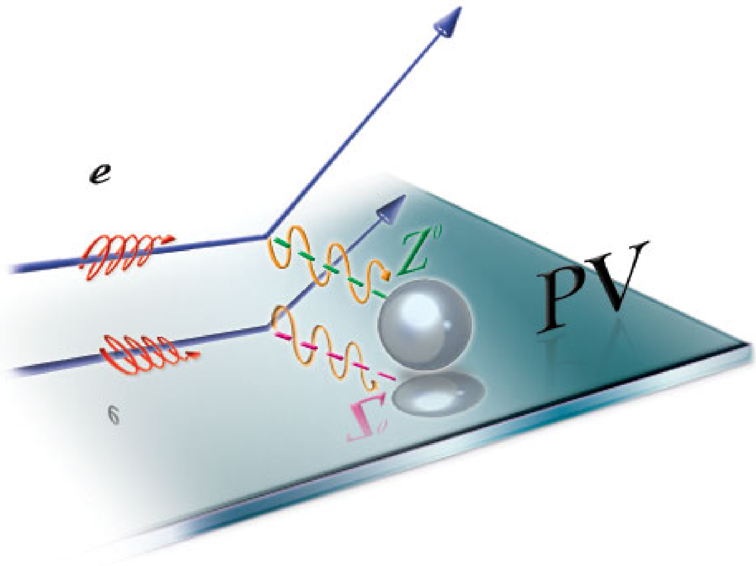
Parity Violation in Forward Angle Elastic e^- Scattering

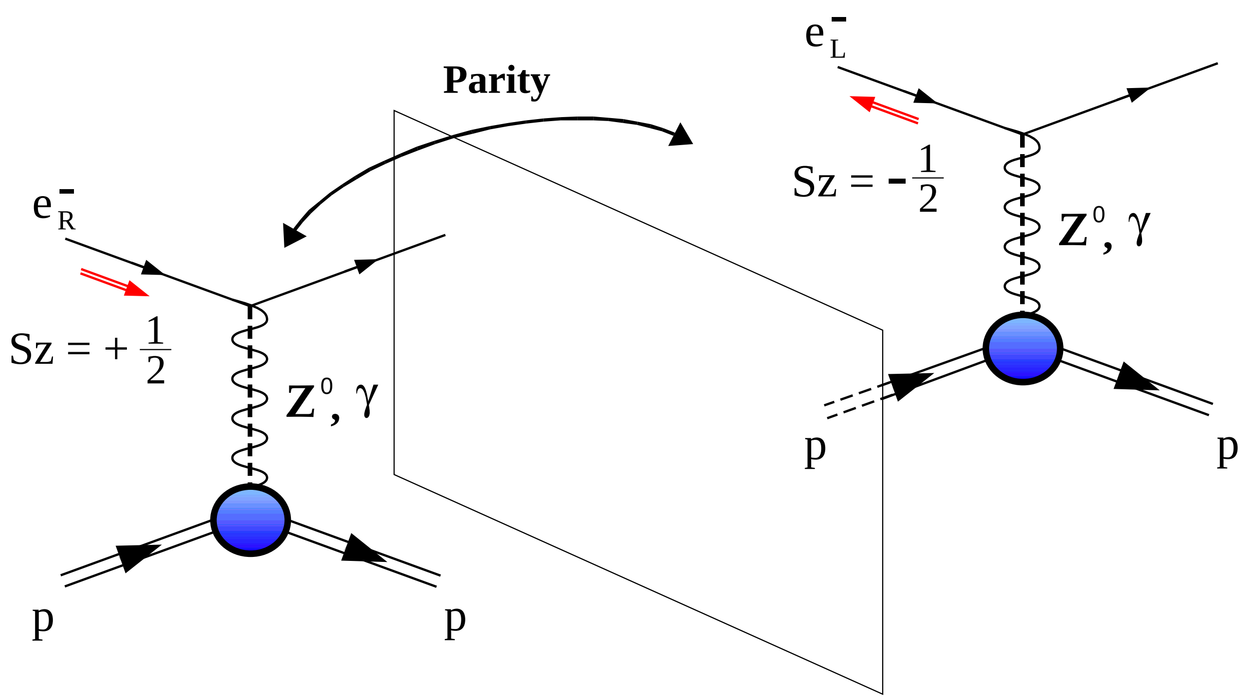


HAPPEx Experiments @ Jlab - Hall A

* HAPPEx data taking and results
* Future measurements on proton and helium 4

D.Lhuillier - CEA Saclay

Parity Violation in elastic e-p scattering



$$\sigma = |\mathcal{M}_\gamma + \mathcal{M}_Z|^2$$

$$A^{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{\mathcal{M}_\gamma \mathcal{M}_Z^*}{\mathcal{M}_\gamma^2}$$

Weak Form Factors

$$A^{PV} = \left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right] \times \mathcal{F}\left(G_{E,M}^{p\gamma}, G_{E,M}^{pZ}\right)$$

↓

3 sets of form factors: (γp), (γn), (Zp)

Isospin symmetry

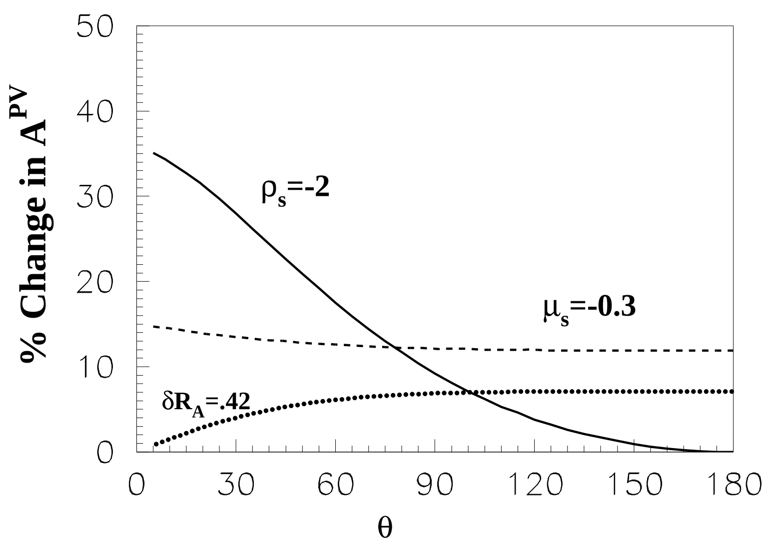
↓

$$G_{E,M}^{p,Z} = \frac{1}{4}\left(G_{E,M}^{p,\gamma} - G_{E,M}^{n,\gamma}\right) - \sin^2\theta_W G_{E,M}^{p,\gamma} - \frac{1}{4} G_{E,M}^{s}$$

Proton target:

$$A^{PV} = \left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right] \times \Big\{ (1 - 4\sin^2\theta_W) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n - (1 - 4\sin^2\theta_W)\delta G_M^p G_A^{(1)}}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2} - \frac{\varepsilon G_E^p G_E^s + \tau G_M^p G_M^s + \frac{1}{2}(1 - 4\sin^2\theta_W)\delta G_M^p F_A^s}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2} \Big\}$$

HAPPEx Kinematics



Forward angle measurement:

E = 3.3 GeV

Θ = 12.5 deg.

Q^2 = 0.47 GeV/c^2

A^{PV} ~ - 15 ppm

Rate = 2 Mhz @ 100 μA

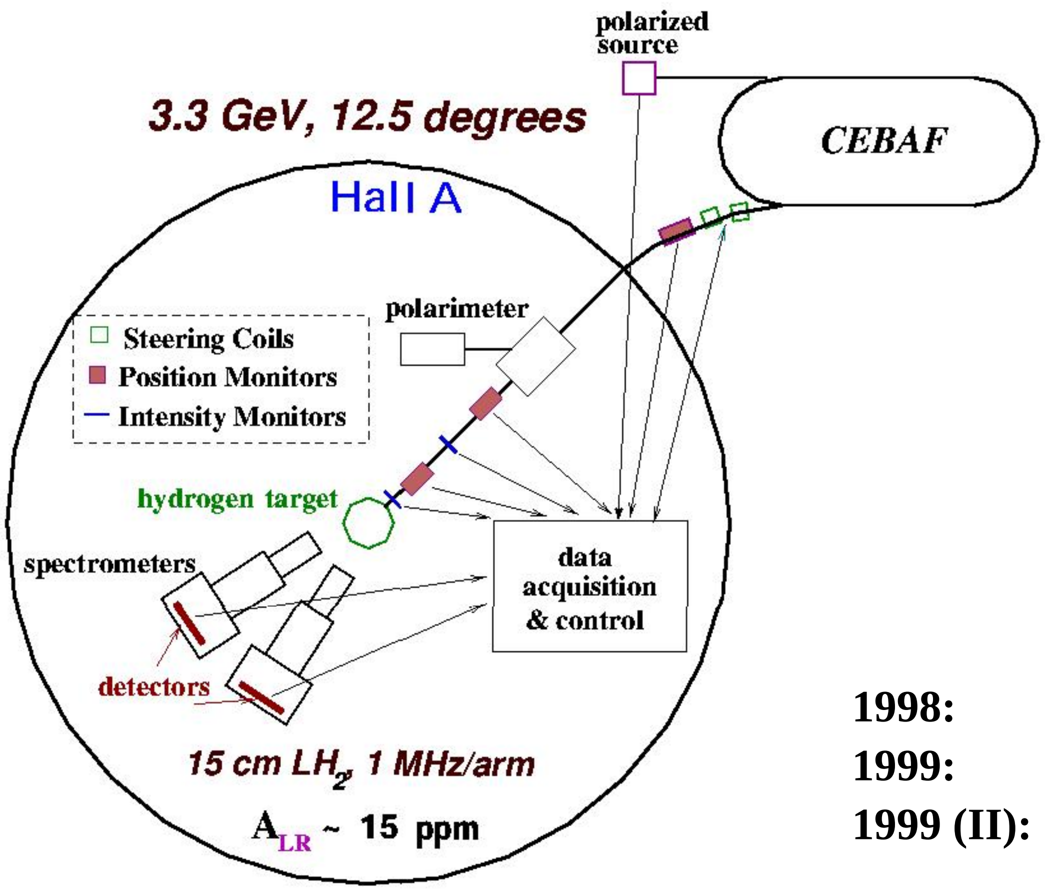
*** Mostly sensitive to electric form factor**

