



# The FLUKA Code

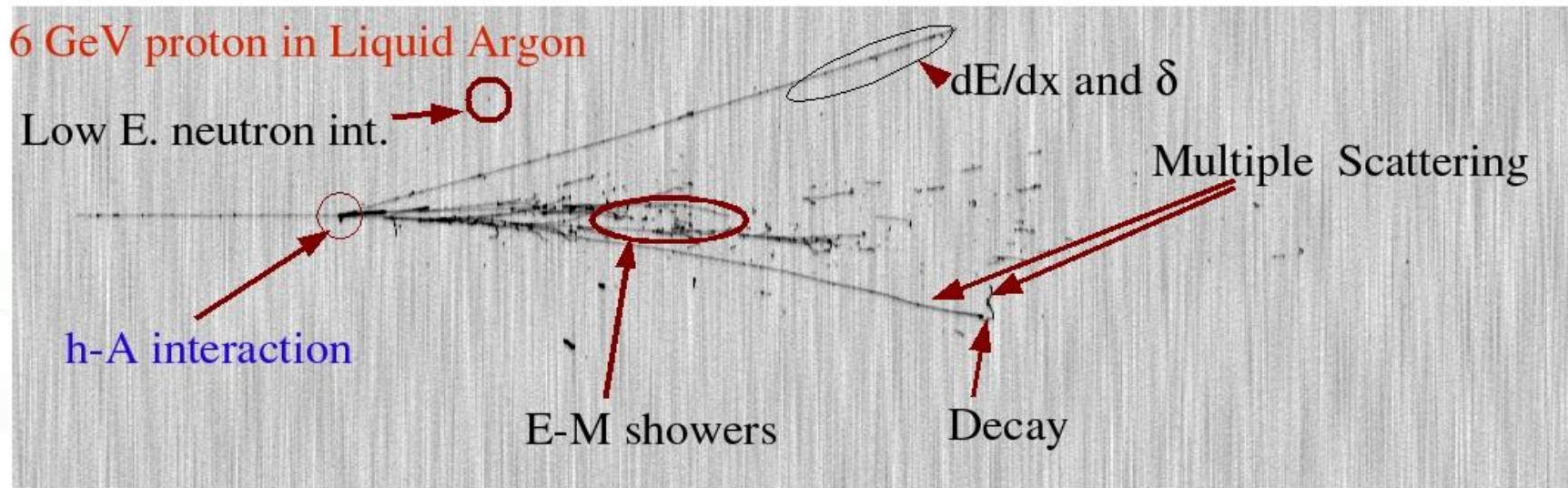
An Introduction to FLUKA:  
a multipurpose Interaction and Transport MC code

Beginners' FLUKA Course

# FLUKA

**Main authors:** A. Fassò, A. Ferrari, J. Ranft, P.R. Sala

**Contributing authors:** G.Battistoni, F.Cerutti, T.Empl, M.V.Garzelli, M.Lantz, A. Mairani, V.Patera, S.Roesler, G. Smirnov, F.Sommerer, V.Vlachoudis



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>3000 users

<http://www.fluka.org>

# The FLUKA international Collaboration

M.Brugger, F. Cerutti, A. Ferrari, S. Roesler, L. Sarchiapone, G. Smirnov,  
C. Theis, S. Trovati, H. Vinke, V.Vlachoudis  
CERN



A. Fassò, J.Vollaire  
SLAC, USA

J. Ranft  
Univ. of Siegen, Germany

G. Battistoni, F. Broggi, M. Campanella, P. Colleoni, E. Gadioli, A. Mairani, S. Muraro, P.R. Sala  
INFN & Univ. Milano, Italy



M. Carboni, C. D'Ambrosio, A. Ferrari, A. Mostacci, V. Patera, M. Pelliccioni, R. Villari  
INFN Frascati



M.C. Morone  
Univ. Roma II, Italy

A. Margiotta, M. Sioli  
INFN & Univ. Bologna, Italy



GERMAN  
CANCER RESEARCH CENTER  
IN THE HELMHOLTZ ASSOCIATION

K. Parodi, F. Sommerer  
DKFZ & HIT, Heidelberg, Germany

A. Empl, L. Pinsky  
Univ. of Houston, USA



K.T. Lee, T. Wilson, N. Zapp  
NASA-Houston, USA

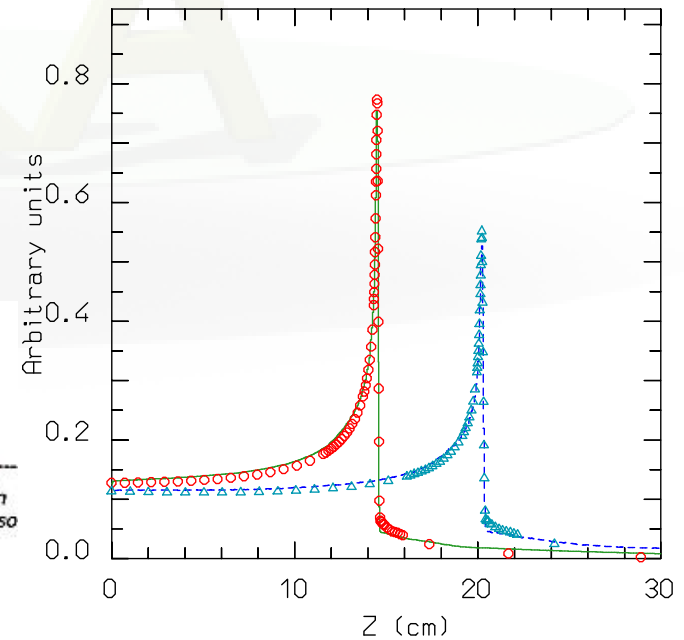
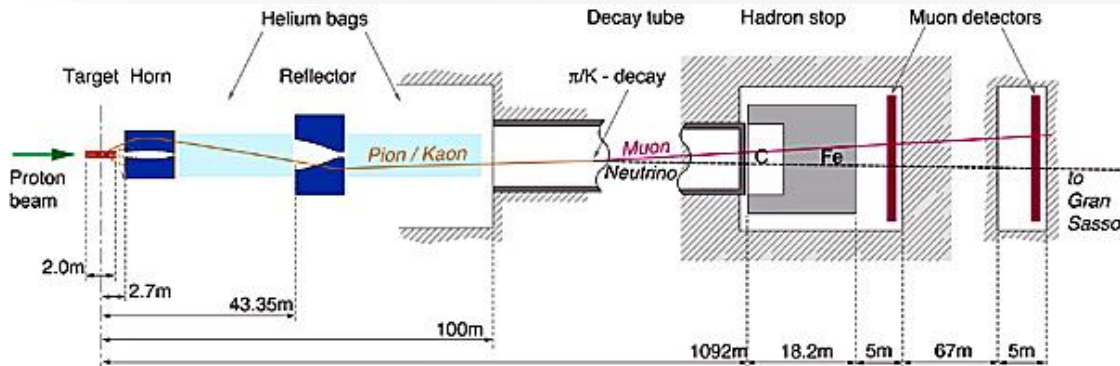
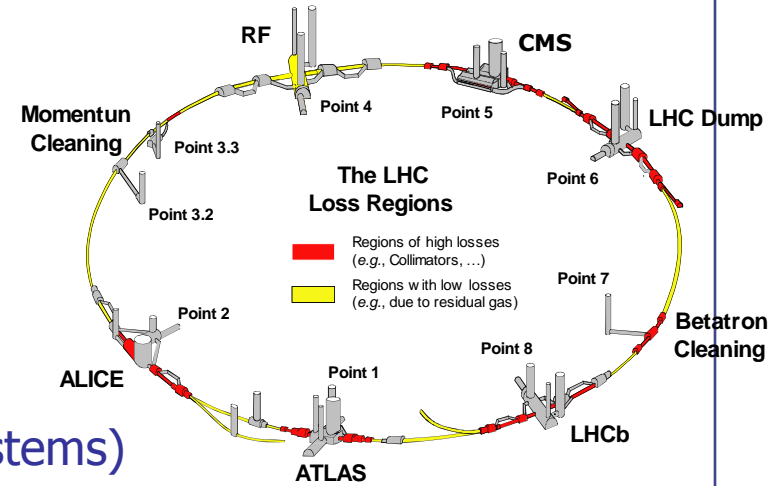


S. Rollet  
ARC Seibersdorf Research, Austria

M. Lantz  
Chalmers Univ. of Technology, Sweden

# 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  $\mu$  interactions 1 keV – 10000 TeV
  - Hadron-hadron and hadron-nucleus interactions 0–10000 TeV
  - Neutrino interactions  (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 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

