Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
THE Tuscany Health Ecosystem

Tomographic Reconstruction of Dose Distribution for 3D-Dosimetry in FLASH-RT using a Monolithic Plastic Scintillator Block

Eleonora Ravera
Università di Pisa

IN SUPREMÆ DIGNITATIS 1343
INFN Istituto Nazionale di Fisica Nucleare

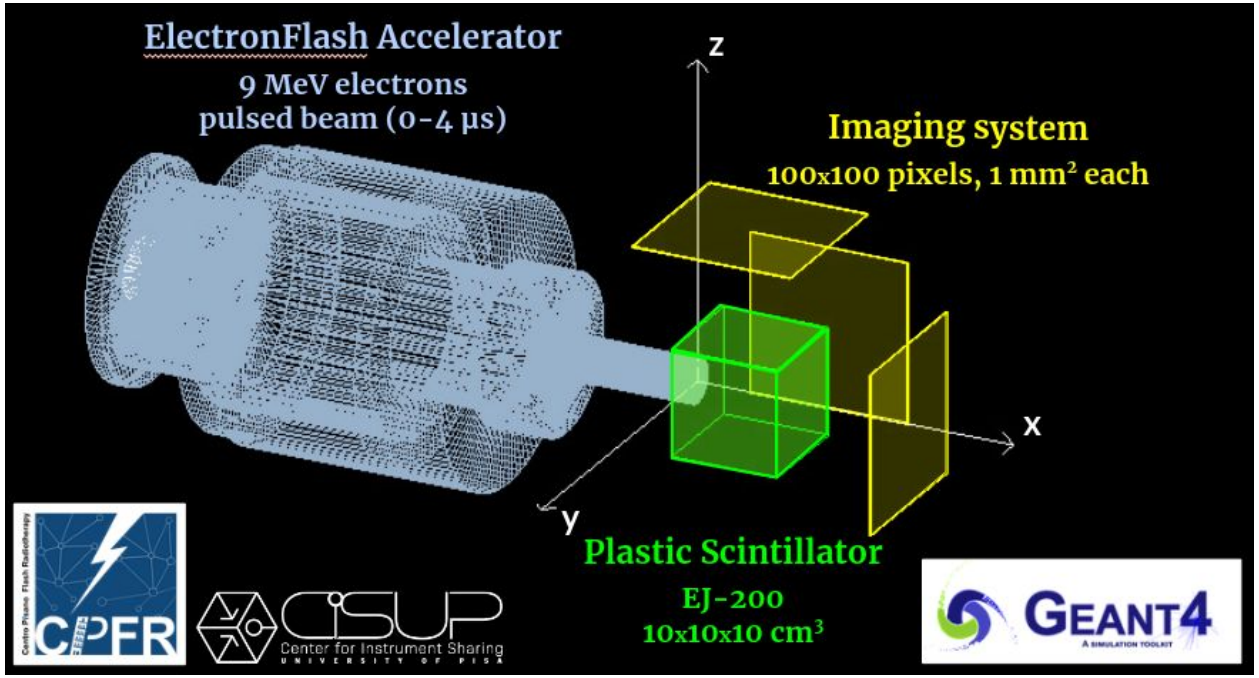
4°incontro sull'ecosistema toscano per l'innovazione - Spoke 1: advances radiotherapies and diagnostic in oncology

CNR Pisa, 12/12/2024

Proof-of-concept detector for 3D online dosimetry

MILESTONE 1.1

- **Objective**: Reconstruct the **volumetric dose distribution** absorbed by a plastic scintillator cube using tomography.
- **Methodology**:
  - **2D light maps** are captured by photodetectors from multiple views.
  - A **collimation system** is required to accurately define the position of the scintillation light's generation center.
  - The **3D dose distribution** is reconstructed using a tomographic algorithm.



The detector is tailored for use with a **9-MeV electron FLASH beam** (ElectronFlash @CPFR):

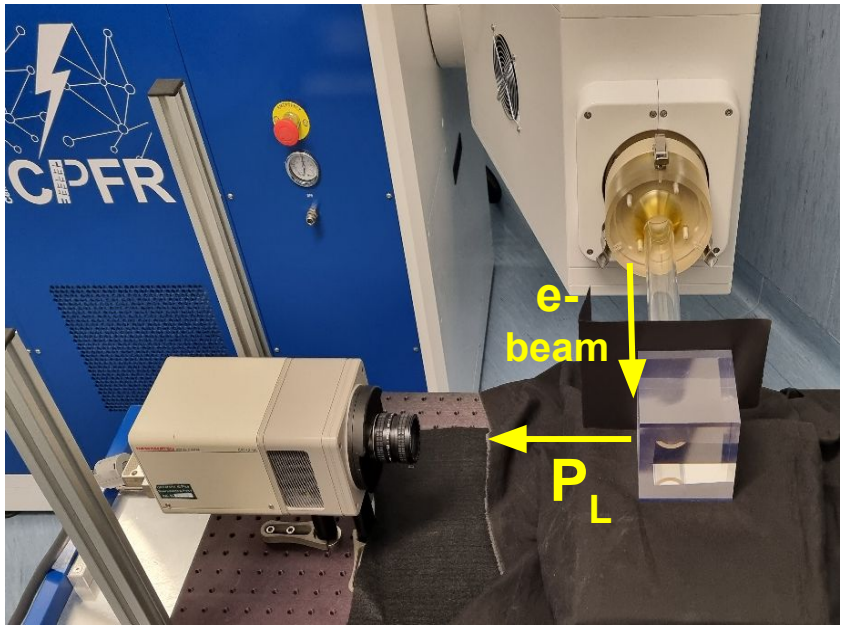
- **Linearity** at high Dose Per Pulse (DPP) has been tested with other plastic scintillator detectors
- The 9-MeV electrons are absorbed in **< 10 cm**, which is the side of the scintillator block

