Magnetic and electric fields

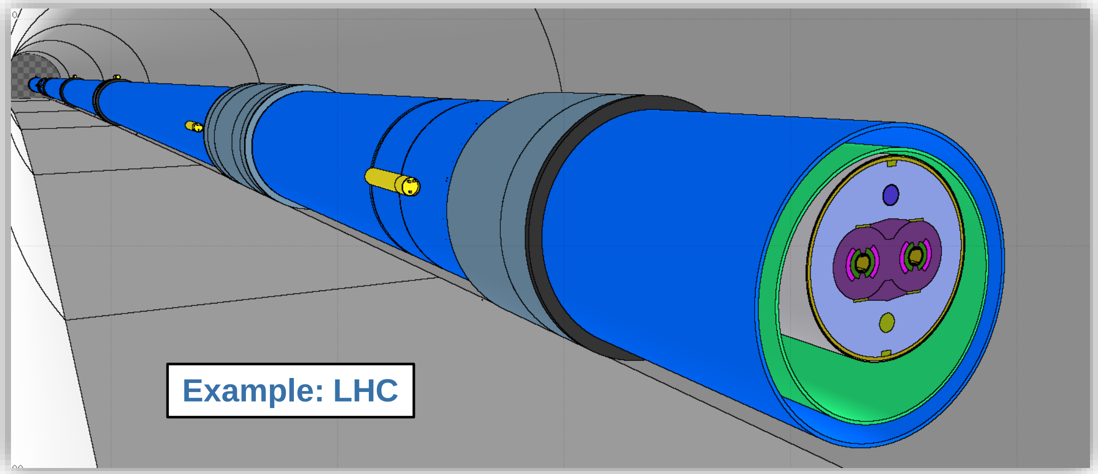
How to define basic fields and adjust transport settings

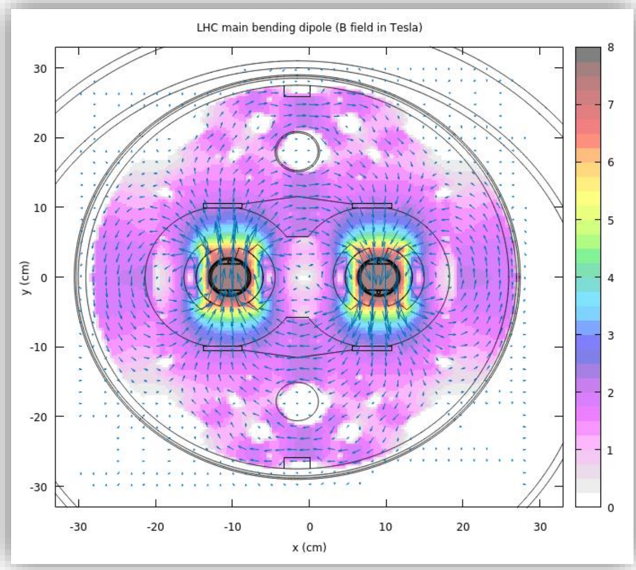
Outline

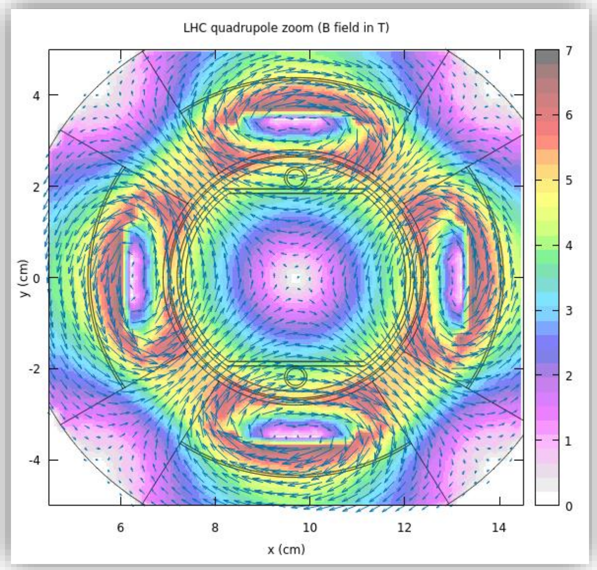
- Introduction
- Electric and magnetic fields
  - Required cards (+ examples)
  - Plotting fields using Flair
  - User routines
- Particle transport settings in fields
  - Required cards (+ examples)

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

Electric and magnetic fields

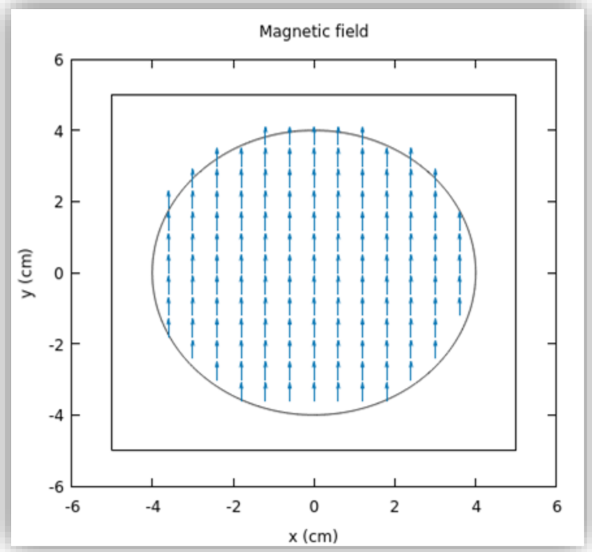
Required cards: **`ELCFIELD`**, **`MGNFIELD`**, **`MGNCREATE`**, **`MGNDATA`** (+ examples)

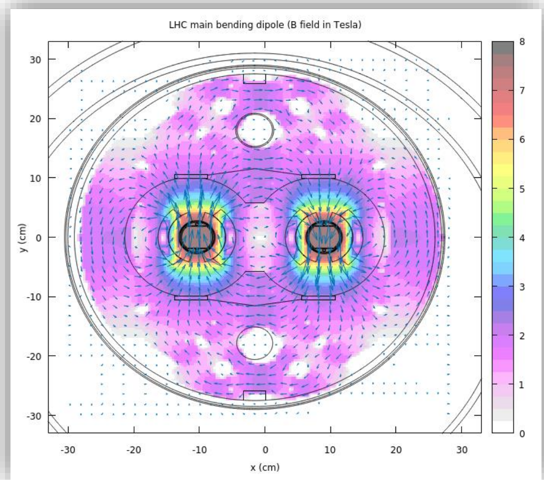
Plotting fields using Flair

User routines **`elefld.f`** and **`magfld.f`**

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 **`MGNCREAT`**e cards defining the type of field as well as field strength, region association, symmetry, …
  - Interpolated fields (2D, cylindrical, 3D) require additional **`MGNDATA`** cards
  - Arbitrarily complex fields can be implemented using user routines **`elefld.f`** and **`magfld.f`**





Magnetic and electric fields in FLUKA

In any material

MAGNETIC

Constant field

Global field setting using card **MGNFIELD** in all materials marked using **ASSIGNMAt** card

Common field

Per-region or lattice cell basis using combination of **MGNCREATe** and **MGNFIELD** cards to define up to decapole fields. Interpolated fields require additional **MGNDATA** cards

Arbitrary field

Using routine **magfld.f**

Only in vacuum (!)

ELECTRIC

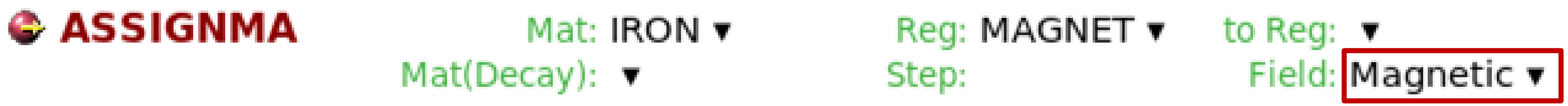
Constant field

Global field setting using card **ELCFIELD** in all materials marked using **ASSIGNMAt** card

Arbitrary field

Using routine **elefld.f**

Magnetic and electric fields in FLUKA

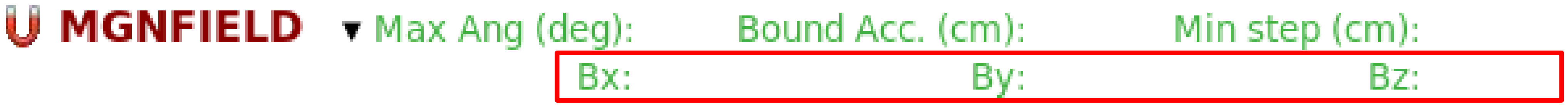


- Fields are activated on a per-region basis with the `ASSIGNMAt` card
- Strongly recommended to define as such only regions where a magnetic field actually exists, due to the less efficient and less accurate tracking algorithm used in magnetic fields
- Activates an electric or magnetic field if defined using `ELCFIELD` **or** `MGNFIELD` with additionally `MGNCREATe/MGNDATA` or using a routine (`elefld.f/magfld.f`)
- Selecting “Electric” or “Magnetic” in Flair activates a field both for prompt and decay radiation, one can however also selectively switch on a field for either of the two (prompt or decay) *
- Go to “Add > Transport” to add these cards to the input in Flair.

** The option to activate both types of fields in the same region is shown in Flair but is presently not implemented in FLUKA.)*

Magnetic and electric fields: the cards

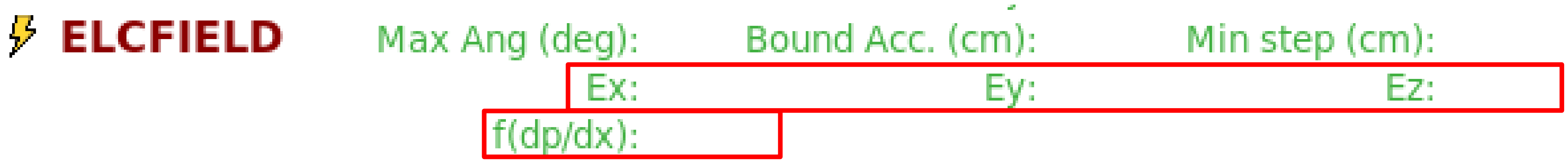
SDUM = blank



- The `MGNFIELD` card defines a **constant** magnetic field, where WHAT(4-6) are the Bx, By, Bz components of the magnetic field in the Cartesian coordinate axes.
- Units: Tesla
- In case no values are specified or all components are set to zero (= default setting!) a user-defined subroutine `magfld.f` is expected to deliver the values (see below).
- The defined magnetic field is applied to **all** regions set as magnetic using the `ASSIGNMAt` card, it is therefore strongly recommended to restrict this to regions where a field effectively exists

Magnetic and electric fields: the cards

SDUM = blank



- The `ELCFIELD` card defines a constant electric field with WHAT(4-6) the Ex, Ey, Ez components of the electric field in the Cartesian coordinate axes.
- Units: kV/cm
- In case no values are specified or all components are set to zero (= default setting!) a user-defined subroutine `elefld.f` is expected to deliver the values (see below).
- **f(dp/dx)** is a factor to extend the upper dp/dx tabulation for charged particles (≥1)
- The defined electric field is applied in **all** regions set as electric using the `ASSIGNMAt` card, it is therefore strongly recommended to restrict this to regions where a field effectively exists

Magnetic and electric fields: the cards

SDUM = blank

- The **MGNFIELD** card associates a common field, defined by an **MGNCREATe** card (here named “FIELD”), to a specific region.
- Still required to explicitly flag the region as magnetic using an **ASSIGNMAt** card, it is not done automatically.
- The magnetic field strength given in WHAT(2) is expressed according to the common field type defined in the associated **MGNCREATe** card:

  Dipole: intensity in T

  Quadrupole: intensity in T/cm

  Sextupole: expansion coefficient in T/cm^2

  Octupole: expansion coefficient in T/cm^3

  Decapole: expansion coefficient in T/cm^4

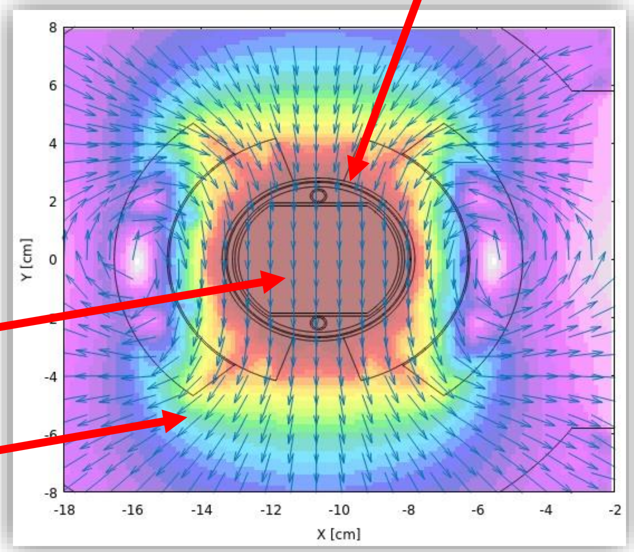
  Any other (including constant): a multiplicative factor

Magnetic and electric fields: the cards

- In combination with the **MGNFIELD** card, the **MGNCREATe** card defines
  - Any common 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

- Functionality that was formerly only available through user-defined subroutine **magfld.f**



Magnetic and electric fields: the cards

type = const

MGNCREATE

type: CONST ▾

U: V: W:

$$B_x = K \cdot u$$
$$B_y = K \cdot v$$
$$B_z = K \cdot w,$$

- The **MGNCREATe** card for type **CONST** allows to define the X, Y and Z components of a constant magnetic field (first continuation card), with the strength K defined in the associated **MGNFIELD** card.

Magnetic and electric fields: the cards

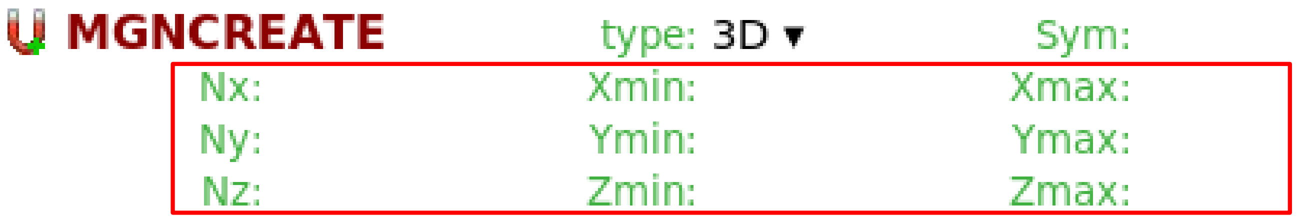
type = DIPOLE, …, DECAPOLE

$$B_x = 0$$
$$B_y = K$$
$$B_z = 0$$

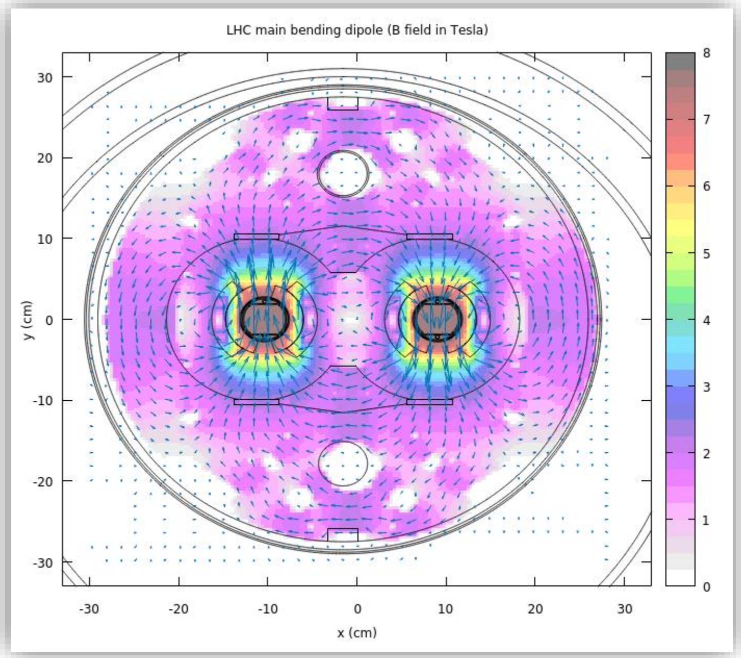
- The **MGNCREATe** card for types **DIPOLE**, … up to **DECAPOLE** define along with the associated **MGNFIELD** card any common analytical field along with parameters:
  - R: radius (in cm) of the “core” analytical field
  - Sym: mirror symmetries in the magnetic field frame to be applied along each axis, encoded as `Sx + Sy*10 + Sz*100`, with `Si` one of `Sx`, `Sy`, `Sz`.
  - X0, Y0 : Additional offset along the X and Y axes of the magnet frame for the analytical core region
  - Azm: Azimuthal angle around Z
  - Rbend: the magnet bending radius

Magnetic and electric fields: the cards

type = 2D, RZ, 3D



$$B_x = K \cdot B_{(i,x)}$$
$$B_y = K \cdot B_{(i,y)}$$
$$B_z = K \cdot B_{(i,z)},$$

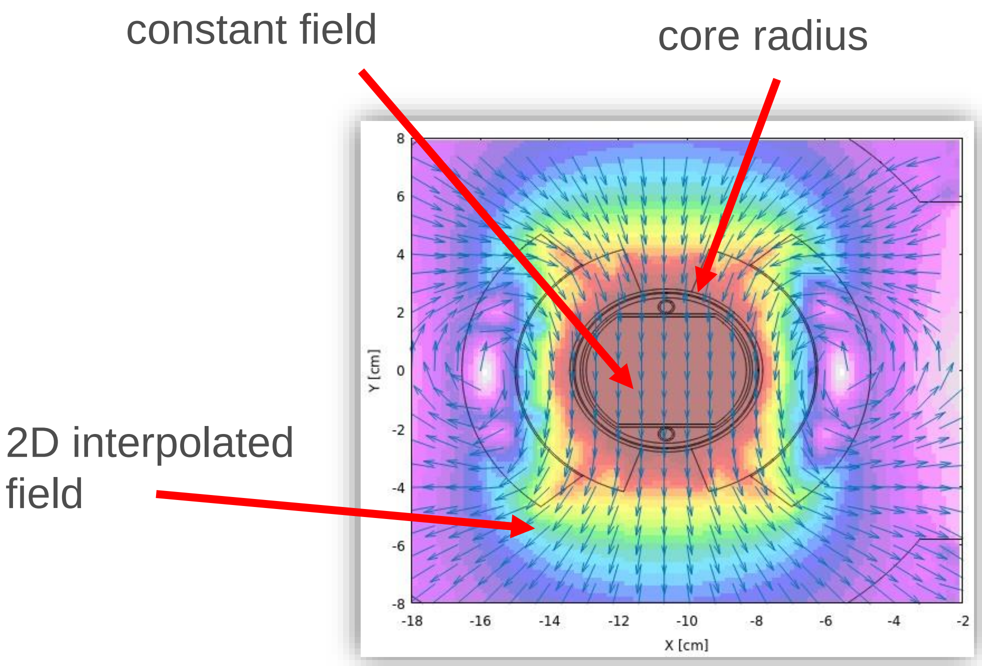


- The **MGNCREATe** card for types **2D, RZ, 3D**, allow to define interpolated fields in combination with **MGNDATA** cards.
- Toroidal RZ field is a particular kind of 2D field (field coordinates in the XY grid extruded in Z)
  - $N_x \rightarrow N_r$, $X_{min} \rightarrow R_{min}$, $X_{max} \rightarrow R_{max}$
  - $N_y \rightarrow N_z$, $Y_{min} \rightarrow Z_{min}$, $Y_{max} \rightarrow Z_{max}$

Magnetic and electric fields: the cards

type = 2D/3D + DIPOLE, …, DECAPOLE

- The MGNCREATe card can define the combination of an analytical field + an interpolated field in combination with MGNDATA cards.
- Not possible in combination with RZ toroidal interpolated field!
- Radius R defines the radius of the analytical core region



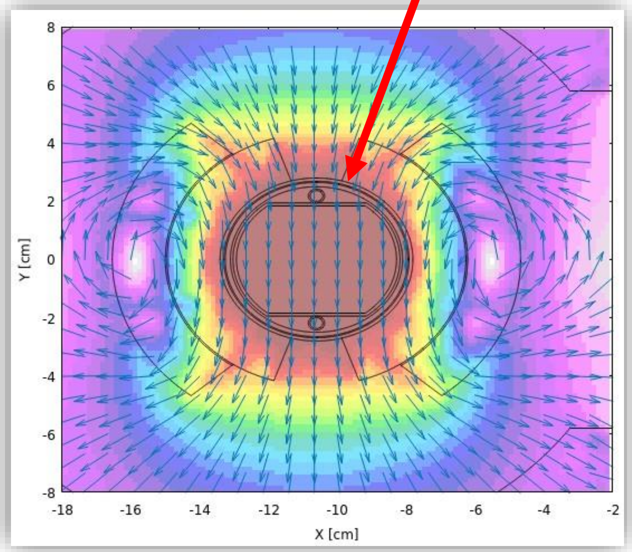
Magnetic and electric fields: the cards

type = 2D/3D + DIPOLE, …, DECAPOLE

MGNCREATE	FIELD	type:	2D+DIPOLE ▾	Sym:		Azm:	
	R: 5	Xo:		Yo:		Rbend:	
	Nx: 10	Xmin:		Xmax:			
	Ny: 10	Ymin:		Ymax:			
MGNFIELD	FIELD ▾	Strength:	2	Rotdefi:	▾	On:	Region ▾
		Reg:	▾	to Reg:	@LASTREG ▾	Step:	
MGNDATA	FIELD ▾	Bx:		By:	1	Bz:	
MGNDATA	FIELD ▾	Bx:		By:	1	Bz:	
MGNDATA	FIELD ▾	Bx:		By:	1	Bz:	

$$B_x = K \cdot B_{(i,x)}$$
$$B_y = K \cdot B_{(i,y)}$$
$$B_z = K \cdot B_{(i,z)},$$

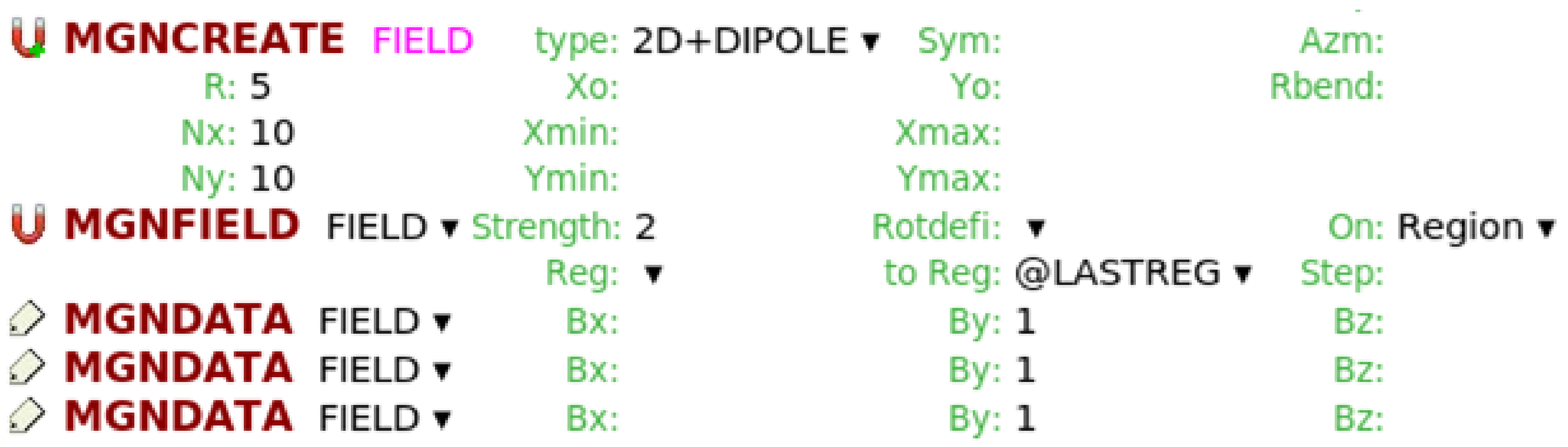
core radius = 5 cm



- Example: combination of **MGNCREATe** + **MGNFIELD** + **MGNDATA** cards to create combination of analytical + interpolated field called “FIELD”
  - Field strength: 2 T
  - Core analytical radius: 5 cm

Magnetic and electric fields: the cards

type = 2D/3D + DIPOLE, …, DECAPOLE



$$B_x = K \cdot B_{(i,x)}$$
$$B_y = K \cdot B_{(i,y)}$$
$$B_z = K \cdot B_{(i,z)},$$

- **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
```

Plotting the field in Flair

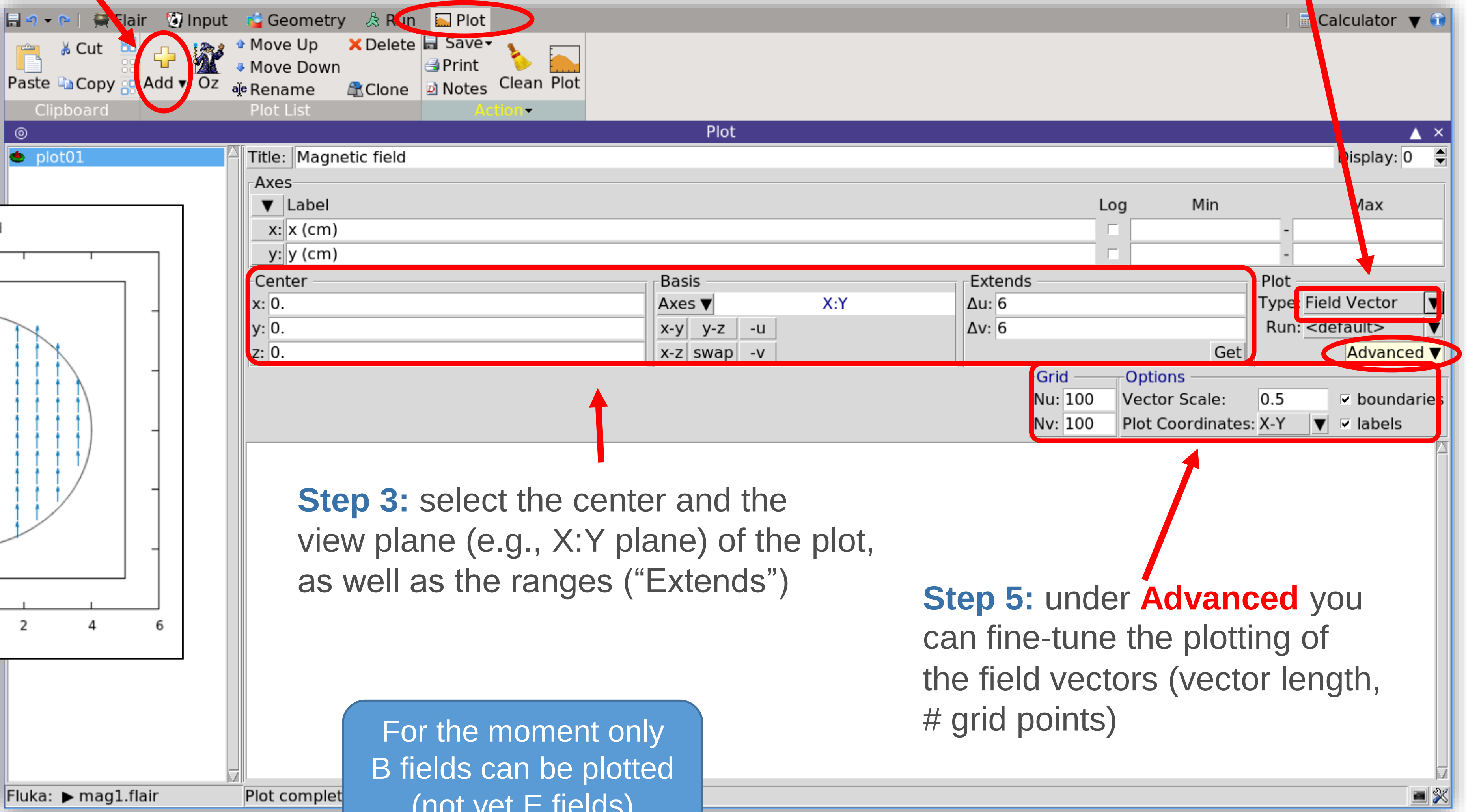
Step 1: select the **Plot** tab

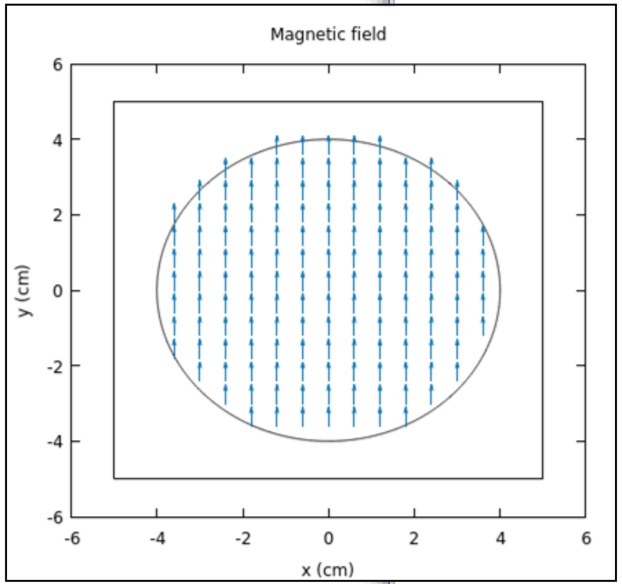
Step 2: add a **Geometry** plot

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)





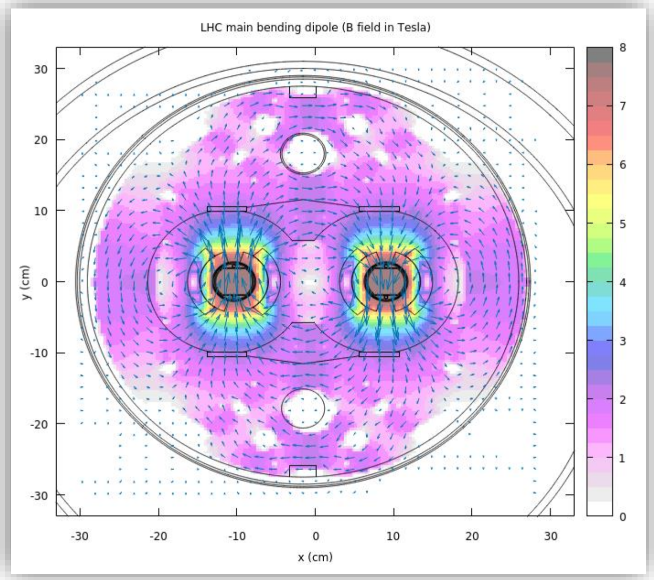
For the moment only B fields can be plotted (not yet E fields)

User routines

- In the case where the standard FLUKA magnetic/electric field implementations are insufficient, dedicated routines can be used to simulate more complex problems

- Such fields can be described in the user subroutines `src/user/magfld.f` and `src/user/elefld.f`

- In these routines, the field components and field strength can be defined as a function of the coordinates. They are only called in regions declared as magnetic/electric via the relevant **ASSIGNMA** card.




```
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
```

Particle transport settings in fields

FLUKA implementation of tracking in fields

Required cards: **ELCFIELD**, **MGNFIELD**, **STEPSIZE** (+ examples)

Remarks concerning the tracking in fields

- When tracking in magnetic fields, FLUKA accounts for:
  - The **precession of the MCS (Multiple Coulomb Scattering) 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)

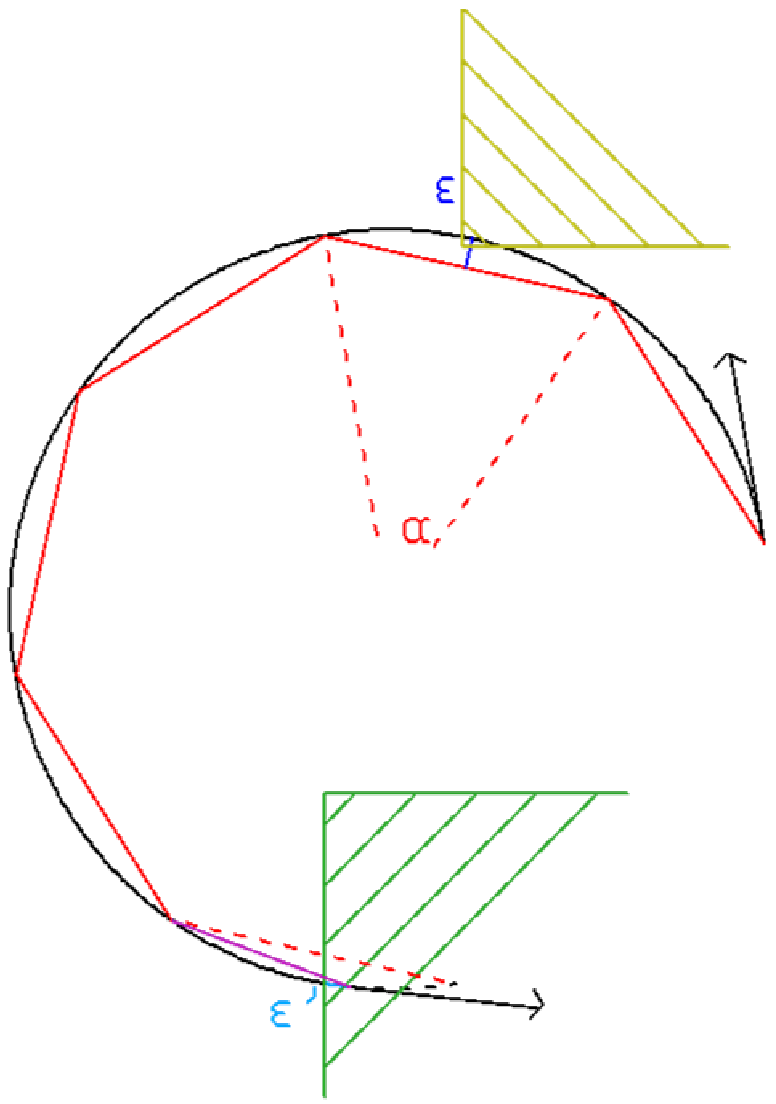
- When tracking in electric fields inside vacuum, FLUKA accounts for:
  - The **change of the projectile energy** due to the electric field itself

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 centre 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

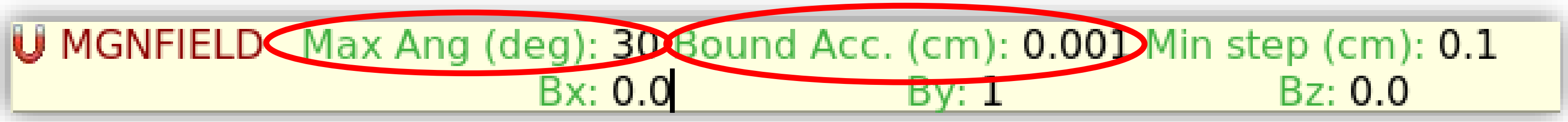


Global transport settings for B (and E) fields

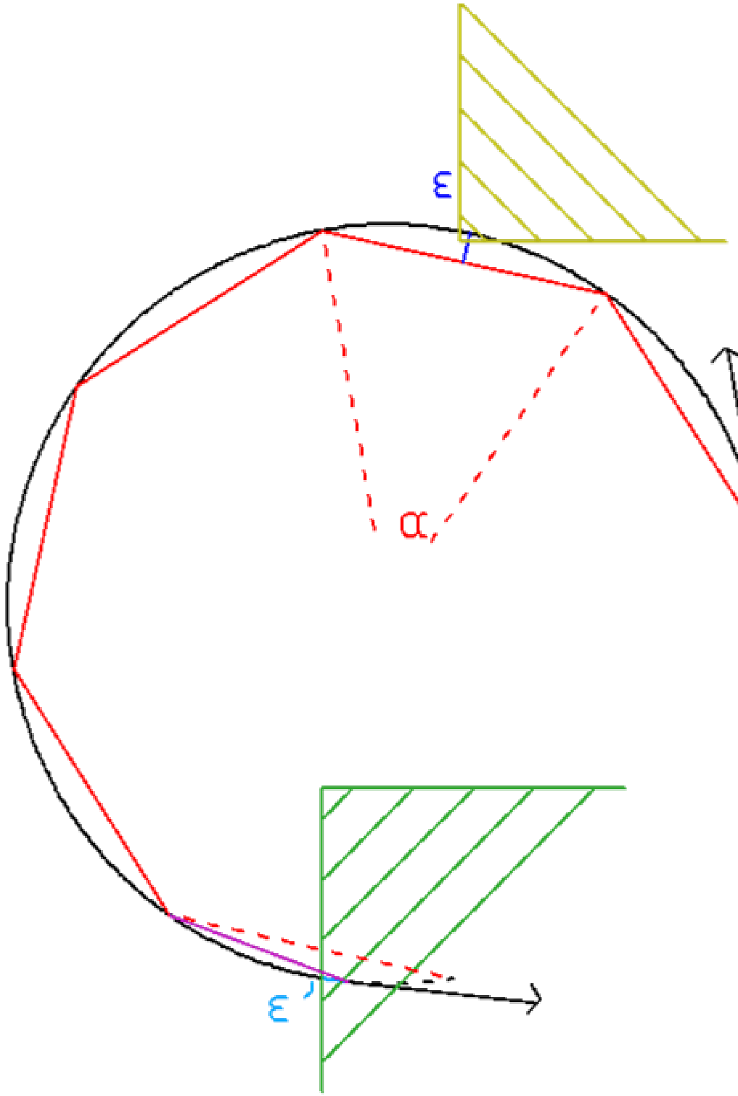
- The transport parameters can be globally set on the **MGNFIELD** (and **ELCFIELD**) cards

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!)

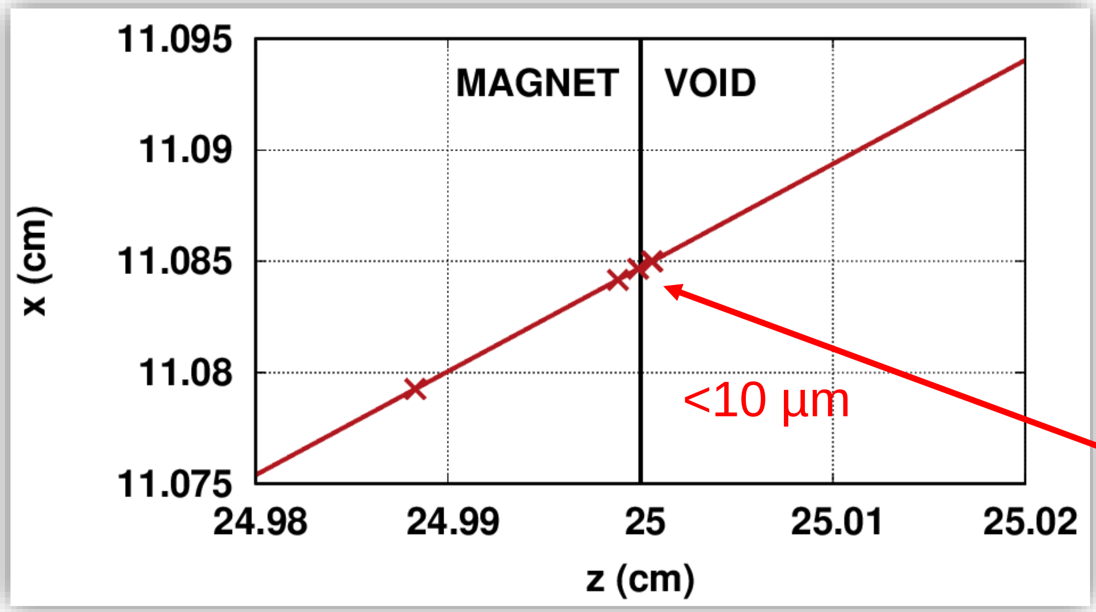


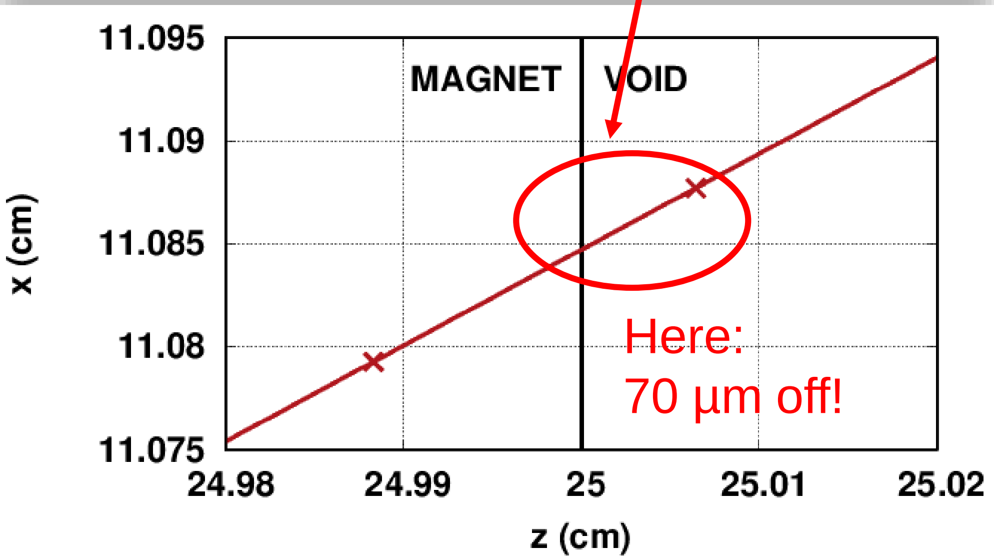