Minor version

Patch  
level

Respin

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

In this course we are using FLUKA2008.3b.2

# 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

**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

# The FLUKA mailing lists

- [fluka-users@fluka.org](mailto: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](mailto:fluka-discuss@fluka.org)

Users are encouraged to subscribe at registration time, 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**

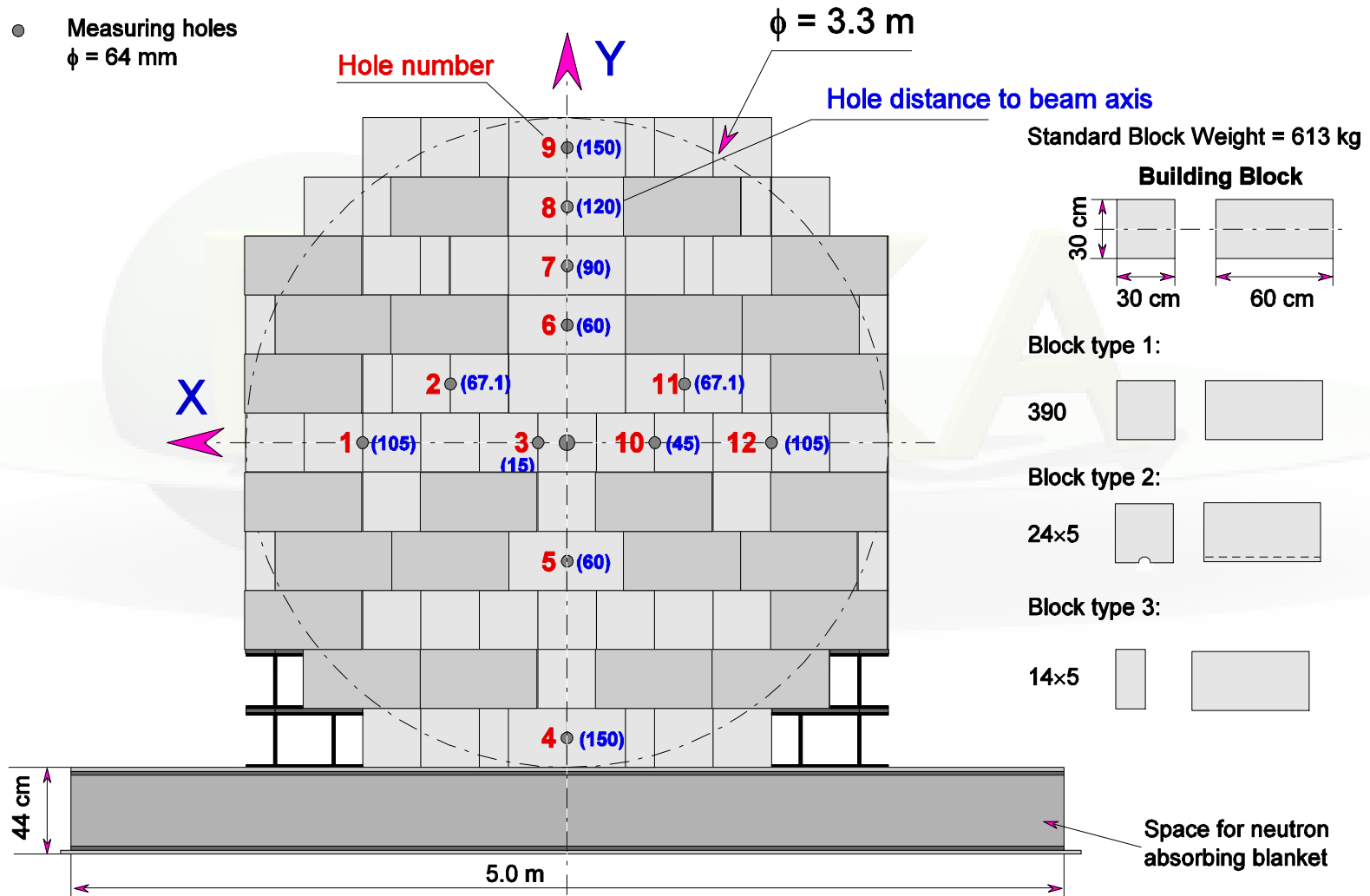




# Examples of FLUKA Applications

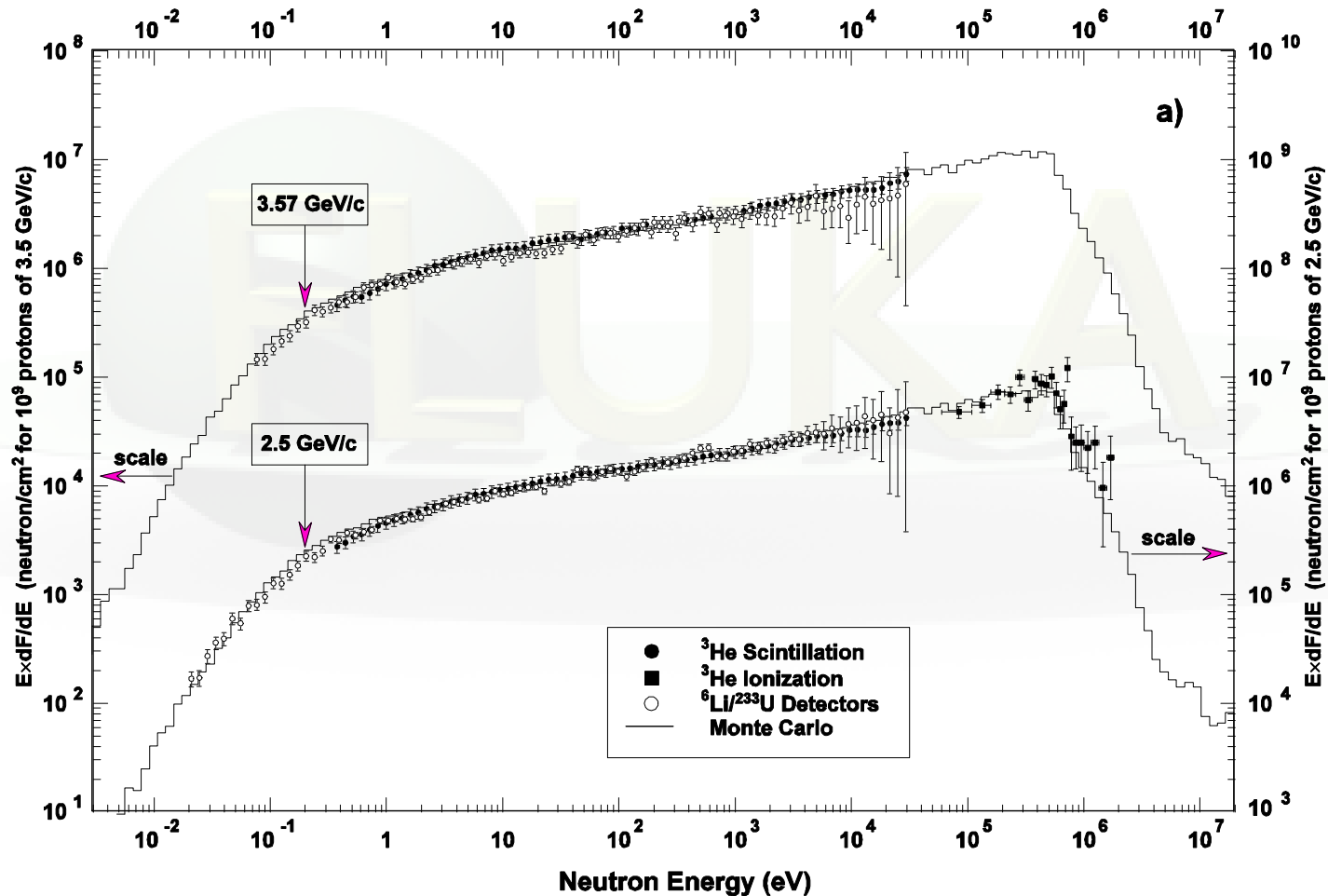
# The TARAC experiment at CERN:

- Beam hole  
 $\phi = 77.2 \text{ mm}$
- Measuring holes  
 $\phi = 64 \text{ mm}$

