Seminar of the Institute of Radiaton Physics HZDR

Muon Flux measured in the Felsenkeller by the Regard Muon Tomograph

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25th March 2013

REGARD

RMKI ELTE Collaboration on Gaseous Detector Research and Development

Outline

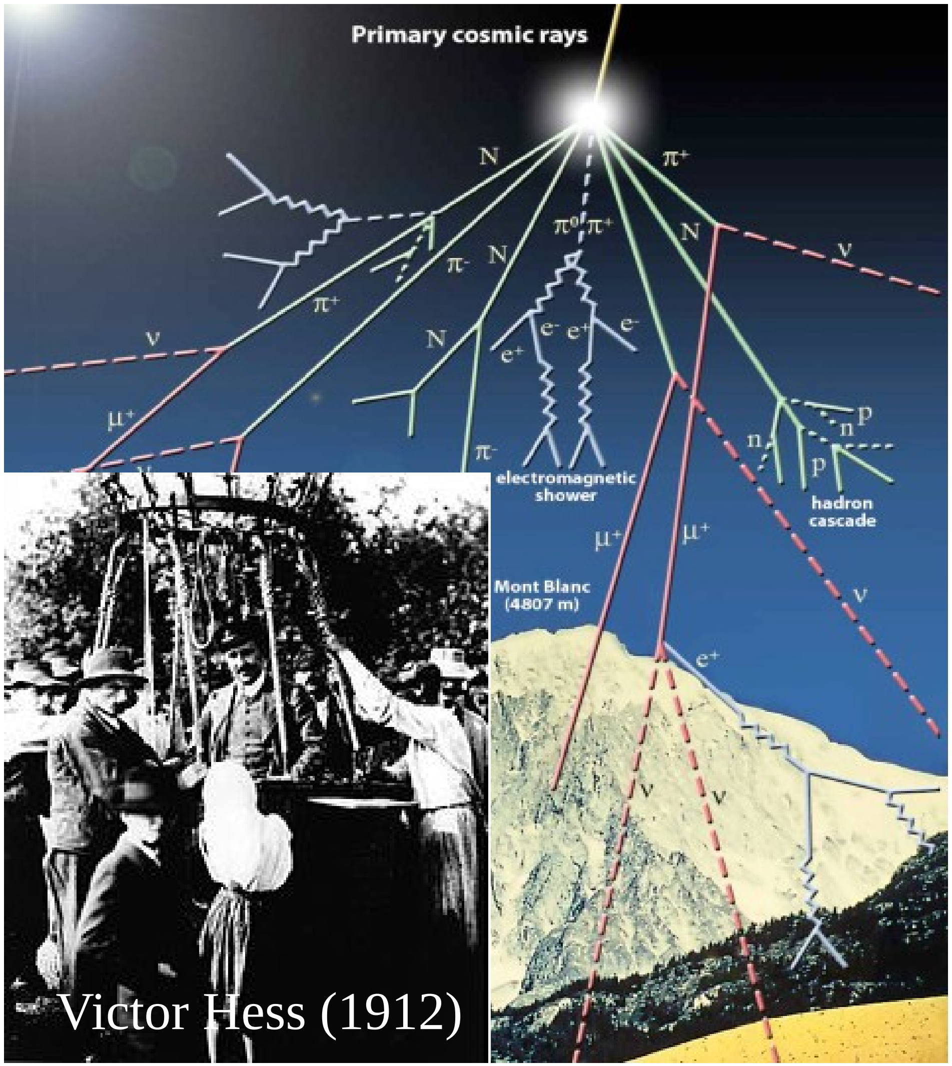
I. Motivation

II. The REGARD Muon Tomography Project

III. Underground Tests

IV. Measurements in Felsenkeller, Dresden

I. Motivation: Cosmic Rays at Earth

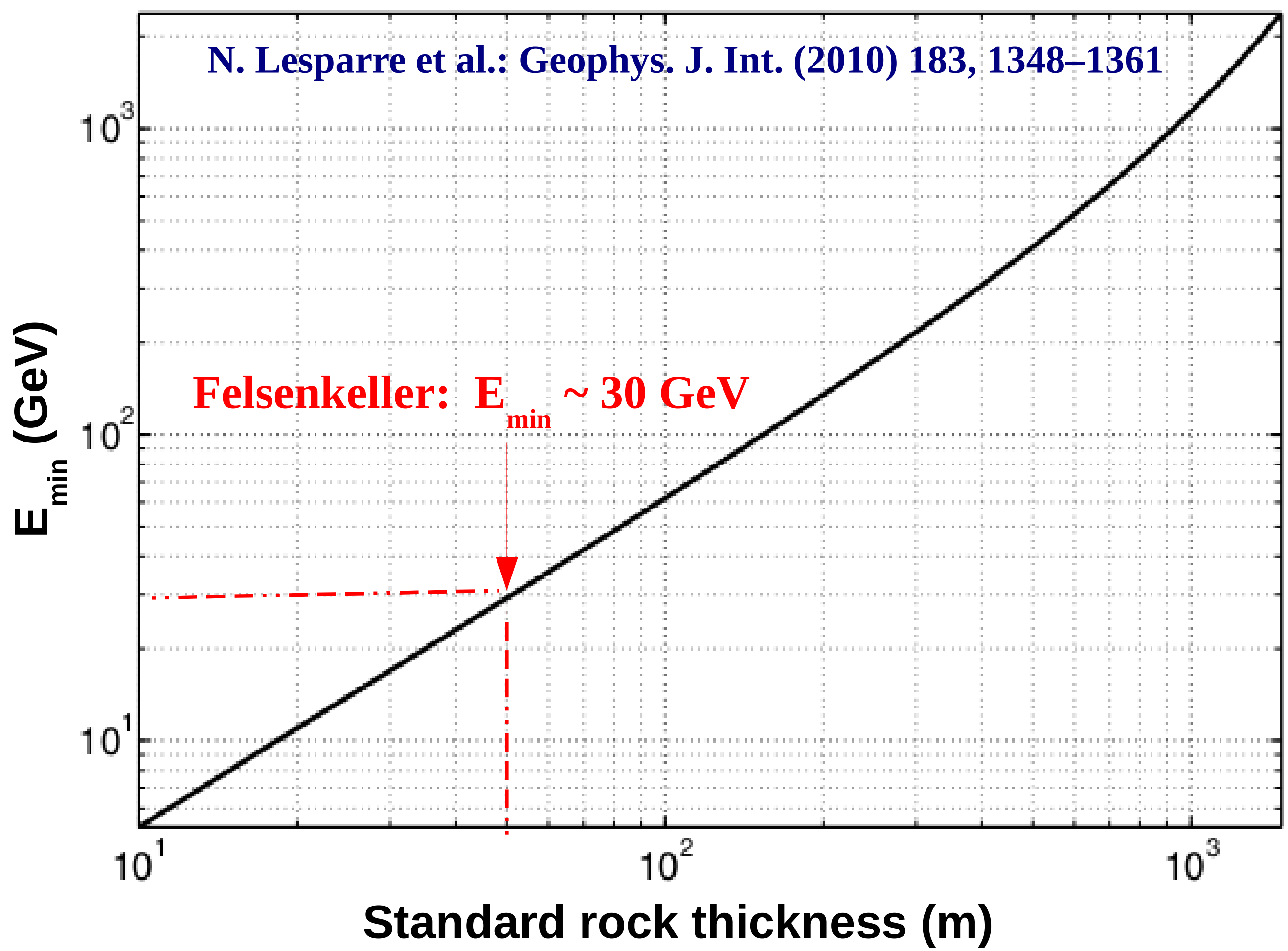


