TÉCNICO LISBOA

Fundação para a Ciência e a Tecnologia

LIP

Real-Time Beam Monitoring Device For FLASH RT

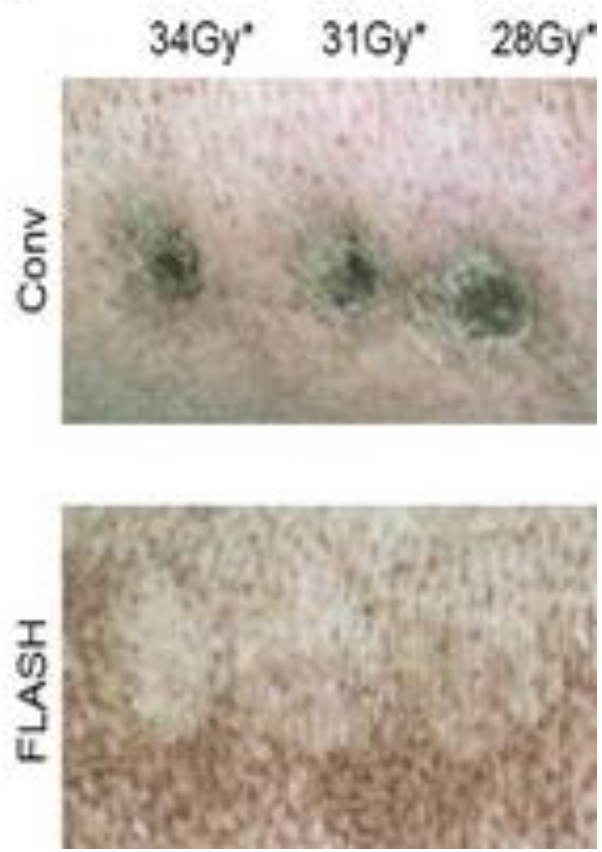
Gonçalo Ribeiro

8th LIP/IDPASC Workshop, 17th October 2024, Braga, Portugal

Supervisors: Prof. Pedro Assis (LIP), Prof. Patrícia Gonçalves, (LIP), Dr. Maurizio Vretenar (CERN)

Introduction

- Radiotherapy represents nearly 50% of therapies prescribed for treating tumours.
- A novel technique: FLASH Radiotherapy
  - Uses high dose rates (> 40 Gy/s) to an increased sparing of healthy tissue.
- High dose rates poses several challenges:
  - Standard Dosimeters saturate.
  - Real-time feedback for machine needed.
  - What are the requirements of a beam monitoring device for FLASH?



Skin of pig 36-week post-RT - CONV (5 Gy/min) and FLASH (300 Gy/s), from Mazal, Alejandro, et al. *"FLASH and minibeams in radiation therapy: the effect of microstructures on time and space and their potential application to protontherapy."* The British Journal of Radiology 93.1107 (2020): 20190807.

Beam Monitoring for FLASH RT?