*** Axial contribution suppressed**

*** Measured combination**

$$G_E^s + 0.4 G_M^s$$

Overview



Hall A Collaboration - JLab

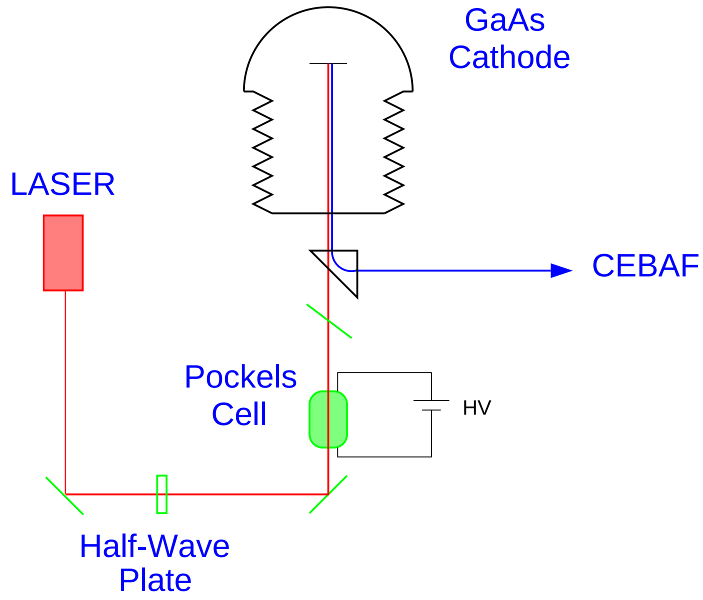
Key features:

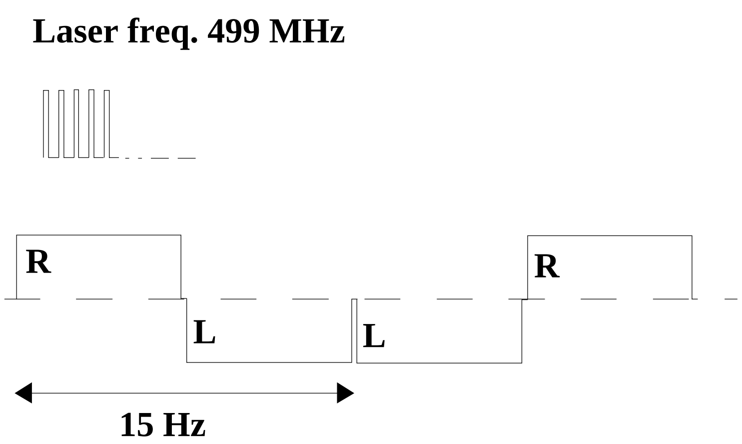
* High polarization
* Helicity flip
* Online syst. Errors
* Feedback
* Integrating detectors

	P_e	I	Charge
1998:	37%	100μA	80C
1999:	70%	35μA	75C
1999 (II):	75%	45μA	10C

1999: First parity run using strained GaAs cathode

Polarized Source





$$A_{Pair} = \frac{N_R - N_L}{N_R + N_L}$$

$$\delta A = \frac{\sigma(A)}{\sqrt{N_{windows}}}$$

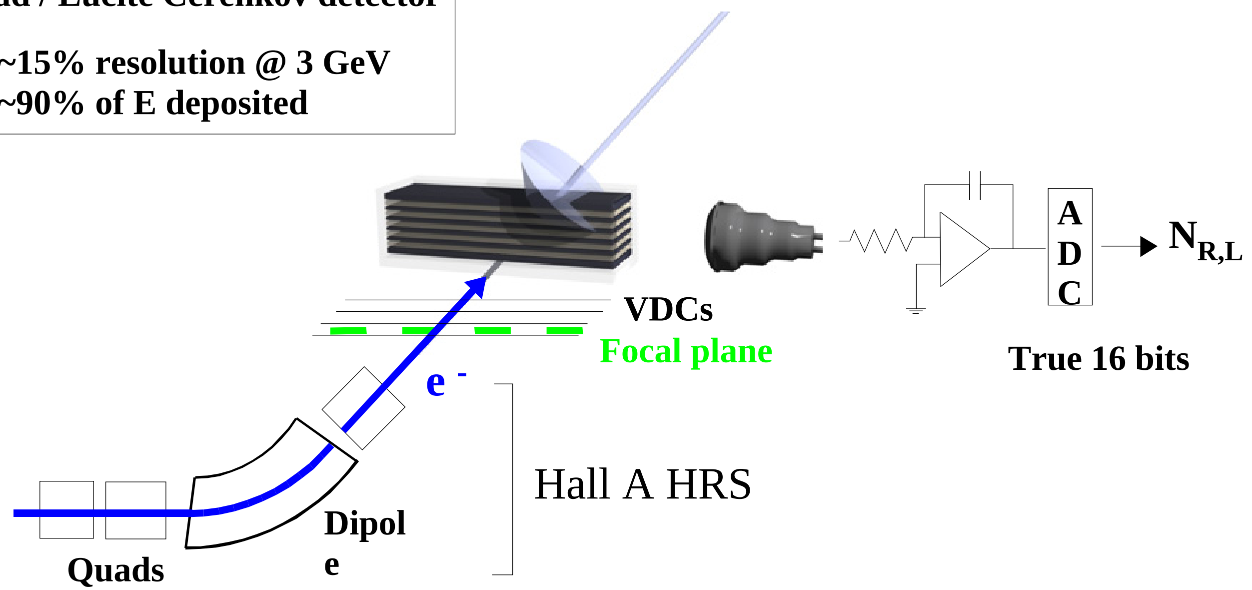
HAPPEx ~ 2.5 10^6 pairs

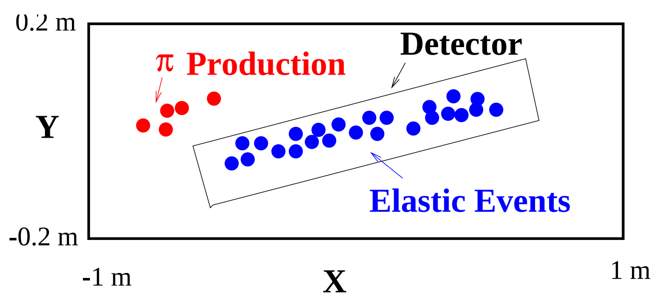
* Rapid helicity flips
* First polar state of a pair is random
* Harmonic of 60 Hz
* Sign reversal of A^{PV} using insertable $\lambda/2$ plate

Detection

Lead / Lucite Cerenkov detector

~15% resolution @ 3 GeV
~90% of E deposited





Pion threshold 20 cm away from elastic evts in focal plane

Signal integrated over helicity pulse:

- No dead time
- HRS magnetic optics clean up the det. Acceptance

Beam parameters helicity correlations

$$A_{pair} = \frac{\frac{N_R}{I_R} - \frac{N_L}{I_L}}{\frac{N_R}{I_R} + \frac{N_L}{I_L}} \qquad N_i = N_i(I_i, x_i, y_i, \theta_i, \varphi_i, E_i, \ldots)$$

