A quantitative assessment of the role of nuclear reaction processes in the observed boron induced radiosensitization of proton beams

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Geant4 Monte Carlo Geometry

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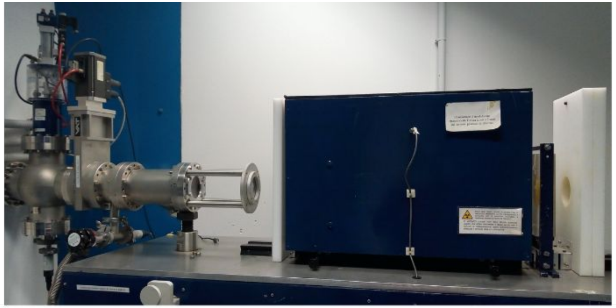
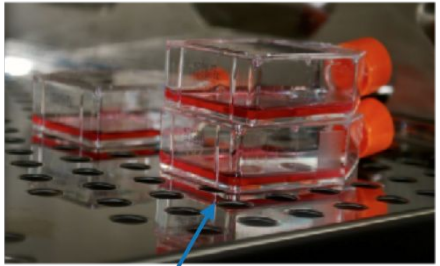
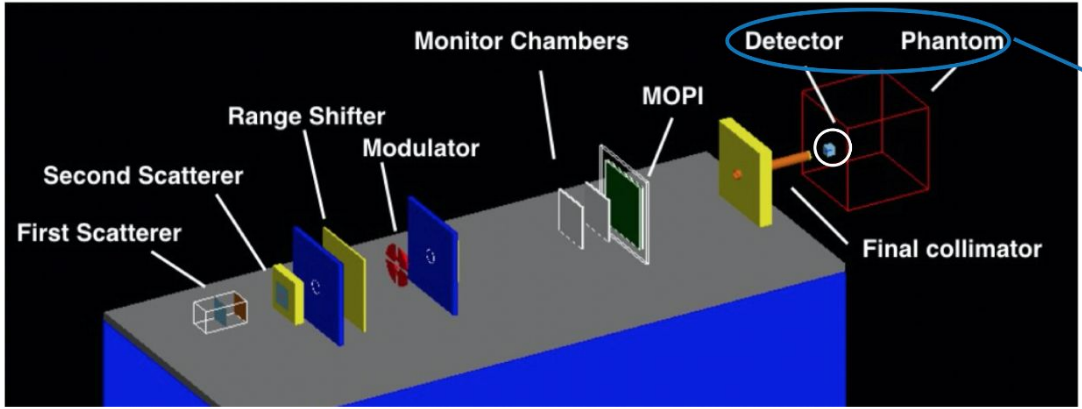
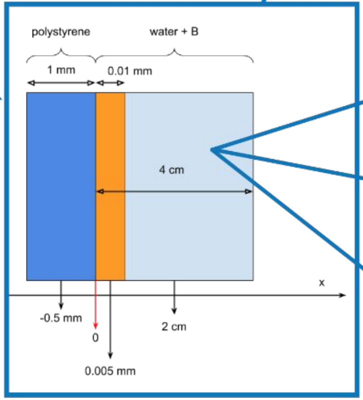
Hadrontherapy Official Geant4 Advanced Example
modelling the CATANA eye proton therapy facility @ LNS-INFN









$\rho_{water+B}$ = 1*g/cm^3

B[%] = 5%

B with natural abundance

Geant4 Monte Carlo Physics

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Geant4 simulation: geant4-10-06-patch-01 (14-February-2020)
G4PHP_DO_NOT_ADJUST_FINAL_STATE=1

TALYS calculations:TALYS-1.9

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G4TENDL1.3.2/Proton/Inelastic/CrossSection
G4TENDL1.3.2/Proton/Inelastic/F02
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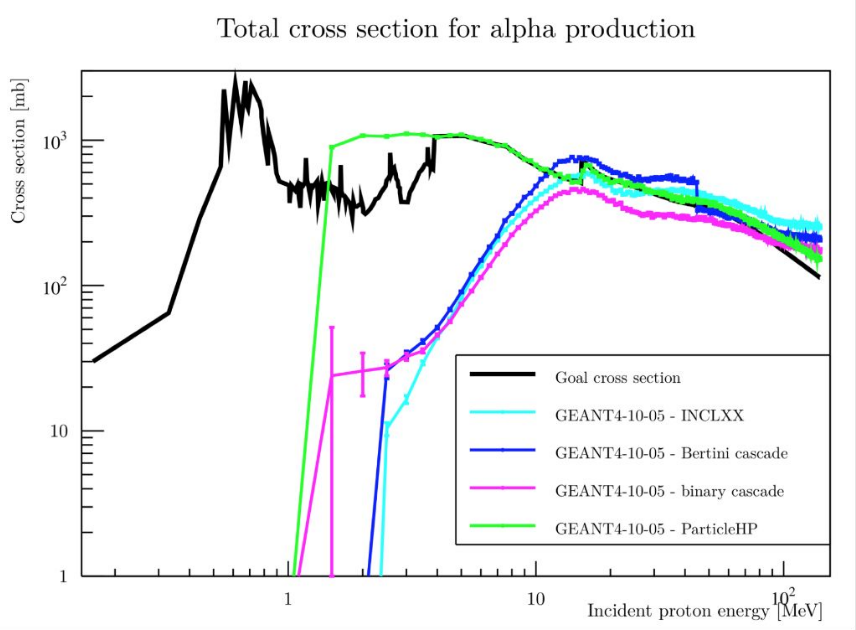

