ПОЛЯРИЗУЕМОСТЬ НУКЛОНА

СТАТУС
СОВМЕСТНОГО (ПИЯФ-ИКП) ЭКСПЕРИМЕНТА НА ЭЛЕКТРОННОМ УСКОРИТЕЛЕ В ДАРМШТАДТЕ

РОССИЙСКАЯ АКАДЕМИЯ НАУК
ПЕТЕРБУРГСКИЙ ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
ИМ. Б.П.КОНСТАНГИНОВА

D.V. Balin, M.J. Borkowski, V.P. Chizhov,
G.A. Kolomensky, E.M. Maev, D.M.Seliverstov,
G.G. Semenchuk, Yu.V. Smirenin, A.A.Vasiliev,
A.A. Vorobyov, N.Yu. Zaitsev

Compton Scattering on Protons:

Project of Experimental Determination of Electric and Magnetic Polarizabilities of the Proton

ГАТЧИНА 1996

The electric and magnetic nucleon polarizabilities of the nucleon, α and β, characterize the response of its internal structure to applied electric and magnetic fields.

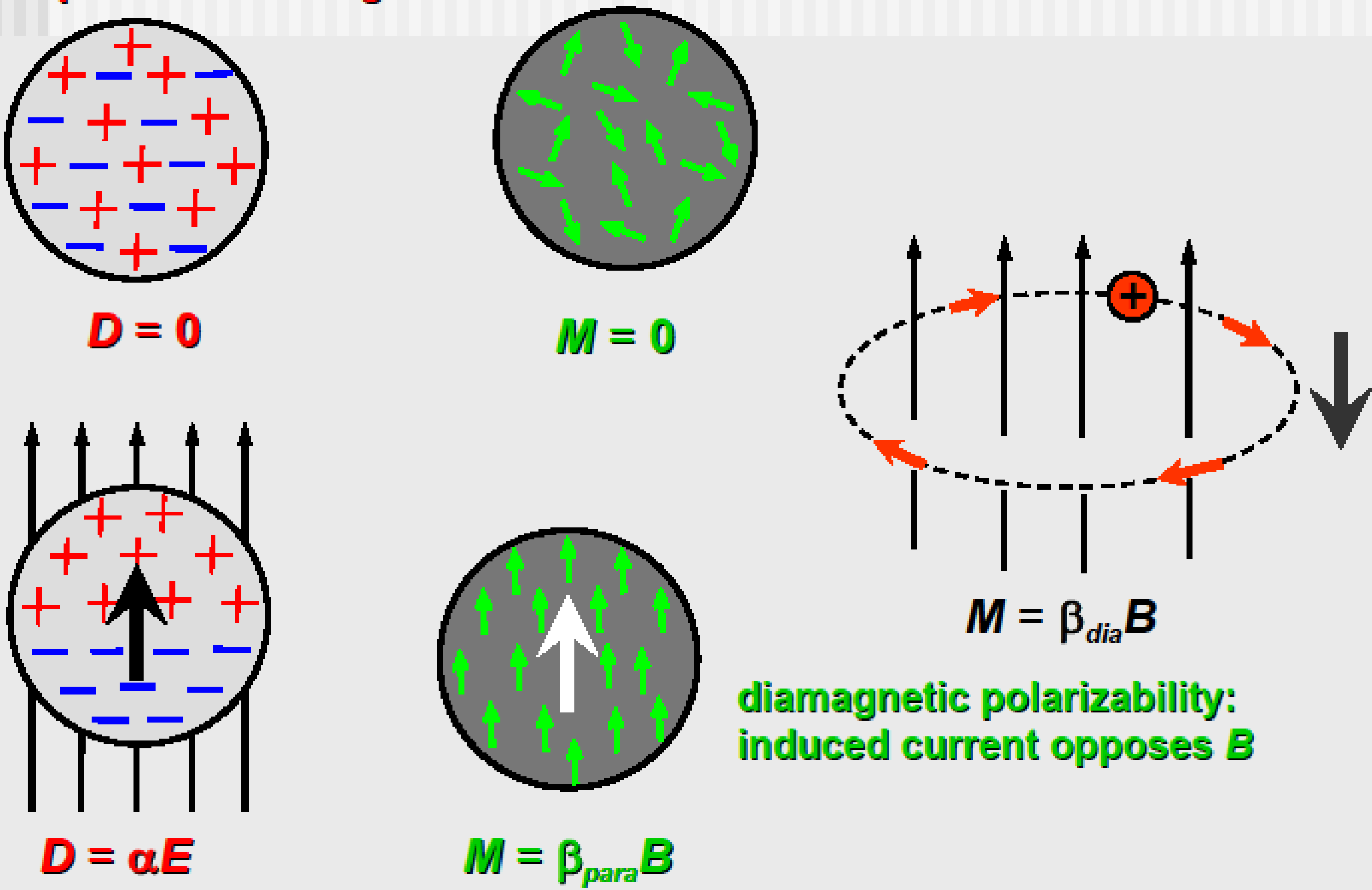
$$\mathbf{d} = \alpha \mathbf{E} \qquad \boldsymbol{\mu} = \beta \mathbf{B}$$

$$\overline{\alpha} = 2 \sum_{n \neq N} \frac{\left| \langle n | D_z | N \rangle \right|^2}{E_n - E_N} + \Delta\alpha \equiv \alpha_0 + \Delta\alpha \, ,$$

$$\overline{\beta} = 2 \sum_{n \neq N} \frac{\left| \langle n | M_z | N \rangle \right|^2}{E_n - E_N} + \Delta\beta \equiv \beta_0 + \Delta\beta \, .$$

electric polarizability:
separation of charge

paramagnetic polarizability:
moments align with *B*



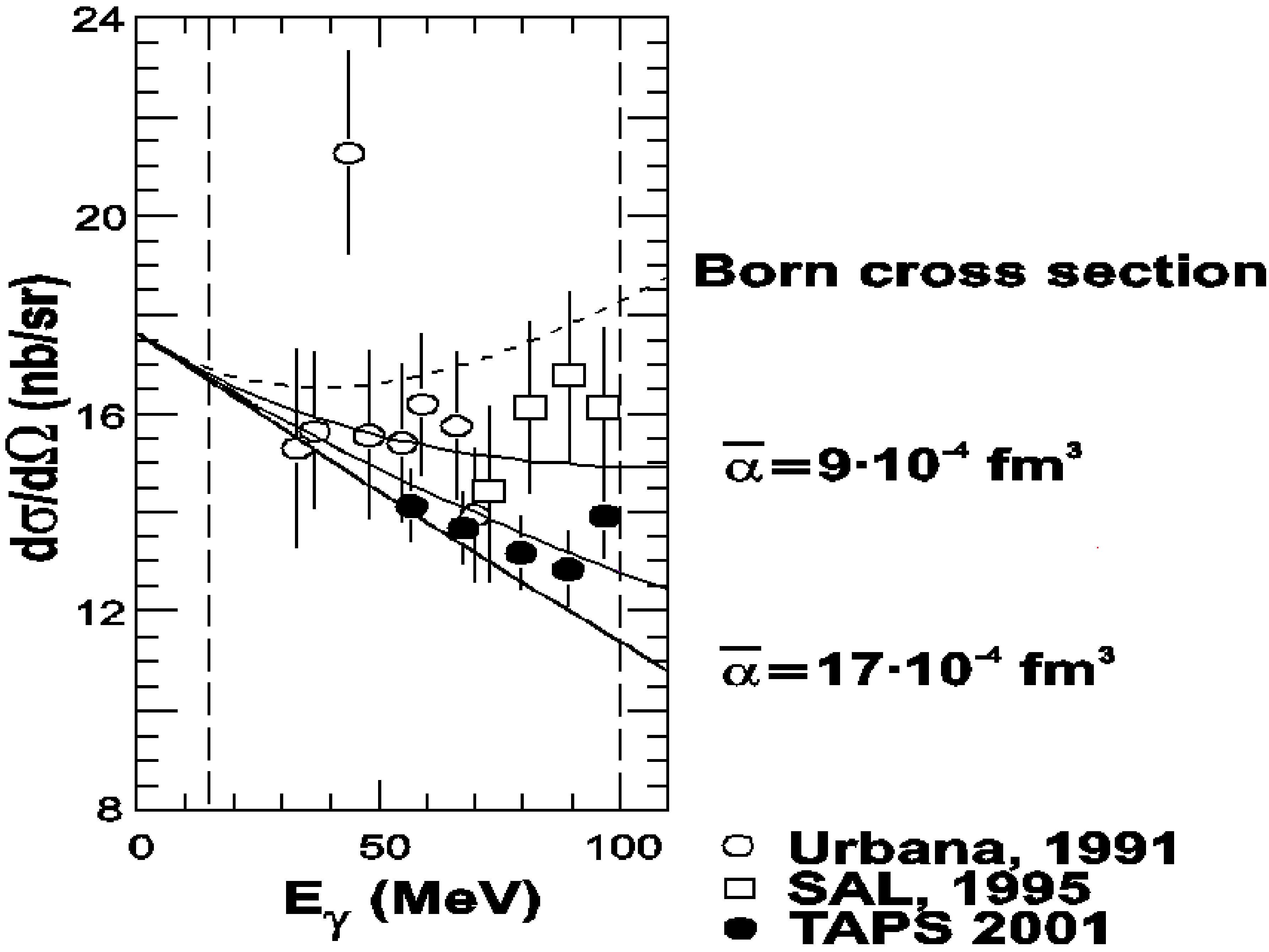
diamagnetic polarizability:
induced current opposes *B*

Cross section for Compton scattering

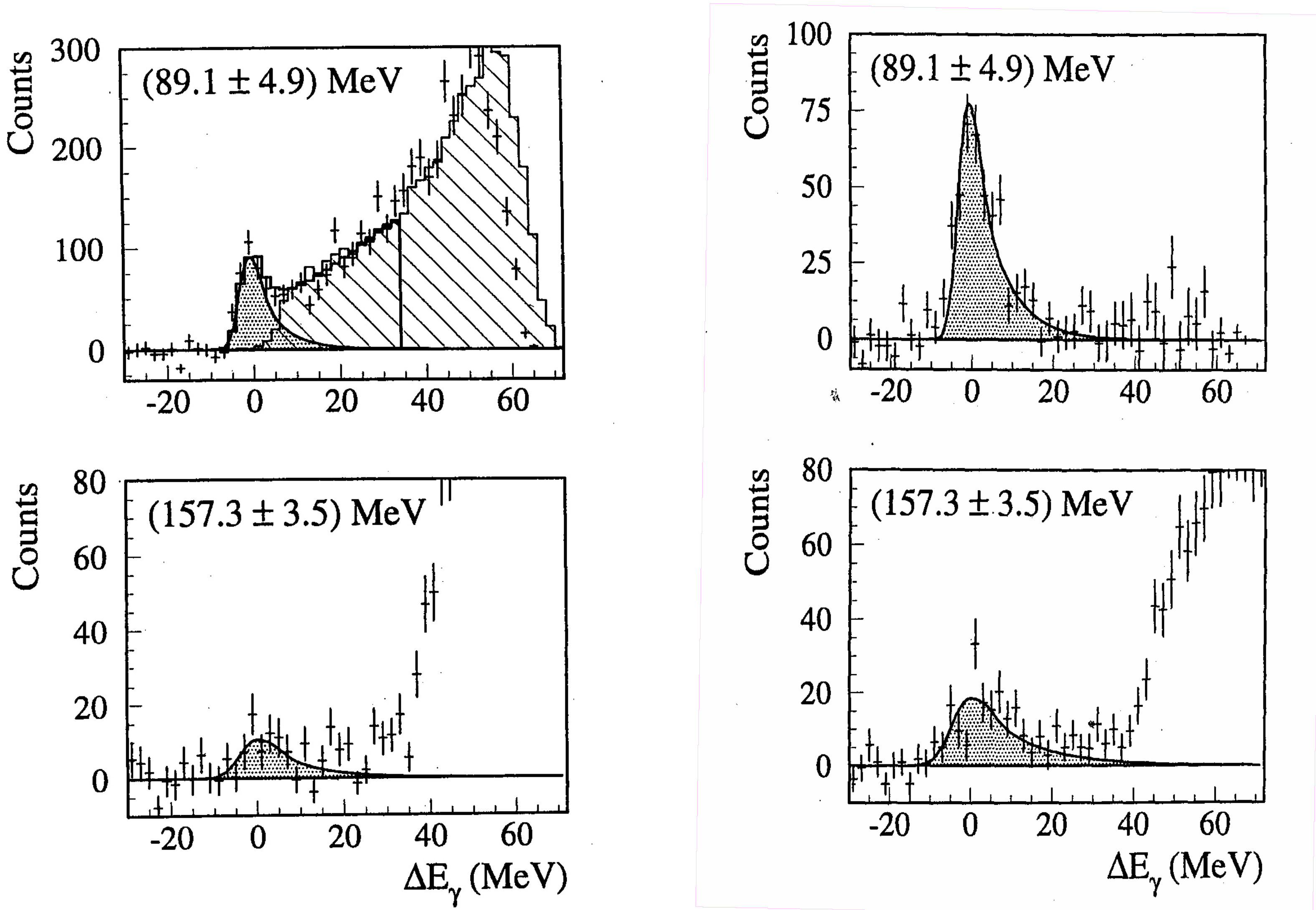
$$\left[\frac{d\sigma(E_\gamma,\theta)}{d\Omega}\right]_{\rm LET} = \left[\frac{d\sigma(E_\gamma,\theta)}{d\Omega}\right]_{\rm Powell} - \rho + \mathcal{O}(E_\gamma^4)$$

$$\rho = \frac{e^2}{4\pi m_p}\left(\frac{E_{\gamma'}}{E_\gamma}\right)^2 \frac{E_\gamma E_{\gamma'}}{(\hbar c)^2} \times$$

$$\times \left[\frac{\overline{\alpha}+\overline{\beta}}{2}(1+\cos\theta)^2 + \frac{\overline{\alpha}-\overline{\beta}}{2}(1-\cos\theta)^2\right]$$