but in principle applicable in other context

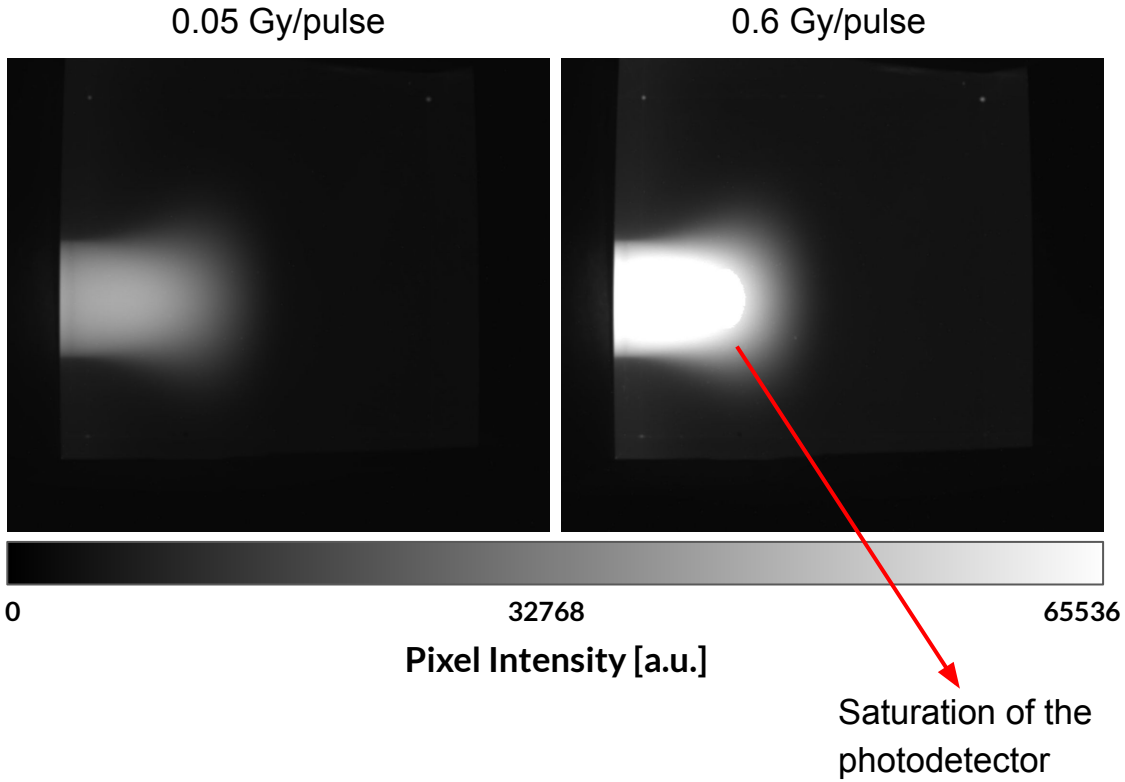
-> **Upcoming tests @CNR-Ino , with the VHEE laser driven accelerator**

Preliminary test @CPFR

- ElectronFlash LINAC: 9 MeV electron, 4 μm single pulse, **DPP: 0.05–0.6 Gy/pulse**.
- **Saturation of the photodetector** @0.6 Gy/pulse due to the high amount of emitted light
- The **lateral light distribution** was acquired with a single camera - **insufficient to apply a reconstruction algorithm**



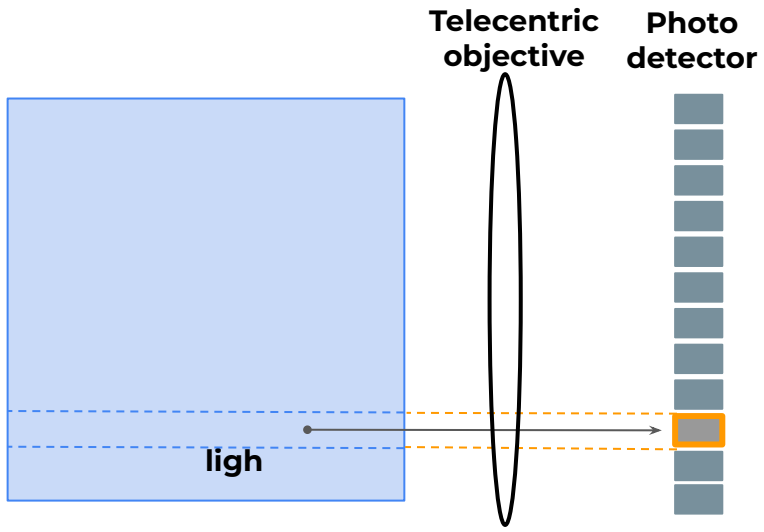
Hamamatsu ORCAII-BT-512G
Schneider Optics Xenon 0.95/25



