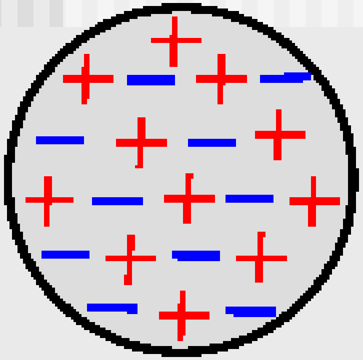
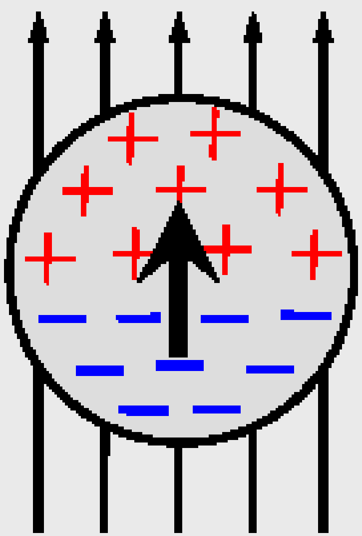
Измерение поляризуемостей протона и нейтрона на сильноточном электронном ускорителе MESA в Майнце

electric polarizability:
separation of charge

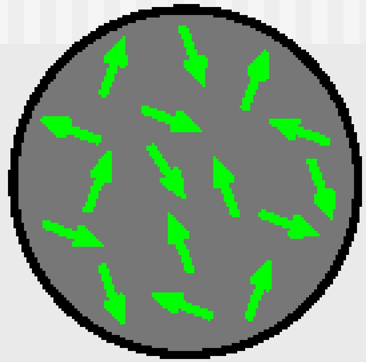


$D = 0$

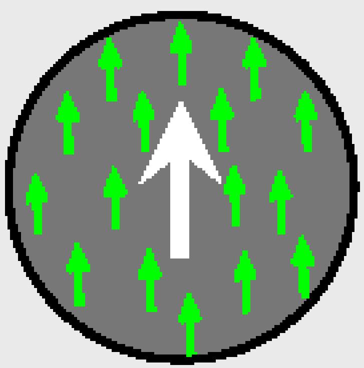


$D = \alpha E$

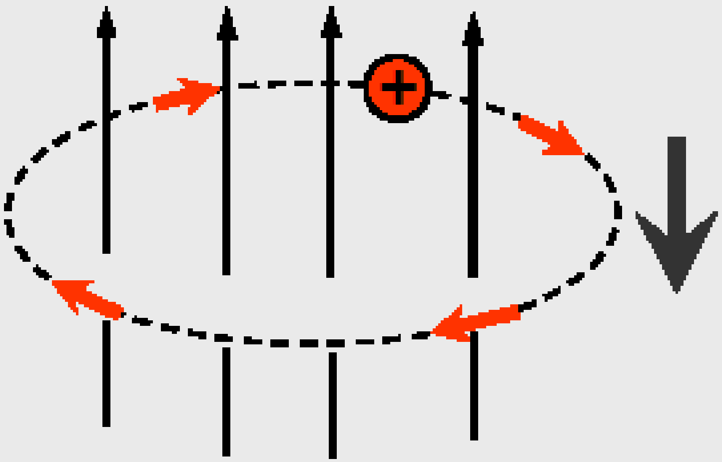
paramagnetic polarizability:
moments align with *B*



$M = 0$



$M = \beta_{para} B$



$M = \beta_{dia} B$

diamagnetic polarizability:
induced current opposes *B*

Cross section for Compton scattering at low energy

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

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

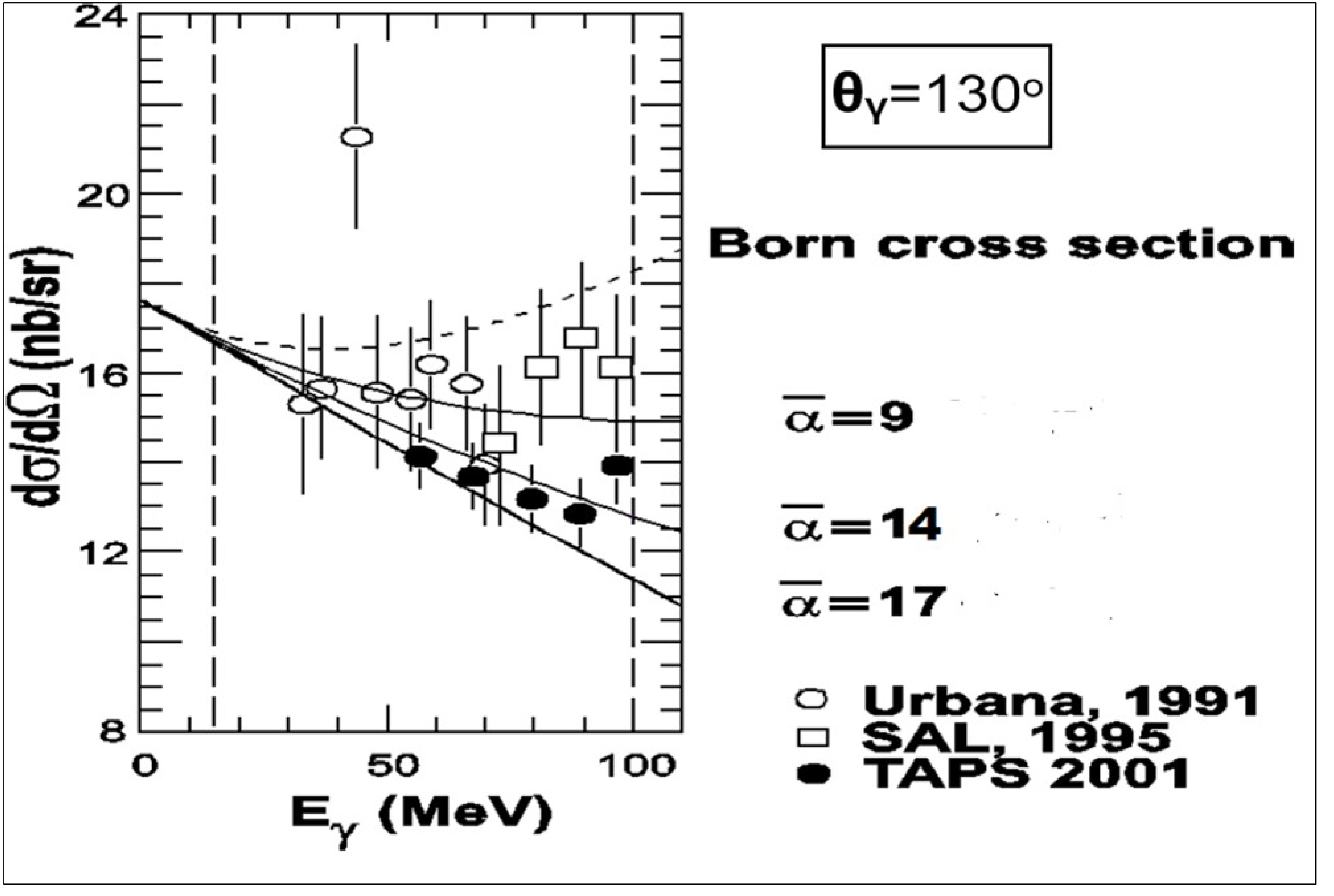
$$\times \left[\frac{\overline{\alpha}+\overline{\beta}}{2}(1+\cos\theta)^2 + \frac{\overline{\alpha}-\overline{\beta}}{2}(1-\cos\theta)^2\right]$$

α and β are defined in units 10^{-4} fm^3

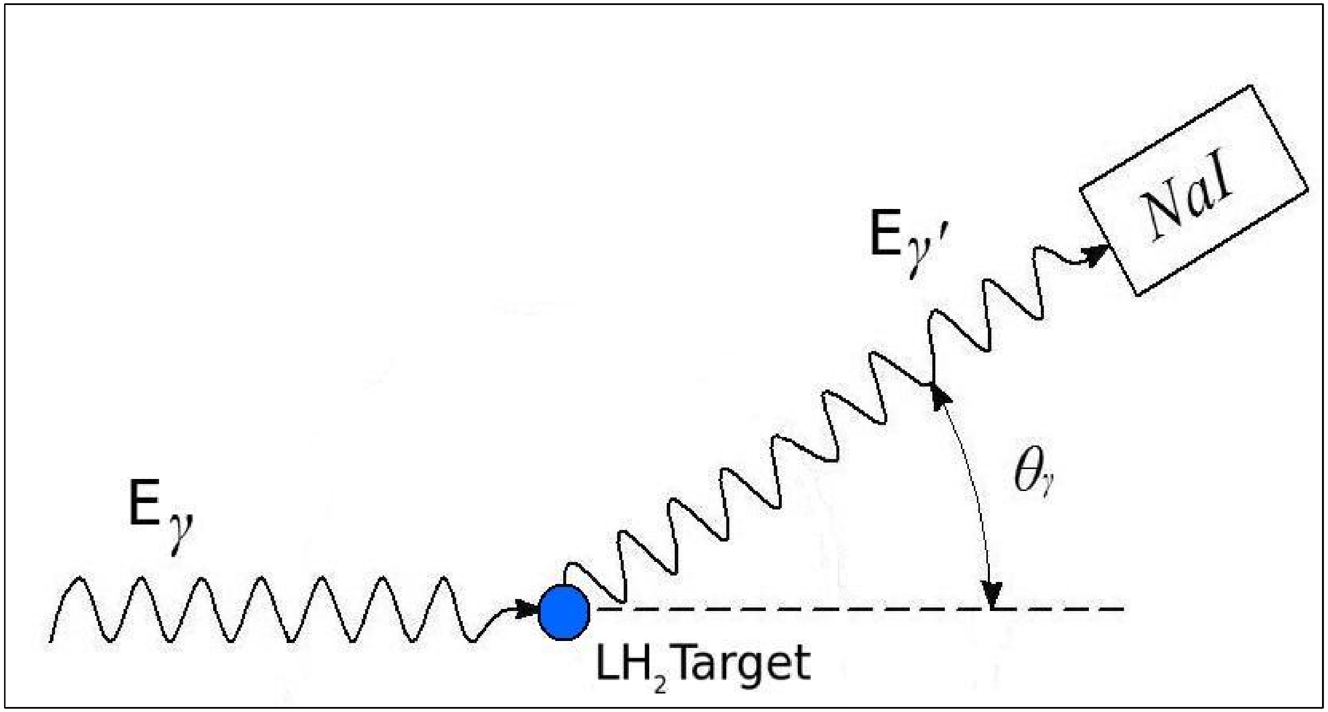
LET-formula describes the γ-p scattering with high precision at Eγ <100 MeV.

- dσ(Eγ,θγ)/dΩ (Powell) describes the γ-p scattering for point-like proton.
- Structure term ρ describes negative contribution from polarizabilities α and β.
- At θγ=90 deg, dσ(Eγ,θγ)/dΩ) sensitive to α only.
- At backward angles (e.g. θγ=130deg.), sensitive mostly to α-β.

Low energy (Eγ <100 MeV) Compton scattering data

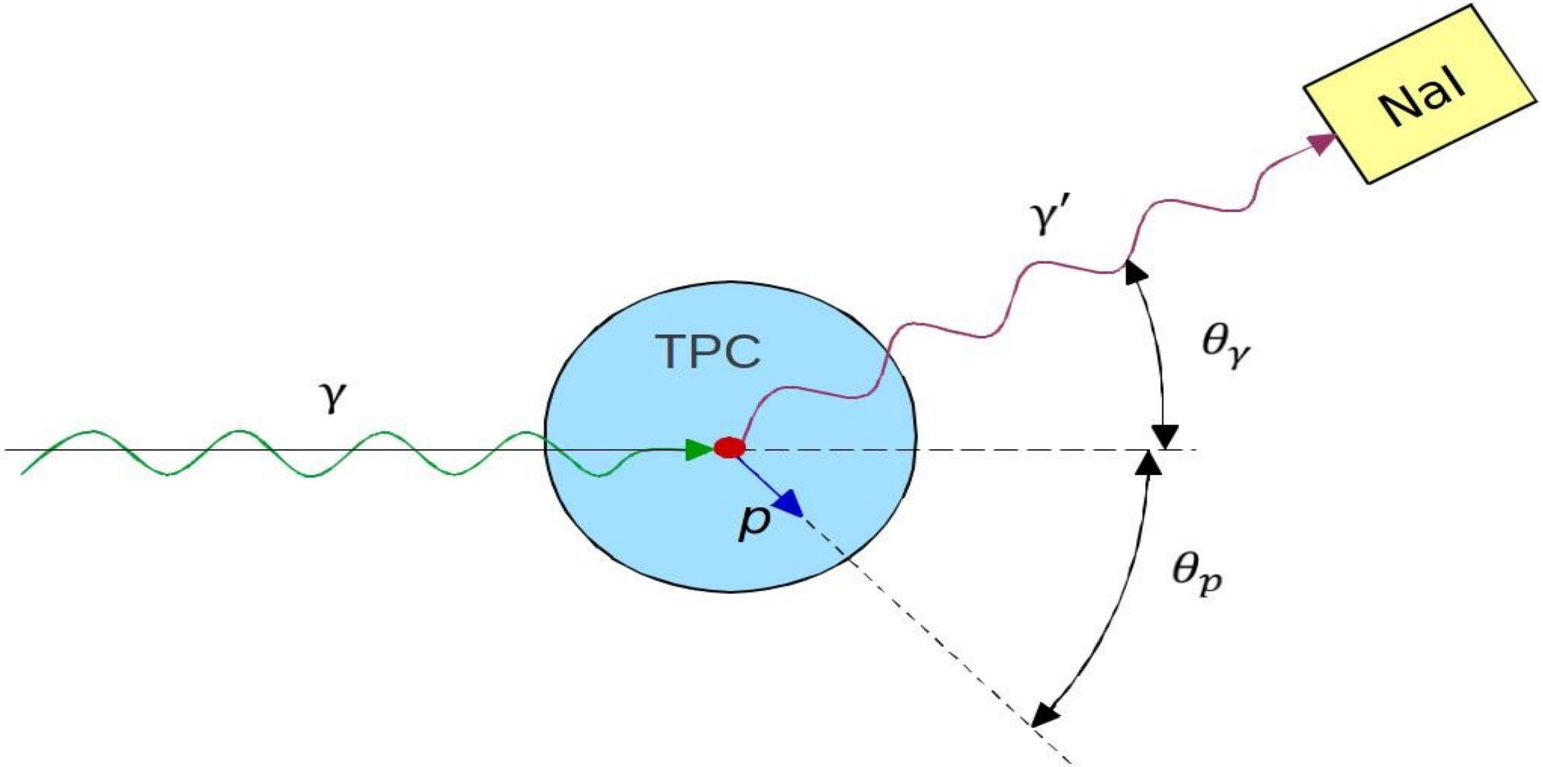


Typical tagged photon beam Copmton scattering experiment



measured are **Eγ , Eγ' θγ'** -kinematics reconstruction complete

Compton scattering using γ-p coincidence technique



Measured are **Eγ' θγ', Ep , θp** - kinematics reconstruction redundant. We sacrifice Eγ measurement (no tagging) thus gain essentially in counting rate. Very good background suppression due to strong γ'p kinematic correlation. **Problem:** *detection of low energy recoils (protons, deutrons …)*

