Jefferson Lab Hall A neutron spin structure program

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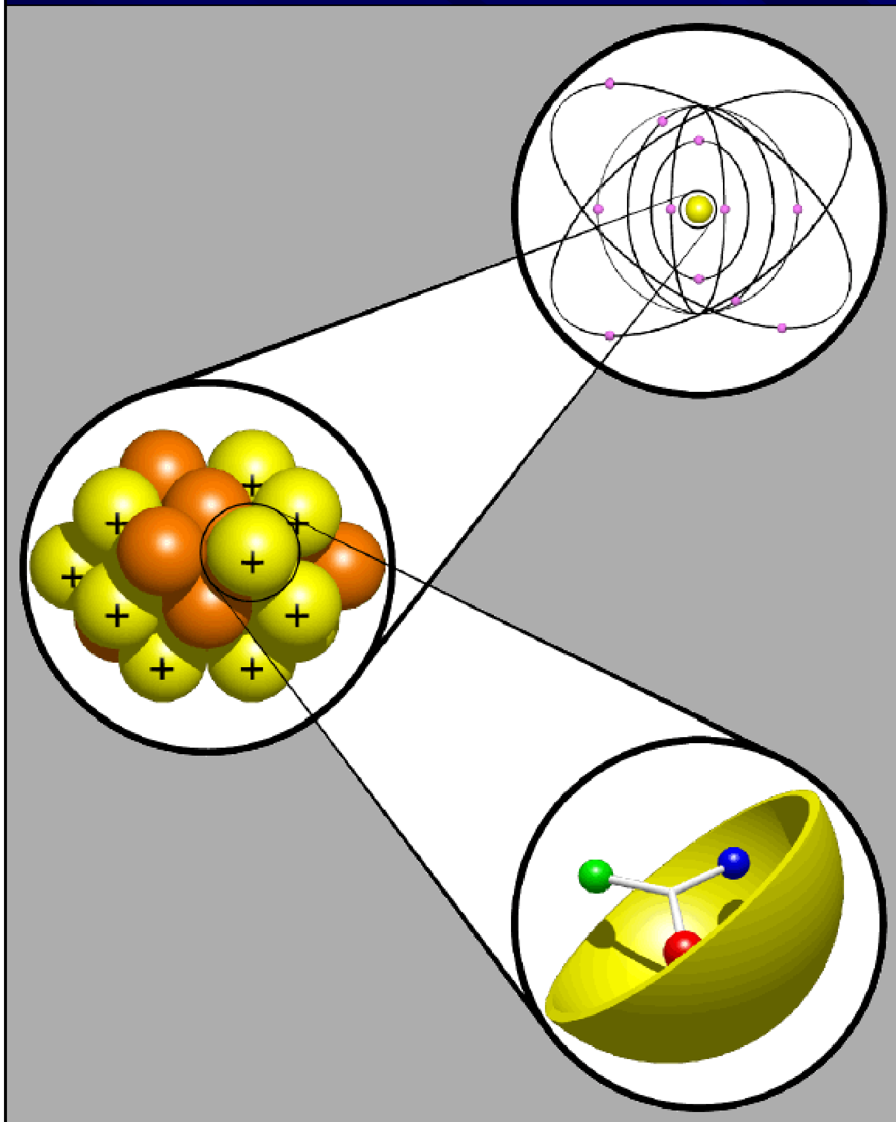
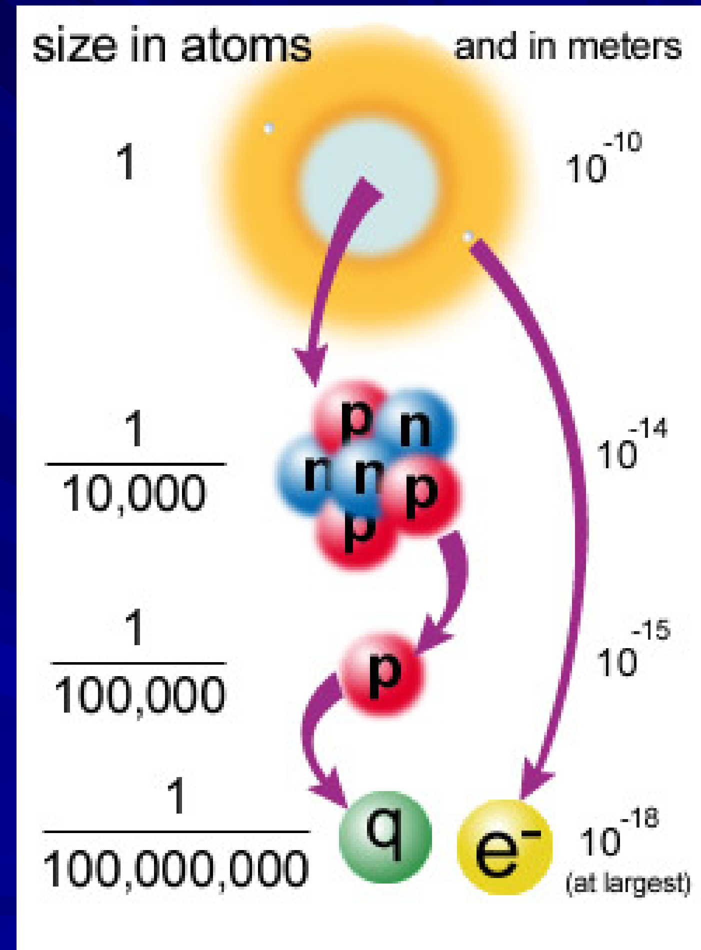
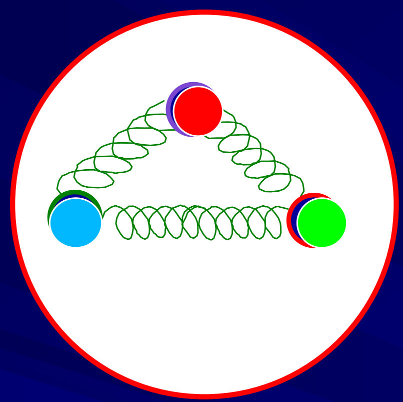
Outline

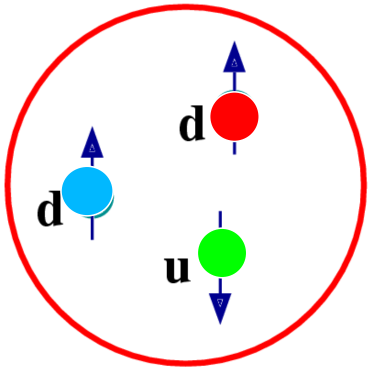
- Introduction
- Neutron spin structure in the resonance region:
    - Jefferson lab Experiment 01-012 spin duality
- Neutron spin structure at high x with upgraded Jefferson lab.
    - Jefferson lab Experiment E12-06-112
- Conclusion



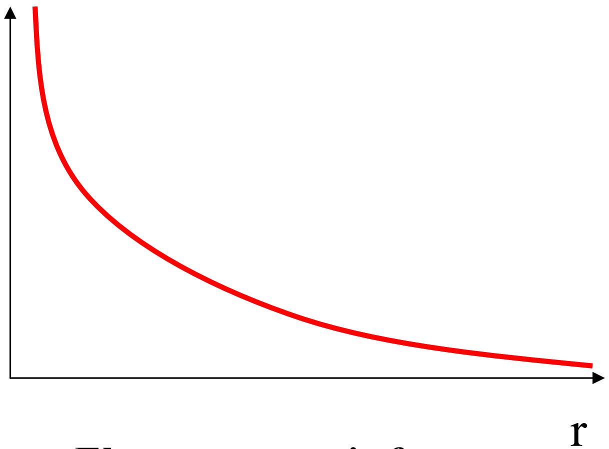

size in atoms
and in meters
1
10-10
p n
n n p
p
1/10,000
10-14
p
1/100,000
10-15
q
e-
1/100,000,000
10-18
(at largest)

Quark structure of the nucleon

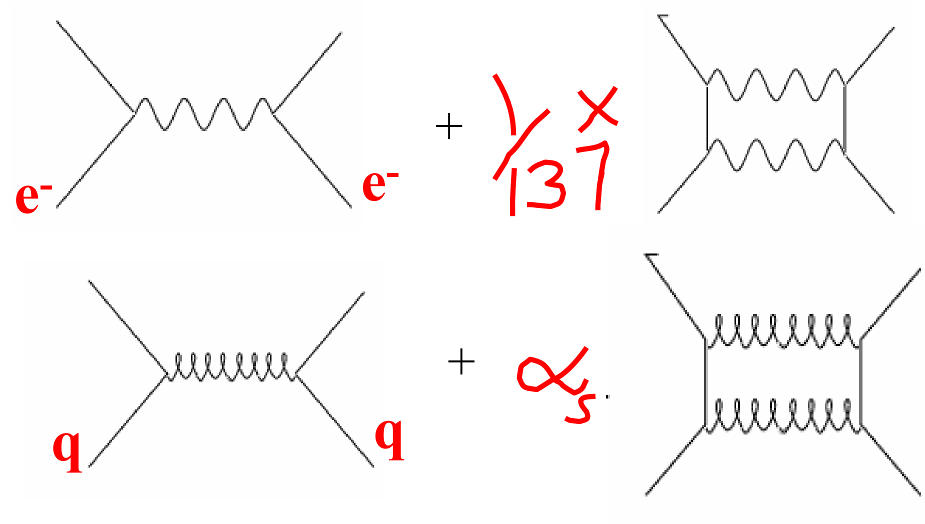


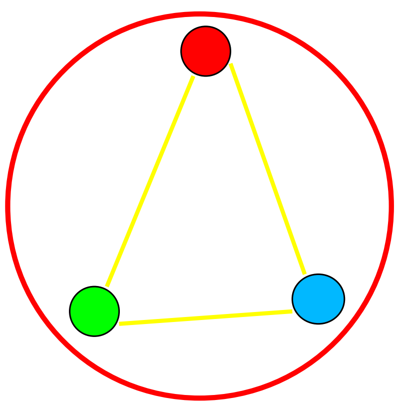


- Three u and d valence quarks
- Also gluons and a “sea” of $q, \bar{q}$ pairs
- Strong interaction between quarks
- Governed by QCD
- Mediated by gluons
- Gluons interact with other gluons: self coupling



Electro-magnetic force





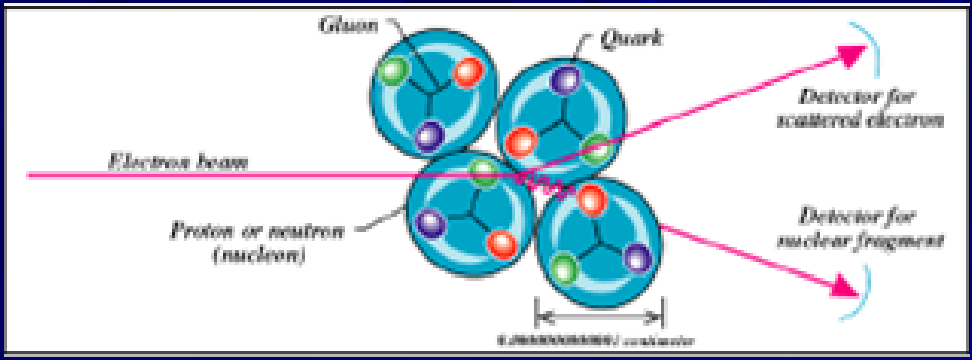
(Short distances)

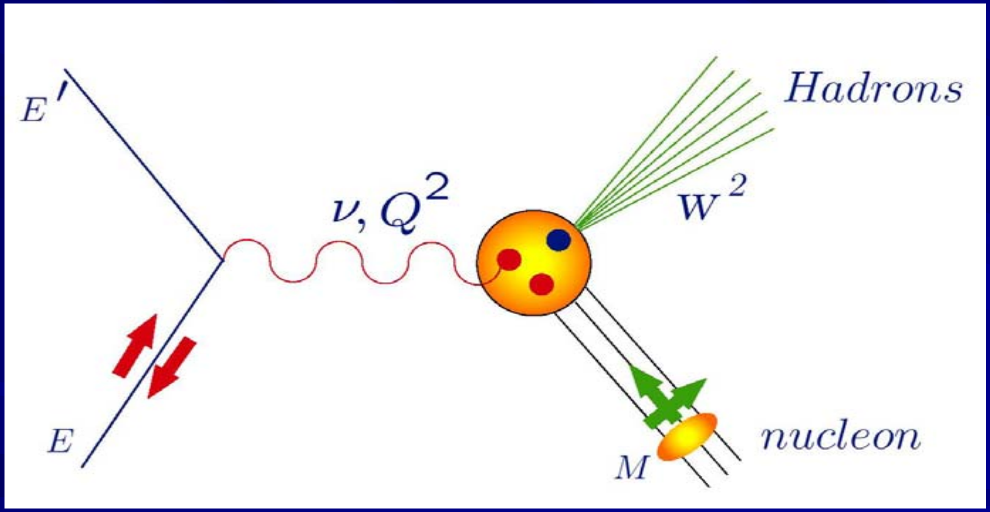
- $\alpha_s \to 0$
- $\Rightarrow$ Quarks are free (Asymptotic freedom)
- $\Rightarrow$ pQCD applicable

(larger distances)

- Strong coupling between quarks
- Confinement important
- QCD has not been solved here

Understanding confinement in terms of QCD: an unresolved problem of particle physics





4-momentum transfer squared

$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

Invariant mass squared

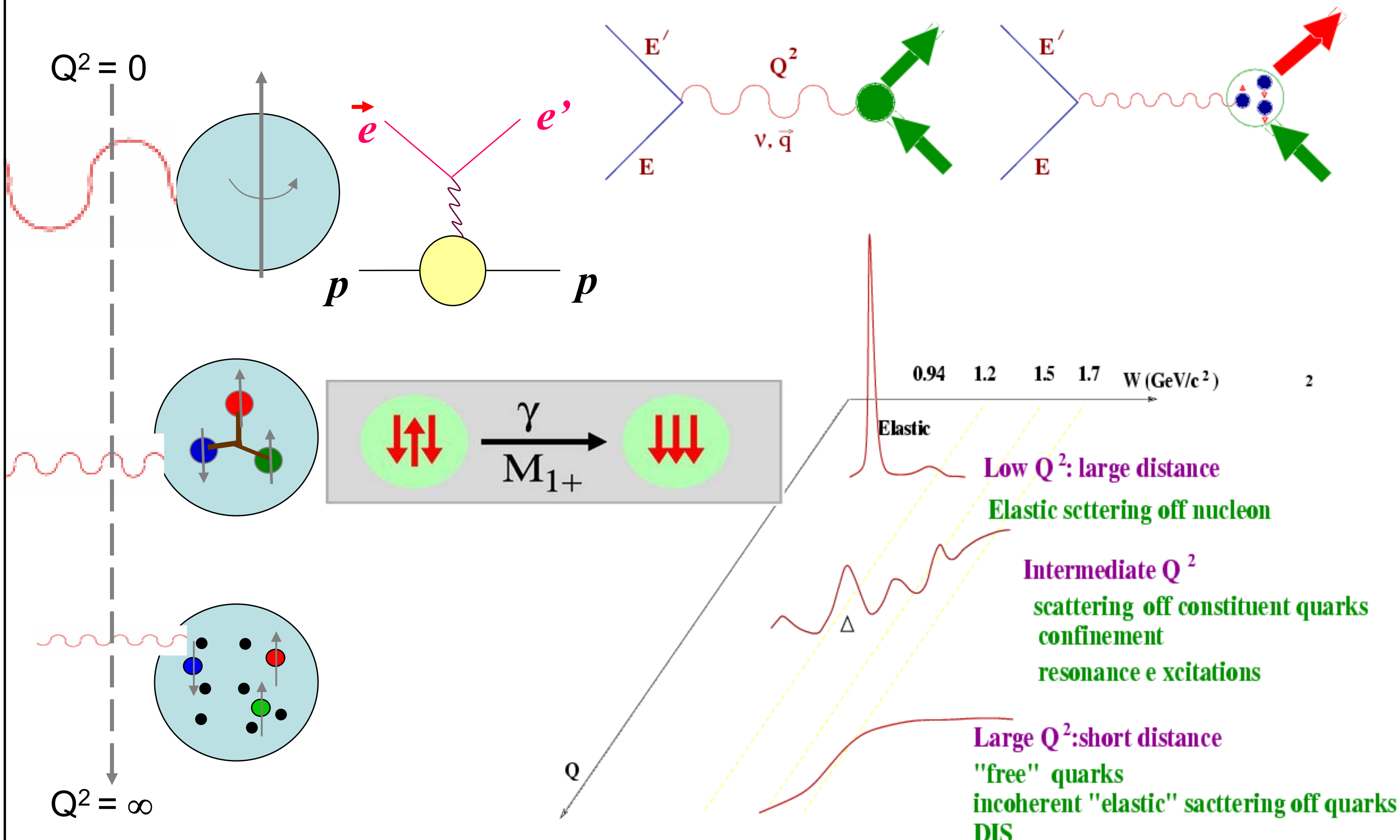
$$W^2 = M^2 + 2M\nu - Q^2$$

Bjorken variable

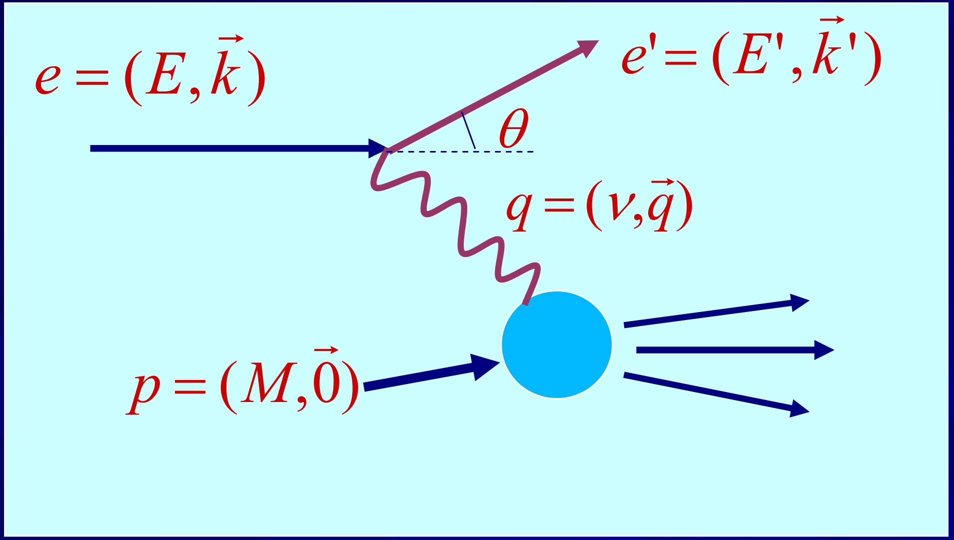
$$x = \frac{Q^2}{2M\nu}$$

Resolution of the probe

$$\lambda = \frac{h}{\vec{q}} = \frac{h}{\sqrt{Q^2}}$$



Inclusive Electron Scattering



<u>4-momentum transfer squared</u>

$$Q^2=-q^2=4EE'\sin^2\tfrac{\theta}{2}$$

<u>Invariant mass squared</u>

$$W^2=M^2+2M\nu-Q^2$$

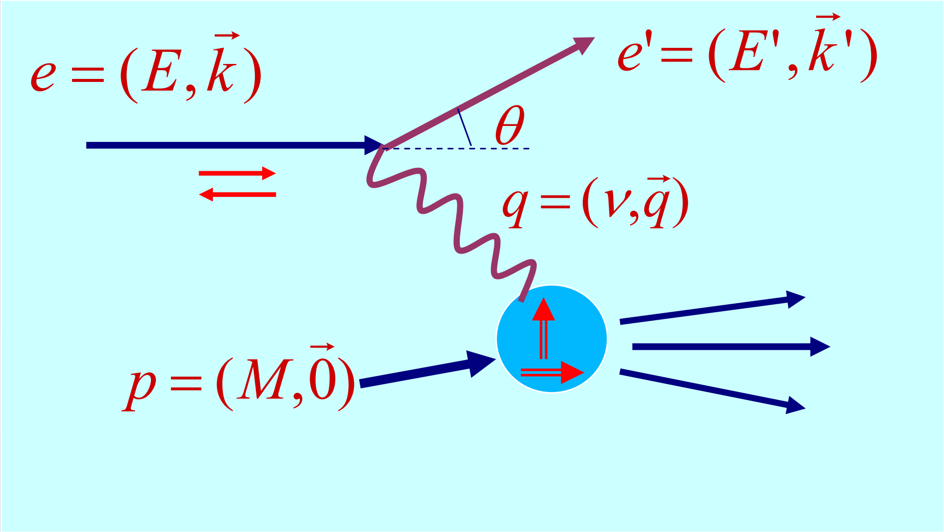
<u>Bjorken variable</u>

$$x=\frac{Q^2}{2M\nu}$$

Unpolarized case

$$\frac{d^2\sigma}{d\Omega dE'}=\sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2)+\frac{2}{M}F_1(x,Q^2)\tan^2\tfrac{\theta}{2}\right]$$

