Magnetic and electric fields

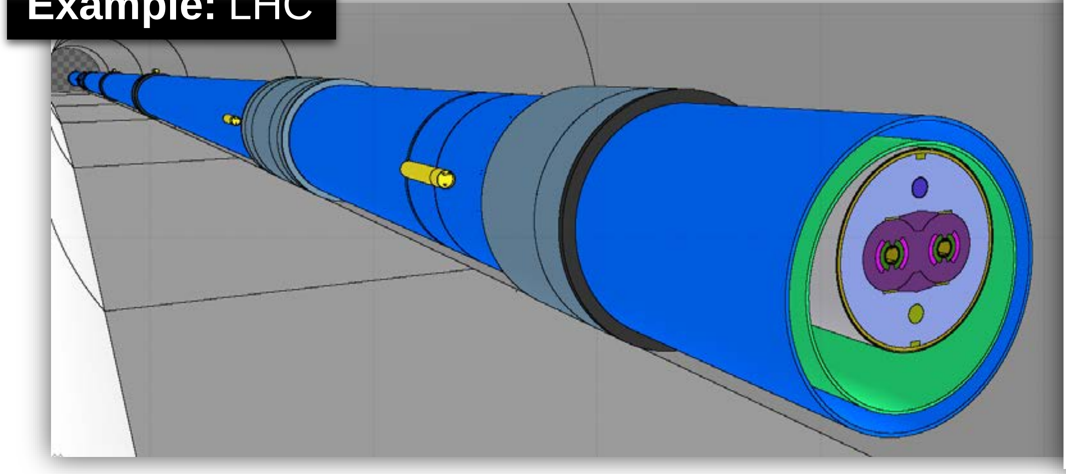
How to define basic fields and adjust transport settings

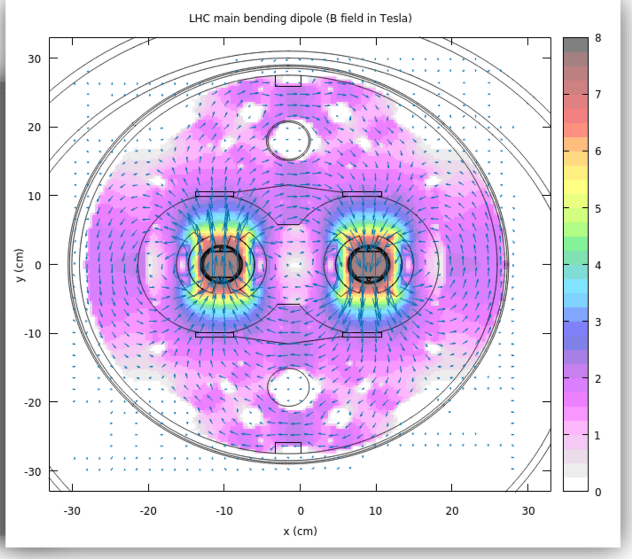
Beginner online training, Fall 2020

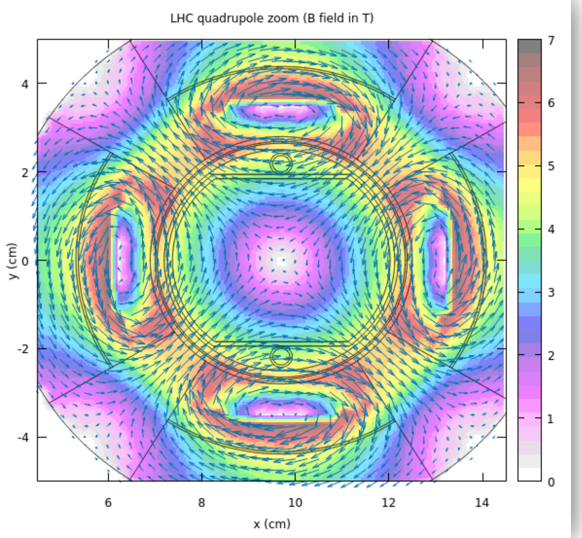
Introduction

- Magnetic and/or electric fields are crucial for many simulation problems
  - Accelerator magnets, transfer line magnets, solenoids, spectrometers, magnetic horns, …

Example: LHC



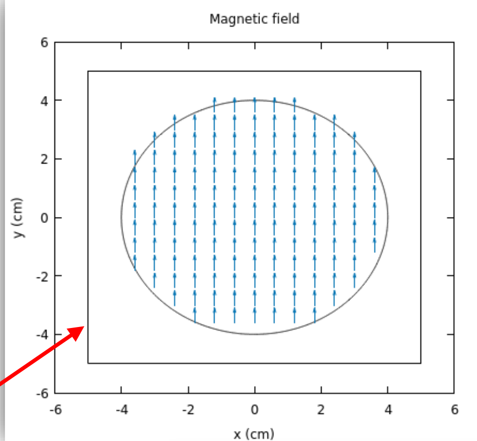




- FLUKA supports the transport of charged particles in *arbitrary* static B and E fields (the latter since FLUKA 4-0.0)
  - This lecture gives a basic introduction how to define **uniform** fields and presents the relevant transport parameters

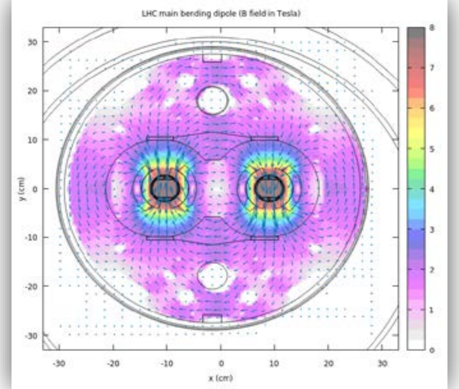
Magnetic and electric fields in FLUKA

- Fields are activated on a per-region basis
  - **Magnetic fields** can be defined **in any region** (filled with any material)
  - **Electric fields** can presently be defined **only in vacuum regions**
  - A region can contain **only one type of field** (magnetic *or* electric)



- How to define magnetic or electric fields
  - Basic (**homogeneous**) fields can directly be defined in the **input file**
  - More complex fields require the programming of **user routines**

  (user routines are not discussed here but are part of the advanced course)



- Transport settings
  - **Particle transport** in the presence of fields entails **some approximations** (true trajectory is decomposed in small straight-line steps)
  - Attention has to be paid to chose adequate transport settings according to your application

