GDH Sum Rule at JLab Hall B

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For the CLAS and EG4 collaborations

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GDH Sum Rule

$$I_{GDH} = \frac{M^2}{8\alpha\pi^2}\int_{thr}^{\infty}\left(\sigma_{1/2} - \sigma_{3/2}\right)\frac{d\nu}{\nu} = -\frac{1}{4}\kappa^2$$

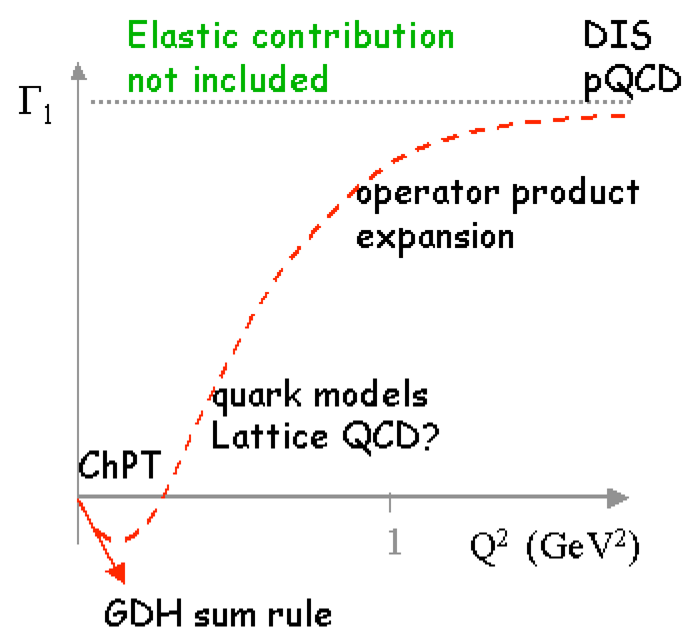
- relates the difference of the photo-absorption cross section for helicity 1/2 and 3/2 to the nucleon magnetic moment, i.e. a connection between dynamic and static properties. Recent measurements at Bonn and Mainz, ongoing efforts at other labs

- based on very general principles, as gauge invariance, dispersion relation, low energy theorem

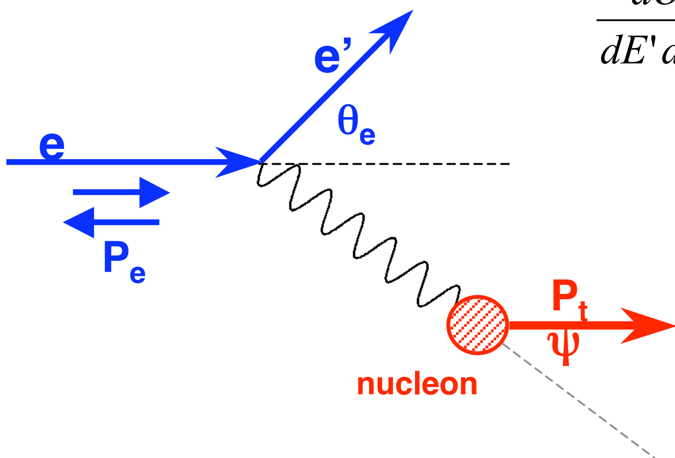
- at non-zero Q^2 can be related to the integral of the spin structure function g_1

$$\Gamma_1 = \int g_1\left(x, Q^2\right)dx \xrightarrow[Q^2 \to 0]{} \frac{Q^2}{2M^2} I_{GDH}$$

- strong variation of nucleon spin properties as a function of Q^2



Asymmetries and Spin Structure Functions



$$\frac{d\sigma}{dE'd\Omega} = \Gamma_v \left[\sigma_T + \varepsilon\sigma_L + P_e P_t \left(\sqrt{1-\varepsilon^2}\,\mathbf{A_1}\sigma_T\cos\psi + \sqrt{2\varepsilon(1-\varepsilon)}\,\mathbf{A_2}\sigma_T\sin\psi\right)\right]$$

$$\mathbf{A_1} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_T} \qquad \mathbf{A_2} = \frac{\sigma_{LT'}}{\sigma_T}$$

the structure functions $\mathbf{A_1}$ and $\mathbf{A_2}$ can be extracted by varying the direction of the nucleon polarization

