

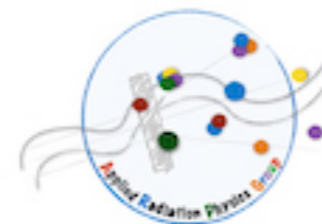


# Applicazioni di tecniche computazionali di Fisica (Machine Learning e metodi Monte Carlo) alla Medicina

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Retreat della sezione INFN di Roma  
Assisi, martedì 14 giugno 2022



# Progetti di ricerca

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## Machine Learning

- ATTRACT-AI  
(Radiogenomics)
- NEPTUNE  
( $^{19}\text{F}$  MRI)
- MUCCA  
(AI explainability)
- MRI motion correction
- + other smaller projects

ML\_INFN

- Radiotherapy treatment planning optimisation with DL
- Emulation of a low energy nuclear model (GeNIALE spinoff)

## MC-INFN

- Geant4
- Geant4-DNA for atmosphere
- FRED
- FLUKA

Monte Carlo

# Progetti di ricerca

Parlerò solo di alcuni di questi progetti

Machine Learning

MC-INFN

quelli che a mio avviso mostrano in maniera più chiara  
il contributo che un fisico può dare

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# The NEPTUNE project

Nuclear process-driven Enhancement of Proton Therapy UNravEled

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- Financed as CALL CNS 5
- Goal: enhancement of proton therapy effectiveness using nuclear reactions. In particular:  $p + {}^{11}\text{B} \rightarrow 3\alpha$
- Administering borated pharmaceutical before irradiation
- WP2: Evaluate bio-distributions of borated & fluorinated tracers (F-BPA is one of the candidate pharmaceutical) using  ${}^{19}\text{F}$ -MRI

# The NEPTUNE project

Nuclear process-driven Enhancement of Proton Therapy UNravEled

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- $^{19}\text{F}$  has extremely favourable magnetic properties:
- 100% natural abundance, spin  $\frac{1}{2}$
- Gyromagnetic ratio very close to  $^1\text{H}$
- Only trace amounts in human body
- Can be used to detect fluorinated pharmaceuticals
- $^{19}\text{F}$ -MRI is limited by low SNR ratio



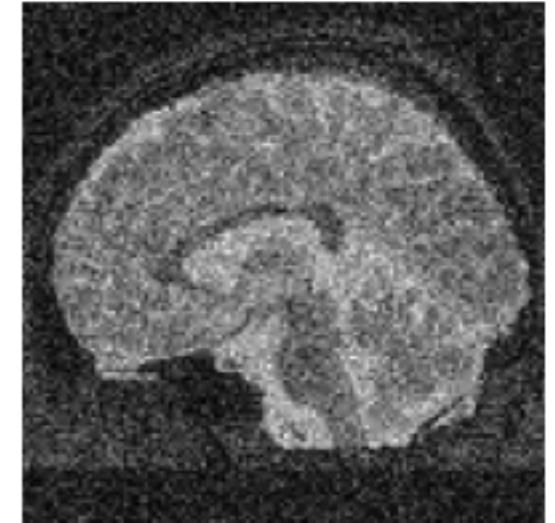
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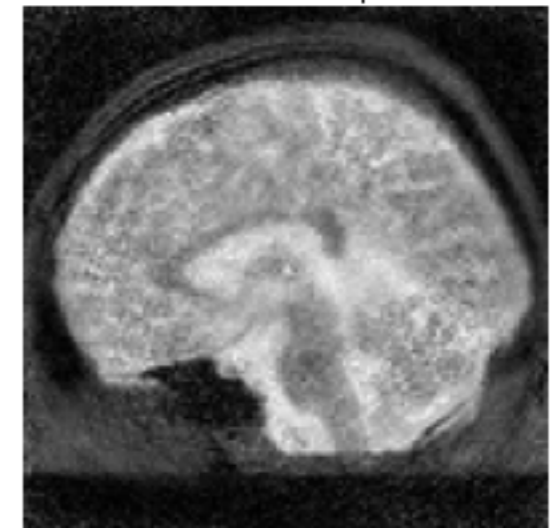
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- Developed a new antenna
- and an SDR-based system to improve SNR ratio in  $^{19}\text{F}$ -imaging
- V. Bocci, A. Cruciani, L. Ficcadenti
- Deep learning based denoiser in k-space for MRI images
  - Residual learning approach (learn noise)
- A. Ciardiello, R. Faccini, S. Giagu, C. Voena