Inclusive Electron Scattering



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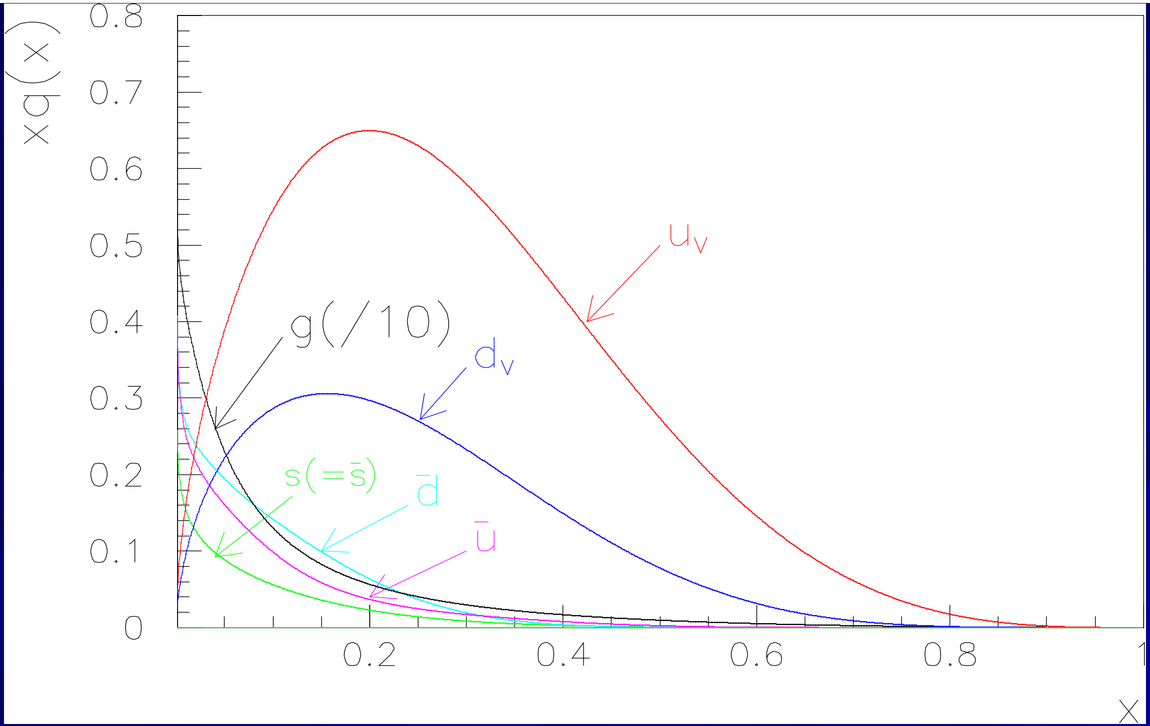
Polarized case

$$\frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{\nu E Q^2}\left[(E + E'\cos\theta)g_1(x,Q^2) - 2Mxg_2(x,Q^2)\right]$$



- Low x: sea region, large contribution from quark-antiquark pairs
- High x: valence region:

- The three valence quarks dominate the wave function
- "Clean" - No "pollution" from sea quarks
- Constituent Quark Models are applicable
- Essential for understanding the valence structure of the nucleon
- Essential for connecting DIS with resonance and elastic regions

Structure functions in the parton model

- Partons are point-like non-interacting particles:

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 q_i(x) = \frac{1}{2}\sum_i e_i^2 [q_i^{\uparrow}(x) + q_i^{\downarrow}(x)]$$

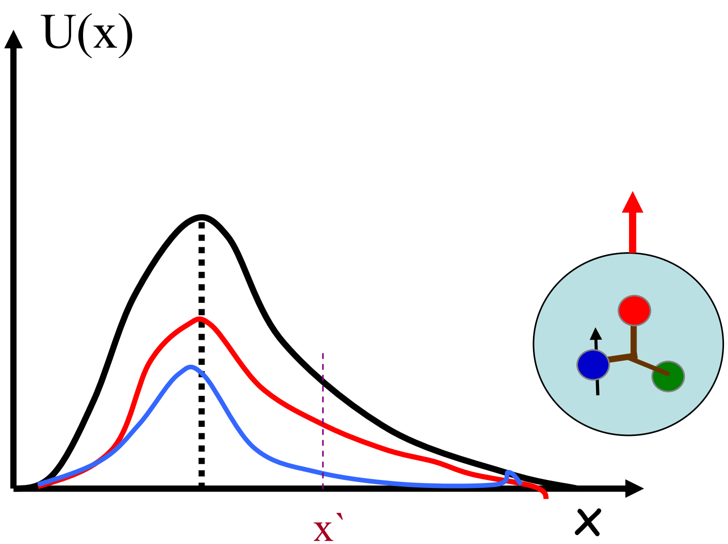
$$F_{1p} = \frac{1}{2}\left[\frac{4}{9}u(x) + \frac{1}{9}d(x)\right]$$

$$F_{1p} = \frac{1}{2}\left[\frac{4}{9}(u(x)^{\uparrow} + u(x)^{\downarrow}) + \frac{1}{9}(d(x)^{\uparrow} + d(x)^{\downarrow})\right]$$

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x) = \frac{1}{2}\sum_i e_i^2 [q_i^{\uparrow}(x) - q_i^{\downarrow}(x)]$$

$$g_{1p} = \frac{1}{2}\left[\frac{4}{9}(u(x)^{\uparrow} - u(x)^{\downarrow}) + \frac{1}{9}(d(x)^{\uparrow} - d(x)^{\downarrow})\right]$$

Neglecting strange quarks and anti-quarks



$$A_1 = \frac{g_1}{F_1}$$

Nucleon Structure at large x_{Bj}

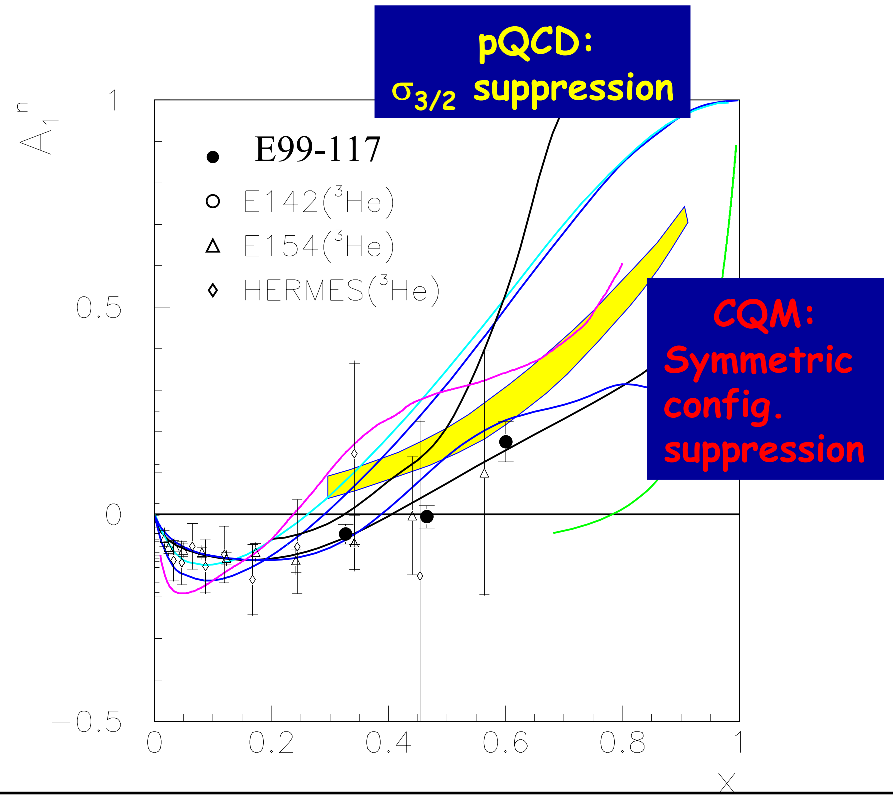
Neutron Wavefunction (Spin and Flavor Symmetric)

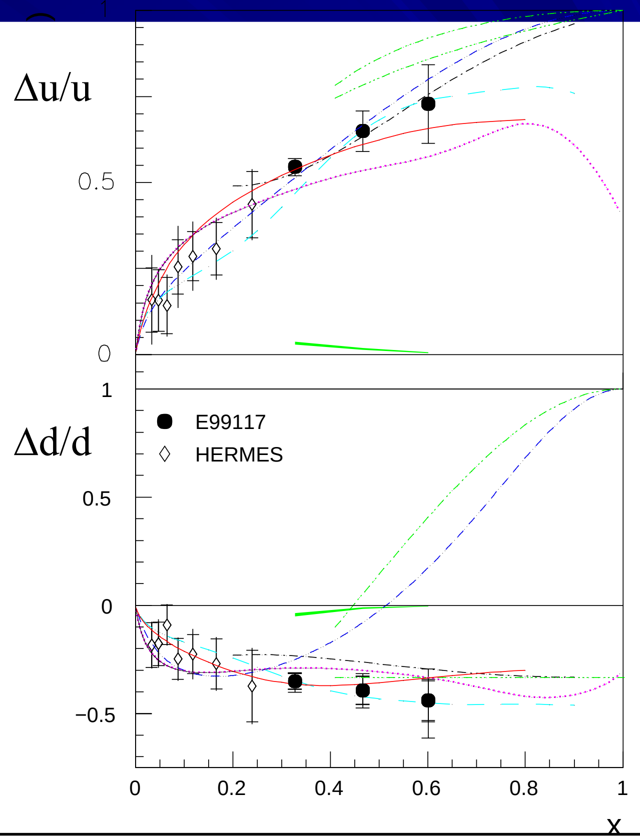
$$\left| n\uparrow \right\rangle = \frac{1}{\sqrt{2}}\left| d\uparrow (ud)_{S=0} \right\rangle + \frac{1}{\sqrt{18}}\left| d\uparrow (ud)_{S=1} \right\rangle - \frac{1}{3}\left| d\downarrow (ud)_{S=1} \right\rangle$$

$$- \frac{1}{3}\left| u\uparrow (dd)_{S=1} \right\rangle - \frac{\sqrt{2}}{3}\left| u\downarrow (dd)_{S=1} \right\rangle$$

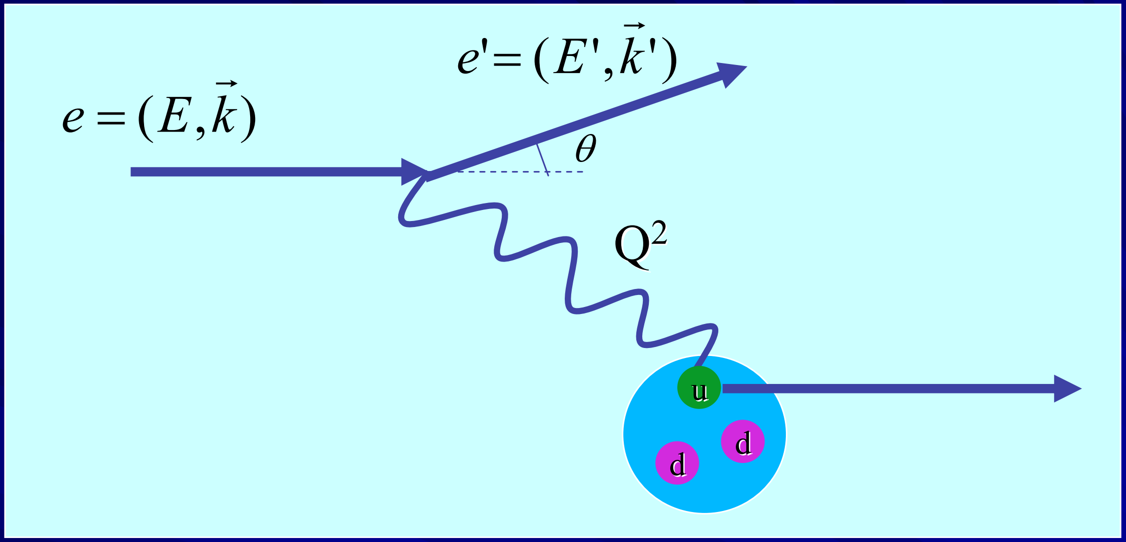
Nucleon Model					A_1^n	A_1^p
SU(6)					0	5/9
Valence Quark					1	1
pQCD					1	1

- pQCD and SU(6) breaking quark models
  - A1p, A1n → 1 as x → 1 and large Q2
- But the mechanisms are very different
  - CQM – hyperfine interaction between quarks: symmetric configurations suppressed.
  - pQCD – at high x quark carrying the much of the nucleon momentum has the same spin direction as the nucleon: HHC





Deep Inelastic Scattering



High Q^2 and W>2GeV: fine resolution → we see partons

→ scaling → asymptotic freedom of the strong interaction

Scaling of F_2

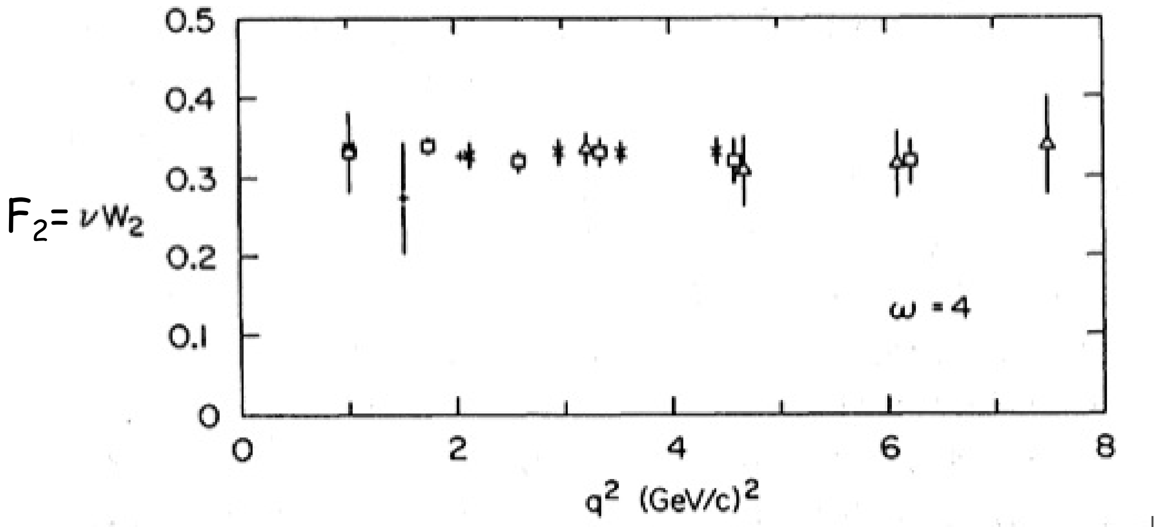
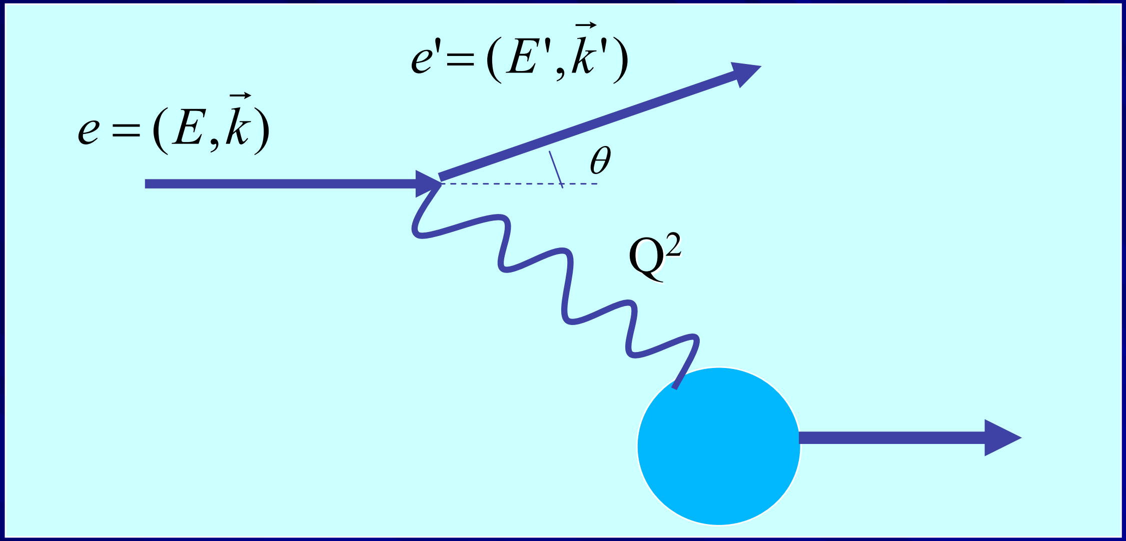


Figure from: H. W. Kendall, Rev. Mod. Phys. 63 (1991) 597

1990 Nobel Prize

J. I. Friedman, H. W. Kendall and R. E. Taylor

Resonance region



Low Q^2 and W<2 GeV : coarse resolution → we don't see partons.

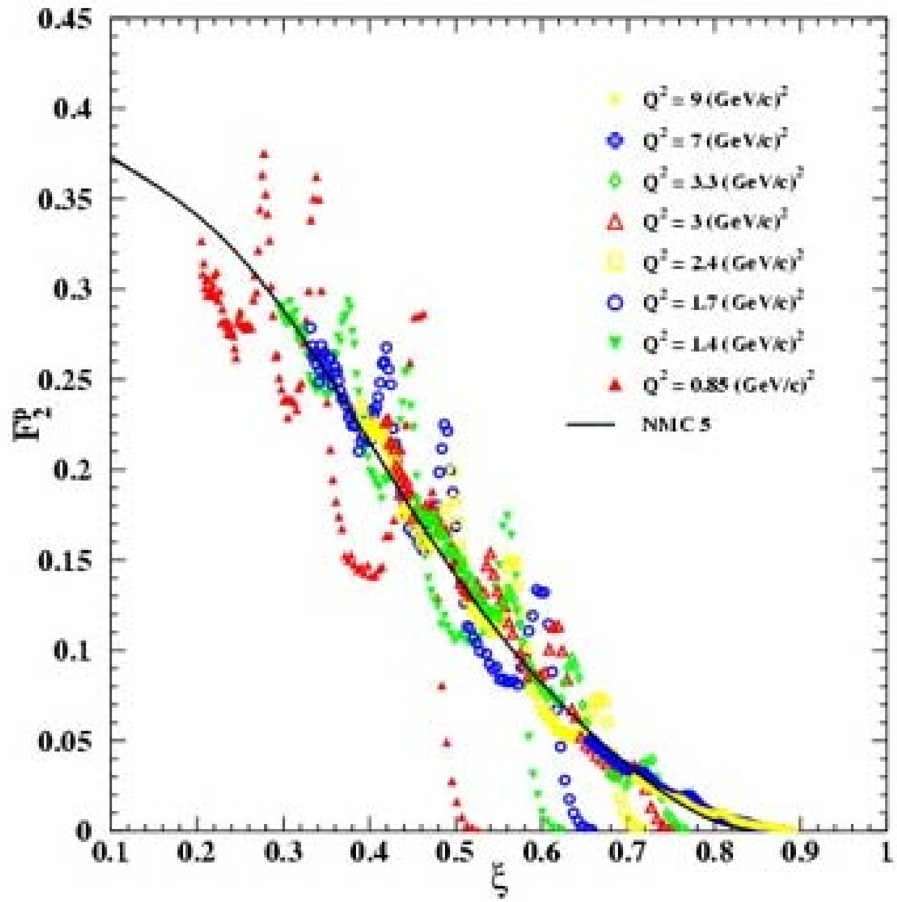
→ The nucleon goes through different excited states: the resonances

DIS versus resonance:

two very different pictures of the nucleon.

