A_1^n / d_2^n Measurement with JLab 12 GeV

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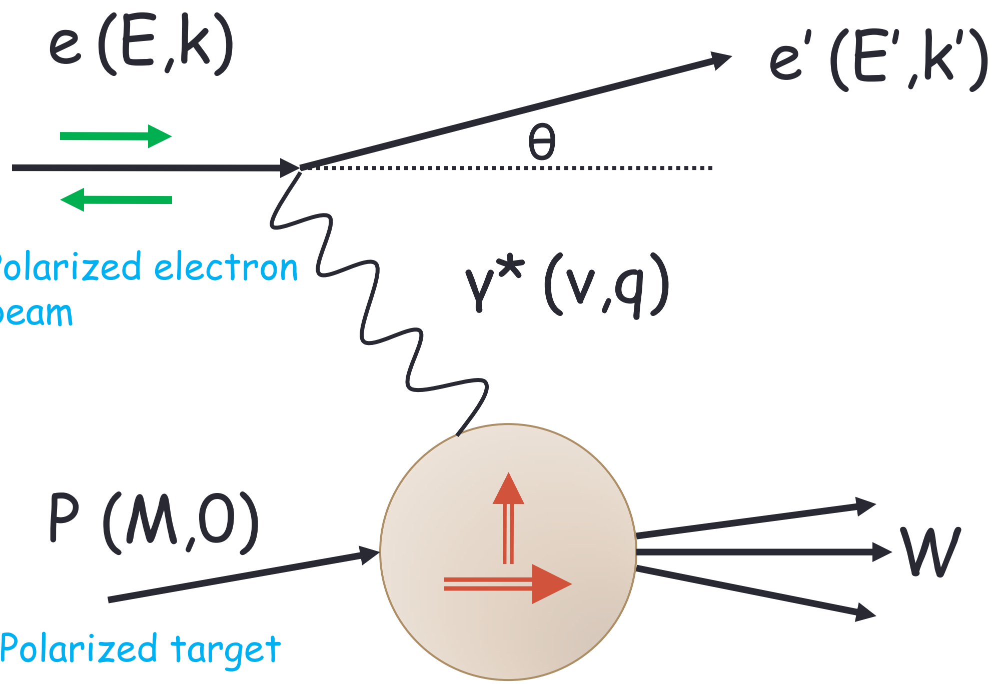
Outline

- Introduction
- Jlab 12GeV A_1^n/d_2^n Experiment
- Jlab Polarized ^3He Target Upgrade
- Summary

Electron Scattering



- Invariant Mass
  $W^2 = M^2 + 2M\nu - Q^2$
- Four momentum transfer squared
  $Q^2 = -q^2$
- Bjorken variable
  $x = Q^2/2M\nu$ for fixed target

g_1, g_2: polarized nucleon Spin structure function

$$\frac{d^2\sigma}{d\Omega dE'} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} (\alpha F_1(x,Q^2) + \beta F_2(x,Q^2) + \gamma g_1(x,Q^2) + \delta g_2(x,Q^2))$$

Structure Functions

- At the Bjorken limit, F_1, F_2 and g_1 related to

$$F_1(x) = 1/2\sum_i e_i^2\,(q_i^{\uparrow}(x) + q_i^{\downarrow}(x)) \qquad F_2(x) = 2xF_1(x)$$

$$g_1(x) = 1/2\sum_i e_i^2\,(q_i^{\uparrow}(x) - q_i^{\downarrow}(x))$$

- No simple interpretation for g_2 in naive parton model

- g_2 can be separated into leading and higher-twist components :

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2)$$

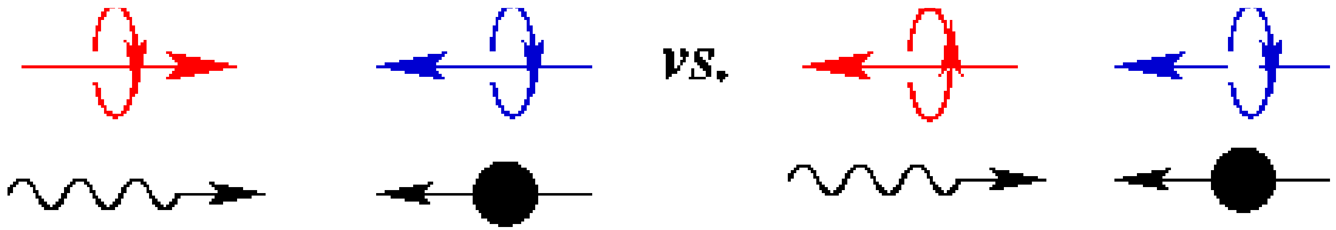
$$\overline{g_2}(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M}h_T(y,Q^2) + \varsigma(y,Q^2)\right]\frac{dy}{y}$$

