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Comparison of Scintillation Detectors based on BGO and LSO for Prompt Gamma Imaging in Ion Beam Therapy

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Motivation

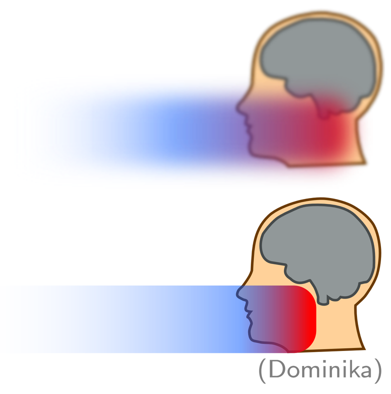
Cancer treatment → (promising method) → Ion beam therapy → (Achilles' heel) → Range uncertainties → (need of) → In-vivo verification → In-beam PET / Prompt gamma / ...

Prompt gamma → ($E_\gamma \sim$ 2-6 MeV measured with) → Gamma detectors

- Position sensitive
- High absorption efficiency
- Good time & energy resolution

→ (Candidate materials) → LSO / BGO scintillators → (Purpose) →

- Compare performance in clinical scenario
- Is BGO competitive enough with LSO?



Materials

Scintillator properties

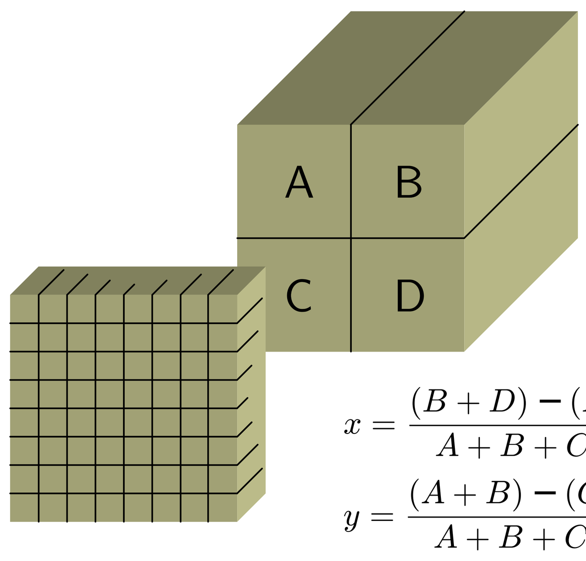
	LSO	BGO
Density (g/cm^3)	7.40	7.13
Z_{eff}	66	74
Light yield (% NaI)	85	21
Decay time (ns)	40	300
Activity (Bq/cm^3)	280	0

Available detectors (SIEMENS)

	LSO	BGO
Pixel matrix	13×13	8×8
Pitch (mm×mm)	4×4	6.5×6.5
Light guide	Yes	No

Sketch of the block detector

(J. Maus)



$$x = \frac{(B+D)-(A+C)}{A+B+C+D}$$

$$y = \frac{(A+B)-(C+D)}{A+B+C+D}$$

Experimental setup

Tests at accelerators

Accelerator name	ELBE	Tandetron	AGOR
Accelerator type	LINAC	Tandem	Cyclotron
Accelerated particles	Electrons	Protons	Protons
Kinetic energy	12.5 MeV	924 keV	150 MeV
Bunch frequency	13 MHz	/	55 MHz
Target material	Nb	TiN	Graphite
Gamma field	Continuous	Monoenergetic	Characteristic
Gamma energy range	$\lesssim$ 12.5 MeV	4.4 MeV	$\lesssim$ 10 MeV
Physical process	Prompt bremsstrahlung photons	Resonant nuclear reaction	Prompt nuclear reactions
Background rate *vs* signal rate	Very low	Medium: natural, cosmic	High: neutrons, activation

Results

ENERGY

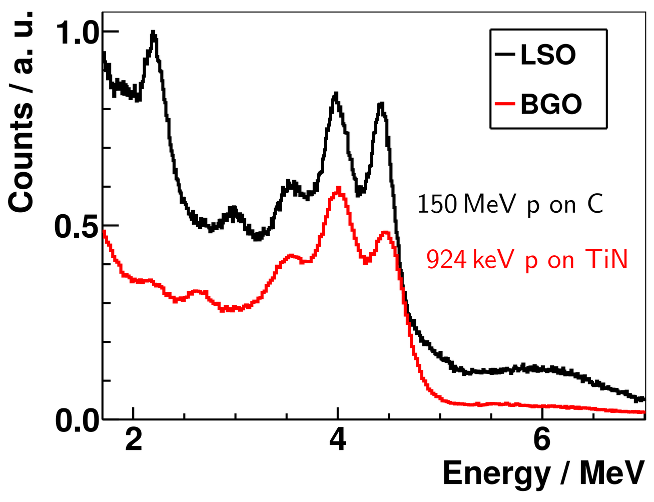


Fig. 1 - Detector response spectrum of the LSO detector (black line) at the prompt gamma field at AGOR with a graphite target compared to the BGO detector (red line) at Tandetron. Vertical scale is arbitrary.

