an introduction

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On behalf of the FLUKA collaboration

CAoPAC: Computer-Aided Optimization of Particle Accelerator Workshop
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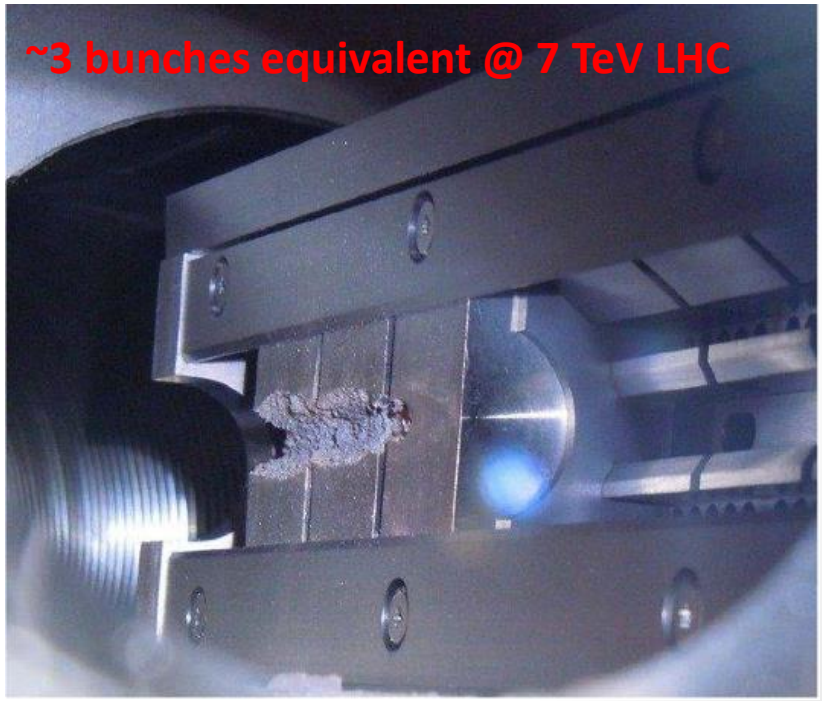
Introduction (1)

The development of MC codes for particle transport and interaction with matter, such as Fluka, are driven by applications, i.e. high power accelerator, accelerator driven systems, high energy colliders, medical facilities, etc.

In particular the next generation of medium and high energy accelerators brings to a completely new domain of extreme conditions of beam interaction with matter.

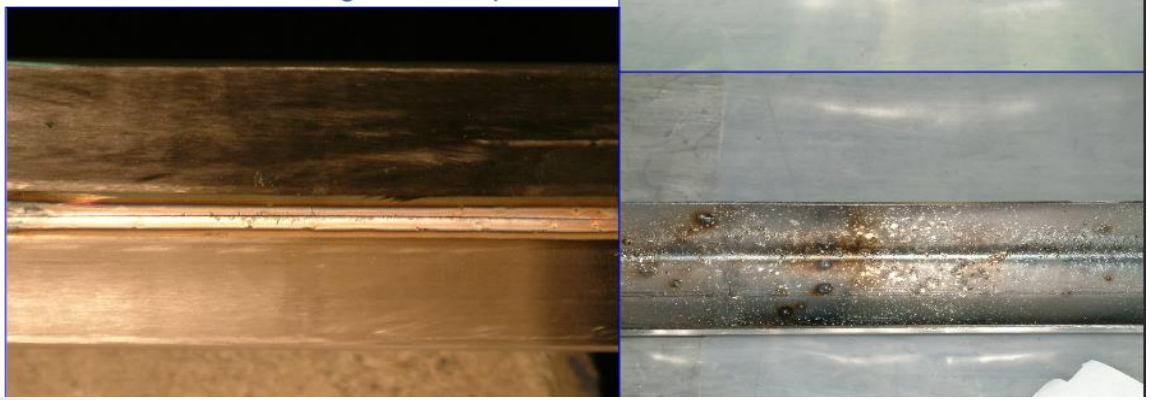


Courtesy A. Bertarelli et al. (CERN)

Introduction (2)

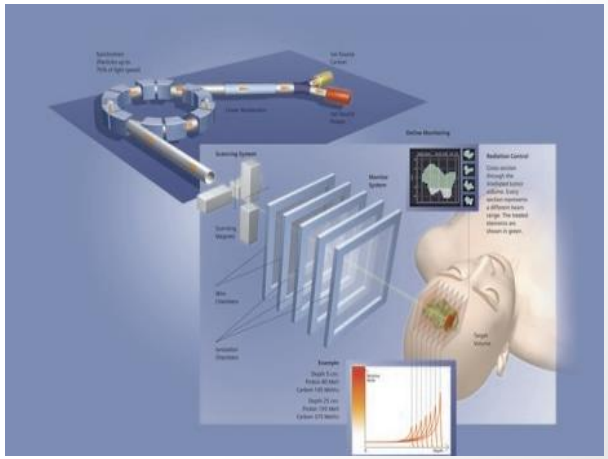
Challenges also arise from increasing complexity of accelerators and experimental setups, as well as from design, engineering and performance constraints.

- 450 GeV protons, 2 MJ beam in **2004**
- Failure of a septum magnet induced beam drift
- Cut of 25 cm length, groove of 70 cm on **Stainless Steel vacuum chamber**
- Condensed drops of steel on opposite side of the vacuum chamber
- Vacuum chamber and magnet to be replaced



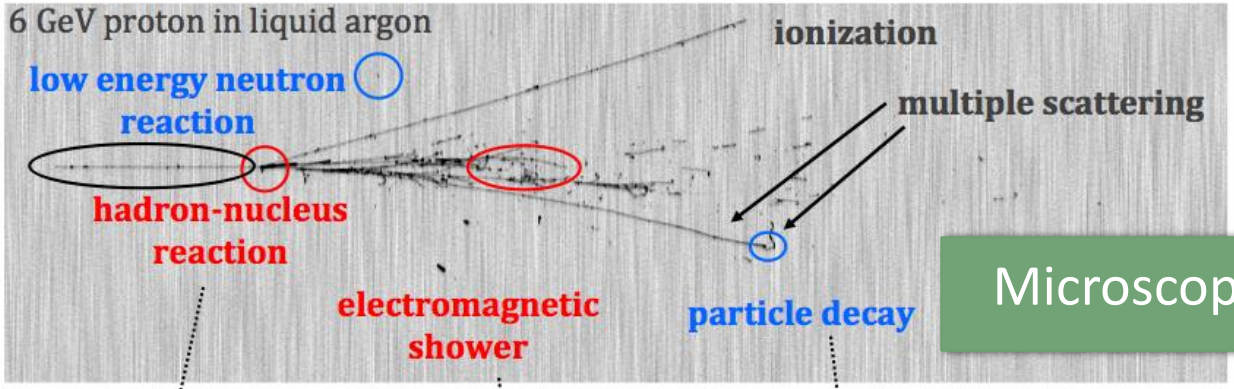
Courtesy B. Goddard et al. (CERN)

Accelerator for Proton Therapy



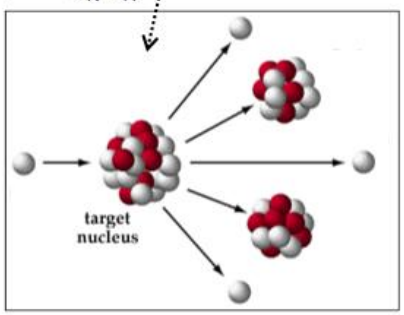
Introduction (3)

It translates in putting strong requirements on the accuracy of particle production predictions and the capability and reliability of the codes used in planning new accelerator facilities and experiments.