  - $h_T(y,Q^2)$: *from quark transverse momentum contribution, suppressed by nucleon mass*
  - $\varsigma(y,Q^2)$: *from quark gluon interaction*

What is A_1

- Virtual photon-nucleon asymmetry

Photon Spin   Nucleon Spin



Opposite helicity $\sigma_{1/2}$ Same helicity $\sigma_{3/2}$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1 - \gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1} \quad \text{at large } Q^2 \qquad \gamma^2 = \frac{Q^2}{\nu^2} = \frac{4M^2x^2}{Q^2}$$

- Flavor decomposition to obtain Δu/u and Δd/d in the large x valence quark region from A_1^p, A_1^n

What is d_2

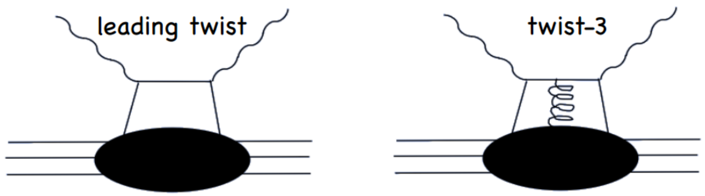
- The 2nd moment of a sum of the spin structure functions

$$d_2(Q^2) = \int_0^1 x^2\left(2g_1(x,Q^2) + 3g_2(x,Q^2)\right)dx = 3\int_0^1 x^2\left(\overline{g_2}(x,Q^2)\right)dx$$

- d_2 is the average transverse Lorentz color force acting on a quark immediately after being struck by a virtual photon

- Can be calculated in lattice QCD

- d_2 is a clean probe of higher twist effects, quantify quark-gluon correlations.



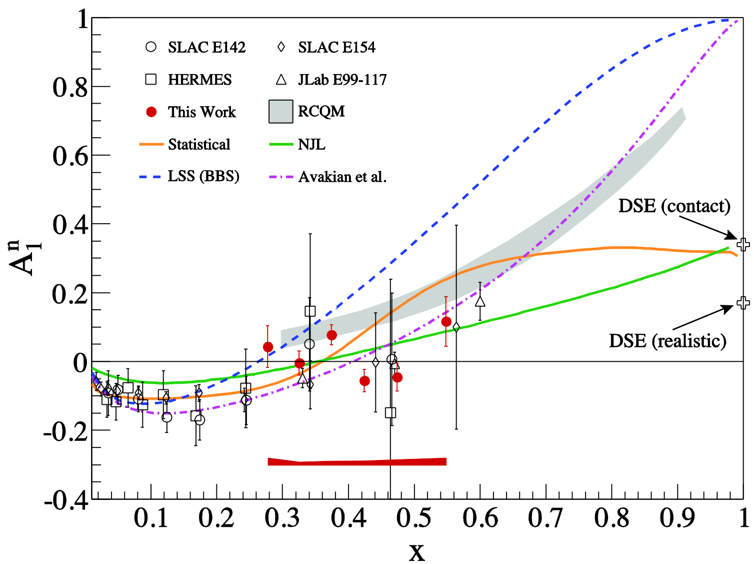
More Neutron A_1 and d_2 Data Needed

- Various Model predictions

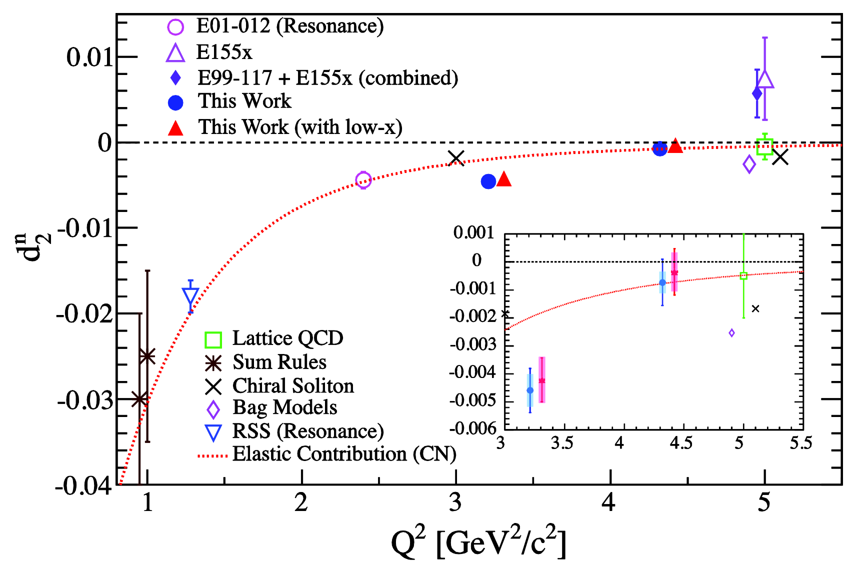
  eg. pQCD predicts $\lim_{x\to 1} A_1^n(x,Q^2) = 1$

