Weak Interaction Studies with $\vec{e} + {}^{3}\mathrm{He} \rightarrow {}^{3}\mathrm{H} + \nu$

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in collaboration with
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PEB Workshop
@ MIT
March 14-16, 2013

Weak Currents and QCD

- One of the main goals of QCD is to understand nucleons and nuclei in terms of quarks and the forces of QCD.
- We believe that the spontaneous breaking of chiral symmetry of QCD is responsible for the large effective mass of quarks confined in nucleons and nuclei.
- The best way to study these effects is to measure the weak currents in nucleons and nuclei. The axial current is of primary importance.
- However, the axial form factor of light nuclei such as ^{3}He has never been measured.
- Weak interaction measurements will also provide information about axial two-body currents.
- Weak capture of polarized electrons in ^{3}He has great potential to fill this gap and also help test for 2^{nd} class currents.
- Complementary to e-capture in proton discussed by A. Deur.

Second Class Currents

Introduced by Weinberg Phys. Rev. **112**, 1375 (1958)

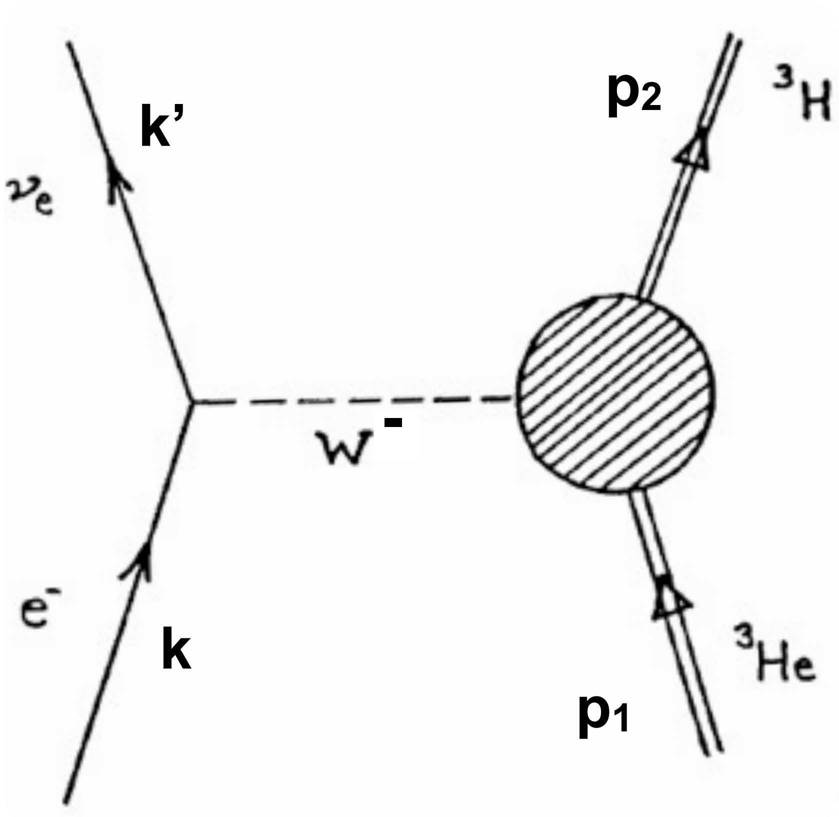
Represent the properties of strangeness conserving (ΔS=0)
Vector and Axial currents under G-parity transformation

First class: $$GV_\mu^{(I)\pm}G^{-1} = V_\mu^{(I)\pm}, \quad GA_\mu^{(I)\pm}G^{-1} = -A_\mu^{(I)\pm}$$

Second class: $$GV_\mu^{(II)\pm}G^{-1} = -V_\mu^{(II)\pm}, \quad GA_\mu^{(II)\pm}G^{-1} = A_\mu^{(II)\pm}$$

Experimentally, so far there is no evidence for or against the existence of second class currents

The $e + {}^3He \rightarrow {}^3H + \nu$ Reaction



q = k-k', **P** = p_1-p_2

Neglecting lepton masses

$$\frac{d\sigma}{d\Omega_n} = K(E_e, E_\nu, \theta_\nu)\sigma_0(f_E, f_M, f_A)$$

f_E, f_M, f_A are the electric, magnetic and axial formfactors of ^3He

Neglecting electron mass, there are no contributions from 2nd class currents and no spin-momentum correlations.

Small cross section ~ 10^{-40} cm^2/sr

Spin Dependent e-Capture

If the mass of the electron is not neglected
(relevant for the low energies proposed here)

$$\frac{d\sigma}{d\Omega_n} = K(E_e, E_\nu, \theta_\nu)\sigma_0 \left[1 + \frac{m_e}{\sigma_0}[(k' \cdot s)g_1(W_1, W_2, W_5) + (P \cdot s)g_2(W_2, W_5) + (q \cdot s)g_3(W_5, W_6)]\right]$$

q = k - k'; **P** = p_1 - p_2 ; **s** = electron spin vector

W_{1-6} are functions of the nuclear form factors
with **W_5** and **W_6** entirely due to second class currents

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Observation of a non-zero correlation between q-vector and electron spin direction would be sufficient to verify the existence of second-class currents.

