



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 $dt/\cos\theta$ inside the volume.

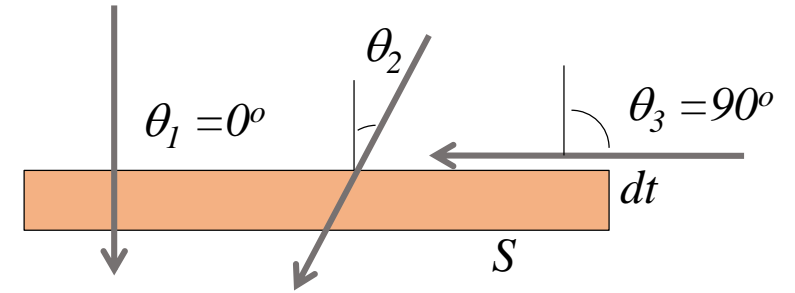
- The **average fluence F** over the surface S is defined as:

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

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

$\Delta\phi$: Gauss ▼ $\Delta\phi$ (FWHM): 1.7

Shape(X): Rectangular ▼ Δx :

Shape(Y): Rectangular ▼ Δy :

 **BEAMPOS**

x:

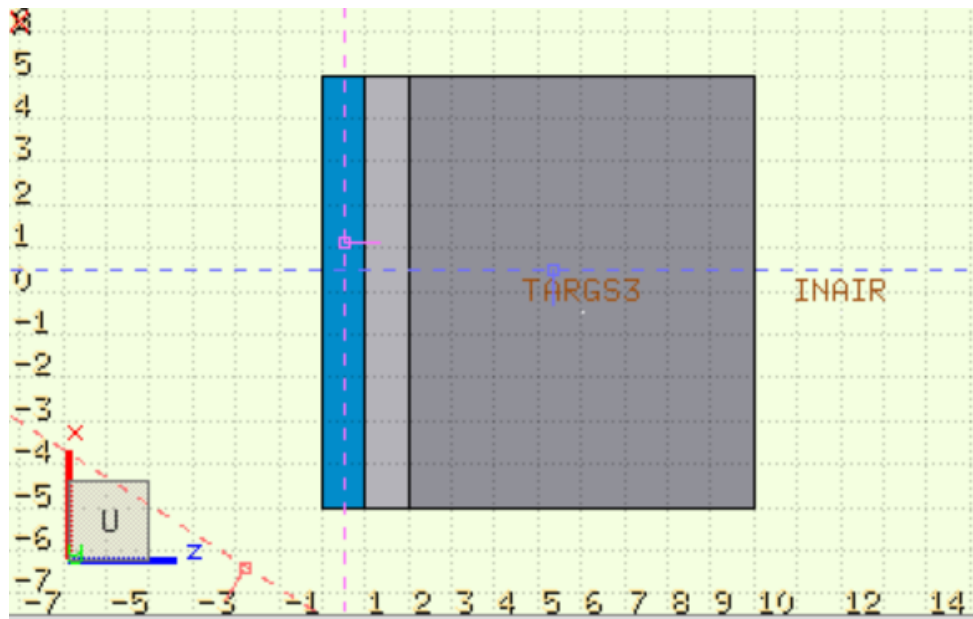
y:

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 var₁ and var₂ [var₁unit⁻¹ var₂unit⁻¹].
 - All results are **formatted** → Flair can plot from this file.

- **FLUKA results in *_sum.lis:**

These files include a cumulative distribution, in addition to the above differential distributions.

The integration is made w.r.t. the 1st variable (energy for USRTRACK, USRCOLL, USRBDX, and var₁ 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 NOT normalized by region volume [boundary area].**

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

Unit: 21 BIN ▼

Name: TrkChH

Vol:

Bins: 40

40 bins in energy

Particle type:
charged
hadrons

USRTRACK

Type: Log ▼

Reg: TARGETS3 ▼

Part: HAD-CHAR ▼

Emin: 0.001

Emax: 10

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 → Flair uses this file

Plotting – single diff. fluence in volume (USRTRACK)

Title: Charged hadron tracklength in Al

Display: 0

Log Min Max

Label

x: Energy [GeV]

y: Charged hadron tracklength in Al [cm⁻² per primary]

Detectors

#TrkChH

Detector Info

File: demo_scoring_21_tab.lis

Show Plot

graph Type: histerror X:

legend Value: <X>*Y Y: 1./628.318530718

Options

Color: red Line width: 1 Dash type: 0

Point type: dot Point size: 1 Axes:

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

Only one detector available: single differential spectra

set format y '10^{%T}'

set ylabel offset -1

Lethargy plot

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

(2) **Flair** multiplies by $\langle X \rangle = E$

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

The multiplication is handled via e.g. gnuplot.

(3) One gets $Edl/dE = dl/d(\log E)$

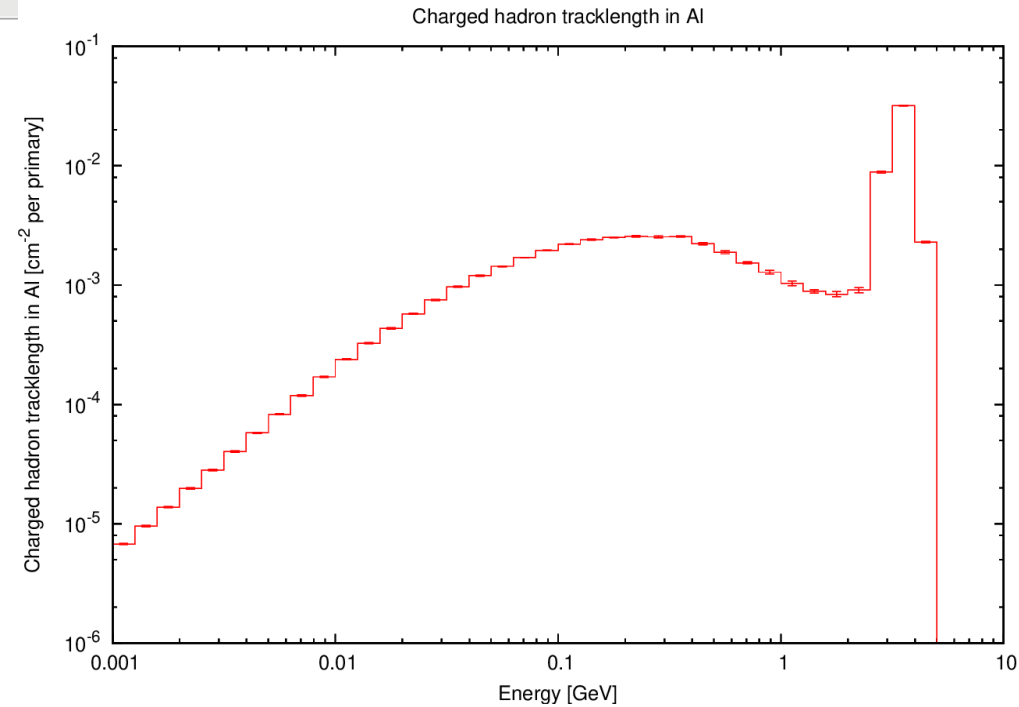
Note: Dimensionless

Normalization factor

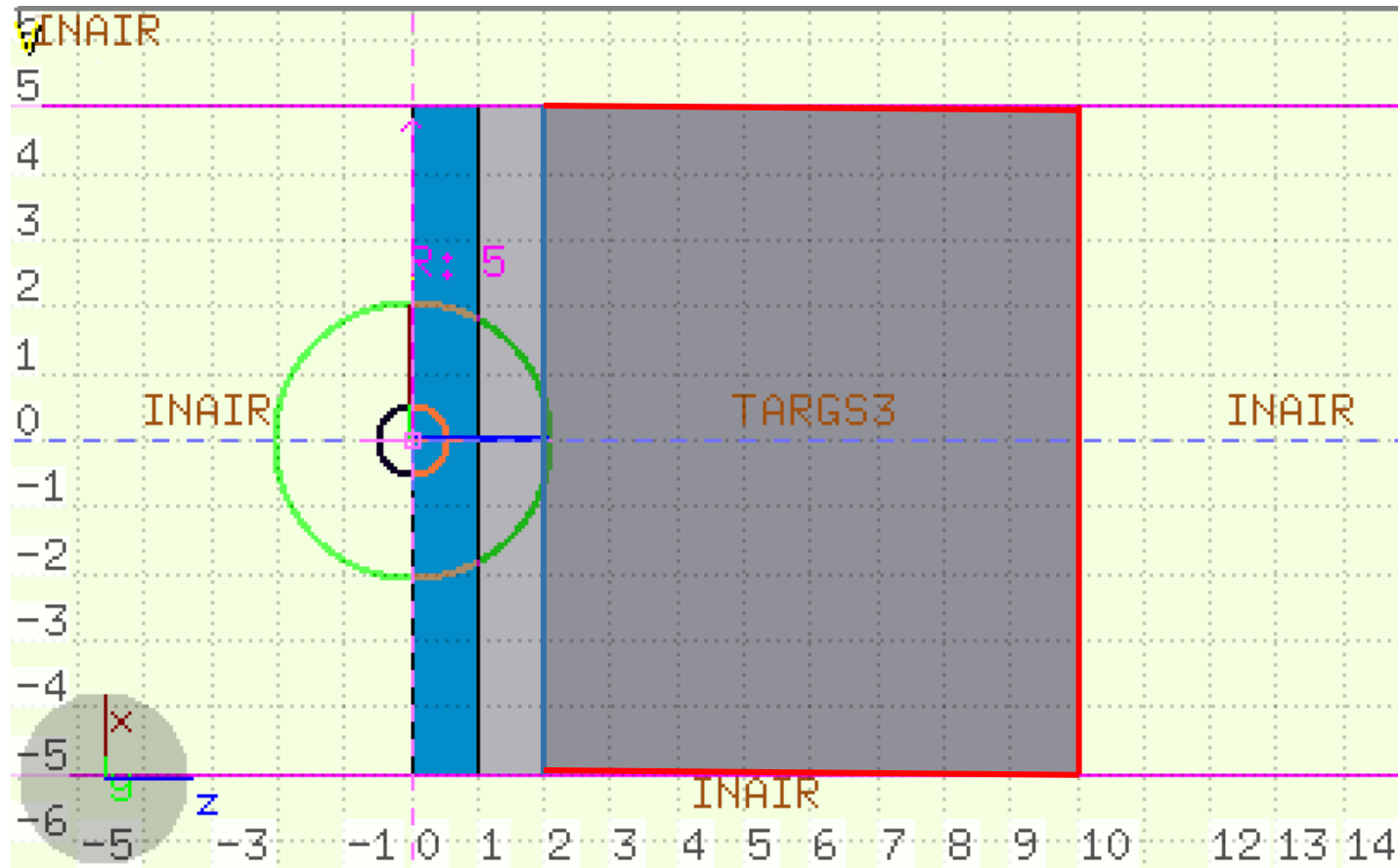
Divide by target volume

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

Value: <X>*Y



USRBDX area normalization



$$\begin{aligned}R_{\text{TARG}} &= 5 \text{ cm} \\ \Delta Z_{\text{TARGS1}} &= 1 \text{ cm} \\ \Delta Z_{\text{TARGS2}} &= 1 \text{ cm} \\ \Delta Z_{\text{TARGS3}} &= 8 \text{ cm}\end{aligned}$$

Area between TARGS2 and TARGS3: $\pi R_{\text{TARG}}^2 = 78.5398 \text{ cm}^2$

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

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)

charged hadron fluence at boundaries between target segments

USRBDX	Unit: 50 BIN	Name: Sp1ChH
Type: Φ 1,LogE,Lin Ω	Reg: TARGS1 to Reg: TARGS2	Area: 78.5398
Part: HAD-CHAR	Emin: 0.001 Emax: 10.0	Ebins: 40.0
	Ω min: Ω max:	Ω bins:

charged hadron fluence exiting lead target

USRBDX	Unit: 50 BIN	Name: Sp2ChH
Type: Φ 1,LogE,Lin Ω	Reg: TARGS2 to Reg: TARGS3	Area: 78.5398
Part: HAD-CHAR	Emin: 0.001 Emax: 10.0	Ebins: 40.0
	Ω min: Ω max:	Ω bins:

double-differential charged hadron fluence entering lead target

USRBDX	Unit: 54 BIN	Name: Sp3ChH
Type: Φ 1,LogE,Lin Ω	Reg: TARGS3 to Reg: INAIR	Area: 329.87
Part: HAD-CHAR	Emin: 0.001 Emax: 10.0	Ebins: 40.0
	Ω min: Ω max:	Ω bins:

USRBDX	Unit: 54 BIN	Name: Sp2ChHA
Type: Φ 1,LogE,Lin Ω	Reg: TARGS2 to Reg: TARGS3	Area: 78.5398
Part: HAD-CHAR	Emin: 0.001 Emax: 10.0	Ebins: 40.0
	Ω min: Ω max:	Ω bins: 3.0

Particle type: charged hadrons

3 angular bins

USRBDX scoring (boundary crossing) output

```
double-differential charged hadron fluence entering lead target
⚠ USRBDX                               Unit: 54 BIN ▾   Name: Sp2ChHA
Type: Φ1,LogE,LinΩ ▾   Reg: TARGS2 ▾   to Reg: TARGS3 ▾   Area: 78.5398
Part: HAD-CHAR ▾   Emin: 0.001       Emax: 10.0       Ebins: 40.0
                   Qmin:              Qmax:              Qbins: 3.0
```

Surface area [cm²]
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 sr⁻¹

Plotting – single diff. fluence on boundary (USRBDX)

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

Title: Spectra at different boundaries Display: 3

Axes

Label	Log	Min	Max
x: E [GeV]	<input checked="" type="checkbox"/>		
y: dN/d(logE) [cm-2 per primary]	<input checked="" type="checkbox"/>	1e-6	

Detectors

- Water -> Aluminum
- Aluminum -> Lead
- Lead -> CO2

Detector Info

File: demo_scoring_50_tab.lis Det: 1 Sp1ChH

Show Plot

graph Type: histerror X Norm: Y Norm:

legend Value: <X>*Y

Options

Color: Line width: 1

Point type: * Point size: 1

set key top left
set format y '10^{%T}'
set ylabel offset -3

Fluka: demo_scoring.flair Plot completed

As lethargy plot $dN/d(\log E)$
→ $d(\log E) = dE/E$ (dimensionless)

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)

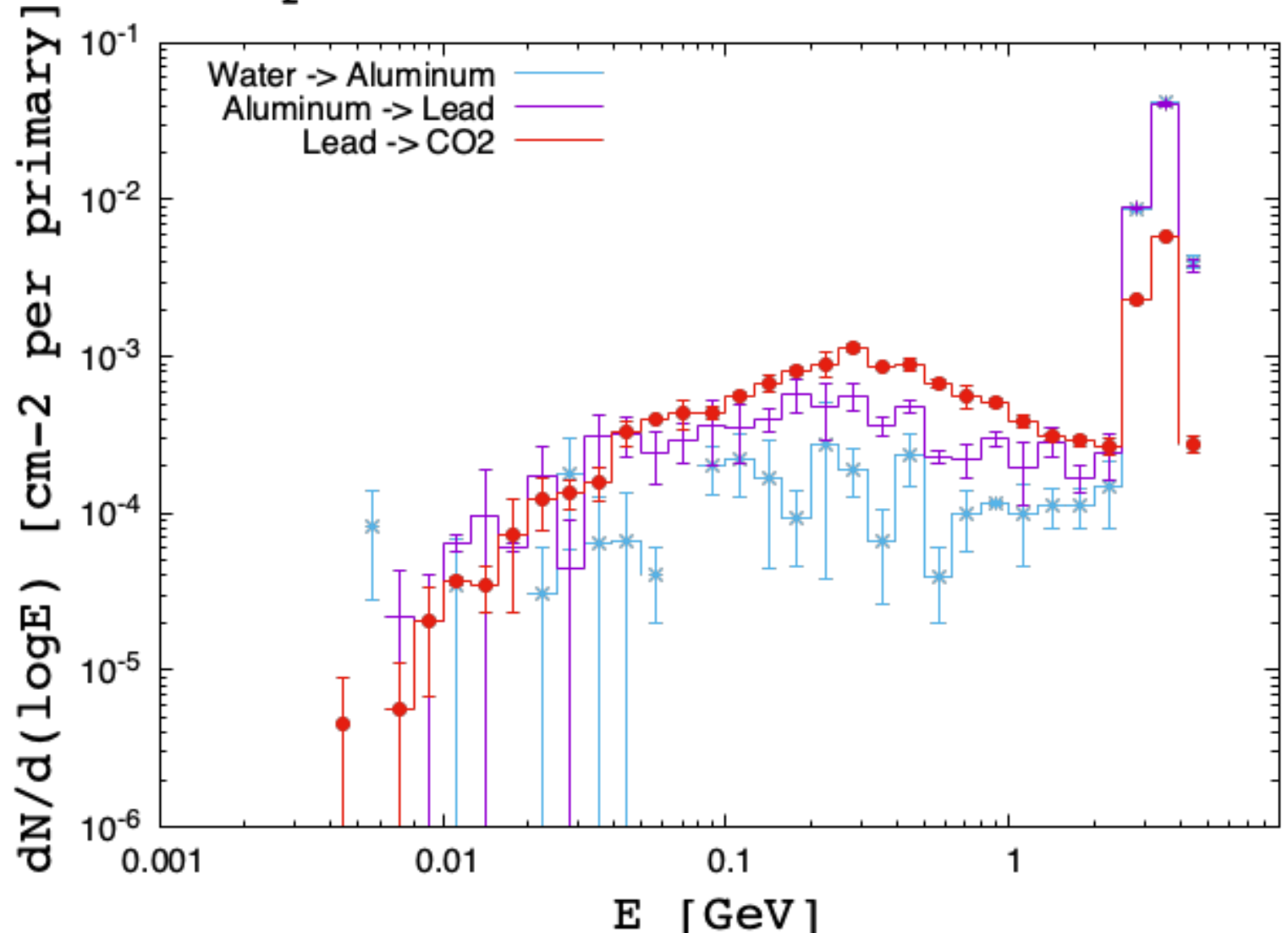
Plotting – single diff. fluence on boundary (USRBDX)

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

Value: <X>*Y

Lethargy plot

Spectra at different boundaries



Plotting – double diff. fluence on boundary (USRBDX)

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

Title: Charged hadron spectra at different angles Display: 4

Axes

Label	Log	Min	Max
x: E [GeV]	<input checked="" type="checkbox"/>	0.01	
y: $d^2N/(d(\log E)d\{\text{Symbol } W\})$ [cm ⁻² sr ⁻¹ per proton]	<input checked="" type="checkbox"/>		

Detectors

- 0 - 90 deg
- 0 - 48 deg
- 48 - 71 deg
- 71 - 90 deg

Sp2ChH-2D

Detector Info

File: demo_scoring_54_tab.lis Det: 2-1 Sp2ChHA 0.00000000 : 2.0943951

Show Plot

graph Type: histerror X Norm: Y Norm:

legend Value: <X>*Y

Options

Color: Line width: 1

Point type: + Point size: 1

set key top left
set format y '10^{%T}'
set ylabel offset -2

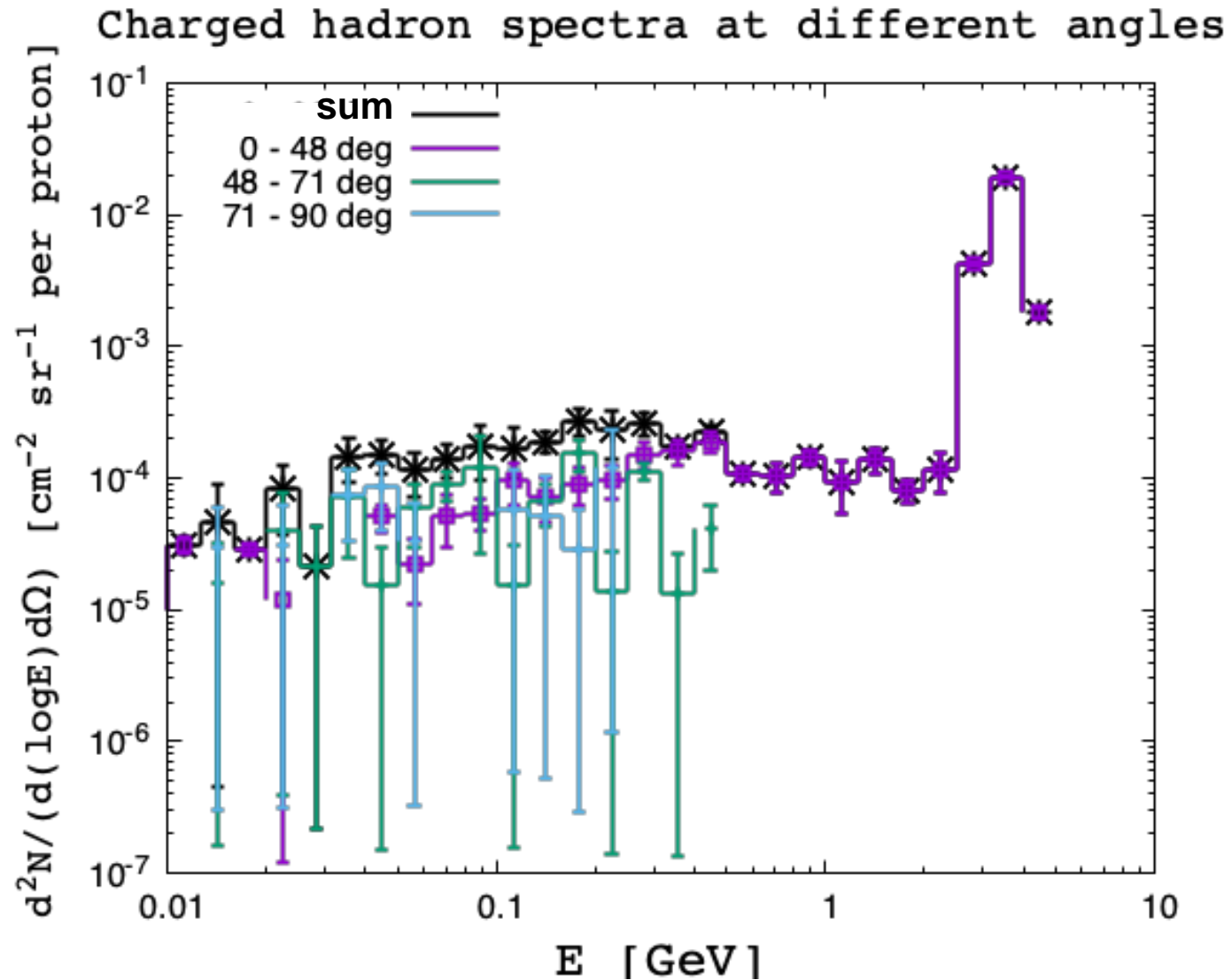
Fluka: demo_scoring.flair Plot completed

$2\pi/3$
(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 $dN/d(\log E)$
→ $d(\log E) = dE/E$ (dimensionless)

Plotting – double diff. fluence on boundary (USRBDX)



USRYIELD scoring definition

1st differential variable 2nd differential variable

USRYIELD	Type: Yield ▼	Unit: 23 BIN ▼	Name: LET
ie: Particle LET ▼	ia: Particle charge ▼	Log: Linear ▼	Norm:
Part: ALL-PART ▼	Yield: ▼	Reg: DEVICE ▼	to Reg: VOID ▼
Min1: 0	Max1: 5000	Nbins1: 200	
Min2: 0.5	Max2: 100.5	Kind: d2N/dx1dx2 ▼	Mat: SILICON ▼

1st differential variable min / max / binning

2nd differential variable min / max num bins = 1

Kind: d^2N/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.