  Basic SU(6) model $A_1^n = 0$

- discrepancy between data and theories at average $Q^2 \approx 5\ GeV^2$
- Need large x



X. Zheng et al., PRL **92**, 012004 (2004)
D.S.Parno, PLB 744 (2015) 309-314



M.Posik et al., PRL 113, 022002 (2014)

A_1^n / d_2^n Measurement

- Polarized ^{3}He target ⟹ Effective polarized neutron target
- A_1: through the double-spin asymmetries

$$A_1 = \frac{1}{D(1+\eta\xi)} A_{\parallel} - \frac{\eta}{d(1+\eta\xi)} A_{\perp}$$

- d_2: through the measurement spin dependent cross sections differences

$$\widetilde{d_2} = x^2(2g_1 + 3g_2) = \frac{MQ^2\nu}{4\alpha^2} \frac{Ex^2(4-3y)}{E'(E+E')} \left[\left(\frac{(4-y)}{(1-y)(4-3y)\sin\theta} - \cot(\theta)\right)\Delta\sigma_{\perp} + \Delta\sigma_{\parallel}\right]$$

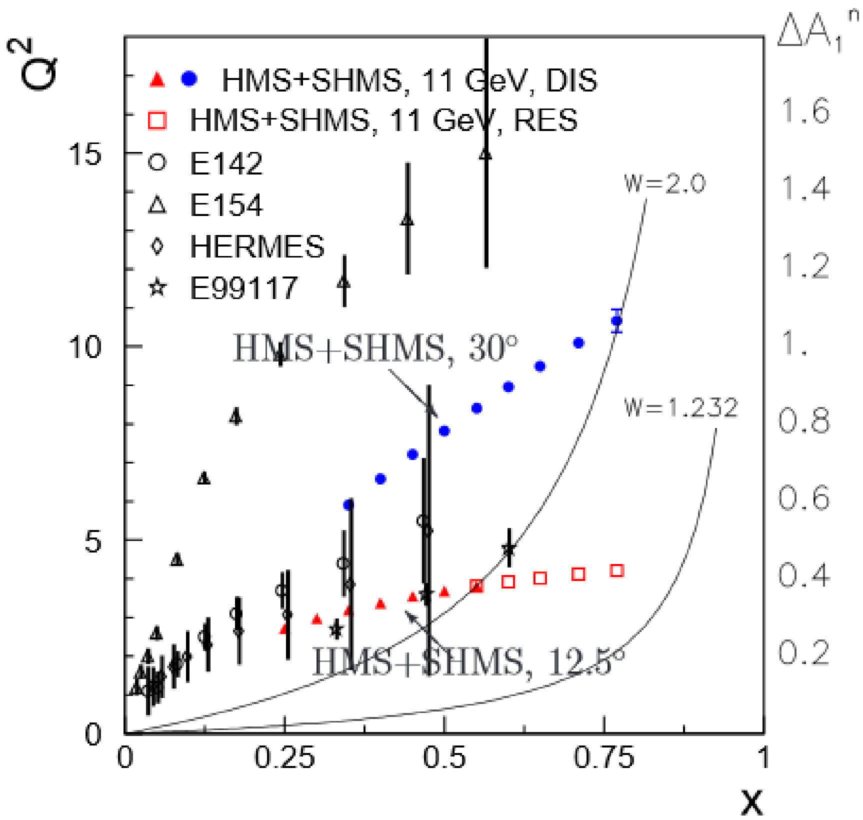
- Here $\Delta\sigma_{\parallel} = \sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}$ and $\Delta\sigma_{\perp} = \sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}$

❑ Experiments approved in JLab 12 GeV:

- A_1^n Hall A (E12-06-122) and A_1^n Hall C (E12-06-110)
- d_2^n Hall C (E12-06-121)

E12-06-110: A_1^n At 12 GeV

- Approved with A rating 36 days in Hall C
- Electron beam 11 GeV, $P_{beam} = 0.85$
- ^{3}He target: 60cm length, $pol = 60\%$, 3% uncertainty, at $60\mu A$ beam