Two imaging systems studied

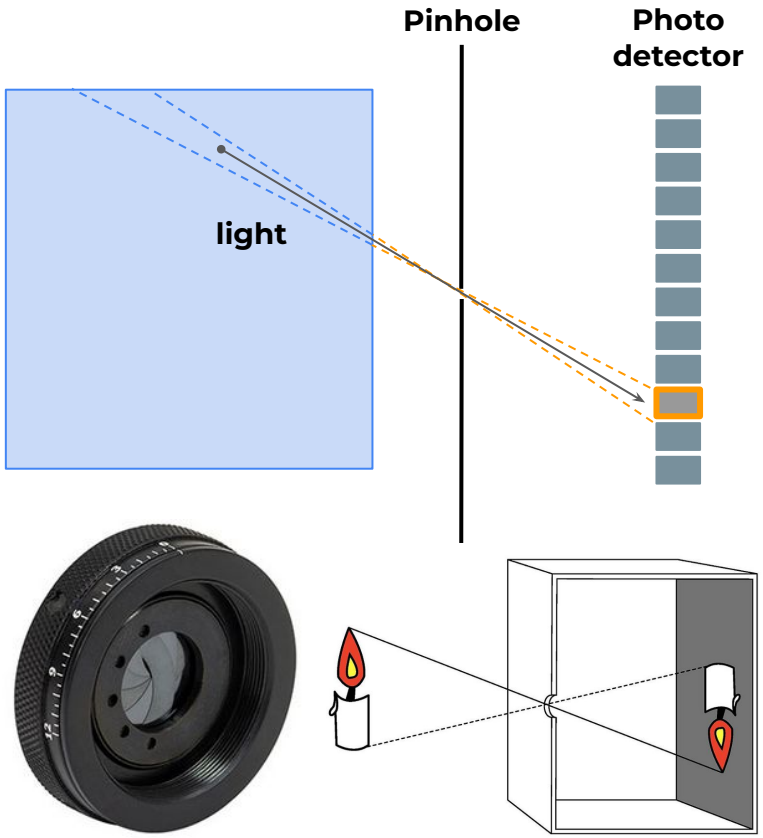
Telecentric Objective

→ Allows to selects parallel rays



Pinhole camera

→ Allows to selects rays passing through a small aperture



- Both have been *simulated* and *integrated* in the reconstruction algorithm
- The **pinhole system** is:
  - ✓ Easier to handle
  - ✓ Cheaper

  → this makes the system **scalable** for the measurements of more projections
- A pinhole objective has been *purchased*
  (Thorlabs SM1D12CZ, Zero Aperture)

Reconstruction algorithm

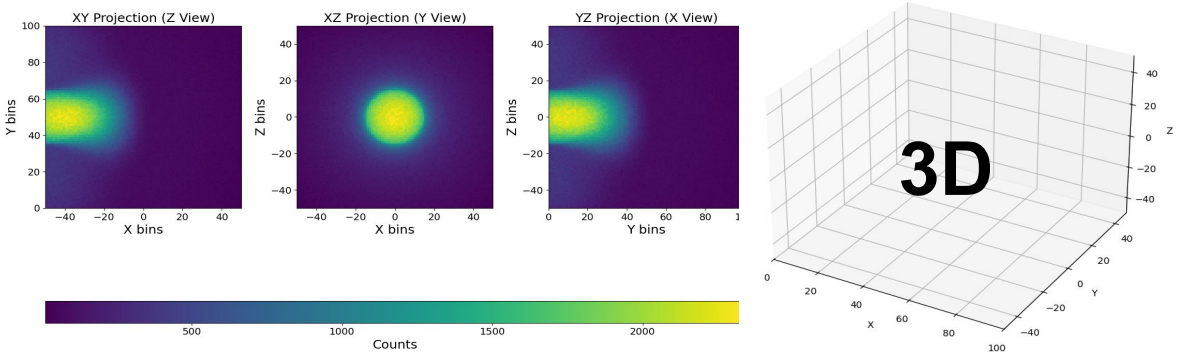
Tomographic problem

$L = M\,D$ *direct problem*

$D = M^{-1}\,L$ *inverse problem*

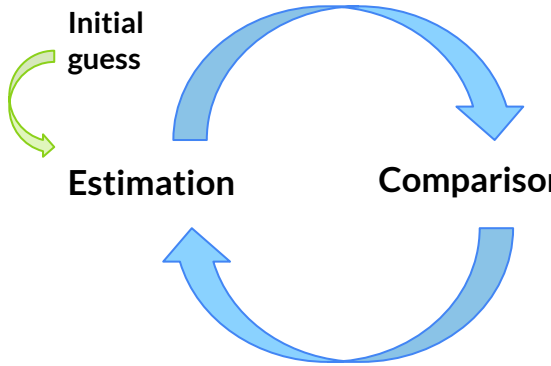
with:

L = light maps
D = 3D dose distribution
M = system matrix → Represents the experimental setup



Maximum likelihood approach

Maximum Likelihood Estimation Maximization algorithm (**MLEM**) to account for *Poissonian nature scintillation of photon emission*