Noised with std = 280



Denoised in K-space



# MUCCA

Multi-disciplinary Use Cases for Convergent new Approaches to AI explainability

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- CHIST-ERA IV xAI H2020 EU grant 2.2021-7.2024
- Ultimate goal: quantifying strengths and solving weaknesses of new and state of the art xAI methods
- Strategy: study explainability techniques in different use-cases intentionally chosen to be heterogeneous with respect to the types of data, learning tasks, scientific questions
- Multidisciplinary collaboration that brings together researchers from different fields:
  - high energy physics
  - applied physics in medicine
  - neuroscience
  - computer science



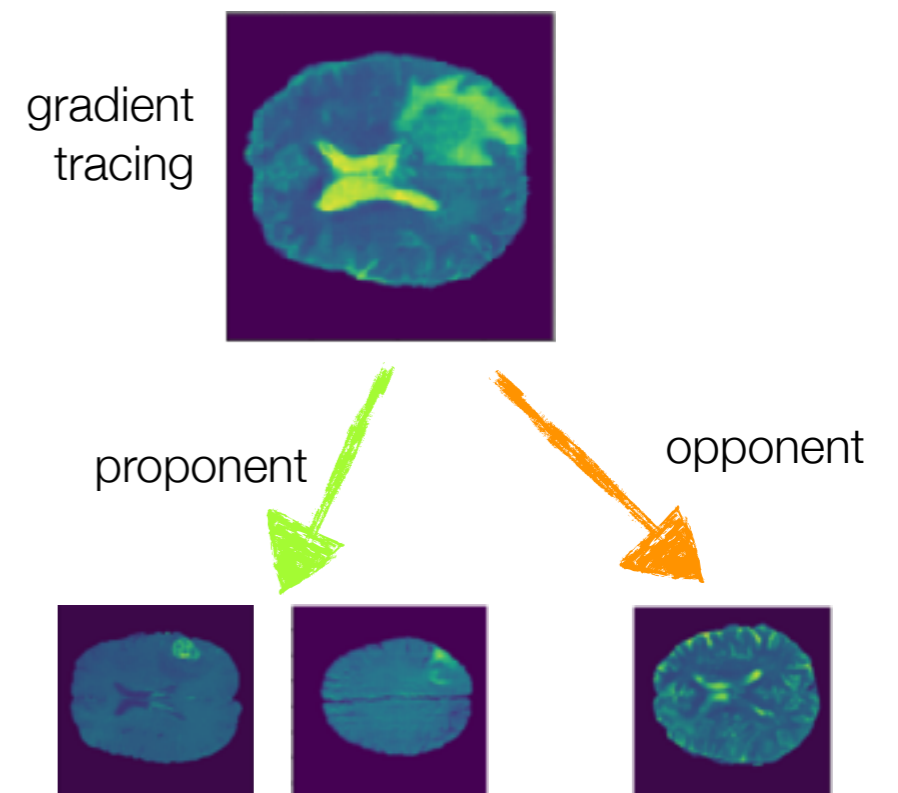
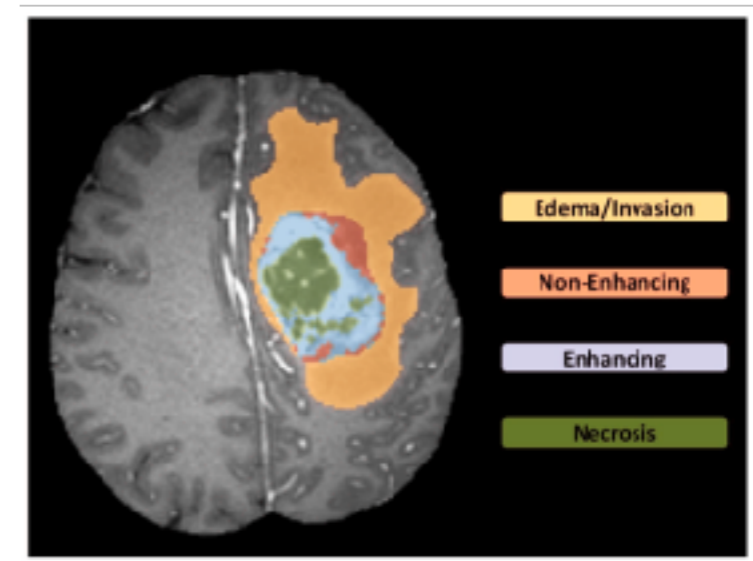
# AI explainability

