

Hadrontherapy: status, recent updates, and new developments

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Geometry:

- PassiveProtonBeamLine**
- PassiveCarbonBeamLine**
- LaserDrivenBeamLine**
- TIFPAPassiveProtonBeamLine**

Physics Lists:

- HADRONTHERAPY_1**
- HADRONTHERAPY_2**
- HADRONTHERAPY_3**

Hadrontherapy

Calculation of radiobiological quantities:

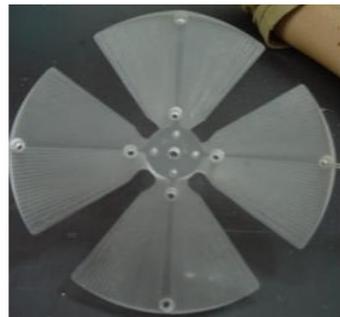
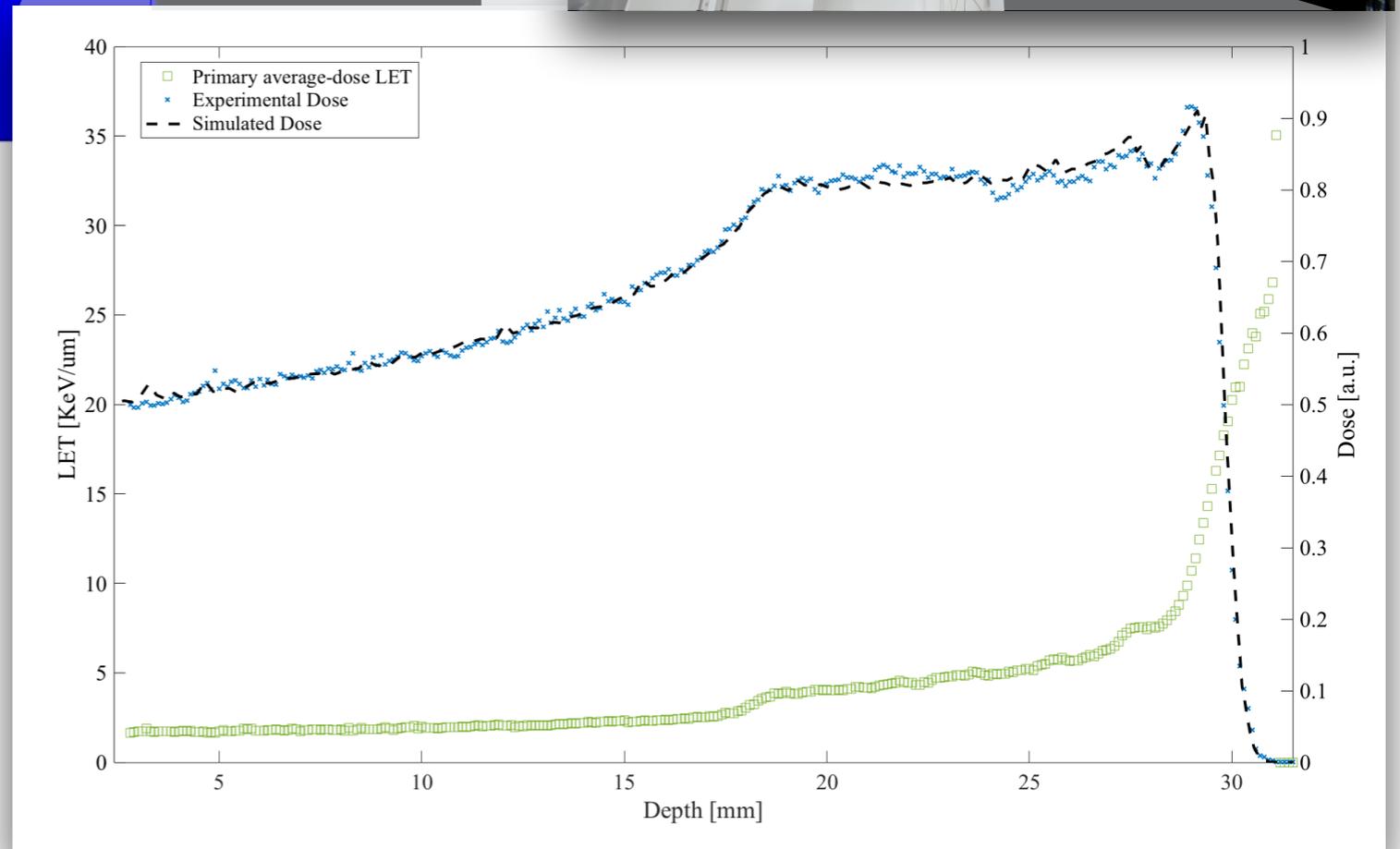
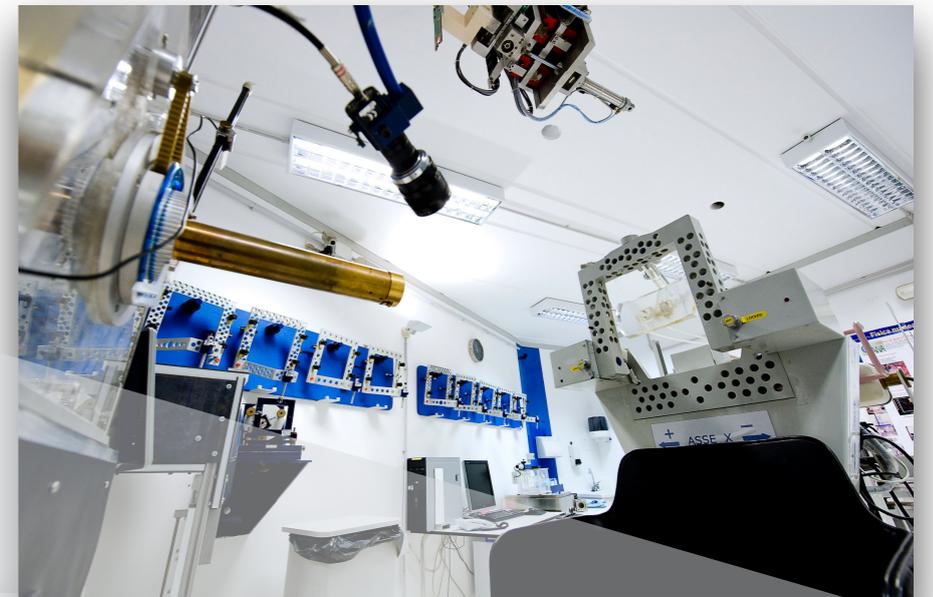
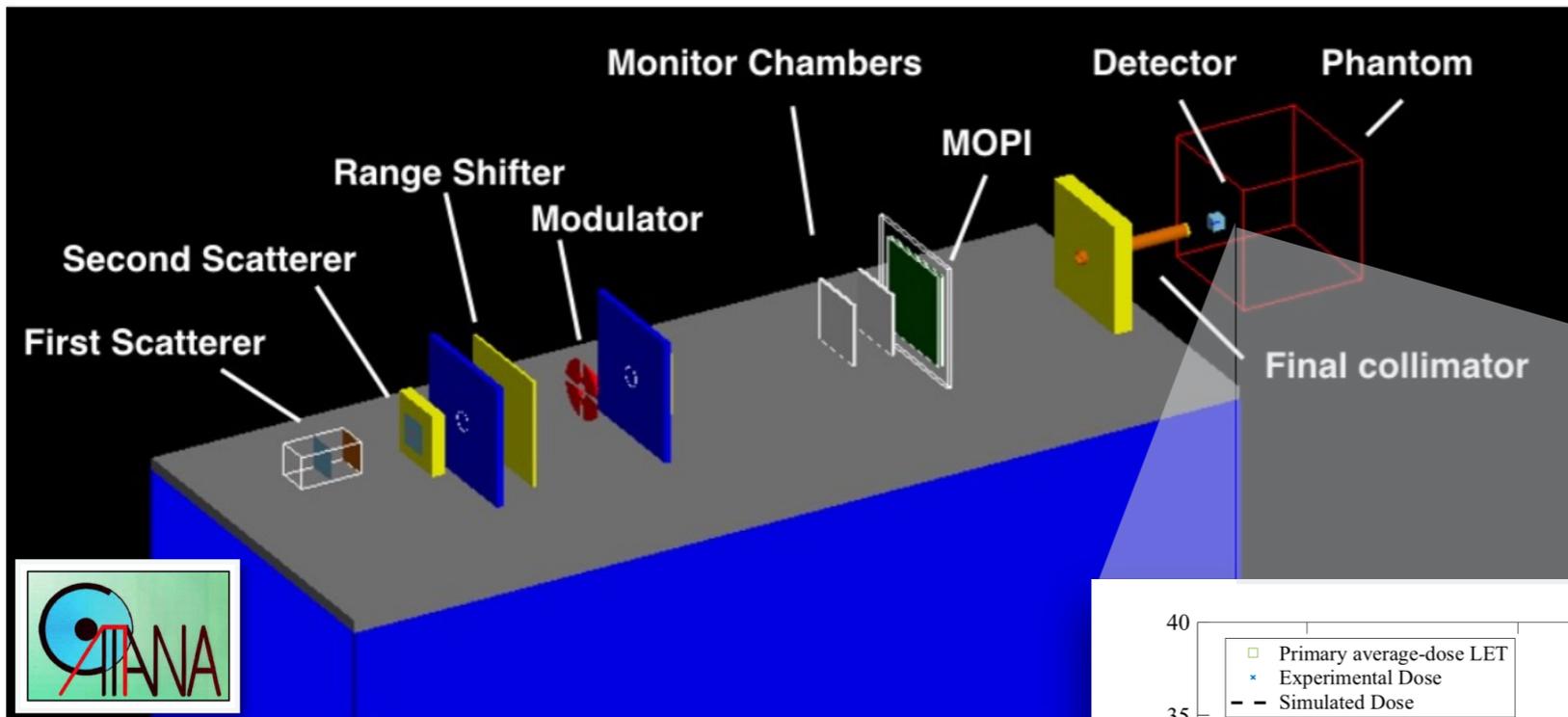
- Dose**
- LET-dose**
- LET-track**
- RBE**

