PSI

Implementing Electromagnetic Fields in GATE 10

GATE Scientific Meeting 2026

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Before starting... who is this guy?

Marc Ballestero Ribó

- Ph.D. Student at the PSI Center for Proton Therapy (PSI-CPT) / ETH Zürich (CH).
  - ↳ Supervised by Dr. Sairos Safai, Prof. Dr. Tony Lomax.
- Project:

  Faraday Cup Reference Dosimetry in Proton Therapy Traceable to a Primary Standards Laboratory

  SNF Grant no. 10002635

  - ↳ Monte Carlo simulations for a new fluence-based reference dosimetry protocol.
- Participation in the GATE Hackathon 2026 (HollandPTC, NL).

Overview

Motivation

PSI

In Medical Physics:

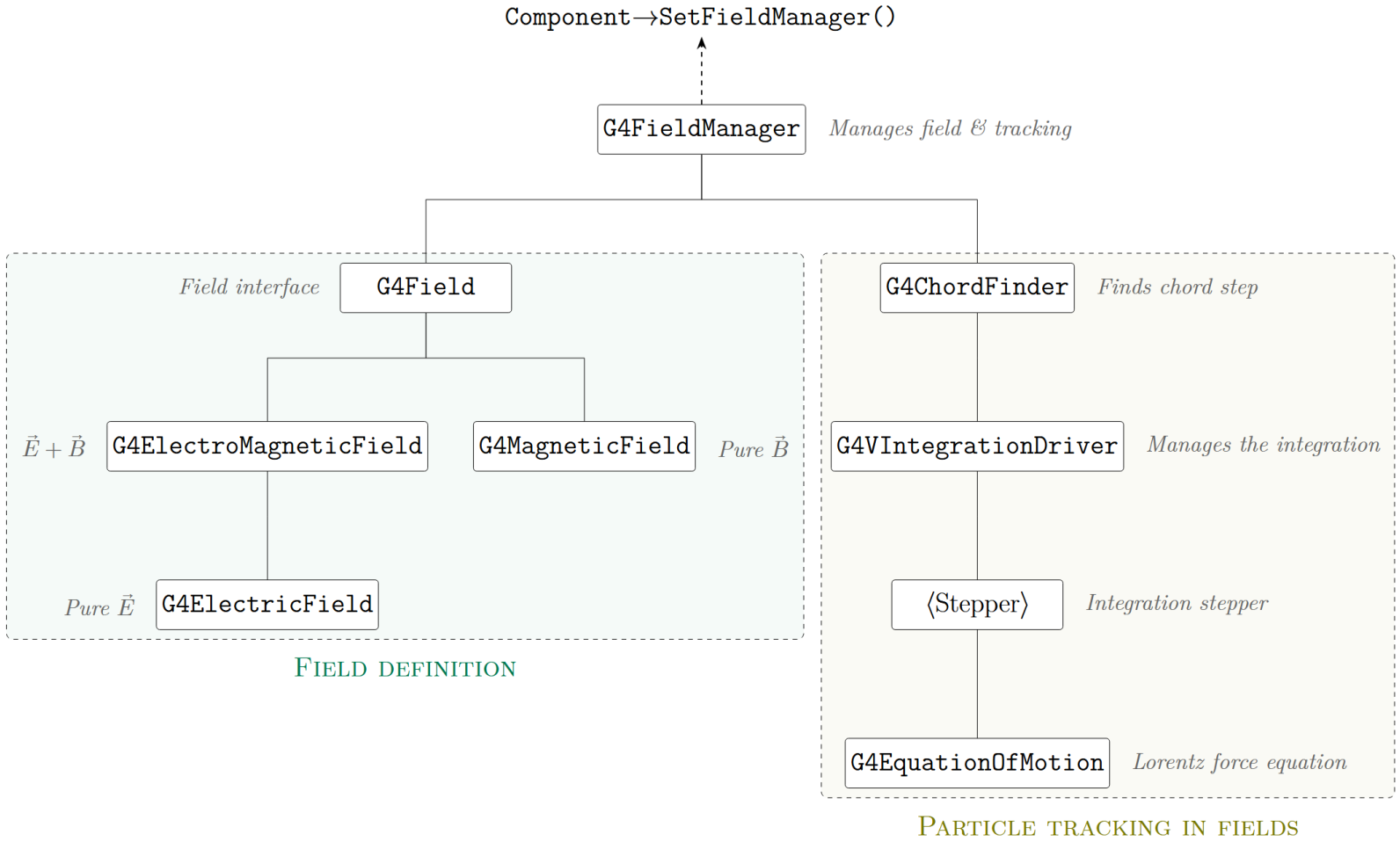
- Electric and magnetic fields are fundamental for the operation of detectors and beam transport systems.
- Accurate simulations of require tracking the particles in the corresponding fields.
- Real-world geometries have complex, non-uniform fields. Importing user-defined field maps enables accurate simulations of real instruments.

