The FLUKA Code

An Introduction to FLUKA: a multipurpose Interaction and Transport MC code

7th FLUKA Course

NEA Paris, Sept. 29-Oct. 3, 2008

FLUKA

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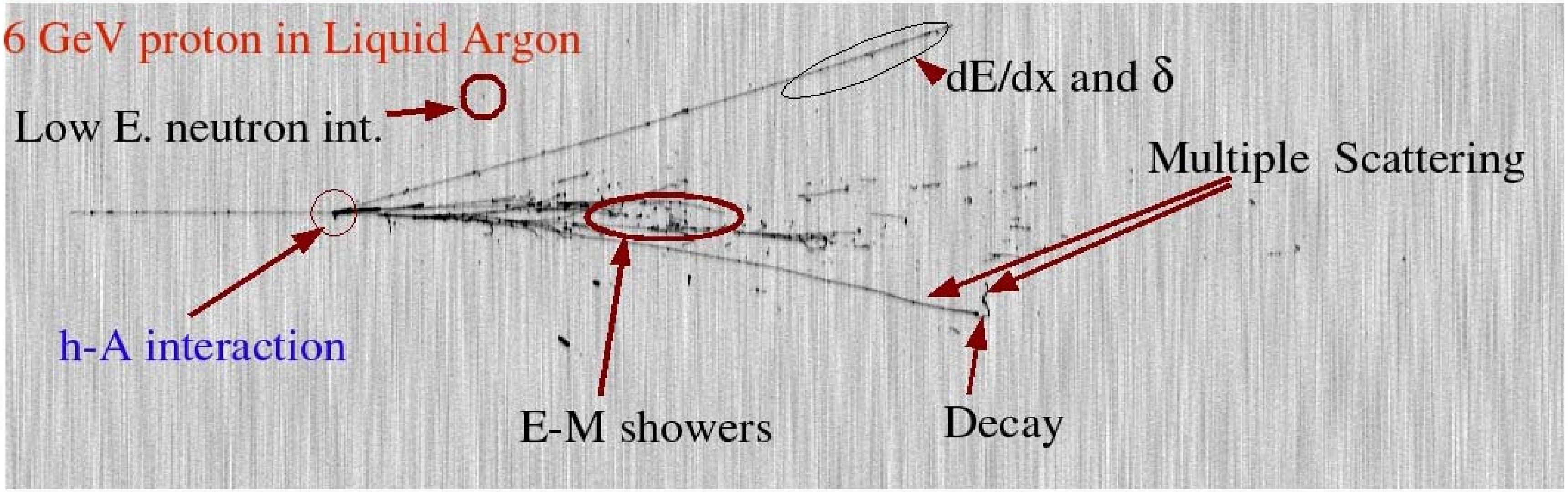

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>2000 users **http://www.fluka.org**

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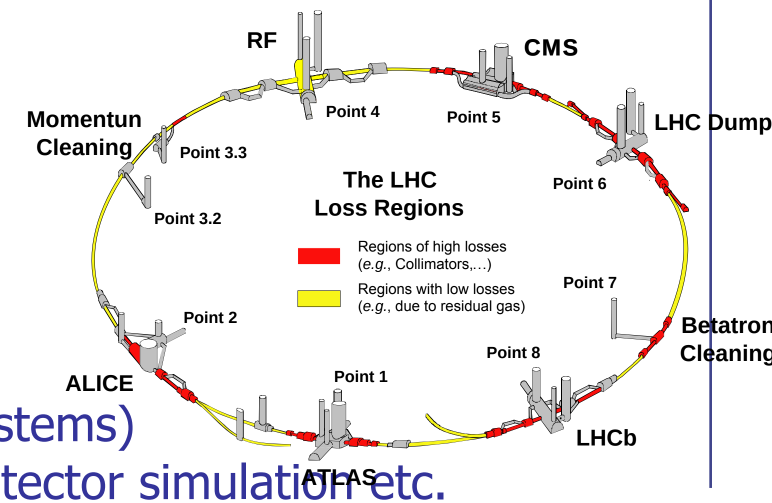
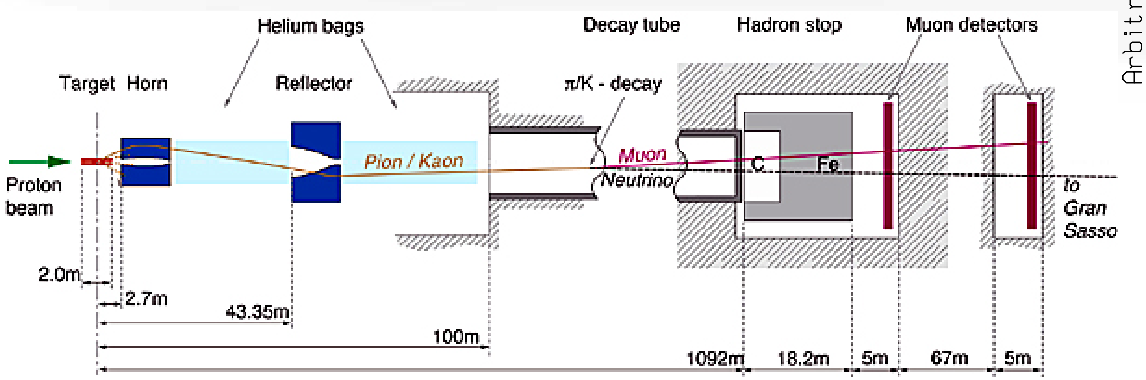
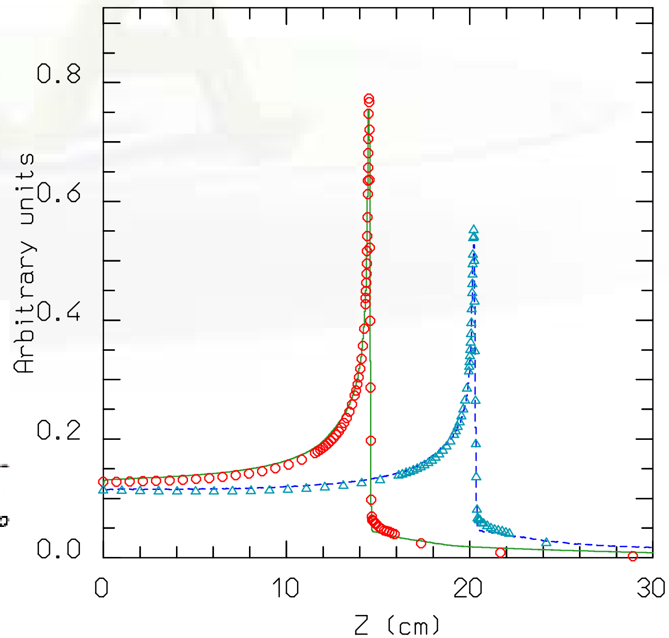
FLUKA Applications



- Cosmic ray physics
- Neutrino physics
- Accelerator design (→ n_ToF, CNGS, LHC systems)
- Particle physics: calorimetry, tracking and detector simulation etc. (→ ALICE, ICARUS, ...)
- ADS systems, waste transmutation, (→"Energy amplifier", FEAT, TARC,...)
- Shielding design
- Dosimetry and radioprotection
- Space radiation
- Hadrontherapy
- Neutronics





The History

The early days

The beginning:

1962: Johannes Ranft (Leipzig) and Hans Geibel (CERN): Monte Carlo for high-energy proton beams

The name:

1970: study of event-by-event fluctuations in a NaI calorimeter (FLUktuierende KAskade)

Early 70's to ≈1987: J. Ranft and coworkers (Leipzig University) with contributions from Helsinki University of Technology (J. Routti, P. Aarnio) and CERN (G.R. Stevenson, A. Fassò)

Link with EGS4 in 1986, later abandoned

The modern code: some dates

Since 1989: mostly INFN Milan (A. Ferrari, P.R. Sala): little or no remnants of older versions. Link with the past: J. Ranft and A. Fassò

1990: LAHET / MCNPX: high-energy hadronic FLUKA generator *No further update*

1993: G-FLUKA (the FLUKA hadronic package in GEANT3). *No further update*

1998: FLUGG, interface to GEANT4 geometry

2000: grant from NASA to develop heavy ion interactions and transport

2001: the INFN FLUKA Project

2003: official CERN-INFN collaboration to develop, maintain and distribute FLUKA

The FLUKA Code design - 1

- Sound and updated physics models
  - Based, as far as possible, on original and well-tested microscopic models
  - Optimized by comparing with experimental data at single interaction level: ***"theory driven, benchmarked with data"***
  - Final predictions obtained with minimal free parameters fixed for all energies, targets and projectiles
  - Basic conservation laws fulfilled "a priori"

➔ ***Results in complex cases, as well as properties and scaling laws***, arise naturally from the underlying physical models

➔ ***Predictivity where no experimental data are directly available***

It is a "condensed history" MC code, with the possibility use of single instead of multiple scattering

The FLUKA Code design - 2

- Self-consistency
  - Full cross-talk between all components: hadronic, electromagnetic, neutrons, muons, heavy ions
  - Effort to achieve the same level of accuracy:
    - for each component
    - for all energies
  - → Correlations preserved fully within interactions and among shower components
  - → ***FLUKA is NOT a toolkit! Its physical models are fully integrated***

The Physics Content of FLUKA

- Nucleus-nucleus interactions 100 MeV/n – 10000 TeV/n
  New model (BME, under development): from Coulomb Barrier
- Electromagnetic and μ interactions 1 keV – 10000 TeV
- Hadron-hadron and hadron-nucleus interactions 0–10000 TeV
- Neutrino interactions NEW! (new DIS and RES generator!)
- Charged particle transport including all relevant processes
- Transport in magnetic field
- Neutron multigroup transport and interactions 0 – 20 MeV
  NEW! new library with 260 groups
- Analog calculations, or with variance reduction

The FLUKA course: an Introduction

How:

This course is intended to provide users with the basic (and possibly more than basic!) knowledge of:

a) The most relevant FLUKA instructions and options
b) The physics models adopted in FLUKA
c) The different scoring options embedded in FLUKA
d) The different running options
e) How to insert user code in FLUKA
f) The tools to plot results
g) The right approach to the existing documentation
h) The procedures to overcome difficulties and problems and related debugging tools
i) etc. etc.

