
RIKEN
NISHINA
CENTER

SHOGUN Spectrometer Simulation Status

Pieter Doornenbal
ピーター　ドルネンバル

Outline

- In-beam Gamma-ray spectroscopy at high energies
- Aims, restrictions for SHOGUN
- Basic concept of SHOGUN geometry
- Simulation results
  - Example configurations

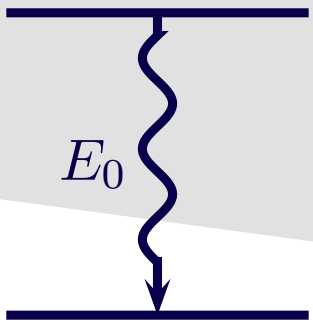
In-beam Gamma-ray Spectroscopy at High Energies

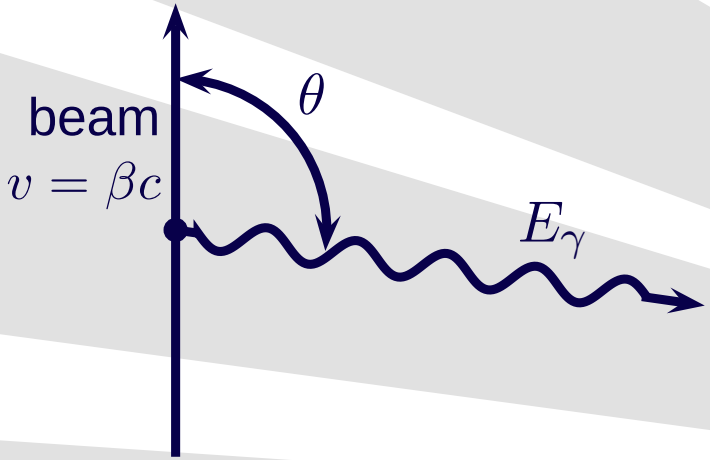
Doppler Shift

- Lorentz transformation of 4-momenta between laboratory frame and frame of emitting nucleus

$$E_\gamma = \frac{E_0}{\gamma(1-\beta\cos\theta)} \qquad d\Omega_0 = \left(\frac{E_\gamma}{E_0}\right)^2 d\Omega$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$





Doppler Broadening

Due to:

- Uncertainty of θ
- Uncertainty of β

$$\Delta E^2 = \left(\frac{\partial E}{\partial \beta}\right)^2 \Delta\beta^2 + \left(\frac{\partial E}{\partial \theta}\right)^2 \Delta\theta^2$$

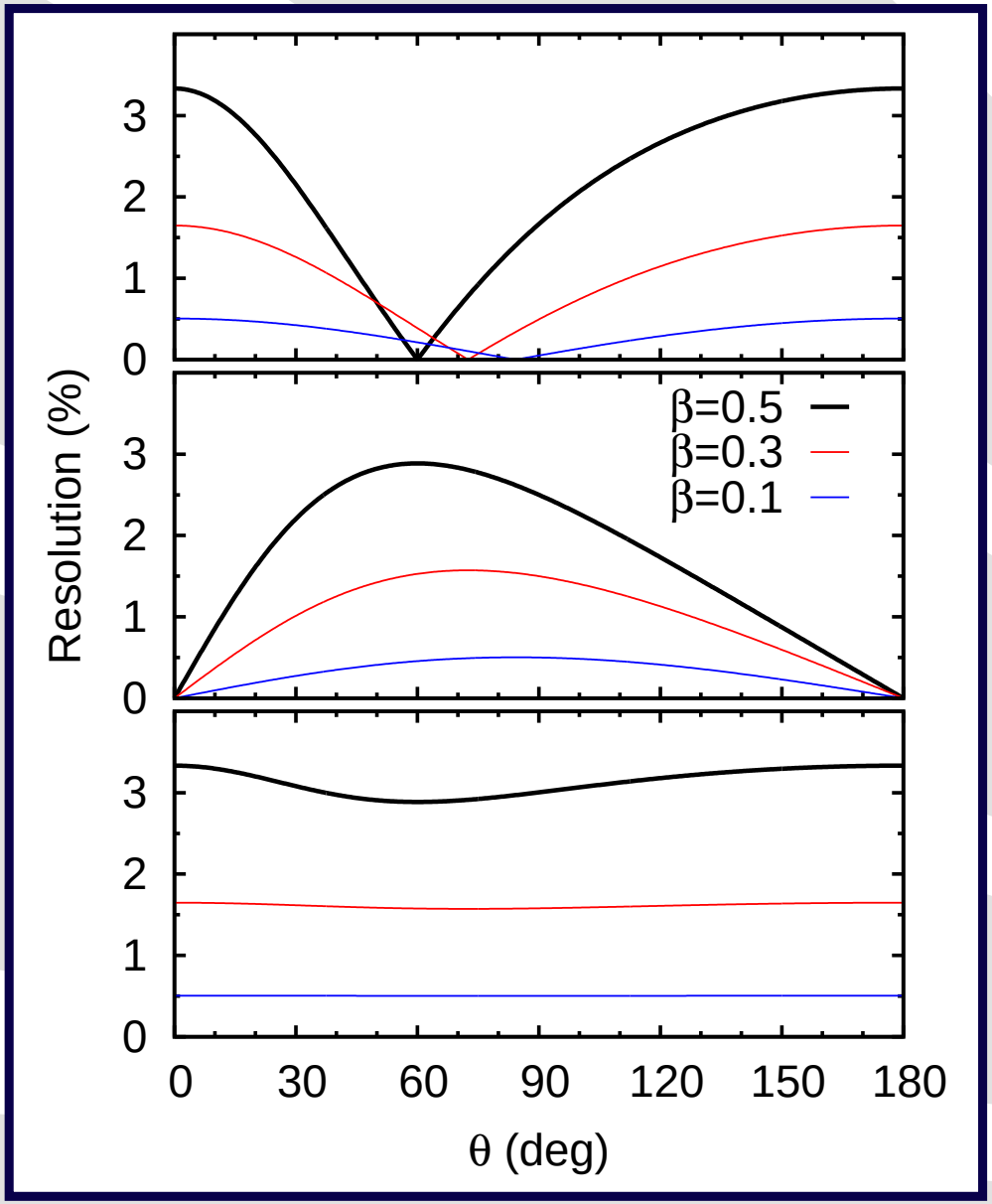
$$\frac{1}{E}\frac{\partial E}{\partial \beta} = \frac{\cos(\theta)}{1-\beta\cos(\theta)} - \beta\gamma^2$$

$$\frac{1}{E}\frac{\partial E}{\partial \theta} = \frac{\beta\sin(\theta)}{1-\beta\cos(\theta)}$$

Doppler Broadening: Summary

- There is a sizable Doppler broadening even with a perfect detector, due to
  - Uncertainty in beam velocity (energy loss in the target)
  - Uncertainty in the emission point of the γ-ray (target thickness, lifetime of excited state)

Doppler Broadening



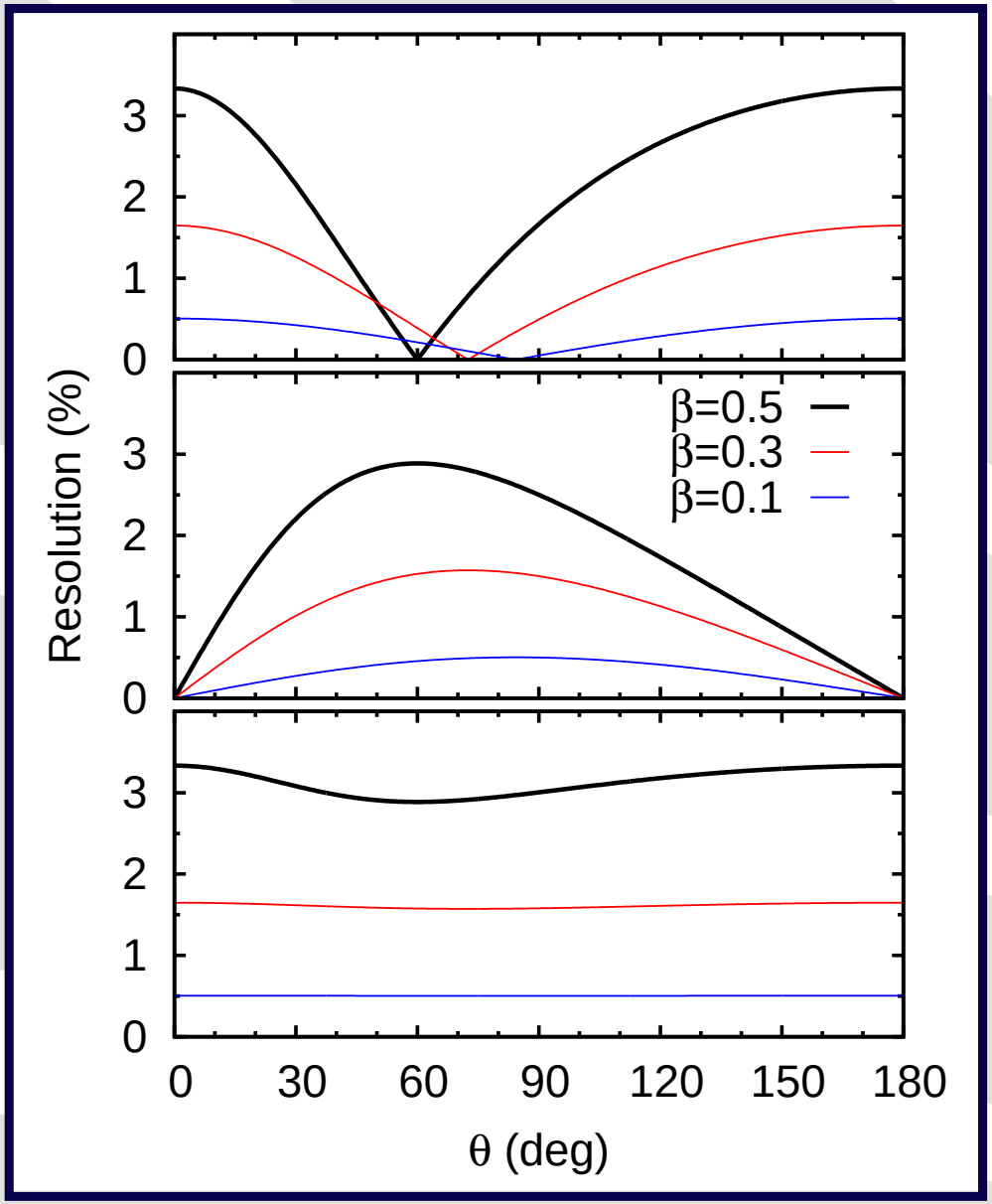
$|\partial E/\partial\beta| \cdot \Delta\beta$