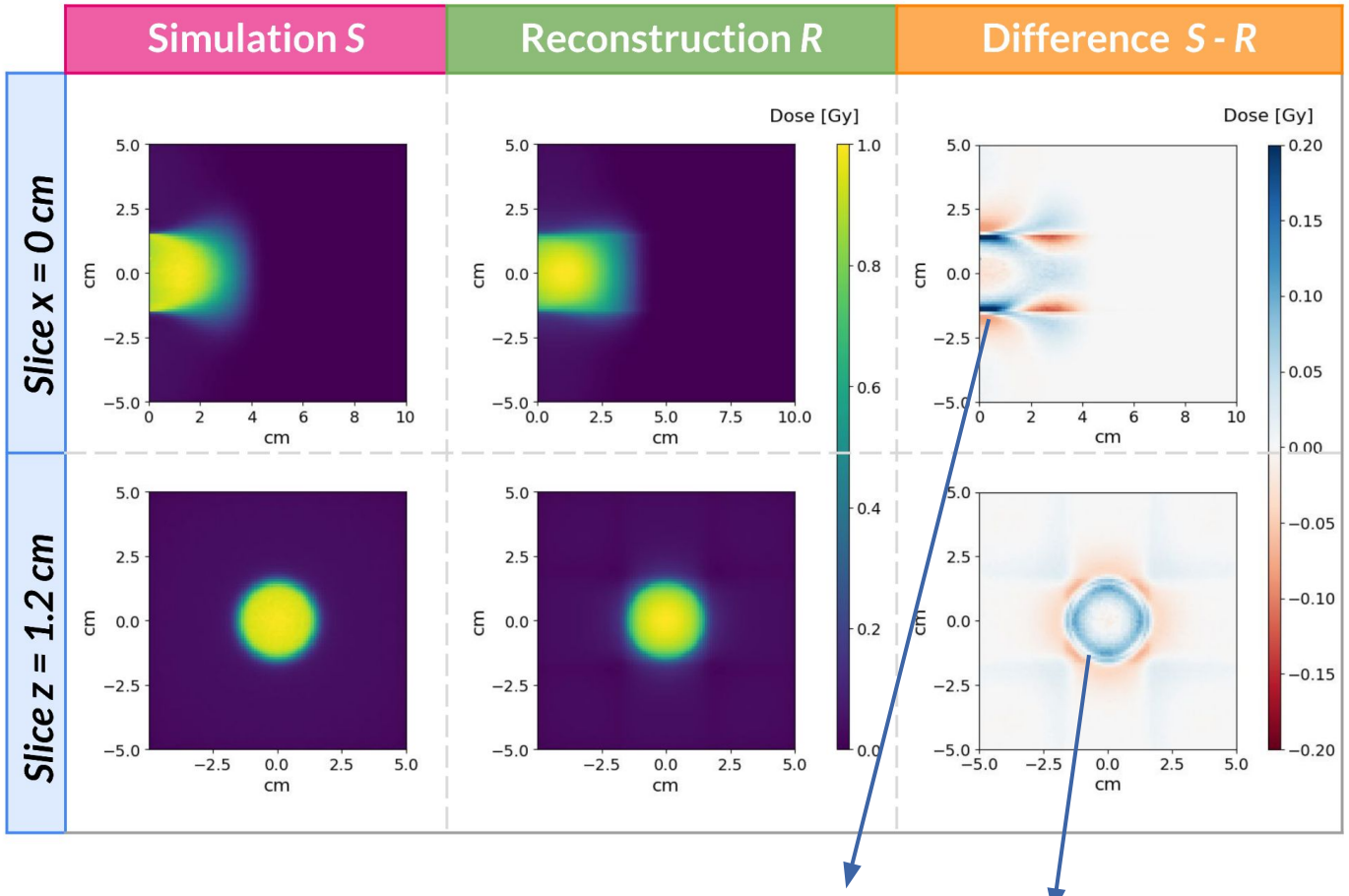


Updating rule

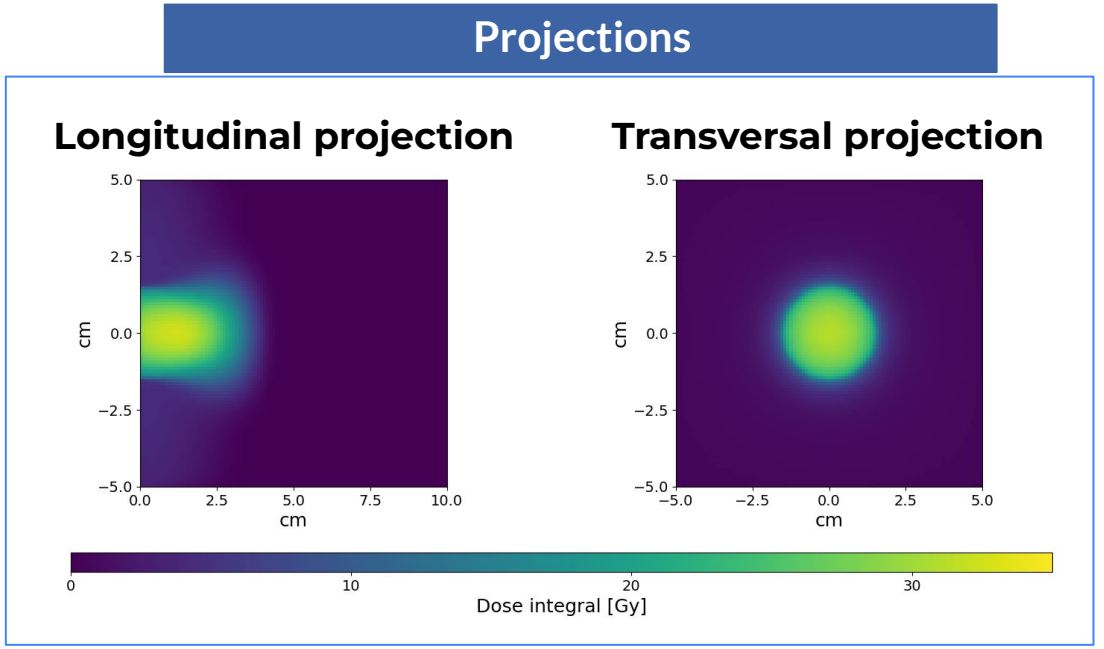
$$D_j^{n+1} = \frac{D_j^n}{\sum_i M_{ij}} \frac{\sum_i M_{ij} L_i}{\sum_j M_{ij} D_j^n}$$

- Algorithm Developed in Python using DAPHNE libraries:
  - Not optimized for speed
  - Limited in modeling certain effects
- The **reconstruction algorithm** has been tested so far using **simulated data**, specifically the 3D dose distributions used for analytically calculating the projections

