FLUKA

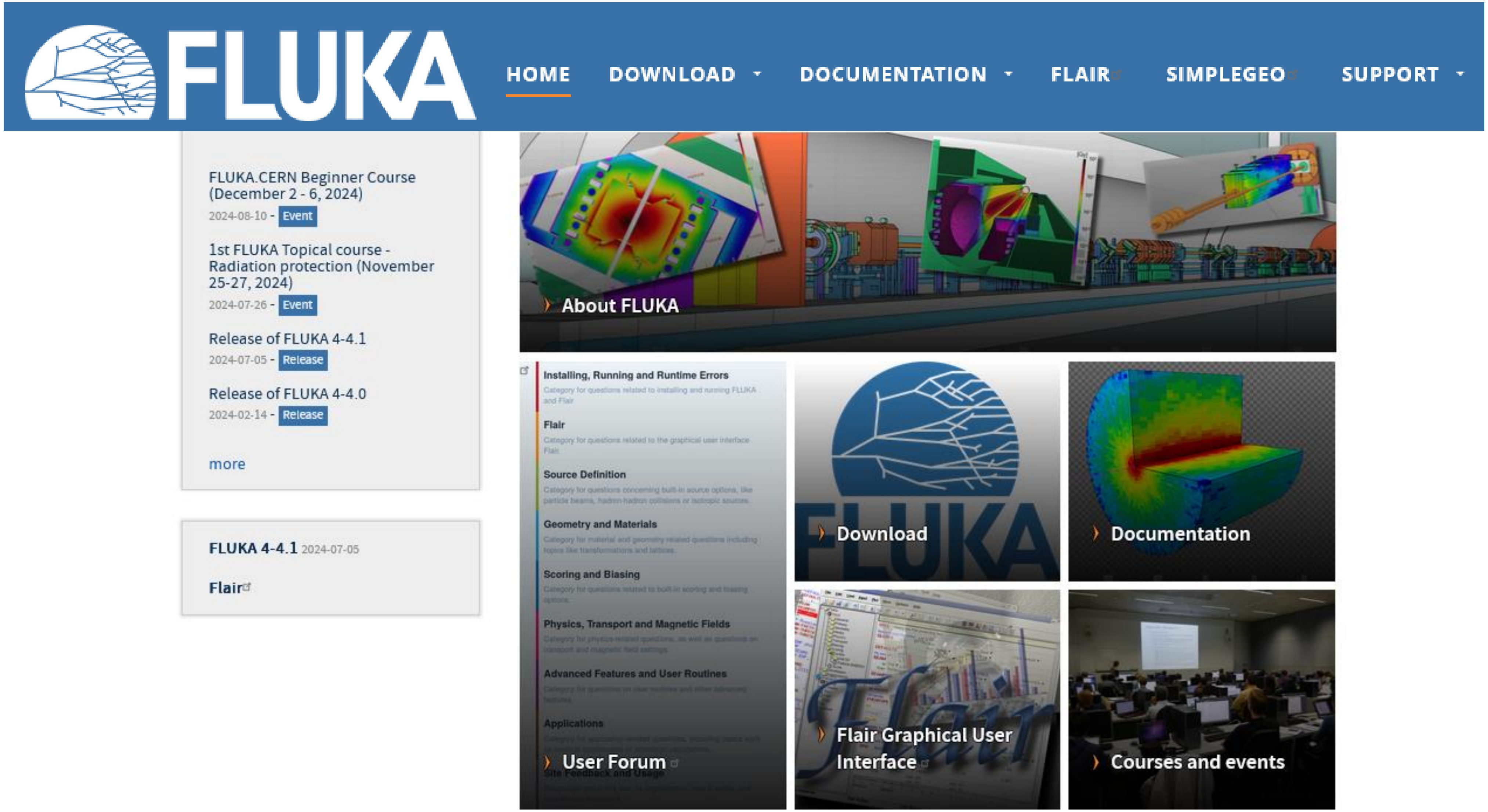
Introduction to FLUKA

Where we come from

- FLUKA was born in the 60's at **CERN** with Johannes Ranft
- It was further developed in the 70s and 80s in a collaboration between **Leipzig University**, **CERN** and **Helsinki University of Technology** for applications, e.g., at CERN's high energy accelerators, and in the 90s with **INFN**, among others for the design of SSC and LHC
- From 2003 until August 2019 maintained and developed under a **CERN & INFN** agreement
- From December 2019, new **CERN** distribution aiming to ensure FLUKA's long-term sustainability and capability to meet the evolving requirements of its user community, welcoming contributions by both established FLUKA contributors as well as new partners within an **international collaboration**.
- Presently a joint development & management team based in the **CERN Accelerators and Technology Sector and Radiation Protection Group and at ELI-Beamlines (Prague),** with contributors from the CERN Research and Computing Sector, JRC-Geel, ANL, BNL, and STFC, is in place.

FLUKA.CERN distribution

https://fluka.cern



Licensing Scheme

Registration options
FLUKA **Single User License Agreement**
Affiliates of institutes with a FLUKA **Institutional License Agreement**
CERN Staff members and Fellows
Affiliates of institutes which signed the FLUKA **Memorandum of Understanding**
Companies which purchased a FLUKA **Commercial License Agreement**

Includes access to:

source code (Institutional License Agreement; CERN Staff members and Fellows)

development version (Memorandum of Understanding)

- **Licenses are free** except for commercial use
- They are granted for **non-military use** only

- For **central FLUKA installations on computing clusters** of universities/institutes it is not necessary to obtain an Institutional FLUKA Licence. However, it is mandatory that all FLUKA users register on this website and accept the Single User Licence Agreement.

Recent developments of FLUKA.CERN

Coherent transport effects for charged particles in **bent crystals**; electric field in vacuum; electronuclear reactions; direct (p,n) reactions.

Compound nucleus spin and parity accounted for in evaporation and Fermi break-up; **new generation source routine** for users.

Low-energy **deuteron interaction** model; proton reaction cross section refinement; ICRP116 and ICRU95 dose equivalent conversion coefficients; simplified out-of-the-box usage of multiple magnetic fields

Point-wise treatment for **low-energy neutron** interactions; **synchrotron radiation** emission during charged particle tracking

Proton nuclear elastic scattering improvement at low energies; gamma cascade improvement for thermal neutron capture; (d,2n) improvement on heavy targets

FLUKA 2011-3	*December 2019*
FLUKA 4-0	***June 2020***
FLUKA 4-0.1	*August 2020*
FLUKA 4-1	***November 2020***
FLUKA 4-1.1	*February 2021*
FLUKA 4-2	***October 2021***
FLUKA 4-2.1	*December 2021*
FLUKA 4-2.2	*March 2022*
FLUKA 4-3	***September 2022***
FLUKA 4-3.1	*December 2022*
FLUKA 4-3.2	*March 2023*
FLUKA 4-3.3	*May 2023*
FLUKA 4-3.4	*September 2023*
FLUKA 4-4	***February 2024***
FLUKA 4-4.1	*July 2024*
FLUKA 4-5	***January 2025***

The most recent reference

New Capabilities of the FLUKA Multi-Purpose Code

C. Ahdida[1], D. Bozzato[1,2], D. Calzolari[1], F. Cerutti[1]*, N. Charitonidis[1], A. Cimmino[3], A. Coronetti[1,4], G. L. D'Alessandro[1], A. Donadon Servelle[1,5], L. S. Esposito[1], R. Froeschl[1], R. García Alía[1], A. Gerbershagen[1], S. Gilardoni[1], D. Horváth[3], G. Hugo[1], A. Infantino[1], V. Kouskoura[1], A. Lechner[1], B. Lefebvre[3], G. Lerner[1], M. Magistris[1], A. Manousos[1,6], G. Moryc[1], F. Ogallar Ruiz[1,7], F. Pozzi[1], D. Prelipcean[1,8], S. Roesler[1], R. Rossi[1], M. Sabaté Gilarte[1], F. Salvat Pujol[1], P. Schoofs[1], V. Stránský[3], C. Theis[1], A. Tsinganis[9], R. Versaci[3], V. Vlachoudis[1], A. Waets[1] and M. Widorski[1]