High Temporal Resolution

Absence of saturation effects

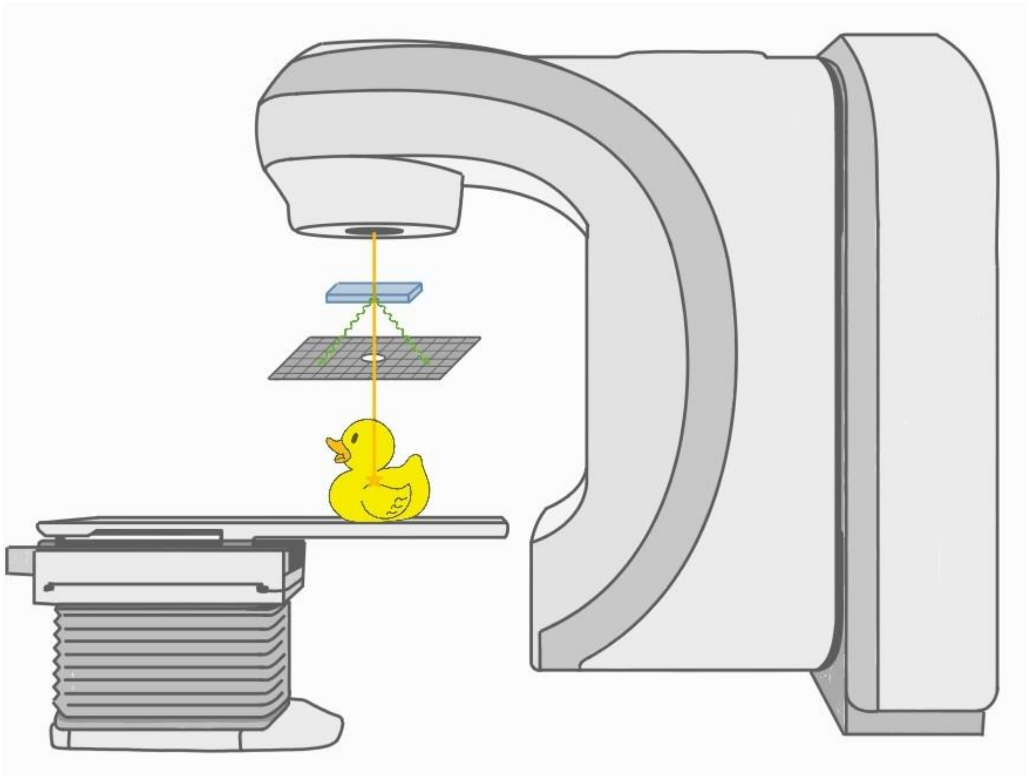
Key Characteristics

Minimal Impacts

Fast Feedback to Machine

Ducks?

Our approach



Thin Radiator (~mm) in Beamline to Produce Cherenkov Photons

→

Photodetector to detect them and estimate no. of beam particles

→

Provide **Machine Feedback** using Fast Electronics

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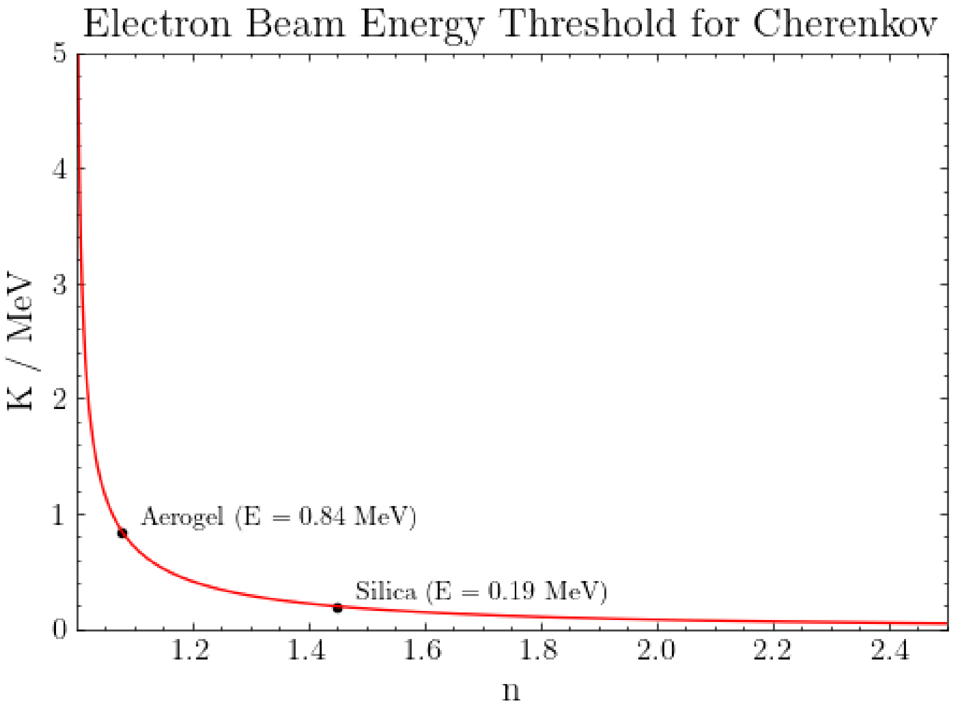
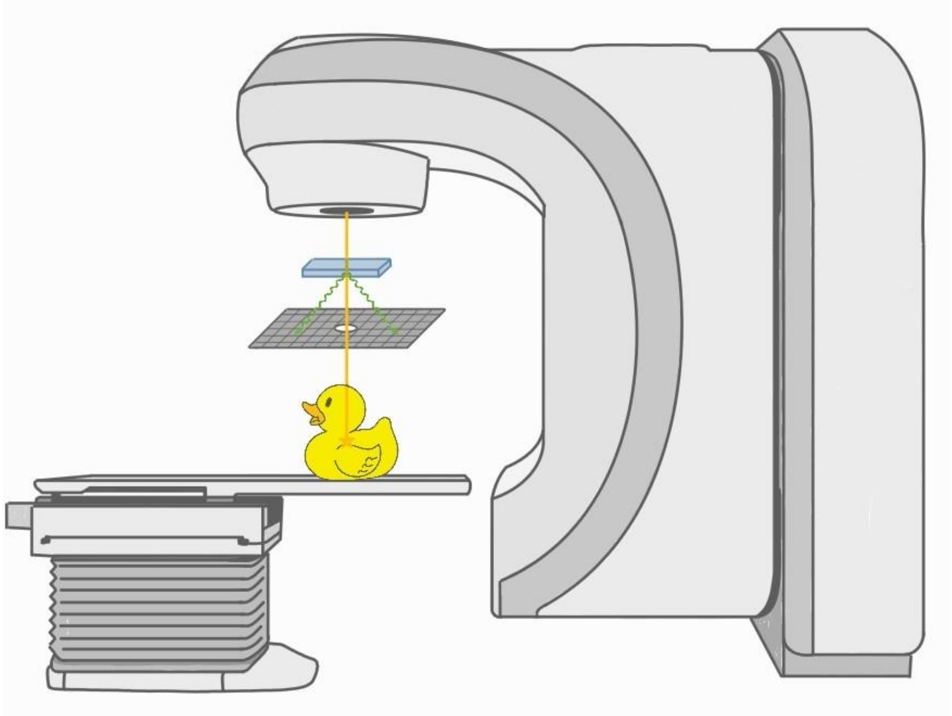
Our approach

