



# The FLUKA Code

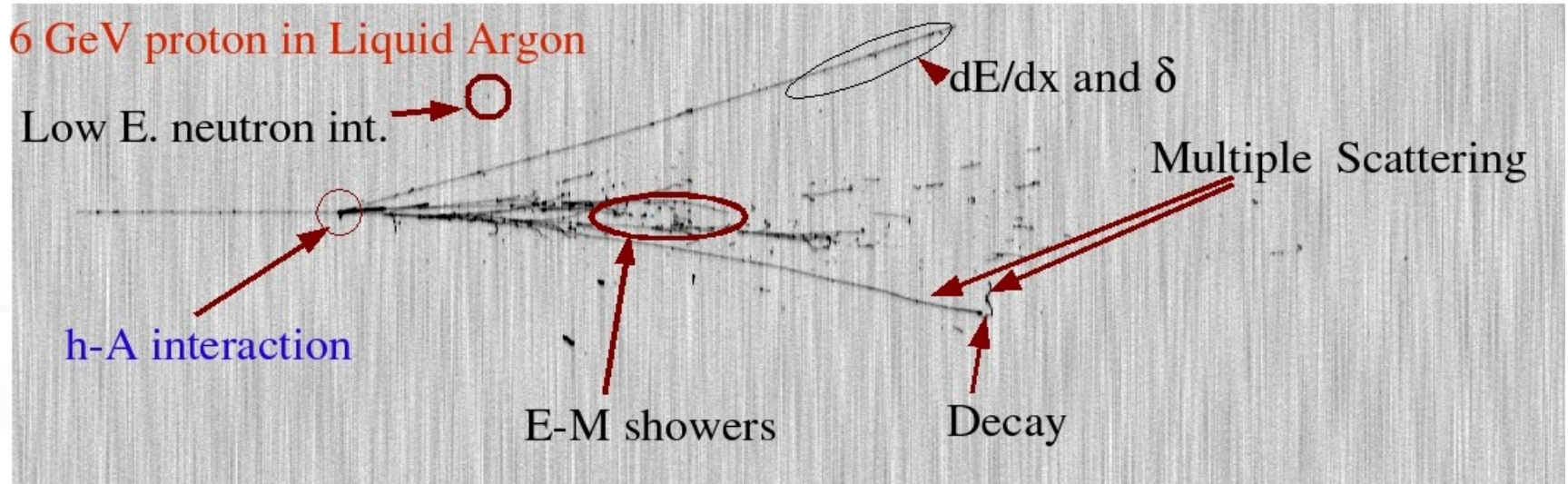
An Introduction to FLUKA:  
a Multipurpose Interaction and Transport MC code

FLUKA Beginner's Course

# FLUKA

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>5000 users

<http://www.fluka.org>

# The FLUKA international Collaboration



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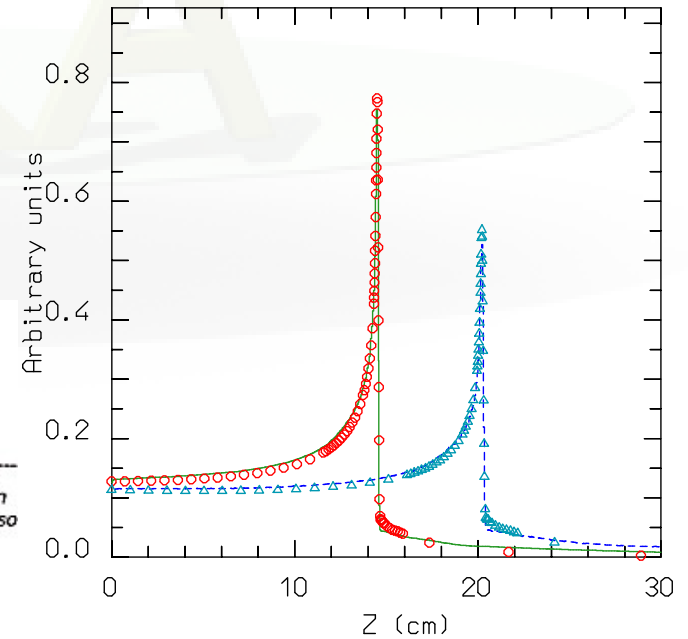
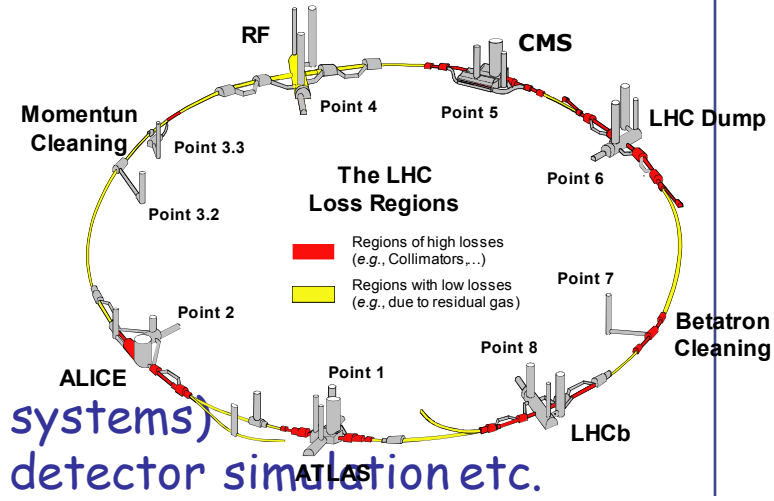
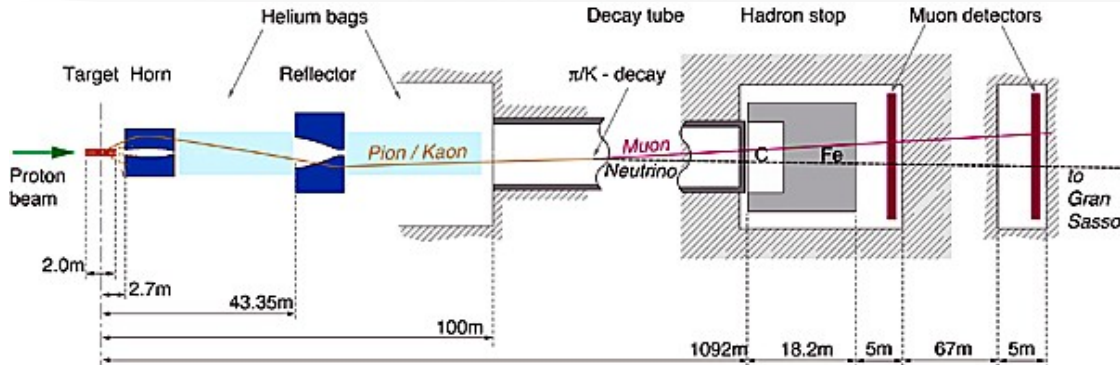
Anna Ferrari, FZR Rossendorf, Germany



Forschungszentrum  
Rossendorf

# 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
- Radiation damage
- Space radiation
- Hadron therapy
- 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, however with the possibility to use 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 fully preserved within interactions and among shower components
- FLUKA is NOT a toolkit! Its physical models are fully integrated

# The Physics Content of FLUKA

## ➤ 60 different particles + Heavy Ions

- Nucleus-nucleus interactions from Coulomb barrier up to 10000 TeV/n
- Electron and  $\mu$  interactions 1 keV - 10000 TeV
- Photon interactions 100 eV - 10000 TeV
- Hadron-hadron and hadron-nucleus interactions 0-10000 TeV
- Neutrino interactions
- Charged particle transport including all relevant processes
- Transport in magnetic fields
- Neutron multigroup transport and interactions 0 - 20 MeV
- 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) The tools to plot results
- f) The right approach to the existing documentation
- g) The procedures to overcome difficulties and problems and related debugging tools
- h) etc. etc.

# Method

- There will be formal lectures but they will be followed as much as possible by practical (simple) examples.
- Emphasis will be put on the practice.
- If possible we shall try to transform your questions into cases of general interest.

# A possible problem

- People here are not all 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

FLUKA20xx.n(y)(.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 FLUKA2011.2

# 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)
  - Users can add their own scoring, sources, etc. through a wide set of user routines, provided they do not 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 the source for researchers of scientific/academic Institutions. (*!!! now from NEA as well !!!*)**
  - FLUKA can neither be copied into other codes (not even partially), nor 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 and gfortran

Work in progress: Mac OSX with gfortran

*The code can be compiled/run only using 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**



# Disclaimer

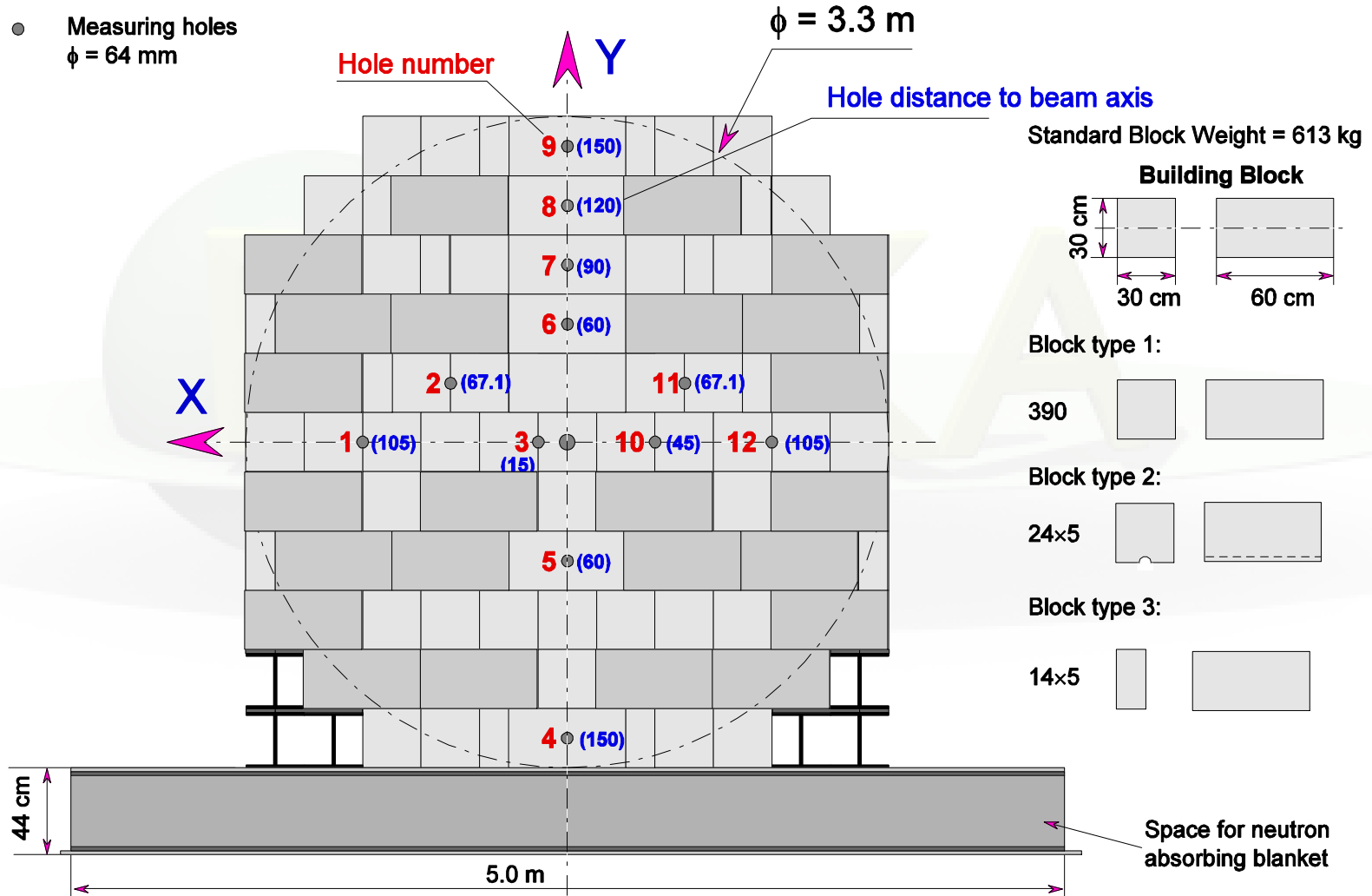
- A good FLUKA user is **not** one that **only** masters **technically** the program
- BUT a user that:
  - Indeed masters technically the code;
  - Know its limitations and capabilities;
  - Can tune the simulation to the specific requirements and needs of the problem under study;but most of all
  - **Has a critical judgment on the results**
- Therefore in this course we will equally focus on:
  - **The technical aspects of the code**  
[building your input, geometry, scoring, biasing, extracting results...]as well as
  - **The underlying physics and MC techniques**



