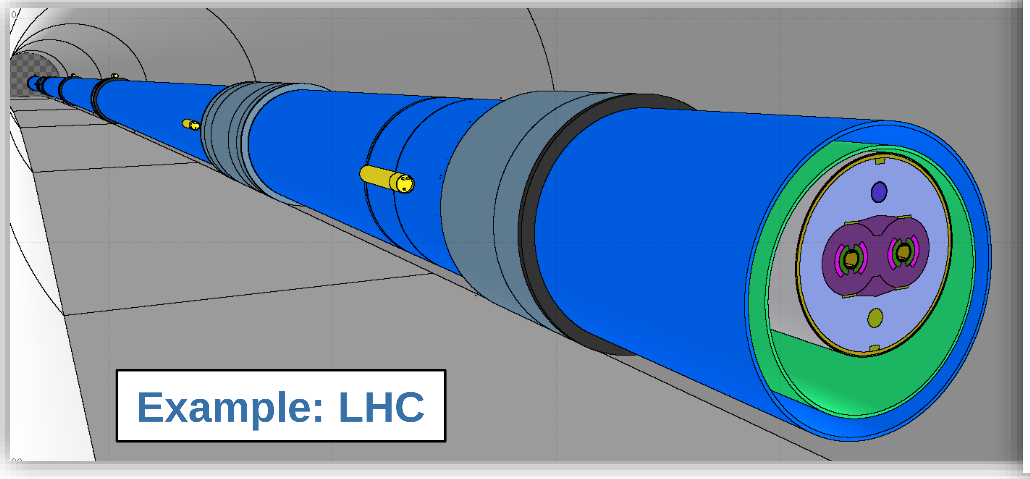
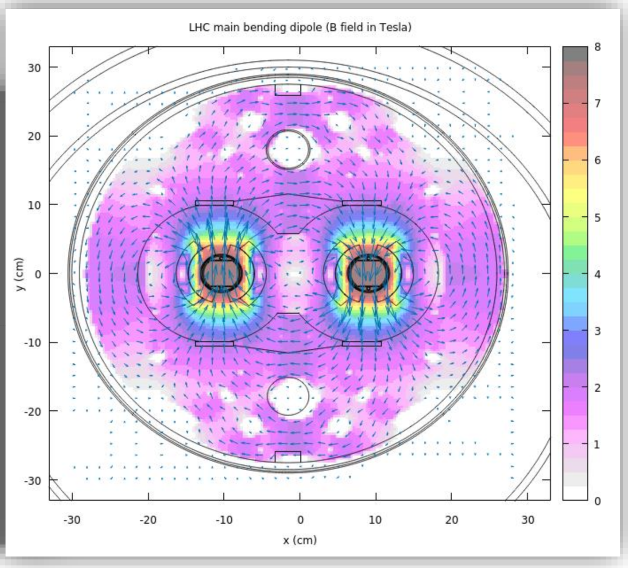
Magnetic and electric fields

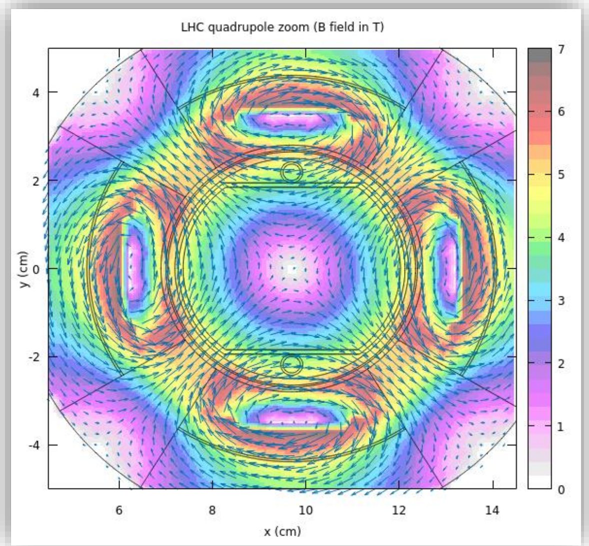
How to define basic fields and adjust transport settings

Introduction

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



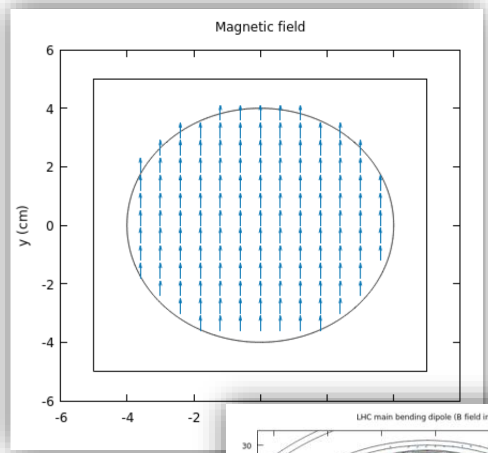


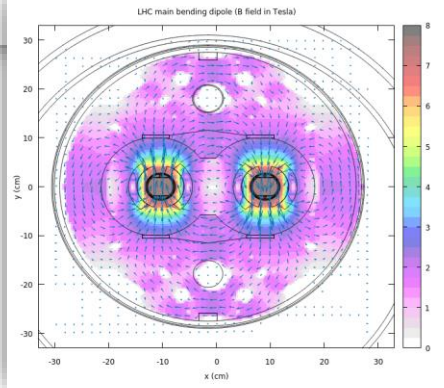


- FLUKA supports the transport of charged particles in *arbitrary* static B and E fields (the latter since FLUKA 4-0.0)
  - This lecture gives a basic introduction how to define fields and presents the relevant transport parameters

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
  - Common (e.g. dipole up to decapole) fields can directly be defined in the **input file** using the **ELCFIELD**, **MGNFIELD** and **MGNCREATe** cards defining the type of field as well as field strength, region association, symmetry, …
- 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 choose adequate transport settings according to your application

The relevant cards

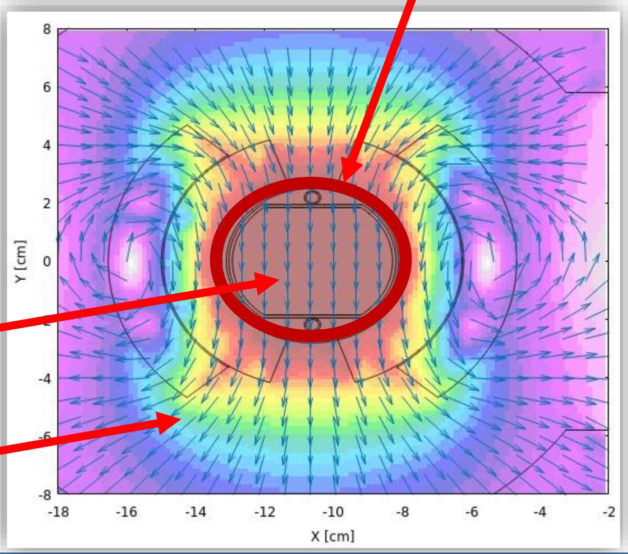
- Fields need to be activated in the respective regions using the **ASSIGNMA** card
- The field components can be specified different ways:
  a) For homogeneous fields: using the **MGNFIELD** or **ELCFIELD** cards*
  b) For common magnetic analytical fields and field maps: using **MGNFIELD** in combination with **MGNCREATe** (+ **MGNDATA** for interpolated fields)
  c) For arbitrary fields: using dedicated user routines (see **`src/user/magfld.f`** and **`src/user/elcfld.f`**) if more complex fields need to be implemented
- 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).