Quark-hadron duality

- First observed by Bloom and Gilman in the 1970's on F_2
- Scaling curve seen at high Q^2 is an accurate average over the resonance region at lower Q^2
- Global and Local duality are observed for F_2

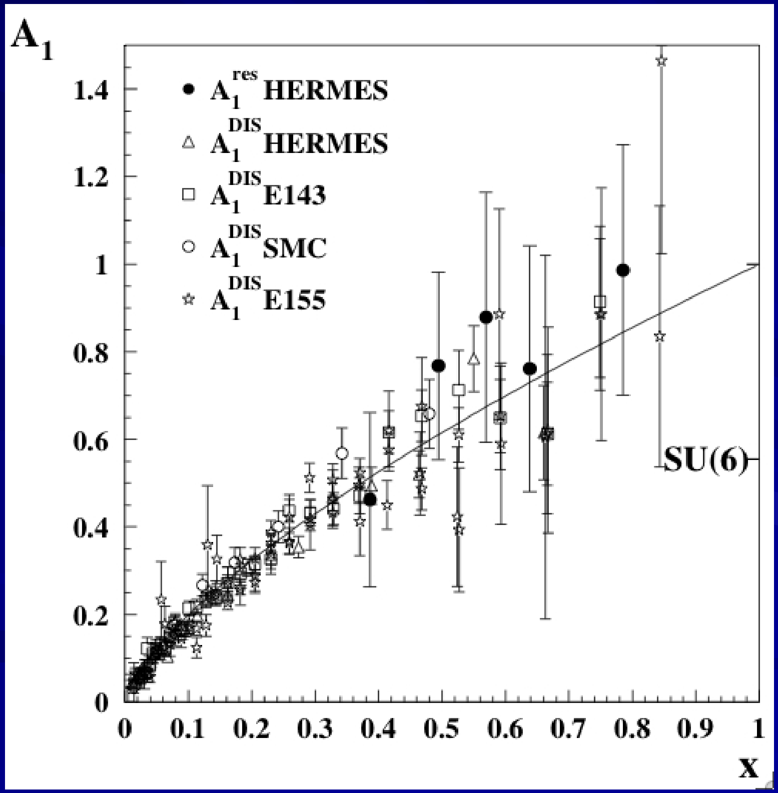


I. Niculescu et al., PRL 85 (2000) 1182

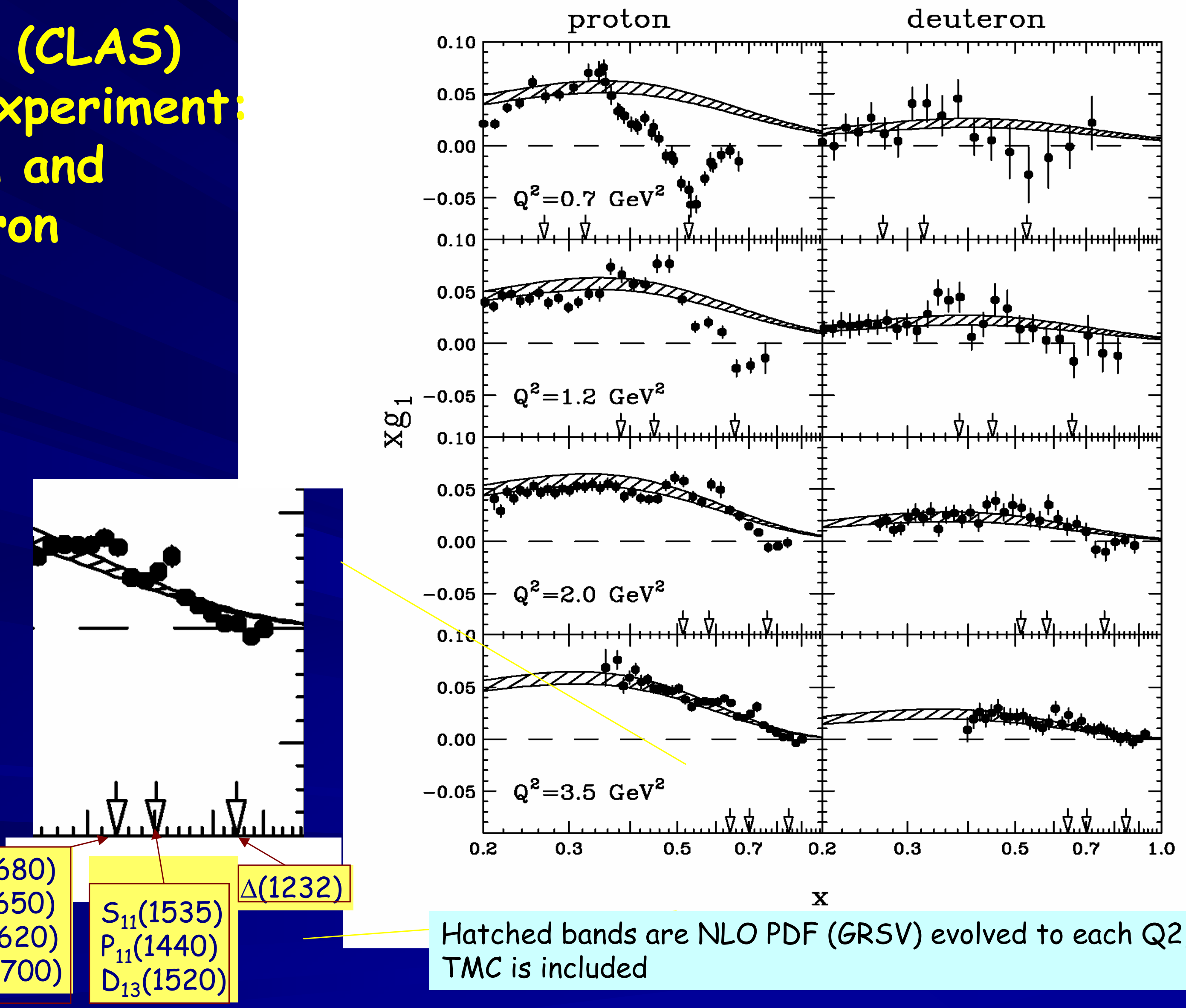
World data

HERMES for A_1^p

A. Airapeian et al., PRL 90 (2003) 092002



Hall B (CLAS) EG1 experiment: proton and deuteron



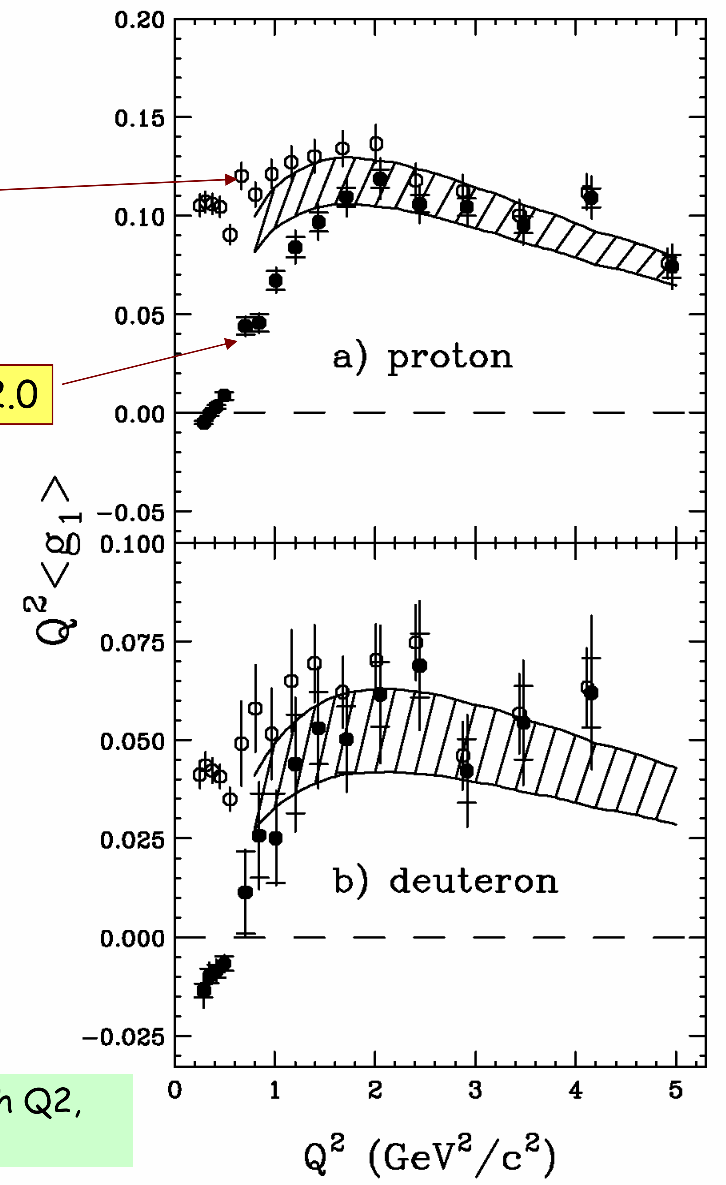
Hatched bands are NLO PDF (GRSV) evolved to each Q2, TMC is included

Test of “global” duality

Including elastic

1.08 < W < 2.0

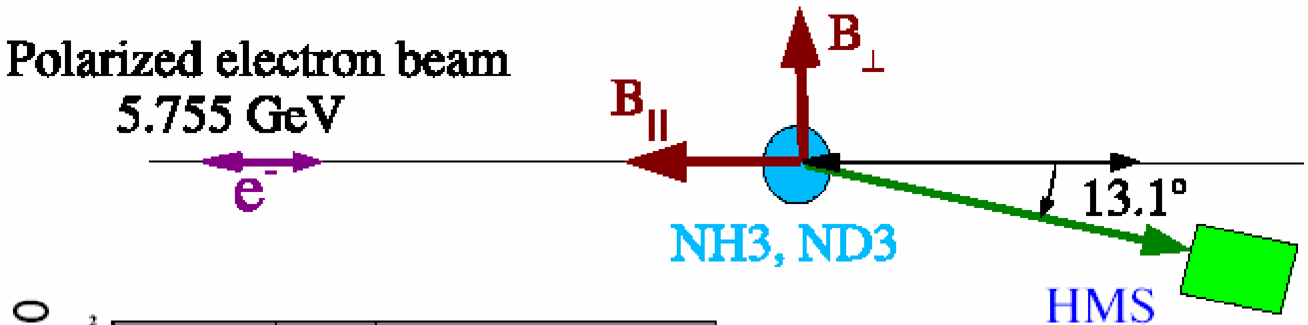
$$\langle g_1(Q^2)\rangle = \frac{\int_{x_h}^{x_l} g_1(x,Q^2)\,dx}{(x_h - x_l)}$$

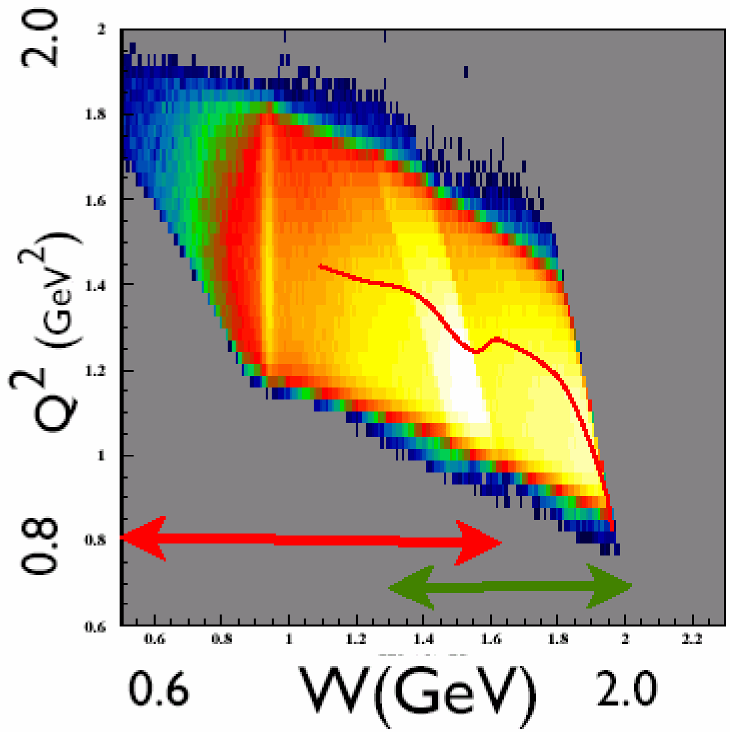


Global duality appears to hold for Q^2>1.7 GeV^2 for both g_1^p and g_1^D

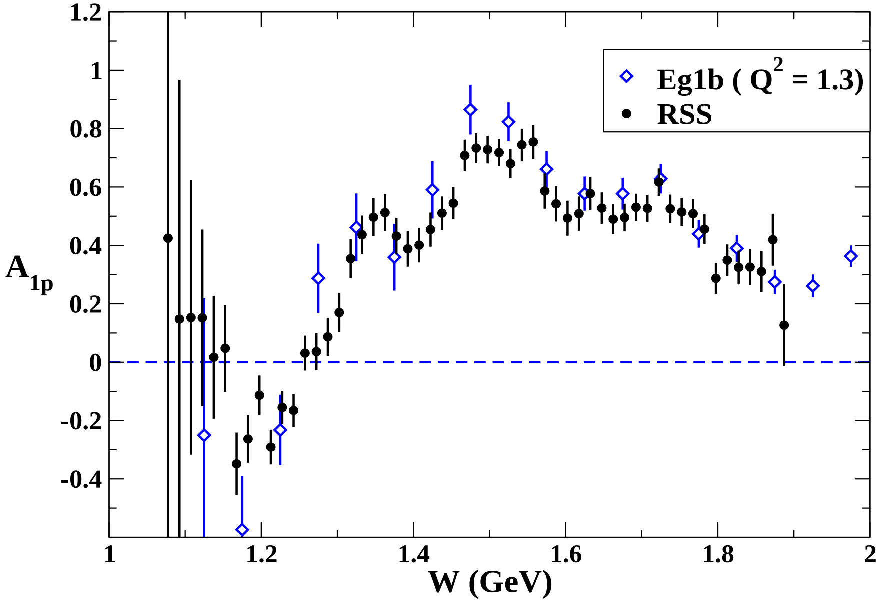
Hatched bands are NLO PDF (GRSV) evolved to each Q2, TMC is included

Jefferson Lab Hall C E-01-006: Resonances Spin Structure (RSS)
Spokesmen: Oscar A. Rondon (UVA) and Mark K. Jones (JLab)

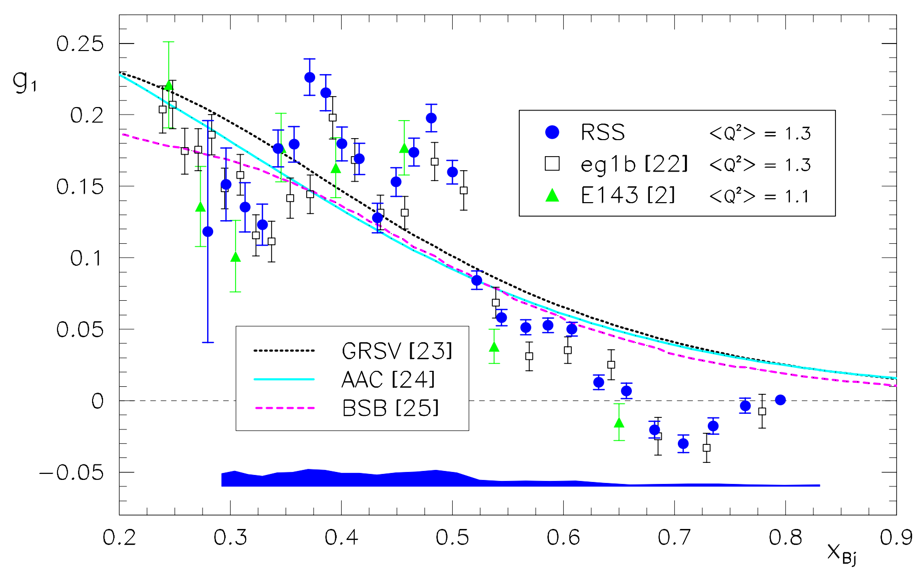




- HMS detects scattered electrons. Momentum settings: 4.7 , 4.1 GeV/c
- $\langle Q^2 \rangle = 1.3\ GeV^2$, $0.8 < W < 2.0$ GeV
- I ~ 100nA for NH_3 and ND_3
- Beam Polarization (P_B) by Moller:
  - $P_B = 65.5 \pm 2.6$ (%) for $B_{||}$
  - $P_B = 70.9 \pm 1.7$ (%) for $B_{\perp}$
- Beam charge asym. < 0.1%



$$\frac{\int_{x_l}^{x_h} g_1^{\,p}(NLO - PDF)\,dx}{\int_{x_l}^{x_h} g_1^{\,p}(resonance)\,dx} = 1.17 \pm 0.08$$



