The FLUKA Code

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

FLUKA Beginner’s Course
FLUKA

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6 GeV proton in Liquid Argon
Low E. neutron int.

h-A interaction

E-M showers

Decay

Multiple Scattering

dE/dx and δ

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>5000 users

http://www.fluka.org
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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

Diagram of LHC Loss Regions:

Regions of high losses (e.g., Collimators, ...)
Regions with low losses (e.g., due to residual gas)

ATLAS
Regions with low losses (e.g., due to residual gas)

ALICE

LHCb

Momentum Cleaning

RF

CMS

Point 1

Point 2

Point 3.3

Point 3.2

Point 4

Point 5

Point 6

Point 7

Point 8

LHC Dump

Betatron Cleaning

Graph showing arbitrary units against distance Z (cm).
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
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

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 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**
  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:

- Beam hole: \( \phi = 77.2 \text{ mm} \)
- Measuring holes: \( \phi = 64 \text{ mm} \)

- Hole number
- Hole distance to beam axis

Standard Block Weight = 613 kg

Building Block:
- Block type 1:
  - 390
- Block type 2:
  - 24\times5
- Block type 3:
  - 14\times5

Space for neutron absorbing blanket

Dimensions:
- 5.0 m
- 44 cm
- 30 cm
- 60 cm
The TARC experiment: neutron spectra

FLUKA + EA-MC (C. Rubbia et al.)
Test quench induced by the wire scanner on 2010 Nov 1 on the left of P4 at 3.5TeV
Applications – *LHC collimation region*

The LHC Loss Regions

- Regions of high losses (e.g., Collimators, …)
- Regions with low losses (e.g., due to residual gas)

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**FLUKA geometry visualized with SimpleGeo**
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
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

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

Muons in muon pits: horiz. distribution for beam alignment

CNGS cible, 4 mm dia .53 mm sigma

ν CC events at GranSasso

CNGS 1 mm beam displacement

- 1st muon pit
- 2nd muon pit X 100
Applications – CNGS

Example:

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

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)

Samples in contact with a 50 cm long, 7 cm diameter copper target, centred on the beam axis.
Test of instrumentation: Beam Loss Monitors at CERF

CERN setup

BLM's positions

CERN-EN-NOTE-2010-002-STI
CERF particle spectra

Neutron spectra

Ch. Had. and $\gamma$

BLM 1

CERF particle spectra

Ch. Had. and $\gamma$

BLM 6
(3D) Calculation of Atmospheric $\nu$ 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 $\nu_\mu$, $\bar{\nu}_\mu$, $\nu_e$, $\bar{\nu}_e$

In red: 1-D calculation
Negative muons at floating altitudes: CAPRICE94

Open symbols: CAPRICE data
Full symbols: FLUKA

primary spectrum normalization ~AMS-BESS
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:
Dosimetry Applications


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

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. 2006
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, $\Delta T_1 \sim 26$ min, $\Delta T_2 \sim 16$ min

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