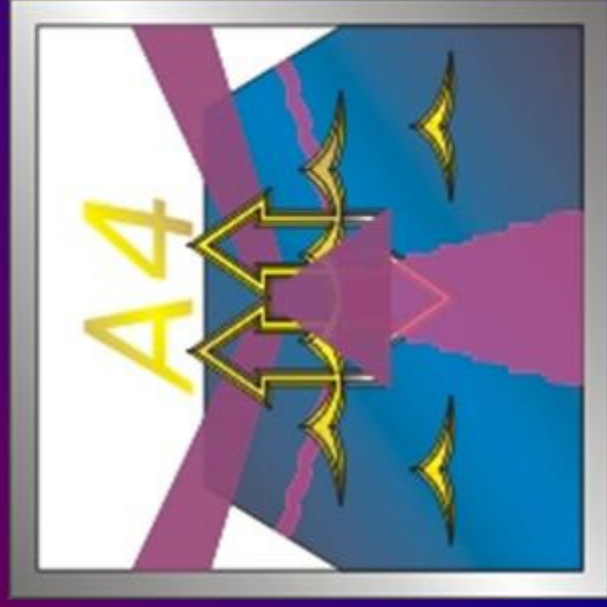


Status of the A4 Parity Violation Experiment



Simon Taylor
Ohio University
(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

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

Strange quark contribution:

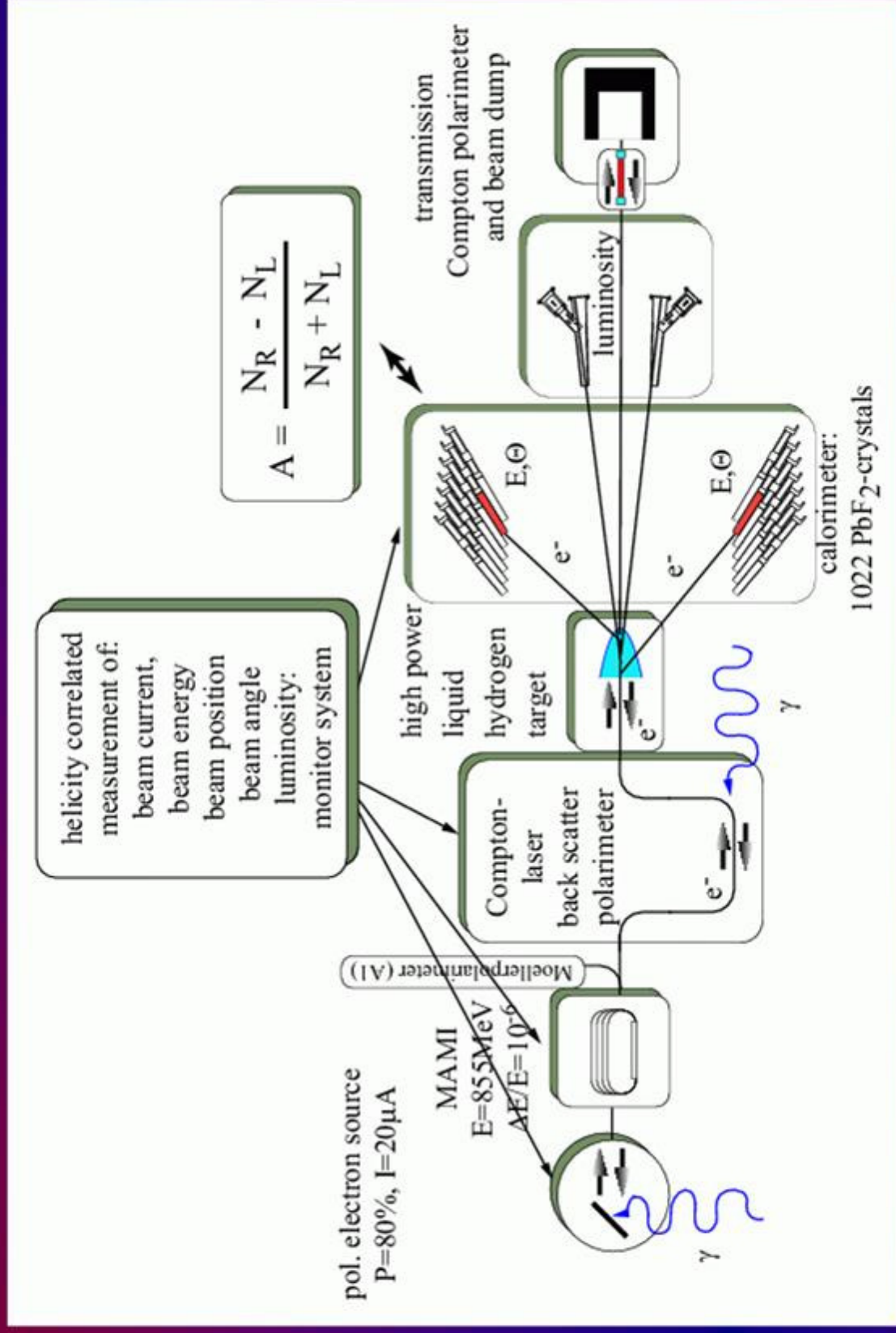
$$A_S = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \frac{\varepsilon G_E^p(G^s_E)^2 + \tau G_M^p(G^s_M)^2}{\varepsilon(G_E^p)^2 + \tau(G_M^p)^2}$$

Asymmetry in absence of strange quarks:

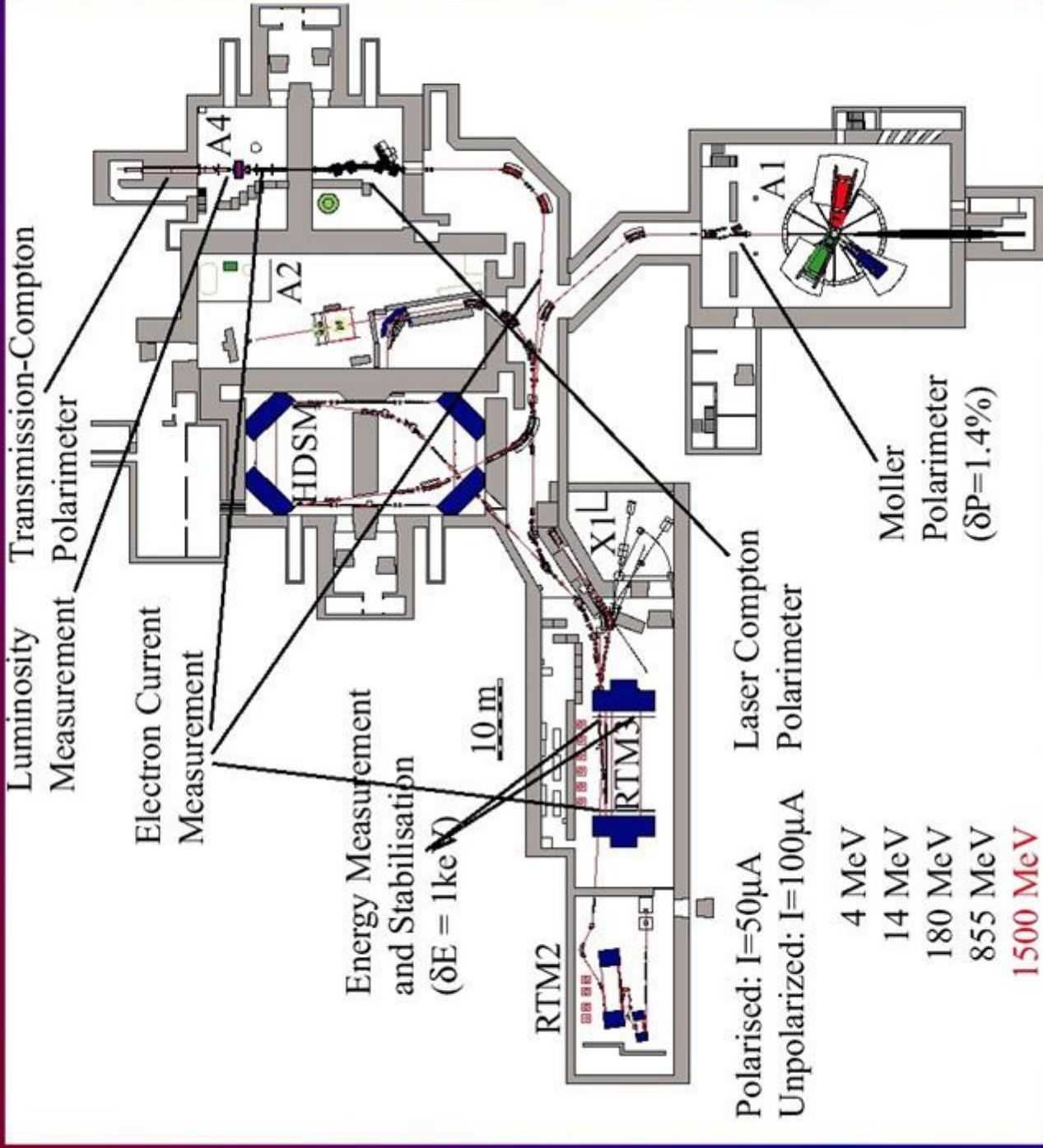
$$A_0 = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times [(1 - 4\sin^2\theta_W) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon(G_E^p)^2 + \tau(G_M^p)^2}] - \left\{ \frac{(1 - 4\sin^2\theta_W)\sqrt{1 - \varepsilon^2}\sqrt{\tau(1 + \tau)}G_M^p \tilde{G}_A^p}{\varepsilon(G_E^p)^2 + \tau(G_M^p)^2}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

- 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...

- $\Delta E < 1 \text{ keV}$
- $\Delta T < 0.1 \text{ K}$

• Measure energy, position, angle, current

Beam current $\sim 20 \mu\text{A}$

- Stabilized to $\delta I/I \approx 10^{-3}$
- Polarization $\sim 80\%$

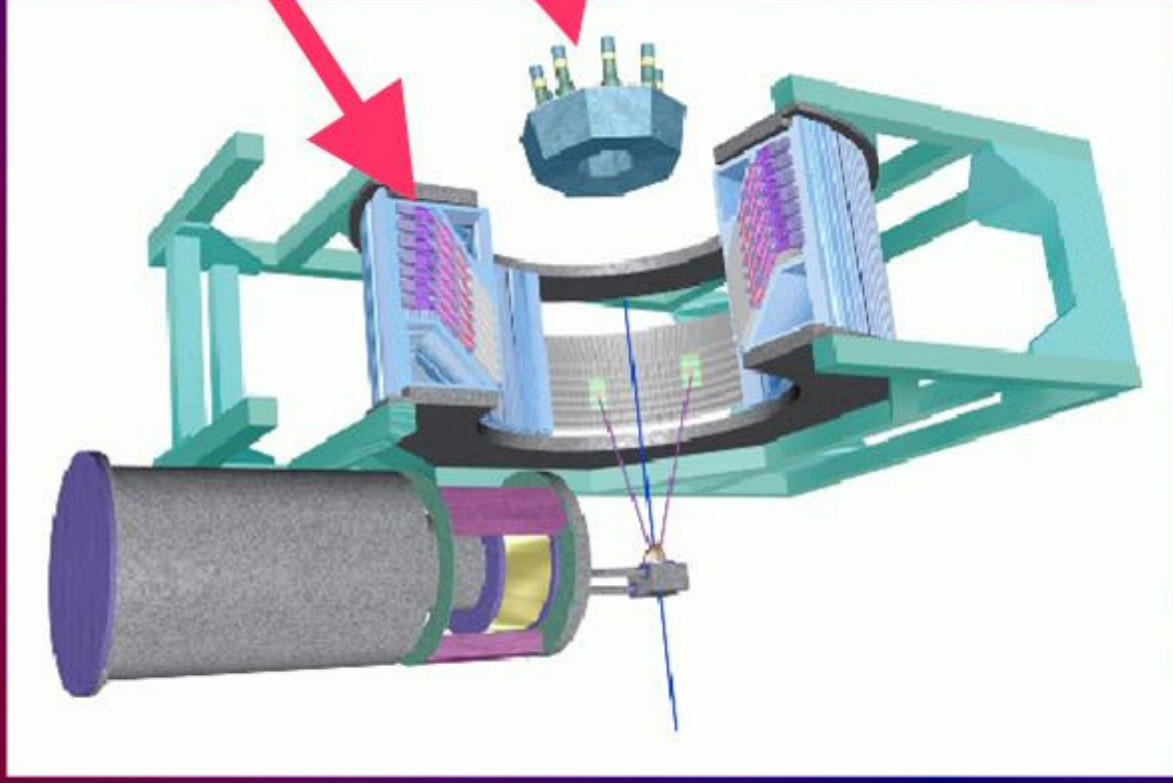
Experimental arrangement in A4 Hall

Fast PbF₂ calorimeter

- 1022 crystals in 146 frames
- $\theta = 30-40^\circ$, $\varphi = 0-360^\circ$

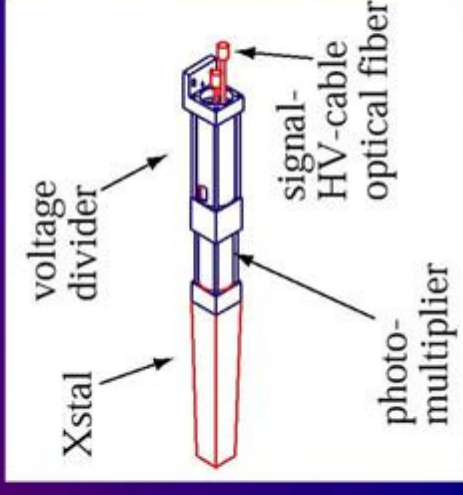
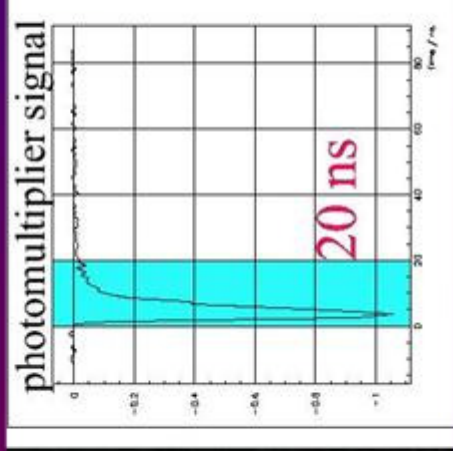
Luminosity monitors

