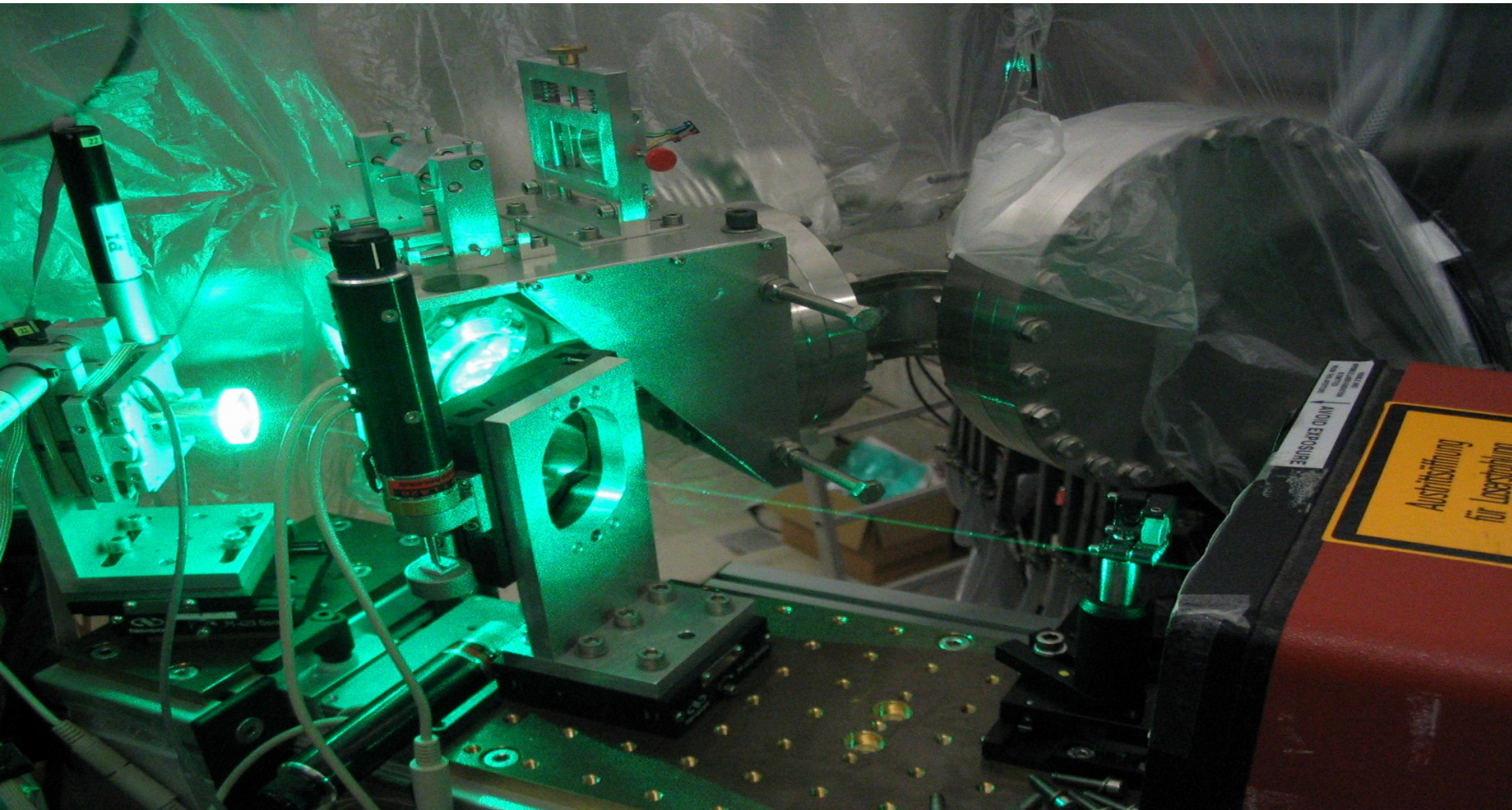
A4 - Mainz

PAVI 09, Bar Harbor, Maine – June 22, 2009

Sebastian Baunack, University of Mainz



Outline

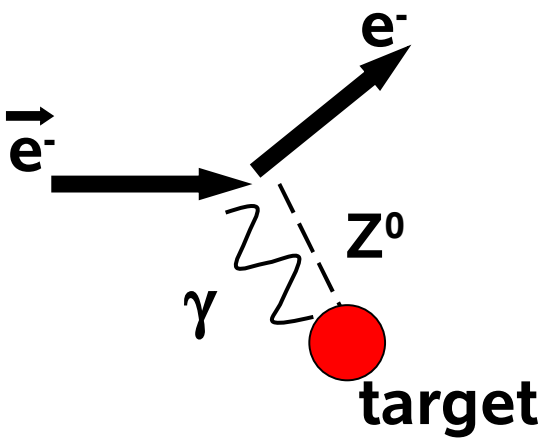
- A4 Experimental Setup
- H_2 backward angle measurement

  Recent results
- D_2 backward angle measurement

  Short overview of the existing data

- Outlook: “A4-III” 0.62 GeV² forward angle measurement

Parity violating electron scattering



Asymmetry measurement

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \frac{|M^{NC}|}{|M^{EM}|} \sim \frac{Q^2}{(M_Z)^2} \approx 10^{-6}$$

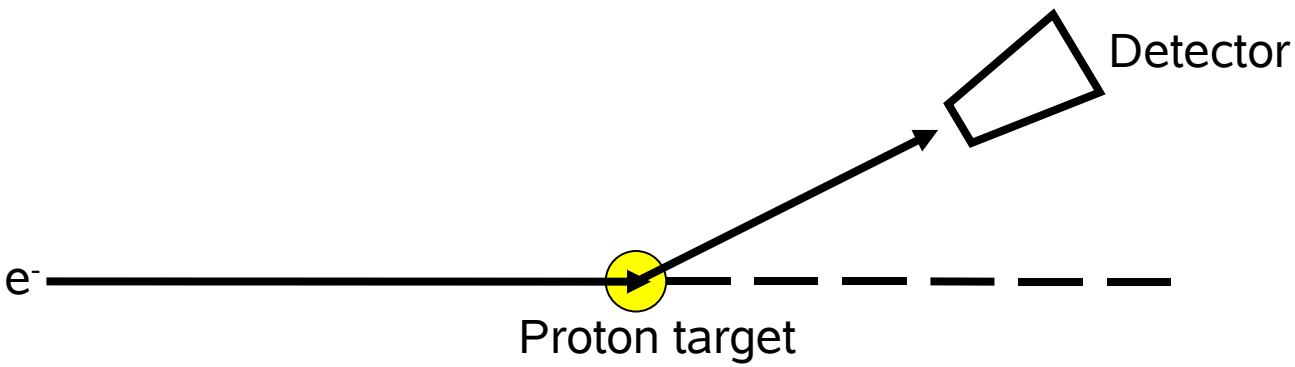
•Statistics: $A^{PV} \approx ١٠^{-٦}$

$$N \approx 10^{12} - 10^{14}$$

•Demands:

- Separation of elastic and inelastic events
- Control of false asymmetries, polarization measurement, ...

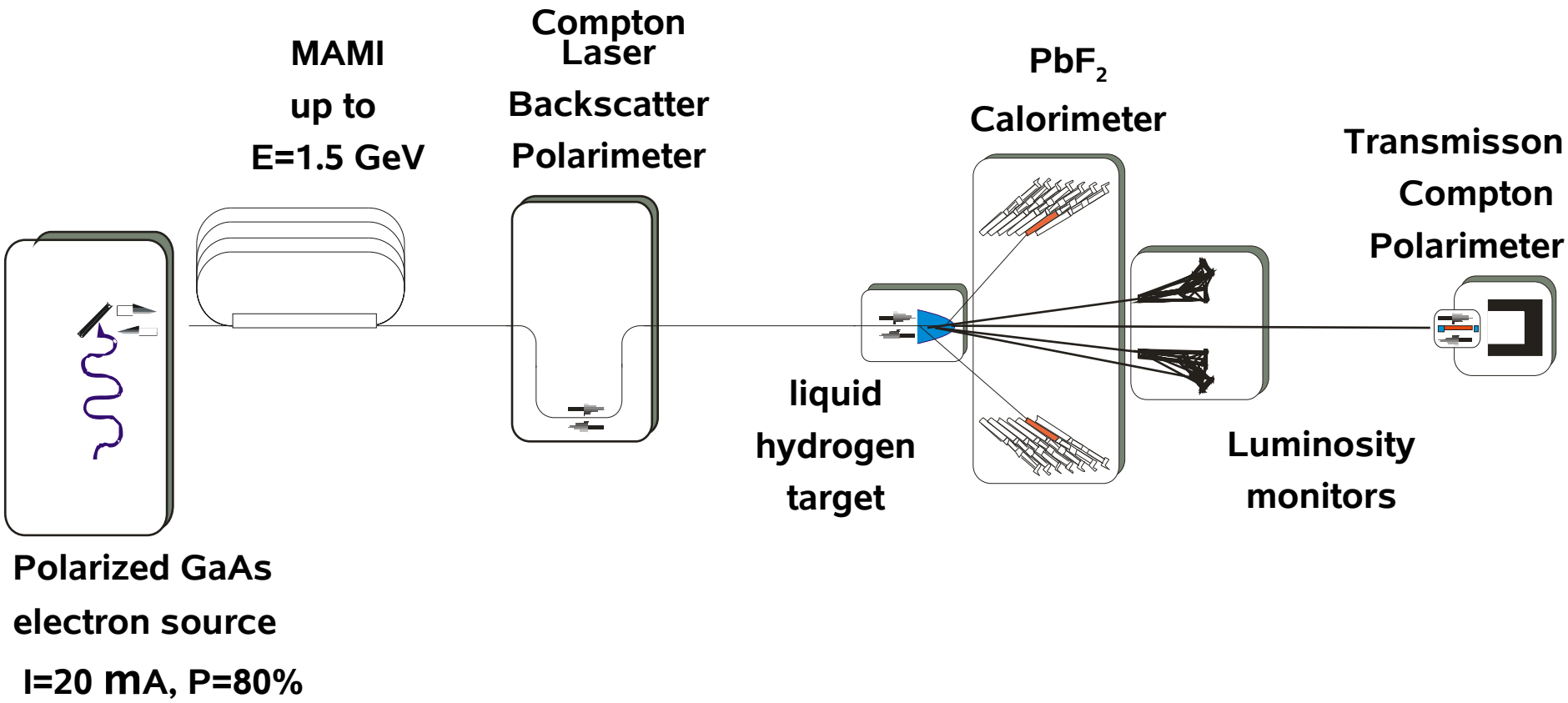
A4 Experiment at MAMI



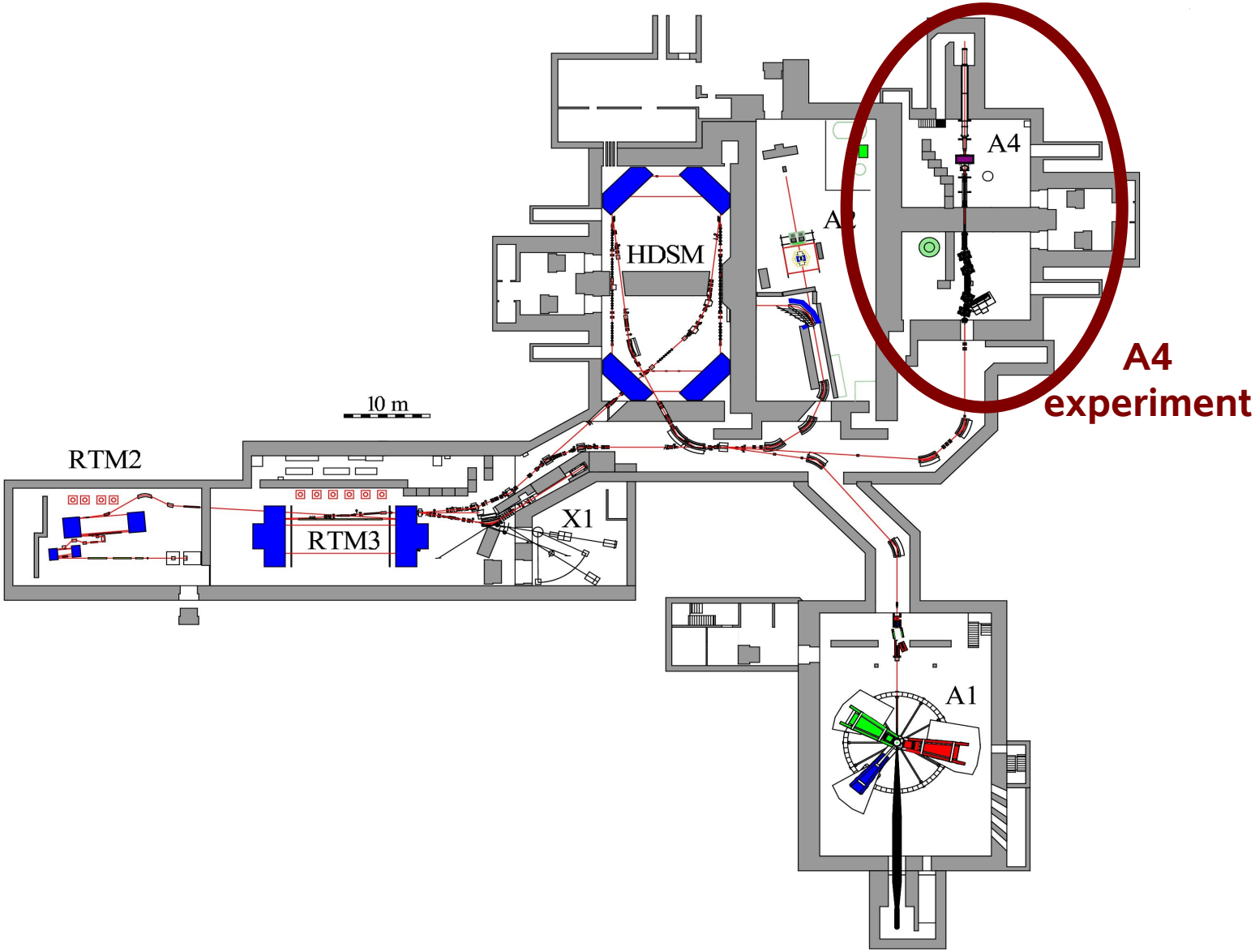
- Scatter polarized electrons off unpolarized protons
- Place a detector under a certain scattering angle
- Count single events

$$A^{PV} = \frac{\sigma^{+} - \sigma^{-}}{\sigma^{+} + \sigma^{-}} = \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

