Compton Imaging for Dose Monitoring in Boron Neutron Capture Therapy

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Outline

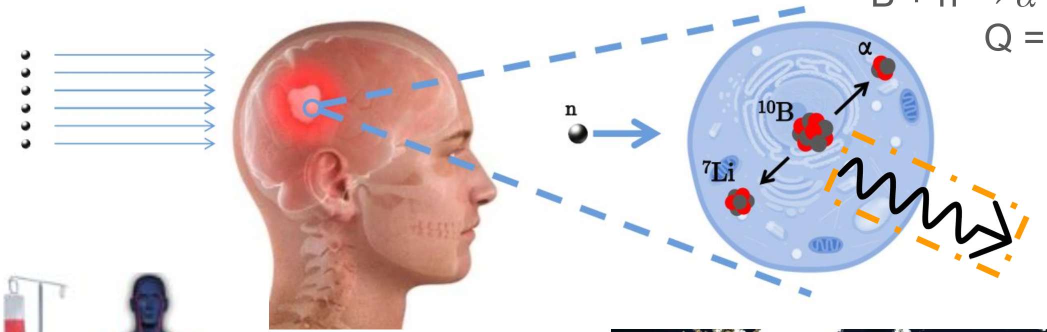
- Introduction: Boron Neutron Capture Therapy
- i-TED Upgrades towards BNCT
- Experimental Campaigns at ILL
- Next Steps & Conclusion

Introduction

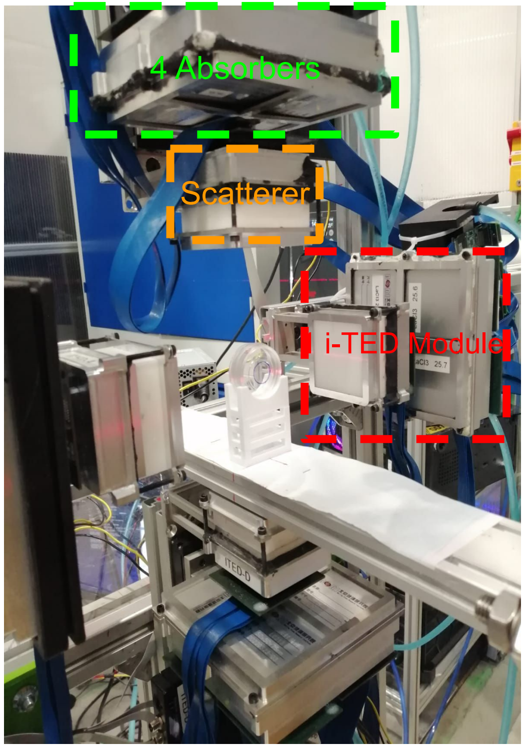
ERC-POC AMA (Spinout of ERC-CoG HYMNS)

Boron Neutron Capture Therapy (BNCT)

^{10}B + n $\rightarrow \alpha$ + ^{7}Li + γ (478 keV)
Q = 2.79 MeV



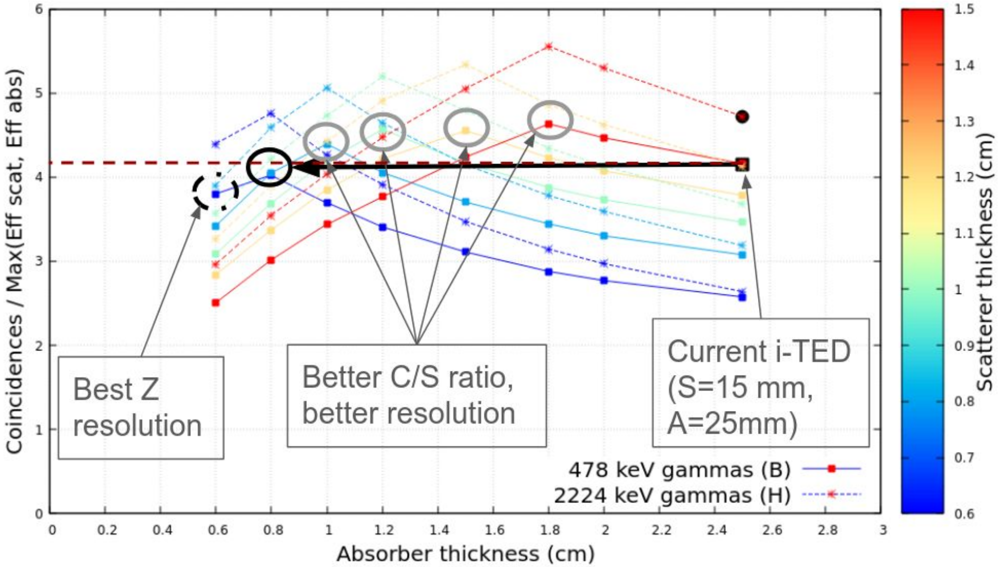
^{10}BPA intravenous infusion / 20 ppm ^{10}B in blood

