Parity-violating electron scattering

Strangeness contribution to the vector coupling of the nucleon

Luigi Capozza

A4 Collaboration

Institut für Kernphysik
Johannes Gutenberg-Universität, Mainz

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Outline

- Strangeness matrix elements and the hadron structure
- Parity-violating (PV) electron scattering
- The A4 experiment at MAMI
- Results
- Conclusions and Outlook

Strangeness matrix elements

- Why quark operator matrix elements?

Short distance degrees of freedom: QCD quarks and gluons ⟷ ??? ⟷ Long distance: hadrons

- Why the strange quark in the nucleon?

Flavour decomposition → valence sector ⇒ constituent quarks: effective d.o.f.?

Flavour decomposition → sea quarks

- Candidates?

$\langle N|\, \bar{s}s \,|N\rangle$ πN-Σ-term

$\langle N|\, \bar{s}\gamma^{\mu}\gamma_5 s \,|N\rangle$ DIS (Δs)

$\langle N|\, \bar{s}\gamma^{\mu} s \,|N\rangle$ PV electron scattering

Pion-Nucleon Σ-Term

- Contribution to the nucleon mass

$$M_N = M_0 + \sigma + \sigma_s$$

$$\sigma = \frac{\hat{m}}{2M_N} \langle N |\, \bar{u}u + \bar{d}d \,| N \rangle \ ,$$

$$\sigma_s = \frac{m_s}{2M_N} \langle N |\, \bar{s}s \,| N \rangle$$

- From the pion-nucleon Σ-term $\quad \sigma \simeq 45 \text{ MeV}$

- SU(3) symmetry in the chiral limit

$$\delta = \frac{\hat{m}}{2M_N} \langle N |\, \bar{u}u + \bar{d}d - 2\bar{s}s \,| N \rangle = \frac{3}{2} \frac{m_\pi^2}{m_K^2 - m_\pi^2} (M_\Xi - M_\Lambda) \simeq 25 \text{ MeV} \ .$$

- SU(3) symmetry breaking $\quad \delta \simeq 35 \text{ MeV}$

$\Rightarrow \quad \sigma_s \simeq 130 \text{ MeV}$

J.F. Donoghue, C.R. Nappi, Phys. Lett. B 168 (1986), 105-109
J. Gasser, H. Leutwyler, M.E. Sainio, Phys. Lett. B 253 (1991), 252-259

Polarised DIS - Δs

•Polarised structure functions in the parton model

$$\Delta q(x) = q_+(x) - q_-(x) \qquad x = -q^2/2q \cdot P$$

$$g_1(x) = \frac{1}{2} \sum_j Q_j^2 \left[\Delta q_j(x) + \Delta \bar{q}_j(x)\right]$$

•Quark contribution to the spin

$$\Delta q_j = \int dx \, (\Delta q_j(x) + \Delta \bar{q}_j(x))$$

$$\Delta\Sigma = (\Delta \mathrm{u} + \Delta \bar{\mathrm{u}}) + (\Delta \mathrm{d} + \Delta \bar{\mathrm{d}}) + (\Delta \mathrm{s} + \Delta \bar{\mathrm{s}})$$

•Ellis-Jaffe sum rule: $(\Delta \mathrm{s} + \Delta \bar{\mathrm{s}} = 0)$ ⇨ $\Delta\Sigma \simeq 0.59$

J. Ellis, R.L. Jaffe, Phys. Rev. D 9 (1974), 1444-1446

•EMC result: $\Delta\Sigma \simeq 0$ ⇨ $\langle N | \, \bar{s} \, \gamma^\mu \gamma_5 \, s \, | N \rangle \neq 0$

EMC Coll. - J. Ashman *et al*., Phys. Lett. B 206 (1988), 364-370

Flavour vector form factors

Nucleon EM current:

$$\langle J^\mu_\gamma \rangle = \sum_{f=u,d,s} Q_f \langle \mathrm{N}| \bar{f}\gamma^\mu f |\mathrm{N}\rangle$$

$$= \bar{\mathrm{N}}(p') \left[\gamma^\mu F_1(q^2) + i\frac{\sigma^{\mu\nu}q_\nu}{2M} F_2(q^2) \right] \mathrm{N}(p)$$

Definition of flavour vector form factors:

$$\langle \mathrm{N}| \bar{f}\gamma^\mu f |\mathrm{N}\rangle \equiv \bar{\mathrm{N}}(p') \left[\gamma^\mu F_1^f(q^2) + i\frac{\sigma^{\mu\nu}q_\nu}{2M} F_2^f(q^2) \right] \mathrm{N}(p)$$

$$F_{1,2}(q^2) = \sum_{f=u,d,s} Q_f F^f_{1,2}(q^2)$$

$$G_{E,M}(q^2) = \sum_{f=u,d,s} Q_f G^f_{E,M}(q^2)$$

Sachs form factors:

$$G_E^{(f)} \equiv F_1^{(f)} - \tau F_2^{(f)}$$

$$G_M^{(f)} \equiv F_1^{(f)} + F_2^{(f)}$$

$$(\tau = -q^2/4M^2)$$

Strangeness vector coupling

- Dispersion theory analysis of the isoscalar form factors

$$F_i^{I=0}(Q^2) = \frac{1}{2}\left[F_i^{\mathrm{p}}(Q^2) + F_i^{\mathrm{n}}(Q^2)\right]$$

- Multipole fit assuming Vector Meson Dominance (VMD)

- Contributions from: ω(780), ϕ(1020), X(?)

coupling to $\bar{\mathrm{s}}\gamma^\mu \mathrm{s}$

Strangeness contribution to the static e.m. properties

$$r_s^2 = -6\frac{dG_E^s}{dQ^2}(Q^2=0)$$
$$\mu_s = G_M^s(Q^2=0)$$

R.L. Jaffe, *Stranger than fiction: the strangeness radius and magnetic moment of the nucleon*, Phys. Lett. B229-3 (1989)

$$r_s^2 = (0.16 \pm 0.06)\ \mathrm{fm}^2$$
$$\mu_s = (-0.31 \pm 0.09)\ \mathrm{n.m.}$$

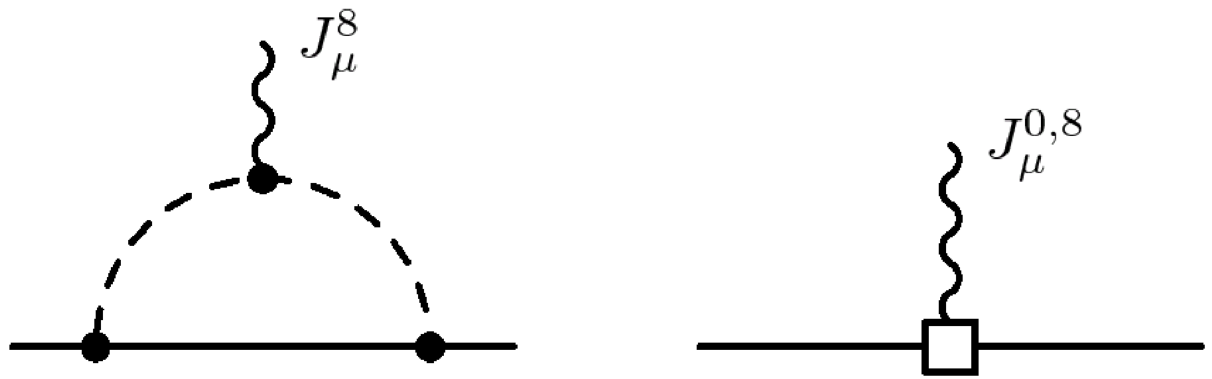
Q^2 dependence

Using SU(3) symmetry:

$$\begin{aligned} \langle N|\,\bar{s}\gamma_\mu s\,|N\rangle &= \langle N|\,\bar{q}\gamma_\mu \left(\frac{\lambda^0}{3} - \frac{\lambda^8}{\sqrt{3}}\right) q\,|N\rangle \\ &= \frac{1}{3} J_\mu^0 - \frac{1}{\sqrt{3}} J_\mu^8 \end{aligned}$$

Connection to hadron currents

To order O(p^3) in HBχPT:



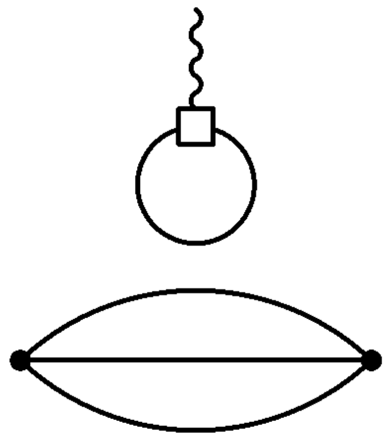
Q^2 dependence is a <u>parameter free</u> prediction

T.R. Hemmert, U.-G. Meißner, S. Steininger, Phys. Lett. B 437 (1998), 184-190

Lattice QCD

- Quenched
- Chiral extrapolations (using QchPT)
- Small masses (physical for s-quark)

"Direct Method": Insertion into a fermion loop in correlation with a proton propagator



$$G_M^s(Q^2 = 0.1\ \mathrm{GeV}^2) = 0.05 \pm 0.06\ \mathrm{n.m.}$$

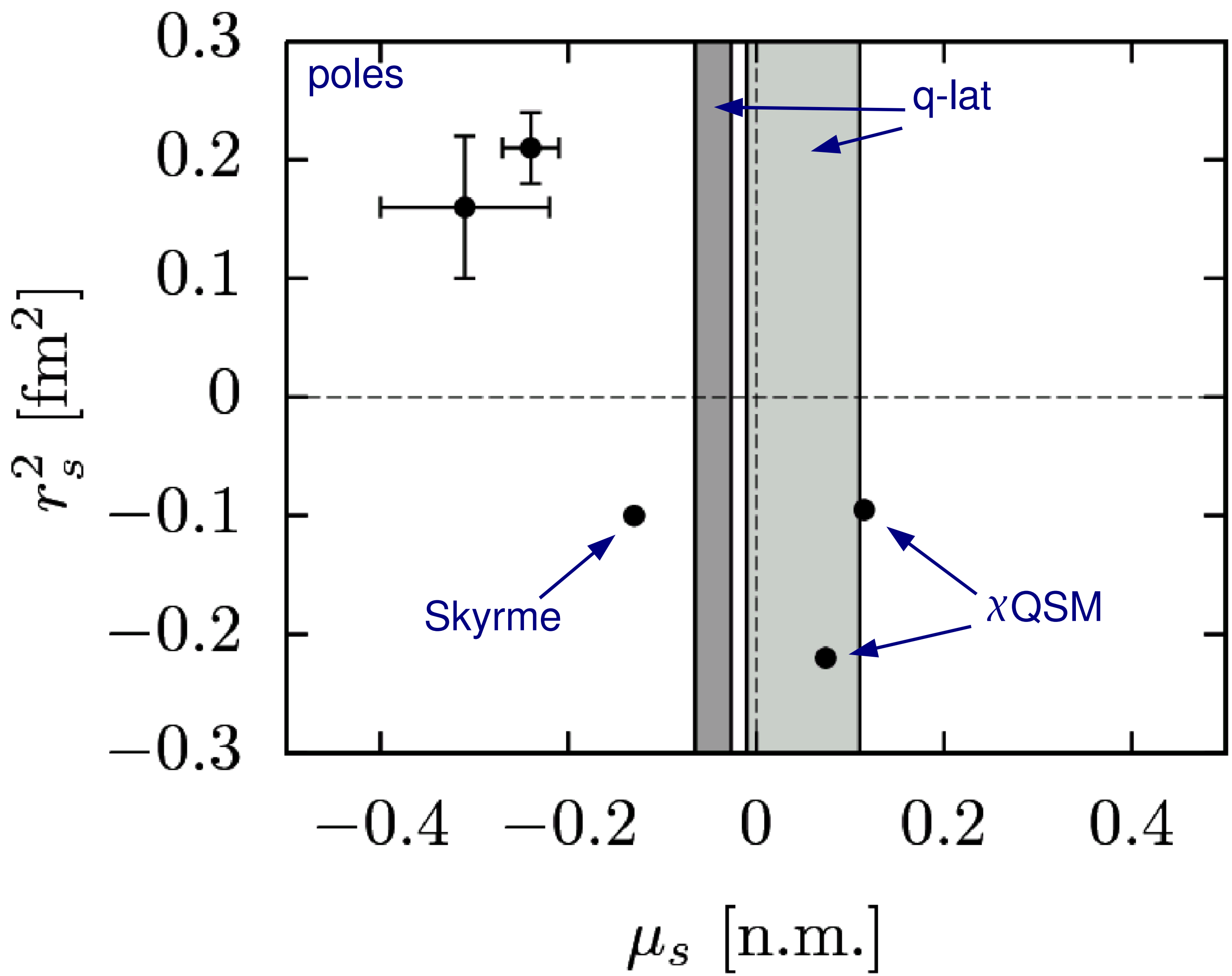
R. Lewis *et al.*, Phys. Rev. D 67 (2003), 013003

"Alternative Method": use of baryon octett magnetic moments and charged symmetry
Only moderate model dependency from ${}^l R_d^s \equiv {}^l G_M^s / {}^l G_M^d$

$$\mu_s = (-0.046 \pm 0.019)\ \ \mathrm{n.m.}$$

D.B. Leinweber *et al.*, Phys. Rev. Lett. 94 (2005), 212001

Predictions



Access to flavour form factors

EM form factors: 4 measurements, 12 unknowns:

$G^{\mathrm{p}}, G^{\mathrm{n}}$

	p	n
u	$G^{\mathrm{u,p}}$	$G^{\mathrm{u,n}}$
d	$G^{\mathrm{d,p}}$	$G^{\mathrm{d,n}}$
s	$G^{\mathrm{s,p}}$	$G^{\mathrm{s,n}}$

Charge symmetry:

$$G^{\mathrm{u,p}} = G^{\mathrm{d,n}} \equiv G^{\mathrm{u}}$$
$$G^{\mathrm{d,p}} = G^{\mathrm{u,n}} \equiv G^{\mathrm{d}}$$
$$G^{\mathrm{s,p}} = G^{\mathrm{s,n}} \equiv G^{\mathrm{s}}$$

$\Rightarrow$ 6 unknowns!

Nucleon neutral current

$$\langle J_Z^\mu \rangle = \bar{\mathrm{N}}(p') \left[\gamma^\mu \tilde{F}_1(q^2) + i \frac{\sigma^{\mu\nu} q_\nu}{2M} \tilde{F}_2(q^2) + \gamma^\mu \gamma_5 G_A(q^2) \right] \mathrm{N}(p)$$
$$= \langle V_Z^\mu \rangle + \langle A_Z^\mu \rangle$$

$$\langle V_Z^\mu \rangle = \sum_{f=u,d,s} Q_f^w \langle \mathrm{N} | \bar{f} \gamma^\mu f | \mathrm{N} \rangle$$

$$\langle J_\gamma^\mu \rangle = \sum_{f=u,d,s} Q_f \langle \mathrm{N} | \bar{f} \gamma^\mu f | \mathrm{N} \rangle$$

universal

$$\tilde{G}_{E,M}(q^2) = \sum_{f=u,d.s} Q_f^w \, G_{E,M}^f(q^2)$$

$$G_{E,M}(q^2) = \sum_{f=u,d.s} Q_f \, G_{E,M}^f(q^2)$$

are the same

⇒ two missing constraints: in principle solved!

PV electron scattering

EW cross section: $\sigma \propto \left| \frac{j_{\gamma,\mu} \langle J^\mu_\gamma \rangle}{q^2} + \frac{j_{Z,\mu} \langle J^\mu_Z \rangle}{M_Z^2} \right|^2$ $\quad j_{Z,\mu} = a_\mu + v_\mu$

PV Asymmetry:

$$A_{\rm RL} = \frac{\sigma_{\rm R} - \sigma_{\rm L}}{\sigma_{\rm R} + \sigma_{\rm L}} \qquad q^2 \ll M_Z^2$$

$$= \frac{q^2}{M_Z^2} \frac{2 j_{\gamma,\mu} \langle J^\mu_\gamma \rangle \left(a_\mu \langle V^\mu_Z \rangle + v_\mu \langle A^\mu_Z \rangle \right)}{\left| j_{\gamma,\mu} \langle J^\mu_\gamma \rangle \right|^2} \sim 10^{-5}$$

Dependence on FFs:

$$A_{\rm RL} = \underbrace{A_{\rm V} + A_{\rm A}}_{= A_0} + A_{\rm S} \quad \begin{cases} A_{\rm V} = -a\rho'_{eq} \left[(1 - 4\hat{\kappa}'_{eq}\hat{s}_Z^2) - \frac{\epsilon G_E^{\rm p} G_E^{\rm n} + \tau G_M^{\rm p} G_M^{\rm n}}{\epsilon (G_E^{\rm p})^2 + \tau (G_M^{\rm p})^2} \right] \\ A_{\rm A} = a \frac{(1 - 4\hat{s}_Z^2)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)} G_M^{\rm p} \tilde{G}_A^{\rm p}}{\epsilon (G_E^{\rm p})^2 + \tau (G_M^{\rm p})^2} \\ A_{\rm S} = a\rho'_{eq} \frac{\epsilon G_E^{\rm p} G_E^{\rm s} + \tau G_M^{\rm p} G_M^{\rm s}}{\epsilon (G_E^{\rm p})^2 + \tau (G_M^{\rm p})^2} \end{cases}$$

$$a = -G_F q^2 / 4\pi\alpha\sqrt{2}, \quad \tau = -q^2/4M_{\rm p}^2, \quad \epsilon = [1 + 2(1+\tau)\tan^2\theta/2]^{-1}$$

Kinematics and targets

Proton:

forward: G_M, G_E^s — backward: G_M^s, G_A

$$A_{\mathrm{A}} = a\frac{(1-4\hat{s}_Z^2)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)}G_M^{\mathrm{p}}\tilde{G}_A^{\mathrm{p}}}{\epsilon(G_E^{\mathrm{p}})^2+\tau(G_M^{\mathrm{p}})^2}$$

$$A_{\mathrm{S}} = a\rho'_{eq}\frac{\epsilon G_E^{\mathrm{p}}G_E^{\mathrm{s}}+\tau G_M^{\mathrm{p}}G_M^{\mathrm{s}}}{\epsilon(G_E^{\mathrm{p}})^2+\tau(G_M^{\mathrm{p}})^2}$$

$$\epsilon = [1+2(1+\tau)\tan^2\theta/2]^{-1}$$

Quasielastic scattering (deuteron)

backward

$G_A^{(T=1)}$

- Little uncertainty from nuclear structure
- Suppression of isoscalar contribution

Elastic scattering on a spin=0 isoscalar (^{4}He)

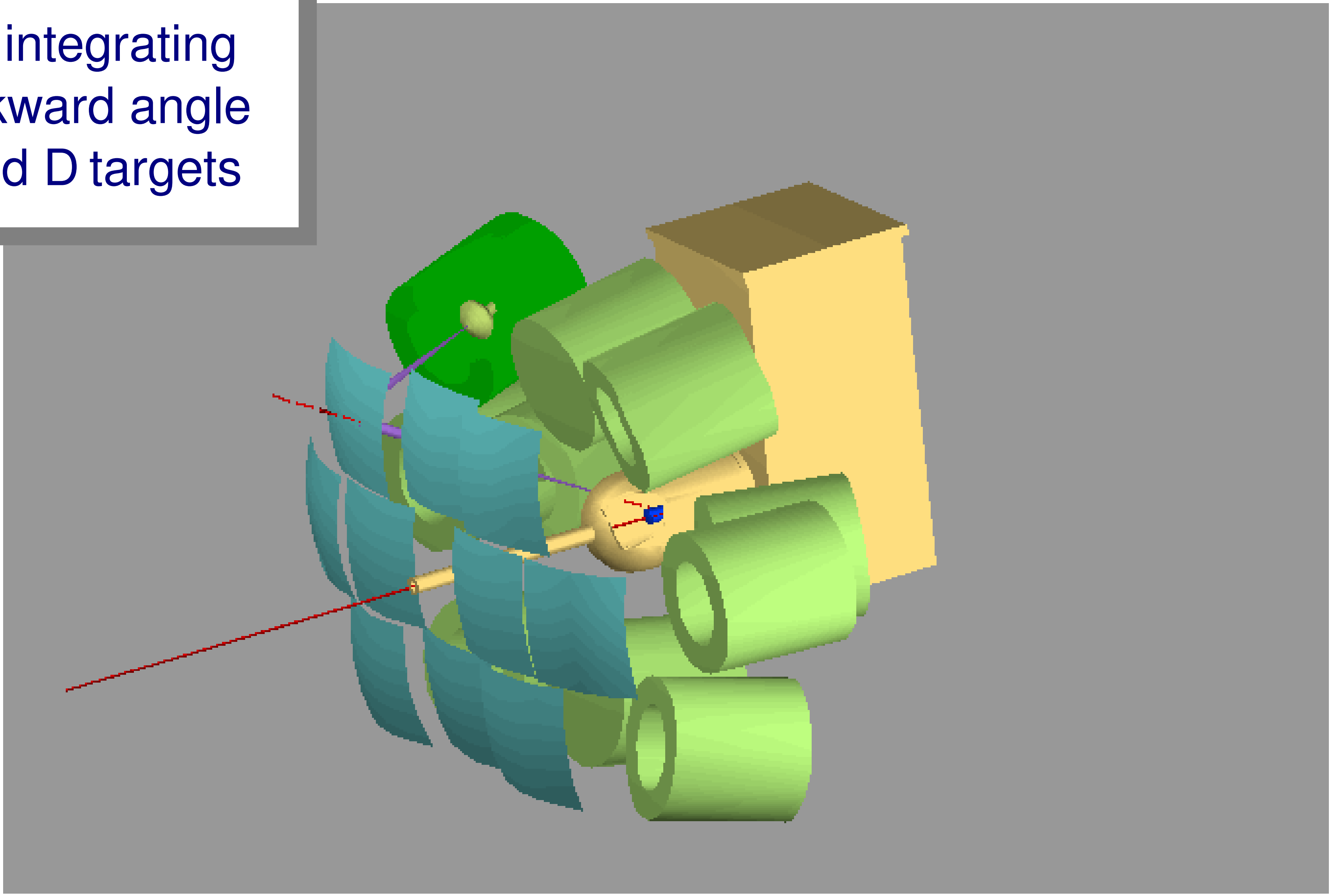
forward

G_E^s

- Magnetic and Axial contributions filtered out

SAMPLE (MIT-BATES)