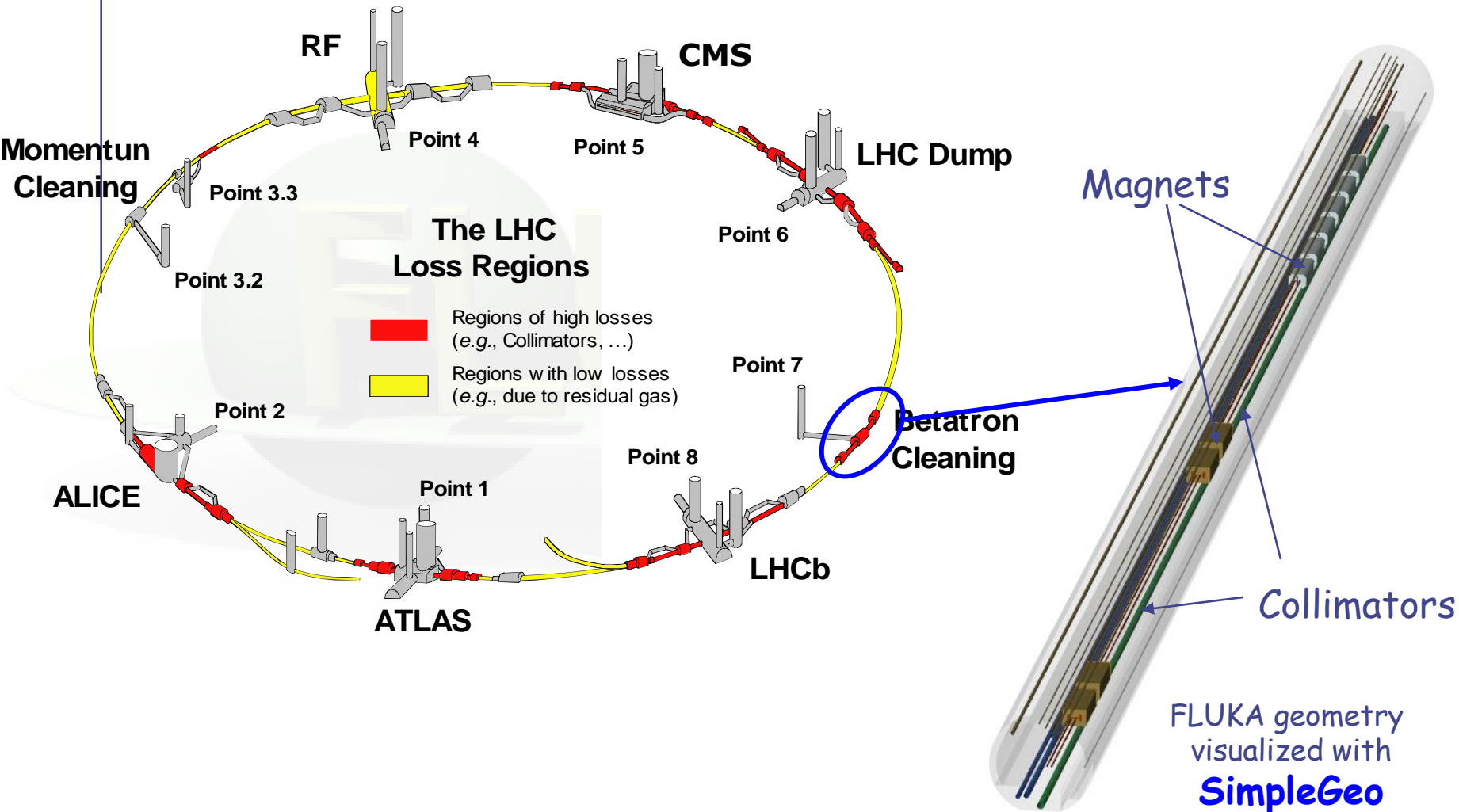


# The TARC experiment: neutron spectra

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



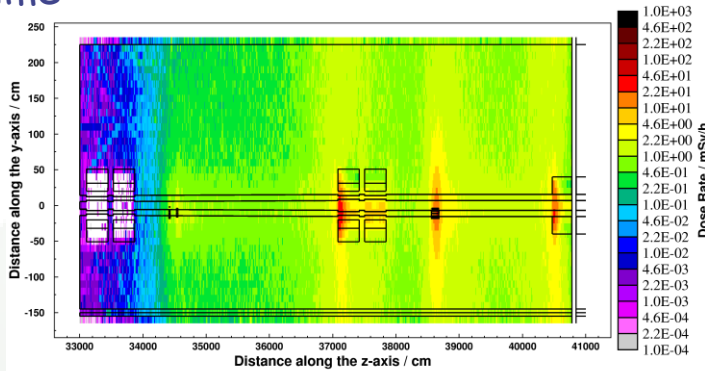
# Applications – *LHC collimation region*



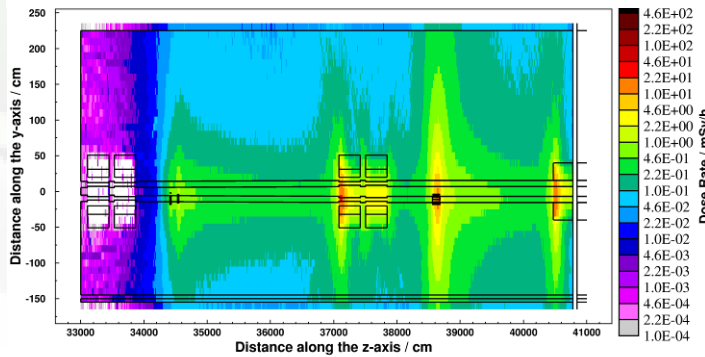
# Applications – *LHC collimation region*

