# Measurement of the Neutron Electric Form Factor ($G_E^n$) in $\overrightarrow{D}(\overrightarrow{e}, e'n)p$ Quasi-elastic Scattering at $Q^2 = 0.5(GeV/c)^2$

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# $G_e^N$ definition

$e - N$ cross section (one photon exchange):

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_m \frac{E'}{E_0} \left\{ F_1^2 + \tau \left[ 2\left(F_1 + F_2\right)^2 \tan^2\left(\Theta_e\right) + \left(F_2\right)^2 \right] \right\}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_m = \frac{\alpha^2 \cos^2\left(\Theta/2\right)}{4E^2 \sin^4\left(\Theta/2\right)}$$

$$Q^2 = \vec{q}^{\,2} - \nu^2 = 4EE' \sin^2\left(\Theta_e/2\right) \;;\; \tau = Q^2/4M^2$$

Sachs Form Factors:

$$G_E\left(Q^2\right) = F_1(Q^2) - \tau F_2\left(Q^2\right)$$

$$G_M\left(Q^2\right) = F_1\left(Q^2\right) + F_2\left(Q^2\right)$$

$Q^2 = 0$ limit

$$G_E^p = 1 \;\; G_E^n = 0 \quad G_M^p = 2.79 \;\; G_M^n = -1.91$$

Interpretation in the Breit Frame:
$G_E$ is F.T. of the charge distribution $\rho(r)$:

$$G_E\left(\vec{q}^{\,2}\right) = \frac{1}{(2\pi)^3} \int d^3 r \rho(\vec{r}) \exp(-i\vec{q} \cdot \vec{r})$$

# $G_E^n$ Models

- Low $Q^2$: *Vector Meson Dominance Model (VMD)*
  The virtual photon couples to the nucleon through a vector meson
  *G. Höhler et al, Nucl. Phys. B114 (1976) 505*

- High $Q^2[> \ 6(GeV/c)^2]$: *Perturbative QCD (PQCD)*
  Photon couples directly to nucleon or its quark constituents
  Predicts scaling behaviour for large $Q^2$ :
  $G_{E,M} \propto 1/Q^4$

- Intermediate $Q^2$: *Phenomenological Model*
  incorporates constraints from VMD and asymptotic predictions of PQCD
  *M. Gari and W.Kruempelmann, Z. Phys. A322 (1985) 689*

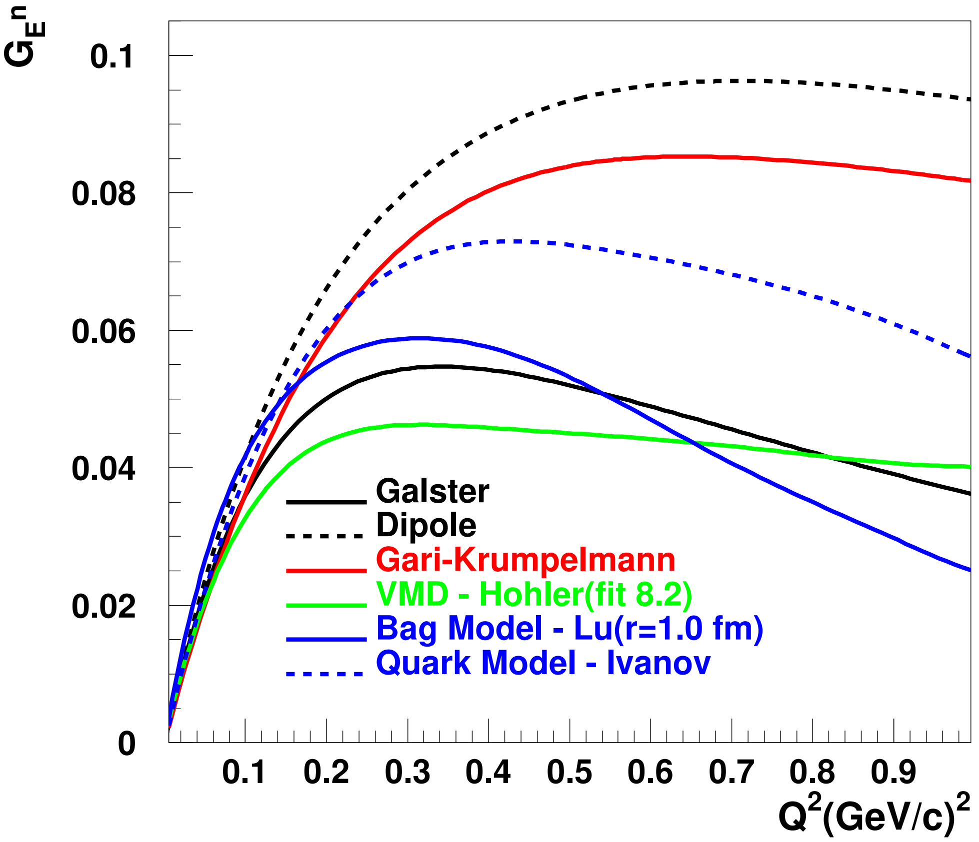
# Parametrizations:

