A1 Collaboration
presented by
Michael Seimetz
Institut für Kernphysik, Univ. Mainz
Mainz, Bonn, Darmstadt, Glasgow, Ljubljana, Zagreb

Measurement of the Electric Form Factor of the Neutron at MAMI

- Introduction
- Measurement of $G_{E,n}$ in $D(\vec{e}, e'\vec{n})p$
- The A1 Experiment
- Data Analysis
- Summary

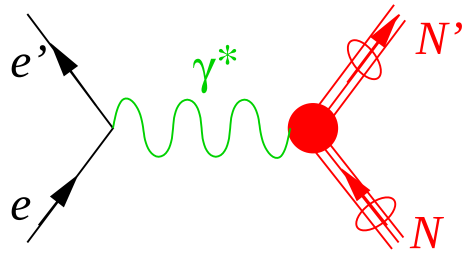
Spin 2002
Brookhaven National Laboratory
Upton, NY, September 9-14, 2002

*supported by Deutsche Forschungsgemeinschaft, SFB 443

Nucleon Form Factors

Form factors parametrize finite size of a particle

- Electromagnetic current:



$$\bar{N}_{\rm point}\gamma_\mu N_{\rm point} \to \bar{N}\Gamma_\mu N$$
$$= \bar{N}[\gamma_\mu F_1(Q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2M_N}\kappa F_2(Q^2)]N$$

$F_1(Q^2)$: Dirac form factor
$F_2(Q^2)$: Pauli form factor

- Sachs form factors:

$$\begin{aligned} G_E(Q^2) &= F_1(Q^2) - \tau\kappa F_2(Q^2) \\ G_M(Q^2) &= F_1(Q^2) + \kappa F_2(Q^2) \end{aligned}$$

with $\tau = Q^2/4M_N^2$.

$\mathbf{G_{E,n}}$ Measurements

Difficulties in measurement of $G_{E,n}$:

- No free neutron target available; use of D, ^{3}He in general model dependent

- Rosenbluth cross section:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{M}} \cdot \frac{E'_e}{E_e} \cdot \left(\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2 \frac{\vartheta_e}{2}\right)$$

$G_{E,n}^2 \ll \tau G_{M,n}^2 \Rightarrow$ Rosenbluth separation difficult

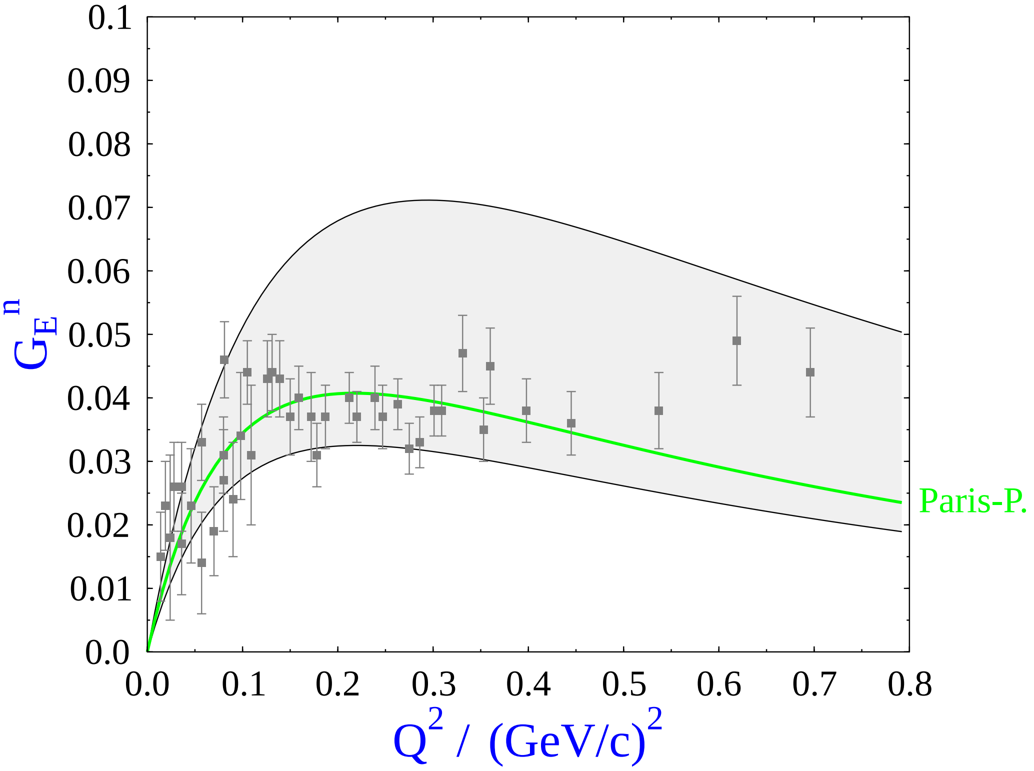
However, $G_{E,n} \neq 0$ at finite Q^2, as proved in two kinds of experiments:

- $< r_{ch,n}^2 >= -0.1148(23)\,\mathrm{fm}^2 / -0.1243(28)\,\mathrm{fm}^2$
  (S. Kopecky et al., PRC **56** (1997), 2229)

- $G_{E,n}$ from $\mathrm{D}(e,e')d$
  (S. Platchkov et al., Nucl. Phys. **A510** (1990), 740)