Cooling time

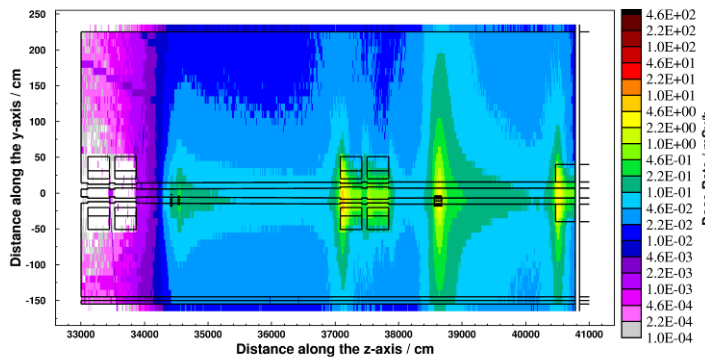
8 hours



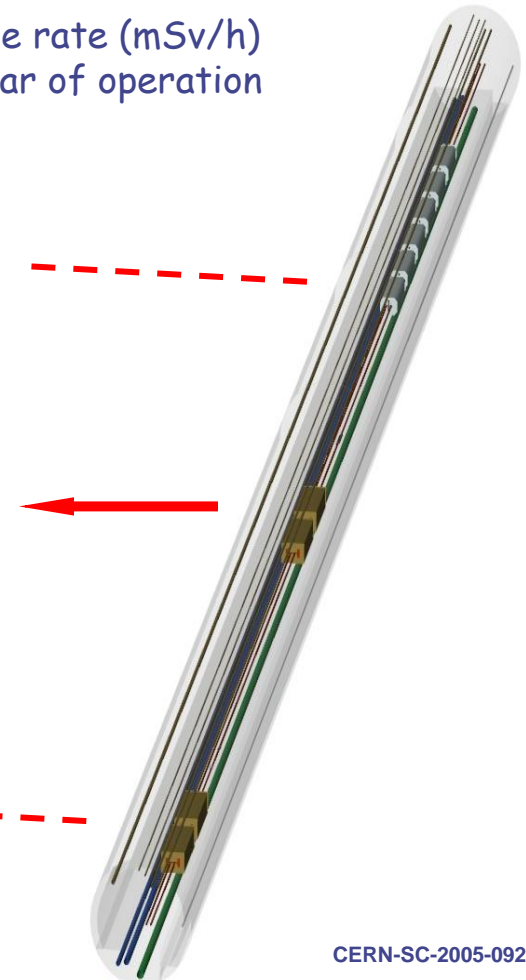
1 week



4 months



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



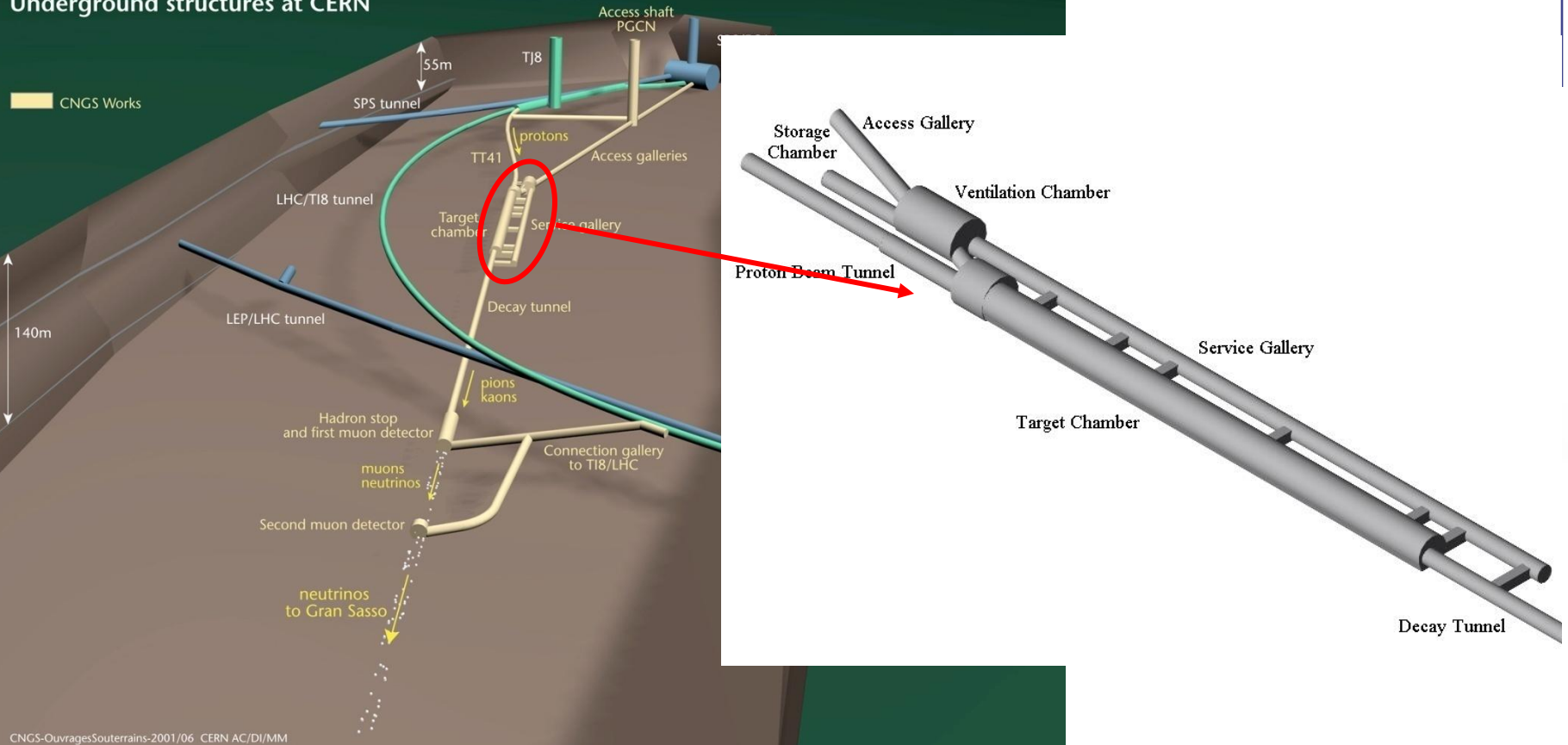
CERN-SC-2005-092-RP-TN

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

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

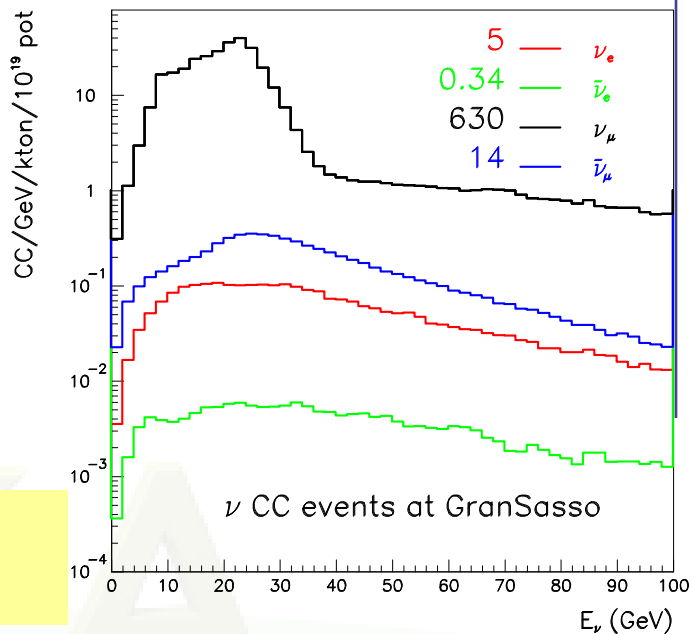
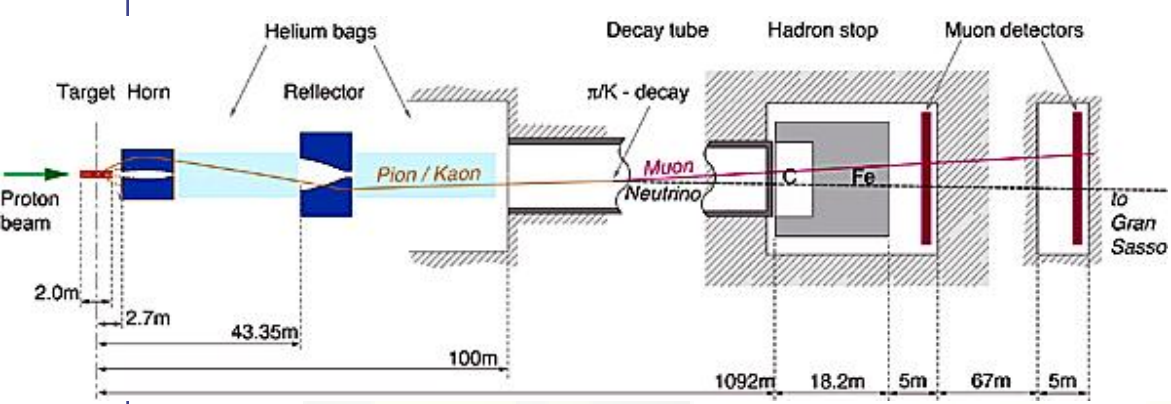
# Applications – CNGS

## CERN NEUTRINOS TO GRAN SASSO Underground structures at CERN

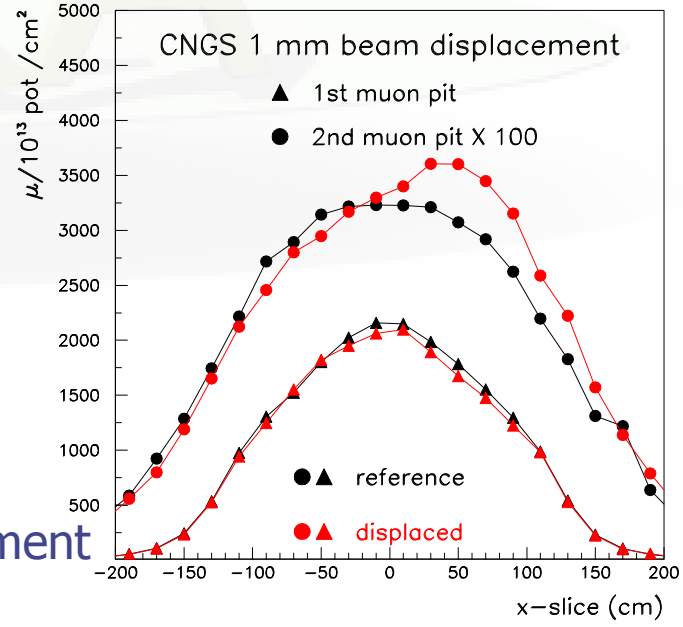
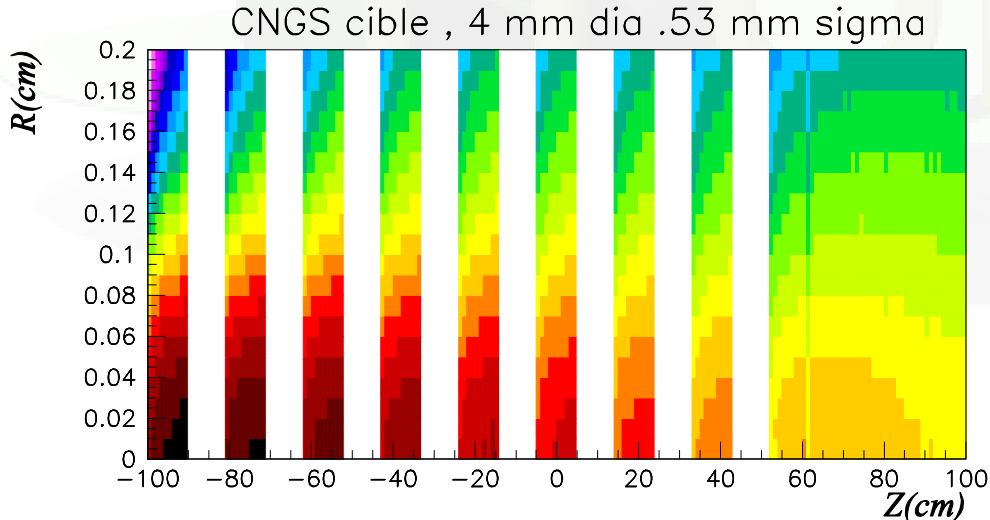