This is standard in MC codes, particularly in **Geant4**.

Our goal is to implement support for user-defined EM fields in GATE 10, making native Geant4 capabilities accessible to users.

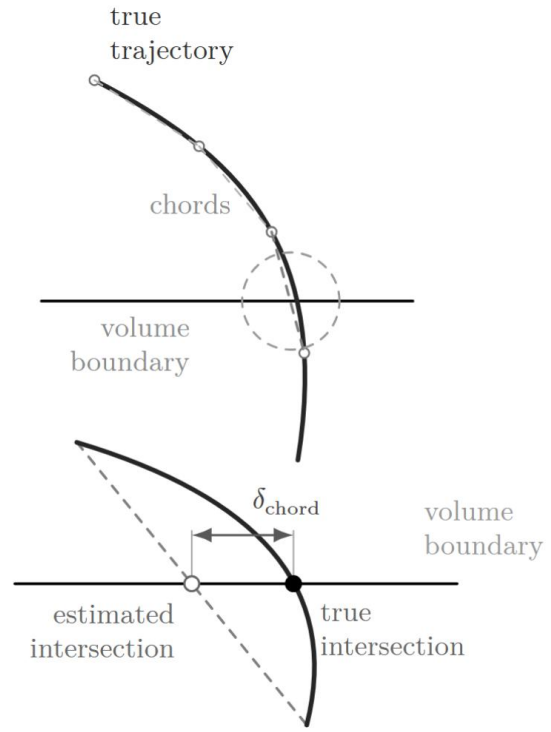
Implementation

EM Fields in Geant4



Field definition

Particle tracking in fields



Implementation

GATE Integration :: Overview

C++ Bindings

New bindings in `opengate_core`:

- Field definition classes
- Tracking infrastructure
- Field manager

Python-side Design

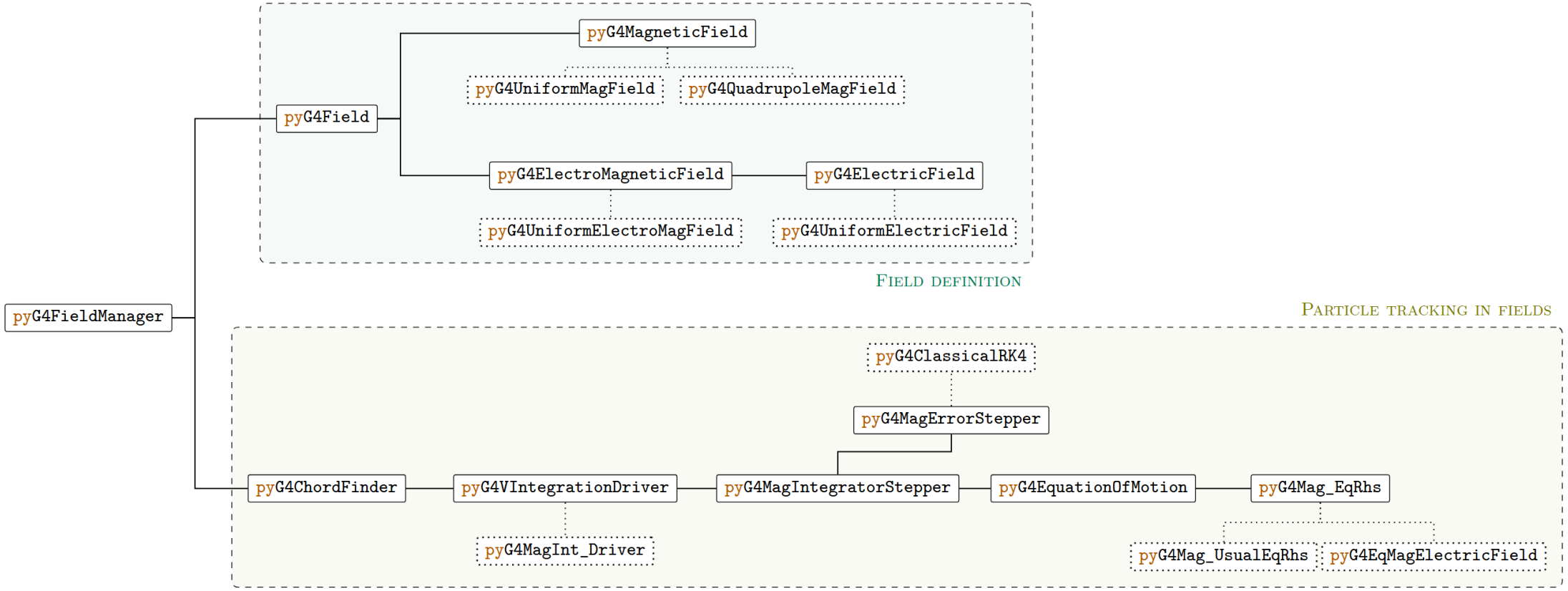
Additions to `opengate`:

- New module `fields.py`
  - ↳ Python-side field object abstraction.
- User interface
  - ↳ `volume.add_field(field)`
- Field registration, initialization and construction.
  - ↳ `VolumeBase.field`
  - ↳ `VolumeBase.g4_field_manager`
  - ↳ `VolumeManager.fields`
  - ↳ `VolumeEngine.ConstructSDandField`

Implementation

GATE Integration :: C++ Bindings

New bindings in `opengate_core` to expose all the needed classes for field implementation:

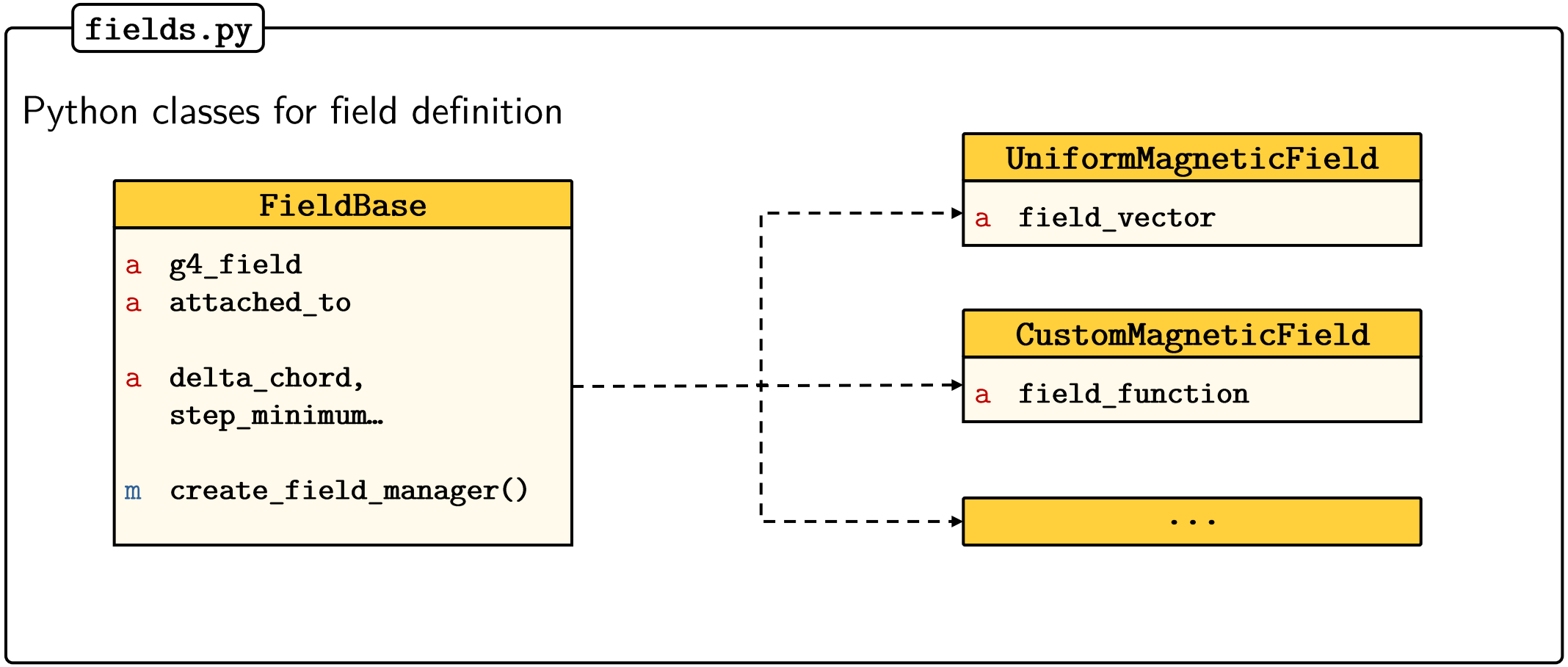


pybind11

Implementation

GATE Integration :: Python-side Design

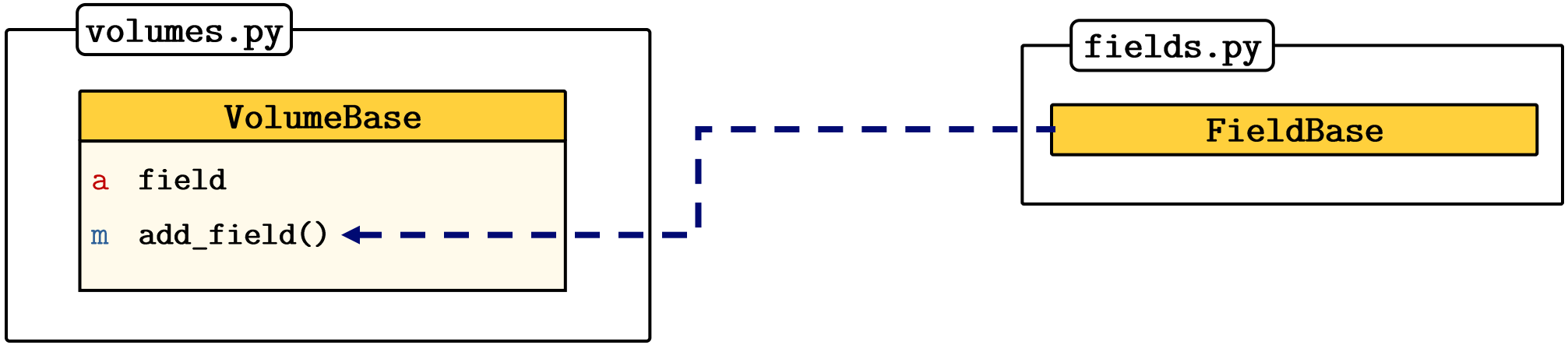