- Applies to **charged particle beams**: electrons, protons and heavy ions.
- Electron beam energies are ~ MeV scale: no constraints on refractive index!
- Aerogel can be used as radiator. ☺





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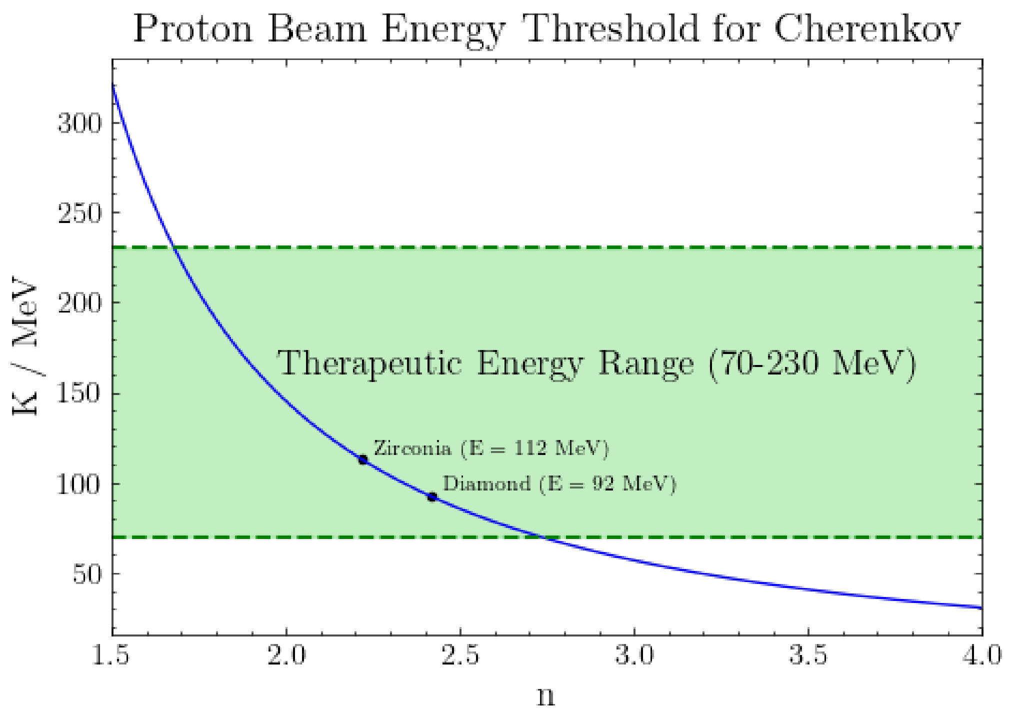
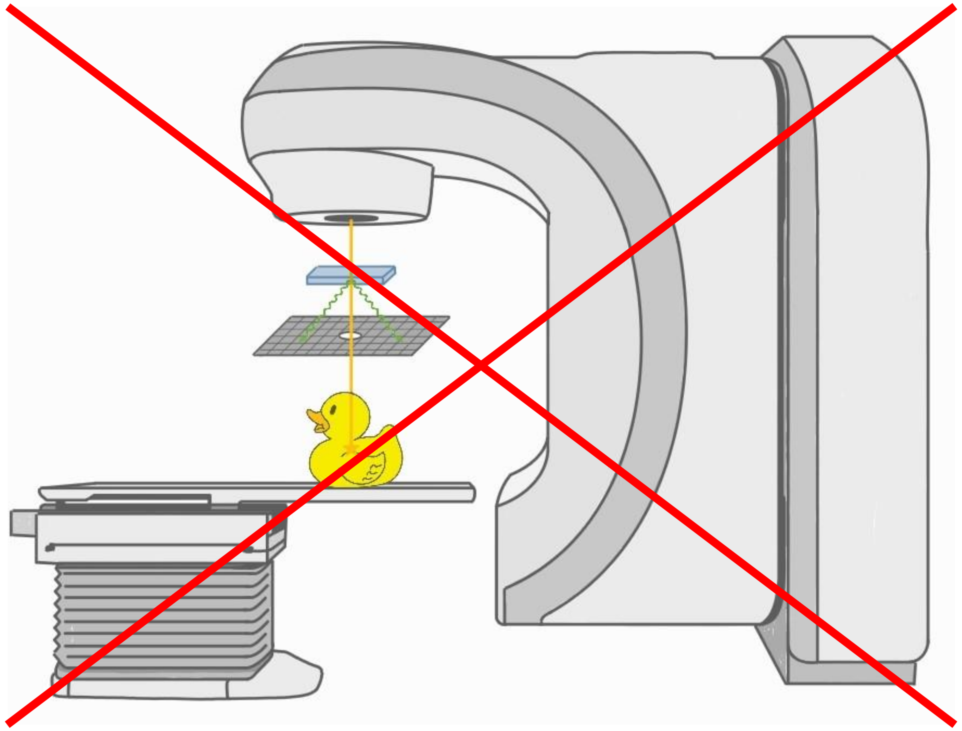
Our approach works for protons and heavy ions?

