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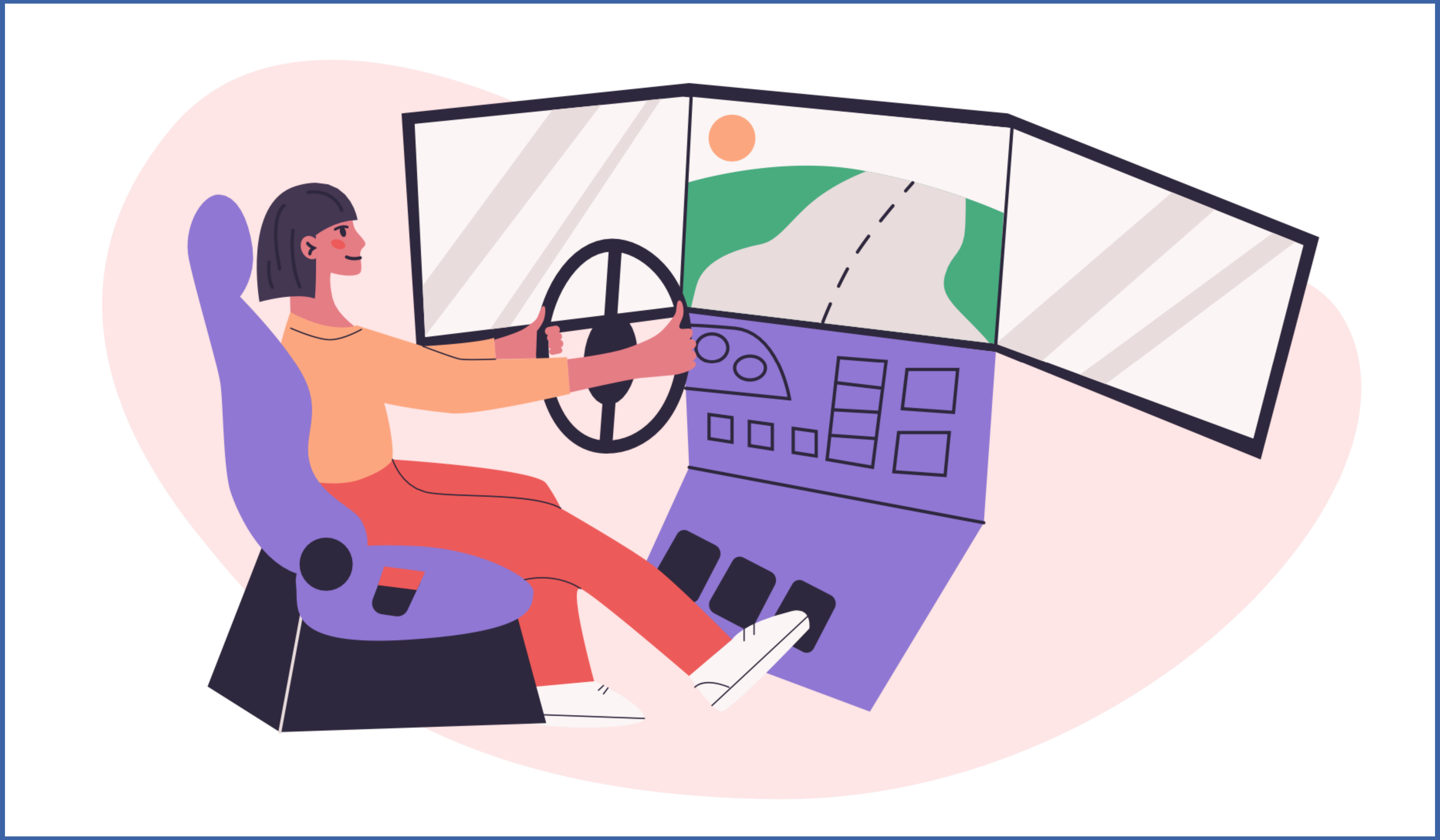
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
THE Tuscany Health Ecosystem



THE, Spoke 1, Milestones 1.1, 1.2, 1.6

THE
Tuscany Health Ecosystem

The future of VHEE medical applications: what simulations are telling us.

C. Panaino, F. Avella

1. Introduction: VHEE in Radiotherapy—Why, Where, and How?

2. Particle In Cell (Pic) simulations

3. Monte Carlo simulations

   3.1 VHEE PDDs database

   3.2 VHEE focusing study

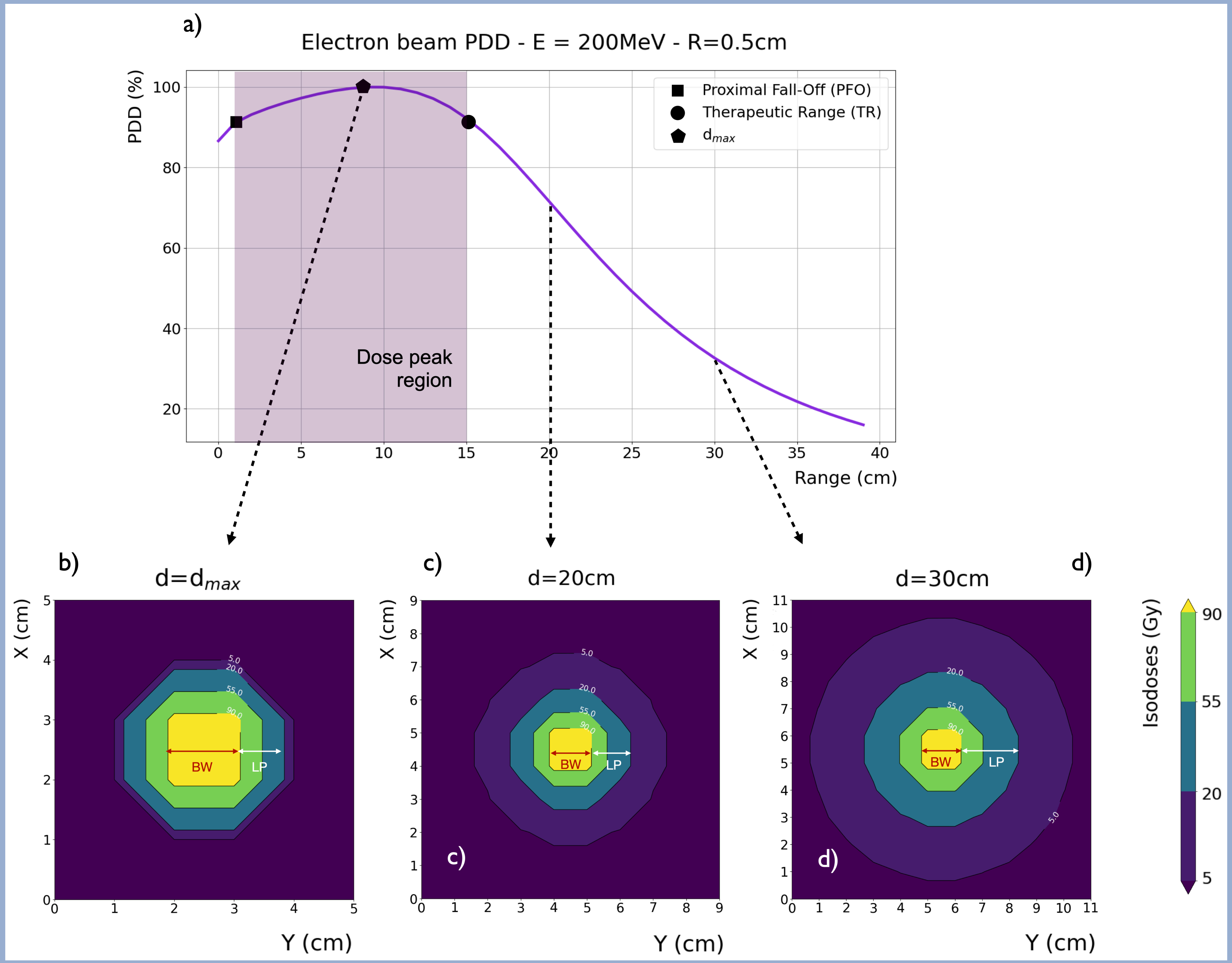
   3.3 VHEE dosimetric assessment

   3.4 OPTIMA: VHEE Treatment Planning System (TPS)

4. Conclusions

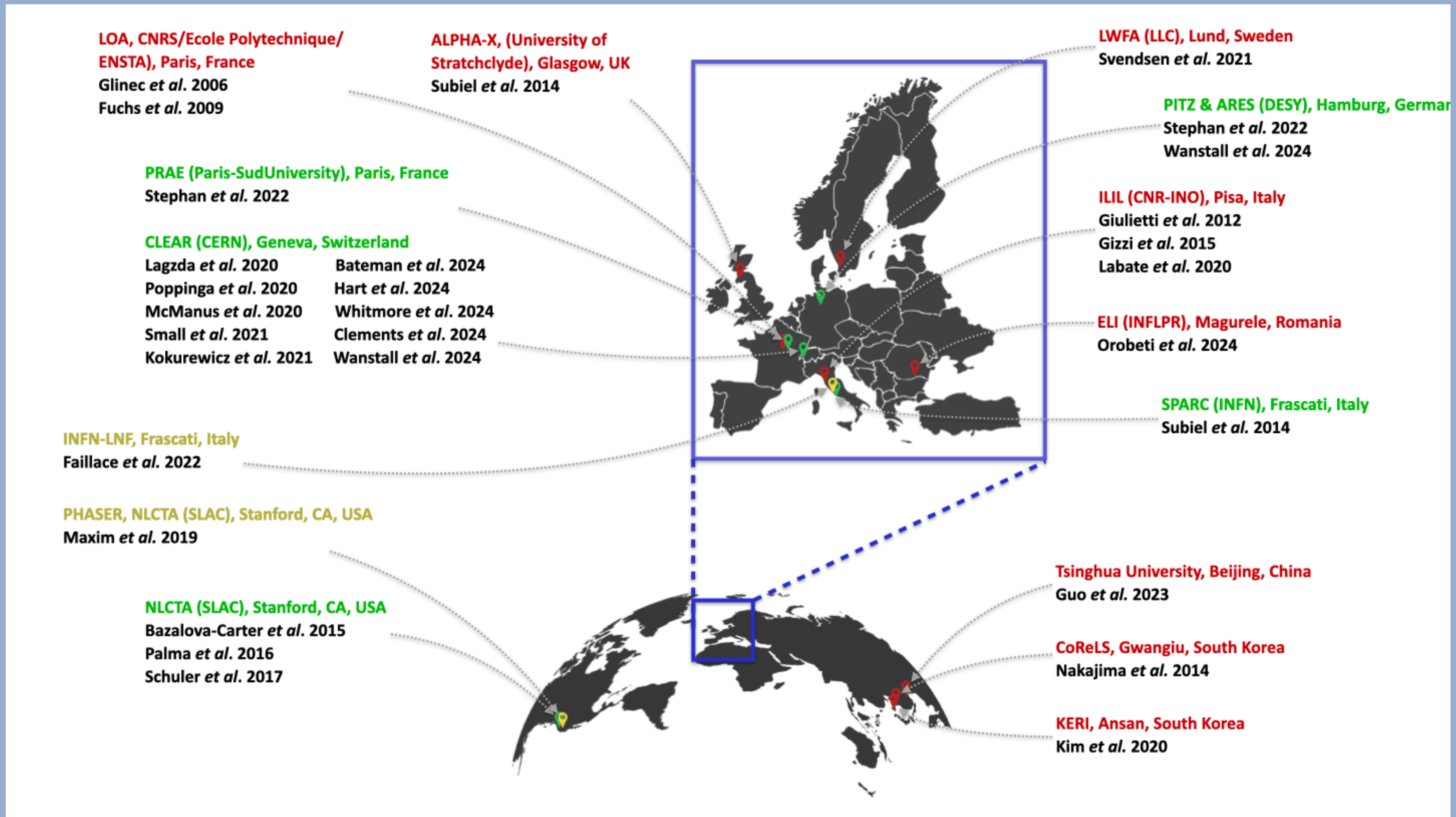
Very High Energy Electrons

There is a new ingredient on radiotherapy's shelves!



Very High Energy Electrons

Where VHEE research is taking place?



Very High Energy Electrons

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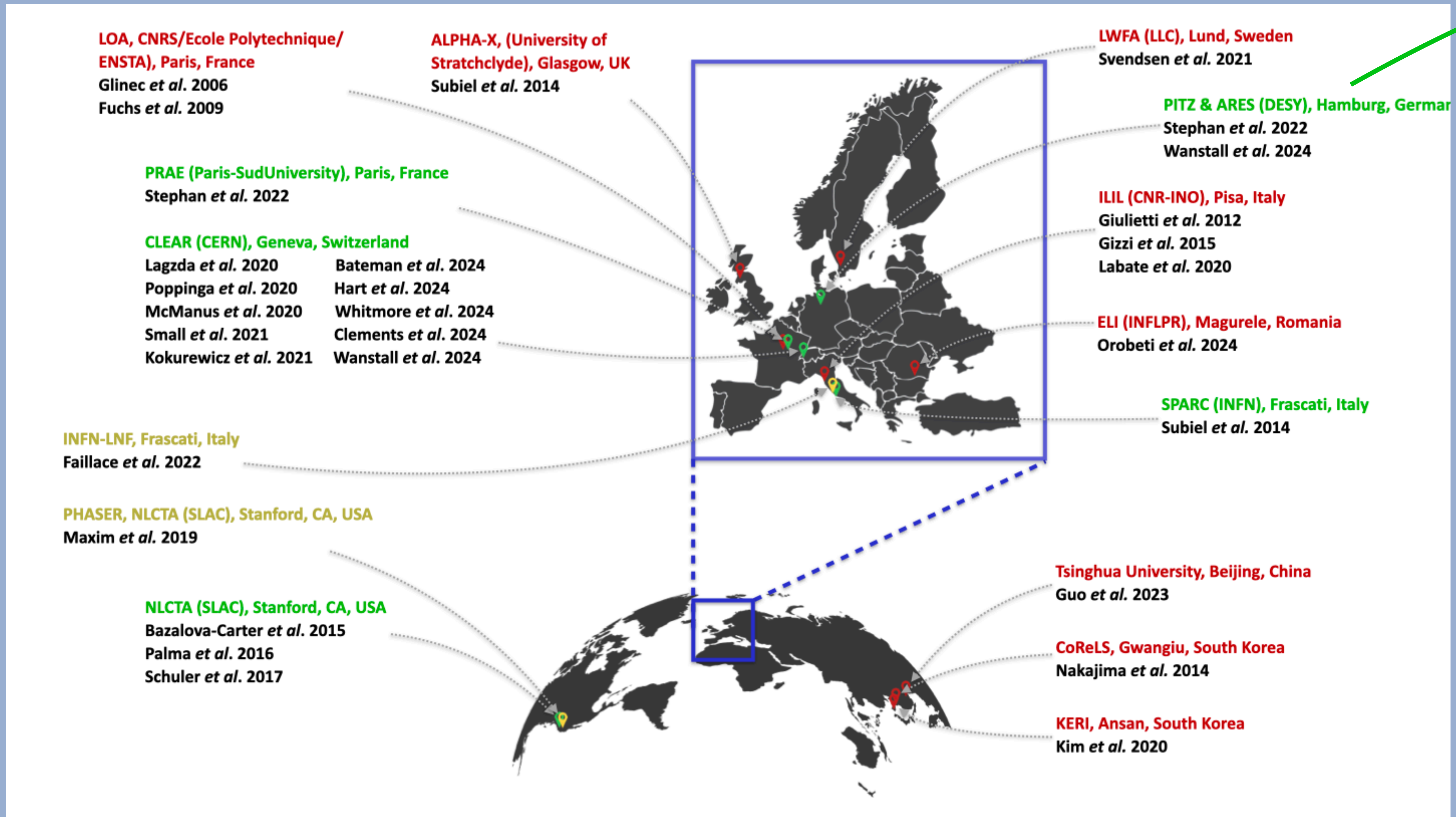
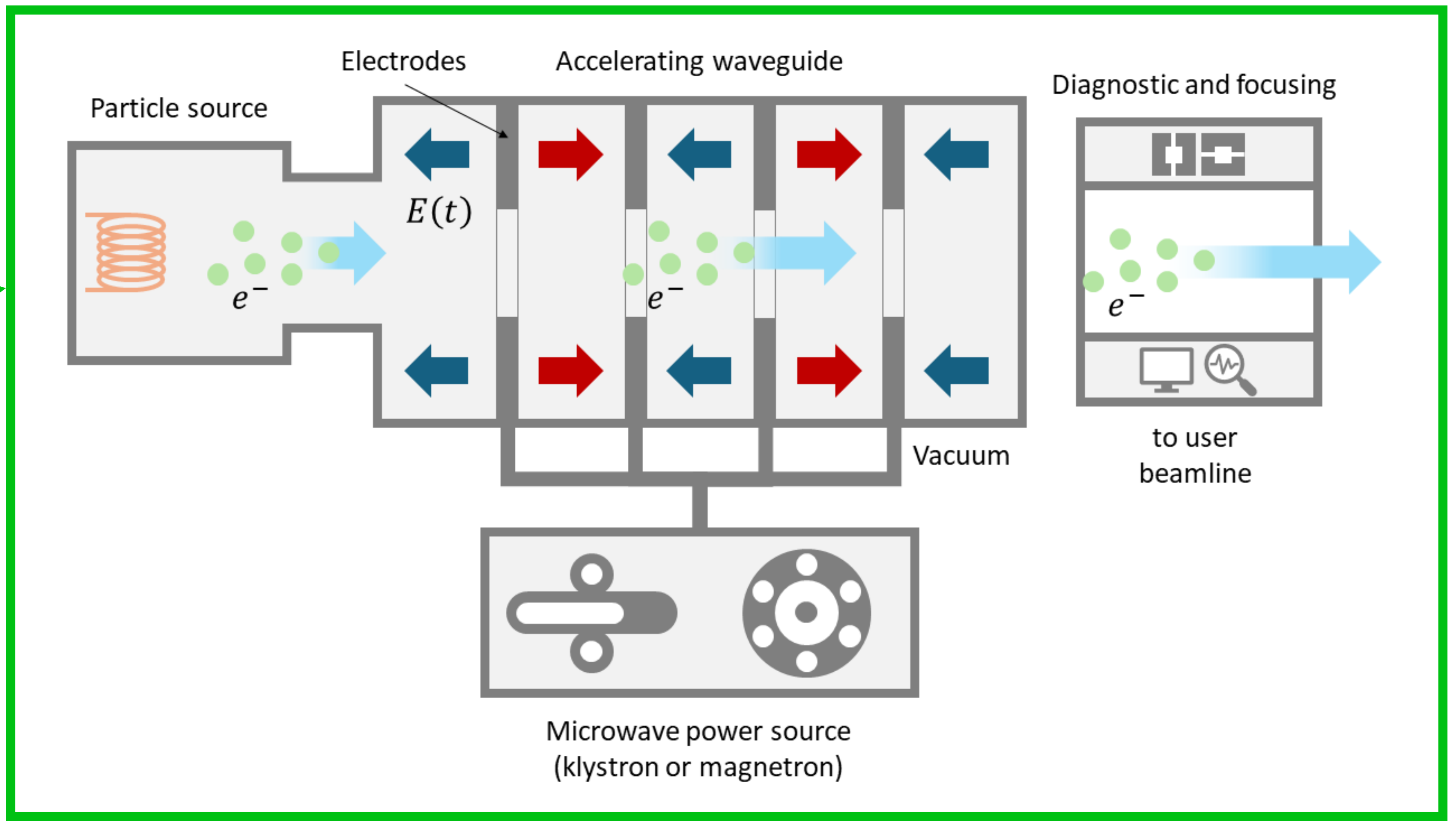


RF-based VHEE systems



Very High Energy Electrons

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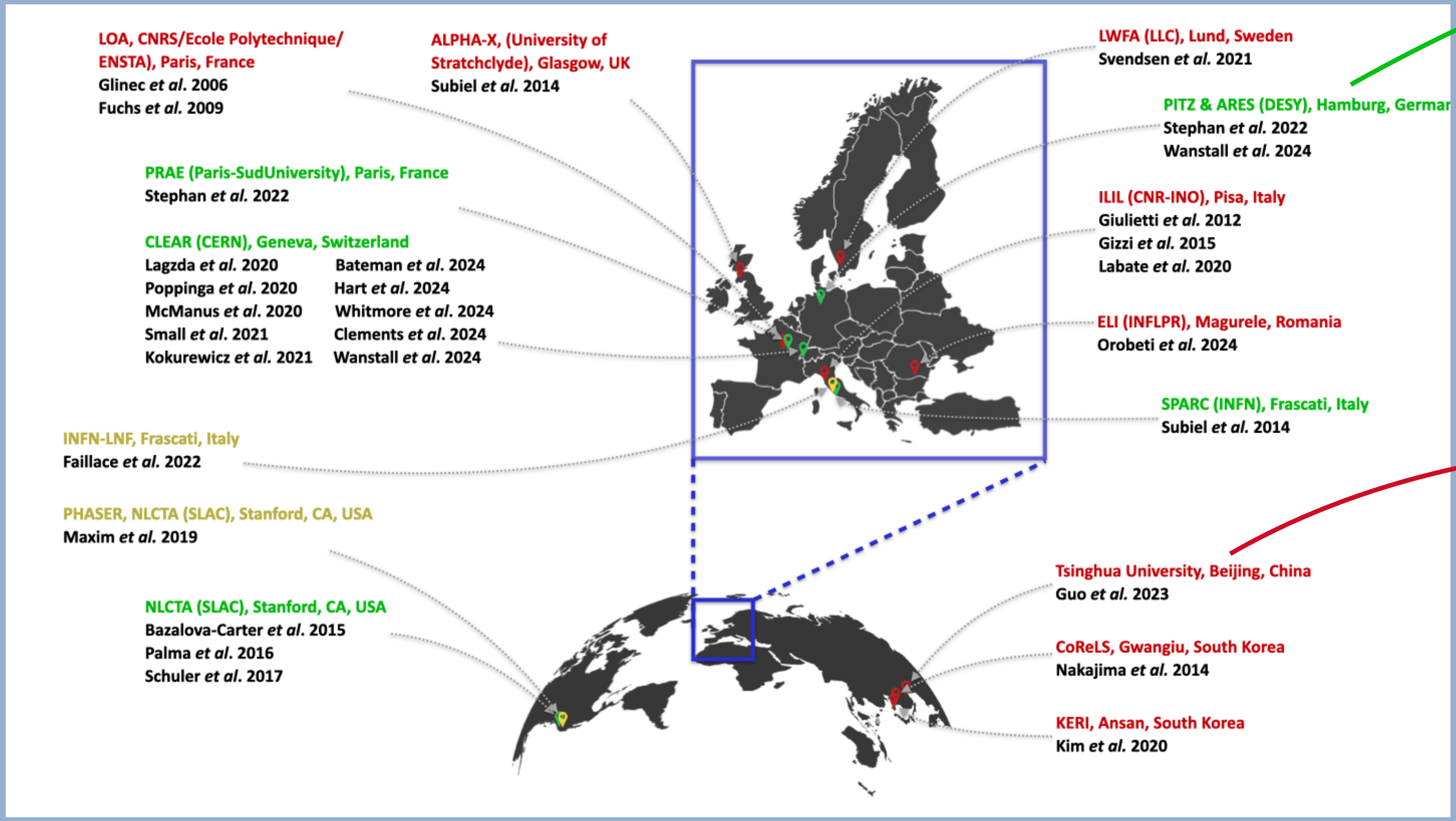

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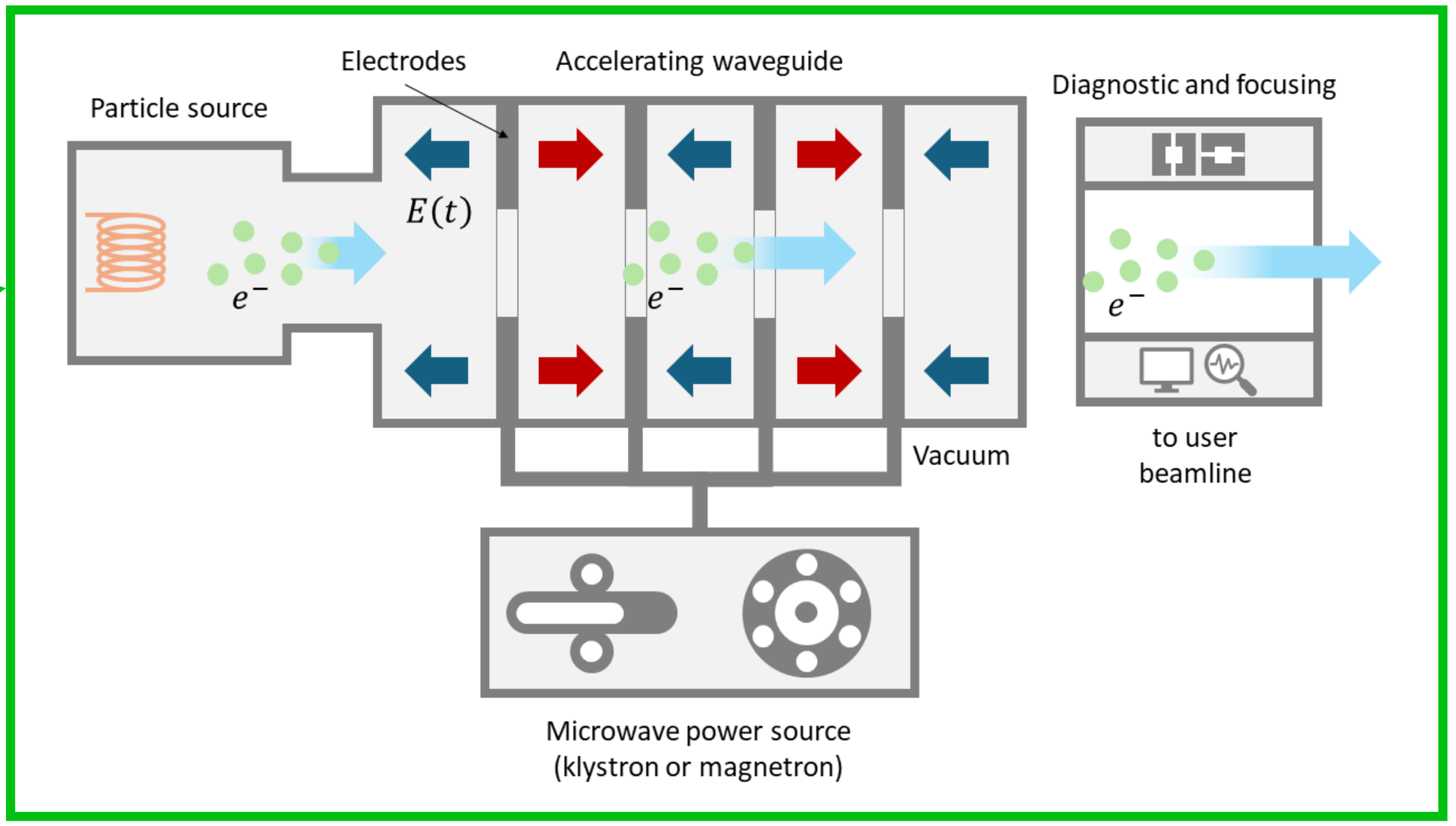
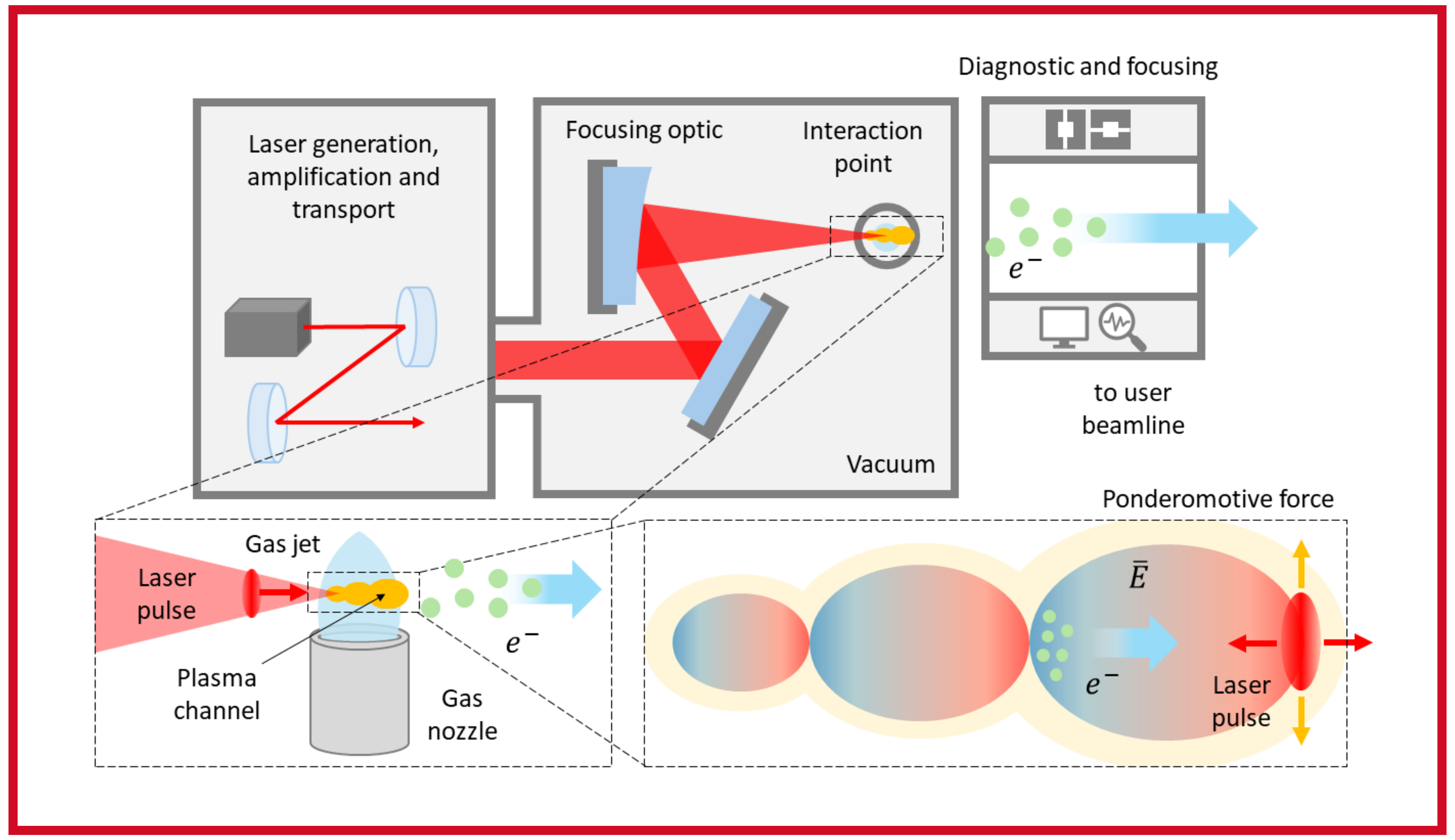
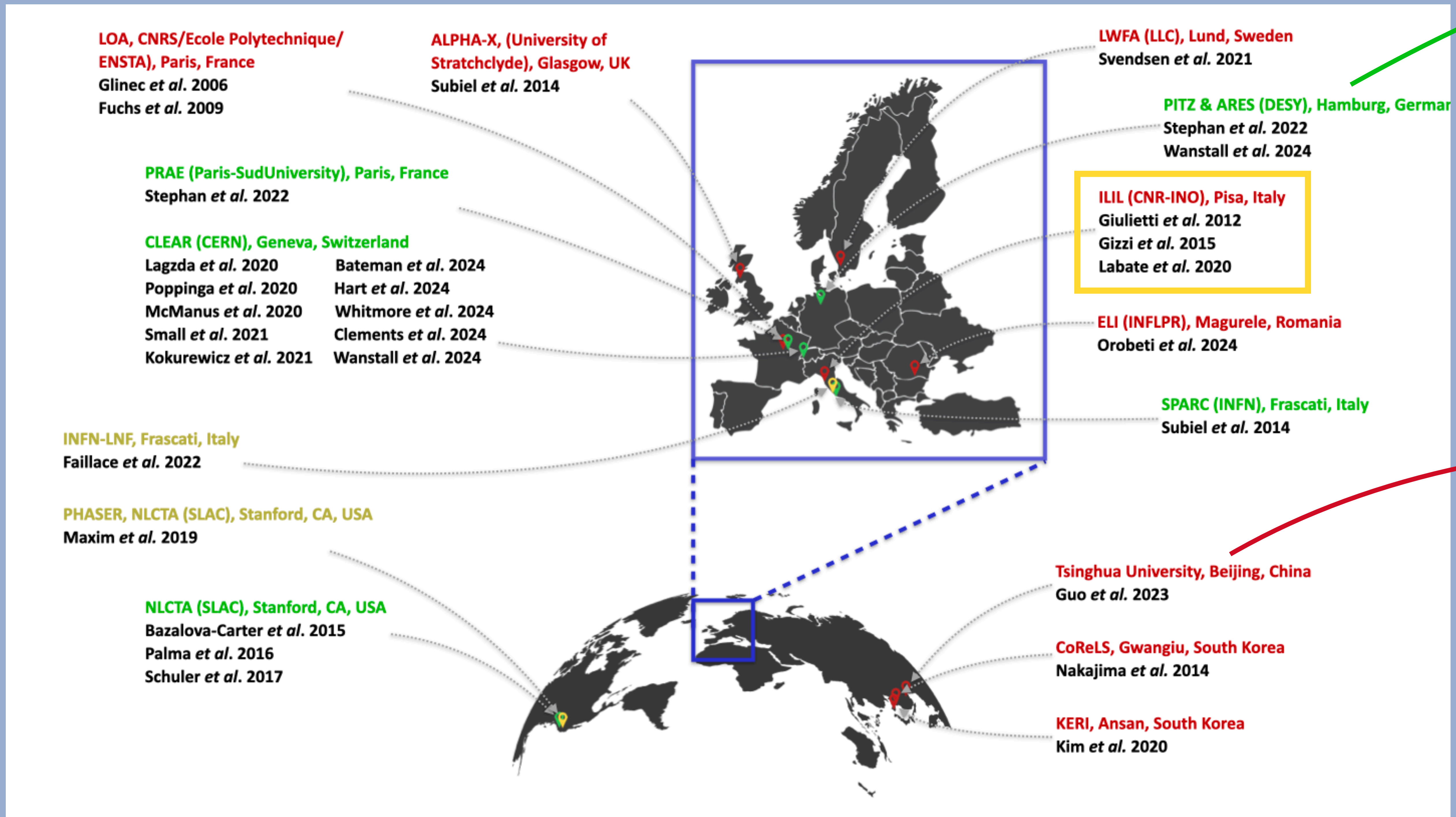