Remarks concerning the tracking in fields

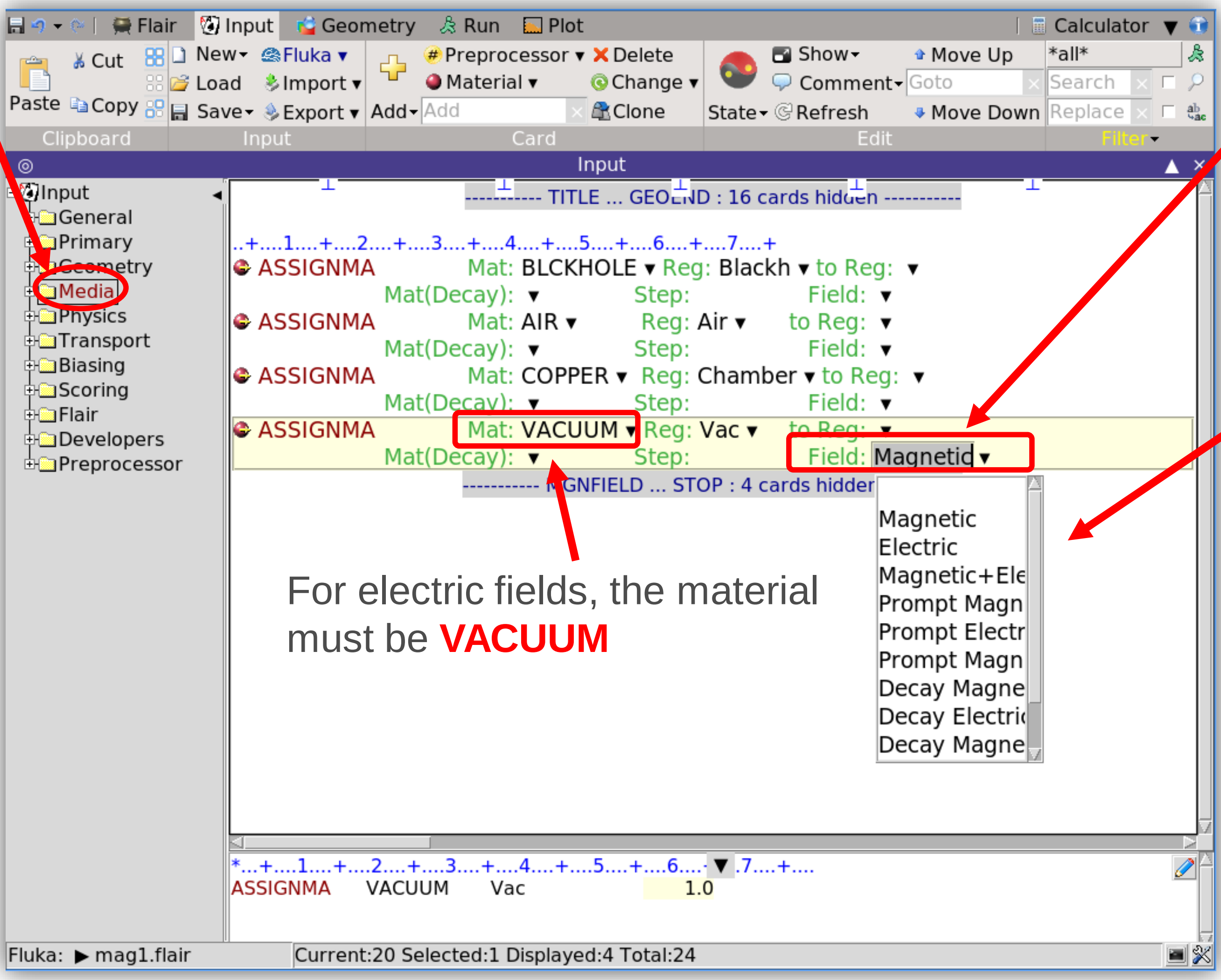
- When tracking in magnetic fields, FLUKA accounts for:
    - The **precession of the MCS final direction** around the particle direction: this is critical in order to preserve the various correlations embedded in the FLUKA MCS algorithm
    - The **decrease of the particle momentum** due to energy losses along a given step and hence the corresponding **decrease of its curvature radius**.
    - The **precession of a (possible) particle polarization** around its direction of motion: this matters only when polarization of charged particles is a issue (mostly for muons in Fluka)
- When tracking in electric fields inside vacuum, FLUKA accounts for:
    - The **change of the projectile energy** due to the electric field itself

The relevant cards

- Fields need to be activated in the respective regions using the **`ASSIGNMA`** card
- The field components can be specified in two different ways:
  a) on the **`MGNFIELD`** or **`ELCFIELD`** cards in case of a homogeneous field (note: in that case the defined magnetic or electric field is applied in *all* regions where magnetic or electric fields have been activated via **`ASSIGNMA`**).
  b) in dedicated user routines (see **`src/user/magfld.f`** and **`src/user/elcfld.f`**) if more complex fields need to be implemented or if different fields need to be applied in different regions.
- The transport settings for particles moving in a field can be defined as follows:
  - Globally for all regions via the **`MGNFIELD`** or **`ELCFIELD`** cards.
  - On a region-by-region basis via the **`STEPSIZE`** card (overwrites global settings for these regions).

Activating a field inside a region

Select the **Media** folder



```
---------- TITLE ... GEOEND : 16 cards hidden ----------
..+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
ASSIGNMA      Mat: BLCKHOLE ▾ Reg: Blackh ▾ to Reg: ▾
         Mat(Decay): ▾        Step:              Field: ▾
ASSIGNMA      Mat: AIR ▾       Reg: Air ▾    to Reg: ▾
         Mat(Decay): ▾        Step:              Field: ▾
ASSIGNMA      Mat: COPPER ▾   Reg: Chamber ▾ to Reg: ▾
         Mat(Decay): ▾        Step:              Field: ▾
ASSIGNMA      Mat: VACUUM ▾   Reg: Vac ▾     to Reg: ▾
         Mat(Decay): ▾        Step:              Field: Magnetic ▾
---------- MGNFIELD ... STOP : 4 cards hidden
```

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+ ▼ .7....+....
ASSIGNMA     VACUUM     Vac              1.0
```