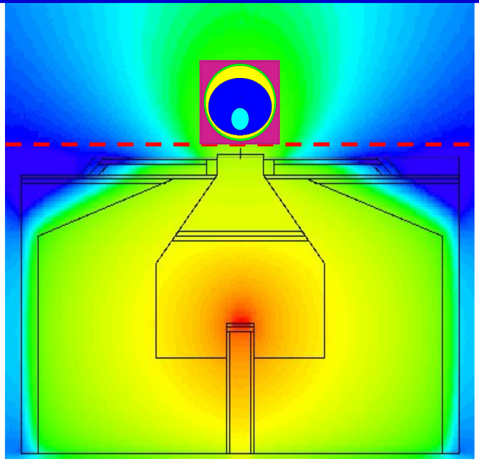


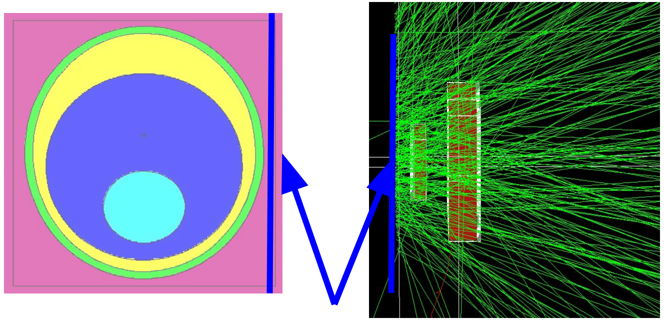
V. Babiano, et al., NIMA 953, 163228 (2020),
J. Lerendegui-Marco, et al., EPJ Web Conf. 279, 13001(2023)

Methodology / Simulations

Simulation pipeline: MCNP + Geant4





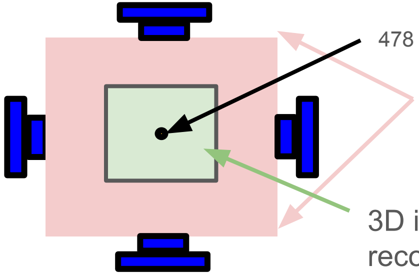


MCNP to Geant4
Surface Source (MCPL)

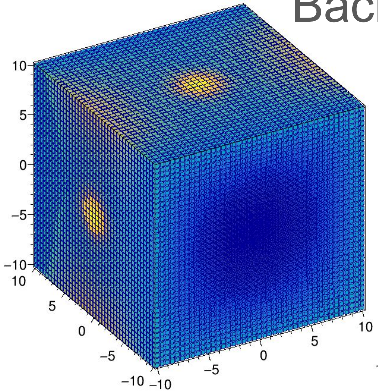
P. Torres-Sánchez *et. al.* https://doi.org/10.48550/arXiv.2409.10107

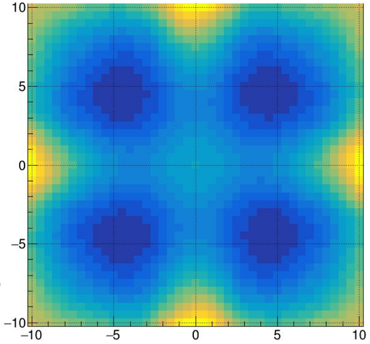
3D reconstruction with simulated i-TED coincidence data

Point source (478 keV) at the center of the field of view.
21 cm from each of the 4 scatterers front surfaces.