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Also relevant for the $\vec{e} + p \rightarrow \nu + n$ reactions discussed in the previous talk

Spin Dependent e-Capture

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Ignoring second class currents and for $q^2 << M^2_{Targ}$

$$\frac{d\sigma}{d\Omega_n} = K(E_e, E_\nu, \theta_\nu)\sigma_0[1 + A_1 + \gamma h m_e A_2 \cos\theta_n (1 + \frac{|f_A(q^2)|^2}{|f_V(q^2)|^2})],$$

h is electron helicity, f_A and f_V are axial and vector formfactors of ^3He

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The coefficient of the $\cos\theta_n$ moment of the longitudinal asymmetry can give us the ratio of the axial to vector formfactor

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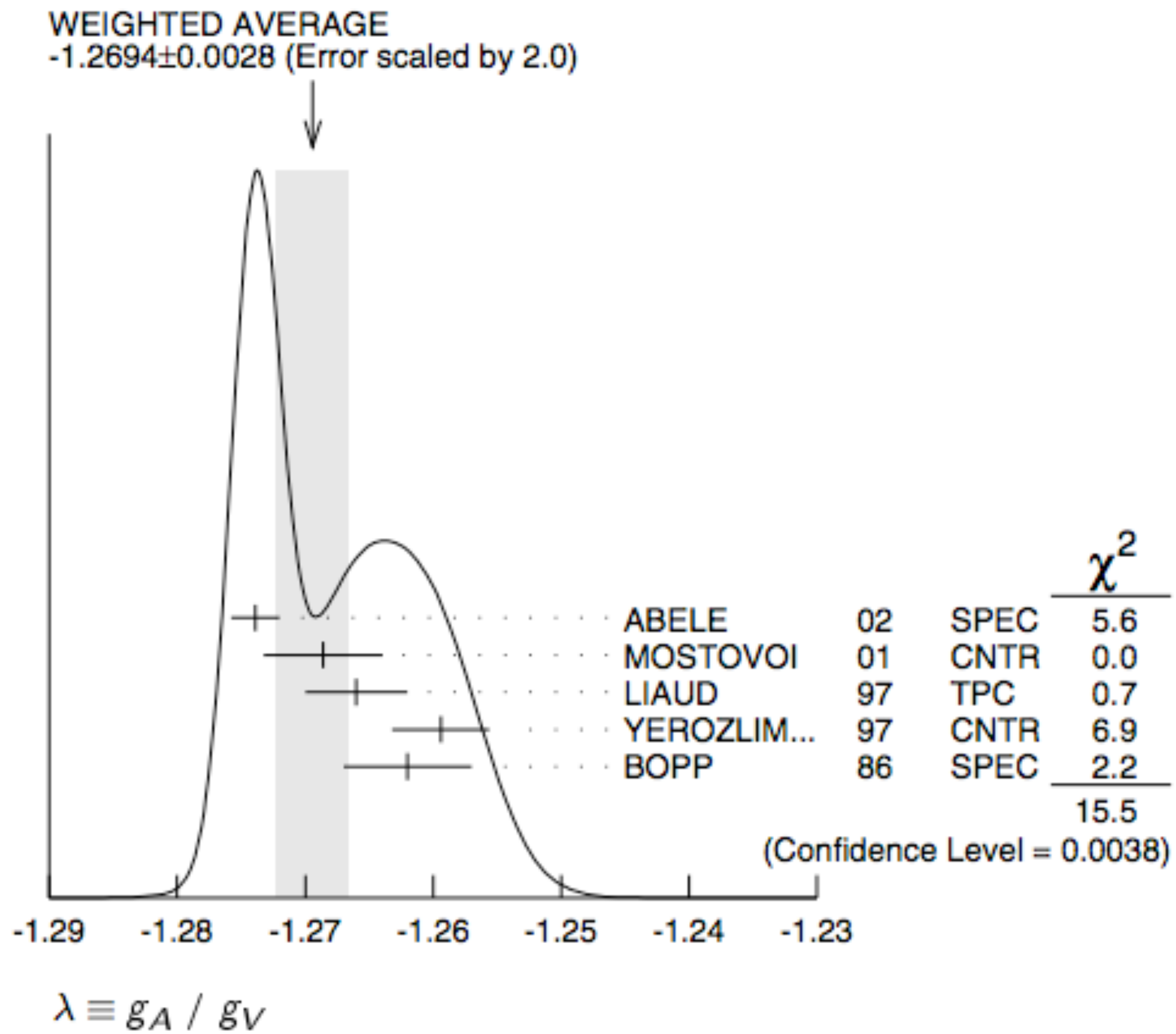
Implies that $\vec{e} + p \rightarrow \nu + n$ reaction will allow access to $|g_A(Q^2)/g_V(Q^2)|$ via a new method unlike the ones traditionally used to measure this ratio.

PDG Compilation of g_A/g_V



The most precise measurements of g_A/g_V from neutron beta decay seems to be inconsistent with each other.