**Examples of FLUKA Applications**

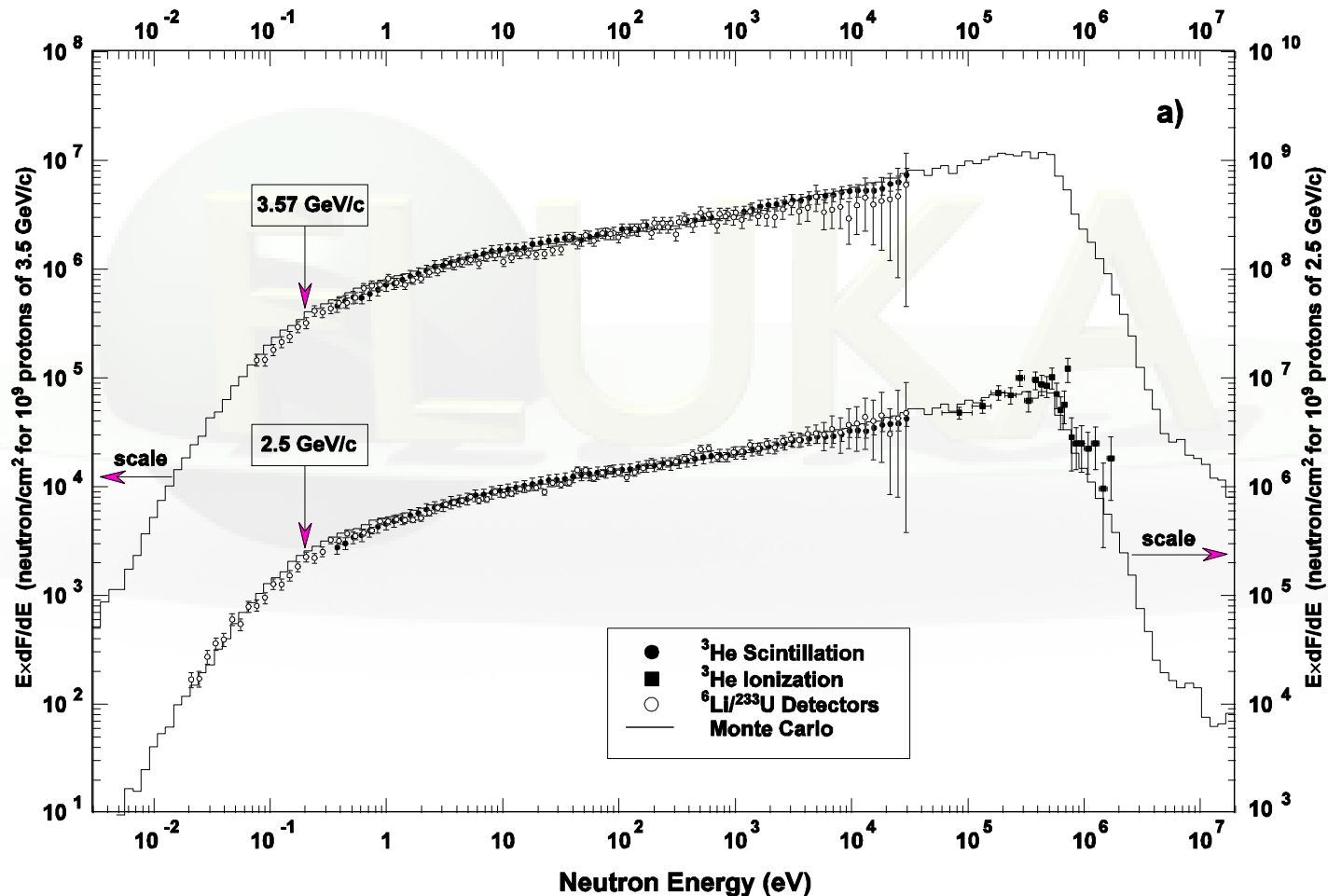
# The TARIC experiment at CERN:

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



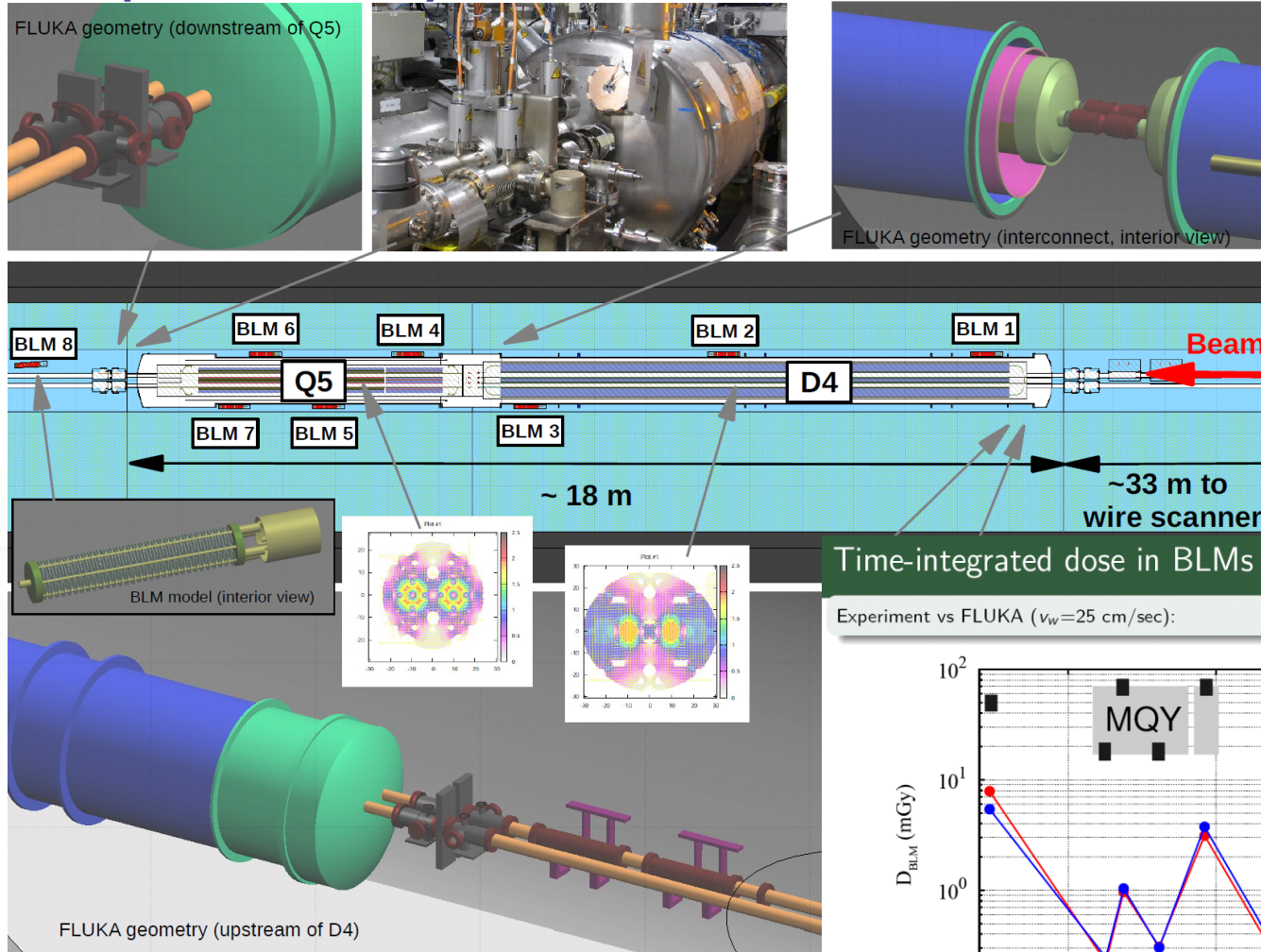
# The TARC experiment: neutron spectra

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

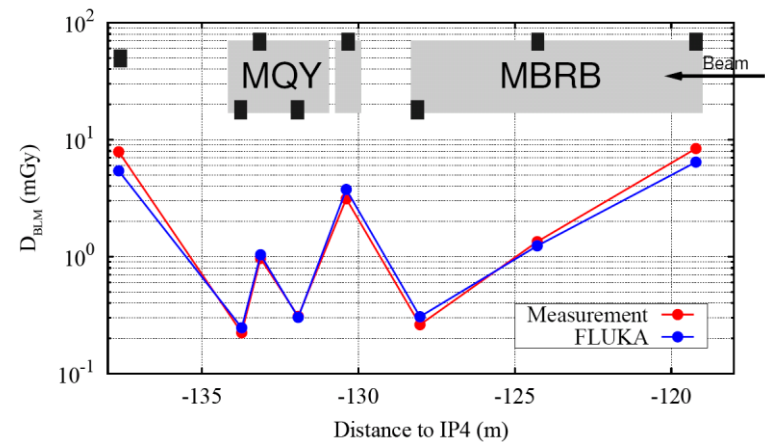


# Application & Benchmarking – *LHC operation*

Test quench induced by the wire scanner on 2010 Nov 1 on the left of P4 at 3.5TeV

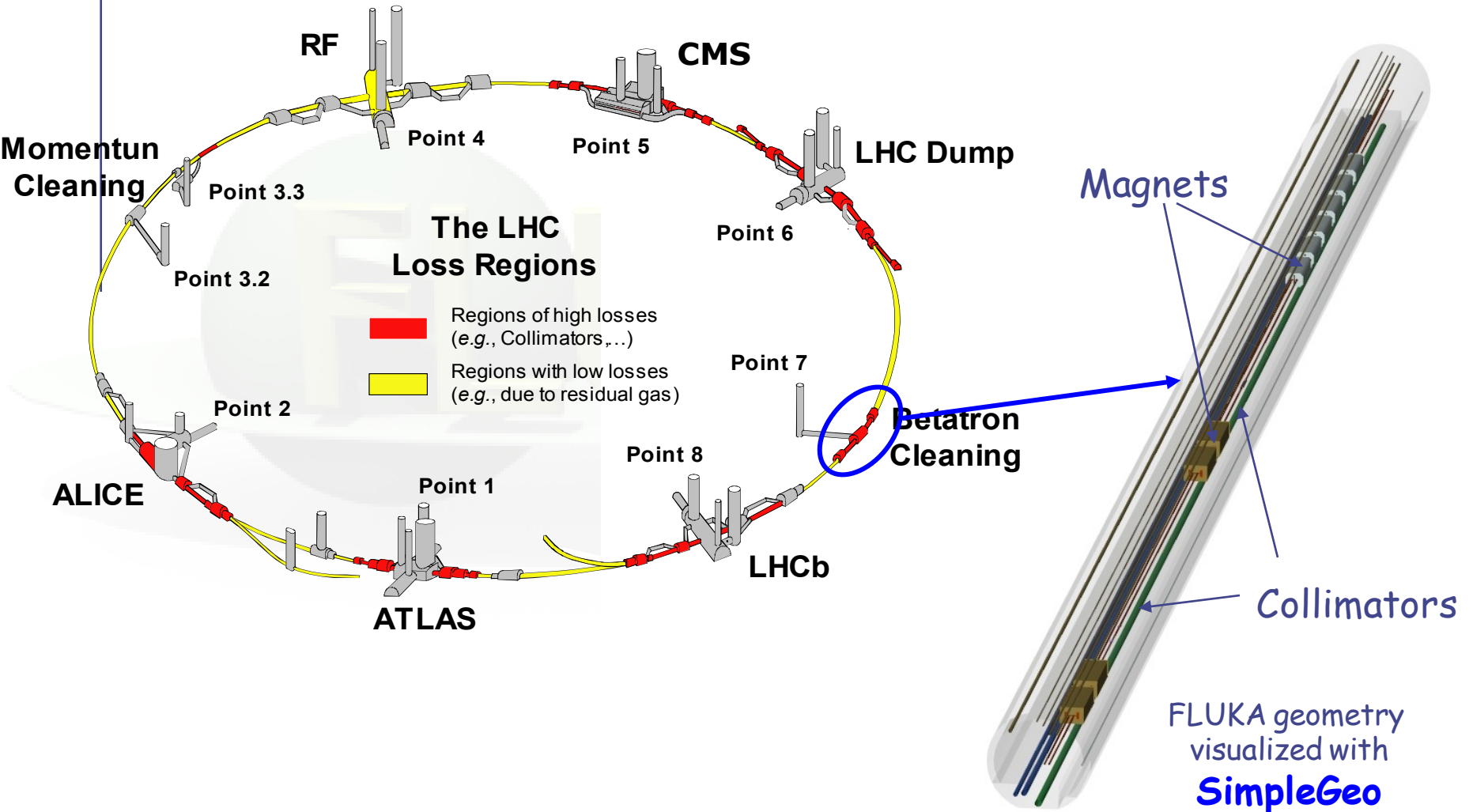


Time-integrated dose in BLMs  
Experiment vs FLUKA ( $v_w=25$  cm/sec):