Victor Hess (1912)

- Our Earth is continually bombarded by high energy particles (p, ...).
- They interact with the atmosphere: producing pions, muons, etc.
- Cosmic particles reach the surface of the Earth, and penetrate to underground!

Penetration of Cosmic muons into underground

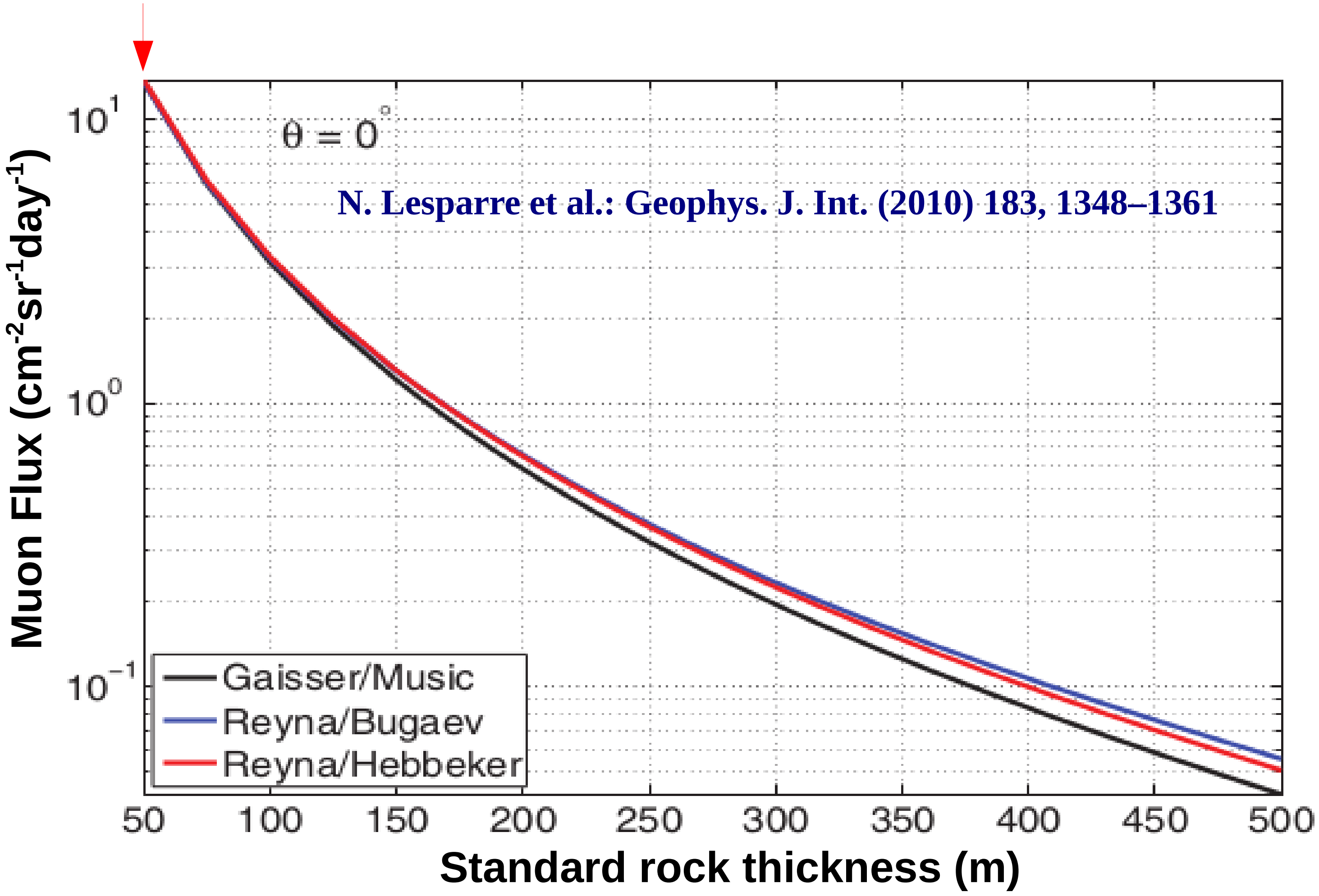
- Cosmic muons mainly loss their energy by ionization:
  $-dE/dL/\rho = a(E)+b(E)E$
- Bremstrahlung, nuclear interactions and direct e^-- e^+ pair production from Monte Carlo modelling