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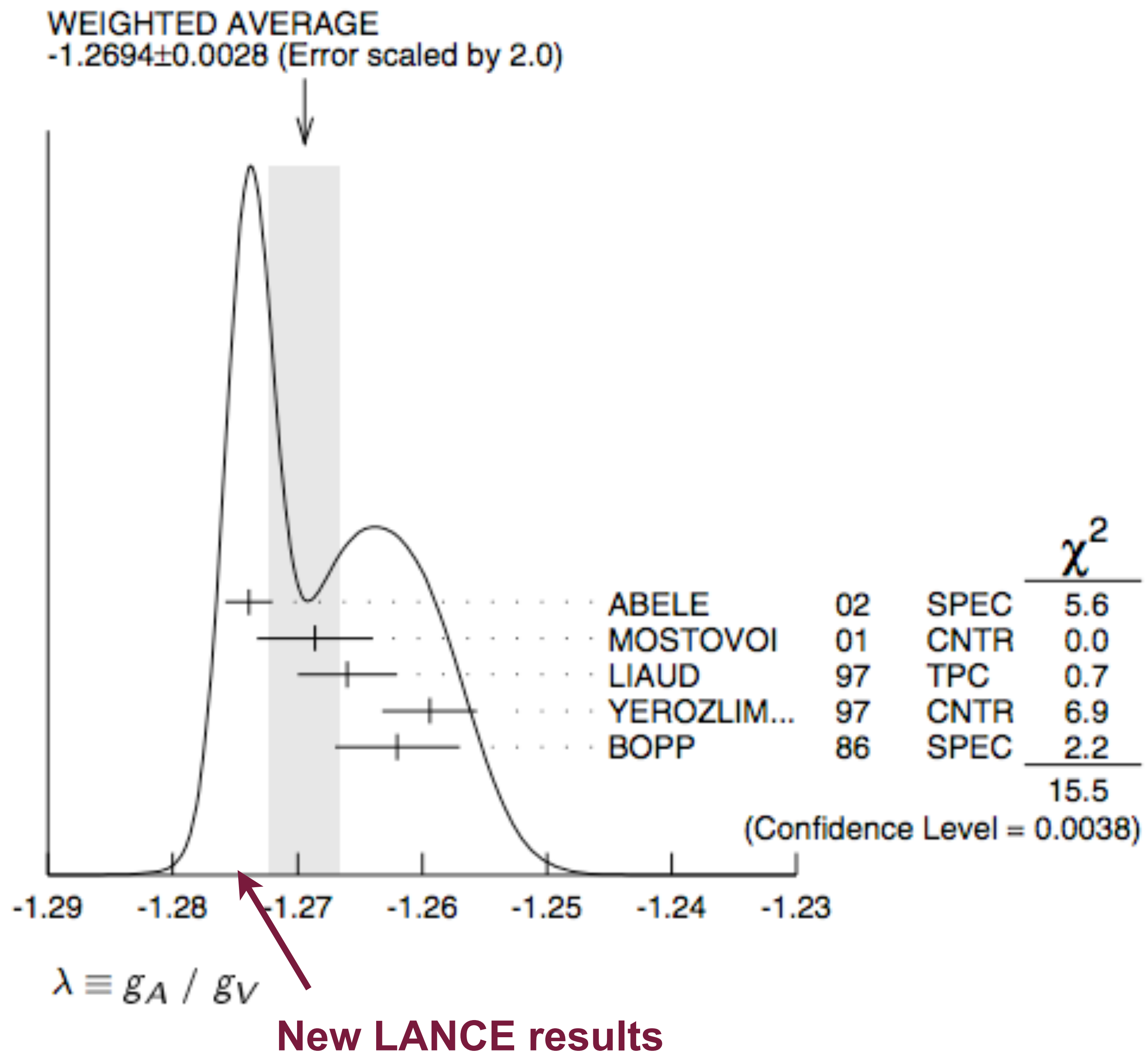

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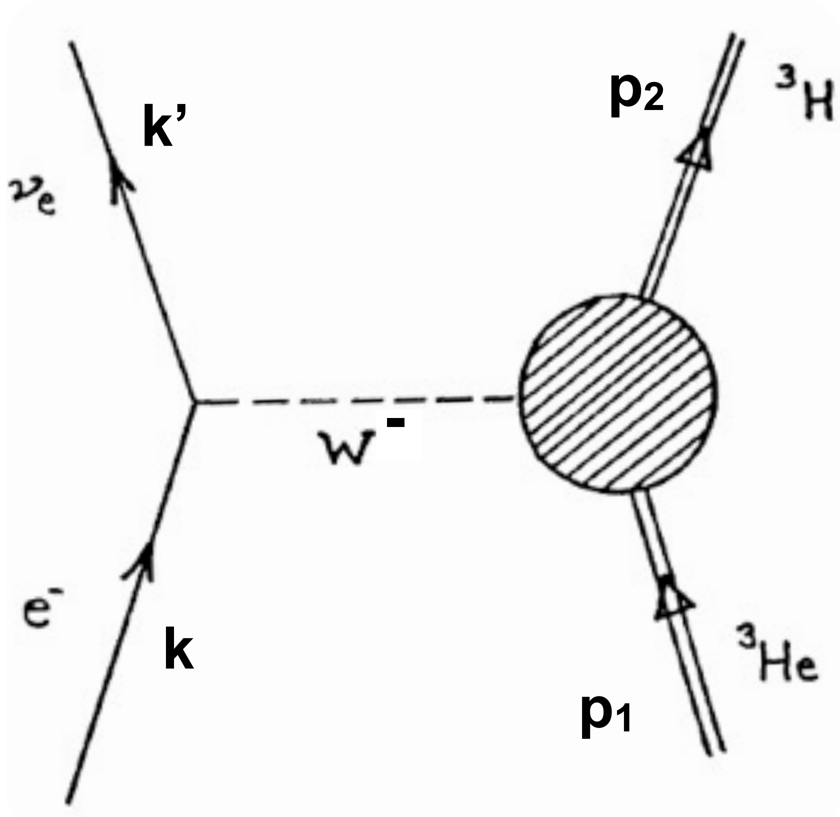