Method:

There will be formal lectures but they will be followed much as possible by practical (simple) examples.

Emphasis will be given to practice.

If possible we shall try to transform your questions into cases of general interest.

A possible problem:

People here are not at the same level of FLUKA knowledge. There are those who already have some experience, maybe not negligible.

However we need to start from scratch.

We apologize to the experienced people and beg them to be patient: it's not excluded a-priori that they can learn something new also concerning the very basic elements!

A glimpse of FLUKA

The FLUKA version

FLUKA2008.n(x)(.m)

Major version

Respin

Minor version

Patch level

Since 2006 each version is going to be maintained for 2 years max.

In this course we are using FLUKA2008.3 (just released a few days ago)

The FLUKA license (it is not GPL):

- Standard download: binary library + user routines.
  - FLUKA can be used freely for scientific and academic purposes, ad-hoc agreement for commercial purposes
  - It cannot be used for weapon related applications
  - It is not permitted to redistribute the code (single user, single site)
  - User can add their own scoring, sources etc through a wide set of user routines, provided they don't modify the physics
  - Relevant references for each FLUKA version can be found in the documentation
- It is possible, by explicit signature of license, to download *(!!! now from NEA as well !!!)* the source for researchers of scientific/academic Institutions.
  - FLUKA cannot be copied, even in part, into other codes, or translated into another language without permission.
  - The user cannot publish results with modified code, unless explicit authorization is granted in advance.

Using FLUKA

Platform: Linux with g77, Linux with g95, Mac OSX with g95

Under test: Linux and Mac OSX (gfortran), Windows-Cygwin (g95)

The code can compiled/run only on with operating systems, compilers (and associated) options tested and approved by the development team

Standard Input:

• Command/options driven by "data cards" (ascii file) . Graphical interface is available!!!!

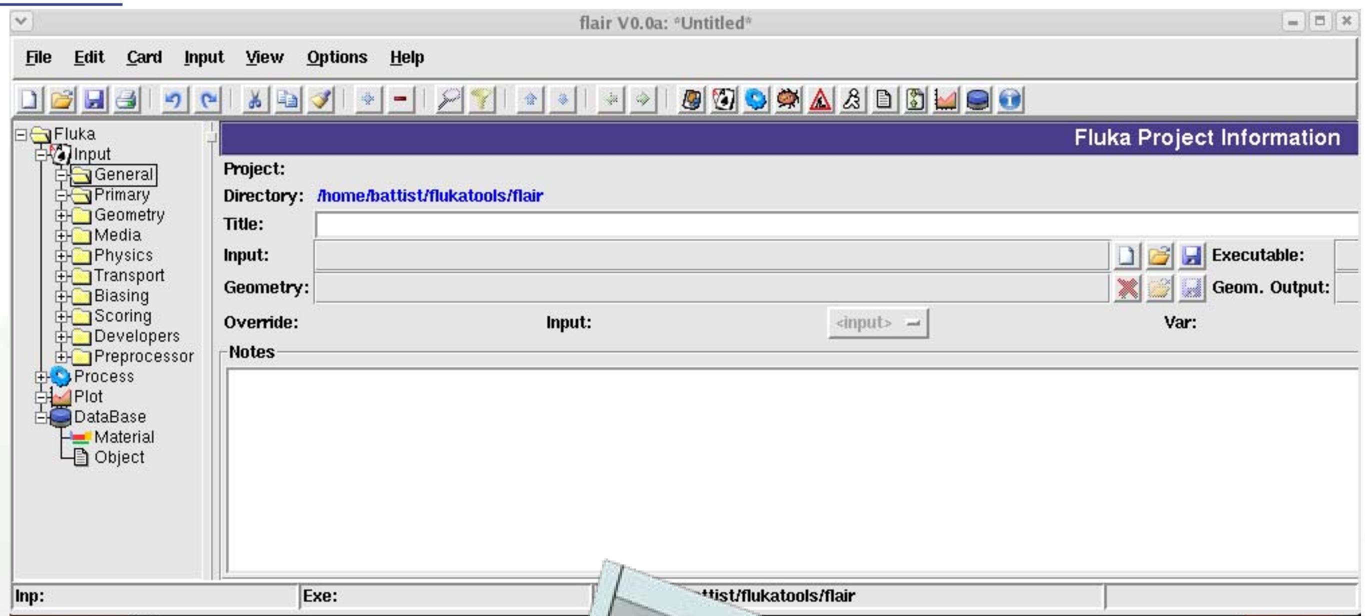
• Standard Geometry ("Combinatorial geometry"): input by "data cards"

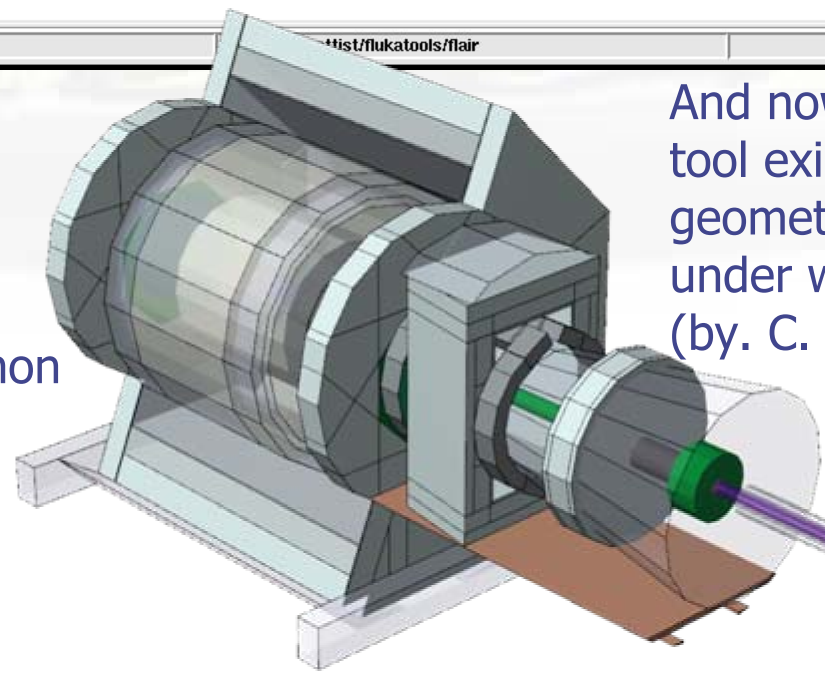
Standard Output and Scoring:

• Apparently limited but highly flexible and powerful

• Output processing and plotting interface available

Examples of user interfaces





A FLUKA run can be managed through a graphical interface. Here is an example using python + Tk (***FLAIR***, V.Vlachoudis, CERN)

And now a graphical tool exists to prepare geometry, running under windows (by. C. Theis, CERN)

FLUKA-2008.3 Release Notes

This FLUKA release is a major step in the FLUKA development cycle with respect to the last official release version Fluka2006.3b. It adds a few new features and there are a few major physics improvements.

As it is obvious from the name, the major revision number of this release is 2008 and the minor revision number is 3.

With this release all FLUKA version older or equal to 2006.3 are obsolete and they shall no longer be used

FLUKA Release New Features

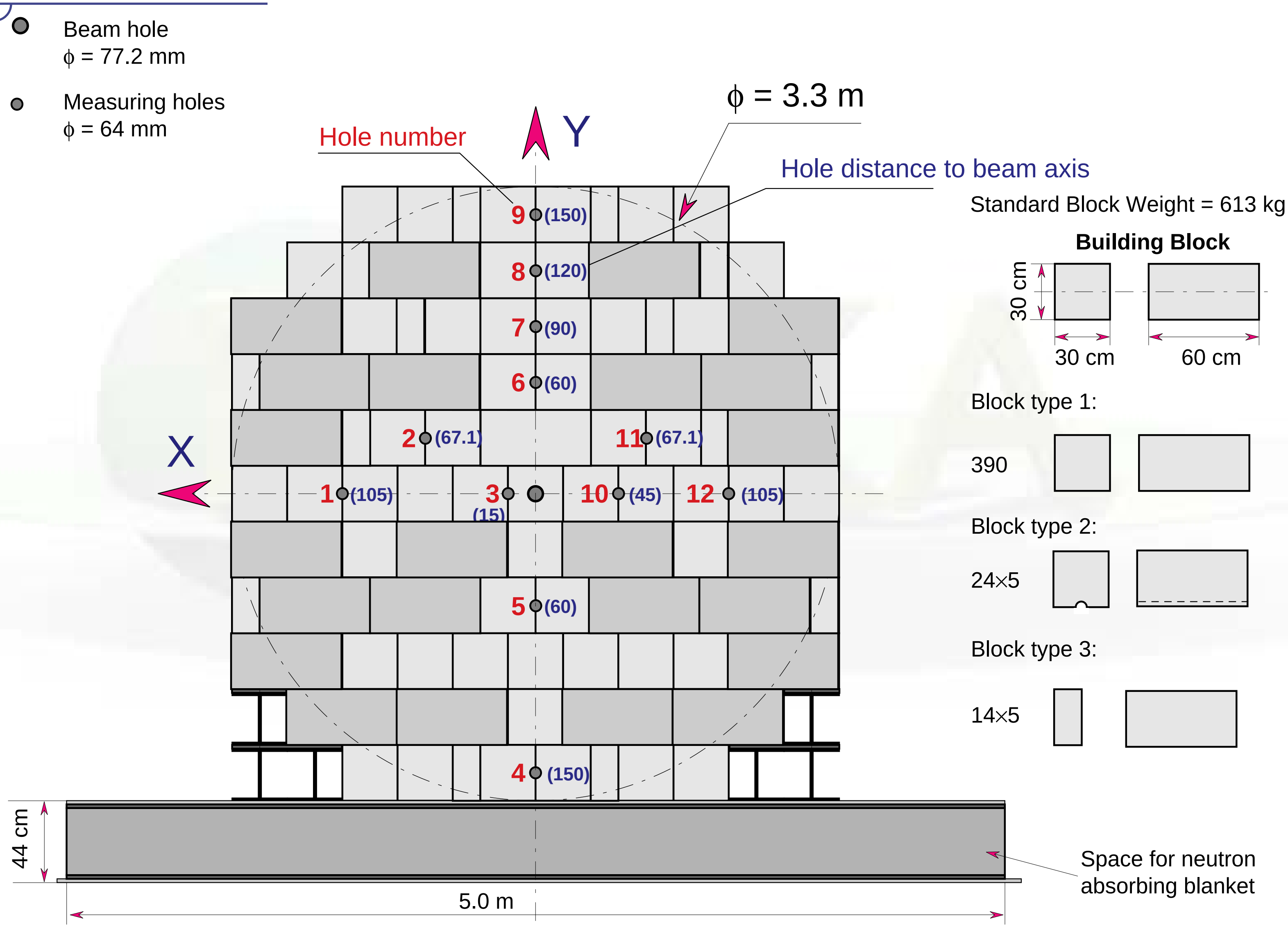
- New neutron cross section library below 20 MeV, including 260 neutron and 42 gamma groups: 31 neutron groups are thermal (1 in the previous library) (thanks to D. Ene, A. Fassò, A.Ferrari, G. Panini, F. Sommerer) . .
  - Please note that the new 260 group library is now the default one (even though the "old" 72 group one is still distributed).
- Heavy ion pair production
- New implementation of the BME model with vastly improved performances for peripheral collisions (BME is available on request)
- A new neutrino-nucleus event generator, including quasi-elastic, resonance, and deep-inelastic interactions (thanks to M. Lantz, P.R. Sala, G. Smirnov, G. Battistoni, and A. Ferrari)
- An enhanced version of the PEANUT event generator which should significantly improve residual nuclei predictions in the intermediate energy range, and more in general should further improve predicted particle spectra