Validation with the Telecentric setup



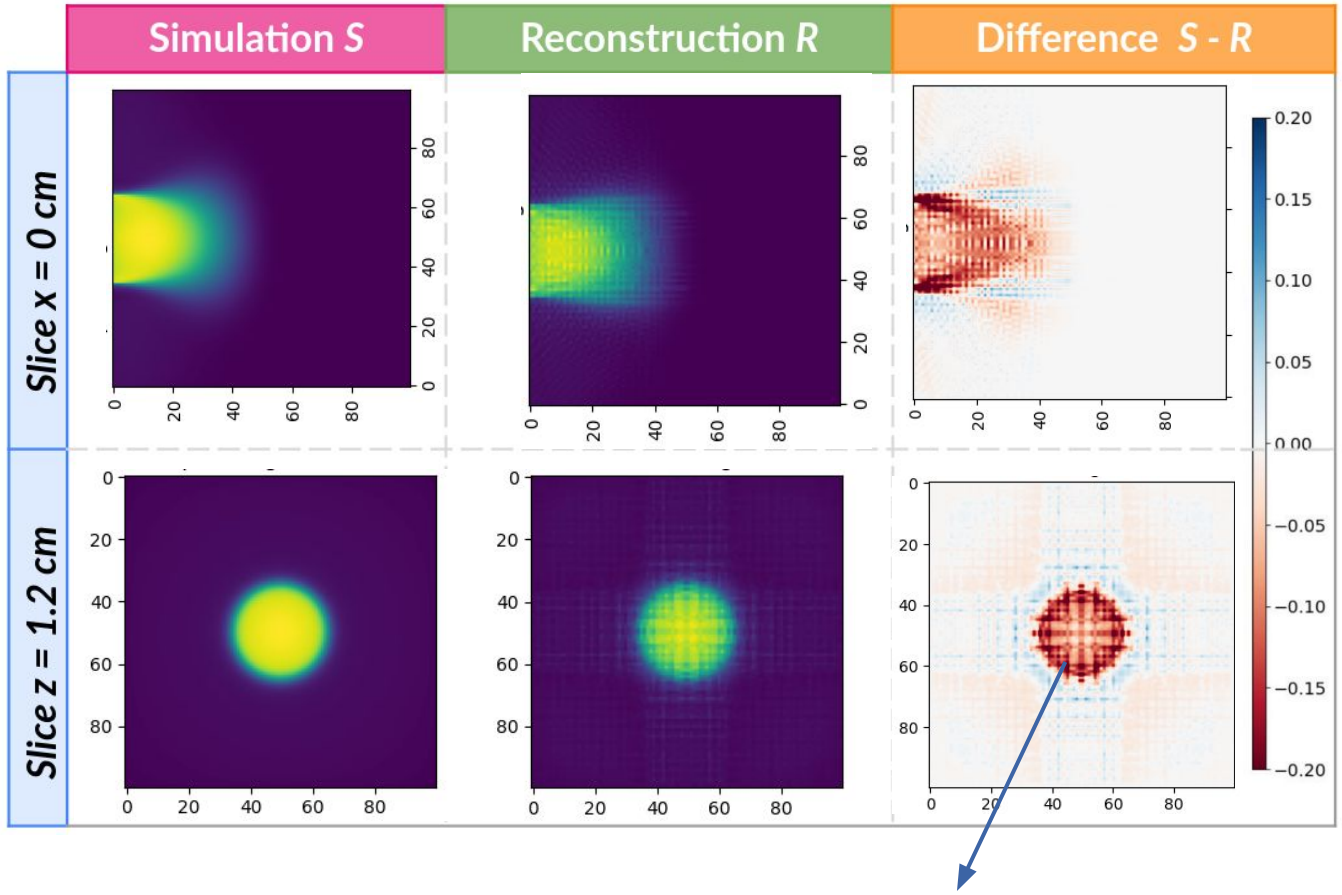
Edge effects can be reduced with finer pixels, as better sampling improves results



Reconstruction assuming ***3 photodetectors*** with *100x100 pixels* with *1 mm pitch*

To reconstruct a volume of 100x100x100 voxels each with 1 mm^3 volume

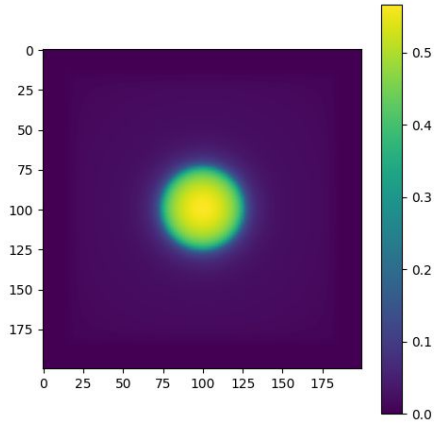
Validation with the Pinhole camera



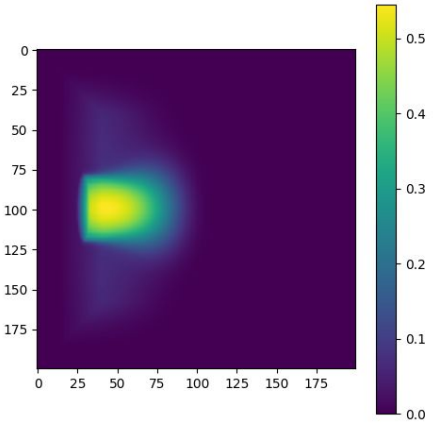
Systematic effects needs to be further investigation