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Neglecting lepton masses

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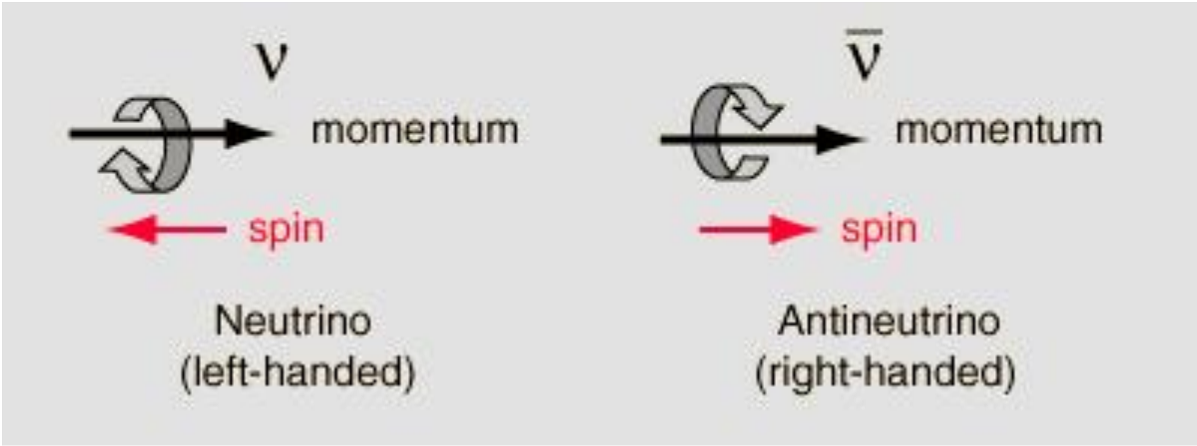
f_E, f_M, f_A are the electric, magnetic and axial formfactors of ^{3}He

Want to measure a small cross section buried under electromagnetic background to extract the axial formfactor of ^{3}He

Strategy:

- Detect 3H in backward lepton kinematics to enhance Weak/EM cross sections
- Detect elastic backward going electrons in coincidence to reduce backgrounds
- Use high intensity low energy beam with a thin target
- Use polarization degrees of freedom to cleanup parity conserving backgrounds

Spin Dependent e-Capture



Only left-handed neutrinos exist in the Standard Model with massless neutrinos.

If polarized electrons are used

$$\vec{e} + {}^{3}He \rightarrow {}^{3}H + \nu$$

cross section is non-zero only for left handed electrons

For a symmetric detector any parity conserving (electromagnetic) background would cancel in:

$$\sigma\ (h=+1)\ \ -\ \sigma\ (h=-1)$$

Backgrounds

- Elastic scattering from ^3He and ^3H (cross sections 8 - 9 orders of magnitude larger)
  - Elastic rates ~ 10^5 - 10^6 Hz compared to 10^{-3} Hz for signal
  - Target must be ultra-pure with ^3H contamination at 10^{-9} level
  - Elastic background can be reduced by detecting the scattered e^- in coincidence

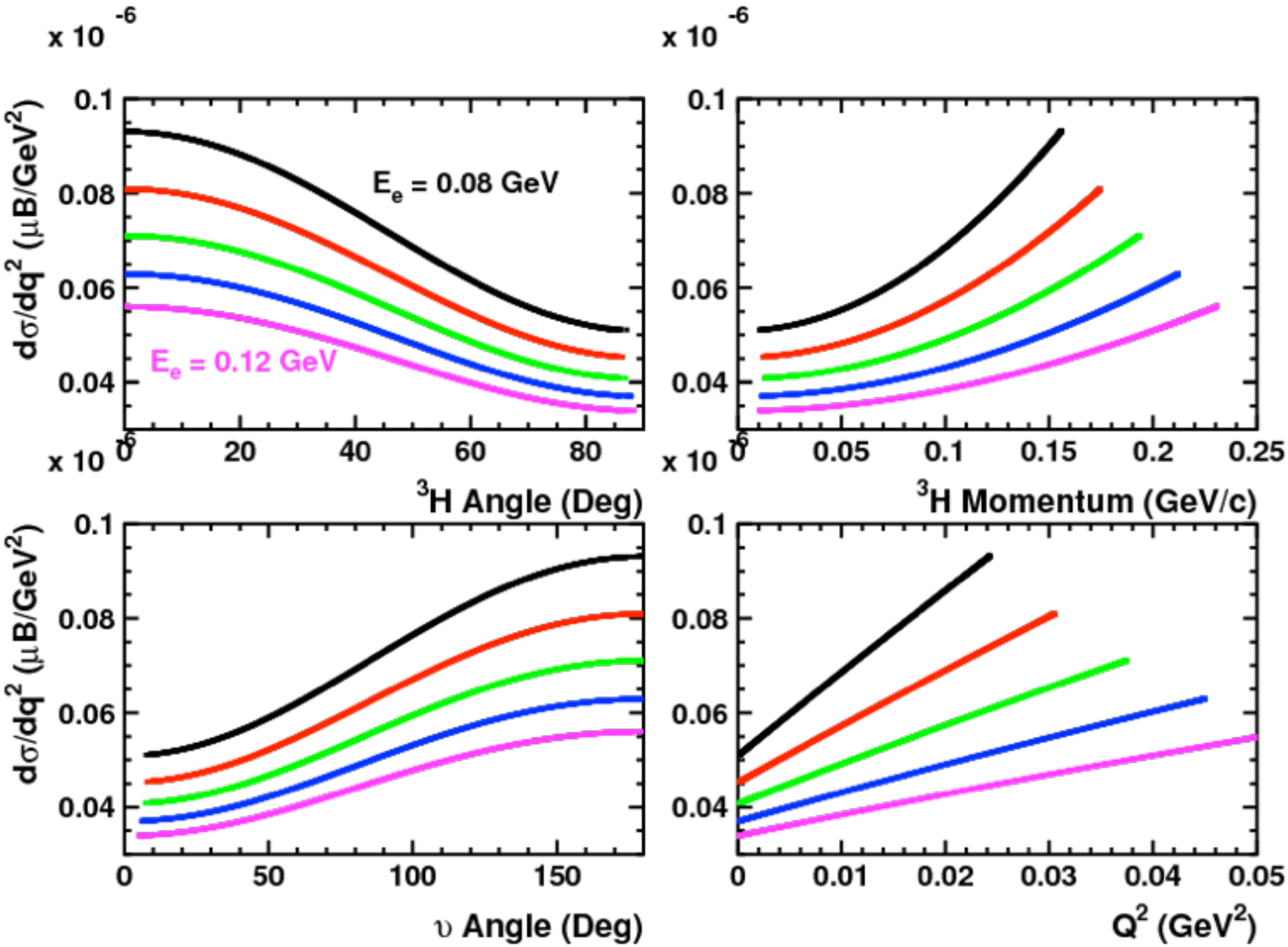
- Elastically scattered ^3He undergoes charge exchange with cell wall to yield ^3H
  - Detect scattered e^- in coincidence

