Application of MWPC based muography in geophysics, experiments and planning

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EGU General Assembly 2024

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REGARD
RMKI ELTE Collaboration
on Gaseous Detector
Research and Development

1. HUN-REN Wigner Research Centre for Physics
2. Eötvös Loránd University, Faculty of Science, Department of Geophysics and Space Science

Table of contents

Muography

1911: Victor Hess: Cosmic ray

Primarily and secondary particles

1936:C. D. Anderson: muon identification

1970: L.Alvarez: first muography experiment

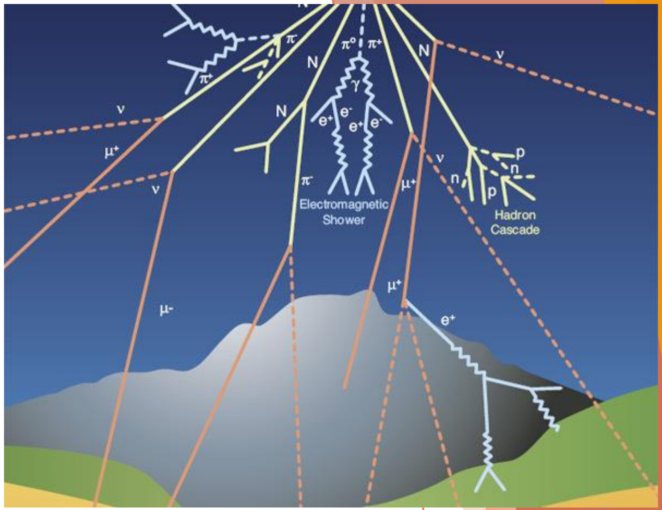
Its characteristics :

- wide energy spectrum
- slow energy loss (Bethe-Bloch formula->$\Delta E \sim \rho l$)
- **The energy loss is proportional to the density of the rock and the trajectory length in the rock**

The muonfield: F = $N/(t\Omega A)$

Muon flux on ground roughly: F= $F_0 \cos^2 \vartheta$ (100/ sec/m^2)

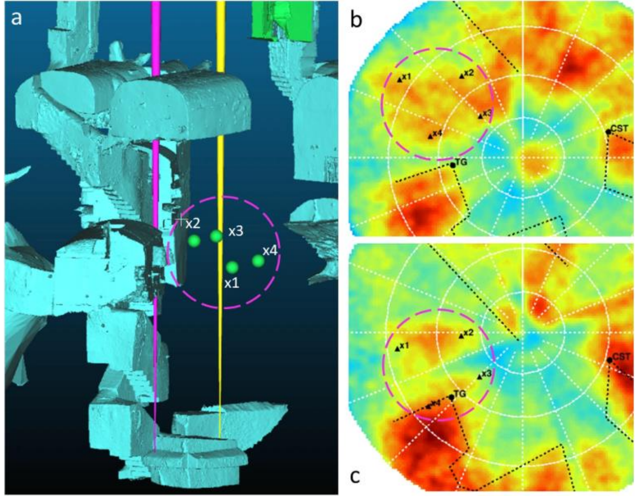
Muography uses cosmic muons to image the internal density structure of large objects.



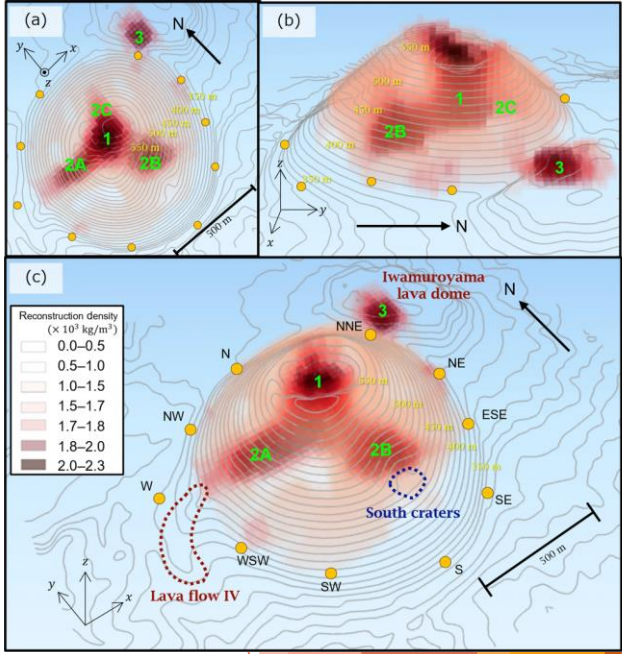
Cosmic rays[2]

Muography application

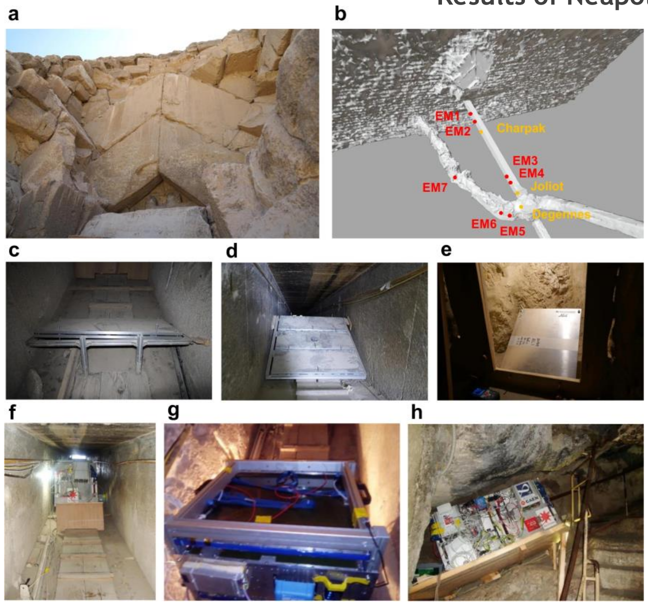
- Vulcanology
- Speleology
- Mining
- Archaeology application
- Structural analysis
- Monitoring



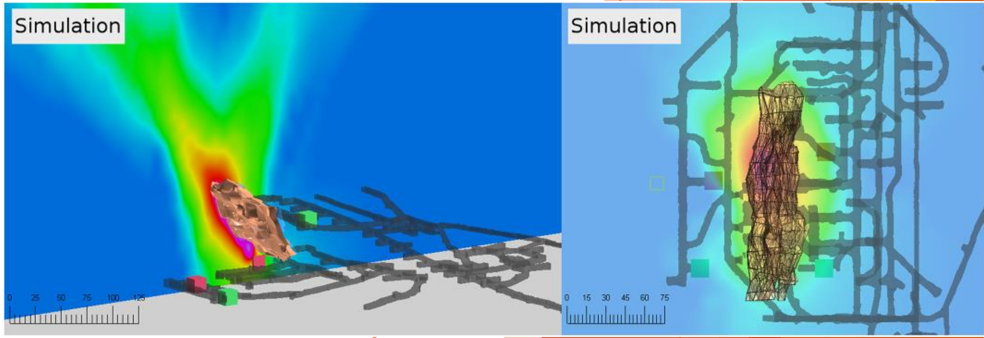
Results of Neapolis (Naples) measurements[3]



3D density tomography of Omuroyama scoria cone[4]



Archeology measurements in the Khufu's Pyramid[5]



Simulate data of uranium deposit[6]

HUN-REN Wigner Group from Hungary

Country	Mining	Target
Finland	Kemi chromium mine	granite and ore bedrock localization (2.3-3.3g/cm3; 2.65g/cm3)
Hungary	Janossy underground laboratory	test site, hidden inhomogeneities
Hungary	Királylaki tunnels	unknown caves, hidden inhomogeneities
Hungary	Esztramos mine	Well explores hill, unknown caves
Hungary	Underneath the Castle of Buda	expected medieval tunnels
Italy	Castello di Mussomeli	medieval tunnels
Japan	Sakurajima Muography Observatory	vulcanology

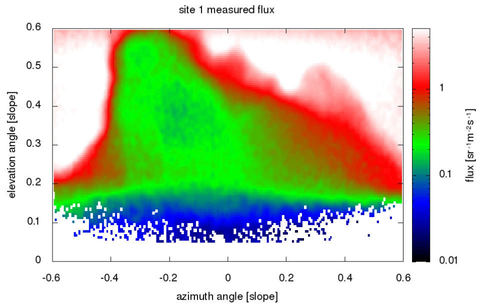
Underground measurement arrangement

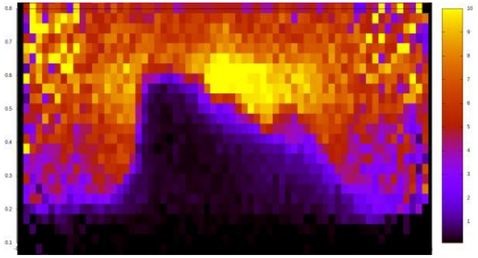
```
Load readout settings from file 'Default.rsini' ...
From event 1 the ebe file is ../Measurements/Mts8_Run120.ebe (filenumber:0)
Event 0 ,   2018-04-26_16:59:57 ,  dt : 3616236
.............................................XX............   ..........XX.............................................
.........................................XX................   ........XX...............................................
......................................X....................   ......X..................................................
...................................XX......................   ...XX....................................................
...............................XX..........................   ..XX.....................................................
............................XX.............................   X........................................................
Adc :    2464    3202    3072    3584    3084    3447
THP :  T= +19.75 oC, H= 40.0%, P= 968.0 mBar, ThpId: 0
Counter :       +19 (19)
Pattern :      Triggered on :  1 1 1 1 1 1 0 0 0 0 0 0      (ok)
```

An event

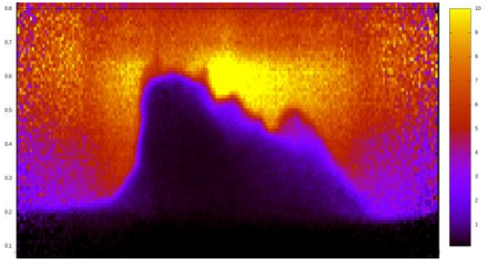
A new research group has recently been set up, the High-Energy Geophysics Research Group.