- Air Cherenkov
- Flux integrating
- Backward angle
- H and D targets



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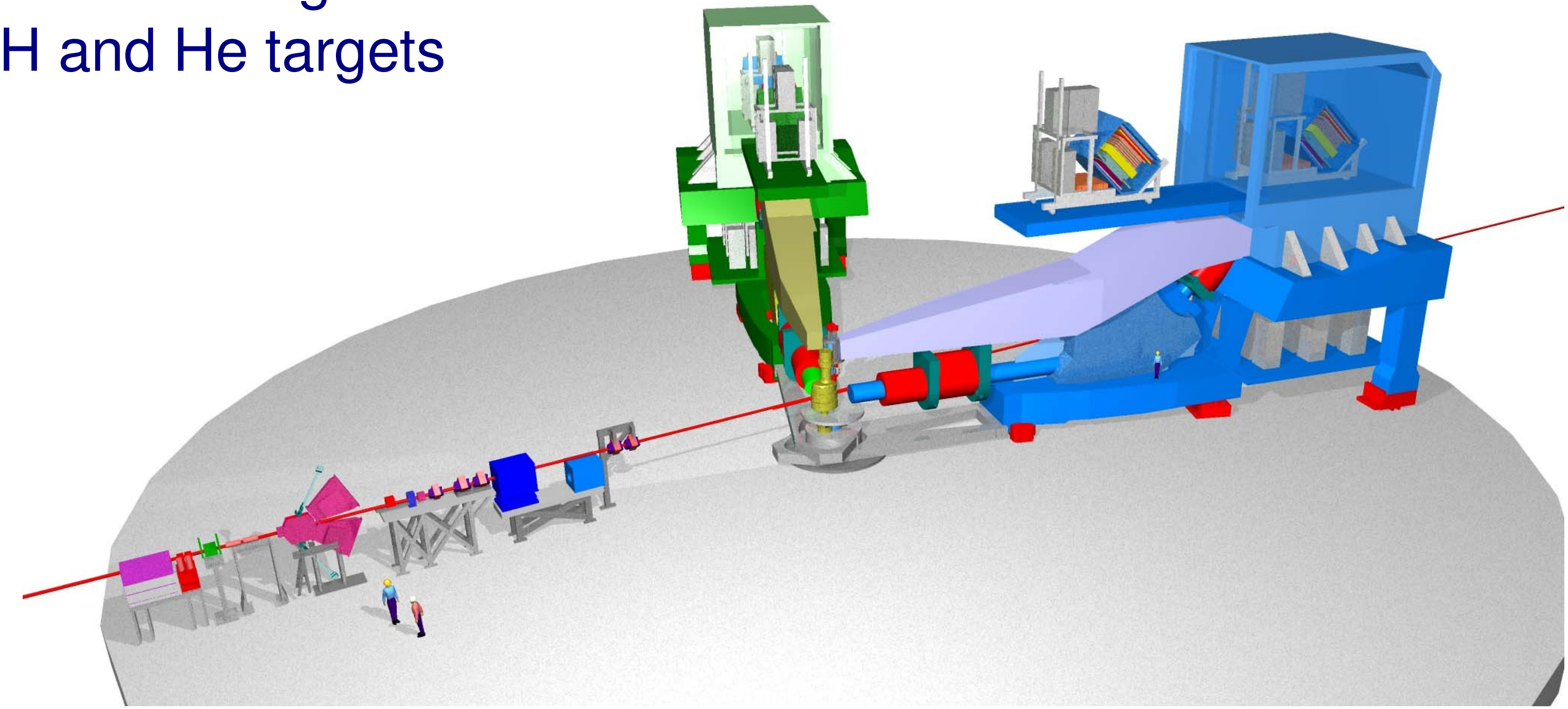
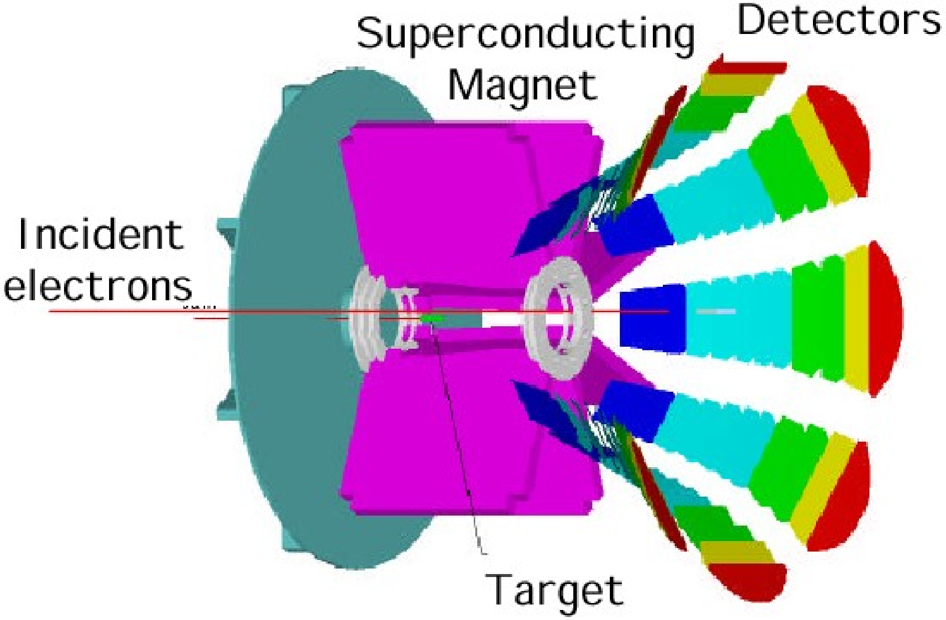
HAPPEx (JLAB)

- Magnetic spectrometer
- Flux integrating
- Forward angle
- H and He targets

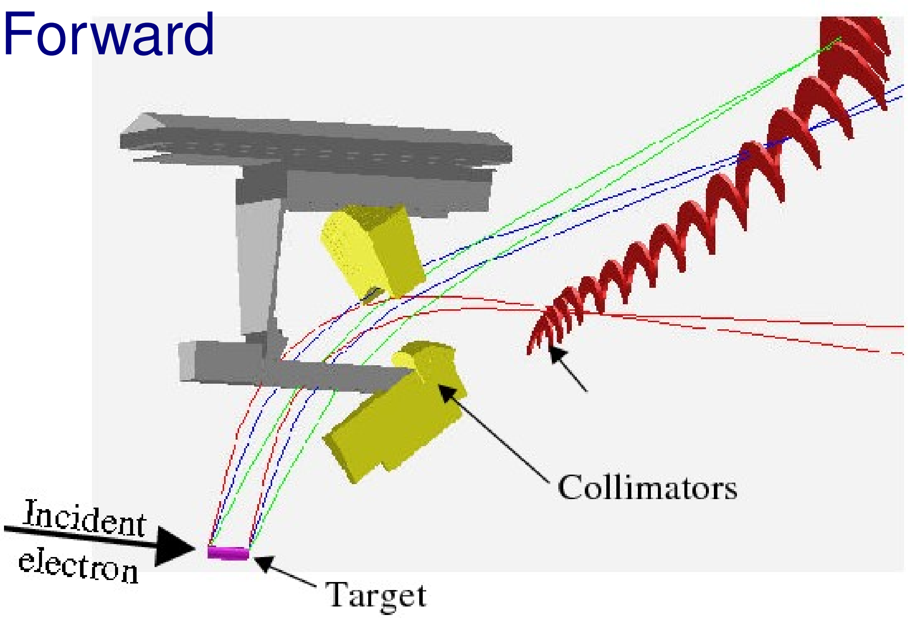


G0 (JLAB)

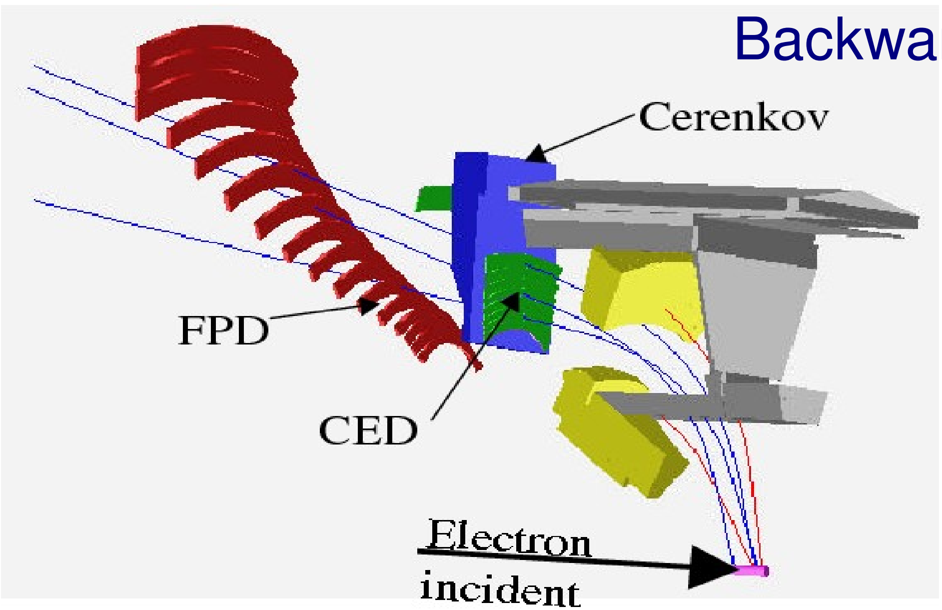
- Toroidal spectrometer
- Single event counting
- Forward and Backward angle
- H and D targets



Forward

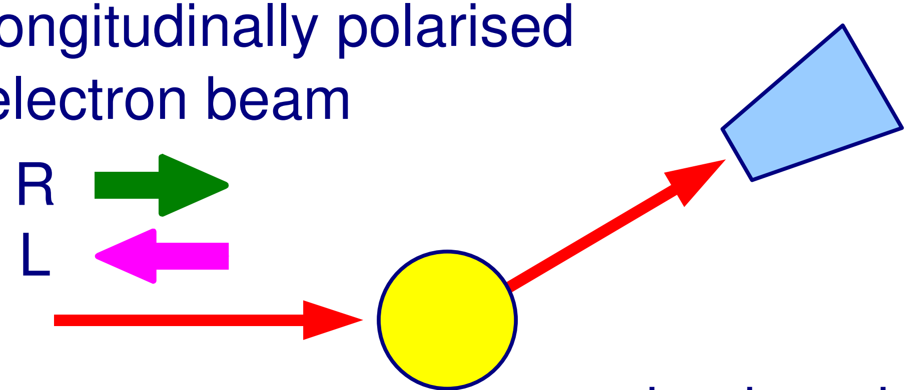


Backward



A4 experimental principle

longitudinally polarised electron beam



proton target

detector

$N_\mathrm{R},\ N_\mathrm{L}$

$$\Rightarrow A_\mathrm{RL} = \frac{N_\mathrm{R} - N_\mathrm{L}}{N_\mathrm{R} + N_\mathrm{L}}$$

Statistical uncertainty

for a counting experiment:

$$A = 10^{-6}$$

$$\delta A = \frac{1}{\sqrt{N}} \simeq 10^{-7}$$

$$\Rightarrow N \simeq 10^{14}$$

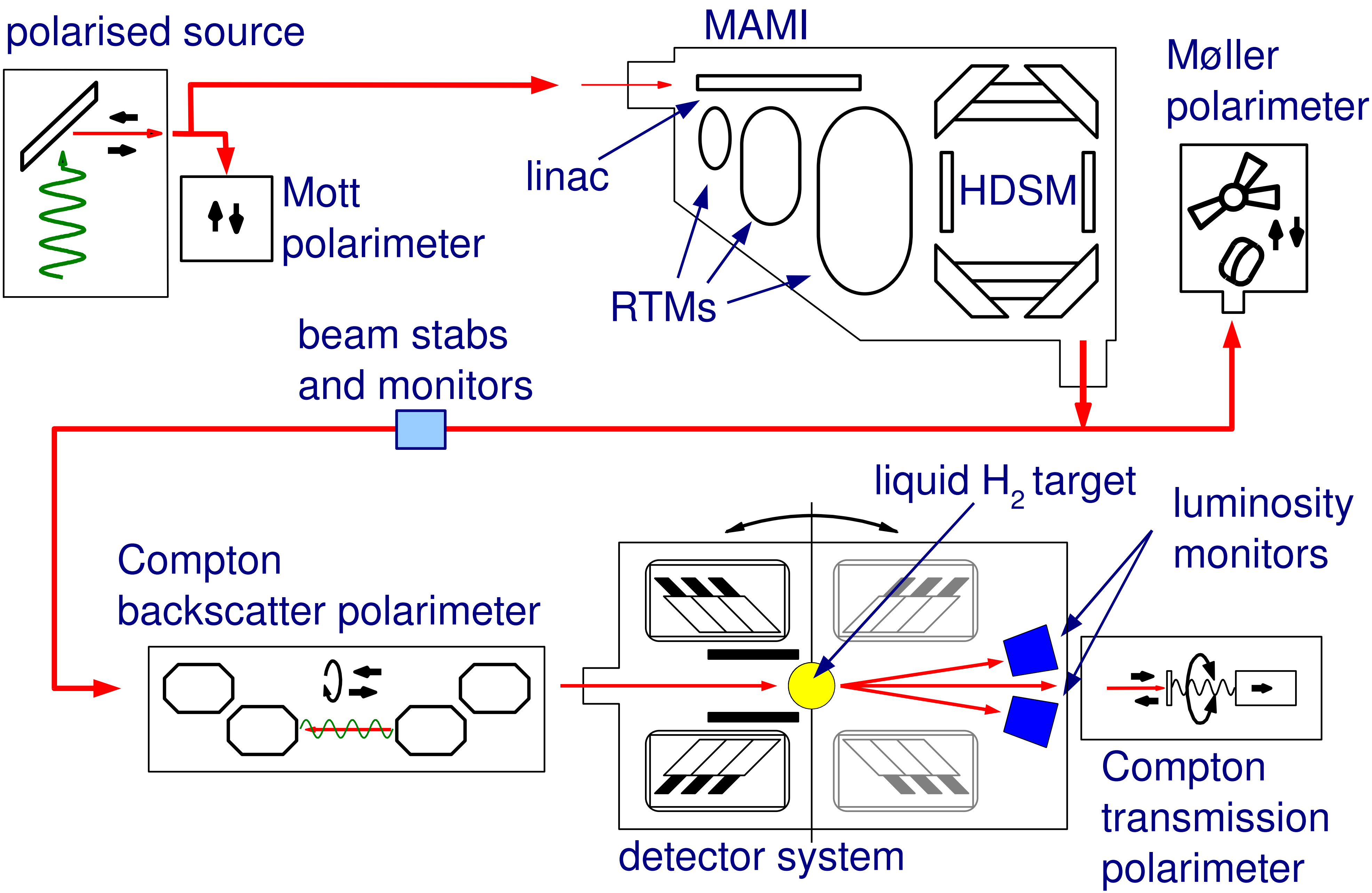
1000 hours $\Rightarrow$ $\sim$10 MHz

- high luminosity
- large acceptance
- fast detector

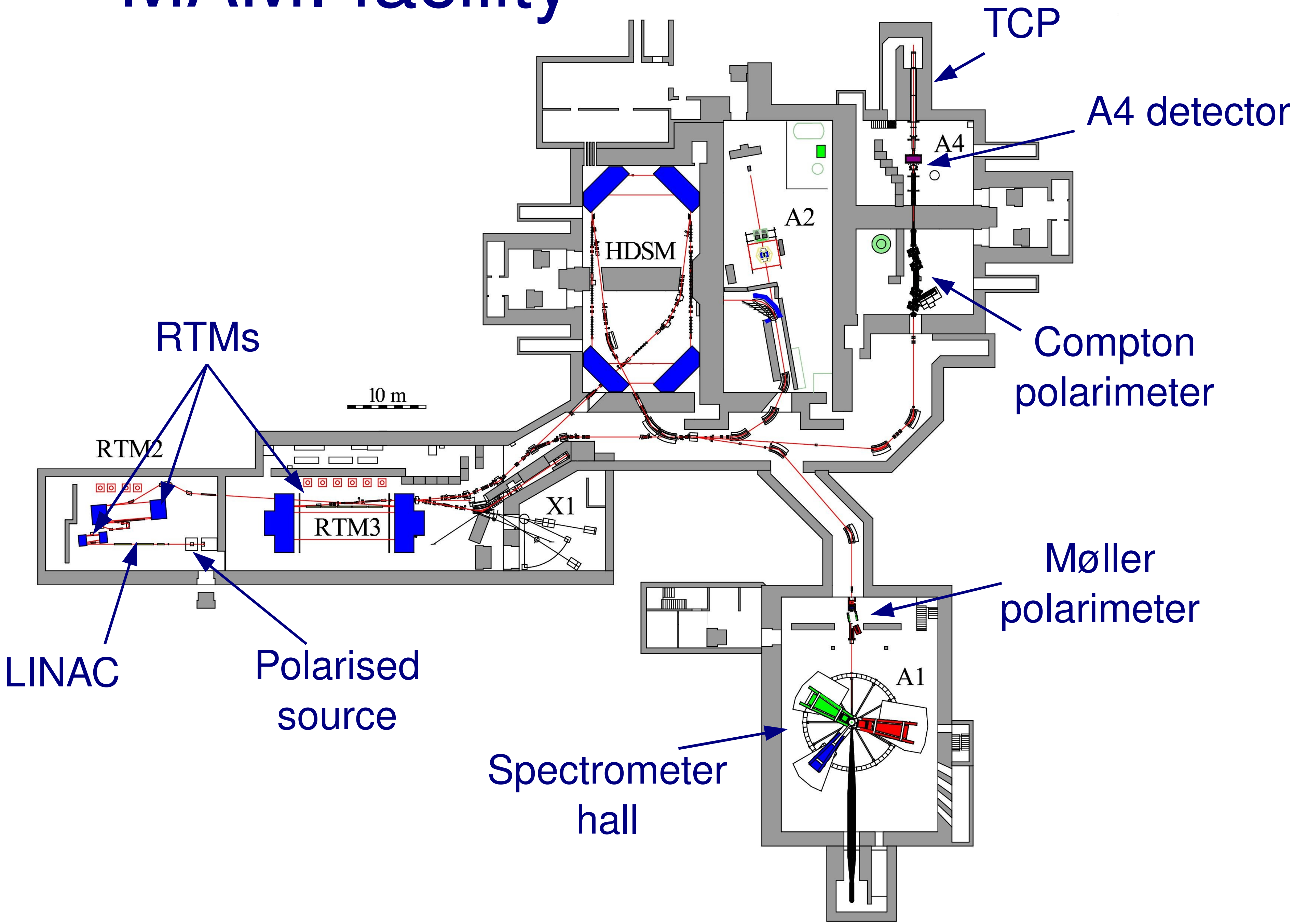
Systematic uncertainty

- helicity correlated fluctuations
- polarisation measurement

A4 experimental setup



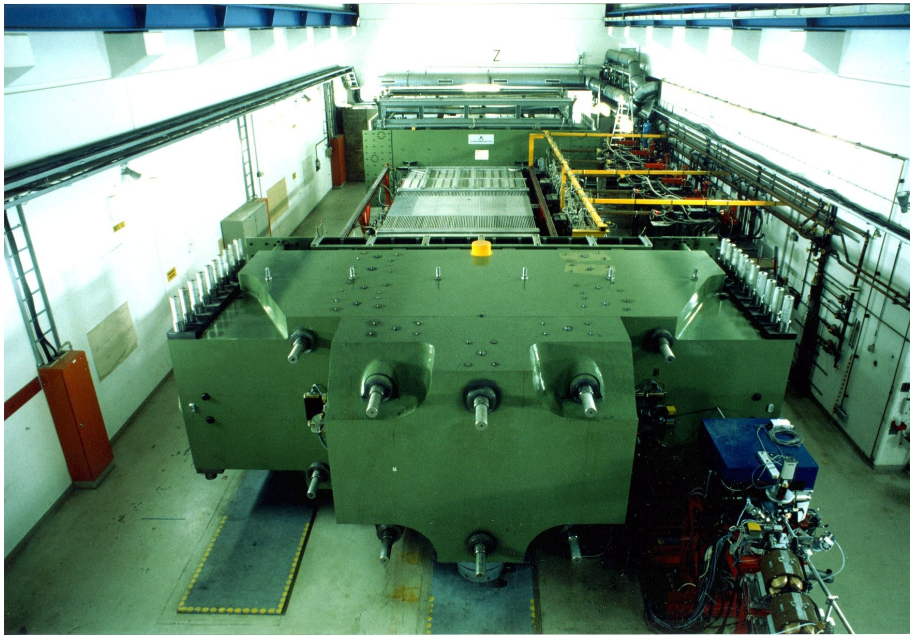
MAMI facility



Electron beam

Polarised Source

- Longitudinal polarisation
- Current: 20 μA
- Pockels cell: 50 Hz pol. switch
- $\lambda/2$-plate: global pol. inversion



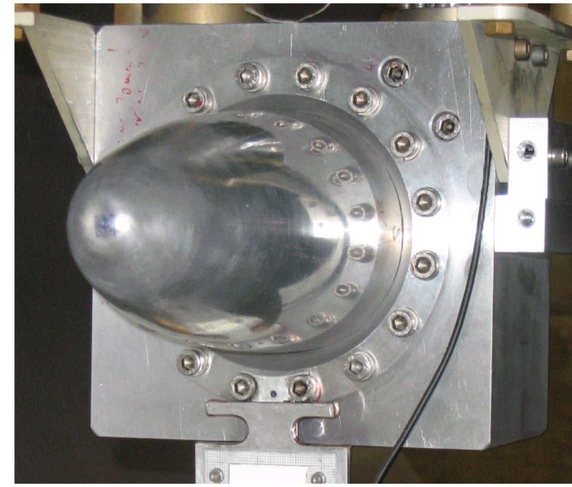
MAMI Accelerator

- Energy: 315 MeV @ backward

  (855 MeV @ forward)
- Beam stabilisation systems
- Beam monitors: parameter measurement every 20 ms