* in that case the defined magnetic or electric field is applied in _all_ regions where magnetic or electric fields have been activated via **ASSIGNMA**)

The relevant cards: common fields

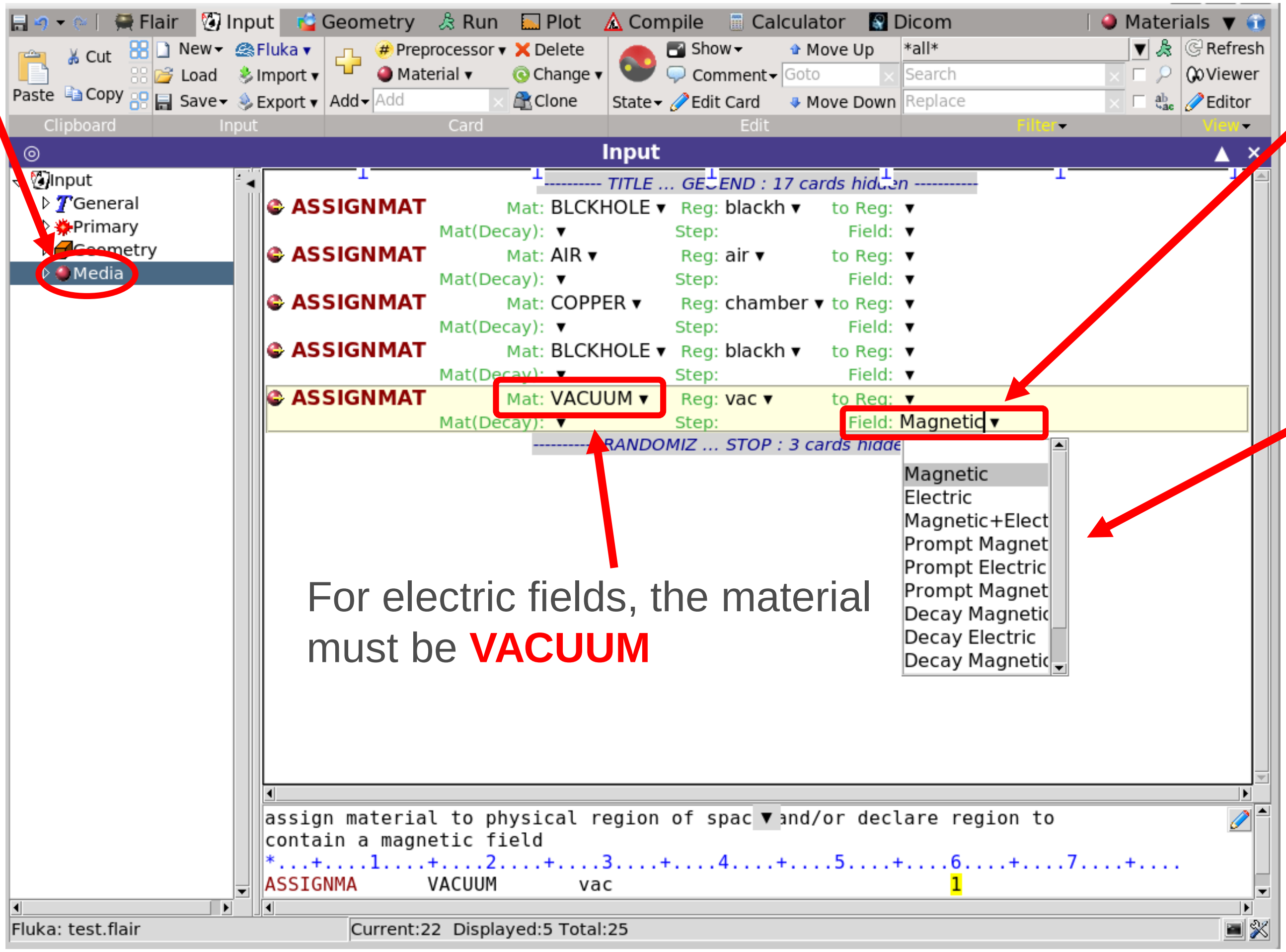
- For common fields, the **MGNFIELD** card is used
  - to set the field **strength**
  - to apply a **transformation** or associate the field to a **region** (or several) or to a **lattice**
- In combination with the **MGNFIELD** card, the **MGNCREATe** card defines
  - the field **type**, which can be
    - **analytical**: constant, dipole, quadrupole, ...
    - **interpolated**: in 2D or 3D field

    } or a **combination** of both
  - the **radius** of the core region where an analytical field is defined
  - grid parameters for the interpolated field (in combination with **MGNDATA**)
  - (mirror symmetries if applicable)