LWFA-based VHEE systems

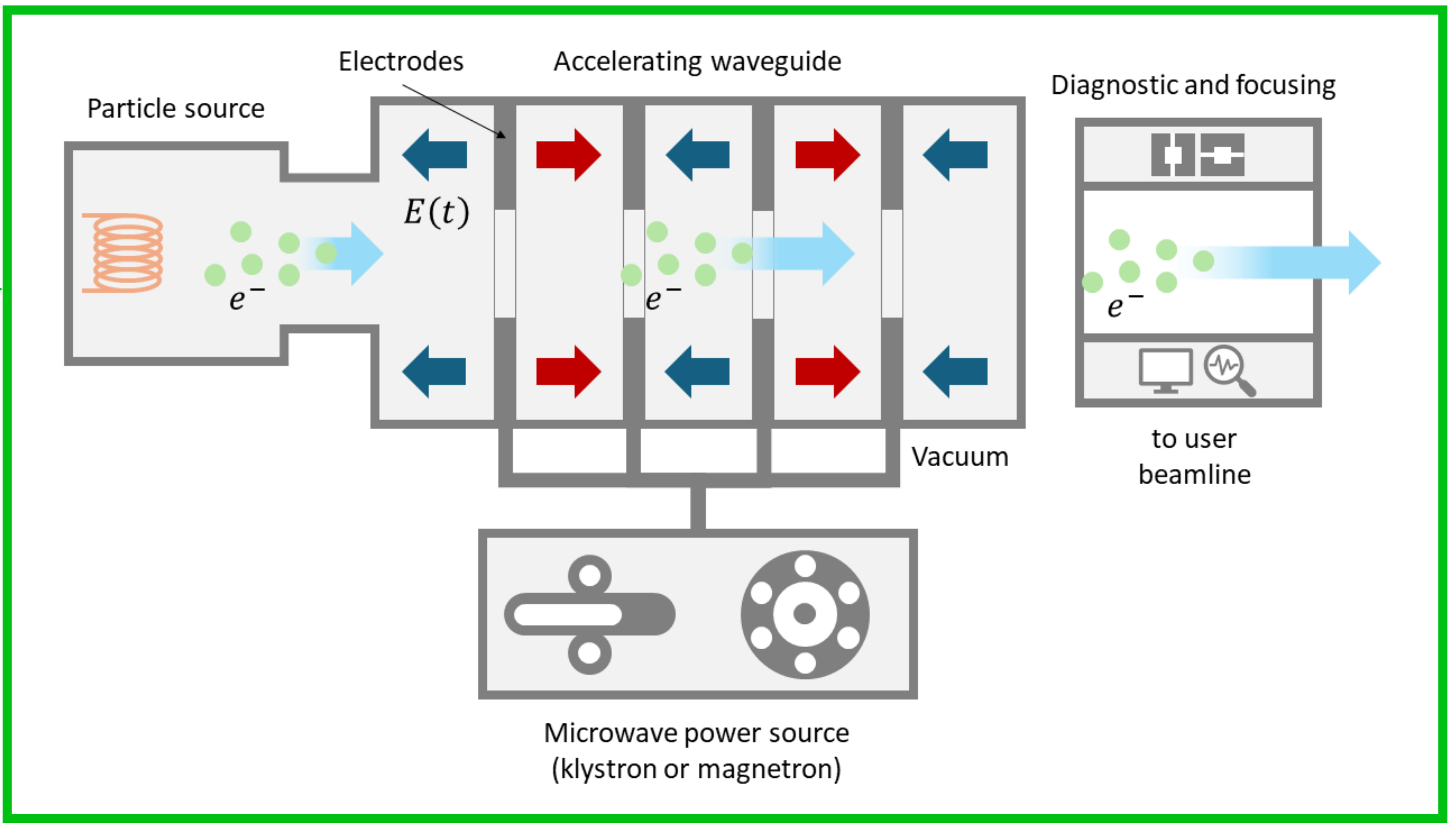


Very High Energy Electrons

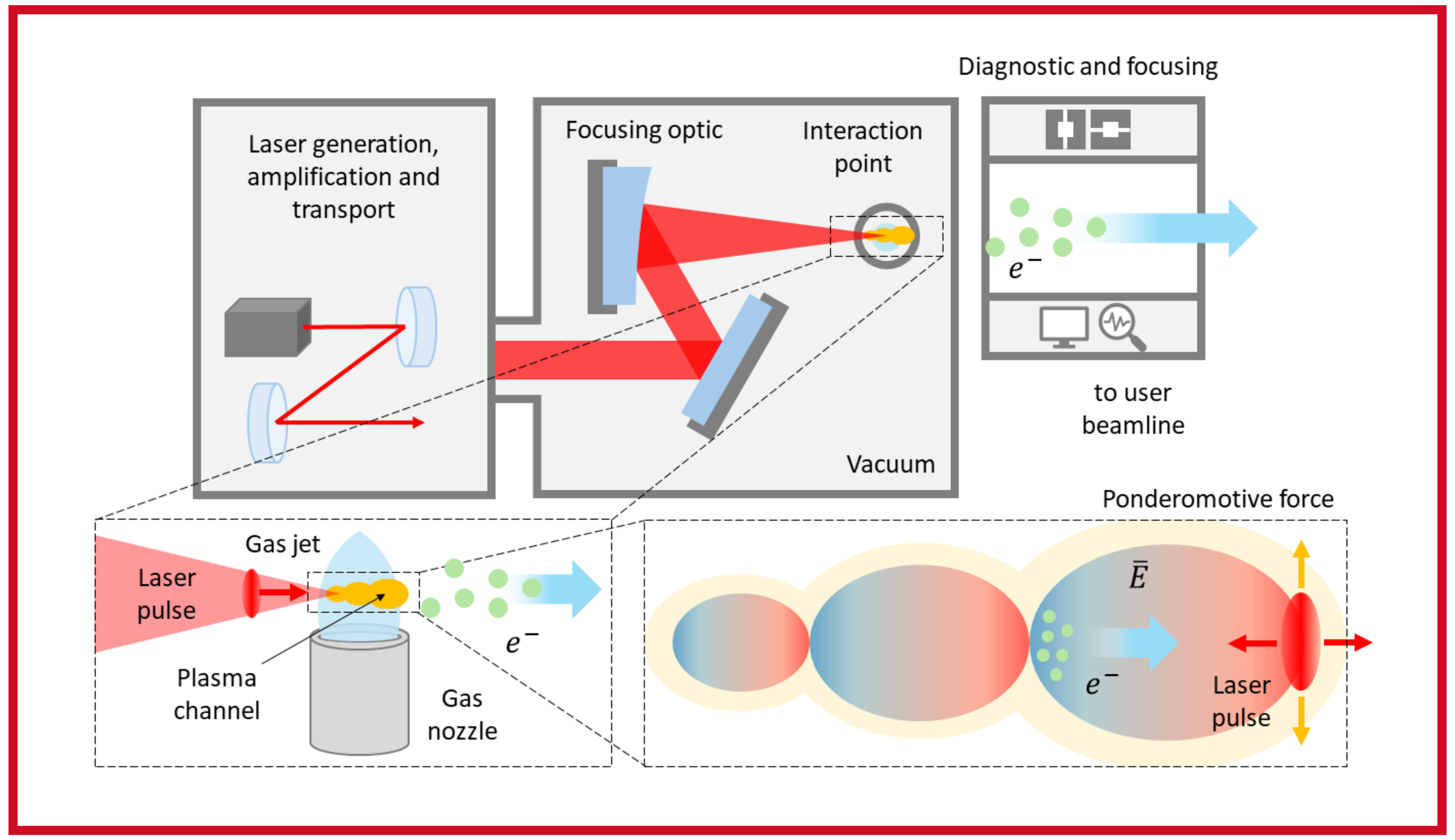
Where VHEE research is taking place?



RF-based VHEE systems

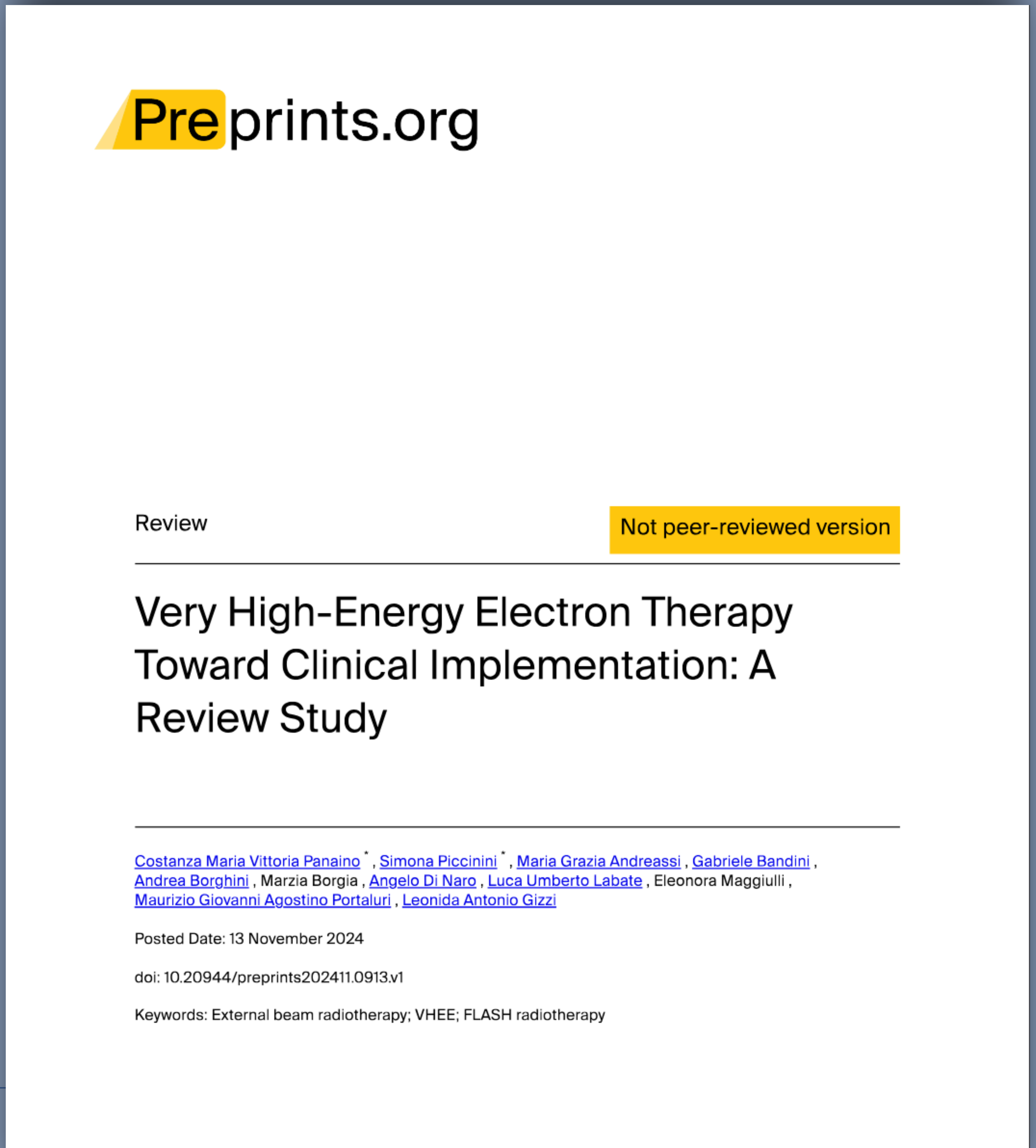


LWFA-based VHEE systems



Very High Energy Electrons

Do you want to know more?



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Review

Not peer-reviewed version

Very High-Energy Electron Therapy Toward Clinical Implementation: A Review Study

Costanza Maria Vittoria Panaino *, Simona Piccinini *, Maria Grazia Andreassi, Gabriele Bandini, Andrea Borghini, Marzia Borgia, Angelo Di Naro, Luca Umberto Labate, Eleonora Maggiulli, Maurizio Giovanni Agostino Portaluri, Leonida Antonio Gizzi

Posted Date: 13 November 2024

doi: 10.20944/preprints202411.0913.v1

Keywords: External beam radiotherapy; VHEE; FLASH radiotherapy

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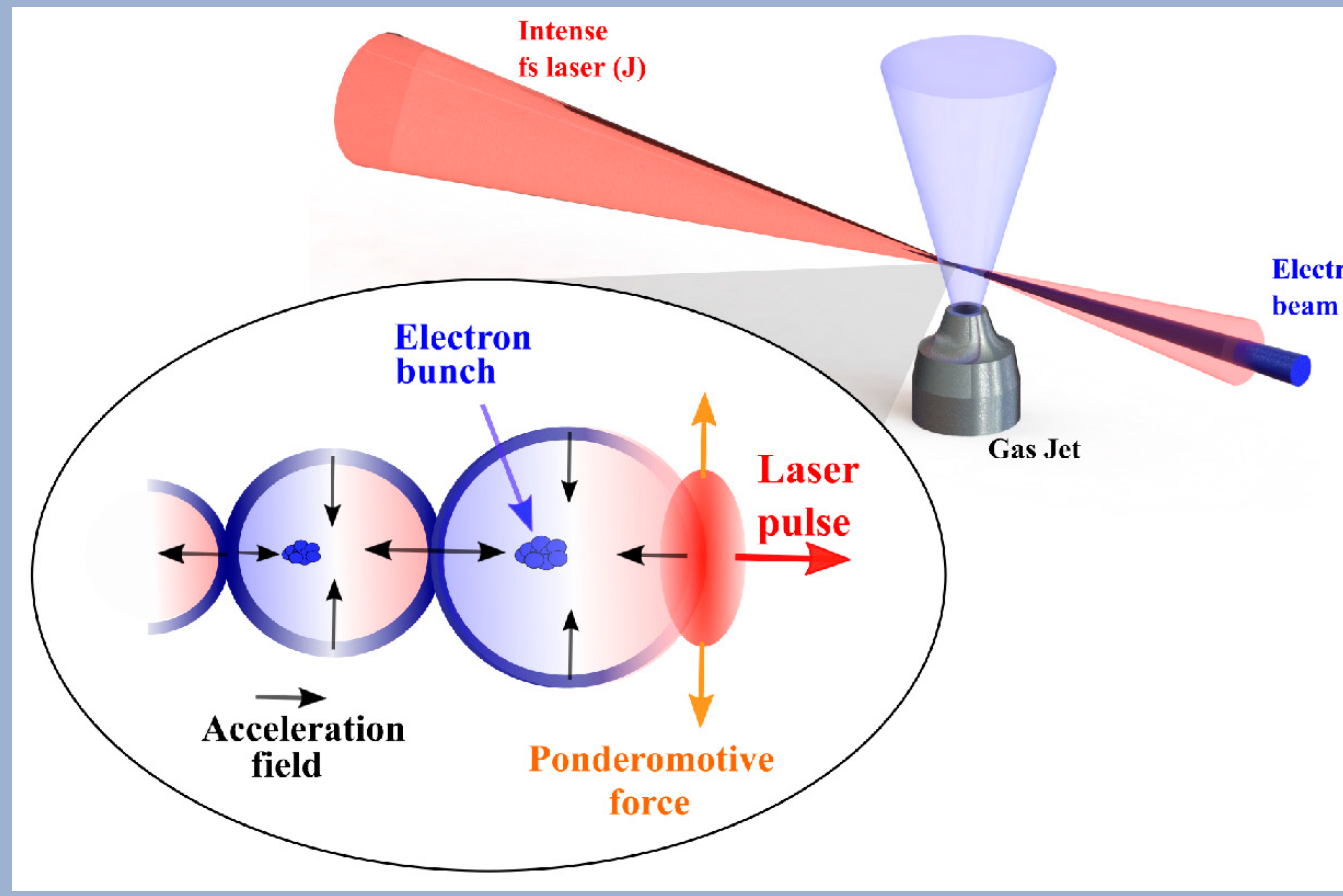
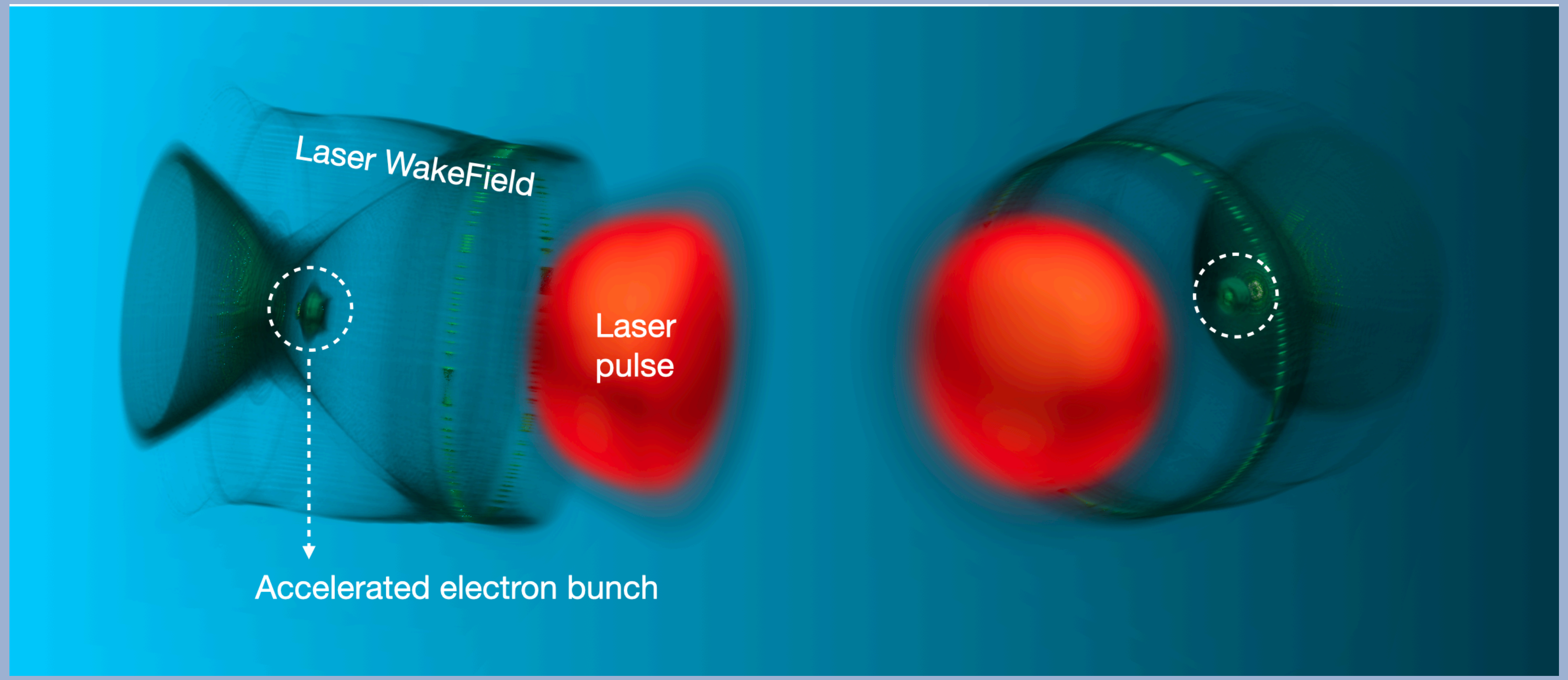
In laser-plasma accelerators, VHEE beams are produced by focusing an intense and ultrashort laser on a target.

- **Target** = supersonic helium gas jet, a "transparent" plasma through which the laser can propagate.





PIC (Particle-In-Cell) is a numerical technique allowing to simulate the dynamics of a large collection of charged particles (e.g, electrons or ions) interacting with electromagnetic fields *in a reduced description* (i.e, dynamics of macroparticles).

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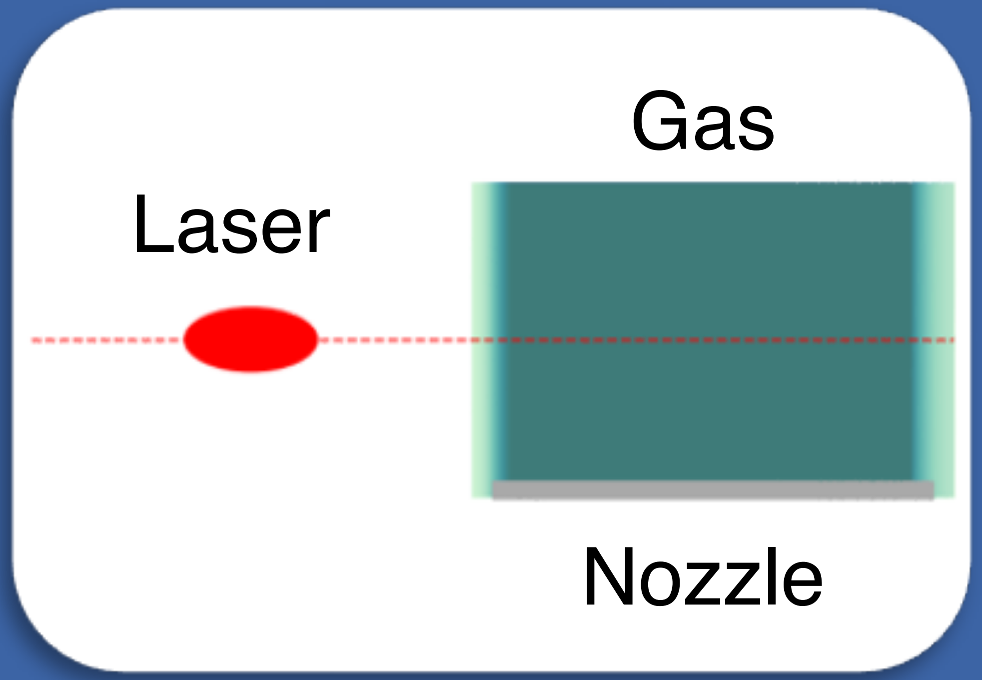
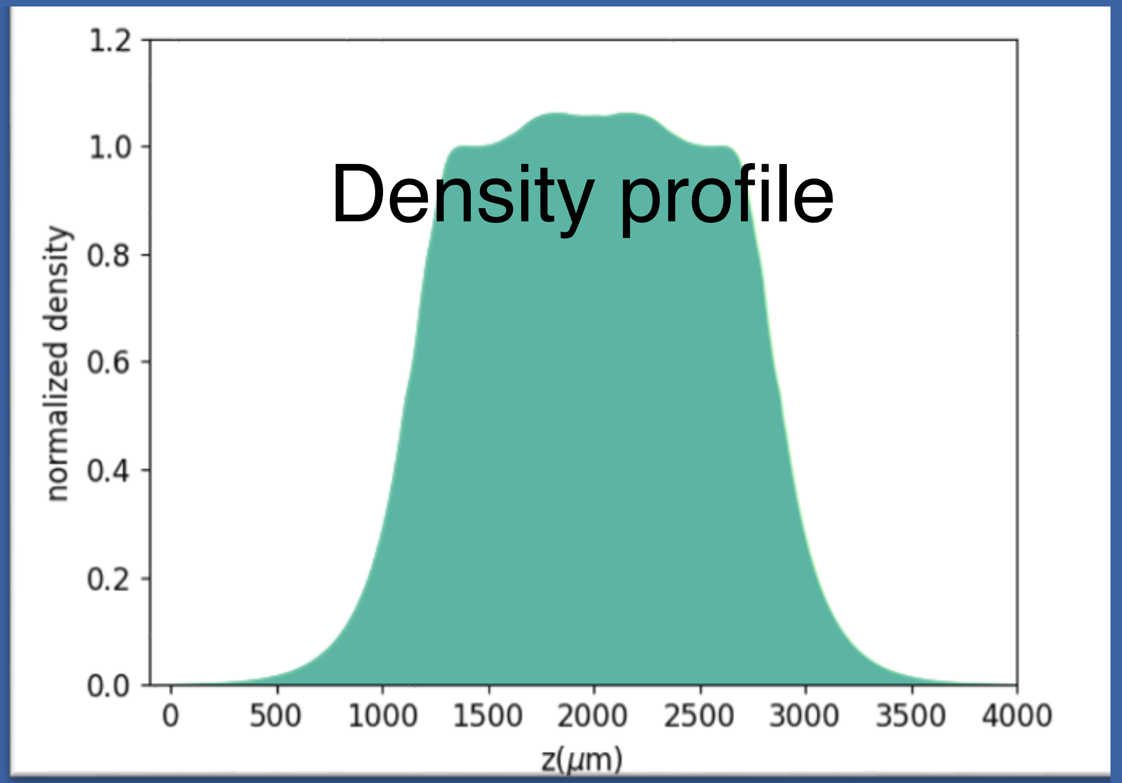
PIC simulations can handle scenarios of increasing complexity, starting from simple systems like a single nozzle.