Target

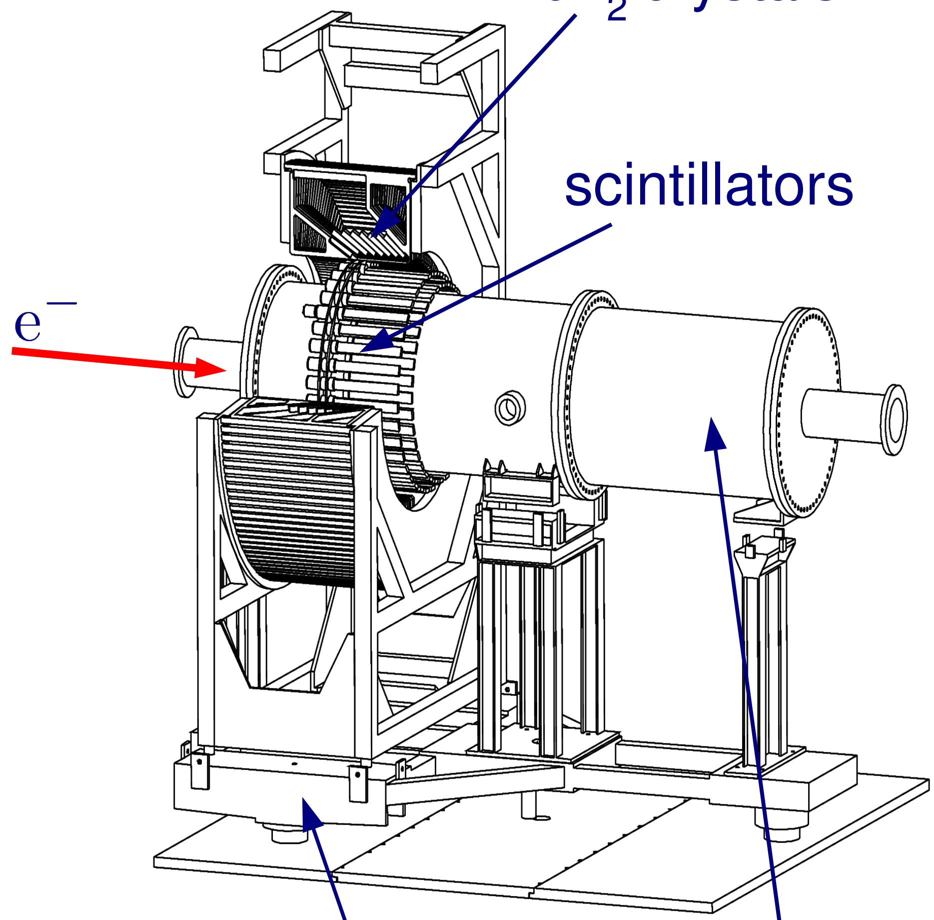
- liquid hydrogen (deuterium)
- forward: 10 cm, backward: 23.4 cm
- T=14 K, density fluctuations < 10^{-3}
- absorbed power: 100 W @ 20 µA



Luminosity monitors

- water Cherenkov
- flux integrating
- acceptance: 4° to 10°
- monitor target density fluctuations

A4 detector



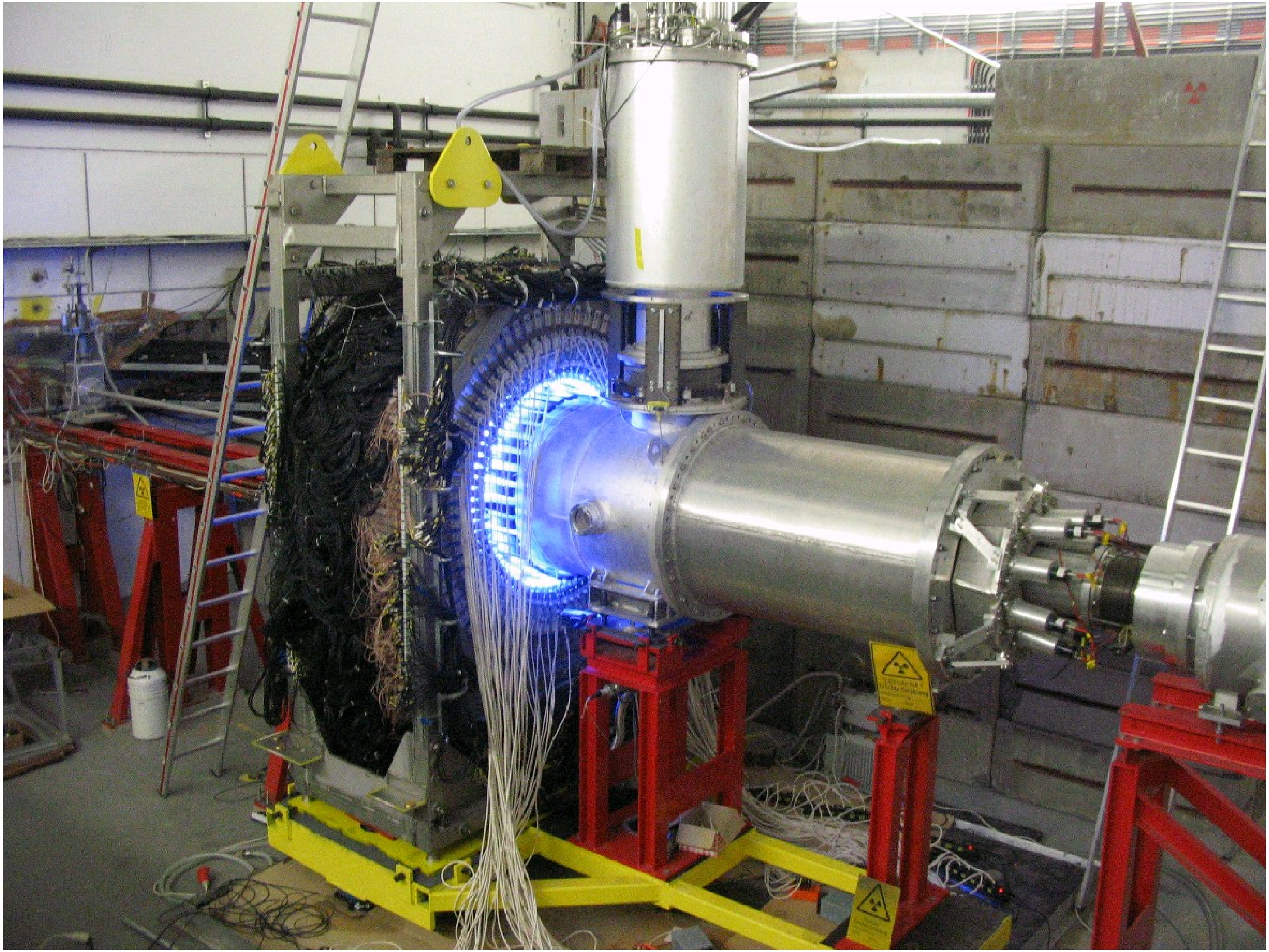
PbF_2 calorimeter:

- pure Cherenkov radiator
- count rate: 100 MHz
- acceptance: 0.6 sr
  (30° to 40° or 140° to 150°)
- 1022 crystals in 7 rings
- fully absorbing

Electron tagger (backward):

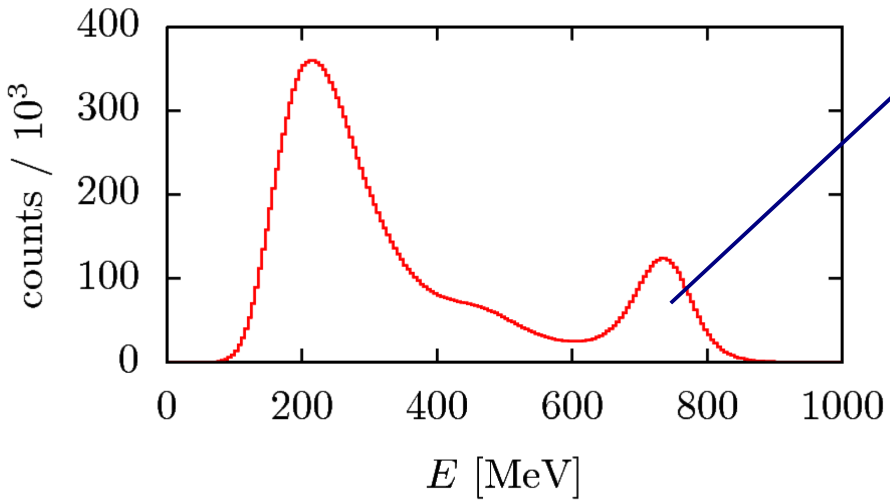
- 72 plastic scintillators

A4 hall



Data analysis

855 MeV forward



2044 spectra every 5 min.

Extraction of elastic events

$$N_R, N_L$$

Target density normalisation:

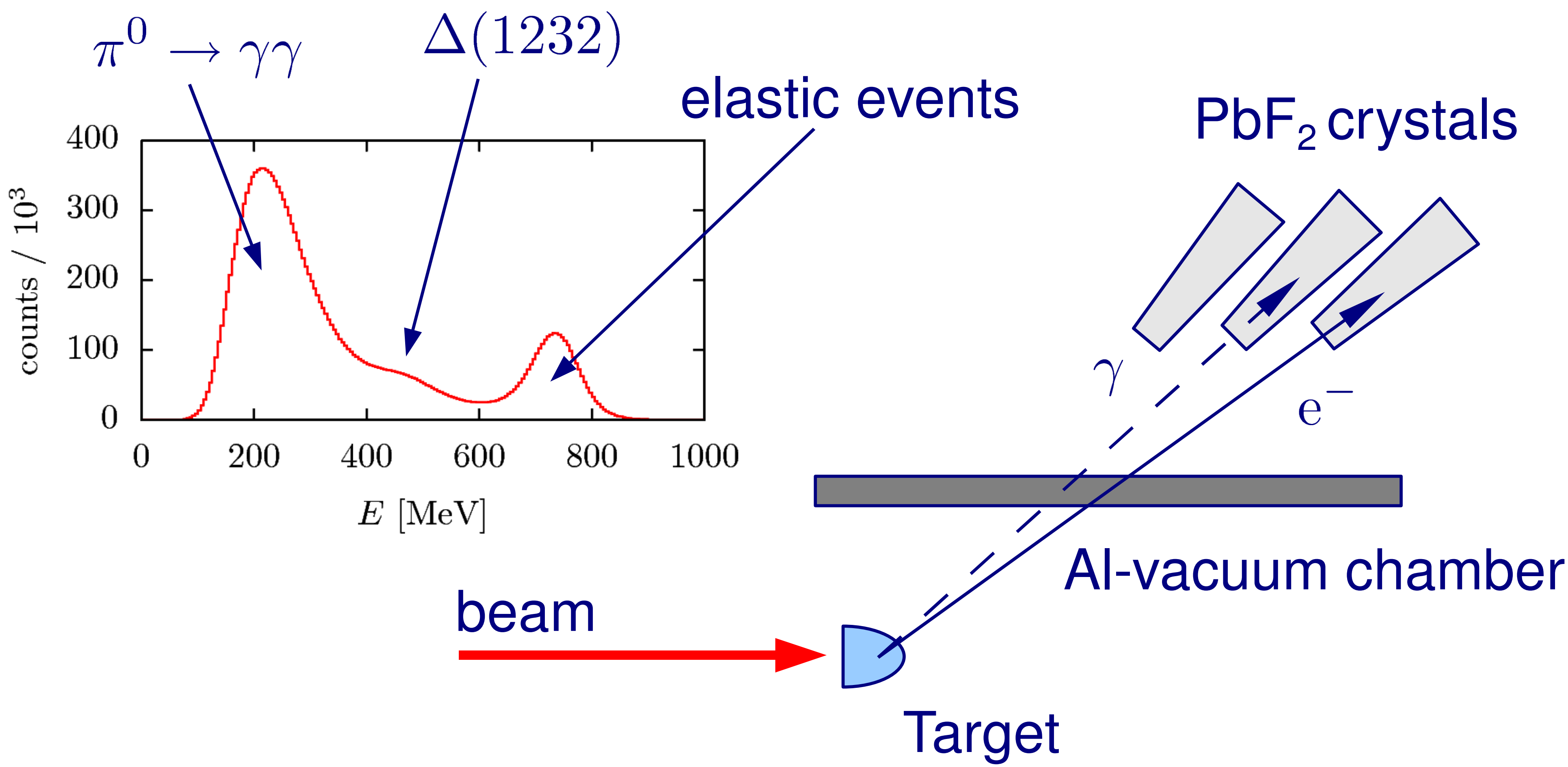
$$A_{\mathrm{meas}} = \frac{N_R/\rho_R - N_L/\rho_L}{N_R/\rho_R + N_L/\rho_L}$$

Correction for false asymmetries and polarisation:

$$A_{\mathrm{meas}} = P A_{\mathrm{RL}} + \sum a_i X_i$$

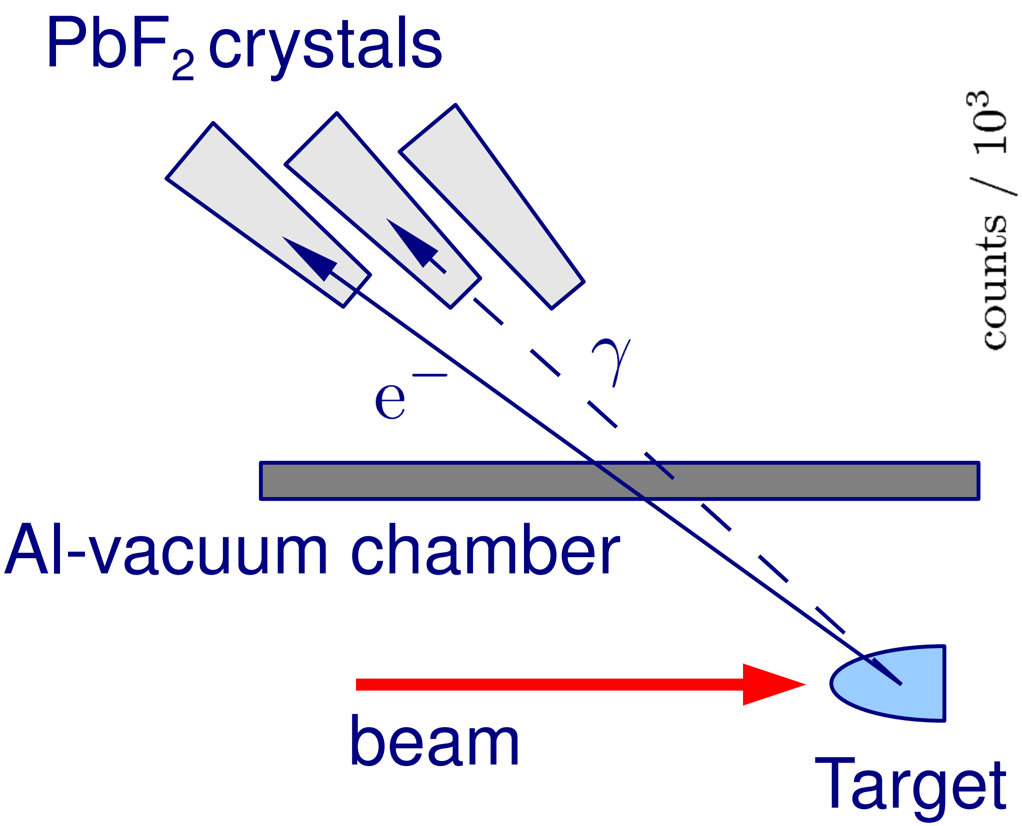
Background

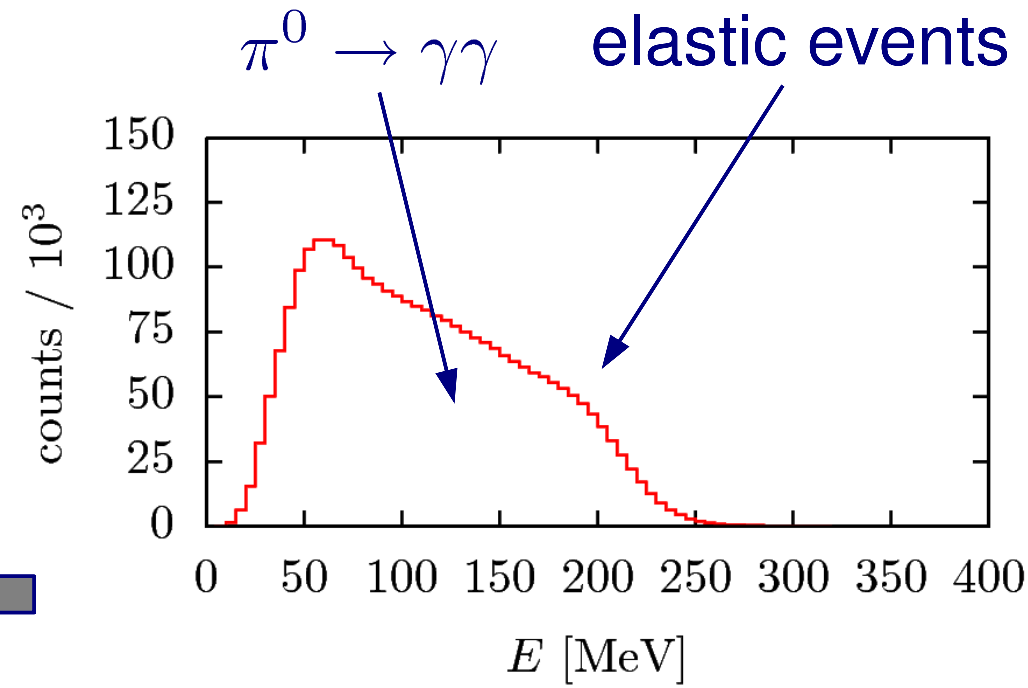
Forward angle (855 MeV):



Background

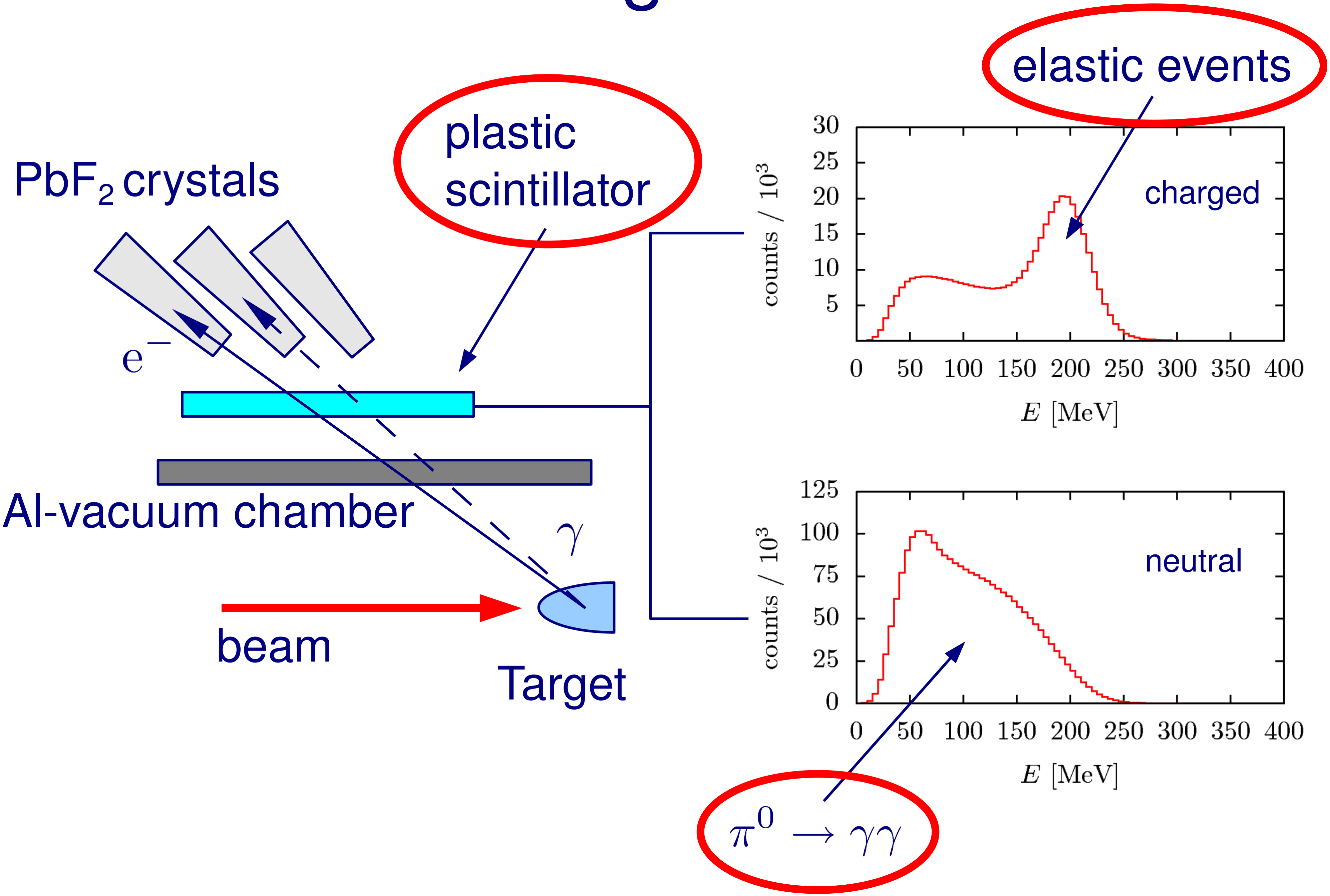
Backward angle (315 MeV):