Ionization chamber (TPC) as active target

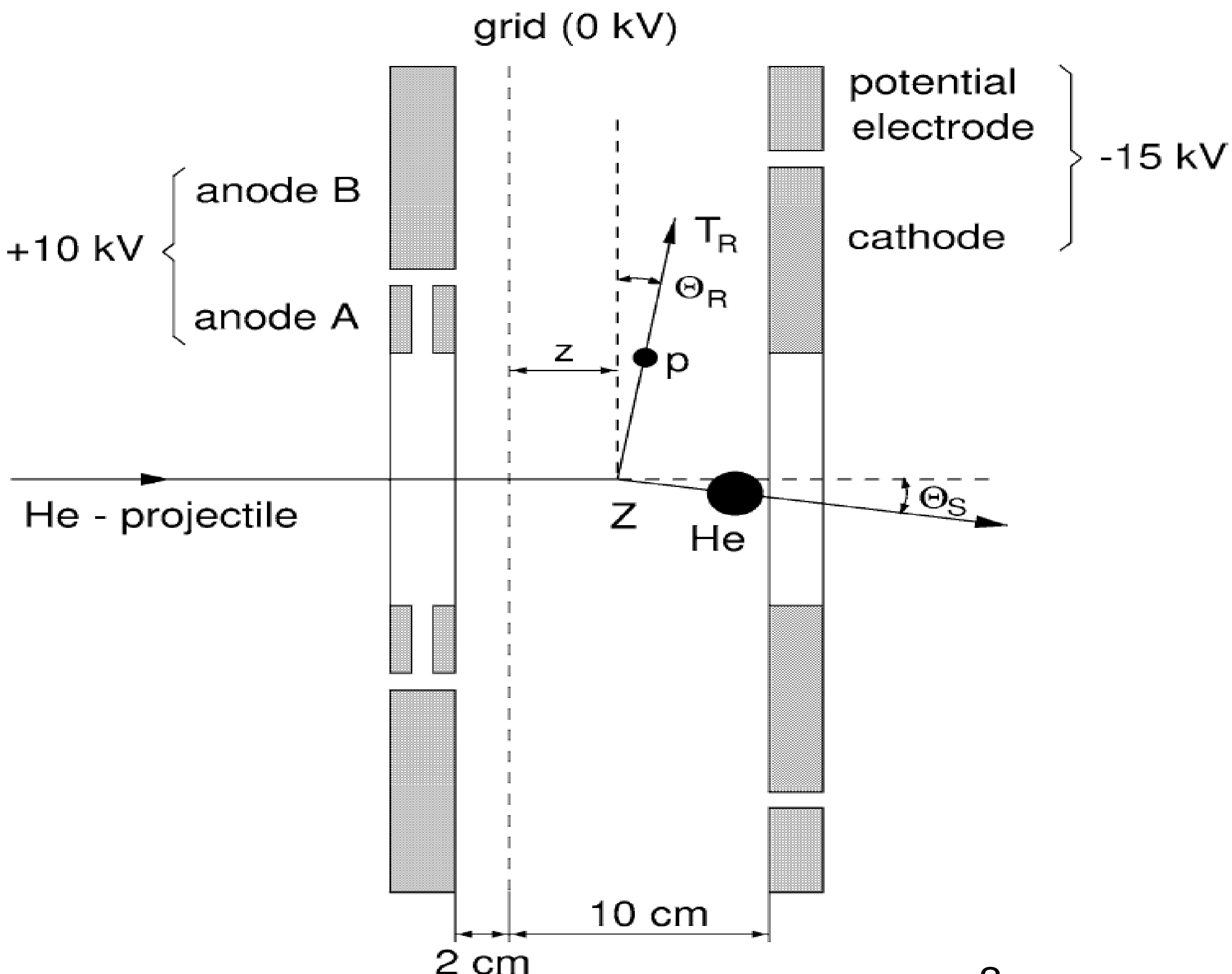
The problem of low energy recoil detection can be solved with the help of a ionization chamber used as active target.

active target properties:

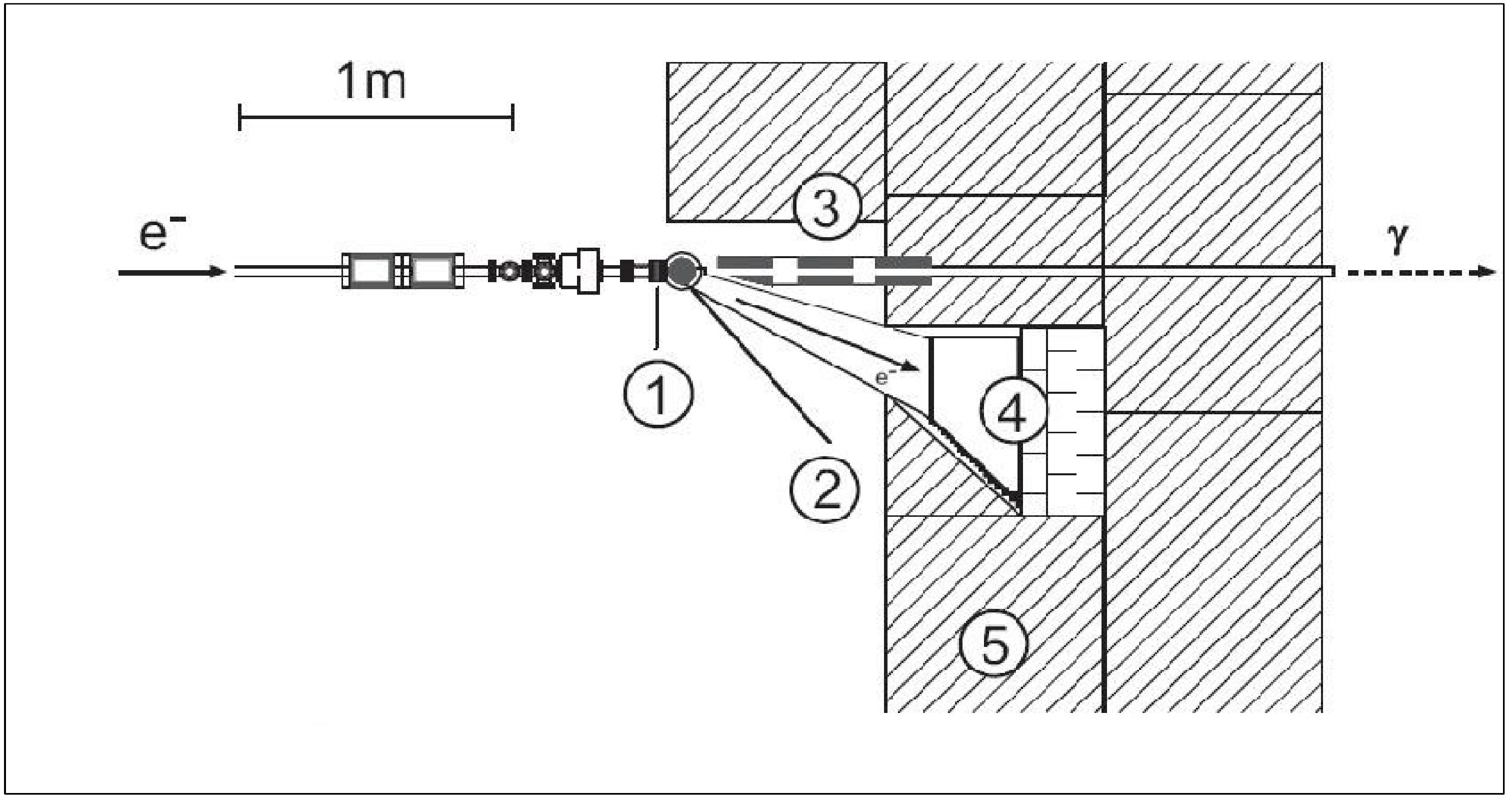
- Working gas - H2, D2, He3, He4 under pressure up to 200 bar;
- Registration of recoil protons in the range of 0.5 -20 MeV;

  Possibility to detect other recoils (D, H3, He3,..) ;
- Recoil proton energy resolution $\sigma \approx$ 20-30 keV;
- High (~100%) proton detection efficiency;
- Reconstruction of interaction point coordinate in direction of electrical field with resolution of $\sigma \approx$ 0.5 mm ;
- Possibility to apply effective fiducial volume cut.

