Monte Carlo Tutorial

Part 2 – Practical MC

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AARHUS PARTICLE THERAPY GROUP

General recipe to setup a MC run

How to setup a MC run

First:
think very hard on what **question** you want to calculate, and **what you need** in order to achieve it.

Remember ***GIGO*** principle: **G**arbage **in** = **G**arbage **o**ut.

How to setup a MC run

GIGO applied on multiple levels:

- User input (specification of problem to be solved)
- Developer input (underlying models, transport engine, etc...)

Therefore:

- Do not trust MC simulation blindly
- Check your results:
    - experiments (ideally),
    - Hand / numerical calculations (or even estimates)
    - possibly supplemented by other MC codes..

How to setup a MC run

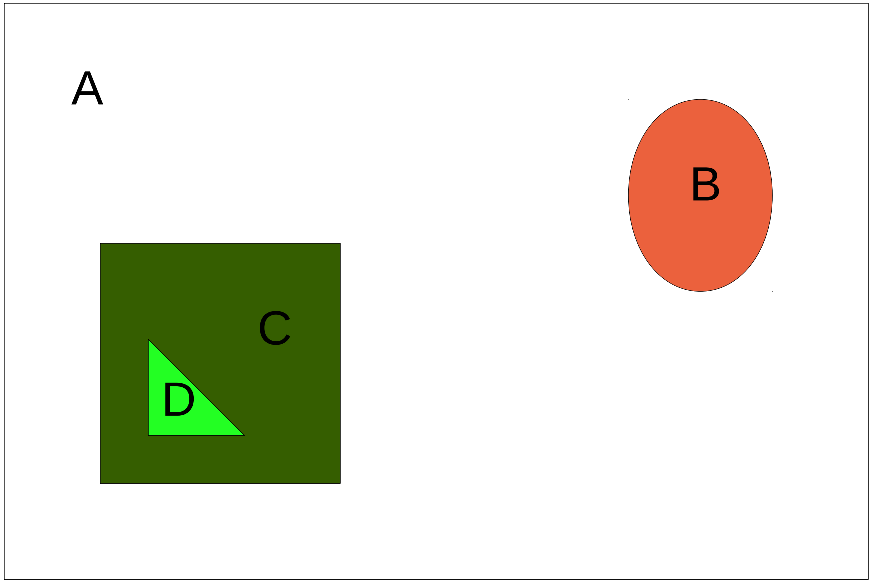
Then:

- Setup geometry
- Assign materials
- Setup beam
- Select physics to use
- Specify what to score
- **Hit the run button** (if there is one)

Then post-processing / analyzing your data follows.

Specify Geometry

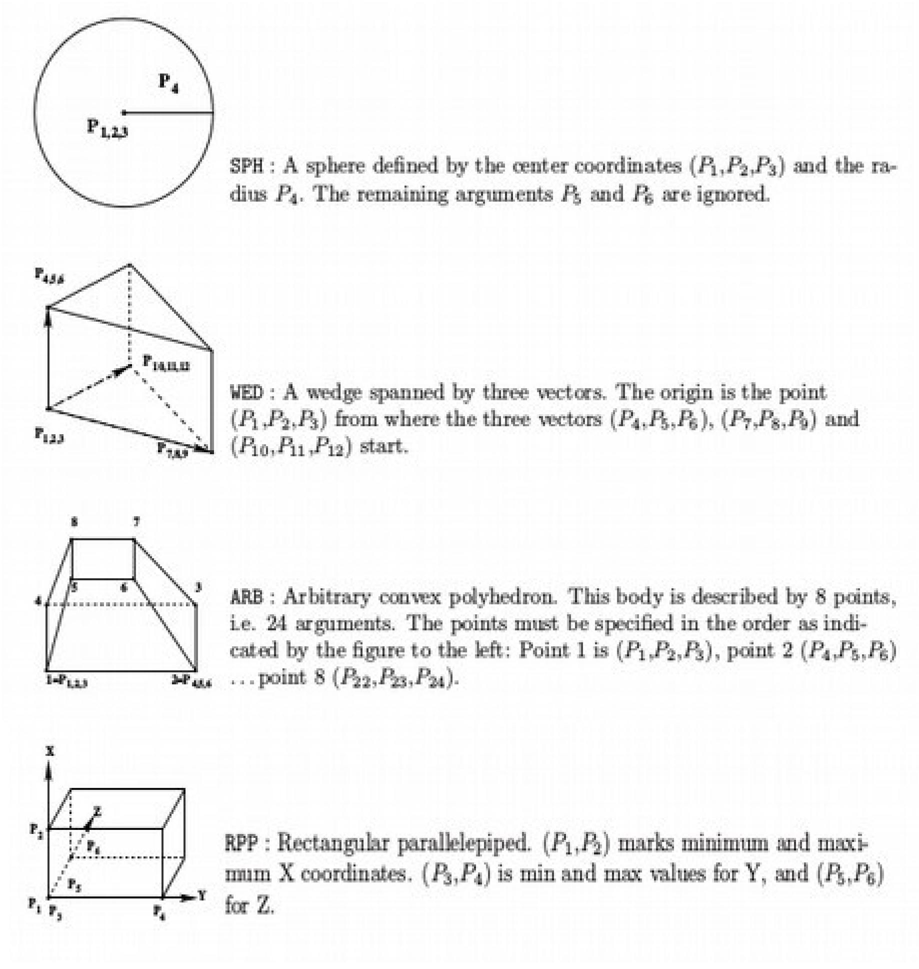
- A particle needs to know where it is
- A particle needs to know where it is going
- Geometry often constructed from primitives using boolean logic



Geometric Primitives

Bodies in SHIELD-HIT12A and FLUKA

(figures from SHIELD-HIT manual)

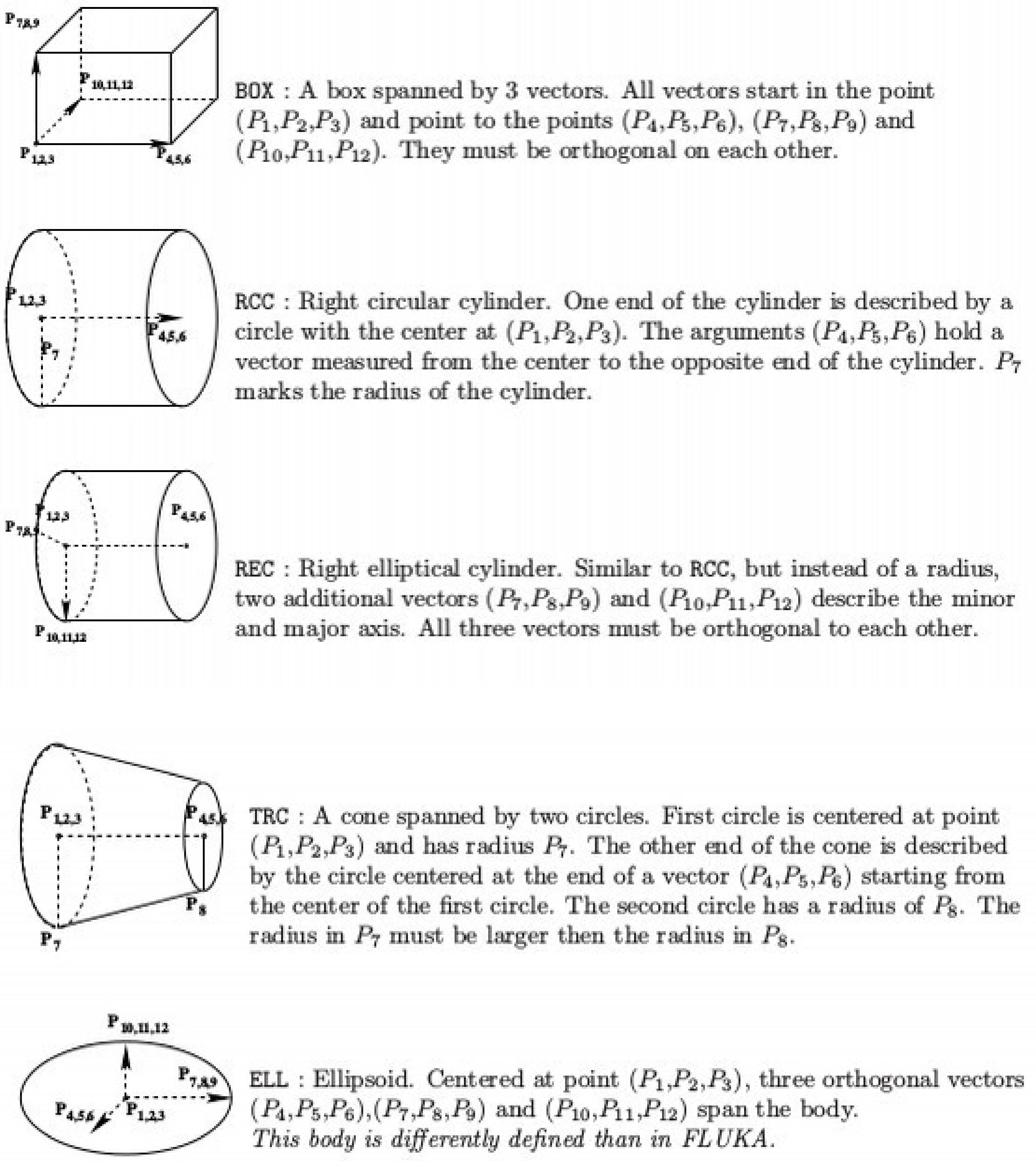


SPH : A sphere defined by the center coordinates (P_1,P_2,P_3) and the radius P_4. The remaining arguments P_5 and P_6 are ignored.

WED : A wedge spanned by three vectors. The origin is the point (P_1,P_2,P_3) from where the three vectors (P_4,P_5,P_6), (P_7,P_8,P_9) and (P_{10},P_{11},P_{12}) start.

ARB : Arbitrary convex polyhedron. This body is described by 8 points, i.e. 24 arguments. The points must be specified in the order as indicated by the figure to the left: Point 1 is (P_1,P_2,P_3), point 2 (P_4,P_5,P_6) . . . point 8 (P_{22},P_{23},P_{24}).

RPP : Rectangular parallelepiped. (P_1,P_2) marks minimum and maximum X coordinates. (P_3,P_4) is min and max values for Y, and (P_5,P_6) for Z.



BOX : A box spanned by 3 vectors. All vectors start in the point (P_1,P_2,P_3) and point to the points (P_4,P_5,P_6), (P_7,P_8,P_9) and (P_{10},P_{11},P_{12}). They must be orthogonal on each other.

RCC : Right circular cylinder. One end of the cylinder is described by a circle with the center at (P_1,P_2,P_3). The arguments (P_4,P_5,P_6) hold a vector measured from the center to the opposite end of the cylinder. P_7 marks the radius of the cylinder.

REC : Right elliptical cylinder. Similar to RCC, but instead of a radius, two additional vectors (P_7,P_8,P_9) and (P_{10},P_{11},P_{12}) describe the minor and major axis. All three vectors must be orthogonal to each other.

TRC : A cone spanned by two circles. First circle is centered at point (P_1,P_2,P_3) and has radius P_7. The other end of the cone is described by the circle centered at the end of a vector (P_4,P_5,P_6) starting from the center of the first circle. The second circle has a radius of P_8. The radius in P_7 must be larger then the radius in P_8.

ELL : Ellipsoid. Centered at point (P_1,P_2,P_3), three orthogonal vectors (P_4,P_5,P_6),(P_7,P_8,P_9) and (P_{10},P_{11},P_{12}) span the body.
This body is differently defined than in FLUKA.

Combinational Geometry (CG)

Boolean logic applies:

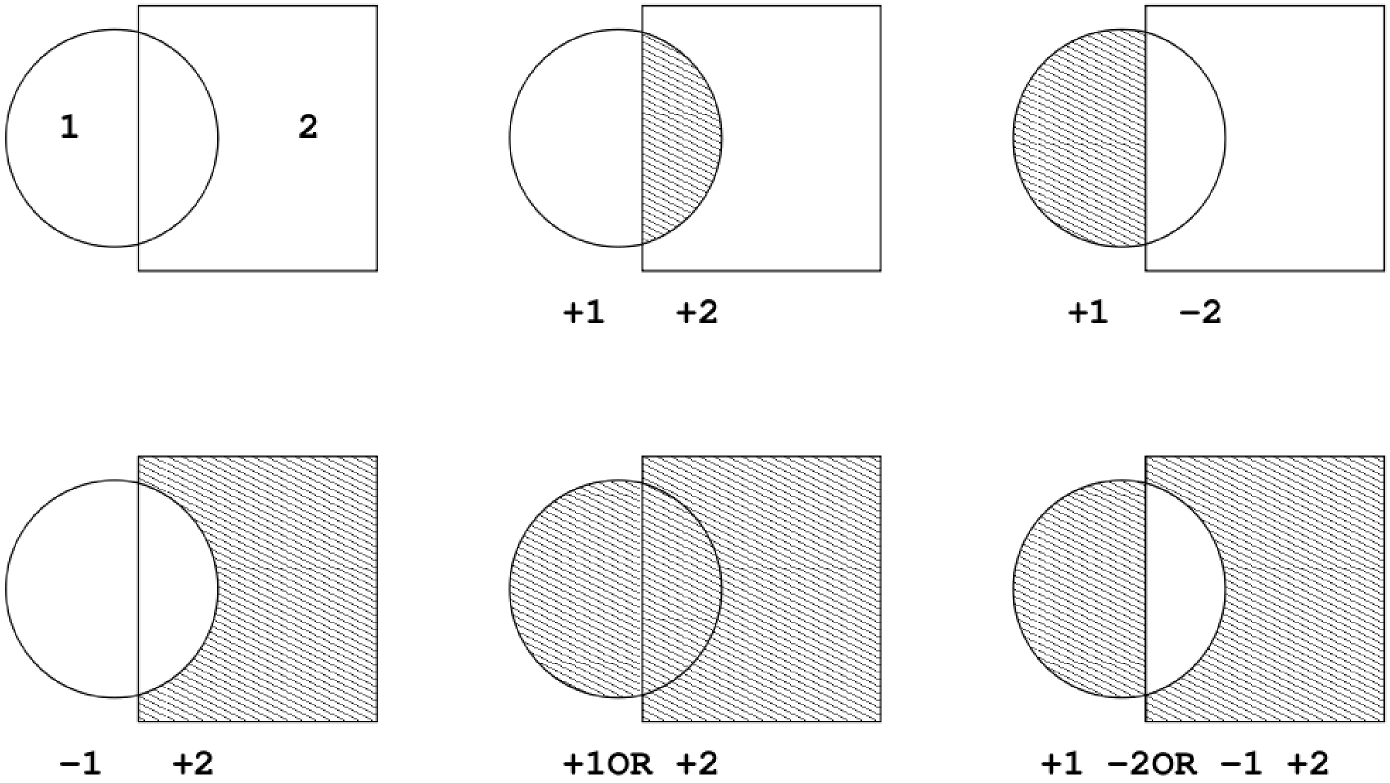


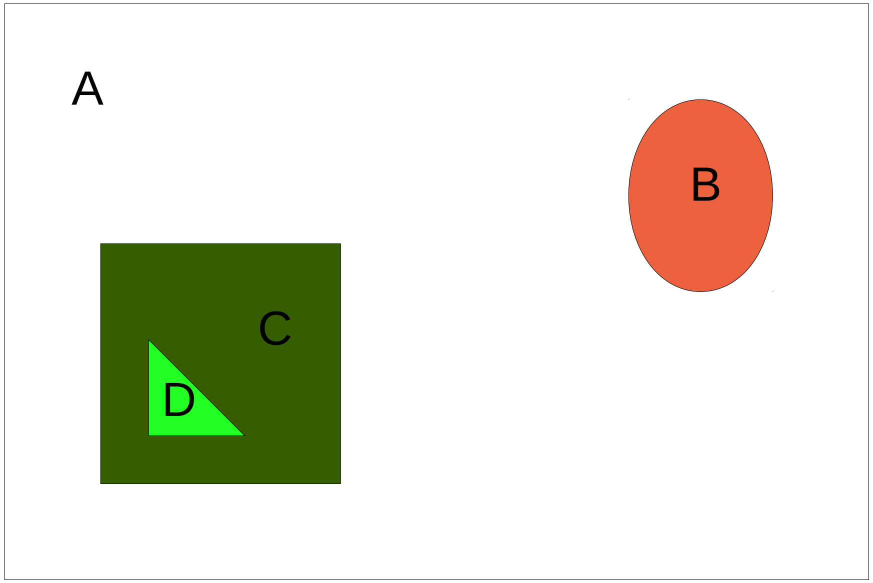
Figure 8.1: Two bodies (marked as 1 and 2) describing 5 different zones.

(figure from SHIELD-HIT manual)

Regions and Bodies

A **region** (lower case letters) is composed of **bodies** (upper case letters)

a = A – B – C
b = B
c = C – D
d = D

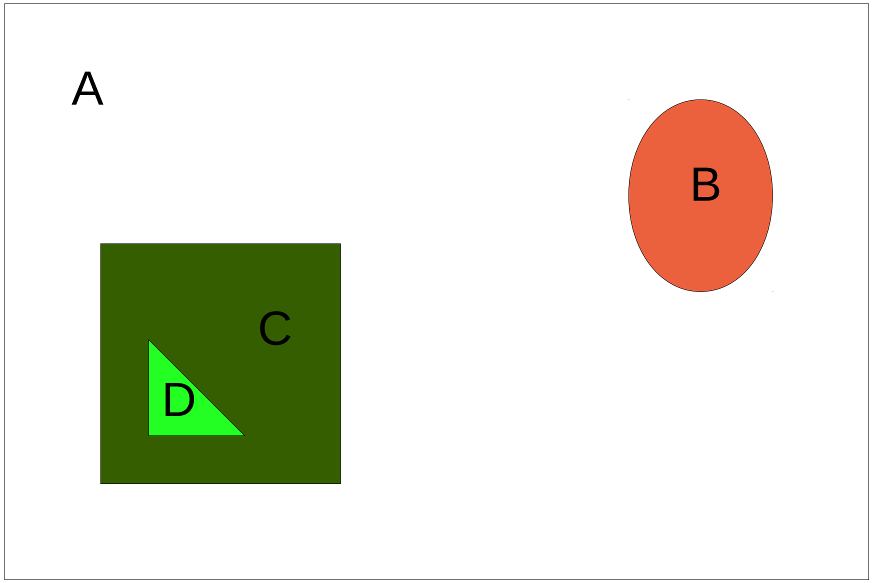


Important: **any point** in the universe **MUST** be assigned to ***one*** and ***only one* region**.

Regions and Bodies

A region is composed of bodies

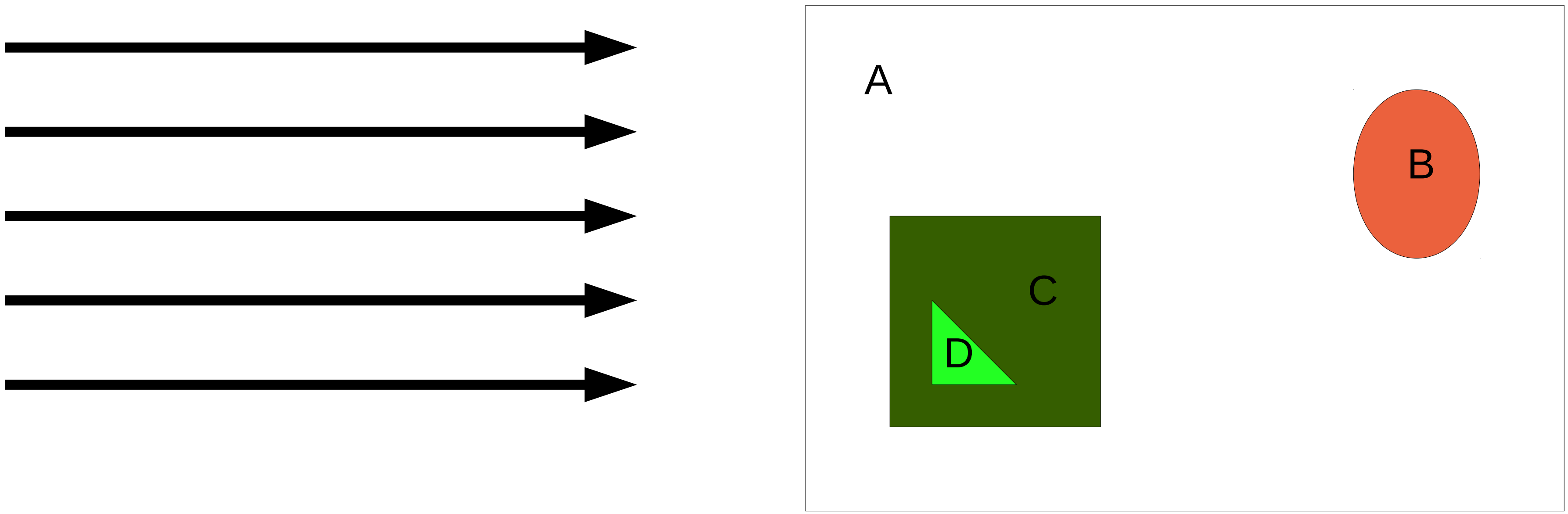
a = A – B – C
b = B
c = C – D
d = D



Next: assignment of regions to materials

a → Vacuum
b → Polyethylene
c → Water
d → Silicon

Specify a Beam



Such as: 25 MeV electrons, 15 x 15 cm², flat square.

Or more complex beams:
- Divergent beam, momentum spread, cicurlar/annular shape

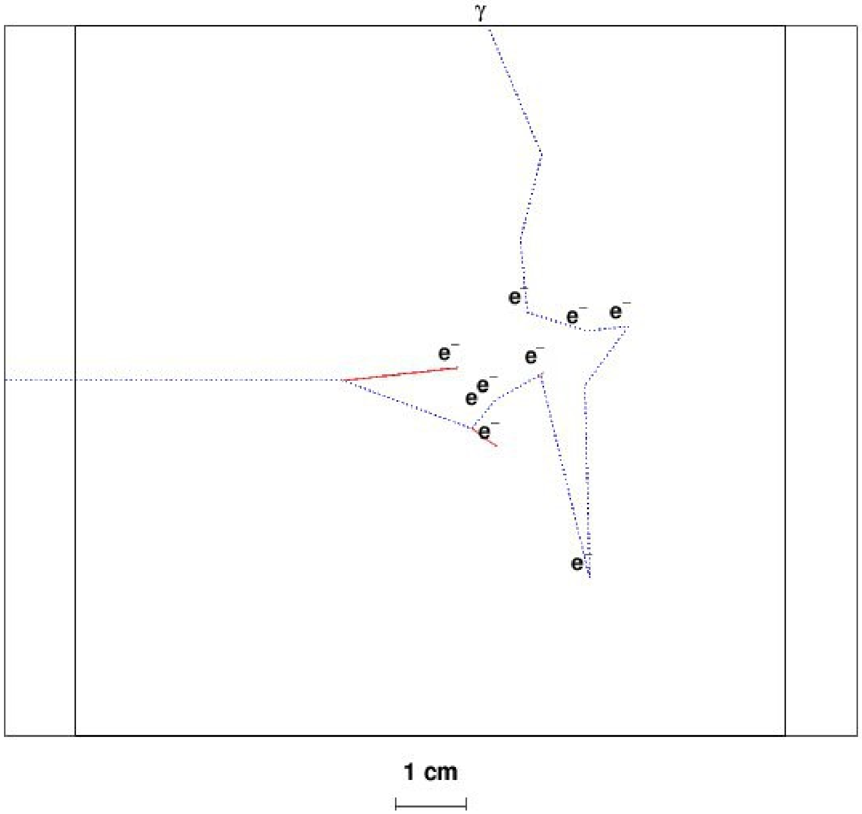
Or even more complex beams:
- Energy spectrum, particle spectrum, beam sampled from phase-space file, Isotropic distributions (space)
- Think if you can reduce beam to only irradiate areas you want to score -> saves time.

Setup Physics to Use

- A full simulation can be CPU intensive without adding any value to the result.
- If you can, limit physics to what is necessary to answer the question
  - Do we need electron transport down to 1 keV? Or is 100 keV sufficient?
  - Do we need neutron transport? What cutoff energy?
  - Do we need optical photons or fluorescence photons?

Physics

- A particle will undergo a range of steps,
  - what happens on its way?



(figure from Geant4 course)

Codes like Geant4 provide several different models → things get very complicated.

Assume you want to simulate 25 MeV electron beam

- Photon processes
  - Compton scattering (class name **G4ComptonScattering**)
  - Gamma conversion (also called pair production, class name **G4GammaConversion**)
  - Photo-electric effect (class name **G4PhotoElectricEffect**)
  - Muon pair production (class name **G4GammaConversionToMuons**)
- Electron/positron processes
  - Ionisation and delta ray production (class name **G4eIonisation**)
  - Bremsstrahlung (class name **G4eBremsstrahlung**)
  - Multiple scattering (class name **G4eMultipleScattering**)
  - Positron annihilation into two gammas (class name **G4eplusAnnihilation**)
  - Positron annihilation into two muons (class name **G4AnnihiToMuPair**)
  - Positron annihilation into hadrons (class name **G4eeToHadrons**)
- Muon processes
  - Bremsstrahlung (class name **G4MuBremsstrahlung**)
  - Ionisation and delta ray production (class name **G4MuIonisation**)
  - Multiple scattering (class name **G4MuMultipleScattering**)
  - e+e- pair production (class name **G4MuPairProduction**)
- Hadron/ion processes
  - Bremsstrahlung (class name **G4hBremsstrahlung**)
  - Ionisation (class name **G4hIonisation**)
  - e+e- pair production (class name **G4hPairProduction**)
  - Ionisation for ions (class name **G4ionIonisation**)
  - Multiple scattering (class name **G4hMultipleScattering**)
  - Ionisation for heavy exotic particles (class name **G4hhIonisation**)
  - Ionisation for classical magnetic monopole (class name **G4mplIonisation**)
- Coulomb scattering processes
  - Alternative process for simulation of single Coulomb scattering of all charged particles (class name **G4CoulombScattering**)
  - Alternative process for simulation of single Coulomb scattering of ions (class name **G4ScreenedNuclearRecoil**)
- Processes for simulation of polarized electron and gamma beams
  - Compton scattering of circularly polarized gamma beam on polarized target (class name **G4PolarizedCompton**)
  - Pair production induced by circularly polarized gamma beam (class name **G4PolarizedGammaConversion**)
  - Photo-electric effect induced by circularly polarized gamma beam (class name **G4PolarizedPhotoElectricEffect**)
  - Bremsstrahlung of polarized electrons and positrons (class name **G4ePolarizedBremsstrahlung**)
  - Ionisation of polarized electron and positron beam (class name **G4ePolarizedIonisation**)
  - Annihilation of polarized positrons (class name **G4eplusPolarizedAnnihilation**)
- Processes for simulation of X-rays and optical protons production by charged particles
  - Synchrotron radiation (class name **G4SynchrotronRadiation**)
  - Transition radiation (class name **G4TransitionRadiation**)
  - Cerenkov radiation (class name **G4Cerenkov**)
  - Scintillations (class name **G4Scintillation**)
- The processes described above use physics model classes, which may be combined according to particle energy.

It is possible to change the energy range over which different models are valid, and to apply other models

specific to particle type, energy range, and G4Region. The following alternative models are available:

  - Ionisation in thin absorbers (class name **G4PAIModel**)

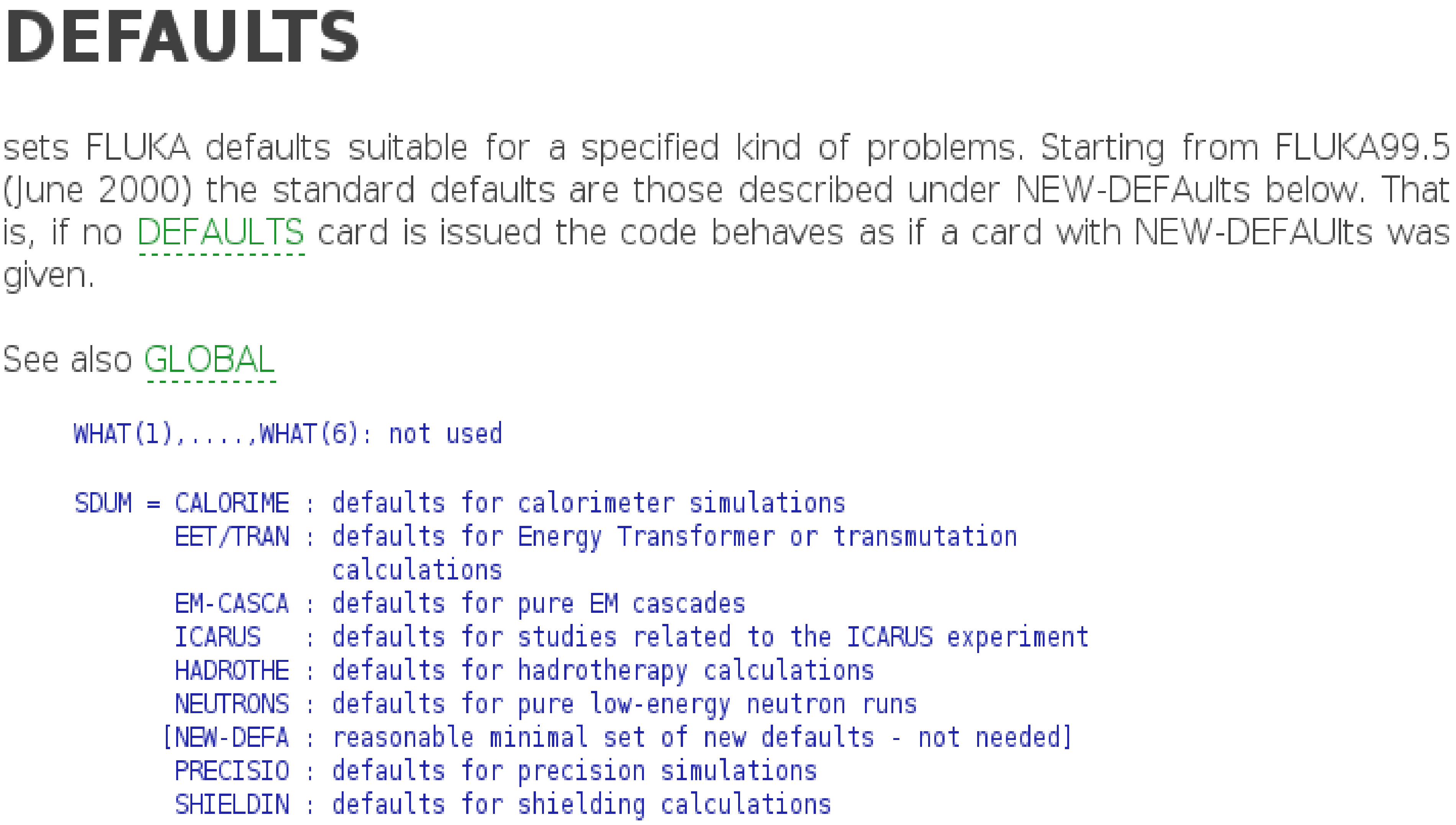
And of course,
remember to set the appropriate options and the scope of applicability of the physics models:

```
SetLossFluctuations(G4bool)
SetSubCutoff(G4bool, const G4Region* r=0)
SetIntegral(G4bool)
SetMinSubRange(G4double)
SetMinEnergy(G4double)
SetMaxEnergy(G4double)
SetMaxEnergyForCSDARange(G4double)
SetMaxEnergyForMuons(G4double)
SetDEDXBinning(G4int)
SetDEDXBinningForCSDARange(G4int)
SetLambdaBinning(G4int)
SetStepFunction(G4double, G4double)
SetRandomStep(G4bool)
SetApplyCuts(G4bool)
SetSpline(G4bool)
SetBuildCSDARange(G4bool)
SetVerbose(G4int, const G4String name= "all")
SetLambdaFactor(G4double)
SetLinearLossLimit(G4double)
ActivateDeexcitation(G4bool val, const G4Region* r = 0)
SetMscStepLimitation(G4MscStepLimitType val)
SetMscLateralDisplacement(G4bool val)
SetSkin(G4double)
SetMscRangeFactor(G4double)
SetMscGeomFactor(G4double)
SetLPMFlag(G4bool)
SetBremsstrahlungTh(G4double)
SetPolarAngleLimit(G4double)
SetFactorForAngleLimit(G4double)
```

- But fortunately Geant4 offers some pre-configured physics packages, else you can copy from some of the examples.
    - **`G4EmStandardPhysics`**
    - **`G4Decay`**
    - **`G4EmExtraPhysics`**
        - Eg: gamma-nuclear
    - **`G4HadronElasticPhysics`**
    - **`G4HadronInelasticPhysics`**
    - **`G4StoppingPhysics`**
        - For particle at rest
    - **`G4IonPhysics`**

- FLUKA is very different, tries to “take the best”, and has a set of default physics configurations.

Example for default physics configurations, FLUKA:



DEFAULTS

sets FLUKA defaults suitable for a specified kind of problems. Starting from FLUKA99.5 (June 2000) the standard defaults are those described under NEW-DEFAults below. That is, if no DEFAULTS card is issued the code behaves as if a card with NEW-DEFAUlts was given.

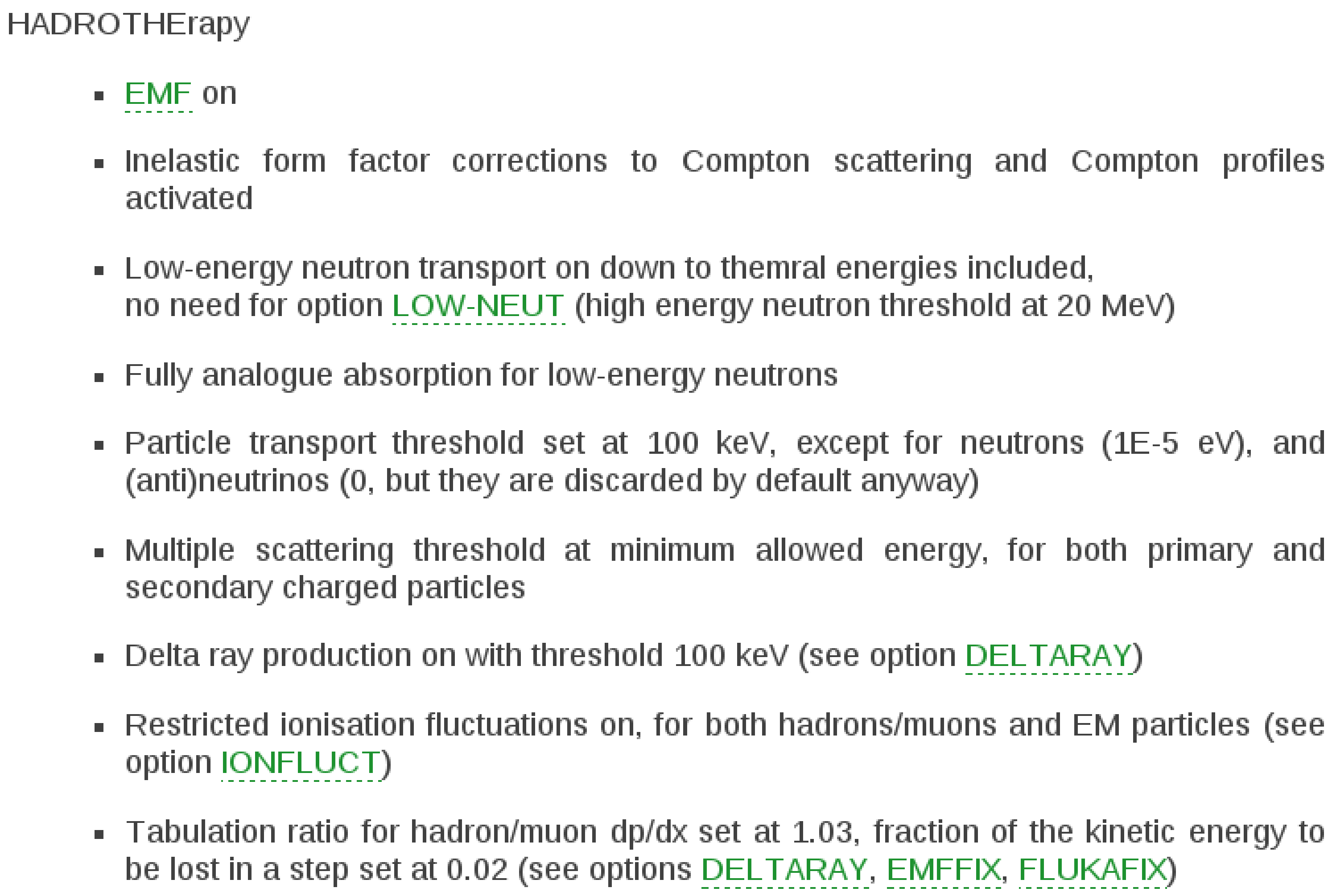
See also GLOBAL

```
     WHAT(1),.....,WHAT(6): not used

     SDUM = CALORIME : defaults for calorimeter simulations
            EET/TRAN : defaults for Energy Transformer or transmutation
                       calculations
            EM-CASCA : defaults for pure EM cascades
            ICARUS   : defaults for studies related to the ICARUS experiment
            HADROTHE : defaults for hadrotherapy calculations
            NEUTRONS : defaults for pure low-energy neutron runs
           [NEW-DEFA : reasonable minimal set of new defaults - not needed]
            PRECISIO : defaults for precision simulations
            SHIELDIN : defaults for shielding calculations
```

Default configuration in FLUKA

In this couse's exercises we will always use the HADRONTHE defaults.



HADROTHErapy

- EMF on
- Inelastic form factor corrections to Compton scattering and Compton profiles activated
- Low-energy neutron transport on down to themral energies included,
  no need for option LOW-NEUT (high energy neutron threshold at 20 MeV)
- Fully analogue absorption for low-energy neutrons
- Particle transport threshold set at 100 keV, except for neutrons (1E-5 eV), and (anti)neutrinos (0, but they are discarded by default anyway)
- Multiple scattering threshold at minimum allowed energy, for both primary and secondary charged particles
- Delta ray production on with threshold 100 keV (see option DELTARAY)
- Restricted ionisation fluctuations on, for both hadrons/muons and EM particles (see option IONFLUCT)
- Tabulation ratio for hadron/muon dp/dx set at 1.03, fraction of the kinetic energy to be lost in a step set at 0.02 (see options DELTARAY, EMFFIX, FLUKAFIX)

(Says 0.05 elsewhere in Manual)

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Scoring – Examples

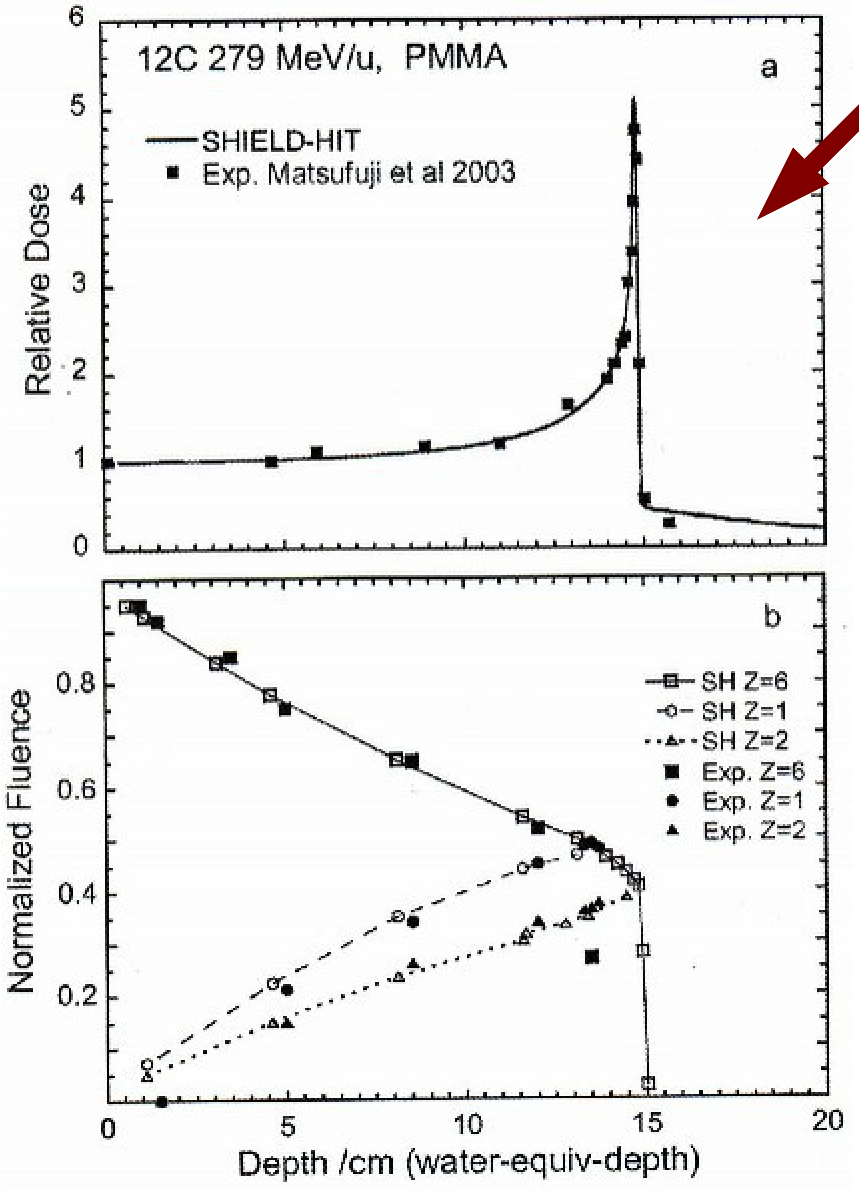
- Dose deposition (1D, 2D, 3D maps)
- Fluence, or planar fluence of any particle, or particle group
- Energy deposited (in total, by any particle or particle group)
- Energy spectrum of any particle
- Fluence spectrum of any particle
- Generation or transmutation of particles
- Calculate material activation
- Record a phase-space file in a plane

Comparison with experiment

I.Gudowska and N.Sobolevsky Rad.Protect.Dos. **116** (2005) 301.

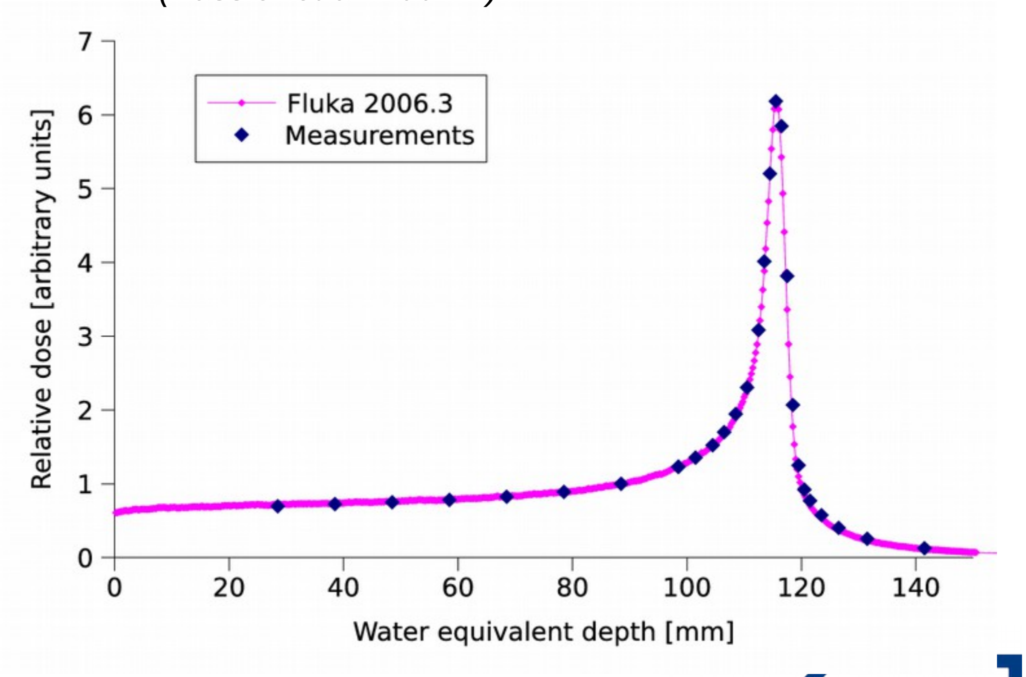
1D depth dose and fluence curve

SHIELD-HIT, Carbon ions on PMMA

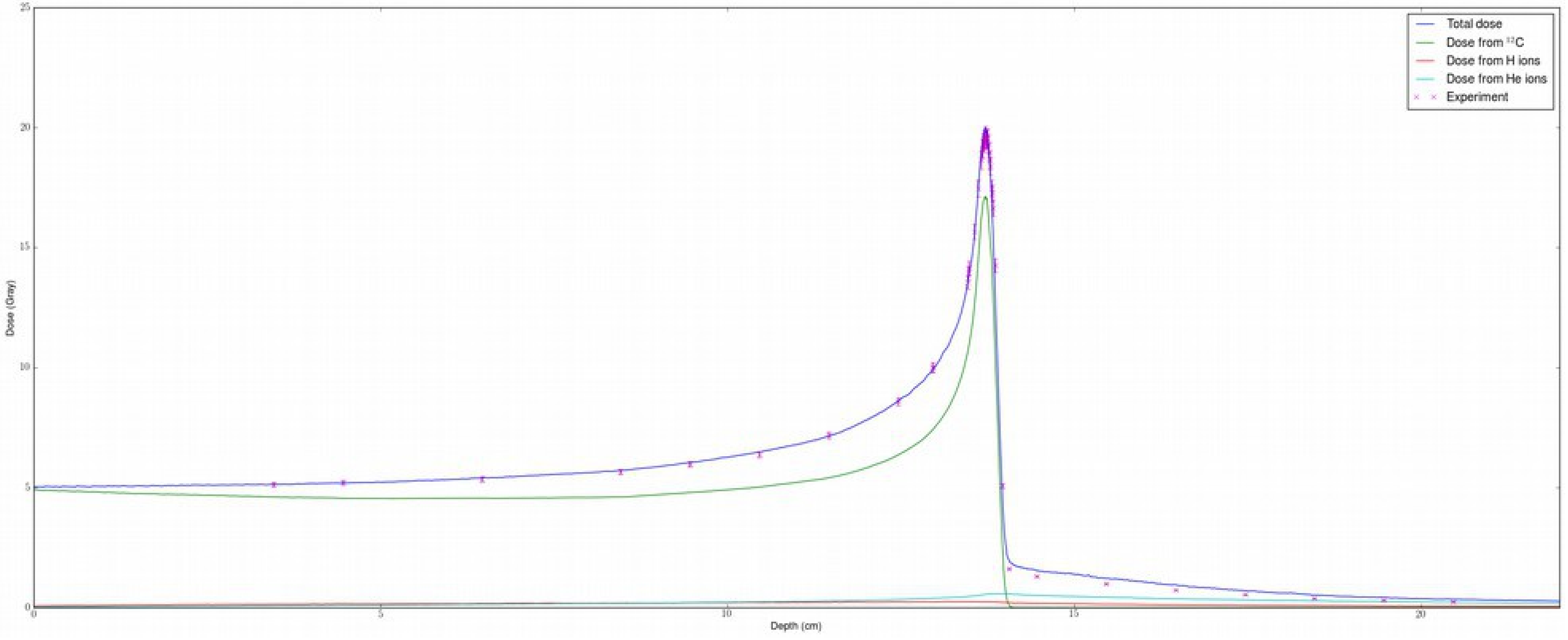


FLUKA: Antiprotons on Water

(Bassler et al. 2007 :-)

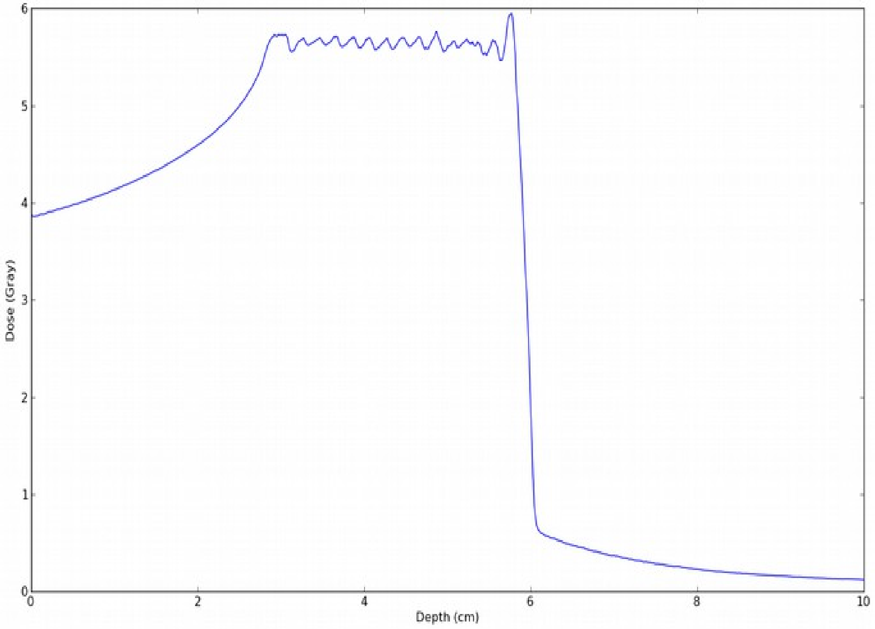


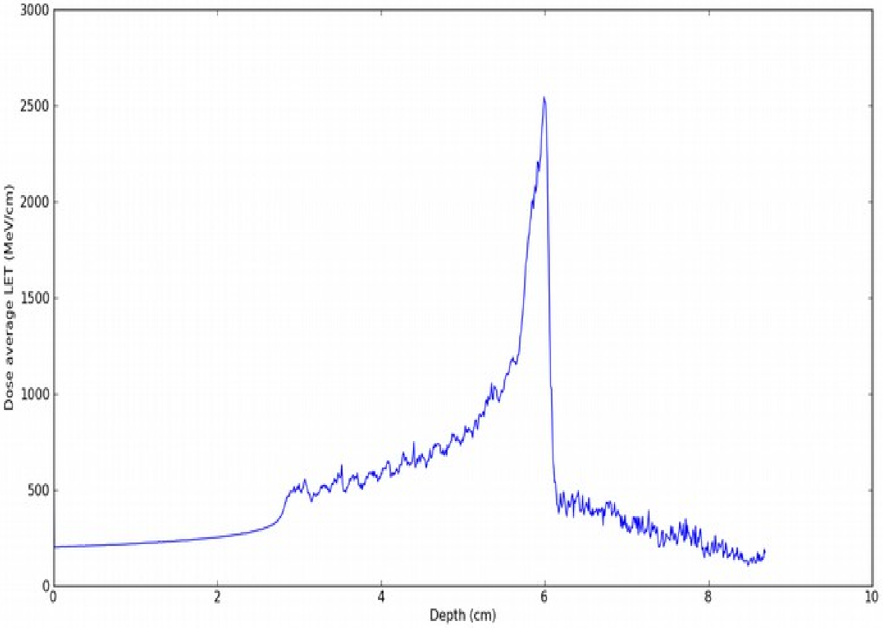
SHIELD-HIT12A DDCs.



(David C. Hansen)

Scoring





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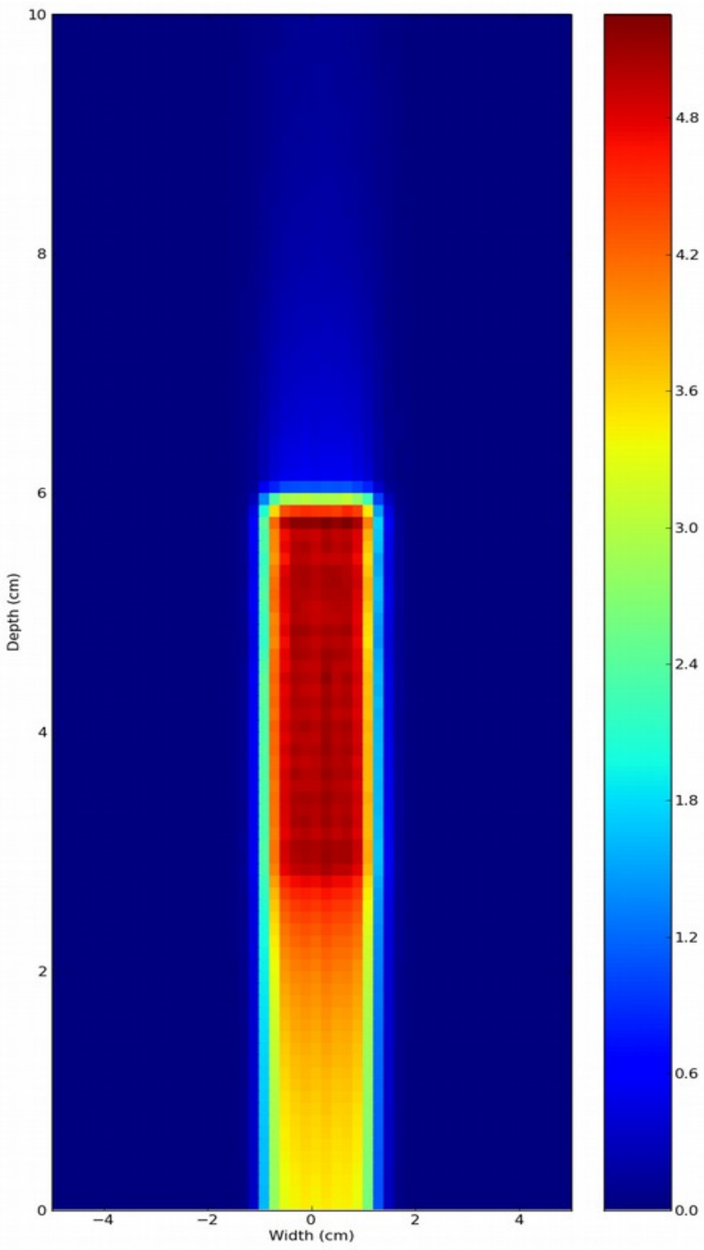
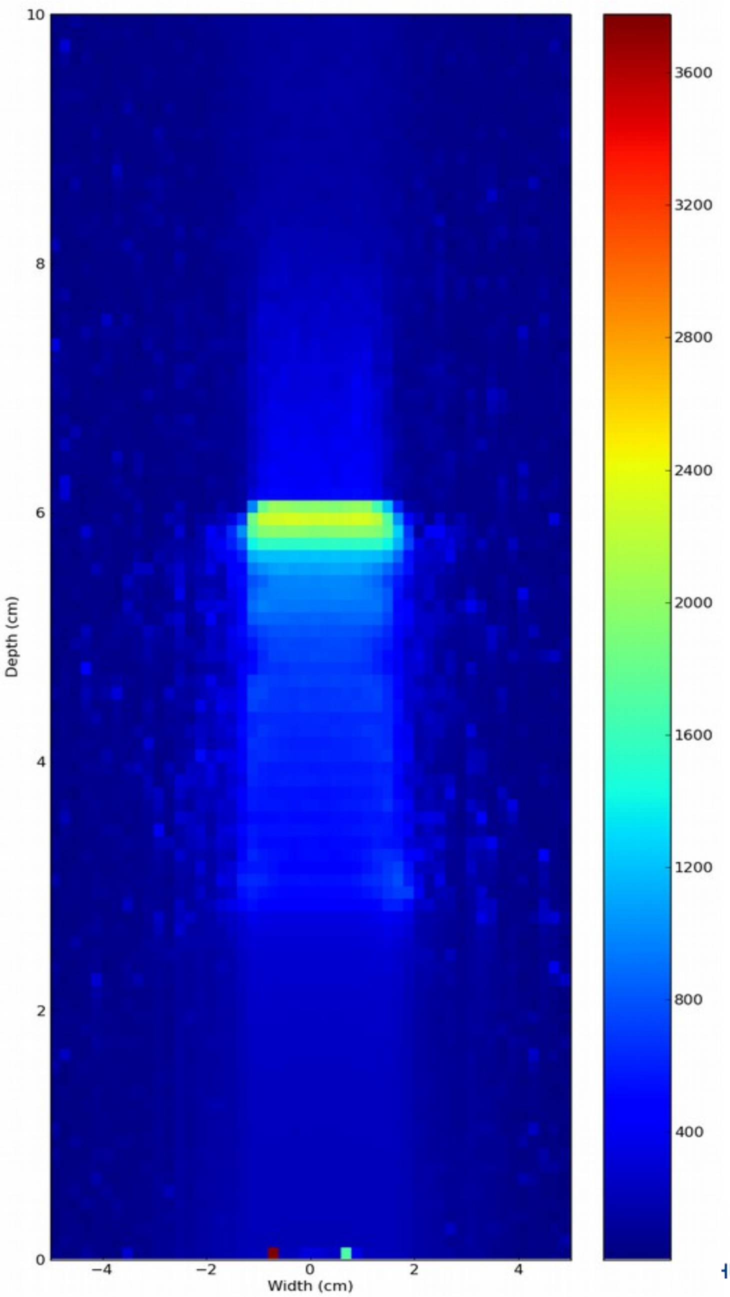
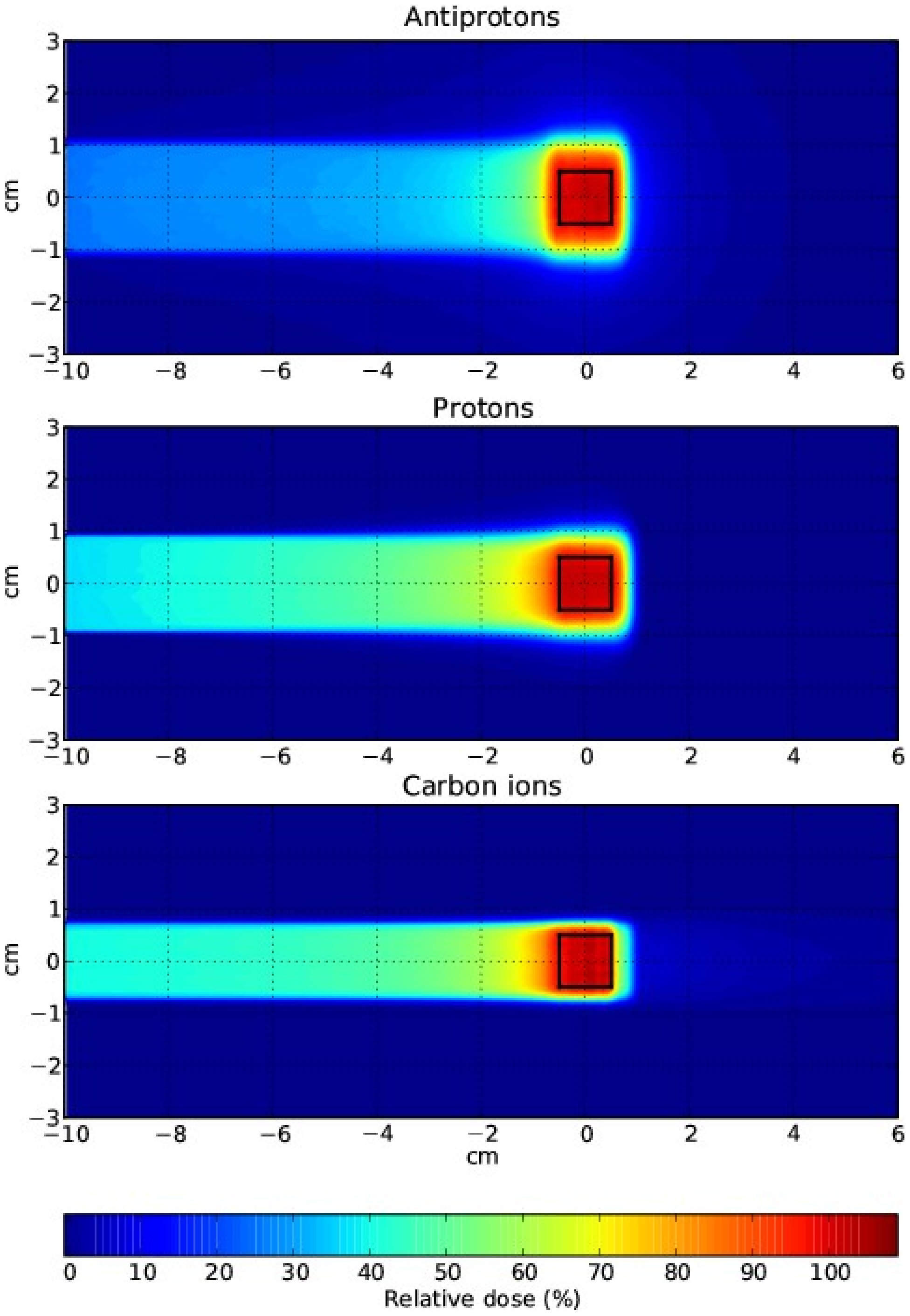
Scoring - Dose and LET maps







2D dose maps of a

- antiproton,
- proton and
- carbon ion beam

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- Compare MC codes with cars:

  http://willworkforscience.blogspot.com/

  → “Monte Carlo Programs in Particle Therapy Research”

A FLUKA car

A Geant4 car

A SHIELD-HIT car

FLUKA

FLUKA

- In this course we will concentrate on FLUKA, since this is
  - easy to use
  - gives excellent results and
  - is very versatile.

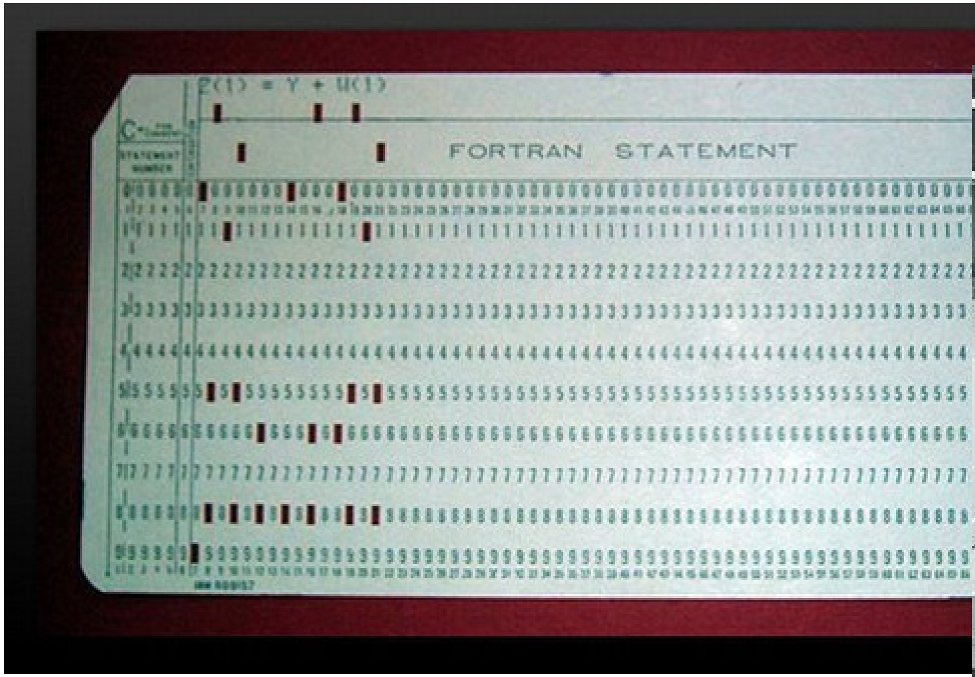
- You can register at www.fluka.org and download it yourself
- Use online manual from webpage during exercises
- There is a Graphical User Interface “Flair”, which we will use in this course.
- Closed-source! But free to download object files, which can be linked to produce an executable.

FLUKA

- FLUKA is written in FORTAN 77, requires fortran compiler for linking the object files and generate executable.
- All configuration is handled by one monolithic input file
  - Fancy stuff which goes beyond, needs to be handled by user routines which can hook your own code into the FLUKA run-time.

- Input file is parsed by FLUKA. Old-schoolnik fortran 77 requires user adapts to computer language.

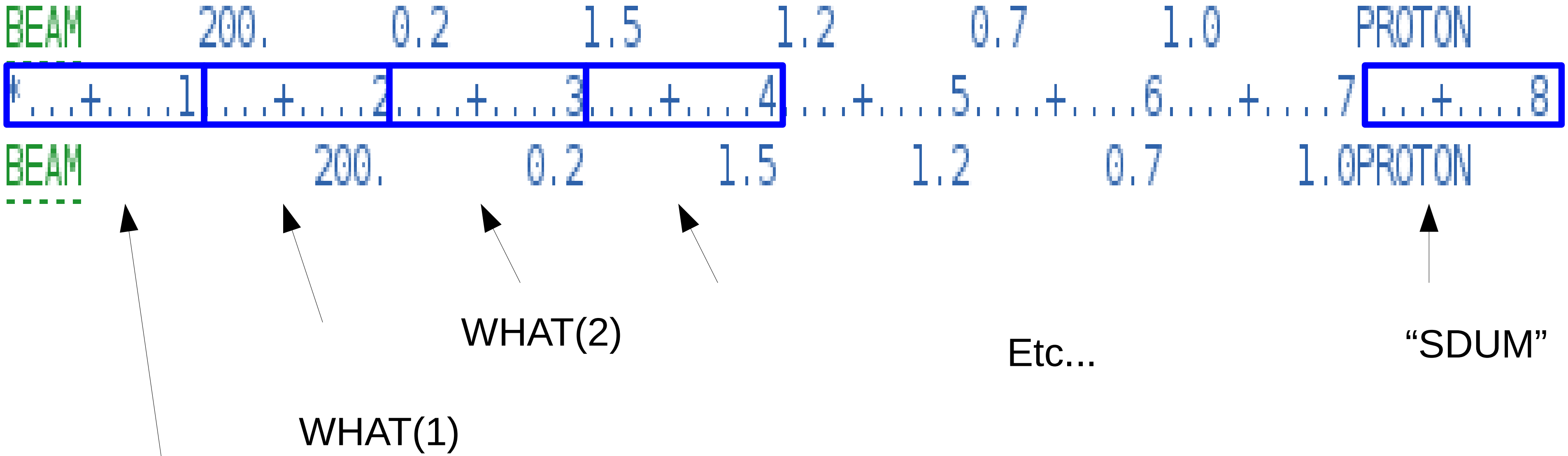
- Any idea what this is?



It is a punch card, an USB stick of the 60ies, so to say...
This one has 80 columns of data, holding one line of code.
There is one card for each line.
Only [0-9] and [A-Z] + a few extra characters are used.
In “binary mode” each card holds two 36 bit words.

FLUKA – input file format

- Not only Fortran77 language reflects this, also input files.
- Because of the Punch card reminiscence, the input format to FLUKA is rather restricted. (There is also “FREE” mode.)
- These three lines thus corresponds to 3 punch cards:



```
BEAM      200.      0.2       1.5       1.2       0.7       1.0       PROTON
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
BEAM            200.       0.2       1.5       1.2       0.7       1.0PROTON
```

WHAT(2)

Etc...

“SDUM”

WHAT(1)

Command field

NO TABS ALLOWED! ONLY SPACES!

(sooner or later you will have a tab in your file and you will spend hours trying to find the mistake!)

FLUKA – Example 1

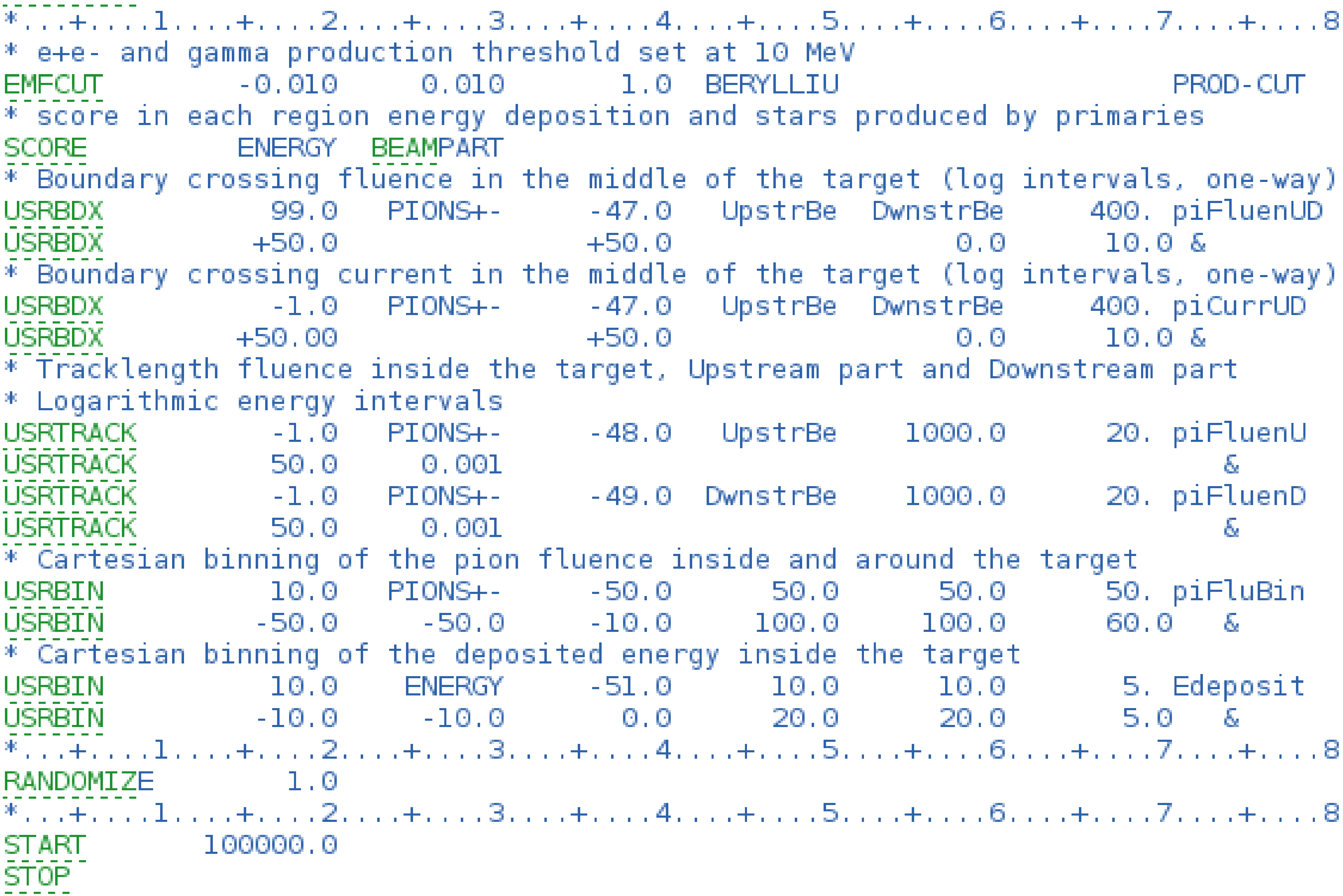
THE TASK IS TO:

- Calculate charged pion fluence produced by monoenergetic proton beam with p = 50 GeV/c, hitting a 5 cm Beryllium target.
- Target is 20 x 20 x 5 cm^3
- Surroundings are vacuum

FLUKA – Example input file (part 1)

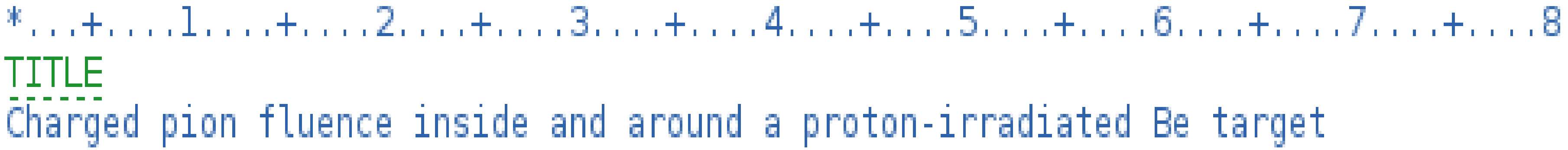
```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
TITLE
Charged pion fluence inside and around a proton-irradiated Be target
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
BEAM         50.E+00                                                  PROTON
BEAMPOS          0.0       0.0     -50.0
*
 GEOBEGIN                                                              COMBNAME
                         A simple Be target inside vacuum
  RPP blakhole -5000000.0  +5000000.0  -5000000.0  +5000000.0  -5000000.0  +5000000.0
  RPP vacumbox -1000000.0  +1000000.0  -1000000.0  +1000000.0      -100.0  +1000000.0
  RPP betarget      -10.0       +10.0       -10.0       +10.0         0.0        +5.0
* plane to separate the upstream and downstream part of the target
  XYP cutplane        2.5
  END
* black hole
  Blckhole  5  +blakhole -vacumbox
* vacuum around
  Vacarund  5  +vacumbox -betarget
* Be target 1st half
  UpstrBe   5  +betarget +cutplane
* Be target 2nd half
  DwnstrBe  5  +betarget -cutplane
  END
GEOEND
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
MATERIAL         4.0    9.0122     1.848       5.0                    BERYLLIU
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
*  Be target, 1st and 2nd half
ASSIGNMAT   BERYLLIU   UpstrBe  DwnstrBe
*  External Black Hole
ASSIGNMAT   BLCKHOLE  Blckhole
*  Vacuum
ASSIGNMAT     VACUUM  Vacarund
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
* e+e- and gamma production threshold set at 10 MeV
EMFCUT        -0.010     0.010       1.0  BERYLLIU                    PROD-CUT
```

FLUKA – Example input file (part 2)



```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
* e+e- and gamma production threshold set at 10 MeV
EMFCUT        -0.010     0.010       1.0  BERYLLIU                    PROD-CUT
* score in each region energy deposition and stars produced by primaries
SCORE         ENERGY  BEAMPART
* Boundary crossing fluence in the middle of the target (log intervals, one-way)
USRBDX          99.0   PIONS+-     -47.0   UpstrBe  DwnstrBe      400.piFluenUD
USRBDX         +50.0               +50.0                   0.0      10.0 &
* Boundary crossing current in the middle of the target (log intervals, one-way)
USRBDX          -1.0   PIONS+-     -47.0   UpstrBe  DwnstrBe      400.piCurrUD
USRBDX        +50.00               +50.0                   0.0      10.0 &
* Tracklength fluence inside the target, Upstream part and Downstream part
* Logarithmic energy intervals
USRTRACK        -1.0   PIONS+-     -48.0   UpstrBe    1000.0       20.piFluenU
USRTRACK        50.0     0.001                                           &
USRTRACK        -1.0   PIONS+-     -49.0  DwnstrBe    1000.0       20.piFluenD
USRTRACK        50.0     0.001                                           &
* Cartesian binning of the pion fluence inside and around the target
USRBIN          10.0   PIONS+-     -50.0      50.0      50.0       50.piFluBin
USRBIN         -50.0     -50.0     -10.0     100.0     100.0      60.0   &
* Cartesian binning of the deposited energy inside the target
USRBIN          10.0    ENERGY     -51.0      10.0      10.0        5.Edeposit
USRBIN         -10.0     -10.0       0.0      20.0      20.0       5.0   &
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
RANDOMIZE        1.0
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
START       100000.0
STOP
```

FLUKA – Example 1: Specify Title



```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
TITLE
Charged pion fluence inside and around a proton-irradiated Be target
```

Next: setup physics...

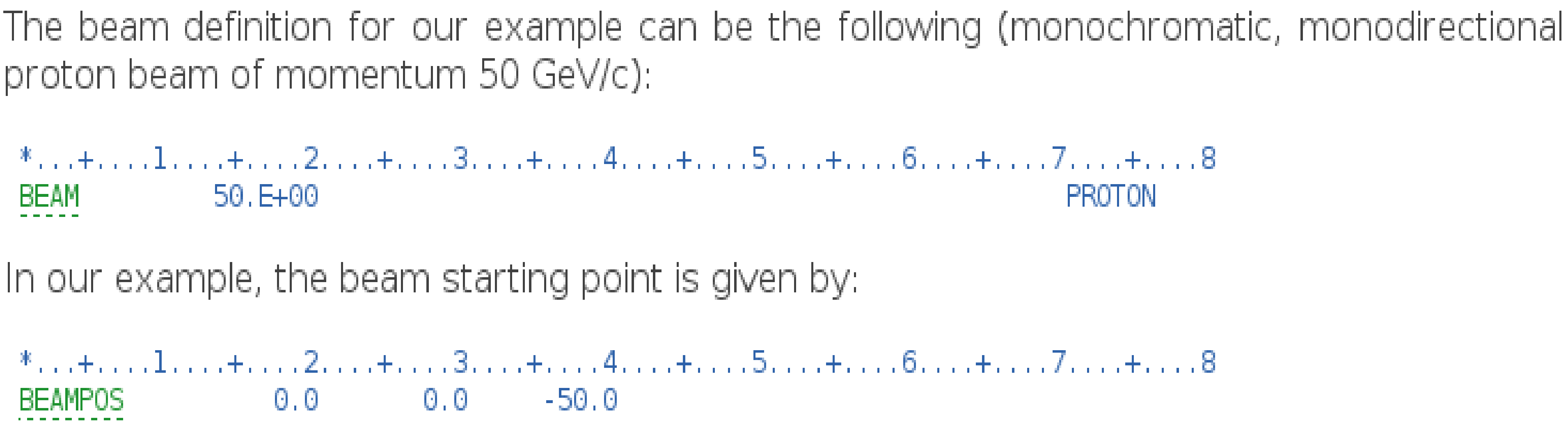
A “DEFAULT” card should follow, if anything else than the “NEW-DEFAults” are needed.

FLUKA – Example 1: Specify Physics

NEW-DEFAults (standard defaults active even if the DEFAULT card is not present)

- EMF on, with electron and photon transport thresholds to be set using the EMFCUT command
- Inelastic form factor corrections to Compton scattering activated (no need for EMFRAY)
- Low energy neutron transport on down to thermal energies included,
- (no need for LOW-NEUT). The neutron high energy threshold is set at 20 MeV.
- Non analogue absorption for low energy neutrons with probability 0.95 for the last (thermal) groups
- Particle transport threshold set at 10 MeV, except for neutrons (1E-5 eV), and (anti)neutrinos (0, but they are discarded by default anyway)
- Multiple scattering threshold for secondary charged particles lowered to 20 MeV (equal to that of the primary ones)
- Delta ray production on with threshold 1 MeV (see option DELTARAY)
- Restricted ionisation fluctuations on, for both hadrons/muons and EM particles (see option IONFLUCT)
- Heavy particle e+/e- pair production activated with full explicit production (with the minimum threshold = 2m_e)
- Heavy particle bremsstrahlung activated with explicit photon production above 1 MeV
- Muon photonuclear interactions activated with explicit generation of secondaries

FLUKA – Example 1: Specify Beam



The beam definition for our example can be the following (monochromatic, monodirectional proton beam of momentum 50 GeV/c):

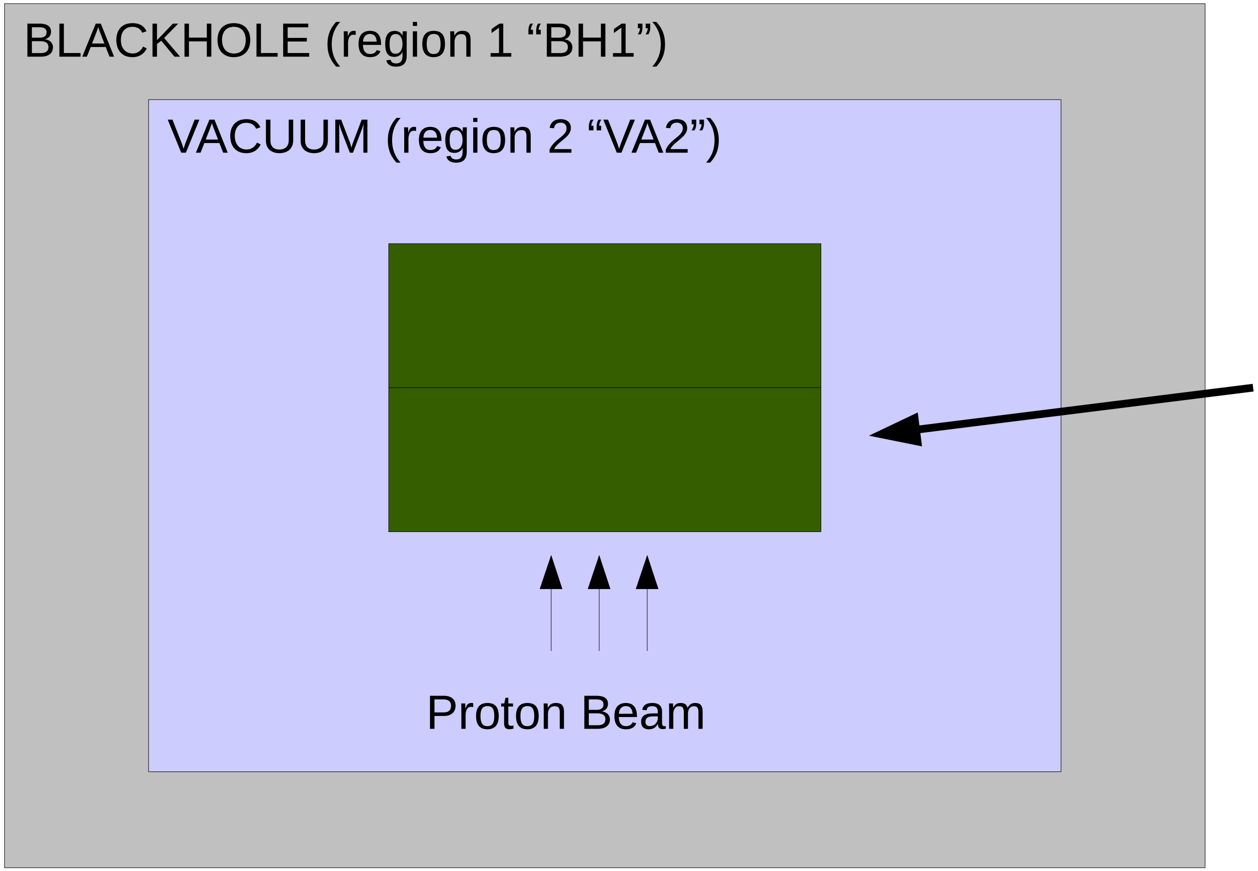
```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
BEAM         50.E+00                                                  PROTON
```

In our example, the beam starting point is given by:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
BEAMPOS          0.0       0.0     -50.0
```

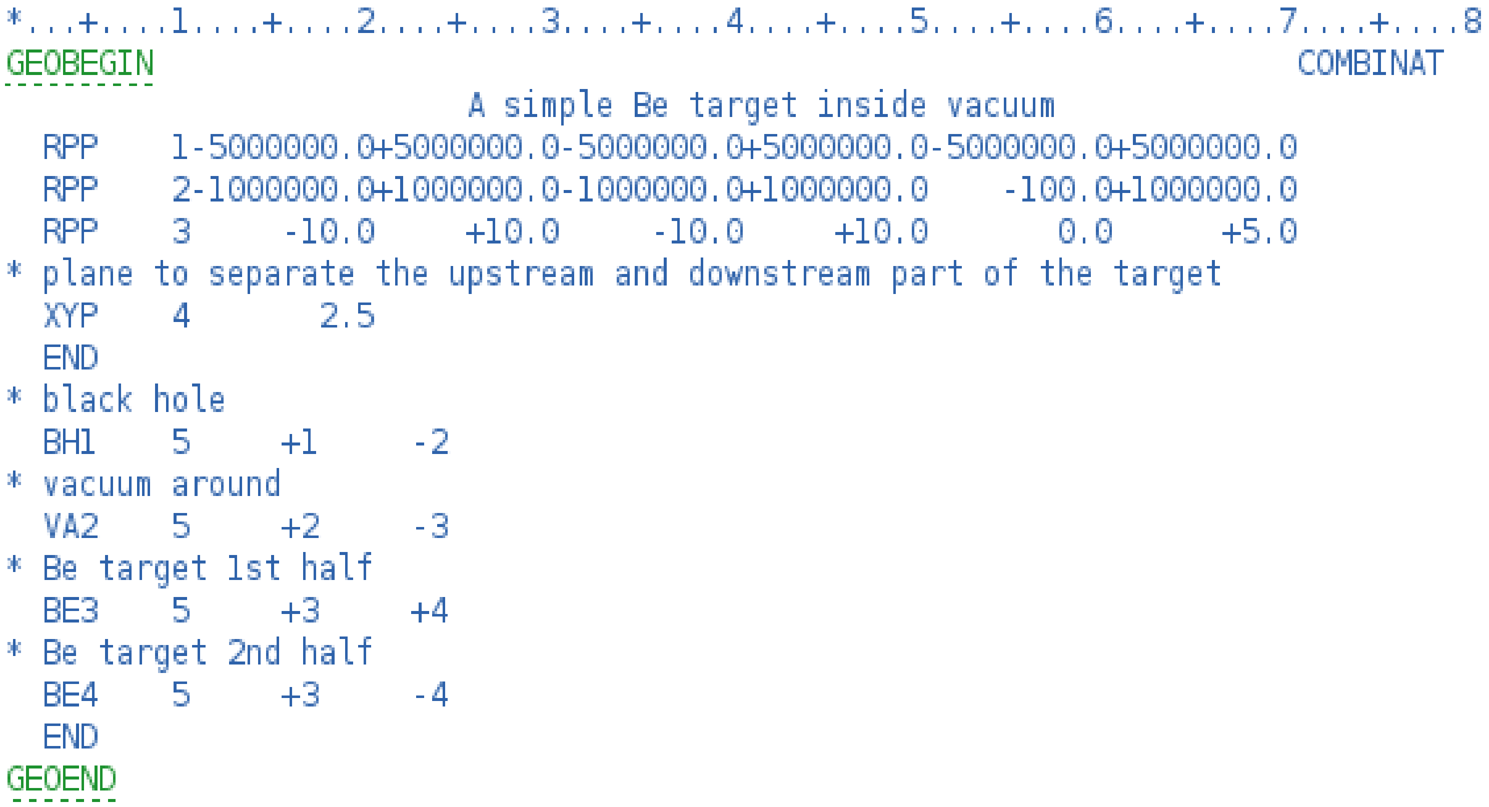
The BEAM card takes a lot of options, read the manual carefully...

FLUKA – Example 1: Specify Geometry



Be target (region 3 and 4, separated by plane)

FLUKA – Example 1: Specify Geometry

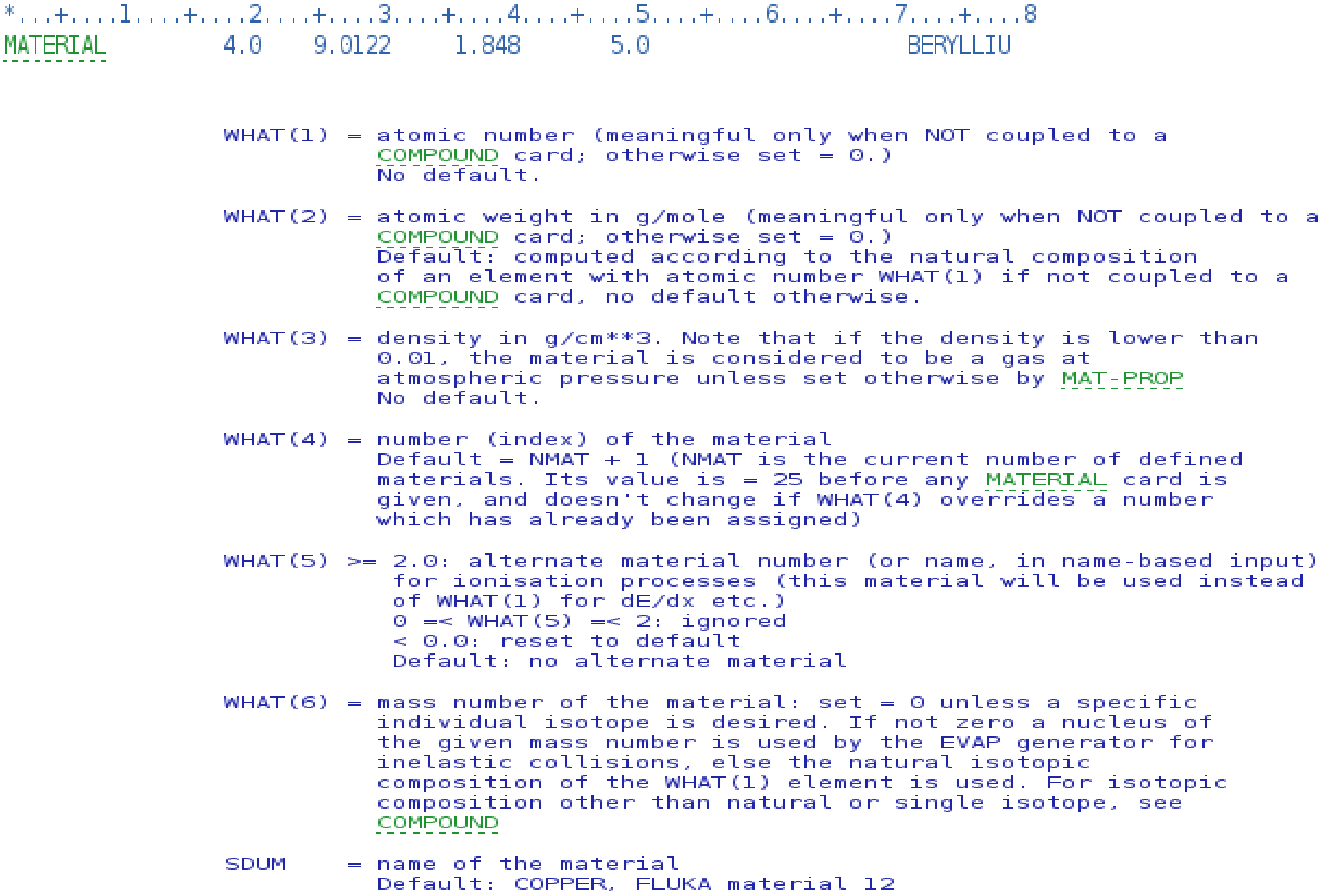


```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
GEOBEGIN                                                              COMBINAT
                         A simple Be target inside vacuum
  RPP    1-5000000.0+5000000.0-5000000.0+5000000.0-5000000.0+5000000.0
  RPP    2-1000000.0+1000000.0-1000000.0+1000000.0     -100.0+1000000.0
  RPP    3     -10.0     +10.0     -10.0     +10.0       0.0      +5.0
* plane to separate the upstream and downstream part of the target
  XYP    4       2.5
  END
* black hole
  BH1    5     +1     -2
* vacuum around
  VA2    5     +2     -3
* Be target 1st half
  BE3    5     +3     +4
* Be target 2nd half
  BE4    5     +3     -4
  END
GEOEND
```

BH1 = +1 - 2
VA2 = +2 – 3
BE3 = +3 +4
BE4 = +3 -4

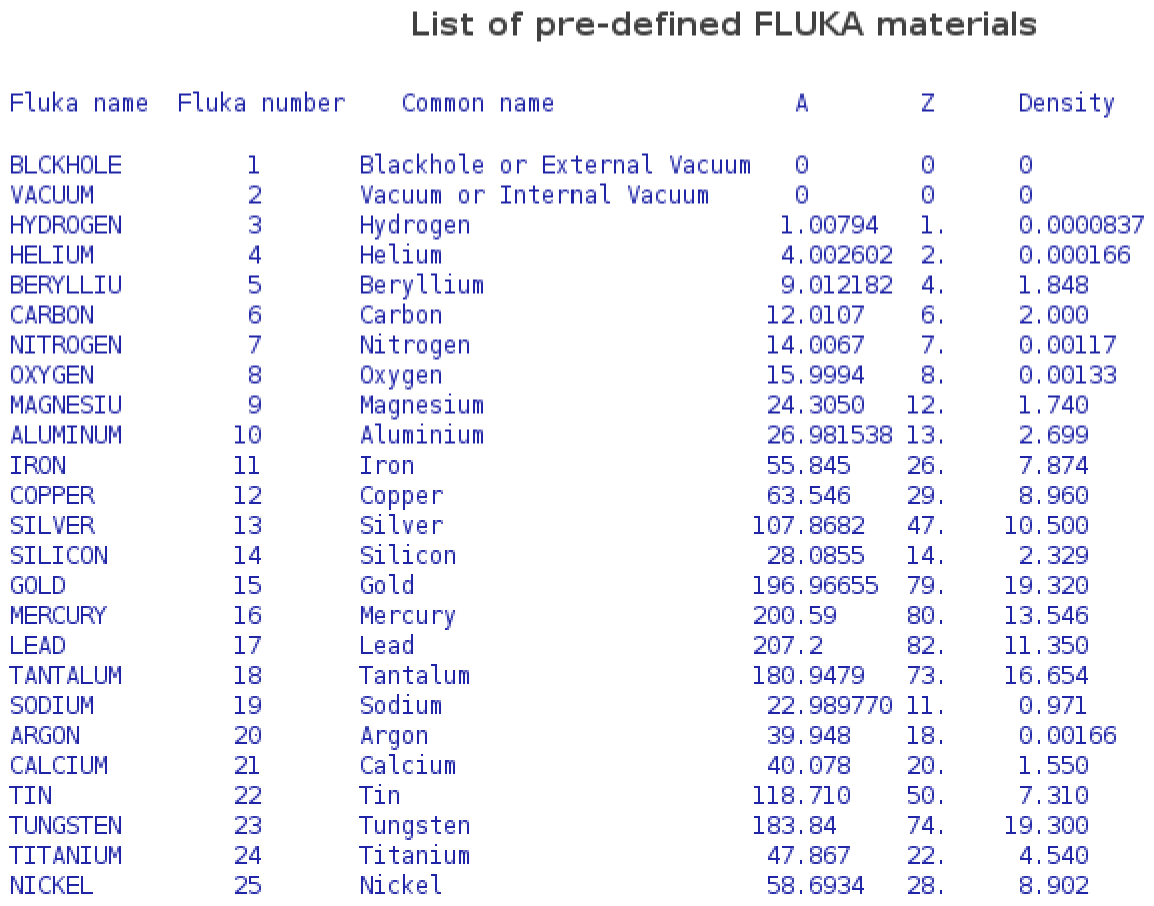
RPP

FLUKA – Example 1: Define Materials



```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
MATERIAL          4.0    9.0122     1.848       5.0                       BERYLLIU


               WHAT(1) = atomic number (meaningful only when NOT coupled to a
                         COMPOUND card; otherwise set = 0.)
                         No default.

               WHAT(2) = atomic weight in g/mole (meaningful only when NOT coupled to a
                         COMPOUND card; otherwise set = 0.)
                         Default: computed according to the natural composition
                         of an element with atomic number WHAT(1) if not coupled to a
                         COMPOUND card, no default otherwise.

               WHAT(3) = density in g/cm**3. Note that if the density is lower than
                         0.01, the material is considered to be a gas at
                         atmospheric pressure unless set otherwise by MAT-PROP
                         No default.

               WHAT(4) = number (index) of the material
                         Default = NMAT + 1 (NMAT is the current number of defined
                         materials. Its value is = 25 before any MATERIAL card is
                         given, and doesn't change if WHAT(4) overrides a number
                         which has already been assigned)

               WHAT(5) >= 2.0: alternate material number (or name, in name-based input)
                          for ionisation processes (this material will be used instead
                          of WHAT(1) for dE/dx etc.)
                          0 =< WHAT(5) =< 2: ignored
                          < 0.0: reset to default
                          Default: no alternate material

               WHAT(6) = mass number of the material: set = 0 unless a specific
                         individual isotope is desired. If not zero a nucleus of
                         the given mass number is used by the EVAP generator for
                         inelastic collisions, else the natural isotopic
                         composition of the WHAT(1) element is used. For isotopic
                         composition other than natural or single isotope, see
                         COMPOUND

               SDUM    = name of the material
                         Default: COPPER, FLUKA material 12
```

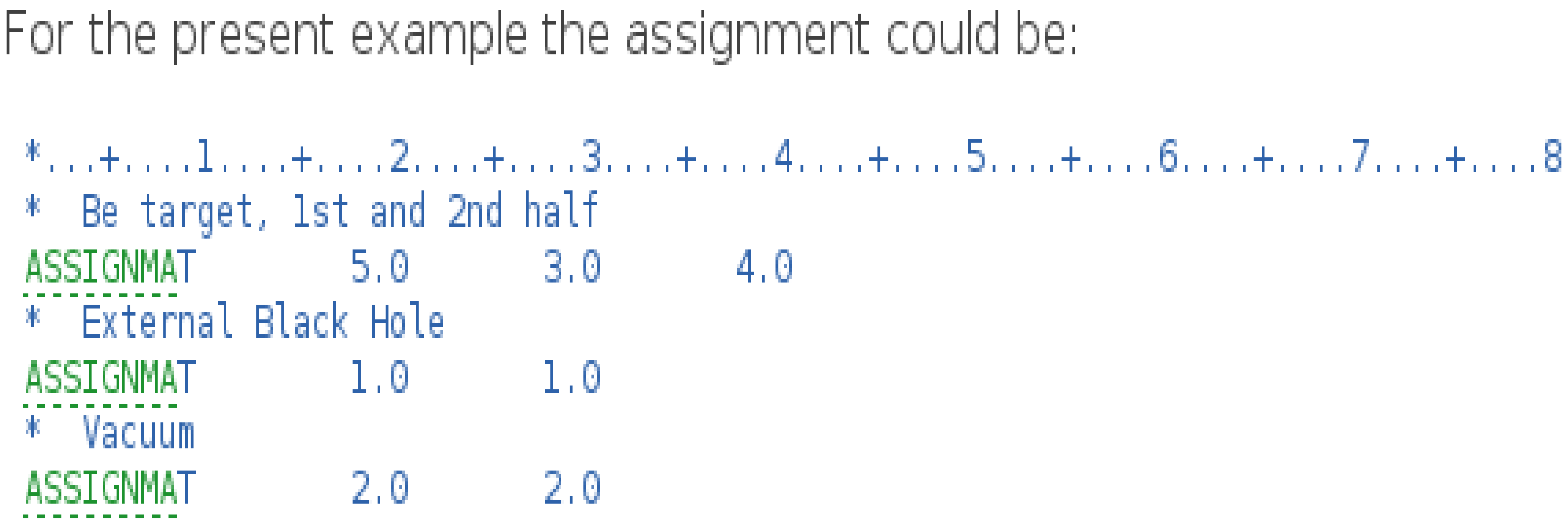
FLUKA – Example 1: Define Materials



List of pre-defined FLUKA materials

Fluka name	Fluka number	Common name	A	Z	Density
BLCKHOLE	1	Blackhole or External Vacuum	0	0	0
VACUUM	2	Vacuum or Internal Vacuum	0	0	0
HYDROGEN	3	Hydrogen	1.00794	1.	0.0000837
HELIUM	4	Helium	4.002602	2.	0.000166
BERYLLIU	5	Beryllium	9.012182	4.	1.848
CARBON	6	Carbon	12.0107	6.	2.000
NITROGEN	7	Nitrogen	14.0067	7.	0.00117
OXYGEN	8	Oxygen	15.9994	8.	0.00133
MAGNESIU	9	Magnesium	24.3050	12.	1.740
ALUMINUM	10	Aluminium	26.981538	13.	2.699
IRON	11	Iron	55.845	26.	7.874
COPPER	12	Copper	63.546	29.	8.960
SILVER	13	Silver	107.8682	47.	10.500
SILICON	14	Silicon	28.0855	14.	2.329
GOLD	15	Gold	196.96655	79.	19.320
MERCURY	16	Mercury	200.59	80.	13.546
LEAD	17	Lead	207.2	82.	11.350
TANTALUM	18	Tantalum	180.9479	73.	16.654
SODIUM	19	Sodium	22.989770	11.	0.971
ARGON	20	Argon	39.948	18.	0.00166
CALCIUM	21	Calcium	40.078	20.	1.550
TIN	22	Tin	118.710	50.	7.310
TUNGSTEN	23	Tungsten	183.84	74.	19.300
TITANIUM	24	Titanium	47.867	22.	4.540
NICKEL	25	Nickel	58.6934	28.	8.902

FLUKA – Example 1: Assign Materials

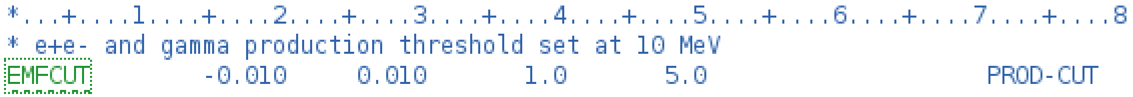


For the present example the assignment could be:

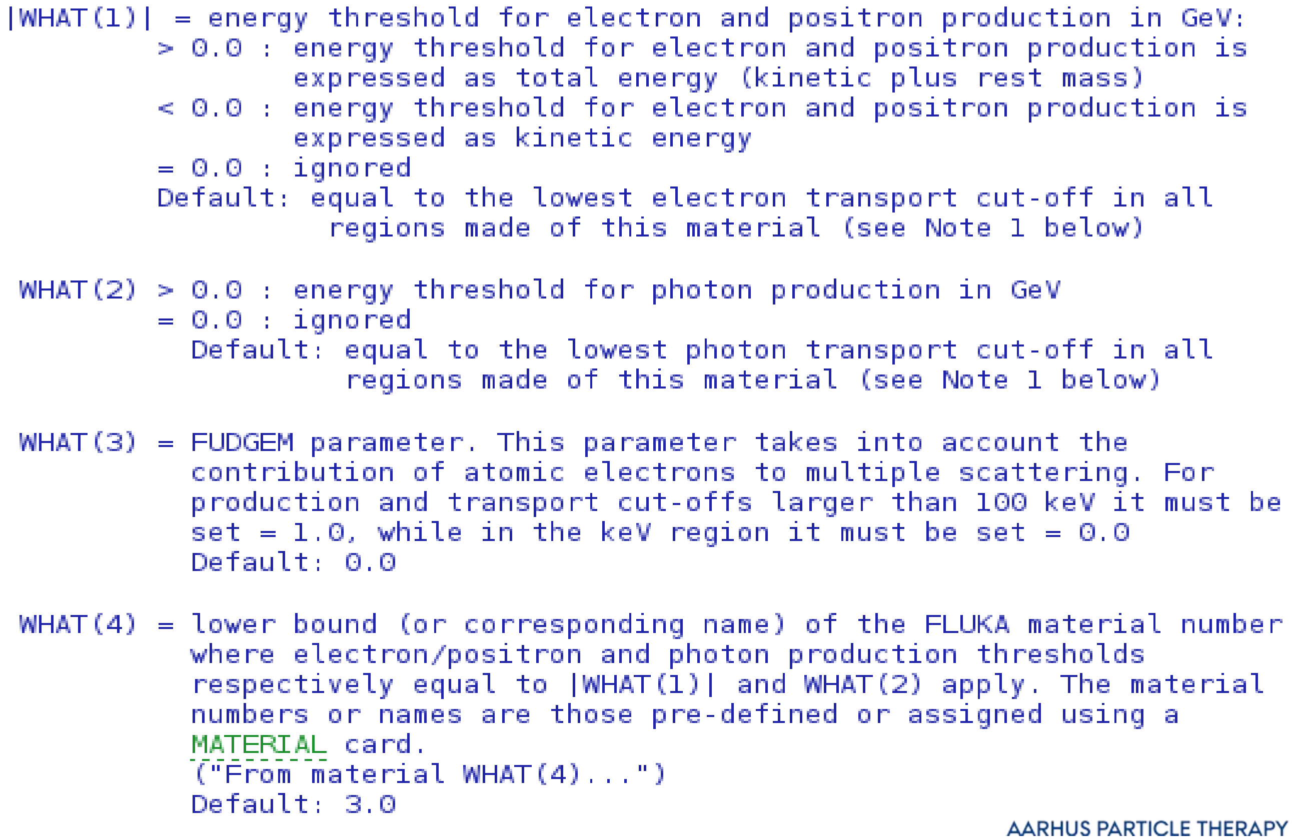
```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
*  Be target, 1st and 2nd half
ASSIGNMAT        5.0       3.0       4.0
*  External Black Hole
ASSIGNMAT        1.0       1.0
*  Vacuum
ASSIGNMAT        2.0       2.0
```

FLUKA – Example 1: Set cut-off values

The implicit NEW-DEFA default setting adopted in the example, sets, among other things, the production and transport threshold of heavy particles to 10 MeV. Production thresholds for e+e- and photons must be explicitly set using the EMFCUT command for all materials in the problem. Let us choose also in this case a 10 MeV threshold for the single material of the example (previously marked with material index 5 and name BERYLLIU). Following the instructions about the EMFCUT option, the card can be written as:

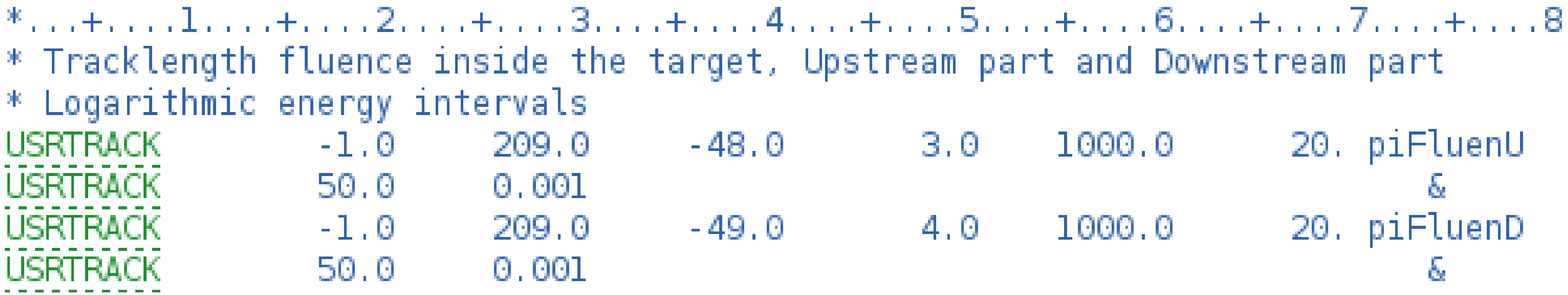