User API :: *How can a field be defined?*



Implementation

GATE Integration :: Python-side Design

User API :: *How can a field be attached to a component?*



Example: Custom B field

```python
def B_func(x, y, z, t):
    return [
        0.,
        (1 + x*z / m**2) * tesla,
        0.]
field = fields.CustomMagneticField(name="B_custom")
field.field_function = B_func
box.add_field(field)
```

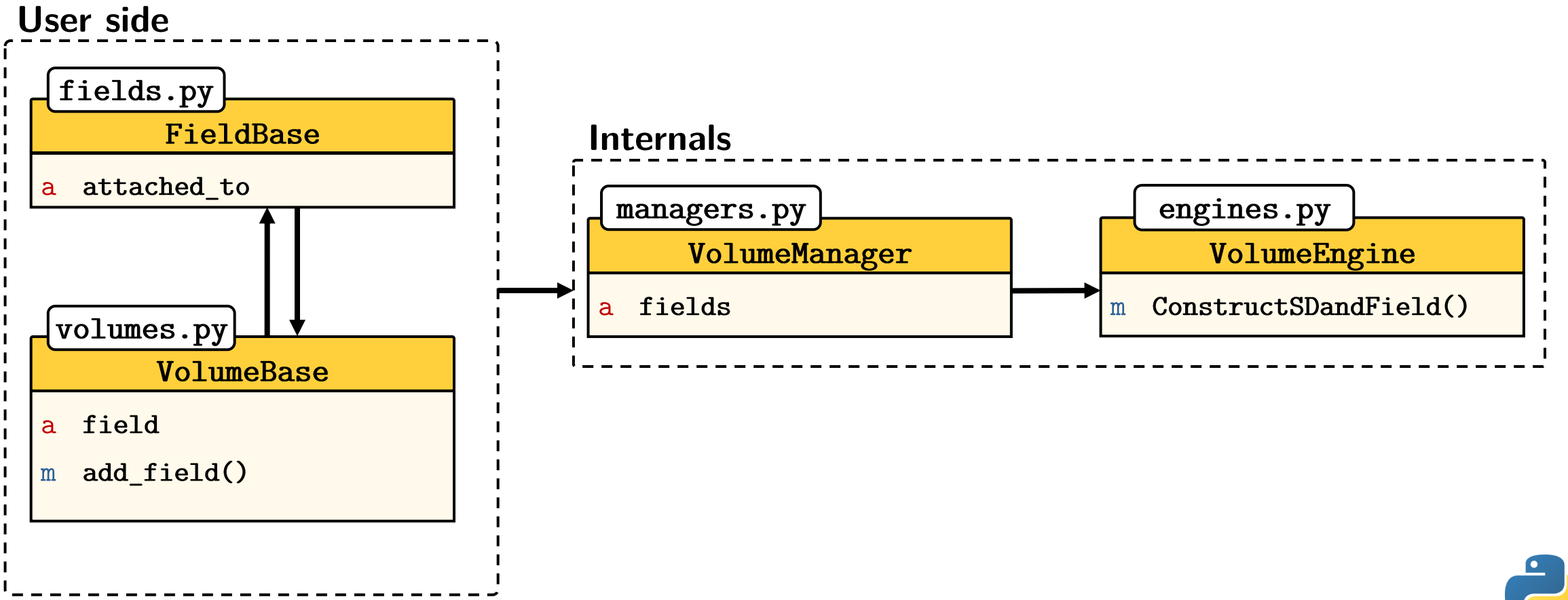
Example: Uniform B field

```python
field = fields.UniformMagneticField(name="B_uniform")
field.field_vector = [0, 1 * tesla, 0]
box.add_field(field)
```