Muography Campaign Examples



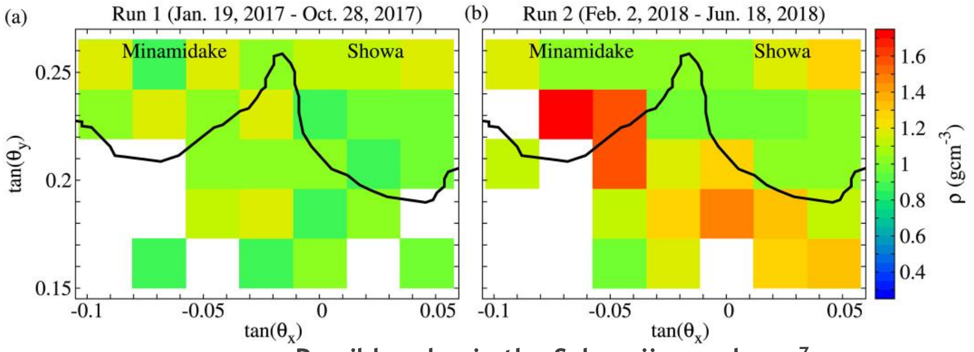


1 day



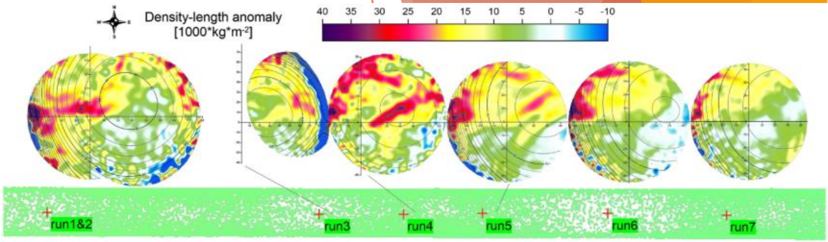
30 day

Raw data of campaign of Mussomeli castle

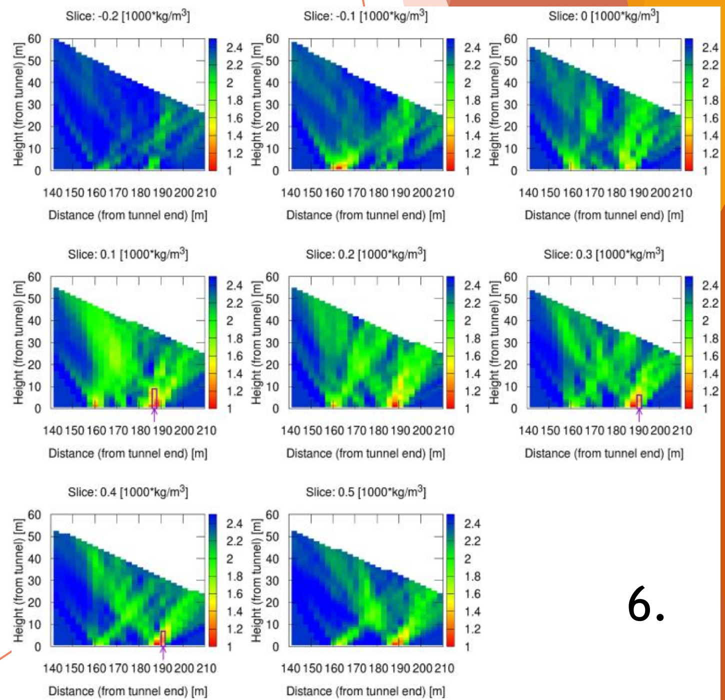


Possible plug in the Sakurajima vulcano[7]

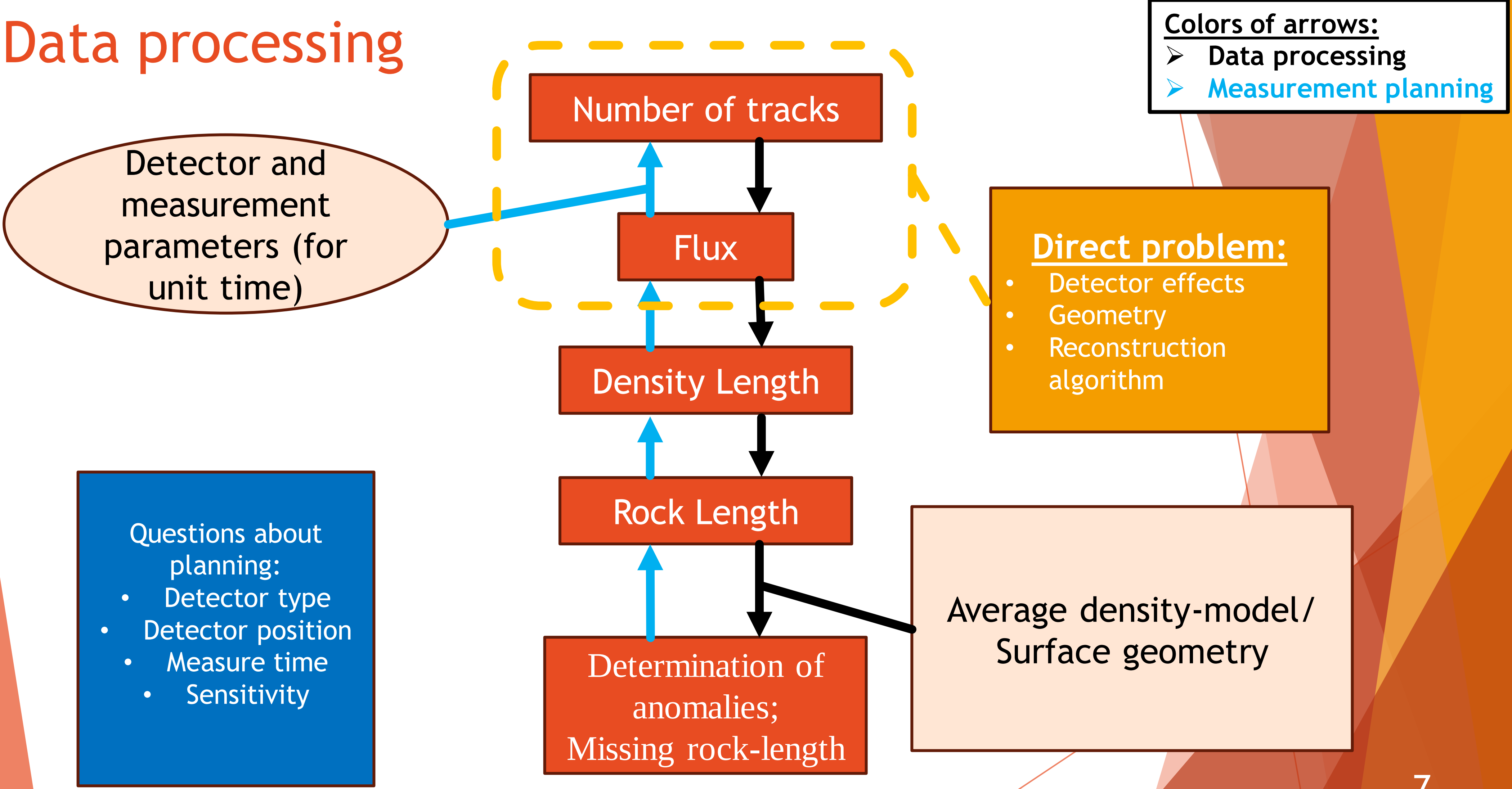
Results of campaign of Királylaki tunnel[8]



Results slices of muontomographic inversion[8]



Data processing



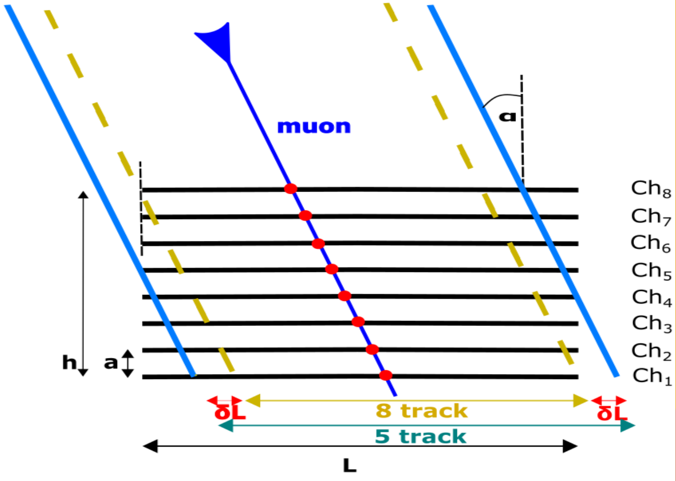
Direct problem models

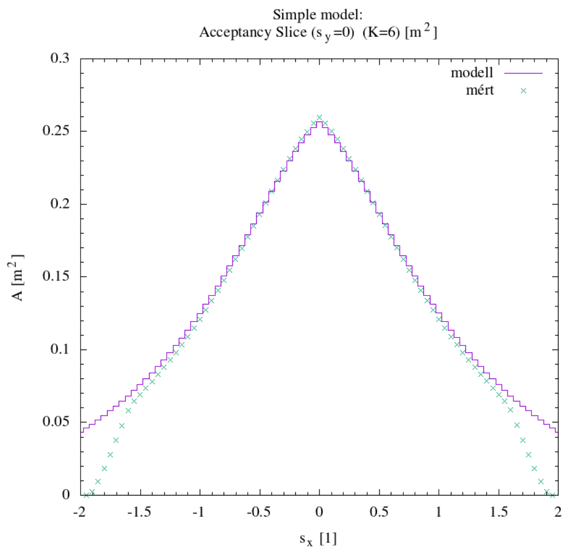
$N = Ft\Omega A_{eff}$

Equidistant model

$s_x = tan(\alpha_x)$, $s_y = tan(\alpha_y)$

$$A_{eff} = (L_x - hs_x + 2(N_K - K)as_x)(L_y - hs_y + 2(N_K - K)as_y)\frac{1}{\sqrt{1+s_x^2+s_y^2}}\eta$$