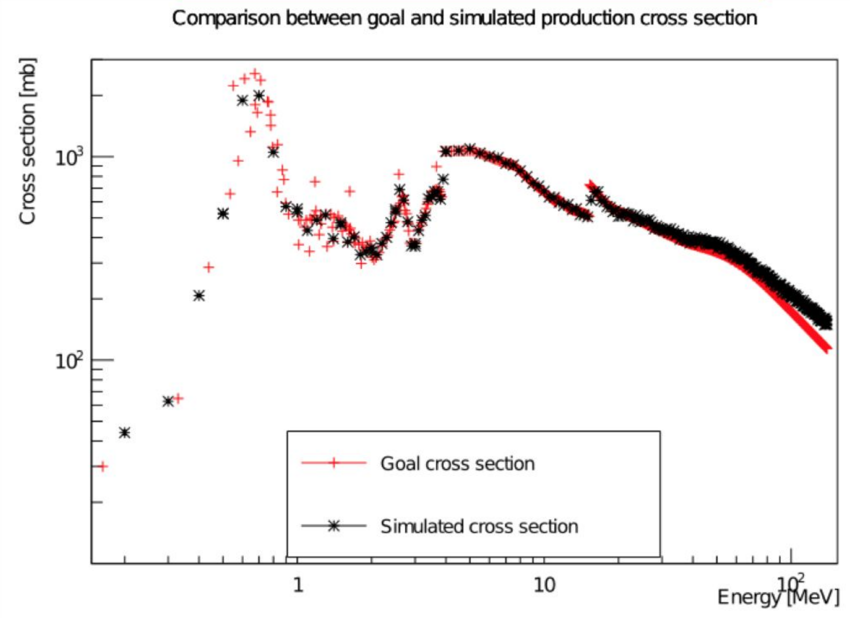

Monte Carlo strategy

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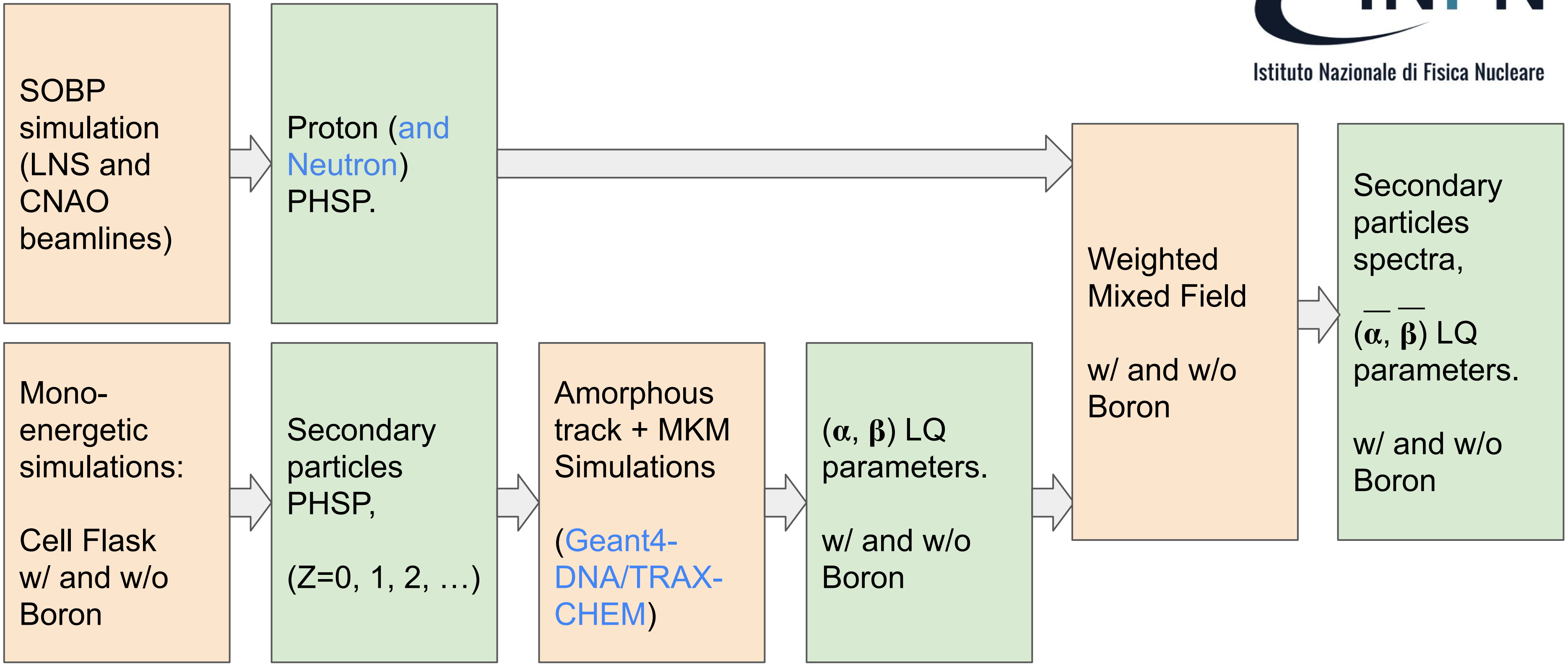