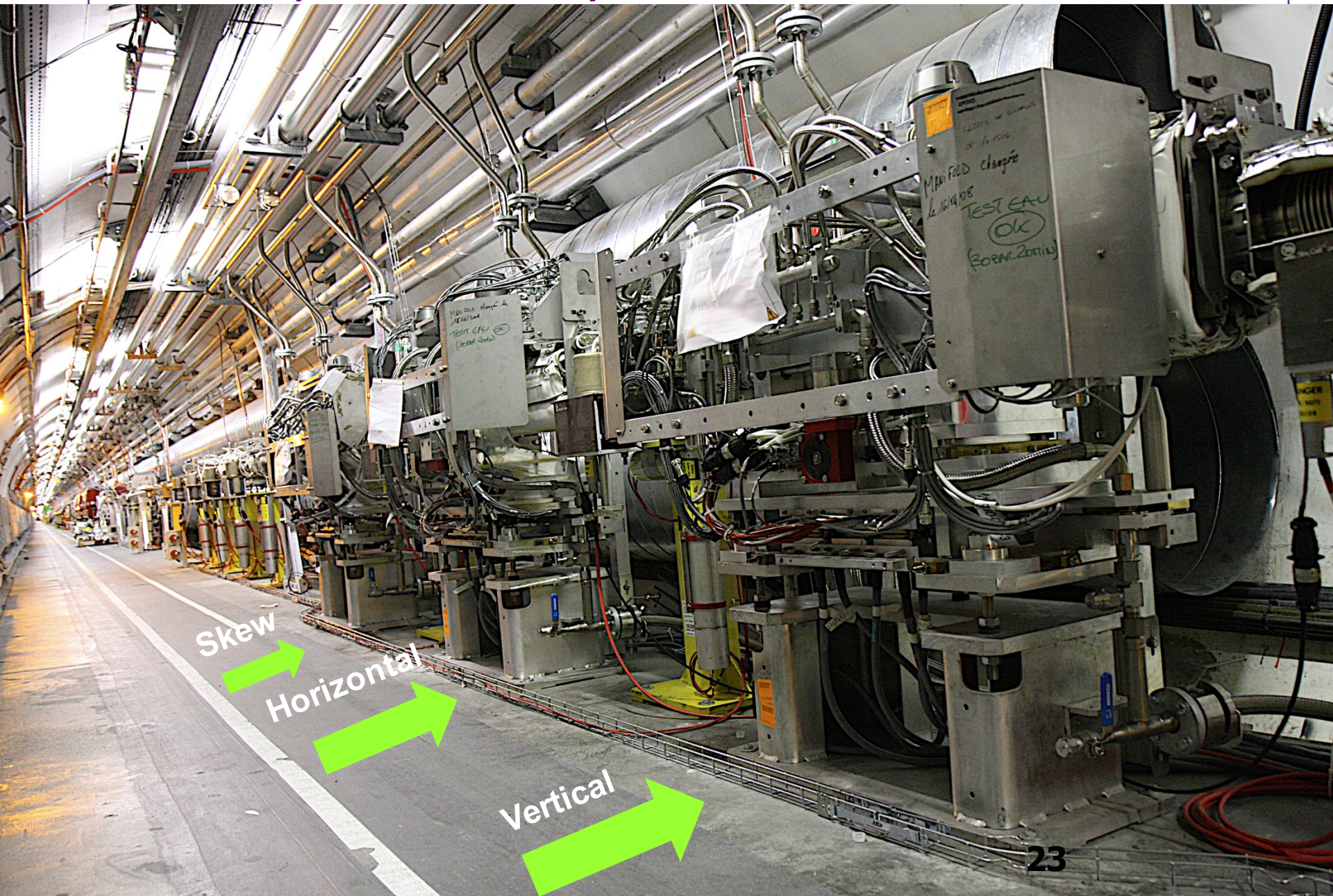


Absolute comparison!

# Applications – *LHC collimation region*



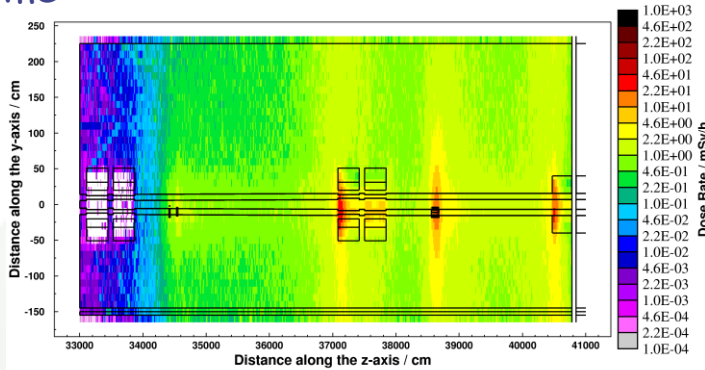
# Example: 3 Primary Collimators IR7



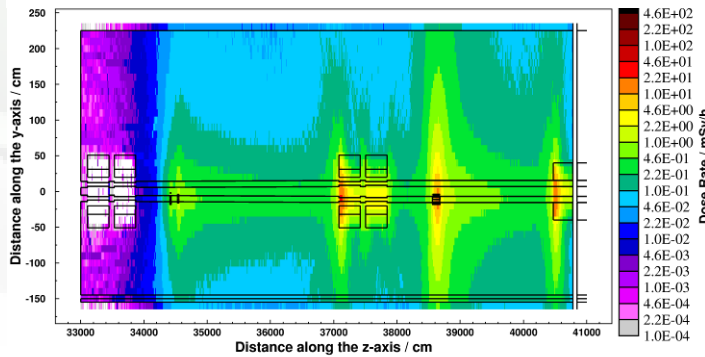
# Applications – LHC collimation region

Cooling time

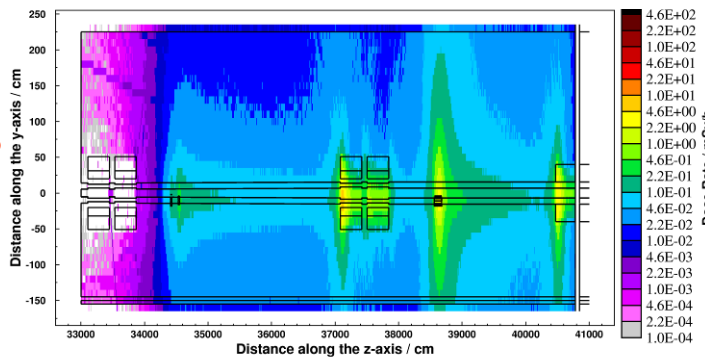
8 hours



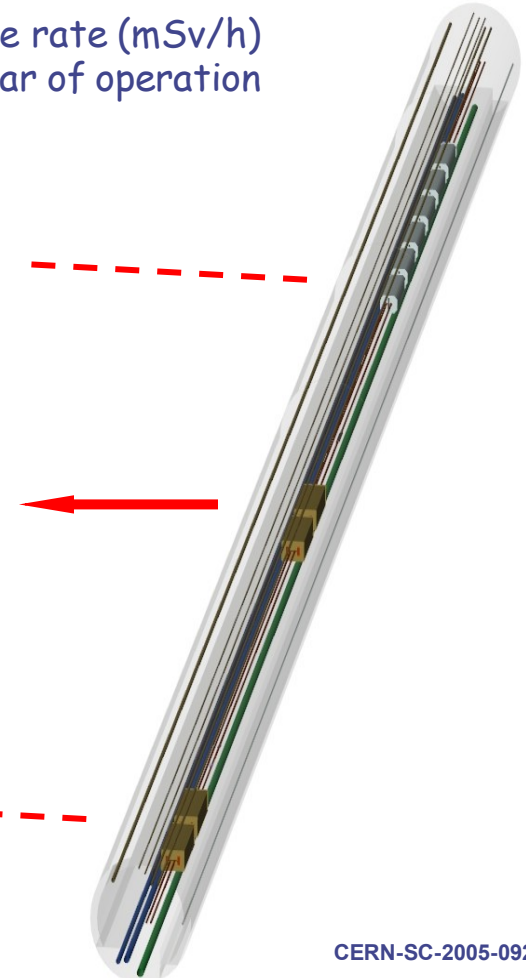
1 week



4 months



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



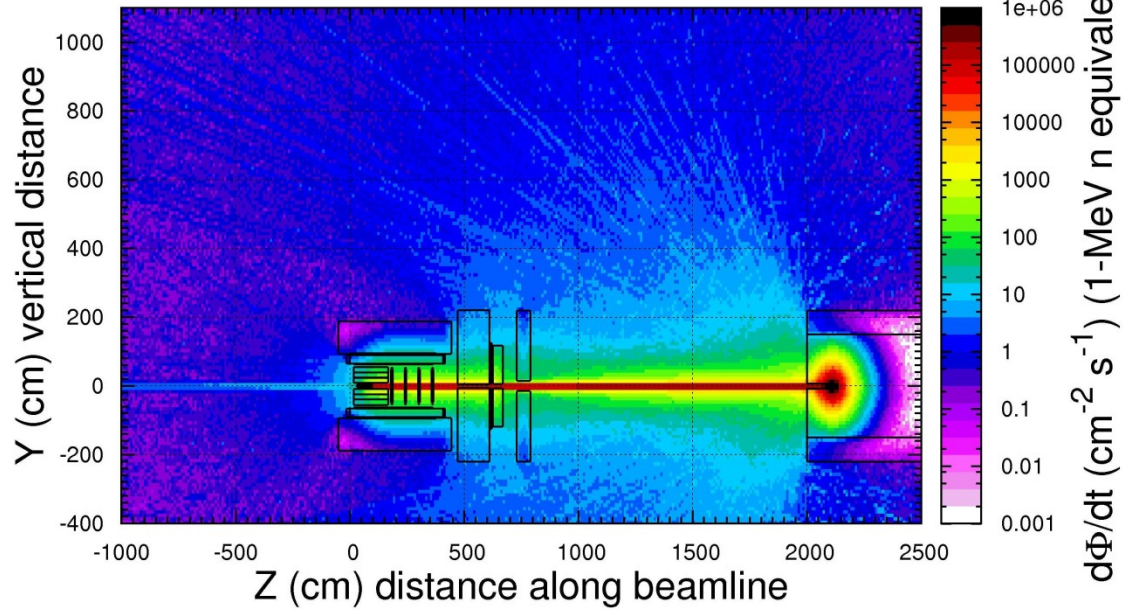
CERN-SC-2005-092-RP-TN

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

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

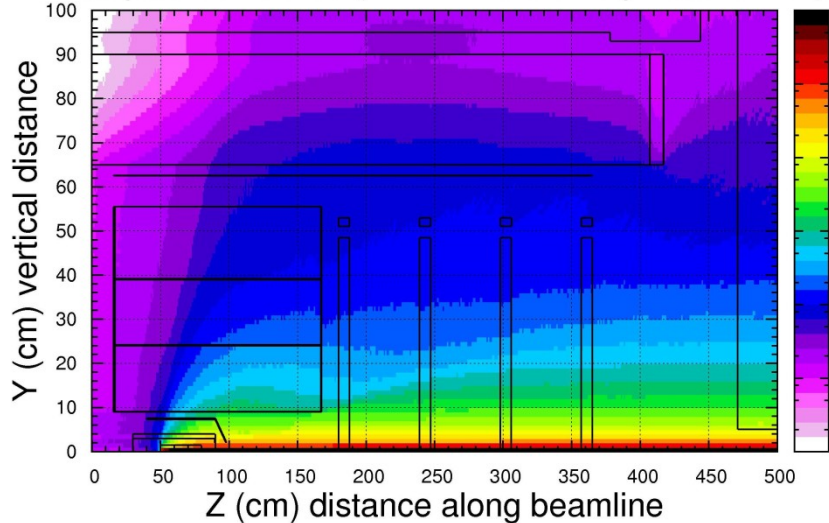


Total particle fluence in Hall D (1-MeV neutron equivalent in Si)

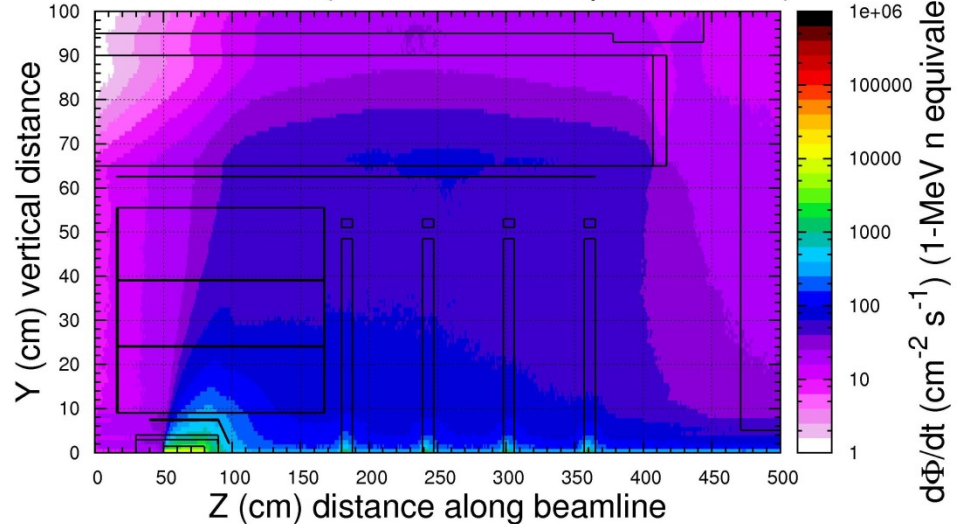


Calculated 1-MeV neutron equivalent fluence rate in Si (GlueX experiment at Jlab)

Total particle fluence (1-MeV neutron equivalent in Si)