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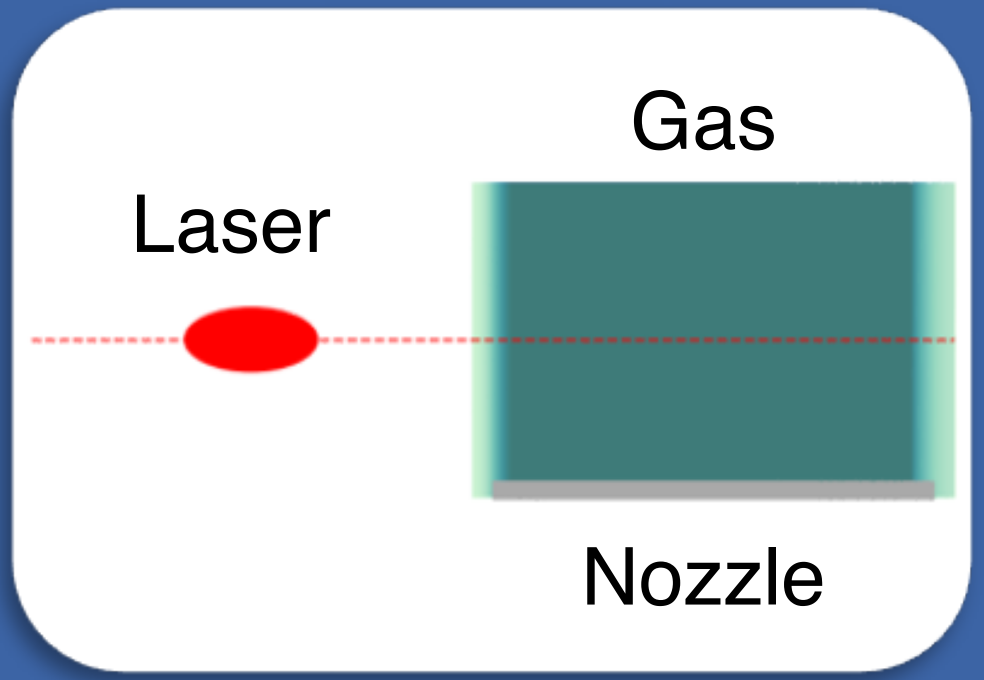
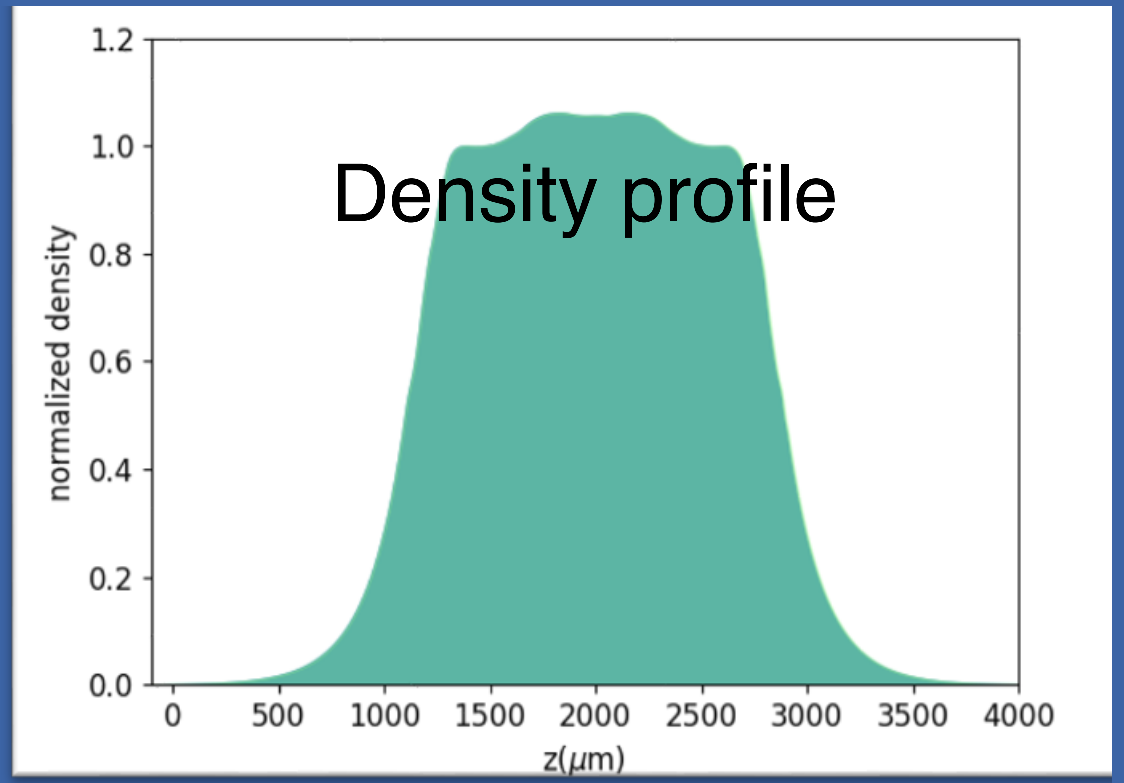
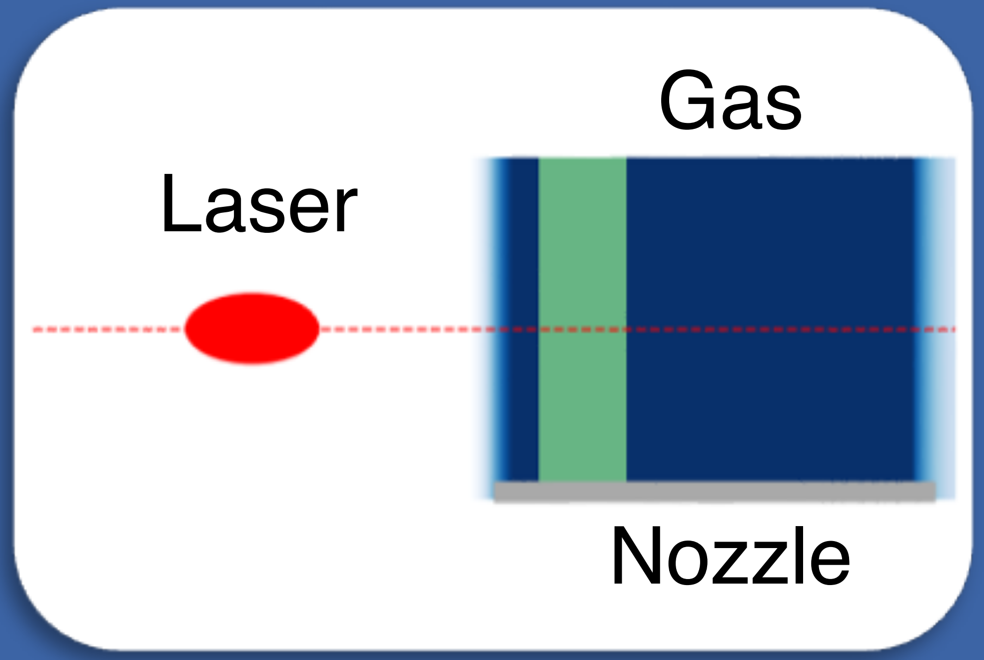
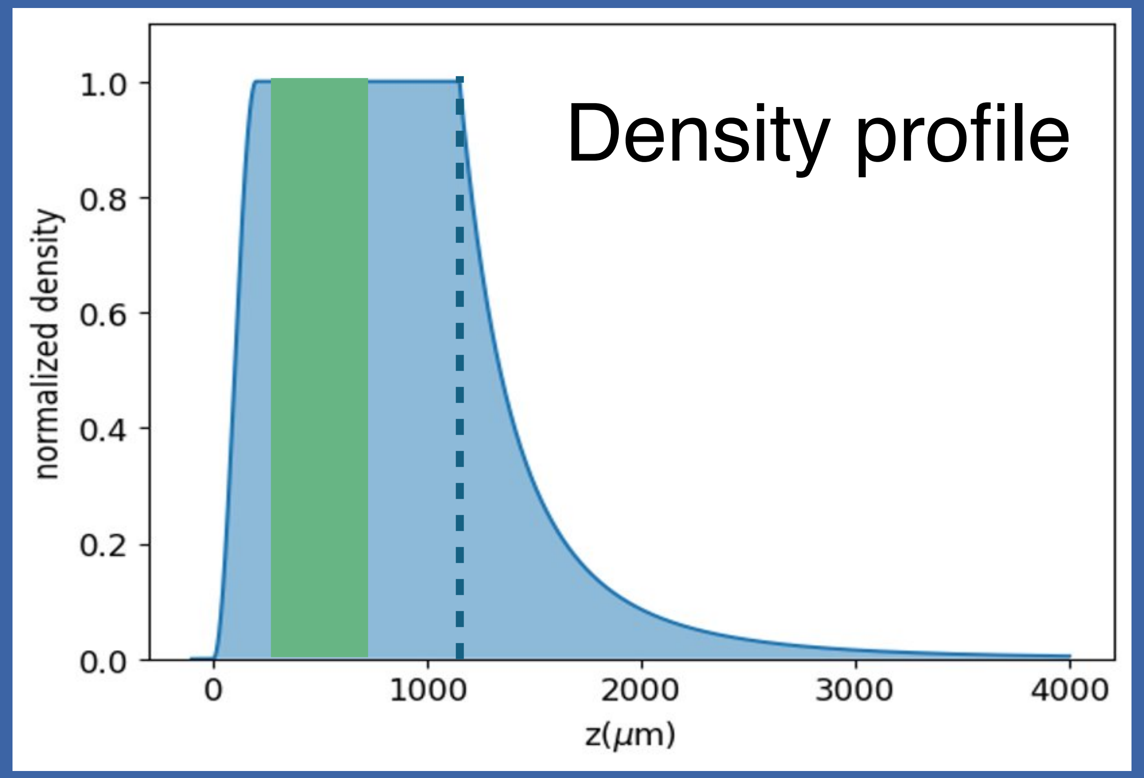




PIC simulations can also model complex systems that encompass all three stages of laser-plasma interactions: injection, acceleration, and extraction.



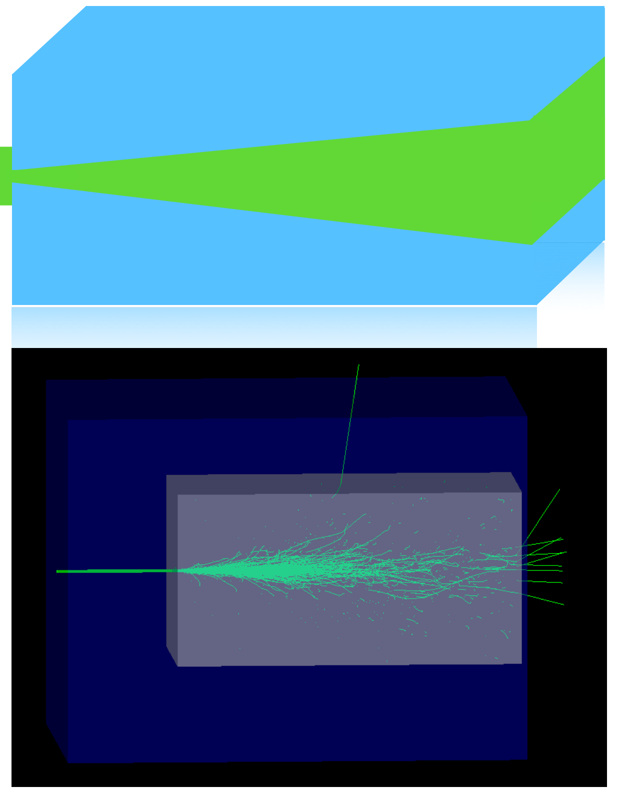


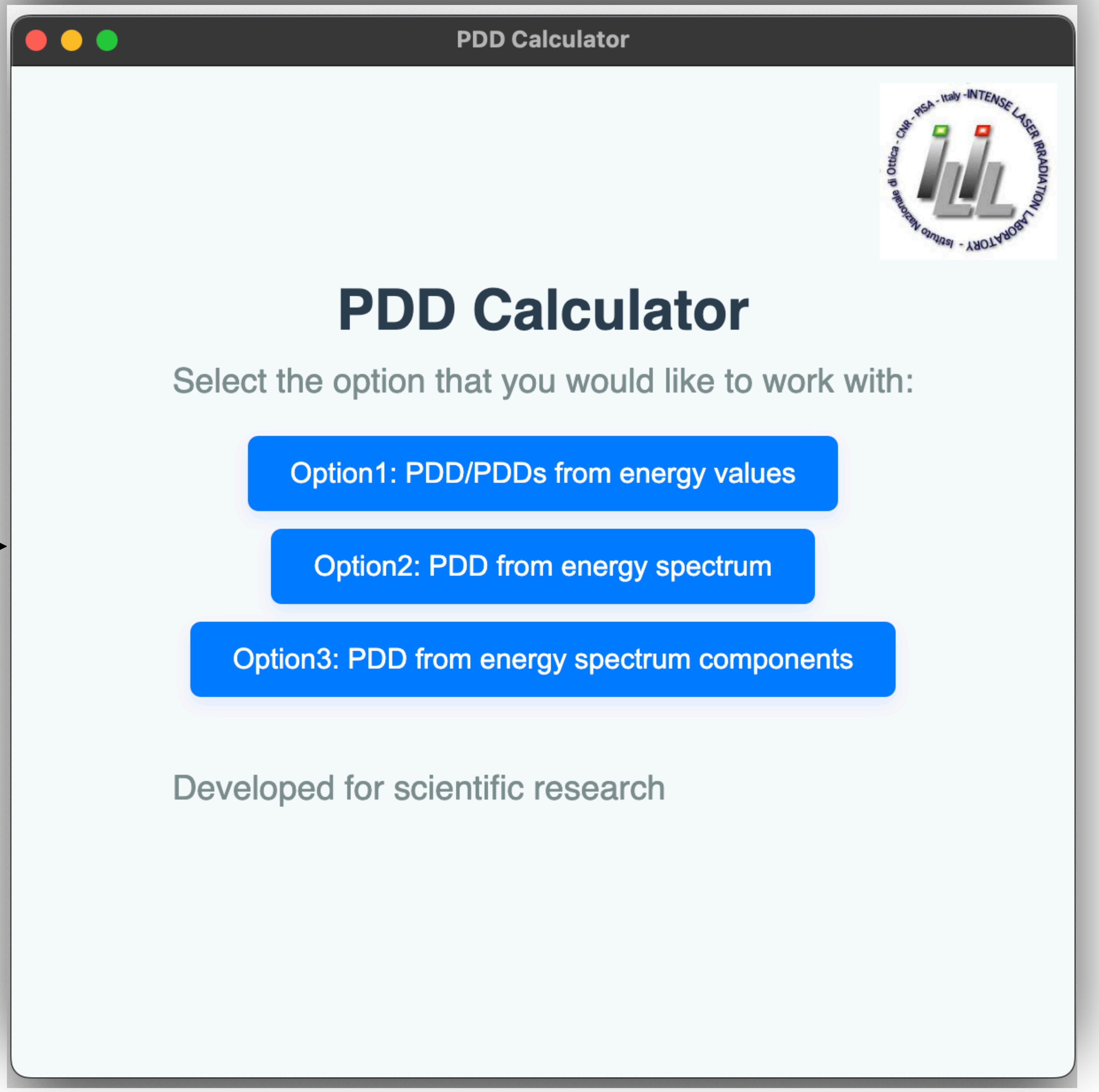
JET-LEA, Bando a cascata PNRR.

R. Buonpane, Università della Campania

VHEE PDD database

50pm2_5.txt	200pm5.txt	300pm40.txt
50pm5.txt	200pm10.txt	300pm50.txt
50pm10.txt	200pm20.txt	300pm60.txt
50pm15.txt	200pm30.txt	300pm90.txt
50pm20.txt	200pm40.txt	300pm120.txt
50pm30.txt	200pm50.txt	350pm5.txt
100pm5.txt	200pm60.txt	350pm10.txt
100pm10.txt	200pm80.txt	350pm17_5.txt
100pm20.txt	250pm5.txt	350pm20.txt
100pm30.txt	250pm10.txt	350pm30.txt
100pm40.txt	250pm12_5.txt	350pm35.txt
150pm7_5.txt	250pm20.txt	350pm40.txt
150pm5.txt	250pm25.txt	350pm50.txt
150pm10.txt	250pm30.txt	350pm70.txt
150pm15.txt	250pm40.txt	350pm105.txt
150pm20.txt	150pm75.txt	350pm140.txt
150pm30.txt	150pm100.txt	400pm160.txt
150pm40.txt	300pm5.txt	400pm120.txt
150pm45.txt	300pm10.txt	400pm80.txt
150pm50.txt	300pm15.txt	400pm40.txt
150pm60.txt	300pm30.txt	400pm20.txt





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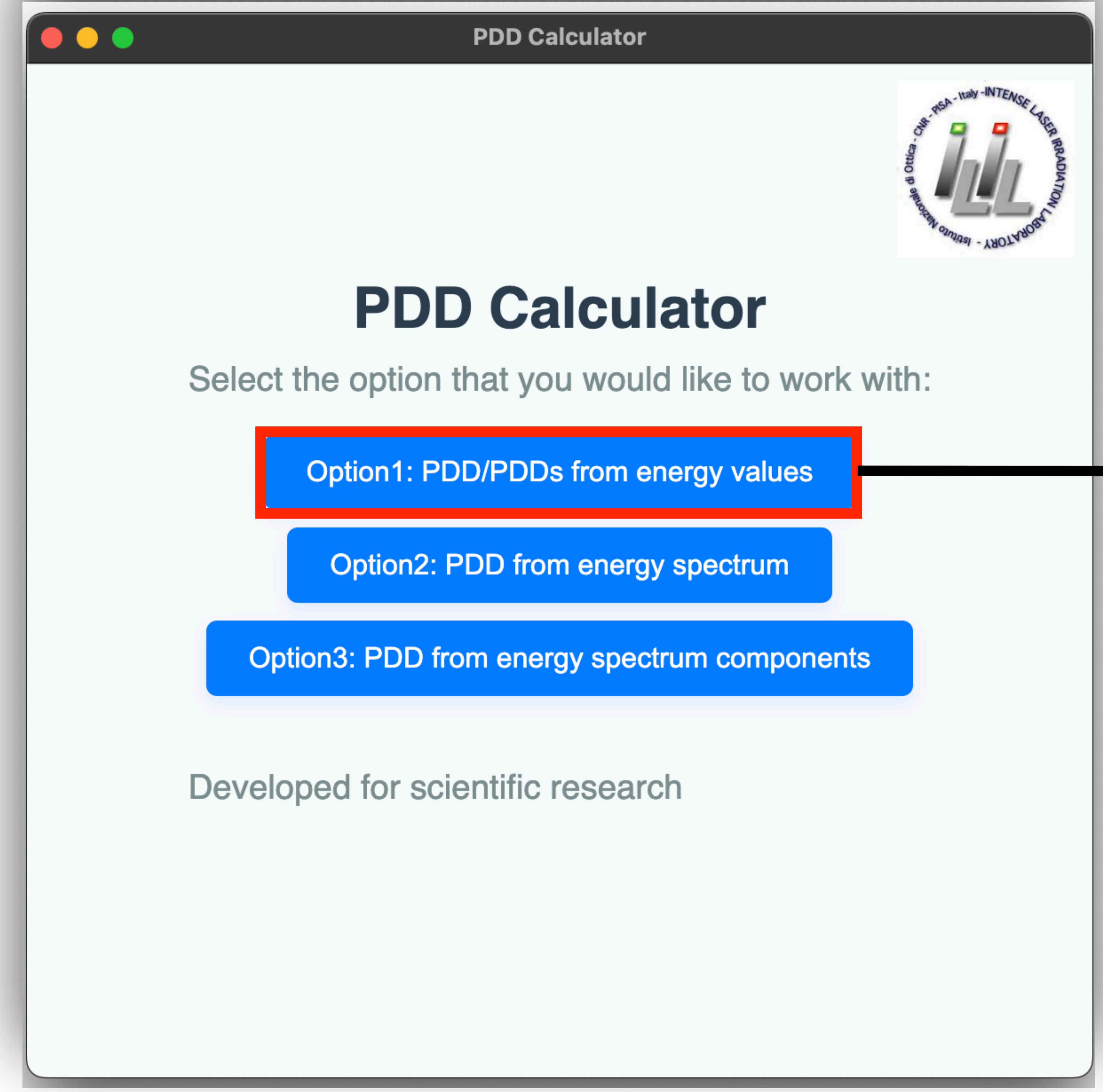

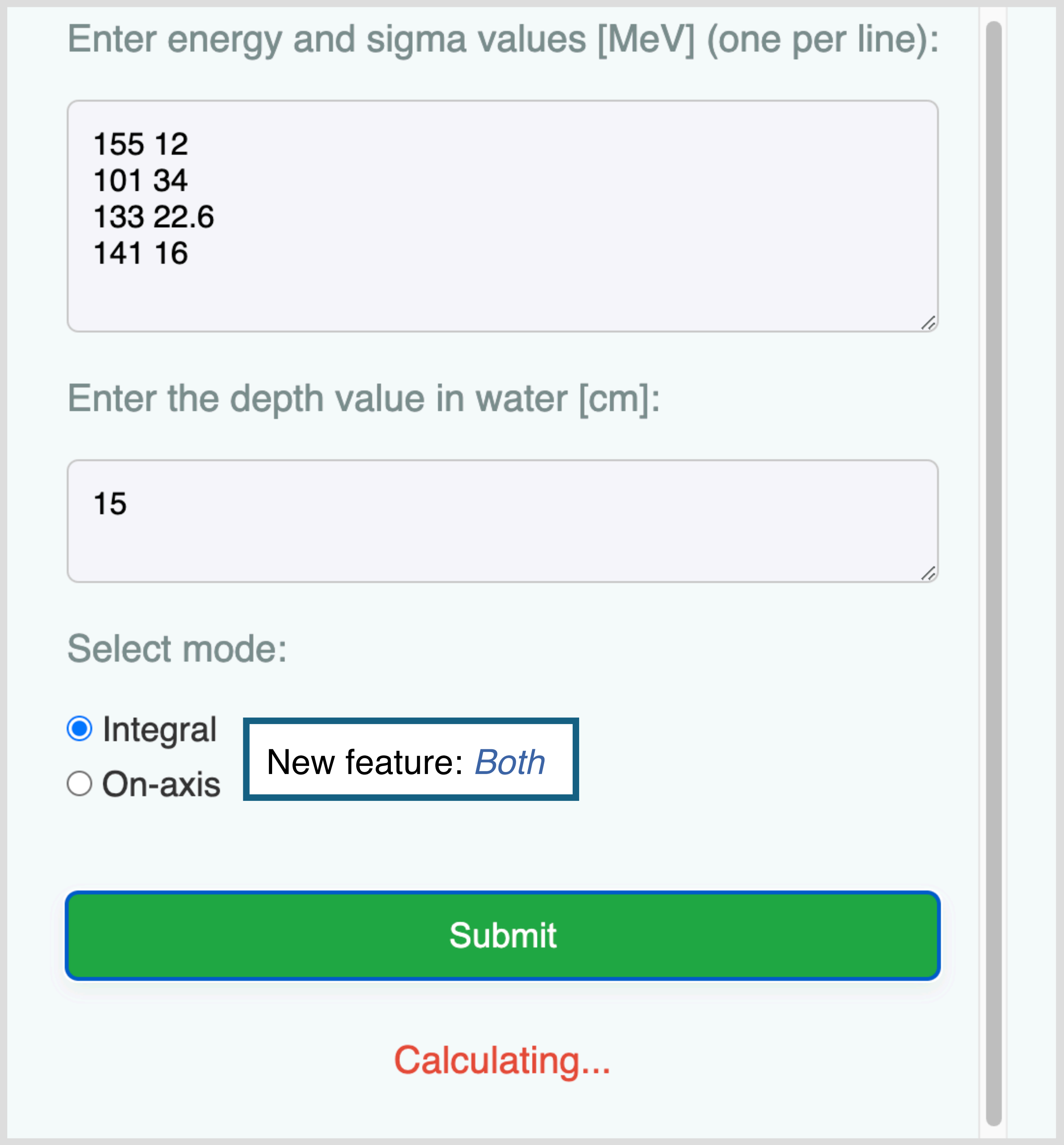

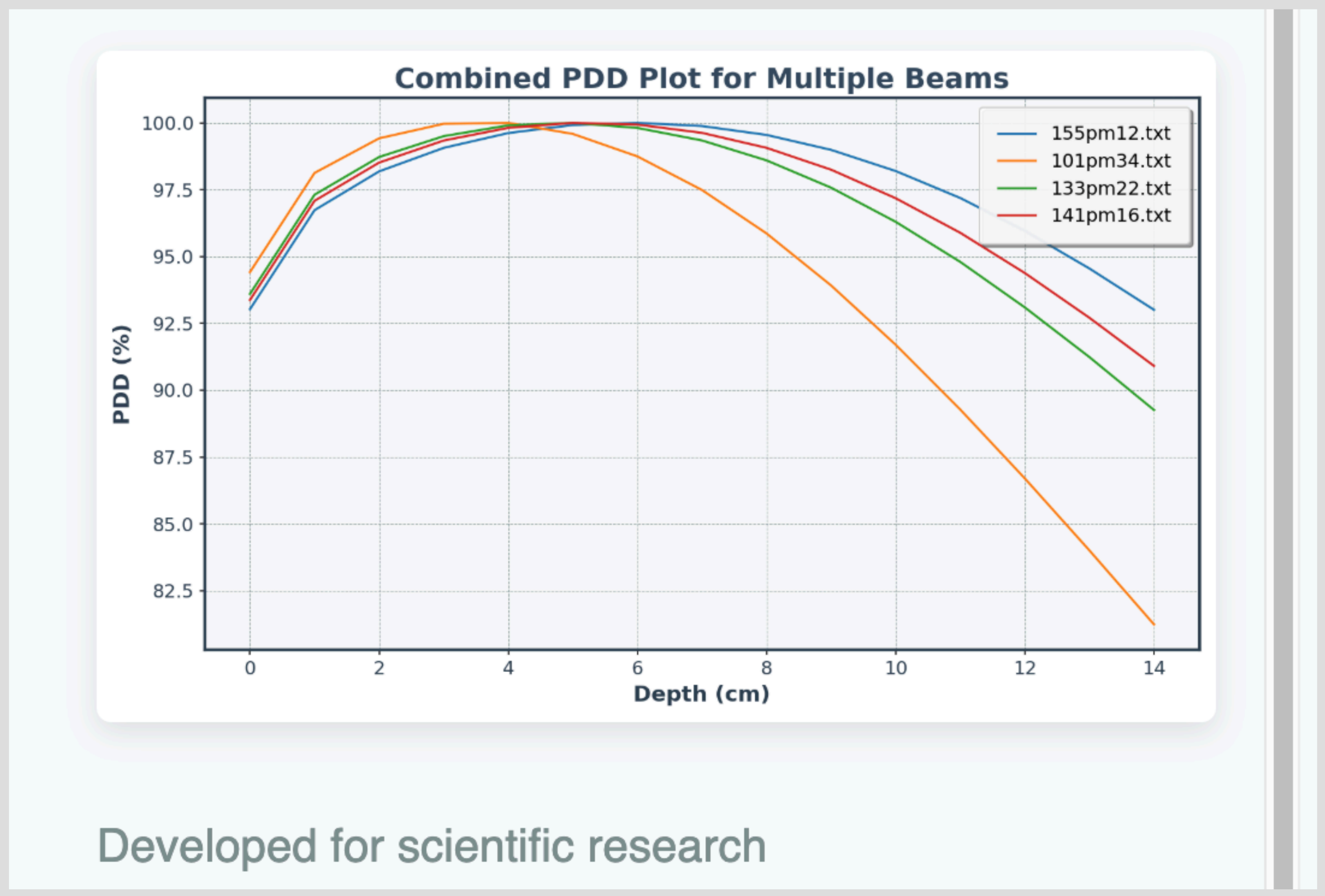

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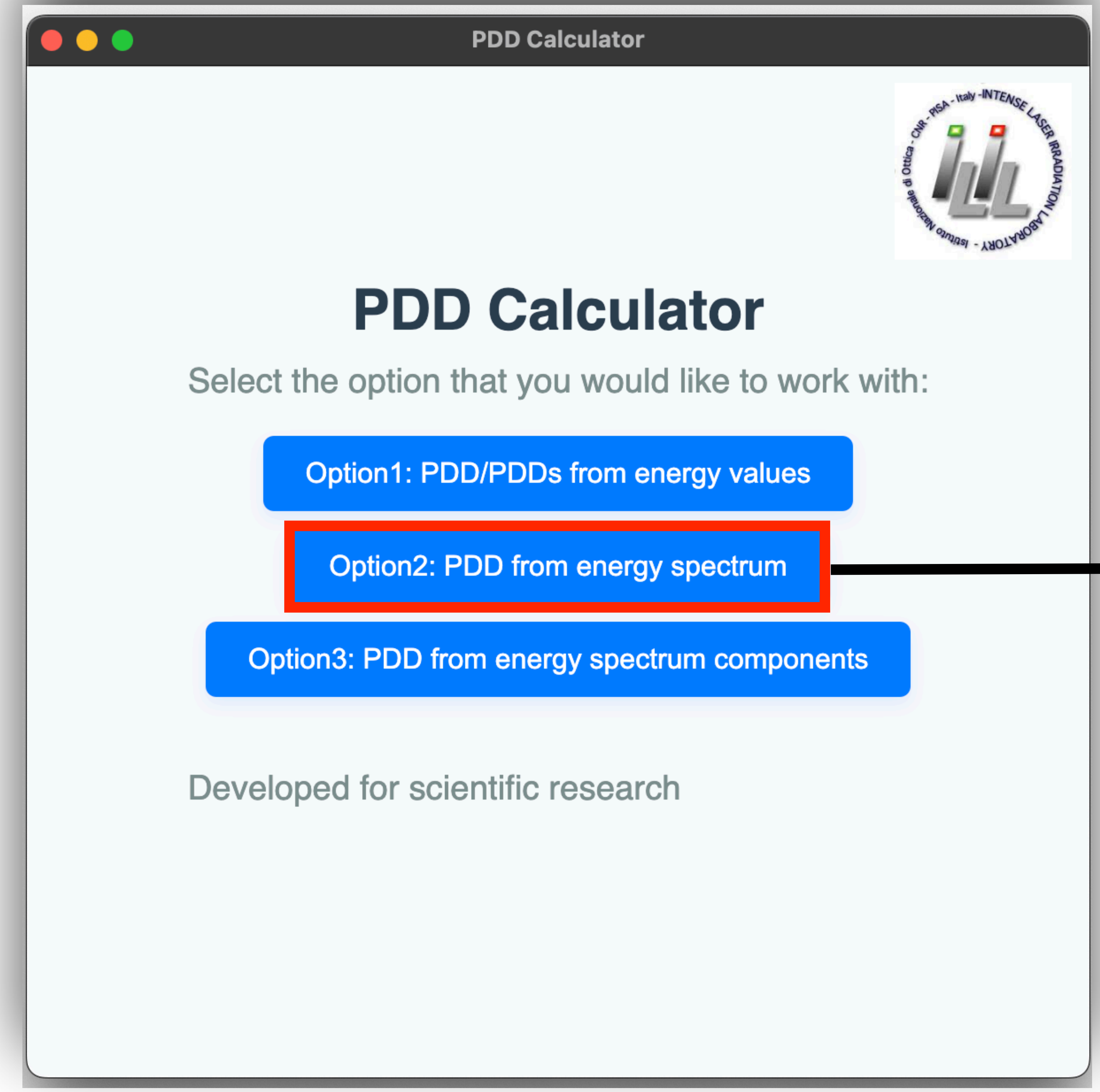