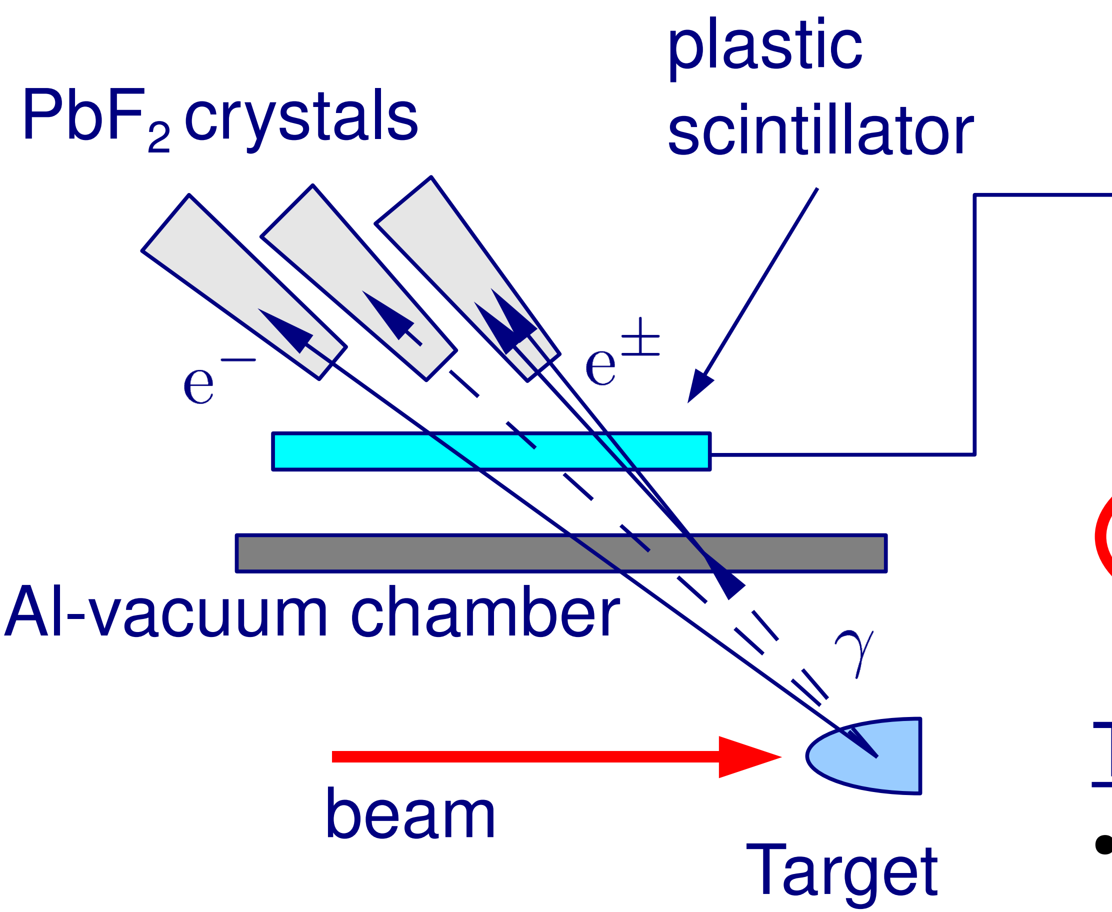
No energy separation at backward angle

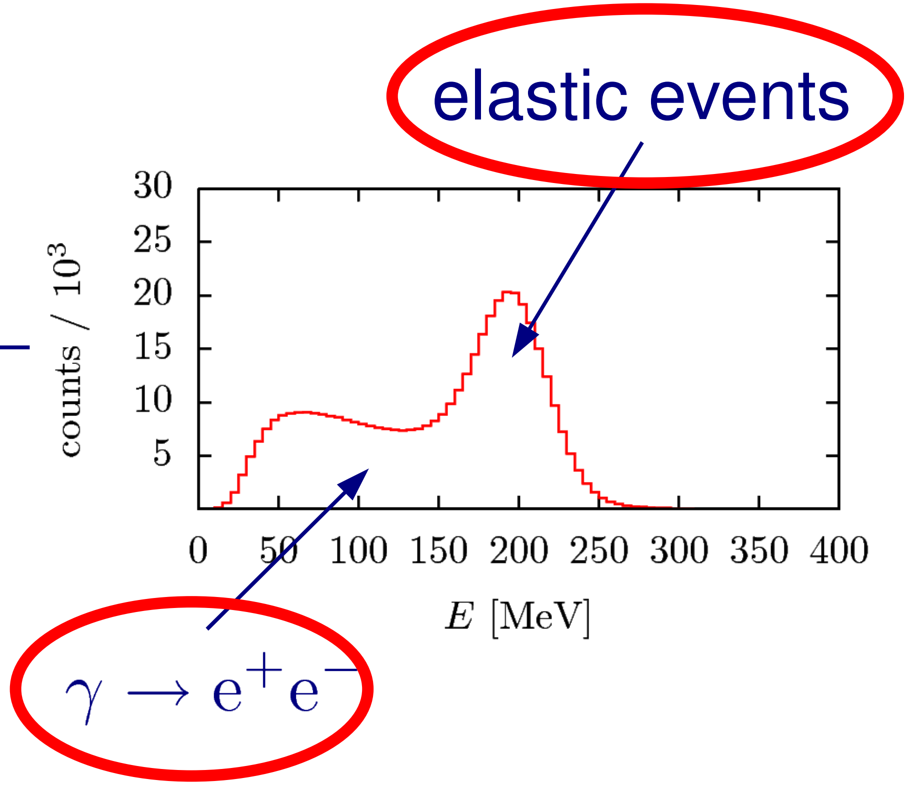
Background



plastic scintillator
elastic events
PbF_2 crystals
e^-
Al-vacuum chamber
γ
beam
Target
counts / 10^3
30
25
20
15
10
5
0
50
100
150
200
250
300
350
400
E [MeV]
charged
counts / 10^3
125
100
75
50
25
0
0
50
100
150
200
250
300
350
400
E [MeV]
neutral
$\pi^0 \to \gamma\gamma$

Background



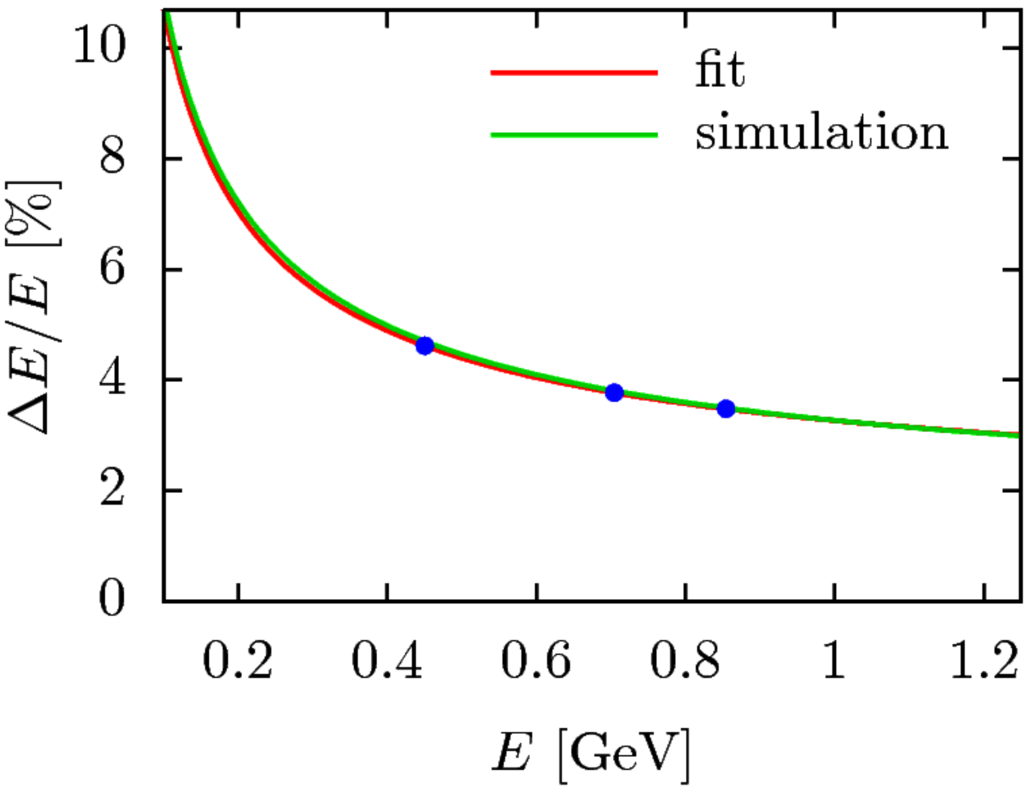


<u>Tasks:</u>

- understanding the spectrum
- handling the background

Detector response

Comparison with data (1998) on energy resolution



$$\frac{\Delta E}{E} = a \oplus \frac{b}{\sqrt{E}} \oplus \frac{c}{E}$$

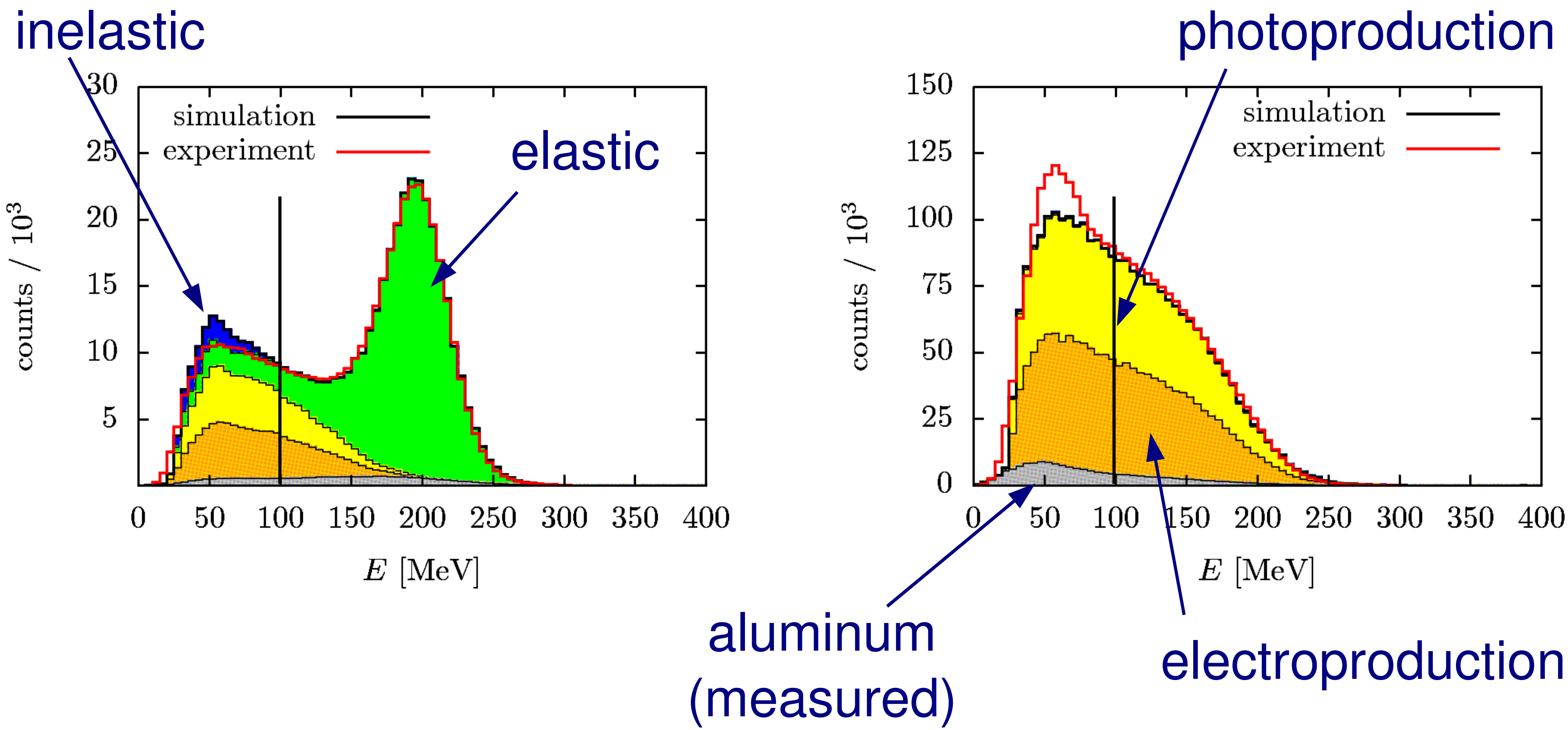
	a	b [$\mathrm{GeV}^{\frac{1}{2}}$]
exp.	1.67 %	2.75 %
sim.	1.48 %	2.86 %

$$c = (0.60 \pm 0.05)\%/\mathrm{GeV}$$

(measured)

Simulation results

charged particles | neutral particles

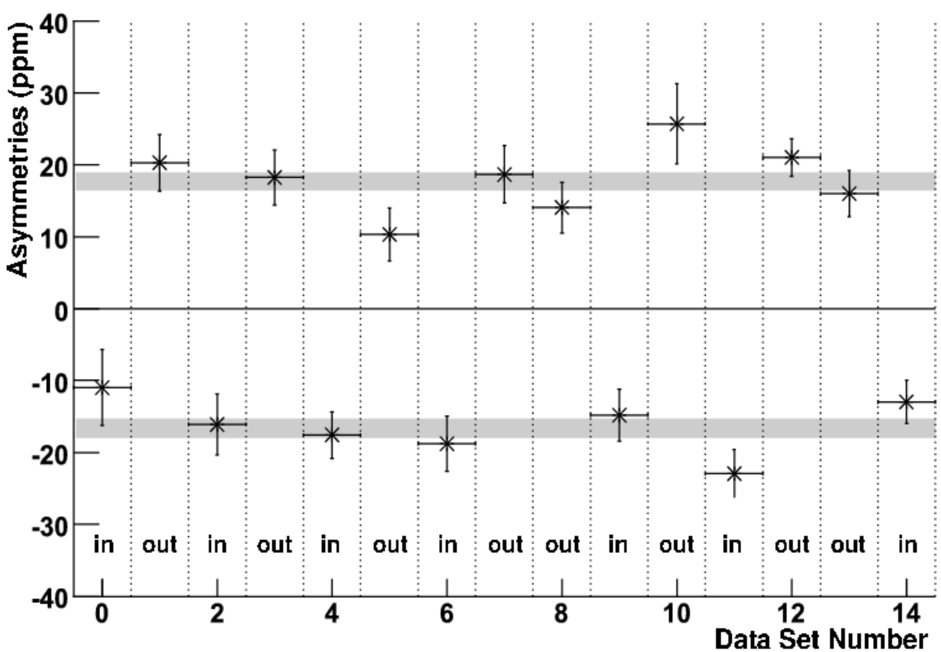


agreement (100-300 MeV): charged - 3%
neutral - 5%

Backward measurement

Parameter	X		a X (ppm)
Current asymmetry	-0.30	ppm	-0.25
Horiz. position diff.	-86.97	nm	0.61
Vert. position diff.	-23.84	nm	-0.86
Horiz. angle diff.	-8.53	nrad	-0.09
Vert. angle diff.	-2.40	nrad	0.10
Energy diff.	-0.41	eV	0.16

	Factor	Error
Polarisation	0.68	0.04
	Corr. (ppm)	Error (ppm)
Hel. corr. asym.	0.14	0.39
Random coinc.	-0.19	0.02
Al windows	0.29	0.04
Background subtr.	-1.49	0.28



$$A_{\mathrm{RL}} = (-17.23 \pm 0.82_{\mathrm{stat}} \pm 0.89_{\mathrm{syst}})\,\mathrm{ppm}$$

$$A_0 = (-15.87 \pm 1.22)\,\mathrm{ppm}$$

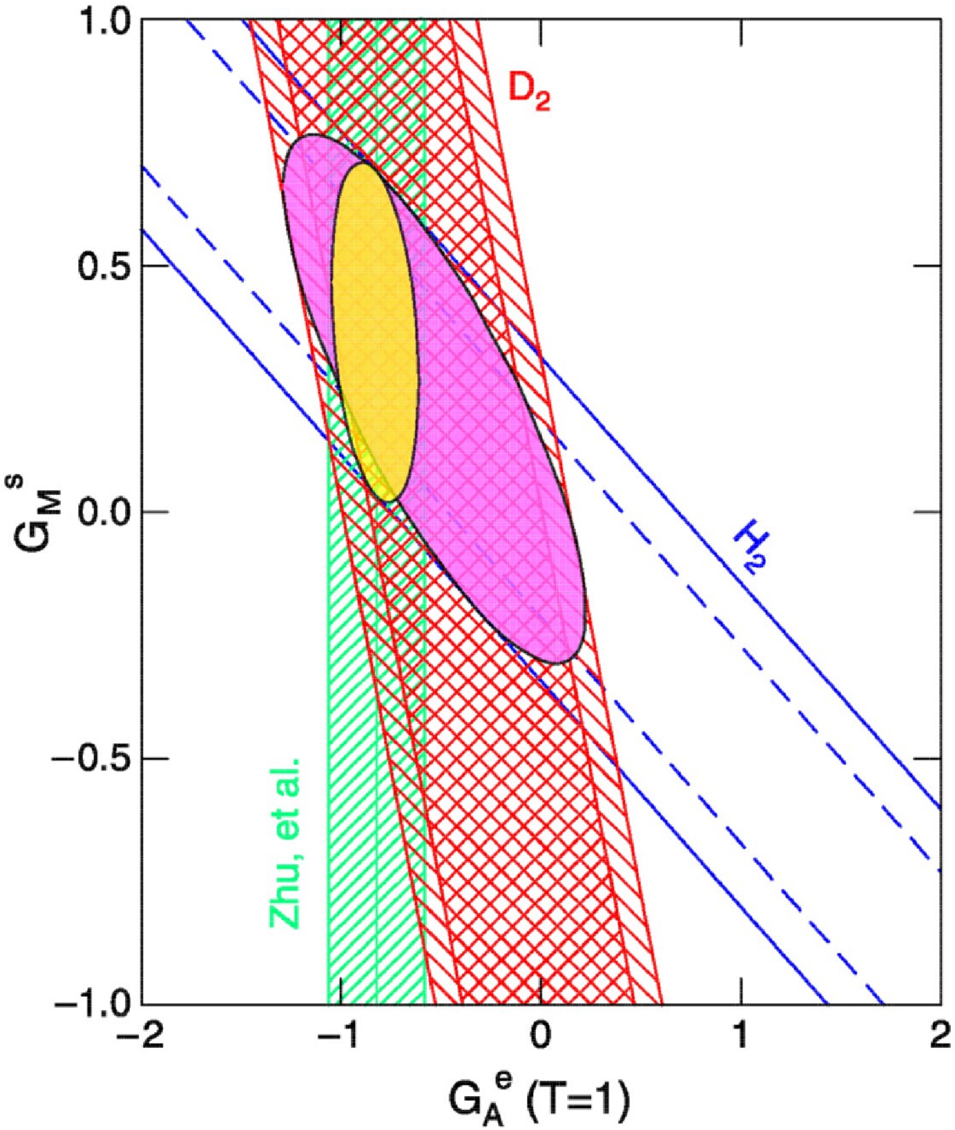
Measurements

$Q^2 (\mathrm{GeV}/c)^2$	e+p forward	e+p backward	e+^{4}He forward	e+d backward
SAMPLE MIT/BATES		0.1		0.04, 0.1
HAPPEx JLAB	0.1, 0.48 0.6		0.1	
G0 JLAB	0.12...1.0	0.22, 0.62		0.22
A4 MAMI	0.1, 0.22 0.62	0.22		0.22