- Dipole Model (good description of early $G^p_{E,M}$ measurements):

$$
\begin{aligned}
G_D &= \left(1 + \frac{Q^2}{0.71(GeV/c)^2}\right)^{-2} \\
G^p_E &= G_D = \frac{G^p_M}{\mu_p} = \frac{G^n_M}{\mu_n} \\
G^n_E &= -\tau\mu_n G_D\,;\;\; \tau = \frac{Q^2}{4M^2}
\end{aligned}
$$

- Galster Parametrization (from $e-d$ elastic scattering):

$$G^n_E = -\frac{\tau\mu_n}{1+5.6\tau}G^p_E$$

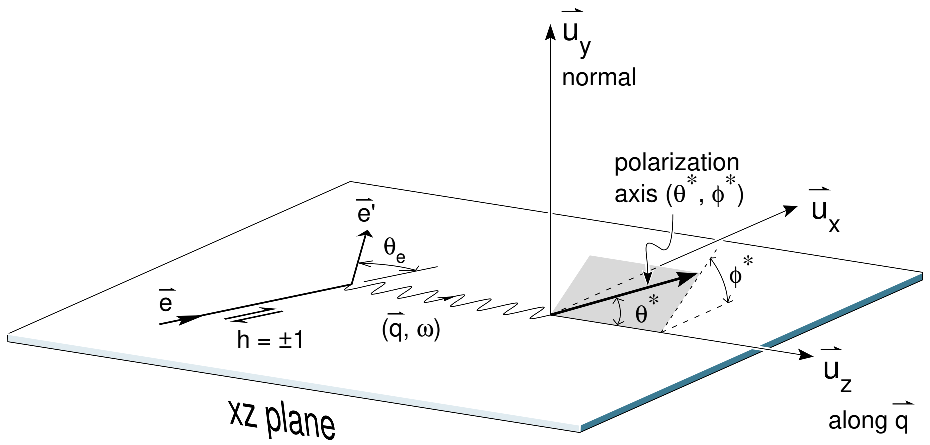


$G_E^n$
0.1
0.08
0.06
0.04
0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
$Q^2(GeV/c)^2$
Galster
Dipole
Gari-Krumpelmann
VMD - Hohler(fit 8.2)
Bag Model - Lu(r=1.0 fm)
Quark Model - Ivanov

## $G_E^n$ Measurements

- Basic problem: No free neutron target
- Inclusive measurements on deuterium are dominated by systematic errors:
  - Elastic $e-d$ scattering at small angles:
    $\rightarrow$ assumption on deuteron wave function
    $\rightarrow$ subtraction of dominant proton contribution
  - Quasielastic $e-d$ scattering
    $\rightarrow$ Rosenbluth separation
    $\rightarrow$ Sensitive to deuteron structure
- Polarization measurements
  are less sensitive to deuteron structure
  avoid Rosenbluth separation
  avoid subtraction of proton contribution
  - $D(\vec{e}, e'\vec{n})p$
  - $\vec{D}(\vec{e}, e'n)p$, $\overrightarrow{^3He}(\vec{e}, e'n)pp$