Mono simulation → secondary part. PHSP

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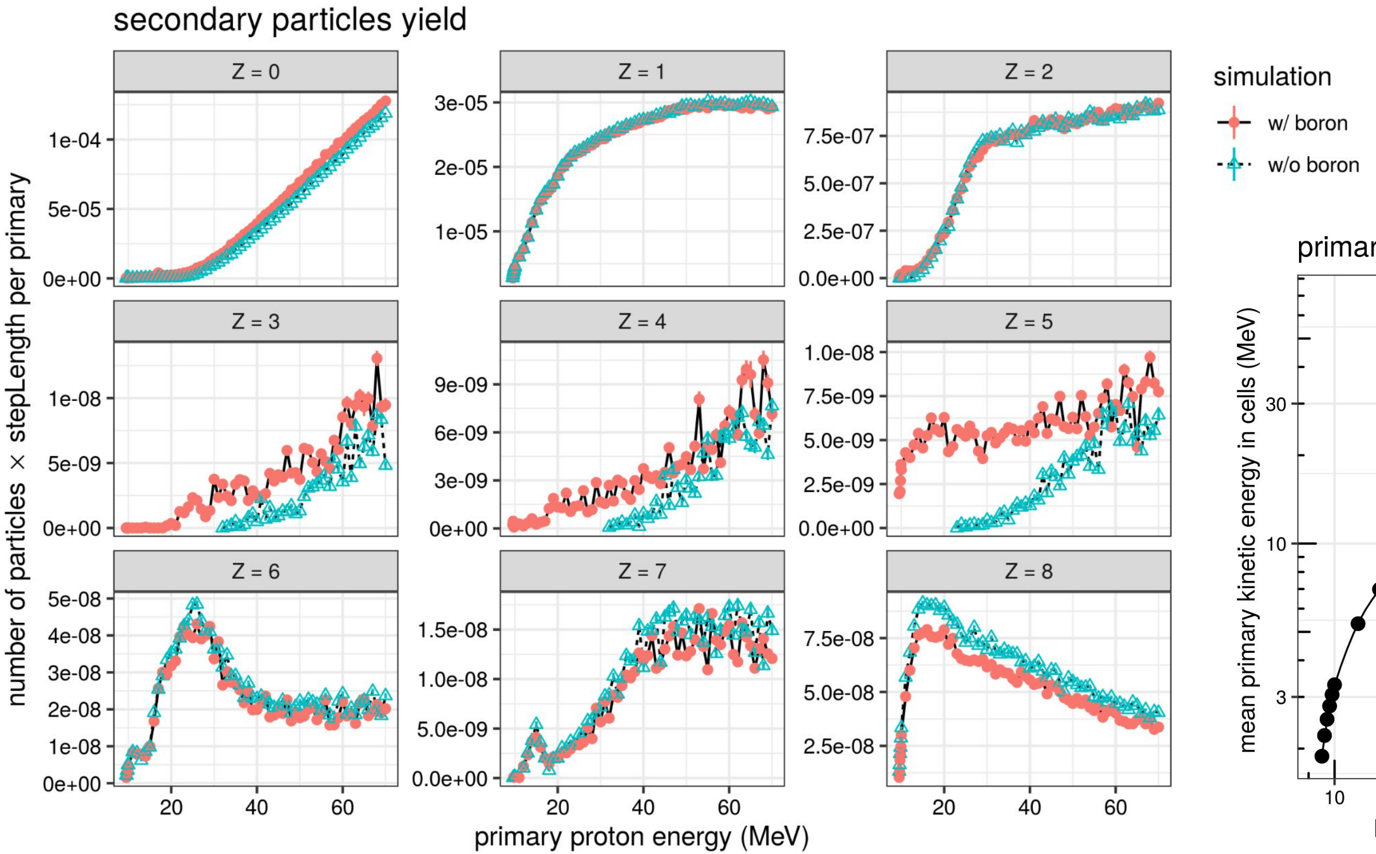
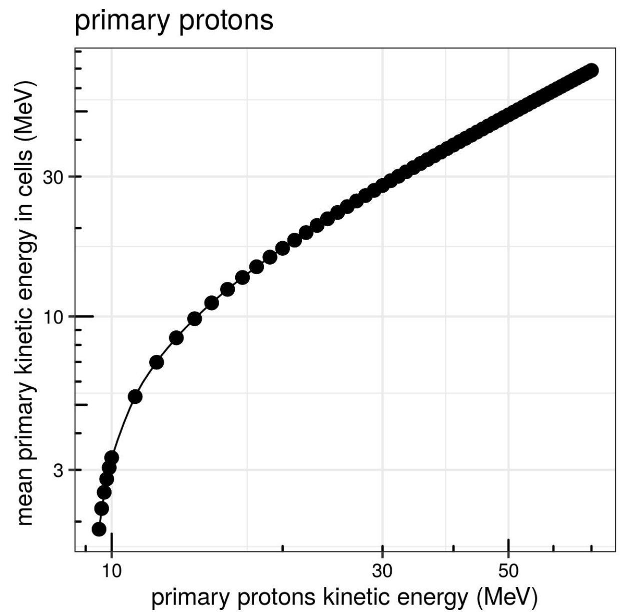
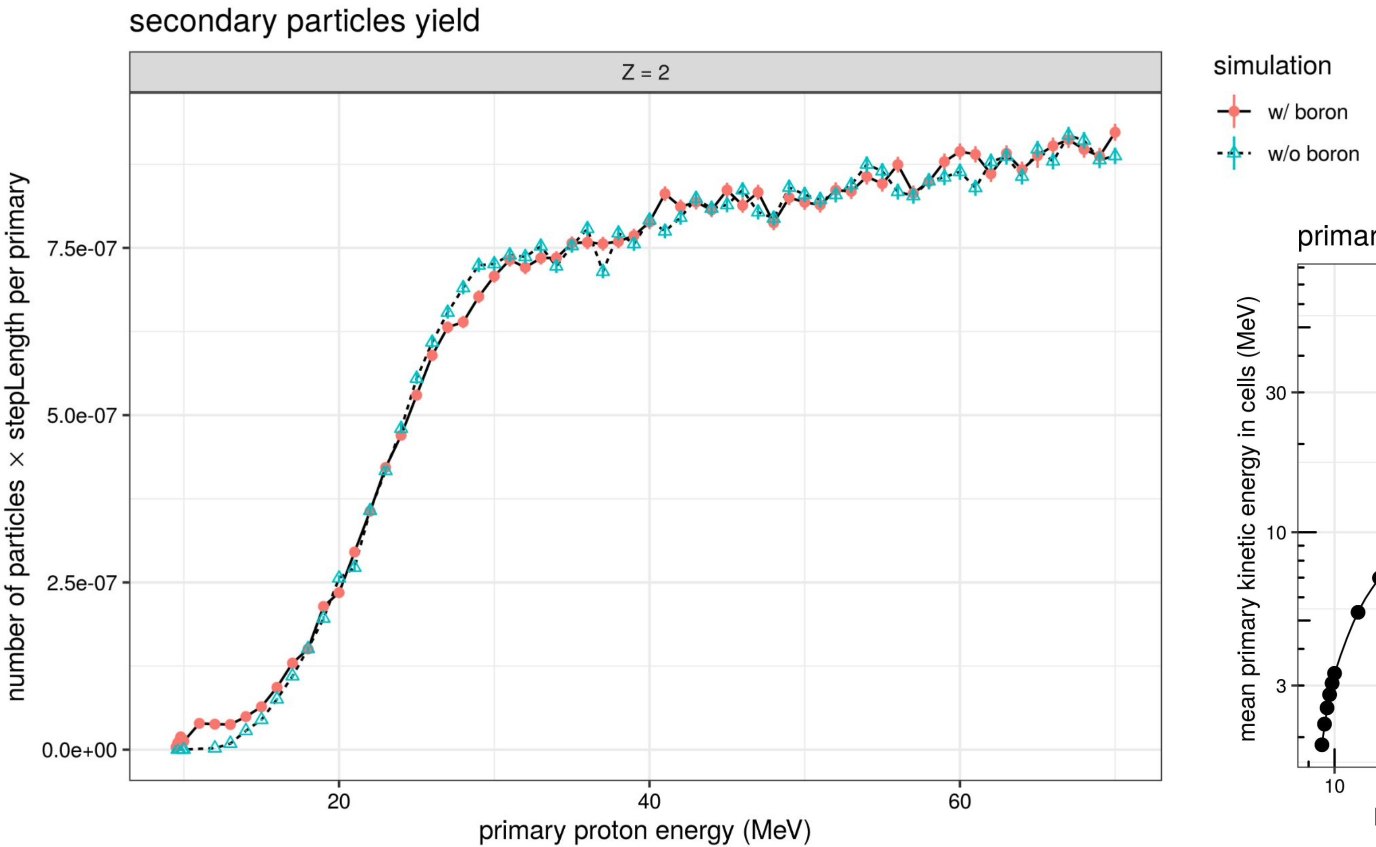
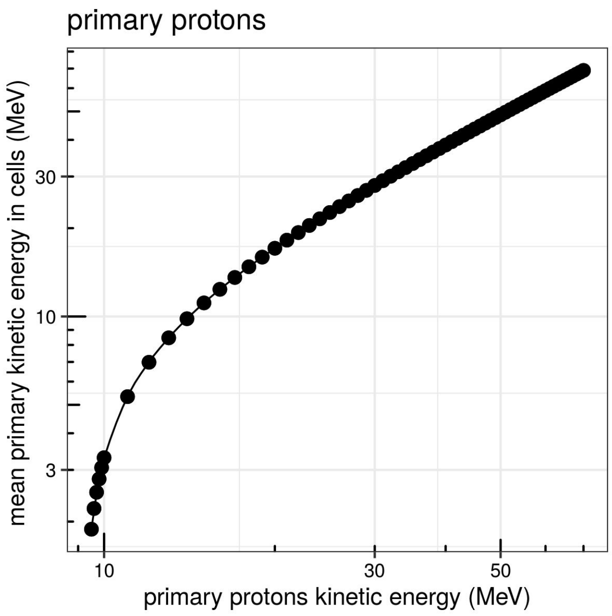