Projections

Transversal projection



Longitudinal projections



Longitudinal projections are flipped because of the pinhole effect

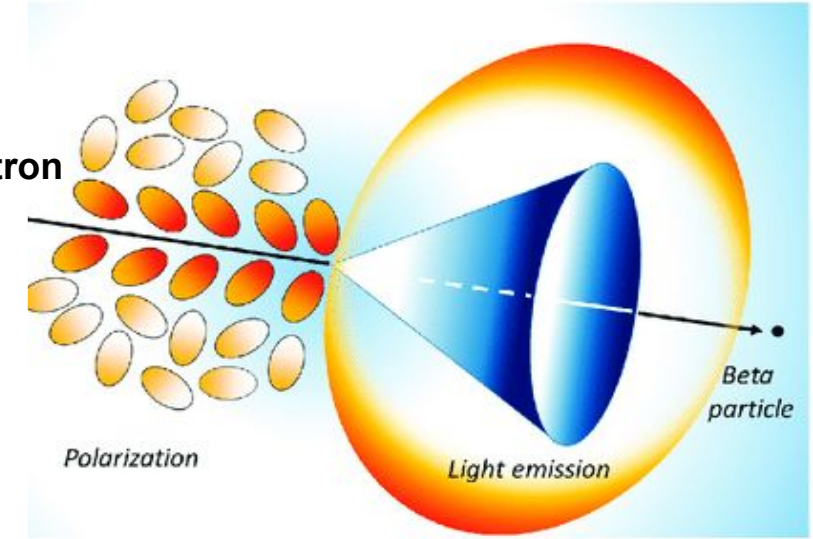
Reconstruction assuming **5 photodetectors** with *100x100 pixels* with *1 mm pitch*

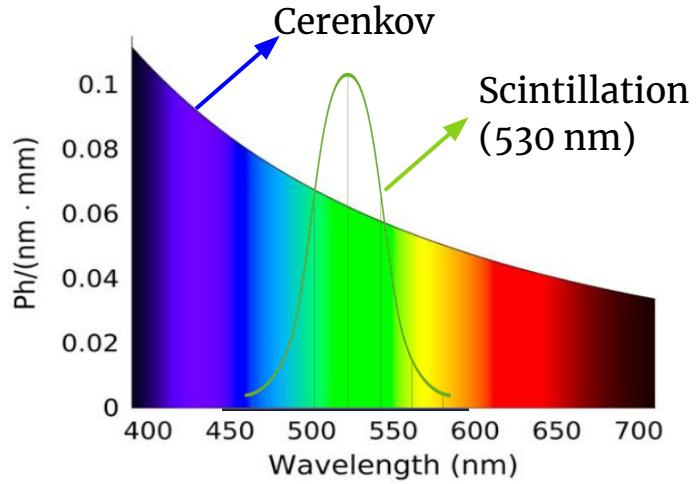
To reconstruct a volume of 100x100x100 voxels each with 1 mm^3 volume

Feasibility study of cerenkov based dosimetry → MILESTONE 1.6

Cerenkov Light Emission:

- Emitted when the particle velocity exceeds *c/n* (**threshold effect**)
- Characterized by a typical $\propto 1/\lambda^2$ spectrum
- Occurrence in *all media*: a *plastic material* can be used as an emitter, or *tissues* for *in-vivo dosimetry*