ORIGINAL RESEARCH article

Front. Phys., 27 January 2022 | https://doi.org/10.3389/fphy.2021.788253

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[4]Department of Physics, University of Jyväskylä, Jyväskylä, Finland
[5]Ecole Polytechnique Fédérale de Lausanne, Institute of Physics, Lausanne, Switzerland
[6]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[7]Department of Atomic, Molecular and Nuclear Physics, University of Granada, Granada, Spain
[8]Department of Physics, Technical University of Munich (TUM), Munich, Germany
[9]European Commission, Joint Research Centre (JRC), Geel, Belgium

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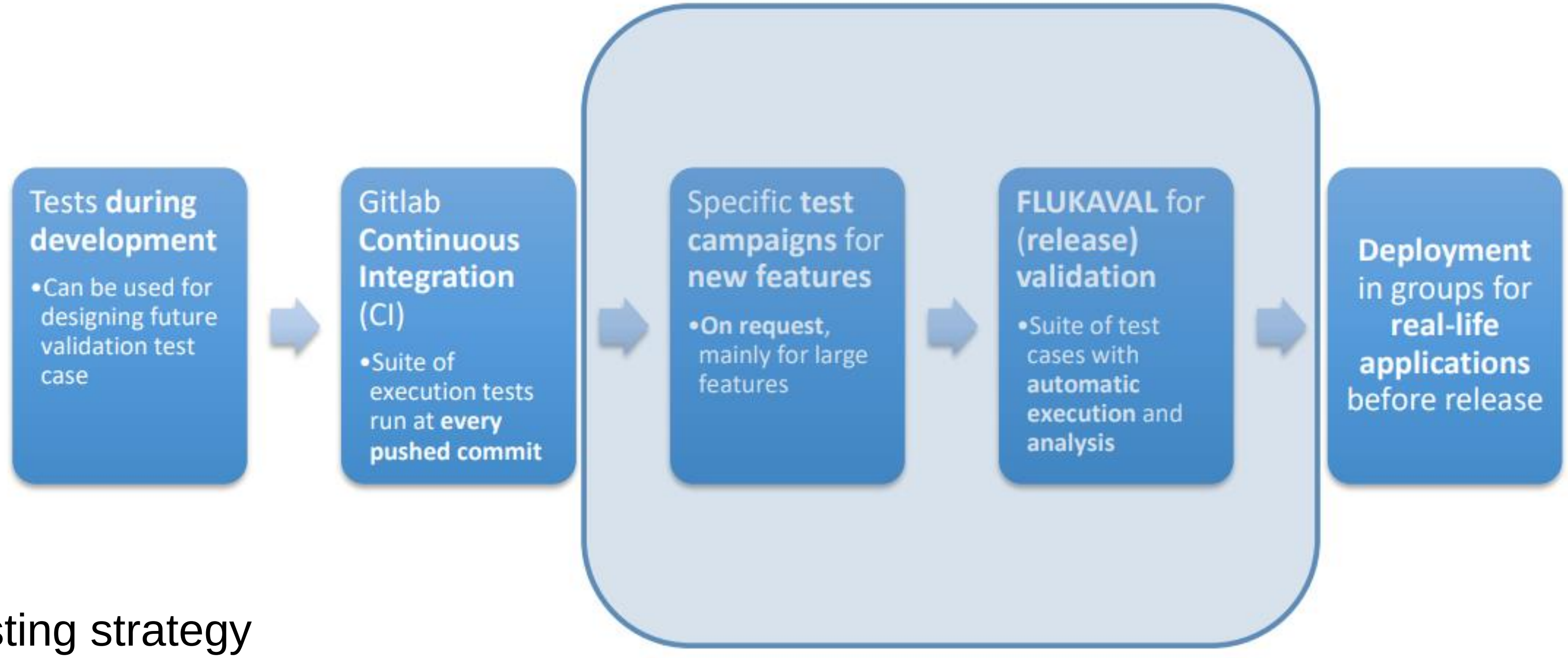
- Please always check the FLUKA.CERN website for the updated list of references that should be cited in publications: https://fluka.cern/documentation/references

Quality assurance



- Multi-layered testing strategy
- Dedicated validation suite, called FLUKAVAL, with several hundreds test cases and detailed reports prior to public release
- *Regression checks among releases*, benchmarks against experimental data, MC results inter-comparisons
- Generic infrastructure: FLUKA v4 and *v5* support