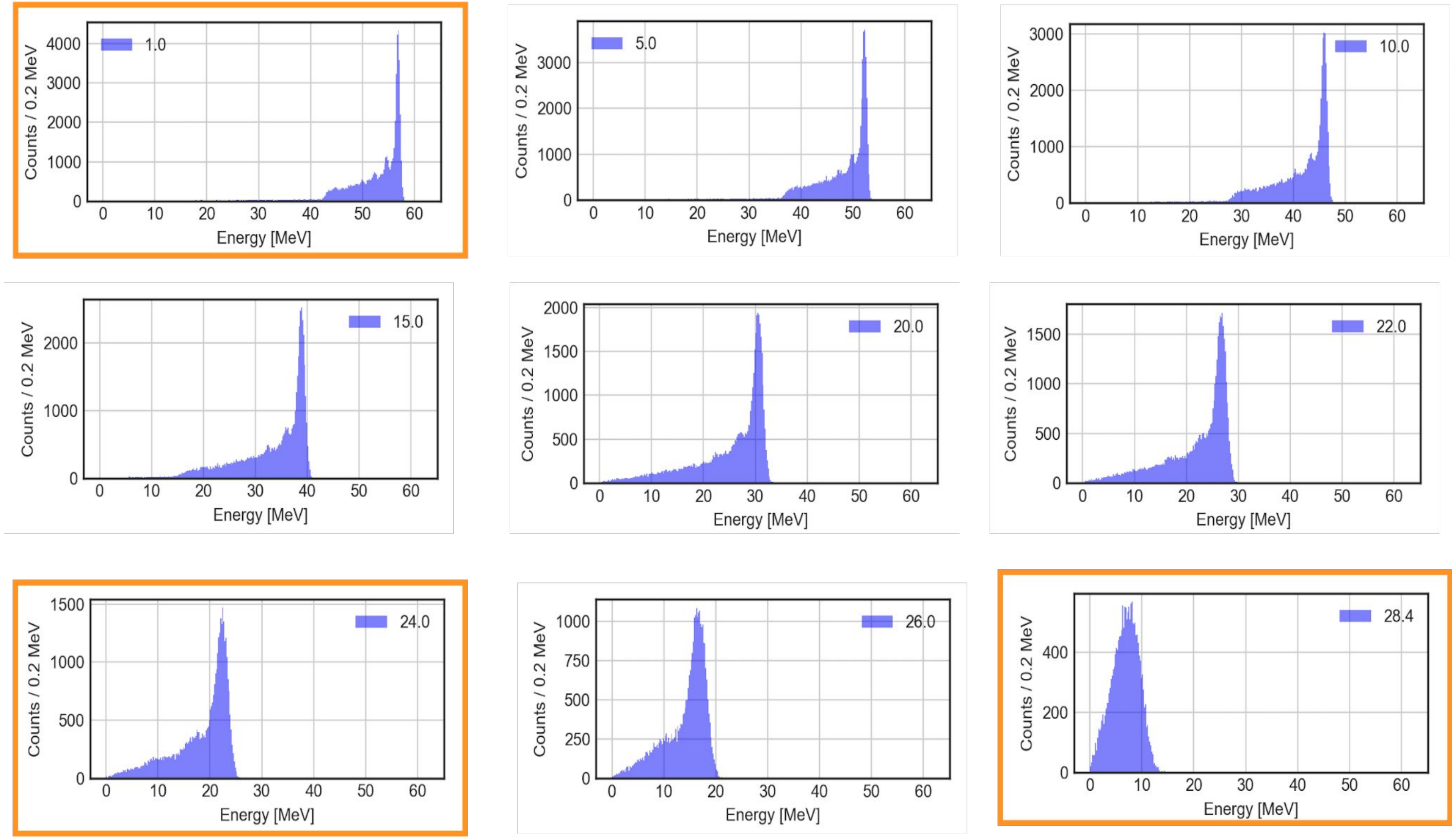


Mono simulation → secondary part. PHSP





SOBP simulations → Proton PHSP



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SOBP simulations → Proton PHSP

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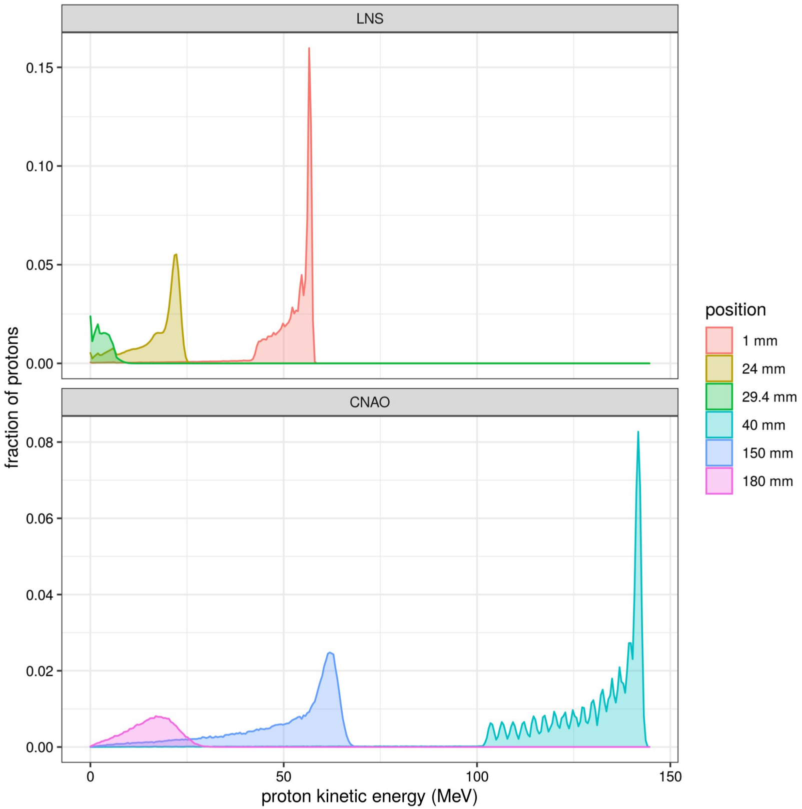

