The FLUKA Monte Carlo code

Giuseppe Battistoni
INFN Milano

Overview:

Assumption:

- We presume that you are familiar with Monte Carlo foundations, Sampling techniques, Statistical issues

1) The FLUKA code

- History, general content, design criteria
- Distribution and licensing
- Short review of applications
- A few words on physics models
- The FLUKA geometry

2) Learning how to run FLUKA code

- Running FLUKA with Flair: the graphical user interface

3) The application to particle therapy

- The relevant physics
- The voxel geometry
- Import of CT scans
- Treatment Planning and PET in-beam, examples
- Simulation of instruments

Running examples

Disclaimer

- A good MC 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

  - Knows physics
  - Understand at the least the basic content of physics moldes in the code
  - Has a critical judgment on the results

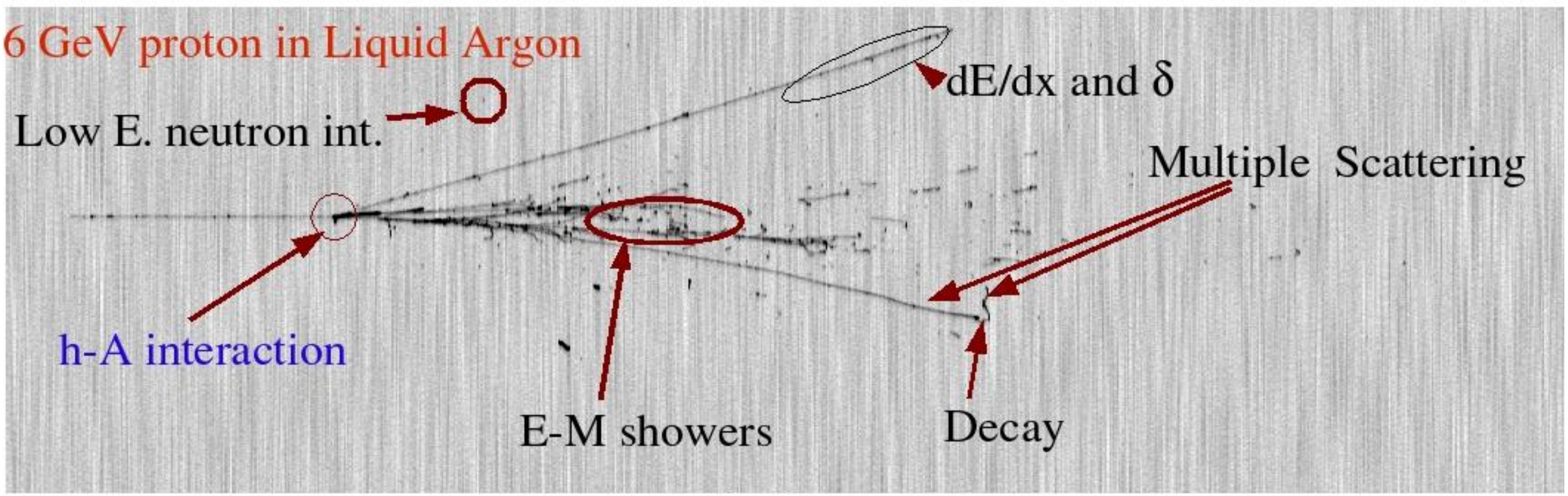
The FLUKA Code

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

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,



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>4000 users

http://www.fluka.org

The FLUKA international Collaboration

T. Boehlen, M. Brugger, F. Cerutti, M. Chin, Alfredo Ferrari, A. Lechner, A. Mereghetti, S. Roesler, G. Smirnov, C. Theis, R. Versaci, Heinz Vincke, Helmut Vincke, V. Vlachoudis, J.Vollaire, CERN

A. Fassò, Jefferson Lab, USA

J. Ranft, Univ. of Siegen, Germany

G. Battistoni, F. Broggi, M. Campanella, F. Cappucci, E. Gadioli, S. Muraro, 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 La Sapienza, Ital

. 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, HIT, Heidelberg, Germany

L. Lari, Univ. of Valencia, Spain

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

V. Boccone, Univ. of Geneva, Switzerland

K.T. Lee, T. Wilson, N. Zapp, NASA-Hous

S. Rollet, AIT, Austria

M. Lantz, Uppsala Univ., Sweden

S. Trovati, PSI, Switzerlanc

G. Lukasik, Poland

P. Colleoni, Ospedali Riuniti di Bergamo, Italy

V. Garzelli, Nova Gorica Univ., Slovenia

Anna Ferrari, FZR Rossendorf, Germany

The FLUKA web site (www.fluka.org)

FLUKA

CERN INFN

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Last version:

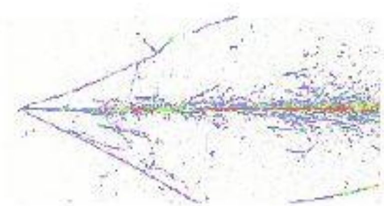
FLUKA 2011.2.13, May 15th 2012
(last respin)
FLAIR 0.9.5

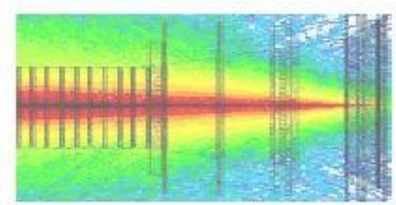
News:

Fluka Release
(*16.05.2012*)
FLUKA 2011.2.13 has been released.

A A A

FLUKA is a fully integrated particle physics MonteCarlo simulation package. It has many applications in high energy experimental physics and engineering, shielding, detector and telescope design, cosmic ray studies, dosimetry, medical physics and radio-biology.

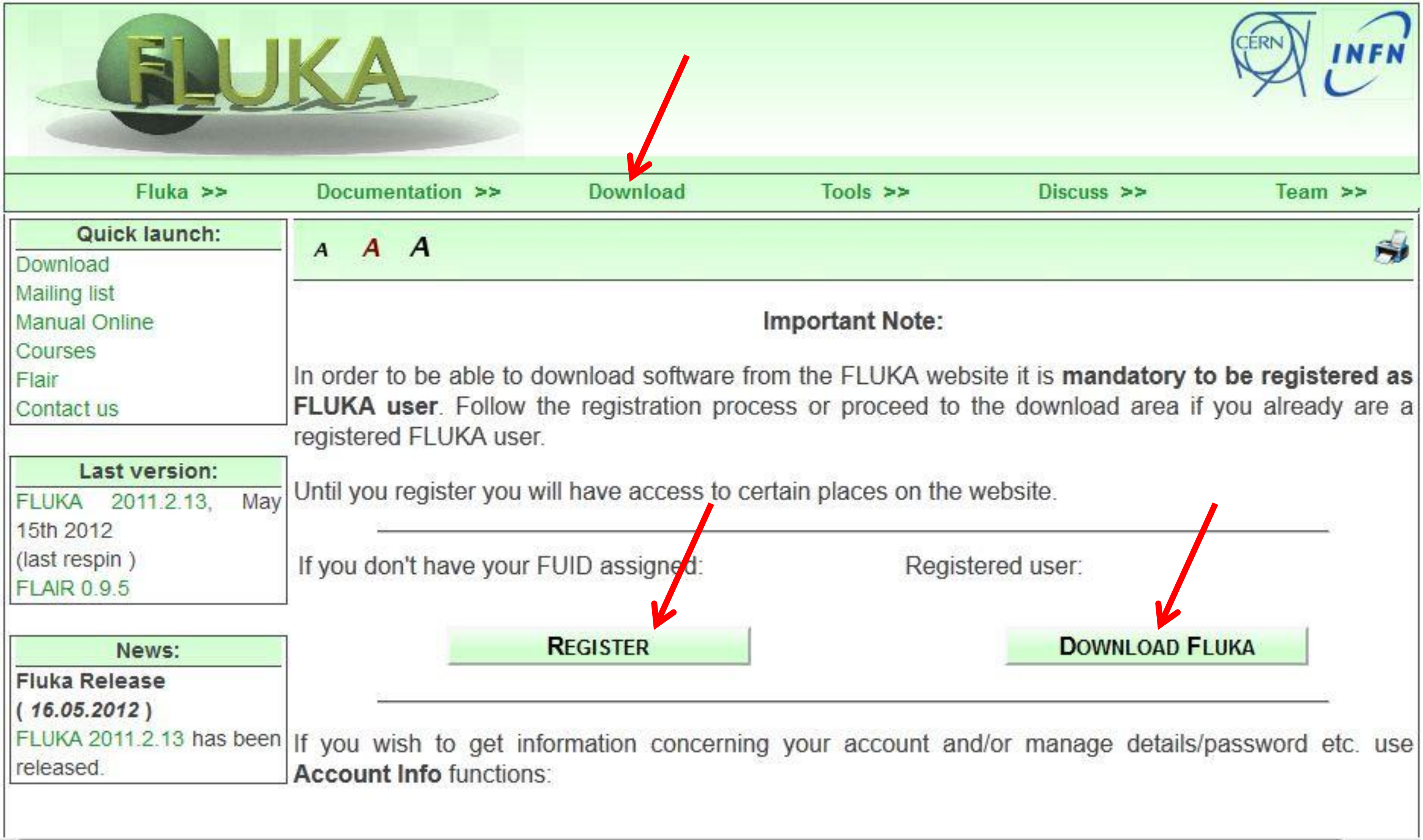




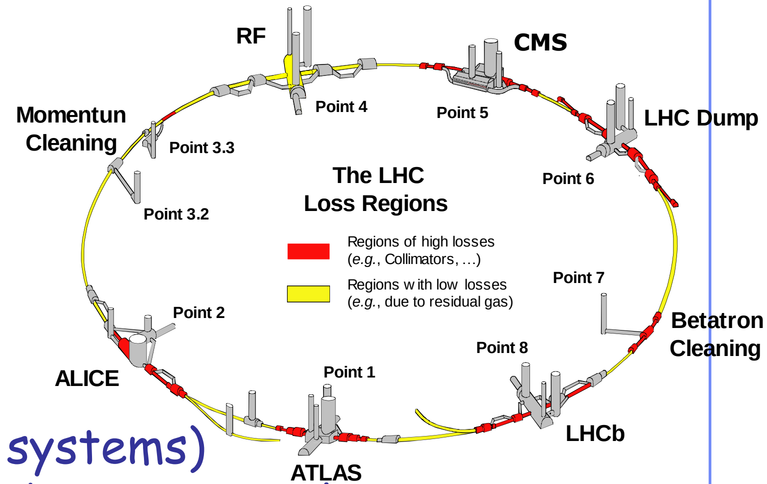
For more info see for about page and manuals.

Last updated: 21st of May, 2010

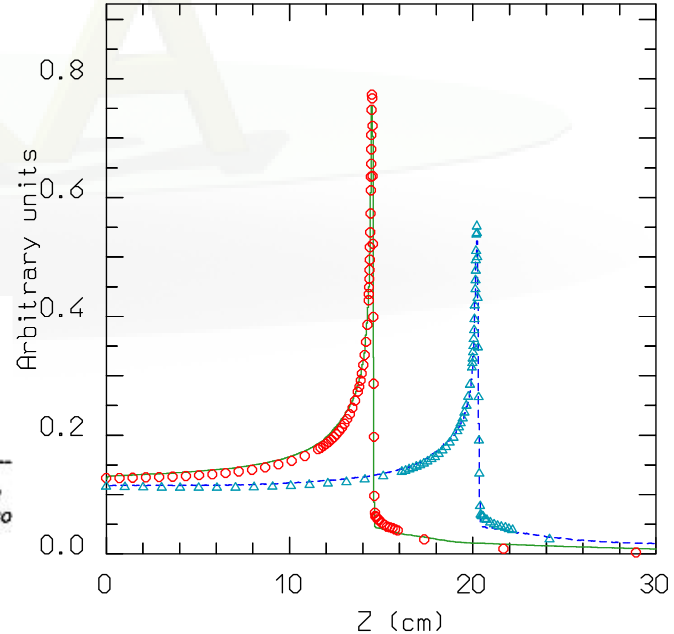
Registering and downloading FLUKA

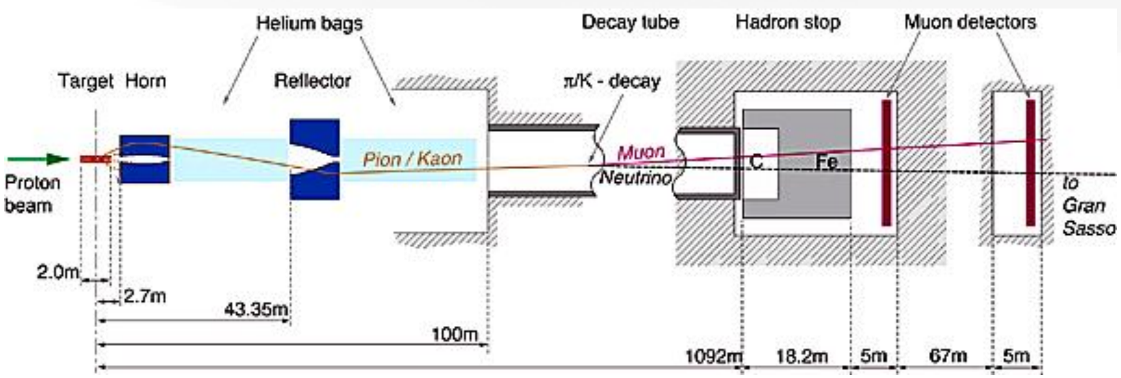


FLUKA Applications



- 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
- Space radiation
- Hadrontherapy
- 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, with the possibility use of single instead of multiple scattering

The FLUKA Code design - 2

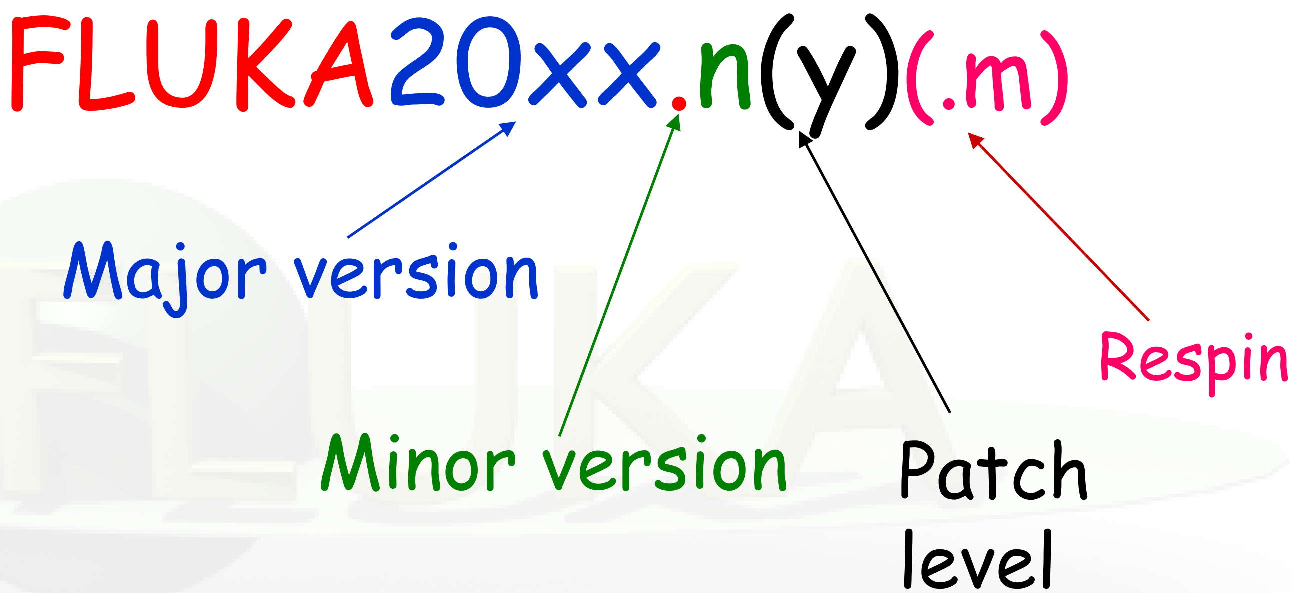
- Self-consistency
  - Full cross-talk between all components: hadronic, electromagnetic, neutrons, muons, heavy ions
  - Effort to achieve the same level of accuracy:
    - for each component
    - for all energies
  - → Correlations preserved fully within interactions and among shower components
  - → *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**

