Strange form factors of the proton : Results from HAPPEX at Jefferson Lab

The physics case

Experimental set-up

Analysis and errors

Results and prospects

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Structure of the proton

- In QCD

  quark (u, d, s ...) and gluon fields
  α_s increases when $Q^2 \to 0$

- In the constituants quarks model

  Elementary bricks : U, D, S ...
  Weakly interacting
  Describe static properties of hadrons

  "Q's are q's surrounded with
  $q\bar{q}$ pairs and gluons"

  $\Rightarrow$ Look for strangeness !
  Proton = UUD
  $m_s \sim \Lambda_{\mathrm{QCD}}$

Evidences for strangeness

- **Neutrino scattering**

  $\Rightarrow$ **3% of total momentum**
  $\Rightarrow$ $s(x) = \bar{s}(x)$ **within errors**

- **Polarized DIS**

  $\Rightarrow$ $< N|\bar{s}\gamma_\mu\gamma_5 s|N > \neq 0$
  $\Rightarrow$ **In naive QPM** $\Delta s = -0.10$
  Gluons ? SU(3) ?

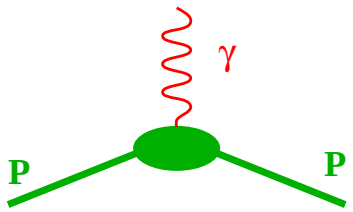
- π **N scattering (sigma term)**

  $\Rightarrow$ $< N|\bar{s}s|N > \neq 0$
  $\Rightarrow$ **From 0 to 15 % of mass.**
  Analysis ?

$< N|\bar{s}\gamma_\mu s|N >$ **accessible in** $\vec{e}$**P elastic scattering**

Form factors and definitions

- **Electromagnetic current**

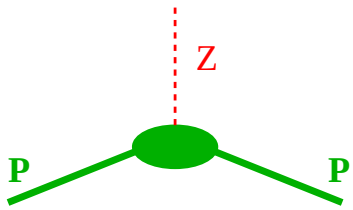


$$< P'|J_\mu^{EM}|P >=$$

$$\bar{U}(F_1(Q^2)\gamma_\mu + i\frac{\sigma_{\mu\nu}q^\nu}{2M_N}F_2(Q^2))U$$

$$G_E = F_1 - \frac{Q^2}{4M_n^2}F_2 \qquad G_M = F_1 + F_2$$

- **Neutral weak current**



$$< P'|J_\mu^{Z}|P >=$$

$$\bar{U}(F_1^Z(Q^2)\gamma_\mu + i\frac{\sigma_{\mu\nu}q^\nu}{2M_N}F_2^Z(Q^2) + G_A^Z(Q^2)\gamma_\mu\gamma_5)U$$

Weak form factors :

$\Rightarrow$ **New observables of proton structure**

Flavor decomposition

- **Electromagnetic interaction**

$$G_{E,M}^{\gamma,p} = \tfrac{2}{3} G_{E,M}^{u} - \tfrac{1}{3} G_{E,M}^{d} - \tfrac{1}{3} G_{E,M}^{s}$$

  - $G_{E,M}^{\gamma}$ **measured for proton & neutron**
  - **Isospin :** $G^{u,p} = G^{d,n} = G^{u}$

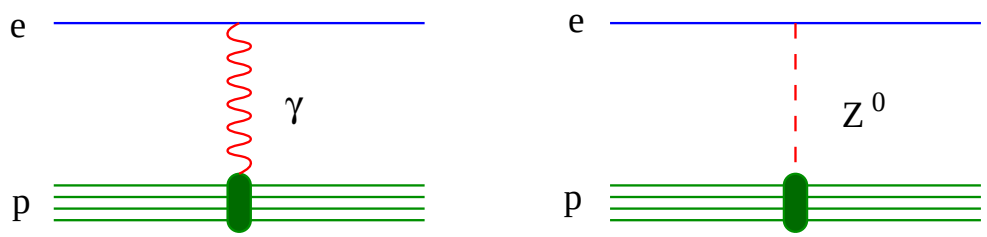
  $\Rightarrow$ **Need another measurement !**

- **Weak interaction**

  - **EW :** $G^{\gamma,f} = G^{Z^0,f} = G^{f}$

$$\begin{aligned} G_{E,M}^{Z,p} = & \left(\frac{1}{4} - \frac{2}{3}\sin^2\theta_W\right) G_{E,M}^{u} \\ & + \left(-\frac{1}{4} + \frac{1}{3}\sin^2\theta_W\right) G_{E,M}^{d} \\ & + \left(-\frac{1}{4} + \frac{1}{3}\sin^2\theta_W\right) G_{E,M}^{s} \end{aligned}$$

Parity Violation in $\vec{e}$ P scattering



- **With polarized electrons**

$$\mathcal{A}_{PV} = \frac{\sigma^{\Rightarrow} - \sigma^{\Leftarrow}}{\sigma^{\Rightarrow} + \sigma^{\Leftarrow}} \simeq \frac{\mathcal{M}_{\gamma}\mathcal{M}^{*}_{Z^0}}{\mathcal{M}^{2}_{\gamma}} \simeq \frac{G_F Q^2}{\alpha_{QED}}$$

- **Depends on strange form factors**

$$\mathcal{A}_{PV} \simeq -3.2\,10^{-4}\tau\Big[(1-4\sin^2\theta_W) - \frac{\epsilon G_E^p(G_E^n+G_E^s)+\tau G_M^p(G_M^n+G_M^s)}{\epsilon(G_E^p)^2+\tau(G_M^p)^2}\Big]$$