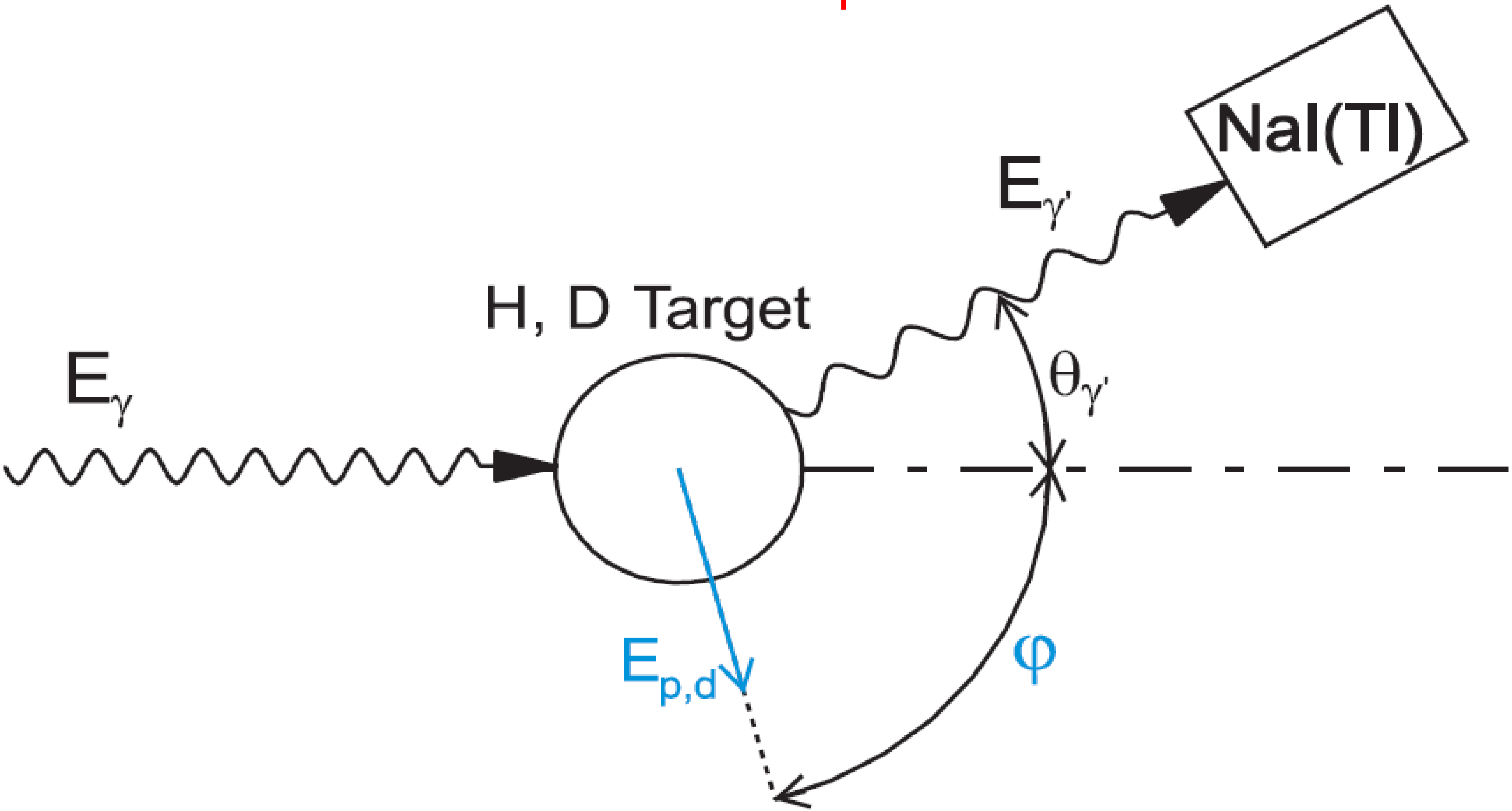


24
20
16
12
8
0
50
100
dσ/dΩ (nb/sr)
Eγ (MeV)
Born cross section
ᾱ=9·10⁻⁴ fm³
ᾱ=17·10⁻⁴ fm³
Urbana, 1991
SAL, 1995
TAPS 2001



V. Olmos de Leon et al., Eur. Phys. J. A 10, 207 (2001).

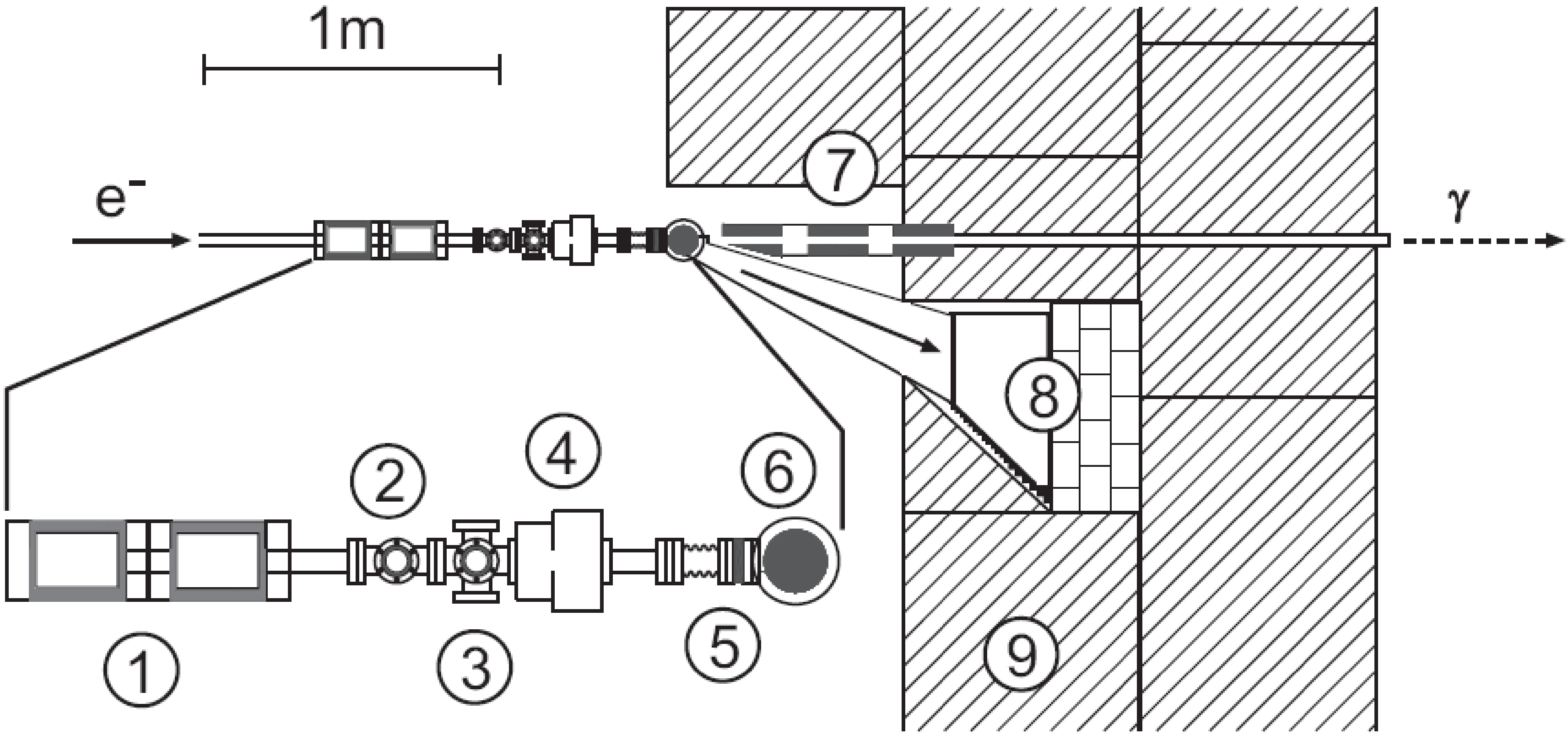
Kinematics of the experiment



$\varphi \sim 90° - \theta_\gamma/2$

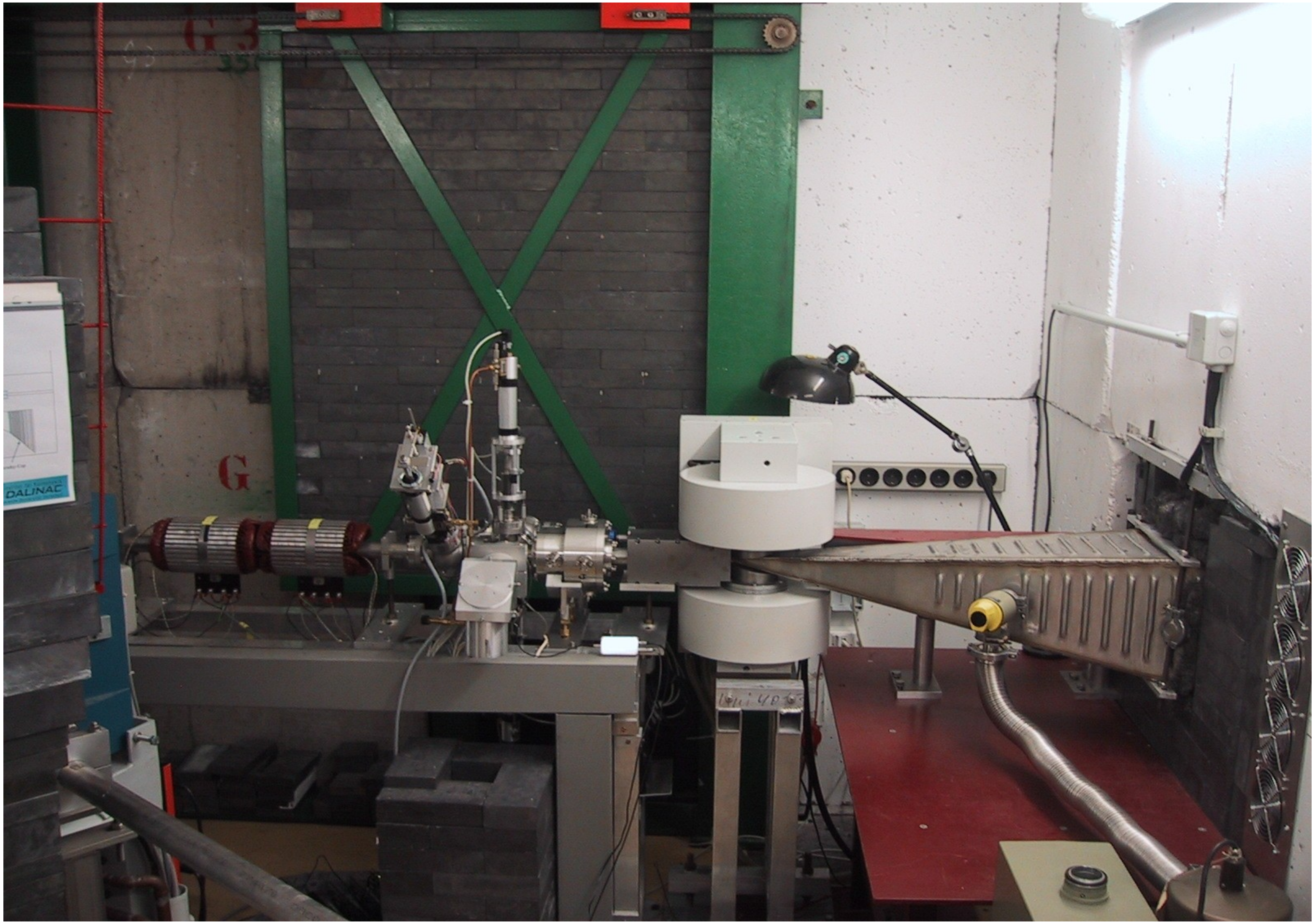
$E_{p.d}$ is measured with the help of the ionization chambers

Schematic view of the bremsstrahlung facility

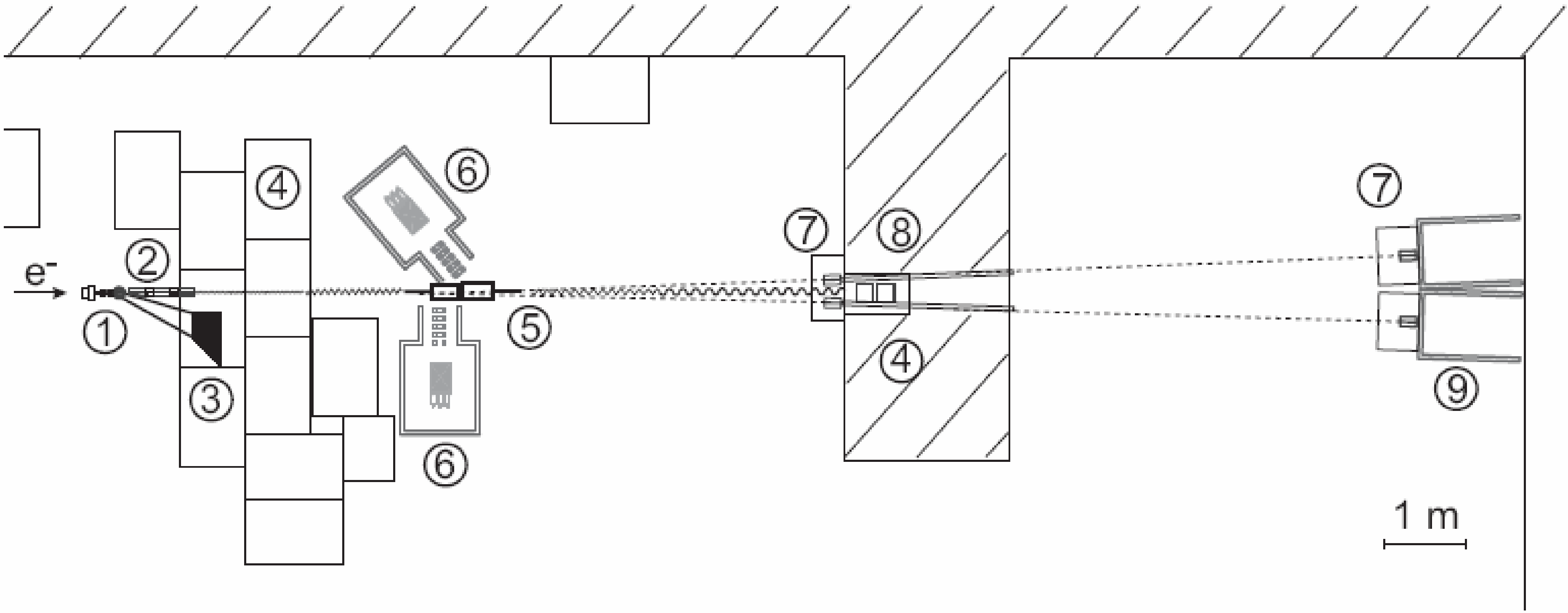


1 – direction correcting magnets, 2 – wire scanner, 3 – targets for beam position control, 4 – beam intensity and position rf monitor, 5 – bremstrahlung converter target, 6 – cleaning magnet, 7 – γ- beam collimator, 8 – electron beam dump, 9 – concrete shielding

