The FLUKA Code

An Introduction to FLUKA:

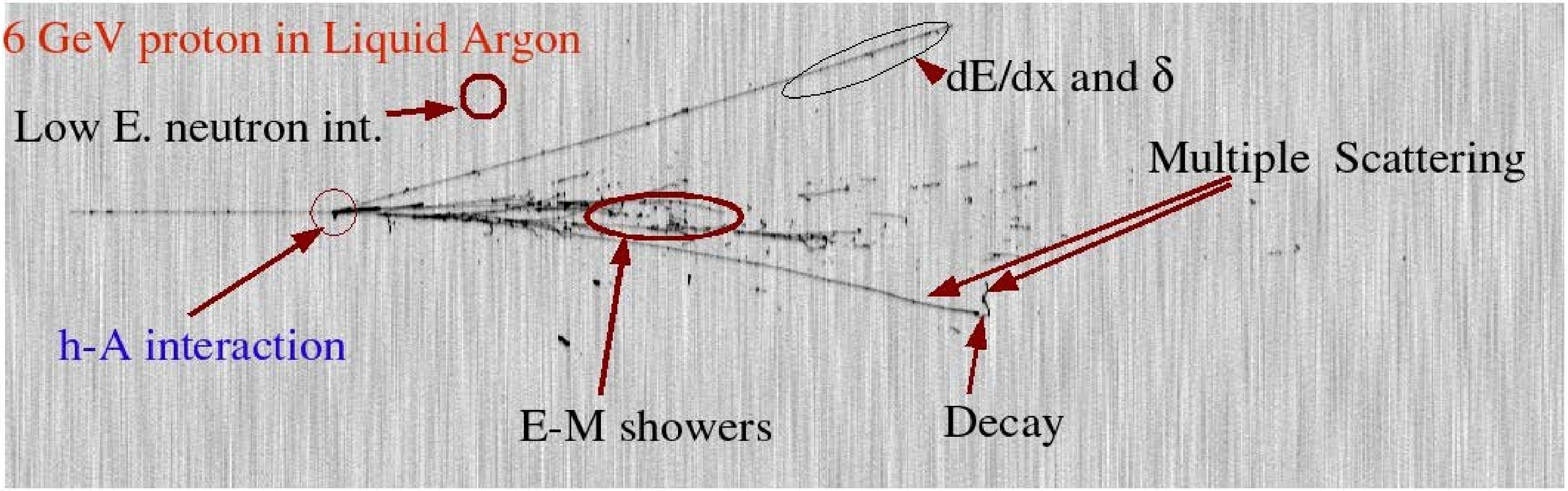
a Multipurpose Interaction and Transport MC code

FLUKA Beginner's Course

FLUKA

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

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



Developed and maintained under an INFN-CERN agreement Copyright 1989-2011 CERN and INFN

>5000 users

http://www.fluka.org

The FLUKA International Collaboration

M. Brugger, M. Calviani, F. Cerutti, M. Chin, Alfredo Ferrari, P. Garcia Ortega, A. Lechner, C. Mancini-Terracciano, M. Magistris, A. Mereghetti, S. Roesler, G. Smirnov, C. Theis, Heinz Vincke, Helmut Vincke, V. Vlachoudis, J.Vollaire, CERN

G. Kharashvili, Jefferson Lab, USA

J. Ranft, Univ. of Siegen, Germany

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

L. Sarchiapone, INFN Legnaro, Italy

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

V. Patera, INFN Frascati & Univ. Roma Sapienza, Italy

M. Pelliccioni, INFN Frascati & CNAO, Pavia, Italy

A. Mairani, CNAO Pavia, Italy

M. Santana, SLAC, USA

M.C. Morone, Univ. Roma II, Italy

K. Parodi, I. Rinaldi, LMU Munich, Germany

L. Lari, Univ. of Valencia, Spain

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

M. Nozar, TRIUMF, Canada

V. Boccone, Univ. of Geneva, Switzerland

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

T. Boehlen, S. Rollet, AIT, Austria

A. Fassò, R. Versaci, ELI-Beamlines, Prague, CR

M. Lantz, Uppsala Univ., Sweden

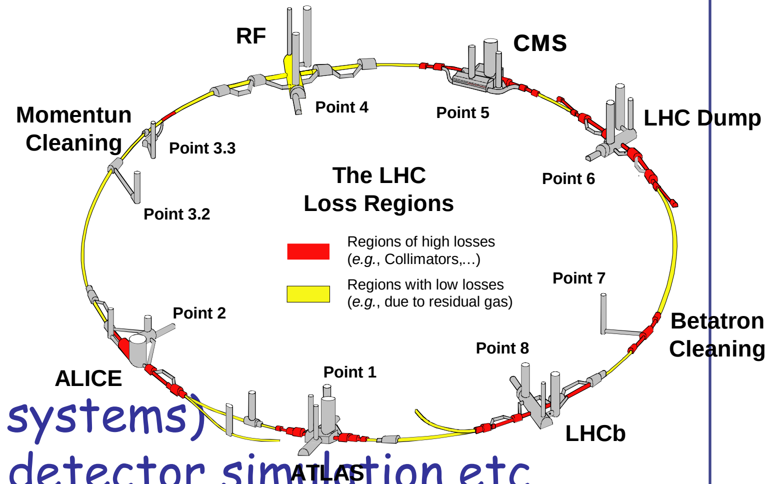
S. Trovati, PSI, Switzerland

P. Colleoni, Ospedali Riuniti di Bergamo, Italy

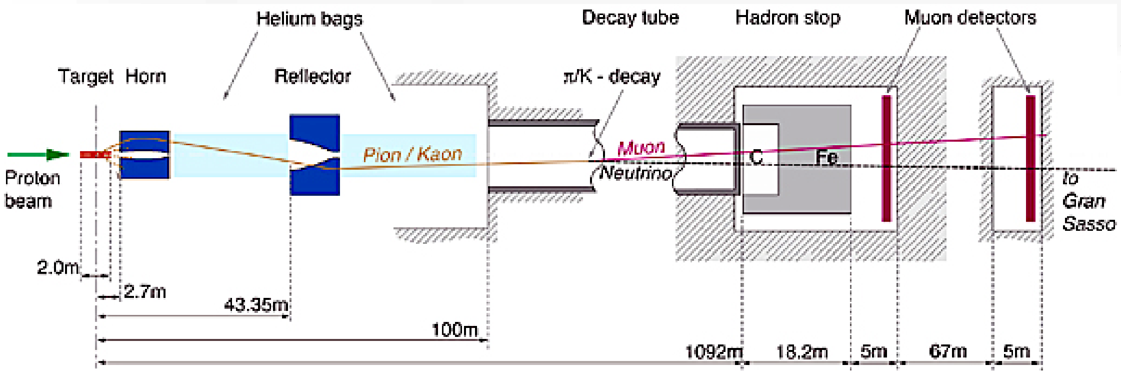
M.V. Garzelli, Nova Gorica Univ., Slovenia

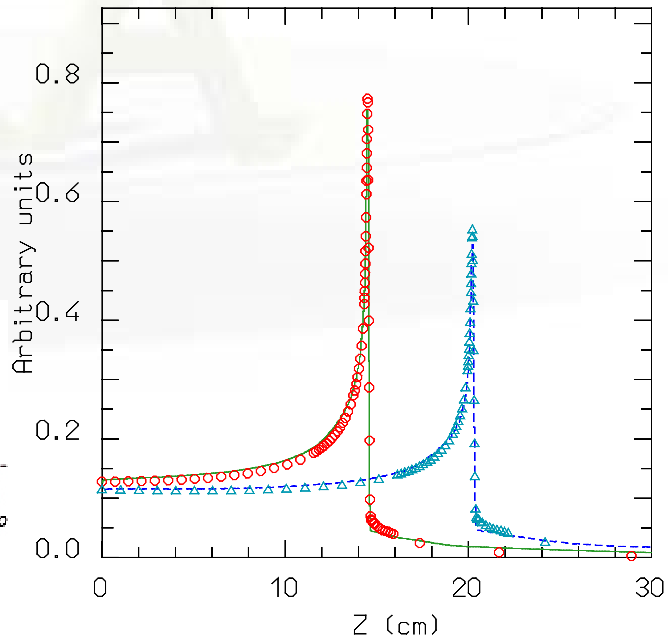
Anna Ferrari, S. Mueller HZDR Rossendorf, Germany

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 μ 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** → 20xx
- **Minor version** → n
- **Patch level** → (y)
- **Respin** → (.m)

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

In this course we are using FLUKA2011.2b

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 signing of license, to download the **source** for researchers of scientific/academic Institutions. *(!!! 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.
- For **commercial use**, trial version (limited in time and random seeds) available. Commercial license to be negotiated.

Using FLUKA

Platform: Linux with **g77** (in 32bit mode)
and **gfortran** (on 64bit machines)

Work in progress: Mac OSX with gfortran

The code may 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

  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 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

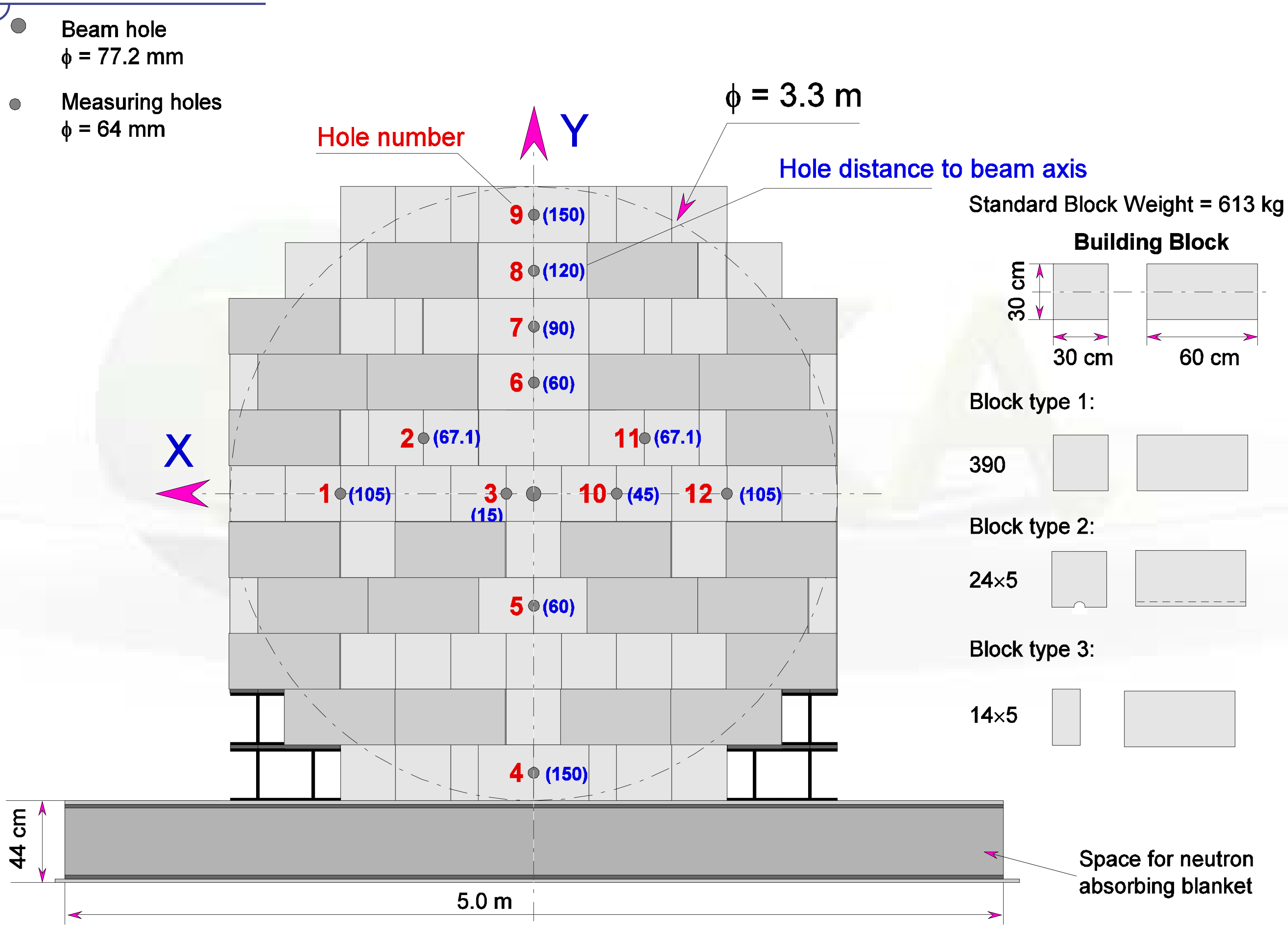
  - Has a critical judgment on the results
- Therefore in this course we will equally focus on:
  - The technical aspects of the code
    [building your input, geometry, scoring, biasing, extracting results...]