Experiment E01-012

Spokespersons: N. Liyanage, J. P. Chen, S. Choi; PhD student: P. Solvignon

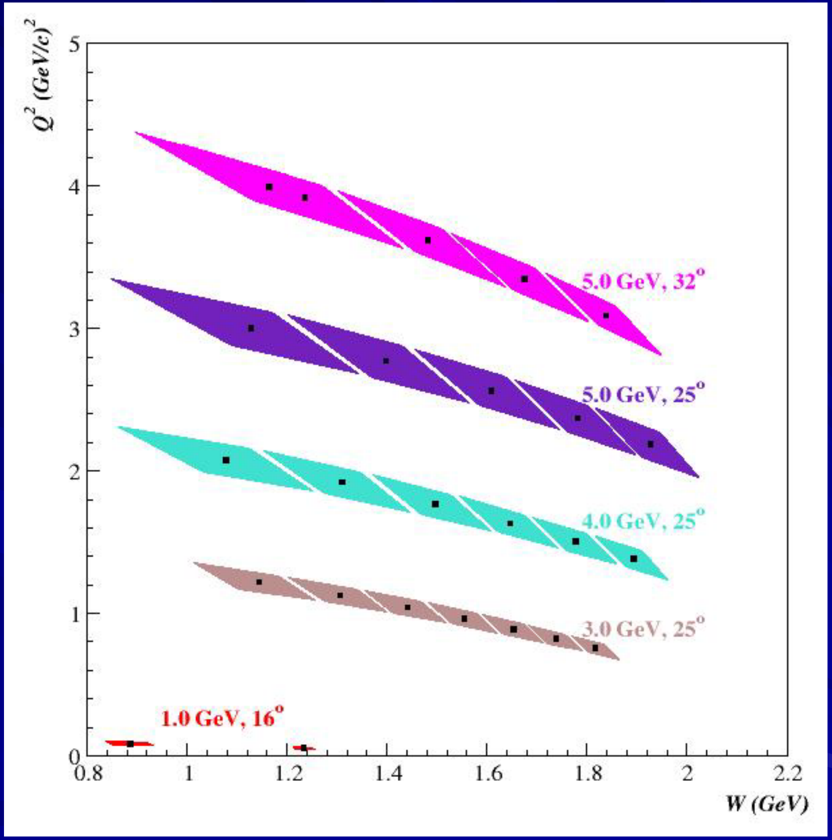
- Ran in Jan.-Feb. 2003

- Inclusive experiment:

$$^3\vec{He}(\vec{e},e')X$$

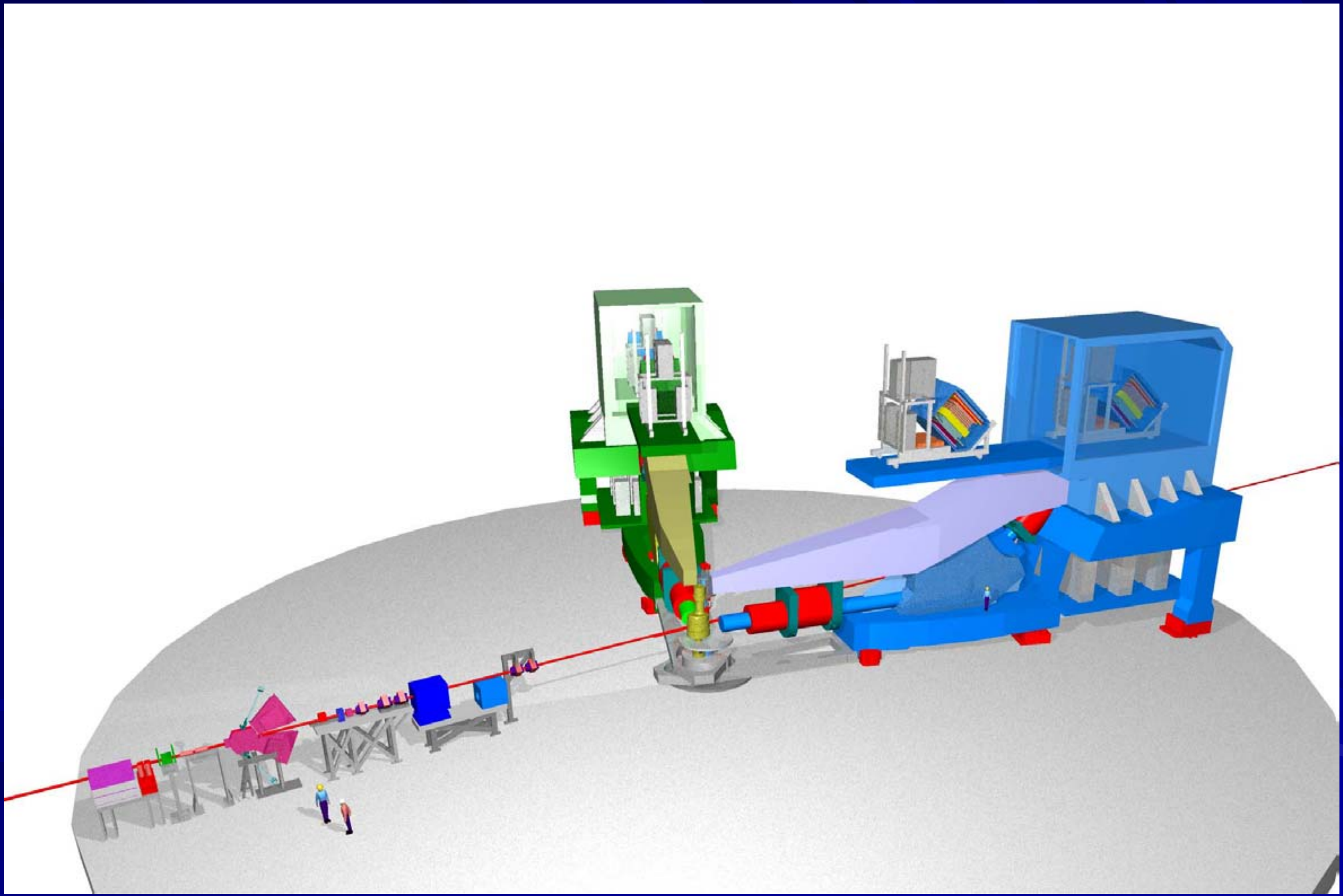
- Measured polarized cross section differences

- Form g_1 and g_2

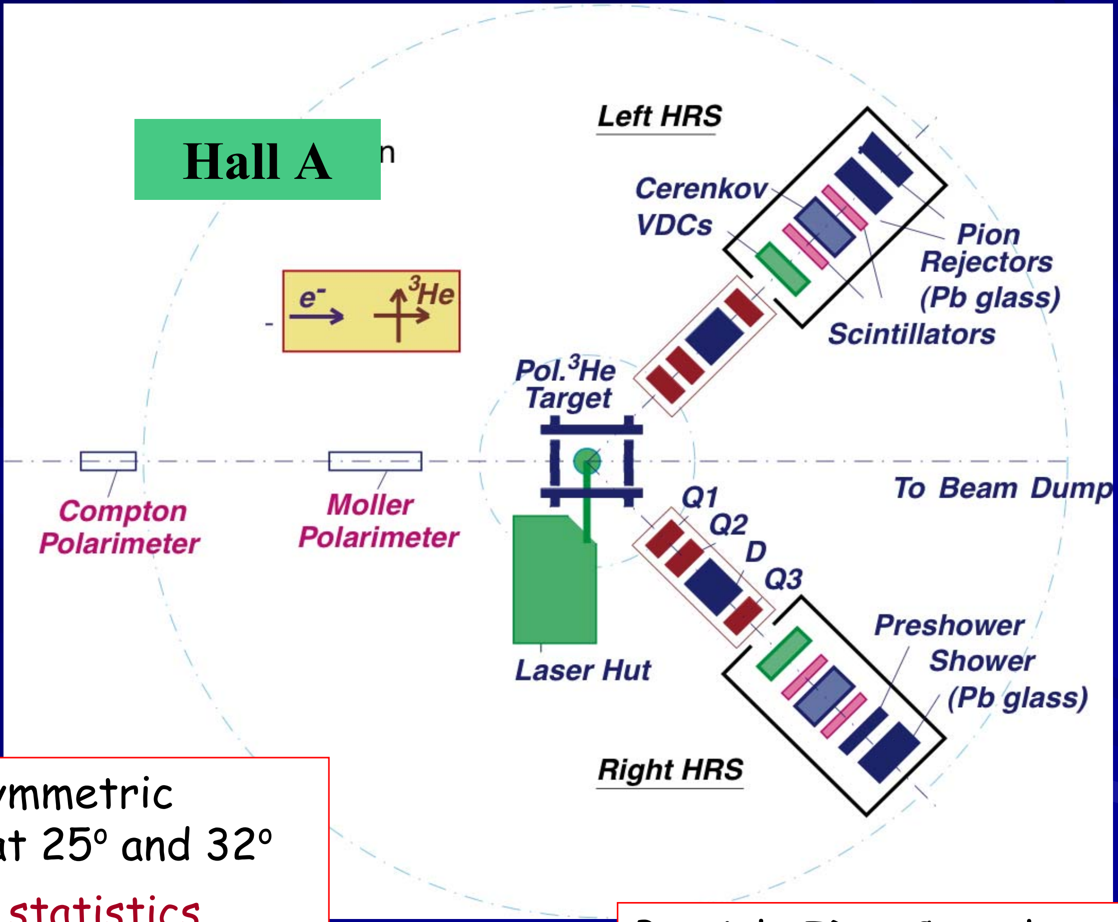


↪ **Test of spin duality on the neutron (and ^{3}He)**

Jefferson Lab Accelerator



Experimental setup



Both HRS in symmetric configuration at 25° and 32°

➥ double the statistics

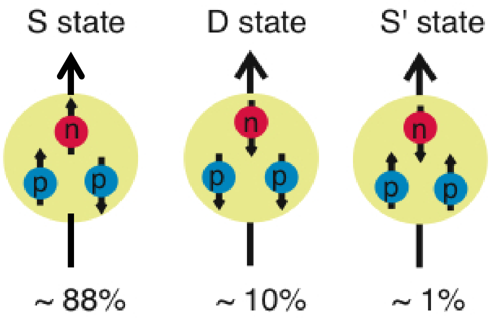
➥ control the systematics

Particle ID = Cerenkov + EM calorimeter

➥ π/e reduced by 10^4

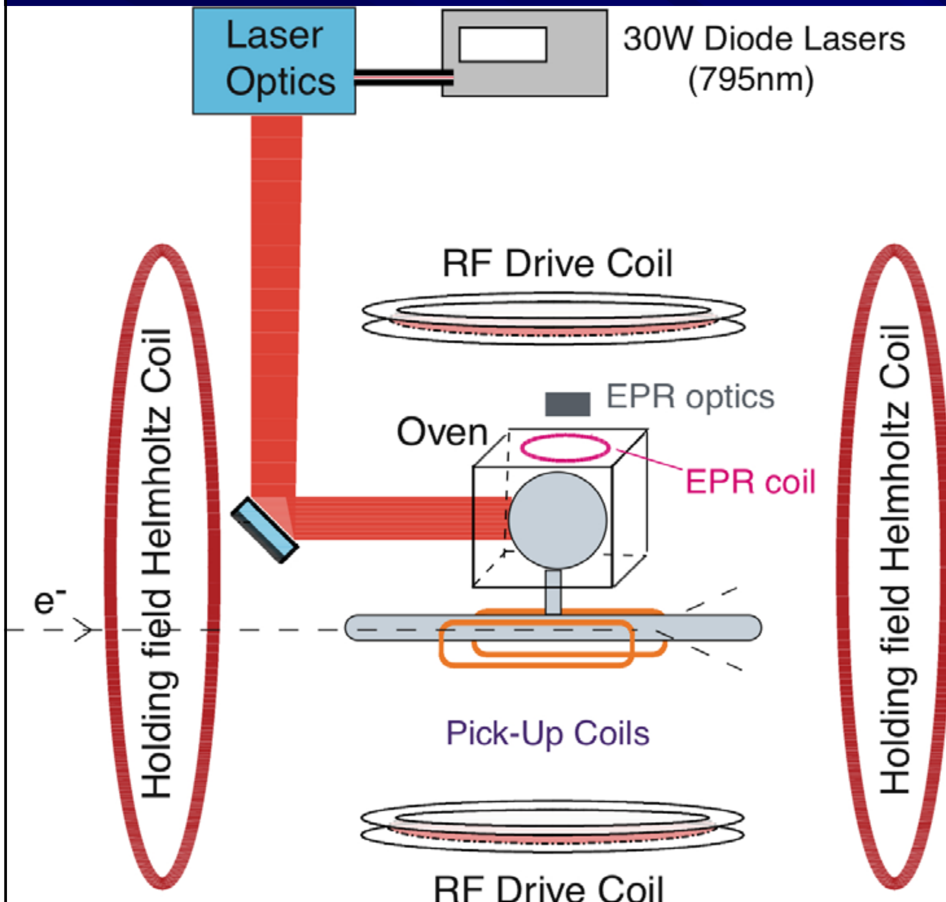
^3He as an effective neutron target

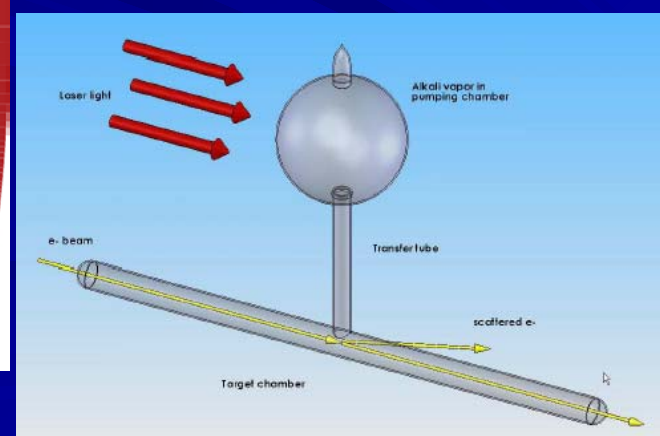
^3He as neutron target



$P_n = 86\%$ and $P_p = -2.8\%$

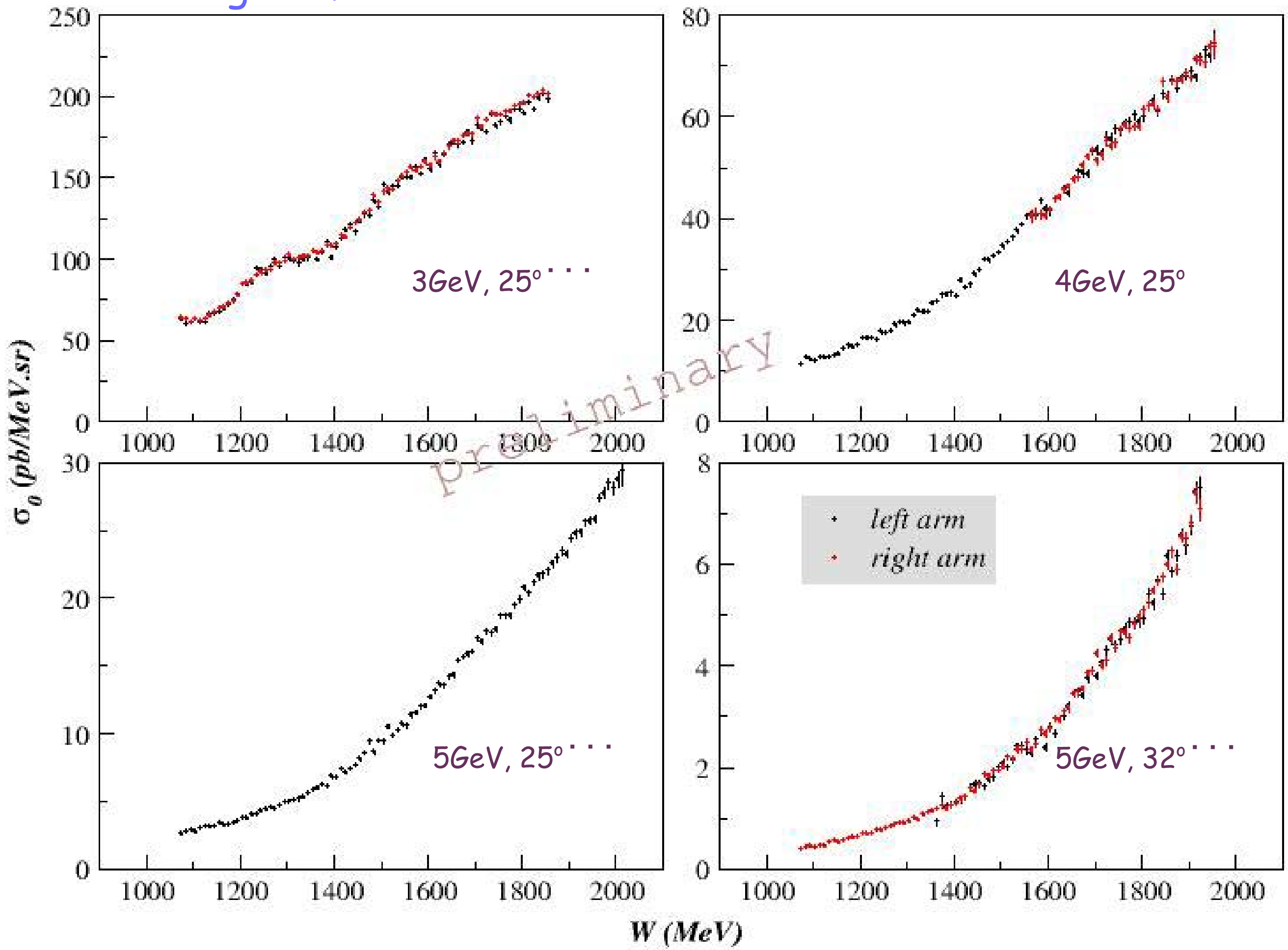
The Polarized ^{3}He Target



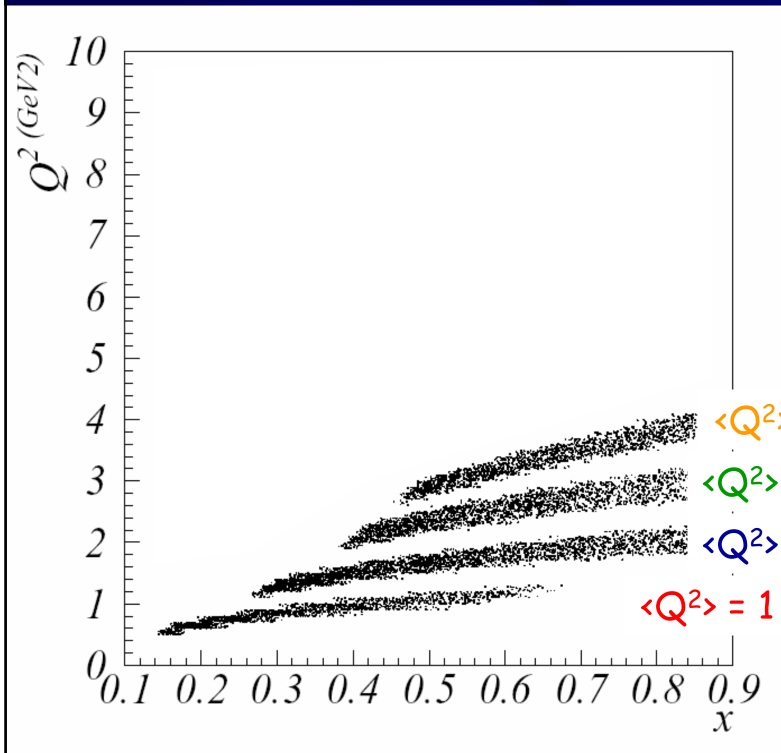


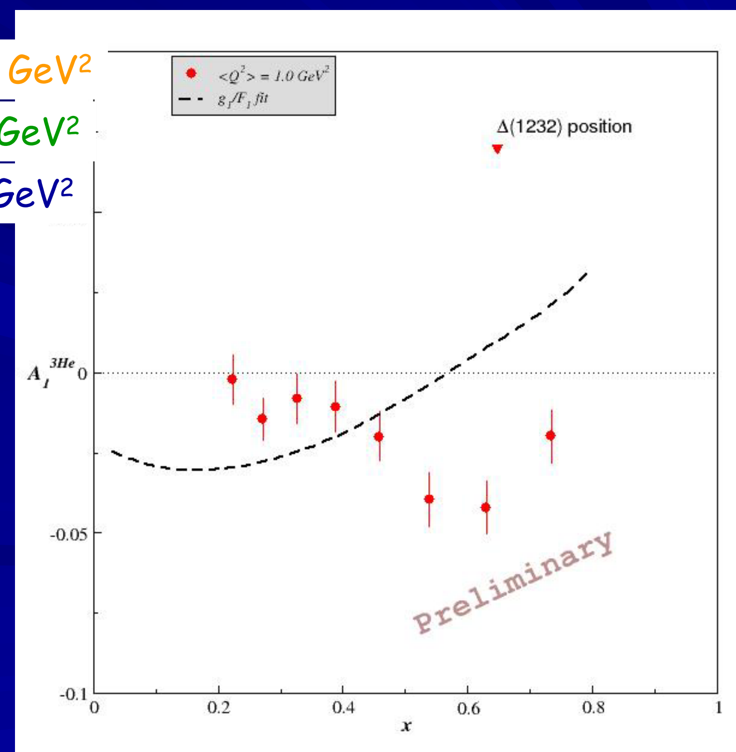
Unpolarized cross sections

Agreement between both HRS better than 2%



New A_1 results from Hall A experiment E01-012





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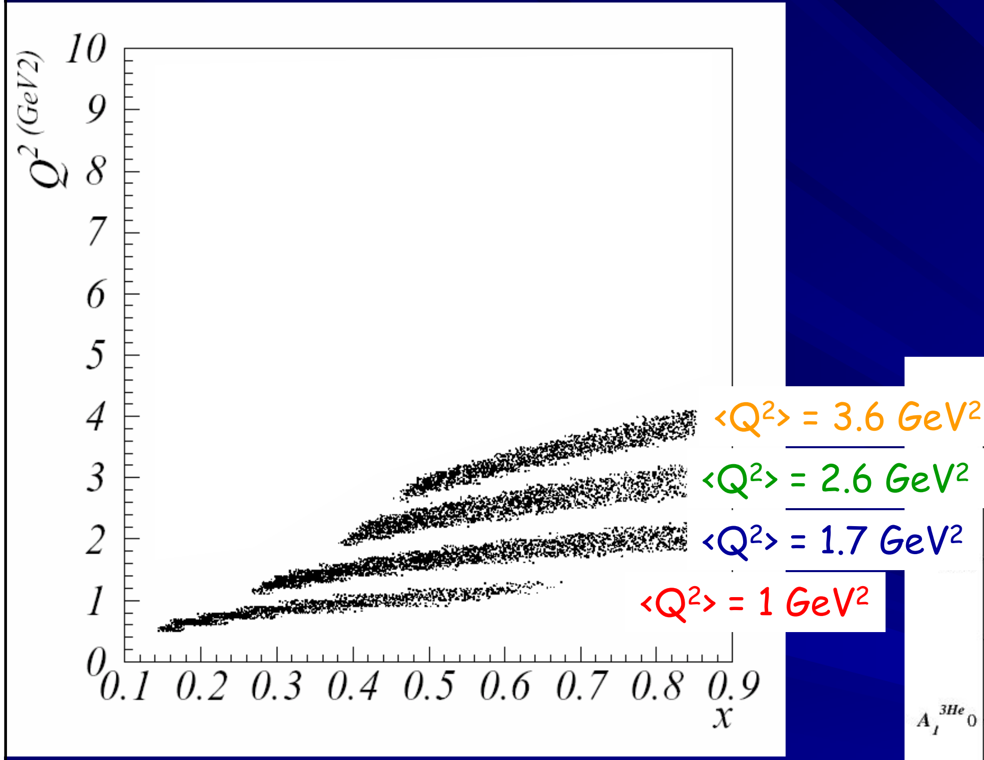