Bremsstrahlung facility

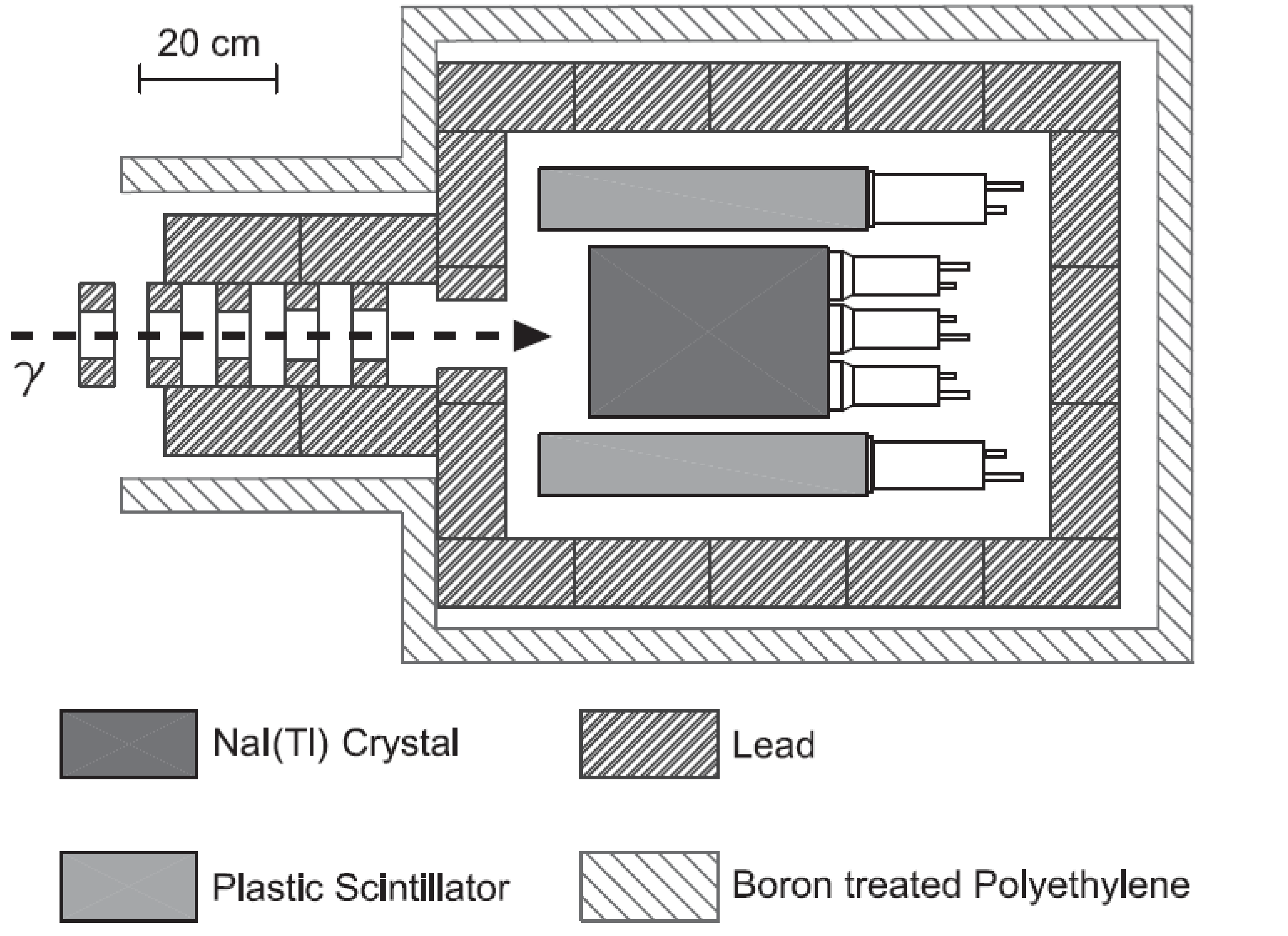


Schematic view of the experimental setup

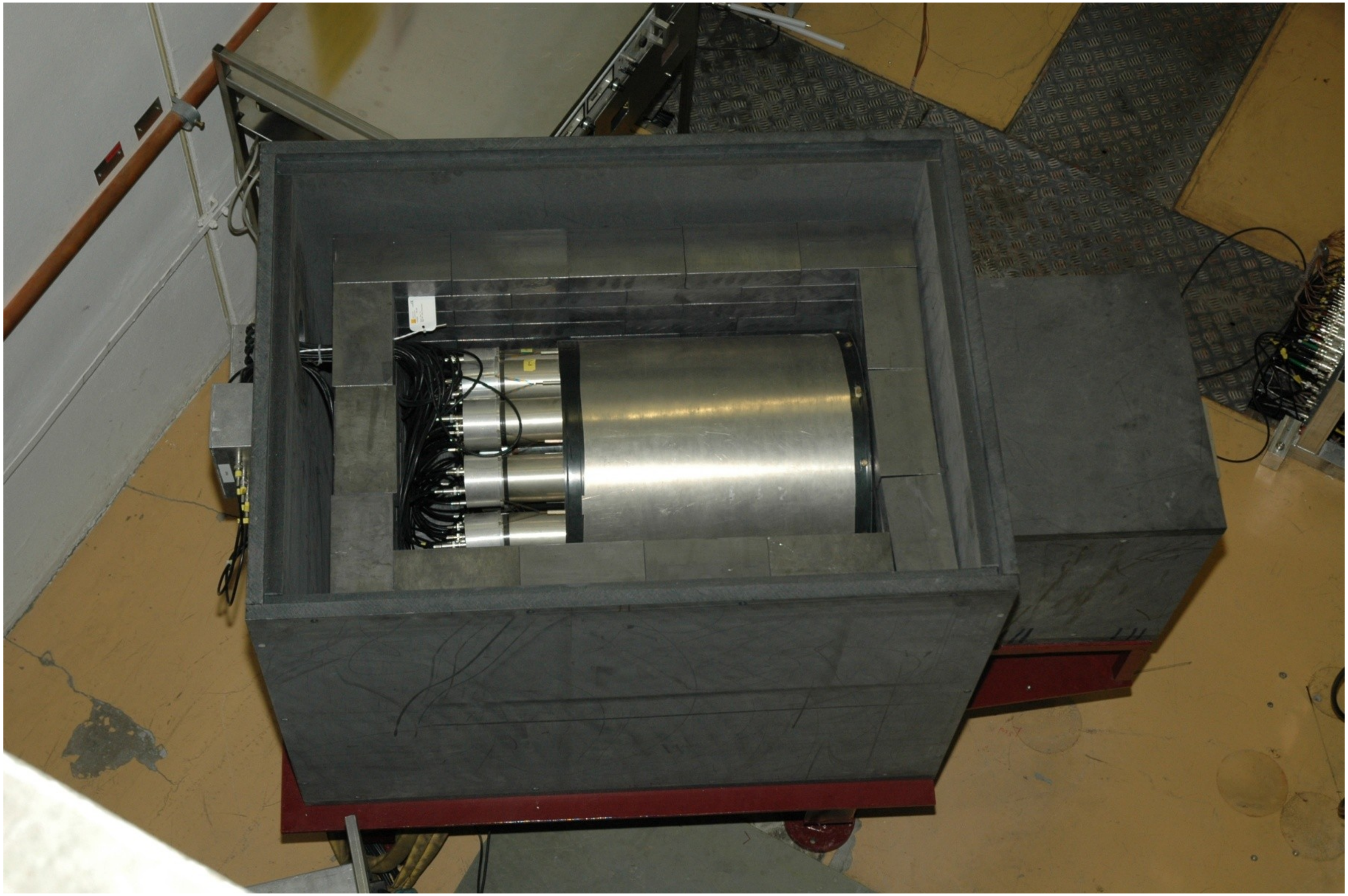


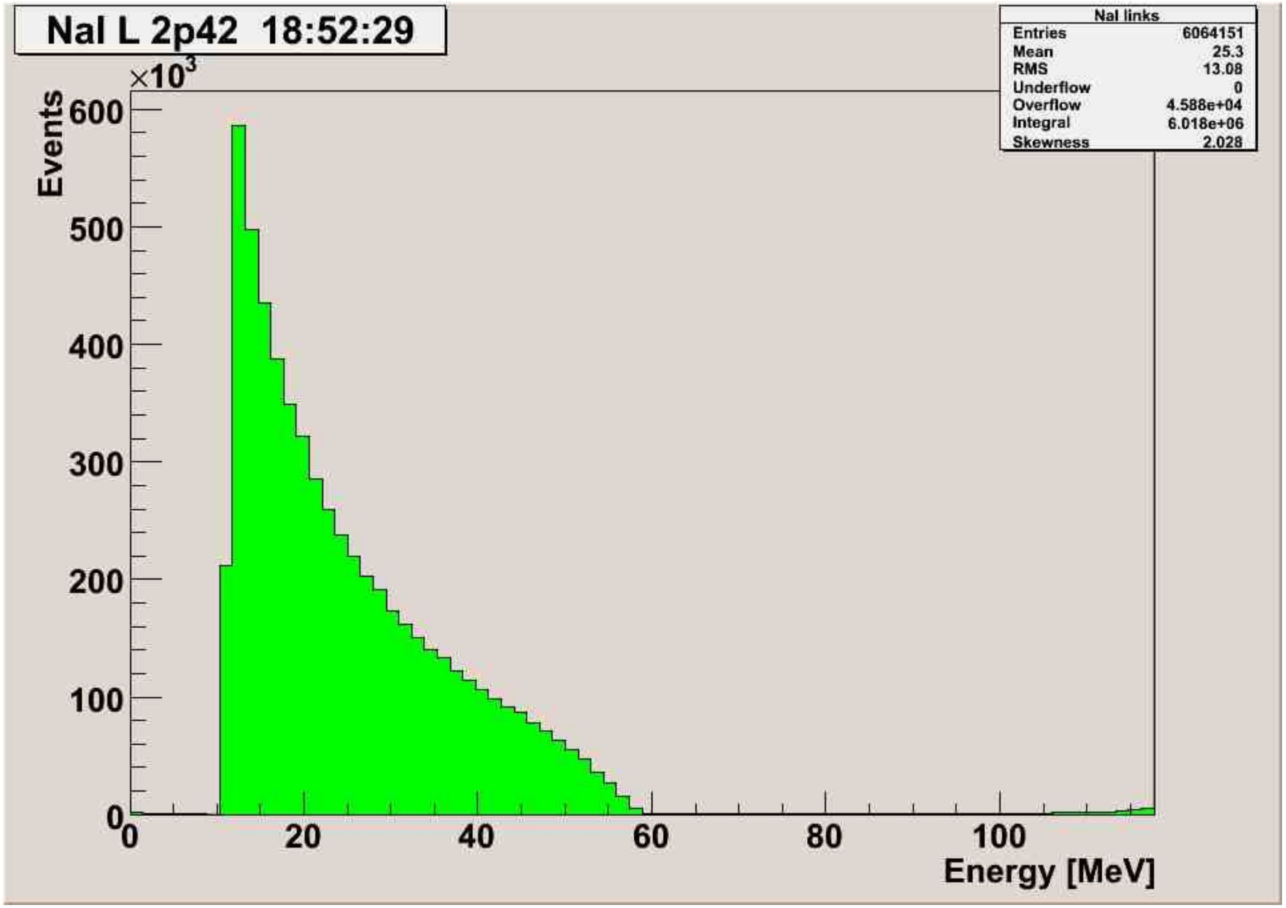
1 – bremsstrahlung converter, 2 – collimation system, 3 – electron beam dump, 4 – concrete shielding, 5 – hydrogen-filled ionization chambers, 6 – γ spectrometers, 7 – collimation system, 8 – position sensitive ionization chamber, Gaussian quantometer, γ beam dump, 9 – γ spectrometers

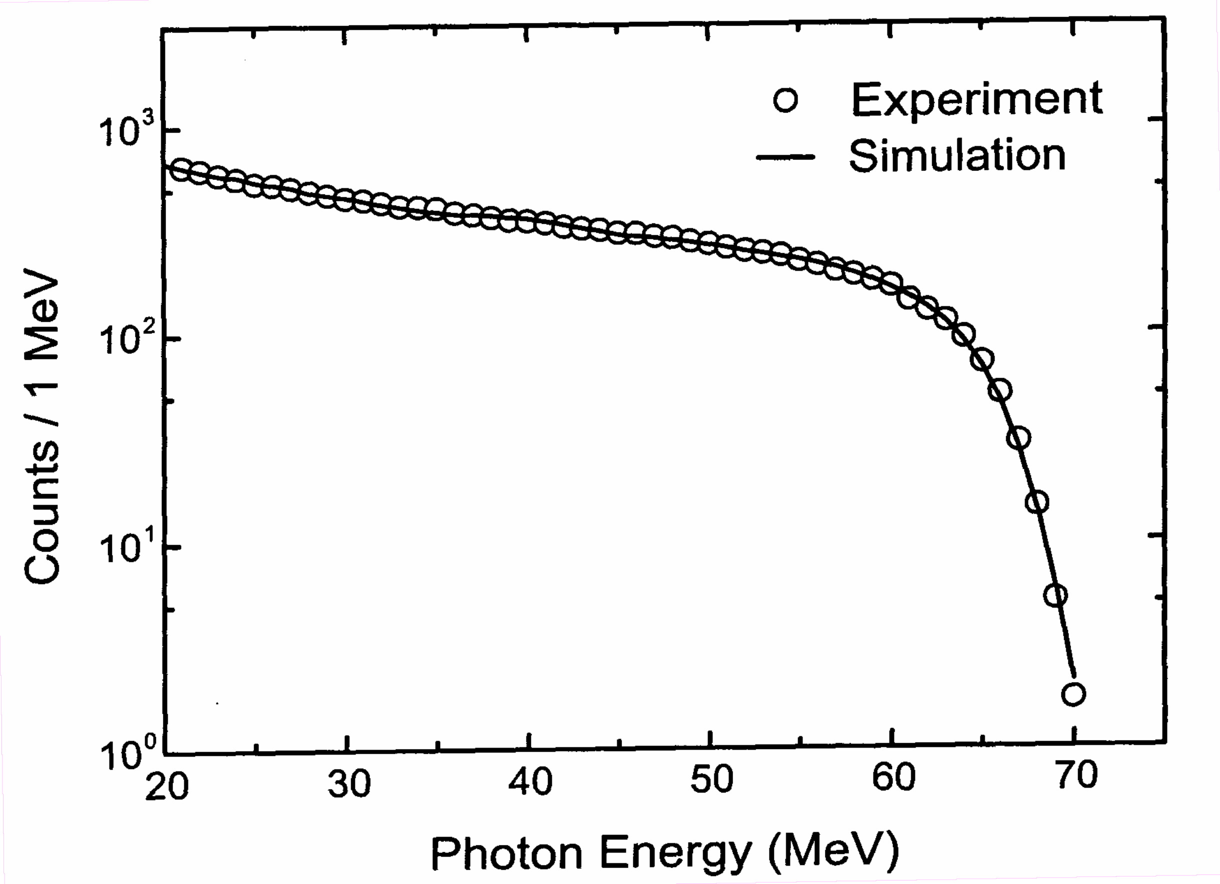
Schematic view of a 10” x 14” NaI(Tl) spectrometer



