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Design of MWPC-based muography measurements for geophysical research

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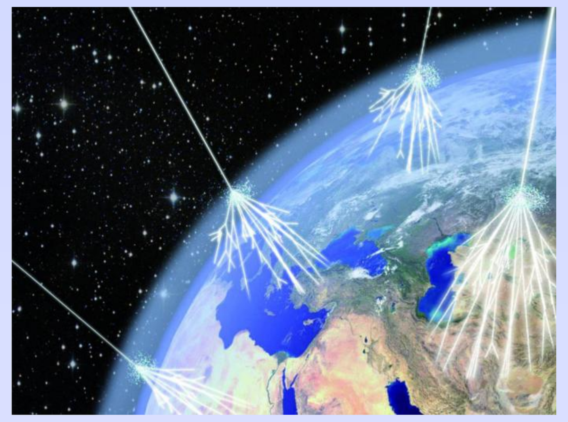
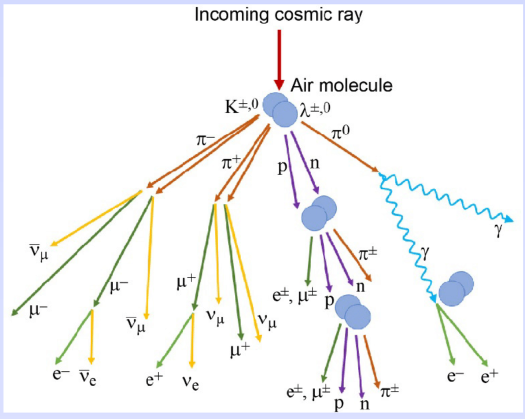
1. Muography

Cosmic-ray induced muon particles reaching down to Earth's surface and penetrating into natural and human-made structures (Figures 1-2). Muons' energy loss is proportional to the distance they travel in the medium (e.g. rock) and the density of the medium. Less muons are expected from higher density medium and more muons from lower density medium. Thus the measurement of the yield of muons by particle detectors (e.g., scintillators, nuclear emulsions, gaseous detectors) allows to observe density contrasts. This measurement procedure is called muography. A wide range of applications has been developed in mining, civil engineering, volcano monitoring, archaeology, speleology (Figure 3), etc. [1].



1. Fig: Cosmic ray [2]



2. Fig: particle physics interactions in cosmic rays [3]

3. Fig: Installing a detector in a cave

2. Muography in HUN-REN Wigner RCP

HUN-REN Wigner RCP focusing on application oriented research and development of muography instrumentation using gaseous detectors and applications in various fields from civil engineering to volcanology. One of the main applications is utilization of muography in mining industry. Portable, robust, and low-power instruments have been developed and tested in different mines, such as in Esztramos, Hungary or in Kemi, Finland (Figures 4-5).

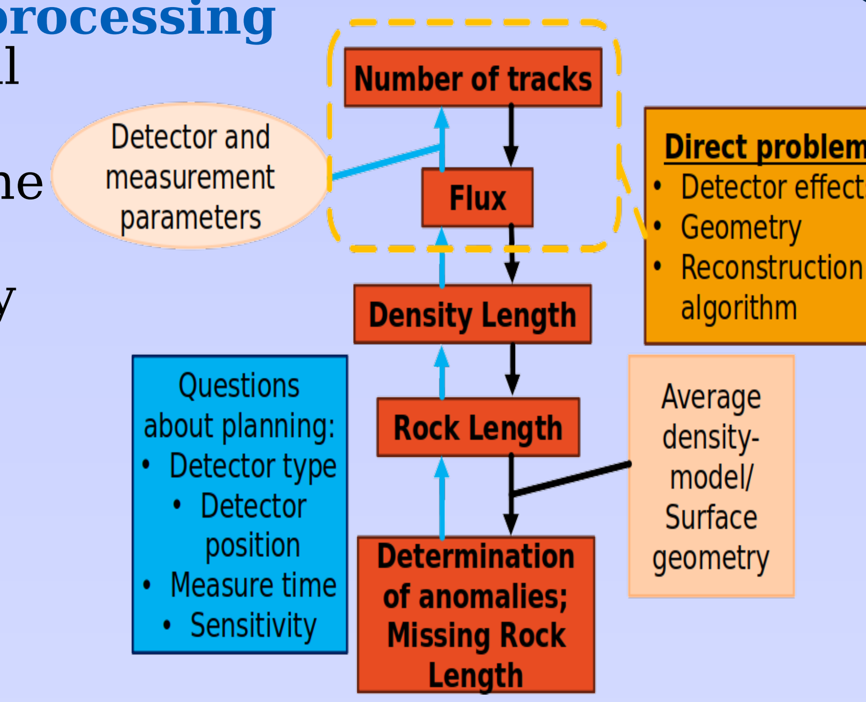
4. Fig : Active measurements are being carried out in the now defunct Esztramos Hill mine in northern Hungary