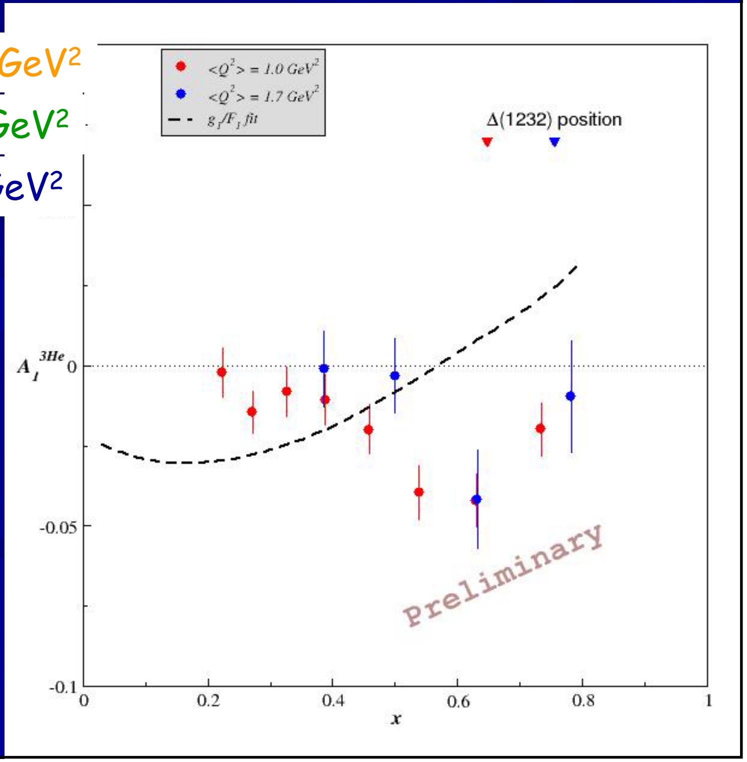

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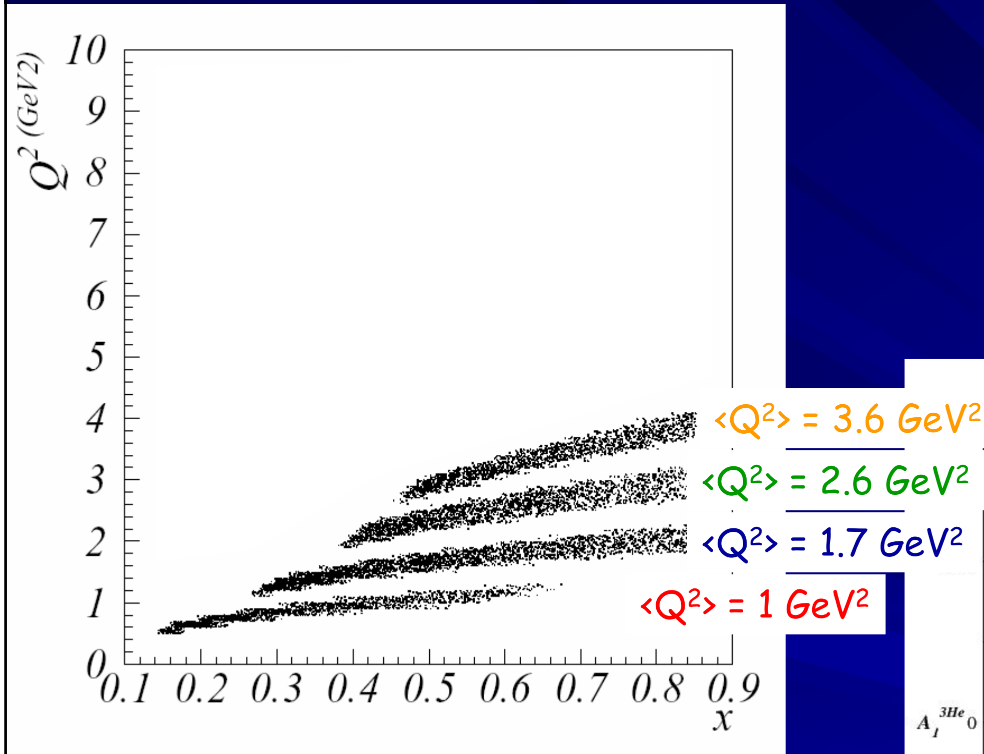

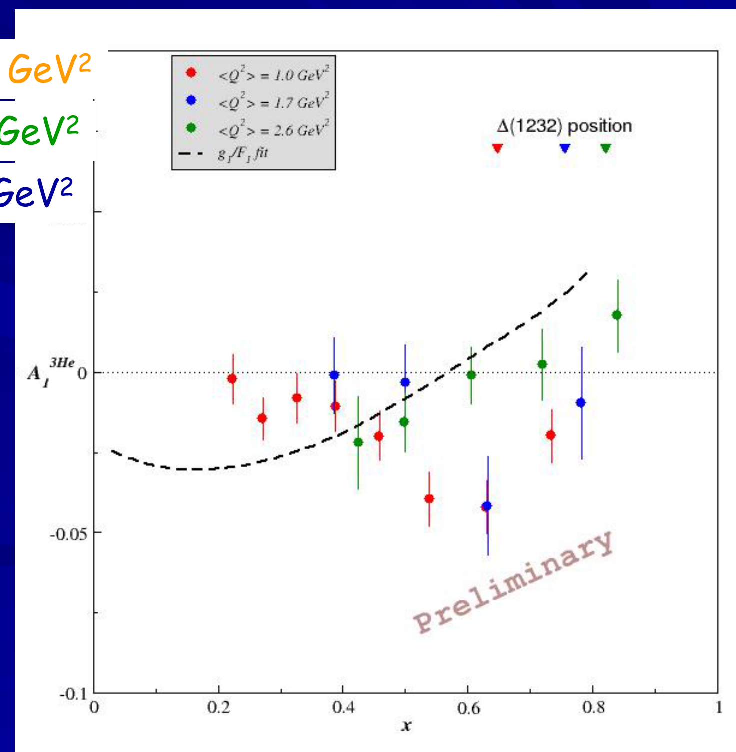

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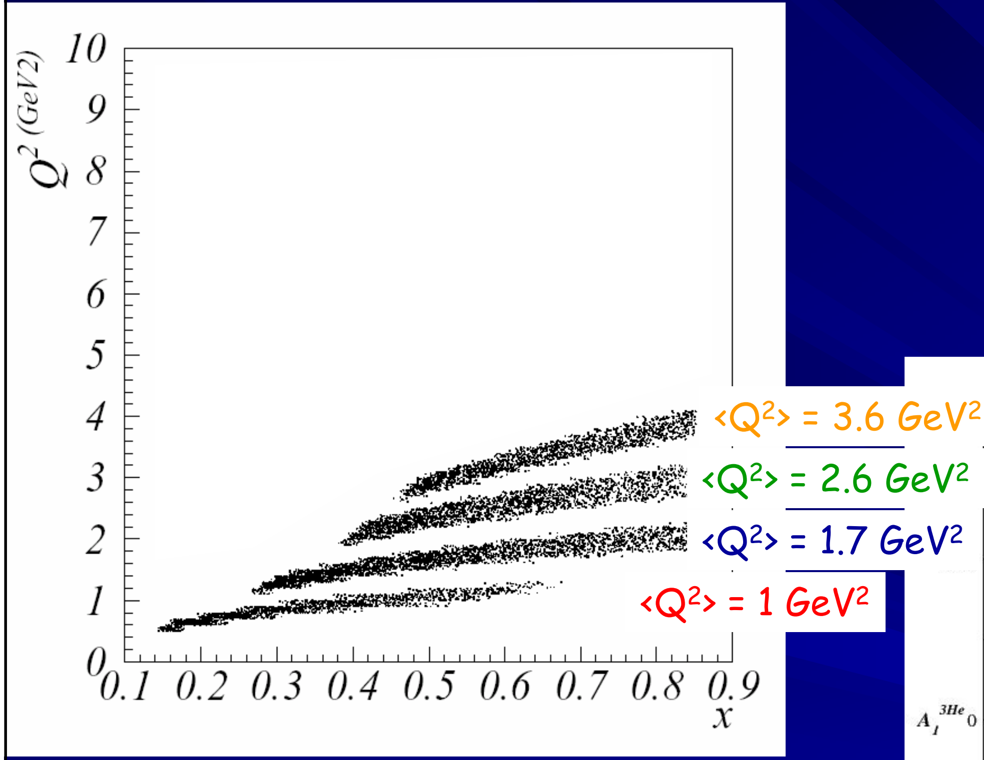
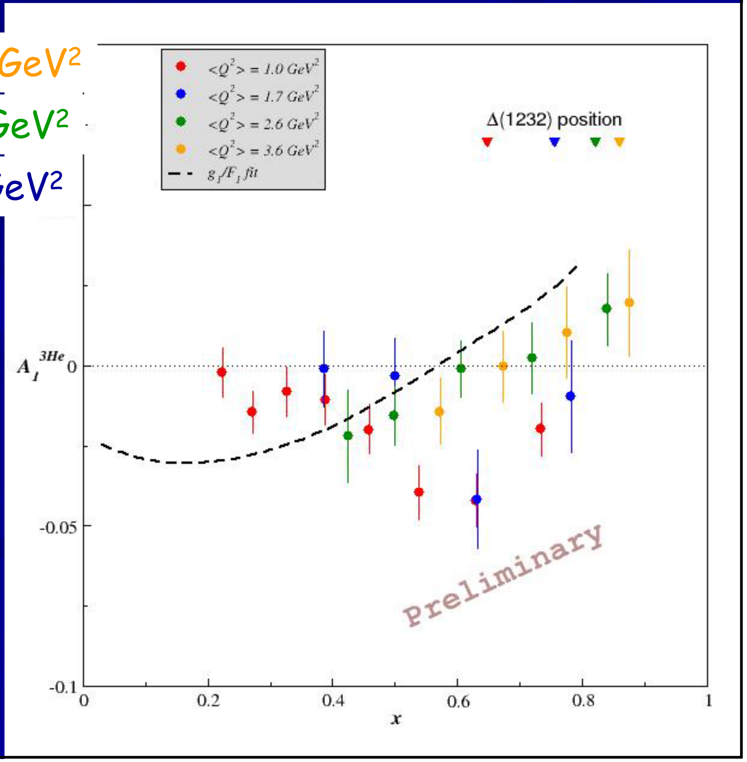




Test of Duality on Neutron and ^3He

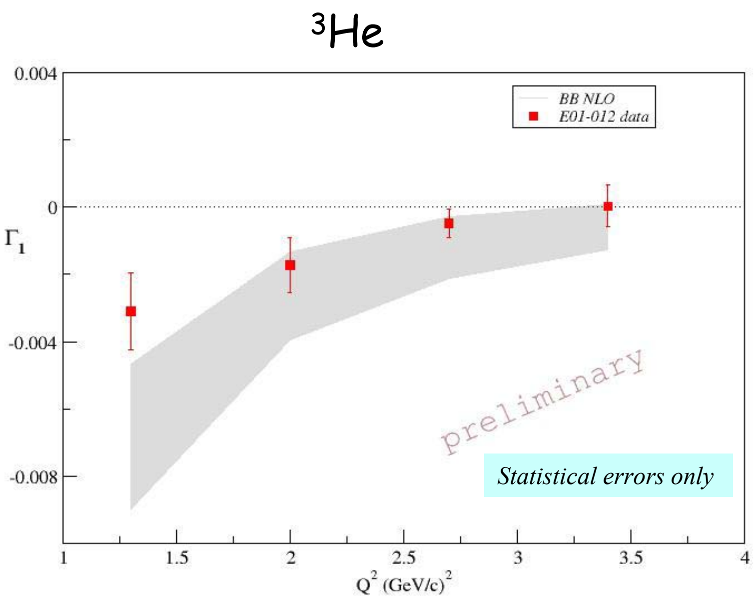
Used method defined by N. Bianchi, A. Fantoni and S. Liuti on g_1^p PRD 69 (2004) 014505

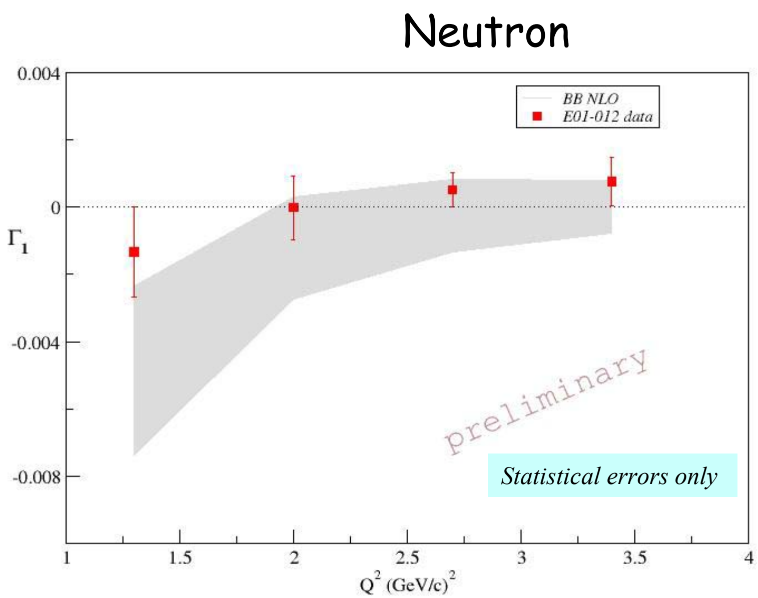
1. Get g_1 at constant Q^2
2. Define integration range in the resonance region in function of W
3. Integrate g_1^{res} and g_1^{dis} over the same x-range and at the same Q^2

$$\tilde{\Gamma}_1^{res} = \int_{x_{\min}}^{x_{\max}} g_1^{res}(x,Q^2)dx \qquad \tilde{\Gamma}_1^{dis} = \int_{x_{\min}}^{x_{\max}} g_1^{dis}(x,Q^2)dx$$

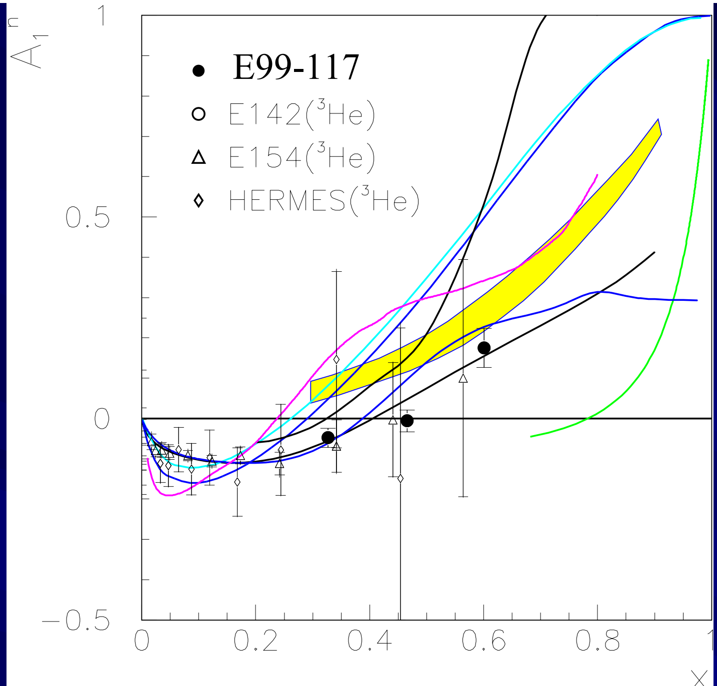
If $\tilde{\Gamma}_1^{res} = \tilde{\Gamma}_1^{dis}$ $\Rightarrow$ **duality is verified**