- To produce Cherenkov light, high refractive index materials are needed!
- Light is internally reflected: it is trapped inside the radiator…
- Our approach works for protons and heavy ions? **With this set-up, no.**





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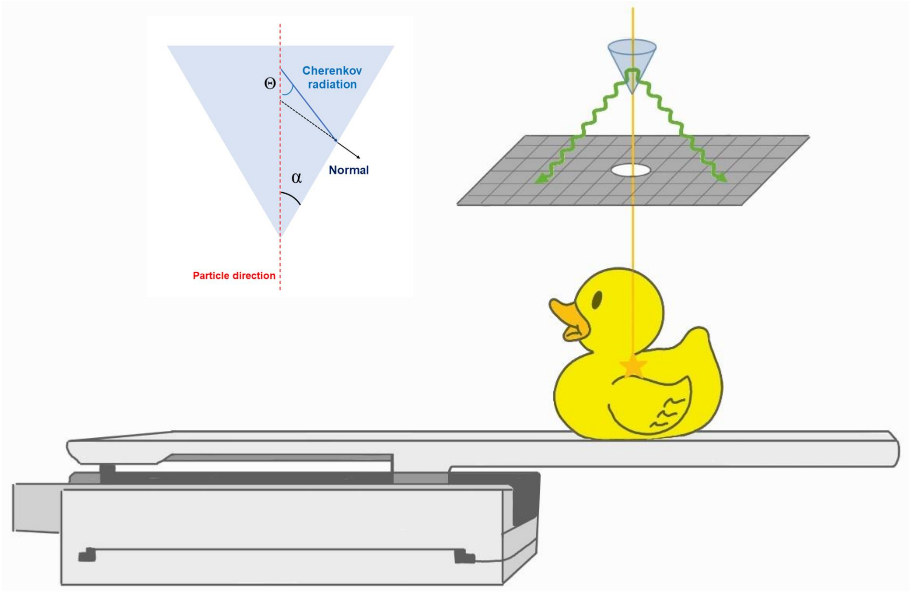
Our approach: protons and heavy ions adaptation