# Experimental technique for $\vec{D}(\vec{e}, e'n)p$




Cross section:

$$\sigma = \Sigma + h\Delta\,; \quad h = \pm P_B$$

Asymmetry

$$A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{\Delta}{\Sigma}$$

$\Sigma$ is the elastic unpolarized $e - n$ cross section

$$\Sigma = \sigma m \frac{E'}{E_0}\left(\frac{\left(G_E^n\right)^2 + \tau\left(G_M^n\right)}{(1+\tau)} + 2\tau\left(G_M^n\right)^2 \tan^2\left(\frac{\Theta_e}{2}\right)\right)$$

$\Delta$ depends on direction of target polarization ($\Theta^\star$, $\Phi^\star$)

$$\begin{aligned}\Delta \quad &= \quad -2\sigma m \frac{E'}{E_0}\sqrt{\frac{\tau}{1+\tau}}\tan\left(\frac{\Theta_e}{2}\right) \\ &\left\{\sqrt{\tau\left(1 + (1+\tau)\tan^2\left(\frac{\Theta_e}{2}\right)\right)}\cos\Theta^\star\left(G_M^n\right)^2 + \sin\Theta^\star\cos\Phi^\star G_E^n G_M^n\right\}\end{aligned}$$

Neutron Asymmetry for $\Theta^\star = \pi/2$ and $\phi^\star = 0$

$$A_n = \frac{-2\sqrt{\tau(1+\tau)}\tan\left(\Theta_e/2\right) G_E^n G_M^n}{\left(G_E^n\right)^2 + \tau\left(1 + 2\left(1+\tau\right)\tan^2\left(\Theta_e/2\right)\right)\left(G_M^n\right)^2}$$

Deuteron asymmetry $A_{ed}^V = \gamma A_n$ ($\gamma = 0.92$, correction factor for the D-state of the deuteron)

Theoretical Calculations of $A_{ed}^V$ by Arenhövel for the quasielastic region show low sensitivity to potential models and subnuclear degrees of freedom (MEC, IC)

# EXPERIMENT E-93026

- Measured in Hall C at Thomas Jefferson National Accelerator Facility (Jlab) in Newport News, Virginia, USA

- Measuring period: Aug 1998 - Oct 1998 (Continuation in 2001)

