Expected performance of GRETINA with fast beams

This document summarizes the performance of GRETINA for fast-beam experiments at NSCL as expected from simulations. Simulations were carried out by I-Yang Lee, LBNL.

Estimate of in-beam efficiency

GRETINA consists of 7 detector modules. Positions for the modules are listed in table 1. The expected in-beam efficiency of GRETINA for gamma rays emitted at 40% of the speed of light (β=0.4) can be estimated from figure 1. It shows the efficiency for a single module (4 crystals) at each available position versus the gamma-ray energy in the rest system of the gamma-emitting nucleus. Add-back of events scattered between the four crystals within a module is included in the quoted efficiencies. Adding the efficiencies for seven detector positions yields the expected total efficiency of GRETINA.

RING	ANGLE	SLOTS	REMARK
1			Not existing
2	58^o	4	
3	90^o	8	
4	122^o	4	
5	148^o	5	Not available at NSCL

Table 1: GRETINA detector positions available at NSCL. Ring 5 is blocked by the 6 inch diameter beam pipe.

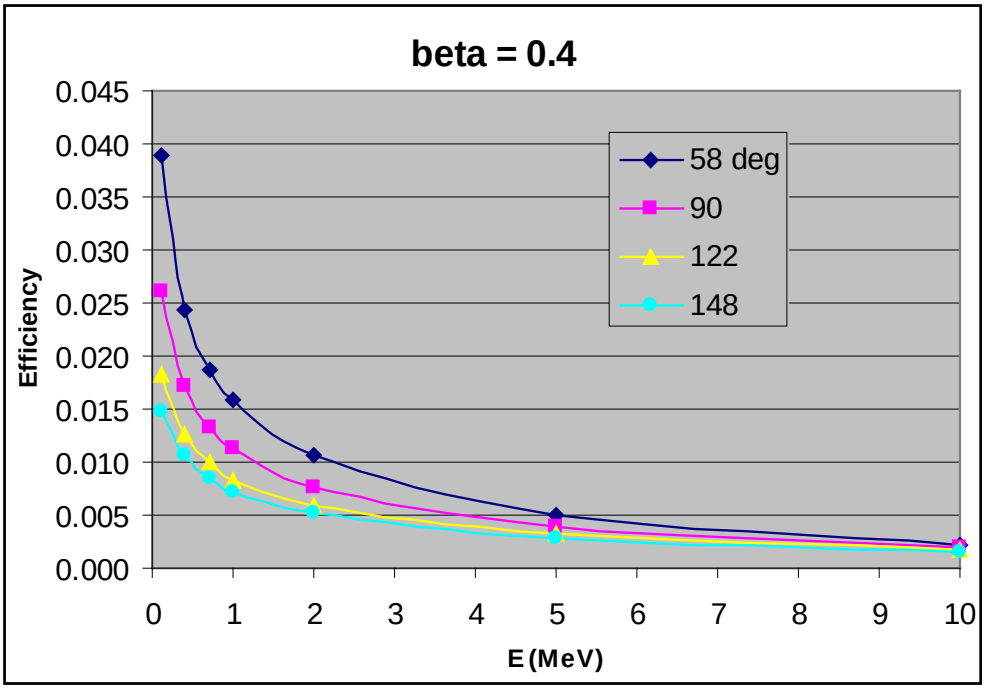

Figure 1: Full-energy-peak efficiency of a GRETINA module placed at the indicated positions for a gamma ray emitted at 0.4 c. Add-back is employed for four crystals of a module. Note that 148^o is NOT available at NSCL.

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Estimated energy resolution

GRETINA has a spatial resolution of 11 mrad (rms) after applying signal decomposition. Figure 2 shows the achievable energy resolution as function of the additional uncertainty $\sigma_{\theta x}$, $\sigma_{\theta y}$ of the scattering angle for a gamma-ray emitting projectile moving at 0.4 c. The curves for the different GRETINA module positions available at NSCL are plotted. The S800 spectrograph allows measurement of the scattering angle with an accuracy of 1 mrad (rms) in the dispersive and non-dispersive directions event-by-event.