- 8 integrating Cherenkov detectors filled with water
- $\theta = 4.4-10^\circ$, $\varphi = 0-360^\circ$

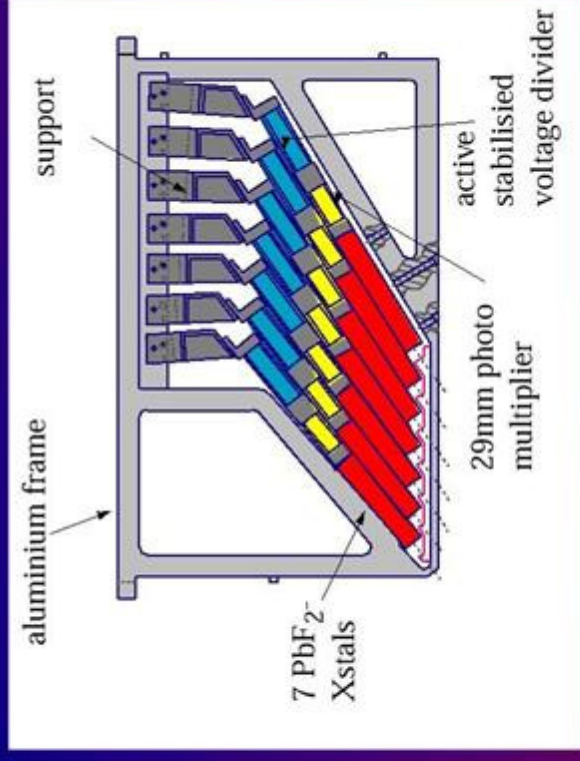


Full coverage in azimuthal angle φ

The A4 Fast Calorimeter

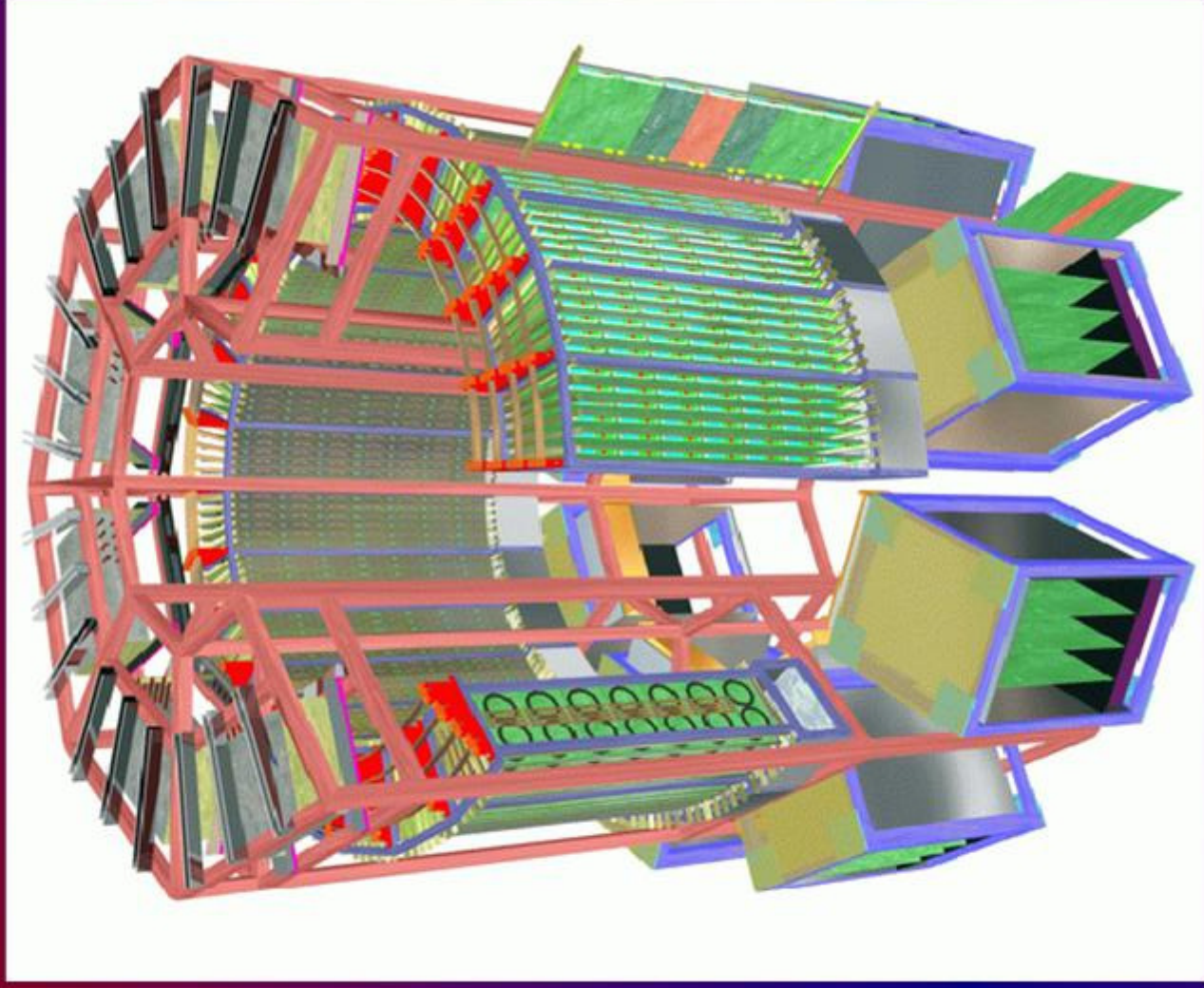


- Crystals: $\text{PbF}_2 \rightarrow$ Cherenkov light
- Very dense: $\rho = 7.8 \text{ g/cm}^3$,
 - $r_M = 1.8 \text{ cm}$, $X_0 = 0.9 \text{ cm}$
- Fast timing characteristics
- Energy resolution, 3×3 array:
 - $\delta E / E = 3.9\% / \sqrt{E}$ (elastic peak)