NaI(Tl) spectrometer



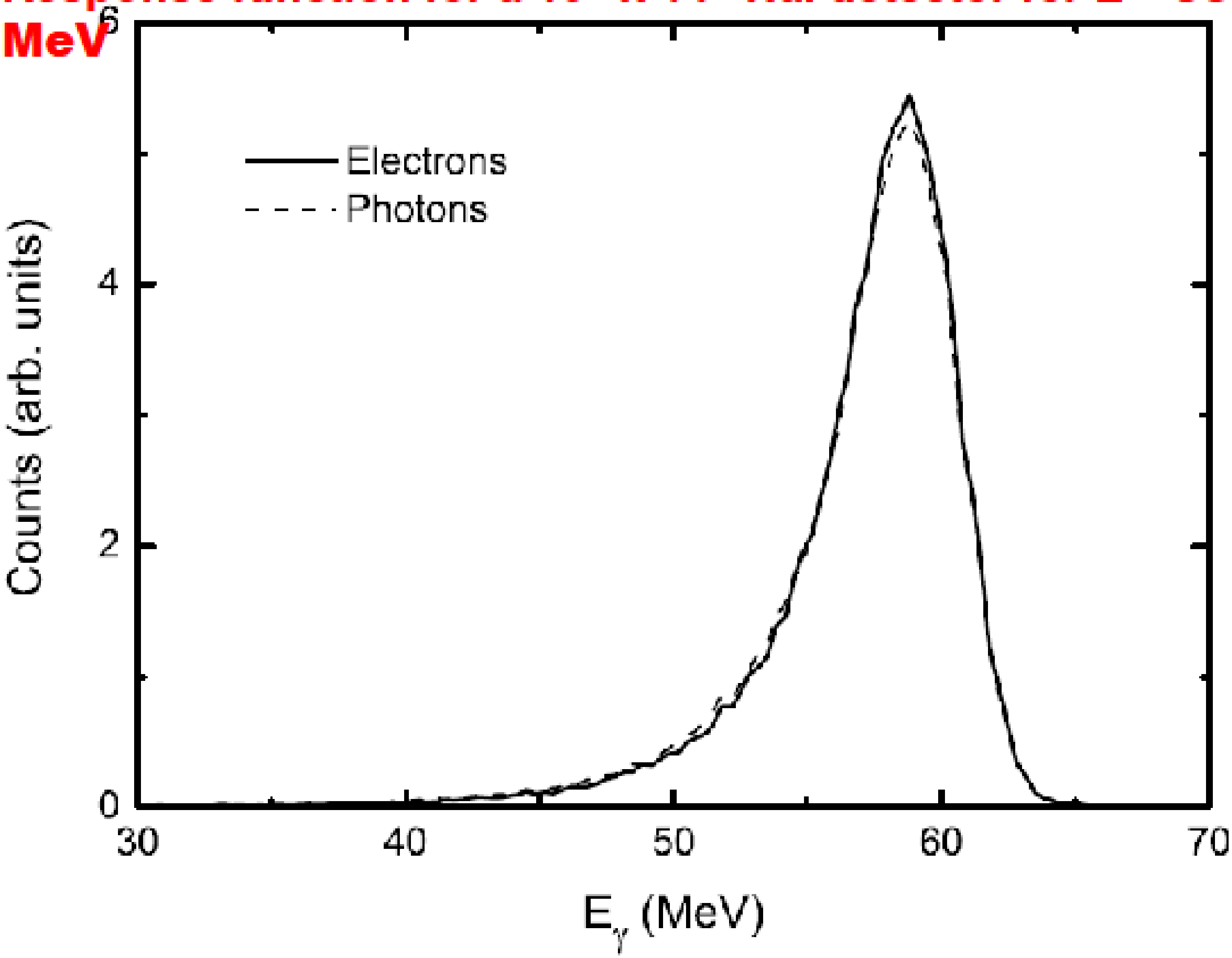

NaI L 2p42 18:52:29
NaI links
Entries 6064151
Mean 25.3
RMS 13.08
Underflow 0
Overflow 4.588e+04
Integral 6.018e+06
Skewness 2.028
×10^3
Events
0
100
200
300
400
500
600
0
20
40
60
80
100
Energy [MeV]



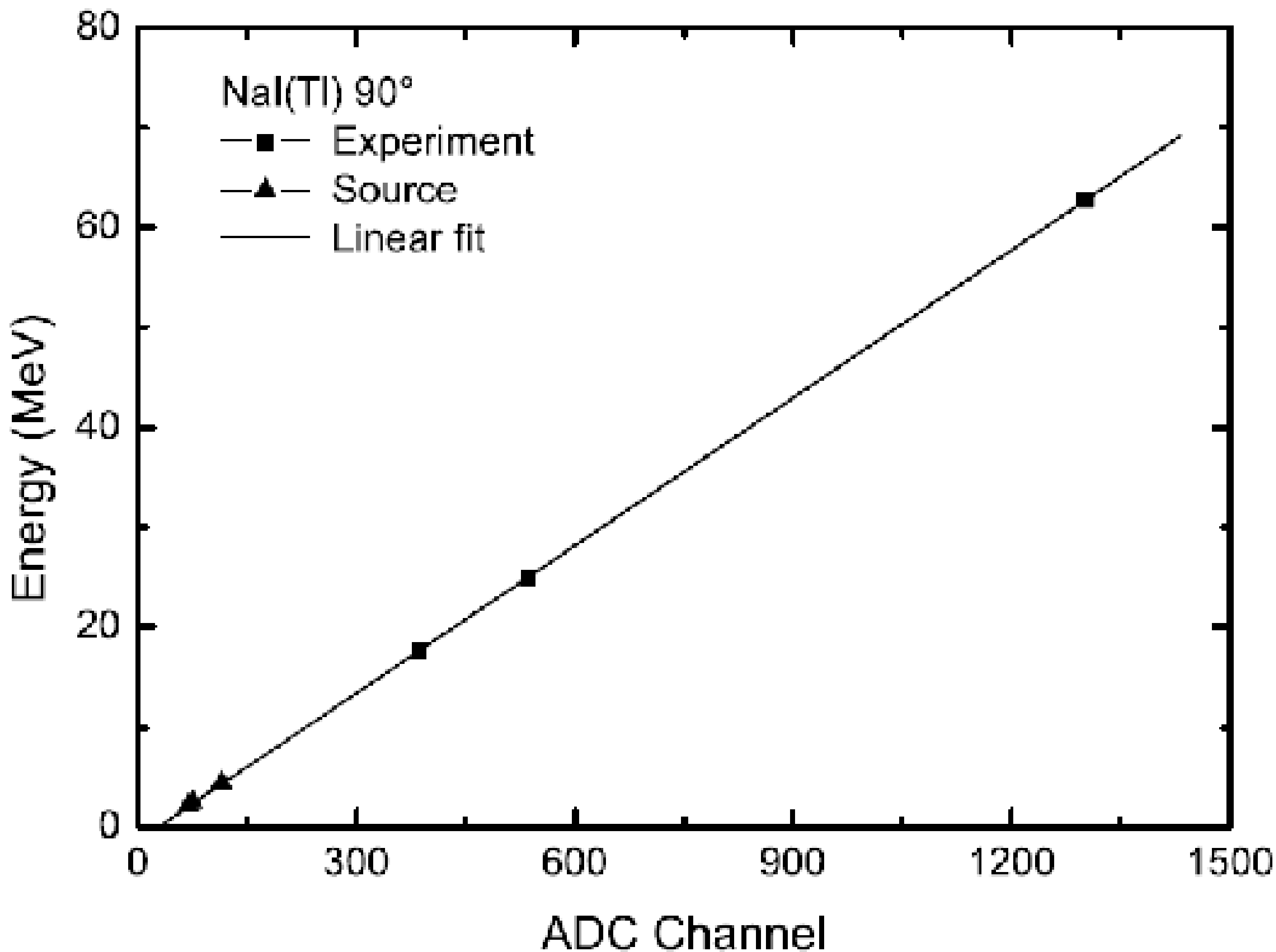
Experiment
Simulation
Counts / 1 MeV
10^3
10^2
10^1
10^0
20
30
40
50
60
70
Photon Energy (MeV)

γ

Response function for a 10” x 14” NaI detector for E =60 MeV

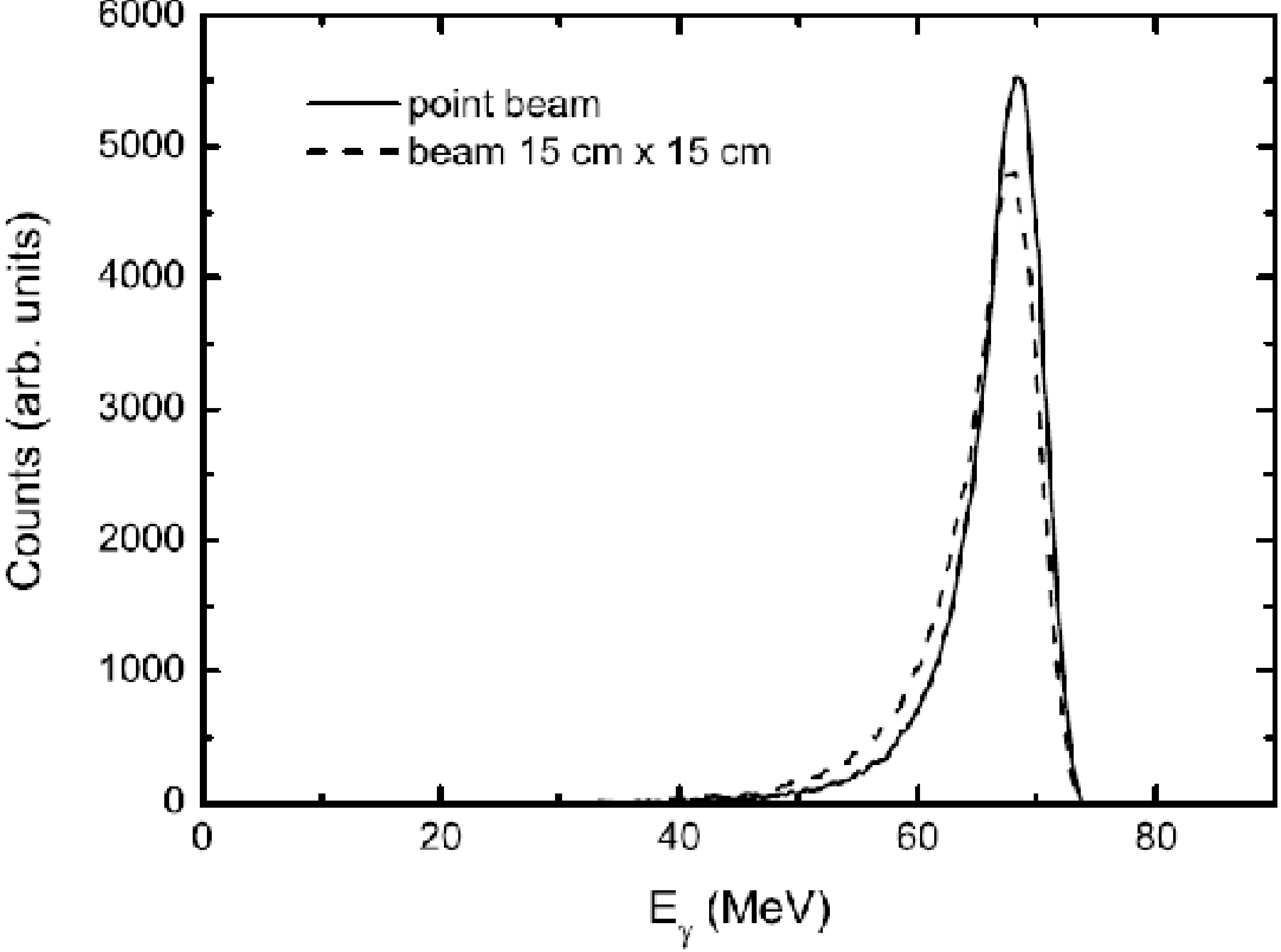


Energy calibration of one of the NaI spectrometers



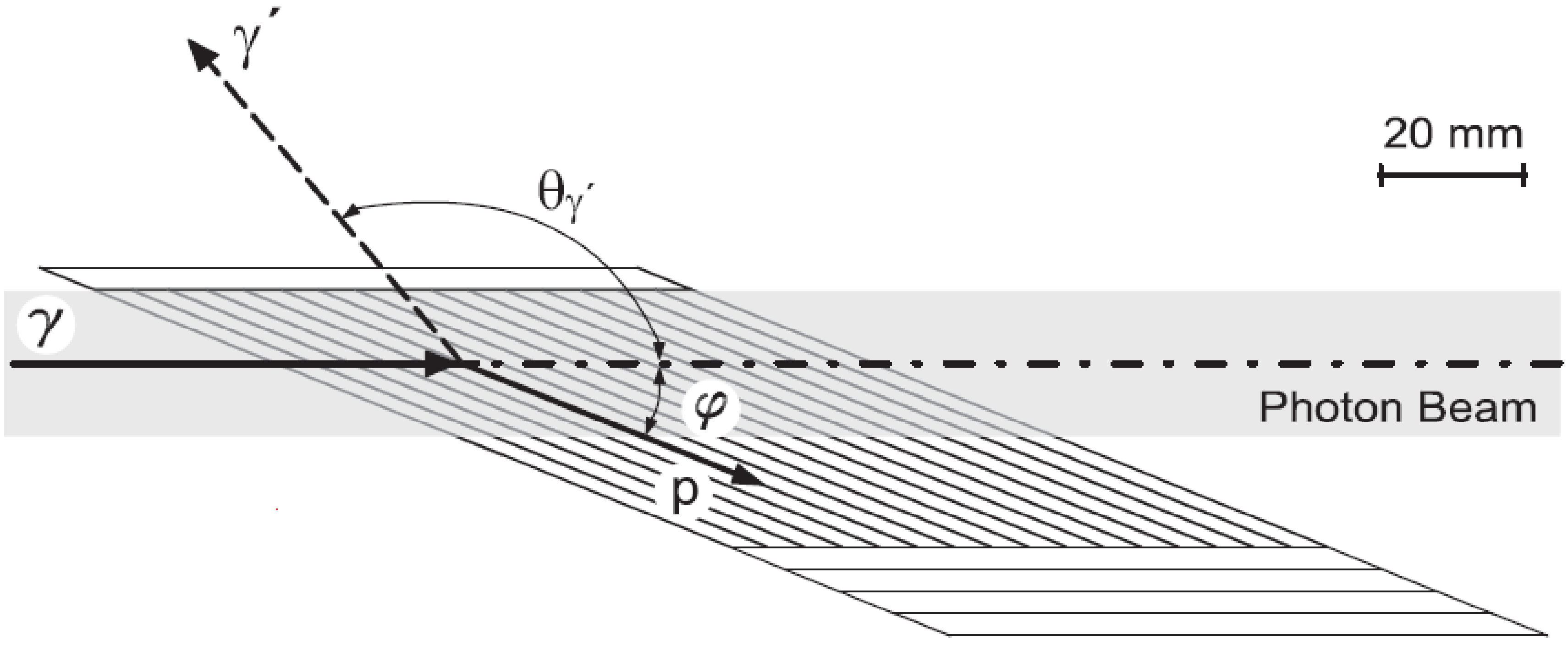
▲ – 60Co (1.3 MeV) and Am-Be (4.4 MeV) γ sources; ■ – calibration with e-A scattering γ