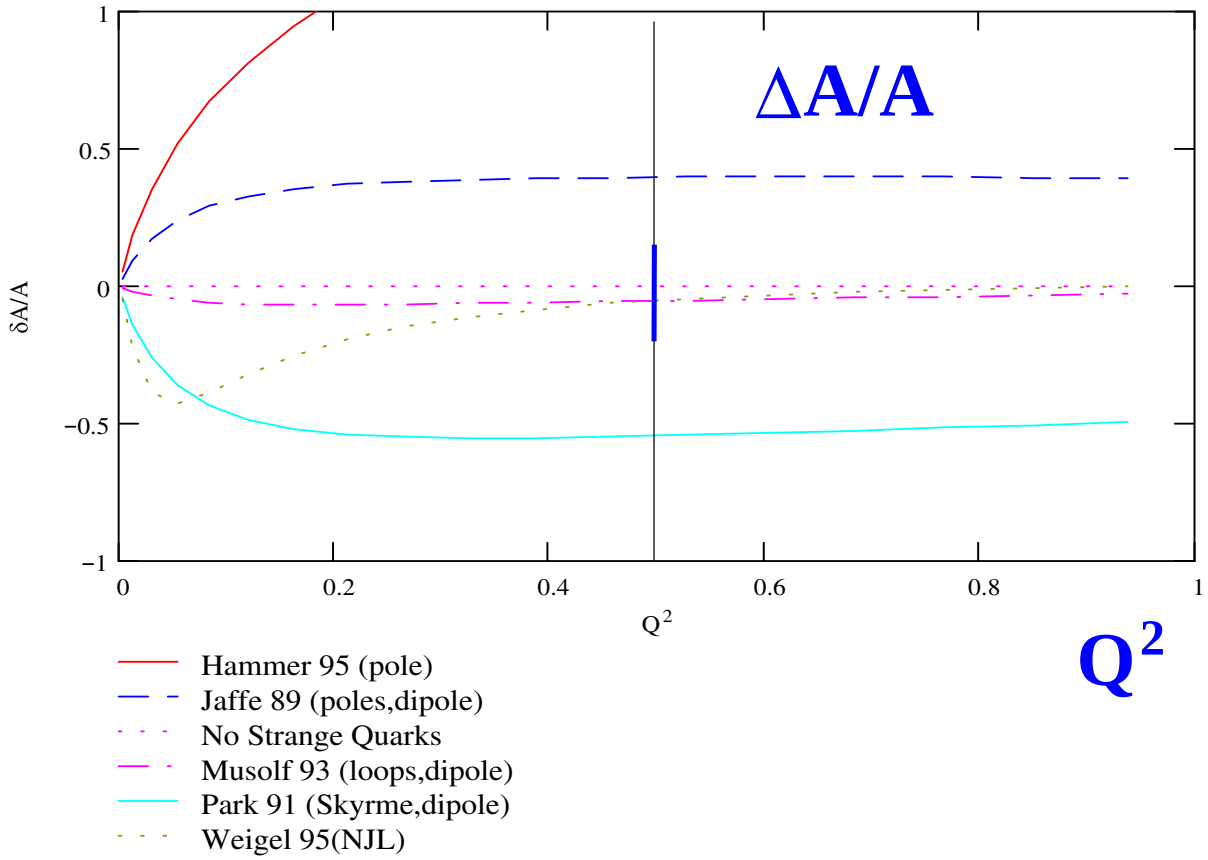
- **Kinematics**

$$Q^2 = \mathbf{0.5\ (GeV/c)^2},\ \theta = 12.5^{\circ}$$

$\mathcal{A}_{PV}$ = -15 ppm

Sensitivity of the measurement

- Various models ...



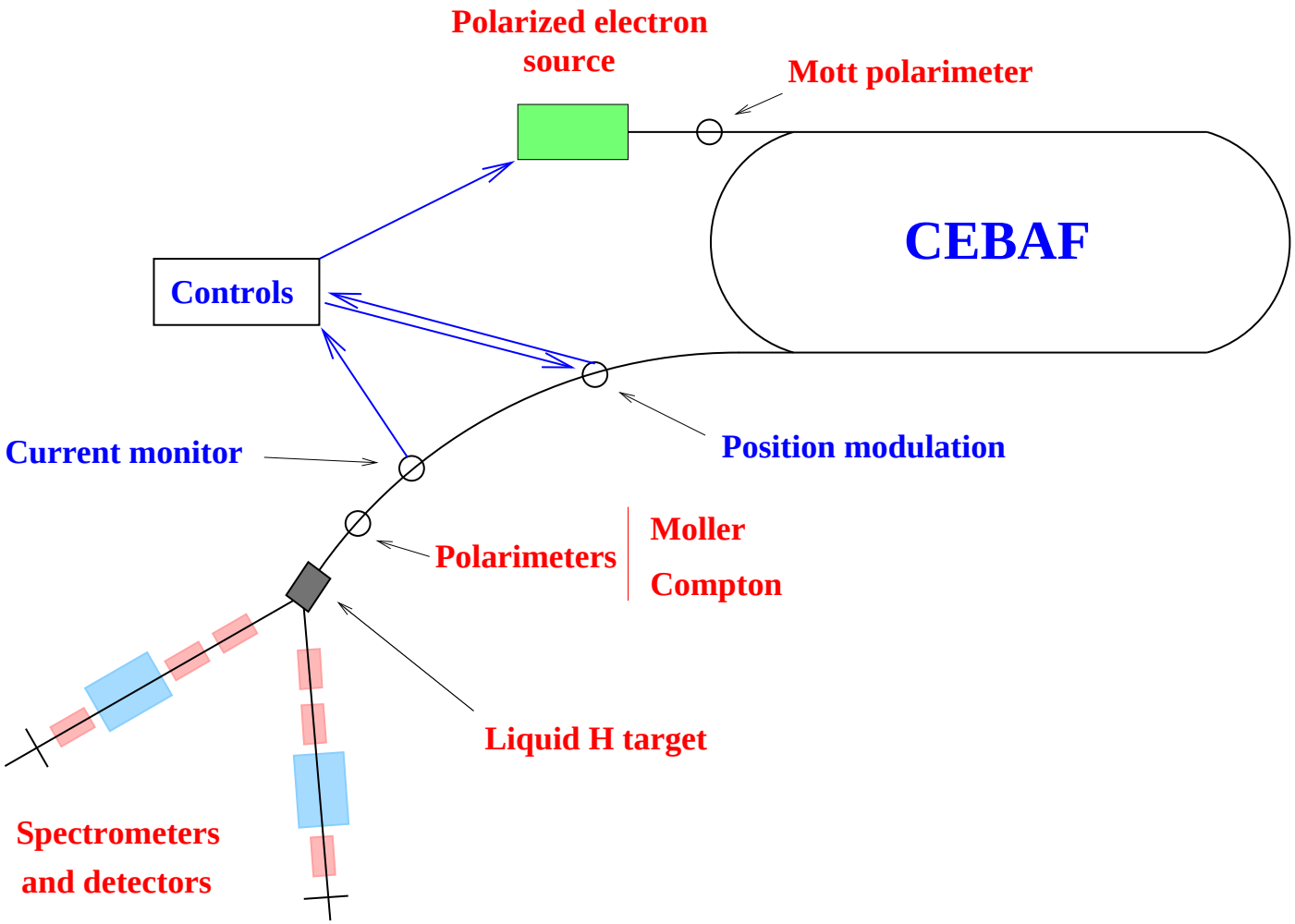
$\Rightarrow$ **Which degrees of freedom ?**

- This data : $\Delta A/A = 15\%$

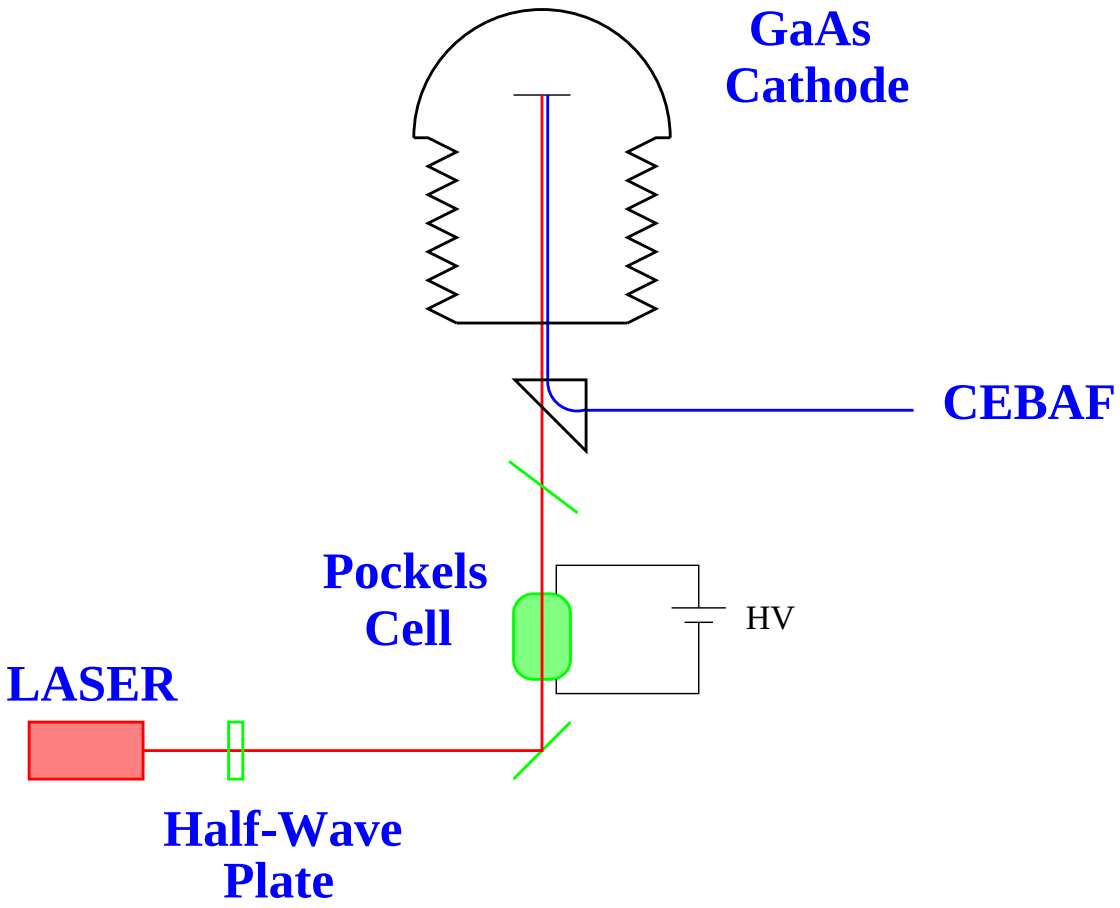
Overview of HAPPEX

Hall A Proton Parity EXperiment at Jefferson Lab, Virginia, USA.