Spurious asymmetries :

$$A_{\exp} = \frac{\Delta D}{2D} - \frac{\Delta I}{2I} + \alpha_i \Delta X_i$$

Depend on experimental setup

Scale : window-to-window statistical fluctuations $\sigma(A_{pair}) = 3.10^{-3}$

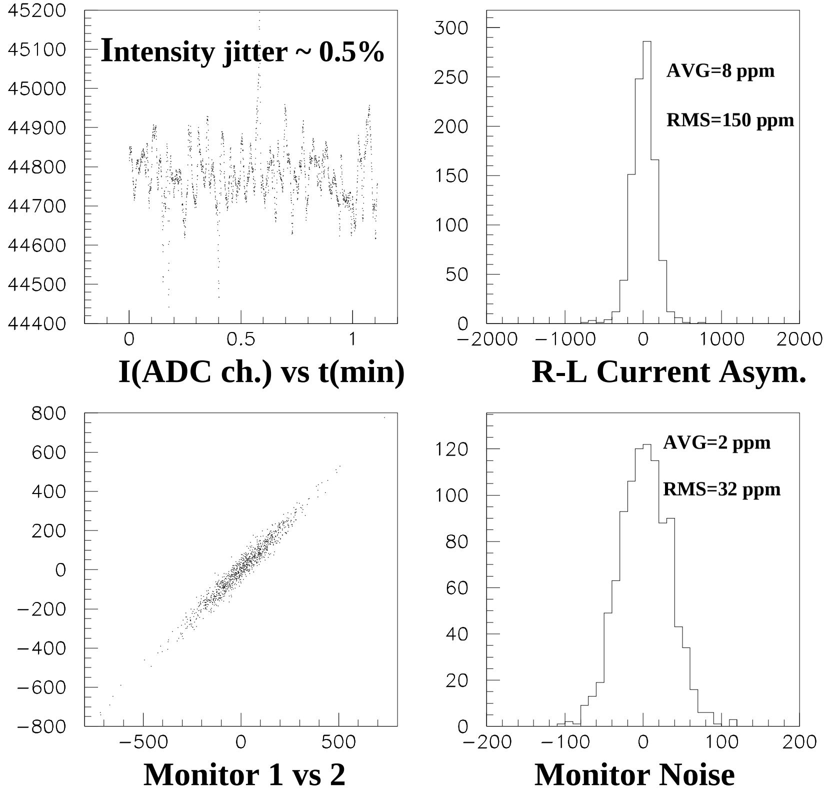
Control of the systematics :

* Window-to-window fluctuations < $\sigma(A_{pair})$

* Electronic noise << $\sigma(A_{pair})$

Beam Current Fluctuations

HAPPEx data



Jitter per window ↕ Frequency of diagnostic

A_I to 1.5 ppm whithin 10 min.

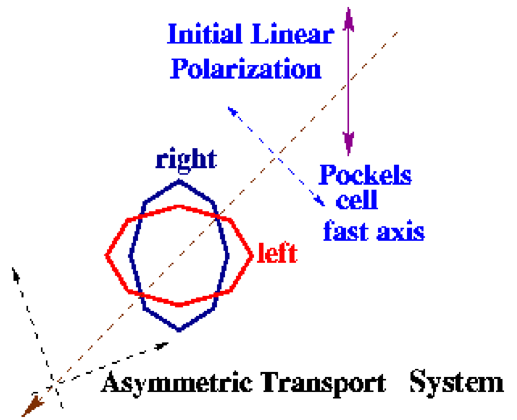
Electronic Noise ↕ Error in the correction

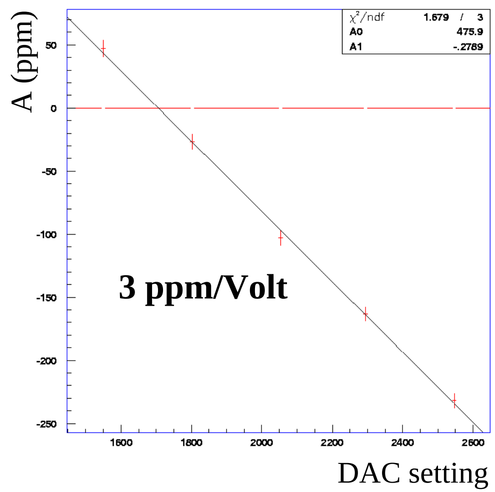
*** Need redundant beam monitors**

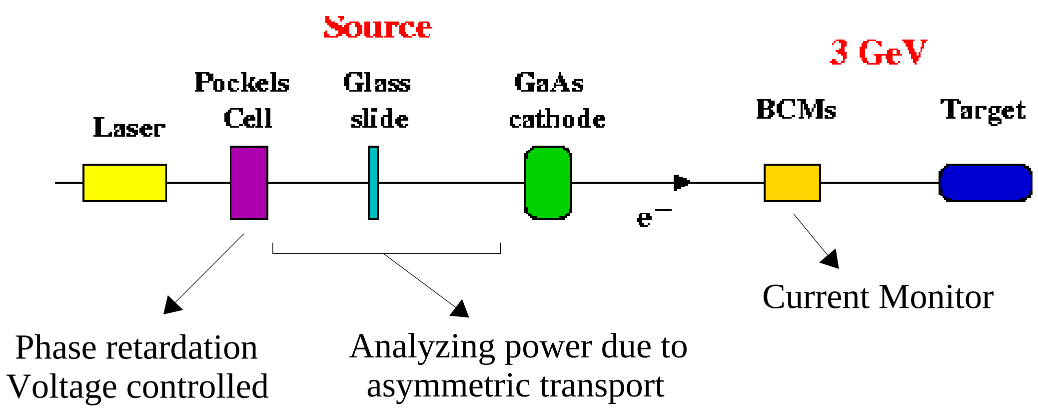
*** CEBAF: high quality beam**

Intensity Feedback

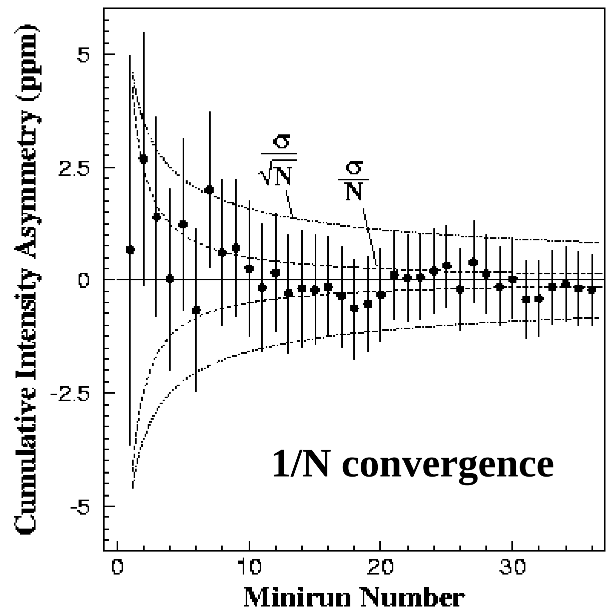
The PITA effect



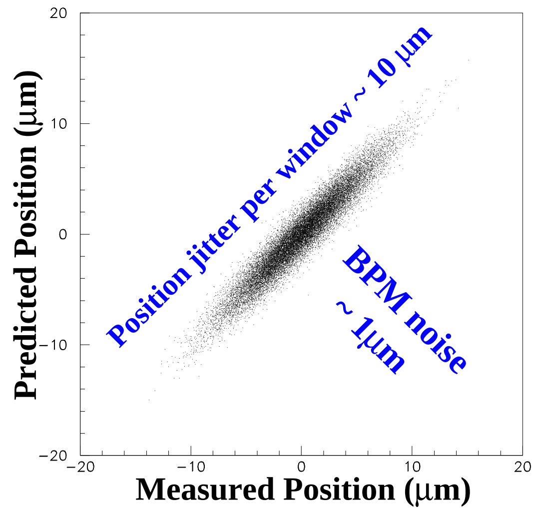




Feedback on the Pockels Cell voltage



Position differences

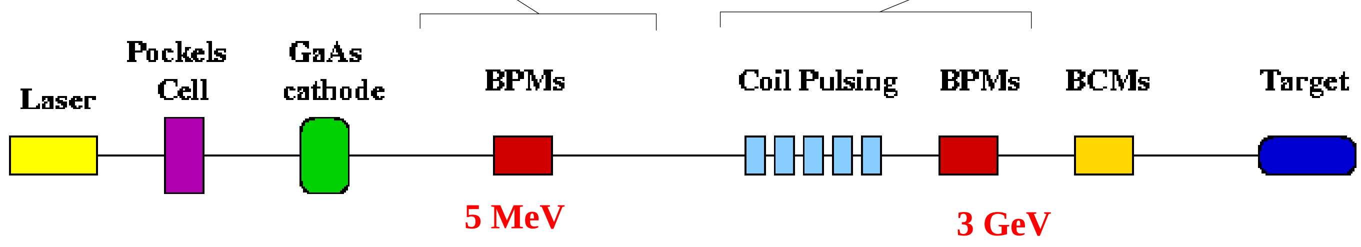


* Beam Damping due to acceleration:
(factor 1/30 from injector to target @ 3 GeV)