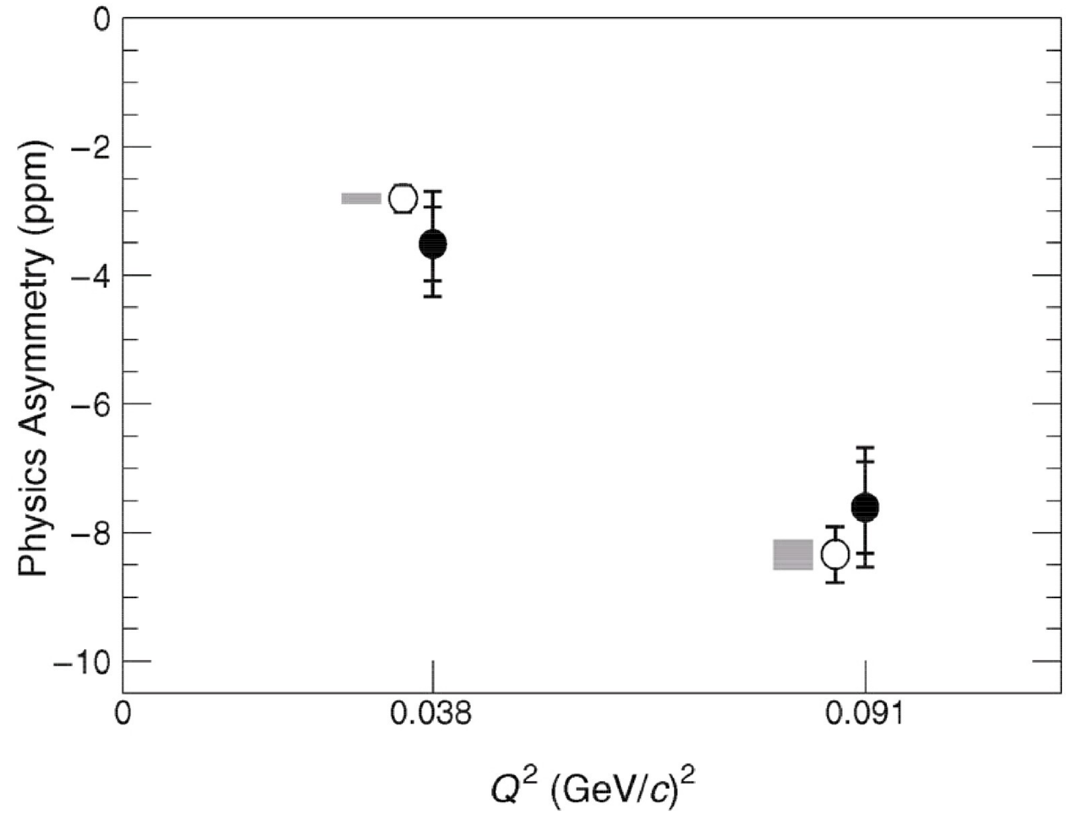
published
analysis ongoing

SAMPLE results

$Q^2 = 0.1\ (\mathrm{GeV}/c)^2$



QE scattering on D_2

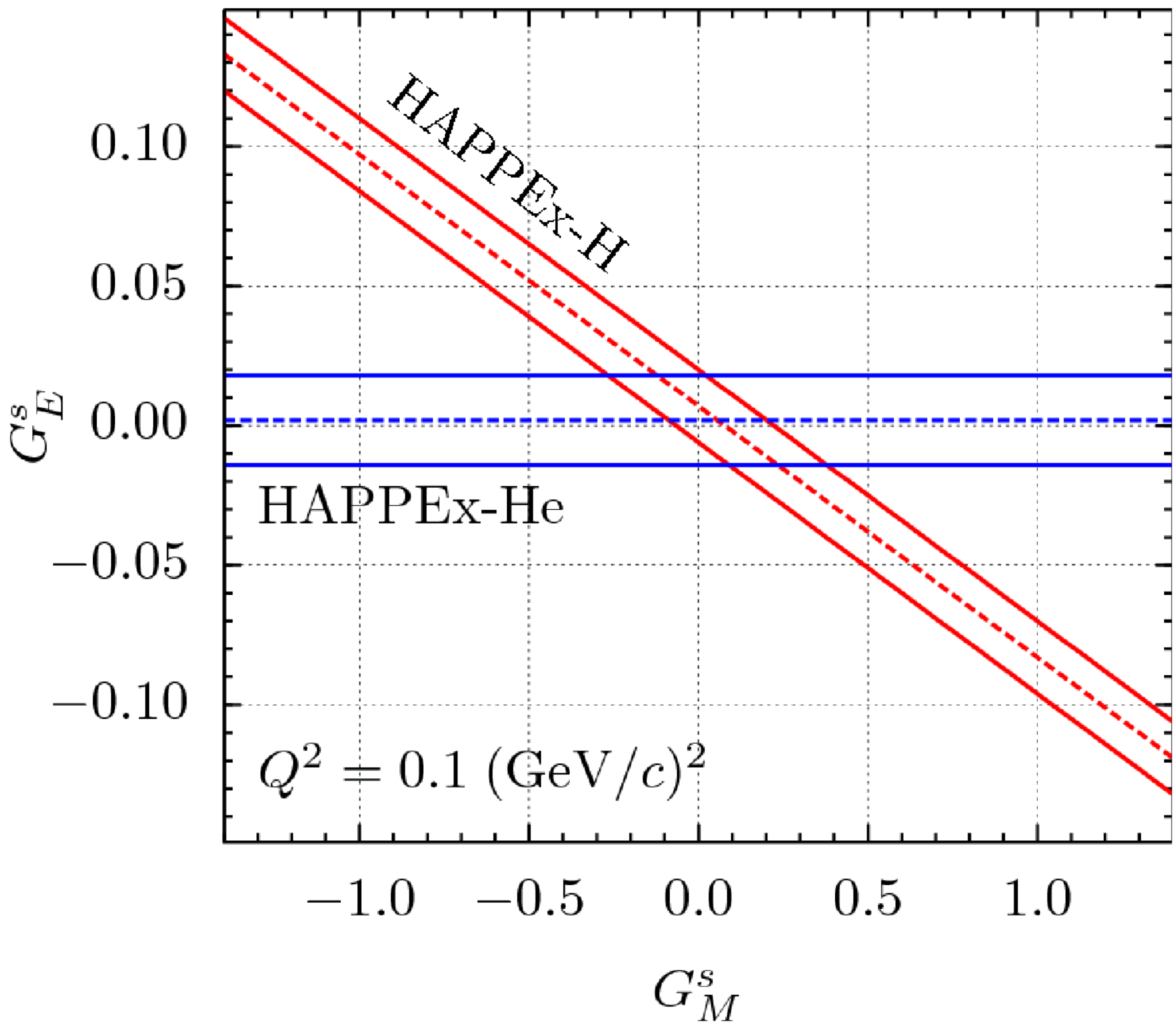


E.J. Beise, M.L. Pitt, D.T. Spayde,
Prog. Part. Nucl. Phys. 54 (2005), 289-350

HAPPEx at 0.1 (GeV/c)^2

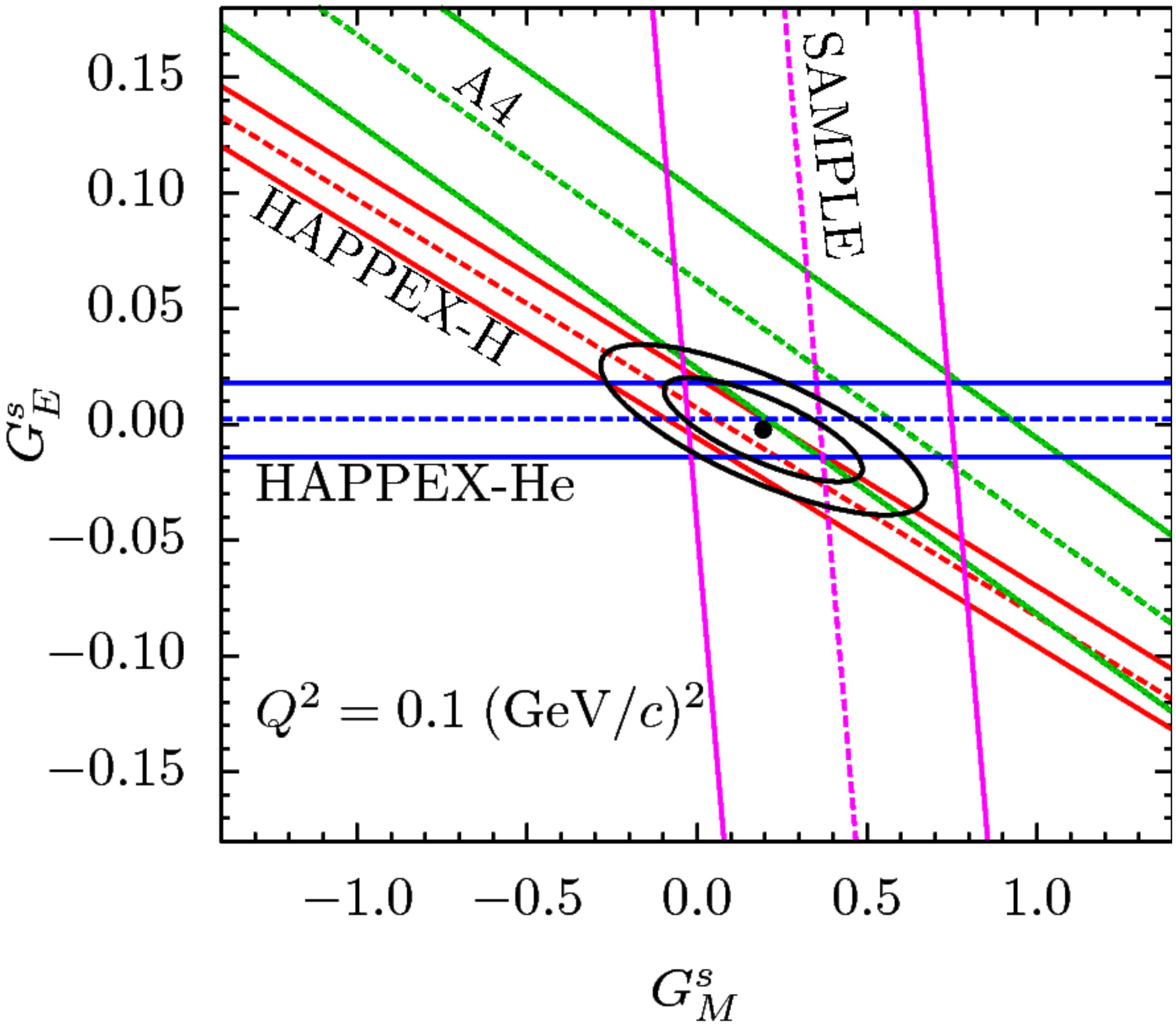
H: $G_E^s + 0.09 G_M^s = 0.007 \pm 0.017_{\text{exp}} \pm 0.005_{\text{theo}}$

He: $G_E^s = 0.002 \pm 0.014_{\text{exp}} \pm 0.007_{\text{theo}}$



A. Acha *et al.*,
Phys. Rev. Lett. 98 (2007), 032301

Combination at 0.1 $(GeV/c)^2$

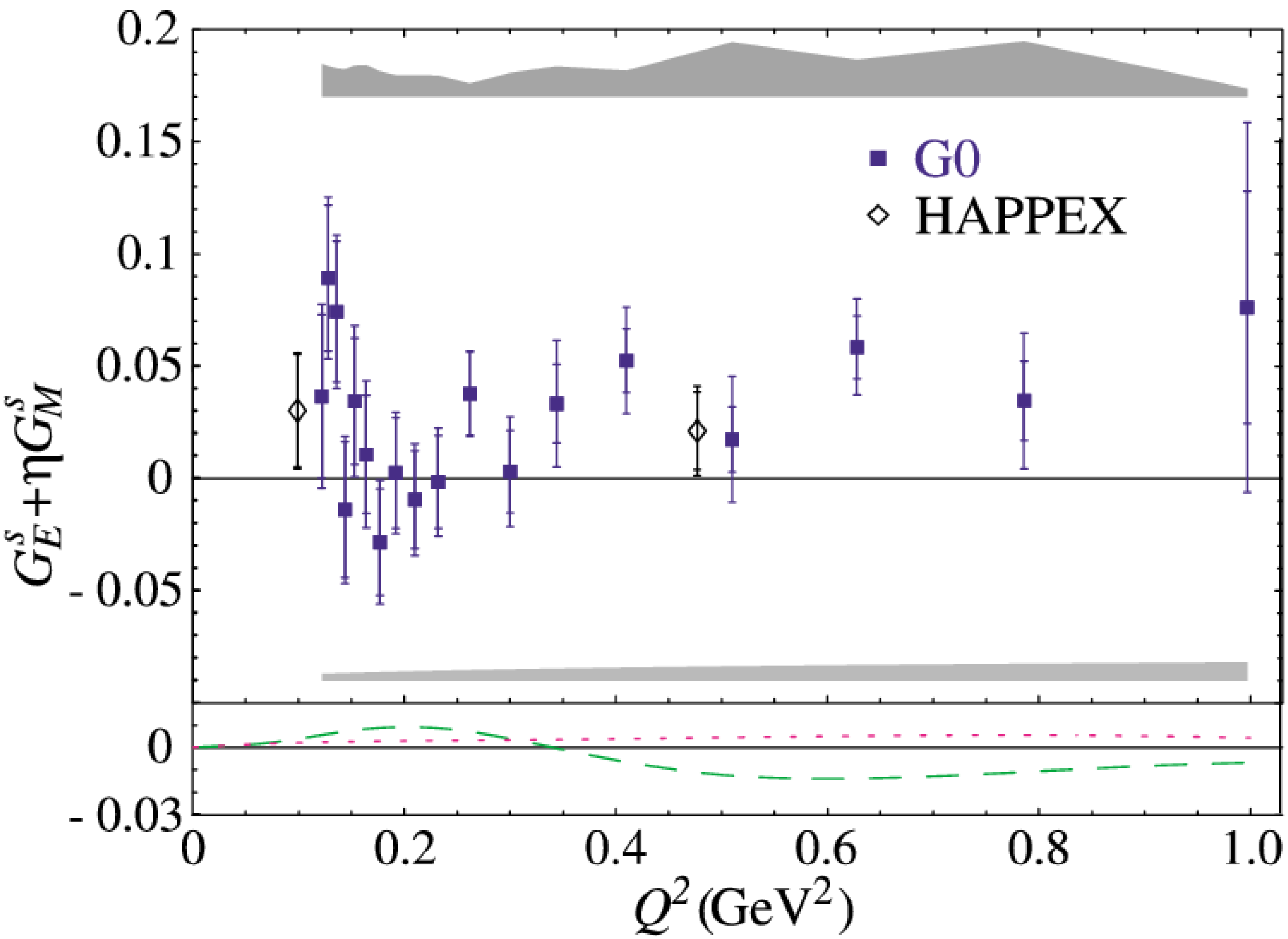


χ^2-fit:

$$G_M^s = 0.19 \pm 0.29\,,$$
$$G_E^s = -0.002 \pm 0.022\,.$$

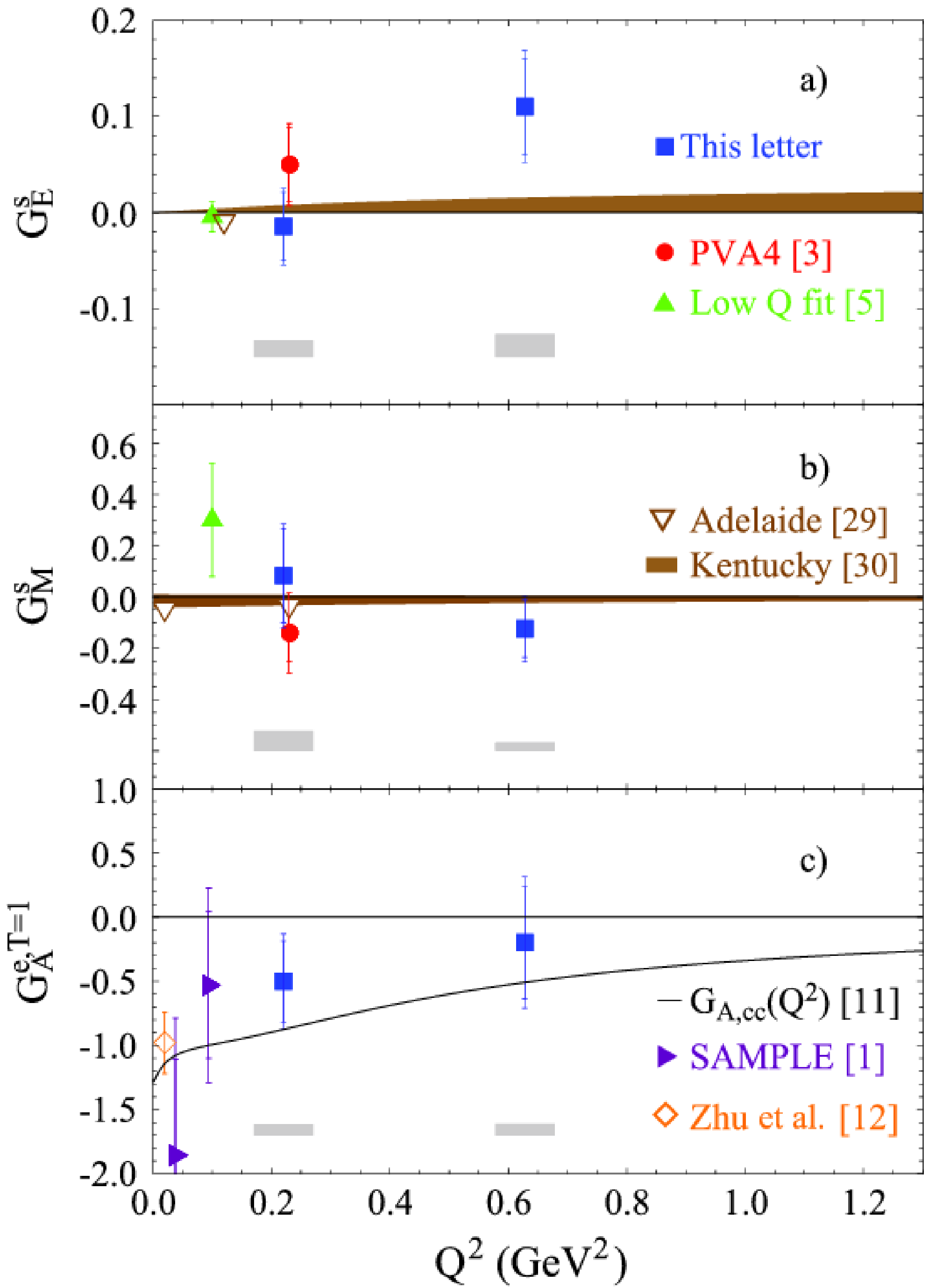
A4 data: **F.E. Maas *et al.***, Phys. Rev. Lett. 94 (2005), 152001

G0 forward angle



G0: **D.S. Armstrong *et al.***, Phys. Rev. Lett. 95 (2005), 092001
HAPPEx: **A. Acha *et al.***, Phys. Rev. Lett. 98 (2007), 032301

G0 at backward angle



D. Androić *et al.*,
Phys. Rev. Lett. 104 (2010), 012001

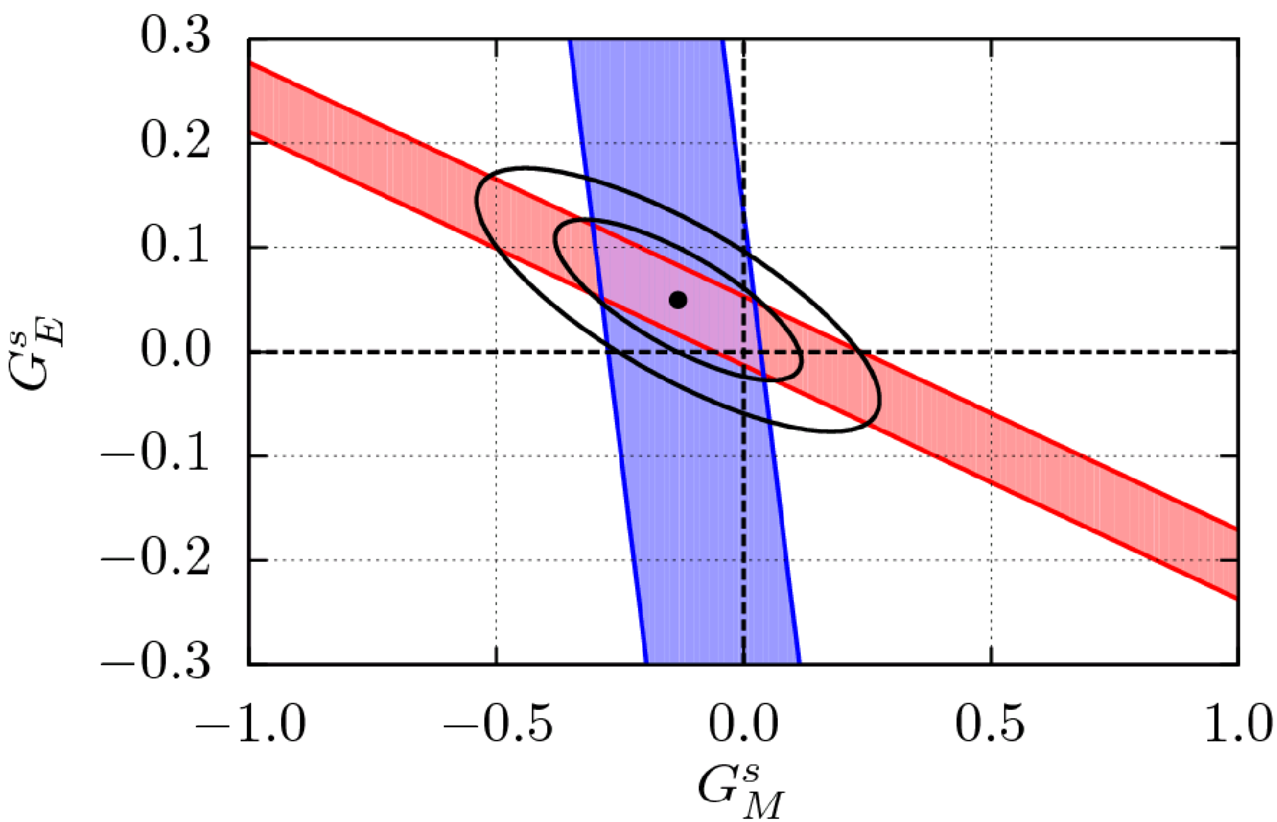
A4 at Q^2=0.22(GeV/c)^2

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

$$G_E^s + 0.224 G_M^s = 0.020 \pm 0.029 \pm 0.016$$

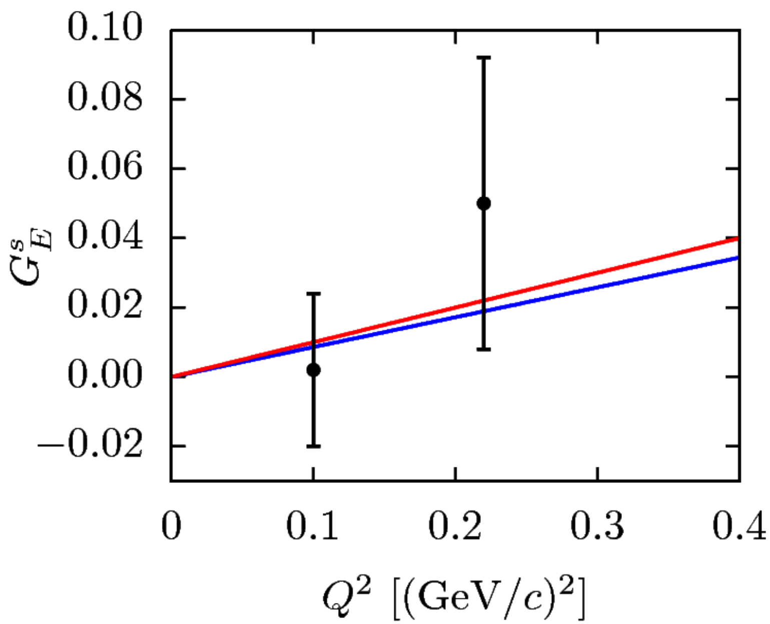
$$G_M^s = -0.14 \pm 0.11 \pm 0.11$$

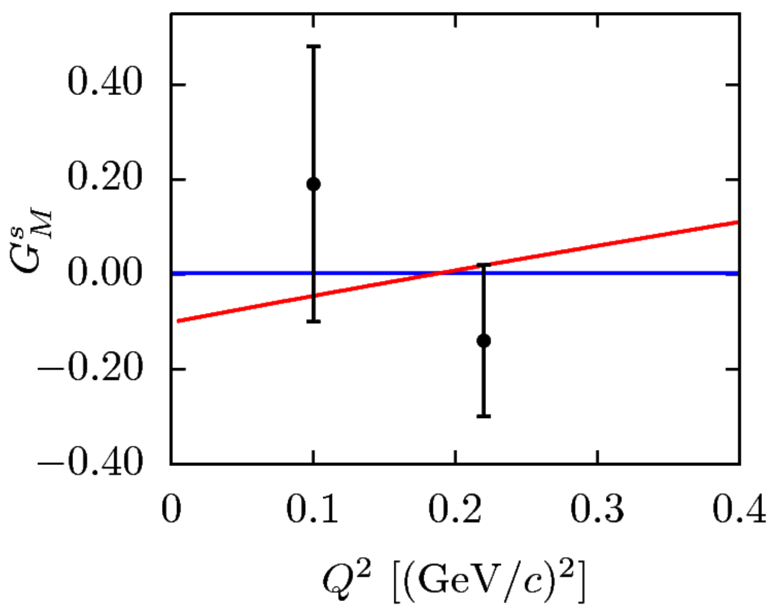
$$G_E^s = 0.050 \pm 0.038 \pm 0.019$$



Baunack S. *et al.*, Phys. Rev. Lett. 102, 151803 (2009)

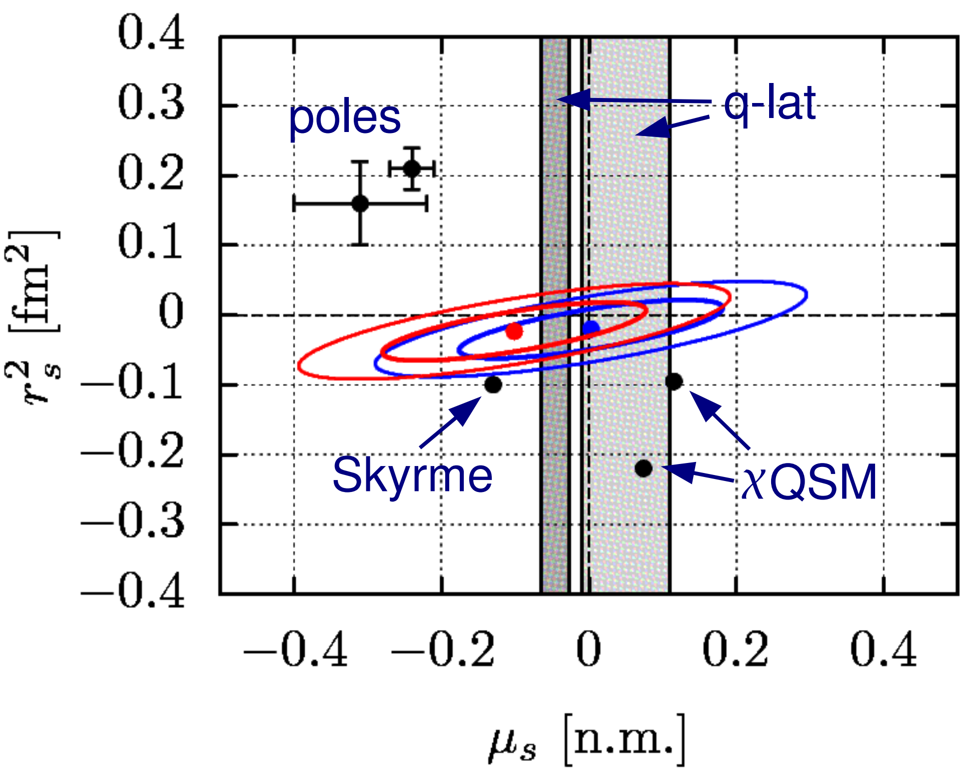
Q^2 dependence





$$r_s^2 = -6\frac{dG_E^s}{dQ^2}(Q^2=0)$$

$$\mu_s = G_M^s(Q^2=0)$$



See also: **R.D. Young *et al.***, Phys. Rev. Lett. 97 (2006), 102002

Impact on SM physics

Parity violating effective electron-quark coupling:

$$\mathcal{L}_{\rm NC}^{eq} = -\frac{G_F}{\sqrt{2}}\,\bar{\rm e}\gamma_\mu\gamma_5{\rm e}\sum_q C_{1q}\,\bar{q}\gamma^\mu q$$

PV electron scattering results → C_{1q} → SM extension constrained at the TeV scale

(factor 5 improved)

R.D. Young *et al.*, Phys. Rev. Lett. 99 (2007), 122003

<u>Future:</u>

- Qweak (JLAB)
- A4 (MAMI/MESA?)