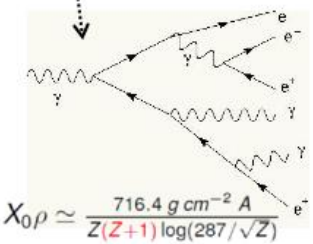


Microscopic view

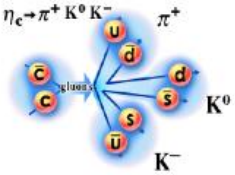
$\lambda\rho = \frac{A}{\sigma_R N_A}$ $\sigma_R \simeq \pi r_0^2 A^{2/3}$



interplay of many physical processes described by different theories/models

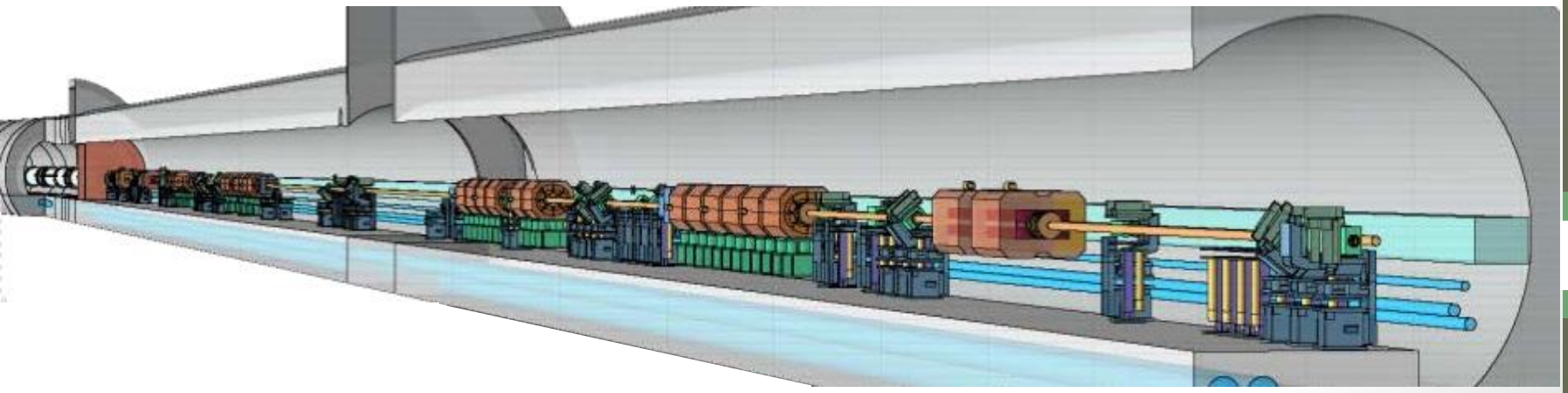


$X_0\rho \simeq \frac{716.4\ g\ cm^{-2}\ A}{Z(Z+1)\log(287/\sqrt{Z})}$



Introduction (4)

The challenge requires detailed and accurate (to a % level) modeling of all particle interactions with 3D system components (up to tens of Kilometers of the accelerator lattice in some cases) in energy region spanning up to 20 decades as a basis of accelerator, detector and shielding designs and their performance evaluation, for both short-term and long-term effects.



See A. Letcher lecture for details

Introduction (5)

In such a context, Fluka is extensively used worldwide. In details, Fluka is a general purpose tool for calculations of particle transport and interaction with matter, covering an extended range of applications: from proton and electron accelerator shielding to target design, calorimetry, activation, dosimetry, detector design, accelerator driven system, cosmic rays, neutrinos physics, radiotherapy, etc.

Introduction (6)

A substantial amount of effort has been put into development of MC Fluka code over the last few decades.

More than 7000 registered users

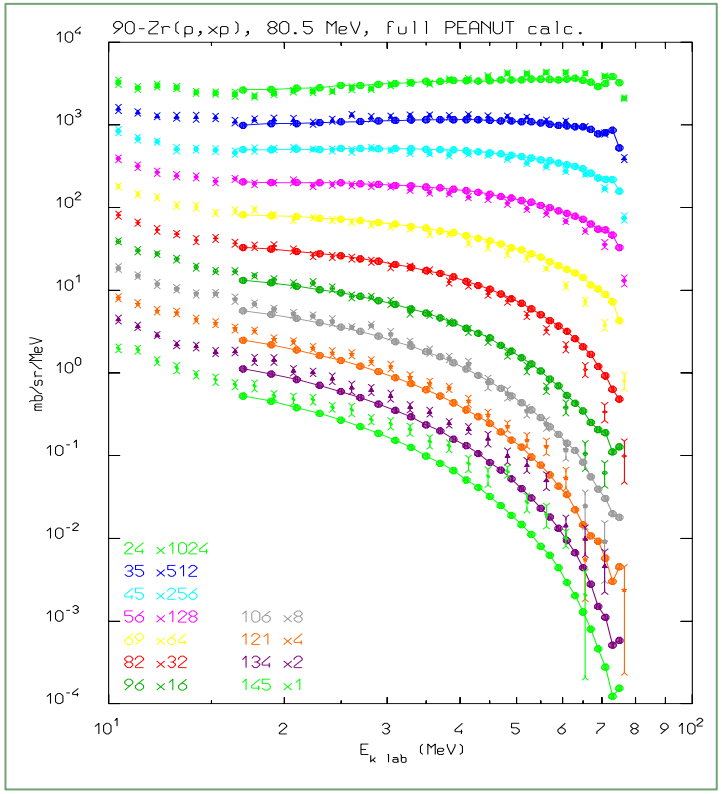
In details Fluka is able to track 60 different particles + Heavy Ions:

- Hadron-hadron and hadron-nucleus interaction "0"-10000 TeV
- Electromagnetic and μ interactions 1 keV-10000 TeV
- Nucleus-nucleus interaction up to 10000 TeV/n
- Charged particle transport and energy loss
- Neutron multi-group transport and interactions 0-20 MeV
- ν interactions
- Transport in magnetic field
- Combinatory (Boolean) and Voxel geometries
- Double capability to run either fully analogue and/or biased calculations
- On-line evolution of induced radioactivity and dose
- User-friendly Graphical User Interface (GUI) thanks to the Flair interface

Microscopic
& Model Benchmarking
(some selections)

Microscopic Benchmarking (1/2)