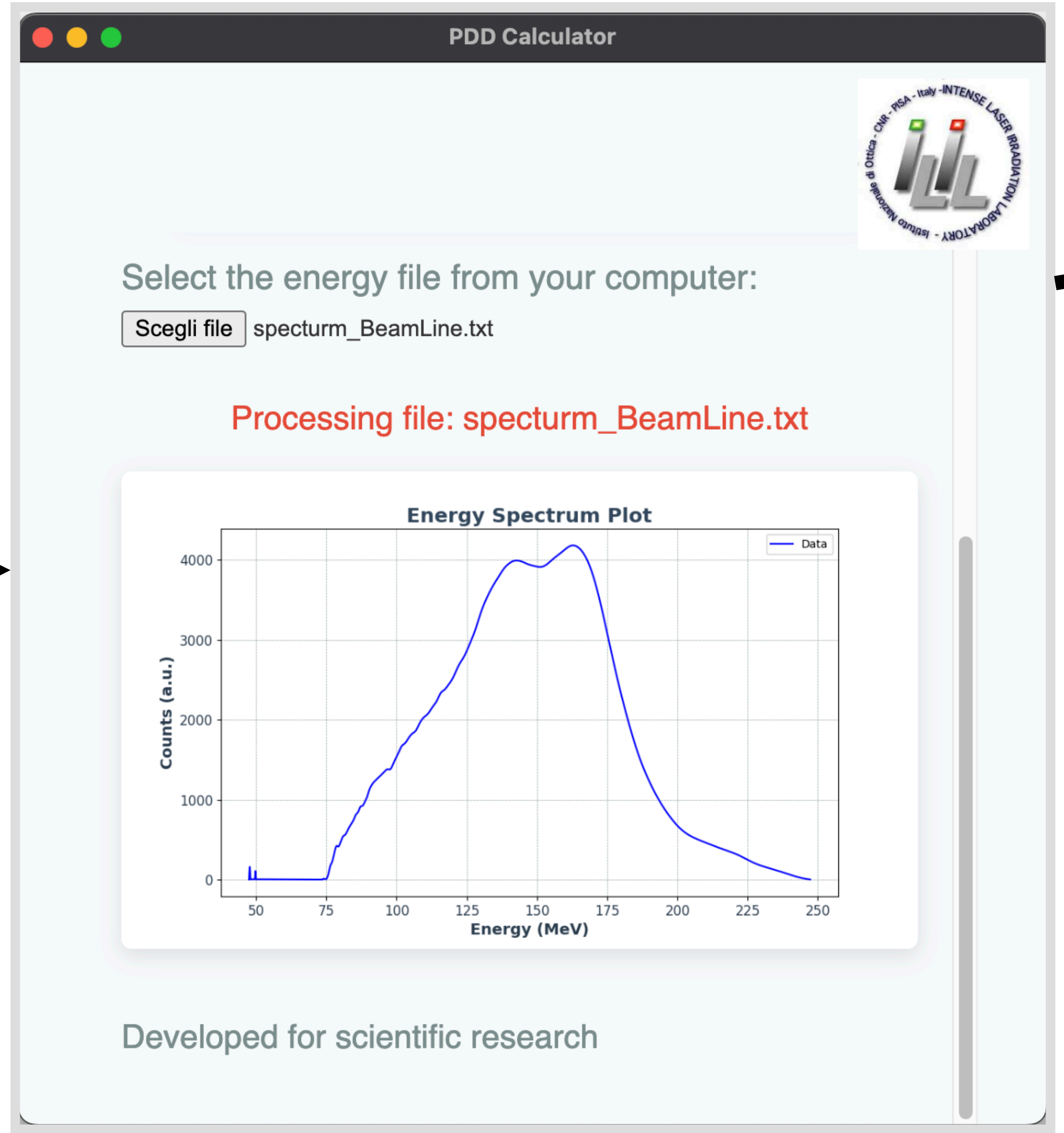

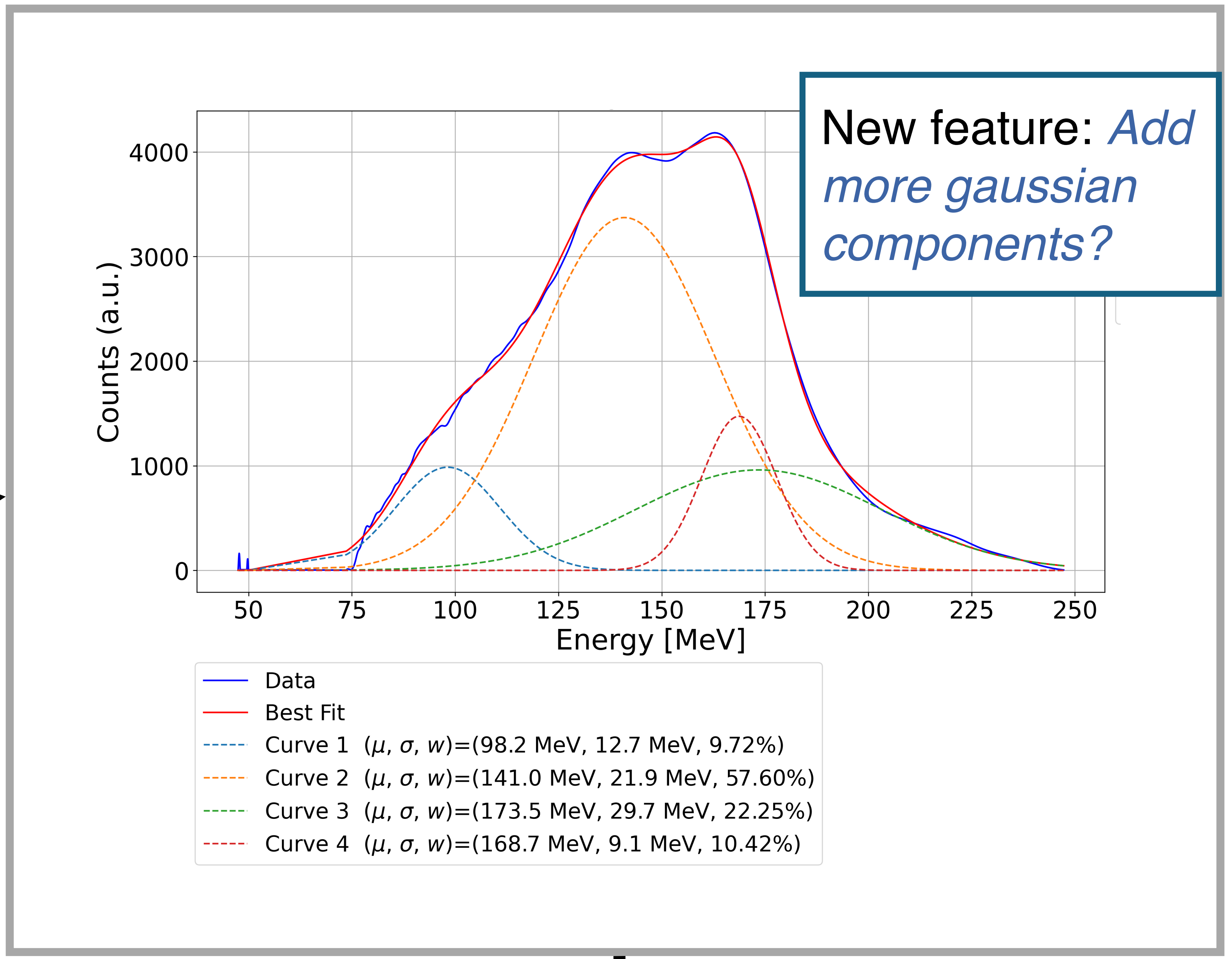

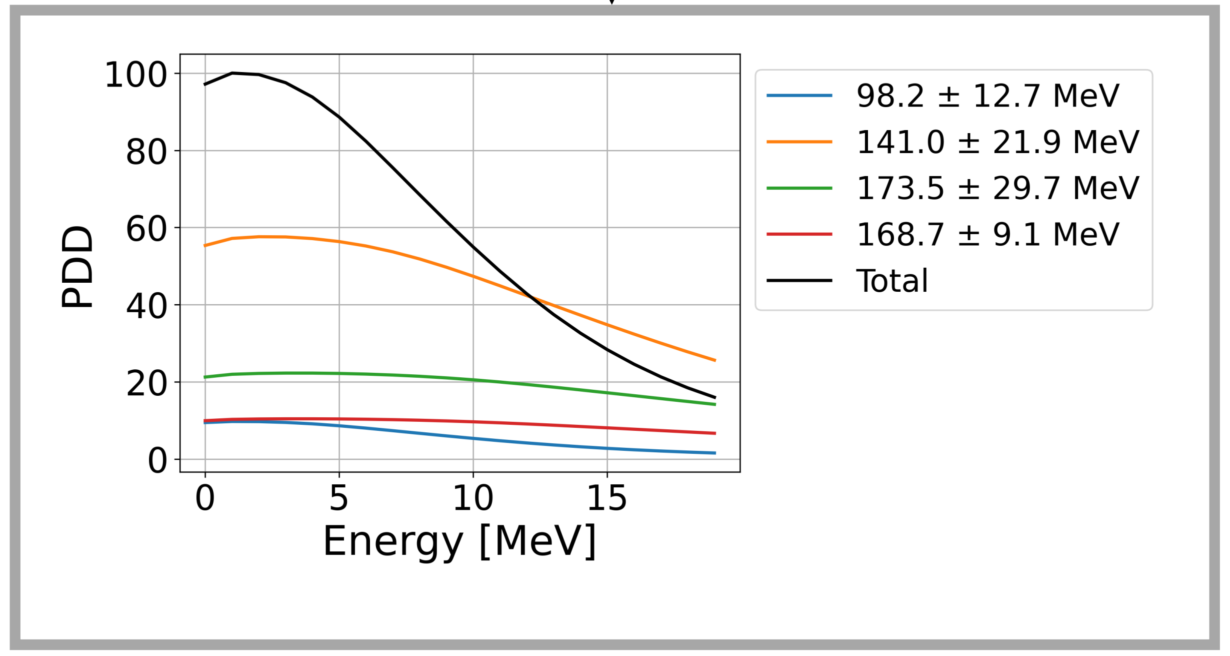

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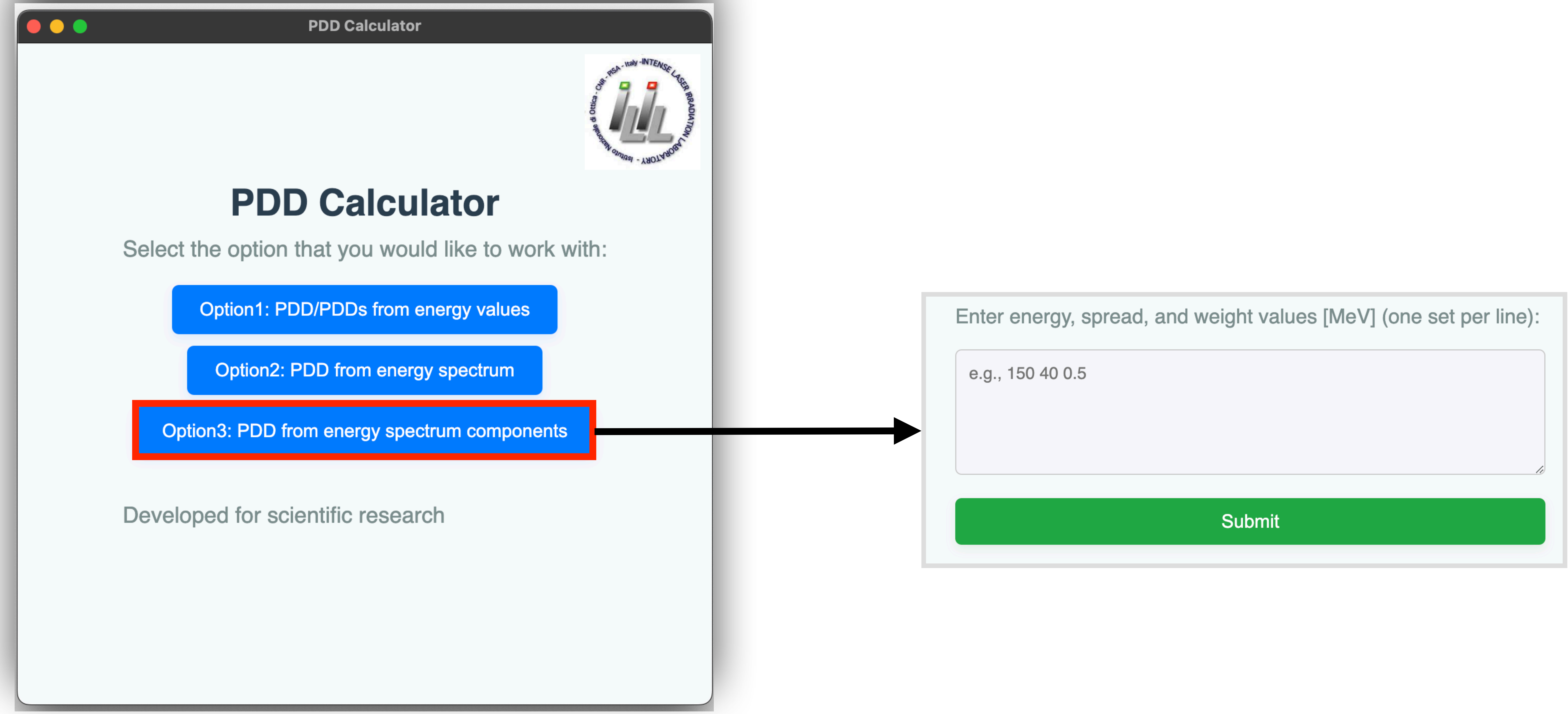
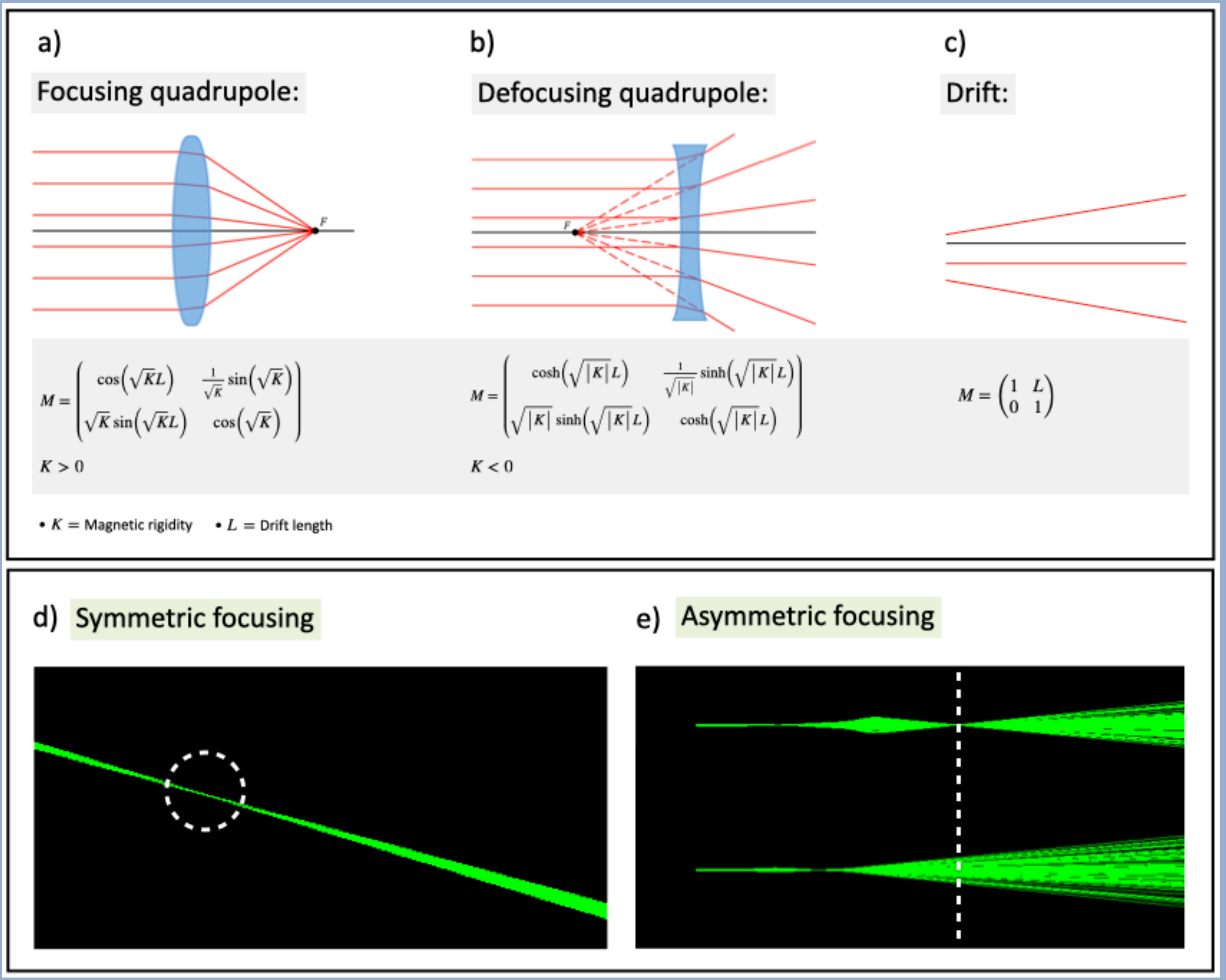


Beam Focusing

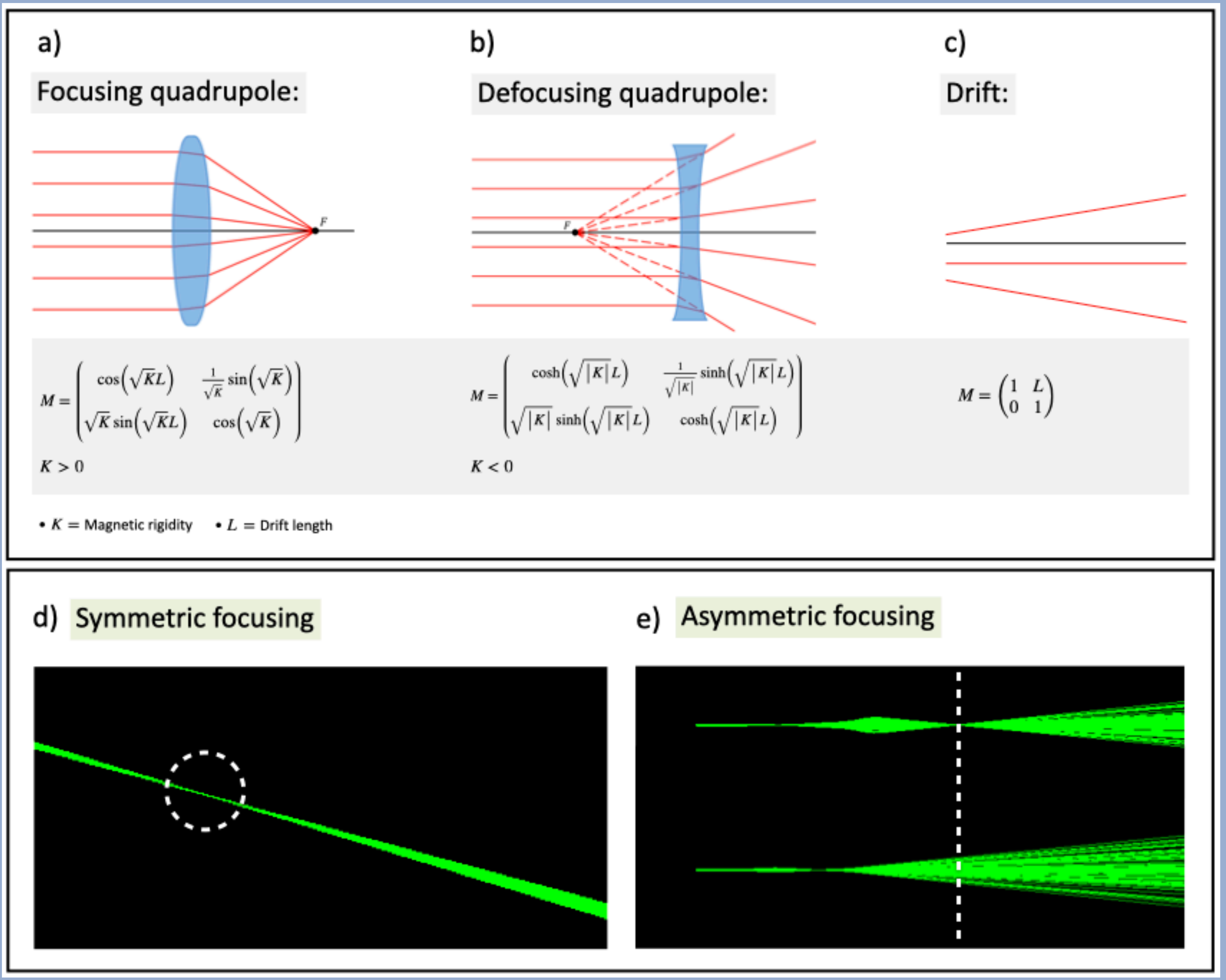


From a clinical prospective beam focusing offers several benefits such as:

- lowering entrance dose;
- reducing lateral scattering in depth;
- precisely targeting small 3D volumes

It also allows to improve the beam point stability!

Beam Focusing



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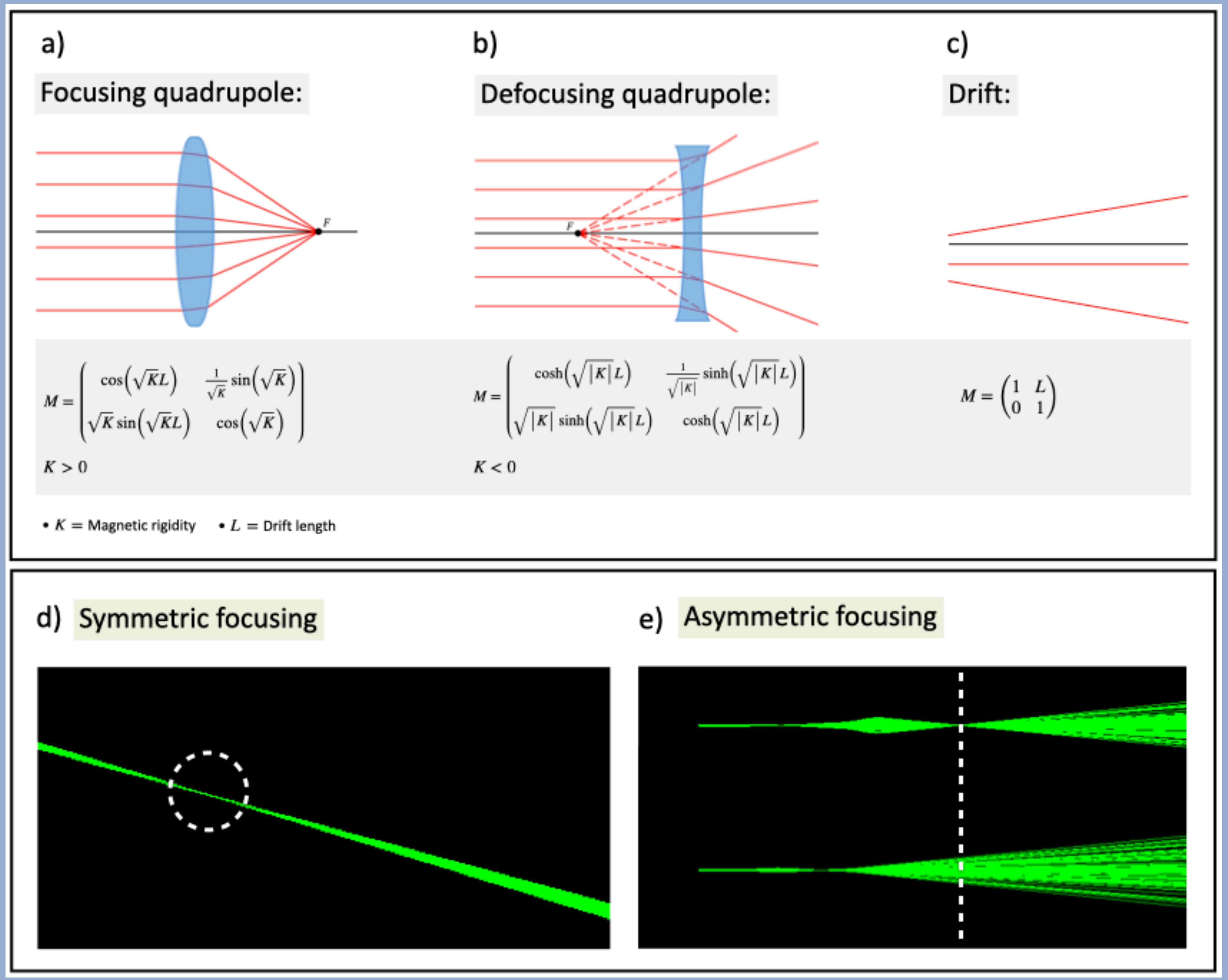