Activating a field inside a region

Select the **Media** section



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

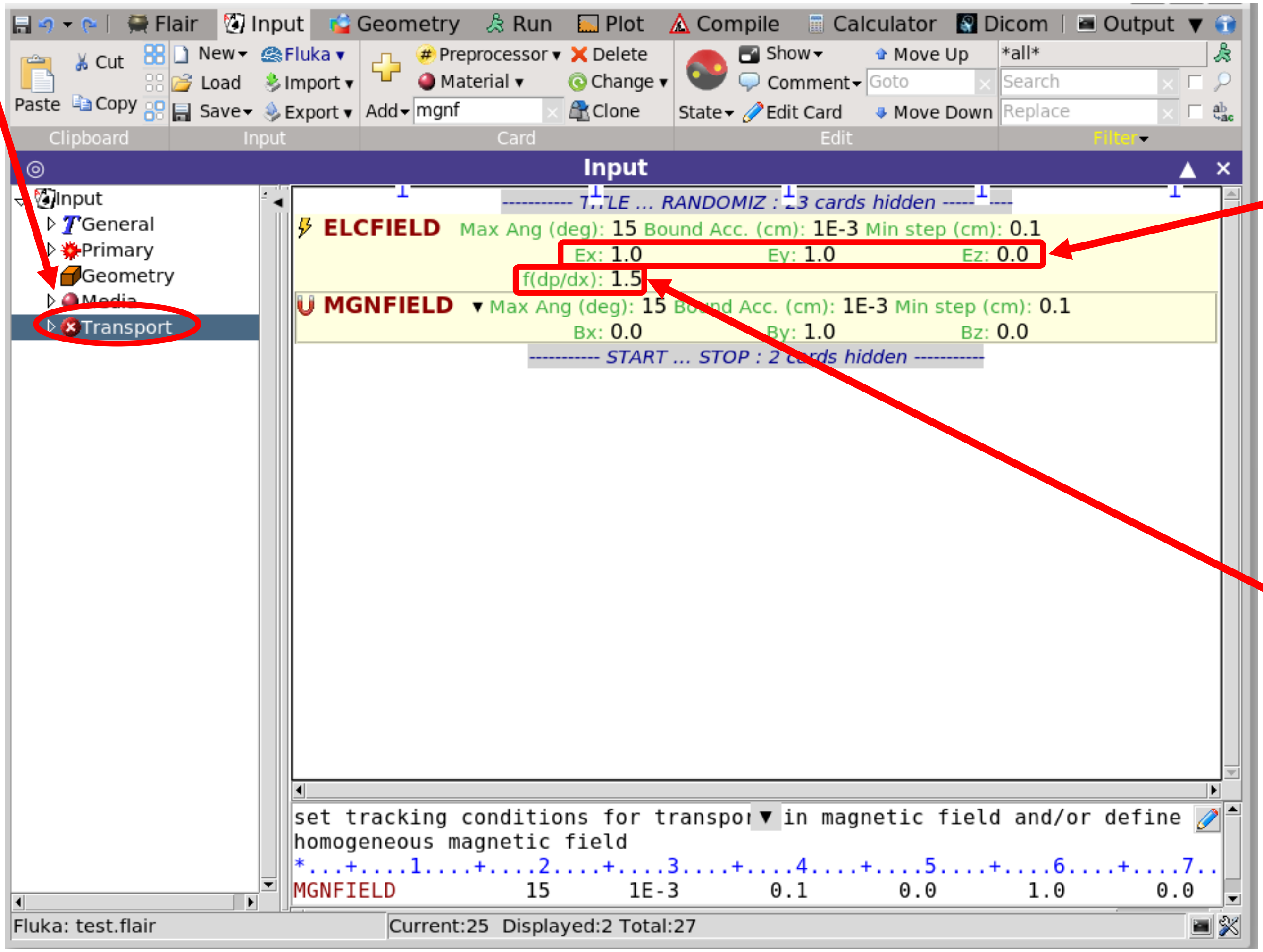
Fields are activated on the **ASSIGNMA** card (under the option "**Field**")

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 E field

Select the **Transport** section



The Cartesian components of a 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.

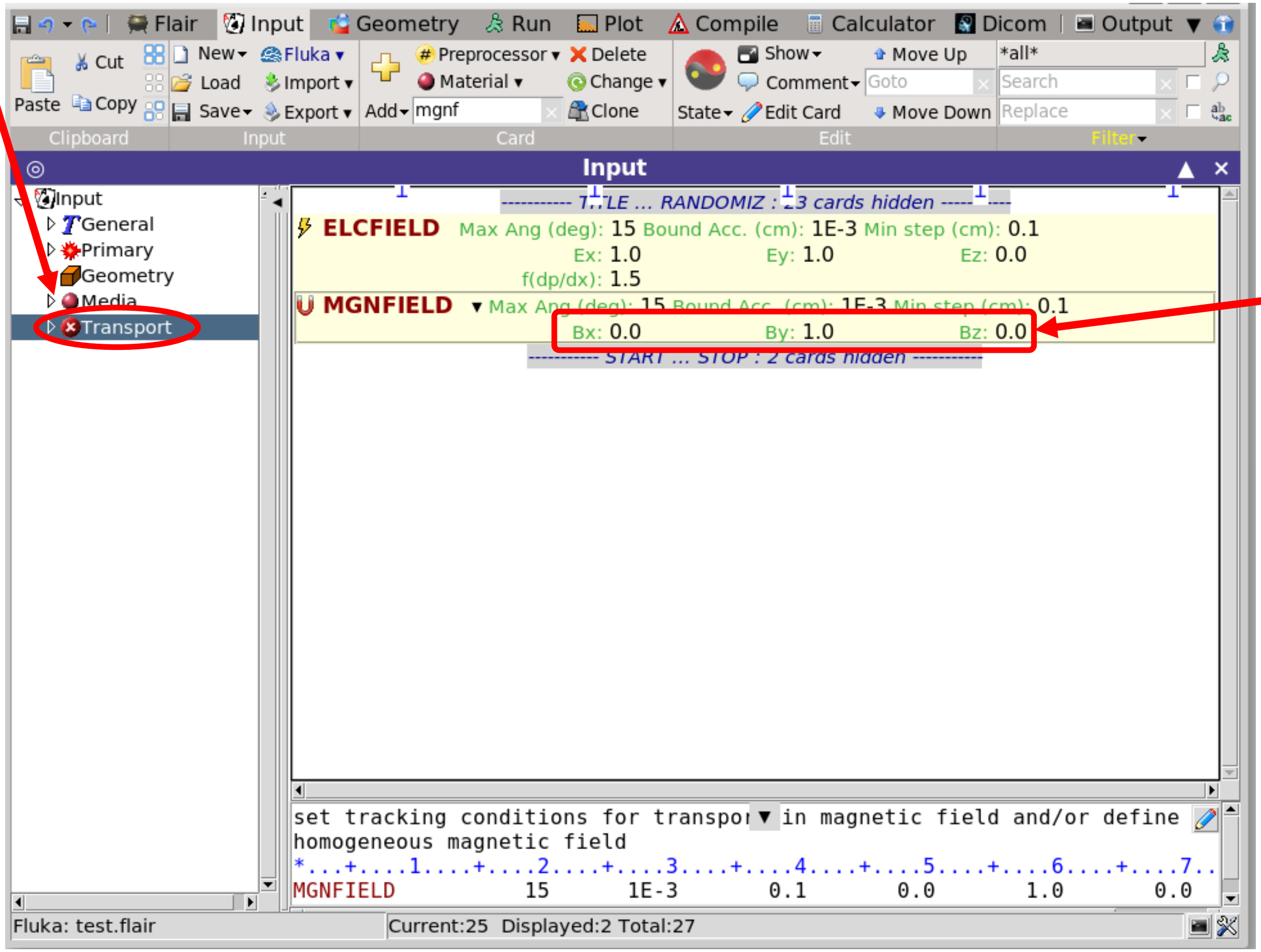
In general, cross section tables are created up to the beam energy (BEAM card).

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.