- 5 GeV → 10 m
- 30 GeV → 50 m
- 50 GeV → 100 m
- 1 TeV → 1 km

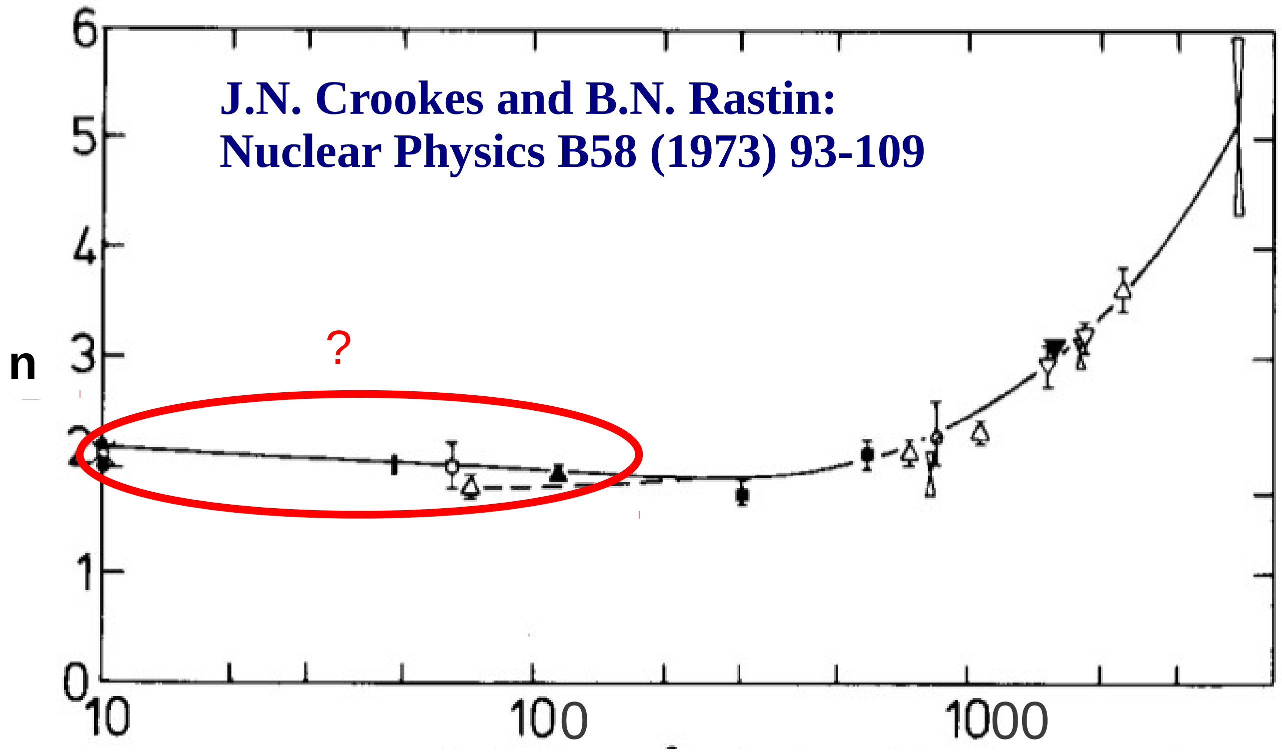
Muon Flux at Underground

- Vertical muon flux ~ 100 $m^{-2}sr^{-1}s^{-1}$ (864 $cm^{-2}sr^{-1}day^{-1}$) at the Surface of the Earth
- Muon flux decreases with the depth by the energy loss
- Expected vertical muon flux in Felsenkeller is ~ 2% of ground flux