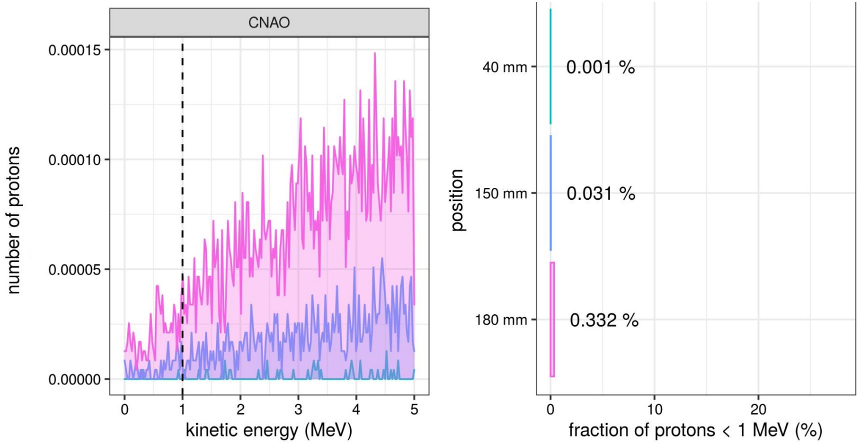

SOBP simulations → Neutron PHSP

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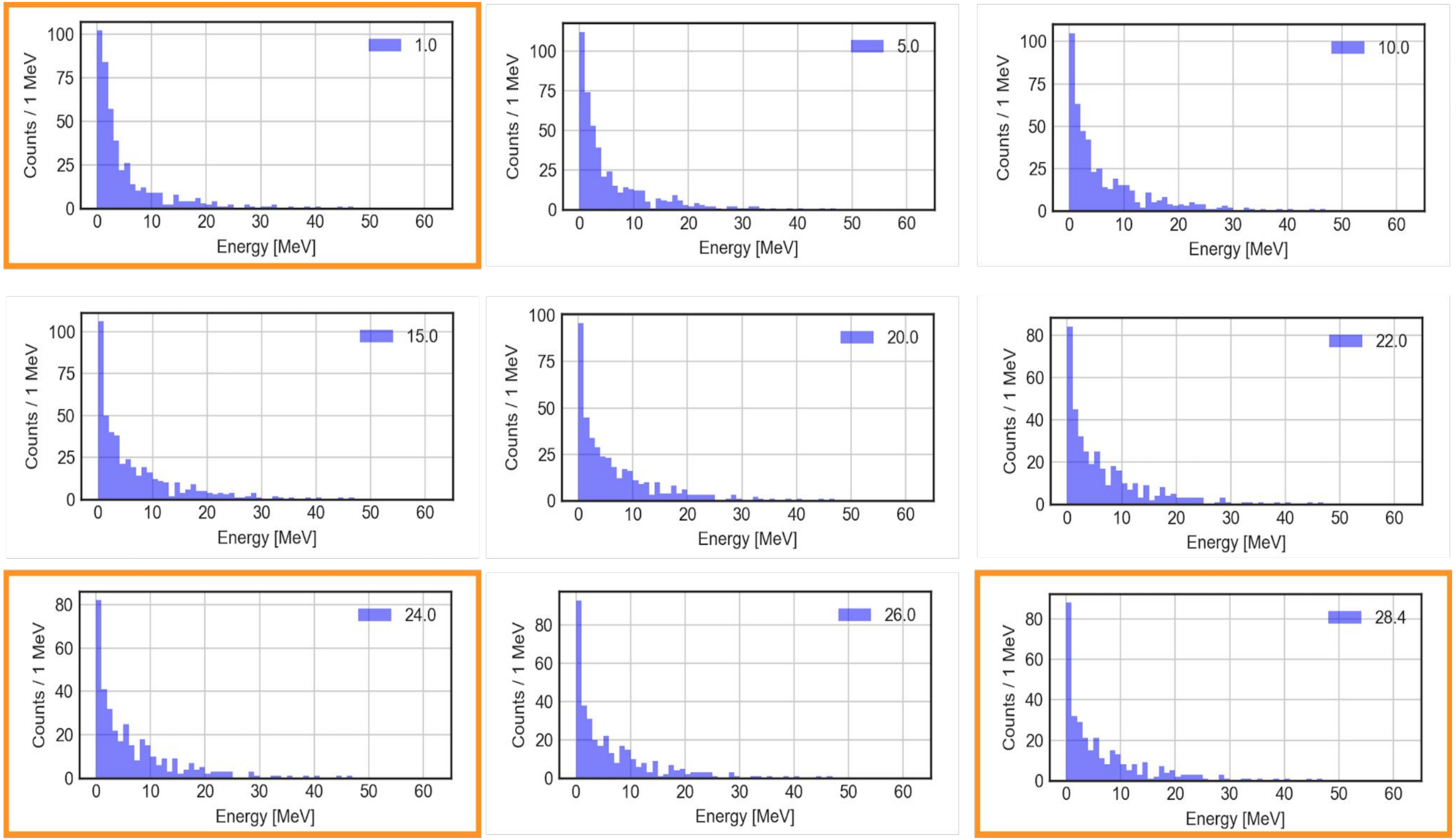
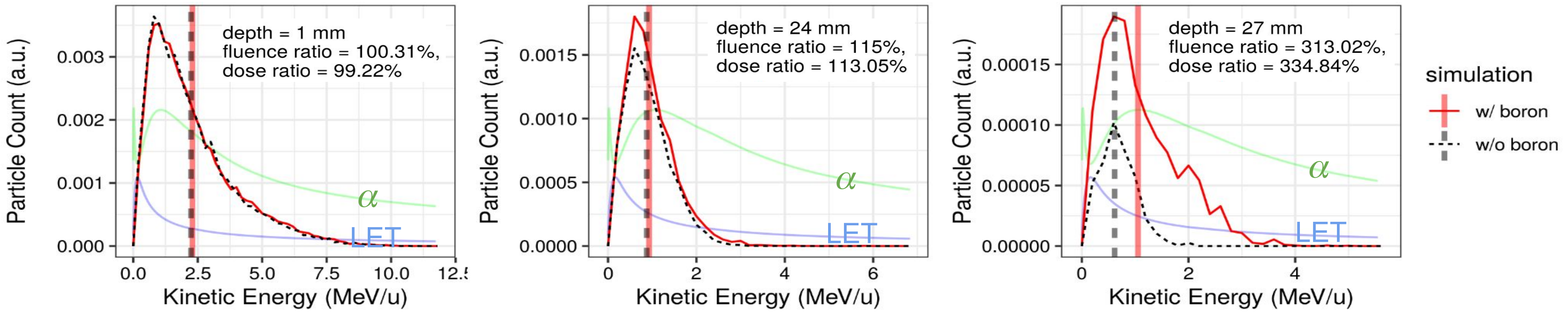
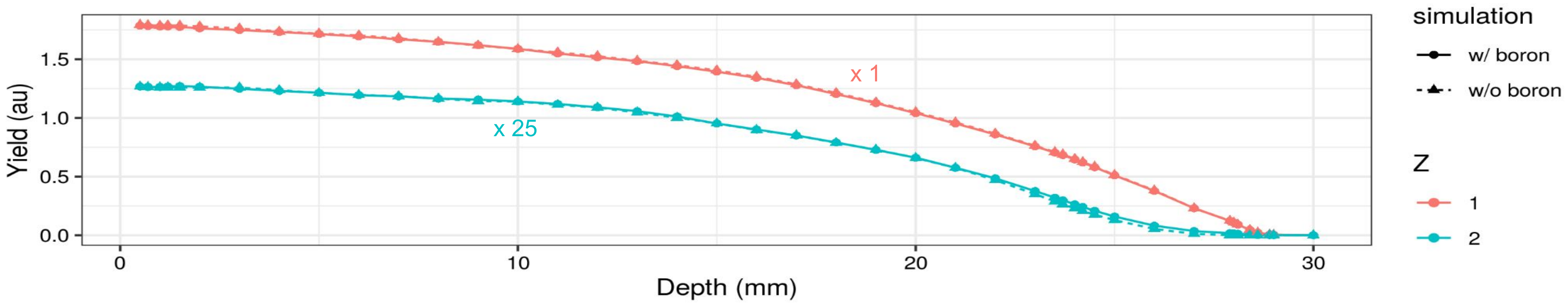
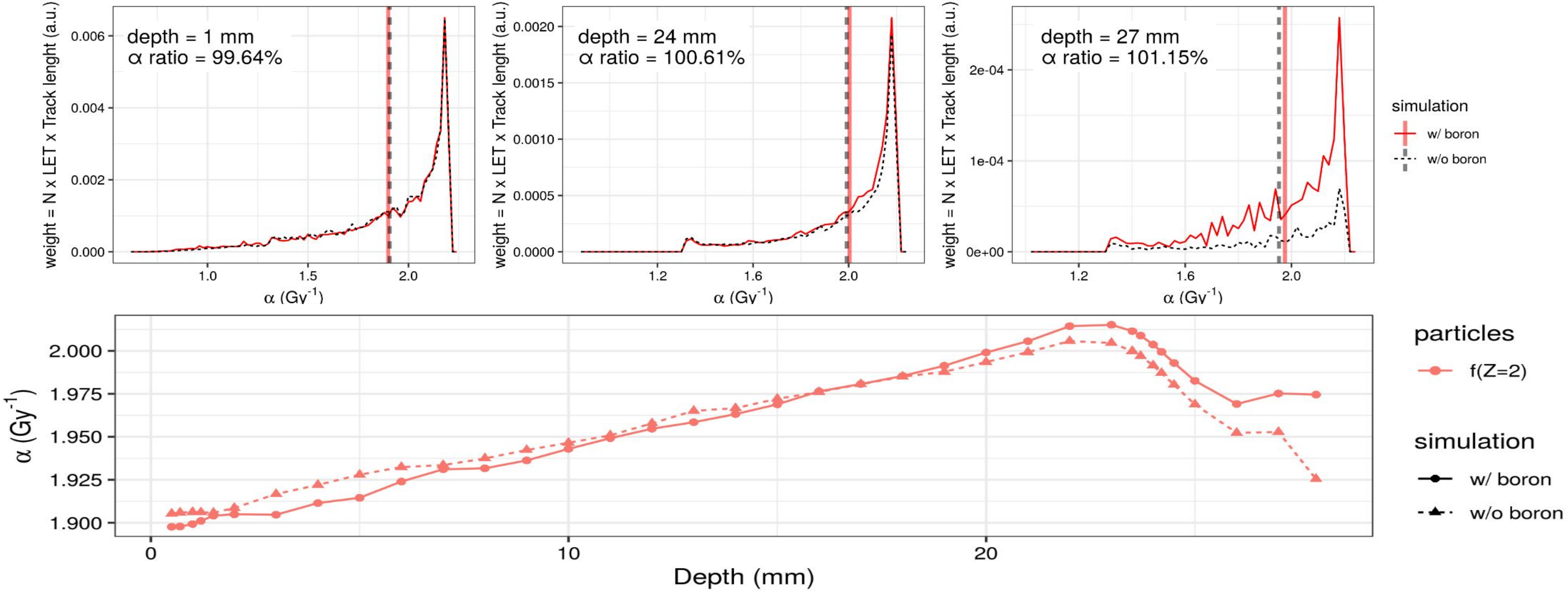