Setting the components of a homogeneous B field

Select the **Transport** section



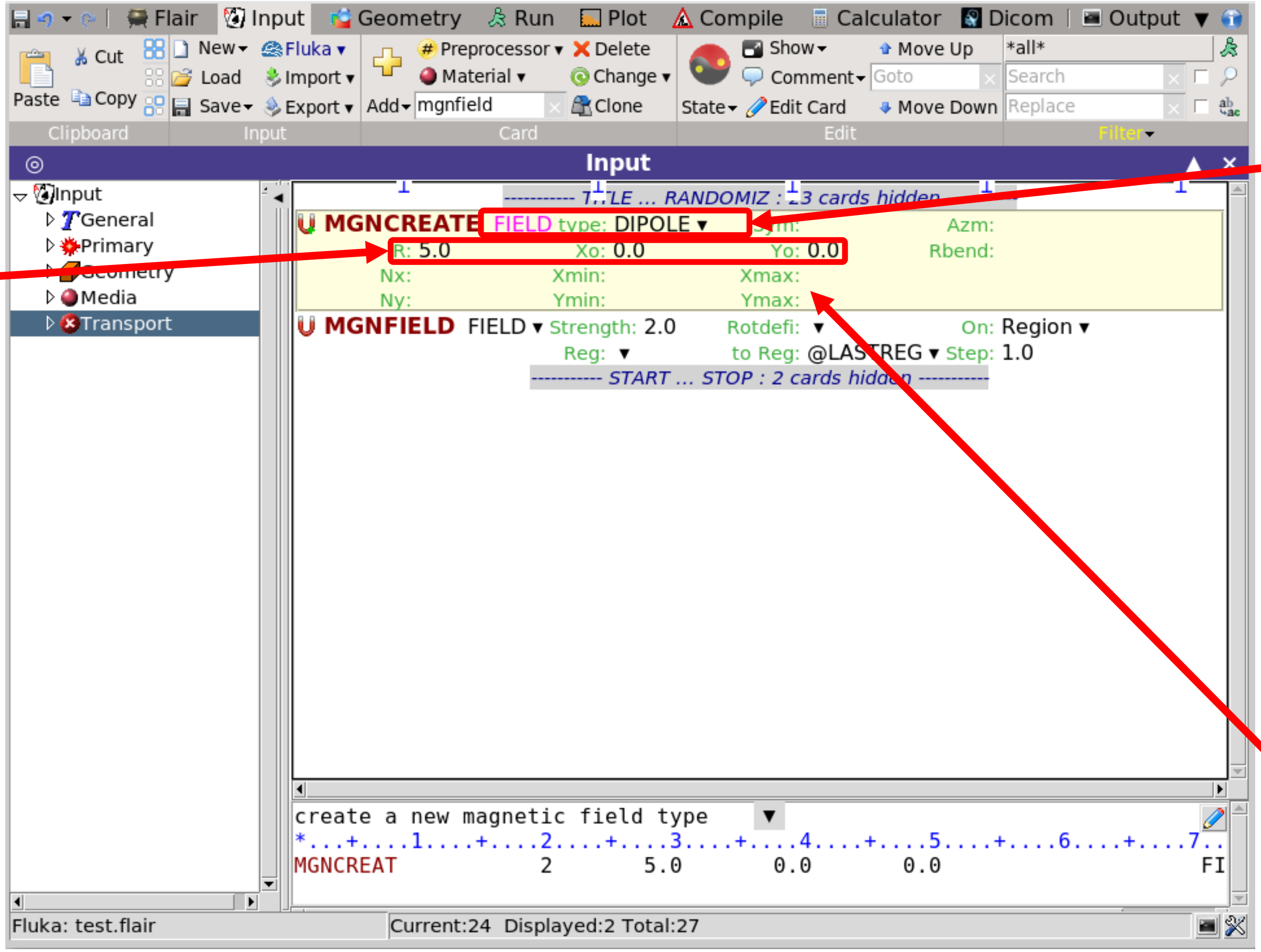
SDUM = BLANK

The Cartesian components of a 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 common B field

Core radius of analytical field and center offset in X and Y



MGNCREATe: creation of a **dipole** field called "Field". Other options are:

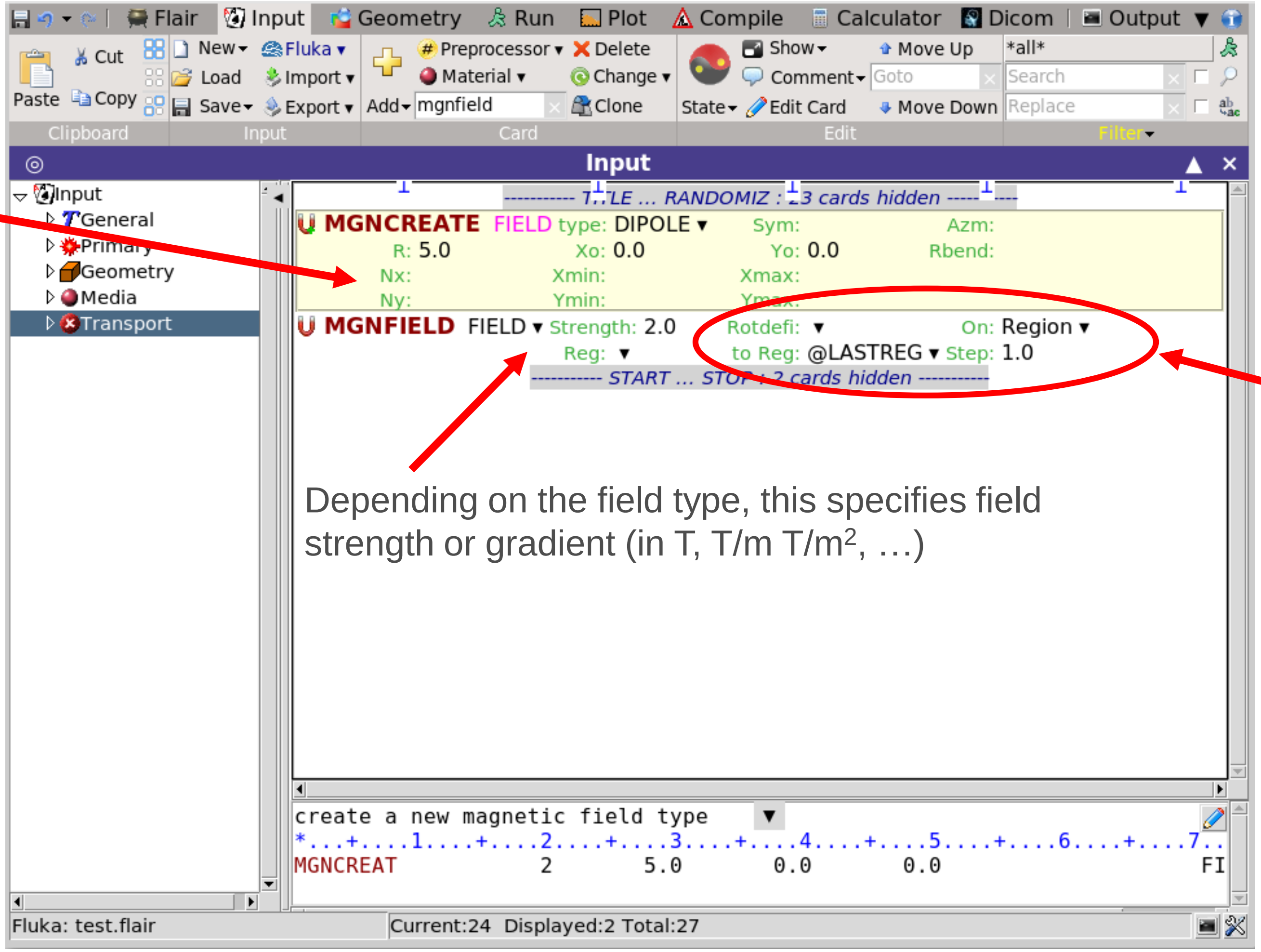
- Constant
- Multipole (quadrupole up to decapole)
- RZ (cylindrical)
- 2D interpolated field
- 2D + analytical field
- 3D interpolated field
- 3D + analytical field