Angular distribution at under the Ground

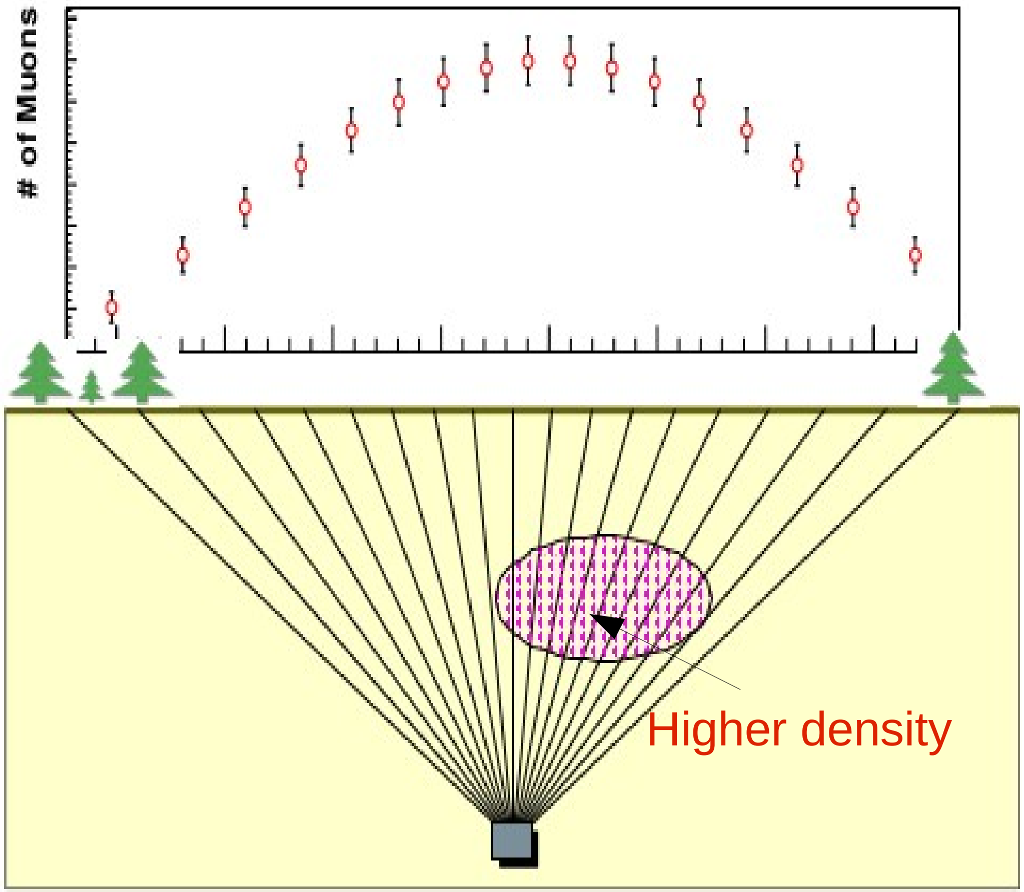
- **$f(\theta) \sim \cos^n(\theta)$**, where θ is the zenith- angle and n is the exponent
- The n exponent varies with the depth (Decay ratio for $\pi^{\pm}/K^{\pm}$: 80% - 20%)
- The exponent is about 2 at shallow depths



Depth (hgcm^{-2} below the top of the atmosphere)

Density-length: 1 hgcm^{-2} = 100cm · 1 gcm^{-3} ≈ 1 meter-water-equivalent

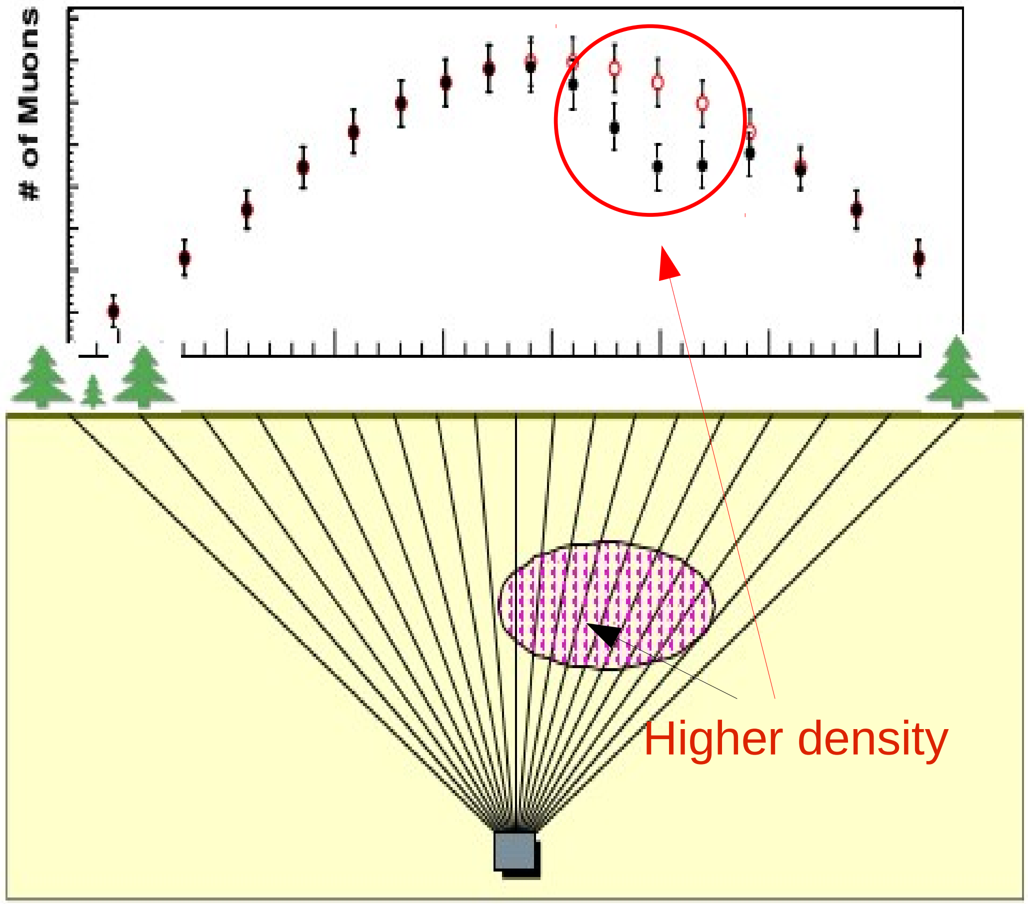
Muon Radiography



See Zhiyi Liu talk at MNR2012 (Clermont Ferrand)

- **Aim:** detect rock/soil inhomogeneities by measuring the cosmic muon flux
- Difficulties:
  - muon source is not isotrope
  - large target with unknown structure