Side view of TPC IKAR for small angle elastic scattering experiment S105 at GSI

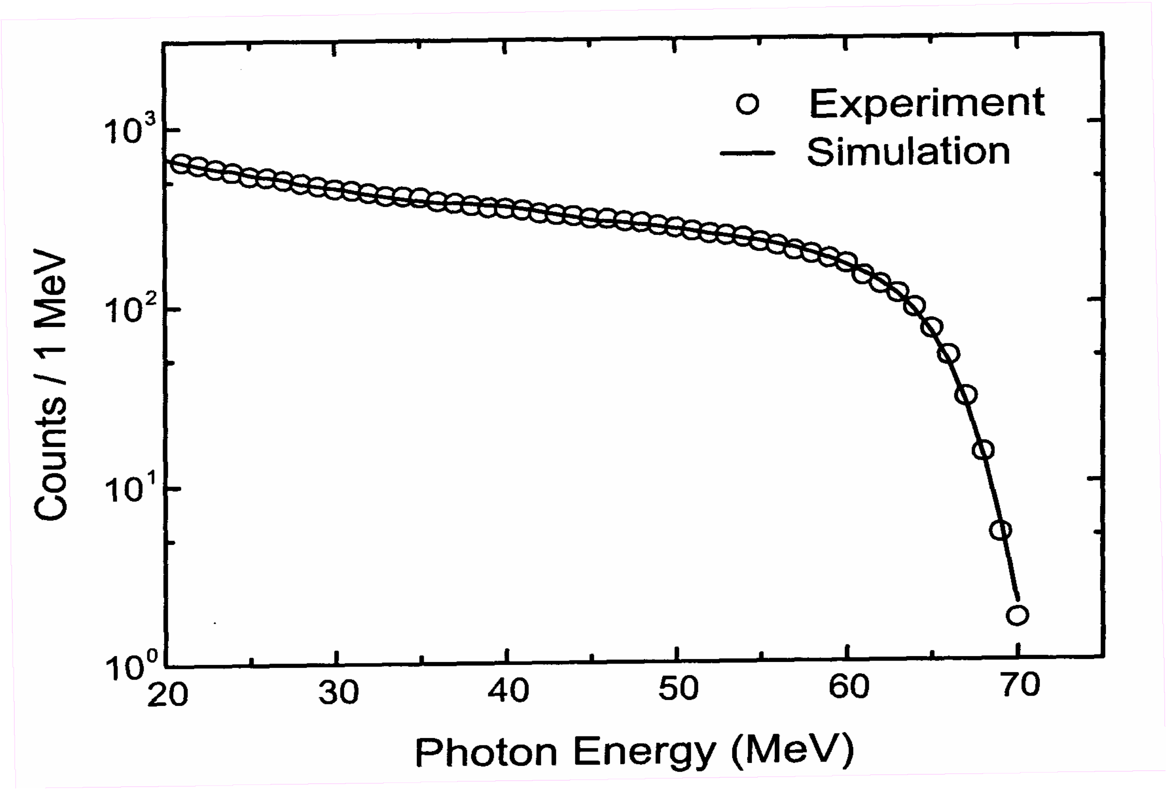


Test experiment at IKP Darmstadt. Setup of bremsstrahlung facility



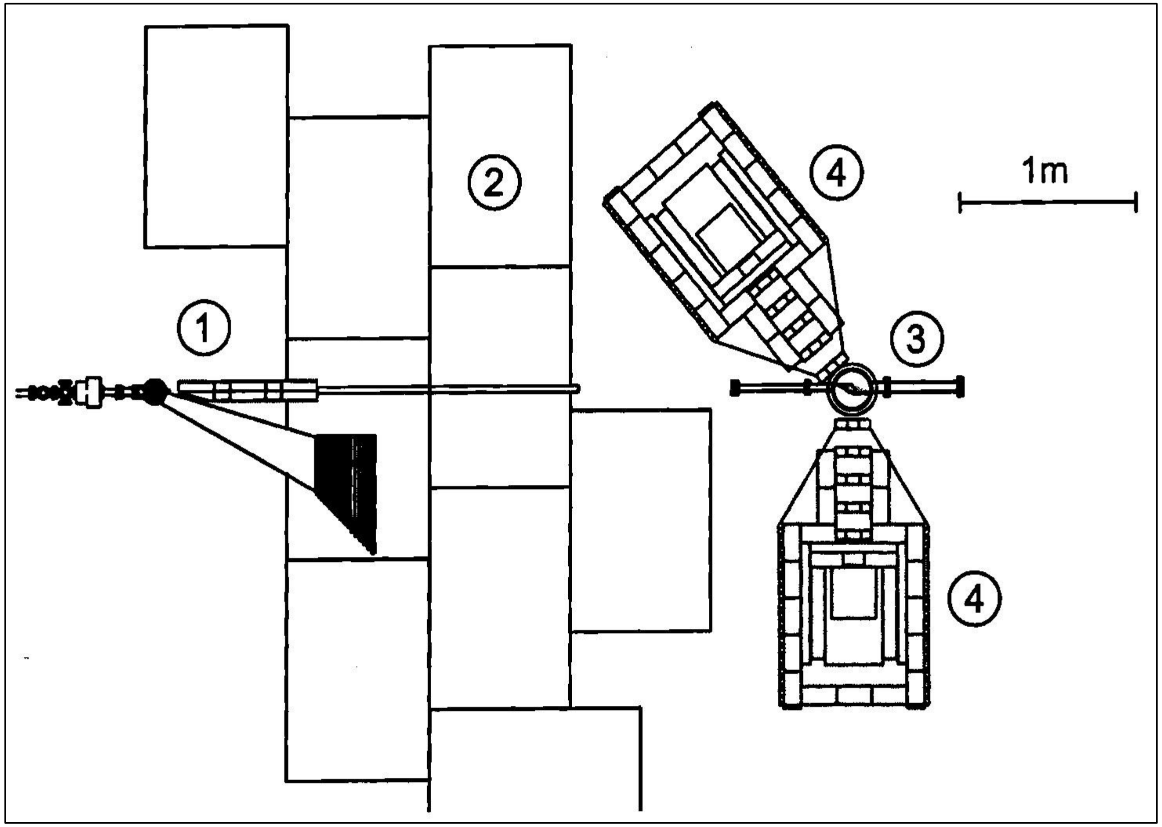
1 – bremsstrahlung converter target (0.3mm gold), **2** – cleaning magnet,
3 – **γ-** beam collimator, **4** – electron beam dump (Faraday cup), **5** – concrete shielding

Bremsstrahlung spectrum at 70MeV electron beam in IKP Darmstadt



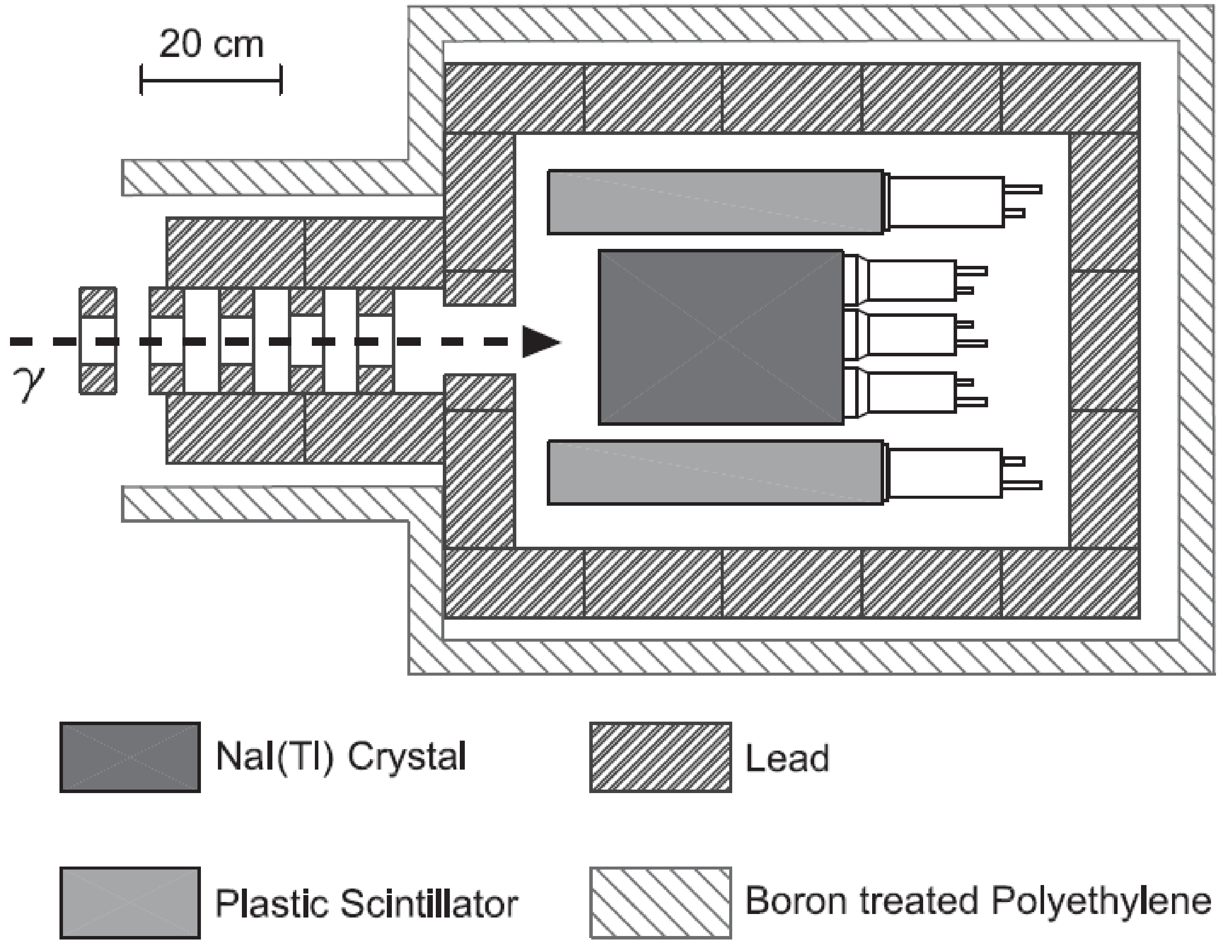
Untagged bremsstrahlung photon spectrum measured in the test experiment at S-Dalinac (IKP Darmstadt). The electron beam energy is 70 MeV. The Geant 4 routine was used for simulation of the bremsstrahlung photon spectrum.

Test experiment setup at IKP Darmstadt

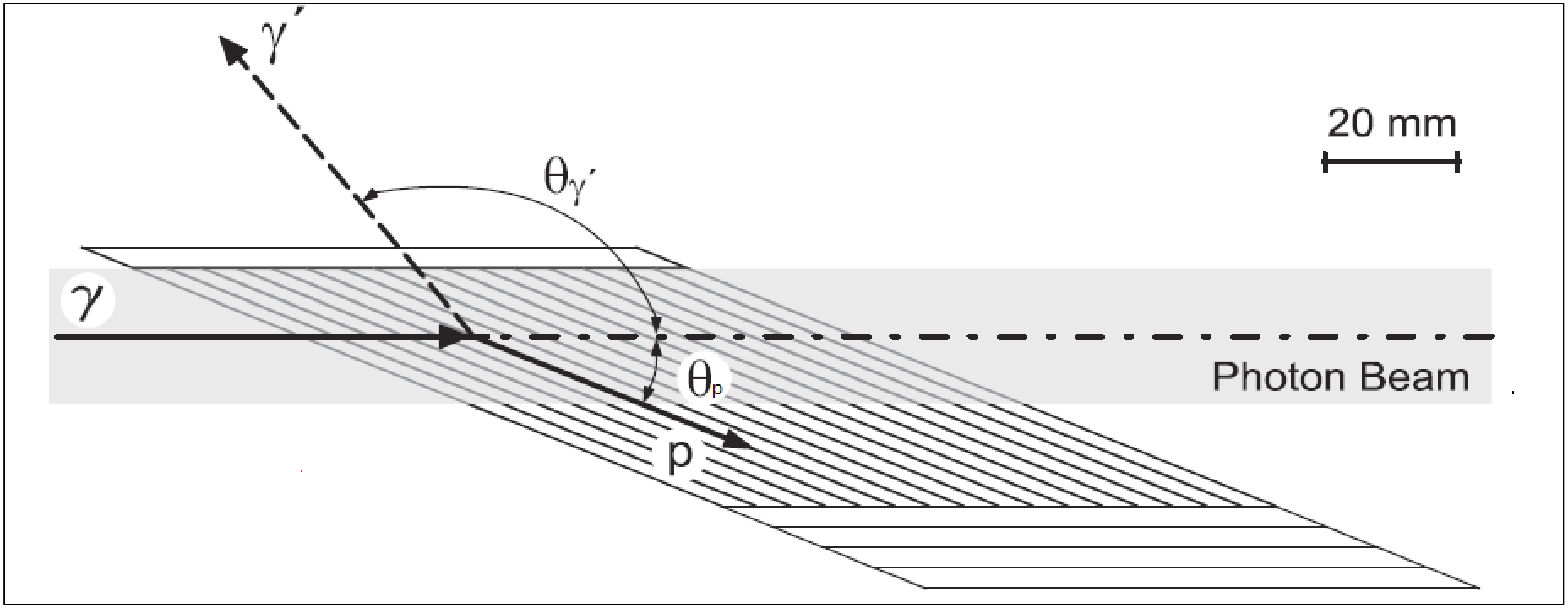


1 – bremsstrahlung facility, 2 – concrete shielding, 3 – high pressure ionization chamber (active target), 4 – γ-detectors (NaI) at θ_γ=130 and θ_γ =90 deg.

Schematic view of a 10 in x 14 in NaI(Tl) detector

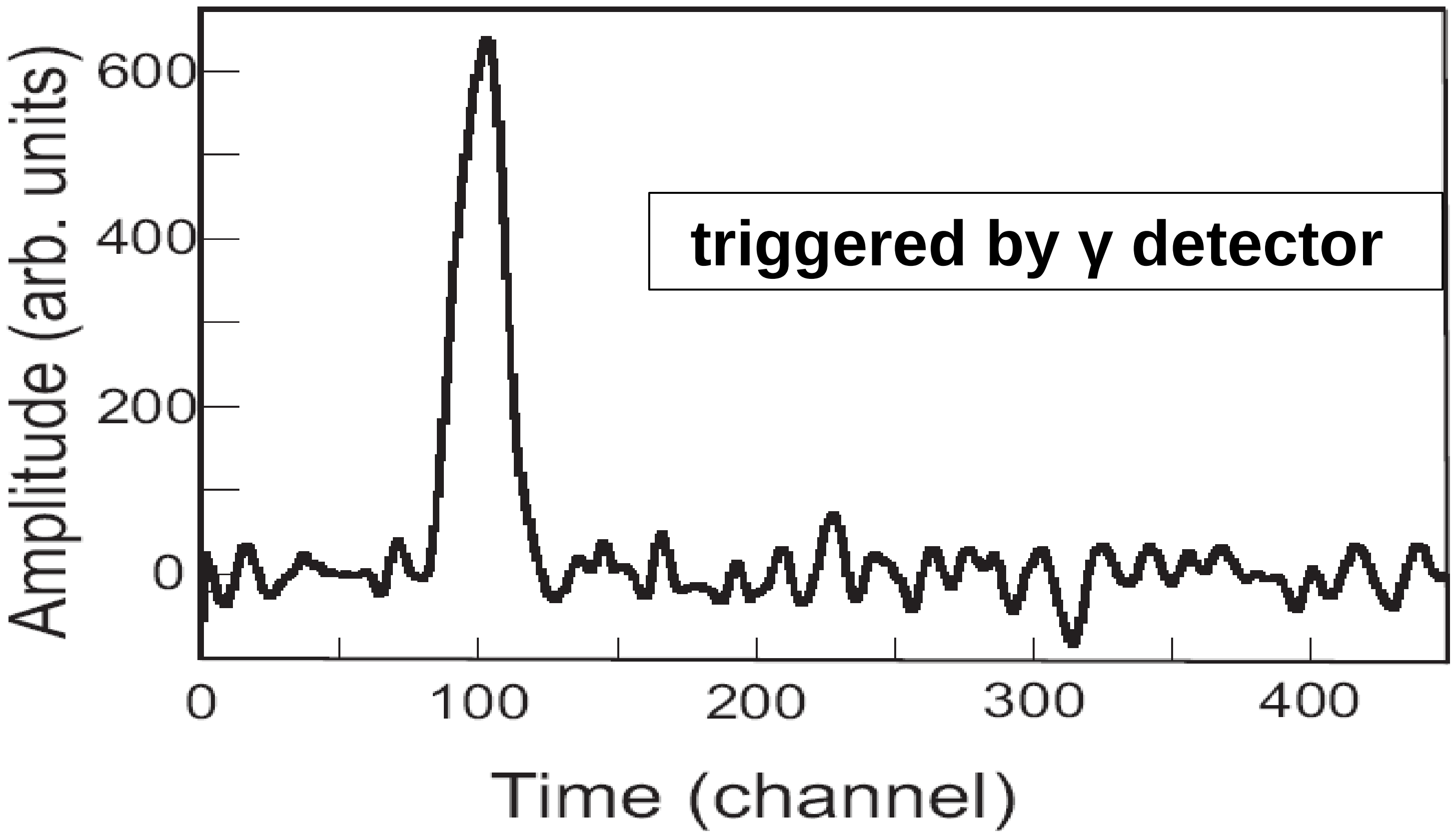


Top view on a multy-strip anode plane at θγ=130°



Multy-strip TPC anode plane for the scattering photon angle θγ=130deg. The angle of recoil proton θp =22deg, detected recoil proton energies Ep =0.5-10MeV, the ranges of protons Rp =0.2-90mm (at hydrogen pressure 75 bar, length of anodes strip is 90mm.