Grid parameters for interpolated field (using **MGNDATA** cards) in case it is used

(Not shown: symmetry options)

Setting the components of a common B field

SDUM entry links to right **MGNCREATe** card



Depending on the field type, this specifies field strength or gradient (in T, T/m T/m^2, …)

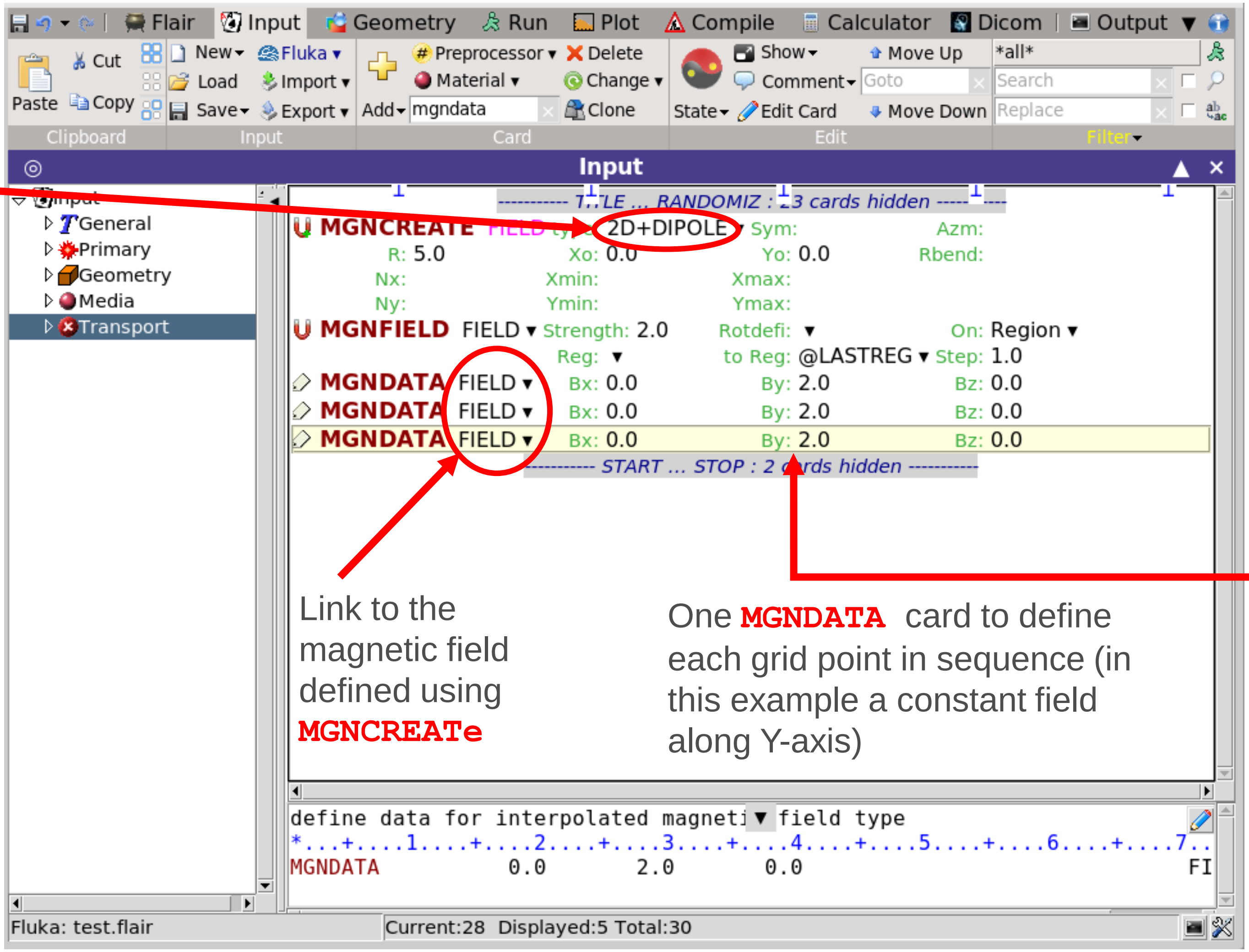
SDUM = field name defined by MGNCREATe card

MGNFIELD card associates a specific magnetic field on a **region-by-region** basis OR with a **lattice** cell through a **ROTDEFi** which maps either prototype or container coordinates on magnetic field system coordinates.

Regions are automatically flagged as magnetic (no need for **ASSIGNMAt** card)

Setting the components of a common B field

To use interpolated maps the type can be set to include "2D" or "3D"

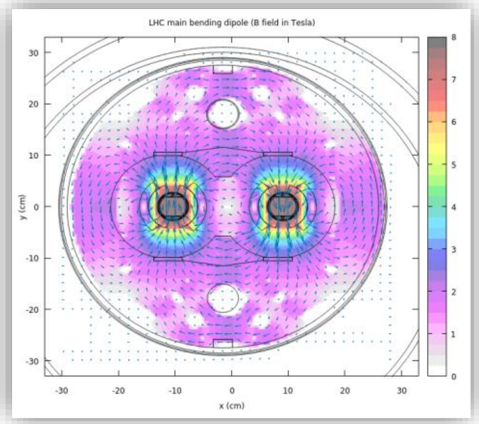


Link to the magnetic field defined using **MGNCREATe**

One **MGNDATA** card to define each grid point in sequence (in this example a constant field along Y-axis)

MGNDATA cards allow the user to input the values of the field in the interpolation grid described via the **MGNCREATe** card. One such card should be provided per grid point in the order as shown below, to describe more complex fields*:

```
y
^
|
9-----10------11------12
|       |       |       |
5------6-------7-------8
|       |       |       |
1------2-------3-------4---> x
```



* For RZ interpolation, same as above replacing X↔R and Y↔Z, for 3D interpolation, same as for 2D plane by plane for each Z slice.

Plotting the field

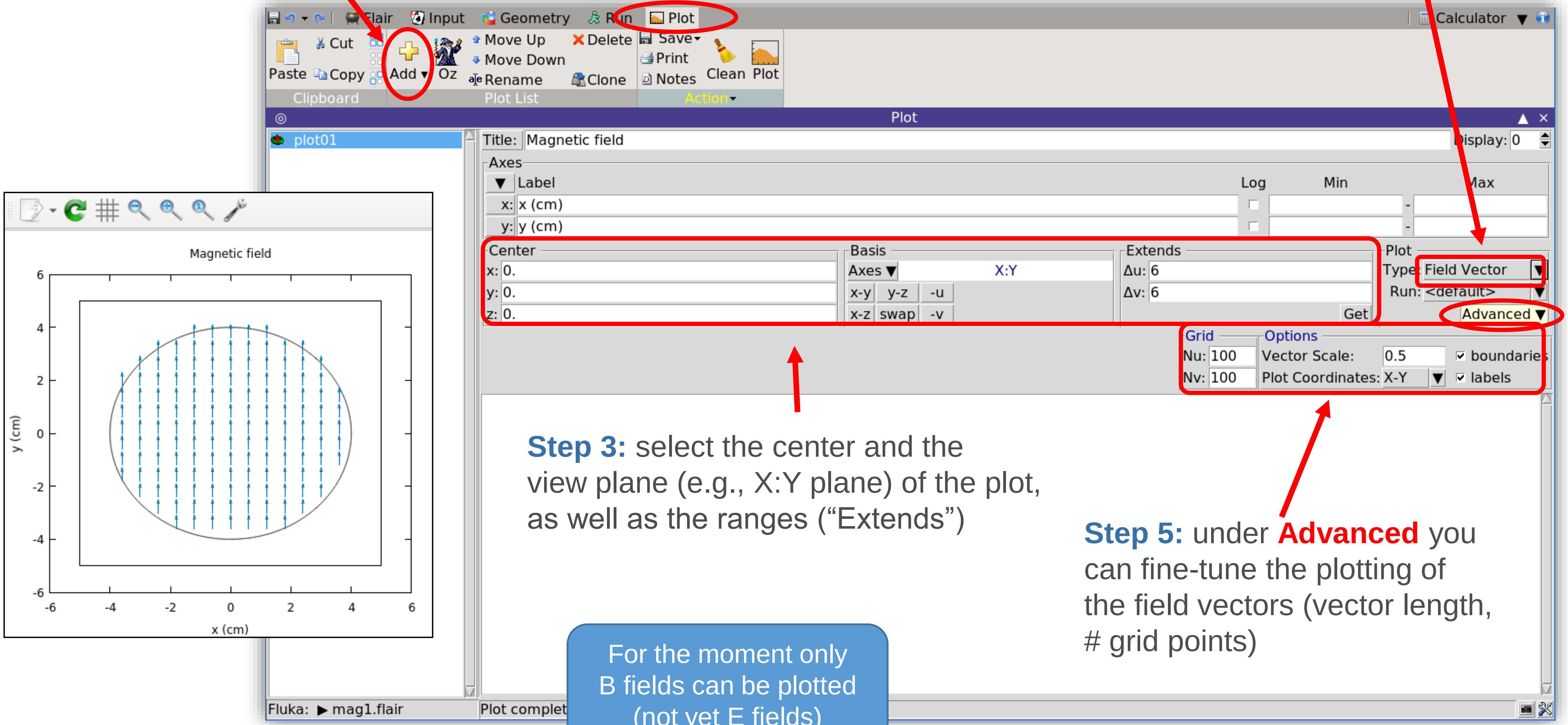
Step 1: select the **Plot** tab

Step 2: add a **Geometry** plot

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

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

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)

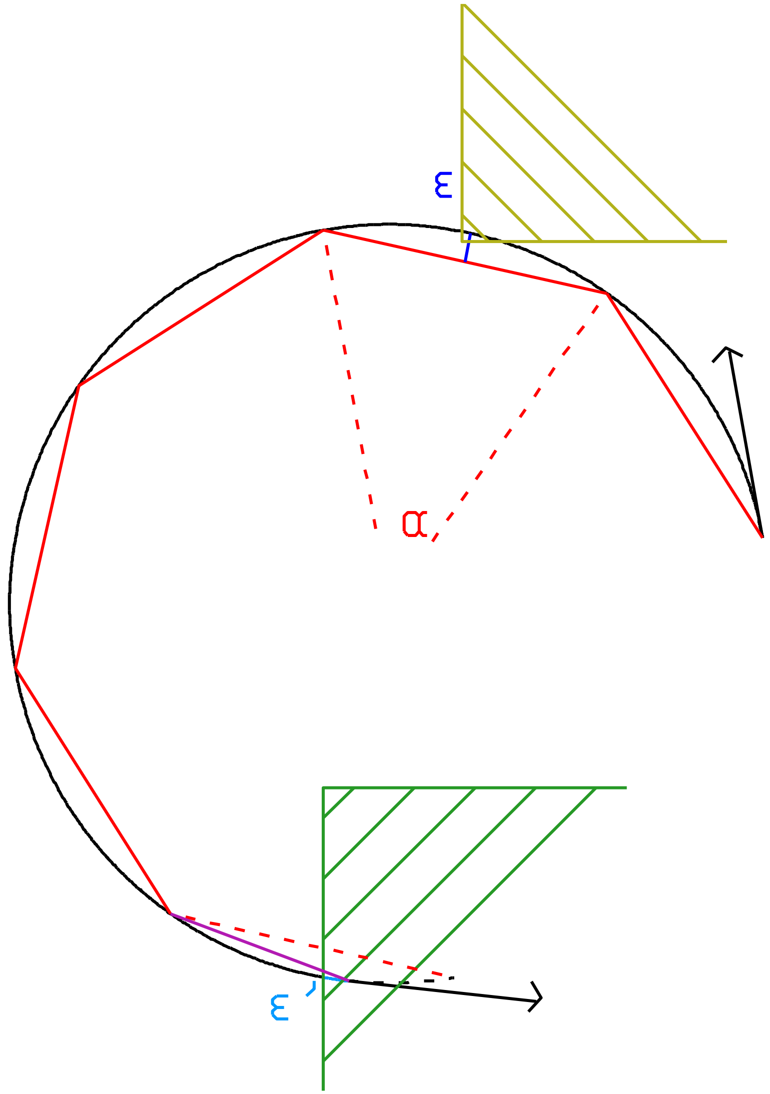
Remarks concerning the tracking in fields

