# Application of MWPC based muography in geophysics, experiments and planning

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ELTE EÖTVÖS LORÁND TUDOMÁNYEGYETEM

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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

# Muography in geophysics: model validation and optimization

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# Muography

1911: Victor Hess: Cosmic ray

Primarily and secondary particles

1936:C. D. Anderson: muon identification

1970: L.Alvarez: first muography experiment

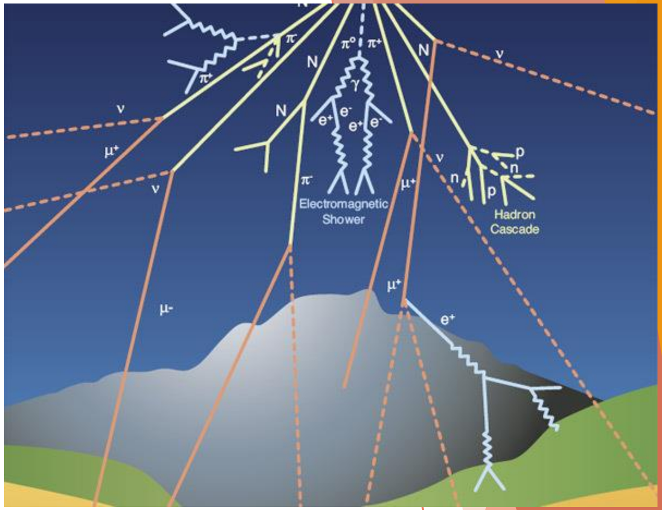
Its characteristics :

- 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= $F_o \cos^2\vartheta$ (100/ sec/m²)

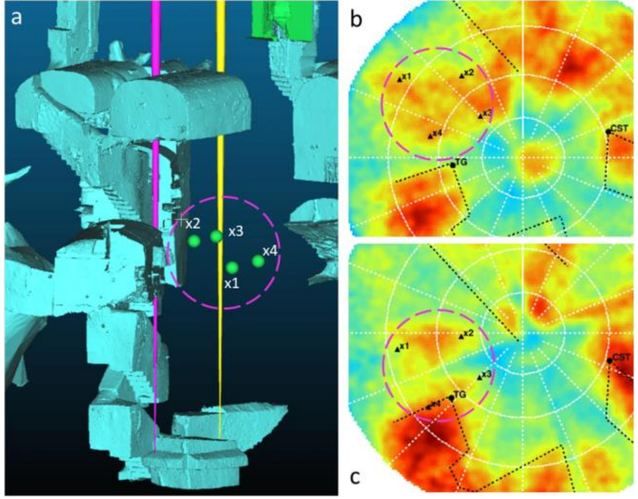
Muography uses cosmic muons to image the internal density structure of large objects.



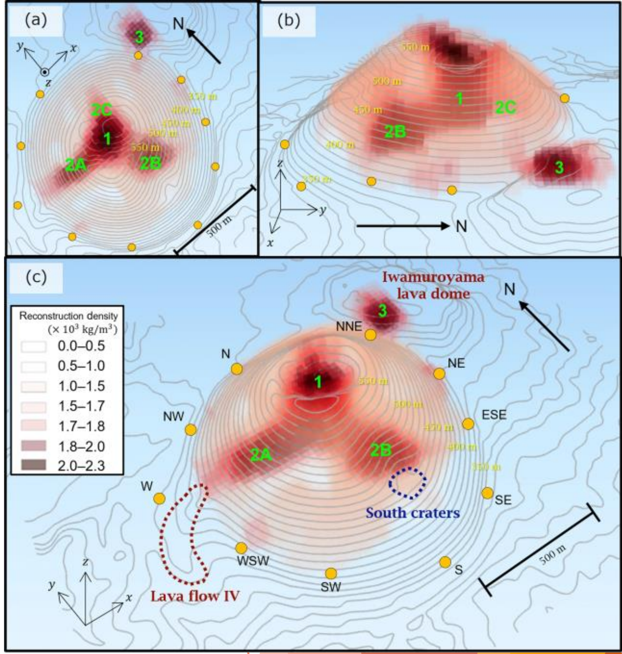

Cosmic rays[2]

# Muography application

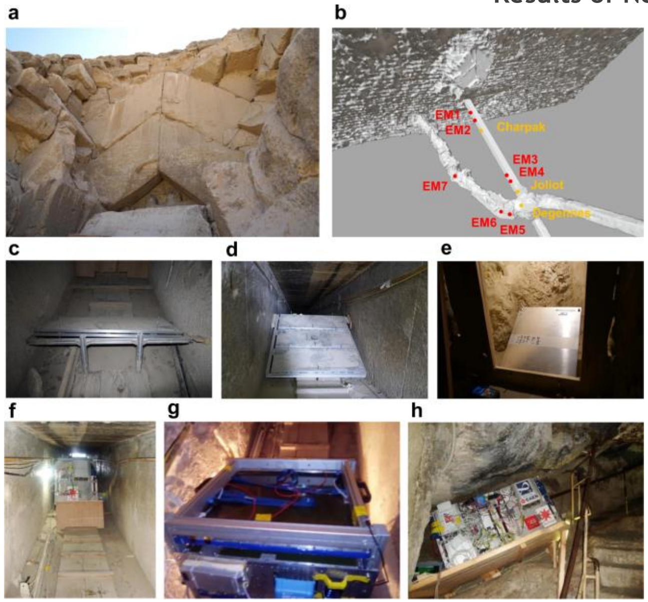
- Vulcanology
- Archaeology application
- Speleology
- Structural analysis
- Monitoring
- Mining



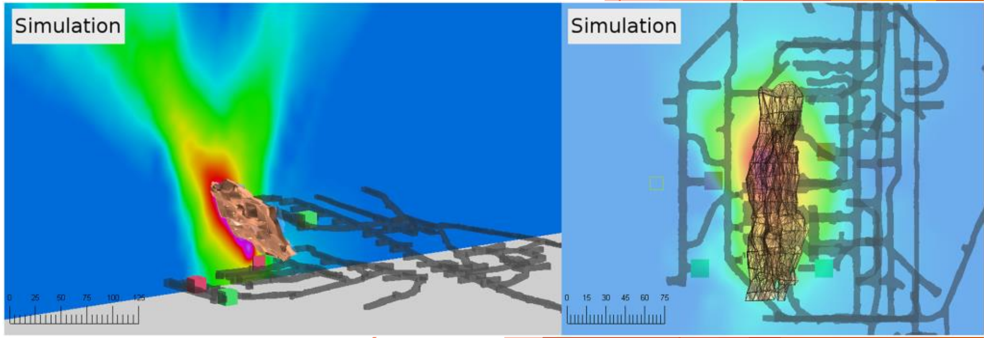
Results of Neapolis measurements[3]



3D density tomography of Omuroyama scoria cone[4]



Archeology measurements in the Khufu's Pyramid[5]




Simulate data of uranium deposit[6]