E=3.355 GeV, $Q^2 = 0.5$ (GeV/c)^2
Counting rate : 2 MHz
$\mathcal{A}_{\rm exp}$: 6 ppm



The polarized source



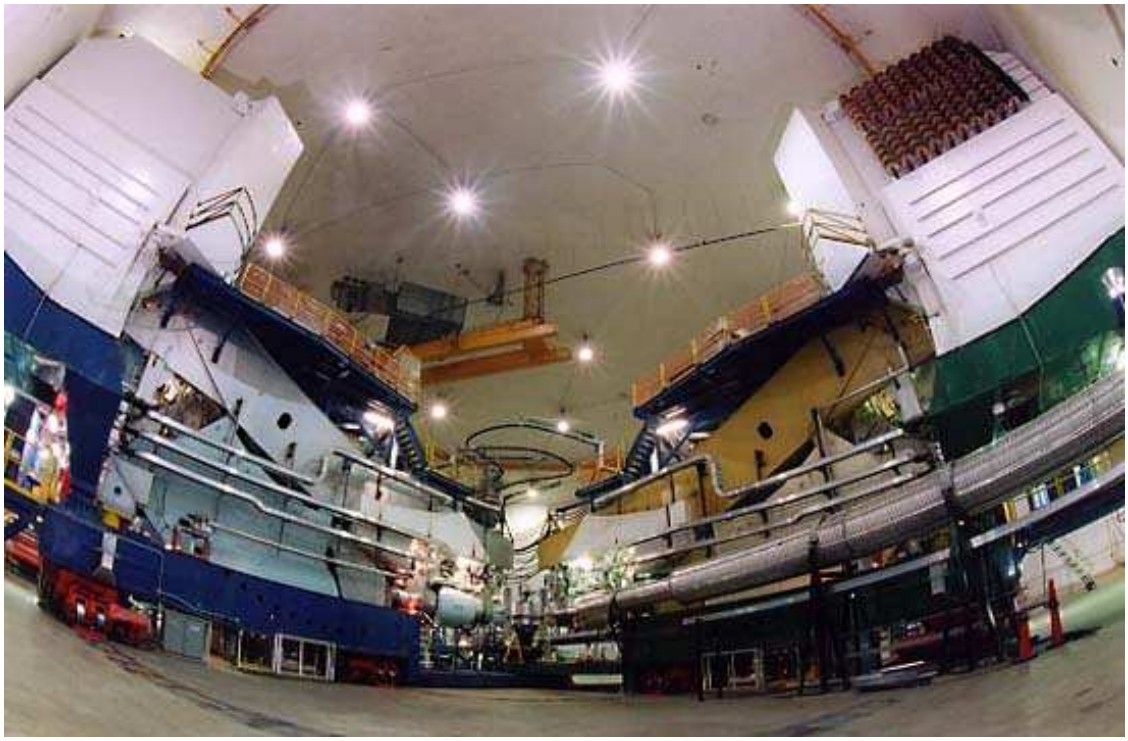
- P_e=40%, I=100 μA, 85 C on target.

- Helicity flipping
  - Locked to 60 Hz
  - First of a pair is pseudo-random

- Half-wave plate
  - $\Rightarrow$ Reverse sign of $\mathcal{A}_{\rm exp}$

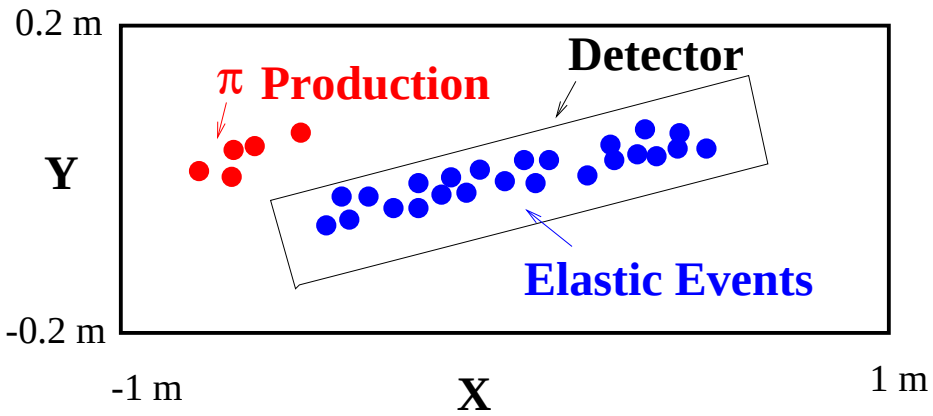
Spectrometers

- Detect elastically scattered electrons



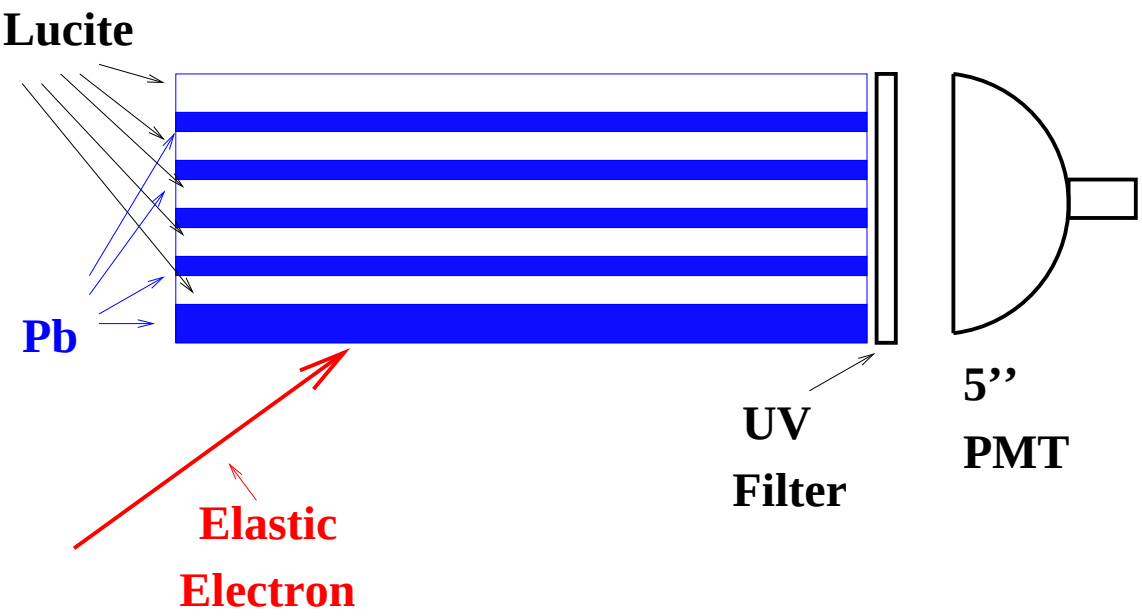
- Inelastic discrimination

  Pion production 20 cm away



Focal Plane Detectors

- Electron calorimeter
  Lead lucite sandwich



- Signal Integrated over helicity pulse

  No dead time / rate dependance
  No background subtraction possible

Beam instrumentation

- Beam current monitors
  - Microwave cavities
  - $\Rightarrow$ Intensity feed-back

