Transverse Single Spin Asymmetries in Electron Scattering on Hydrogen Targets

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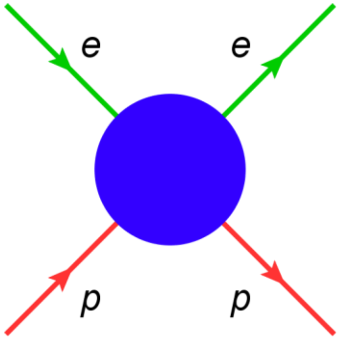
Spin 2018, Ferrara

Outline

- Proton form factor puzzle and two-photon exchange
- Two-photon exchange study at MAMI-A4
- Plan for asymmetry measurement in inelastic region

Proton form factors

General e-p scattering amplitudes

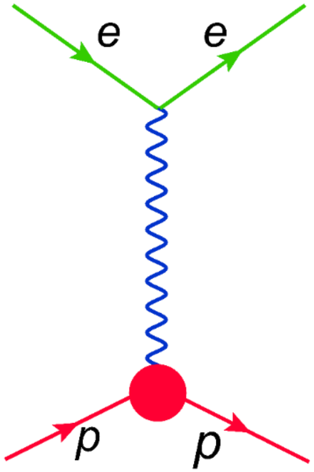


Elastic scattering of two spin-1/2 particles can be described by 6 amplitudes.

$$\tilde{G}_M, \tilde{F}_2, \tilde{F}_3, \tilde{F}_4, \tilde{F}_5, \tilde{F}_6$$

- Small coupling (1/137) -> small higher order contributions
- One-photon exchange approximation are regareded as sufficient

Born approximation



$$\mathrm{G_E}(\mathrm{Q}^2) = \mathrm{F_1}(\mathrm{Q}^2) - \tau \mathrm{F_2}(\mathrm{Q}^2)$$
$$\mathrm{G_M}(\mathrm{Q}^2) = \mathrm{F_1}(\mathrm{Q}^2) + \mathrm{F_2}(\mathrm{Q}^2)$$

Form factors

- Dirac (F_1) and Pauli (F_2) form factors represents the helicity conserving and flip processes respectively
- Sachs form factors (G_E, G_M) describe the charge and magnetization distribution

Methods for form factor measurement

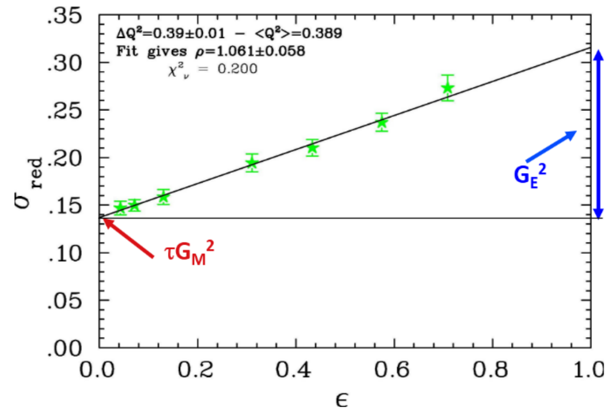
Rosenbluth separation

$$\frac{d\sigma}{d\Omega}=\left(\frac{\alpha}{4MQ^2}\frac{E'}{E}\right)^2|\mathcal{M}_\gamma|^2=\frac{\sigma_{Mott}}{\epsilon(1+\tau)}\sigma_R$$

$$\sigma_{Mott}=\frac{\alpha^2 E'\cos^2\frac{\theta_e}{2}}{4E^3\sin^4\frac{\theta_e}{2}}$$ (Point-like)

$$\tau=\frac{Q^2}{4M^2}\qquad \varepsilon=\left[1+2(1+\tau)\tan^2\frac{\theta_e}{2}\right]^{-1}$$

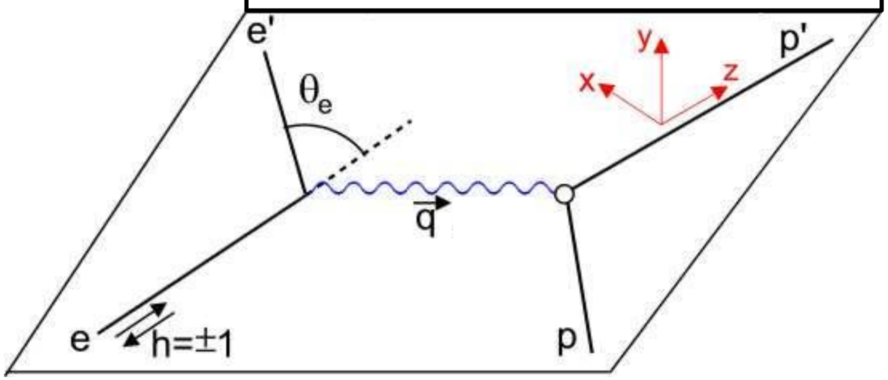
$$\boxed{\sigma_R=\varepsilon G_E^2(Q^2)+\tau G_M^2(Q^2)}$$



- FFs extracted as intercept and slope
- The signs of the FFs can not be determined
- At large Q^2, uncertainty of G_E gets larger

Spin-transfer method

Spin transfer reaction: $\vec{e}p\rightarrow e\vec{p}$



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$$I_0P_x=-2\sqrt{\tau(1+\tau)}G_EG_M\tan\frac{\theta_e}{2}$$