FLUKA Release New Features

- New radioactive decay database, now including also conversion electron and Auger lines
- New generalized particles:
  - Dose (GeV/g) (DOSE, generalized particle id 228)
  - Dose equivalent (pSv) (DOSE-EQ, generalized particle id 240)
  - 1 MeV neutron Si equivalent fluence (for Silicon damage) (SI1MEVNE, generalized particle id 236)
  - High energy hadron fluence scoring (hadrons with energy larger than 20 MeV) (HADGT20M, generalized particle id 237)
- New option AUXSCORE
  - easy filtering of estimators (see scoring lecture)
  - choice of conversion coefficients for DOSE-EQ

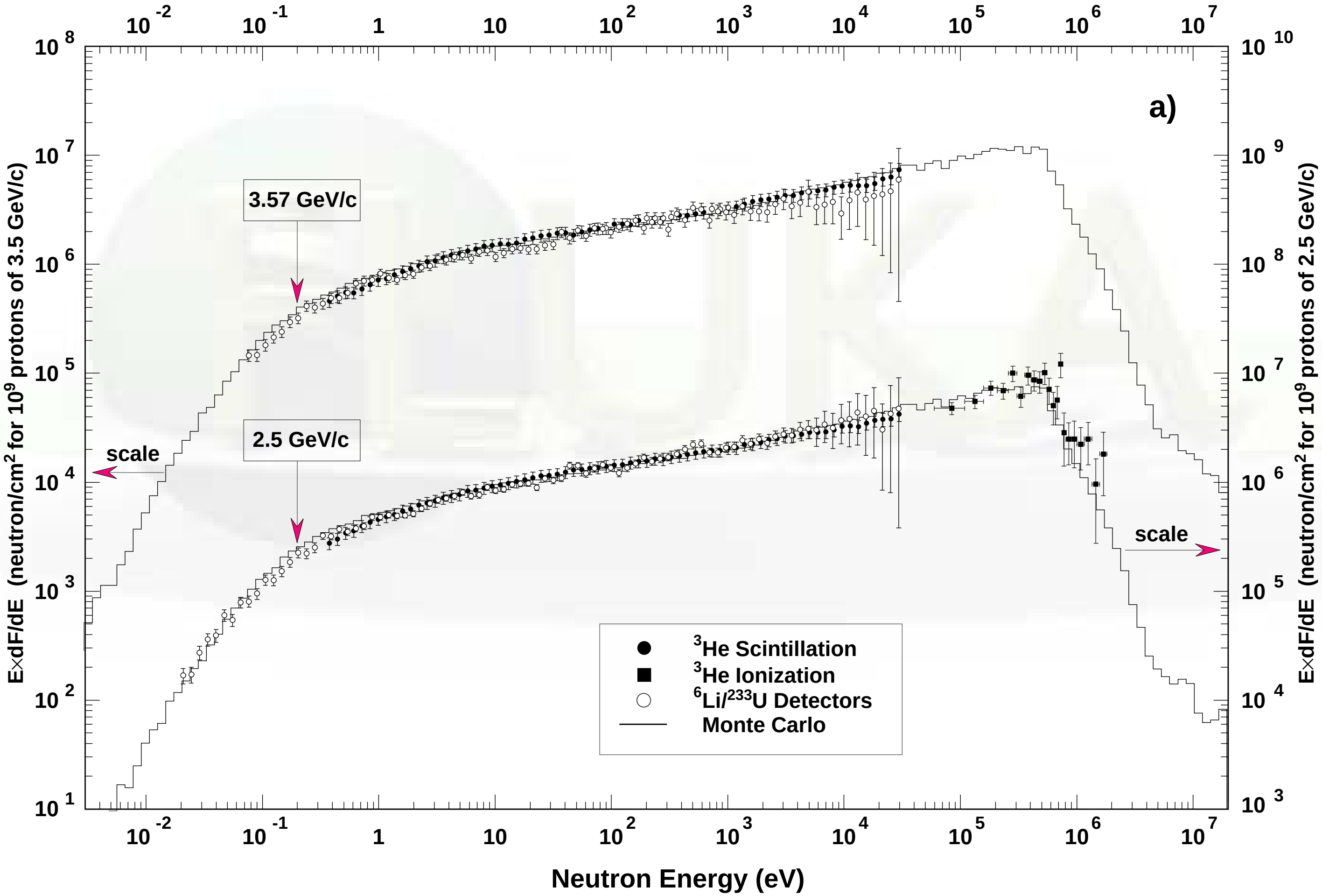
Examples of FLUKA Applications

The TARC experiment at CERN:

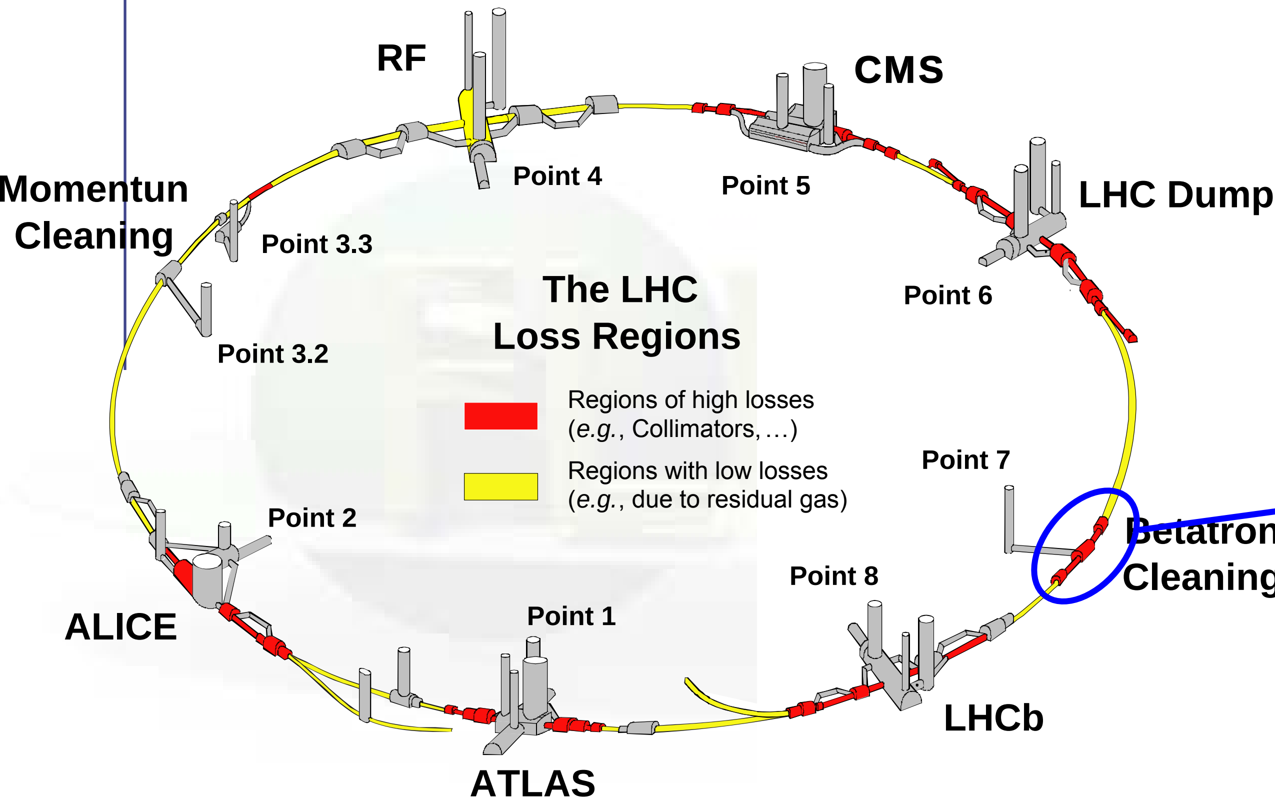


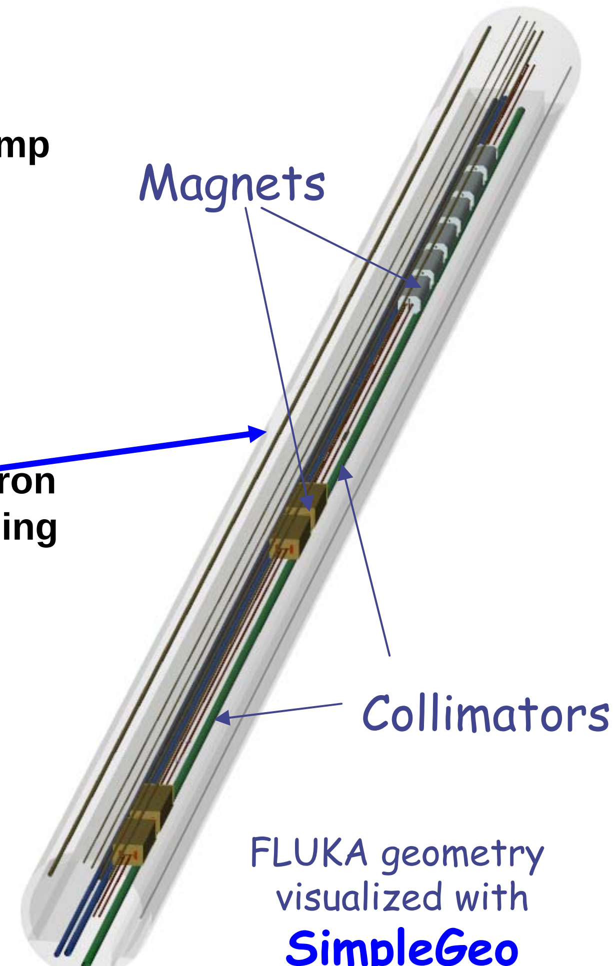
The TARC experiment: neutron spectra

FLUKA + EA-MC (C.Rubbia et al.)