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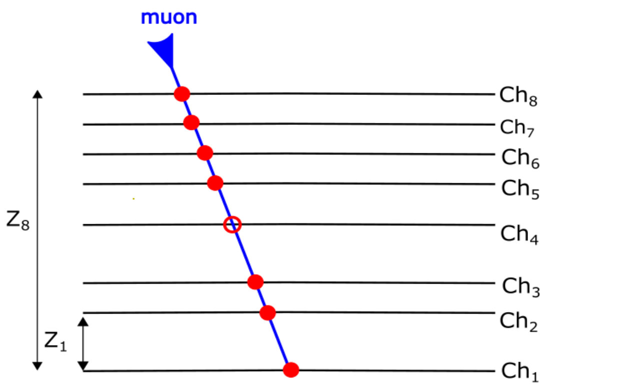
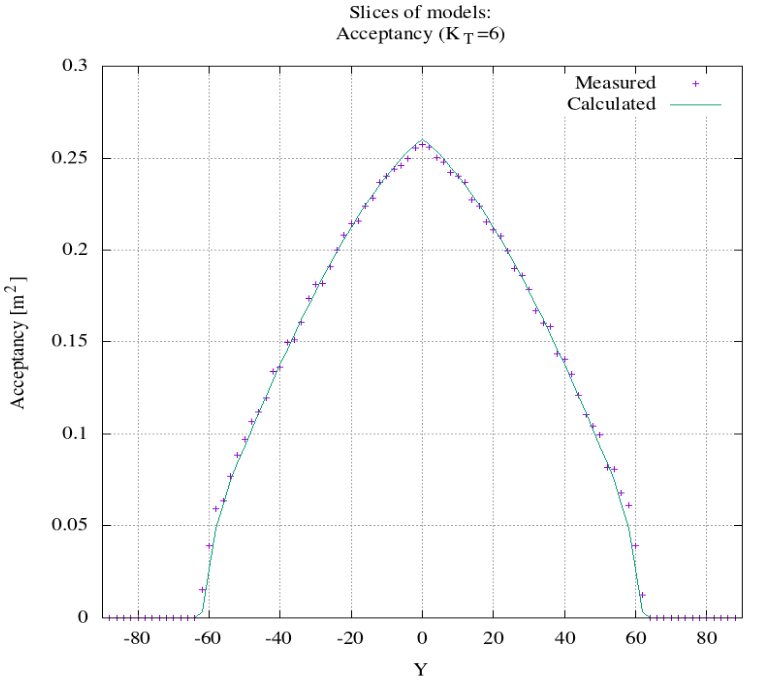
Model for general detector geometry

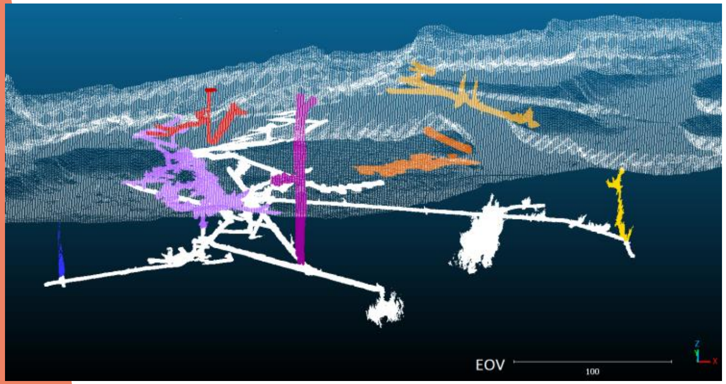
$$A_{eff} = \int_{X_{1_1}+S_{x_1}}^{X_{2_{N_K}}+S_{x_{N_k}}} \int_{Y_{1_1}+S_{y_1}}^{Y_{2_{N_K}}+S_{y_{N_k}}} \eta(x,y)\,dy\,dx \frac{1}{\sqrt{1+s_x^2+s_y^2}}$$

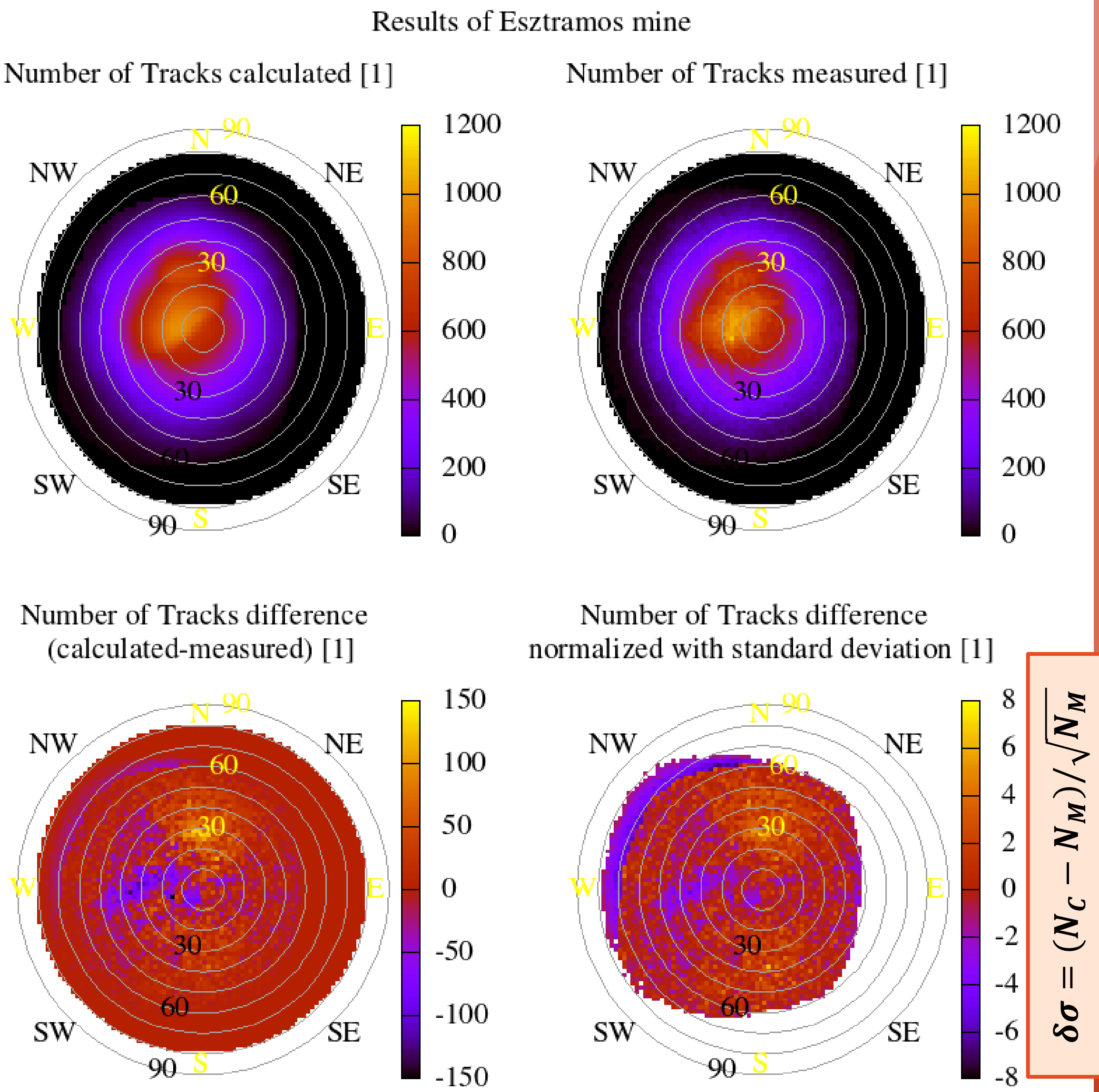




Esztramos mine

- **Goal: * Model verification on real active underground measurement;**
  ***quantitative assessment of the certainty of anomalies**
- No active mining in the mine = stable surface
- Active exploration in the mine
- A domestic measurement area





$$\delta\sigma = (N_C - N_M)/\sqrt{N_M}$$

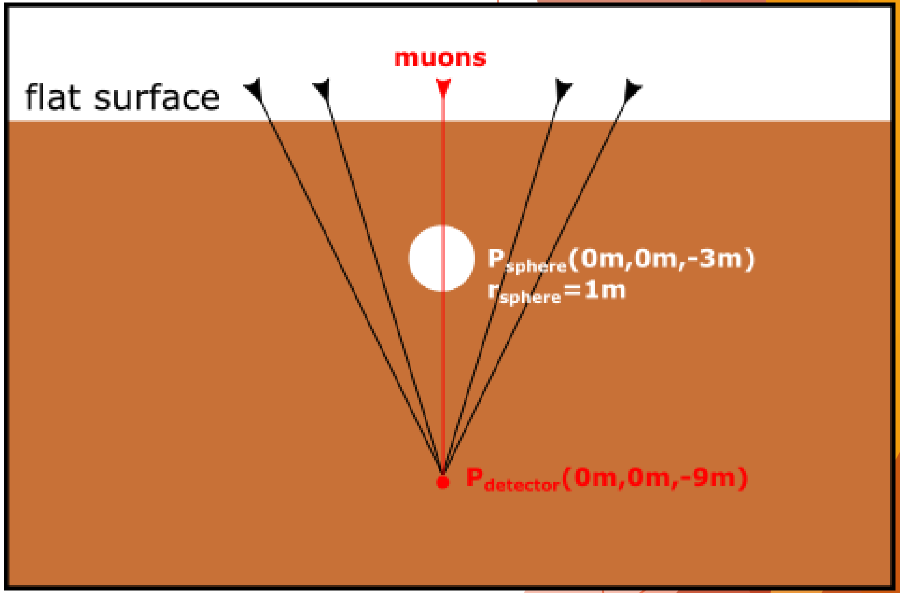
Simple model : flat surface with an anomalous sphere

- **Goal: Presenting the measurment time estimation for a simple anomaly.**
- Different geology situtations become possibly to search by this method
- We can review many questions with given series of measurement
  e.g.: What kind type of detector should we use in a measurement?