  as well as

  - The underlying physics and MC techniques

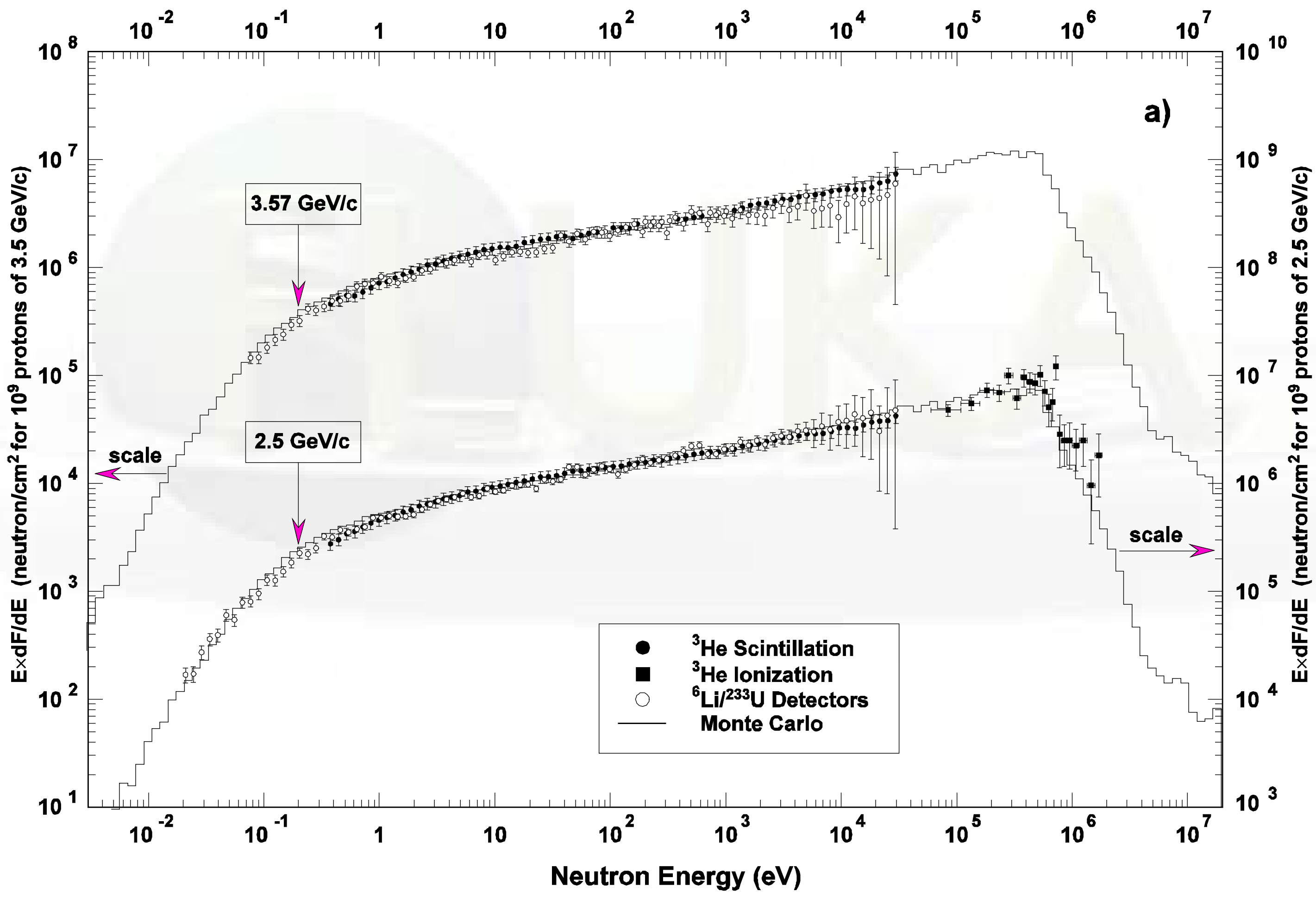
Examples of FLUKA Applications

The TARC experiment at CERN:



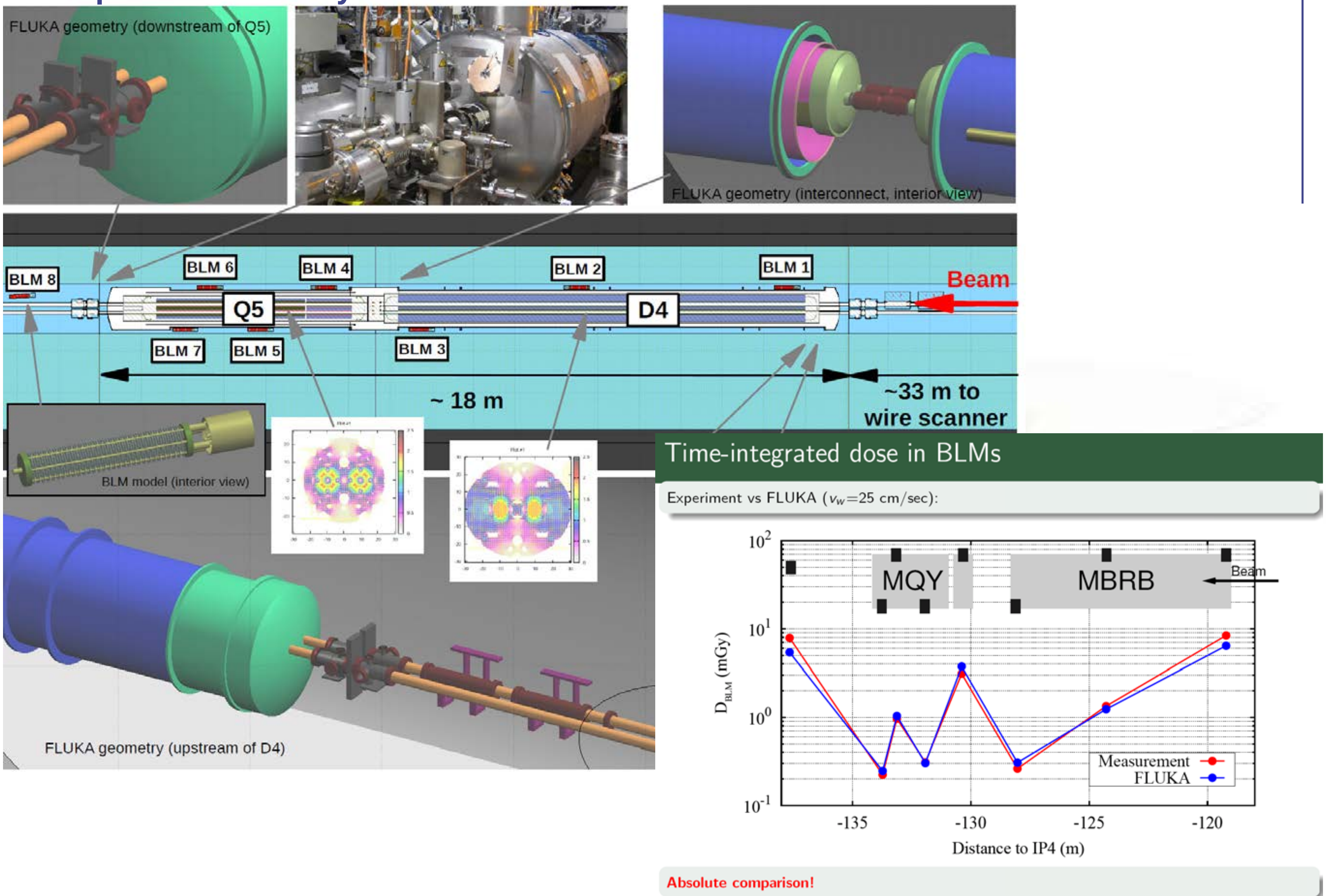
The TARC experiment: neutron spectra

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

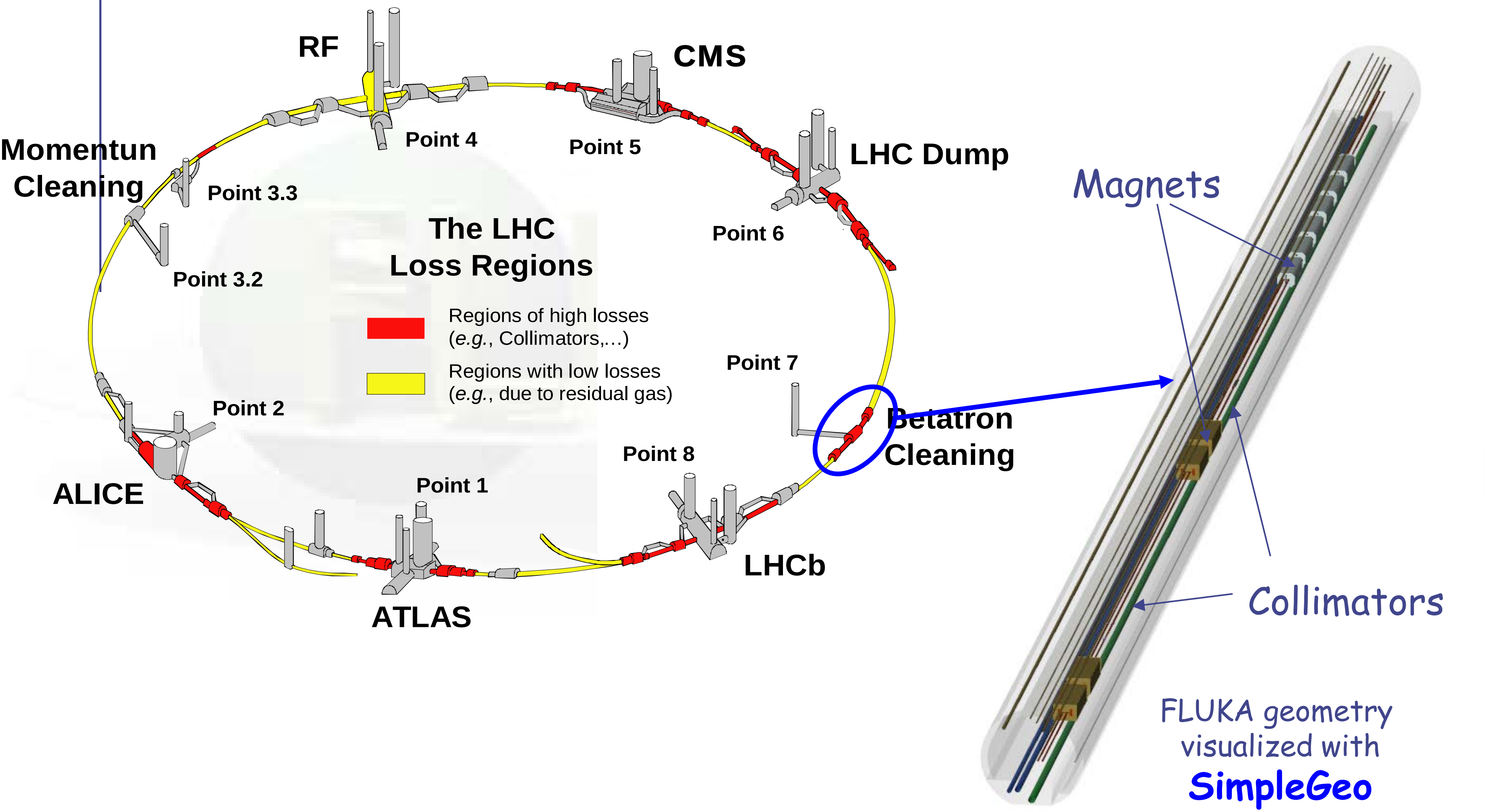


Application & Benchmarking – *LHC operation*

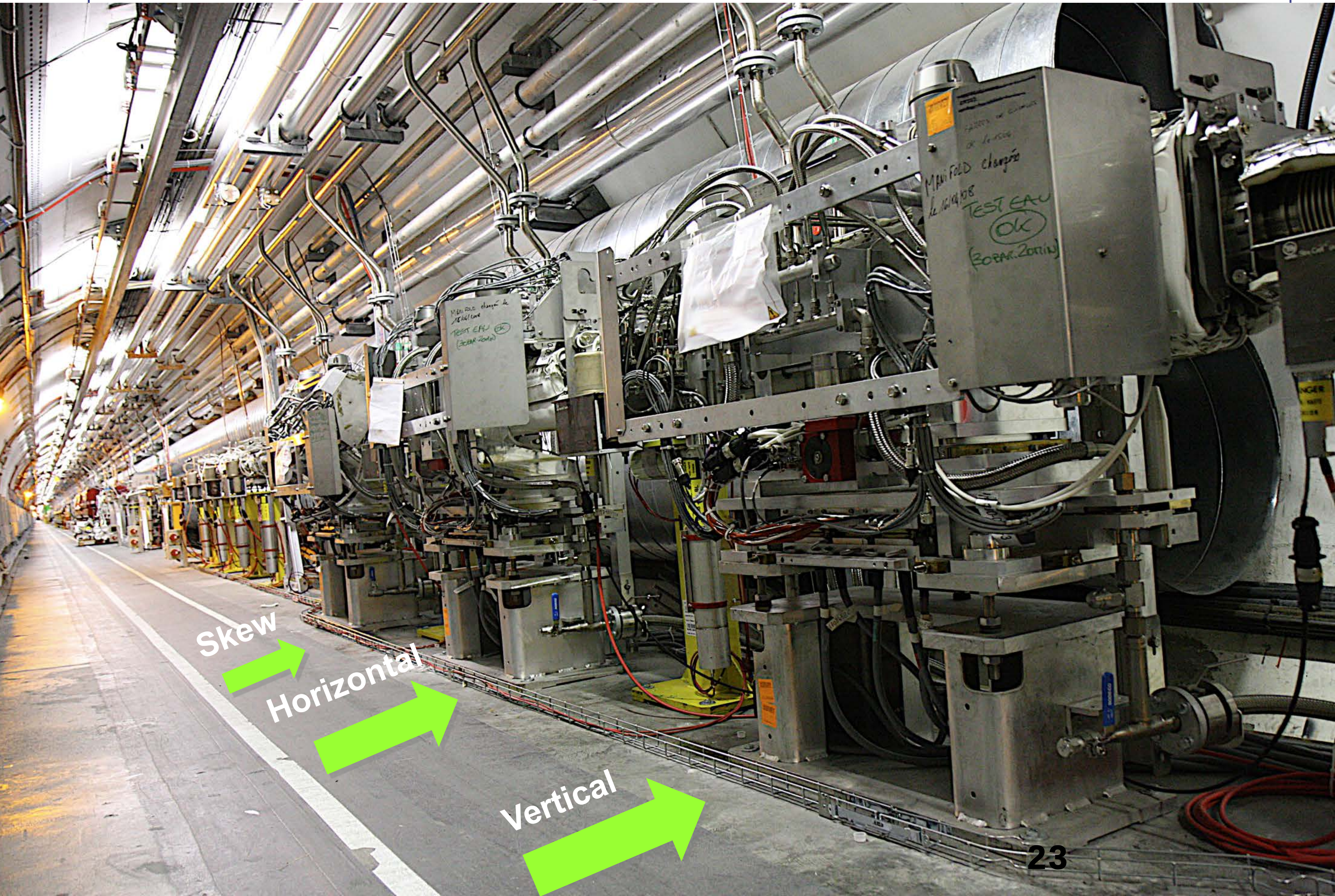
Test quench induced by the wire scanner *on 2010 Nov 1* on the left of P4 at 3.5TeV



Applications – *LHC collimation region*



Example: 3 Primary Collimators IR7

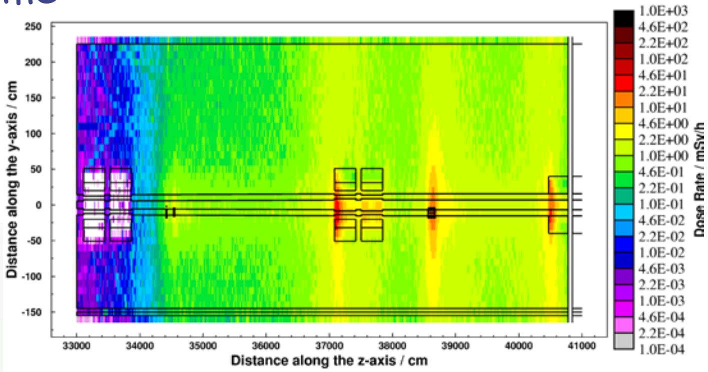


Applications – *LHC collimation region*

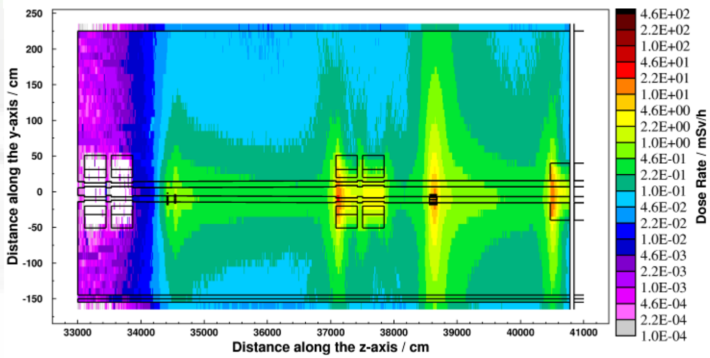
Cooling time

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

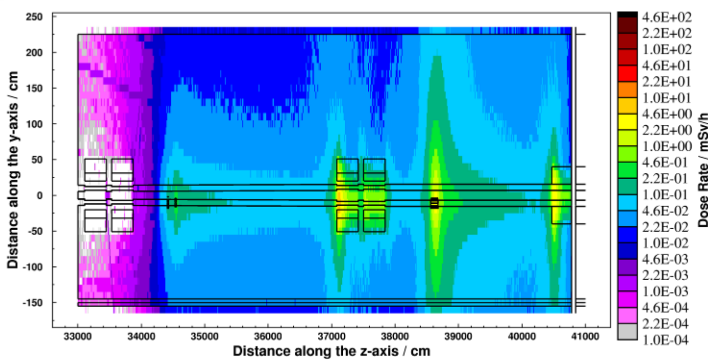
8 hours

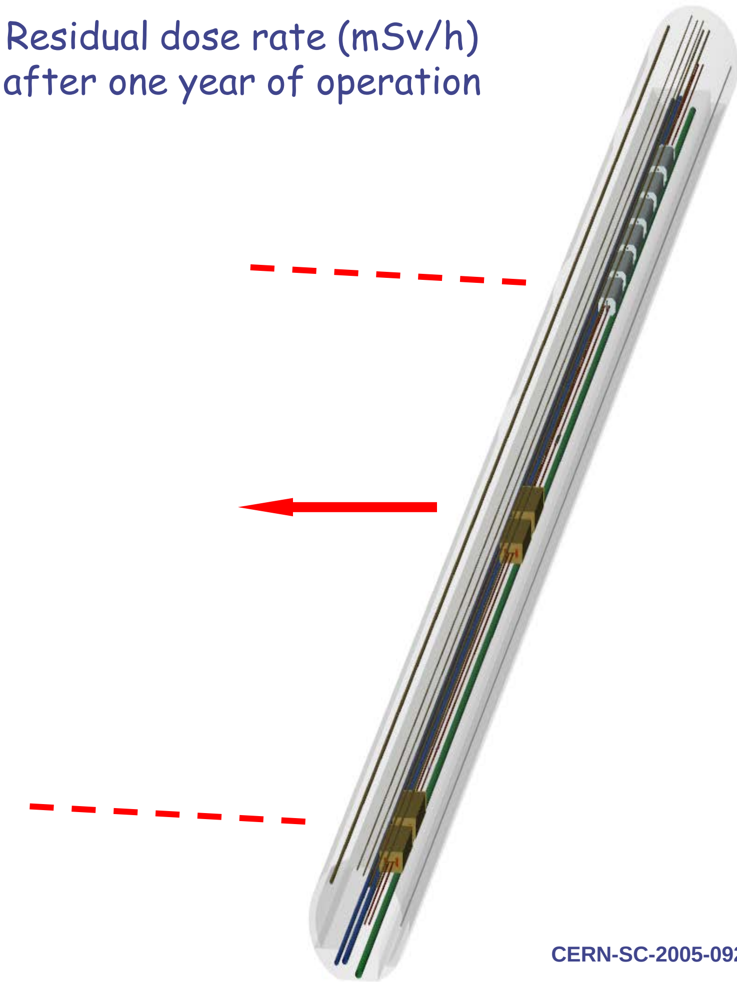


1 week



4 months

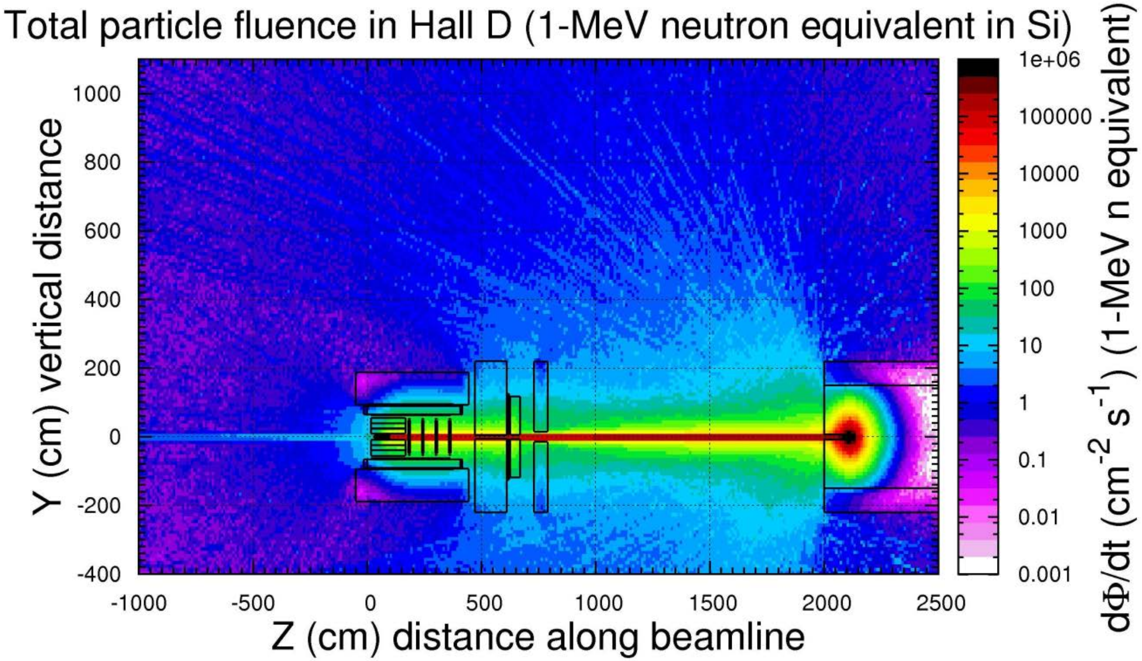




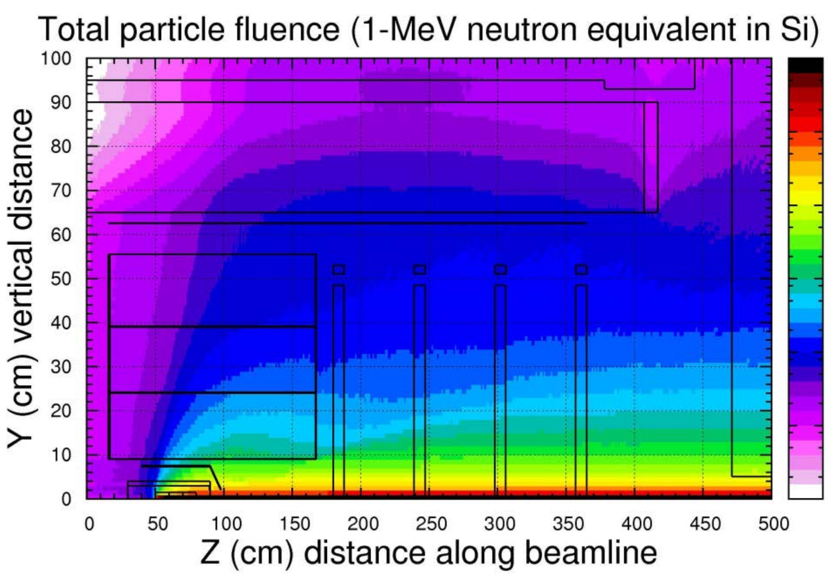
CERN-SC-2005-092-RP-TN

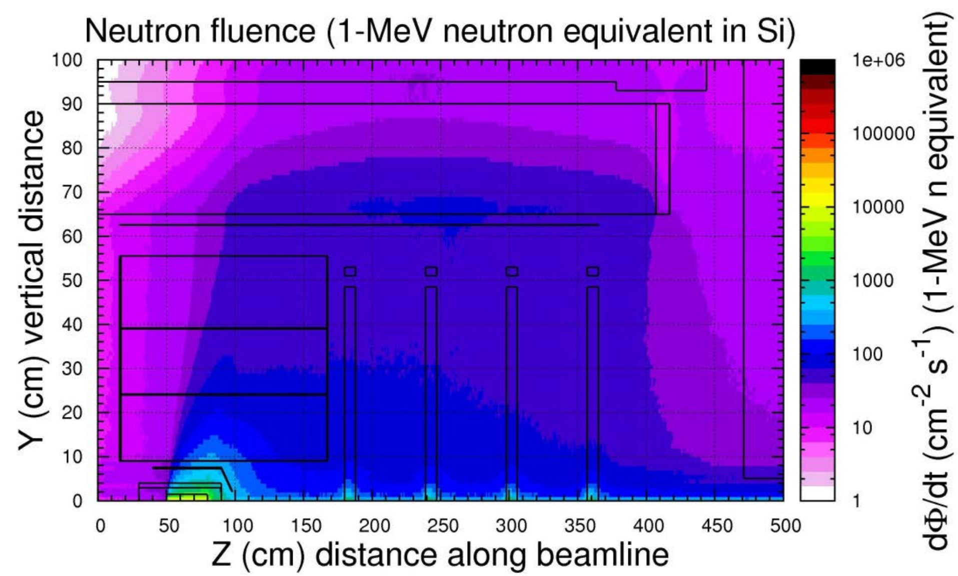
REMANENT DOSE RATE MAPS OF THE LHC BETATRON CLEANING INSERTION (IR7)