- Beam position monitor
  - Stripline monitors
  - $\Rightarrow$ Measure X, Y, θ, ϕ, E
  - $\Rightarrow$ Beam modulation

- Signal also integrated

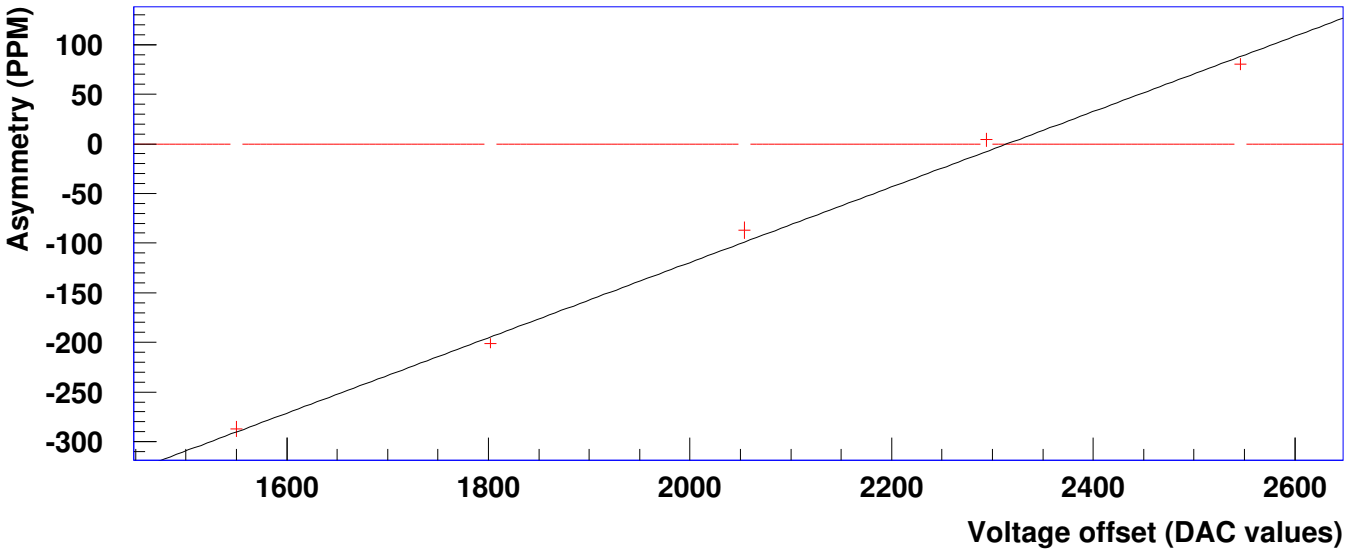
- Polarimeters
  - Mott, Moller
  - Compton

Intensity Feed-Back

- Annihilate effect of non-linearities

$$\Delta A_{nl} \;=\; \beta \cdot A_I$$

- Handle on A_I : V_{Pockels}



- On-line feed-back

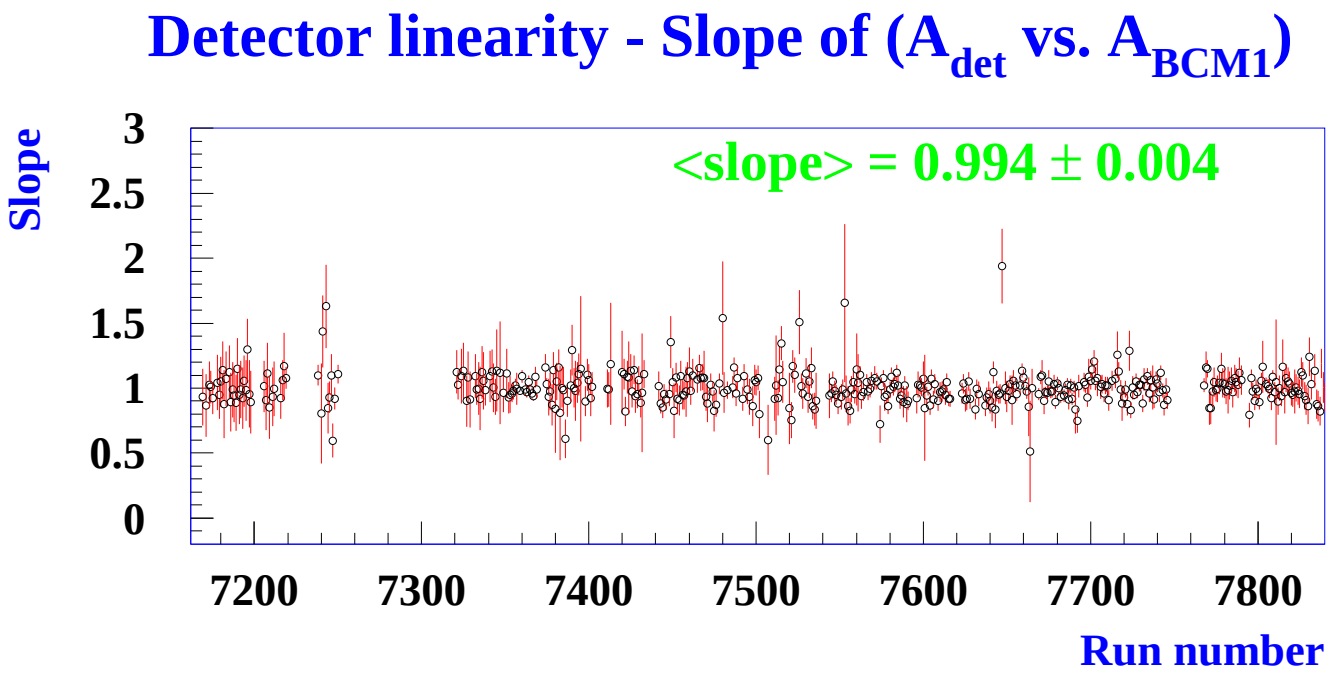
  Measure A_I ($\sim$ 60 ppm)