  How long do we have to measure in a position?

  Which setup can optimal ?

  What type of anomaly can we detect?
- Ground model: flat surface, homogeneous, $\rho_a = 2.4 \ g/cm^3$
- Detector type= Mtl2, Position[0,0,-9]m, Inclination=0° and Rotation=0°
- Sphere: *Position [0,0,-3]m, Radius=1m,* $\rho_{sphere} = 1 \ g/cm^3$ *(water) and* $\rho_{sphere} = 0 \ g/cm^3$ *(air)*



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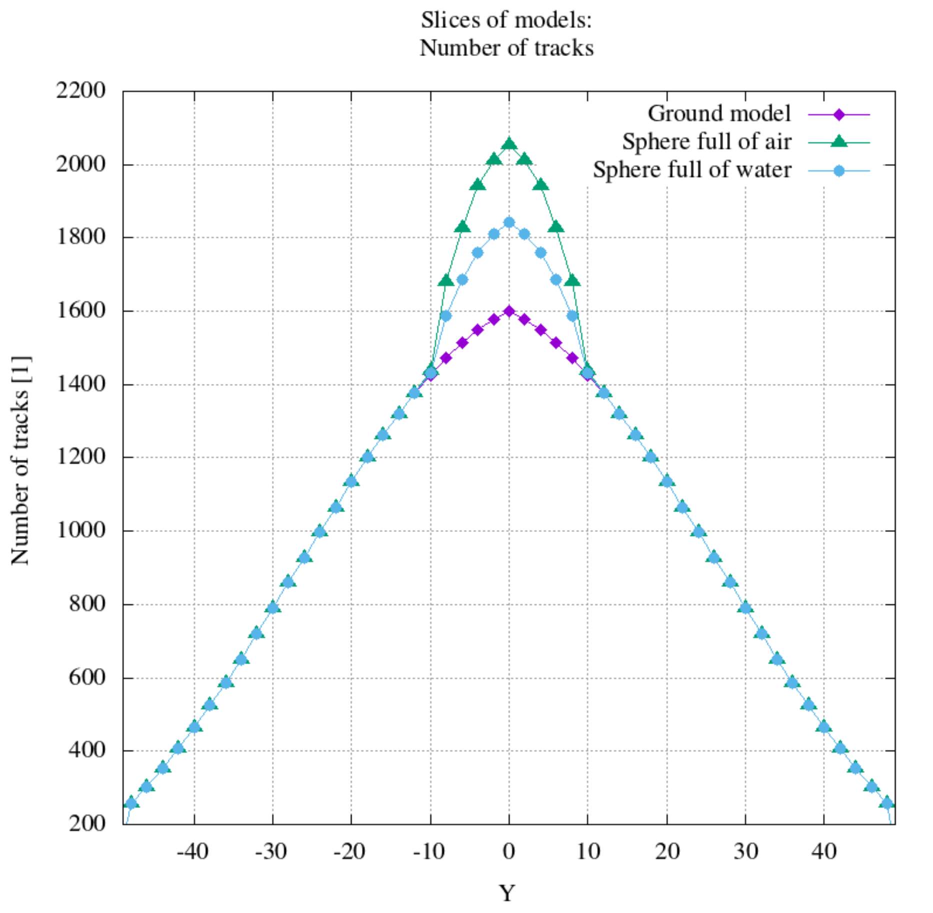

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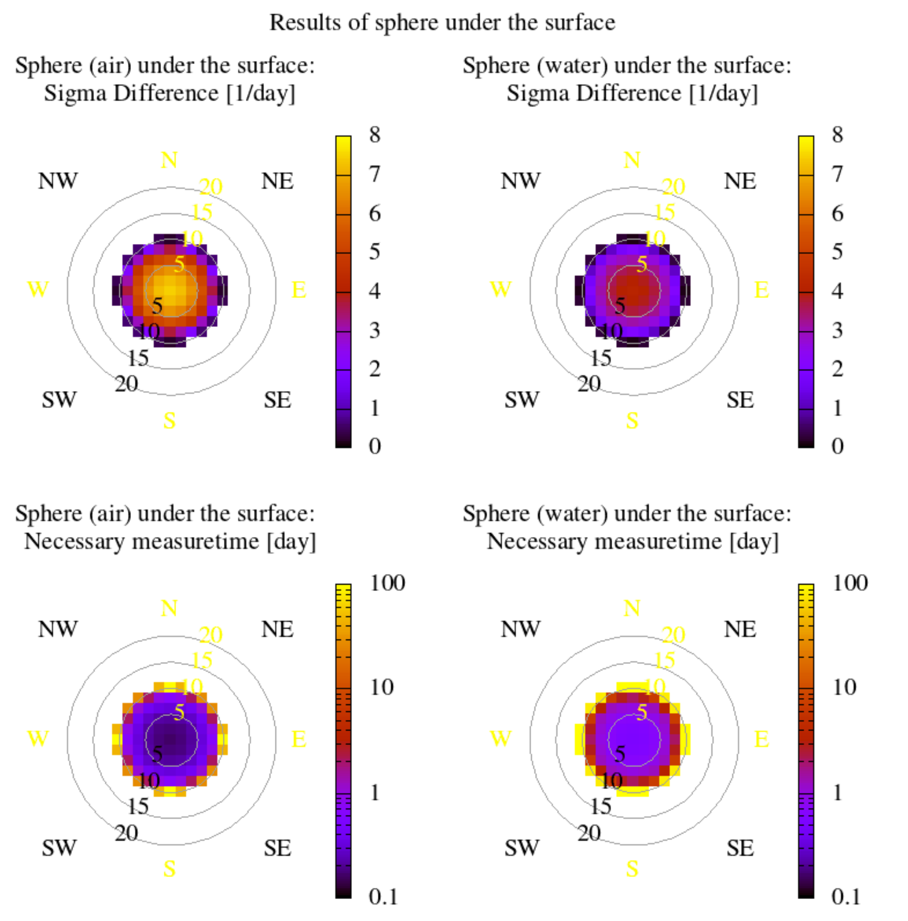
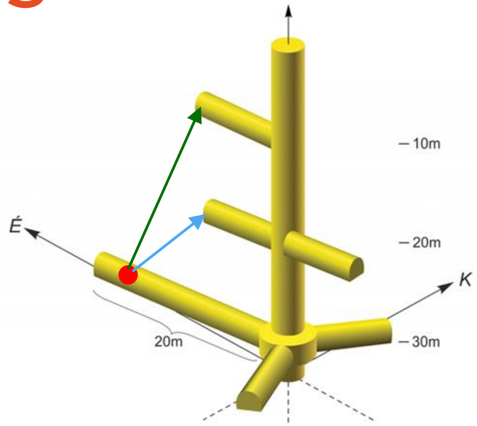
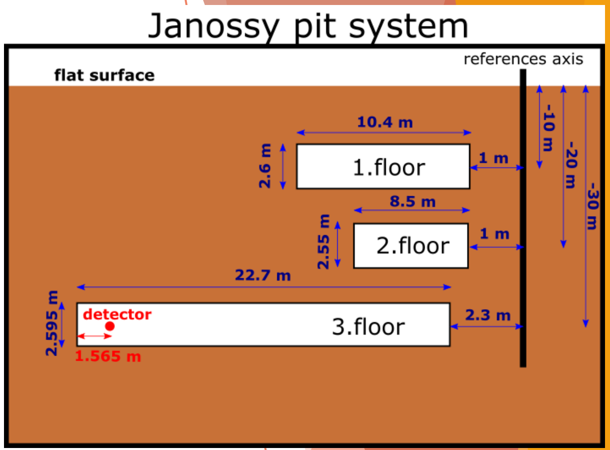