```
Fluka: ▶ mag1.flair    Current:20 Selected:1 Displayed:4 Total:24
```

Fields are activated on the **ASSIGNMA** card (under the option "**Field**")

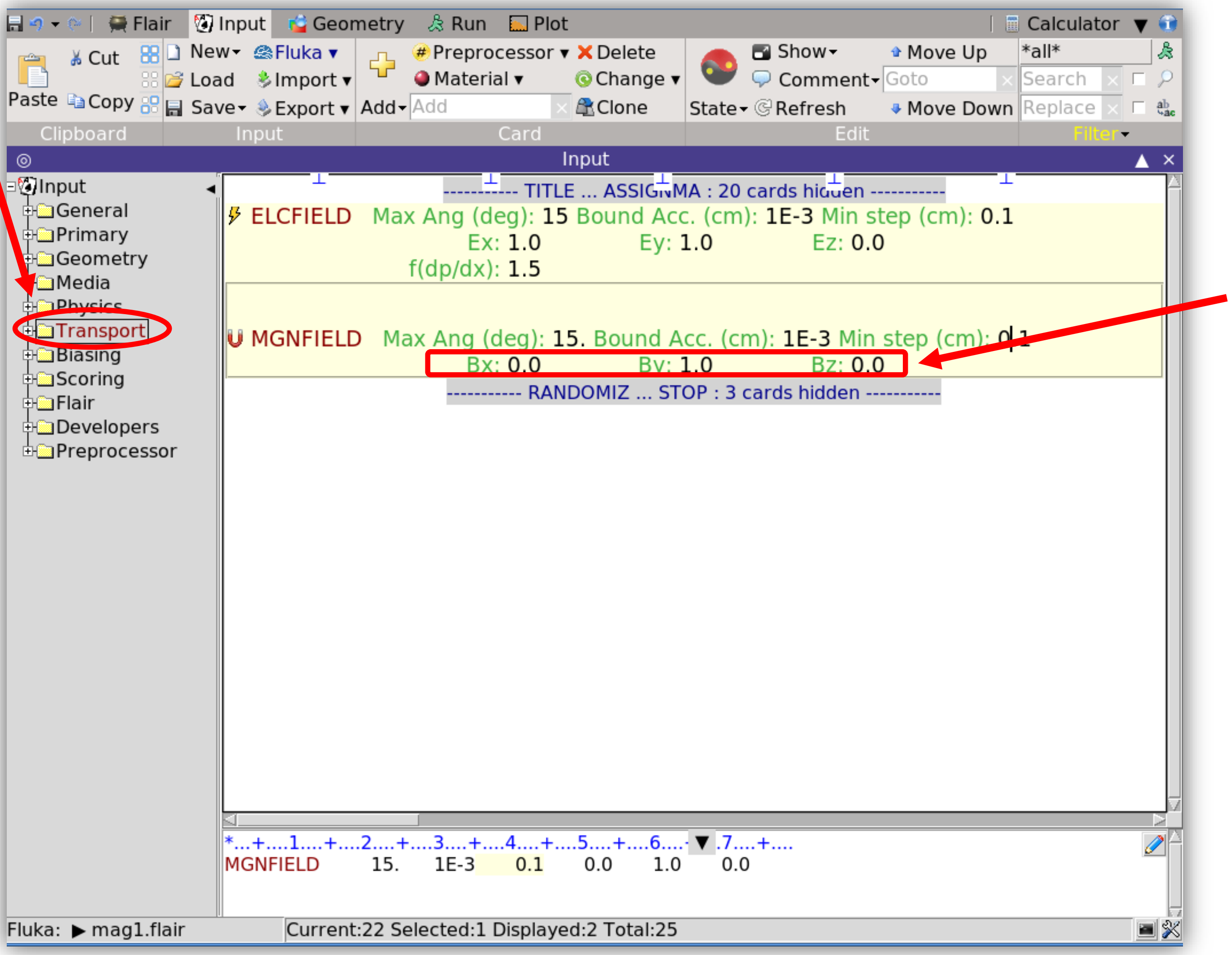
For electric fields, the material must be **VACUUM**

Use the drop-down list to activate an electric **or** magnetic field in all regions listed on **ASSIGNMA**

- *The option to activate both types of fields in the same region is shown in Flair but is presently not implemented in FLUKA*
- The first two options activate a magnetic or electric field both for prompt and decay radiation
- One can however also selectively switch on a field for either of the two (prompt or decay)

Setting the components of a homogeneous B field

Select the **Transport** folder



----------- TITLE ... ASSIGNMA : 20 cards hidden -----------

ELCFIELD Max Ang (deg): 15 Bound Acc. (cm): 1E-3 Min step (cm): 0.1
Ex: 1.0 Ey: 1.0 Ez: 0.0
f(dp/dx): 1.5

MGNFIELD Max Ang (deg): 15. Bound Acc. (cm): 1E-3 Min step (cm): 0.1
Bx: 0.0 By: 1.0 Bz: 0.0

----------- RANDOMIZ ... STOP : 3 cards hidden -----------