(analogous for ELCFIELD card)



Beware of default settings (here: ε)

Default settings





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

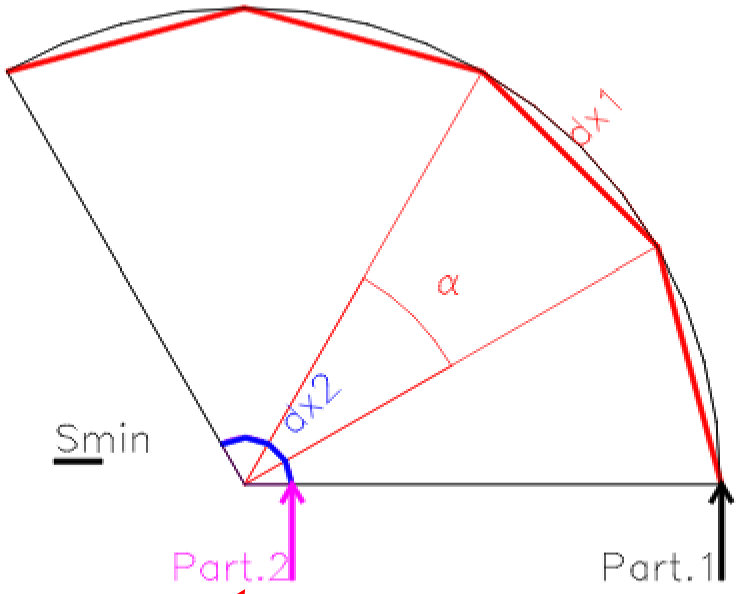
Global transport settings for B (and E) fields (cont.)

- 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)



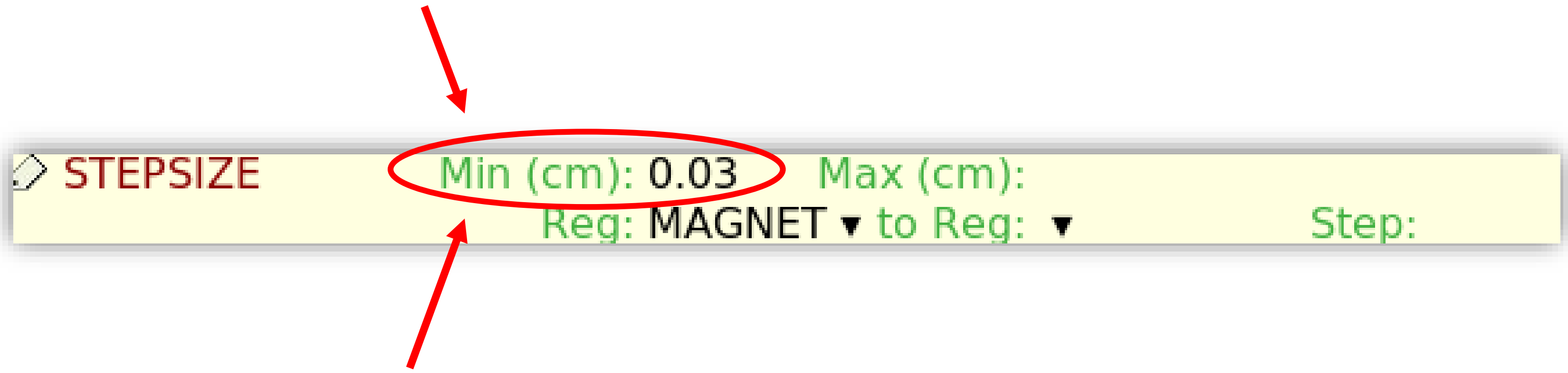
α leads to too small steps (< Δs):
Sub-step size increased to Δs

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

Summary

- EM fields of arbitrary complexity can be included in FLUKA simulations
  - Region-activated using **ASSIGNMAt** card
  - Using a combination of **MGNFIELD** and/or **MGNCREATe** and or **MGNDATA** cards
  - Using dedicated user subroutines **magfld.f**, **elefld.f** when standard FLUKA implementation does not suffice
  - In all materials for magnetic fields, in vacuum only for electric fields (!)
  - Only one type of field per region

- Fields can be plotted using Flair for visual inspection

- Tracking settings are a trade-off between accuracy and CPU time
  - Global setting: **MGNFIELD**, **ELCFIELD**
  - Locally: **STEPSIZE**

FLUKA