Future experimental prospects for polarizability measurements

New experimental method for investigation of the nucleon polarizabilities at MESA

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on behalf of

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Cross section for Compton scattering at low energy

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

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

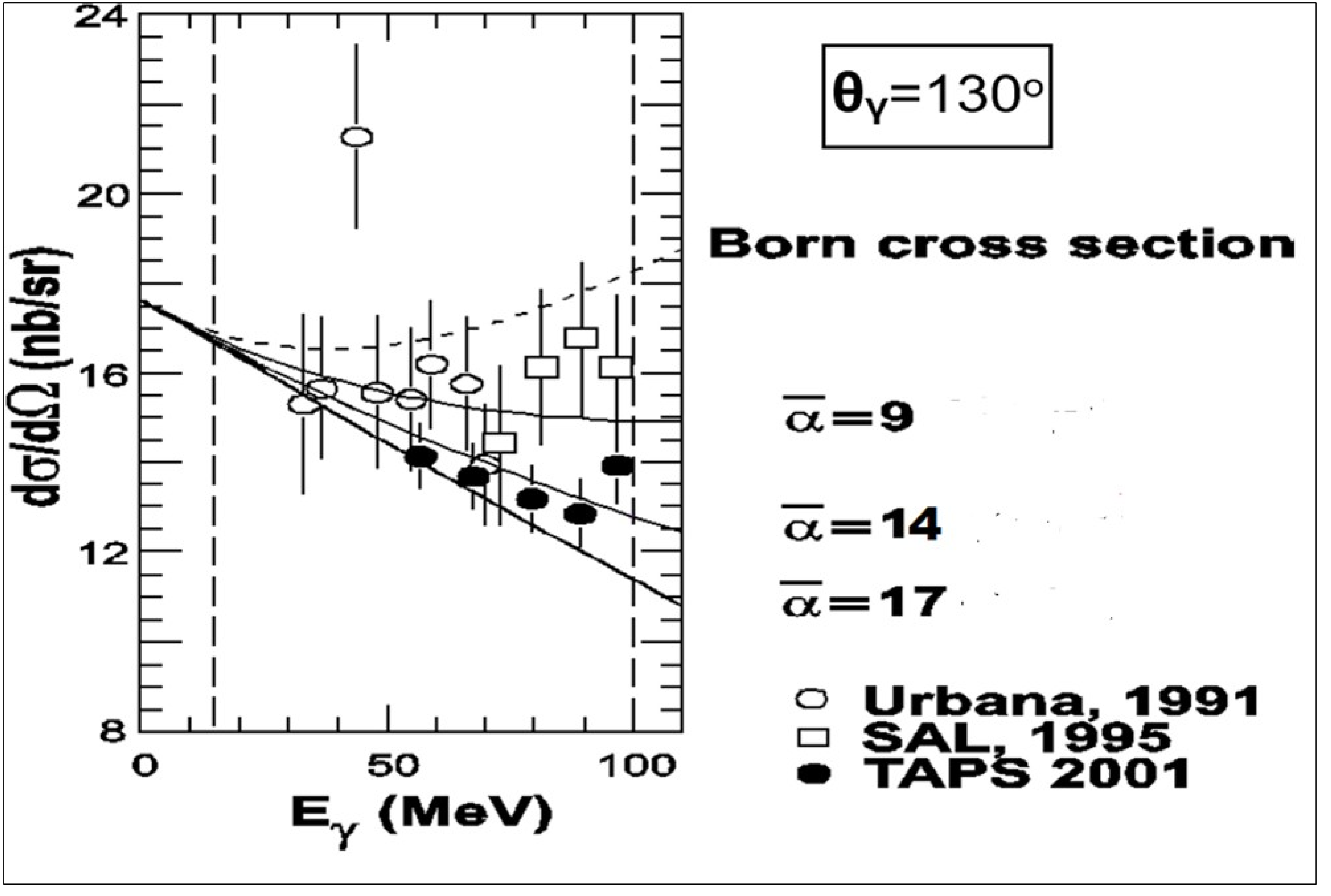
$$\times \left[\frac{\overline{\alpha}+\overline{\beta}}{2}(1+\cos\theta)^2 + \frac{\overline{\alpha}-\overline{\beta}}{2}(1-\cos\theta)^2\right]$$

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

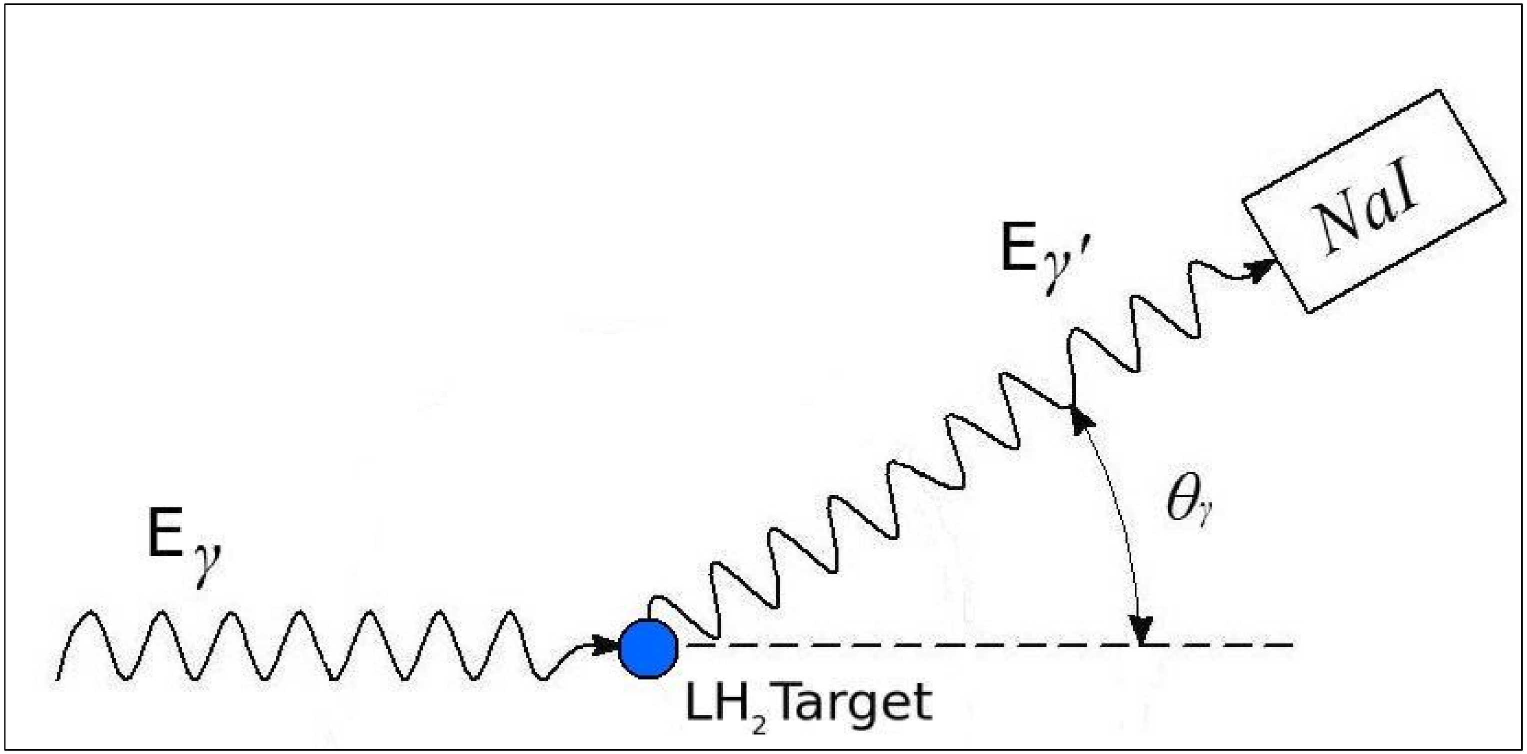
LET-formula describes the γ-p scattering with high precision at Eγ <100 MeV.