- 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 an 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

*Multiple Coulomb Scattering

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

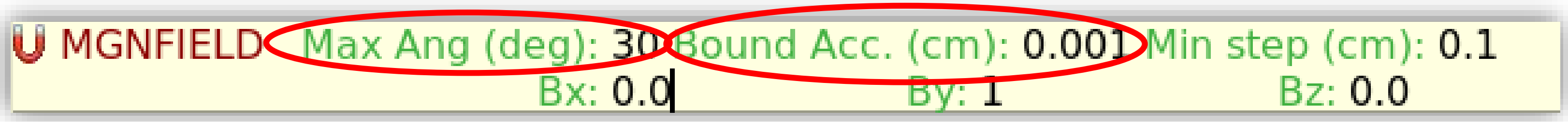


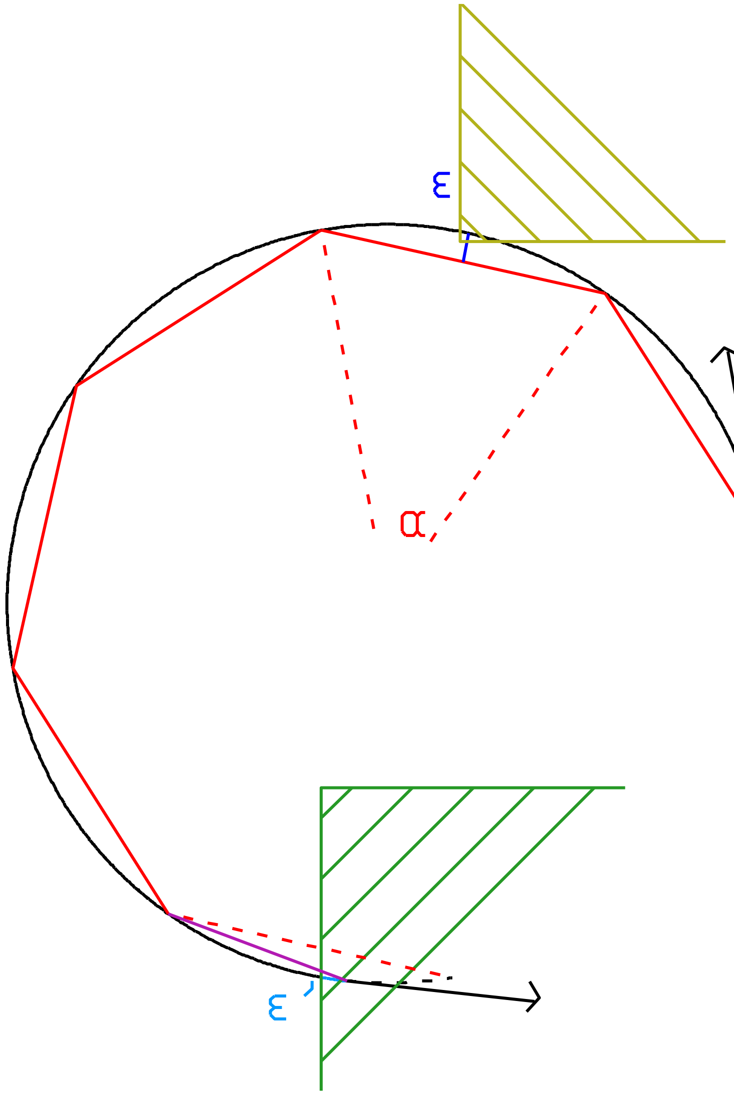
Global transport settings for B (and E) fields

- 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!)