```
*...+....1....+....2....+....3....+....4....+....5....+....6....  .7....+....
MGNFIELD        15.      1E-3       0.1       0.0       1.0       0.0
```

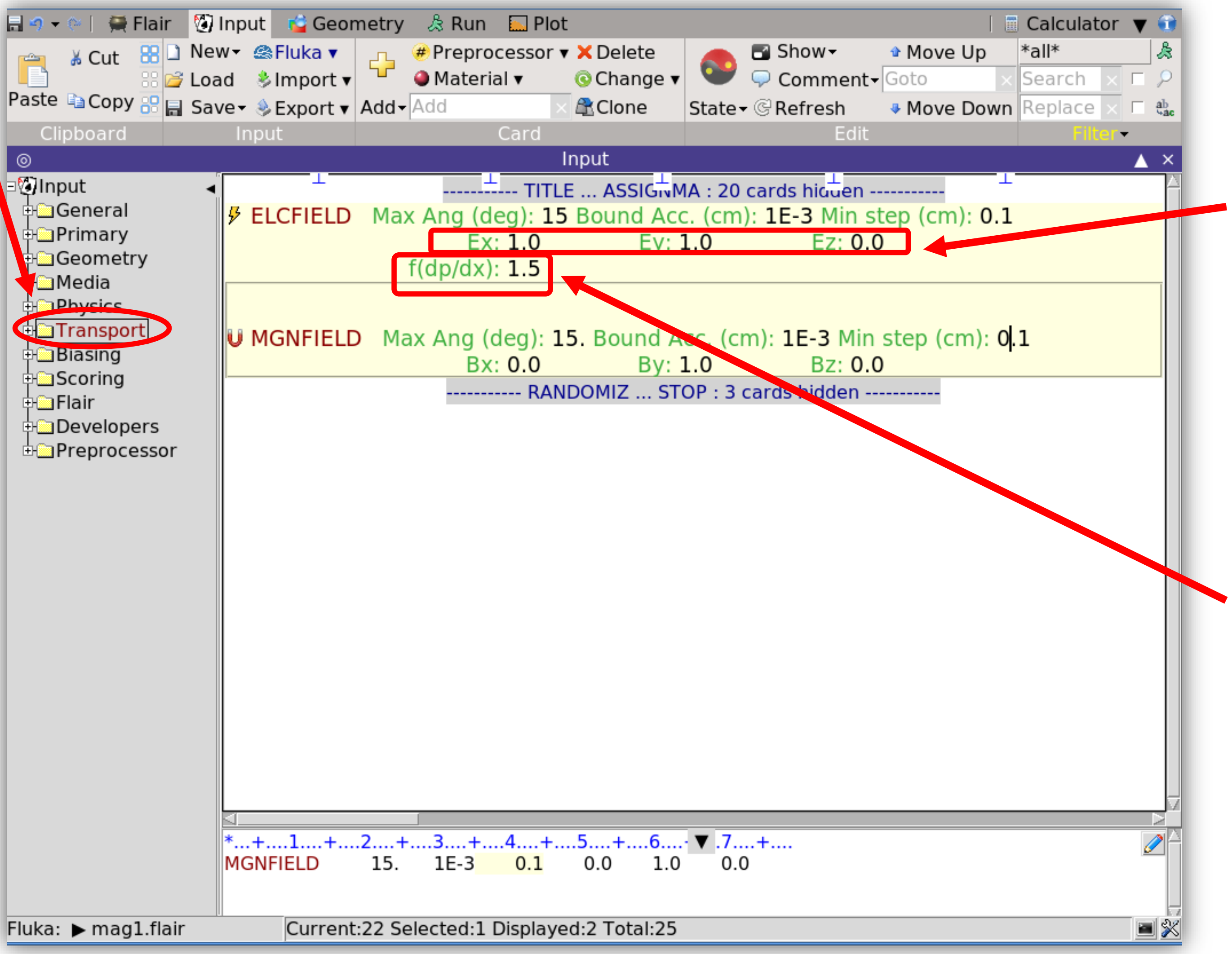
Fluka: ▶ mag1.flair Current:22 Selected:1 Displayed:2 Total:25

The Cartesian components of an uniform *magnetic* field can be set on the **MGNFIELD** card (variables Bx, By, Bz)
Units: **Tesla**

In case no values are specified (or all components are set to zero) a user-defined routine is expected to deliver the values.

Setting the components of a homogeneous E field

Select the **Transport** folder



```
----------- TITLE ... ASSIGNMA : 20 cards hidden -----------
ELCFIELD   Max Ang (deg): 15 Bound Acc. (cm): 1E-3 Min step (cm): 0.1
                 Ex: 1.0            Ey: 1.0            Ez: 0.0
           f(dp/dx): 1.5

MGNFIELD   Max Ang (deg): 15. Bound Acc. (cm): 1E-3 Min step (cm): 0.1
                 Bx: 0.0            By: 1.0            Bz: 0.0
----------- RANDOMIZ ... STOP : 3 cards hidden -----------
```

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....
MGNFIELD        15.      1E-3      0.1       0.0       1.0       0.0
```

Fluka: ▶ mag1.flair Current:22 Selected:1 Displayed:2 Total:25

The Cartesian components of an uniform *electric* field can be set on the **ELCFIELD** card (variables Ex, Ey, Ez)
Units: **kV/cm**

In case no values are specified (or all components are set to zero) a user-defined routine is expected to deliver the values.

In general, cross section tables are created up to the beam energy (BEAM card).

However, charged particles travelling in electric fields can gain energy: this can result in the special case that particles reach higher energies than the beam energy.

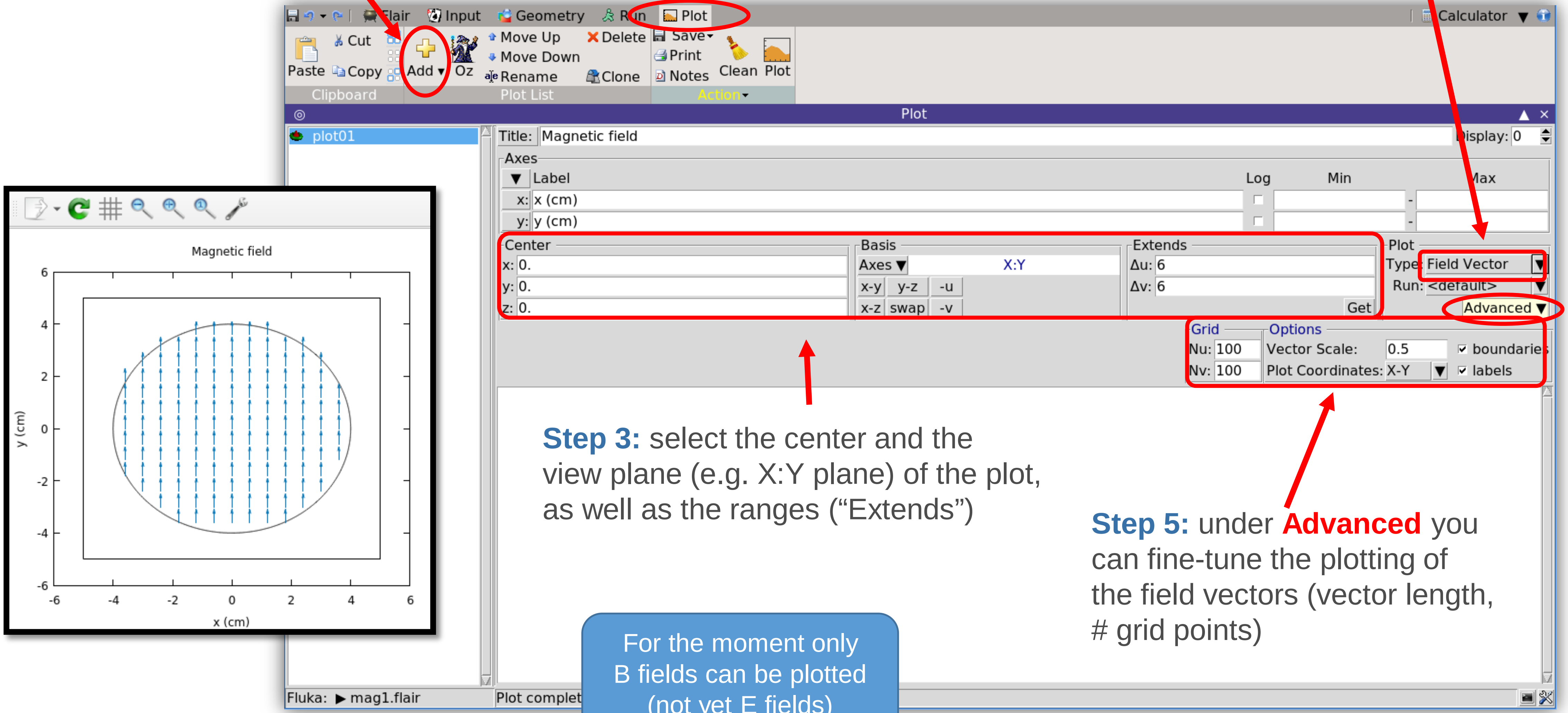
f(dp/dx) is a factor to extend the upper dp/dx tabulation for charged particles.