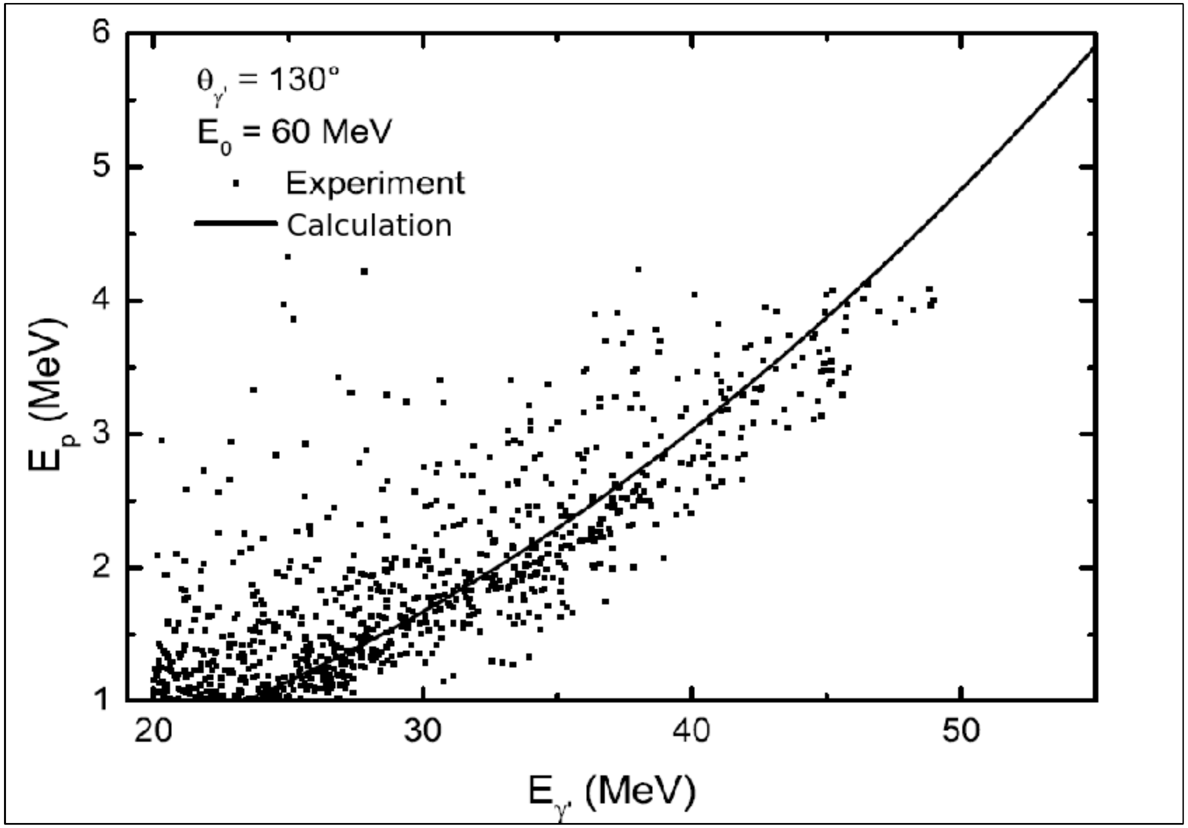
Example of a signal in TPC from 2 MeV recoil proton, registed by FADC



Signal from recoil proton on anode of TPC in **γ-p** scattering experiment at IKP

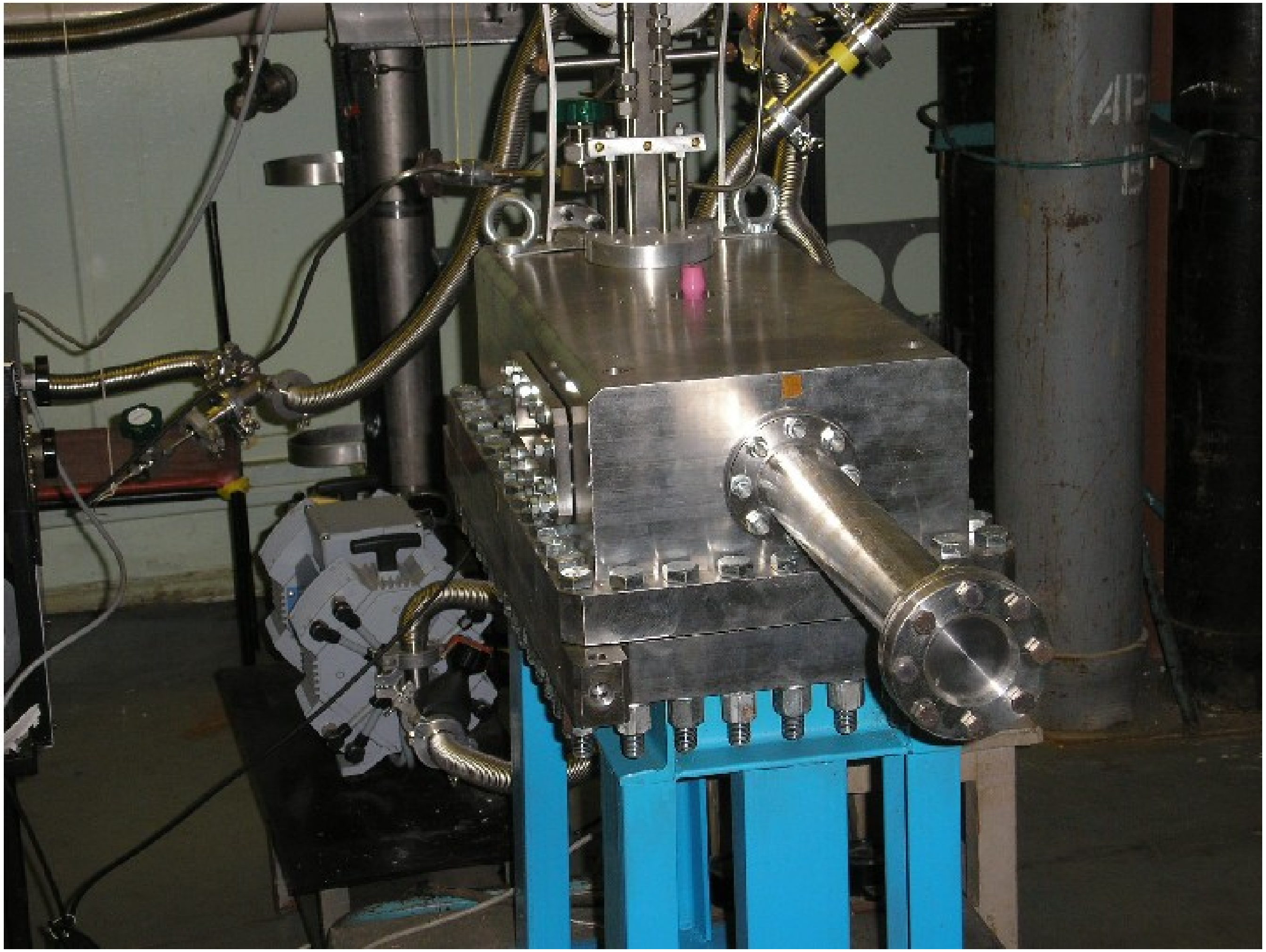
Ep- Eγ correlations.

Not enough statistics !!

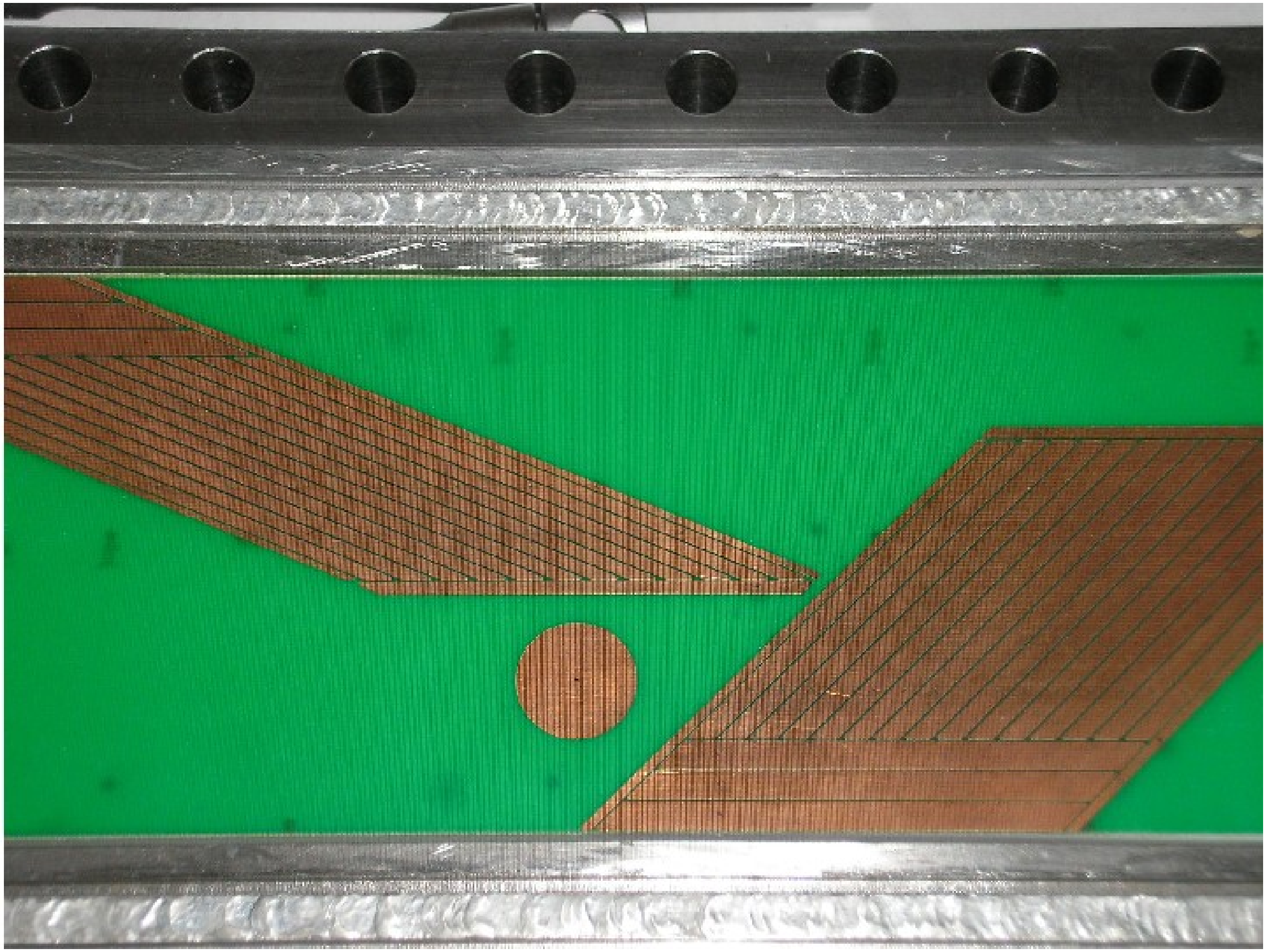


Ep- Eγ correlations in γ-p scattering experiment at IKP at electron beam energy 60MeV and θγ=130deg. The calculation is pure kinematic correlation.

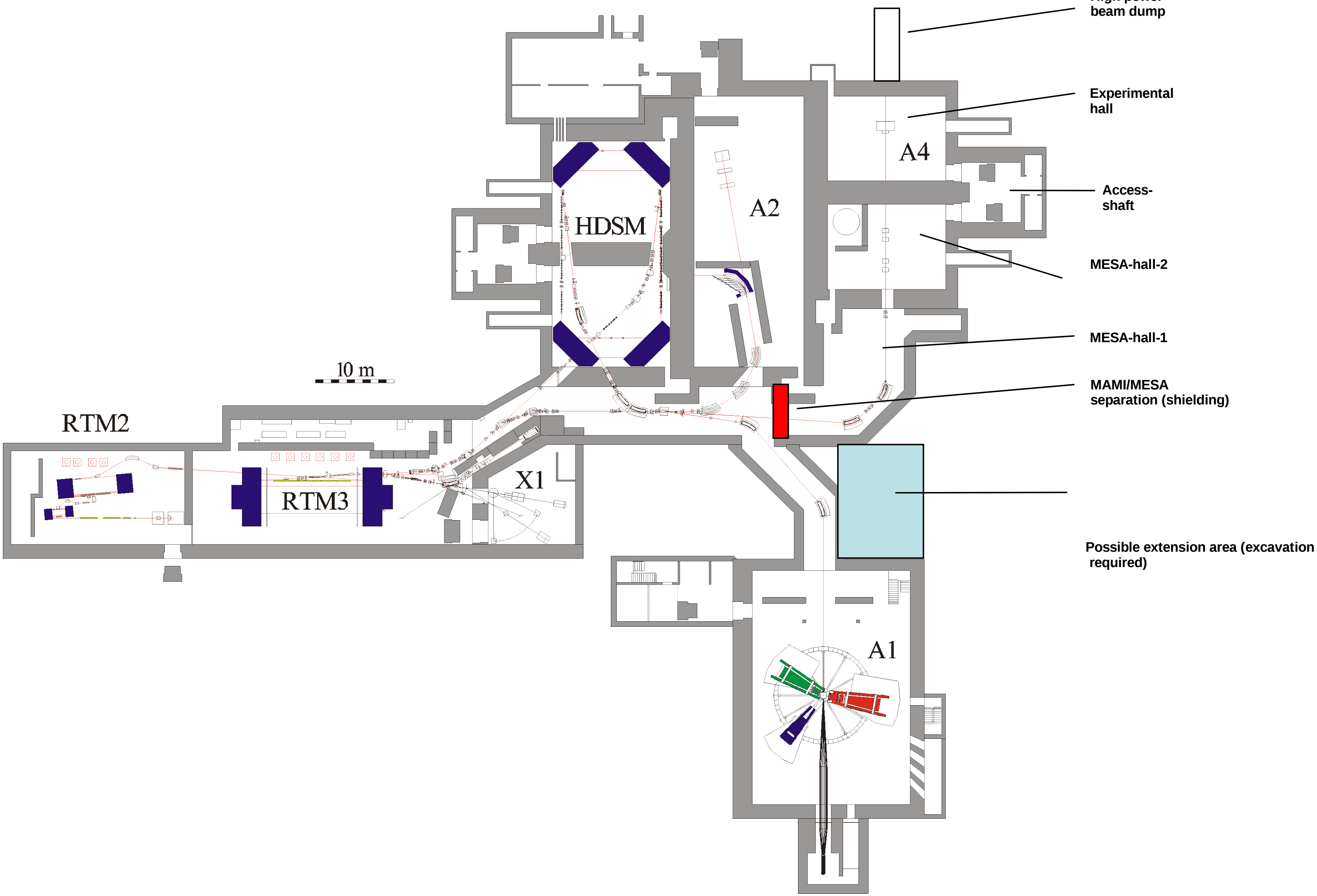
Newly fabricated TPC for Compton scattering experiments