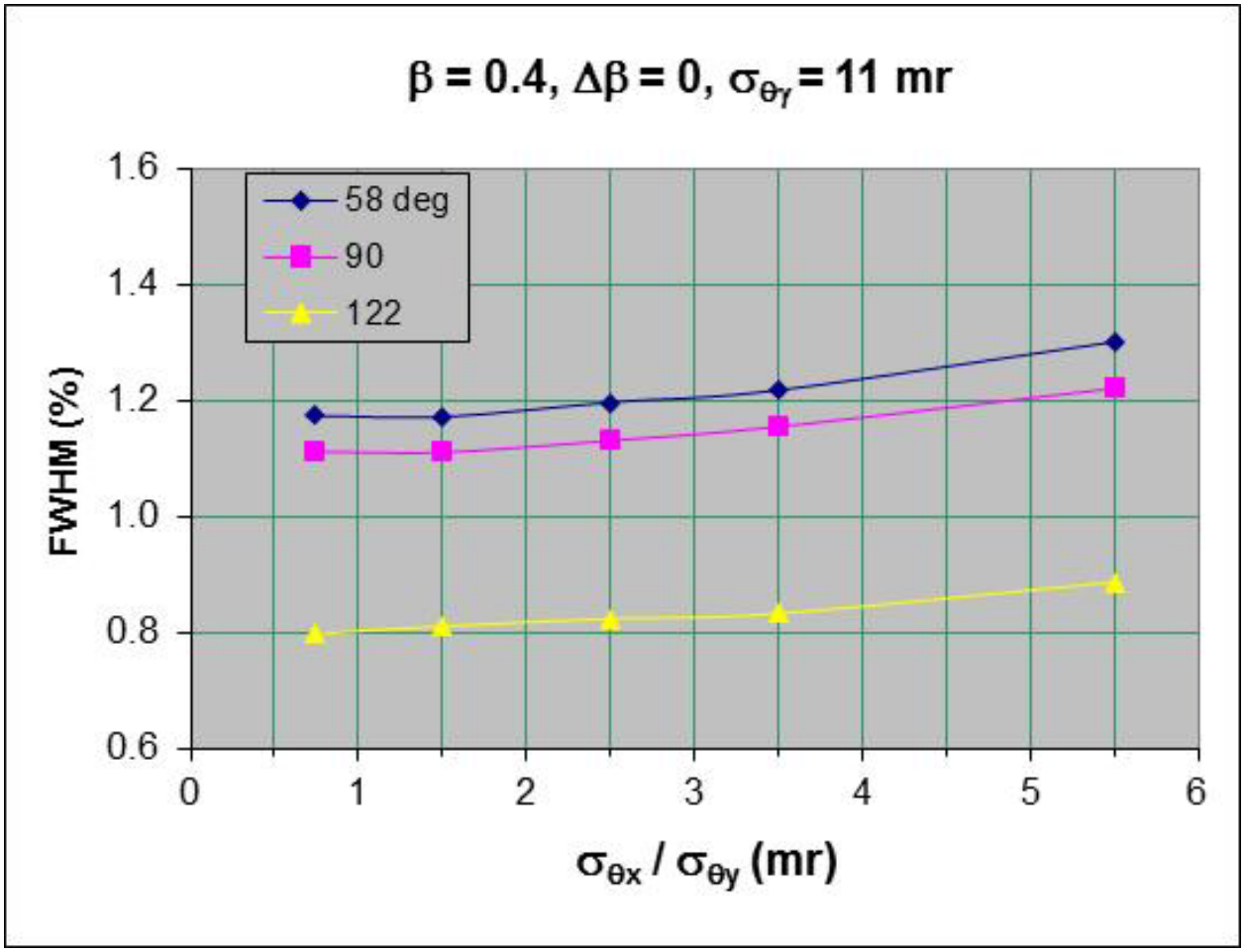

Figure 2: Energy resolution of GRETINA after Doppler-shift reconstruction for γ-rays emitted at 0.4c. No effects other than the spatial resolution of GRETINA are taken into account. The x-axis shows the dependence with the uncertainty $\sigma_{\theta x}$, $\sigma_{\theta y}$ of the projectile's scattering angle.