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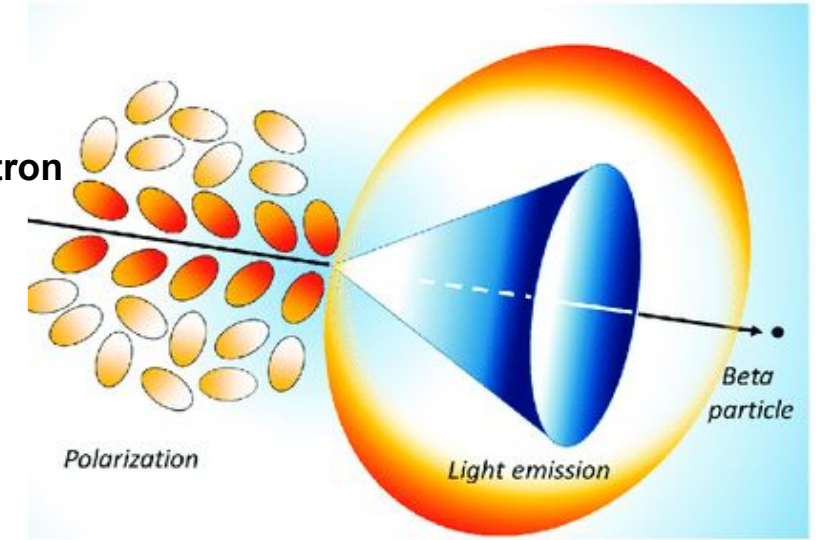
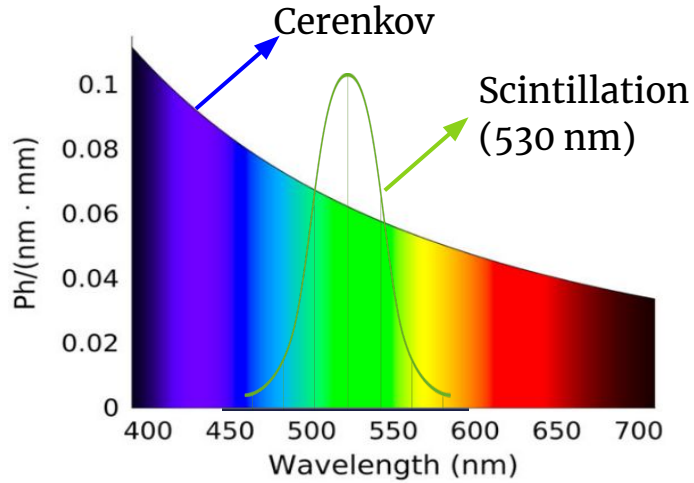
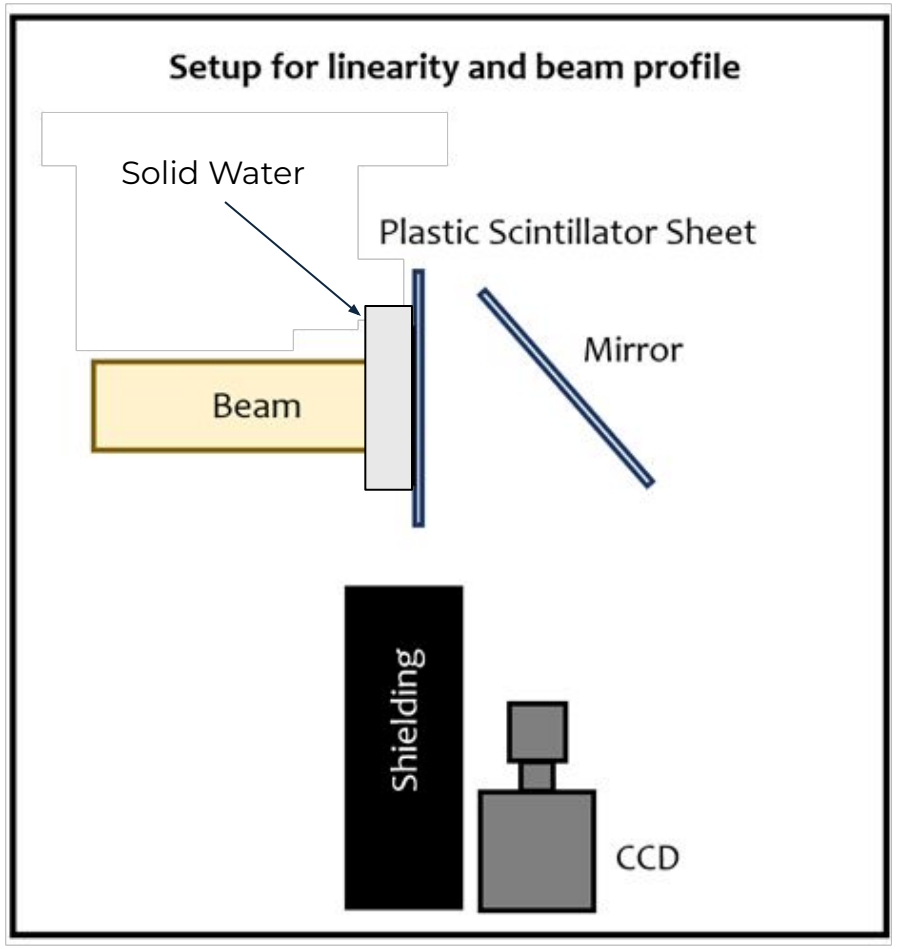
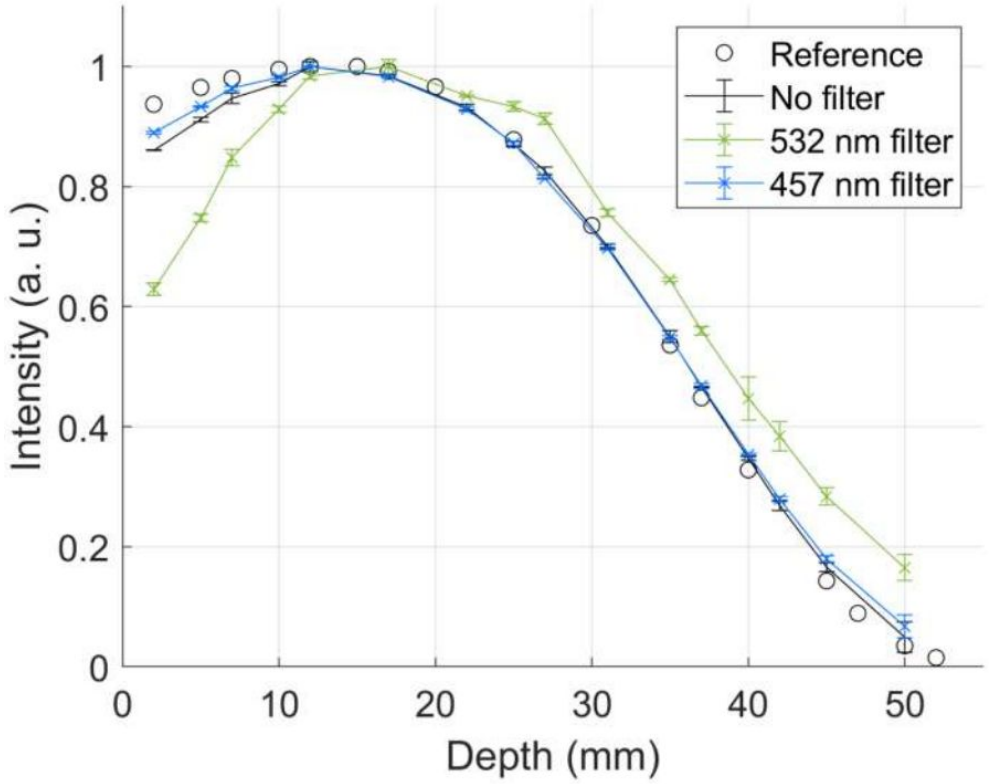


- **Scintillators** can emit both scintillation and Cerenkov light, and can be used **as Cerenkov emitters**
- The approach takes advantage of the *spectral differences* between the two emissions.