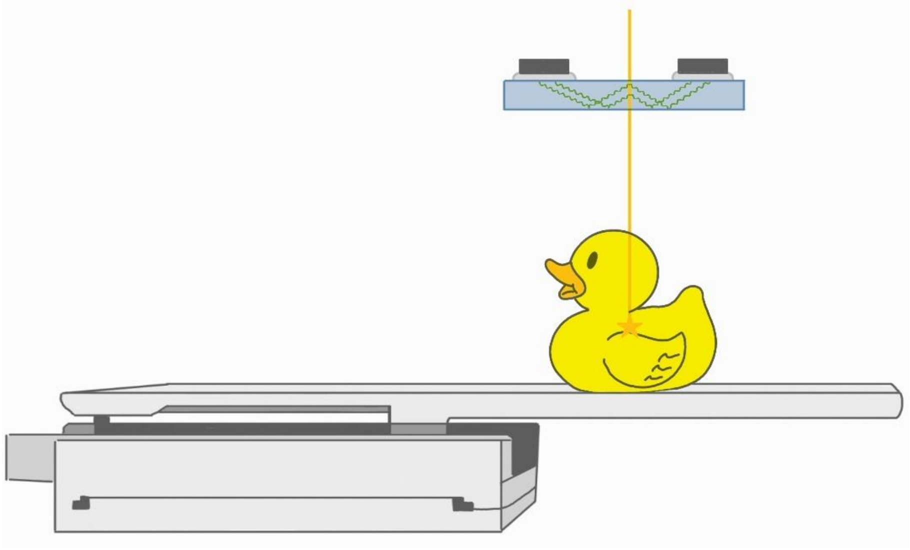
Conical Shape Radiator

- With this geometry, photons are not internally reflected – they can be detected!



Take advantage of Internal Reflection

- Use a photoacoplator to avoid the existence of a air gap between radiator and photodetector.



Why is this a solution?

Requirement	Device Performance
High Temporal Resolution	
Absence of saturation effects	
Minimal Impacts	
Fast Feedback to Machine	

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Requirement	Device Performance
High Temporal Resolution	~ns (Fast photodetector + electronics)
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Requirement	Device Performance
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Minimal Impacts	Miniaturized device (Radiator thickness ~mm)
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Fast Feedback to Machine	Electronics

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Acknowledgments

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  - Bruna Lima.
  - João Joaquim.
  - Inês Alvito and Manuel Ratola.
  - Inês Nunes.

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Real-Time Beam Monitoring Device For FLASH RT

Gonçalo Ribeiro

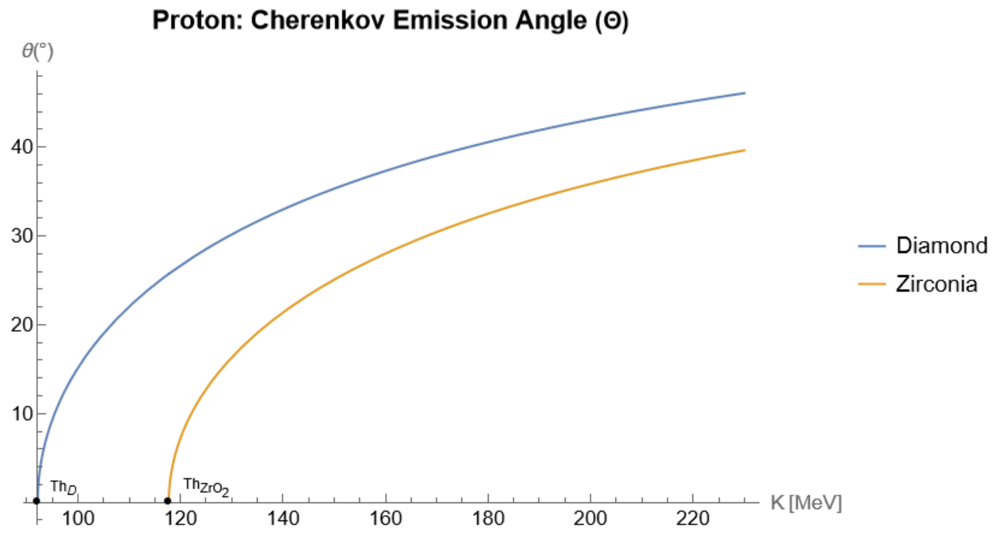
2nd ProtoTera Workshop, 9th October 2024, Lisbon, Portugal