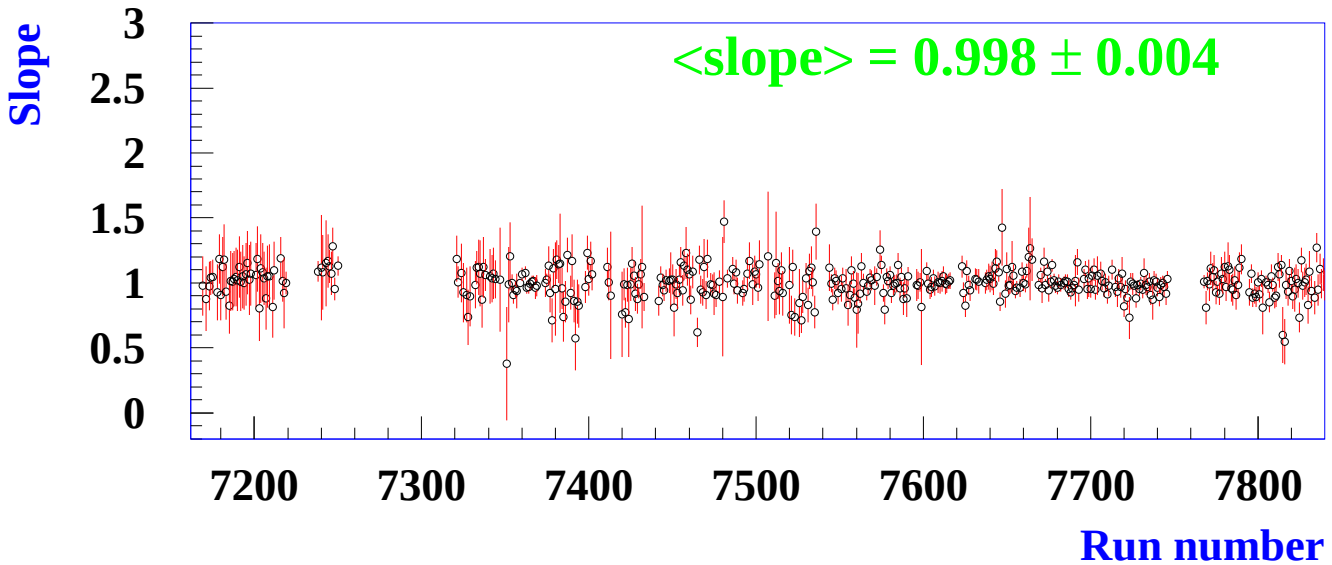
  Correct accordingly every few minutes

$$\Rightarrow \; < A_I >= 0.3 \pm 0.45 \text{ ppm}$$

Non-linearities

- All data





- Upper limit : 5.10^{-3}

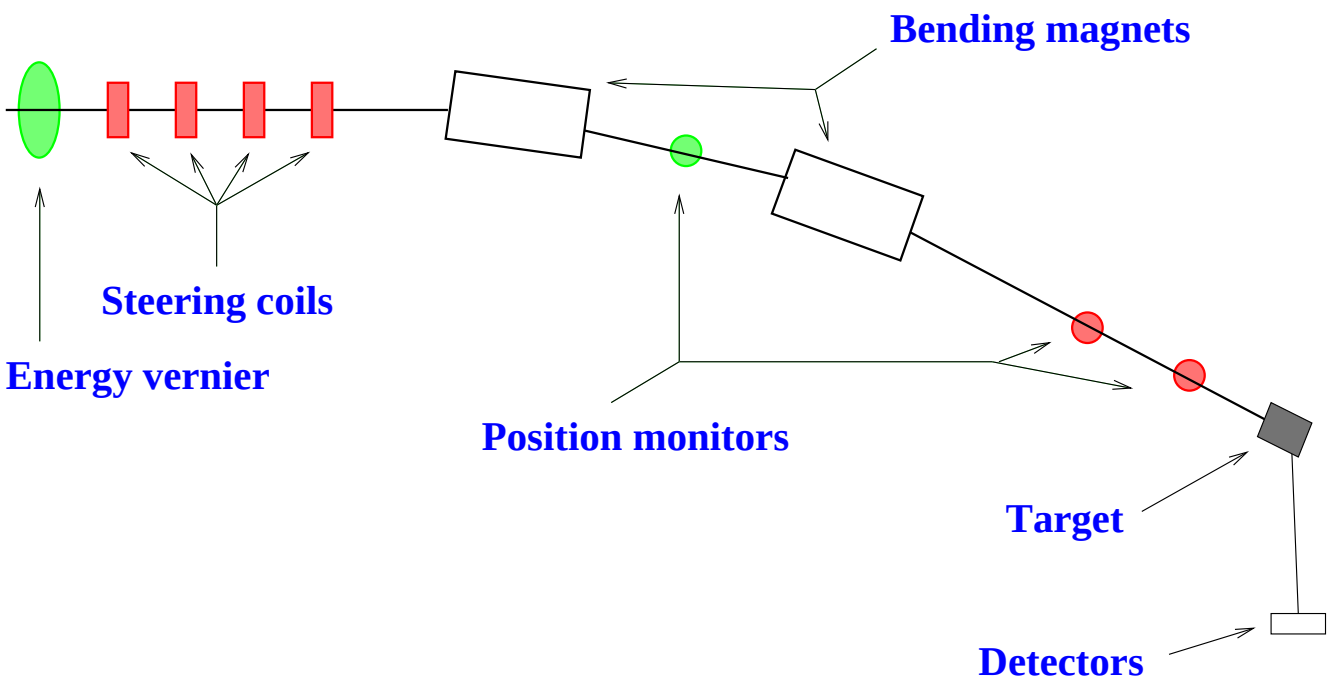
Beam Modulation

- Observed helicity correlations :
  $\Rightarrow \Delta X < \mathbf{5\ nm}$
  $\Rightarrow \Delta E/E < 10^{-8}$