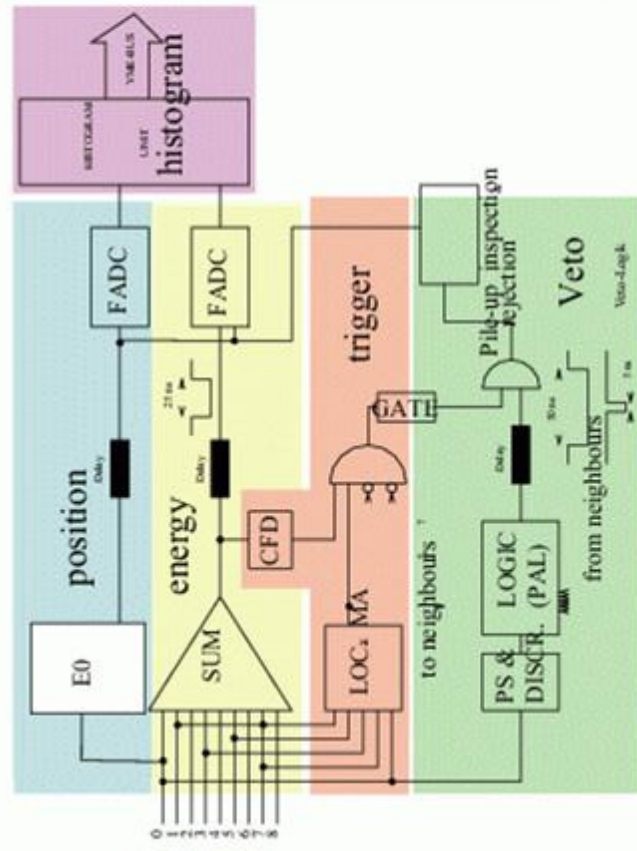
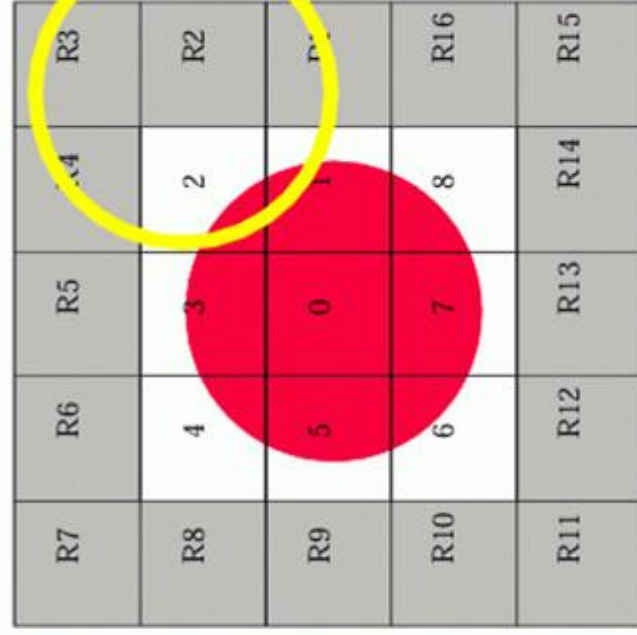
Electronics

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

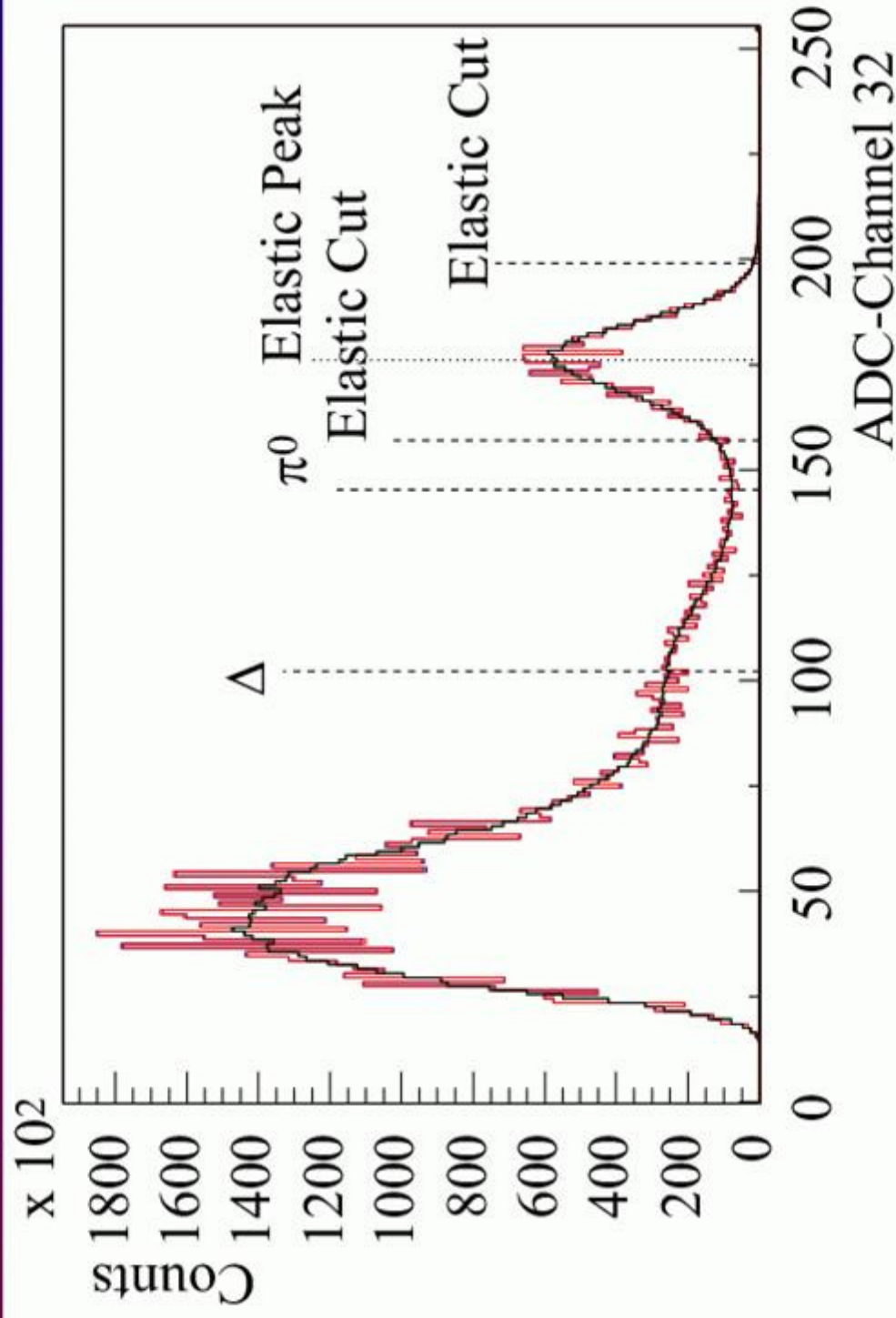


Electronics II

- 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 \rightarrow 3D histogram



Energy Spectrum



For $Q^2=0.108 \text{ (GeV/c)}^2$, 16×10^6 histograms $\rightarrow 10^{13}$ 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
- $A_{\text{raw}} = (N^+/\rho^+ - N^-/\rho^-) / (N^+/\rho^+ + N^-/\rho^-)$
- 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

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

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

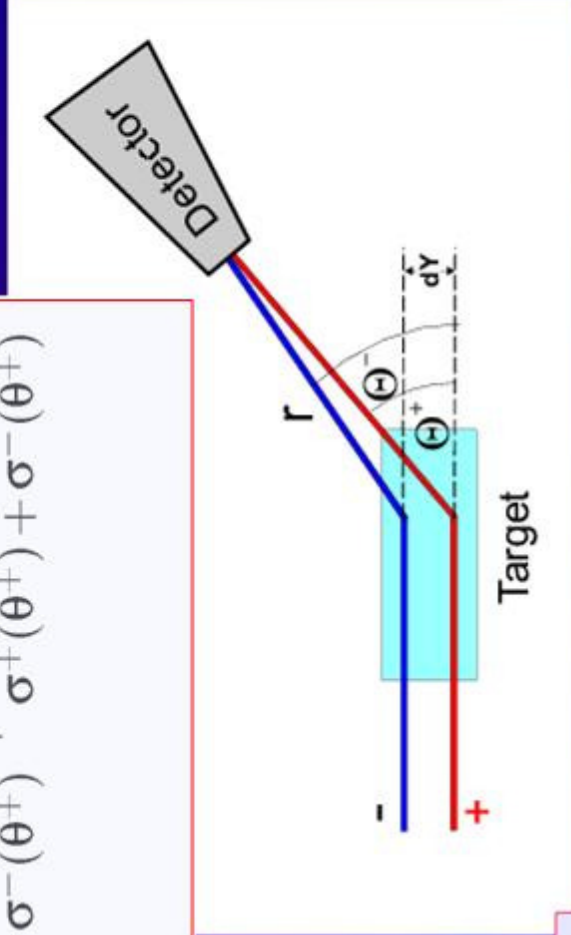
Systematic differences in (for example) position of beam on target for different helicity states
 → false asymmetries.