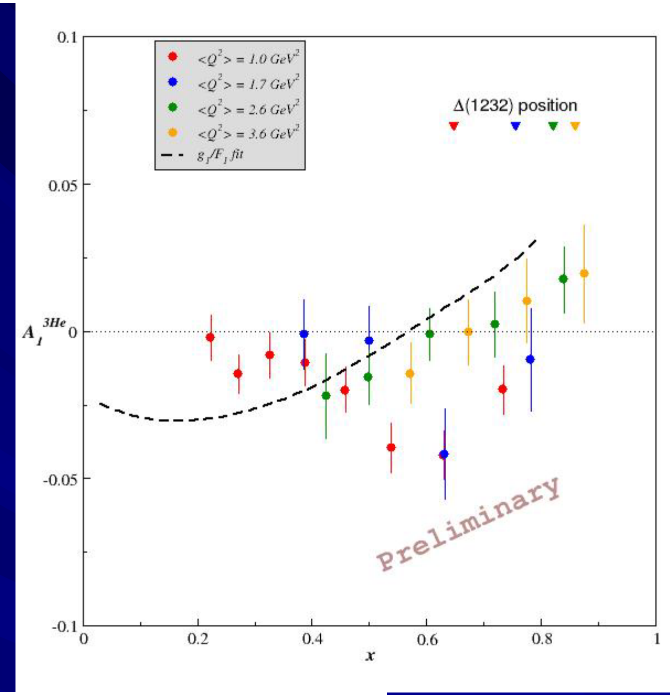
Test of Duality on Neutron and ^{3}He

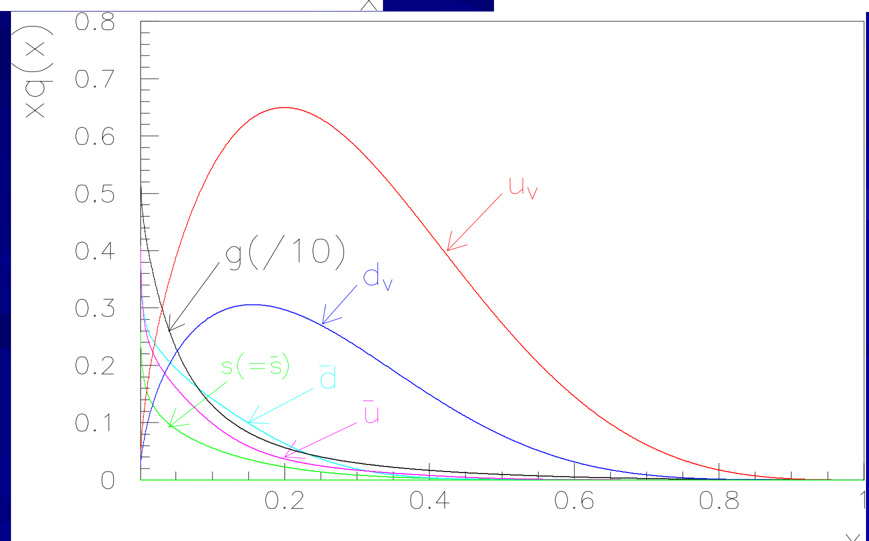


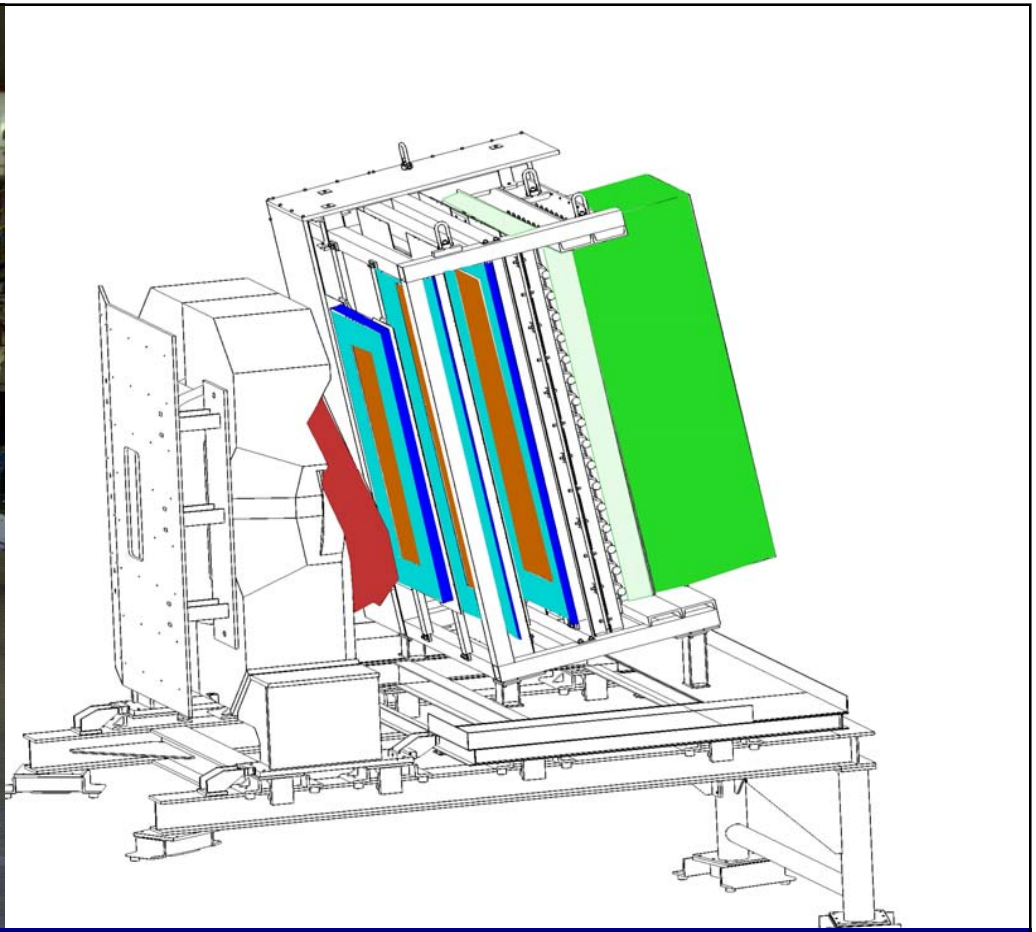


Global duality seems to work for all our Q^2

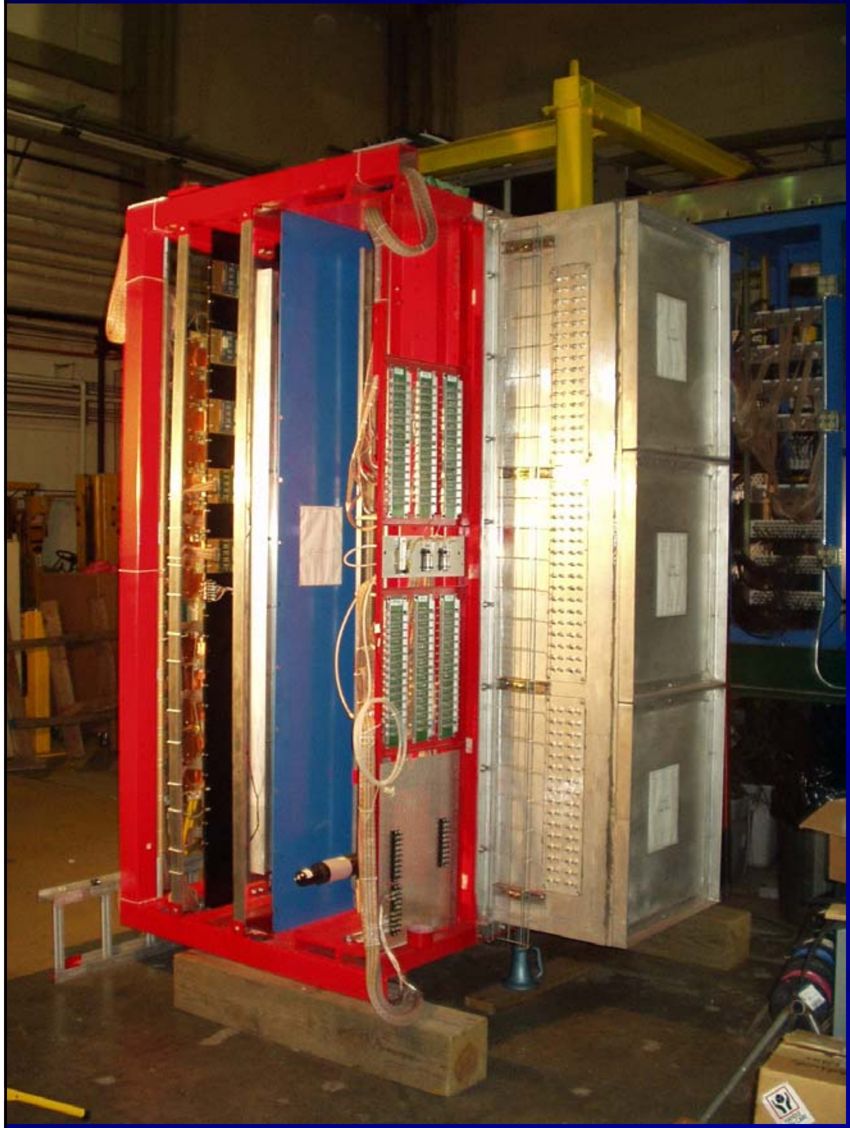
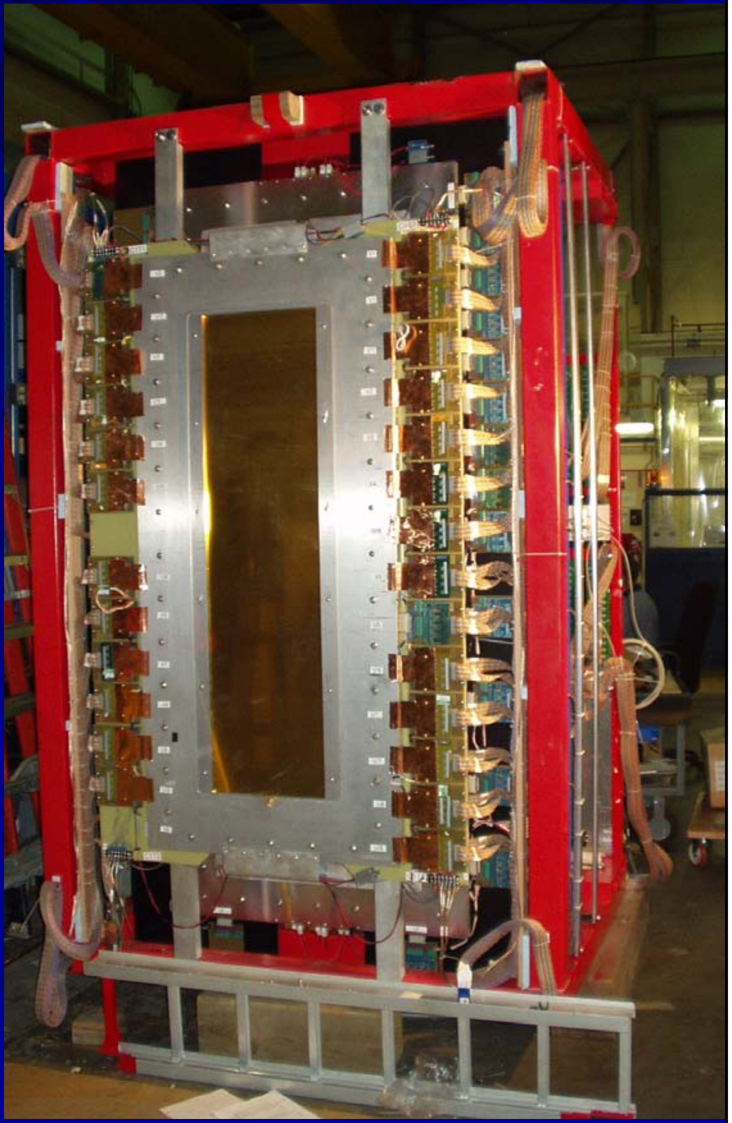

E99-117
E142(³He)
E154(³He)
HERMES(³He)
A_1^n
x

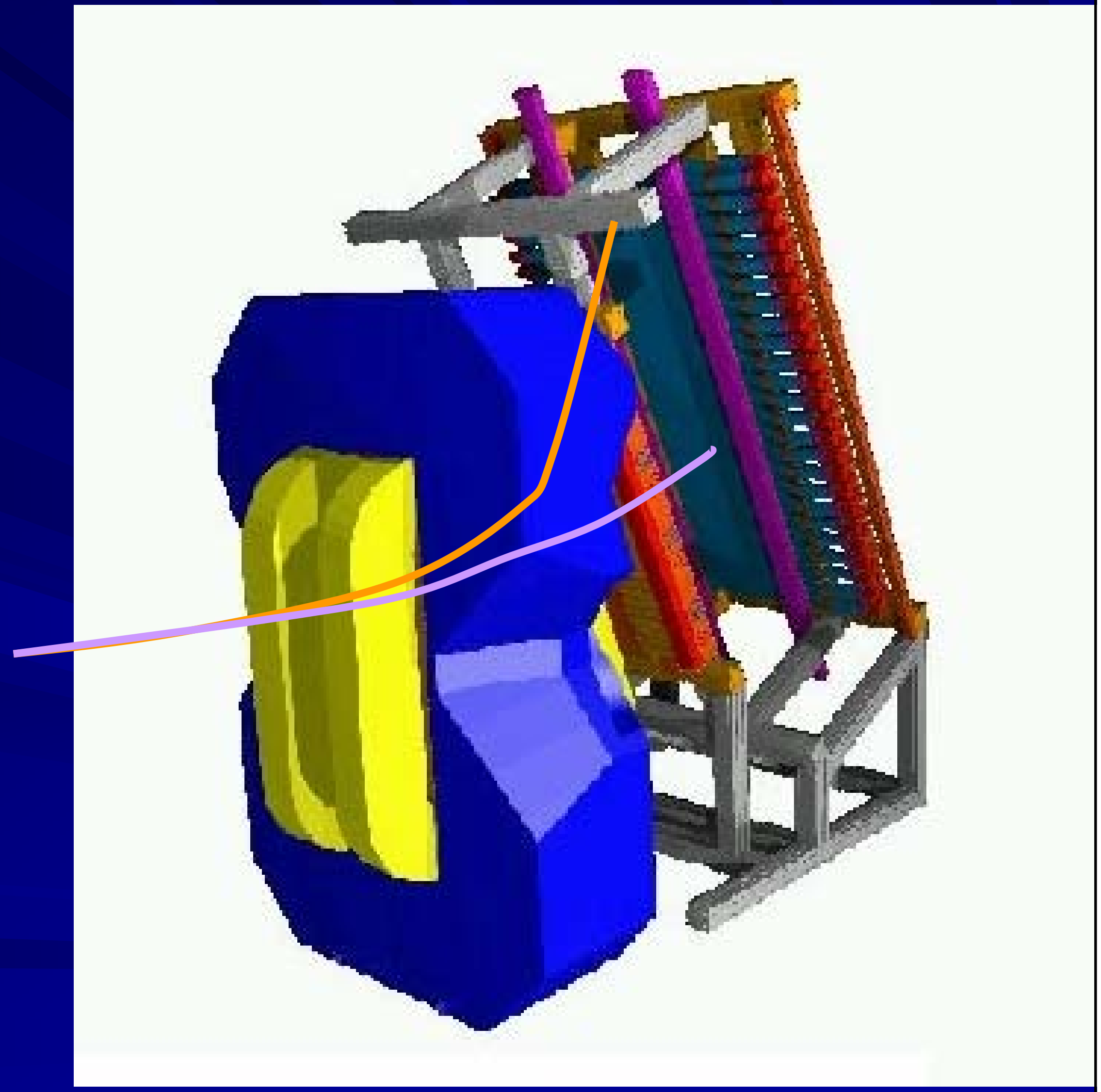

<Q²> = 1.0 GeV²
<Q²> = 1.7 GeV²
<Q²> = 2.6 GeV²
<Q²> = 3.6 GeV²
g₁/F₁ fit
Δ(1232) position
A_1^{3He}
Preliminary
x

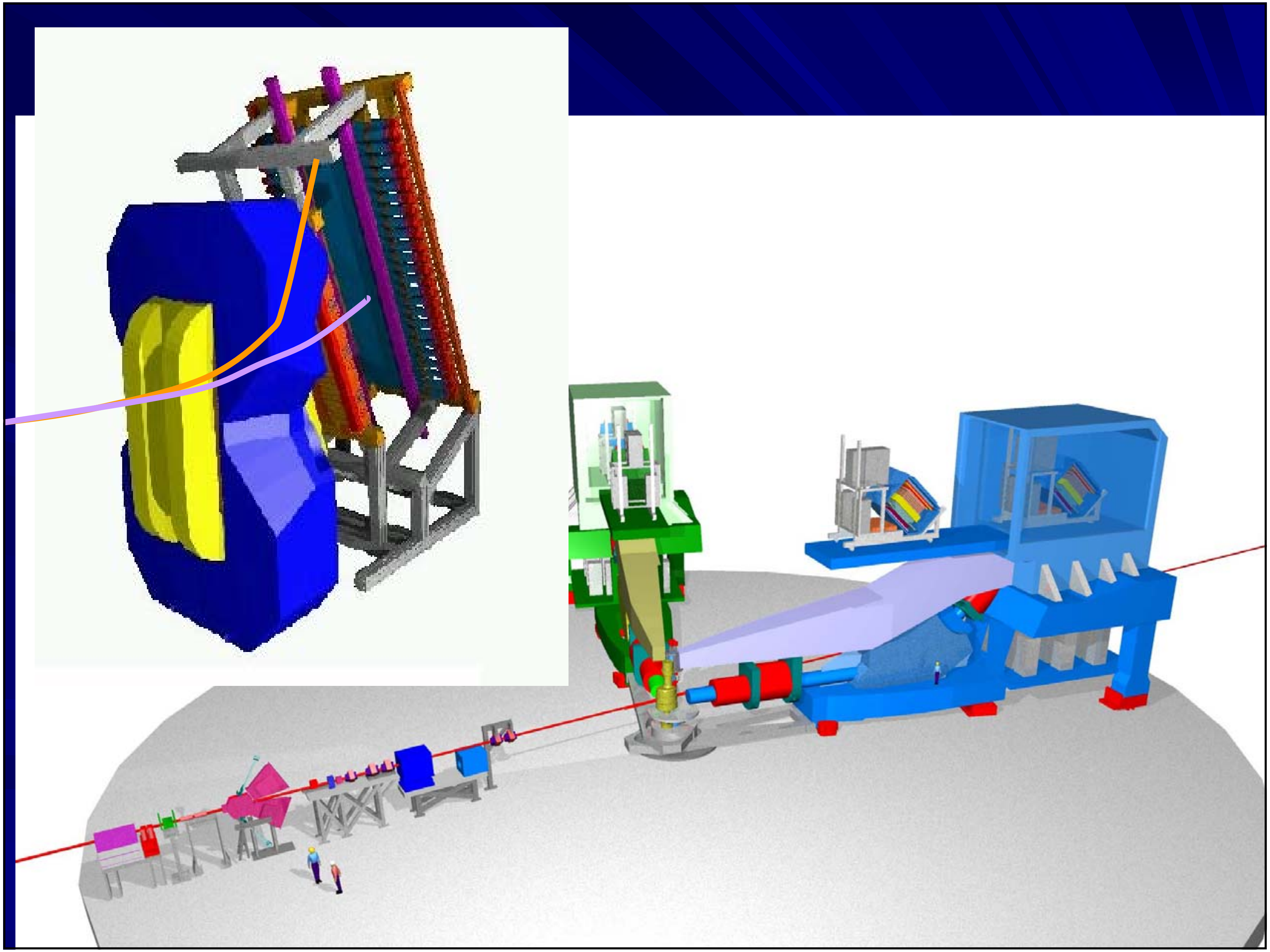

xq(x)
u_v
d_v
g(/10)
s(=s̄)
d̄
ū
x



Bigbite Spectrometer for Hall A:
Recently commissioned for high Q^2 neutron electric form factor (G_e^n)measurement

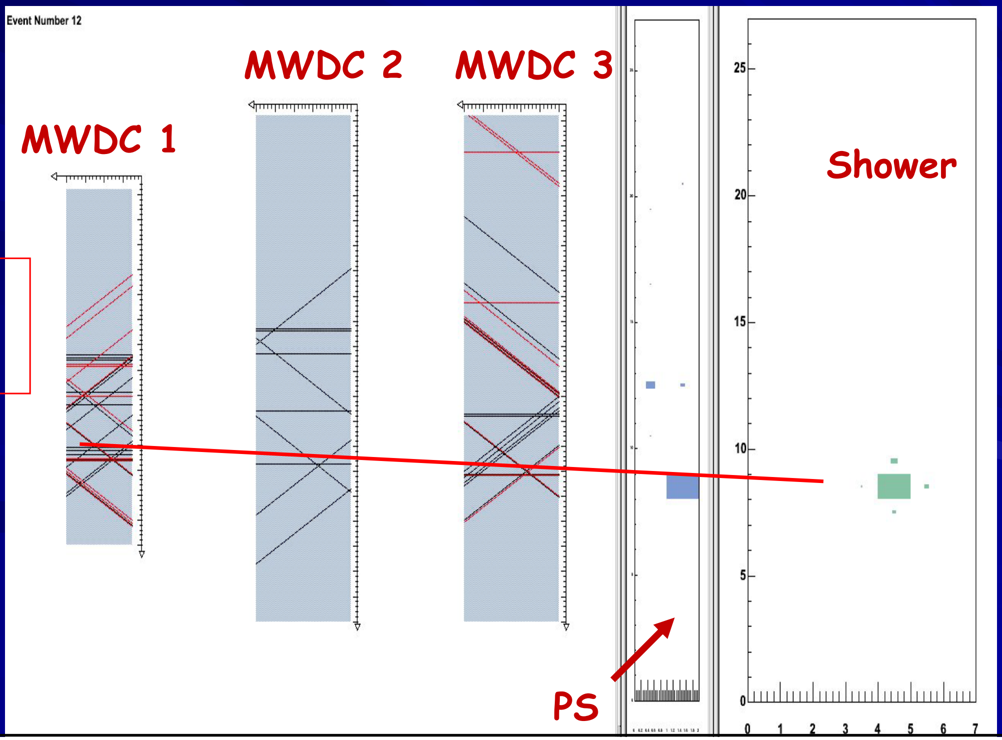




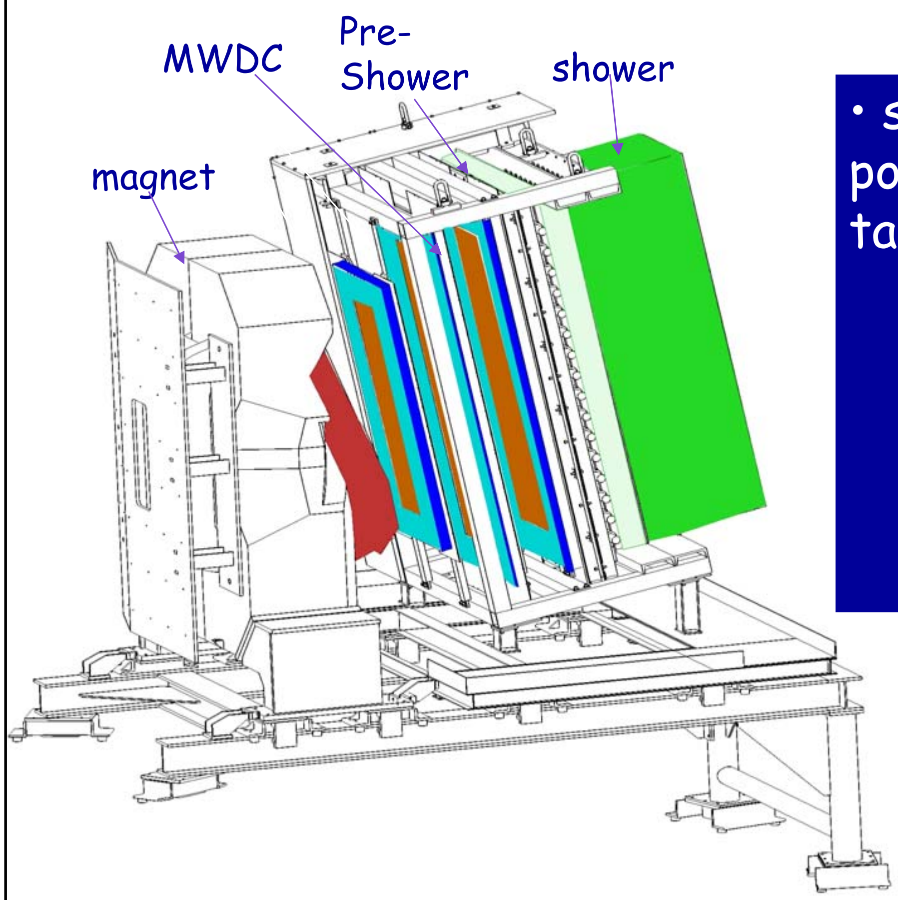
Background under Control

- Open configuration of Bigbite: Background is a serious issue.
- Background levels in Bigbite extensively studied in Gen

