Polarization capabilities of AGATA

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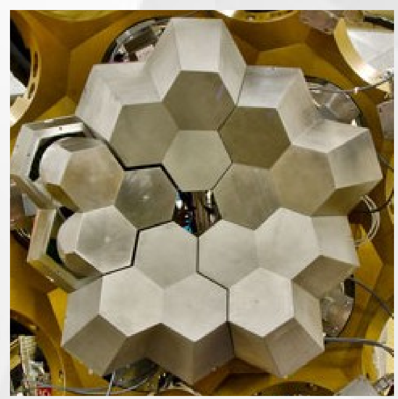

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Linear polarization measurements

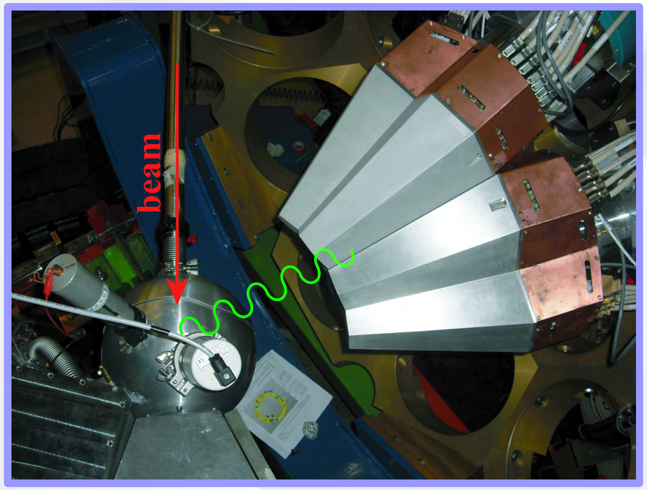
- Measurements of the linear polarization can provide information on the type of multipolarity (electric or magnetic) of γ transitions, hence on the parity of the deexciting nuclear level.
- The angular distribution of Compton scattering is sensitive to the linear polarization of the incoming radiation:

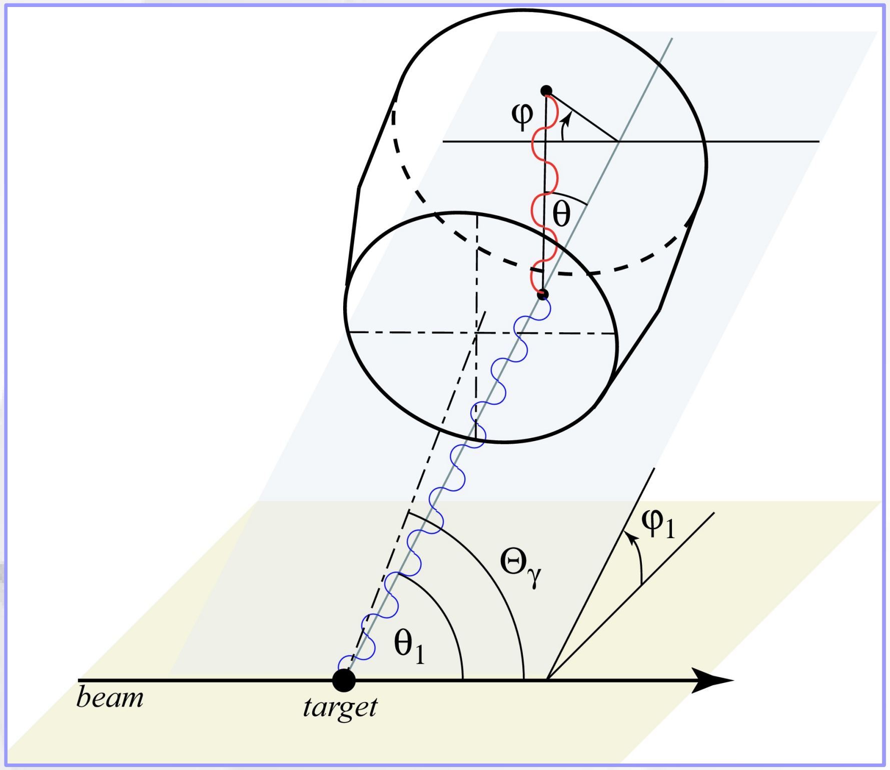
$$\frac{d\sigma}{d\Omega}=\frac{r_0^2}{4}\left(\frac{k}{k_0}\right)^2\left[\frac{k_0}{k}+\frac{k}{k_0}+2\left(\cos^2\theta-P\sin^2\theta\, cos2\varphi\right)\right]$$

  where P is the polarization and φ is the azimuthal angle.

- In the usual Compton polarimeters, the cross section is measured only at a few values of φ . With the tracking of the Compton scattering, the complete angular distribution can be measured.
- The advent of the AGATA array offers the possibility of detecting linear polarization with hight efficiency.

AGATA modules as Compton polarimeters





- Two AGATA Demonstrator modules (six counters) positioned in a way to select γ not far from 90º with respect to the beam direction
- Reaction: ^{12}C beam @ 32MeV onto enriched 1 mg/cm^2 ^{104}Pd and ^{108}Pd targets
- Partially polarized γ rays are produced by CoulEx of the first excited states in ^{104}Pd and ^{108}Pd, which deexcite by emission of 555.8keV and 433.9keV γ rays, respectively.
- In addition, measurement of the distribution of unpolarized γ rays from a ^{137}Cs (661.7 keV) source have been performed.

module	Counter	Angle to the beam	Azimuthal Angle
I	3	105.4	3.7
I	4	101.1	18.2
I	5	90.8	6.3
II	6	117.2	15.8
II	7	128.2	27.8
II	8	112.9	32.4

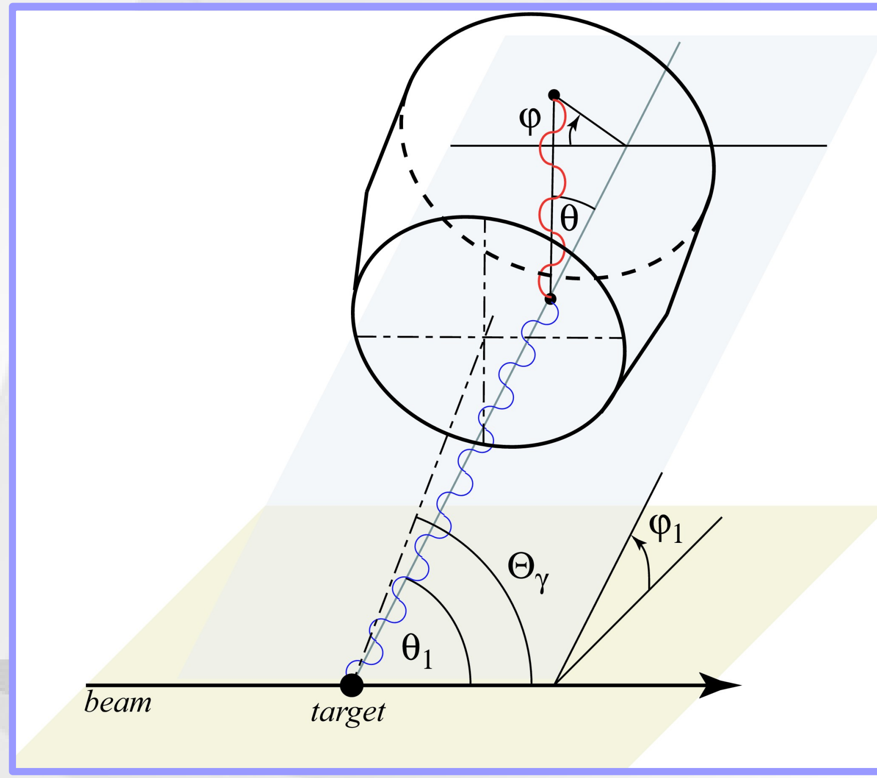
Analysis in ^{104,108}Pd

$$\Theta_\gamma \approx 90^o$$

θ → from the energy released to the e- → θ_E

↘ from the position of the 1st and 2nd interaction points → θ_G

$$\Delta = |\cos\theta_E - \cos\theta_G|$$



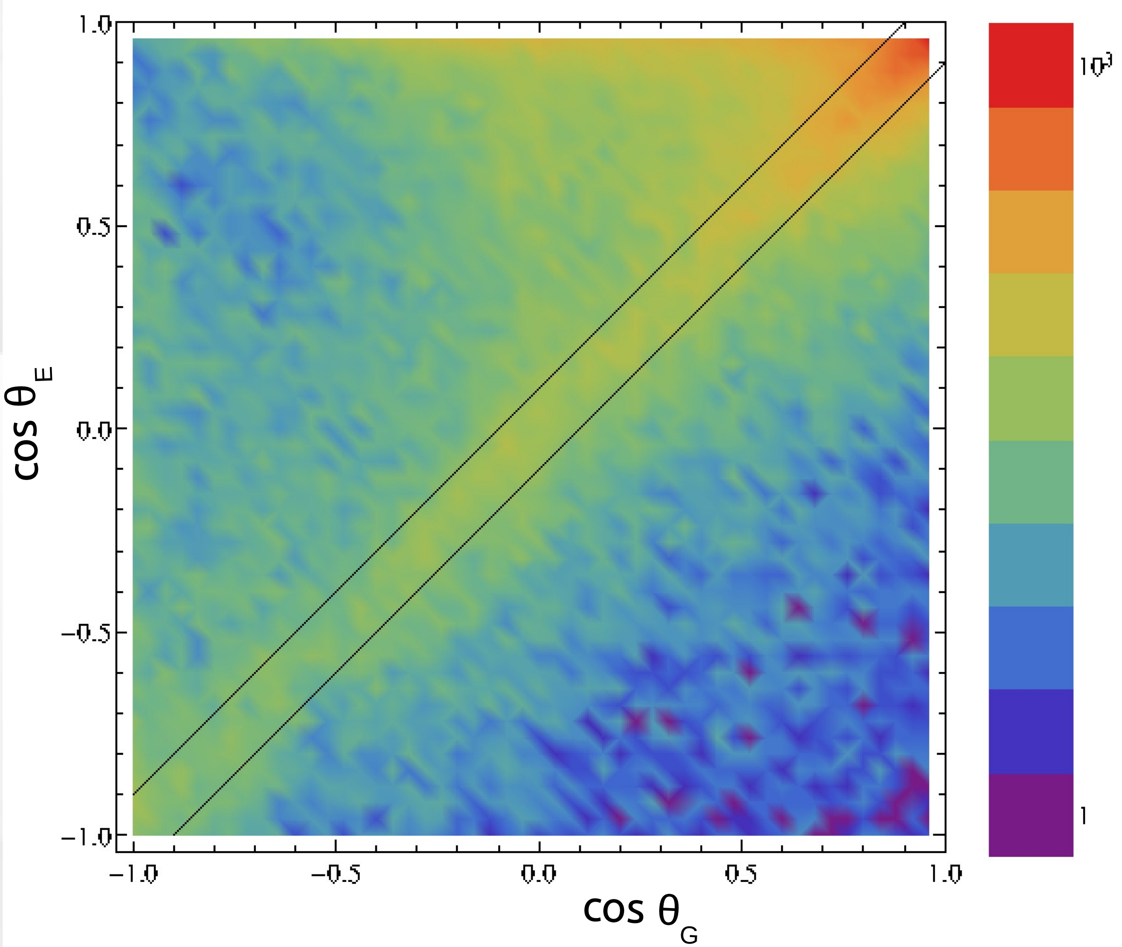
The angular distribution in φ are built setting cuts:

- on the distance between the 1st and 2nd interaction points r_{12}
- on the difference Δ
- on the value of $\cos\theta$

Note: we have accepted only those events for which the 1st and 2nd interaction points are in the same module

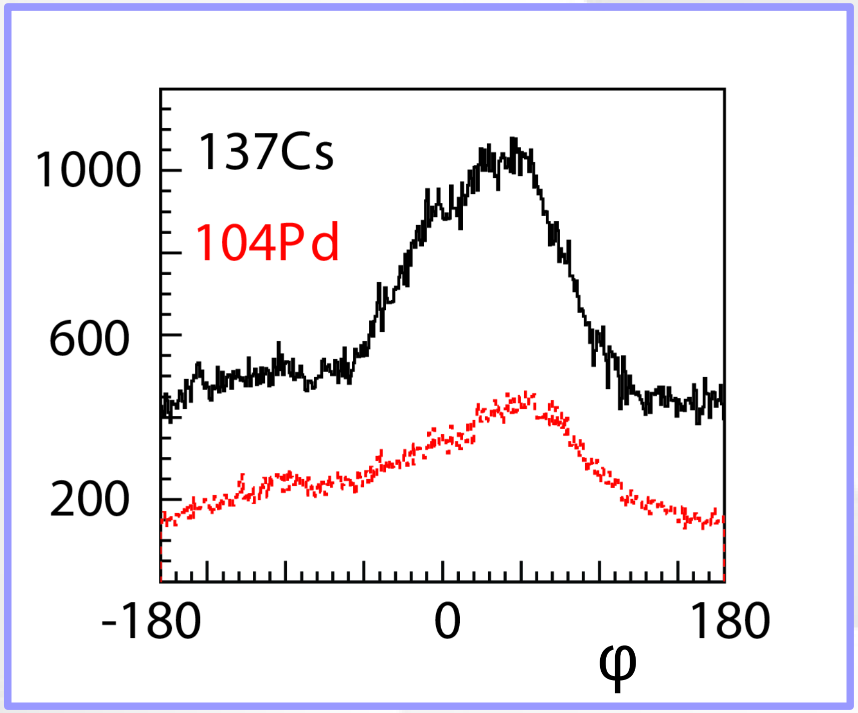
Scatter plot of $\cos\theta_E$ vs $\cos\theta_G$

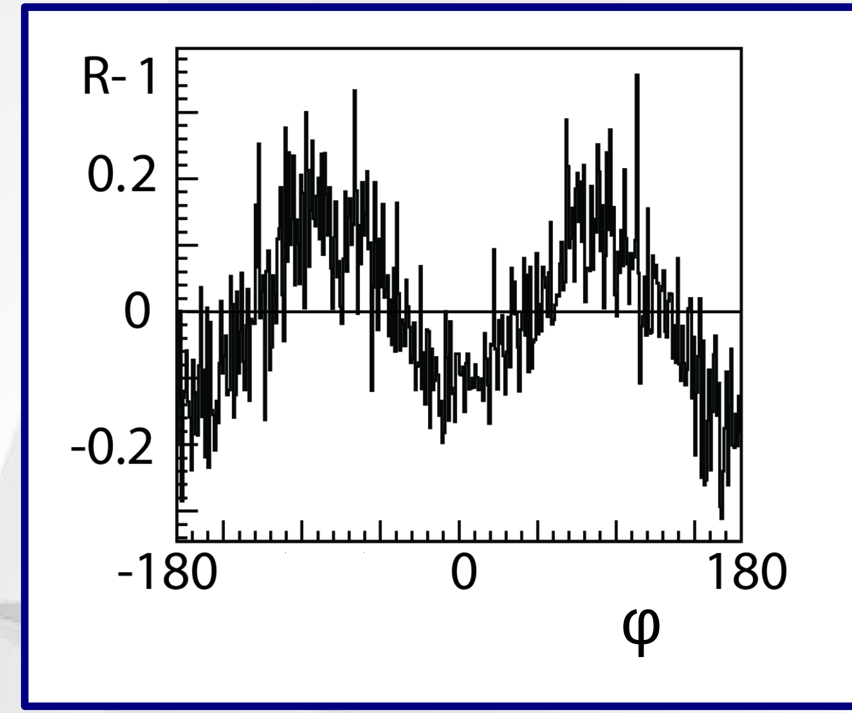
The events corresponding to the real Compton scattering of 555.8 keV gamma ray cluster around the diagonal



$\Delta = |\cos\theta_E - \cos\theta_G| < 0.1$

Distribution in φ for the counter # 5 (at ~ 90° to the beam)





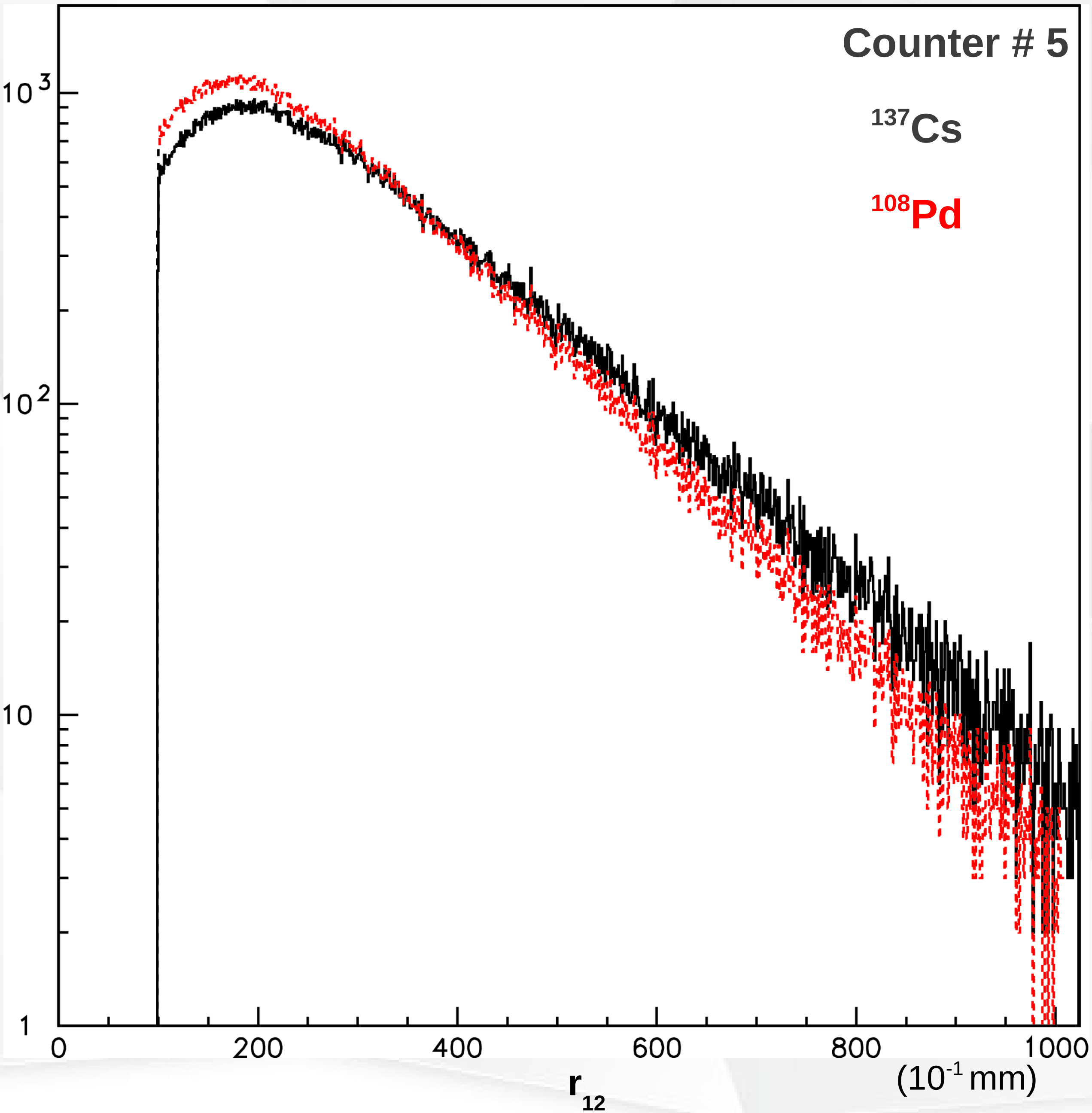
$$R(\varphi)=\frac{F_{Pd}(\varphi)}{F_{Cs}^{corr}(\varphi)}$$

the expected dependence on cos2φ shows in the ratio

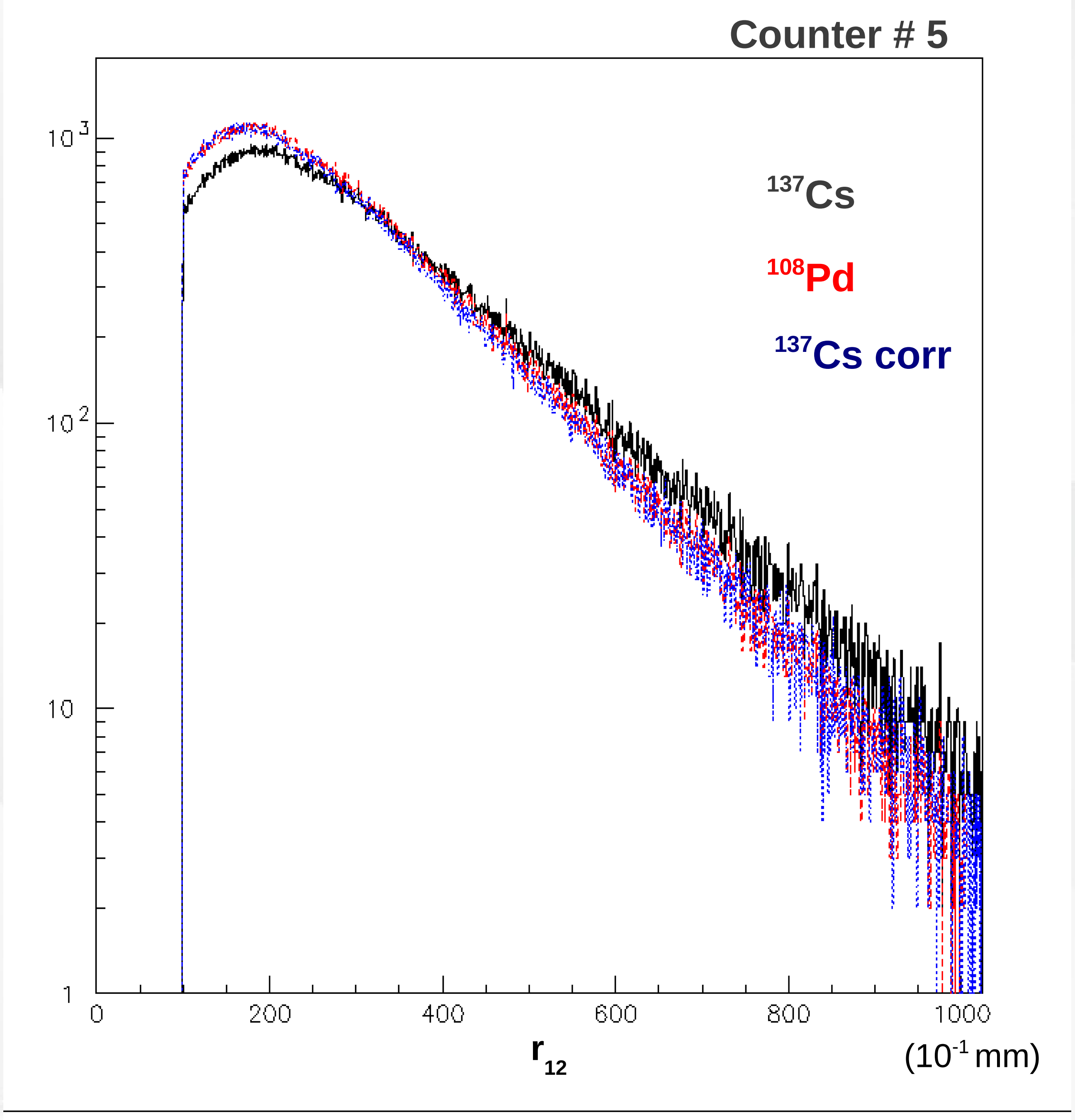
NOTE: The comparison with the distribution in φ of ^{137}Cs can raise some criticism due to the different energies of the γ . To take into account this difference at each event of ^{137}Cs it was assigned a weight

$$p(\theta,r_{12})=\frac{\sigma(E_{Pd},\theta)}{\sigma(E_{Cs},\theta)}\cdot\frac{e^{-\mu(E'_{Pd}(\theta))r_{12}}}{e^{-\mu(E'_{Cs}(\theta))r_{12}}}\cdot\frac{\mu(E'_{Pd}(\theta))}{\mu(E'_{Cs}(\theta))}$$

The r_{12} distribution



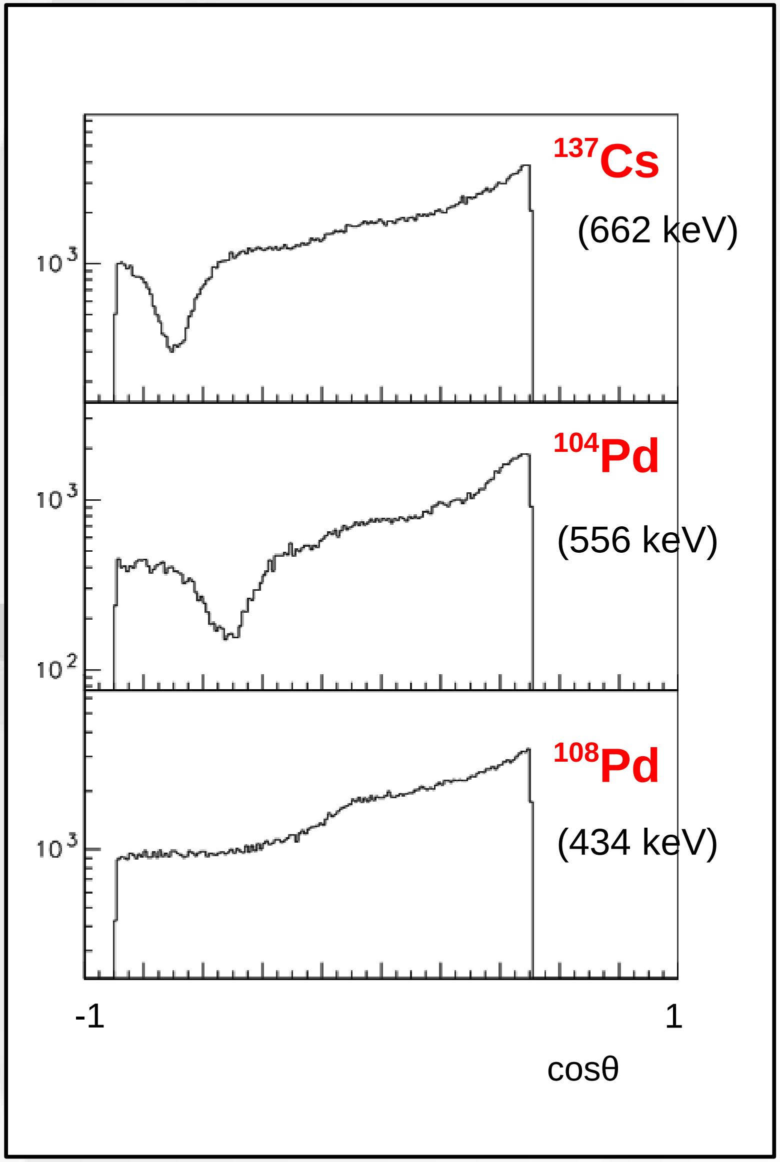
The r_{12} distribution



We observed a ***deep hole*** in the distribution of cosθ of ^{137}Cs and ^{104}Pd (not in ^{108}Pd)

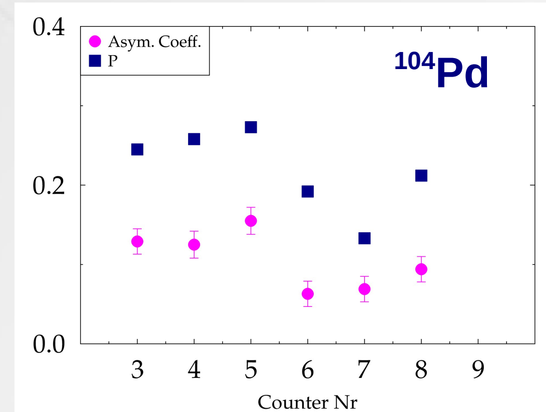
Actually, for E> 511keV there is the possibility that to a certain scattering angle and to its supplementary, corresponds a symmetric energy partition between the e^- and the secondary γ in the Compton scattering.
This happens at cosθ ~ ± 0.64 for ^{137}Cs and cosθ ~ ± 0.39 for ^{104}Pd.
This makes it impossible to establish the order of the interactions for those events having cosθ close to one of these values, when the energy of the primary γ is splitted between two points (2 hits).
To exclude this region in the analysis we have put a cut on cosθ (from -0.35 to 0.35).

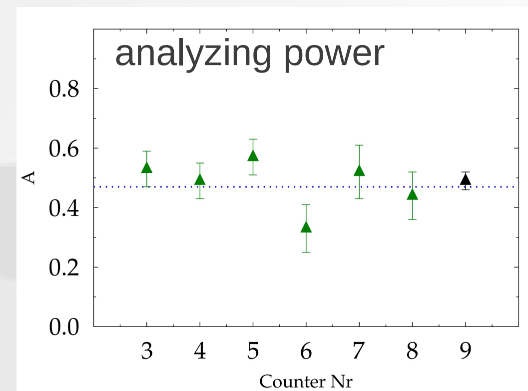
This uncertainty has almost no effect on the determination of the angular distributions and Doppler shift corrections, as the value of the emission angle θ_γ is almost independent of the assumed order of the two interactions.

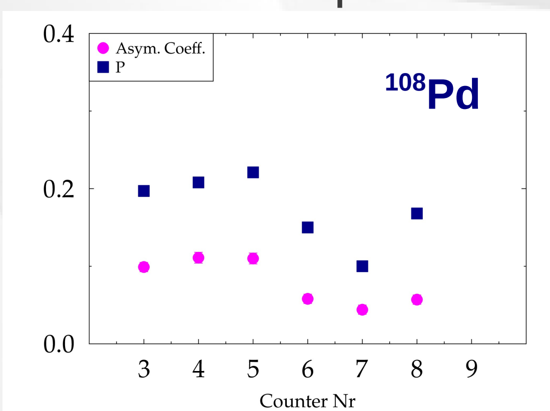


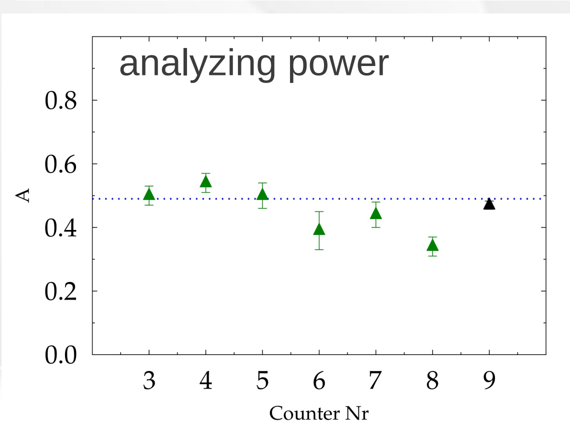
Results for ^{104,108}Pd

The theoretical value of the polarization has been calculated by means of the Gosia code taking into account the small effect of the partial deorientation of excited nuclei exiting from the target into the vacuum (~1%).
The mean values of the analyzing power in each counter is given by the ratio of the measured asymmetry (coeff. of cos2φ in the Fourier expansion) and the calculated polarization.







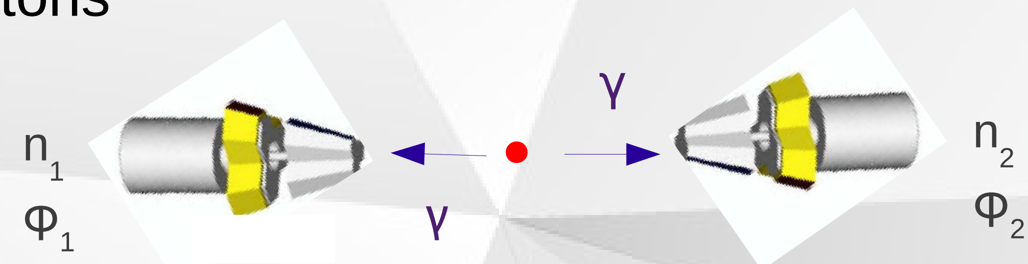


These values can be compared to those obtained by averaging the analyzing powers obtained on an event- by -event basis from the measured value of θ and the expression for the Compton scattering cross section. The latter has been properly corrected (reduced) taking into account the finite spatial resolution.

Quantum entanglement of annihilation photons

Recently, we have performed a measurement of the linear polarization correlations of two entangled photons produced from a s-state e^+e^- annihilation

- Two AGATA modules positioned symmetrically at opposite sides with respect to the annihilation source to detect the coincidences of the two 511 keV photons



- The singlet positronium e^+e^- provides a clean source of pairs of entangled photons (back to back emission)

- Since the position of the first interaction of the two photons are known to be collinear with the annihilation source, the tracking is expected to be easier than for a single photon of the same energy

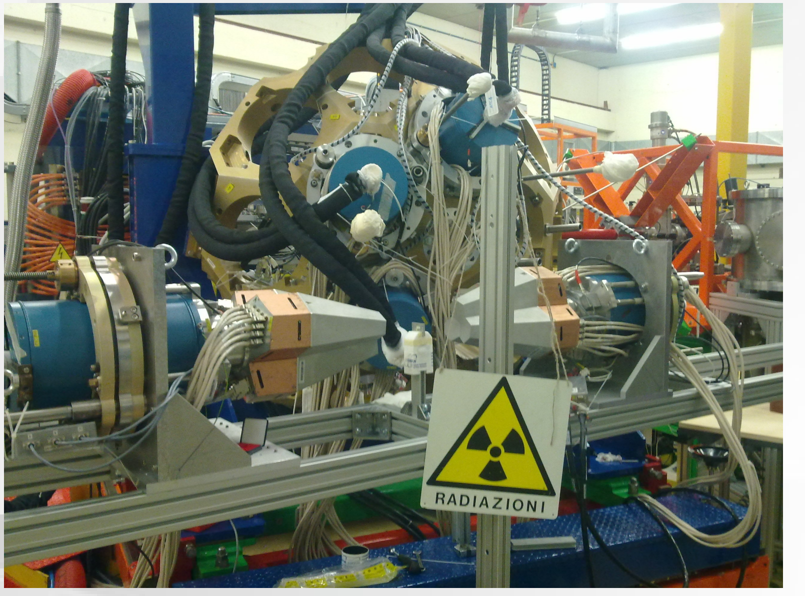
- $F(\theta_1,\varphi_1;\theta_2,\varphi_2) = A(\theta_1,\theta_2) + B(\theta_1,\theta_2) \cos 2(\varphi_1-\varphi_2)$
- N true coincidences ($n_1=n_2$) will show expected angular dependence
- N(N-1) random pairs ($n_1 \neq n_2$) will provide a reference distribution to correct for geometrical asymmetries

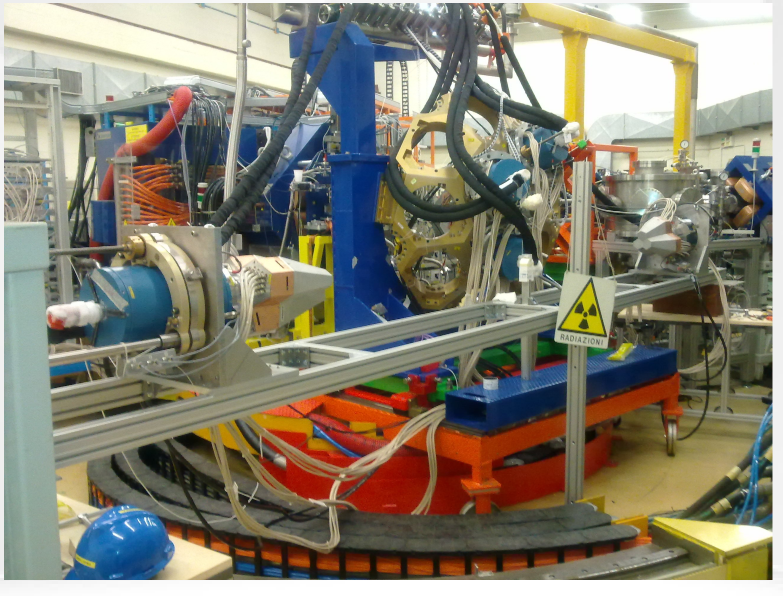
Experimental details

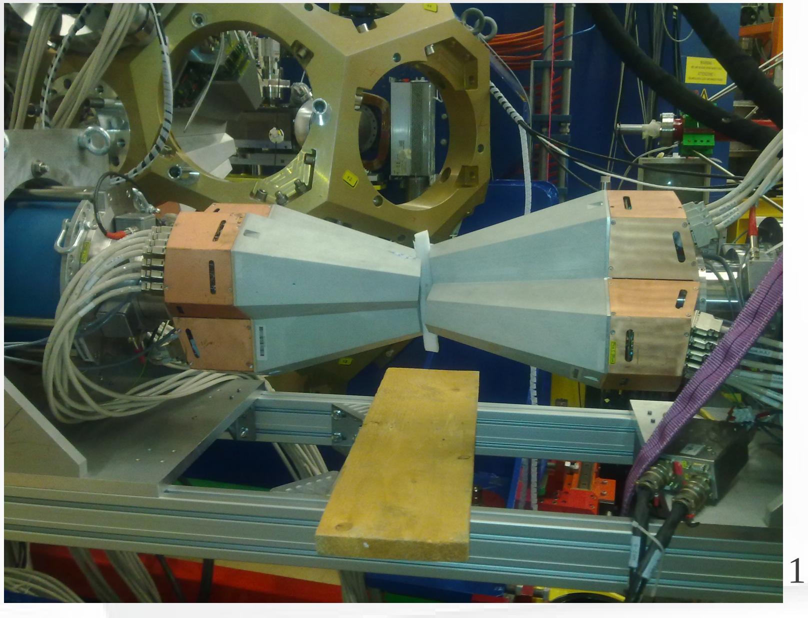
LNL 23rd Dec. 2011 – 8th Jan. 2012

- Two AGATA modules mounted diametrically opposed
- β^+ source: ^{22}Na
- 30TB of data collected at 3 different face-to-face distances (~ 3, 30, 300 cm)

Analysis in progress…







CONCLUSIONS

The capability of an AGATA module to measure linear polarization of γ-rays at an energy $E\gamma$ around 500keV has been demonstrated using partially polarized gammas produced via CoulEx of ^{104,108}Pd.

Of decisive importance has been the ability to correct for instrumental distortions of the expected azimuthal angle distribution of the Compton scattering by normalization to the distribution of unpolarized gamma rays.

We expect

to reach a high accuracy in the measurement of the relative polarization of the two entangled 511 keV γ rays from the decay of singlet positronium

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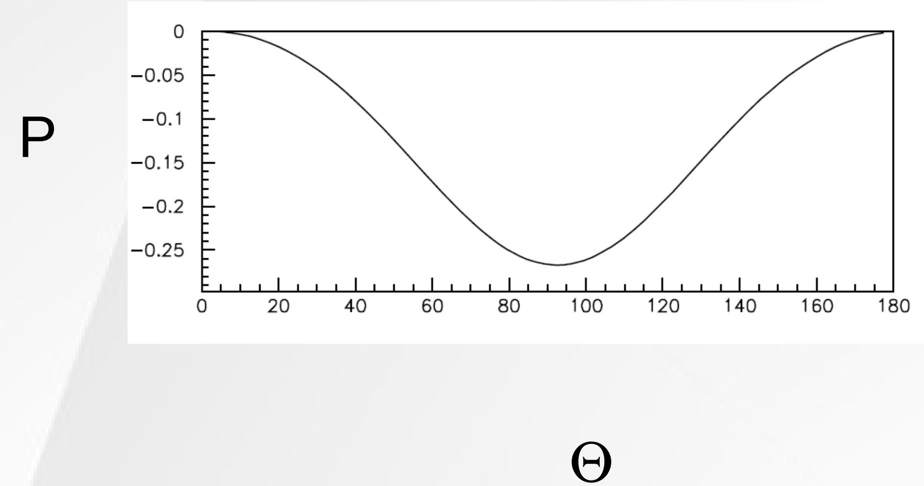
Expected linear polarization of gamma rays from Coulomb excitation of the lowest 2^+ of ^{104}Pd, as function of the emission angle Θ



Polarization

$$P = \frac{W_{\parallel} - W_{\perp}}{W_{\parallel} + W_{\perp}}$$

W|| and W⊥ are the number of rays emitted with the electric vector parallel and perpendicular to the plane defined by the beam and the gamma detector axis, respectively.

The analyzing power A is defined through the relation:

$$PA = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$

where N|| and N⊥ are the number of detected photons in the full energy peak which have first suffered a Compton scattering at a polar angle Θ ~ 90° and an azimuthal angle φ = 0° and φ = 90° respectively.

$$\mathcal{A}(r,\theta) = \mathcal{A}_0(\theta)\ \exp\left(-\frac{4\Delta^2}{r^2 \sin^2\theta}\right)$$

The Ps source: ^{22}Na