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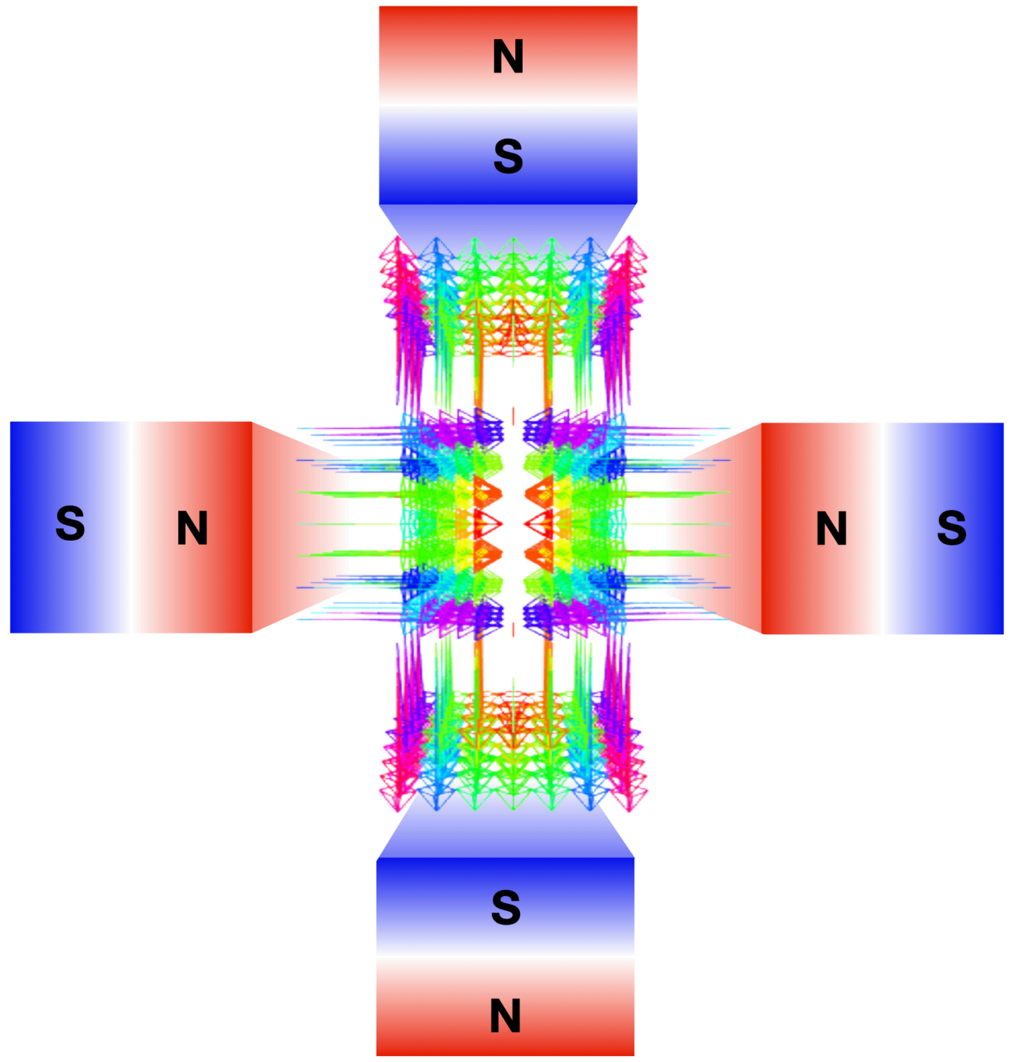


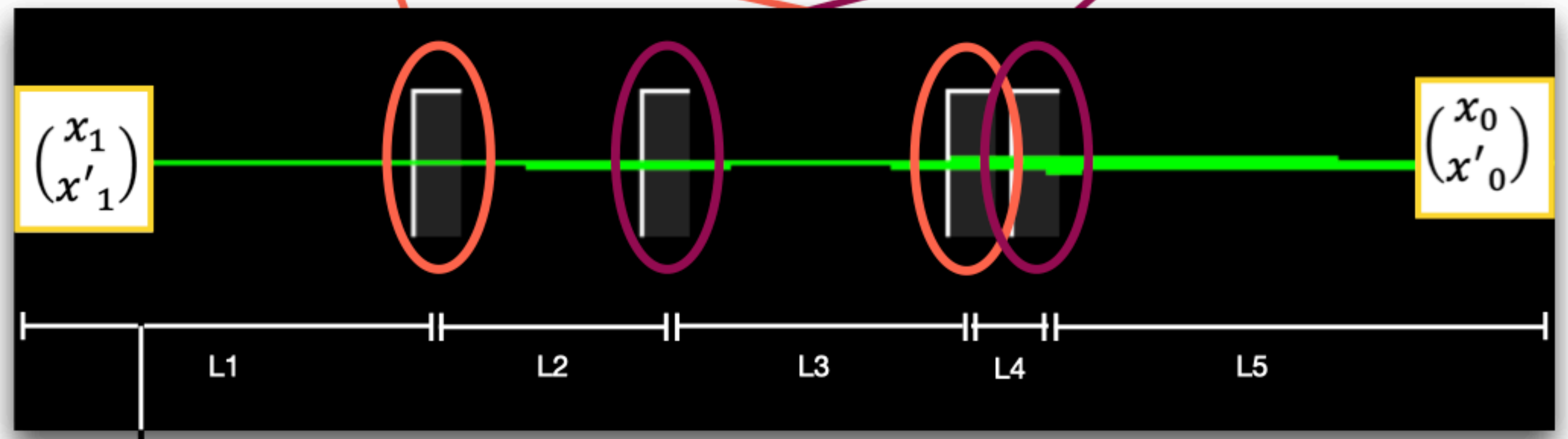
Beam Focusing

Defocusing quadrupole:
Length L, $K < 0$

$$M = \begin{pmatrix} \cosh\left(\sqrt{|K|}L\right) & \frac{1}{\sqrt{|K|}}\sinh\left(\sqrt{|K|}L\right) \\ \sqrt{|K|}\sinh\left(\sqrt{|K|}L\right) & \cosh\left(\sqrt{|K|}L\right) \end{pmatrix}$$

Focusing quadrupole:
Length L, $K > 0$

$$M = \begin{pmatrix} \cos(\sqrt{K}L) & \frac{1}{\sqrt{K}}\sin(\sqrt{K}L) \\ -\sqrt{K}\sin(\sqrt{K}L) & \cos(\sqrt{K}L) \end{pmatrix}$$



$$\begin{pmatrix} x_1 \\ x'_1 \end{pmatrix} = M_{Dn} \cdot M_{Qn} \cdot M_{Dn-1} \cdots M_{B1} \cdot M_{D2} \cdot M_{Q1} \cdot M_{D1} \cdot \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

$$\begin{pmatrix} x_1 \\ x'_1 \end{pmatrix} = M(s_1, s_0) \cdot \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

$$M_{Drift} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}$$

α, β and γ are the Twiss parameters

$$\begin{pmatrix} x(s) \\ x'(s) \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{\beta_s}{\beta_0}}[\cos\varphi_s + \alpha_0 sin\varphi_s] & \sqrt{\beta_s\beta_0}\, sin\varphi_s \\ \frac{1}{\sqrt{\beta_s\beta_0}}[(\alpha_0 - \alpha_s)\cos\varphi_s - (1+\alpha_0\alpha_s) sin\varphi_s] & \sqrt{\frac{\beta_s}{\beta_0}}[cos\varphi_s - \alpha_s\, sin\varphi_s]x'_0 \end{pmatrix} \cdot \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

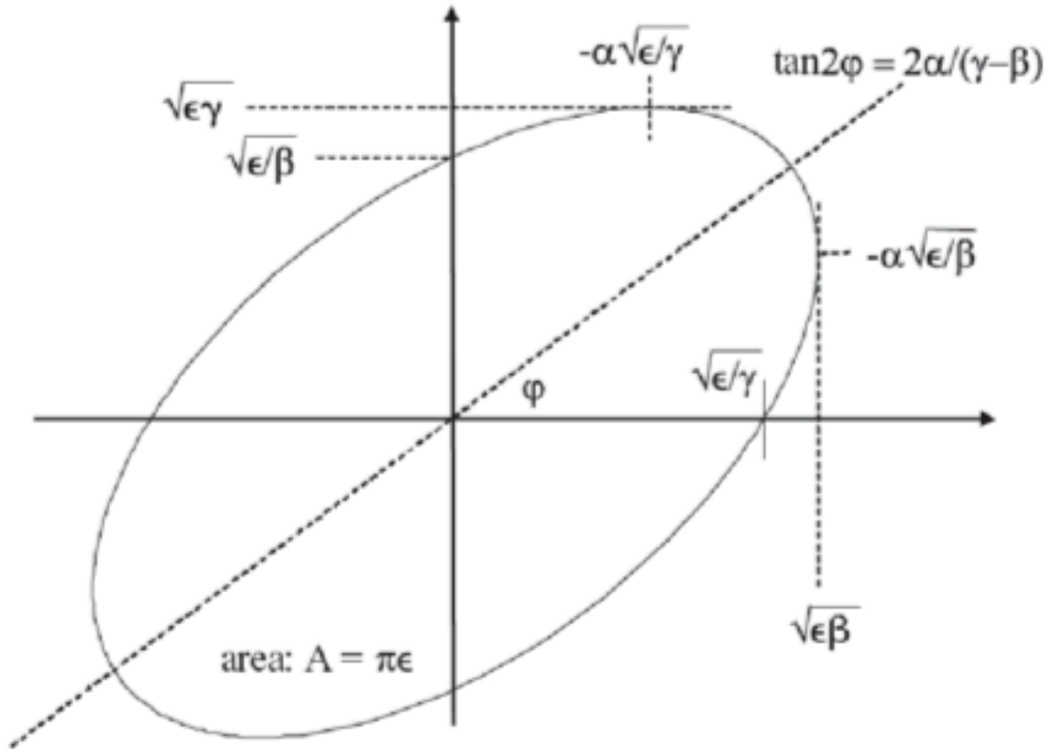
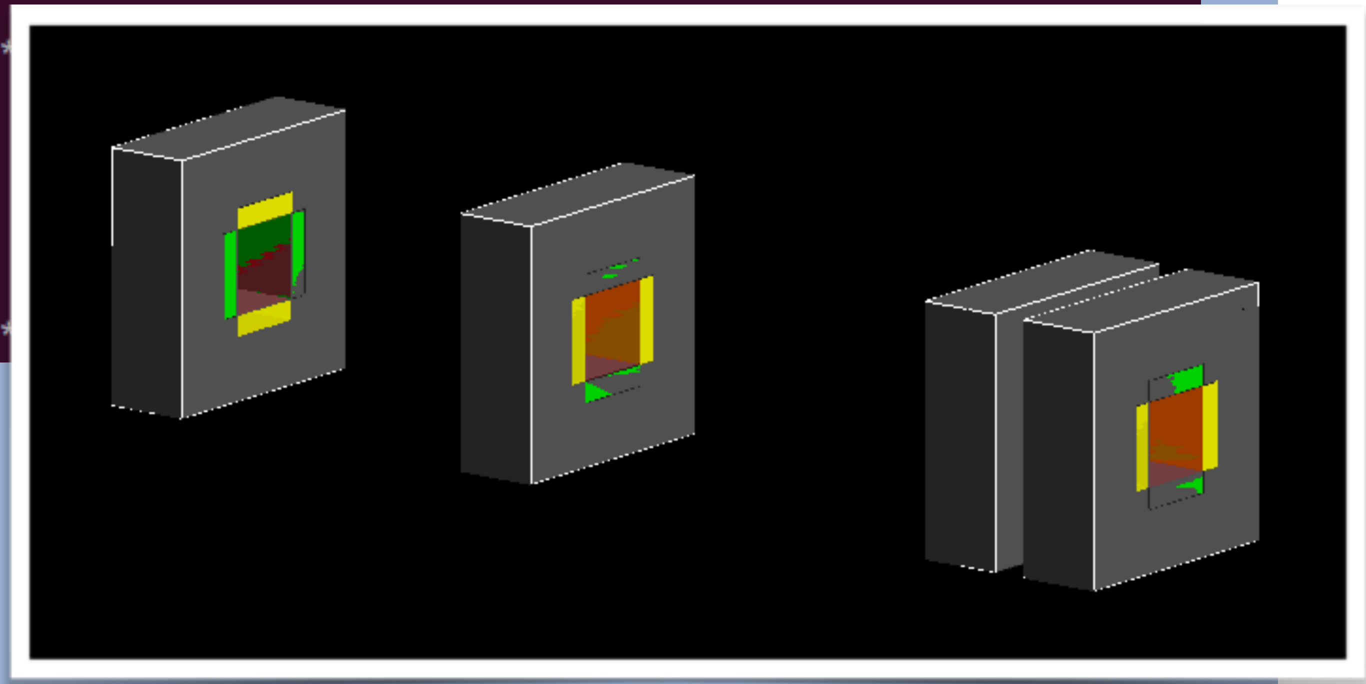


Fig. 5.2. Phase space ellipse

Development of an optimisation algorithm (Python) that identifies the optimal L1, L2, L3, L4 values

Beam Focusing

```
>>>> QCVhee, a GEANT4 based code              >>>>
<<<< written on 202311 by Costanza Panaino   <<<<
<<<< based on LEPre by Luca Labate           >>>>
>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

  Configuration file: configQCVhee.txt
  Entering batch mode
--> Number of lines excluding comments: 53
Inside readMandatoryMulti
Inside readMandatoryMulti
Inside readMandatoryMulti
Inside readMandatoryMulti
Inside readMandatoryMulti
Inside readMandatoryMulti
Inside readMandatoryMulti
Inside readMandatoryMulti

-----------------------------------------------
>> Config file successfully read
-----------------------------------------------
OutputPath      1
OutputFrequency 1
Nquad   1
Nprimaries      1
Qz      4
Qy      4
Qx      4
Qbeta   4
Qtype   4
Qgamma  4
Qvolume 4
Qalpha  4
OutputPrefix    8

***************
 Geant4 version



***************
```



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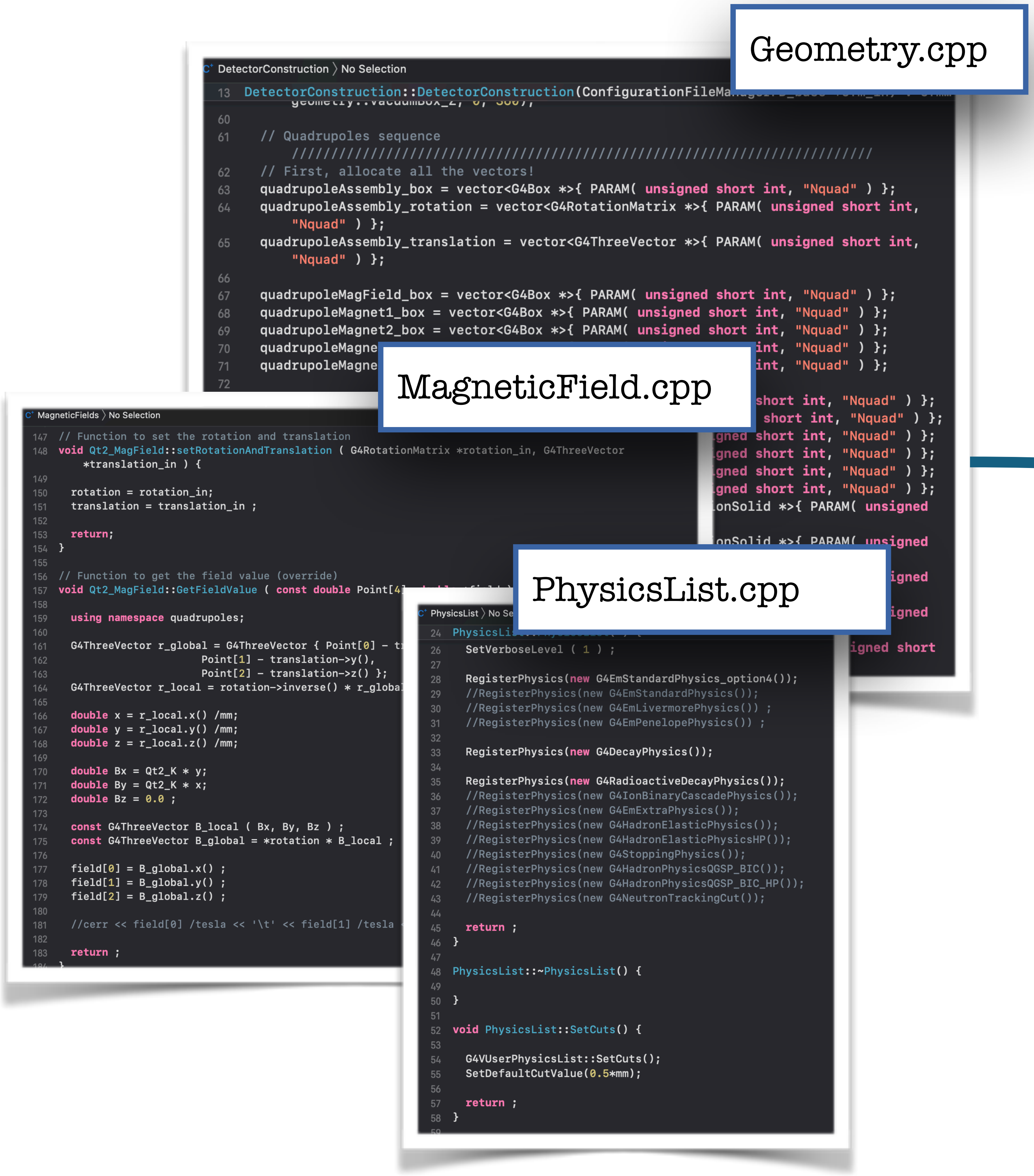
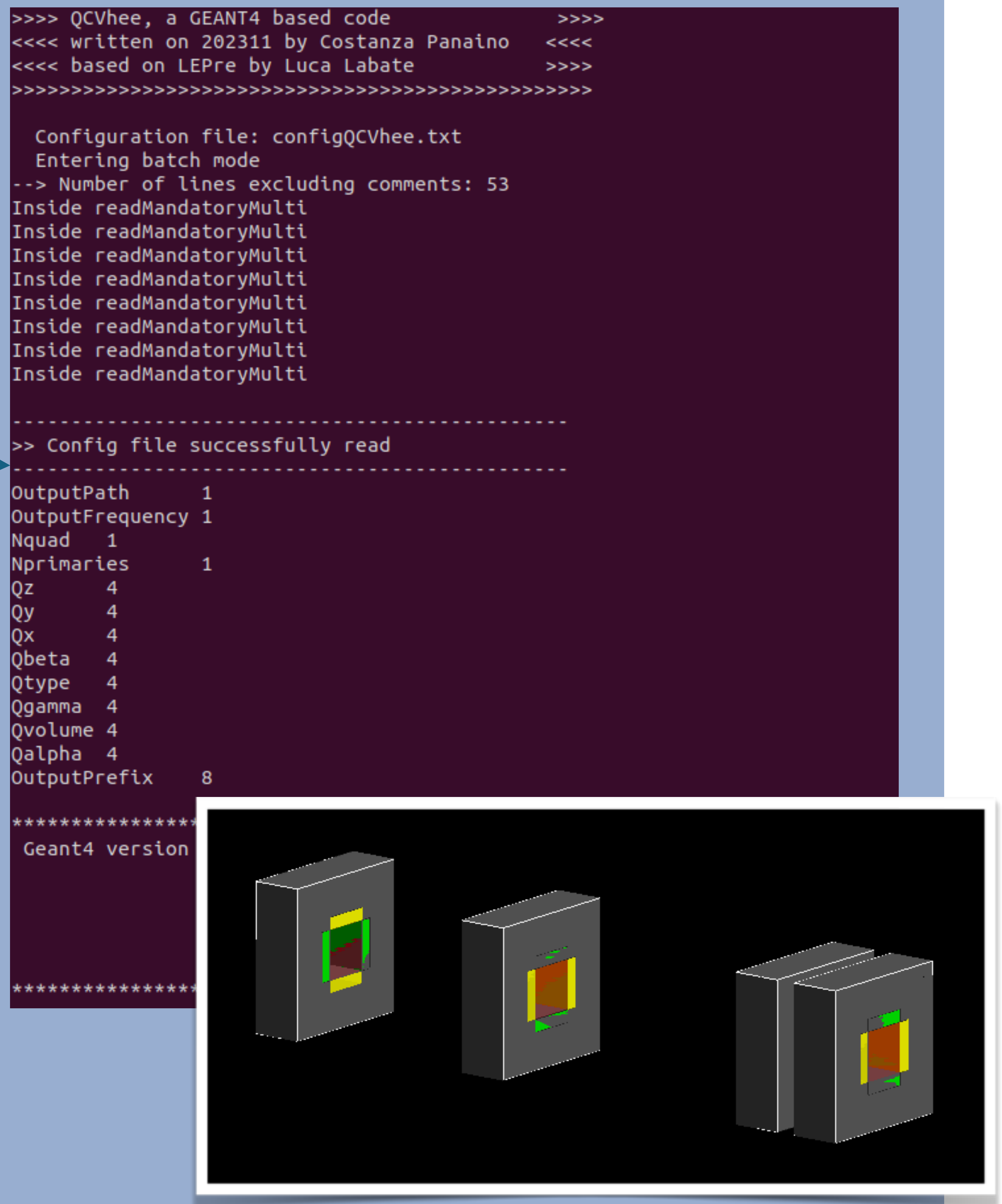
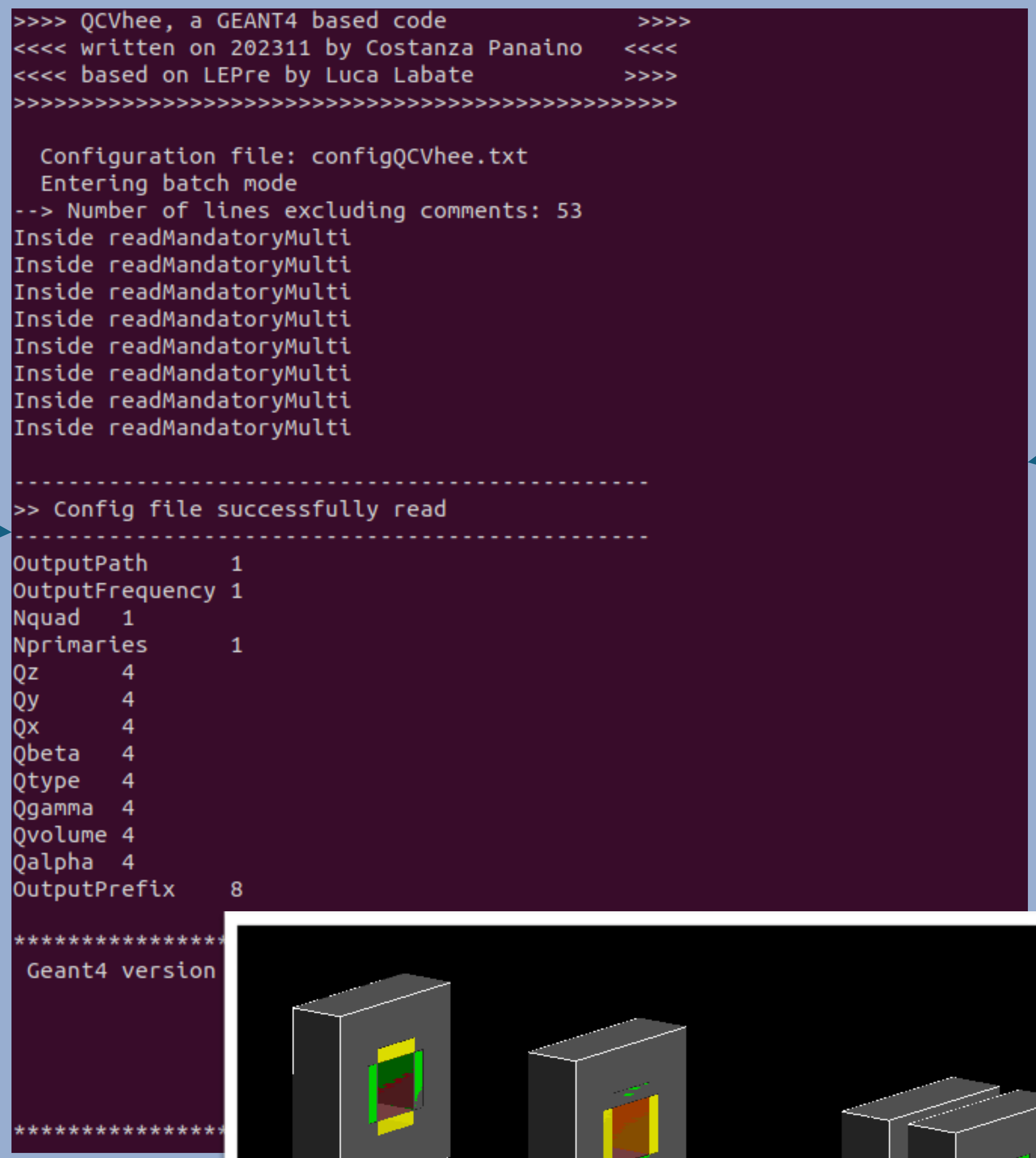
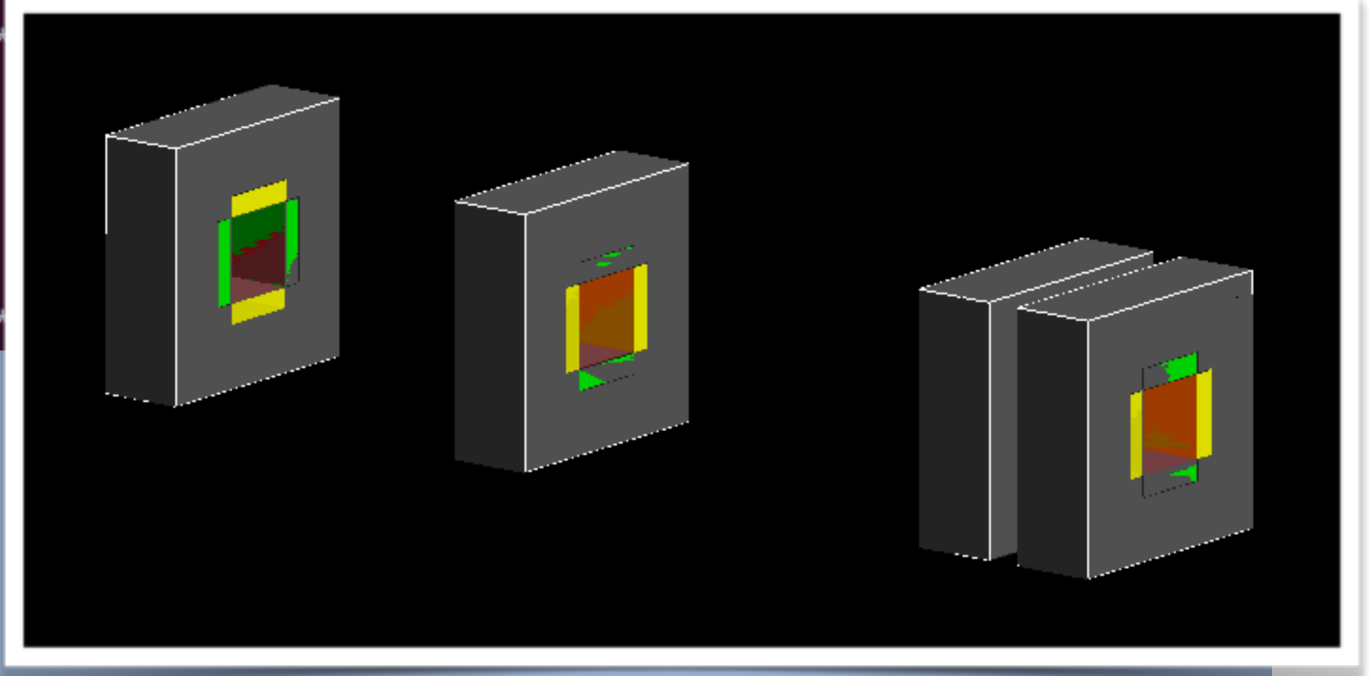