$\Delta\beta/\beta = 5\%$

$|\partial E/\partial\theta| \cdot \Delta\theta$

$\Delta\theta = 50$ mrad

Doppler Broadening



$|\partial E/\partial\beta| \cdot \Delta\beta$

$\Delta\beta/\beta = 5\%$

$|\partial E/\partial\theta| \cdot \Delta\theta$

$\Delta\theta = 50$ mrad

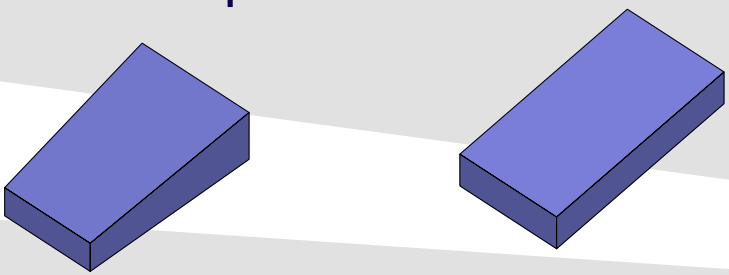
achievable energy resolution:

3%

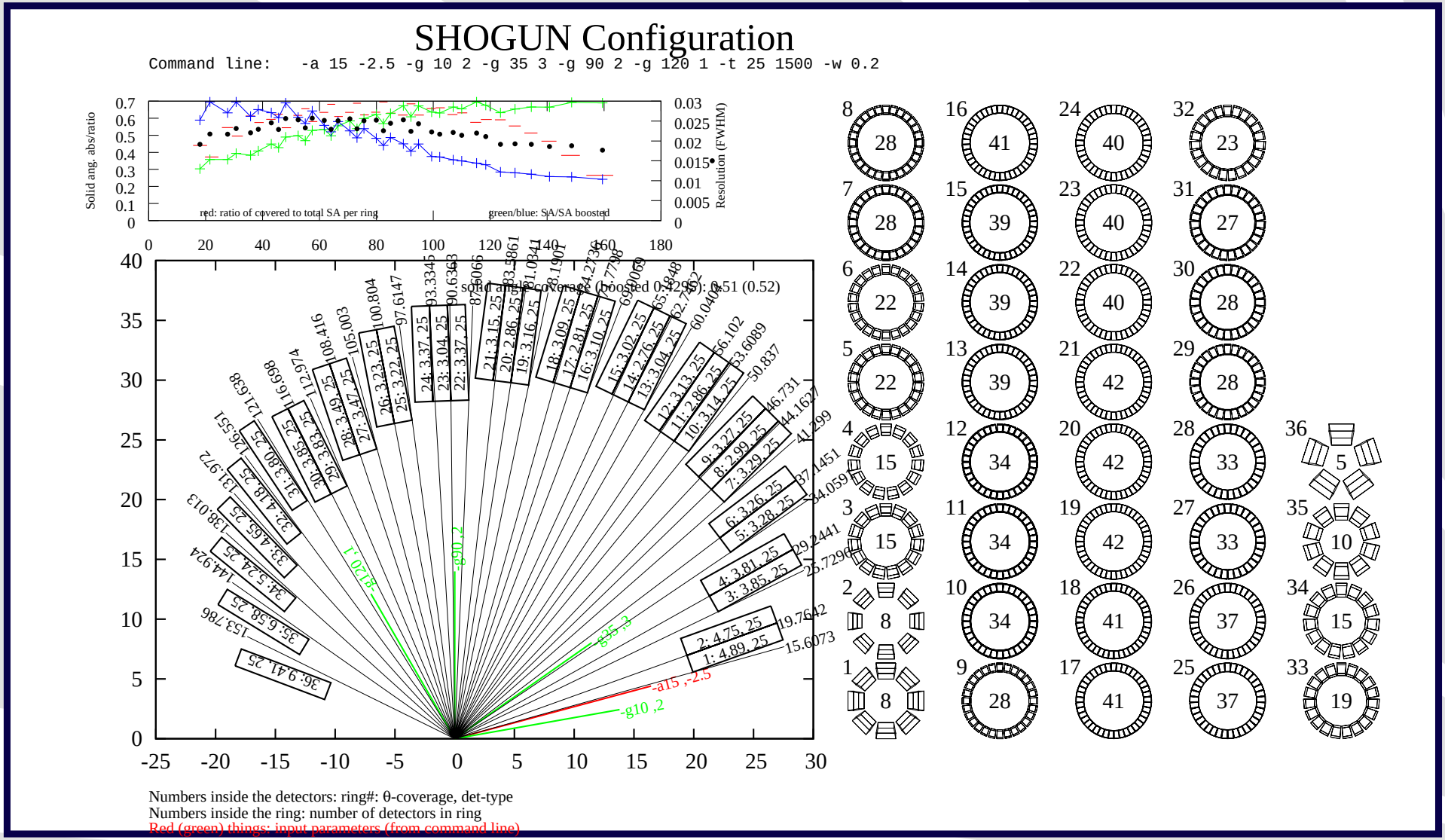
Detector Configuration

Considerations

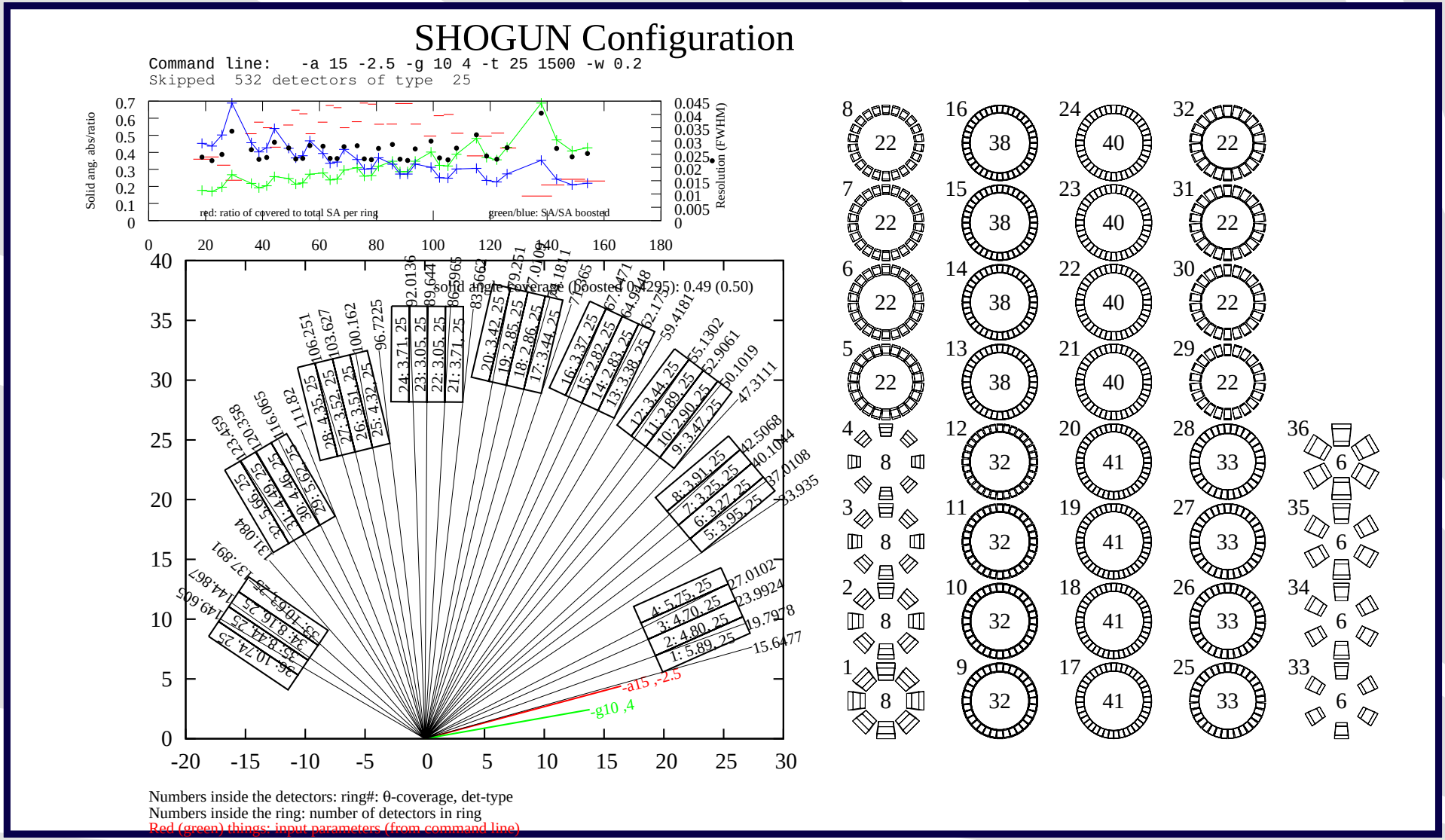
- Need to keep the opening angle small to minimize Doppler Broadening
- Too small detectors result in efficiency losses
- Doppler Broadening maximized at $cos\vartheta_\gamma = \beta$
- Cluster detectors into common housing to minimize efficiency losses for add-back
- Simple shape to allow for easy reconfigurations
  - Box
  - Trapezoid