- Kinematics:
  $Q^2 = 0.5(GeV/c)^2$ and $Q^2 = 1.0(GeV/c)^2$

## E93-026 Collaboration

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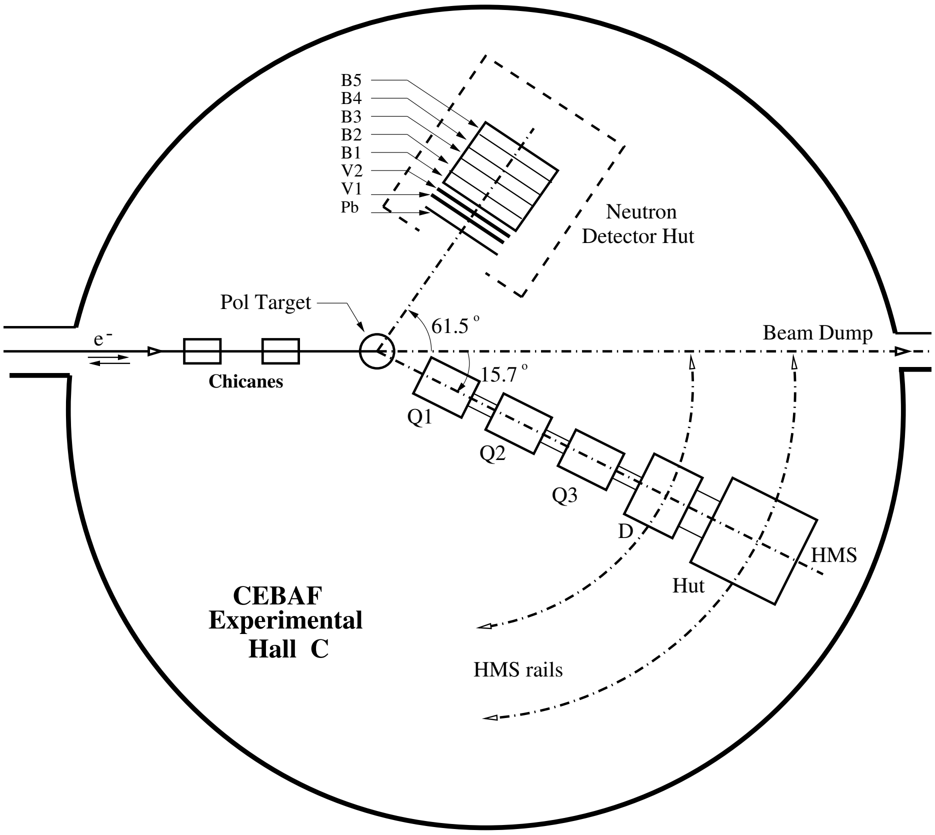
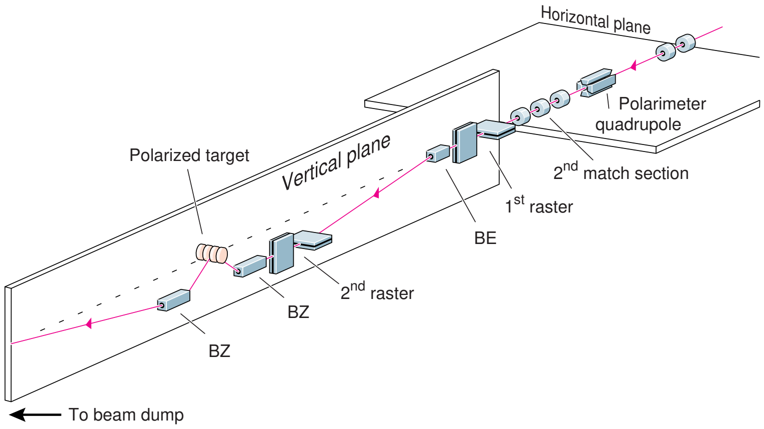
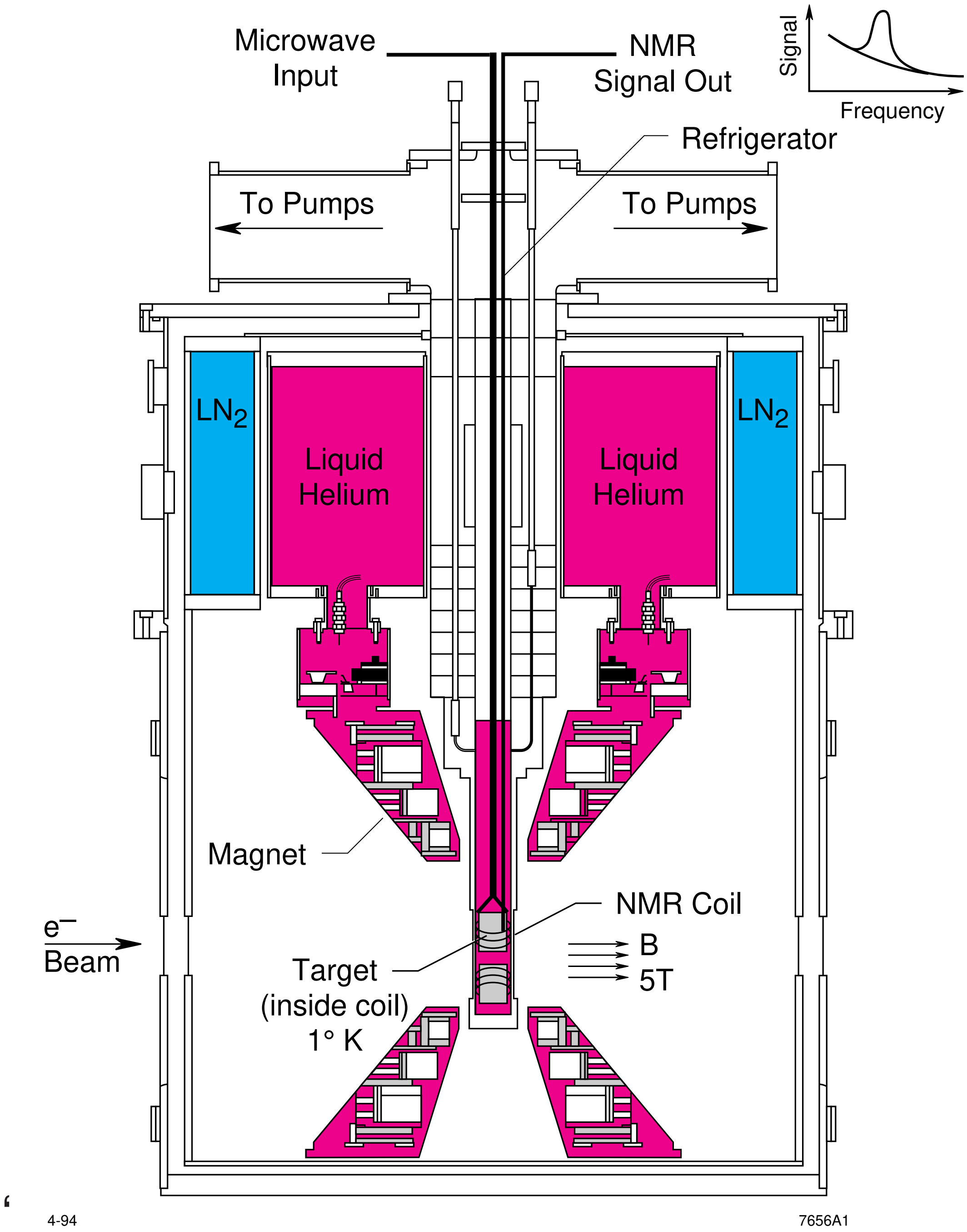
# Setup in Hall C