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Impact of the energy-loss in the target

The energy loss of the gamma-ray emitting projectile in the target can contribute considerably to the energy resolution achievable with GRETINA. Figure 3 shows the resolution as function of the energy loss, parameterized as change of the projectile's velocity Δβ through a target. The change of β can be calculated using LISE++. A velocity change of Δβ=0.02 c already has a significant impact on the in-beam resolution of GRETINA modules placed upstream of the target.

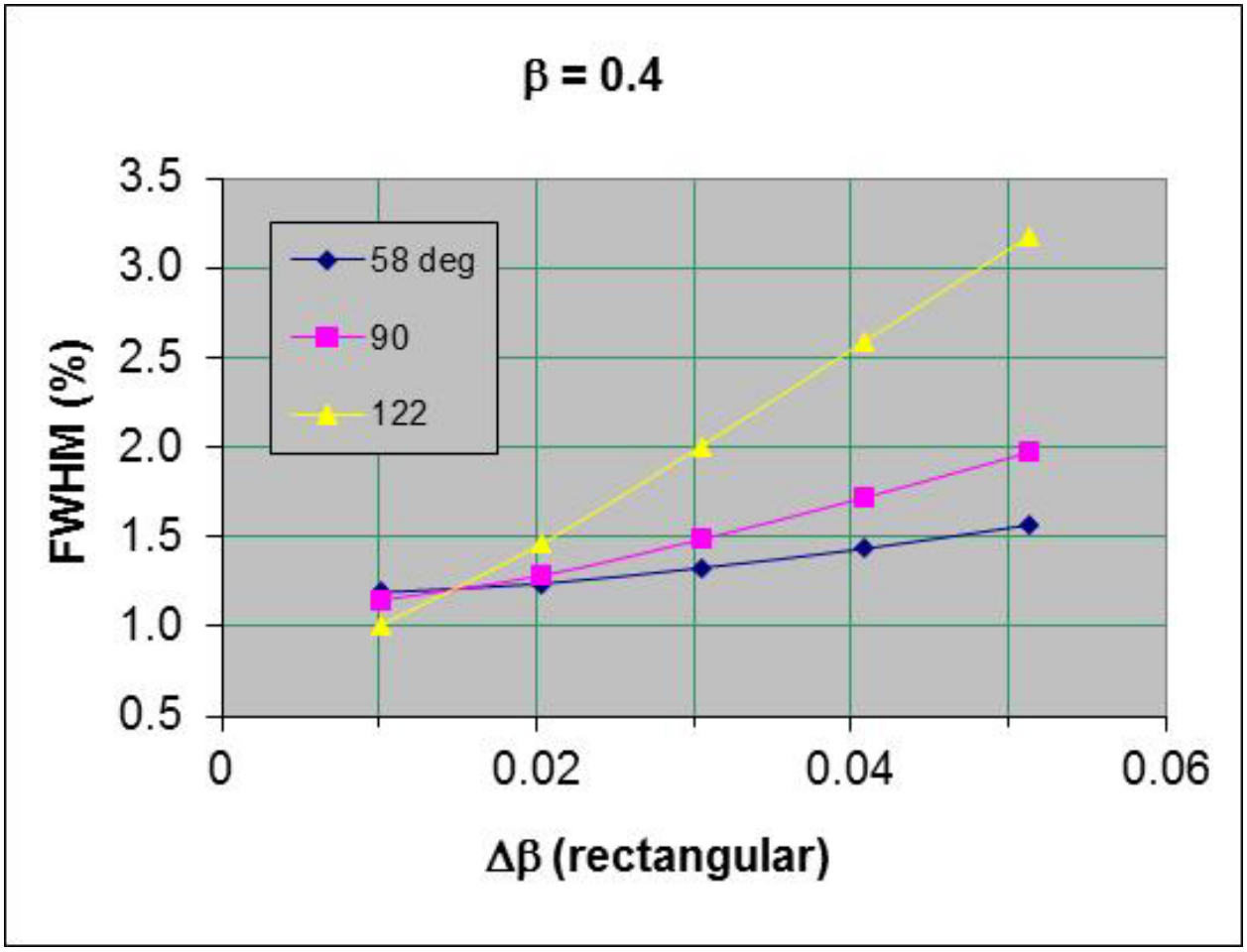

Figure 3: Energy resolution of GRETINA plotted as function of energy loss of the projectile in the target. The energy loss is given as change of its velocity β in the target.