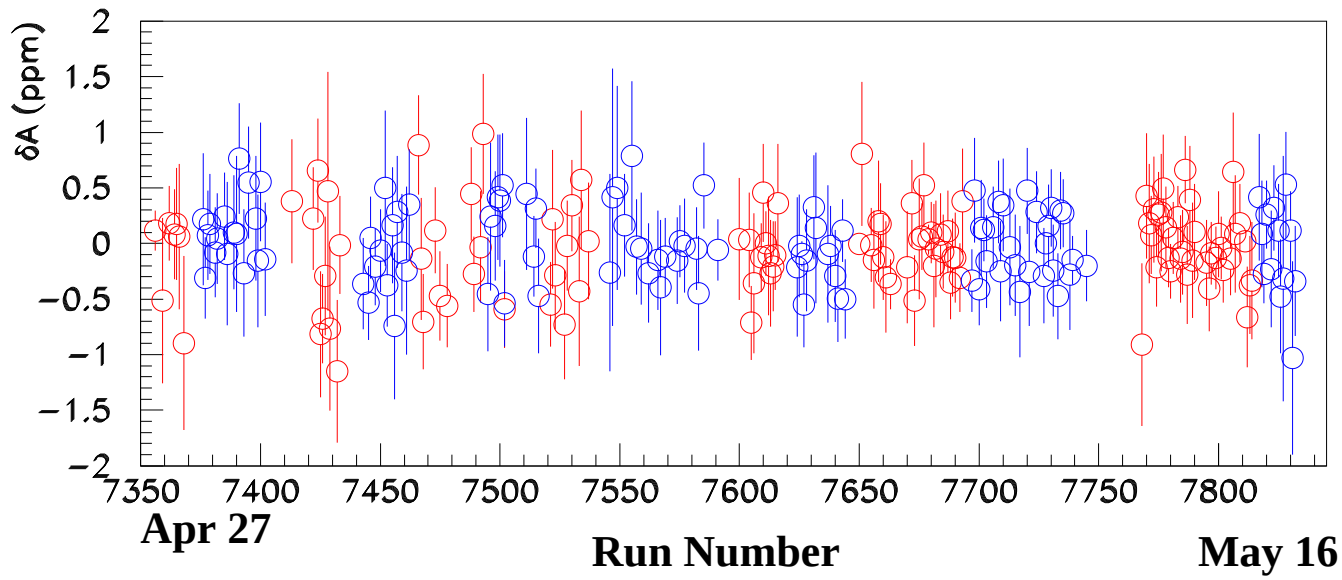
- Measure sensitivity

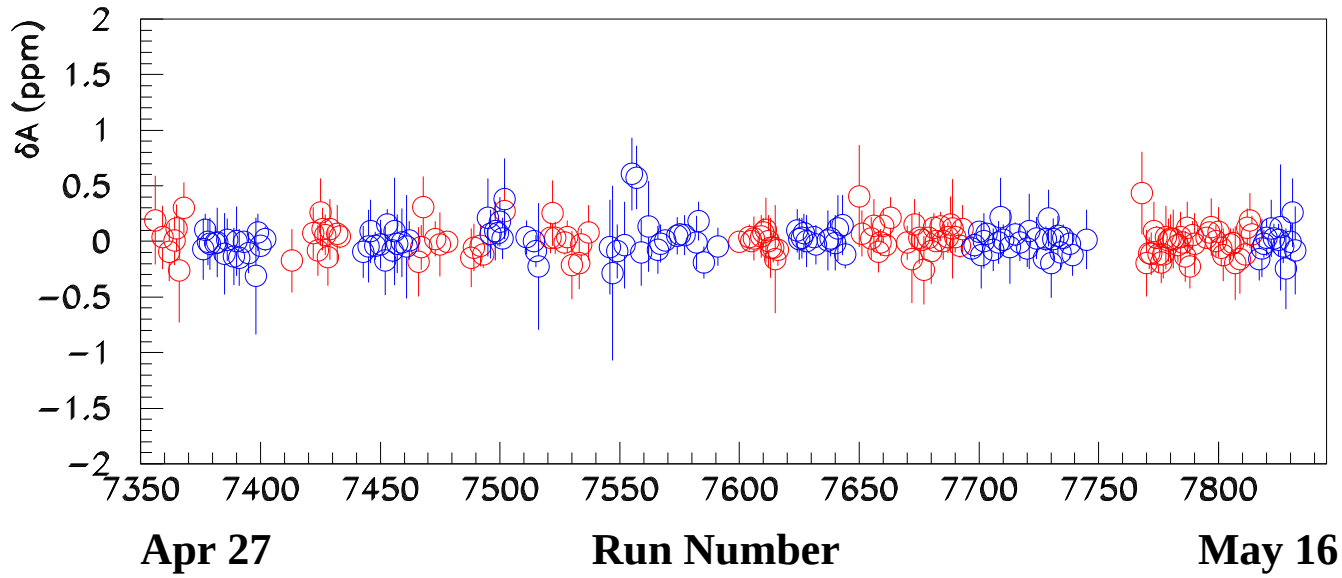
$$\frac{\partial N}{\partial \mathrm{X_i}} \qquad \frac{\partial N}{\partial \mathrm{E}}$$