→ Position diagnostics at the injector

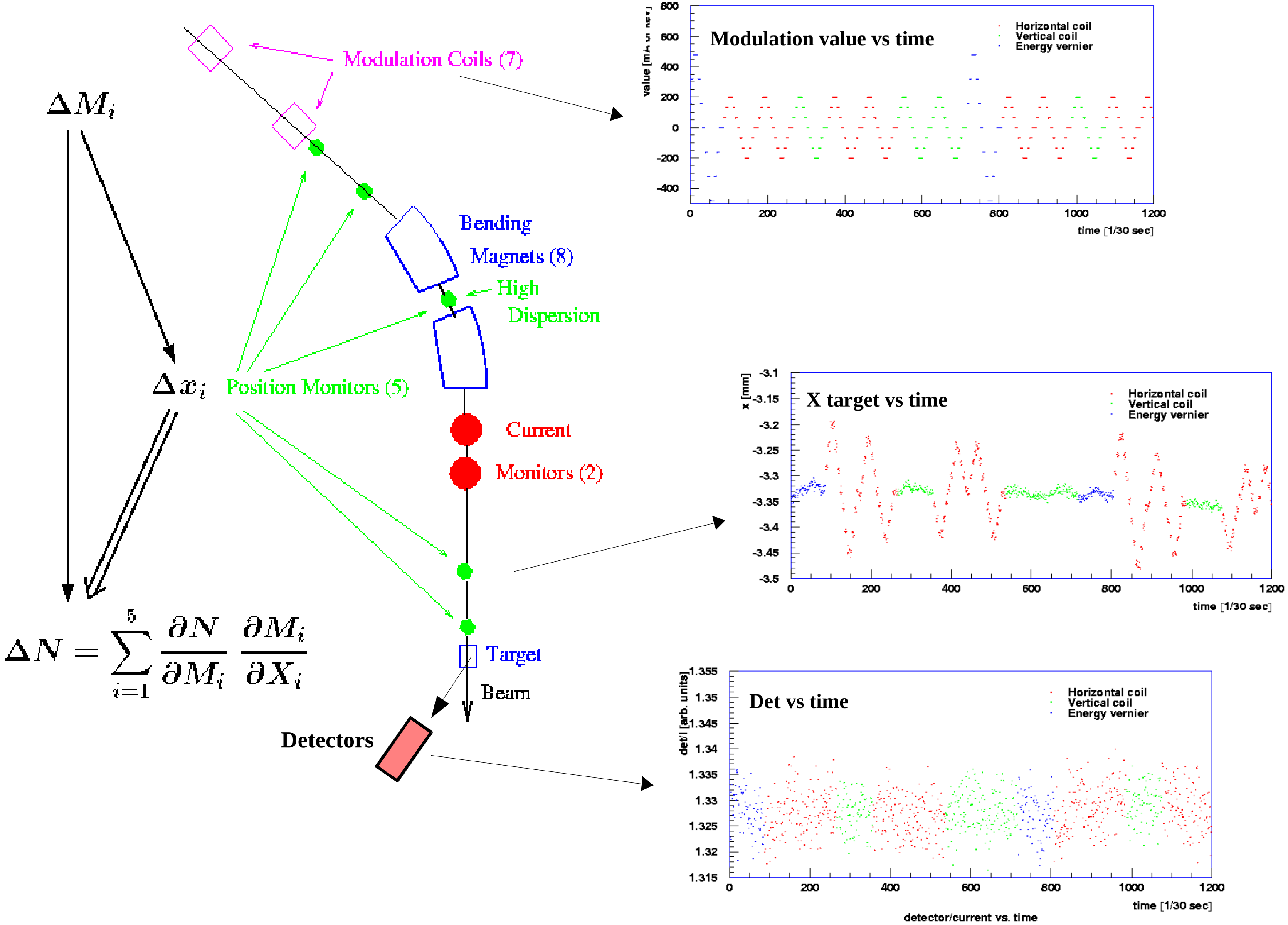
$$A_X = \alpha_i \Delta X_I$$

* Beam modulation
to extract α's coefficients



Beam Modulation

Online monitoring of sensitivity to beam parameters helicity correlations

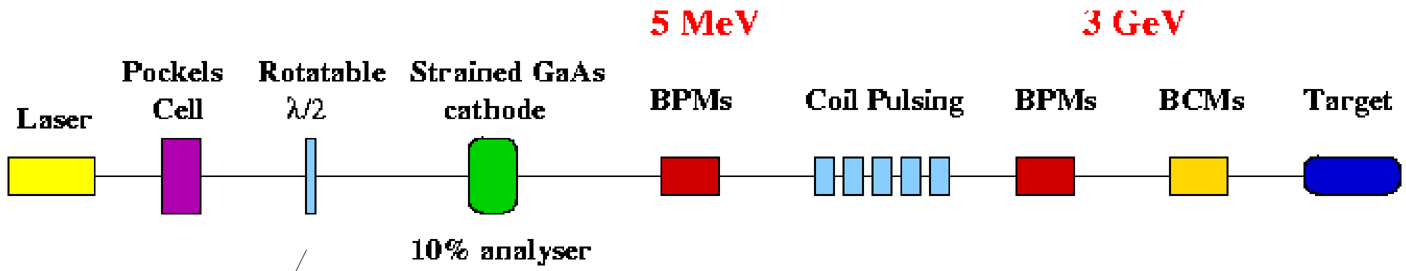


$$\Delta N = \sum_{i=1}^{5} \frac{\partial N}{\partial M_i} \frac{\partial M_i}{\partial X_i}$$

Strained Cathode

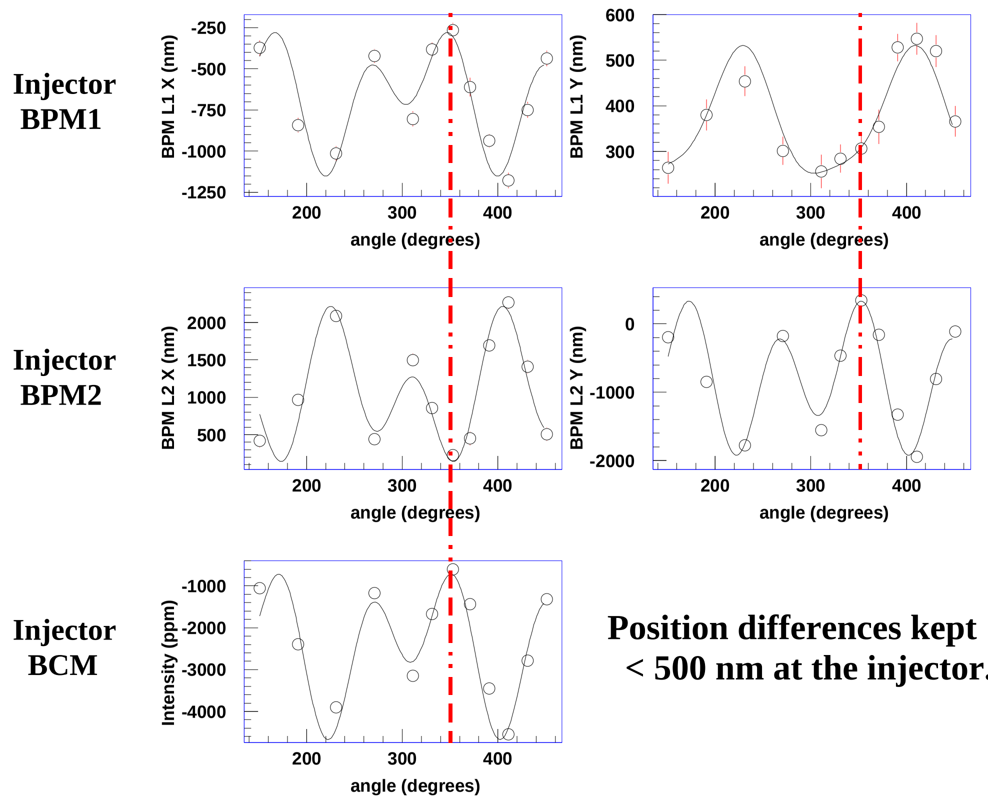
* Photocathode itself provides large analyzing power

* Increased charge and position asymmetries



" Sweet spot " procedure

Optimal alignment of the residual linear polarization

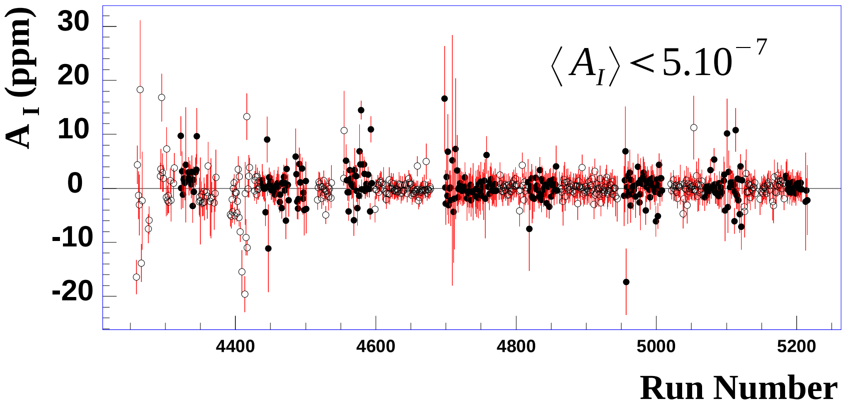


Position differences kept < 500 nm at the injector.