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

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

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

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



Asymmetry result and systematic errors

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

	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
$\Delta x, \Delta y$	-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

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

	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
$\Delta x, \Delta y$	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

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

- Weak mixing angle: $\sin^2\theta_W = 0.23113(15)$ at M_Z in MS-bar scheme
- G_E^p, G_E^n from parametrization of Friedrich and Walcher
- Assume $\delta G_M^p / G_M^p = \delta G_E^p / G_E^p = 3\%$, $\delta G_M^n / G_M^n = 5\%$, $\delta G_E^n / G_E^n = 10\%$
- Electroweak radiative corrections evaluated in MS-bar scheme
 - $\sim -1\%$ correction (following Marciano and Sirlin) to first line of expression
 - effects also included in G_A^p (from Zhu, et al.)
- Correct for electromagnetic radiative effects + energy loss in target
 - -1.3% correction to A_0

Asymmetry without Strangeness II

$$A_0(0.23 \text{ GeV}^2) = -6.30 \pm 0.44 \text{ ppm}$$

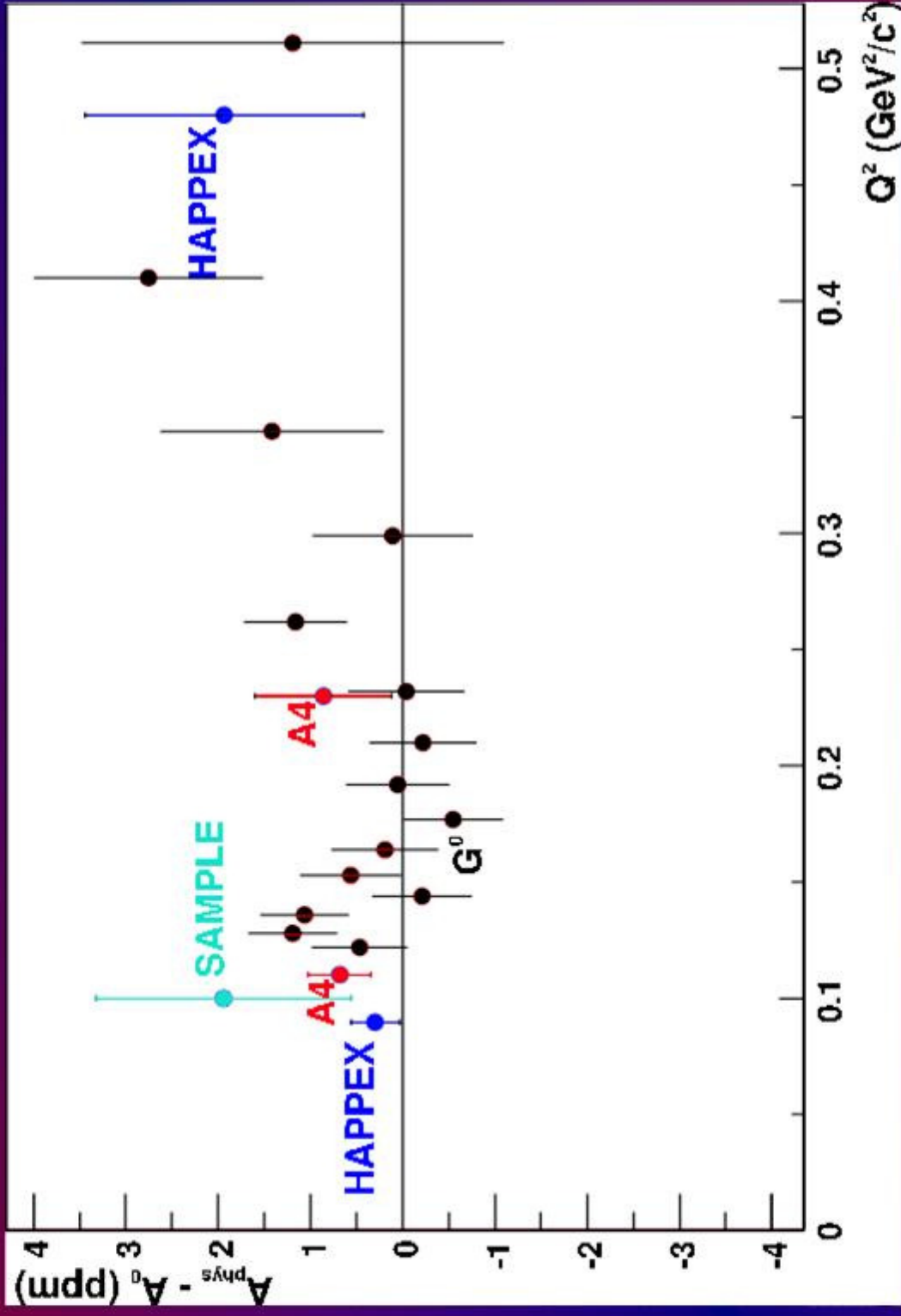
$$A_0(0.11 \text{ GeV}^2) = -2.06 \pm 0.14 \text{ ppm}$$