Response functions for a 10" x 14" NaI detector for E = 70 MeV

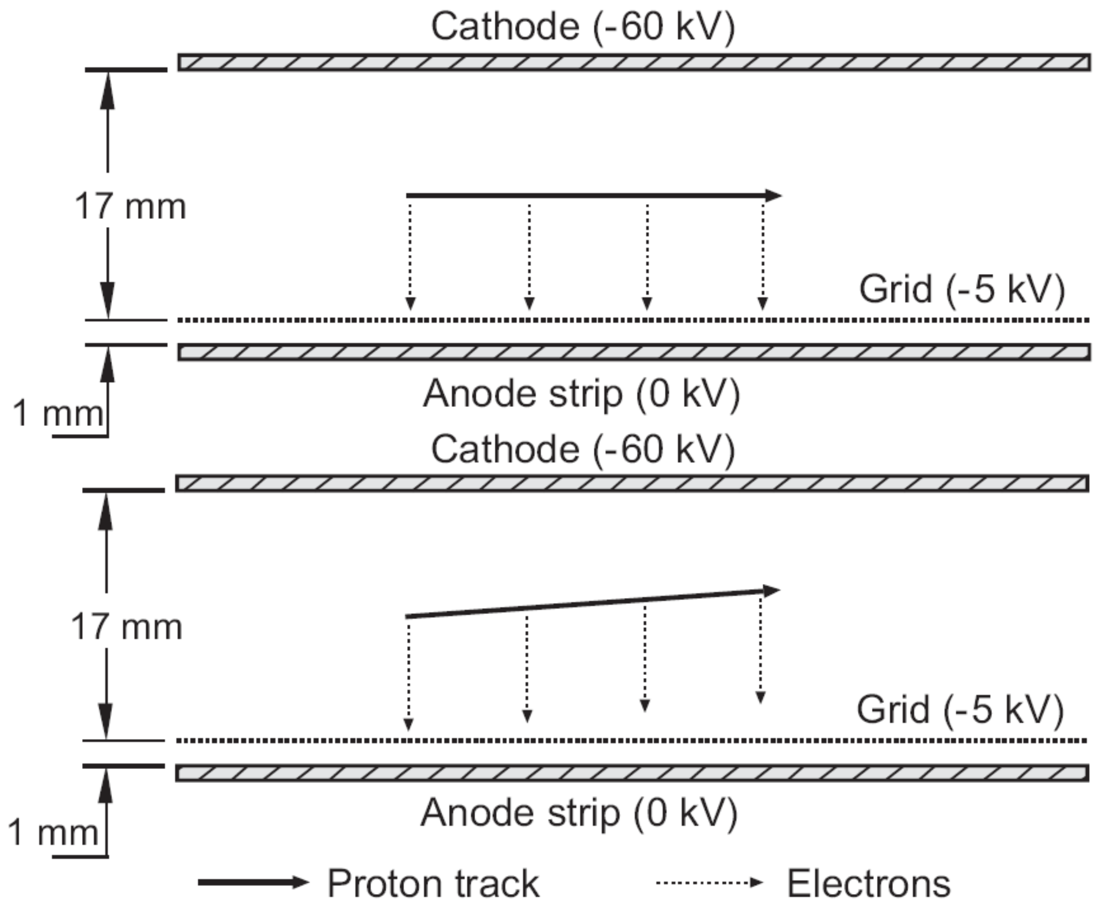


High-pressure (90 bar) hydrogen-filled ionization chambers at TUD

Anode-strips geometry (top view)

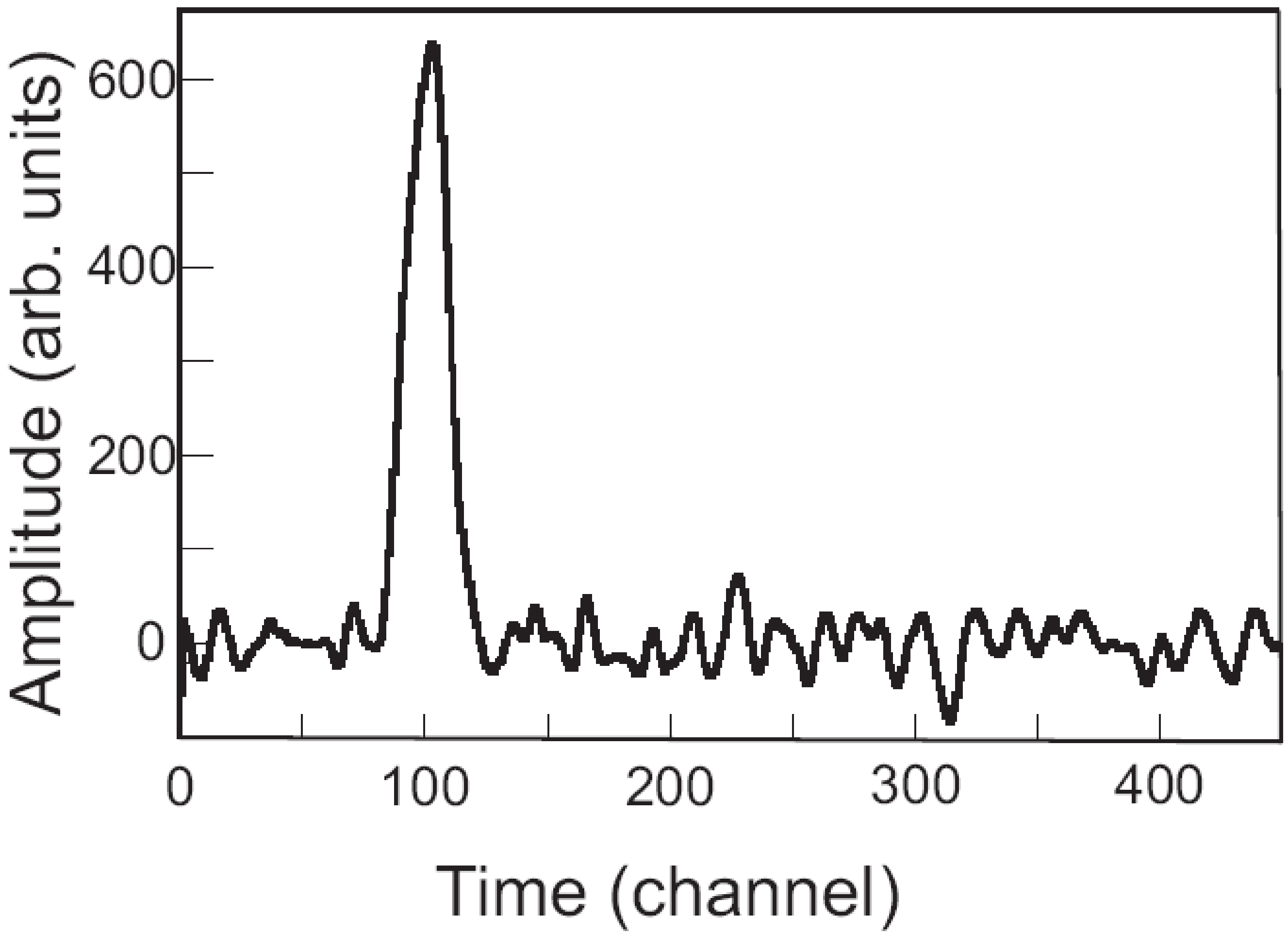


Cathode-grid-anode geometry of the chambers (side view)