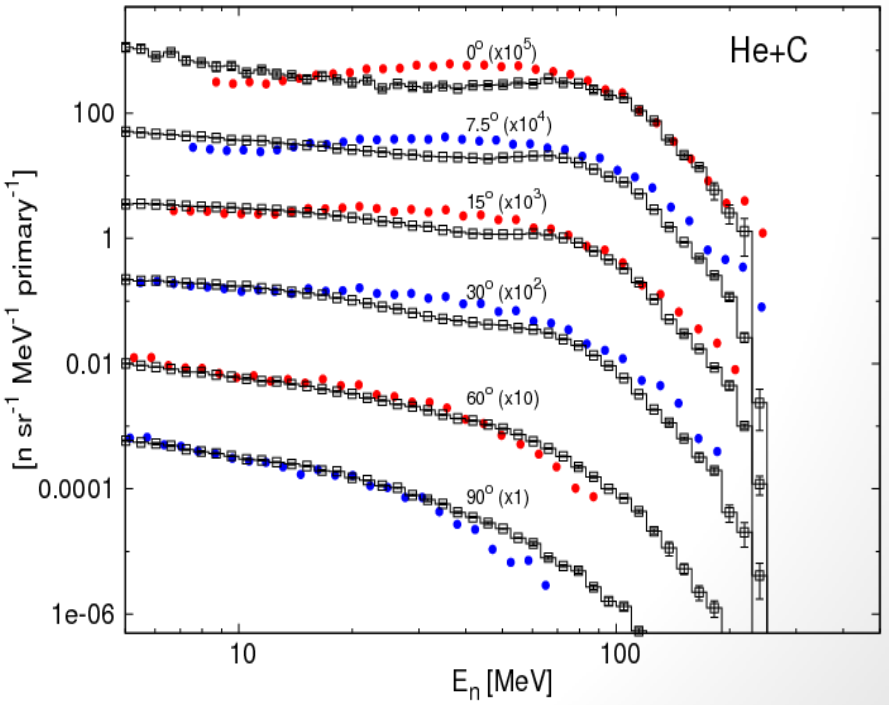
80 MeV p + ^{90}Zr → p + X



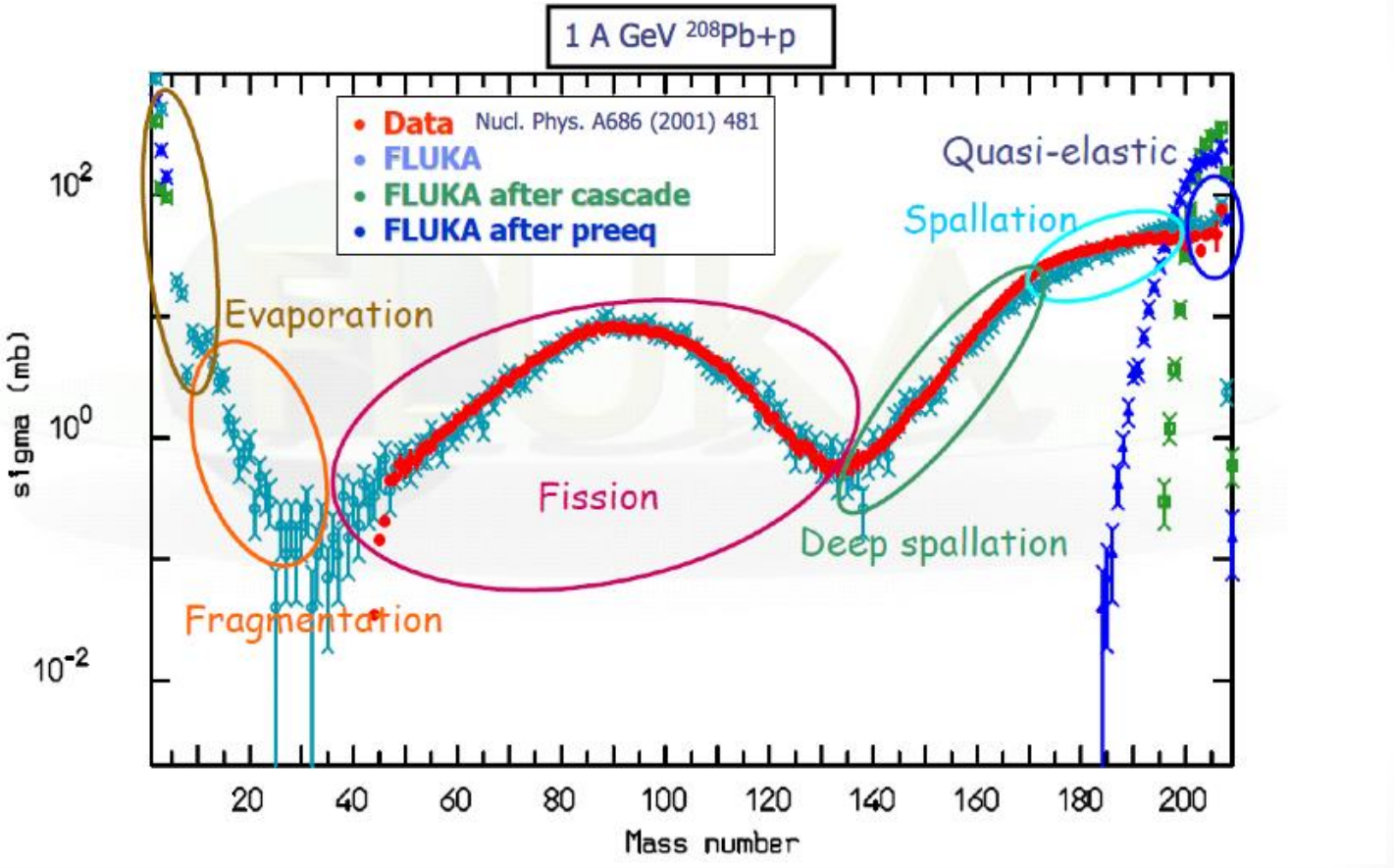
Thin target: emitted proton spectra @ different angles

Thick target: emitted neutron spectra @ different angles

neutrons from 400 MeV α on carbon



Microscopic Benchmarking (2/2)