A typical electron event in Bigbite



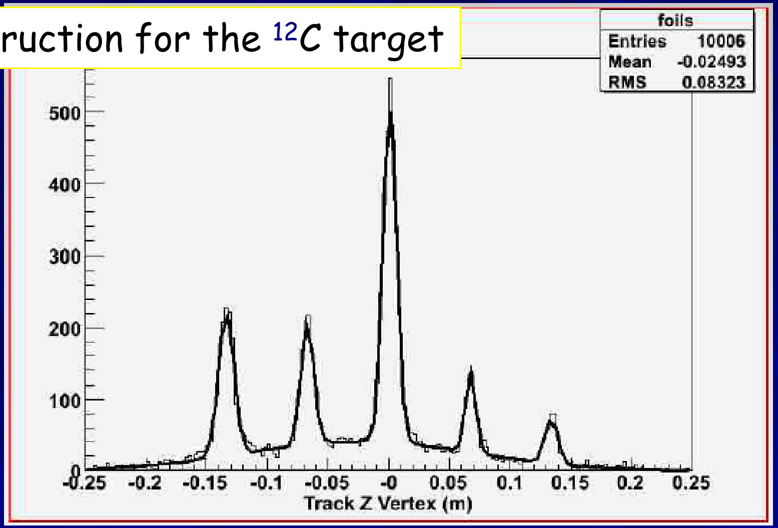
Bigbite Spectrometer in Gen



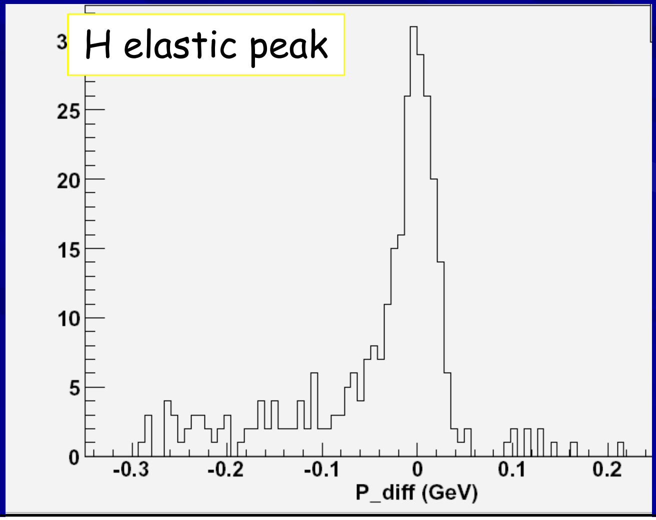
- successfully used for Gen with pol. ^{3}He (@ 50^o and 1.1 m from target).
  - 76 msr over 40 cm of target.
  - 20 MHz/plane on MWDC.
  - ~1% momentum resolution
  - ~5 mm y_tg resolution

Bigbite Performance at high Rates During Gen

Vertex reconstruction for the ^{12}C target



H elastic peak

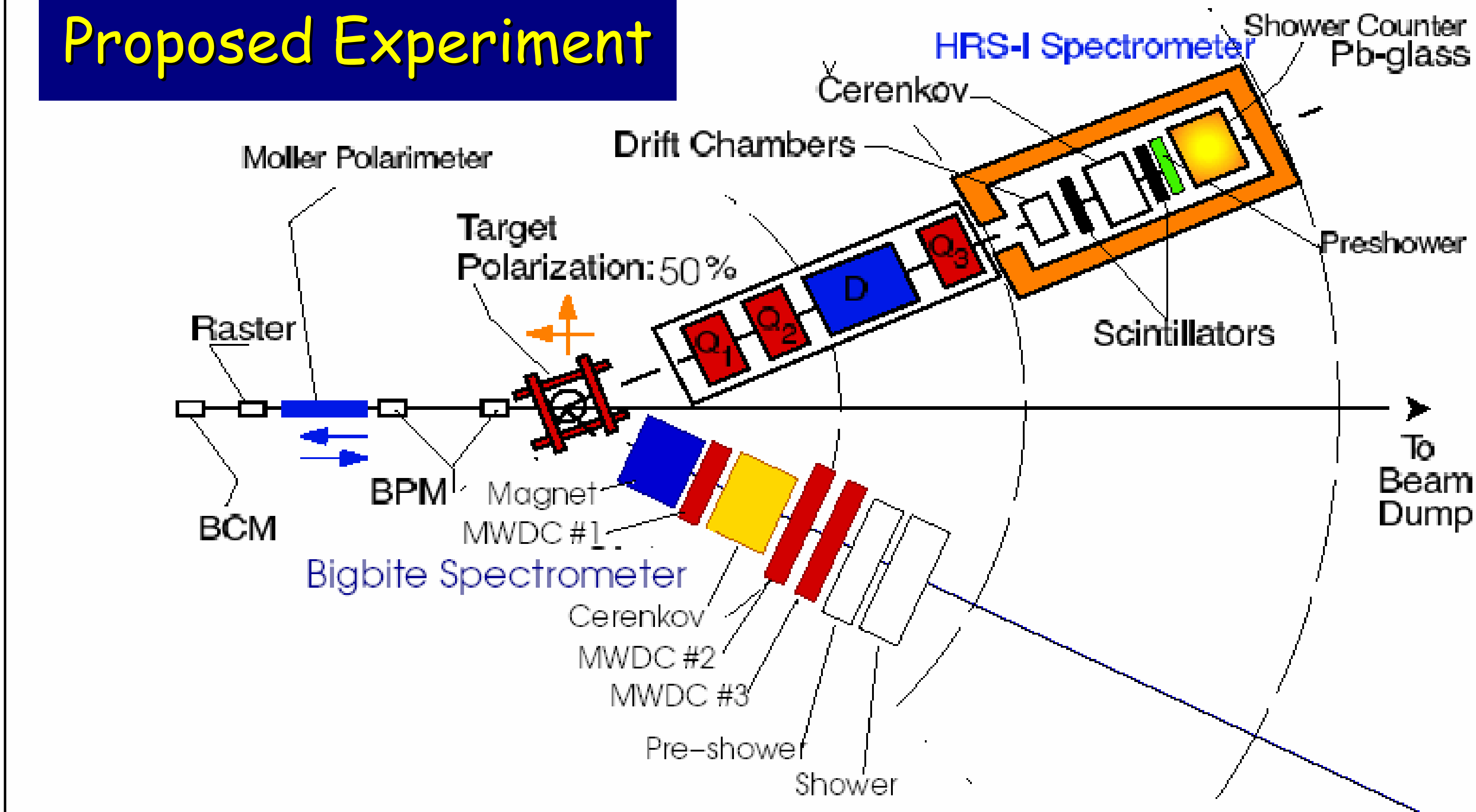


A new Experiment for upgraded Jefferson Lab: A_1^n in the high-x region using Bigbite spectrometer in hall A

G. Cates, N. Liyanage, Z.-E. Meziani, G. Rosner B. Wojtsekhowski and X. Zheng – spokespeople.

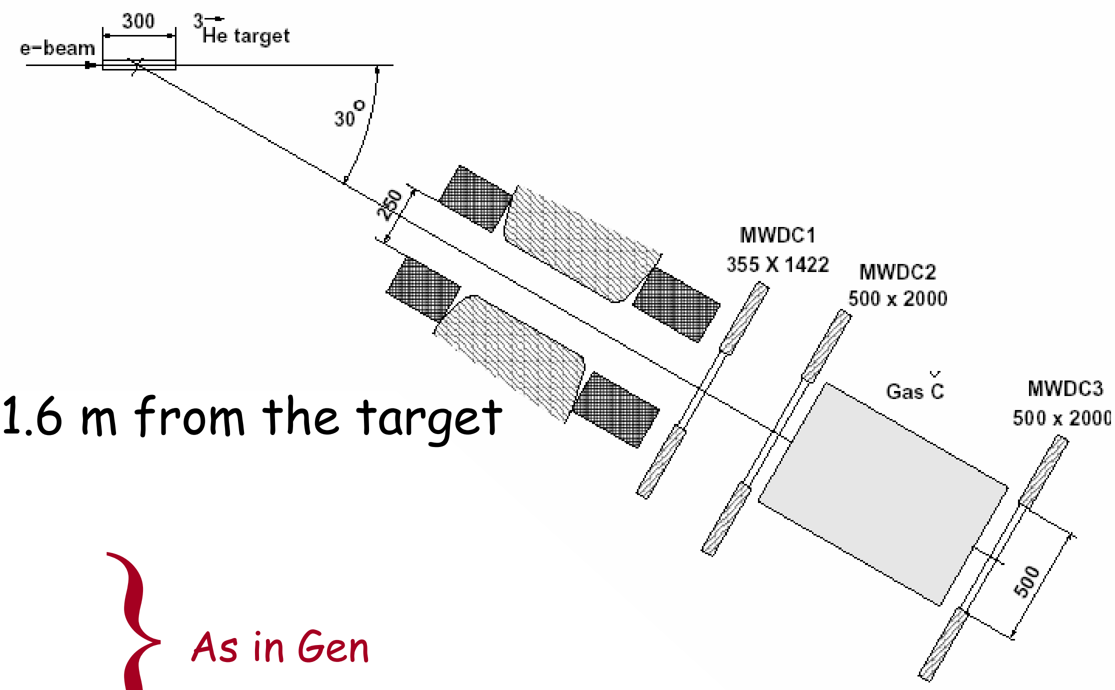
Use first high energy beams of 6.6 GeV and 8.8 GeV electron beams for a precision measurement of A1n up to x~0.72 in 550 h

Proposed Experiment



- 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^{o}
- HRS-L @ 30^{o}

Proposed Bigbite Configuration



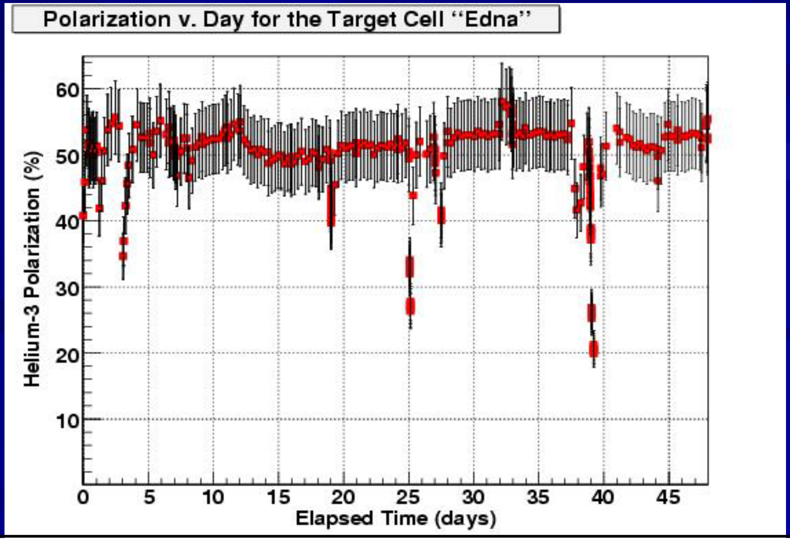
- Located at 30° and 1.6 m from the target
- Detector package
  - 3 MWDC
  - Pre-shower
  - Shower
  - Scintilator plane
  - Gas Cerenkov -

  } As in Gen

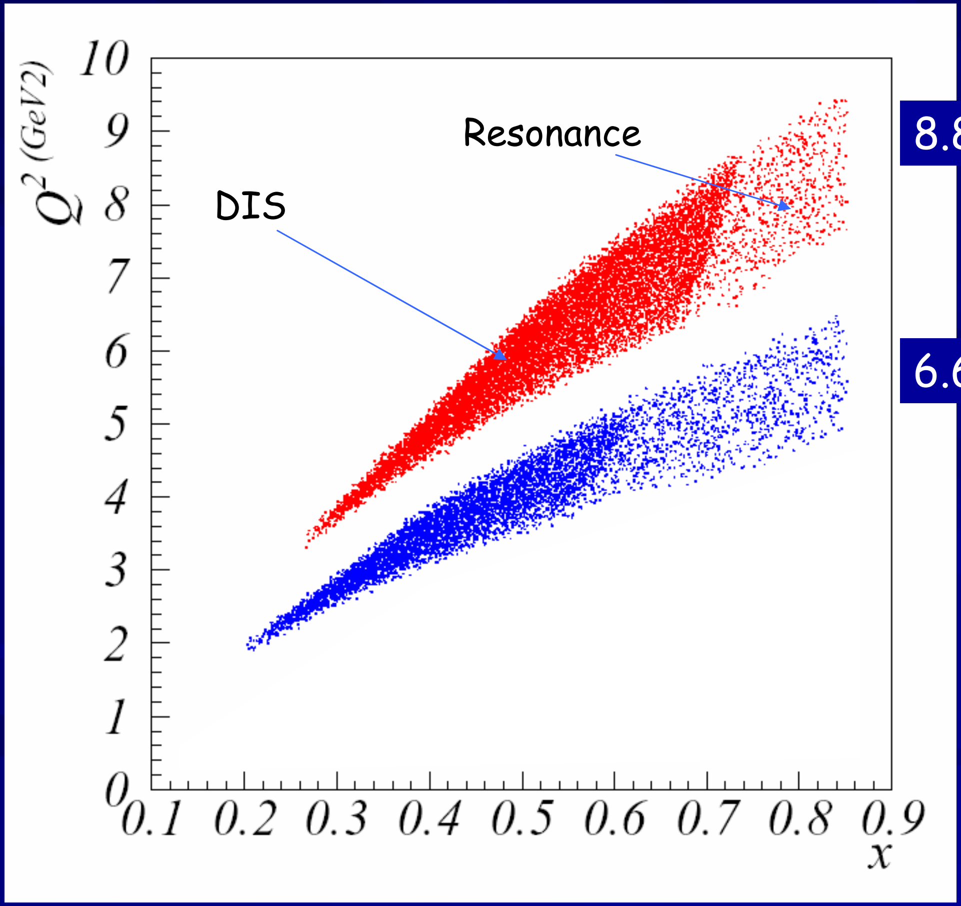
  being designed for E06-014
- MWDC#1 to #3 distance doubled
- Detect electrons up to 3.2 Gev

The Polarized ^{3}He Target

- This collaboration just completed a successful upgrade of the pol ^{3}He target for Gen
  - New hybrid technology: alkali mixture (Rb and K)
  - 100 W of laser power.
  - Pumping cell volume doubled.
    - ➢ ~55% polarization over the long run
    - ➢ no cell ruptures: a single cell for last six weeks