Error Contributions in ppm

E=854.3 MeV E=570.4 MeV

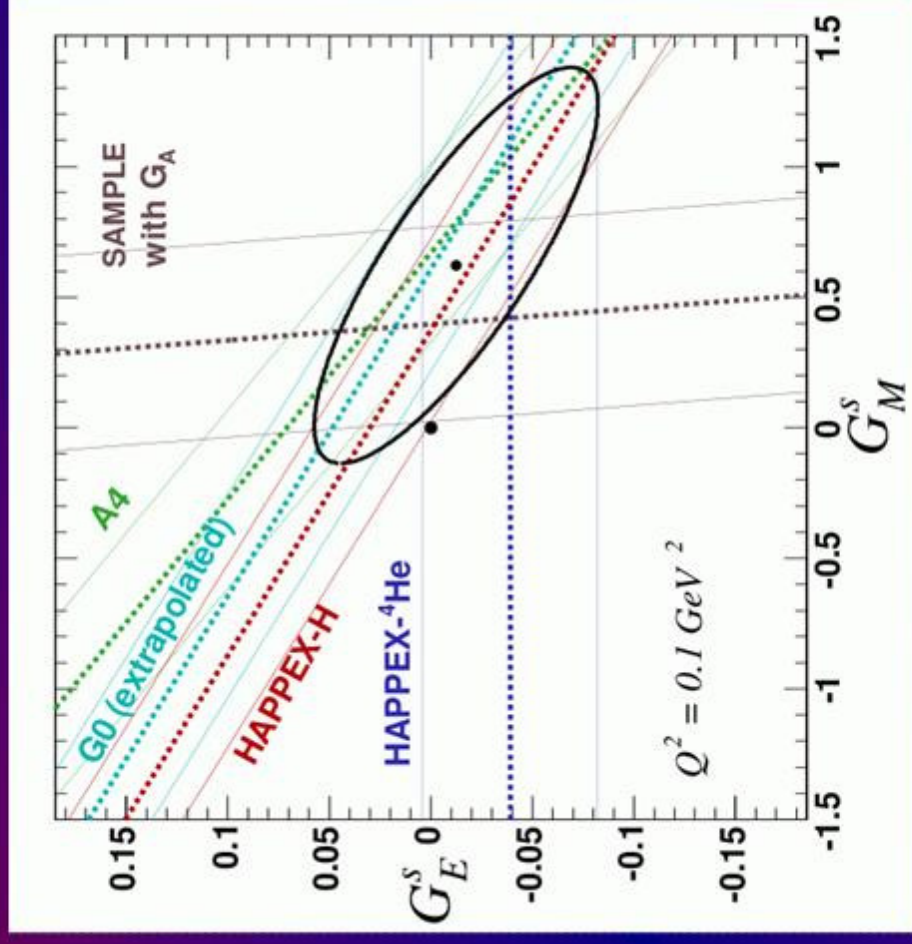
G_F	0.00	0.00
$\hat{s}_Z^2 = \sin^2 \Theta_W$	0.02	0.01
G_E^P	0.21	0.07
G_M^P	0.07	0.03
G_E^n	0.12	0.04
G_M^n	0.27	0.07
\tilde{G}_A^P	0.24	0.09
Sum	0.44	0.14

Comparison to World Data



Comparison to World Data II

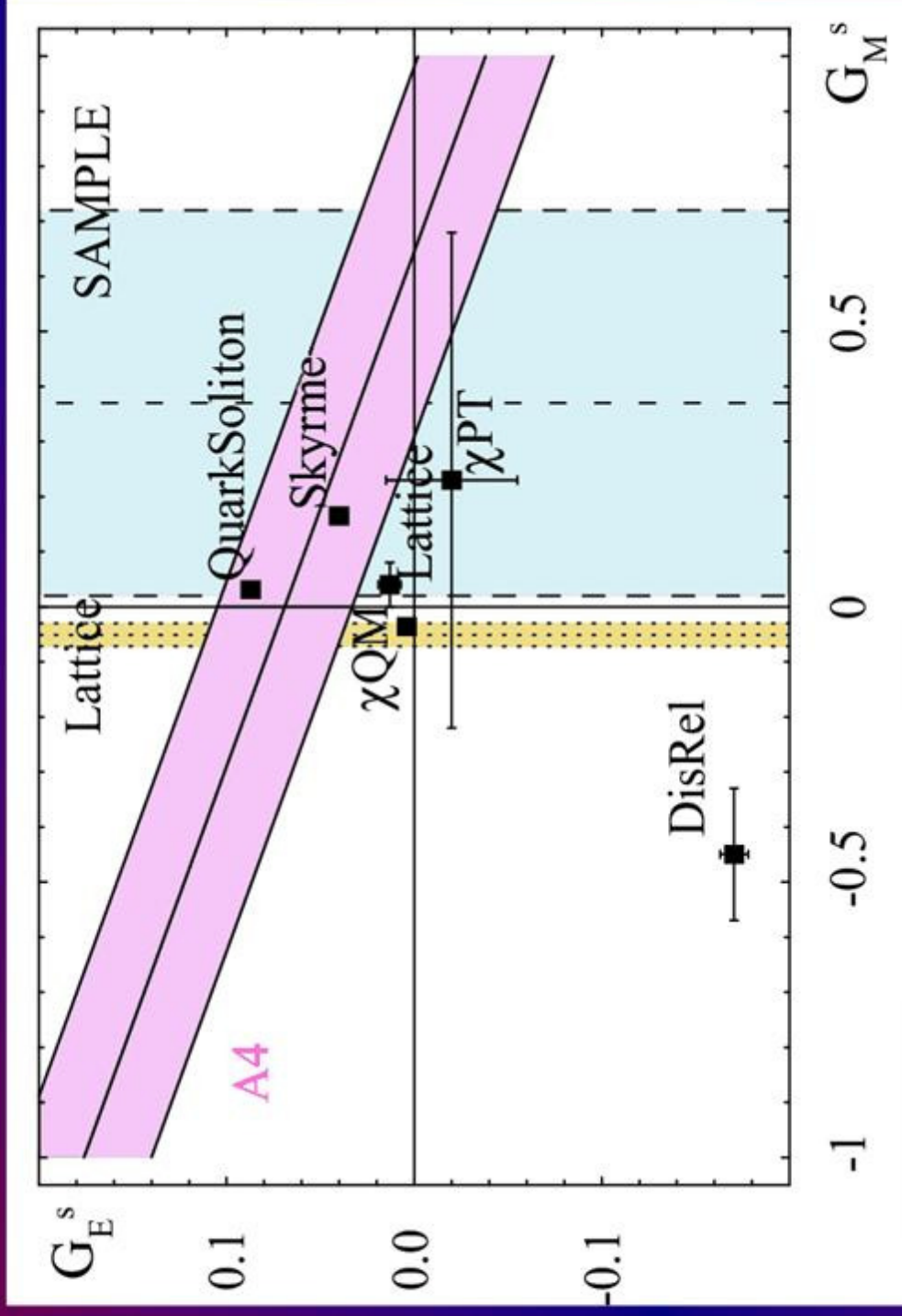
At $Q^2=0.108 \text{ (GeV/c)}^2$, $G_E^S + 0.106 G_M^S = 0.071 \pm 0.036$