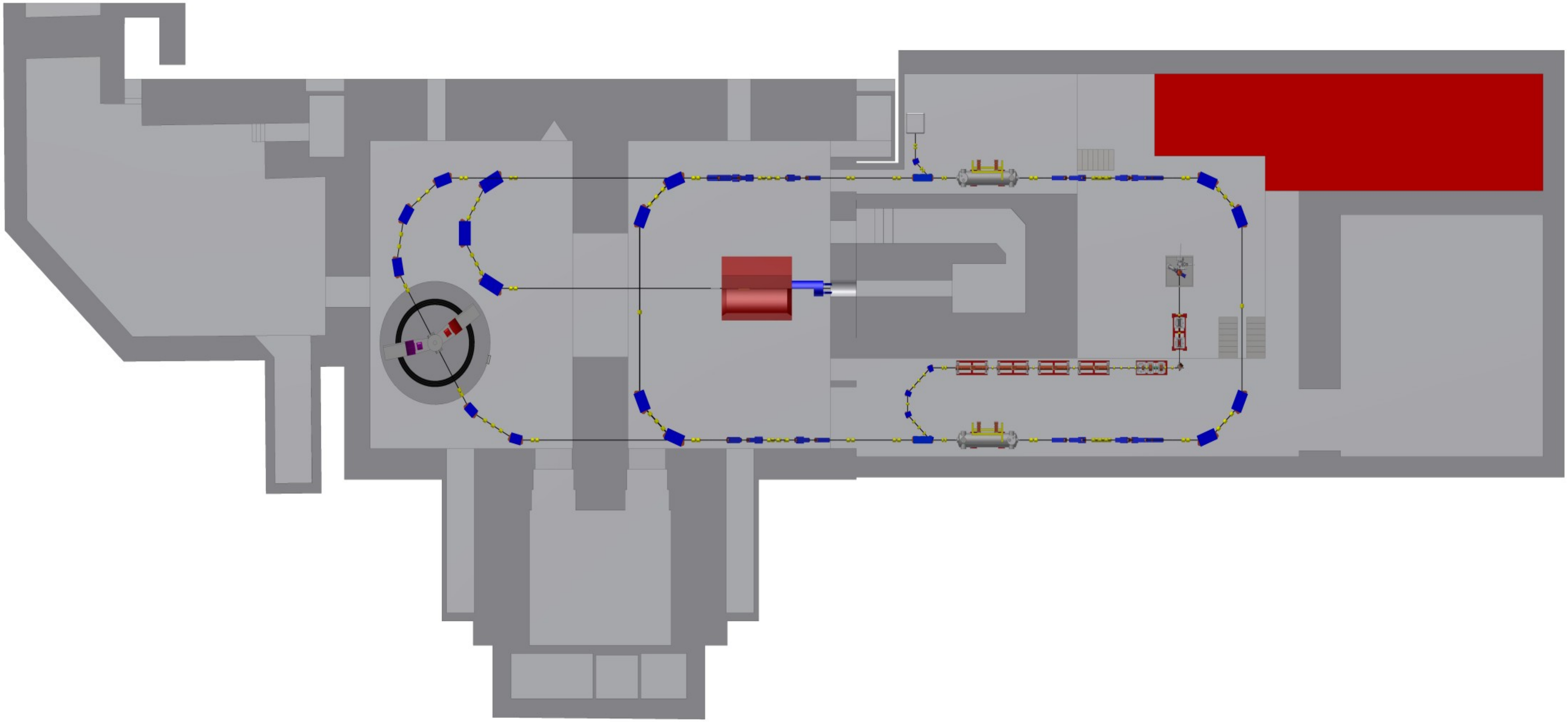
The anode plane of new TPC for simultaneously measurements of Compton scattering at two photon scattering angles θγ=90 and θγ=130 deg.



MAMI (Mainz Microtron - 1.6 GeV)



MESA (Mainz Energy Recovering Super Conducting Accelerator)



MESA parameter set for stage-1 (stage-2).
ERL-energy recovery mode, EB- external beam mode.

Beam Energy ERL/EB [MeV]	105/155 (105/205)
Operating mode	1300 MHz, c.w.
Source type	Photosource d.c. 100keV, polarized (Photosource 200keV, non-polarized)
Bunch charge EB/ERL [pC] /[μA]	0.115/0.77 (0.115/7.7) 150μA/1000μA(150μA/10mA)
Norm. Emittance EB/ERL [μm]	0.2/<1 (0.2/<1)
Beam polarization (EB-mode only)	> 0.85
Beam recirculations	2 (3)
Beam power at exp. ERL/EB [kW]	100/22.5 (1000/30)
Total R.f.-power installed [kW]	120 (160)

Counting rate estimation at MESA

- electron beam **$E_e = 110$ MeV, $I_e = 50\mu A$**
- bremsstralung target convertor *0.3 mm Au (≈0.1 rad. length)*
- bremsstrahlung photon beam $E\gamma = 20\text{-}100 MeV$, $I\gamma = 2x10^{11}\ s^{-1}$
  at $E\gamma$ =60MeV, $I\gamma \sim 2x10^{9}\ MeV^{-1}s^{-1}$
- γ- beam spot at active target (TPC) $1x2\ cm^{-2}$
- H2 active target density (20 cm, 75 bar) $8x10^{22} cm^{-2}$
- γ-spectrometer $E\gamma \sim 20\text{-}100$ MeV, $\theta\gamma = 90$ and 130 deg.
  $\Delta\Omega = 0.025 sr.$ $\delta E\gamma / E\gamma = 4\%$
- recoil proton detection $Ep \sim 0.5\text{-}10$ MeV $\theta p = 44$ and 22 deg.
  $\delta (Ep) = 30\text{-}40$ KeV

Expected count rate 5 s-1

3 weeks of data taking corresponds to 8 000 000 γp events

Planned precision of α_p and β_p measurements at MESA

Statistical uncertainty: $\Delta\alpha_p = 0.07$, $\Delta\beta_p = 0.12$

Systematical uncertainty: $\Delta\alpha_p = 0.11$, $\Delta\beta_p = 0.12$

Total uncertainty (in quadrature): $\Delta\alpha_p = 0.13$, $\Delta\beta_p = 0.17$

world measurements of α_p and β_p

PDG (2010) $\alpha_p = 12.0 \pm 0.6$, $\beta_p = 1.9 \pm 0.5$

PDG (2014) $\alpha_p = 11.2 \pm 0.4$, $\beta_p = 2.5 \pm 0.4$

Planned precision of α_s and β_s measurements at MESA

Statistical uncertainty: $\Delta\alpha_s = 0.07$, $\Delta\beta_s = 0.12$

Systematical uncertainty: $\Delta\alpha_s = 0.13$, $\Delta\beta_s = 0.16$

Total uncertainty (in quadrature): $\Delta\alpha_s = 0.15$, $\Delta\beta_s = 0.20$

$\alpha_s = (\alpha_p + \alpha_n)/2$, $\beta_s = (\beta_p + \beta_n)/2$ (isoscalar average)

Max-lab (Lund,2014) $\alpha_s = 12.1 \pm 0.8$stat, $\beta_s = 2.4 \pm 0.8$stat

world measurements of α_n and β_n

PDG (2010) $\alpha_n = 12.5 \pm 1.7$, $\beta_n = 2.7 \pm 1.8$

PDG (2014) $\alpha_n = 11.6 \pm 1.5$, $\beta_n = 3.7 \pm 2.0$

Max-lab(Lund, 2014) $\alpha_n = 11.55 \pm 1.25$stat, $\beta n = 3.65 \pm 1.25$stat

Conclusion

We propose a coincidence method to precisely measure differential cross section of γp Compton scattering using bremsstrahlung photon beam (E_γ <100 MeV) of the MESA facility (under construction). The experiment would aim at improved precision of knowledge of proton (neutron) polarizabilities.

The virtues of proposed method:

1. The measurements can be performed at a rather low photon energy allowing for the data analysis to be performed in a model-independent way.

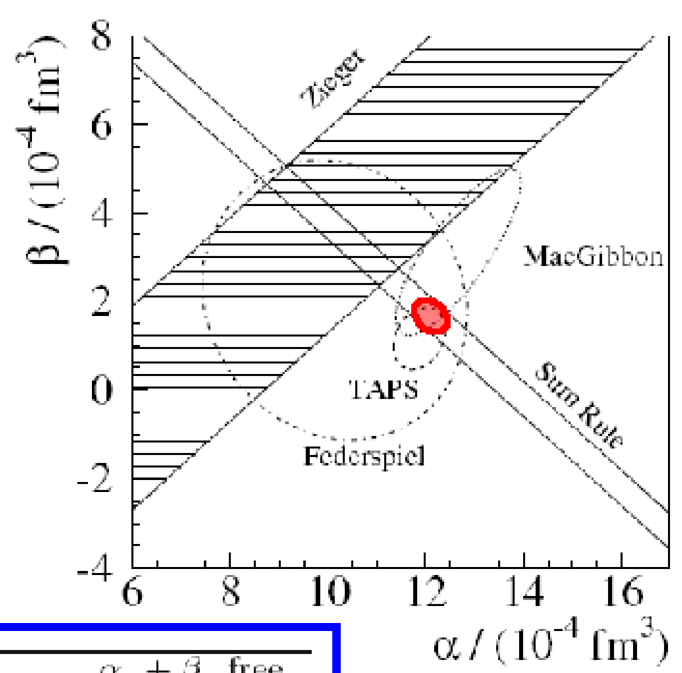
2. The experimental data can be normalized to the theoretical value of $d\sigma(E_\gamma,\theta_\gamma)/d\Omega$ at the primary photon energy of 20-30 MeV where the contribution from polarizability terms is small.

3. The method provides effective background rejection due to strong correlation between the kinematic variables of the scattered photon and the recoil proton (or recoil deuteron) in the case of elastic scattering.

4. Count rate of Compton scattering events substantially larger than in the tagged photon experiments

Supporting slides

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

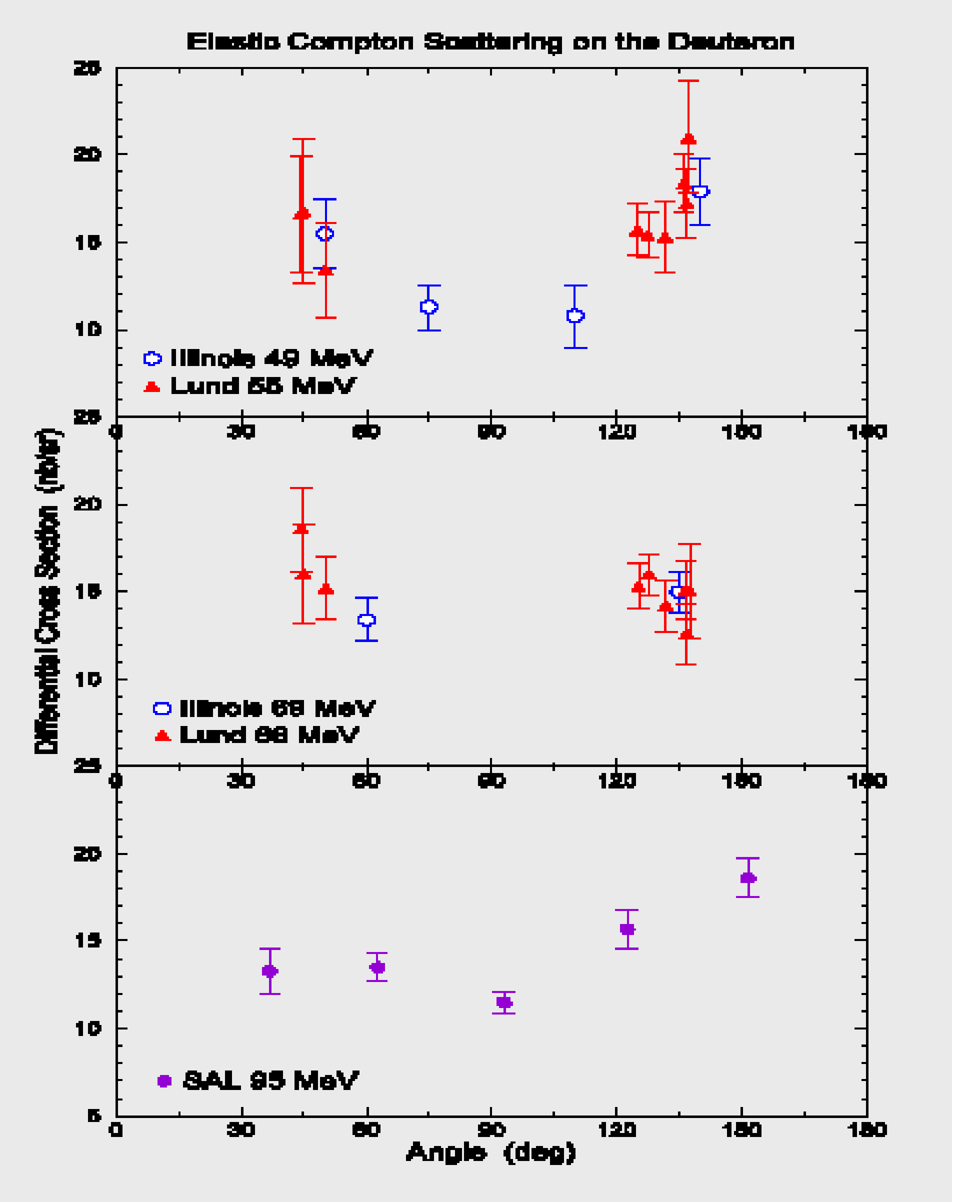
Coherent DCS

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



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)