Implementation

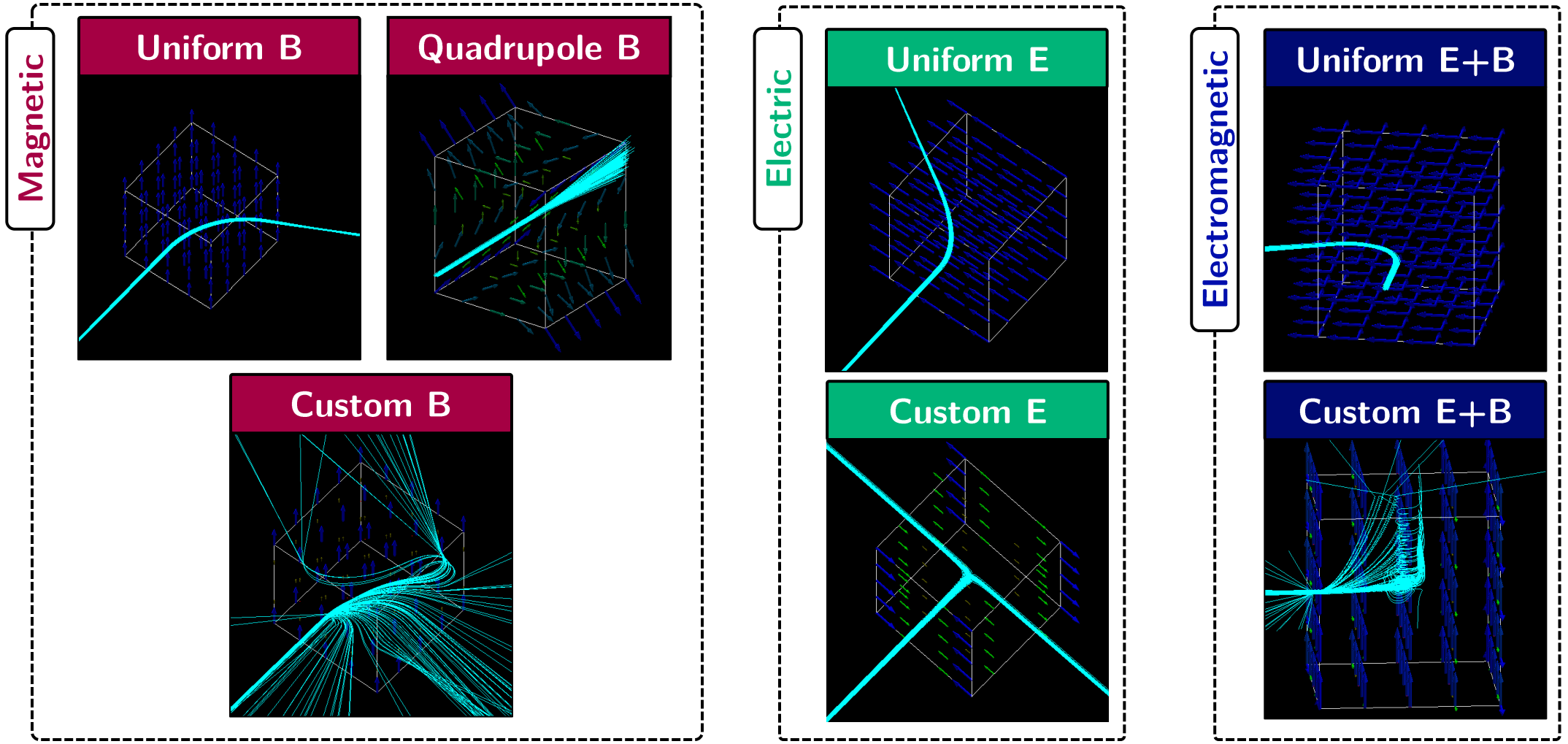
GATE Integration :: Python-side Design

Internal Plumbing :: *How is a field managed in GATE?*



Implementation

GATE Integration :: Current Capabilities



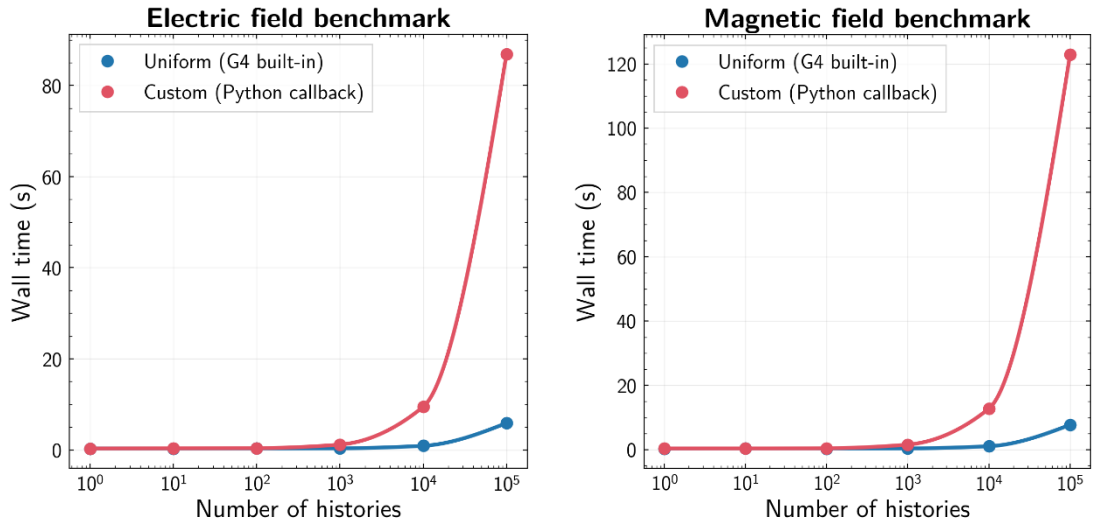
Implementation

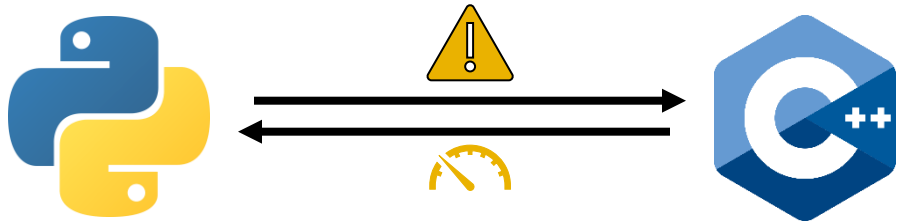
Tests & Benchmarks

Implemented Tests

- **Uniform B Field**
  - ☑ Particles follow a circular trajectory.
  - ☑ No deflection parallel to B.
  - ☑ Energy is conserved.
- **Uniform E Field**
  - ☑ Particles follow a parabolic trajectory.
  - ☑ No deflection perpendicular to E.
  - ☑ Energy gain is consistent with work done by the field.

Benchmarks





Outlook

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Known TO DO's

- ☐ Choose tracking hyperparameters from the user-side (stepper, step sizes, etc.).
- ☐ Bind the rest of G4-native fields (sextupole B, ...).
- ☐ Implement mapped fields (e.g. from a matrix).
- ☐ Fix the callback overhead for custom fields $\rightarrow$ `C++` side implementation.
- ☐ New tests & benchmarks.
- ☐ ...

GATE at PSI-CPT

Track End simulations for proton therapy treatment planning

- Investigation of track-end scoring for proton therapy treatment planning (idea from Oeden J., Traneus E. IJROBP 2021).
- Using a (newly developed) actor in GATE 10 to validate a fast, GPU based Monte Carlo engine (FRED).