Primary Event Generator:

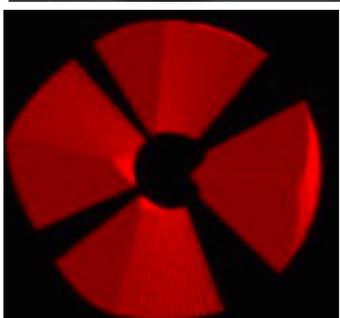
- Standard GPS definition**
- External Source**

Passive Proton BeamLine

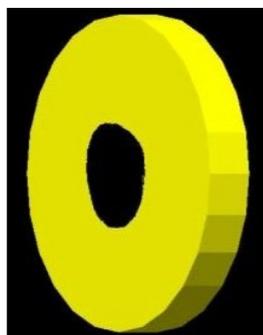
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Modulation

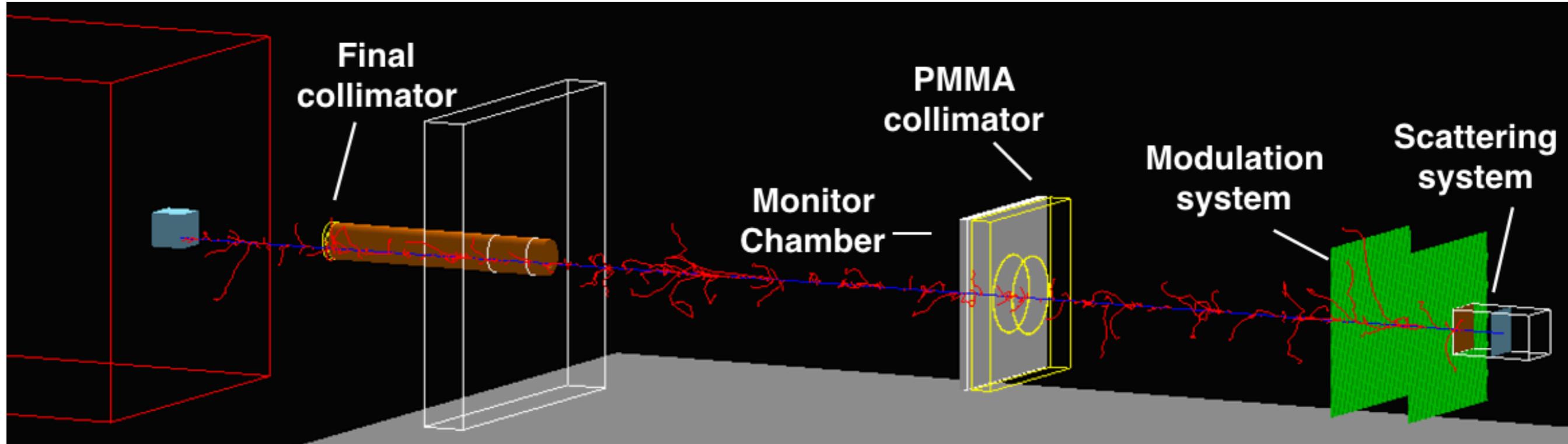


Collimation



Passive Carbon Beam Line

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Zero Degree Beamline
of LNS-INFN for
radiobiological experiments
with ions beams

New implemented Elements

Modulation system:

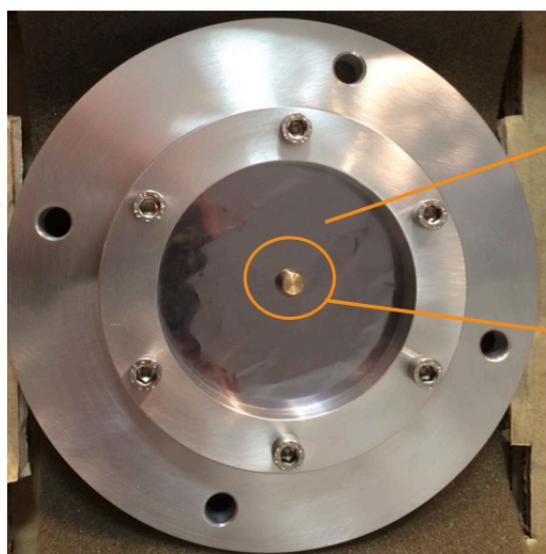
- **Ripple Filters (I2C)**
- **Ridge Filter (I6O and 4He)**

Scattering system:

Double foil with a central stopper

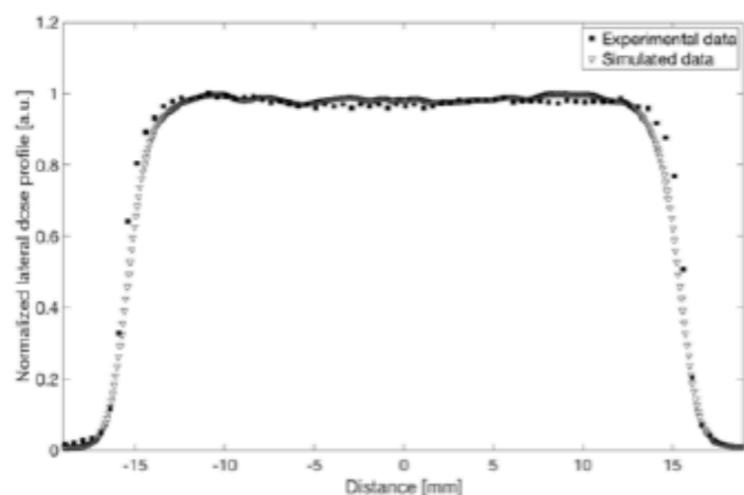
Scattering System

Double scattering foil with a central stopper



Tantalium
20um

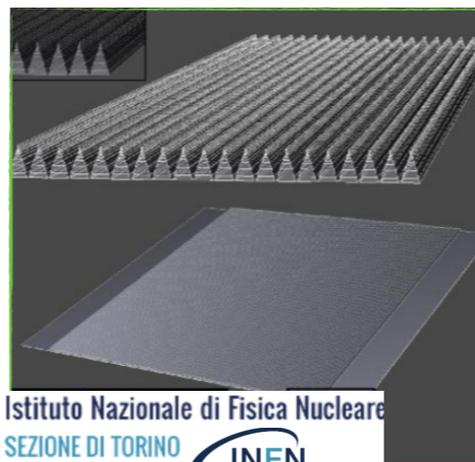
Brass
4 mm in diameter
7 mm in thickness