$$A^{\parallel} = D(A_1 + \eta A_2)$$
$$A^{\perp} = d(A_1 + \zeta A_2)$$

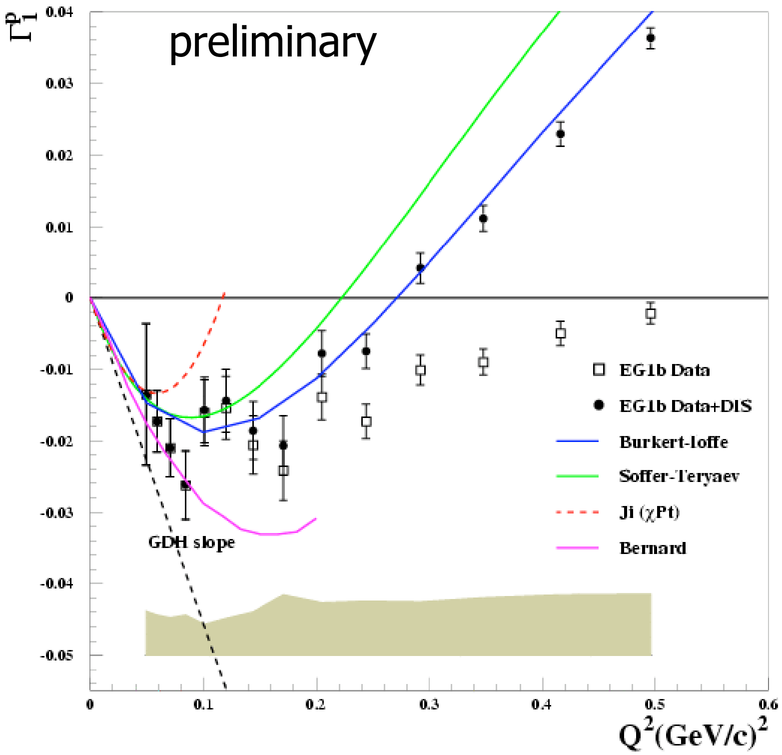
where D, η, d, ξ are function of Q^2, W, E_0, R

the structure functions $\mathbf{g_1}$ and $\mathbf{g_2}$ are linear combination of $\mathbf{A_1}$ and $\mathbf{A_2}$

$$\mathbf{g_1(x,Q^2)} = \frac{Q^2}{Q^2 + 4M^2x^2}\left(A_1 + \frac{2Mx}{\sqrt{Q^2}}A_2\right)F_1(x,Q^2)$$

$$\mathbf{g_2(x,Q^2)} = \frac{Q^2}{Q^2 + 4M^2x^2}\left(\frac{\sqrt{Q^2}}{2Mx}A_2 - A_1\right)F_1(x,Q^2)$$

Recent Measurements with CLAS



$$g_1(x,Q^2) = \frac{Q^2}{Q^2 + 4M^2x^2}\left(A_1 + \frac{2Mx}{\sqrt{Q^2}}A_2\right)F_1(x,Q^2)$$

$$\Gamma_1 = s\ g_1(x,Q^2)\ dx$$

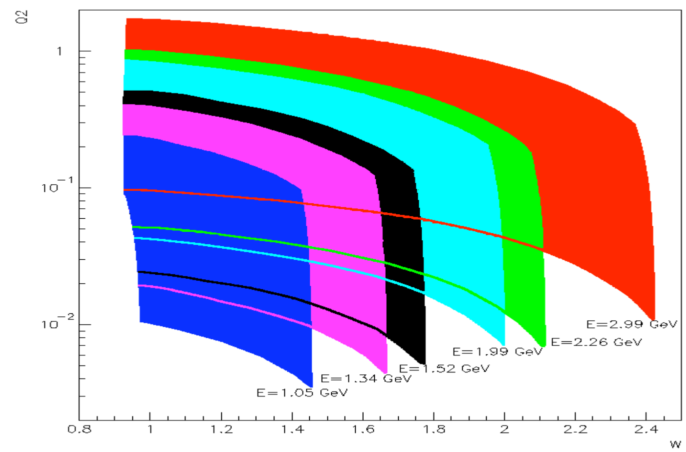
Integral goes down to Q^2 of 0.05 GeV^2

Shows strong Q^2 dependence varying from negative to positive values as Q^2 increases

Significant systematic uncertainties due to parameterization of F_1 and R

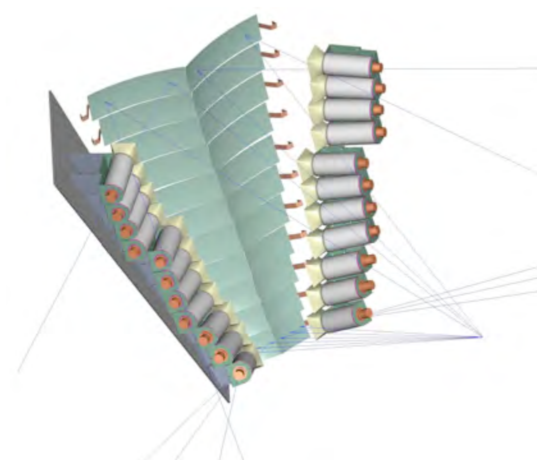
E-03-006 (EG4)
The GDH Sum Rule with nearly real photons

- Measurement of spin structure function $g_1(x,Q^2)$ at Q^2 down to 0.015 GeV^2 (θ_{min}= 6 degrees)
- Test of χPT at Q2$\rightarrow$ 0
- Measurement of the absolute cross section difference:

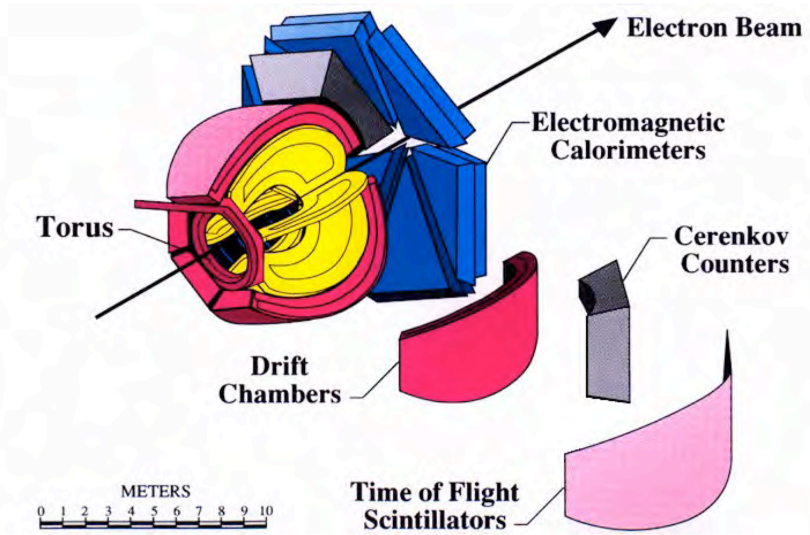


$$\frac{d\sigma^{\rightarrow\Leftarrow}}{d\Omega dE'} - \frac{d\sigma^{\rightarrow\Rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{M E \nu Q^2}\left[(E - E'\cos\theta) g_1(x,Q^2) - 2Mx g_2(x,Q^2)\right]$$

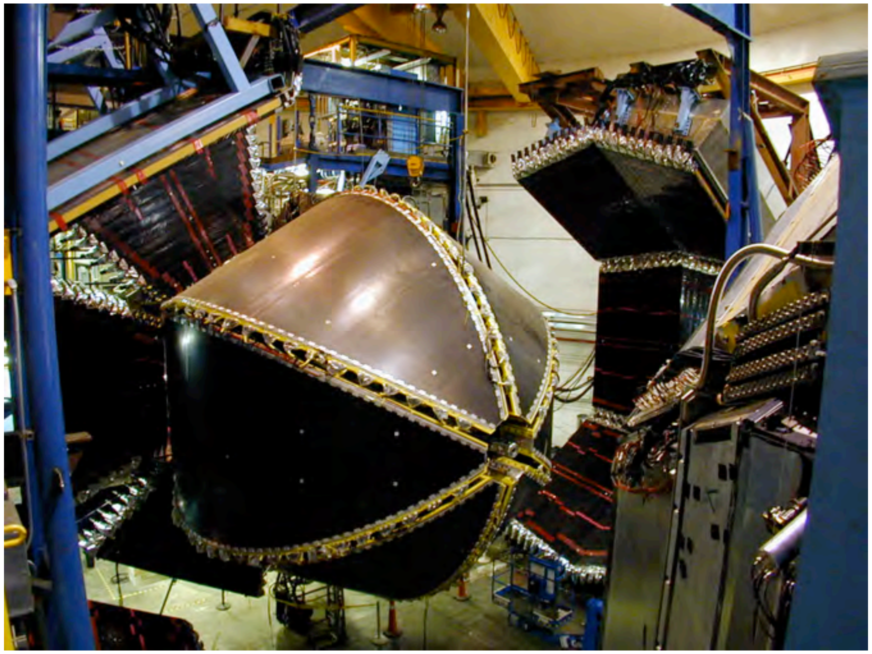
Cross section measurement requires uniform detection efficiency at low Q^2! new Cerenkov detector built by INFN-Genova to detect scattered electrons down to 4.5 degrees



Experimental Setup



CEBAF
Large
Acceptance
Spectrometer

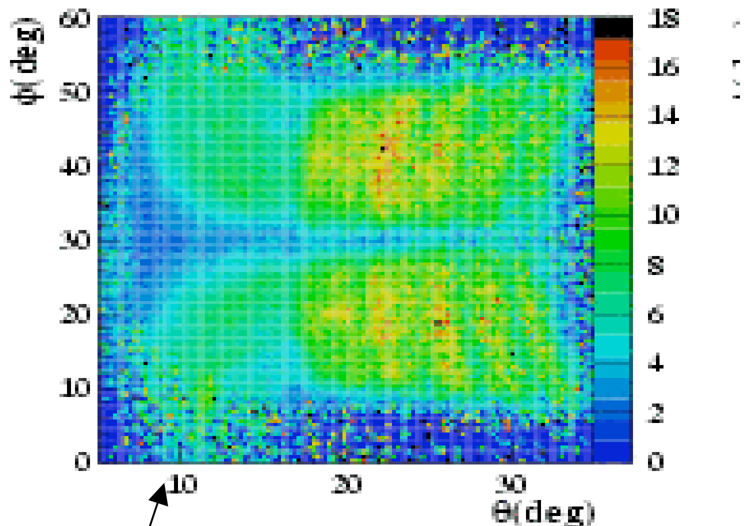


- large kinematical coverage
- simultaneous measurement of exclusive and inclusive reactions
- central field-free region well suited for the insertion of the polarized target

