Parity violating asymmetry at backward angles on deuterium at $Q^2 = 0.23$ (GeV/c)^2 and axial form factor

David Balaguer Ríos

A4 Collaboration at Institut für Kernphysik:

Frank Maas, Sebastian Baunack, Dominik Becker, Luigi Capozza, Boris Gläser, Yoshio Imai, Ernst Schilling.

Johannes Gutenberg Universität, Mainz

Workshop to Explore Physics Opportunities with Intense, Polarized Electron Beams up to 300 MeV

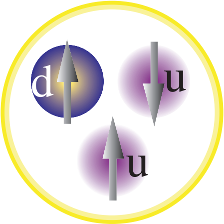
March 14-16, 2013, MIT, Cambridge, Massachusetts

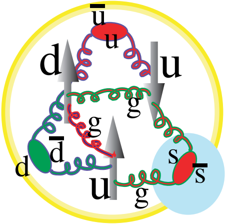
March 15, 2013

Outline

Parity violating asymmetry and axial form factor

The strange and axial vector form factors



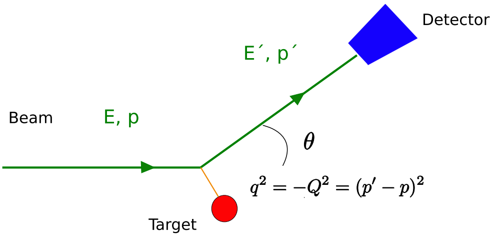


Nucleon: constituent quarks u,d, gluons, sea quarks $q\bar{q}$ ($q =$ u,d,s)
$\Rightarrow$s in nucleon: pure sea quark effect

Measurement of the strange vector electric and magnetic form factors: G_E^s and G_M^s

Using deuterium as target measurement of the axial vector form factor $\tilde{G}_A$

Parity violating asymmetry



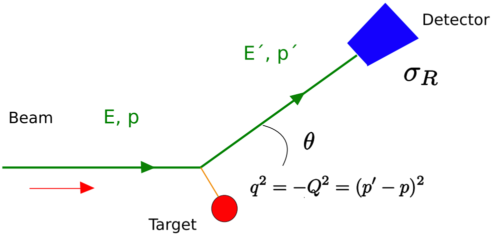
$$A_{PV} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L} \sim \frac{|\, M_\gamma M_{Z^0} \,|}{|\, M_\gamma \,|^2}$$

$$A_{PV} \sim \frac{g^2 Q^2}{M_Z^2 \alpha} \frac{a_A(\epsilon G_E^p \tilde{G}_E^p + \tau G_M^p \tilde{G}_M^p) + a_V(\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)} G_M^p \tilde{G}_A^p)}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

where $\tau = \frac{Q^2}{4M^2}$ and $\epsilon = \frac{1}{1+2(1+\tau)\tan^2\frac{\theta}{2}}$

$$A_{PV} = A_V + A_s(G_E^s,\ G_M^s) + A_A(\tilde{G}_A)$$

Parity violating asymmetry



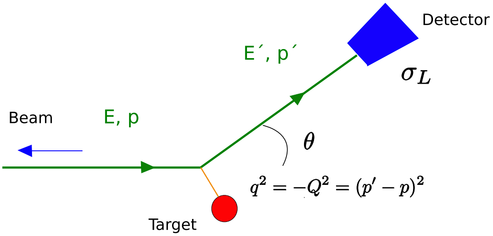
$$A_{PV} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L} \sim \frac{|\, M_\gamma M_{Z^0} \,|}{|\, M_\gamma \,|^2}$$

$$A_{PV} \sim \frac{g^2 Q^2}{M_Z^2 \alpha} \frac{a_A(\epsilon G_E^p \tilde{G}_E^p + \tau G_M^p \tilde{G}_M^p) + a_V(\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)} G_M^p \tilde{G}_A^p)}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

where $\tau = \frac{Q^2}{4M^2}$ and $\epsilon = \frac{1}{1+2(1+\tau)\tan^2\frac{\theta}{2}}$