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Uncertainty in z

The target thickness and the lifetime of a nuclear state introduce an uncertainty in the location of the decay position along the beam axis. This uncertainty is parameterized here as σ_z (rms). A target thickness w translates as σ_z = w/3. The correspondence between a lifetime τ and σ_z is approximately $\sigma_z = \tau * \beta c$. Lifetime effects impact the peak shape and FWHM. Example spectra are shown in figure 4.

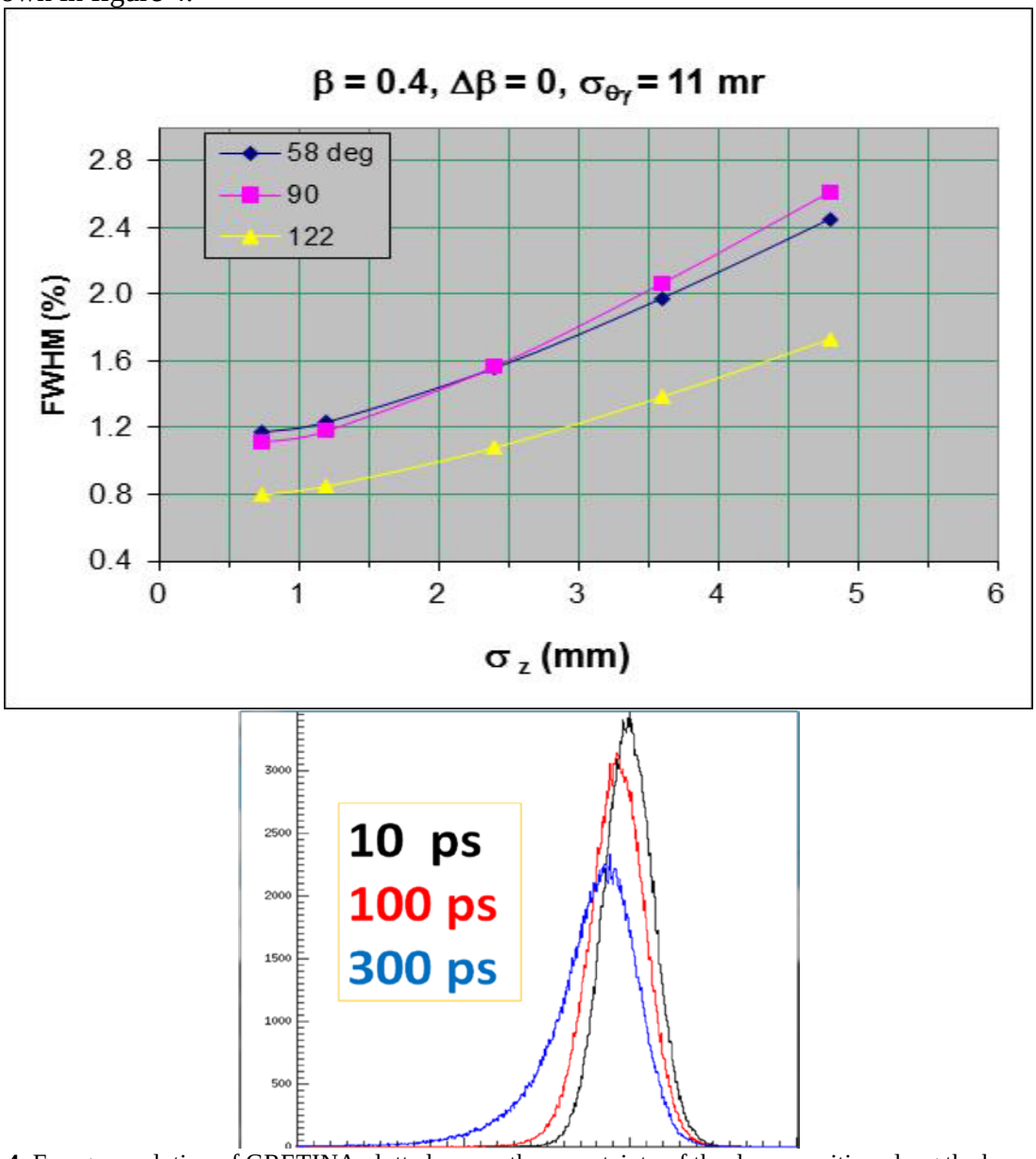

Figure 4: Energy resolution of GRETINA plotted versus the uncertainty of the decay position along the beam axis (top). The line shape of the Doppler-reconstructed gamma-ray peak is shown for different lifetimes (bottom).