Before compiling…

Beam Focusing

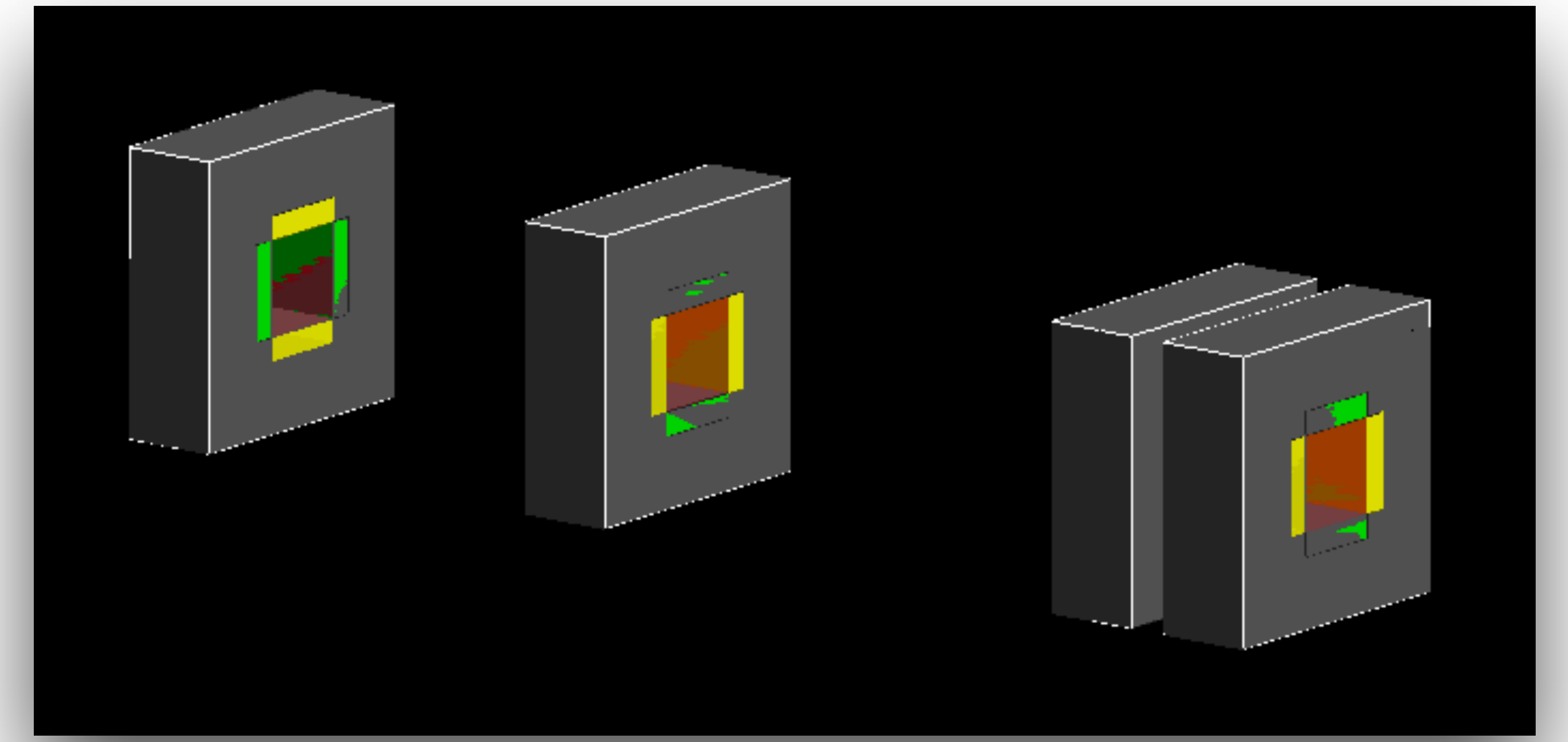


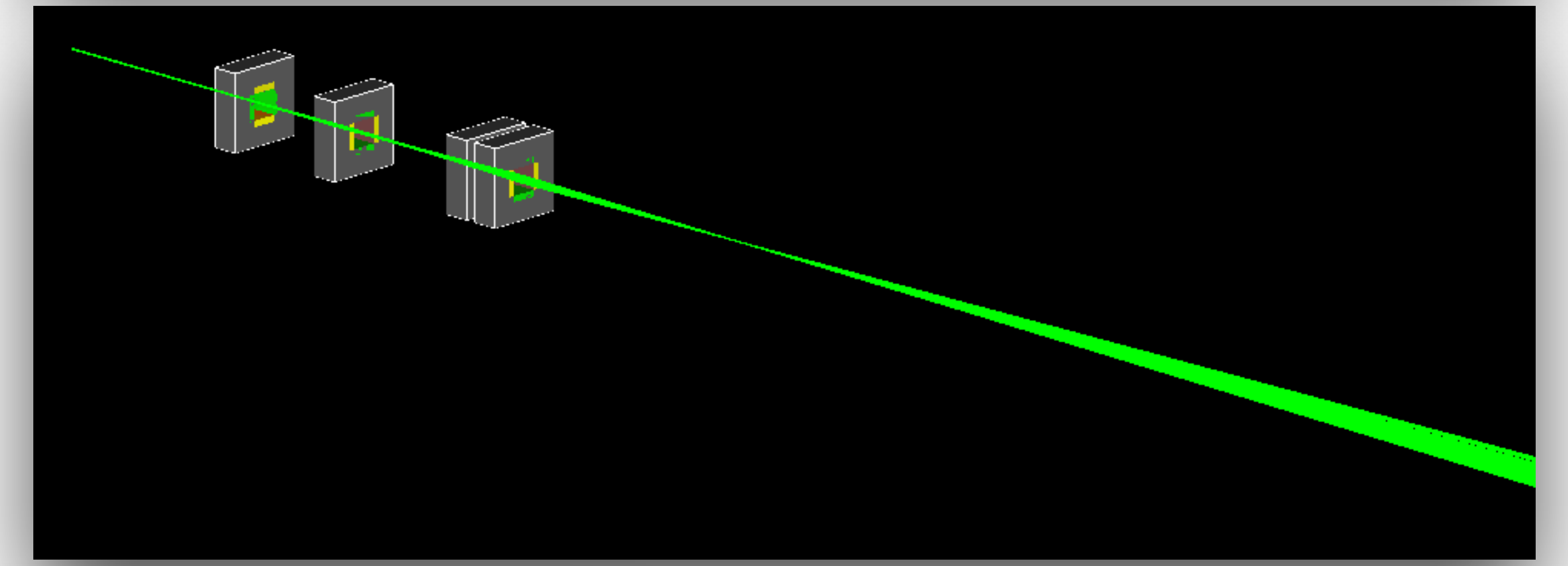


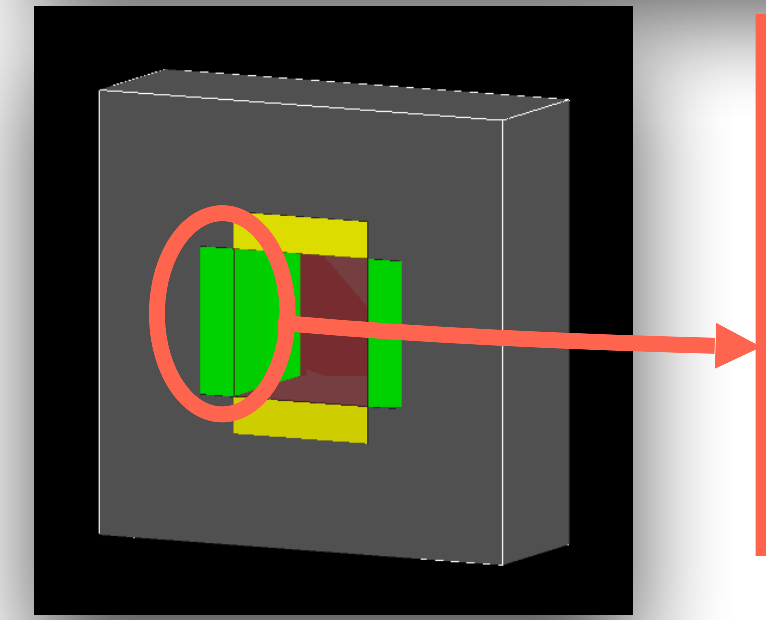
Before compiling…

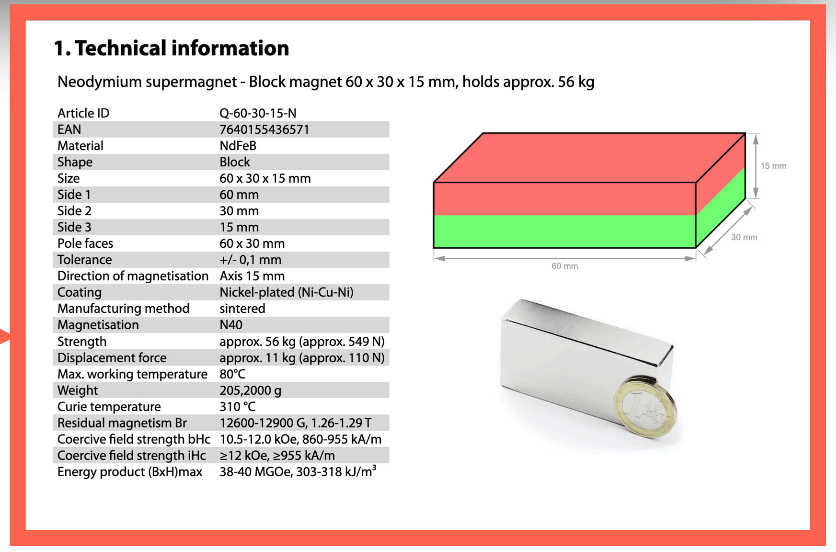
After compiling…

Focusing









1. Technical information

Neodymium supermagnet - Block magnet 60 x 30 x 15 mm, holds approx. 56 kg

Article ID	Q-60-30-15-N
EAN	7640155436571
Material	NdFeB
Shape	Block
Size	60 x 30 x 15 mm
Side 1	60 mm
Side 2	30 mm
Side 3	15 mm
Pole faces	60 x 30 mm
Tolerance	+/- 0,1 mm
Direction of magnetisation	Axis 15 mm
Coating	Nickel-plated (Ni-Cu-Ni)
Manufacturing method	sintered
Magnetisation	N40
Strength	approx. 56 kg (approx. 549 N)
Displacement force	approx. 11 kg (approx. 110 N)
Max. working temperature	80°C
Weight	205,2000 g
Curie temperature	310 °C
Residual magnetism Br	12600-12900 G, 1.26-1.29 T
Coercive field strength bHc	10.5-12.0 kOe, 860-955 kA/m
Coercive field strength iHc	≥12 kOe, ≥955 kA/m
Energy product (BxH)max	38-40 MGOe, 303-318 kJ/m^3

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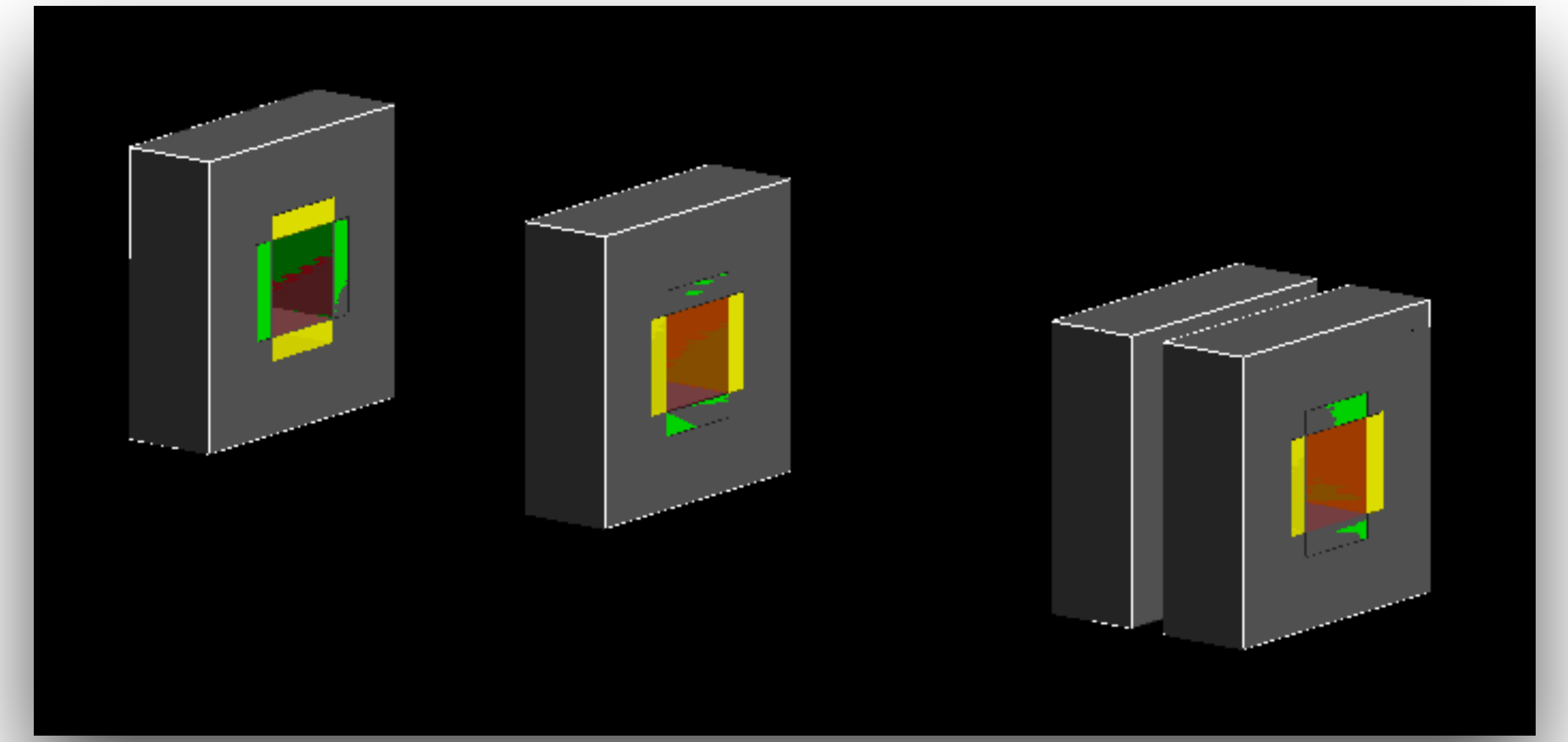
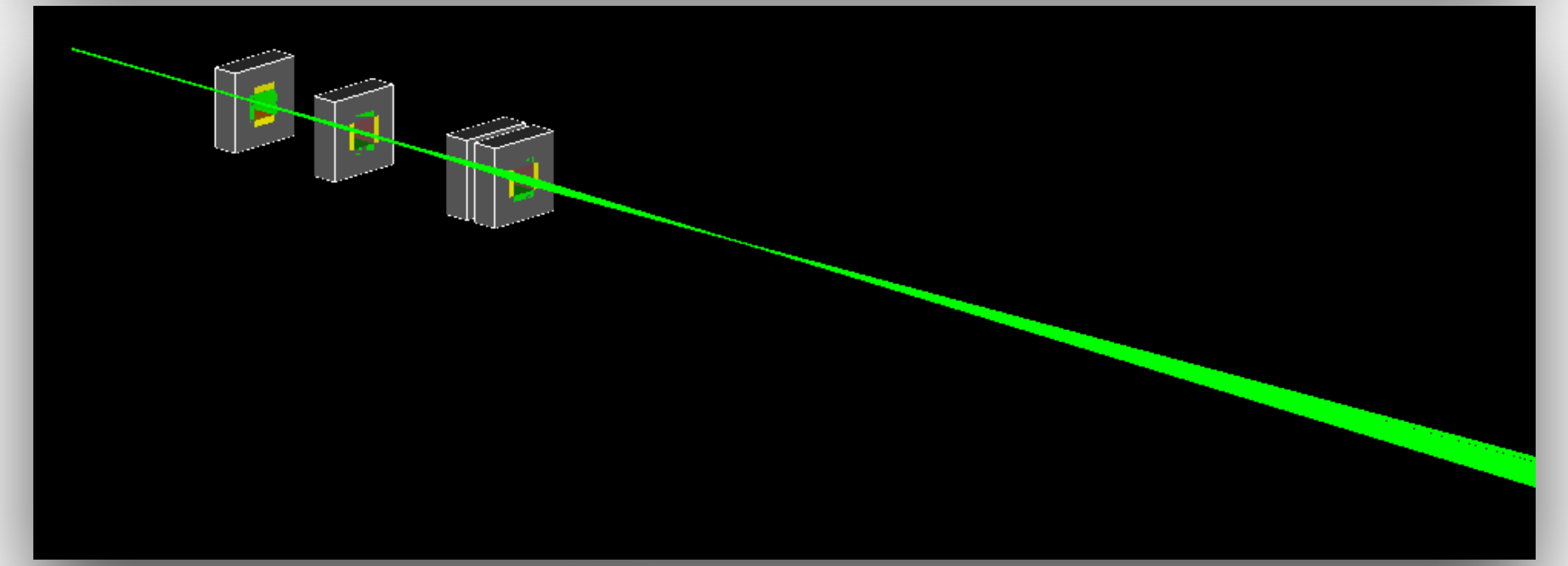
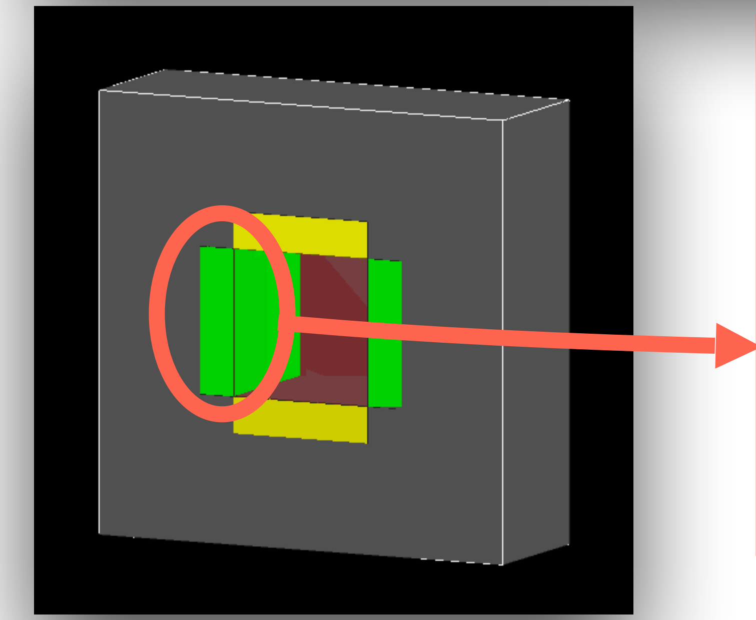
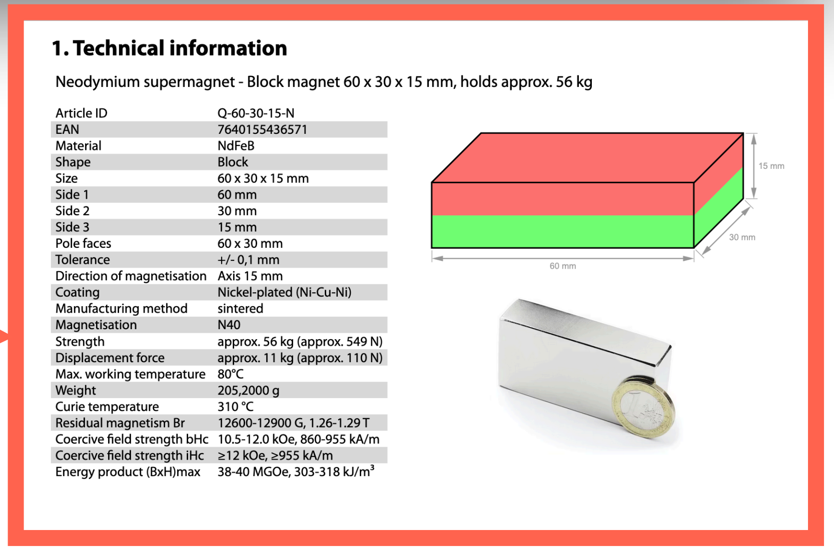
Focusing









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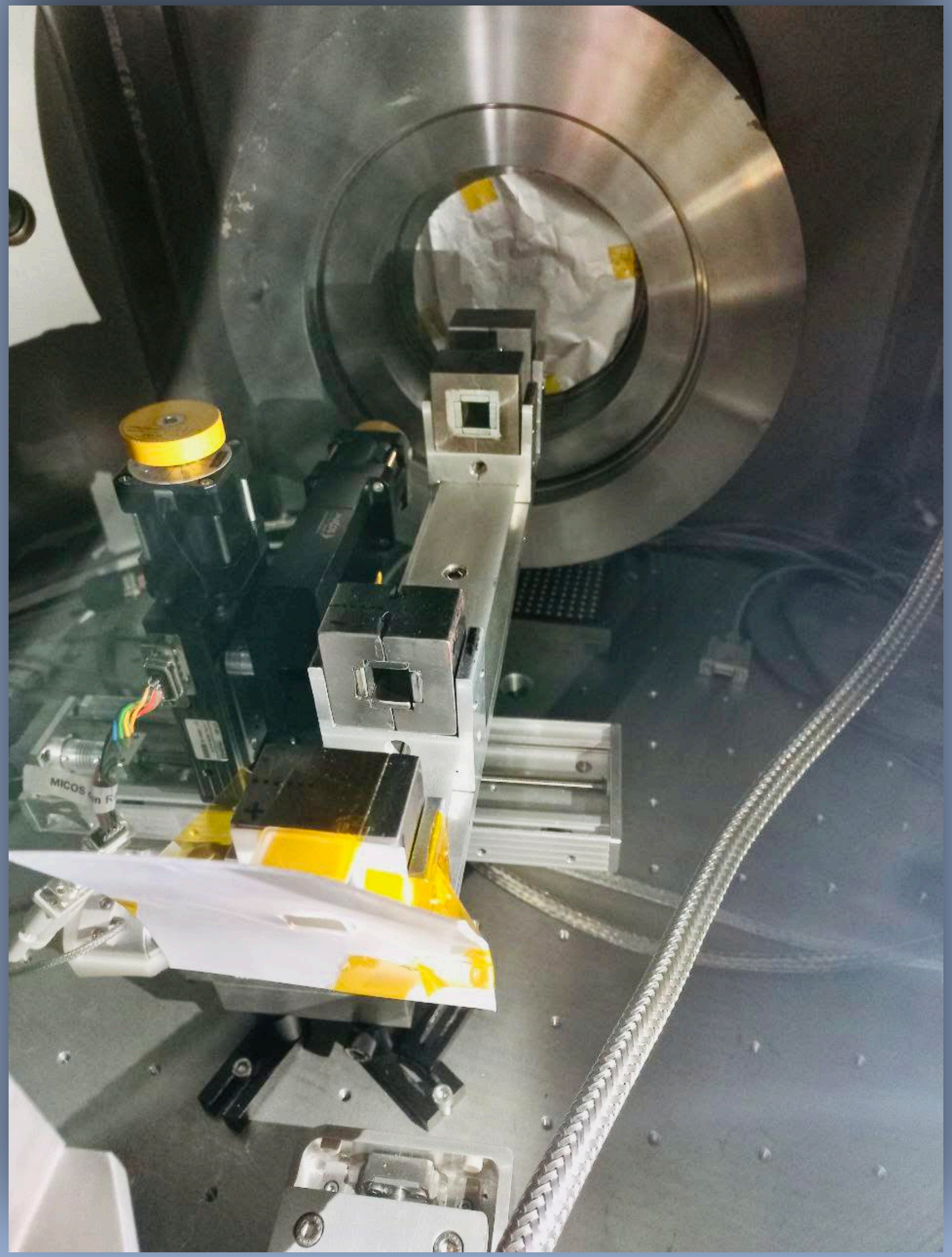
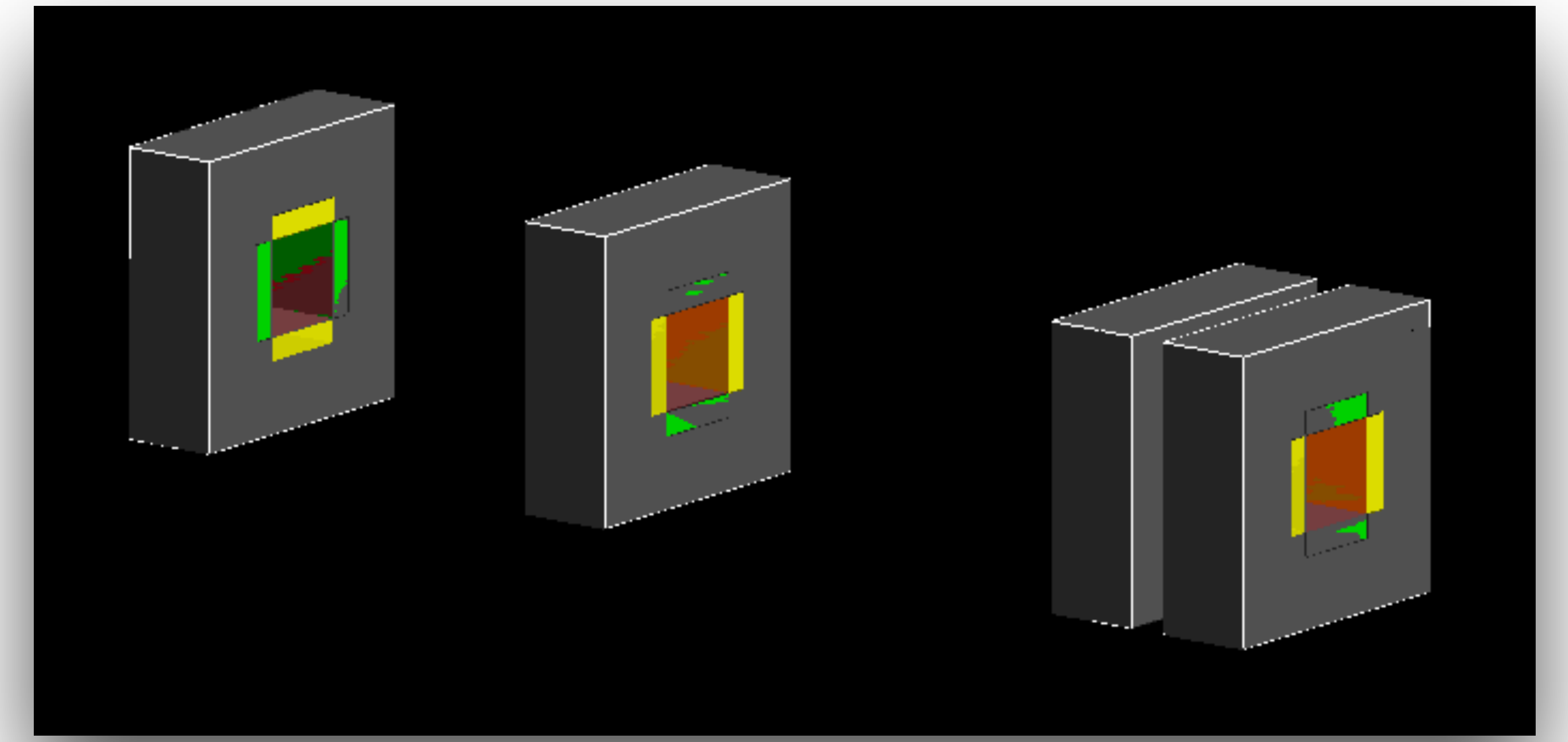
Displacement force	approx. 11 kg (approx. 110 N)
Max. working temperature	80°C
Weight	205,2000 g
Curie temperature	310 °C
Residual magnetism Br	12600-12900 G, 1.26-1.29 T
Coercive field strength bHc	10.5-12.0 kOe, 860-955 kA/m
Coercive field strength iHc	≥12 kOe, ≥955 kA/m
Energy product (BxH)max	38-40 MGOe, 303-318 kJ/m^3

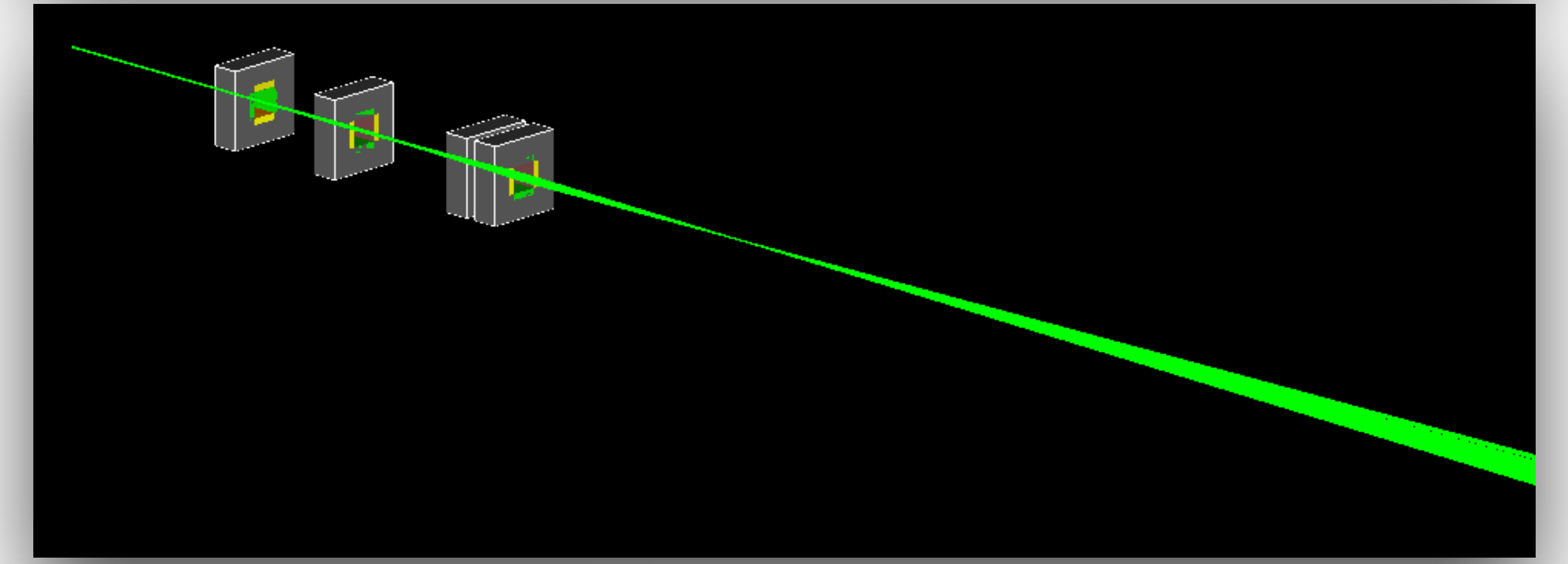
In the lab…

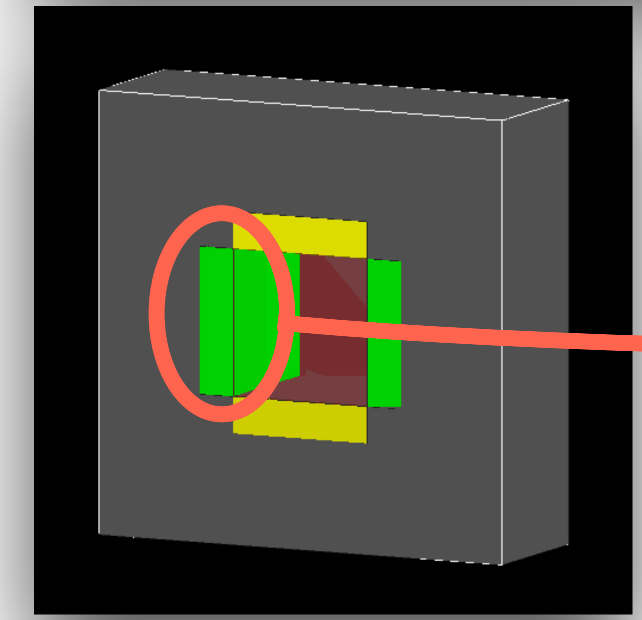


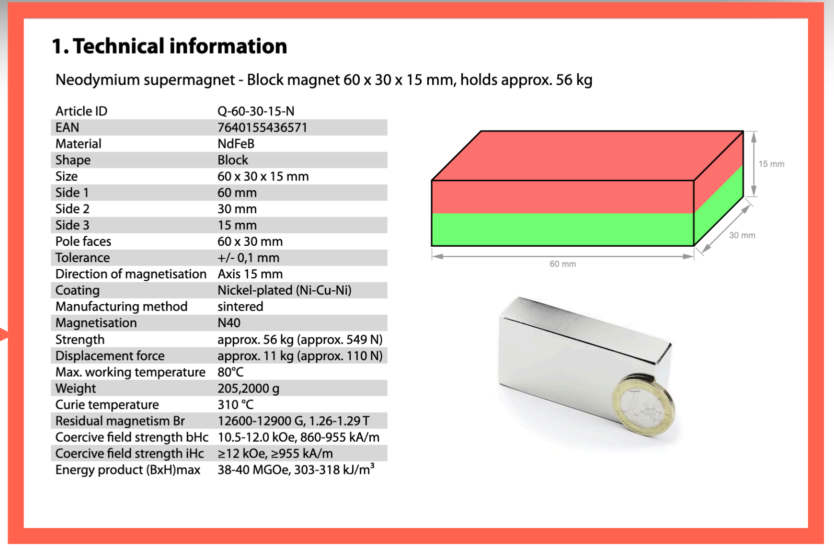
With the MBL the point size is reduced from 1.15 $\times$ 0.90 cm to 0.60 $\times$ 0.44 cm, whereas the point stability deviation is reduced from 1.99 to 0.55 and from 2.81 to 0.44, for σ_x and σ_y, respectively.