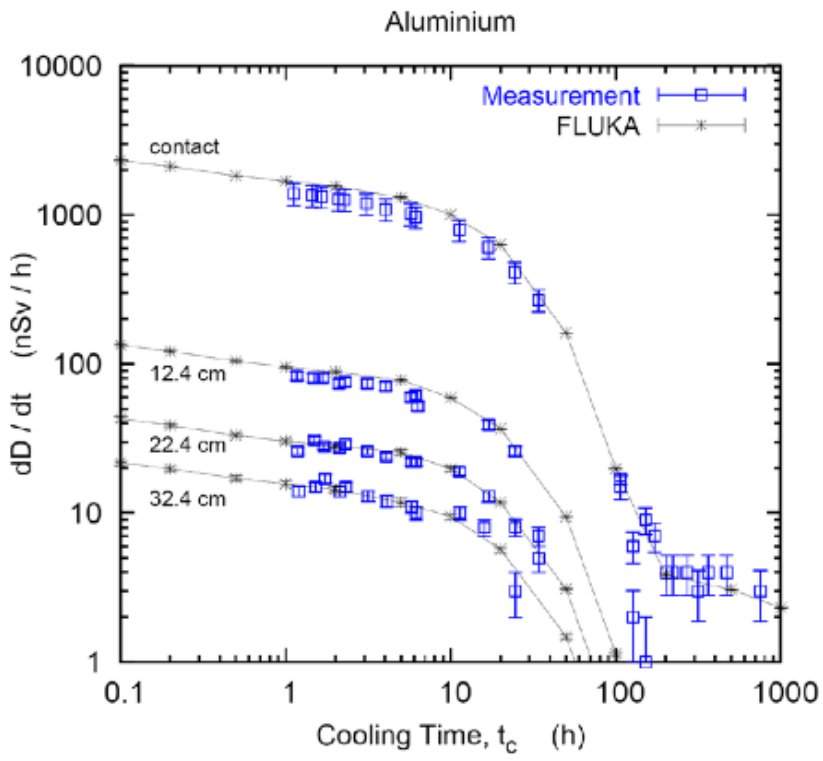


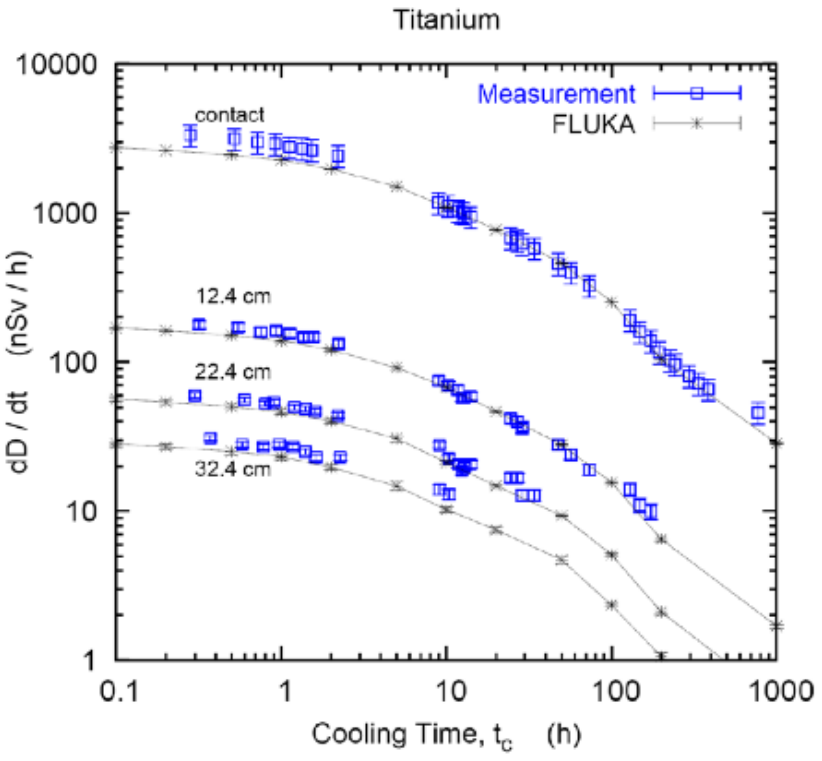
Residual nuclei production from 1 GeV protons on Lead.

A High Energy nuclear reaction on a high Z nucleus, fills roughly the whole charge and mass intervals of the nuclide chart.

Model Benchmarking (1/3)

The time evolution of activation and residual dose rates, as given by FLUKA, has been extensively benchmarked.
At CERF facility @ CERN several materials have been irradiated e.g.

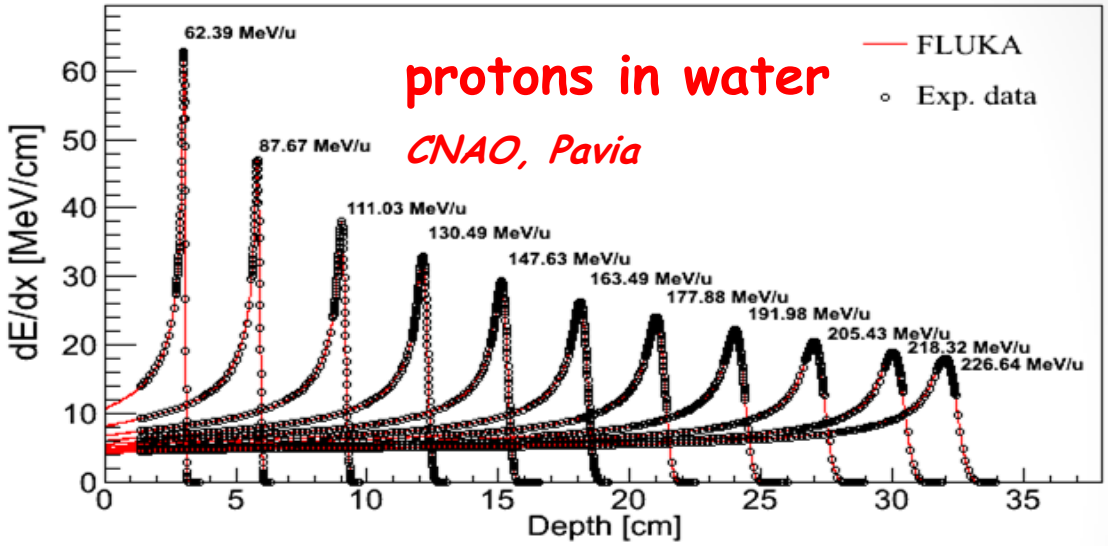


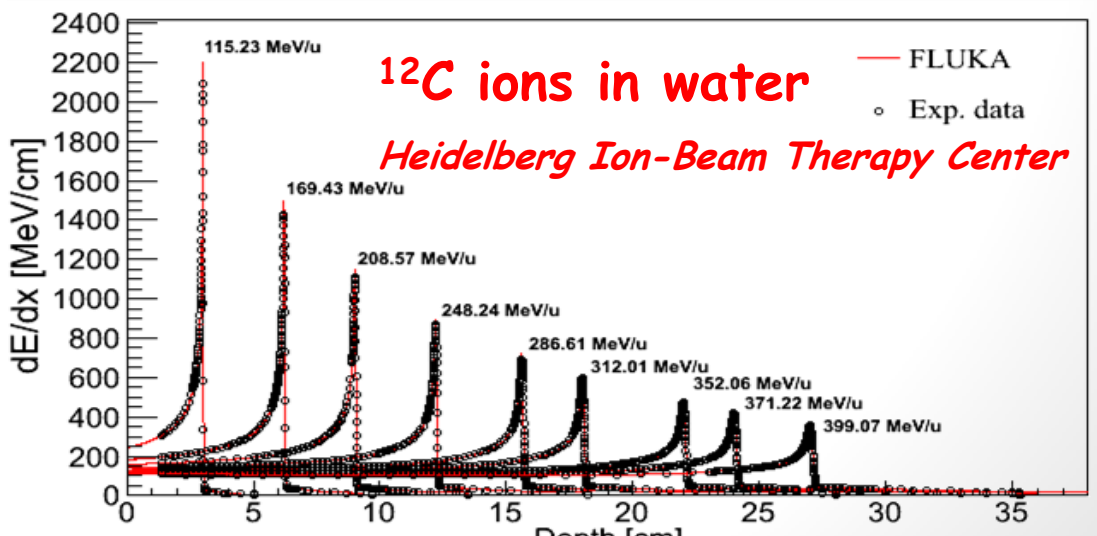


Courtesy M. Brugger et al. (CERN)

Model Benchmarking (2/3)

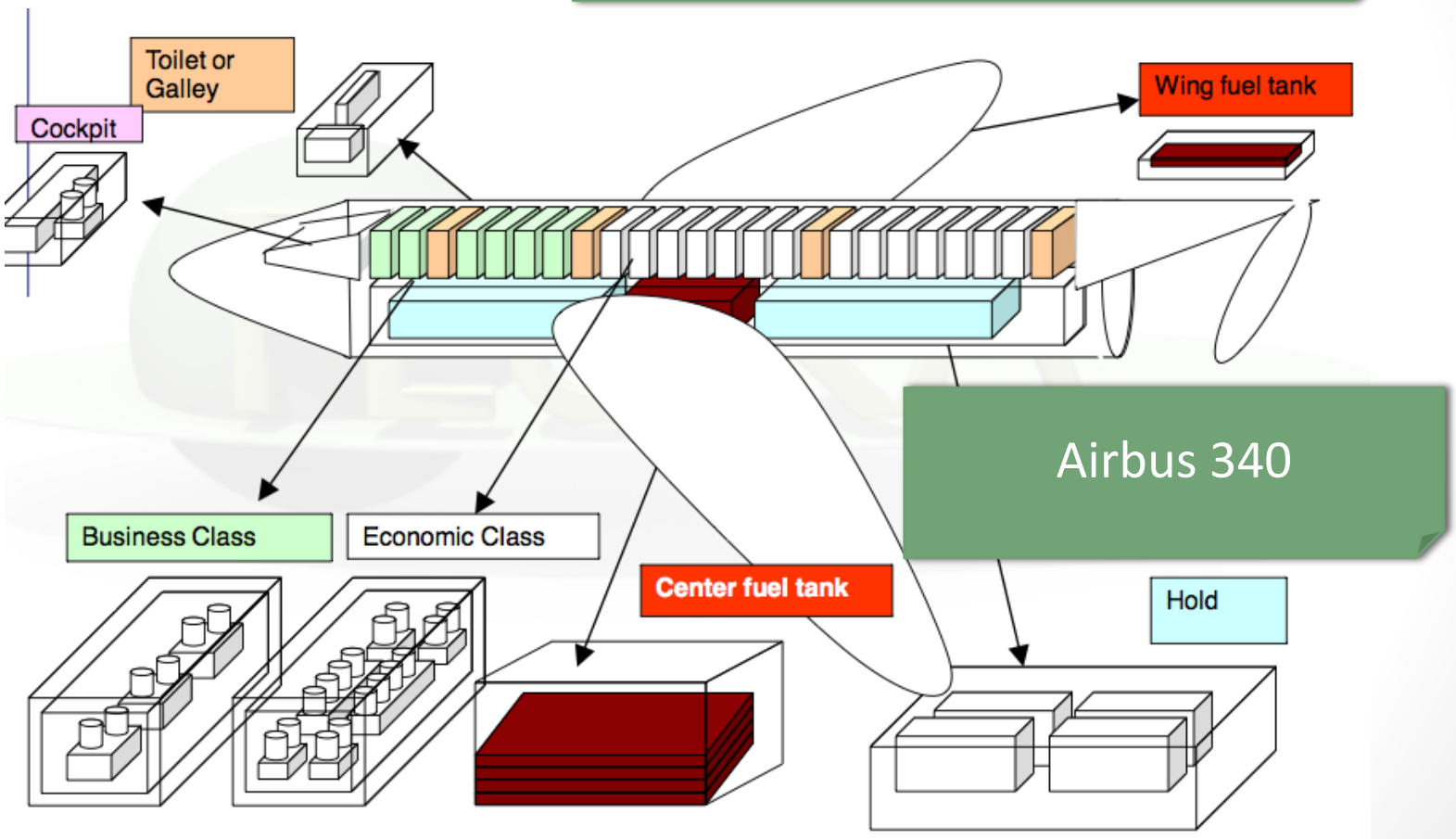
Energy Deposition and *Bragg peaks* *for medical applications*