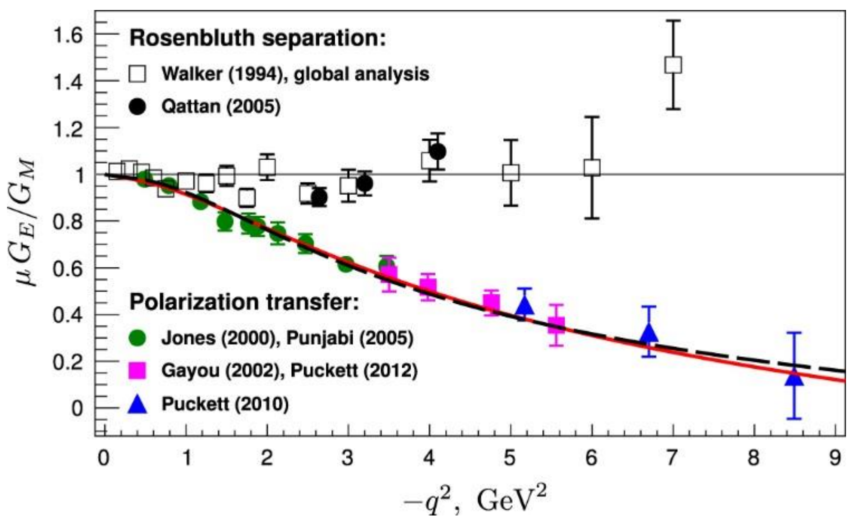
$$P_y=0$$

$$I_0P_z=\frac{E_0+E'}{M}\sqrt{\tau(1+\tau)}G_M^2\tan\frac{\theta_e}{2}$$

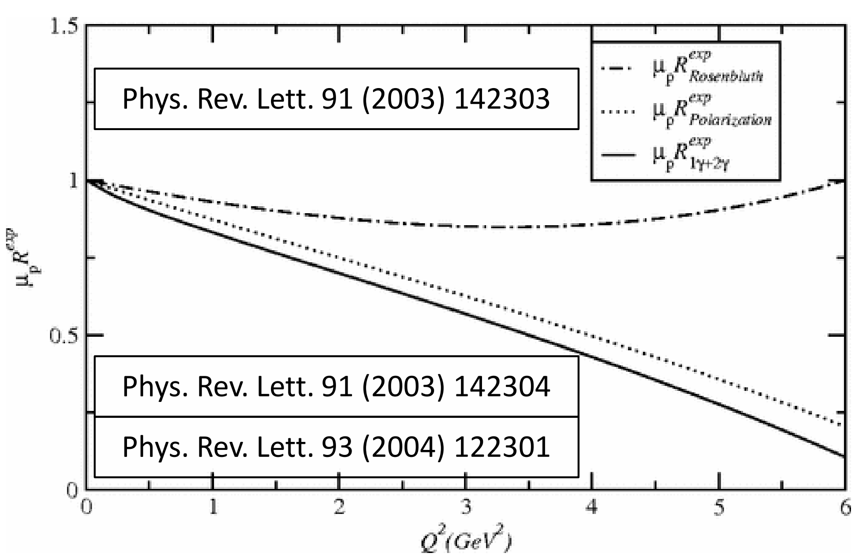
$$I_0=G_E^2(Q^2)+\frac{\tau}{\varepsilon}G_M^2(Q^2)$$

$$\frac{G_E}{G_M}=-\frac{P_t}{P_l}\frac{E_0+E'}{M}\tan\frac{\theta_e}{2}$$

Proton form factor puzzle



- Discrepancy between Rosenbluth separation and spin transfer experiments.
- Failure of the Born approximation in electron scattering .

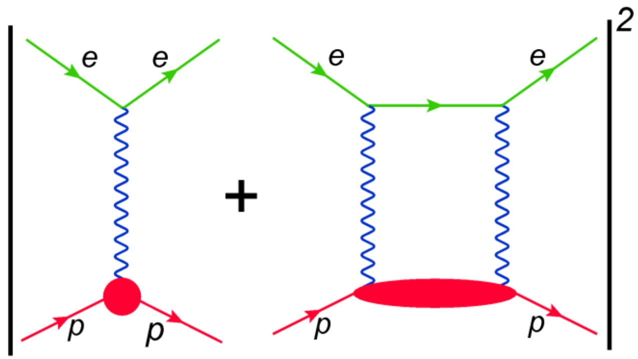


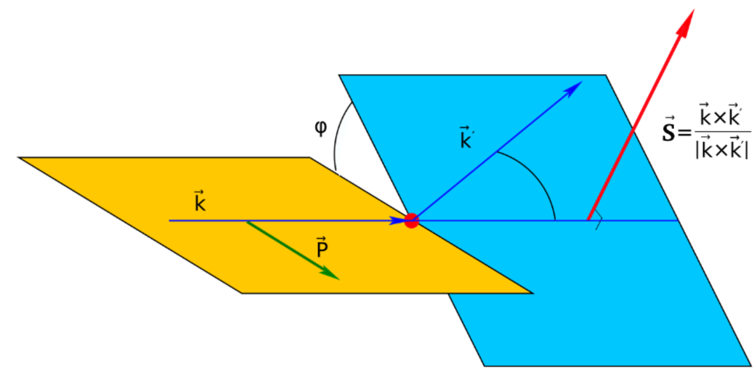
- A two-photon exchange correction could explain the discrepancy.
- Two-photon exchange mechanism needs to be understood systematicly.
- Both theoretical and experimental investigations are needed.