Focusing









1. Technical information

Neodymium supermagnet - Block magnet 60 x 30 x 15 mm, holds approx. 56 kg

Article ID	Q-60-30-15-N
EAN	7640155436571
Material	NdFeB
Shape	Block
Size	60 x 30 x 15 mm
Side 1	60 mm
Side 2	30 mm
Side 3	15 mm
Pole faces	60 x 30 mm
Tolerance	+/- 0,1 mm
Direction of magnetisation	Axis 15 mm
Coating	Nickel-plated (Ni-Cu-Ni)
Manufacturing method	sintered
Magnetisation	N40
Strength	approx. 56 kg (approx. 549 N)
Displacement force	approx. 11 kg (approx. 110 N)
Max. working temperature	80°C
Weight	205,2000 g
Curie temperature	310 °C
Residual magnetism Br	12600-12900 G, 1.26-1.29 T
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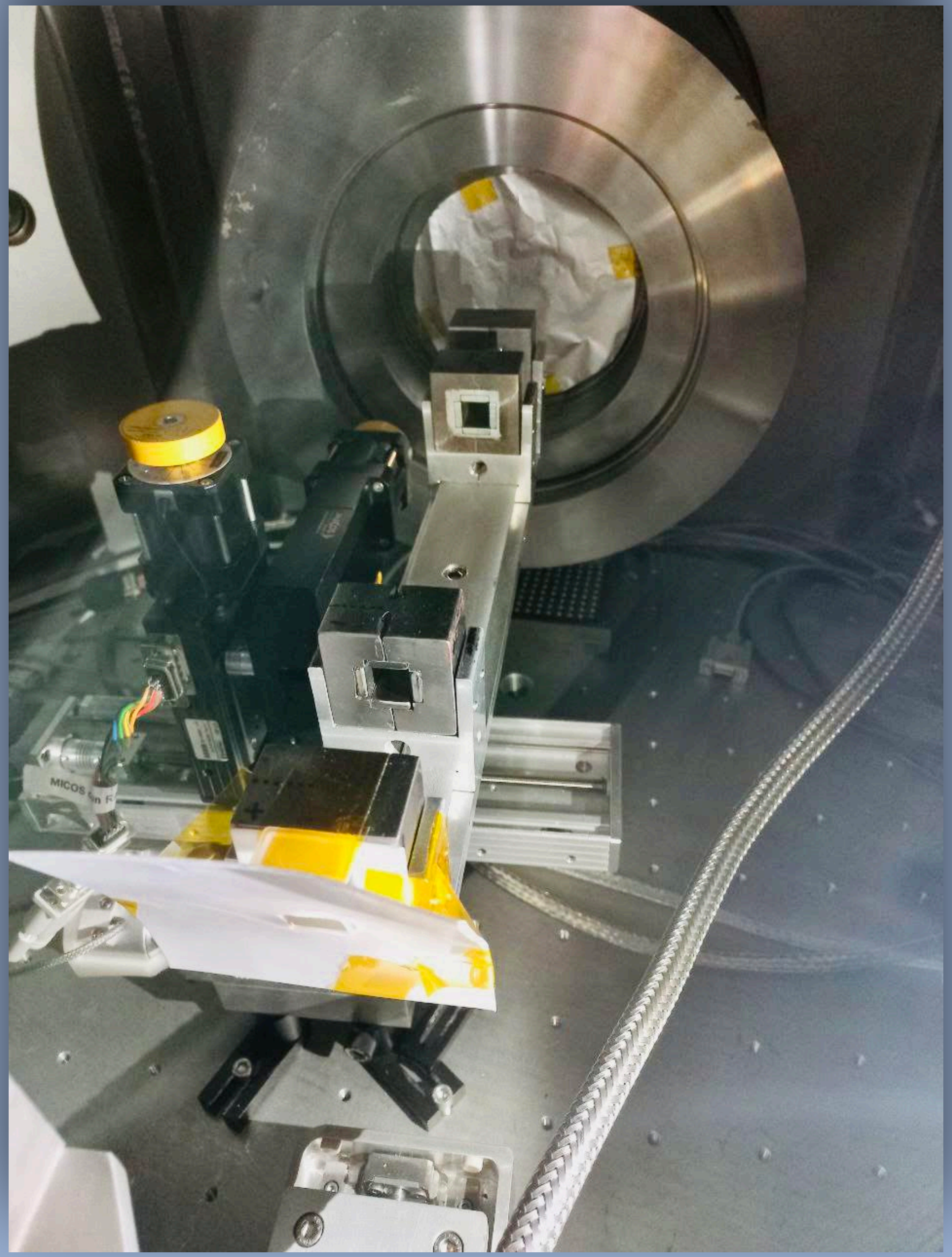
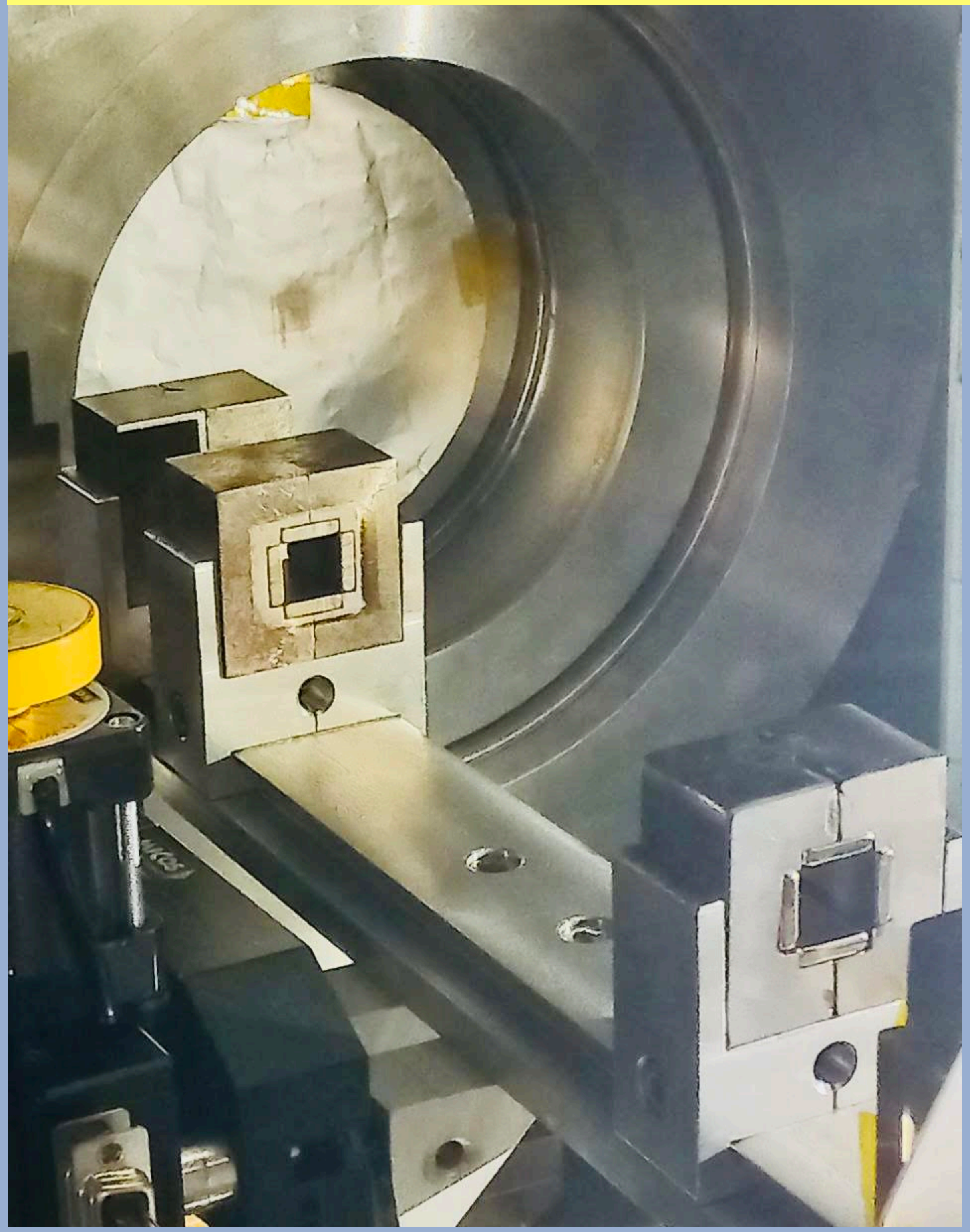


See Dr M. Salvadori talk…



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2. Particle In Cell (Pic) simulations

3. Monte Carlo simulations

   3.1 VHEE PDDs database

   3.2 VHEE focusing study

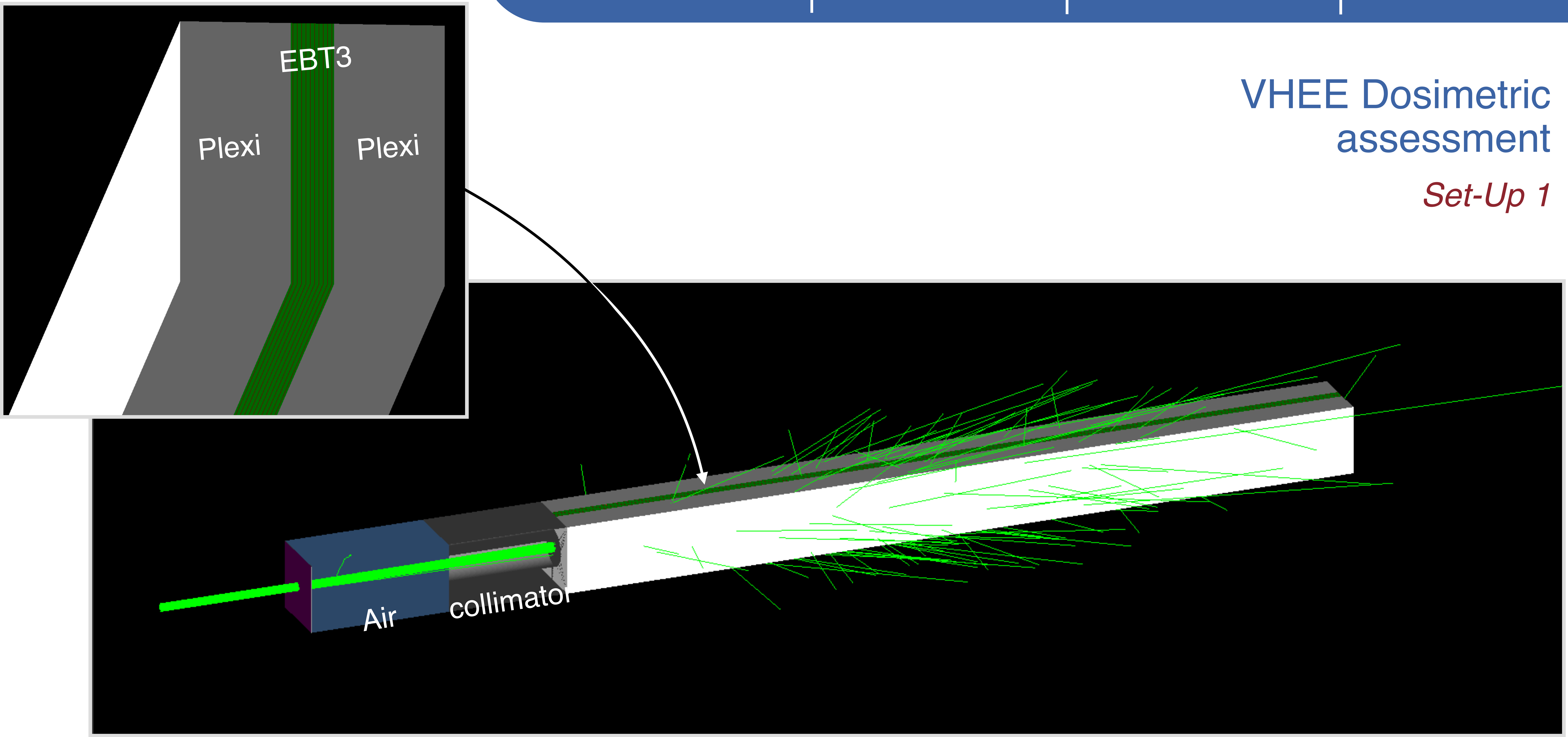
   3.3 VHEE dosimetric assessment

   3.4 OPTIMA: VHEE Treatment Planning System (TPS)

4. Conclusions

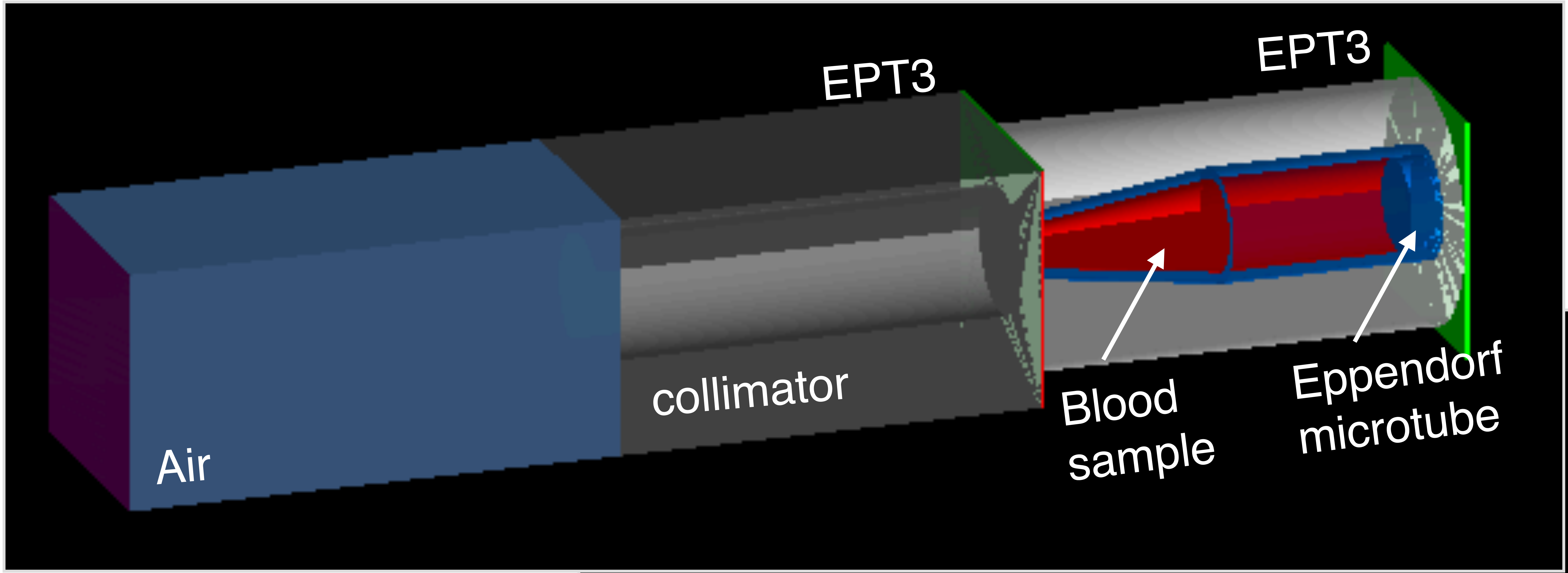
VHEE Dosimetric assessment

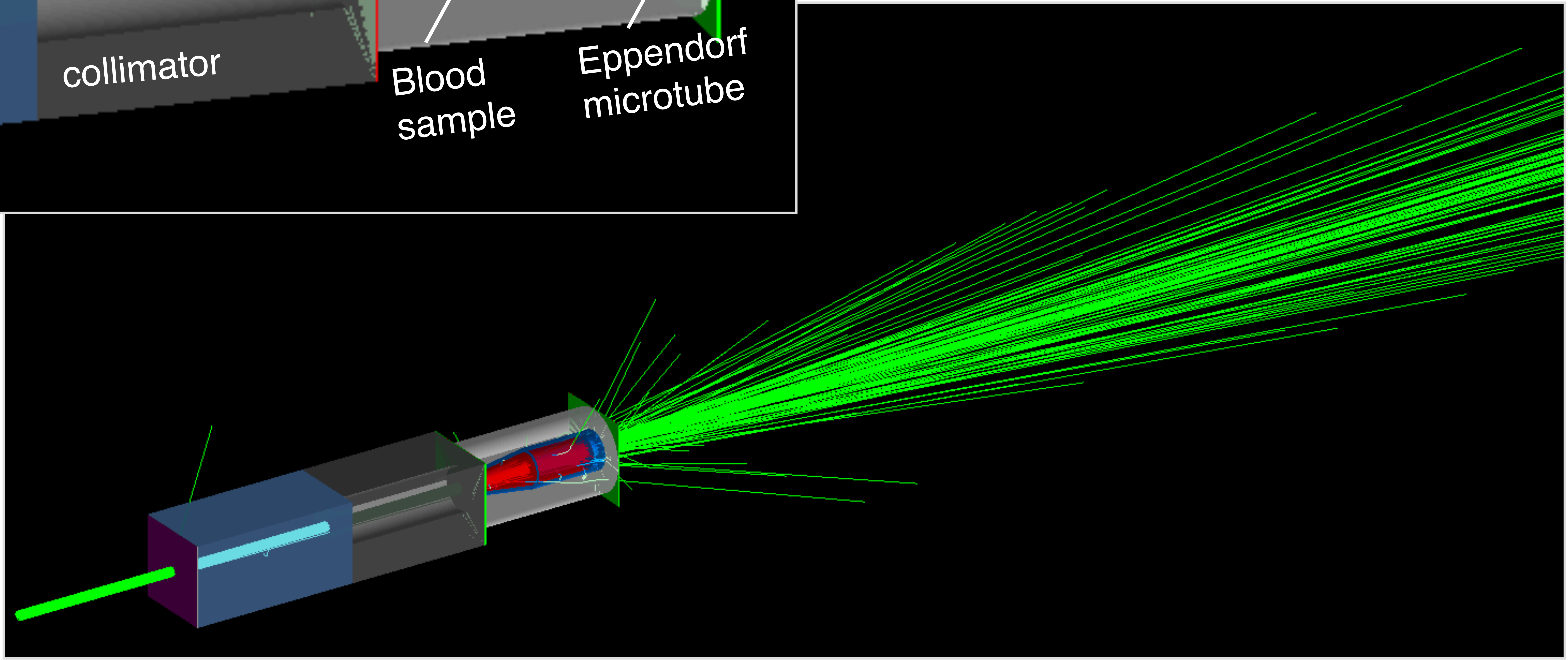
Set-Up 1



VHEE Dosimetric assessment

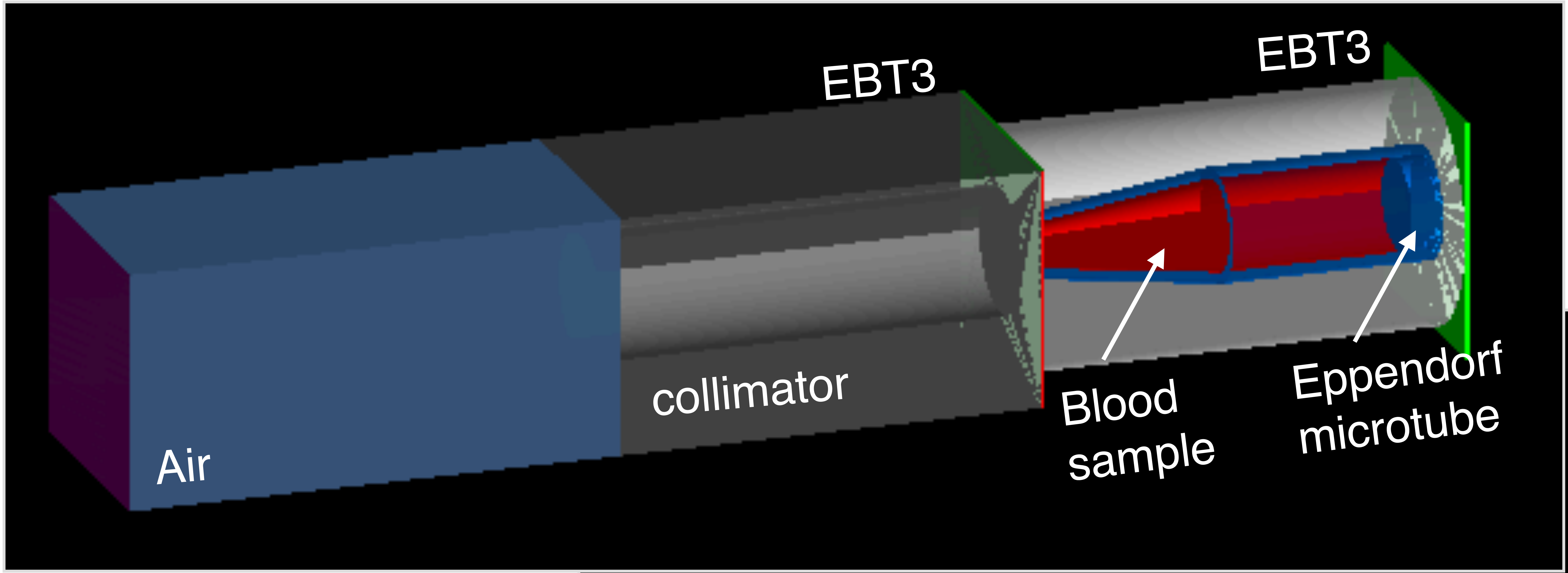
Set-Up 2

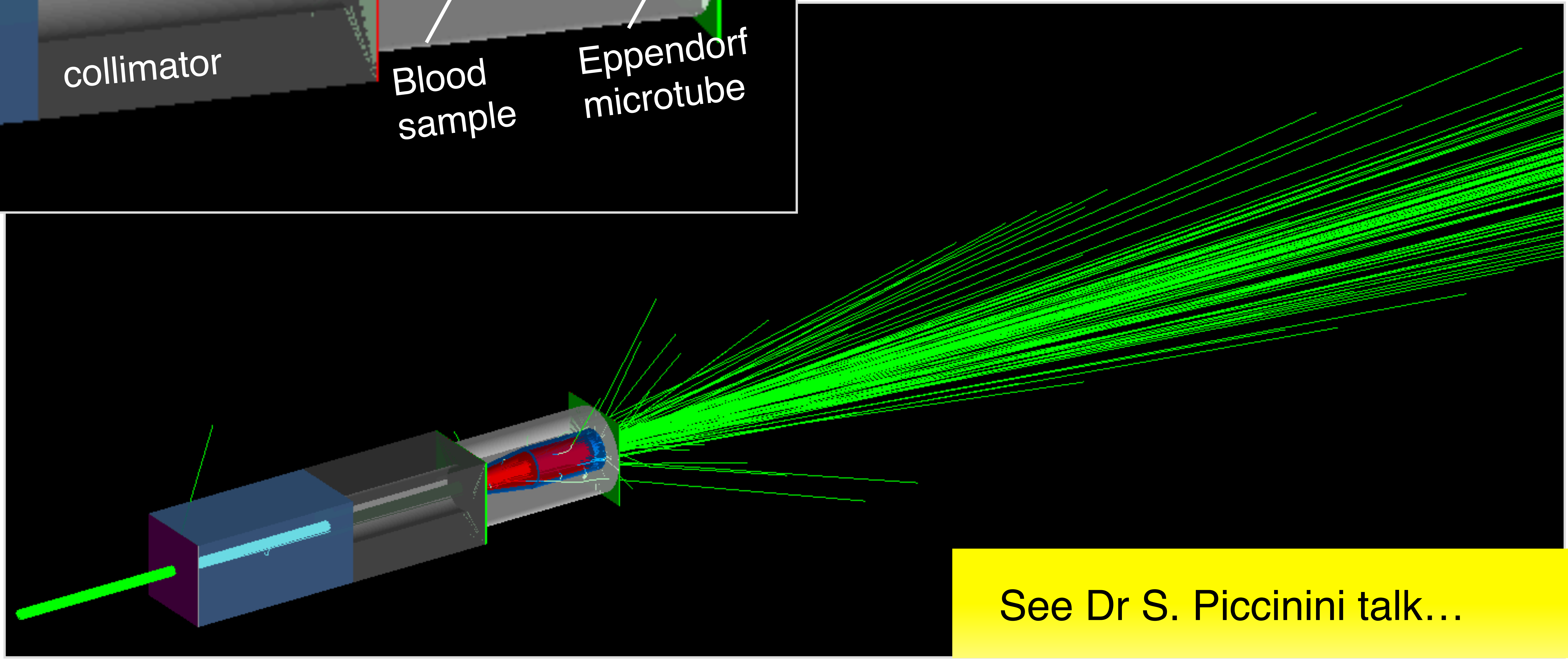




VHEE Dosimetric assessment

Set-Up 2



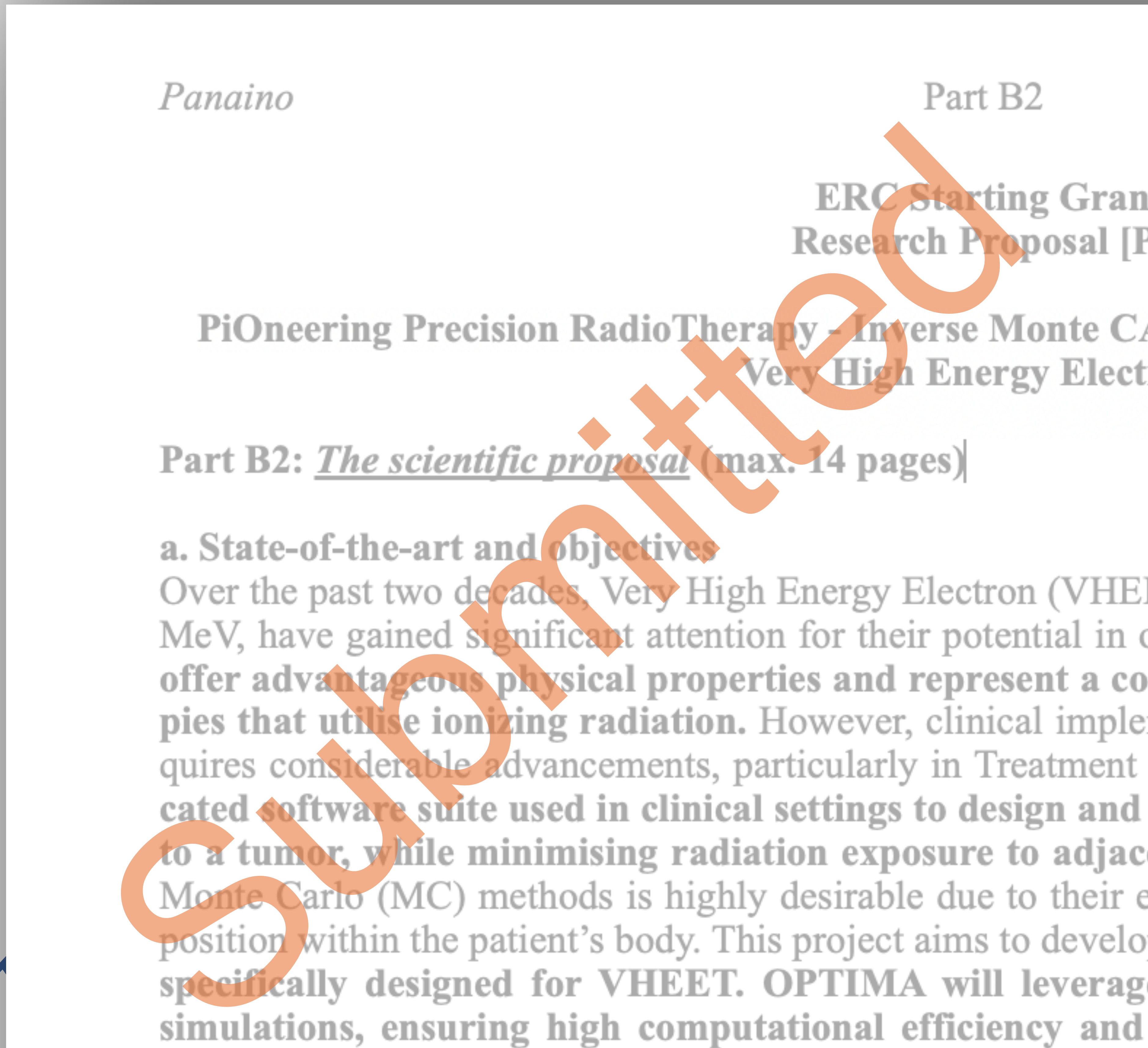


See Dr S. Piccinini talk…

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

PiOneering Precision RadioTherapy - Inverse Monte CArlo-based Treatment Planning System for Very High Energy Electron Beams

