Status of the A4 Parity Violation Experiment

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(for the Mainz A4 collaboration)

Outline

- Brief introduction
- PVA4 experimental setup
- Measured asymmetries and estimates for systematic errors
- Standard model predicted asymmetries without strangeness
- Comparison to world data and model/lattice calculations
- Plans for the future

Overview of the Experiment

- Goal: determine contribution of strange quarks to proton structure
- Method: measure asymmetry due to parity violation in elastic electron-proton scattering with polarized electrons, unpolarized target protons

Strange quark contribution:

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

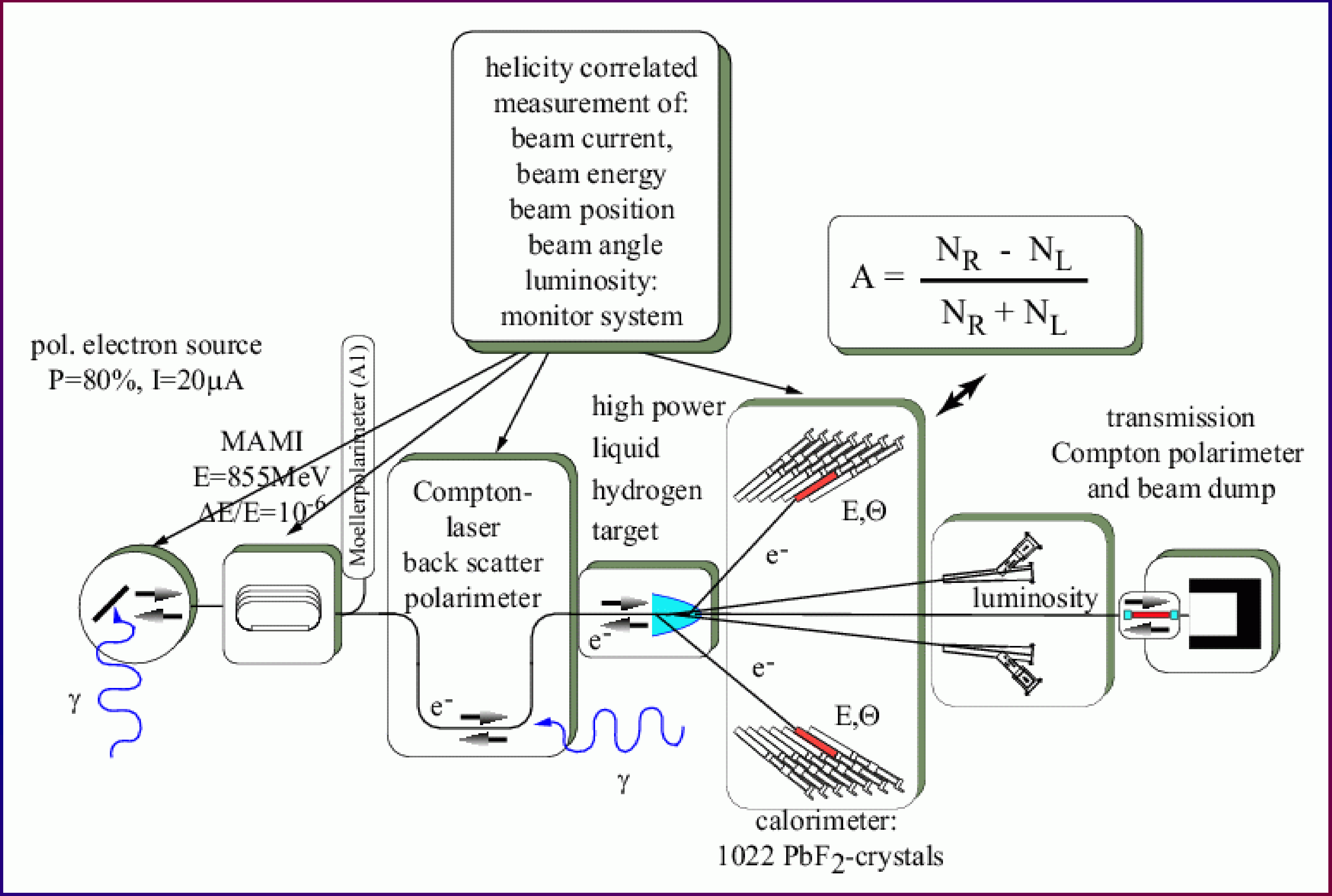
$$A_S = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \frac{\epsilon G_E^p G^s{}_E + \tau G_M^p G^s{}_M}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

Asymmetry in absence of strange quarks:

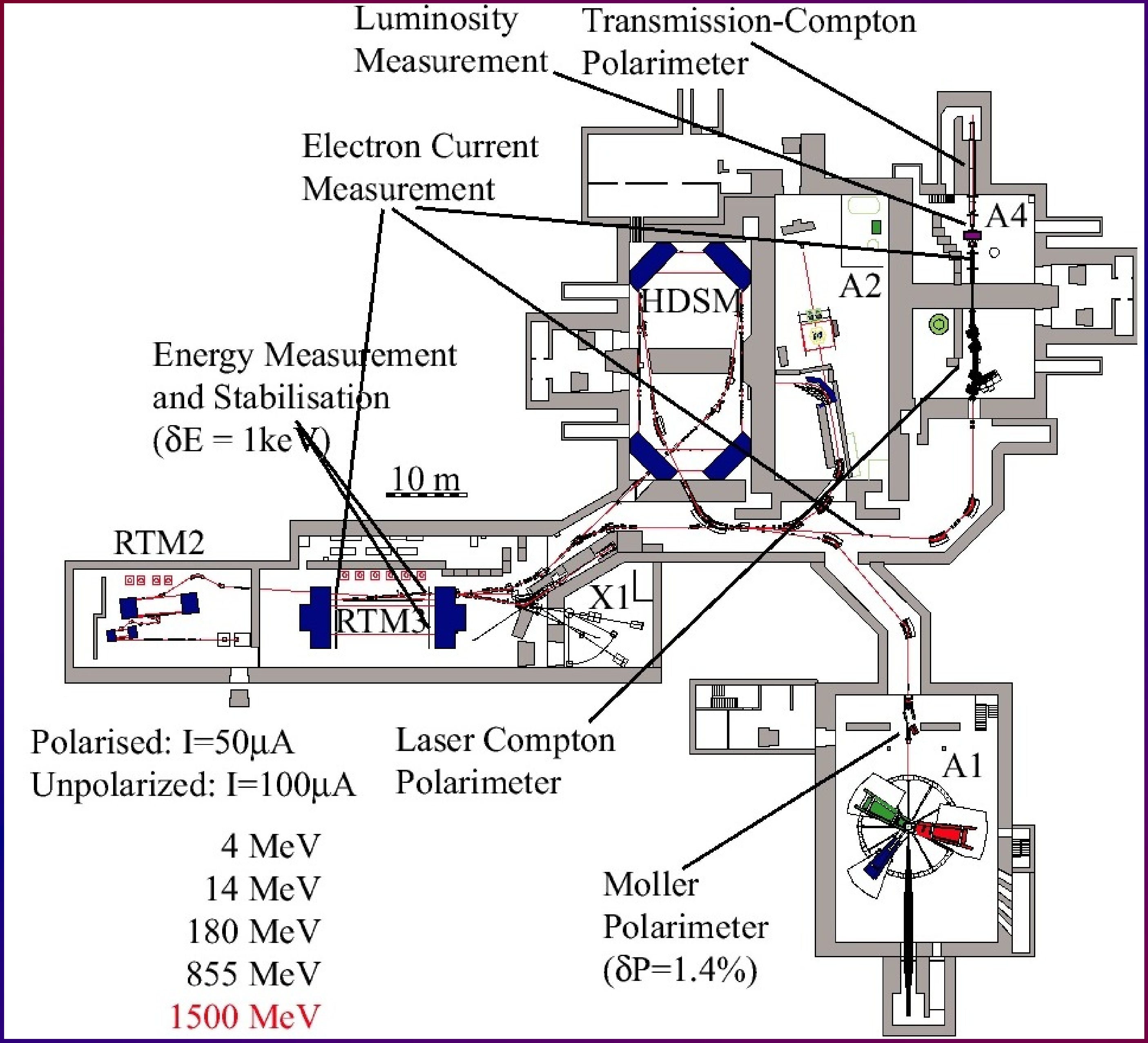
$$A_0 = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times [(1-4\sin^2\theta_W) - \frac{\epsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2} - \{\frac{(1-4\sin^2\theta_W)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)}\,G_M^p \tilde{G}_A^p}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}\}]$$

- Experiment took place at Mainz using MAMI and A4 Calorimeter

Schematic of A4 Experiment



Controlling quality of MAMI beam



For parity-quality beam:
37 stabilization systems in operation...

