The FLUKA Code: a short introduction

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

FLUKA

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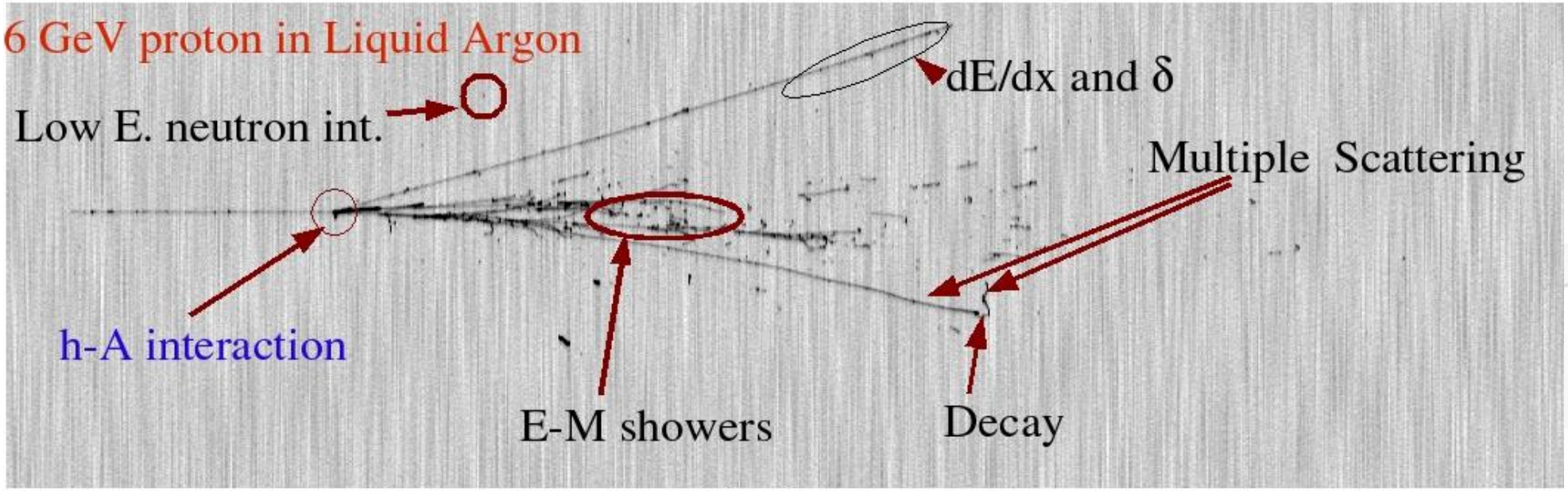

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http://www.fluka.org

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FLUKA short description:

- FLUKA is a general purpose tool for calculations of particle transport and interactions with matter
- All Hadrons (p, n, π, K,pbar, nbar, (anti)hyperons…) [0-10000 TeV]
- Electromagnetic (γ, $e^{+/-}$) and μ and ν [1 keV - 10000 TeV]
- Nucleus-nucleus [0-10000 TeV/n]
- Low energy neutrons (0-20 MeV, multigroup, ENDF…)
- Transport in magnetic field
- Combinatorial (boolean) and Voxel geometries
- Double capability to run either fully analogue and/or biased calculations
- On-line evolution of induced radioactivity and dose
- Radiation damage predictions (NIEL, DPA)
- User-friendly GUI interface thanks to the Flair interface

http://www.fluka.org

Particles transported by FLUKA:

FLUKA name	FLUKA number	Symbol	Common name	Standard PDG number (Particle Data Group) [142]
4-HELIUM (1)	-6	α	Alpha	—
3-HELIUM (1)	-5	^{3}He	Helium 3	—
TRITON (1)	-4	^{3}H	Triton	—
DEUTERON (1)	-3	^{2}H	Deuteron	—
HEAVYION (1)	-2	—	Generic Heavy Ion with Z > 2 (see command HI-PROPE)	—
OPTIPHOT	-1	—	Optical Photon	—
RAY (2)	0	—	Pseudoparticle	—
PROTON	1	p	Proton	2212
APROTON	2	$\bar{p}$	Antiproton	-2212
ELECTRON	3	e^-	Electron	11
POSITRON	4	e^+	Positron	-11
NEUTRIE	5	ν_e	Electron Neutrino	12
ANEUTRIE	6	$\bar{\nu}_e$	Electron Antineutrino	-12
PHOTON	7	γ	Photon	22
NEUTRON	8	n	Neutron	2112
ANEUTRON	9	$\bar{n}$	Antineutron	-2112
MUON+	10	μ^+	Positive Muon	-13
MUON-	11	μ^-	Negative Muon	13
KAONLONG	12	K^0_L	Kaon-zero long	130
PION+	13	π^+	Positive Pion	211
PION-	14	π^-	Negative Pion	-211
KAON+	15	K^+	Positive Kaon	321
KAON-	16	K^-	Negative Kaon	-321
LAMBDA	17	Λ	Lambda	3122
ALAMBDA	18	$\bar{\Lambda}$	Antilambda	-3122
KAONSHRT	19	K^0_S	Kaon-zero short	310
SIGMA-	20	Σ^-	Negative Sigma	3112
SIGMA+	21	Σ^+	Positive Sigma	3222
SIGMAZER	22	Σ^0	Sigma-zero	3212
PIZERO	23	π^0	Pion-zero	111
KAONZERO	24	K^0	Kaon-zero	311
AKAONZER	25	$\bar{K}^0$	Antikaon-zero	-311
Reserved	26	—	—	—
NEUTRIM	27	ν_μ	Muon Neutrino	14
ANEUTRIM	28	$\bar{\nu}_\mu$	Muon Antineutrino	-14
Blank	29	—	—	—

table continues

FLUKA name	FLUKA number	Symbol	Common name	Standard PDG (Particle Data
Reserved	30	—	—	—
ASIGMA-	31	$\bar{\Sigma}^-$	Antisigma-minus	-3222
ASIGMAZE	32	$\bar{\Sigma}^0$	Antisigma-zero	-3212
ASIGMA+	33	$\bar{\Sigma}^+$	Antisigma-plus	-3112
XSIZERO	34	Ξ^0	Xi-zero	3322
AXSIZERO	35	$\bar{\Xi}^0$	Antixi-zero	-3322
XSI-	36	Ξ^-	Negative Xi	3312
AXSI+	37	$\bar{\Xi}^+$	Positive Xi	-3312
OMEGA-	38	Ω^-	Omega-minus	3334
AOMEGA+	39	$\bar{\Omega}^+$	Antiomega	-3334
Reserved	40	—	—	—
TAU+	41	τ^+	Positive Tau	-15
TAU-	42	τ^-	Negative Tau	15
NEUTRIT	43	ν_τ	Tau Neutrino	16
ANEUTRIT	44	$\bar{\nu}_\tau$	Tau Antineutrino	-16
D+	45	D^+	D-plus	411
D-	46	D^-	D-minus	-411
D0	47	D^0	D-zero	421
D0BAR	48	$\bar{D}^0$	AntiD-zero	-421
DS+	49	D^+_s	D_s-plus	431
DS-	50	D^-_s	D_s-minus	-431
LAMBDAC+	51	Λ^+_c	Lambda$_c$-plus	4122
XSIC+	52	Ξ^+_c	Xi$_c$-plus	4232
XSIC0	53	Ξ^0_c	Xi$_c$-zero	4132
XSIPC+	54	Ξ'^+_c	Xi$'_c$-plus	4322
XSIPC0	55	Ξ'^0_c	Xi$'_c$-zero	4312
OMEGAC0	56	Ω^0_c	Omega$_c$-zero	4332
ALAMBDC-	57	$\bar{\Lambda}^-_c$	Antilambda$_c$-minus	-4122
AXSIC-	58	$\bar{\Xi}^-_c$	AntiXi$_c$-minus	-4232
AXSIC0	59	$\bar{\Xi}^0_c$	AntiXi$_c$-zero	-4132
AXSIPC-	60	$\bar{\Xi}'^-_c$	AntiXi$'_c$-minus	-4322
AXSIPC0	61	$\bar{\Xi}'^0_c$	AntiXi$'_c$-zero	-4312
AOMEGAC0	62	$\bar{\Omega}^0_c$	AntiOmega$_c$-zero	-4332
Reserved	63	—	—	—
Reserved	64	—	—	—

The FLUKA Code design

- Based, as far as possible, on original and well-tested microscopic models
- Full cross-talk between all components: hadronic, electromagnetic, neutrons, muons, heavy ions
- It is a "condensed history" MC code, however with the possibility to use single instead of multiple scattering

FLUKA is NOT a toolkit! Its physical models are fully integrated

- **The user does not need to choose a "physics list"**
- **The user has, however, the possibility to optimize CPU vs accuracy when needed**

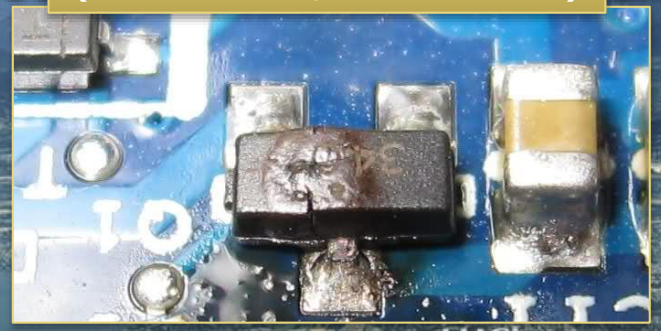
- Fluka provides powerful built-in scoring, well tested and suited for most applications
  - **The user does not need to write external code to get results and statistics**

What can be done with FLUKA?

Some examples

Cern & Fluka (~90 orldwide, http://www.fluka.org)

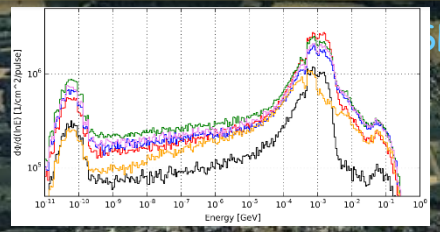
Radiation damage (electronics, insulations)



Shielding, residual dose rates

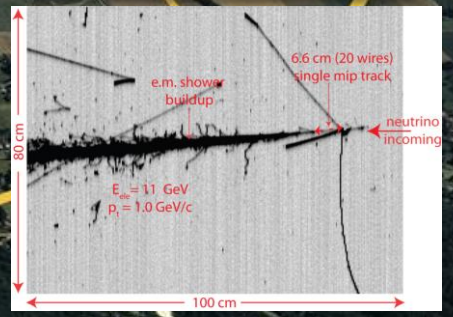
Activation, Waste disposal

Spallation sources (n_ToF), secondary beams (ν!!)



Energy deposition (quenching, damage)

(ν) Experiments



LHCb
ATLAS
SUISSE
FRANCE
SPS 7 km
ALICE
SPS: 450 GeV p
LHC 27 km

Dosimetry + cosmic rays

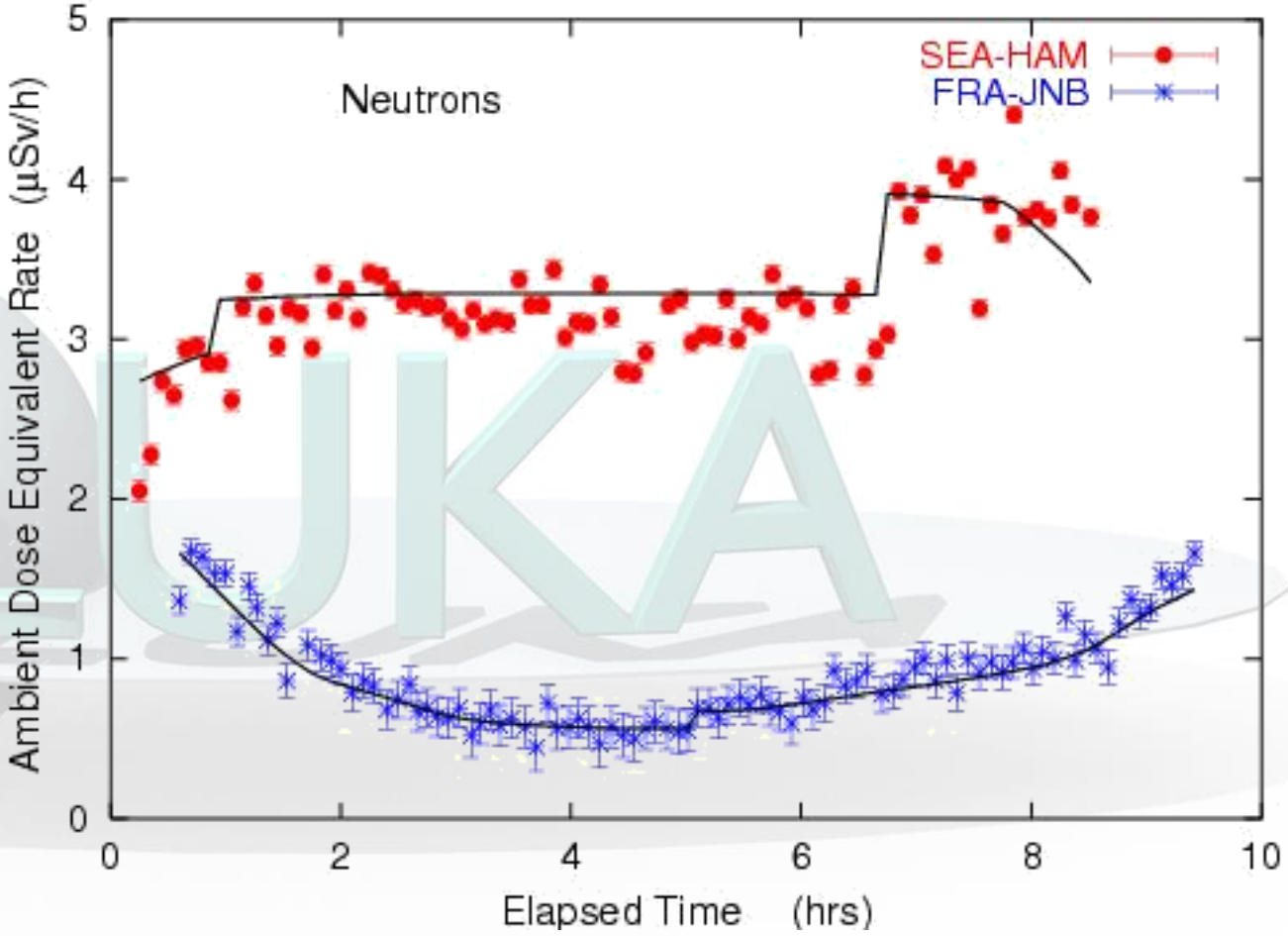
Complete simulation of cosmic rays interactions in the atmosphere

- Dedicated "cosmic" package available to users

Model of airplane geometry

Response of dosimeters

Dose to aircrew on commercial flights , depending on route



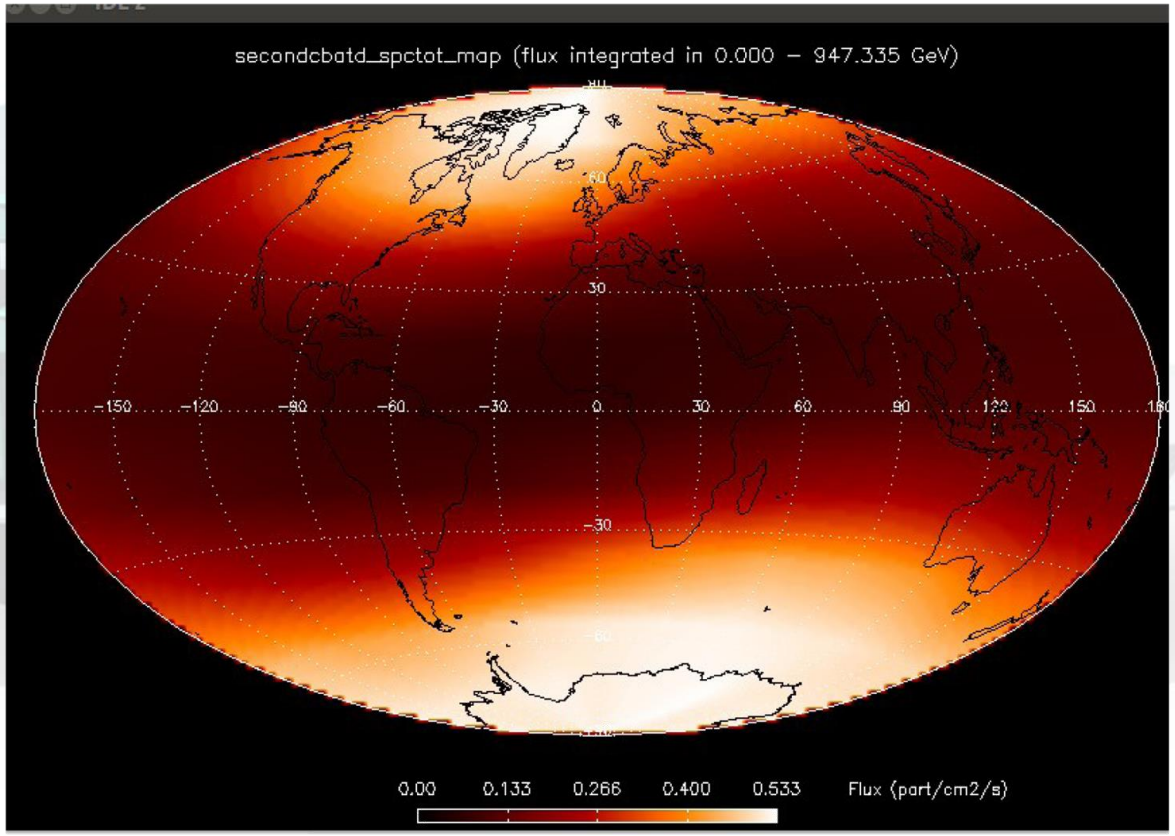
Ambient dose equivalent from neutrons at solar maximum on commercial flights from Seattle to Hamburg and from Frankfurt to Johannesburg.