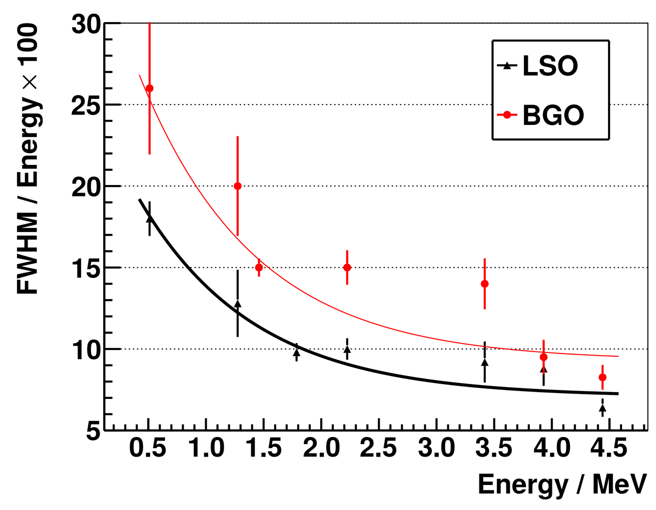


Fig. 2 - Relative energy resolution FWHM/E for the LSO (black line) and BGO (red line) block detectors. The results obtained at different accelerators (photopeaks) are combined.