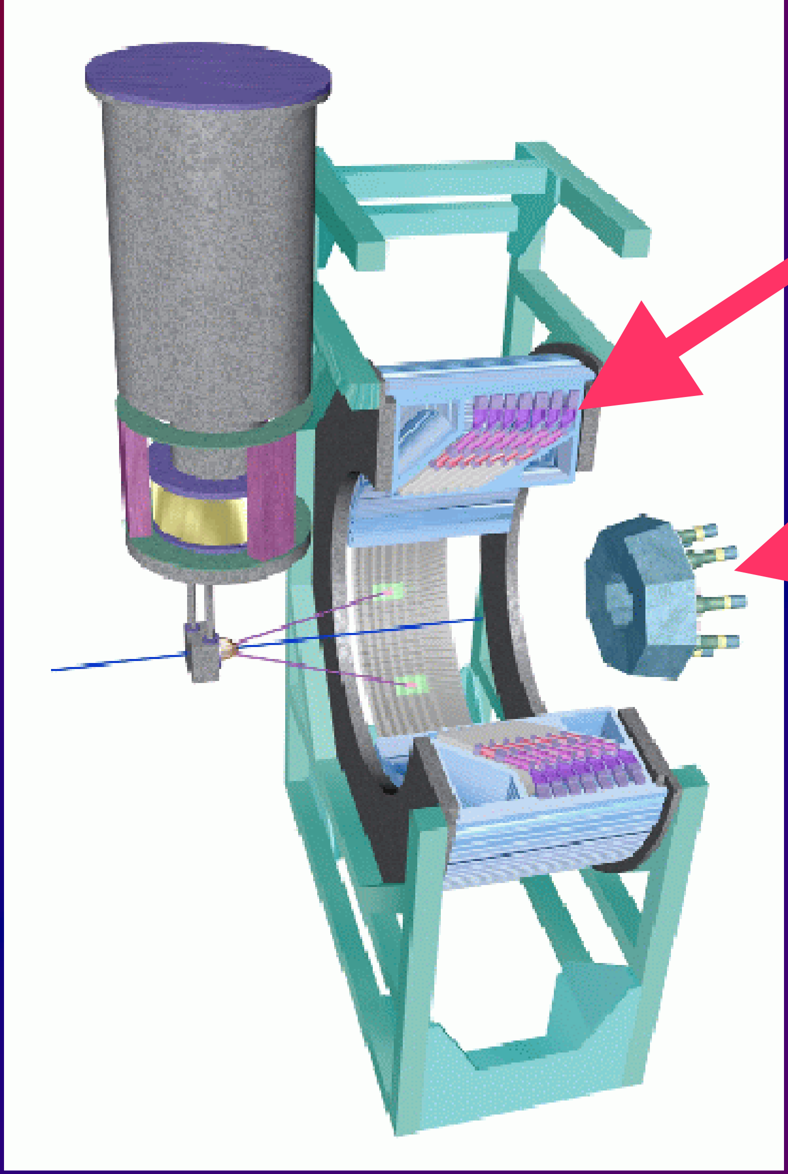
- $\Delta E < 1$ keV
- $\Delta T < 0.1$ K
- Measure energy, position, angle, current

Beam current ~ 20 µA

- Stabilized to $\delta I/I \approx 10^{-3}$

Polarization ~ 80 %

Experimental arrangement in A4 Hall



Fast PbF_2 calorimeter

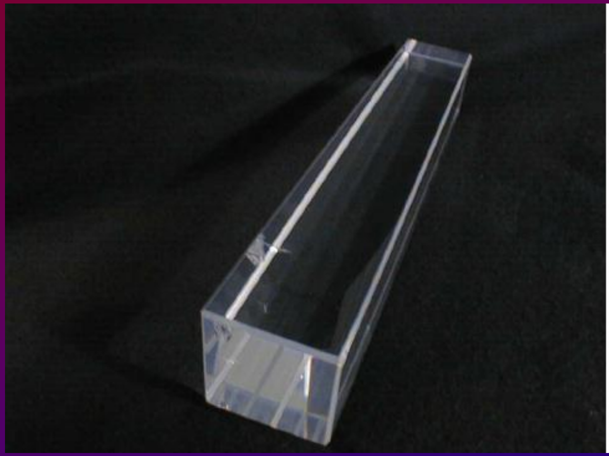
- 1022 crystals in 146 frames
- $\theta = 30\text{-}40^o$, $\varphi = 0\text{-}360^o$

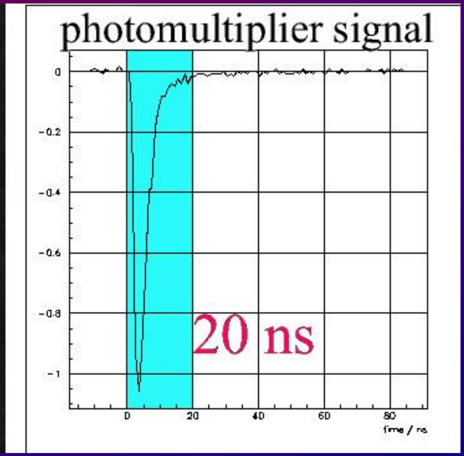
Luminosity monitors

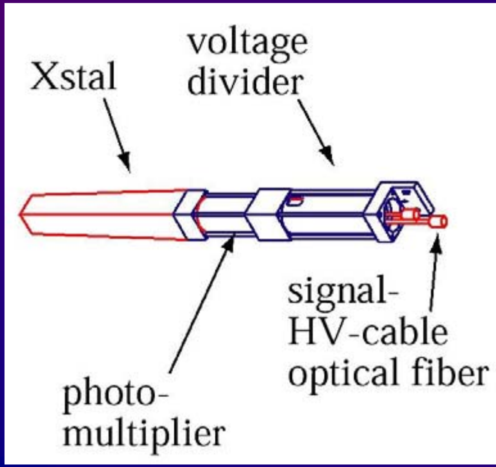
- 8 integrating Cherenkov detectors filled with water
- $\theta = 4.4\text{ -}10^o$, $\varphi = 0\text{-}360^o$