Applications – *LHC collimation region*





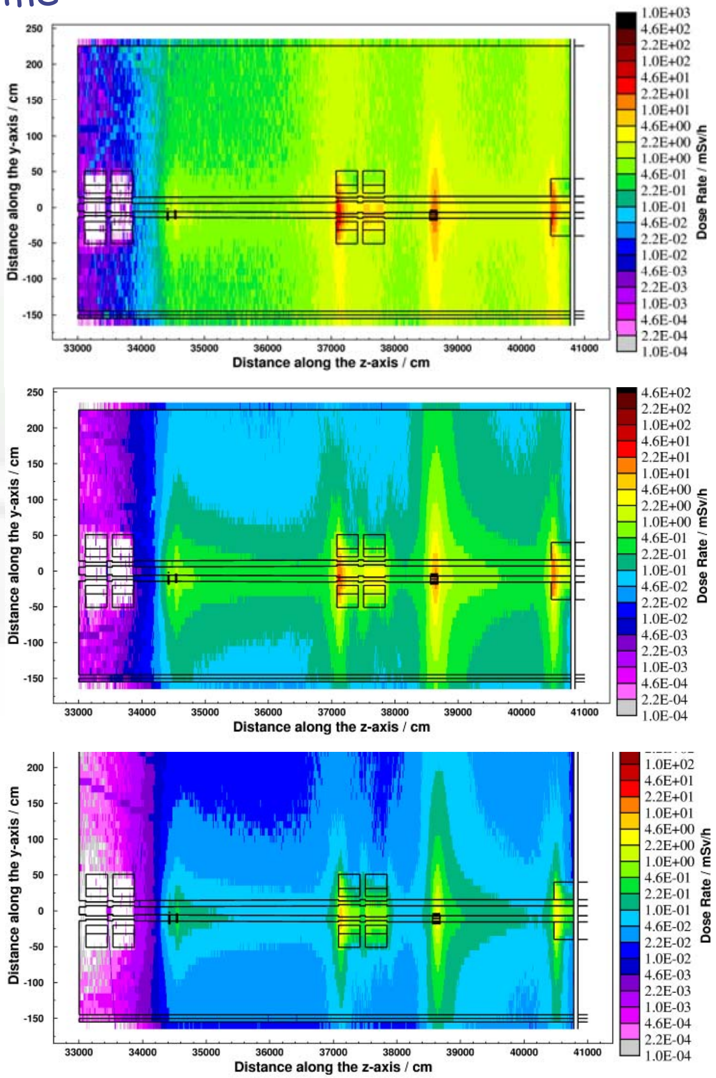
Applications – *LHC collimation region*

Cooling time

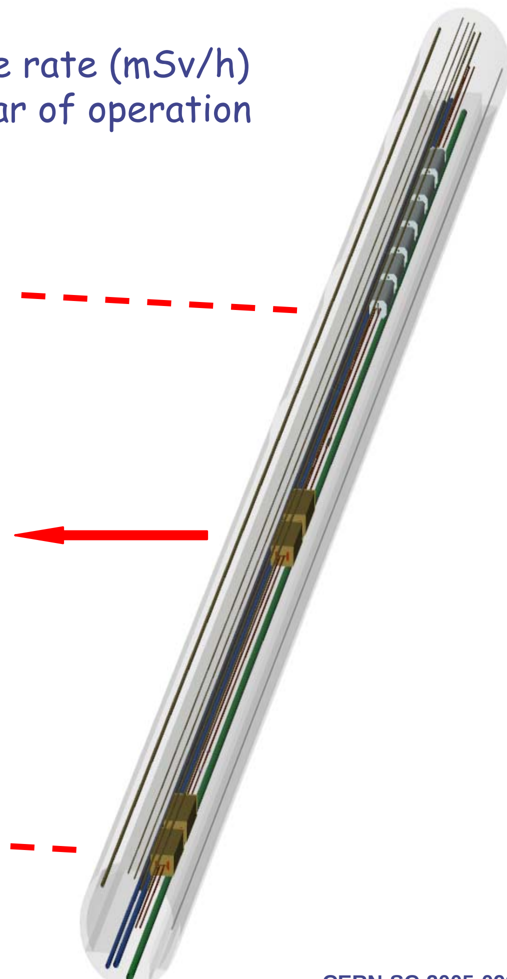
8 hours

1 week

4 months



Residual dose rate (mSv/h) after one year of operation

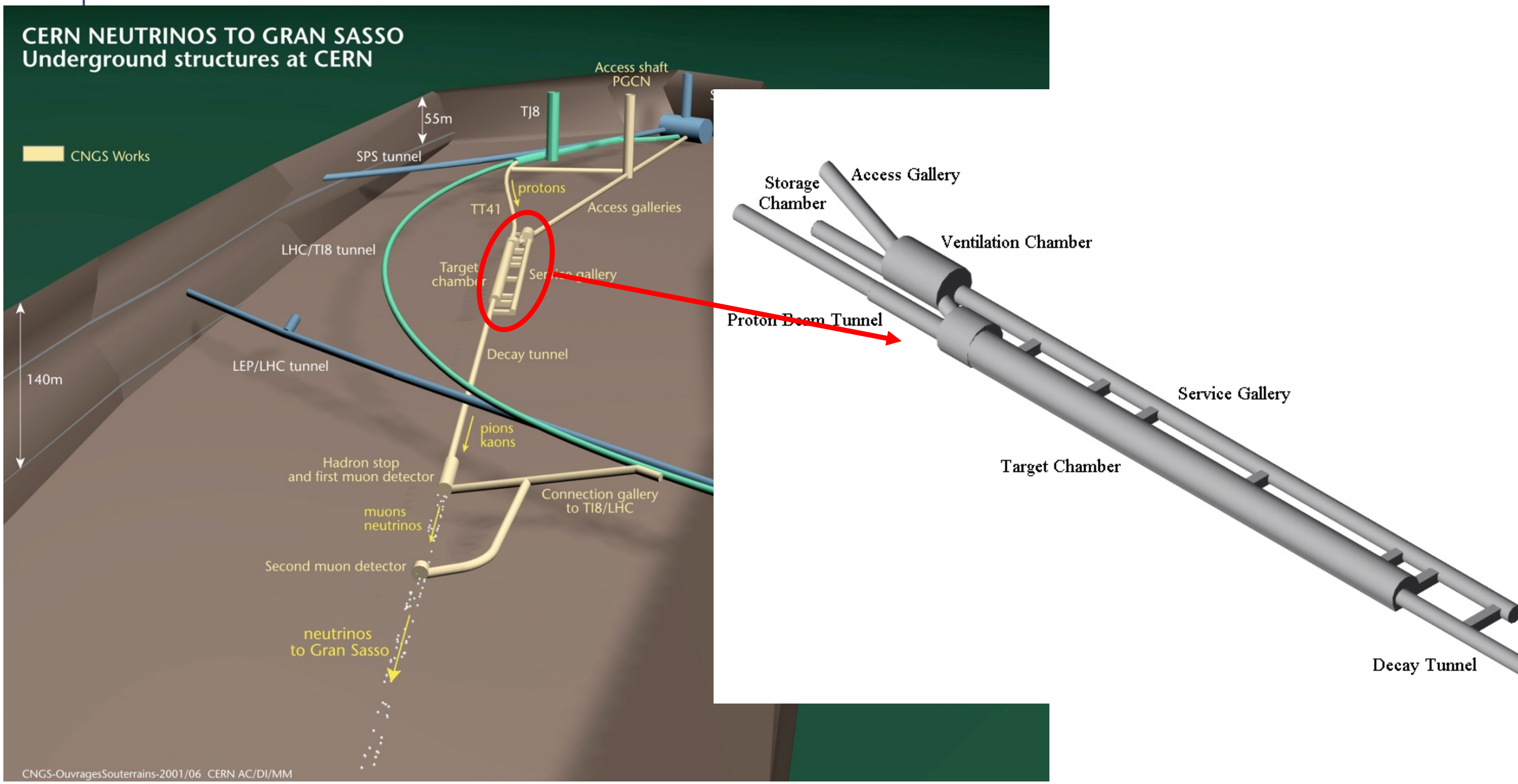


CERN-SC-2005-092-RP-TN

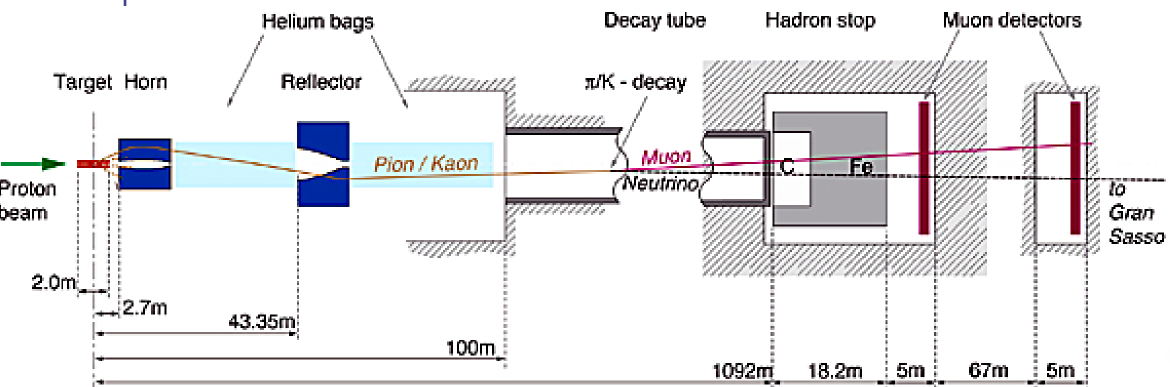
REMANENT DOSE RATE MAPS OF THE LHC BETATRON CLEANING INSERTION (IR7)