$$A_{PV} = A_V + A_s(G_E^s,\ G_M^s) + A_A(\tilde{G}_A)$$

Parity violating asymmetry



$$A_{PV} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L} \sim \frac{\mid M_\gamma M_{Z^0} \mid}{\mid M_\gamma \mid^2}$$

$$A_{PV} \sim \frac{g^2 Q^2}{M_Z^2 \alpha} \frac{a_A(\epsilon G_E^p \tilde{G}_E^p + \tau G_M^p \tilde{G}_M^p) + a_V(\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)} G_M^p \tilde{G}_A^p)}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

where $\tau = \frac{Q^2}{4M^2}$ and $\epsilon = \frac{1}{1+2(1+\tau)\tan^2\frac{\theta}{2}}$

$$A_{PV} = A_V + A_s(G_E^s,\ G_M^s) + A_A(\tilde{G}_A)$$

PVA on proton: kinematics

$$A^p_{PV} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left((1-4\sin^2\theta_W) - \frac{(\epsilon G^p_E G^n_E + \tau G^p_M G^n_M)}{\epsilon(G^p_E)^2+\tau(G^p_M)^2}\right.$$
$$- \frac{\epsilon G^p_E G^s_E + \tau G^p_M G^s_M}{\epsilon(G^p_E)^2+\tau(G^p_M)^2}$$
$$\left.+ \frac{(1-4\sin^2\theta_W)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)}G^p_M(\ \ G^{T=1}_A - G^s_A)}{\epsilon(G^p_E)^2+\tau(G^p_M)^2}\right)$$

if $\theta \to 0 \Rightarrow \epsilon \to 1 \quad \sqrt{1-\epsilon^2} \to 0 \Rightarrow A \sim G^s_E + G^s_M$
if $\theta \to \pi \Rightarrow \epsilon \to 0 \quad \sqrt{1-\epsilon^2} \to 1 \Rightarrow A \sim G^s_M,\ \tilde{G}^p_A$

2 meas. A^p_{PV}, for- backwards, equal Q^2, input $\tilde{G}_A \Rightarrow$ separation $G^s_E,\ G^s_M$

PVA on neutron

$$A_{PV}^{n} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \left((1 - 4\sin^2\theta_W) - \frac{(\epsilon G_E^n G_E^p + \tau G_M^n G_M^p)}{\epsilon (G_E^n)^2 + \tau (G_M^n)^2} \right.$$
$$- \frac{\epsilon G_E^n G_E^s + \tau G_M^n G_M^s}{\epsilon (G_E^n)^2 + \tau (G_M^n)^2}$$
$$\left. + \frac{(1 - 4\sin^2\theta_W)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)} G_M^n (-G_A^{T=1} - G_A^s)}{\epsilon (G_E^n)^2 + \tau (G_M^n)^2} \right)$$

$G_{E,M}^{n} \leftrightharpoons G_{E,M}^{p}$
$G_A^{T=1} \to -G_A^{T=1}$

Measurement not directly on n but on deuteron d

PVA on deuteron

Static approximation

$$A^d_{PV} = \frac{\sigma_p A^p_{PV} + \sigma_n A^n_{PV}}{\sigma_p + \sigma_n}, \qquad \sigma_{p,n} \propto \epsilon (G_E^{p,n})^2 + \tau (G_M^{p,n})^2$$

$$\begin{aligned} A^d_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}} \Bigg[& (1 - 4\sin^2\theta_W) - \frac{2(\epsilon G_E^p G_E^n + \tau G_M^p G_M^n)}{\epsilon\left[(G_E^p)^2 + (G_E^n)^2\right] + \tau\left[(G_M^p)^2 + (G_M^n)^2\right]} \\ & - \frac{\epsilon (G_E^p + G_E^n) G_E^s + \tau (G_M^p + G_M^n) G_M^s}{\epsilon\left[(G_E^p)^2 + (G_E^n)^2\right] + \tau\left[(G_M^p)^2 + (G_M^n)^2\right]} \\ & + \frac{(1 - 4\sin^2\theta_W)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)}\left((G_M^p - G_M^n) G_A^{T=1} + (G_M^p + G_M^n) G_A^s\right)}{\epsilon\left[(G_E^p)^2 + (G_E^n)^2\right] + \tau\left[(G_M^p)^2 + (G_M^n)^2\right]} \Bigg] \end{aligned}$$

