Precise measurements of n-γ angular correlations in inelastic scattering of 14 MeV neutrons on nuclei

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ISINN-2018

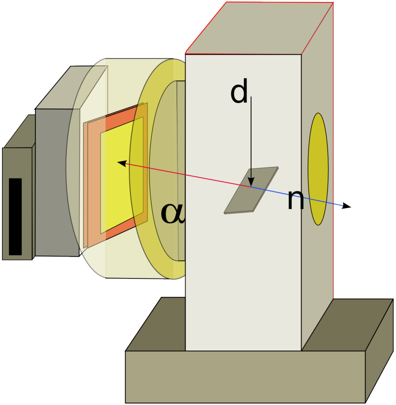
Introduction

An investigation of the angular and energy distributions of gamma rays from the inelastic scattering of 14 MeV neutrons on a number of light nuclei was performed in the frame of the project TANGRA (TAgged Neutron and Gamma RAys) at JINR Frank Laboratory of Neutron Physics.

Motivation

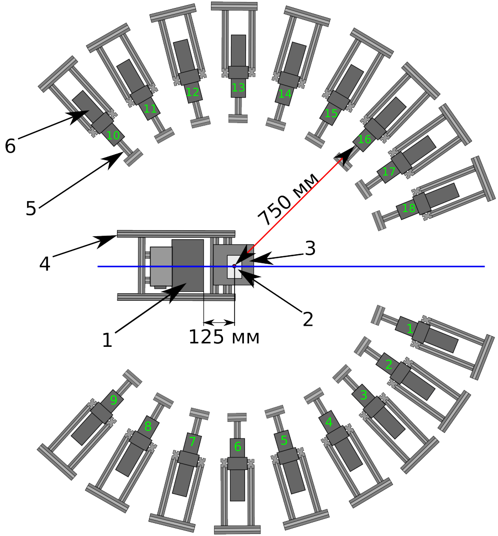
- There are some discrepancies between available experimental data
- Investigation of possible differences between neutron and proton scattering
- Angular anisotropy of the emitted gamma-rays has to be taken into account if the tagged neutron method is used for elemental analysis

The Idea of the ”tagged” neutron method



- $d + t \rightarrow \alpha + n + 17.6\text{MeV}$
- In the center-of-momentum frame n and α fly in opposit directions.
- Minimal angle between α and n in the lab frame about 173^o at deutron energy about 100 keV.
- For registration of the α-particles 64-pixel silicon detector is used. The dimensions of a single pixel are 6×6 mm. The α-particle registration allows one to determine the directon of neutron’s momentum.

The TANGRA setup



1. Neutron generator ING-27
2. Sample
3. Sample's support
4. ING-27 holder
5. Gamma-detector holder
6. BGO gamma-detector, a part of the «Romasha» multi-detector system

Sample size and shape optimization

- Neutron generator ING-27 produce 64 tagged beams so there are 1152 pixel-detector combinations
- We want use as many beams as possible to increase number of measurement points
- In the other hand, if we want to increase number of the used beams we have to increase the sample sizes
- If we increase the sample's sizes, we will lose gammas. Moreover observable angular distribution strictly depends on the sample's shape.

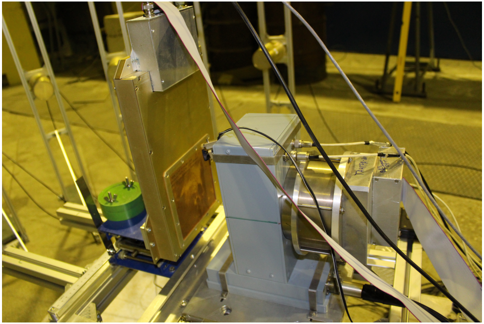
We have to choose optimal geometry of the sample

Sample size and shape optimization

Our procedure for sample's shape optimization consists 3 steps:

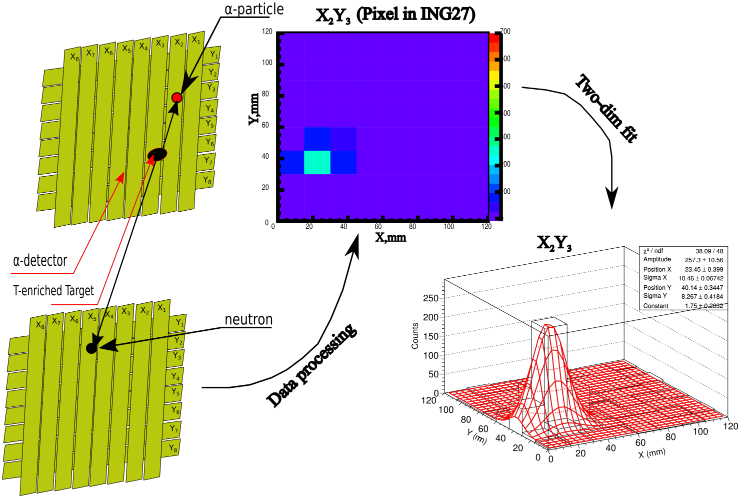
1. Neutron spartial distribution measurement
2. Monte-Carlo simulation of our experimental setup with different sample's sizes and shapes
3. Discussion

Step 1: Beam profile measurement

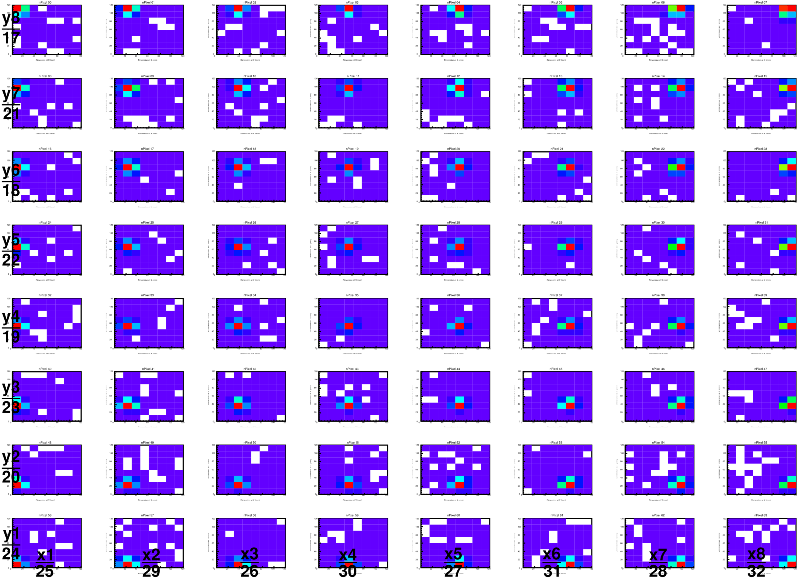


- Information about space distribution of the tagged beams is very important for the data processing.
- A silicon charged particle strip detector was used for beam profile measurement.
- Neutrons were registered by reactions ^{28}Si(n, α) and ^{28}Si(n, p).

Step 1: Beam profile measurement



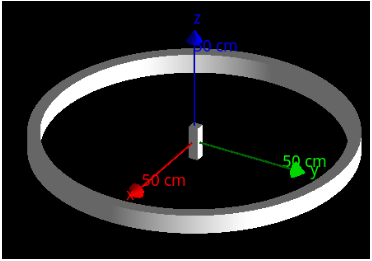
Step 1: Beam profile measurement



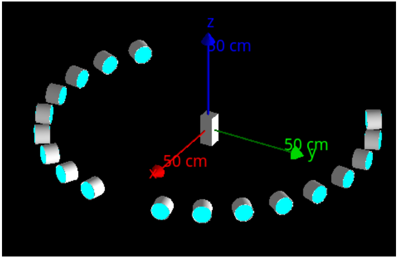
Step 2: Monte-Carlo simulation

- Geant4 includes nuclear data libraries with cross-sections for different nuclear processes
- Geant4 also includes predefined $\frac{d\sigma}{d\Omega}$ for (n, n') reactions
- To establish the influence of the sample's shape on the observable angular distribution we "manually" change the gamma-quanta angular distribution to isotropic.
- To simplify the simulation procedure and increase the simulation speed we replace our 18 gamma-detectors to a single solid ring.