Average Correlations

$A_{exp} \sim 10$ ppm

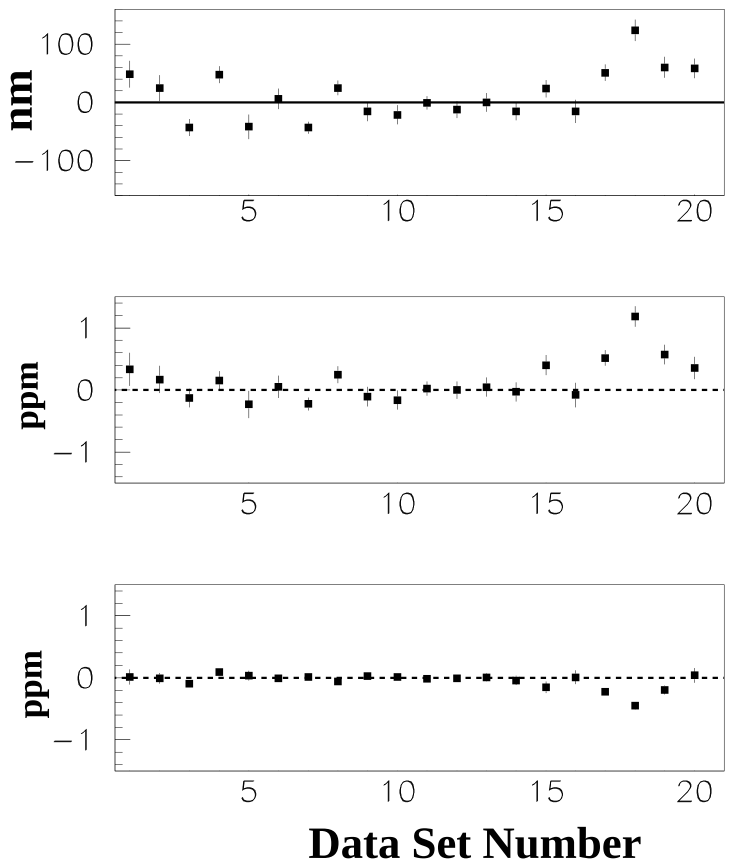
Current :



Linearity better than 1%

→ Negligible corrections

Position :

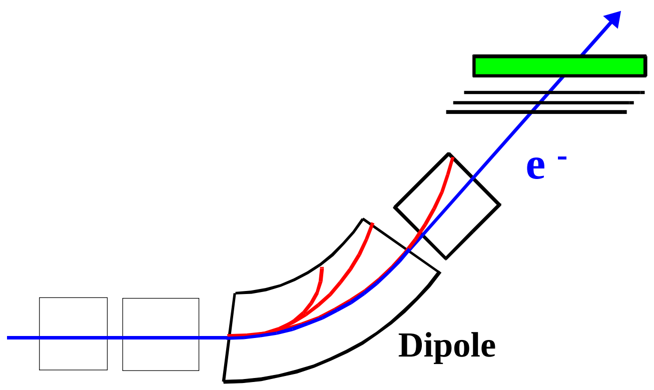


Background

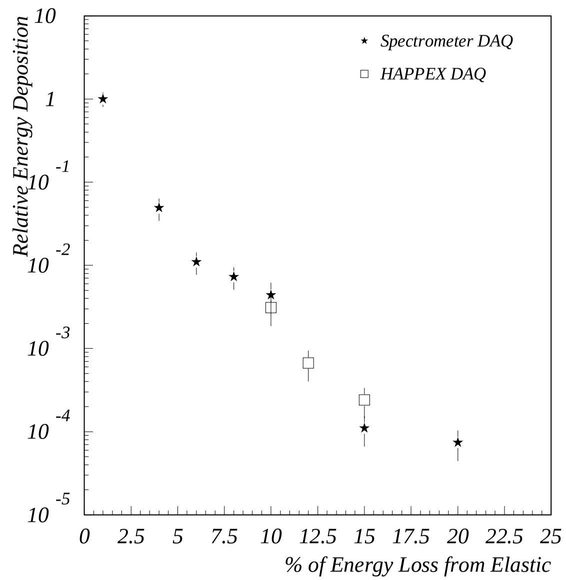
Dedicated runs at low current using standard HRS equipment

*** Quasi-elastic in target end-caps: 1.5% in flux**

*** Rescattering of inelastic events:**



Dipole scan

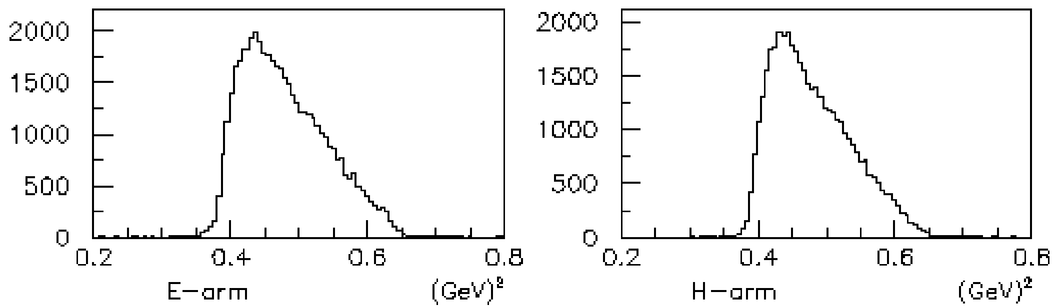


*** Pole tip scattering negligible**

Total Correction = 1.2 +/- 0.6 %

Q^2 determination

Dedicated runs at low current using standard HRS equipment



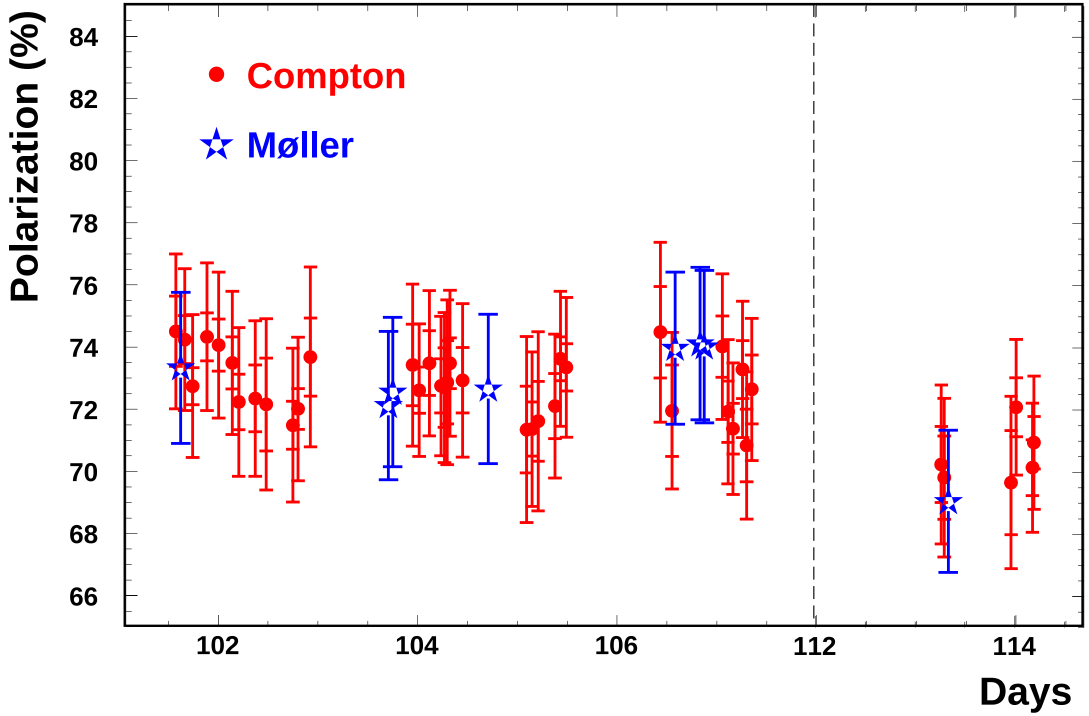
$\langle Q^2 \rangle = 0.47 \pm 0.006\ GeV/c^2$

* Main incertainty from reconstruction of the scattering angle

* Consistency check between 4 different methods

Total syst. = 1.2 %

Polarimetry



* Moller polarimeter

* Compton polarimeter operational at the end of the HAPPEx run

→ Monitoring of the beam polarization in the running conditions.