Solid lines: FLUKA simulation

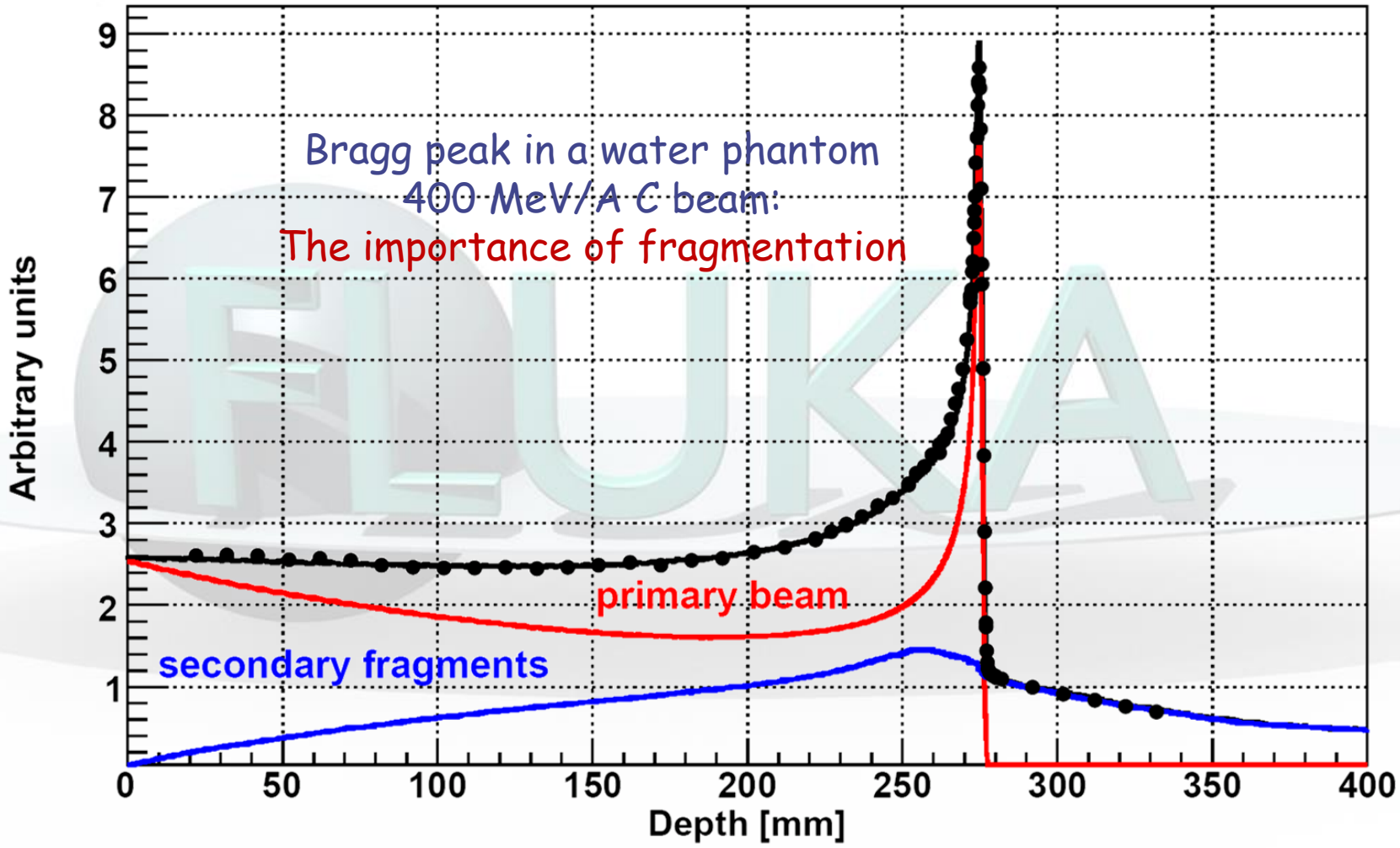
Roesler et al., Rad. Prot. Dosim. 98, 367 (2002)

The neutron albedo from GCR's at 400 km altitude*

*In collaboration with CEA-Saclay



Medical physics : Radiotherapy



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

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.

Possible problems

- 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!
- FLUKA is written in fortran. No knowledge of fortran or other languages is needed in this course, however some of the terminology used might be derived from fortran. If this happens and gives problems, please ask!
- FLUKA runs in a Linux environment. A basic knowledge of most common Linux commands is required, as well as the capability to use a text editor (emacs, vi, gedit..). If some of you has troubles with this, please tell us

Agenda

Monday, 28 May 2018	
09:00	Course start
09:20	Introduction to FLUKA
10:00	Statistics and sampling
11:00	Coffe break
11:30	Exercise 1 - Running
12:30	Lunch break
14:00	FLUKA manual and basic input
15:00	Flair
16:00	Coffee break
16:30	Exercise 2 - Compound materials

Tuesday, 29 May 2018	
09:00	Geometry
10:30	Coffee break
11:00	Exercise 3 - Geometry
12:30	Lunch break
14:00	Physics models - Hadronic interactions
15:00	Scoring
16:00	Coffee break
16:30	Exercise 4 - Scoring
17:30	Handling of errors and crashes

Wednesday, 30 May 2018	
08:30	Low-energy neutrons
10:00	Coffe break
10:30	Exercise 5 - Low-energy neutrons
12:00	Lunch break
13:30	Biasing
14:30	Exercise 6 - Biasing
15:30	Coffee break
16:00	Geometry II
17:00	Physics models II - EM interactions

Thursday, 31 May 2018	
08:30	Ionization and transport
09:15	Exercise 7 - Cutoffs
10:15	Coffee break
10:45	Physics models III - Heavy ions
11:45	Lunch break
13:00	Exercise 8 - Heavy ions
14:00	Coffee break
14:30	Medical applications
15:30	Tour of iThemba labs
18:30	Dinner

Friday, 1 June 2018	
09:00	Radioactivity
10:00	Exercise 9 - Activation
11:00	Coffee break
11:30	Advanced topics
12:30	Closing
12:50	Lunch break

A glimpse of FLUKA

The FLUKA version

FLUKA20xx.n(y)(.m)

Major version

Minor version

Patch level

Respin

In this course we are using FLUKA2011.2x

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 possible, by explicit signing of license, to download the **source** for researchers of scientific/academic Institutions.
  - FLUKA can neither be copied into other codes (not even partially), nor translated into another language without permission
- For **commercial use**, trial version (limited in time and random seeds) available. Commercial license to be negotiated with CERN & INFN.

Please register on www.fluka.org .....and read the license!

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

Using FLUKA

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

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

The course team

- Teachers, please introduce yourself

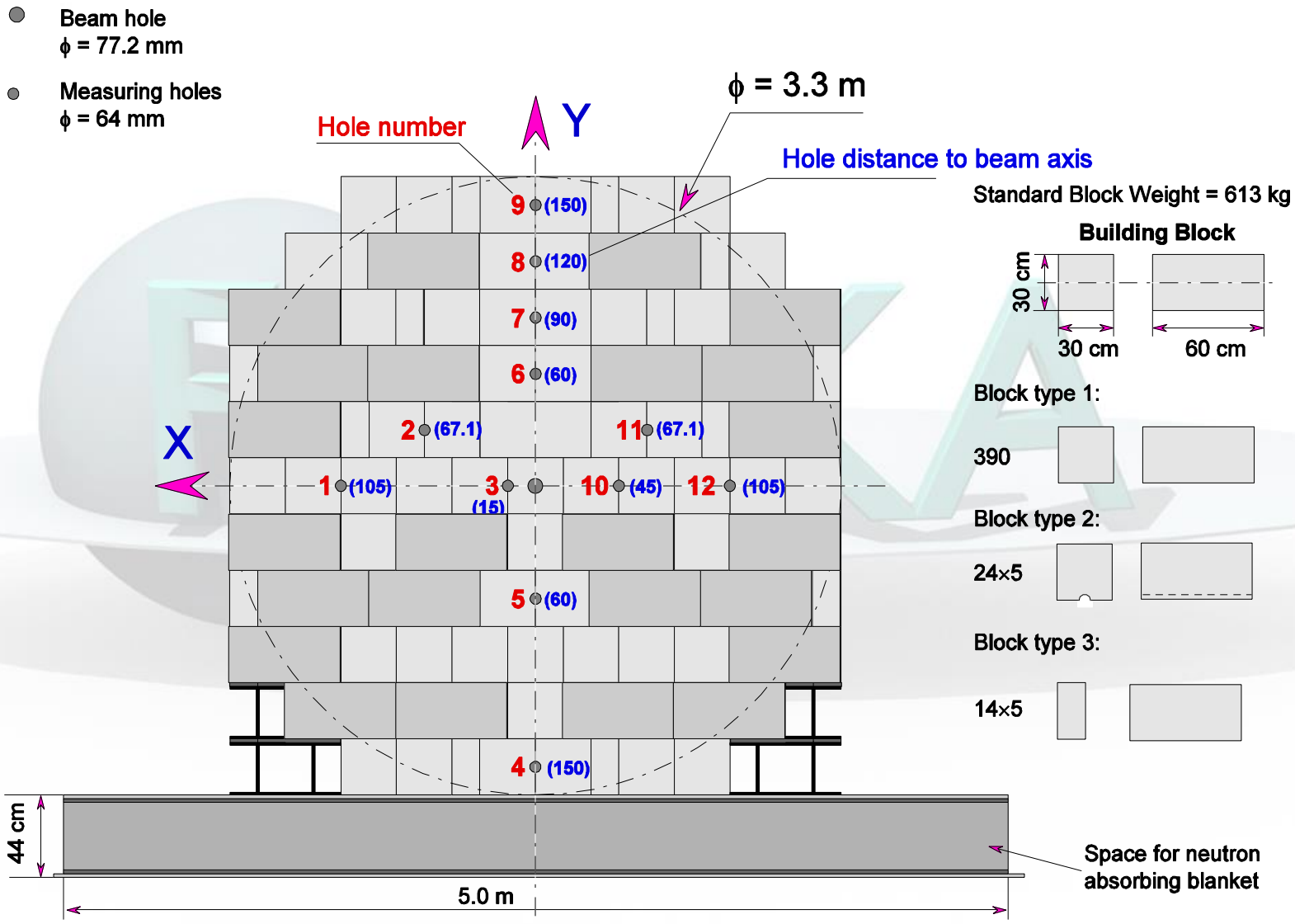
The students

- Students, please introduce yourself, with a word on your application field

Thanks for your attention!

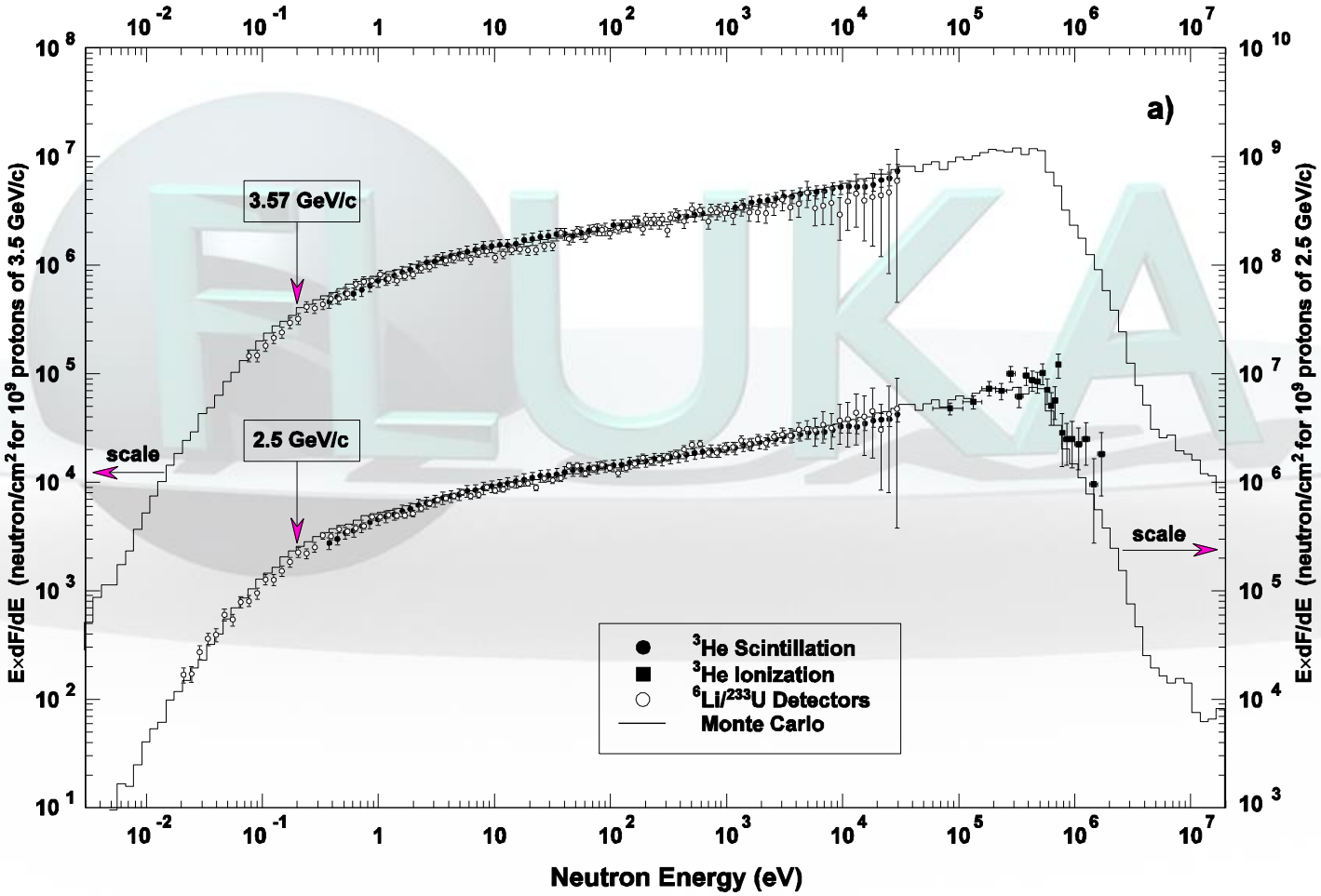
Examples of FLUKA Applications

The TARC experiment at CERN:



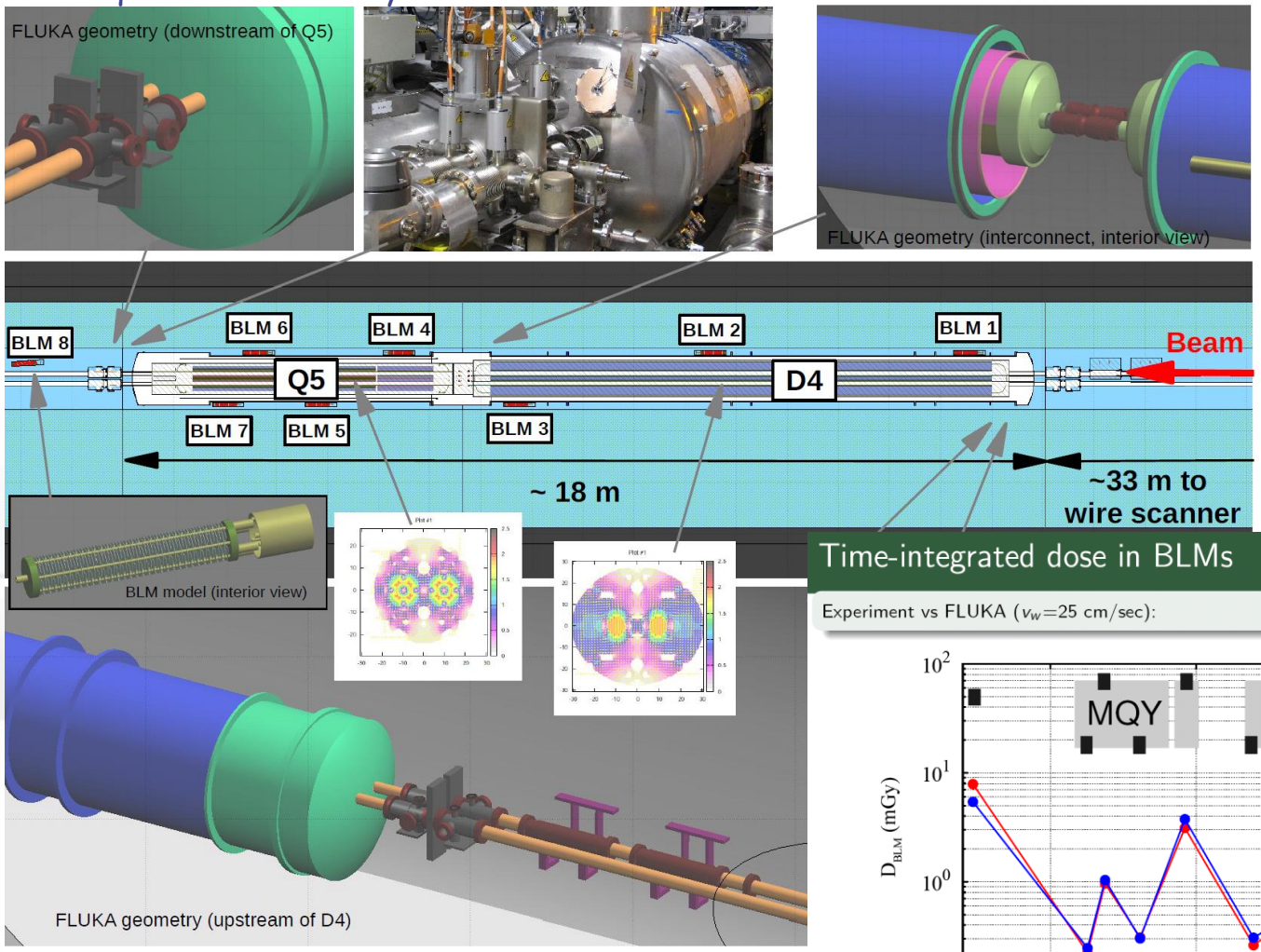
The TARC experiment: neutron spectra

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



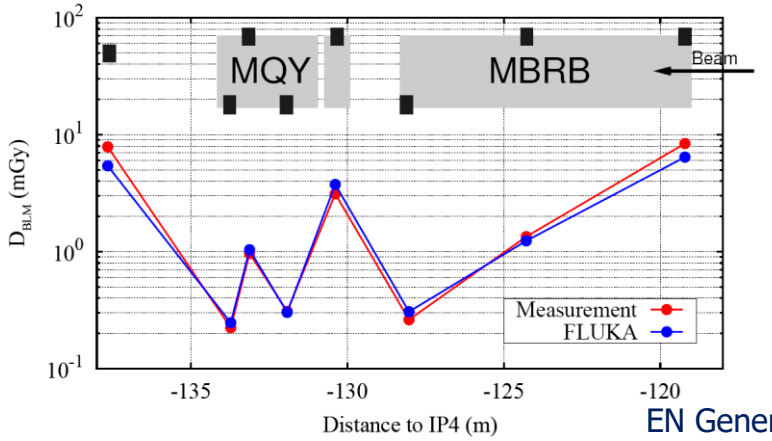
Application & Benchmarking – *LHC operation*

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



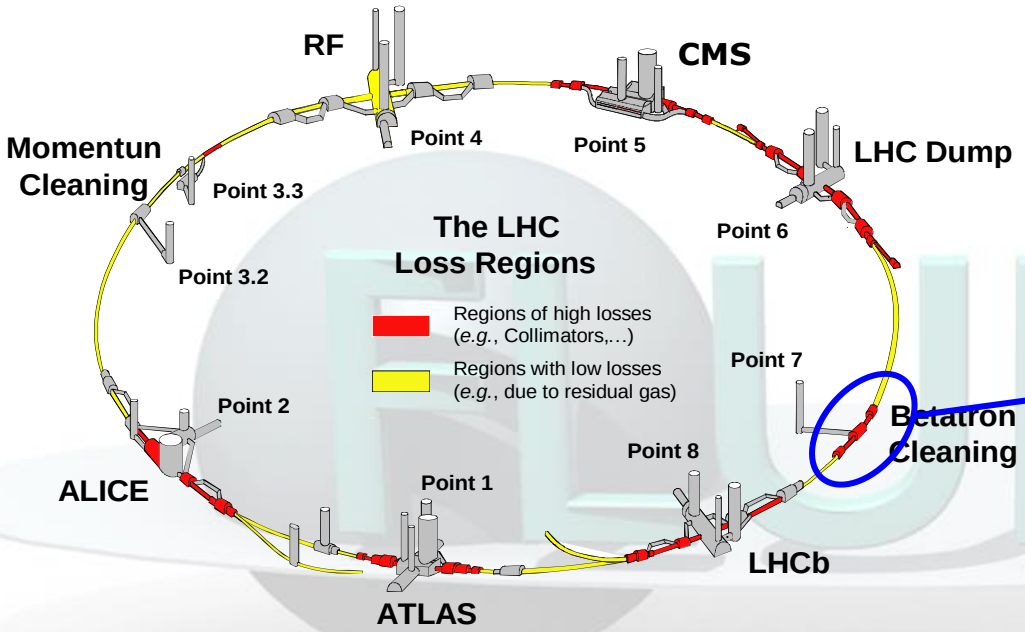
Time-integrated dose in BLMs

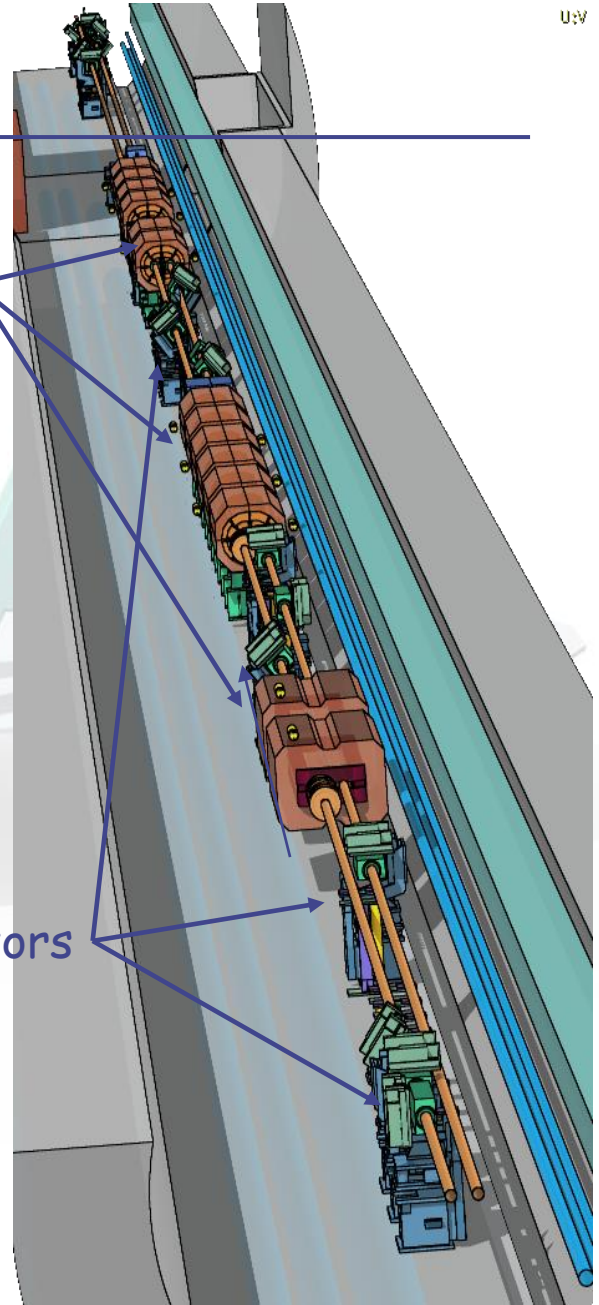
Experiment vs FLUKA (v_w=25 cm/sec):



Absolute comparison!