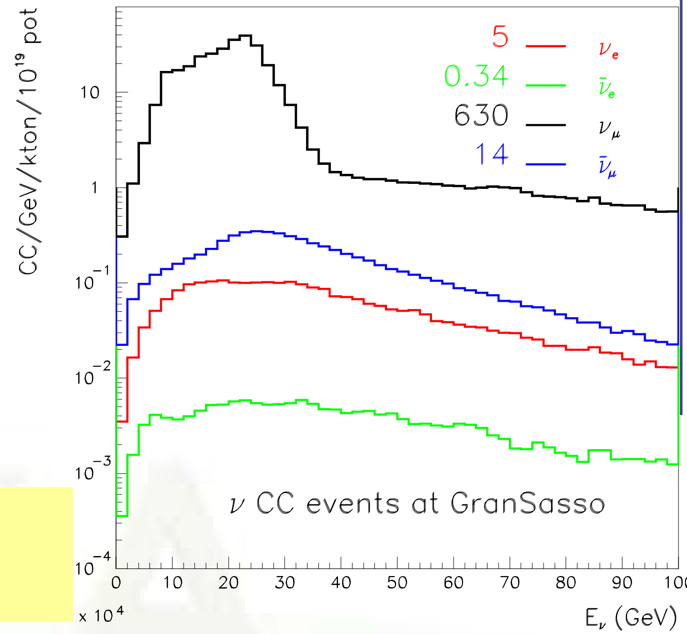
M. Brugger, D. Forkel-Wirth, S. Roesler

Applications – *CNGS*

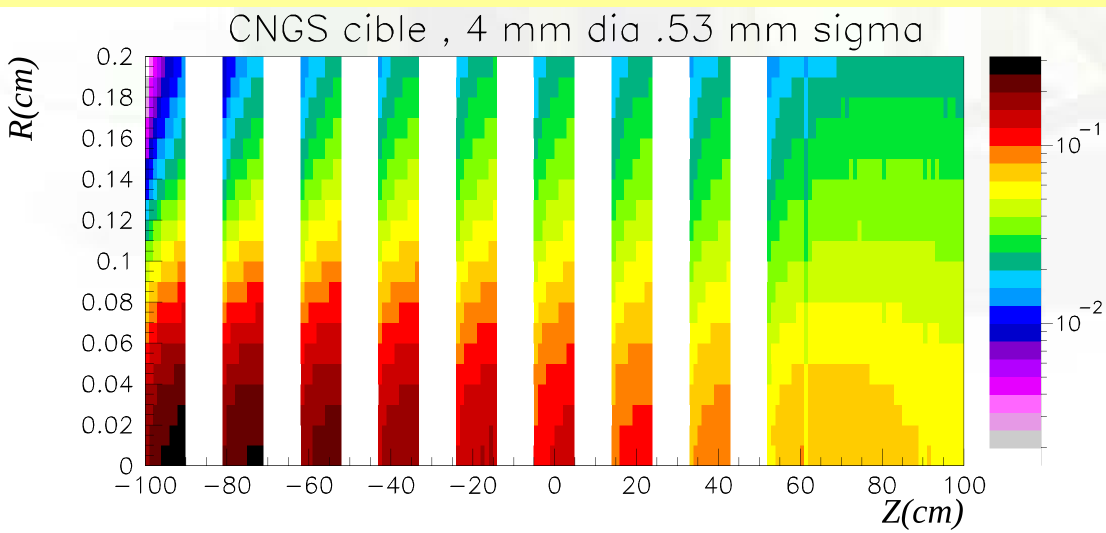


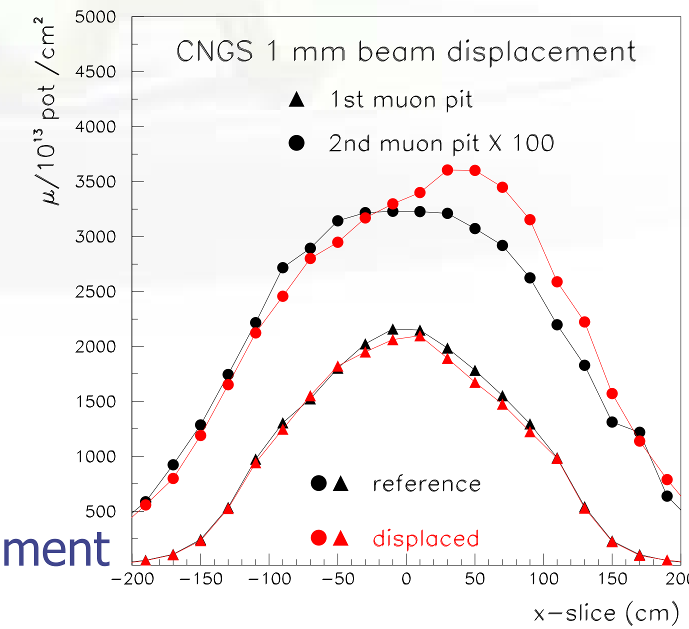
Cern Neutrino to Gran Sasso





Engineering and physics: target heating, shielding, activation, beam monitors, neutrino spectra

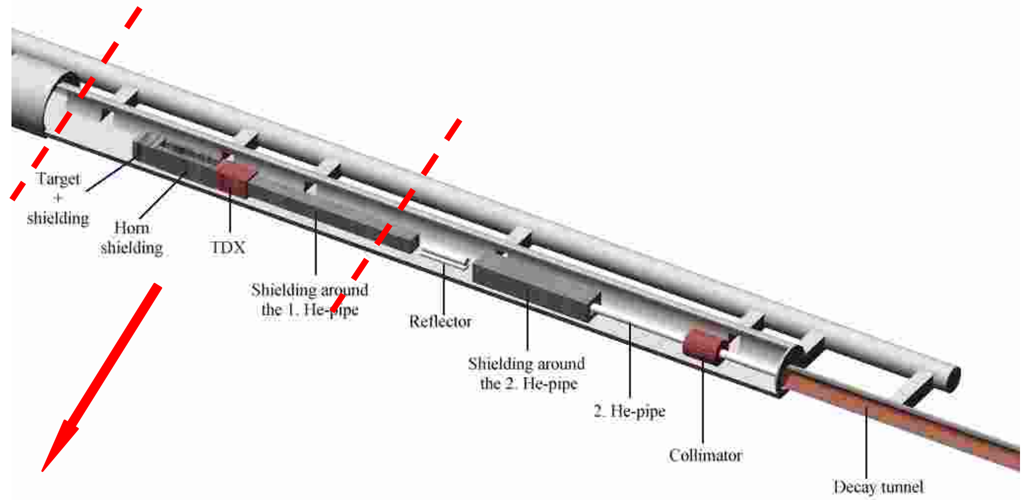




Muons in muon pits: horiz. distribution for beam alignment

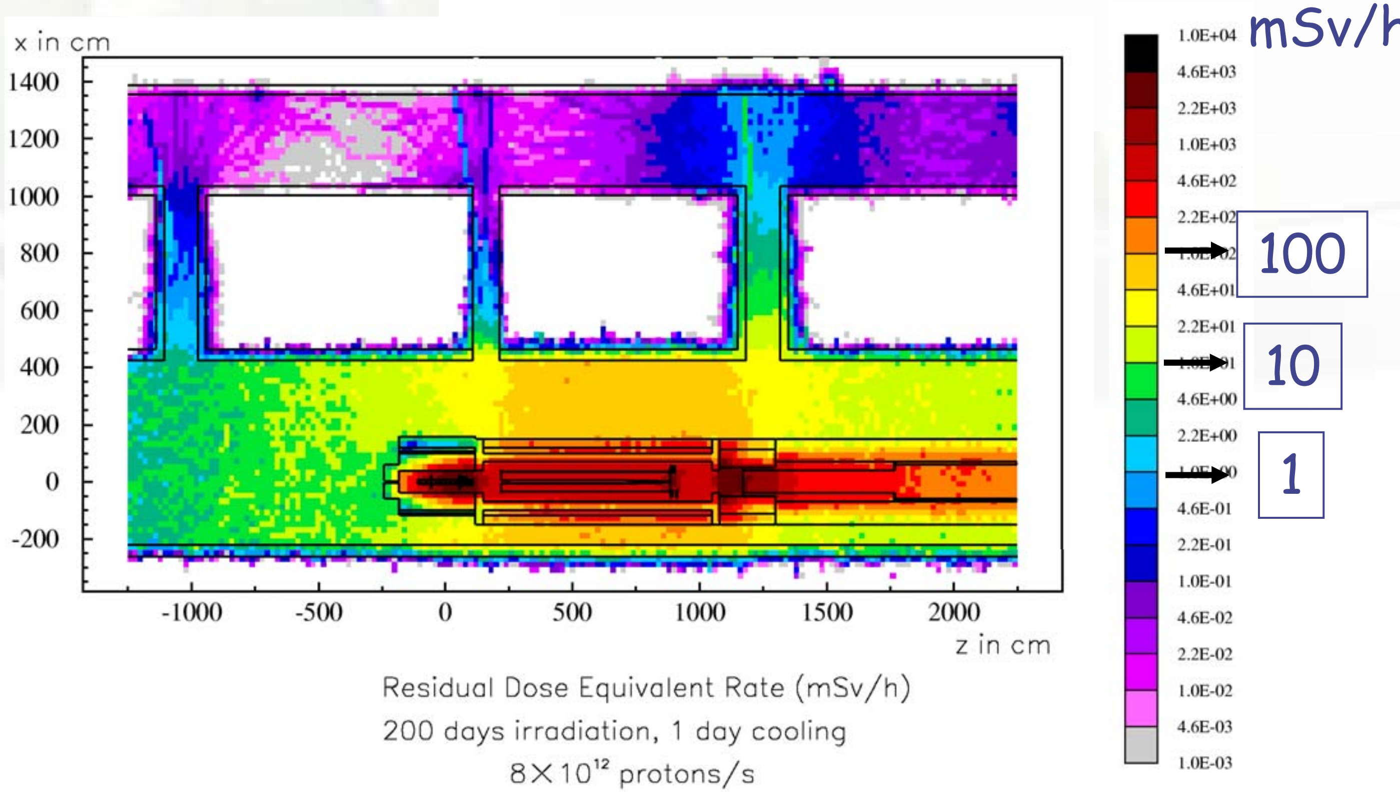
Energy dep. in CNGS target rods, GeV/cm^3/pot