Full coverage in azimuthal angle φ

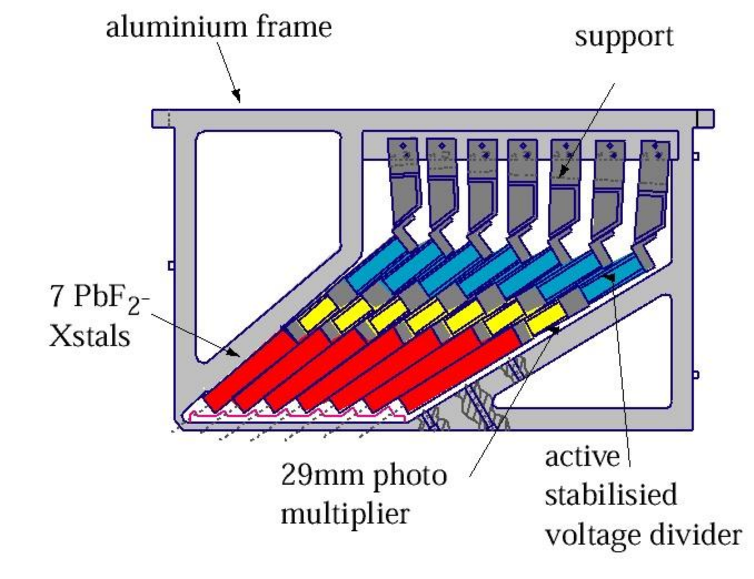
The A4 Fast Calorimeter



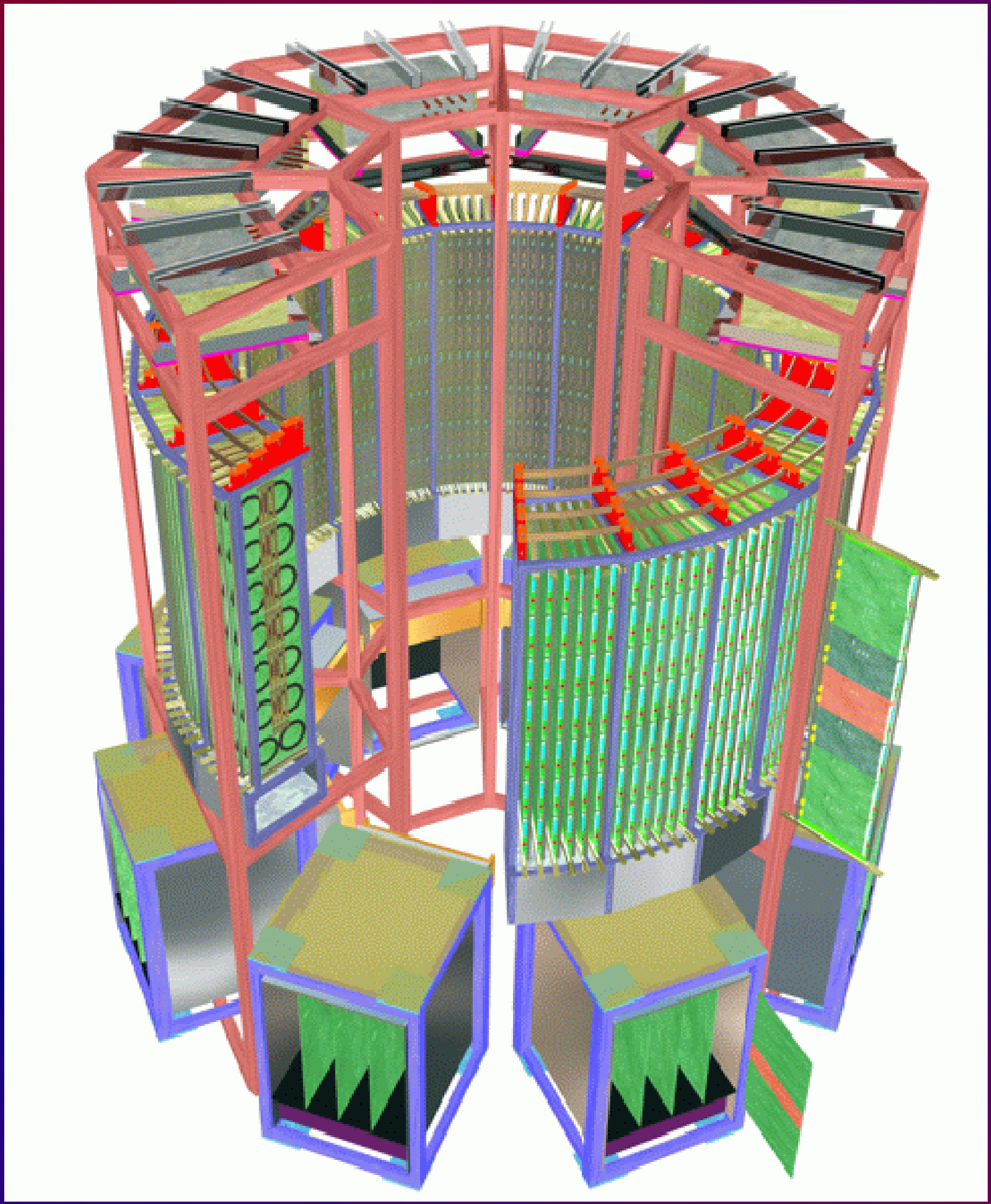




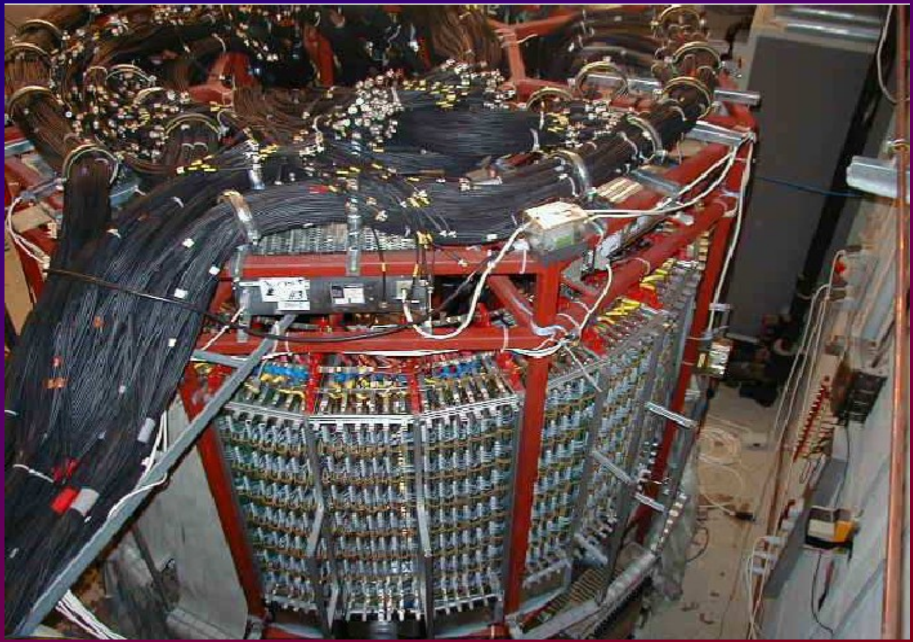
- Crystals: PbF_2 → Cherenkov light
  - Very dense: $\rho = 7.8\ g/cm^3$,
    - $r_M = 1.8$ cm, $X_0 = 0.9$ cm
  - Fast timing characteristics
  - Energy resolution, 3 × 3 array:
  $\delta E / E = 3.9\% / \sqrt{E}$ (elastic peak)



Electronics

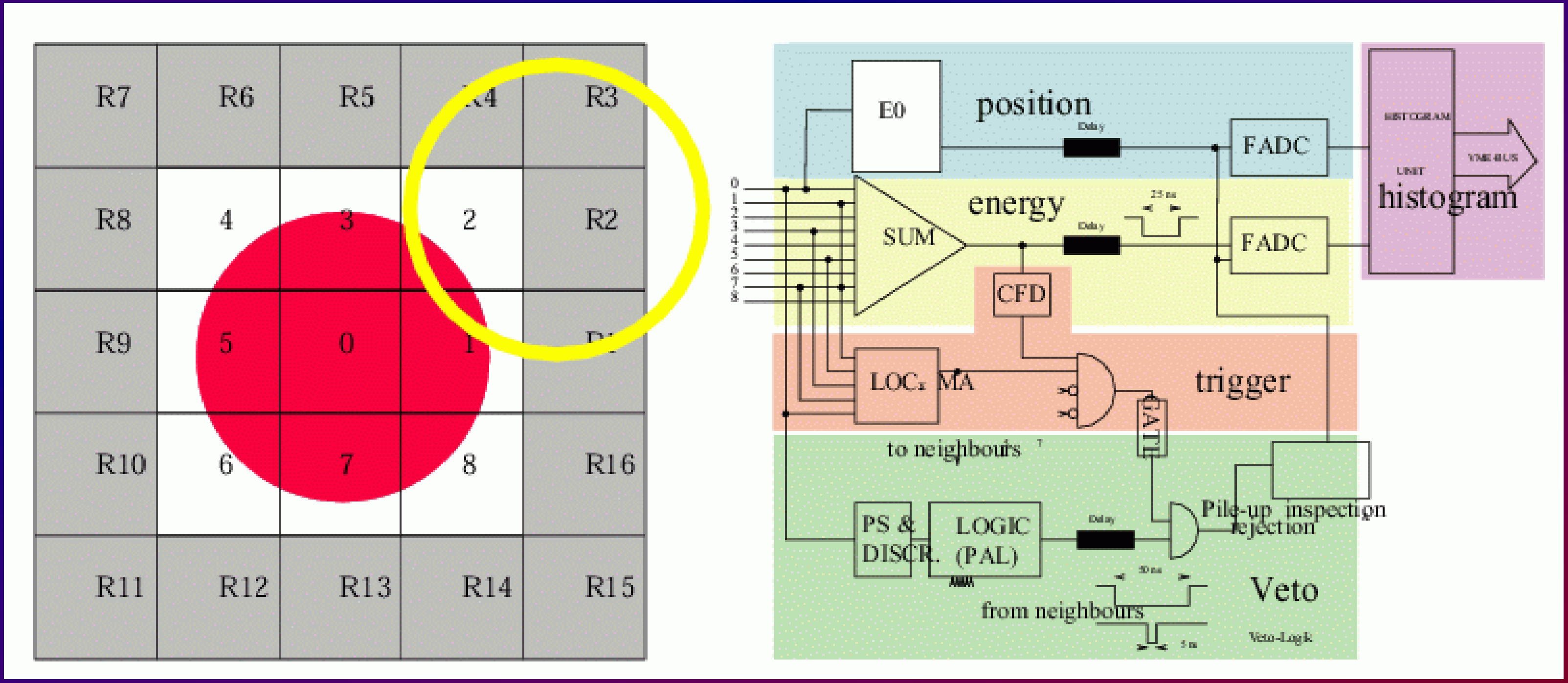


- Custom-built, VME-bus electronics
- Real-time analog event processing
- Low dead time (20 ns)
- Histogramming of energy spectrum