Muon Radiography



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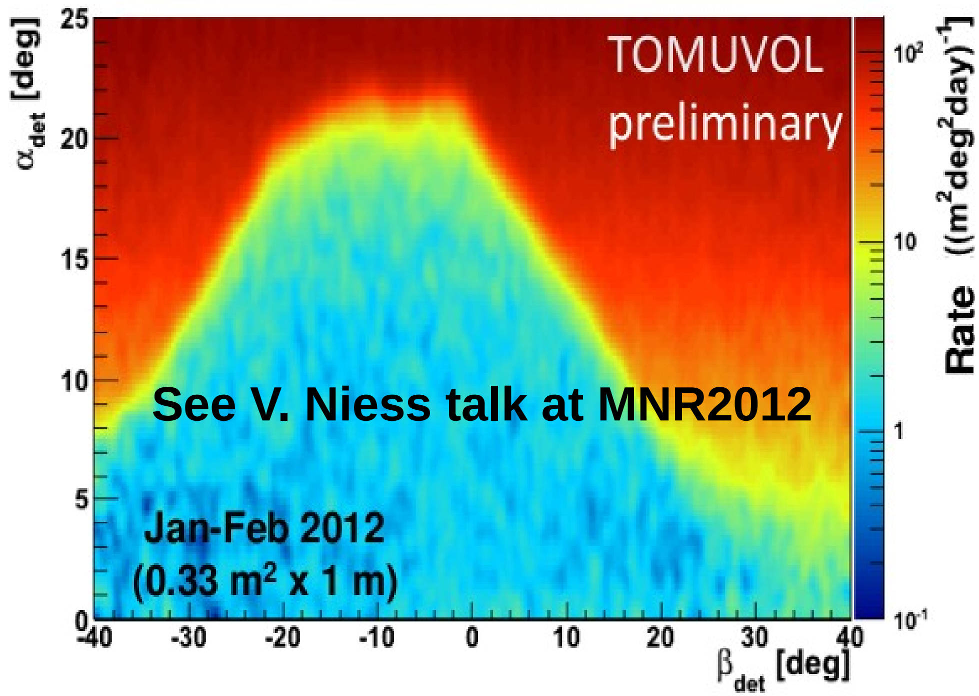
- **Aim:** detect rock/soil inhomogeneities by measuring the cosmic muon flux
- Difficulties:
  - muon source is not isotrope
  - large target with unknown structure

Underground rock inhomogenity with higher (lower) density the cause of the decrease (increase) in muon flux.

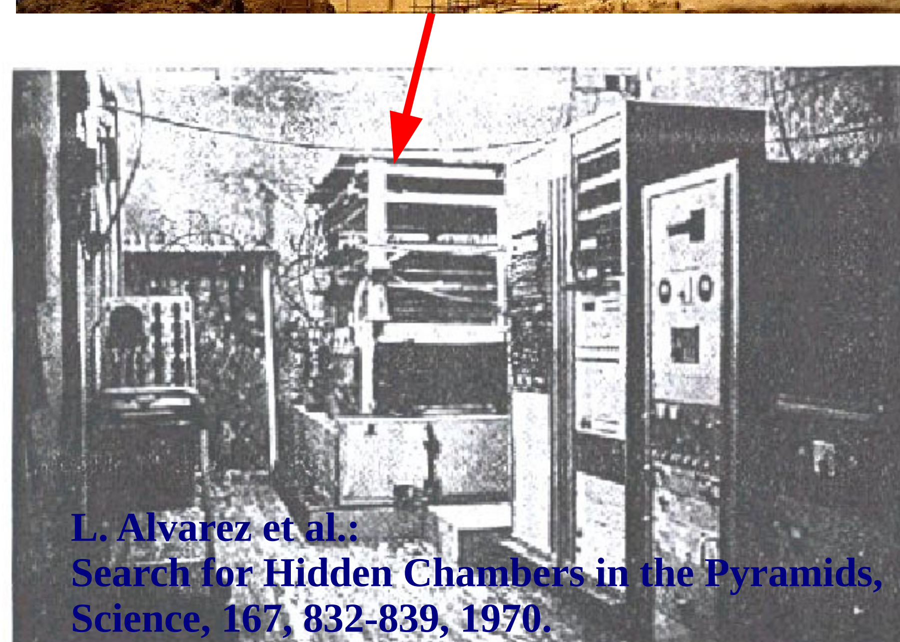
Vulcanology:

predict the eruptions



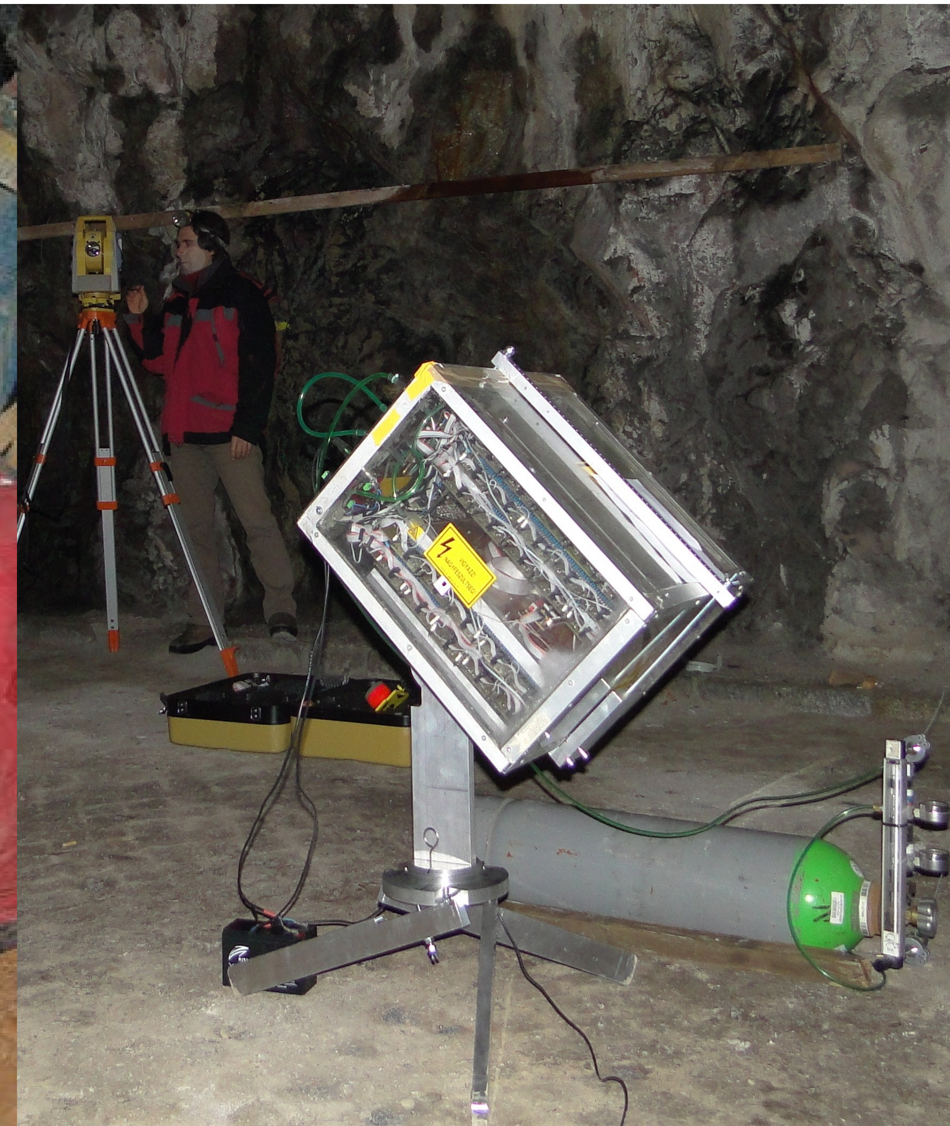
Archeology:

search for hidden chambers

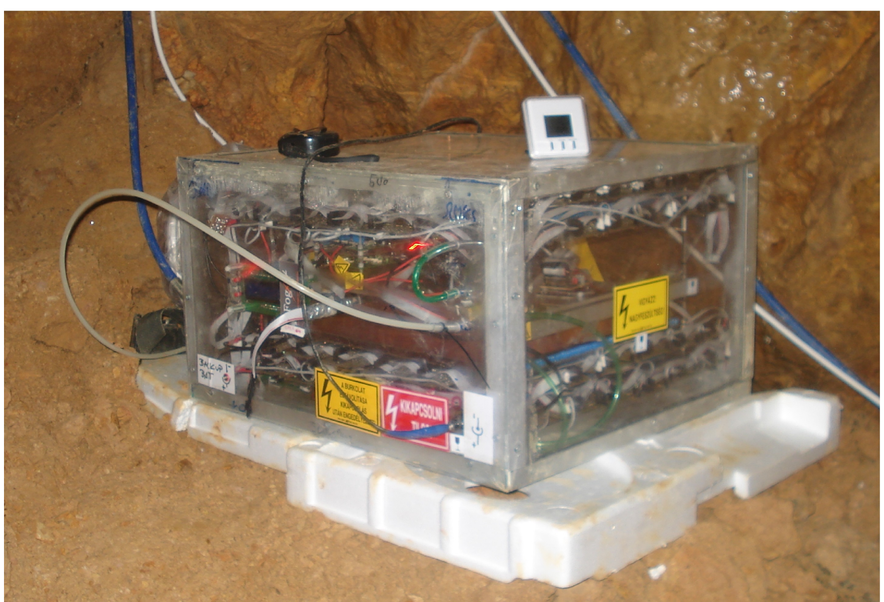


L. Alvarez et al.:
Search for Hidden Chambers in the Pyramids,
Science, 167, 832-839, 1970.

II. The REGARD Muon Tomography Project



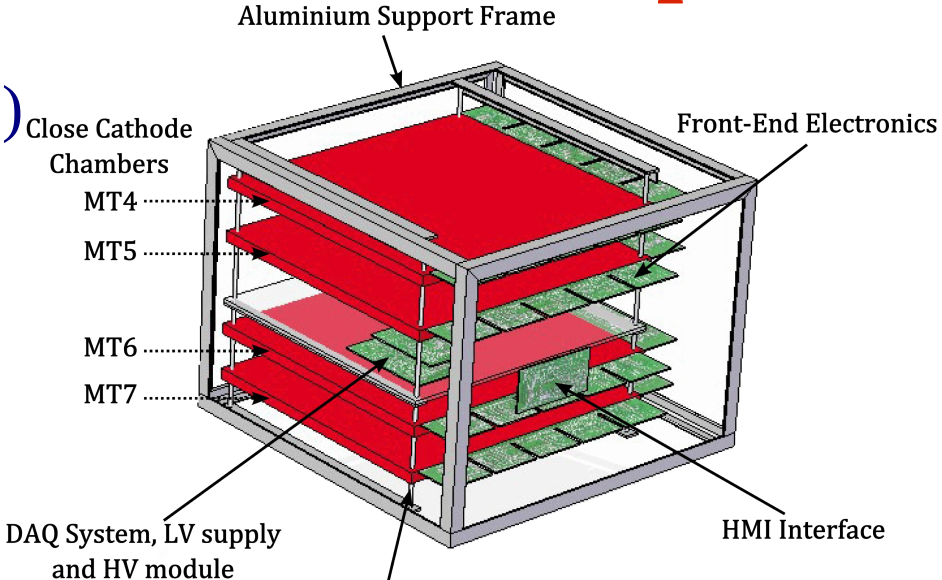
Our Motivation

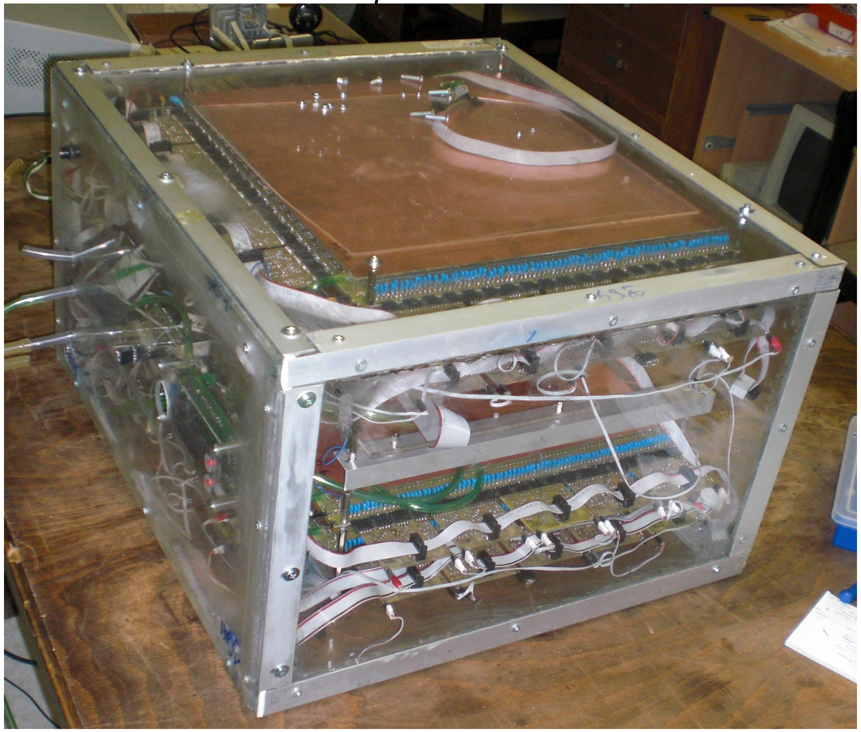


- **Aim of Our Research:**
  - High precision
    muon flux measurement
  - investigating unexplored
    part of caves
  - searching underground rock
    inhomogeneities
- **Portable Muontelescope:**
  - precision:
    - 1.5 mm spatial resolution
    - 10 mrad angular resolution
  - use in high humidity
    (~ 100%) environment
  - cheap and power efficient (< 5 W)

Structure of the Portable Muontelescope

- 4 (or 5) Close Cathode Chambers (CCC)
- Sensitive area per layer:
  32 cm by 32 cm
- Plexiglass box
- Easy to handle manually:
  - volume: 51 x 46 x 32 cm^3
  - total weight: 15 kg
- Data acquisition (DAQ) system integrated into one unit
- Human Machine Interface (HMI):
  - LCD display, SD card