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

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

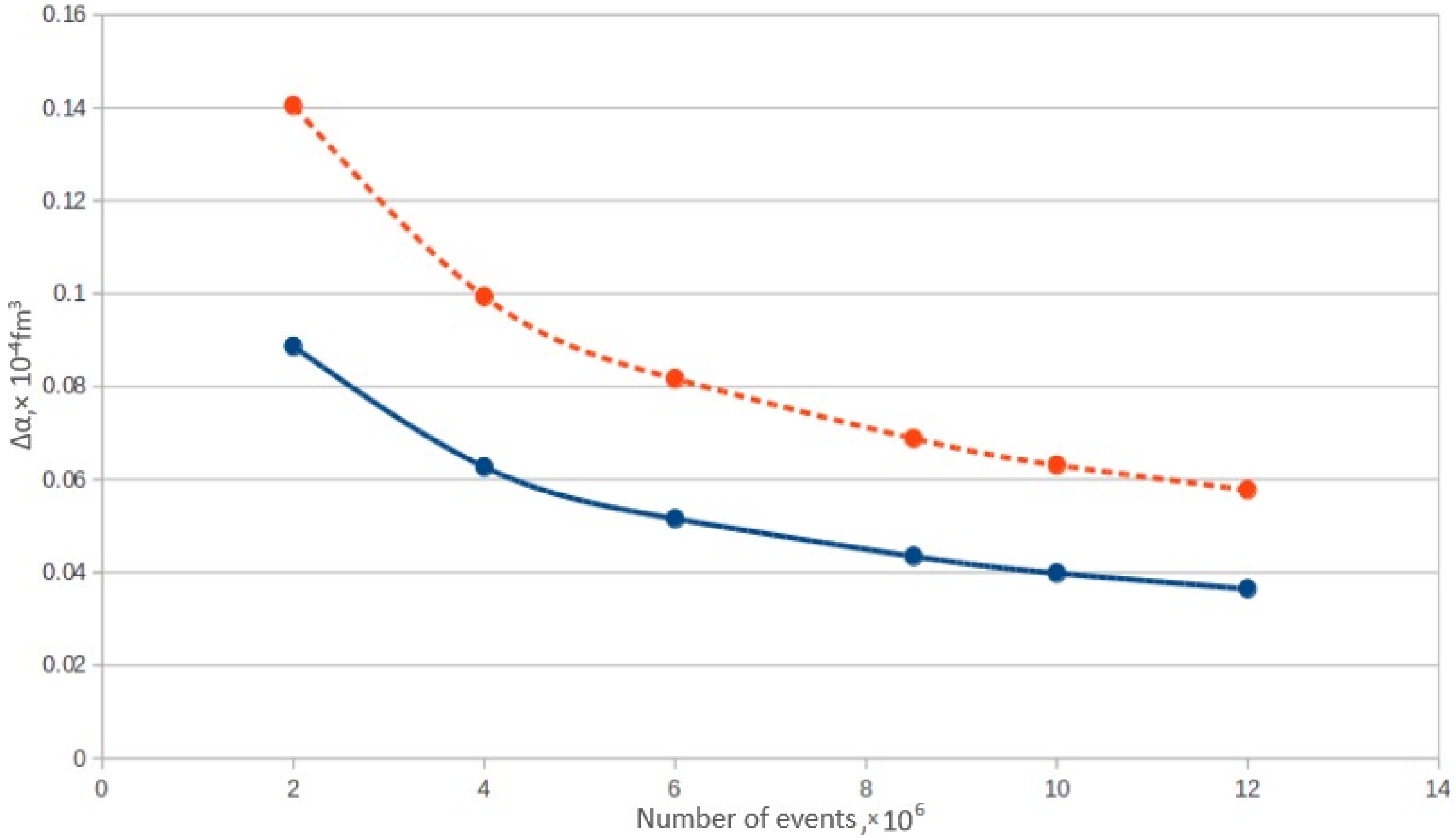
- Elastic Compton scattering
  - data from Lucas (94), Hornidge (00), Lundin (03)
  - global fit by Hildebrandt (05)

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

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

We can do better . . .