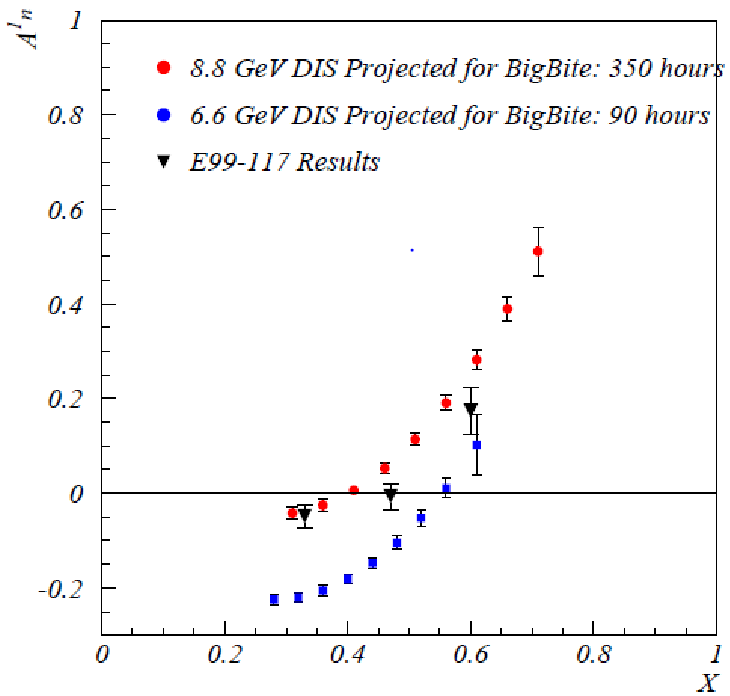


- Use HMS + SHMS simultaneously
- Push to high x, up to 0.77
- Explore Q^2 dependence

Spokespeople:
G. Cates
J.-P. Chen
Z.-E. Meziani
X. Zheng

E12-06-122: A_1^n At 12 GeV

- Approved with A- rating 23 days in Hall A
- Electron beam 6.6, 8.8 GeV, $P_{beam} = 0.8$
- $^3\mathrm{He}$ target: 40cm length, $pol = 65\%$, 3% uncertainty, at $30\mu A$ beam
- Third set of Q^2 values for interpolation

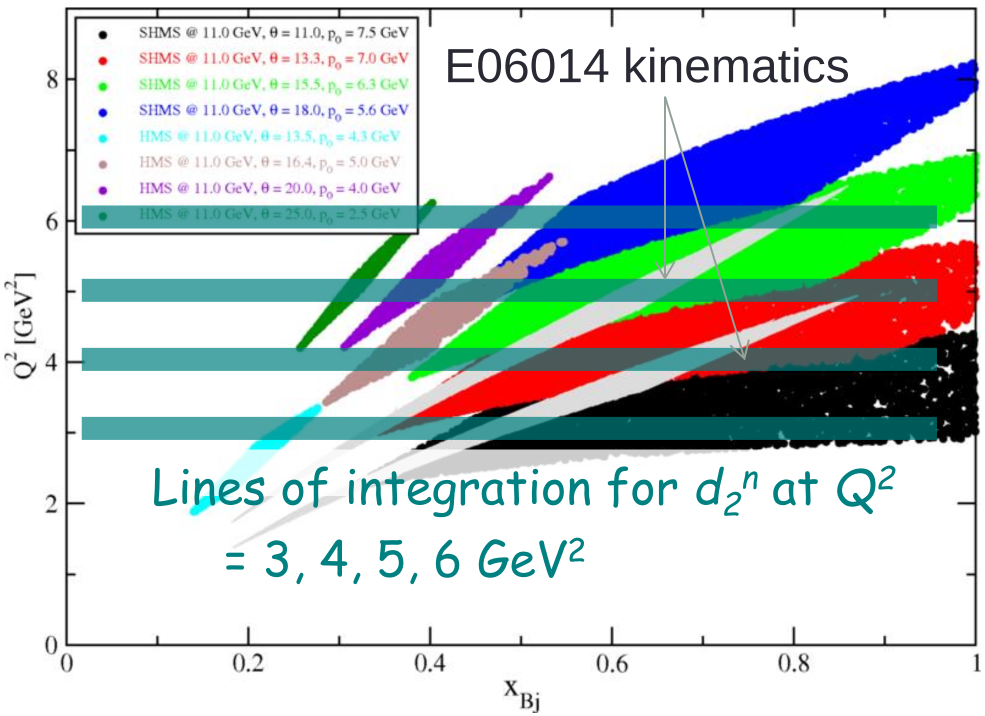


- BigBite: Primary measurement
- LHRS: Cross-check (lower statistics)
- Test of open-geometry measurement technique

Spokespeople:
T. Averett
G. Cates
N. Liyanage
G. Rosner
B. Wojtsekhowski
X. Zheng

E12-06-122: d_2^n At 12 GeV

- Approved with A- rating 29 days in Hall C
- Electron beam 11 GeV, $P_{beam} = 0.8$
- $^3\mathrm{He}$ target: 40cm length, $pol = 55\%$, 3% uncertainty, at $30\mu A$ beam
- Directly Measure at 4 constant Q2 values