PVA on deuteron

$$
\begin{array}{ll}
G_M^s & \times(G_M^p + G_M^n) \\
G_A^s & \times(G_M^p + G_M^n) \\
G_A^{T=1}(p) = -G_A^{T=1}(n) & \times(G_M^p - G_M)
\end{array}
$$

$$
\frac{ZG_M^p + NG_M^n}{ZG_M^p - NG_M^n} = \frac{Z\mu_p + N\mu_n}{Z\mu_p - N\mu_n} \begin{cases} = 1 & \text{if } Z = 1 \\ \simeq 0.187 & \text{if } Z = N \end{cases}
$$

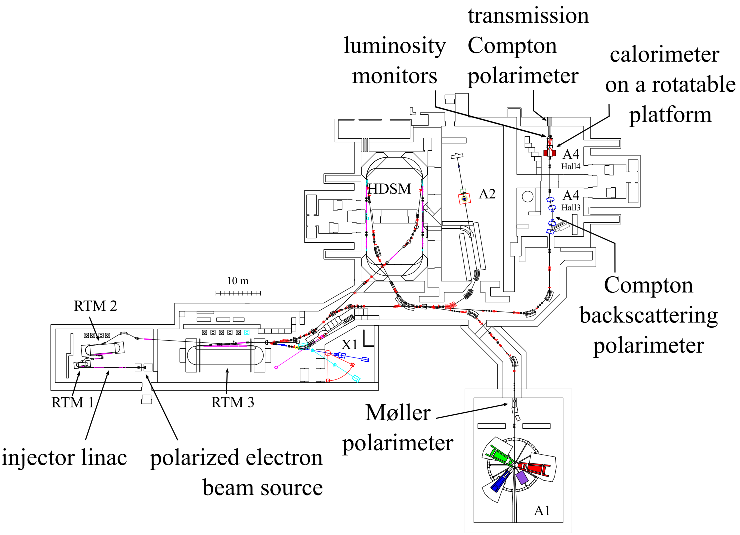
A_{PV}^d is more sensitive to the isovector axial vector form factor $G_A^{T=1}$

$\boxed{\text{2 meas. } A_{PV}^p,\ A_{PV}^d\text{, backwards, equal } Q^2 \Rightarrow \text{separation } G_M^s,\ \tilde{G}_A}$

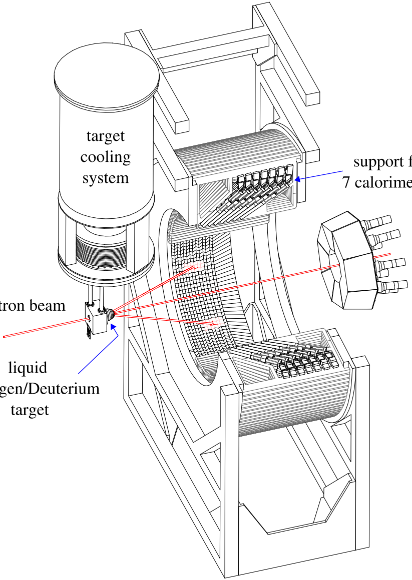
Outline

A4 experimental setup

A4 experiment at MAMI, Mainz

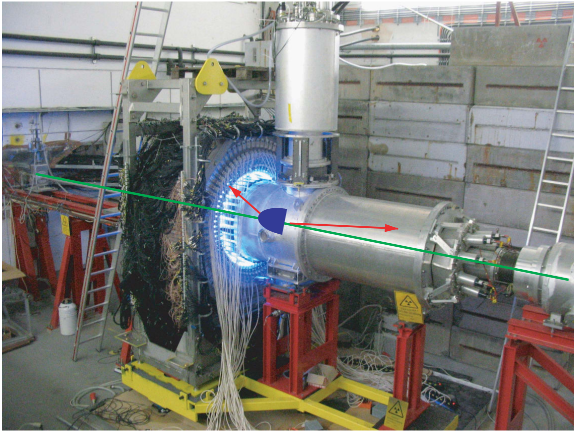


Target and detectors at forward angles



- Detector covers full azimuthal angle (frames).
- Counts single events with high rate $\sim$ MHz
- measures energy, good energy resolution $\frac{3.9\%}{\sqrt{E(\mathrm{GeV})}}$
- Target of liquid H_2 and D_2.