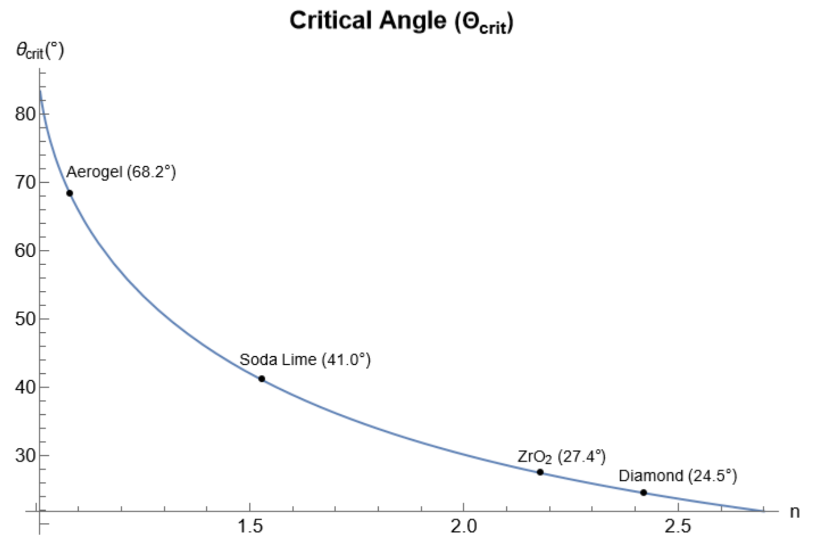
Supervisors: Prof. Pedro Assis, Prof. Patrícia Gonçalves, Dr. Maurizio Vretenar

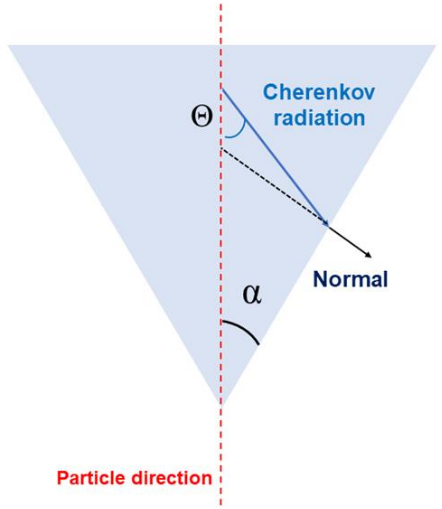
Other Dosimeters

- Ionization chambers, semiconductors, and scintillators are common examples.
- Exhibit saturation effects for dose-per-pulse, respectively, > 1 Gy/s, 15cGy/p, and 11-36 Gy/p, according to Di Martino, Fabio, et al. "*FLASH radiotherapy with electrons: issues related to the production, monitoring, and dosimetric characterization of the beam.*" Frontiers in Physics 8 (2020): 570697.

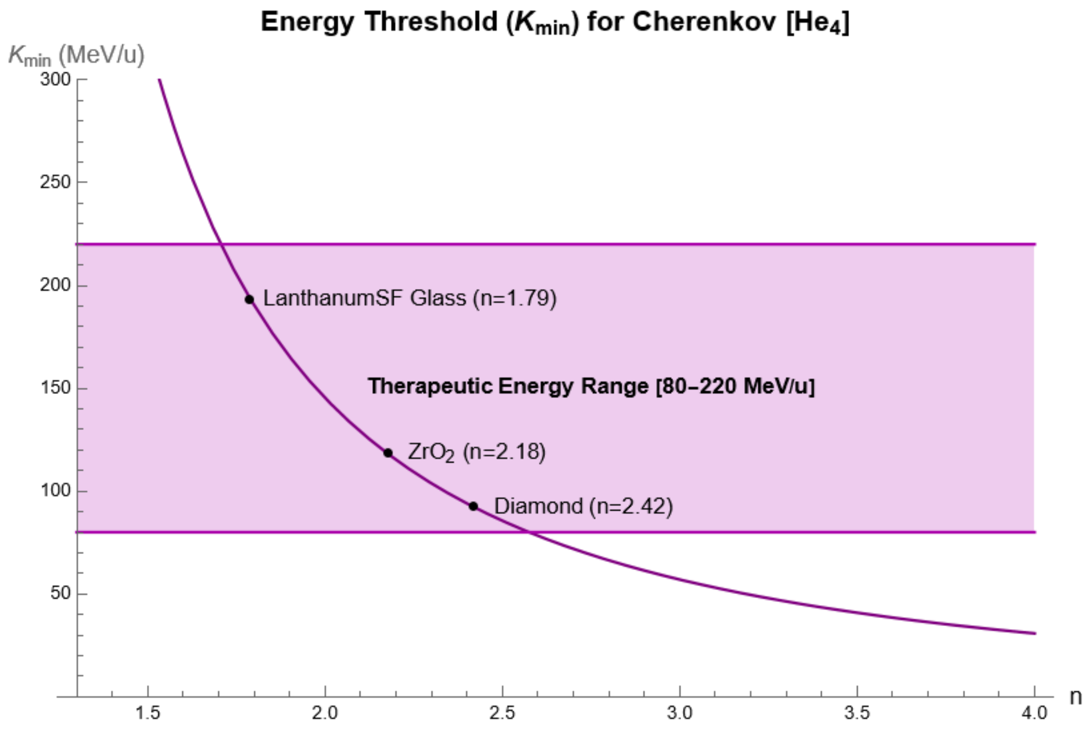
Why a conical radiator?