A4 Experiment at MAMI



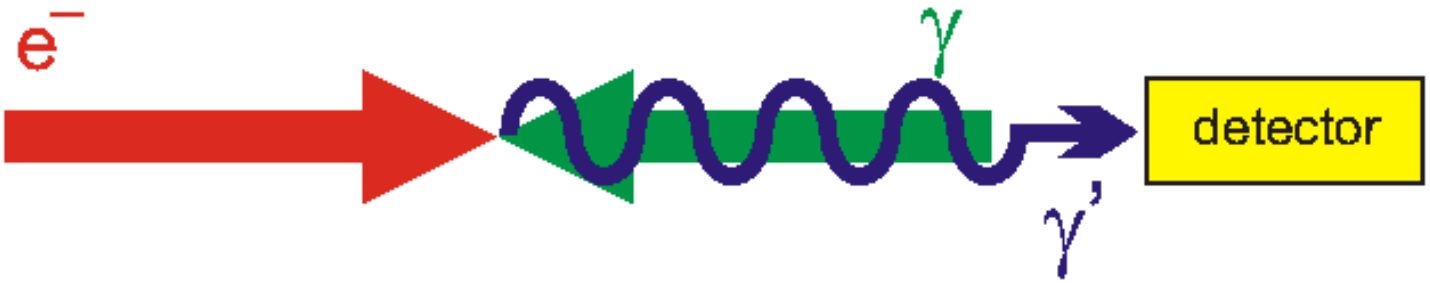
MAMI accelerator

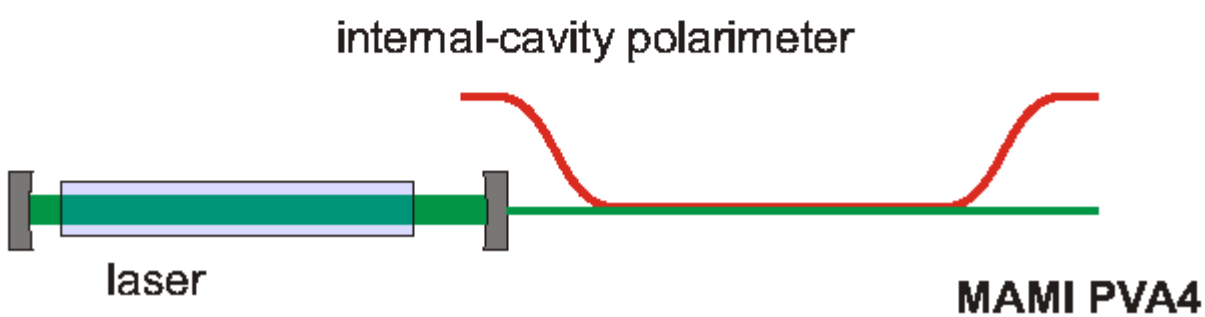


Compton Backscatter Polarimeter

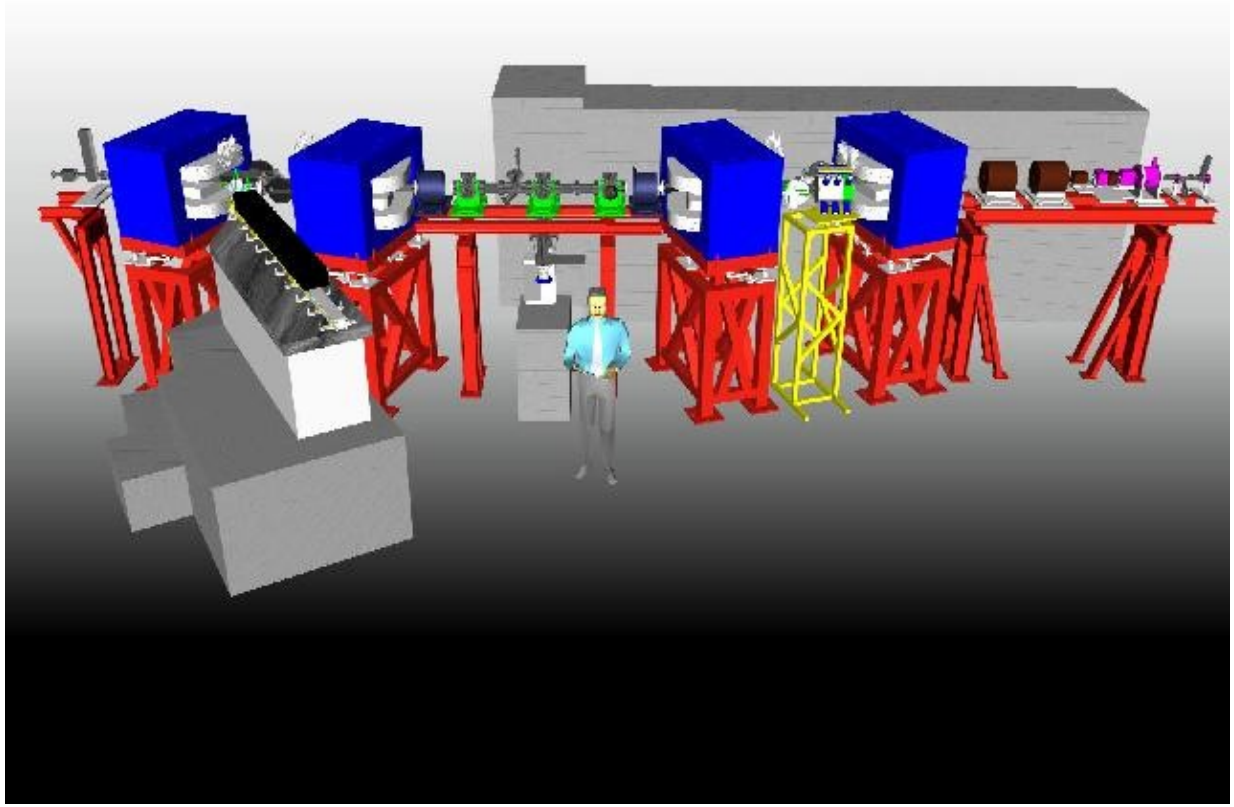
Measured asymmetry: $$A_{\exp} = P \cdot A_{PV}$$

=> P has to be measured!
Principle of compton backscatter polarimeter

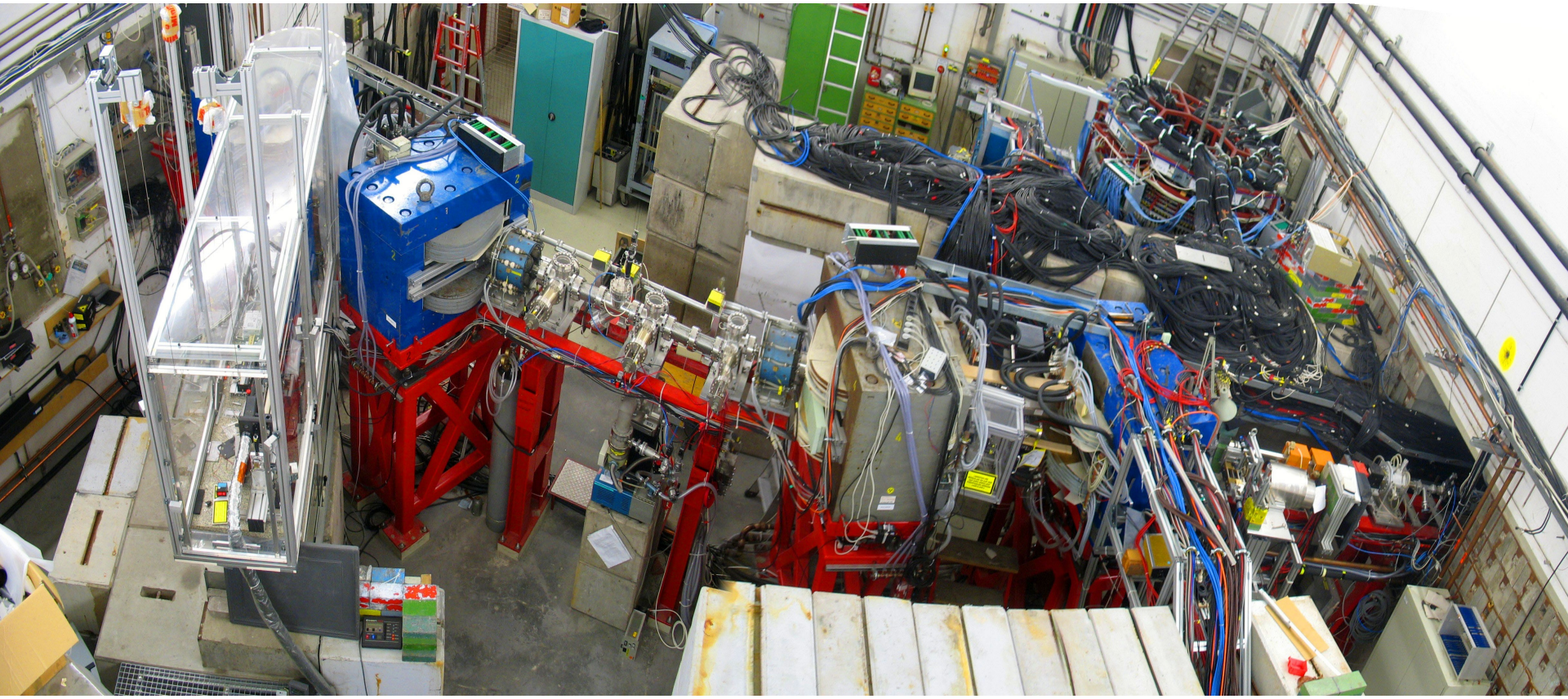




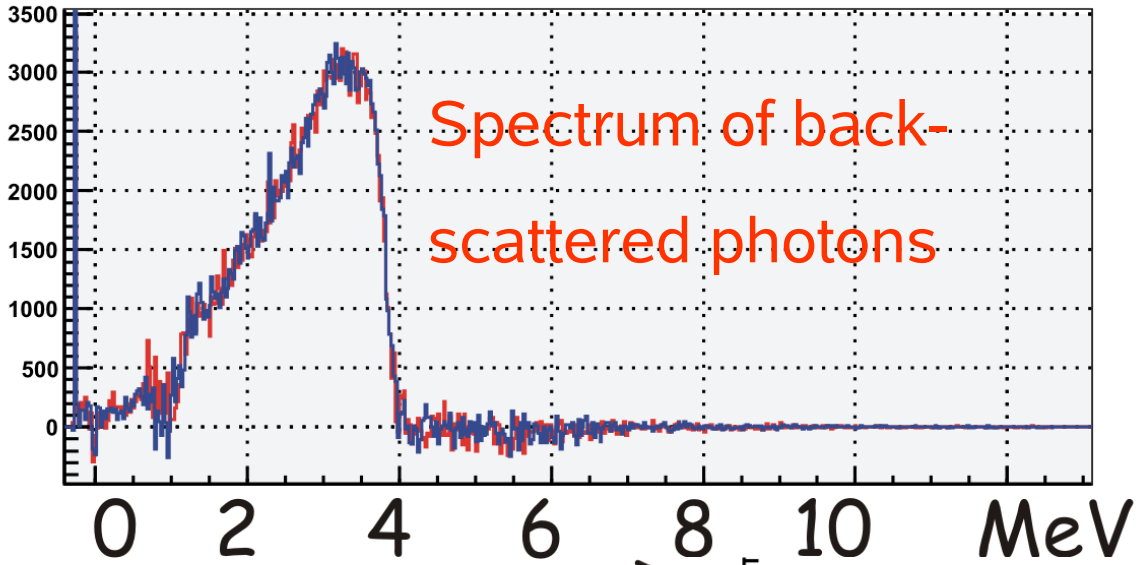
Compton Backscatter Polarimeter



Compton Backscatter Polarimeter



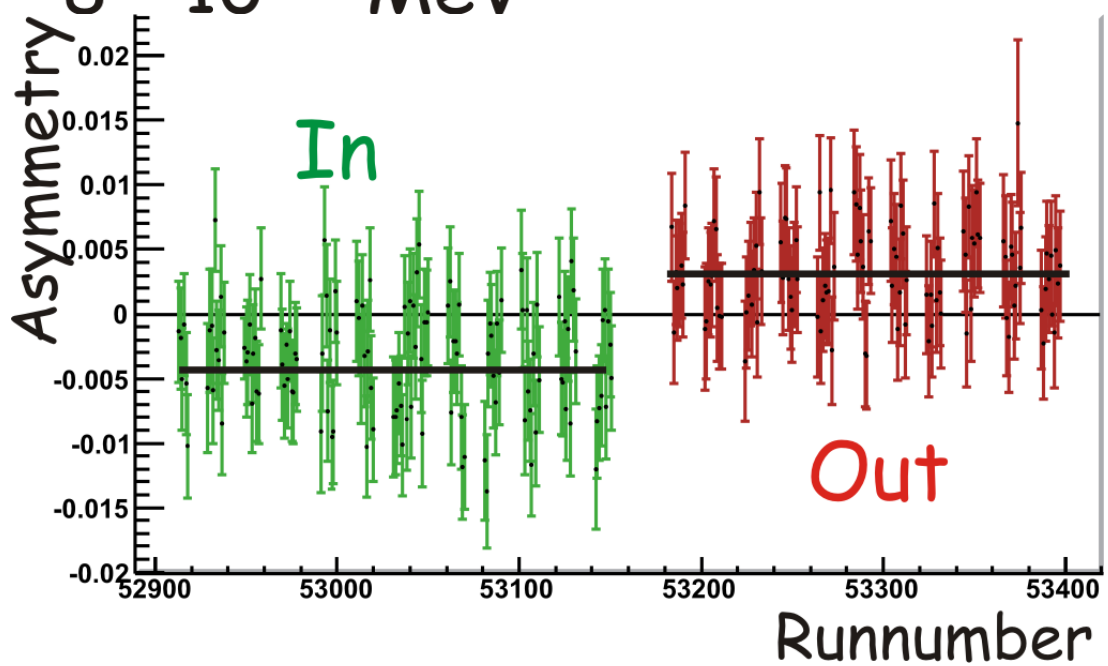
Compton Backscatter Polarimeter



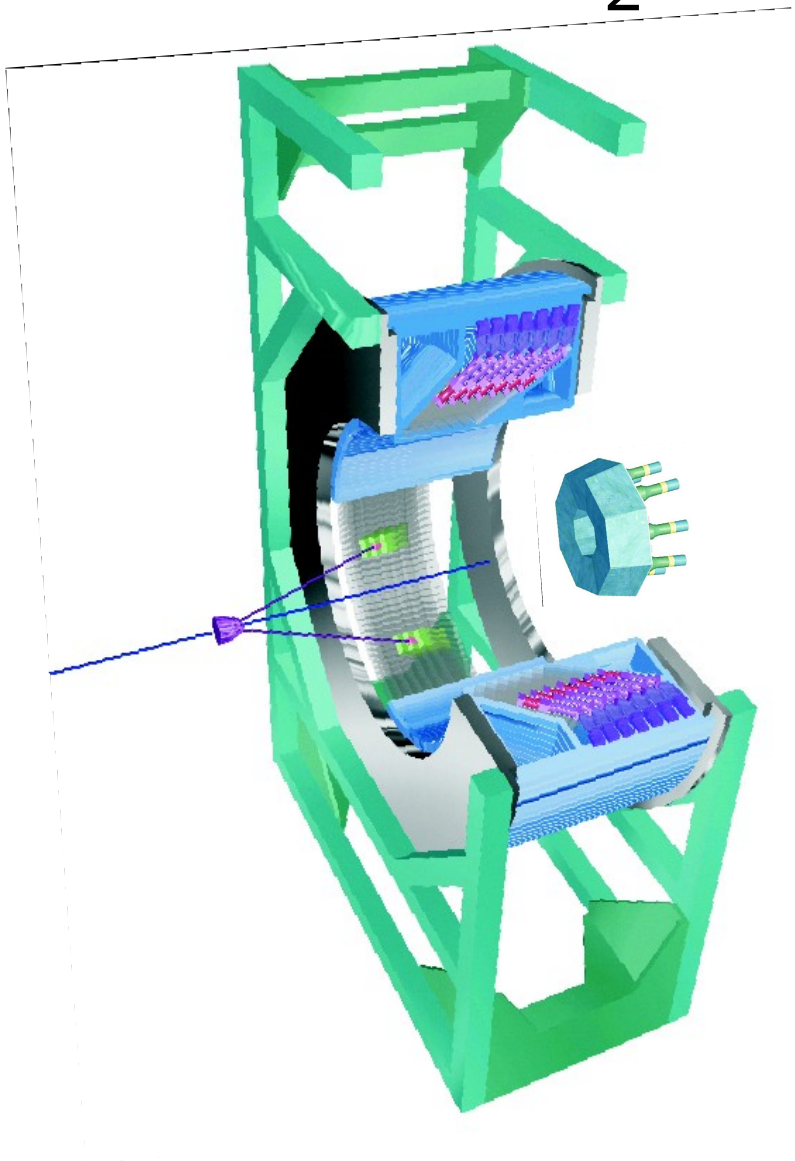
Low beam energy:

E_{beam}=315 MeV !

