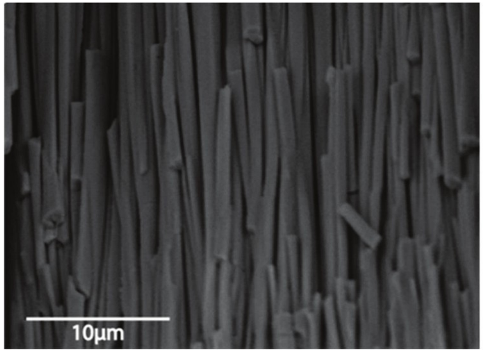
nuclear physics

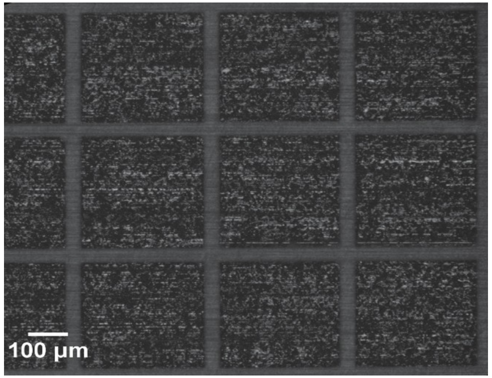
Advancing high-energy gamma imaging with pixelated scintillator technologies

Raluca-Andreea Miron
GDED

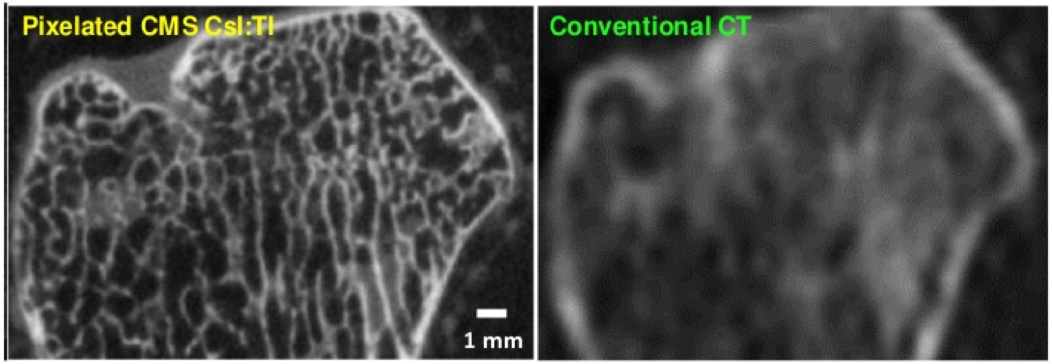
Structured detectors

Columnar and **Pixelated** CsI(Tl) configurations





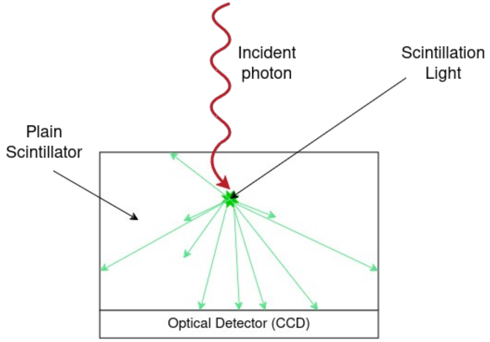
L. K. Jambi et al, *Comparison of columnar and pixelated scintillators*
DOI:10.1109/NSSMIC.2016.8069402



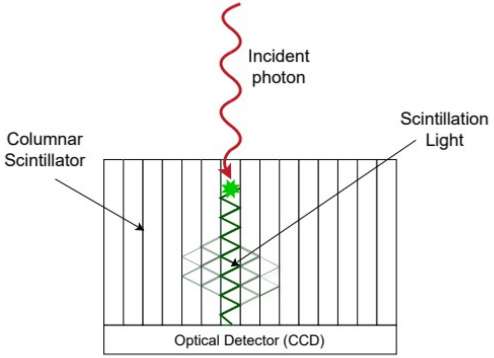
Images of a bone obtained using the CBCT based on pixelated CsI:Tl and conventional CT (for illustrative purposes only).