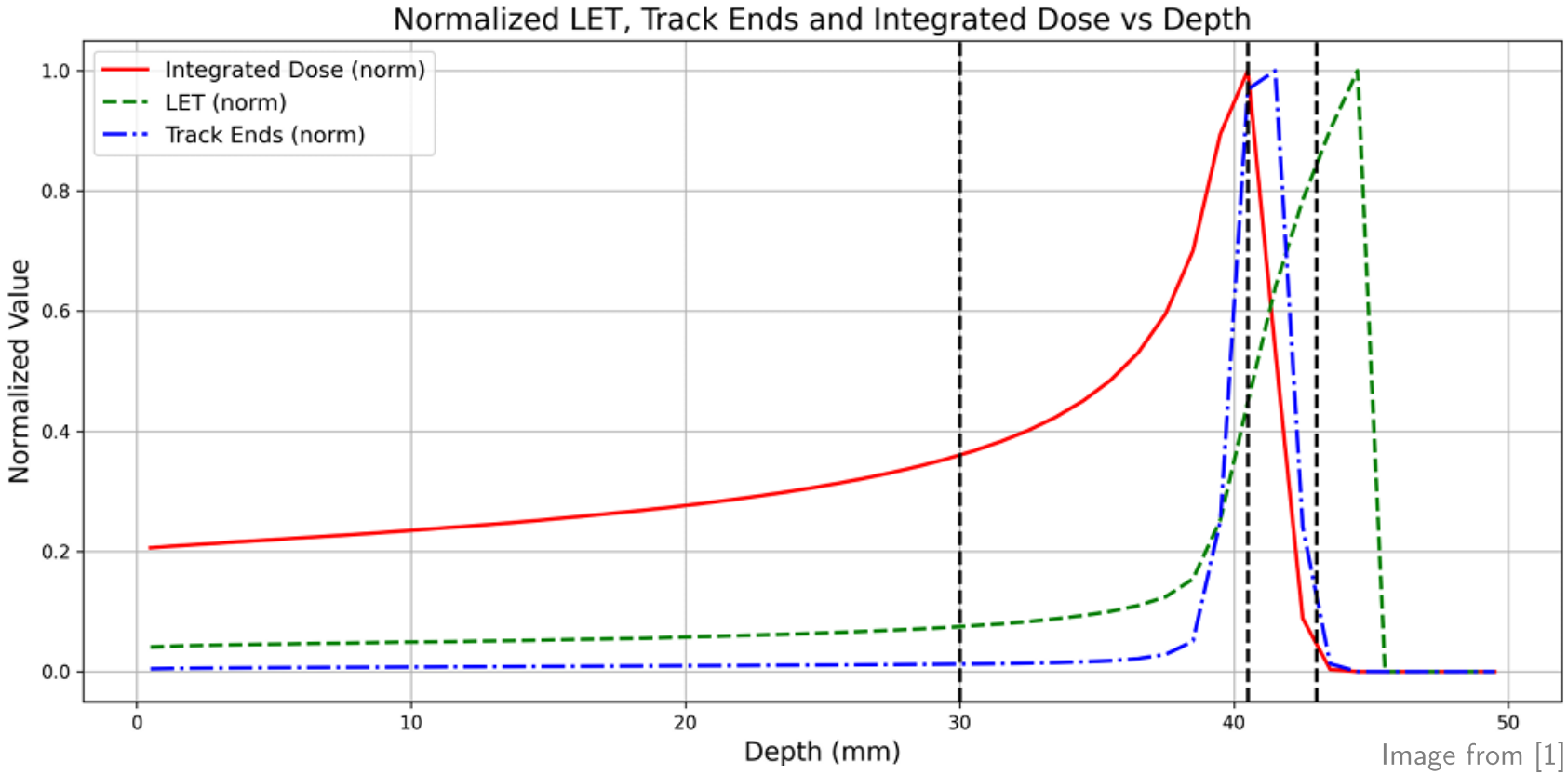


Image from [1]

Projects performed by:

[1] Alberto Ambruosi (master thesis Politecnico Di Torino 2025, supervised by Carla Winterhalter & Diana Nada Caterina Massai).