Two-photon exchange

R(e⁺p/e⁻p)⇒$\mathrm{Re}\left(\tilde{F}_{1,2,3}\right)$

Single Spin Asymmetry (SSA) $\Rightarrow Im\left(\tilde{F}_{1-5}\right)$





$$\mathcal{M}_{ep\to ep} = q_e q_p \mathcal{M}_\gamma + q_e^2 q_p^2 \mathcal{M}_{2\gamma}$$

$$\left|\mathcal{M}_{ep\to ep}\right|^2 = q_e^2 q_p^2 \mathcal{M}_\gamma + q_e^3 q_p^3 \mathcal{M}_\gamma \mathcal{M}_{2\gamma}$$

$$\sigma_{e^-p} = \alpha^2 \mathcal{M}_\gamma^2 - \alpha^3 \mathcal{M}_\gamma Re(\mathcal{M}_{2\gamma}) + \cdots$$

$$\sigma_{e^+p} = \alpha^2 \mathcal{M}_\gamma^2 + \alpha^3 \mathcal{M}_\gamma Re(\mathcal{M}_{2\gamma}) + \cdots$$

$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \approx 1+2\alpha \frac{Re\left(\mathcal{M}_{2\gamma}\right)}{\mathcal{M}_\gamma}$$

Azimuthal asymmetry

$$A_{exp} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = A_\perp \frac{\vec{s}\cdot\vec{p}}{|\vec{s}||\vec{p}|} = -A_\perp \cos\varphi$$

$$A_\perp \propto \frac{Im\left(\mathcal{M}_\gamma^* \mathcal{M}_{2\gamma}\right)}{\left|\mathcal{M}_\gamma\right|^2} \sim \alpha \cdot \frac{m_e}{E} \sim 10^{-5} - 10^{-6}$$

Nucl. Phys. B 35 (1971) 365.

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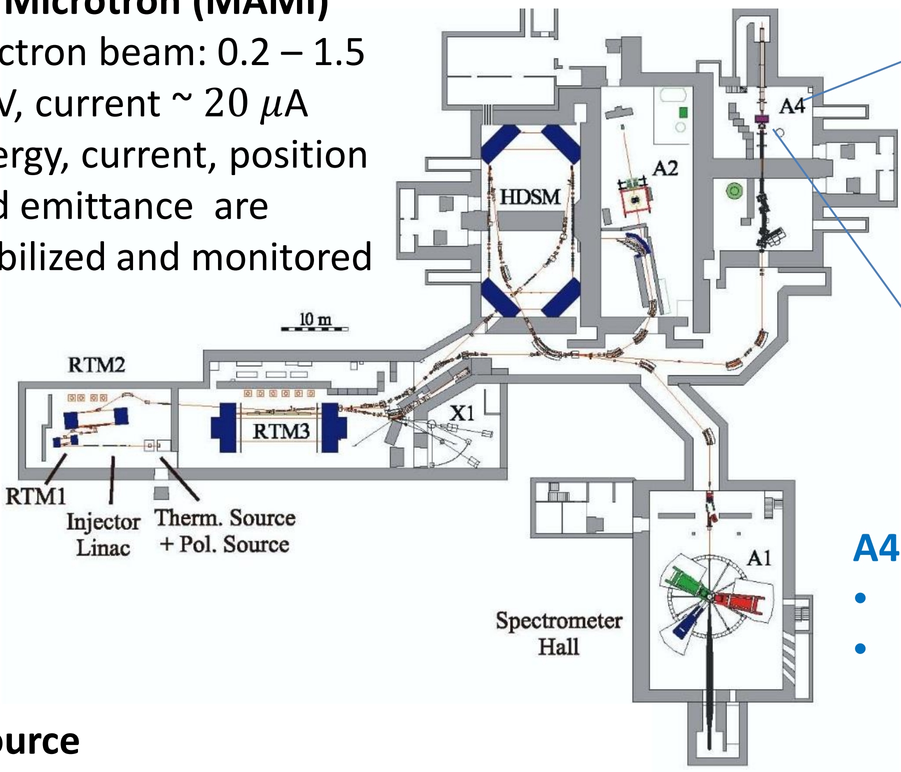
- OLYMPUS@DESY

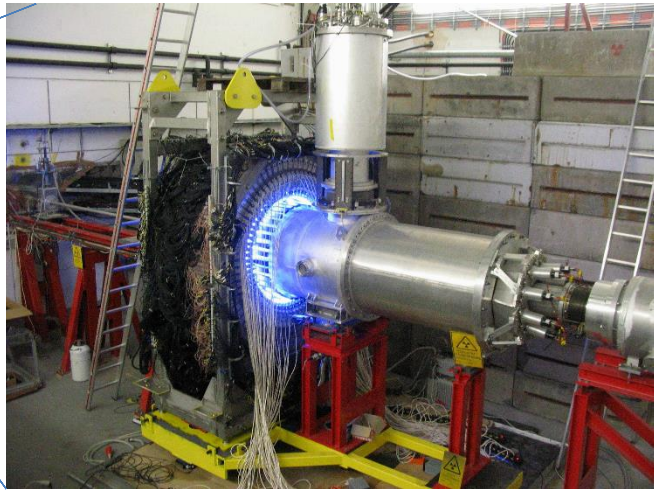
- SAMPLE@MIT-Bates
- HAPPEX, G0, Q_{weak} @JLab
- A4@MAMI