S. Miller et al, *Pixelated Columnar CsI:Tl Scintillator for High Resolution Radiography and Cone-Beam CT*
DOI:10.1117/12.2550196

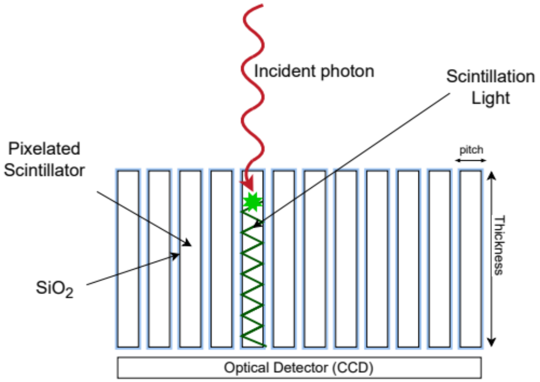
<u>The high resolution of the pixelated scintillator enables the visualization of many details in imaging of the bone microarchitecture.</u>



Plain



Columnar



Pixelated

- Goal: Optimization of the structured scintillator by using Monte Carlo Simulations – **GEANT4**

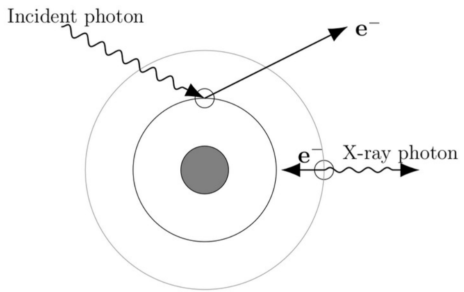
Geant4 simulations

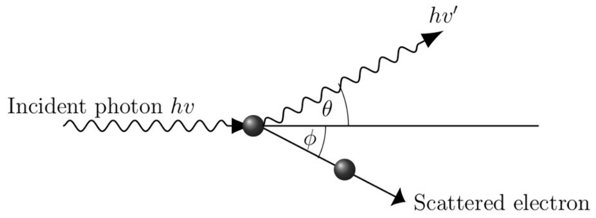
Components:

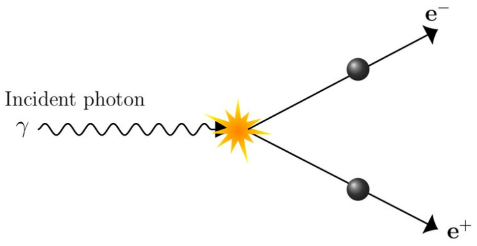
- **Materials:** BGO, CsI (Tl), LYSO;
- **Panel thickness:** [0.5, 1, 2] mm;
- **Beam energies:** [0.1, 0.5, 1, 3, 5, 10] MeV;

Objectives:

- **Energy Deposition:** Study how deposited energy varies with photon energy.
- **Scintillation Yield:** Determine the number of scintillations produced in the detector.
- **Energy Distribution:** Analyze spatial distribution of deposited energy.