$G_M^S = 0.62 \pm 0.31$, $G_E^S = -0.012 \pm 0.029$

Comparison to Theory

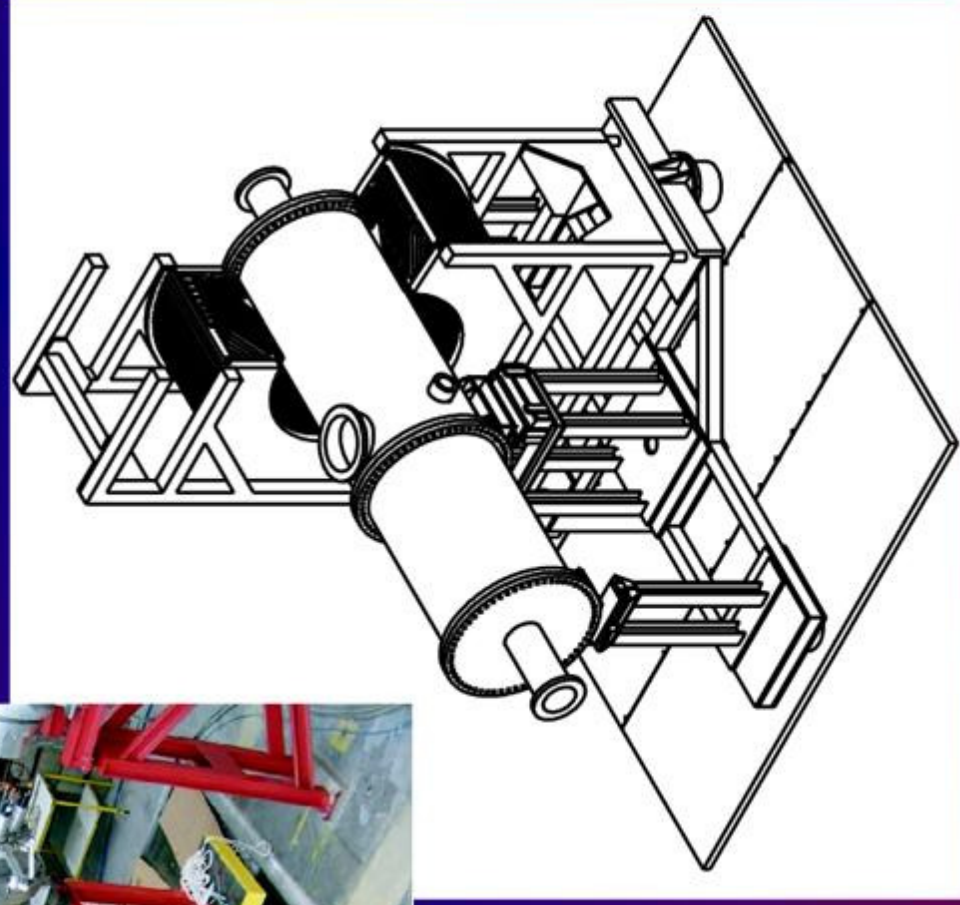
At $Q^2=0.108 \text{ (GeV/c)}^2$, $G_E^s = 0.071 \pm 0.036$



Future plans: backward angle



$$140^\circ < \theta_e < 150^\circ$$



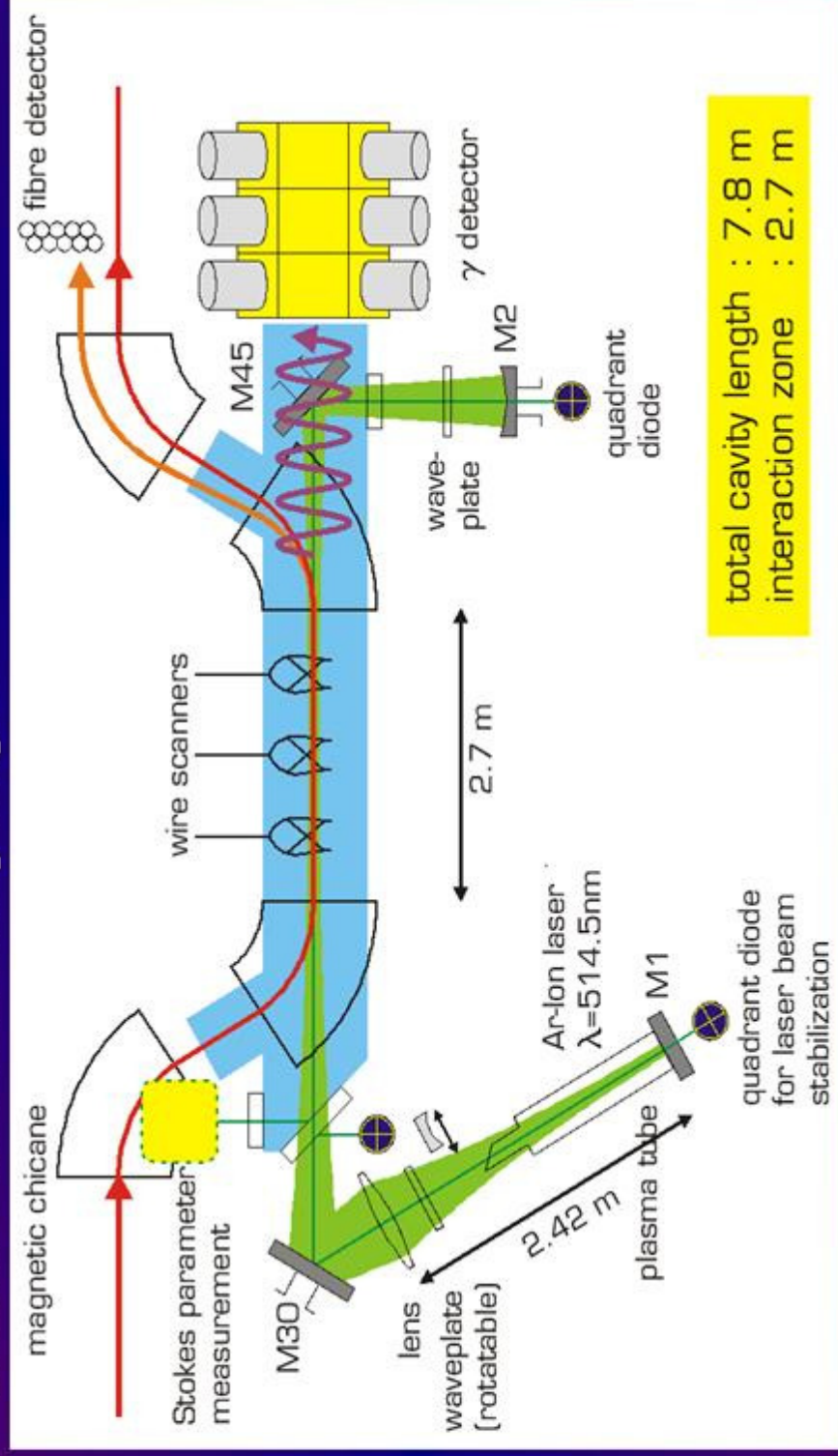
Proton, deuteron targets

→ separate G_E^s and G_M^s

Commissioning started,
run coming up...

Compton Back-scatter Polarimeter

- Scatter **green** laser light off electron beam
- Intra-cavity design → maximize interaction region
- Achieved ~90 W (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 $Q^2=0.108 \text{ (GeV/c)}^2$, $G_E^S + 0.106 G_M^S = 0.071 \pm 0.036$
 - At $Q^2=0.230 \text{ (GeV/c)}^2$, $G_E^S + 0.225 G_M^S = 0.039 \pm 0.034$
- $G_E^S + b G_M^S > 0$ by $\sim 1-2$ standard deviations
 - Combination with world data suggests $G_M^S > 0$
- Beam polarization = significant source of error
 - Compton Polarimeter development
- Backward angle measurement coming up soon...