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- xAI is a broad field of research in AI concerning development of tools to increase trust and understanding of a model's predictions
- Main issues with xAI:
  - strong trade-off between interpretability and representation power of ML models
  - intrinsically interpretable models (e.g.: linear regression, decision trees) orthogonal to models with strong representational power (Deep NN)
- different xAI methods may disagree on the “explanation”, they may not be always accurate, and they lack principled evaluation metrics

# A MUCCA use case: medical imaging

- brain segmentation task on MRI images
- apply and test xAI algorithms in producing consensus on final users and quantifying it by appropriate metric
- study stability of the metric
  - different datasets
  - training strategies
  - architecture constraints
  - data augmentation...



# Value added by physicist

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- Understand (and explore the dependencies) the response function of the model
- Explore systematic errors
- Parallelism with physical models (e.g.: spin glasses)
- Habit to understand data
- Availability of large dataset (already flagged) thanks to MC

# MRI motion correction

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- Project submitted as a PRIN (positively valued but not financed). Will be re-submitted as an *ERC Synergy*
- Motion is a major limitation of several MRI applications
  - Fetus brain diagnosis
  - Alzheimer and Parkinson patients
  - Children?



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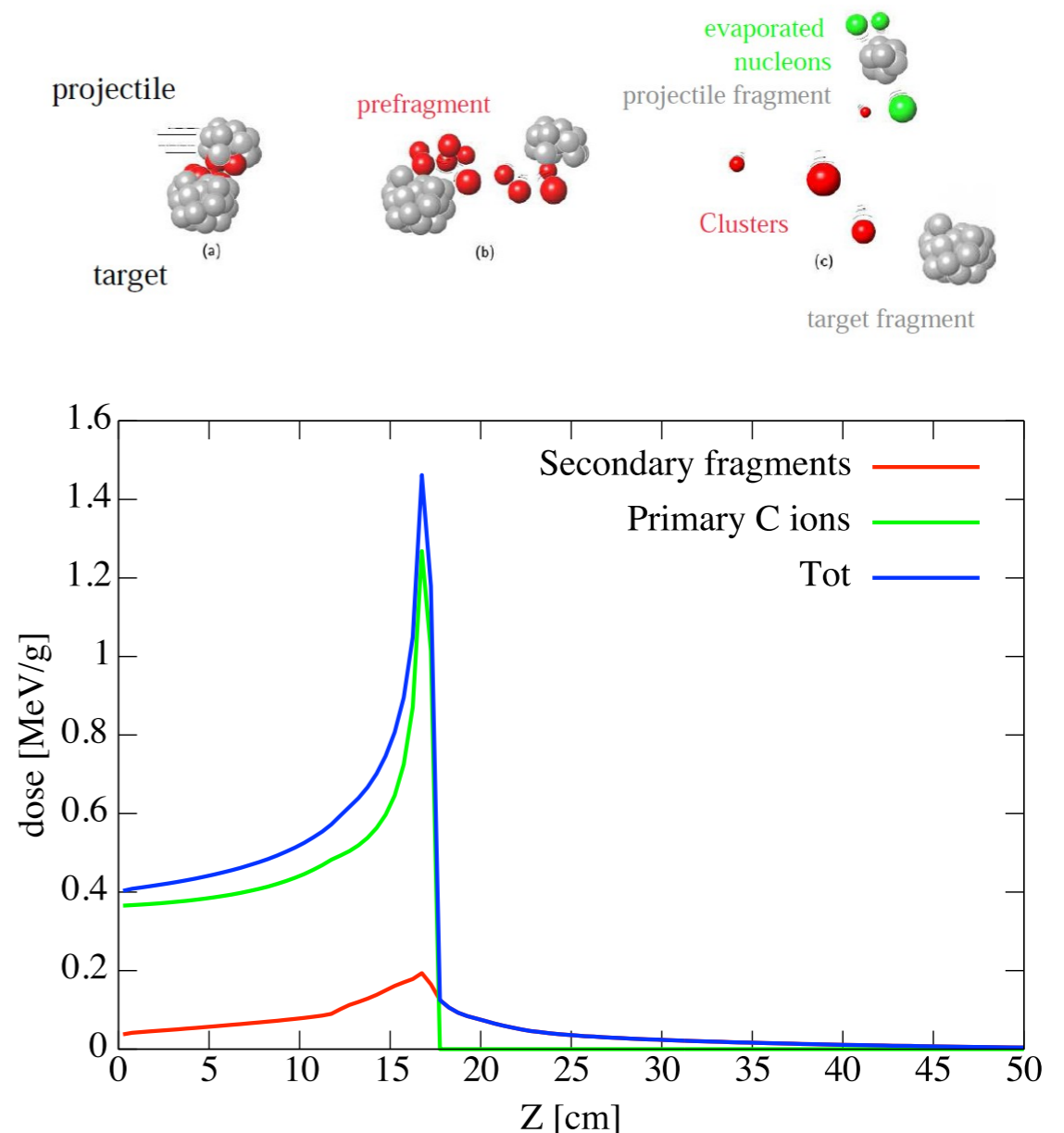
# Value added by physicist