Summary

- Measurement of strange vector form factors via neutral current observables
- Landscape of PV electron scattering experiments
- Results: measurement programme almost complete

Outlook for A4

- backward analysis: deuterium
- forward analysis: 1.5 GeV

Outlook for PVES

- SM physics (Qweak, A4?)

Spectrum simulation

Goal:

identify contributing processes

reproduce the measured spectrum

To do:

event generator

simulation of detector response

Event Generator

Requirements

sample final state of scattering events

take into account finite target size

energy losses

deviations

Idea

tracking beam electrons with Geant

use step info for sampling initial state

Physical processes

Signal

elastic scattering { radiative corrections
radiative tail

Background

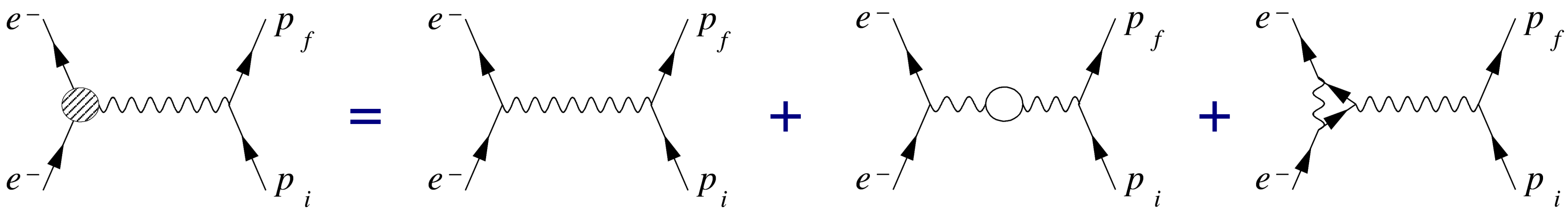
inelastic scattering

Al quasielastic/inelastic scattering (measured)

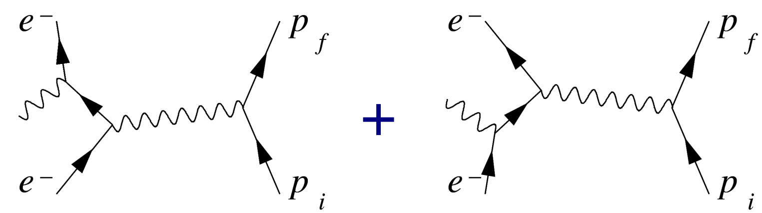
π^0 production and decay

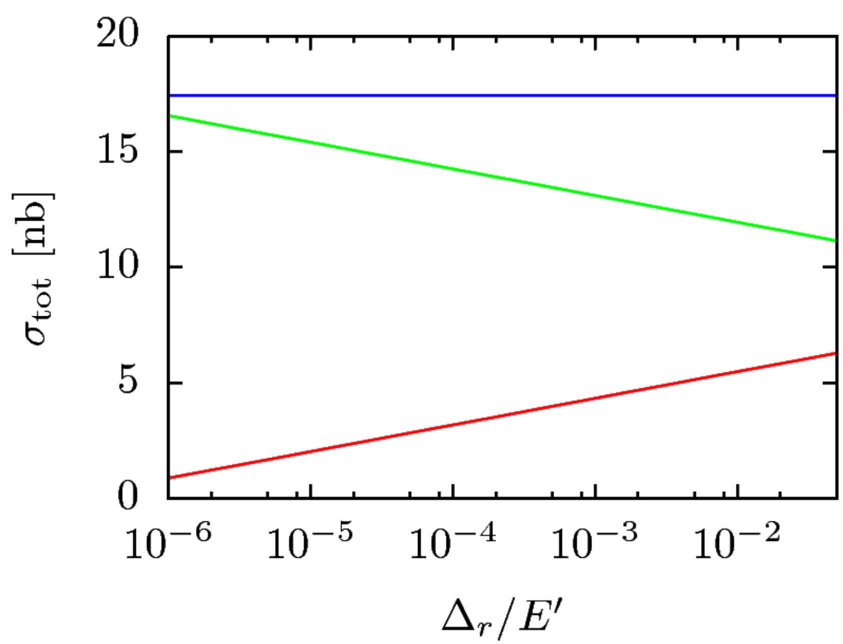
Processes: Signal

Rosenbluth + virtual rad. corrections (Mo, Tsai 1969)



Real corrections: Bethe-Heitler



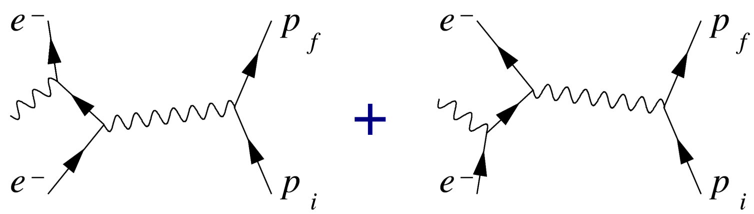


$$\sigma_{\mathrm{peak}} + \sigma_{\mathrm{tail}}$$

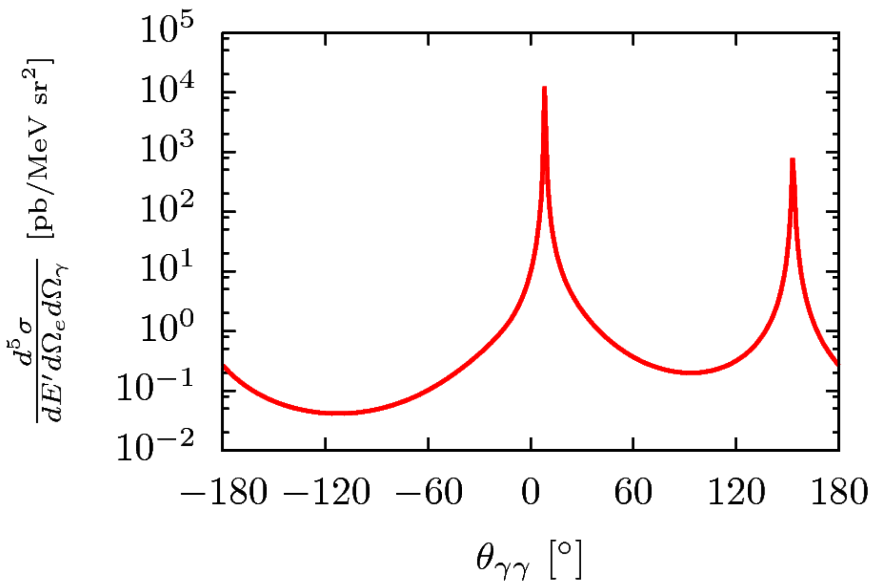
$$\sigma_{\mathrm{tail}} = \int_{\Delta} dk \frac{d\sigma_{\mathrm{BH}}}{dk}$$

$$\sigma_{\mathrm{peak}} = (1 + \delta_{\Delta})\sigma_{\mathrm{Ros}}$$

Radiative Tail



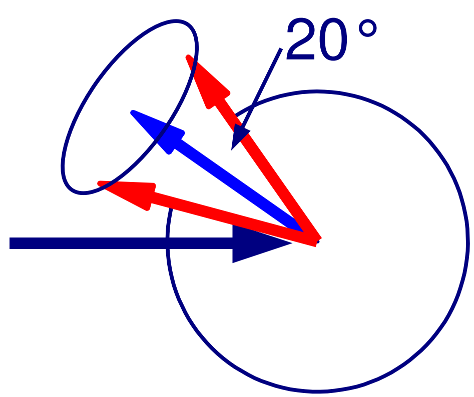
$$\Rightarrow \frac{d^5\sigma}{dE_e d\Omega_e d\Omega_\gamma}$$



Peaking approximation ($k_\gamma \parallel k_e$) not possible

Integration for "initial state radiation"

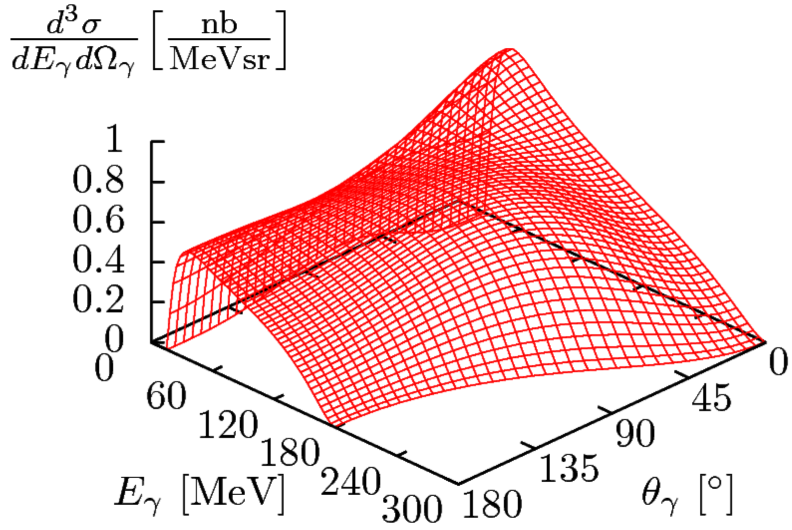
Sampling of both particles for "final state radiation"

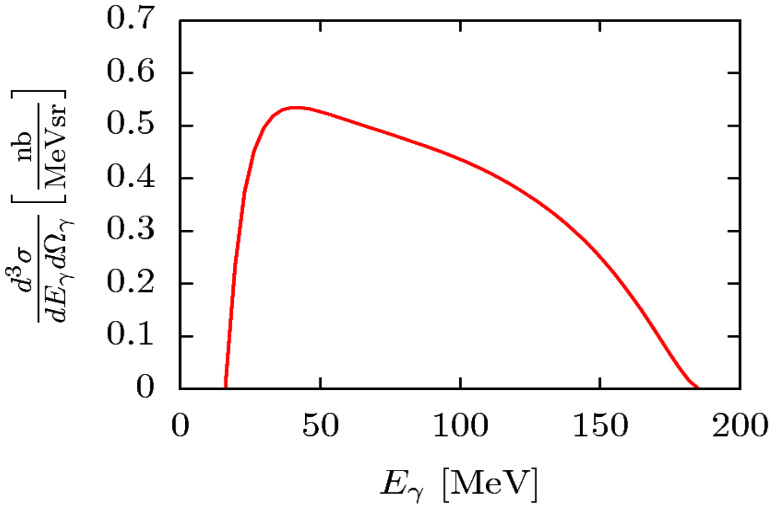


Processes: Background

Pion electroproduction: $\mathrm{e(p,pe)}\pi^0 \to \gamma\gamma$

$$\frac{d^3\sigma}{dE_\gamma d\Omega_\gamma}(E_\gamma,\theta_\gamma) = \int dE_\pi d\Omega_\pi \frac{d^3\sigma}{dE_\pi d\Omega_\pi}(E_\pi,\theta_\pi)\cdot\frac{d^2\rho}{d\Omega_\gamma}\,\delta(\tilde{E}_\gamma - E_\gamma)$$

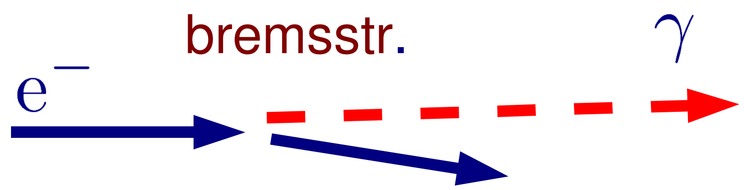




MAID: **D. Drechsel** *et al.*, Nucl. Phys. A645 (1999) 145

Processes: Background

Pion photoproduction:



$$\pi^0 \rightarrow \gamma\gamma$$

Tsai, Rev. Mod. Phys. 46 (1974), 815-851
"... the contribution due to direct electroproduction is approximately equal to the contribution from a real bremsstrahlung beam produced by letting the electron pass through a radiator of ~1/50 radiation lengths."

@A4 backward:

$$\frac{\ell}{X_0} = \frac{234\ \mathrm{mm}}{9.4\ \mathrm{m}} = 0.025$$

Event generator: let Geant simulate bremsstrahlung
track gammas
sample final states

Detector Response

Geometry

Materials

Acceptance

Energy Resolution

EM showers

Cherenkov light:

yield,

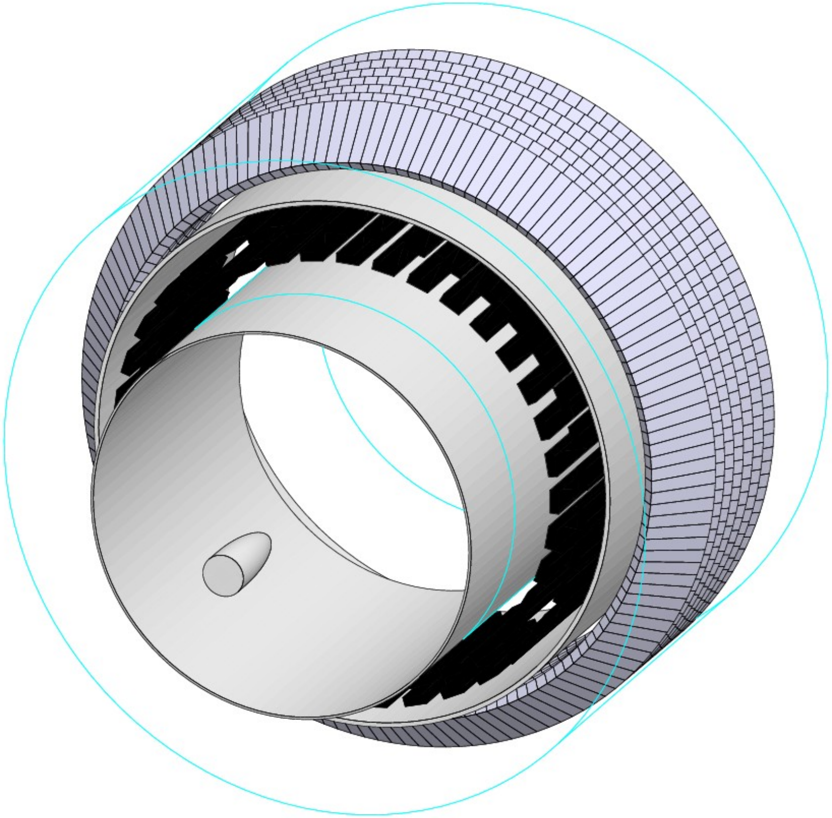
collection,

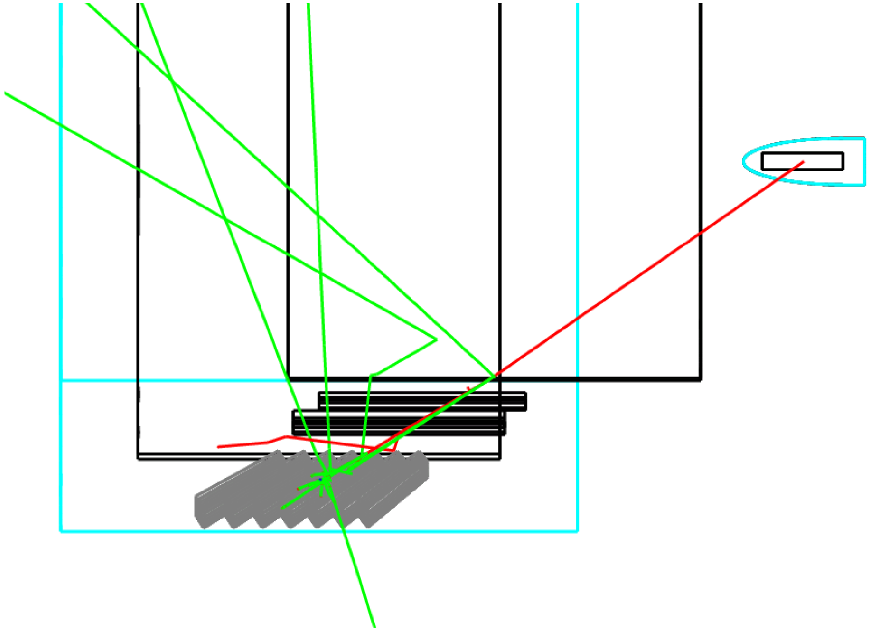
and detection

Geant4 Simulation

Detector geometry and materials

Particle tracking with EM processes





Cherenkov Light

production

sampling from stepping info

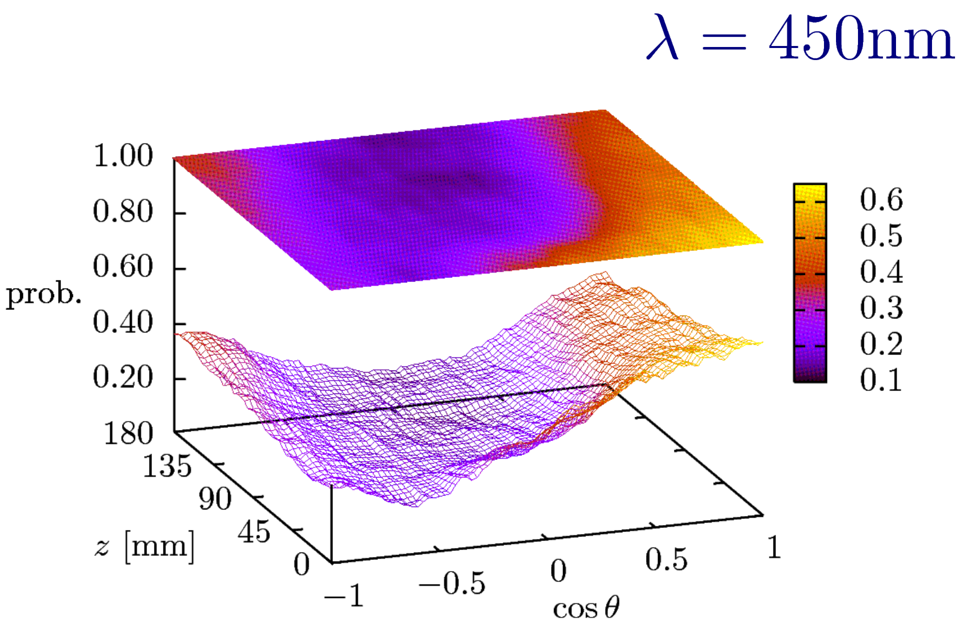
of shower particles

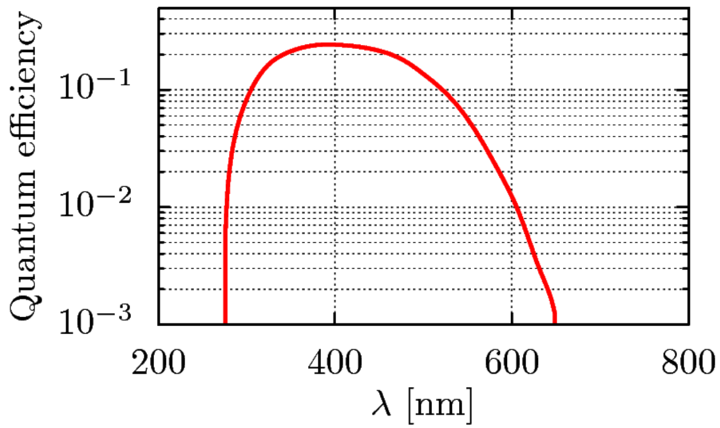
collection probability

tracking optical photons

through crystals

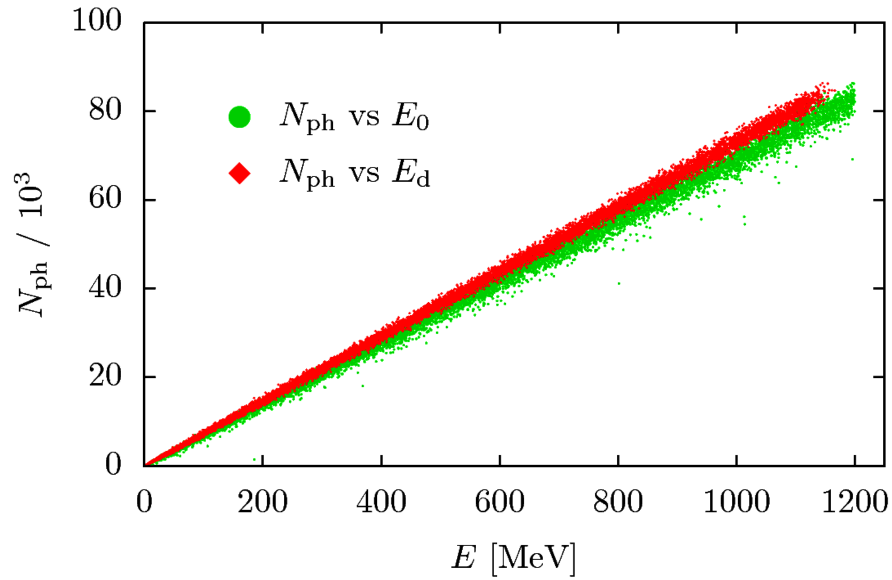
detection (QE)