Target and detectors at backward angles



Backward angles: plastic scintillators, discrimination of γ, from $\pi^0 \rightarrow 2\gamma$

List of A4 measurements of PVA

θ	E [MeV]	Q^2 [(GeV/c)^2]	target
$30^\circ - 40^\circ$	570	0.11	H_2
$30^\circ - 40^\circ$	855	0.23	H_2
$30^\circ - 40^\circ$	1508	0.62	H_2
$140^\circ - 150^\circ$	315	0.23	H_2
$140^\circ - 150^\circ$	315	0.23	D_2
$140^\circ - 150^\circ$	210	0.10	H_2
$140^\circ - 150^\circ$	210	0.10	D_2

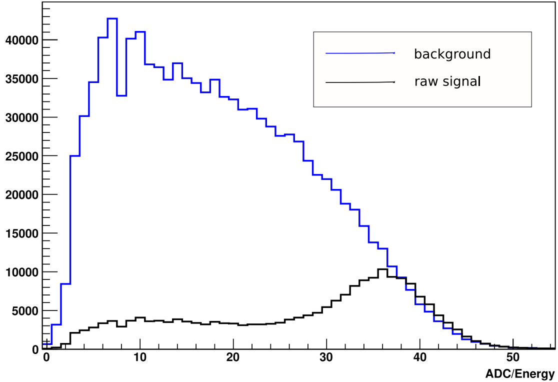
Published, F. Maas et al. Phys. Rev. Lett. 94, 152001 (2005)
Published, F. Maas et al. Phys. Rev. Lett. 93, 022002 (2004)
Published, S. Baunack et al. Phys. Rev. Lett. 102, 151803 (2009)
Measurement presented in this talk
Analysis in progress

Outline

Extraction of the parity violating asymmetry

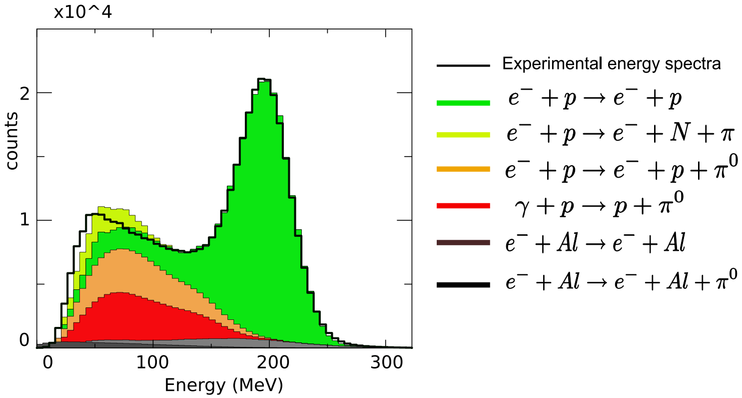
Energy spectrum

Energy spectrum of scattered electrons



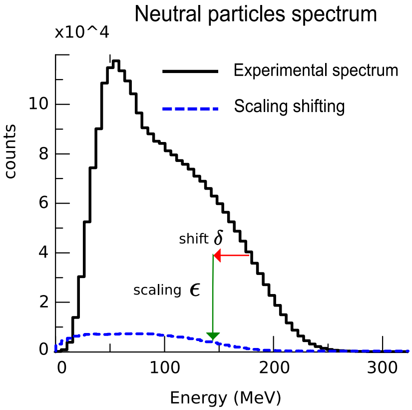
Method to extract background pollution and its asymmetry from spectrum of neutral particles based on Geant4 simulation.