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

Low energy (Eγ <100 MeV) Compton scattering data

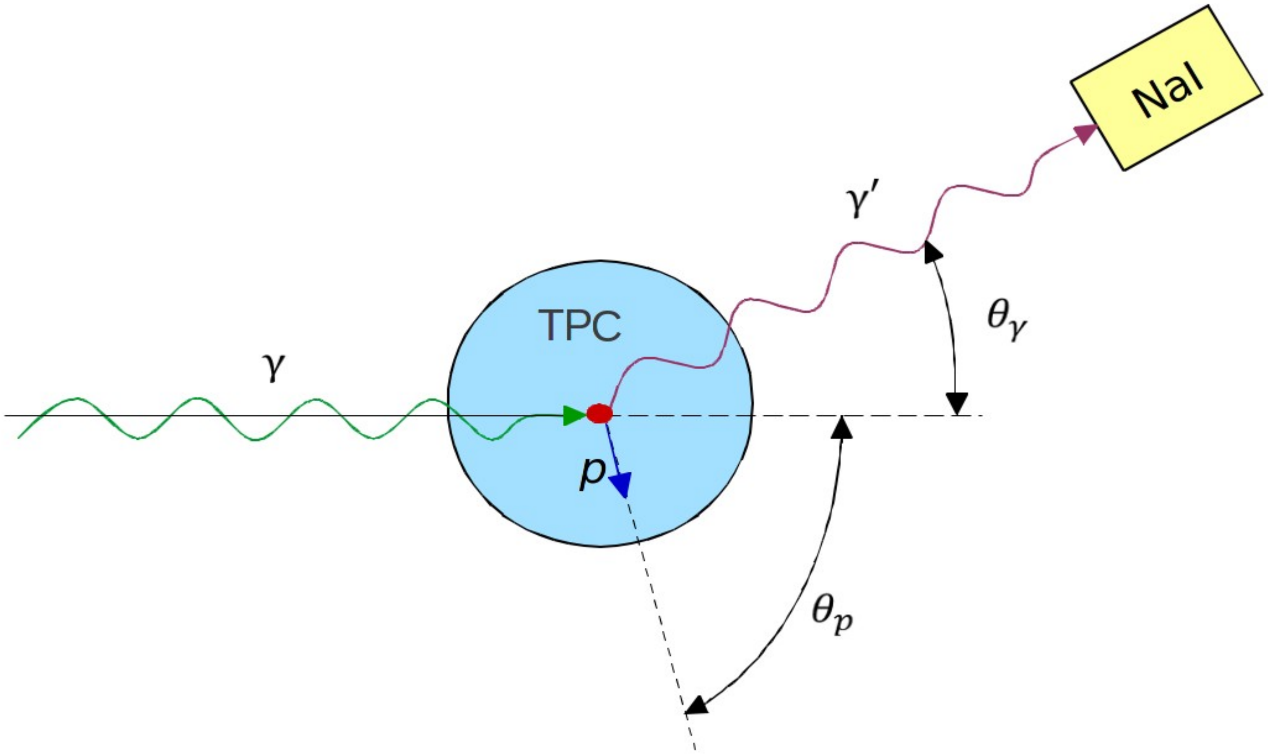


Typical tagged photon beam Copmton scattering experiment



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

Compton scattering using γ-p coincidence technique



TPC
active target