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- Online correction and guidance of the MRI machine
- ML with high throughput  Similarly to a 2<sup>nd</sup>/3<sup>rd</sup> level trigger of a HEP experiment
- Applications of different techniques developed for HEP
  - Distillation to equivalent (and simpler) model
  - Porting model to FPGA
- Different groups involved: APE, HEP, Applied Ph., CNR, Naples

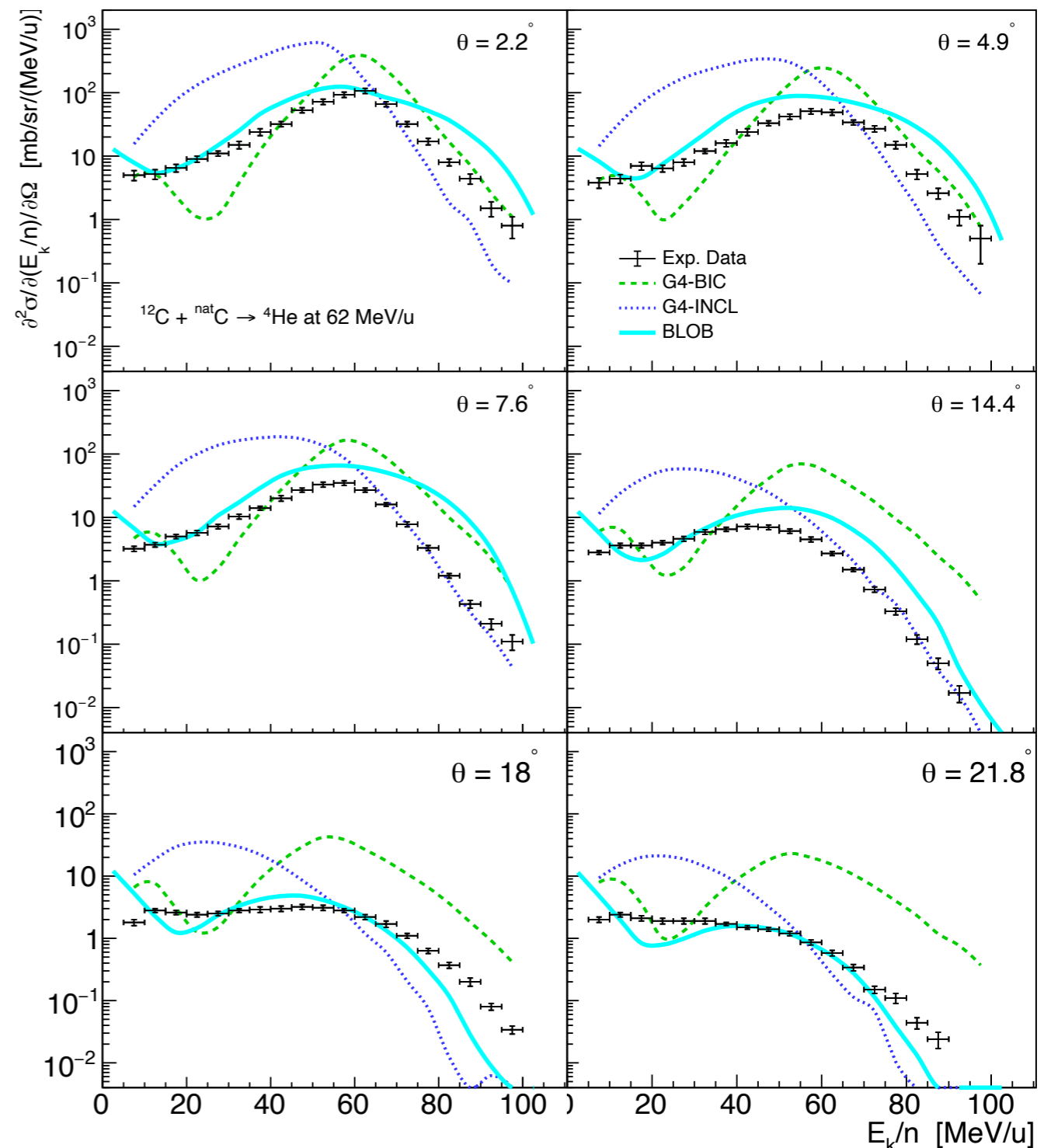
# Emulating BLOB with Deep Learning

- MC is the gold standard for ion-therapy dosimetry
- Nuclear fragmentation is of utmost importance as fragments contribute significantly to the total dose
- BLOB (Boltzmann-Lagevein One Body) is a model developed by LNS theoreticians