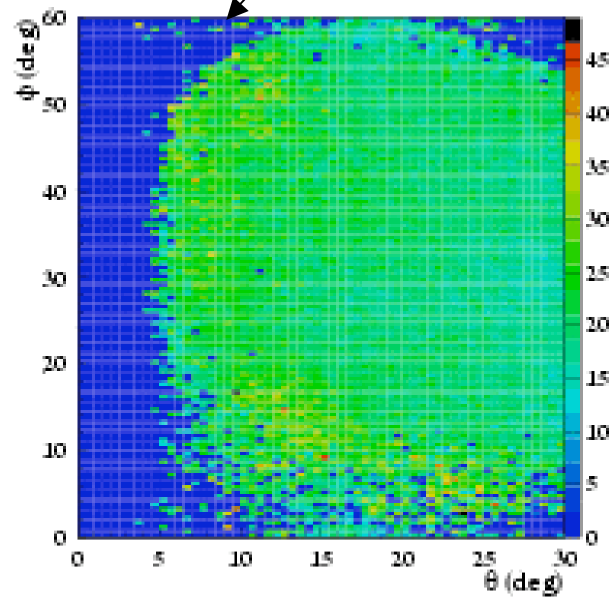
New Cerenkov Counter

"Old" Cerenkov counter was designed to maximize the azimuthal coverage
Complex geometry
Components optimized for high Q^2, low-rate experiments
using the inbending electron tracks.