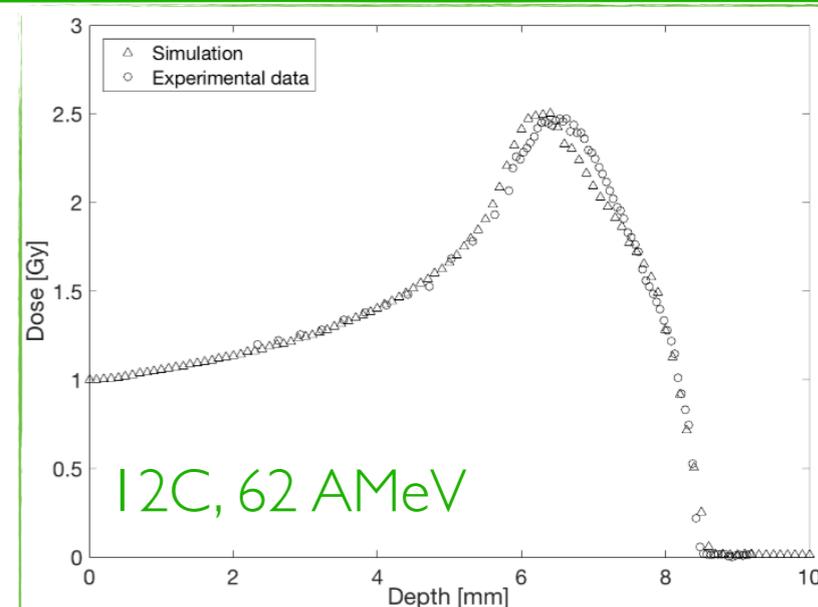
4He, 62 AMeV
12C, 62 AMeV
16O, 62 AMeV

Modulation System

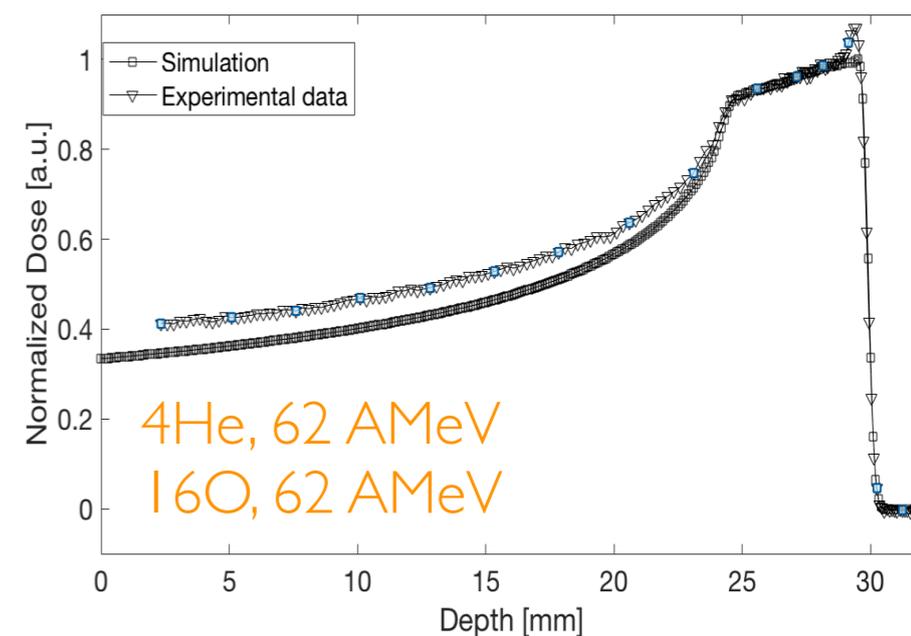
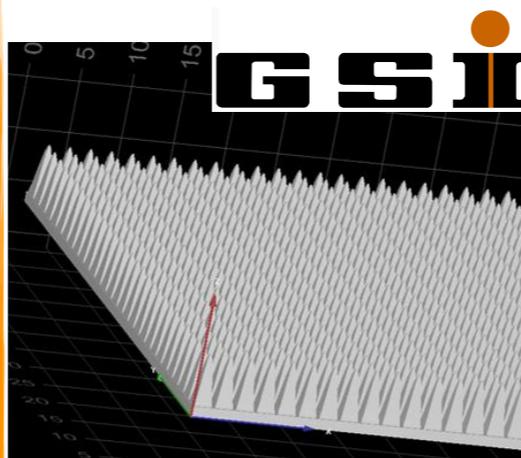
Ripple Filters