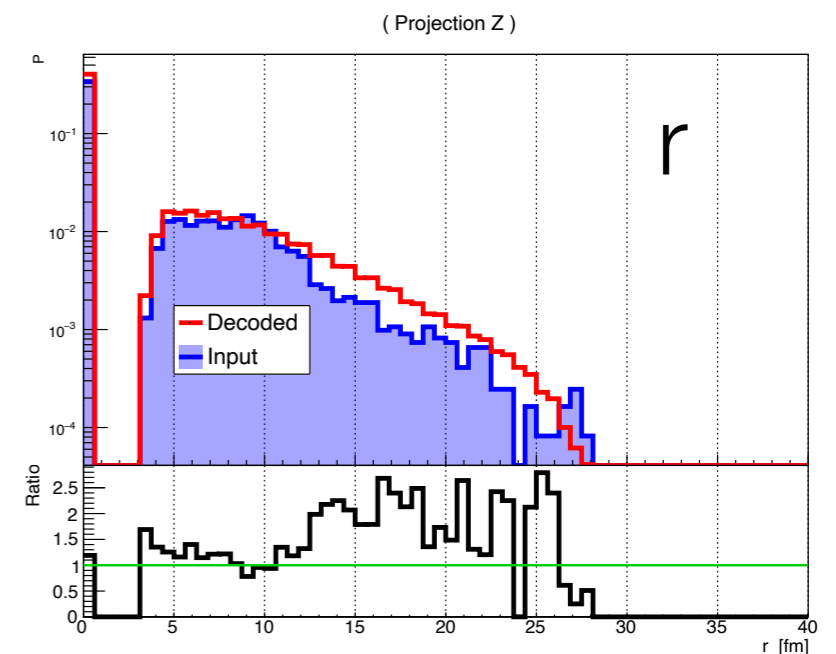
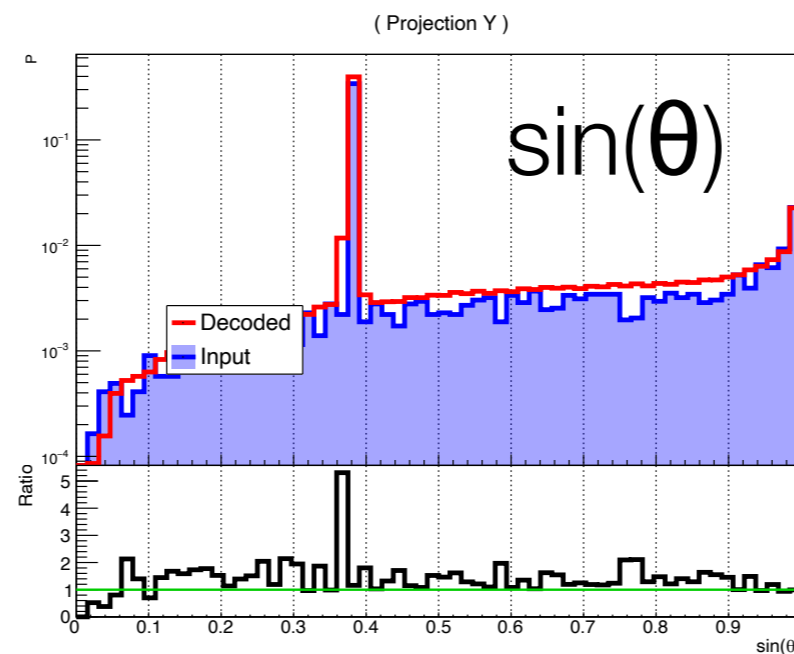