# The Innovative Gaseous Detector R&D Group

| Country | Mining | Target |
|---|---|---|
| Finland | Kemi chromium mine | granite and bedrock localization (2.3-3.3g/cm3; 2.65g/cm3) |
| Hungary | Janossy pit system | test site, hidden inhomogeneous |
| Hungary | Királylaki tunnel | unknown caves, hidden inhomogeneous |
| Hungary | Esztramos tunnels | well-tunneled hill, unknown caves? |
| Hungary | Underneath the Castle of Buda | expected covered medieval tunnels |
| Italy | Castello di Mussomeli | mediavel tunnels |
| Japan | Sakurajima Muography Observatory | vulcanology |

Underground measurement arrangement

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464
465 Event 33000 ,   2018-04-27_08:06:33 ,  dt : 389590
466 ...............................................................   ...............................................................
467 ...............................................................   ...............................................................
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471 .........XXXXX..................X..............................   .................XXX..........XXXX............................
472 Adc :    2888    3725    3208    2289    2810    2091
473 THP :  T= +19.75 oC, H= 39.0%, P= 972.0 mBar, ThpId: 0
474 Counter :       +1 (95)
475 Pattern :      Triggered on :  0 0 1 1 1 1 0 0 0 0 0 0      (ok)
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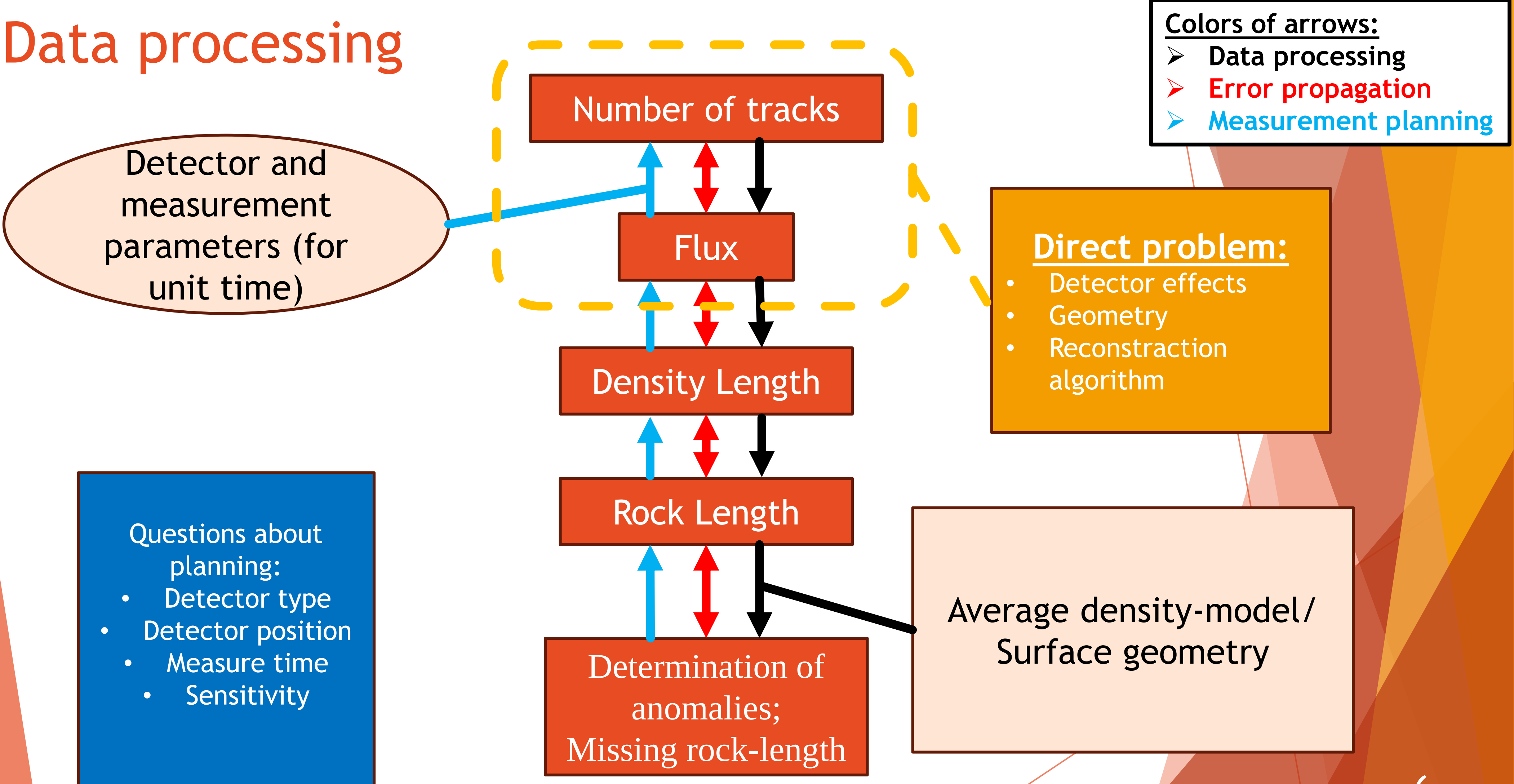
An event