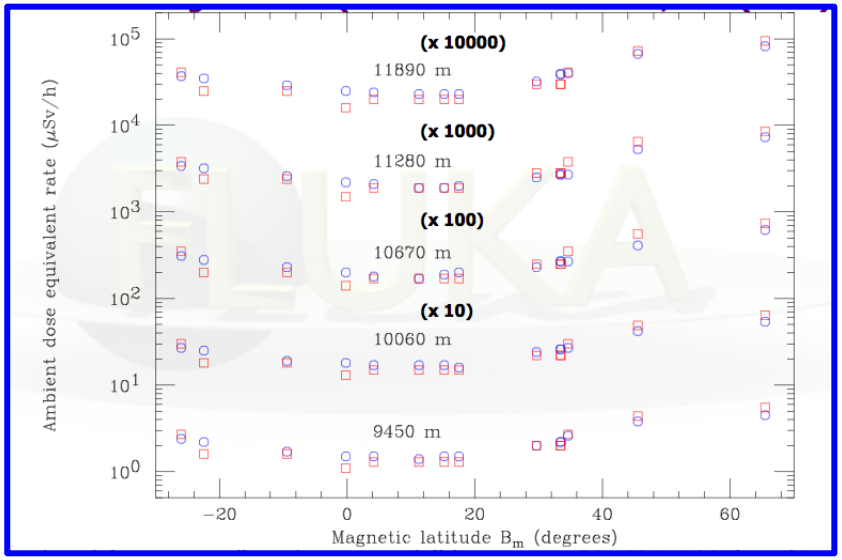
Model Benchmarking (3/3)

Dose to aircrew and passengers



Airbus 340

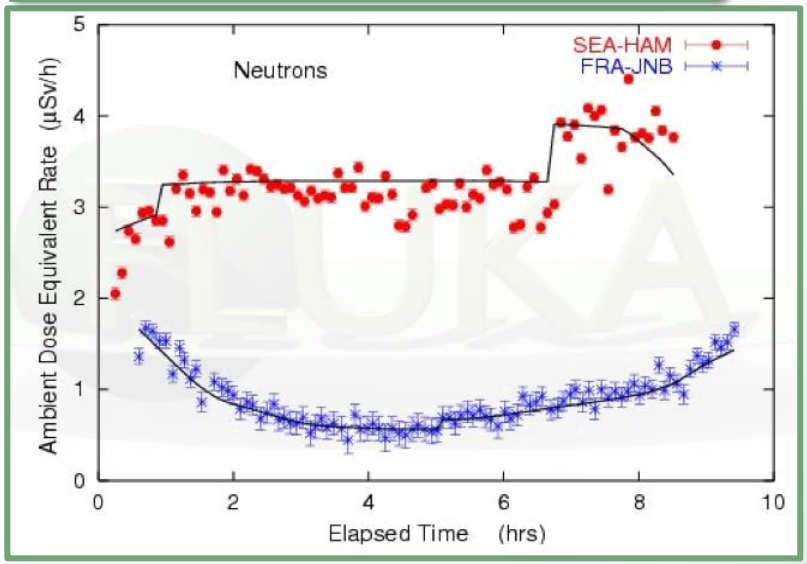
Model Benchmarking (3/3)



Simulated (Fluka, red) and measured (blue) ambient dose equivalent for various altitudes (scale by one decade) and geomagnetic cut-off's

Courtesy M. Pelliccioni et al. (INFN)

Ambient dose equivalent from neutrons at solar maximum on commercial flights from Seattle to Hamburg and from Frankfurt to Johannesburg (Fluka =solid lines)

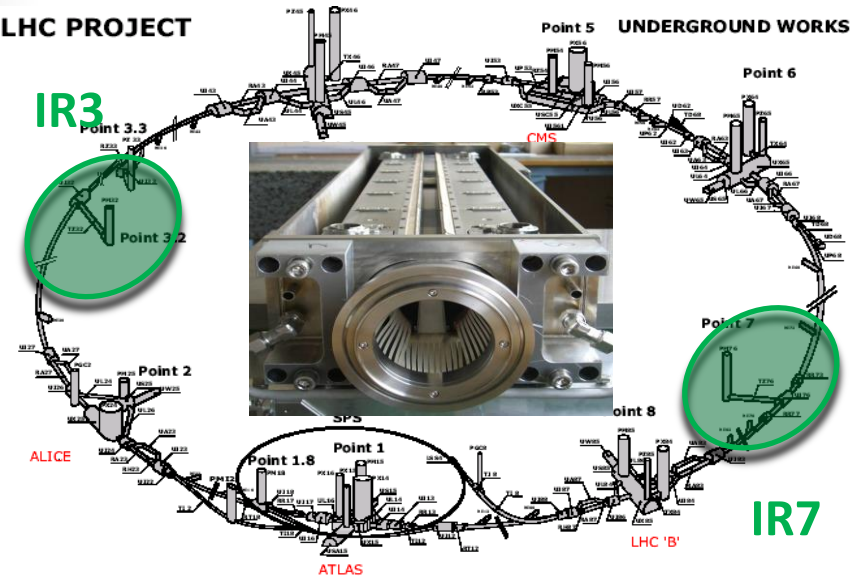


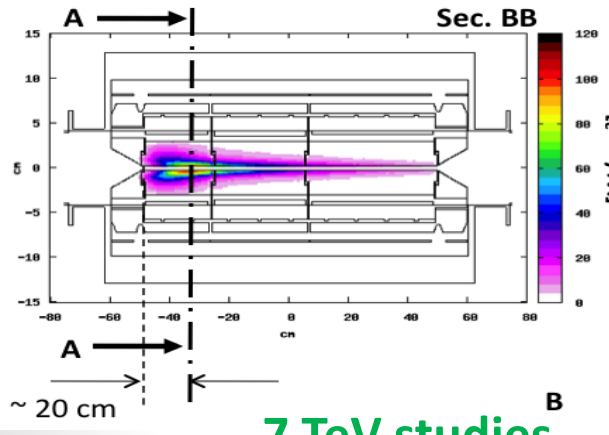
Courtesy S. Roesler et al. (CERN)