5. Fig : We have carried out successful measurements in Kemi, the largest underground mine in Finland.

6. Fig: Testing the Posseidon detector type developed for underwater measurements in Kőbánya, Budapest

3. Data processing

For ore exploration, it is crucial to have a sufficient density contrast($>0.2 g/cm^3$) between the targeted ore body and the bedrock. Mineral exploration by muography requires careful planning of surveys and application oriented design of observation instruments. This work is focusing on design of muographic surveys and optimization of observational instruments. Figure 7 shows the parts of data processing.



7. Fig: Flowchart of data processing

7. Summary

Muography is a dynamically developing interdisciplinary research field. This measurement method has a wide range of applications from volcanology to mining. Both measurement tools and procedures are constantly evolving. We developed a data analysis chain for planning of muographic surveys and optimization of instrumentation for underground mining applications. The methodology has been tested and validated in underground tunnels in Budapest, Hungary.

Our Supporters

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References

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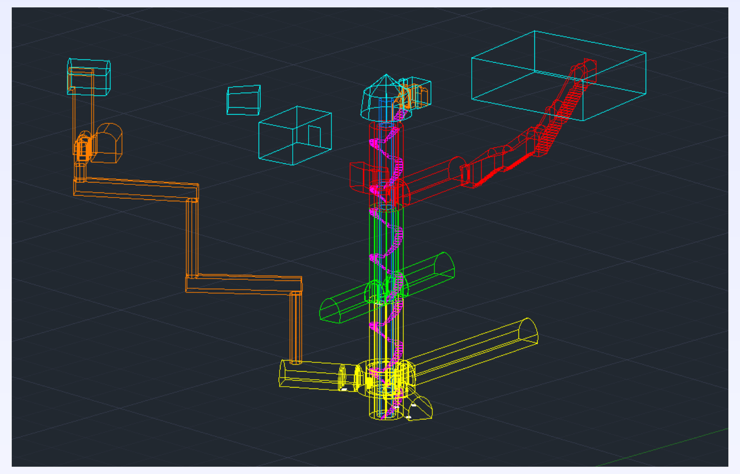
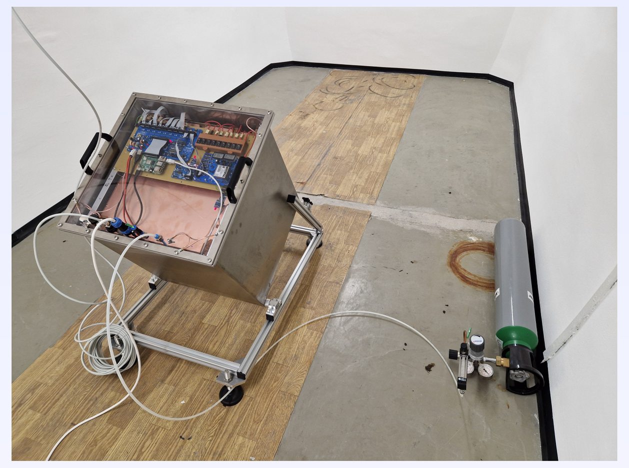
[3] John Wrbanek, Susan Wrbanek, 2020. Space Radiation and Impact on Instrumentation Technologies
[4] László Balázs, Gábor Nyitrai, Gergely Surányi, et al., 2024. 3-D muographic inversion in the exploration of cavities and low-density fractured zones, Geophysical Journal International, Volume 236, Issue 1, Pages 700–710, https://doi.org/10.1093/gji/ggad428

4. Jánossy Underground Laboratory (JURLab)

The Jánossy Underground Laboratory was one of the first to be built on the area of the HUN-REN Wigner Physics Research Center in the 1950s. It is an underground laboratory with simple geometry (Figure 8), with three levels, two horizontal branches on the second level, three branches on the third level and two emergency tunnels. This makes it the perfect place to carry out detector test measurements (Figure 9).