Plotting the field

Step 2: add a **Geometry** plot

Step 1: select the **Plot** tab

Step 4: select **Field** (or **Field Vector**, or **Field Intensity**)



Plot

Title: Magnetic field

Display: 0

Axes

Label	Log	Min	Max
x: x (cm)	☐		
y: y (cm)	☐		

Center
x: 0.
y: 0.
z: 0.

Basis
Axes: X:Y
x-y y-z -u
x-z swap -v

Extends
Δu: 6
Δv: 6
Get

Plot
Type: Field Vector
Run: <default>
Advanced

Grid
Nu: 100
Nv: 100

Options
Vector Scale: 0.5
Plot Coordinates: X-Y
☑ boundaries
☑ labels

Fluka: ▶ mag1.flair

Plot complet

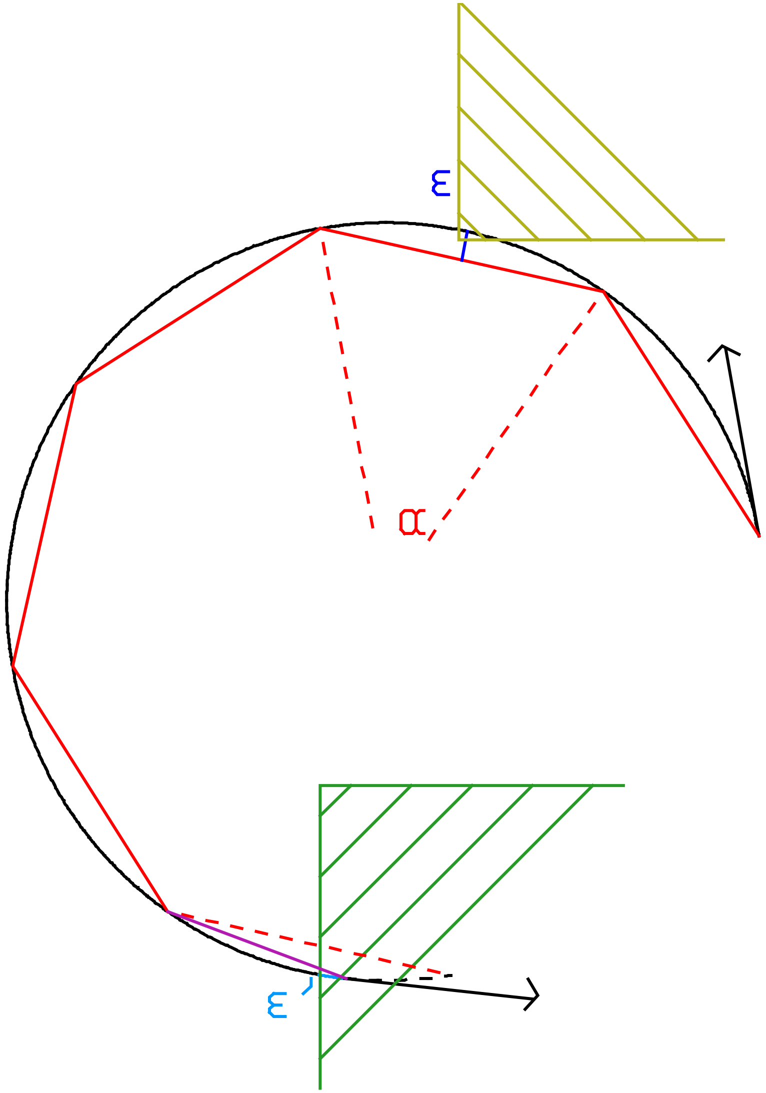
Step 3: select the center and the view plane (e.g. X:Y plane) of the plot, as well as the ranges (“Extends”)

Step 5: under **Advanced** you can fine-tune the plotting of the field vectors (vector length, # grid points)

For the moment only B fields can be plotted (not yet E fields)

Transport settings

- The true trajectory of a charged particle inside a field (black) is approximated by linear steps (red)
    - The end point will always be on the true path, but generally not exactly on the region boundary
    - An iteration is performed until a certain boundary crossing accuracy is achieved
- The tracking accuracy can be tuned by the user:
    - The maximum angle (α - in deg) subtended by a single step from the origin of the curved path.
    - The maximum permissible error (ε in cm) in geometry intersections.
- Note:
    - Both conditions (α and ε) are fulfilled during tracking
    - If α and/or ε are too large then geometry boundaries can be missed
    - If they are too small then the CPU time can increase a lot

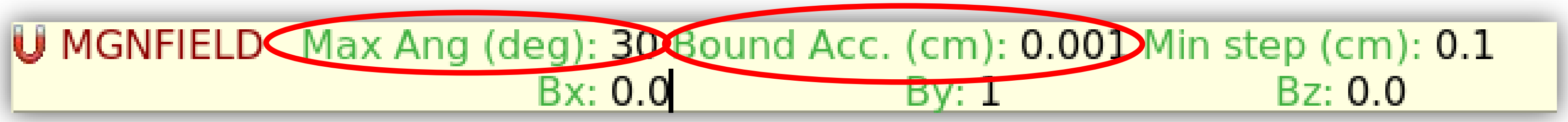


Global transport settings for B (and E) fields

- The transport parameters can be globally set on the **MGNFIELD** (and **ELCFIELD**) cards