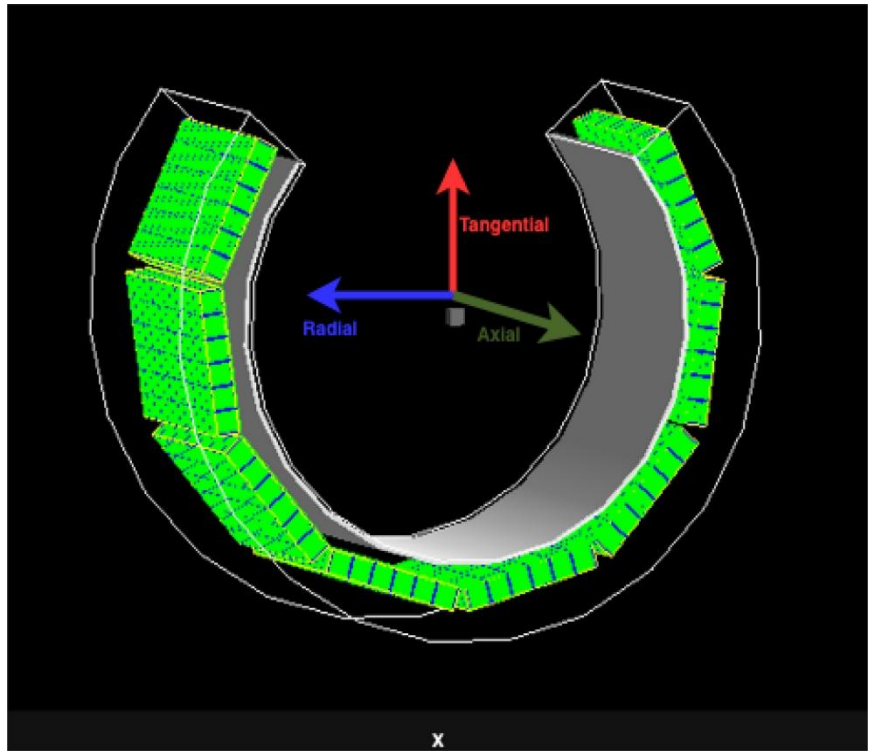
[2] Valentino Wiedmer (semester thesis ETH Zurich 2025, supervised by Carla Winterhalter & Tony Lomax).

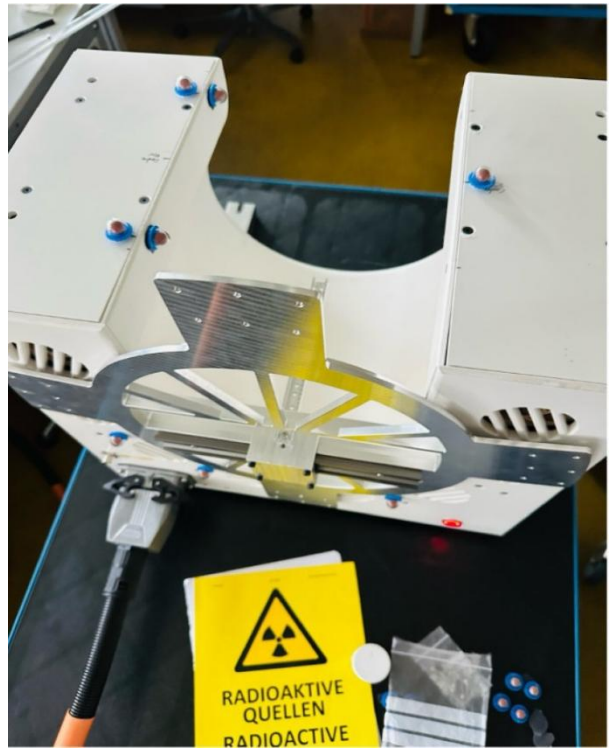
Slide courtesy of C. Winterhalter

GATE at PSI-CPT

PETITION (PET for InTensive care units and Innovative protON therapy)

- Collaboration between PSI, ETH & CHUV.
- Developement of an **open-ring in-beam PET scanner** for proton therapy.
- **Simulations & experiments** with the open-ring PET detector, simulation based investigation of a rotating PET detector system.





Images from [1]

Recent, GATE based publications:

[1] Makkar, S., ..., Winterhalter, C. "Simulation and experimental characterisation of in-beam PETITION PET scanner for proton therapy." *Nuclear Instruments and Methods in Physics Research Section A* 1084 (2026): 171230.

[2] McNamara, K., ..., Winterhalter, C. "Iterative reconstruction with a rotating open-ring PET scanner for proton therapy range verification." *Physics in Medicine & Biology* 70.18 (2025): 185003.

Slide courtesy of C. Winterhalter

GATE at PSI-CPT

Upcoming SNF Weave-UNISONO project: Computational and experimental nanodosimetry for proton radiotherapy

Nanodosimetric parameters...

- ... to improve our **understanding of clinical effects** of protons
- ... to **optimize** a proton therapy **treatment plan**
- ... will be validated **experimentally**

PSI	Universität Zürich[UZH]	Cyclotron Centre Bronowice CCB
Carla Winterhalter Tony Lomax Damien C. Weber Giovanni Fattori	Uwe Schneider Jürgen Besserer	Antoni Rucinski Jan Gajewski Medical Physicists
1 Ph.D. Student (4 yrs) 1 PostDoc (2 yrs)	1 Ph.D. Student (4 yrs)	1 Ph.D. Student (4 yrs) 1 PostDoc (4 yrs)

International partners: Bruce Fadeggon (University of California San Francisco), Reinhard Schulte (Loma Linda University), Beata Brzozowska (University of Warsaw)

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Thank you very much for your attention!