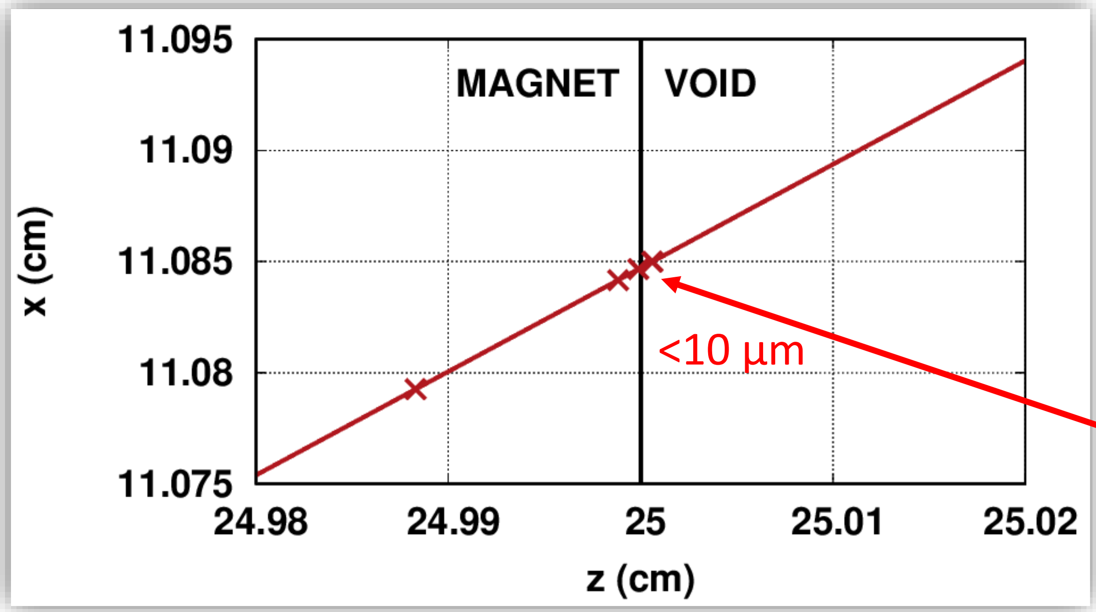


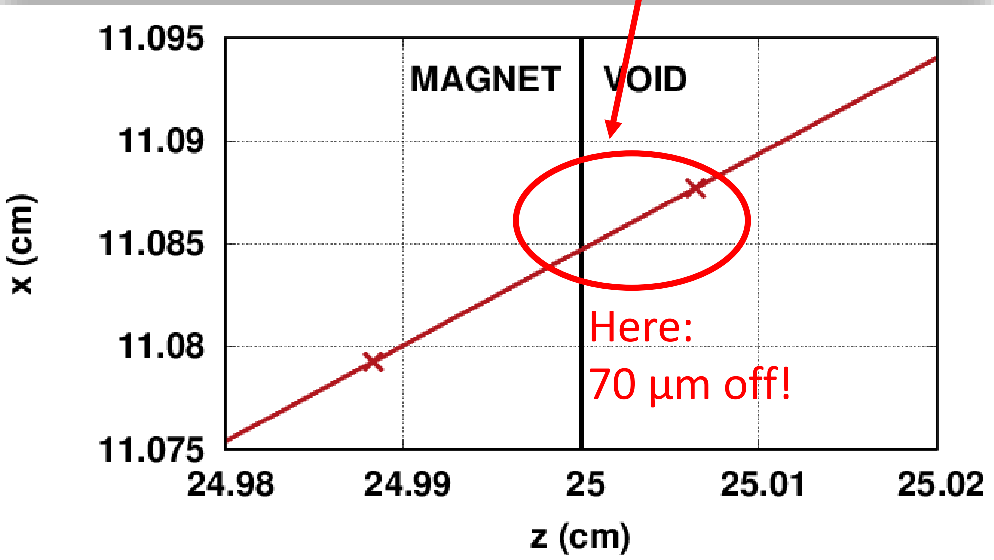
(analogous for **ELCFIELD** card)

Beware of default settings (here: ε)

Default settings

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





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

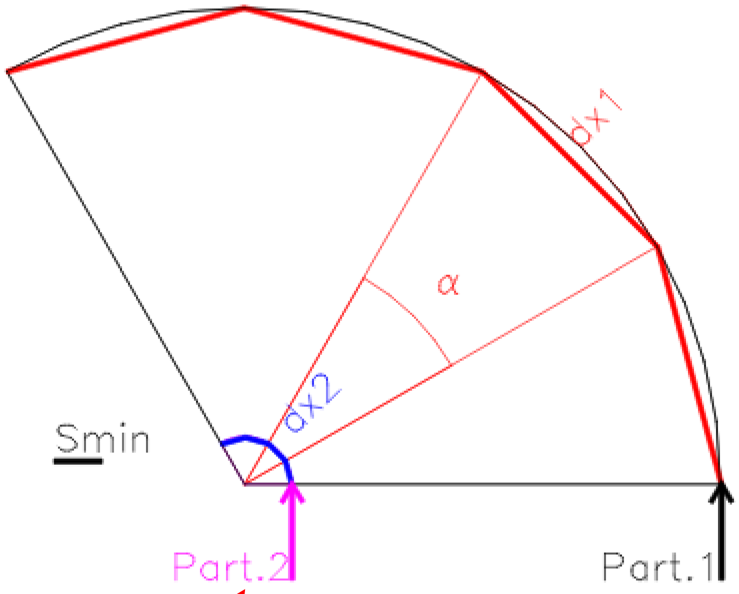
Rule of thumb: ε shall be *smaller than the region dimensions* (be careful in presence of small structures), but watch out for excessive CPU times

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);

(analogous for **ELCFIELD** card)



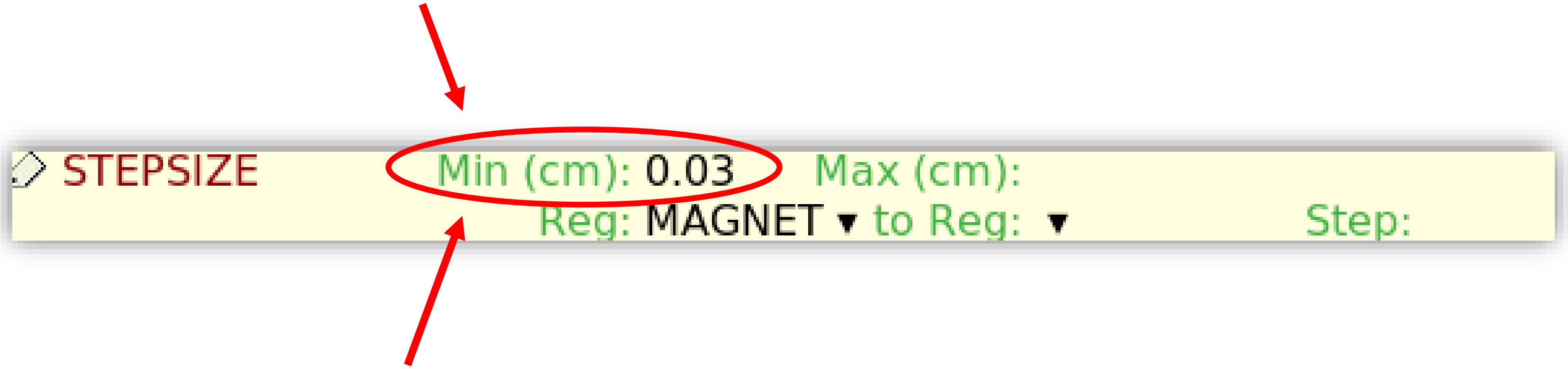
α leads to too small steps (< Δs):
Sub-step size increased to Δs

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

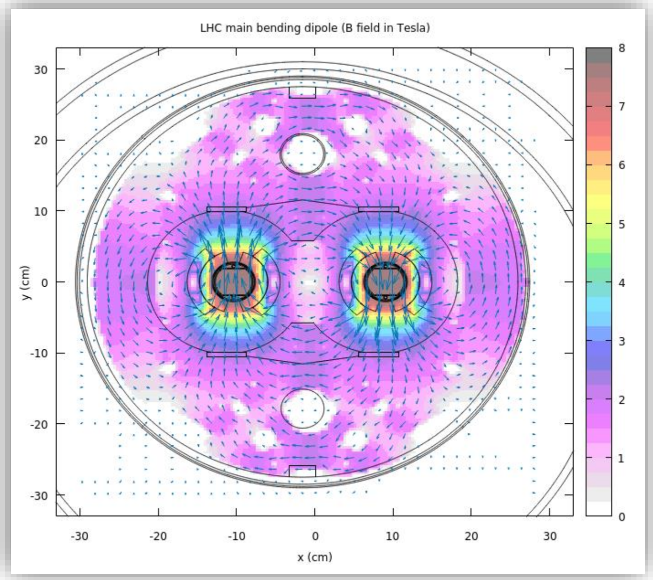
If negative value given: abs. value defines the max. error on boundary intersection iteration ε (in cm) for the given



If positive value given: minimum sub-step size Δs

Outlook (advanced features)

- In the case where the FLUKA magnetic/electric are insufficient, dedicated routines can be used to simulate more complex problems
- Such fields can be described in the **`MAGFLD`**/**`ELEFLD`** routines (**`src/user/magfld.f`** and **`src/user/elcfld.f`**)
  - In these routines, the field components and field strength can be defined as a function of the coordinates. Only called in regions declared as magnetic/electric via the relevant **`ASSIGNMA`** card



FLUKA