MAMI

Mainz Microtron (MAMI)

- Electron beam: 0.2 – 1.5 GeV, current ~ 20 μA
- Energy, current, position and emittance are stabilized and monitored





A4 experiment

- Parity violation asymmetry: Strange form factor
- Azimuthal asymmetry: Two-photon exchange

Pol. Source

- Photoelectric effect on GaAs with circularly polarized laser: **longitudinal** polarized electrons
- Wien filter: longitudinal → **transverse**
- Solenoid: transverse → **vertical**
- Pol. states switched by Pockels cell
- An extra half-wave plate GaAs (Gallium Arsenide)

Beam polarization ~ 80%

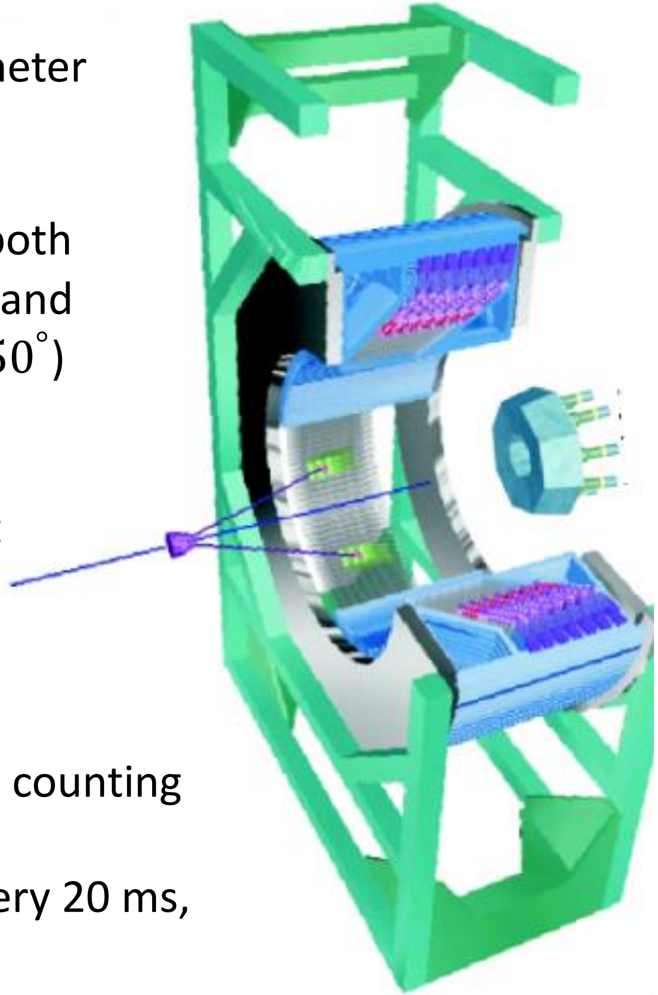
- Møller polarimeter (A1)
- Compton laser backward scattering polarimeter
- Transmission Compton polarimeter

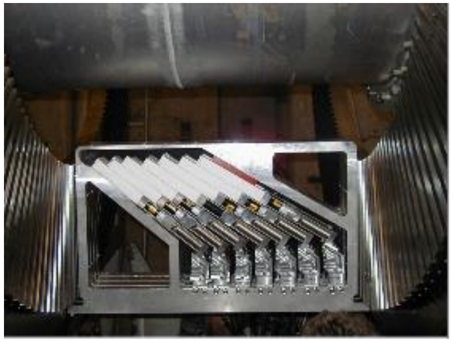
A4 experiment

Electromagnetic Calorimeter
- 7x146 PbF_2 crystals
- φ: $(0,\ 2\pi)$
- Rotatable platform: both forward $(30^{\circ} - 40^{\circ})$ and backward $(140^{\circ} - 150^{\circ})$

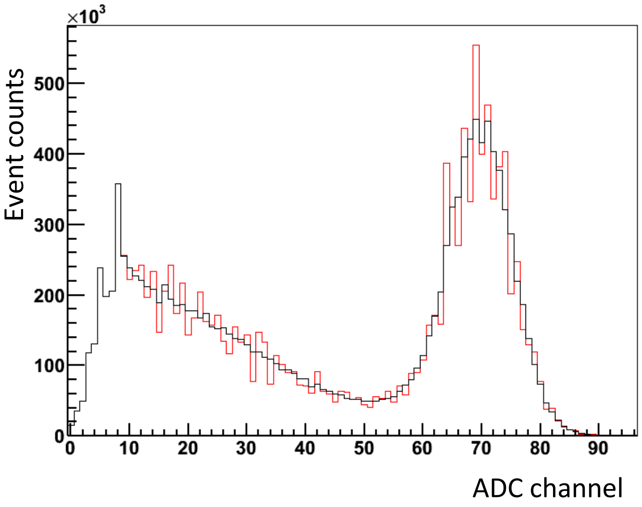
High power liquid target
- Hydrogen
- Deuterium

- Dead time 20 ns, high counting rate: >10 MHz
- Pol. state changed every 20 ms, each run last 5 min