- Modulation of energy and position



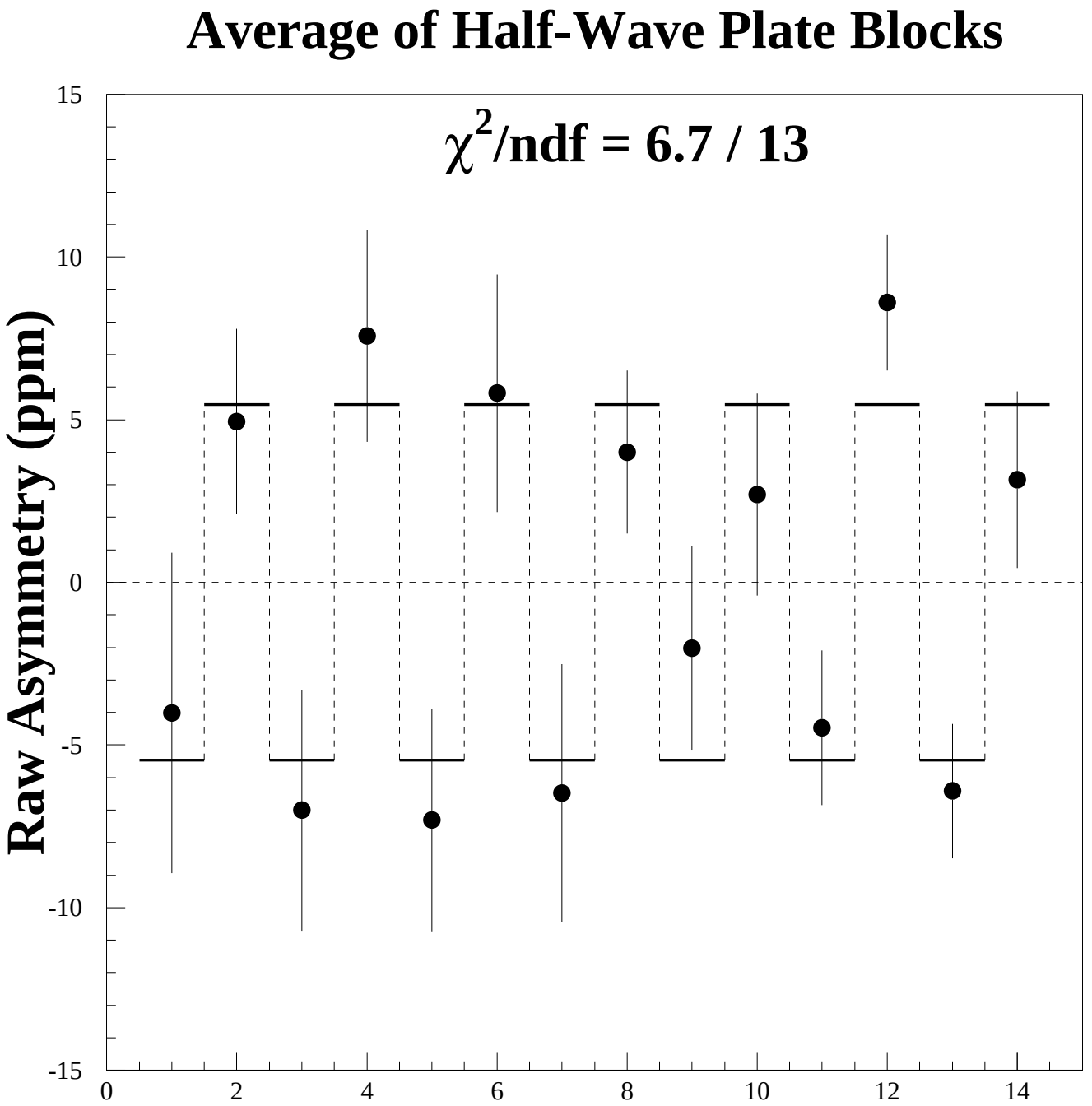
Phase space corrections





- Overall correction
  - ⇒ less than 0.01 ppm

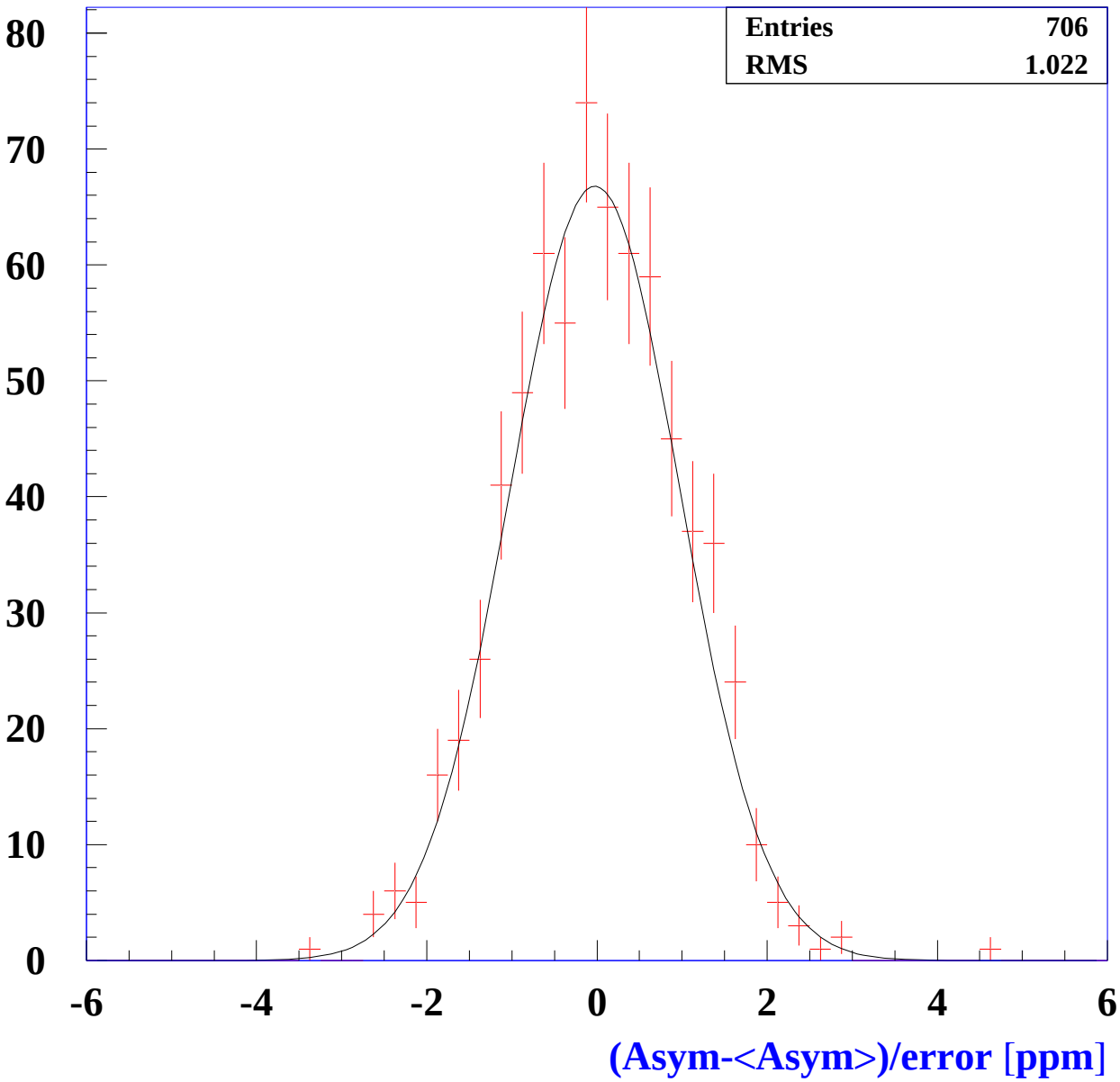
Raw asymmetry



$$\mathcal{A}_{\rm raw} = -5.64 \pm (0.75)_{\rm stat}$$

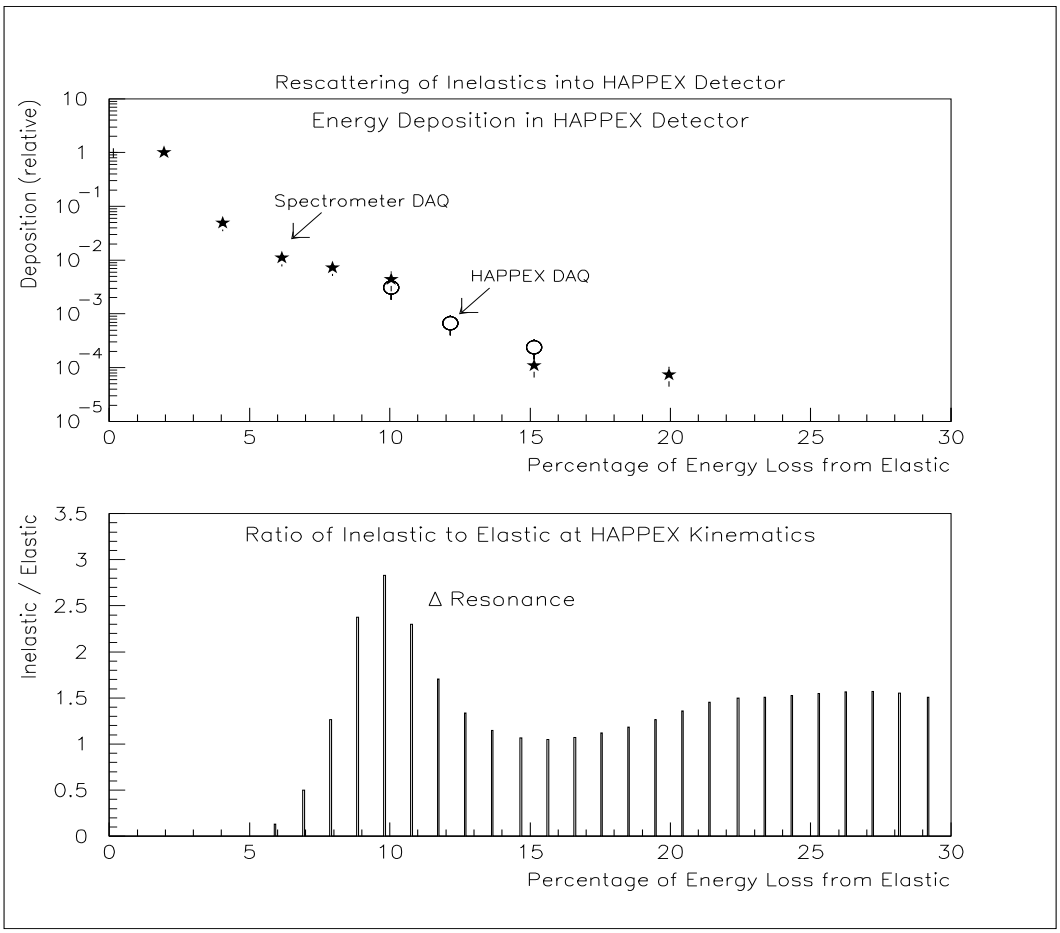
Distribution of runs

Run asymmetry residuals (normalized to error)



Background

- Sources
  - Inelastic contamination
  - Quasi-elastic on target window
  - Scattering on magnetized iron
- Estimation of the effect



- Contribution : $\Delta A/A = 0.6 \pm 1.7\%$

Beam polarisation

- Mott Polarimeter (*See S. Prices's talk*)

  Principal errors :

Foil thickness	5 %
Background	3 %
Intensity dependence	3 %
Total	7 % ($\Rightarrow$ 3%)

- Moller Polarimeter

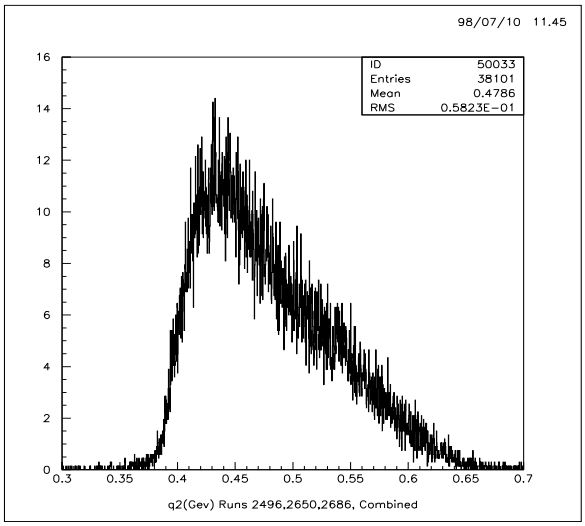
  Comissioning phase

Target polarization	5 %
Intensity dependence	3 %
Target angle	2.5 %
Total	7 % ($\Rightarrow$ 3%)

$$P_e = 0.385 \pm 0.027$$

Determination of Q^2

- Dedicated runs
  - Spectrometer detector package



- Technique
  - Optimization of optics
  - Attenuation of light

$$< Q^2 >= 0.47(\mathrm{GeV/c})^2$$

- Error : **3 %** ($\Rightarrow$ <1%)

Summary of the experiment

- Experimental errors

	Error
Beam polarization	7 %
Q^2 determination	3 %
Backgrounds	2 %
Spectrometer alignment	1 %
Finite acceptance	1 %
Helicity correlations	< 0.2 %

