Parity violating electron backscattering

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A4 Collaboration
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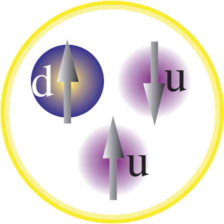
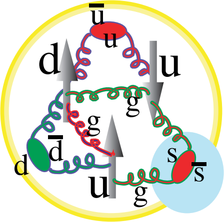
Outline

Introduction

The strange vector form factor





- Nucleon: constituent quarks u,d, gluons, sea quarks $q\bar{q}$ ($q =$ u,d,s)
- s in nucleon: pure sea quark effect
- Contribution of s to the electromagnetic vector form factors of the nucleon?
- Measurement of the strange vector electric and magnetic form factors: G_E^s and G_M^s

Form factors flavor decomposition

Flavor decomposition

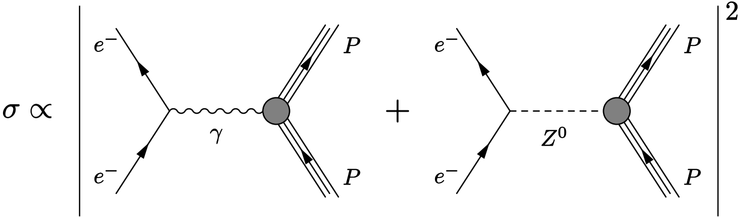
$$G^p_{E,M} = \frac{2}{3} G^u_{E,M} - \frac{1}{3} G^d_{E,M} - \frac{1}{3} G^s_{E,M}$$

$$G^n_{E,M} = \frac{2}{3} G^d_{E,M} - \frac{1}{3} G^u_{E,M} - \frac{1}{3} G^s_{E,M}$$

Weak form factors to access the strange vector form factor

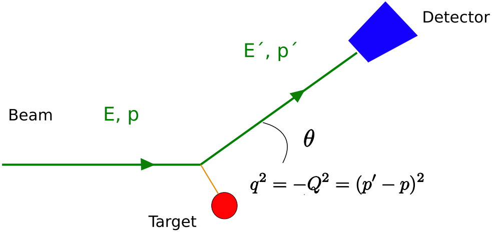
$$\tilde{G}^p_{E,M} = \left(\frac{1}{4} - \frac{2}{3}\sin\theta_W\right) G^u_{E,M} - \left(\frac{1}{4} - \frac{1}{3}\sin\theta_W\right) G^d_{E,M} - \\ - \left(\frac{1}{4} - \frac{1}{3}\sin\theta_W\right) G^s_{E,M}$$

Parity violating elastic electron scattering



- Parity violating elastic electron scattering to access $\tilde{G}^p_{E,M}$
- Parity violation: interference between electromagnetic and weak amplitudes

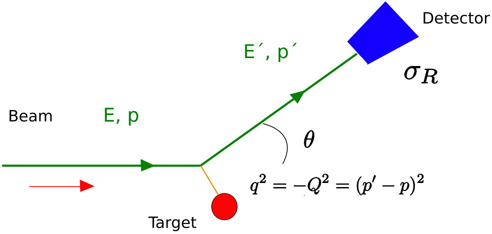
Parity violating asymmetry



- To measure: parity violating asymmetry in the cross section

$$A_{PV} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L}$$

Parity violating asymmetry



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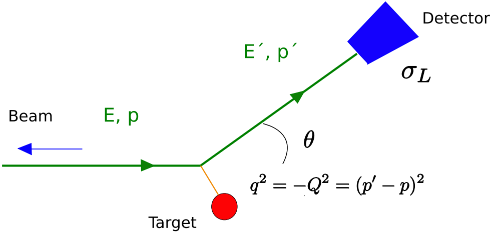


- To measure: parity violating asymmetry in the cross section

$$A_{PV} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L}$$

Parity violating asymmetry

$$A_{PV} = A_0 + A_s$$

- A_0 calculated
- Input parameters: G_E^p, G_M^p, G_E^n, G_M^n, $\tilde{G}_A^p$, G_μ, α, Q^2, θ

$$Q^2 = 0.23\ \left(\text{GeV/c}\right)^2, \quad \text{A4 backwards kinematics}$$
$$A_0 = (-15.87 \pm 1.22) \cdot 10^{-6}$$