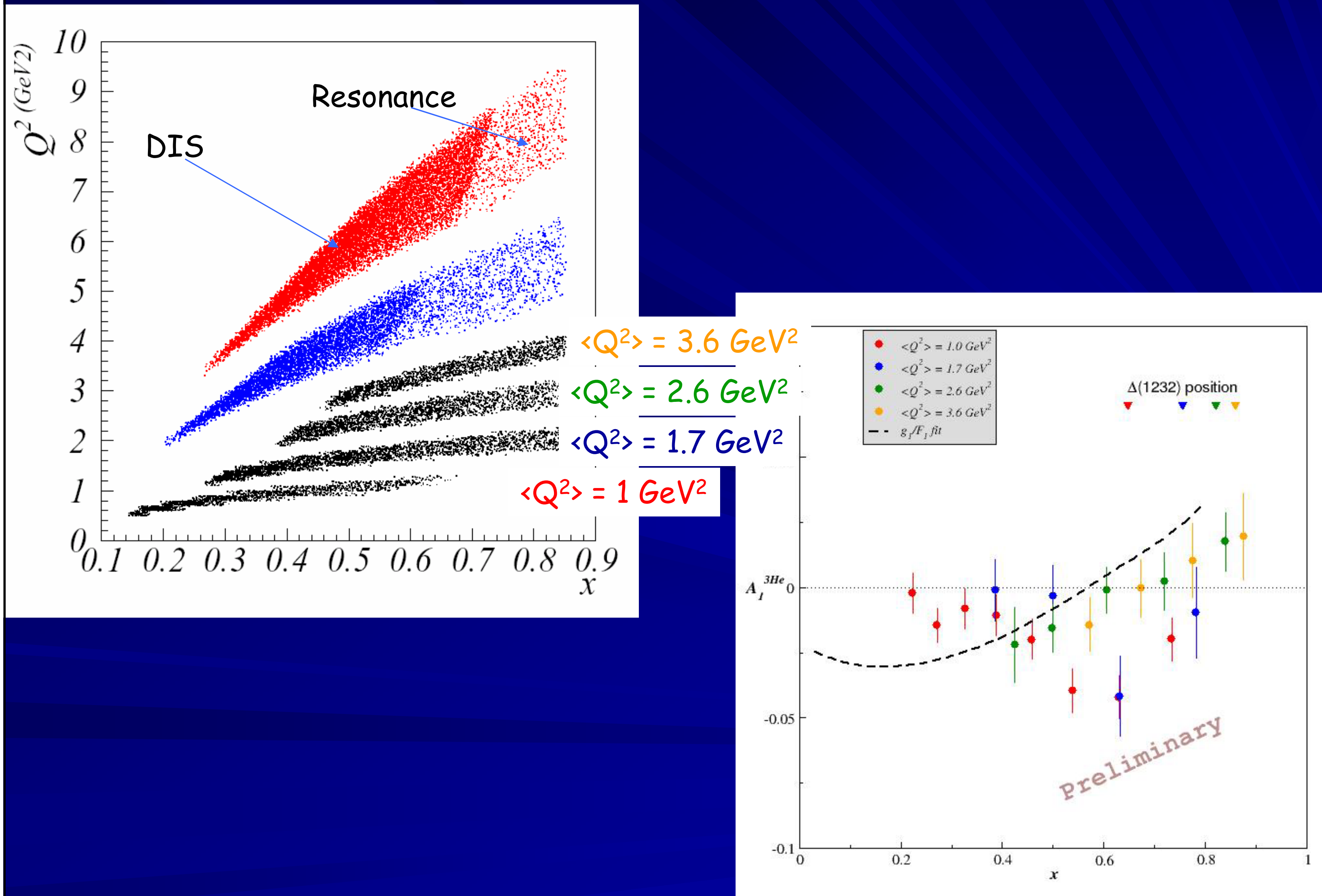


Kinematic Coverage



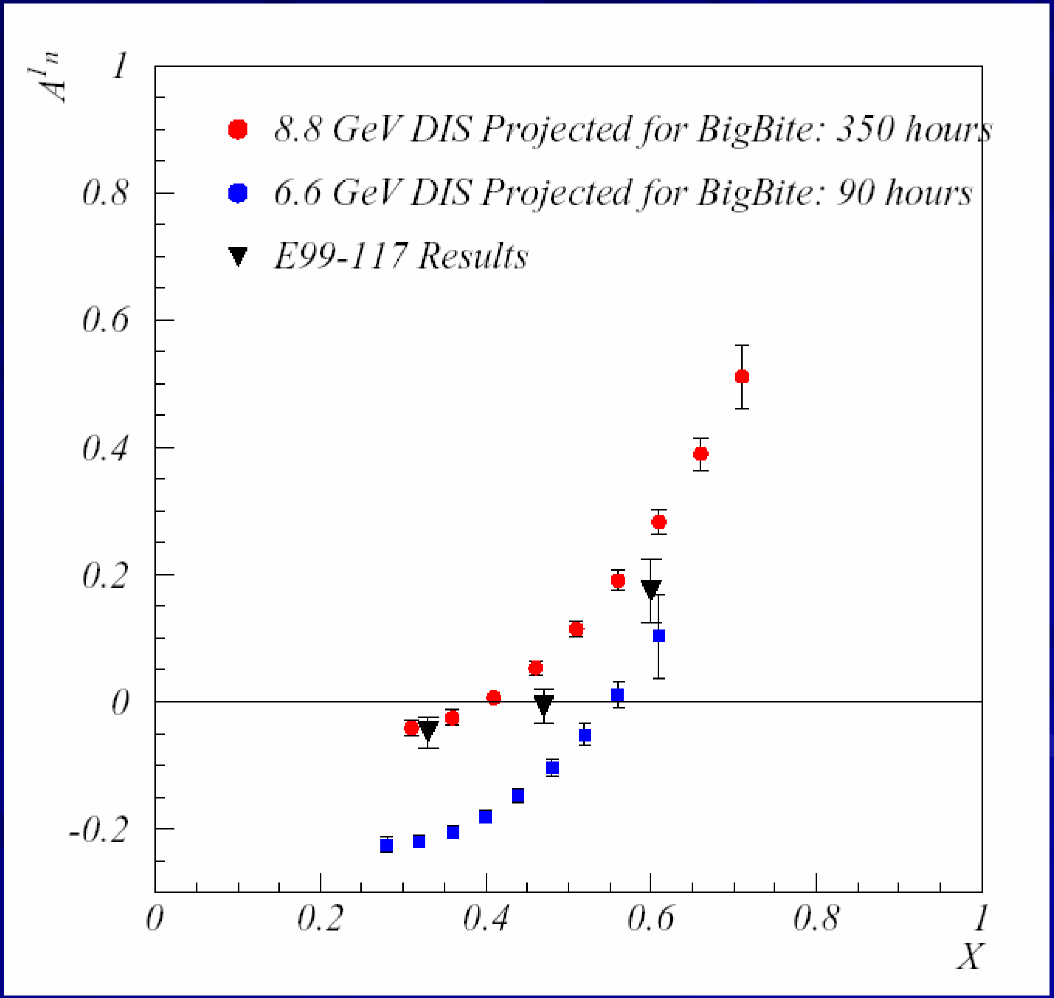
8.8 Gev beam Bigbite @ 30 °

6.6 Gev beam Bigbite @ 30 °



Q^2 (GeV2)
Resonance
DIS
x
$\langle Q^2 \rangle = 3.6$ GeV^2
$\langle Q^2 \rangle = 2.6$ GeV^2
$\langle Q^2 \rangle = 1.7$ GeV^2
$\langle Q^2 \rangle = 1$ GeV^2
$\langle Q^2 \rangle = 1.0$ GeV^2
$\langle Q^2 \rangle = 1.7$ GeV^2
$\langle Q^2 \rangle = 2.6$ GeV^2
$\langle Q^2 \rangle = 3.6$ GeV^2
g_1/F_1 fit
Δ(1232) position
A_1^{3He}
Preliminary

Projected data: DIS



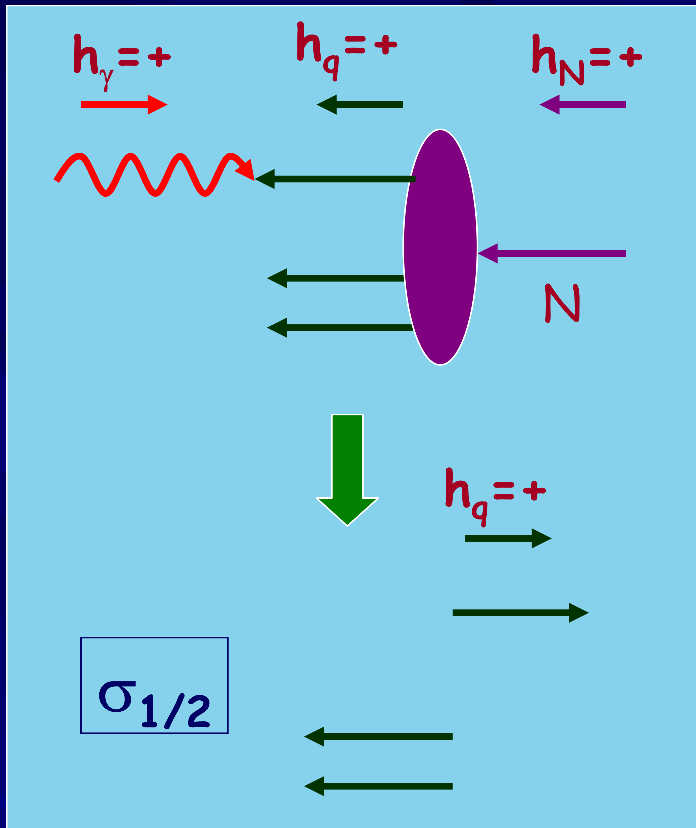
Summary

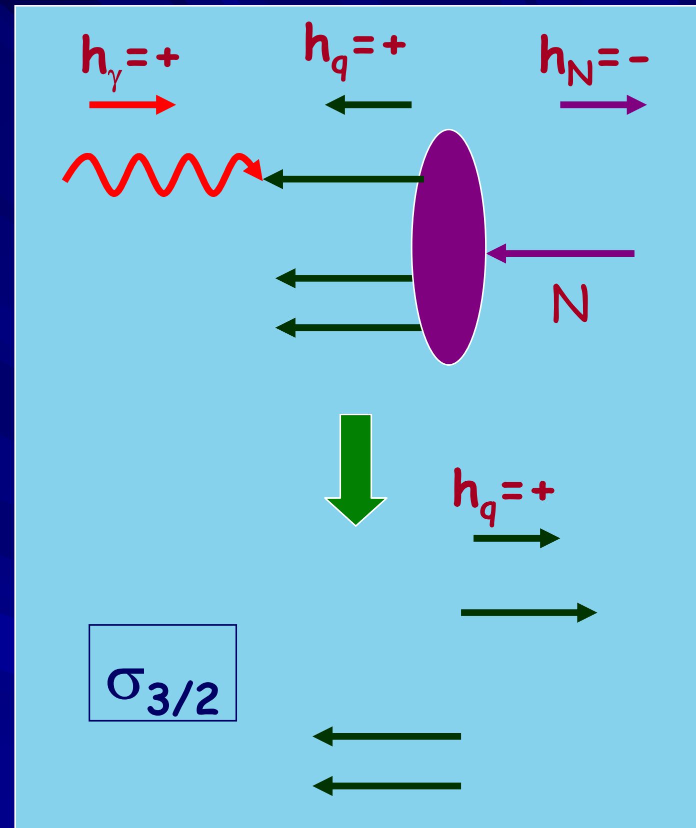
- Nucleon spin structure in the resonance region:
  - Three Jefferson lab experiments have provided precision data for neutron and proton spin structure functions in the resonance region:
    - **For $Q^2 < 2$ GeV^2, quark-hadron duality is violated in $\Delta(1232)$ and higher resonance regions.**
    - **Global duality for $Q^2 > 1.0$ GeV^2.**
- Bigbite + pol. ^{3}He target: a powerful combination
  - 5×10^{35} e-n luminosity with 50% polarization
  - 50 msr solid angle over 30 cm

• A recently approved measurement for upgraded Jlab will provide most precise data for A_1^n up to x ~ 0.72.

•A crucial step in understanding valence nucleon structure

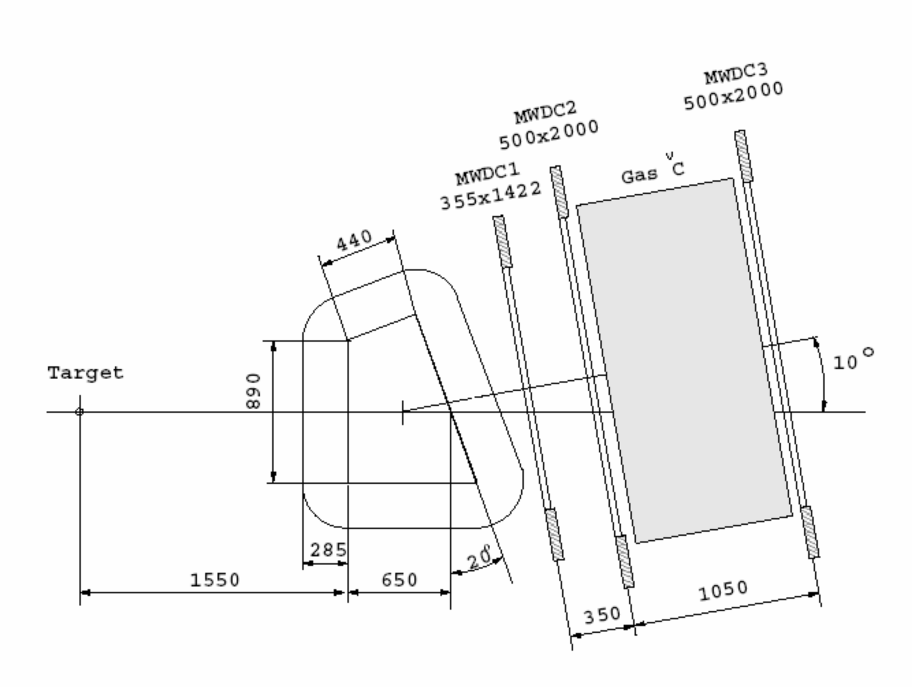
Virtual Photon Asymmetry

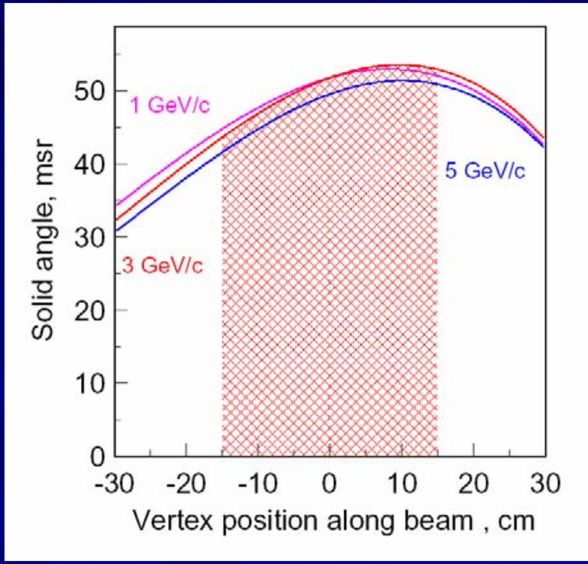


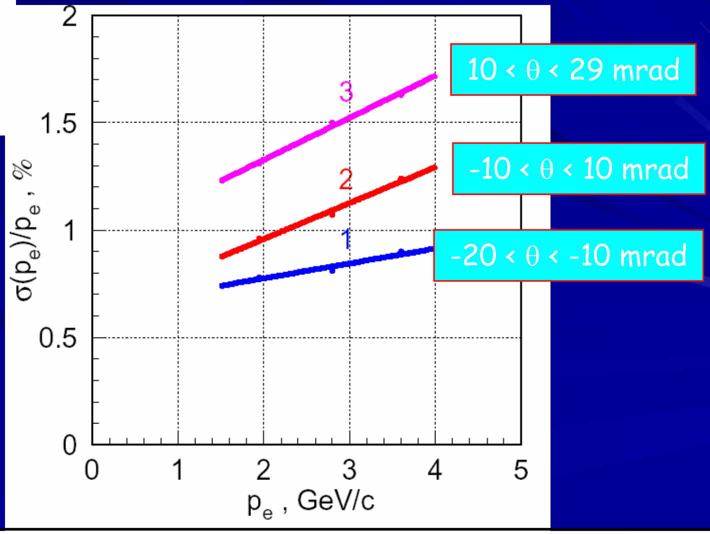


$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{g_1}{F_1}$$

Bigbite Simulations







- A Complete Geant Simulation for the proposed setup
- Acceptance 50 msr averaged over 30 cm of target
- Momentum resolution ~ 1%

The Polarized ^{3}He Target

- This collaboration just completed a successful upgrade of the pol ^{3}He target for Gen
  - New hybrid technology: alkali mixture (Rb and K)
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  - Pumping cell volume doubled.
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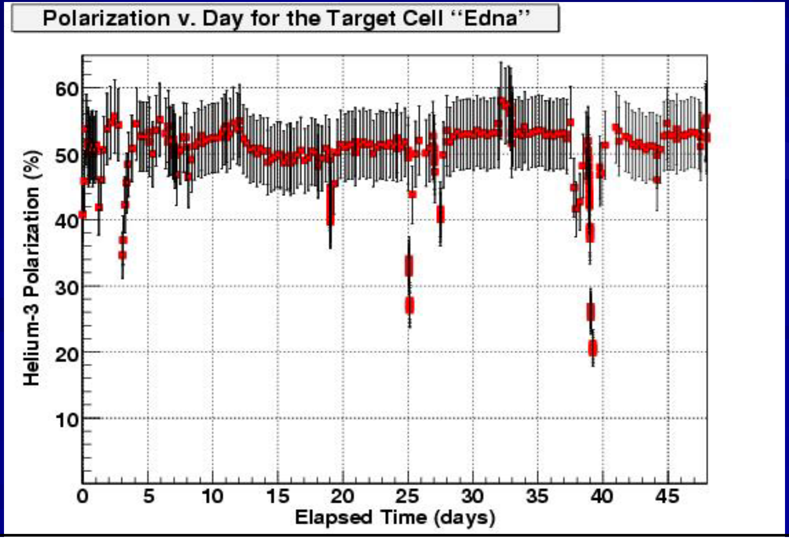


Theoretical Analysis

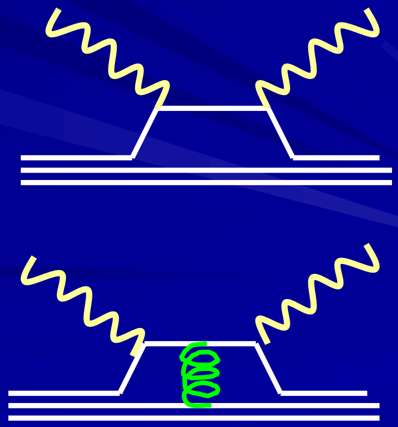
Using Operator Product Expansion (Rujula, Georgi, Politzer):

n^{th} Moment of Structure Function:

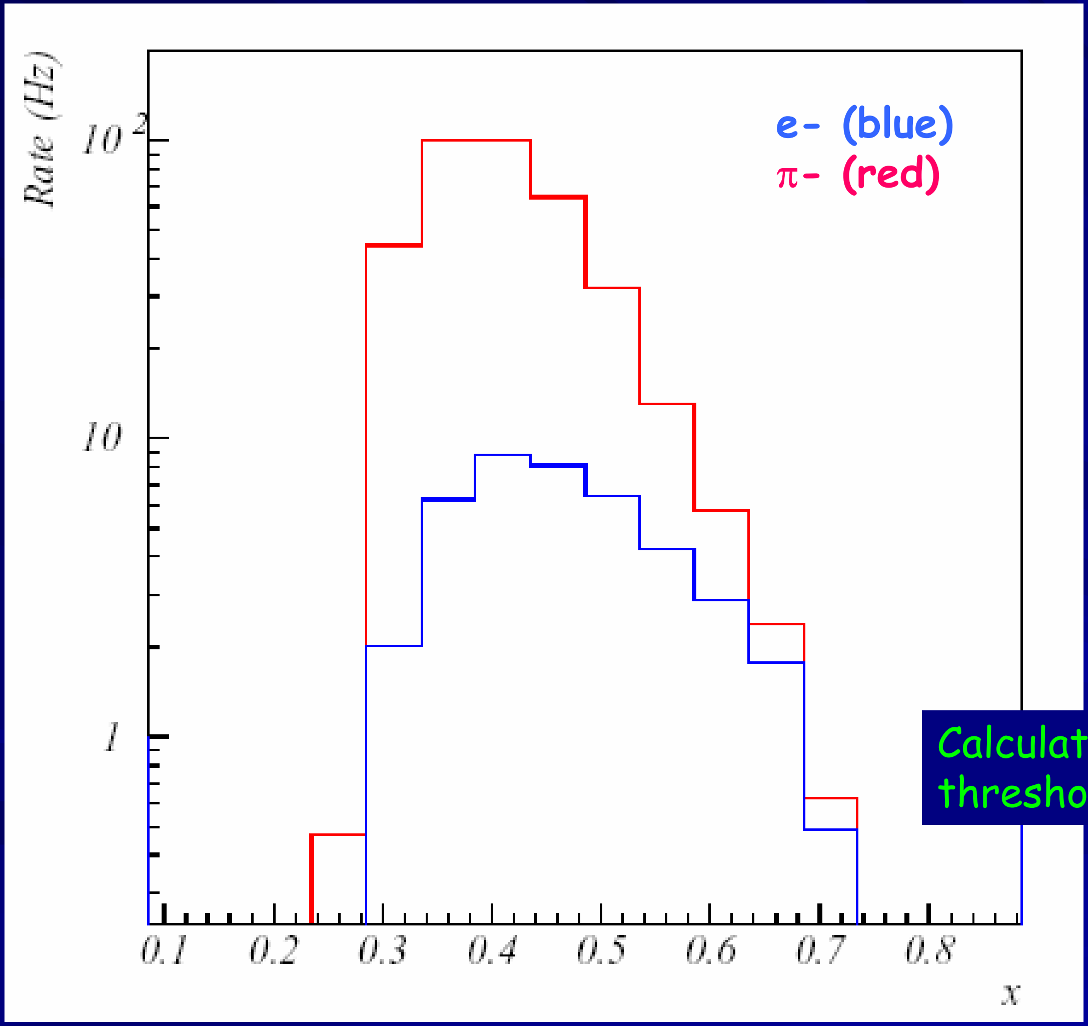
$$M_n(Q^2) = \int_0^1 dx\ x^{n-2} F_2(x, Q^2)$$

$$M_n(Q^2) = A_n^{(0)} + \frac{A_n^{(2)}}{Q^2} + \frac{A_n^{(4)}}{Q^4} + \ldots\ldots$$

- **OPE of QCD moments of structure functions.**
- Leading terms $\Rightarrow$ free quark scattering $\Rightarrow$ scaling
- $1/Q^2$ terms $\Rightarrow$ interactions between quarks and gluons



π/e Ratio estimates for 8.8 GeV



Worst case
π/e ratio ~ 20
Can be handled with
Shower + Pre-shower
and Cerenkov

Calculated with a 2 GeV
threshold on momentum