ESSnuSB coordinate systems

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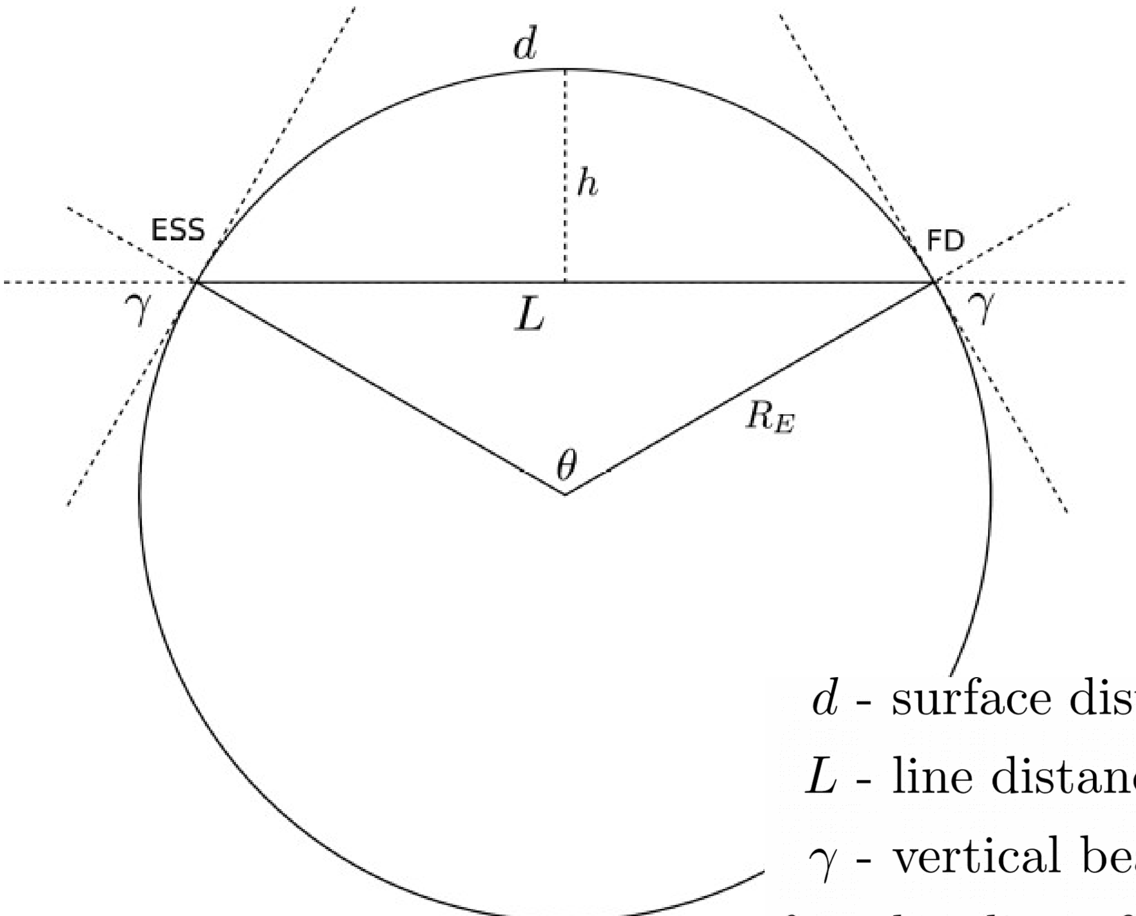
Before you start solving a problem, always draw a picture and define your coordinate system.

Every professor during my undergrad study

Beamline



d - surface distance from TS to FD

L - line distance from TS to FD (this is **the baseline**)

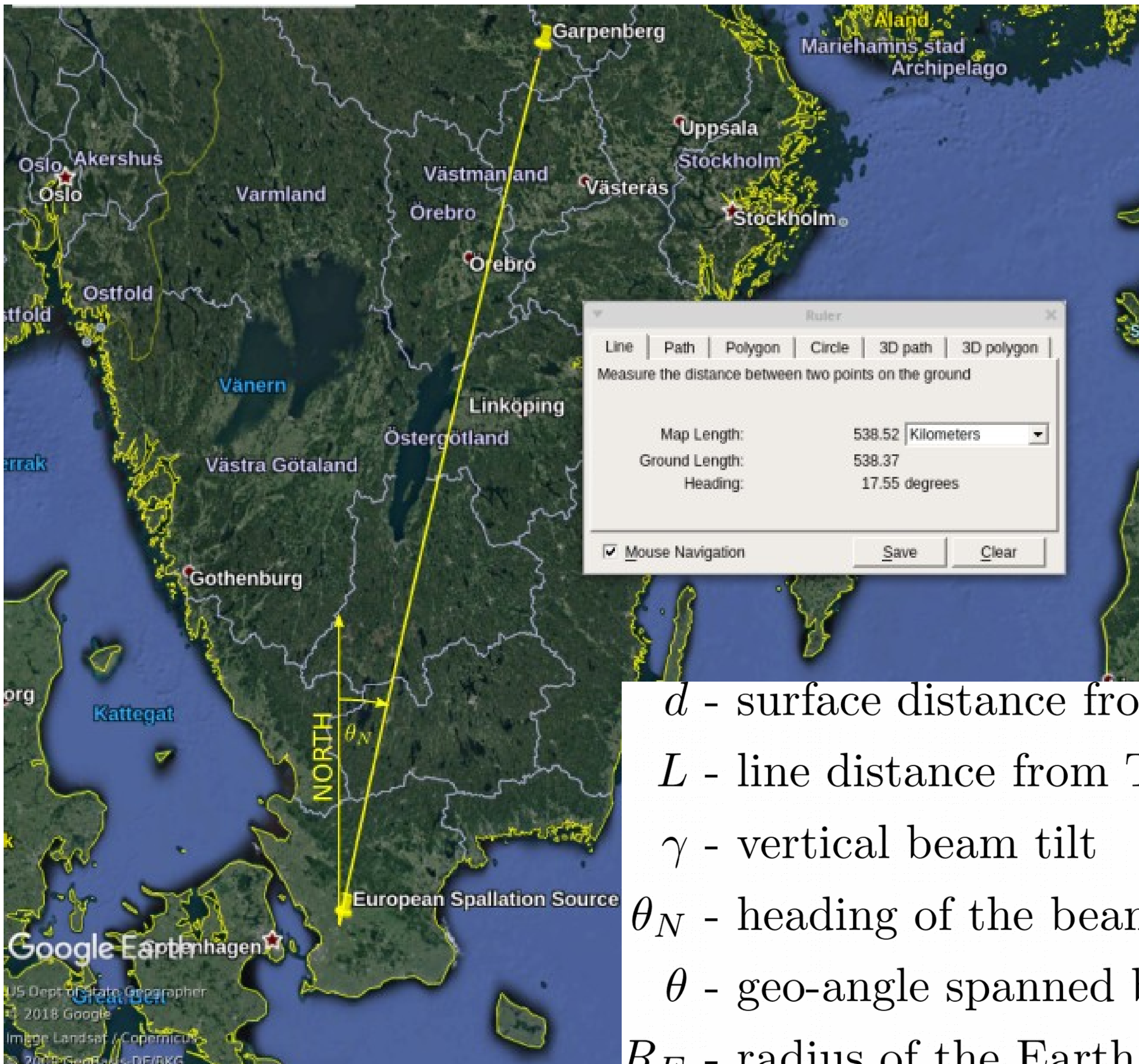
γ - vertical beam tilt

θ_N - heading of the beam

θ - geo-angle spanned between TS and FD

R_E - radius of the Earth

Beamline



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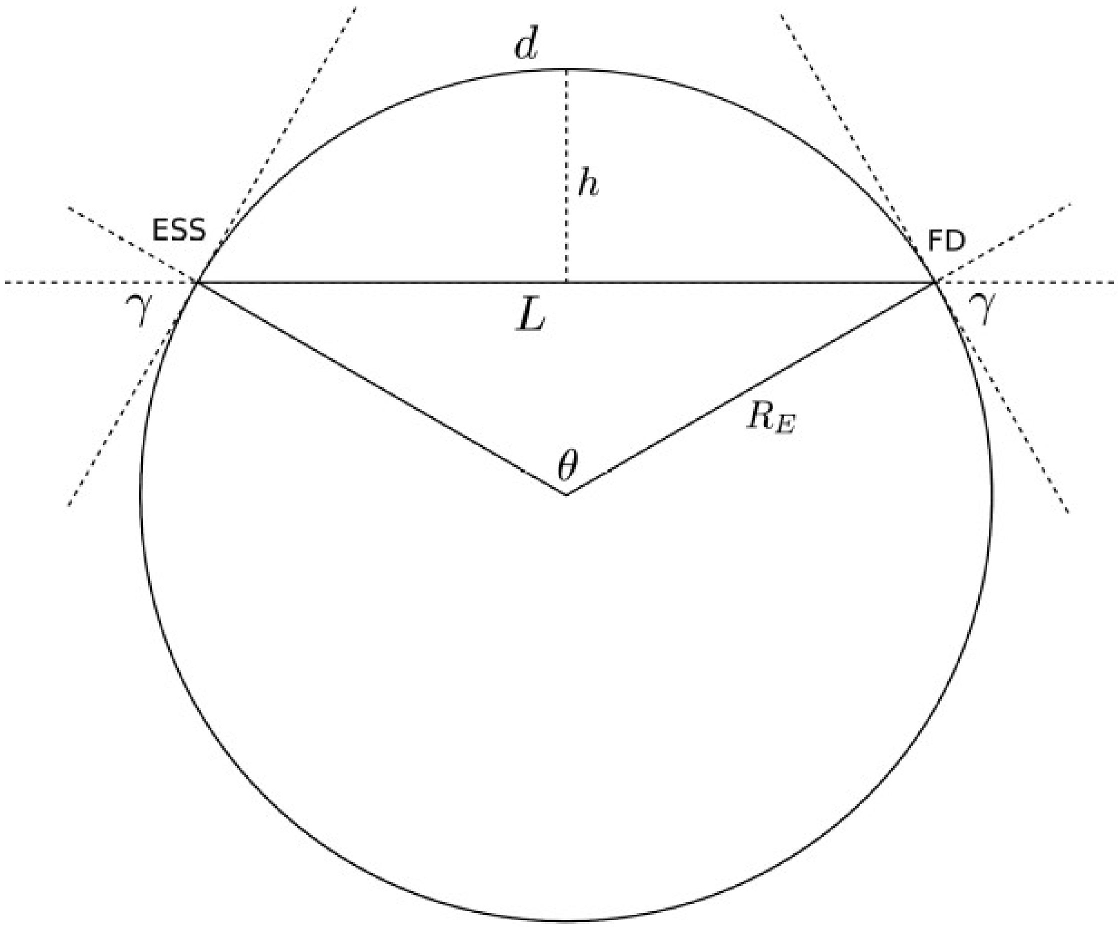


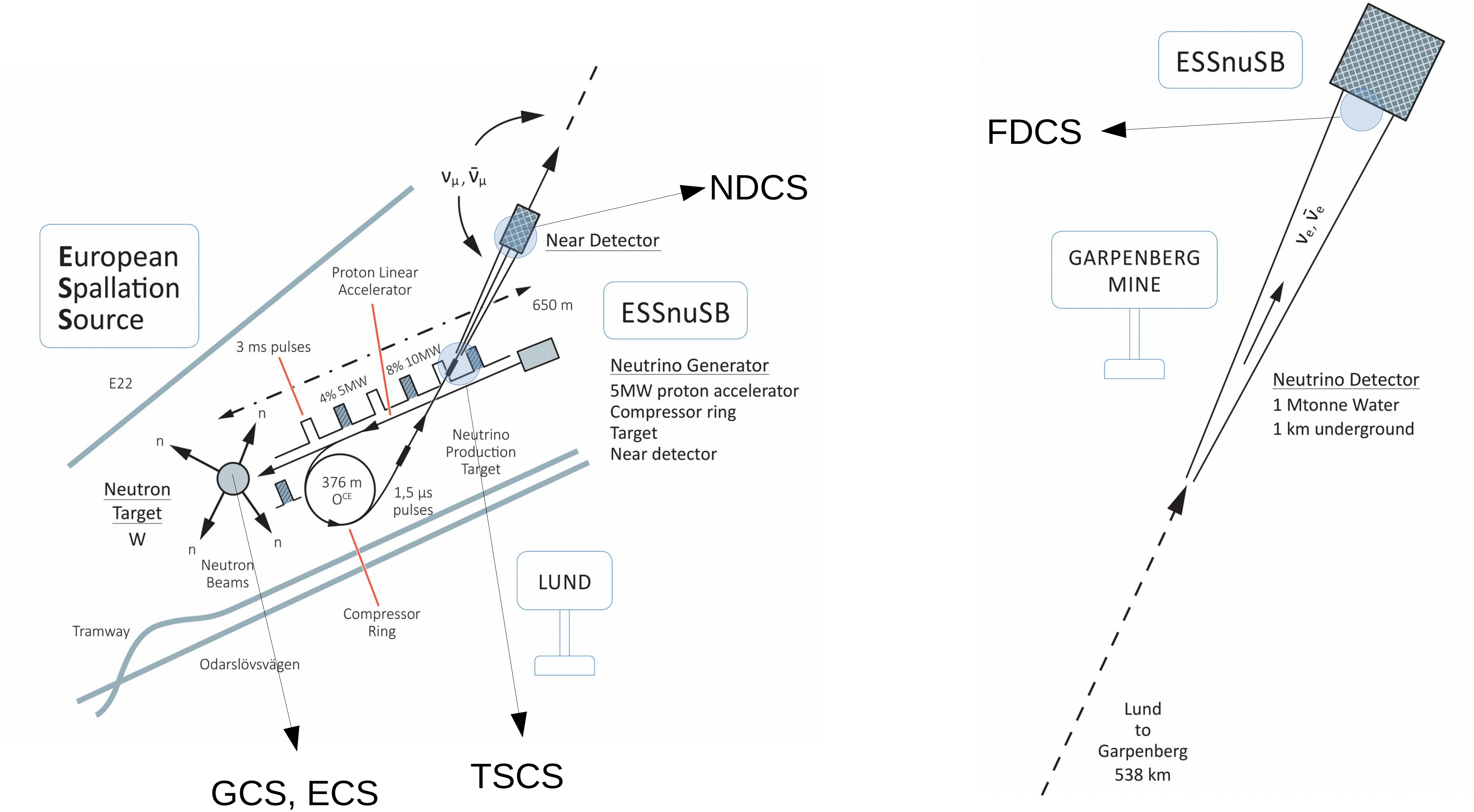
Input

$$d \approx 538 \text{ km}$$
$$R_E \approx 6471 \text{ km}$$
$$\theta_N \approx 17.5^\circ$$

Calculated

$$L \approx 537.84 \text{ km}$$
$$\gamma \approx 0.042 \text{ rad} \approx 2.42^\circ$$
$$h \approx 5.68 \text{ km}$$

ESSnuSB layout (by Colin)



Design considerations

- It must be extremely easy and unambiguous to apply CS to CS transformations given transformation parameters
- Main idea: define global coordinate system (GCS) and place all others in it
  - GCS must be indepentend of ESSnuSB design
  - GCS must be defined within the existing ESS coordinate system
- Conventions used in the CS transformations must be the same as those of ESS
- All predefined local CS:
  - must be right-handed
  - y-axis must point up, z axis must be horizontal and pointing (almost) in the direction of the beam
  - The origin must be on the central beam axis. This was before we considered off-axis detector placement, will change.

Global coordinate system

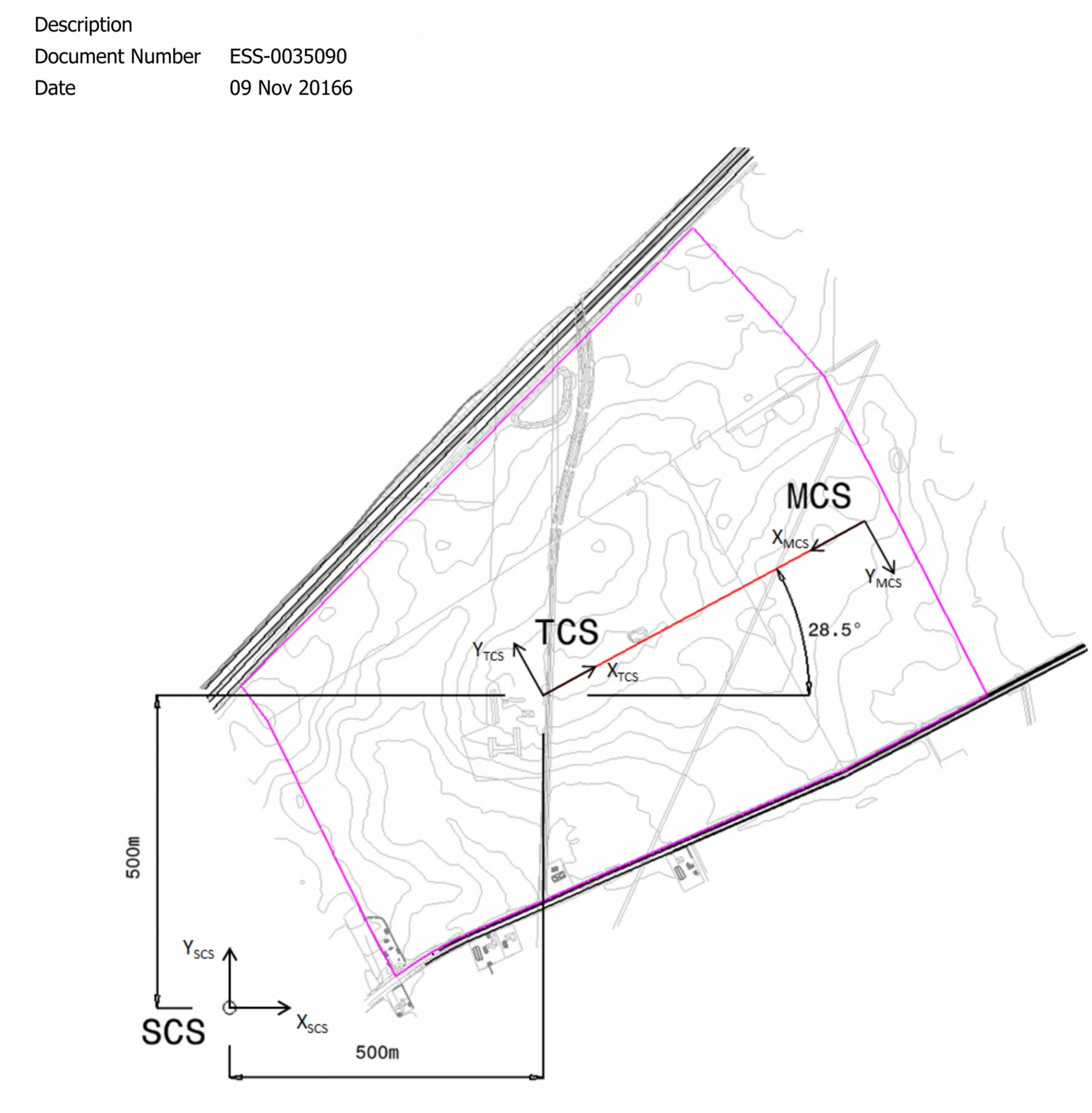


Figure 3. View of the TCS, the MCS and the SCS on the ESS site

- ESSnuSB GCS is the same as ESS TCS (Target Coordinate System)
- Defined as:
  - origin in the center of ESS target
  - z-axis points up
  - x-axis opposite to the direction of proton beam
  - y-axis to make right-handed CS

Proposed ESSnuSB local CSs

- Earth coordinate system (ECS)
  - origin as GCS, y-up, z-north, x-east
- Accumulator ring (ACCS)
- Target station (TSCS)
- Near detector (NDCS)
- Far detector (FDCS)

Definition of LCS

- A local CS is defined within the global CS by position vector transformation

$$\vec{r}_{\mathrm{G}} \equiv R_{\mathrm{L}}\,\vec{r}_{\mathrm{L}} + \vec{T}_{\mathrm{L}}$$

Position in LCS

Position in GCS

3x3 rotation matrix
(special orthogonal)

Displacement of origin

Inverse formulae

- Global to local

$$\vec{r}_{\mathrm{L}} = R_{\mathrm{L}}^{-1}\left(\vec{r}_{\mathrm{G}} - \vec{T}_{\mathrm{L}}\right)$$

- Local A to local B

$$\vec{r}_{\mathrm{B}} = R_{\mathrm{B}}^{-1}\left(R_{\mathrm{A}}\vec{r}_{\mathrm{A}} + \vec{T}_{\mathrm{A}} - \vec{T}_{\mathrm{B}}\right)$$

All you need to know.

Transformation parameters

- Rotation matrices in ESSnuSB are defined by 9 real numbers
  - not by 3 Euler angles, to avoid confusion
- Translation vectors are given in **mm**
- They can be obtained from:
  - geodetic measurements - later in the project
  - calculated from some parameters

Preliminary parametrization of ESSnuSB CSs

The transformations are defined using these parameters:

- $\theta_E = +28.5°$ - angle defining the ECS defined in [1].
- θ_N - heading of the ESSnuSB beam as defined in [2].
- γ - angle between the beam axis and the horizontal plane as defined in [2].
- $\vec{T}_{\mathrm{TS}} = \begin{pmatrix} T_{\mathrm{TS}x} \\ T_{\mathrm{TS}y} \\ T_{\mathrm{TS}z} \end{pmatrix}$ - origin of the Target Station as seen from the ESS TCS coordinate system [3].
- L_{ND} - distance along the neutrino beam axis between Target Station coordinate system (TSCS) and Near Detector coordinate system (NDCS) origins.
- L_{FD} - distance along the neutrino beam axis between Target Station coordinate system (TSCS) and Far Detector coordinate system (FDCS) origins.