Parity violating asymmetry

$$A_s = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \left\{ -\frac{\epsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2} \right\}$$

$$\tau = \frac{Q^2}{4M^2}$$

$$\epsilon = \frac{1}{1 + 2(1+\tau)\tan^2\frac{\theta}{2}}$$

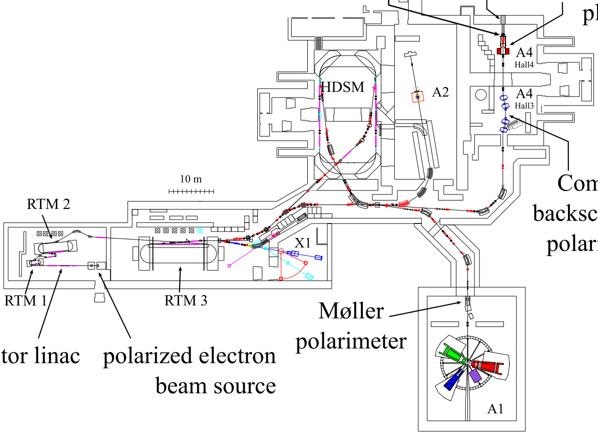
$$A_s = A_{\mathsf{PV}} - A_0$$

- Single measurement of A_s: linear combination of G_E^s and G_M^s.
- Two different measurements of A_s: separation of G_E^s and G_M^s.