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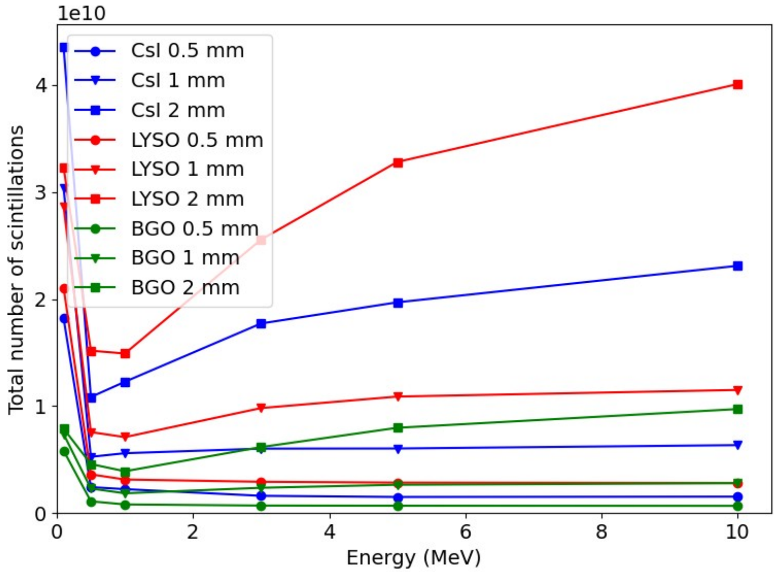
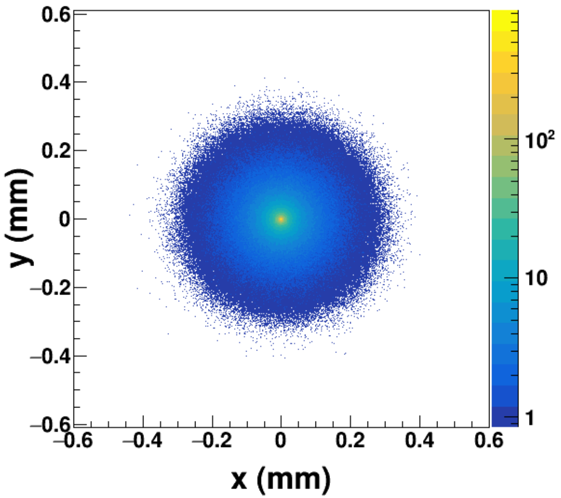
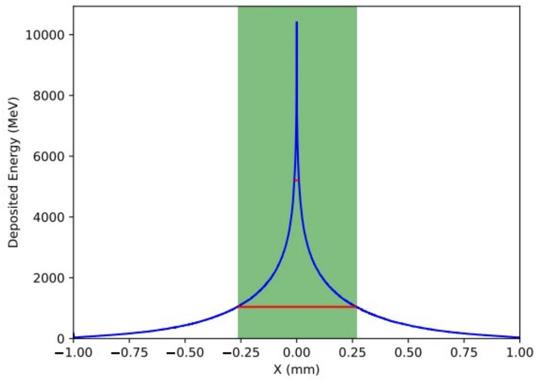