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

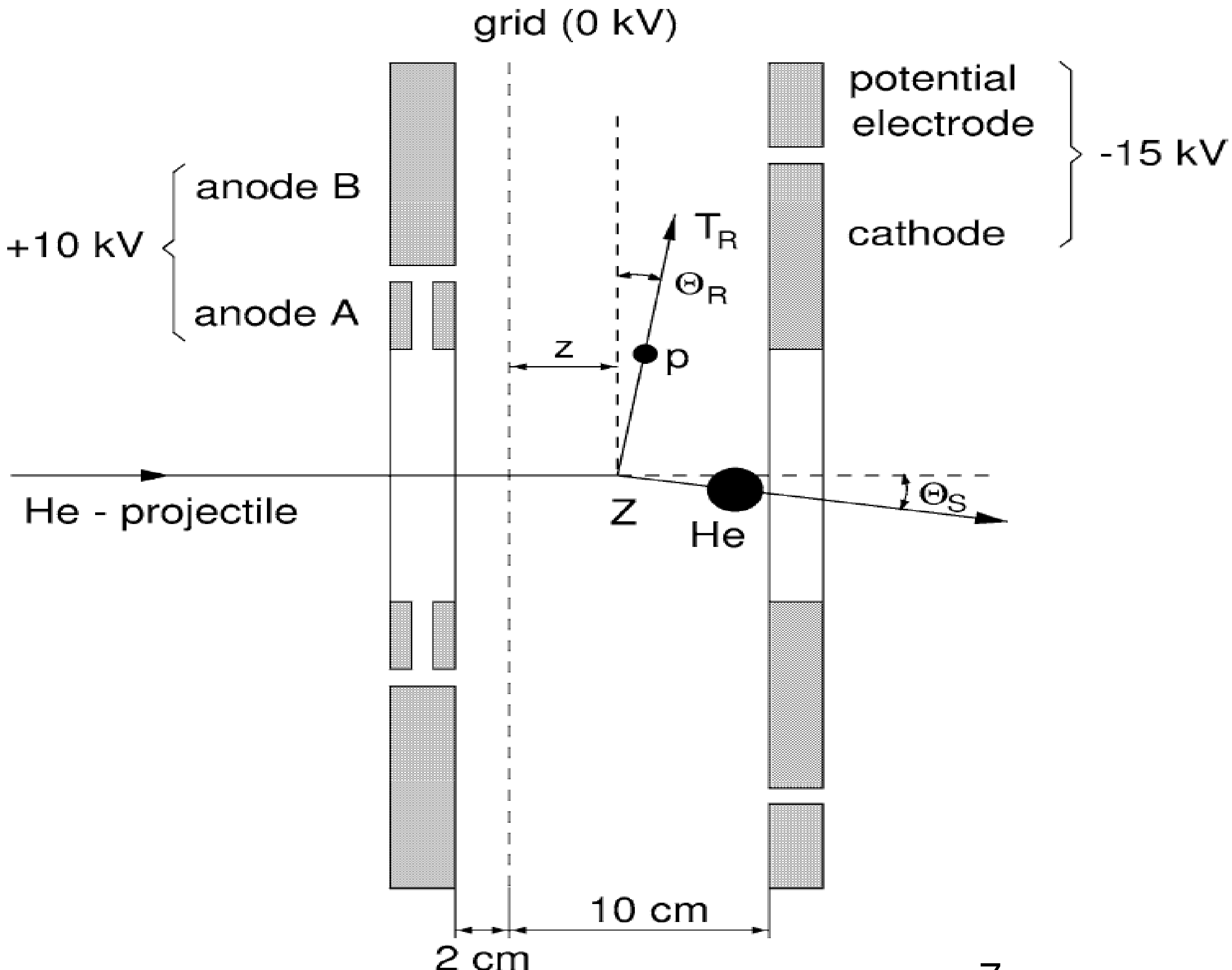
Ionization chamber (TPC) as active target

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

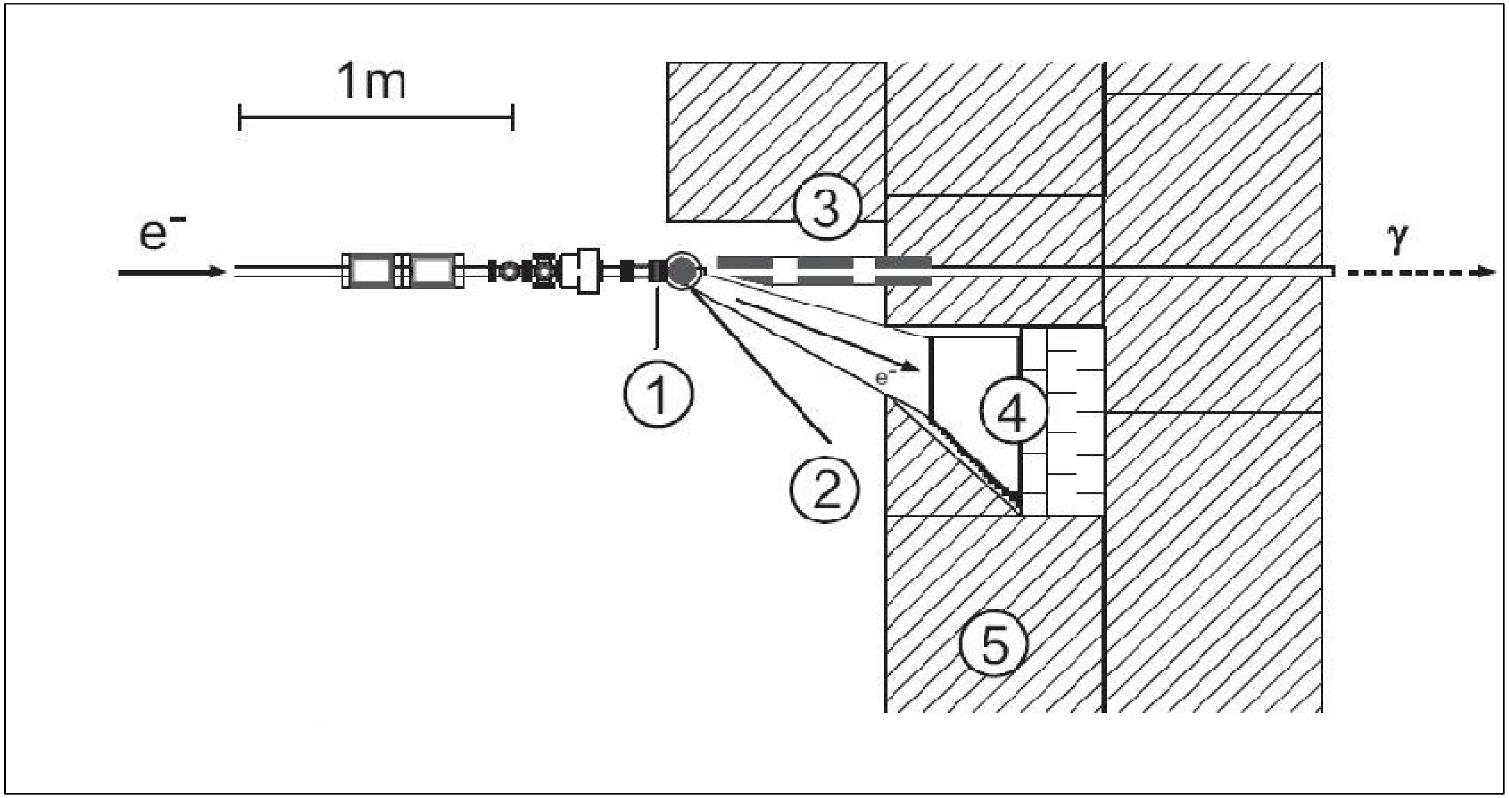
active target properties:

- 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. (no wall related background)