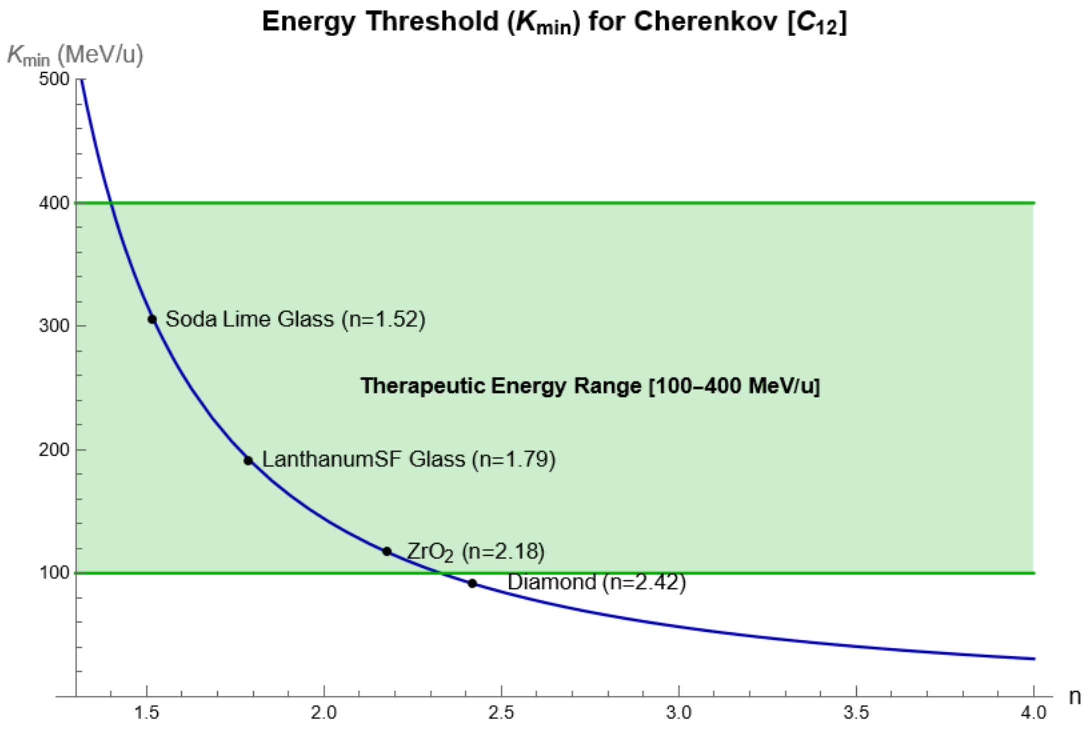




Heavy Ions



Energy Threshold (K_{min}) for Cherenkov [He_4]
K_{min} (MeV/u)
300
250
200
150
100
50
1.5
2.0
2.5
3.0
3.5
4.0
n
LanthanumSF Glass (n=1.79)
Therapeutic Energy Range [80–220 MeV/u]
ZrO_2 (n=2.18)
Diamond (n=2.42)



Energy Threshold (K_{min}) for Cherenkov [C_{12}]
K_{min} (MeV/u)
500
400
300
200
100
1.5
2.0
2.5
3.0
3.5
4.0
n
Soda Lime Glass (n=1.52)
Therapeutic Energy Range [100–400 MeV/u]
LanthanumSF Glass (n=1.79)
ZrO_2 (n=2.18)
Diamond (n=2.42)

Ongoing Work

With Theory

- Define materials that meet the requirements to be considered as radiators, namely refractive index.
- Light propagation using Cherenkov angle.
- Feasibility: expected light yield using Cherenkov's expressions and PDE of a photodetector.
- Predict the material with less impacts on beam.

With Simulation

- Simulation with Geant4 toolkit.
- Test realistic beams.
- Estimate light collection efficiency.
- Assess impacts on dose delivery profile.
- Test different geometries for optimisation.

