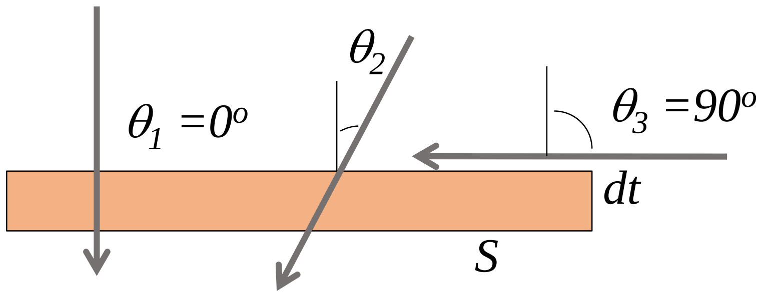
Scoring physics quantities II

Differential spectra (**USRTRACK**, **USRBDX**, **USRYIELD**)

Fluence vs Current (1/2)

Surface crossing estimation



- Consider the volume generated by a surface *S* times an infinitesimal thickness *dt.*
  A particle incident with *an angle θ with respect to the normal to the surface S* travels a segment *dt/cosθ* inside the volume.
- The **average fluence** F over the surface S is defined as*:*

$$\Phi = \lim_{dt \to 0} \frac{\sum_i \frac{dt}{\cos\theta_i}}{S\,dt}$$

total tracklength inside the volume

volume

- While the **average current** J over the surface S is given by the number of particles crossing the surface divided by the surface area:

J = N/S

Fluence vs Current (2/2)

- Fluence is **independent** of the orientation of the surface S, while current is **not** !
  - On a flat surface in an isotropic particle field $J = \Phi/2$

- Current is meaningful in case one needs to count particles (e.g. for a signal trigger)

- But to estimate dose, activation, radiation damage, instrument response… the relevant quantity to be used is fluence, since it is proportional to the interaction rate

Main FLUKA estimators

- **`USRBIN`** scores the **spatial distribution** of **energy density** or **fluence** (or star* density) in a **selection of regions** or in a **regular mesh** (cylindrical, cartesian) described by the user.

- **`USRTRACK`** (**`USRCOLL`**) scores 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**.

- **`USRYIELD`** scores a **double differential yield** of particles on a **given surface**.
  - The distribution can be with respect to energy and angle, but also other more “exotic” quantities

- All scorings write their results into **logical output units assigned by the user**
  - Unit numbers must be >20.
  - The only exception is SCORE: its output is printed in the **standard output**.

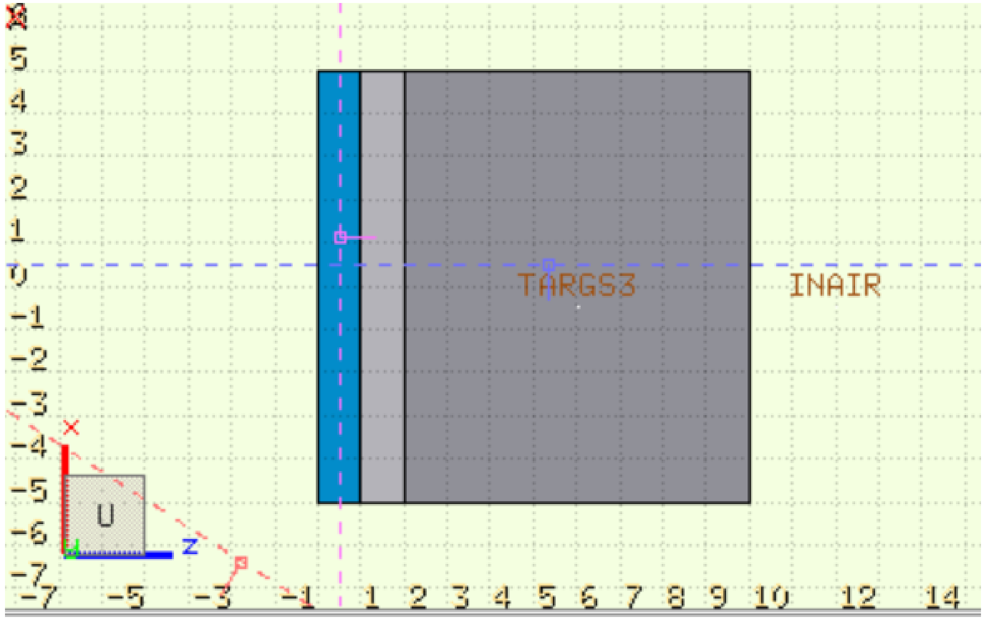
** A star is a hadronic inelastic interaction*

Scoring example

beam definitions

BEAM Beam: Energy ▾ E: 3.5 Part: PROTON ▾
Δp: Gauss ▾ Δp(FWHM): 0.8 Δϕ: Gauss ▾ Δϕ (FWHM): 1.7
Shape(X): Rectangular ▾ Δx: Shape(Y): Rectangular ▾ Δy:

BEAMPOS x: y: z: -0.1
cosx: cosy: Type: POSITIVE ▾



3.5 GeV protons on water → aluminum → lead

Results and units

- **FLUKA results in *_tab.lis:**
  - **USRTRACK, USRCOLL**: **single differential distribution in energy [GeV^{-1}]**.
  - **USRBDX**: **single differential distribution in energy [GeV^{-1}] (integrated over solid angle)**.
    In addition, **double differential distribution in energy and solid angle [GeV^{-1} sr^{-1}]**.
  - **USRYIELD**: **double differential distribution in var_1 and var_2 [$var_1 unit^{-1}$ $var_2 unit^{-1}$]**.
  - All results are **formatted** → Flair can plot from this file.

- **FLUKA results in *_sum.lis:**
  These files include a <u>cumulative distribution</u>, in addition to the above differential distributions.
  The integration is made w.r.t. the 1st variable (energy for USRTRACK, USRCOLL, USRBDX, and var_1 for USRYIELD).

  $N = \int \frac{dN}{dE} dE$ *dN/dE:* value of each energy bin → Useful to get **integral over an energy range**.

  dE: bin width

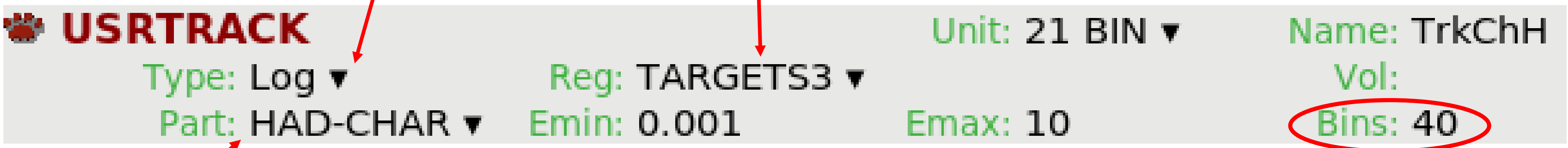
- **FLUKA results are <u>NOT normalized by region volume [boundary area]</u>.**
  For example, as scoring particle *fluence* with **USRTRACK** [**USRBDX**, **USRYIELD**], results will only be in cm^{-2}:
  - If the user had provided the region volume [boundary area] in the respective card field (before run).
  - Otherwise, if the user applies the desired normalization at post-processing level (e.g. Flair Y Norm).

USRTRACK scoring definition

Tracklength spectrum
(differential in **energy**)

Log binning in energy

Region choice



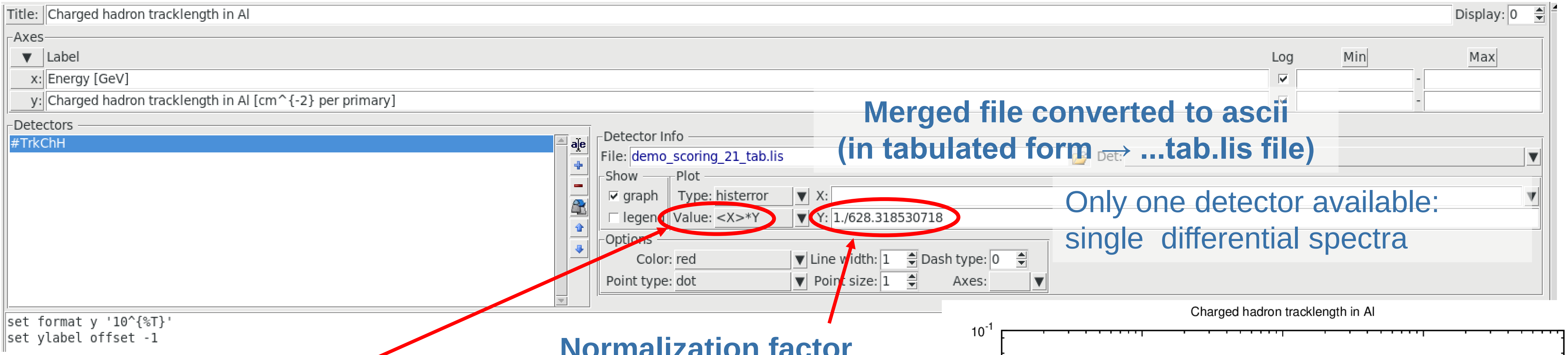
Particle type:
charged
hadrons

40 bins in energy

The merging/processing action will create 3 files for each **`USRTRACK`** unit:

- **`demo_scoring_21.trk`**: binary file containing the merged data from several runs
- **`demo_scoring_21_sum.lis`**: ascii file containing energy spectra,
  and in addition energy-integrated cumulative spectra
- **`demo_scoring_21_tab.lis`**: ascii file containing energy spectra → <u>Flair uses this file</u>

Plotting – single diff. fluence in volume (USRTRACK)



Merged file converted to ascii (in tabulated form → ...tab.lis file)

Only one detector available: single differential spectra

Normalization factor

Divide by target volume

Note: Flair can compute volumes stochastically (convenient for complex shapes)

Lethargy plot

(1) **Data in *tab.lis** is Y = dl/dE

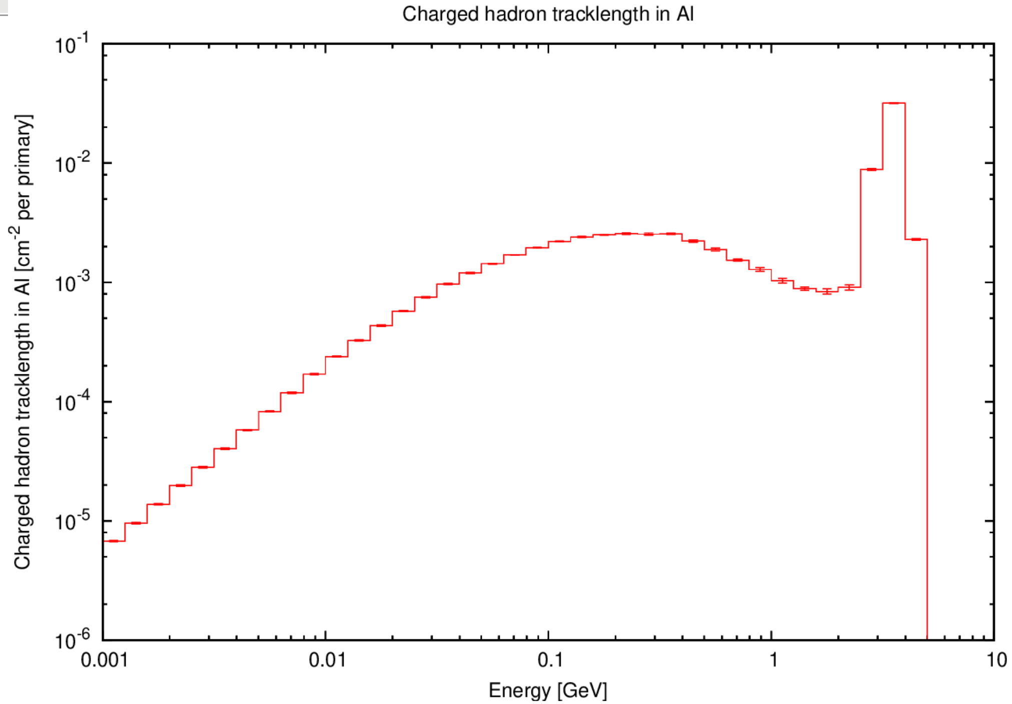
(2) **Flair** multiplies by <X> = E

Note: E is the geometric mean of the energy bin extrema.

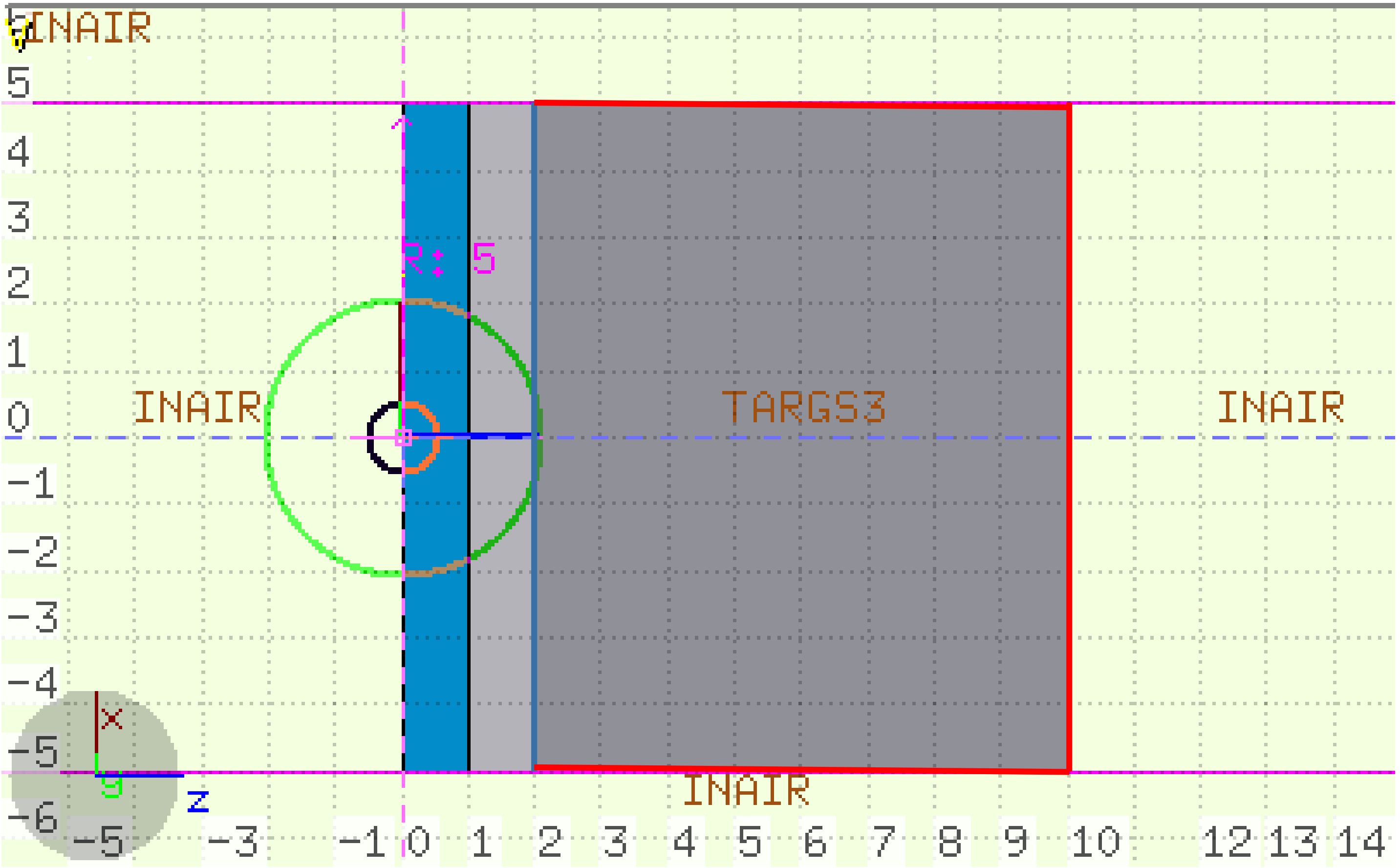
The multiplication is handled via e.g. gnuplot.

(3) One gets **Edl/dE = dl/d(logE)**

Note: Dimensionless



USRBDX area normalization



R_{TARG} = 5 cm
ΔZ_{TARGS1} = 1 cm
ΔZ_{TARGS2} = 1 cm
ΔZ_{TARGS3} = 8 cm

Area between TARGS2 and TARGS3: πR_{TARG}^2 = 78.5398 cm^2

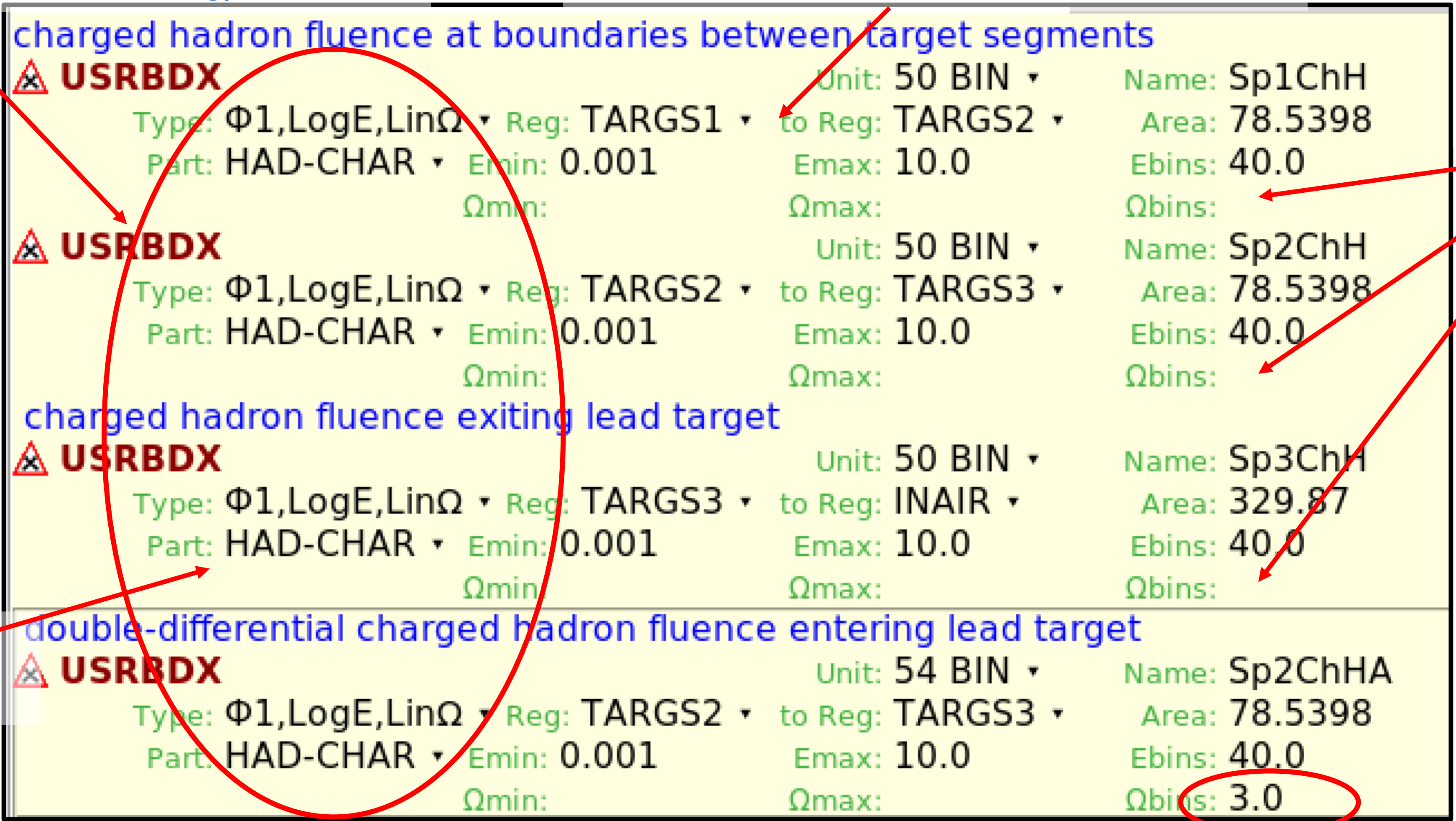
Area between TARGS3 and INAIR: $2\pi R_{TARG}\ \Delta Z_{TARGS3} + \pi R_{TARG}^2$ = 329.87 cm^2

USRBDX scoring (boundary crossing) definition

One-way fluence across **boundary**, differential in **energy** (**log** binning) and **angle** (**linear** binning)

Only count particles **from TARGS1 to TARGS2 (one-way)**, **not** from TARGS2 to TARGS1

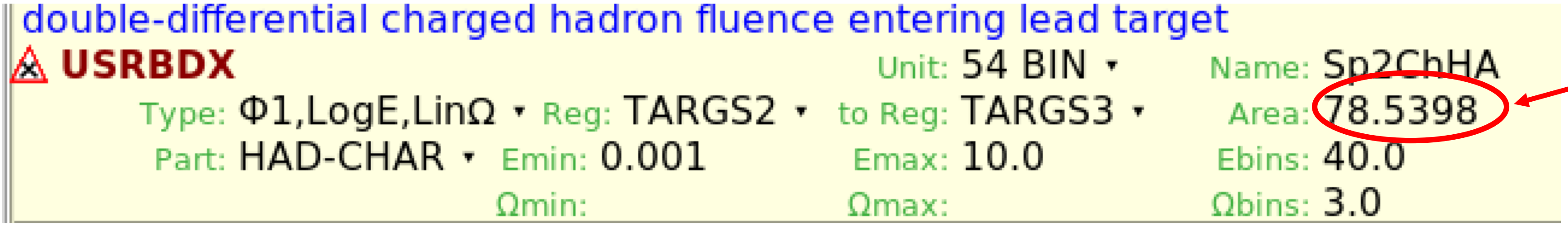
By default **ONE angular bin** (no angular distribution)



Particle type: **charged hadrons**

3 angular bins

USRBDX scoring (boundary crossing) output



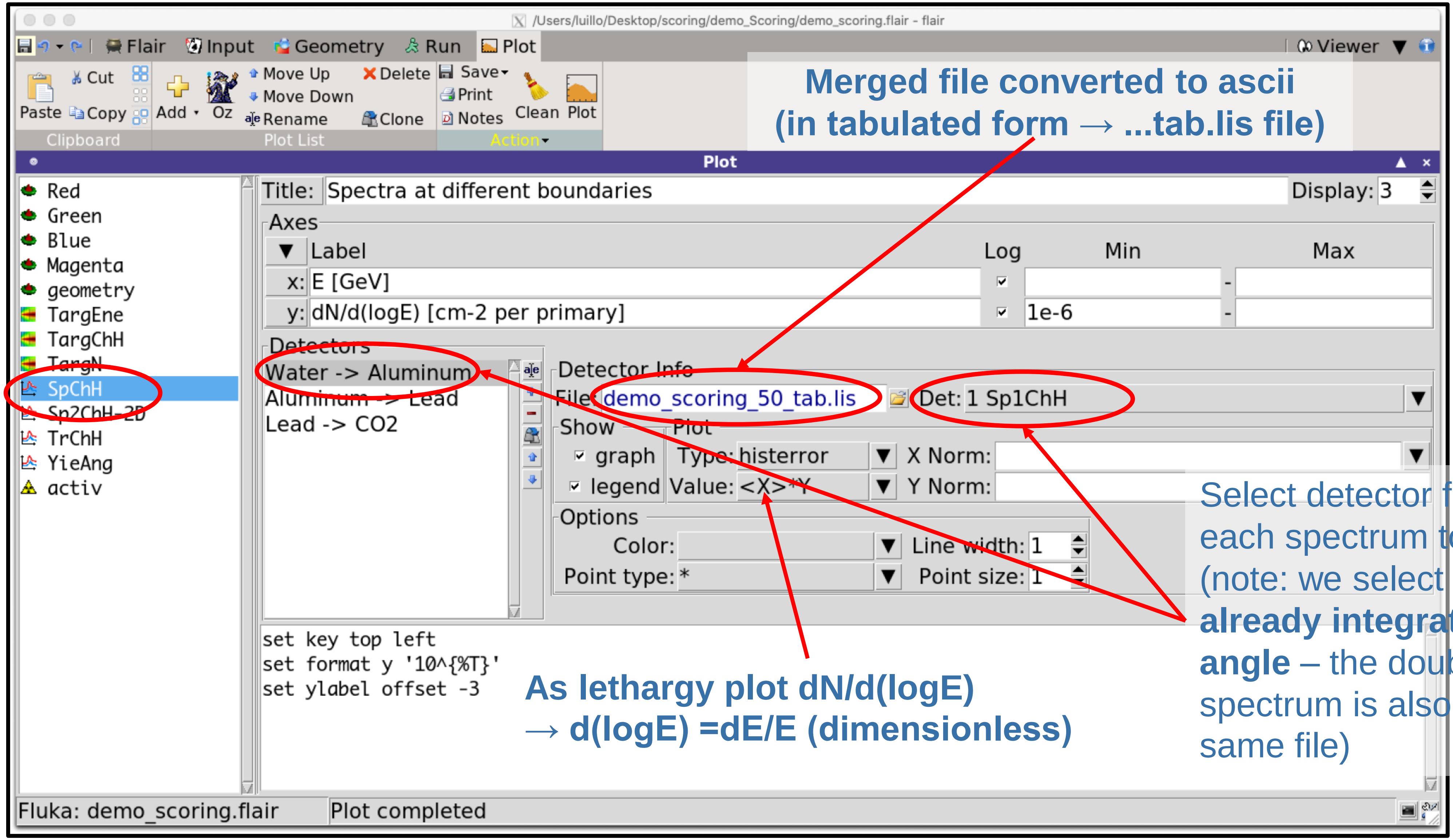
Surface area [cm^2] normalization, which can be independently done at post-processing

The merging/processing action will create 3 files for each **USRBDX** unit:

- **demo_scoring_54.bnx**: binary file containing the merged data from several runs
  [it can replace the N unformatted estimator files for further postprocessing]
- **demo_scoring_54_sum.lis**: ascii file containing all information and in addition energy-integrated cumulative spectra
- **demo_scoring_54_tab.lis**: ascii file containing the double differential fluence and angle-integrated fluence in tabulated form for immediate plotting → Flair uses this file

Note: even if only one angular bin was requested, differential spectra are always double differential in GeV^{-1} $\mathbf{sr^{-1}}$

Plotting – single diff. fluence on boundary (USRBDX)



Merged file converted to ascii (in tabulated form → ...tab.lis file)

Select detector from file for each spectrum to be plotted (note: we select the data set that is **already integrated over solid angle** – the double differential spectrum is also available in the same file)

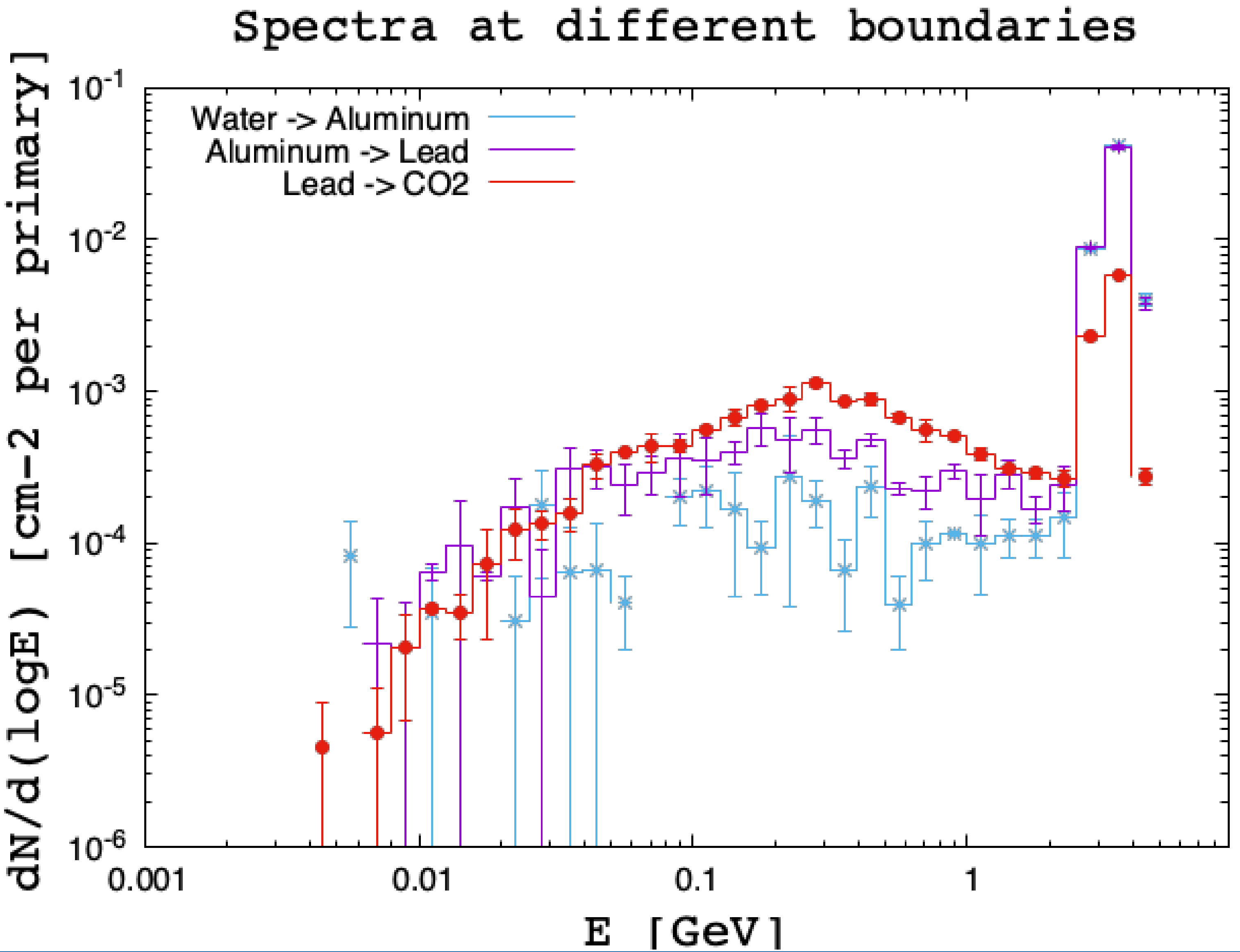
As lethargy plot dN/d(logE) → d(logE) =dE/E (dimensionless)

Plotting – single diff. fluence on boundary (USRBDX)

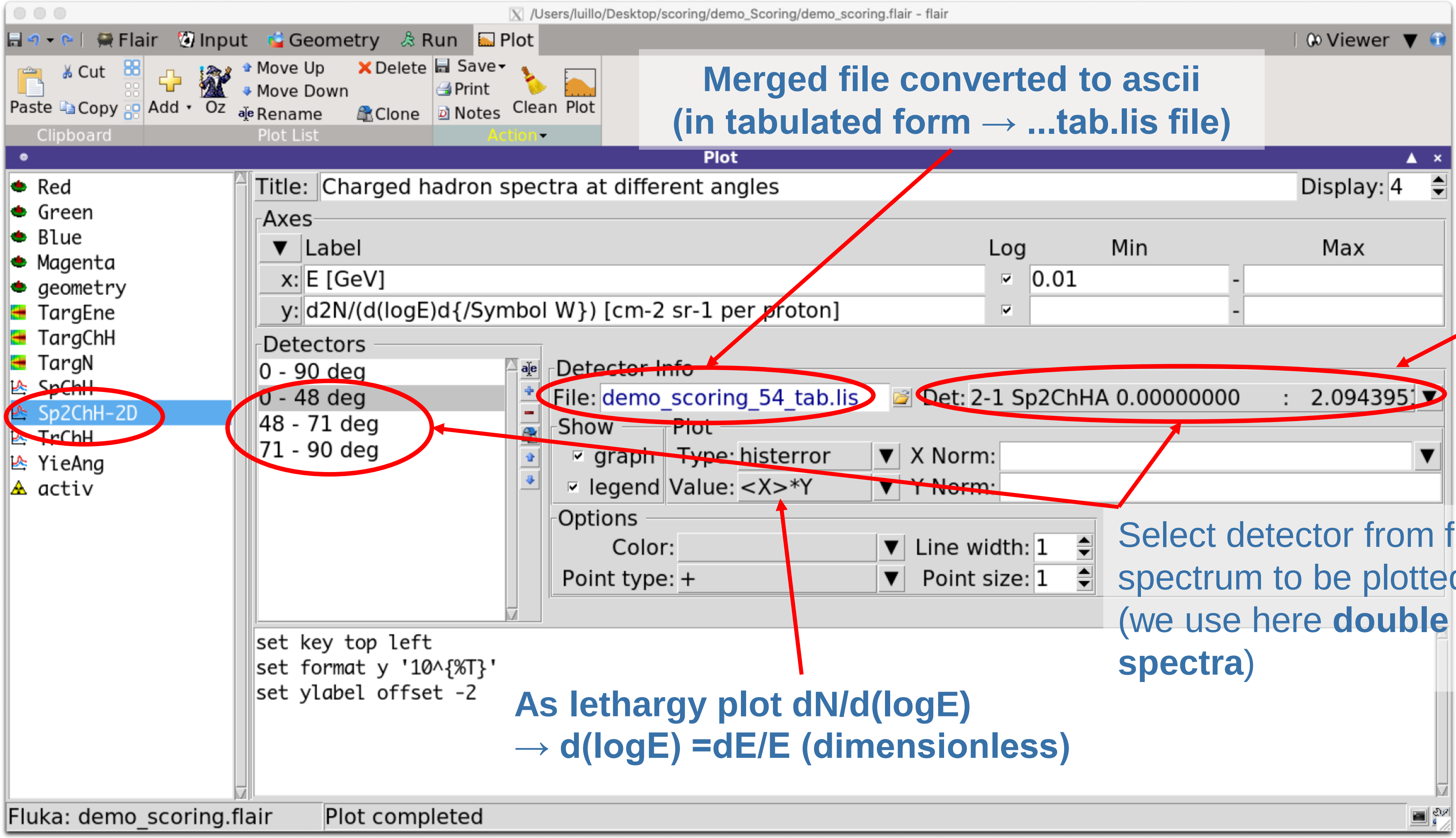
$$y = \frac{dN}{d(logE)} = E\frac{dN}{dE}$$

Value: <X>*Y

Lethargy plot



Plotting – double diff. fluence on boundary (USRBDX)