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

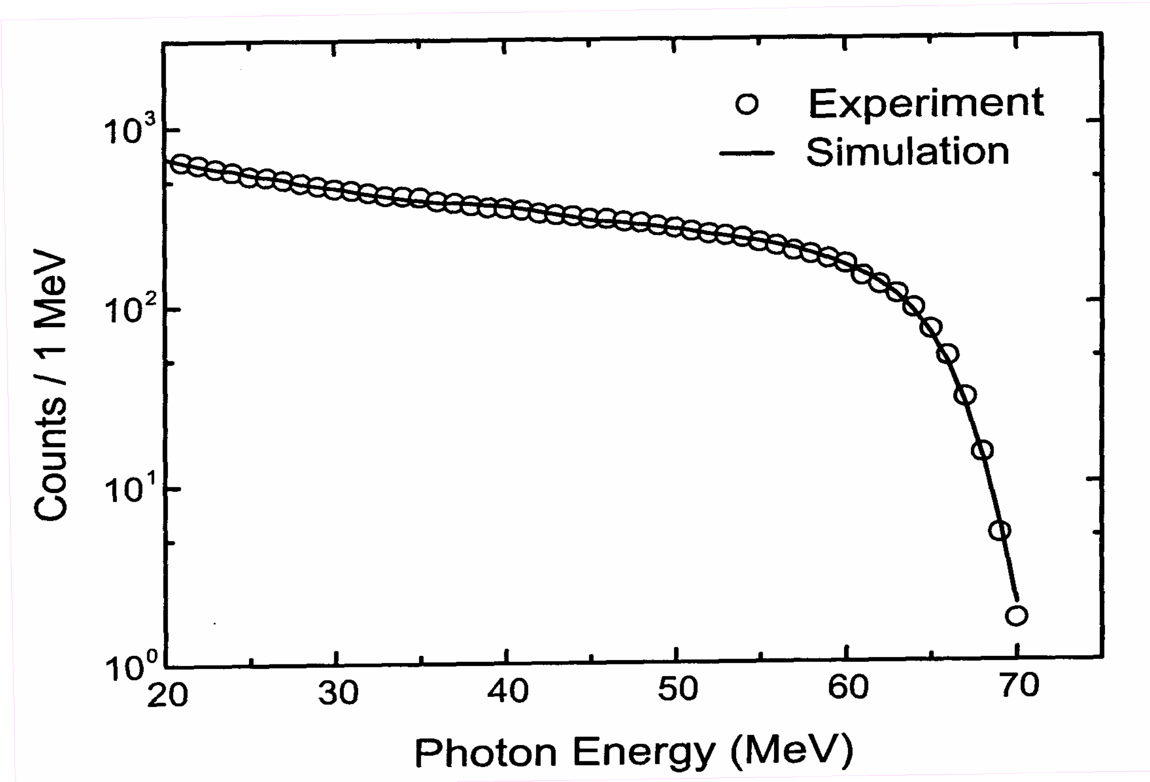


Test experiment at IKP Darmstadt. Setup of bremsstrahlung facility



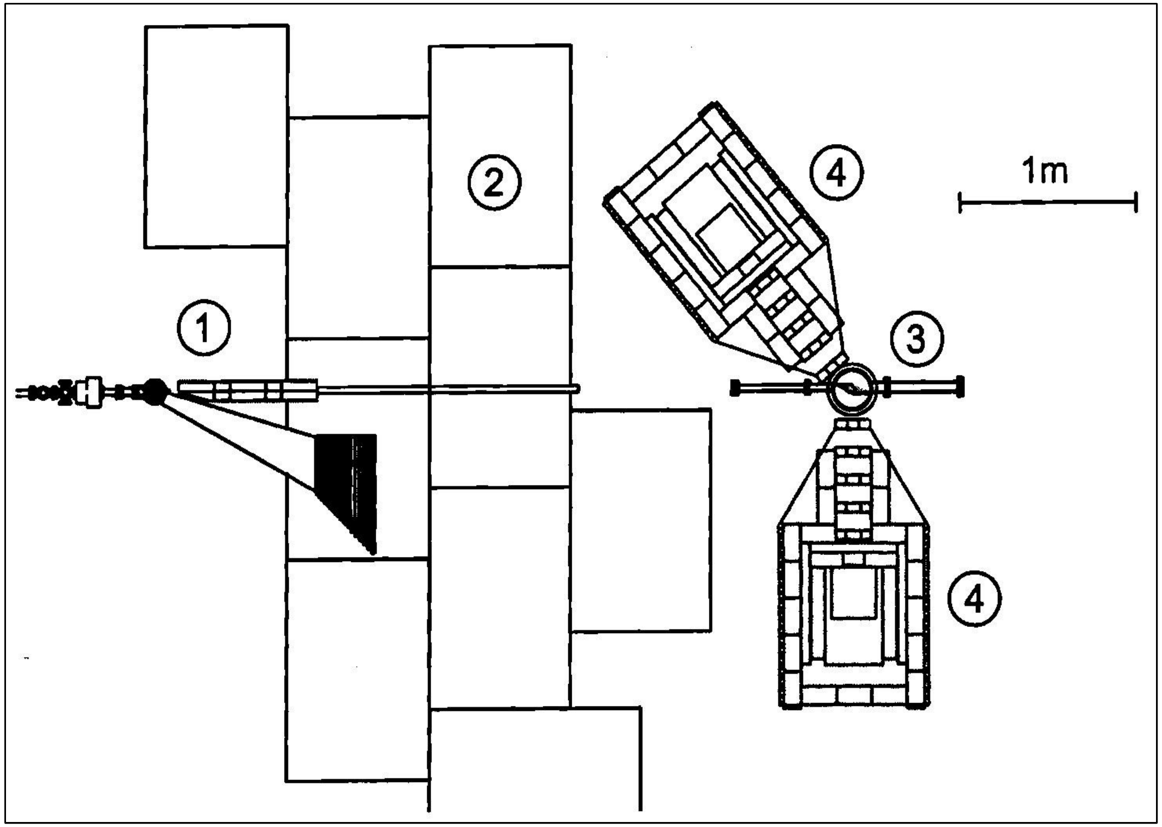
1 – bremsstrahlung converter target (0.3mm gold), **2** – cleaning magnet,
3 – **γ-** beam collimator, **4** – electron beam dump (Faraday cup), **5** – concrete shielding