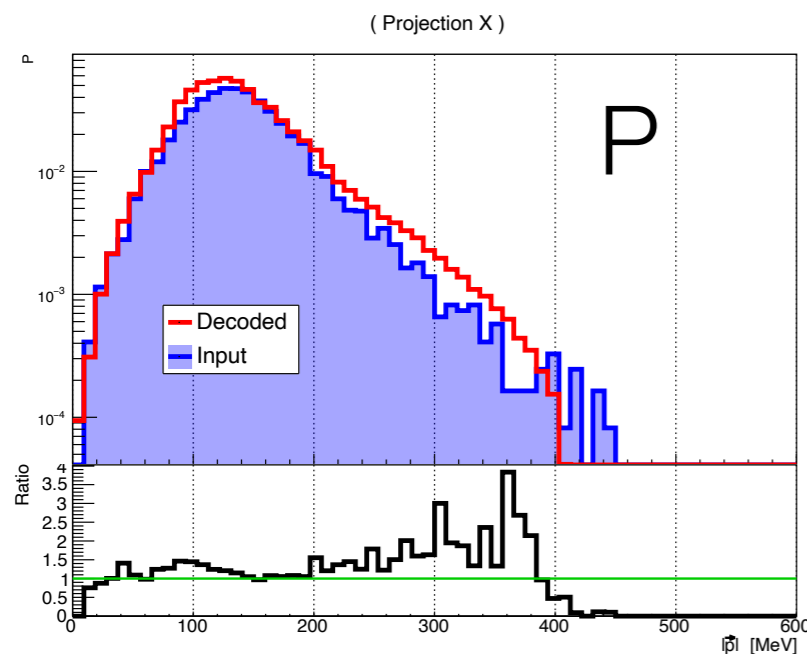
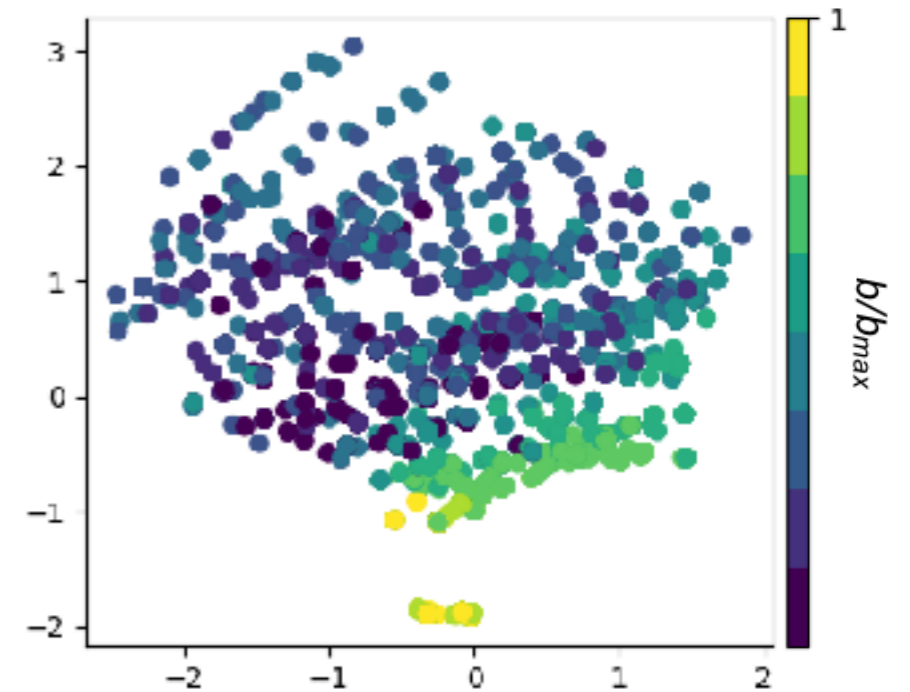
# Emulating BLOB with Deep Learning