SPACE

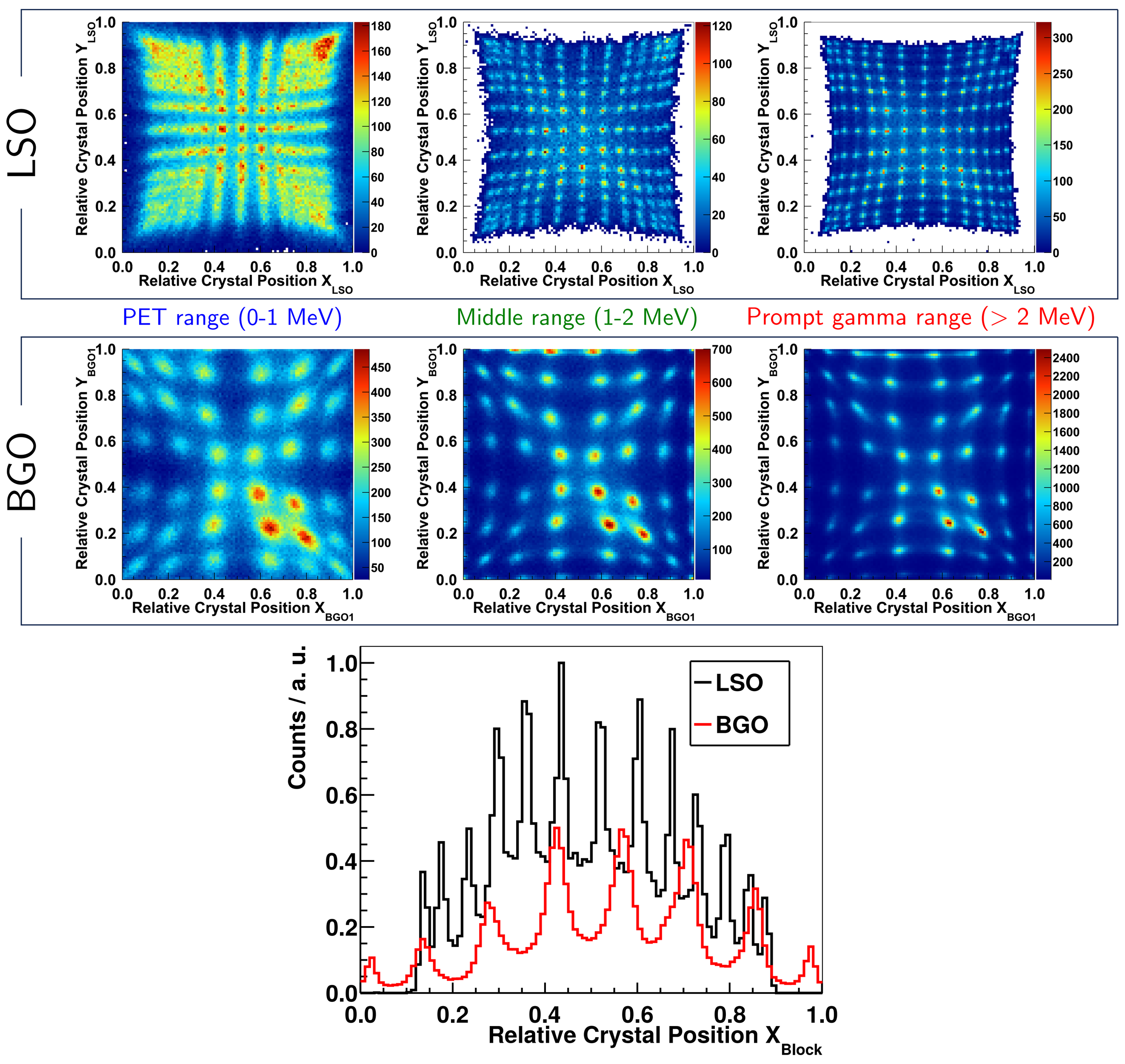


Fig. 3 - Block detector flood map (top figure: LSO, middle figure: BGO) for different energy ranges at the ELBE accelerator. Projection (bottom figure) of the flood map for the PGI range along a single crystal row for the LSO (black line) and BGO (red line) block detectors; vertical scale is arbitrary.

TIME

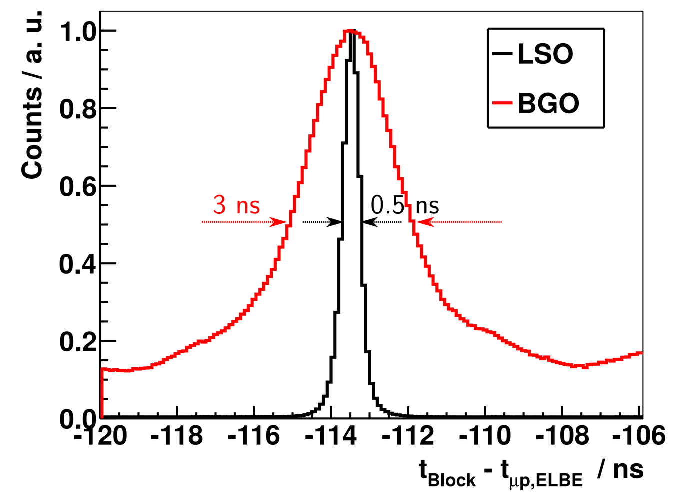


Fig. 4 - Time spectrum of the LSO detector (black line) compared to the BGO detector (red line) at the ELBE accelerator. The difference between detector signal and accelerator pulse is represented. Vertical scale is arbitrary.

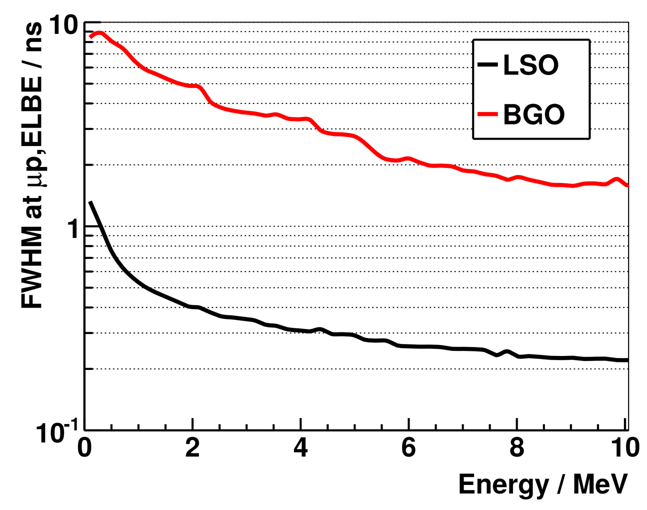


Fig. 5 - Time resolution (FWHM) for the LSO (black line) and BGO (red line) block detectors measured at the ELBE accelerator as a function of the measured energy.

- LSO better energy resolution
- BGO higher absorption efficiency

- Prompt gamma range: BGO pixels are cleary discriminated
- BGO crystal can be segmented in more pixels per block

- LSO significantly better time resolution
- BGO timing acceptable for high energies

Conclusions

⇒ For the prompt gamma energy range, BGO energy / space resolution trends towards LSO ⇐

⇒ BGO lower price makes it promising candidate as absorber material in a Compton camera ⇐

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