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

# Data processing

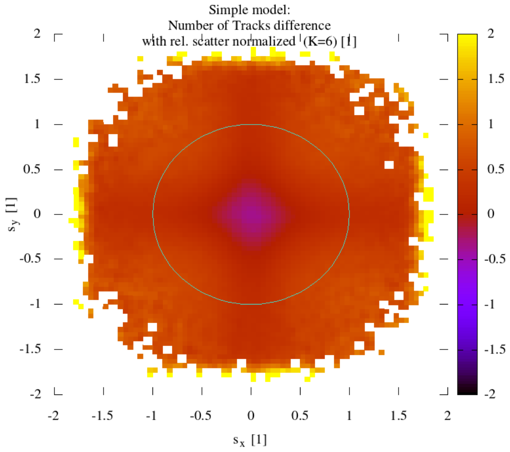


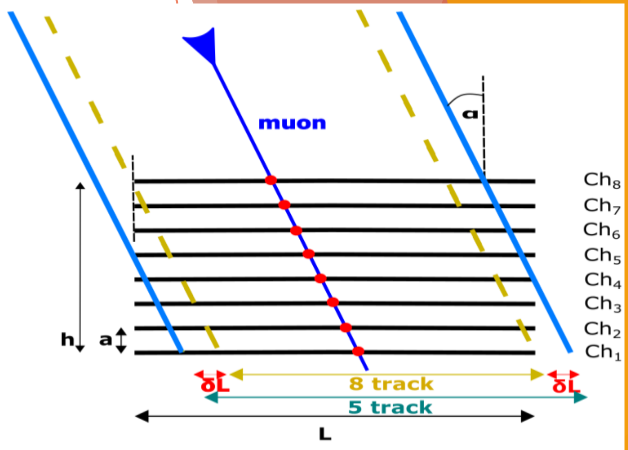
# Direct problem models

**N= F$t\Omega A_{eff}$**

## Equidistant model

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




Slice: $s_y = 0$

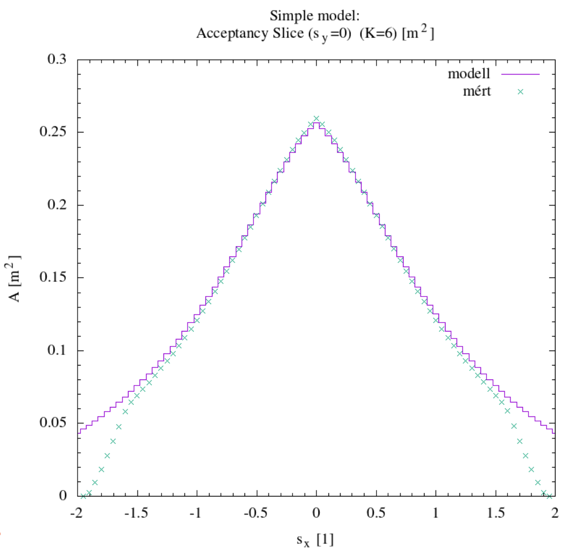
## Extended equidistant model in 1D

- $l_x(s_x) =$

$$\begin{cases} L - h|s_x| + 2(N_K - K)a|s_x|, & |s_x| < L/h \\ (L - (K-1)a|s_x|) + (N_K - K)a|s_x|, & L/h < |s_x| < L/(Ka) \\ \left(N_K - (K-1)\right)\left(L - (K-1)a|s_x|\right), & L/(Ka) < |s_x| < L/((K-1)a) \\ 0, & |s_x| > L/((K-1)a) \end{cases}$$

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

- $A_{eff} = l_x L_y \frac{1}{\sqrt{1+s_x^2}}\eta$

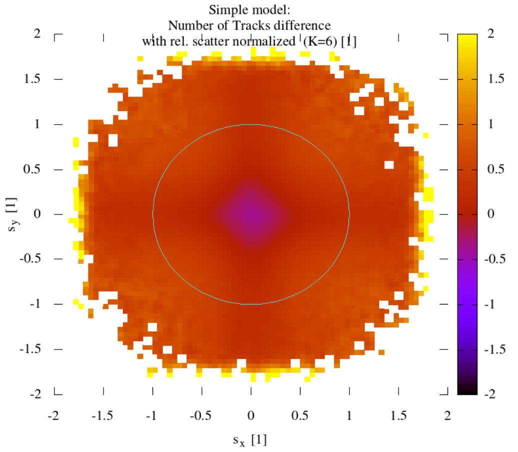


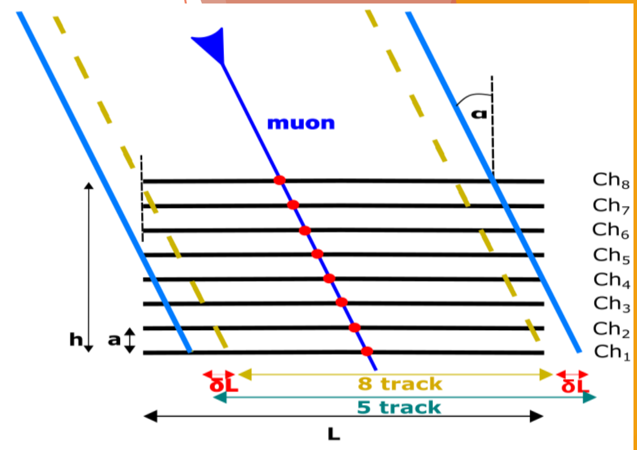
# Direct problem models

## $N = F t \Omega A_{eff}$

## Equidistant model

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

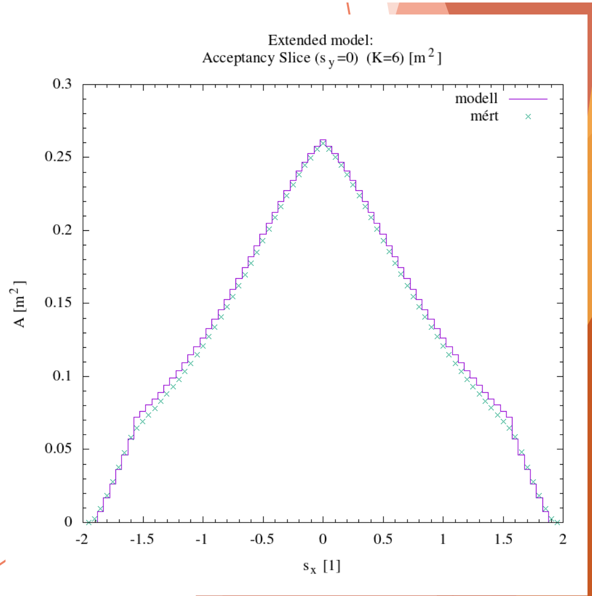


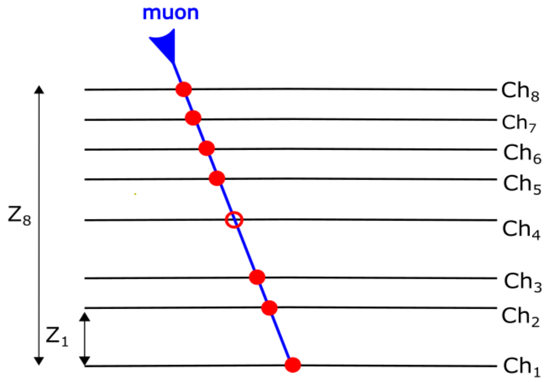

Slice: $s_y = 0$

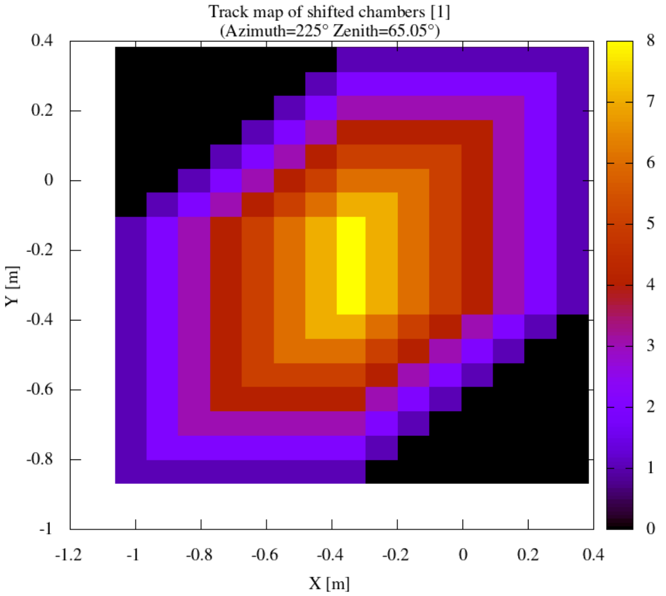
## Extended equidistant model in 1D

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



# Direct problem model for general detector geometry




- Different approach was used
- What happen to 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

