FLUKA

Advanced geometry

Transformations and modular geometries

Beginner course – INTA, April 2024

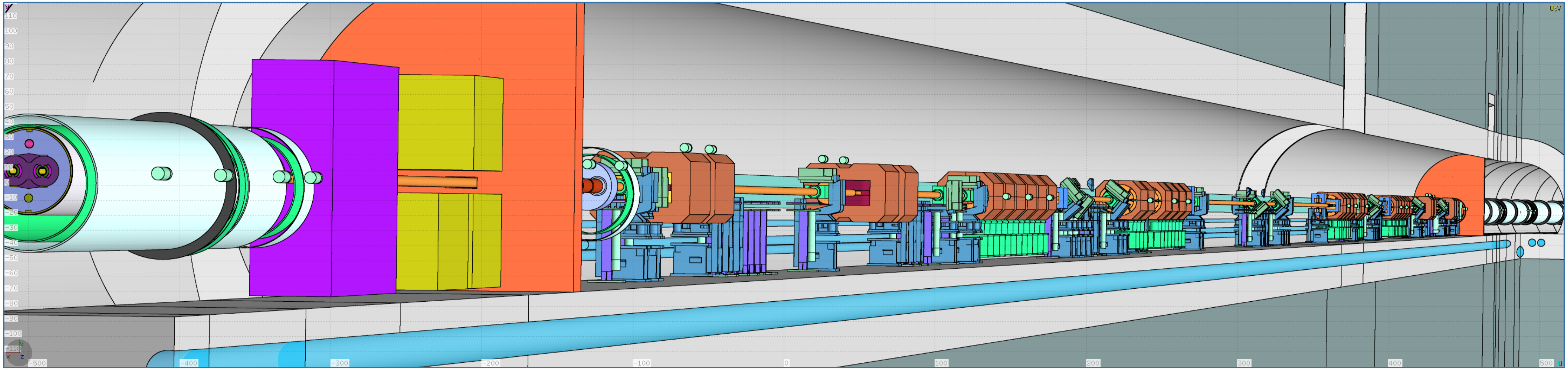
Basic geometry concepts

Three concepts are fundamental in the FLUKA Combinatorial Geometry, which have been described earlier in the course:

- **Bodies**: basic convex objects + infinite planes & cylinders + generic quadric
- **Zones**: portion of space defined by intersections **(+)** and subtractions **(-)** of bodies (used internally)
- **Regions**: union of multiple zones **(|)**
  (or a single zone)

Complex and modular geometries

3D rendering of LHC IR7



Complex and modular geometry models like the one shown here are built with LineBuilder [A. Mereghetti et al., IPAC2012, WEPPD071, 2687]

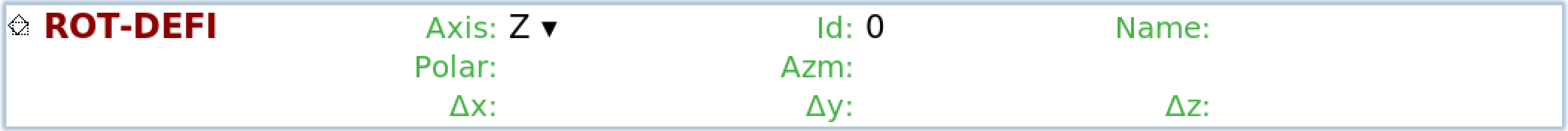
Such a geometry model heavily depends on **`LATTICE`s** (i.e. duplication of existing regions) which are not covered here

In this lecture

- Roto-translation transformations
  - `ROT-DEFIni` card
- Geometry directives
  - `translat`
  - `transform`
  - `expansion`
- Additional card related to a transformation
  - `ROTPRBIN` card
- Tips for building a modular geometry

The `ROT-DEFI` card

ROT-DEFI card – Introduction



ROT-DEFI Axis: Z ▾ Id: 0 Name:

Polar: Azm:

Δx: Δy: Δz:

The ROT-DEFI card defines roto-translations that can be applied to:

- Bodies:

  To move and rotate geometry

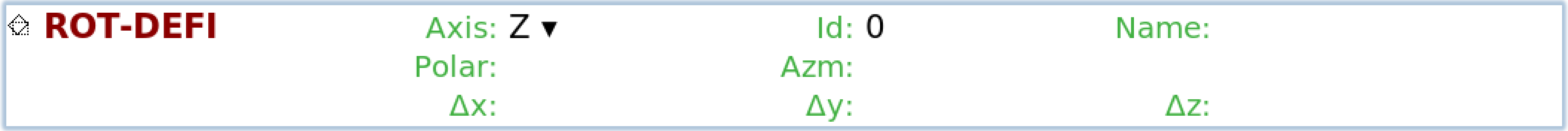
- USRBIN and EVENTBIN cards (see ROTPRBIN card later)

  To move and rotate scorings

- LATTICE (not covered here)

The roto-translation places the body (or USRBIN etc) in the **lab** frame of reference.

ROT-DEFI card – Definition



ROT-DEFI Axis: Z ▾ Id: 0 Name:
Polar: Azm:
Δx: Δy: Δz:

Axis: reference axis

Id: transformation index. If set to 0, then Id is automatically assigned

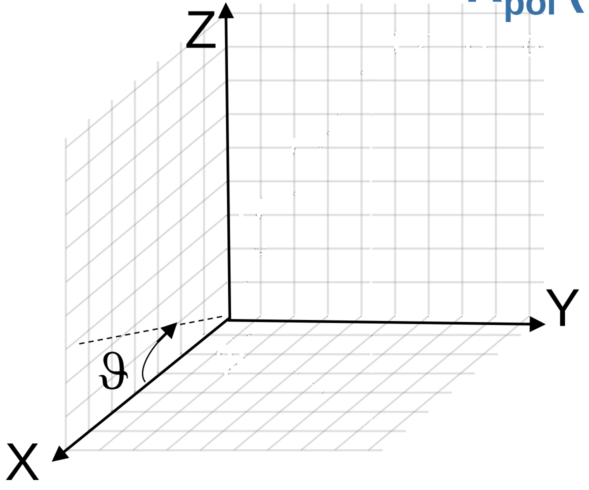
Name: transformation name. Optional, but recommended for easy referencing

Polar: polar angle of the rotation $\mathbf{R}_{\mathbf{pol}}$ ($0 \le \vartheta \le 180$ degrees) [clockwise]

Azm: azimuthal angle of the rotation $\mathbf{R}_{\mathbf{azm}}$ ($-180 \le \varphi \le 180$ degrees) [clockwise]

Δx, Δy, Δz: vector components for the translation **T**

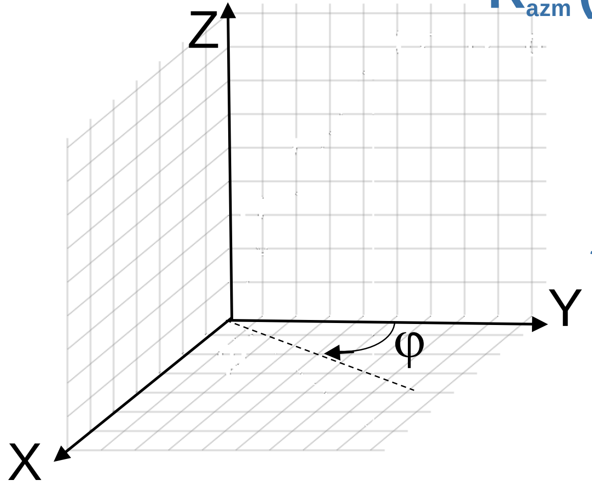
R_{pol} (ϑ)



When reference axis is Z:
Clockwise rotation around Y
with angle ϑ

* More generally, with ref. axis X_0:
Clockwise rotation around X_2
with angle ϑ
"X_1 goes towards X_0"

R_{azm} (φ)

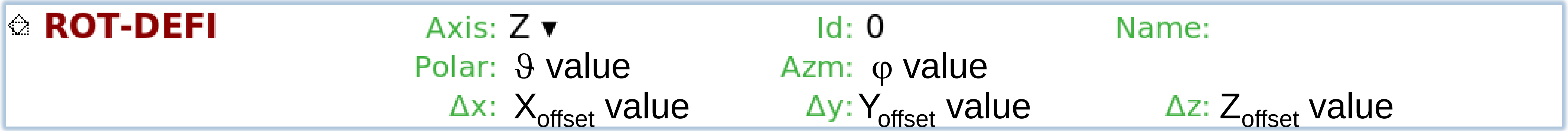


When reference axis is Z:
Clockwise rotation around Z
with angle φ

* More generally, with ref. axis X_0:
Clockwise rotation around X_0
with angle φ
"X_2 goes towards X_1"

** Let (X0, X1, X2) be a right-handed orthogonal system in a 3D space. For example: **(Z, X, Y)**, or (X, Y, Z), or (Y, Z, X).*

ROT-DEFI card – Definition



ROT-DEFI Axis: Z ▾ Id: 0 Name:

Polar: ϑ value Azm: φ value

Δx: X_{offset} value Δy: Y_{offset} value Δz: Z_{offset} value

The ROT-DEFI card roto-translation is defined as:

$$\underset{3.}{\mathbf{R}_{\mathbf{pol}}(\vartheta)} \circ \underset{2.}{\mathbf{R}_{\mathbf{azm}}(\varphi)} \circ \underset{1.}{\mathbf{T}}$$

Composition order matters!
First T, then R_{azm}, then R_{pol}

For example, for a ROT-DEFI card with **Axis = Z**, the roto-translation is:

$$\begin{vmatrix} X_{\mathrm{new}} \\ Y_{\mathrm{new}} \\ Z_{\mathrm{new}} \end{vmatrix} = \begin{vmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{vmatrix} \begin{vmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{vmatrix} \begin{vmatrix} X_{\mathrm{old}} + X_{\mathrm{offset}} \\ Y_{\mathrm{old}} + Y_{\mathrm{offset}} \\ Z_{\mathrm{old}} + Z_{\mathrm{offset}} \end{vmatrix}$$

See ROT-DEFI in manual!

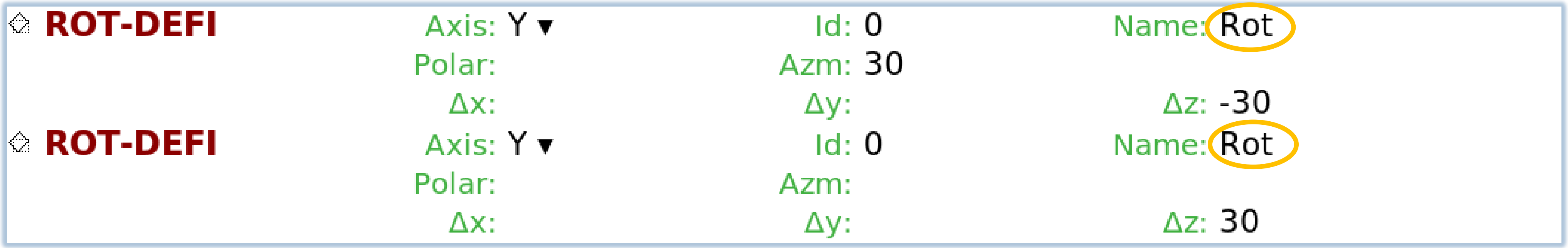
rotation around Y axis
with clockwise angle ϑ

rotation around Z axis
with clockwise angle φ

It is preferable to define rotations through the azimuthal angle.

ROT−DEFI cards – “Chaining” / Inverse

- It is possible to use multiple ROT−DEFI cards to define a single transformation (**compositon, or "chaining"**):
  - The Name (or Id) on the “chained” ROT−DEFI cards has to be the same.
  - The transformations associated with the ROT−DEFI cards are applied from top to bottom.



1. ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot
Polar: Azm: 30
Δx: Δy: Δz: -30

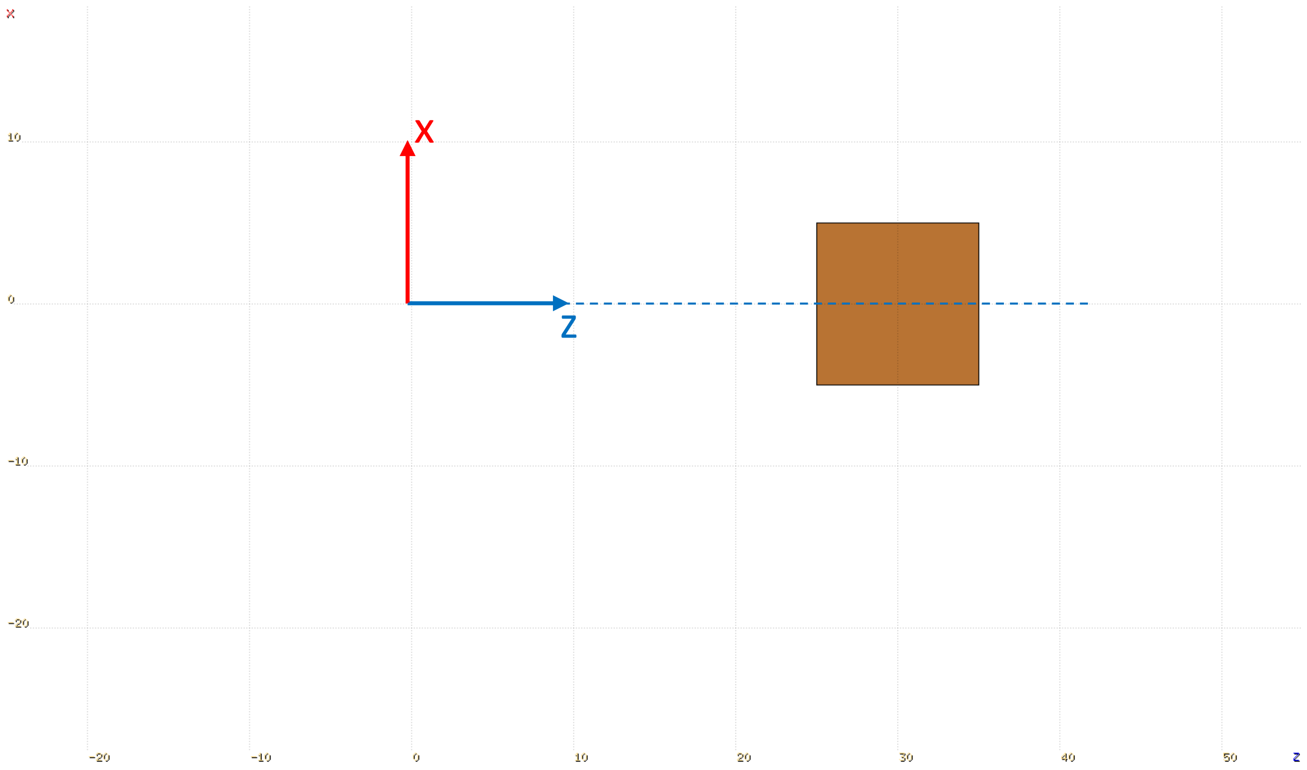
2. ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot
Polar: Azm:
Δx: Δy: Δz: 30

- It is also possible to access the **inverse** of the transformation associated with a ROT−DEFI card.
  - Just refer to the existing ROT−DEFI card with a minus sign (“−”) before its name or Id number.
  - Example use with ROTPRBIN card later in the lecture.

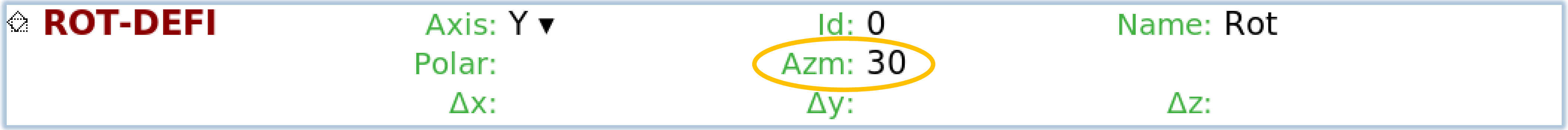
ROT-DEFI card – Example 1

Body located away from the origin of the coordinate system.

Initial state



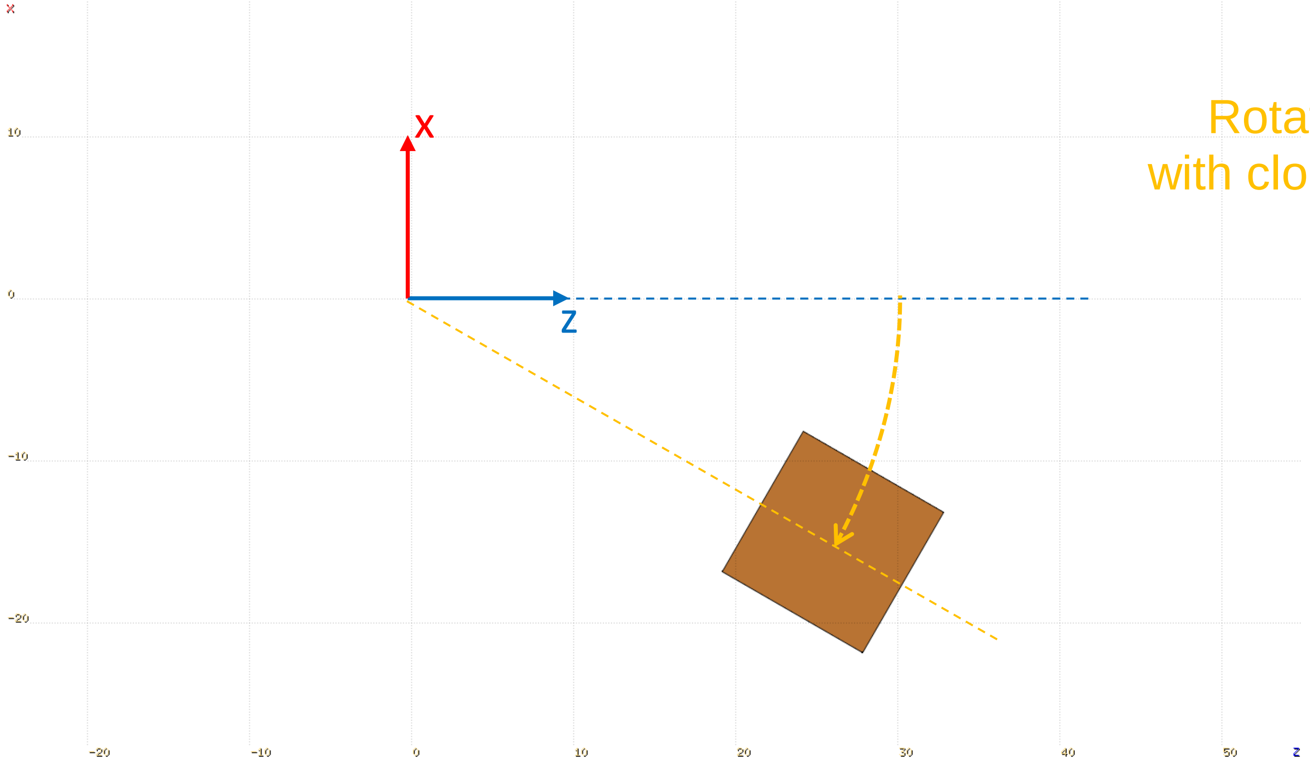
ROT-DEFI card – Example 1



ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot

Polar: Azm: 30

Δx: Δy: Δz:

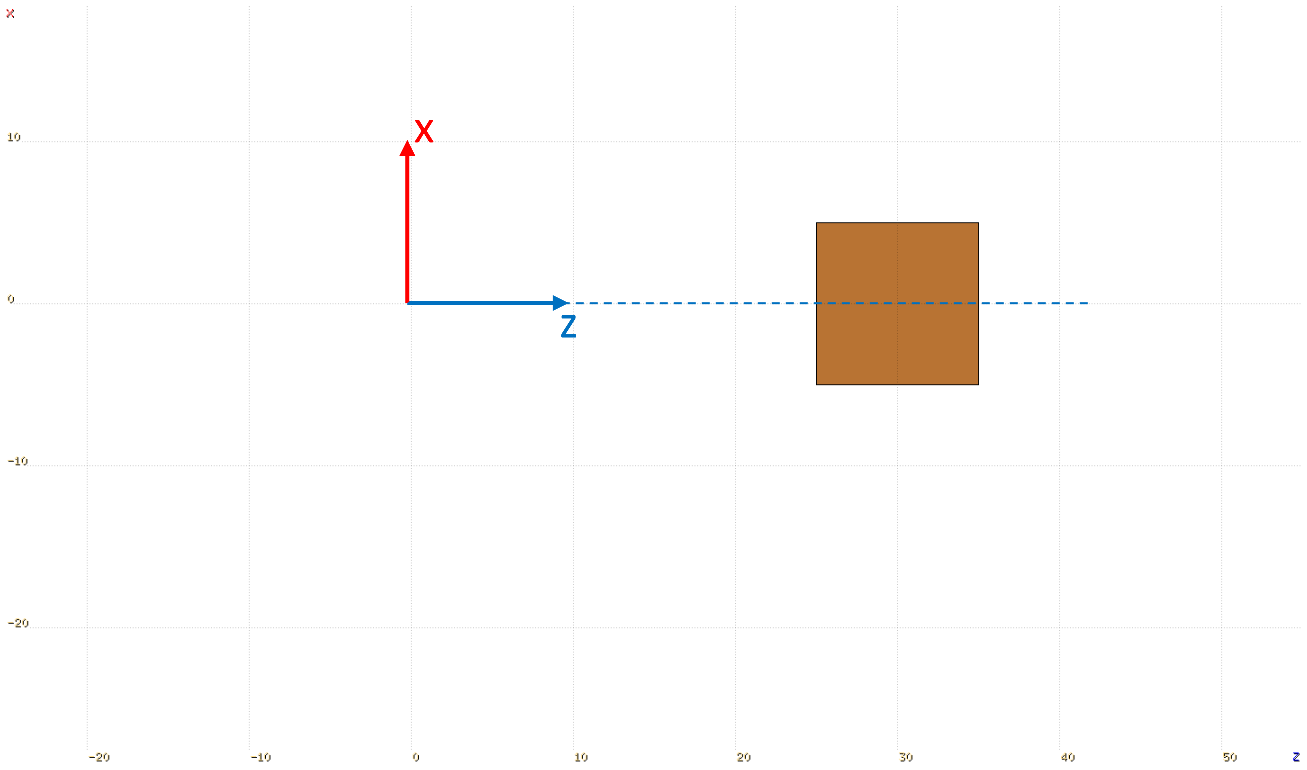


Rotation around Y axis
with clockwise angle φ = 30°

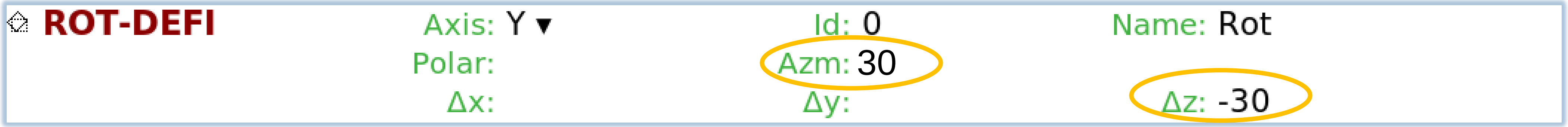
`ROT-DEFI` card – Example 2

Body located away from the origin of the coordinate system.

Initial state



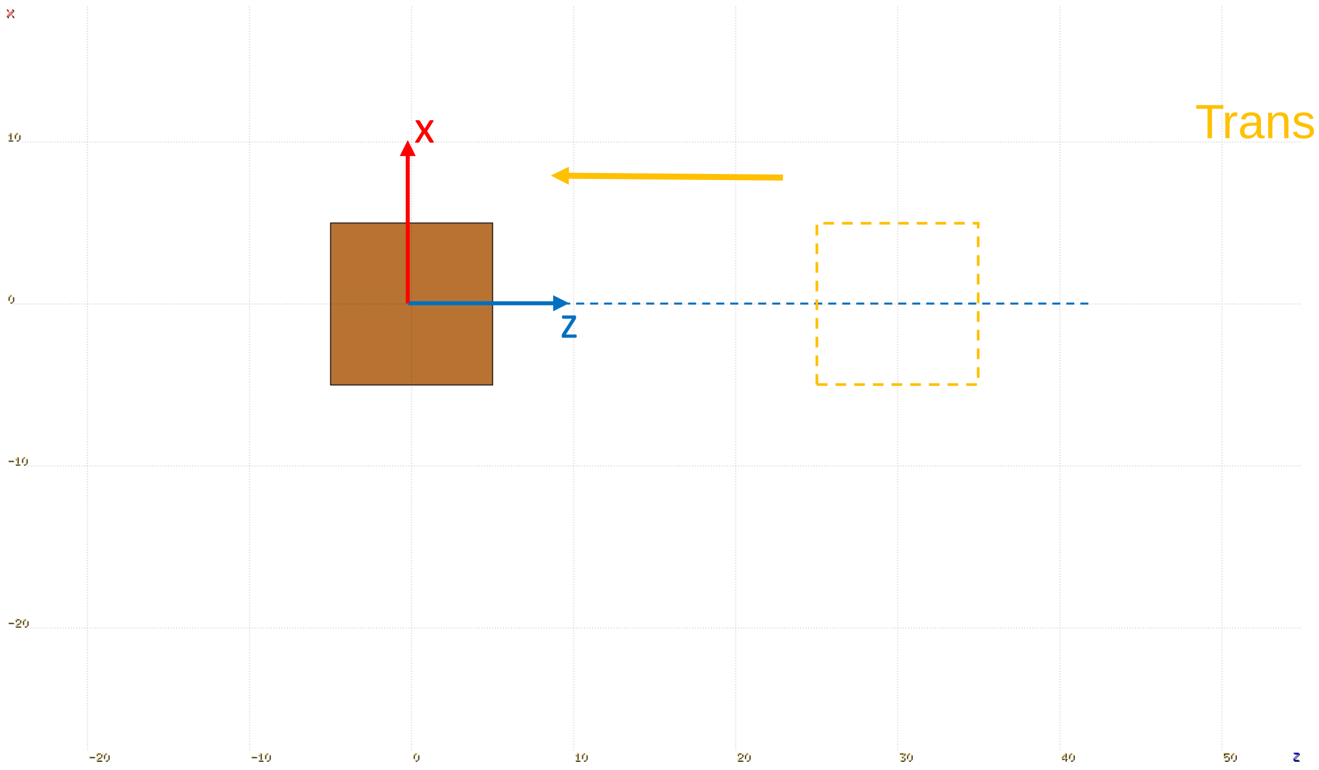
ROT−DEFI card – Example 2



ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot

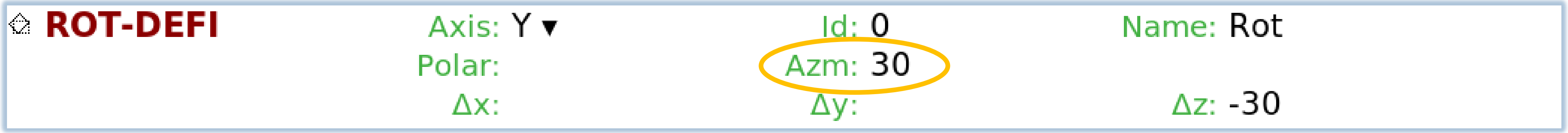
Polar: Azm: 30

Δx: Δy: Δz: -30



Translation along Z axis

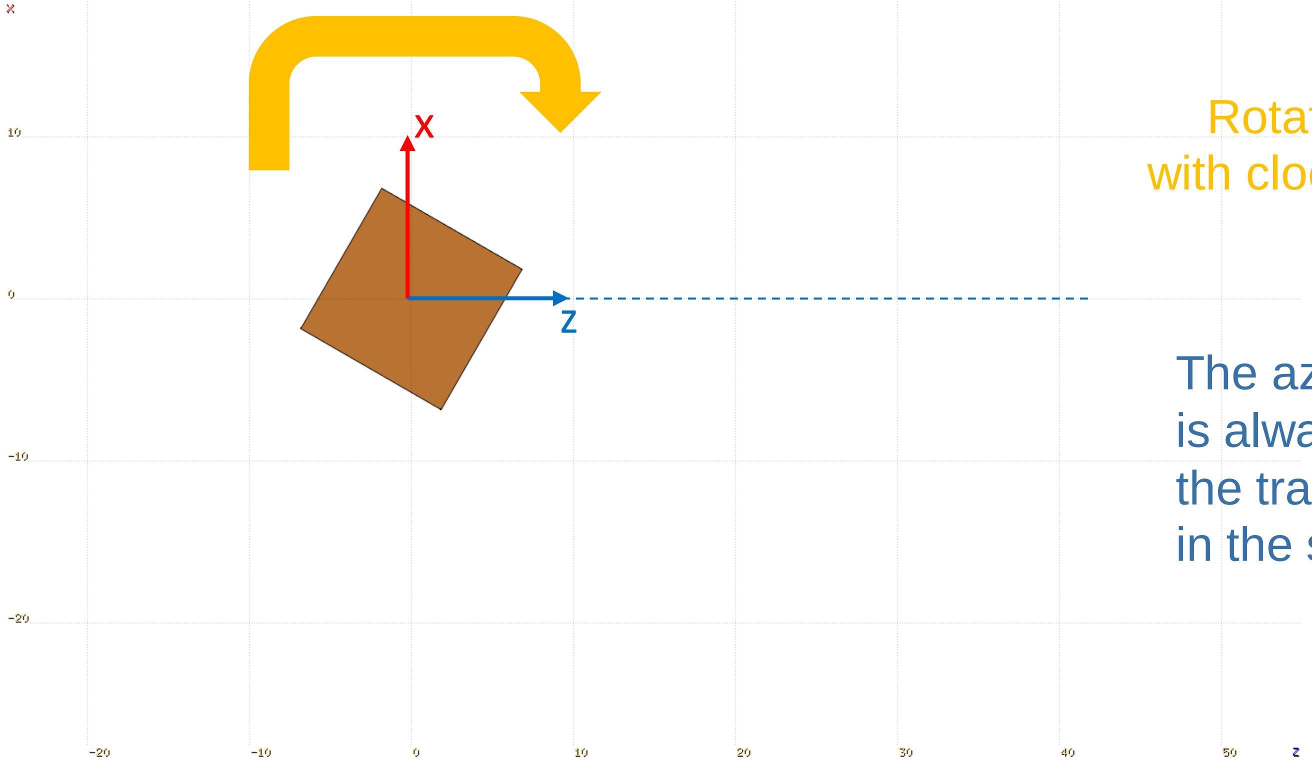
ROT−DEFI card – Example 2



ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot

Polar: Azm: 30

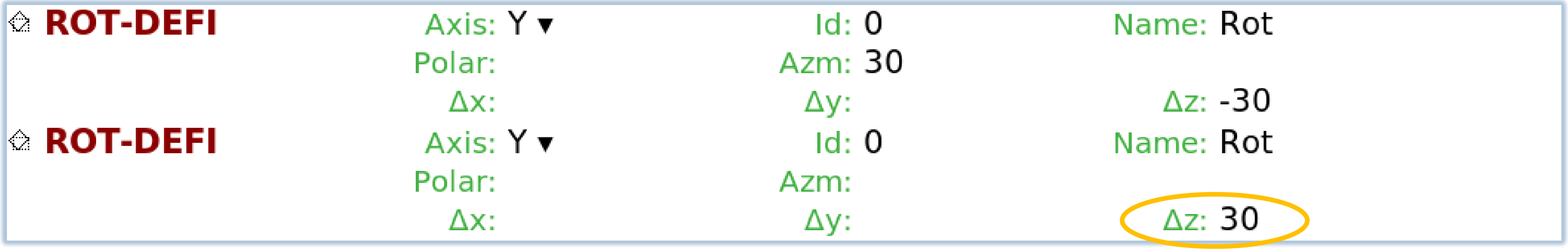
Δx: Δy: Δz: -30



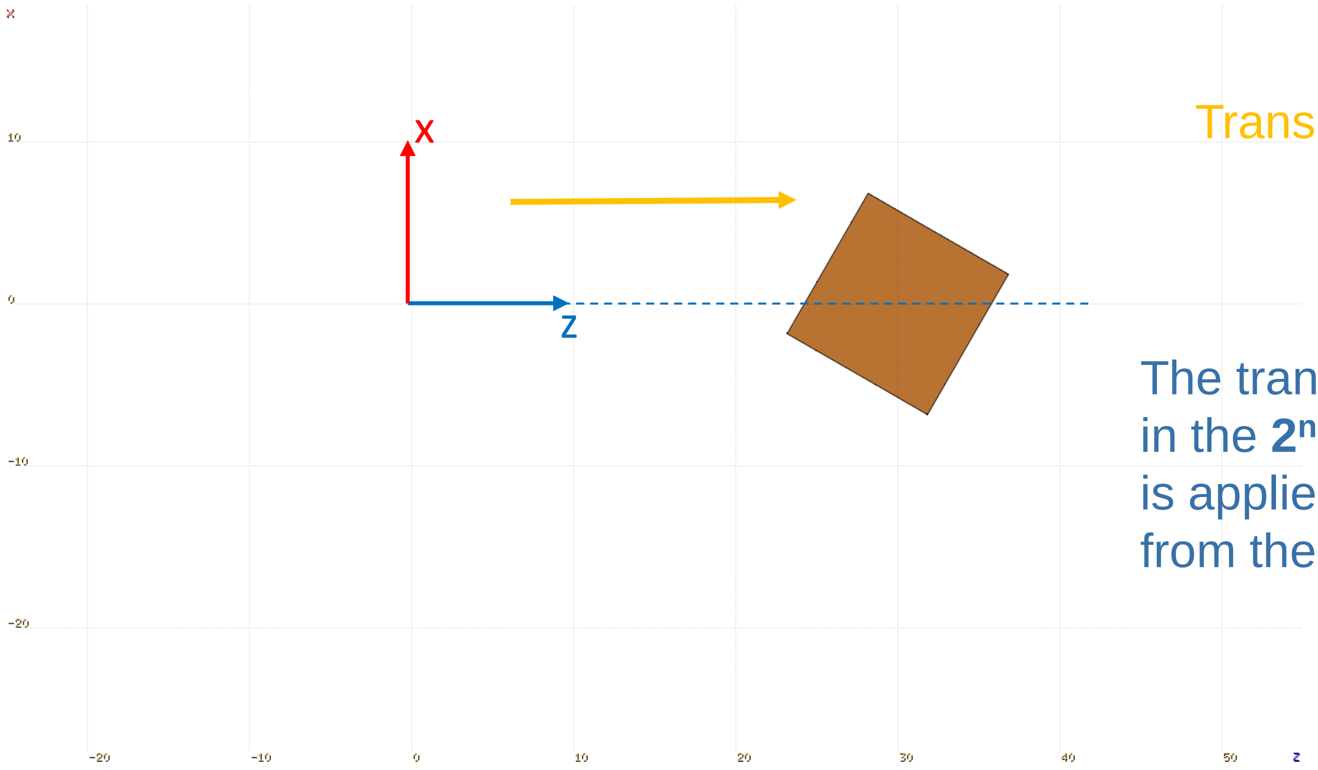
Rotation around Y axis
with clockwise angle φ = 30°

The azimuthal rotation
is always performed **after**
the translation defined
in the same ROT-DEFI card.

ROT-DEFI card – Example 2



1. ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot
   Polar: Azm: 30
   Δx: Δy: Δz: -30
2. ROT-DEFI Axis: Y ▾ Id: 0 Name: Rot
   Polar: Azm:
   Δx: Δy: Δz: 30



Translation along Z axis

The transformation defined in the 2nd **ROT-DEFI card** is applied **after** the roto-translation from the 1st ROT-DEFI card.

Geometry directives

Geometry directives

- Special commands enclosing a body (or a list of bodies) definition:

```
$start_xxx
...
$end_xxx
```

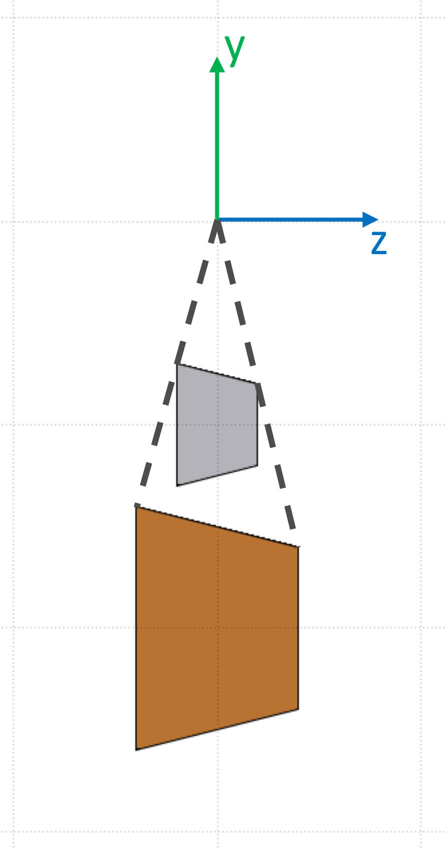
- Where “`xxx`” stands for “`translat`”, “`transform`” or “`expansion`”

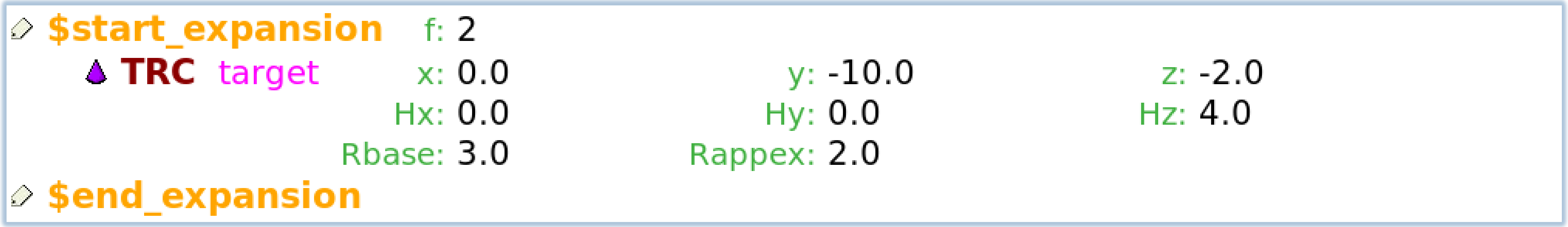
- The directive is applied to the list of the bodies embedded between the starting and the ending directive lines

Directives in geometry: expansion

```
$start_expansion
...
$end_expansion
```

provides an expansion (or reduction)
of all body components (dimensions and placement)
by a defined scaling factor (f),
for all bodies included in the directive



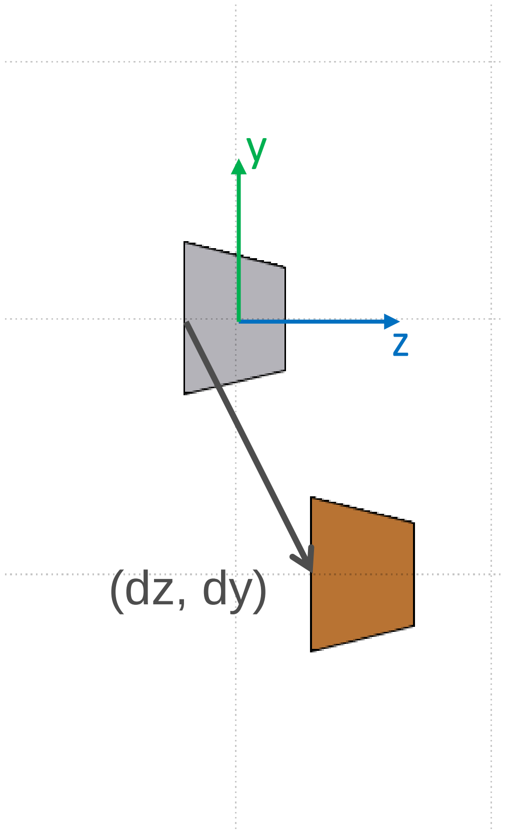


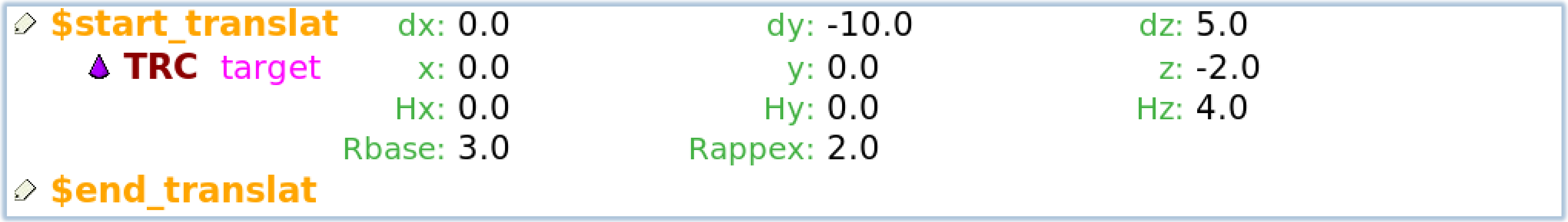
```
$start_expansion     f: 2
  TRC  target        x: 0.0          y: -10.0        z: -2.0
                    Hx: 0.0         Hy: 0.0         Hz: 4.0
                 Rbase: 3.0     Rappex: 2.0
$end_expansion
```

Directives in geometry: translation

```
$start_translat
...
$end_translat
```

provides a coordinate translation (dx, dy, dz)
for all bodies embedded within the directive

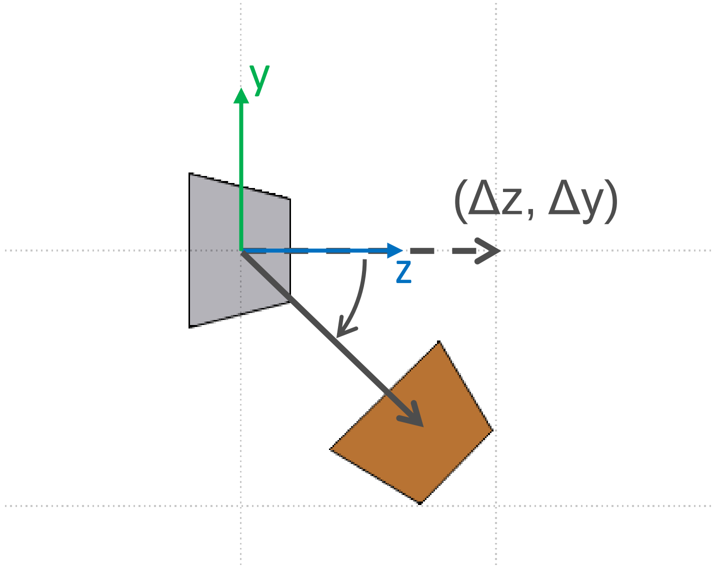




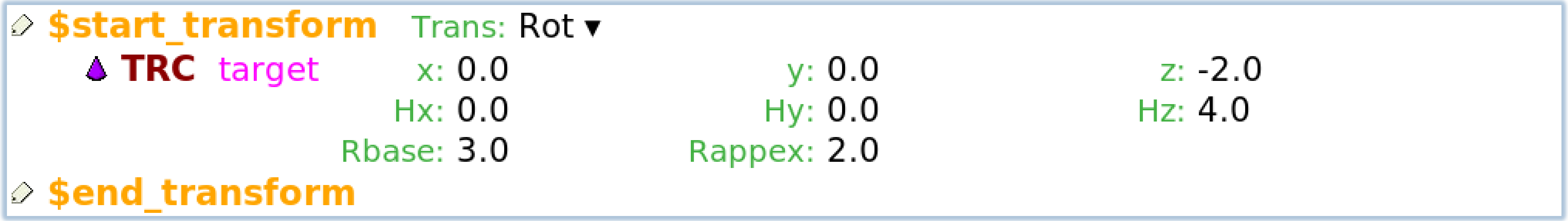
```
$start_translat      dx: 0.0          dy: -10.0       dz: 5.0
   TRC  target        x: 0.0           y: 0.0          z: -2.0
                     Hx: 0.0          Hy: 0.0         Hz: 4.0
                  Rbase: 3.0      Rappex: 2.0
$end_translat
```

Directives in geometry: transform

```
$start_transform
...
$end_transform
```



applies a roto-translation (pre-defined via **ROT-DEFI**) to all bodies embedded within the directive



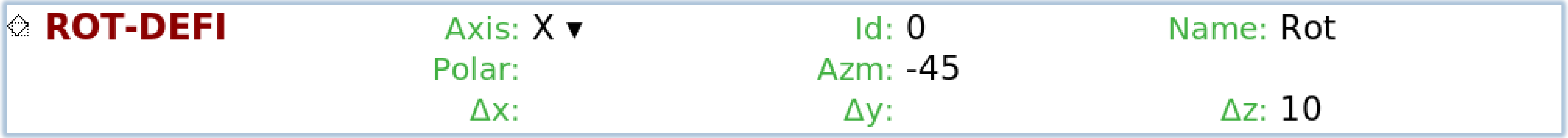
$start_transform Trans: Rot ▾

TRC target x: 0.0 y: 0.0 z: -2.0

Hx: 0.0 Hy: 0.0 Hz: 4.0

Rbase: 3.0 Rappex: 2.0

$end_transform



ROT-DEFI Axis: X ▾ Id: 0 Name: Rot

Polar: Azm: -45

Δx: Δy: Δz: 10

Directives in geometry: warnings

- `$start_expansion` and `$start_translat` are applied at intialisation
  → no CPU penalty

  `$start_transform` is applied runtime
  → some CPU penalty

- One can nest the different directives (at most one per type) but, no matter the input order, the adopted sequence is always the following:

```
$start_transform
   $start_translat
         $start_expansion
         ...
         $end_expansion
   $end_translat
$end_transform
```

The ROTPRBIN card

The `ROTPRBIN` card

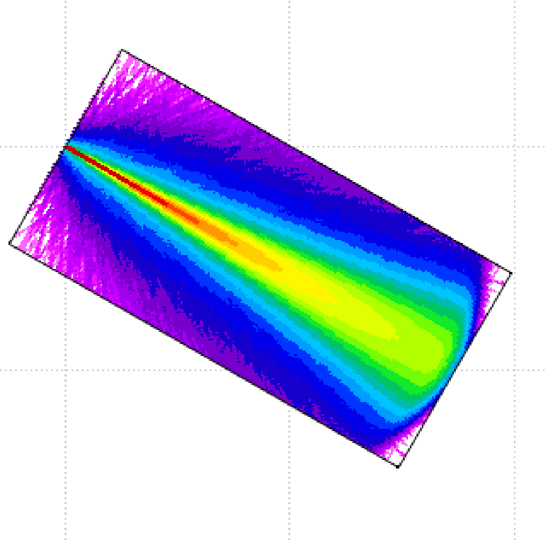
- Consider the following problem:
  - Pencil beam impinging on a cylindrical target
  - Using the R-Φ-Z USRBIN scoring, for symmetry
  - The beam and the target are rotated by 30 degrees around the **y** axis

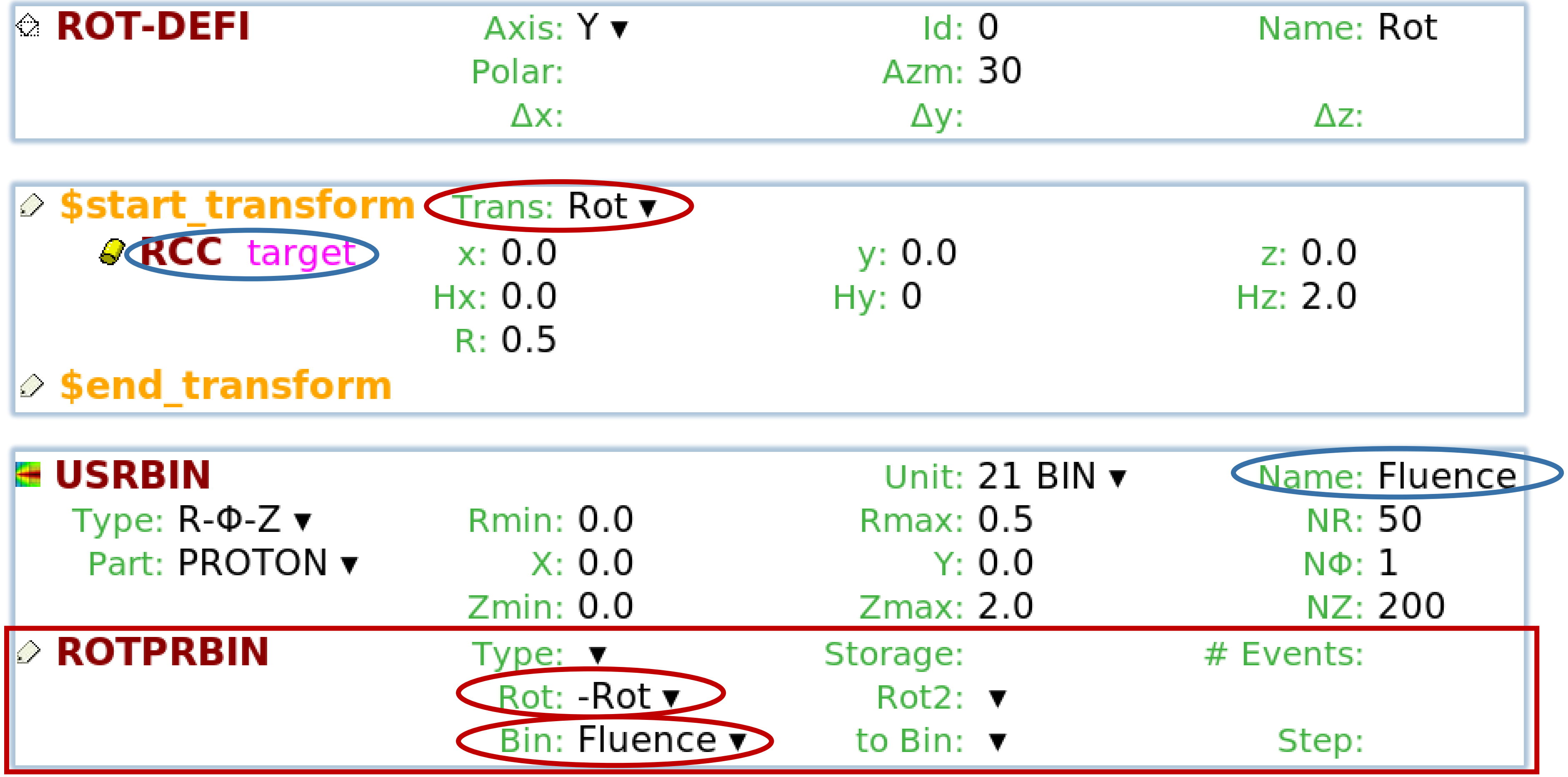
- Solution: **`ROTPRBIN`** card
  - Allows to apply a roto-translation transformation (**`ROT-DEFIni`** cards) to **`USRBIN`** or **`EVENTBIN`** scorings

  - **Important:** In the **ROTPRBIN** card, the **transformation which is specified is NOT the usual placement of the mesh in the lab frame of reference** (i.e., the transformation: lab frame of reference → mesh frame of reference), but its **inverse**.

The `ROTPRBIN` card

- Example: **Both** the "target" solid and the "Fluence" mesh are rotated with "Rot":





```
ROT-DEFI                Axis: Y ▾            Id: 0              Name: Rot
                        Polar:               Azm: 30
                        Δx:                  Δy:                Δz:

$start_transform        Trans: Rot ▾
    RCC  target         x: 0.0               y: 0.0             z: 0.0
                        Hx: 0.0              Hy: 0               Hz: 2.0
                        R: 0.5
$end_transform

USRBIN                                       Unit: 21 BIN ▾     Name: Fluence
  Type: R-Φ-Z ▾         Rmin: 0.0            Rmax: 0.5          NR: 50
  Part: PROTON ▾        X: 0.0               Y: 0.0             NΦ: 1
                        Zmin: 0.0            Zmax: 2.0          NZ: 200
ROTPRBIN                Type: ▾              Storage:           # Events:
                        Rot: -Rot ▾          Rot2: ▾
                        Bin: Fluence ▾       to Bin: ▾          Step:
```

Solid placement:
Call "Rot"

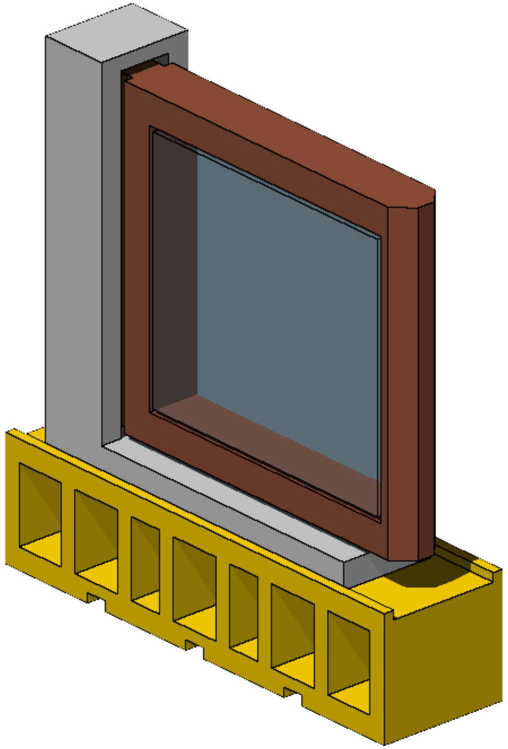
Mesh placement:
Call "- Rot"

Building modular geometries

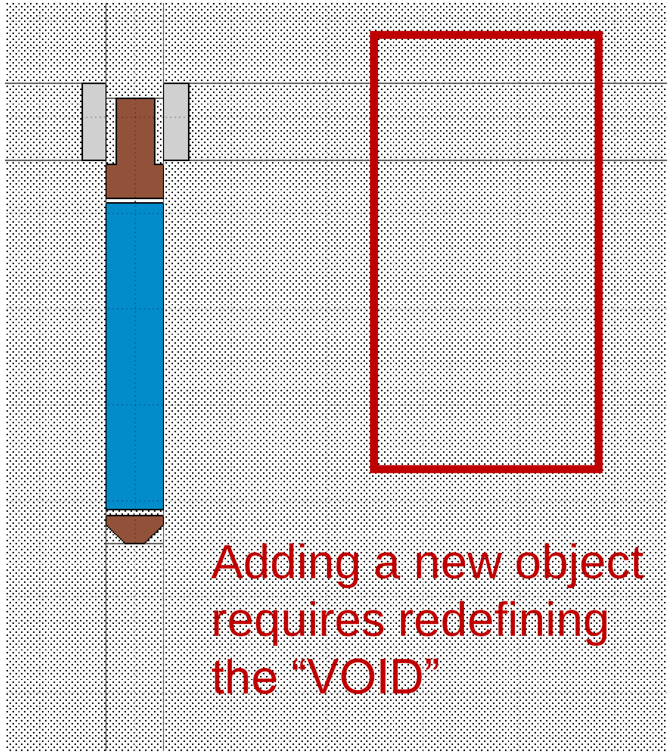
Bounding box

In the geometry lectures we saw that defining the “VOID” around objects can be quite difficult