# Polarized Target

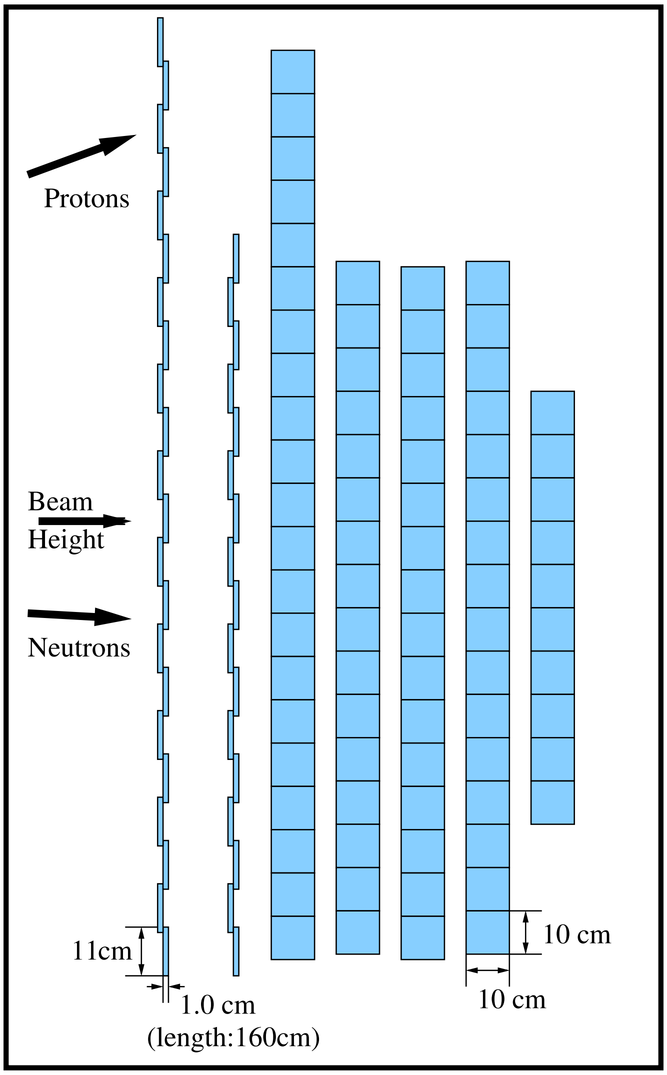



Target material: $^{15}ND_3$

dynamically polarized using Microwaves

NMR readout

# Neutron Detector




Detector material: Plastic Scintillator

79 Bars & 39 Paddles: PM’s on each side

# ANALYSIS

- Event Reconstruction
  - HMS standard reconstruction + target magnet + raster
  - NDET tracking: Particle Identification