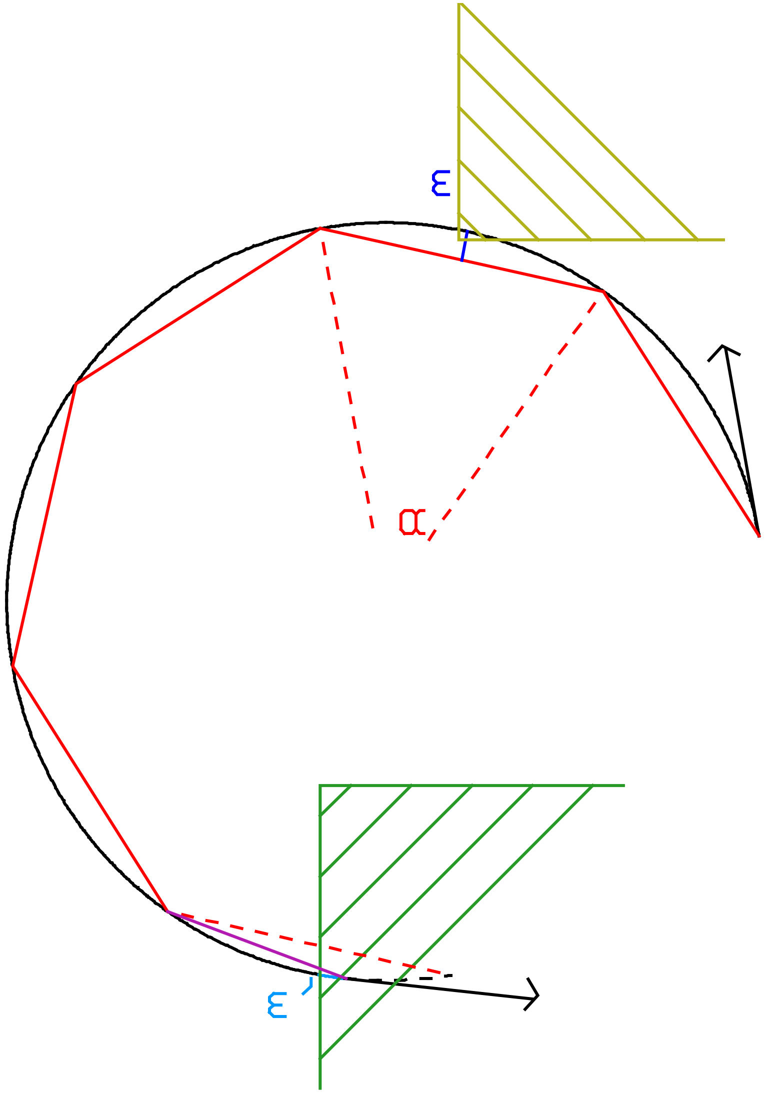
Maximum angle α (in deg)
(default: 57 deg, max.
recommended: 30 deg)

Max. error on boundary
intersection iteration ε (in cm)
(default: 0.5 mm!)



MGNFIELD Max Ang (deg): 30 Bound Acc. (cm): 0.001 Min step (cm): 0.1
Bx: 0.0 By: 1 Bz: 0.0

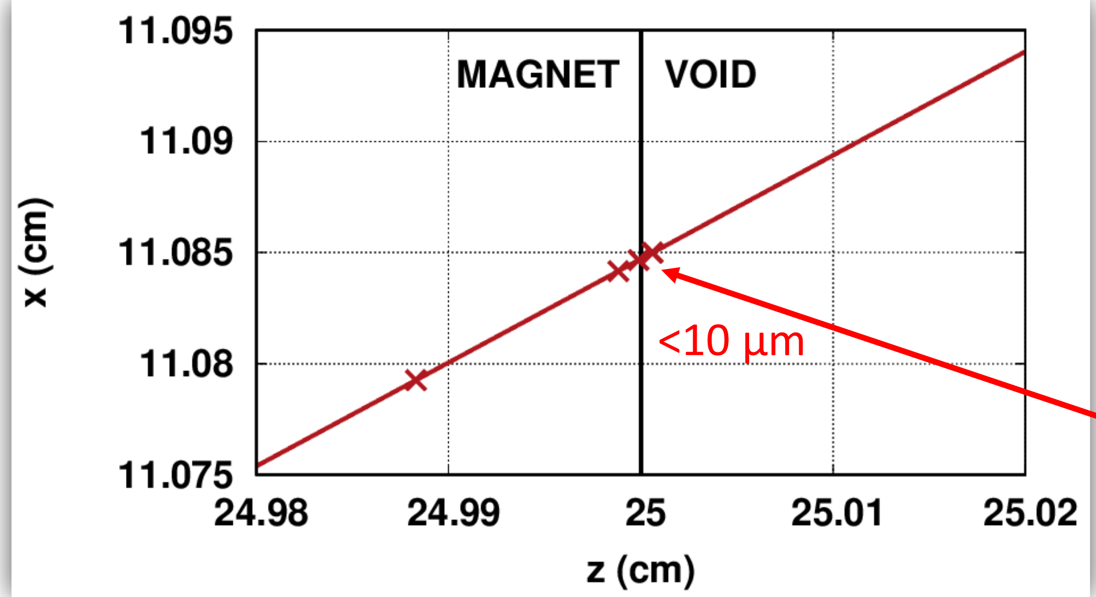
(analogous for ELCFIELD card)