CNGS-OuvragesSouterrains-2001/06 CERN AC/DI/MM

# Cern Neutrino to Gran Sasso

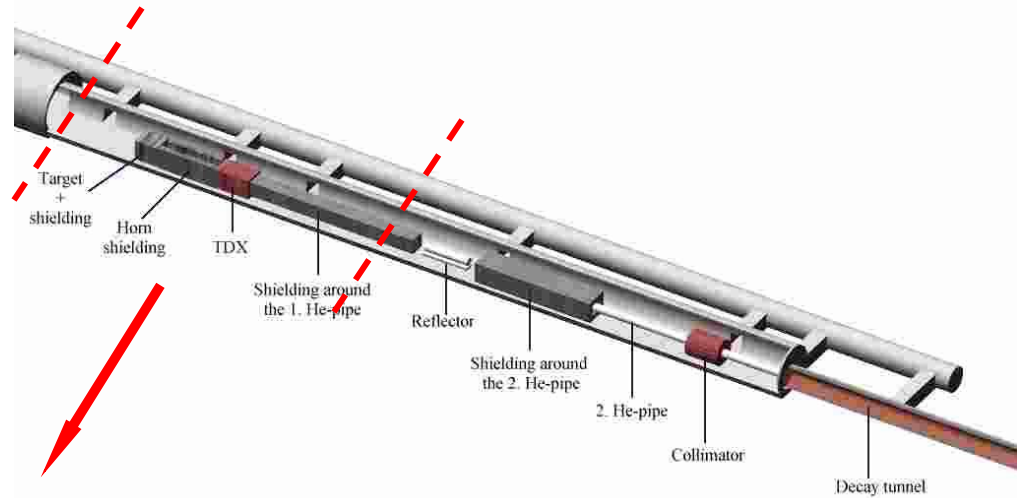


Engineering and physics: target heating, shielding, activation, beam monitors, neutrino spectra



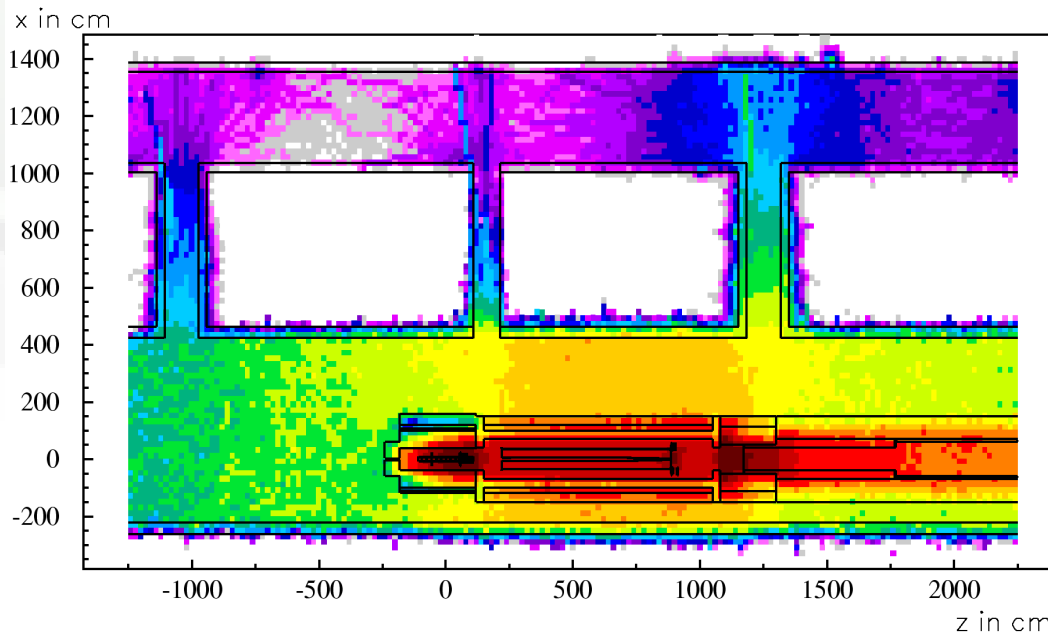
Muons in muon pits: horiz. distribution for beam alignment  
Energy dep. in CNGS target rods, GeV/cm<sup>3</sup>/pot

# Applications – CNGS

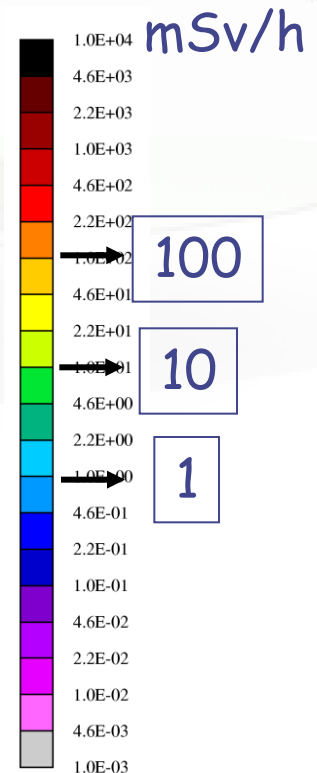


Example:

$t_{cool} = 1 \text{ day}$



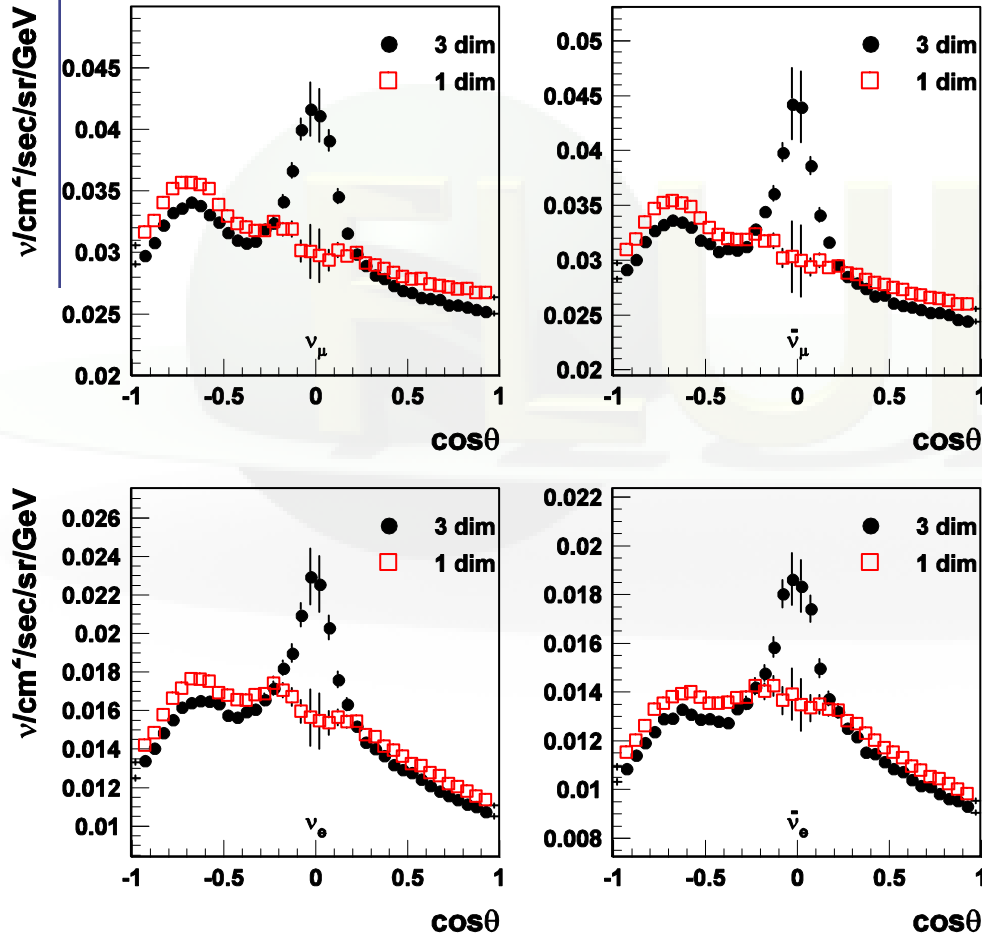
Residual Dose Equivalent Rate (mSv/h)  
200 days irradiation, 1 day cooling  
 $8 \times 10^{12}$  protons/s