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SEZIONE DI TORINO
INFN

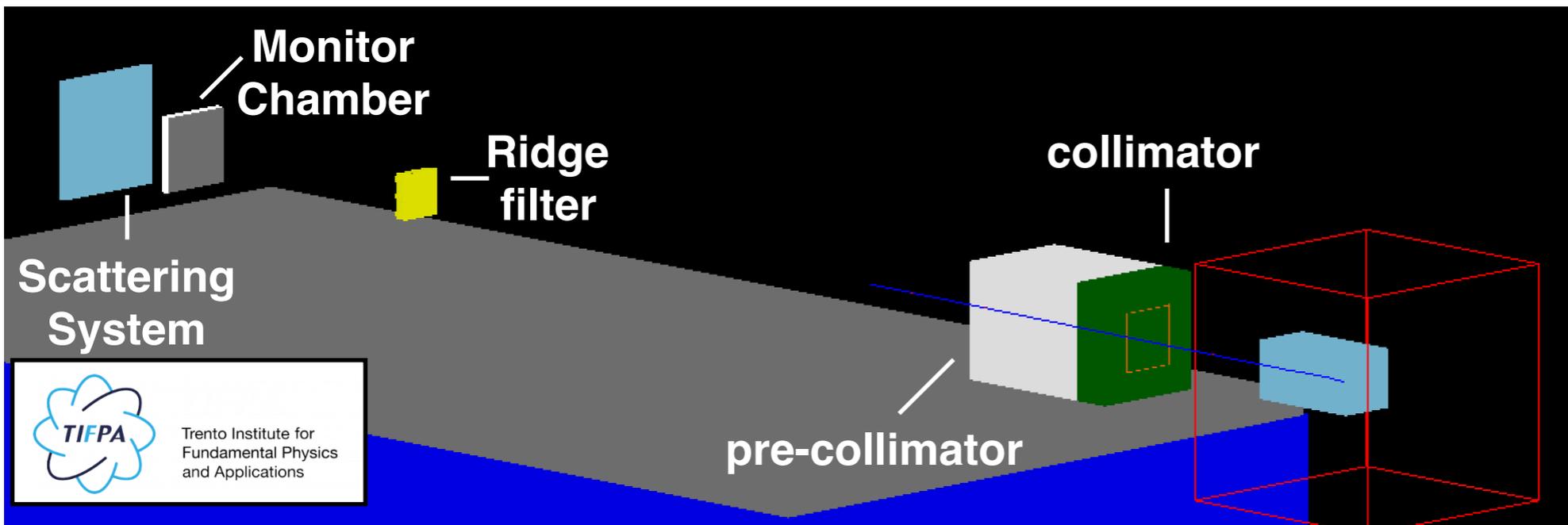


Ridge Filter

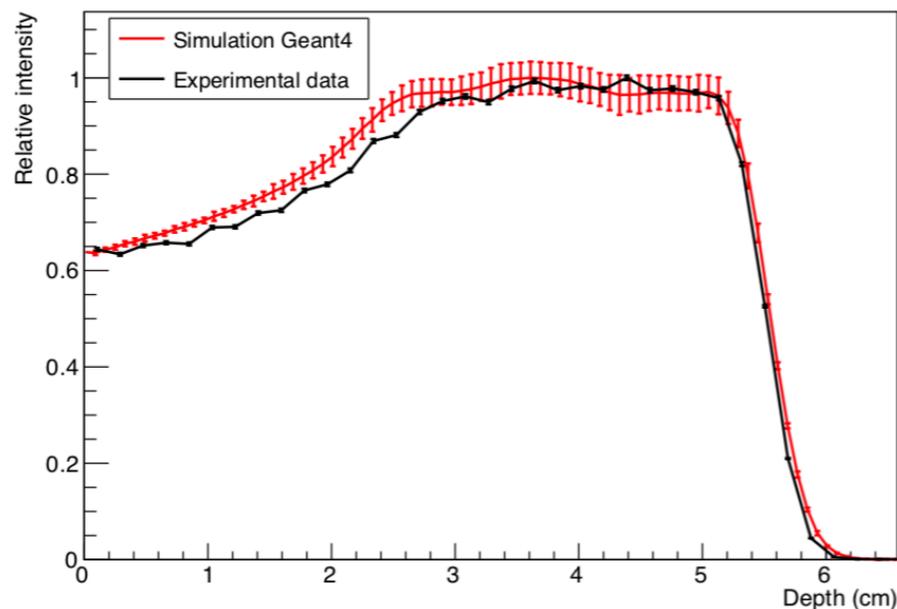


TIFPA Passive Proton Beam Line

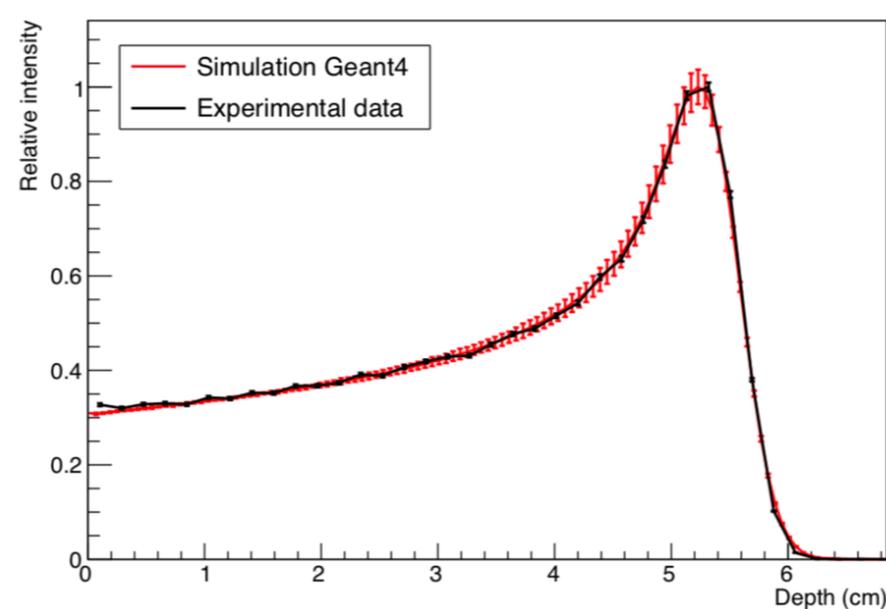
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Modulated Beam (p, 100 MeV)



Pristine Bragg Peak (p, 100 MeV)



Passive proton beam line

✓ Energy: from 70 MeV to 250 MeV

✓ Fluency: from 10^5 p/sec to 10^8 p/sec

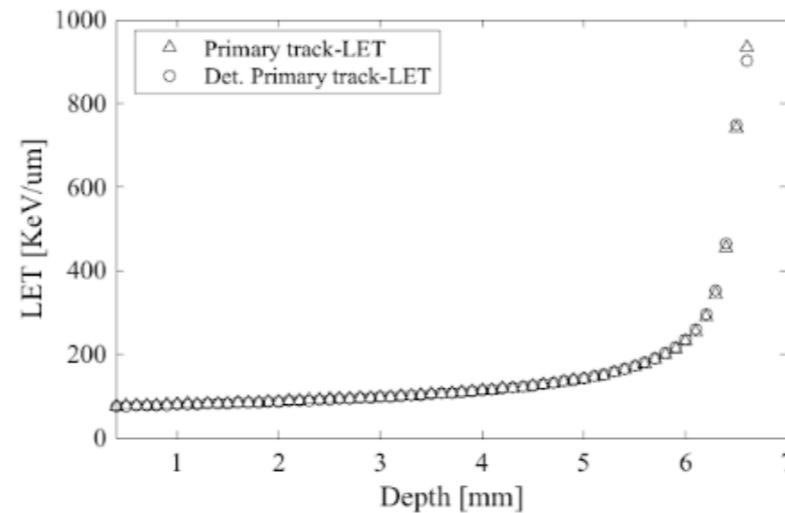
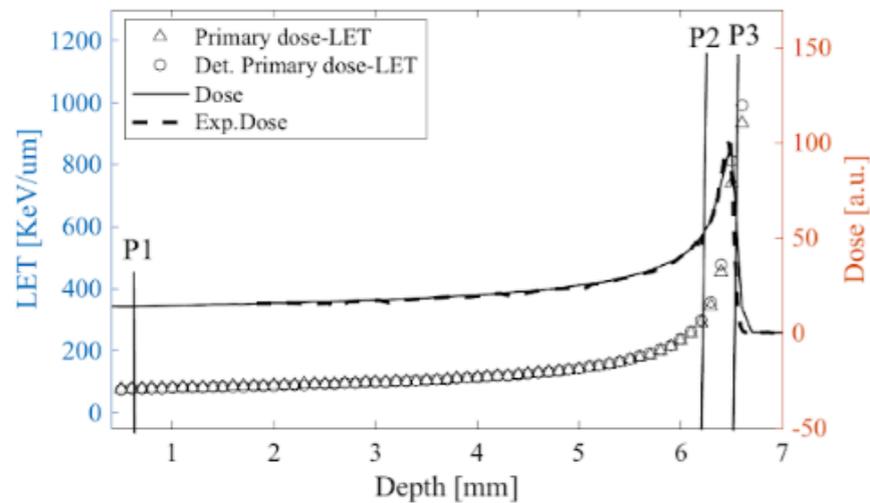
	HADRONTHERAPY_1	HADRONTHERAPY_2	HADRONTHERAPY_3
Electromagnetic	standard_opt4	standard_opt4	standard_opt4
	G4EmExtraPhysics	G4EmExtraPhysics	– G4EmLivermorePhysics
Hadronic	–	–	G4DecayPhysics
	G4DecayPhysics	G4DecayPhysics	G4DecayPhysics
	G4RadioactiveDecayPhysics	G4RadioactiveDecayPhysics	–
	G4IonBinaryCascadePhysics	–	G4IonBinaryCascadePhysics
	G4HadronElasticPhysicsHP	G4HadronElasticPhysicsHP	G4HadronElasticPhysics
	G4StoppingPhysics	G4StoppingPhysics	G4StoppingPhysics
	G4HadronPhysicsQGSP_BIC_HP	G4HadronPhysicsQGSP_BIC_HP	G4HadronPhysicsQGSP_BIC
G4NeutronTrackingCut	–	G4NeutronTrackingCut	