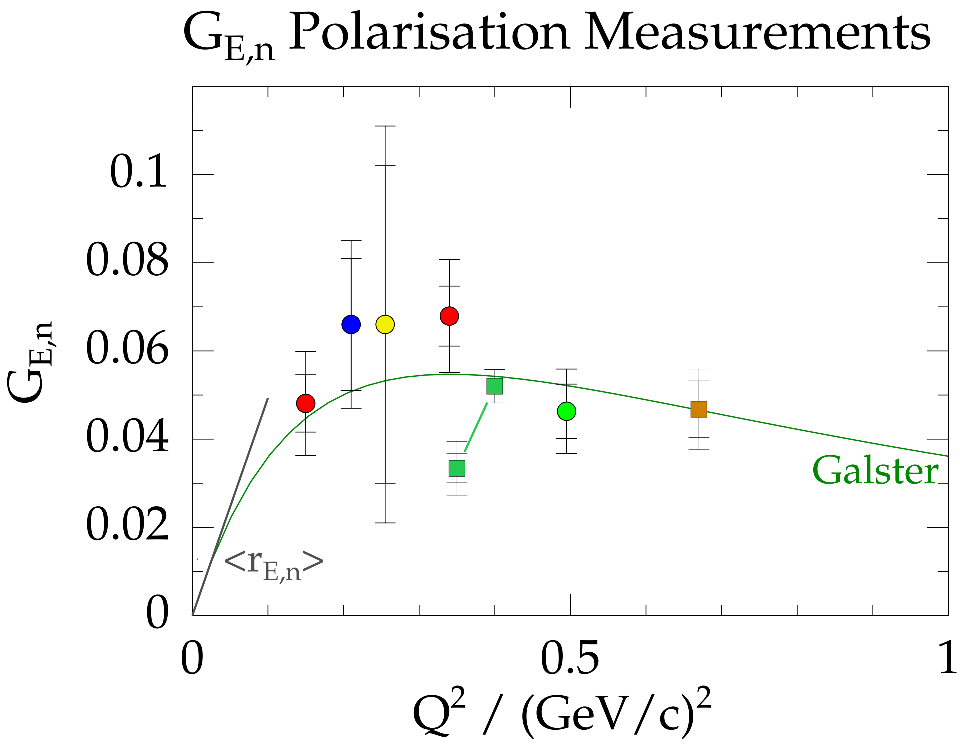
$G_{E,n}$ Measurements

Platchkov et al.:



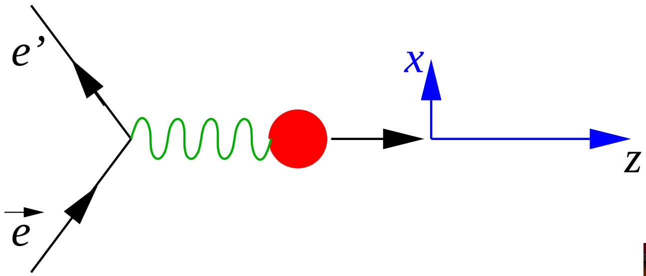
- $\mathrm{D}(e,e')d$ model dependent!
- Model-independent results achieved in double polarization experiments

$\mathbf{G_{E,n}}$ Data



○ (yellow)	$\mathrm{D}(\vec{e}, e'\vec{n})p$	at MIT-Bates, 1994
● (red)	$\mathrm{D}(\vec{e}, e'\vec{n})p$	at MAMI (A3), 1999
● (blue)	$\vec{\mathrm{D}}(\vec{e}, e'n)p$	at NIKHEF, 1999
■ (dark green)	$^3\vec{\mathrm{He}}(\vec{e}, e'n)pp$	at MAMI (A3), 1999
● (green)	$\vec{\mathrm{D}}(\vec{e}, e'n)p$	at JLab, 2001
■ (orange)	$^3\vec{\mathrm{He}}(\vec{e}, e'n)pp$	at MAMI (A1), 2001