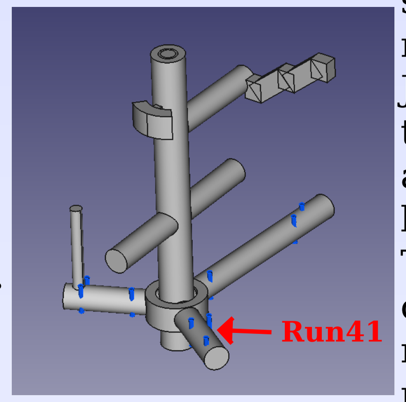
8. Fig: Detailed CAD model of the JURLab. The light blue indicates the buildings and the parts of the JURLab on the surface.



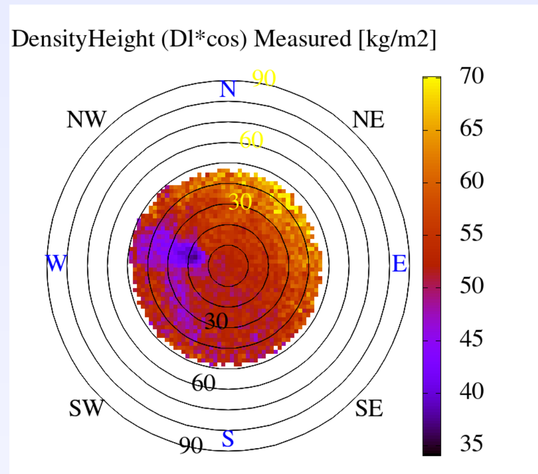
9. Fig: The JURLab gives us a great opportunity to test the systems we build under field conditions before we install them . The Mtm40 detector measures at 3rd floor of JURLab.

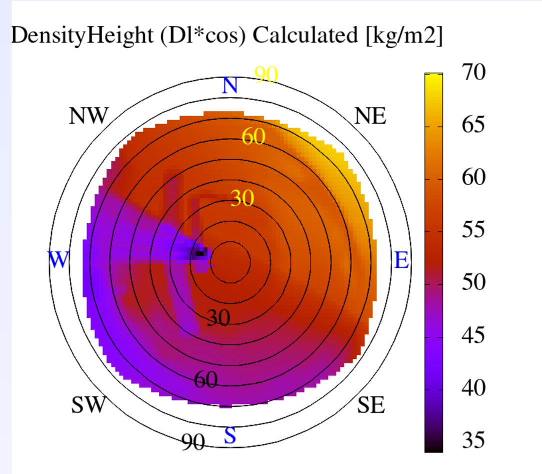
5. Testing of methodology

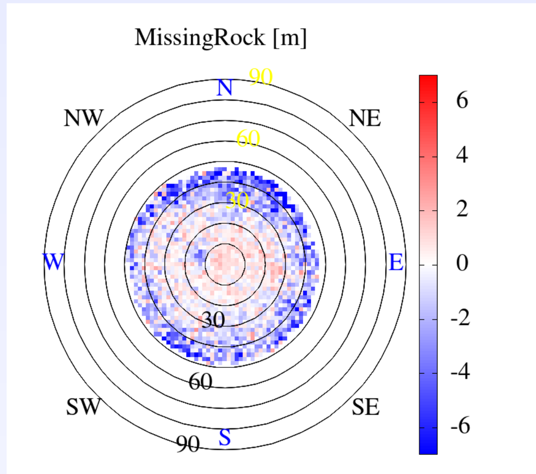
We conducted a series of measurements in JURLab with a dual purpose. The primary purpose was to test the accuracy of our inversion procedure and to make further improvements. Also, to validate the direct problem model with real field measurements. We have 13 measurements at 9 positions (Figure 10).An example of the Run41 measurement results is shown in Figures 11-13.