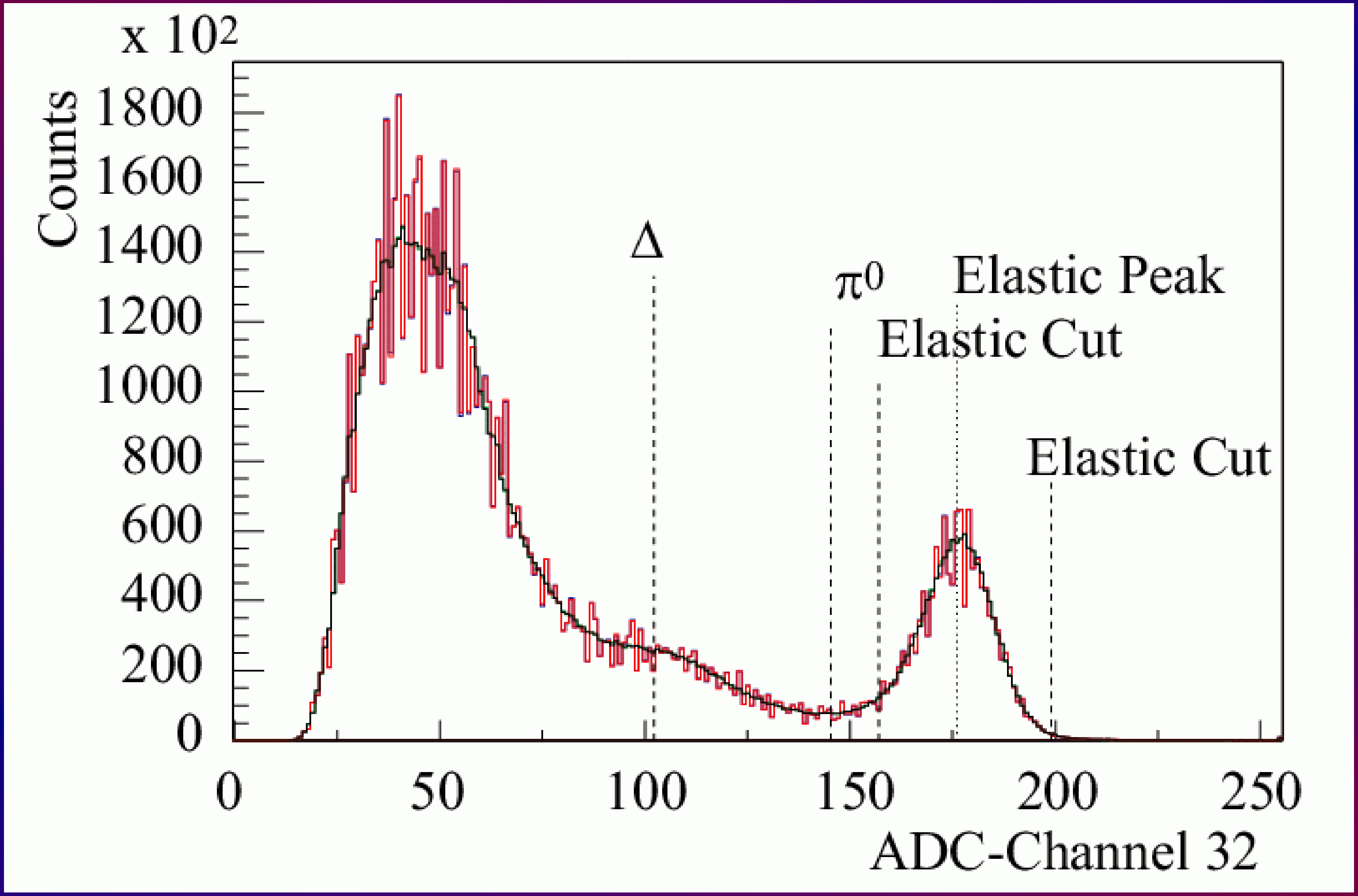


Electronics II

- Deposited energy over 3 × 3 array of adjacent crystals summed
  - Trigger: local maximum + minimum energy deposition
  - Veto: look for local maxima in 16 crystals around 3 × 3 array
    - Reject pile-up events
  - PMT signals integrated for 20 ns
  - Digitized with 8-bit Flash-ADCs
- Energy, impact position, helicity state → 3D histogram



Energy Spectrum



For Q^2=0.108 $(GeV/c)^2$, 16× 10^6 histograms → 10^{13} elastic scattering events!

Analysis

- Count elastic events in two helicity bins

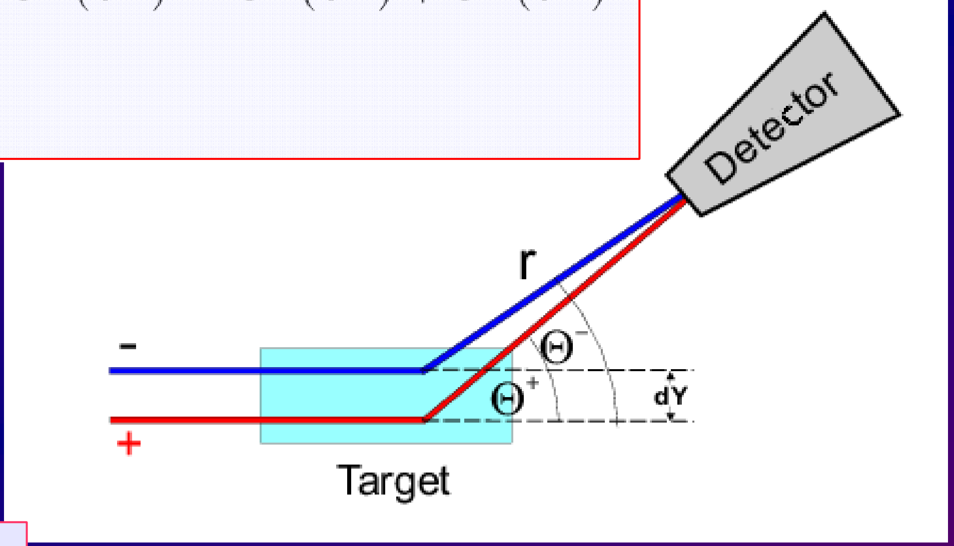
E (MeV)	N^+	N^-
570.4	9,903,050,444,801	9,903,056,510,539
854.3	2,412,117,276,275	2,412,084,765,681

- Correct for target density variations
  - $A_{raw} = (N^+/\rho^+ - N^-/\rho^-) / (N^+/\rho^+ + N^-/\rho^-)$
- Correct for quasi-elastic scattering off aluminum windows of target cell
- Correct for polarization P_e of electron beam
  - Møller polarimeter in A1 Hall
  - Measure once a week and interpolate...
- Correct for false asymmetries...

False Asymmetries

$$A_{exp} = \frac{\sigma^+(\theta^+) - \sigma^-(\theta^-)}{\sigma^+(\theta^+) + \sigma^-(\theta^-)} = \frac{\sigma^+(\theta^+) - \sigma^-(\theta^+)}{\sigma^+(\theta^+) + \sigma^-(\theta^+)} + \frac{\frac{d\sigma}{d\theta}(\theta^- - \theta^+)}{\sigma^+(\theta^+) + \sigma^-(\theta^+)}$$

$$= A_{PV} + A_f^{\Delta\theta}$$



Systematic differences in (for example) position of beam on target for different helicity states → false asymmetries.

$$A_{raw} = P_e A_{phys} + \sum_i a_i X_i$$

From A_{raw} to A_{phys} : multi-dimensional linear regression

- $X_i = \{A_I, \Delta x, \Delta y, \Delta x', \Delta y', \Delta E\}$

Difference in energy
Differences in angle
Differences in position
Asymmetry in beam current

Asymmetry result and systematic errors

$A_{phys}(0.23\ GeV^2) = -5.44 \pm 0.54 \pm 0.26$ ppm

	correction [ppm]	error [ppm]
Statistics		0.54
Target density, luminosity	0.58	0.09
Target density, beam current	0.00	0.04
Nonlinearity of LuMo	0.30	0.04
Deadtime correction	-0.11	0.08
A_I	0.64	0.04
ΔE_e	-0.05	0.02
Δx, Δy	-0.03	0.02
$\Delta x'$, $\Delta y'$	0.03	0.03
Aluminum windows (H_2 target)	0.16	0.02
Dilution from π^0 decay	0.00	0.06
P_e measurement	-1.07	0.11
P_e interpolation	0.00	0.19
Systematic error		0.26

Largest single contribution to systematic error: P_e interpolation

Asymmetry result and systematic errors

$A_{phys}(0.11\ GeV^2) = -1.36 \pm 0.27 \pm 0.13$ ppm

	correction [ppm]	error [ppm]
Statistics		0.29
Target density, luminosity	-0.32	0.01
Target density, beam current	0.00	0.02
Nonlinearity of LuMo	0.05	0.00
Deadtime correction	0.03	0.02
A_I	-0.33	0.04
ΔE_e	0.03	0.03
Δx, Δy	0.01	0.09
$\Delta x'$, $\Delta y'$	0.01	0.09
Aluminum windows (H_2 target)	0.06	0.03
Dilution from π^0 decay	0.00	0.02
P_e measurement	-0.34	0.03
P_e interpolation	0.00	0.05
Systematic error		0.13

Largest single contribution to systematic error: position/angle variation

Asymmetry without Strangeness

$$A_0 = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times [(1-4sin^2\theta_W) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2} - \{\frac{(1-4sin^2\theta_W)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)} G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\}]$$

- Weak mixing angle: $\sin^2\theta_W = 0.23113(15)$ at M_Z in MS-bar scheme
- $G^p_{E,M}$, $G^n_{E,M}$ from parametrization of Friedrich and Walcher
  - Assume $\delta G^p_M/G^p_M = \delta G^p_E/G^p_E = 3\%$, $\delta G^n_M/G^n_M = 5\%$, $\delta G^n_E/G^n_E = 10\%$
- Electroweak radiative corrections evaluated in MS-bar scheme
  - ~ -1% correction (following Marciano and Sirlin) to first line of expression
  - effects also included in G^p_A (from Zhu, et al.)
- Correct for electromagnetic radiative effects + energy loss in target