- Preliminary result :

  $Q^2 = 0.47$ (GeV/c)^2, $\theta = 12.5$ °

$$\mathcal{A}_{\rm PV}({\rm ppm}) = -14.7 \pm (1.9)_{\rm stat} \pm (1.1)_{\rm syst}$$

Theoretical prediction

- **Form factors**
  - Use dipole approximation
  - Galster parametrization for G_E^n

- **Errors**

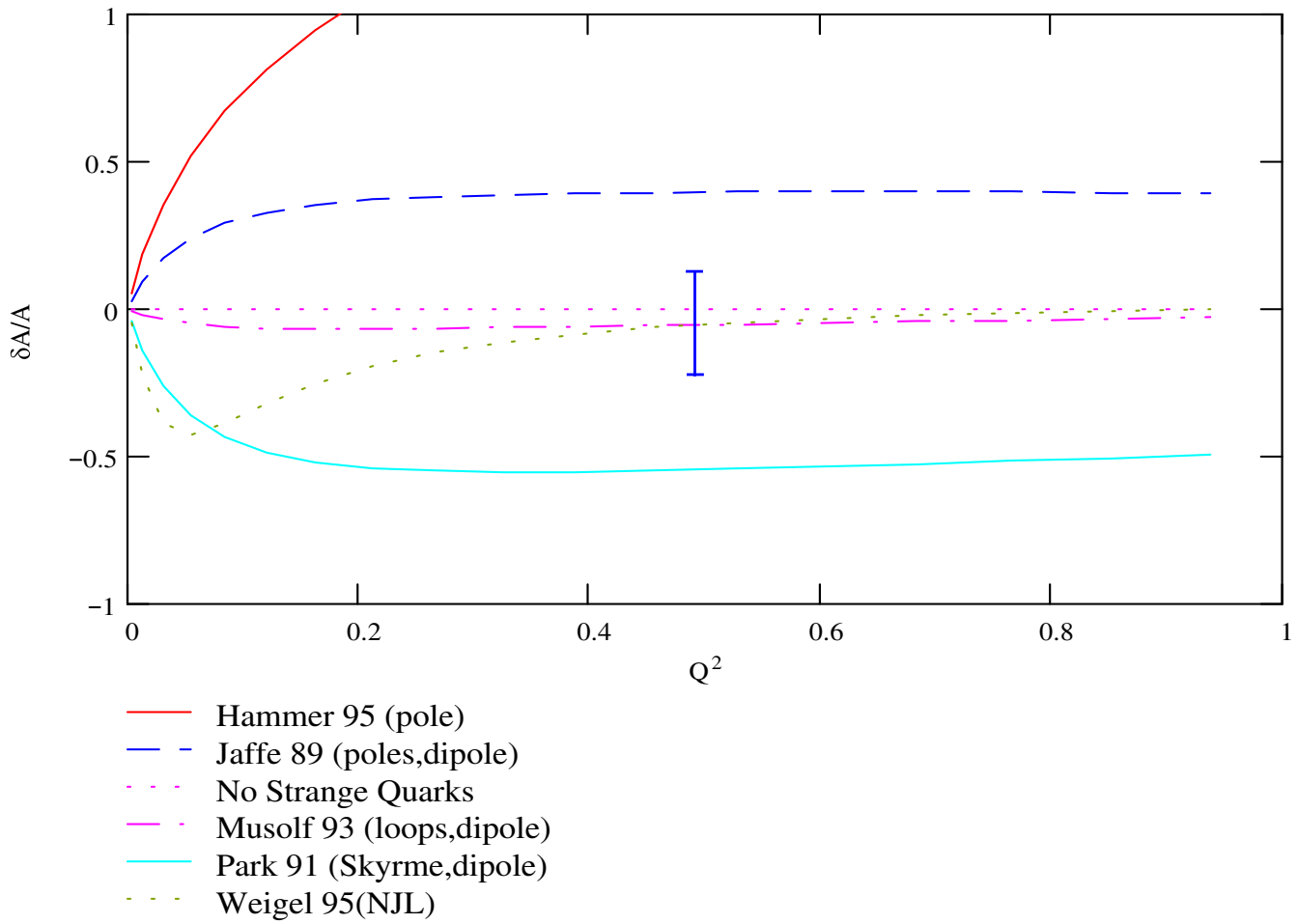
	Error
G_E^n (50 % variation)	9.6 %
Other form factors	4 %
Axial radiative corrections	1.4 %
Vector radiative corrections	0.5 %

$$\mathcal{A}_{\rm th}({\rm ppm}) = -15.6 \pm (0.7)_{\rm syst} \pm (1.6)_{G_N^e}$$

Sensitivity of the measurement

- **Difference of asymmetries :**

$$\Delta\mathcal{A}(\text{ppm}) = 0.9 \pm (1.9)_{\text{stat}} \pm (1.3)_{\text{syst}} \pm (1.6)_{G_N^e}$$



- **Goal for next year's run**

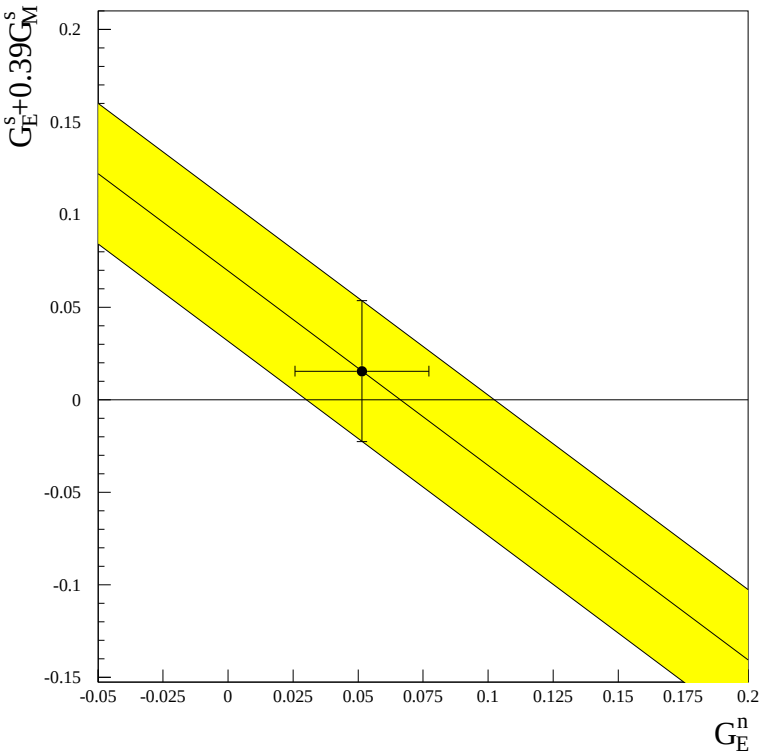
$$\Rightarrow \Delta A/A = 8\%$$

Strangeness content of the proton

- Vector strange form factors

$$G_E^s + 0.39 G_M^s = 0.016 \pm 0.048$$

- Sensitivity to G_N^e



- Previous measurements :
  - ⇒ All consistent with no strangeness
  - ⇒ Less sensitive

Conclusions

- Strange effects seem to be small

- Improvements for next run
  - $\Rightarrow$ Statistics ...
  - $\Rightarrow$ Better precision on G_N^e
  - $\Rightarrow$ Compton polarimeter

    see talk of T. Pussieux

- A very nice tool
  - $\Rightarrow$ Robust : Beam quality
  - $\Rightarrow$ Fast : Integration

- A broad physics program ahead
  - $\Rightarrow$ Separation G_E, G_M
  - $\Rightarrow$ Q^2 Dependance
  - $\Rightarrow$ Neutron radius
  - $\Rightarrow$ Tests of the Standard Model