Step 2: Monte-Carlo simulation



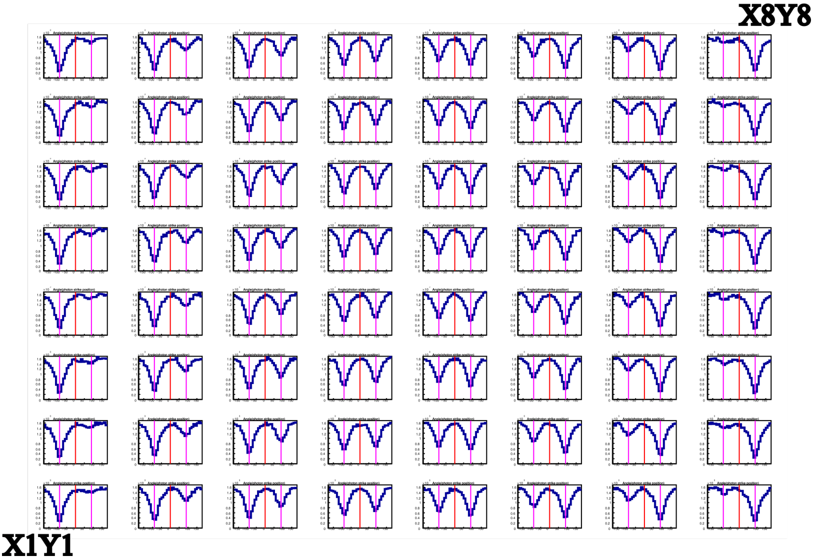
a) Simulation variant with the ring detector



b) Simulation variant with ”normal” BGO detectors.

Step 2: Monte-Carlo simulation

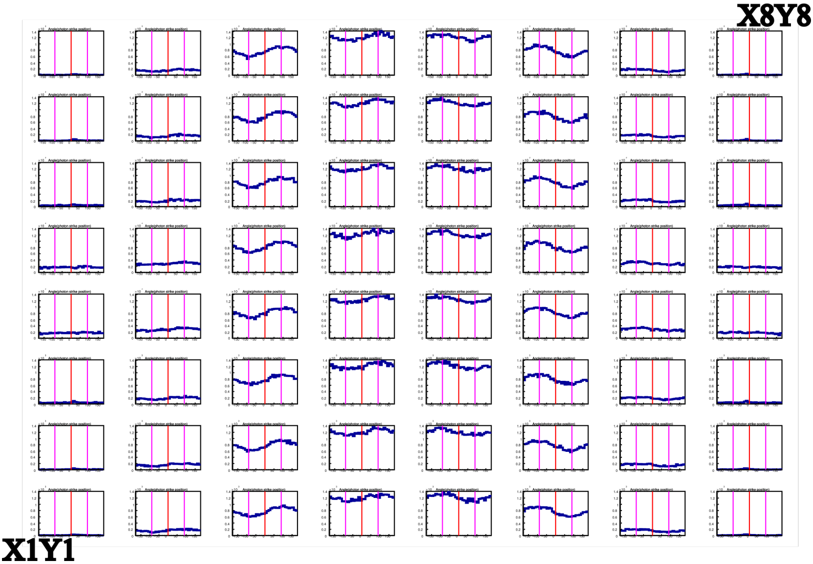
γ-quanta angular distribution for $14 \times 14 \times 4$ cm^3, $E_\gamma = 0.8$MeV



- Red line matchs 0^o, magenta lines match $\pm 90^o$

Step 2: Monte-Carlo simulation

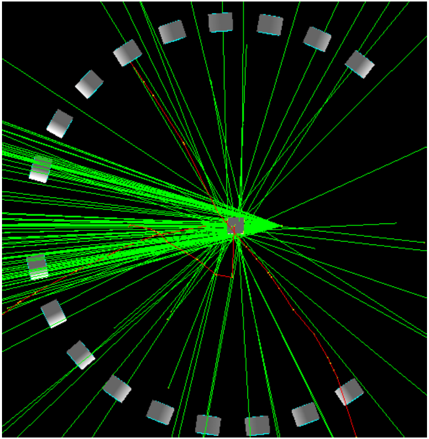
γ-quanta angular distribution for $4 \times 14 \times 4$ cm^3, E_γ=846.7keV