Outline

Experimental set up

MAMI floor plan



luminosity monitors

transmission Compton polarimeter

calorimeter on a rotatable platform

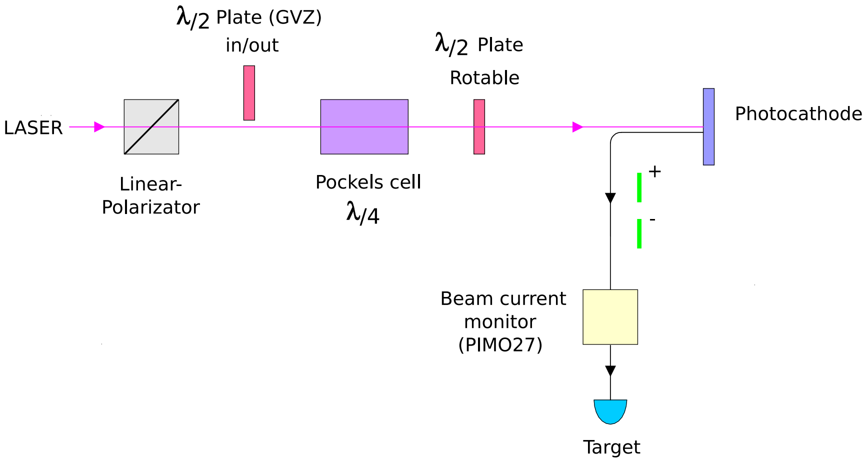
Compton backscattering polarimeter

Møller polarimeter

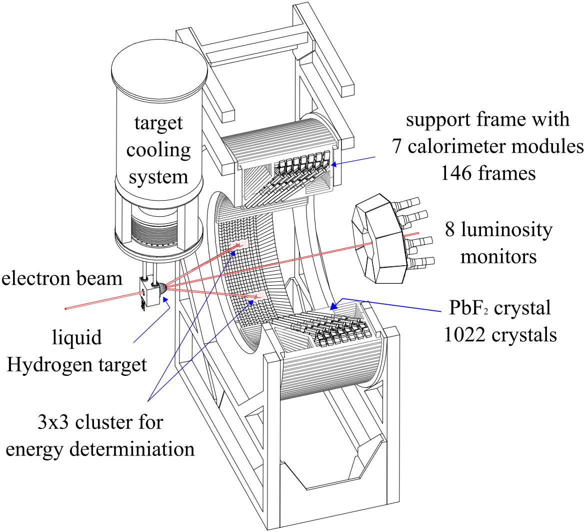
injector linac

polarized electron beam source

Polarized electron beam source

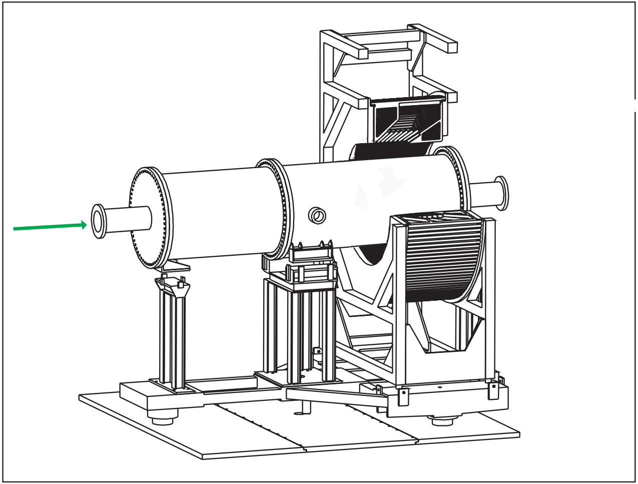


Target, calorimeter and luminosity monitors

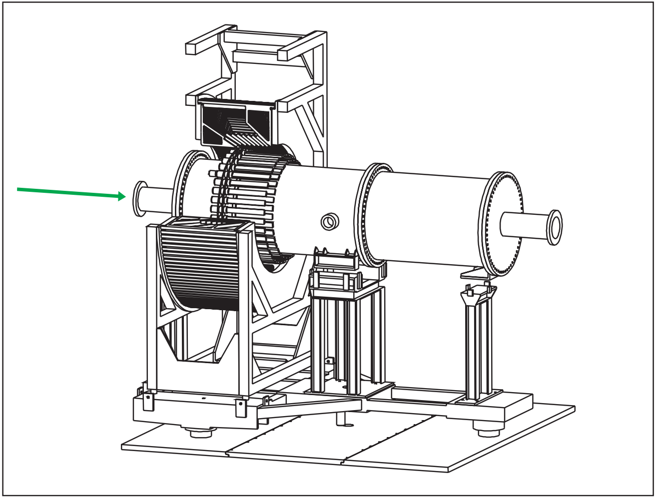


- Cooling system: avoid boiling and ρ_t fluctuations
- Calorimeter energy resolution $3.9\%/\sqrt{E}$
- Calorimeter and electronics: 20 ns dead time
- LuMos: measurement of luminosity fluctuations

Detector at forward angles

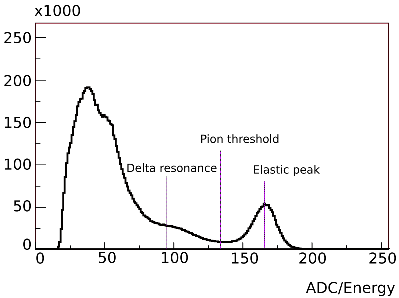


Rotated detector at backward angles

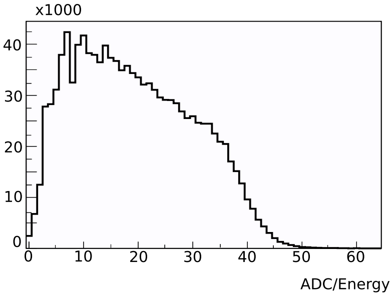


PbF_2 energy spectrum

Forwards, E = 854.3 MeV



Backwards, E = 315.1 MeV



- Elastic peak clearly separated
- Background of $\pi^0 \rightarrow 2\gamma$ energetically separated.

- Elastic peak not separated
- Background of γs and elastic peak: same energy range

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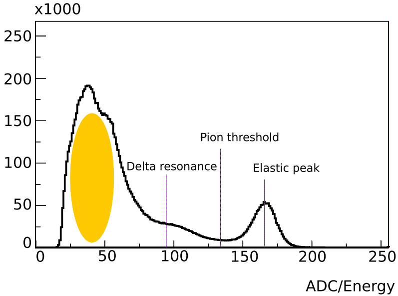

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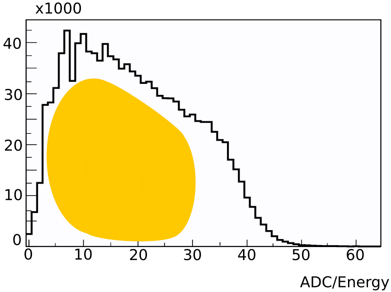
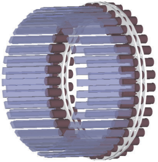


- Elastic peak not separated
- Background of γs and elastic peak: same energy range

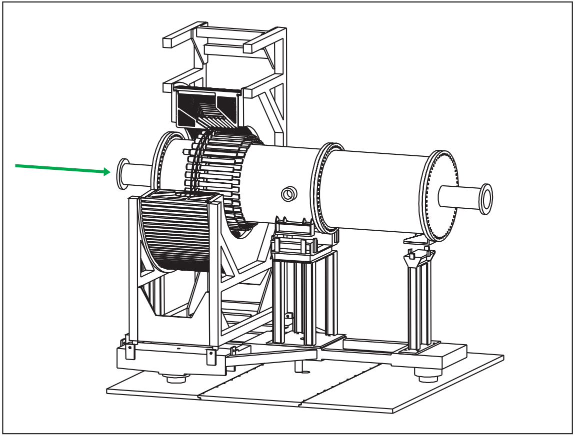
Plastic scintillators

- Plastic scintillators detect charged particles. Neutral particles not detected.