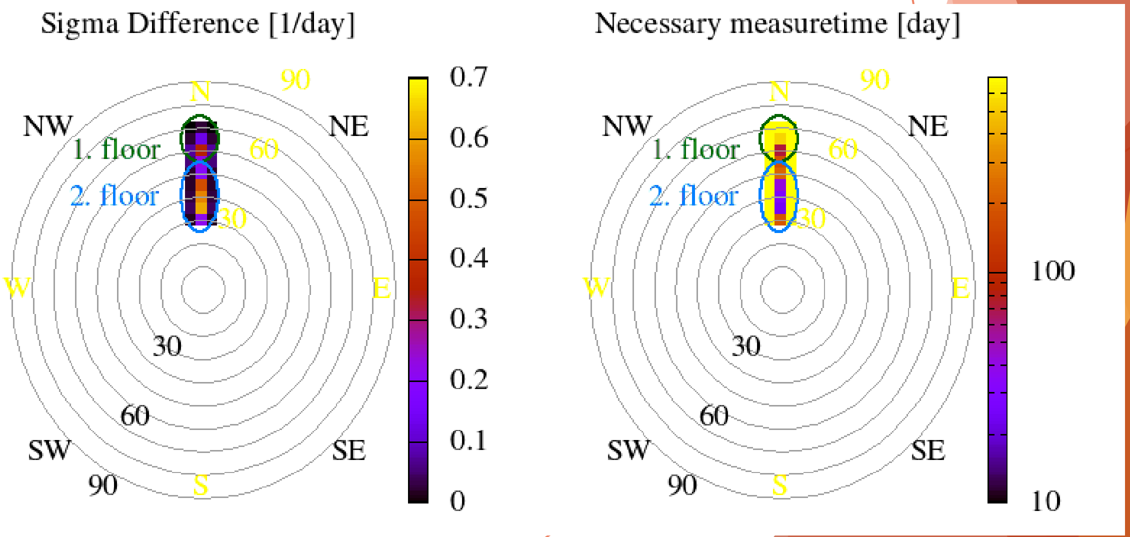
Test site: Janossy underground laboratory

- **Goal: Demonstration of time estimation for real underground measurements for known tunnels**
- Janossy underground laboratory : simple geometry (built for particle physics measurements 60 years ago)
- 3 floors:
  1. 1 tunnel at -10 m (0°)
  2. 2 tunnel at -20 m (0°, 180°)
  3. 3 tunnel at -30 m (0°, 120°, 240°)
- Mts8 detector: position: 3. floor 1. tunnel, 156.5cm from the end of the tunnel; Inclination=-45°; Rotation=-90°
- Ground model: flat surface, (NOT jet the original surface); homogeneous $\rho_a = 2.2\ g/cm^3$
- Geology model: Shape of the tunnels were modelled as cylinders. $\rho_{tunnels} = 0\ g/cm^3$



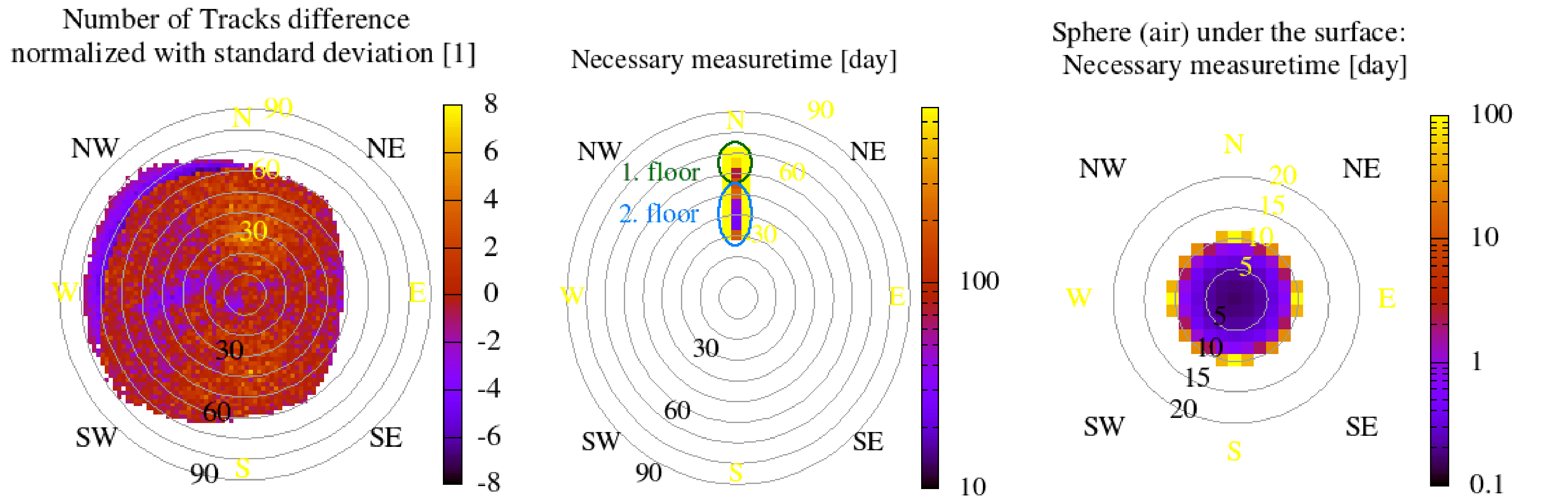
Janossy underground laboratory geometry[1]





Conclusion

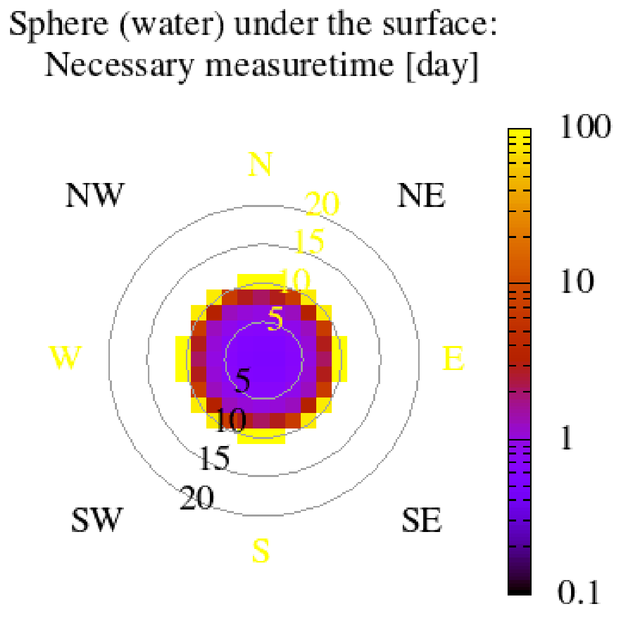
- Muography uses cosmic muons to image the internal density structure of large objects.
- Muography applications: geophysics, mining, volcanology, speleology, Archaeology, Structural analysis, Monitoring application
- Precise model for Direct problem for general geometry -> Detector Optimization (type, position, inclination, rotation), Necessary Time estimation
- Model proved for : laboratory, underground, estimation demonstration



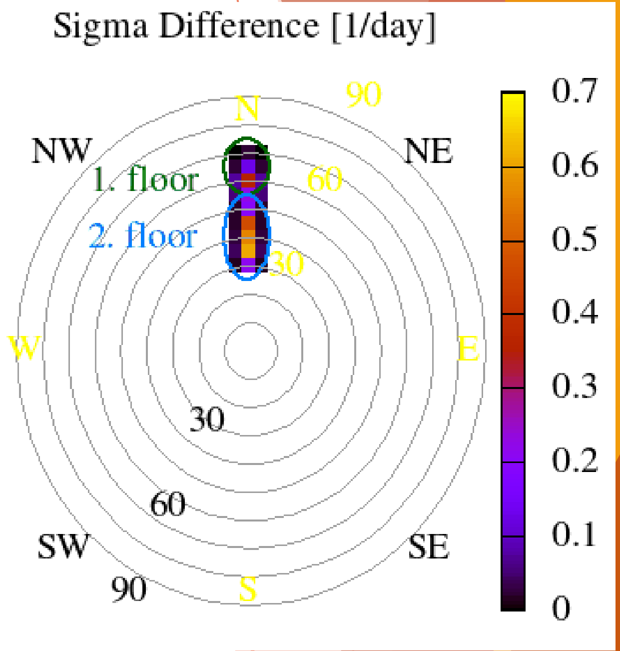
Acknowledgement

- I would like to express my special thanks of gratitude to WignerRCP, REGARD Group, Gergő Hamar and László Balázs.
- This project is supported by:

OTKA-FK135349, ELKH-KT-SA-88/2021, NKFIH-TKP2021-NKTA-10, KSZF-144/2023



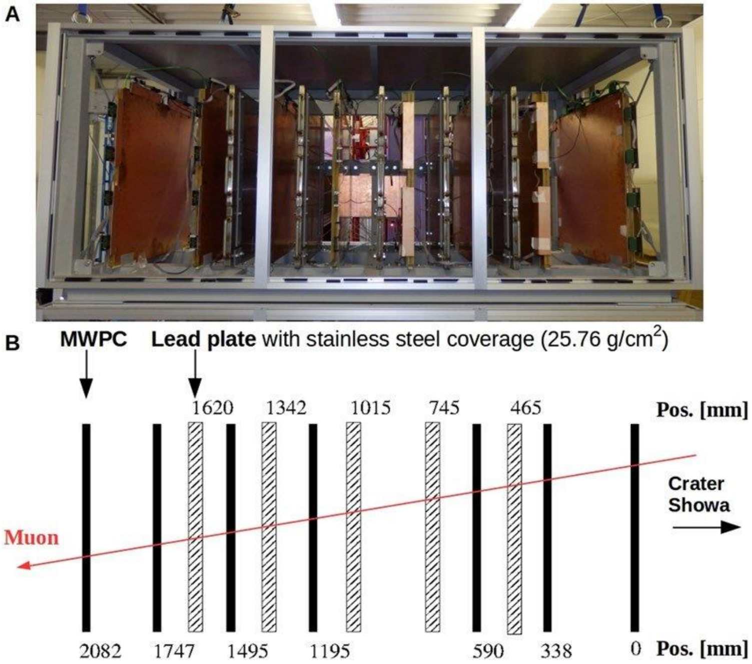
Thank you for your attention!