$A_{compton} \sim P_{beam}$



PbF_2 Calorimeter



- 1022 PbF_2 crystals in 7 rings and 146 frames
- Pure Cherenkov radiator, intrinsically fast
- Solid angle:

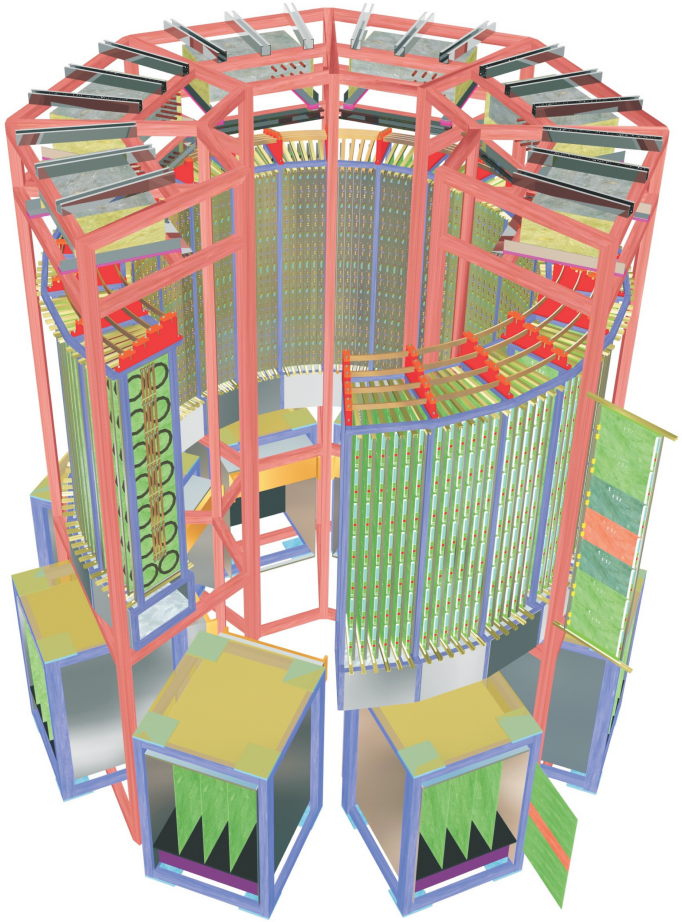
Ω=0.6 sr, $0 \leq \Phi \leq 2\pi$

$30° \leq \Theta \leq 40°$ or
$140° \leq \Theta \leq 150°$

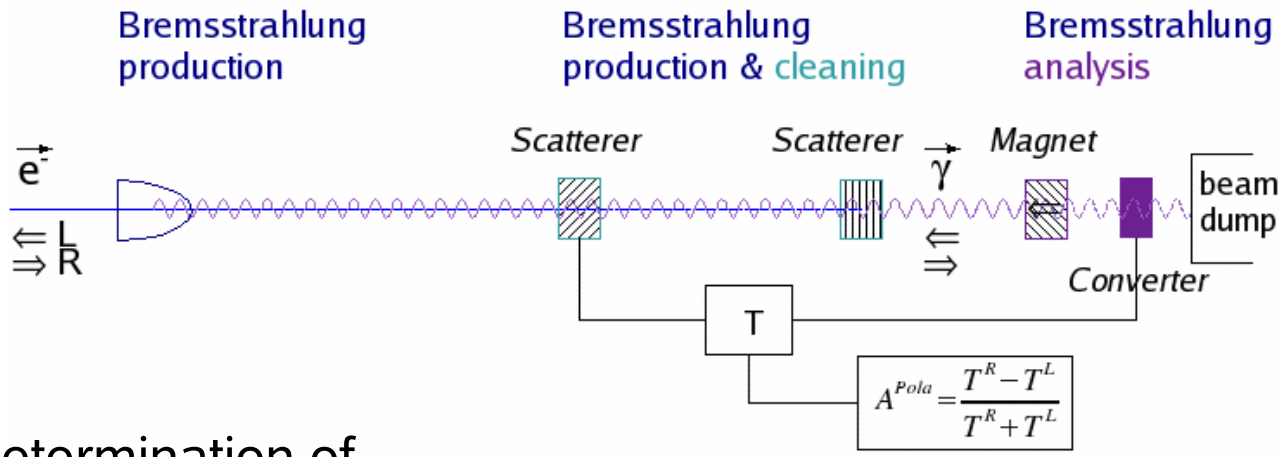
- Total rate ≈ 100 MHz
- Sum of 3x3 crystals

PbF_2 Cal. Readout electronics

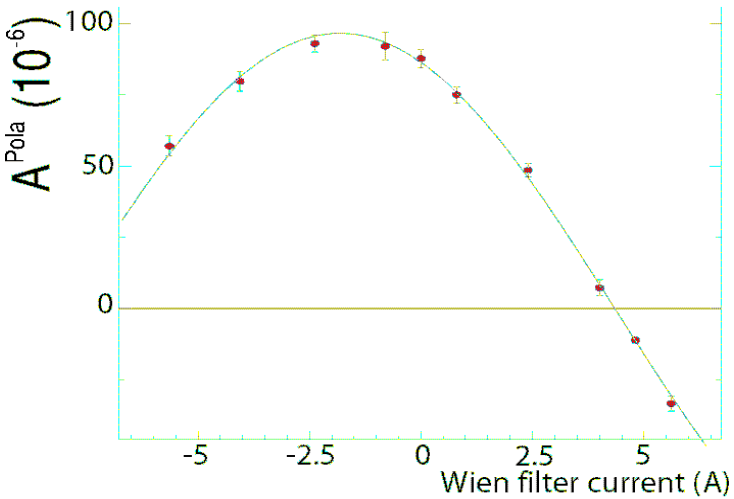
- Analog and digital part
- 1022 individual channels
- Full analog sumup of incoming signals
- More than 6000 cables for data, trigger and veto information



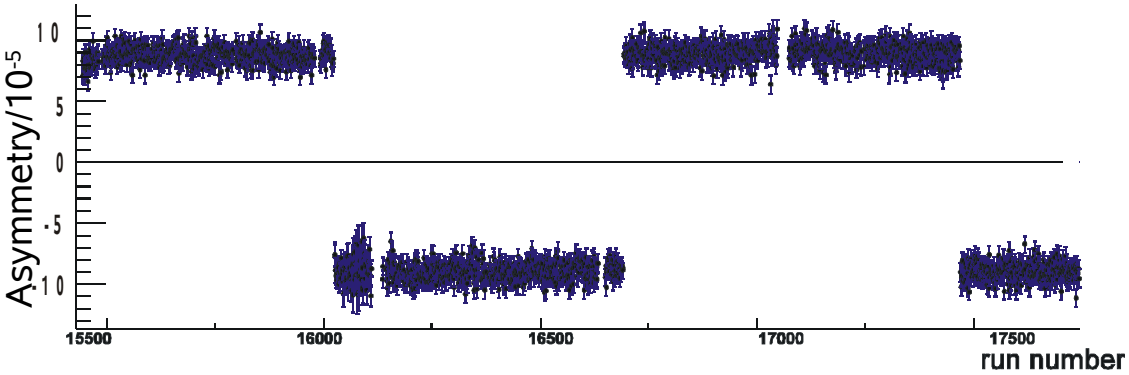
Transmission Compton Polarimeter (TCP)



- Determination of electron spin angle



- Relative measurement of polarization
- Control of halfwave plate status



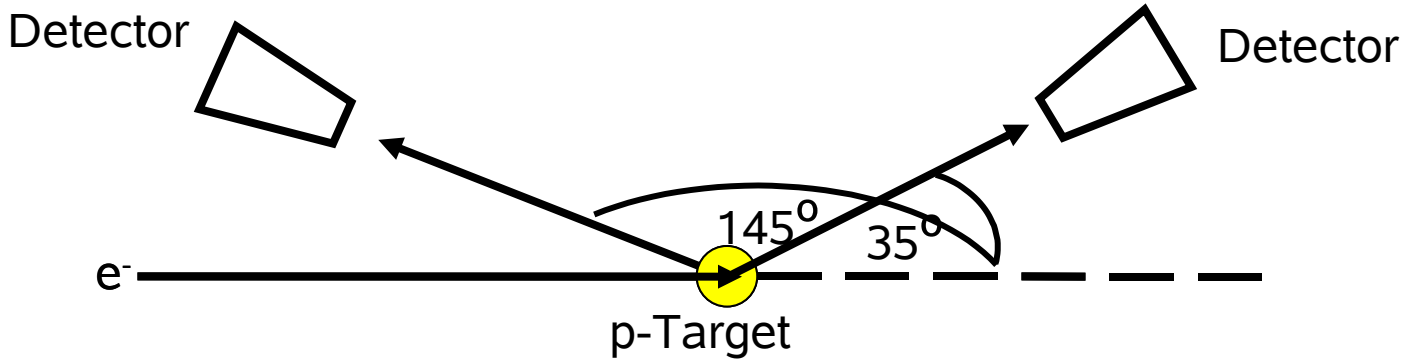
A4 backward angle measurements

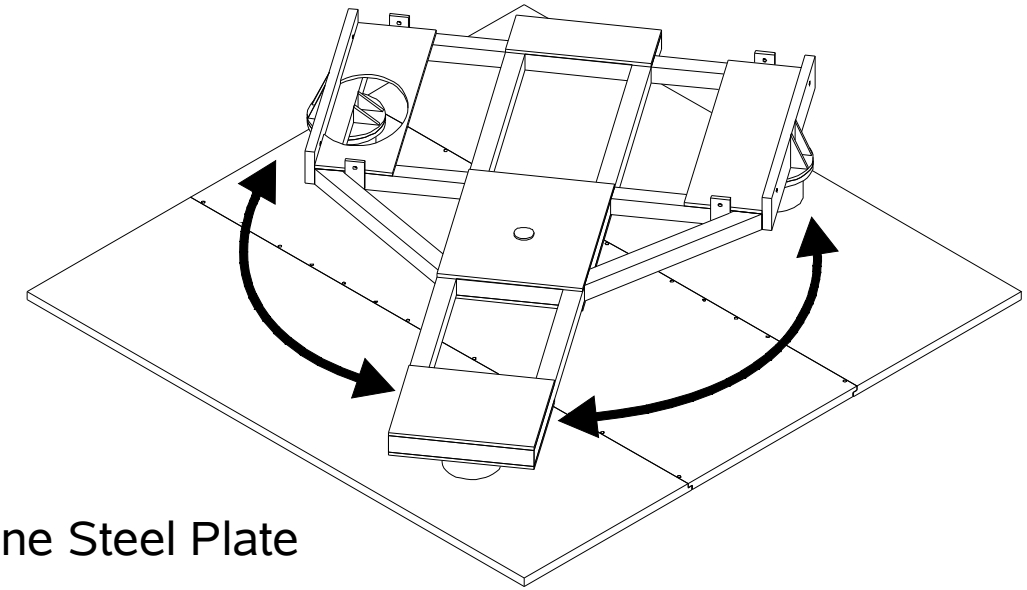
	e+p forward	e+p backward	e+^{4}He forward	e+d backward
Sample		**0.1 (GeV/c)^2**		**0.04 (GeV/c)^2** **0.1 (GeV/c)^2**
Happex	**0.1 (GeV/c)^2** **0.48 (GeV/c)^2** 0.6 (GeV/c)^2		**0.1 (GeV/c)^2**	
A4	**0.1 (GeV/c)^2** **0.23 (GeV/c)^2** 0.6 (GeV/c)^2	**0.23 (GeV/c)^2**		**0.23 (GeV/c)^2**
G^0	**(0.12… 1.0) (GeV/c)^2**	**0.23 (GeV/c)^2** **0.62 (GeV/c)^2**		**0.23 (GeV/c)^2** **0.62 (GeV/c)^2**

A4 backward angle measurements

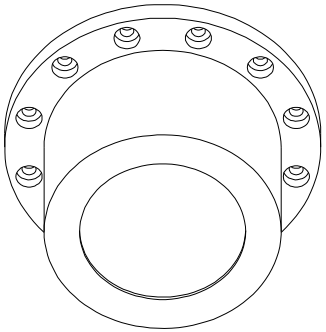
	e+p forward	e+p backward	e+^{4}He forward	e+d backward
Sample		**0.1 (GeV/c)^2**		**0.04 (GeV/c)^2** **0.1 (GeV/c)^2**
Happex	**0.1 (GeV/c)^2** **0.48 (GeV/c)^2** 0.6 (GeV/c)^2	**E=315.3 MeV**	**0.1 (GeV/c)^2**	**E=315.3 MeV**
A4	**0.1 (GeV/c)^2** **0.23 (GeV/c)^2** **E=854.3 MeV**	**0.23 (GeV/c)^2**		**0.23 (GeV/c)^2**
G^0	**(0.12… 1.0) (GeV/c)^2**	**0.23 (GeV/c)^2** **0.62 (GeV/c)^2**		**0.23 (GeV/c)^2** **0.62 (GeV/c)^2**

A4 Detector rearrangement



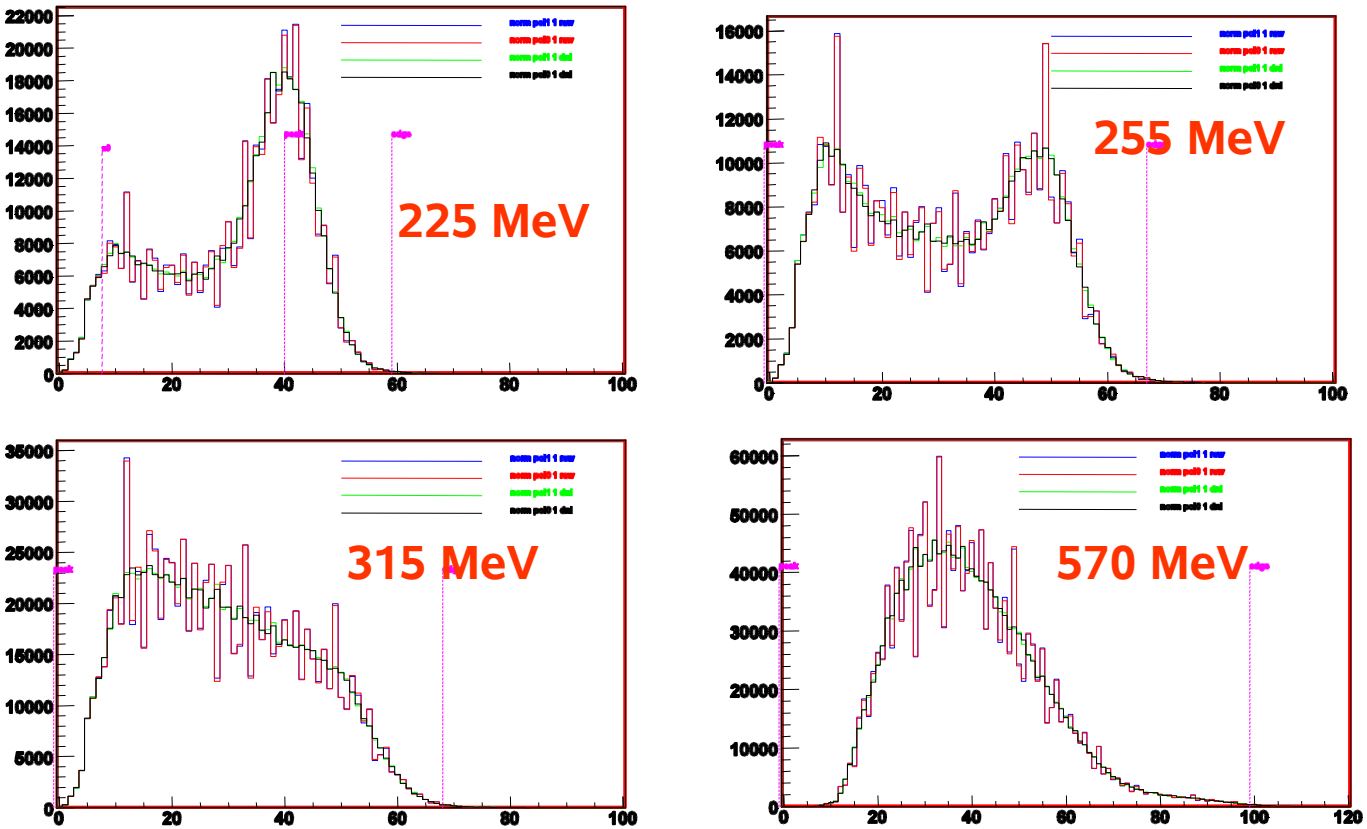


Plane Steel Plate



Hydraulic Oil Plunger

A4 backward measurements

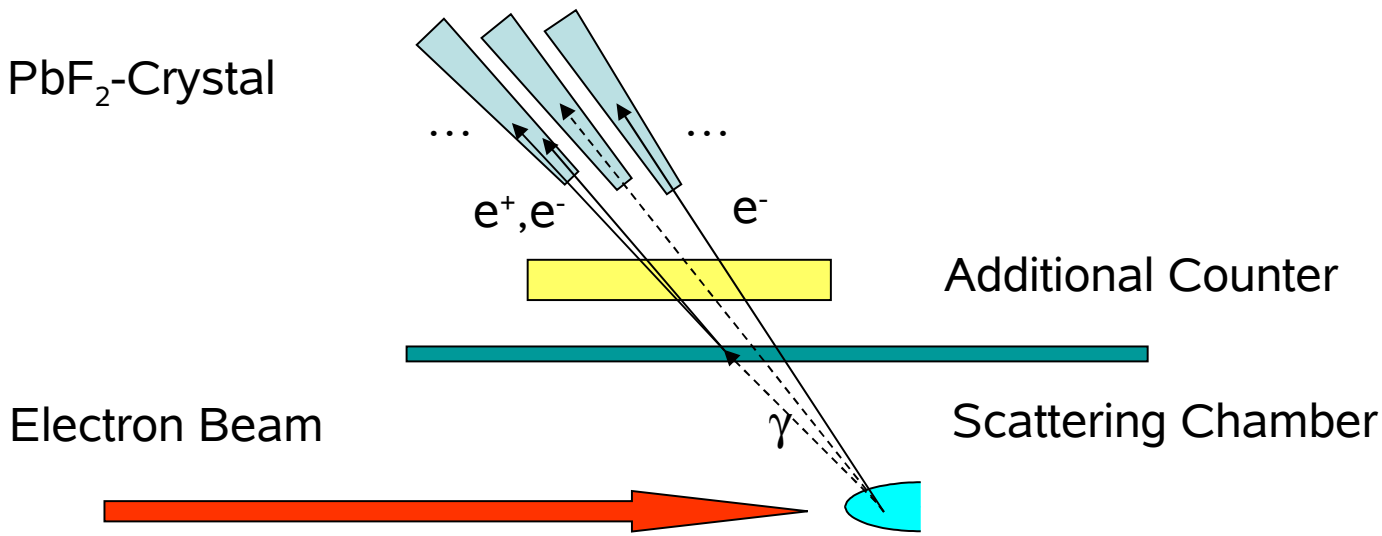


Additional background in the energy region of the elastic peak:

Photons from pion decay. Pions coming from

- Pion electroproduction
- Pion photoproduction

Additional scintillator system



Separation of charged and neutral particles

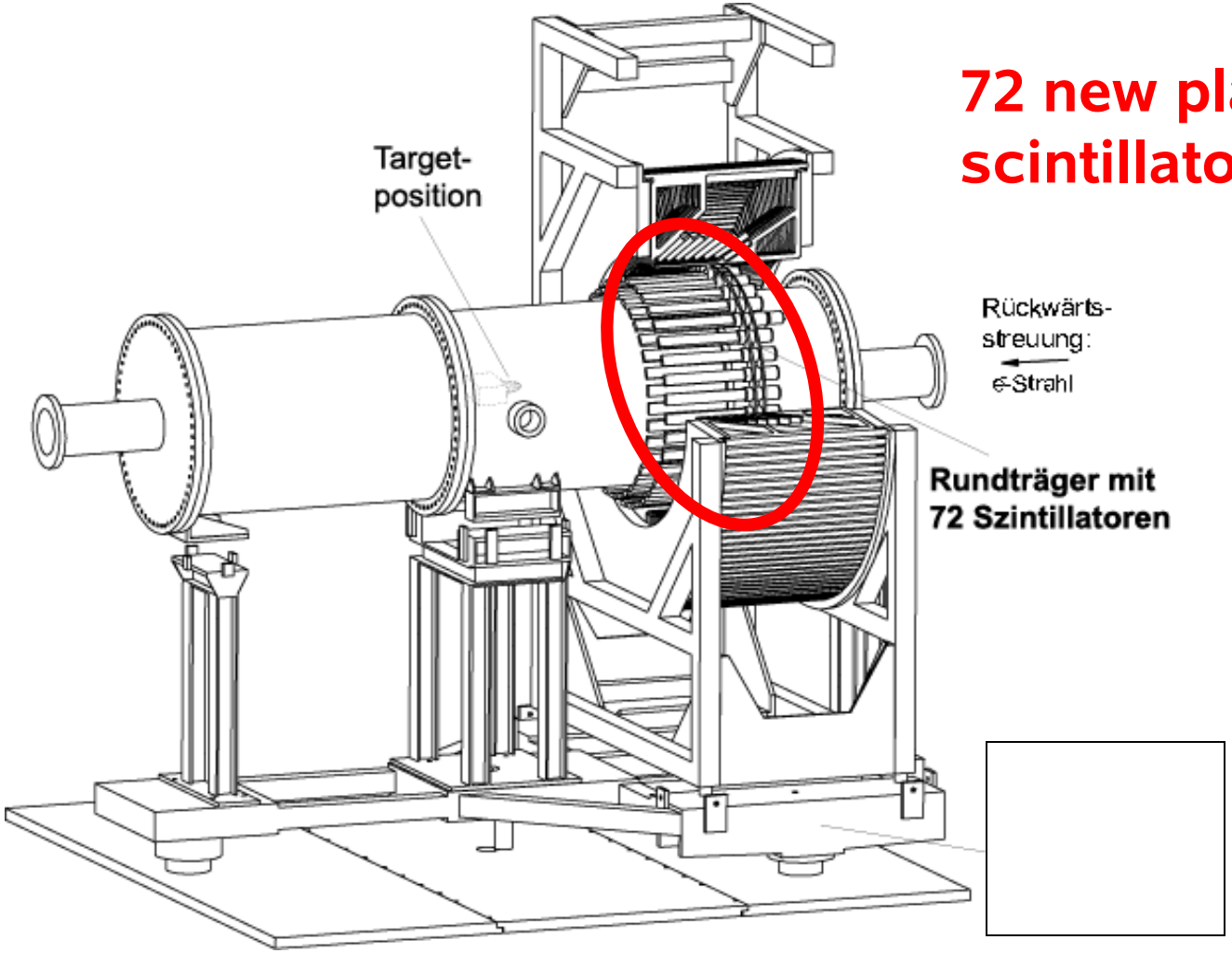
Additional scintillator system

Plastic Scintillator (EJ-204)

Photomultiplier Housing (XP2262B)

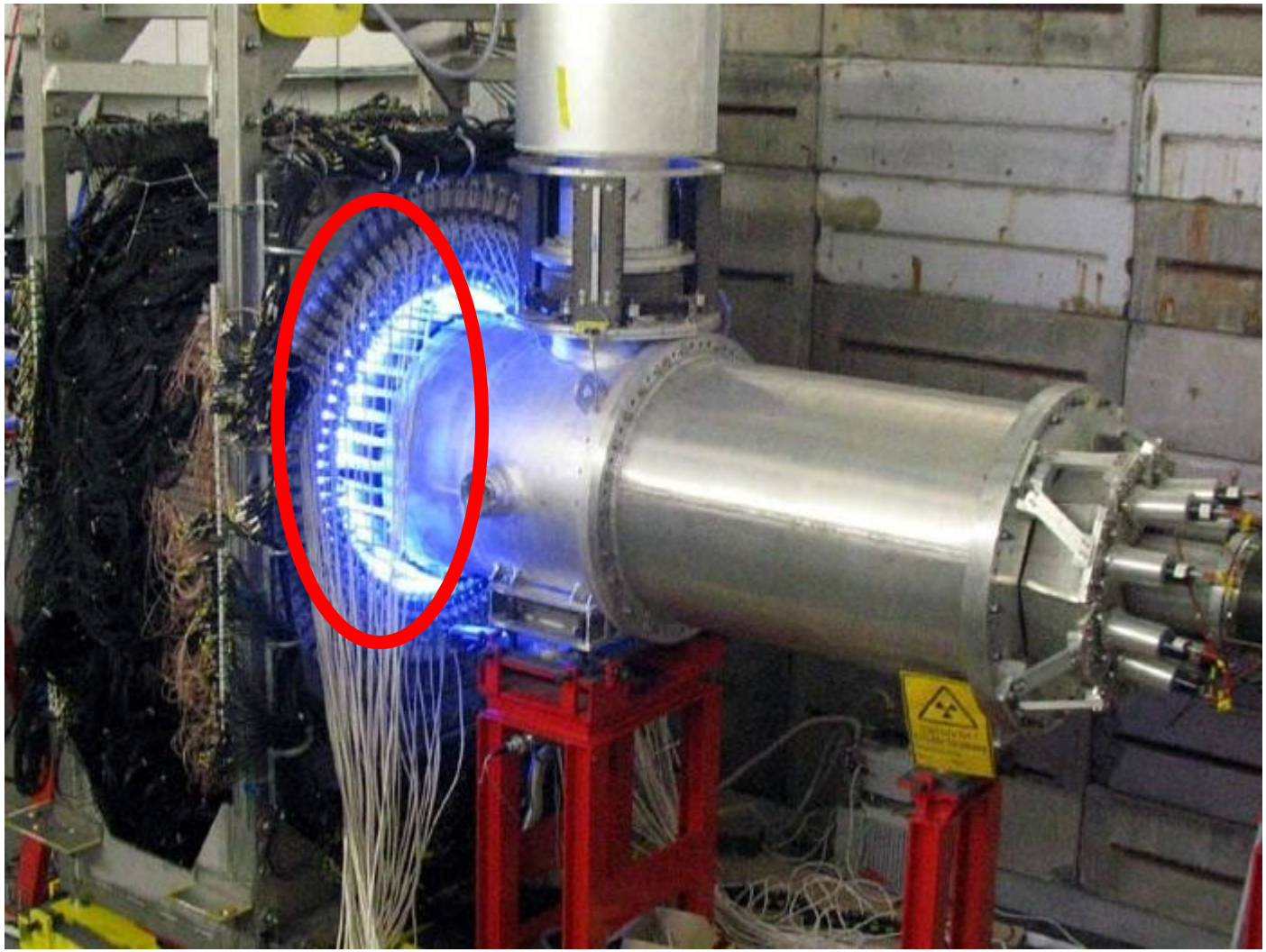
Scintillator Dimension : 20 mm x 50 mm x 400mm