New CC counter
Optimized for this experiment
Uniform detection efficiency

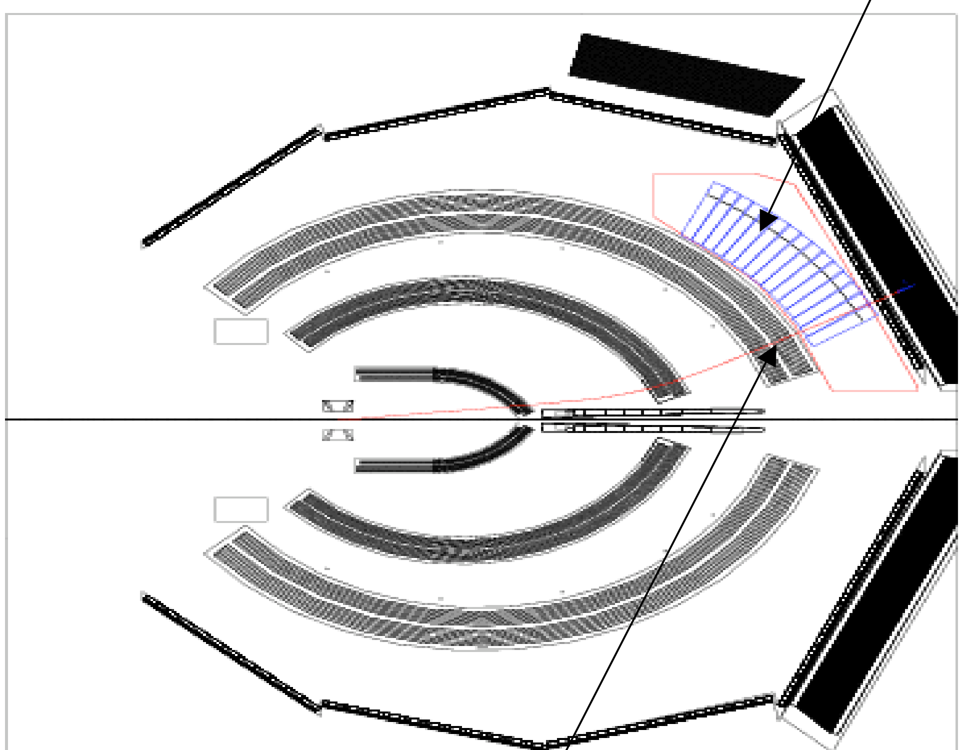


"Old" CC with outbending configuration, P_{el}=0.6 GeV



Side view of CLAS with new CC

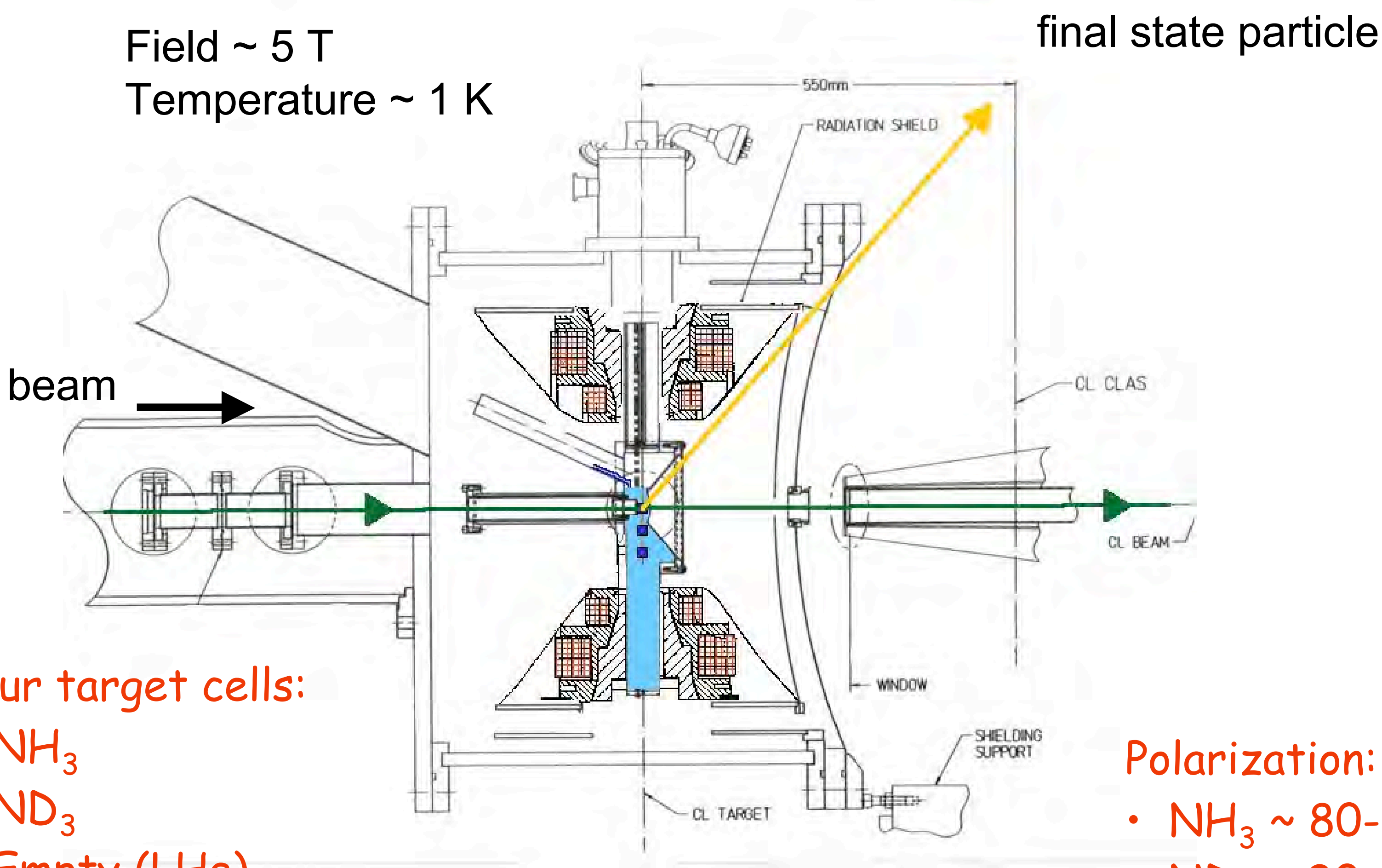
The new detector fits inside of existing volume (sector 6)



The red track corresponds to an electron emitted at 6 degrees

Polarized Target

Field ~ 5 T
Temperature ~ 1 K



Four target cells:

- NH_3
- ND_3
- Empty (LHe)
- ^{12}C

Polarization:

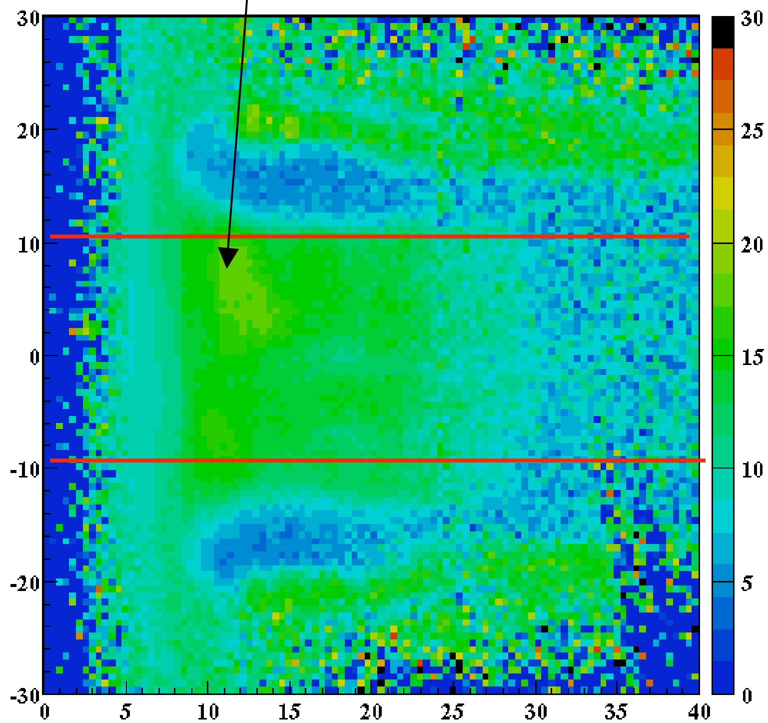
- NH_3 ~ 80-90 %
- ND_3 ~ 30-45 %

E03-006 /E03-111 Status

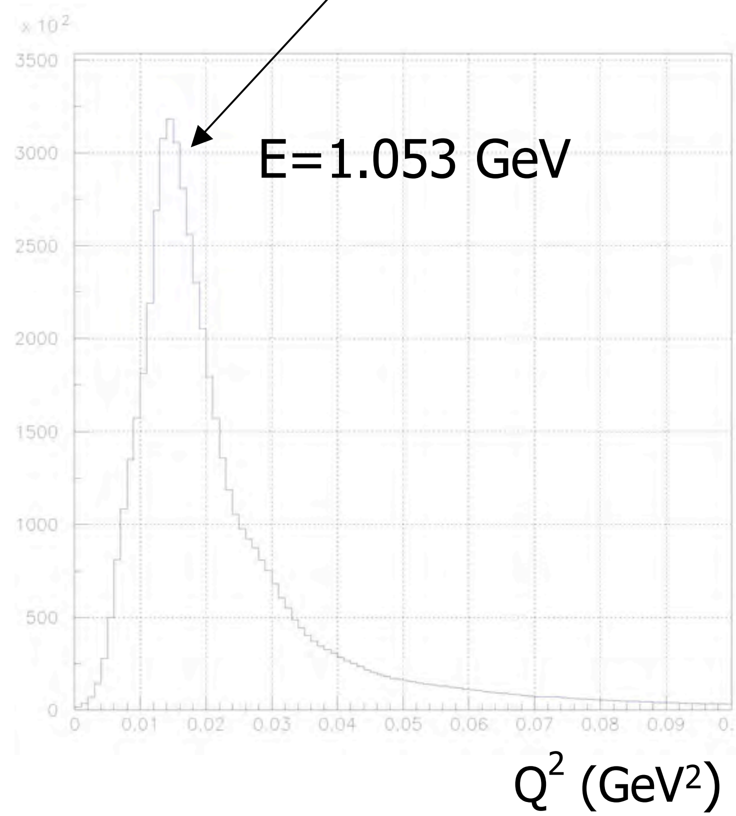
- Completed data taking in May 2006
- $^{15}NH_3$ target:
  E=1.0, 1.3, 1.5, 2.2, 3.0 GeV
  15.8 billion triggers
  Target polarization 80-90%
- $^{15}ND_3$ target
  E=1.3, 2.0 GeV
  6.3 billion triggers
  Target Polarization 30-45%
- Improved DAQ rate, ~8.5 kH

E-03-006 (cont)

