Investigation of 14.1 MeV neutron inelastic scattering on Silicon and Oxygen

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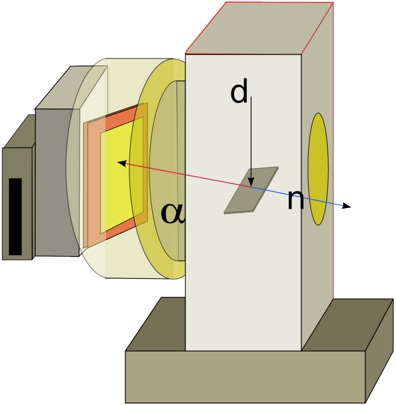
An investigation of the angular and energy distributions of gamma rays from the inelastic scattering (reaction $^{A}\mathrm{Z}(n,n')^{A}\mathrm{Z}^{*} \rightarrow {}^{A}\mathrm{Z}{+}x\gamma$) of 14 MeV neutrons on a number of light nuclei was performed in the frame of the project TANGRA (TAgged Neutron and Gamma RAys) at JINR Frank Laboratory of Neutron Physics.

Motivation

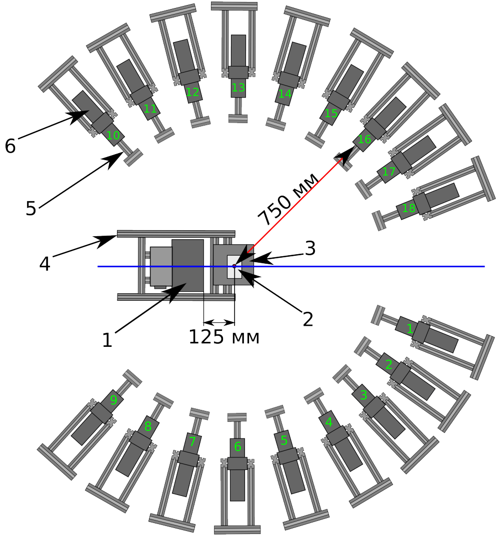
- There are some discrepancies between available experimental data
- Investigation of possible differences between neutron and proton scattering
- Angular anisotropy of the emitted gamma-rays has to be taken into account if the tagged neutron method is used for elemental analysis

The Idea of the ”tagged” neutron method



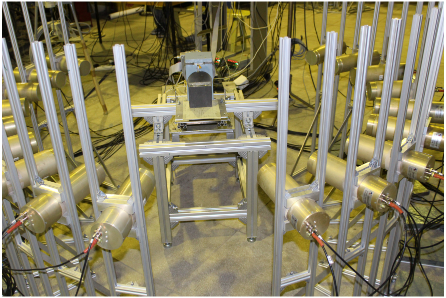
- $d + t \rightarrow \alpha + n + 17.6\text{MeV}$
- In the center-of-momentum frame n and α fly in opposit directions.
- Minimal angle between α and n in the lab frame about 173^o at deutron energy about 100 keV.
- For registration of the α-particles 64-pixel silicon detector is used. The dimensions 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

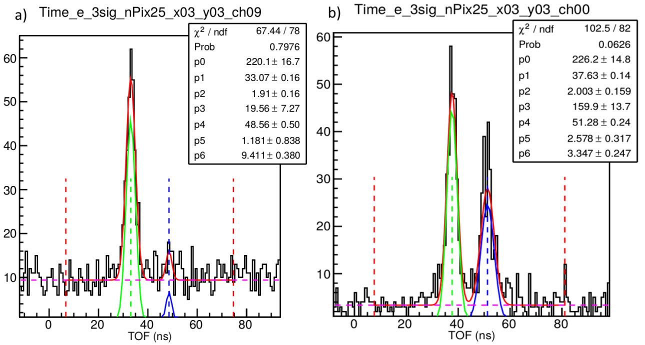
Experiment



- Sample: a glass brick with dimensions $10 \times 10 \times 5$ cm.
- A threefold coincidence circuit was used for γ-quanta registration. (strips X and Y in α-detector placed in the neutron generator and gamma-detector in the "Romasha" system)

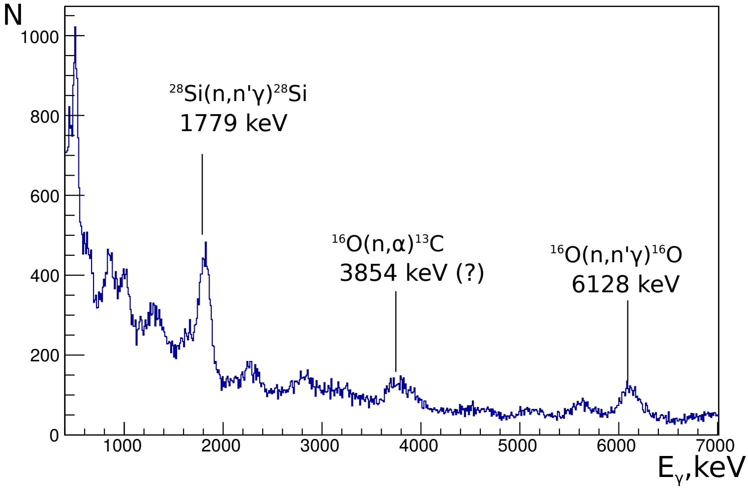
Data processing

Neutron-γ separation using time spectra



Time spectra. a)–time spectra obtained by detector # 10 far from tagged neutron beam, b)–time spectra obtained by detector # 1 placed on neutron's beam trajectory. Peak related to γ-quanta fitted by green curve, n-peak fitted by the blue curve.

Data processing: Gamma-spectrum for SiO_2

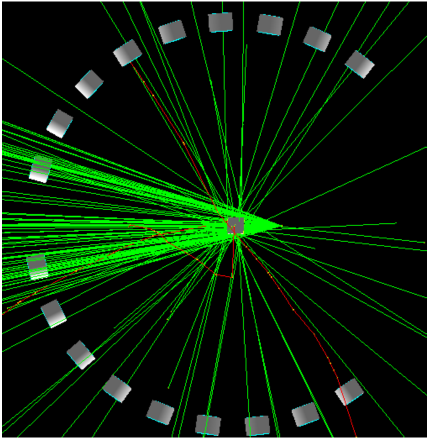


Influence of the sample's shape and size to observable angular distributions

- Intensity of the gamma-quanta flux decrease when gamma-quanta travel across the substance.
- The correction coefficient would be different for each pixel-detector combination because the average distance which gamma-quantum pass from the inelastic scattering point to gamma-detector is individual.

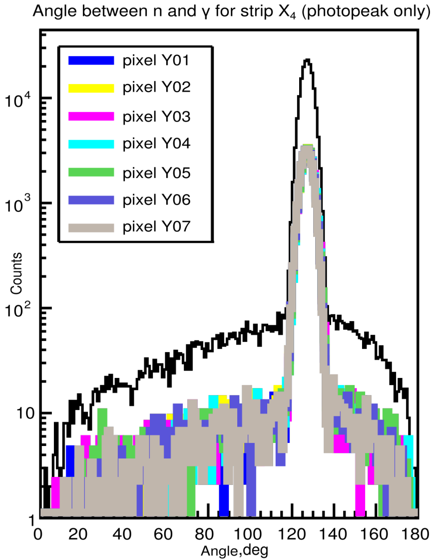
Correction coefficient calculation

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



- To establish the influence of the sample's shape on the observable angular distribution we "manually" change the gamma-quanta angular distribution to isotropic.
- 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

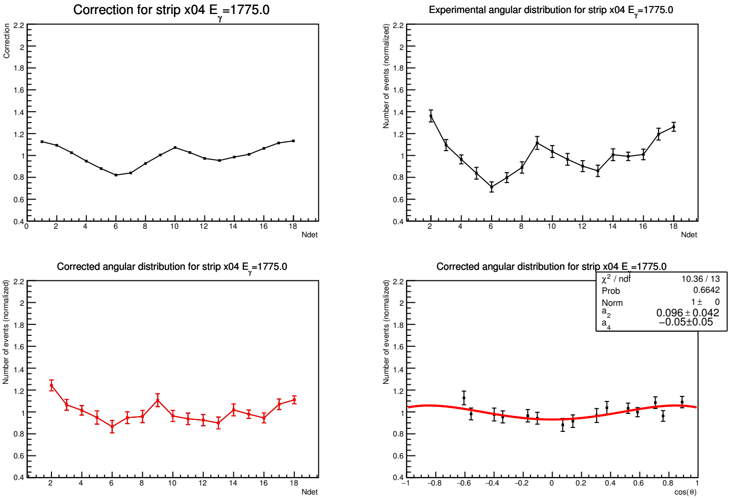
Angle between neutron and gamma-quantum



- $\cos(\theta) = \frac{(\vec{P_n}, \vec{P_\gamma})}{|\vec{P_n}||\vec{P_\gamma}|}$
- 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

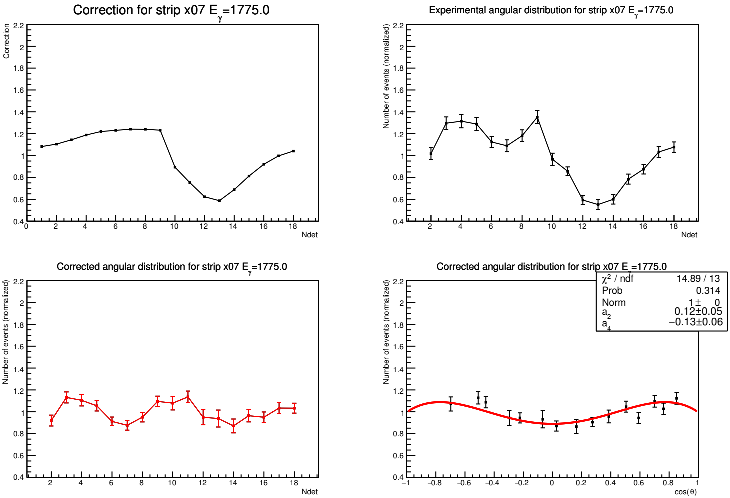
Example for central beam (strip 5)



$$W(\cos(\theta)) = 1 + \sum_{\nu}^{\nu=2,4\ldots 2M} a_\nu P_\nu(\cos(\theta)) \quad (1)$$

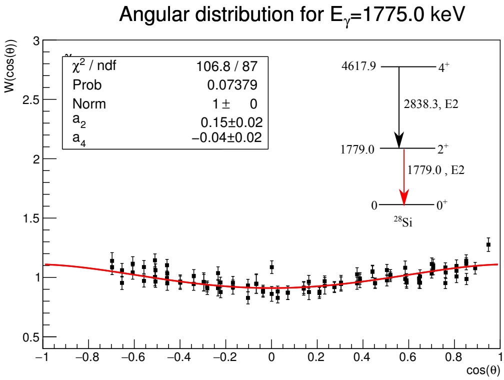
Correction procedure

Example for non-central beam (strip 7)



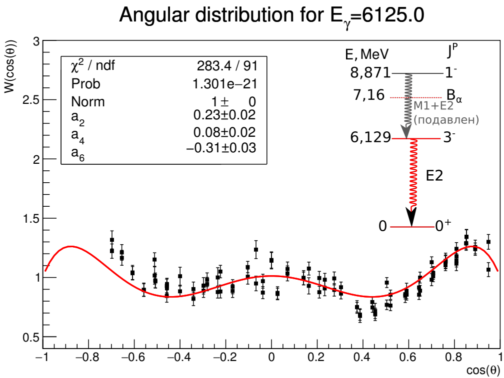
$$W(\cos(\theta)) = 1 + \sum_{\nu}^{\nu=2,4\ldots 2M} a_\nu P_\nu(\cos(\theta)) \qquad (2)$$

Results: ^{28}Si



Experiment	a_2	a_4
Abbondanno (original)	0.16	0.02
Abbondanno (our fit)	0.2 ± 0.09	0.11 ± 0.14
Zhou (original)	0.21 ± 0.02	–
Zhou (our fit)	0.17 ± 0.14	-0.05 ± 0.16
«Romashka-BGO»	0.15 ± 0.02	-0.04 ± 0.02

Results: ^{16}O, 6128 keV



Experiment	α_2	α_4	α_6
Kozlowski (our fit)	0.18 ± 0.33	-0.2 ± 0.5	-0.7 ± 0.5
Morgan (our fit)	0.34 ± 0.04	0.012 ± 0.06	-0.04 ± 0.06
«Romashka-BGO»	0.23 ± 0.02	0.08 ± 0.02	-0.31 ± 0.03

Conclusion

- Angular distributions of the gamma-radiation emmited in neutron inelastic scattering on ^{28}Si, ^{16}O have been measured, data for other elements is on the way.
- The Geant4 based simulation program for TANGRA setup was built and simulation results were used in data processing.
- The correction factors were calculated and experimental data was reestimated.

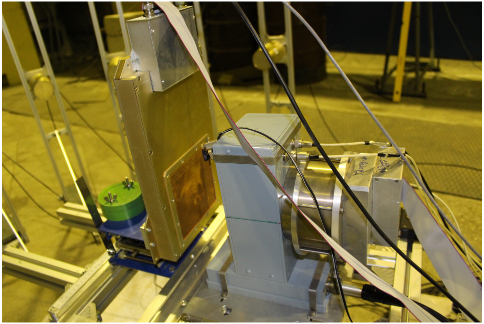
Thank you for your attention!

Sample size and shape optimization

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

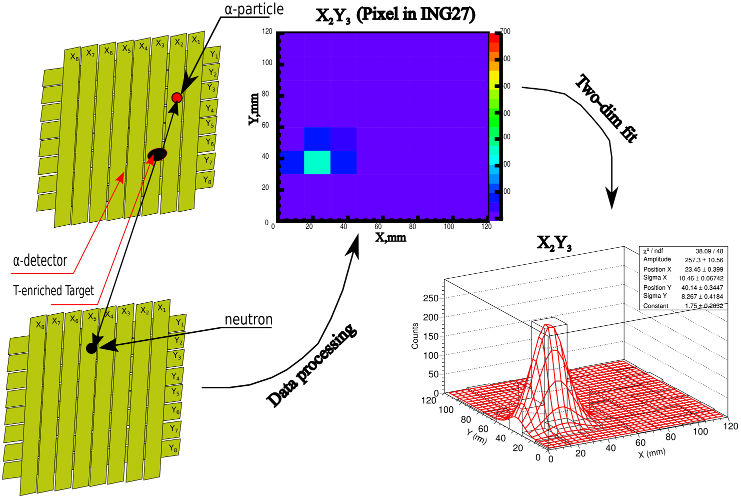
1. Neutron spartial distribution measurement
2. Monte-Carlo simulation of our experimental setup with different sample's sizes and shapes
3. Discussion

Step 1: Beam profile measurement

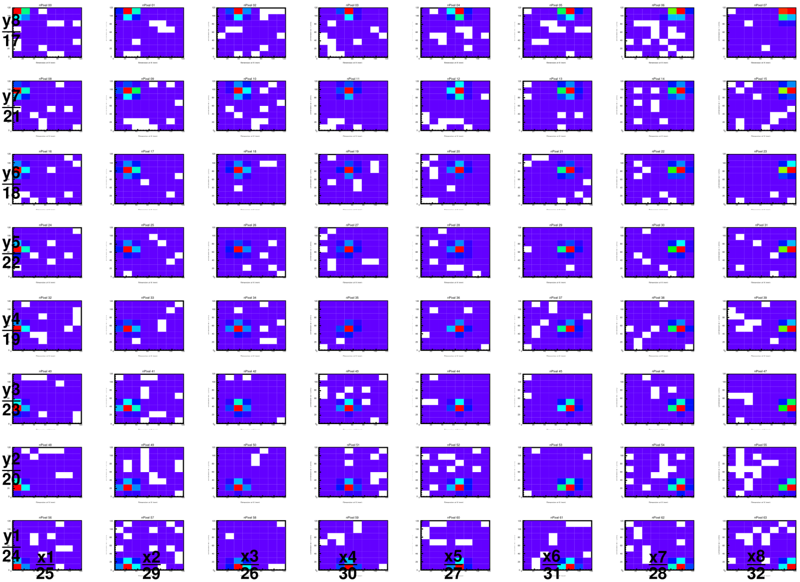


- Information about space distribution of the tagged beams is very important for the data processing.
- A silicon charged particle strip detector was used for beam profile measurement.
- Neutrons were registered by reactions $^{28}\mathrm{Si}(n,\alpha)$ and $^{28}\mathrm{Si}(n,p)$.

Step 1: Beam profile measurement



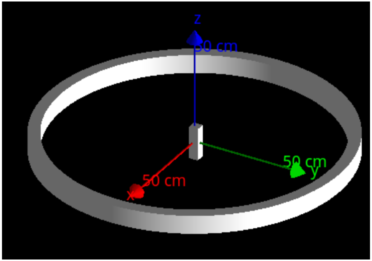
Step 1: Beam profile measurement



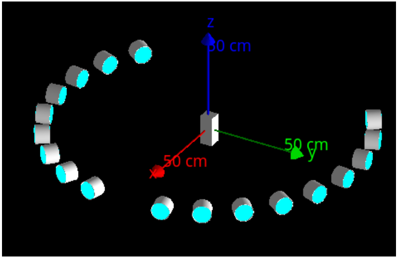
Step 2: Monte-Carlo simulation

- 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



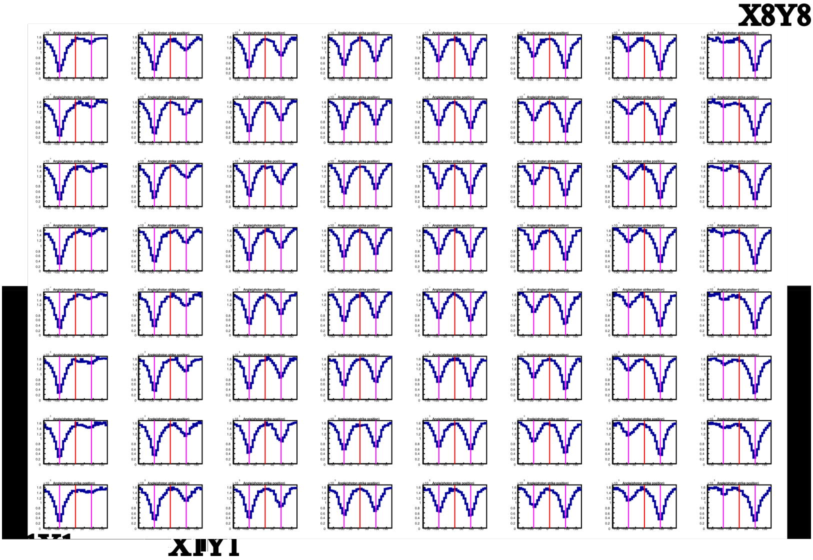
a) Simulation variant with the ring detector



b) Simulation variant with ”normal” BGO detectors.

Step 2: Monte-Carlo simulation

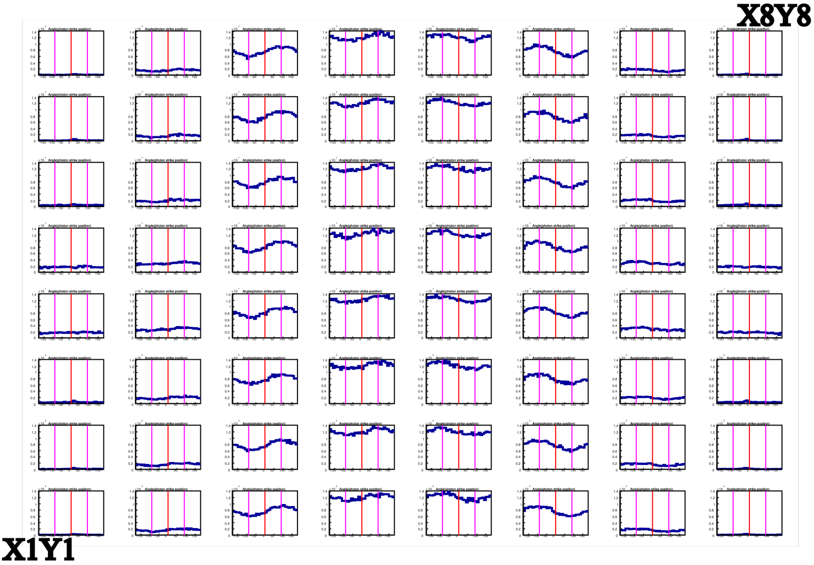
γ-quanta angular distribution for $14 \times 14 \times 4\ \mathrm{cm}^3$ (4 cm along beam), $E_\gamma = 0.8\mathrm{MeV}$



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

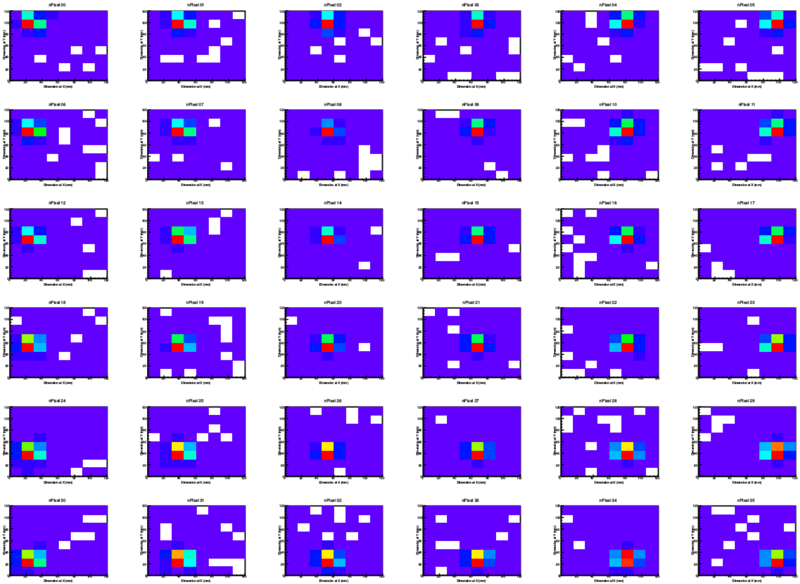
Step 2: Monte-Carlo simulation

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

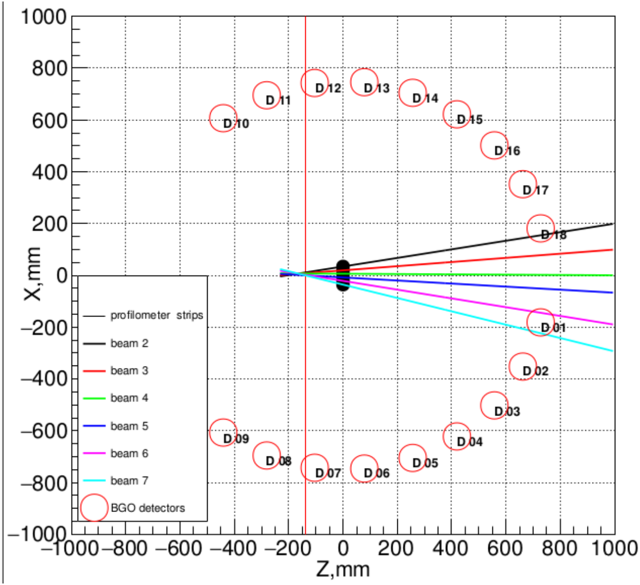


- Red line matchs 0^o, magenta lines match $\pm 90^o$

Tagged beam profile



Trajectories of the tagged beams



Angle between neutron and alpha