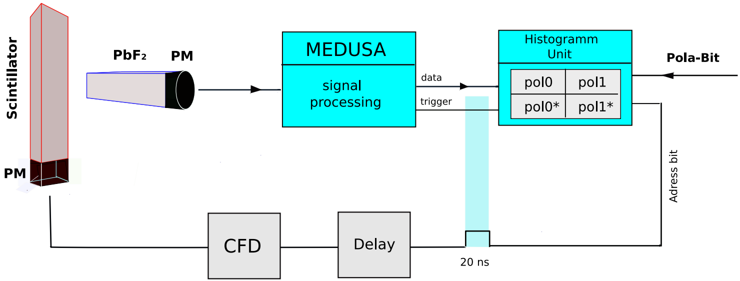
- 72 plastic scintillators: two rings of 36 with overlap.

Plastic scintillators location



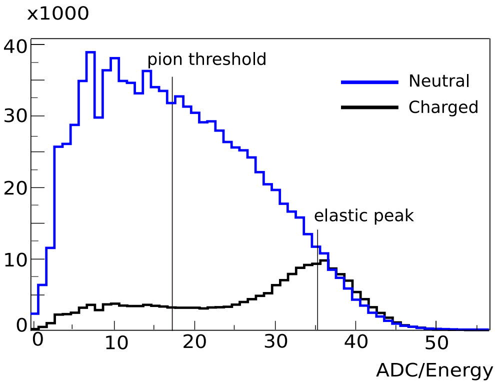
- Plastic scintillators located in front of calorimeter.
- One scintillator covers two frames: 14 modules.

Generated histograms



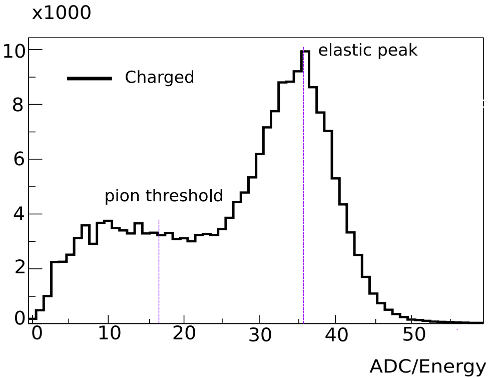
- Pola-bit signal: two histograms: two polarization states
- Plastic scintillators add an Address-bit: two histograms: one of neutral particles and one of charged particles
- Every 5 min four histograms are generated

Neutral and charged particles spectra



- Separation of the elastic peak in the charged particles spectrum
- The scintillators do their job!
- Still some γ background mixed with elastic peak

Neutral and charged particles spectra



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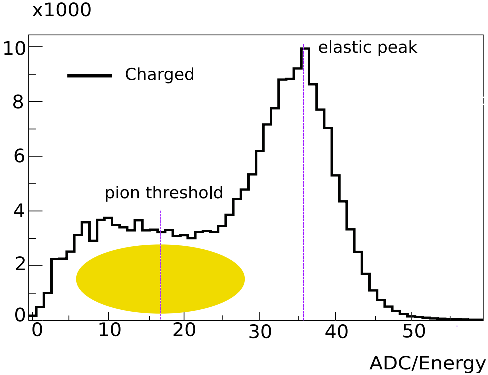

- Separation of the elastic peak in the charged particles spectrum
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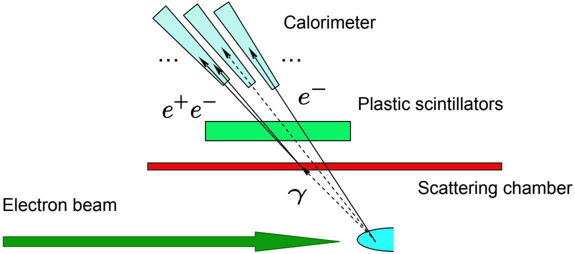
Background in the charged particles spectrum

- $\pi^0 \rightarrow 2\gamma$ and $\gamma \rightarrow e^+ + e^-$ in materials before calorimeter