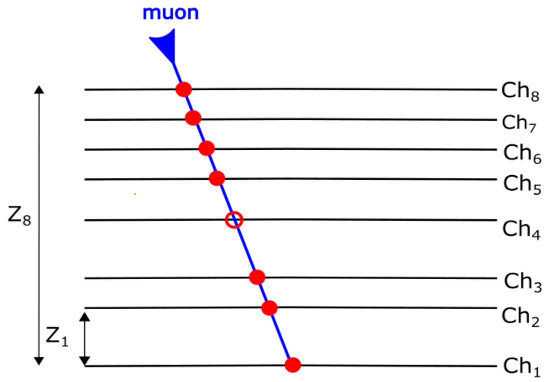
$$S_{x_i} = Z_i s_x, \qquad S_{y_i} = Z_i s_y, \qquad i = 1, \dots N_K$$

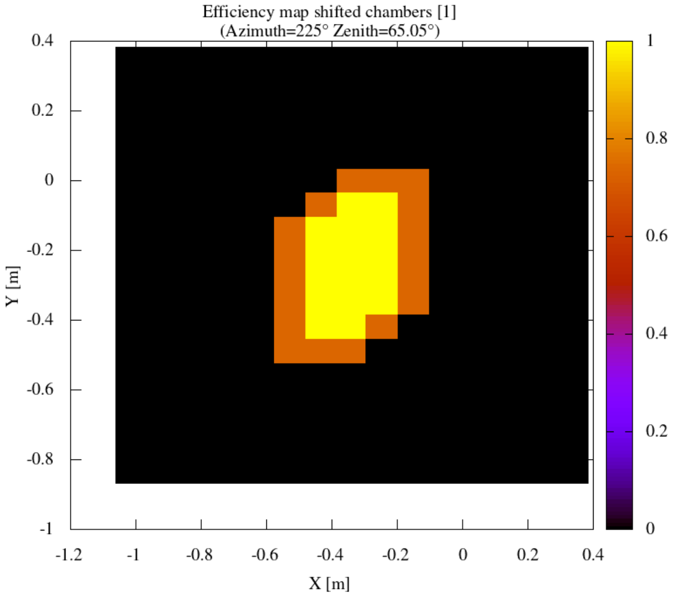
$$K_T(x,y) = \sum_i^{N_K} \begin{cases} 1, & (X_{1_i} + S_{x_i}) \le x \le (X_{2_i} + S_{x_i}) \text{ és } (Y_{1_i} + S_{y_i}) \le y \le (Y_{2_i} + S_{y_i}) \\ 0 \end{cases}$$

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

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

# Direct problem model for general detector geometry




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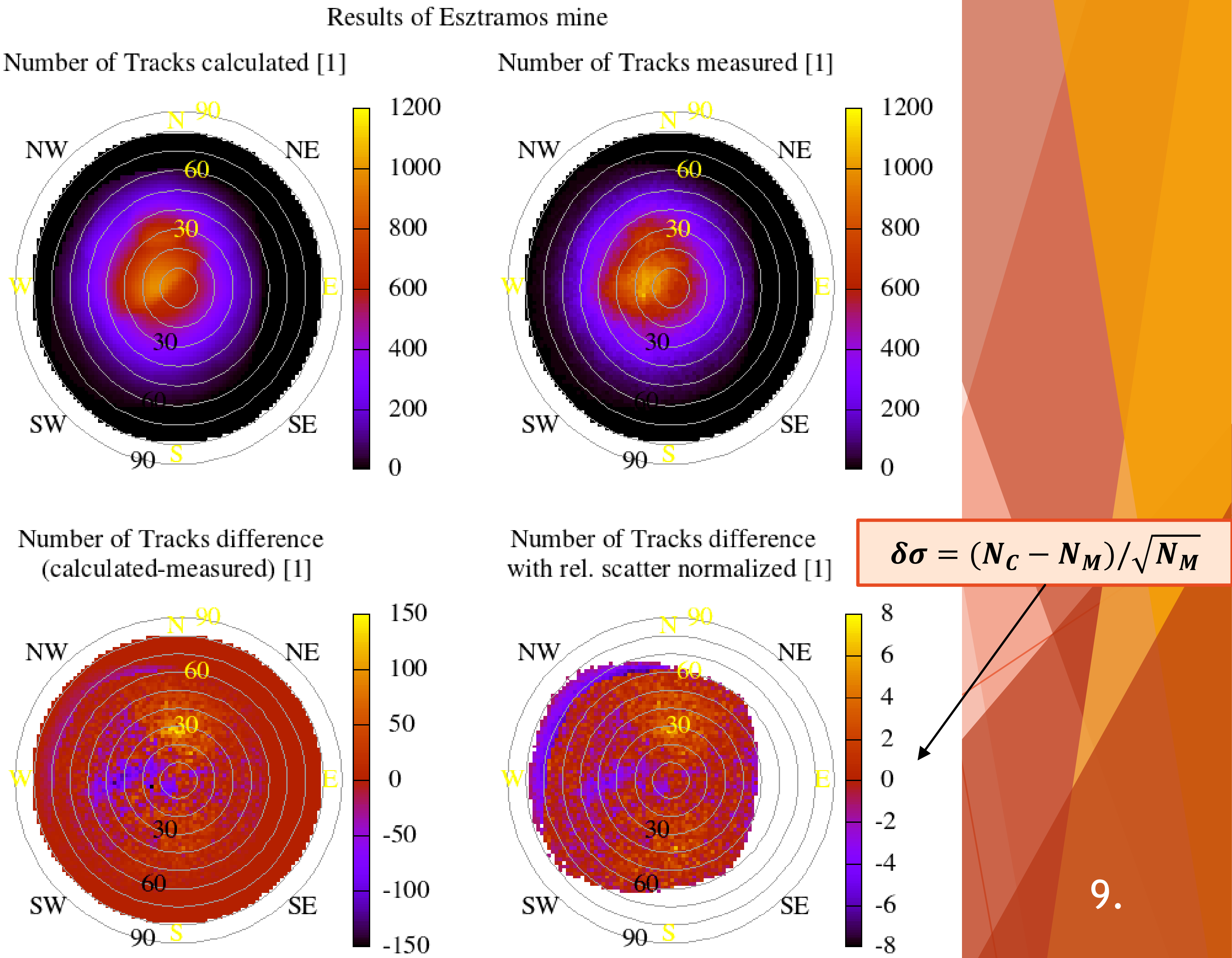
$$\eta(x,y) = \begin{cases} 1, & K_T > K \\ \eta^K_{Chamber}, & K_T == K \\ 0 & \end{cases}$$

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

# Esztramos mine

- No active mining in the mine = stable surface
- Active exploration in the mine (more details in Rábóczki Bence's presentation)
- A domestic measurement area
- The target: comparison of the result from measurement with homogeneous model with original surface