User Support

FLUKA User Forum

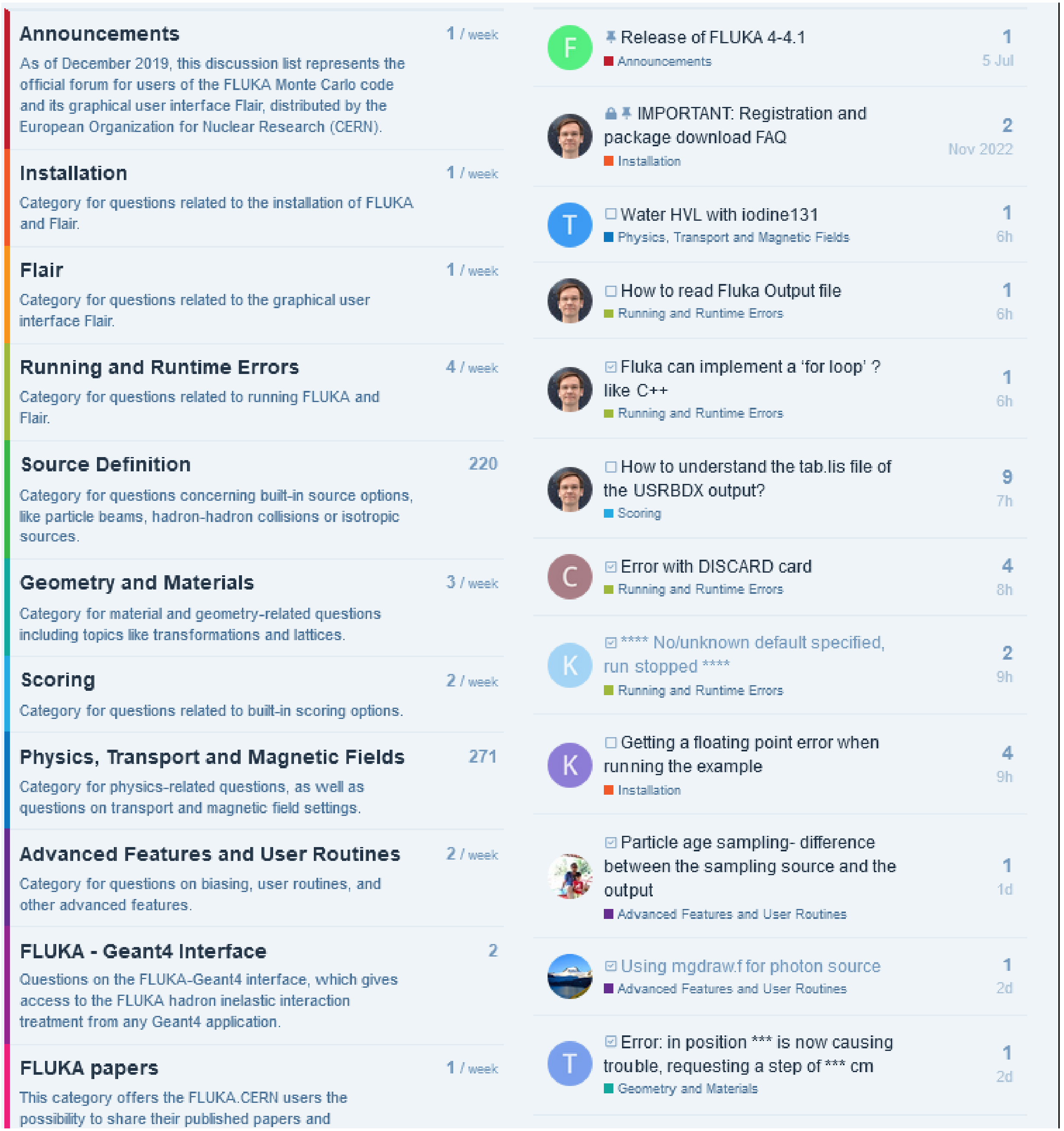
https://cern.ch/fluka-forum

Note: an independent one-time registration is required to be able to participate

FLUKA Training

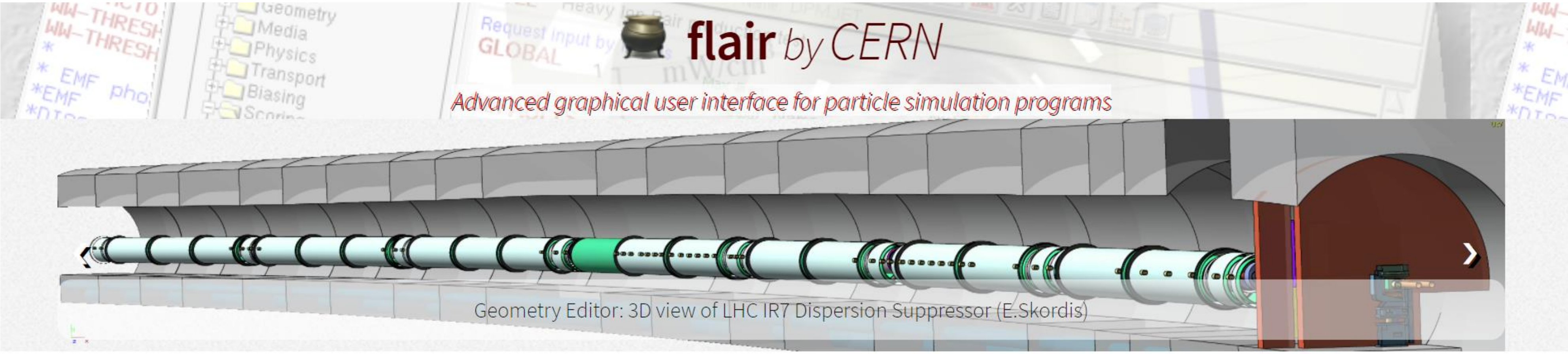
https://indico.cern.ch/category/9178

- Beginner and advanced courses are held on a regular basis across the world
- The first topical course (on Radiation Protection) was held last week



Flair

https://flair.cern



Geometry Editor: 3D view of LHC IR7 Dispersion Suppressor (E.Skordis)


Head CT with PET CT dose distribution

Authors

authors: Vasilis Vlachoudis *(lead author)*
Christian Theis
Wioletta Kozlowska

Current Version

- Latest version: **3.3-1**
- Released on: ***Tue 05-Mar-2024***
- Powered by python**3**, tkinter, gnuplot, pydicom

Features

- modern and intuitive design
- Input editor for error free inputs
- Interactive geometry editor, photorealistic ray tracer and debugger
- run and monitor the simulation
- back-end for post-processing of results
- I/O of other simulation formats (MCNPX,GDML,...)
- Medical file importing, DICOM, RT-PLAN,DOSE,...
- extended material library

Microscopic process modeling for macroscopic quantity assessment

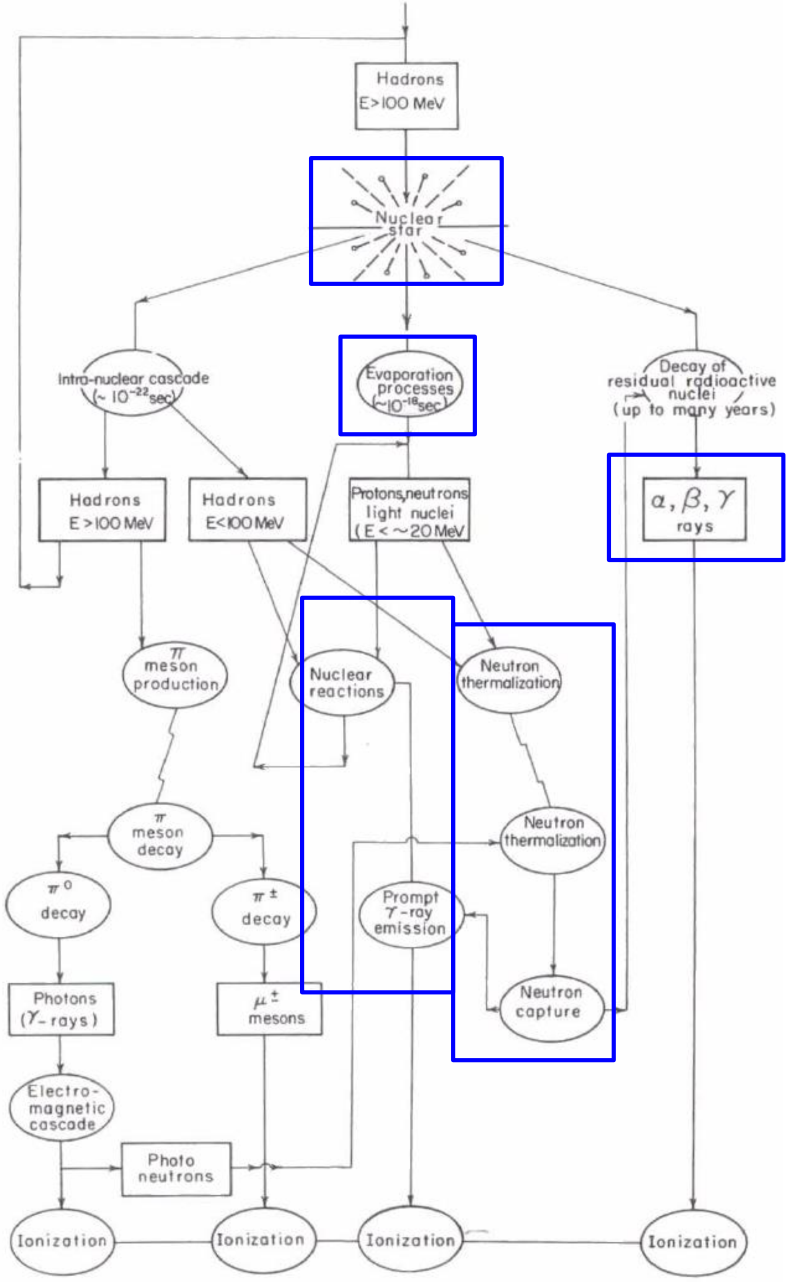
A (hadronic) shower implies a lot of different physics processes, touching a very broad energy [time-space] scale

Its description relies on the organic integration of diverse **theories and models**, and requires as essential pieces of **information**:

- reaction cross sections
- exclusive fragment production
- nuclide structure and decay data
- evaluated quantities of neutron induced reactions

Monte Carlo simulation is an effective way to calculate macroscopic quantities (such as energy deposition, dpa, particle fluence, activation and residual dose rate) with an accuracy reflecting the quality of the implementation of critical processes

Multipurpose codes are widely available: FLUKA, GEANT4, MCNP, PHITS, MARS...