Understanding the energy spectrum



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

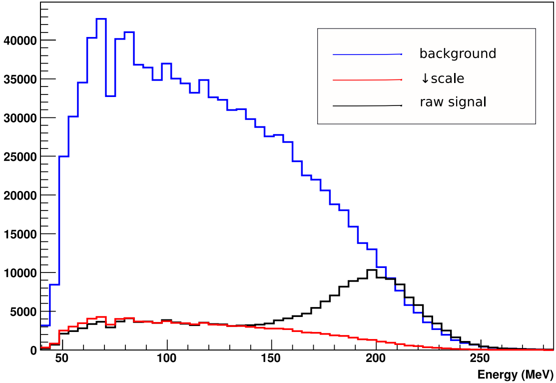
Background obtained from neutral spectrum



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

Background subtraction method

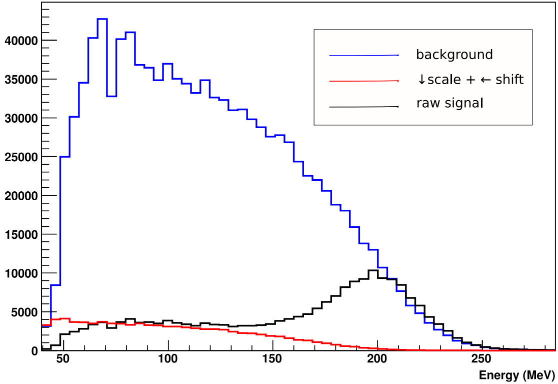
Energy spectrum of scattered electrons



Two parameters: shift $\delta \sim 35 - 50$ MeV and scaling factor $\epsilon \sim 0.10 - 0.12$

Background subtraction method

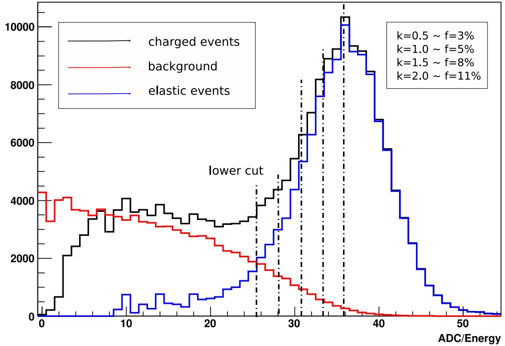
Energy spectrum of scattered electrons



$$A^{\text{raw}}_{\text{phys}} = \frac{A_e - fA_\gamma}{1-f}, \qquad f = N_\gamma / N_e$$

Energy spectrum with H_2

target H_2, E$= 315$ MeV, $Q^2 = 0.23$ (GeV/c)^2, $\theta = 145°$



Experimentally observed spectrum

Elastically scattered electrons

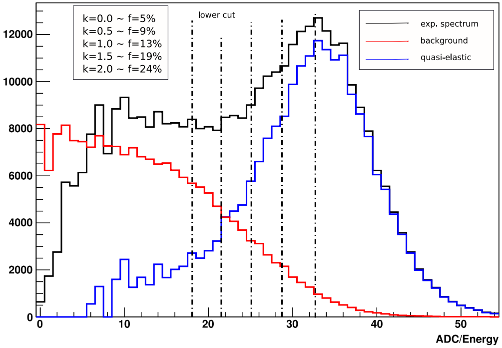
Background, $\pi^0 \to 2\gamma$, $\gamma \to e^+e^-$

Upper cut and lower cut ($= \mu - k \cdot \sigma$), integration $N^{\pm}$, $A_O = \dfrac{N^+ - N^-}{N^+ + N^-}$

$A_{\mathrm{PV}} = \dfrac{A_O - f \cdot A_\gamma}{1 - f}$, dilution factor $f = \dfrac{N_\gamma}{N_O}$