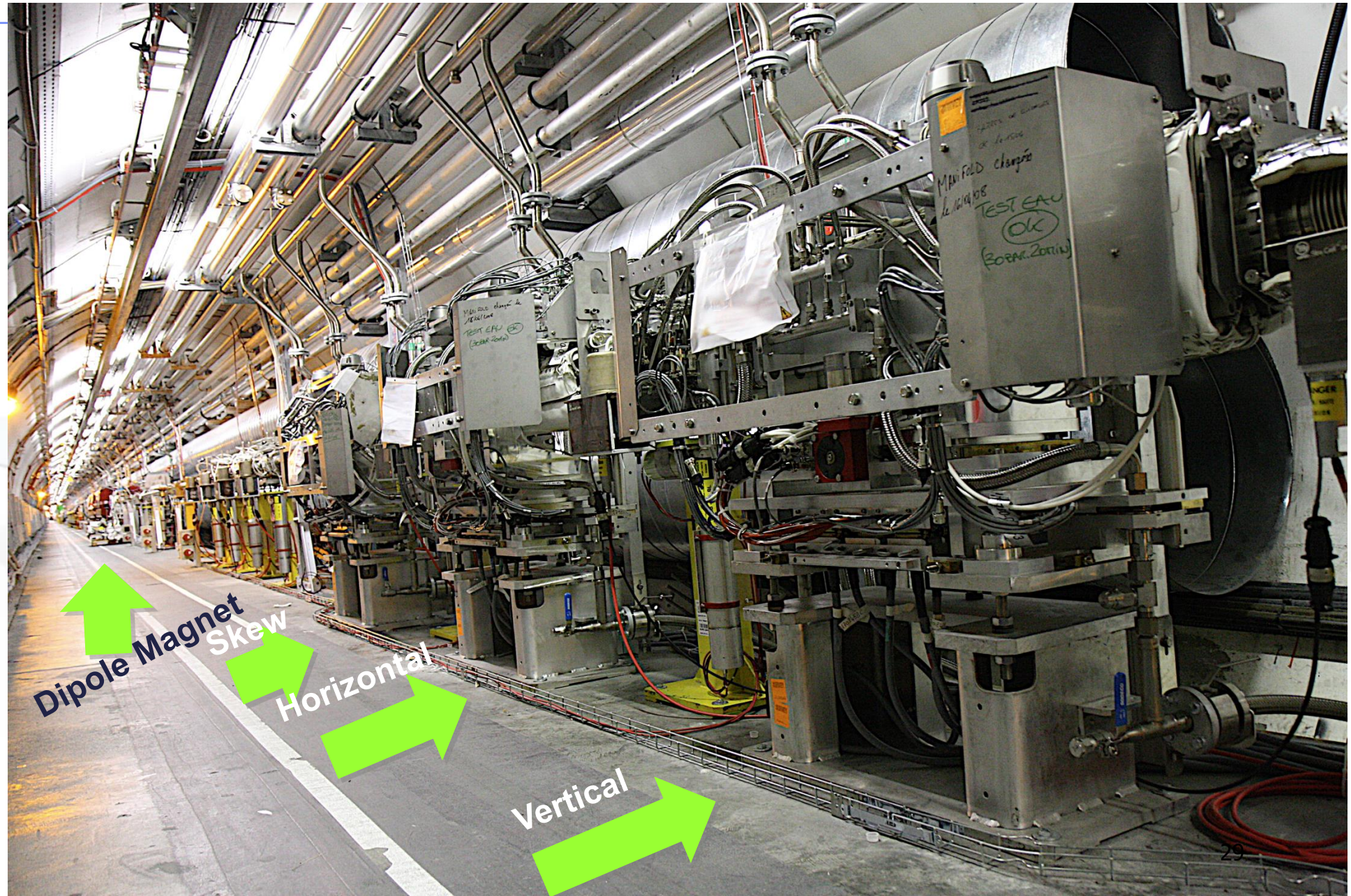
Applications – *LHC collimation region*



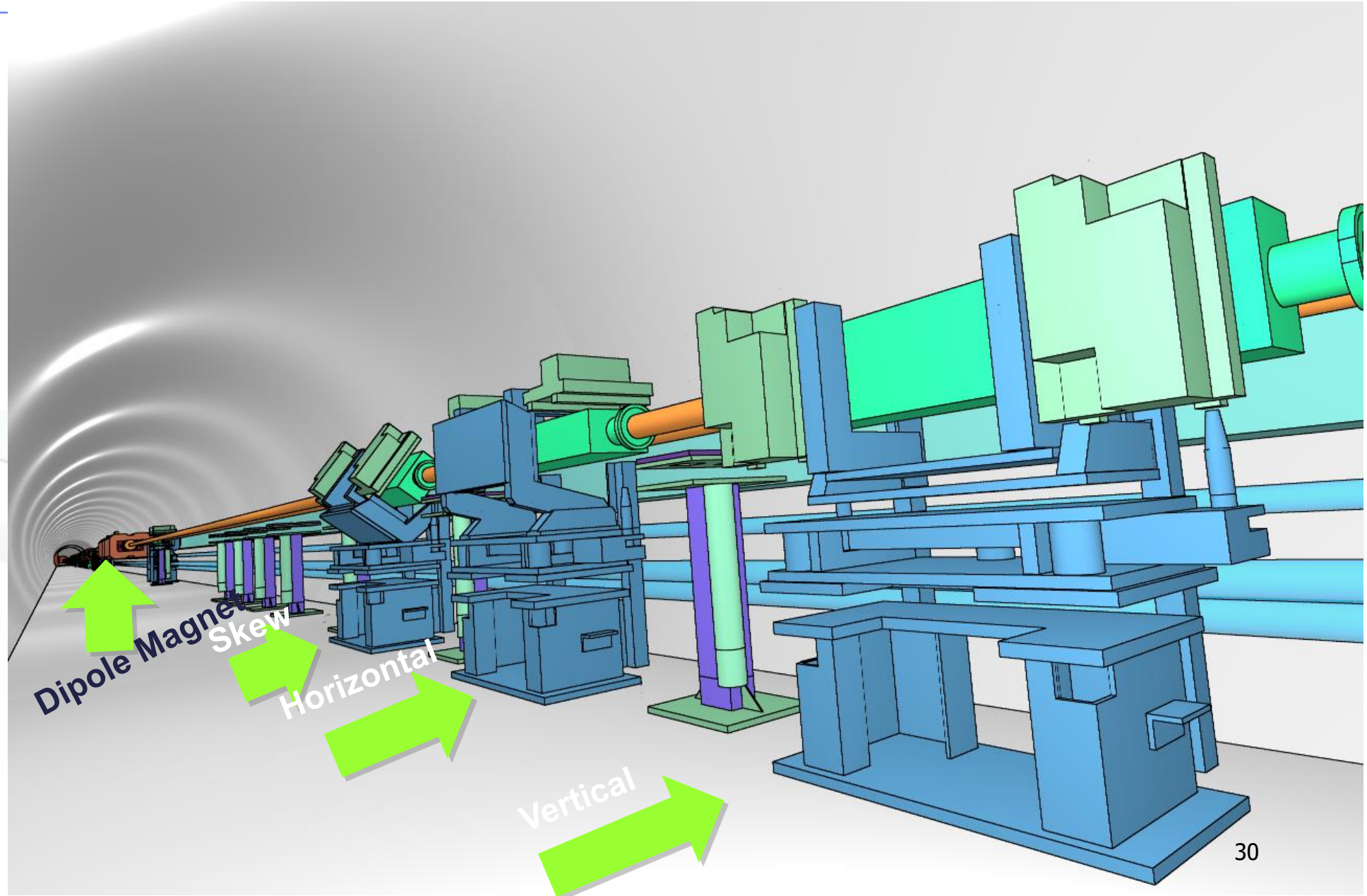


FLUKA geometry visualized with flair

Example: 3 Primary Collimators IR7



Example: 3 Primary Collimators IR7



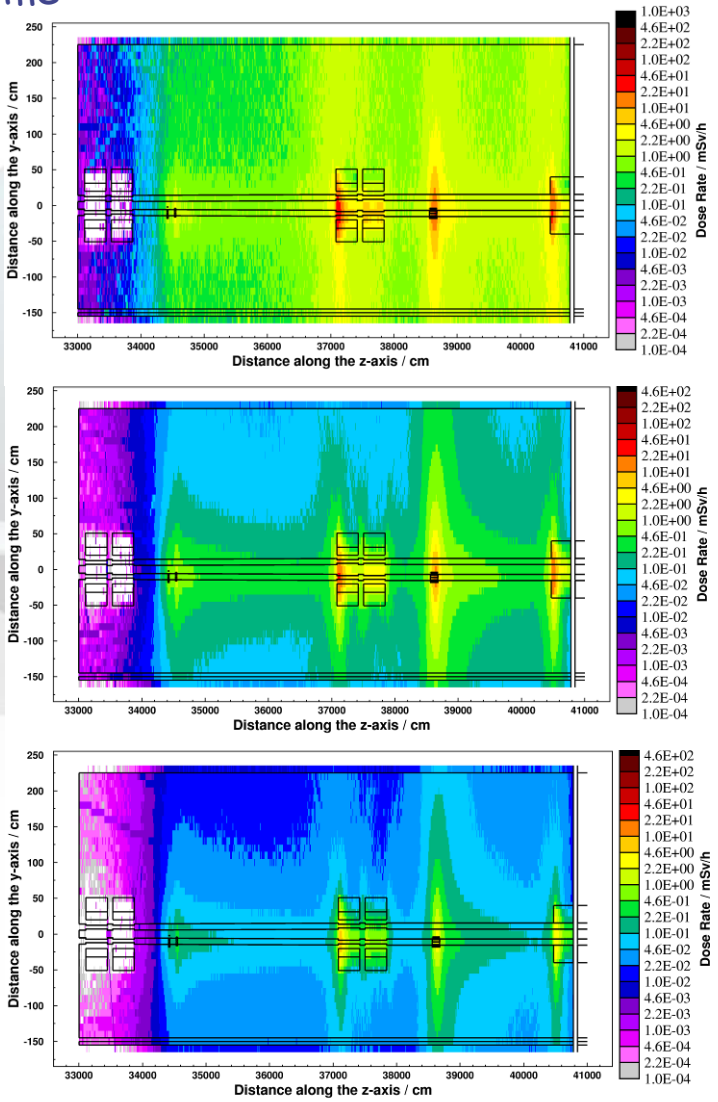
Applications – *LHC collimation region*

Cooling time

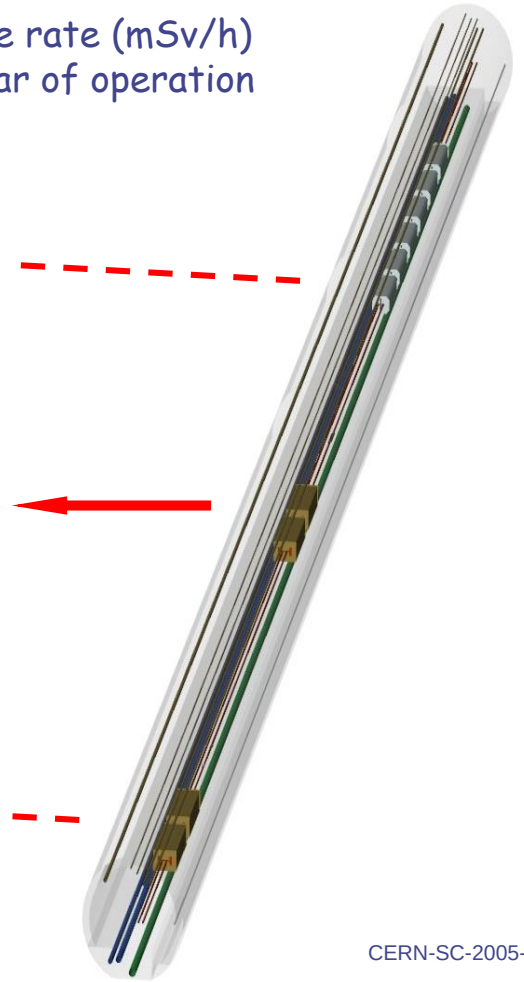
8 hours

1 week

4 months



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

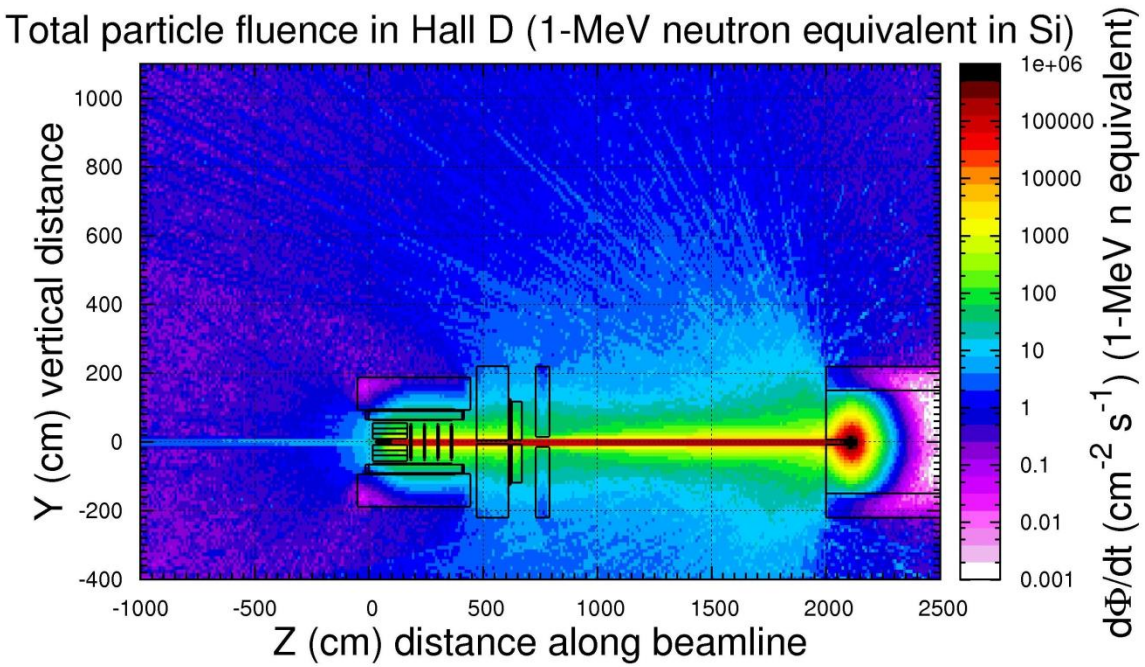


CERN-SC-2005-092-RP-TN

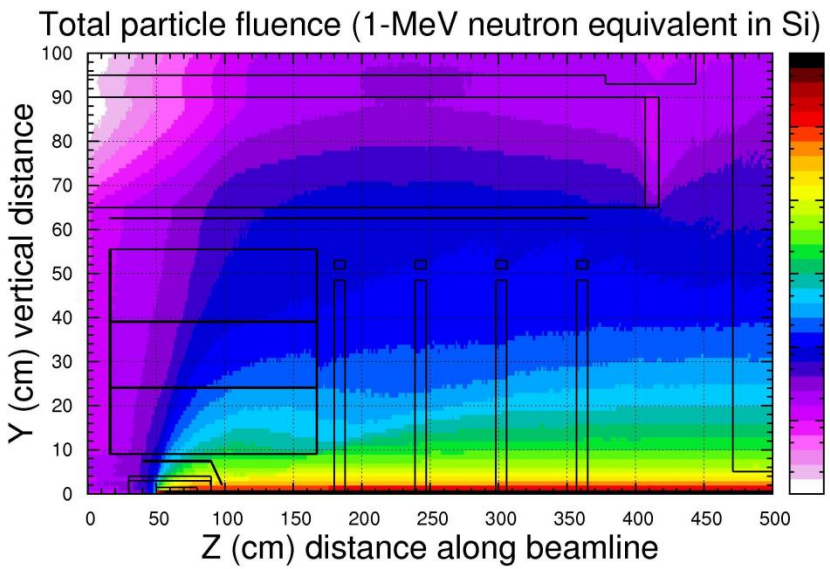
REMANENT DOSE RATE MAPS
OF THE LHC BETATRON CLEANING INSERTION (IR7)

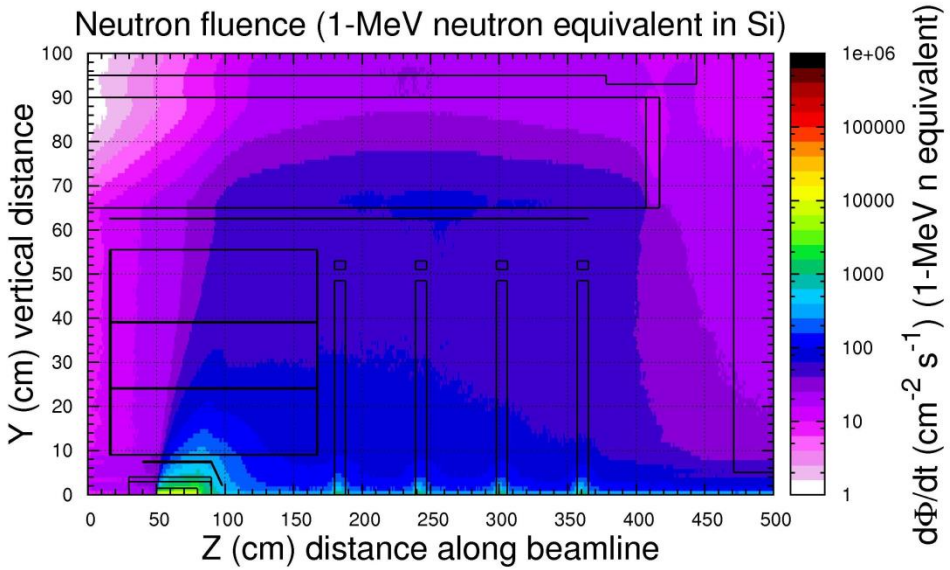
M. Brugger, D. Forkel-Wirth, S. Roesler

Applications – total and Neutron Dose from PHOTON beam

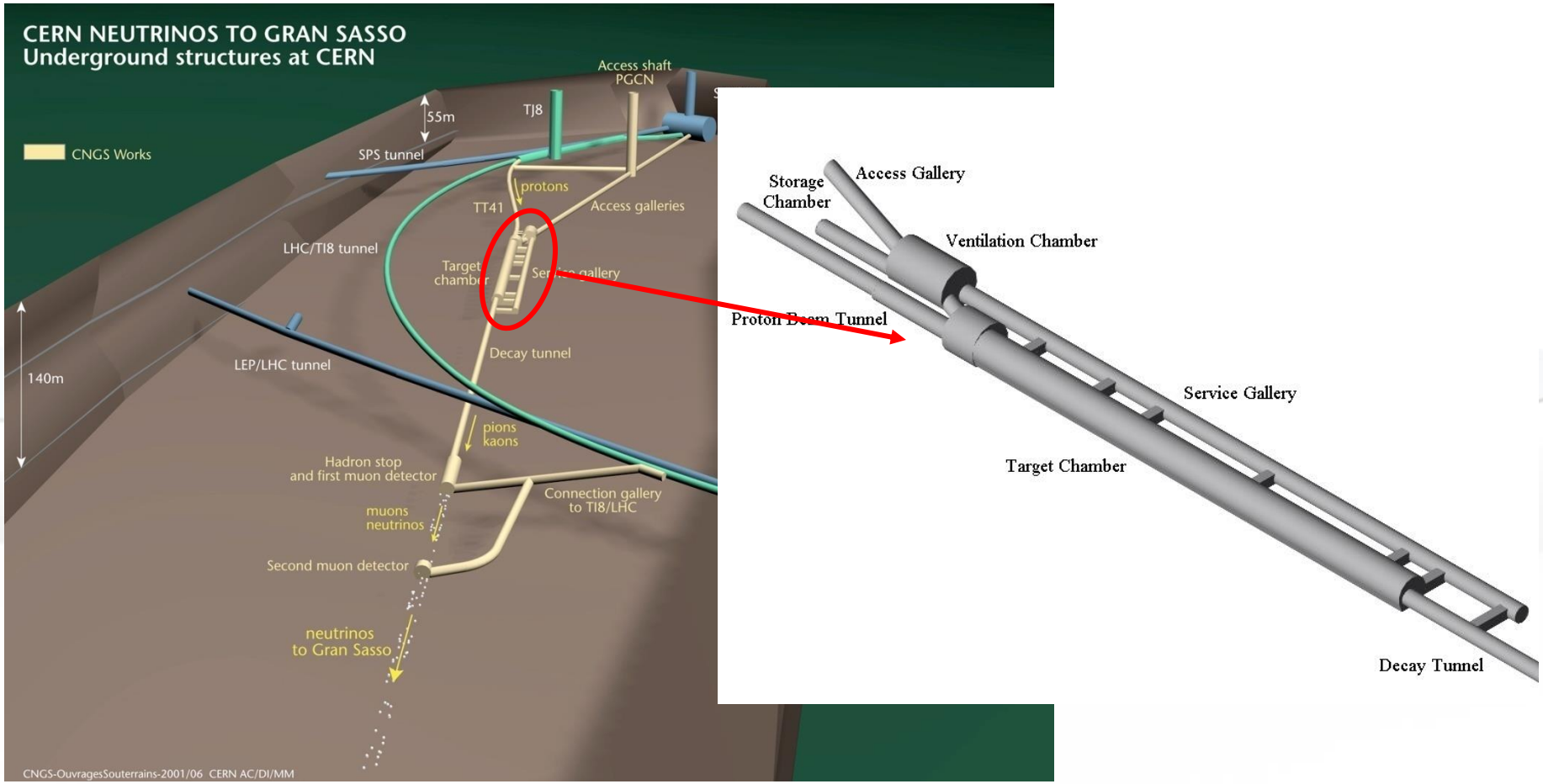


Calculated 1-MeV neutron equivalent fluence rate in Si
(GlueX experiment at Jlab)
Beam : 8-9 GeV photons, From the CEBAF electron accelerator