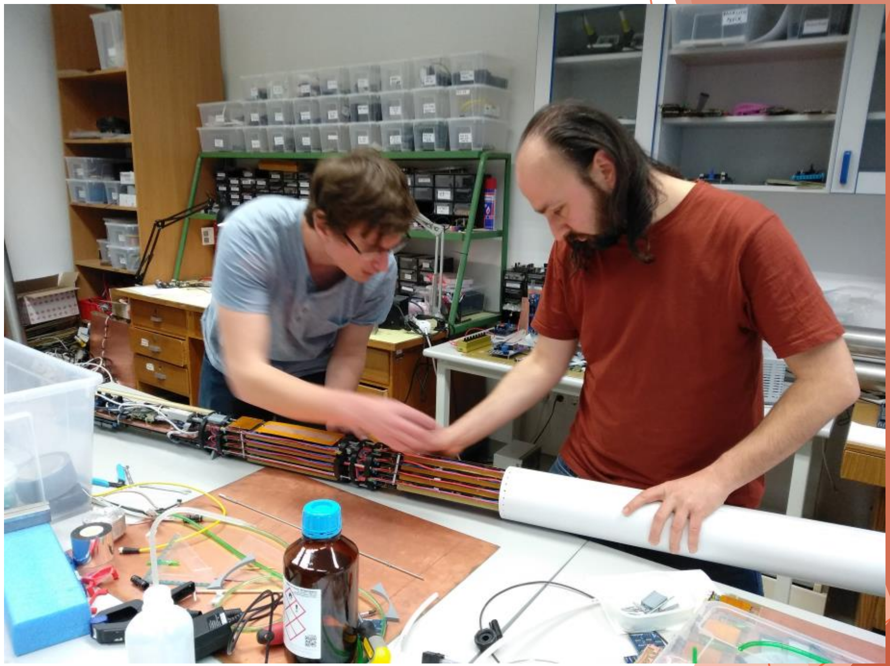
References

1. https://rtl.hu/tudomany-tech/2023/08/18/janossy-lajos-kutato-labor-akna-foldalatti
2. https://home.cern/science/physics/cosmic-rays-particles-outer-space
3. https://www.nature.com/articles/s41598-023-32626-0?fromPaywallRec=true
4. https://link.springer.com/article/10.1007/s00445-022-01596-y/figures/9
5. https://www.nature.com/articles/s41467-023-36351-0
6. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JB015626
7. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL084784
8. https://academic.oup.com/gji/article/236/1/700/7335291

Back up slides

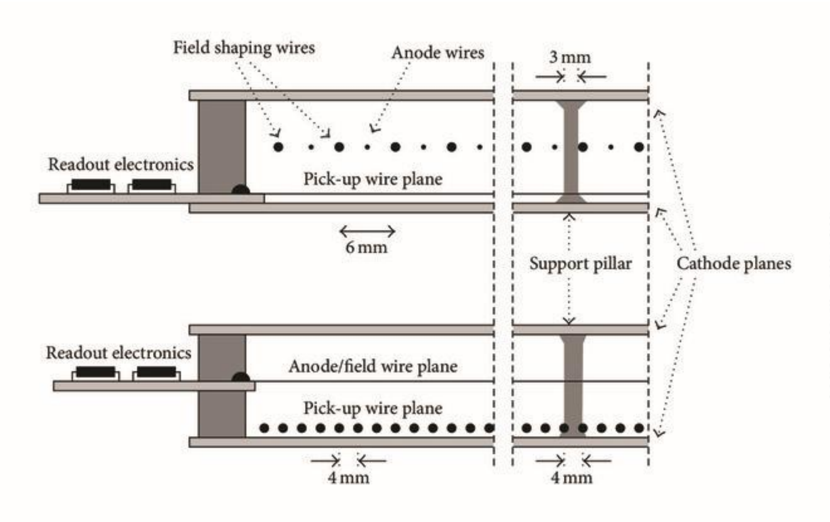


Surface measurement arrangement

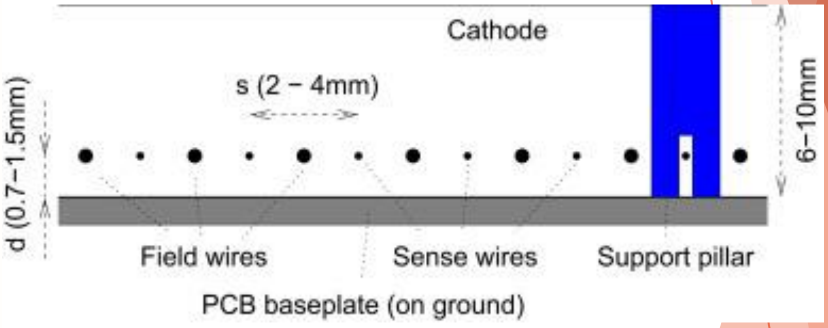


Borehole measurement arrangement

Detector types



MWPC



CCC

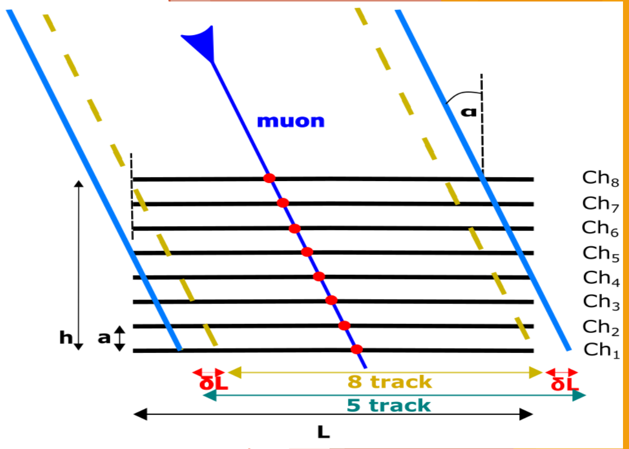
Direct problem models

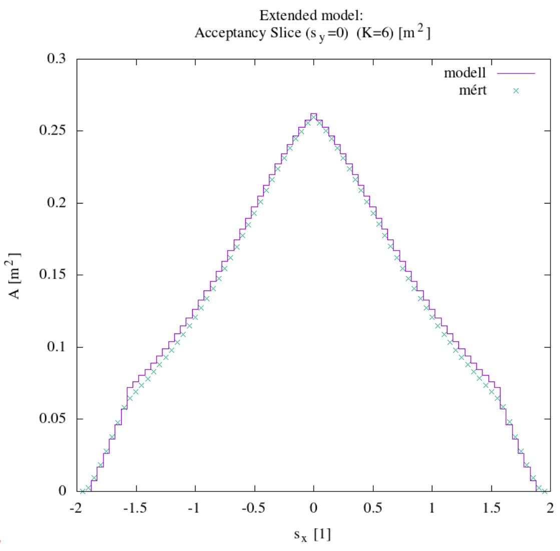
N= $Ft\Omega A_{eff}$

Extended equidistant model in 1D

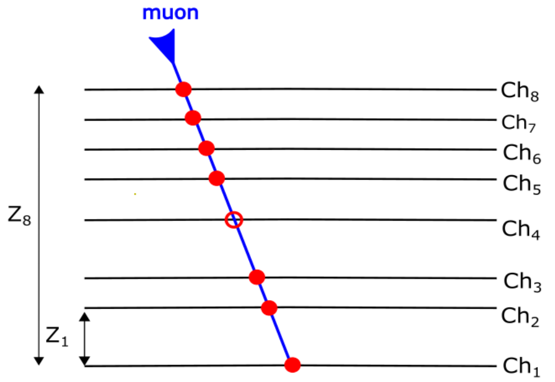
Slice: $s_y = 0$

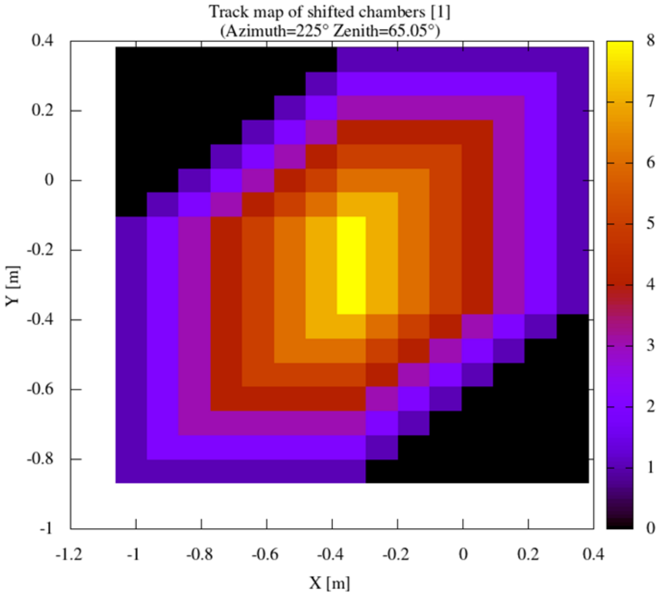
- $l_x(s_x) = \begin{cases} L - h|s_x| + 2(N_K - K)a|s_x|, & |s_x| < L/h \\ (L-(K-1)a|s_x|) + (N_K - K)a|s_x|, & L/h < |s_x| < L/(Ka) \\ \big(N_K - (K-1)\big)(L-(K-1)a|s_x|), & L/(Ka) < |s_x| < L/((K-1)a) \\ 0, & |s_x| > L/((K-1)a) \end{cases}$
- $\eta(K_T) = \begin{cases} 1, & K_T > K \\ \eta^K_{Chamber}, & K_T == K \\ 0 & \end{cases}$
- $A_{eff} = l_x L_y \frac{1}{\sqrt{1+s_x^2}}\eta$