Measurement of $G_{E,n}$ in $\mathrm{D}(\vec{e}, e'\vec{n})p$



$$\text{Asymmetry } A = P_e \mathcal{A}_{\text{eff}} P_t \sin \Phi_n$$

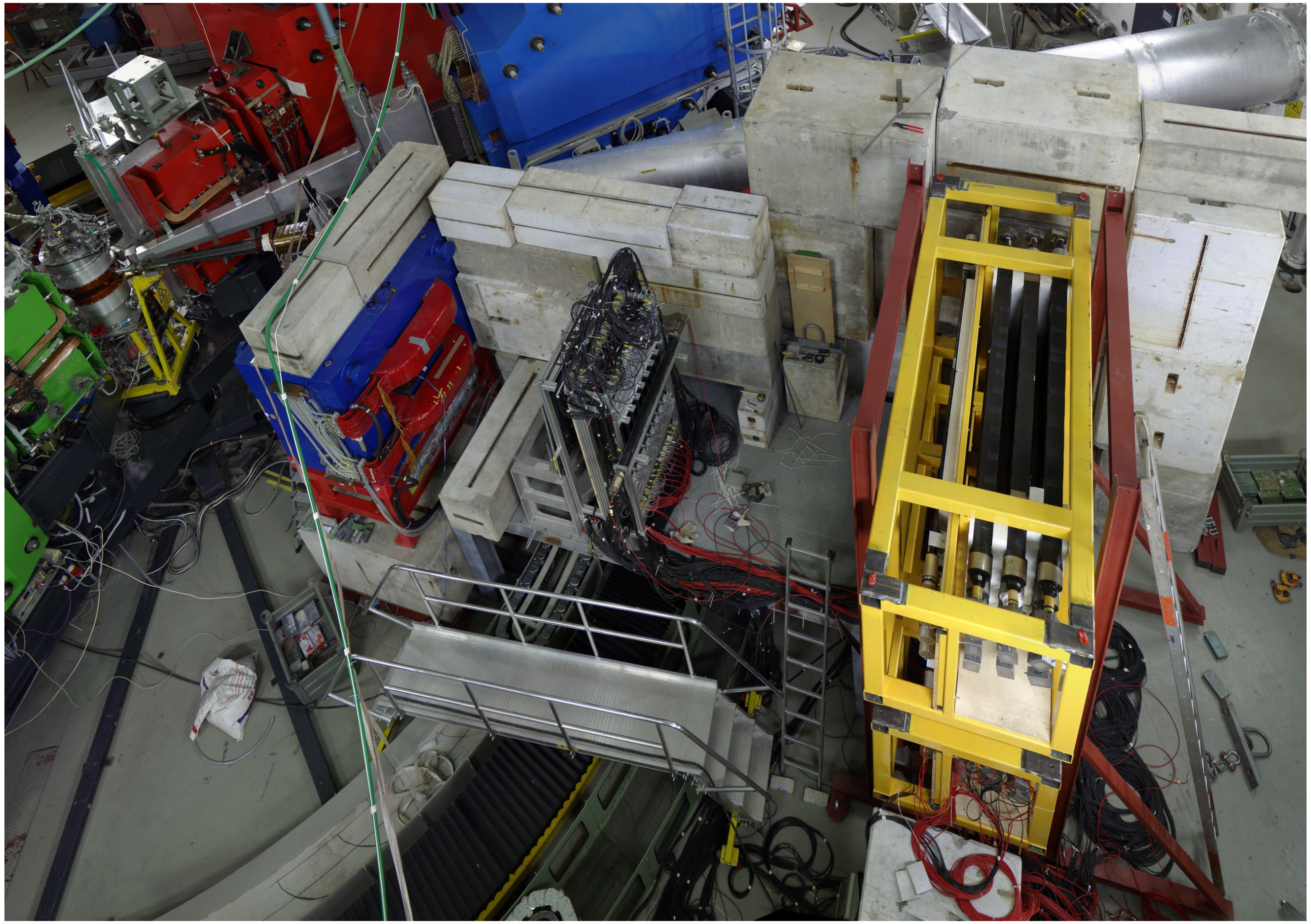
$$\mathcal{P}_x = -hP_e \frac{aG_E G_M}{G_E^2 + bG_M^2}$$

$$\mathcal{P}_y = 0$$

$$\mathcal{P}_z = hP_e \frac{cG_M^2}{G_E^2 + bG_M^2}$$

Arnold, Carlson & Gross, PR C **23** (1981), 363

LD_2 Target | Dipole Magnet | Front Wall | Rear Wall



Method:
T. N. Taddeucci et al., NIM **A241** (1985), 448

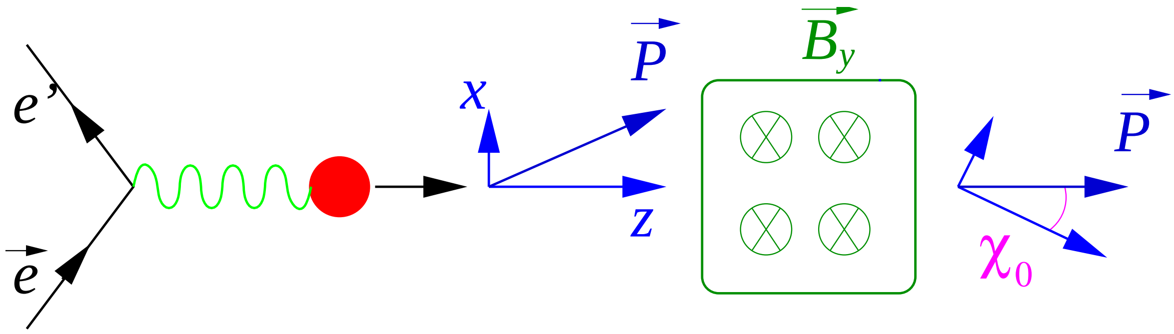
Michael Seimetz

Spin Precession Method

Mixing of two spin components by precession of neutron spin in magnetic field,

$$\mathcal{P}_t(\chi) = \mathcal{P}_x \cos(\chi) + \mathcal{P}_z \sin(\chi) =: \mathcal{P}_0 \sin(\chi - \chi_0)$$

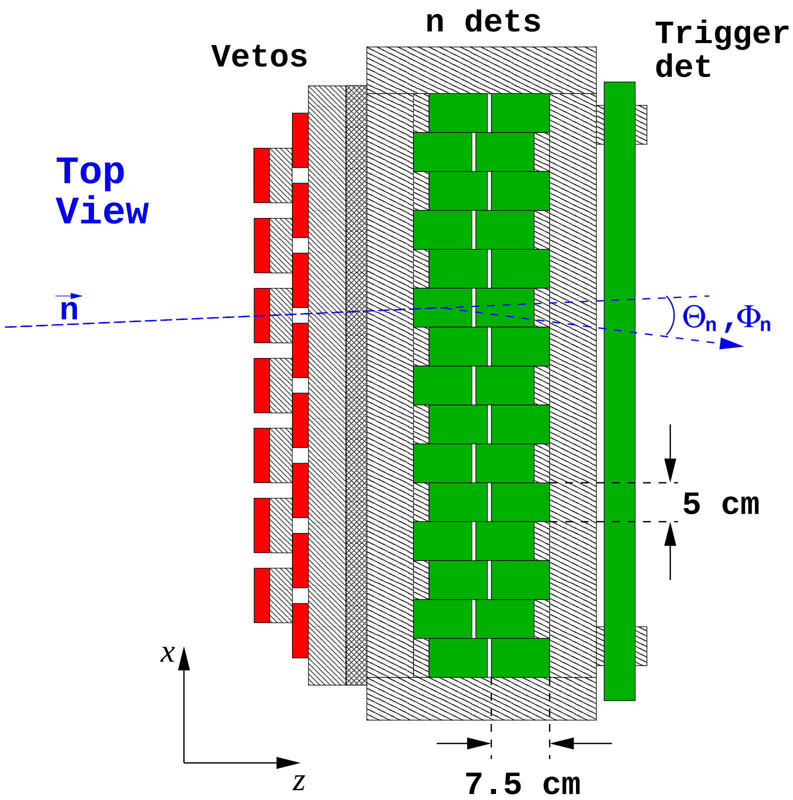
(M. Ostrick et al., PRL **83** (1999) 276)