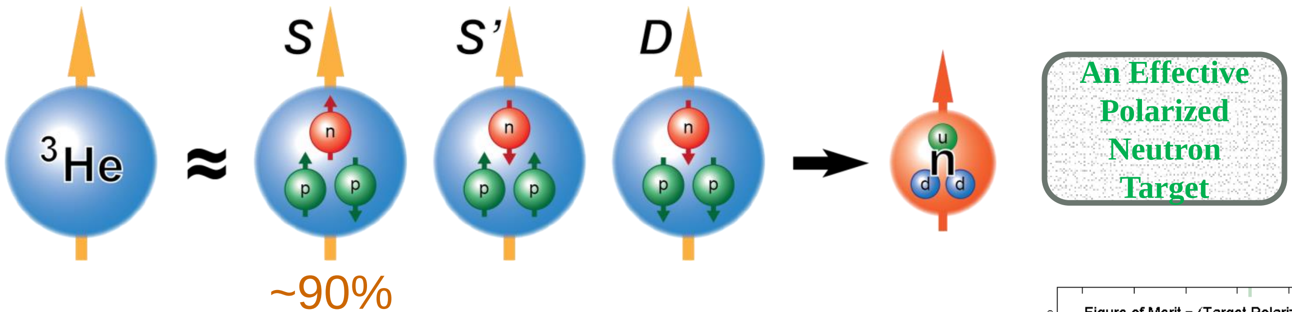
- SHMS: large x range at nearly constant Q2
- HMS: fill in gaps at low $x < 0.5$

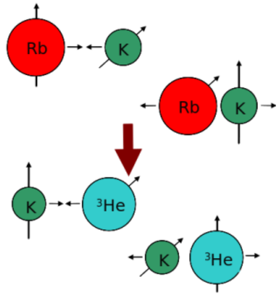
***Spokespeople*:**
T. Averett
W. Korsch
Z.-E. Meziani
B. Sawatzky

Polarized ^3He target

❑Why ^{3}He target

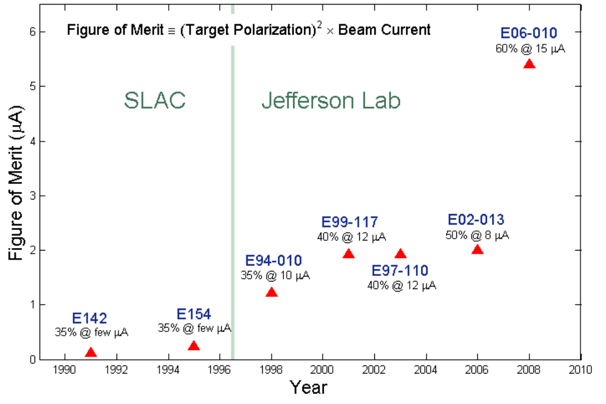
- Polarized targets essential for nucleon spin structure study
- Free neutrons, short lifetime < 15 minutes





❑How to polarize ^{3}He Target

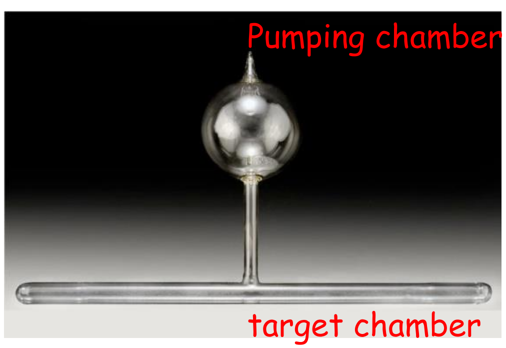
➢ Spin-exchange optical pumping (**SEOP**)
- Polarize the alkali metal atoms
- Exchange spin with ^{3}He

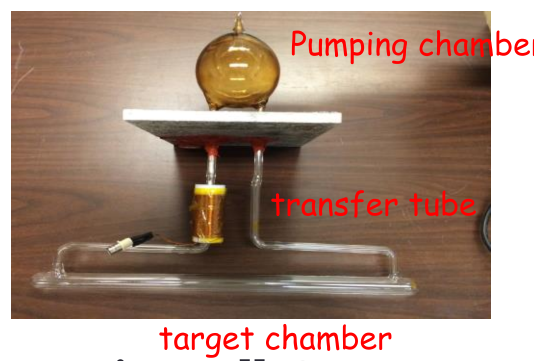


❑ 6GeV era: In-beam target polarization 60% with 5% uncertainty at 15μA

^3He target Upgrade

- Firstly upgrade the target with a factor of 2~3 in FOM of the best achieved, to satisfy A_1^n-Hall A (d_2^n-Hall C) requirements/plan:
  - 30 uA on 40 cm convection cell, 60% in beam, 3% polarimetry
  - Use transversity setup with convection cell
    - Uniform polarization between target and pumping chambers
    - → 60% achievable
    - → Eliminate diffusion uncertainty
  - Pulsed NMR, calibrated with EPR and AFP NMR/water ,
  - k_0 measurements (UVa and W&M)