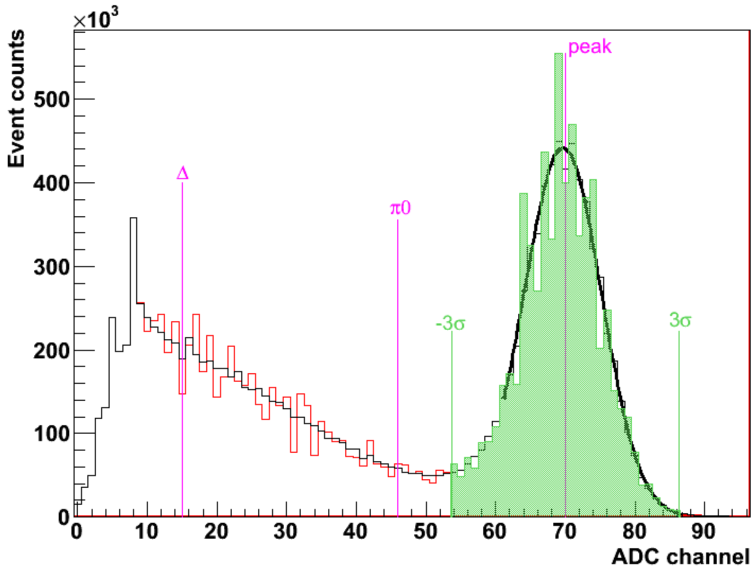


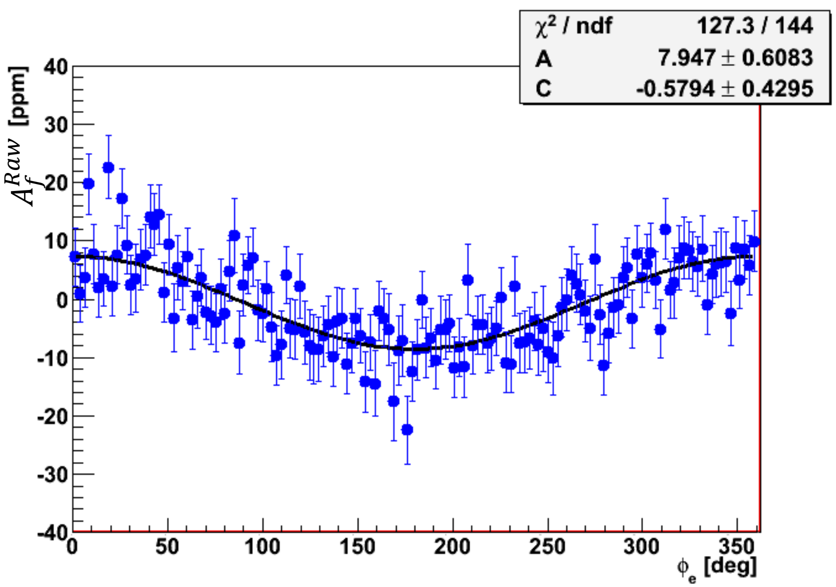


Luminosity monitored by 8 water Cherenkov counters

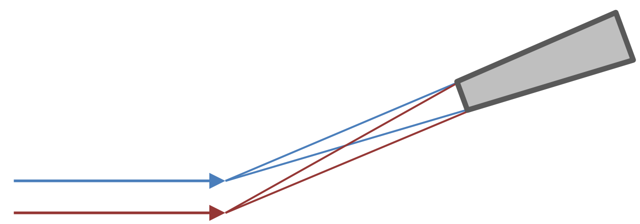


Asymmetry extraction





- Integrate spectra under elastic peak -> $N^{\uparrow}(N^{\downarrow})$
- Raw asymmetry for each frame $A_f = \frac{N^{\uparrow}-N^{\downarrow}}{N^{\uparrow}+N^{\downarrow}}$
- Correct helicity related false aymmetry $A_f^{Raw} \rightarrow A_f$



False asymmetry caused by difference in

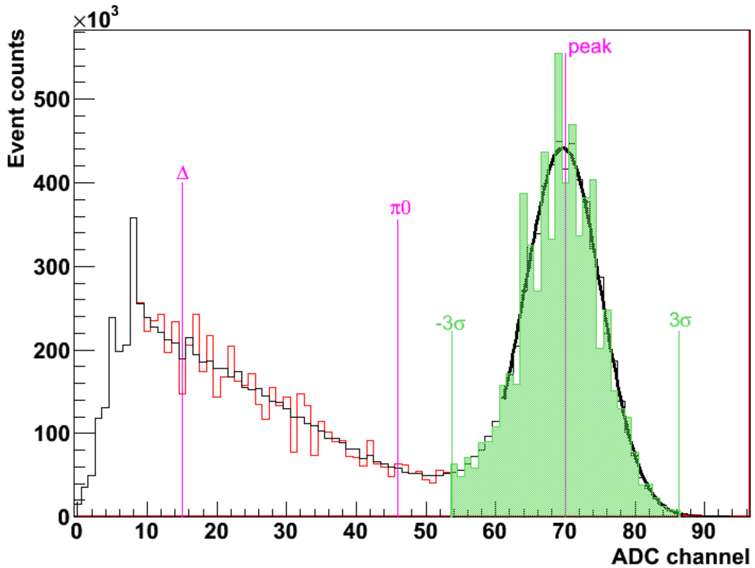
- Beam position $(\Delta X, \quad \Delta Y)$
- Beam angle $(\Delta X', \Delta Y')$
- Beam current ΔI
- Beam energy ΔE