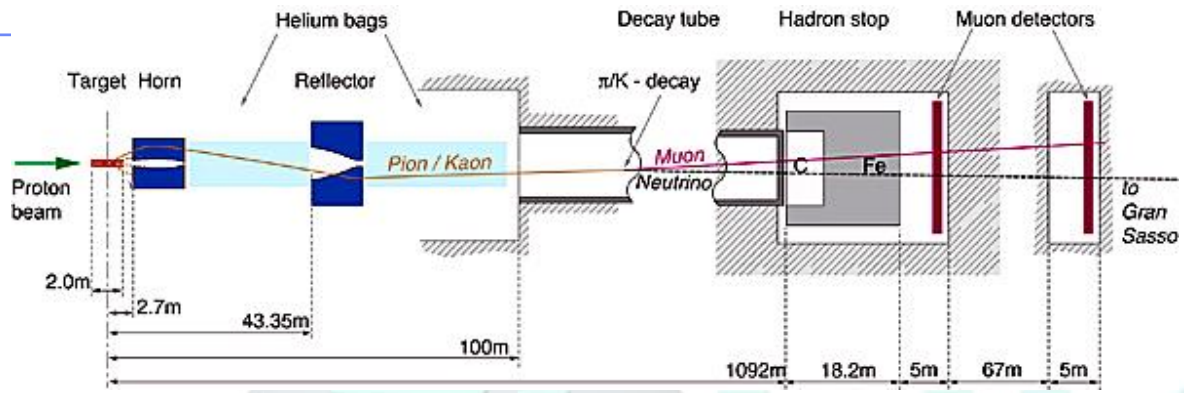


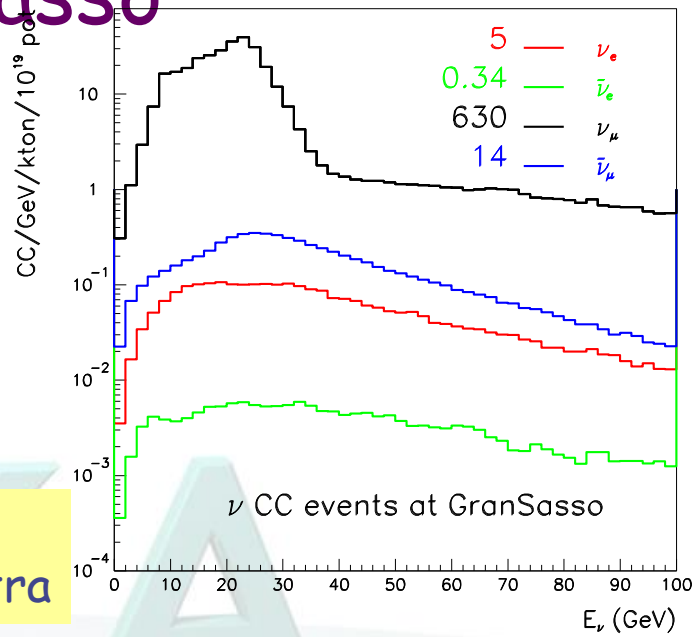


Applications – CNGS

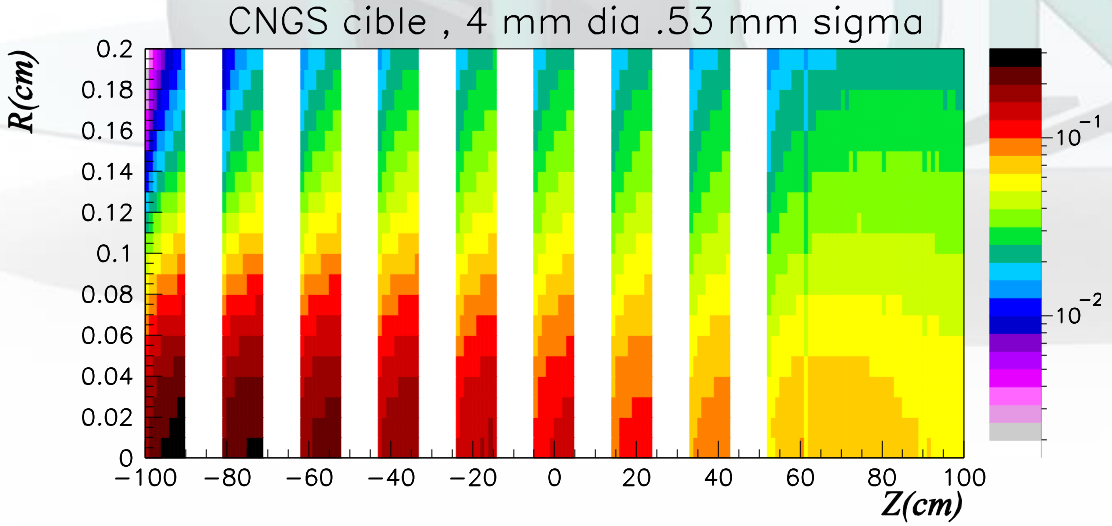


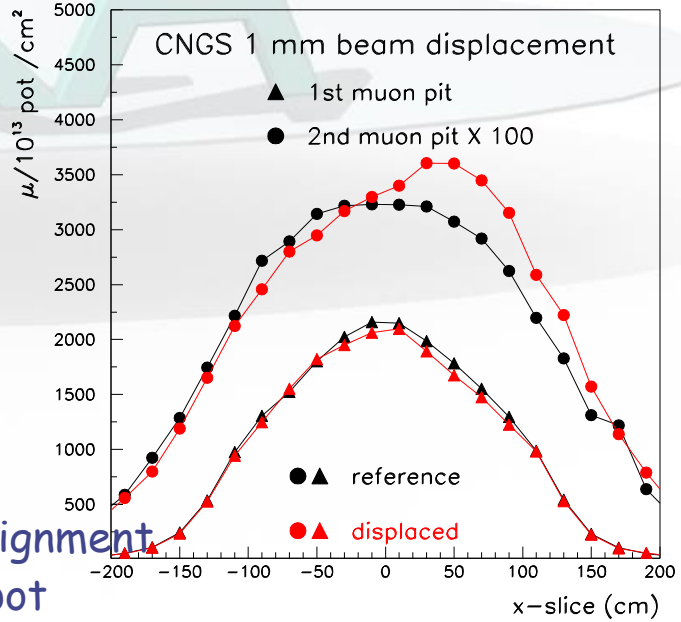
Cern Neutrino to Gran Sasso





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

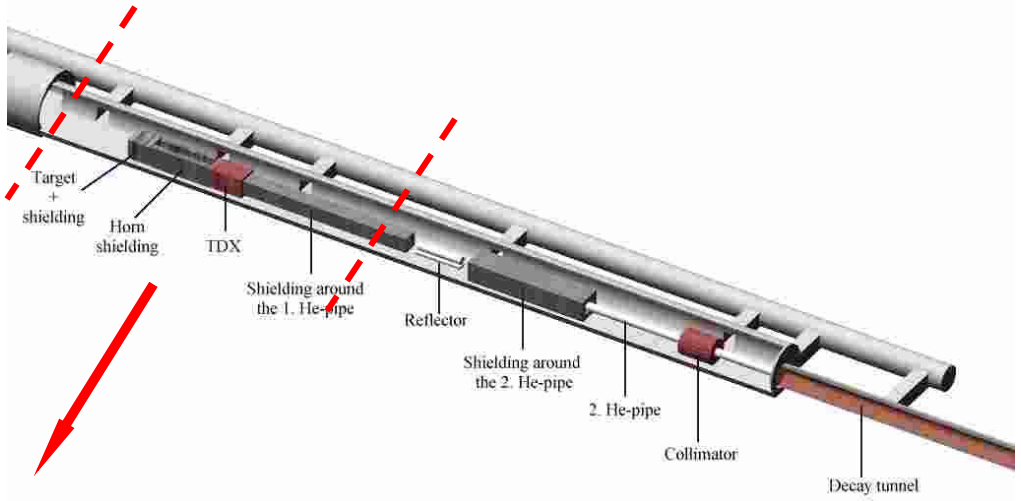




Muons in muon pits: horiz. distribution for beam alignment

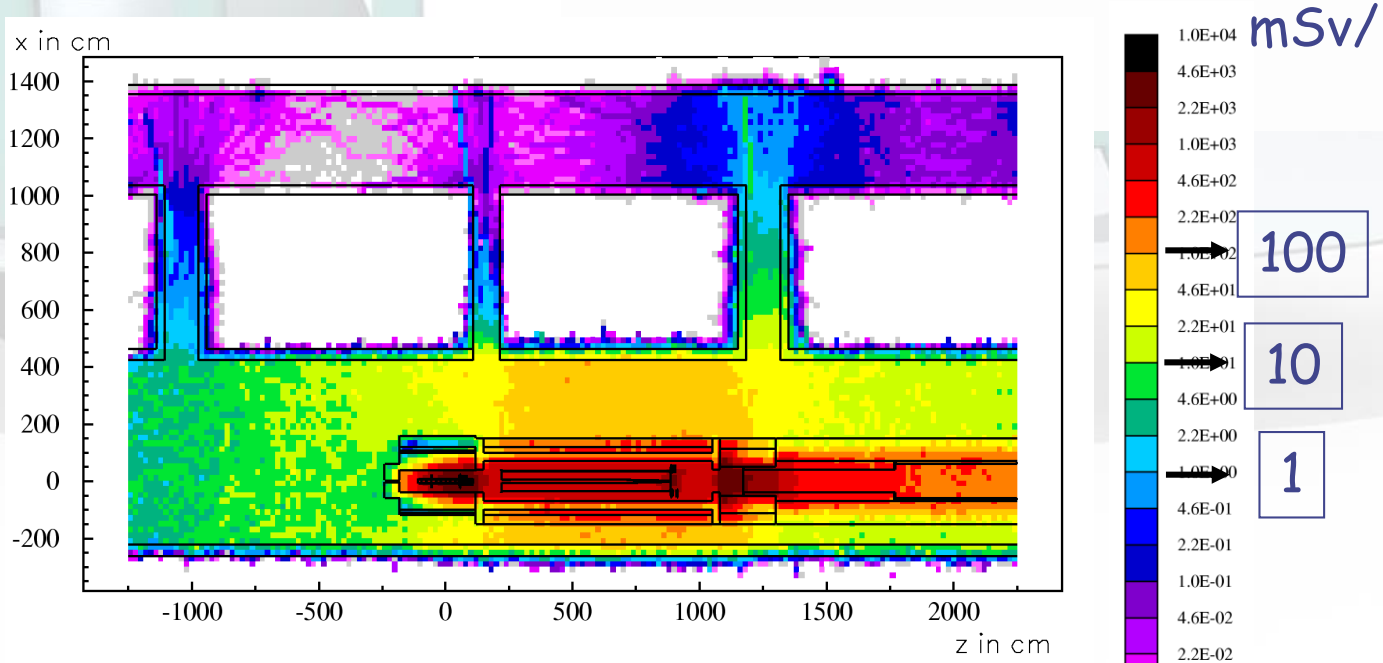
Energy deposition in CNGS target rods, GeV/cm³/pot

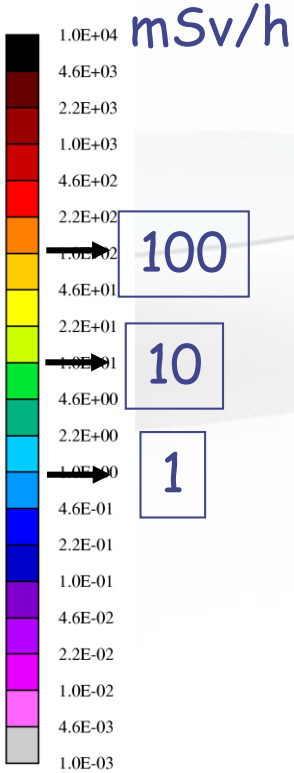
Applications – CNGS



Example:

t_{cool} = 1 day





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

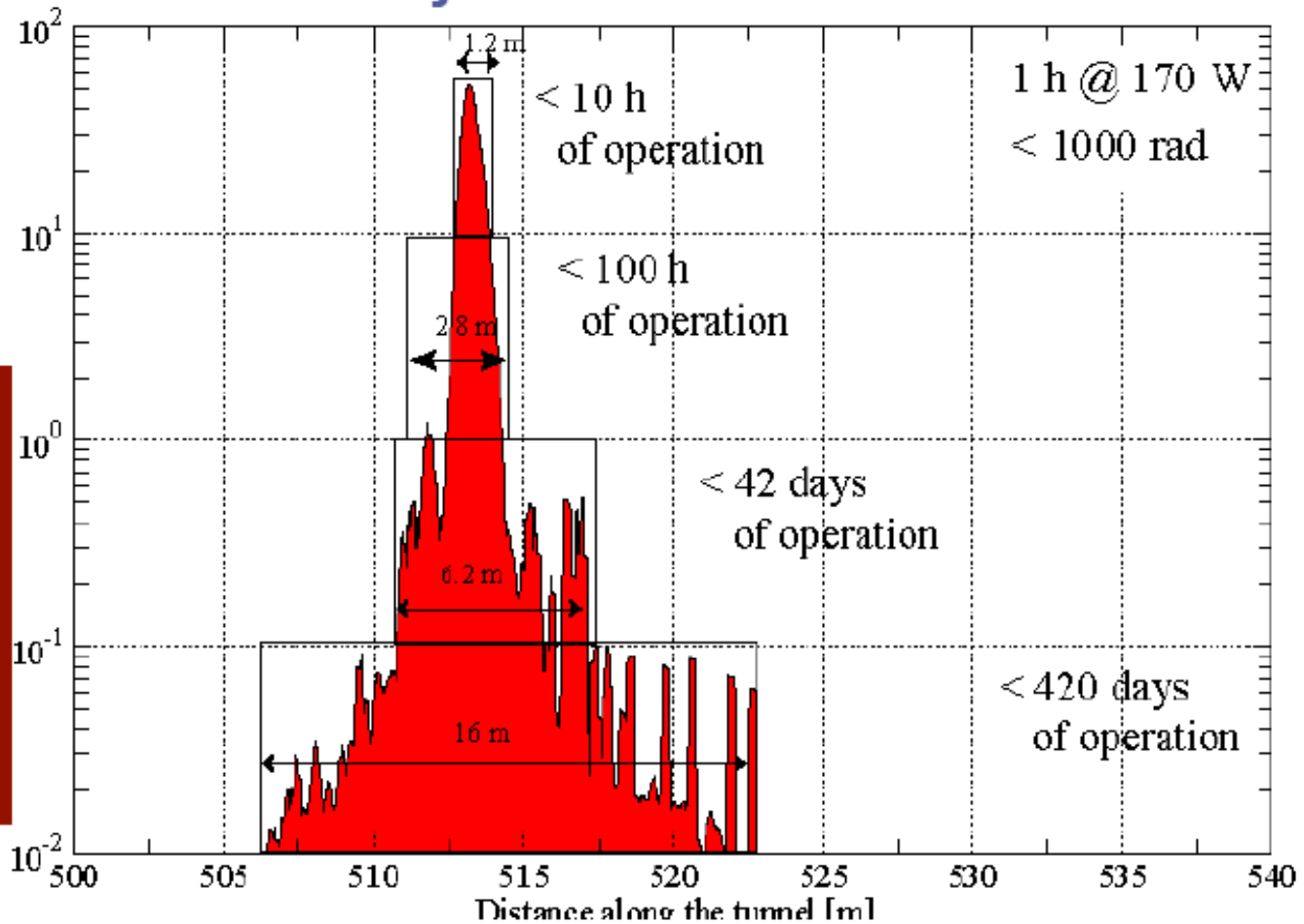
Damage to electronics

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

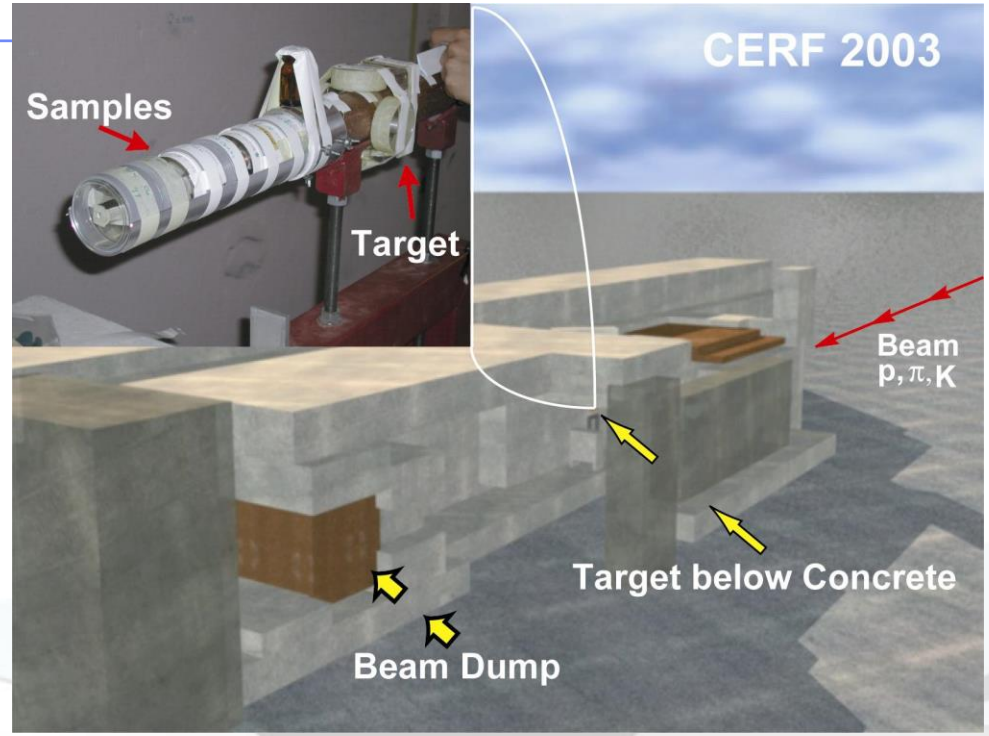
The lifetime of electronic components can be estimated as a function of the distance to major sources of radiation

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)