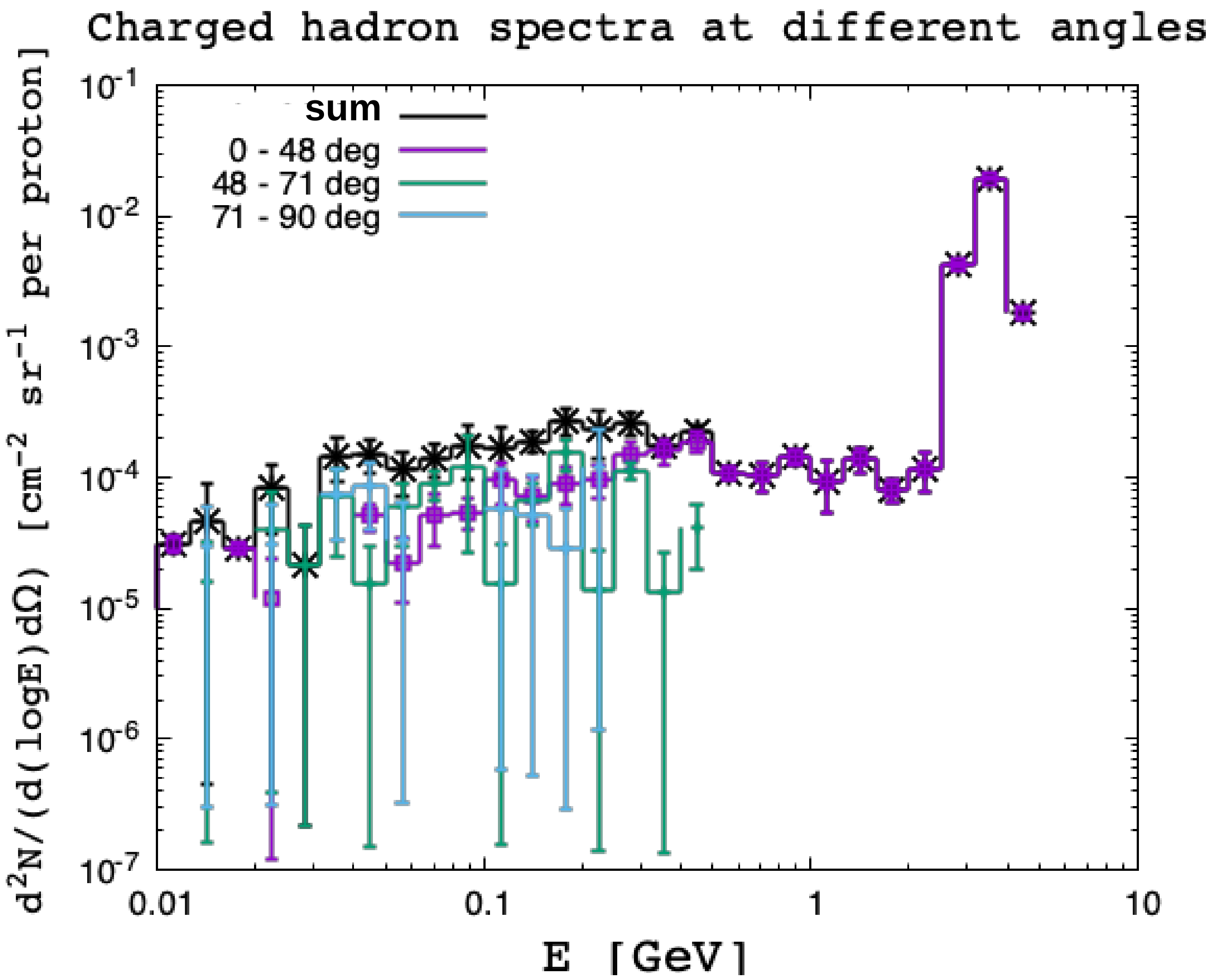
Merged file converted to ascii (in tabulated form → ...tab.lis file)

2π/3 (one-way scoring: max is a half-sphere)

Select detector from file for each spectrum to be plotted (we use here **double differential spectra**)

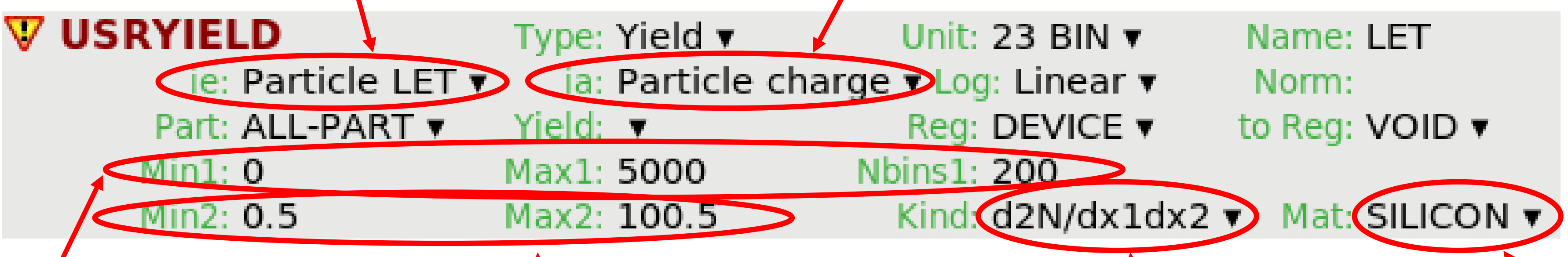
As lethargy plot dN/d(logE) → d(logE) =dE/E (dimensionless)

Plotting – double diff. fluence on boundary (USRBDX)



USRYIELD scoring definition

1st differential variable **2nd differential variable**



1st differential variable
min / max / binning

2nd differential variable
min / max
num bins = 1

Kind:
$d2N/dx_1dx_2$
⇔ current

Material
(Optional)
Needed here because of LET

USRBDX and **USRYIELD** both provide **differential spectra across a boundary**.
USRYIELD provides a richer choice of weights (see "Kind") and differential variables (see "ie" and "ia").

NB: **USRYIELD** can additionally be used to score yields of particles emerging from inelastic hadronic interactions with single nuclei (note shown here).

Summary

- **USRTRACK**, **USRBDX** and **USRYIELD** are scoring cards which allow to get **differential spectra**.
- Score **tracklength** density in a **volume**
  single differential in energy
  → **USRTRACK**
- Score **fluence or current** across a **boundary**
  single differential in energy, or **double differential in energy and angle with boundary normal**
  → **USRBDX**
- Score **particles count** across a **boundary** in a more customized way:
  more complex weights, or differential variables other than energy / angle with boundary normal (e.g. angle with beam direction, LET, …), etc
  → **USRYIELD**
- It is the user responsibility to ensure normalization by region volume / boundary area.

FLUKA