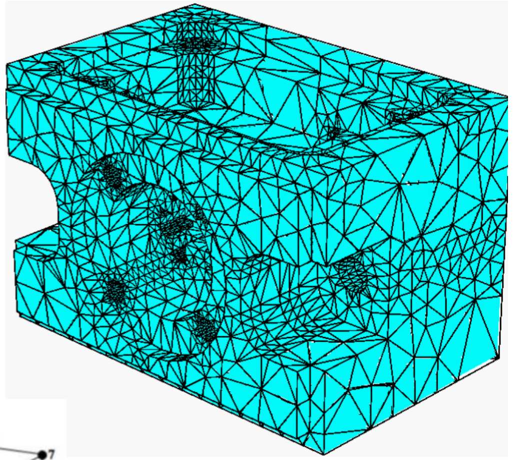
FLUKA capabilities

- hadron-hadron and hadron-nucleus interactions
- nucleus-nucleus interactions (including deuterons!)
- photon interactions (>100 eV)
- electron interactions (> 1 keV; including electronuclear)
- muon interactions (including photonuclear)
- neutrino interactions
- low energy (<20 MeV) neutron interactions and transport
- particle decay
- ionization and multiple (single) scattering (including all ions down to 1 keV/u)
- coherent effects in crystals (channelling)
- magnetic field, and electric field in vacuum
- combinatorial geometry and lattice capabilities
- voxel geometry and DICOM importing
- analogue or biased treatment
- on-line buildup and evolution of induced radioactivity and dose
- built-in scoring of several quantities (including DPA and dose equivalent)

In support of a
wide range of applications

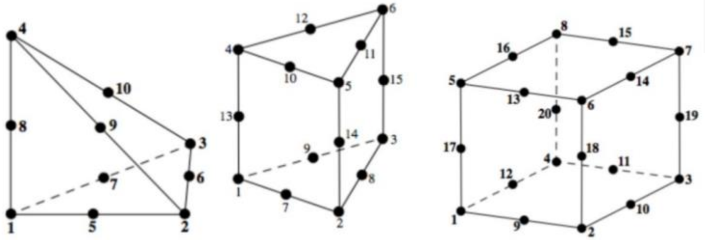
✓Accelerator design
✓Particle physics
✓Cosmic ray physics
✓Neutrino physics
✓Medical applications
✓Radiation protection (shielding design, activation)
✓Dosimetry
✓Radiation damage
✓Radiation to electronics effects
✓ADS systems, waste transmutation
✓Neutronics

Next release (early 2025):
Unstructured mesh geometries [I]



Unstructured mesh is a tessellation of the Euclidean space by simple solids, such as tetrahedra, in an irregular pattern (different sizes and shapes).

Supported solids are *tetra-, penta-, hexahedra of 1st order*.



(a) Tetrahedron (b) Pentahedron (c) Hexahedron

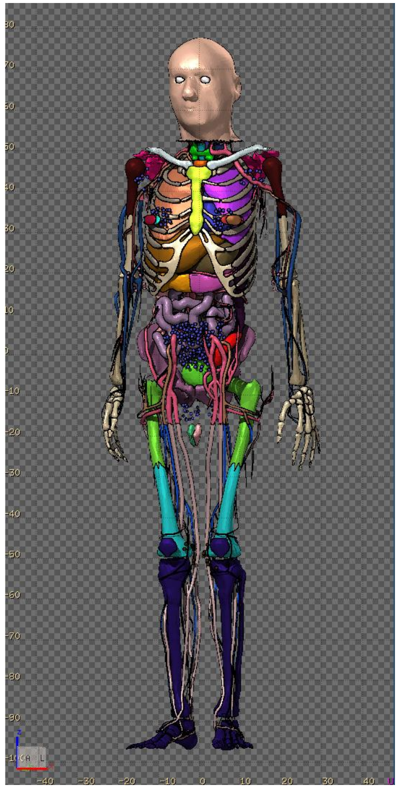
Supported input formats:

TetGen (used by PHITS)

Abaqus (used by MCNP6)

ANSYS (used by ANSYS FEM)

Or a combination of them!



ICRP P145 phantom
(initialization < 10 s)

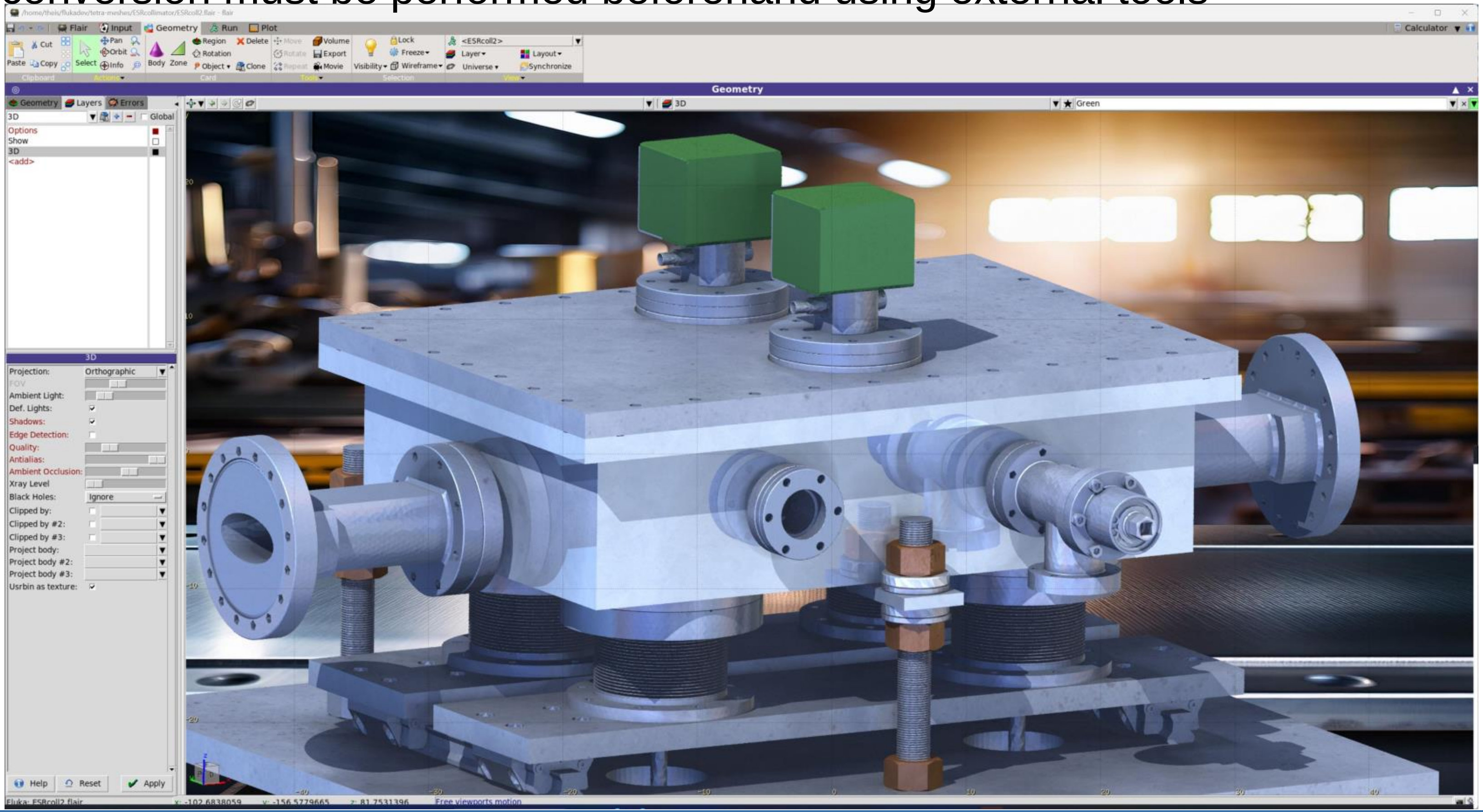
Next release (early 2025): Unstructured mesh geometries [II]

For **CAD models** until now: support via fluDAG interface only (CAD models → Cubit → DAGMC → FluDAG);