Macroscopic quantities (some selections)

Example (1)

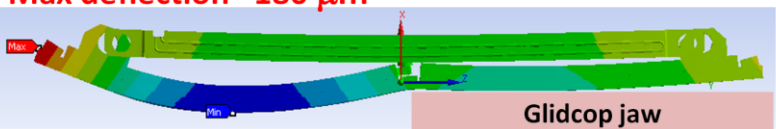
Advanced LHC collimator studies





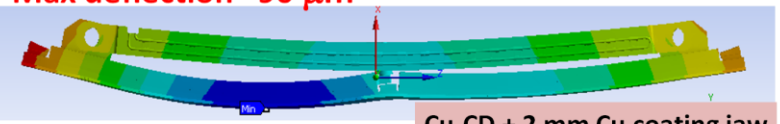
7 TeV studies

Max deflection ~180 µm



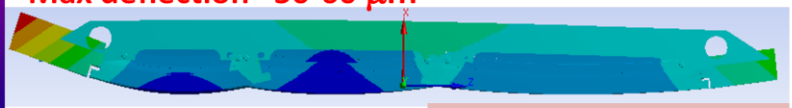
Glidcop jaw
1 fine adjustment system

Max deflection ~90 µm

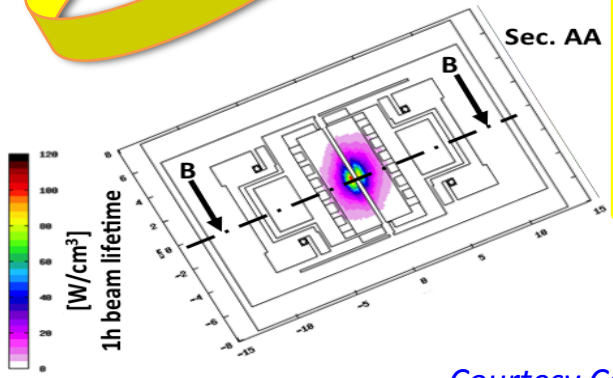


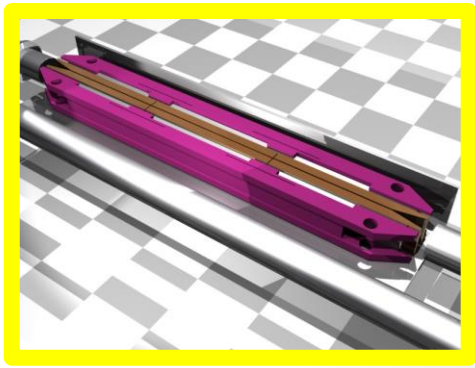
Cu-CD + 2 mm Cu coating jaw
1 fine adjustment system

Max deflection ~50-60 µm



Glidcop (3 cut) jaw
2 fine adjustment systems





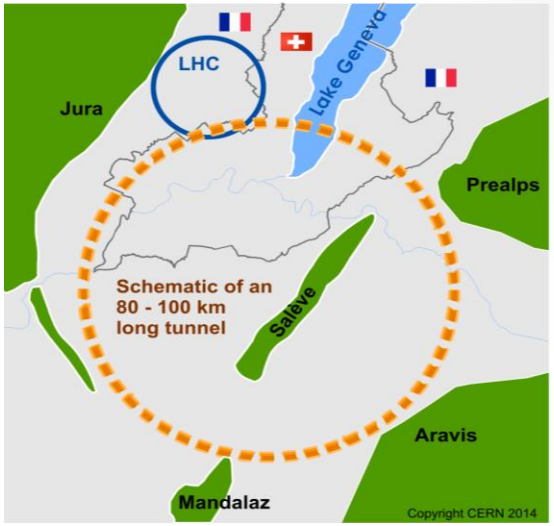
Fluka model example

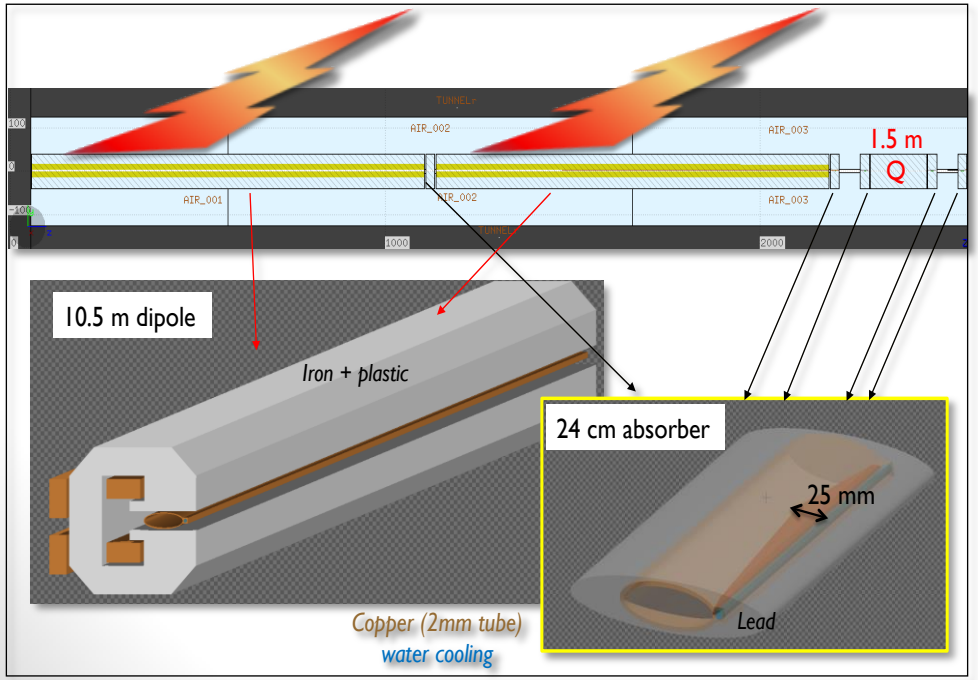
Courtesy Collimation & Fluka Team (CERN)

Example (2)

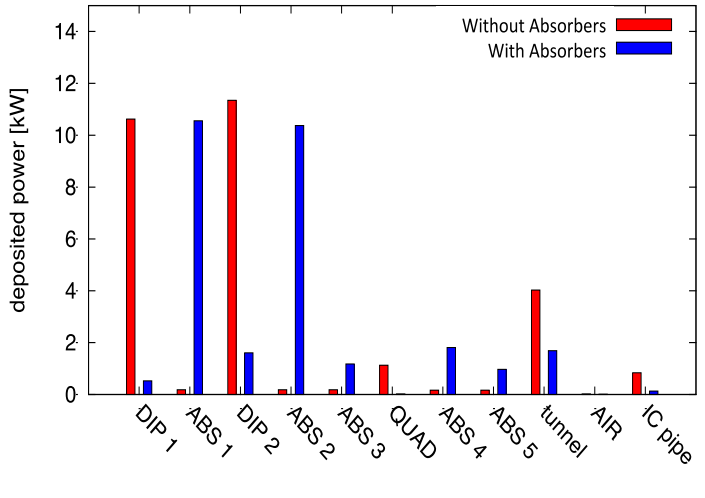
Mitigation of Synchrotron Radiation

Main parameters	80 km
Beam Energy [GeV]	175
Fill factor	81%
Dipole Bending Radius [km]	9.8
Critical Energy [MeV]	1.21
Energy lost per turn [GeV/turn]	8.5
Energy lost in the dipole [keV/cm]	1.375
Beam current [mA]	10
Power lost in the whole accelerator [MW]	85
Power lost in the dipole [W/cm]	13.75