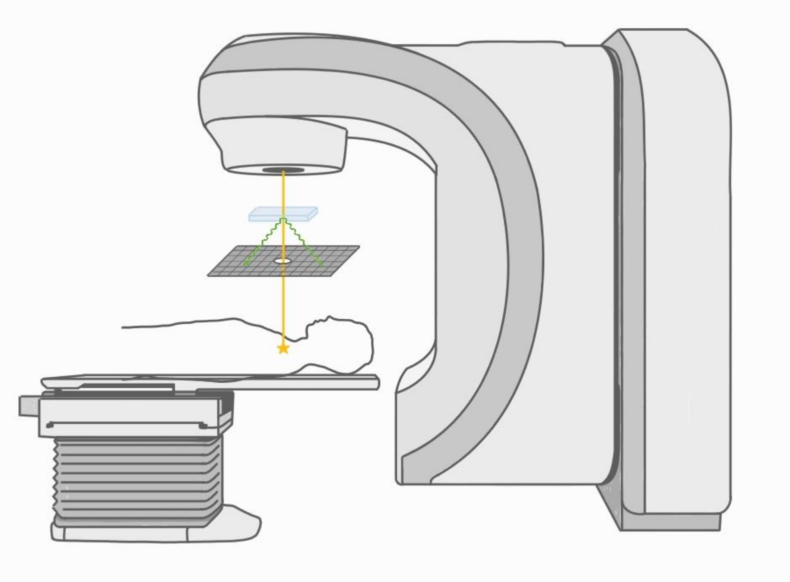
Geant4-Simulation Private

Geant4 is a simulation toolkit. This simulation is built in C++ and intends to test a novel monitoring device for FLASH Radiotherapy.

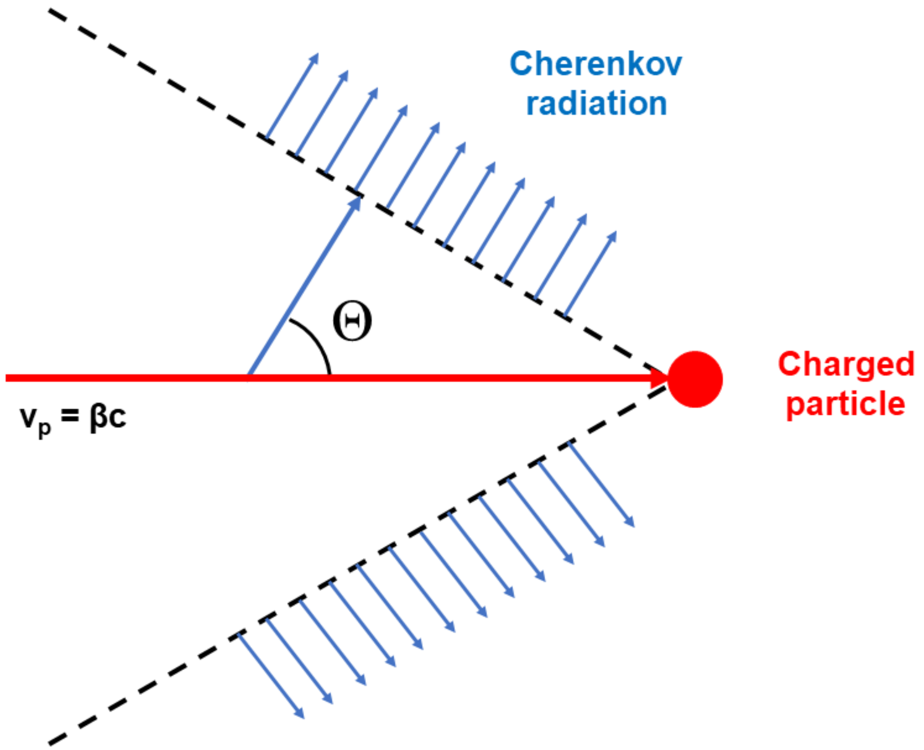
Makefile   Updated on Aug 16

Conclusions

- Beam monitoring for FLASH RT: we propose a Cherenkov based device.
- Device suitable for all charged particle beams: electron, proton and heavy ions.
- Miniaturized particle counter with:
  - High temporal resolution (~ns);
  - Minimal Impacts on beam;
  - Absence of saturation effects;
  - Real-time feedback to machine.
- Optimisation: theory and MC simulation.
- Submitted a patent application last August.



Cherenkov Effect



$$\Theta = \cos^{-1}\frac{1}{\beta n}$$

Charged particle travels **faster than light** in a medium (energy threshold!)

Photons are **emitted along a cone** with a defined angle Θ

Emitted photons per transversed material can be computed (particle charge = e):

$$\frac{dN}{dx} = 2\pi\alpha \int d\lambda \left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)\frac{1}{\lambda^2}$$