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

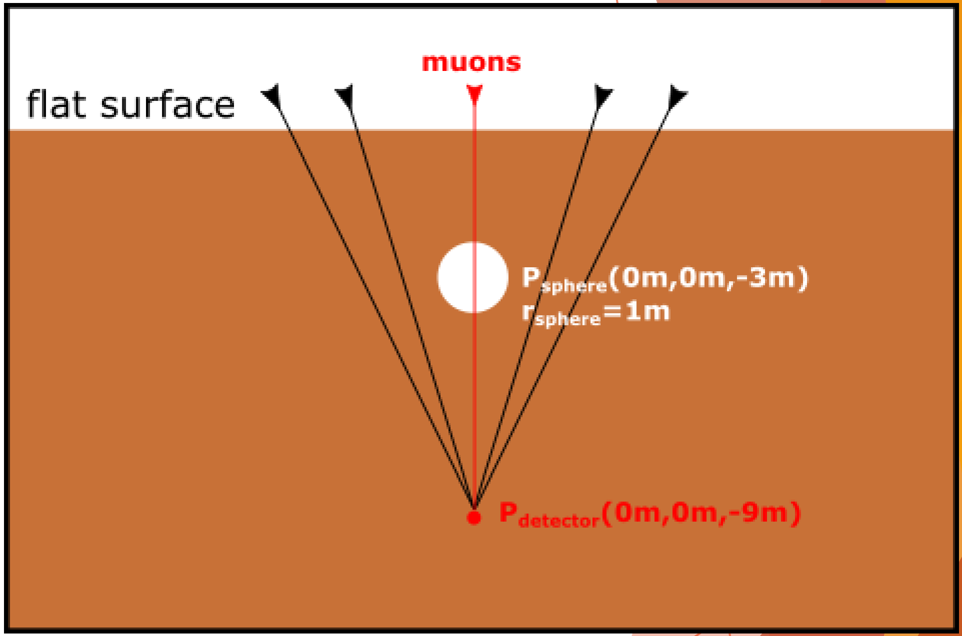
# Simple model : flat surface with an anomaleous sphere

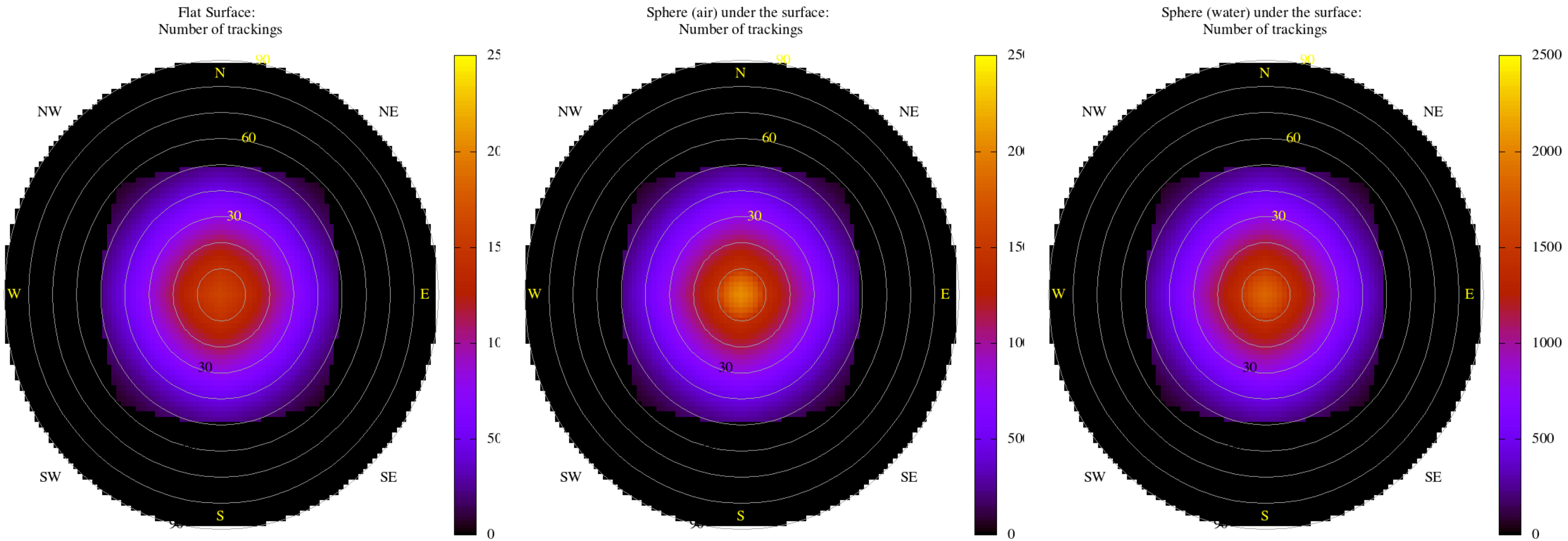
- Different geology situtations become possibly to search by this method
- We can review many questions with given series of measurement
  *e.g.*: What kind type of detector should we use in a measurement?

  **How long have we to measure in a position?**

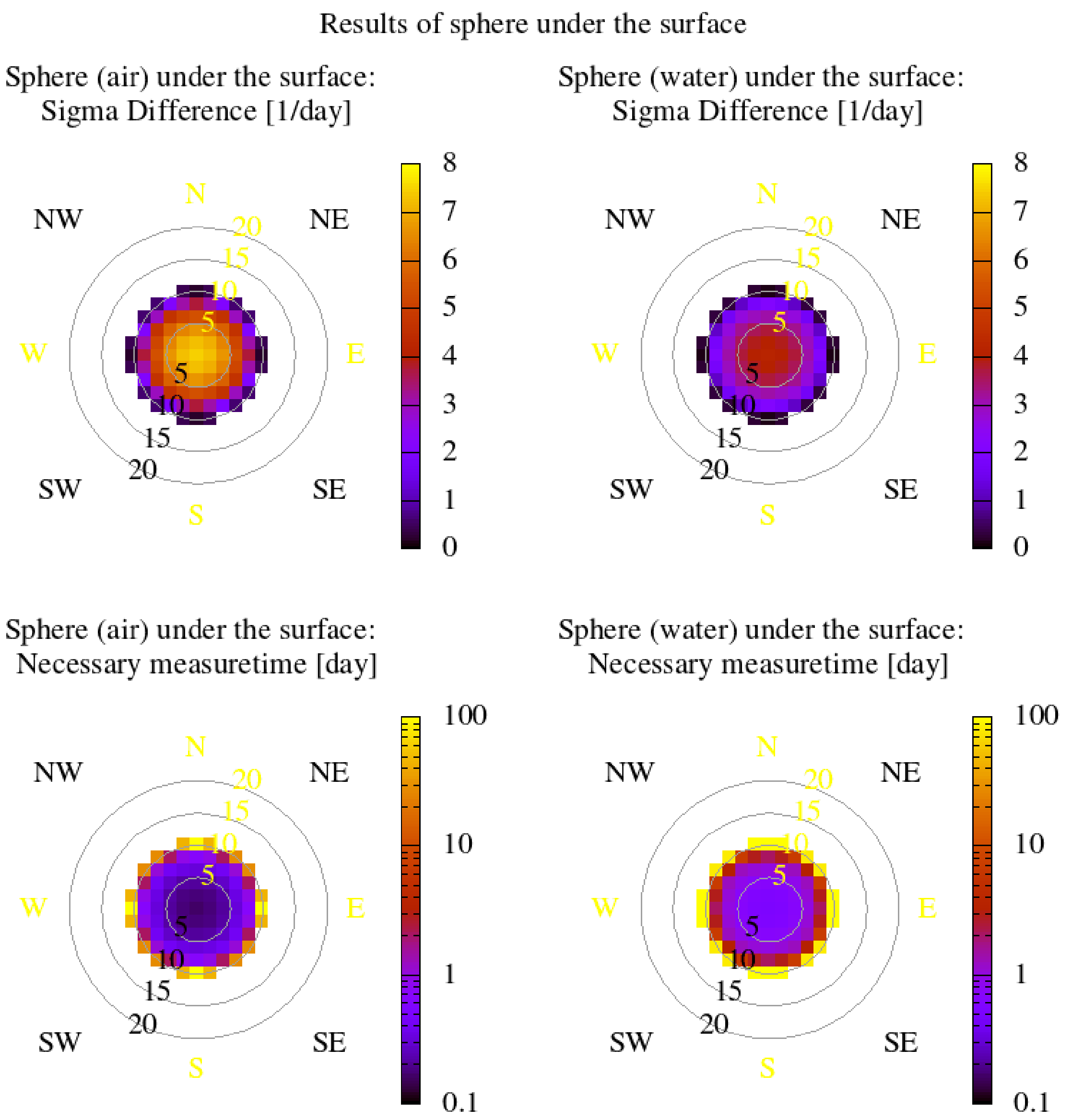
  Which setup can optimal ?