$$\tan\chi_0 = \frac{\mathcal{P}_x}{\mathcal{P}_z} = \frac{A_x}{A_z} = \frac{a\,\mathcal{A}_{\text{eff}} P_e}{c\,\mathcal{A}_{\text{eff}} P_e} \cdot \frac{G_{E,n}}{G_{M,n}} \quad .$$

Neutron Polarimeter, Front Wall

- Overall size: 80×80 cm^2
- 5 cm scintillator width
  at 6 m target distance
  $\Rightarrow$ Angular resolution 0.48° FWHM
- Charged particle vetoing
- Single rates $\simeq 1\,\mathrm{MHz}$
- 15% neutron detection efficiency

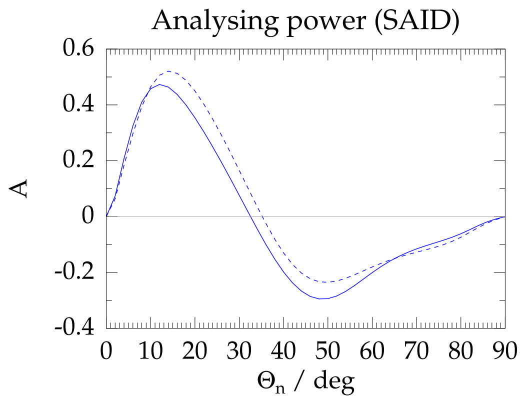


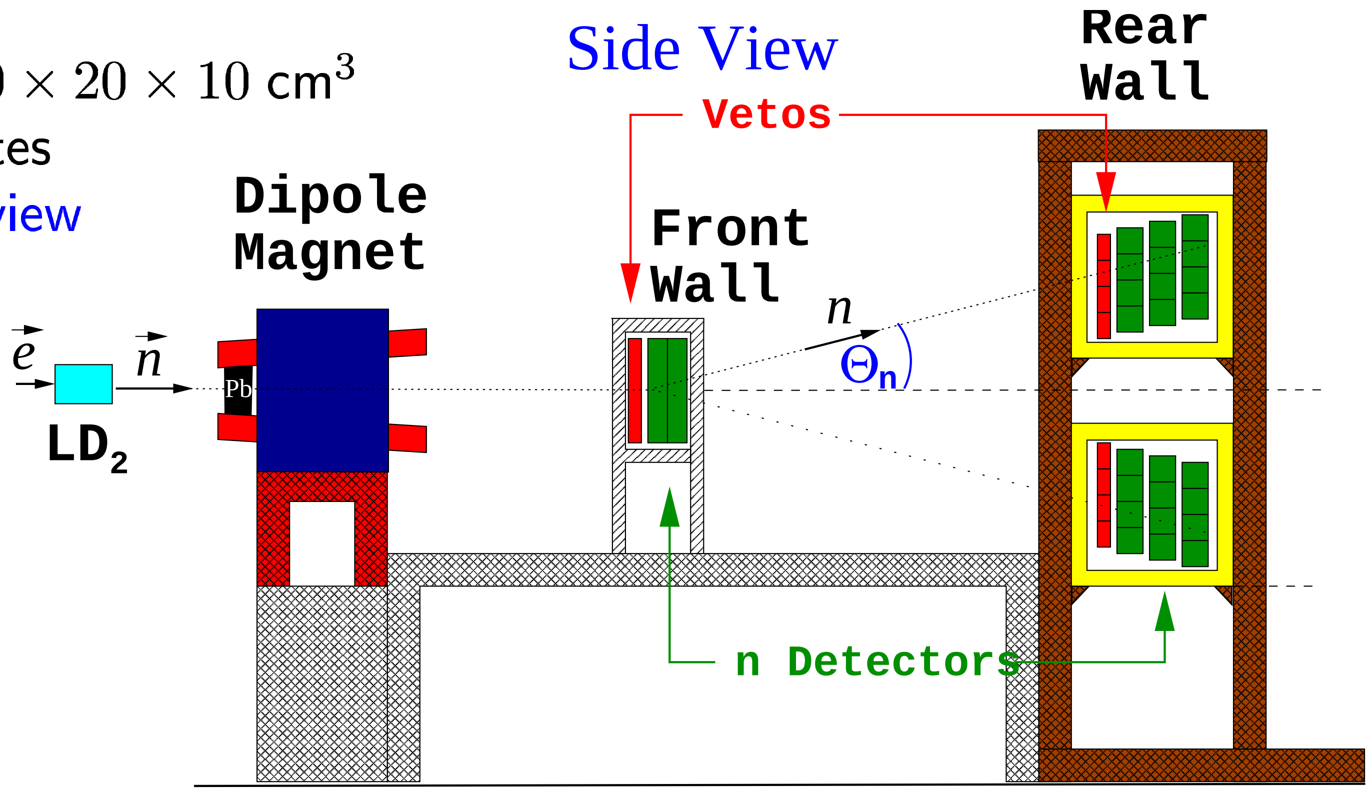