A systematic study on the possibility to include the QGSP_BIC_ALLHP is on going

➔ ProtonHP: Status and Problems - Pablo Cirrone

LET calculation

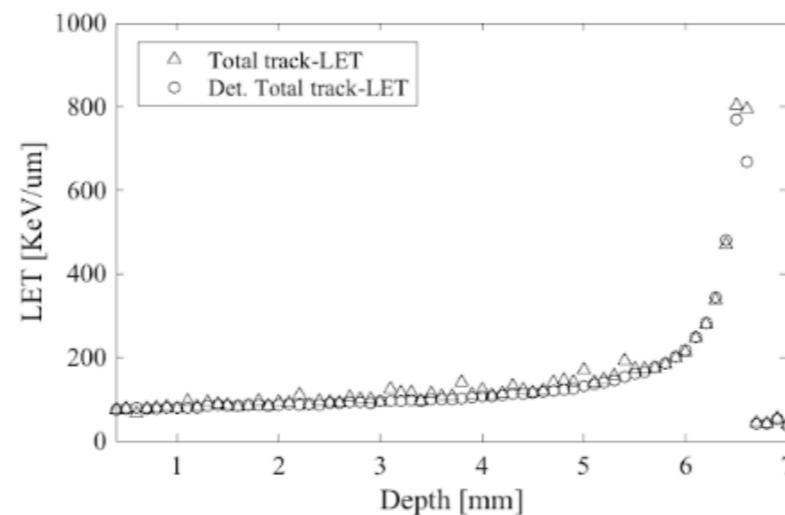
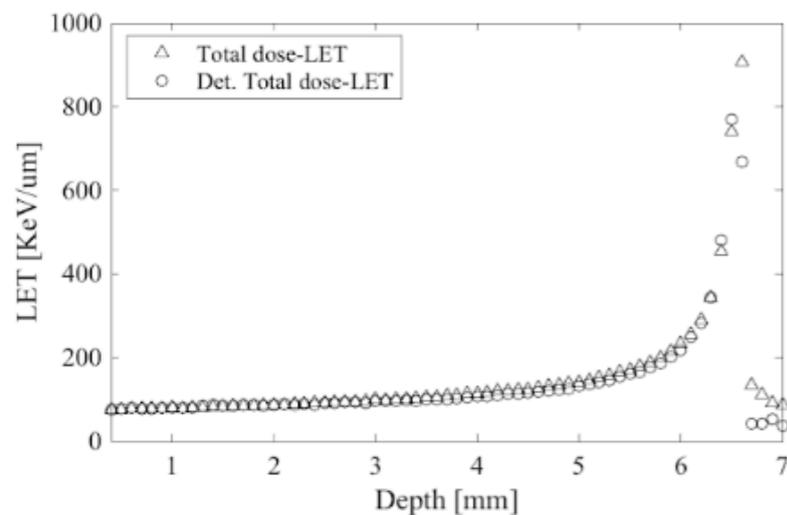
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New LET class based on G4EmCalculator:

LET track

$$\bar{L}_T = \frac{\sum_{i=1}^N L_i l_i}{\sum_{i=1}^N l_i} \quad \bar{L}_T^{Total} = \frac{\sum_{j=i}^n \left[\sum_{j=1}^N L_i l_i \right]_j}{\sum_{j=i}^n \left[\sum_{i=1}^N l_i \right]_j}$$



LET dose

$$\bar{L}_D = \frac{\sum_{i=1}^N L_i \epsilon_i}{\sum_{i=1}^N \epsilon_i} \quad \bar{L}_D^{Total} = \frac{\sum_{j=i}^n \left[\sum_{j=1}^N L_i \epsilon_i \right]_j}{\sum_{j=i}^n \left[\sum_{i=1}^N \epsilon_i \right]_j}$$

M.G. Cortes et al. "A critical study of different Monte Carlo scoring methods of dose averaged linear-energy-transfer maps calculated in voxelized geometries irradiated with clinical proton beams", Phys. Med. Biol. 60 (2015) 2645-2669

A comparison with experimental data is already ongoing

Computation Method coupling Geant4 to LEM

Generation of Look Up Table based on LEM (Survival code)



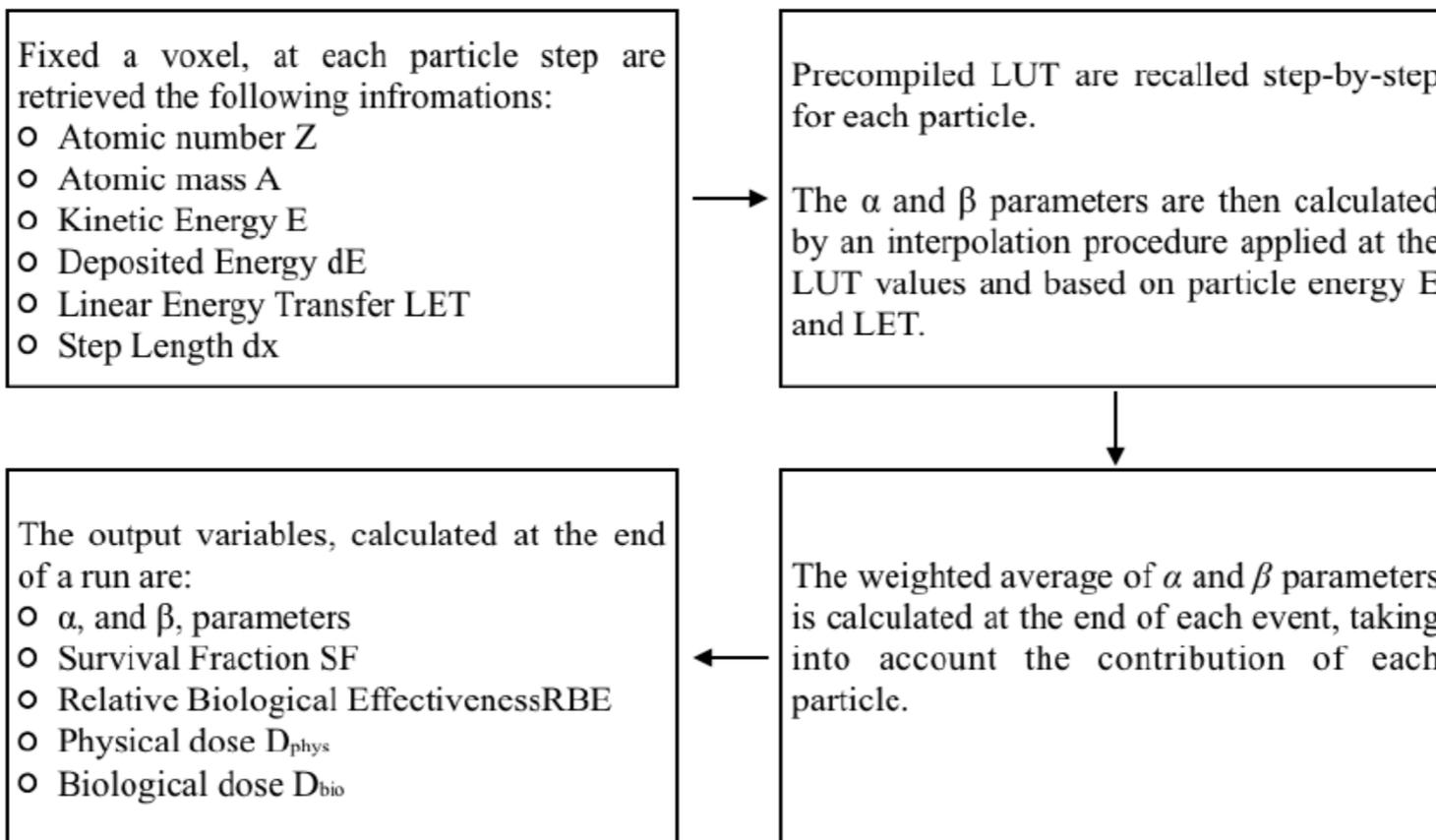
$$\langle \alpha_D \rangle = \frac{\sum_i \alpha_{D_i} \cdot D_i}{\sum_i D_i}$$
$$\langle \beta_D \rangle = \left(\frac{\sum_i \sqrt{\beta_{D_i}} \cdot D_i}{\sum_i D_i} \right)^2$$