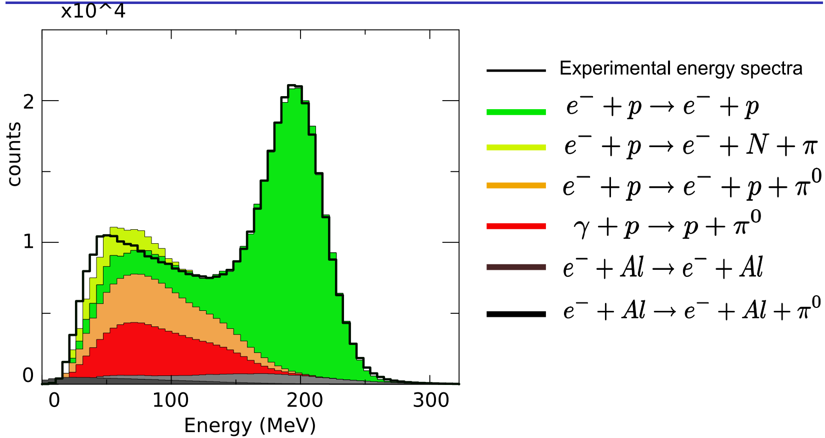


- γ background in the spectrum of charged particles

Outline

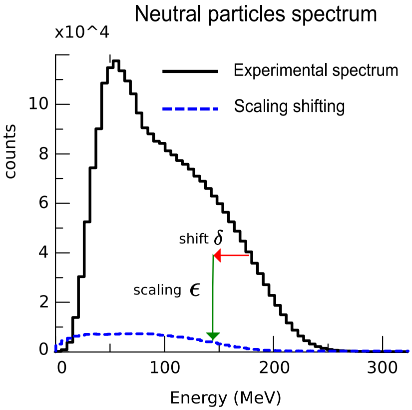
Monte Carlo studies

Understanding the energy spectrum



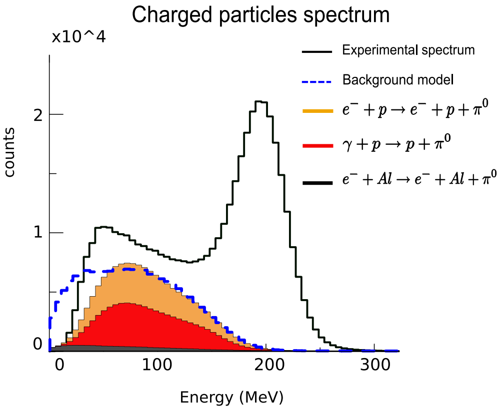
- Monte Carlo Geant4 simulation: e^- processes and γs
- Background from Al walls: measurement with empty target
- Agreement above 125 MeV

Background obtained from neutral spectrum



- γ background PVA?
- From experimental spectrum of neutral particles
- Model to obtain γ background
- Parameters
  - shift δ
  - scaling factor ϵ

Background obtained from neutral spectrum

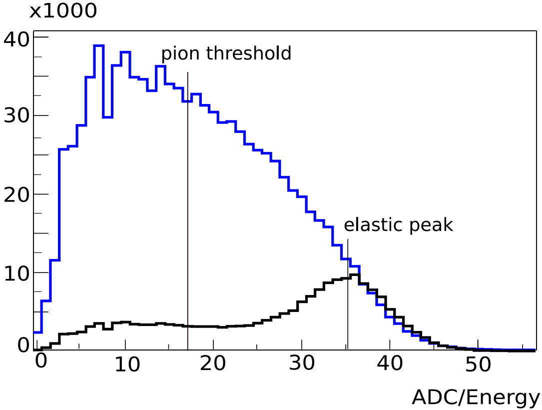


- Scaling shifting model agrees with simulated background:
- above 125 MeV
- energy range of our interest

Outline

Data analysis

Extraction of the asymmetry from the spectra



- $f = \frac{N_e^{back}}{N_e^{back} + N_e^{el}} (1 - 10\%)$
- Cuts applied
- $A_e = \frac{N_e^+ - N_e^-}{N_e^+ + N_e^-}$
- $A_\gamma = \frac{N_\gamma^+ - N_\gamma^-}{N_\gamma^+ + N_\gamma^-}$
- $A_{phys}^{raw} = \frac{A_e - f A_\gamma}{1 - f}$