Preliminary test with a Plastic Scintillating Sheet





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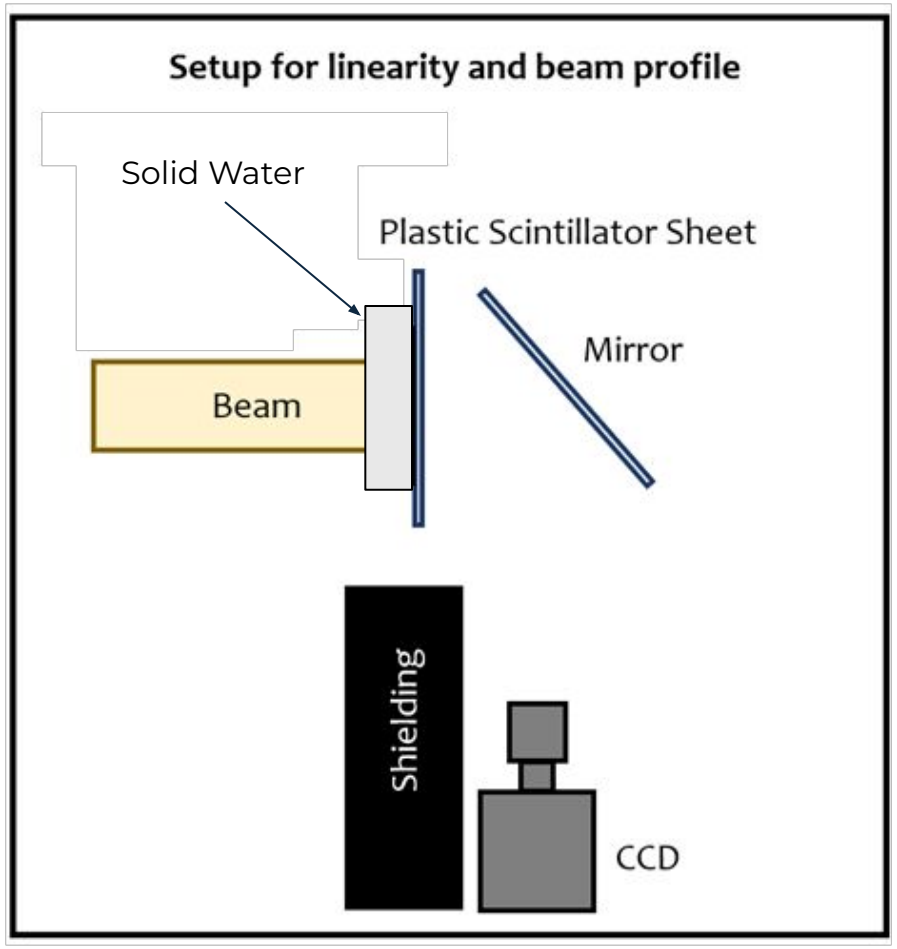

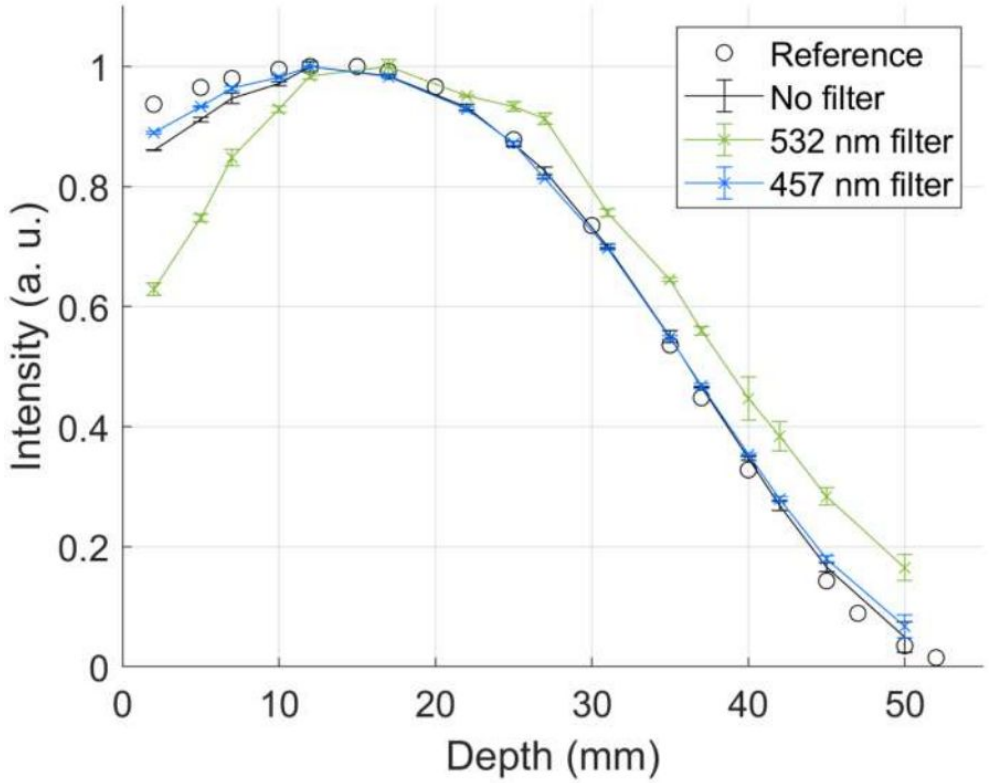

Discrepancies due to differences in the **angle emission** of the Cerenkov and scintillation light

Conclusions

➢ Milestone 1.1

- A geant4 simulation and a basic reconstruction software have been implemented
- Good results, especially increasing the number of projections measured
- A pinhole collimator has been purchased.
- Tests in plan at CNR-Ino with VHEE electron beam and CPFR with 9-MeV electron beam
- Outlook: study in mode detail the scalability and also a multi-pinhole collimator

➢ Milestone 1.6

- Cerenkov light can be used for dosimetry applying a correction
- Cerenkov light amount less than scintillation light but ok for flash applications
- Ongoing development of simulation for modelling cerenkov light emission in depth
- Outlook: application for in-vivo dosimetry

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Thank you for your attention!

Project 1.1 Co-authors:

M. G. Bisogni, E. Ciarrocchi, E. Ravera, V. Rosso

Project 1.6 Co-authors:

M. G. Bisogni, E. Ciarrocchi, M. Massa, A. Moggi, A. Retico, C. Scapicchio

Other special thanks:

C. D'Orazio, M. Morrocchi, D. Panetta

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Contact:

eleonora.ravera@phd.unipi.it