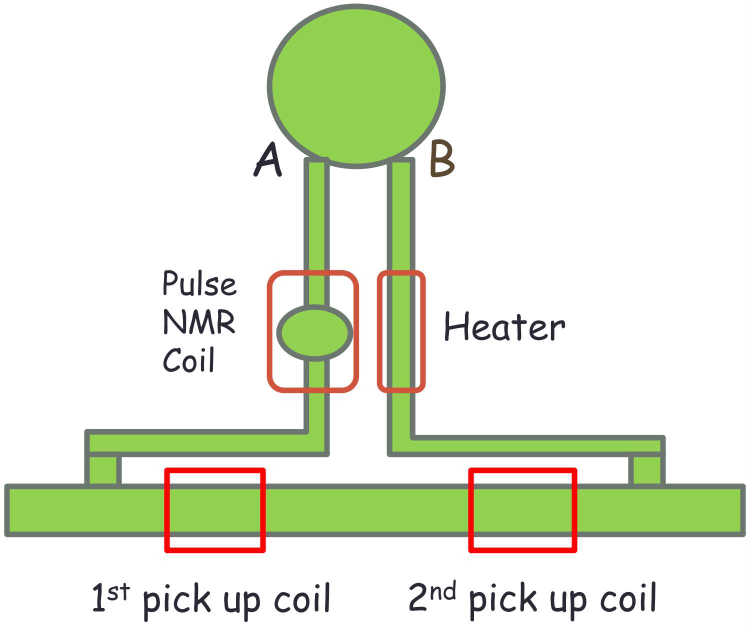


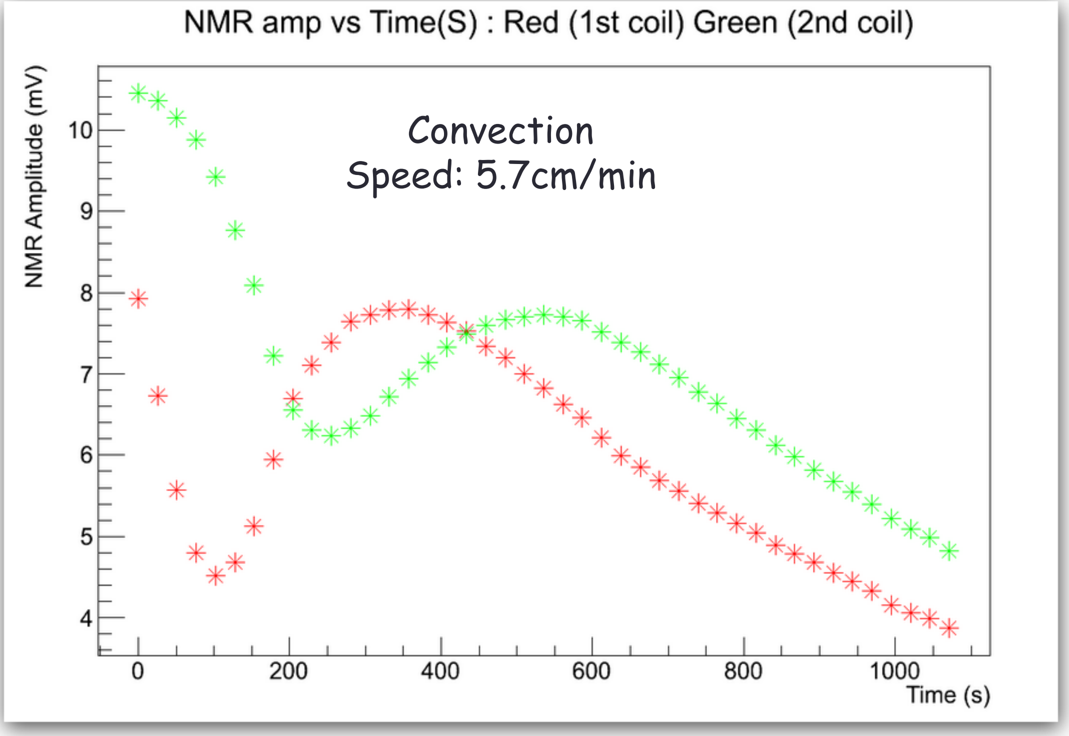


- **Secondly upgrade to meet the need for A_1^n in Hall C**

^{3}He Convection Speed Test

- Convection can be much fast than diffusion (~40mins)