Applications – *CNGS*

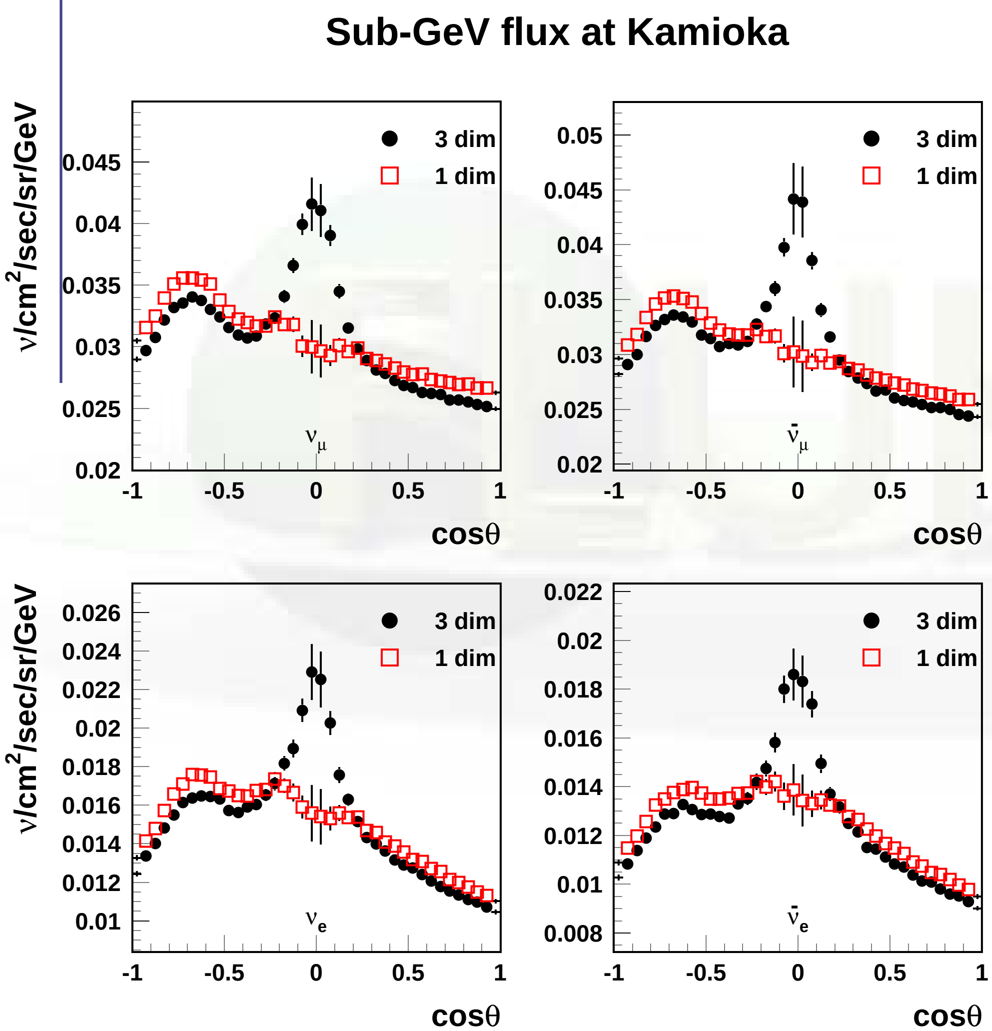


Example:

t_{cool} = 1 day



(3D) Calculation of Atmospheric ν Flux



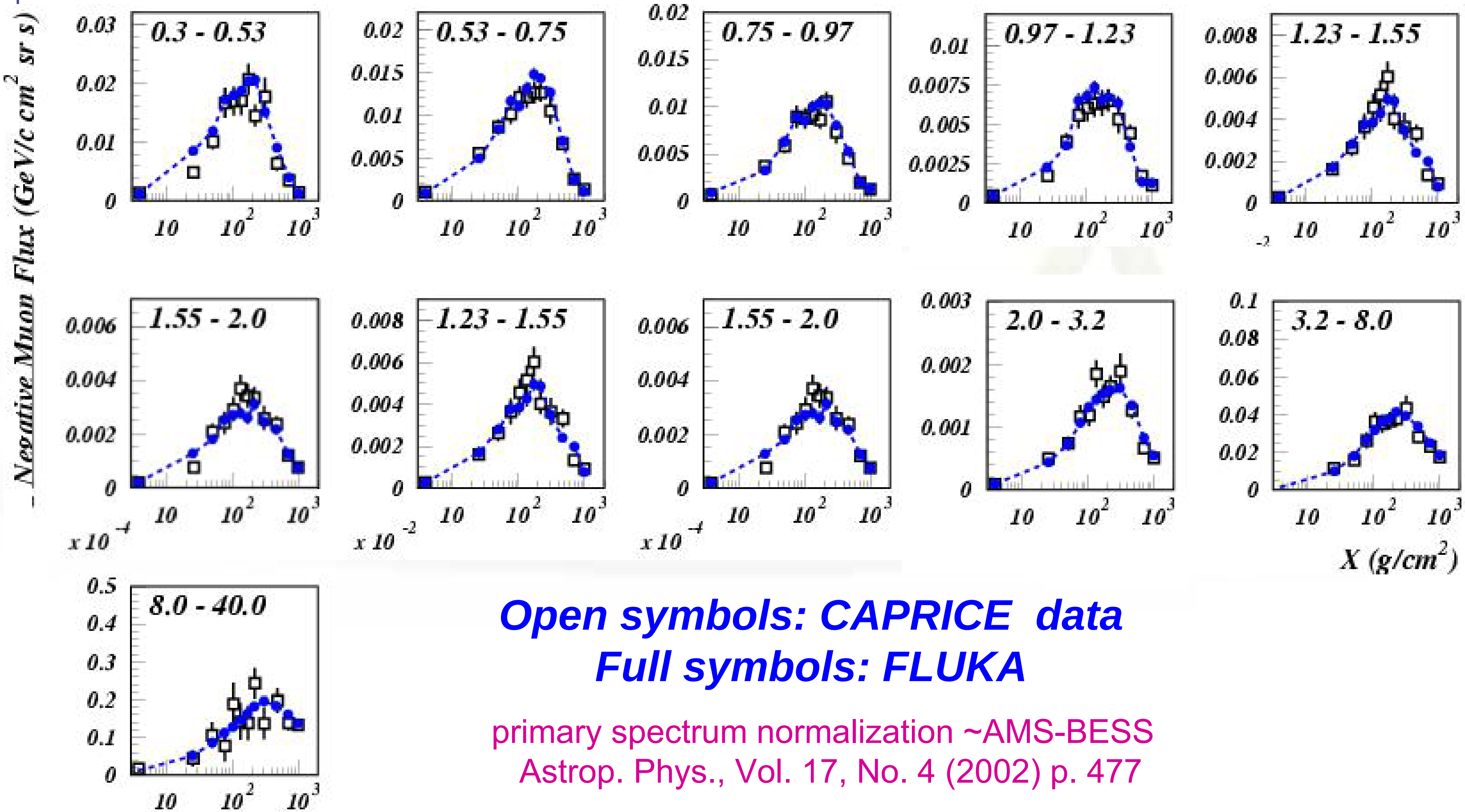
The first 3-D calculation of atmospheric neutrinos was done with FLUKA.

The enhancement in the horizontal direction, which cannot be predicted by a 1-D calculation, was fully unexpected, but is now generally acknowledged.

In the figure: angular distribution of ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$.

In red: 1-D calculation

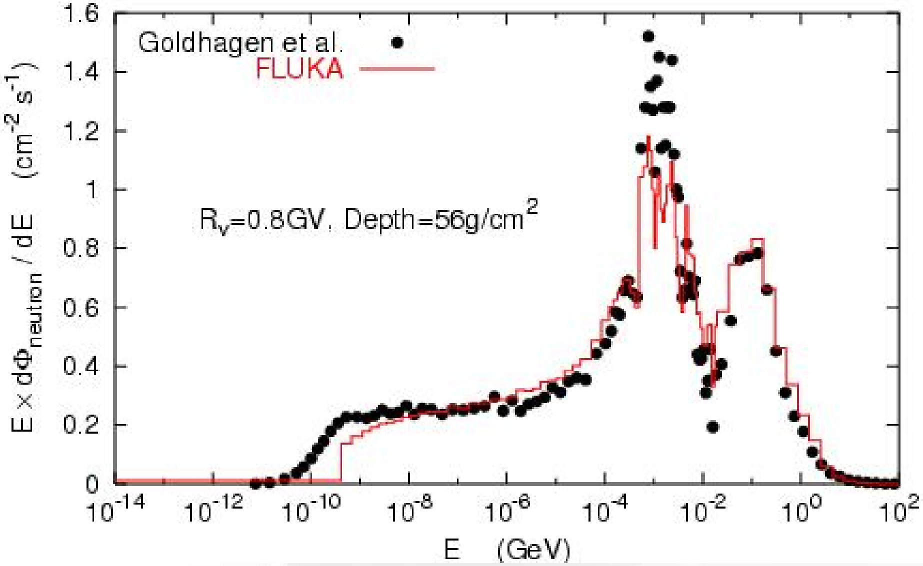
Negative muons at floating altitudes: CAPRICE94