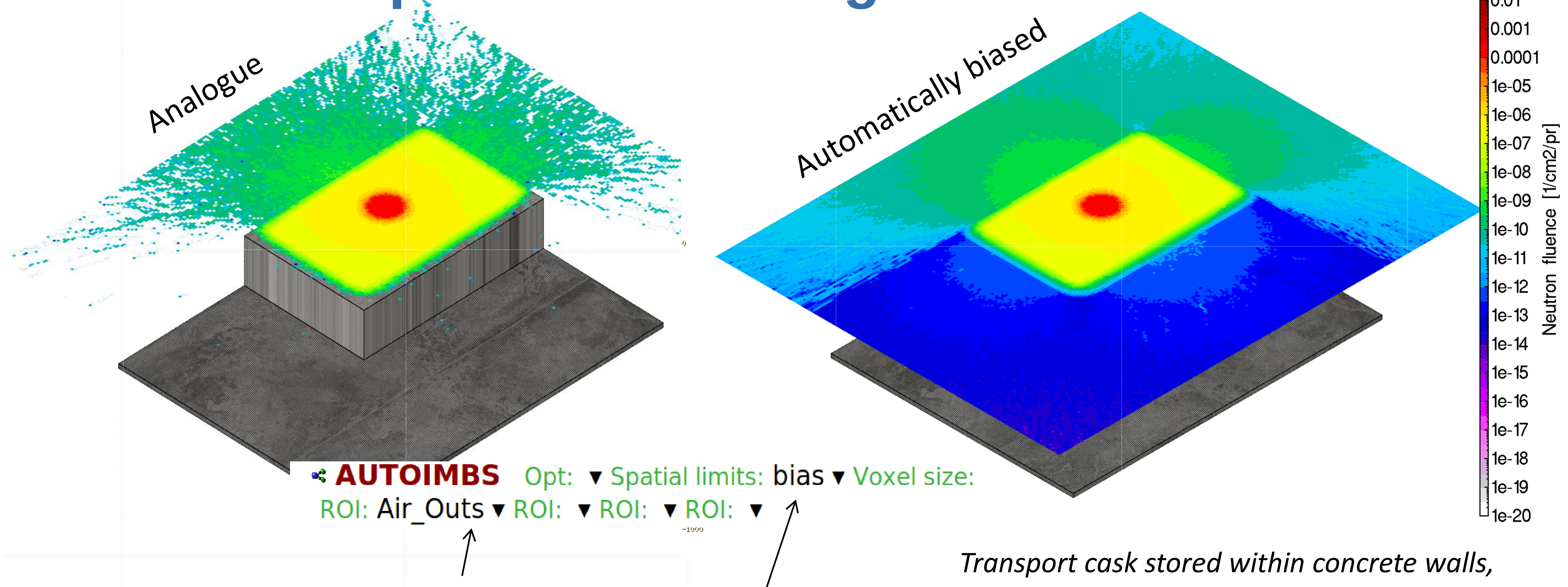
from now on: also supported via unstructured meshes!

Note that a CAD → unstructured mesh conversion must be performed beforehand using external tools (gmesh, TetGen, ANSYS, Cubit, Attila4MC, ...).

Performance: *~20% overhead* versus simplified CGs in the tested studies.



Next release (early 2025): Automatic Importance Biasing



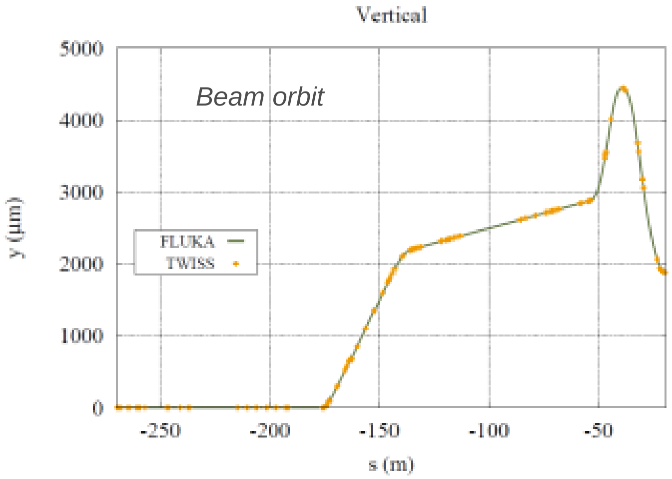
Region surrounding the room

Surface enclosing the geometry

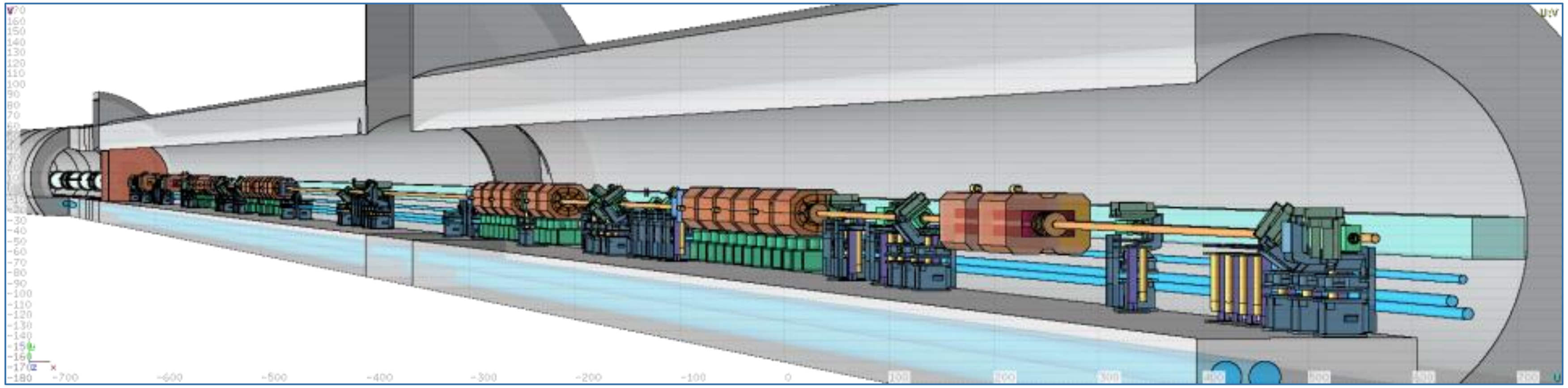
Transport cask stored within concrete walls, neutron source filling the cask

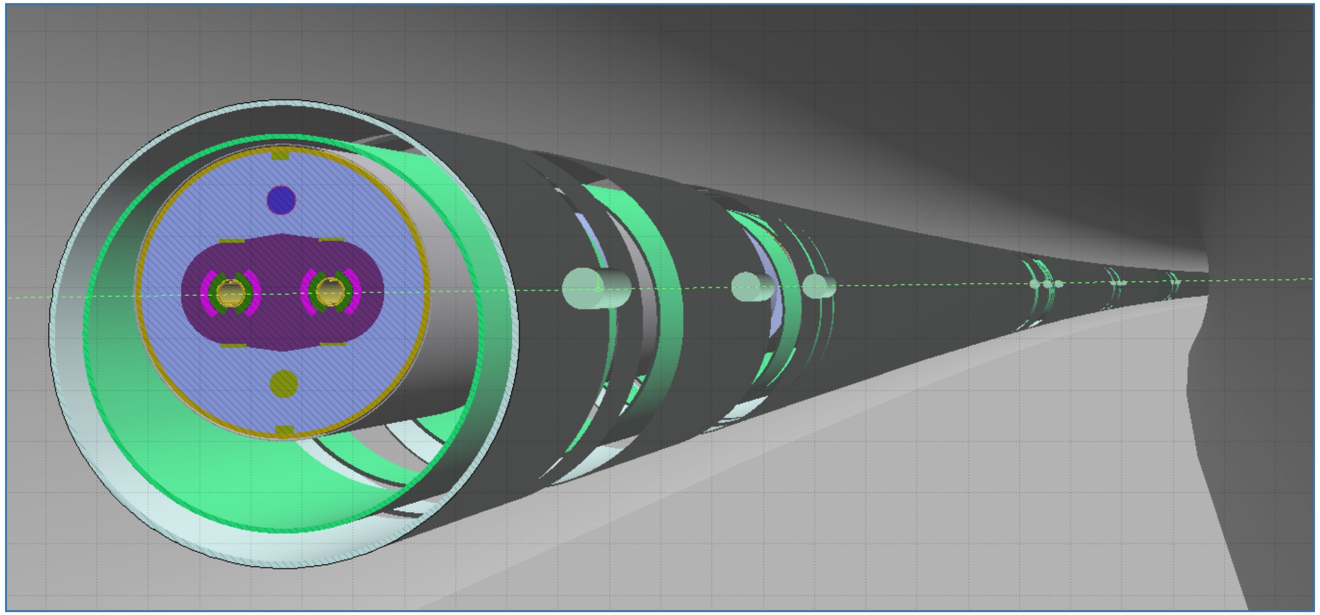
Some examples

Accelerator geometries



LHC IR7 long straight section





From **detailed models of accelerator components with associated scoring** and the **element sequence and respective magnetic strengths**, as given in the **machine optics (twiss) files**…