Additional scintillator system

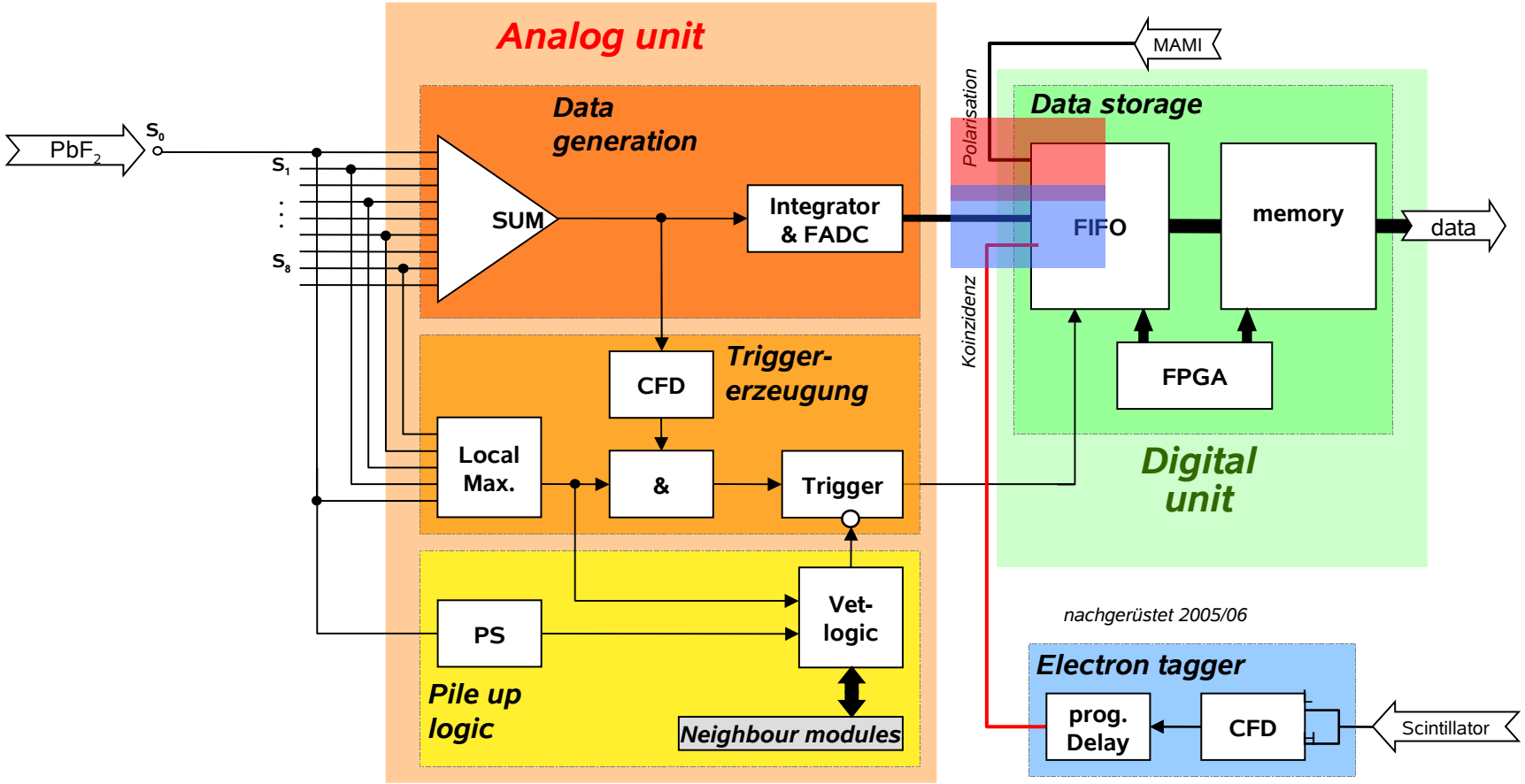


72 new plastic scintillators

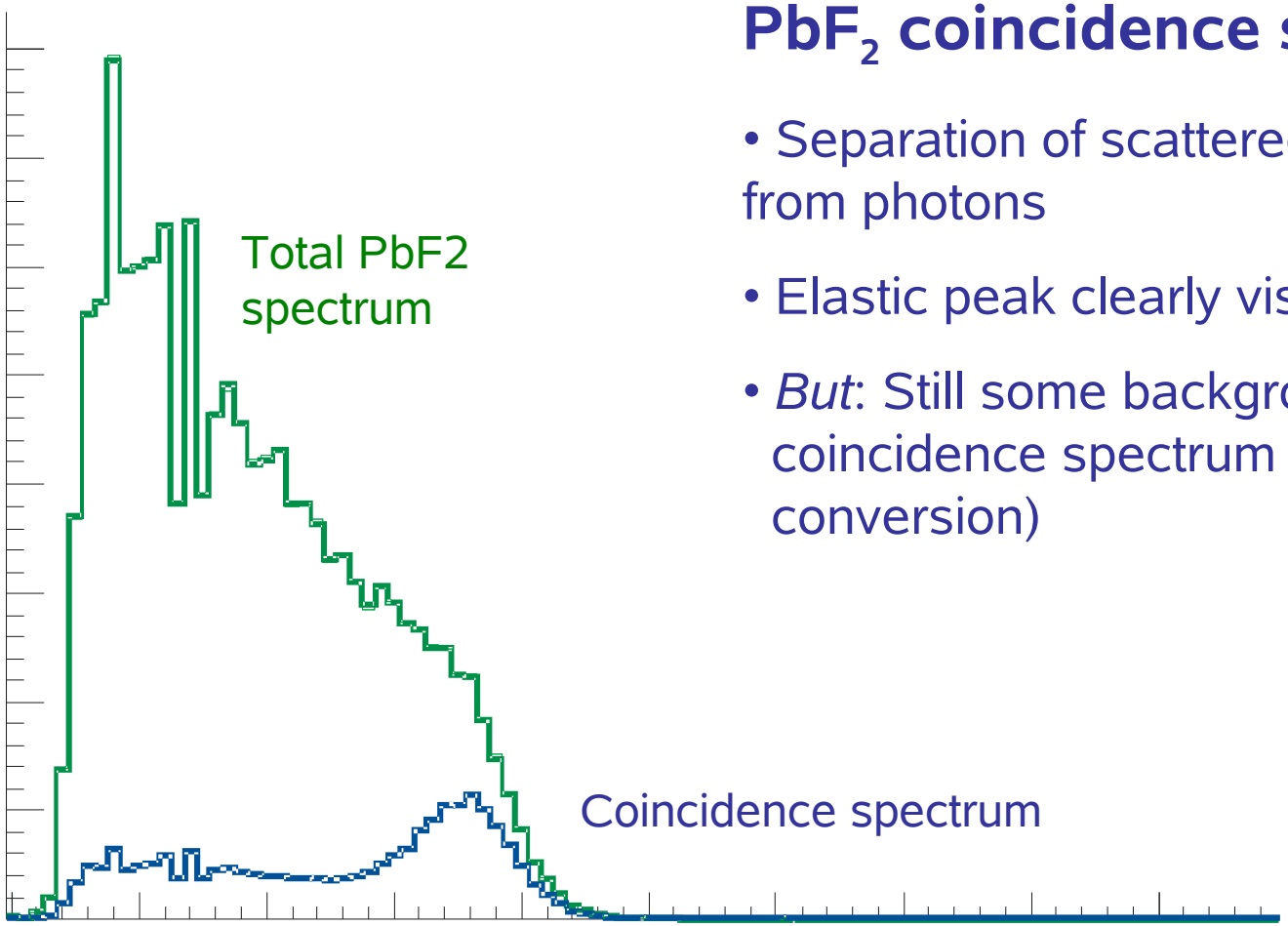
Additional scintillator system



Readout and trigger electronics



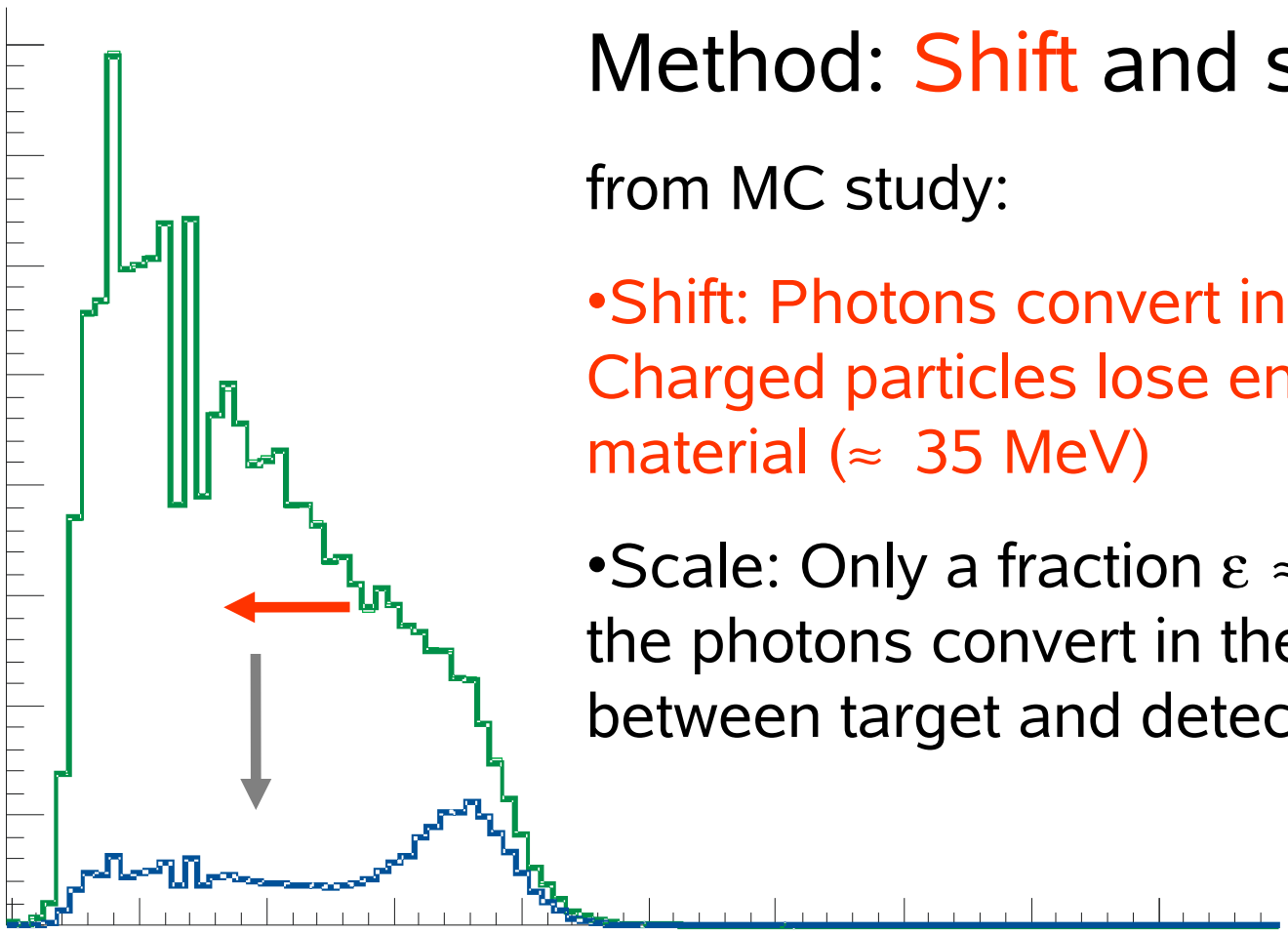
Coincidence spectrum



PbF_2 coincidence spectrum

- Separation of scattered electrons from photons
- Elastic peak clearly visible
- *But*: Still some background in the coincidence spectrum (gamma conversion)

Background subtraction

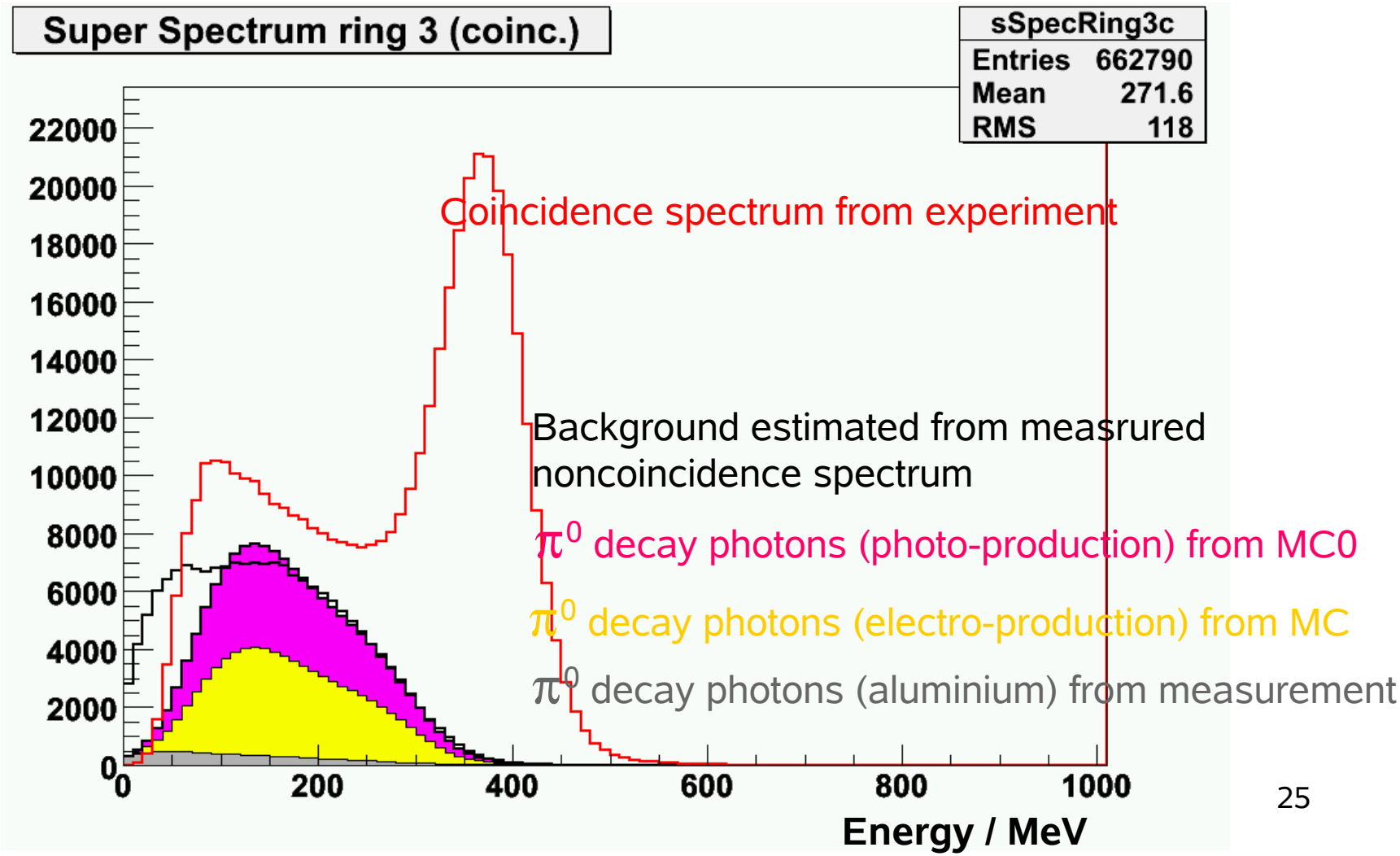


Method: Shift and scale

from MC study:

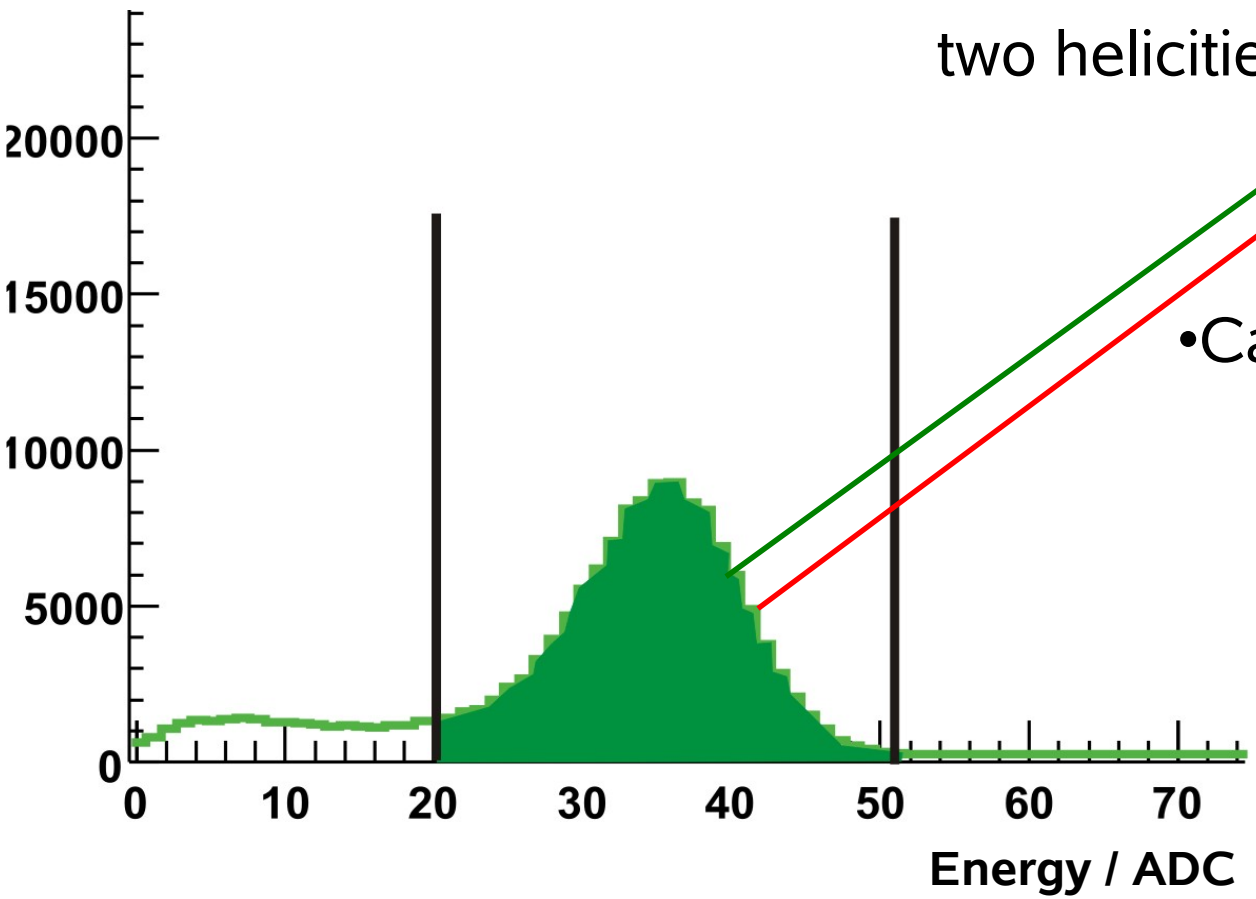
- Shift: Photons convert into e^+e^- pairs. Charged particles lose energy in the material ($\approx$ 35 MeV)
- Scale: Only a fraction $\varepsilon \approx 0.11$ of the photons convert in the material between target and detector

Shift and scale: Data and MC simulation



Extraction of PV asymmetry

- Apply upper and lower cut
- Number of counts for the two helicities N^+, N^-



- Calculate asymmetry:

$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

Analysis

- Elastic events for one run: $N^{+}=\sum_{c=1}^{1022} N_c^{+}, N^{-}=\sum_{c=1}^{1022} N_c^{-}$

- Experimental Asymmetry: $$A_{ex}=\frac{\frac{N^{+}}{\rho^{+}}-\frac{N^{-}}{\rho^{-}}}{\frac{N^{+}}{\rho^{+}}+\frac{N^{-}}{\rho^{-}}}$$ with ρ target density

$$A_{ex}=P\cdot A_{phys}+\sum_{i=1}^{6} a_i X_i$$

P: Beam polarisation

X_1: Current asymmetry

X_2: Horiz. position diff.

X_3: Verti. Position diff.

X_4: Horiz. angle diff.

X_5: Verti. angle diff.

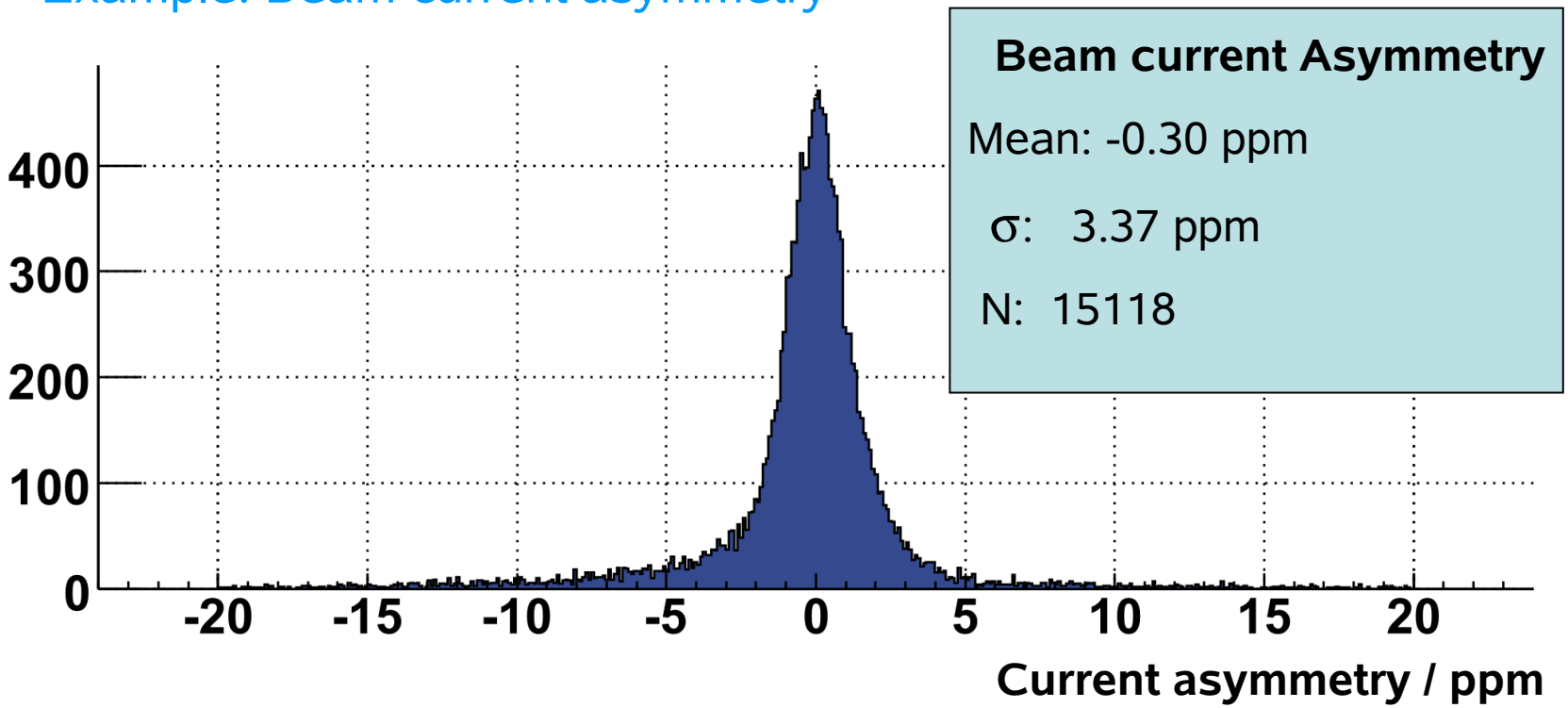
X_6: Energy diff.