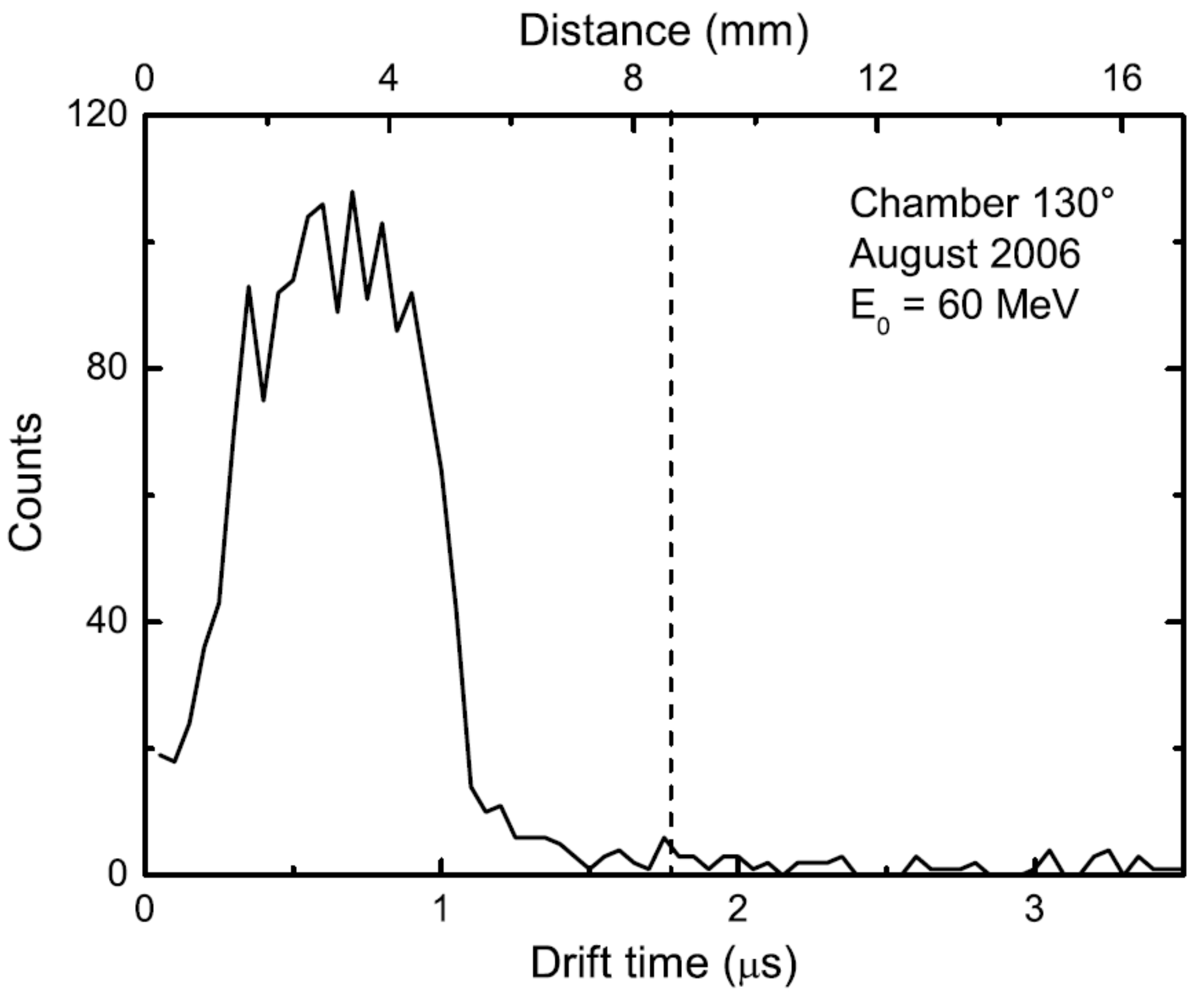


Maximum drift time is ~ 3.5 μs

A signal on the anode of the ionization chamber from a recoil proton

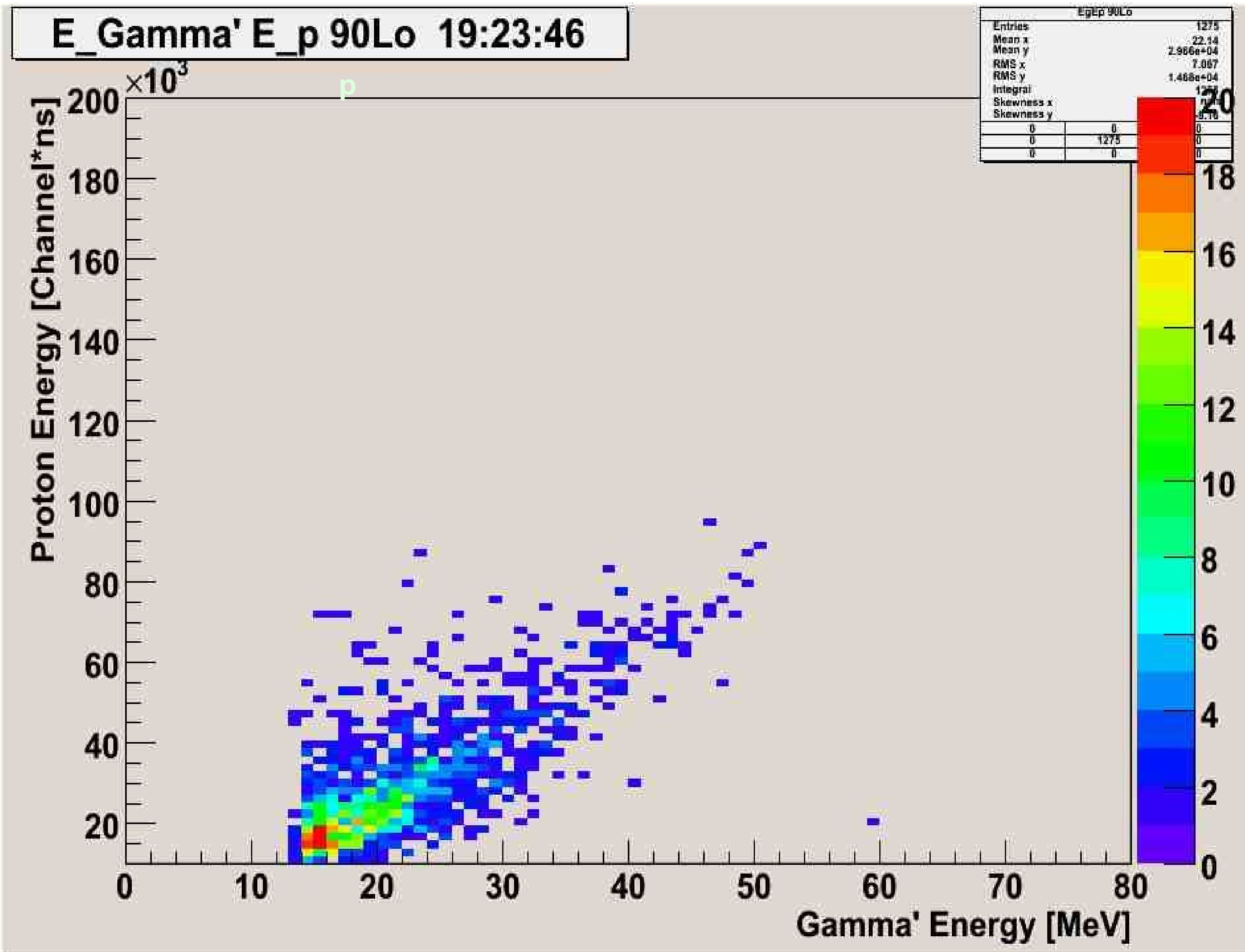


Drift-time distribution of signals from recoil protons

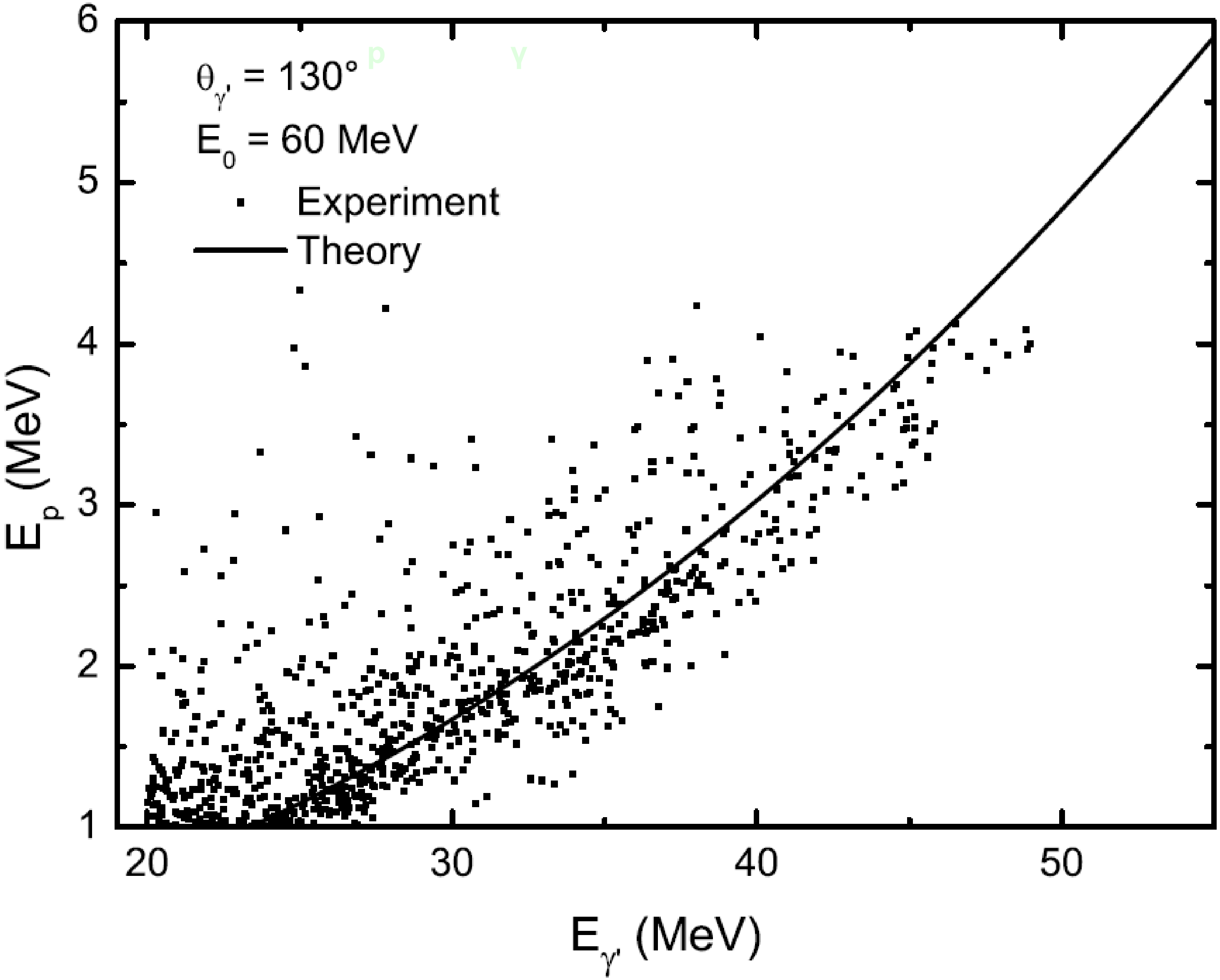


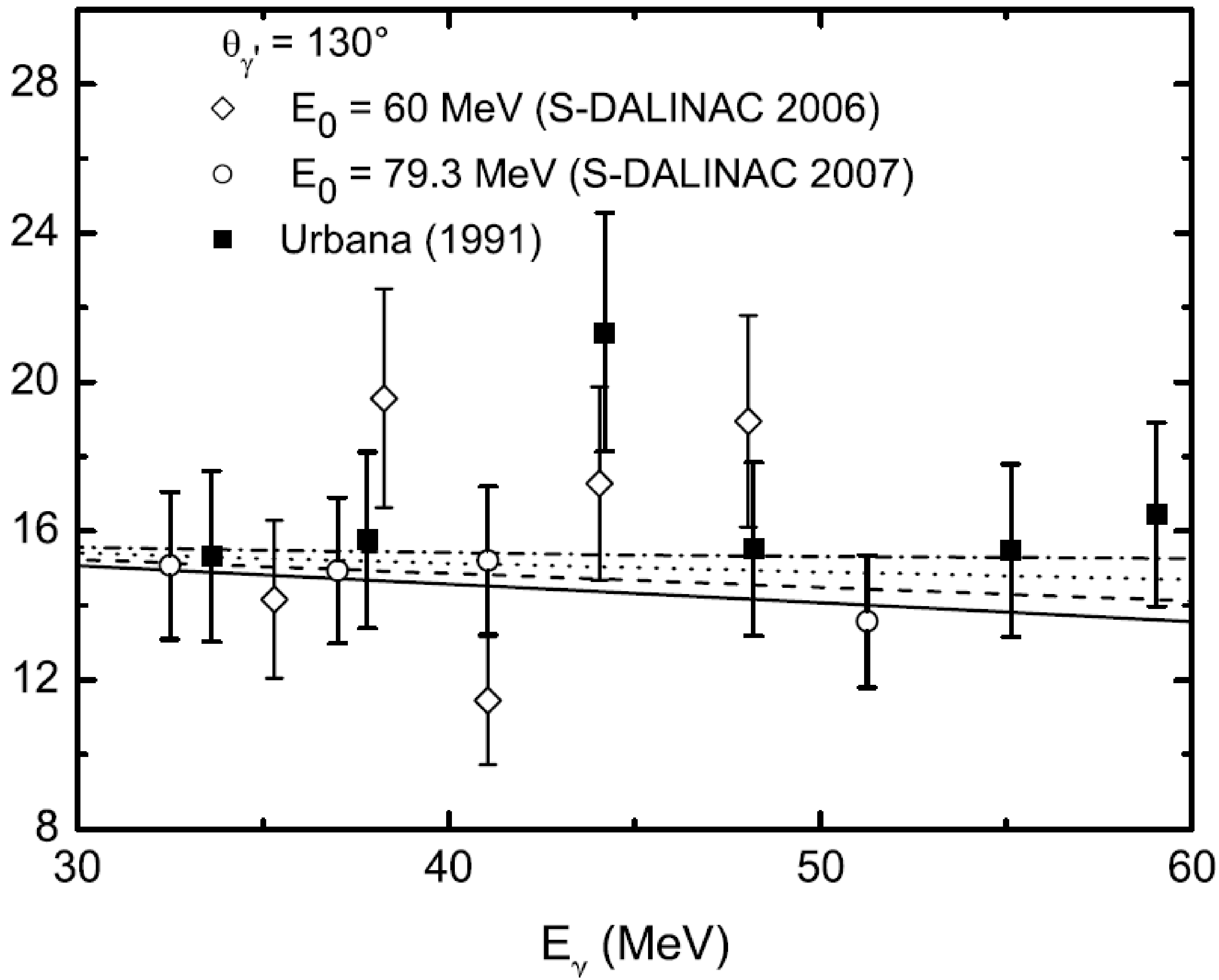
Drift velocity is ~ 5 mm/μs

Ep – Eγ correlation

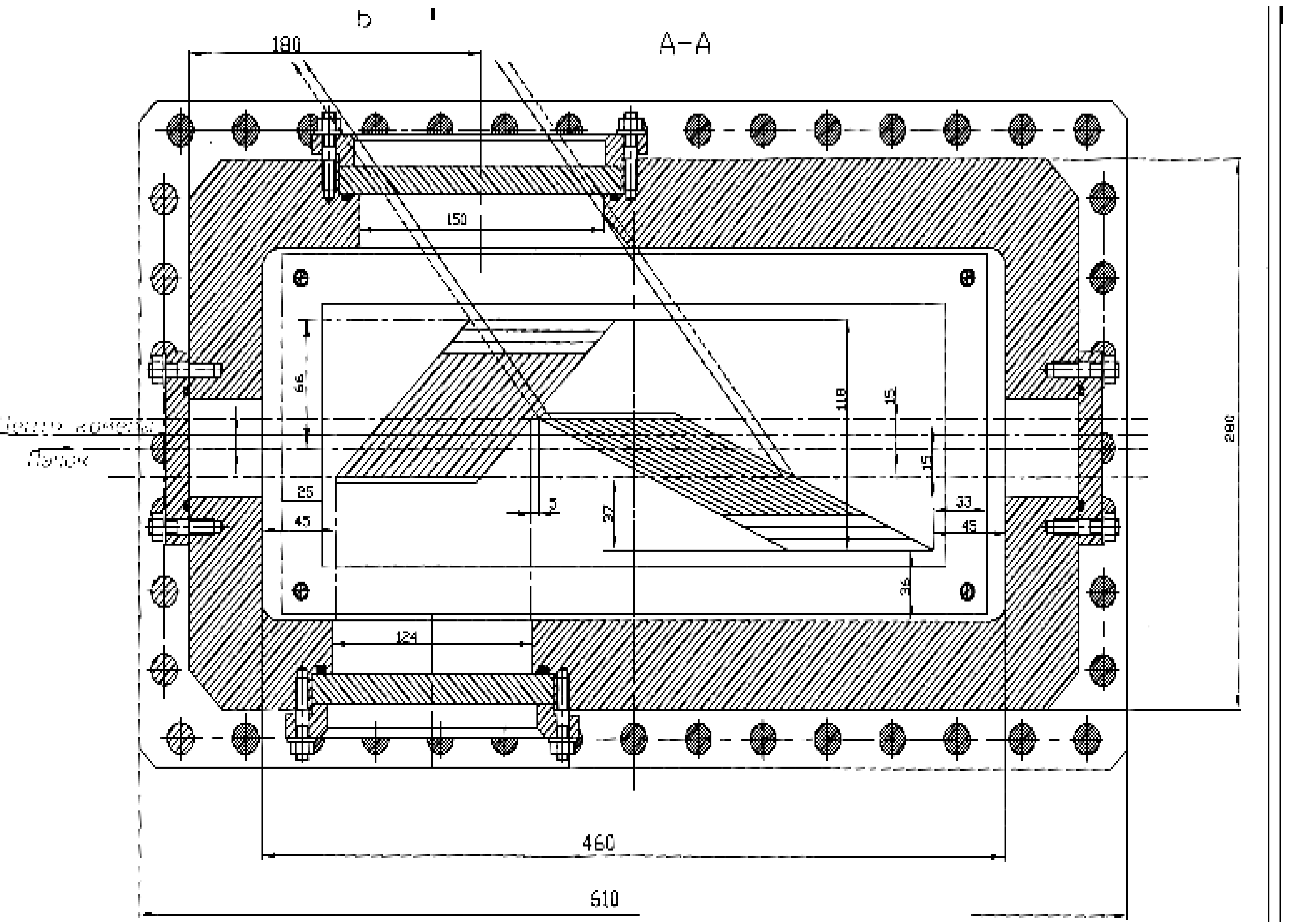


Ep – Eγ correlation

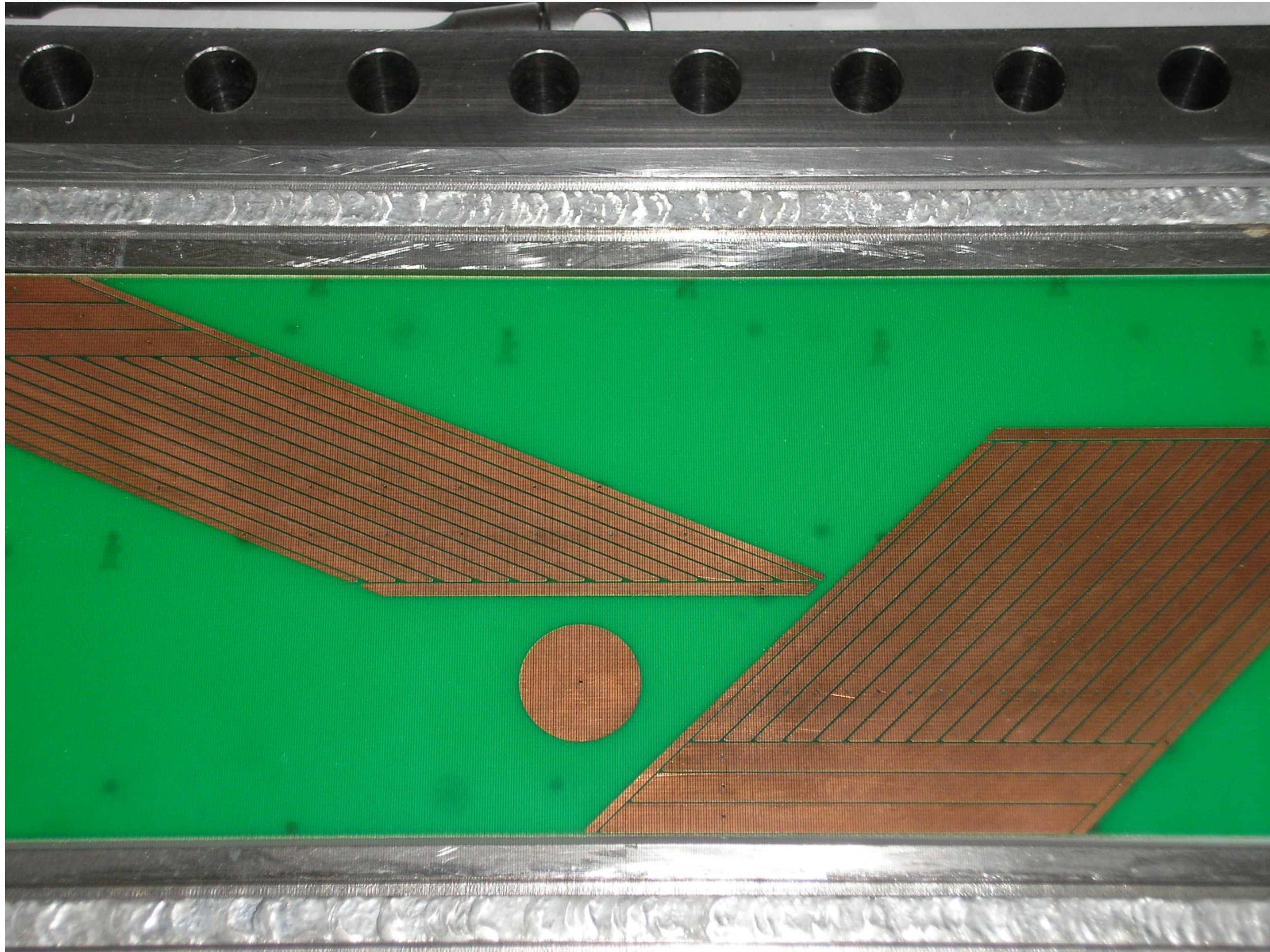


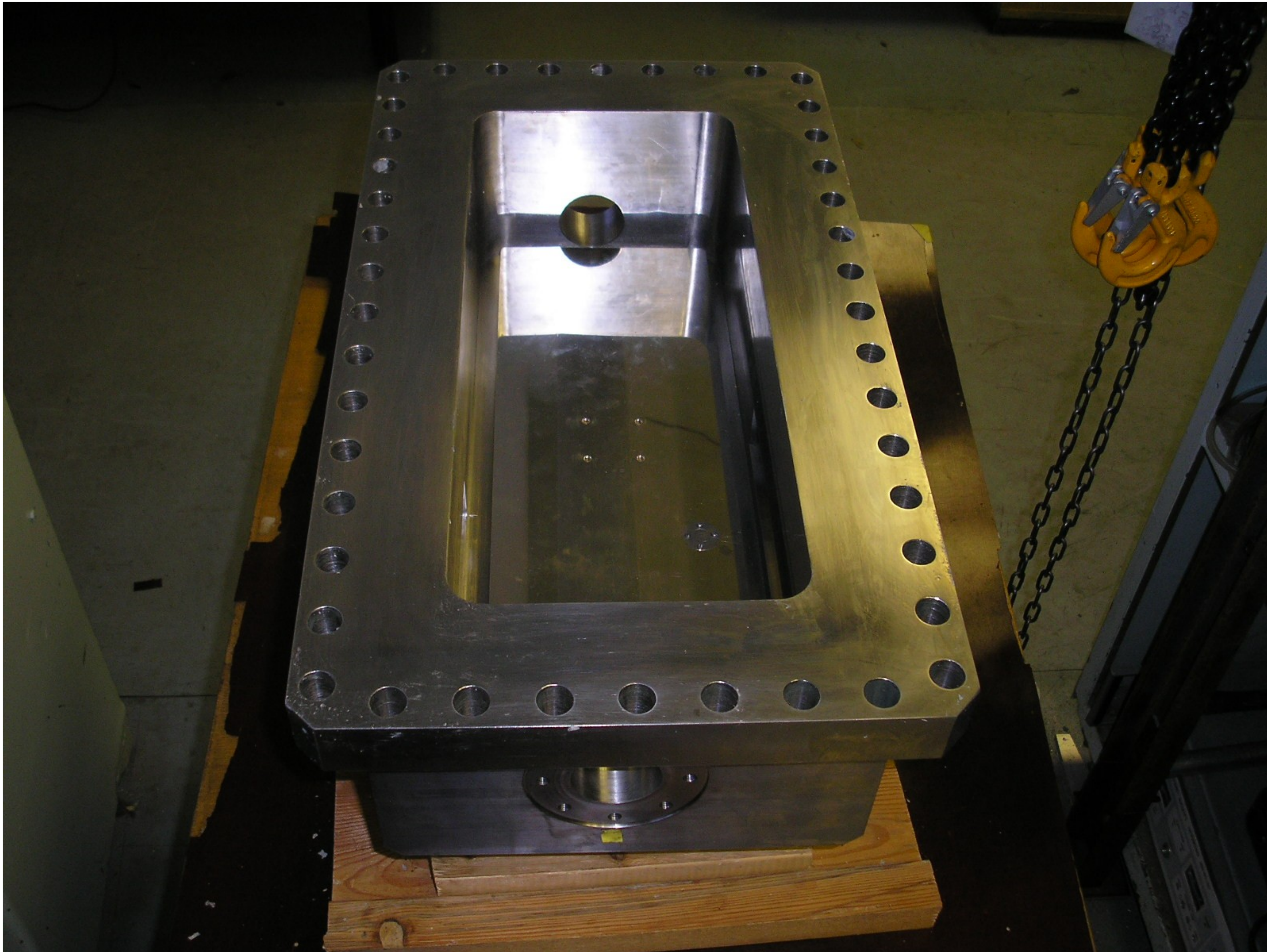


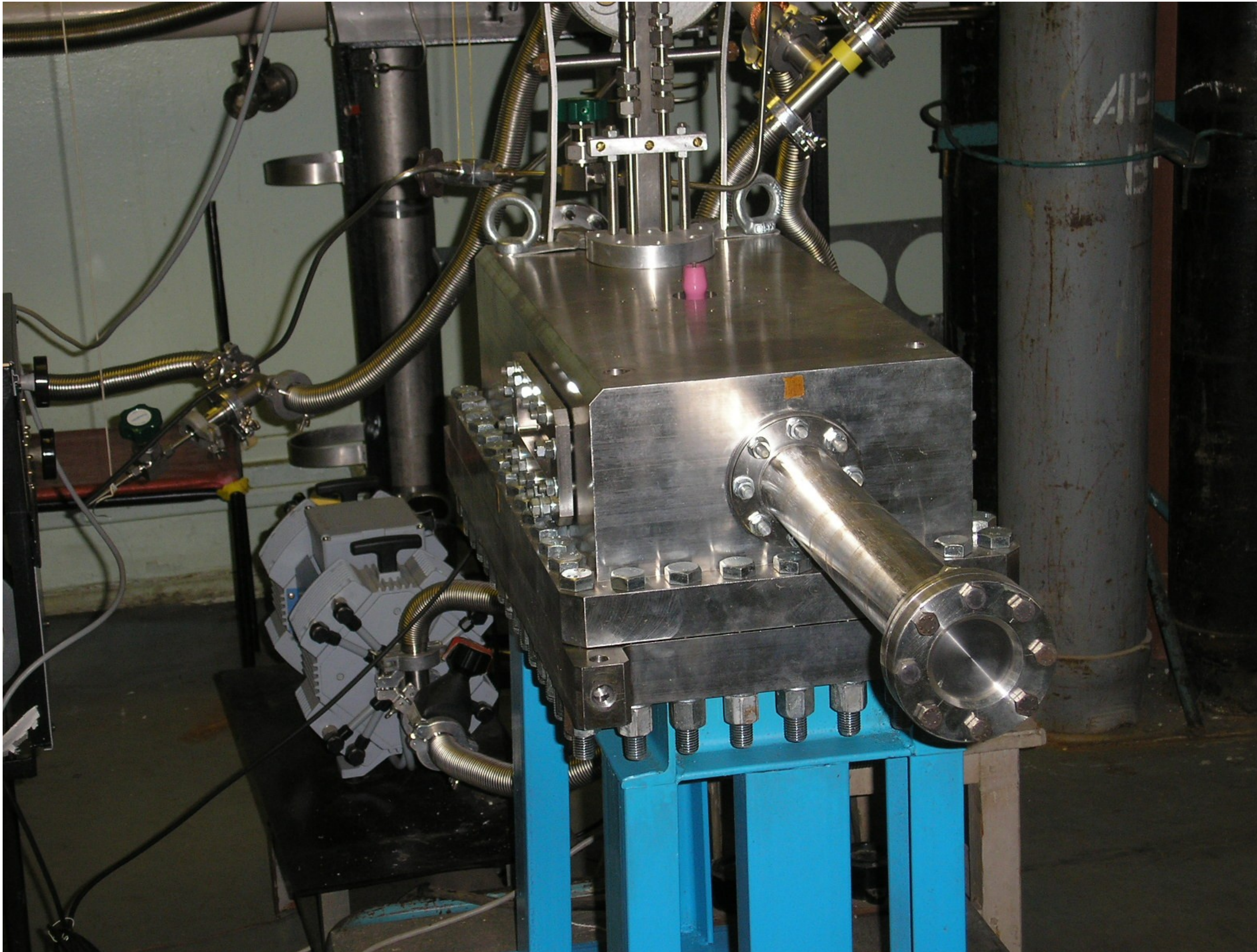
Differential cross-section γp- scattering (dσ/dΩ (nb/sr))

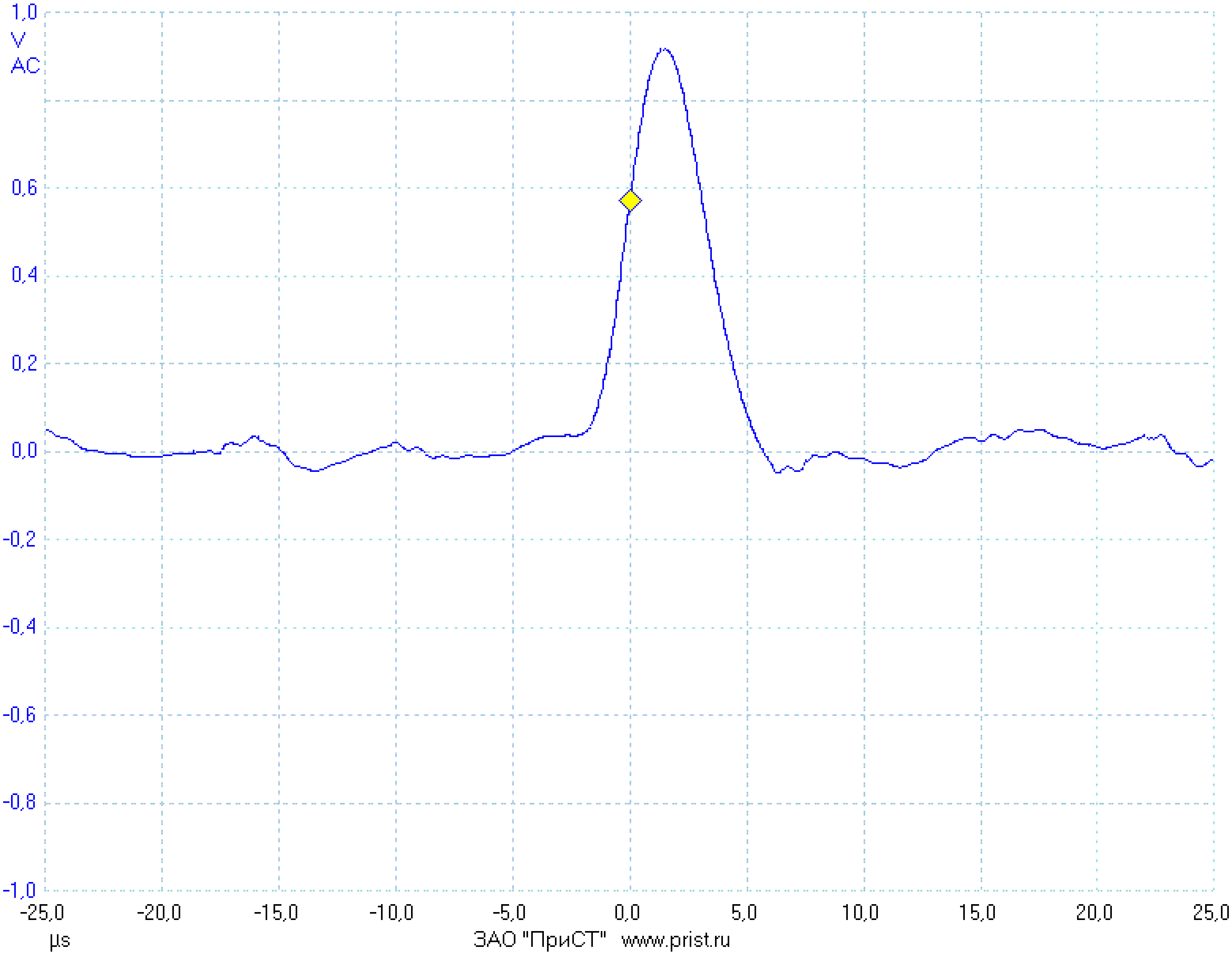


Б
I
А–А
180
150
66
118
15
15
290
25
45
5
37
33
45
36
124
460
610