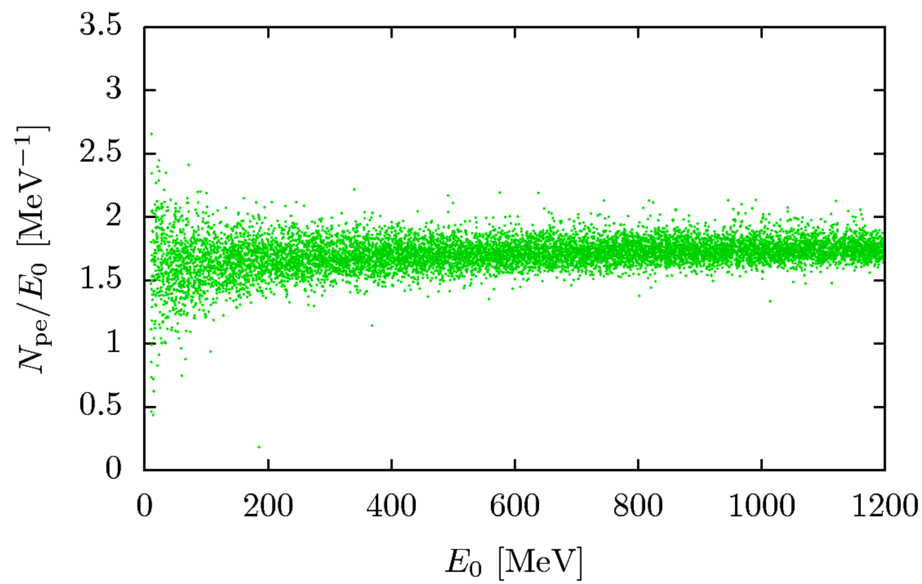




Complete response "only" by EM shower simulation

Energy resolution





Simulation 10^4 showers

Event variables:

$$E_0, \ E_d, \ N_{ph}, \ N_{p.e.}$$

Normalisation:

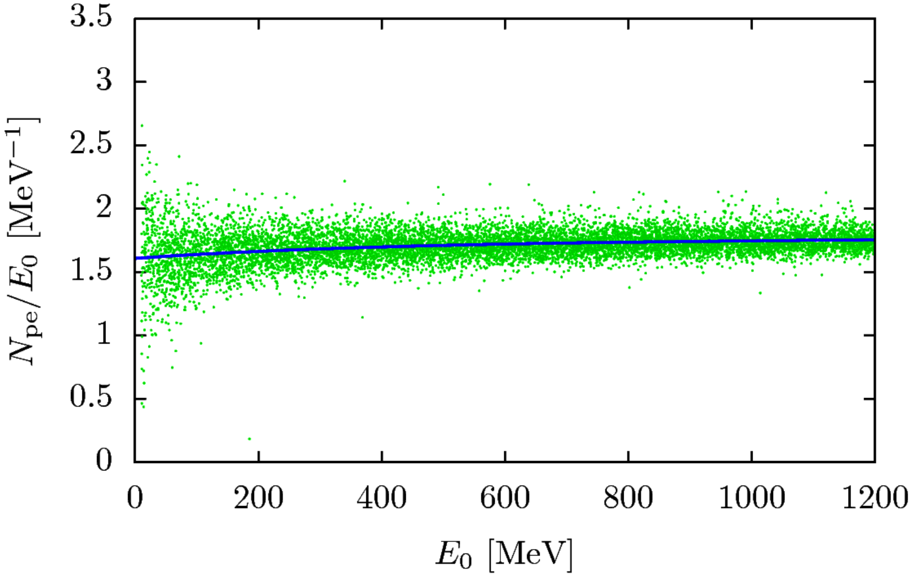
$$\nu = N_{p.e}/E_0$$

Conditional p.d.f.