Configuration with det_place.gawk



Configuration with det_place.gawk



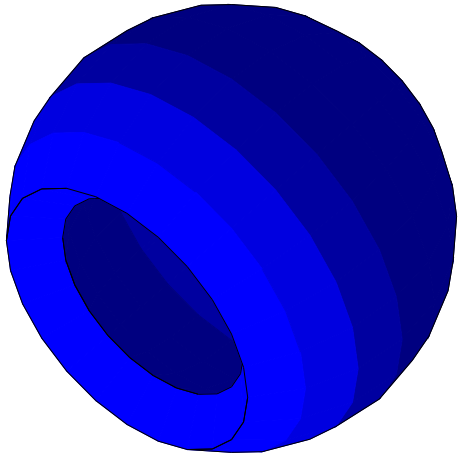
Simulations

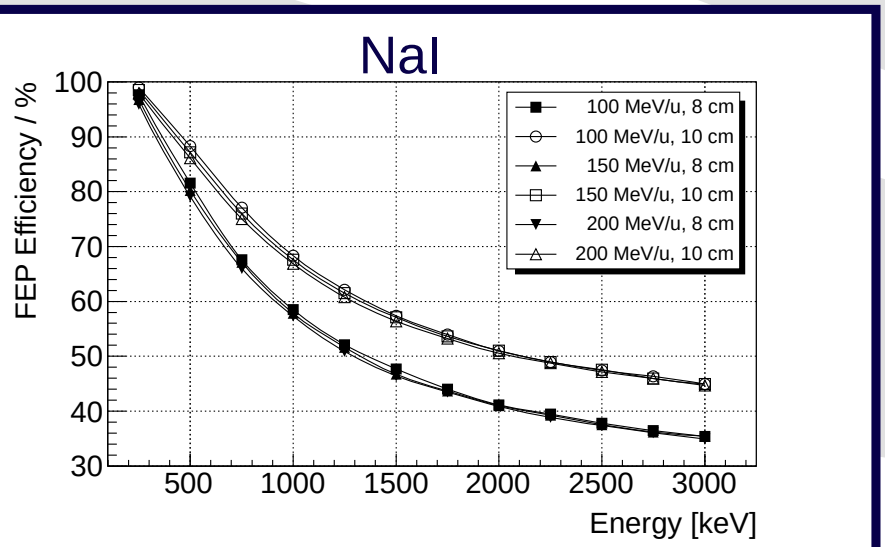
Simulation Concept

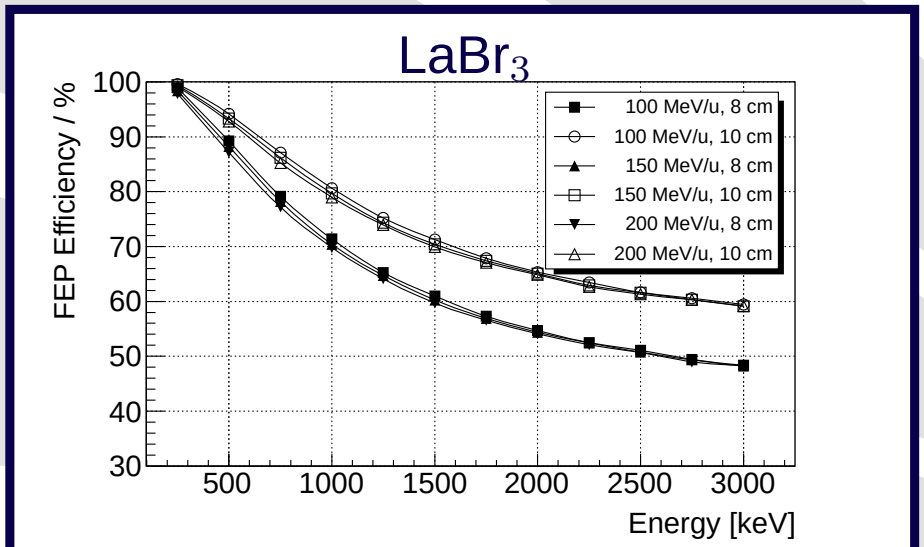
- EventGenerator
  - Heavy ion, γ-ray
  - Energy loss in target
  - γ-ray emission
  - Atomic background
- EventBuilder
  - Detectors, beam pipe, shielding
  - SHOGUN, DALI2, others
  - Simulates detector response
- Reconstructor
  - Doppler correction
  - γ analysis

$LaBr_3$, NaI Sphere

- 8,10 cm thickness
- 100, 150, 200 MeV/u

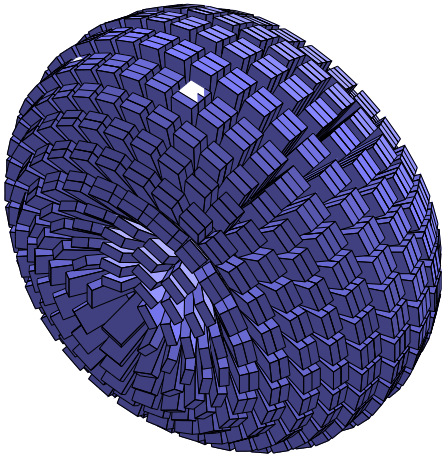


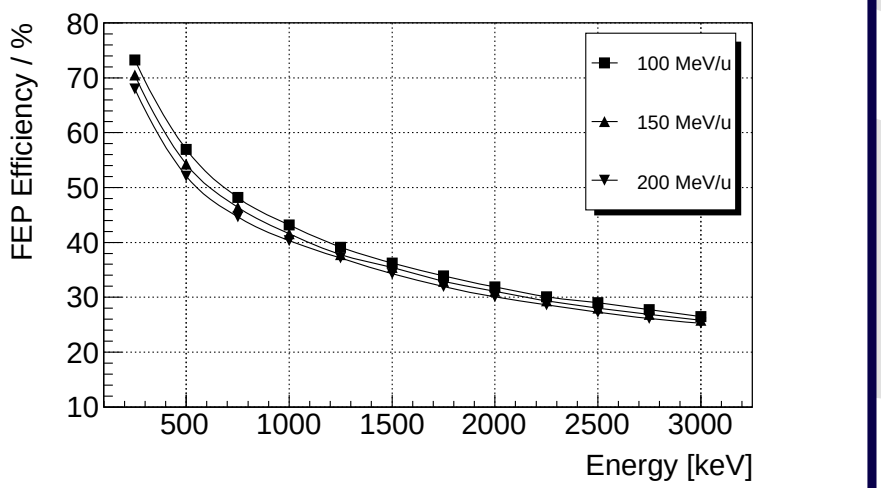


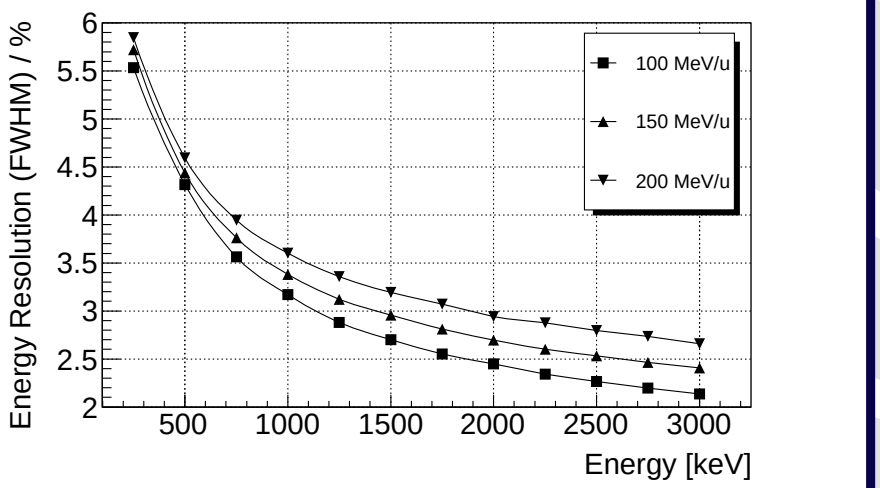


Simulation Results

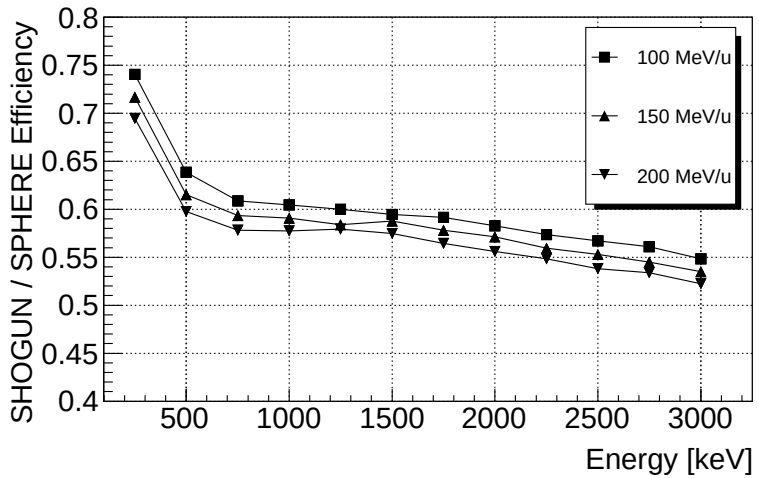
- $15 \times 40 \times 80$ mm^3 box, 1042 det.
- No housing
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