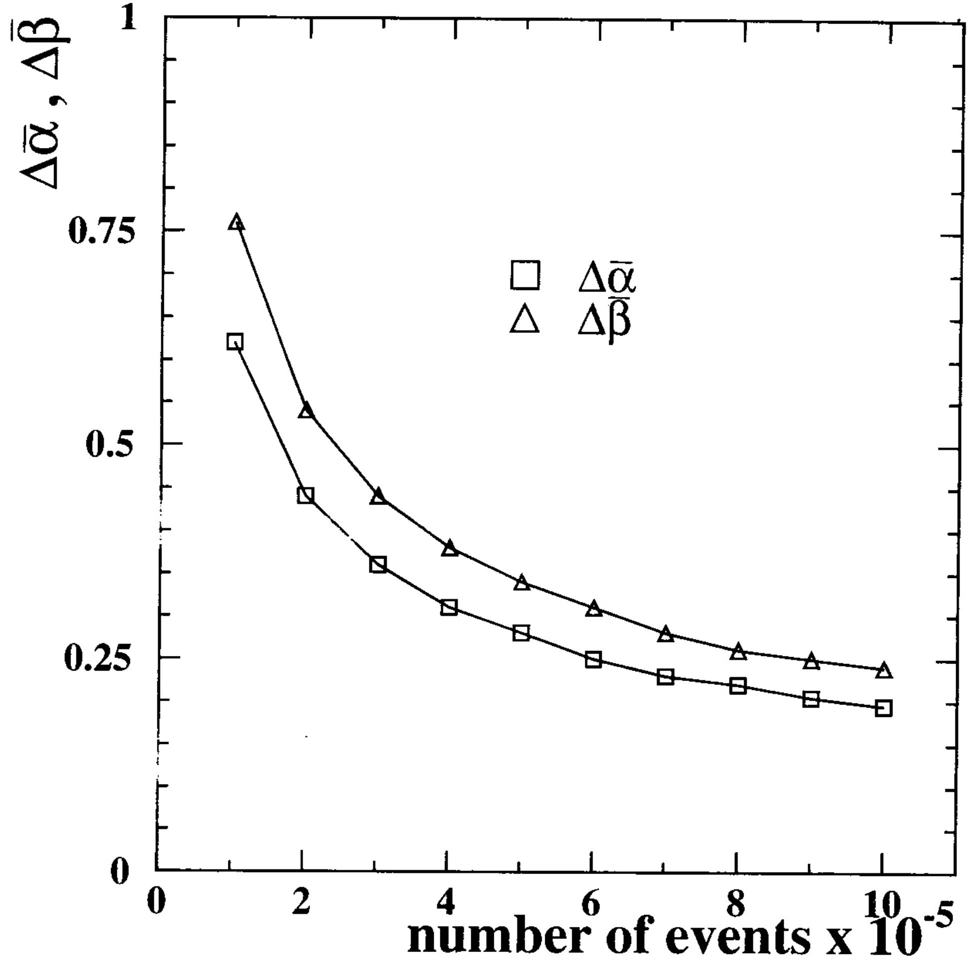

1,0
V
AC
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
-25,0
-20,0
-15,0
-10,0
-5,0
0,0
5,0
10,0
15,0
20,0
25,0
µs
ЗАО "ПриСТ" www.prist.ru

COUNTING RATE INCREASE WITH THE NEW IC CHAMBER

	NEW IC	OLD IC	COUNTING RATE INCREASE
Target length	90 mm	60 mm	1.5
Target width	30 mm	20 mm	1.5
Target height	15 mm	10 mm	1.5

	NEW Nal-IC geometry	OLD Nal-IC geometry	COUNTING RATE INCREASE
IC to Nal distance	60 cm	110 cm	3.3
Horizont. Be windowsize	15 cm	10 cm	
Vertical Be window size	34 mm	20 mm	

TOTAL COUNTING RATE INCREASE ~ 10



Statistical errors in determination of α and β

BEAM TIME ESTIMATION

Minimum scenario:

I = 3 μA, E = 60 MeV, T= 500 h (3 weeks)

e e

N = 50 000 events, Δα ~ 0.8, Δβ ~ 1.0

γp

Maximum scenario:

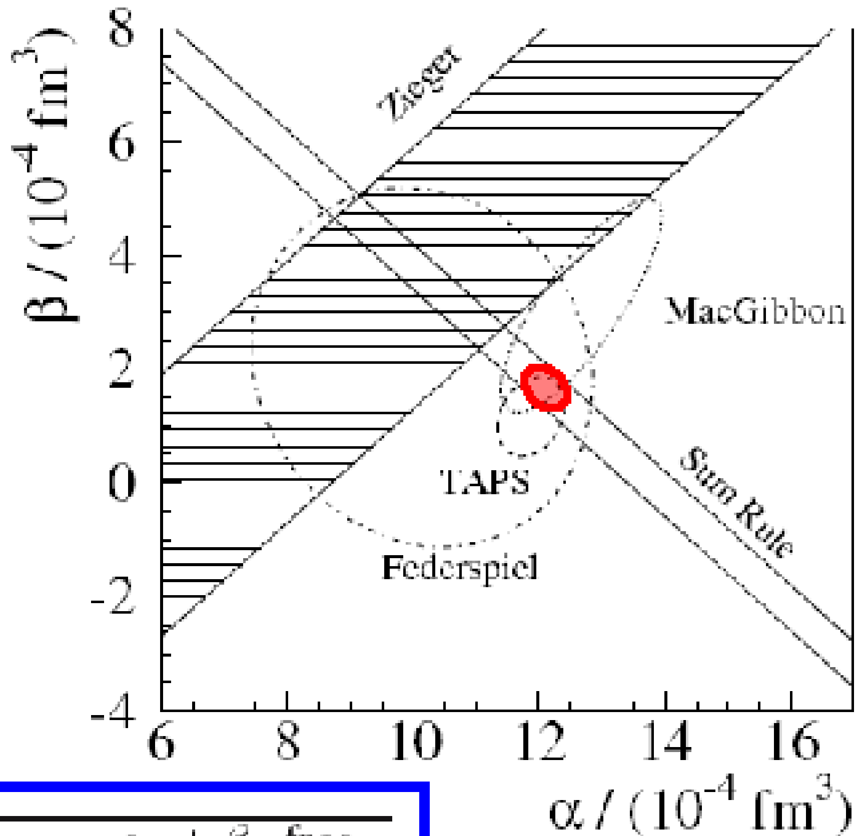
I = 5 μA, E = 110 MeV, T= 1000 h (6 weeks)

e e

N = 600 000 events, Δα ~ 0.25, Δβ ~ 0.35

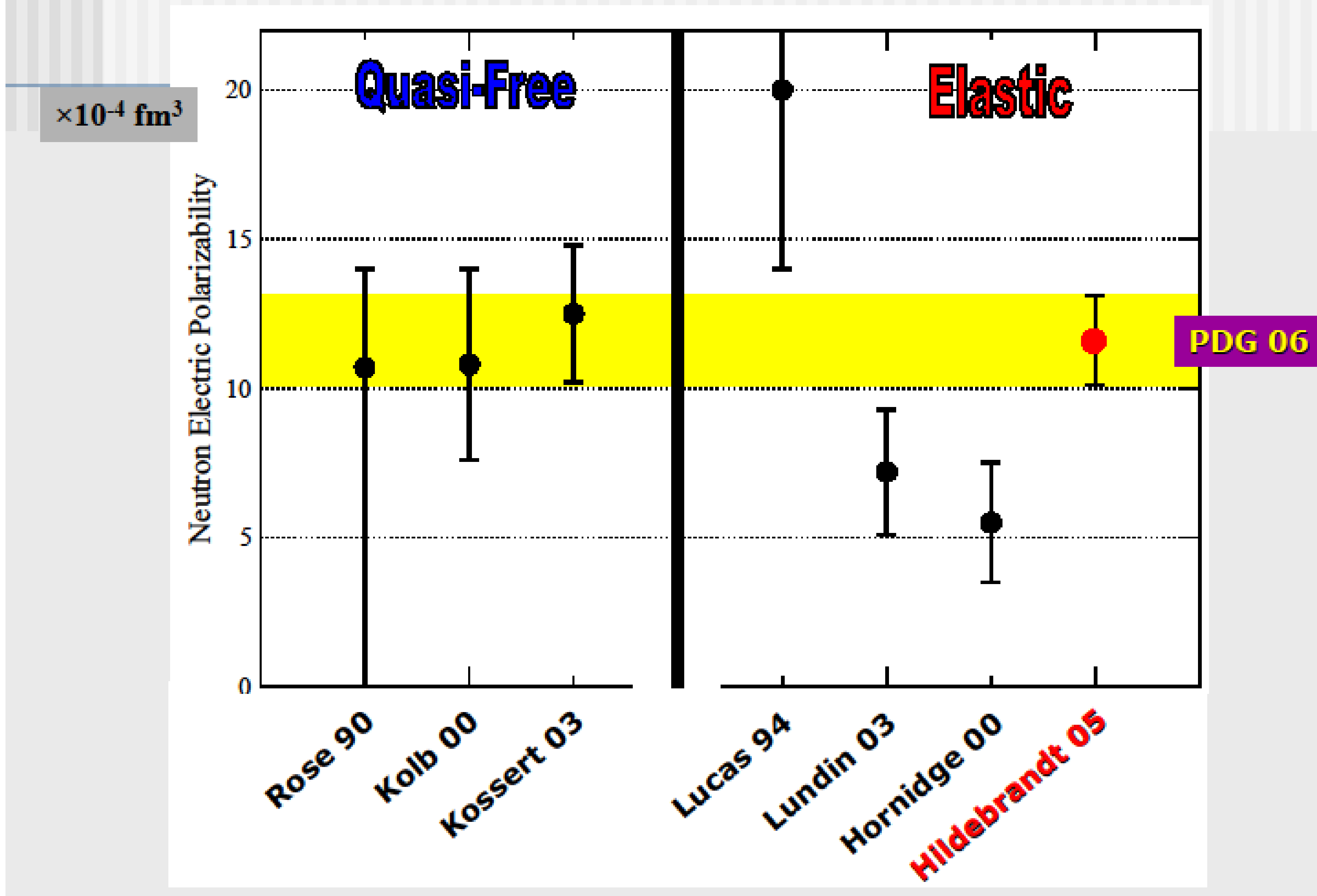
γp

Proton Polarizability



Data		$\alpha_p - \beta_p$ fixed	$\alpha_p + \beta_p$ free
TAPS	α_p	$12.1 \pm 0.4 \mp 1.0$	$11.9 \pm 0.5 \mp 1.3$
Olmos de Leon	β_p	$1.6 \pm 0.4 \pm 0.8$	$1.2 \pm 0.7 \pm 0.3$
MacGibbon	α_p	$11.9 \pm 0.5 \mp 0.8$	$12.6 \pm 1.2 \mp 1.3$
[4]	β_p	$1.9 \pm 0.5 \pm 0.8$	$3.0 \pm 1.8 \pm 0.1$
Federspiel	α_p	$10.8 \pm 2.2 \mp 1.3$	$10.1 \pm 2.6 \mp 2.0$
[3]	β_p	$3.0 \pm 2.2 \pm 1.3$	$2.0 \pm 3.3 \pm 0.3$
Zieger	$\alpha_p - \beta_p$	$6.4 \pm 2.3 \pm 1.9$	
[6]			
Global	α_p	$12.1 \pm 0.3 \mp 0.4$	$11.9 \pm 0.5 \mp 0.5$
fit	β_p	$1.6 \pm 0.4 \pm 0.4$	$1.5 \pm 0.6 \pm 0.2$

Olmos de Leon EPJ 01



×10⁻⁴ fm³
Quasi-Free
Elastic
PDG 06
Neutron Electric Polarizability
20
15
10
5
0
Rose 90
Kolb 00
Kossert 03
Lucas 94
Lundin 03
Hornidge 00
Hildebrandt 05

Summary of Neutron Results

- Neutron scattering
  - Schmiedmayer (91)

$$\alpha_n = 12.6 \pm 1.5(\text{stat}) \pm 2.0(\text{syst})$$

- Quasi-free Compton scattering
  - Kossert (03)

$$\alpha_n = 12.5 \pm 1.8(\text{stat}) \,{}^{+1.1}_{-0.6}\,(\text{syst}) \pm 1.1(\text{model})$$

$$\beta_n = 2.7 \mp 1.8(\text{stat}) \,{}^{+0.6}_{-1.1}\,(\text{syst}) \mp 1.1(\text{model})$$

- Elastic Compton scattering
  - data from Lucas (94), Hornidge (00), Lundin (03)
  - global fit by Hildebrandt (05)

$$\alpha_n = 11.6 \pm 1.5\ (\text{stat}) \pm 0.6\ (\text{Baldin})$$

$$\beta_n = 3.6 \mp 1.5\ (\text{stat}) \mp 0.6\ (\text{Baldin})$$

We can do better . . .

Theory (ChPT)

- MuCap(Gp from PCAC)
- $G_p(q^2) = 2M_\mu \cdot M_N \cdot F_a(0)/(M_\pi^2 - q^2)$

$G_p(q^2) = 8.74$ (LO) (8.26 ± 0.23 (NNLO))

Polarizabilities (α, β)

$\alpha_N = C \cdot R_\pi \cdot F_a(0)^2 / (f_\pi)^2, \quad \beta_N = 0.1 \cdot \alpha$

- $C = 5/(192\pi)$, $R_\pi = e^2/(4\pi \cdot M_\pi)$

$\alpha_N = 12$ (LO) $\qquad \beta_N = 1.2$ (LO)

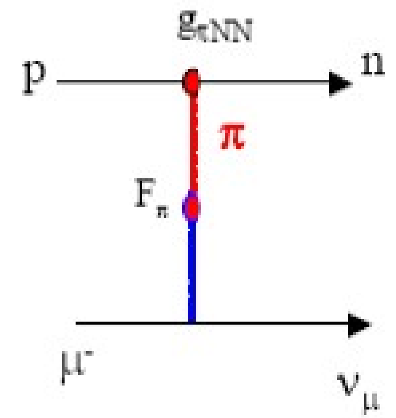
-

pseudoscalar form factor g_P

PCAC:

$$g_P(q^2) = \frac{2 m_\mu M}{m_\pi^2 - q^2} g_A(0)$$

$g_P = 8.7$



heavy baryon chiral perturbation theory:

$$g_P(q^2) = \frac{2 m_\mu g_{\pi NN} F_\pi}{m_\pi^2 - q^2} - \frac{1}{3} g_A(0) m_\mu M r_A^2$$

$g_P = (8.74 \pm 0.23) - (0.48 \pm 0.02) = 8.26 \pm 0.23$

Λ calculations $O(p^3)$ show good convergence: 100 % (LO), 25 % (NLO), 3 % (NNLO)
delta effect small

$g_{\pi NN}$
13.31(34)
13.0(1)
13.05(8)

author	year	g_P	Λ_S	Λ_T	comment
Primakoff	1959		664(20)	11.9(7)	smaller g_A
Opat	1964		634	13.3	smaller g_A
Bernard et al	1994	8.44(23)			
Fearing et al	1997	8.21(9)			
Govaerts et al	2000	8.475(76)	688.4(38)	12.01(12)	
Bernard et al	2000/1		687.4 (711*)	12.9	NNLO, small scale
Ando et al	2001		695 (722*)	11.9	NNLO

*NLO result

μCap

BEAM TIME ESTIMATION

Minimum scenario:

I = 3 μA, E = 60 MeV, T= 500 h (3 weeks)

e e

N = 50 000 events, Δα ~ 0.8, Δβ ~ 1.0

γp

Maximum scenario:

I = 5 μA, E = 110 MeV, T= 1000 h (6 weeks)

e e

N = 600 000 events, Δα ~ 0.25, Δβ ~ 0.35

γp

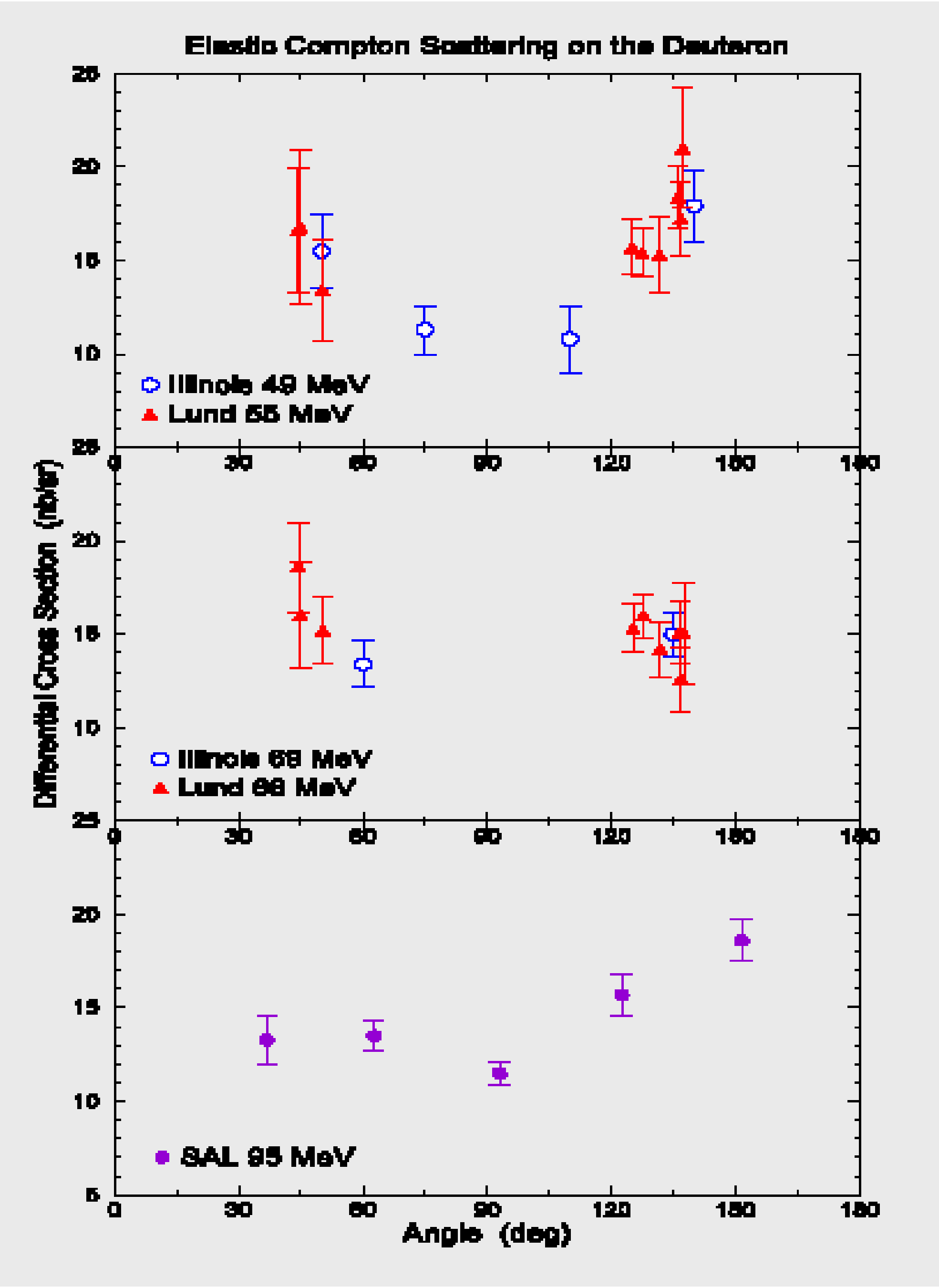
Coherent DCS

Three data sets:

- E ~ 50,70 MeV (Illinois, Lund)
- E = 95 MeV (SAL)

"Issues" with current data:

- Large statistical uncertainties
  (commonly > 7%)
- Wide energy bins
  (ΔE is 6 - 20 MeV)
- Limited kinematic coverage



Baldin sum rule:

$\alpha_p + \beta_p = 13.8 \pm 0.4 \quad [10^{-4}\ \mathrm{fm}^3]$

$\alpha_n + \beta_n = 15.2 \pm 0.5$

$\alpha_p = 12.0 \pm 0.6 \qquad \beta_p = 1.9 \pm 0.5$

Scattering of neutrons on lead: $\alpha_n = 13 \pm 6$; $\alpha_n = 0.6 \pm 5$

Quasi-free Compton scattering from the deuteron:
$\alpha_n = 7.6 - 14 \quad \beta_n = 1.2 - 7.6$

Mainz: $\alpha_n - \beta_n = 9.8 \pm 4.5$