Alpha particle energy spectra and yield





L(Q) parameter alpha analysis (MKM)



Biological effect (α x Dose)

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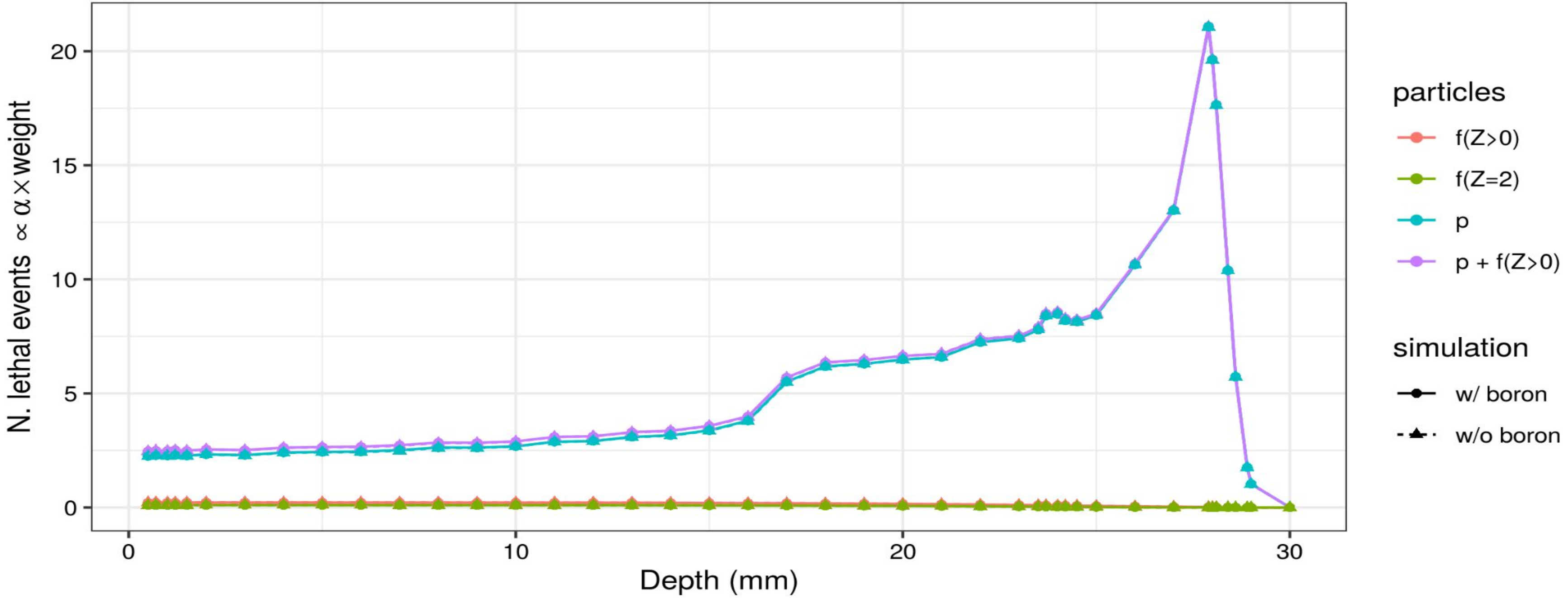

Conclusions

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- The specific biological effectiveness of the secondary alpha produced from proton - boron nuclear reaction has been investigated by means of MC simulations coupled with the MKM.
  - Accounting explicitly for range, energy and LET spectra of the particles
  - The overkill effect and non-track segment condition has also been considered for high-LET particles
- The specific biological effectiveness of these secondary alpha is negligible when compared to the effect of the full mixed field irradiation.
- The observed radiosensitization effect of boron remain to be explained.