- Elastically scattered ^3He picking up an e^- to become indistinguishable from ^3H
  - Charge sensitive detector
  - Detect scattered e^- in coincidence

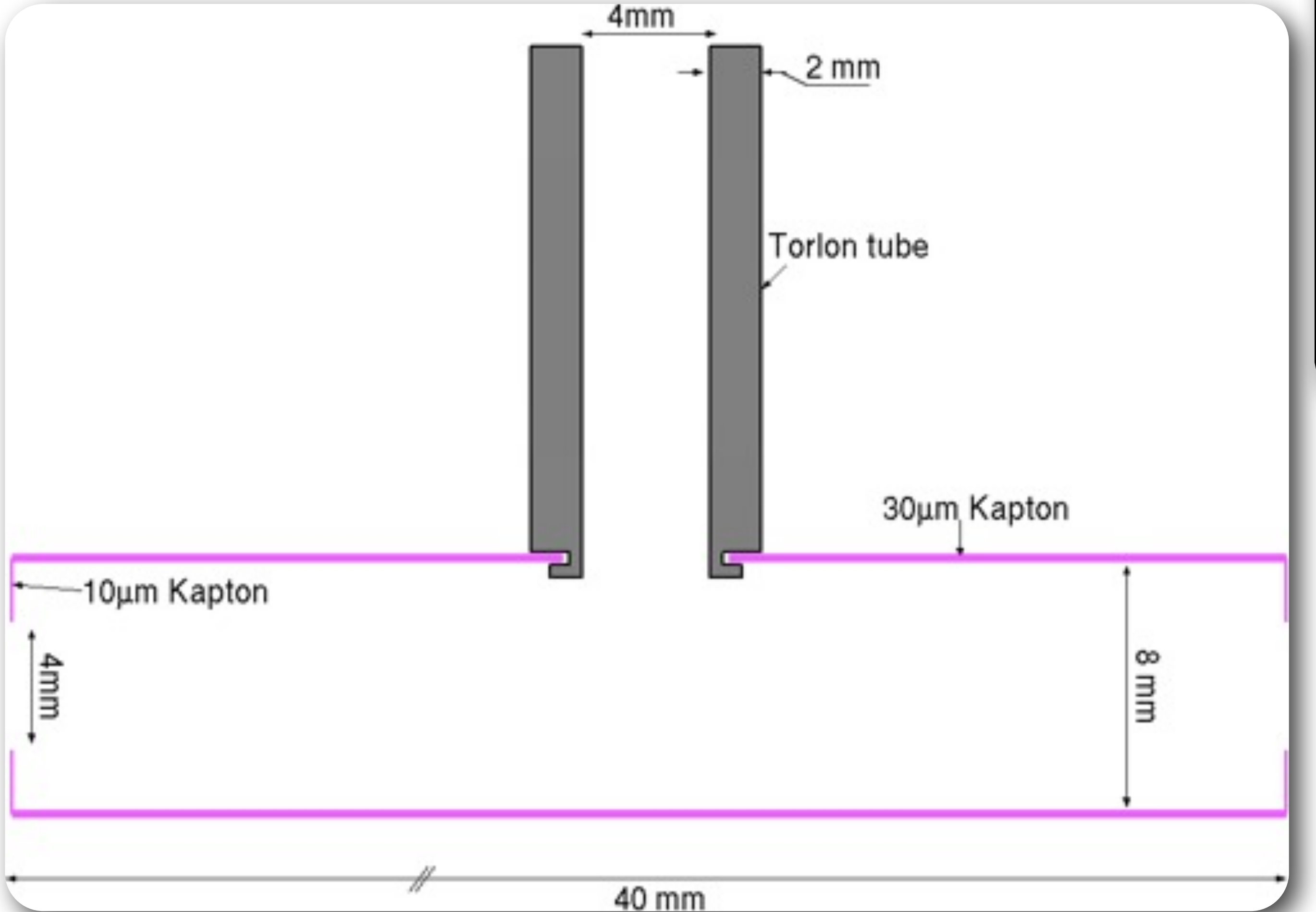
Use longitudinally polarized electrons with high polarization

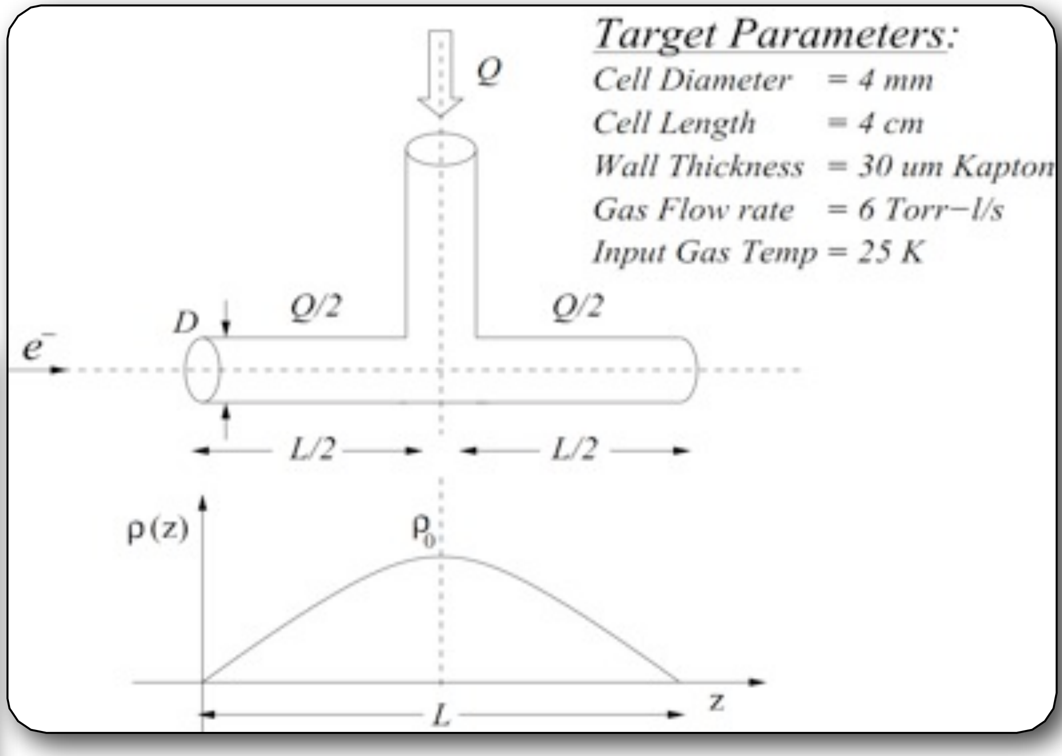
Weak Charged Current Cross Sections

Using $\langle r_c^{3He} \rangle$ = 1.87 fm; $\langle r_m^{3He} \rangle$ = 1.74 fm
$\langle r_c^{3H} \rangle$ = 1.70 fm; $\langle r_m^{3H} \rangle$ = 1.70 fm



Windowless Target





under development at JLab for the

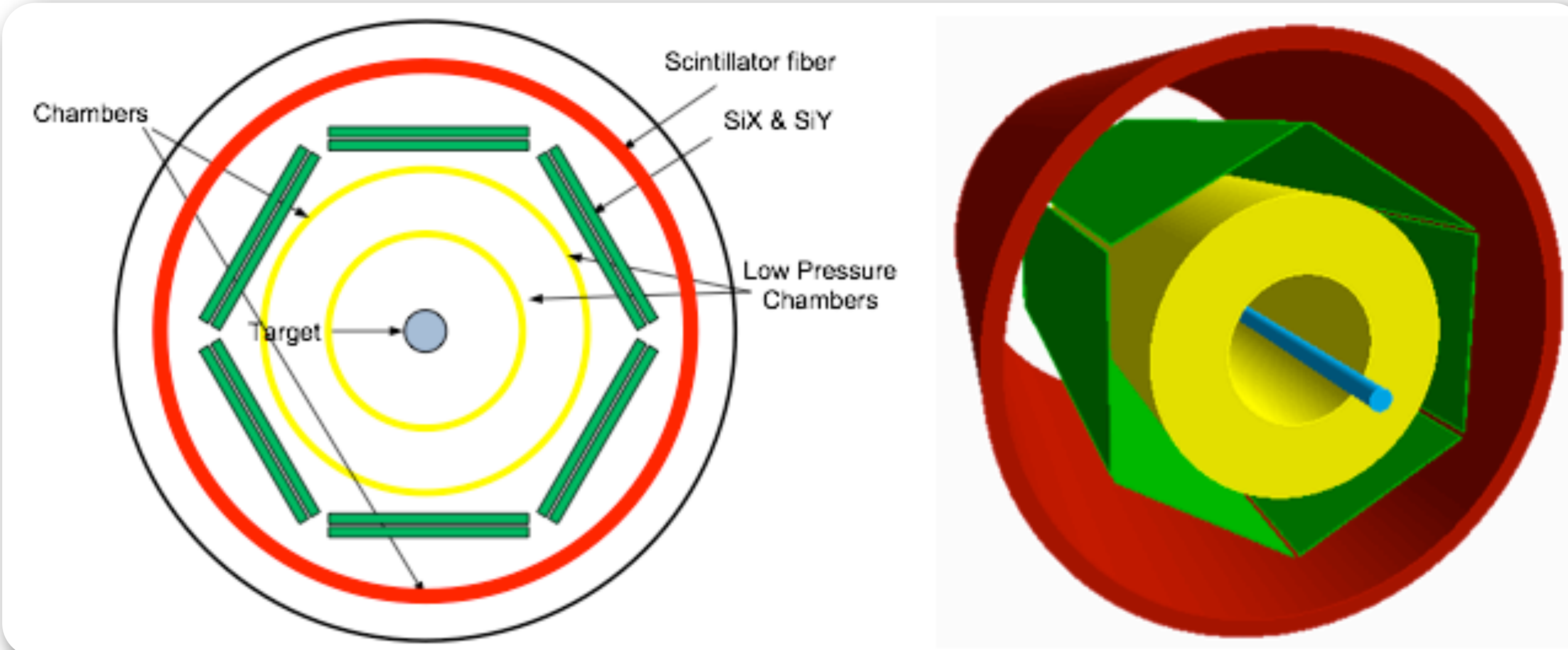
Proton Charge Radius Experiment (PRAD)

A. Gasparian (NCA&T), D. D(Miss. State), H. Gao (Duke) and M. Khandakar (Idaho State)

Similar target also being developed for the DarkLight experiment at the JLab FEL

Detector Design

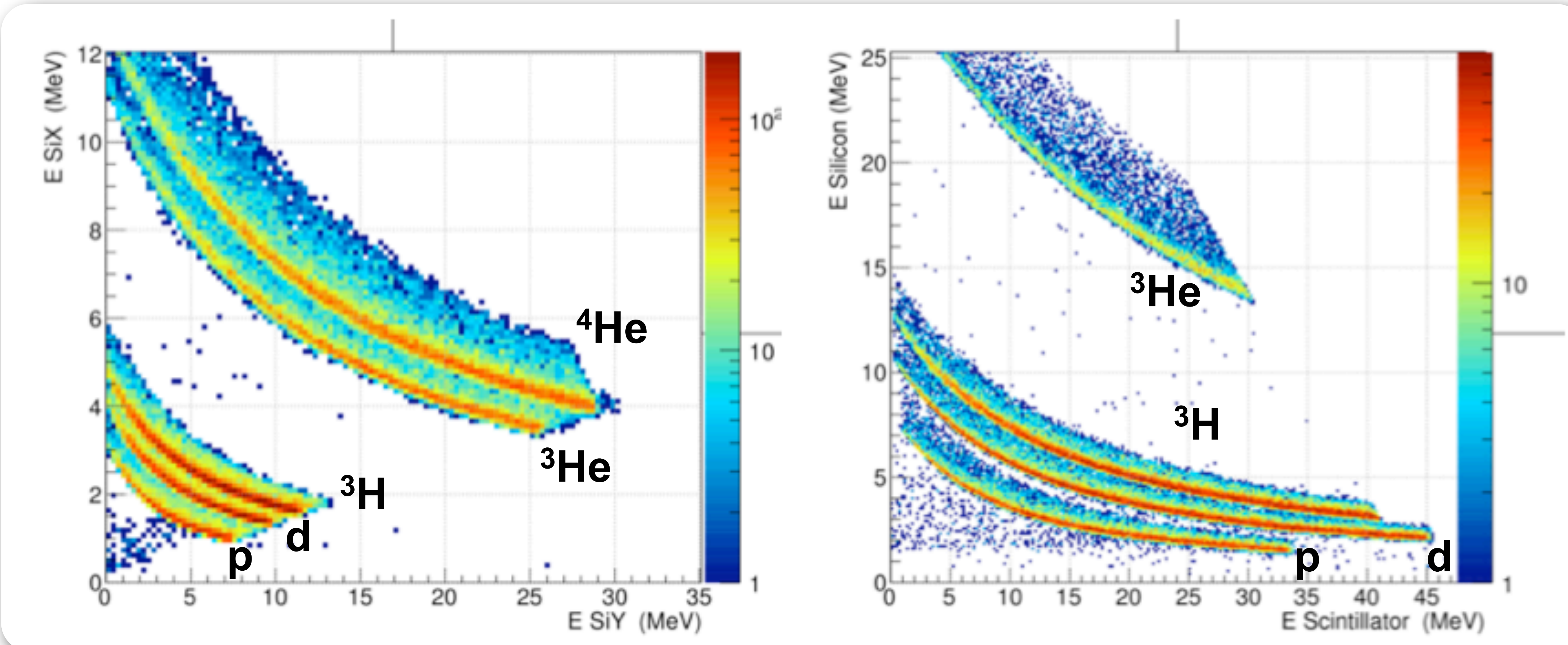
Large acceptance (2π polar angle and 20° - 160° azimuthal)
with a solenoidal/toroidal field



Avalance Chambers	**r = 4 & 8 cm, σ ~ 100 ps/ 200 μm**
Chamber Gas	**2-10 Torr Isobutane**
Chamber Windows	**40-50 μg/cm² Polypropylene**
Silicon Micro-strips	**r = 10 cm, t ~ 100 & 400 μm, σ ~ 100μm**
Scintillator	**r = 15 cm, t ~ 2 cm**

Low Energy Recoil Detector under development
by K. Hafidi (ANL), R. Dupré (Saclay) and S. Stepanyan (JLab)

Detector Design



Momentum range
of ^{3}H 80 - 550 MeV/c

× through tracks
⊗ stopped tracks

Component				Particle	Threshold (MeV/c)				
WC	SiX	SiY	SC	Identification	p	d	^3H	^3He	^4He
×	⊗			$\Delta E_{WC}, E_X, T$	55	75	95	150	180
×	×	⊗		$\Delta E_X, E_Y$	80	120	160	240	290
×	×	×	⊗	$\Delta E_{X+Y}, E_{SC}$	130	210	280	420	