⇒variables: $w$, $Ypos$, $cointime$, $\theta_{nq}$

- Event Selection and Normalization
  $\rightarrow$ Normalized yields: $N^{\uparrow}$, $N^{\downarrow}$

- Experimental asymmetries:
  $\varepsilon = \frac{N^{\uparrow}-N^{\downarrow}}{N^{\uparrow}+N^{\downarrow}} = P_B \cdot P_T \cdot f \cdot A^V_{ed}$
  - Beam Polarization $P_B$ from moller polarimetry, $\simeq 77\%$
  - Target polarization $P_T$: average: 22%
  - Dilution factor $f = \frac{N_{polarized}}{N}$ from $^{12}C$ data and MC

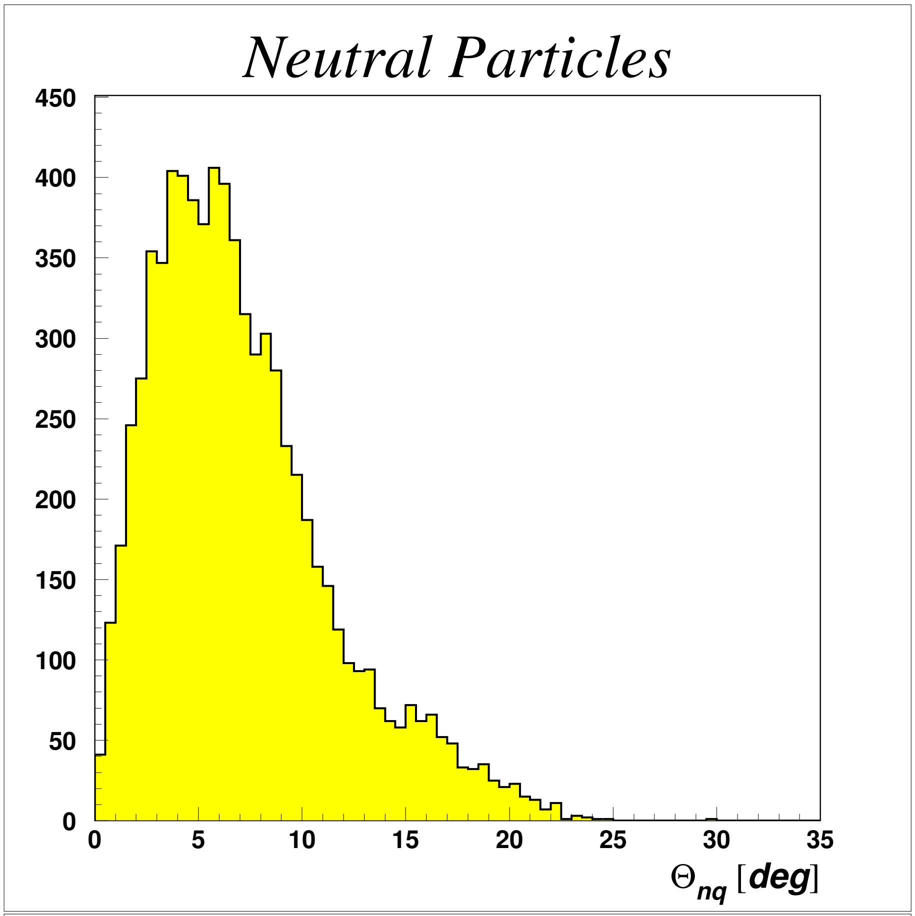
- Radiative corrections, Accidental background subtraction