Next Steps

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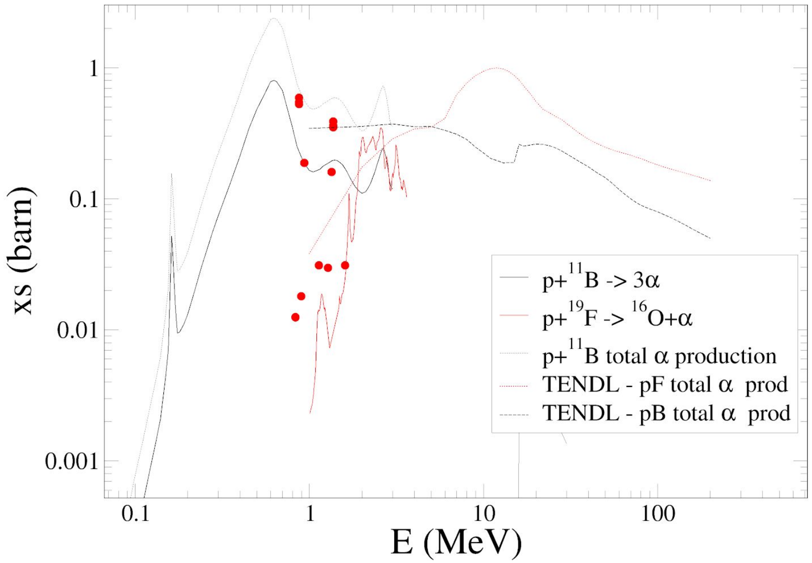
- End 2021 - Further simulations will be investigated including the other indirect reaction channels (**neutron capture**) + Comparisons with survival exp.
- 1 yr Extension - Evaluation of the micro/nanodosimetric spectra & reactive species by means of **Geant4-DNA/Trax-Chem**
    - Fluorine
    - Bystander effect (effect of alpha particle on cell signaling)

S. Fattori … %	E. Scifoni 20 %	G. Petringa … %
A. Attili ... %	F. Tommasino 10 %	P. Cirrone … %

Next Steps: Fluoride Simulations

- Defined Carrier Molecule:
  - F-BPA (double effect? -ready to be tested)
  - FDG (independent effect)
- Similar cross sections for alpha production, different:
  - Multiplicity
  - Energy range of maximum yield
  - Kinetic Energy of produced alpha   fragments
  - concentration/internalization (carrier dependent)
  - nuclear/molecule ratio



Fluoride: Initial Simulations

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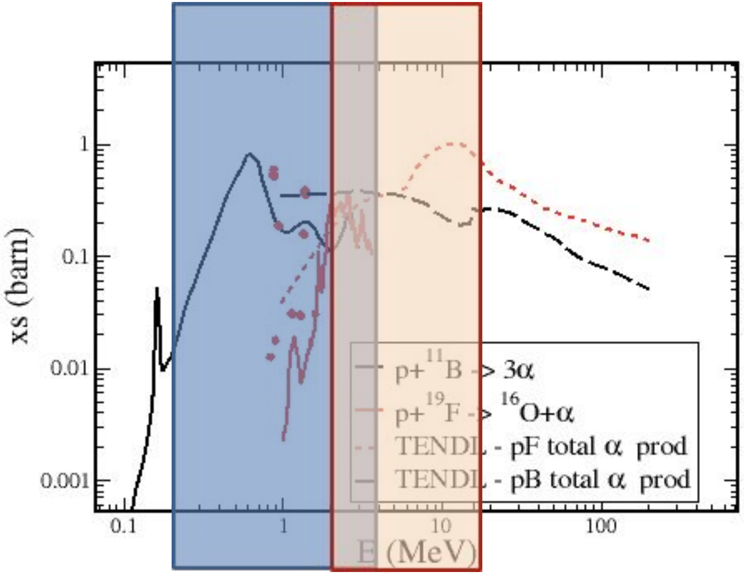
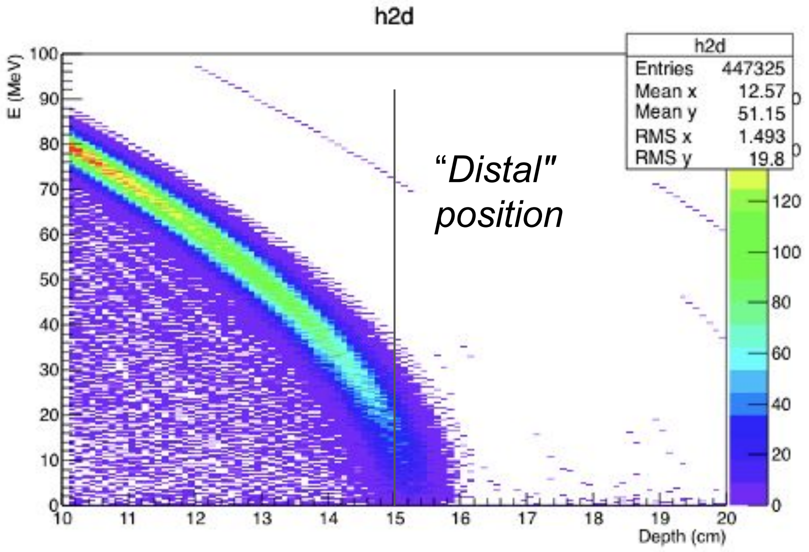
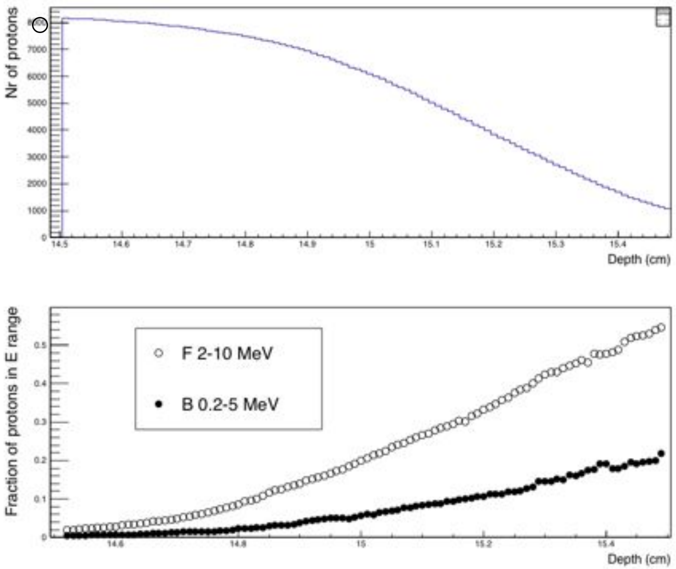