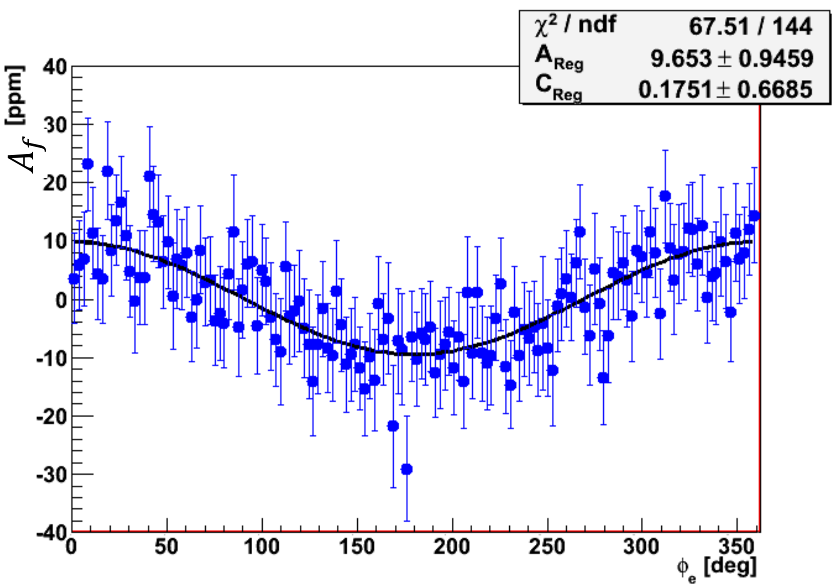
Corrected via regression analyses

$$A_{exp} = P \cdot A_{phy} + \sum_{i=1}^{6} a_i X_i$$

- Fit A_f by $A_f = A\cos\left[\frac{2\pi}{146}\cdot(f-0.5)\right] + C$

Asymmetry extraction





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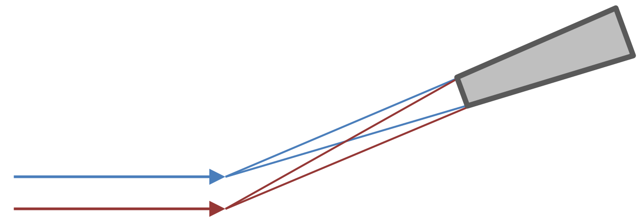

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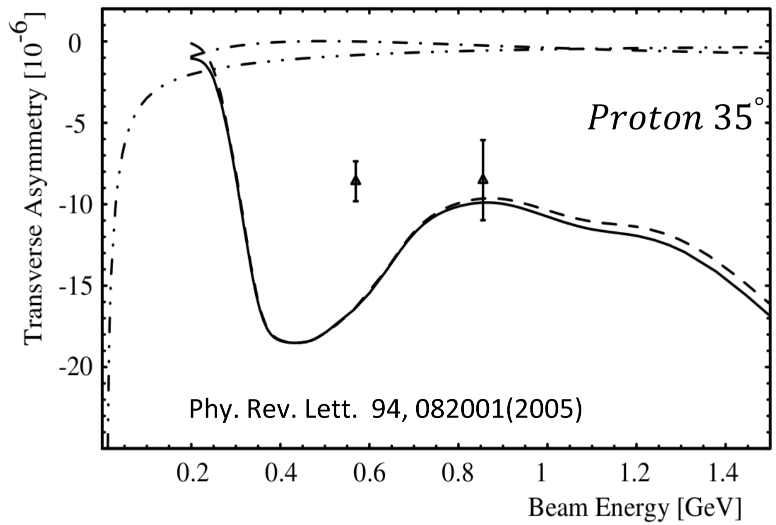
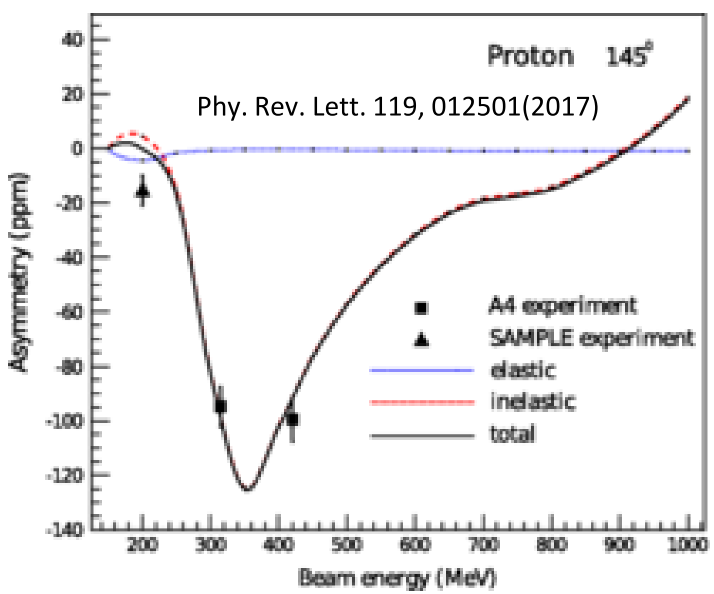
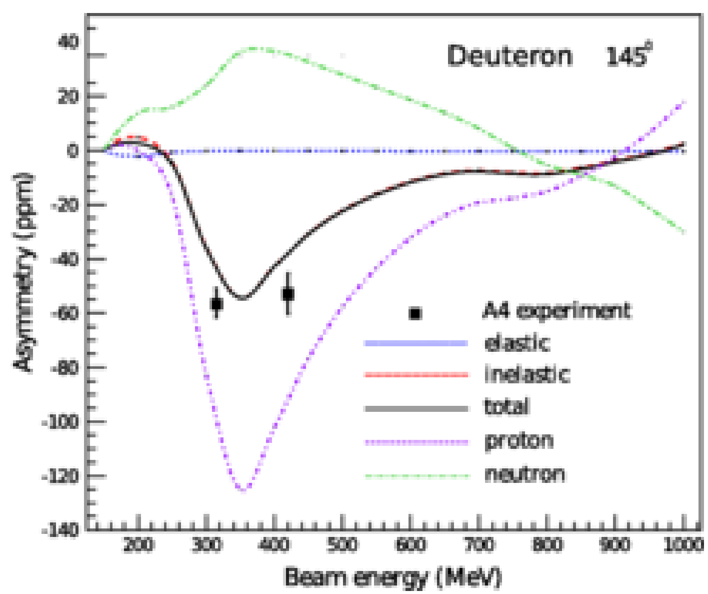
Published data