Direct problem model for general detector geometry





- Different approach was used
- What happens the chamber position from the perspective of incoming muons? ⟶Shifted
- So I can calculate how many chambers the muon has passed in a given area through
- The intersection of the chambers in 2D = how many chambers detected the given angle of the muons in the intersection area

$$\mathbf{S_{x_i} = Z_i s_x, \quad S_{y_i} = Z_i s_y, \quad i = 1, \ldots N_K}$$

$$\mathbf{K_T(x,y) = \sum_i^{N_K} \begin{cases} 1, & (X_{1_i} + S_{x_i}) \leq x \leq (X_{2_i} + S_{x_i}) \text{ és } (Y_{1_i} + S_{y_i}) \leq y \leq (Y_{2_i} + S_{y_i}) \\ 0 & \end{cases}}$$

$$\eta(x,y) = \begin{cases} 1, & K_T > K \\ \eta^K_{Chamber}, & K_T == K \\ 0 & \end{cases}$$

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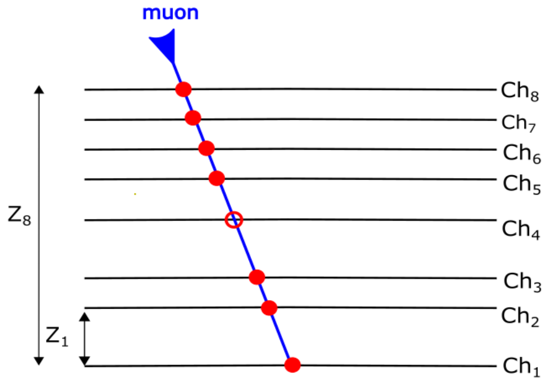
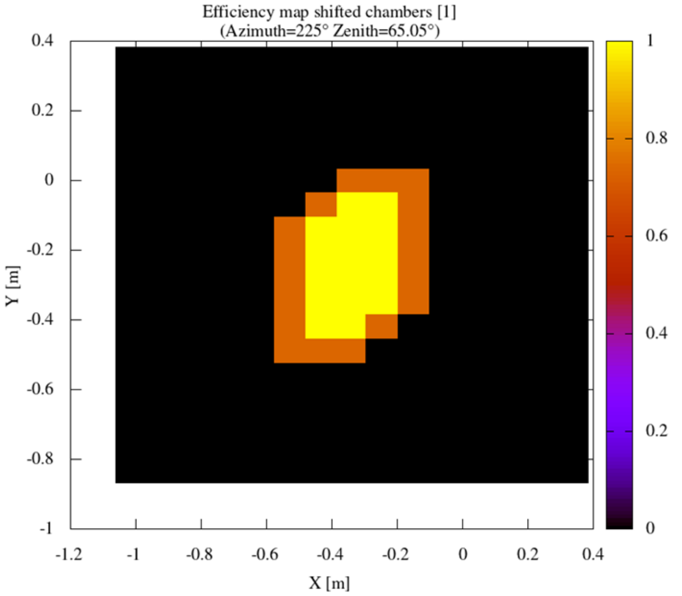
Direct problem model for general detector geometry





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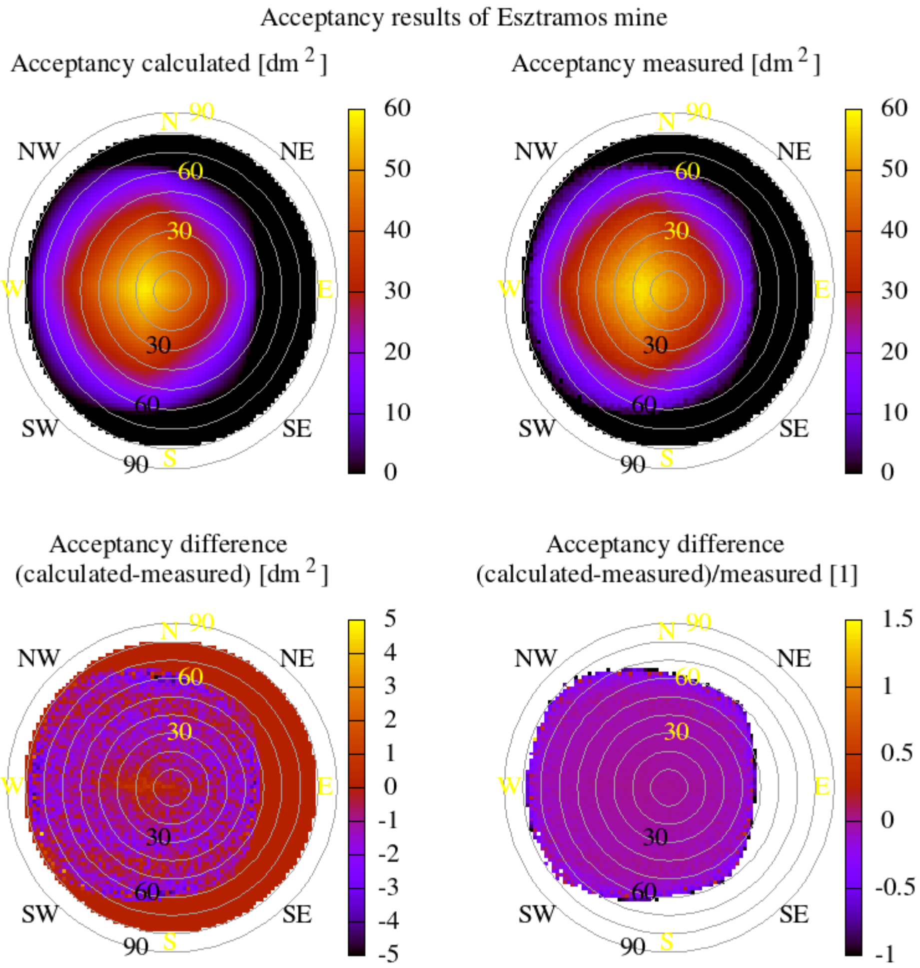
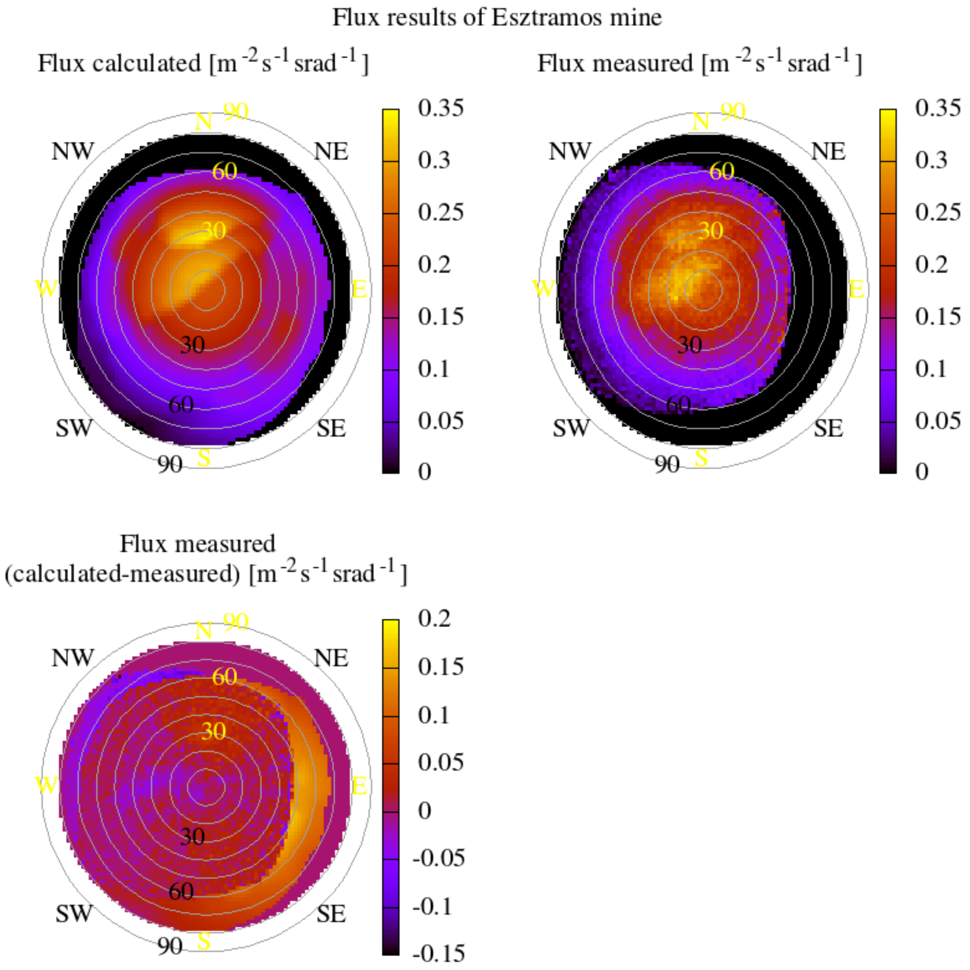
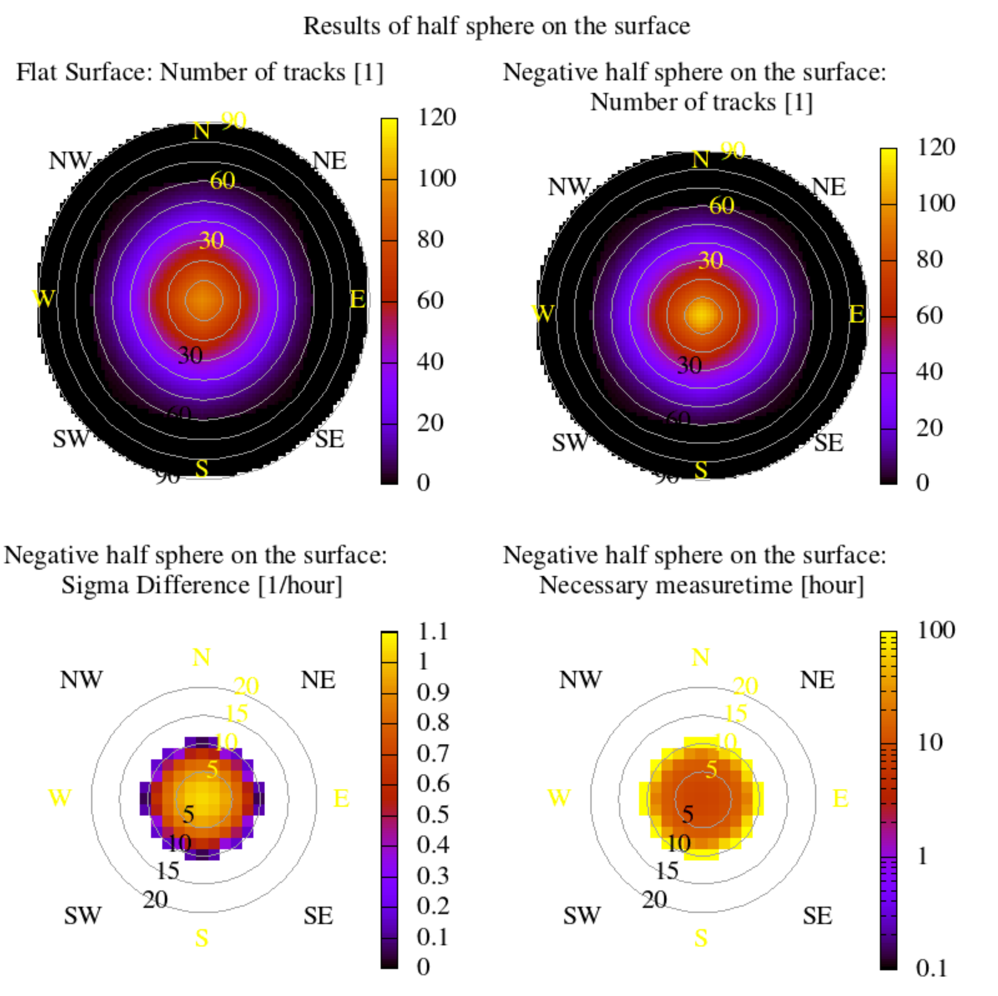
Esztramos mine