10. Fig : A simplified model of JURLab, the tunnels are approximated by a cylinder. The blue cylinders represent the measurement points.

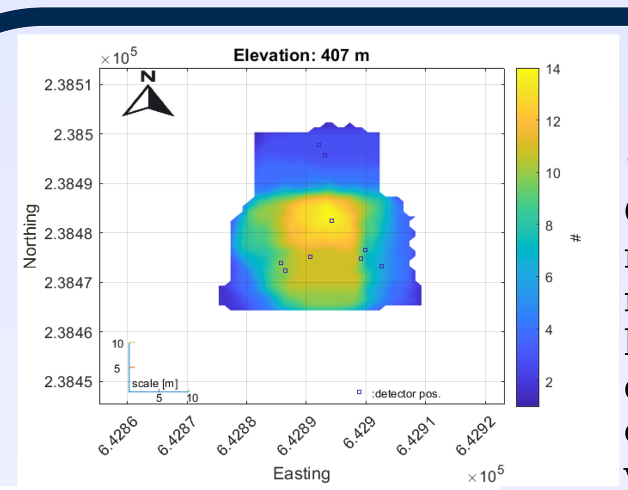




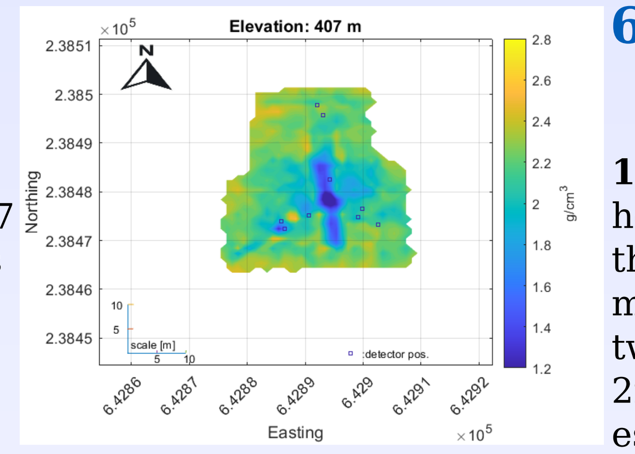


11. Fig (Right): Calculated density height (DL) from Run41 measurement. The result shows the main tunnel, the two branches of 2nd floor and the 1st floor with the escape tunnel.
12. Fig (Center): Density length map calculated based on the priori knowledge of the area and the measurement parameters.
13. Fig (Left): The difference between the measured and calculated rock length us an indication of where anomalies might be possible. For the JURLab measurements, the aim was to refine the geological model so that the difference was as small as possible.

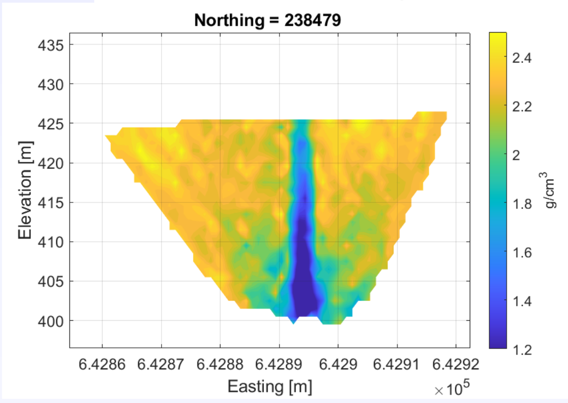
6. Inversion



14. Fig: Coverage map for 407 m. It shows how many detectors can see a voxel.



15. Fig: The horizontal slice of the inversion at 407 m. Visible are the two branches of the 2nd floor and the escape tunnel.



16. Fig: The vertical slice of the inversion. The main tunnel stands out prominently from the inversion.

Proper planning of the measurements is essential, as it determines certain parameters of the inversion, such as the target range. The angular resolution and measurement time of each measurement will affect the density contrast that can be detected.The inversion procedure we use is based on a maximum likelihood inversion method with the combination of geologically relevant Bayesian constrains [4]. Inversions calculated from measurements in JURLab are shown in Figures 14-15.