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

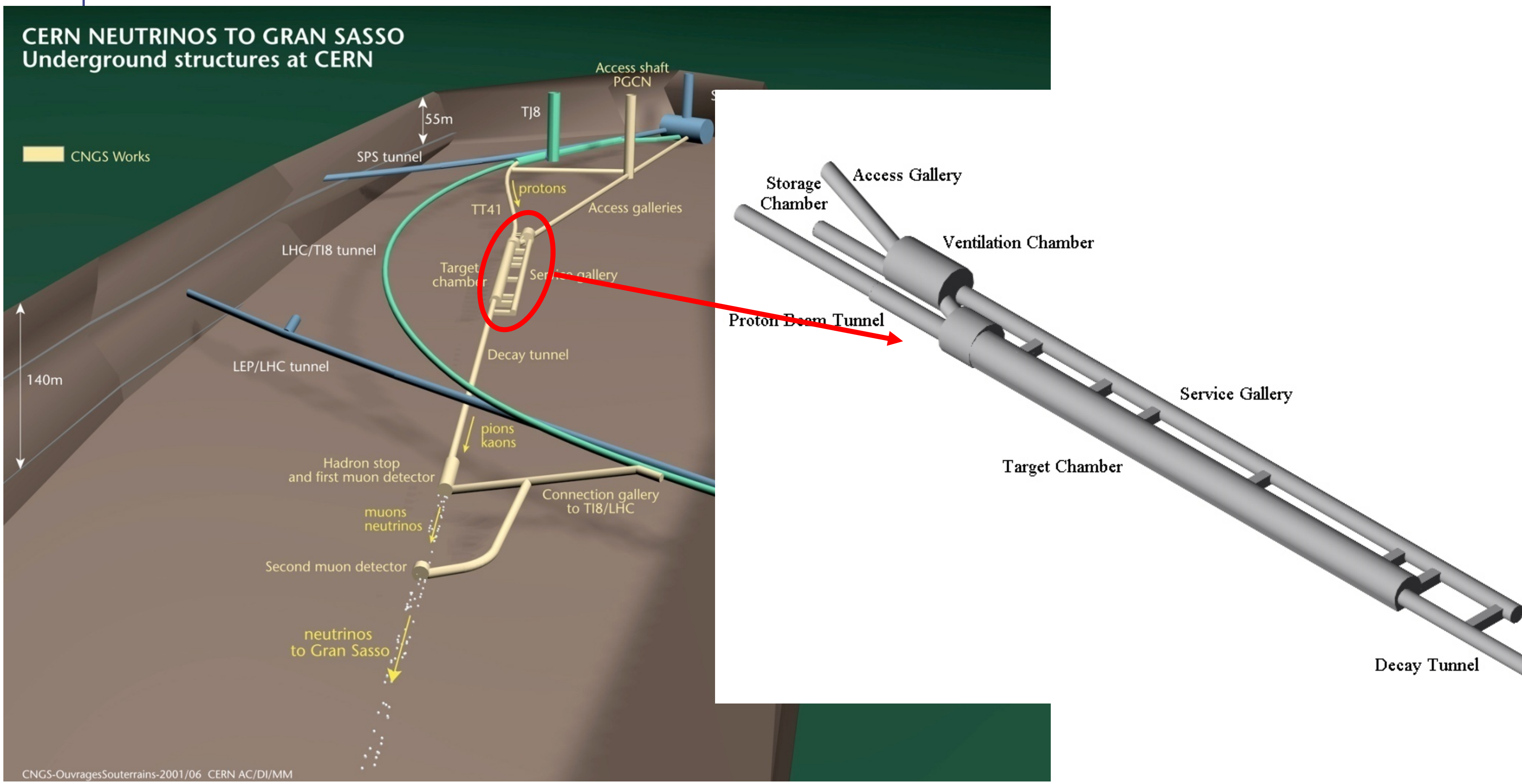


Calculated 1-MeV neutron equivalent fluence rate in Si (GlueX experiment at Jlab)