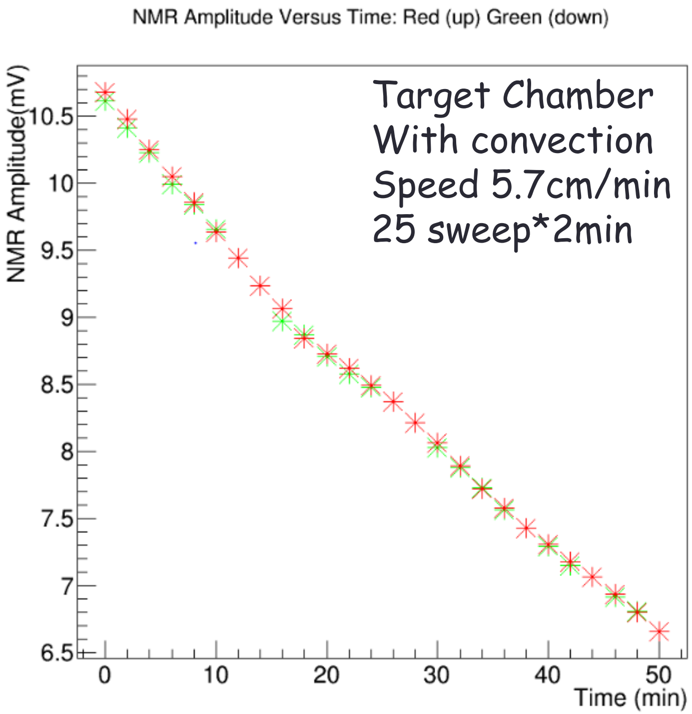


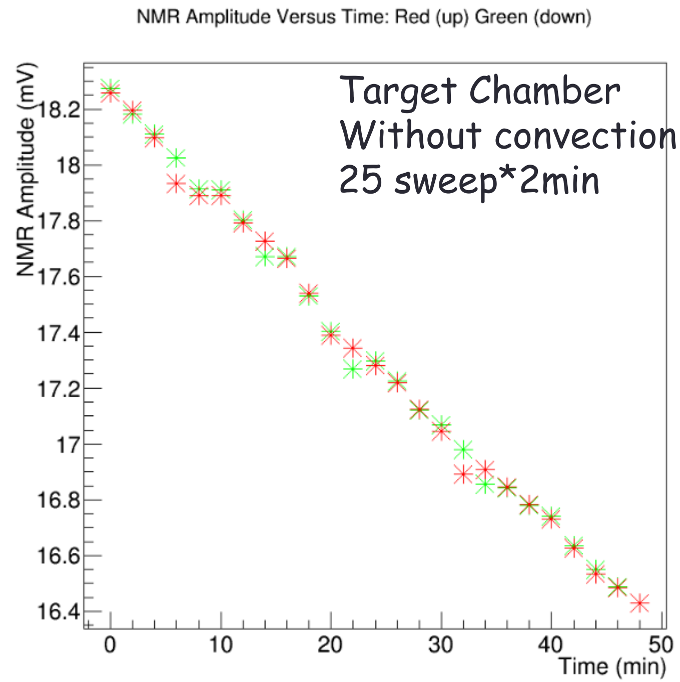


Convection from pumping chamber A to target chamber: ~1 min

Convection from pumping chamber A, through target chamber, back to B: ~8 mins

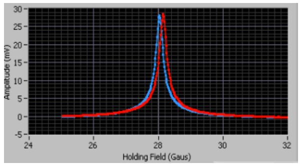
AFP Loss Study





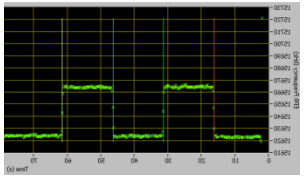
AFP Loss Per Sweep	Target Chamber	Pumping Chamber
AFP Without Convection	0.16%	0.72%
AFP With Convection	0.85%	0.87%

^{3}He Target Polarimetry



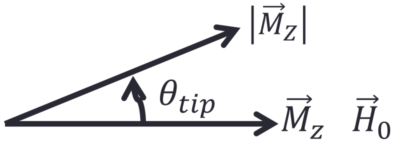
❑Adiabatic Fast Passage (AFP) - NMR

- AFP-NMR works for both 3He and water
- AFP loss significant for longer/larger cell due to field gradient
- Will not work for metal target chambers or hybrid glass/metal cells



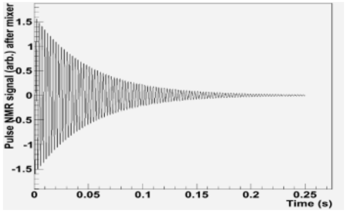
❑Electron Paramagnetic Resonance (EPR)

- EPR will still work



❑Pulsed NMR

- Send a pulse tuned at Larmor Frequency
- Spin presses tipping from holding field
- $\theta_{tip} = \frac{1}{2}\gamma H_1 t_{pulse}$
- Spin components orthogonal to holding field,
- Have free-induction-decay, Amplitude$\propto M_z \sin(\theta_{tip})$

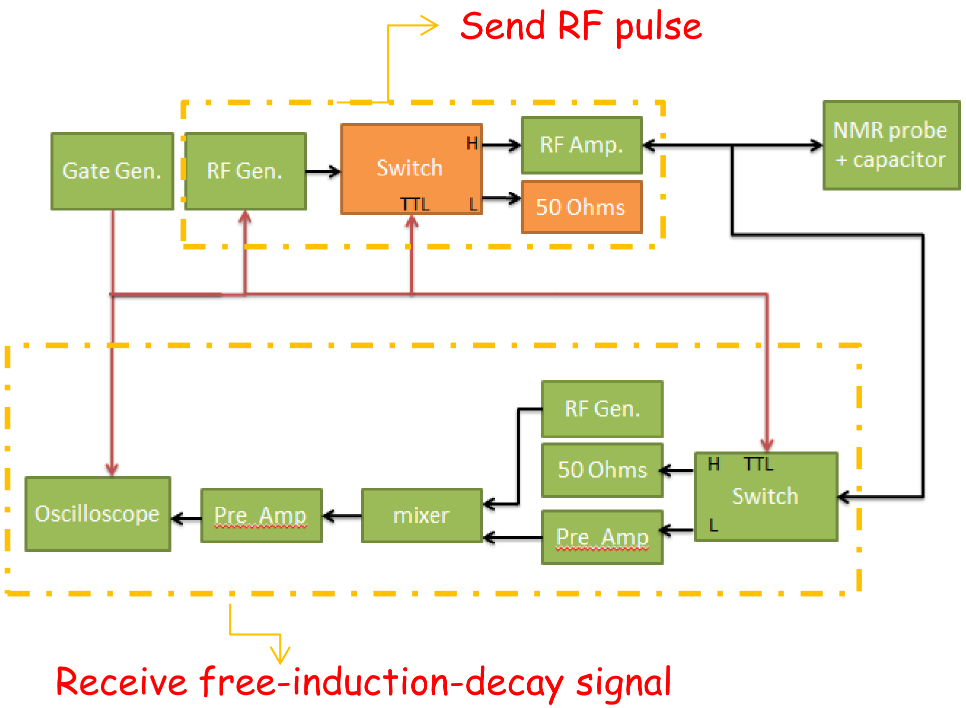


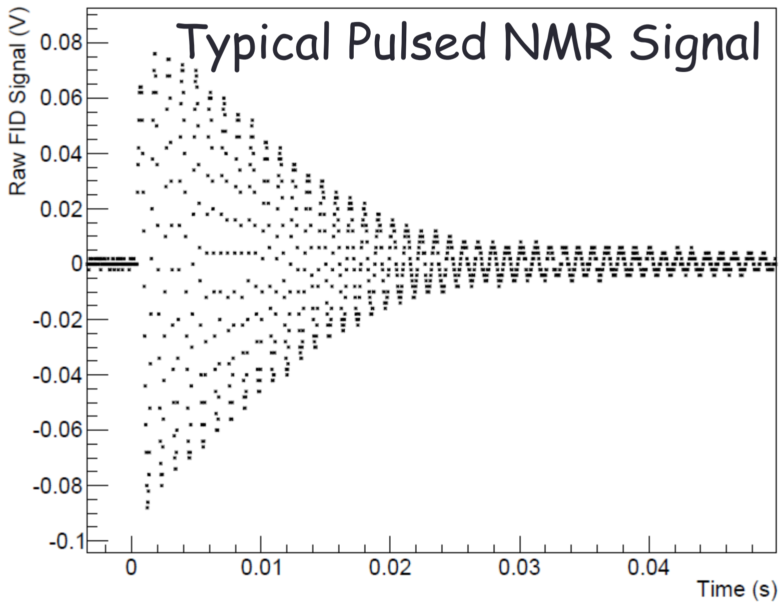
Theory:
$S \propto M_z \sin(\theta_{tip}) e^{-t/T_2} \sin(wt)$

AFP-NMR will not be suitable for measurement on target chamber of glass/metal cell. Pulsed NMR can work on transfer tube

Pulsed NMR @JLab

❑ Pulsed NMR Set Up





To improve Signal/noise

Summary

- The JLab 12GeV ***A_1^n /d_2^n*** experiments will push kinematics to large x and cover a wide Q^2 region
  - test pQCD and Lattice QCD
  - probe higher-twist effects/quark gluon correlation
  - Explore nucleon spin structure
  - Explore Q^2 evolution
- Polarize ^{3}He Target R&D in progress

  Goal: full system ready for 12GeV A_1^n -Hall A experiment by 2016

Thanks