Bremsstrahlung spectrum at 70MeV electron beam in IKP Darmstadt



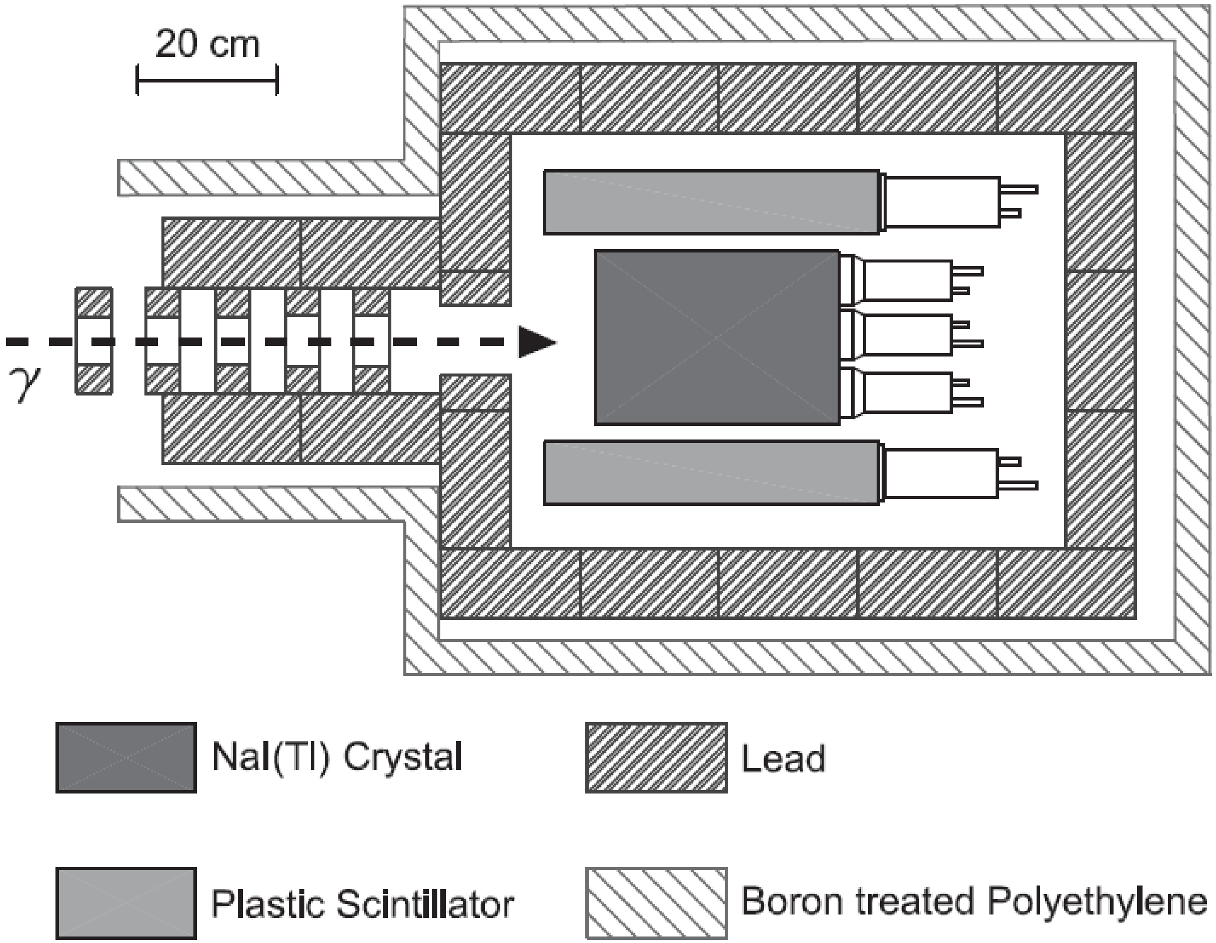
Untagged bremsstrahlung photon spectrum measured in the test experiment at S-Dalinac (IKP Darmstadt). The electron beam energy is 70 MeV. The Geant 4 routine was used for simulation of the bremsstrahlung photon spectrum.

Test experiment setup at IKP Darmstadt

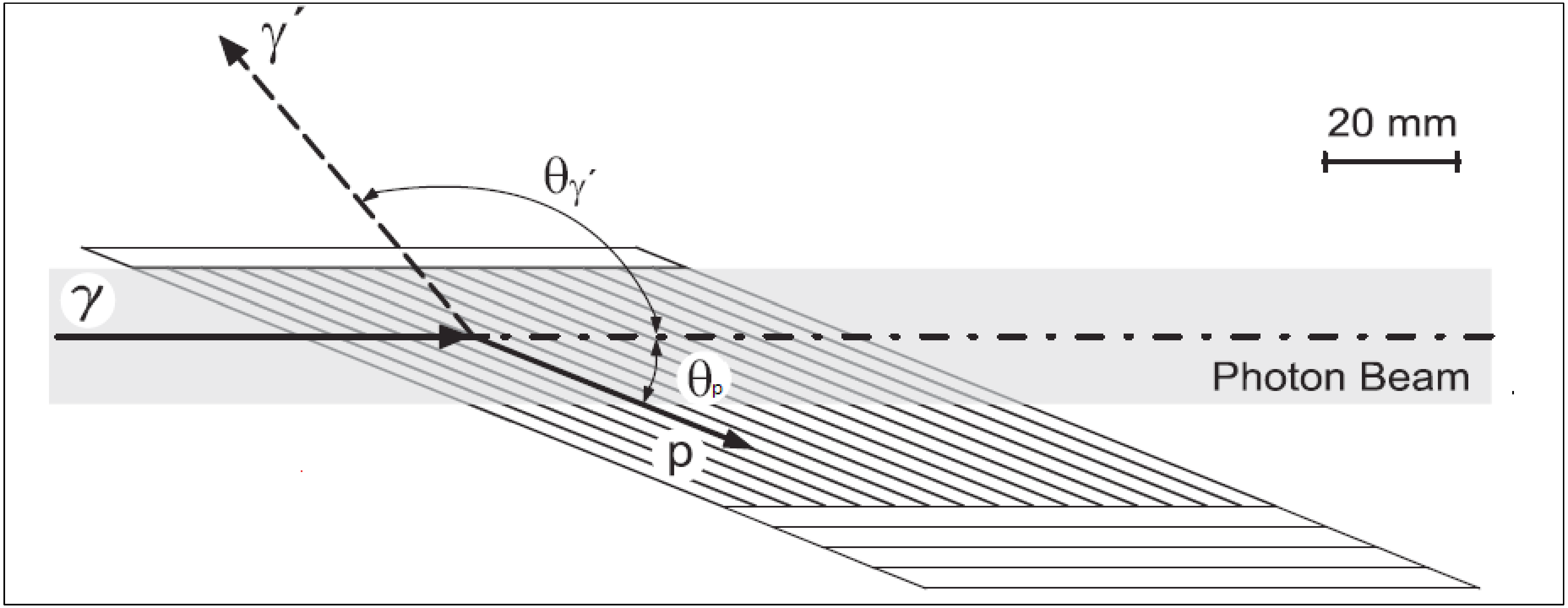


1 – bremsstrahlung facility, 2 – concrete shielding, 3 – high pressure ionization chamber (active target), 4 – γ-detectors (NaI) at θγ=130 and θγ =90 deg.