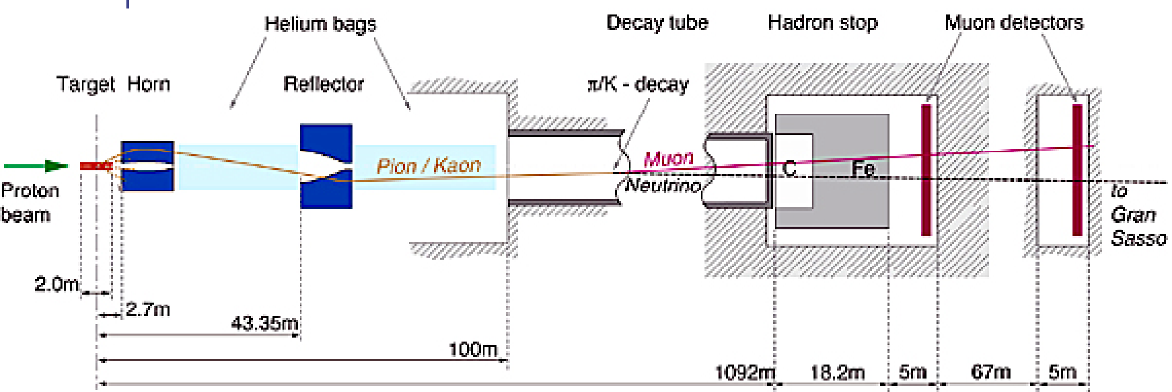


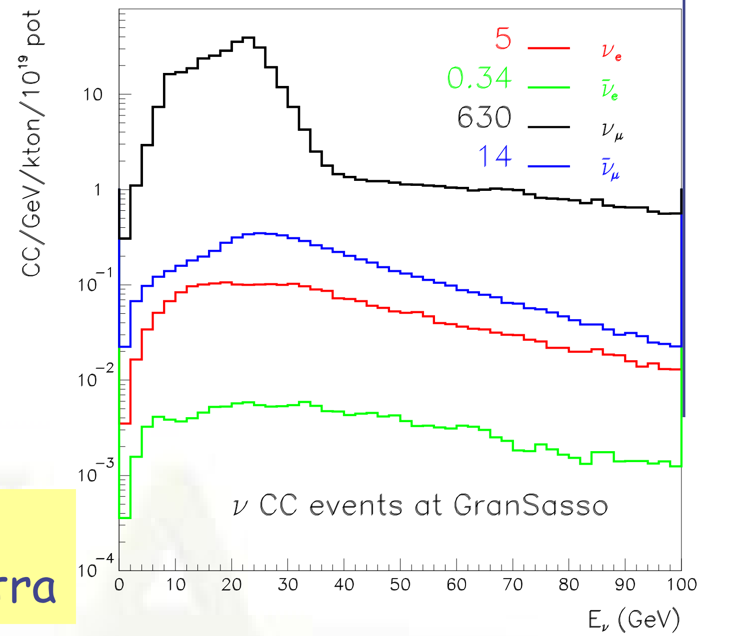


Applications – *CNGS*

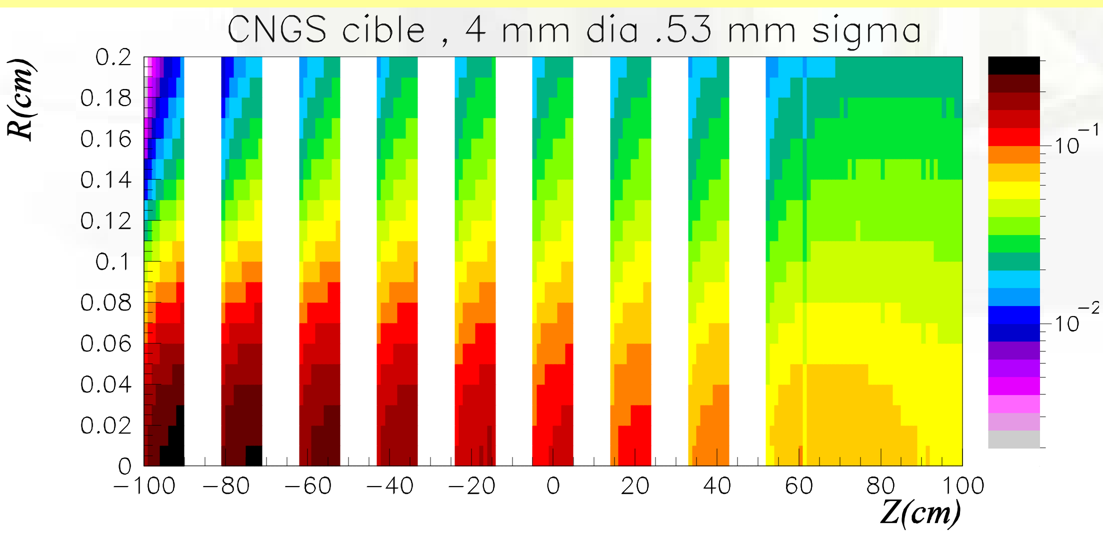


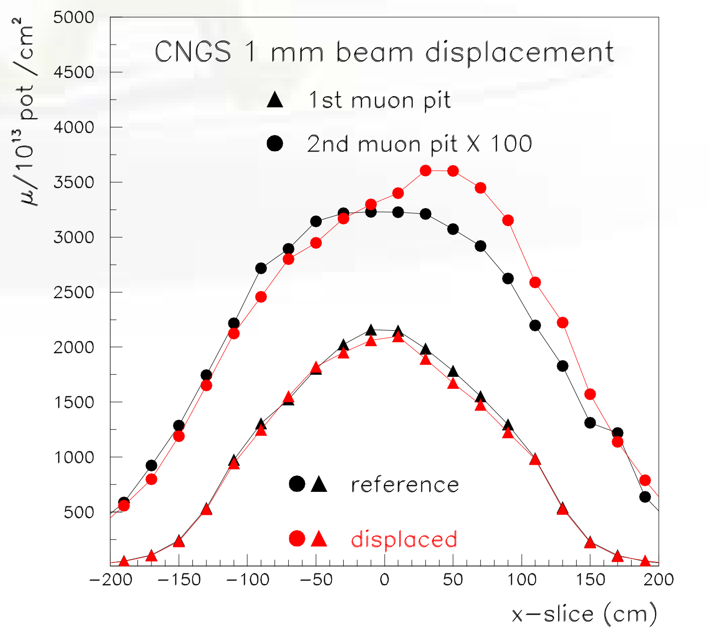
Cern Neutrino to Gran Sasso





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

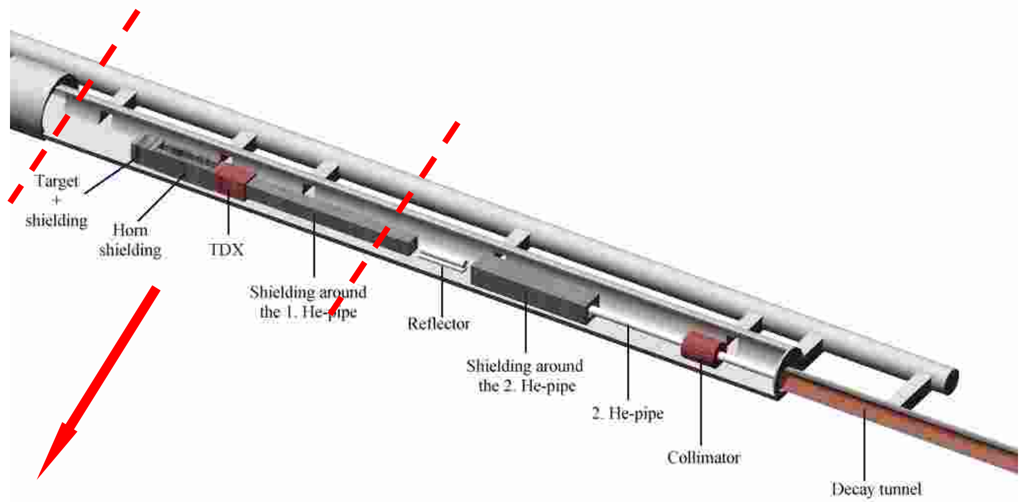




Muons in muon pits: horiz. distribution for beam alignment

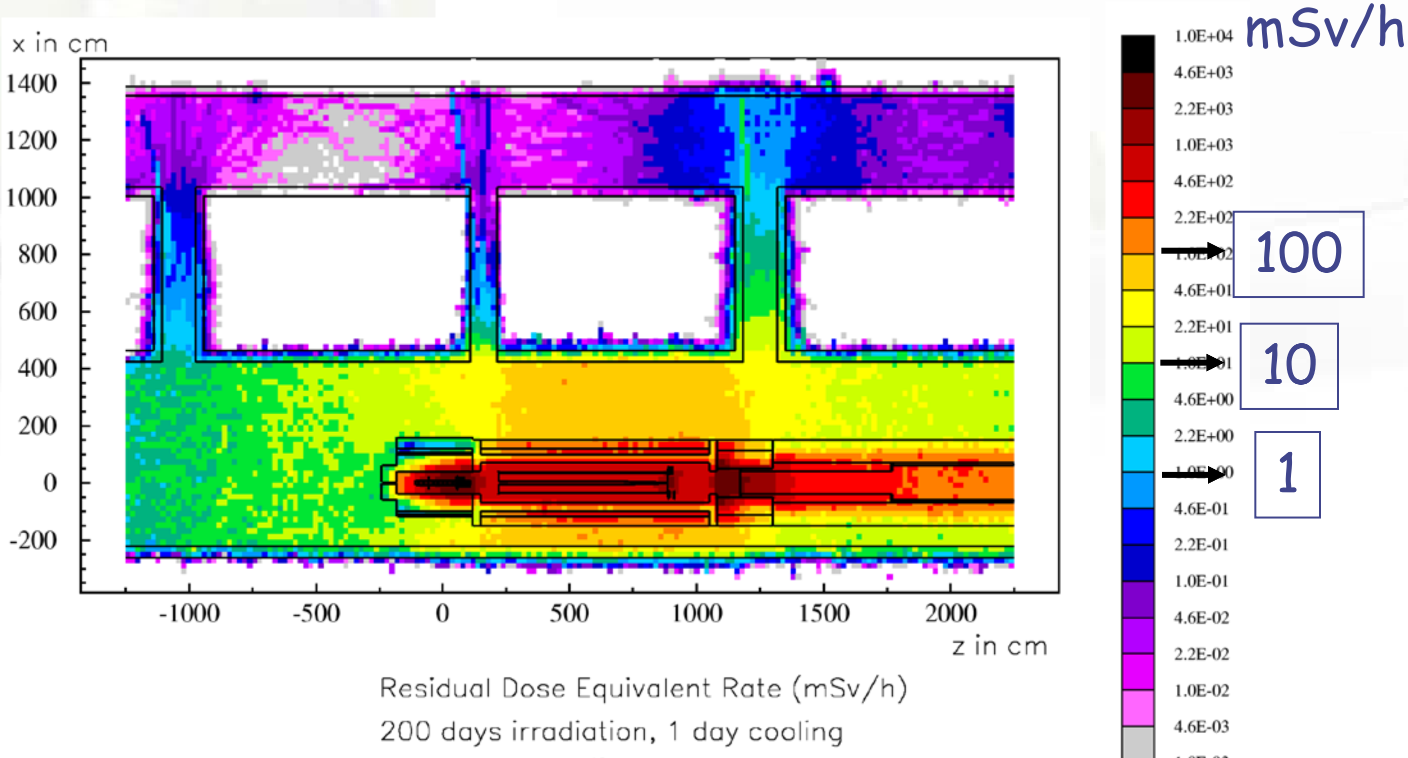
Energy deposition in CNGS target rods, $GeV/cm^3/pot$

Applications – *CNGS*



Example:

t_{cool} = 1 day



Residual Dose Equivalent Rate (mSv/h)

200 days irradiation, 1 day cooling

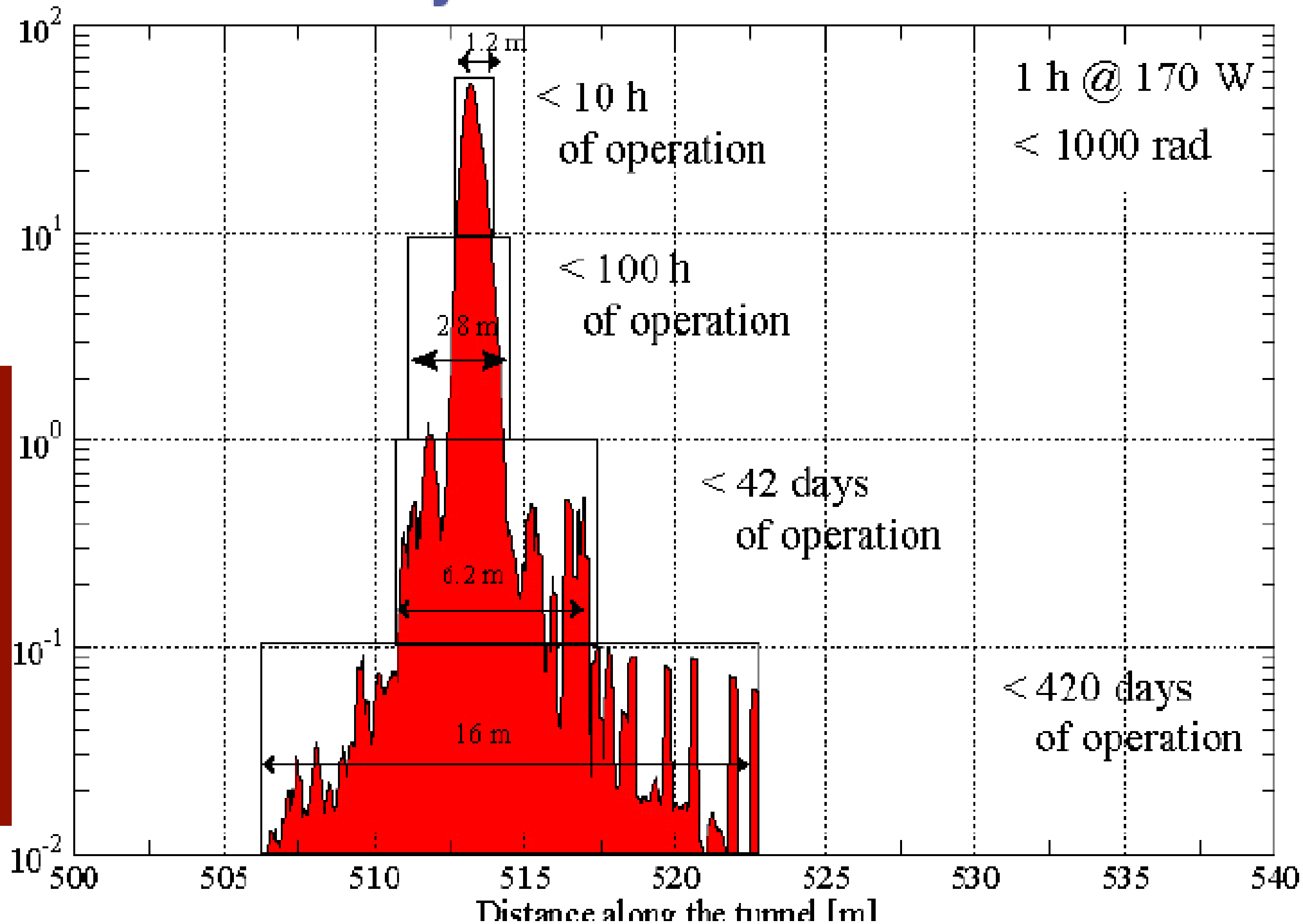
8×10^{12} protons/s

Damage to electronics

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

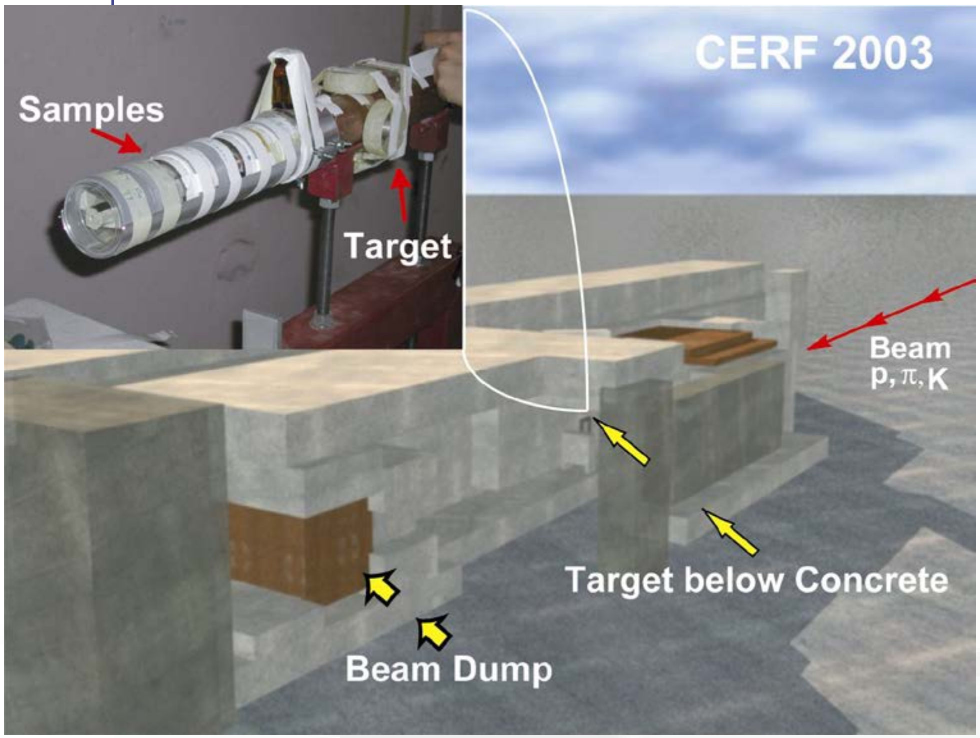
The lifetime of electronic components can be estimated as a function of the distance to major sources of radiation

1-MeV neutron equivalent fluence



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

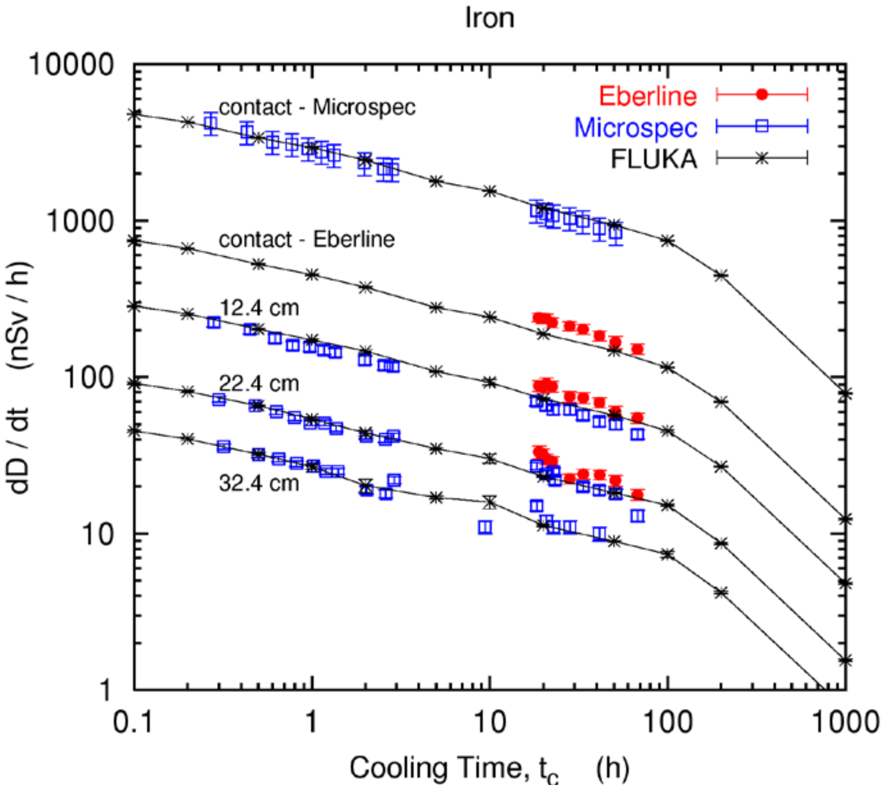
CERN-EU High-Energy Reference Field facility (CERF)