Type	density (g/cm3)	yield (ph/keV)
CsI(Tl)	4.51	54
BGO	7.1	8
LYSO	7.4	33

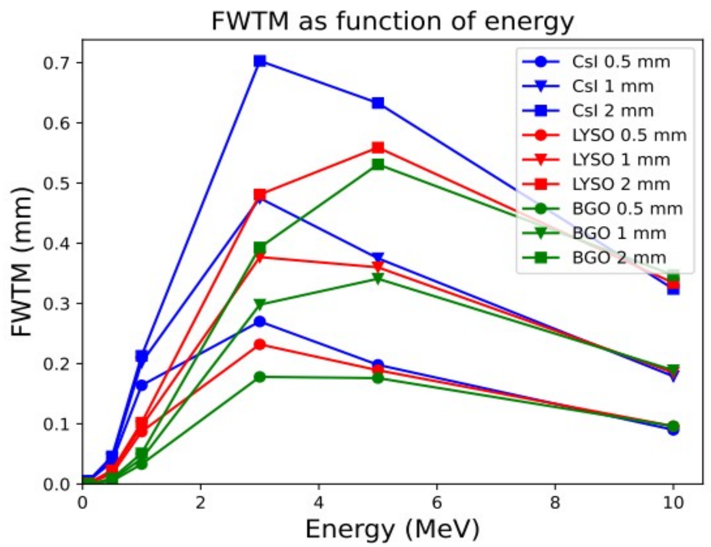
The distribution of deposited energy

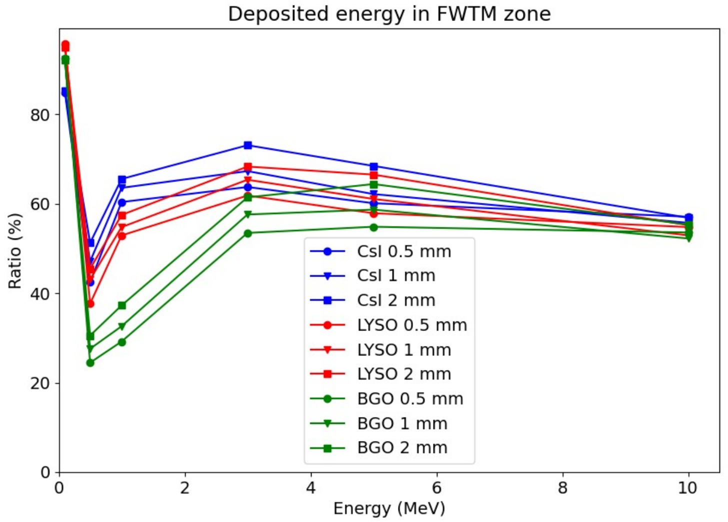




- From the **2D energy deposition** histogram, we obtain the X axis projection.
- The **FWTM** of the profile is related to the dimension of the emission center.
- The energy deposited in this zone is used for the **optimization of the pixel size.**

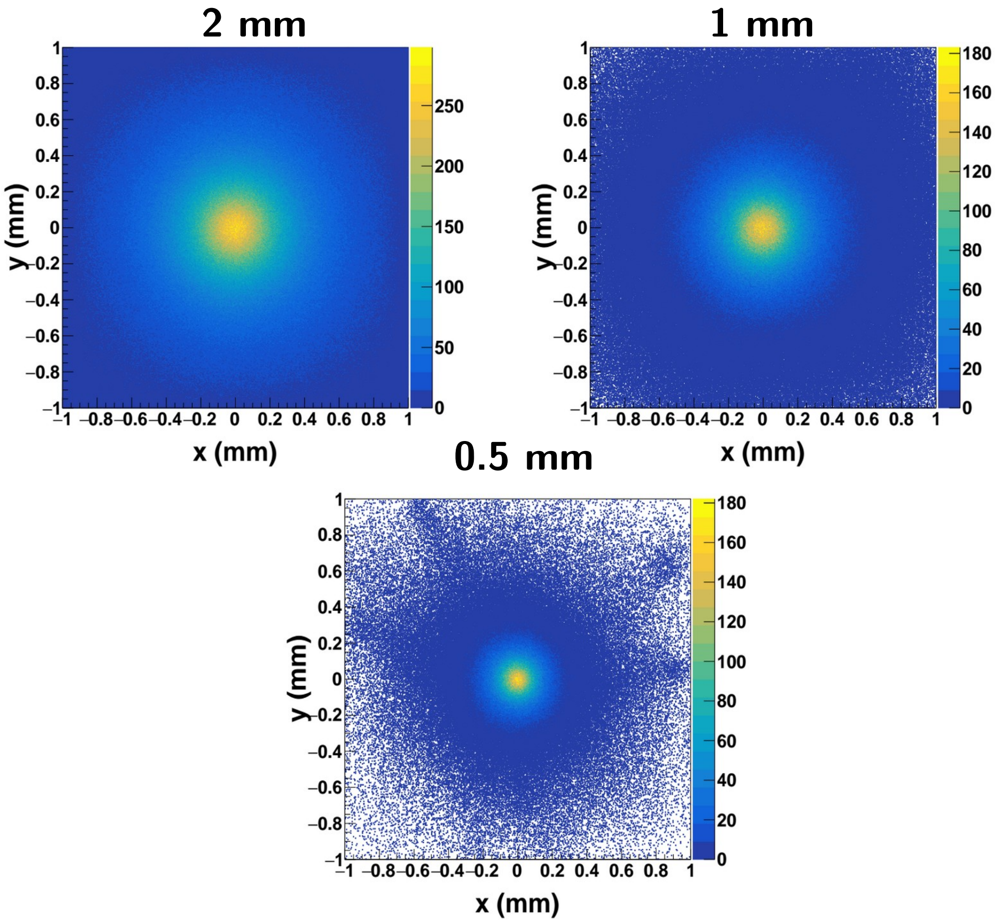
- A **smaller pixel** – a better ability to **distinguish** the position of incoming photons
- Up to 3 MeV, the spread of the emission center increases
- For higher energies, the FWTM decreases substantially
- The emission region **increases** with increasing detector thickness
- Measuring the energy deposited in this zone is useful for the **optimization of the pixel size**