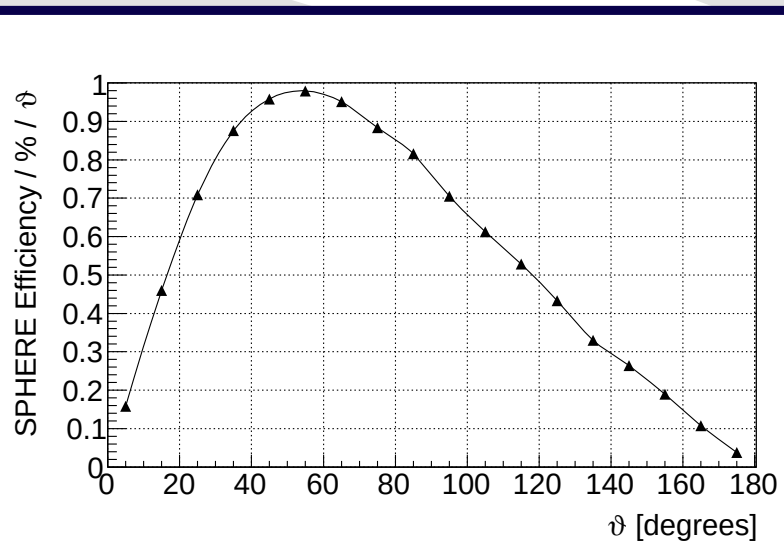




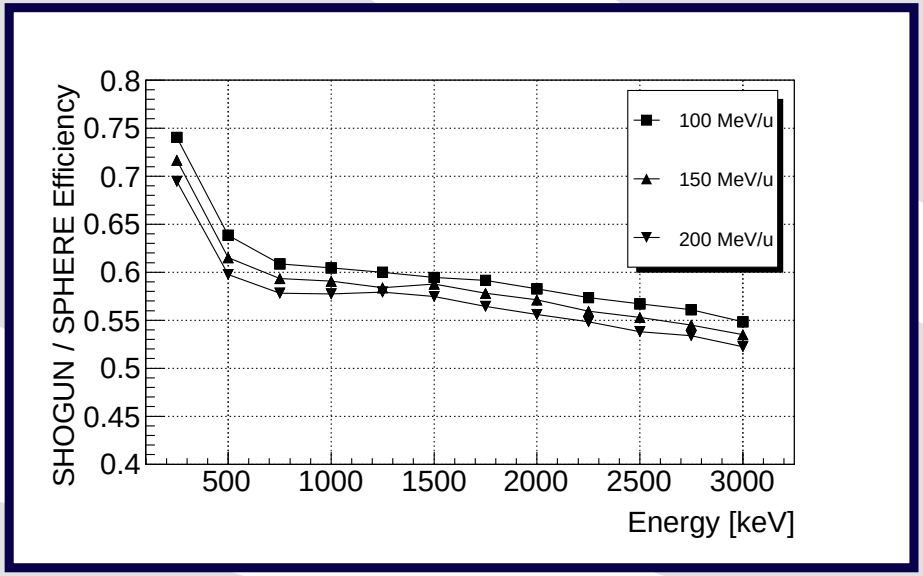


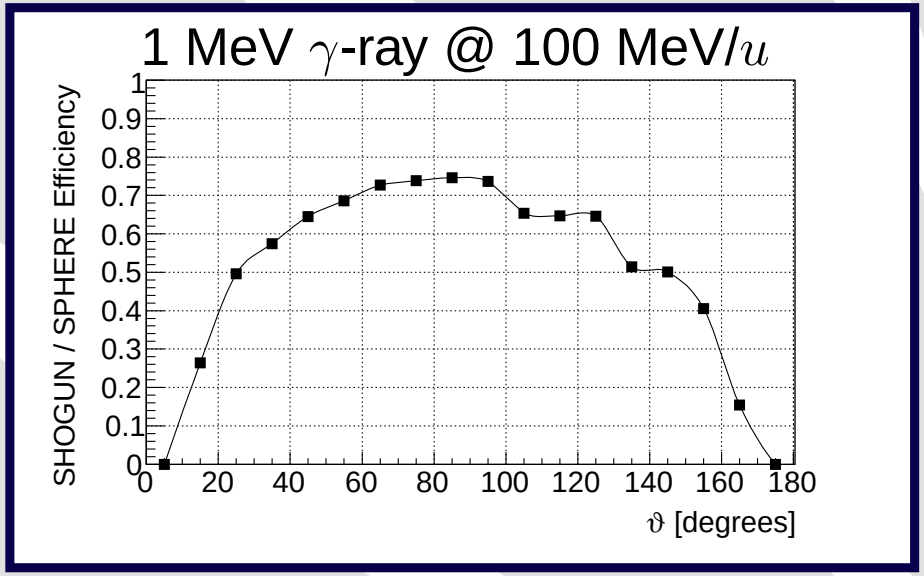
Efficiency Losses

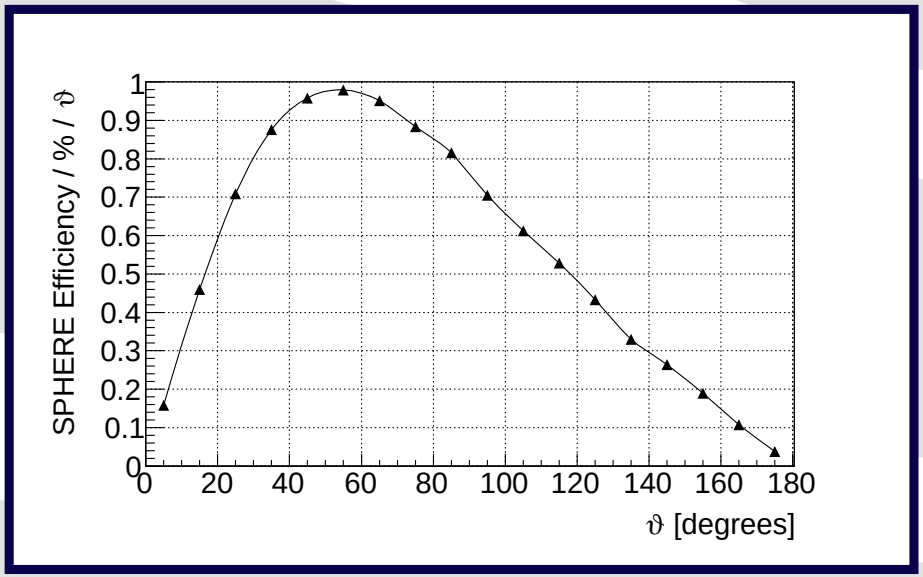




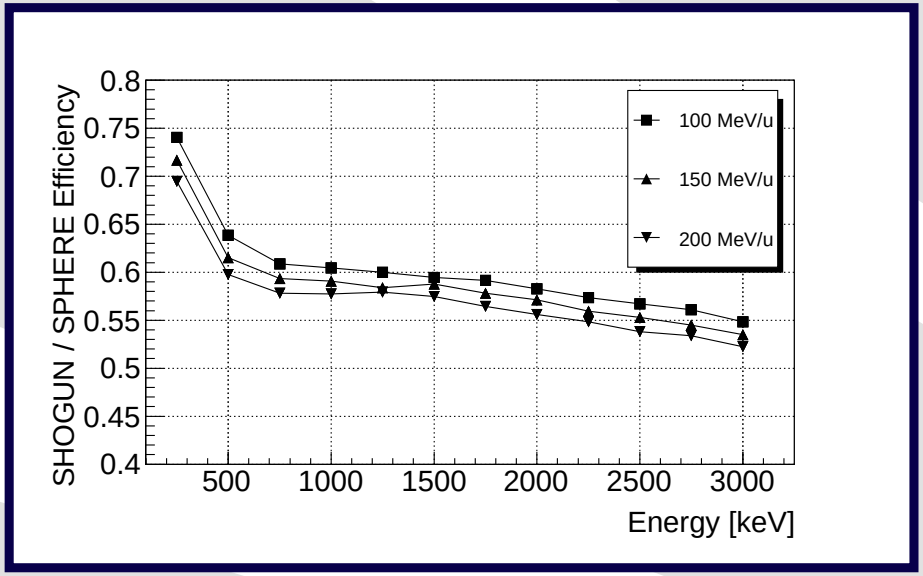
Efficiency Losses

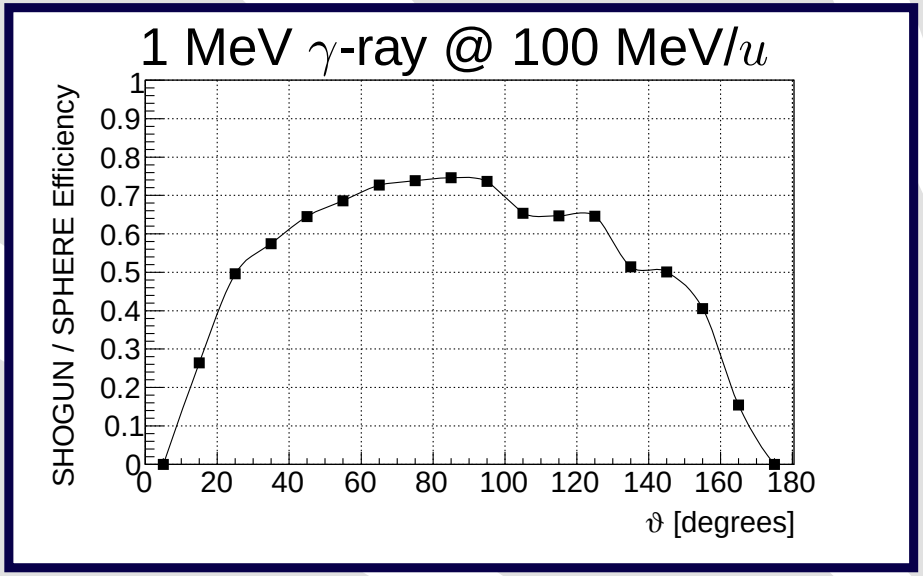


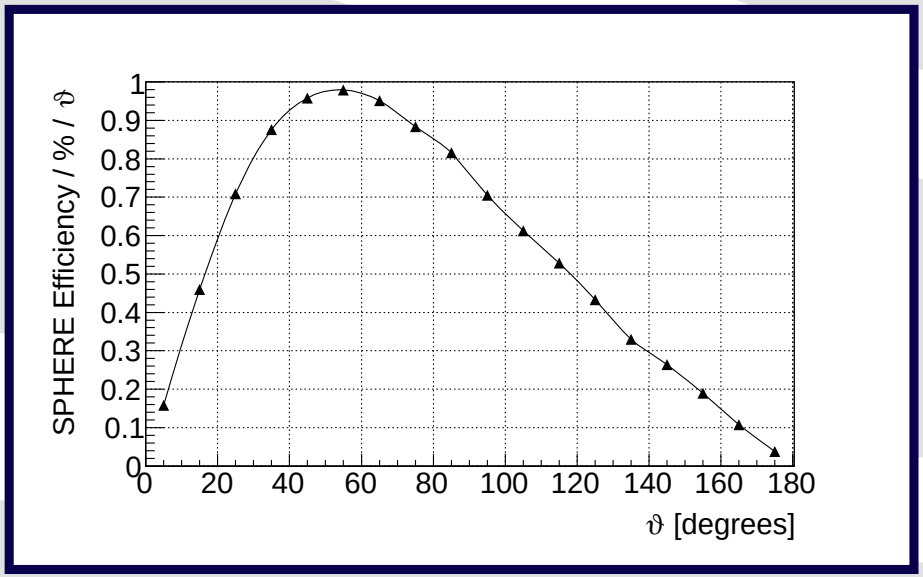


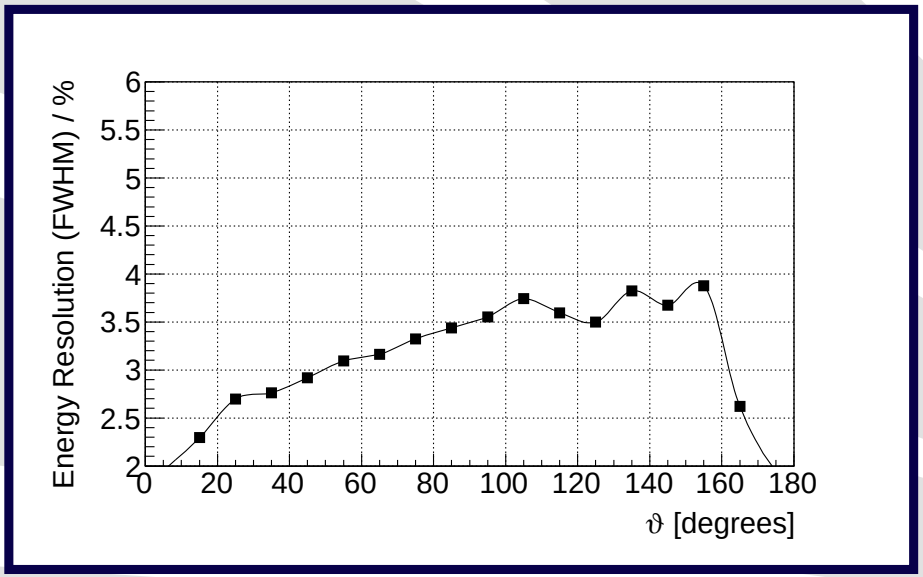


Efficiency Losses



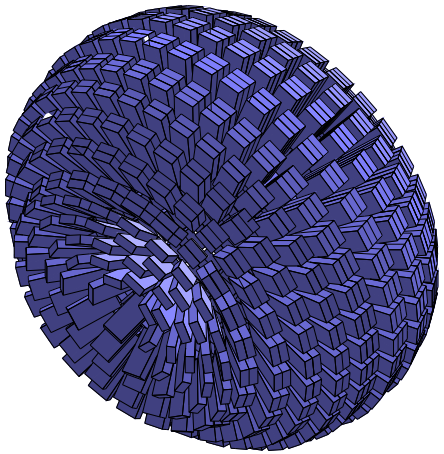


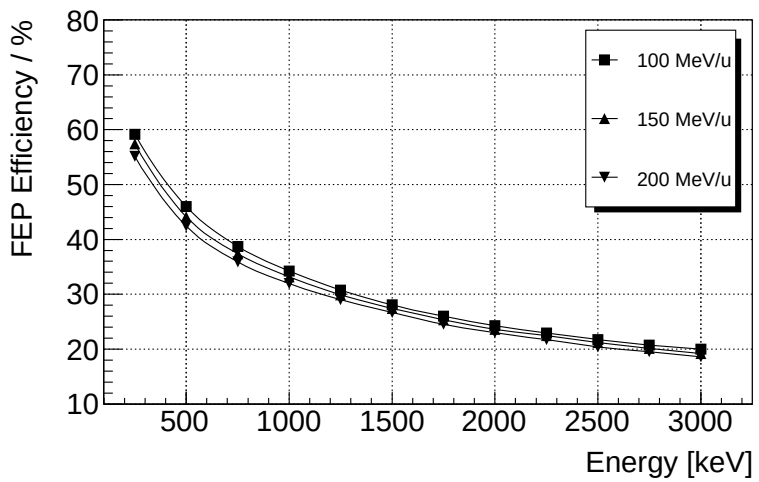