Thermo-Eberline dose-meter FHZ 672

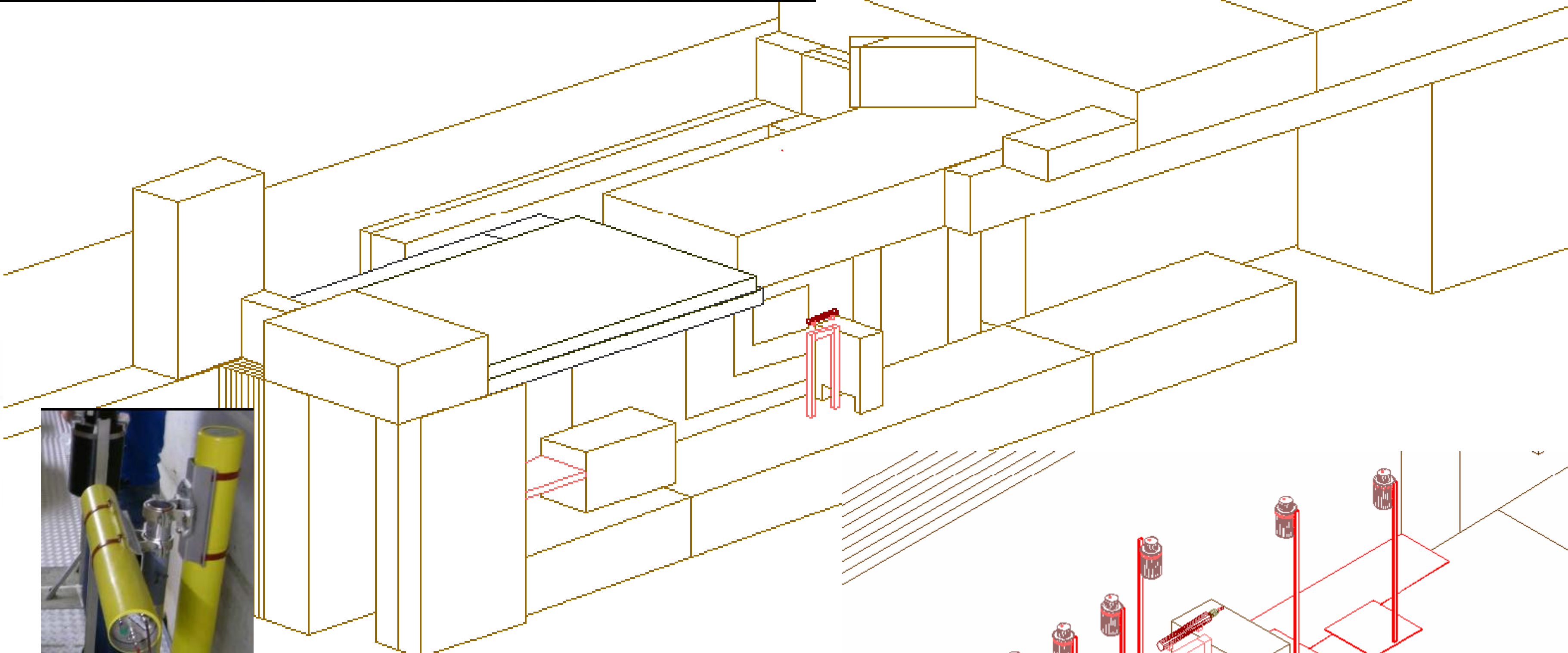
samples in contact with a 50 cm long, 7 cm diameter copper target, centred on the beam axis