- Promising results in interfacing BLOB with Geant4
- Running time too large (mins. per interaction)
- We are exploring the possibility of emulating BLOB with a generative DL algorithm



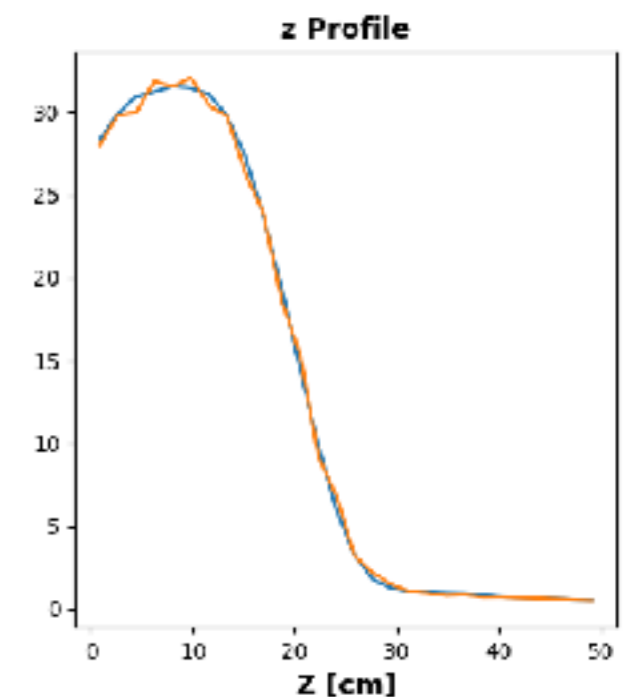
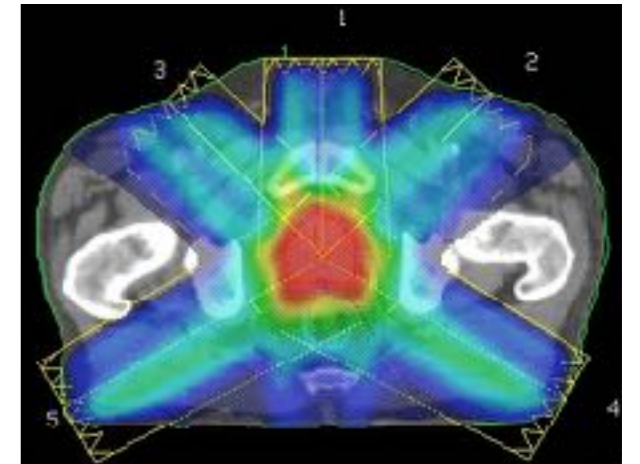
# Emulating BLOB with Deep Learning

- Preliminary results are encouraging
- A model to simulate  $^{12}\text{C}$  interactions will be released soon



# Radiotherapy treatment planning optimisation with DL

- FLASH effect: ultra-high dose rate radiation reduces the normal tissue toxicities
- A robust, reliable treatment plan optimisation strategy is mandatory to evaluate the potential of FLASH effect in a clinical scenario
- No energy-fluence simultaneous optimisation ( huge amount of degrees of freedom, not an easy task...)
- See A. Sarti presentation
- We are exploring the possibility of using generative DL to develop a treatment planning optimisation algorithm



# Summary

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- As physicists, we can contribute with our approach to the research on AI
- Several AI techniques can be effectively applied to many physics field
- and to physic applications to medicine

*Thank you for your attention!*