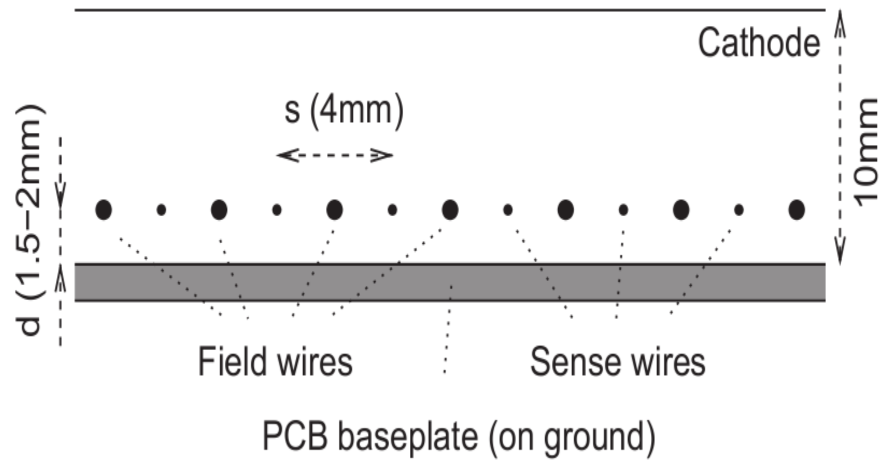


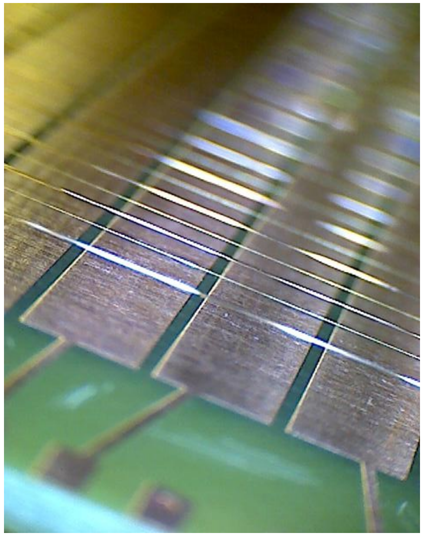
CCC Technology for Muon Detection

- **Close Cathode Chamber** is an Asymmetric **Multiwire Proportional Chamber**

  D. Varga et al.: NIM A 648 (2011) 163

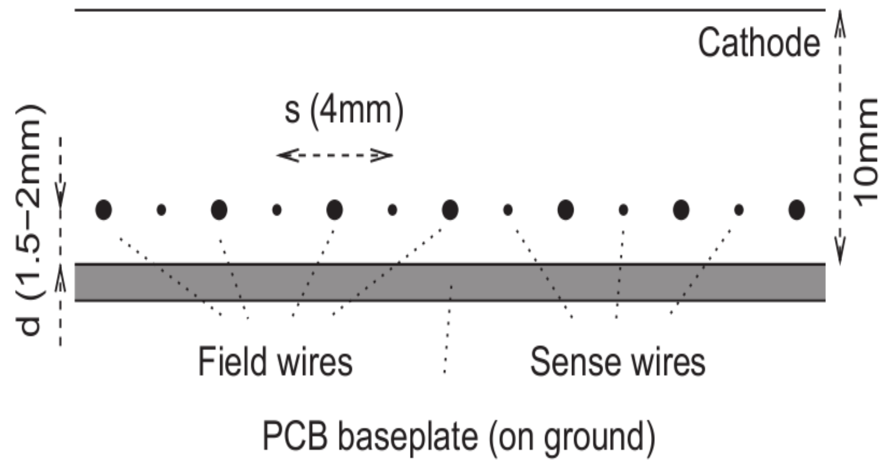
  D. Varga et al.: NIM A 698 (2013) 11
- 2 dimensional location:
  - field wire: distance 4 mm
  - The lower cathode is segmented into 4 mm wide strips (pads) perpendicular to the wires
- Triggering on coincidence of sense wires' signals