See: http://essnusb.eu/docdbprivate/ShowDocument?docid=111

Coordinate system drift

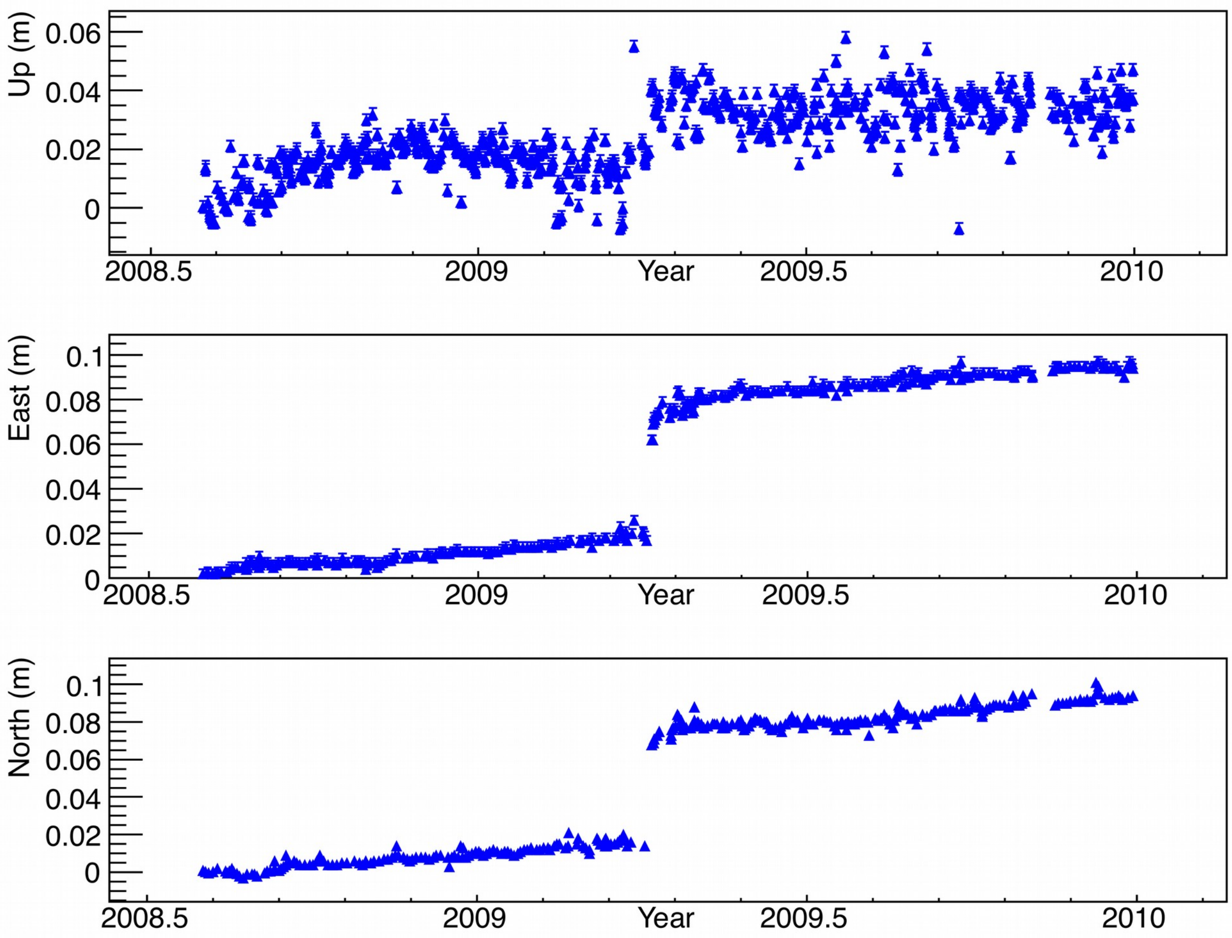


Figure 7. Monitoring of the PolaRx2e GPS antenna position at LNGS showing the slow earth crust drift and the fault displacement due to the 2009 earthquake in the L'Aquila region. Units for the horizontal (vertical) axis are years (metres).

Shoud be kept in mind...

OPERA Collaboration, JHEP 1210 (2012) 093, DOI: 10.1007/JHEP10(2012)093, e-Print: arXiv:1109.4897 [hep-ex]

In short

- You have a vector in CS A and you want it in CS B

$$\vec{r}_{\mathrm{B}} = R_{\mathrm{B}}^{-1}\left(R_{\mathrm{A}}\vec{r}_{\mathrm{A}} + \vec{T}_{\mathrm{A}} - \vec{T}_{\mathrm{B}}\right)$$

$\vec{r}_A, \vec{r}_B$ - 3 component column vectors in CS A, B

$R_{\mathrm{A}}, R_{\mathrm{B}}$ - 3x3 matrices defining CS A, B

$\vec{T}_{\mathrm{A}}, \vec{T}_{\mathrm{B}}$ - 3 component column vectors defining CS A, B

Distances are in **mm**

Conclusions

- **It very important for everybody in ESSnuSB project to use the same coordinate system scheme**
- All details can be found in the notes:
  - ESSnuSB coordinate systems

  http://essnusb.eu/docdbprivate/ShowDocument?docid=102
  - ESSnuSB baseline

  http://essnusb.eu/docdbprivate/ShowDocument?docid=103
  - ESSnuSB CS parametrization

  http://essnusb.eu/docdbprivate/ShowDocument?docid=111
  - ESS coordinate systems

  http://essnusb.eu/docdbprivate/ShowDocument?docid=105
  - ESS CS transformations

  http://essnusb.eu/docdbprivate/ShowDocument?docid=106

The end