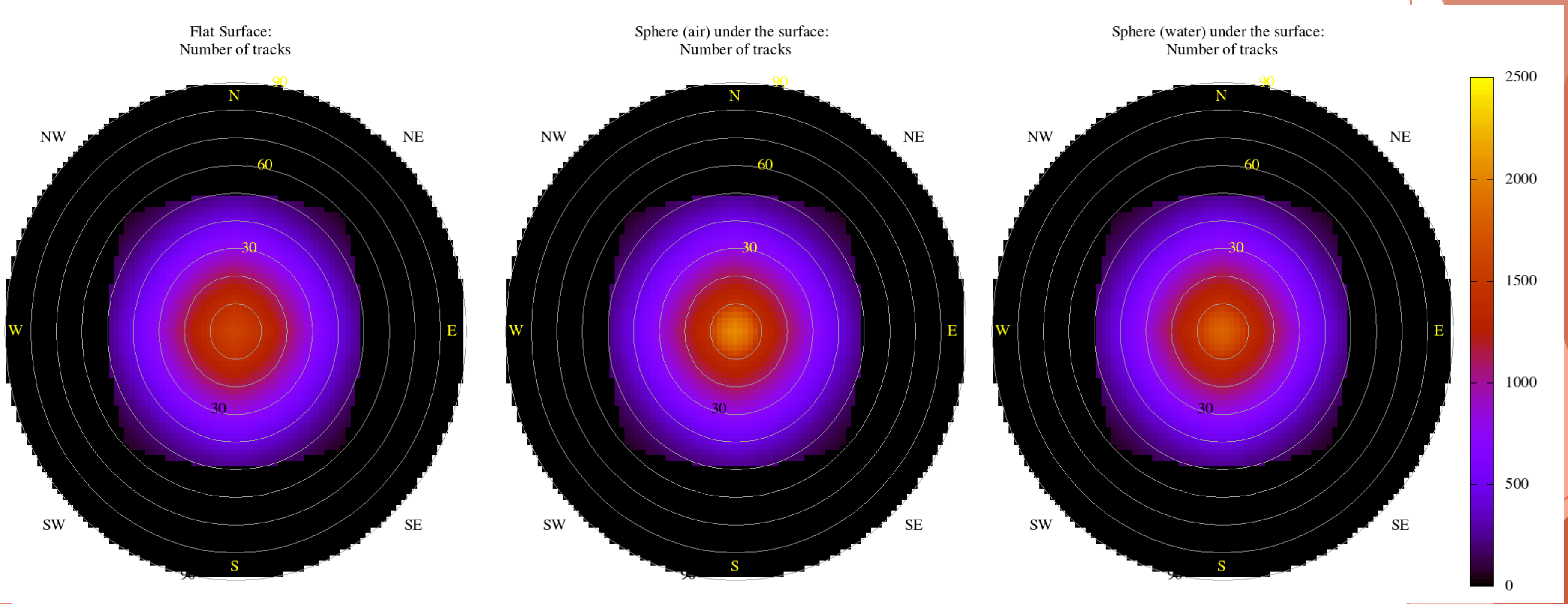


Simple geology model: flat surface with half sphere anomaly on the surface

- Ground model: flat surface, homogeneous, $\rho_a = \ 2.4\ g/cm^3$
- Anomaly:
  - half ball on the surface
  - (Position[0,0,0]m, r=1m)
  - Dector type=Mtl2 ,
  - Position[0,0,-6]m, Inc=0° and Rot=0°



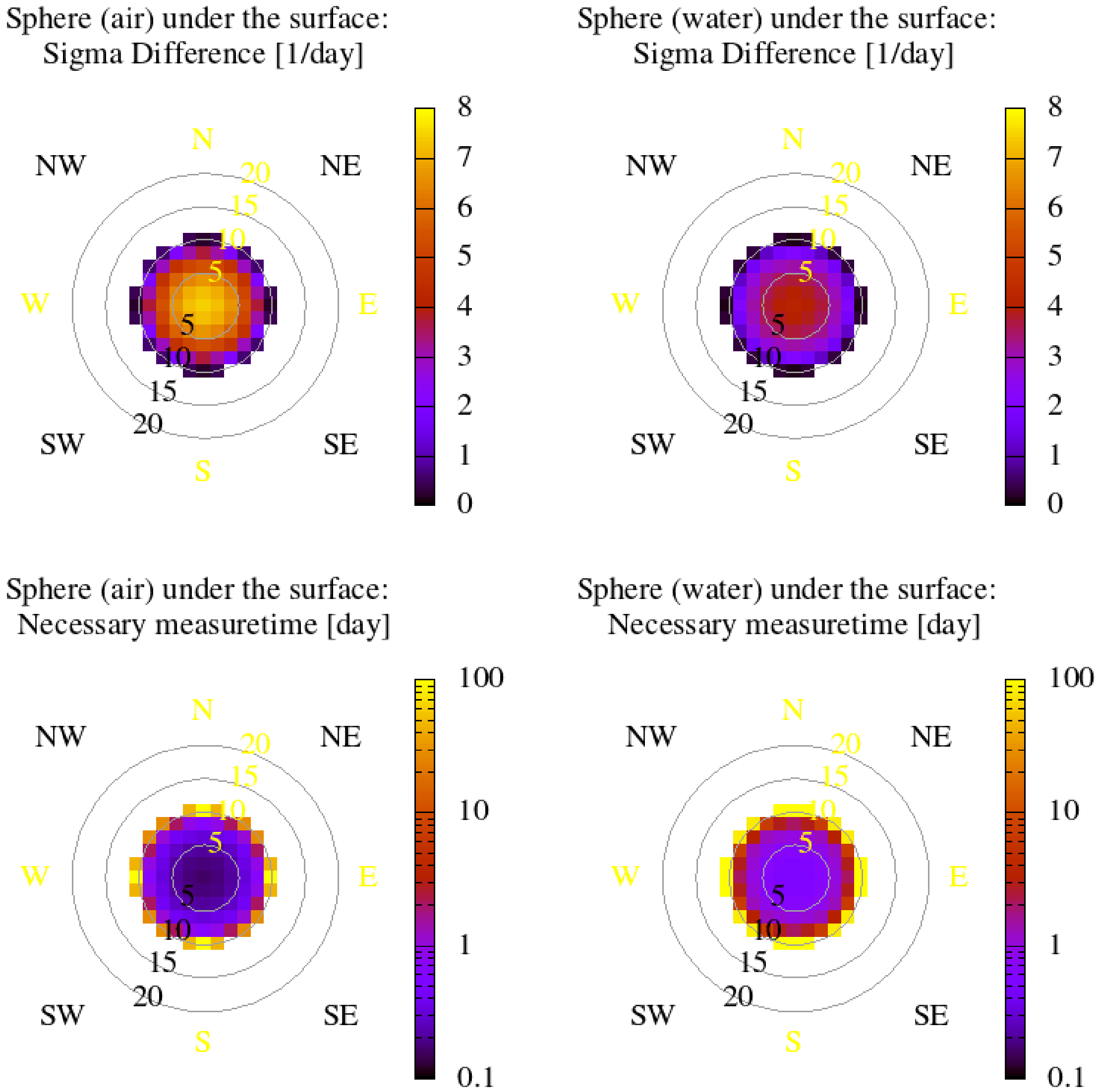
Simple model : flat surface with an anomalous sphere



$$\delta\sigma = (N_C - N_M)/\sqrt{N_M + N_C}$$

$$\sigma_{separation} = 3$$
$$t = \sigma_{separation}/\delta\sigma$$

Results of sphere under the surface



Janossy underground laboratory