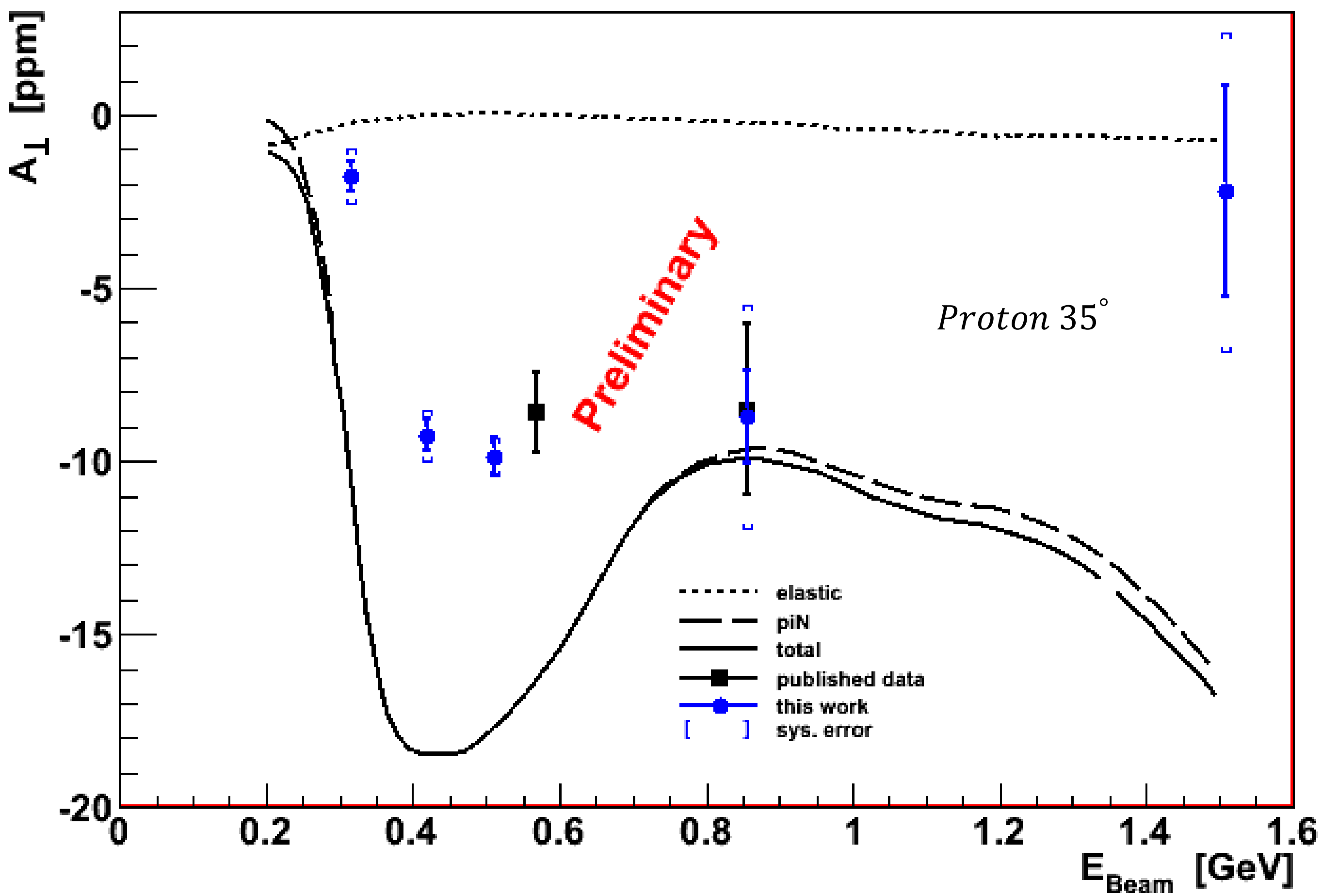


- Direct experimental evidence of two-photon exchange
- Theoratical curves from Phy. Rev. C 70
- Significant inelastic contribution
- Discrepancy between theoretical calculation at 570 MeV forward data.