Mixed Field calculation



$$SF = e^{-\langle \alpha_D \rangle D + \langle \beta_D \rangle D^2}$$

Survival Fraction



A Look Up Table

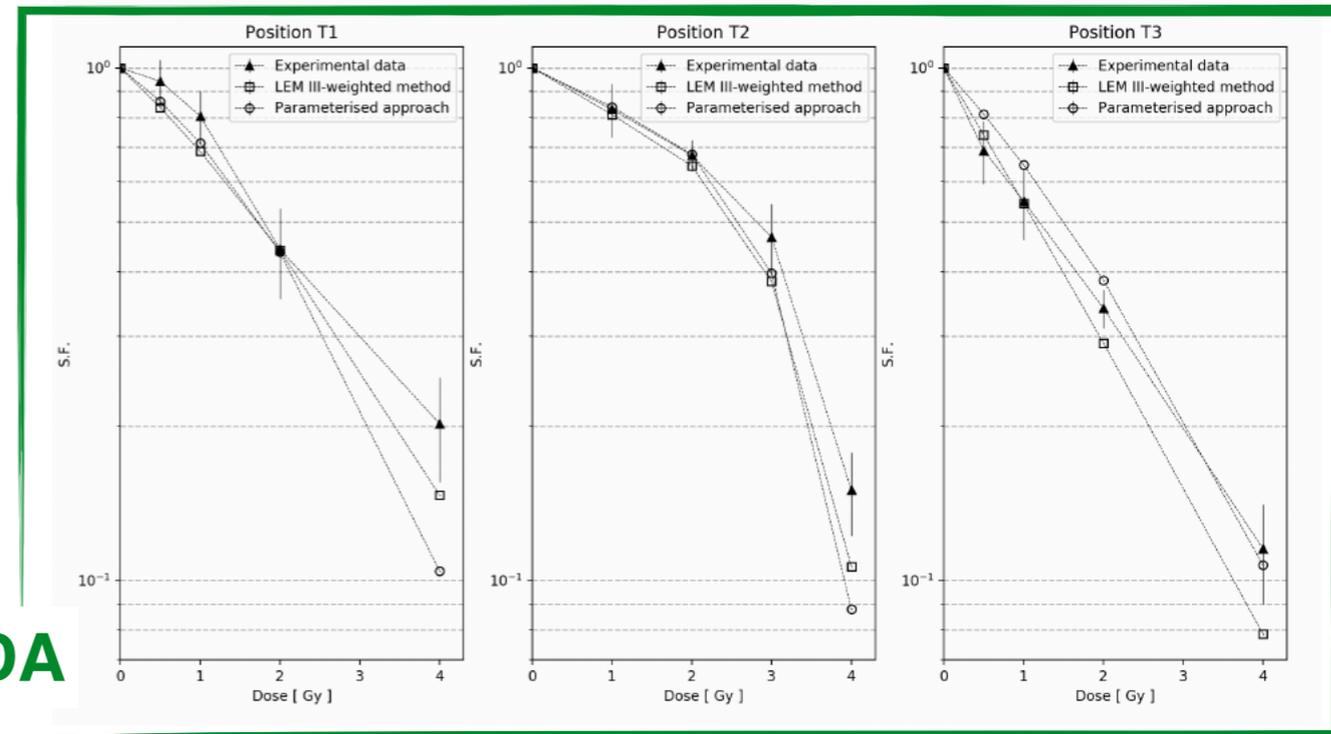
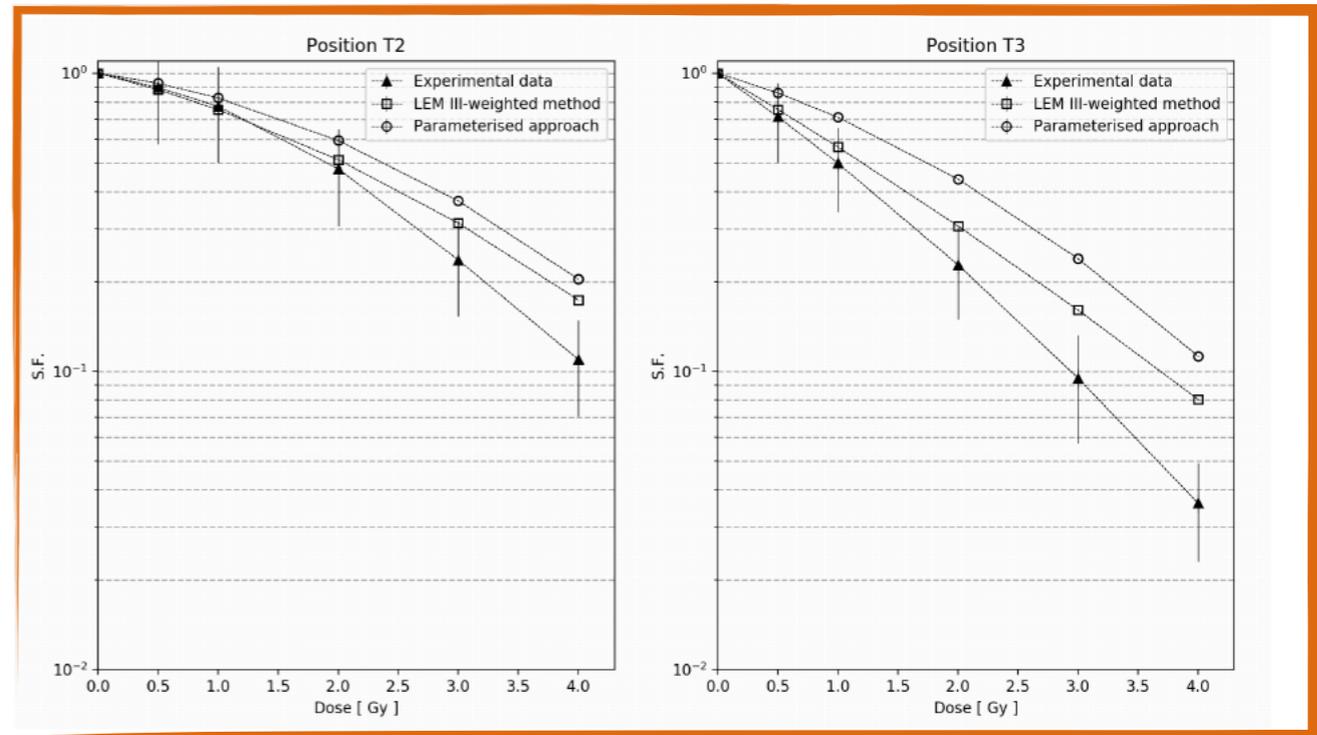
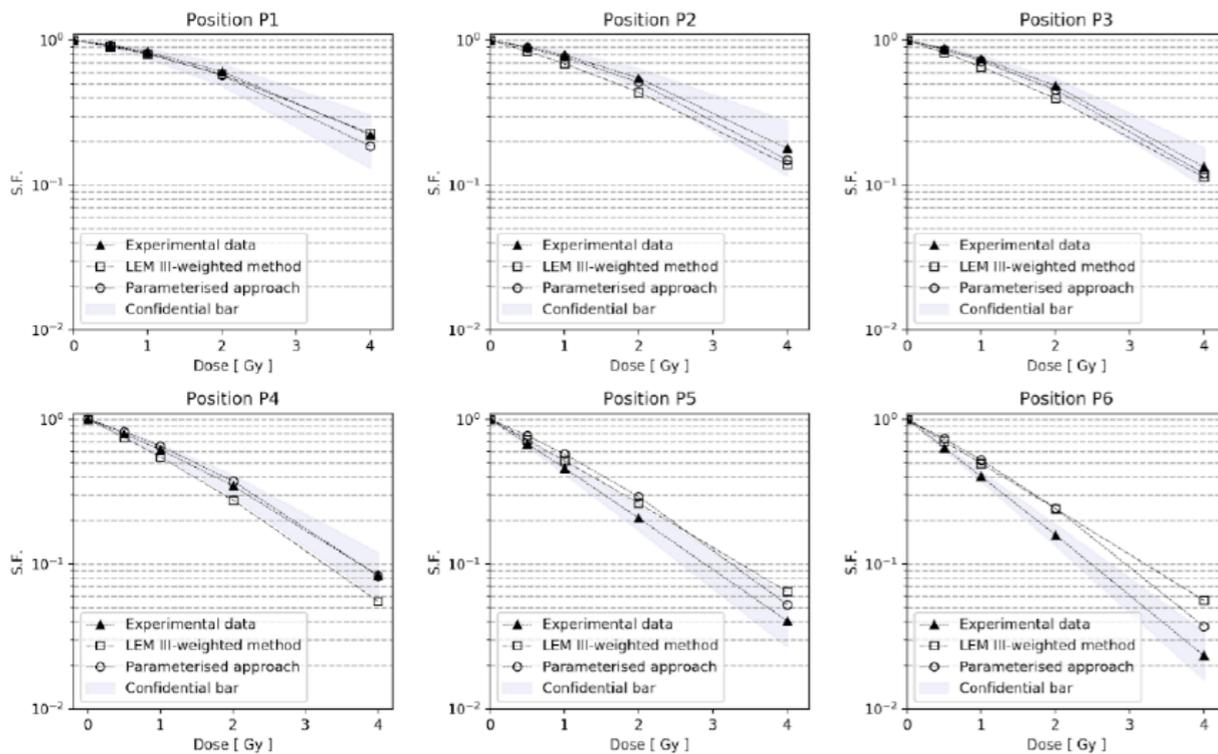
	alpha_x	beta_x	r_nucleus	D_t	specific_energy	let	alpha	beta	cell	particle	RBE_alpha
1	0.11	0.06	6.5	8	172.698	0.5	0.127549	0.0588984	U87	H	1.1595363636363636
2	0.11	0.06	6.5	8	143.534	0.567824	0.138268	0.0582273	U87	H	1.2569818181818182
3	0.11	0.06	6.5	8	119.965	0.644847	0.149487	0.0575248	U87	H	1.3589727272727273
4	0.11	0.06	6.5	8	100.952	0.732319	0.161175	0.0567928	U87	H	1.4652272727272727
5	0.11	0.06	6.5	8	85.4798	0.831656	0.173273	0.0560348	U87	H	1.5752090909090909
6	0.11	0.06	6.5	8	72.4215	0.944468	0.18615	0.0552277	U87	H	1.6922727272727273
7	0.11	0.06	6.5	8	61.3953	1.07258	0.19987	0.0543674	U87	H	1.817
8	0.11	0.06	6.5	8	52.3329	1.21808	0.21415	0.0534717	U87	H	1.9468181818181818
9	0.11	0.06	6.5	8	44.5844	1.3833	0.229405	0.0525143	U87	H	2.0855
10	0.11	0.06	6.5	8	38.033	1.57095	0.245631	0.0514955	U87	H	2.2330090909090909
11	0.11	0.06	6.5	8	32.4783	1.78404	0.262885	0.0504115	U87	H	2.3898636363636364
12	0.11	0.06	6.5	8	27.7871	2.02604	0.281233	0.049258	U87	H	2.5566636363636364
13	0.11	0.06	6.5	8	23.8148	2.30087	0.300765	0.0480292	U87	H	2.7342272727272727