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

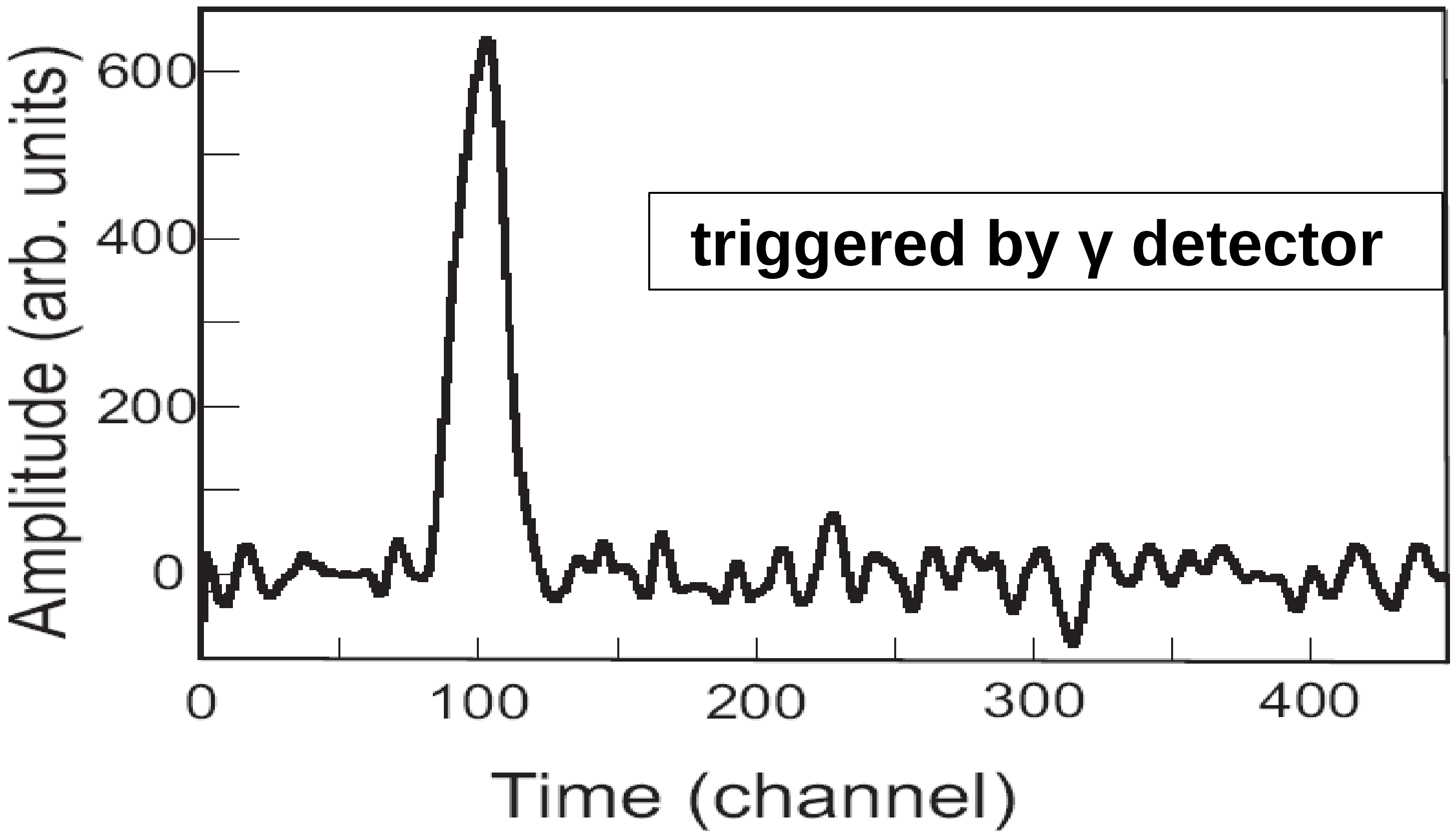


Top view on a multy-strip anode plane at θγ=130°



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.

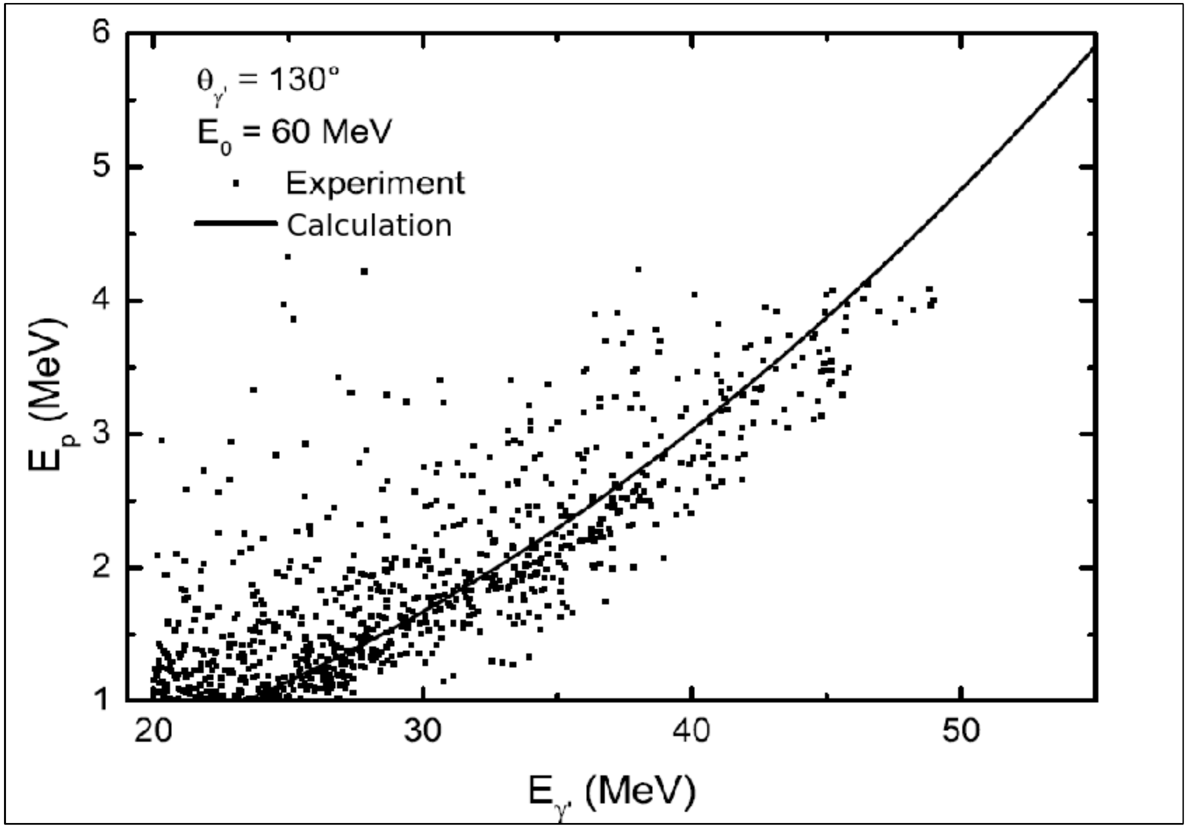
Example of a signal in TPC from 2 MeV recoil proton, registed by FADC



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

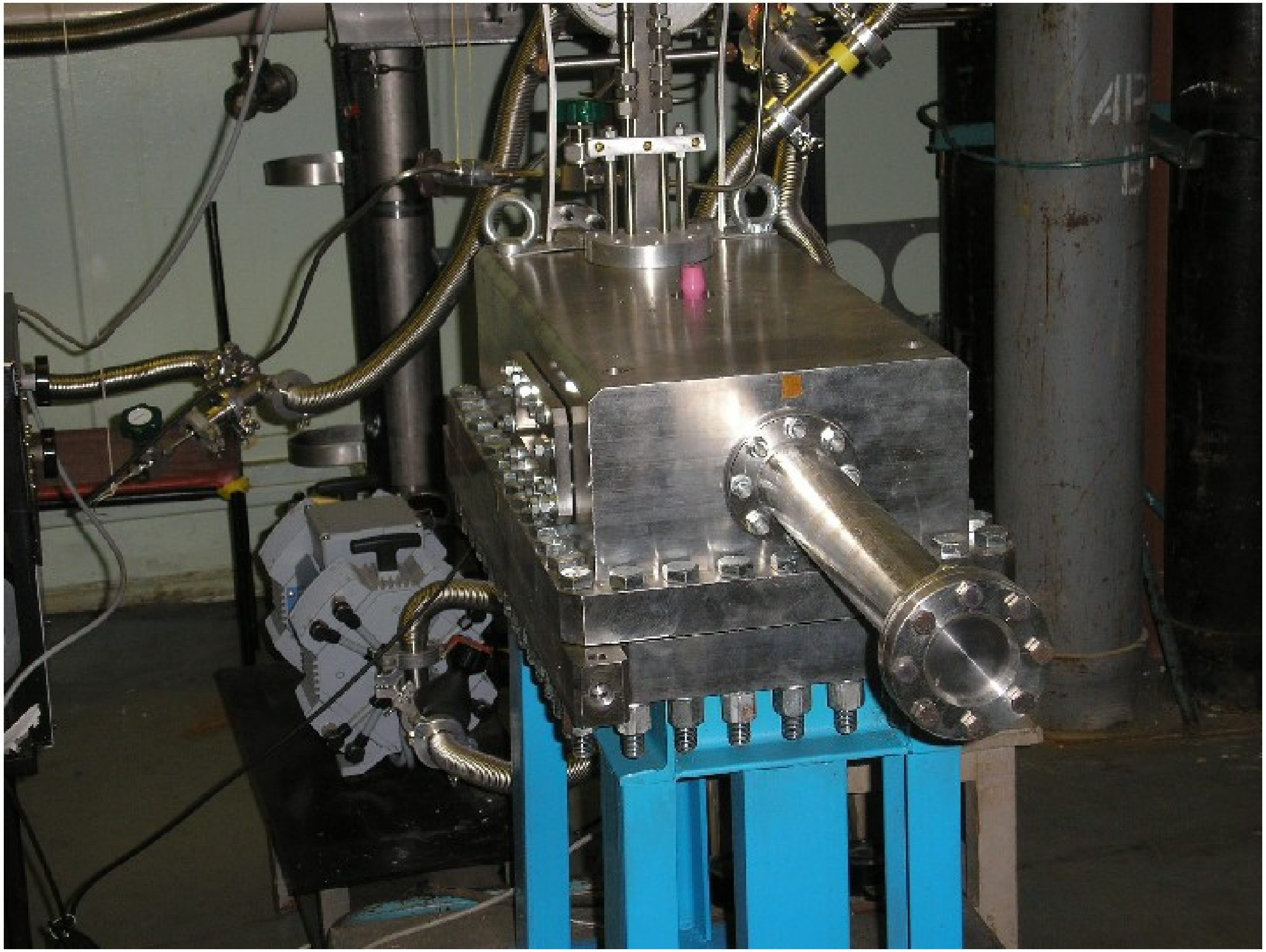
Ep- Eγ correlations.

Not enough statistics !!

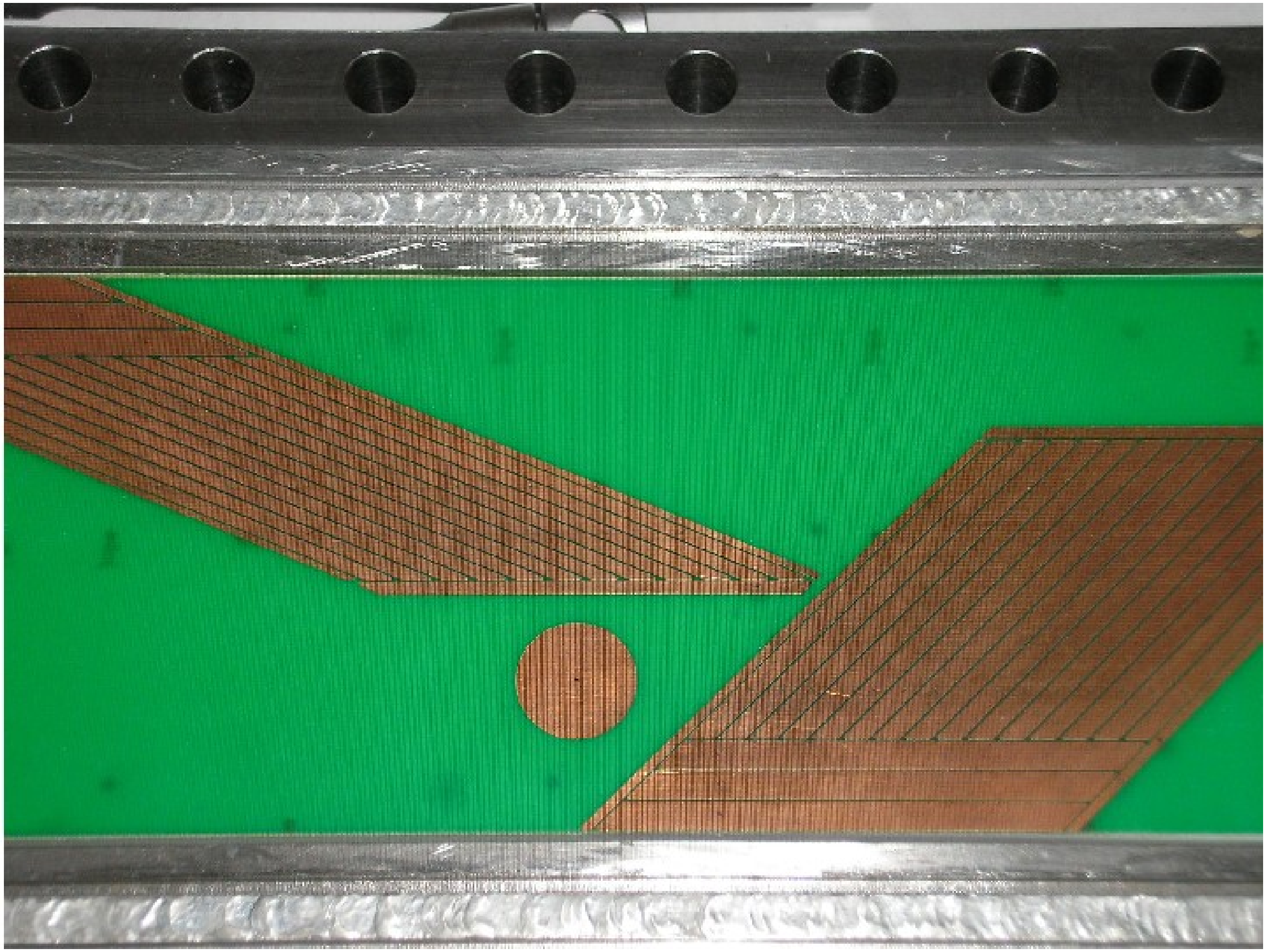


Ep- Eγ correlations in γ-p scattering experiment at IKP at electron beam energy 60MeV and θγ=130deg. The calculation is pure kinematic correlation.

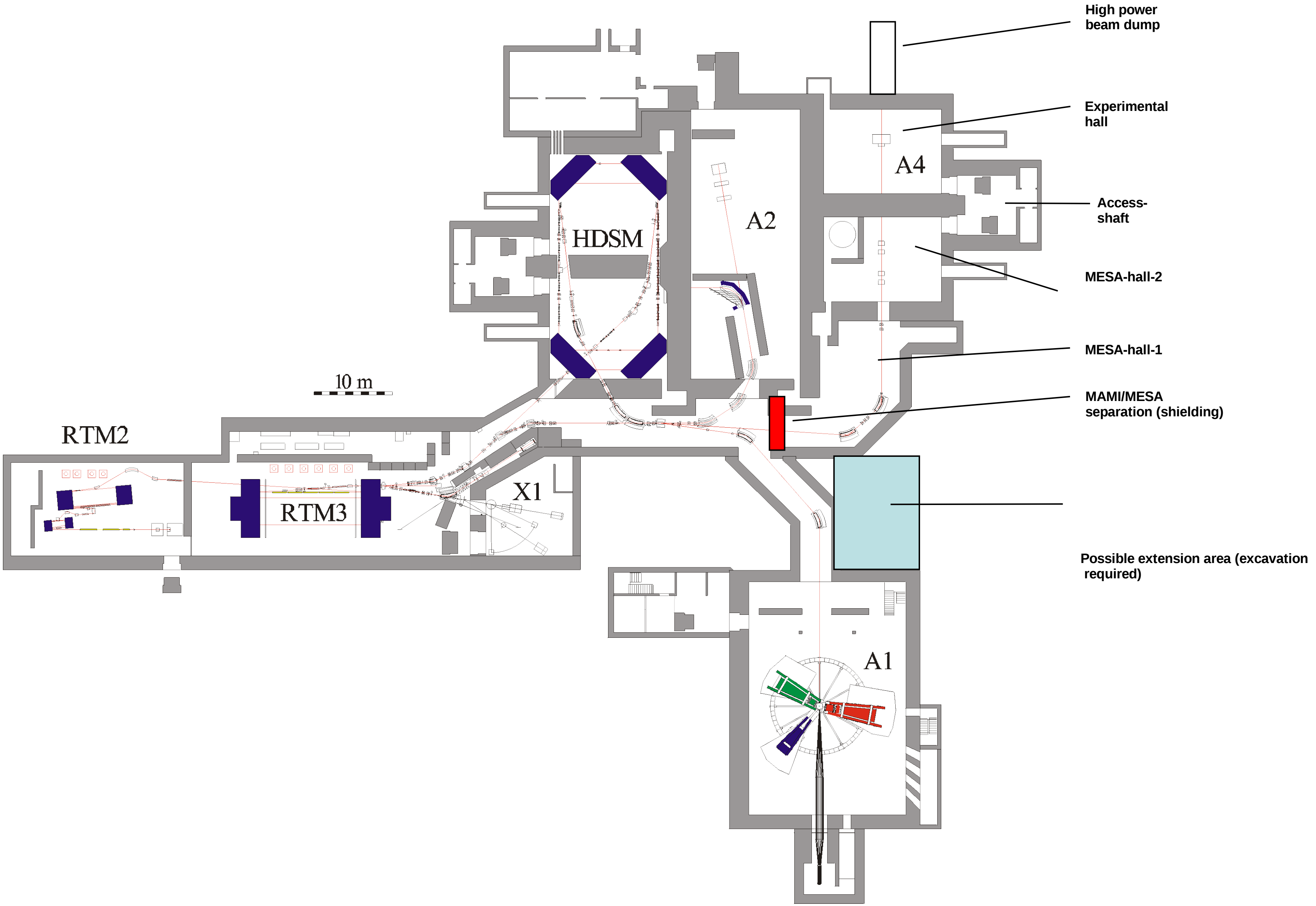
Newly fabricated TPC for Compton scattering experiments



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



MAMI and MESA



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 (2014)	α_p=11.2 ±0.4,	β_p = 2.5 ±0.4
PDG (2010)	α_p=12.0 ±0.6,	β_p = 1.9 ±0.5

Mainz (2001) α_p= 11.9 ±0.5 ±1.3, β_p = 1.2 ±0.7 ±0.3

Deuteron target

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

Counting rate estimation at MESA

- electron beam **$Ee = 110\ MeV$, $Ie = 50\mu A$**
- 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.*
  $\boldsymbol{\delta}\ (Ep) = 30\text{-}40\ KeV$

Expected count rate 5 s-1

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

Conclusion

We propose a coincidence method to precisely measure differential cross section of γp Compton scattering using untagged bremsstrahlung photon beam ($E\gamma$ <100 MeV) of the MESA facility (under construction). The experiment aims at high precision of proton and neutron polarizability measurements.

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