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Projected Rates

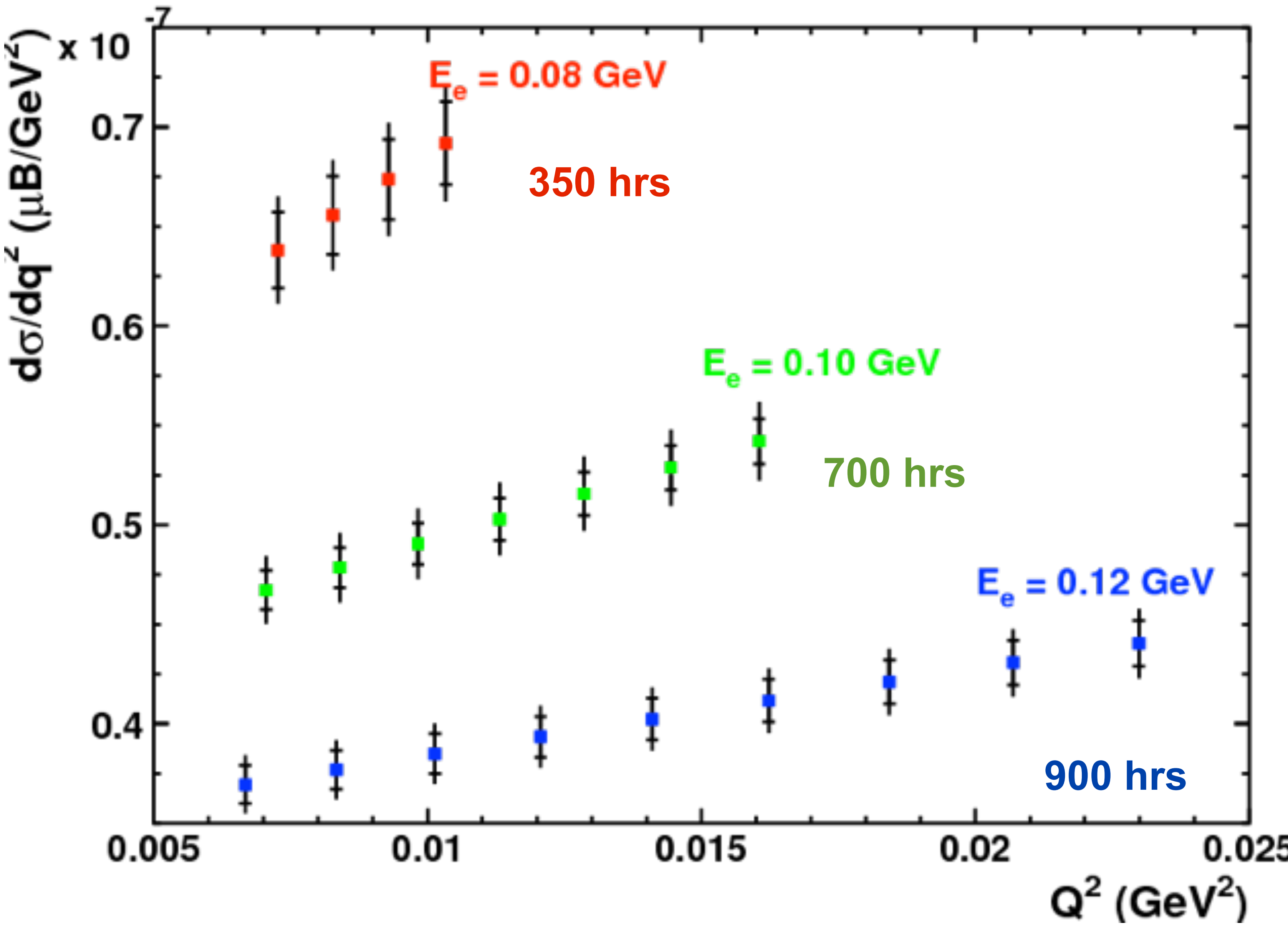
I_e = 600 μA, polarized beam

Target density ~ 10^{19} atoms/cm^2

Luminosity ~ 4×10^{34} /cm^2

Rates @ E_e = 0.08 GeV ~ 8×10^{-4} /sec

⇒ ~3% statistics in 350 hrs



3% systematic uncertainty assumed for all settings.

Stat. and total error shown for each point

Summary of Experiment

1. 0.08 - 0.12 GeV, highly polarized beam with 600 μA current

2. Windowless gas flow/jet target with ultra-pure ^3He

3. Solenoidal magnet (low energy/warm)

4. Large acceptance recoil detector with excellent PID
   detect recoil ^3H
   and elastically scattered electrons in coincidence (to reduce backgrounds)

5. Eliminate parity conserving EM backgrounds using
   $(\sigma(h=+1) - \sigma(h=-1))$

6. Use electron scattering data on $f_M^{3He}(Q^2)$ to extract $f_A^{3He}(Q^2)$

7. Look for spin correlations in search of second class currents

8. Use spin correlations to measure f_A/f_V of ^3He

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Conclusions

- Weak capture of electrons on the proton and ^{3}He can provide unique opportunities to measure the axial formfactor.

- Backgrounds can be controlled using polarized electrons and well designed detectors.

- Several ideal detectors and targets already under development for other experiments.

- At very low energies measurement of spin correlations can test for 2nd class currents.
- On protons one can measure $|g_A/g_V|$ with completely different systematics compared to neutron beta decay.

- Weak capture of electrons would be complementary to the traditional neutrino scattering experiments and less resource intensive.

- Will help launch a new program to measure the charge changing weak current. The next reaction to attempt $e + p \rightarrow \Lambda + \nu$

(cross section 1/25 of capture cross section on p)