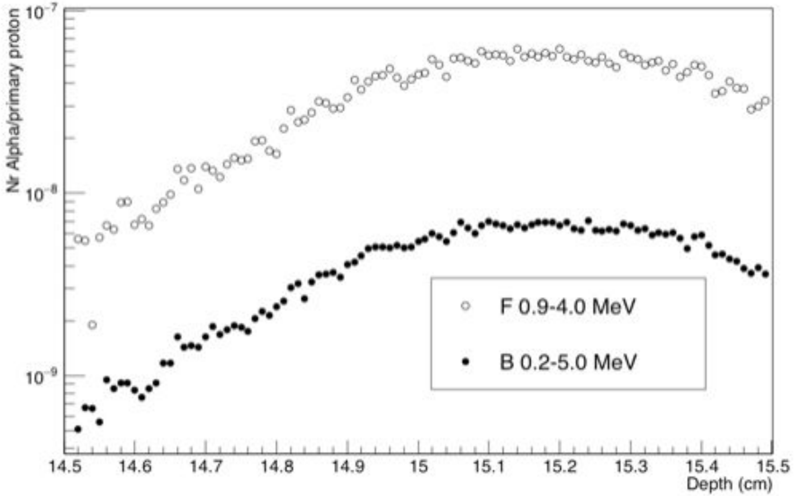


Simulated Proton E spectra across the depth of the "standard" (150 MeV) TIFPA beam (F.Tommasino)

Fluoride: Initial Simulations ^{19}F vs ^{11}B

- Impact of different p energy ranges on overall number of produced alpha





(F.Tommasino)

Fluoride: different alpha range impact

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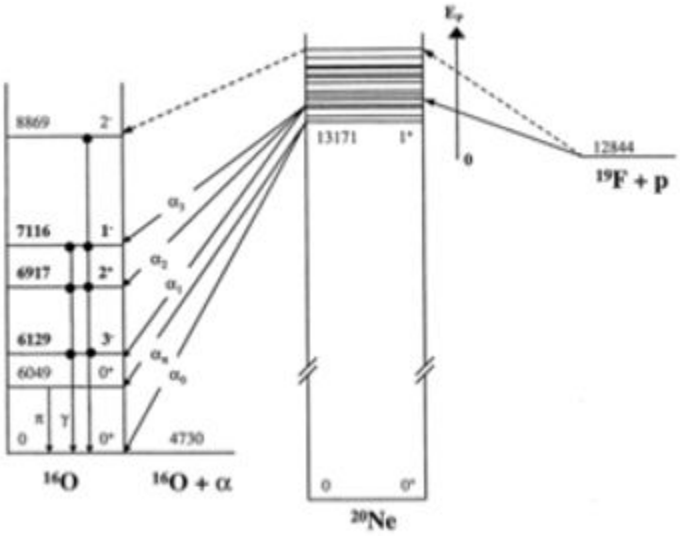
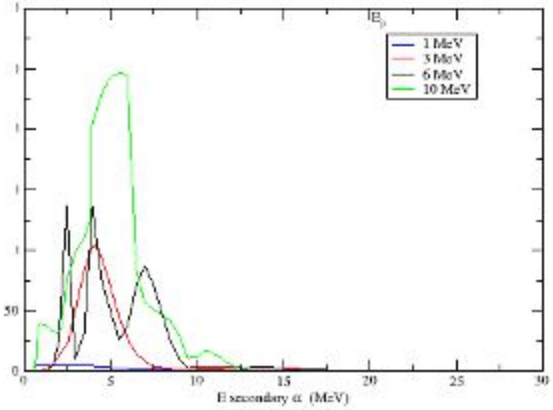


- p-F generated alphas are supposed to be generated at larger energy range, allowing more cell traversal



TENDL – Secondary particle spectra

- The impact of the larger range can be evaluated with the tools developed for p-B generated alpha

Chemical signature characterization

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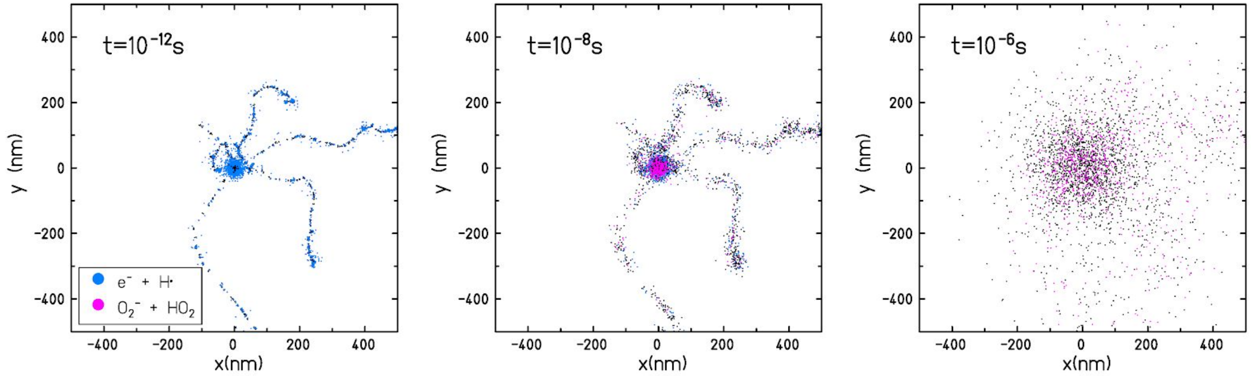

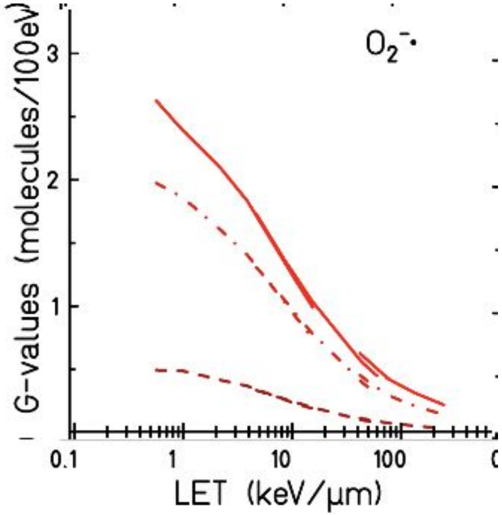

Geant4DNA and TRAXCHEM calculations of chemical profile at different alpha energies

Imaging and quantification → INFN-Roma1 & INFN-Pavia & INFN-Caserta

Radiobiology → INFN-Naples & CNR-IBFM

Microdosimetry → INFN-LNL & INFN-LNS & INFN-MI

Simulation and modeling → INFN-Rome3 & LNS & TIFPA

NEPTUNE
Nuclear process driven Enhancement of Proton Therapy UNravEled

Thank you for your attention!

External Collaborations

FONDAZIONE BRUNO KESSLER

UNIVERSITY OF WOLLONGONG AUSTRALIA

IBFM

BRUKER

CAPiR
Center for Adva

UNIVERSITÀ degli STUDI di CATANIA

eli beamlines

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