICH
Hadron CALO

Beam: 50 μA, E=8.8 and 11 GeV (80% long. Pol.)
Target: 65% polarized 3He ⇐ GEn(2)/PR-09-016
⇨ Luminosity: 1.4×10^{37} $cm^{-2}s^{-1}$, 0.05 sr

Event rate: ~$10^4 \times$ HERMES
60 days of production
expected stat. accuracy:
1/10 of proton HERMES

Q^2 coverage

SIDIS cuts
$Q^2 > 1\ \mathrm{GeV}^2$
$W^2 > 5\ \mathrm{GeV}^2$
$W' > 1.5\ \mathrm{GeV}$
$y < 0.9$
$0.2 < z < 0.7$



We will investigate the Q^2 dependence of the Sivers and Collins functions, with overlap in the region of HERMES; reveal higher twist effects.

Analysis of the Q^2 effect will use also the results of presently running 6 GeV E06-010 Transversity experiment

Conclusion

- Proposed Super-Bigbite and SoLID spectrometers in Hall A enable a very exciting DIS program
- Neutron spin structure at high x: A^1_n
  - test fundamental predictions of nucleon structure.
  - flavor decomposition of polarized pdfs
- Parity violating DIS (PVDIS)
  - Excellent sensitivity to C2u and C2d.
  - Test CSV at quark level.
  - Unique window on higher twists.
- Semi Inclusive DIS (SIDIS)
  - ~3 orders of magnitude improvement
  - Transversity and TMDs
  - Entering a new era of precision study:
  - 3-dimentional "mapping" (x, PT and z)