Microspec

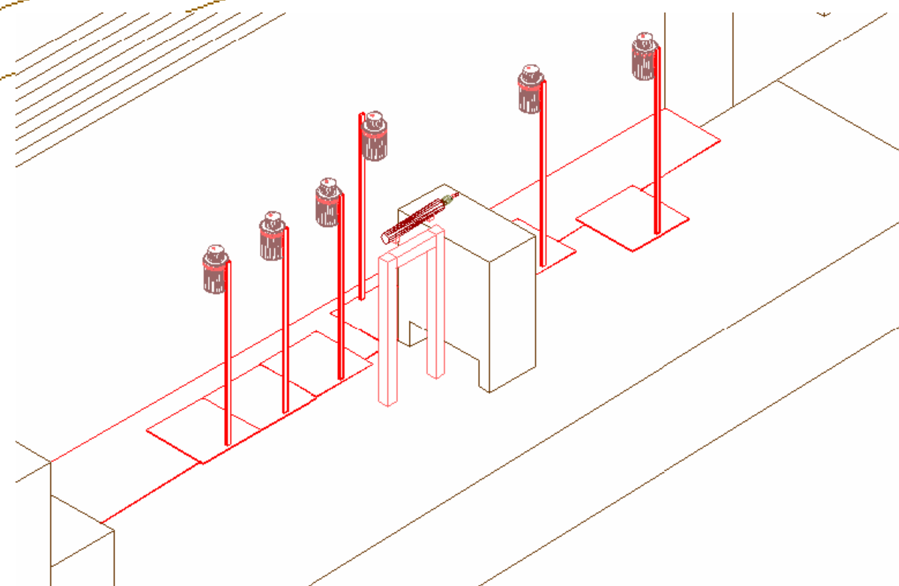


Test of instrumentation : Beam Loss Monitors at CERF

CERN-EN-NOTE-2010-002-STI

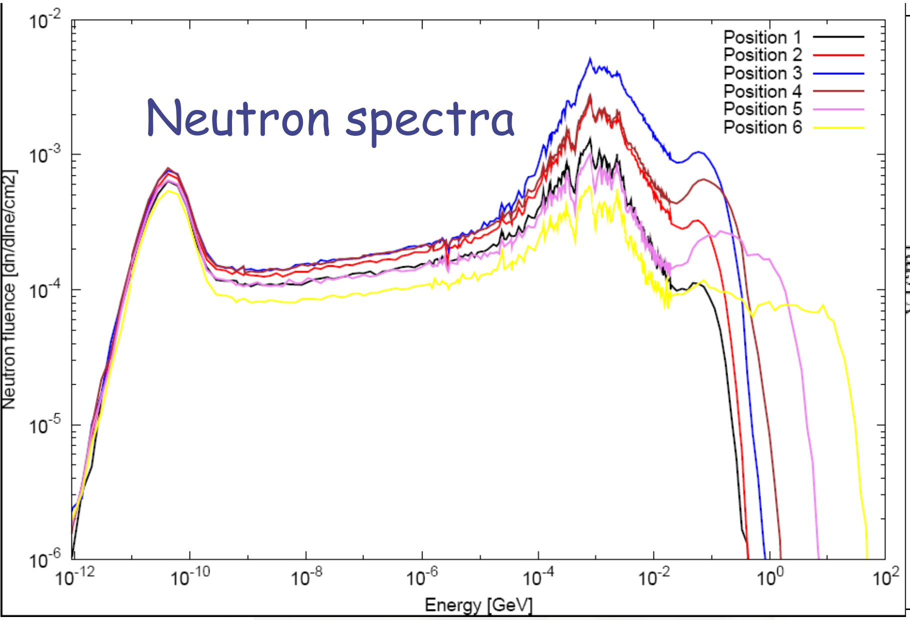


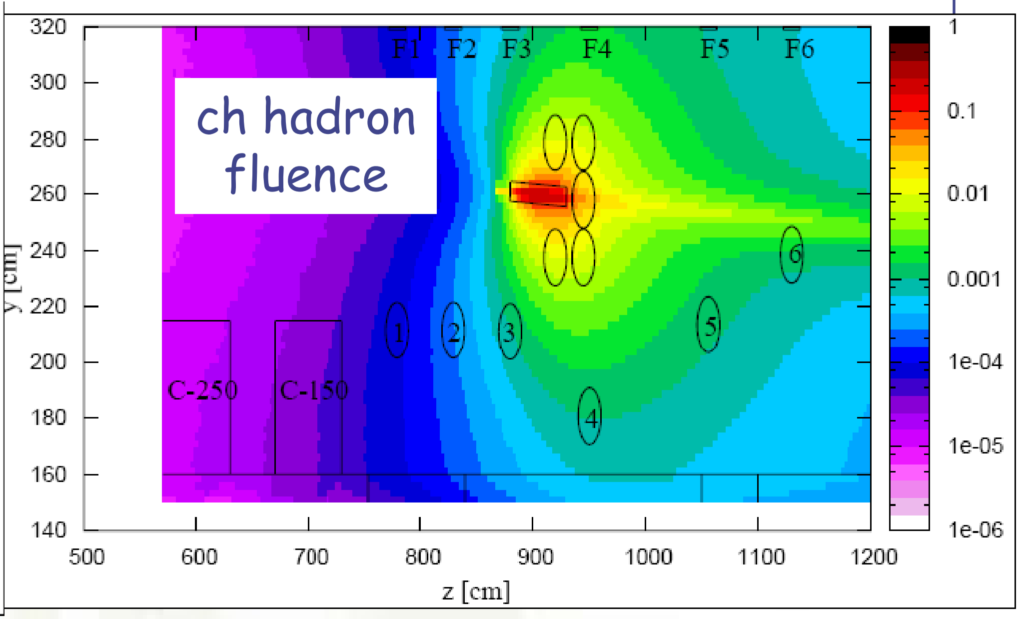
CERF setup

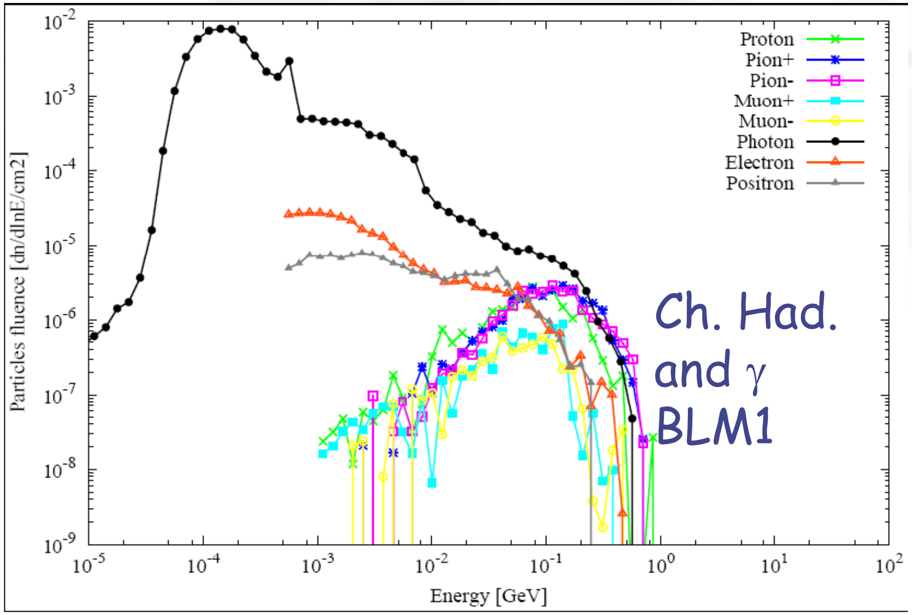


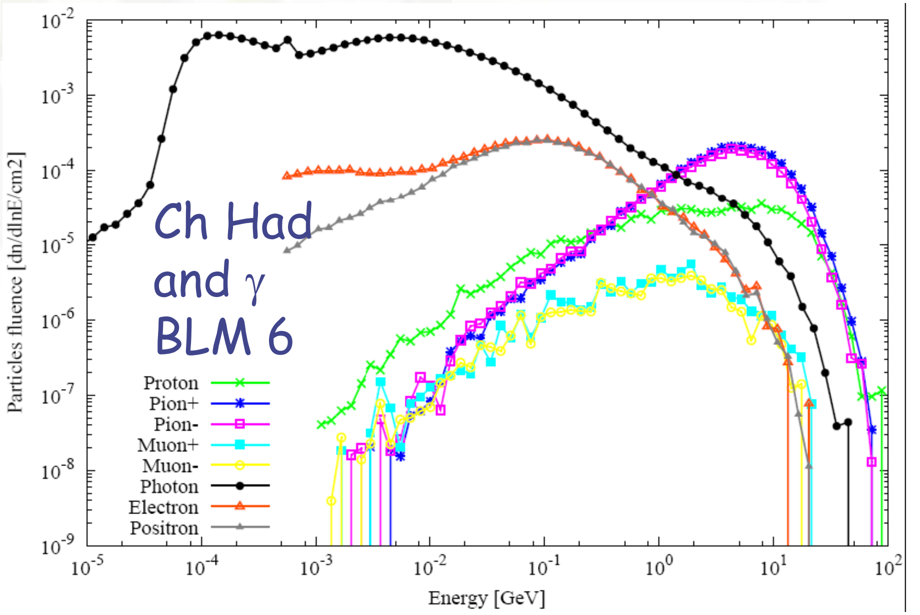
BLM's positions

CERF particle spectra

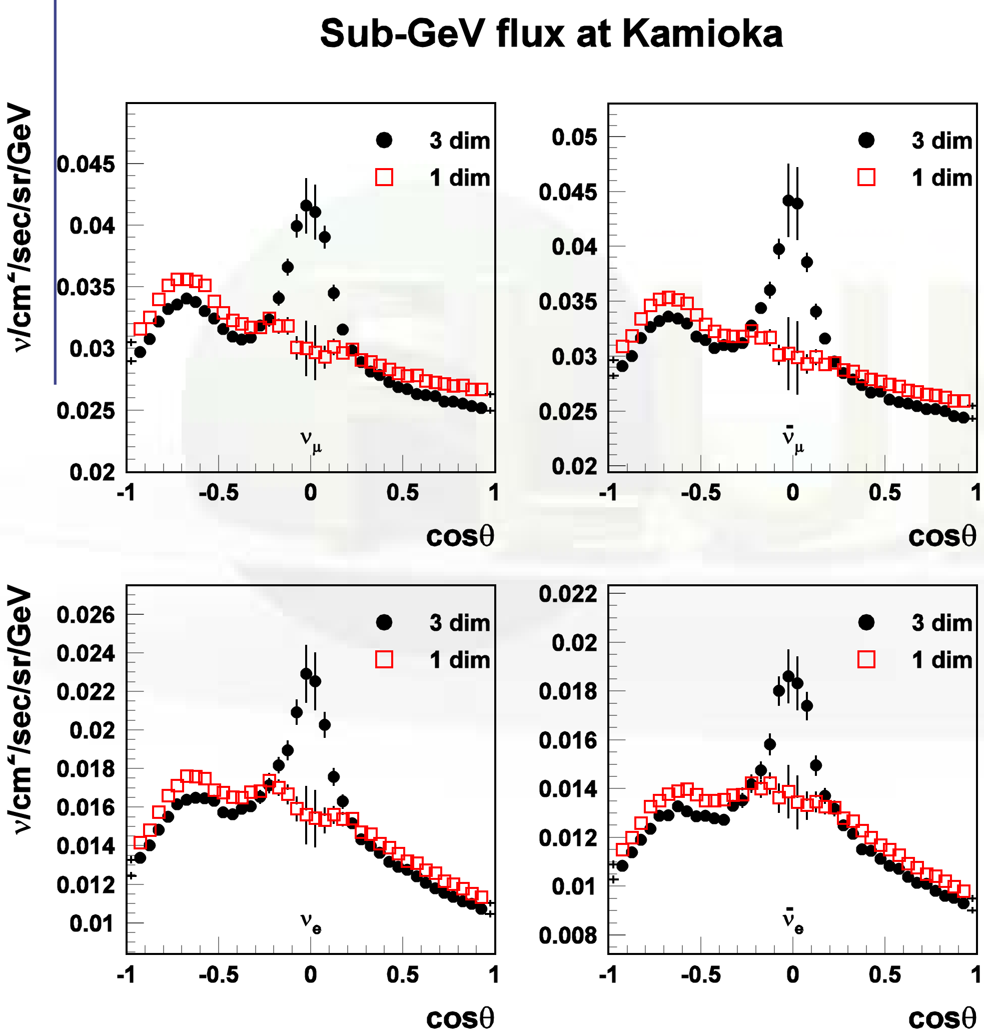








(3D) Calculation of Atmospheric ν Flux



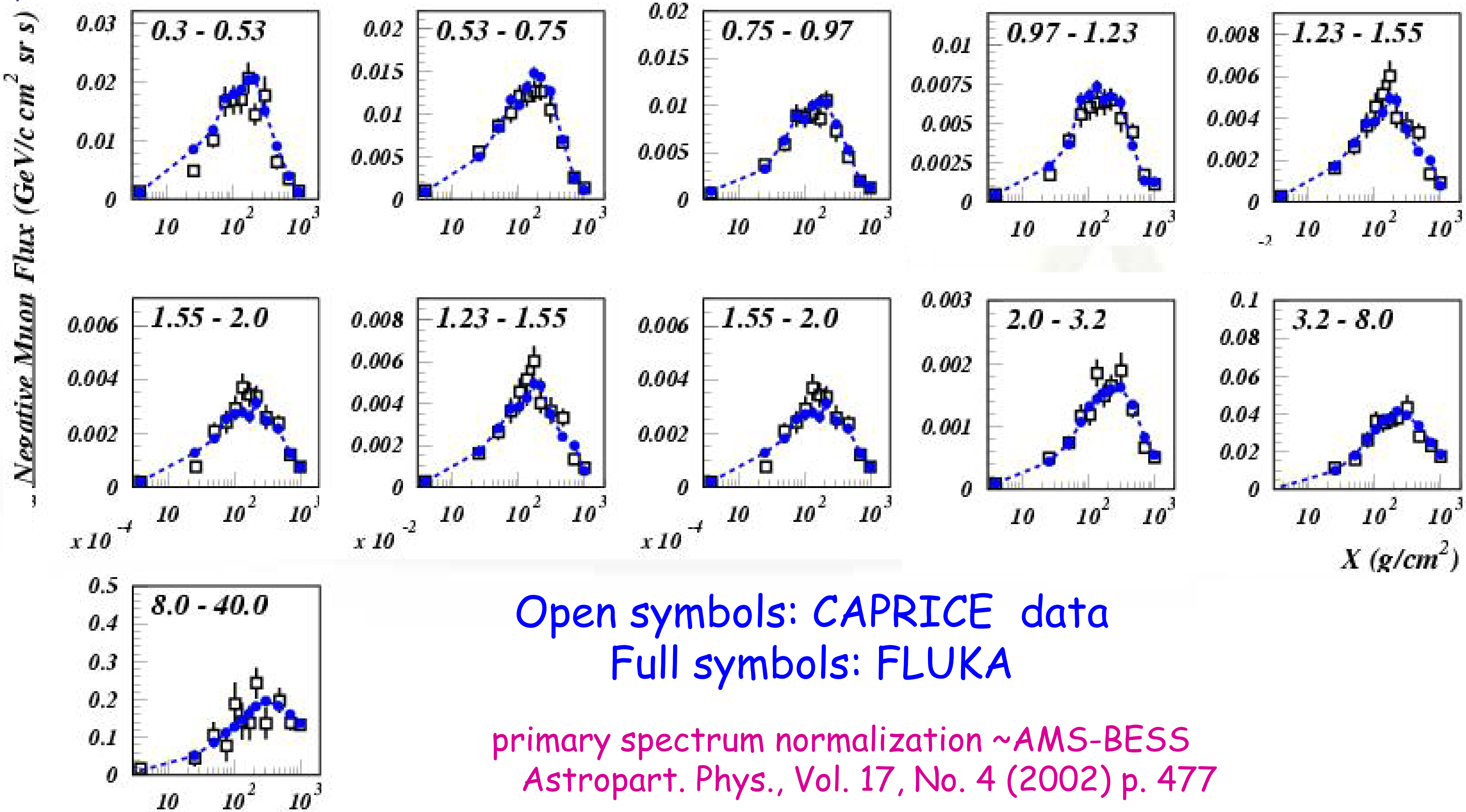
The first 3-D calculation of atmospheric neutrinos was done with FLUKA.

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

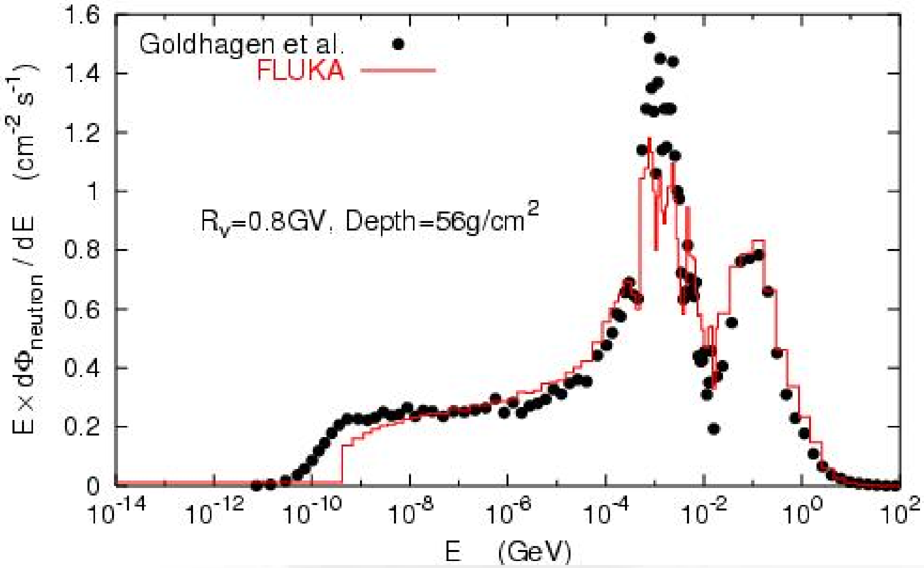
Negative muons at floating altitudes: CAPRICE94



Open symbols: CAPRICE data
Full symbols: FLUKA

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

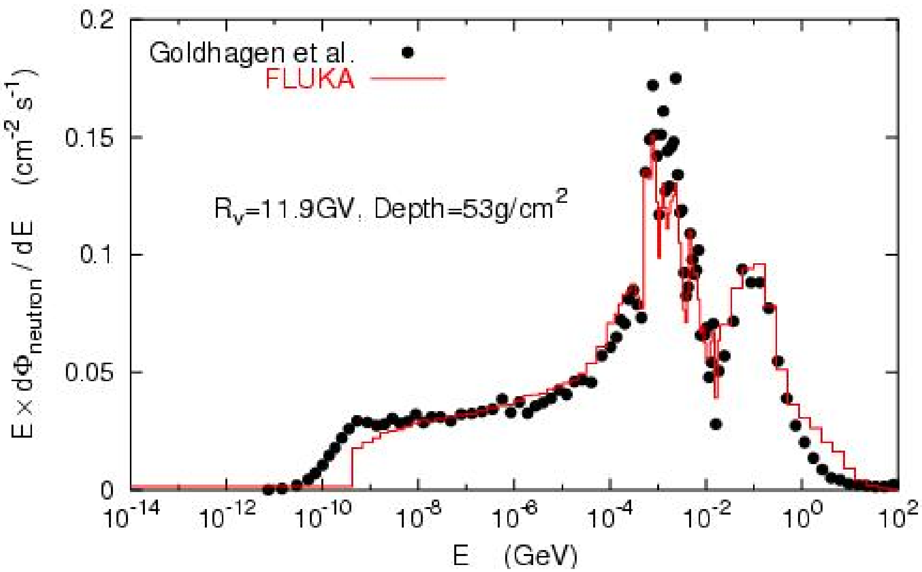
Neutrons on the ER-2 plane at 21 km altitude



Measurements:

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

Note one order of magnitude difference depending on latitude

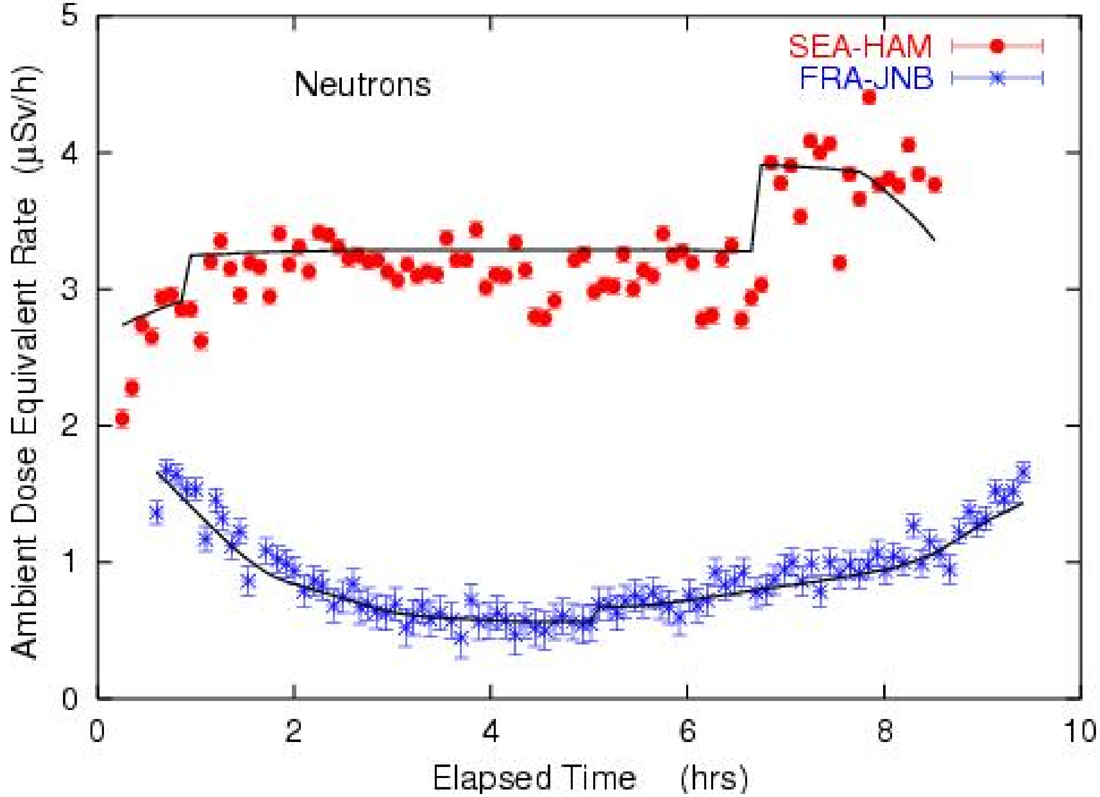


FLUKA calculations:

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

Dosimetry Applications

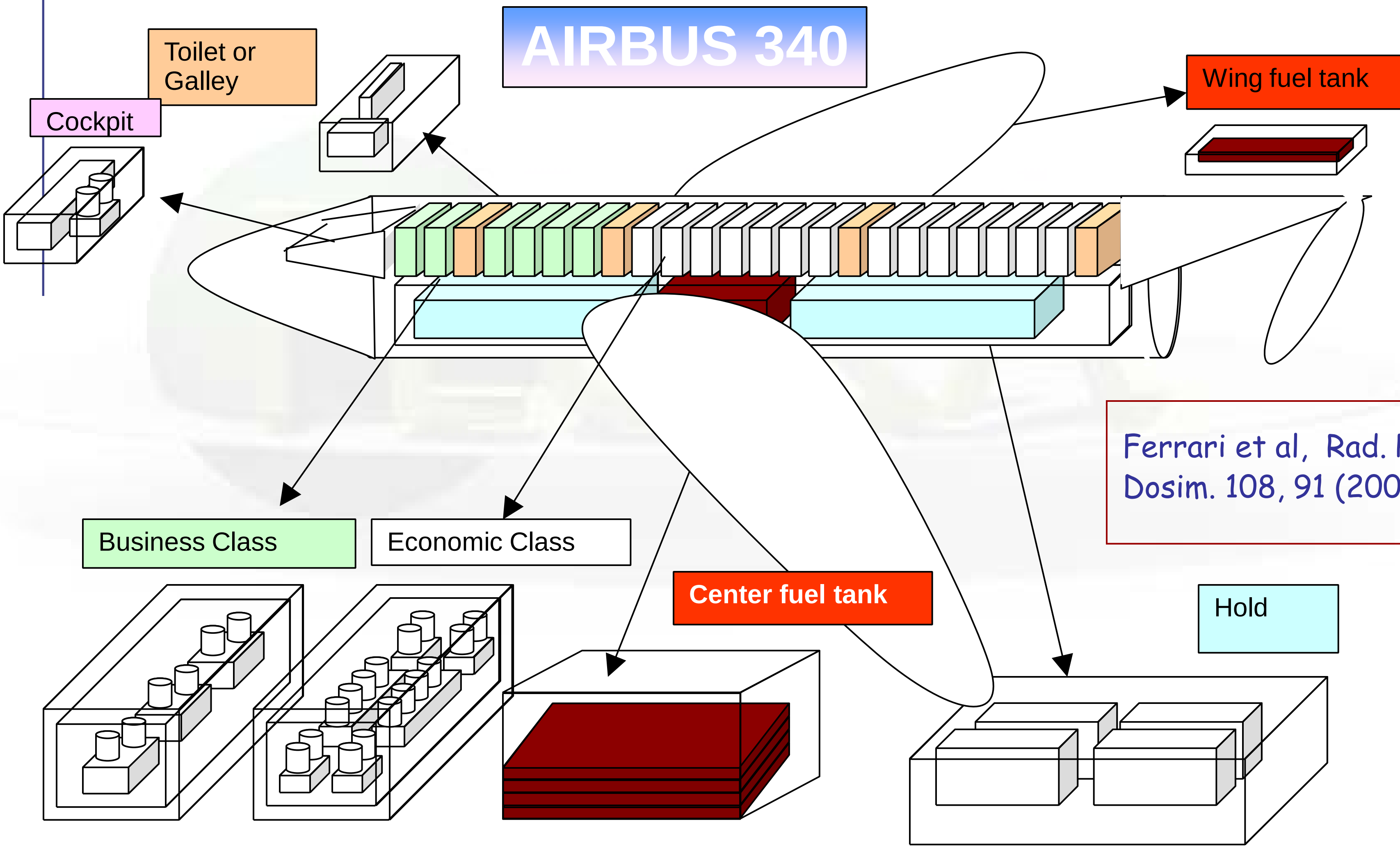
Roesler et al.,
Rad. Prot. Dosim.
98, 367 (2002)



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

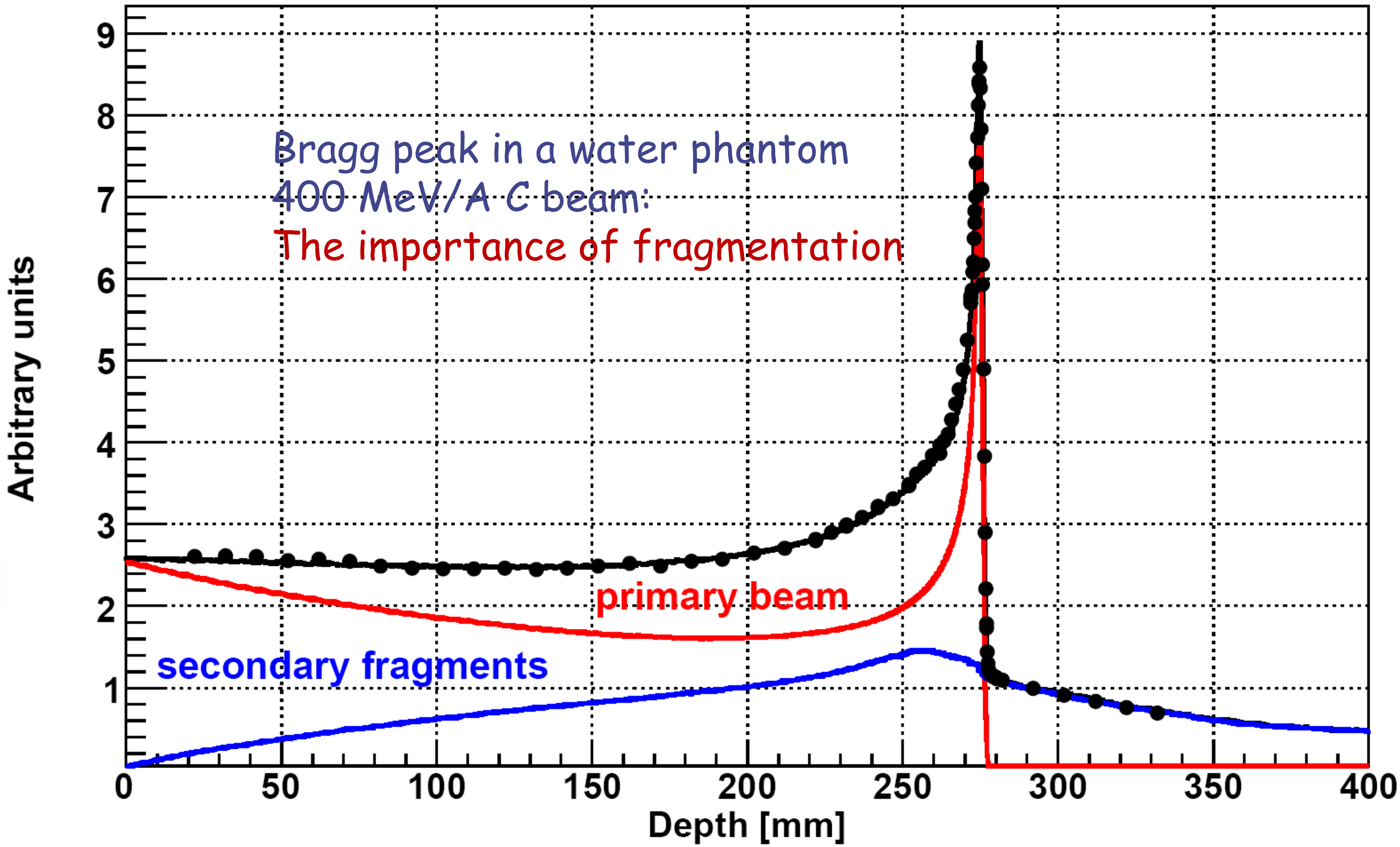
Solid lines: FLUKA simulation

Dosimetry applications: doses to aircrew and passengers



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

Carbon Ion Therapy

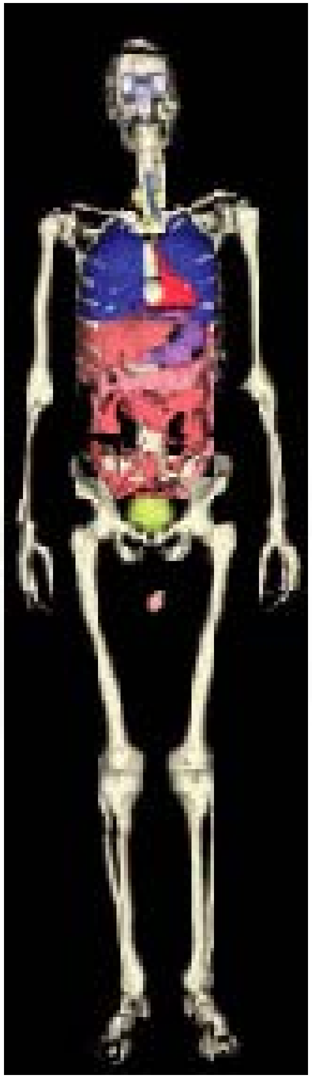


Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, Nuovo Cimento C, 31, 2008

Using the information from the patient CT in the MC

The Voxel Geometry

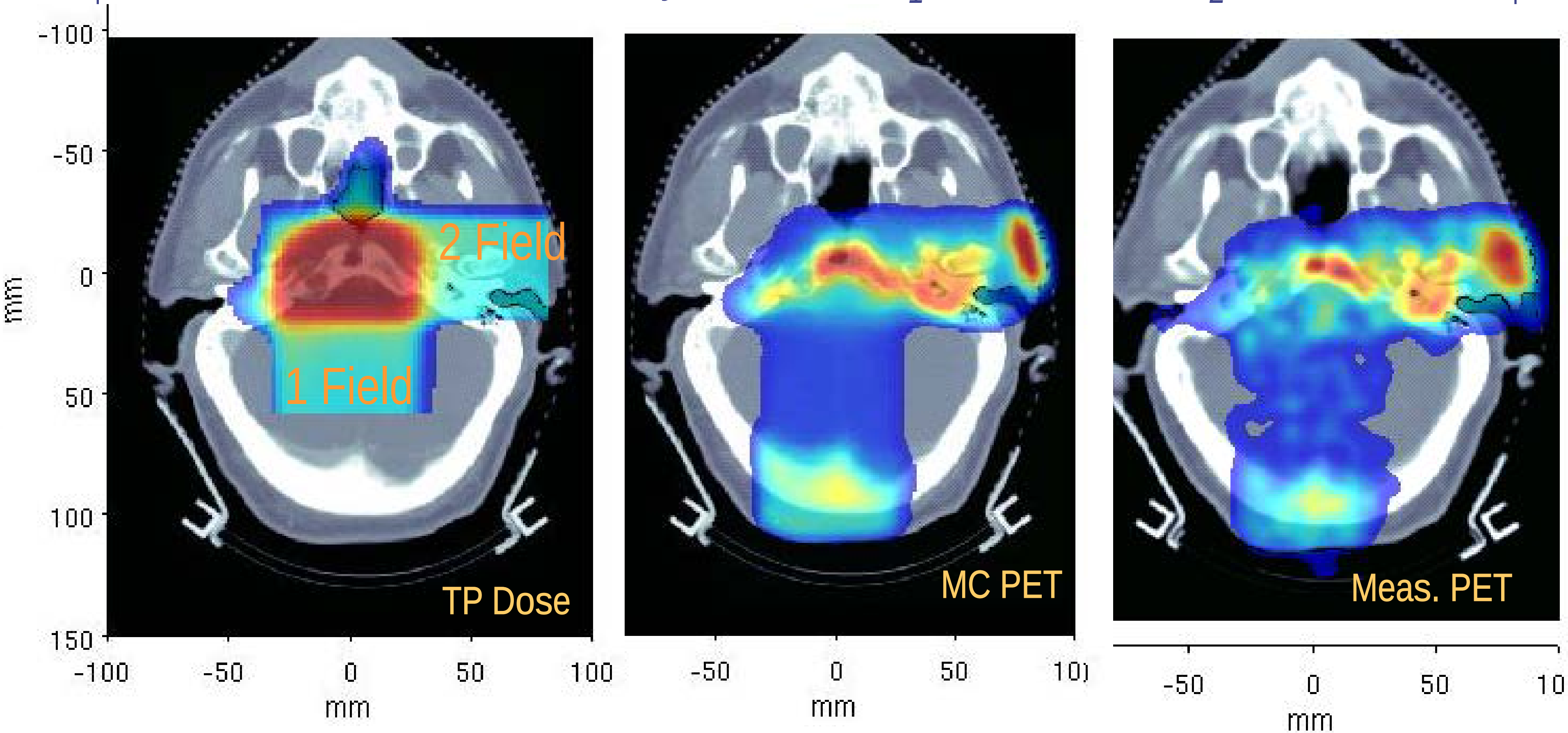
- FLUKA can embed voxel structures within its standard combinatorial geometry
- Transport through the voxels is optimized and efficient
- Raw CT-scan outputs can be imported



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

Proton therapy: dose and PET distributions from MC, Head

Clival Chordoma, 0.96 GyE / field, ΔT_1 ~ 26 min, ΔT_2 ~ 16 min



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