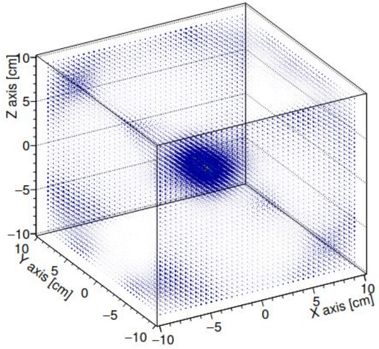
Reconstruction after Backprojection





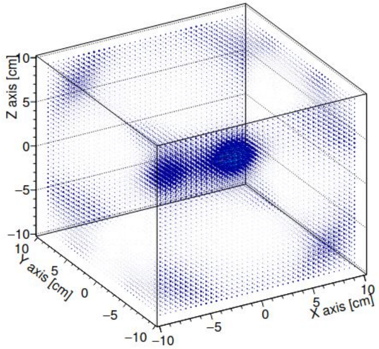
Reconstructions after 200 iterations of LM-MLEM

Parallelized Backprojection algorithm: 8.25 s for processing 50k Compton Coincidence Events



LM-MLEM algorithm (not yet parallelized):

30k Events loaded to 32 GB RAM and 0.5 cm grid resolution →3 min for 200 iterations



First Proof-of-Concept Campaign @ ILL (Grenoble) - Oct 23

NEUTRONS FOR SOCIETY

Main Goal: Proof-of-concept of i-TED in BNCT: **sensitivity of Compton imaging (i-TED) to ^{10}B and measuring boron uptakes of normal and cancerous cell line cultures**

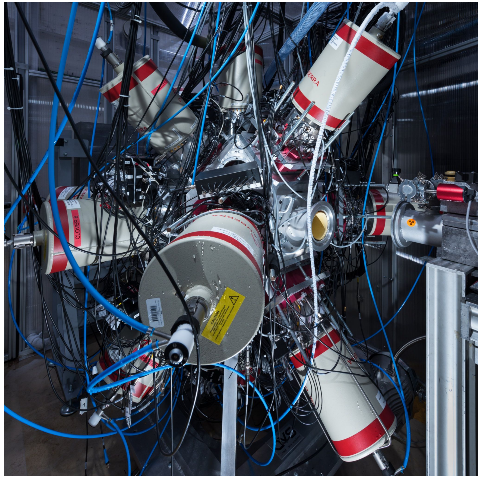
- Performed at the H22 thermal neutron beamline (FIPPS instrument)
- 10^8 n/cm^2/s flux in a 1.5 cm diameter beam
- 1 i-TED module integrated inside FIPPS

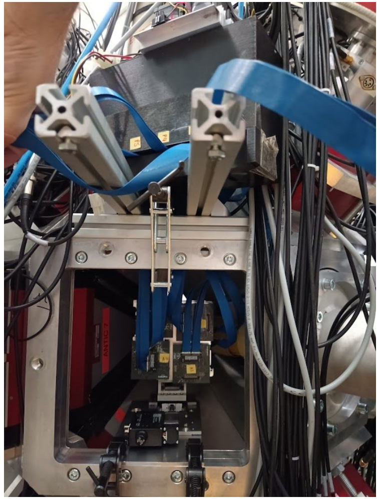
Minimal background conditions, pointwise/small samples

NEUTRONS FOR SOCIETY

Setup at FIPPS Instrument

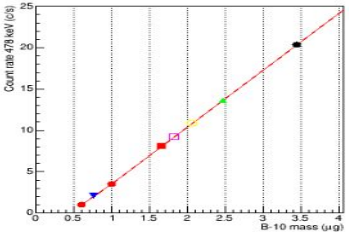
i-TED Compton camera: integrated in FIPPs replacing one of the clovers





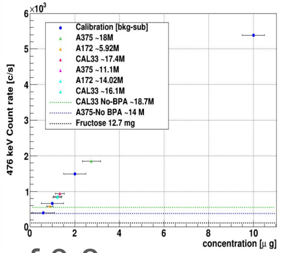
Sensitivity Study:

i-TED



i-TED & FIPPs consistent!

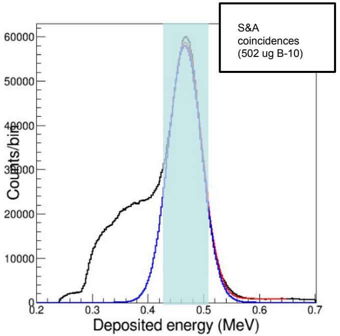
FIPPS



Sensitivity: measured boron uptakes of 0.8 μg

Challenges of Compton imaging at 478 keV:

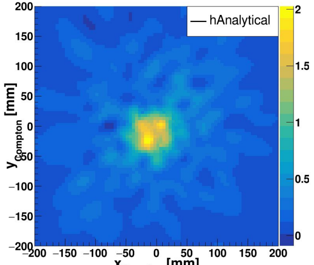
- Low Energy threshold in individual crystals
- Worse energy resolution for low deposited energies



Validation of the imaging capability:

- Nice separation of the 478 keV peak in S-A coincidences

Cell Line: CAL33, 17.41e6 cells 5400 s



J. Lerendegui-Marco *et. al.* https://doi.org/10.48550/arXiv.2409.05687

Second Experimental Campaign @ ILL (Grenoble) - Jun 24

Main Goal: **Testing the i-TED imaging capabilities for BNCT in a controlled realistic environment**

- Performed at the H22 thermal neutron beamline (FIPPS instrument)
- 10^8 n/cm^2/s flux in a 1.5 cm diameter beam
- Full i-TED array with 4 modules in cross configuration

Using Realistic signal-to-background ratios and idealized phantom geometries

Second Experimental Campaign @ ILL (Grenoble) - Jun 24

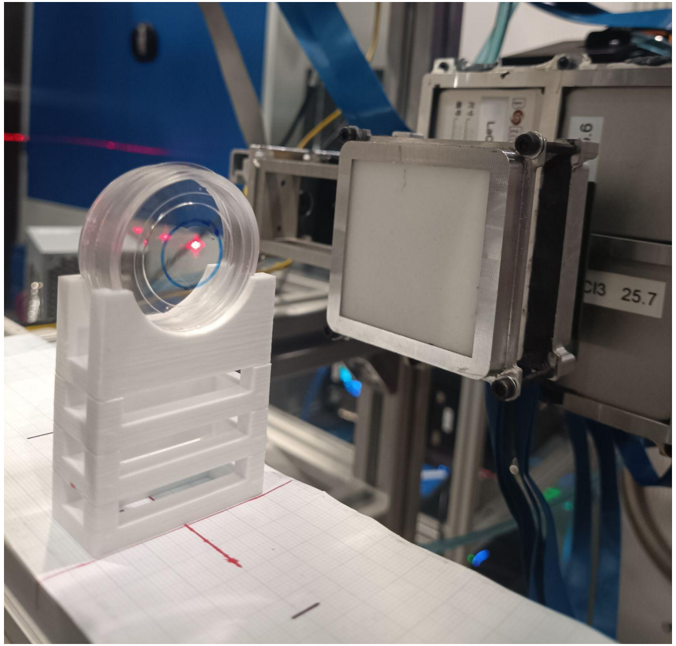
NEUTRONS FOR SOCIETY

Main Goal: Testing the i-TED potentiality for BNCT in a controlled environment

- Performed at the H22 thermal neutron beamline (FIPPS experiment)
- 10^8 n/cm^2/s flux in a 1.5 cm diameter beam

Setups / Tests performed

1) Boron loaded water in dishes, at different boron concentrations
   → **sensitivity** tests



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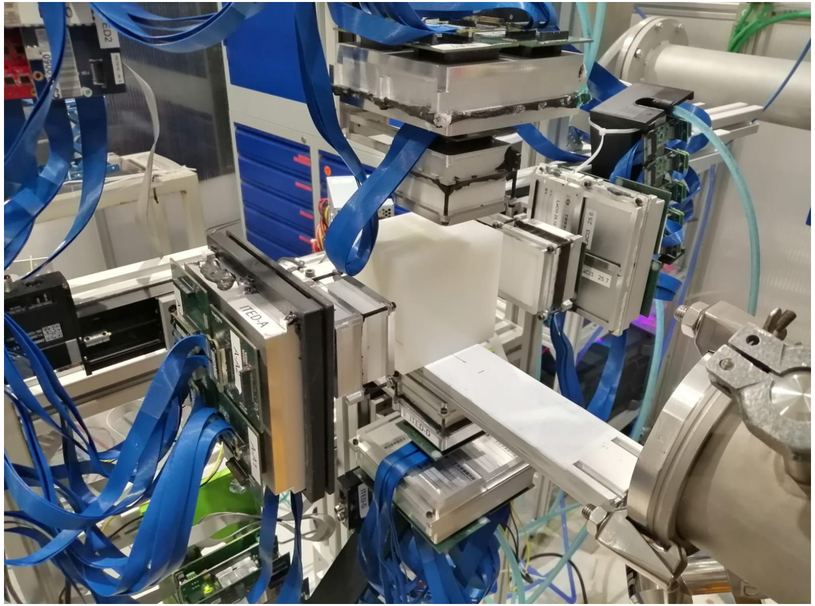
<u>Setups / Tests performed</u>

1) Boron loaded water in dishes, at different boron concentrations
   → **sensitivity** tests
2) Boron dishes inside a PE phantom
   → **sensitivity** tests at **large background** conditions