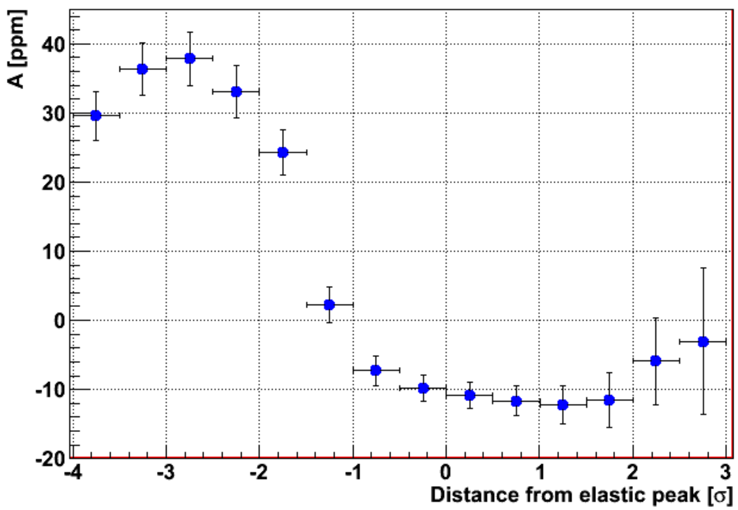
New data

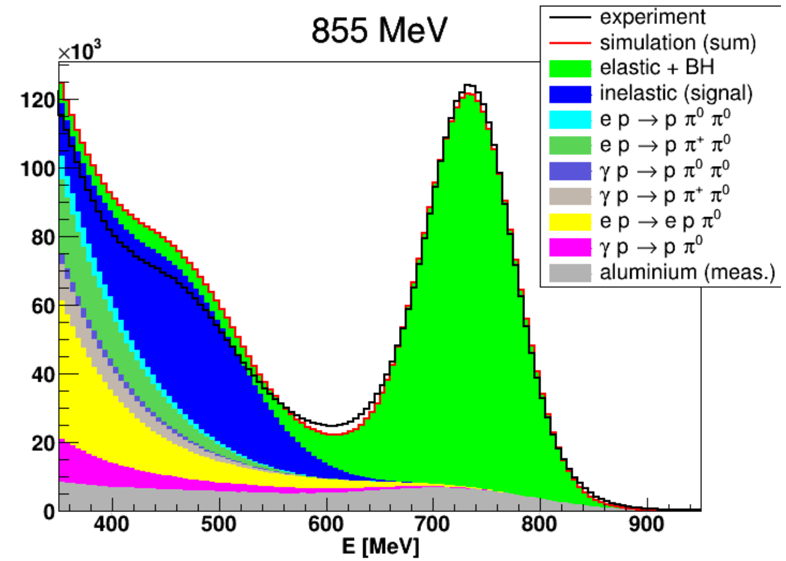


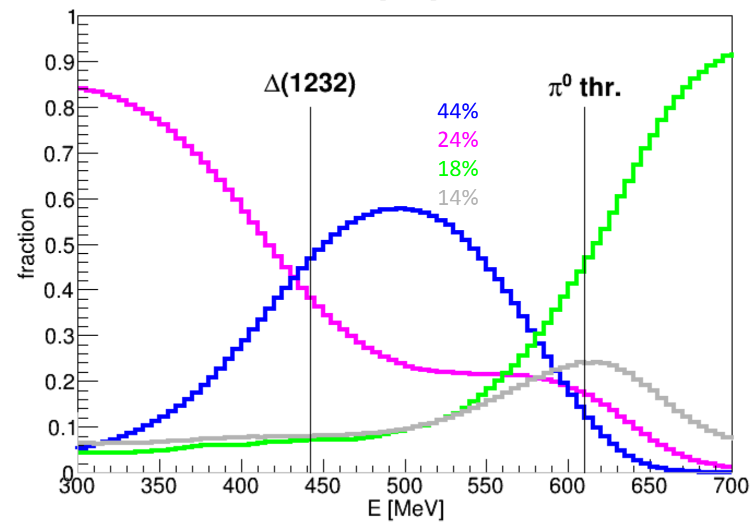
- New measurements performed at 315, 420, 510, 855 and 1508 MeV.
- Systematic error at 855 and 1508 MeV could be reducd.
- Extraction of $Im(\tilde{F}_3)$, $Im(\tilde{F}_4)$ and $Im(\tilde{F}_5)$ become possible?
- New calculations ongoing by B. Pasquini.

Plan: asymmetry in resonance region

510 MeV







Simulation by L. Capozza

- Large asymmetry in inelastic region.
- Test models describling $N \rightarrow \Delta$ transations beyond one-photon exchange.
- Background understood by Monte-Carlo simulation.

Summary

- Discrepancy between Rosenbluth separation and polarization transfer.
- Two-photon exchange could account for the discrepancy.
- Two-photon exchange amplitudes can be accessed via normal single spin asymmetry.
- Study of beam normal asymmetry for elastic channel at MAMI-A4 (new data at 5 energies between 0.3 and 1.5 GeV).
- Plan for future analyses in inelastic region.

Thanks for your attention !