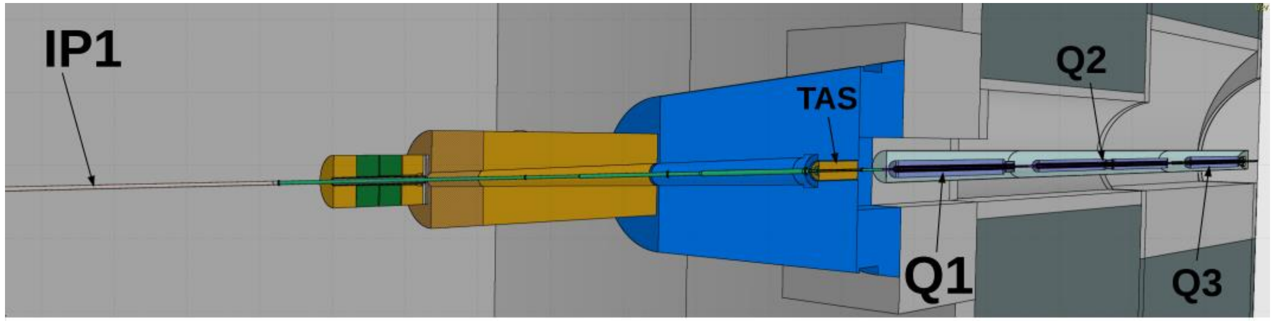
…the **automatic construction of complex beam lines**, including collimator settings and element displacement (BLMs), is achievable, profiting from roto-translation directives and replication (lattice) capabilities.

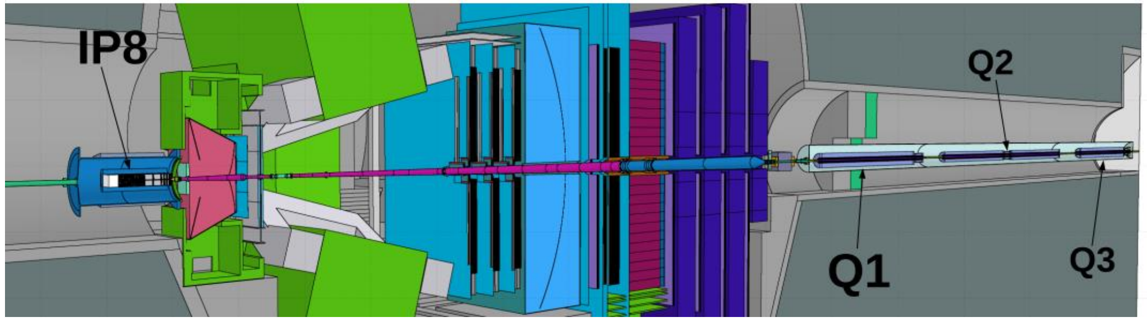
LINE BUILDER

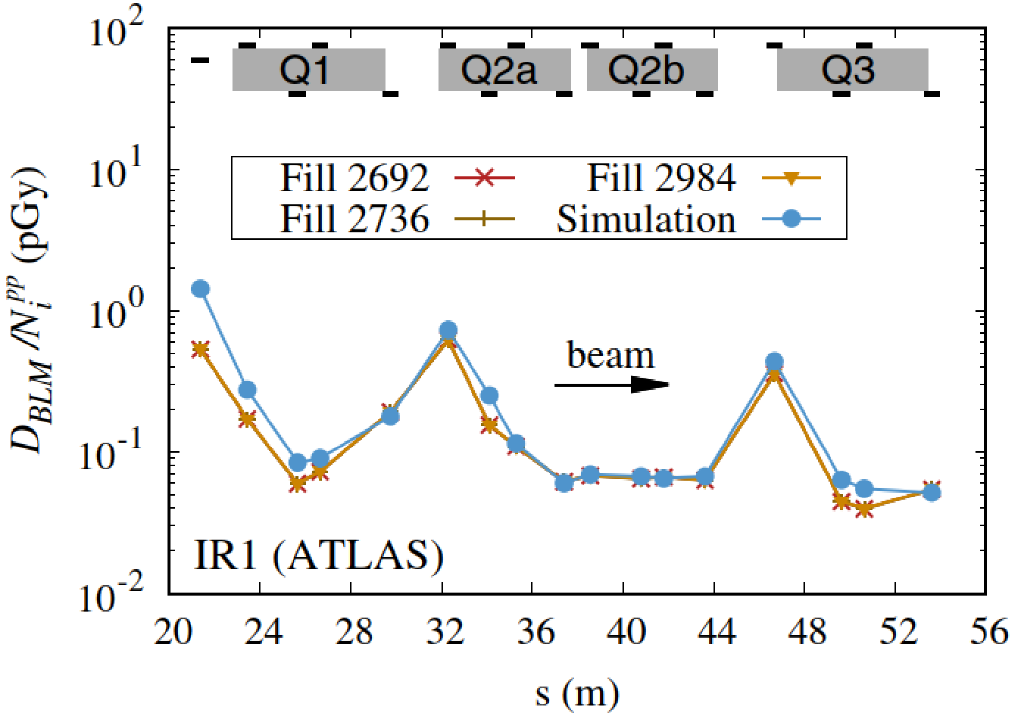
[A. Mereghetti et al., IPAC2012, WEPPD071, 2687]
cds.cern.ch/record/1481554

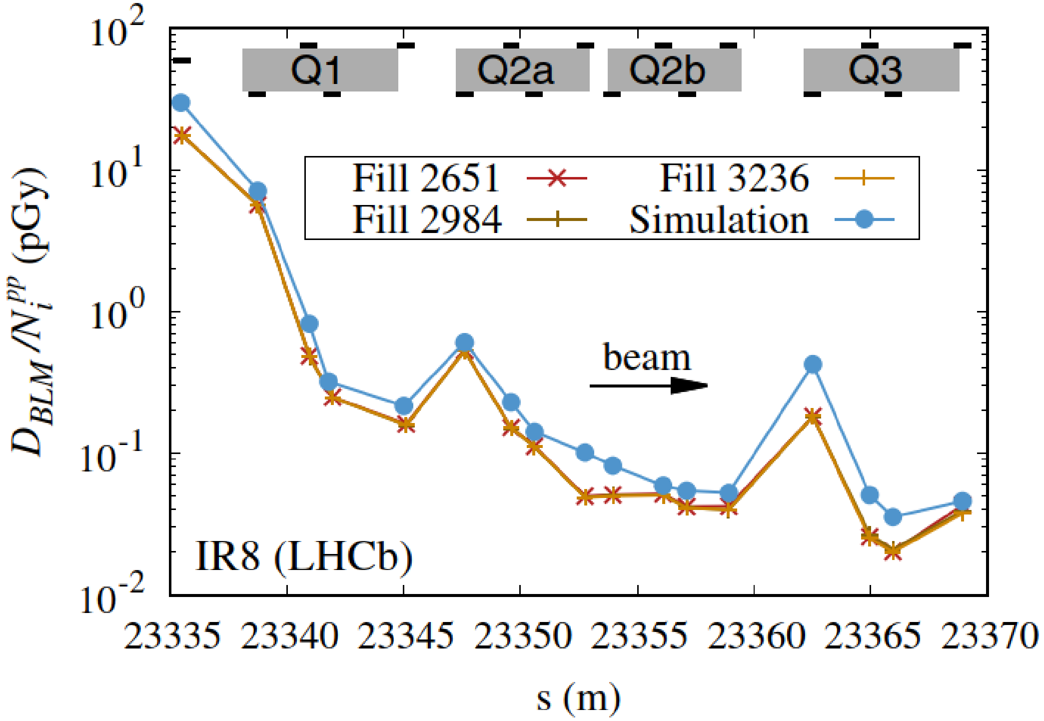
Beam loss description at the LHC

[A. Lechner et al.,
Phys. Rev. AB 22 (2019) 071003]