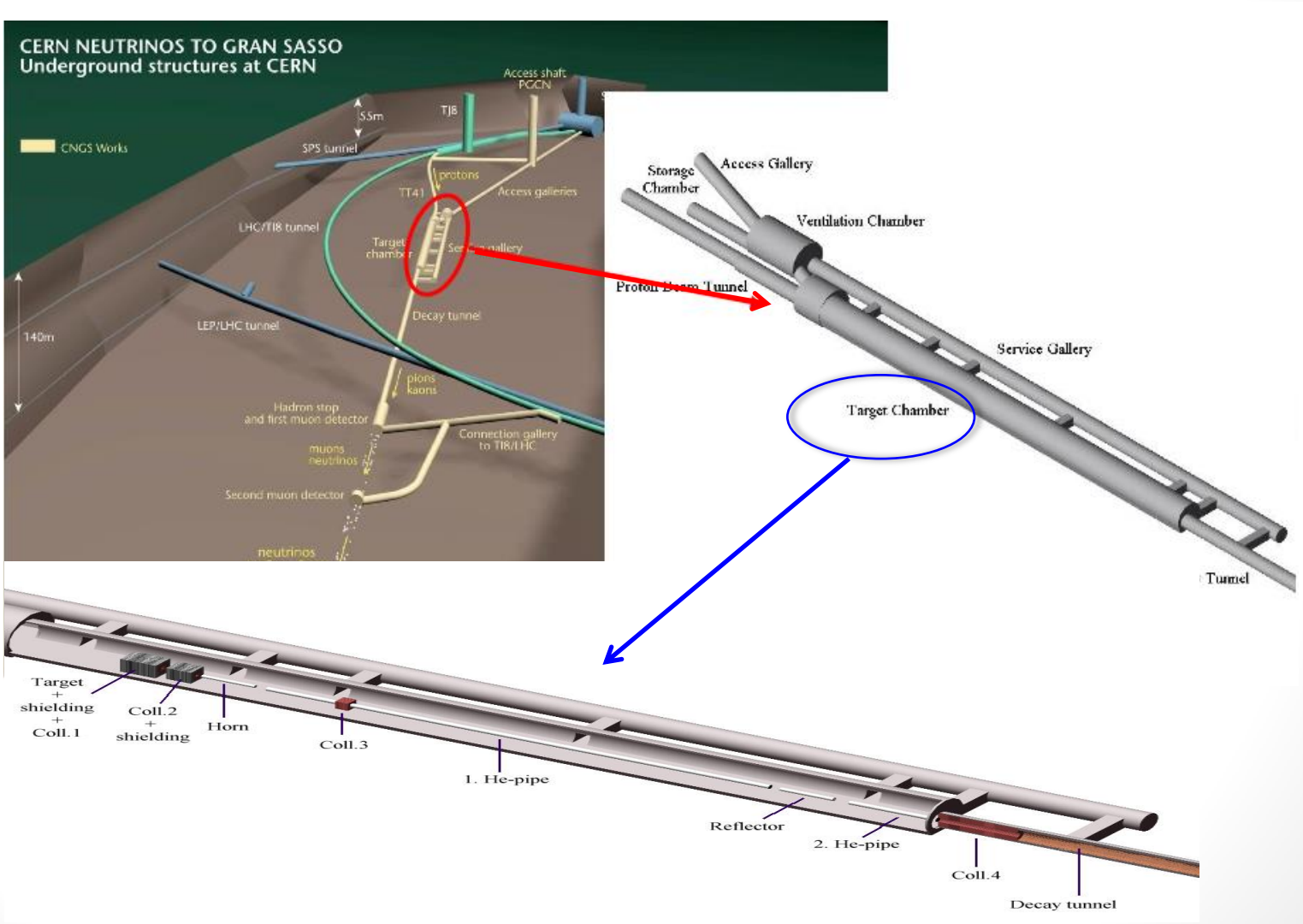
power sharing



Courtesy Fluka Team (CERN)

Example (3/1)

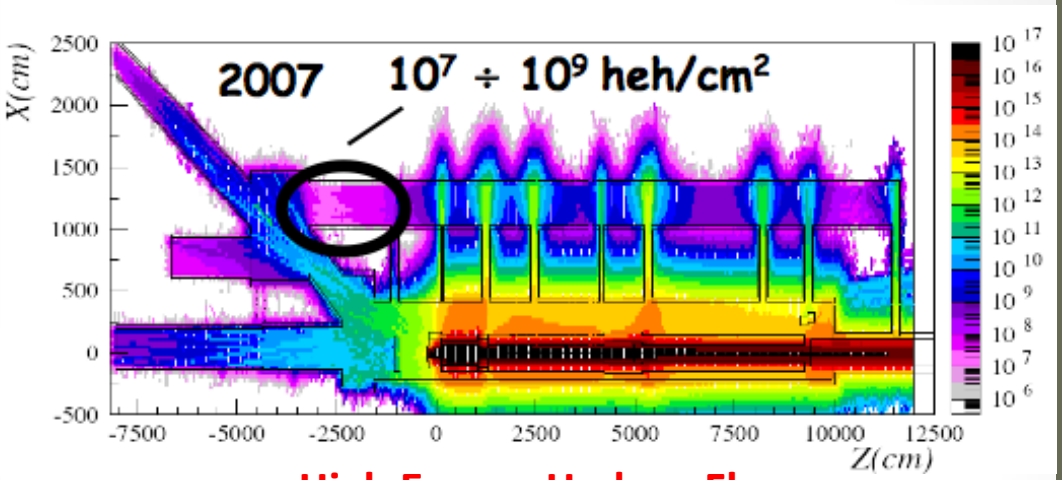
Radiation to Electronics



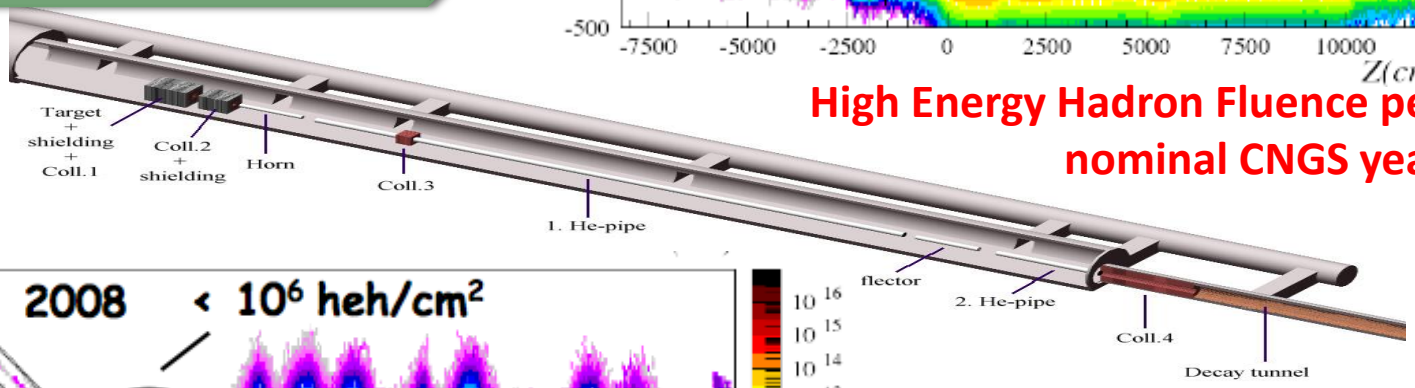
Example (3/2)

