



The FLUKA Code: Insight and features



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Last version:

FLUKA 2011.2c.4, April
17th 2016
(last respin)
flair-2.2-0
13-Apr-2016

News:

**Fluka Release
(17.04.2016)**
FLUKA 2011.2c.4 has
been released.

A A A



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PLEASE: JOIN THE MAILING LIST, READ THE LICENSE (NON-GPL, MILITARY USE FORBIDDEN, ...)

The screenshot shows the FLUKA website homepage. At the top left is the FLUKA logo, and at the top right are the CERN and INFN logos. A navigation bar contains links for Fluka, Documentation, Download, My Account, Tools, Discuss, and Team. The main content area is divided into several sections:

- Quick launch:** A list of links including Download, Mailing list, Manual Online, Courses, Flair, and Contact us.
- Last version:** A section highlighting the latest release: FLUKA 2011.2c.4, April 17th 2016 (last respin), and flair-2.2-0 13-Apr-2016.
- News:** A section titled "Fluka Release (17.04.2016)" stating that FLUKA 2011.2c.4 has been released.
- License:** A section explaining that download and use of the FLUKA package are subject to the conditions in the FLUKA user license. It notes that users received a copy of the conditions when they established their personal FLUKA User ID (FUID).
- Registration:** A red text box with a blue dashed border states: "Only registered users can download! Please enter your FUID (i.e. fuid-XXXX) as 'User Name:'".
- Subscription:** A section suggesting users subscribe to the FLUKA mailing list for help and updates, providing the email Majordomo@fisica.unimi.it and the text "subscribe fluka-discuss".
- Downloads:** A table listing various software packages for download.

Annotations include a blue dashed circle around the "Download" link in the Quick launch section, a blue dashed circle around the "Last version" section, and a blue dashed circle around the registration warning text. A blue arrow points from the "whenever there is a respin" text at the bottom to the "last respin" text in the Last version section.

Name	Comment	Date	Size
fluka-2011.2c-4.x86_64.rpm	rpm for fluka-2011.2c-4	17th of April, 2016	148 MB
fluka-2011.2c-4.i686.rpm	rpm for fluka-2011.2c-4	17th of April, 2016	145 MB
flupix-2011.2c-3_flair-2.2-0.iso	FLUKA Package Version 2011.2c-0	3rd of February, 2016	531 MB
fluka2011.2c-linux-gfor64bitAA.tar.gz	FLUKA GFortran, 64 bits, Package Version 2011.2c-4	17th of April, 2016	158 MB
fluka2011.2c-linuxAA.tar.gz	FLUKA Package Version 2011.2c-4	17th of April, 2016	147 MB
flupix-vdi.zip	Auxiliary files for FLUPIX	28th of September, 2009	526 kB

Last updated: 13th of August, 2012

whenever there is a respin (announced on the mailing list)
please update your installation

FLUKA Description

- ❑ FLUKA is a general purpose tool for calculations of particle transport and interactions with matter, covering an extended range of applications: from proton and electron accelerator shielding to target design, calorimetry, activation, dosimetry, detector design, Accelerator Driven Systems, cosmic rays, neutrino physics, radiotherapy etc.
- ❑ 60 different particles + Heavy Ions
 - Hadron-hadron and hadron-nucleus interaction "0"-10000 TeV
 - Electromagnetic and μ interactions 1 keV - 10000 TeV
 - Nucleus-nucleus interaction up to 10000 TeV/n
 - Charged particle transport and energy loss
 - Neutron multi-group transport and interactions 0-20 MeV
 - n interactions
 - 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
 - User-friendly GUI interface thanks to the Flair interface
- ❑ Maintained and developed under CERN-INFN agreement and copyright 1989-2016
- ❑ More than 9000 registered users

Full mixed field capability

<http://www.fluka.org>

Preliminary considerations:

What this course is *not* about:

This is an advanced course, *no detailed instructions* will be given on

- Installing and running the code
- Using the basic Flair features
- Writing/debugging a simple geometry
- Writing/debugging a simple input file
- Use the built-in scoring, and process the results

Moreover, there will be no lecture on the physics embedded in the code.

However, a few reminders / summaries will be provided

What this course is about:

- New features in **FLUKA**
- A bit of the internal structure of the code
- Advanced geometry issues
- Advanced biasing
- User routines, with examples
- And in general how to exploit at best the code

This course relies heavily on the experience of past advanced courses: feedback is welcome!!!

Release / Registration

- ❑ You received a USB stick with **Fluka2016.2pre (pre-release/alpha version of Fluka2016)**, that is **not** yet publicly distributed. The public release will occur in 2016/2017
- ❑ If you are not a registered user, **PLEASE REGISTER NOW** on the **fluka** web site
- ❑ This pre-release **should not be used for scientific work, neither** results obtained with this pre-release should be used **for any project, publication or comparison**. Its use is strictly limited at getting a flavour of the new features at the course, and its lifespan is limited
- ❑ Please download the public fluka2016/7 version as soon as it will available on the web site sometimes next year
- ❑ Bugs/questions related to this pre-release version should be addressed to **fluka-discuss@fluka.org** only if strictly necessary, with the tag **[fluka2016]** in the subject

Important notice:

- PEANUT has been extended to cover the whole energy range since several years. The extended PEANUT is **NOW THE DEFAULT** at all energies, that is the default is now the equivalent of:

```
PHYSICS 100000. 100000. 100000. 100000. 100000. 100000. PEATHRESH
```

- Coalescence and heavy evaporation are still required to be activated explicitly for precise calculations (hopefully changed for the final release at least for coalescence):

```
PHYSICS 1.
```

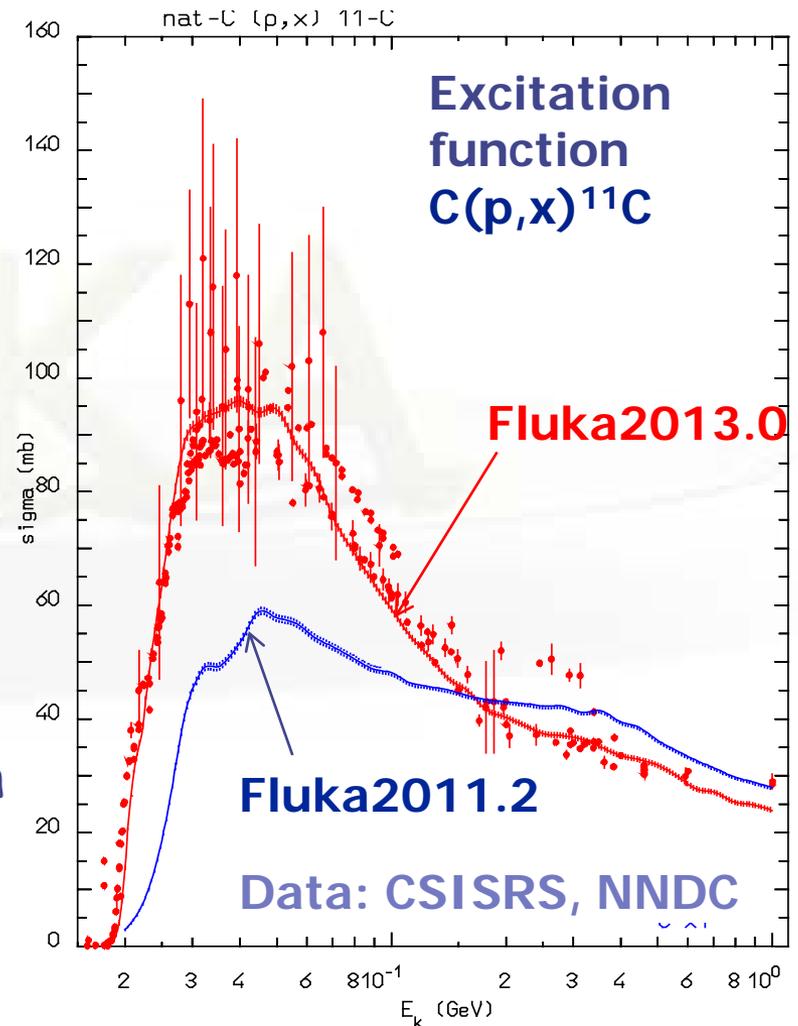
```
COALESCE
```

```
PHYSICS 3.
```

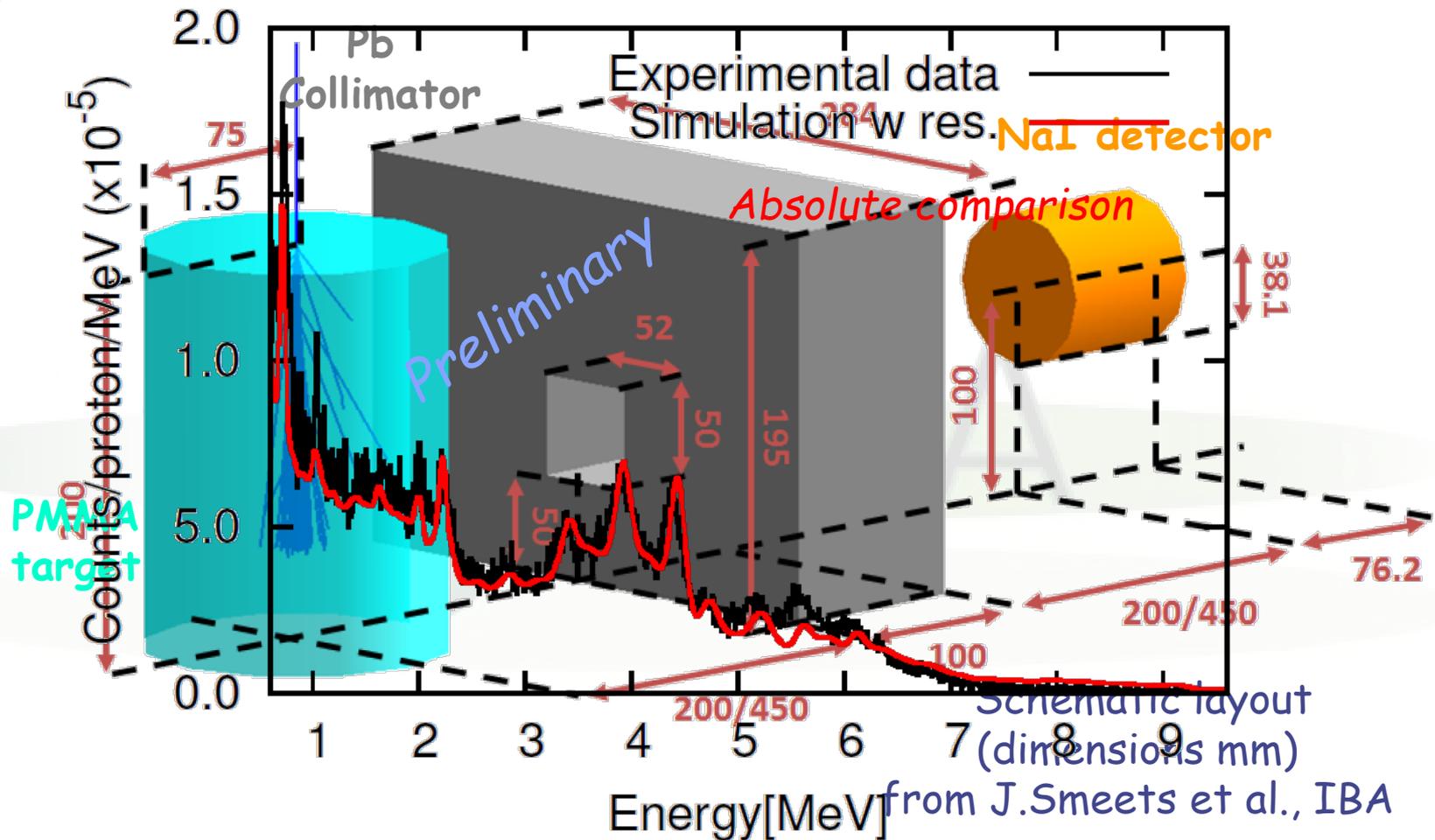
```
EVAPORAT
```

New features in low energy nuclear int.

- Direct (p,α) reactions introduced for light nuclei
- New model for "first interaction" deuteron production for light nuclei
- General cleanup/retuning of PEANUT for p/n at low energies
 - ✓ Example: effect on the production of β^+ emitters, important for medical (PET on line) applications
- De-excitation γ angular distribution according to multipolarity and spin orientation
- Example of prompt photon emission: see next slide



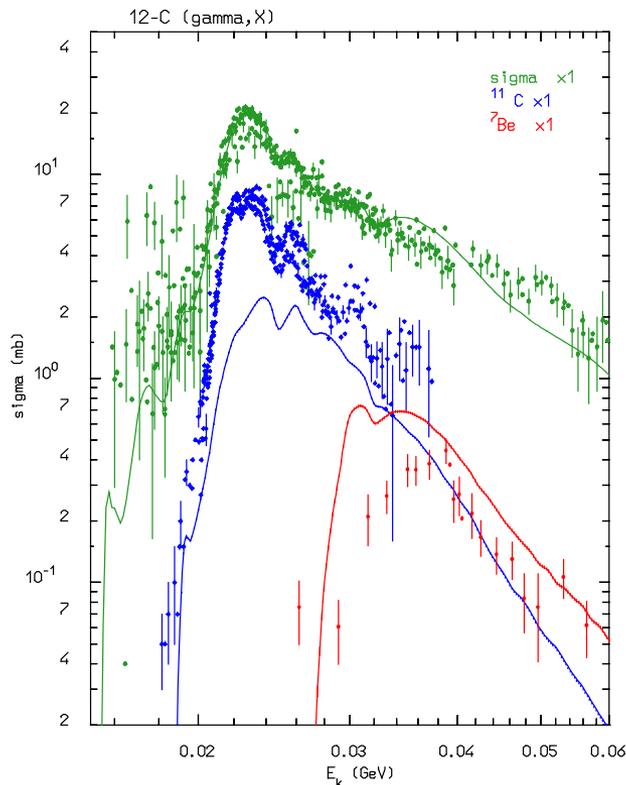
Photon yields by 160 MeV p in PMMA



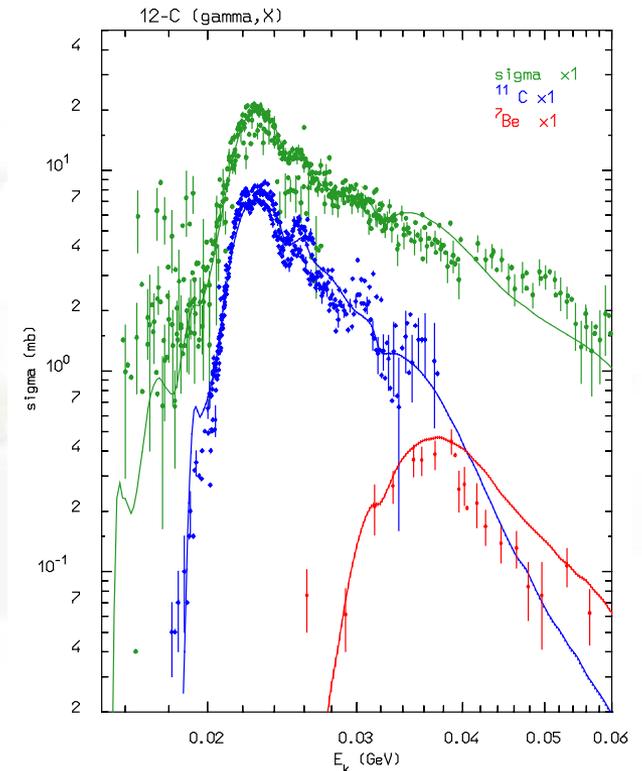
Energy spectrum of "photons" after background subtraction (collimator open - collimator closed) for 160 MeV p on PMMA. FLUKA **red line**, data **black line** (J.Smeets et al., IBA, ENVISION WP3)

New features in Fermi break-up

- Account for initial spin and parity, when known, in Fermi break-up
→ major improvement for (γ, X) reactions on light targets.



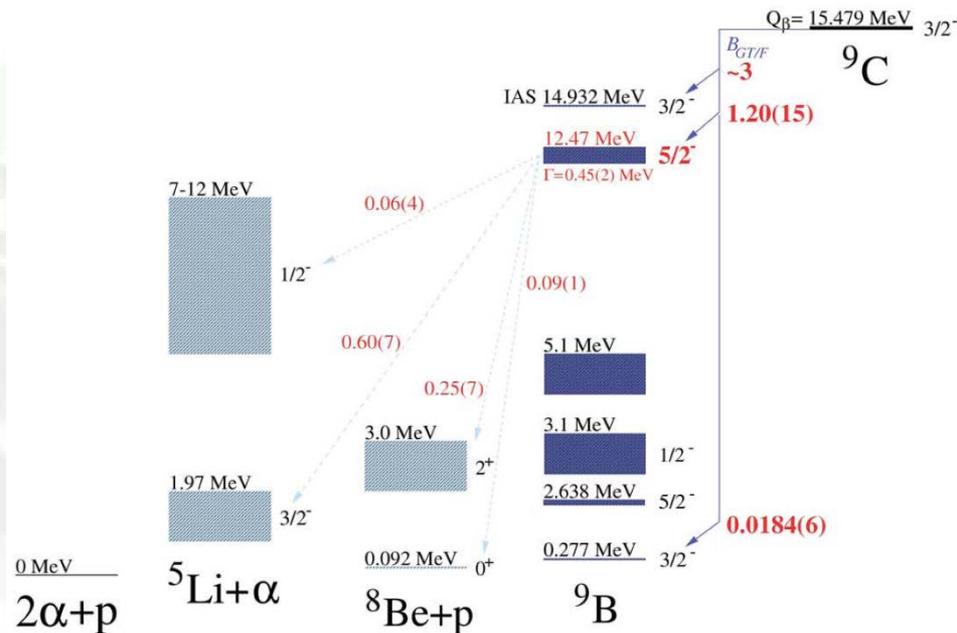
12C + γ in GDR
→ $J^\pi = 1^-$
→ 3α and $\alpha + {}^8\text{Be}$
impossible in
 $L=0$
→ Factor 3 on ${}^{11}\text{C}$
production



- Broad ${}^8\text{Be}^*$ 1st excited state now accounted for in Fermi break-up

New features in Decays etc

- Emission of α particles in radioactive decays added
- Special decay model for 9-C

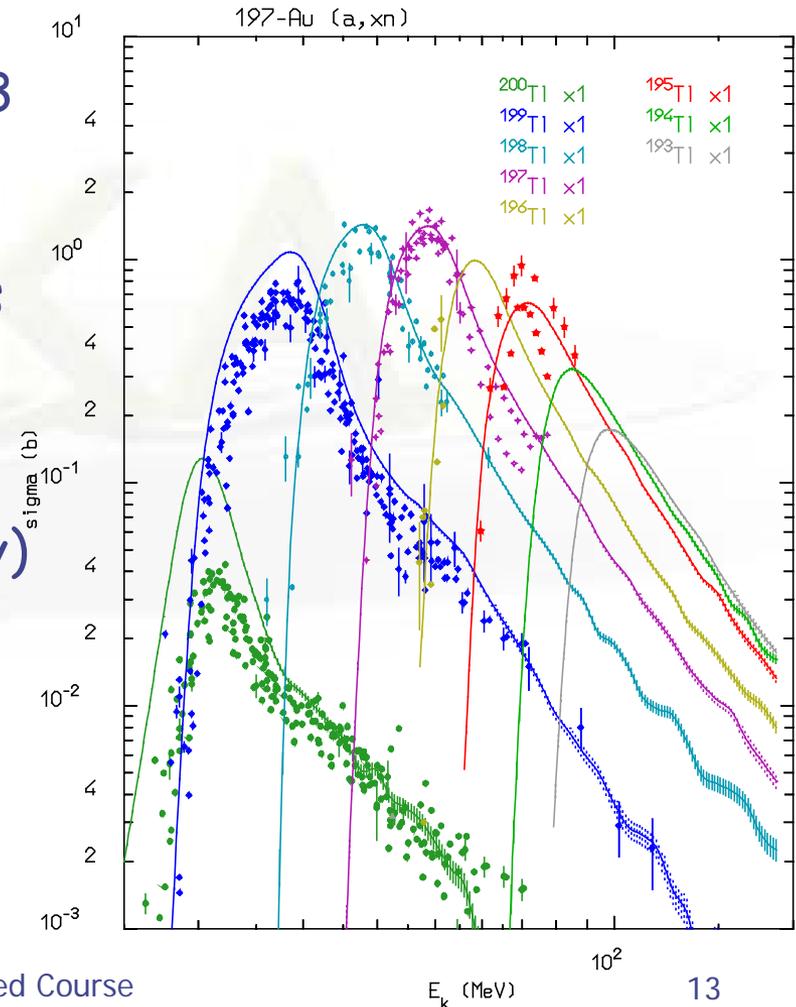


- New masses/half-lives/decays/radiations database
- Branchings for isomer production by neutrons below 20 MeV now based on JEFF activation file and no longer on a naive 50-50% assumption

New features in ion-ion generators

- Nuclear discrete levels accounted for in BME, rQMD and DPMJET interactions when considering fragment excitation
- (Initial) extension of BME to $A=3$ projectiles
- BME coupled with Peanut preequilibrium for configurations where the BME native preequilibrium is not available \rightarrow major improvement in the description of alpha (and not only) induced reactions

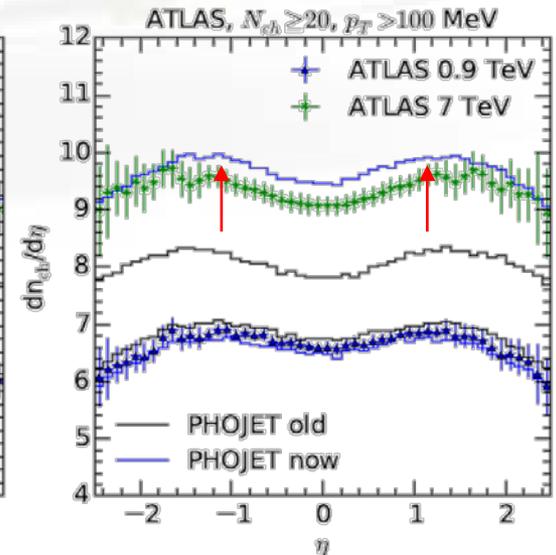
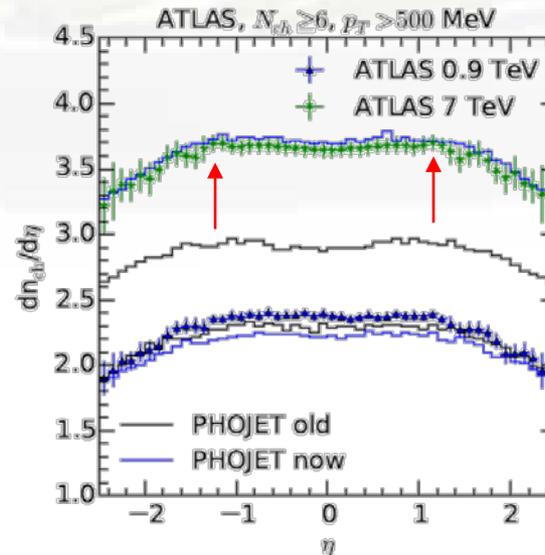
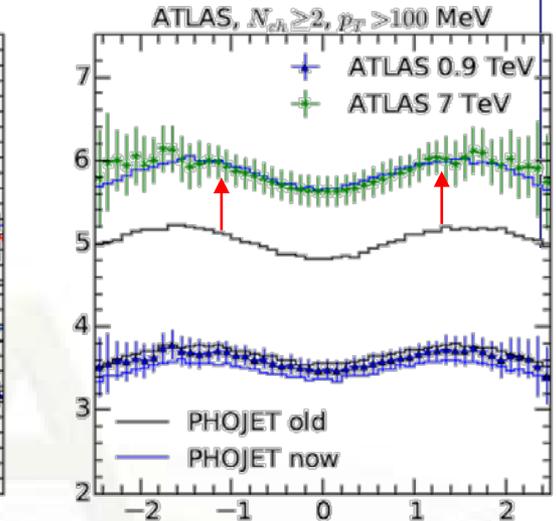
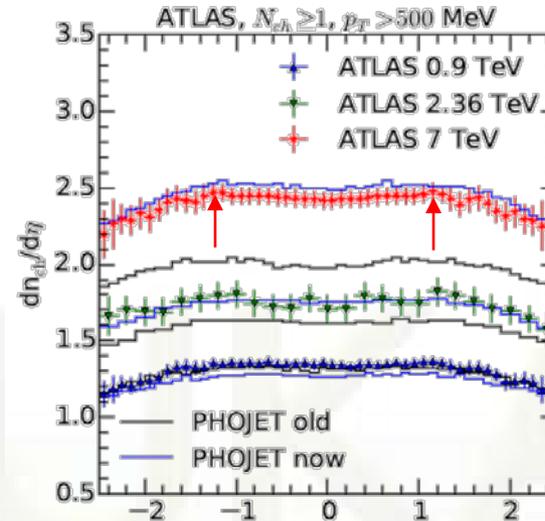
Excitation functions for the production of radioisotopes from α interactions on Au (left) and Pb (right) (Data: CSISRS, NNDC)



New features in Dpmjet-3

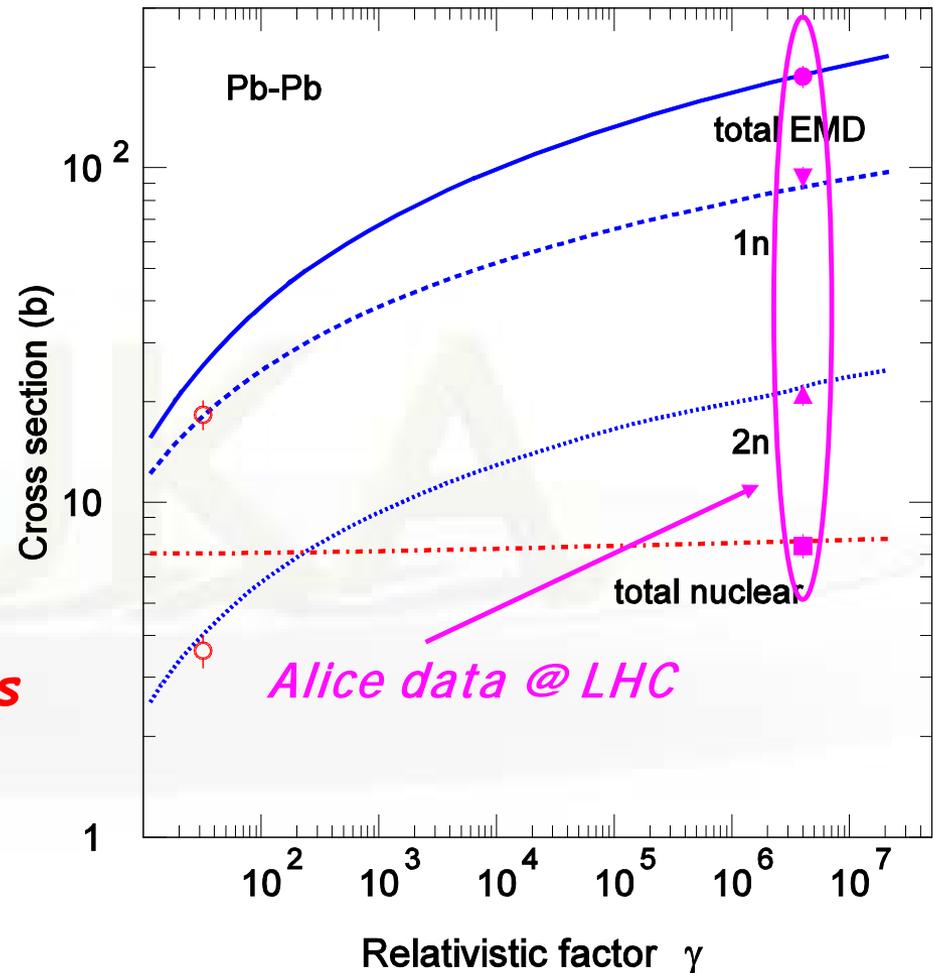
ATLAS - Charged particle pseudorapidity density.

- Dpmjet-3 used for heavy ion interactions above 5 GeV/A, pp and hA above 20 TeV
- Major revision with significant improvement of agreement with LHC data
- New model for high energy p/pbar-p elastic and total cross sections and elastic scattering



New features in EMD

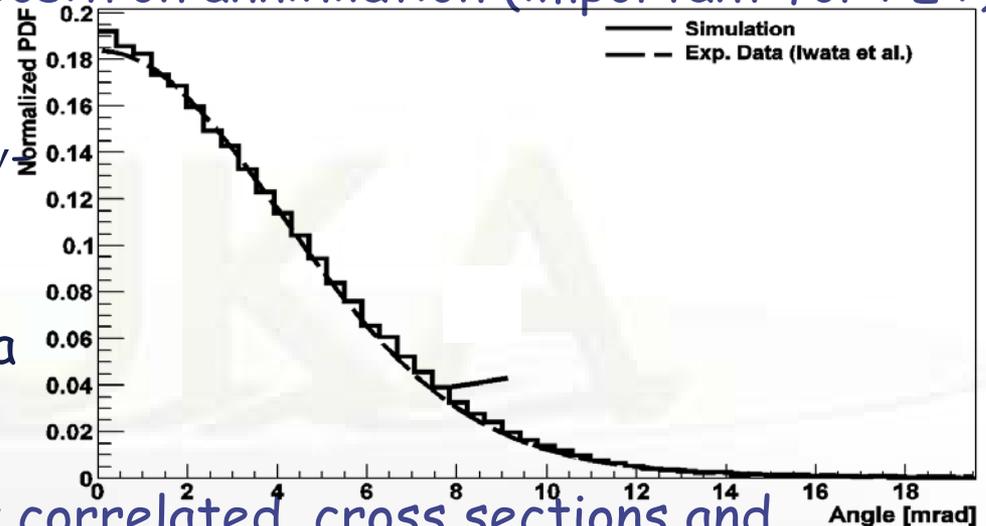
- General improvement of ElectroMagnetic Dissociation (EMD), now including the ***E2 multipolarity*** → important at low energies and for μ^\pm and e^\pm
- EMD extended to μ^\pm below the γ -N threshold
- EMD extended to e^\pm → ***electronuclear interactions*** now implemented (see exercise)
- ***Deuteron Coulomb dissociation*** (stripping). Please note ***nuclear stripping not yet implemented***



More new features..

- Improvement of the transition between the resonance and DPM models for Nucleon-Nucleon interactions
- Acolinearity model for positron annihilation (important for PET)

Example: deviation from γ co-linearity after positron annihilation in H_2O , FLUKA(line) vs data (histo)



- Neutron pointwise, fully correlated, cross sections and interactions for 2-H, 3-He and 4-He
- Synchrotron radiation generation through a new SPECSOUR option (see lecture on sources)
- Offset dipole and IGRF11 (possibly IGRF15 for the release) magnetic field tracking for cosmic ray module (see lecture on cosmic rays)

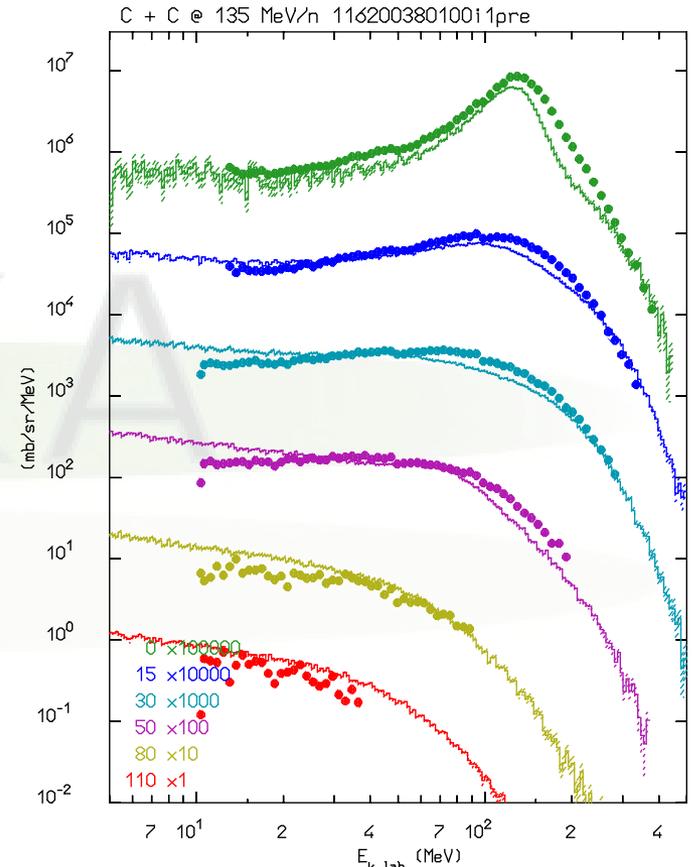
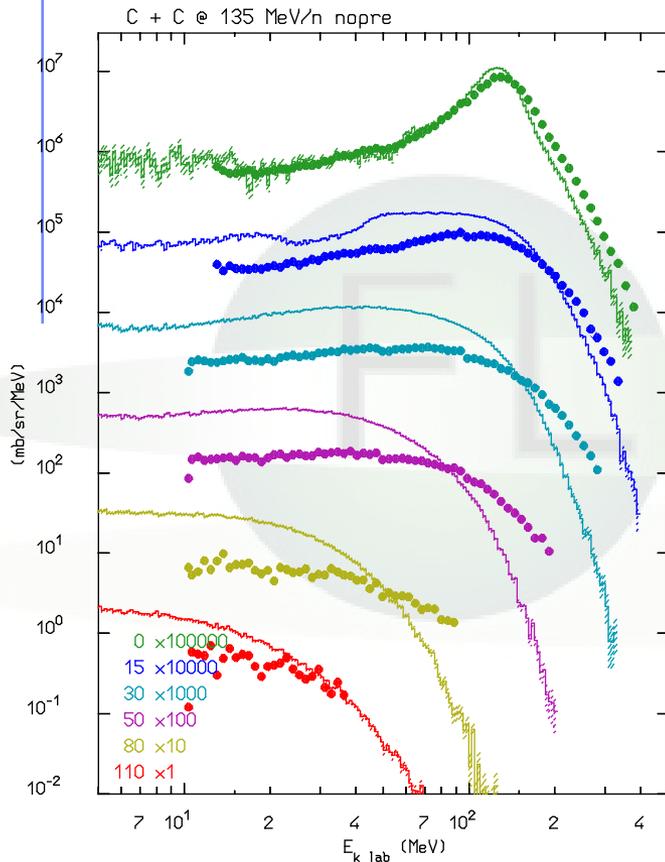
C on C @ 135 MeV/n: rQMD before and after

Neutron
double
differential
spectra at
various
angles
Histos:
rQMD
Symbols:
exp. data

New

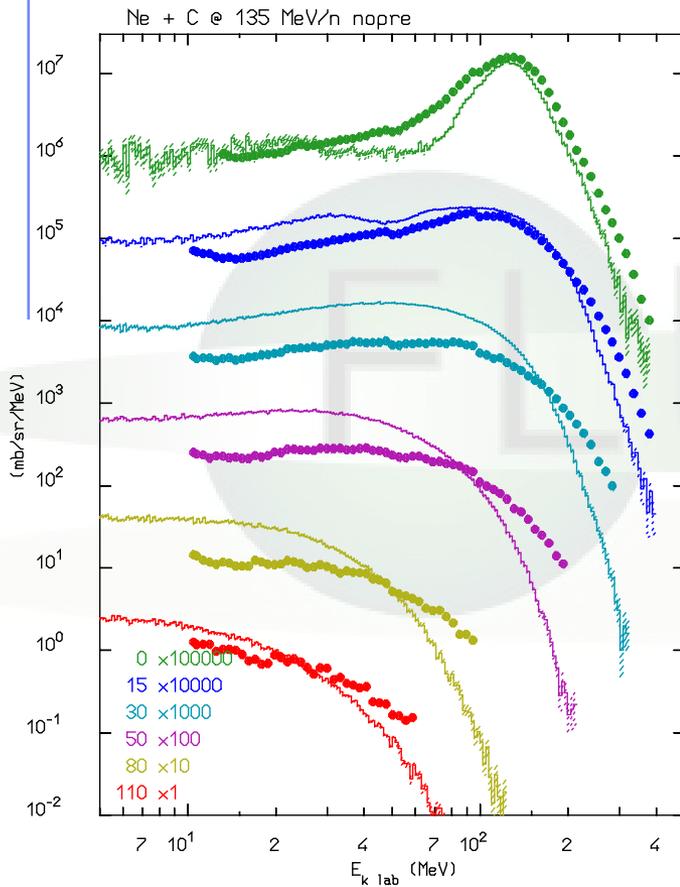


Old



Improvements in the intermediate energy ion-ion generator at its lowest energy range (please note that @ 135 MeV/n events are shared between rQMD and BME)

Ne on C @ 135 MeV/n: rQMD before and after

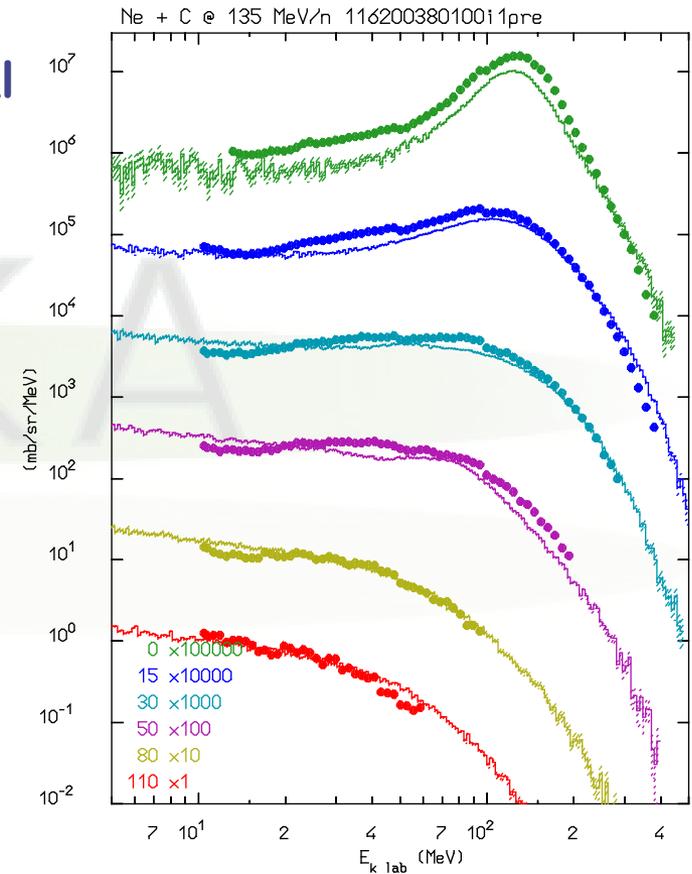
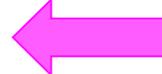


Neutron
double
differential
spectra at
various
angles
Histos:
rQMD
Symbols:
exp. data

New



Old



Technical improvements

- Alternate material for radioactive decays extended to support whichever material, not only vacuum
- New **DEFAULT: DAMAGE** for DPA calculations
- **Revised DEFAULTS**, towards better precision in general
- Possibility to **assign** numeric or character **values** to **preprocessor codewords** and then use them in the input file
- Extension of **signed** rotation indexes to lattices and geometry, even in preprocessor parameterized form
- Multiple **DETECT** estimators with arbitrary number of channels
- New generalized estimators for (rough) Single Event Upset estimates: **HEHAD-EQ, THNEU-EQ**

Technical improvements -II

- New generalized estimators: LGH-IONS, HVY-IONS, E+E-GAMM, DOSE-H2O, LOWENNEU, NTLOWENE, ALL-IONS
- Blank common (initial) **dynamic memory allocation** now possible, and further run-time dynamic allocation for usrbins and voxels, obviously on the *gfortran version only*
- Alarm set up to catch TERM signals and stop runs cleanly
- EMD cross sections for the projectile and all charged hadrons/leptons tabulated at initialization (improved speed)

Technical improvements -III

- AUXSCORE filtering for activity binnings (2016.2pre):
 - ❑ There was a **long standing wish** to be able to filter through **AUXSCORE** the **radioactive isotope** under consideration when scoring an activity binning (eg "I want to know how much activity comes from 60-Co...")
 - ❑ Now (2016.2pre) it is possible!
 - ❑ Please, read ***carefully*** the **manual** about how the **AUXSCORE** filtering works for ions (in particular how to select only the ground state or an isomer, rather than all together)
- New flag for keeping track of (parent) Isotope (2016.2pre):
 - ❑ **Iaztrk** = flag for the parent radioactive isotope if any (**Iaztrk** = $A + 1000 Z + 1000000 * m$)
 - ❑ The variable is in common (**TRACKR**) and propagated throughout the code to daughters etc etc
 - ❑ It is intended for "easy" filtering in user routines like comscw, fluscw etc
- New generalized particle (2016.2pre): β^+ annihilation points:
 - ❑ **ANNIHRST** = generalized particle for scoring β^+ annihilation points
 - ❑ It can be used for (point-like, not track-length like) USBIN's
 - ❑ Together with the previous flag it should allow an easy scoring of annihilation points possibly filtered for the isotope which generated the β^+ decay

Technical improvements -IV

Online parenthesis expansion (2016.2pre): when a region expression containing parentheses would result in too many terms if expanded at initialization time

- The evaluation of the expression is now performed on-line rather than crashing because running out of memory as before
- All terms have to be evaluated → more time consuming than evaluating a single zone
- Performance penalty, depends a lot on the complexity of the region. Test cases it varied from 10% to factors of $\times 10!$
- Luckily the DNEAR is improving a lot.
- However diverging random number sequence vs expanded form with DNEAR ON (not a problem if one or the other approach used all the time) → Same random number sequence with DNEAR OFF
- Possible further improvements in speed optimization

Use with care and only if absolutely required! It is easy to incur large CPU penalties!!!!

Some reminders:

- ❑ The present version works with the g77 (32 bit) and gfortran compilers (64 bit). For 64 bit computers, if you wish to use the 32 bit, g77, version compatibility packages are required
- ❑ gfortran \geq 4.6 required, to avoid mis-compilations
- ❑ On Windows, a virtual-machine package can be installed
- ❑ The code is in fortran, as well as all user routines.
- ❑ The high energy heavy ion interaction generators are external, if needed they have to be linked with the program using the **ldpmqmd** script. There are two of them: DPMJET-3 ($E/A > 5$ GeV), rQMD ($E/A > 100$ MeV)
- ❑ The low energy ion interaction generator (BME) is part of the standard Fluka library (no need for specific linking)
- ❑ Units: **GeV, g, cm, second, radian**, with a few exceptions (for instance the Ionization potential is in eV, as well the DPA damage threshold)

Some reminder: the FLUKA input file jargon

The FLUKA input file is an **ascii** file containing the **COMMANDS**

Command:

One keyword, 6 floating point numbers, one keyword

Example (fixed format, FREE format is available as well):

```
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
BEAM          1.E+04          0.0          0.0          0.0          0.0          0.0PROTON
*
*keyword      momentum mom.spread  diverg.    X-width   Y-width   flag  particle
*            WHAT(1)    WHAT(2)    WHAT(3)    WHAT(4)   WHAT(5)  WHAT(6)  SDUM
```

- We refer to commands also as: **cards**, **options**, **directives**, **definitions**
- We refer to input parameters as **WHAT's**
- Command keywords must be in uppercase, fixed or free format
- Some commands require more than one "card"
- Generally, with few exceptions, the order of commands is irrelevant
- Most commands can be issued several times and each next commands adds information or overrides (in total or in part) the previous ones
- A line with a * character in column 1 is treated as a **comment**
- Nearly always there are default values for WHAT() values!
- **Now most of the difficulties in building of the input file are managed by the FLAIR graphical interface**

Some reminders:

- ❑ The code works under IMPLICIT DOUBLE PRECISION for variables in the range (A-H,O-Z).
 - **Don't forget `..D+/-xx`** (eg 2.3D+00, 7.8D-03) in all numerical settings in user routines, and **be careful in passing variables** to/from Fluka or external packages (eg CERNLIB) routines
- ❑ Most mathematical and physical constants are predefined inside the (DBLPRC) include,
 - **use them whenever possible!**
- ❑ Compilation flags are already included in the **fff** script
 - The script should be used for **user routines** as well
- ❑ **Floating point exceptions** are enabled (hard-wired!!) and **dump core** size set to infinity at the start of each run
- ❑ If **high precision input** (> 10 digit) is required, FREE format can be invoked → no limit

Some reminder: the FLUKA particles

The list of particles transported by fluka is in the manual. Each particle is defined by a NAME and a NUMBER.

Only a few heavy ions have a predefined name and a number, the others are defined by A and Z

FLUKA name	FLUKA number	Symbol	Common name	Standard PDG number (Particle Data Group) [120]
4-HELIUM ⁽¹⁾	-6	α	Alpha	—
3-HELIUM ⁽¹⁾	-5	${}^3\text{He}$	Helium 3	—
TRITON ⁽¹⁾	-4	${}^3\text{H}$	Triton	—
DEUTERON ⁽¹⁾	-3	${}^2\text{H}$	Deuteron	—
HEAVYION ⁽¹⁾	-2	—	Generic Heavy Ion (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

Beginning
Of the list,
More follows

There exists also GENERALIZED particles, mostly used for scoring: ex

ALL-NEGA	204	All negative particles		
ALL-POSI	205	All positive particles		
NUCLEONS	206	Protons and neutrons	DPA-SCO	239 Displacements per atoms
NUC&PI+-	207	Protons, neutrons and charged pions	DOSE-EQ	240 Dose Equivalent (pSv) ⁽⁶⁾
ENERGY	208	For dose scoring: Deposited energy For energy fluence scoring: Kinetic energy		

Some reminders: neutrons

- Transport and interactions of neutrons with energies below 20 MeV are handled by a *dedicated library*
- Neutron interactions at higher energy are handled by FLUKA nuclear models
- In the FLUKA jargon neutrons below 20 MeV are called **low energy neutrons**
- The low energy neutron library uses a **multigroup** approach
- About **280 material/temperature** combinations are available
- The library handles also gamma generation, energy deposition by kerma factors, residual nuclei production (now including isomers), secondary neutrons, fission neutrons, and NIEL
- For some isotopes/materials: self shielding, molecular binding, correlated gamma generation, point-wise transport

Reminder: radioactive isotopes

- In FLUKA, the production, build-up and decay of **radioactive isotopes** can be simulated within the same run
- Radioactive isotopes can also be used as source particles
- **Caveat:** the production of **metastable** states is not yet simulated by the Fluka nuclear models*. When radioactive build-up/decay is requested, it is assumed that the initial isotope production is **equally distributed (half-half)** between the ground state and the (possible) metastable state. However, **metastable** states in the subsequent decay chain are populated and decayed according to the correct branching ratios

**Except low-energy neutrons, where branchings are now computed out of JEFF activation file*

Events, statistics, normalization

- ❑ In a Monte Carlo code, the result is an **estimator** of the desired quantity, and is obtained as the **average over many trials**
- ❑ Mathematically, the MC treatment is based on the **central limit theorem**
- ❑ The higher the number of trials, the better the **error** on the estimator
- ❑ In particle transport MC, a **trial** is the full history following the **primary event**
- ❑ The primary event may be represented by a single particle in a beam (the most common situation), or by a more complex source event, like for instance the decay of a radioactive isotope or the products of an interaction. Therefore, a primary, or **source**, event may be composed by several particles.
- ❑ The estimators are obtained **averaging** over the number of primary events: therefore all results in FLUKA are given **normalized per primary event**.
- ❑ Nevertheless, **event-by-event** quantities are also available from the code and/or can be accessed through user routines. Event-by-event information is useful when **correlations among estimators** are required.

Reminder: biased and analogue

- ❑ Fluka can run both in **fully analog** and in **biased** mode
- ❑ BIASING techniques allow to **improve the statistical convergence** of results in a **selected region** of the problem phase space (see lecture)
- ❑ This is done using modified distributions, and associating corresponding weights to particles
- ❑ However, the statistical convergence usually worsens in other phase space regions
- ❑ BIASING does NOT reproduce correlations among different components of the same event
- ❑ BIASING may not reproduce fluctuations of physical quantities
- ❑ The type of calculation has to be chosen with care!

Initialization

- ❑ The input cards are parsed according to an optimized ordering different from the order in the input file.
- ❑ **Names are converted to numbers for the internal use.** The correspondence is kept and is accessible
- ❑ Geometry data are decoded and stored
- ❑ User scoring is decoded, checked, memory space is allocated
- ❑ External data files (cross sections etc) are read in and processed
- ❑ Neutron cross section sets are read in for used materials
- ❑ Tabulations of partial and total cross sections are generated for the materials in use: dE/dx , bremsstrahlung, pair production..
- The **energy range and the granularity of these tabulations depend on the energy limits of the problem**, essentially on the BEAM card definition and on the production thresholds
- All these quantities, including allocations for scoring, are stored in the Fluka **BLANK COMMON**. Pointers are kept to the different areas.

Consequences

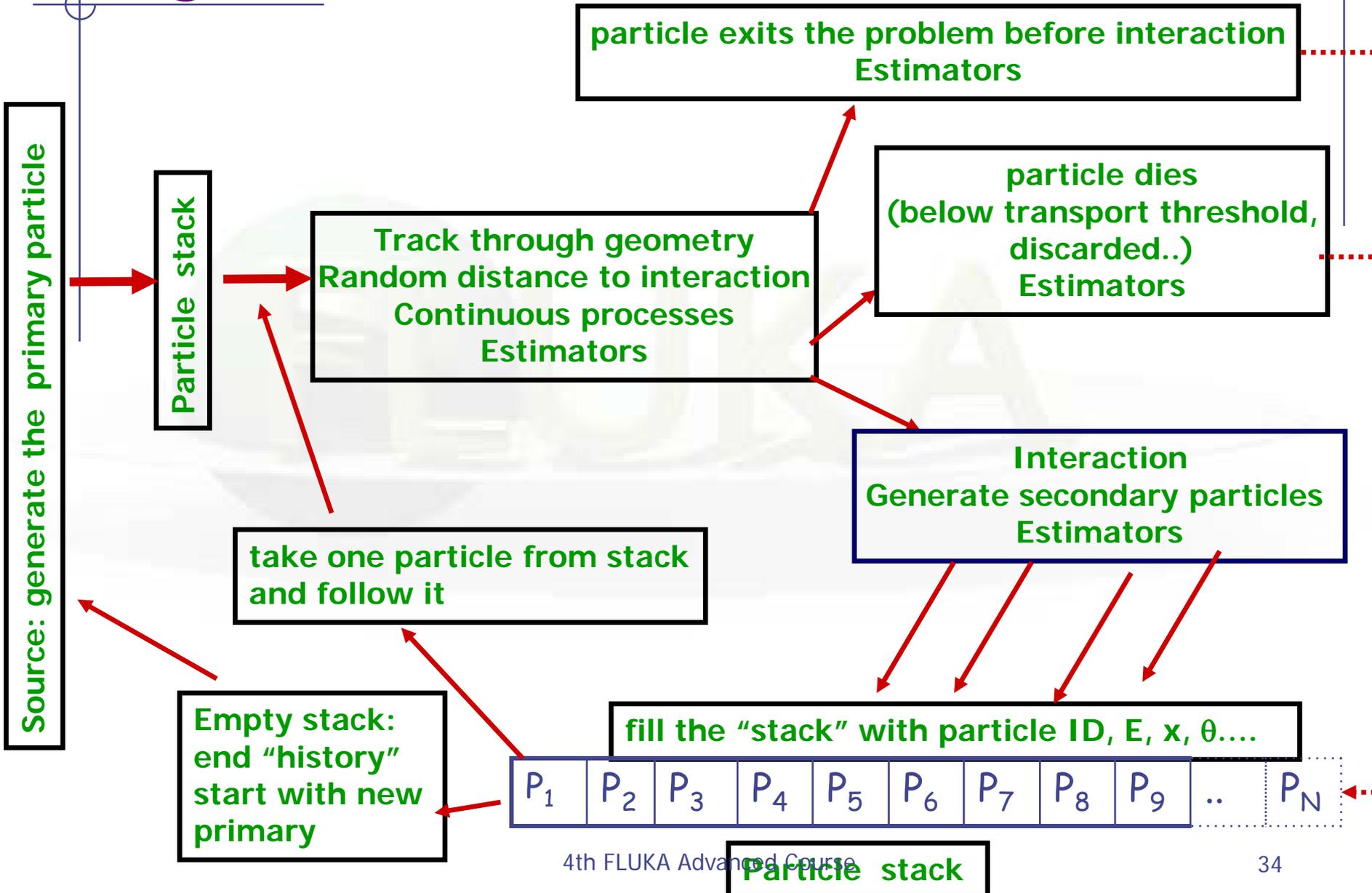
- The TOTAL amount of memory is limited. At present the blank common dimension is about 500 MB: to be kept in mind when asking for estimators *
- The amount of information, thus of memory used, grows with the number of regions and materials used
- User settings have an impact on initialization of physical processes