- Determination of a_i via multiple linear regression

Beam parameter

Asymmetries and differences in current, position, angle, energy

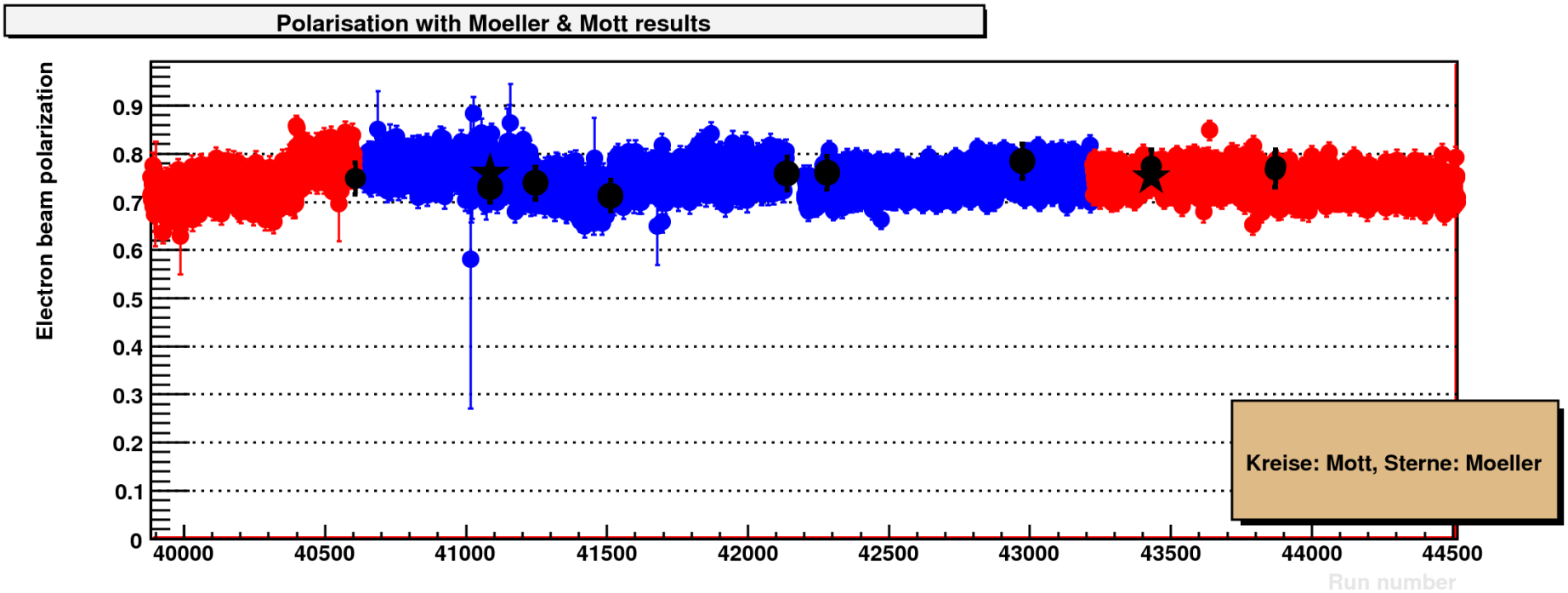
Example: Beam current asymmetry



Beam parameter and false asymmetries

Beam parameter $\overline{X}_i$ (helicity correlated)		False Asymmetry $a_i\overline{X}_i$ (Estimation)
Current Asymmetry A_I	-0.30 ppm	-0.25 ppm
Horizontal position diff. ΔX	-87.0 nm	+0.61 ppm
Vertical position diff. ΔY	-23.8 nm	- 0.86 ppm
Horizontal angle diff. $\Delta X'$	-8.5 nrad	-0.09 ppm
Vertical angle diff. $\Delta Y'$	-2.5 nrad	+0.10 ppm
Energy diff. ΔE	-0.41 eV	+0.16 ppm

Polarization measurement

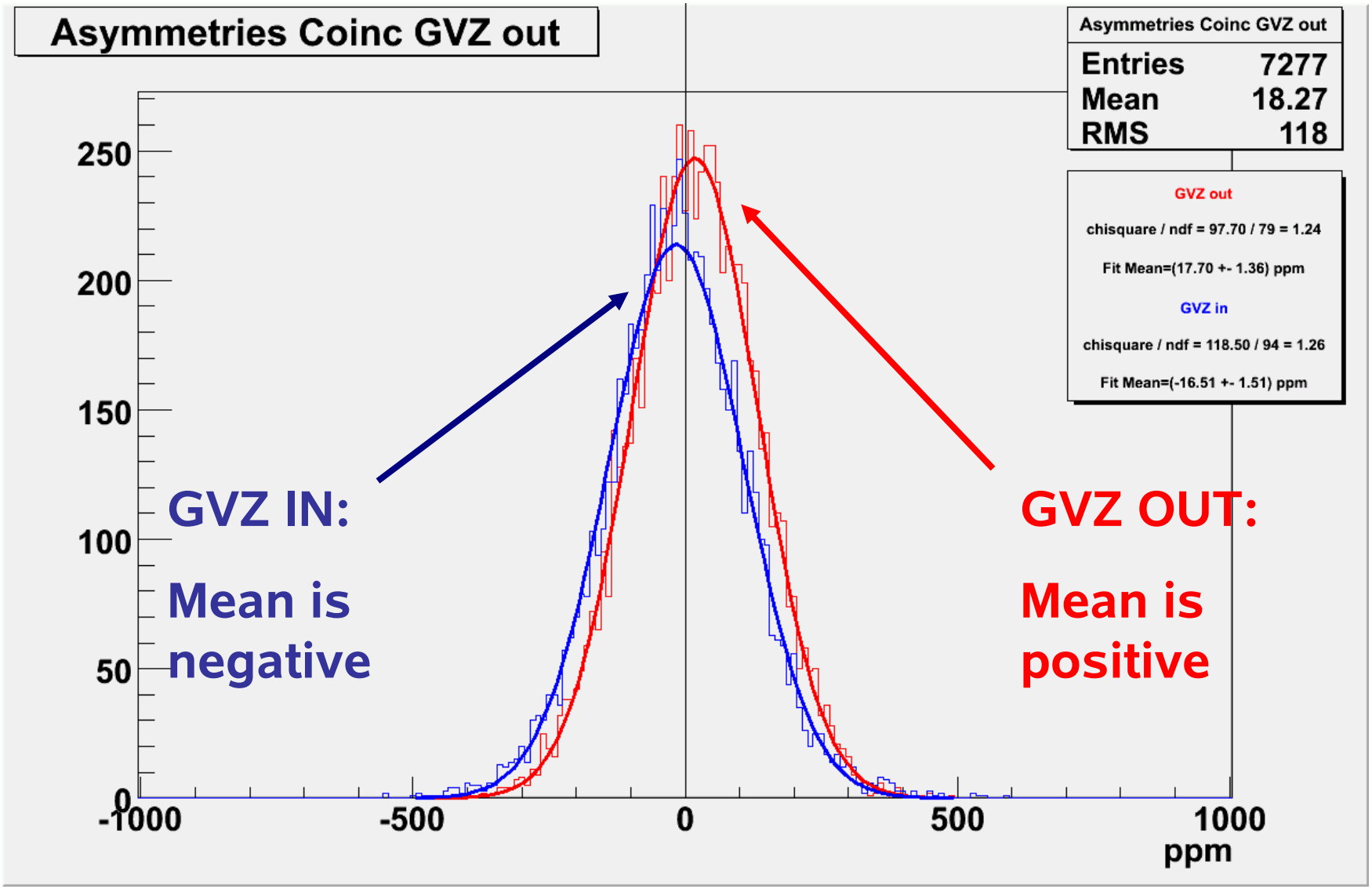


Average polarization: P=70.3 %

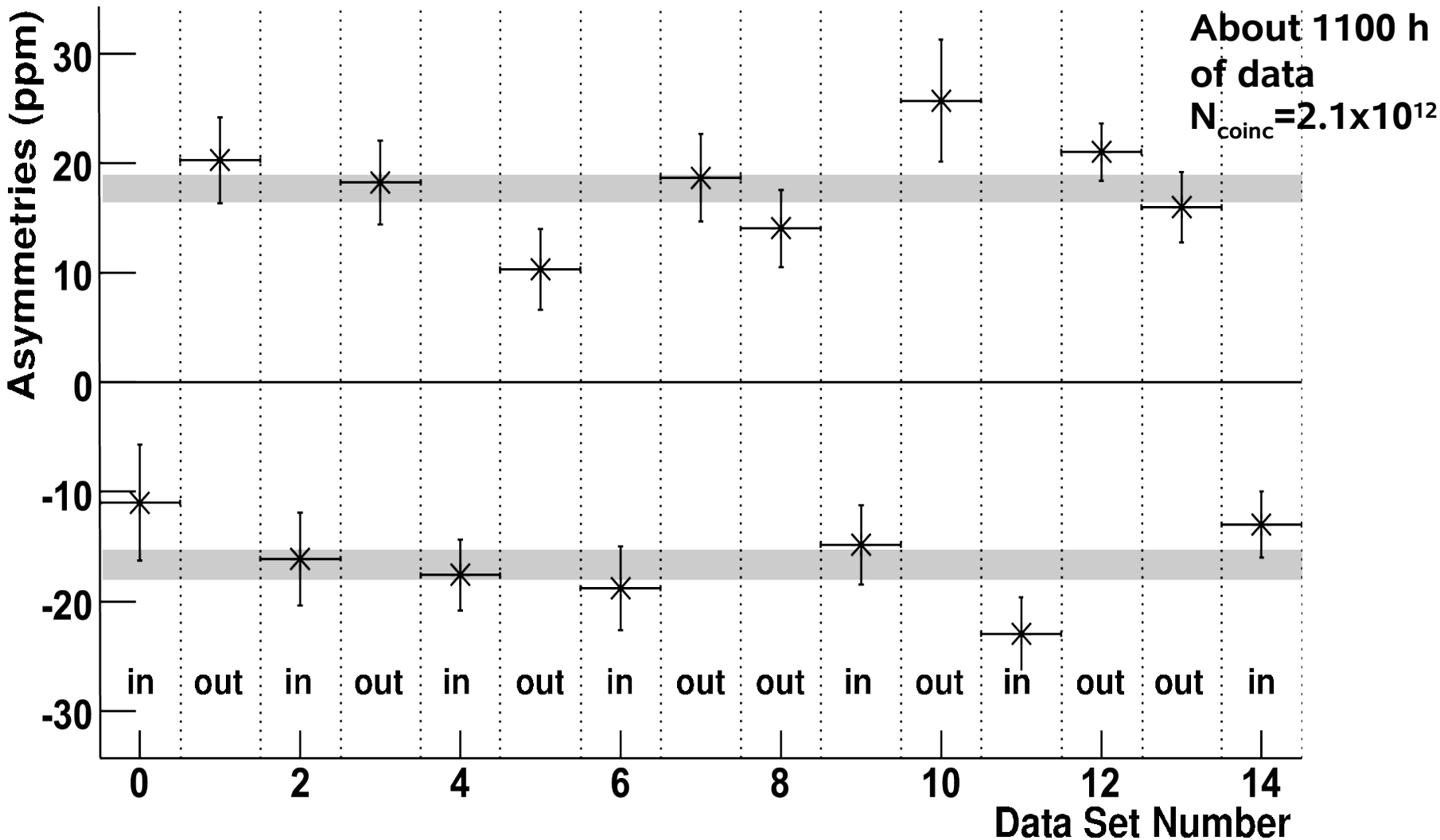
Statistical uncertainty: 0.8 %

Systematic uncertainty: 4 %

Asymmetry analysis results



A4 backward results (H_2)



A_{coinc}= (-17.23 ± 0.84$_{stat}$ ± 0.89$_{syst}$) ppm

$\chi 2$ /NDF=16.70/14=1.19

Q^2=0.23 $(GeV/c)^2$ backward (H_2)

Parity violating asymmetry from experiment:

A_{PV}= (-17.23 ± 1.21) ppm

Standard model calculation with no strangeness assumption:

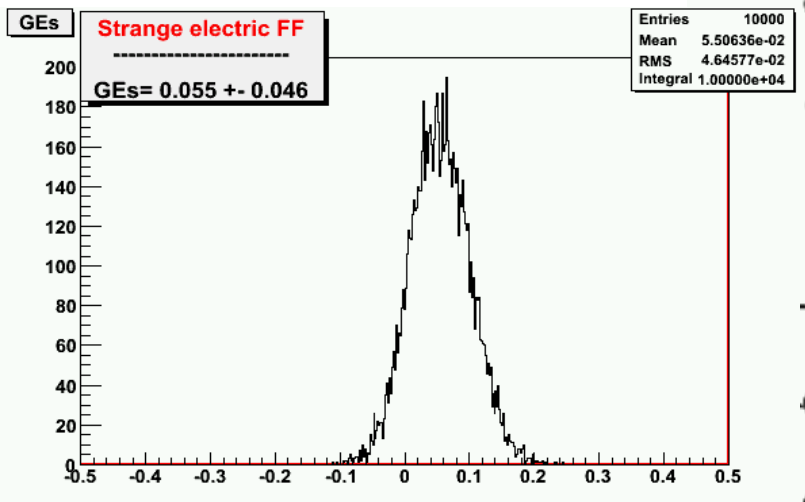
A_0=(-15.87 ± 1.22) ppm

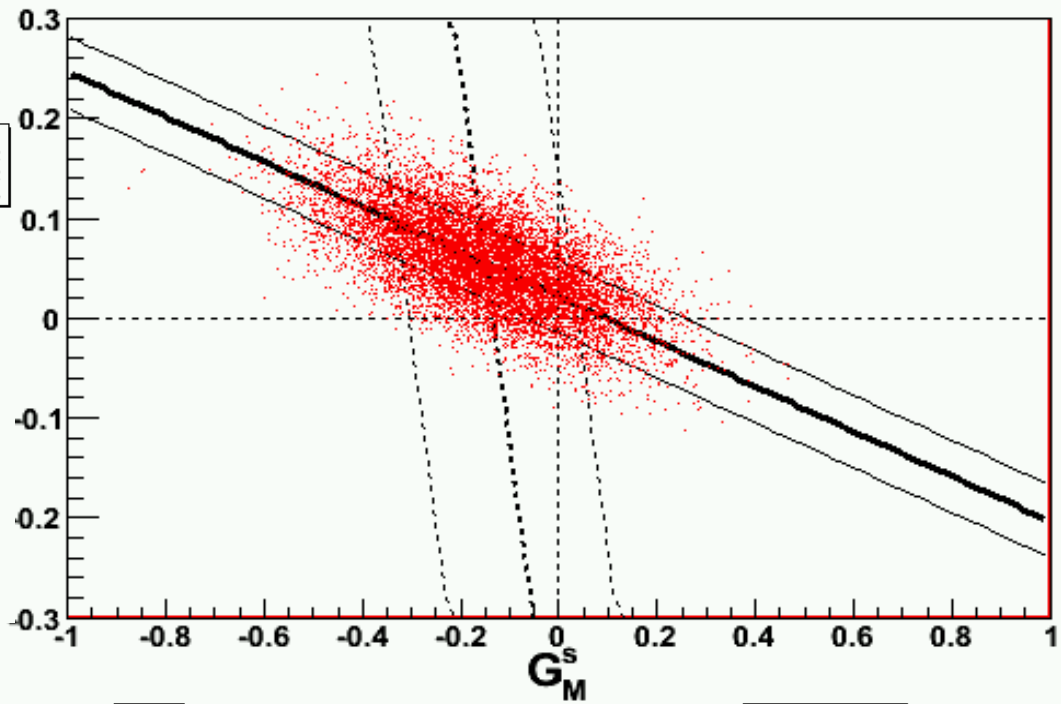
=> Linear combination of strange form factors:

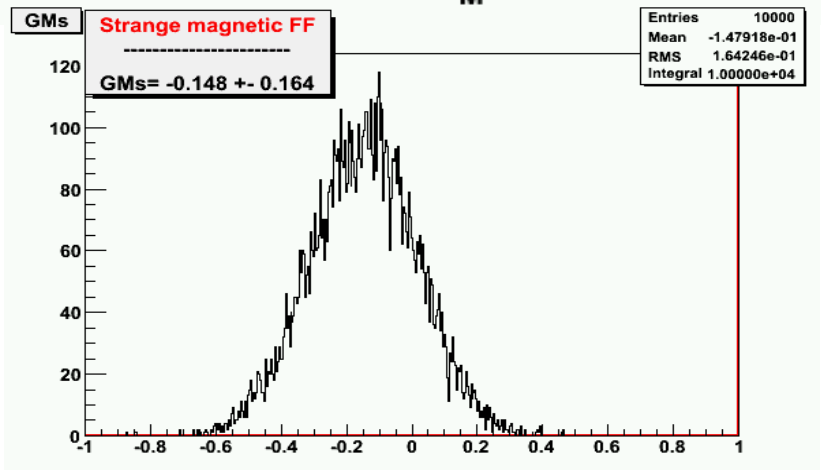
$G_M^s + 0.26\ G_E^s = -0.12 \pm 0.11 \pm 0.11$

A4, Q^2=0.23 $(GeV/c)^2$

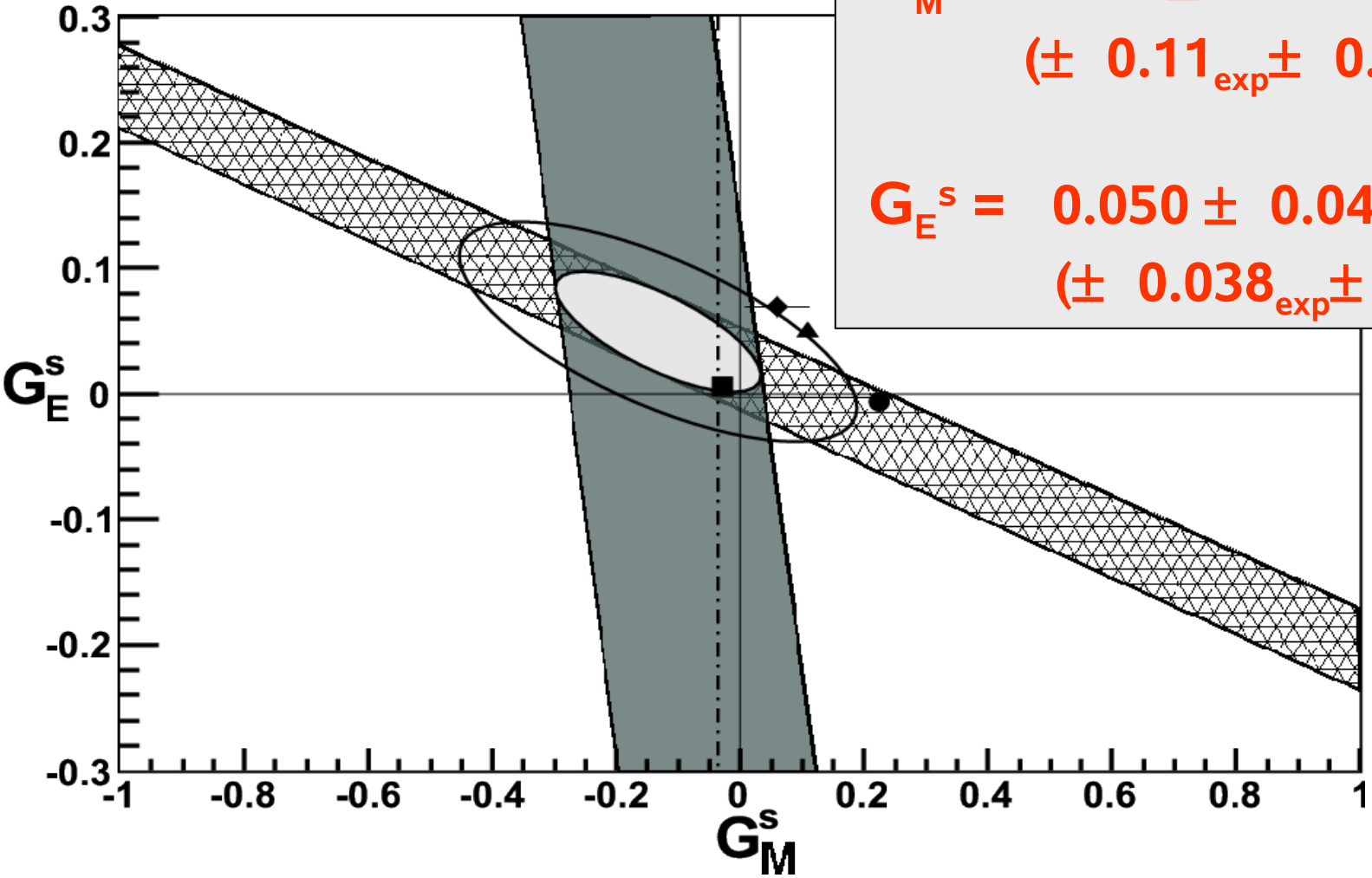
Disentangling of Strange Form Factors







A4, Q^2=0.23 $(GeV/c)^2$
Hydrogen, combined results (H_2)

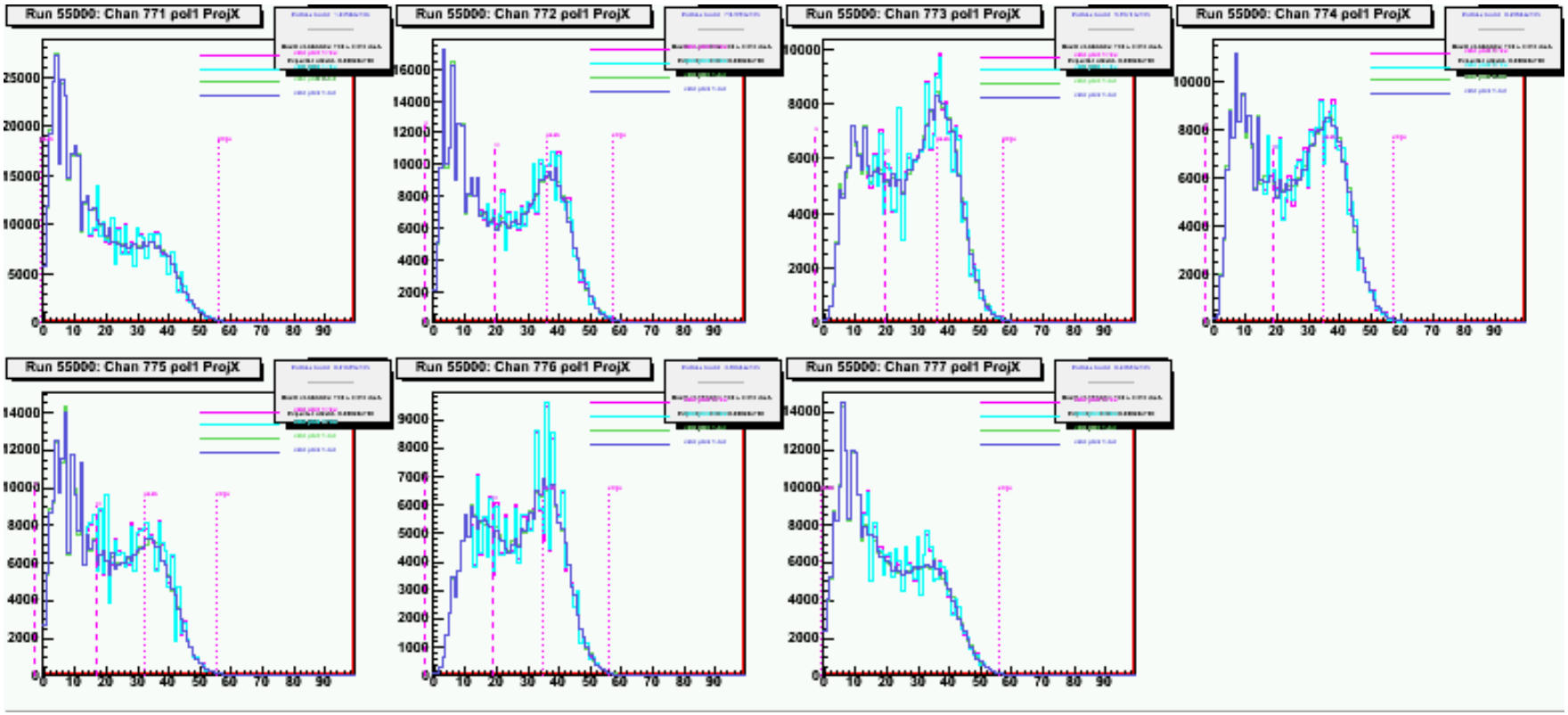


G_M^s = -0.14 ± 0.16
(± 0.11_{exp} ± 0.11_{FF})

G_E^s = 0.050 ± 0.042
(± 0.038_{exp} ± 0.019_{FF})

A4, Q^2=0.23 $(GeV/c)^2$ Deuterium

Aim: Disentangling of G_M^s and G_A^p by experiment

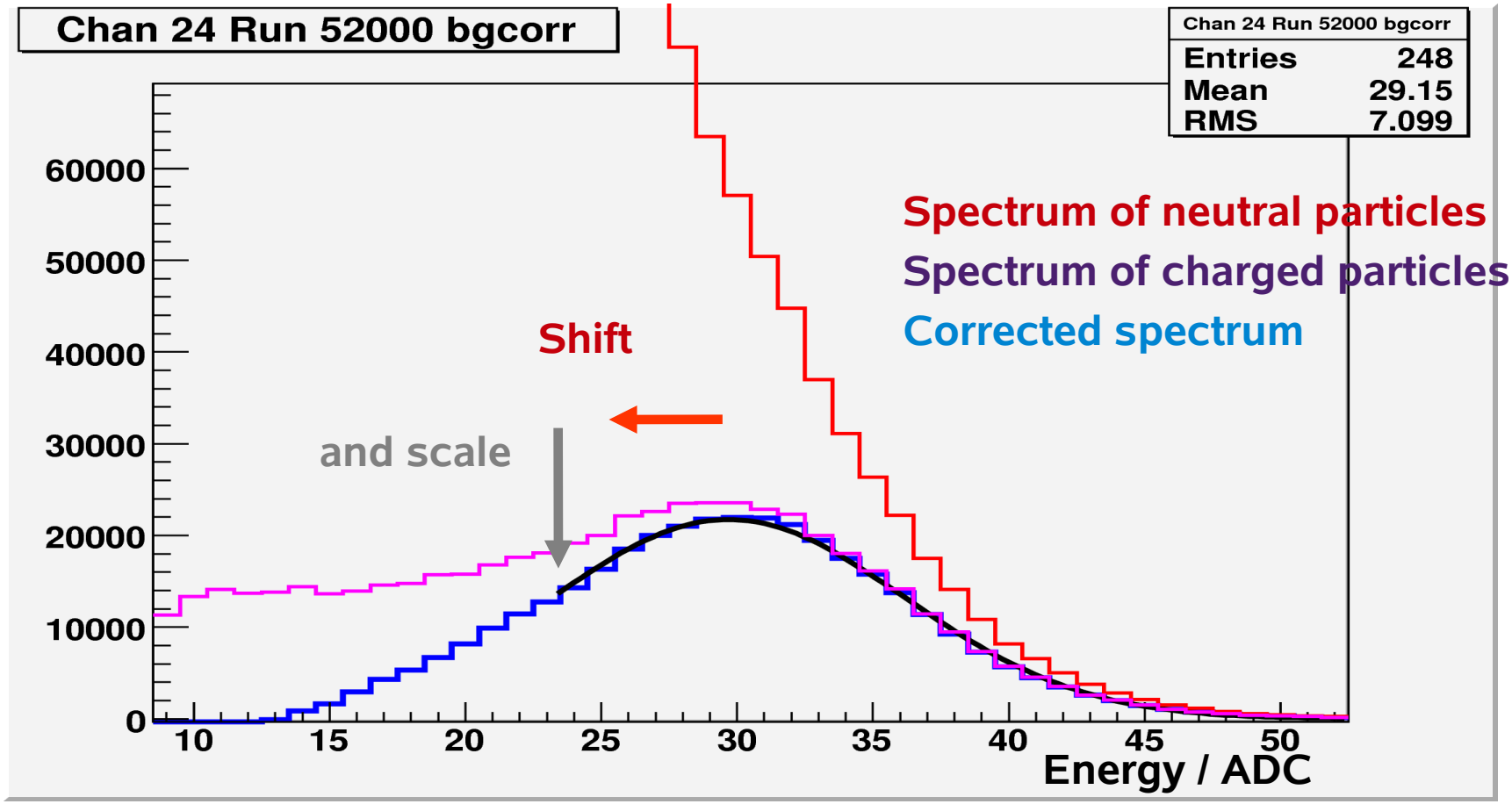


Beam parameter (D_2)

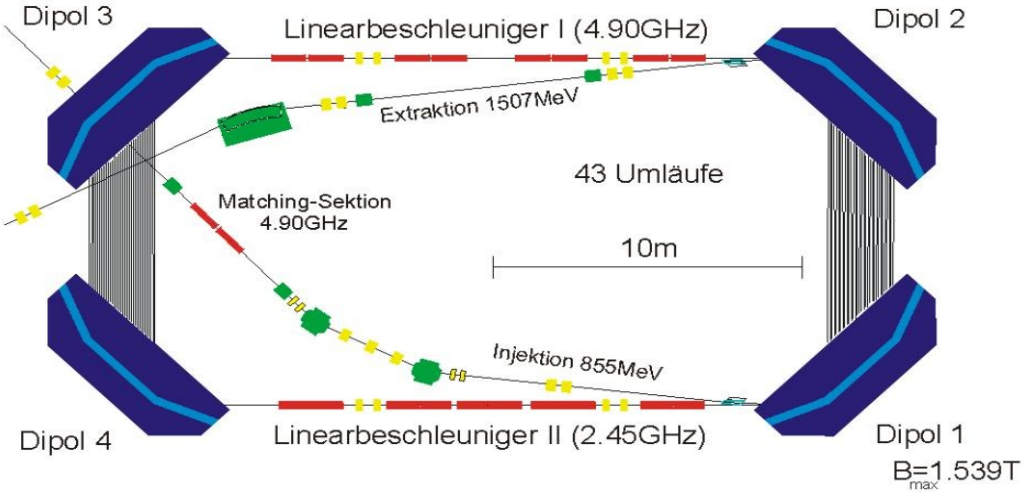
<u>940 hours of asymmetry data on tape:</u>

Label	Parameter	Value
X1	Current asymmetry	0.07 ppm
X2	Position diff. X	-349.8 nm
X3	Position diff. Y	-95.9 nm
X4	Angle diff. X	-38.4 nrad
X5	Angle diff. Y	-8.5 nrad
X6	Energe difference	0.19 eV