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Size of beam spot

The typical size of the beam spot on target is ±5mm in vertical (dispersive, x) and ±12mm in horizontal (non-dispersive, y) direction. These numbers refer to the maximum extent of the beam spot. The horizontal position y at the target will be tracked with the S800 spectrograph with an uncertainty σ_y = 2mm (rms). The position in the dispersive direction (x) cannot be reconstructed by the S800 spectrograph. The impact of this uncertainty[a] on the energy resolution is shown in figure 5 for a configuration consisting of 4 GRETINA modules in ring 2 and 3 GRETINA modules in ring 3.

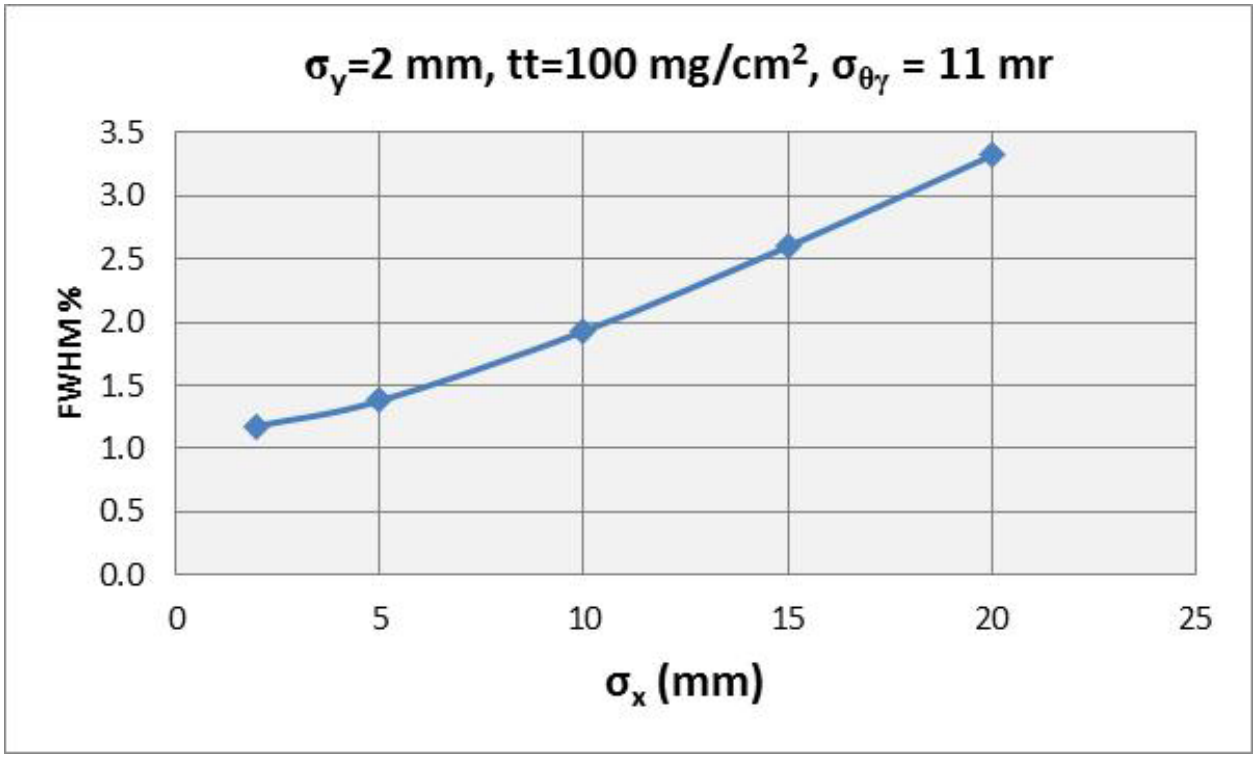

Figure 5: Energy resolution versus position uncertainty σ_x in the dispersive direction of the S800 spectrograph. The curve is calculated for 4 GRETINA modules in ring 2 and 3 GRETINA modules in ring 3.