Complex object

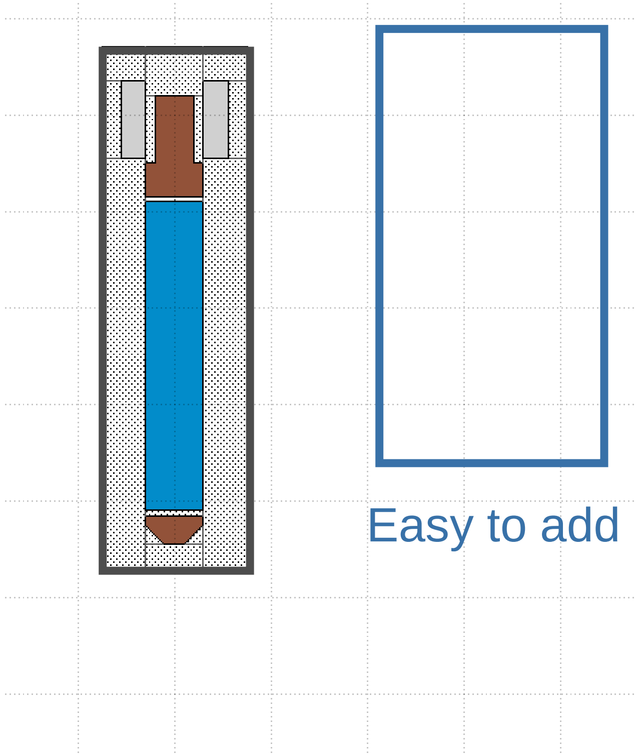


Complex “VOID”



Adding a new object requires redefining the “VOID”

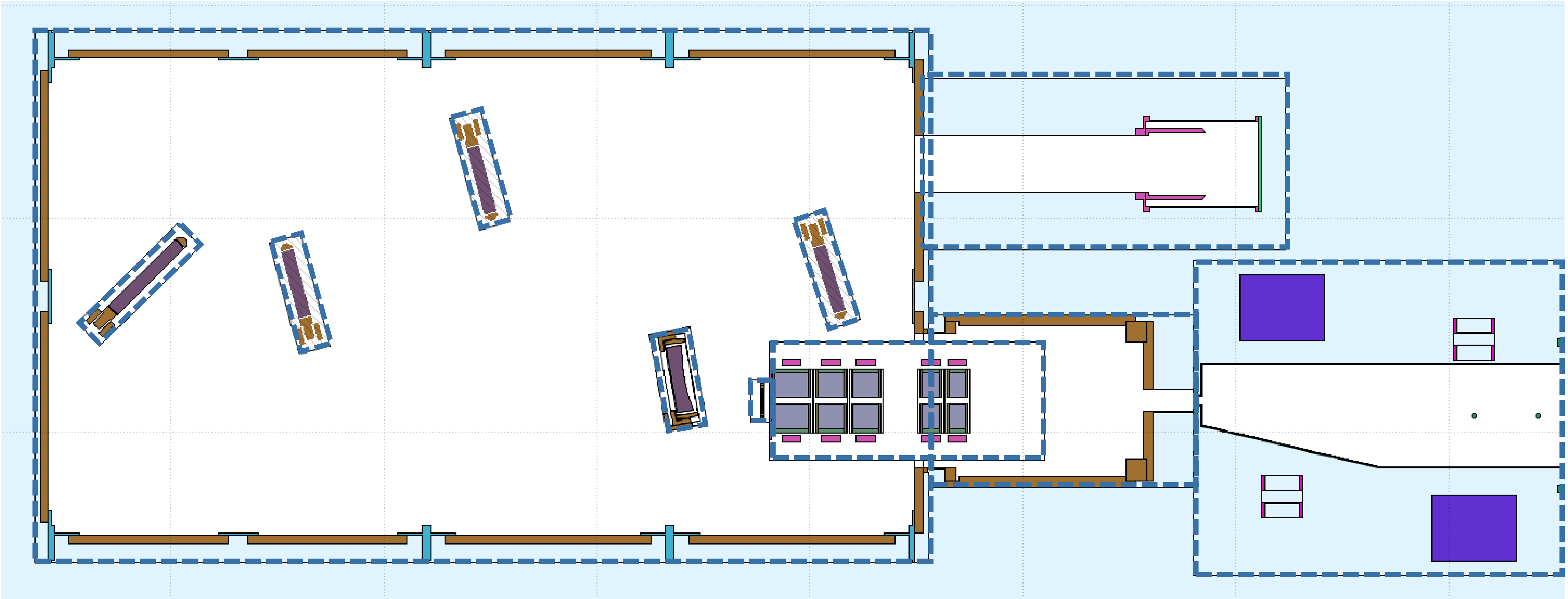
Solution: the Bounding Box



Easy to add

Good practice: use a finite body (**RPP**, **RCC**, etc.) as a **container** for the whole object

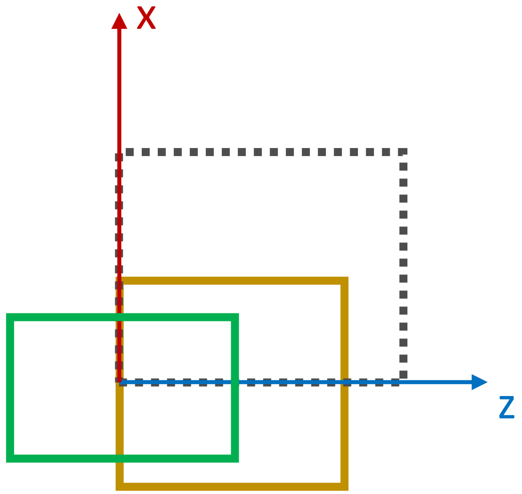
Bounding box

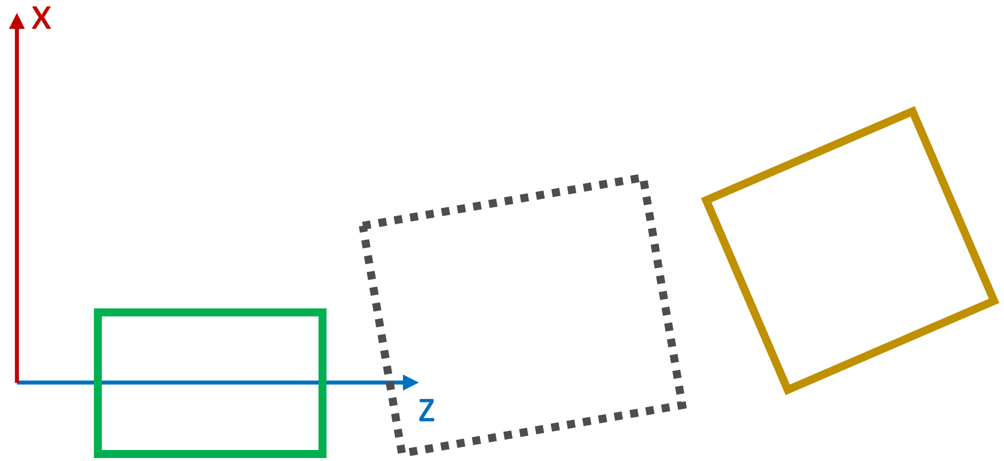


Only the Bounding Boxes have to be subtracted from the surrounding regions

Object location

- It is always easier to build an object around the origin:
  - It makes possible to use measurements from technical drawings directly
  - The final object can be translated / rotated into its final position with geometry directives





Naming conventions

- If multiple people are working on a complex geometry (multiple experimental halls and beamlines) it could happen that a body or region name is used twice, which leads to geometry errors

- Solution: agree on a naming convention, e.g. set prefixes for each object

- For example:
  - 1st character: Beamline
  - 2nd character: Object type
  - 3rd character: Object number
  - 4th-8th character: Free

Summary

- The **ROT-DEFI** card defines roto-translations

- Geometry directives (inside the geometry input) manipulate bodies

  -
    ```
    $start_translat     $end_translat
    $start_transform    $end_transform
    $start_expansion    $end_expansion
    ```

- The **ROTPRBIN** card sets the correspondence between a roto-translation transformation and selected **USRBIN** and **EVENTBIN** scorings

- Tips on how to more easily build complex geometries

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