** Most of the memory limitations disappeared in this (gfortran) pre-release where dynamic memory allocation is introduced with a maximum set a priori by the user, or automatically for scoring and geometry, with a global limit around 4 GB*

Order of input cards parsing

1. DEFAULTS GLOBAL ROT-DEFI TITLE USRGCALL
2. BEAM BEAMAXES BEAMPOS BME DISCARD DPMJET EMF
EVENTYPE GEOBEGIN IONTRANS HI-PROPE MATERIAL
MCSTHRES PART-THR PHYSICS POLARIZAtion RQMD SOURCE
SPECSOUR THRESHOLD
3. COMPOUND RADDECAY RANDOMIZe
4. DETECT WW-FACTO WW-PROFI WW-THRES ASSIGNMAT
CORRFACt DCYTIMES DELTARAY ELCFIELD EMF-BIAS EMFCUT
EMFFIX EMFFLUO EXPTRANS FLUKAFIX IONFLUCT IRRPROFI
LAM-BIAS LOW-BIAS LOW-DOWN LOW-MAT MAT-PROP
MGNFIELD MULSOPT MUPHOTON OPT-PROD OPT-PROP
PAIRBREM PHOTONUC STERNHEI
5. EVENTBIN EVENTDAT RESNUCLEi SCORE TIME-CUT USERDUMP
USERWEIG USRBDX USRBIN USRCOLL USRTRACK USRYIELD
6. AUXSCORE DCYSCORE ROTPRBIN TCQUENCH
7. PLOTGEOM START
8. USROCALL STOP

A generic MC scheme



The stack, secondary particles, tracks

- ❑ The properties of all the particles to be tracked are stored in the "stack": /flkstk/ in '(FLKSTK)'
- ❑ NPFLKA counts the particles on stack
- ❑ The *kaskad* routine loops on NPFLKA until the stack is empty, going from bottom (npflka) to top (1)
- ❑ The "current particle" properties are copied from the stack to the TRACKR common, and updated during tracking
- ❑ At each interaction, secondaries are first stored in temporary stacks (GENSTK, FHEAVY..), then loaded onto the main stack. **The primary particle, if surviving, is loaded on the stack exactly like the others**
- ❑ The particle on top of the stack is followed *first*, generally it is the less energetic, → avoid stack explosion
- ❑ The treatment of the stack for EM particles is slightly different, due to historical reasons EM secondaries are kept on the EMF particle stack, which is emptied before the normal stack

Consequences

- Steps related to the same particle track will (almost) always be non-consecutive in the program flow.
- Primary particles lose their identity as soon as an interaction occurs (this is physical!)
- Therefore, “follow a particle track” may be not straightforward
- However, a “track number” is associated to each “new” particle and it is propagated to the stack and the TRACKR common (see dedicated lecture)
- Moreover, the generation level of each particle is recorded

Main loop

- The loop on events is controlled by the **FEEDER** routine.
 - It checks for run termination conditions (number of primaries)
 - Calls the standard fluka **source(s)** or the user source,
 - May call the **SODRAW**, user routine
 - Then gives the control to the **KASKAD** routine
- **KASKAD** keeps the control until the stack is empty. It handles directly the tracking of hadrons, ions and muons, while it dispatches
 - E.M particles to **KASEMF**,
 - Optical photons to **KASOPH**
 - Low energy neutrons to **KASNEU**
 - Heavy particles to **KASHEA** if approximate treatment is asked for
- Tracking is performed in **steps**, limited by
 - Maximum percentage energy loss in a step
 - Boundary crossing
 - Interaction probability (elastic, non-elastic, δ rays ...)
 - Decay probability

Discrete or continuous processes

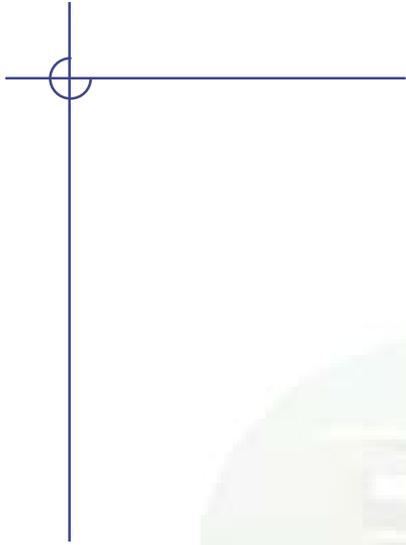
During, and at the end, of a step: **discrete** and **continuous** processes

- **Continuous:** energy deposition by Ionization, bremsstrahlung, and pair production (below explicit production thresholds)
- **Continuous:** multiple scattering, deflection by magnetic field
- **Discrete:** interaction (including low energy neutron ones), particle decay, δ ray production, radioactive decay...
- **Discrete:** track termination conditions, such as time cutoff, energy cutoff, escape in the black hole, boundary crossing
- Estimators can be activated for each of these processes, either built-in, or through user routines
- **Tricky:** energy deposition by recoil nuclei after elastic and inelastic reactions (with some settings) and energy deposition by low-energy neutron reaction products (with exceptions..) are treated as **discrete** events.

Biasing

- At every interactions/boundary crossing/ step biasing is applied if required.
- If necessary, the particle weight is modified, and stored in TRACKR and propagated to the stack.
- Particle weights are automatically taken into account by built-in estimators
- User scoring routines must take care of proper weight handling.

FLUKA provides a large variety of biasing techniques. A proper understanding of their use is essential for many shielding (and not only) problems!



end