European Research Council
Established by the European Commission


Panaino Part B2

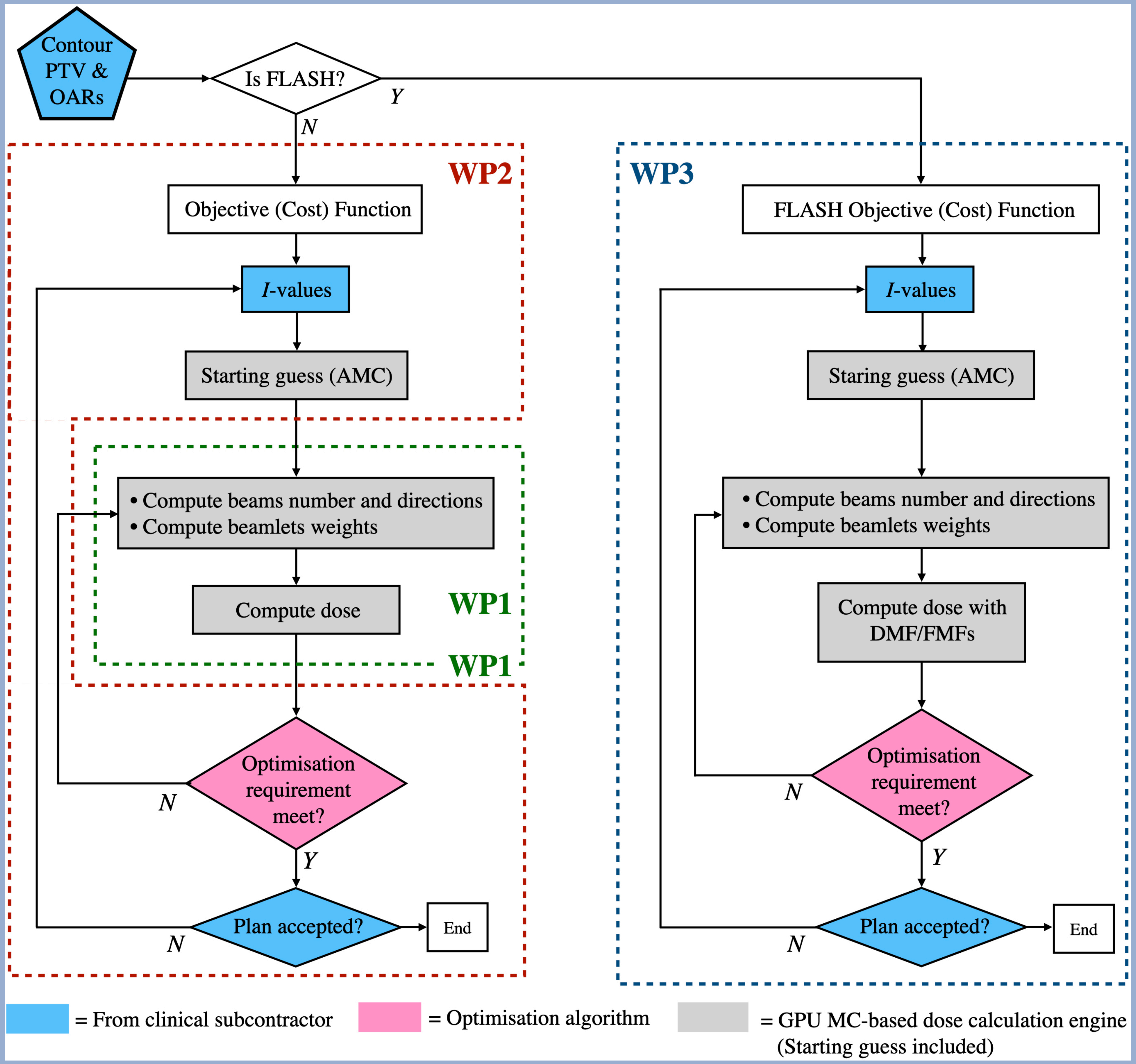
ERC Starting Gran
Research Proposal [I

PiOneering Precision RadioTherapy - Inverse Monte C
Very High Energy Elect

Part B2: *The scientific proposal* (max. 14 pages)

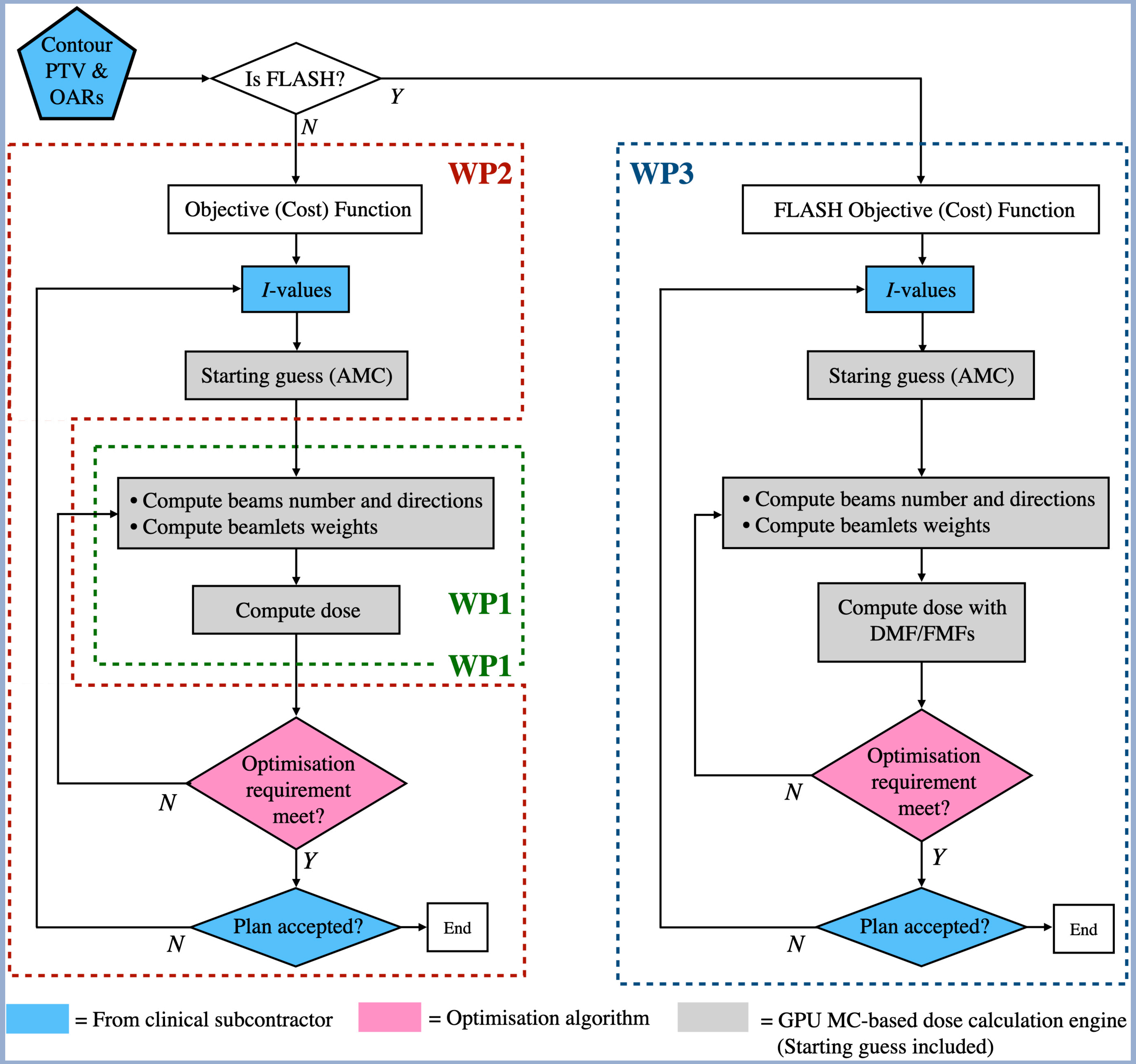
a. State-of-the-art and objectives
Over the past two decades, Very High Energy Electron (VHE
MeV, have gained significant attention for their potential in c
offer advantageous physical properties and represent a co
pies that utilise ionizing radiation. However, clinical imple
quires considerable advancements, particularly in Treatment
cated software suite used in clinical settings to design and
to a tumor, while minimising radiation exposure to adjac
Monte Carlo (MC) methods is highly desirable due to their e
position within the patient's body. This project aims to develo
specifically designed for VHEET. OPTIMA will leverag
simulations, ensuring high computational efficiency and

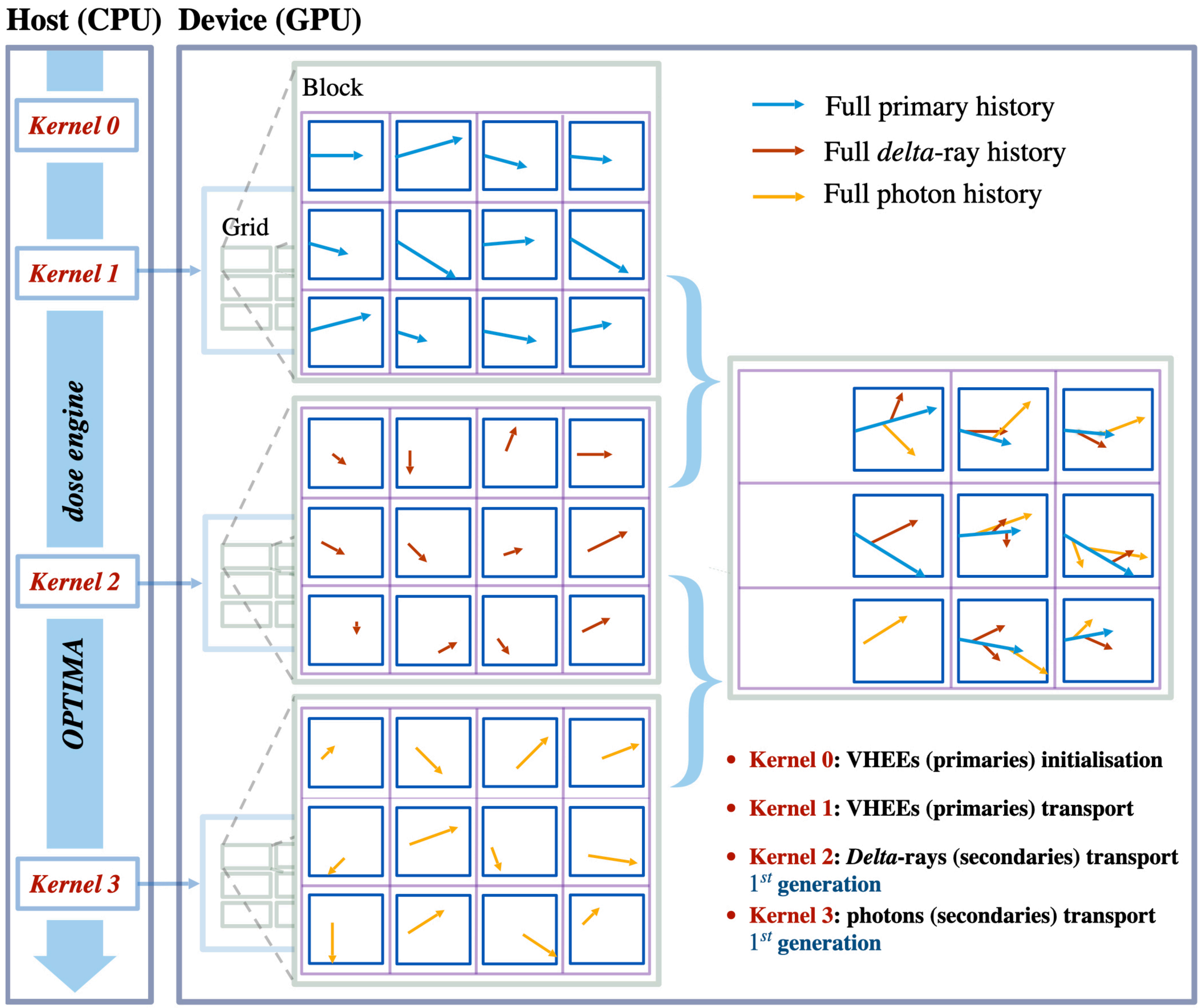
OPTIMA VHEE TPS



Why GPU?

OPTIMA VHEE TPS





FASTEST-THE, Bando a cascata PNRR.

G. De Nunzio, Università del Salento

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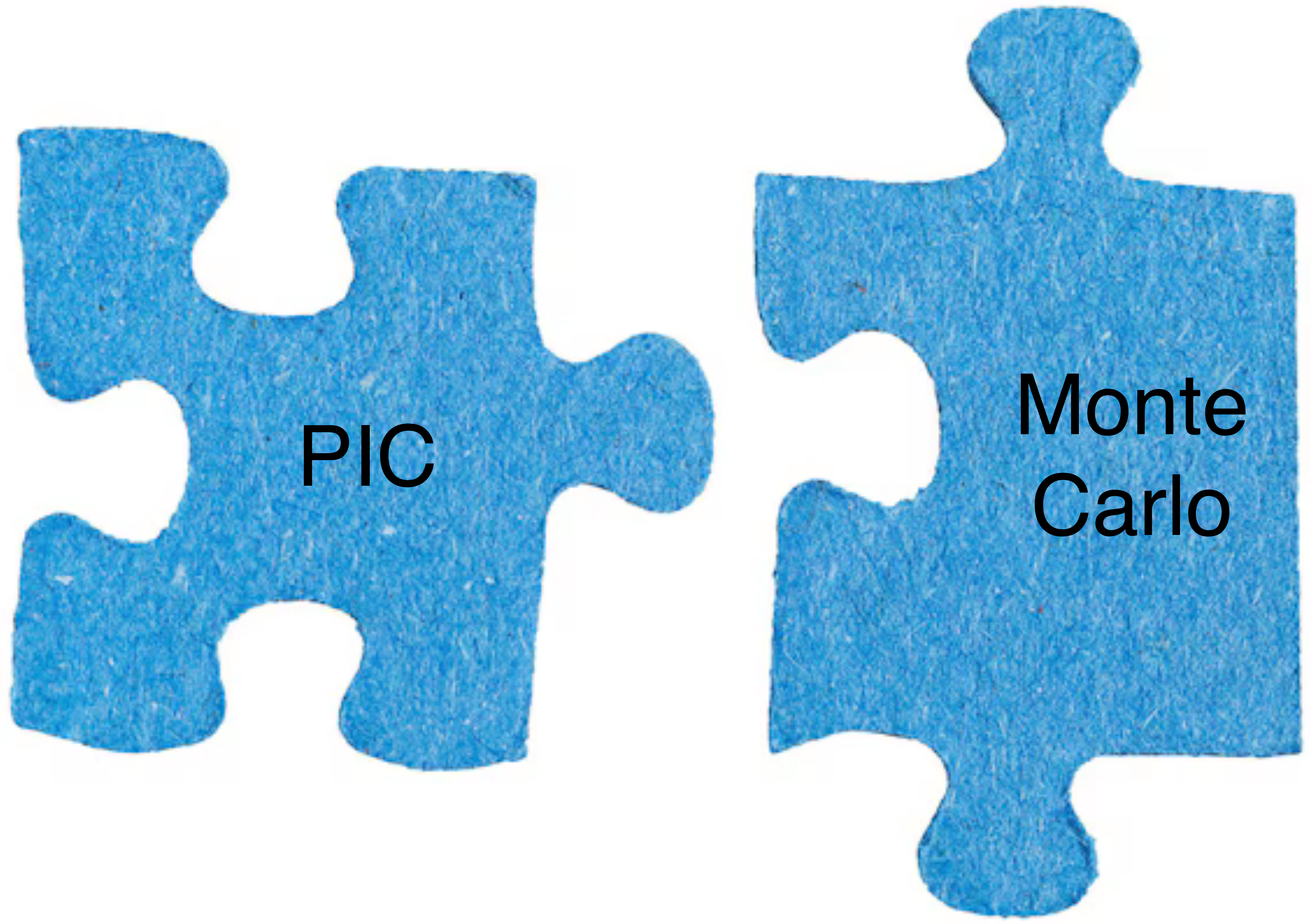
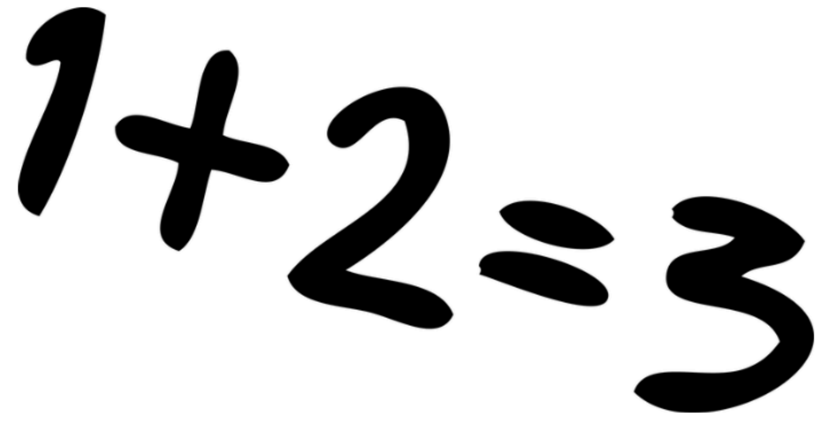


4. Conclusions

What my mum
thinks I am doing



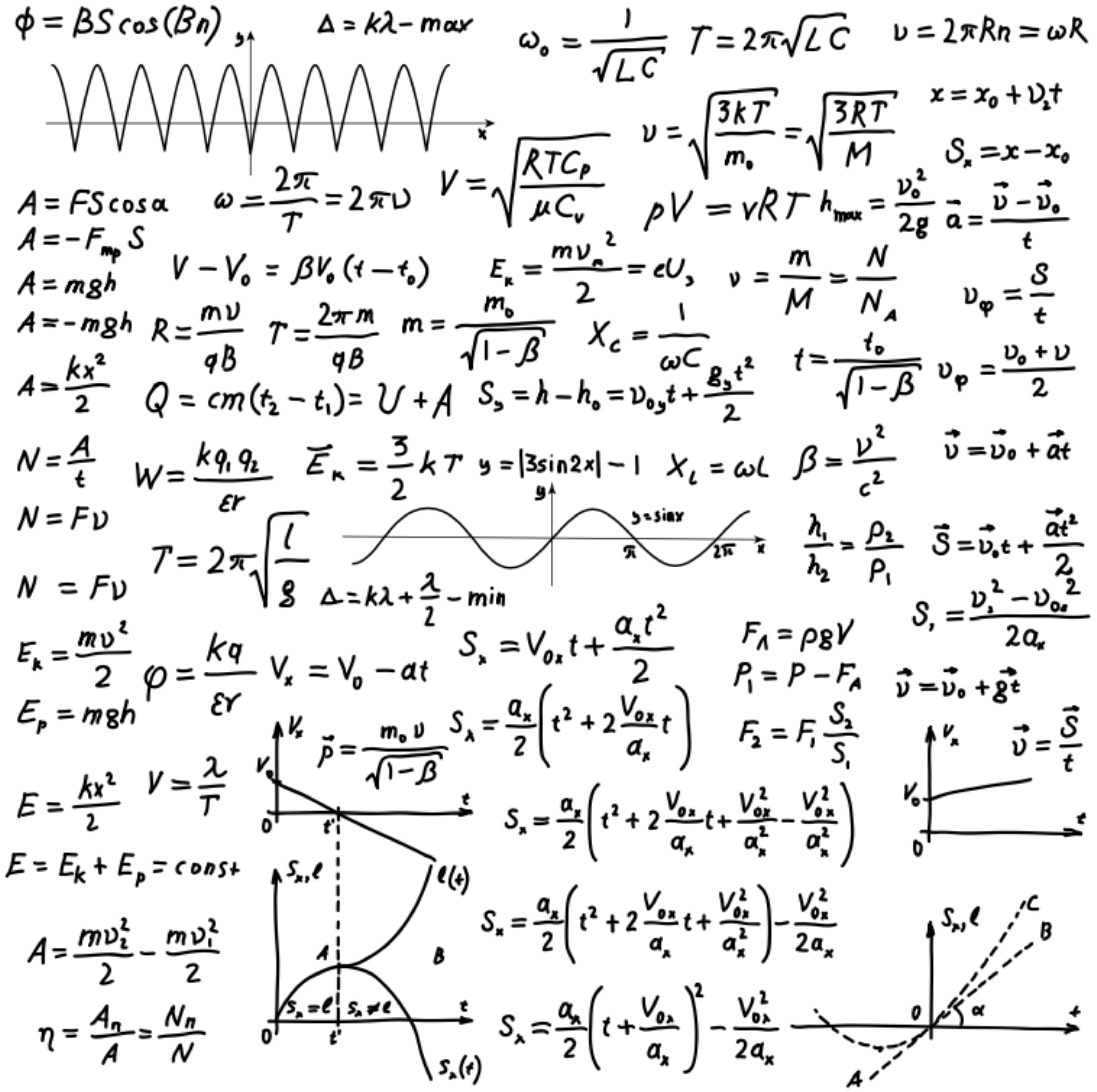
What experimental
physicists think I am doing

What my mum
thinks I am doing

What my mum thinks I am doing

1+2=3

What experimental physicists think I am doing

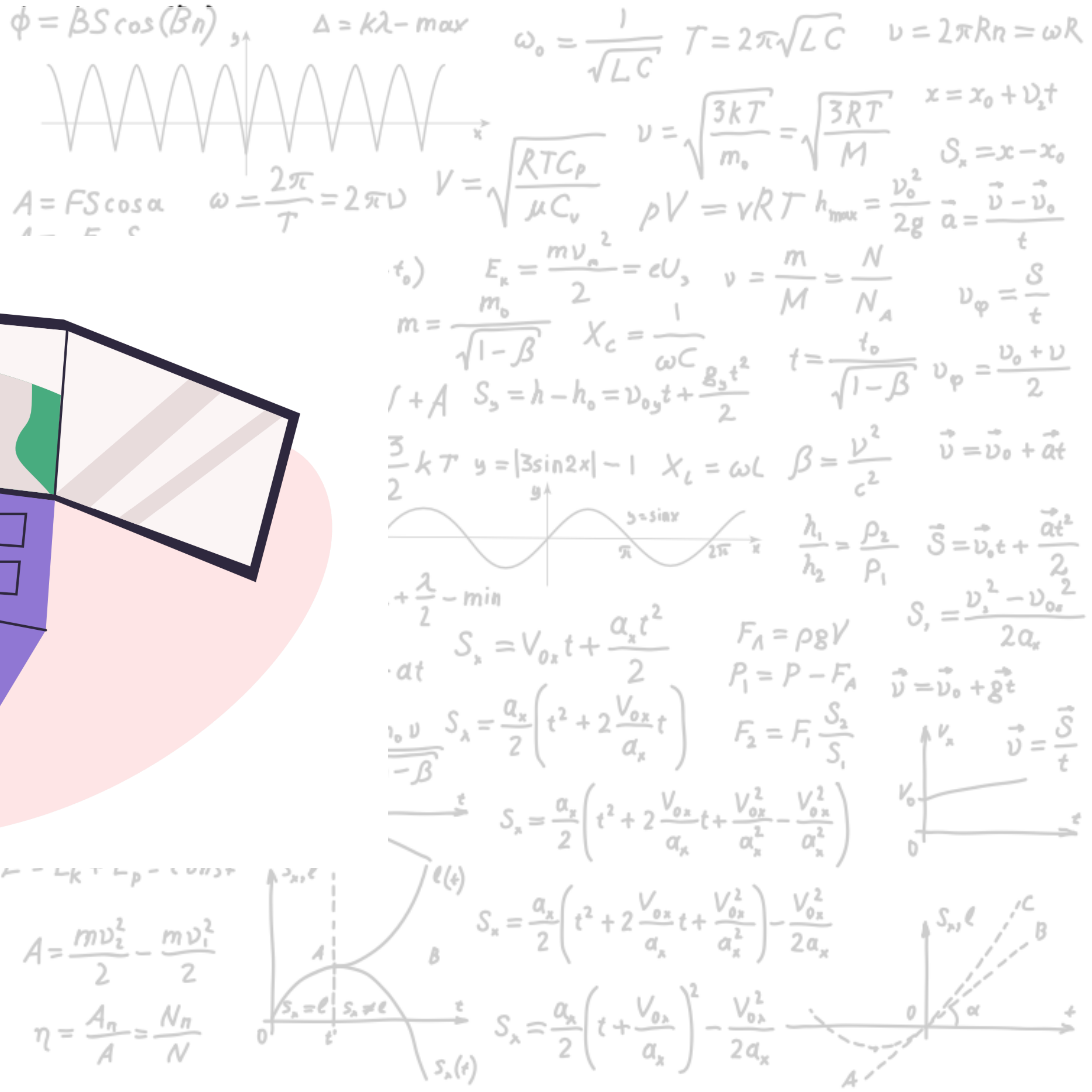


What I think I am doing

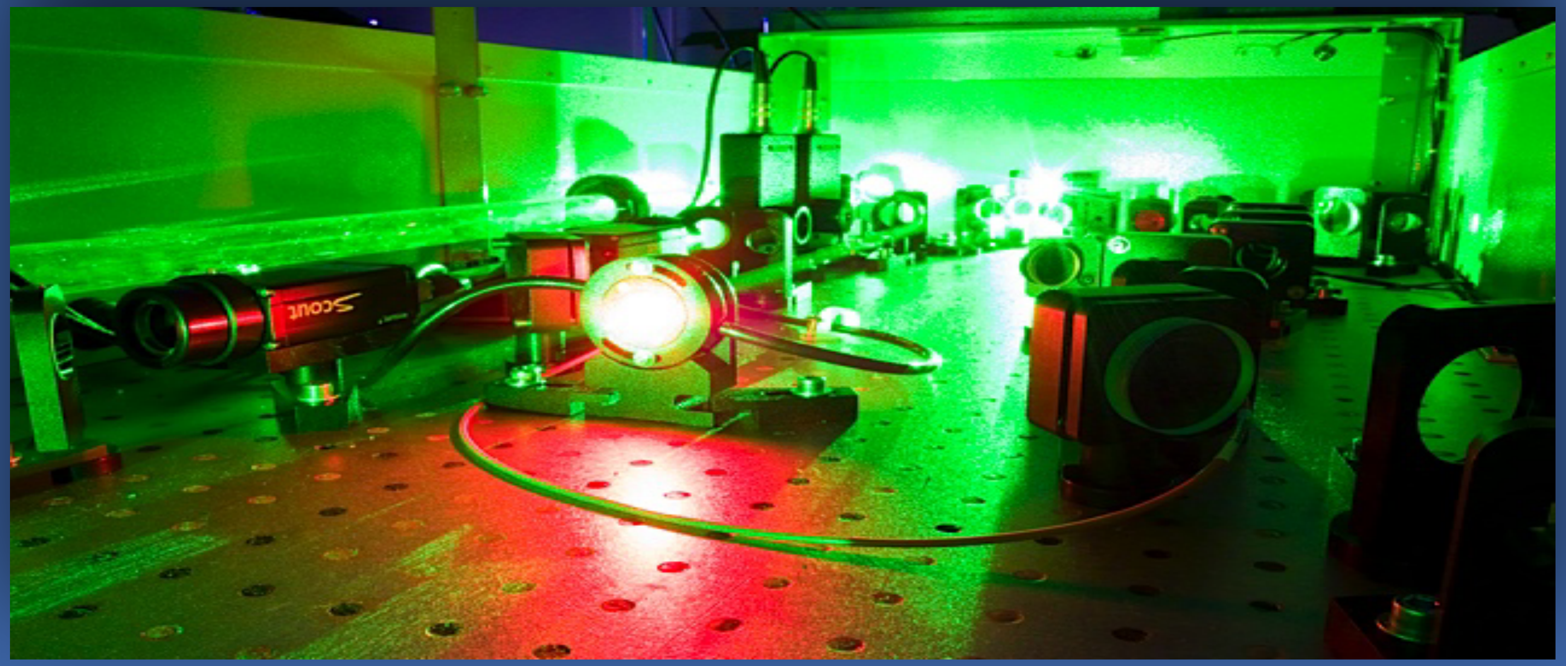
What my mum
thinks I am doing

Wha
phy

What I am actually doing



What I think I am doing



I-PHOQS
INTEGRATED INFRASTRUCTURE INITIATIVE IN PHOTONIC AND QUANTUM SCIENCES

The Intense Laser Irradiation Laboratory INO-CNR, Instituto Nazionale di Ottica, Pisa

- Leonida A. GIZZI (head)
- Luca LABATE
- Fernando BRANDI
- Gabriele CRISTOFORETTI
- Petra KOESTER
- Federica BAFFIGI
- Lorenzo FULGENTINI
- Daniele PALLA
- Martina SALVADORI
- Simona PICCININI
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