Comparison with experimental data

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DU145

U87



G. Petringa, GAP Cirrone et al., "Estimation and validation of radiobiologically and clinically relevant quantities using Geant4-based Monte Carlo simulations", Under review

MDA

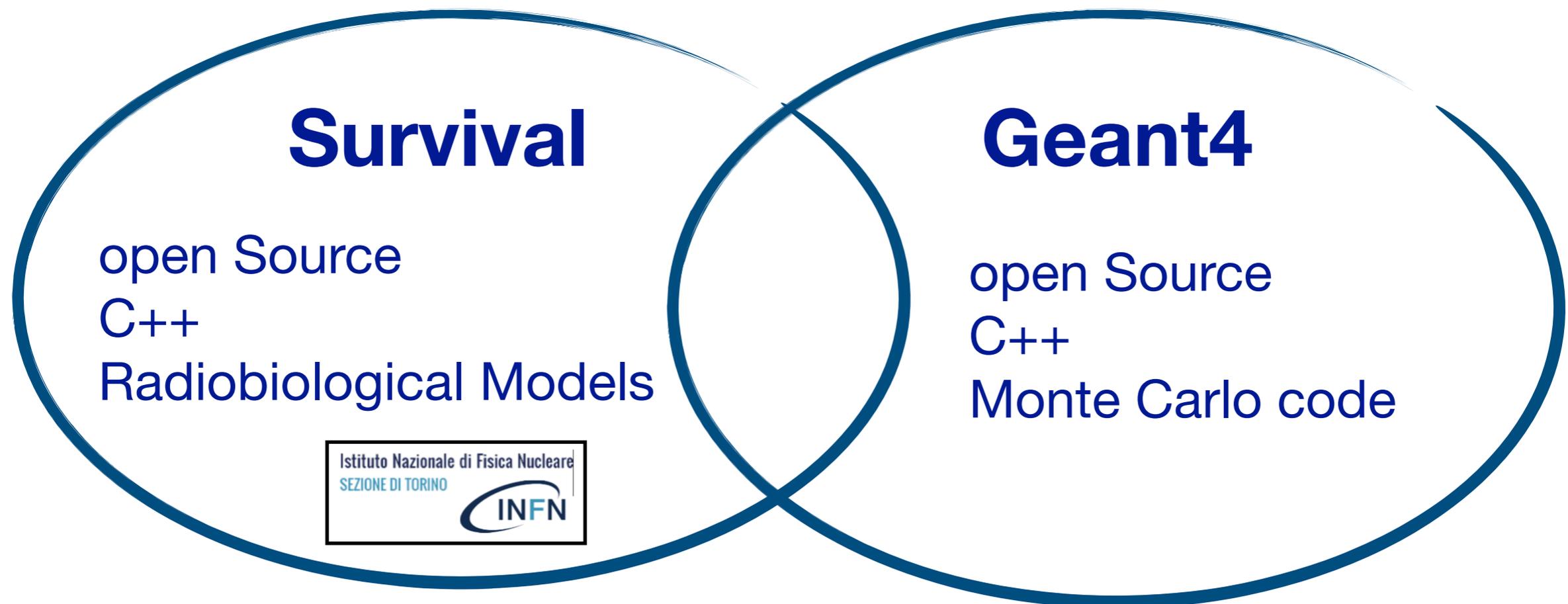
- ❑ **Validate the new class for the LET calculation (Master Thesis, D. Chiappara)**
- ❑ **Validate the new class for the RBE calculation by creation a database with different cell lines: new project in collaboration with INFN-TIFPA, INFN-RM3, INFN-NA, Vinka Institute, GANIL, University of Wollongong**
- ❑ **Insert a class dedicated to the DICOM images (PhD Thesis, P. Pisciotta)**
- ❑ **Insert the geometry of the new ionization chambers installed at TIFPA**



A new extended example...?