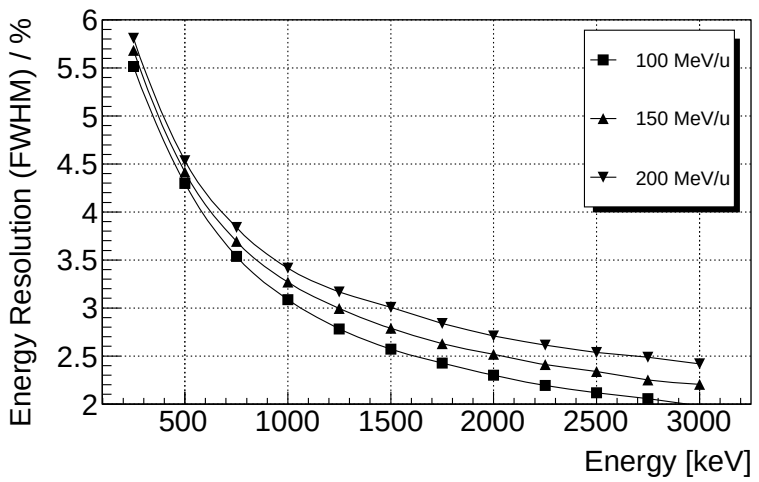


Simulation Results

- $15 \times 40 \times 80$ mm^3 box, 1059 det.
- Making 2 mm space for housing and insulation
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

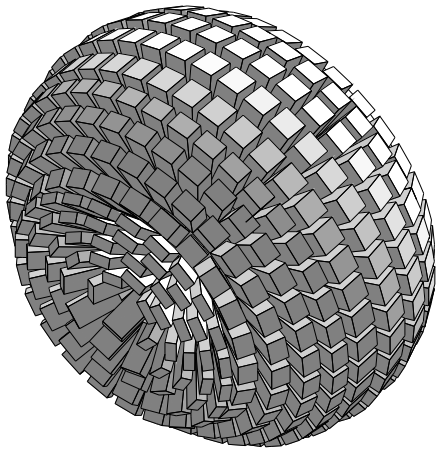


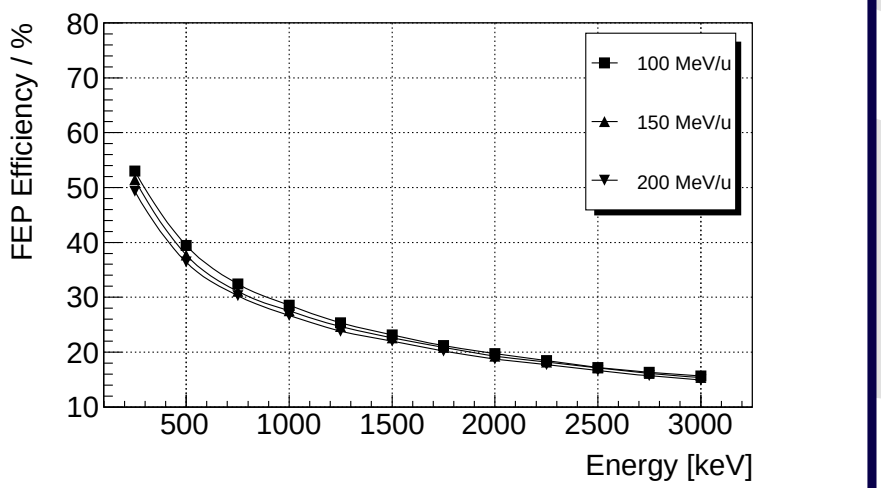


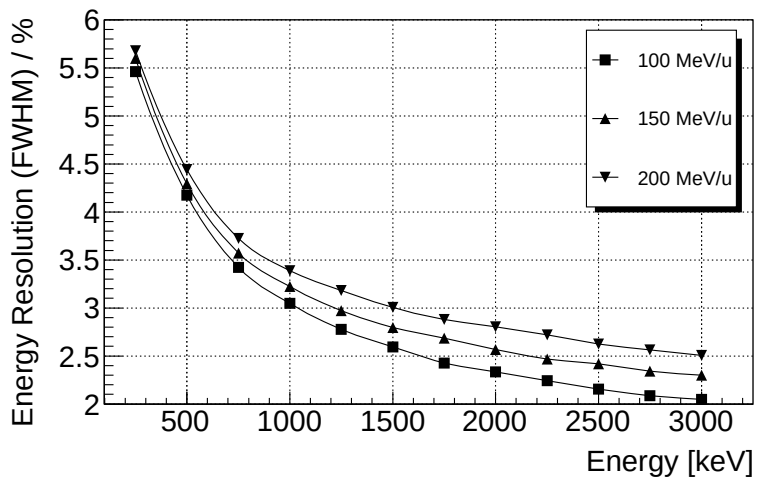


Simulation Results

- $15 \times 40 \times 80$ mm^3 box, 1059 det.
- 1 mm Al, 1 mm Teflon
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