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




Flat Surface:
Number of trackings
Sphere (air) under the surface:
Number of trackings
Sphere (water) under the surface:
Number of trackings
N
NE
E
SE
S
SW
W
NW
90
60
30
0
500
1000
1500
2000
2500

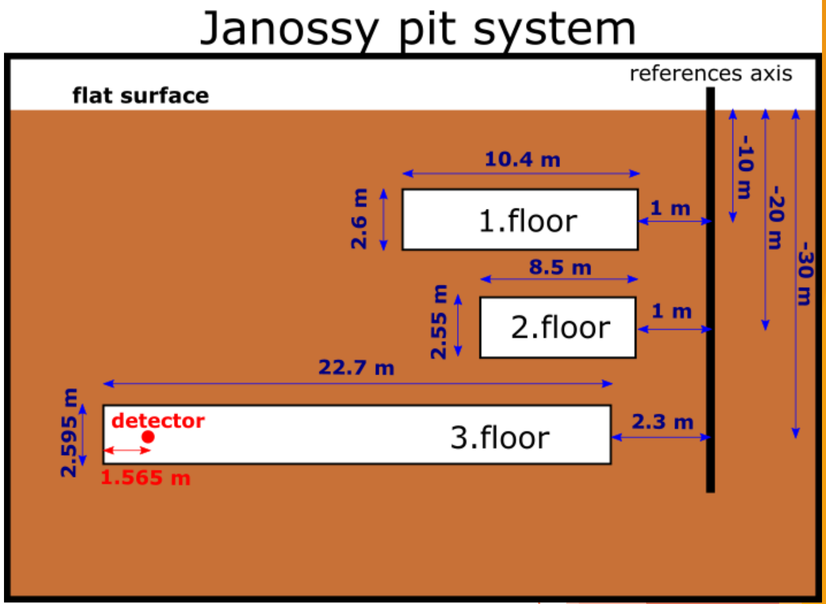
$$\delta\sigma = (N_C - N_M)/\sqrt{N_M + N_C}$$

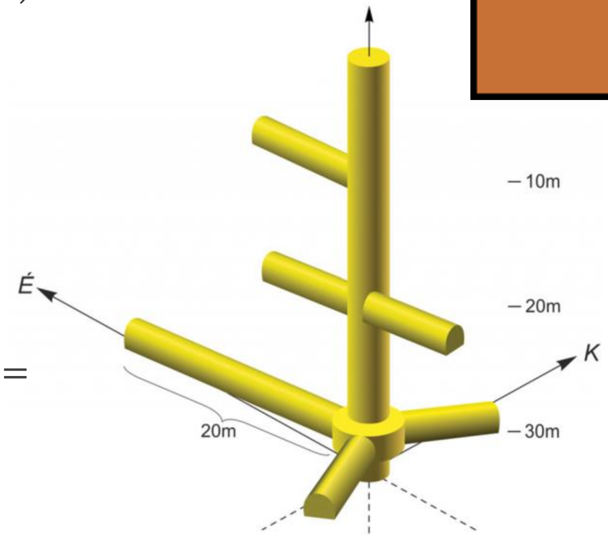



$t = \sigma_{separation}/\delta\sigma$ *!for unit time!*

# Test site: Janossy pit system

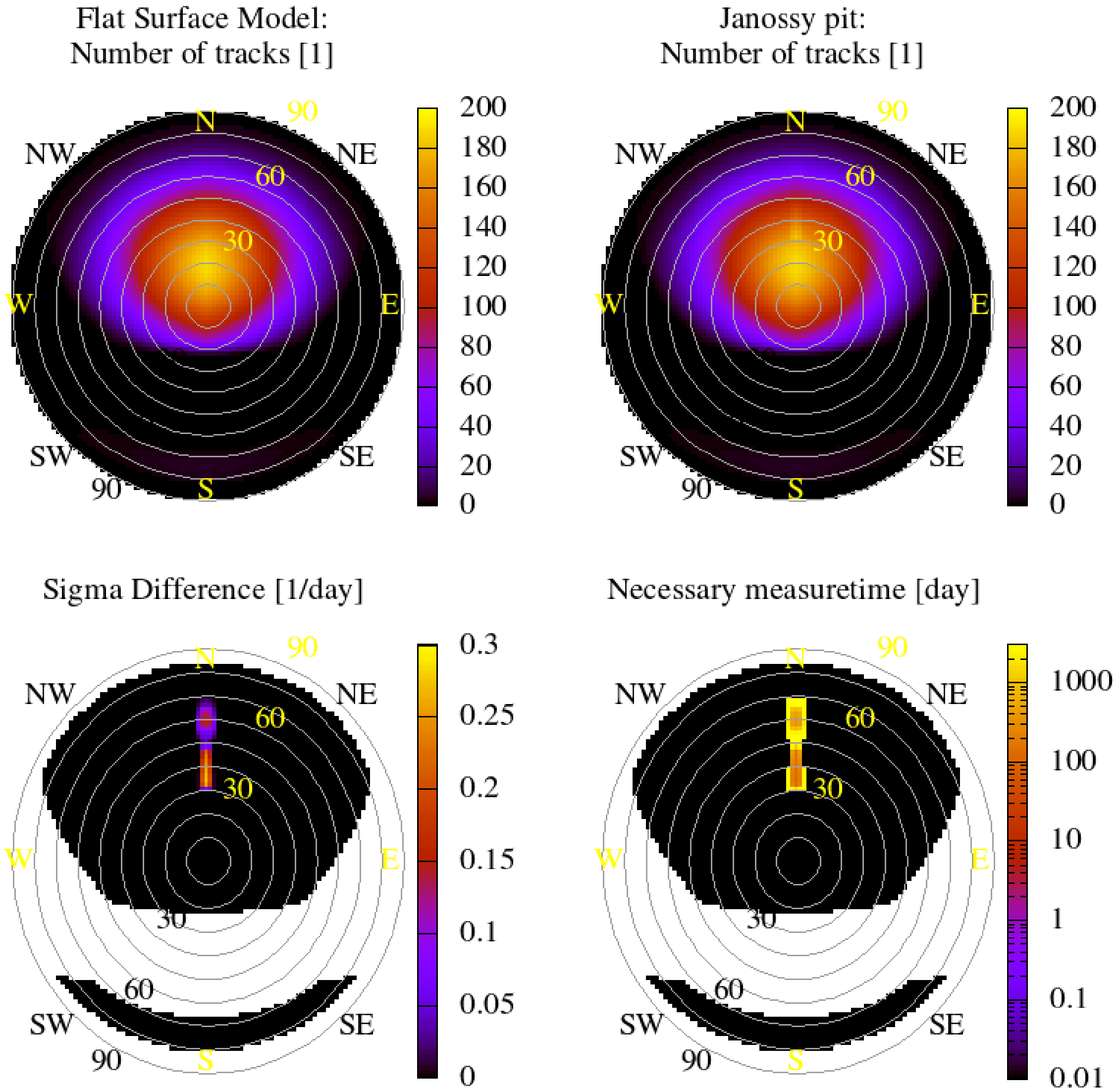
- Janossy pit system: simple geometry -> main goals: particle physics measurements
- 3 floors: 1. 1 tunnel at -10 m (0°)
  2. 2 tunnel at -20 m (0°, 180°)
  3. 3 tunnel at -30 m (0°, 120°, 240°)
- Mts8 detector: position: 3. floor 1. tunnel, 156.5cm from the end of the tunnel; Inc=-45°; Rot=-90°
- Ground model: flat surface, (NOT jet the original surface); homogeneous, $\rho_a = 2.2\ g/cm^3$
- Geology model: Shape of the tunnels was approched with cylinders. $\rho_{tunnels} = 0\ g/cm^3$