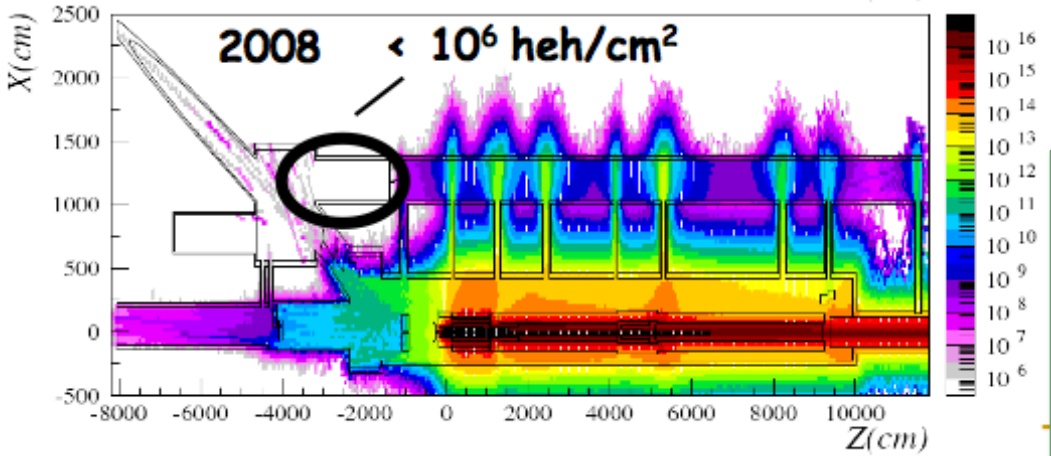
Radiation to Electronics

Single Event Upset in ventilation electronics caused ventilation control failure and interruption of communication



High Energy Hadron Fluence per nominal CNGS year



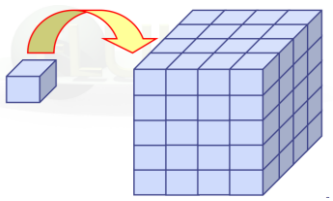


CNGS radiation issue solved by identified of forbidden region and properly mitigation

Courtesy M. Brugger et al. (CERN)

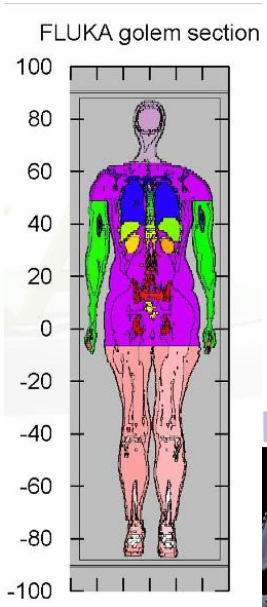
Example (4)

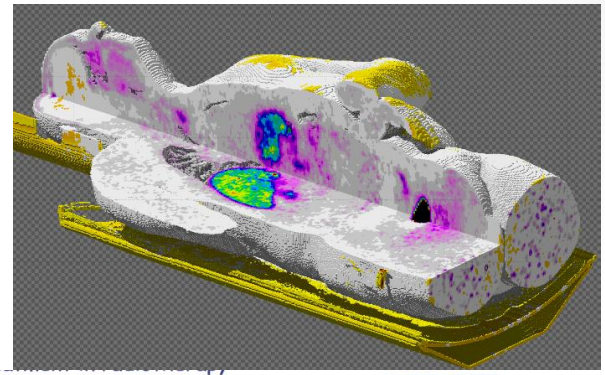
Proton therapy

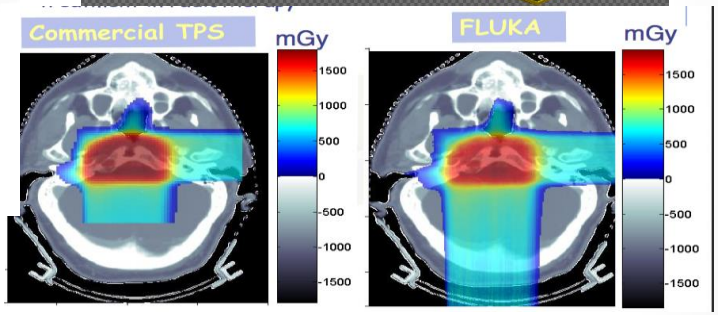


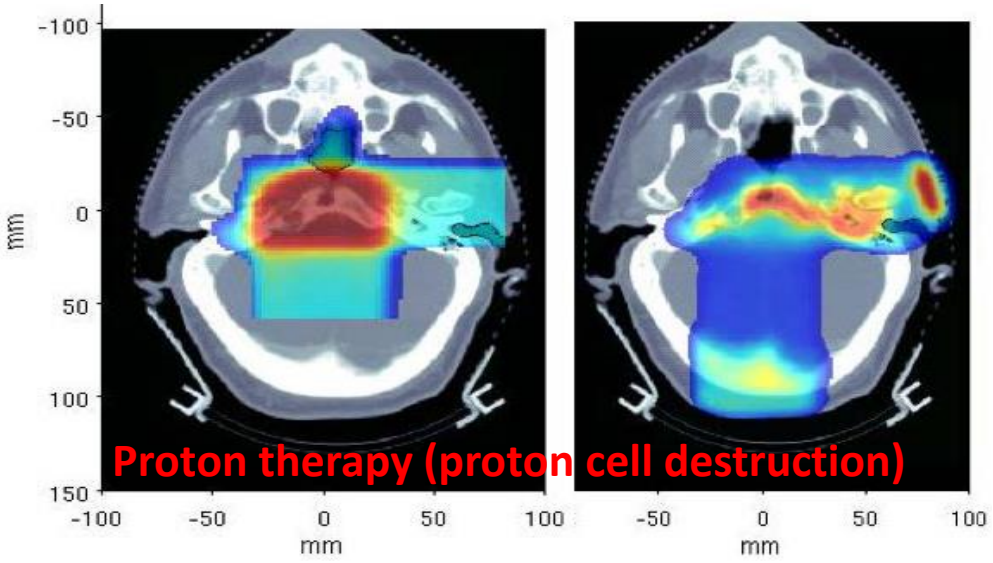
Voxels = tiny parallelepipeds forming a 3-D dimensional grid

Voxels geometry are especially useful to import Computed Tomography (CT) scan of human body e.g. for dosimetry calculations of the planned treatment in radiotherapy

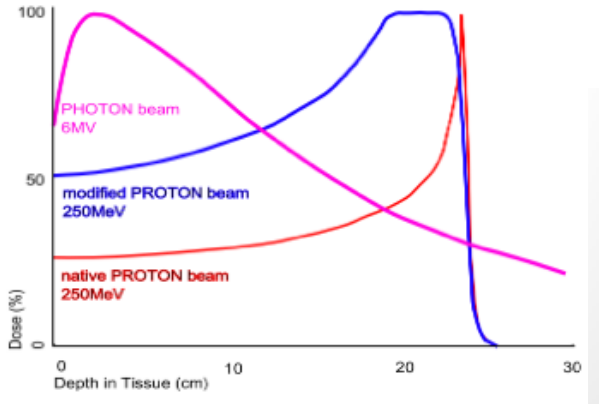








Proton therapy (proton cell destruction)



Courtesy K. Parodi et al. (LMU Munich)

Summary

- The MC Fluka code was presented, focusing on challenging of micro & model benchmarking and user application studies.
- More complex examples/studies will be given in the following lecture by A. Lechner.

Some References

- A. Ferrari et al, *The FLUKA Code: Developments and Challenges for High Energy and Medical Applications,* Nuclear Data Sheets, Volume 120, June 2014, Pages 211–214
- F. Cerutti et al. *Beam-machine Interaction at the CERN LHC,* Nuclear Data Sheets, Volume 120, June 2014, Pages 215–218