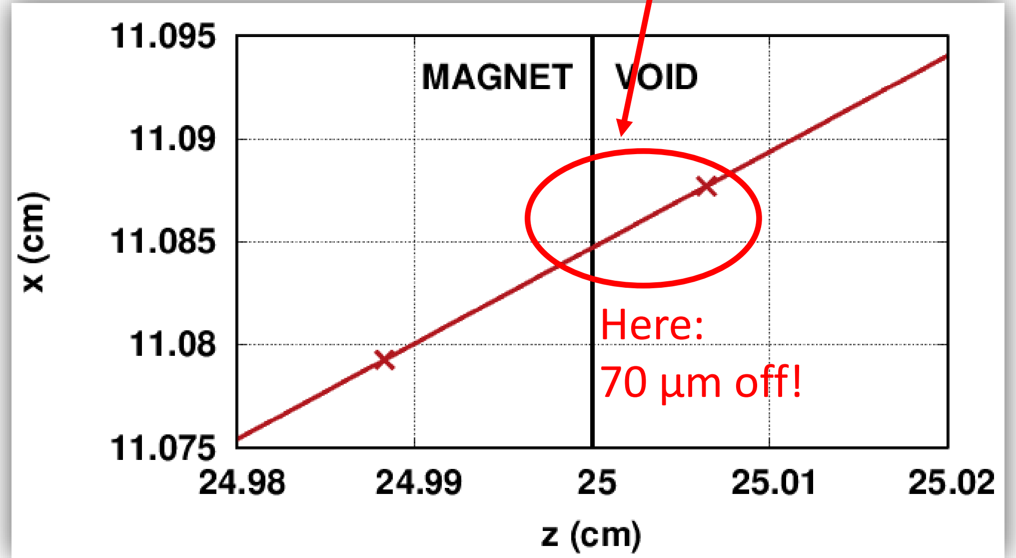
Beware of default settings (here: ε)

Default settings


MGNFIELD Max Ang (deg): Bound Acc. (cm): Min step (cm):



<10 µm



Here:
70 µm off!

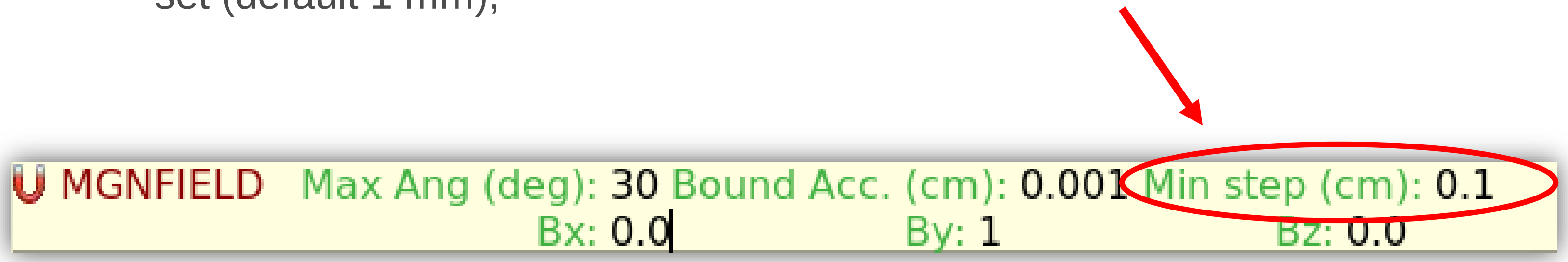

MGNFIELD Max Ang (deg): Bound Acc. (cm): 0.001 Min step (cm):

Rule of thumb: ε shall be *smaller than the region dimensions* (be careful in presence of small structures), but watch out for excessive CPU times

Global transport settings for B (and E) fields (cont.)

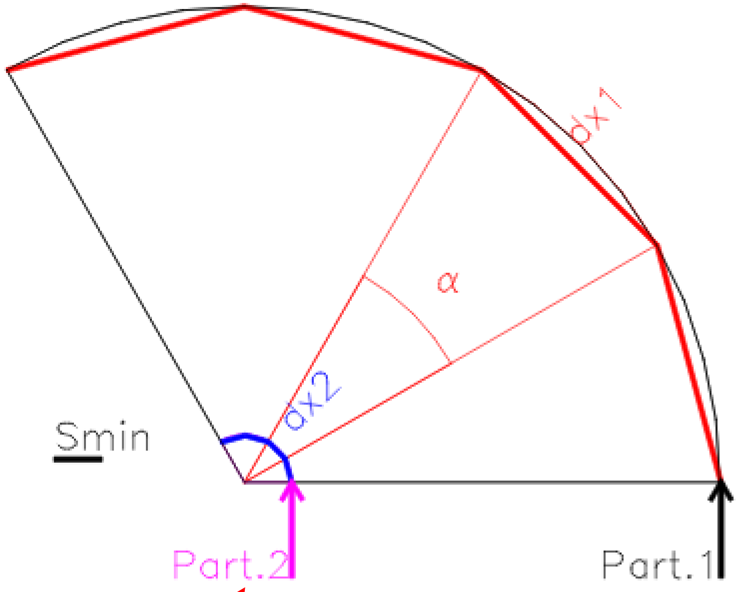
- Avoiding too small steps (endless tracking)

In some cases, the settings can lead to very small steps:
to avoid endless tracking, a minimum sub-step size Δs can be
set (default 1 mm);



MGNFIELD Max Ang (deg): 30 Bound Acc. (cm): 0.001 Min step (cm): 0.1
Bx: 0.0 By: 1 Bz: 0.0

(analogous for ELCFIELD card)



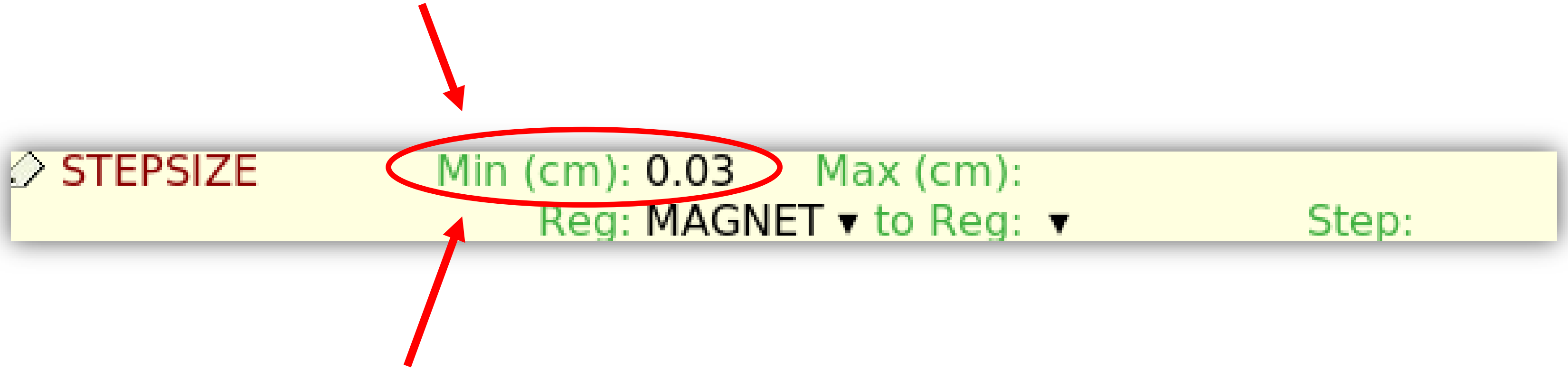
α leads to too small steps (< Δs):
Sub-step size increased too Δs