Activation benchmarking

https://doi.org/10.1080/00223131.2023.2239243

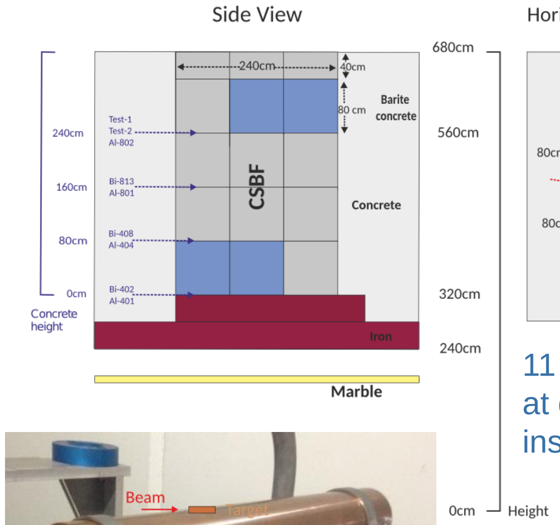
@ **C**ERN **S**HIELDING **B**ENCHMARK **F**ACILITY (24 GeV/c p)

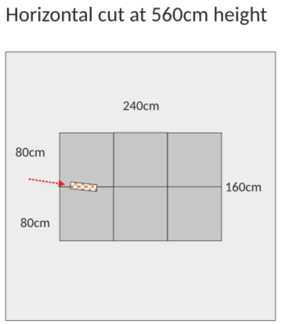
Situated laterally above the CHARM target

for deep shielding penetration studies (Detector calibration, Detector inter-comparison, Activation)

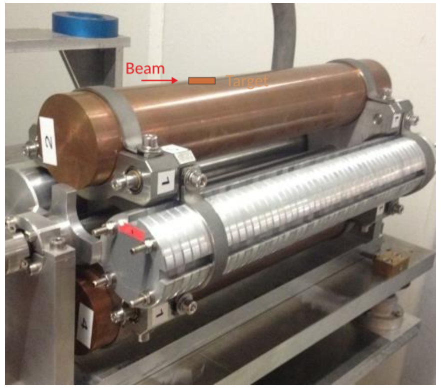
360cm of concrete and barite concrete

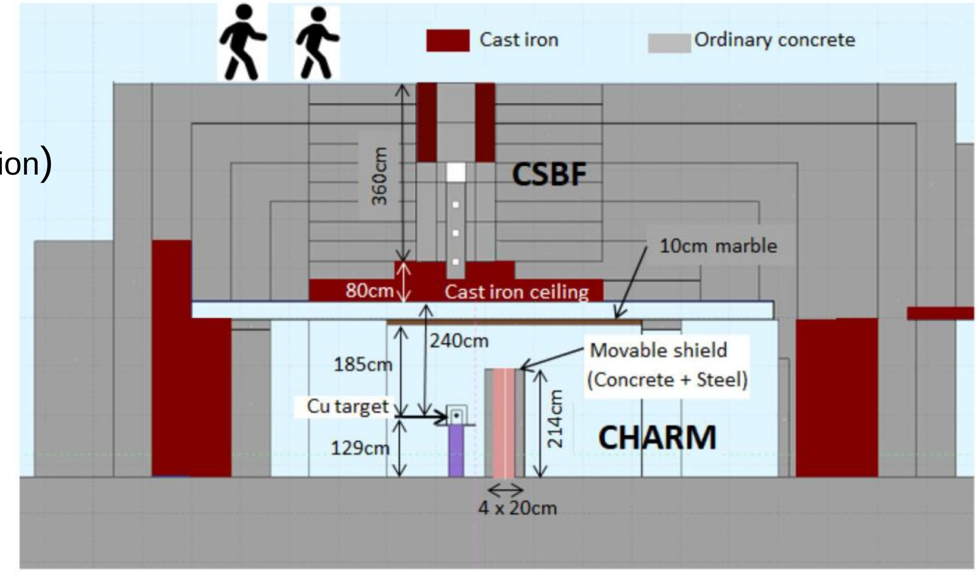
plus 80cm of cast iron

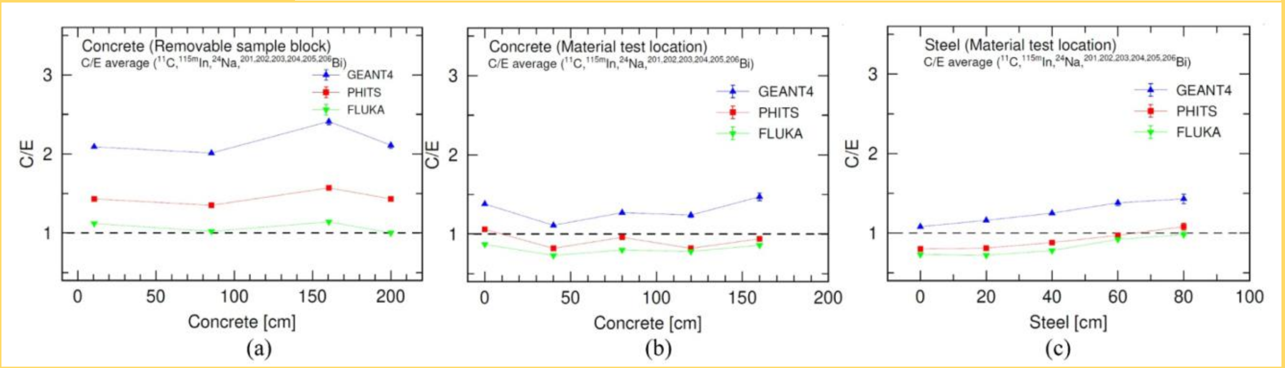




11 Bismuth and Aluminum samples at different heights in CSBF and also inside CHARM (@ -80cm)







@ **CHARM** (**C**ERN **H**igh energy **A**ccele**R**ator **M**ixed field facility,

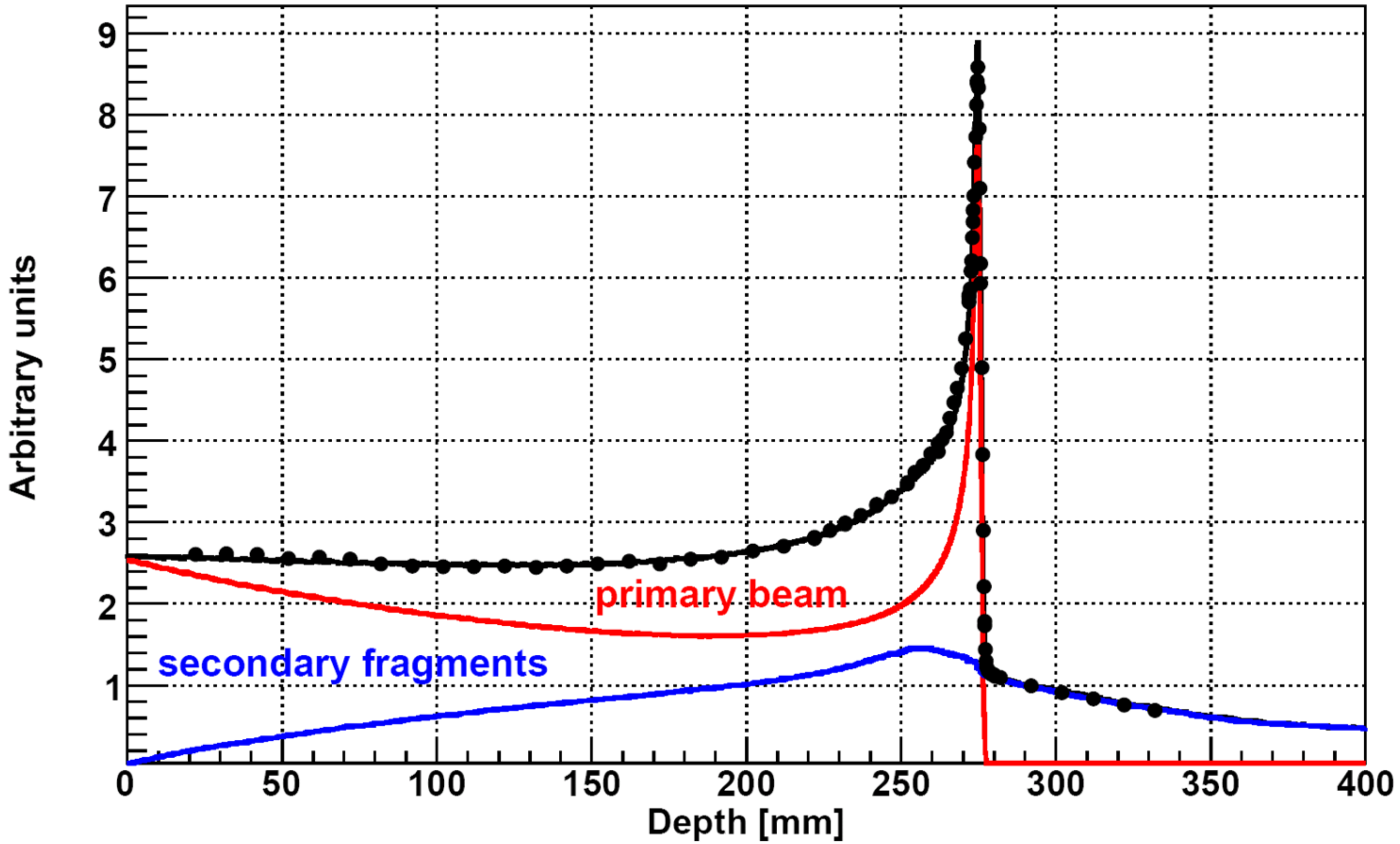
to study radiation effects on electronic components)