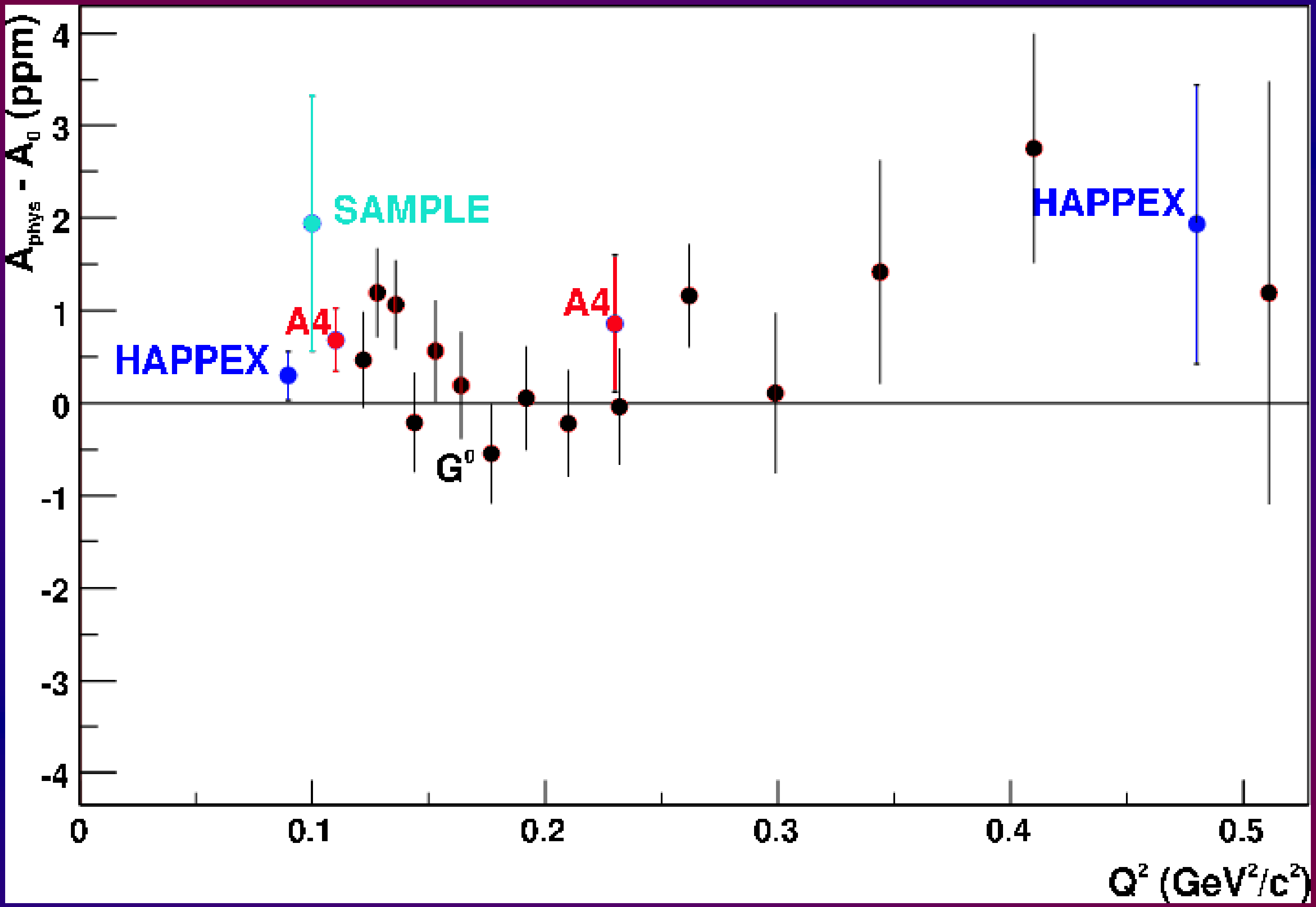
→ -1.3% correction to A_0

Asymmetry without Strangeness II

$A_0(0.23\ GeV^2)$=-6.30 ± 0.44 ppm
$A_0(0.11\ GeV^2)$=-2.06 ± 0.14 ppm

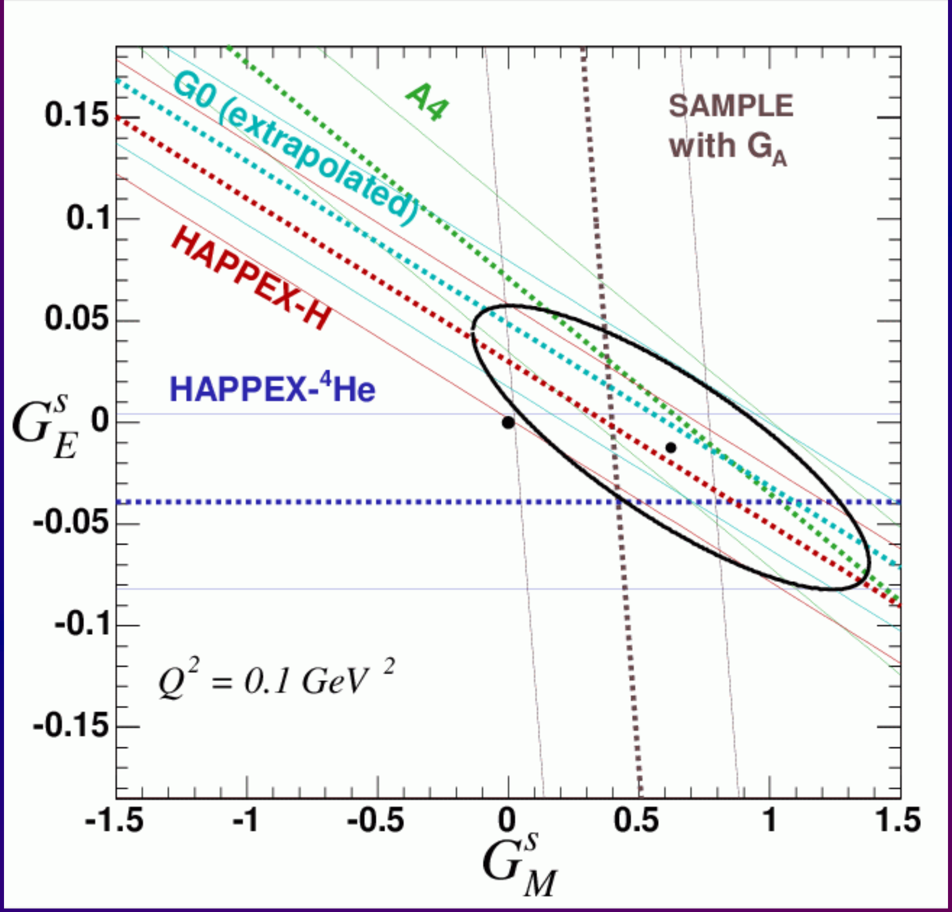
	Error Contributions in ppm	
	E=854.3 MeV	E=570.4 MeV
G_F	0.00	0.00
$\hat{s}_Z^2 = sin^2\Theta_W$	0.02	0.01
G_E^p	0.21	0.07
G_M^p	0.07	0.03
G_E^n	0.12	0.04
G_M^n	0.27	0.07
$\tilde{G}_A^p$	0.24	0.09
Sum	0.44	0.14

Comparison to World Data



Comparison to World Data II

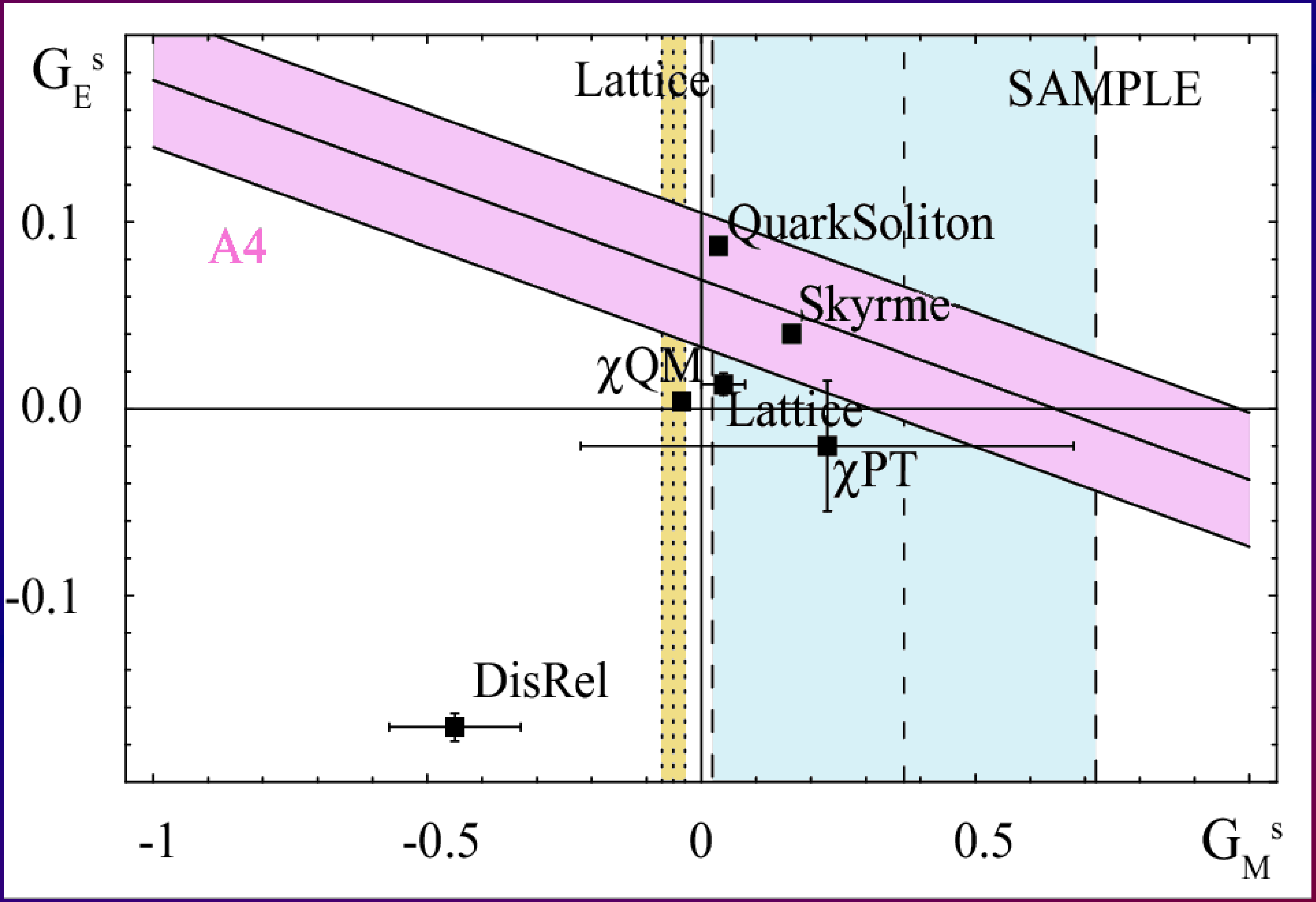
At Q^2=0.108 $(GeV/c)^2$, $G^S_E + 0.106\, G^S_M = 0.071 \pm 0.036$