Janossy pitsystem geometry[1]

## Results of Janossy pit system



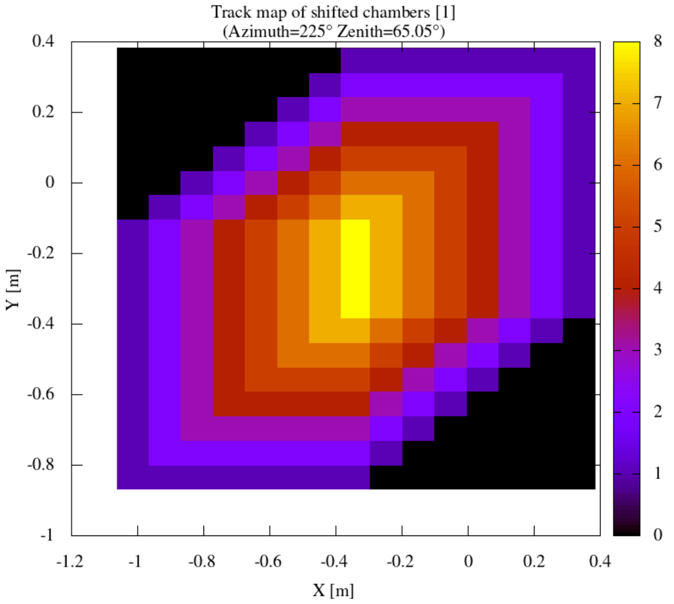
# Conclusion

- I set up a model that can be used for general geometry.
- It can be used to investigate theoretical and practical issues.
- I have used this method successfully for 3 geological models.
- It can be seen that measurement times can be estimated, detector type testing is possible, and measurement positions can be compared.