α leads to steps > Δs:
Sub-step size not changed

Region-by-region transport settings for B/E fields

- The global transport parameters can be overwritten for (selected) regions using the **STEPSIZE** card
- Region-by-region tuning can save CPU time

If <u>negative</u> value given: abs. value defines the max. error on boundary intersection iteration ε (in cm) for the given

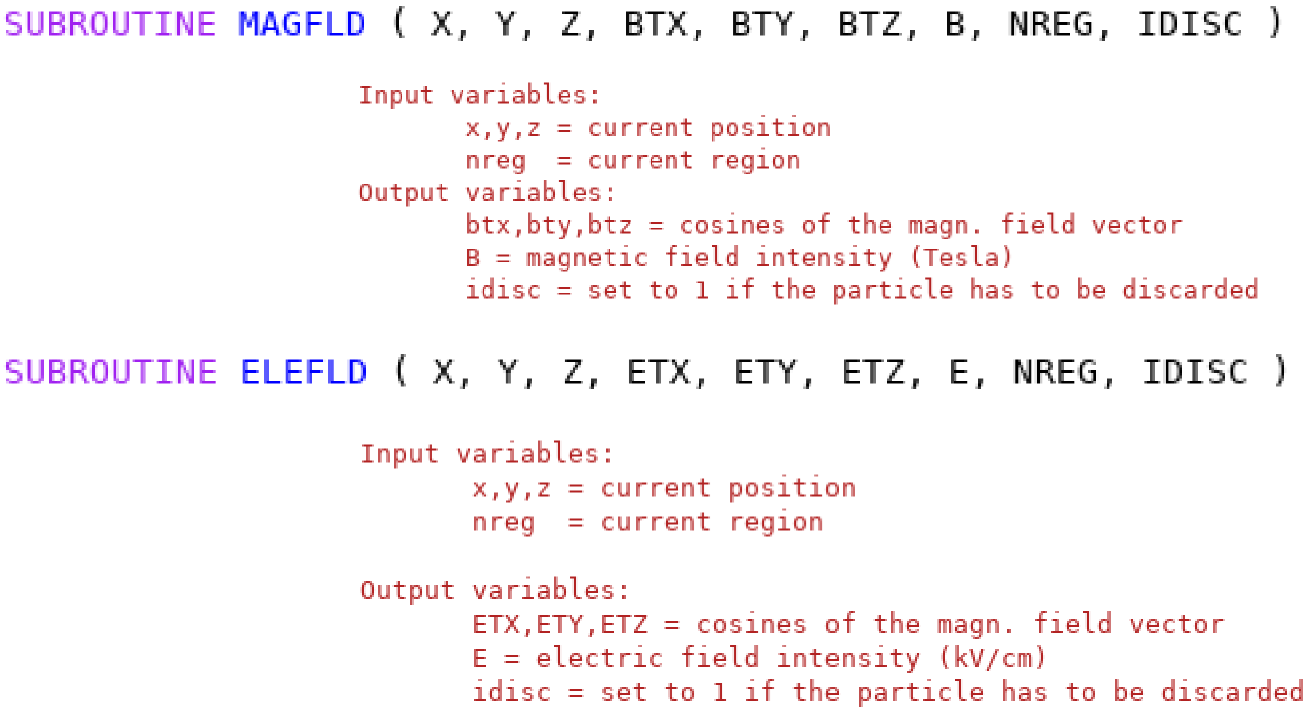


```
STEPSIZE        Min (cm): 0.03    Max (cm):
                     Reg: MAGNET ▾ to Reg: ▾            Step:
```

If <u>positive</u> value given: minimum sub-step size Δs

Outlook (advanced features)

- Simulation problems often involve non-homogeneous fields
- Such fields can be described in the **`MAGFLD`**/**`ELEFLD`** routines
  - In these routines, the field components and field strength can be defined as a function of the coordinates



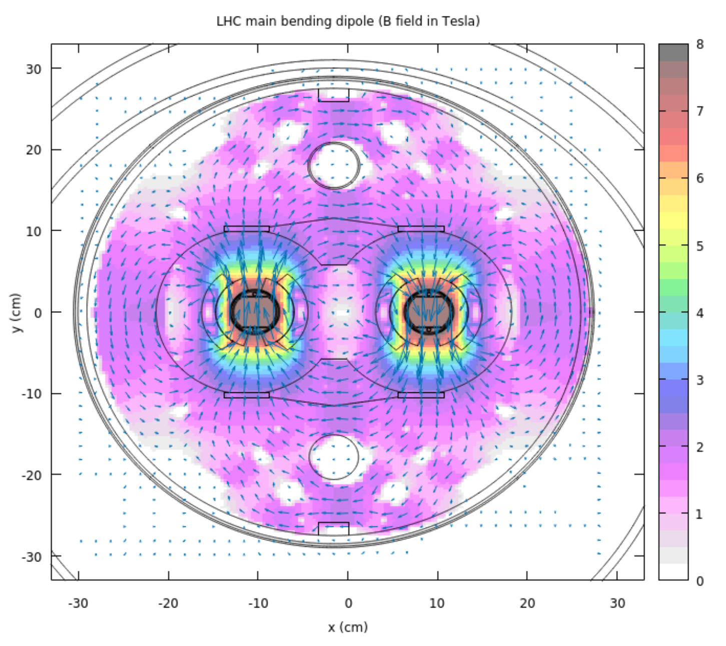
```
SUBROUTINE MAGFLD ( X, Y, Z, BTX, BTY, BTZ, B, NREG, IDISC )

                    Input variables:
                           x,y,z = current position
                           nreg  = current region
                    Output variables:
                           btx,bty,btz = cosines of the magn. field vector
                           B = magnetic field intensity (Tesla)
                           idisc = set to 1 if the particle has to be discarded

SUBROUTINE ELEFLD ( X, Y, Z, ETX, ETY, ETZ, E, NREG, IDISC )

                    Input variables:
                           x,y,z = current position
                           nreg  = current region

                    Output variables:
                           ETX,ETY,ETZ = cosines of the magn. field vector
                           E = electric field intensity (kV/cm)
                           idisc = set to 1 if the particle has to be discarded
```



FLUKA