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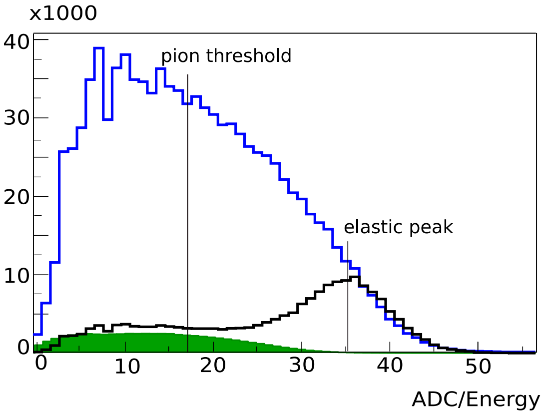

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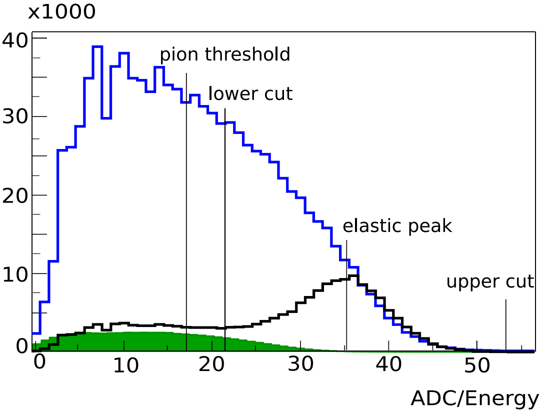

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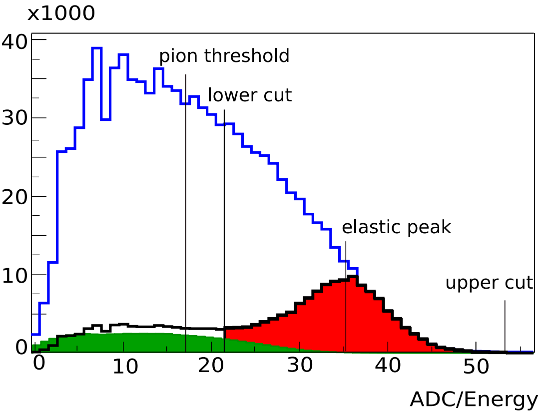

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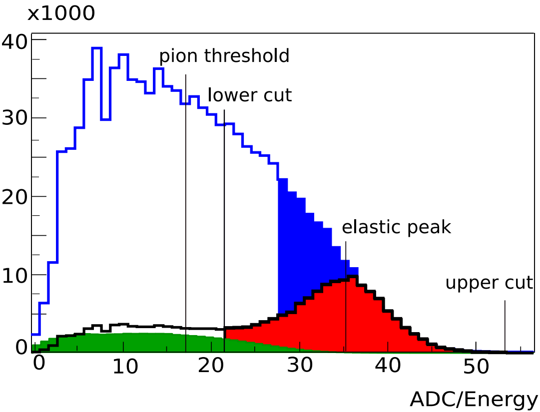

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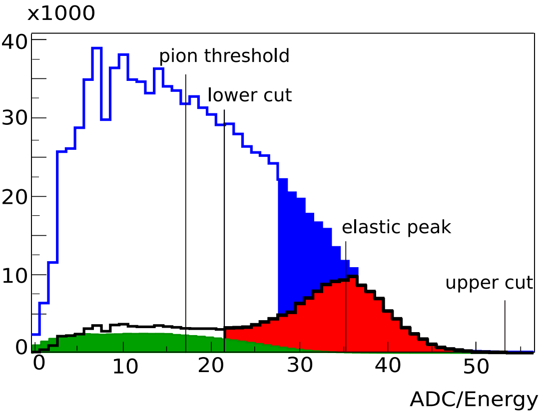

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Data analysis program

- Asymmetry is extracted for every module and every run.
- Statistical treatment of the complete set of asymmetries.
- Correction of systematics and evaluation of systematic errors.
- Normalization to the electron beam polarization $A_{\text{phys}} = \frac{A_{\text{exp}}}{P_e}$