Neutron Polarimeter, Rear Wall

24 scintillator bars, $180 \times 20 \times 10\ \mathrm{cm}^3$

$\Rightarrow$ high background rates

$\Rightarrow$ avoid direct target view





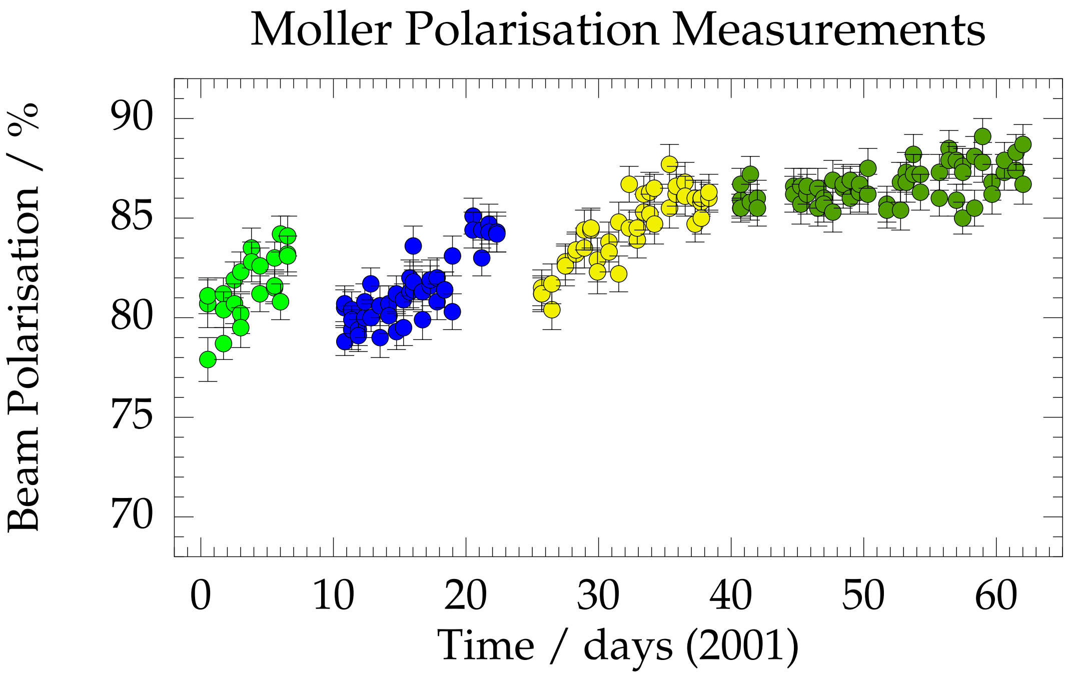
Data Taking

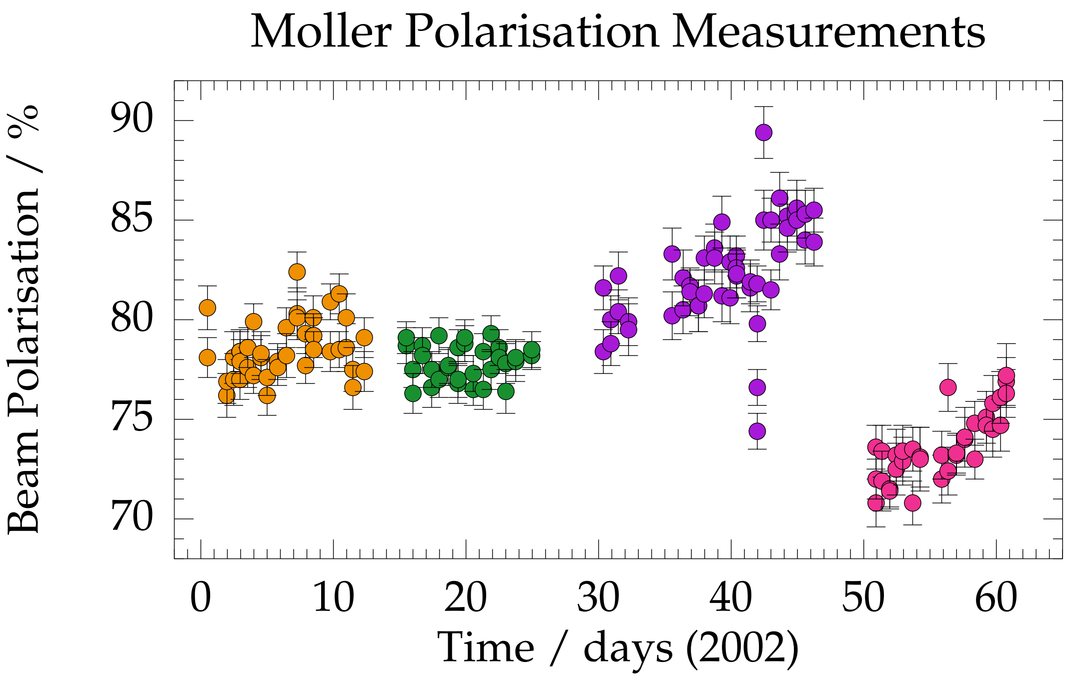
- Three central momentum transfers:

$Q^2/\ (\mathrm{GeV}/c)^2$ $E_e/$ MeV	0.6 855	0.8 883	0.3 660	
$E'_e/$ MeV ϑ_e	536 $70°$	454 $90°$	498 $57°$	Spectrometer A
ϑ_n $T_n/$ MeV	$37°$ 320	$27°$ 427	$47°$ 160	Neutron polarimeter