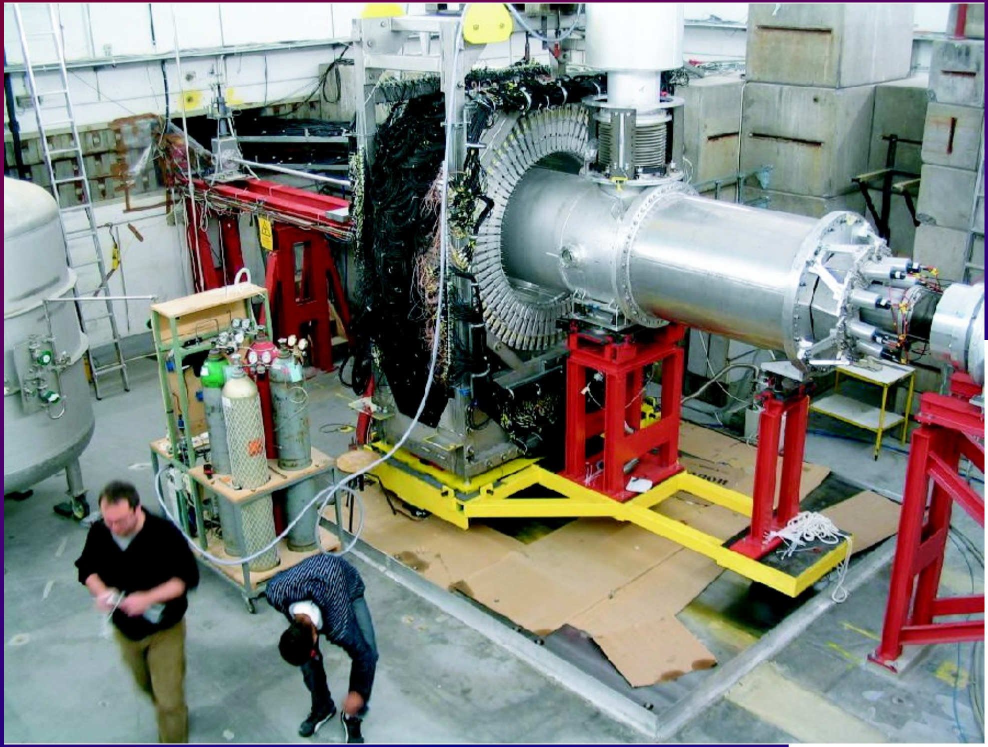
$G^S_M = 0.62 \pm 0.31$, $G^S_E = -0.012 \pm 0.029$

Comparison to Theory

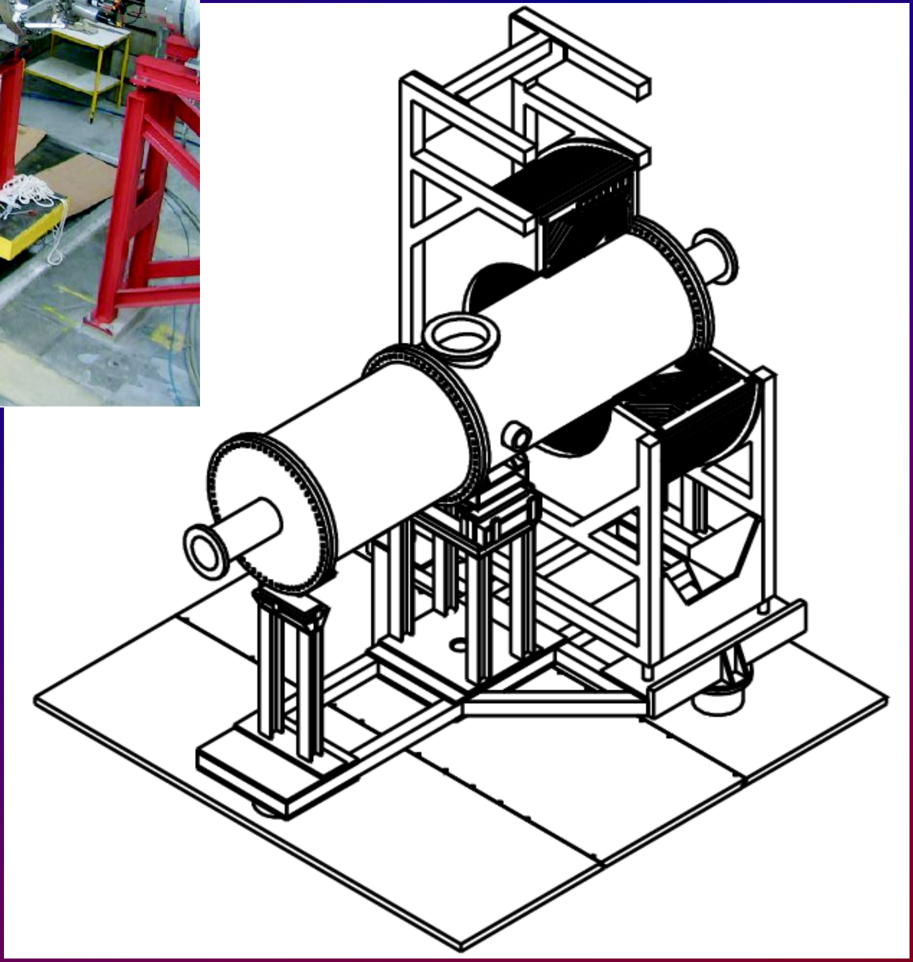
At Q^2=0.108 (GeV/c)^2, $G^S_E + 0.106\, G^S_M = 0.071 \pm 0.036$