Open symbols: CAPRICE data
Full symbols: FLUKA

primary spectrum normalization ~AMS-BESS
Astrop. Phys., Vol. 17, No. 4 (2002) p. 477

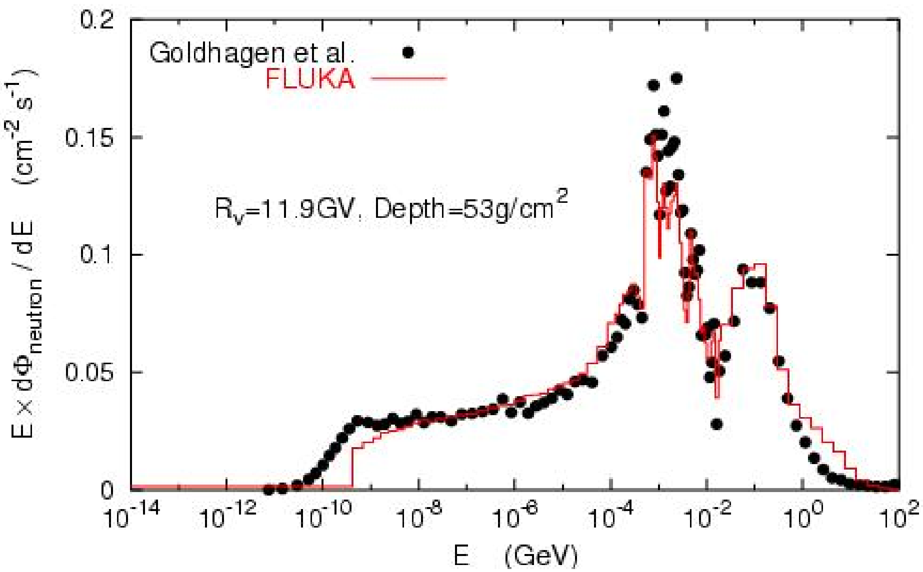
Neutrons on the ER-2 plane at 21 km altitude



Measurements:

Goldhagen et al., NIM A476, 42 (2002)

Note one order of magnitude difference depending on latitude

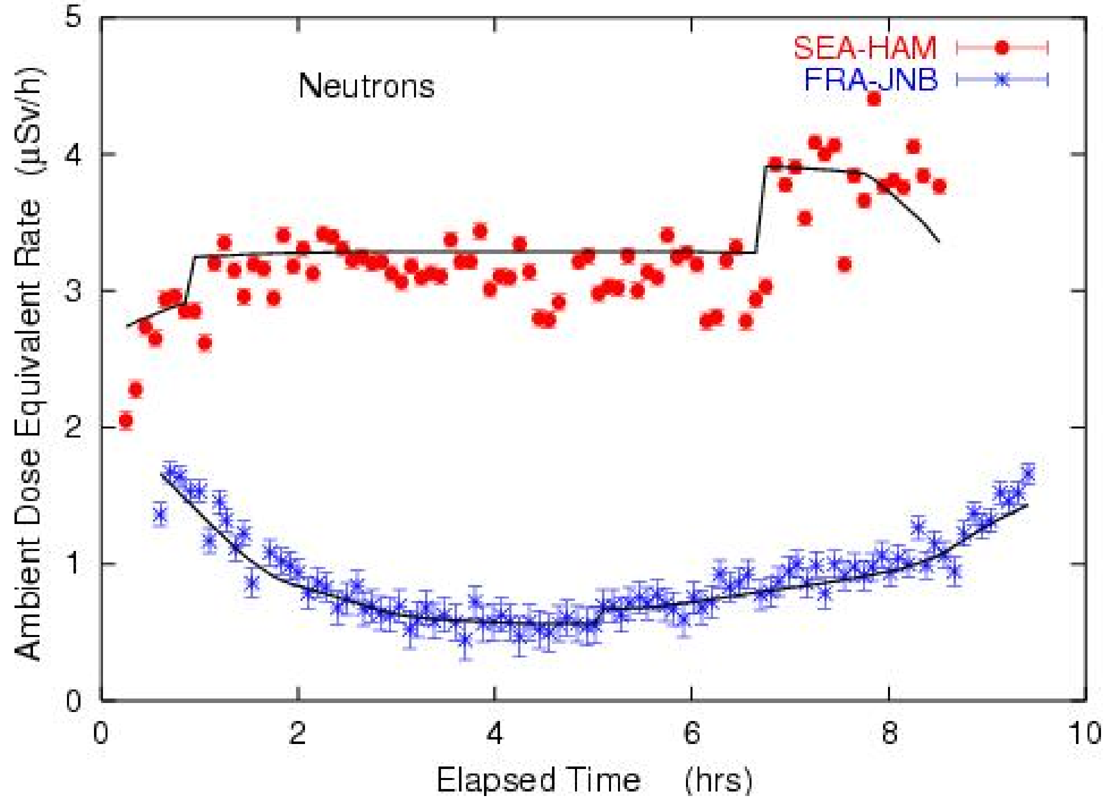


FLUKA calculations:

Roesler et al., Rad. Prot. Dosim. 98, 367 (2002)

Dosimetry Applications

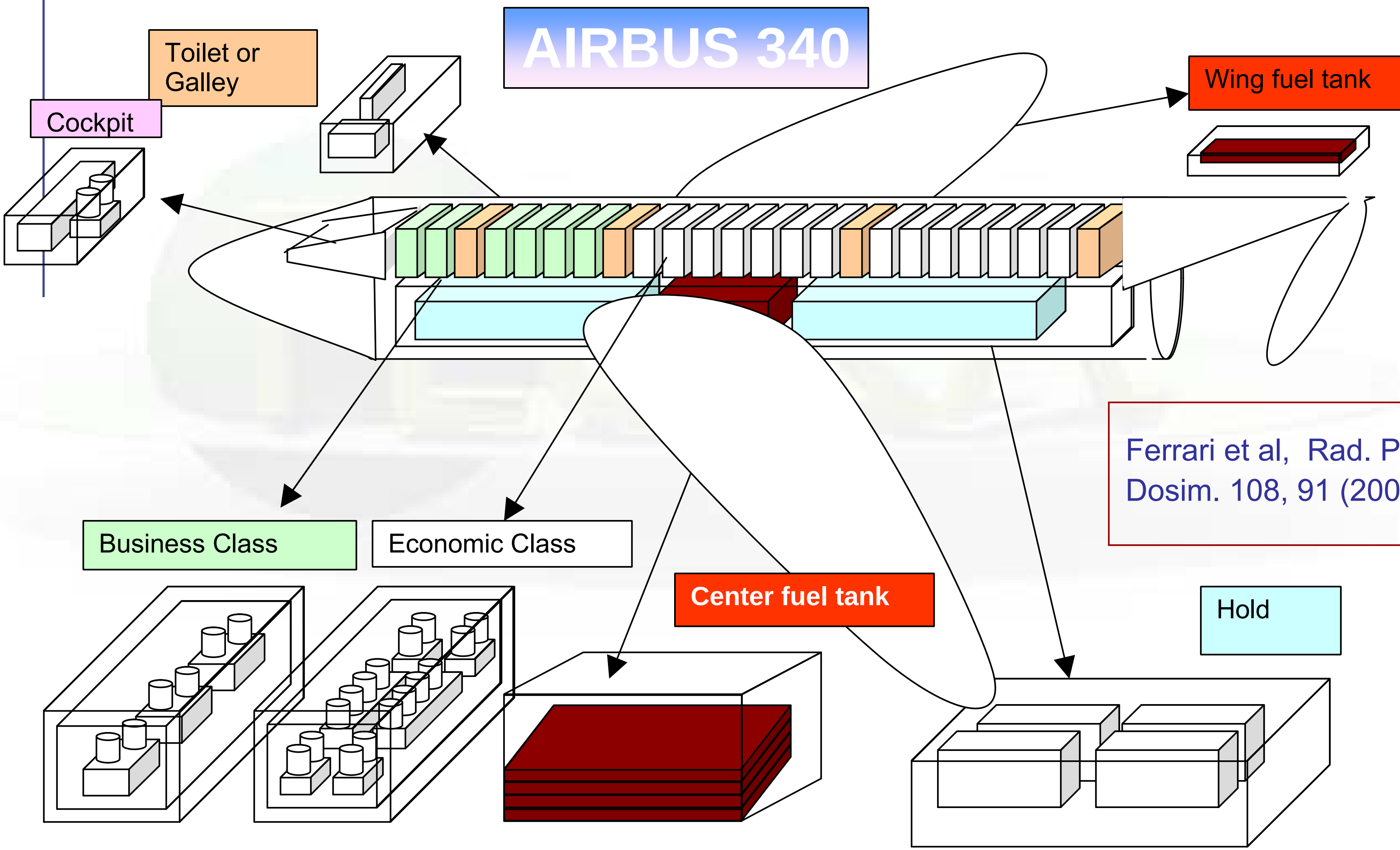
Roesler et al.,
Rad. Prot. Dosim.
98, 367 (2002)



Ambient dose equivalent from neutrons at solar maximum on commercial flights from Seattle to Hamburg and from Frankfurt to Johannesburg.