# (3D) Calculation of Atmospheric $\nu$ Flux

Sub-GeV flux at Kamioka



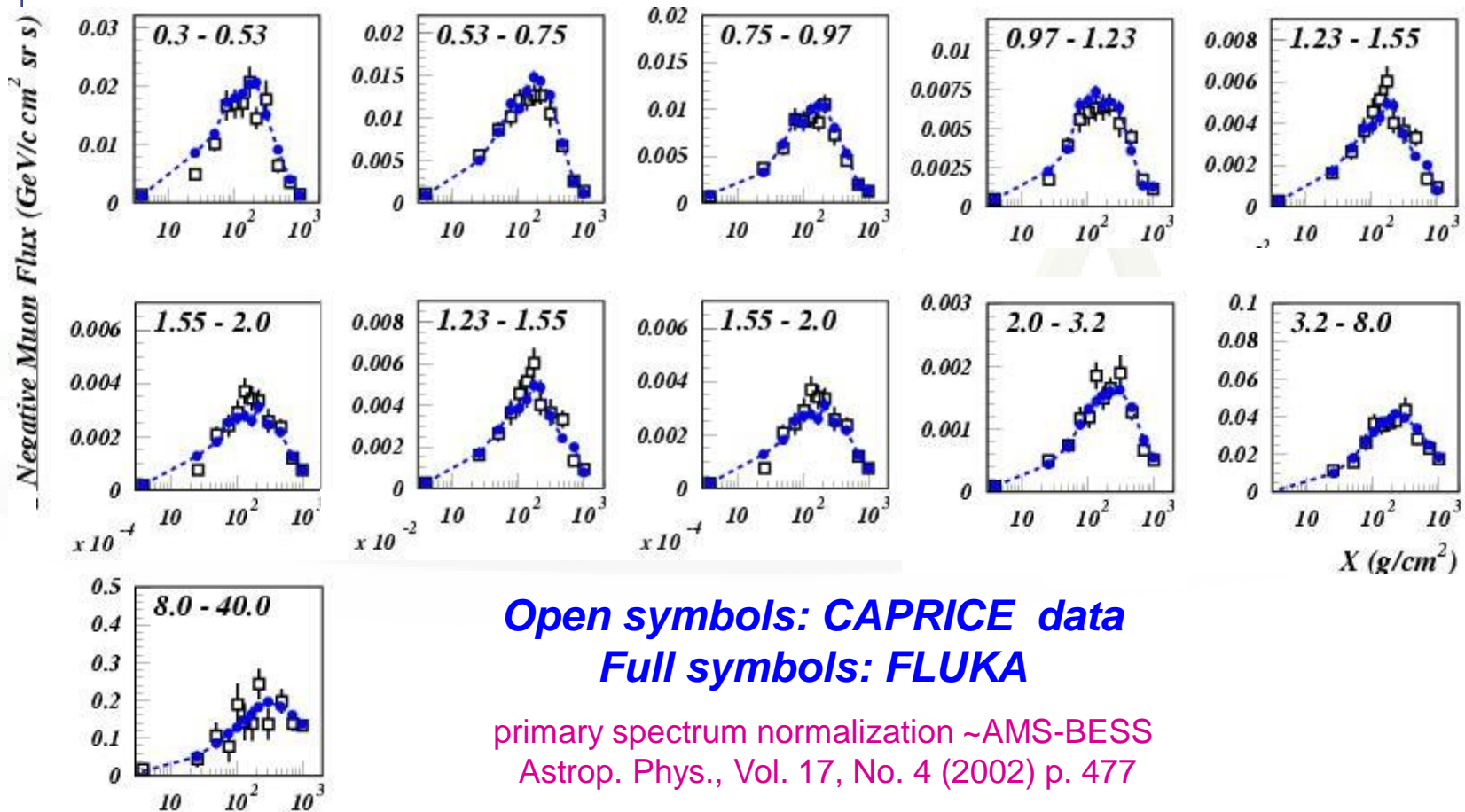
The first 3-D calculation of atmospheric neutrinos was done with FLUKA.

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

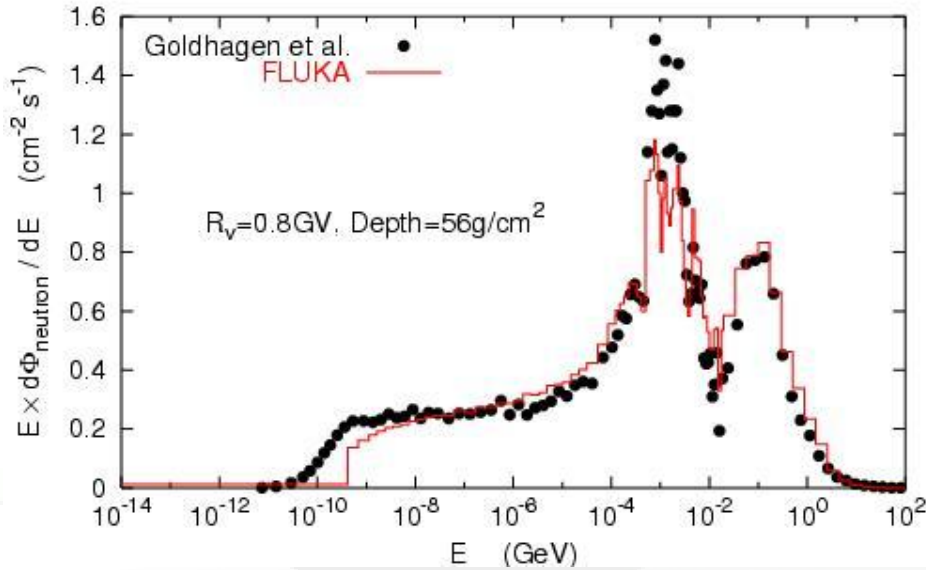
In the figure: angular distribution of  $\nu_\mu$ ,  $\bar{\nu}_\mu$ ,  $\nu_e$ ,  $\bar{\nu}_e$ .

In red: 1-D calculation

# Negative muons at floating altitudes: CAPRICE94



# Neutrons on the ER-2 plane at 21 km altitude



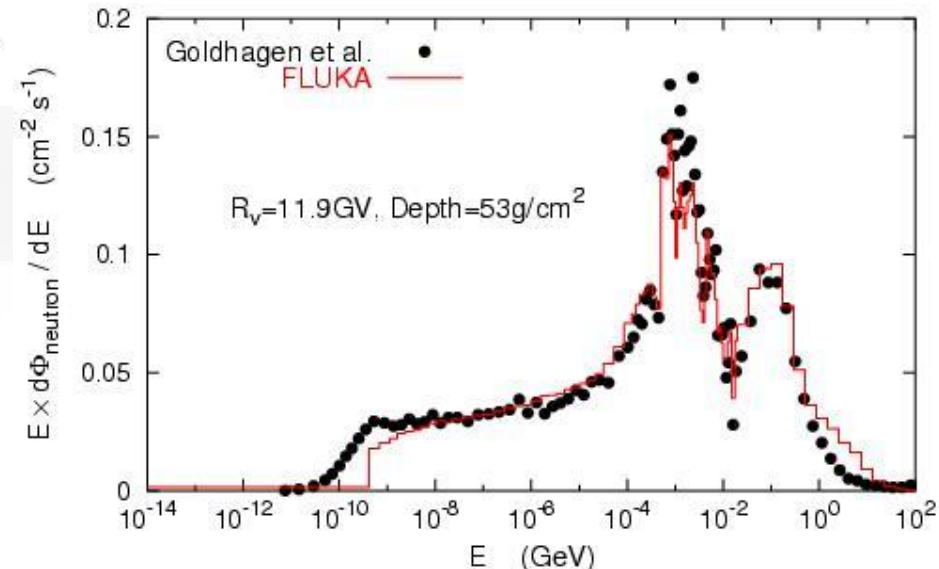
Measurements:

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

Note one order of magnitude difference depending on latitude

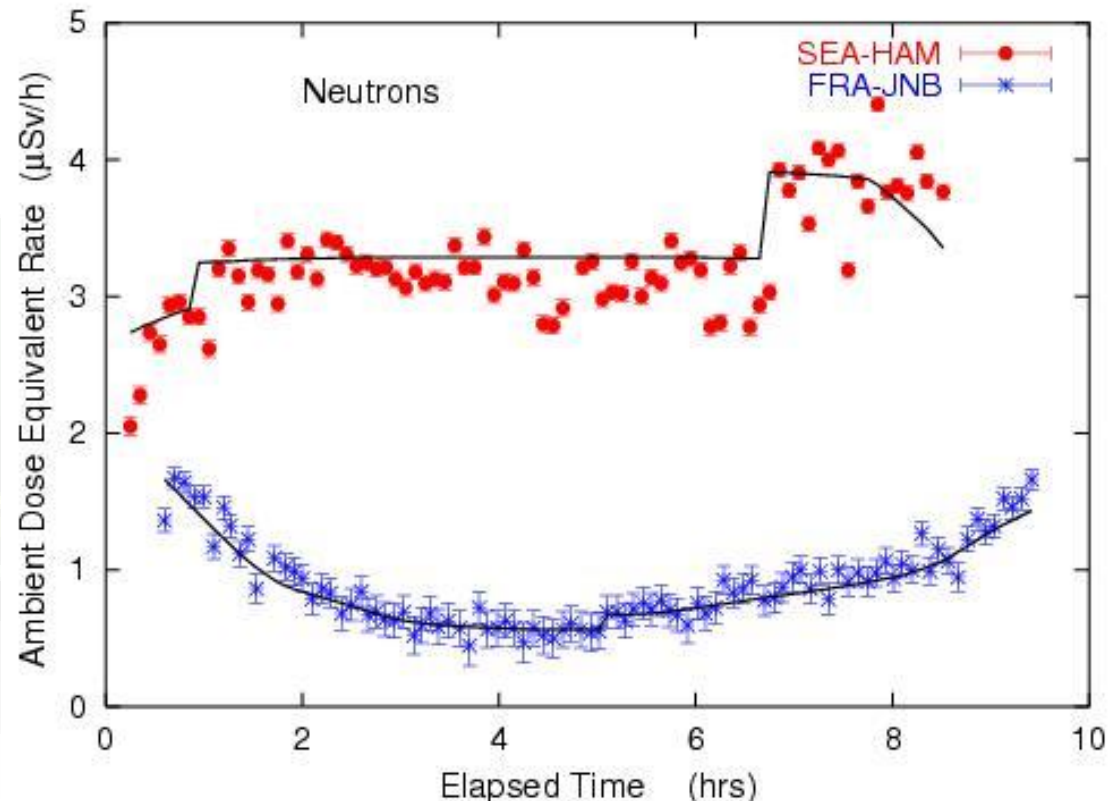
FLUKA calculations:

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



# Dosimetry Applications

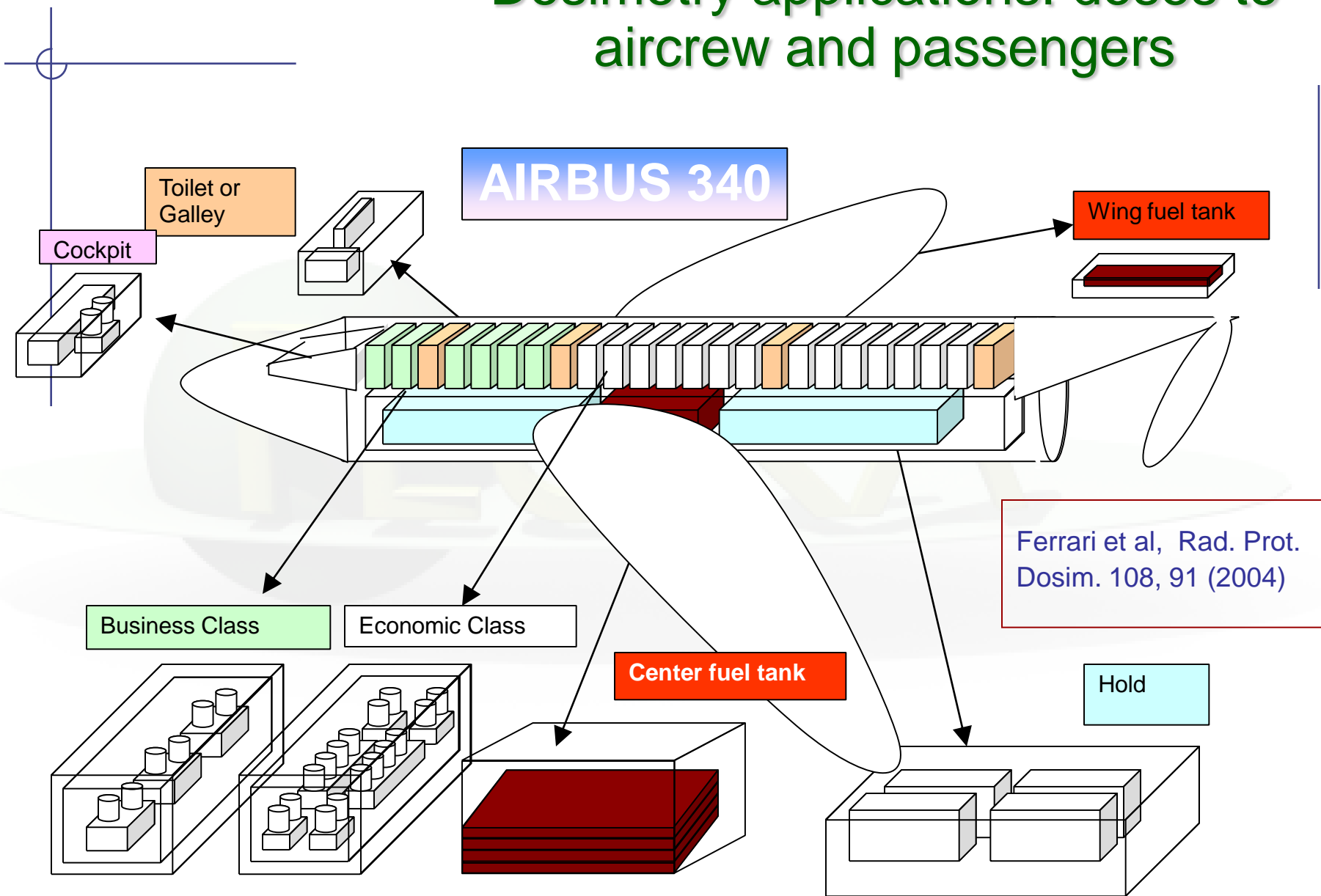
Roesler et al.,  
Rad. Prot. Dosim.  
98, 367 (2002)