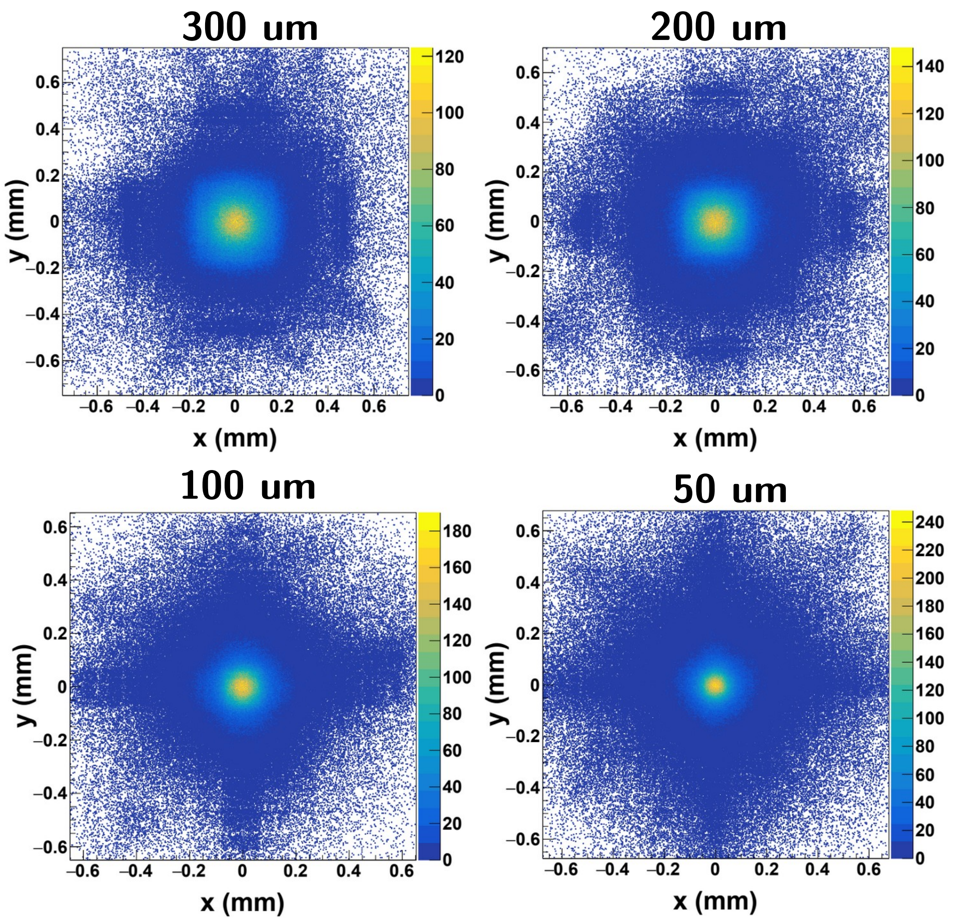
Panel thickness (mm)	**Beam energy (MeV)**	**Pixel size (mm)**	**Number of scintillations (for 10^7 photons)**
0.5 mm	> 3 MeV < 3 MeV	0.1 – 0.3 mm < 0.2 mm	LYSO, BGO, CsI (0.5 MeV – 10 MeV): $< 5 \times 10^9$ LYSO (0.1 MeV): 2.11×10^{10} BGO (0.1 MeV): 5.836×10^9 CsI (0.1 MeV): 1.82×10^{10}
1 mm	< 1 MeV $3 < E < 5$ MeV 10 MeV	0.2 mm 0.3 – 0.5 mm 0.2 – 0.25 mm	LYSO (0.5 MeV – 10 MeV): $7.57 - 11.5 \times 10^9$ LYSO (0.1 MeV): 2.87×10^{10} BGO (0.5 MeV – 10 MeV): $1.8 - 2.8 \times 10^9$ BGO (0.1 MeV): 7.38×10^9 CsI (0.5 MeV – 10 MeV): $5.26 - 6.35 \times 10^9$ CsI (0.1 MeV): 3.03×10^{10}
2 mm	< 1 MeV $3 < E < 5$ MeV 10 MeV	< 0.2 mm 0.4 – 0.7 mm 0.3 – 0.4 mm	LYSO (0.5 MeV – 5 MeV): $1.52 - 3.28 \times 10^{10}$ LYSO (0.1 MeV): 3.23×10^{10} LYSO (10 MeV): 4.01×10^{10} BGO (0.5 MeV – 10 MeV): $4.59 - 9.8 \times 10^9$ BGO (0.1 MeV): 7.89×10^9 CsI (0.5 MeV – 10 MeV): $1.09 - 2.31 \times 10^{10}$ CsI (0.1 MeV): 4.35×10^{10}