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 FLUKA2011.2

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 (only version > 4.5)

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

Code complexity

- Inelastic h-N: ~*72000 lines*
- Cross sections (h-N and h-A), and elastic (h-N and h-A): ~*32000 lines*
- (G)INC and preequilibrium (PEANUT): ~*114000 lines*
- Evap./Fragm./Fission/Deexc.: ~*27000 lines*
- ν-N interactions: ~*35000 lines*
- A-A interactions:
  - ✓ FLUKA native (including BME): ~*8000 lines*
  - ✓ DPMJET-3: ~*130000 lines*
  - ✓ (modified) rQMD-2.4: ~*42000 lines*

- **FLUKA** in total (including transport, EM, geometry, scoring): ~*680000 lines*
- … + ~*20000 lines* of ancillary off-line codes used for data pre-generation
- … and ~*30000 lines* of post-processing codes

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

SOMETHING ABOUT THE PHYSICS CONTENT OF FLUKA

The FLUKA hadronic model(s)

Hadron-Hadron			
Elastic, exchange Phase shifts data, eikonal	P<3-5GeV/c Resonance prod and decay	low E π, K Special	High Energy DPM hadronization

Hadron-Nucleus

PEANUT
Sophisticated GINC
Gradual onset of Glauber-Gribov multiple interactions
Preequilibrium
Coalescence

Nucleus-Nucleus

E< 0.1GeV/u	0.1< E< 5 GeV/u	E> 5 GeV/u
BME Complete fusion+ peripheral	rQMD-2.4 modified new QMD	DPMJET DPM+ Glauber+ GINC

Evaporation/Fission/Fermi break-up
γ deexcitation

The Nuclear environment: PEANUT

Pre**E**quilibrium **A**pproach to **NU**clear **T**hermalization

- PEANUT handles hadron-nucleus interactions from threshold (or 20 MeV neutrons) ~~up to 5 GeV~~ NEW

Sophisticated Generalized IntraNuclear Cascade

Smooth transition (all non-nucleons emitted/absorbed/decayed + all secondaries below 30-50 MeV)

↓

Prequilibrium stage

Standard Assumption on exciton number or excitation energy

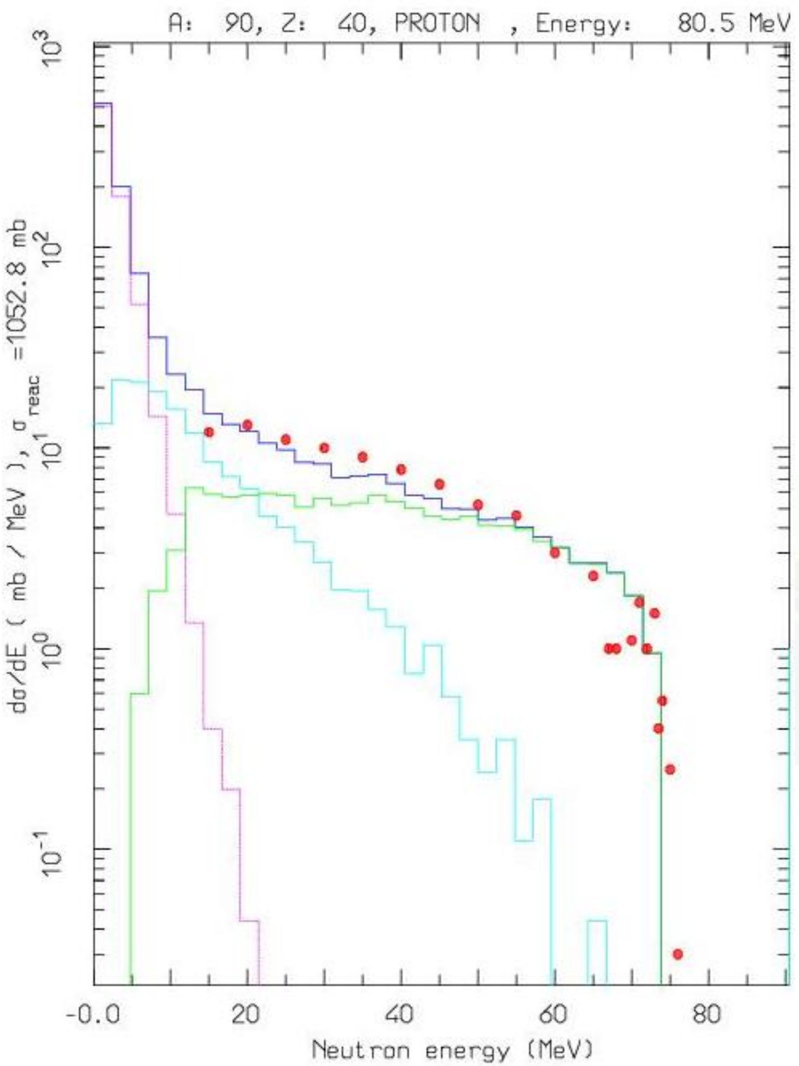
↓

Common FLUKA Evaporation/fission/fragmentation model

Peanut has proven to be a precise and reliable tool for intermediate energy hadron-nucleus reactions

Its "nuclear environment" is also used in the modelization of (real and virtual) photonuclear reactions, neutrino interactions, nucleon decays, muon captures..

Thin target example



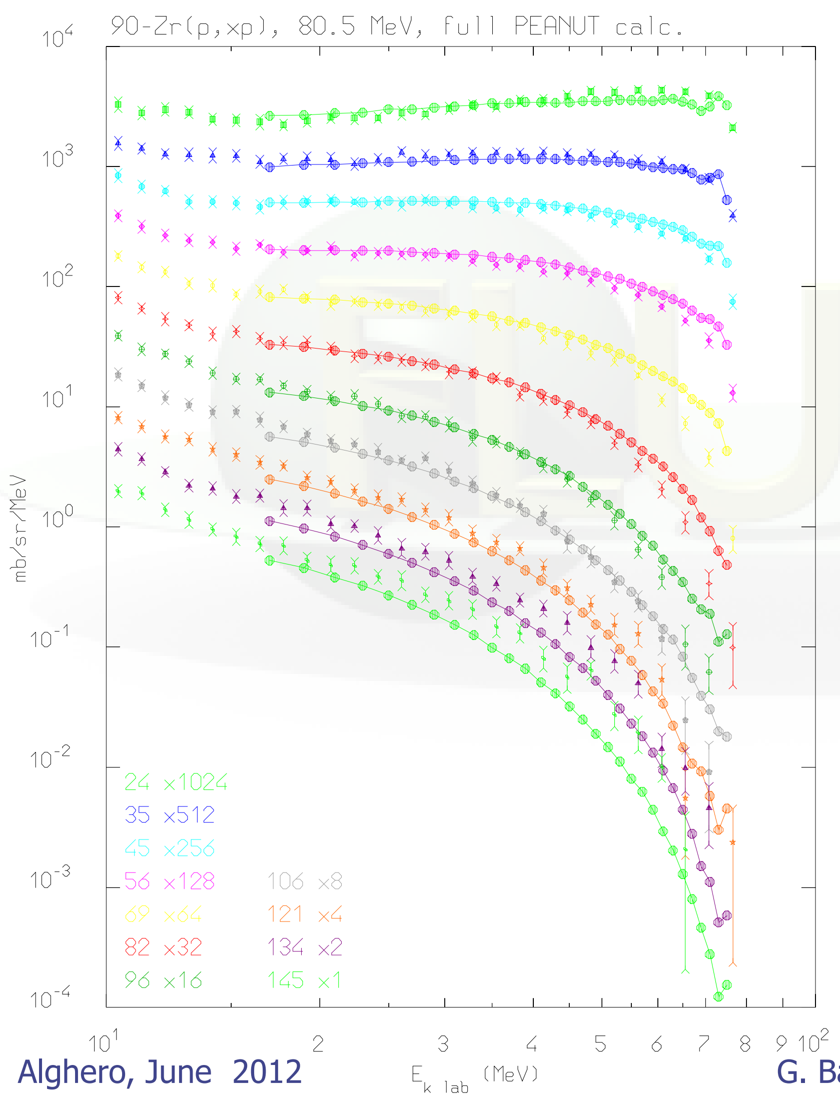
Angle-integrated $^{90}Zr(p,xn)$ at 80.5 MeV

The various lines show the total, INC, preequilibrium and evaporation contributions

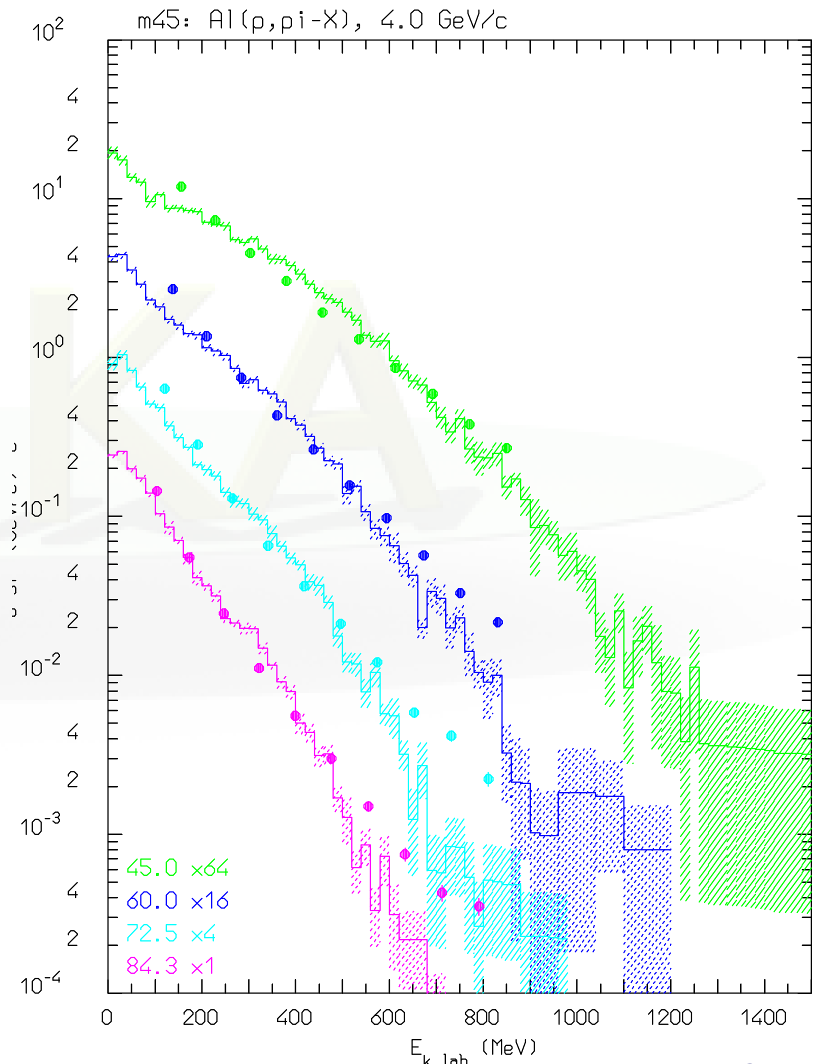
Experimental data from M. Trabandt et al., Phys. Rev. C39, 452 (1989)

Thin target examples

p + ^{80}Zr $\rightarrow$ p + X (80 MeV)



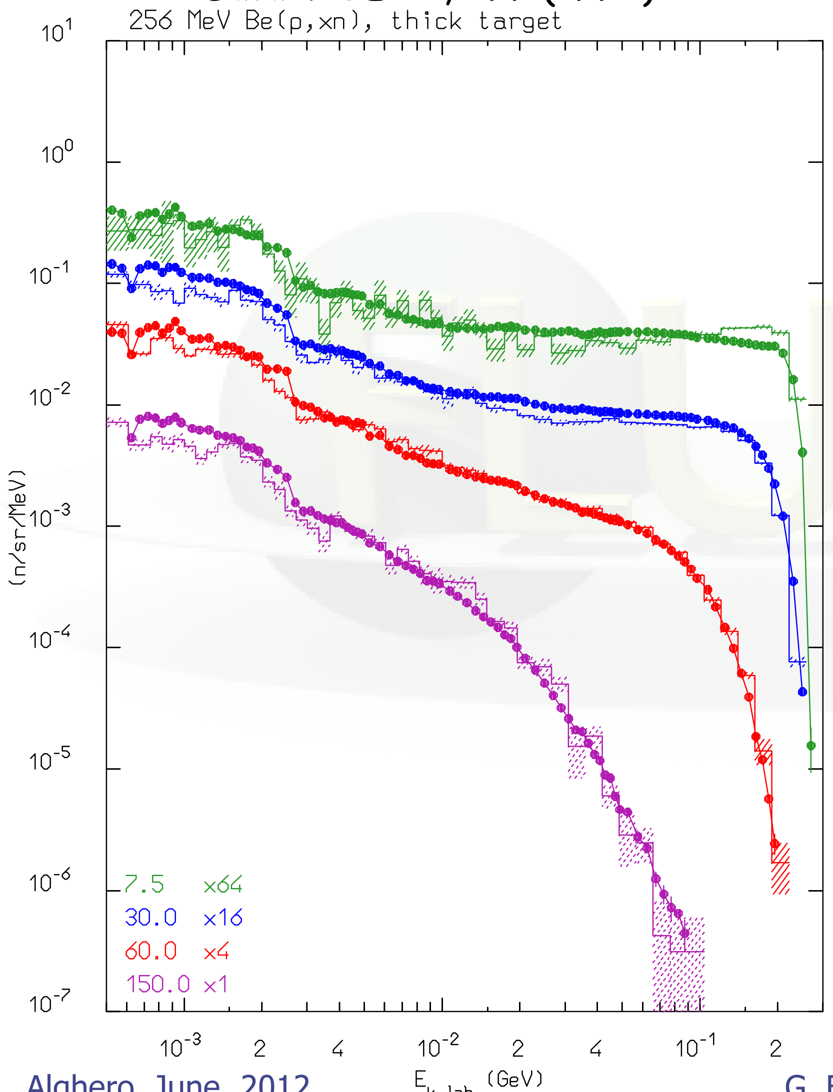
p + Al $\rightarrow$ π^- + X (4 GeV/c)