Total syst. = 3.2 %

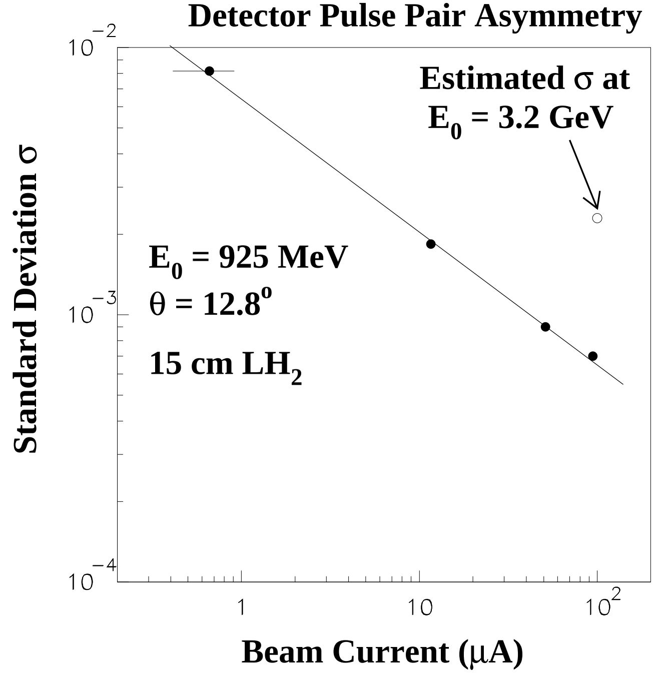
Target Density Fluctuations

$$\sigma(A_I) = \sqrt{\frac{1}{N_i} + \left(\frac{\sigma(l)}{l}\right)^2}$$

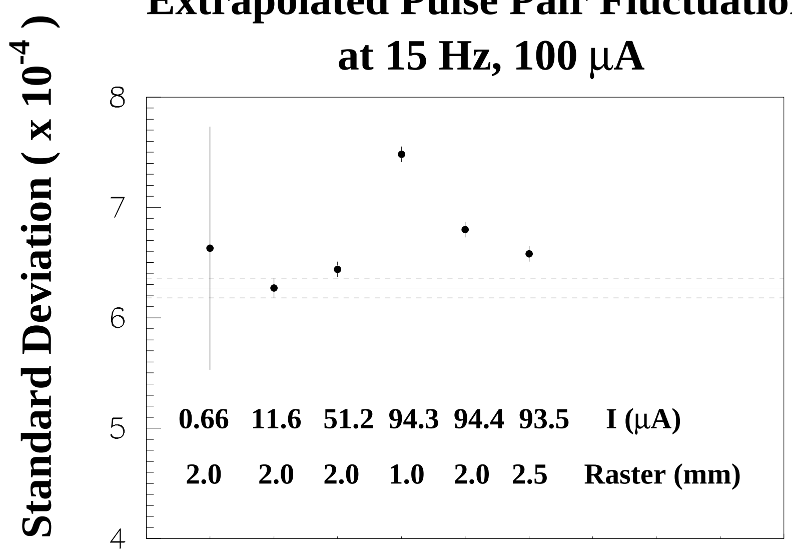
$$\sigma(A^{PV}_{pair}) \approx 3.10^{-3}$$

Want to keep $\frac{\sigma(l)}{l} < few\,10^{-4}$

Measured Fluctuations at 15 Hz in the Detector Pulse Pair Asymmetry

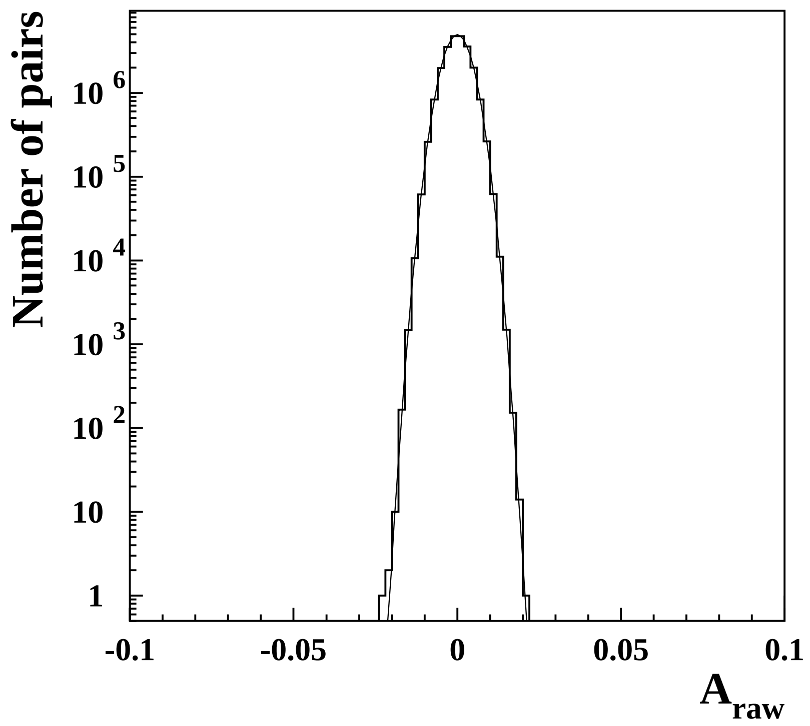


Extrapolated Pulse Pair Fluctuations at 15 Hz, 100 μA

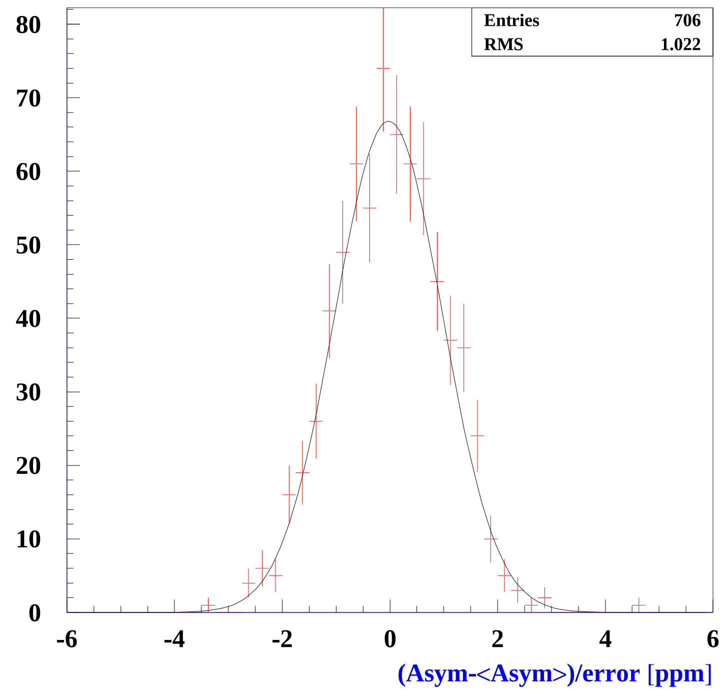


Statistics

Gaussian distribution over
6 orders of magnitude

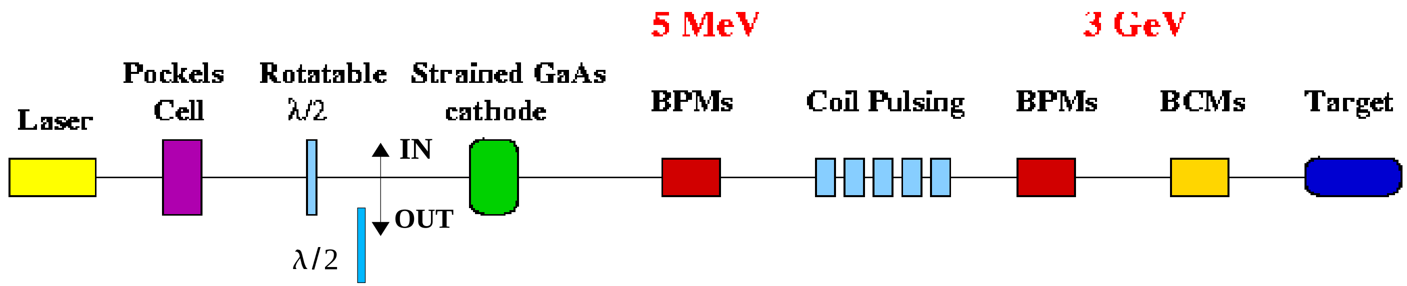


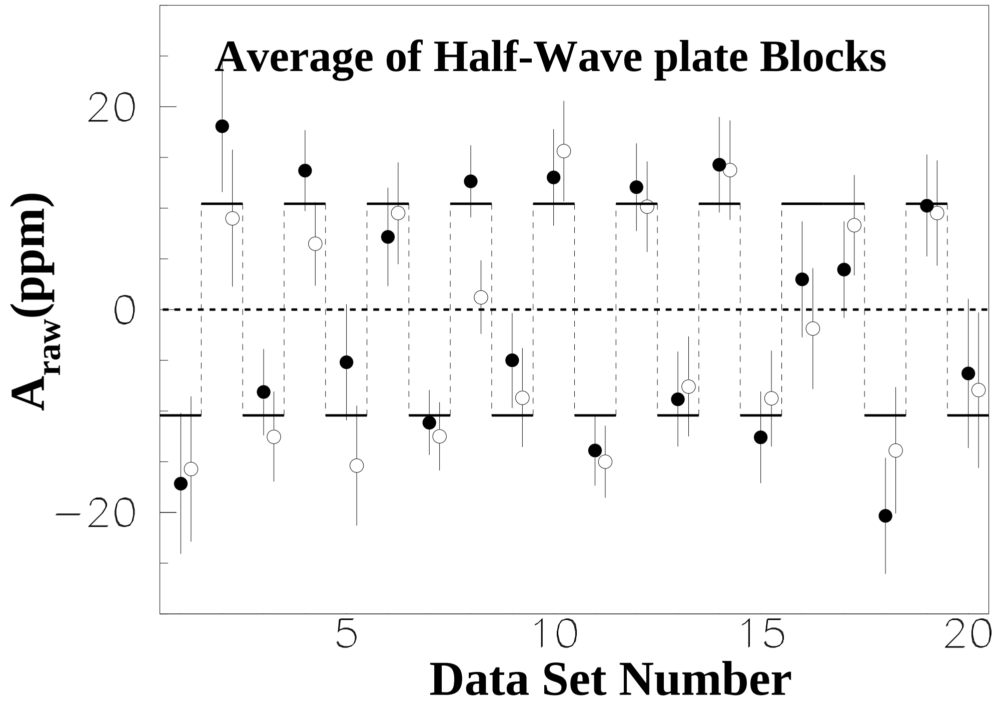
Run asymmetry residuals (normalized to error)