```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
* e+e- and gamma production threshold set at 10 MeV
EMFCUT        -0.010     0.010       1.0       5.0                    PROD-CUT
```



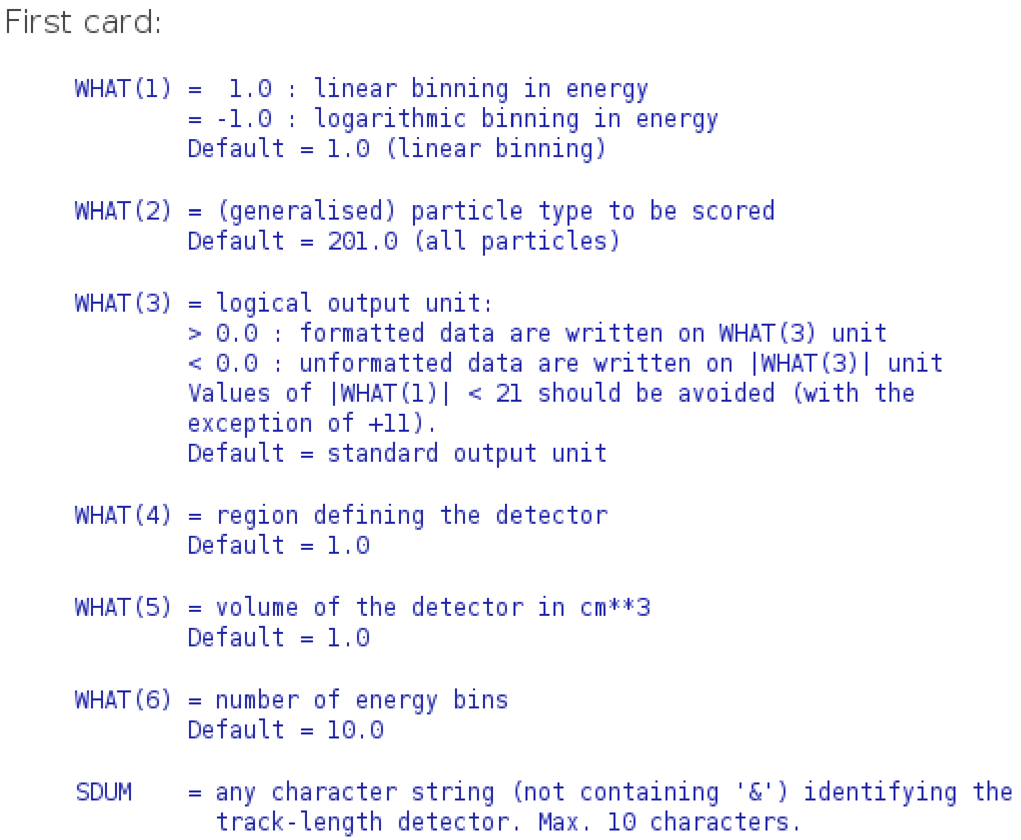
```
|WHAT(1)| = energy threshold for electron and positron production in GeV:
          > 0.0 : energy threshold for electron and positron production is
                  expressed as total energy (kinetic plus rest mass)
          < 0.0 : energy threshold for electron and positron production is
                  expressed as kinetic energy
          = 0.0 : ignored
          Default: equal to the lowest electron transport cut-off in all
                    regions made of this material (see Note 1 below)

 WHAT(2) > 0.0 : energy threshold for photon production in GeV
         = 0.0 : ignored
           Default: equal to the lowest photon transport cut-off in all
                     regions made of this material (see Note 1 below)

 WHAT(3) = FUDGEM parameter. This parameter takes into account the
           contribution of atomic electrons to multiple scattering. For
           production and transport cut-offs larger than 100 keV it must be
           set = 1.0, while in the keV region it must be set = 0.0
           Default: 0.0

 WHAT(4) = lower bound (or corresponding name) of the FLUKA material number
           where electron/positron and photon production thresholds
           respectively equal to |WHAT(1)| and WHAT(2) apply. The material
           numbers or names are those pre-defined or assigned using a
           MATERIAL card.
           ("From material WHAT(4)...")
           Default: 3.0
```

FLUKA – Example 1: Define Scorers



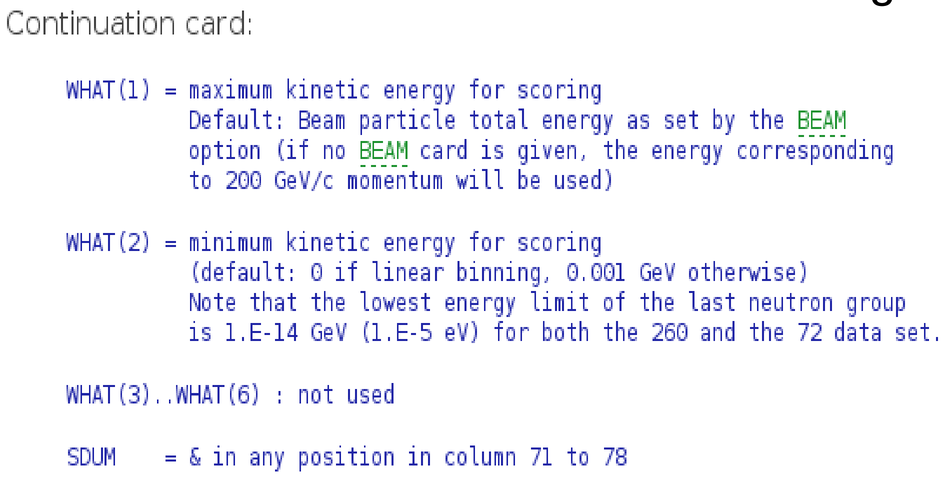
```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
* Tracklength fluence inside the target, Upstream part and Downstream part
* Logarithmic energy intervals
USRTRACK        -1.0     209.0     -48.0        3.0    1000.0       20. piFluenU
USRTRACK        50.0     0.001                                              &
USRTRACK        -1.0     209.0     -49.0        4.0    1000.0       20. piFluenD
USRTRACK        50.0     0.001                                              &
```

Don't forget



First card:

```
WHAT(1) =  1.0 : linear binning in energy
        = -1.0 : logarithmic binning in energy
        Default = 1.0 (linear binning)

WHAT(2) = (generalised) particle type to be scored
        Default = 201.0 (all particles)

WHAT(3) = logical output unit:
        > 0.0 : formatted data are written on WHAT(3) unit
        < 0.0 : unformatted data are written on |WHAT(3)| unit
        Values of |WHAT(1)| < 21 should be avoided (with the
        exception of +11).
        Default = standard output unit

WHAT(4) = region defining the detector
        Default = 1.0

WHAT(5) = volume of the detector in cm**3
        Default = 1.0

WHAT(6) = number of energy bins
        Default = 10.0

SDUM    = any character string (not containing '&') identifying the
          track-length detector. Max. 10 characters.
```



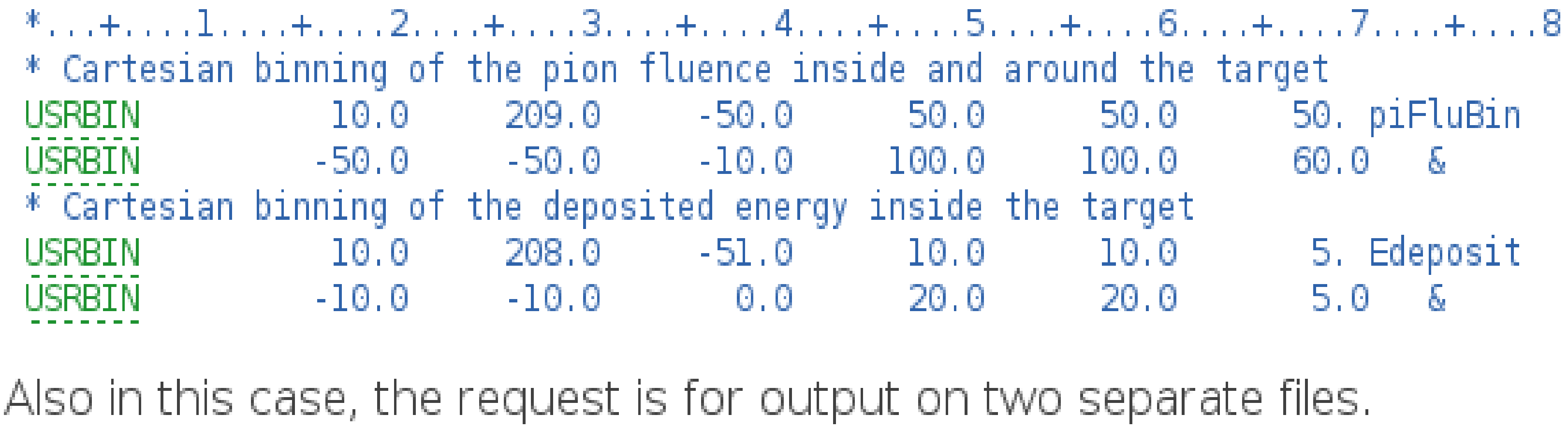
Continuation card:

```
WHAT(1) = maximum kinetic energy for scoring
          Default: Beam particle total energy as set by the BEAM
          option (if no BEAM card is given, the energy corresponding
          to 200 GeV/c momentum will be used)

WHAT(2) = minimum kinetic energy for scoring
          (default: 0 if linear binning, 0.001 GeV otherwise)
          Note that the lowest energy limit of the last neutron group
          is 1.E-14 GeV (1.E-5 eV) for both the 260 and the 72 data set.

WHAT(3)..WHAT(6) : not used

SDUM    = & in any position in column 71 to 78
```

209 = Charged pions

(see manual sec. 5.1 for particle codes!)

FLUKA – Example 1: Define Scorers



```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
* Cartesian binning of the pion fluence inside and around the target
USRBIN          10.0     209.0     -50.0      50.0      50.0      50. piFluBin
USRBIN         -50.0     -50.0     -10.0     100.0     100.0      60.0   &
* Cartesian binning of the deposited energy inside the target
USRBIN          10.0     208.0     -51.0      10.0      10.0       5. Edeposit
USRBIN         -10.0     -10.0       0.0      20.0      20.0       5.0   &
```

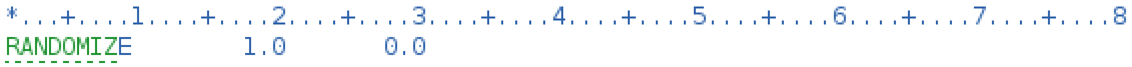
Also in this case, the request is for output on two separate files.

Here USRBIN asks for a 3D pion fluence map which goes into file “50”

Next a 3D energy deposit of the target is stored in file “51”.

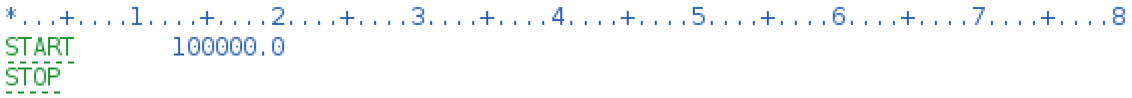
USRBIN is probably **the most important** scorer.
It can be configured in many ways, read the manual entry carefully...

Finally, initialize the random number generator:



```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
RANDOMIZE        1.0       0.0
```

And tell how many primaries are to be simulated:



```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
START       100000.0
STOP
```

Save the file, and you are ready to run!

FLUKA – Example 1: running the example

```
$FLUPRO/flutil/rfluka -N0 -M5 example &
```

It will run 5 times, after run, it will produce a bunch of files for each scorer, and some general run-time information (errors, logs etc.)

The binary output from **USRTRACK** can be translated to ASCII with

ustsuw

The binary output from **USRBIN** can be translated to ASCII with

usbsuw

If you got 100 runs, you get tired of the interactive nature of these scripts. We have wrappers..

(live demonstration with flair)