Statistical error

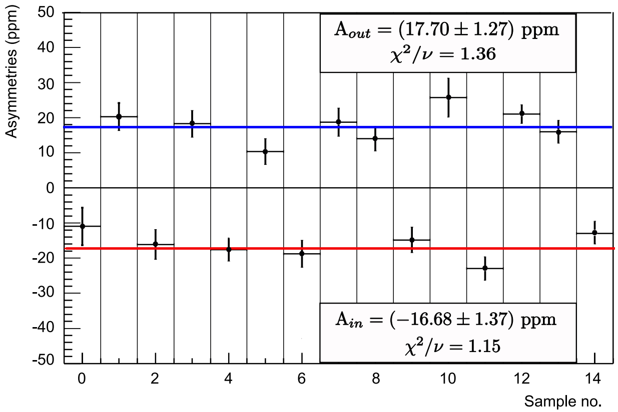
- 5 inner rings of the calorimeter: 730 crystals
- 1100 hours of data taking
- Altogether $3 \cdot 10^{12}$ elastic events
- Statistical error: $\sigma(A) = \frac{1}{P_e \sqrt{N_{el}}} \Rightarrow \sigma(A) = 0.82$ ppm

Systematic errors

	Correction(ppm)	Error(ppm)
Polarization	-5.58	0.69
Helicity corr. beam diff.	0.14	0.39
Dilution of γ backgr.	-1.49	0.28
Al windows	0.29	0.04
Random coinc. events	-0.19	0.02
Sum syst. errors		0.89

- Effective $P_e = 68.3\%$, error $\Delta(P_e) = 4\%$

GVZ checking



- Half of measurement with GVZ in. The rest with GVZ out
- GVZ in: physics asymmetry should flip sign. Same magnitude.

Outline

Results

Physics asymmetry

- Physics asymmetry at $Q^2 = 0.23$ (GeV/c)^2 and A4 backwards kinematics

$$\mathrm{A}_{\mathrm{PV}} = (-17.23 \pm 0.82_{\mathrm{stat}} \pm 0.89_{\mathrm{syst}}) \cdot 10^{-6}$$

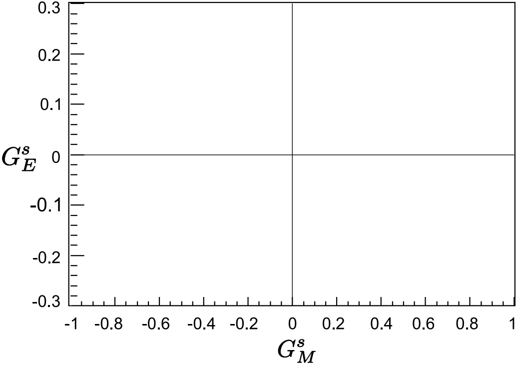
- Expectation A_0

$$\mathrm{A}_0 = (-15.87 \pm 1.2) \cdot 10^{-6}$$

- Origin of $\Delta\mathrm{A}_0$

$$\begin{aligned}
&\tilde{G}_A^p = -0.78 \pm 0.28 \\
&G_E^p = +0.5746 \pm 0.0095 \;\; (1.7\%) \qquad && G_M^p = +1.621 \pm 0.030 \;\; (1.9\%) \\
&G_E^n = +0.0525 \pm 0.0057 \;\; (11\%) \qquad && G_M^n = -1.092 \pm 0.024 \;\; (2.2\%)
\end{aligned}$$

Measurements and predictions of $G^s_{E,M}$



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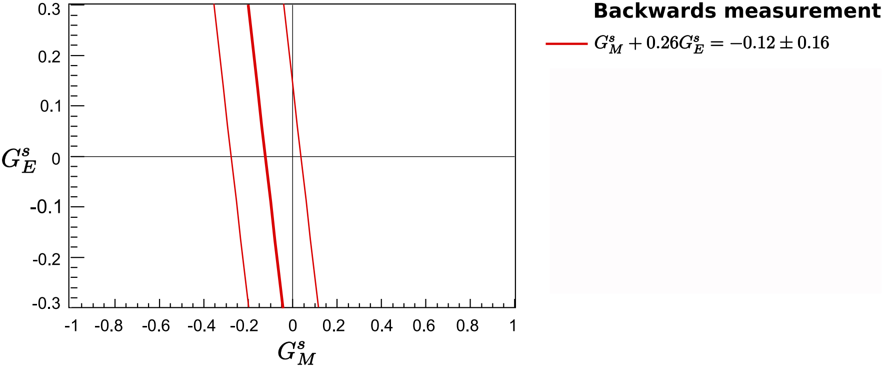