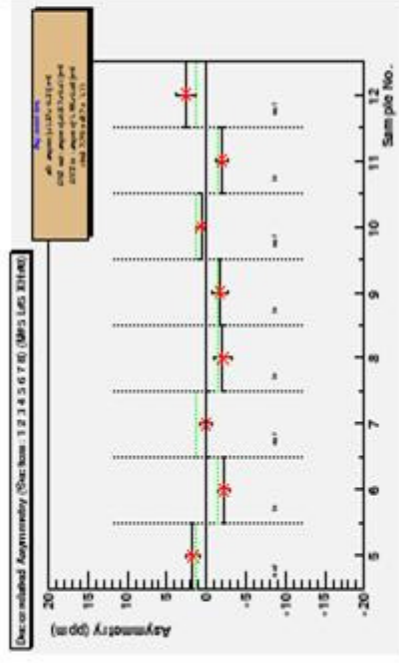
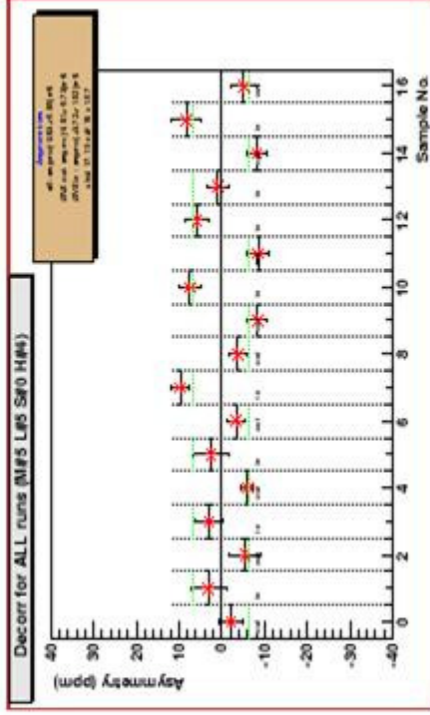
Backup slides



$\lambda/2$ -Samples

854 MeV (0.227 GeV²)

570 MeV (0.101 GeV²)



A

0.230 GeV²

-5.44 ppm

0.60 ppm (0.54stat 0.26sys)

0.108 GeV²

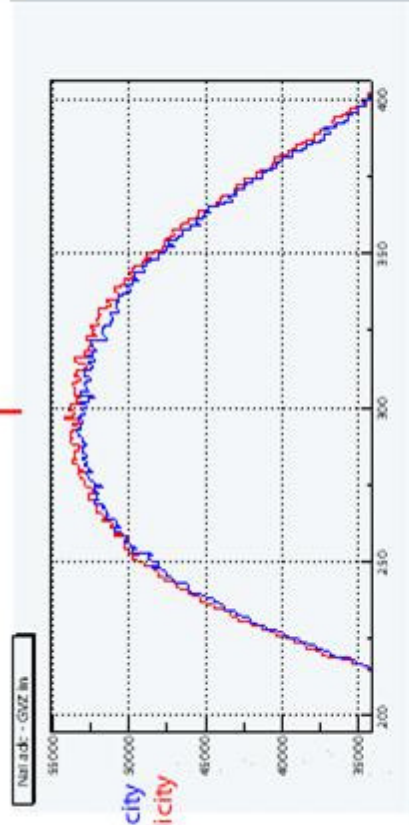
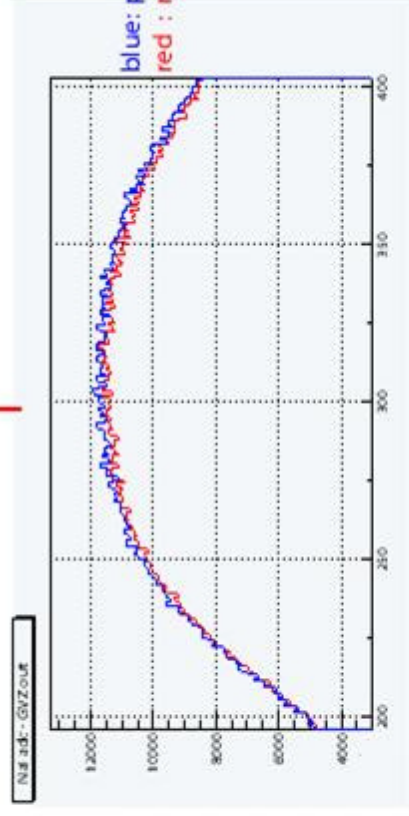
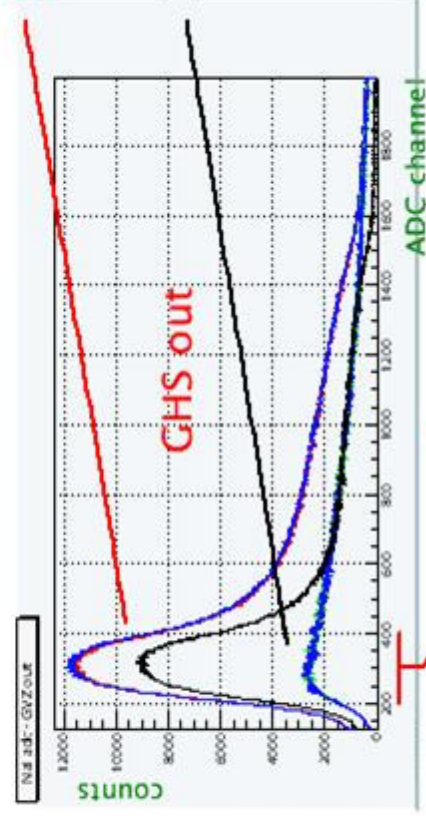
-1.36 ppm

0.27 ppm (0.24stat 0.13sys)

δA

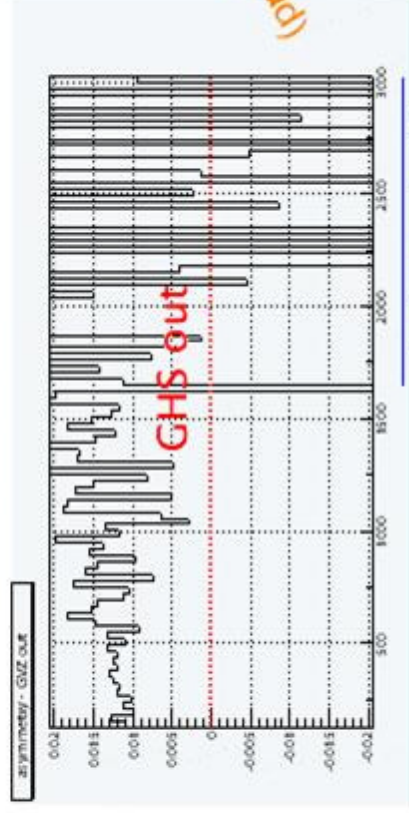
- measured first Compton asymmetry (Aug 2004)

Energy spectra for both electron helicities:

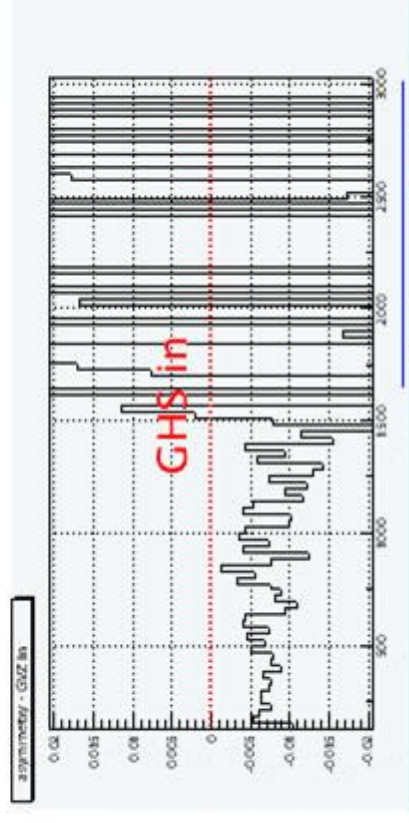


– measured first Compton asymmetry (Aug 2004)

Energy spectrum asymmetries:



(background only)



(background only)

- quantitative analysis running
- check for possible systematics