Background subtraction (D_2)



Outlook: “A4-III”



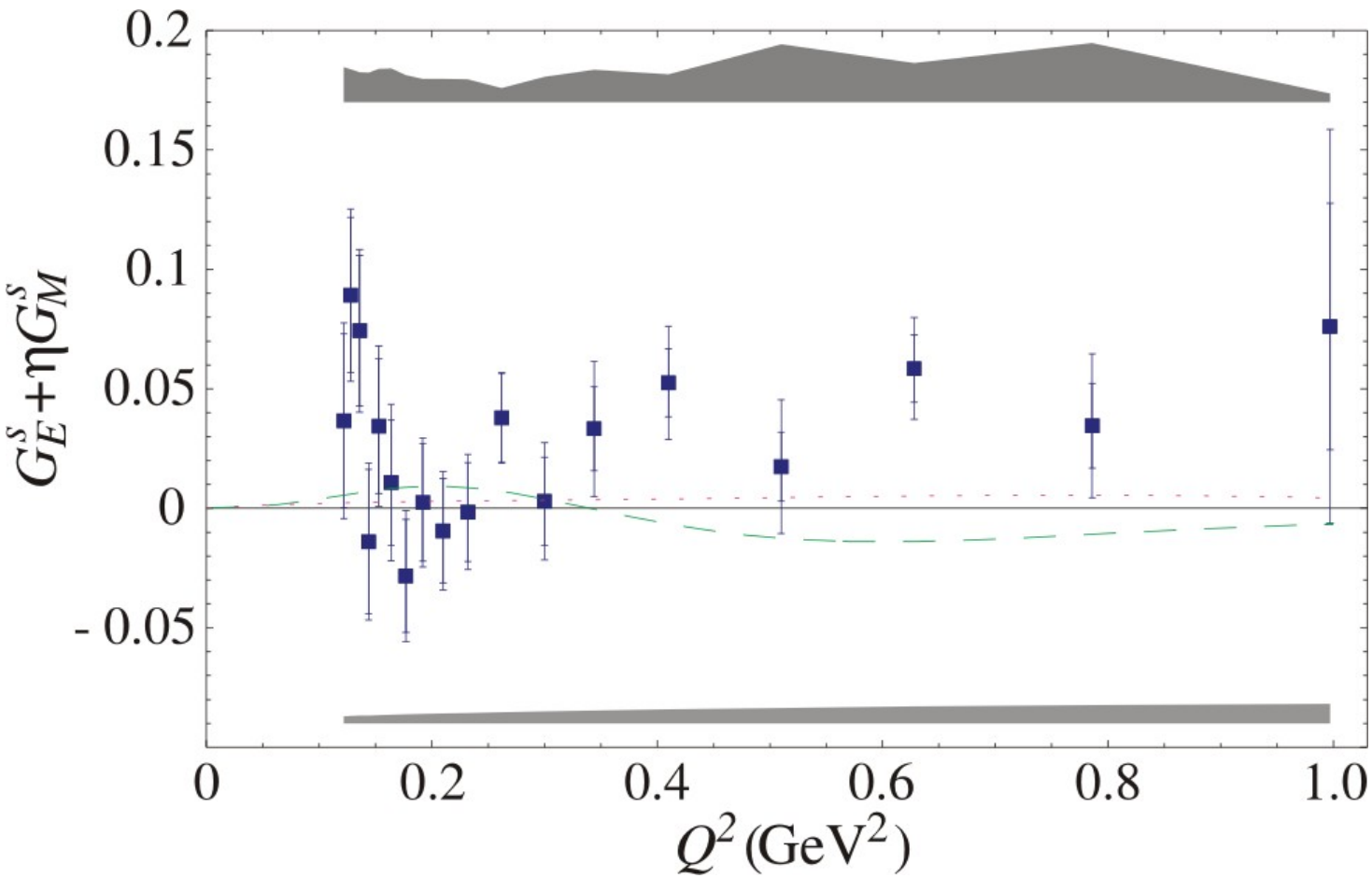
2006: MAMI-C Energy upgrade from E=855 MeV to E=1508 MeV

PbF_2 Calorimeter: Scattering angle θ=35°

=> Elastic scattering: Momentum transfer of Q^2=0.62 GeV^2

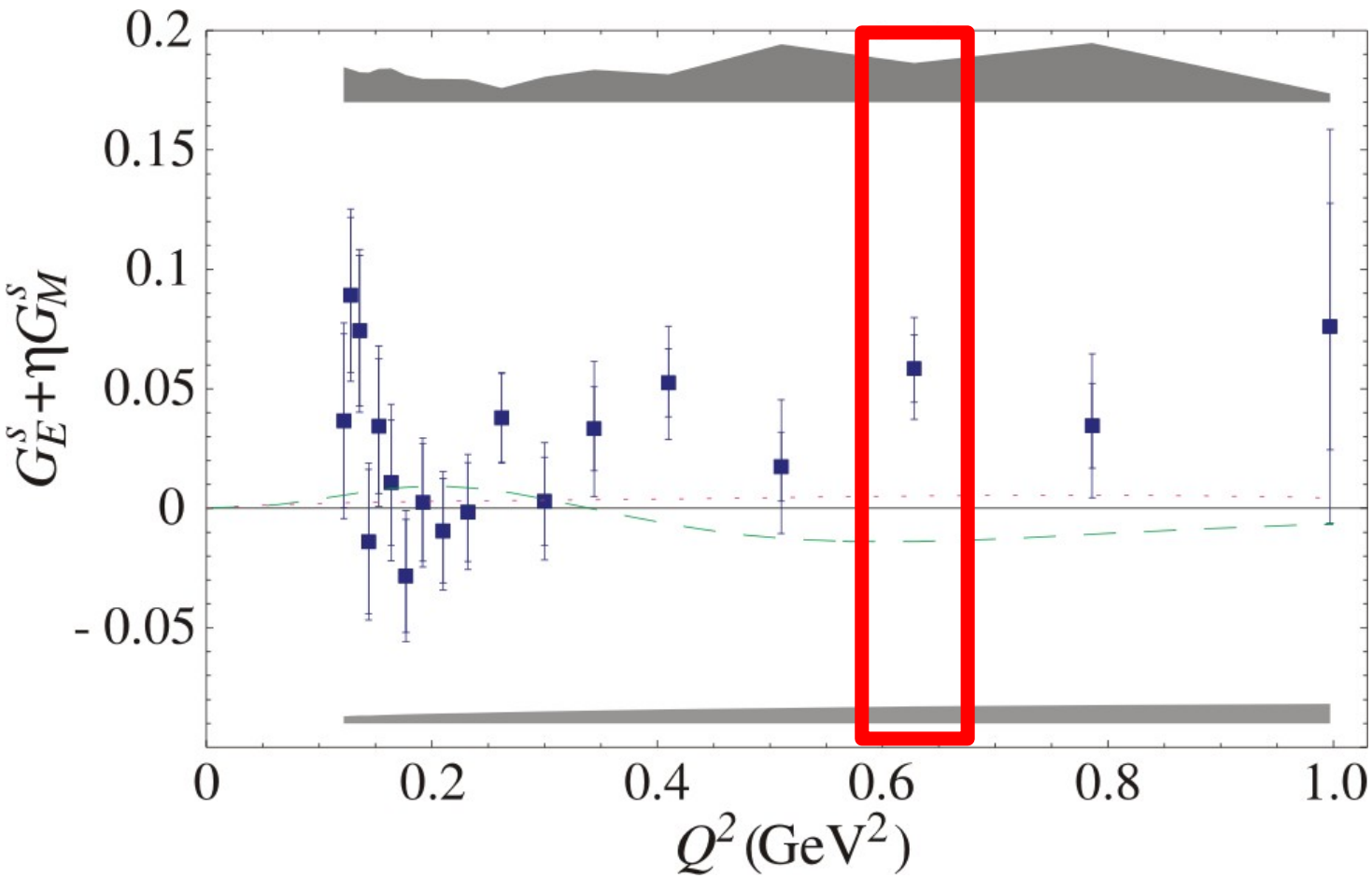
Outlook: “A4-III”

G0 forward angle result:



Outlook: “A4-III”

G0 forward angle result:



Outlook: “A4-III”

Basic parameter:

- Beam energy: E=1508 MeV
- Scattering angle: θ=35°
- Momentum transfer: Q^2=0.62 GeV^2

Requirements:

- Turn calorimeter to forward angle configuration
- Adjust chicane of Compton Polarimeter to higher beam energy
- Adjustment and new installation of beam stabilization systems

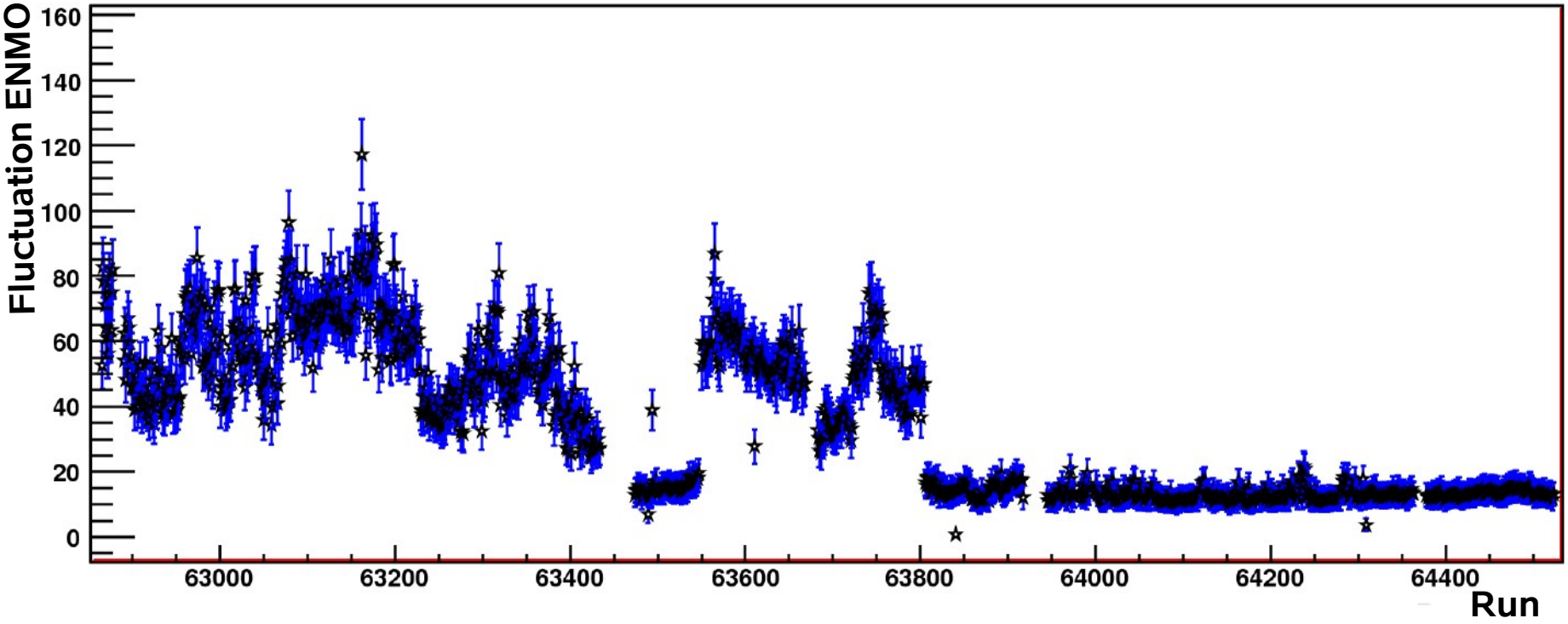
Goal:

- Standard model asymmetry without strangeness A_0=-25.5 ppm
- Collect 700 hours of asymmetry data
- => Measure A_{PV} with statistical uncertainty ΔA_{PV} < 1 ppm

Outlook: “A4-III”

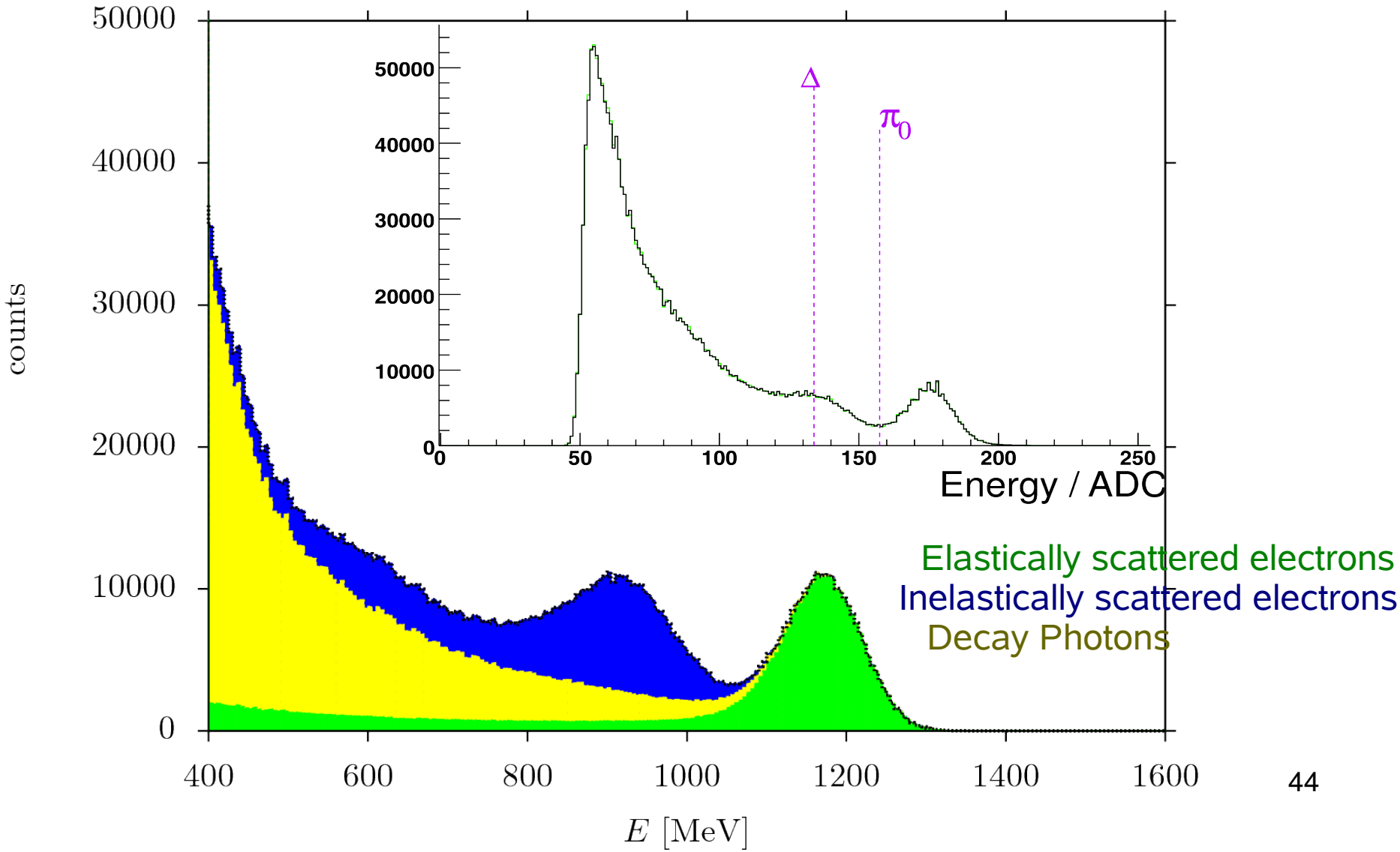
<u>First production beamtime in March 2009:</u>

Commissionning of the new energy stabilization system



Outlook: “A4-III”

Energy spectra: Measurement and MC Studies



Summary

- Backward angle measurements at Q^2=0.22 GeV^2 performed on hydrogen and deuterium
- Hydrogen data: analyzed and combined with A4 forward data
- Strange Form Factors: small, compatible with zero at Q^2=0.22 GeV^2
- Deuterium data: Analysis is ongoing

- Outlook: A4-III, again at forward angles, Q^2=0.62 GeV^2

Full MC simulation results