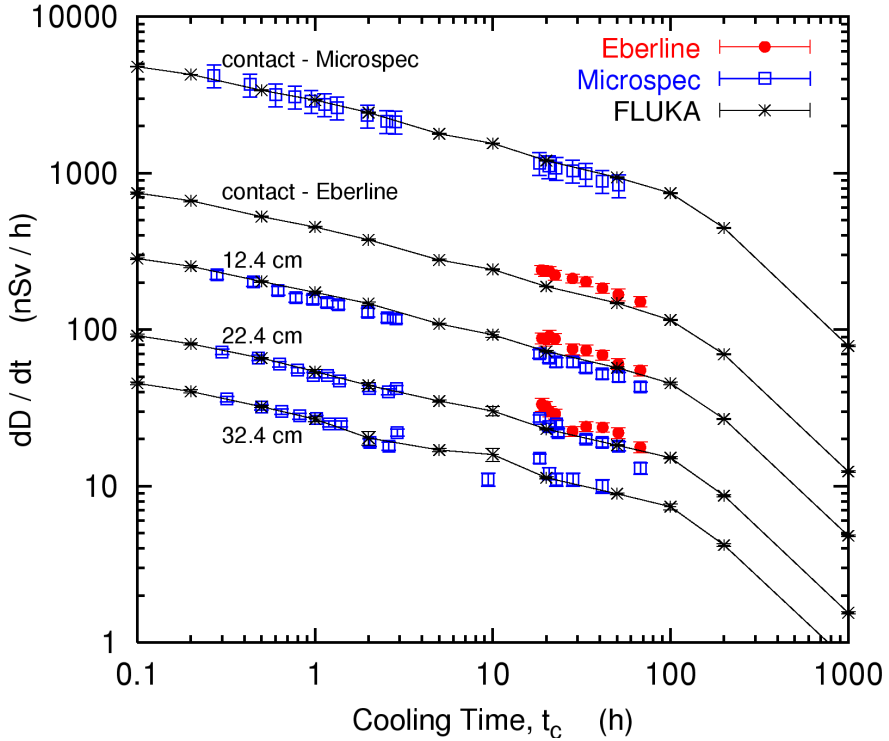


Thermo-Eberline dose-meter FHZ 672

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

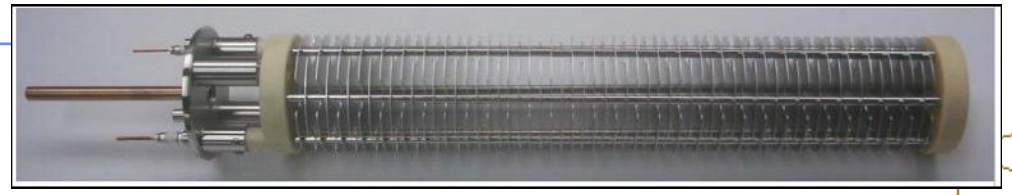
Microspec

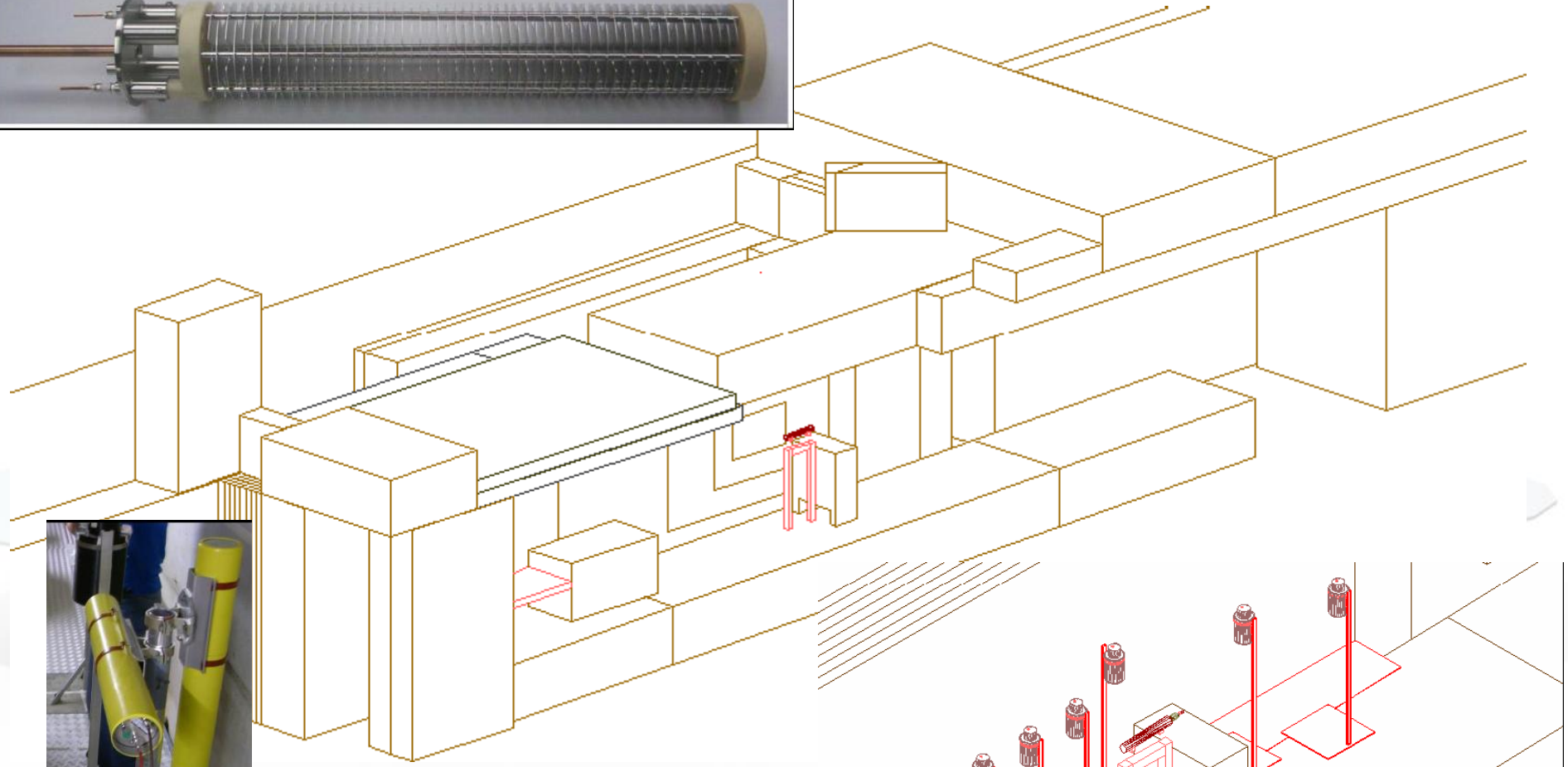
Iron



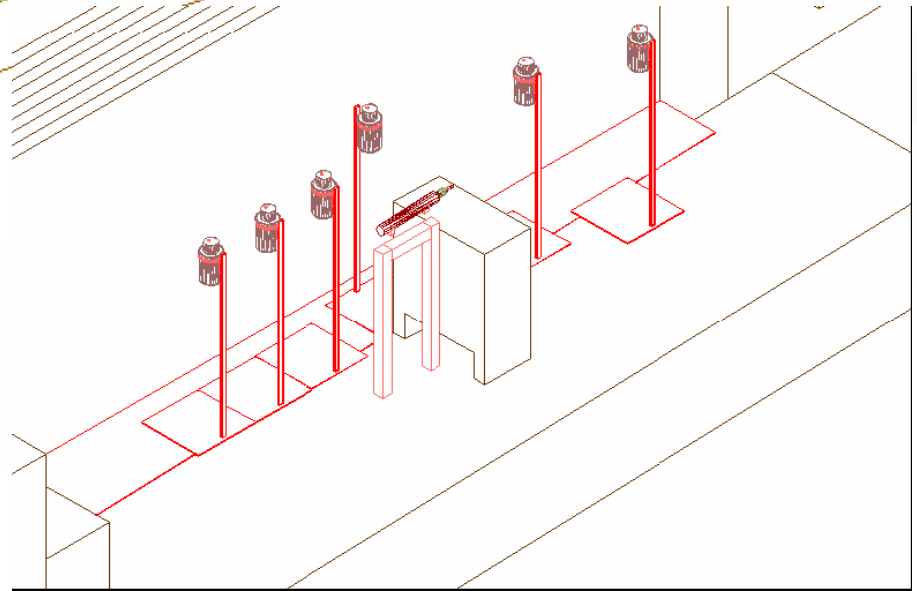
Test of instrumentation : Beam Loss Monitors at CERF