- $\mathrm{LD_2}$ target (length: 5 cm)
- Beam current: $\sim 10 - 15\ \mu$A
- 5 cm lead shielding
- $\mathrm{LH_2}$ data (calibration, proton misidentification)
- Beam polarisation monitored with Møller polarimeter*, $P_e \simeq 80\%$
  *P. Bartsch, PhD thesis, Mainz 2001

Electron Beam Polarisation





Data Analysis

Outline:

- Adjustment of all scintillators ($\Rightarrow$ calibration)
- Reconstruction of reaction kinematics
- Neutron identification, background suppression
- Calculation of beam-helicity asymmetries
- Correction of asymmetry shifts due to
  - Variations of electron beam polarisation
  - p-n conversion in lead shielding
  - Nuclear binding effects

Data Analysis

Reaction Kinematics

Complete reconstruction of quasi-elastic $e-n$ scattering requires 5 observables:

Spectrometer A		n polarimeter	
ϑ_e, φ_e E'_e	$< 2\,\mathrm{mrad}$ 10^{-4}	ϑ_n, φ_n ToF$_n$	8 mrad < 1 ns

In Spectrometer A:

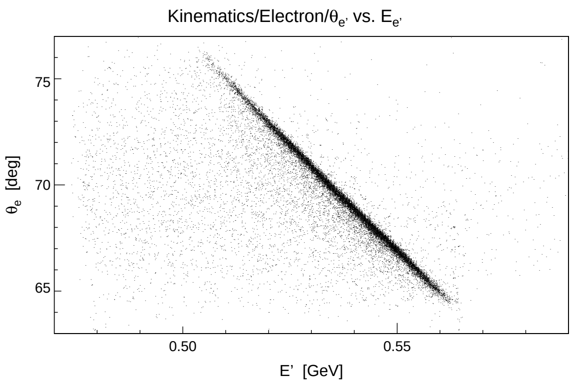
- Preselection of quasielastic events via $e-n$ coincidence time
- Further background reduction, e.g. pion suppression with Cerenkov detector

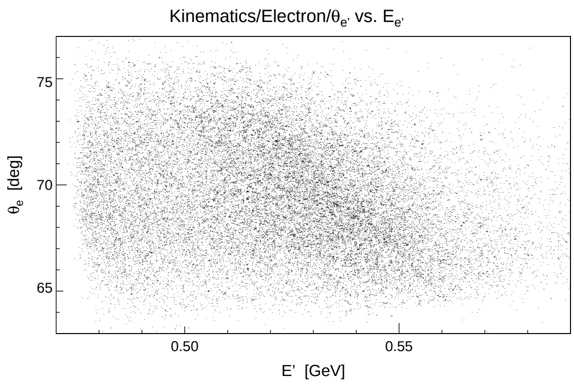
Data Analysis

Effect of cuts on Spectrometer A

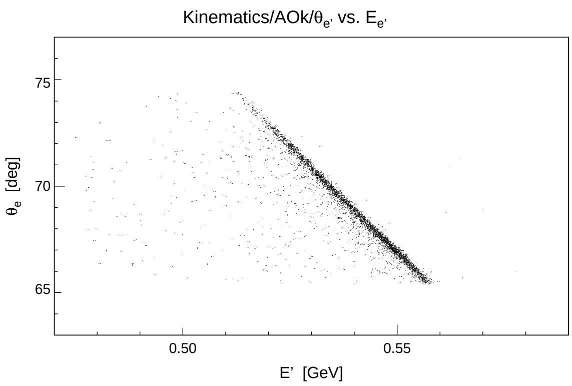
Proton ($\mathrm{LH_2}$) data Neutron ($\mathrm{LD_2}$) data

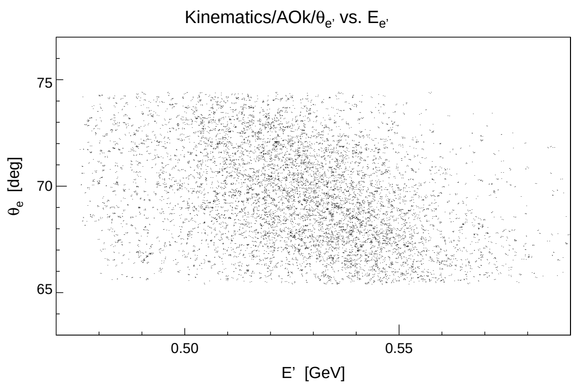
Elastic line in focal plane:





After cuts on Spectrometer A:

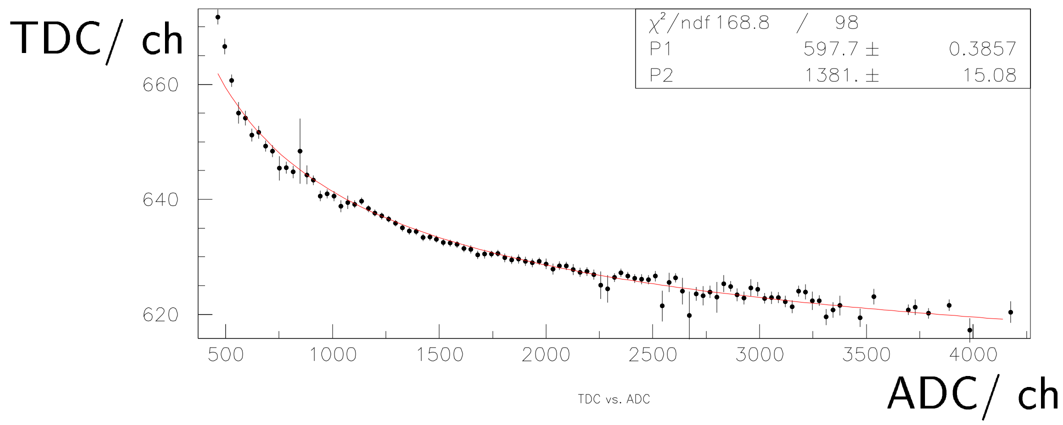




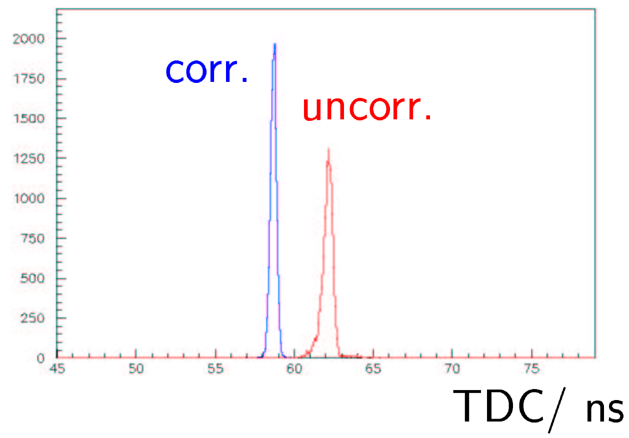
Calibration

Time of Flight

Walk correction (using electrons):



Result:

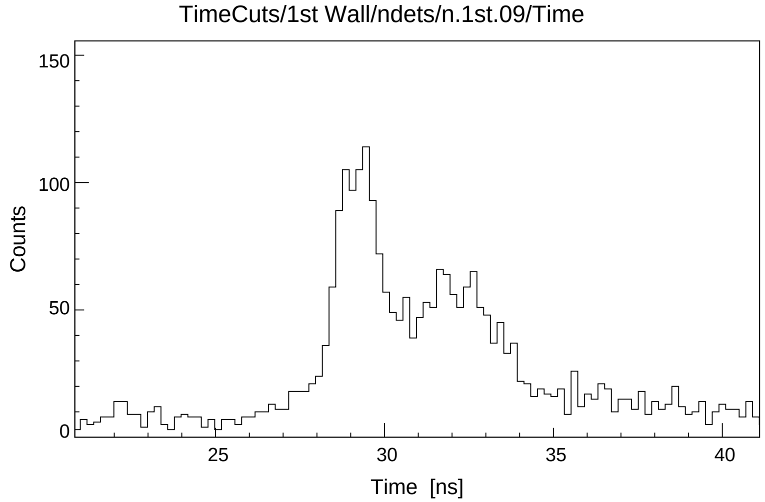


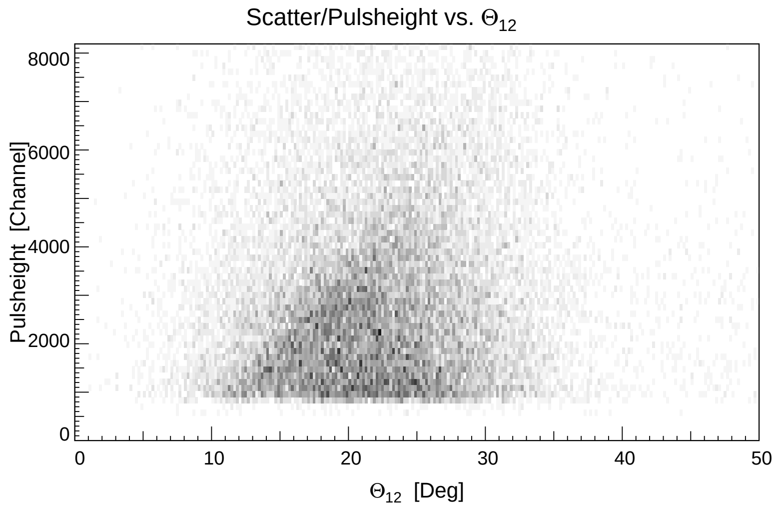
Resolution in neutron detectors: $\sigma_t = 300$ ps
$\Rightarrow$ Spatial resolution: $\sigma_x = 4.5$ cm
$\Rightarrow$ Angular resolution: $\sigma_\vartheta = 7.5\,\mathrm{mrad}$

Neutron Identification

Suppress proton background via

- Charged particle vetoing
- ToF: protons lose kinetic energy in lead shield
- Correlation between energy deposition of neutrons in 1st wall and scattering angle Θ_n



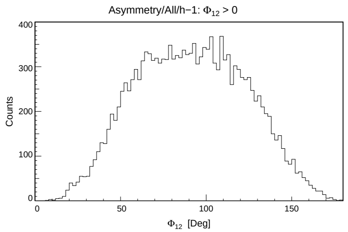


Asymmetries

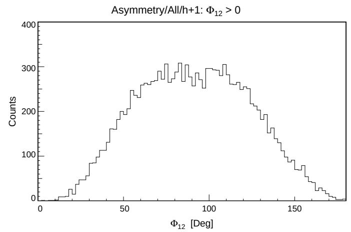
Φ_n distributions:

$$A(\Phi_n) = \frac{\sqrt{N^+(\Phi_n)N^-(\Phi_n+\pi)} - \sqrt{N^+(\Phi_n+\pi)N^-(\Phi_n)}}{\sqrt{N^+(\Phi_n)N^-(\Phi_n+\pi)} + \sqrt{N^+(\Phi_n+\pi)N^-(\Phi_n)}}$$