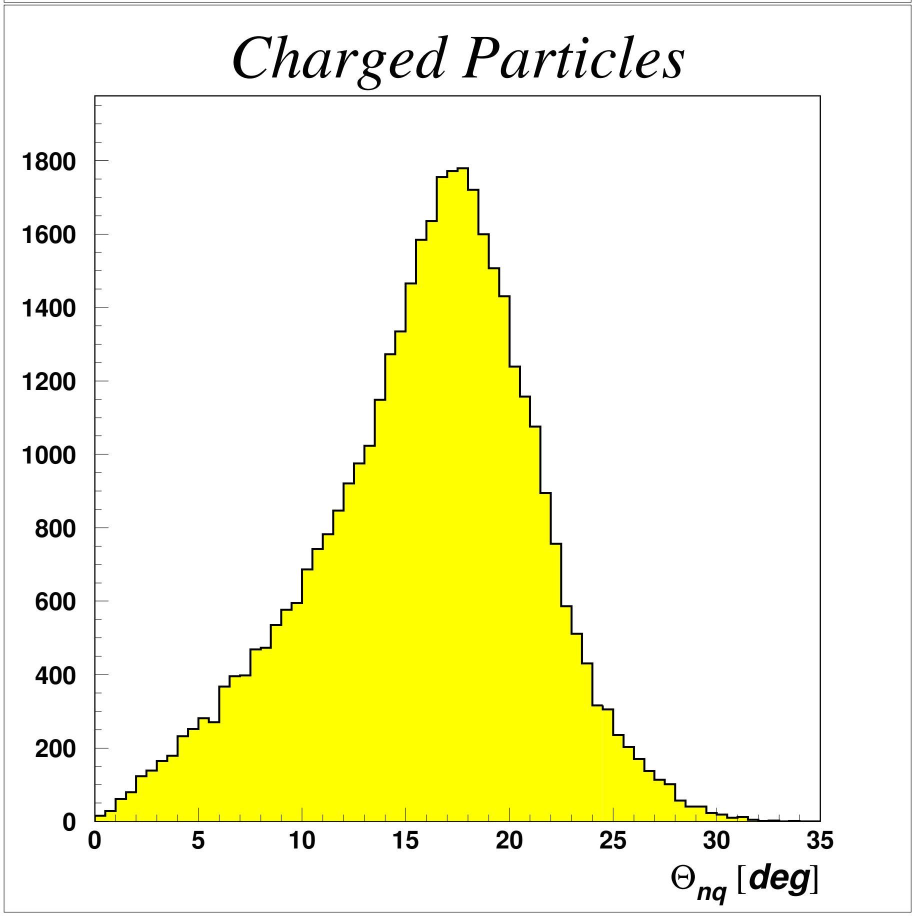
⇒ measured deuteron asymmetry $A^V_{ed}$

- Theoretical calculations of $A^V_{ed}$ (for different $G^n_E$ models) from Arenhövel for a kinematical grid

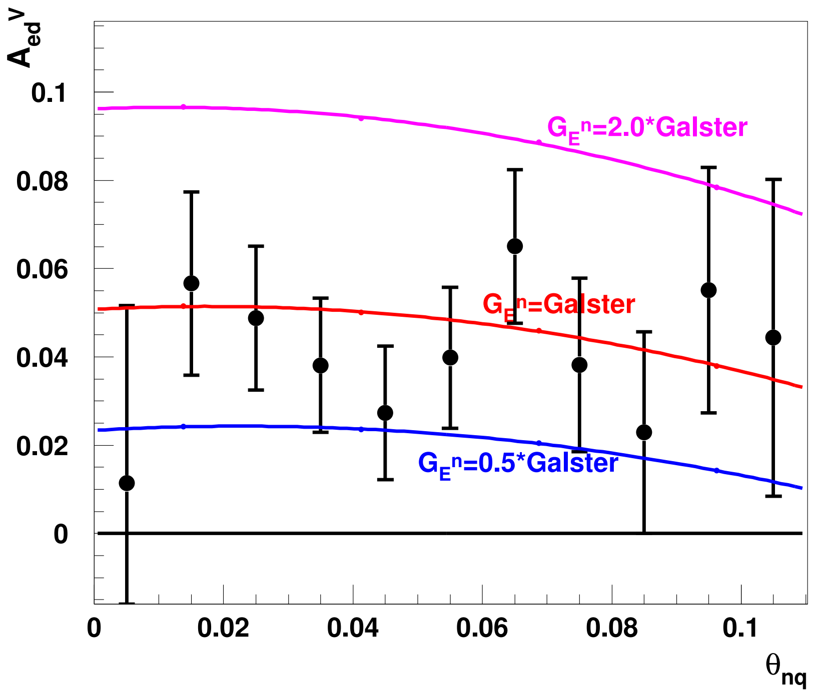
- Average theoretical $A^V_{ed}$ over experimental acceptance using MC and compare with measured $A^V_{ed}$