CERN-EN-NOTE-2010-002-STI



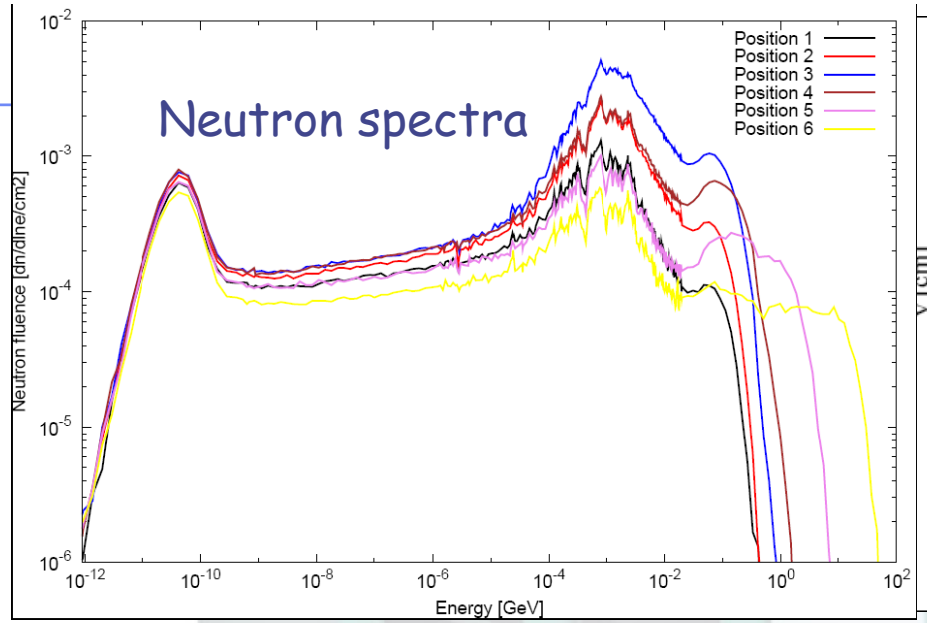


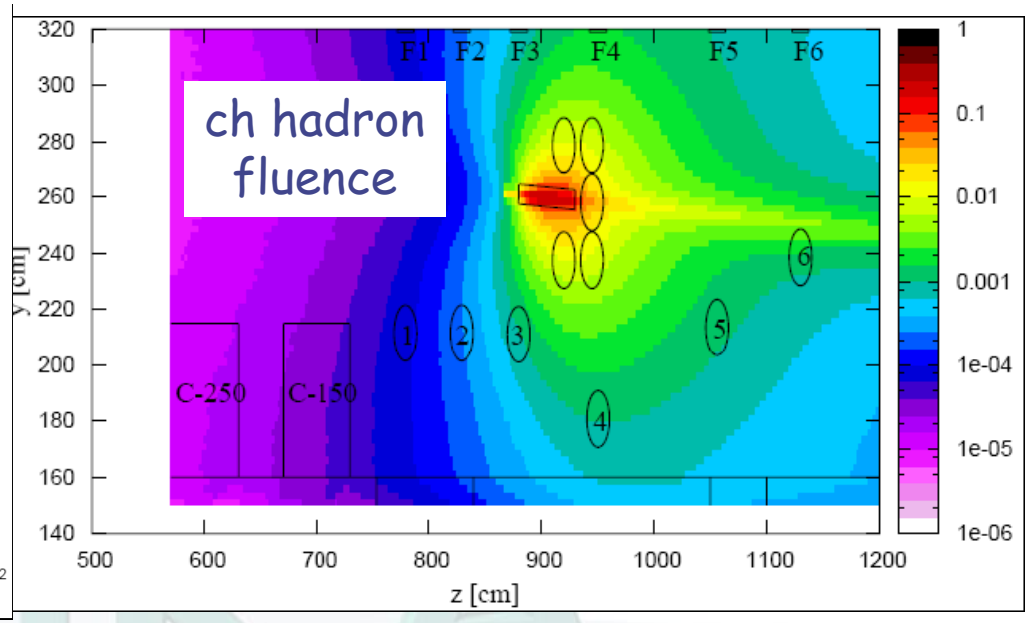
CERF setup

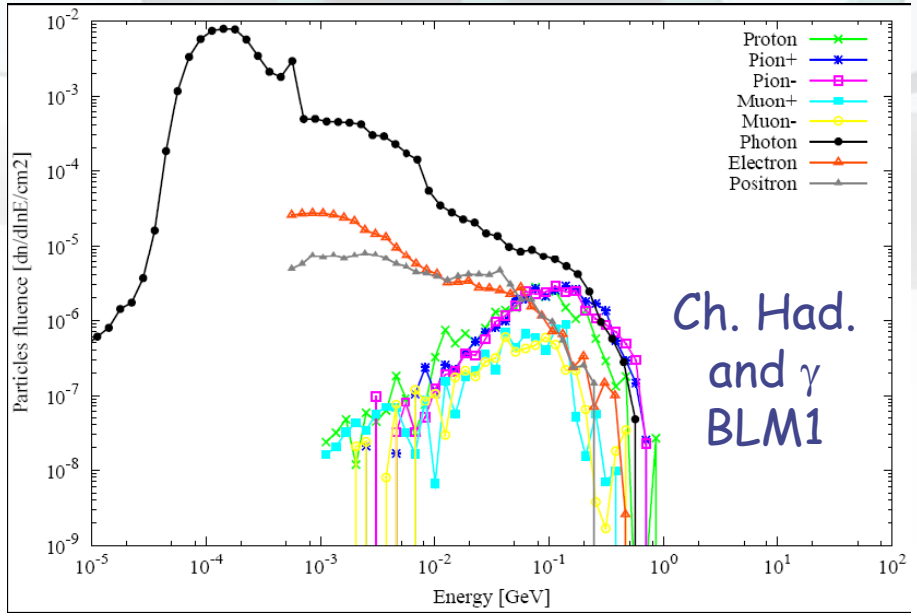


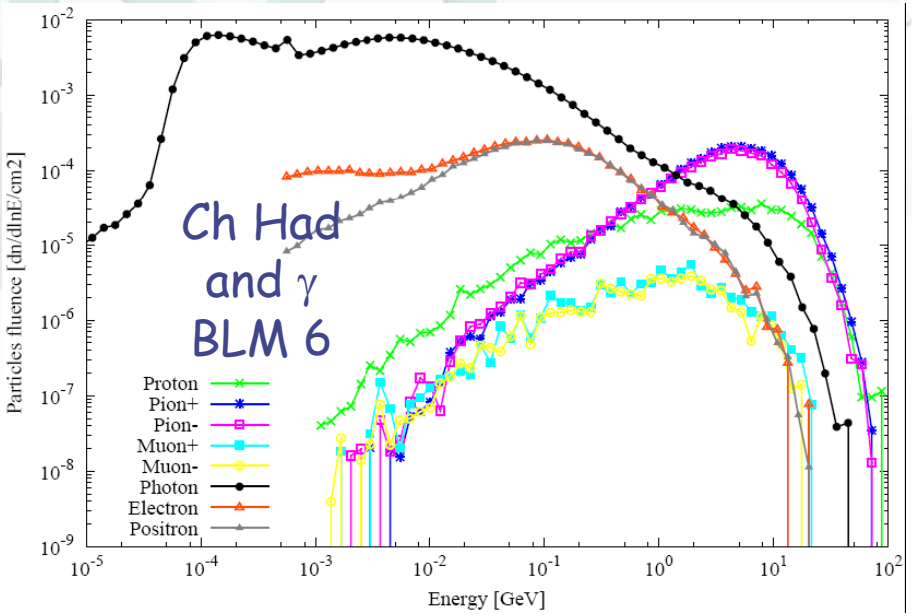
BLM's positions

CERF particle spectra

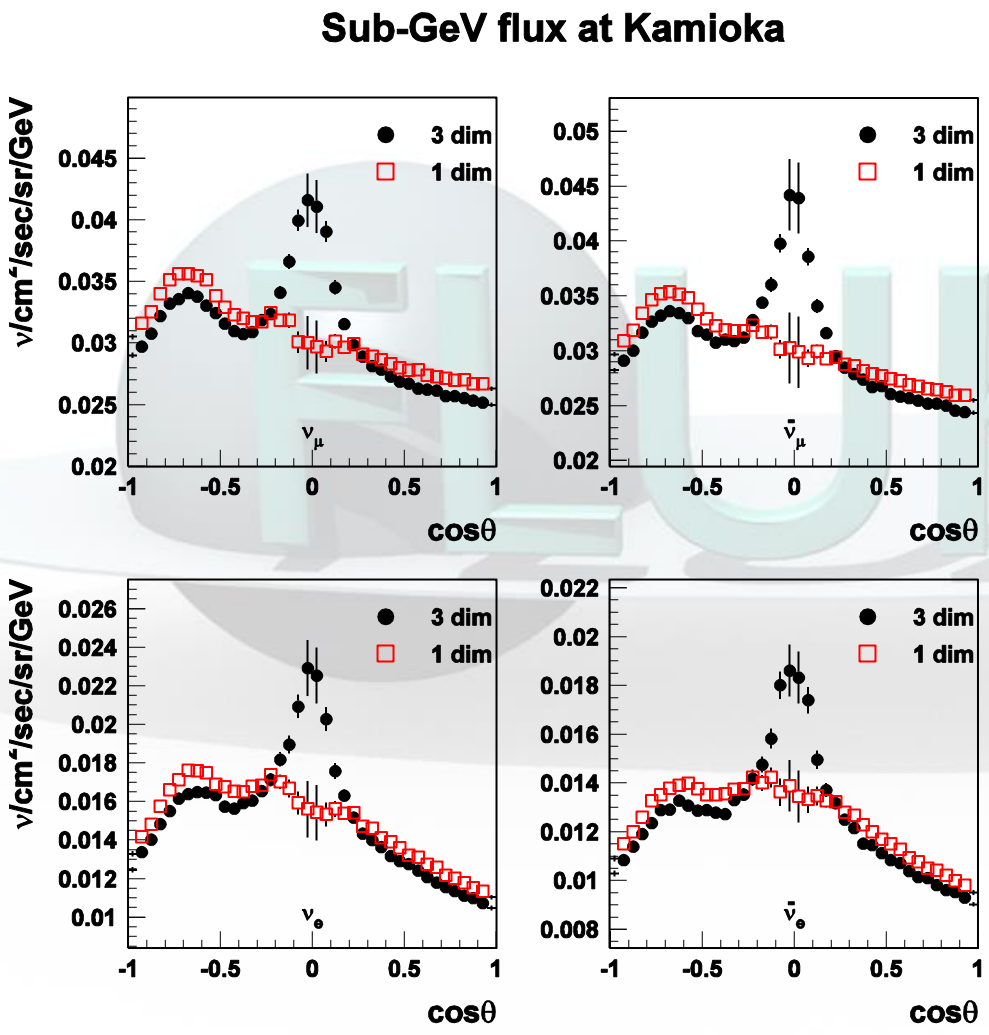








(3D) Calculation of Atmospheric ν Flux



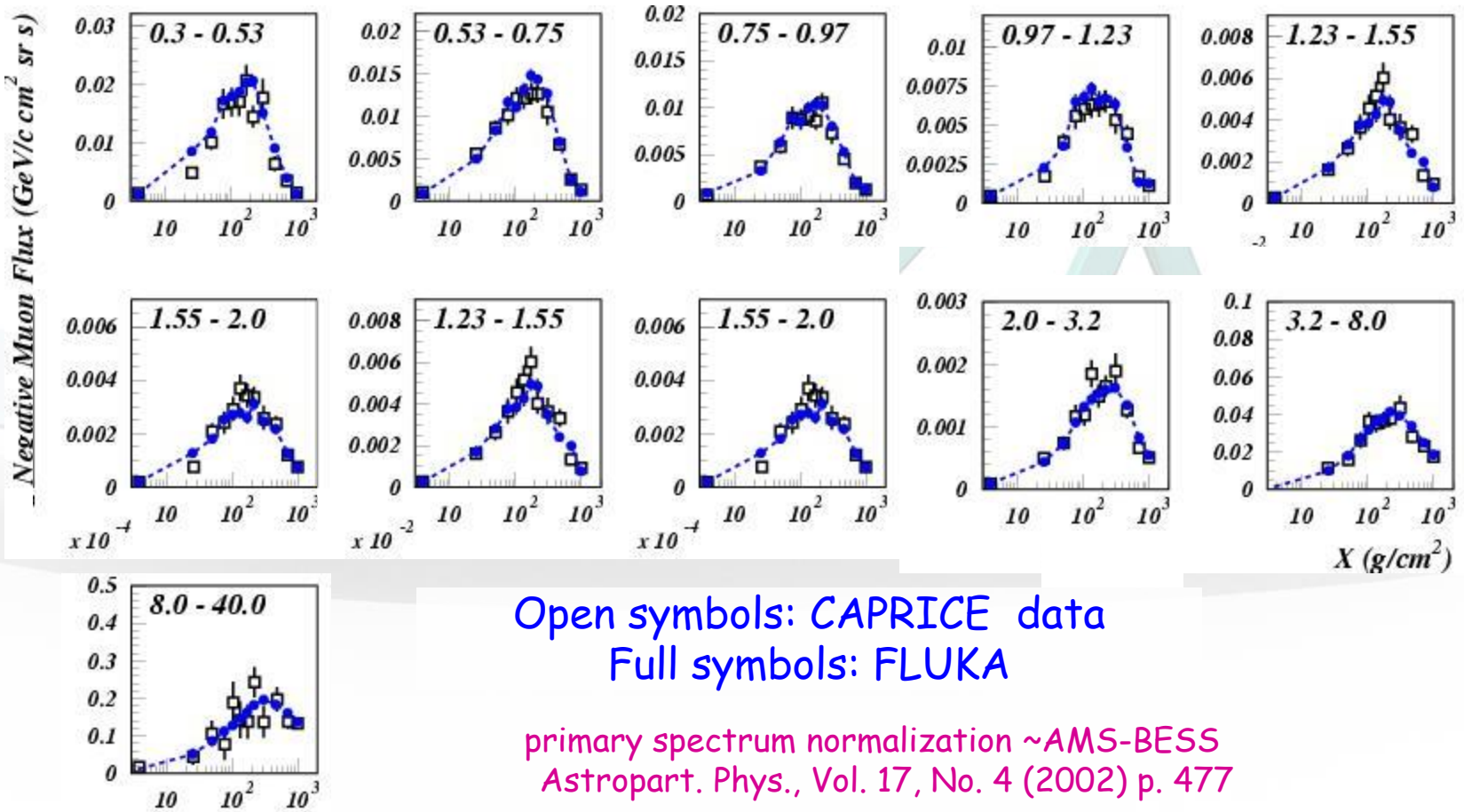
The first 3-D calculation of atmospheric neutrinos was done with FLUKA.

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

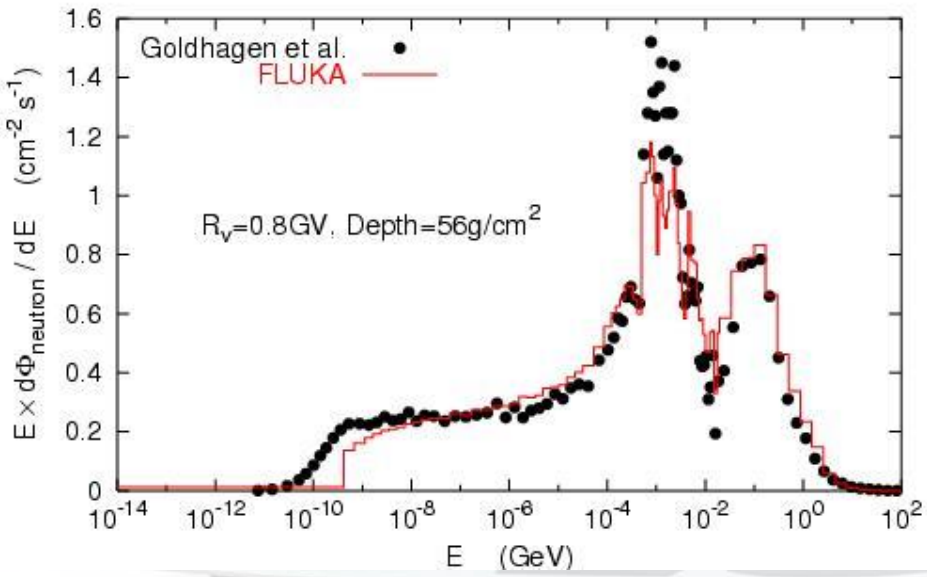
COMIC RAYS: Negative muons at floating altitudes: CAPRICE94



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



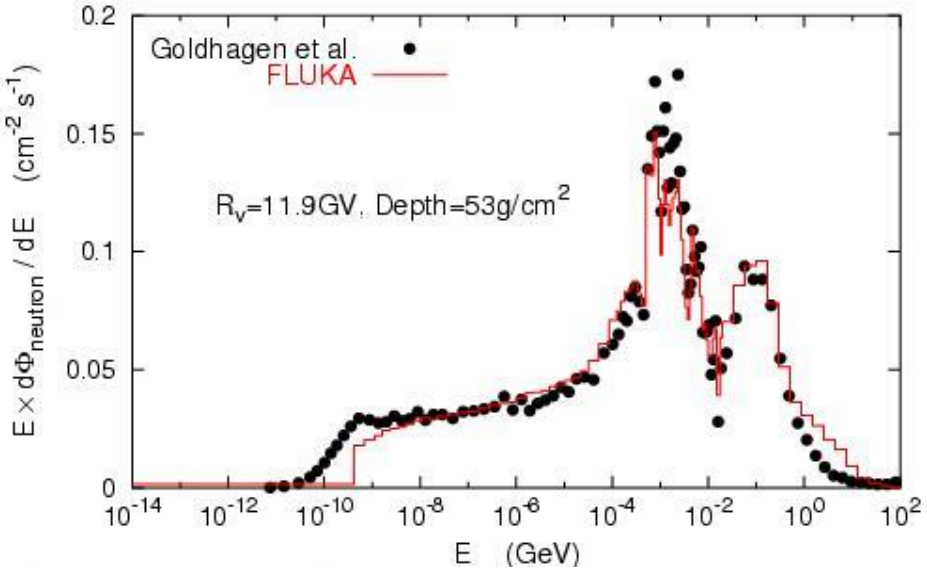
Measurements:

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

Note one order of magnitude difference depending on latitude

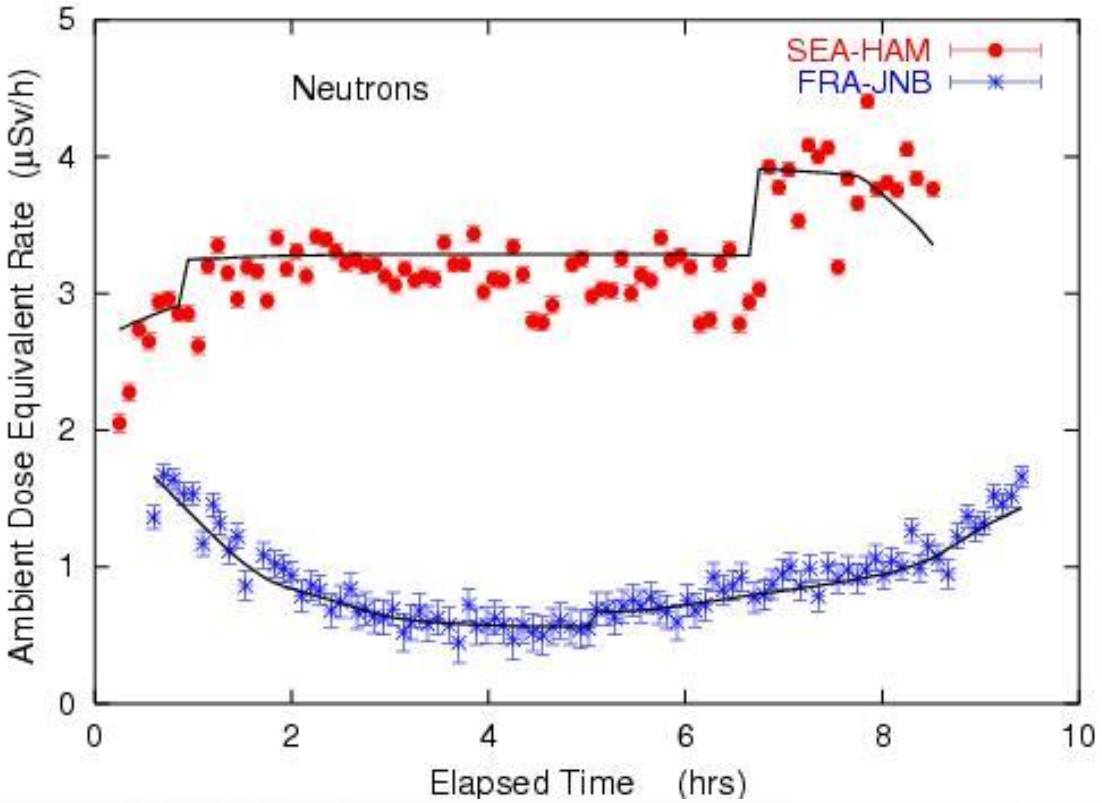
FLUKA calculations:

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



Dosimetry Applications

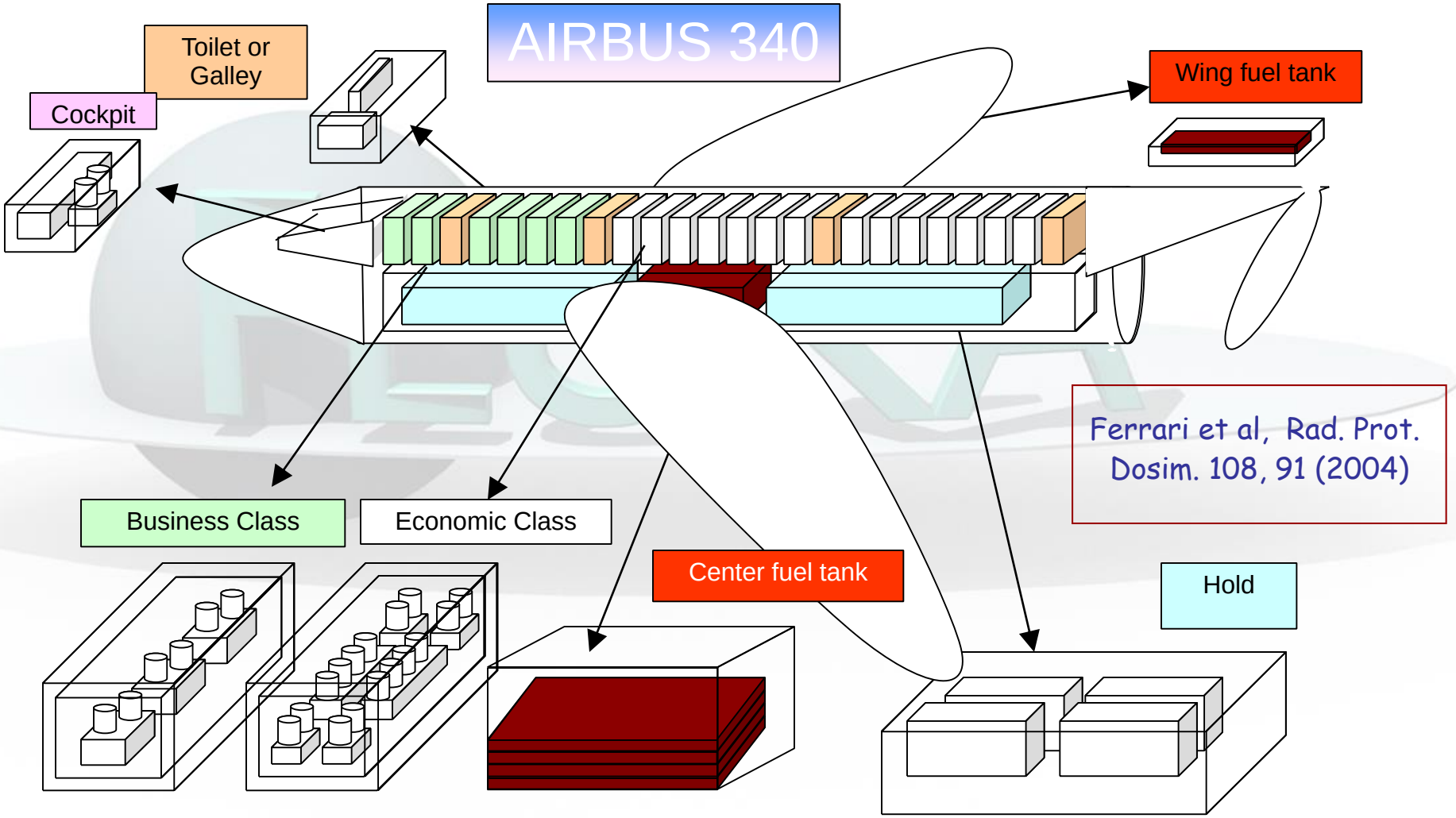
Roesler et al.,
Rad. Prot. Dosim.
98, 367 (2002)



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

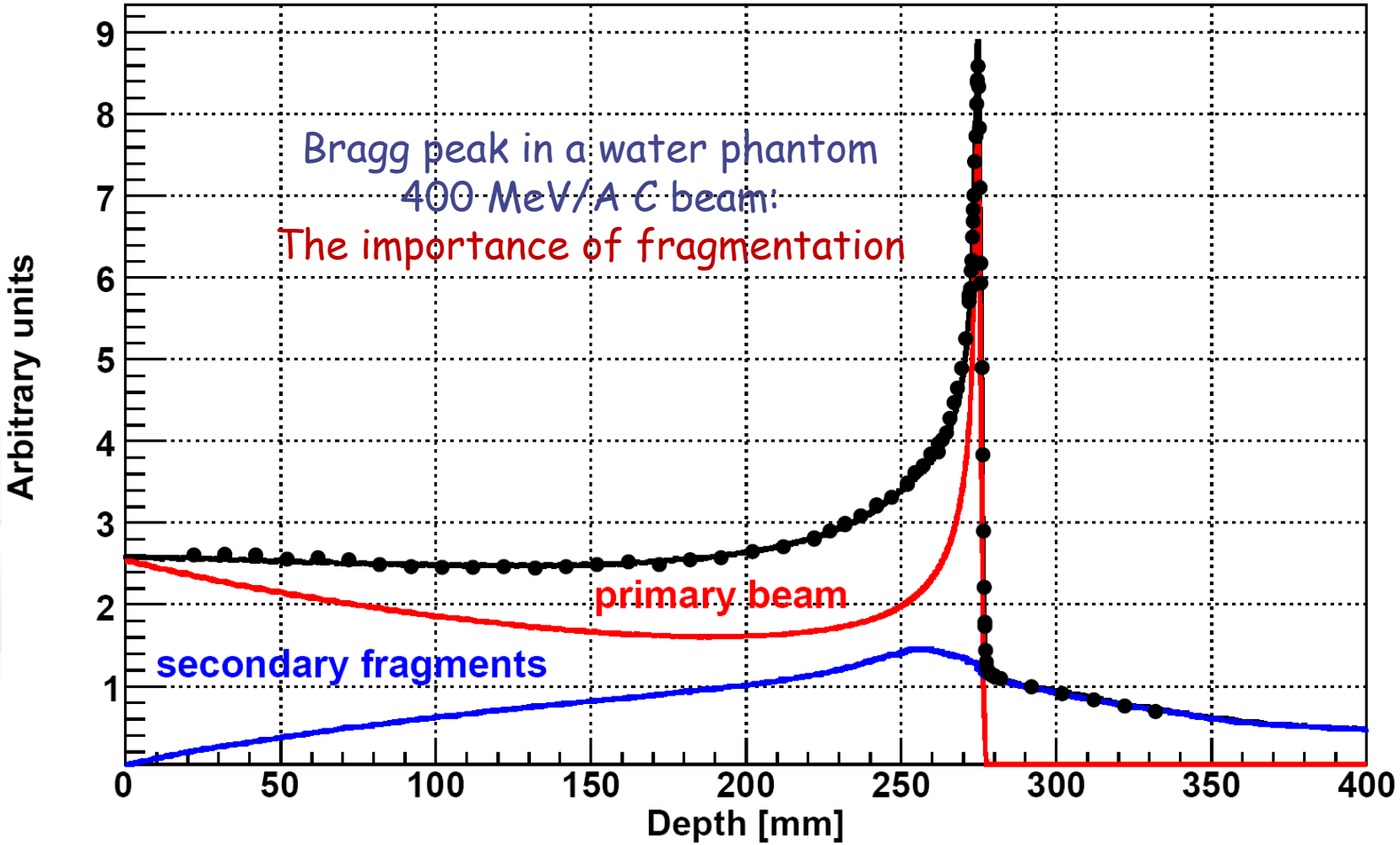
Solid lines: FLUKA simulation

Dosimetry applications: doses to aircrew and passengers



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

Carb



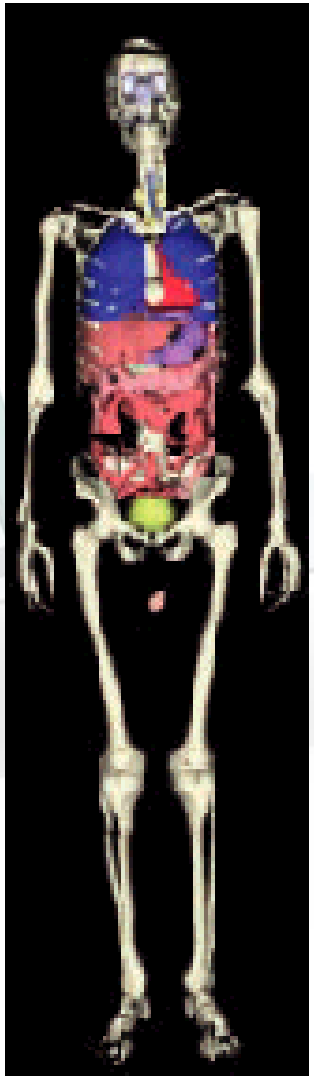
Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, Nuovo Cimento C, 31, 2008