R2E

5 x 10^{11} protons/pulse, 350ms pulse length, max. average beam intensity 6.6 x 10^{10} p/s

three 50cm long 8cm diameter targets: Copper, Aluminum, Aluminum with holes

Medical physics: radiotherapy



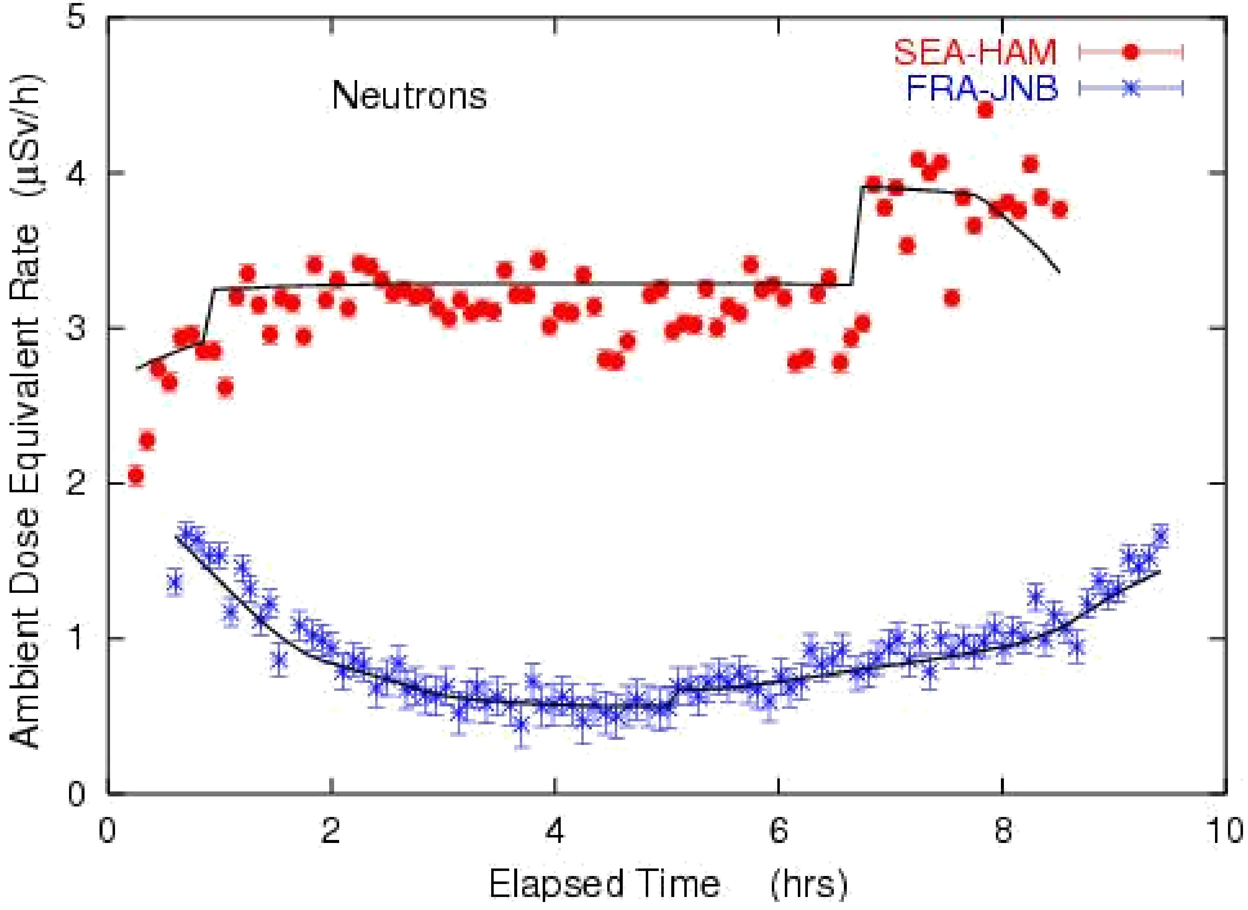
Bragg peak in a water phantom
400 MeV/A C beam:
The importance of fragmentation

[Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 122 (1-4) (2006) pp 485-487
Simulation: A. Mairani PhD Thesis (2007) and G. Battistoni et al., Nuovo Cimento C 31 (2008) pp 69-75]

Dosimetry and cosmic rays

- Complete simulation of cosmic ray interactions in the atmosphere, by means of a dedicated CR package available to users
- Model of airplane geometry
- Response of dosimeters

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



[Data: V. Mares, et al., NIM A 476 (2002), pp 341–346
Solid lines: FLUKA simulation
S. Roesler et al., Rad. Prot. Dosim. 98 (2002) pp 367-388]

Course programme

Course programme

- A very hands-on course
- Almost all lectures come with an attached exercise session
- The course is Flair-based
- Plenty of opportunities to practice the workflow
- The entire teacher team is available to offer assistance during the exercise sessions
- All exercise solutions are explained and provided

Schedule of the week

8	9	10	11	12	13	14	15	16	17	18

Day											
Monday	Registra-tion	Introduction to FLUKA	T+P Introduction	Monte Carlo Basics	Coffee	Basic Input / Introduction to Flair	Lunch	Geometry I	Geometry I	Coffee	Materials	Materials
Tuesday	Scoring I : Intro & USRBIN	Scoring I : Intro & USRBIN	Coffee	Geometry Editor	Geometry Editor	Lunch	Simple Sources	Simple Sources	Coffee	EM fields	EM fields	
Wednesday	EM & Thresholds	EM & Thresholds	Coffee	Biasing	Biasing	Lunch	Scoring II: Diff. Spec.	Scoring II: Diff. Spec.	Coffee	Standard Output and Errors	Standard Output and Errors	
Thursday	Neutronics	Neutronics	Coffee	Hadron Physics	Geometry II	Lunch	Geometry II	Source Routine	Coffee	Source Routine		
Friday	Radioprotection and Activation	Radioprotection and Activation	Coffee	Wrap Up Exercise	Lunch	Course Evaluation	Advanced Topics	Coffee	Visit of CERN facilities			

In conclusion

- While a beginner course, by the end of the week you will be able to tackle even not-so-simple problems

- Let us know of any technical/installation problems ASAP

- Do not hesitate to ask questions and to ask for help! ☺

FLUKA