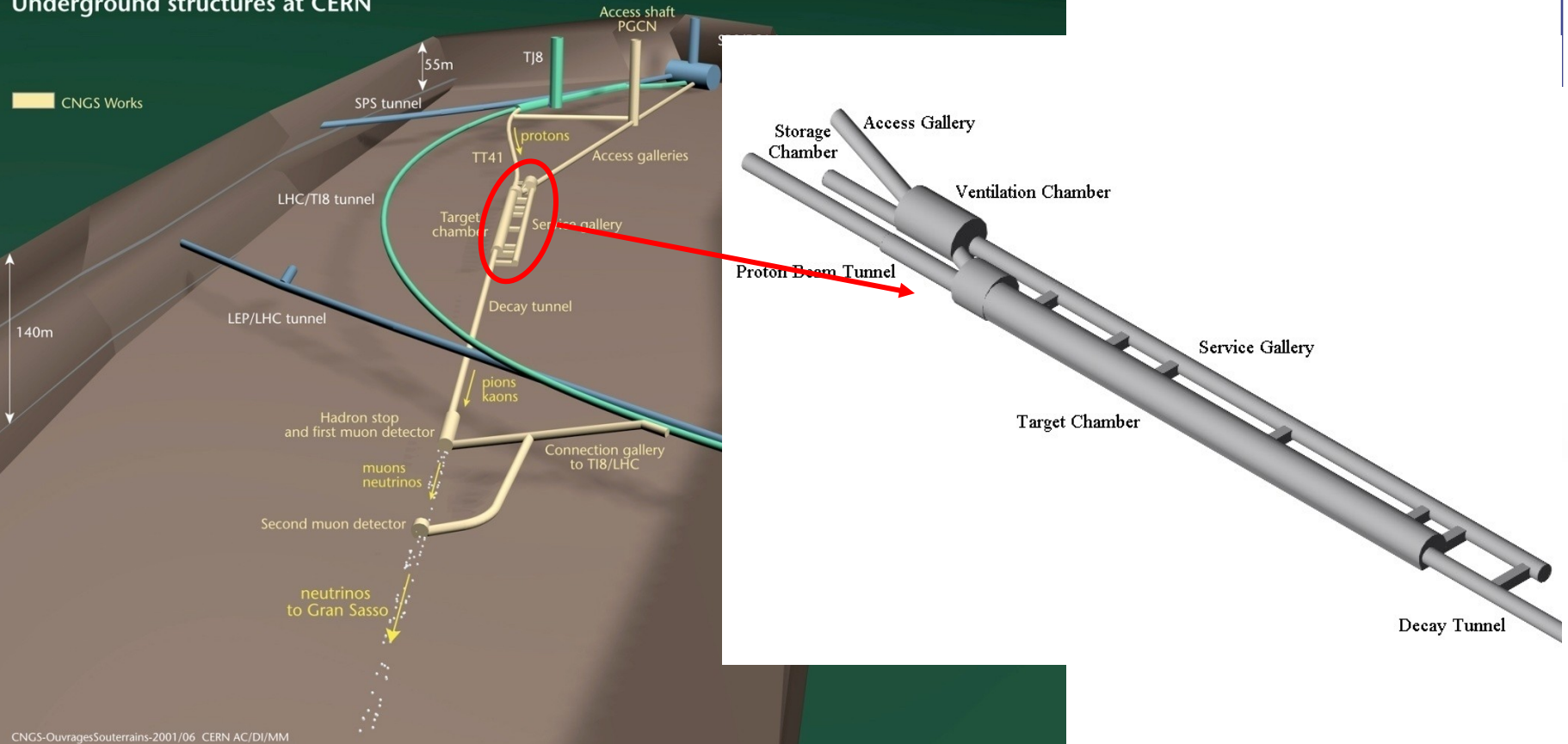


Neutron fluence (1-MeV neutron equivalent in Si)

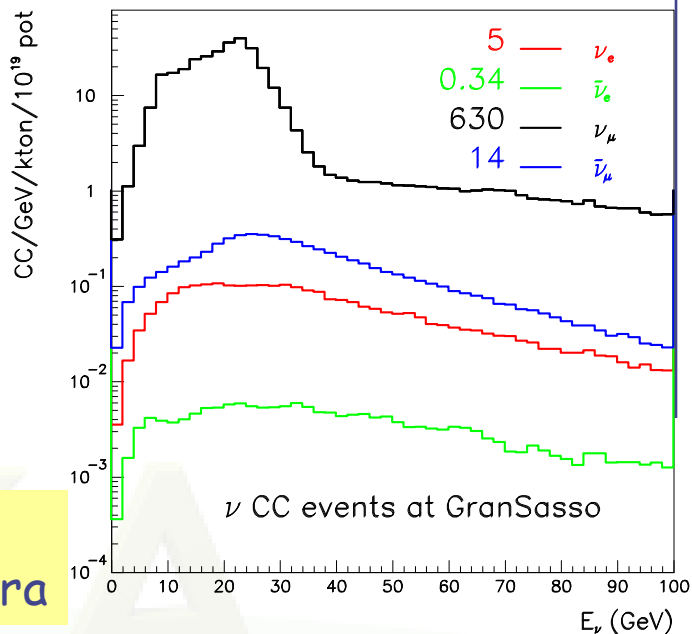
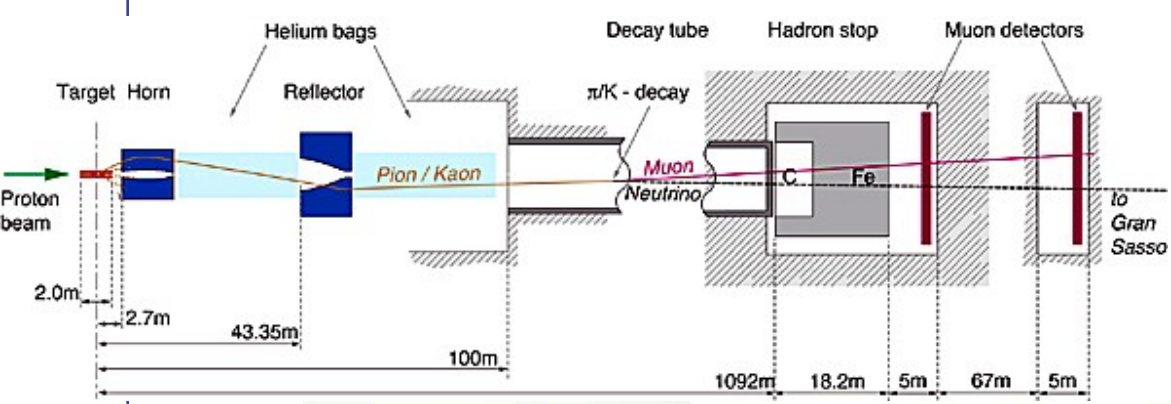


# Applications – CNGS

## CERN NEUTRINOS TO GRAN SASSO Underground structures at CERN

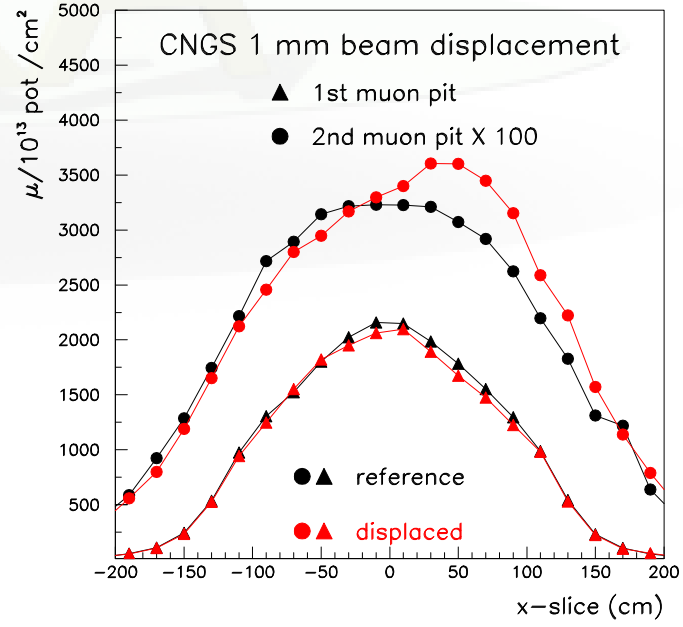
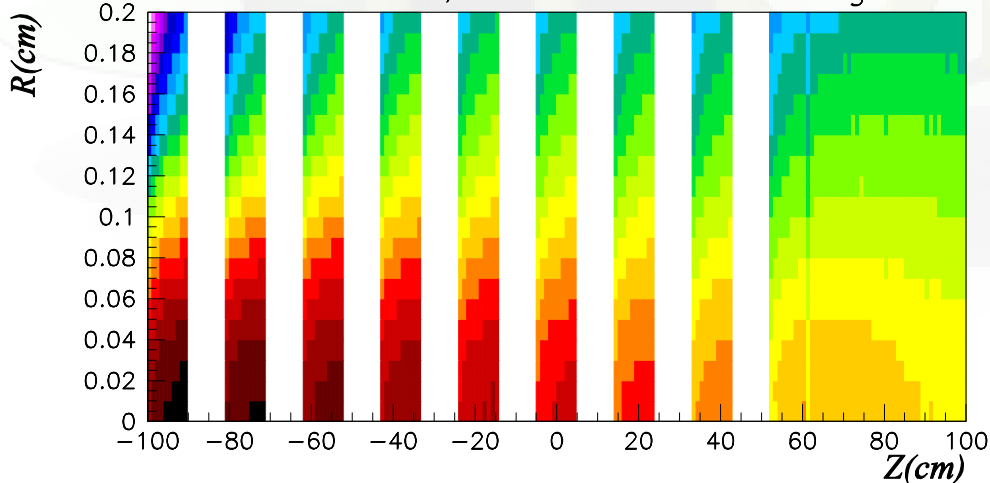


# Cern Neutrino to Gran Sasso



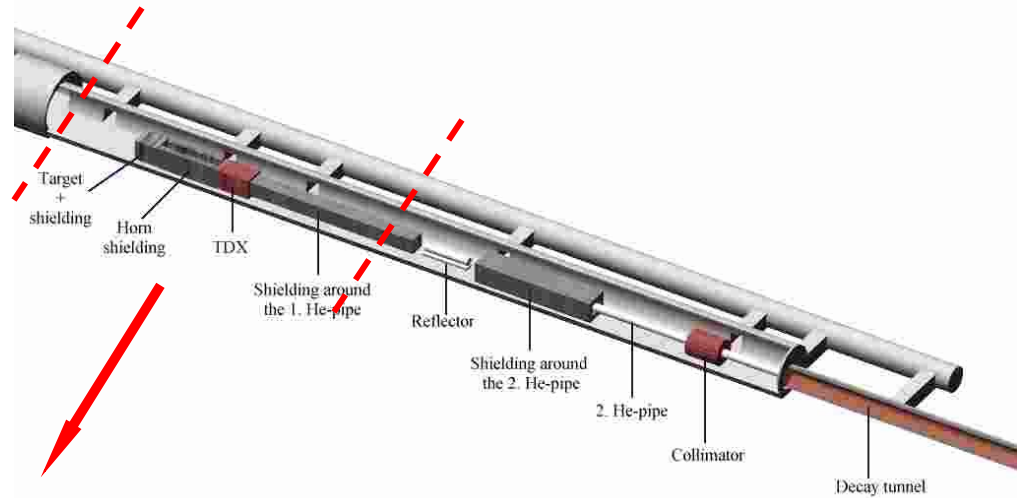
Engineering and physics: target heating, shielding, activation, beam monitors, neutrino spectra

CNGS cible, 4 mm dia .53 mm sigma



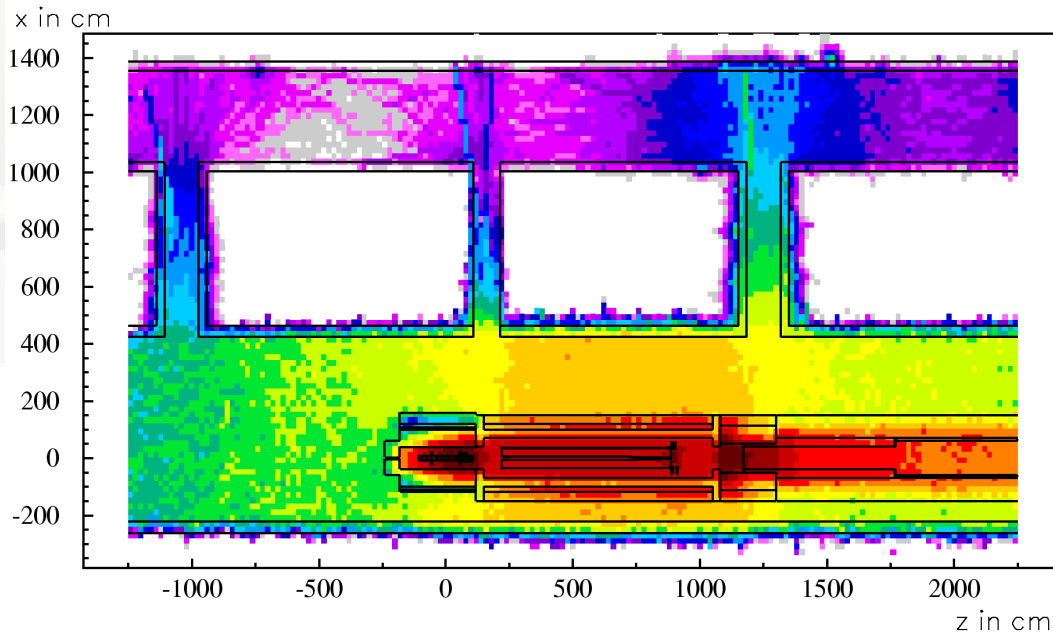
Muons in muon pits: horiz. distribution for beam alignment  
Energy deposition in CNGS target rods,  $GeV/cm^3/pot$

# Applications – CNGS

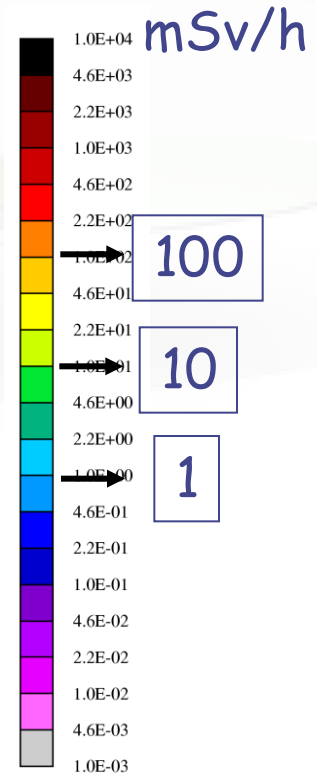


Example:

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

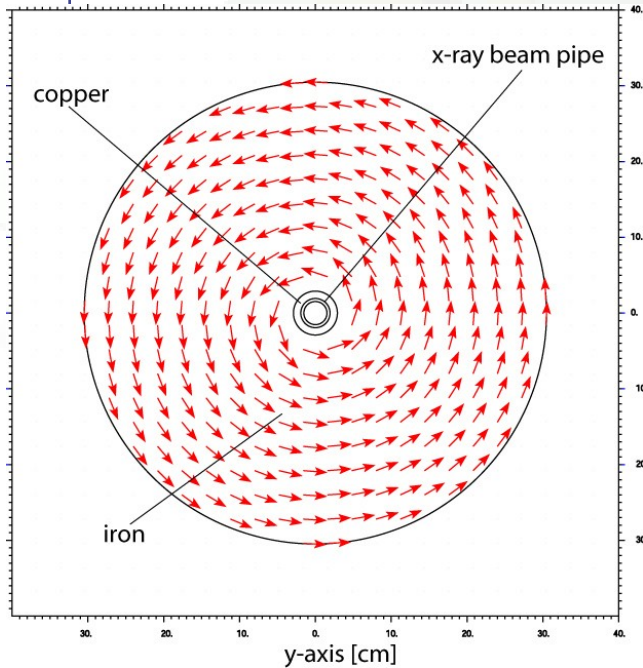


Residual Dose Equivalent Rate (mSv/h)  
 200 days irradiation, 1 day cooling  
 $8 \times 10^{12}$  protons/s

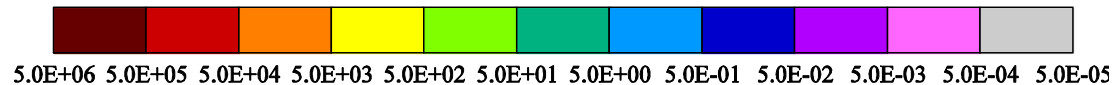
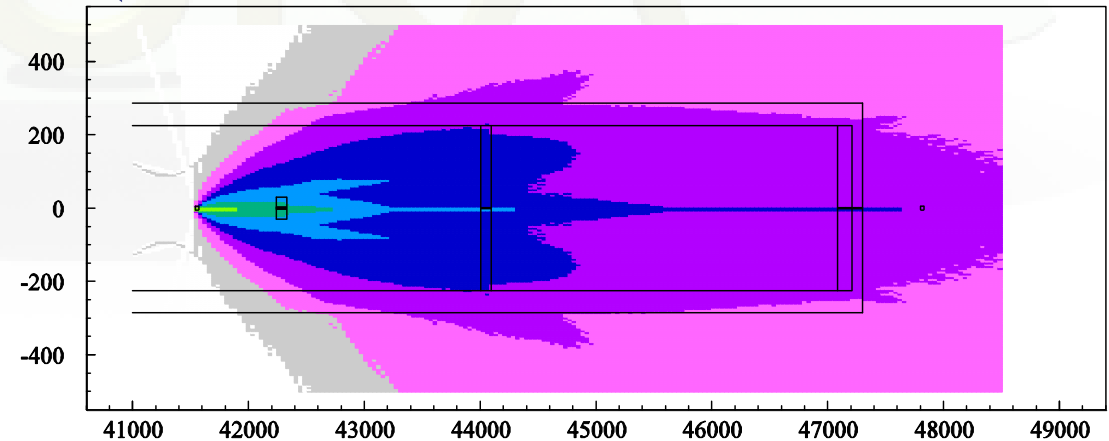
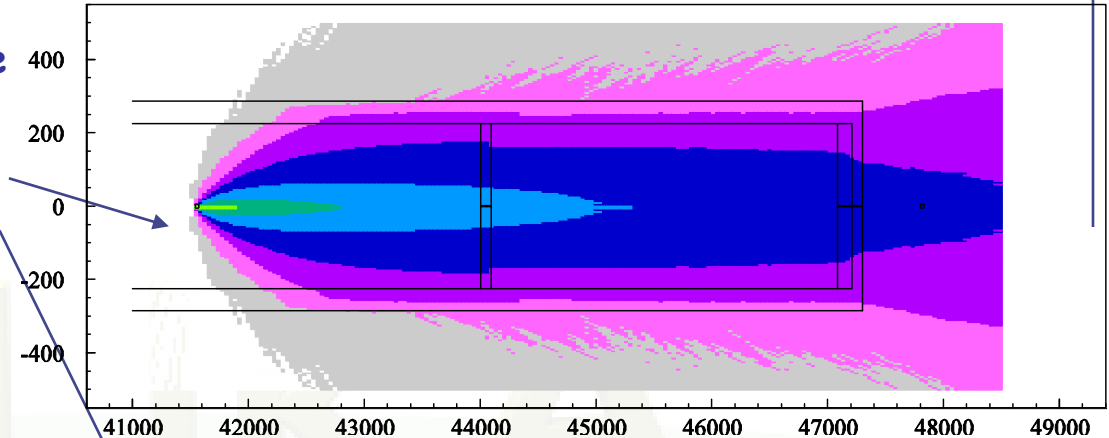


# Effect of a magnetic muon spoiler in the LCLS tunnel

The spoiler allows to reduce the shielding thickness in the forward direction. dose rate map without spoiler the same with spoiler



Magnetic field map used by FLUKA



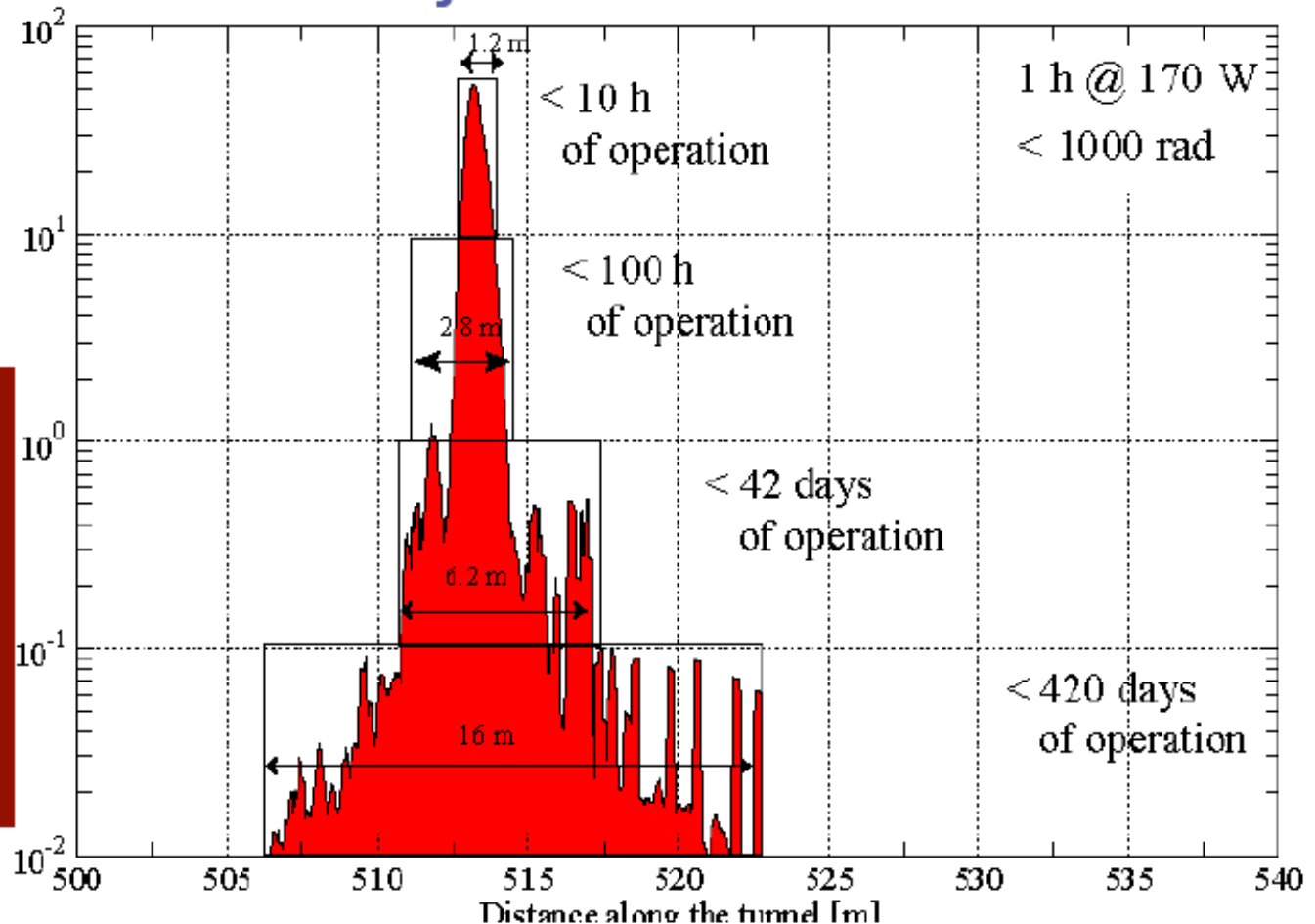
# Damage to electronics

SLAC: Damage to electronics near the dumps at the LCLS (Linear Coherent Light Source)

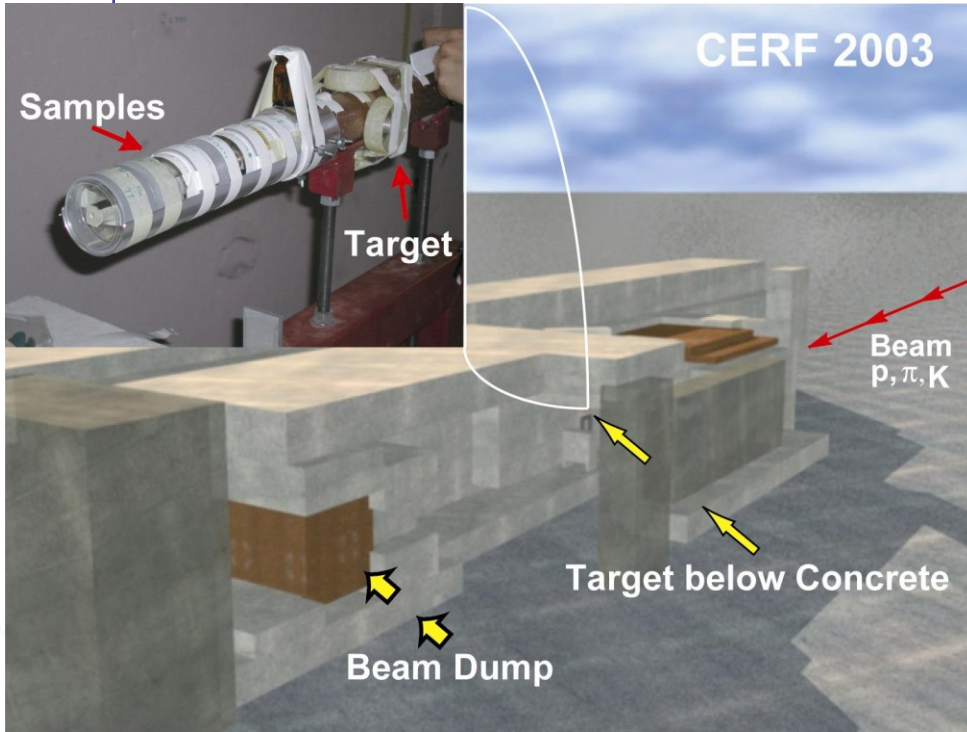
The lifetime of electronic components can be estimated as a function of the distance to major sources of radiation

1-MeV  
neutron  
equivalent  
fluence

Calculation of  
lifetime of  
electronics  
equipment as  
a function of  
the distance to  
TDUND



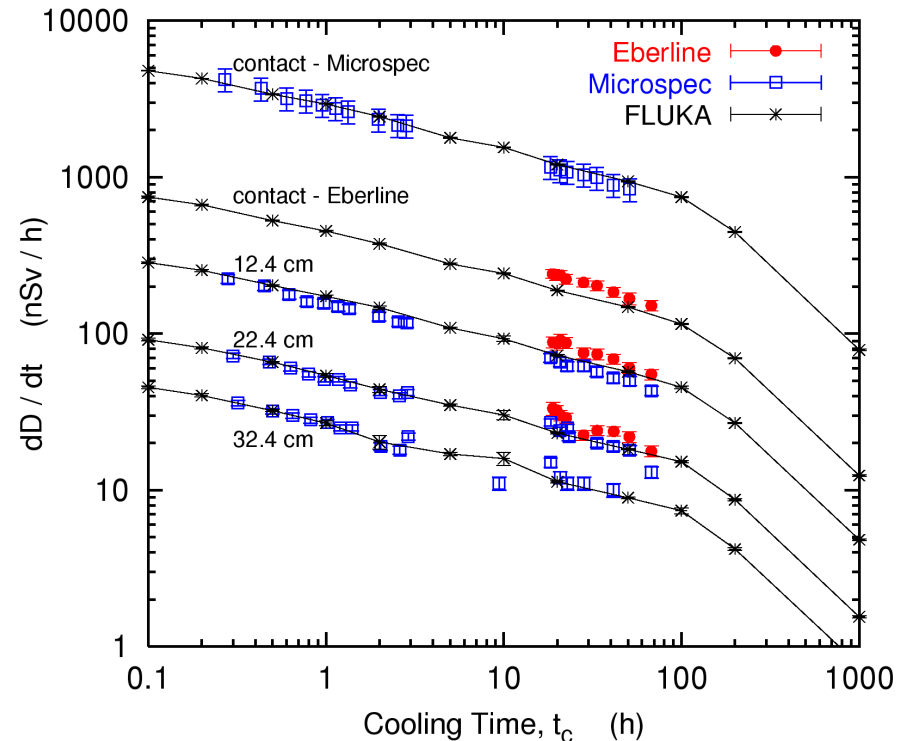
# CERN-EU High-Energy Reference Field facility (CERF)