⇒ $G^n_E$


Neutral Particles
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
$\Theta_{nq}$ [deg]


Charged Particles
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
$\Theta_{nq}$ [deg]

# RESULTS



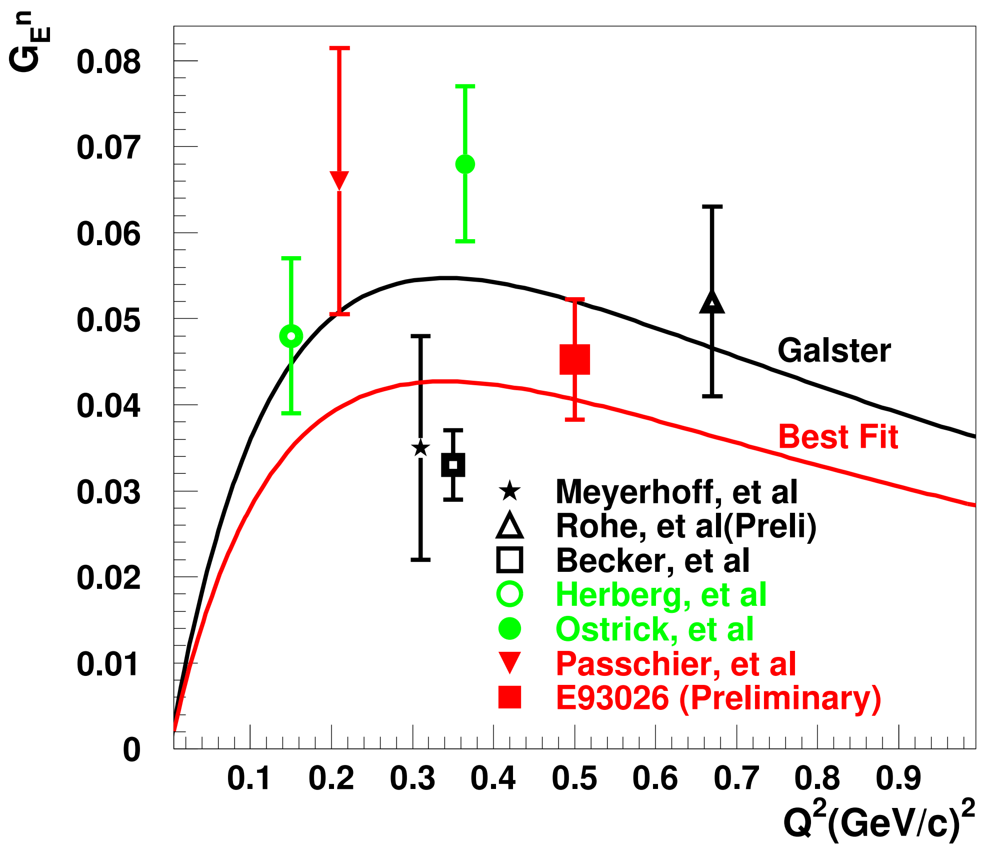

Fit: $G_E^n = 0.87 \cdot (G_E^n)_{Galster}$

- Preliminary result for $Q^2 = 0.5\,(GeV/c)^2$ :

$G_E^n = 0.0453 \pm 0.0068_{stat}$ (15% relative error)

- Systematics:
dominated by target polarization (5%) and dilution factor (>4%, studies in progress)
For now we quote 20% systematic error.

## $G_E^n$ World Data (Polarization Experiments)




Becker, Meyerhoff, Rohe: $\overrightarrow{^3He}(\vec{e}, e'n)pp$
(no corrections for nuclear binding effects applied yet)

Herberg, Ostrick: $D(\vec{e}, e'\vec{n})p$

Passchier, E-93026: $\vec{D}(\vec{e}, e'n)p$