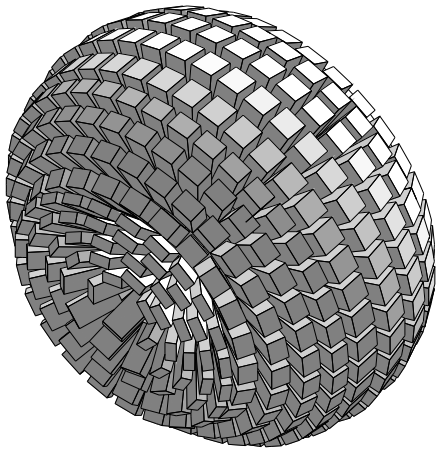


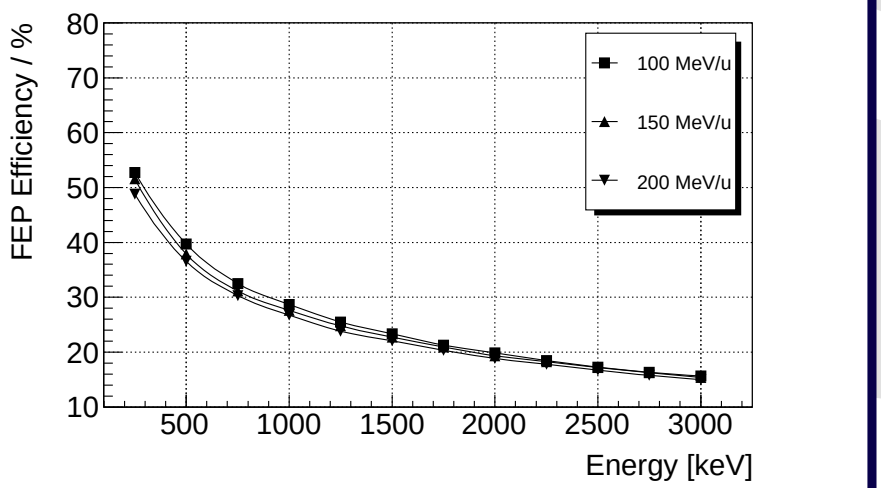


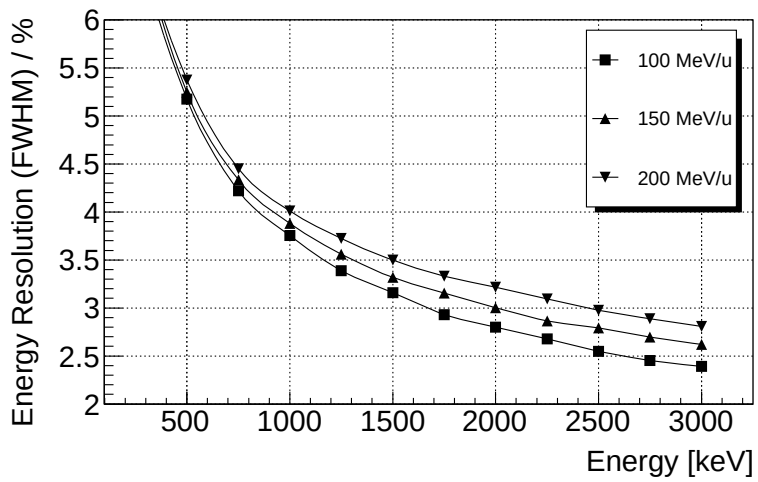


Simulation Results

- $15 \times 40 \times 80$ mm^3 box, 1059 det.
- 1 mm Al, 1 mm Teflon
- 4 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 3.2 % @ 1 MeV

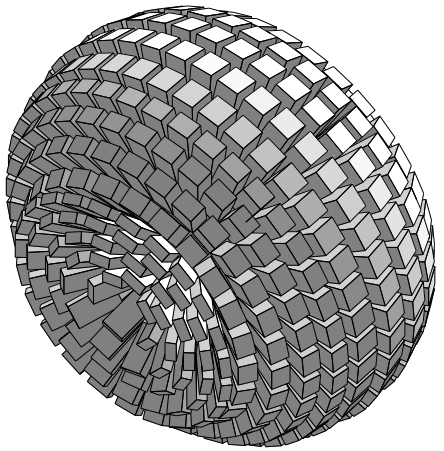


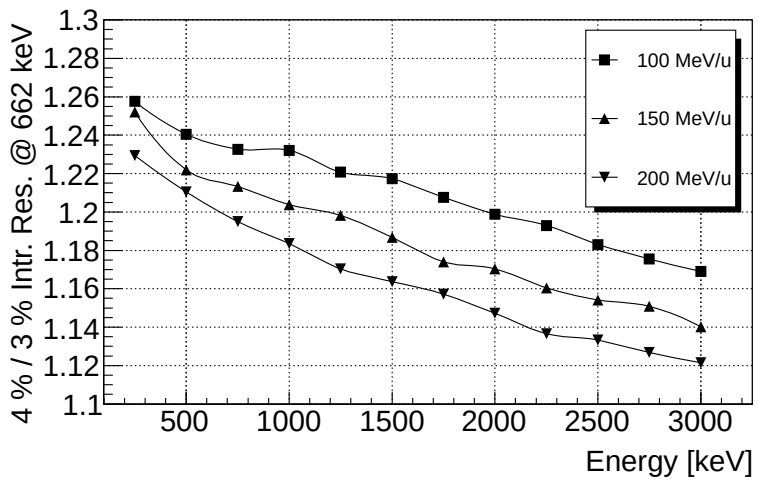


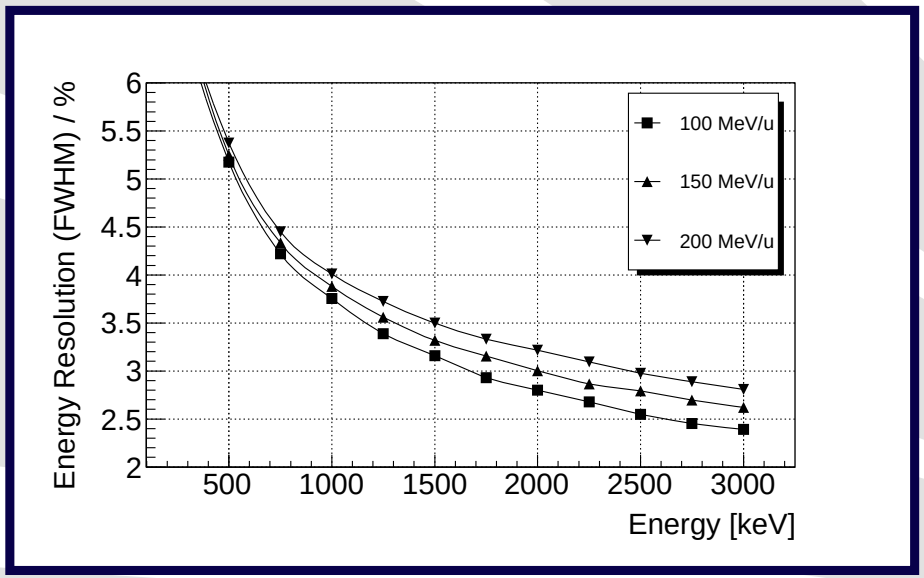


Simulation Results

- $15 \times 40 \times 80$ mm^3 box, 1059 det.
- 1 mm Al, 1 mm Teflon
- 4 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 3.2 % @ 1 MeV

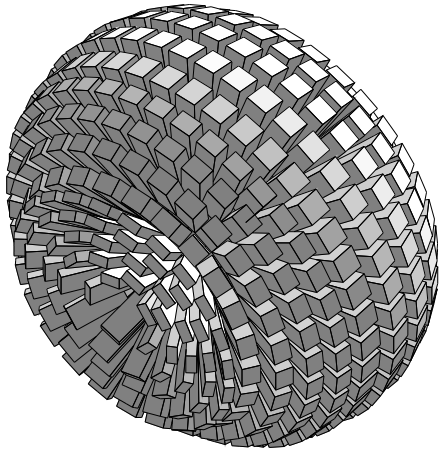


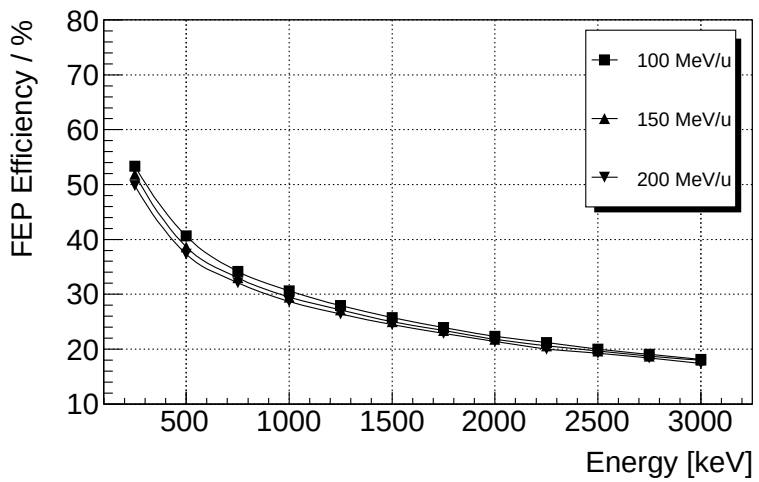


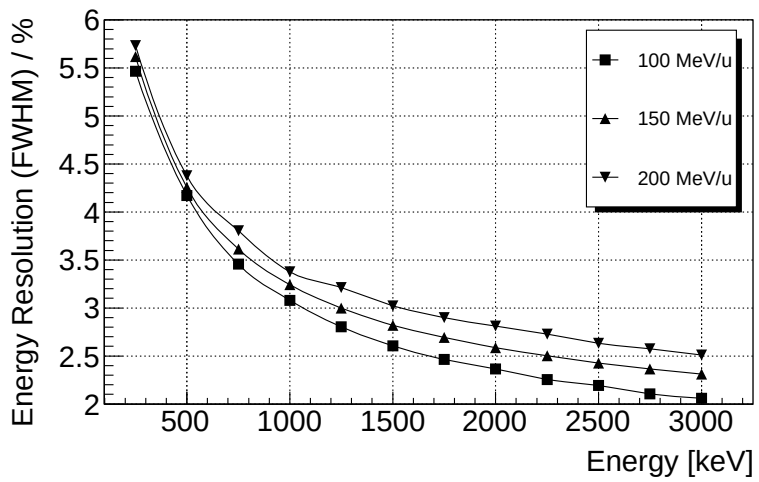


Simulation Results

- $15 \times 40 \times 100$ mm^3 box, 1059 det.
- 1 mm Al, 1 mm Teflon
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