- Red line matchs 0^o, magenta lines match $\pm 90^o$

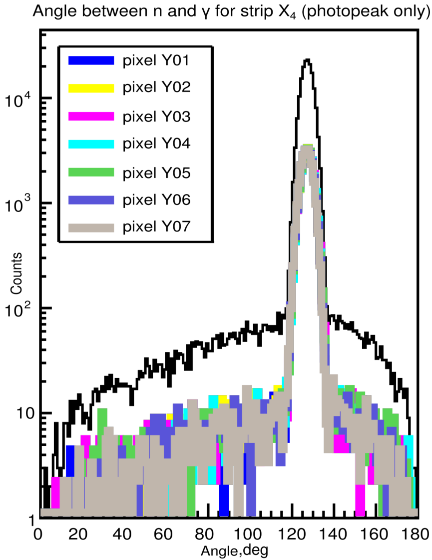
Data correction

Gamma and neutrons absorbtion inside the sample has to be taken into account



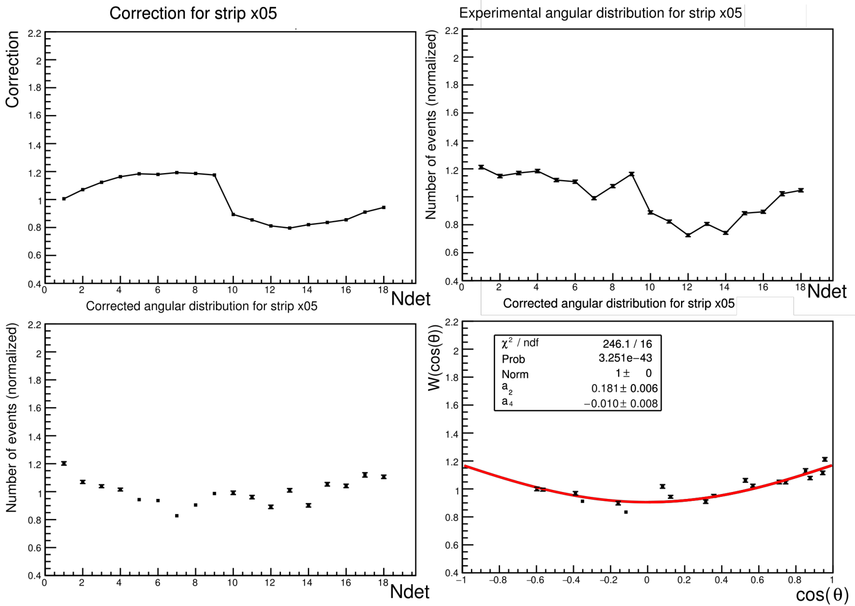
- Models of real detectors were used
- Information about angles between neutrons and gammas for each pixel-detector combination obtained from the simulation
- The correction factor for each pixel-detector pair is proportional to the full energy absorbtion peak obtained in the Monte-Carlo calculation