Energy spectrum with D_2

target D_2, E$= 315$ MeV, $Q^2 = 0.23$ (GeV/c)^2, $\theta = 145°$



Quasi-elastically scattered electrons

Comparison with H_2

Broader peak, Fermi motion

Electron rate ~ 1.5 higher

Background rate ~ 2 higher

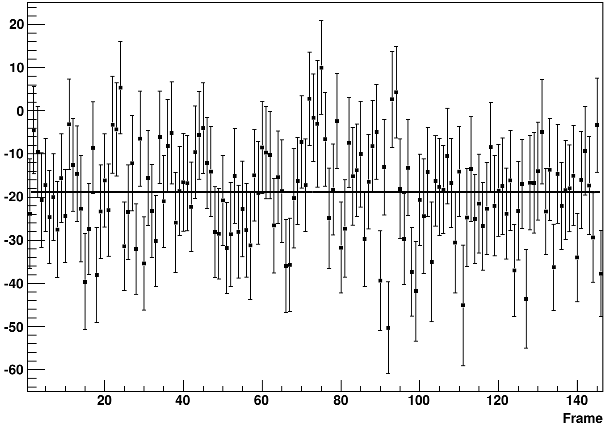
Upper cut and lower cut ($= \mu - k \cdot \sigma$), integration $N^{\pm}$, $A_O = \dfrac{N^+ - N^-}{N^+ + N^-}$

Static approximation $A^d_{\text{PV}} = \dfrac{\sigma_p A^p_{\text{PV}} + \sigma_n A^n_{\text{PV}}}{\sigma_p + \sigma_n}$

Outline

Asymmetry and systematics

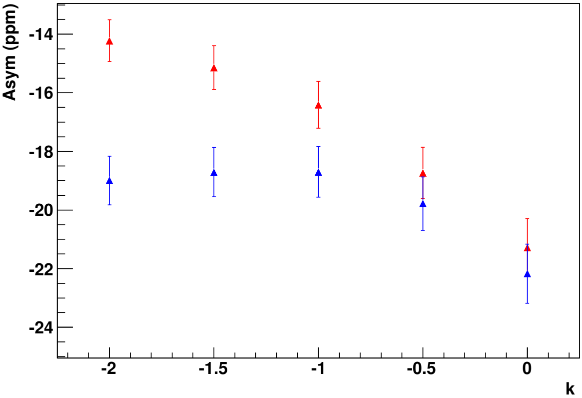
PVA of quasielastic events as function of frame



$\chi^2/\text{ndf} = 147.2/143$

$P = 0.43$

Application of subtraction method



$\mu - k \cdot \sigma \quad \epsilon = 0.10 \quad \delta = 35$ MeV

Statistics and systematics

target D_2, backward angles, preliminary
k = $1.0\ \sigma$ f= 15%
1100 h data taking, $N_e = 2.6 \cdot 10^{12}$
stat. error $= 0.84$ ppm

	Scaling factor	Error(ppm)
Polarization	0.74	0.86
	Correction(ppm)	Error(ppm)
Dilution of γ backgr.	-4.02	0.87
Helicity corr. beam diff.	-0.22	0.09
Al windows	0.01	0.05
Random coinc. events	-1.21	0.05
Luminosity	-0.71	0.11
spin angle deviation	0.01	0.04
Sum syst. errors		1.23

$$\boxed{A^d_{PV} = (-20.77 \pm 0.84 \pm 1.23)\ \text{ppm}}$$

Outline

Results

Asymmetry and form factors

Preliminary at $Q^2 = 0.23$ (GeV/c)^2

$$\boxed{A_{PV}^d = (-20.77 \pm 0.84 \pm 1.23) \cdot 10^{-6}}$$

$$A_V = (-18.63 \pm 0.17) \cdot 10^{-6}$$

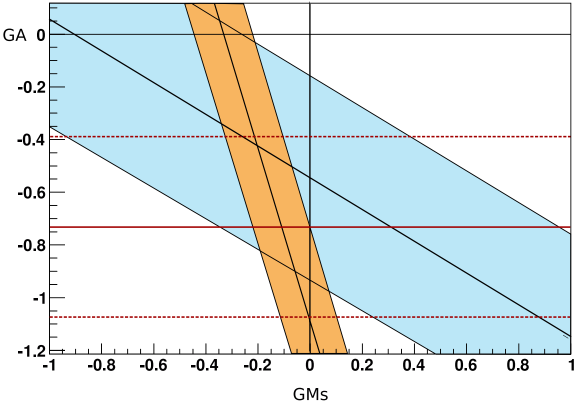
$$A_0 = A_V + A_A = (-21.72 \pm 1.22) \cdot 10^{-6}$$