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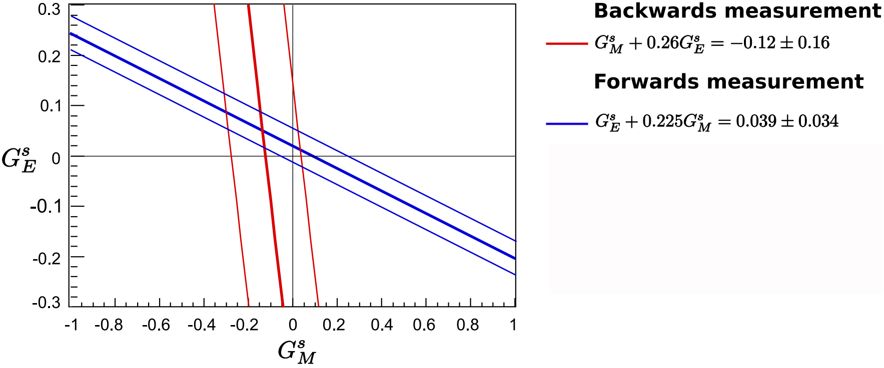

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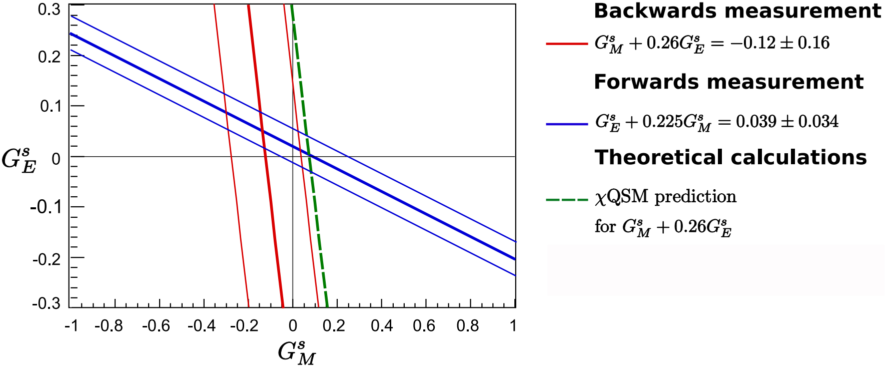

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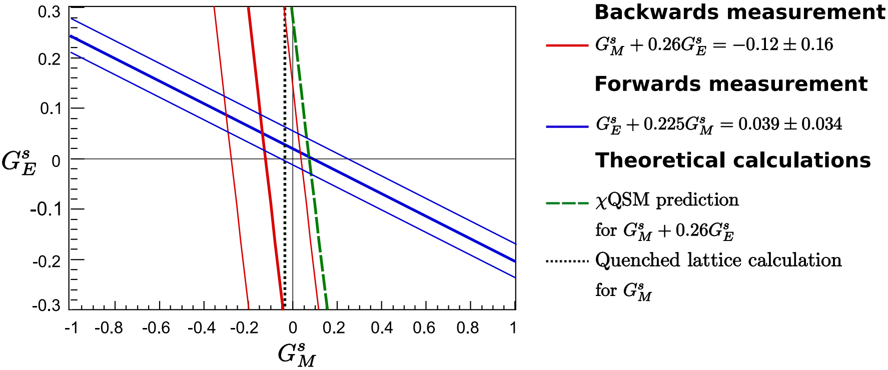

Backwards measurement

$G_M^s + 0.26 G_E^s = -0.12 \pm 0.16$

Forwards measurement

$G_E^s + 0.225 G_M^s = 0.039 \pm 0.034$

Theoretical calculations

χQSM prediction for $G_M^s + 0.26 G_E^s$

Quenched lattice calculation for G_M^s

Separation of G_E^s and G_M^s

- Disentangling the linear combinations:

$$G_E^s = 0.050 \pm 0.038 \pm 0.019$$

$$G_M^s = -0.14 \pm 0.11 \pm 0.11$$

Summary

- The A4 experimental objective: measurement of G_E^s and G_M^s at $Q^2 = 0.23$ (GeV/c)^2 with different kinematics

- Demanding experimental set up to measure $A_{PV} \sim 10^{-5}$
- Rotation of calorimeter to measure at backwards angles

- Detector of plastic scintillators to separate neutral background
- Understading the energy spectrum and mixed γ background

- Successful extraction of PVA from single spectra
- Combination of whole data. Systematic errors. P_e correction.

- Separation of G_E^s and G_M^s from different measurements

Outlook

- A measurement of parity violating asymmetry with deuterium as target is done.
- Analysis in progress.
- This measurement allows the separation of the G_M^s and the $\tilde{G}_A^p$.

- Detector rotated back to forward angles to measure the parity violating asymmetry at 1.5 GeV, $Q^2 = 0.62$ (GeV/c)^2