$$p(\nu|E_0) = \text{gauss}\left[\nu, \mu(E_0), \sigma(E_0)\right]$$

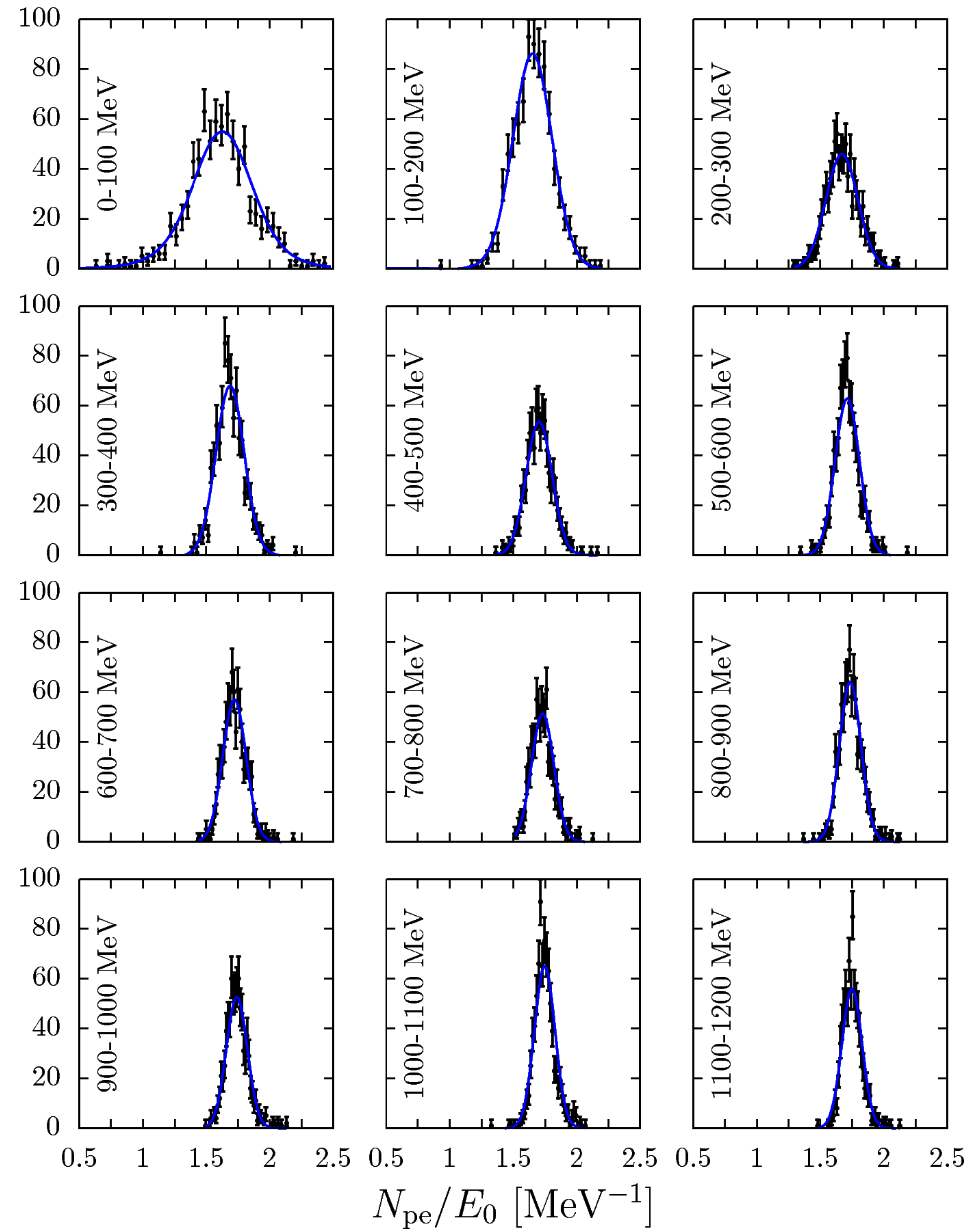
Energy resolution

Conditional fit



$$\mu(E) = \alpha + \frac{\beta}{E}[1 - \exp(-E/\gamma)]$$

$$\sigma(E) = \sqrt{\delta + \frac{\epsilon}{E}}$$

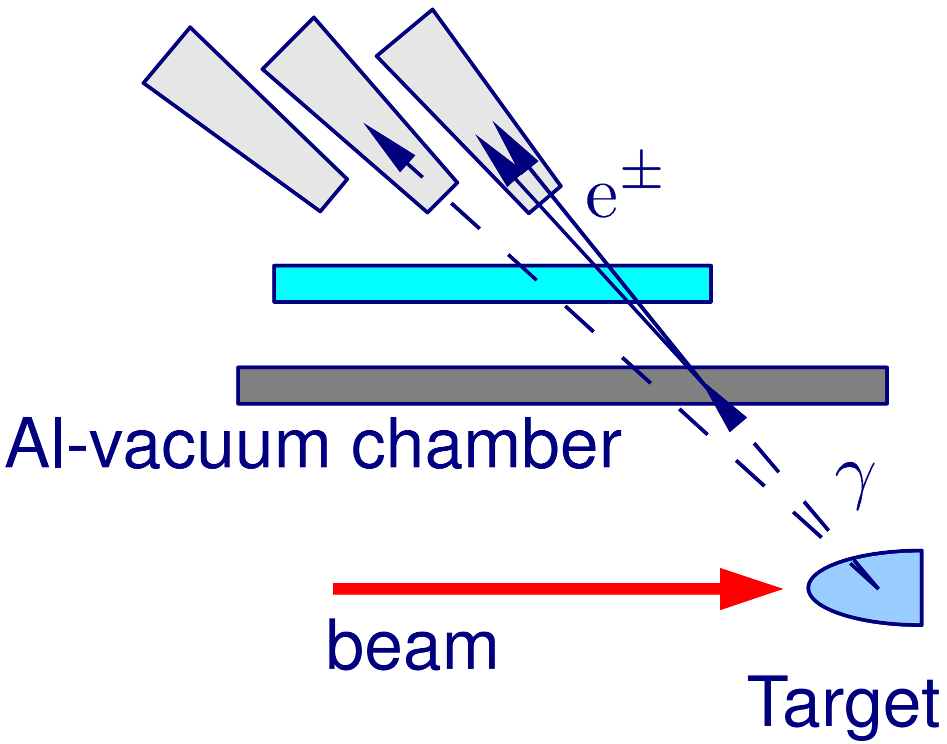


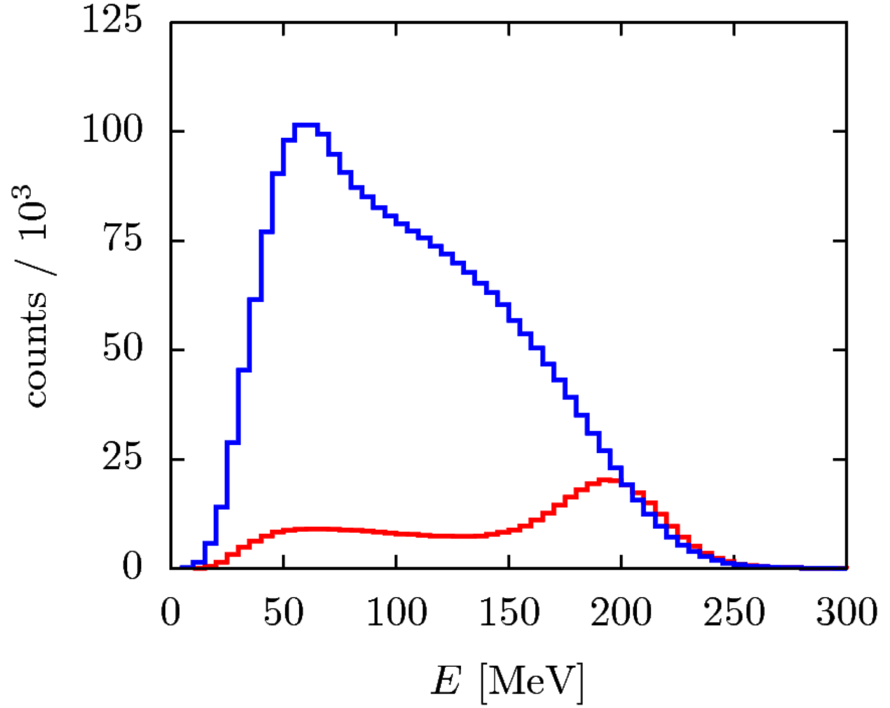
Background subtraction

<u>Idea</u>: γ-spectrum ⇒ background contribution

energy loss

conversion probability



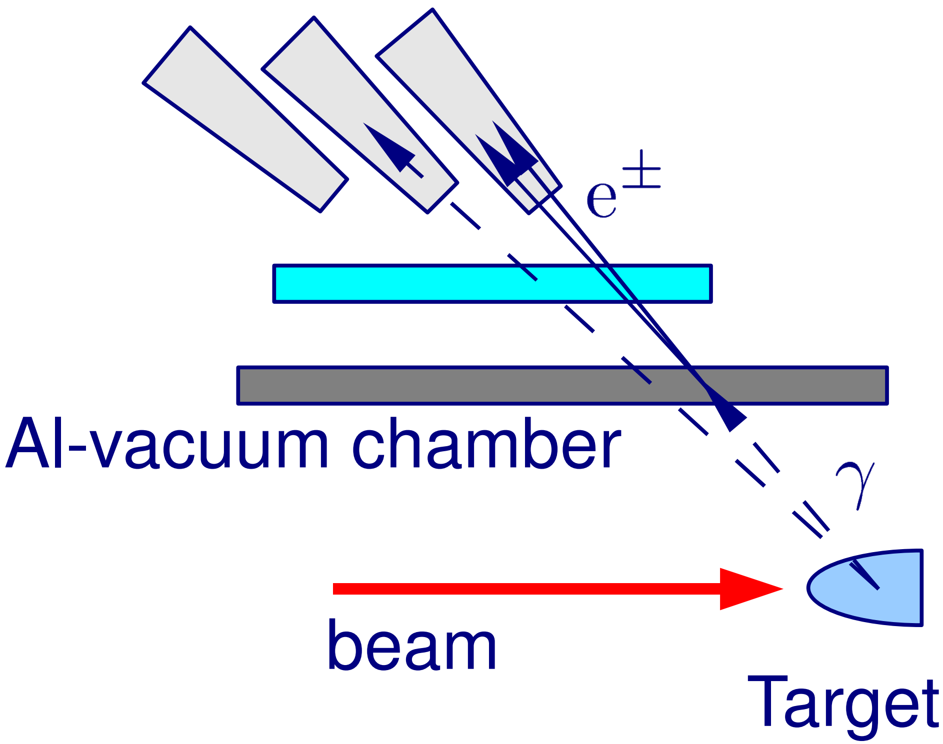


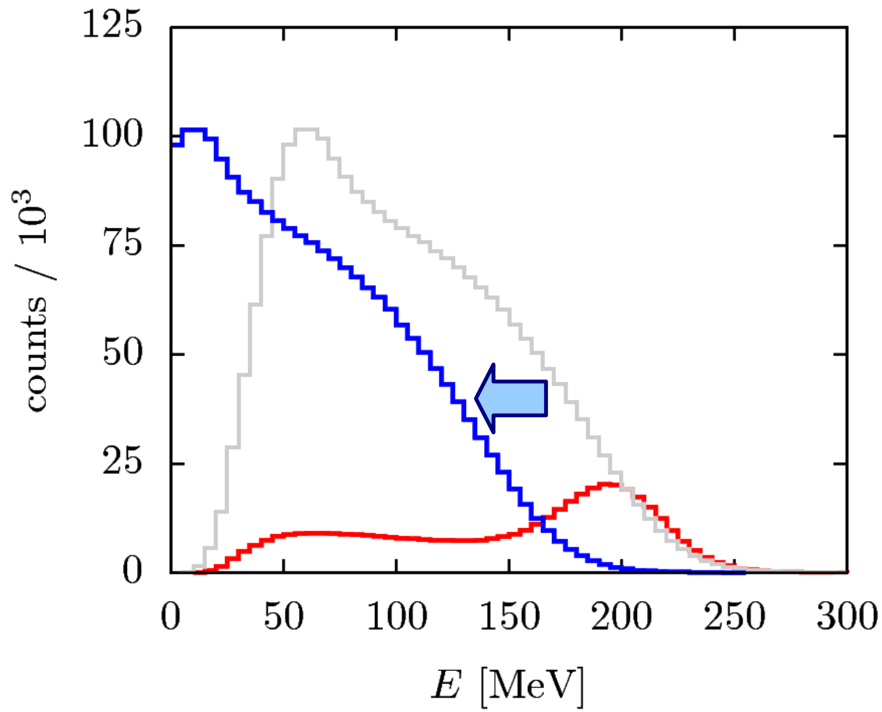
Background subtraction

Idea: γ-spectrum ⇒ background contribution

energy loss

conversion probability



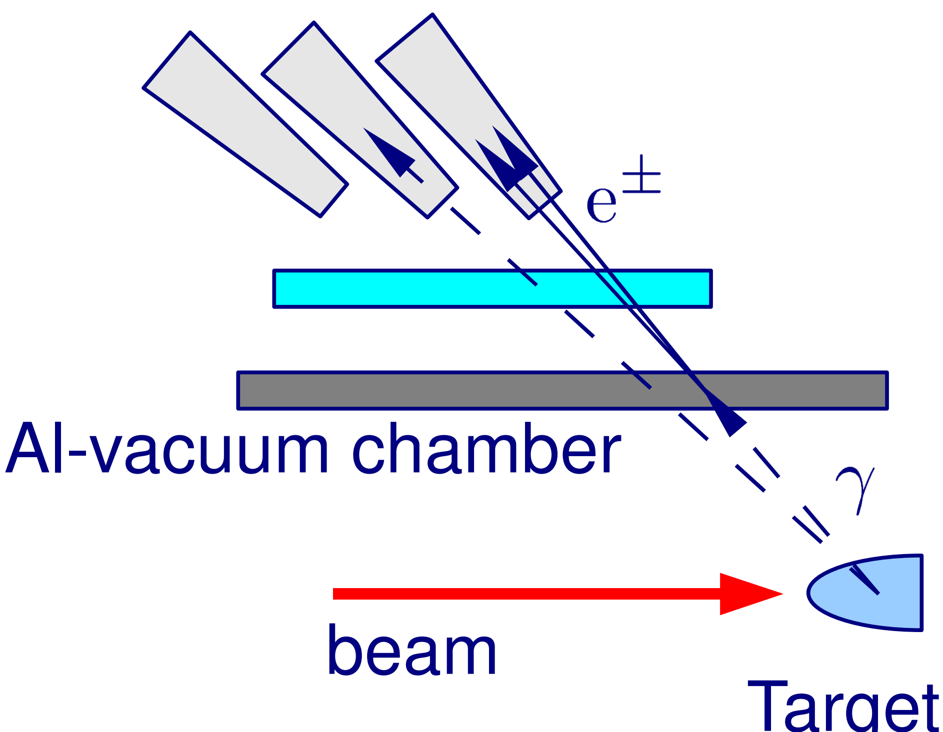


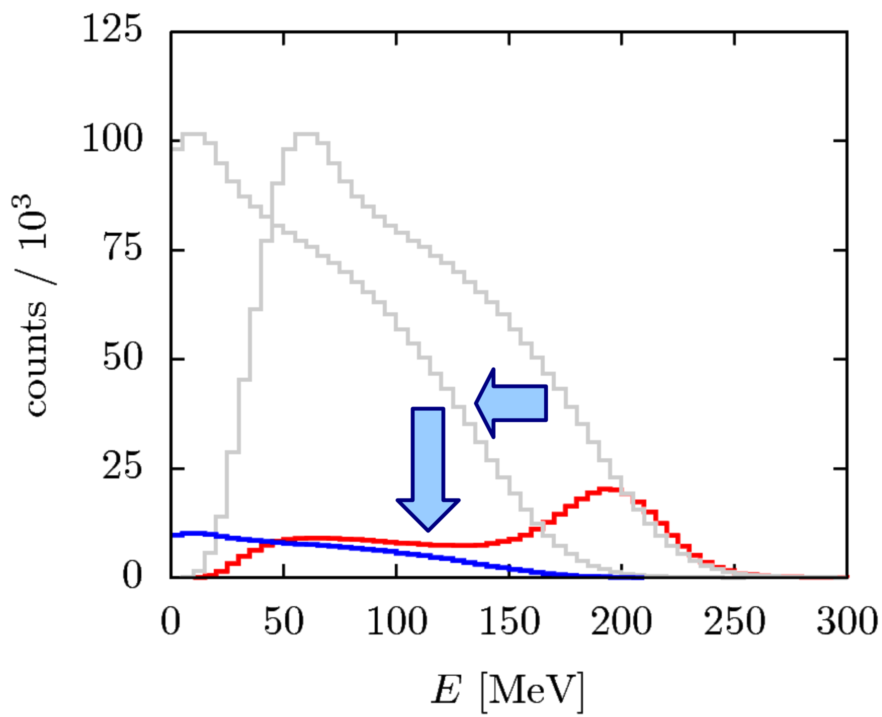
Background subtraction

Idea: γ-spectrum ⇒ background contribution

energy loss

conversion probability



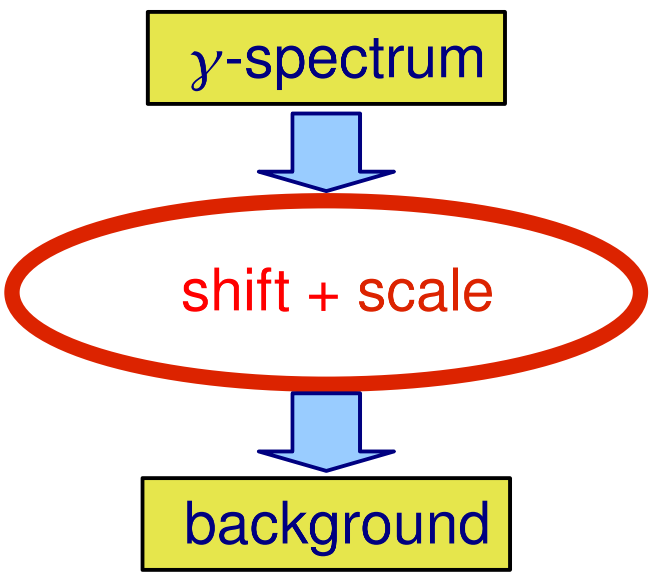


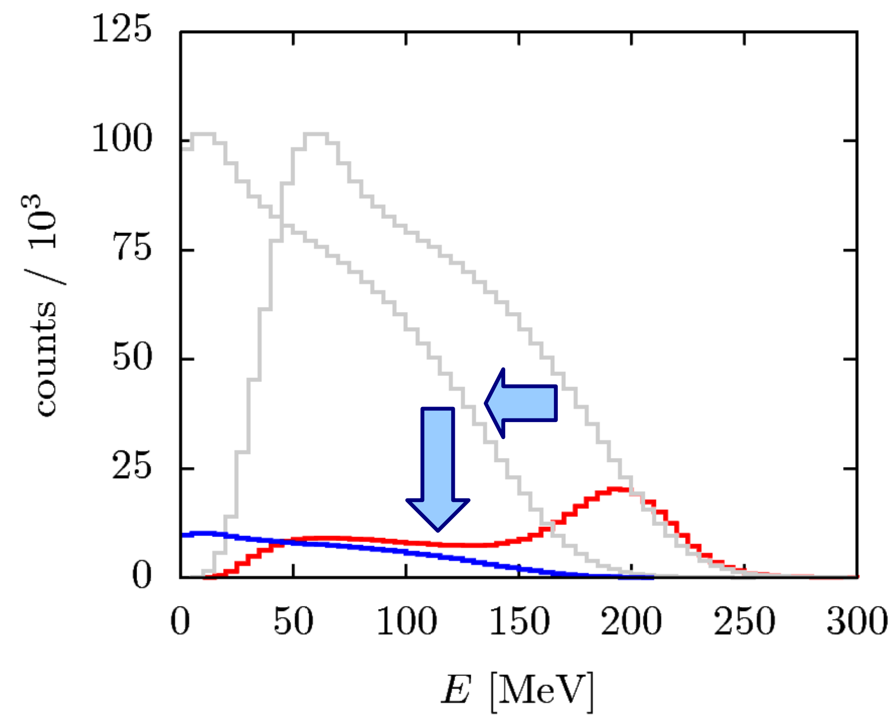
Background subtraction

<u>Idea</u>: γ-spectrum ⇒ background contribution

energy loss

conversion probability





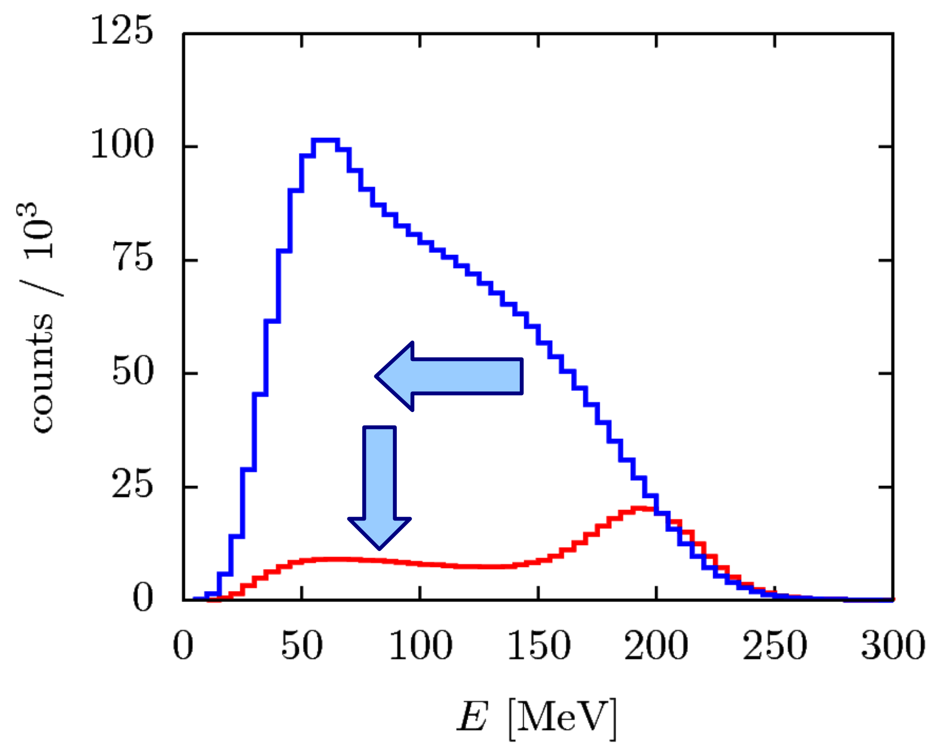
Background subtraction

1. Verify feasibility

response to gammas:

coincidence

non-coincidence



2. Provide parameters

conversion probability

energy shift

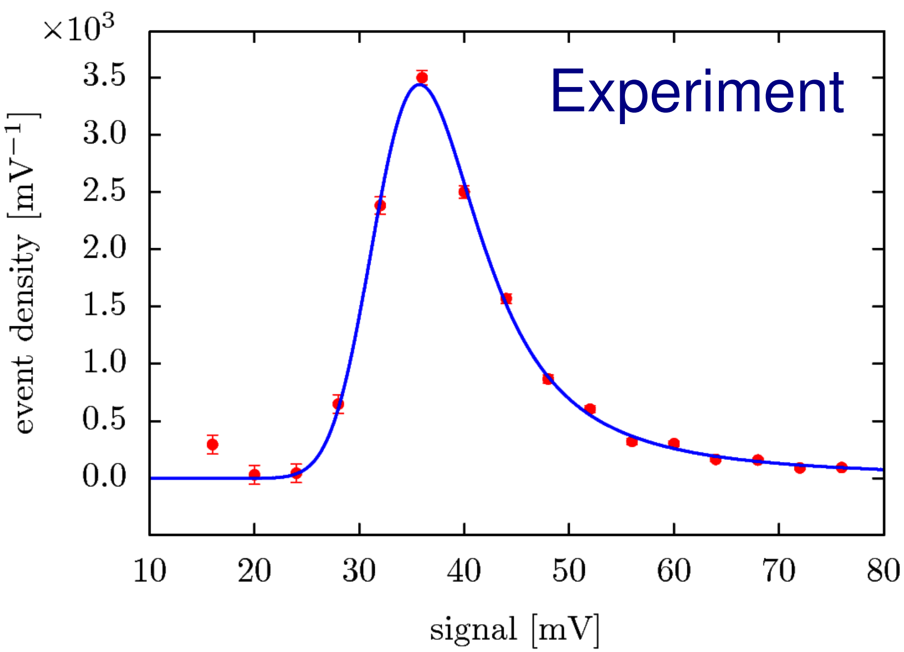
Electron taggers

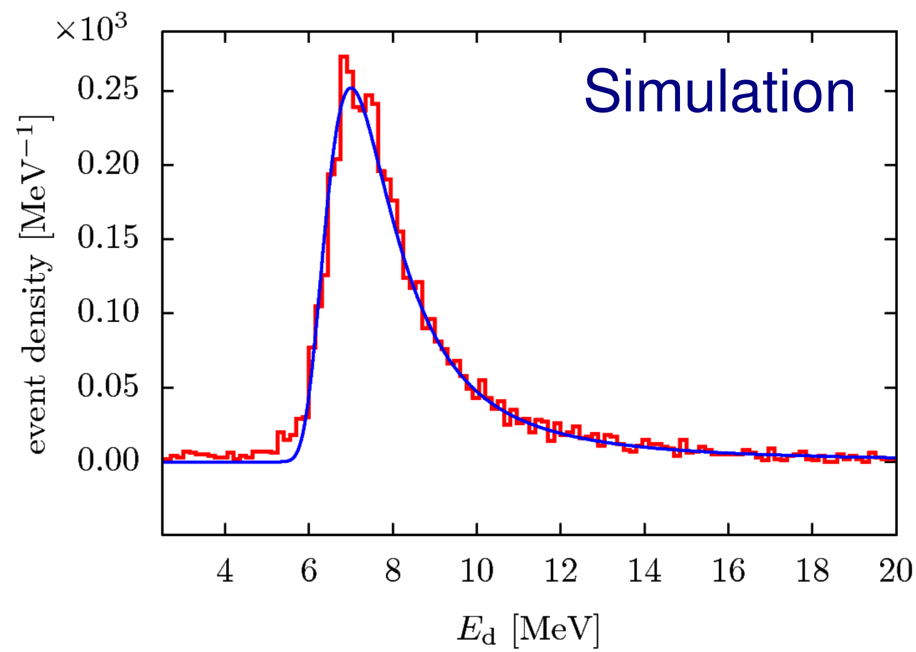
Low threshold scan

Comparison with simulation

(deposited energy)

⇨ **Calibration of scintillator taggers**



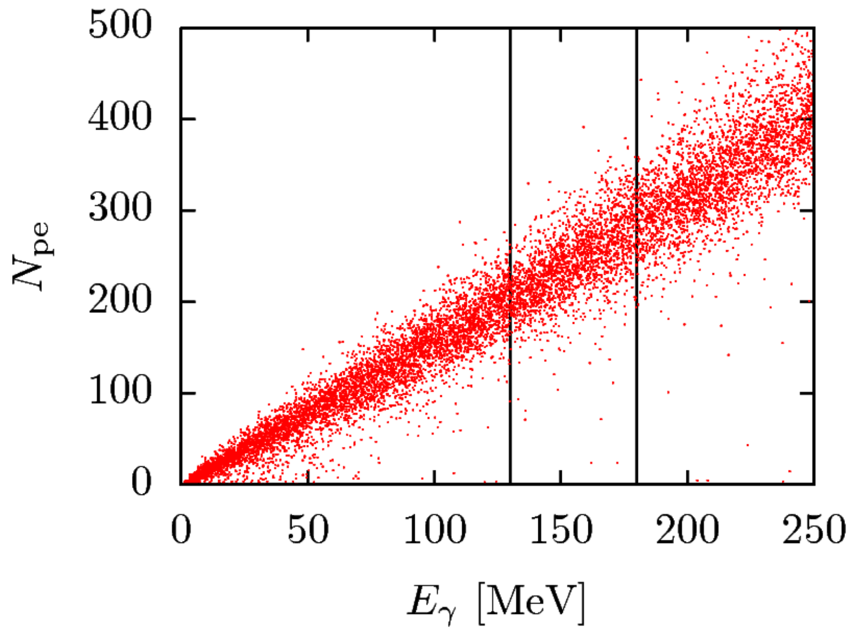


Response to Background

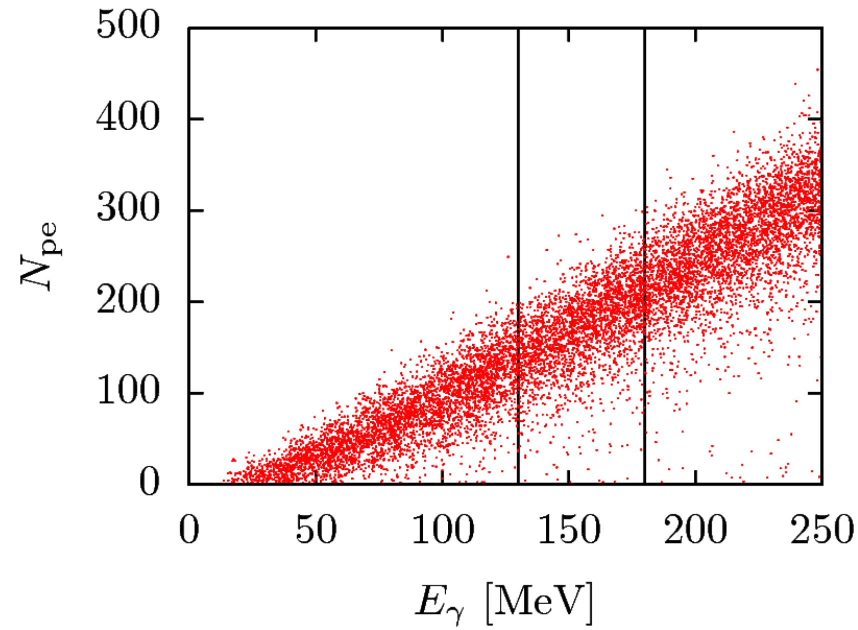
Simulation of γ-events

Deposited energy in scintillator vs threshold:

E < thr.



E > thr.

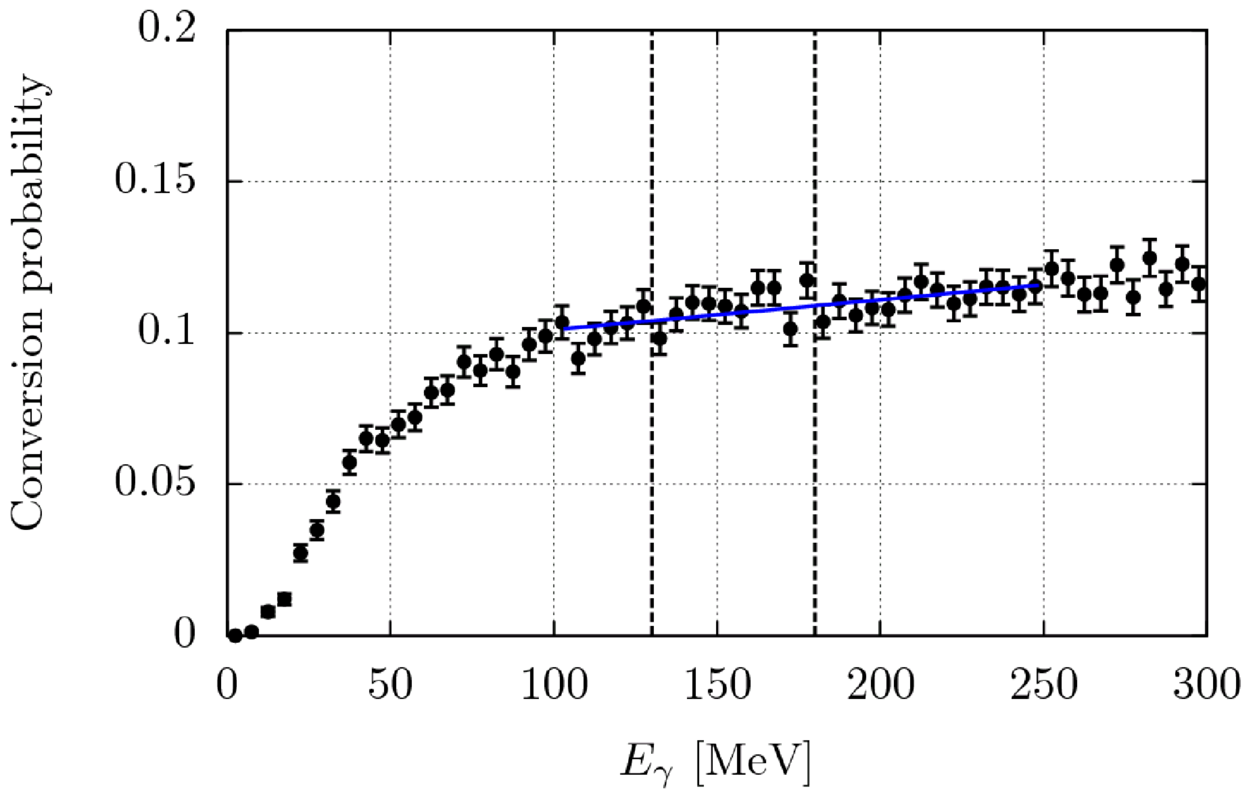


Conditional fit ⇨ shift parameter

7.1% variation between 130 and 180 MeV

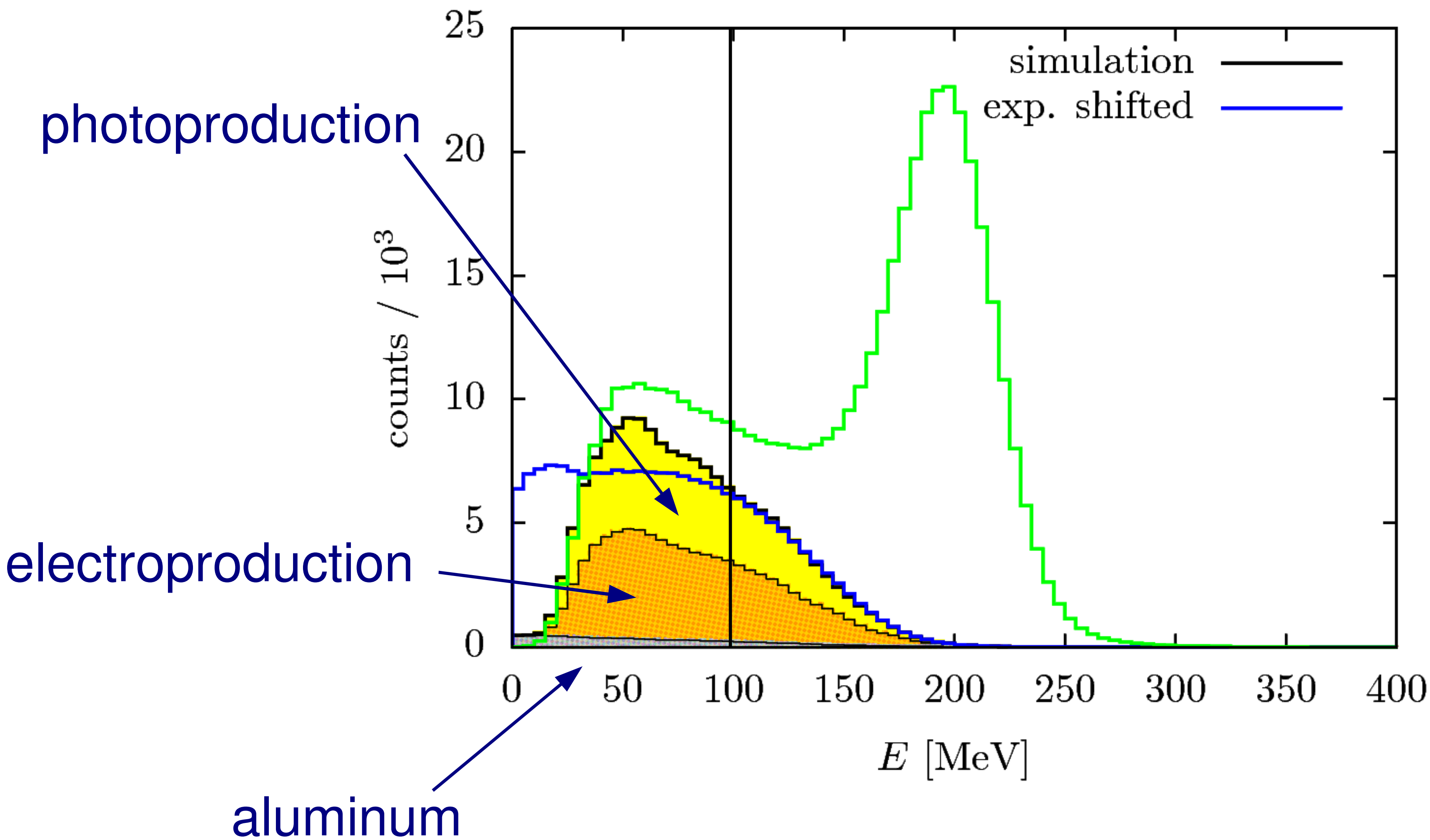
Conversion probability

Binning the photon energy
Calculating the stat. prob. for each bin
Linear fit in the peak region



change of 0.3% between 130 and 180 MeV

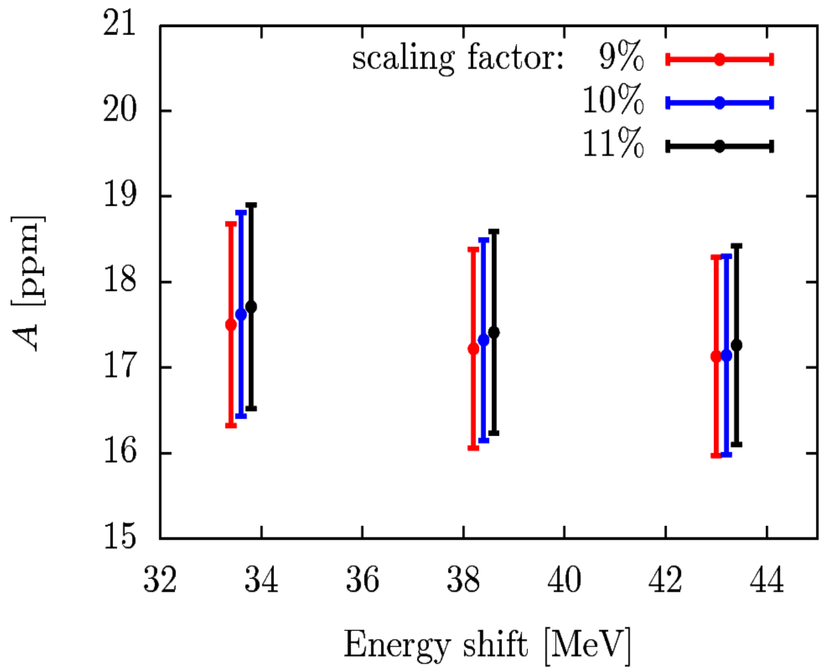
Comparison



agreement (100-300 MeV): 3.8%

Background subtraction

Asymmetry sensibility to parameters:



Dependence on lower cut: