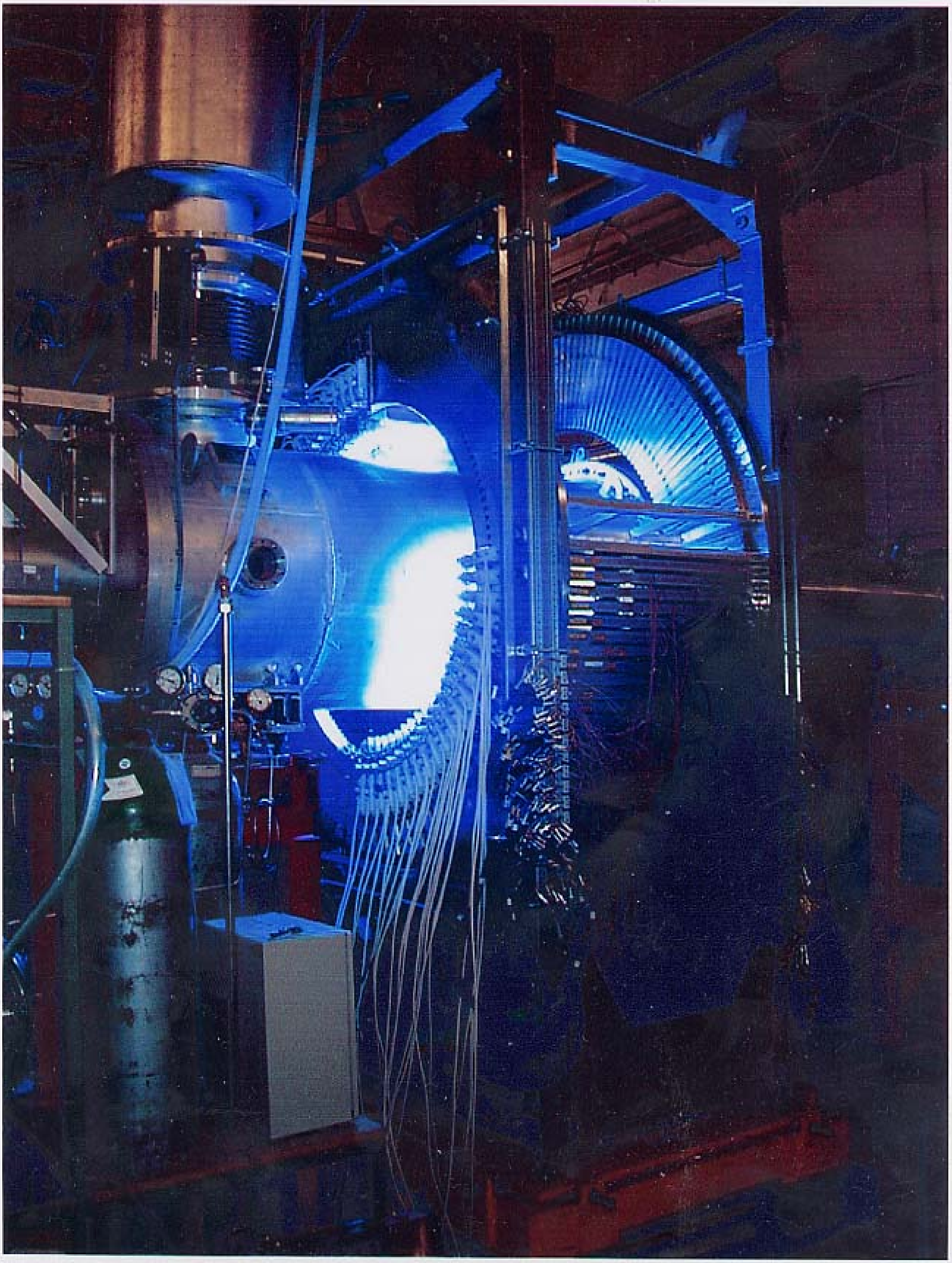
Parity Violating Electron Scattering at MAMI



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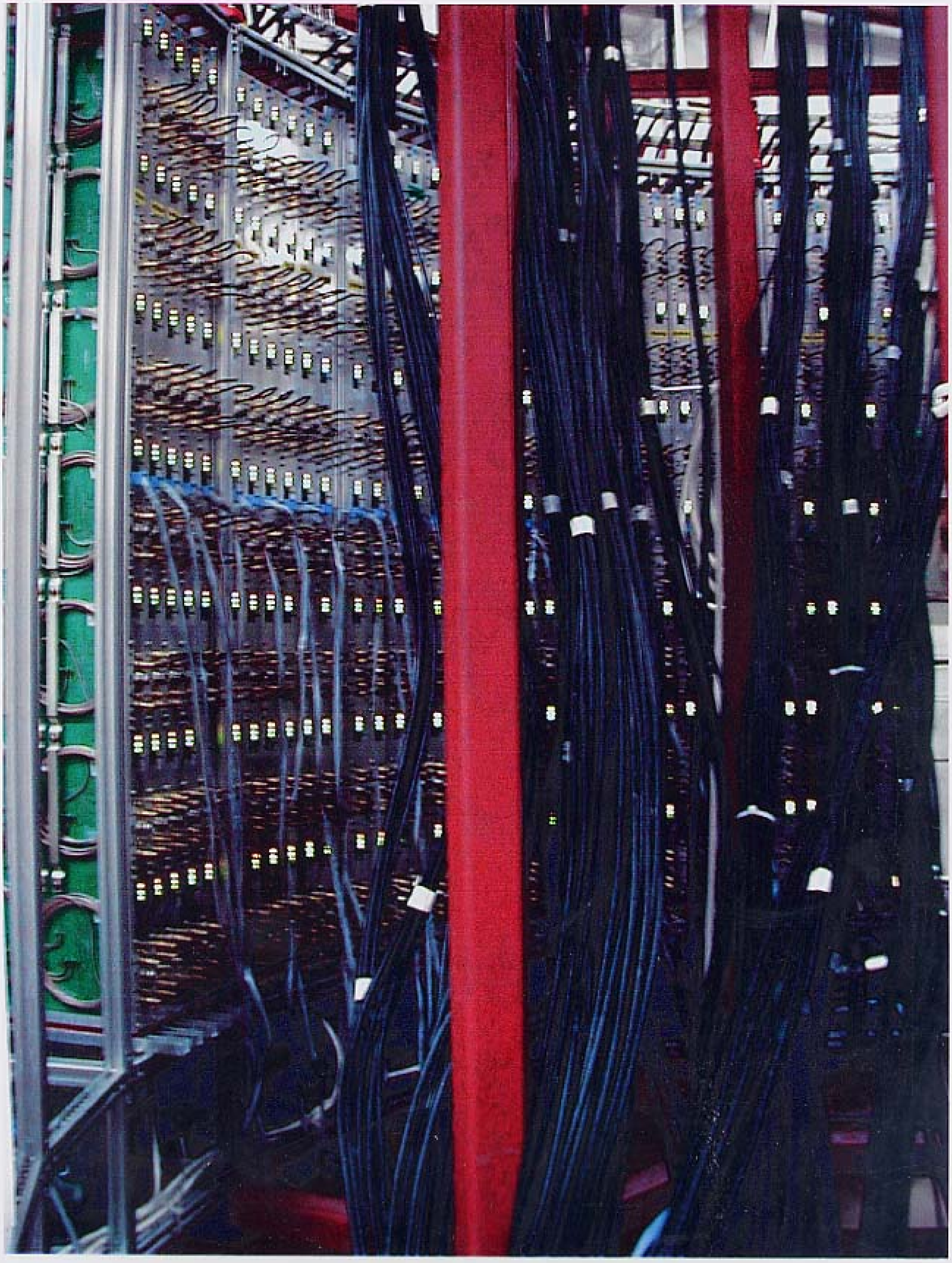

From Parity Violation to Hadronic Structure and more ...

Part I : Mainz June 5-8, 2002

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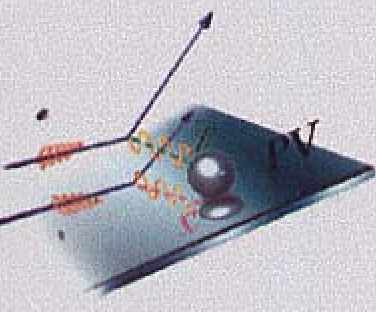

http://www.kph.uni-mainz.de/de/conf/pavi2002

Part II : Grenoble February 2004

Institut des Sciences Nucléaires CNRS-IN2P3, UJF

Crédits photos et logo : Fremdenverkehrsbüro der Stadt Mainz • Maison du tourisme de Grenoble • B. Caplain • J.G. Nosé Dapnia-CEA Saclay
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summary

strange vector form factors by
PV electron scattering

first time counting techniques used
in PV experiment

450 hours data (1200 hours in real time)

A_{phys} = -7.7 ppm +- 1.2 ppm (15% stat)
+- 0.9 ppm (12% sys)

A_{phys}-A_0 = -2.0 ppm+- 1.2 ppm(stat.)
+ -0.8 ppm (nonlin)
+ -0.4 ppm (pol.)

A4

forward scattering, Θ=35
Q^2=0.23GeV^2
δA_{stat}=5.3%

SAMPLE (backwards)
Q^2=0.1GeV^2
δA_{stat}=5.1%

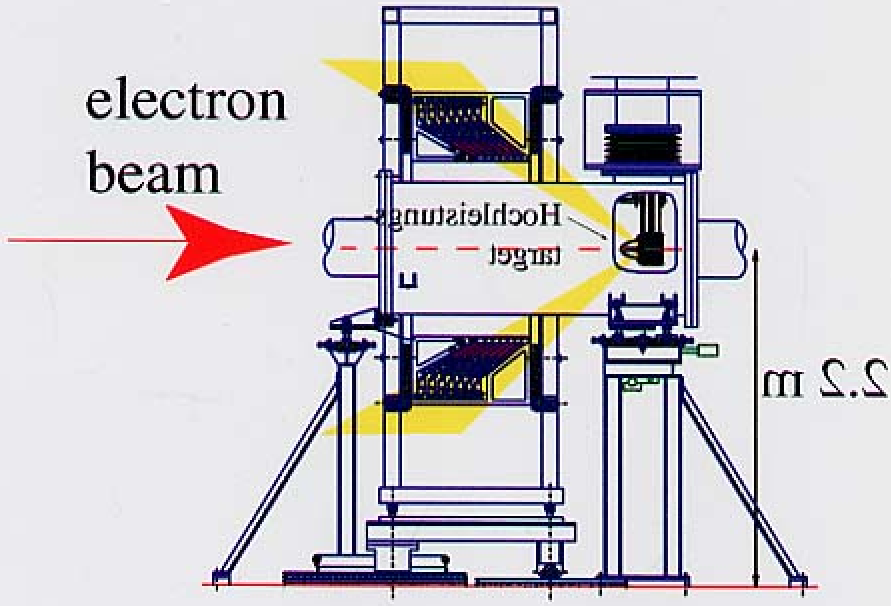
backward scattering, Θ=145°
Q^2=0.23GeV^2
δA_{stat}=3.2%

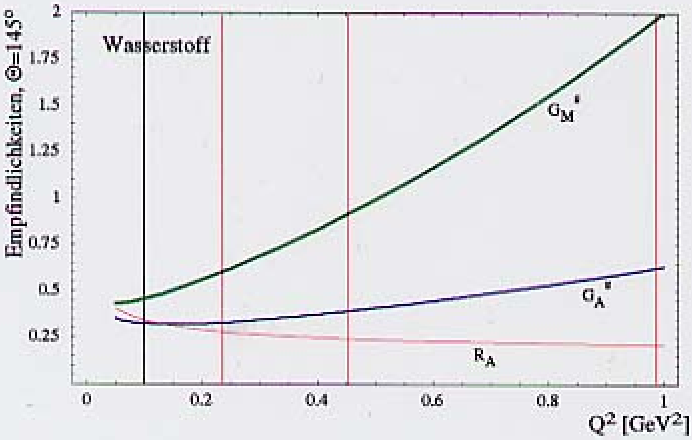
HAPPEX (forward)
Q^2=0.45GeV^2
δA_{stat}=3.2%

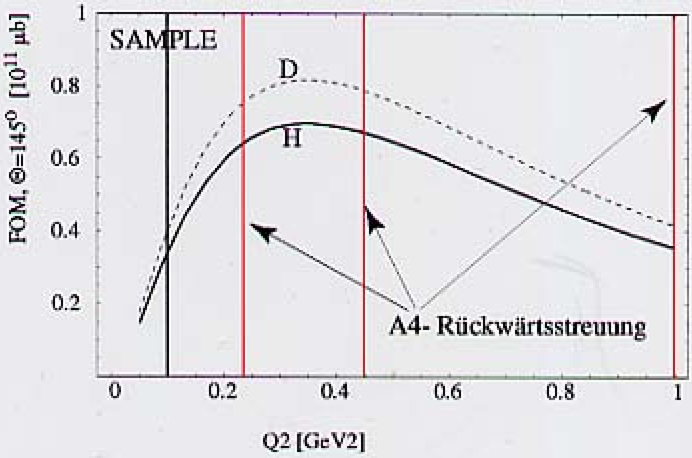
first time flavor decomposition possible

scattering with θ=145°

$$A^p = A_0^p \left(1 - \frac{(\epsilon + \tau\,\mu_p)\,F_1^s + \tau\,(\mu_p - \epsilon)\,F_2^s + \frac{1}{2}\delta\,\mu_p\,G_A^s}{4K}\right)$$



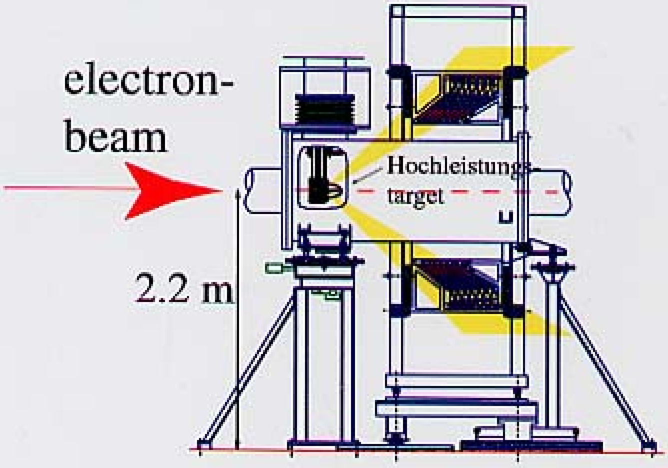


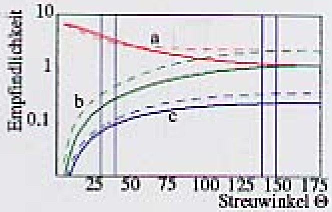


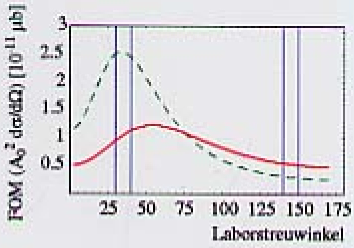
E=817MeV	Q^2=0.94GeV^2	δA_{stat}=8.4%	δA_{stat}=4.2%
E=506MeV	Q^2=0.47GeV^2	δA_{stat}=6.3%	δA_{stat}=3.2%
E=318MeV	Q^2=0.23GeV^2	δA_{stat}=6.3%	δA_{stat}=3.2%

scattering at θ=35°

$$A^p = A_0^p \left(1 - \frac{(\epsilon + \tau\,\mu_p)\,F_1^s + \tau\,(\mu_p - \epsilon)\,F_2^s + \frac{1}{2}\delta\,\mu_p\,G_A^s}{4K}\right)$$

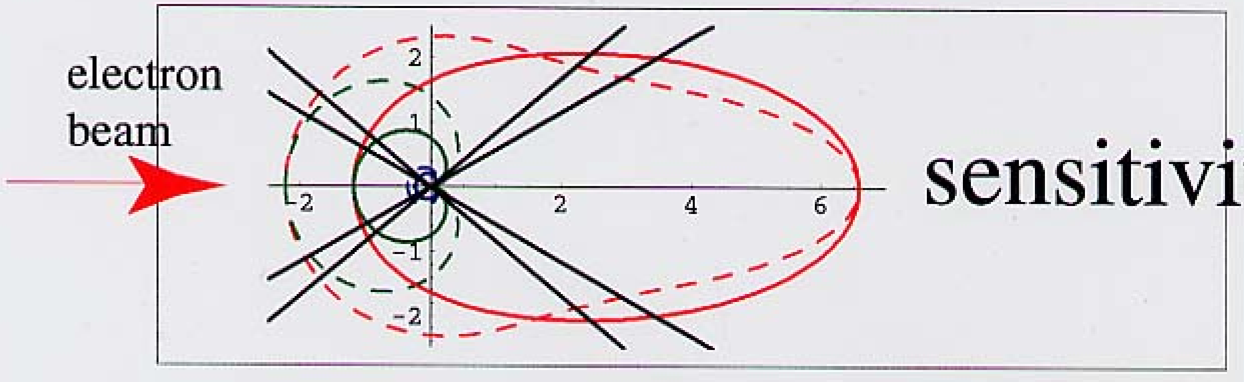


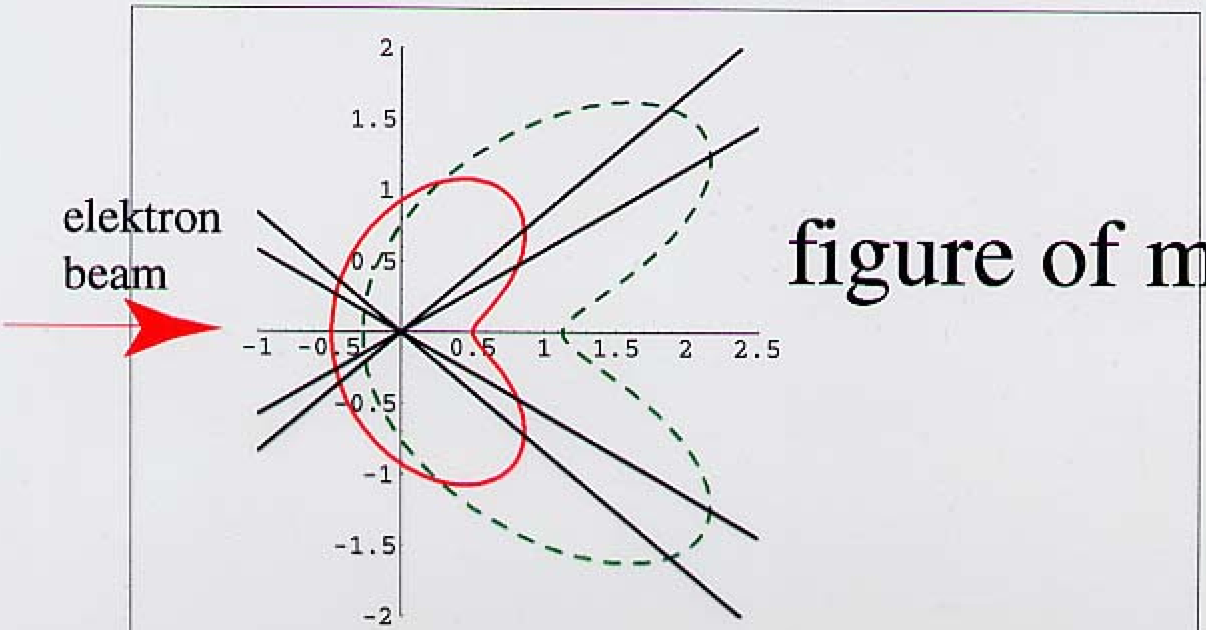




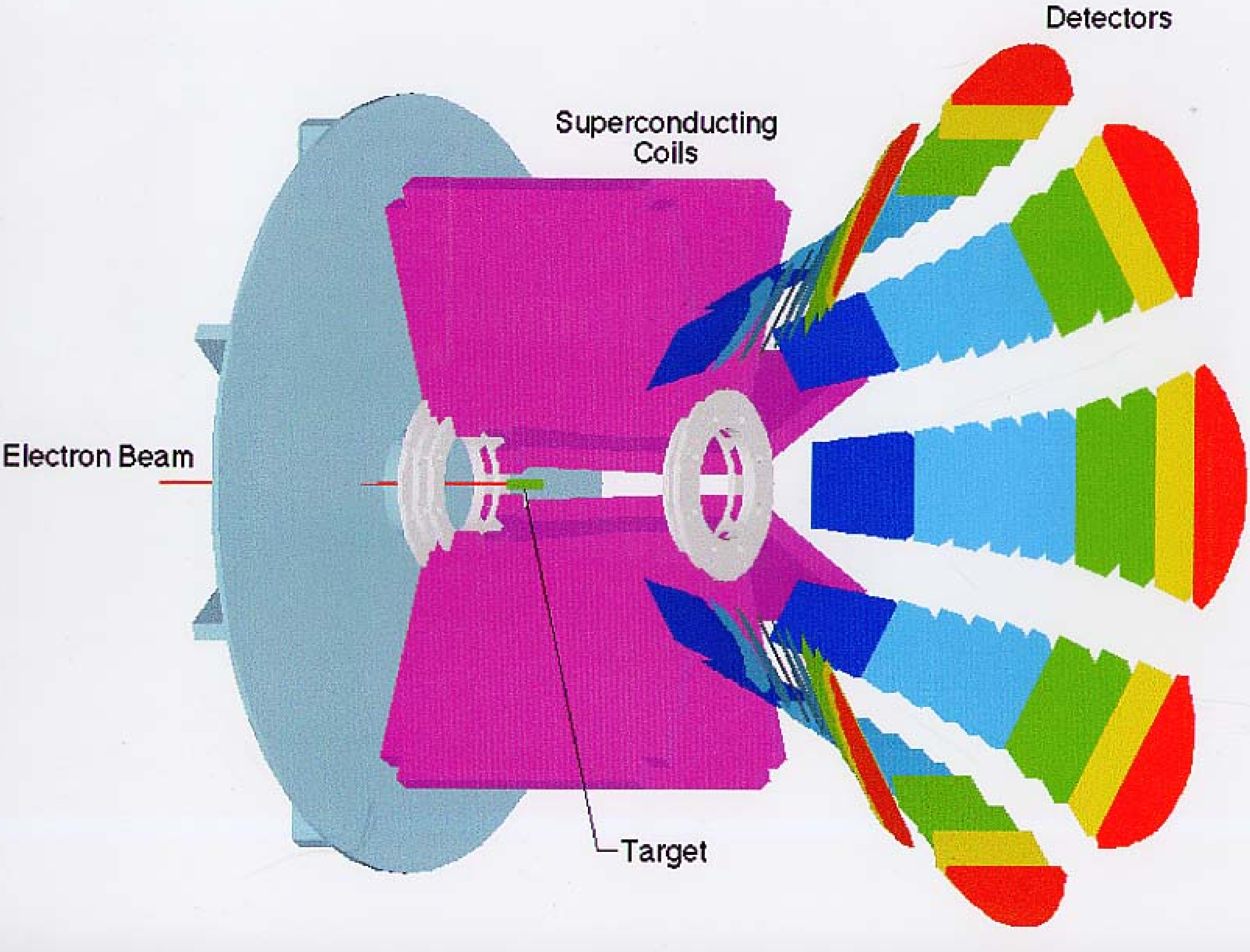
E=855MeV Q^2=0.227GeV^2 δA_{stat}=3.2%

E=570MeV Q^2=0.1GeV^2 δA_{stat}=5.1%





G0 Experiment

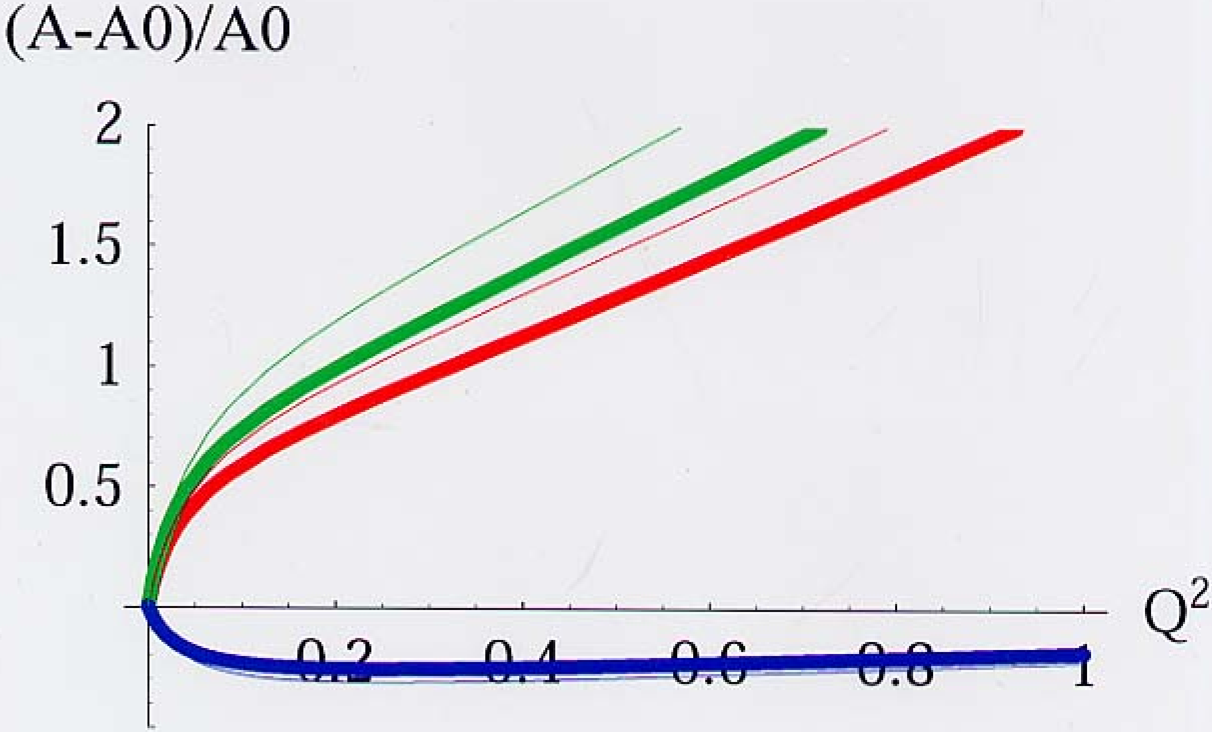


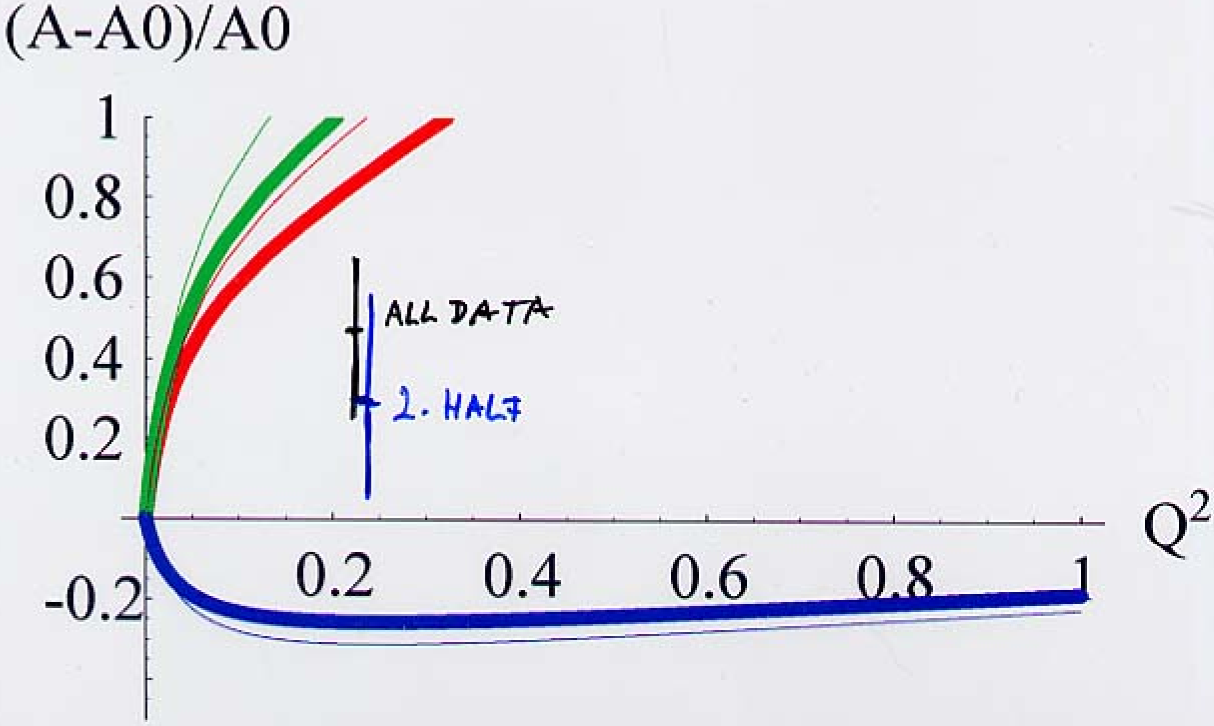
HAPPEX II (proton) and ^{4}He

- JLab, Hall A
- Use HRS (3.7 msr×2) & septum magnets → $\theta = 6°$
- $\langle Q^2 \rangle = 0.1\ (\mathrm{GeV}/c)^2$ [$E_0 = 3.2$ GeV]
- 100 μA, 80% polarization, 30 ms helicity-flip
- Polarimetry: Hall A Møller & Compton (2%)
- Integrating; total absorption Cerenkov counters

	HAPPEX II	^{4}He
Rate/arm	65 MHz	11.9 MHz
$\langle A \rangle$	1.63 ppm	8.43 ppm
$\delta A/A$	5.4%	3.0%
Backgrounds ($\delta A/A$)	0.75%	0.2%

comparision with data

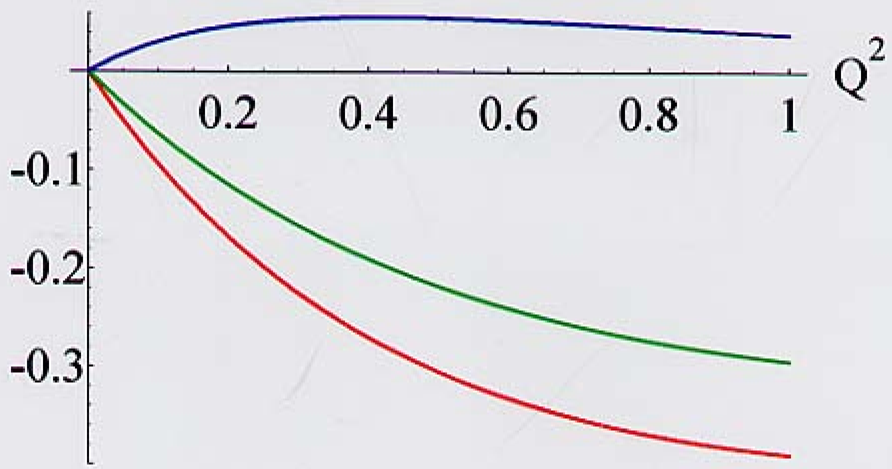




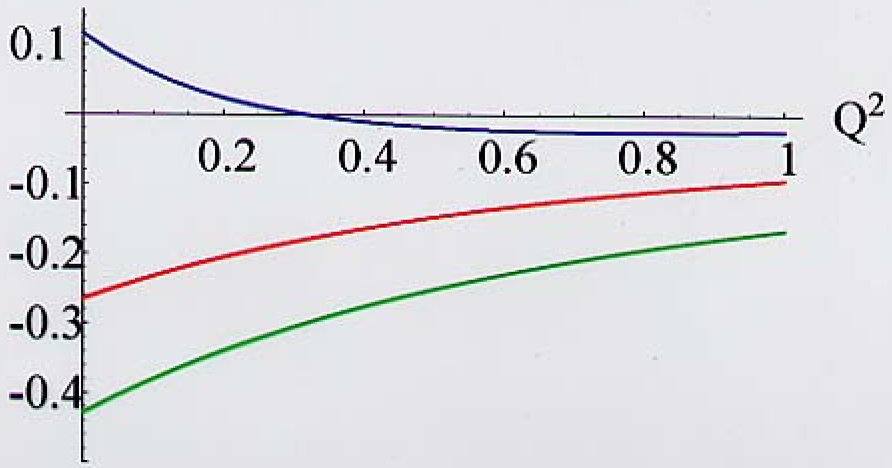
model predictions

red:	pole fit: Hammer, Drechsel et al.
green:	pole fit: Jaffe
blue:	light quarks with instanton forces: Kim/Goeke

F_1s



F_2s



(A-A0)/A0
-preliminary-

A0=-5.7ppm	0-11:	-7.7ppm+-1.2ppm (stat.)
		+-0.8ppm (nonlin)
		+-0.4ppm (pol.)
	0-5:	-9.4ppm+-2.3ppm (stat.)
		+-3.4ppm (nonlin)
		+-0.5ppm (pol.)
	6-11:	-7.1ppm+-1.4ppm (stat.)
		+-0.6ppm (nonlin)
		+-0.4ppm (pol.)

all samples:

0-11 (A-A0)/A0 = (0.45+-0.21+-0.14+-0.07)

first half

0-5 (A-A0)/A0 = (0.74+-0.40+-0.60+-0.09)

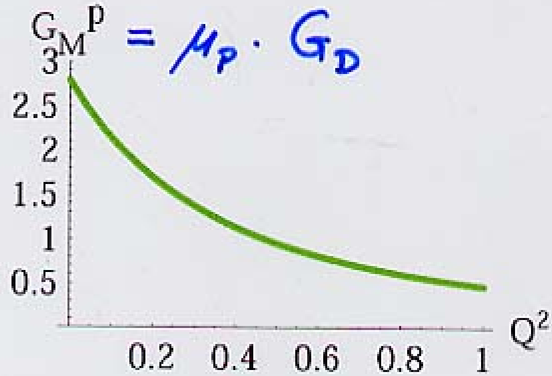
second half

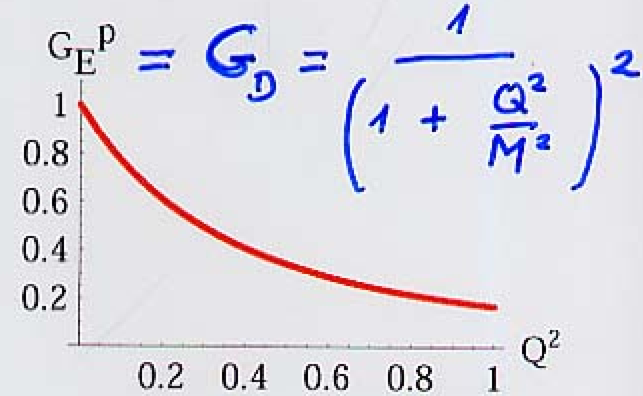
5-11 (A-A0)/A0 = (0.31+-0.24+-0.11+-0.07)

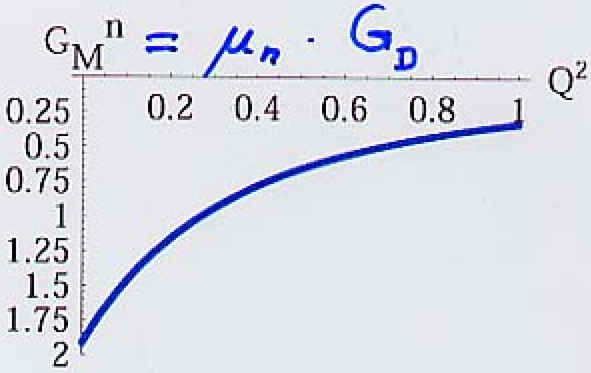
A_0

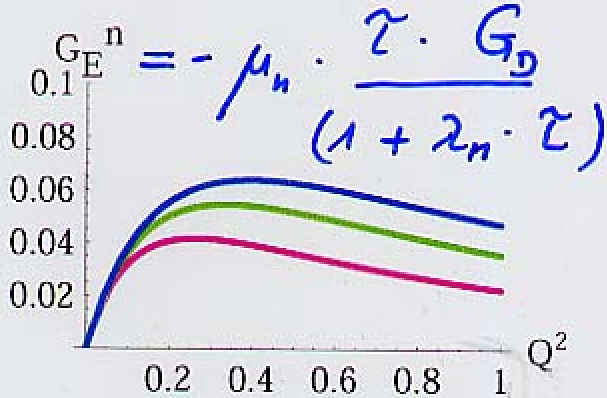
$G_E^p, G_M^p, G_E^n, G_M^n$

μ_p	= 2.79284739
μ_n	= -1.91304428
GD: M	= 840MeV
λ_D	= 4.99
λ_n	= 3.4



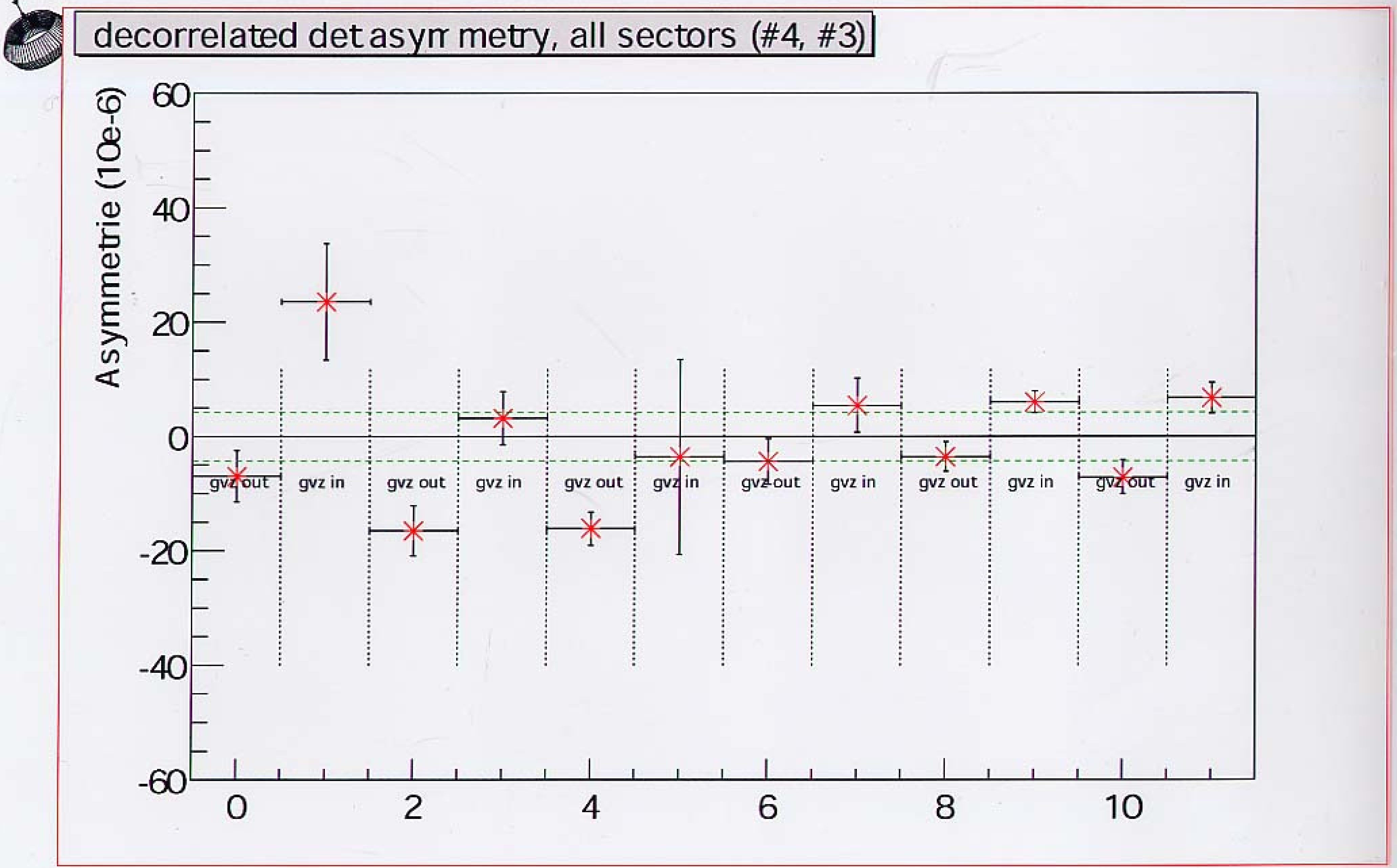




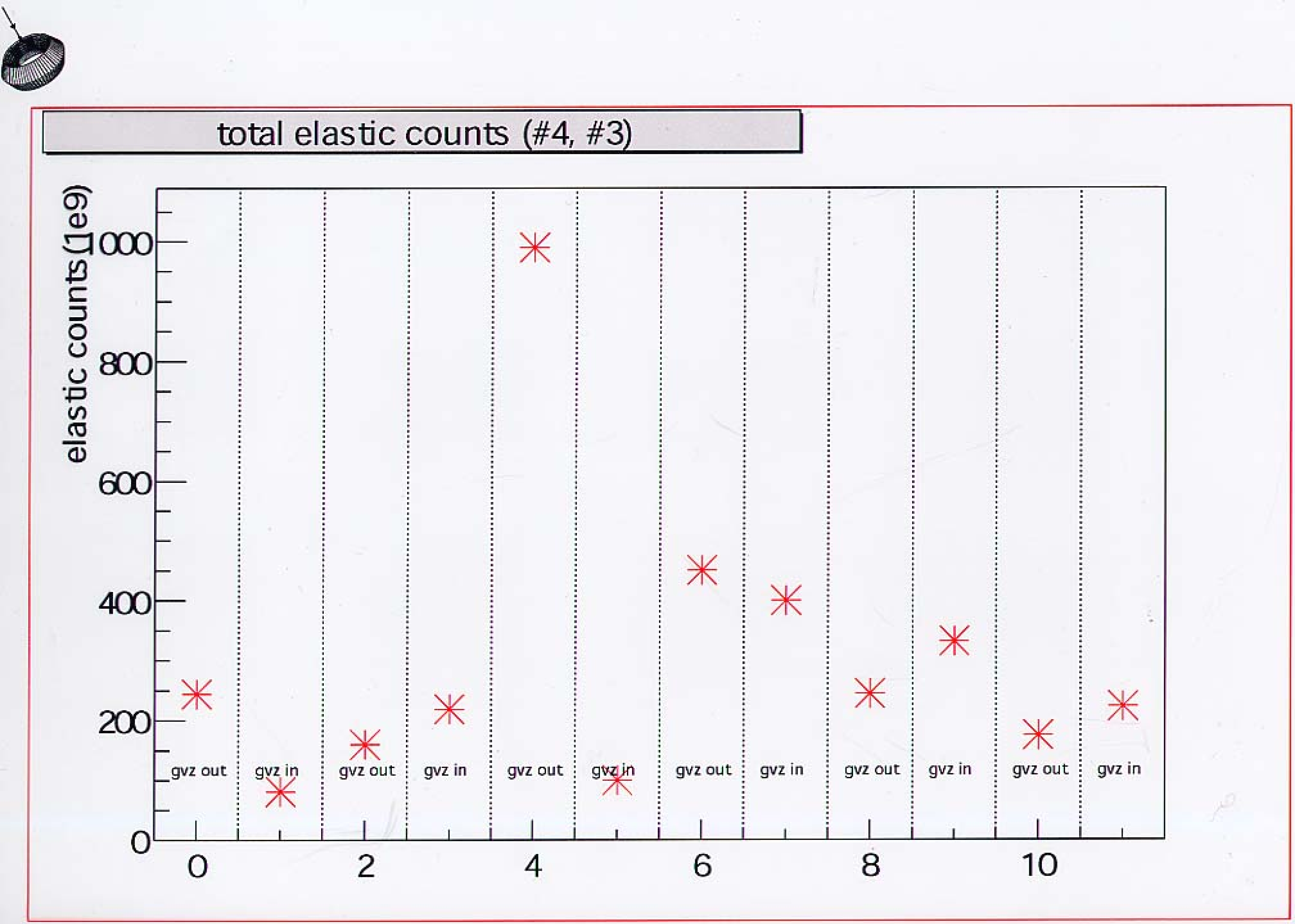


$\sin^2 \theta_W$	= 0.2228*1.072=0.2388
G_F	= Gμ*1.003
α	= (1/137.0359895)*1.014

A_0 = -5.7 ppm

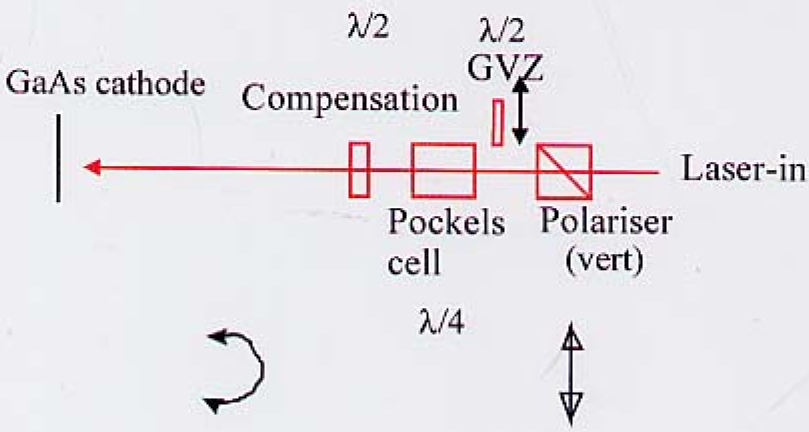


decorrelated det asymmetry, all sectors (#4, #3)
Asymmetrie (10e-6)
60
40
20
0
-20
-40
-60
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
0
2
4
6
8
10

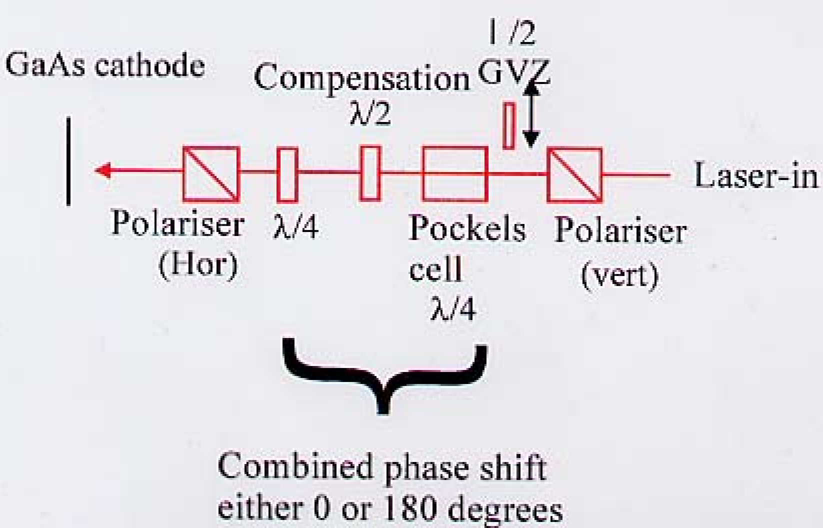

total elastic counts (#4, #3)
elastic counts (1e9)
0
200
400
600
800
1000
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
gvz out
gvz in
0
2
4
6
8
10

GeneralVorZeichenwechsler (GVZ)

A4 data taking setup



A4 setup for determination of sign



Analysis

- detector

  N_{el} (1022 histogramms per run)

  Pola Errors in FIFO

$$A_{raw} = \frac{N^+ - N^-}{N^+ + N^-}$$

- luminosity monitors

  target density fluctuations

  nonlinearities of luminosity monitors

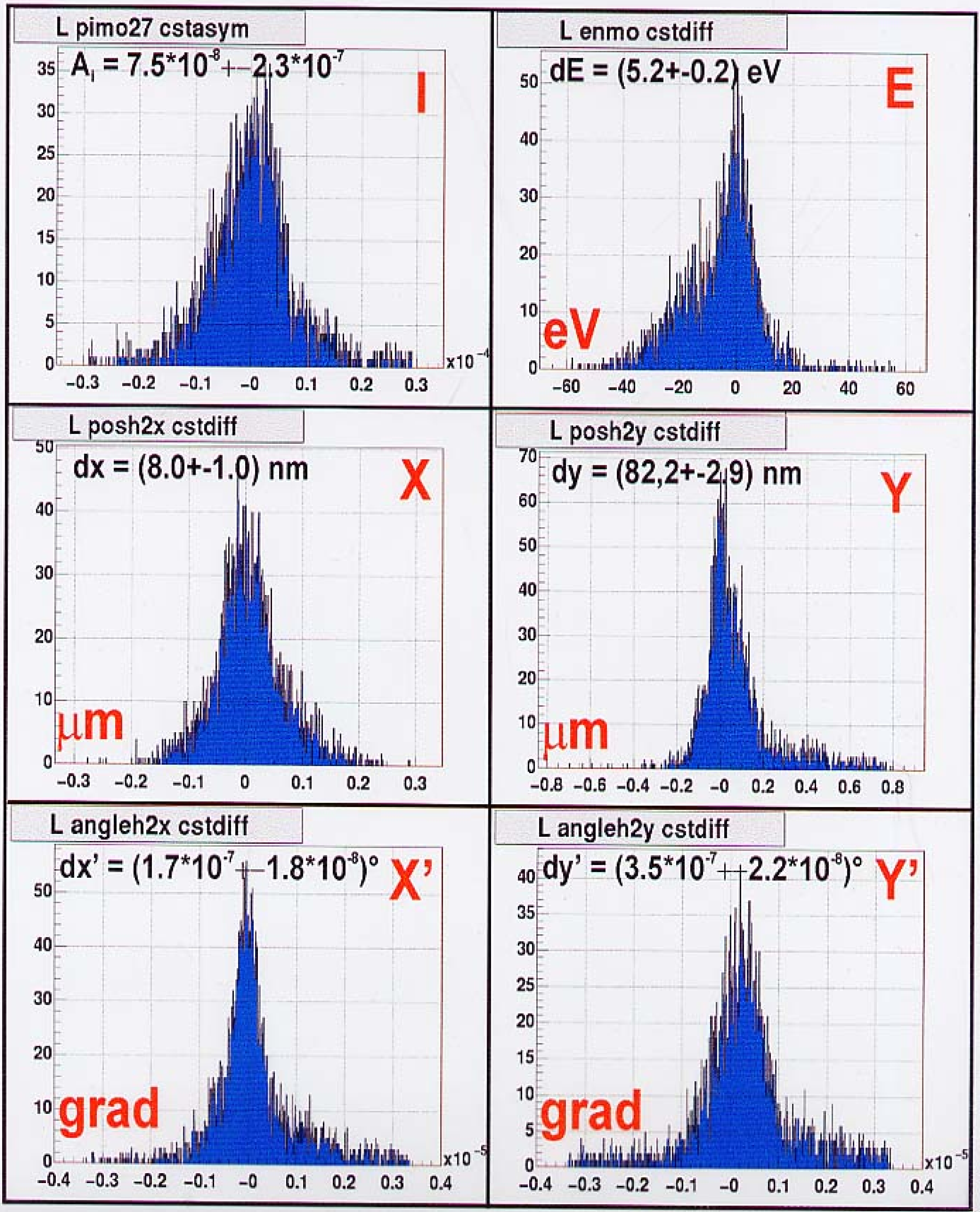
$$A_{raw,L} = \frac{N_\rho^+ - N_\rho^-}{N_\rho^+ + N_\rho^-} \qquad N_\rho^+ = \frac{N^+ \cdot I^+}{L^+}$$

- linear regression with

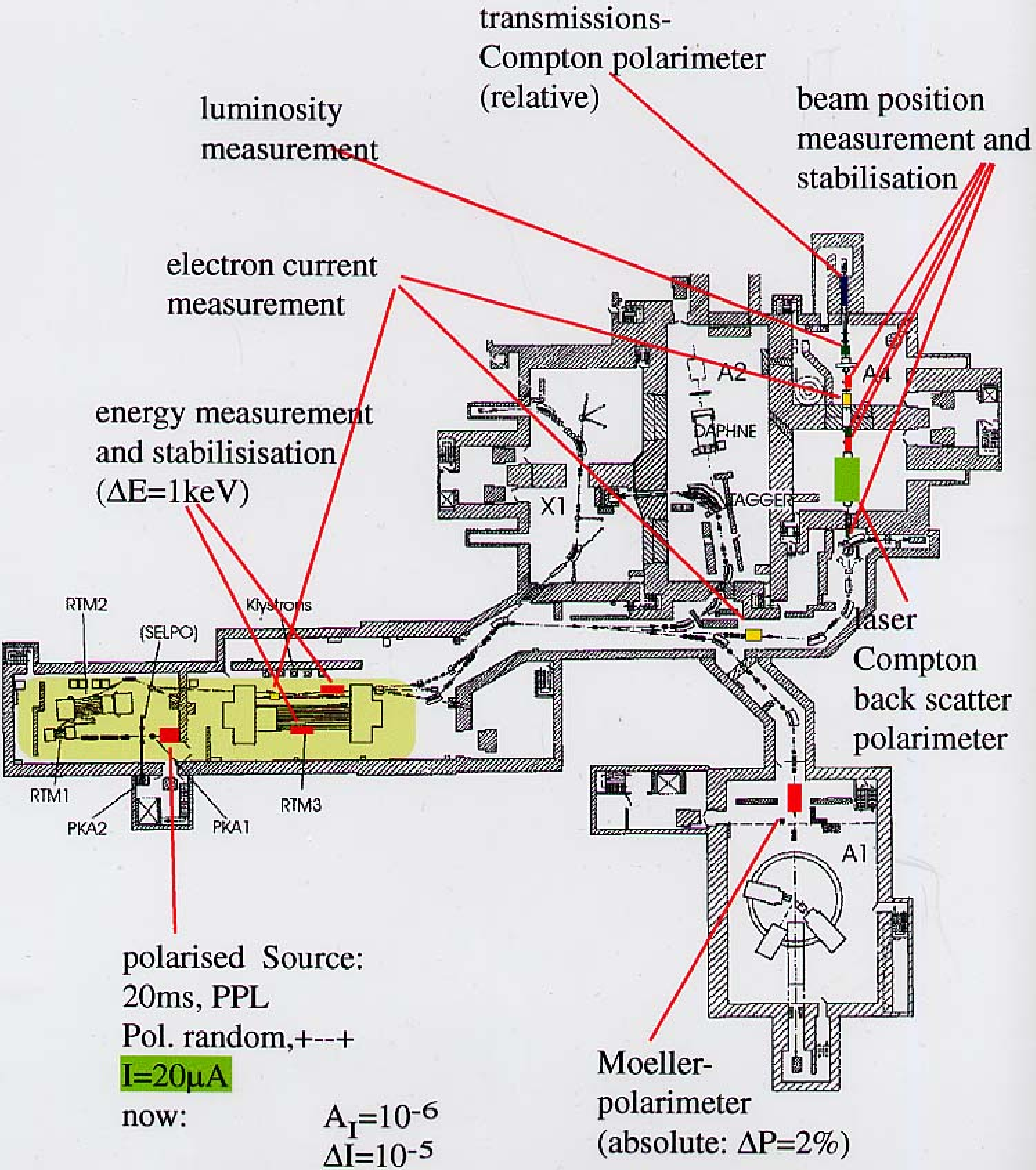
  beam parameters (x,y,x',y',E,I)

$$A_{raw,L} = A_{phys} + \Sigma \frac{d\sigma}{dx_i} \Delta x_i$$

Asymmetries due to e-beam



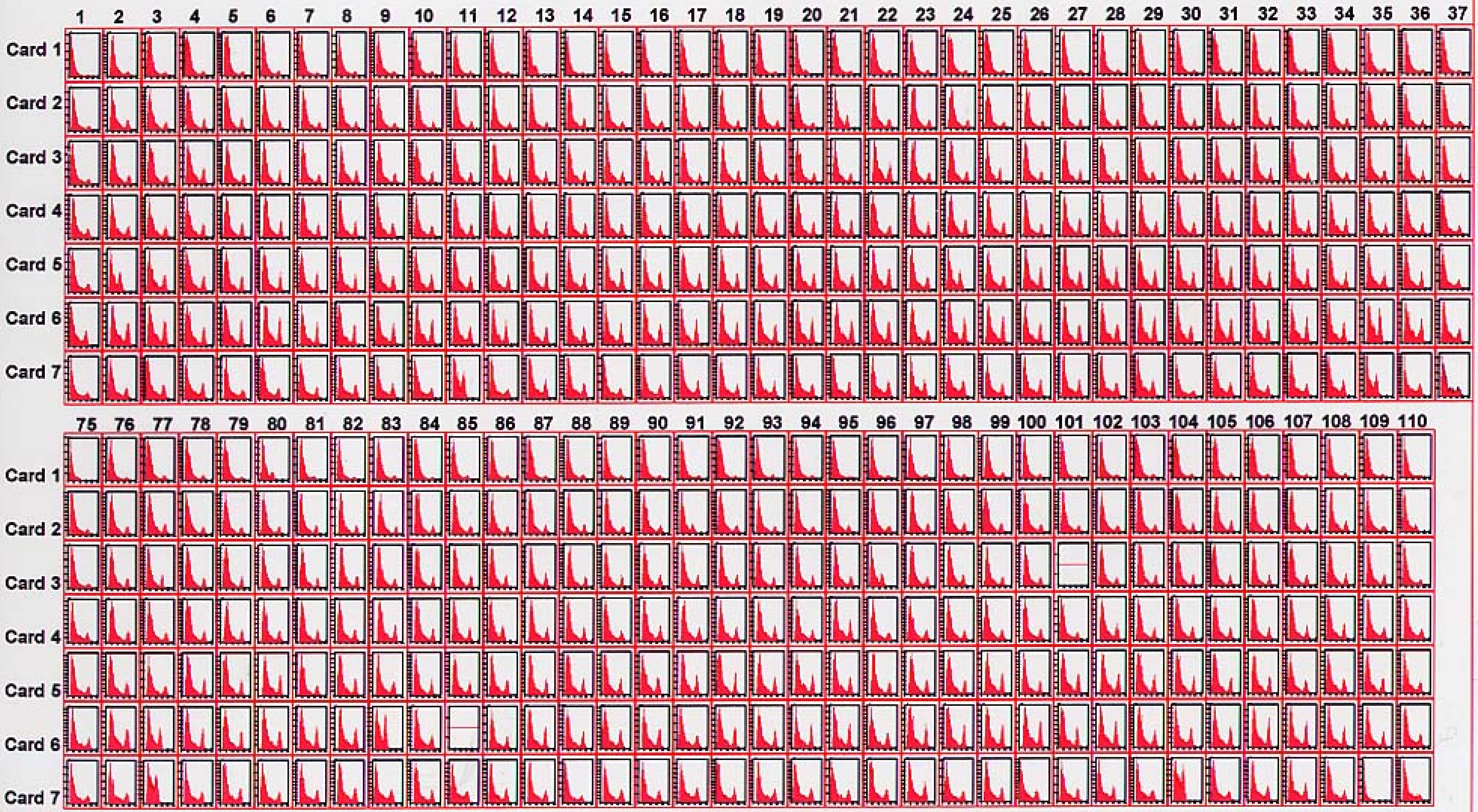
electron beam



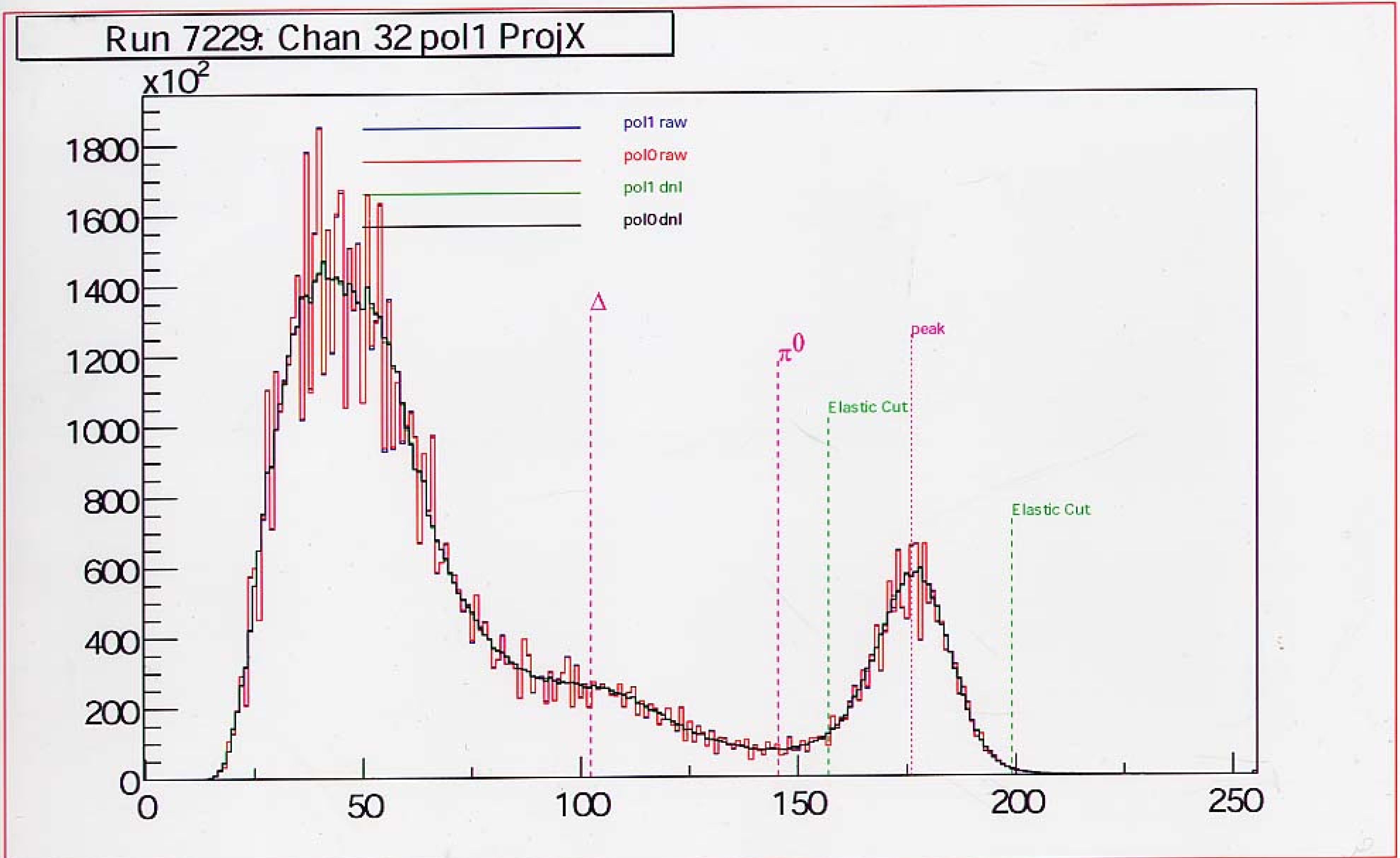
polarised Source:
20ms, PPL
Pol. random,+--+
I=20μA
now: $A_I=10^{-6}$
$\Delta I=10^{-5}$

511 Spectra

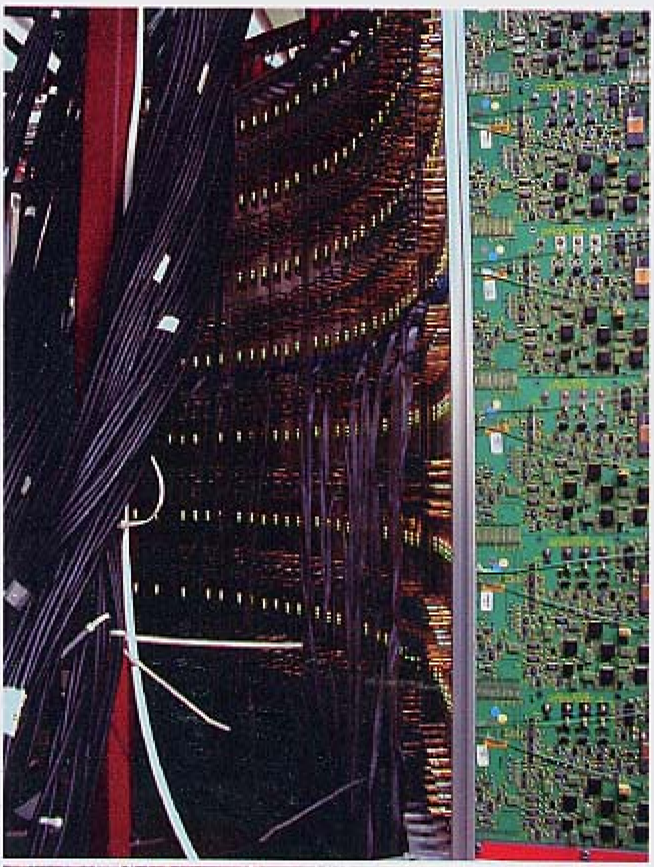
Run 7229

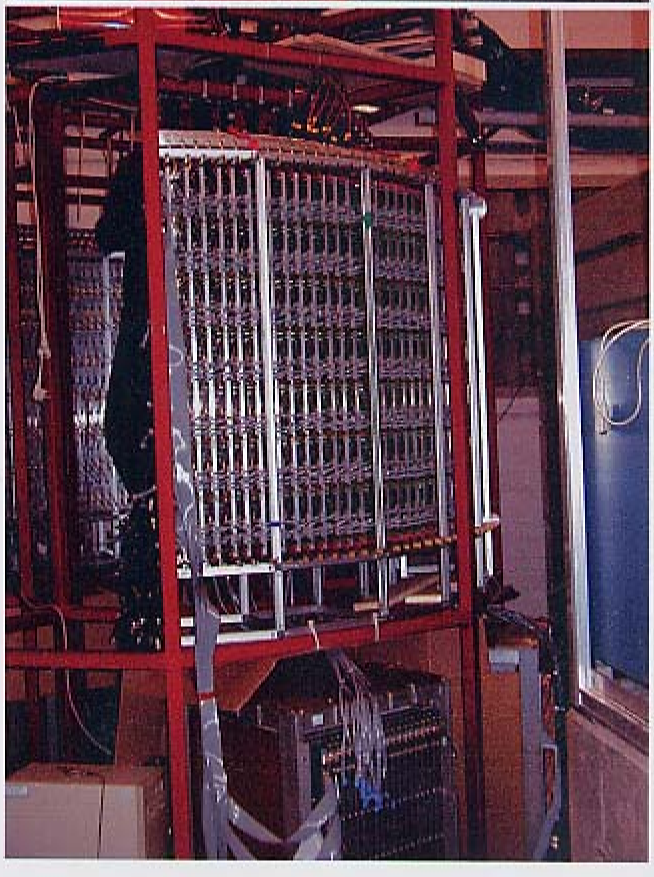


single detector spectrum



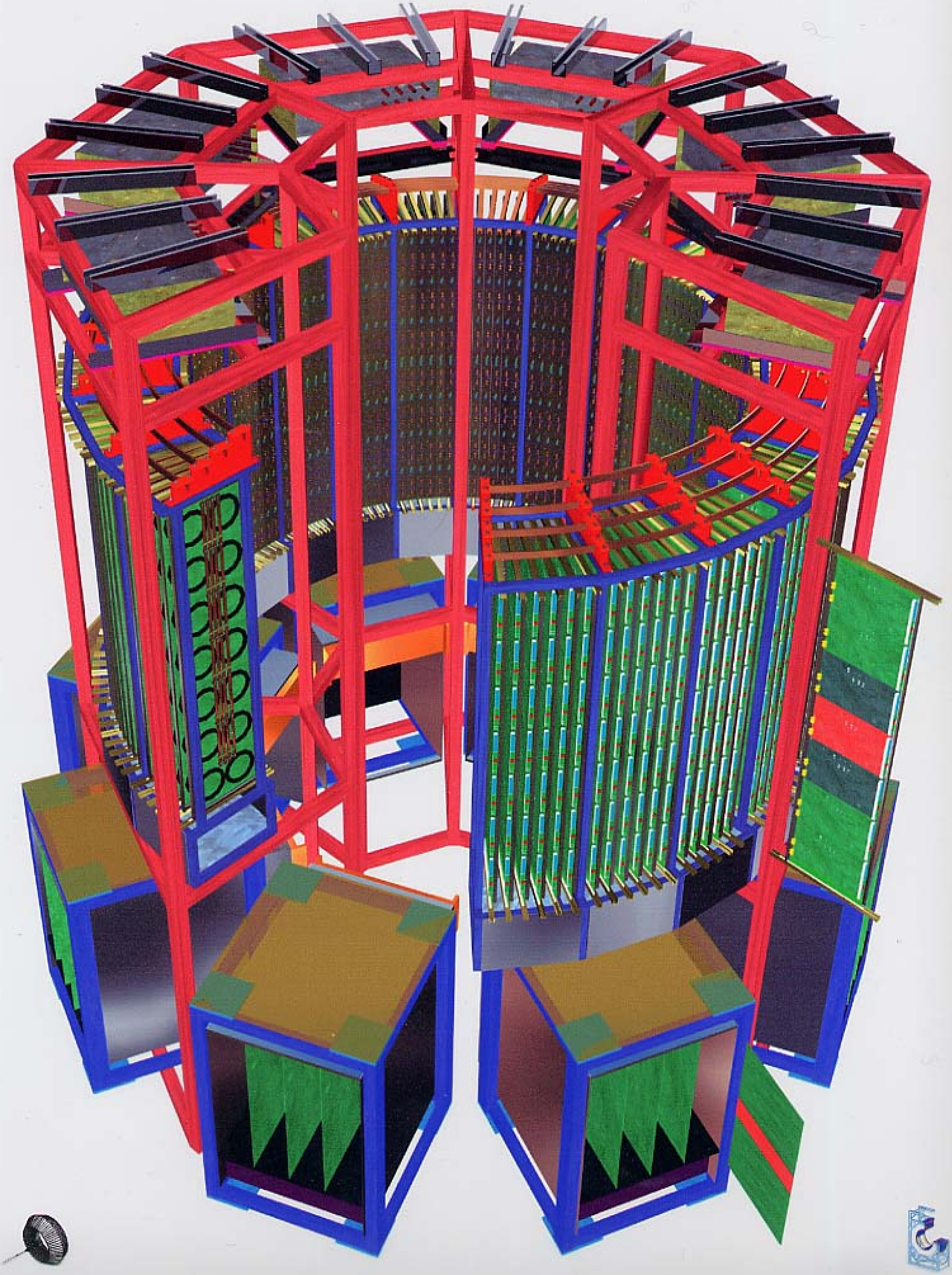
511 MEDUSA-channels





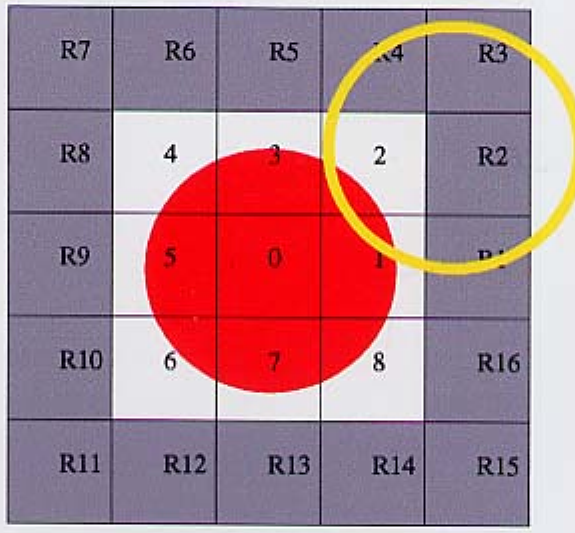
network: 6 cables per channel
(>7600 connectors)

MEDUSA

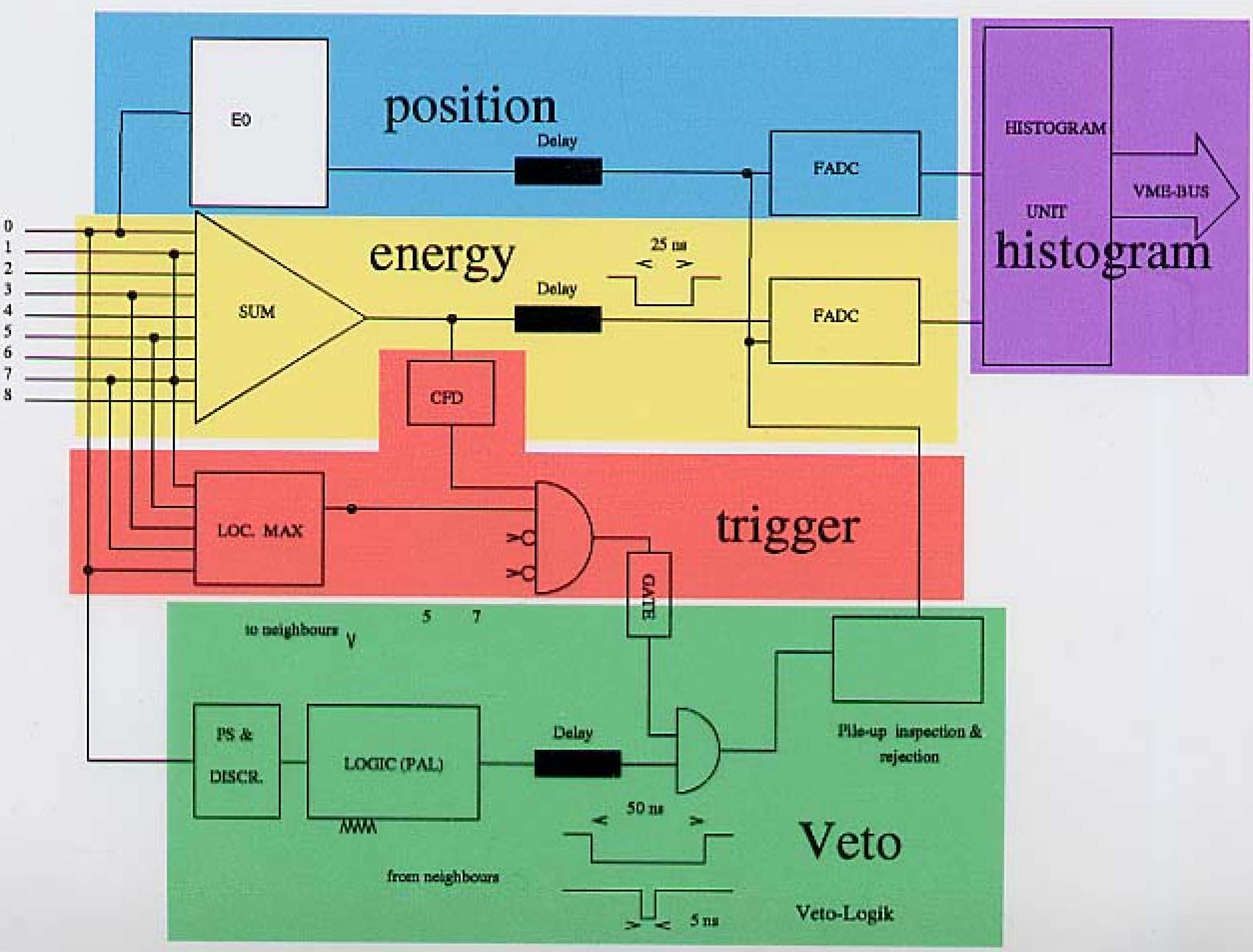


MEDUSA

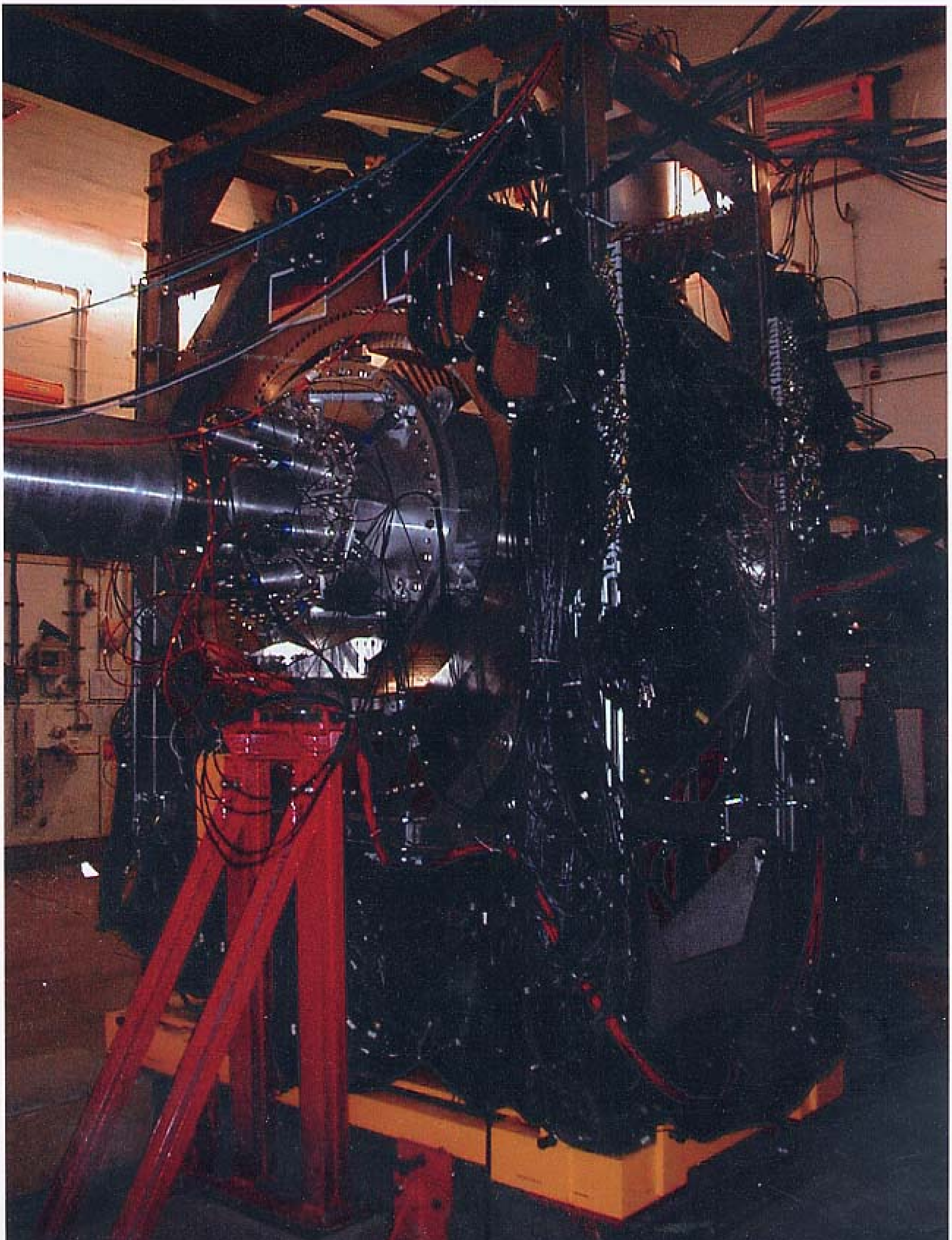
20ns, 3.5%



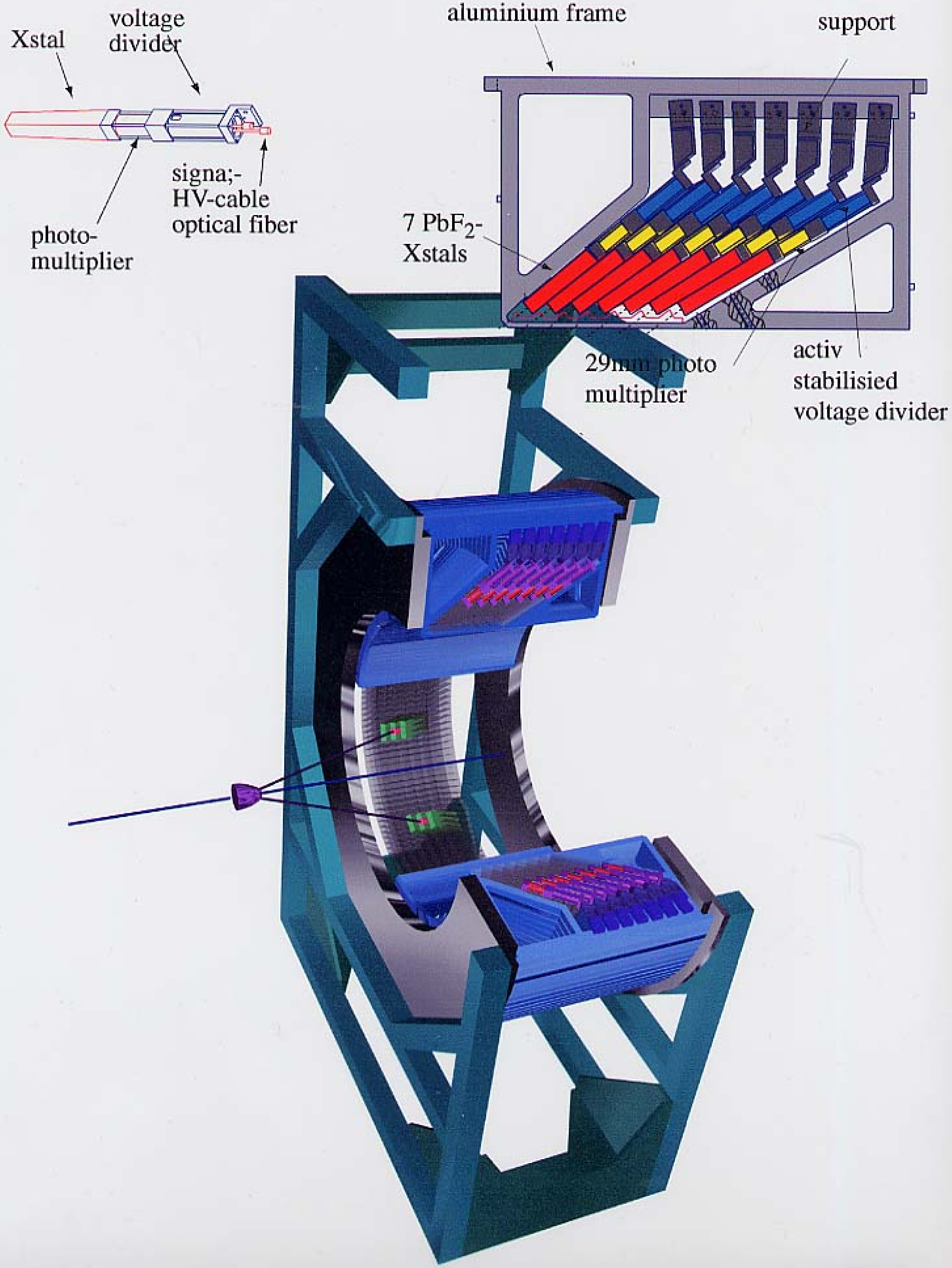
- 1022 parallel modules
- no single events
- 3 dimen. Histogramming
- analogue "Analysis"
- analogue Summation
- temporal and spatial pileup
- 100kHz event processing per channel

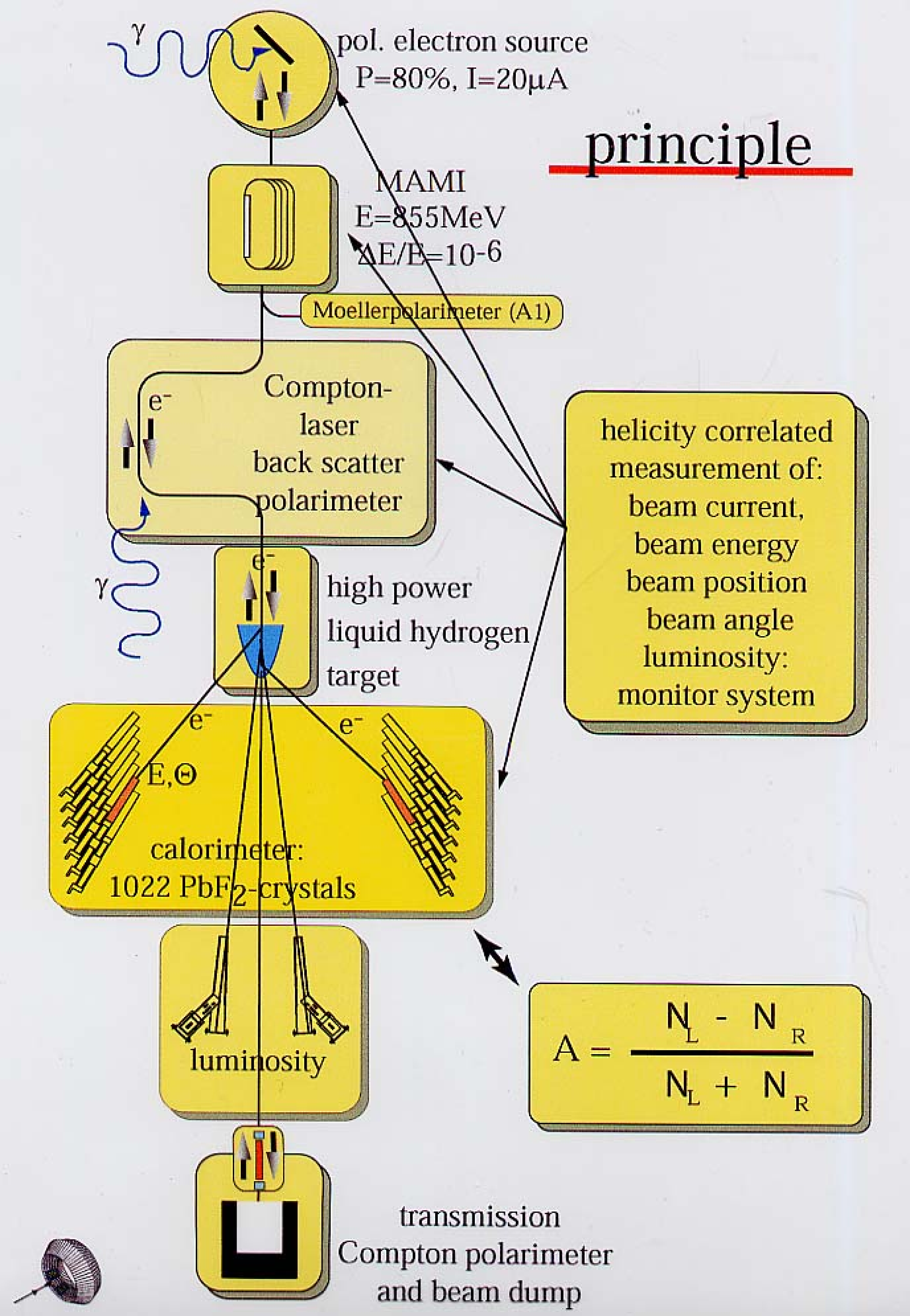


The Mainz (MAMI) A4
Lead Fluoride Detector



511 PbF2 detectors

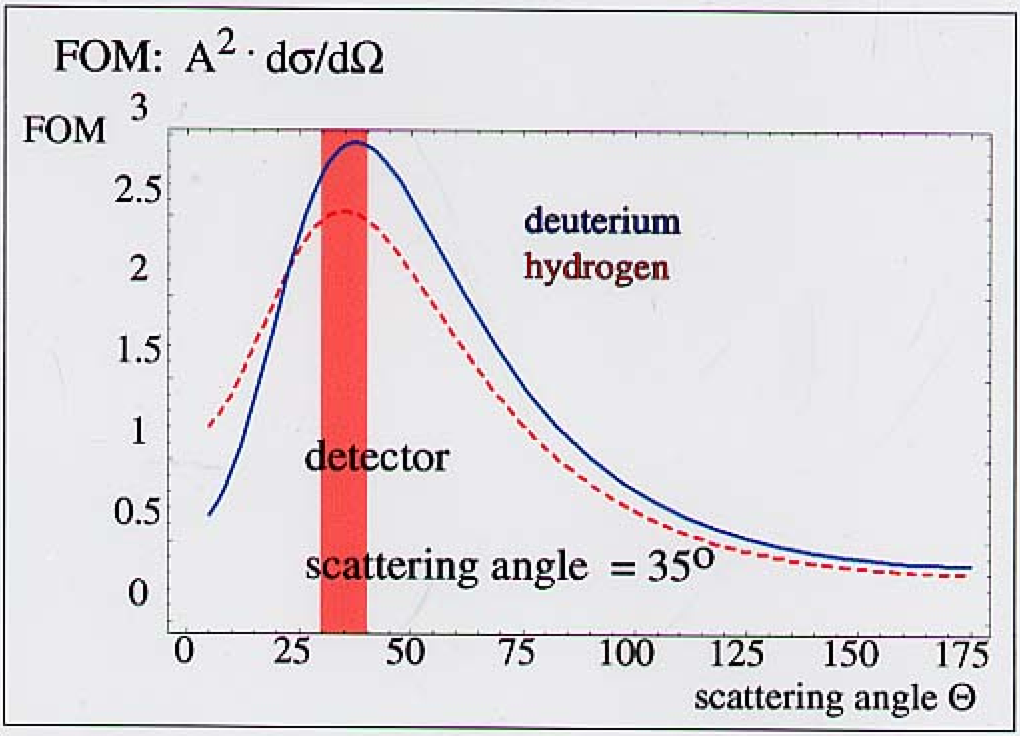


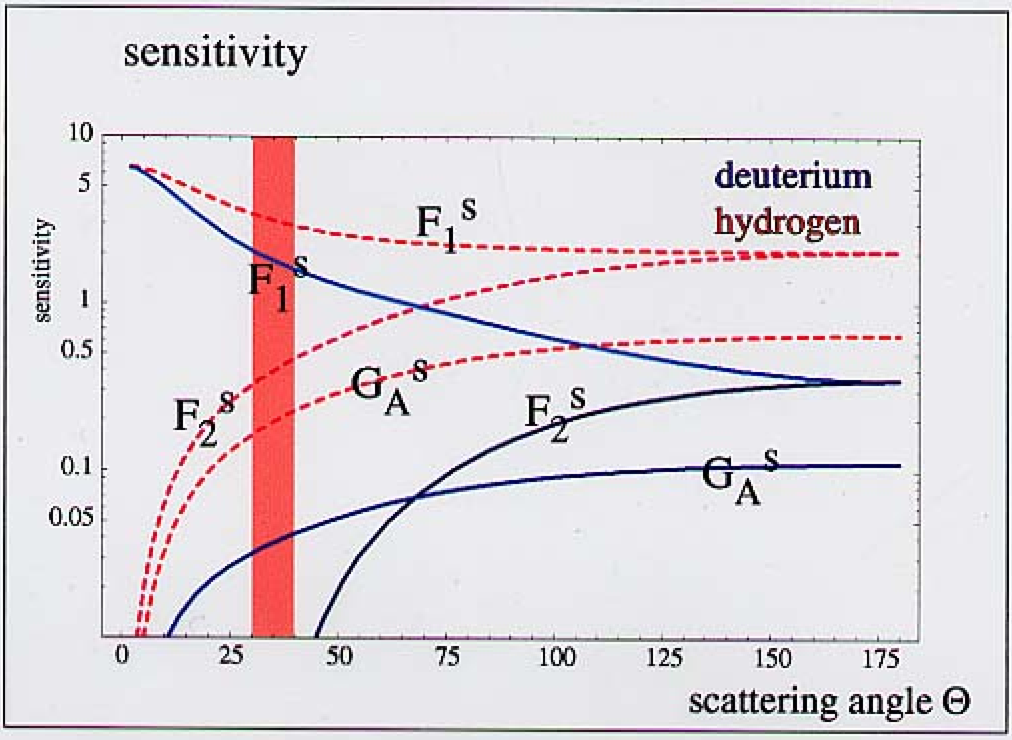


principle
pol. electron source
P=80%, I=20μA
MAMI
E=855MeV
ΔE/E=10-6
Moellerpolarimeter (A1)
Compton-
laser
back scatter
polarimeter
e⁻
γ
high power
liquid hydrogen
target
helicity correlated
measurement of:
beam current,
beam energy
beam position
beam angle
luminosity:
monitor system
E,Θ
calorimeter:
1022 PbF2-crystals
luminosity
A = (N_L - N_R) / (N_L + N_R)
transmission
Compton polarimeter
and beam dump

forward scattering (855 MeV)

F_1^s

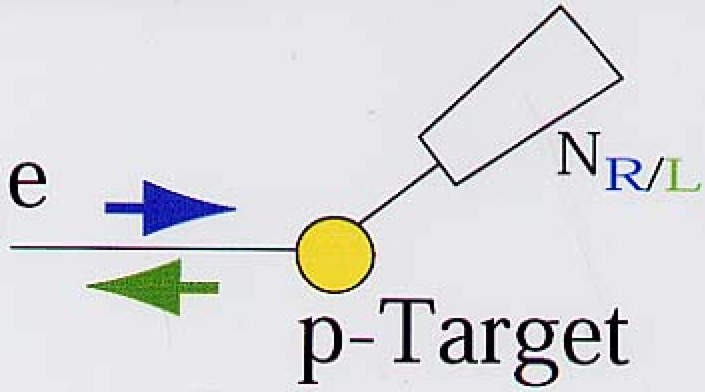




program

goal: determination of F_1^s F_2^s n with $\delta F_1^s=0.02$

method: measurement of A in $p(\vec{e},e')p$



$$A = \frac{N_R - N_L}{N_R + N_L}$$

first point:
$E = 854.3$ MeV, $\theta = 35^o$
$Q^2 = 0.236$ GeV

$$A_0 = -0.0000057 = -5.7 * 10^{-6}$$

$N \sim 10^{14}$ elastic events

elastic:	~ 10 MHz (~ 730 MeV)
inelastic:	~ 90 MHz (~ 610 MeV)
t = 20 ns,	$\frac{\sigma_E}{E} = 3.5\ \%(1\ \text{GeV})$

HAPPEX I - Results

Source of Error	$\frac{\Delta A}{A}$:1998	$\frac{\Delta A}{A}$:1999
Statistics	13.3 %	7.2 %
Polarization	7.0 %	3.2 %
Q^2 Determination	1.8 %	1.8 %
Backgrounds	0.6 %	0.6 %

$$\text{1998: } A = (14.7 \pm 2.2) \times 10^{-6}$$
$$\text{1999: } A = (15.1 \pm 1.3) \times 10^{-6}$$
$$\textit{Combined: } A = (15.0 \pm 1.1) \times 10^{-6}$$

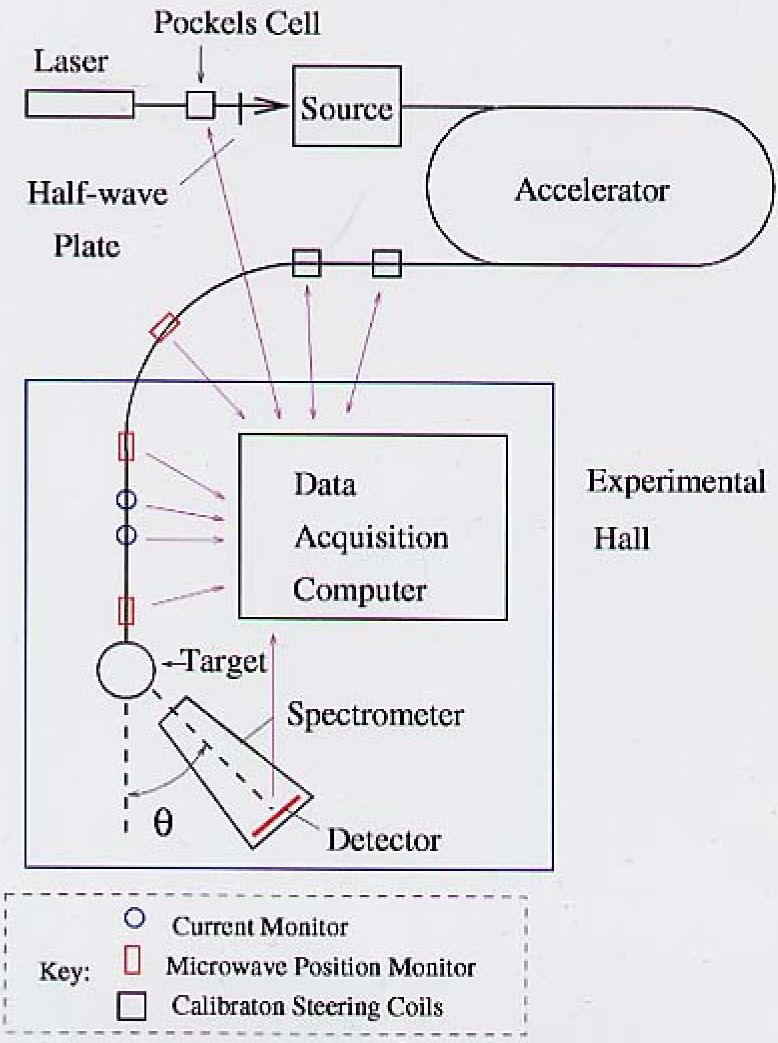
Form Factor	$\frac{\Delta A}{A}$
G_E^n	4%
G_E^p	3%
G_M^n	2%

$$G_E^s + 0.392 G_M^s = 0.025 \pm 0.020 \pm 0.014$$

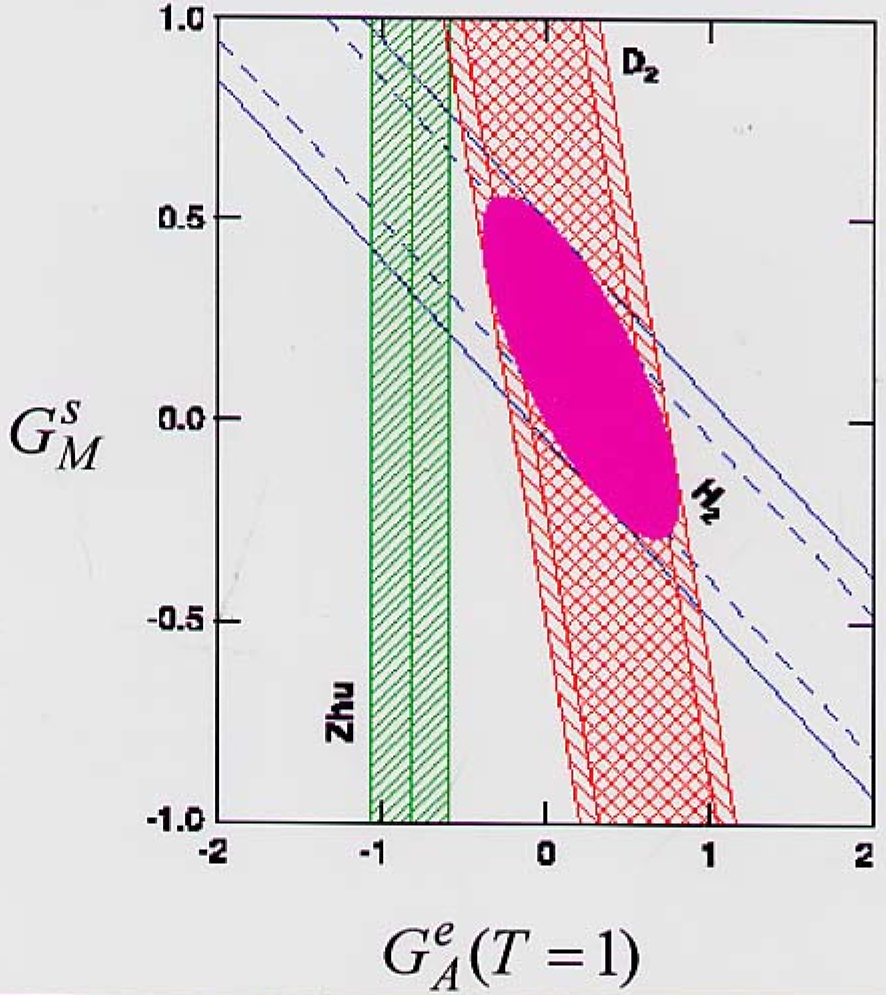
K.A. Aniol *et al.*, PRL 82(1999)1096
K.A. Aniol *et al.*, Phys. Lett. B509(2001)211

HAPPEX measurement principle

Hall A Proton Parity violation EXperiment
at CEBAF/TJNAF



SAMPLE Results (Science 290, 2117 (2000))



Strange magnetism :

$G_M^s(Q^2 = 0.1\,\mathrm{GeV}^2) = 0.14 \pm 0.29 \pm 0.31$

$\mu_s = 0.01 \pm 0.29 \pm 0.31 \pm 0.07$ using χPT extrapolation

→ < 5% of proton magnetic moment due to strange quark sea

e - N axial isovector axial form factor :

$G_A^e(T=1) = +0.22 \pm 0.45 \pm 0.39$ (SAMPLE experiment)

$G_A^e(T=1) = -0.83 \pm 0.26$ (theory, Zhu et al.)

The SAMPLE Experiment at MIT-Bates

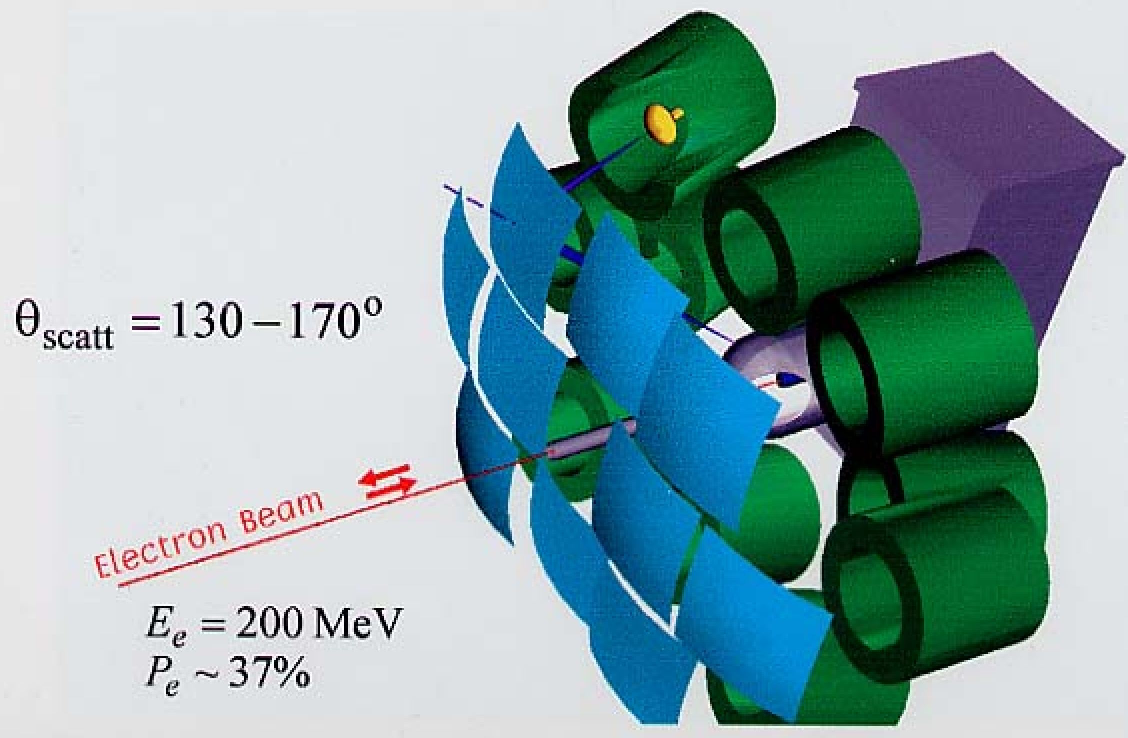
$\vec{e}$(p,p)e elastic $\vec{e}$(d,pn)e quasielastic

Determines G_M^s and G_A^e at low $Q^2 = 0.1$ (GeV/c)^2

- Large solid angle (1.4 sR) air Cerenkov detector
- 40 cm liquid hydrogen/deuterium target (600 W capability)
- Beam time structure: 25 μsec width @ 600 Hz
- Signals in phototubes are integrated over the 25 μsec beam pulse
- Measured detector asymmetry:

$$A = \sum_{i=1}^{10} \frac{Y_i^+ - Y_i^-}{Y_i^+ + Y_i^-}$$

where Y_i = normalized integrated signal for phototube i



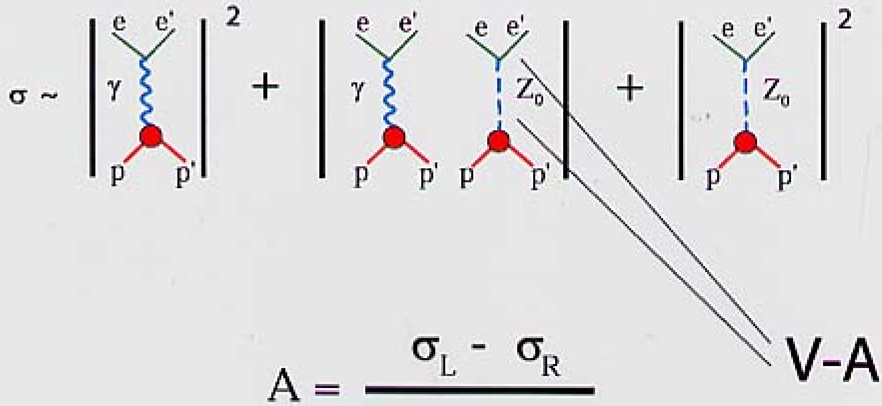
Ingredients

Challenges:
- (quasi) elastic electron scattering
  $0.1 \text{GeV}^2 < Q^2 < 1.0 \text{ GeV}^2$
  inelastic scattering
- asymmetries small (ppm)
  high rates

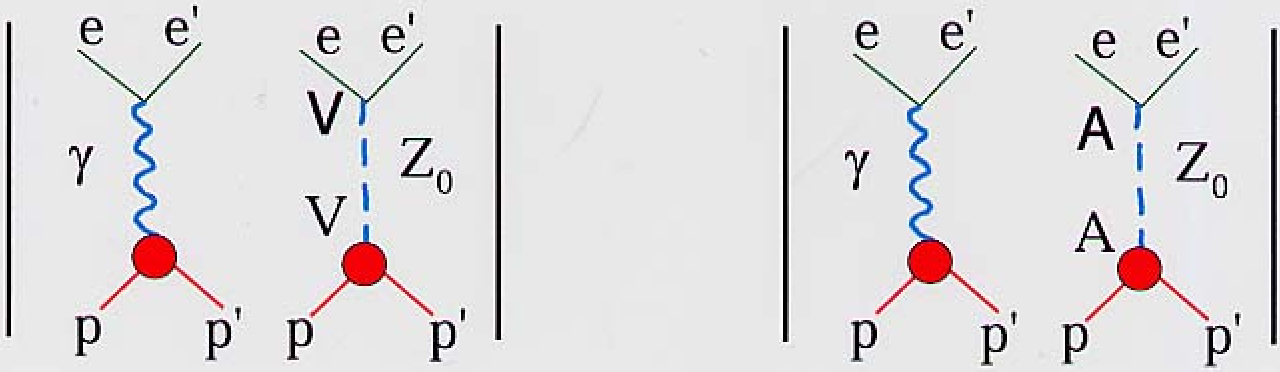
Solutions:
- separate elastic<->inelastic scattering
  low energy (SAMPLE, MIT Bates)
  magnetic spectrometer (HAPPEX, CEBAF)
  crystal calorimeter (A4, MAMI)
  toroidal spectrometer (G0, CEBAF)

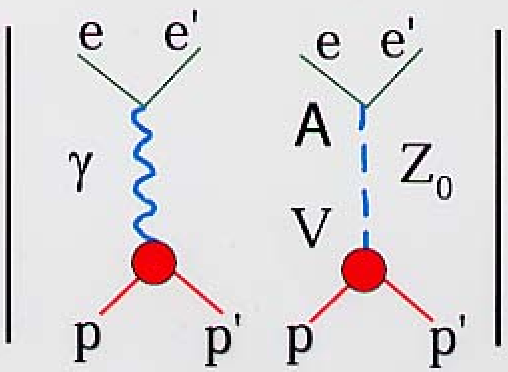
- detection of particles at a high rate
  without spectrometer integrating (SAMPLE)
  focal plane current integrating (HAPPEX)
  elastic and inelastic particles counting
    with PbF_2-calorimeter (A4)
  focal surface particles counting with ToF (G0)

electroweak interaction

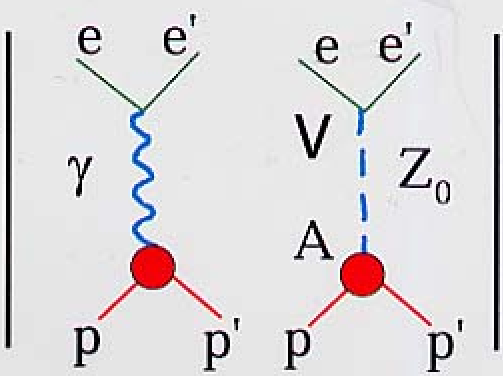


$$A = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



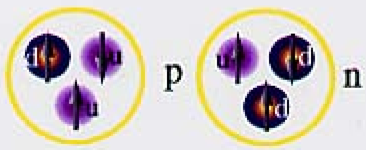


vector form factor

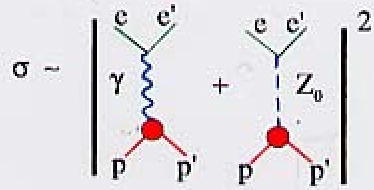


axial form factor

electroweak interaction



+



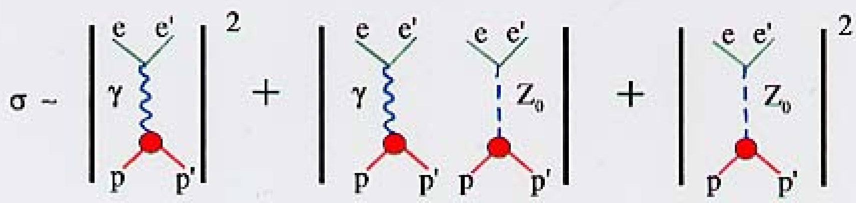
electro magnetic form factor

- Proton : $F^p_{1,2} = +\frac{2}{3} F^u_{1,2} - \frac{1}{3} F^d_{1,2} - \frac{1}{3} F^s_{1,2}$
- Neutron : $F^n_{1,2} = -\frac{1}{3} F^u_{1,2} + \frac{2}{3} F^d_{1,2} - \frac{1}{3} F^s_{1,2}$

weak form factor

$$\tilde{F}^p_{1,2} = \frac{1}{4}(F^u_{1,2} - F^d_{1,2} - F^s_{1,2}) - \sin^2\Theta_W \cdot F^p_1$$

$$= \frac{1}{4}(1 - 4\sin^2\Theta_w) \cdot F^p_{1,2} - \frac{1}{4} \cdot F^n_{1,2} - \frac{1}{4} \cdot F^s_{1,2}$$



$$\sigma \sim 1 + 10^{-5} + 10^{-10}$$

$$A = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

parity violating asymmetry

$$A^p = A^p_0 \left(1 - \frac{(\epsilon + \tau\,\mu_p)\, F^s_1 + \tau\,(\mu_p - \epsilon)\, F^s_2 + \frac{1}{2}\delta\,\mu_p\, G^s_A}{4K}\right)$$

$$\frac{\delta A}{A_0} = \frac{1}{A_0}\frac{\partial A}{\partial F^s_1} \cdot \delta F^s_1 + \frac{1}{A_0}\frac{\partial A}{\partial F^s_2} \cdot \delta F^s_2 + \frac{1}{A_0}\frac{\partial A}{\partial G^s_A} \cdot \delta G$$

$$= -\mathbf{a} \cdot \delta F^s_1 - \mathbf{b} \cdot \delta F^s_2 - \mathbf{c} \cdot \delta G^s_A$$

$$A^{PV} = -\frac{G_F Q^2}{\pi\alpha\sqrt{2}} \frac{\varepsilon G_E^p \tilde{G}_E + \tau G_M^p \tilde{G}_M^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

$$\tilde{G}_E^p = \frac{1}{4}(G_E^p - G_E^n) - \sin^2\theta_W G_E^p - \frac{1}{4} G_E^s$$

$$\tilde{G}_M^p = \frac{1}{4}(G_M^p - G_M^n) - \sin^2\theta_W G_M^p - \frac{1}{4} G_M^s$$

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

$$F_1^p = \frac{2}{3} F_1^u - \frac{1}{3} F_1^d - \frac{1}{3} F_1^s$$

$$F_1^n = \frac{2}{3} F_1^d - \frac{1}{3} F_1^u - \frac{1}{3} F_1^s$$

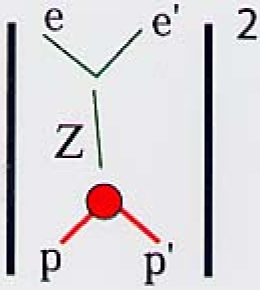
$$F_1^p - F_1^n = F_1^u - F_1^d$$

$$\tilde{F}_1^p = \left(\frac{1}{4} - \frac{2}{3}\sin^2\theta_W\right) \cdot F_1^u - \left(\frac{1}{4} - \frac{1}{3}\sin^2\theta_W\right) \cdot F_1^d - \left(\frac{1}{4} - \frac{1}{3}\sin^2\theta_W\right) \cdot F_1^s$$

$$\tilde{F}_1^p = \frac{1}{4}\underbrace{\left(F_1^u - F_1^d\right)}_{F_1^p - F_1^n} - \frac{1}{4} F_1^s - \sin^2\theta_W \underbrace{\left(\frac{2}{3} F_1^u - \frac{1}{3} F^d - \frac{1}{3} F_1^s\right)}_{F_1^p}$$

$$\tilde{F}_1^p = \frac{1}{4}\left(F_1^p - F_1^n\right) - \sin^2\theta_W F_1^p - \frac{1}{4} F_1^s$$

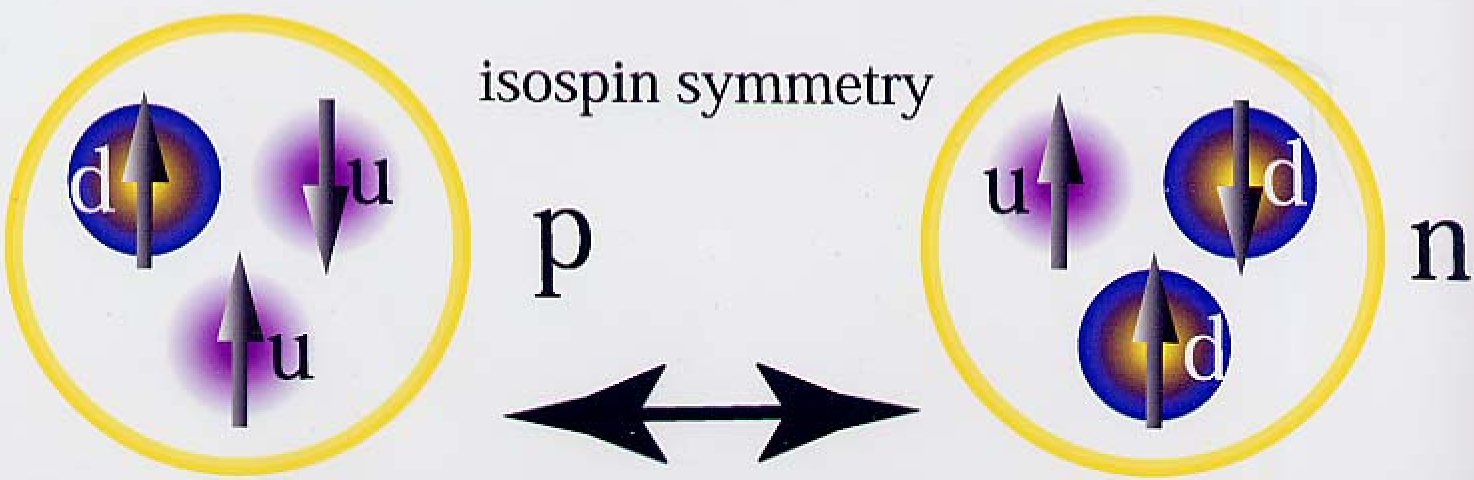
flavor decomposition of vector form factors

$\sigma \sim$ 

$$\tilde{G}_E(Q^2) = \tilde{F}_1(Q^2) - \tau F_2(Q^2)$$
$$\tilde{G}_M(Q^2) = \tilde{F}_1(Q^2) + F_2(Q^2)$$
$$G_A(Q^2)$$

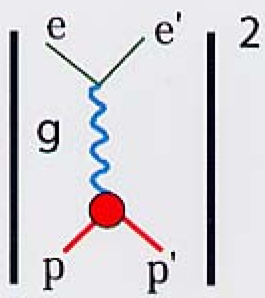
u **d** **s**

$$\tilde{F}_1^{p} = \tilde{Q}_u\, {}^{u}F_1^{p} + \tilde{Q}_d\, {}^{d}F_1^{p} + \tilde{Q}_s\, {}^{s}F_1^{p} + (c,b,t)$$
$$\tilde{F}_2^{p} = \tilde{Q}_u\, {}^{u}F_2^{p} + \tilde{Q}_d\, {}^{d}F_2^{p} + \tilde{Q}_s\, {}^{s}F_2^{p} + (c,b,t)$$
$$\tilde{F}_1^{n} = \tilde{Q}_u\, {}^{d}F_1^{p} + \tilde{Q}_d\, {}^{u}F_1^{p} + \tilde{Q}_s\, {}^{s}F_1^{p} + (c,b,t)$$
$$\tilde{F}_2^{n} = \tilde{Q}_u\, {}^{d}F_2^{p} + \tilde{Q}_d\, {}^{u}F_2^{p} + \tilde{Q}_s\, {}^{s}F_2^{p} + (c,b,t)$$



4 more experimentally accessible quantities (8 equations)
6 unknown flavor form factors

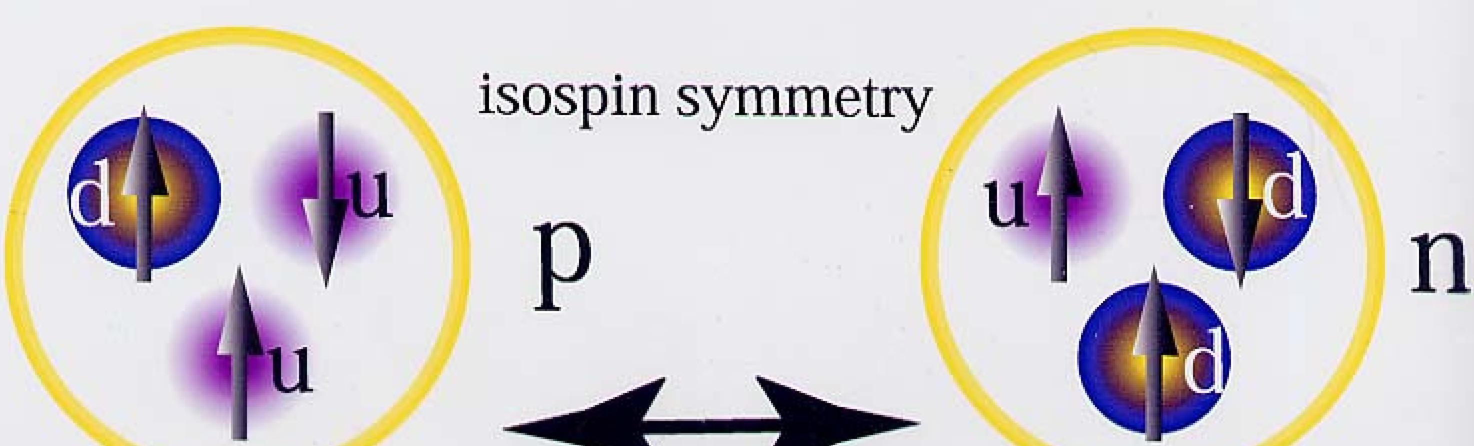
flavor decomposition of vector form factors

$\sigma \sim$ 

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

u d s

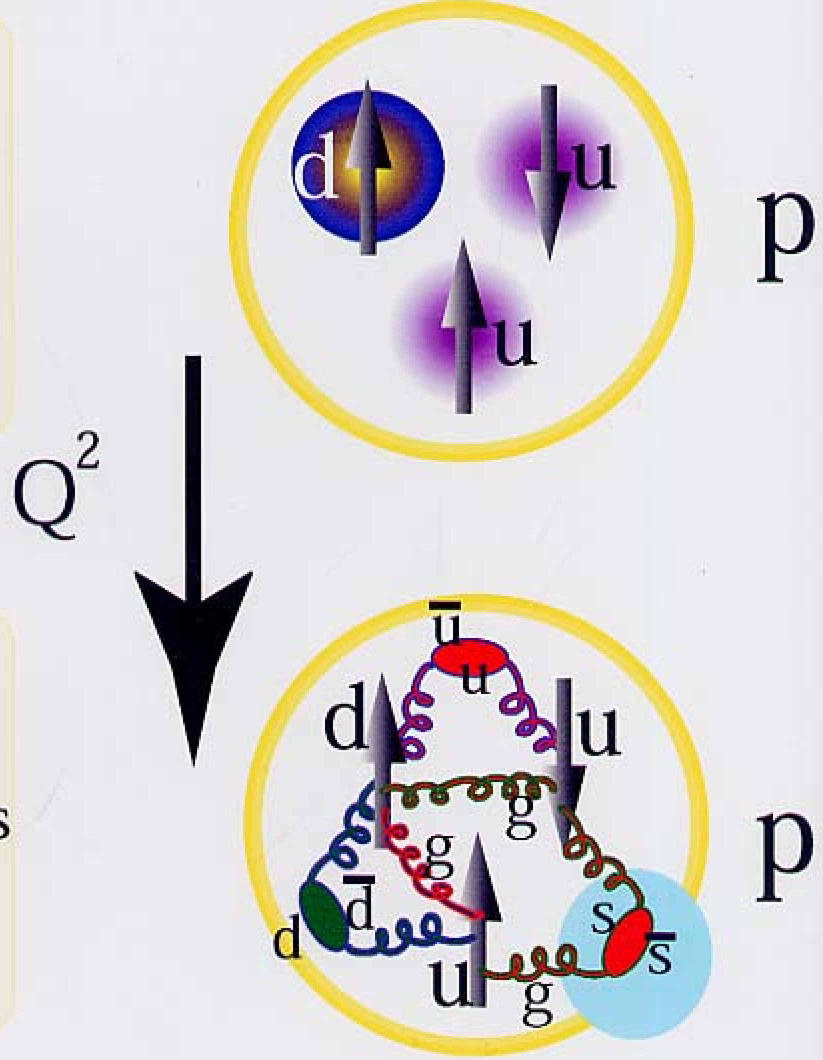
$$F_1^p = Q_u\,{}^{u}F_1^p + Q_d\,{}^{d}F_1^p + Q_s\,{}^{s}F_1^p + (c,b,t)$$
$$F_2^p = Q_u\,{}^{u}F_2^p + Q_d\,{}^{d}F_2^p + Q_s\,{}^{s}F_2^p + (c,b,t)$$
$$F_1^n = Q_u\,{}^{d}F_1^p + Q_d\,{}^{u}F_1^p + Q_s\,{}^{s}F_1^p + (c,b,t)$$
$$F_2^n = Q_u\,{}^{d}F_2^p + Q_d\,{}^{u}F_2^p + Q_s\,{}^{s}F_2^p + (c,b,t)$$



4 experimentally accessible quantities (4 equations)
6 unknown flavor form factors

strangeness in the nucleon

- constituents quarks
  ($Q^2 = 0$ GeV^2)
  baryon octet
  masses
  magn. momenta



- partons
  ($Q^2 > 1$ GeV^2)
  structure functions
  momentum
  spin

pi-N-scattering Σ:	contribution to nucleon mass
$\langle p \vert \bar{s}\, s \vert p \rangle m_s$:	m^s_p = 130-480 MeV
DIS:	contribution to momentum (1%)
	contribution to spin
$\langle p \vert \bar{s} \gamma_\mu \gamma^5 s \vert p \rangle$:	Σ_s = -12 %
PV e^- scattering:	contribution to form factors
$\langle p \vert \bar{s} \gamma_\mu s \vert p \rangle$:	s-charge radius
	s-magn. moment

Strangeness Form Factor of the Nucleon

9th International Conference on the Structure of Baryons

Frank E. Maas
A4-Collaboration
Institut für Kernphysik
Mainz

- Strangeness Form Factors
- Different Experiments
- A4 Experimental Setup
  - Lead Fluoride Calorimeter
  - Electronics
  - Electron Accelerator
- Analysis and Results
- Outlook

3.618.481.131.824

1.809.226.315.794

1.809.254.816.030

-7.88e-06

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