Using the information from the patient CT in the MC

The Voxel Geometry

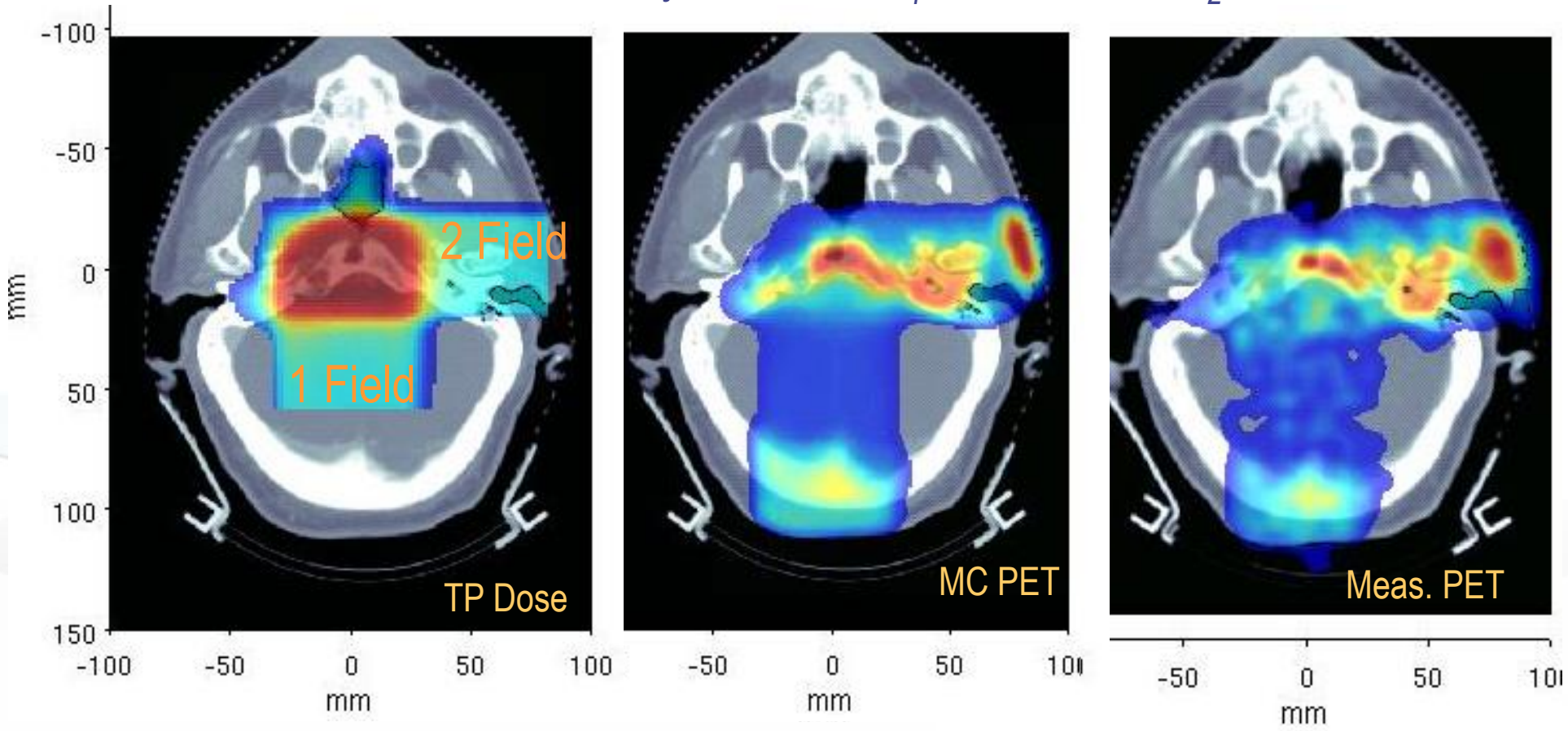
- FLUKA can embed voxel structures within its standard combinatorial geometry
- Transport through the voxels is optimized and efficient
- Raw CT-scan outputs can be imported

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)

Online evolution and buildup of induced activity

In all accelerator-related applications... and in many more, the evaluations of induced activation and prompt/residual dose rates are essential. In **Fluka**:

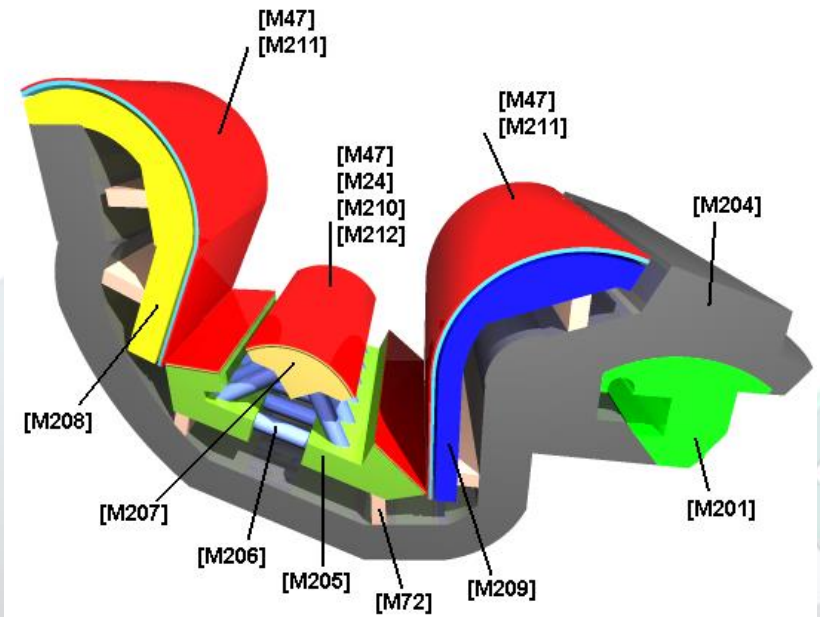
- Reliable interaction models, with particular care of the latest stages (evaporation, fragmentation, break-up)
- Decay β+/-'s, γ's, EC electrons, α's, produced according to a database (based on ENSDF, www.nndc.bnl.gov)
  - Screening and Coulomb corrections for $\beta^{+/-}$ spectra
- Analytical calculation of activity build-up and decay

In the same run, prompt and delayed results according to user-defined irradiation and cooling profiles

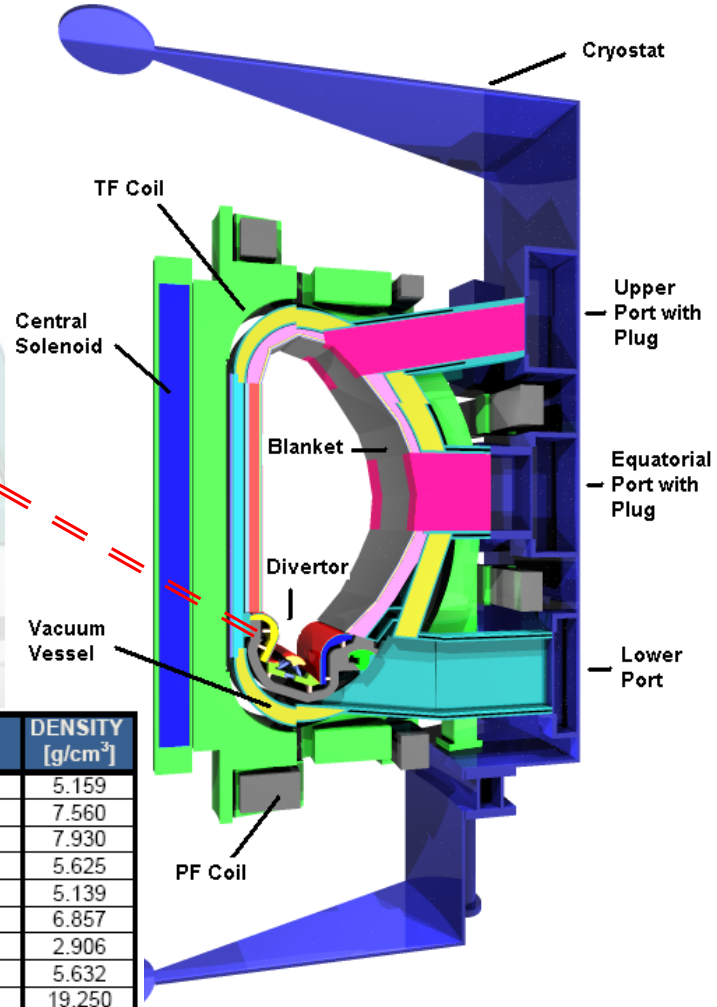
Activities: 2D and 3D distributions, and full inventories at each buildup/cooling time

Energy deposition (dose, decay heat), particle fluences (including dose equivalent with folding online) at each buildup/cooling time

ITER geometry: divertor cassette



[FLUKA ray tracer by D. Pastor]

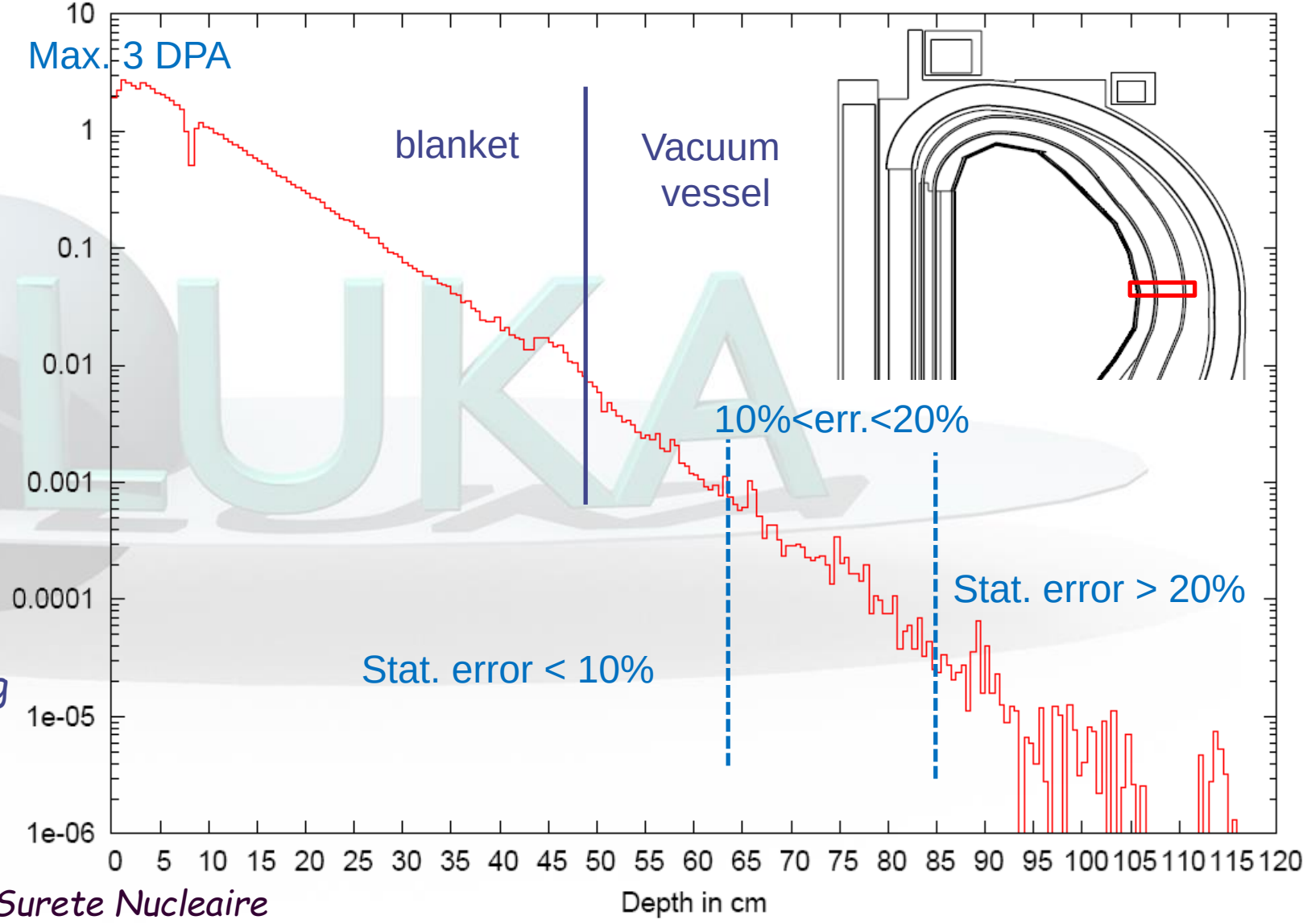


COMPONENT & LOCATION		MATERIAL NAME	DESCRIPTION	DENSITY [g/cm^3]
DIVERTOR CASSETTE	Support Structure 1	M204	H2O (39%), SS316L(N)-IG (52%), M72 (9%)	5.159
	Support Structure 2	M201	NiAl (100%)	7.560
	Inner & Outer Support Structure	M12	SS316L(N)-IG (100%)	7.930
	Target Structure Inboard	M208	H2O (32%), SS316L(N)-IG (50%), M72 (18%)	5.625
	Target Structure Outboard	M209	H2O (39%), SS316L(N)-IG (44%), M72 (17%)	5.139
	Target Structure Dome	M207	H2O (15%), SS316L(N)-IG (85%)	6.857
	Pipes for the Dome	M206	H2O (72%), SS316L (28%)	2.906
	Target Strucure Dome Right & Left	M205	H2O (30%), M72 (70%)	5.632
	Plasma Facing W	M47	TUNGSTEN (100%)	19.250
	Plasma Facing Cu	M24	COPPER (100%)	8.960
	Plasma Facing	M210	Cu-Cr-Zr (100%)	8.814
	Plasma Facing	M211	W (57.65%), H2O (21.1%), Cu-Cr-Zr (11.87%), Cu (9.38%)	13.179
	Plasma Facing	M212	H2O (76.4%), SS316L(N)-IG (23.6%)	2.570
	Connection	M72	Fe (56.62%), Cr (22%), Ni (12.5%), Mo (2.25%), N (0.3%), Mn (5%), C (0.06%), Nb (0.2%), V (0.2%), Si (0.75%), P (0.04%), S (0.03%), Co (0.05%)	7.650

DPA: ITER, blanket module

For a safety evaluation of the ITER machine, IRSN* asked CERN to perform neutronic and activation calculations with the FLUKA Monte Carlo code.

The report presents FLUKA results on radionuclide inventory, ambient residual dose rate, dose evaluation, residual power for the cooling circuit, and displacement per atom (DPA)



*Institute de Radioprotection et Surete Nucleaire