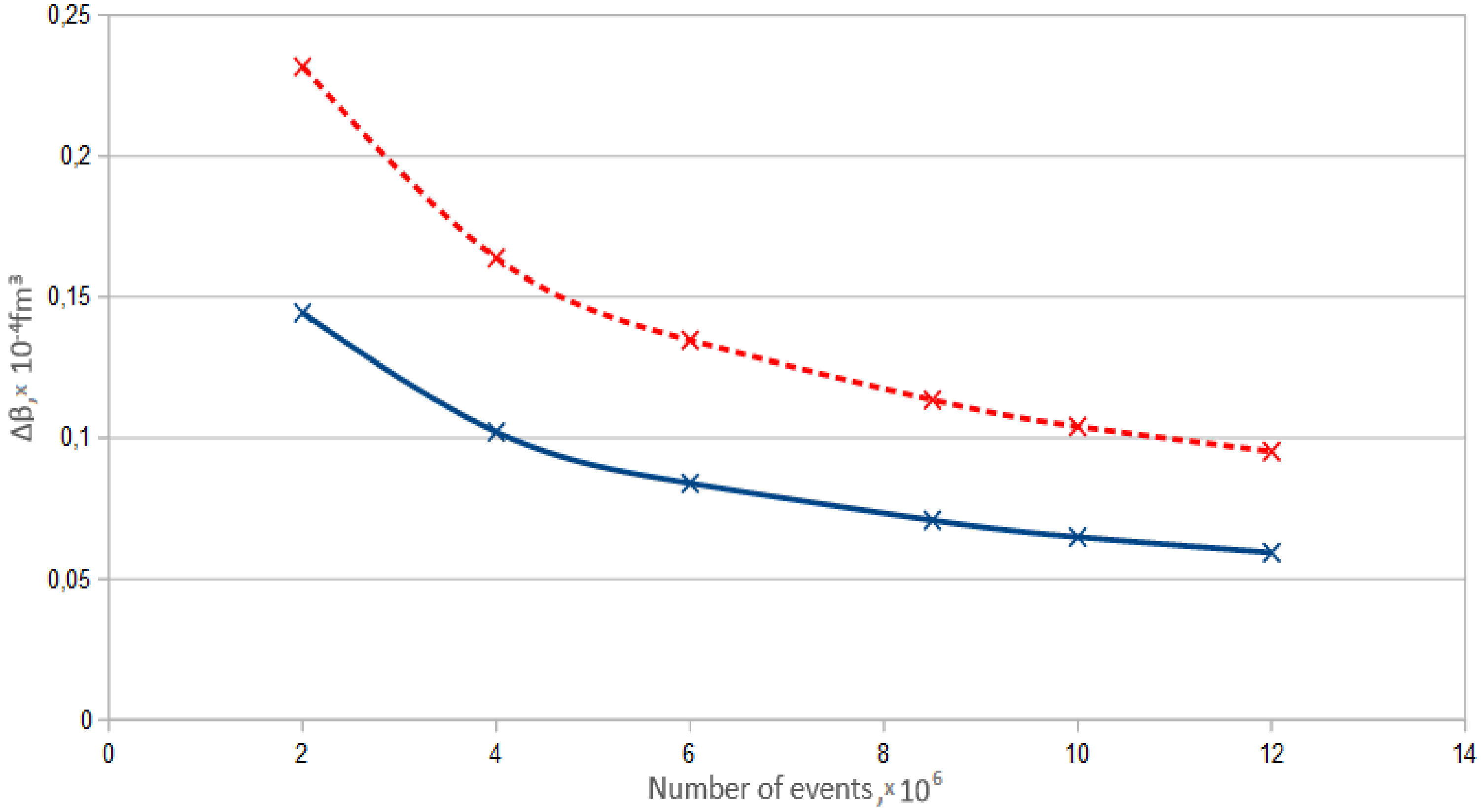
Statistical errors in determination α



___ absolute measurement - only two (α and β) free parameters

___ with additional two (for each θγ) normalization parameters

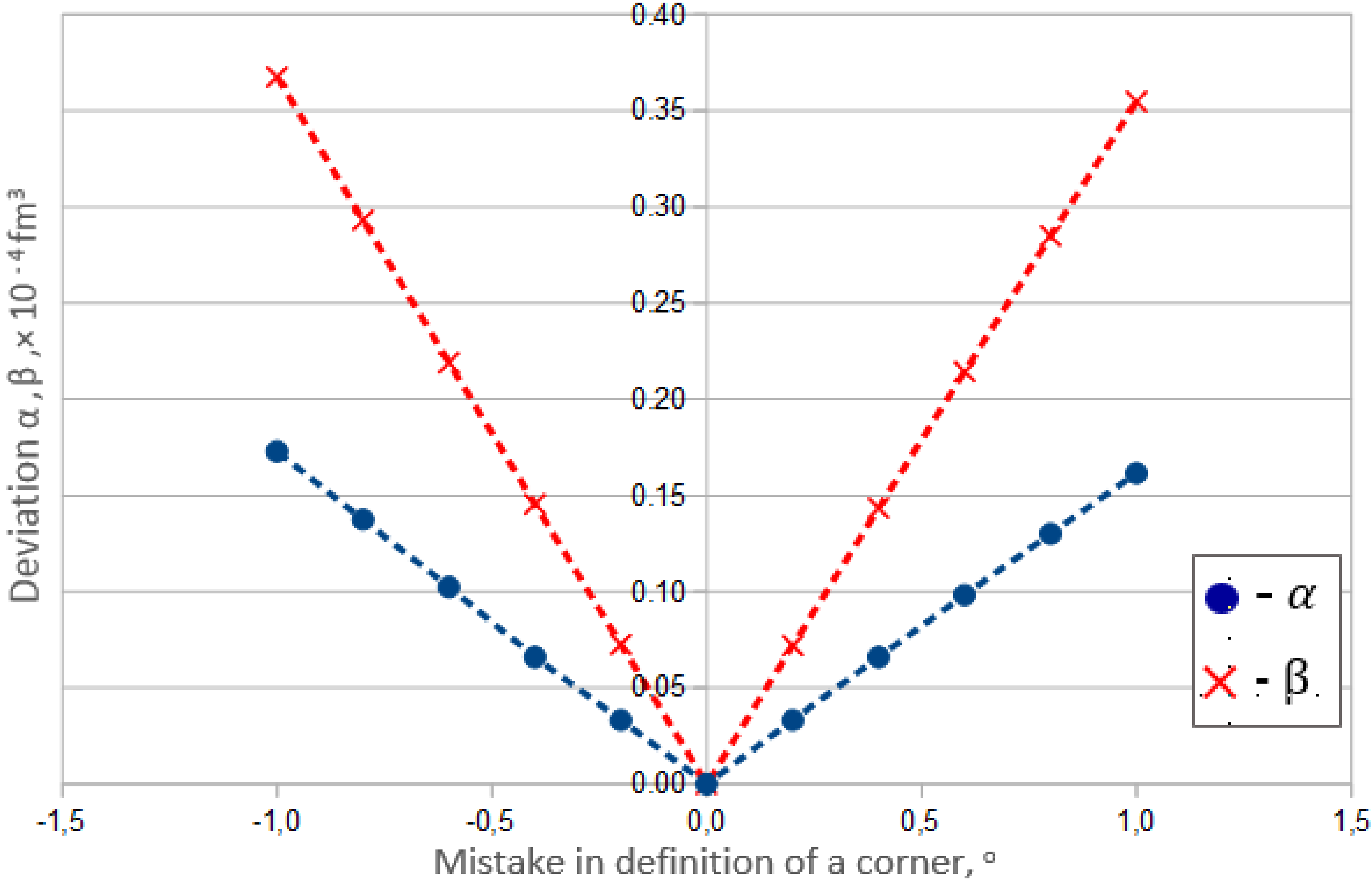
Statistical errors in determination β



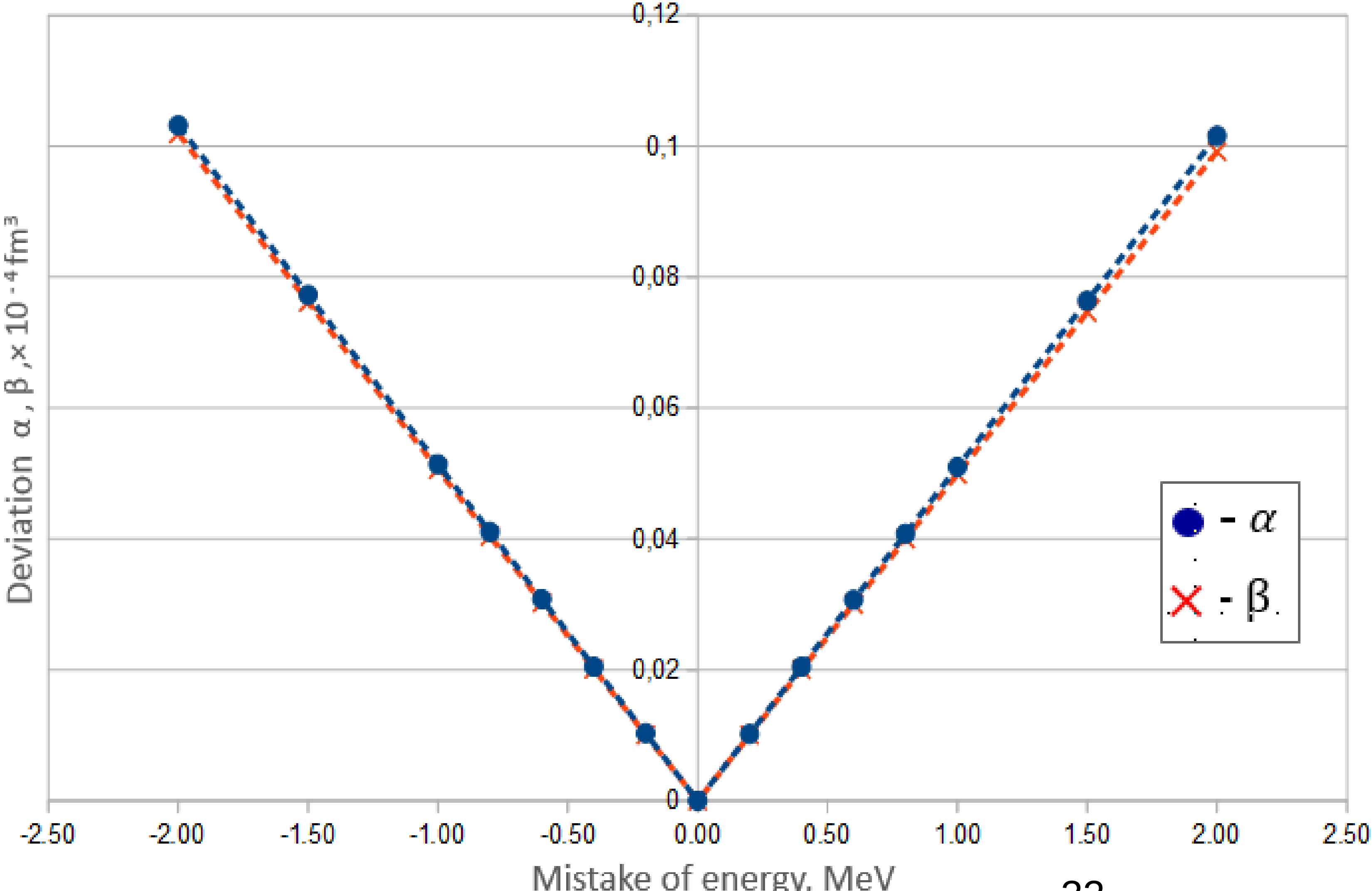
___ absolute measurement - only two (α and β) free parameters

___ with additional two (for each θγ) normalization parameters

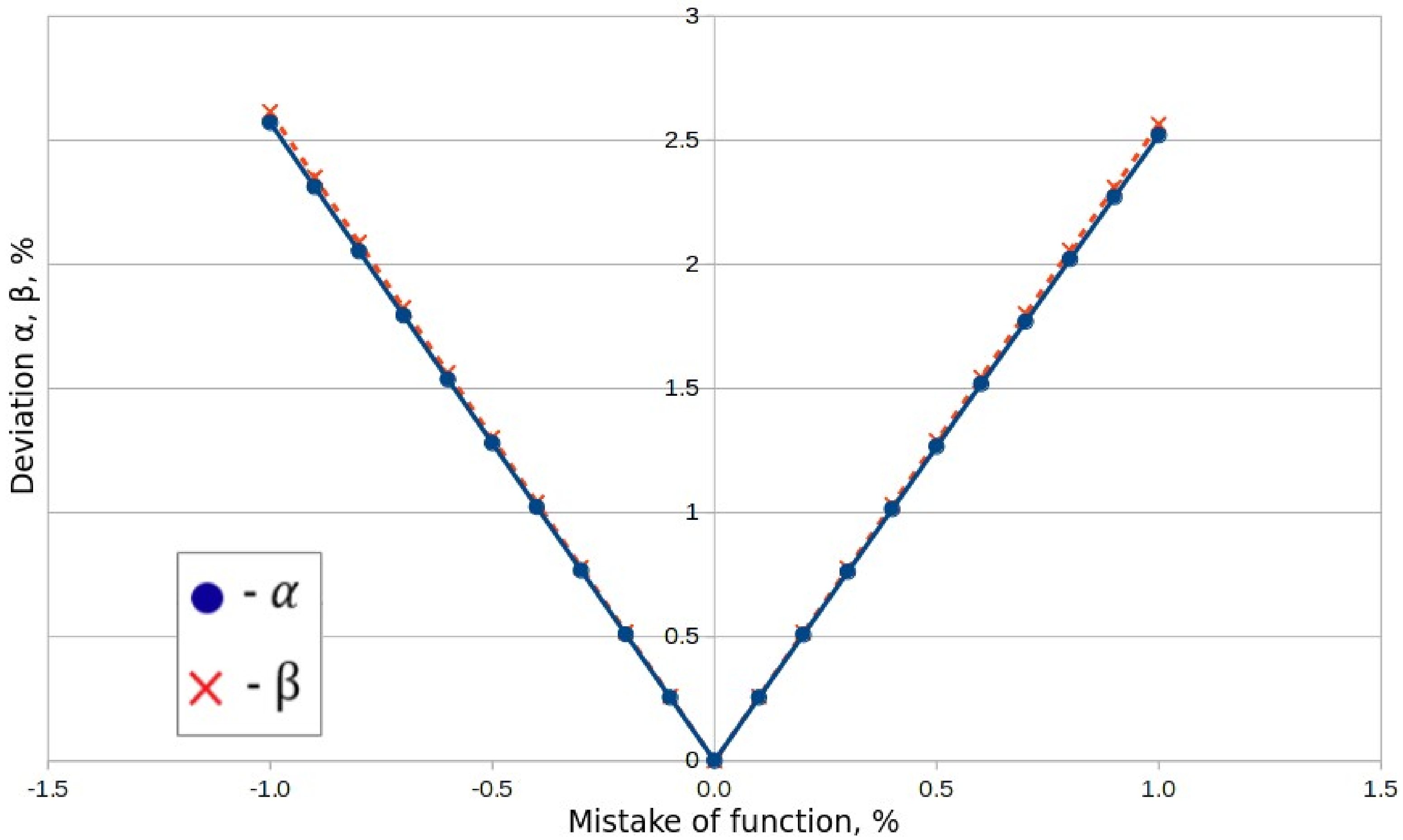
Systematical errors (θγ) in determination of α and β



Systematical errors (Eγ) in determination of α and β



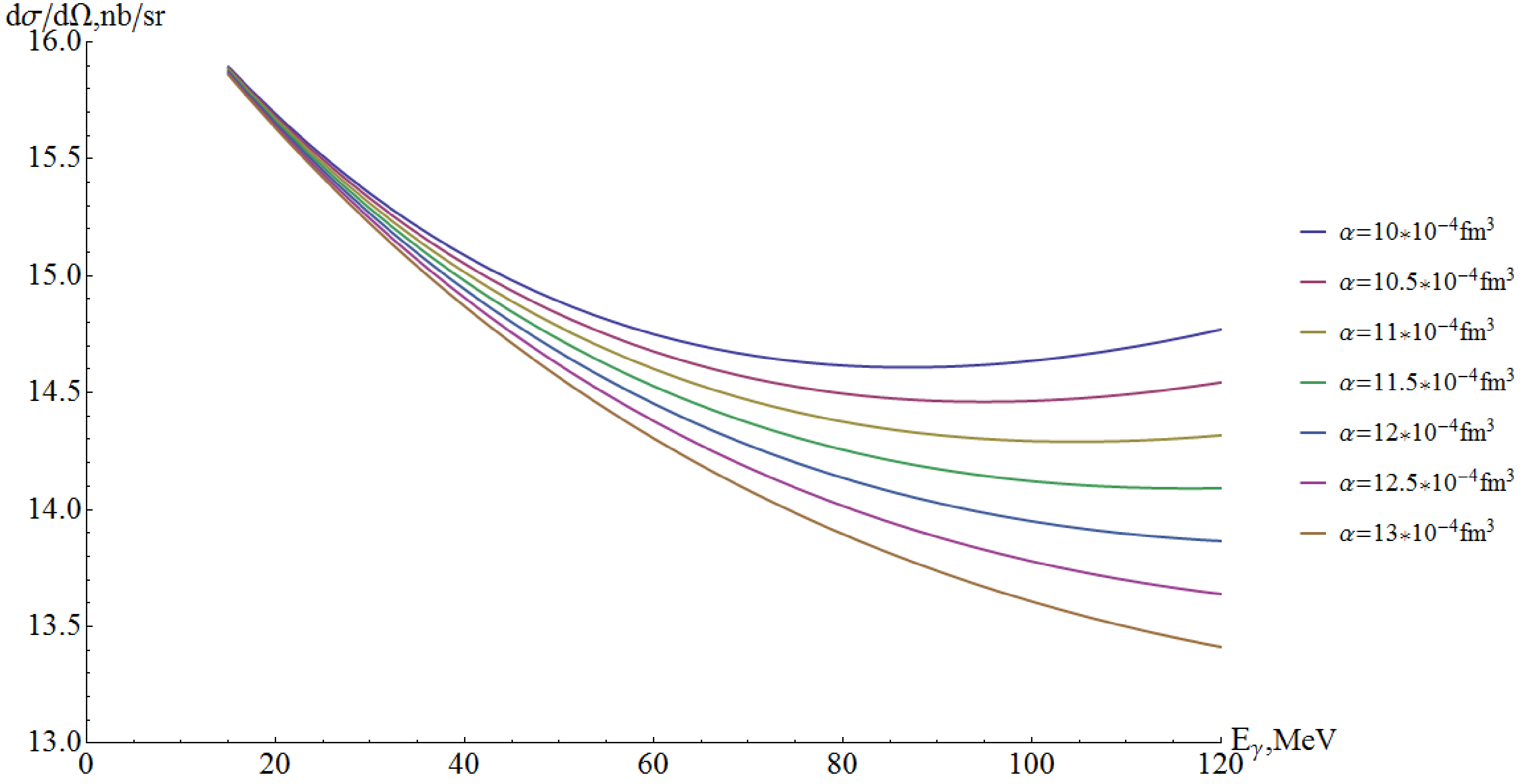
Systematical errors (Nγ) in determination of α and β



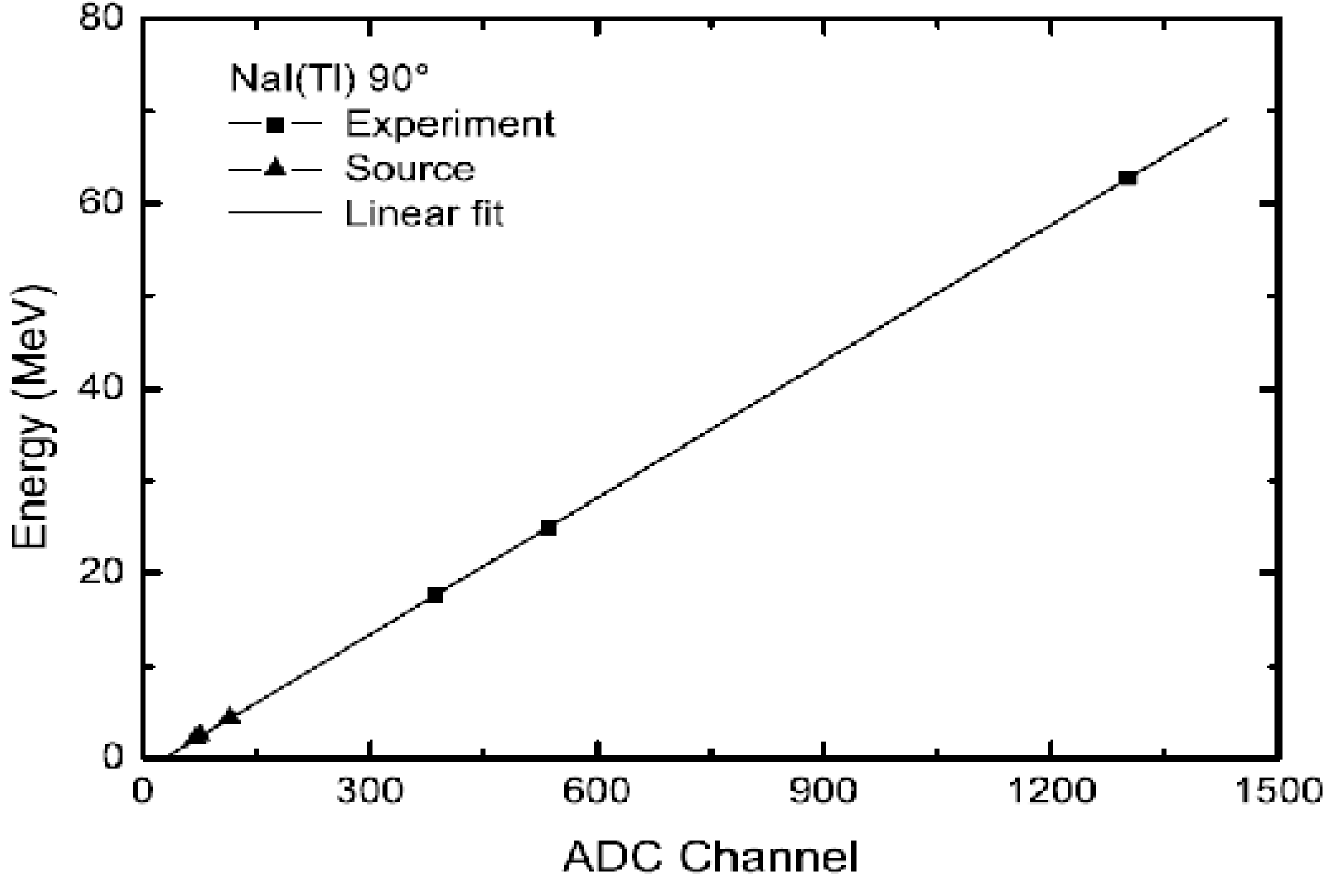
The energy dependence of incident photon beam:

Nγ(Eγ)= F(x)=1/[x(1+Δx)], x=Eγ/Eγmax , Eγmax=100 MeV

Cross section for Compton scattering (θγ = 130°)

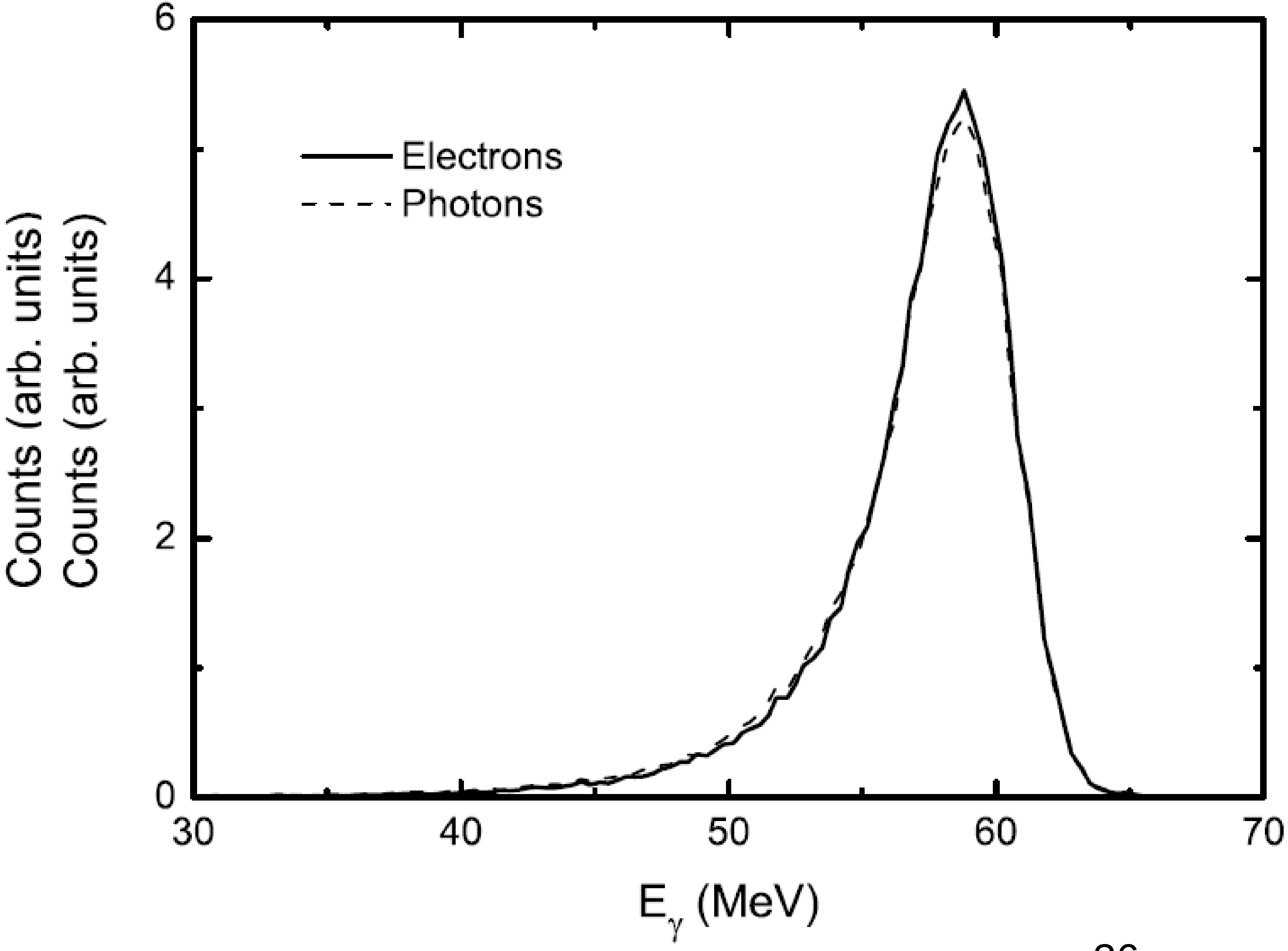


Energy calibration of one of the NaI spectrometers

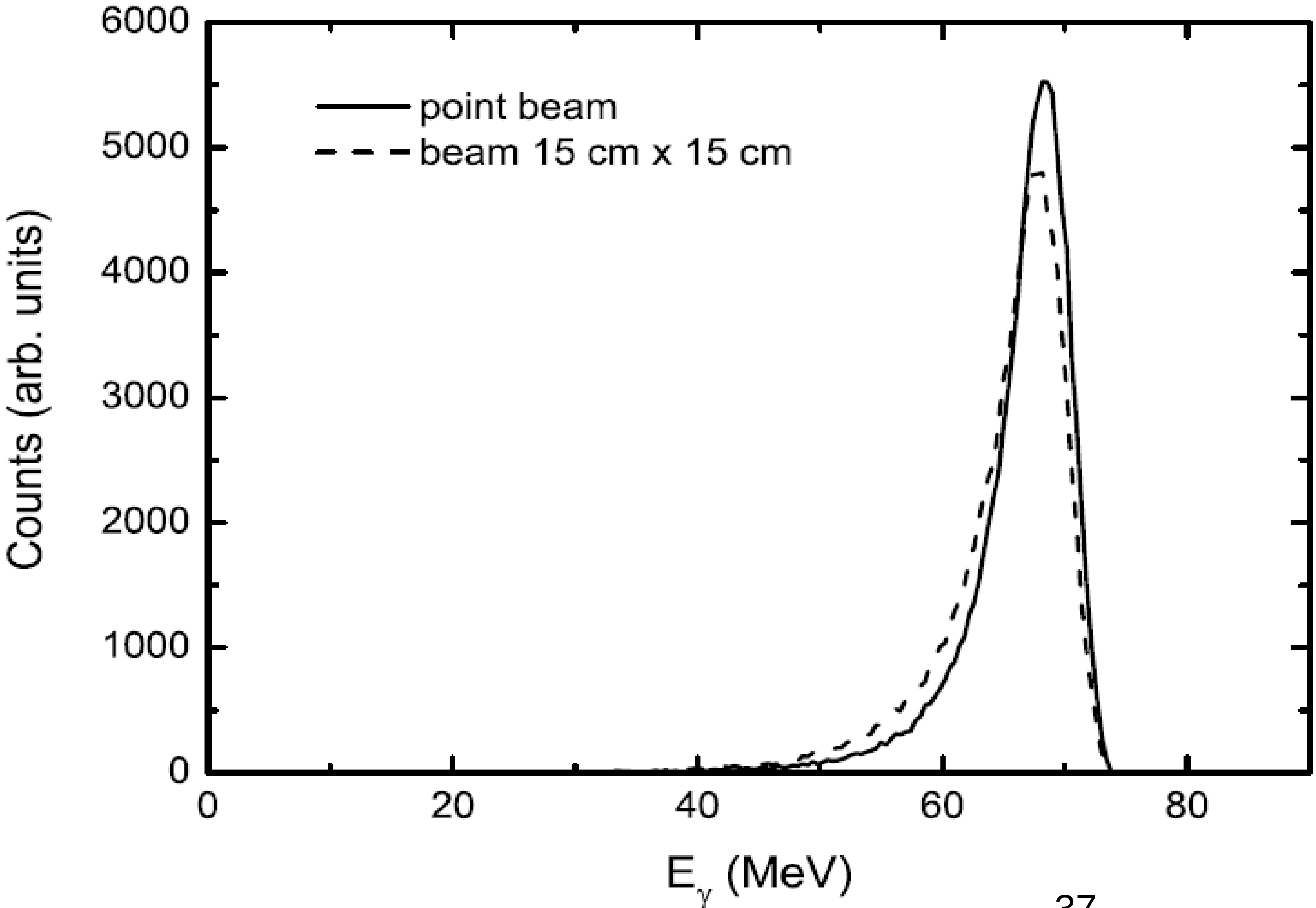


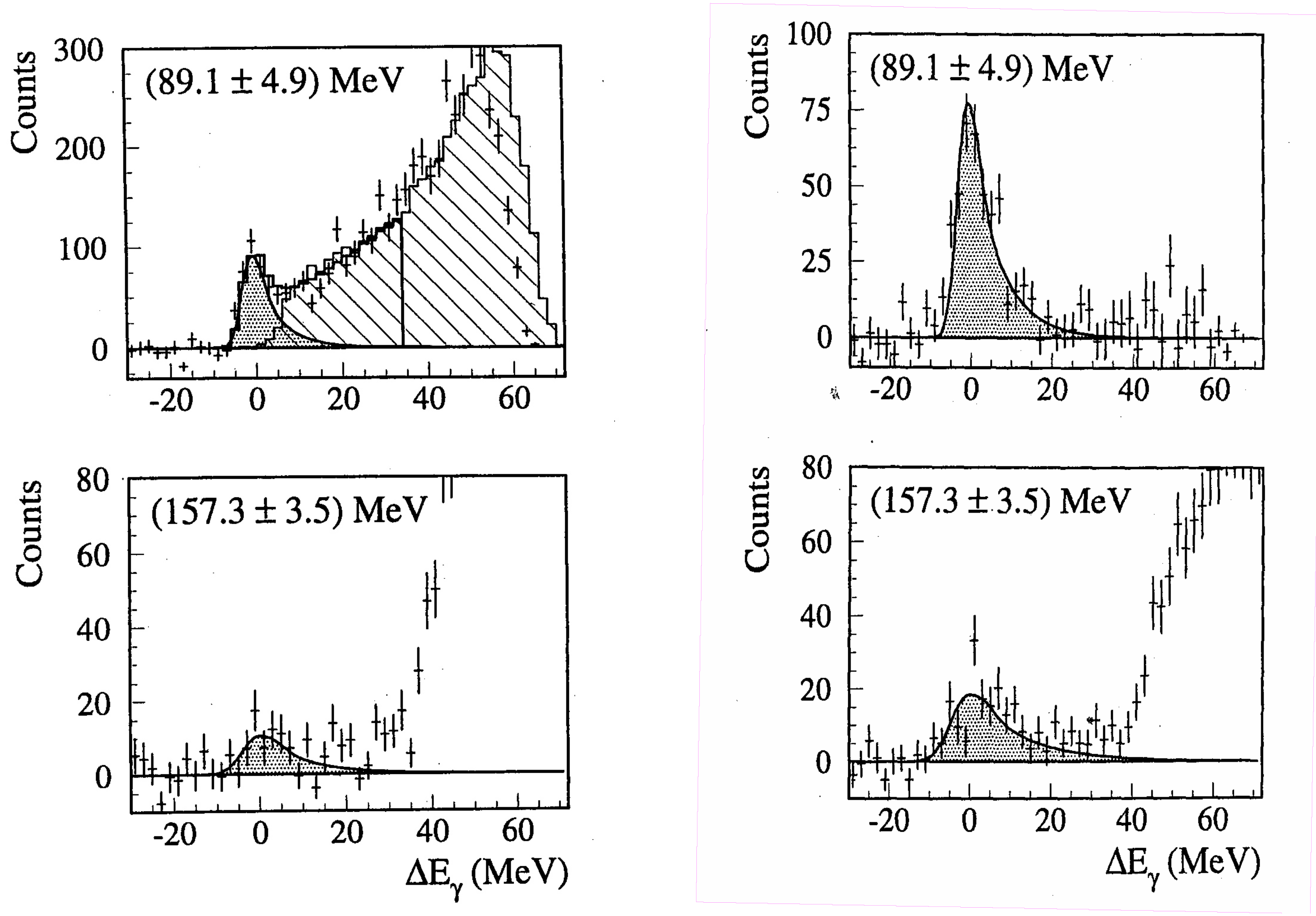
▲ – 60Co (1.3 MeV) and Am-Be (4.4 MeV) γ sources; ■ – calibration with e-A scattering

Responce function of NaI(10”x14”) detector for E=60 MeV



Response functions of NaI(10”x14”)detector for E=70MeV





Mainz (TAPS), Eur. Phys. J. A 10, 207 (2001)

PNPI fabricated a new IC with the relevant electronics

Main parameters of the new IC:

1) Anode and cathode dimensions:
width – 15 cm, length (along the beam direction) –20cm, the cathode-grid distance of 26 mm, the anode-grid distance of 1.3 mm, two segmented of the anode planes: 20 strips of 3 mm width.
2) Filling gas: H_2, D_2, $He3$, $He4$.
3) Pressure: 50-100 bar.
4) Total volume of ionization chamber -6 litres