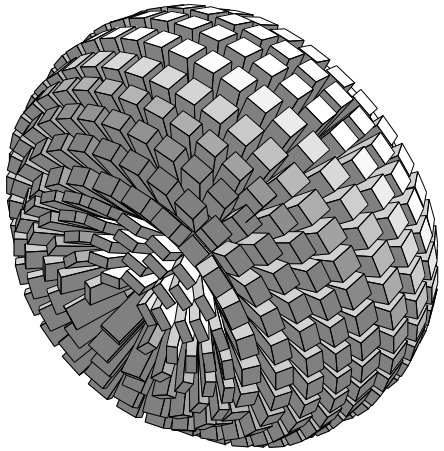


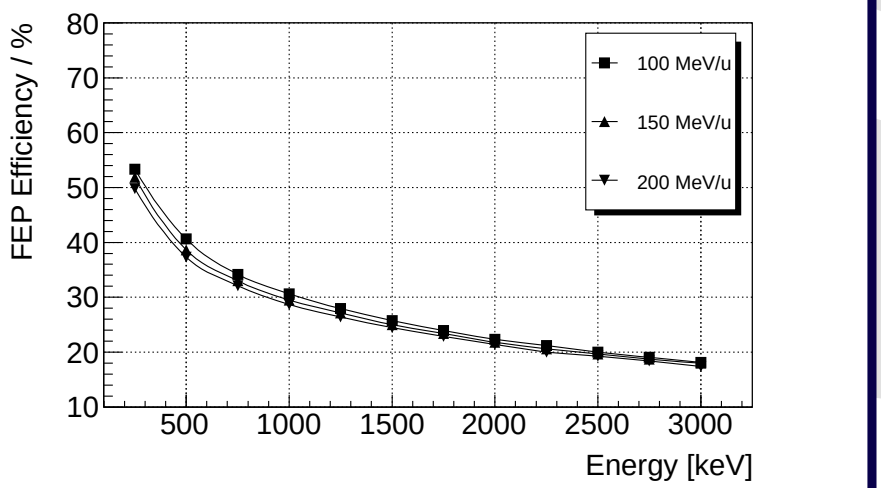


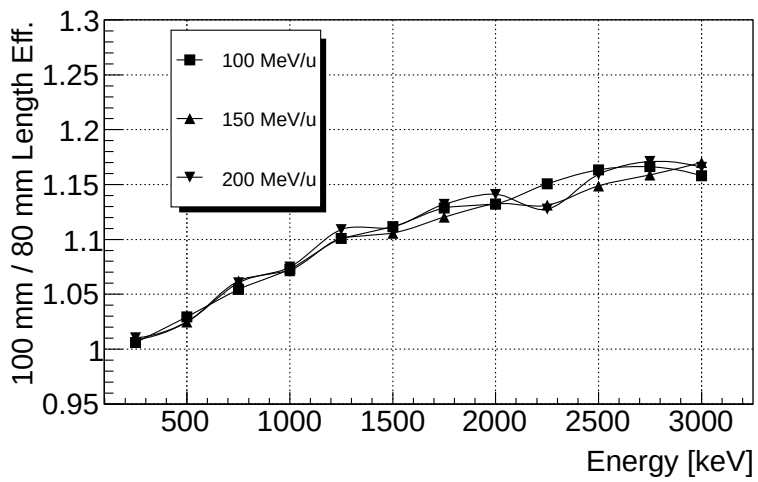


Simulation Results

- $15 \times 40 \times 100$ mm^3 box, 1059 det.
- 1 mm Al, 1 mm Teflon
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

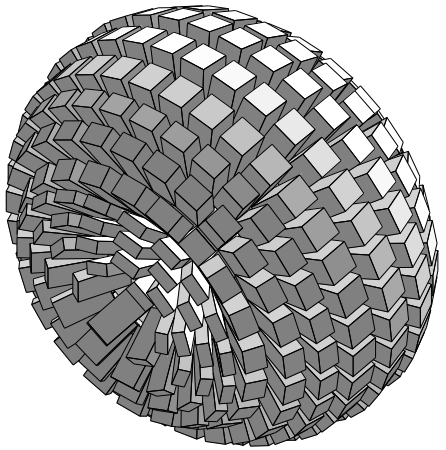


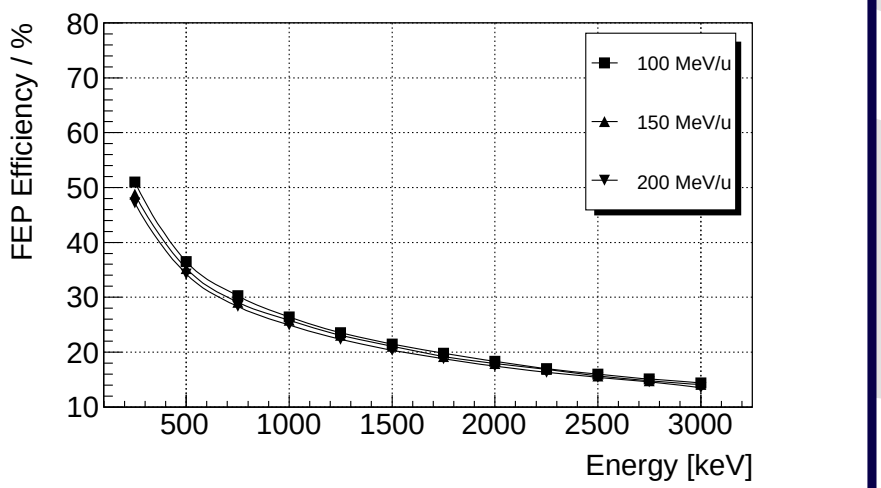


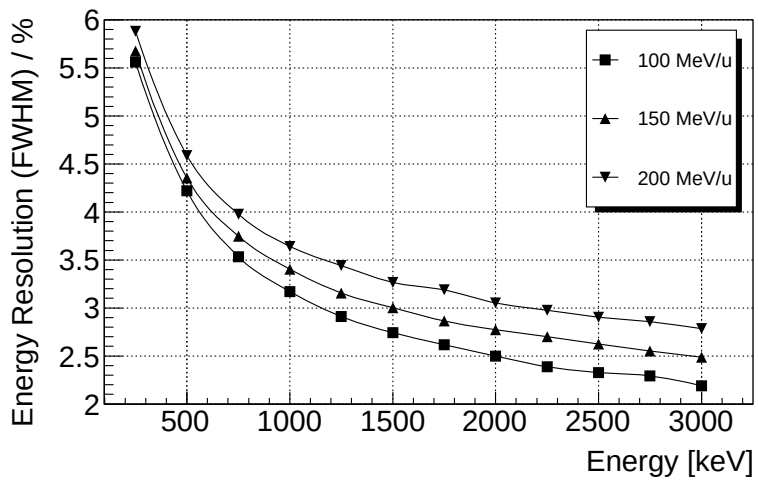


Simulation Results

- $15 \times 40 \times 80$ mm^3 box, 747 det.
- 1 mm Al, 1 mm Teflon
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

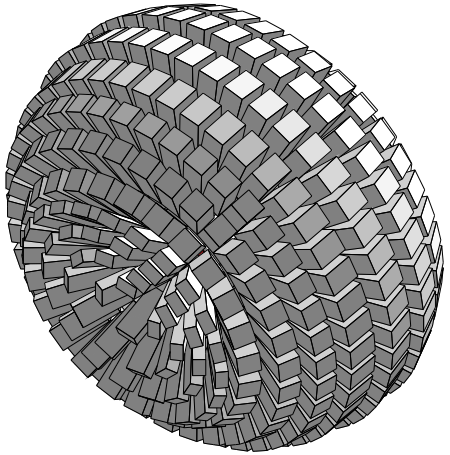


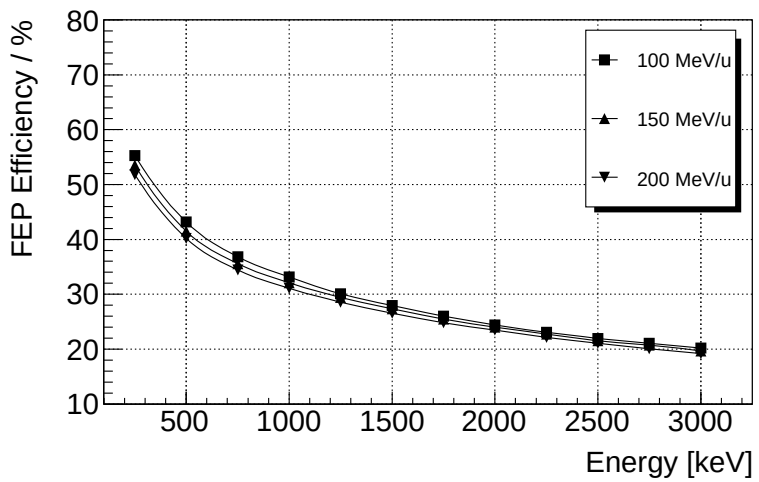


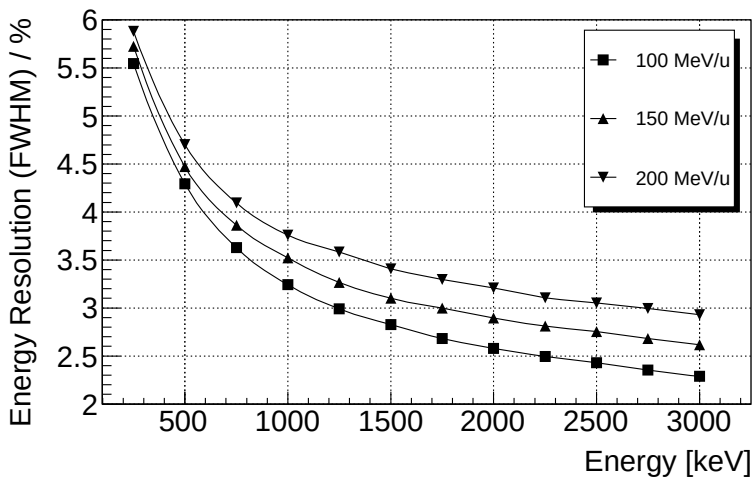


Simulation Results

- $20 \times 40 \times 100$ mm^3 box, 930 det.
- 1 mm Al, 1 mm Teflon
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV

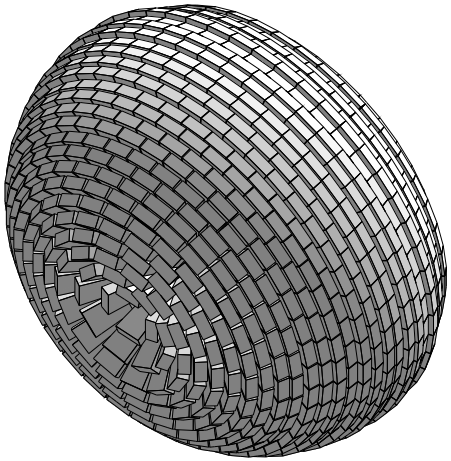


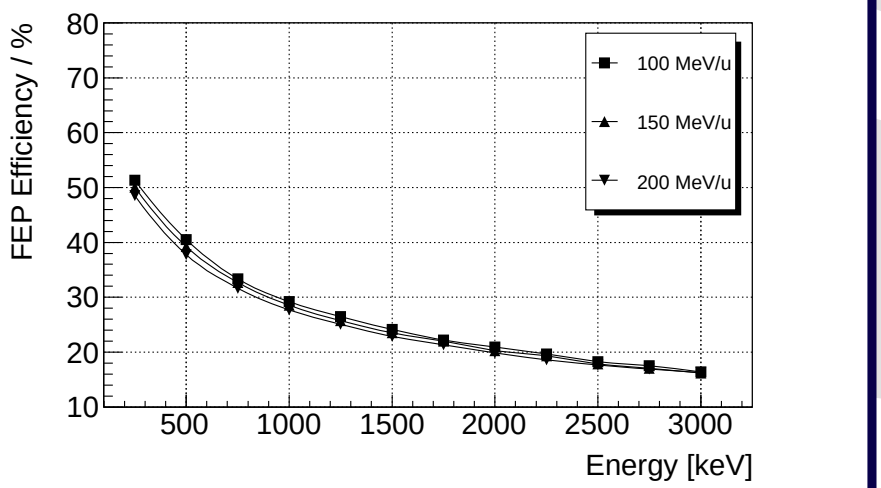


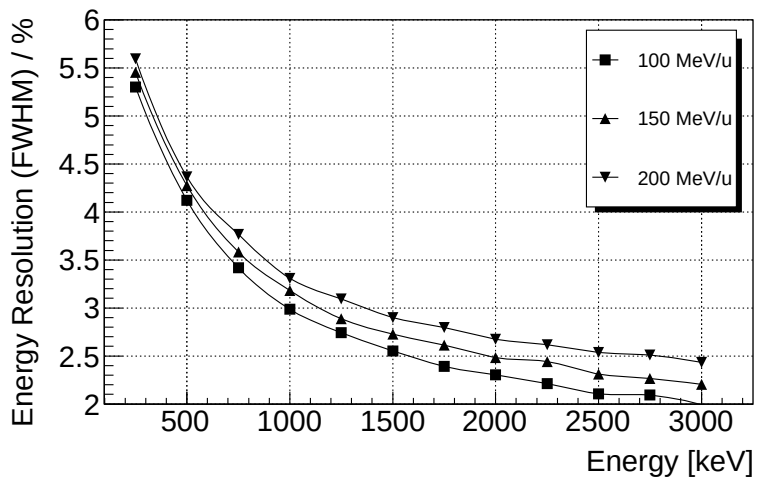


Simulation Results

- 15(20 $\times$ 40(50) $\times$ 80 mm^3 trapezoid, 1252
- 1 mm Al, 1 mm Teflon
- 3 % @ 662 keV, $\Delta E = x \cdot E^{1/2} \rightarrow$ 2.4 % @ 1 MeV





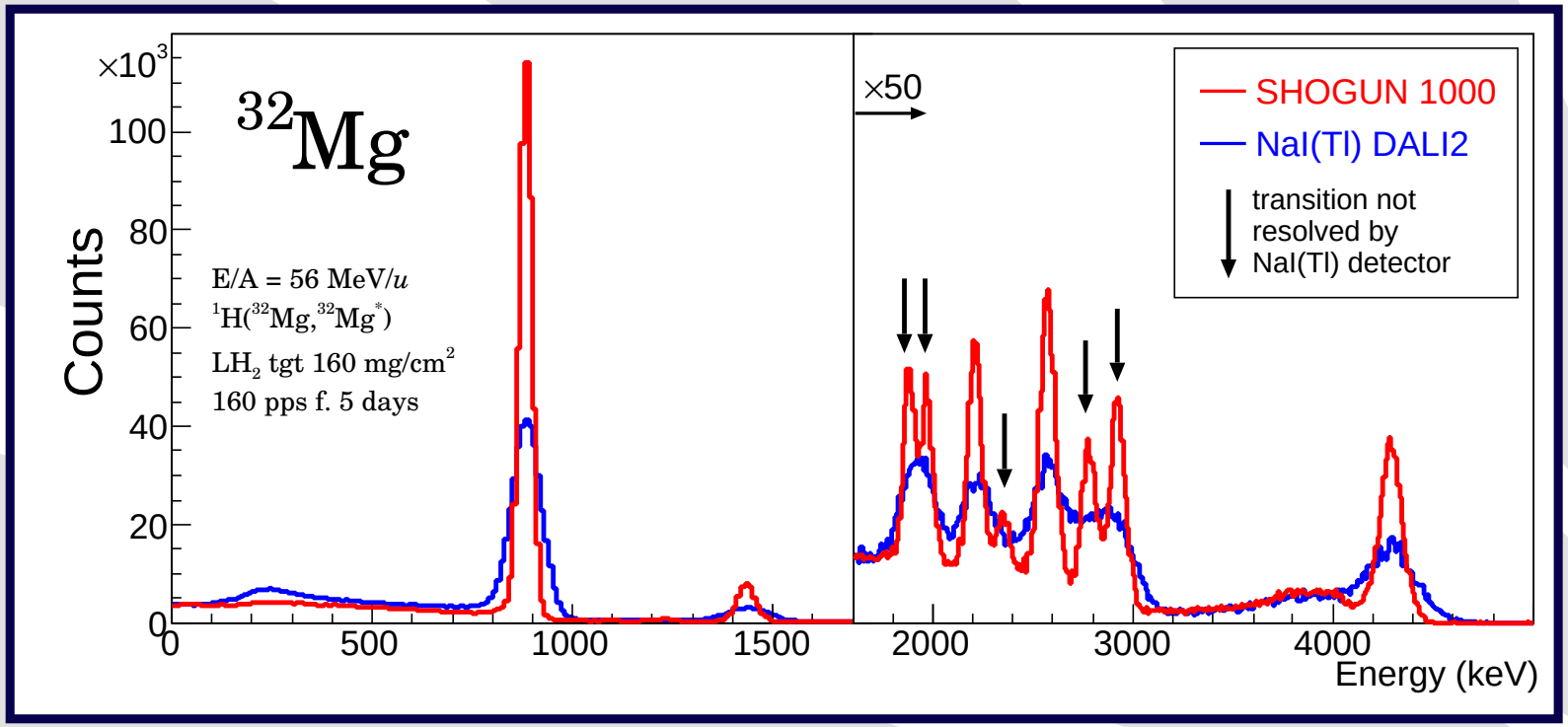


Summary of Simulations

- 15(20) $\times$ 40(50) $\times$ 80(100) mm^3
- Box, trapezoid
- 2.4, 3.2 % @ 1 MeV, $\Delta E = x \cdot E^{1/2}$
- Simulated resolution and efficiency for 1 MeV γ-ray at 100 MeV/u

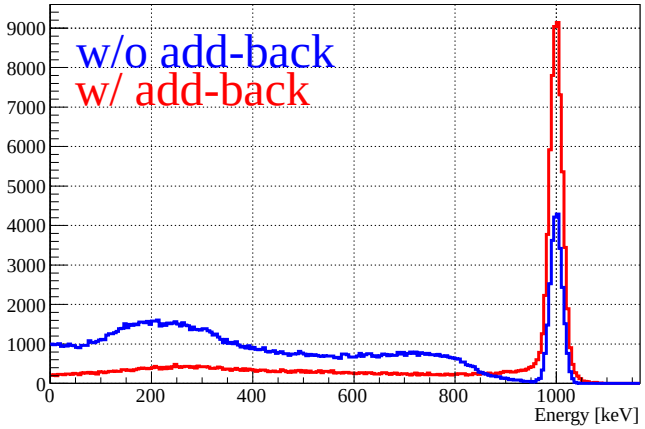
Size / mm^3	Shape	Dopp. Broad. / %	Intr. Res. / %	Housing / mm	Det.	Eff. /% /100kg	Eff. %	Res. %
15×40×80	box	2.5	2.4	–	1042	16.9	43.0	3.2
15×40×80	box	2.5	2.4	2	1059	11.02	28.5	3.0
15×40×80	box	2.5	3.2	2	1059	11.02	28.5	3.7
15×40×80	box	3	2.4	2	747	14.5	26.4	3.2
15×40×100	box	2.5	2.4	2	1059	9.5	30.6	3.1
20×40×100	box	3	2.4	2	930	8.7	33.0	3.2
15×40×80	trap.	2.5	2.4	2	1252	7.2	29.2	3.0

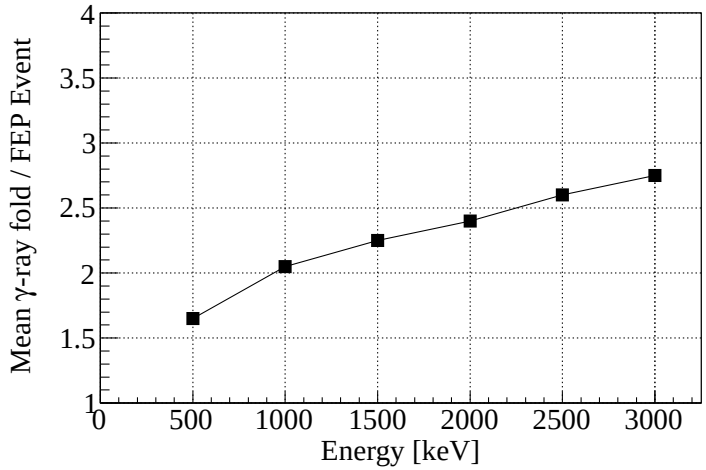
Simulation: SHOGUN 1000 and DALI2



Simulation based on experimental data of
S. Takeuchi *et al.*, PRC 79, 054319 (2009)

Addback





For Doppler-correction: Assume that crystal detecting the highest energy is location of first interaction.
In the present simulations the energy is simply summed up.

Summary

Summary and Outlook

- Simulations show that 3 % energy resolution can be achieved
- Efficiency at forward angles below $\vartheta = 40°$ has to be improved, maybe wall-like structure.
- Need to implement more realistic add-back procedure, momentarily energy is simply summed up

THE END

Backup slides from now