Angle between neutron and gamma-quantum

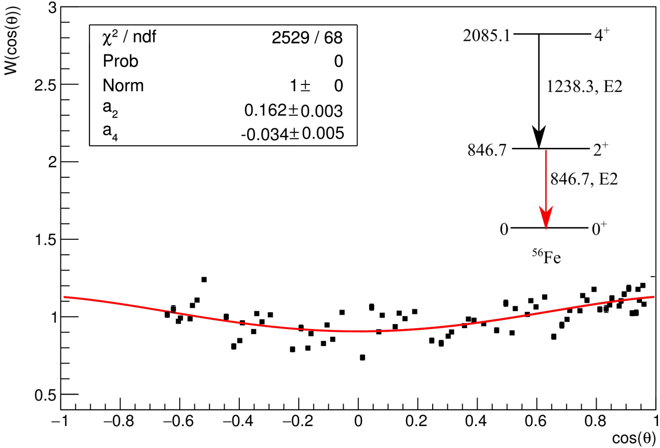


- $\cos(\theta) = \frac{(\vec{P_n}, \vec{P_\gamma})}{|\vec{P_n}||\vec{P_\gamma}|}$
- The substrate in these histograms is formed by multiply scattered neutrons and gammas
- Differences in angles between pixels on one vertical strip are not large
- We can sum pixels on each vertical strip to improve statistics in our data. Also the same operation has to be done with correction.

Correction procedure (Fe, E_γ=846.7keV,2^+)

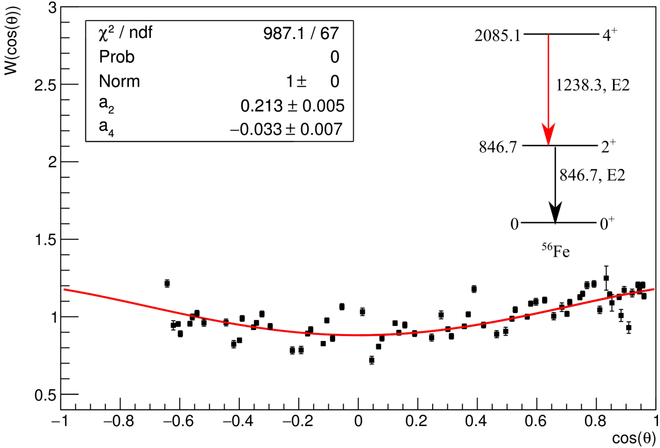


Results: Fe, E_γ=846.7keV; $E2$



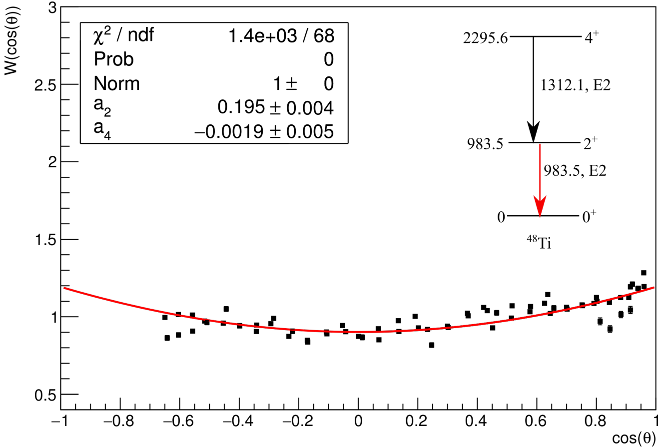
Anisotropy of the γ-radiation emmited by neutron inelastic scattering on the ^{56}Fe. Fit: $1 + (0.162 \pm 0.003)P_2(\cos\theta) - (0.0034 \pm 0.005)P_4(\cos\theta)$

Results: Fe, E_γ=1238.3keV; $E2$



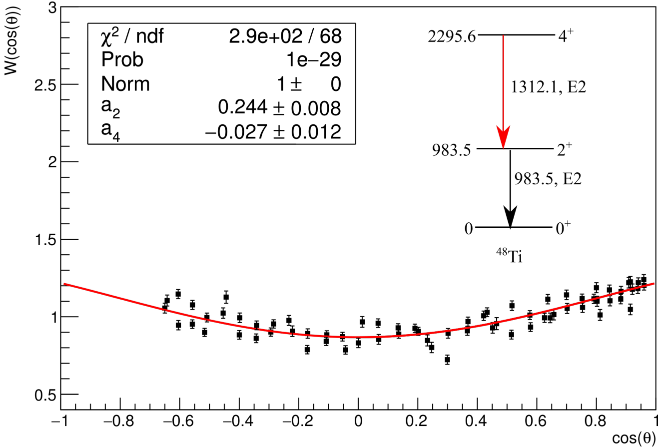
Anisotropy of the γ-radiation emmited by neutron inelastic scattering on the ^{56}Fe. Fit: $1 + (0.213 \pm 0.005)P_2(\cos\theta) - (0.003 \pm 0.007)P_4(\cos\theta)$

Results: Ti, E_γ=983.5keV; $E2$



Anisotropy of the γ-radiation emmited by neutron inelastic scattering on the ^{48}Ti. Fit: $1 + (0.195 \pm 0.004)P_2(\cos\theta) - (0.0019 \pm 0.005)P_4(\cos\theta)$

Results: Ti, E_γ=1312.1keV; $E2$



Anisotropy of the γ-radiation emmited by neutron inelastic scattering on the ^{48}Ti. Fit: $1 + (0.244 \pm 0.008)P_2(\cos\theta) - (0.027 \pm 0.012)P_4(\cos\theta)$

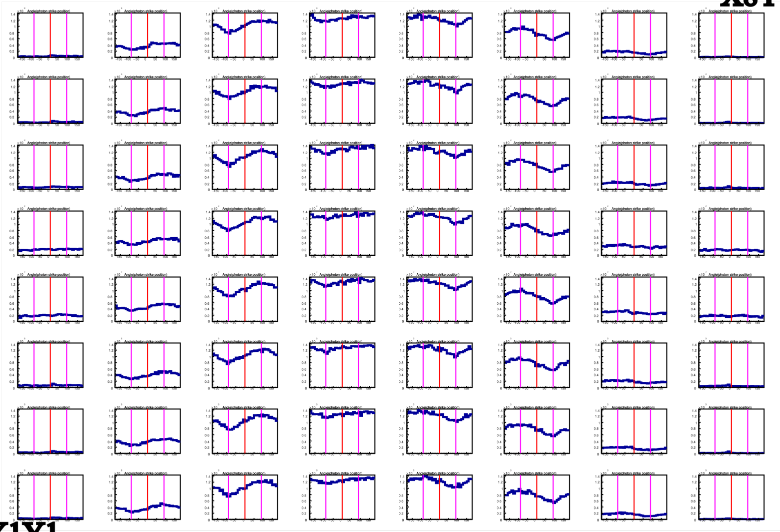
Conclusion

- The optimal size and shape of the targets for different elements were calcuated
- Angular distributions of the gamma-radiation emmited in neutron inelastic scattering on ^{48}Ti, ^{56}Fe have been measured, data for other elements is on the way.
- The correction factors were calculated and experimental data was reestimated.
- We would like to fix our previous measurements using calculated correction factors

Thank you for your attention!

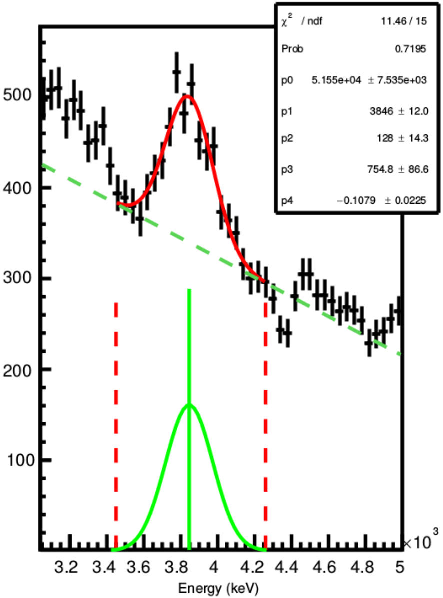
Step 2: Monte-Carlo simulation

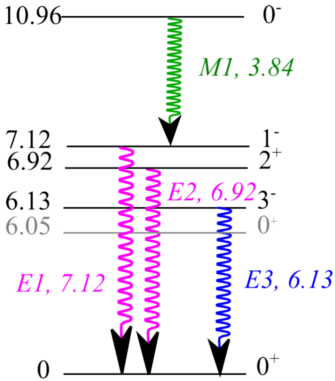
We just have moved the sample...



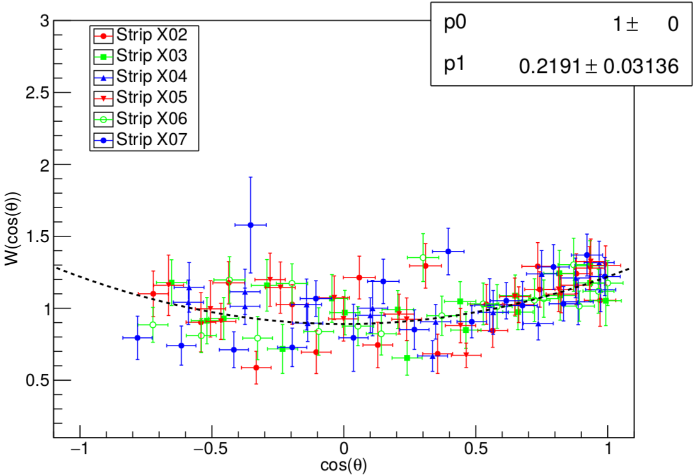
- Red line matchs 0^o, magenta lines match $\pm 90^o$

Results: ^{16}O, E_γ=3.839 MeV; $M1$



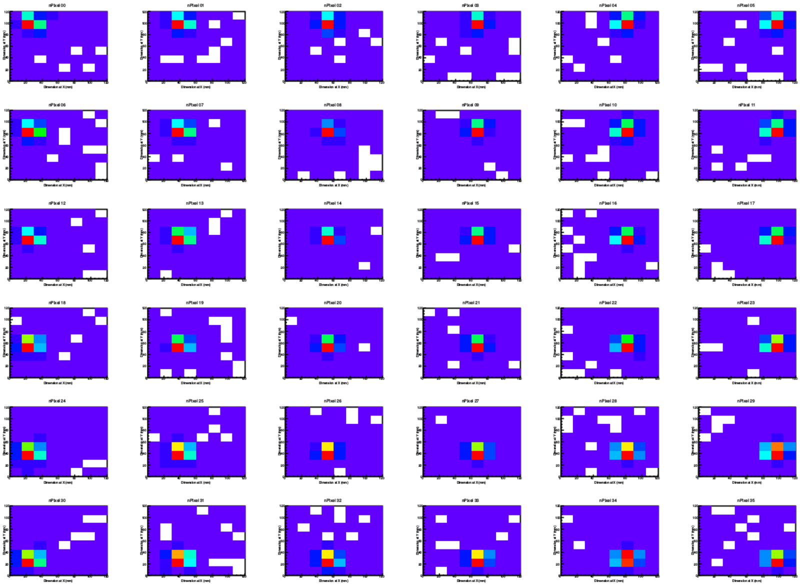


Results: ^{16}O, E_γ=3.839 MeV; $M1$

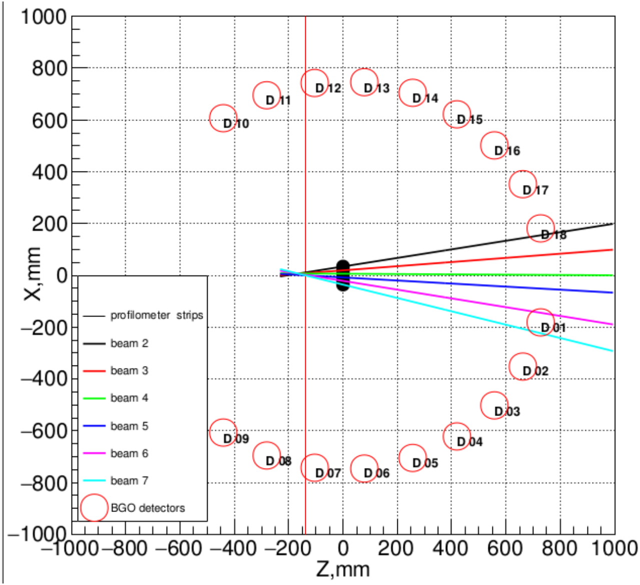


Fit: $1 + (0.22 \pm 0.03)P_2(\cos\theta)$

Tagged beam profile



Trajectories of the tagged beams



Time spectra comparison