Future plans: backward angle



$140^o < \theta_e < 150^o$



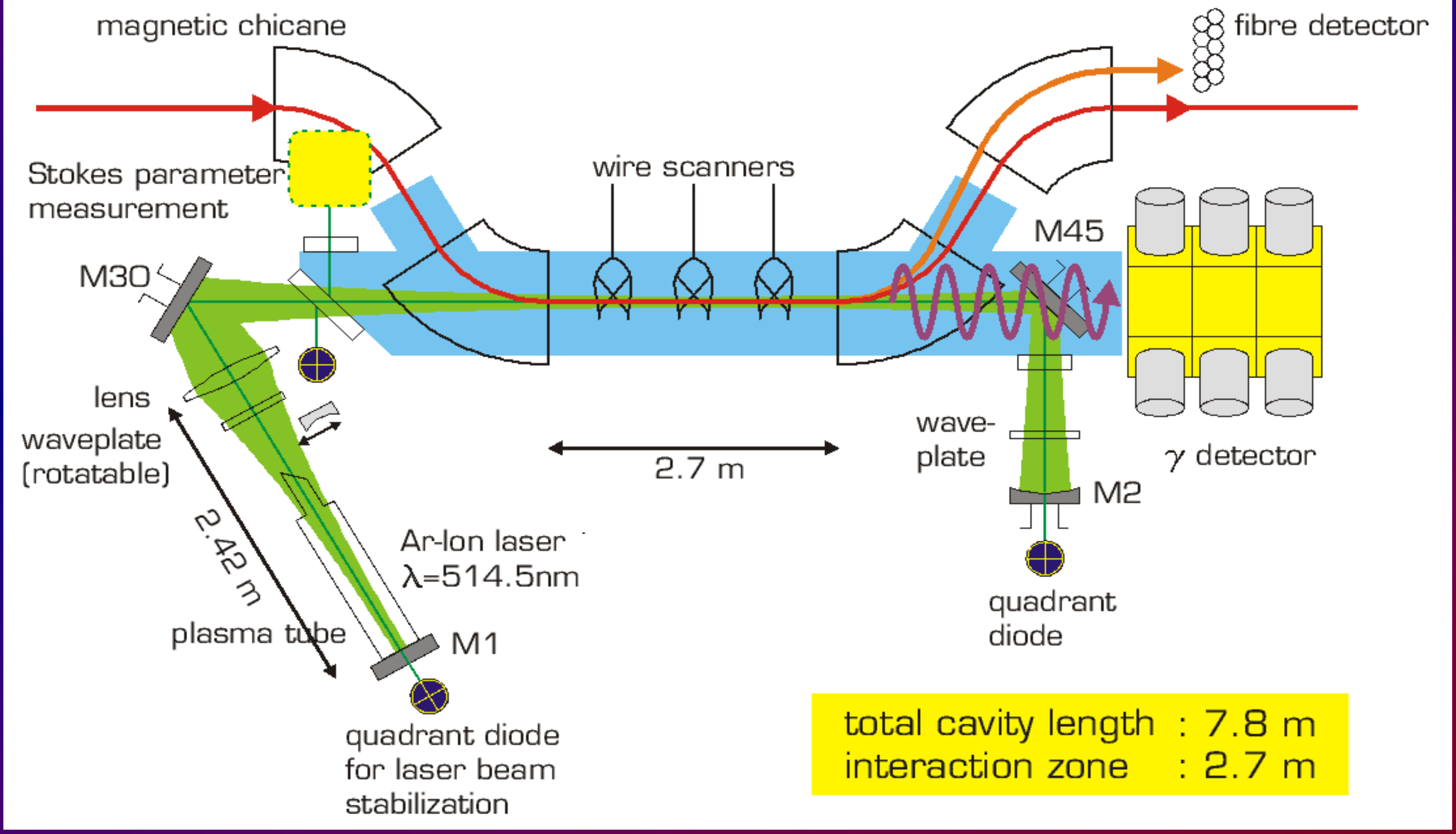
Proton, deuteron targets

→ separate G^s_E and G^s_M

Commissioning started,
run coming up...

Compton Back-scatter Polarimeter

- Scatter green laser light off electron beam
  - Intra-cavity design → maximize interaction region
  - Achieved ~90W (maximum)
- Measure asymmetry in energy of back-scattered photon
  - Measured first Compton asymmetry in Aug'04
- Still in commissioning stage...



Summary

- Experiment took place at Mainz using *ep* elastic scattering with polarized electrons
- Measured A_{PV} for two values of Q^2, 0.108 $(GeV/c)^2$ and 0.230 $(GeV/c)^2$

  At Q^2=0.108 $(GeV/c)^2$, $G^S_E + 0.106\, G^S_M = 0.071 \pm 0.036$

  At Q^2=0.230 $(GeV/c)^2$, $G^S_E + 0.225\, G^S_M = 0.039 \pm 0.034$

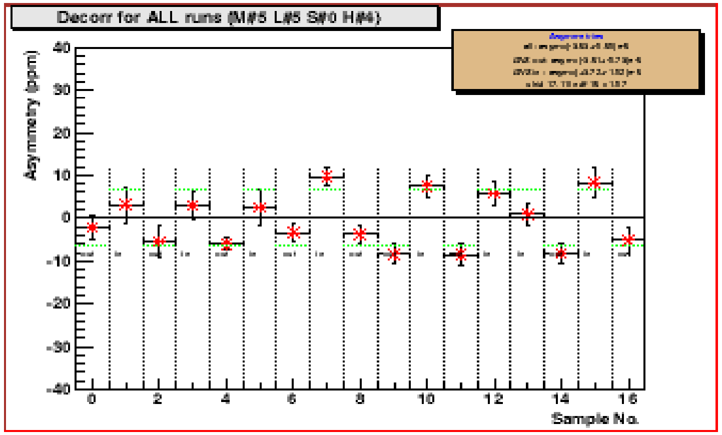
  - $G^s_E + b\, G^s_M > 0$ by ~1-2 standard deviations
    - Combination with world data suggests $G^S_M > 0$
  - Beam polarization = significant source of error

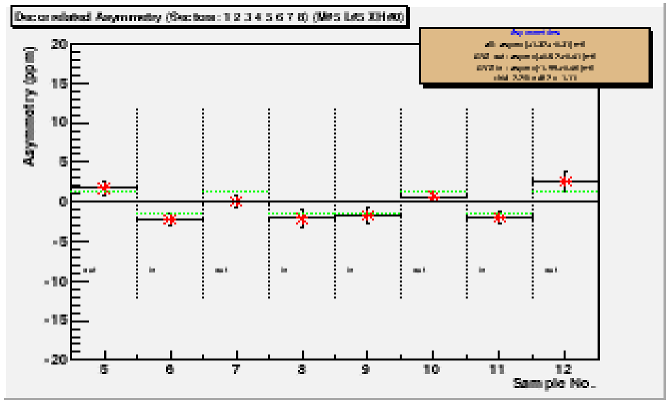
    → Compton Polarimeter development
- Backward angle measurement coming up soon...