Geant4 optical photon simulations

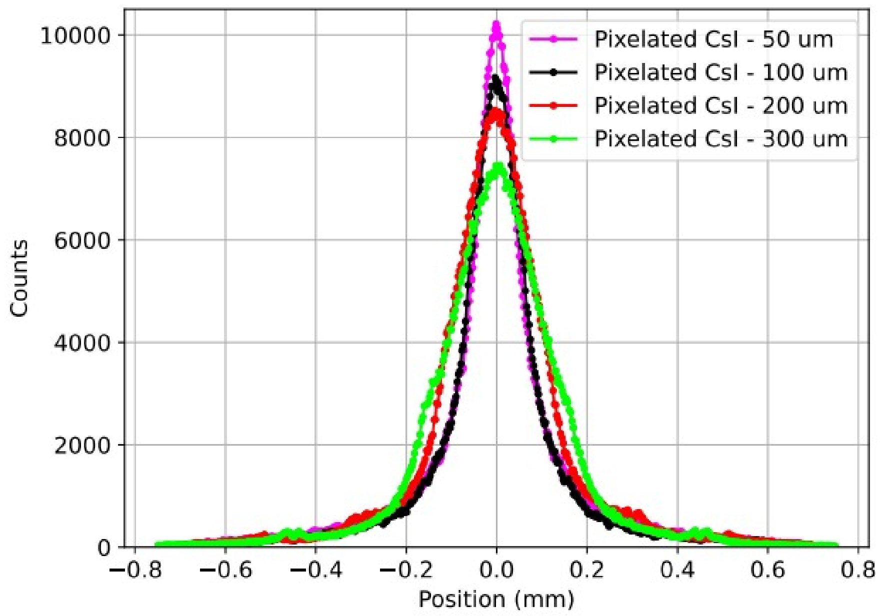


- Simulation of the **optical photons** generated after the panel's interaction with a 5 MeV zero-divergence gamma beam
- Thicker scintillators – **higher light output**, but poorer spatial resolution due to increased dispersion
- The **thinnest** scintillator shows the best light **localization**