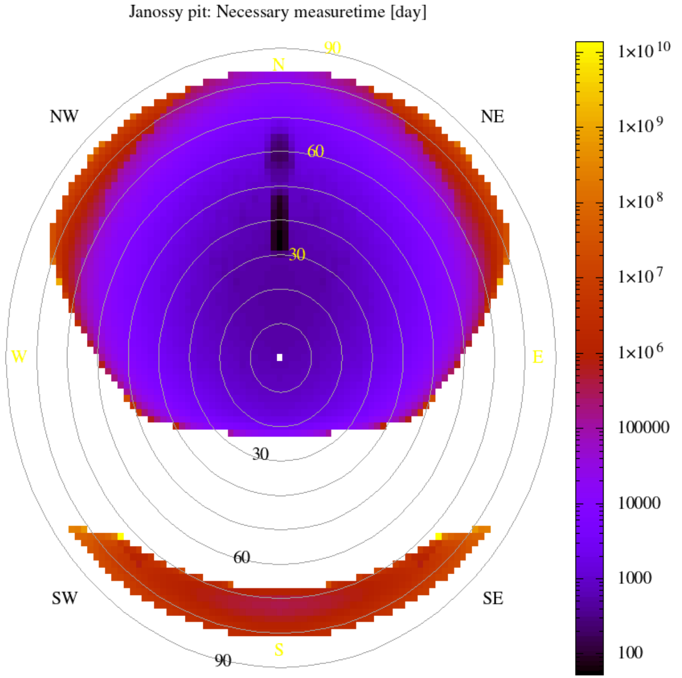
# Acknowledgement

- 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



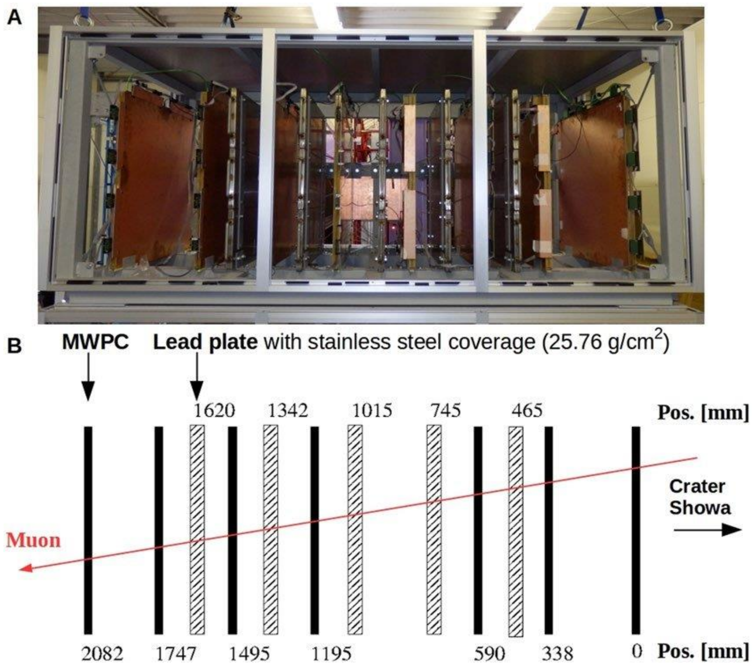

# Thank you for your attention!



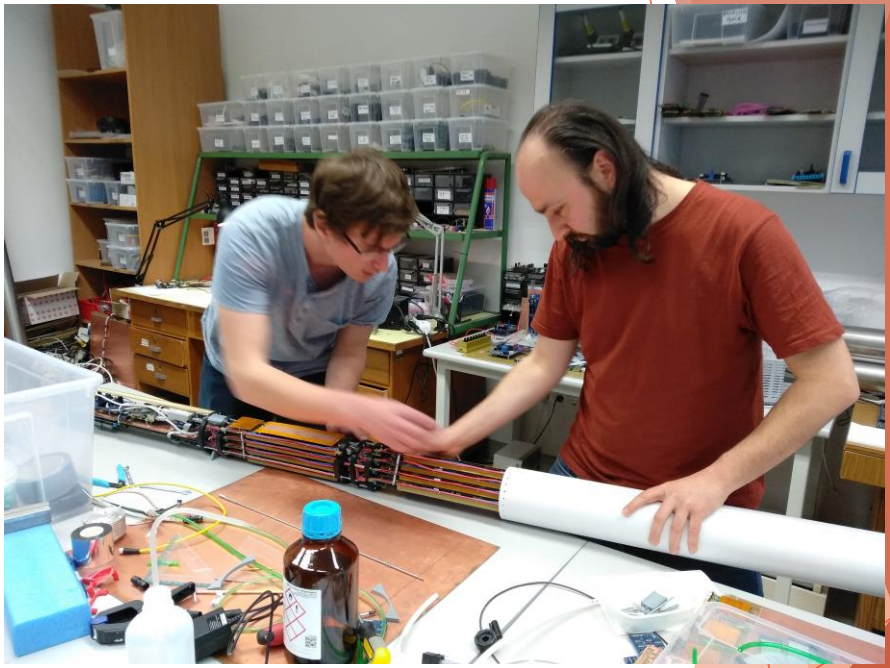
# References


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

# Back up slides

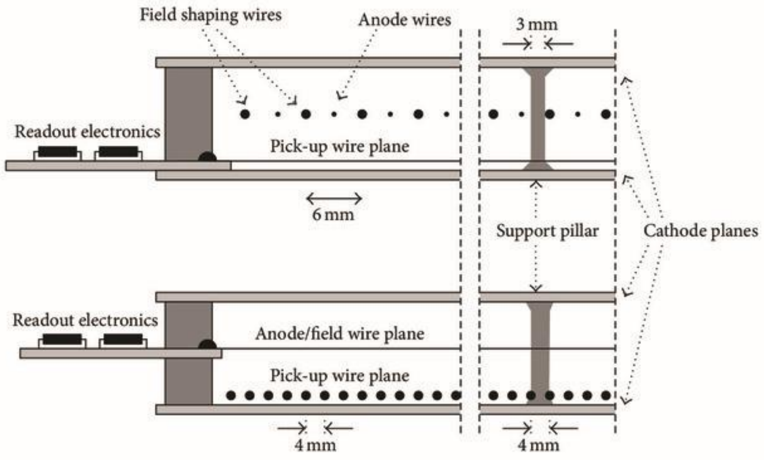



Surface measurement arrangement

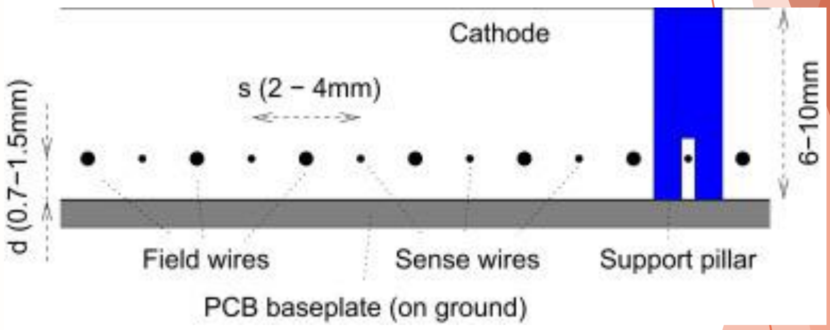


Borehole measurement arrangement

# Detector types




MWPC



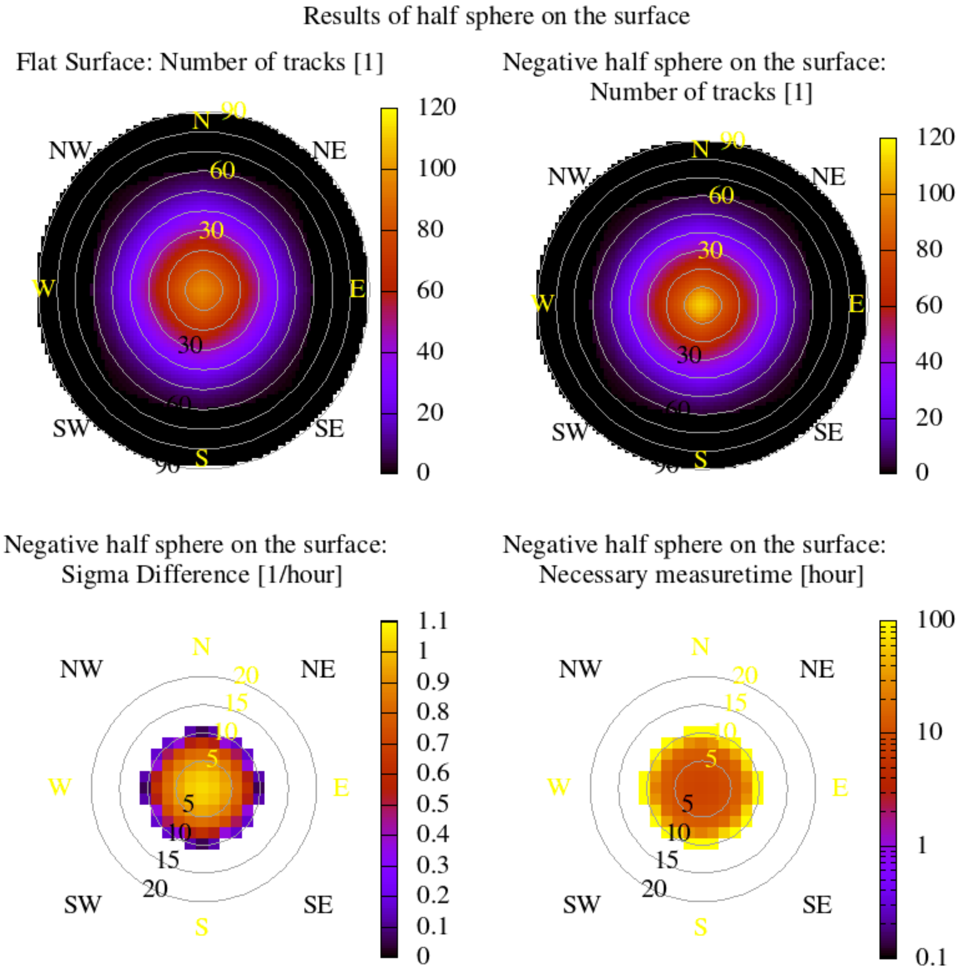

CCC

# 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 geology model: flat surface with sphere ball anomaly on the surface



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