Backup slides

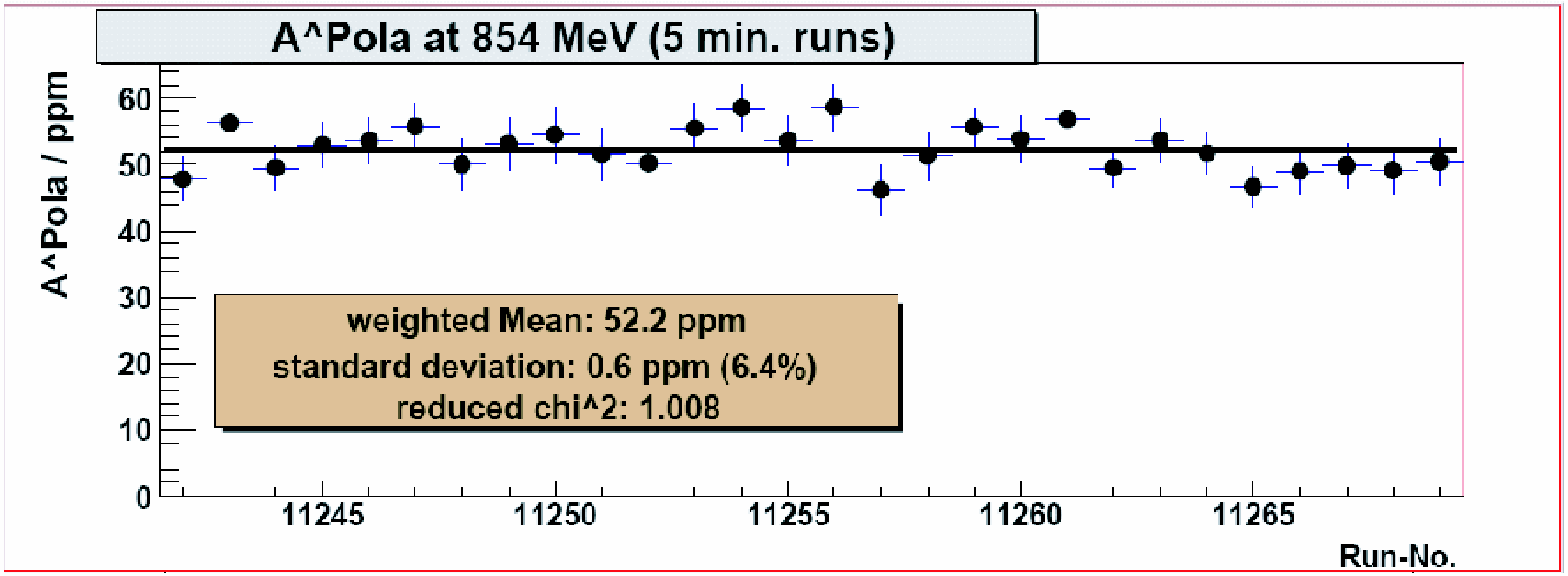
λ/2-Samples

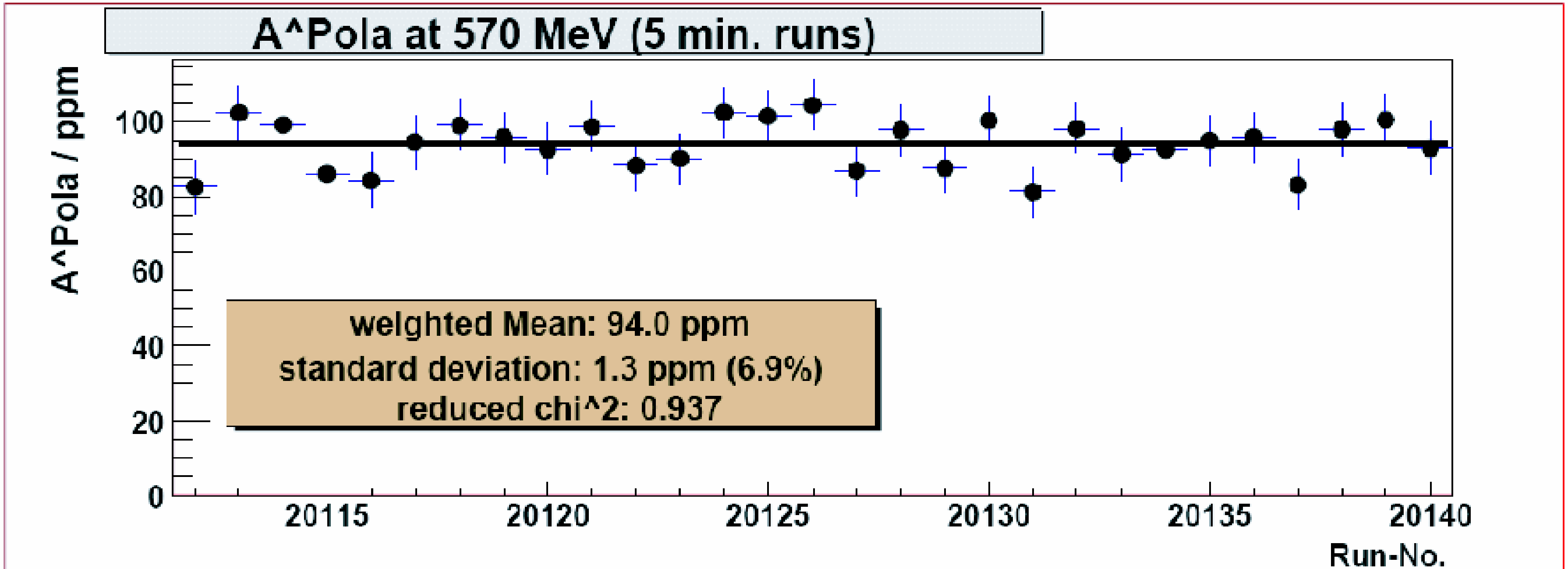
854 MeV (0.227 GeV^2) 570 MeV (0.101 GeV^2)





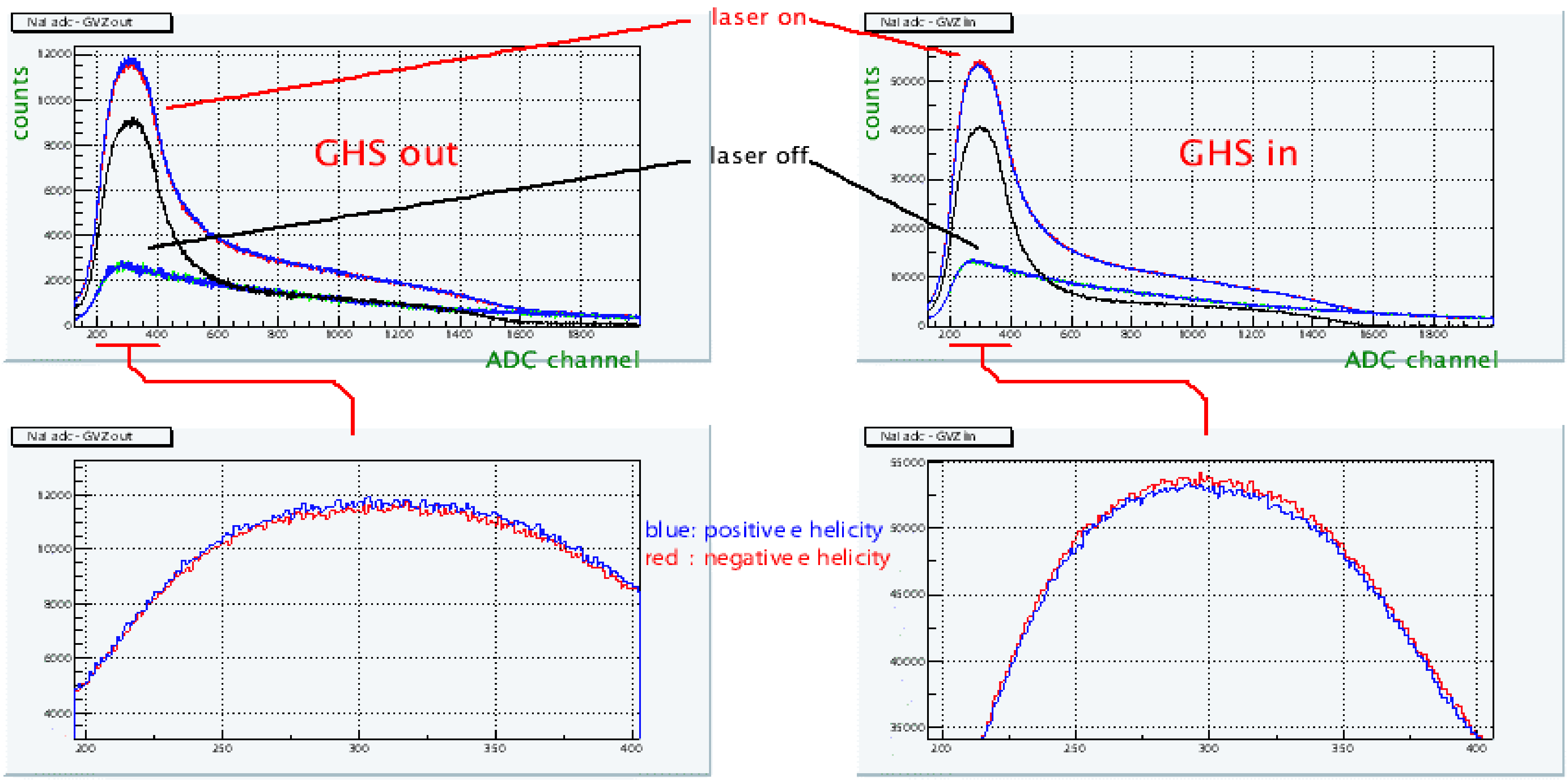
	A	δA
0.230 GeV^2	-5.44 ppm	0.60 ppm (0.54stat 0.26sys)
0.108 GeV^2	-1.36 ppm	0.27 ppm (0.24stat 0.13sys)


A^Pola at 854 MeV (5 min. runs)
A^Pola / ppm
weighted Mean: 52.2 ppm
standard deviation: 0.6 ppm (6.4%)
reduced chi^2: 1.008
Run-No.


A^Pola at 570 MeV (5 min. runs)
A^Pola / ppm
weighted Mean: 94.0 ppm
standard deviation: 1.3 ppm (6.9%)
reduced chi^2: 0.937
Run-No.

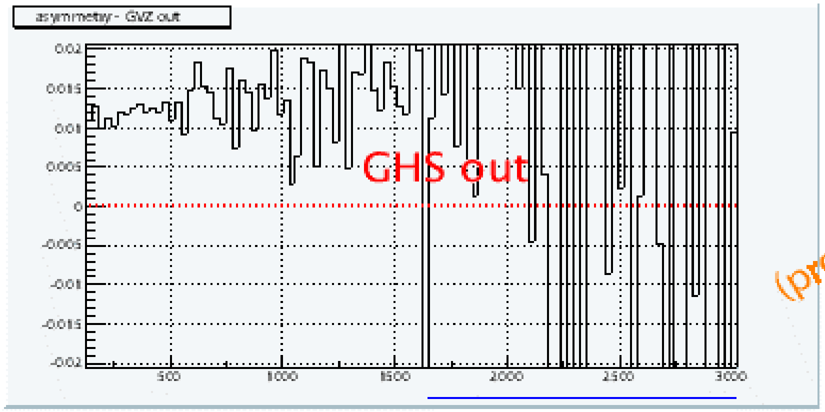
– measured first Compton asymmetry (Aug 2004)

Energy spectra for both electron helicities:



- measured first Compton asymmetry (Aug 2004)

Energy spectrum asymmetries:



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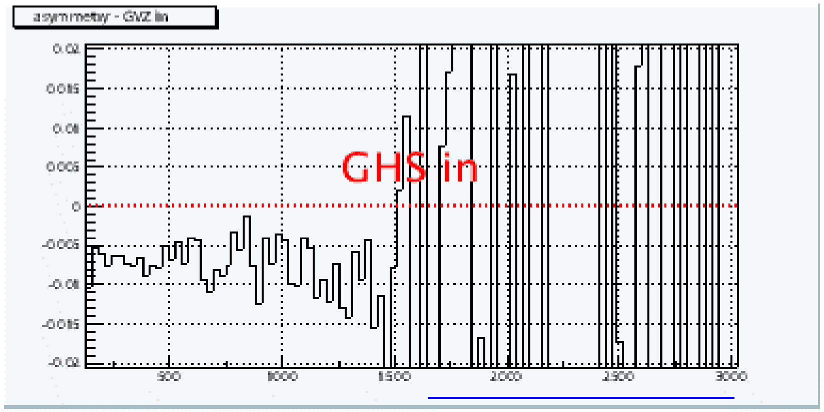
(preliminary)



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- quantitative analysis running
- check for possible systematics