Optical photon simulations



$$LSF(x) = \int_{-\infty}^{\infty} PSF(x,y)dy$$



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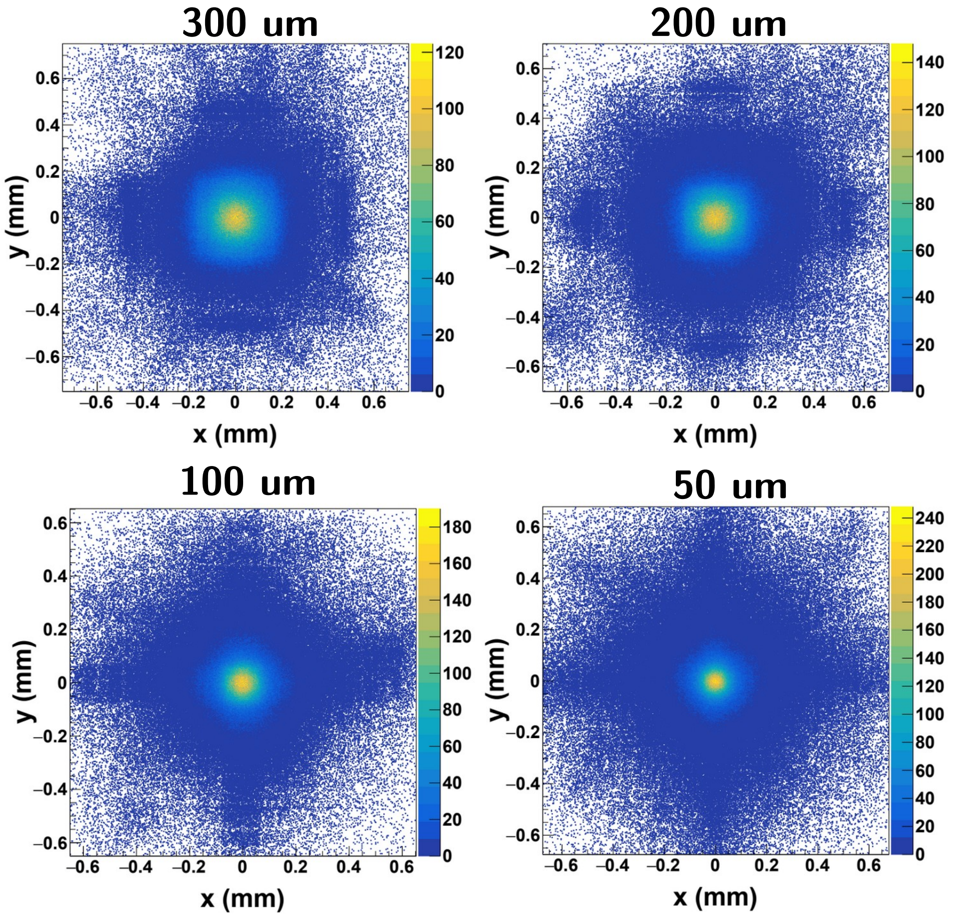
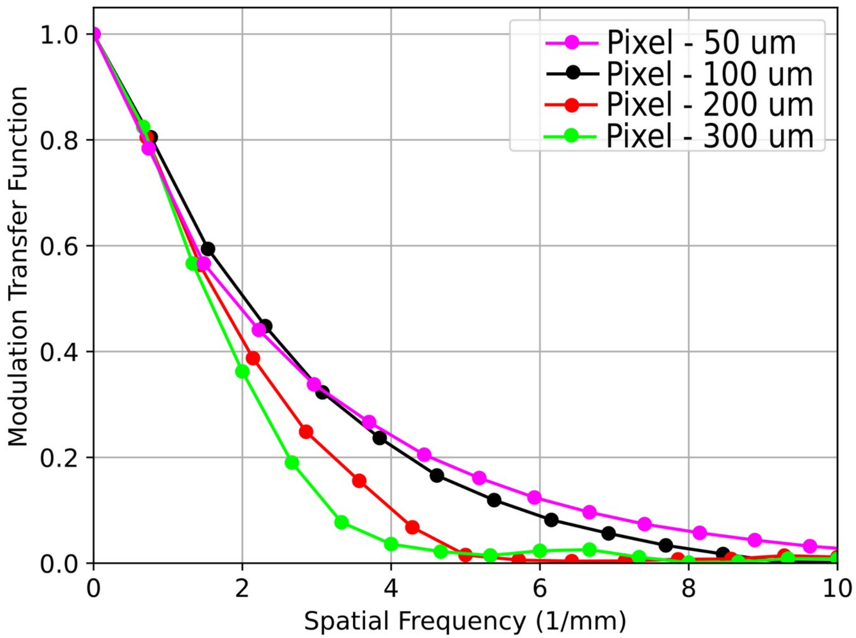
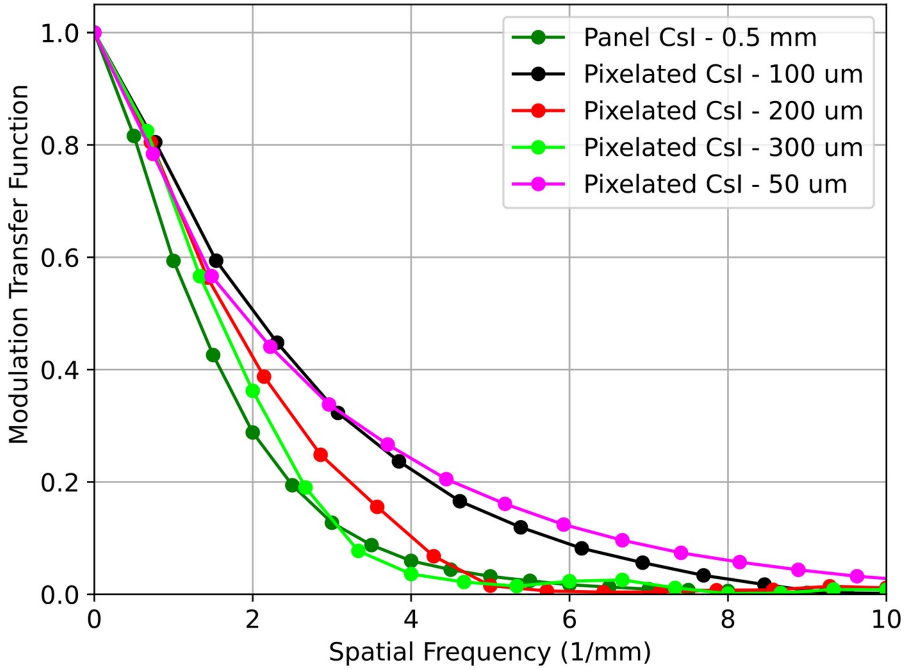


$$MTF(\mu) = \frac{\int_{-\infty}^{\infty} LSF(x)\cos(2\pi\mu x)dx}{\int_{-\infty}^{\infty} LSF(x)dx}$$



Optical photon simulations



panel thickness	0.5 mm	1 mm	2 mm
FWHM (mm)	0.19	0.43	0.66
MTF 10% (mm)	0.30	0.55	0.83

pixel size	50 μm	100 μm	200 μm	300 μm
FWHM (mm)	0.11	0.13	0.21	0.24
MTF 10% (mm)	0.15	0.17	0.25	0.31

Summary and Conclusions

- Simulations with up to 10 MeV gamma photons confirm that **structured scintillators** outperform panel configurations in imaging performance.
- Reducing pixel size **enhances spatial resolution** by confining scintillation photons to a smaller area, minimizing *light spread*.
- **Thinner scintillators** produce sharper images compared to thicker panels, due to **reduced scattering**.

Future Work

- Conduct **experimental validation** of pixelated scintillators.
- Extend the study of structured scintillators using **higher energetic photons.**
- Future use of pixelated scintillators in the gamma beam profile monitoring.