Limited azimuthal coverage
Uniform detection efficiency



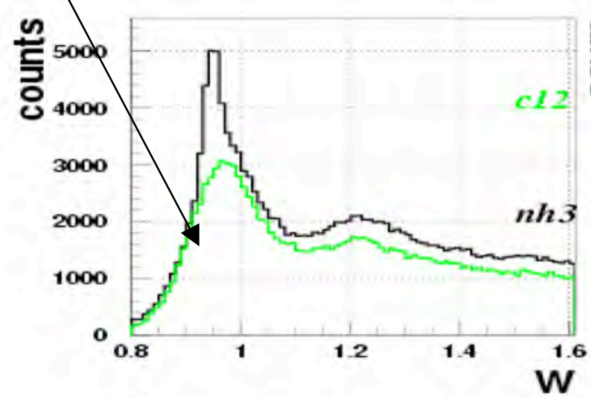
Reaching down to Q^2 ~0.015

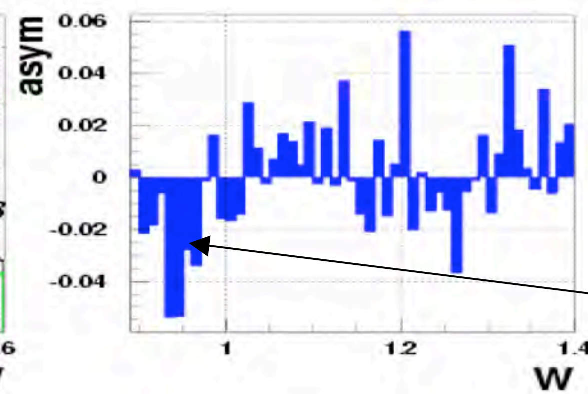


Extraction of P_bP_t

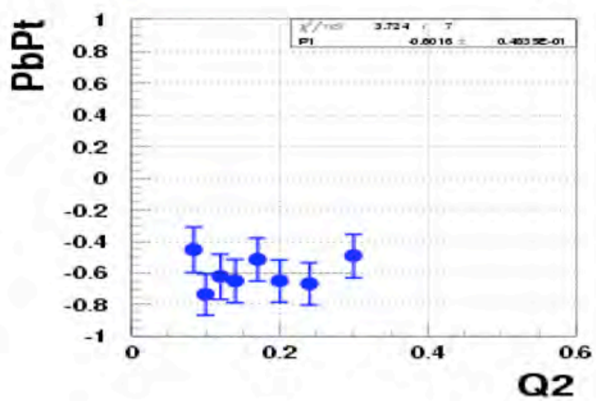
$$A^{el}_{th} = \frac{2\tau r * \left[\frac{m_p}{e} + r(\tau\frac{m_p}{e} + (1+\tau)tan^2(\frac{\theta}{2}))\right]}{1+\tau\frac{r^2}{\epsilon}}$$

Normalize to carbon





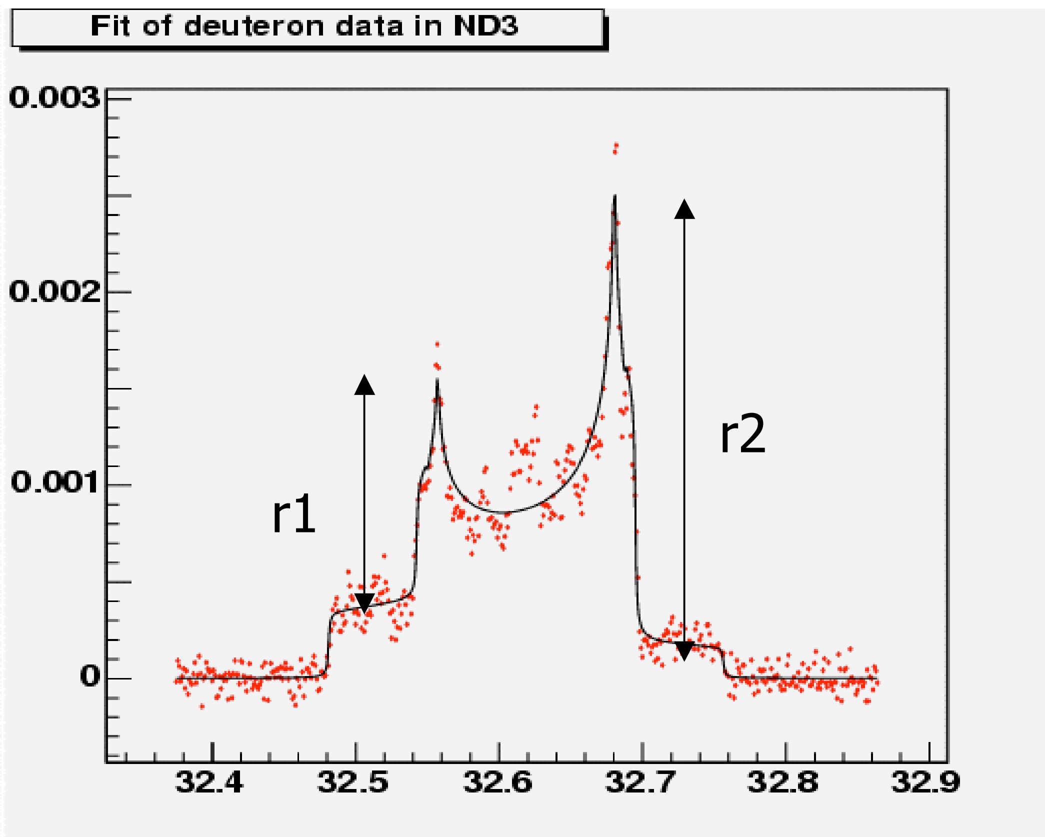
Elastic asymmetry



run=51556 PbPt= -0.601619+-0.04835

$P_bP_t = A_{meas}/A_{el}$, in bins of Q^2

E-03-006 ($^{15}ND_3$ run)



Achieved high deuterium polarization, up to 45 %.