Distribution of residuals for 706 runs
centered at zero with sigma of 1

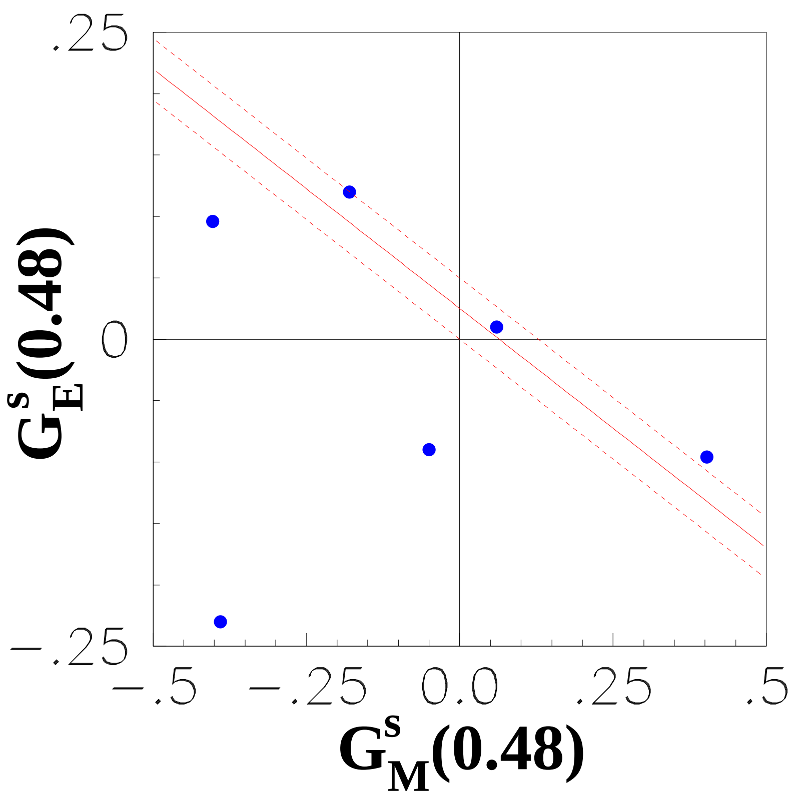
Results





Data compatible with perfect sign reversal

Results



$$A^{PV} = -15.05 \pm 0.98(stat) \pm 0.56(syst)$$

$$(G_E^s + 0.39\,G_M^s) = 0.025 \pm 0.020 \pm 0.014$$

Conclusions:

*** Steep fall off with Q 2 ?**

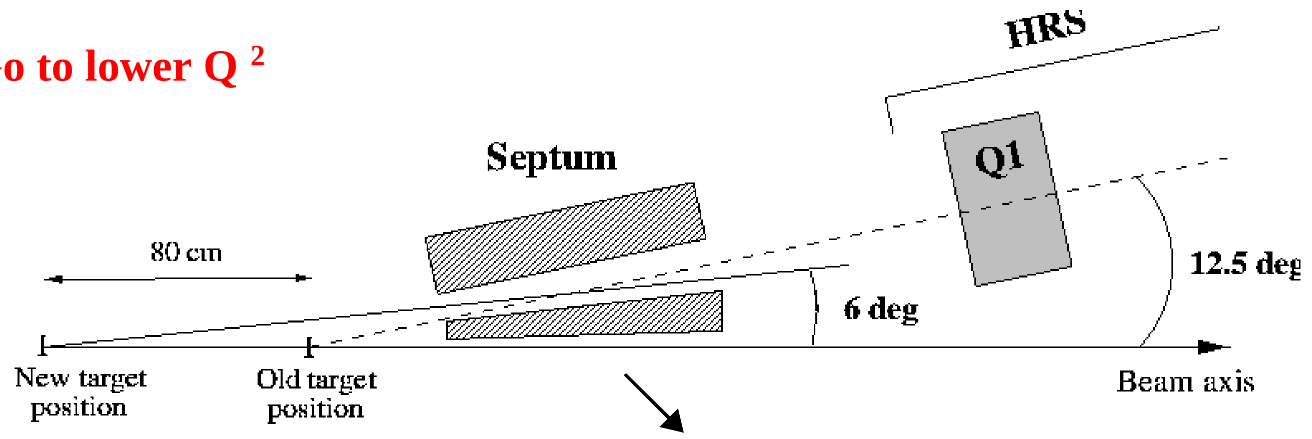
*** GE-GM cancellation ?**

*** Strange vector matrix elements are small ?**

● : **ρs and μs predictions extrapolated to Q^2=0.5 GeV/c^2 using dipole form factors**

Next measurements

Go to lower Q^2



Superconducting dipole (~1 Tesla) upstream each spectrometer

$4 < \theta < 8 \quad deg$

E = 3.2 GeV

$Q^2 = 0.1$ GeV/c^2

To first order in Q^2:

$G_E^s \rightarrow \rho_s$ **Strangeness radius**

$G_M^s \rightarrow \mu_s$ **Strange magnetic moment**

Next measurements

E/M separation :

*** Proton target:**

$G_E^s + 0.08\, G_M^s$

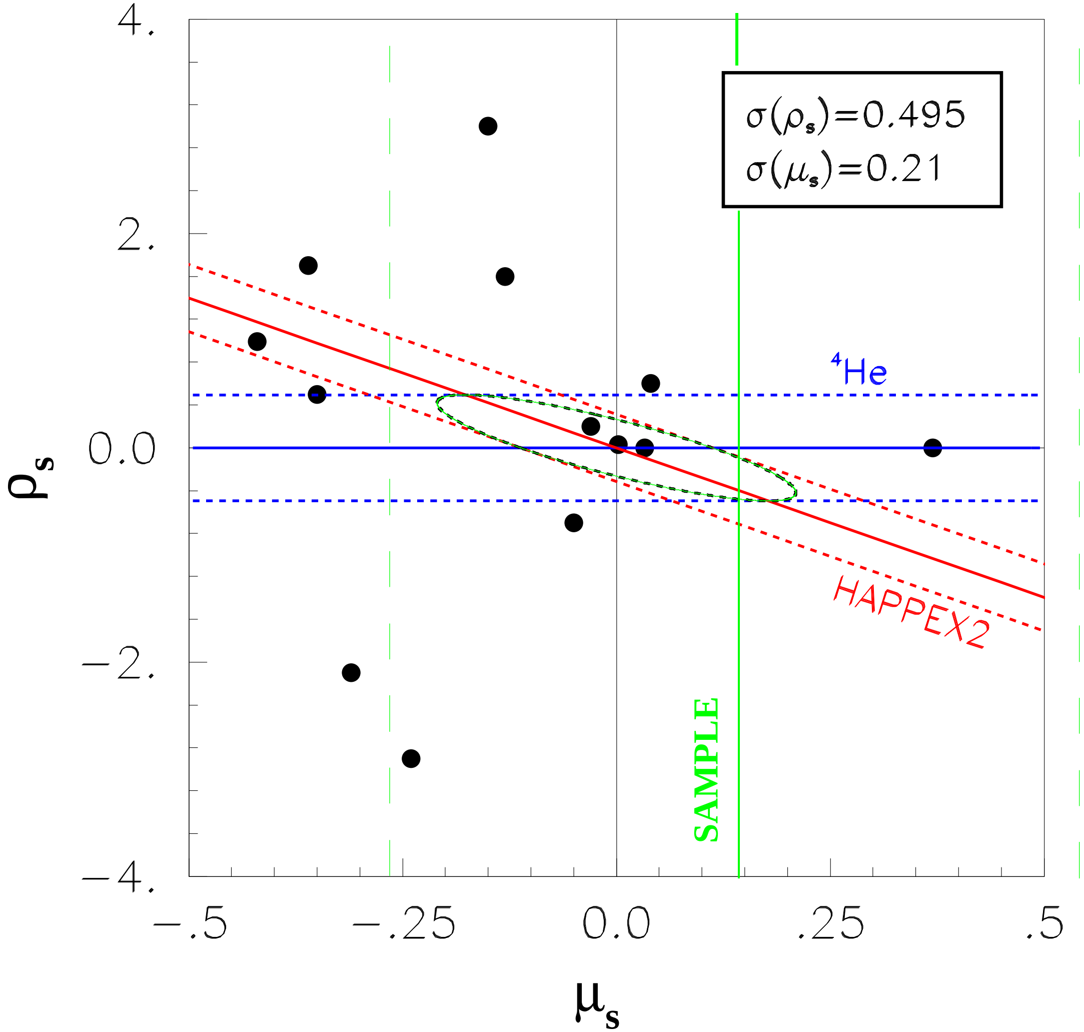
*** ^{4}He target:** **Isoscalar nucleus**