Solid lines: FLUKA simulation

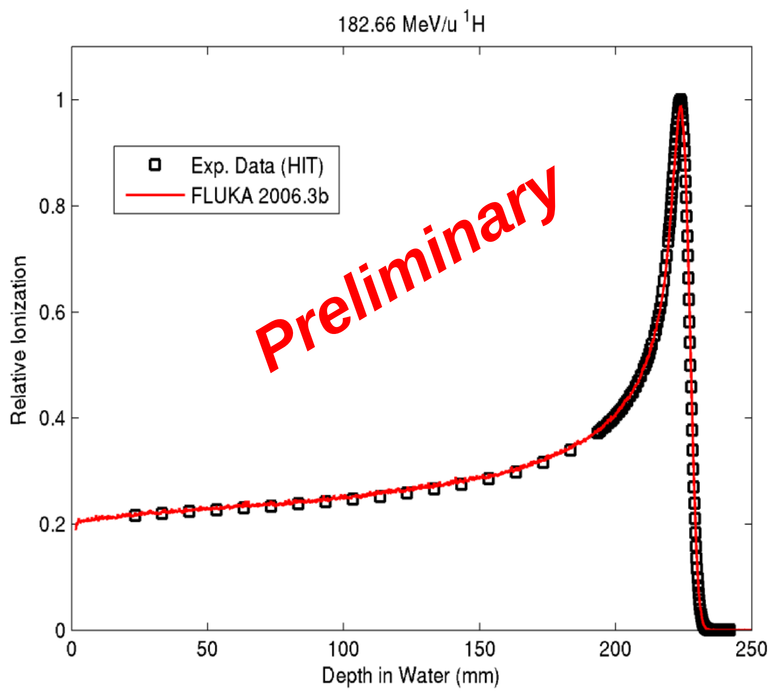
Dosimetry applications: doses to aircrew and passengers



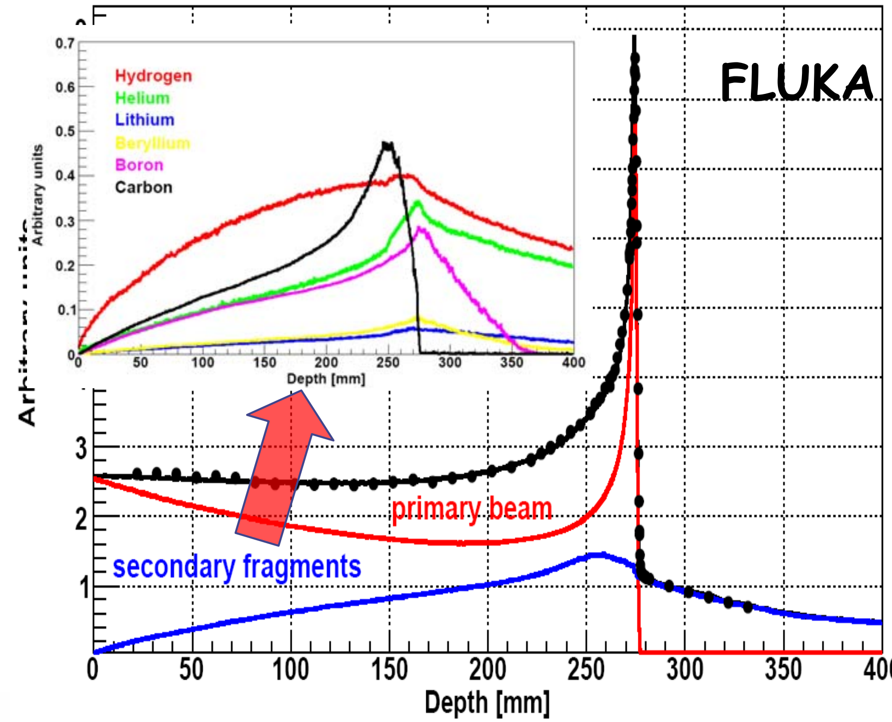
Ferrari et al, Rad. Prot. Dosim. 108, 91 (2004)

Experimental validation against measured Bragg curve in Proton and Carbon ion therapy

Protons (183 MeV/u) in Water



^{12}C ions (400 MeV/u) in Water



Exp. Data (points) taken at HIT: D. Schardt, P. Steidl, K. Parodi, S. Brons et al.

Simulation: K. Parodi

Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006

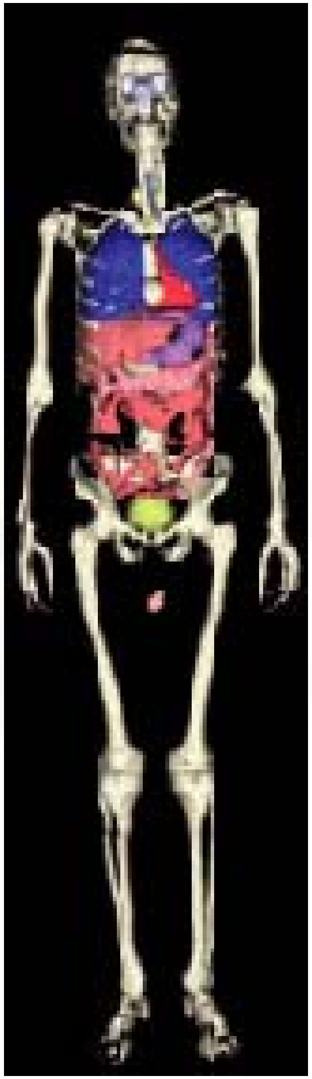
Simulation: A. Mairani, PhD Thesis, Pavia, 2007

Using the information from the patient CT in the MC I

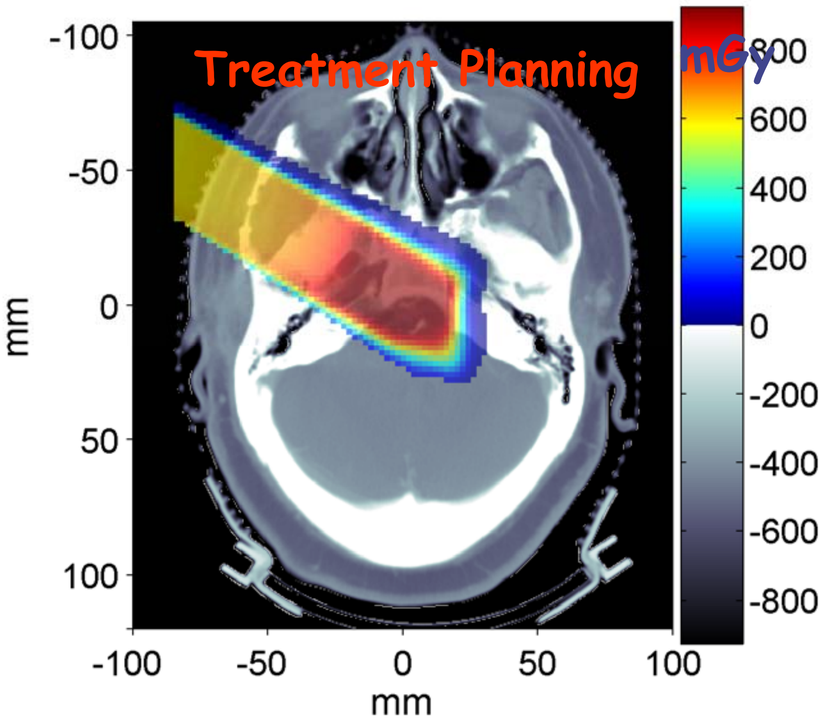
The Voxel Geometry

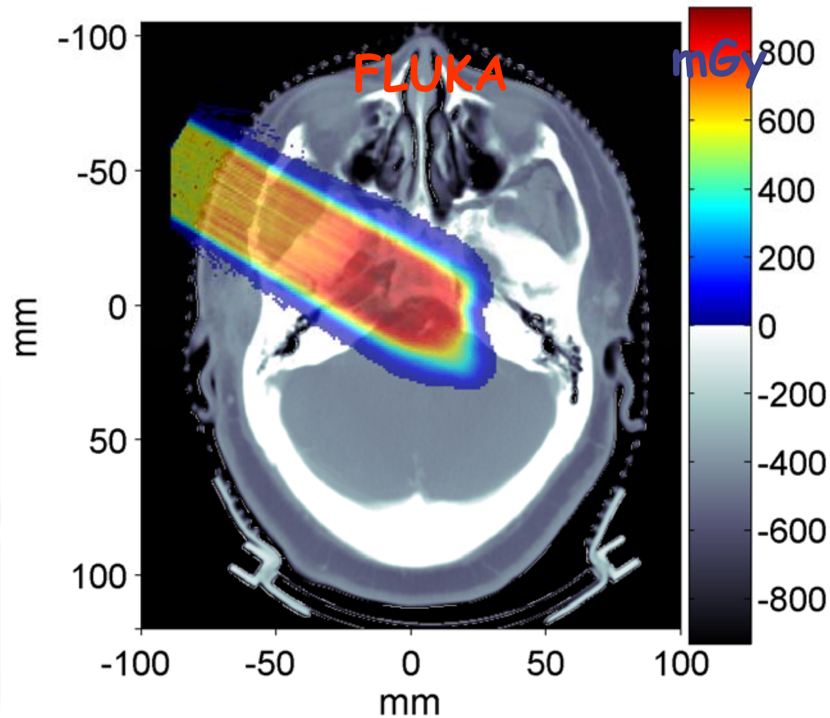
- FLUKA can embed voxel structures within its standard combinatorial geometry
- Transport through the voxels is optimized and efficient
- Raw CT-scan outputs can be imported

The GOLEM phantom
Petoussi-Henss et al, 2002



Proton therapy: MC vs Focus/XiO for a Clivus Chordoma Patient at MGH





Parodi et al, JPCS 74, 2007

Prescribed dose: 1 GyE

MC : ~ 5.5 10^6 protons in 10 independent runs

(11h each on Linux Cluster mostly using 2.2GHz Athlon processors)

The FLUKA mailing lists

- fluka-users@fluka.org

  Users are automatically subscribed here when registering on the web site. It is used to communicate the availability of new versions, patches, etc.

- fluka-discuss@fluka.org

  Users are encouraged to subscribe at registration timed, but can uncheck the relevant box. It is used to have user-user and user-expert communication about problems, bugs, general inquiries about the code and its physics content

users are strongly encouraged to keep this subscription

end

Code complexity

- Inelastic h-N: ~***72000 lines***
- Cross sections (h-N and h-A), and elastic (h-N and h-A): ~***32000 lines***
- (G)INC and preequilibrium (PEANUT): ~***114000 lines***
- Evap./Fragm./Fission/Deexc.: ~***27000 lines***
- ν-N interactions: ~***35000 lines***
- A-A interactions:
  - ✓ FLUKA native (including BME): ~***8000 lines***
  - ✓ DPMJET-3: ~***130000 lines***
  - ✓ (modified) rQMD-2.4: ~***42000 lines***
- **FLUKA** in total (including transport, EM, geometry, scoring): ~***680000 lines***
- … + ~***20000 lines*** of ancillary off-line codes used for data pre-generation
- … and ~***30000 lines*** of post-processing codes

- General use: installation and run by a single user on a single machine
- Run can be managed also in computer farms (clusters)
- experimented under GRID