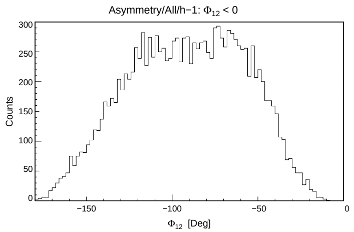
$h = -1,\ \Phi_n > 0$



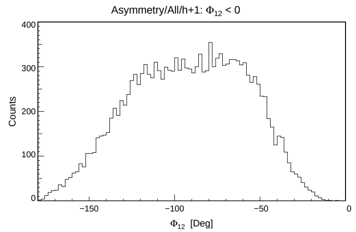
$h = +1,\ \Phi_n > 0$

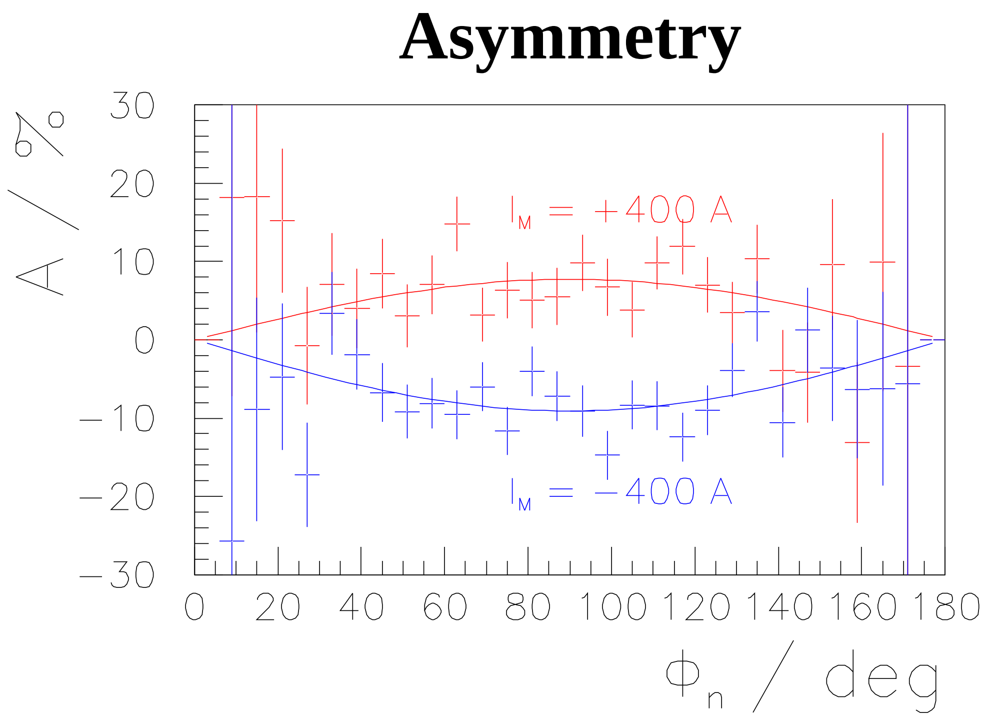


$h = -1,\ \Phi_n < 0$



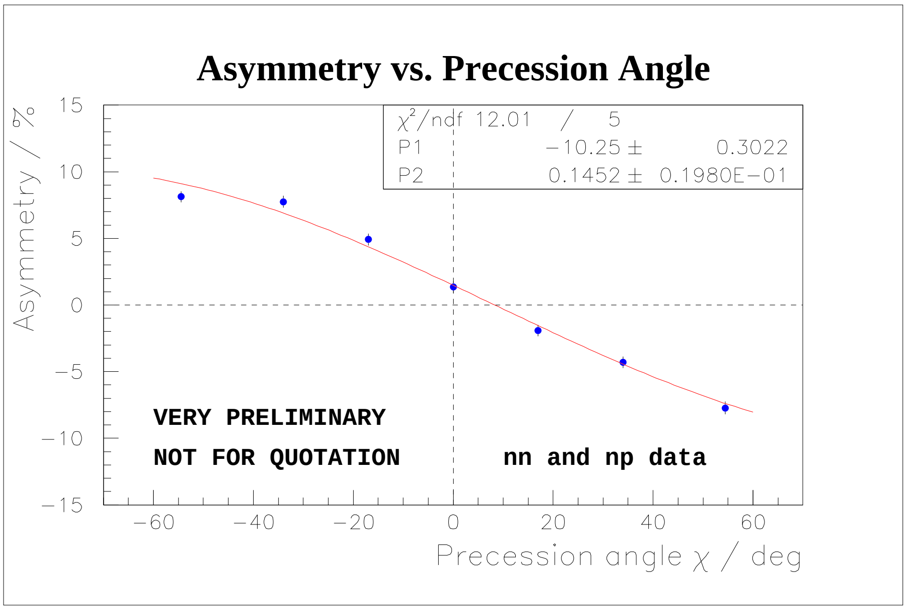
$h = +1,\ \Phi_n < 0$





Asymmetries

Plot asymmetries as function of spin precession angle χ



Michael Seimetz

Summary

- $G_{E,n}$ is a key observable in hadron physics
- Double polarization experiments allow precise, model-independent $G_{E,n}$ measurements
- New $\mathrm{D}(\vec{e}, e'\vec{n})p$ experiment in the A1 collaboration at Mainz
- $Q^2 = 0.3$, 0.6 and 0.8 $(\mathrm{GeV}/c)^2$
- Data taking completed in August 2002
- Data analysis in progress, first promising results available