Pure G_E^s

- No axial contributions

	Θ	Q^2	$A^{PV} * P_e$	Rate @ 100 μA	ΔA/A (stat)
H	6 deg	0.1 1 Gev/c ^{2}	-1.3 ppm	127 Mhz	4.6%
^{4}He	6 deg	0.1 0 Gev/c ^{2}	6.7 ppm	24 Mhz	2.2%

Projected errors



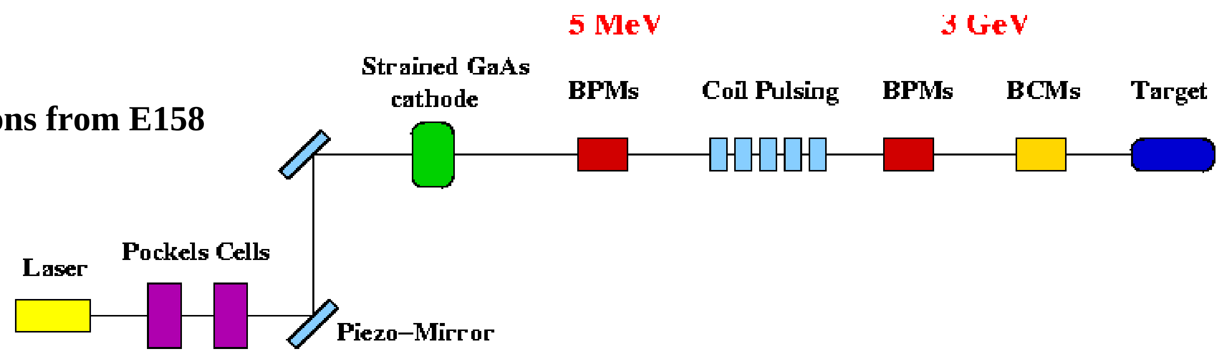
Improved systematic control

HAPPEx2 : $\sigma(A_{paire}) = 350$ ppm

Forward scattering, more sensitive to position and angle : 20 ppm/µrd 20 ppm/µm

*** Better control of ΔX :**

Lessons from E158

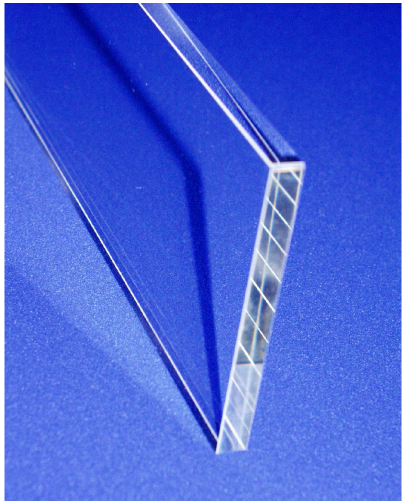


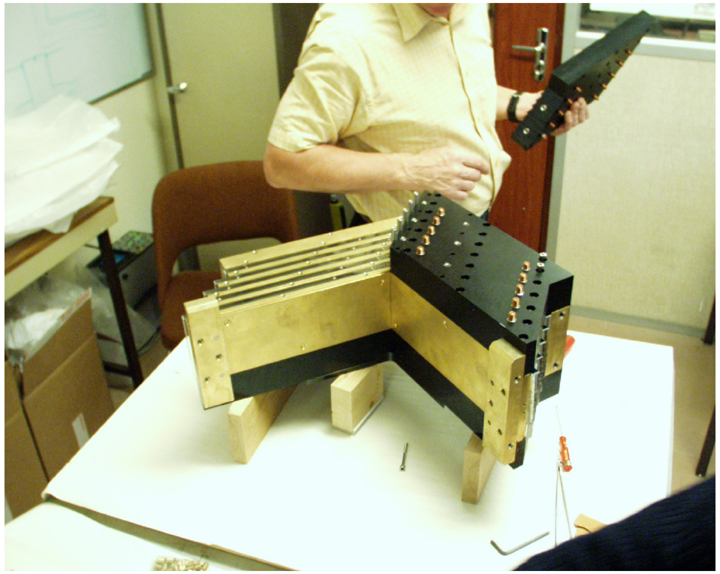
*** Modelisation of beam optics**

*** Reduction of ADC pedestal noise**

Detectors

Thick Cerenkov detector





* Radiation Hard :

Plates made of fused quartz

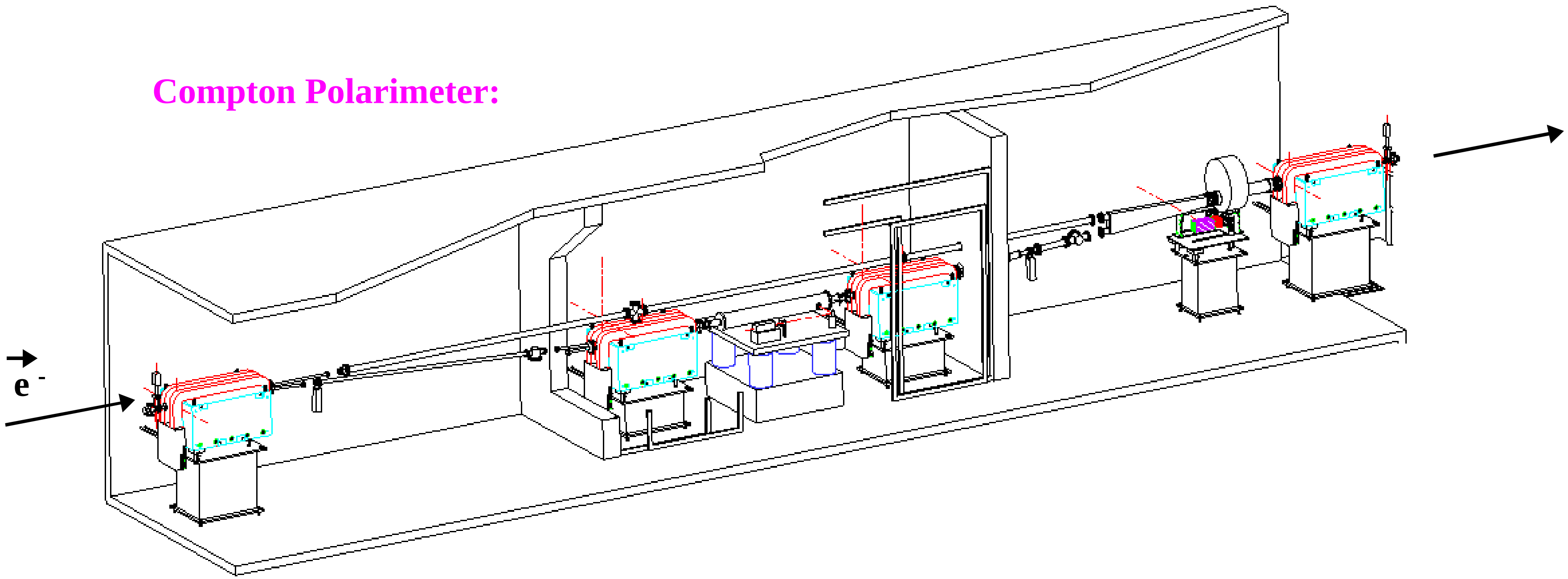
* Segmented :

Gain information and control of syst.
Adaptable to H and ^4He kinematics

See A.Vacheret's poster

Polarimetry

Compton Polarimeter:



* Has already provided 1.4 % total error @4.5 GeV within 40 min
  Meets the requirement of the ^{4}He experiment

* Unique tool for monitoring and accurate absolute measurement
  of the beam polarization in Hall A

Conclusions

* *First parity violation experiment at CEBAF*
  Excellent beam quality for accurate measurements

* *Strange quarks effect measured by HAPPEx found to be small*

* *Measurement at low Q^2 on Proton and ^4He*
  will put stringent constraints on ρ_s and μ_s

* *Rich physics program :*
  - *Strange ff (SAMPLE, HAPPEx, PVA4, G0)*
  - *Neutron radius*
  - *Test of Standard Model*
  - *High x*

HAPPEx Results