Thermo-Eberline dose-meter FHZ 672



Iron



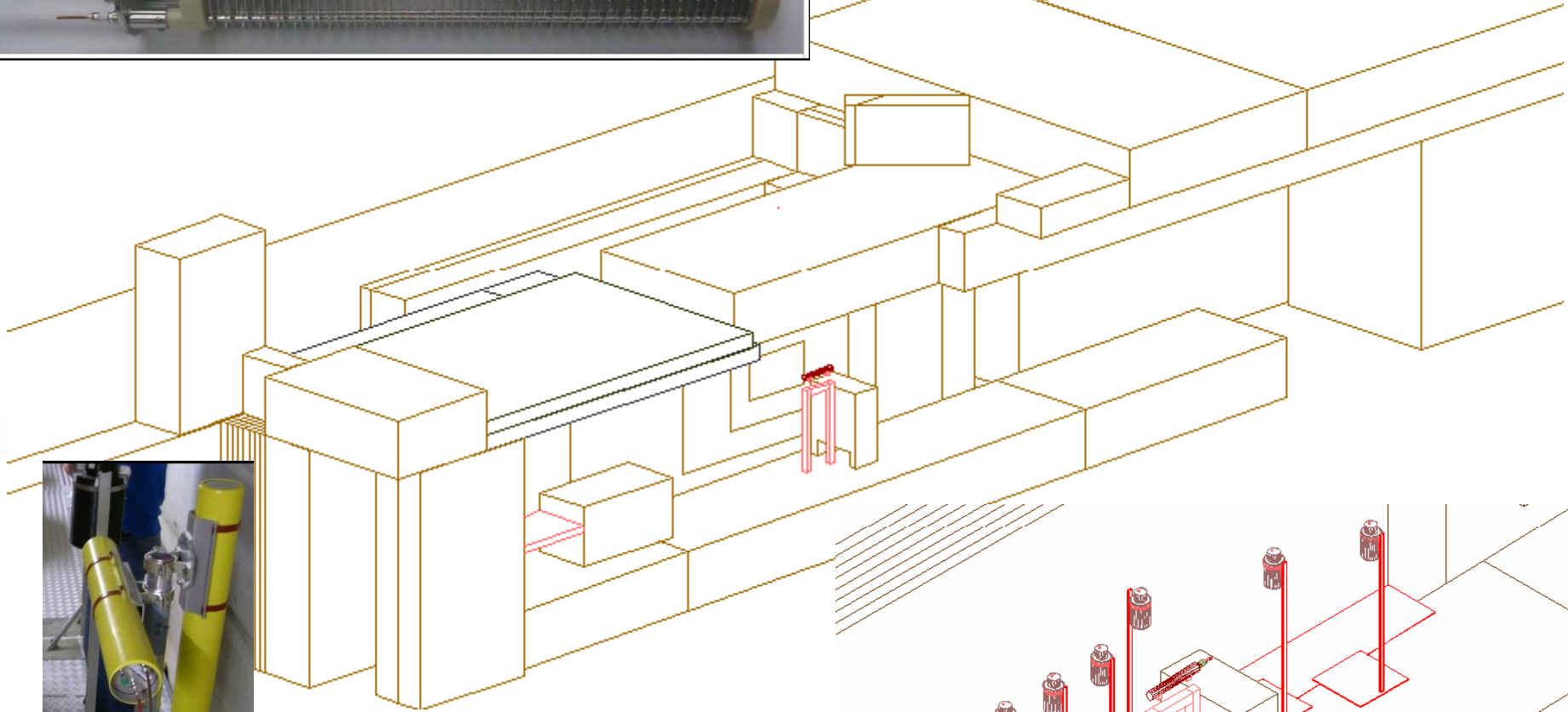
samples in contact with a 50 cm long, 7 cm diameter copper target, centred on the beam axis



Microspec

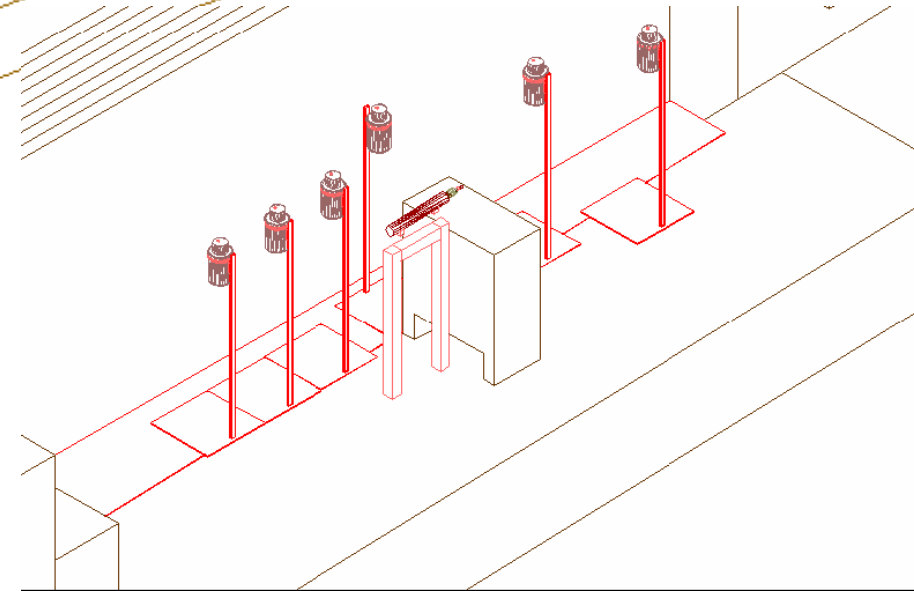
# Test of instrumentation : Beam Loss Monitors at CERF

CERN-EN-NOTE-2010-002-STI



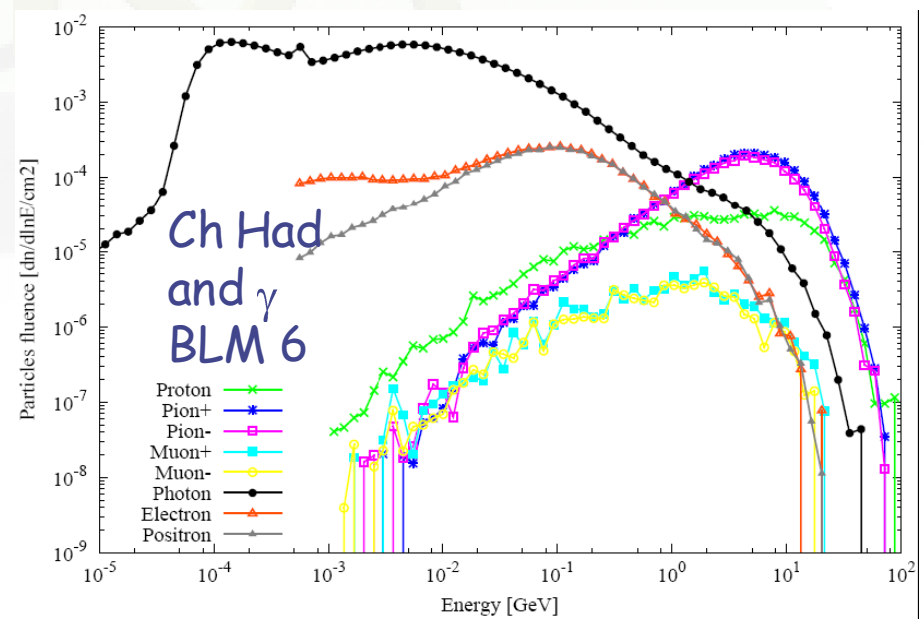
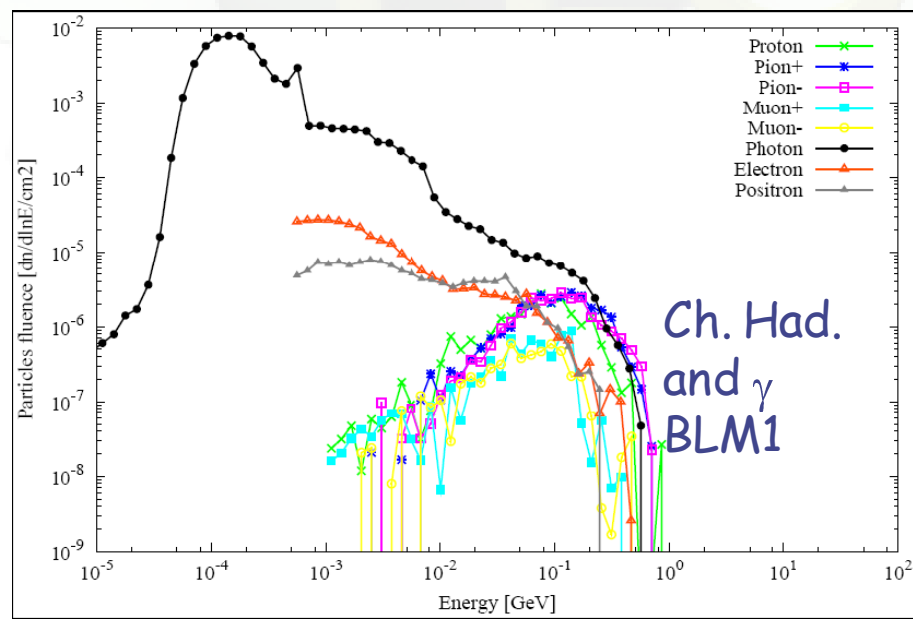
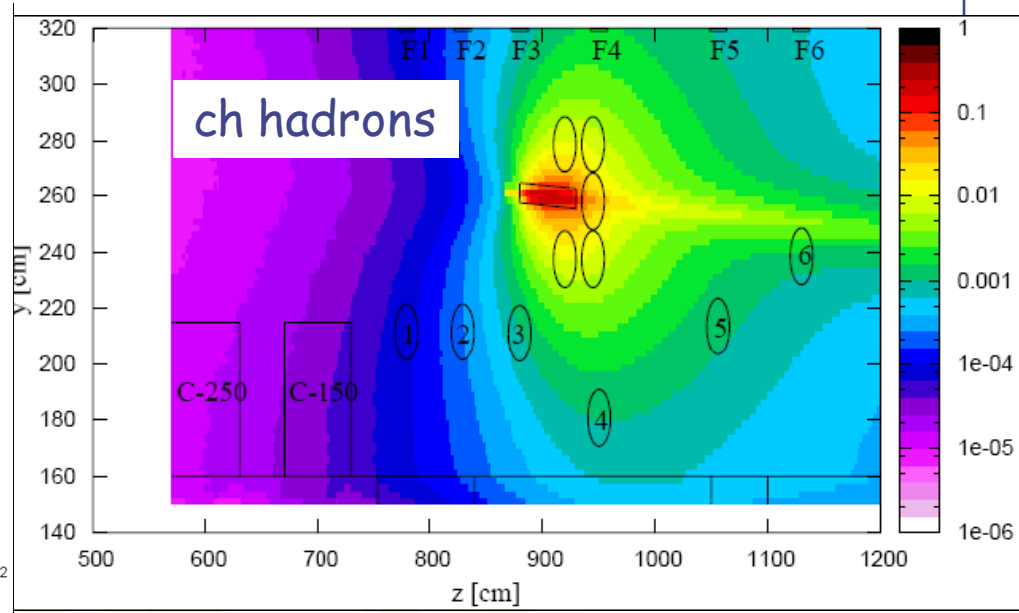
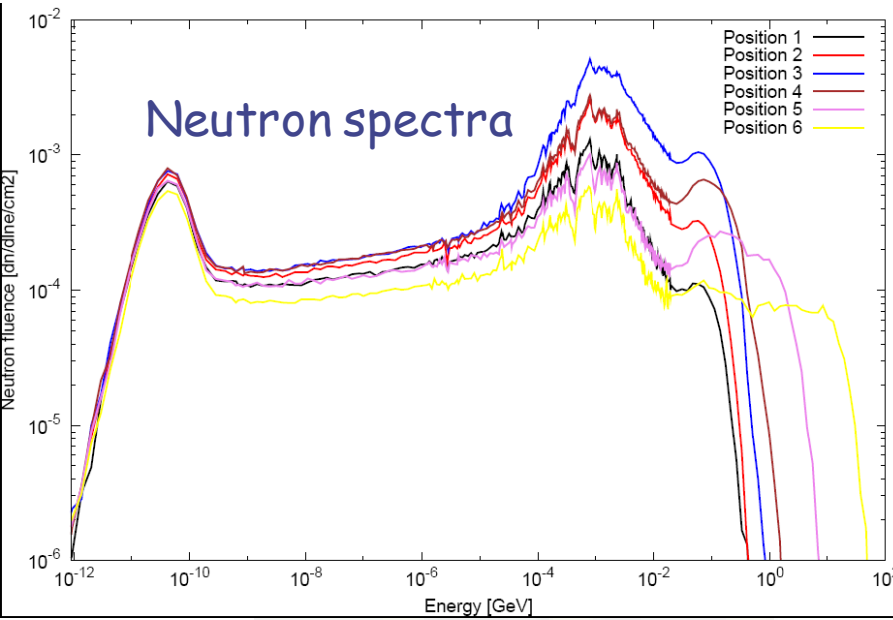
CERF setup