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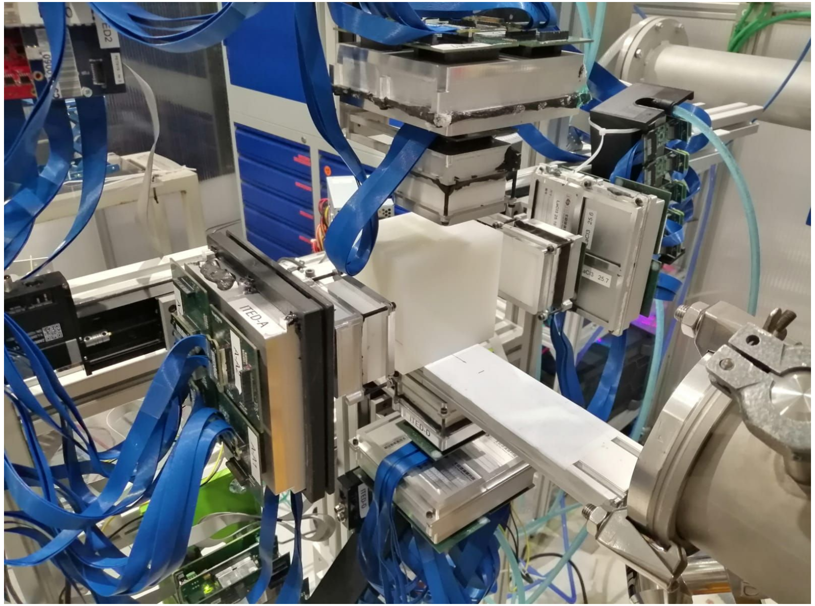


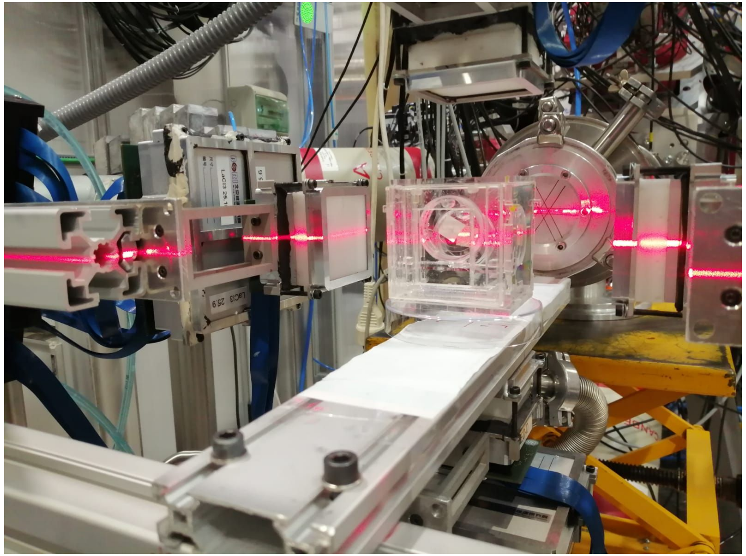
Setups / Tests performed

1) Boron loaded water in dishes, at different boron concentrations
→ **sensitivity** tests
2) Boron dishes inside a PE phantom
→ **sensitivity** tests at **large background** conditions
3) Two Boron dishes inside the PE phantom
→ **resolution** tests

Second Experimental Campaign @ ILL (Grenoble) - Jun 24

Main Goal: Testing the i-TED potentiality for BNCT in a controlled environment

- Performed at the H22 thermal neutron beamline (FIPPS experiment)
- 10^8 n/cm^2/s flux in a 1.5 cm diameter beam



Setups / Tests performed

1) Boron loaded water in dishes, at different boron concentrations
→ **sensitivity** tests
2) Boron dishes inside a PE phantom
→ **sensitivity** tests at **large background** conditions
3) Two Boron dishes inside the PE phantom
→ **resolution** tests
4) Boron dishes inside water and borated container
→ **contrast** tests in closer-to-clinical conditions

We are currently starting the analysis of the data taken in this campaign

Next Steps & Conclusions

Next Steps

- Progress with the analysis of the recent experiments.
- Implement the upgrades and optimizations towards BNCT.
- Improve the 3D reconstruction strategy, including a rotatory gantry.
- New experiments in a clinical-grade neutron beam Facility at Birmingham.

Conclusions

- High resolution Real-time Compton imaging is one key aim in BNCT 🎯
- The i-TED Compton Camera Array looks especially well suited for BNCT ✔
- Upgrades of i-TED towards BNCT are ongoing
- Experiments performed at ILL and planned future tests in clinical beams. 👌

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