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

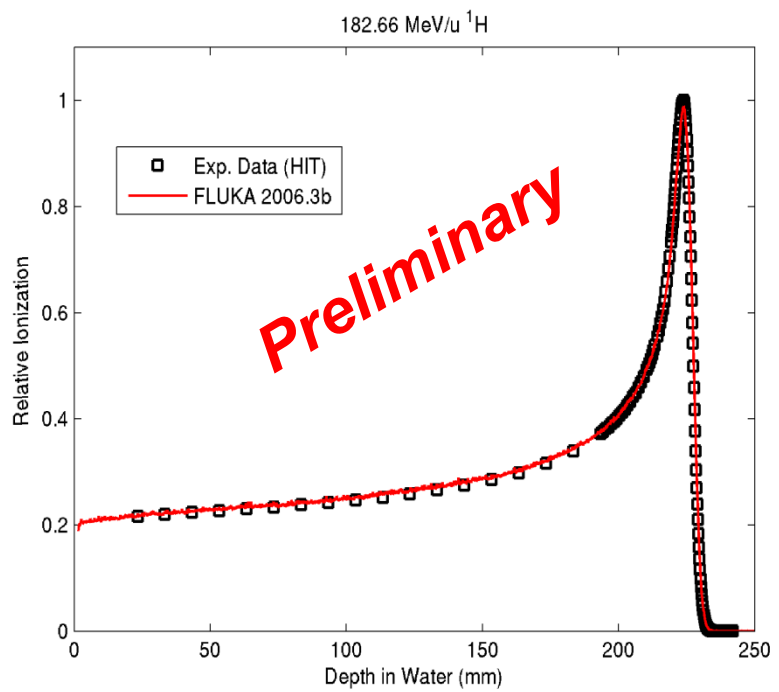
Solid lines: FLUKA simulation

# Dosimetry applications: doses to aircrew and passengers



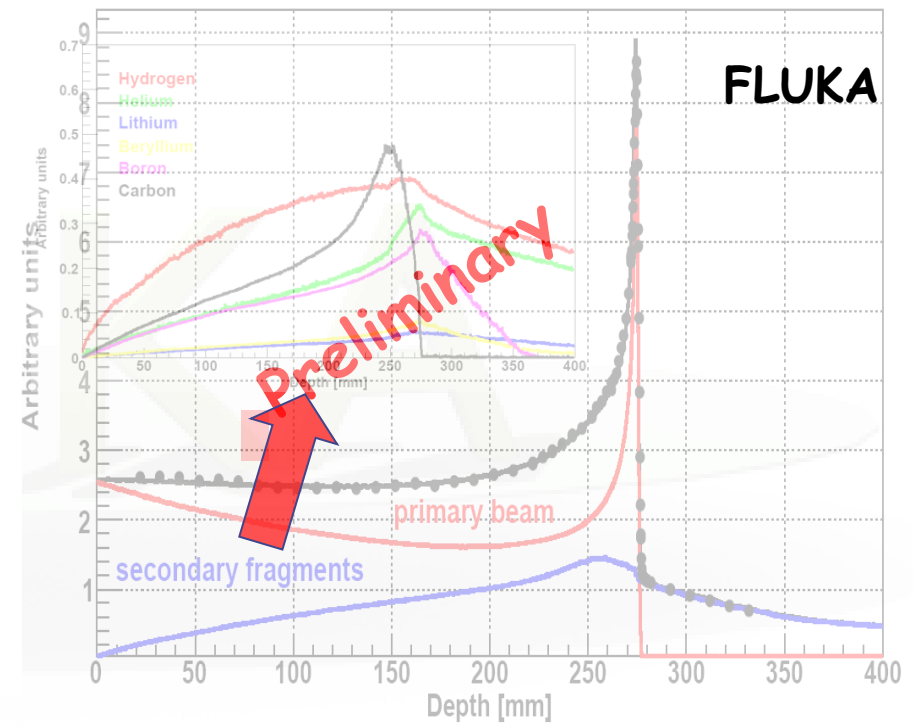
# Experimental validation against measured Bragg curve in Proton and Carbon ion therapy

## Protons (183 MeV/u) in Water



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

## $^{12}\text{C}$ ions (400 MeV/u) in Water



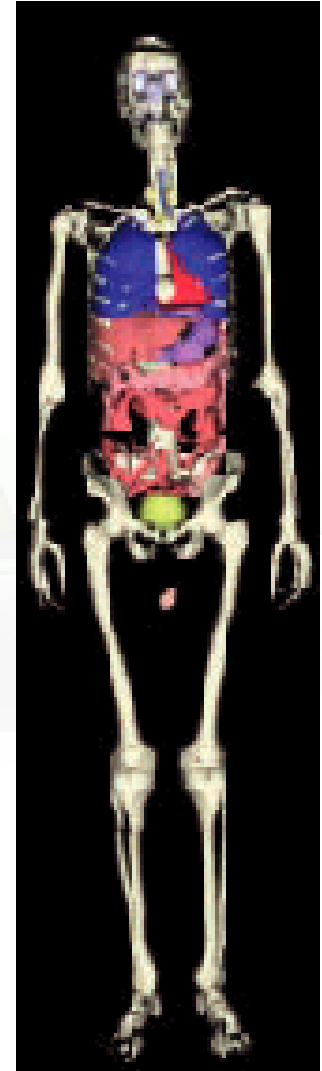
*Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006  
Simulation: A. Mairani, PhD Thesis, Pavia, 2007*

# Using the information from the patient CT in the MC I

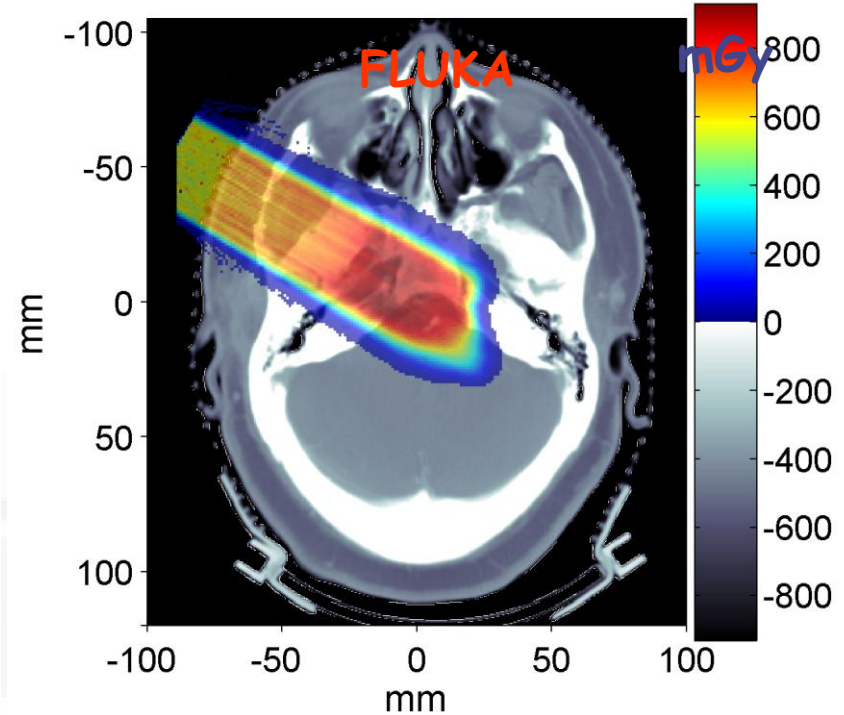
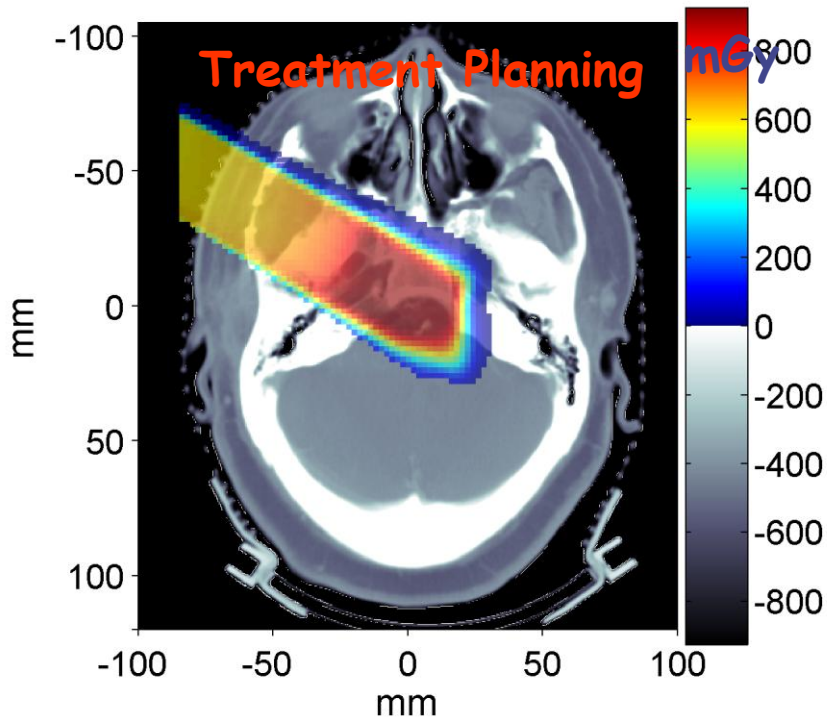
## The Voxel Geometry

- 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



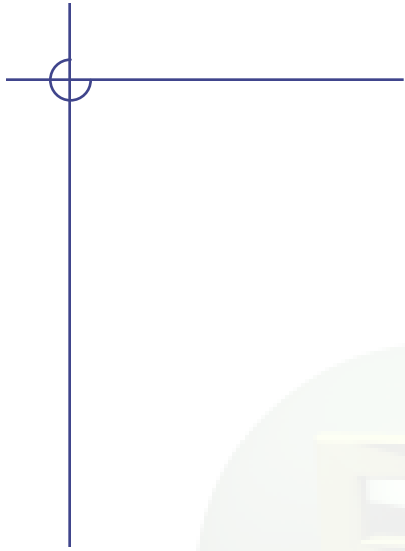
*Parodi et al, JPCS 74, 2007*

Prescribed dose: 1 GyE

MC :  $\sim 5.5 \cdot 10^6$  protons in 10 independent runs

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





FLUKA

# 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**
- $\nu$ -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