[a] A beam spot size of ±5mm corresponds to σ_x = 3.3mm (rms).

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Examples

Table 2 summarizes the expected performance of GRETINA for typical gamma-ray spectroscopy experiments at NSCL using the S800 spectrograph. For all simulations 4 modules are placed at 58^o (ring 2) and 3 at 90^o (ring 3). The uncertainty of the beam position in horizontal, non-dispersive direction (y) is fixed at σ_y=2mm (tracked using the S800). Angular resolution for the particles' trajectory is σ_θ, σ_φ=1 mrad (tracked using the S800). The velocity of the incoming beam is β=0.40. For the momentum reconstruction at mid-target position (and therefore β for Doppler-shift correction) a momentum resolution of $\Delta p/p = 0.00042$ for the S800 spectrograph is assumed.

The effect of the energy loss is parameterized as a flat distribution of β ranging from β-$\Delta\beta$ to β. Lifetimes are given by τ. The uncertainty of the beam position in the dispersive direction is given by σ_x (rms).

For each scenario, full-energy-peak efficiency ε, peak-to-total[b] (P/T), and energy resolution $\Delta E/E$ are given. Add-back of events scattered between GRETINA modules is performed in the simulation. Please note that tracking is NOT employed in the simulation and for the numbers given in Table 2.

Eγ [MeV]	Δβ	τ [ps]	σ_x [mm]	ε	P/T	ΔE/E [%]
0.5	0.01	0	2	0.157	0.66	1.19
1	0.01	0	2	0.117	0.52	1.19
2	0.01	0	2	0.082	0.40	1.19
5	0.01	0	2	0.046	0.25	1.19
1	0.02	0	2	0.117	0.52	1.27
1	0.04	0	2	0.117	0.52	1.54
1	0.06	0	2	0.117	0.52	1.89
1	0.01	10	2	0.117	0.52	1.20
1	0.01	50	2	0.117	0.52	1.24
1	0.01	100	2	0.118	0.52	1.35
1	0.01	300	2	0.118	0.52	2.22
1	0.01	0	4	0.117	0.52	1.31
1	0.01	0	6	0.117	0.52	1.49
1	0.01	0	8	0.117	0.52	1.71
1	0.06	100	2	0.118	0.52	1.99
1	0.06	300	2	0.118	0.52	2.64

Table 2: Performance of GRETINA with 4 modules at 58^o and 3 modules at 90^o for different experimental scenarios expressed in terms of the energy loss $\Delta\beta$ in the target, the lifetime τ of the γ-emitting nuclear state, and the position resolution of the incoming projectile in dispersive direction.

[b] P is the peak area, T the total counts in the spectrum. An energy threshold of ~10 keV is used in the simulation.

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Appendix

List of used variables

β: v/c with v the velocity of gamma-emitting projectile in

$\Delta\beta$: Velocity change of the projectile in the target due to energy loss. β changes to β-$\Delta\beta$ after target

σ_{θ},: Uncertainty (rms) of the scattering angle of the projectile in dispersive direction measured in the S800.

σ_{φ}: Uncertainty (rms) of the scattering angle of the projectile in non-dispersive direction measured in the S800.

σ_y: Uncertainty (rms) of the vertical position (y) where the projectile hits the target. This position y will be measured and reconstructed with the S800.

σ_x: Uncertainty (rms) of the horizontal position (x) where the projectile hits the target. This position x cannot be reconstructed with the S800 and the uncertainty is given by the size of the beam spot.

σ_z: Uncertainty (rms) of the position of the decay along the beam axis.

τ: Lifetime of a nuclear state

E_{γ}: Gamma-ray energy

$\Delta E/E$: Energy resolution of GRETINA

ε: Full-energy-peak efficiency of GRETINA

P/T: Peak-to-total for GRETI NA

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