The idea

create a direct link between the radiobiological models (i.e. LEM and MKM) and Geant4 to calculate the RBE in a mixed field condition



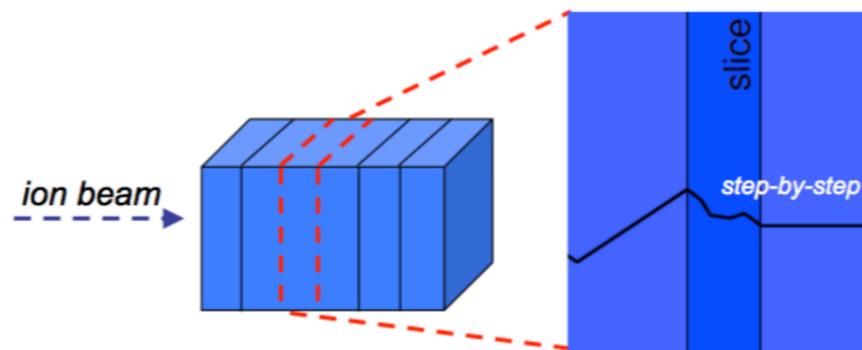
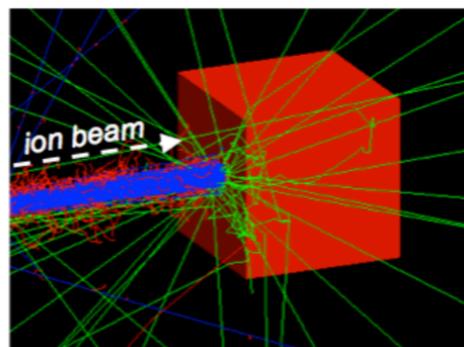
A new extended example...?

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- The Geometry → voxelized water cube
- The Source → two possibilities: import a phase space that reproduce the exactly characteristics of a real beam line or alternatively a standard source defined by the Users
- Specific set of classes dedicated to computing Dose, LET and RBE
- The Geant4 will be connected to the **Survival code** (open source, already written in C++ and able to create the LUT necessary to RBE calculation)

input parameters:

- cell line with related parameters (i.e. alpha and beta)
- model: LEM I, LEM II, LEM III or MKM
- source: phase space or standard definition



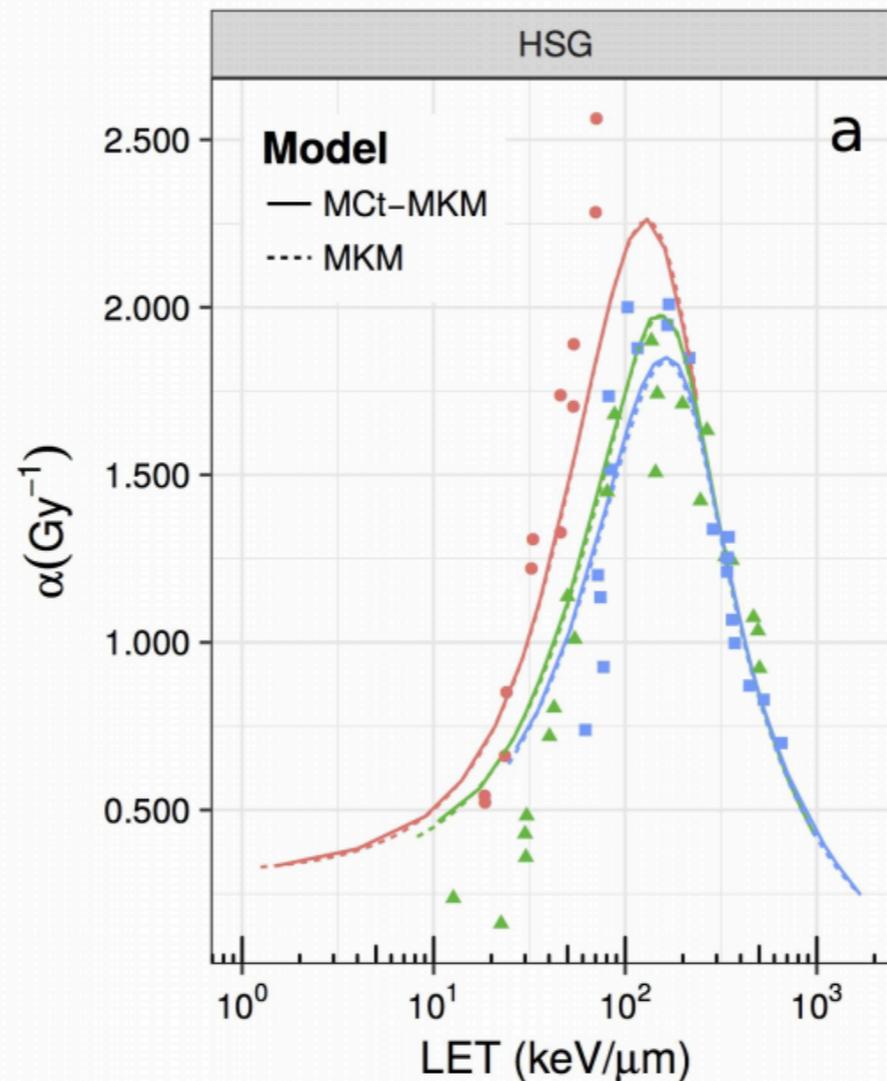
output:

- Dose distribution
- LET distribution
- RBE distribution
- alpha_ion; beta_ion;
- SF calculated with model
- SF calculated with MC

A new extended example...?

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- Modular object-oriented approach for radiobiological modelling (C++).
- Implemented models: LEM1-3, MKM, and variants.
- Evaluation of cell survival, LQ parameters, RBE, etc...
- Monte Carlo and fast approximate methods.
- Open source (<https://github.com/batuff/Survival>)



batuff / Survival

Join GitHub today

Implementation of radiobiological models for radiotherapy.

File	Commit Message	Time Ago
Documentation	updated documentation.	6 months ago
data	Added data folder	3 years ago
ext_include	Added/Updated external libraries (gsl and omp)	6 months ago
ext_lib	Added/Updated external libraries (gsl and omp)	6 months ago
include	Add comment on warnings suppression	6 months ago
run_example	Updated calculusType name.	6 months ago

Courtesy of A. Attili

L. Manganaro, G. Russo, F. Bourhaleb, F. Fausti, S. Giordanengo, V. Monaco, R. Sacchi, A. Vignati, R. Cirio and A. Attili. "Survival": a simulation toolkit introducing a modular approach for radiobiological evaluations in ion beam therapy. *Physics in Medicine and Biology* **63**(8), 08NT01 (2018). <https://doi.org/10.1088/1361-6560/aab697>



Any questions?

Acknowledgements

Andrea Attili (INFN-RM3) - Andrea Di Fini (INFN-LNS) - Jan Pipek (ELIBeamline) -
Francesco Romano (NPL) - Francesco Tommasino (INFN-TIFPA)

LET calculation

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	Depth [mm]	Total		Primary		ICRU
		LET_D	LET_T	LET_D	LET_T	
1mm_0.05mm Cut	1	3.96071	1.1071	1.09802	1.09273	1.097
1mm_0.1mm Cut	1	4.21183	1.10825	1.09657	1.09272	1.097
1mm_1000m mCut	1	3.81923	1.10757	1.10209	1.09275	1.097
Proximal_0.05 mmCut	28.6	4.34534	3.59764	3.84226	3.58081	3.526
Proximal_0.1m mCut	28.6	4.53852	3.59811	3.84059	3.57855	3.526
Proximal_1000 mmCut	28.6	4.20832	3.58846	3.84168	3.5804	3.526
Distal_0.05m mCut	31.1	21.5355	14.5043	21.5093	14.5885	13.77
Distal_0.1mm Cut	31.1	21.6533	14.7085	21.6329	14.7033	13.77
Distal_1000m mCut	31.1	21.7559	14.8026	21.7551	14.8025	13.77