BLM's positions



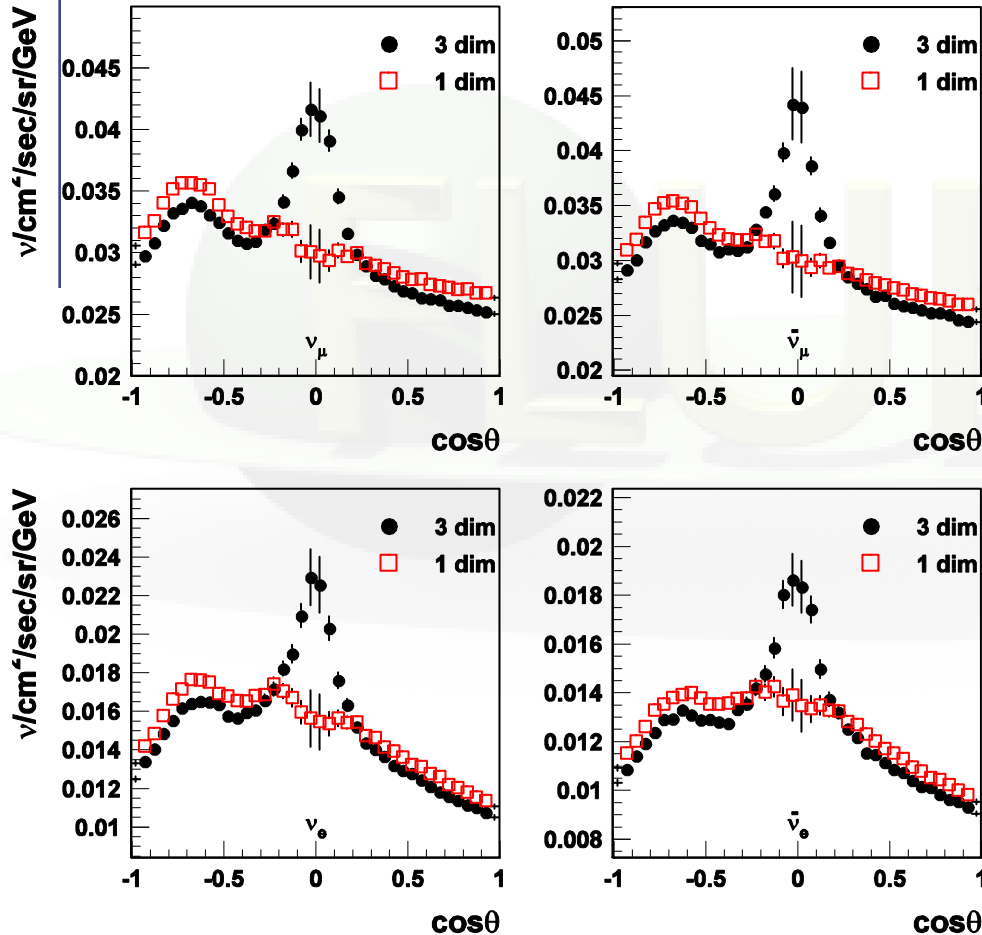


# CERF particle spectra



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

Sub-GeV flux at Kamioka



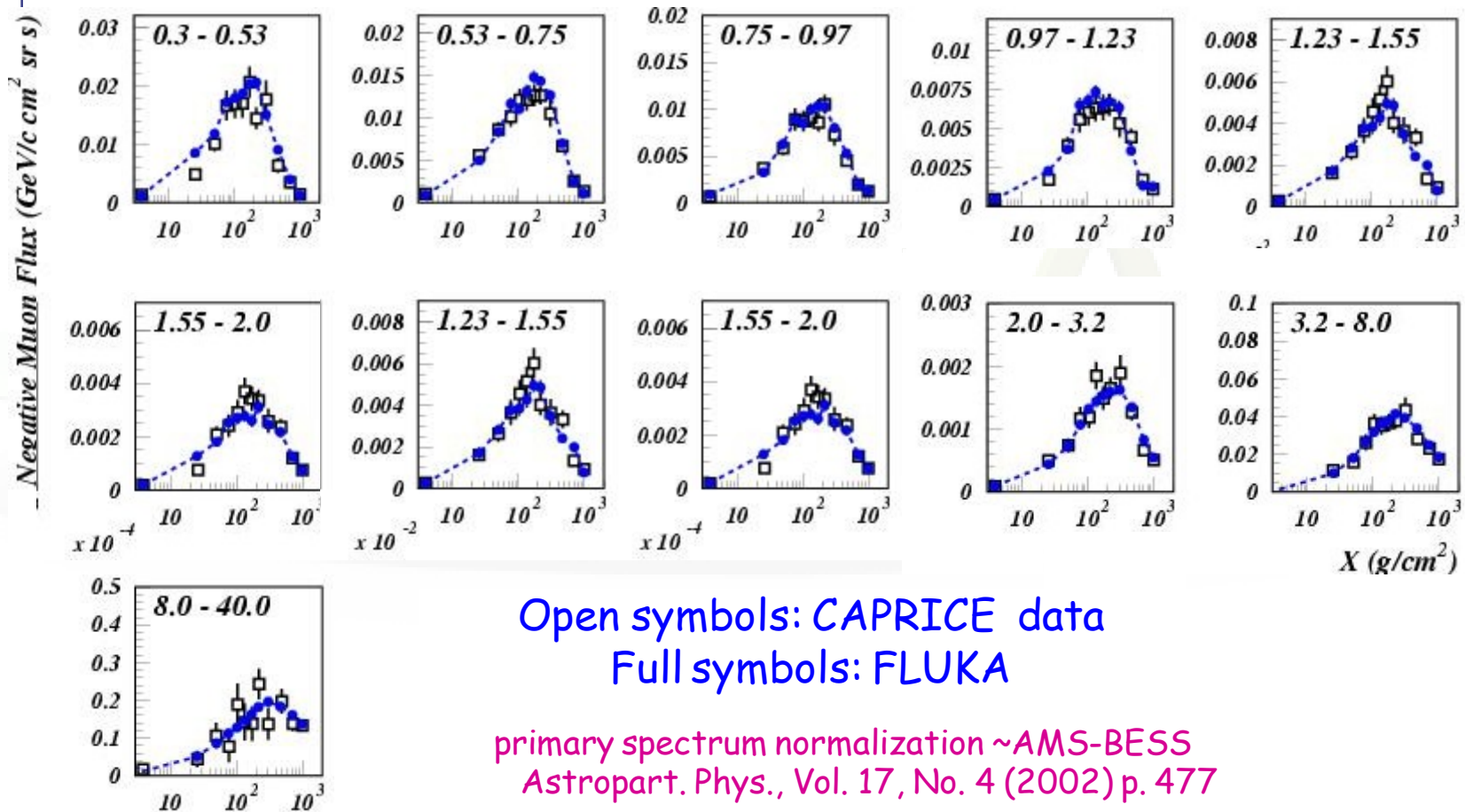
The first 3-D calculation of atmospheric neutrinos was done with FLUKA.

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

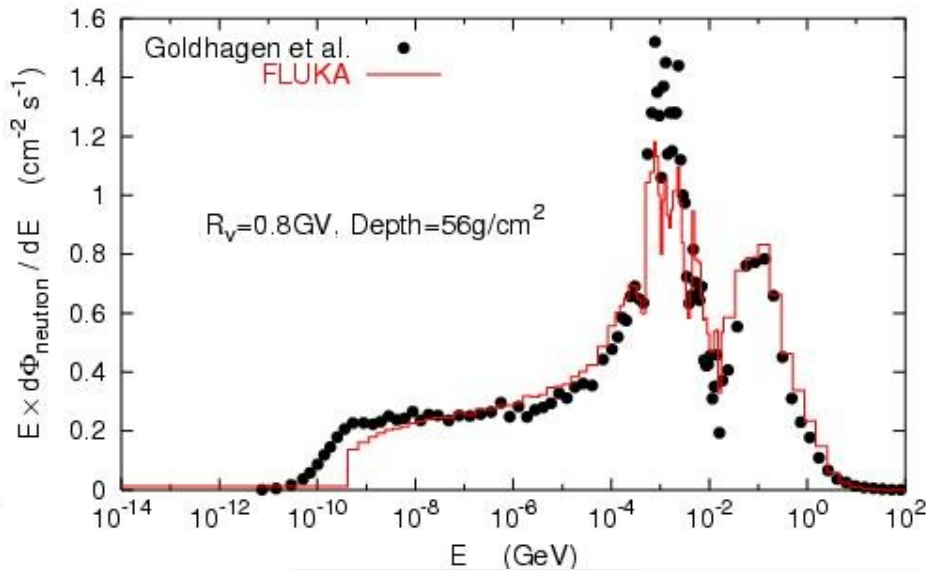
In the figure: angular distribution of  $\nu_\mu$ ,  $\bar{\nu}_\mu$ ,  $\nu_e$ ,  $\bar{\nu}_e$

In red: 1-D calculation

# Negative muons at floating altitudes: CAPRICE94



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



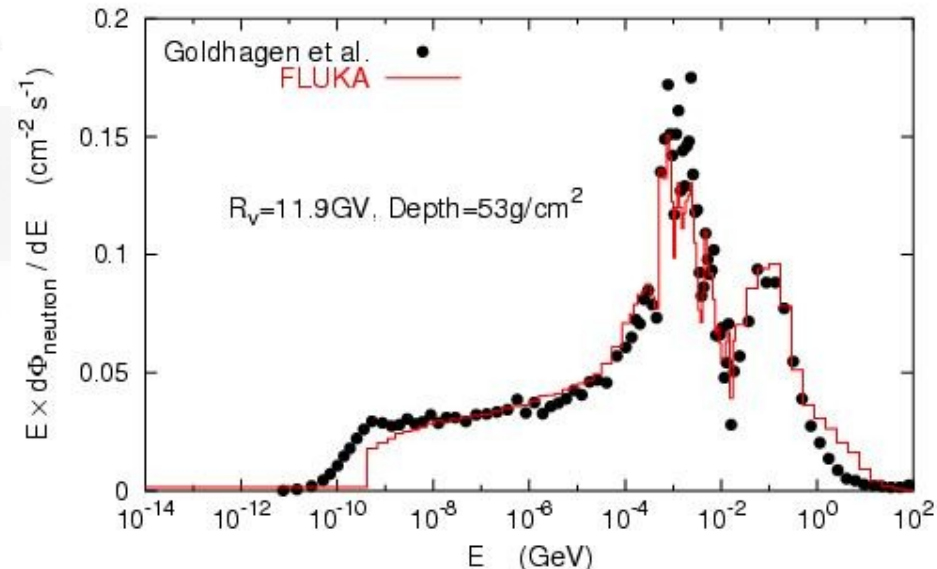
Measurements:

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

Note one order of magnitude difference depending on latitude

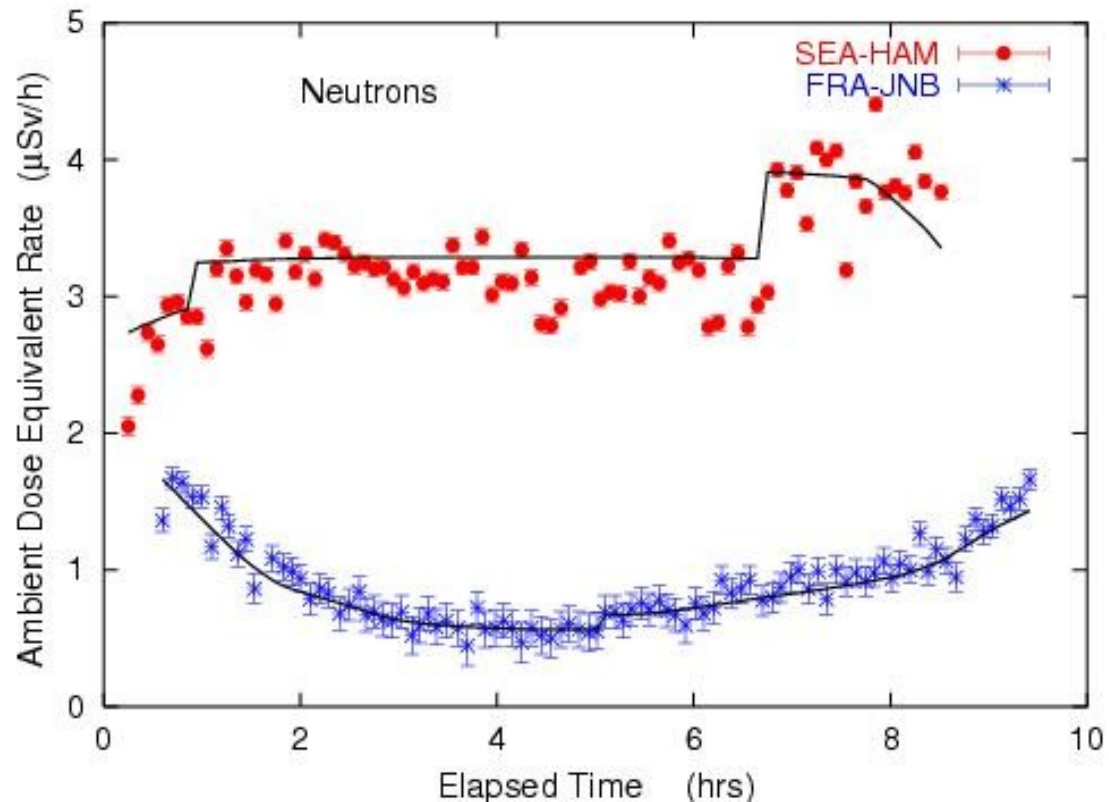
FLUKA calculations:

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



# Dosimetry Applications

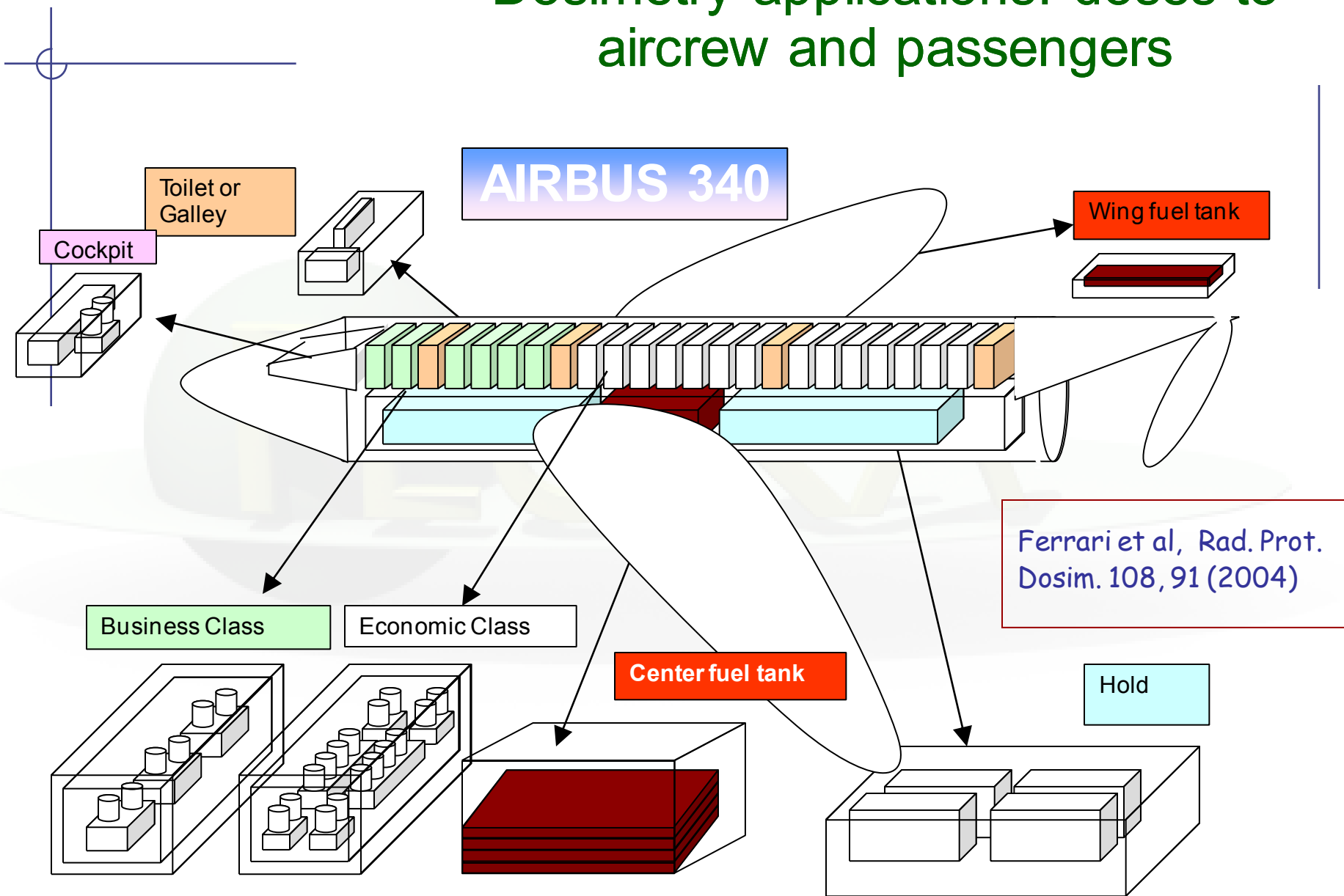
Roesler et al.,  
Rad. Prot. Dosim.  
98, 367 (2002)



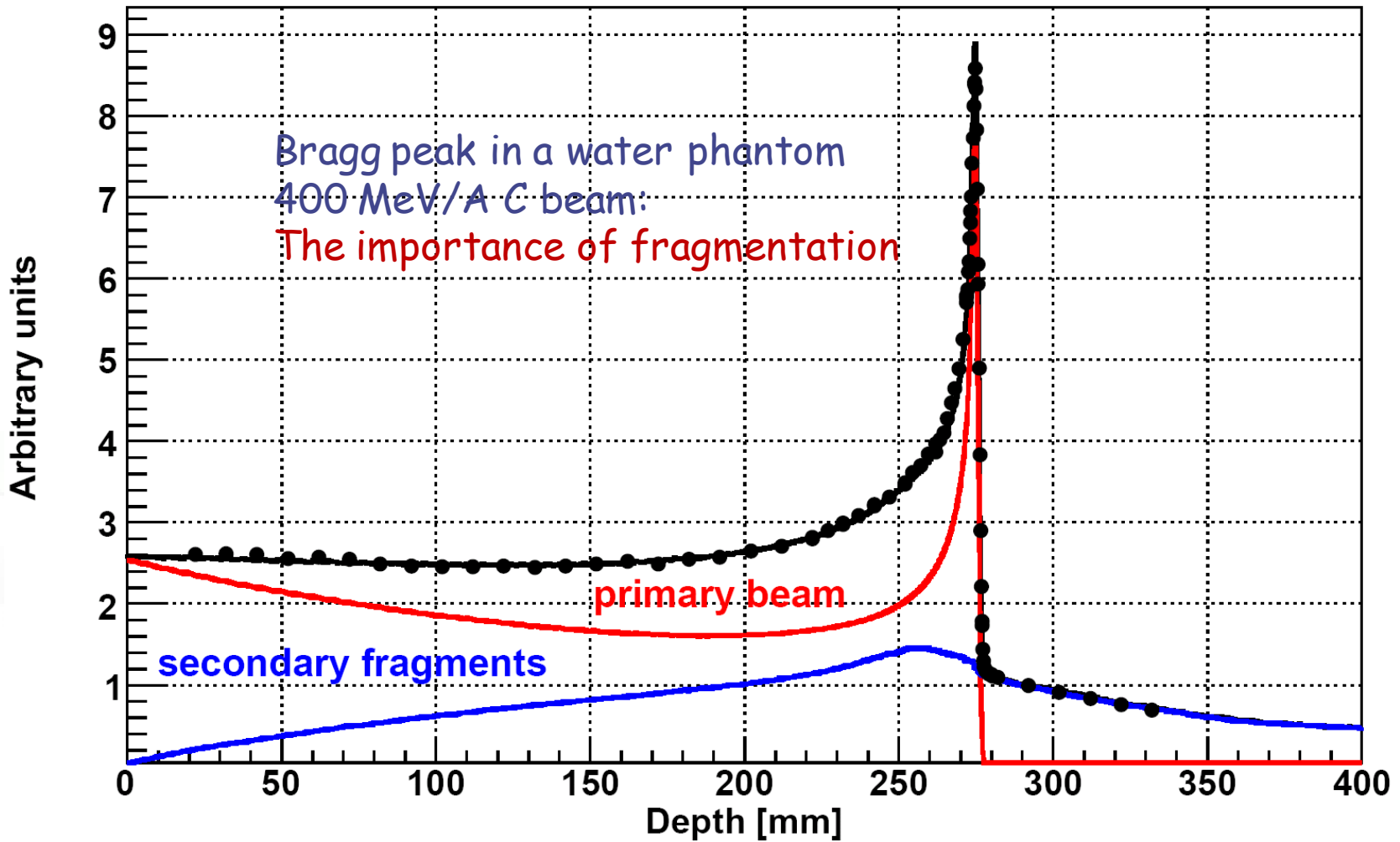
Ambient dose equivalent from neutrons at solar maximum on commercial flights from Seattle to Hamburg and from Frankfurt to Johannesburg.

Solid lines: FLUKA simulation

# Dosimetry applications: doses to aircrew and passengers



# Carbon Ion Therapy



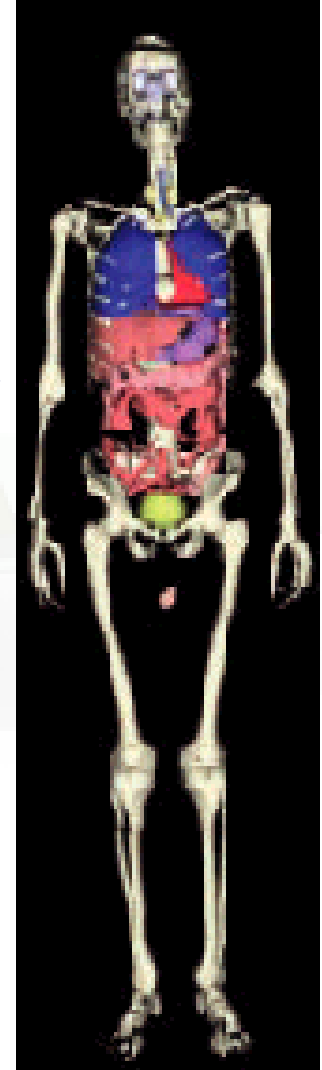
Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006  
Simulation: A. Mairani PhD Thesis, 2007, Nuovo Cimento C, 31, 2008

# Using the information from the patient CT in the MC

## 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

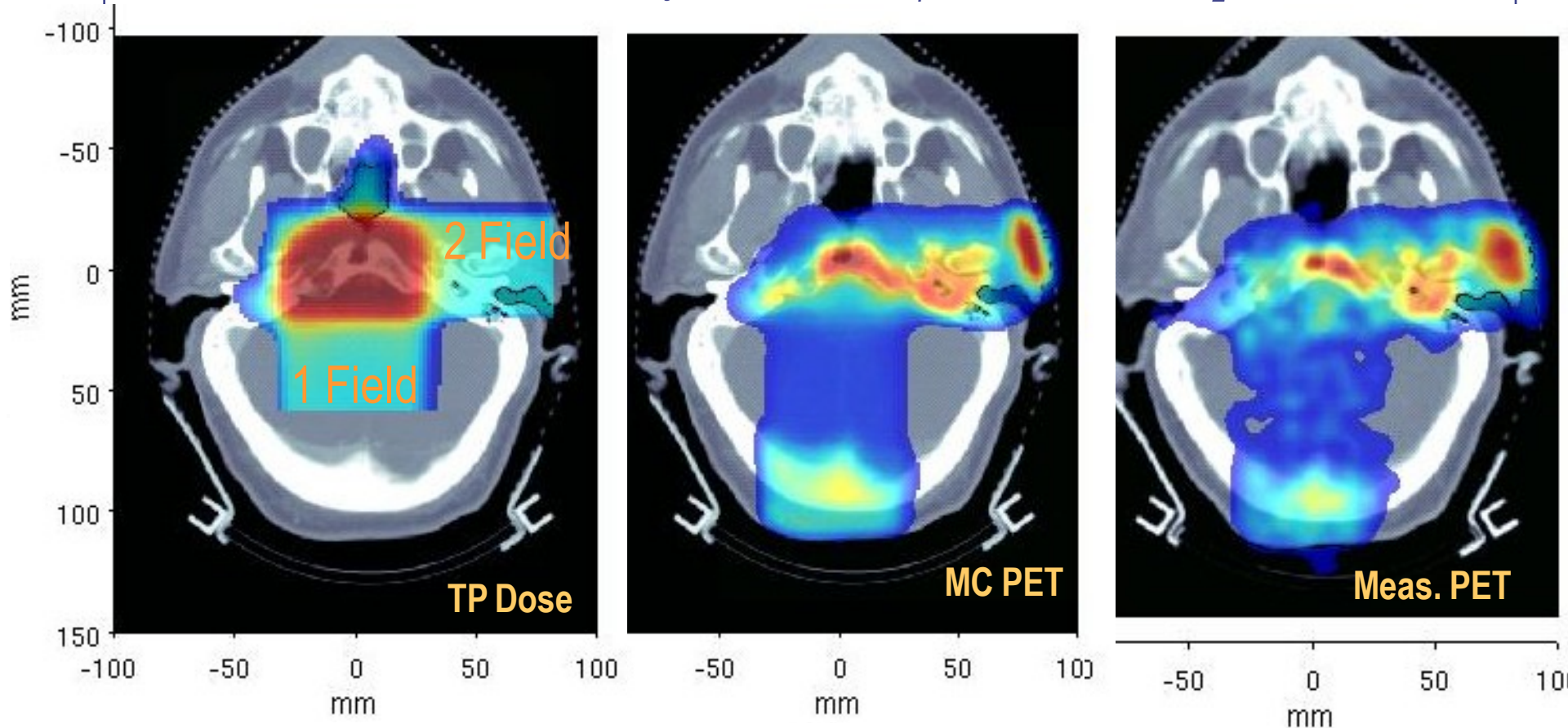
**The GOLEM phantom**  
Petoussi-Hens et al, 2002





# Proton therapy: dose and PET distributions from MC, Head

Clival Chordoma, 0.96 GyE / field,  $\Delta T_1 \sim 26$  min,  $\Delta T_2 \sim 16$  min



*K. Parodi et al., PMB52, 3369 (2007)*