This estimation is based on the method of “peak heights” ratio:

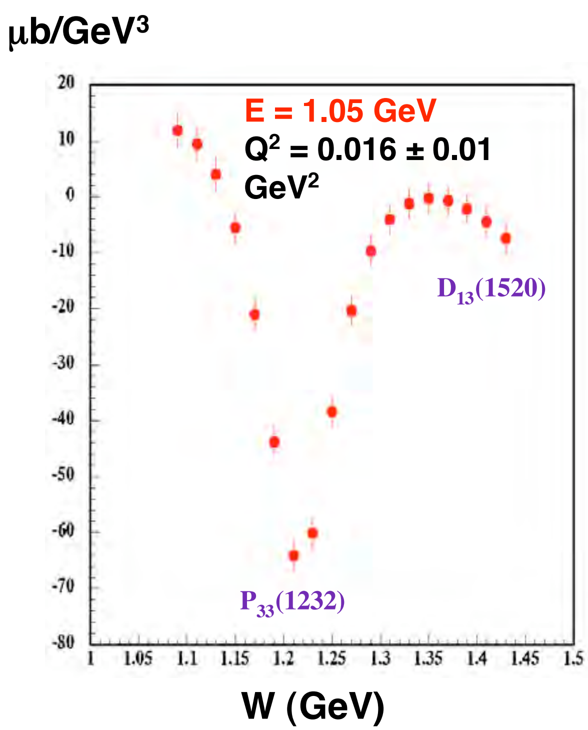
$R=r1/r2$

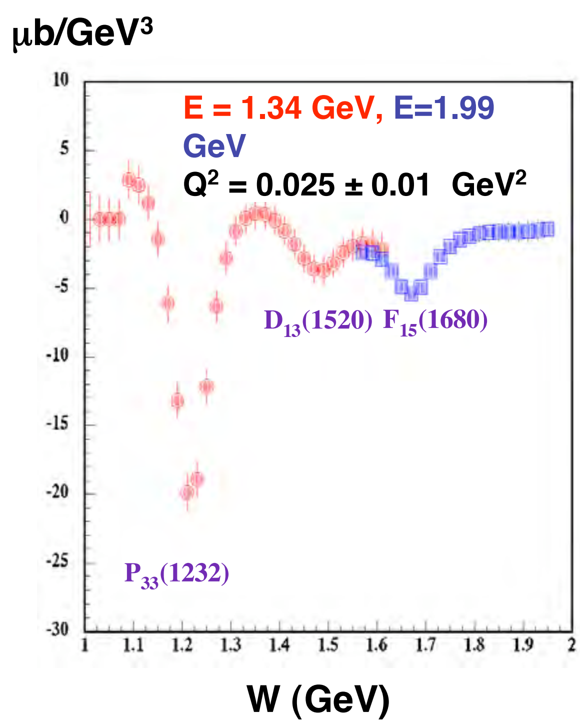
$Pt=(1-R^2)/(R^2+R+1)$

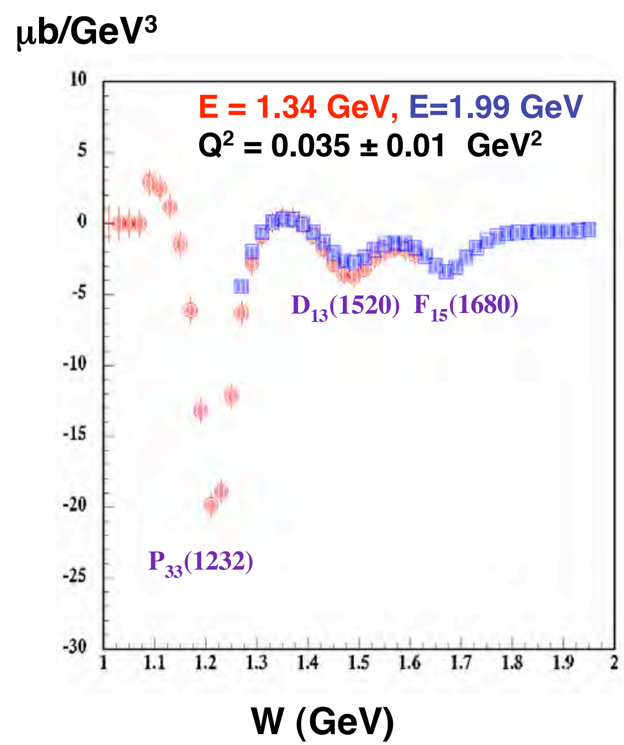
(C.Dulya et al.,NIM A354 (1995) 249)

Expected Results

$$\frac{d\sigma^{\rightarrow\Leftarrow}}{d\Omega dE'} - \frac{d\sigma^{\rightarrow\Rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{ME\nu Q^2}\left[\left(E - E'\cos\theta\right)g_1\left(x,Q^2\right) - 2Mxg_2\left(x,Q^2\right)\right]$$







expected results for statistical errors
on top of THEORETICAL cross section difference
based on S. Simula's parameterization,
S. Simula et al., PRD 65, 034017 (2002)

Summary and Outlook

- Accumulated full statistics proposed for the experiment
- Currently in the calibration stage
- Rich physics program:
  - Behavior of the spin structure function $g_1(x,Q^2)$ at very low Q^2
  - Test of the Generalized GDH Sum rule
  - Study of the single spin asymmetries
  - 2 π and η production
  - …..
- Several dedicated students working on the experiment
- Expect results soon..