Thick/Thin target examples: neutrons

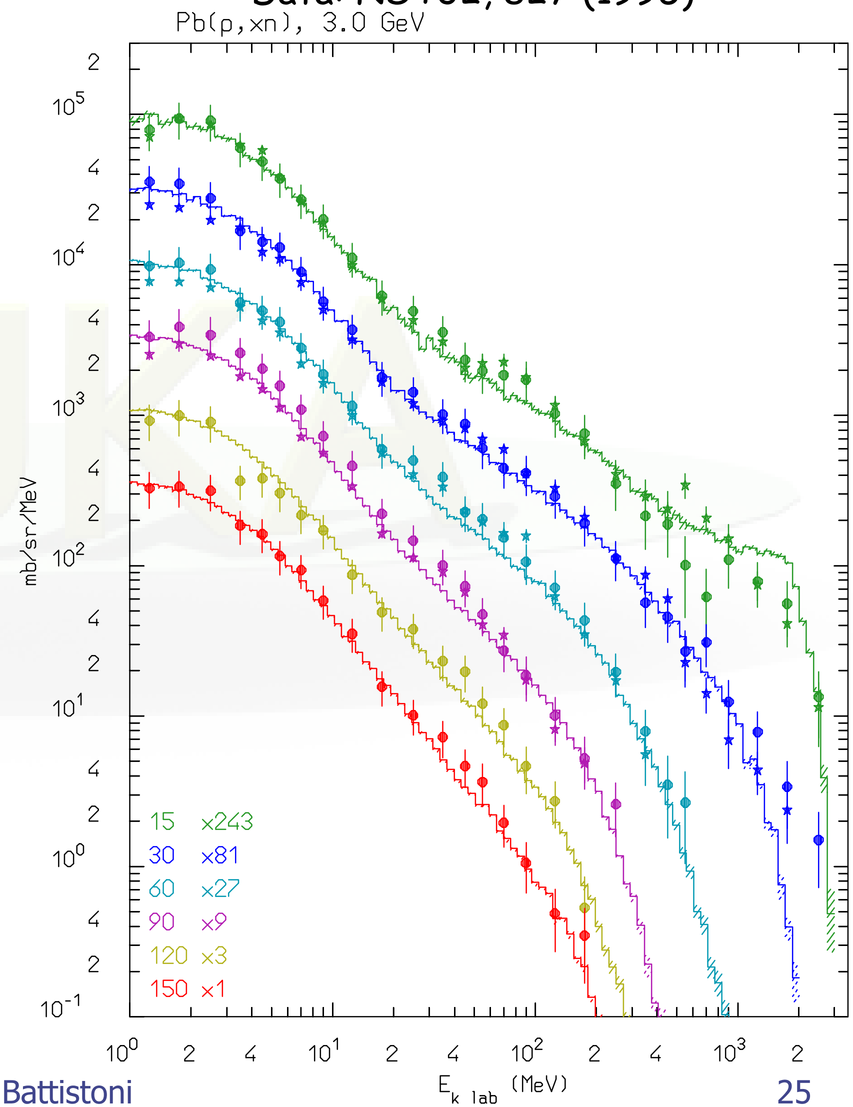
^{9}Be(p,xn) @ 256 MeV, stopping target

Data: NSE110, 299 (1992)



Pb(p,xn) @ 3 GeV, thin target

Data: NST32, 827 (1995)



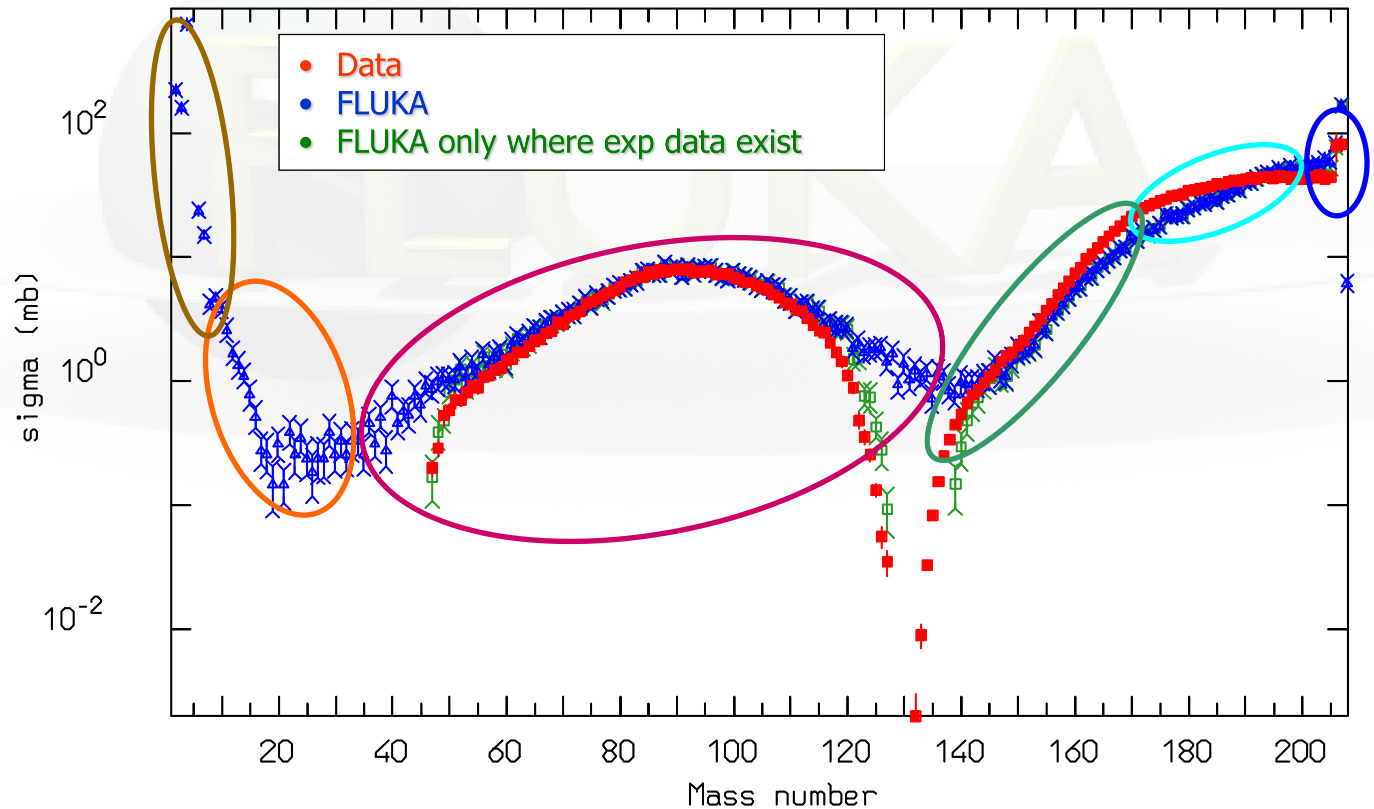
Equilibrium particle emission

- **Evaporation**: Weisskopf-Ewing approach
  - 600 possible emitted particles/states (A<25) with an extended evaporation/fragmentation formalism
  - Full level density formula
  - Inverse cross section with proper sub-barrier
  - Analytic solution for the emission widths
  - Emission energies from the width expression with no. approx.
  - NEW! New energy dependent self-consistent evaporation level densities (IAEA recommendations)
  - NEW! New pairing energies consistent with the above point
  - NEW! Extension of mass tables till A=330 using available offline calculations
  - NEW! New shell corrections coherent with the new masses
- **Fission**:
  - NEW! Actinide fission done on first principles
  - NEW! New fission barrier calculations (following Myers & Swiatecki)
  - NEW! Fission level density enhancement at saddle point washing out with excitation energy (following IAEA recommendations)
  - NEW! Fission product widths and asymmetric versus symmetric probabilities better parameterized
- **Fermi Break-up** for A<18 nuclei
  - ~ 50000 combinations included with up to 6 ejectiles
- γ **de-excitation**: statistical + rotational + tabulated levels

Example of fission/evaporation

- Quasi-elastic products
- Spallation products
- Deep spallation products
- Fission products
- Fragmentation products
- Evaporation products

1 A GeV ^{208}Pb + p reactions Nucl. Phys. A 686 (2001) 481-524

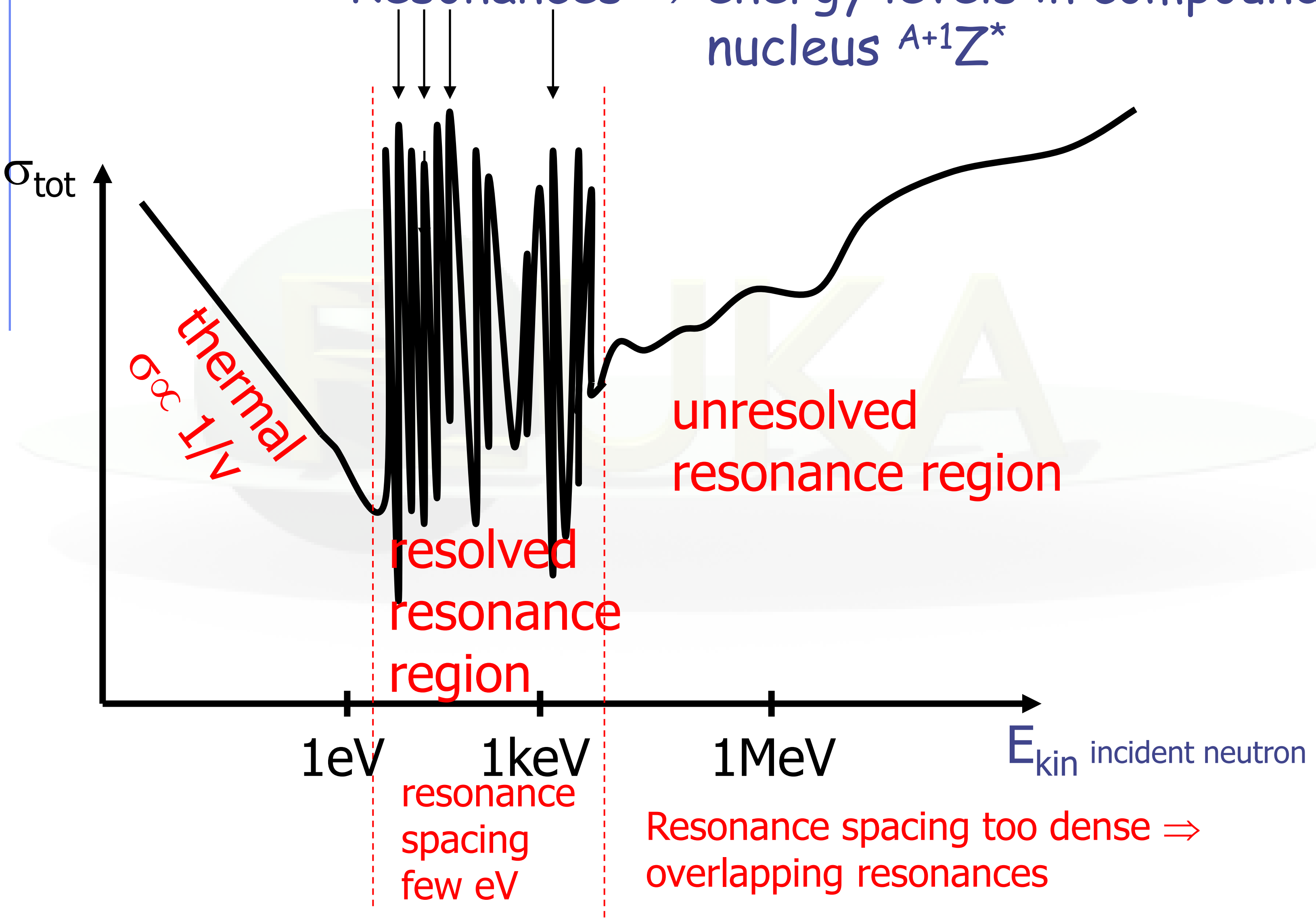


Heavy ion interaction models

- DPMJET-III for energies ≥ 5 GeV/n
  - DPMJET (R. Engel, J. Ranft and S. Roesler) Nucleus-Nucleus interaction model
  - Energy range: from 5-10 GeV/n up to the highest Cosmic Ray energies (10^{18}-10^{20} eV)
  - Used in many Cosmic Ray shower codes
  - Based on the Dual Parton Model and the Glauber model, like the high-energy FLUKA hadron-nucleus event generator
- Modified and improved version of rQMD-2.4 for 0.1 < E < 5 GeV/n
  - rQMD-2.4 (H. Sorge et al.) Cascade-Relativistic QMD model
  - Energy range: from 0.1 GeV/n up to several hundred GeV/n
  - Successfully applied to relativistic A-A particle production
- BME (BoltzmannMasterEquation) for E< 0.1 GeV/n
  - FLUKA implementation of BME from E.Gadioli et al (Milan)
  - Now under test for A≤ 16
- Standard FLUKA evaporation/fission/fragmentation used in both Target/Projectile final deexcitation ⇒ ***Projectile-like evaporation is responsible for the most energetic fragments***
- Electromagnetic dissociation

Typical neutron cross section

Resonances ⇒ energy levels in compound nucleus $^{A+1}Z^*$



Resonance spacing too dense ⇒ overlapping resonances

Evaluated Nuclear Data Files

- Evaluated nuclear data files (ENDF, JEFF, JENDL...)
  - typically provide neutron σ (cross sections) for E<20MeV for all channels
  - σ are stored as continuum + resonance parameters
  - Complex programs like NJOY, PREPRO convert the ENDF file to P-ENDF (point-wise cross sections), or G-ENDF (group-wise) including Doppler broadening etc.

Point-wise and Group-wise cross sections

- In neutron transport codes in general two approaches used: point-wise ("continuous" cross sections) and group-wise transport
- Point-wise follows cross section precisely but is can be time and memory consuming
- Group approach is widely used in neutron transport codes because it is fast and gives good results for most applications

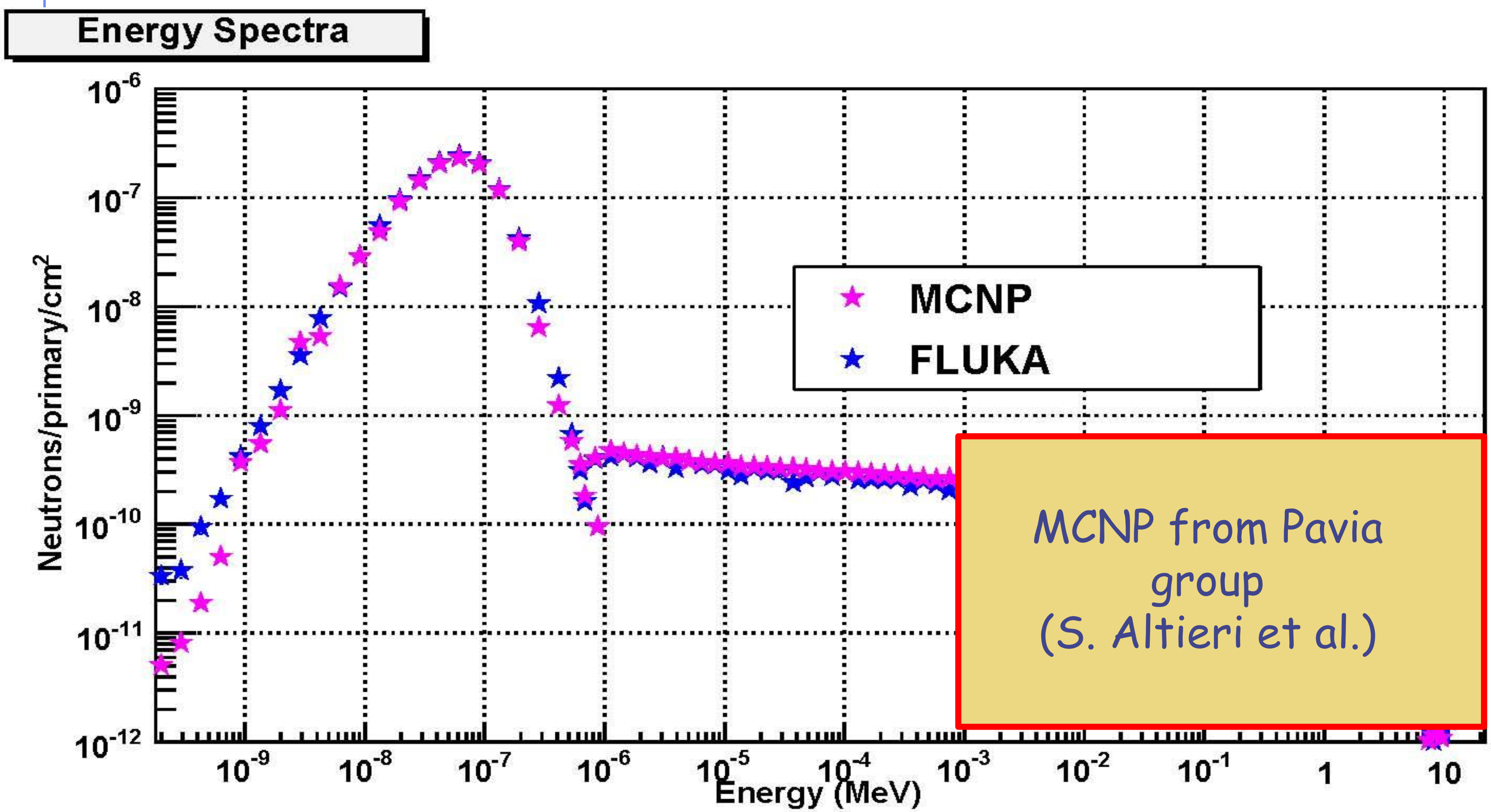
Group Transport Technique

- The energy range of interest is divided in a given number of discrete intervals ("energy groups")
- Elastic and inelastic reactions simulated not as exclusive processes, but by group-to-group transfer probabilities (downscattering matrix)
- Downscattering matrix: if a neutron in a given group undergoes a scattering event and loses energy, it will be transferred to a group of lower energy (each of the lower energy groups having a different probability)
- If the neutron does not lose enough energy to be in another group, it will stay in the same group (in-scattering).
- In thermal region neutrons can gain energy. This is taken into account by an upscattering matrix, containing the transfer probability to a group of higher energy

The FLUKA Low Energy Neutron Library

- FLUKA uses the multigroup transport technique
- The energy boundary below which multigroup transport takes over depends in principle on the cross section library used. In the present library it is 20 MeV.
- Both fully biased and semi-analog approaches are available
- Number of groups: 260 of approximately equal logarithmic with, the actual energies limits of each group can be found in the manual (or can be printed to *.out file)
- N.B. the group with the highest energy has the number 1, the group with the lowest energy has number 260
- 31 thermal groups, with 30 upscattering groups
- Energy range of library: 0.01 meV - 20 MeV

Simulation of neutron spectrum from reactor (Pavia)



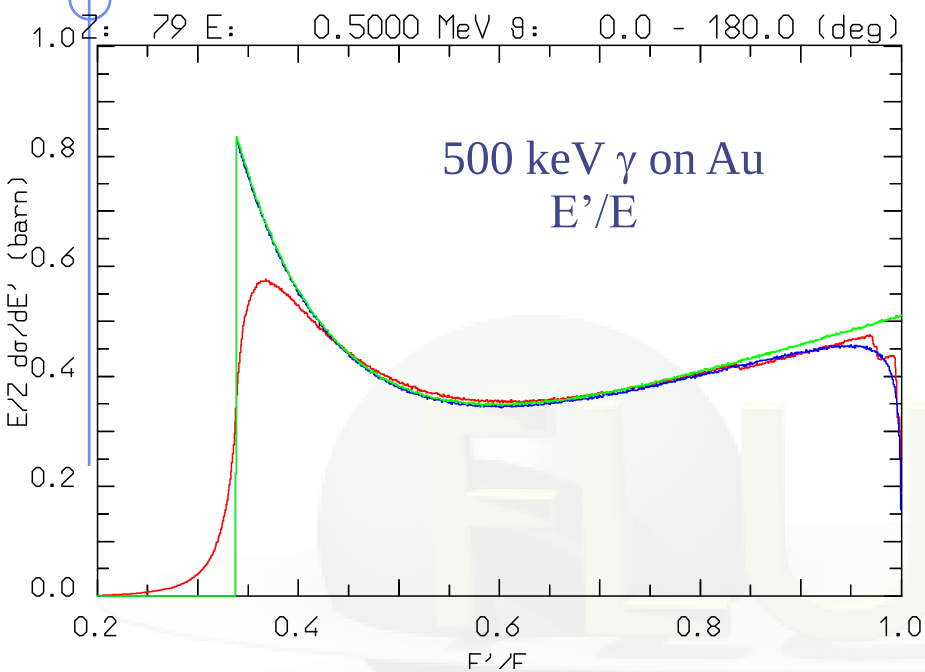
EM Physics

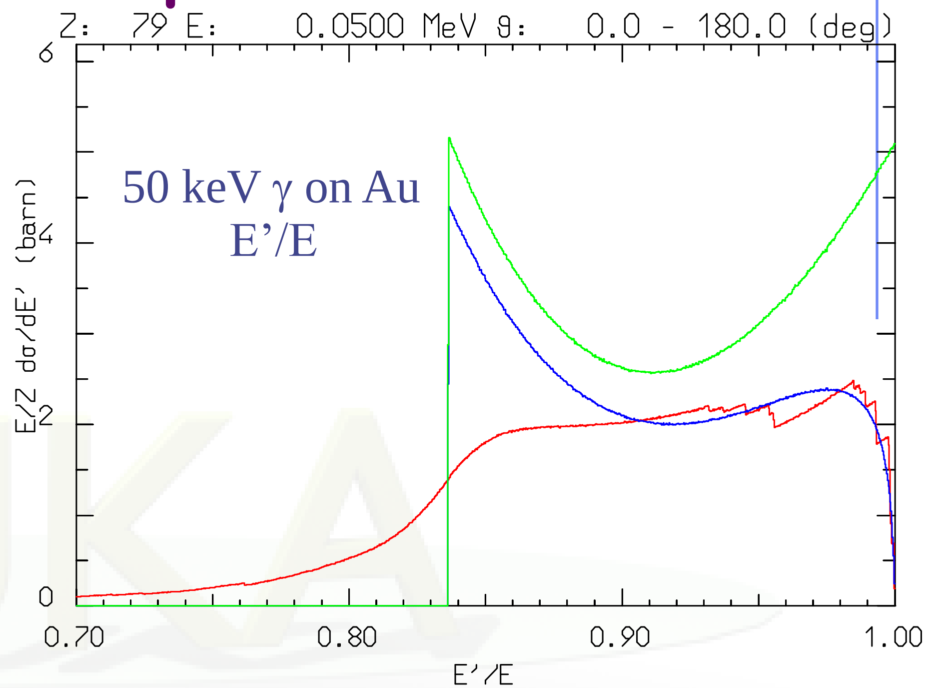
- General settings
- Interactions of leptons/photons
  - Photon interactions
    - Photoelectric
    - Compton
    - Rayleigh
    - Pair production
    - Photonuclear
    - Photomuon production
  - Electron/positron interactions
    - Bremsstrahlung
    - Scattering on electrons
  - Muon interactions
    - Bremsstrahlung
    - Pair production
    - Nuclear interactions

- Ionization energy losses
  - Continuous
  - Delta-ray production
- Transport
  - Multiple scattering
  - Single scattering

These are common to all charged particles, although traditionally associated with EM

Compton profile examples





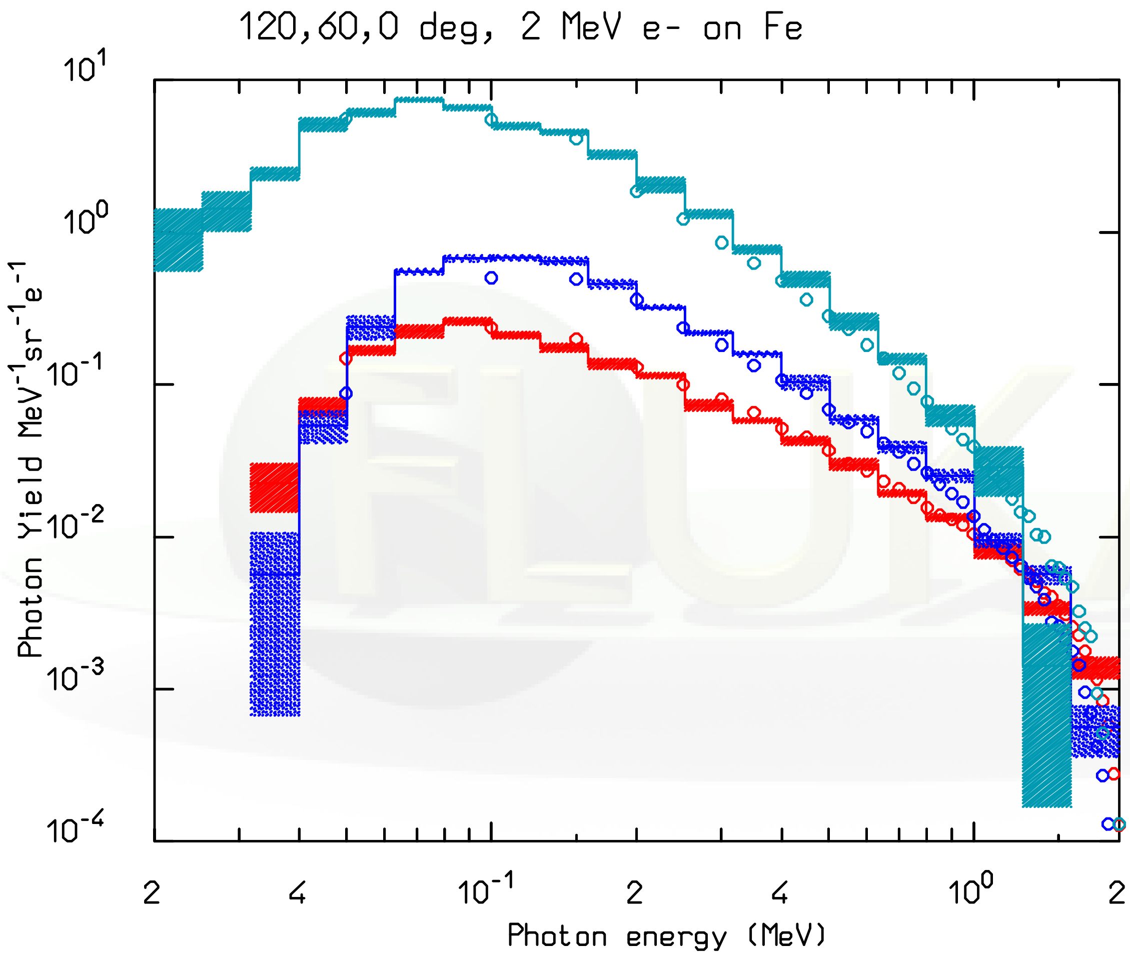
green = free electron
blue = binding with form factors
red = binding with shells and orbital motion

Larger effect at very low energies, where, however, the dominant process is photoelectric.
Visible: shell structure near E'=E, smearing from motion at low E'

Compton and Rayleigh

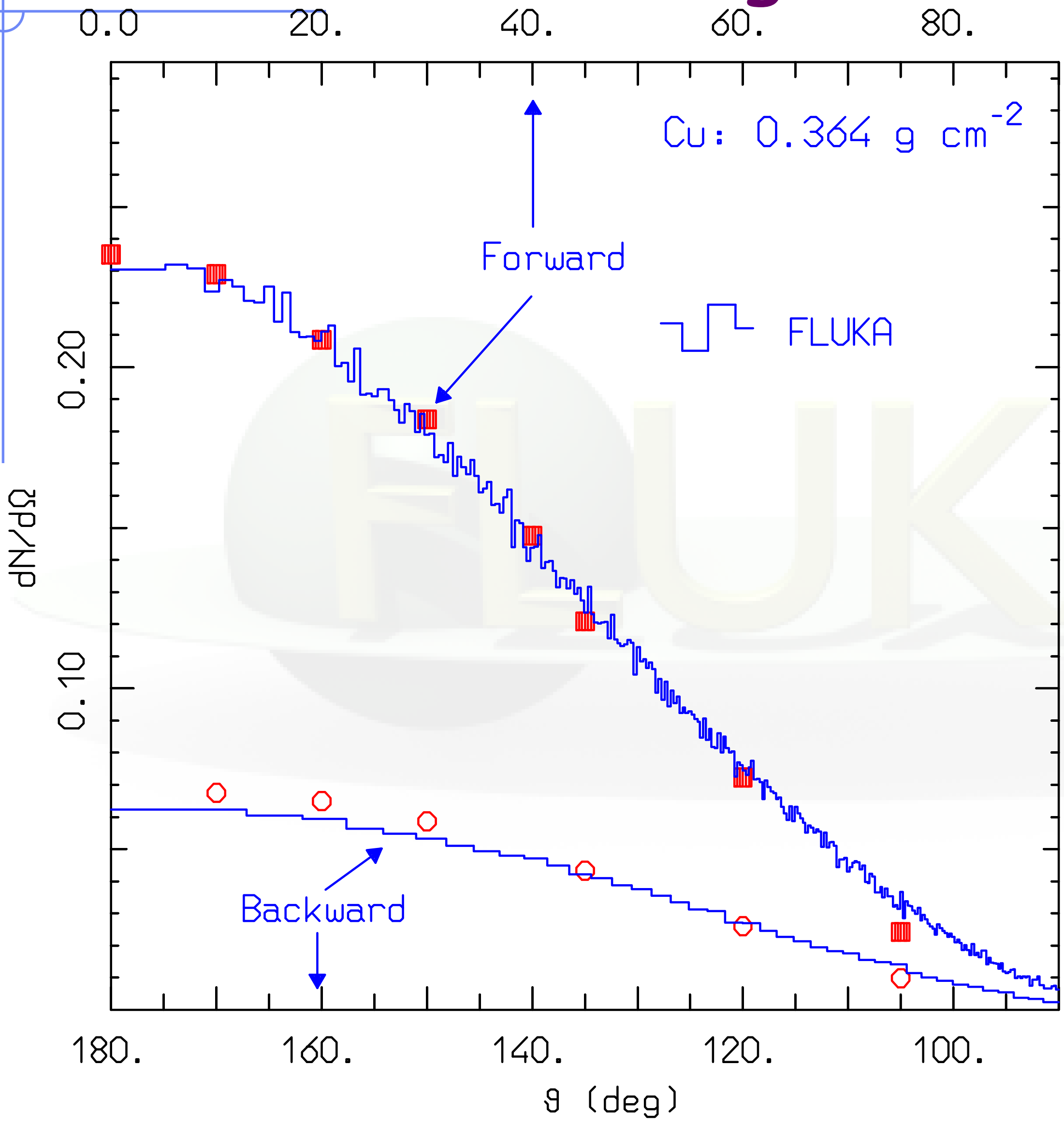
- Account for atomic bonds using inelastic Hartree-Fock form factors (very important at low E in high Z materials)
- NEW : Compton with atomic bonds and orbital motion (as better alternative to form factors)
  - Atomic shells from databases
  - Orbital motion from database + fit
  - Followed by fluorescence
- Account for effect of photon polarization

Bremsstrahlung: benchmark



2 MeV electrons on Iron, Bremsstrahlung photon spectra measured (dots) and simulated (histos) at three different angles

Electron scattering:



Transmitted (forward) and backscattered (backward) electron angular distributions for 1.75 MeV electrons on a 0.364 g/cm^2 thick Copper foil Measured (dots) and simulated (histos) data

Photonuclear int.: example

Reaction:

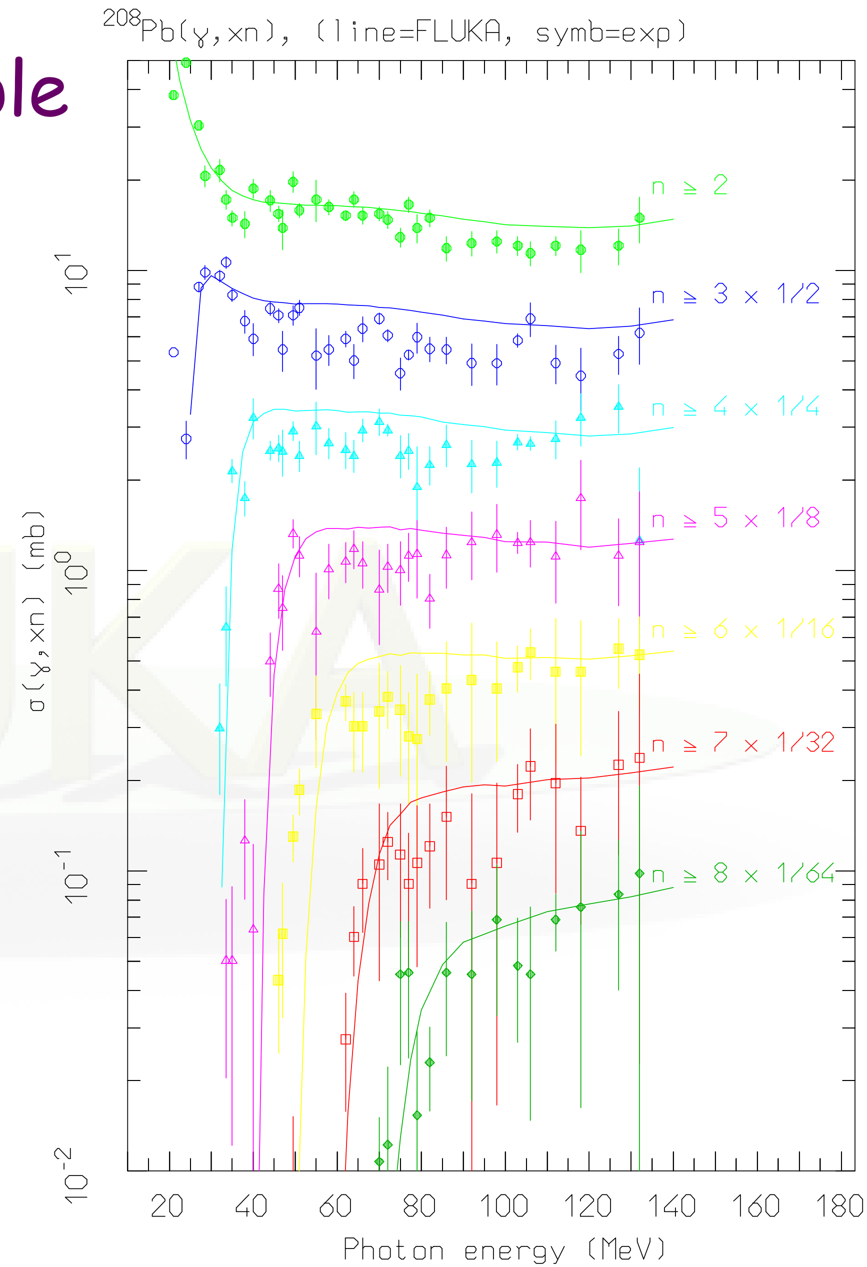
^{208}Pb(γ,x n)

20≤Eγ ≤140 MeV

Cross section for multiple neutron emission as a function of photon energy, **Different colors refer to neutron multiplicity ≥ *n* , with 2 ≤ *n* ≤ 8**

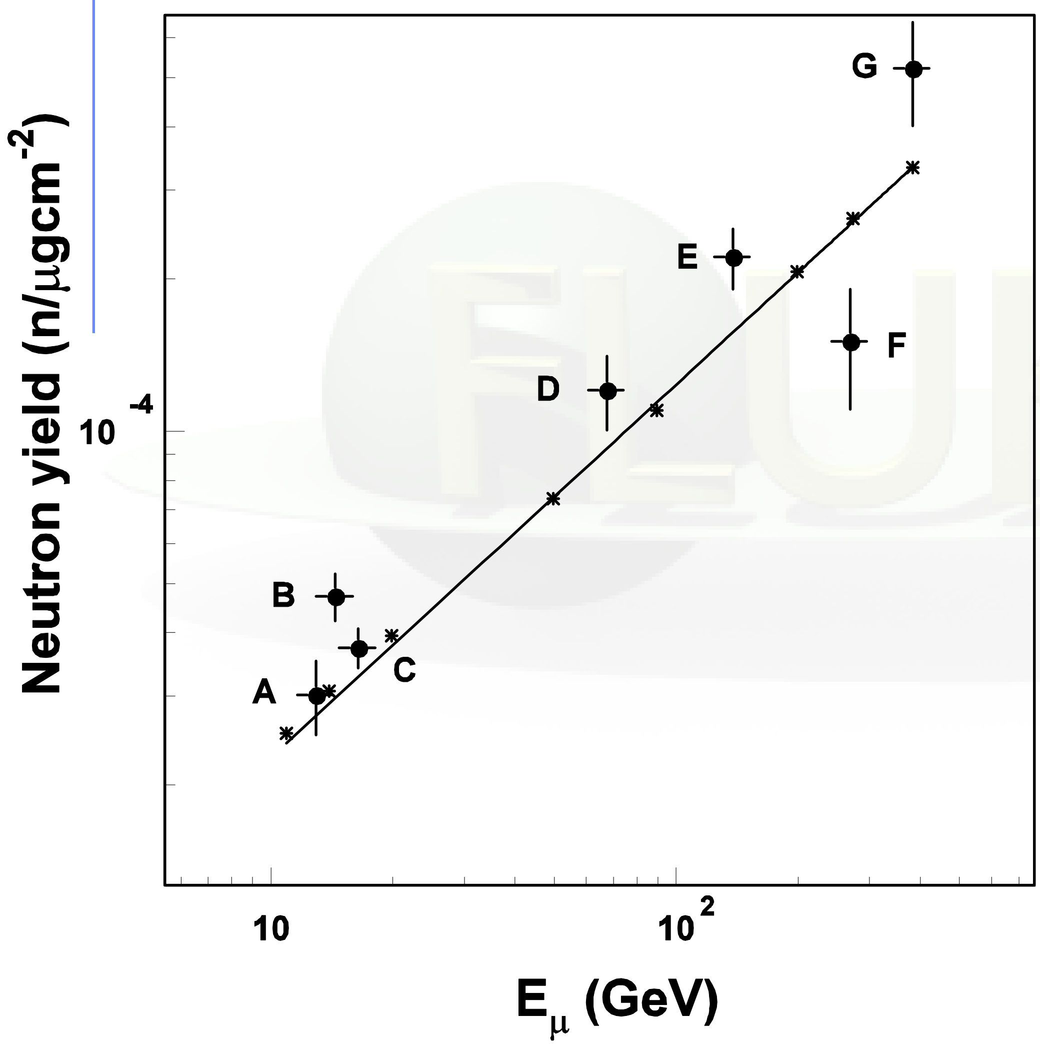
Symbols: exp. data (NPA367, 237 (1981) ; NPA390, 221 (1982))

Lines: FLUKA



Muon-induced neutron background in underground labs

PRD64 (2001) 013012



Neutron production rate as a function of muon energy

Stars+line : FLUKA simulation with a fit to a power law.

Exp. points:
abscissa → average μ energy at the experiment's depth:

A) 20 m.w.e.
B) 25 m.w.e.
C) 32 m.w.e. (Palo Verde)
D) 316 m.w.e.
E) 750 m.w.e.
F) 3650 m.w.e. (LVD)
G) 5200 m.w.e. (LSD)

Charged particle dE/dx: Bethe-Bloch

Spin 0
(spin1 is similar):

~ln $\beta^4\gamma^4$
relativistic rise

$$\left(\frac{dE}{dx}\right)_0 = \frac{2\pi n_e r_e^2 m_e c^2 z^2}{\beta^2}\left[\ln\left(\frac{2m_e c^2\beta^2 T_{\max}}{I^2(1-\beta^2)}\right) - 2\beta^2 + 2zL_1(\beta) + 2z^2 L_2(\beta) - 2\frac{C}{Z} - \delta + G\right]$$

- I : mean excitation energy , material-dependent
- δ : density correction
- C : is the shell correction, important at low energies
- T_{max} : maximum energy transfer to an electron (from kinematics)

Higher order corrections implemented in FLUKA

- L1 : Barkas (z^3) correction responsible for the difference in stopping power for particles-antiparticles
- L2 the Bloch (z^4) correction
- G : Mott corrections

Valid for m>>m_e, However, the formulation for electron/positrons is similar, with the exception of "energetic" collisions with atomic electrons.

Discrete ionization events

Above a pre-set threshold, ionization is modeled as δ ray production (free electrons)

- Spin 0 or 1/2 δ-ray production (charged hadrons, muons)
- Mott for heavy ions
- Bhabha scattering (e^+)
- Møller scattering (e^-)

Below the pre-set threshold for δ ray production:

Restricted energy losses

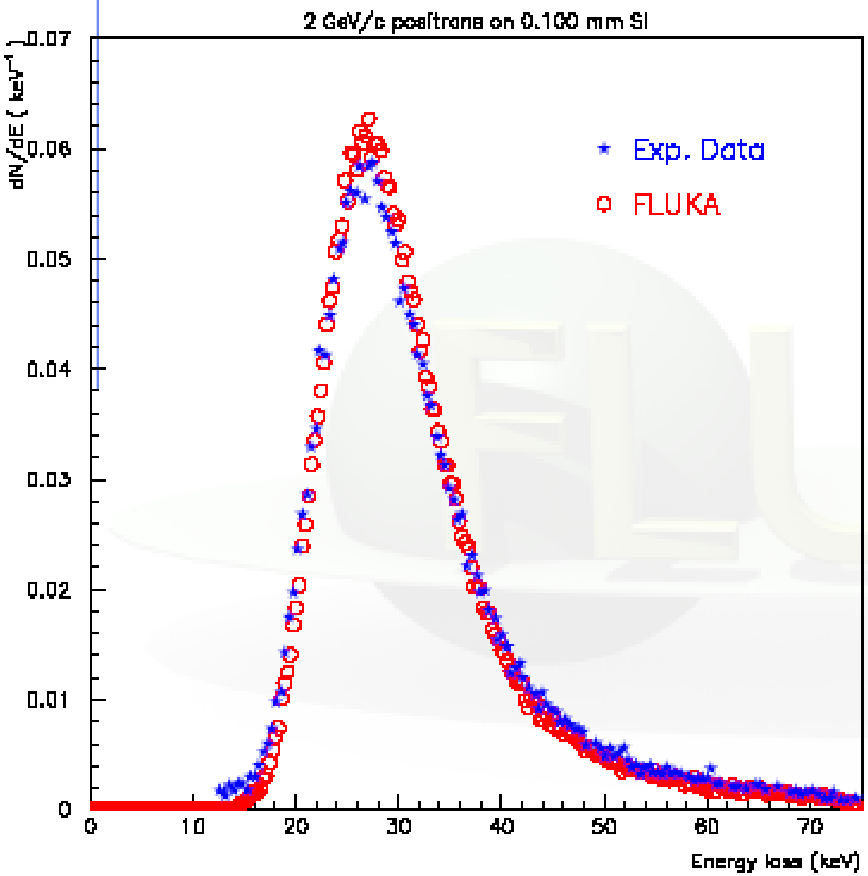
For particles much heavier than electrons and charge z, with energy transfers to atomic electrons restricted at T_δ

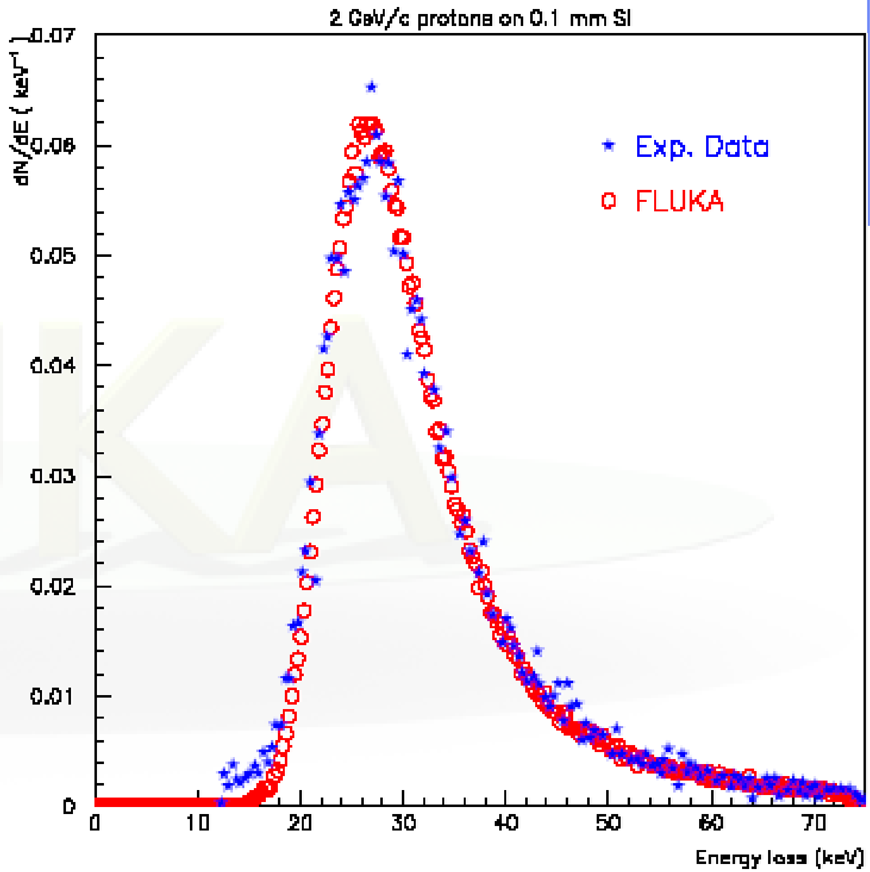
Continuous energy losses

Below the δ-ray threshold, energy losses are treated as "continuous", with some special features:

- Fluctuations of energy loss are simulated with a FLUKA- specific algorithm
- The energy dependence of cross sections and dE/dx is taken into account exactly (see later)
- Latest recommended values of ionization potential and density effect parameters implemented for elements (Sternheimer, Berger & Seltzer), but can be overridden by the user with (set yourself for compounds!)

Ionization fluctuations





Experimental [1] and calculated energy loss distributions for 2 GeV/c positrons (left) and protons (right) traversing 100µm of Si   J.Bak et al. NPB288, 681 (1987)

Nuclear stopping power (NEW)

- Besides Coulomb scattering with atomic electrons, particles undergo Coulomb scattering also with atomic nuclei
- The resulting energy losses, called nuclear stopping power, are smaller than the atomic ones, but are important for
  - Heavy particles (i.e. ions)
  - Damage to materials

INSTALLING FLUKA

How to download and install FLUKA

Two ways of downloading the FLUKA software:

- From the FLUKA website http://www.fluka.org
- From NEA databank http://www.nea.fr through the liaison officer from your institute

It is mandatory to be registered as FLUKA user. Follow the link:

http://www.fluka.org/download.html

After registration (or using your user-id and password) you can proceed in downloading the latest official release version.

How to download and install FLUKA

First identify the location of the FLUKA distribution file: fluka2011.2-linuxAA.tar.gz

Depending on the operating system and the method you used most probably will be located in one of the following directories:

```
   /media/FLUKA/Software      # in case you are using the USB stick
or $HOME                      # if you downloaded from the web
   $HOME/Desktop              # depending on your browser
```

We will create a directory FLUKA under your home directory to install FLUKA.

The following commands issued from a terminal/console window will perform the entire installation.

```
   cd                         # changes directory to your home
   mkdir FLUKA                # creates a directory called FLUKA
   cd FLUKA                   # changes to the FLUKA directory
   tar xzf /media/FLUKA/Software/fluka2011.2-linuxAA.tar.gz
                              # expands the FLUKA package
   # set FLUPRO environment variable
   export FLUPRO=$HOME/FLUKA  # sets FLUPRO in bash shell or similar
or setenv FLUPRO $HOME/FLUKA  # sets FLUPRO in tcsh shell or similar
   make                       # compiles a FLUKA executable and
                                auxiliary programs
```

Persistent settings

To make these settings persistent on your computer, *i.e.*, you don't have to set the FLUPRO environment variable again when you open a new terminal or log into your computer, we will add the following lines into your shell configuration file in your main directory.

bash users:

```
cd
emacs [or any editor] .bashrc
```

add the following:

```
export FLUPRO=${HOME}/FLUKA
export PATH=${PATH}:$FLUPRO:$FLUPRO/flutil
```

tcsh users:

```
cd
emacs [or any editor] .tcshrc
```

add the following:

```
setenv FLUPRO ${HOME}/FLUKA
setenv PATH ${PATH}:$FLUPRO:$FLUPRO/flutil
```

The changes will be activated on the next login or if you type the command

```
source .bashrc
source .tcshrc
```

FLUKA release: main directory $FLUPRO

Main Library:

libflukahp.a (object collection)

Physics data files:

sigmapi.bin
elasct.bin
brems_fin.bin
cohff.bin
gxsect.bin
neuxsc-ind_260.bin
nuclear.bin
fluodt.dat
e6r1nds3.fyi
jef2.fyi
jendl3.fyi
xnloan.dat
Fad/*
DDS/*

Basic Scripts: (in $FLUPRO/flutil)

rfluka
lfluka
fff

Random Number seed

random.dat

Important Directories

flukapro/	all FLUKA commons
usermvax/	user routines
flutil/	general utilities

What's inside the physics data files:

sigmapi.bin:	pion-N double-diff. cross sections
elasct.bin:	elastic scattering cross sections
brems_fin.bin:	Bremsstrahlung cross sections
cohff.bin:	atomic form factor tabulations
gxsect.bin	photon cross sections
neuxsc-ind_260.bin:	low energy neutron multi-group cross sections (260 groups)
nuclear.bin:	nuclear masses, mass excesses, levels, and many other nuclear data for evaporation, pre-equilibrium, Fermi break up and photonuclear cross sections gamma and beta databases
fluodt.dat:	Fluorescence data (photoelectric effect)
e6r1nds3.fyi: jef2.fyi: jendl3.fyi: xnloan.dat:	Fission products (for neutrons with E<20 MeV)
Fad/* :	BME pre-equilibrium particle angular distribution
DDS/* :	BME pre-equilibrium particle energy spectra

Available Documentation

- fluka2011.manual ASCII version of the manual (easy to edit)
- FM.pdf current version of the FLUKA manual
- CERN-2005-10.pdf official reference for FLUKA (manual not up to date)
- or navigate the manual, online version (www.fluka.org)

- or (when using FLAIR) press F1 to get an interactive manual (which can be also called on prompt level by calling '*fm.py*')

- or (at a further stage) the FAQ available at: http://www.fluka.org/fluka.php?id=faq&mm2=3
- or (at a further stage) the archive of fluka-discuss: http://www.fluka.org/MailingList.html
- Release notes

USING FLUKA IN A NUTSHELL

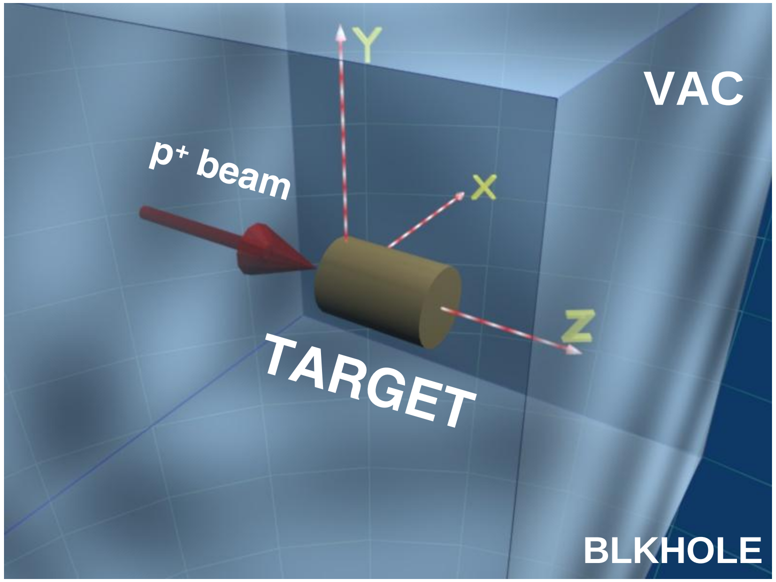
Input example

- FLUKA is driven by the user almost completely by means of an input file (.inp) which contains directives issued in the form of DATA CARDS
- The standard release provides a simple case to test the installation: example.inp *(Production of particles in p-Be collisions with a 50GeV/c proton beam.)*
- Different examples are used along this course, which will be varied in different ways for didactic reasons
- For most of basic applications, **users do not need to write code**
- This is of course not always possible, therefore at some time FLUKA users need to learn how to code and link User Routines…

A Simple Example

```
TITLE
FLUKA Course Exercise
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....*
DEFAULTS                                                            NEW-DEFA
BEAM            -3.5 -0.082425      -1.7       0.0       0.0       1.0PROTON
BEAMPOS          0.0       0.0       0.1       0.0       0.0       0.0
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....*
GEOBEGIN                                                            COMBNAME
    0    0                  Cylindrical Target
SPH BLK 0.0  0.0  0.0  10000.
* vacuum box
RPP VOI -1000. 1000. -1000. 1000. -1000. 1000.
* Lead target
RCC TARG 0.0 0.0 0.0 0.0 0.0 10. 5.
END
* Regions
* Black Hole
BLKHOLE 5   +BLK -VOI
* Void around
VAC     5   +VOI -TARG
* Target
TARGET  5   +TARG
END
GEOEND
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....*
ASSIGNMA    BLCKHOLE   BLKHOLE
ASSIGNMA      VACUUM       VAC
ASSIGNMA        LEAD    TARGET
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....*
RANDOMIZ         1.0
START           10.0       0.0
STOP
```

Geometry



FLUKA Scoring & Results - Estimators

- It is often said that Monte Carlo (MC) is a "mathematical experiment" The MC equivalent of the result of a real experiment (*i.e.*, of a measurement) is called an estimator.
- Just as a real measurement, an estimator is obtained by sampling from a statistical distribution and has a statistical error (and in general also a systematic one).
- There are often several different techniques to measure the same physical quantity: in the same way the same quantity can be calculated using different kinds of estimators.
- FLUKA offers numerous different estimators, *i.e.*, directly from the input file the users can request scoring the respective quantities they are interested in.
- As the latter is implemented in a very complete way, users are strongly encouraged to preferably use the built-in estimators with respect to user-defined scoring
- For additional requirements FLUKA user routines are provided

Built-In and User Scoring

- Several pre-defined estimators can be activated in FLUKA.
- One usually refers to these estimators as "scoring" capabilities
- Users have also the possibility to build their own scoring through user routines, HOWEVER:
  - Built-in scoring covers most of the **common needs**
  - Built-in scoring has been **extensively tested**
  - Built-in scoring takes BIASING **weights automatically into account**
  - Built-in scoring has **refined algorithms** for track subdivision
  - Built-in scoring comes with **utility programs** that allow to evaluate statistical errors
- Scoring can be geometry dependent AND/OR geometry independent FLUKA can score particle fluences, current, track length, energy spectra, Z spectra, energy deposition...
- Either integrated over the "run", with proper normalization, OR event-by event
- Standard scoring can be weighted by means of simple user routines

Related Scoring Commands (main cases)

- USRTRACK, USRCOLL score average $d\Phi/dE$ (differential fluence) of a given type or family of particles in a given region
- USRBDX scores average $d^2\Phi/dEd\Omega$ (double-differential fluence or current) of a given type or family of particles on a given surface
- USRBIN scores the spatial distribution of energy deposited, or total fluence (or star density, or momentum transfer) in a regular mesh (cylindrical or Cartesian) described by the user
- USRYIELD scores a double differential yield of particles escaping from a surface. The distribution can be with respect to energy and angle, but also other more "exotic" quantities
- SCORE scores energy deposited (or star density) in all regions
- The output of SCORE will be printed in the main (standard) output, written on logical output unit LUNOUT (pre-defined as **11** by default)
- All other detectors write their results into logical output units assigned by the user (the unit numbers must be **>20**)

USRBIN

** energy deposition

```
USRBIN        11.0      ENERGY     -40.0      10.0             15.0 TargEne
USRBIN         0.0                  -5.0     100.0            200.0 &
```

- This is an R-Z-Φ binning (what(1)=11), scoring energy deposition (generalized particle ENERGY, or 208), writing the unformatted output on unit 40, spanning 0<R<10 in 100 bins, $0<\Phi<2\pi$ in 1 bin (default), -5<z<15 in 200 bins.

** neutron fluence

```
*             R-Z   EM energy  output unit     Rmax    axis Y     Zmax
*            Rmin      axis X         Zmin  # R-bins # Phi-bins # Z-bins
USRBIN        11.0    NEUTRON      -40.0      10.0             15.0 TargNeu
USRBIN         0.0                  -5.0     100.0            200.0 &
```

- This is a R-Z-Φ binning (what(1)=11), scoring neutron fluence, writing the unformatted output on unit 40, spanning 0<R<10 in 100 bins, $0<\Phi<2\pi$ in 1 bin (default), -5<z<15 in 200 bins.

USRBIN → The Result

WHAT(2) = ENERGY :Energy deposition from a 3.5 GeV proton beam hitting at [0.,0.,0.] directed along z

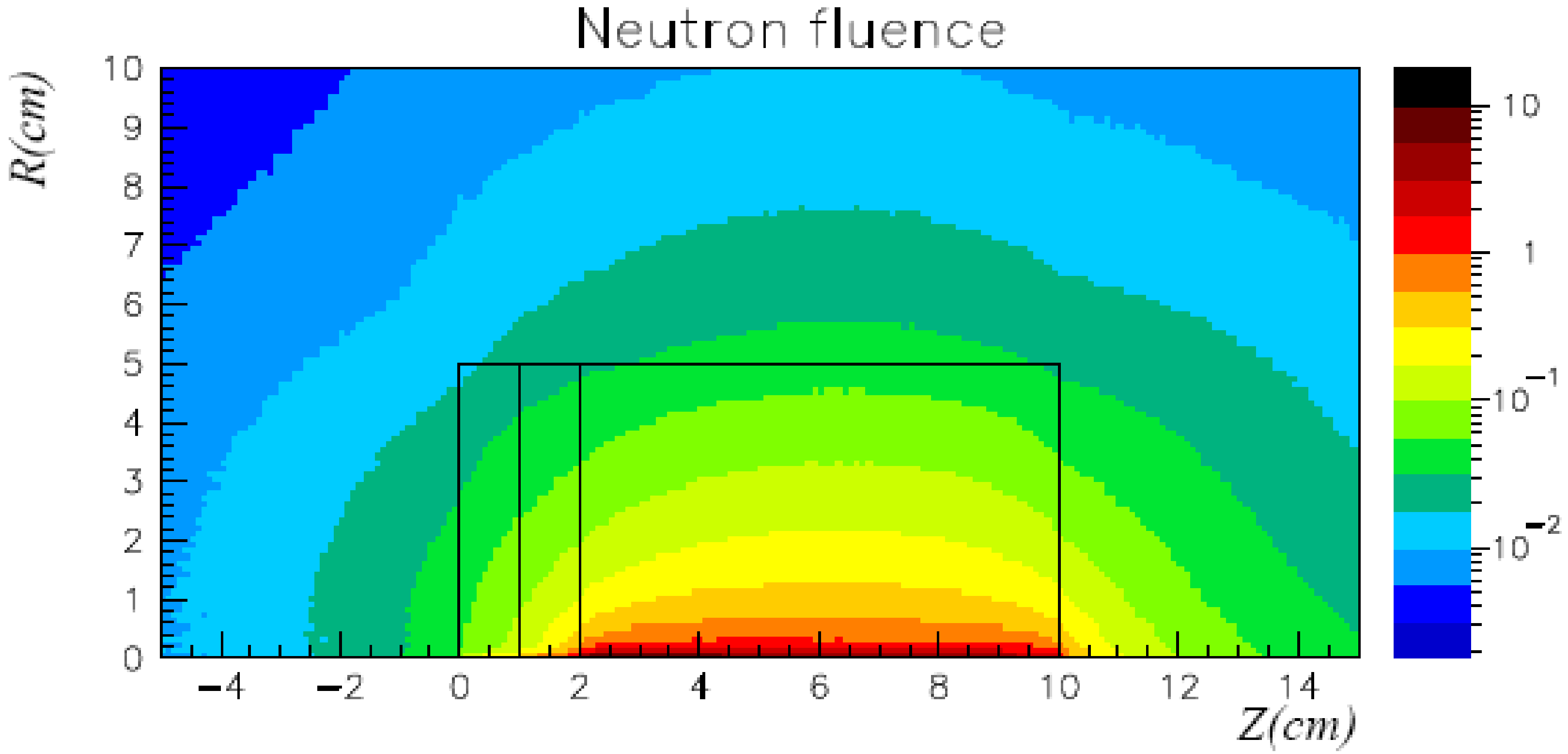
results are normalized to GeV/cm^3 per primary

This image cannot currently be displayed.

USRBIN → The Result

Same, WHAT(2)= NEUTRON   to get neutron fluence

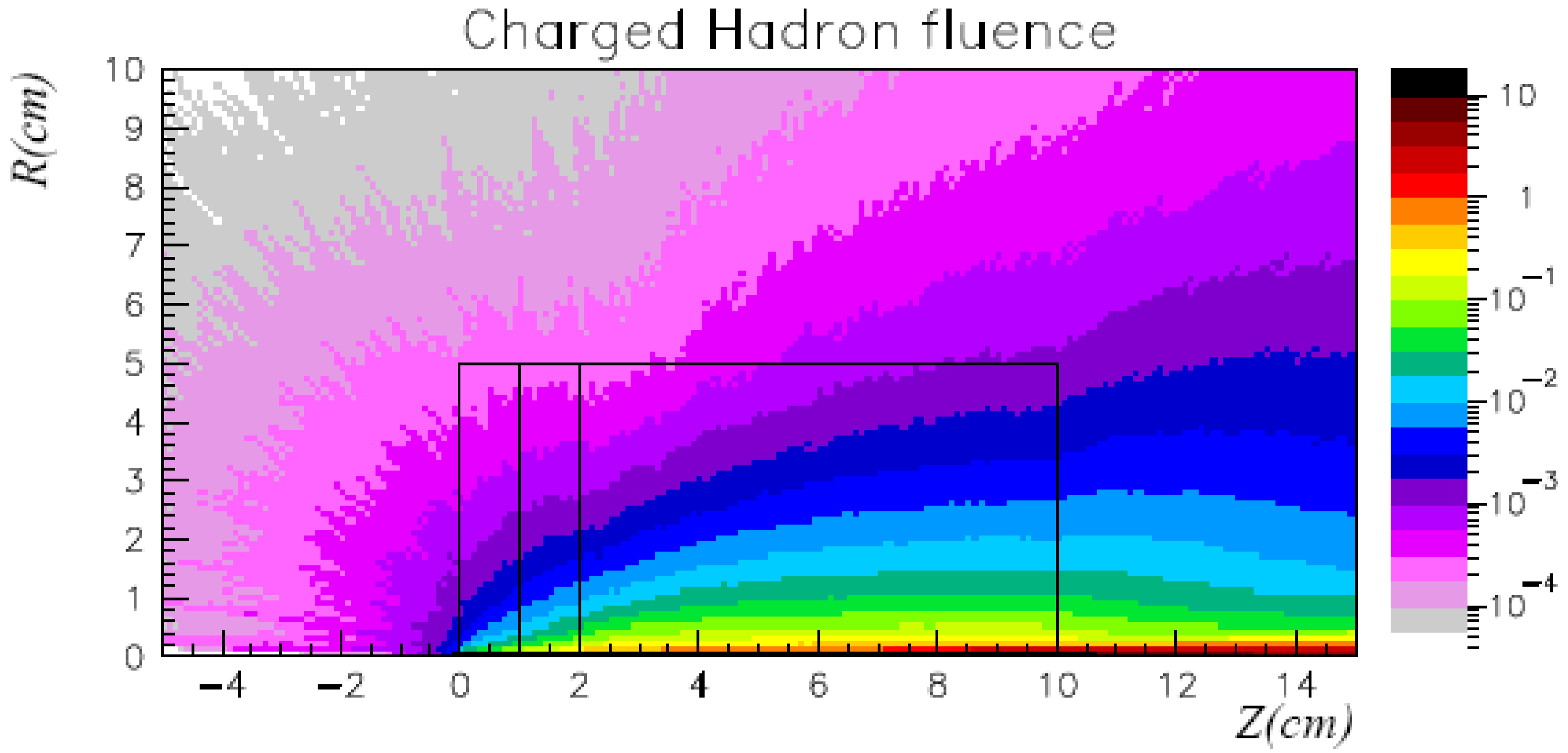
results are normalized to particles/cm^2 per primary



USRBIN → The Result

Same, WHAT(2)= HAD-CHAR to get charged hadron fluence

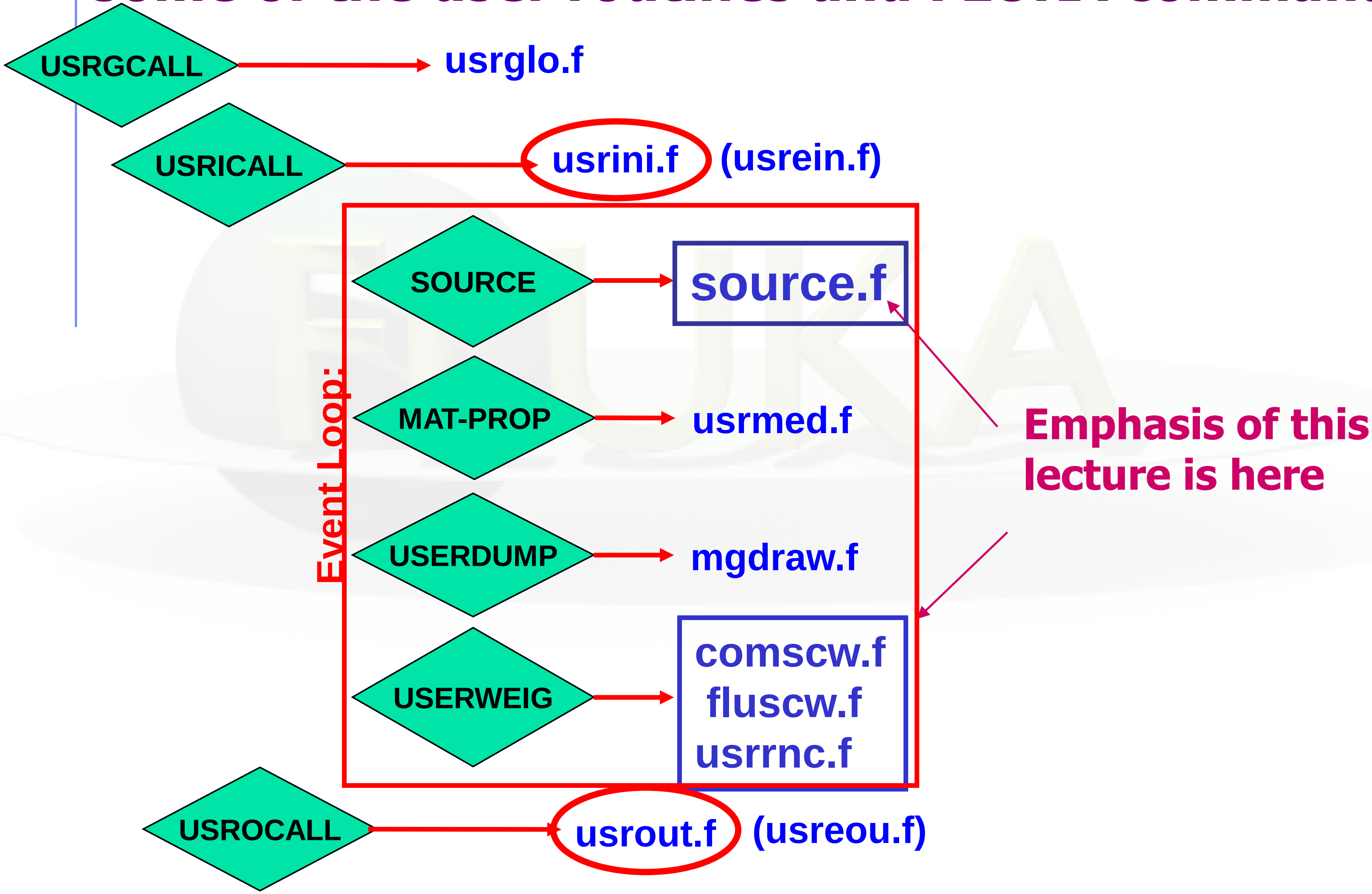
results are normalized to particles/cm^2 per primary



User Routines

- Fluka offers a rich choice of options for scoring most quantities and for applying variance reduction techniques, without requiring the users to write a single line of code.
- However there are special cases where “ad-hoc” routines are unavoidable, because the required information cannot be obtained through standard options.
- A number of template of user routines (available in the usermvax directory) can be modified/activated by the user allow to fulfill non-standard tasks

A first look at the correspondence between some of the user routines and FLUKA commands



THE FLUKA COMBINATORIAL GEOMETRY

Introduction

Principle of Combinatorial Geometry: Basic convex shapes (bodies) such as cylinders, spheres, parallelepipeds, etc. are combined to more complex shapes called regions. This combination is done by the boolean operations union, intersection and subtraction.

The Combinatorial Geometry of FLUKA was initially similar to the package developed at ORNL for the neutron and gamma-ray transport program Morse (M.B. Emmett ORNL-4972 1975) which was based on the original combinatorial geometry by MAGI (Mathematical Applications Group, Inc., W. Guber et al, MAGI-6701 1967).

Basic Concepts

Four concepts are fundamental in the FLUKA CG:

- Bodies - basic convex objects, plus infinite planes, infinite cylinders and generic quadric surfaces
- Zones - sub-regions defined only with intersection and subtraction of bodies
- Regions - defined as boolean operations of bodies (union of zones)
- Lattices - duplication of existing objects (translated & rotated), will be explained in a separate lecture

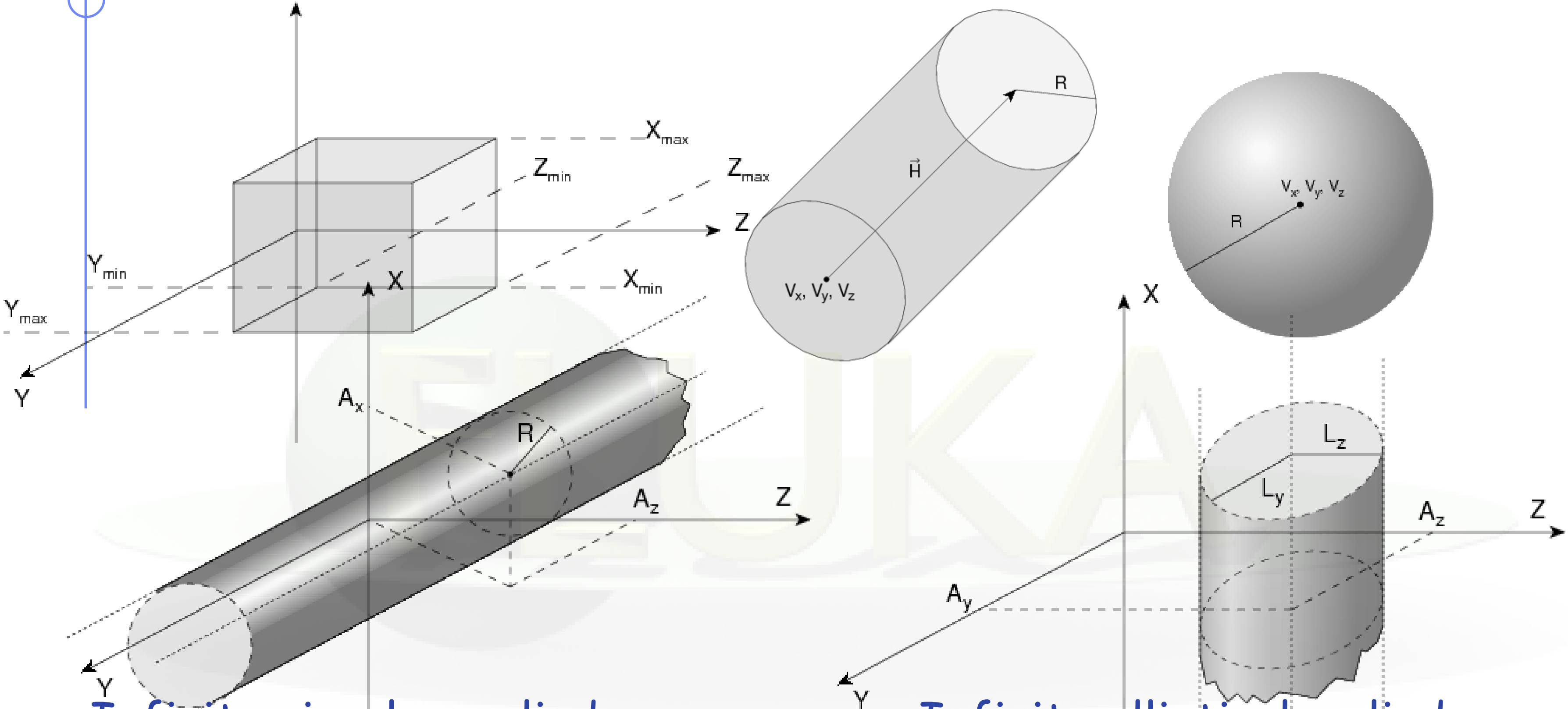
In the original description (Morse) bodies were convex solid bodies (finite portions of space completely delimited by surfaces of first or second degree, i.e. planes or quadrics). In FLUKA, the definition has been extended to include infinite cylinders (circular and elliptical), planes (half-spaces), and generic quadrics (surfaces described by 2nd degree equations)

Use of such "infinite bodies" is encouraged since it makes input less error-prone. They also provide a more accurate and faster tracking.

Bodies

- Each body divides the space into two domains inside and outside. The outside part is pointed to by the normal to the surface.
- 3-character code of available bodies:
  - RPP: Rectangular ParallelePiped
  - SPH: SPHere
  - XYP, XZP, YZP: Infinite half space delimited by a coordinate plane
  - PLA: Generic infinite half-space, delimited by a PLAne
  - XCC, YCC, ZCC: Infinite Circular Cylinder, parallel to coordinate axis
  - XEC, YEC, ZEC: Infinite Elliptical Cylinder, parallel to coordinate axis
  - RCC: Right Circular Cylinder
  - REC: Right Elliptical Cylinder
  - TRC: Truncated Right angle Cone
  - ELL: ELLipsoid of revolution
  - QUA: QUAdric

Example of Bodies



Infinite circular cylinder

Infinite elliptical cylinder

Infinite half-space parallel to coordinate axis

Arbitrarily oriented infinite half-space

Arbitrary generic quadric: corresponding to the equation:

$$A_{xx}\, x^2 + A_{yy}\, y^2 + A_{zz}\, z^2 + A_{xy}\, xy + A_{xz}\, xz + A_{yz}\, yz + A_x\, x + A_y\, y + A_z\, x + A_0 = 0$$

The Black Hole

To avoid infinite tracking the particles must be stopped somewhere. This has to be insured by the user by defining a region surrounding the geometry and assigning the material BLCKHOLE to it.

The outer surface of this region must be defined by a single closed body (generally an RPP or a Sphere).

All particles that enter the blackhole are absorbed (they disappear). Further blackhole regions can be defined by the user if necessary.

The blackhole is the outermost boundary of the geometry. Inside its outer surface:

Each point of space must belong to one and only one region!

Combinatorial Geometry Input

CG input must respect the following sequential order:

- GEOBEGIN card
  - VOXELS card (optional, see Voxel lecture)
  - Geometry title (and reading format options)
    - Body data
  - END card (not needed in flair)
    - Region data
  - END card (not needed in flair)
  - LATTICE cards (optional, see Lattice lecture)
  - Region volumes
    (optionally requested by a flag in the Geometry title, used together with the SCORE command)
- GEOEND card

Cards having a * in column 1 are treated as comments.

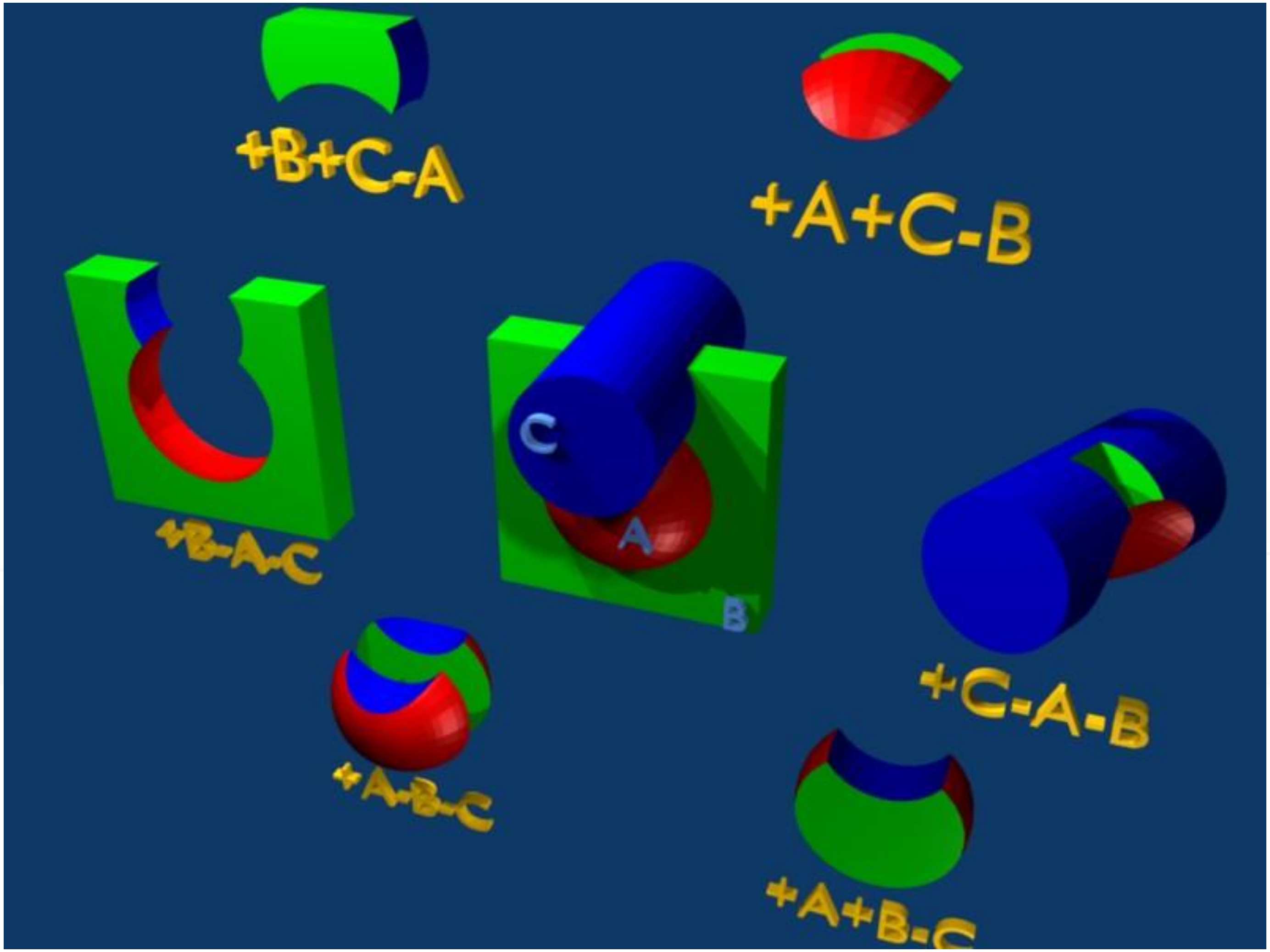
Concept of Region

Regions are defined as combinations of bodies obtained by boolean operations:

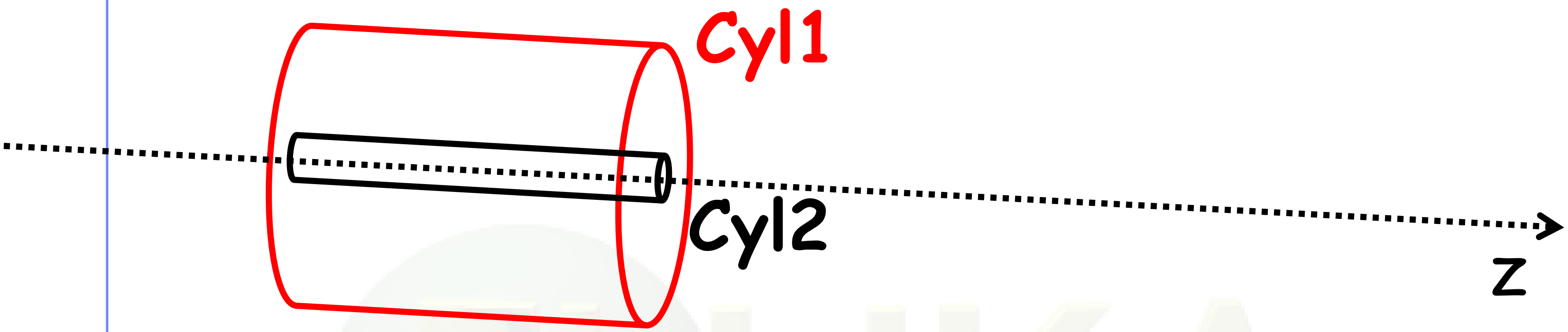
	Union	Subtraction	Intersection
Free Format	|	-	+
Fixed format	OR	-	+
Mathematically	$\cup$	$-$	$\cap$

Regions are not necessarily simply connected (they can be made as the union of two or more non contiguous or partially overlapping zones) but must be of homogeneous material composition.

Illustration of the + and – operators



Example: build a cylindrical collimator

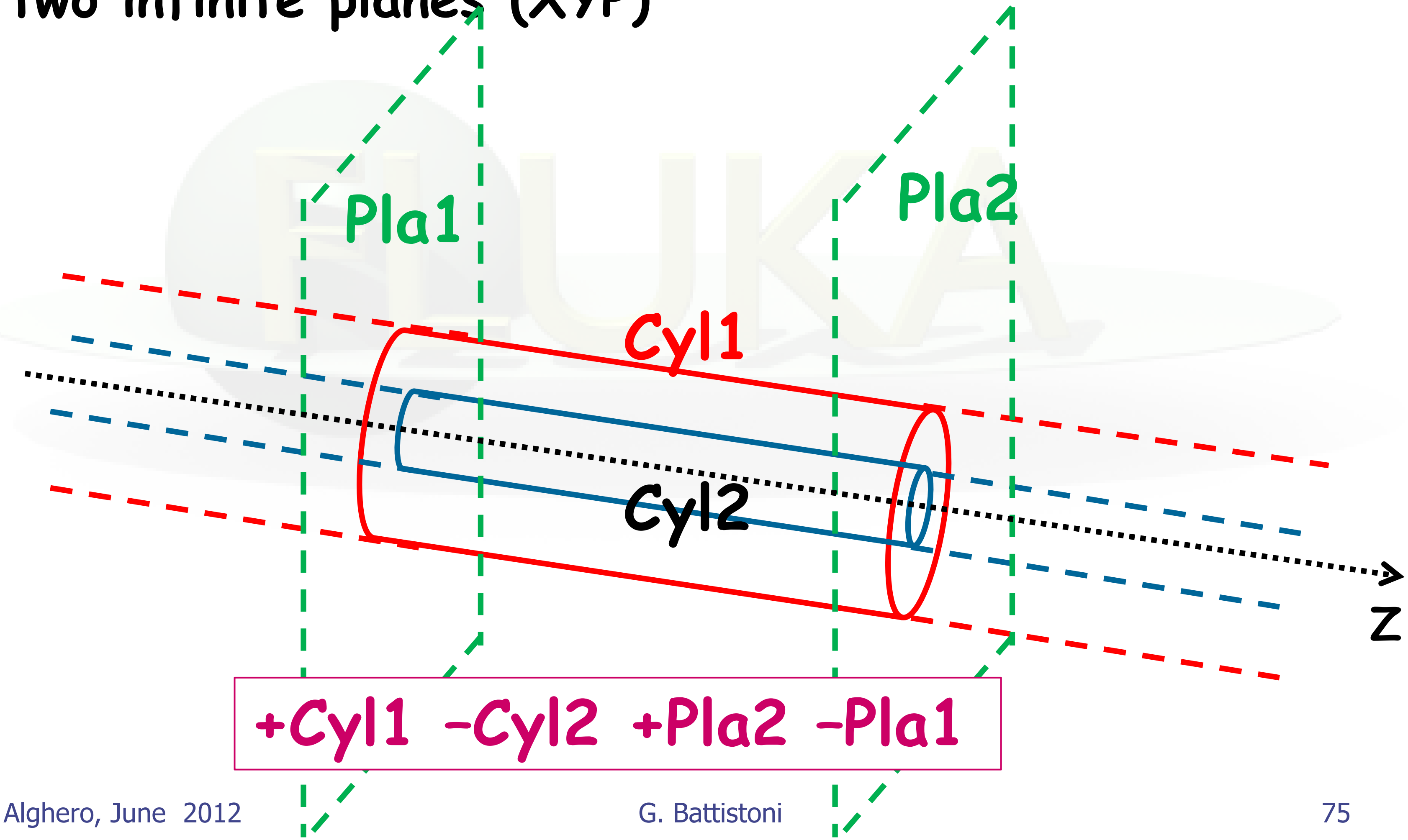


Define 2 coaxial cylindrical bodies (for ex. RCC) having the same length and position: Cyl1 and Cyl2

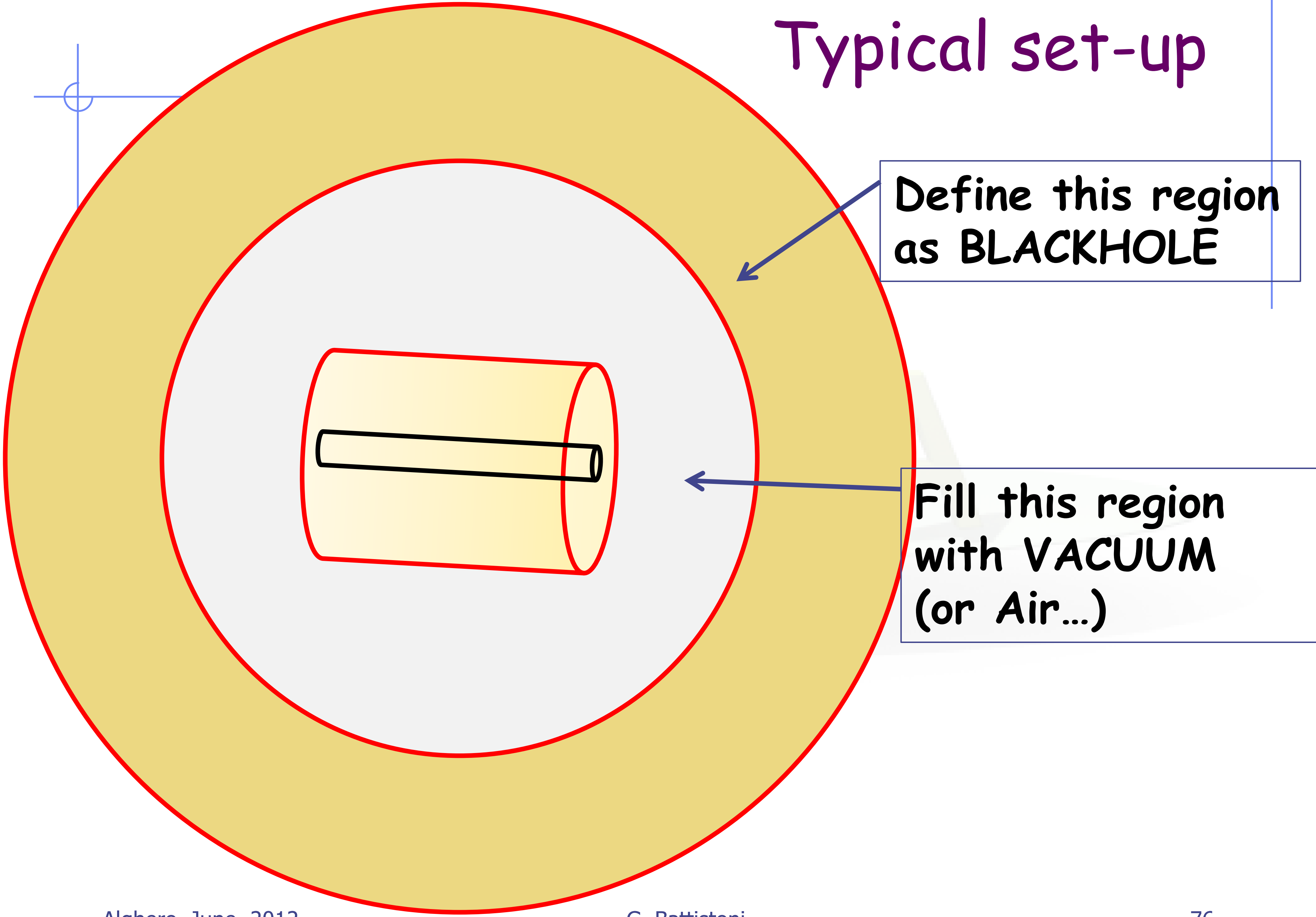
Define the region Collim as the region of space inside body Cyl1 and outside body Cyl2. This is achieved by "subtracting" Cyl2 from Cyl1: +Cyl1 –Cyl22

A better solution in FLUKA (even if it doesn't seem obvious)

Use infinite bodyes: 2 coaxial infinite cylinders (ZCC) cut by two infinite planes (XYP)



Typical set-up

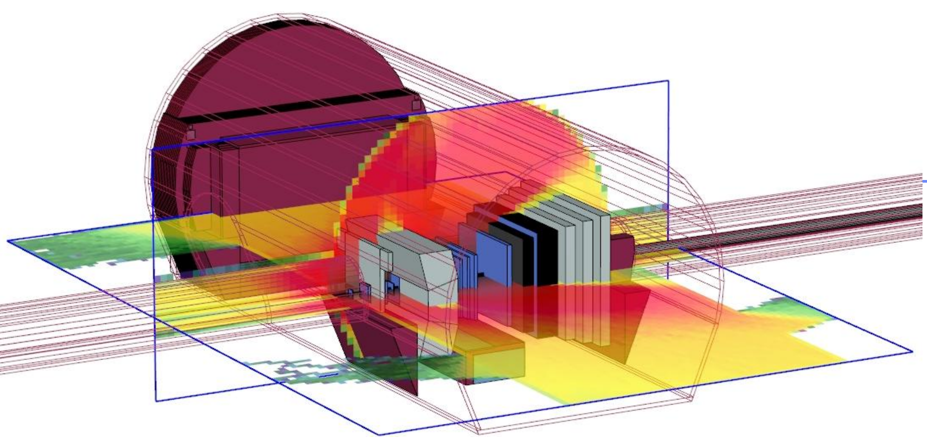


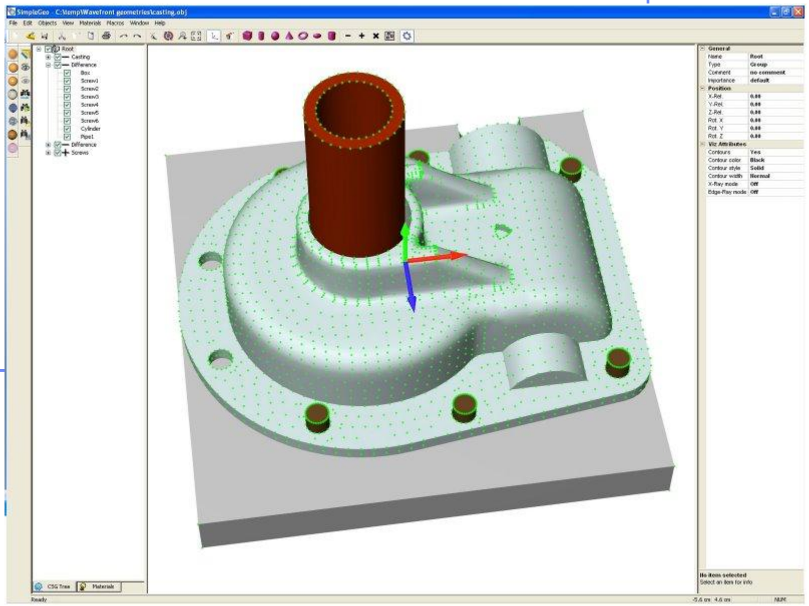
Advanced geometries

- Voxel geometry (fundamental for medical physics applications
- Lattice geometry (to replicate in space a basic cell structure. Very useful, for example in detector simulations)

Auxiliary program: Simple Geo

- SimpleGeo is an interactive solid modeler which allows for flexible and easy creation of the models via drag & drop, as well as on-the-fly inspection
- Imports existing geometries for viewing
- Creating new geometries from scratch
- Export to various formats (FLUKA, MCNP, MCNPX)
- Download, Tutorials, etc.: http://theis.web.cern.ch/theis/simplegeo
- Operating system: Windows only





Learning FLUKA at home

Learning FLUKA at home 2

Fluka >> Documentation >> Download Tools >> Discuss >> Team >>

JLAB2012 Course:

- Introduction
- Program
- Practical info
- Dates and Deadlines
- Register
- Requirements
- Group photo
- Contact Us

News:

Fluka Release (*16.05.2012*)

FLUKA 2011.2.13 has been released.

A A A

12th Fluka Course, Jefferson Lab, Newport News, VA, USA

Dat

Follow all lectures and exercises!

Course Program

Tentative Program

Time	Monday	Tuesday	Wednesday	Thursday	Friday
7:30 - 8:00	Registration				
8:00 - 8:30 8:30 - 9:00	Introduction to FLUKA [PDF 1]	FLUKA Combinatorial Geometry [PDF 1]	Statistics and Sampling [PDF 1]	Physics Models 2 (EM Interactions) [PDF 1]	Activation Studies [PDF 1]
9:00 - 9:30 9:30 - 10:00	Installing and running [PDF 1]	1st Geometry (Exercise 4) [PDF 1] ex4.flair ex4.inp	Low-Energy Neutrons [PDF 1]	Ionization and Transport [PDF 1]	Activation (Exercise 13) [PDF 1] ex13.inp ex13.flair
10:00 - 10:30	Break	Break	Break	Break	Break
10:30 - 11:00	First exercise (Exercise 1) [PDF 1] ex1_numBased.inp	1st Geometry (Exercise 4 cont) (no files)	Low-Energy Neutron (Exercise 9) [PDF 1]	Cutoffs (Exercise 11) [PDF 1]	Handling of Errors, Crashes etc. [PDF 1]

Next courses

- 2012: Advanced course in TRIUMPH (Canada) in late september
- 2013: New beginner courses in Paris (NEA), CERN(?),....