$$A_S + A_A = A - A_V \propto G_A^{T=1} + kG_M^s$$

Deuteron: $G_A^{T=1} + 0.59 \cdot G_M^s = -0.53 \pm 0.37 \pm 0.02$

First error: experimental, second: uncertainty in form factors

Disentangling axial form factor



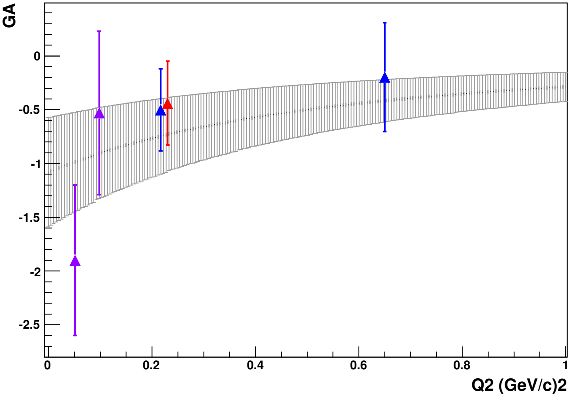
Deuteron: $G_A^{T=1} + 0.59 \cdot G_M^s = -0.53 \pm 0.37 \pm 0.02$

Proton: $0.30 \cdot G_A^{T=1} + G_M^s = -0.30 \pm 0.11 \pm 0.00$

Zhu et al.: $G_A^{T=1} = -0.74 \pm 0.35$

$$\boxed{G_A^{T=1} = -0.43 \pm 0.46}$$

Measurements of axial form factor



G0: *Phys. Rev. Lett. 104, 012001 (2010)*

SAMPLE: *Prog. Part. Nucl. Phys. 54, 289 (2005)*

A4 preliminary measurement at $Q^2 = 0.23$ $(\text{GeV}/c)^2$

Zhu el al.: *Phys. Rev. D 62, 033008 (2000)*

Outline

Summary and outlook

Summary and outlook

Preliminary A_{PV} on D_2 at $Q^2 = 0.23$ (GeV/c)^2 backwards

Preliminary linear combination of G_M^s and $G_A^{T=1}$

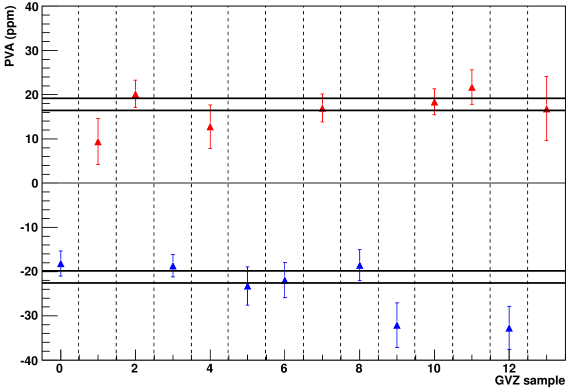
Published A_{PV} on H_2 at $Q^2 = 0.23$ (GeV/c)^2 at backwards and linear combination of G_M^s and $G_A^{T=1}$

Separation of $G_A^{T=1}$, $G_A^{T=1} = -0.43 \pm 0.46$

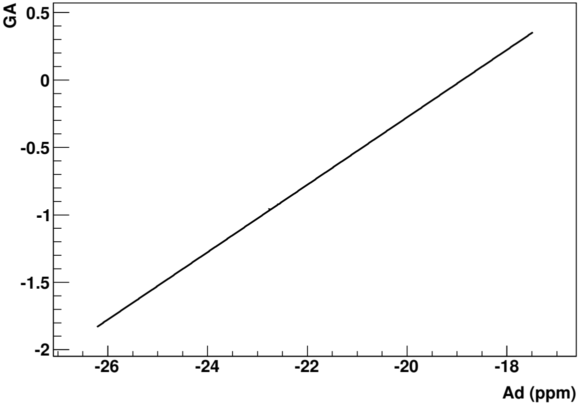
Comparison with another measurements and theoretical calculations of $G_A^{T=1}$

Analysis in progress for the PVA at $Q^2 = 0.63$ (GeV/c)^2 forwards and at $Q^2 = 0.10$ (GeV/c)^2 backwards for H_2 and D_2

GVZ samples



Depedence of axial form factor on asymmetry



The extraction of the axial form factor is very sensitive to the value of the PVA on deuteron.

PVA of background as function of frame