- Requires continuous gas flow during operation: non-flammable Ar – CO_2

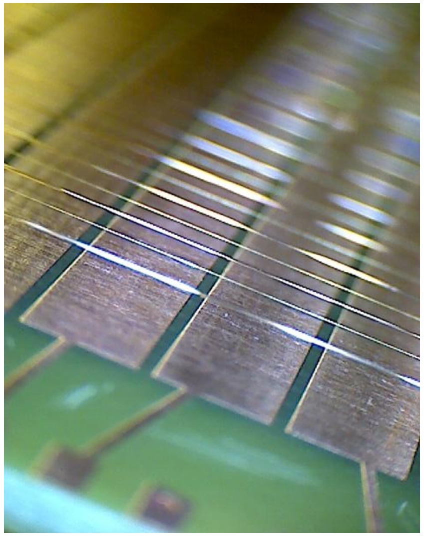




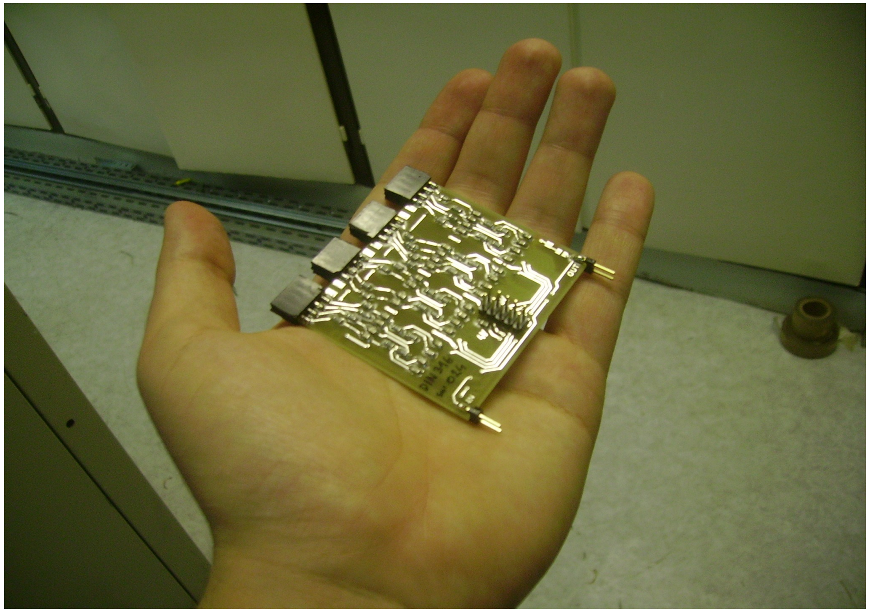
CCC Technology for Muon Detection

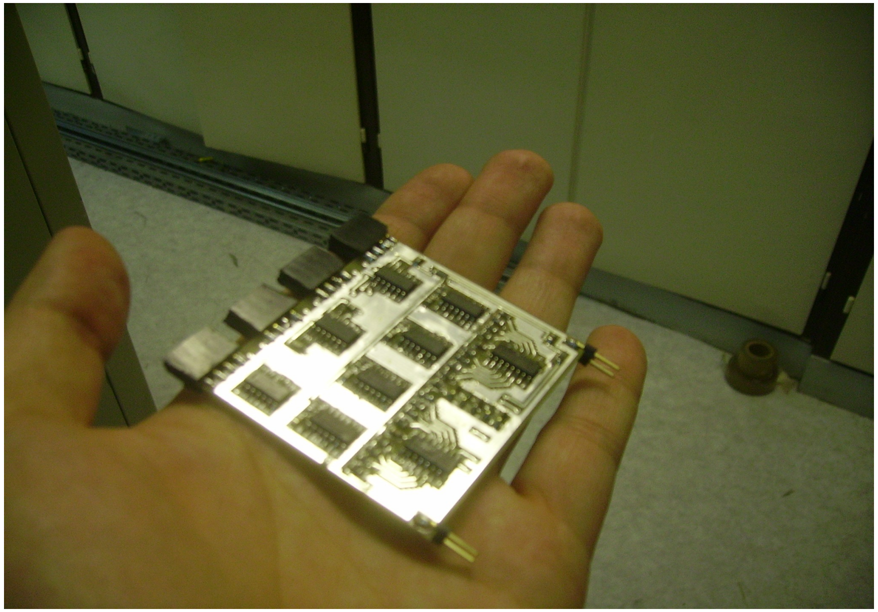
- **Why CCC?**
  - MWPC which does not require weighty outer support frames
  - Optimizes:
    - Weight/Layer (0.88 kg)
    - Position resolution (1.5 mm)
    - Efficiency (> 95 %)
    - Cost
  - High tolerance against mechanical inaccuracies (100-200 μm)





Front-End Electronics for Data Readout

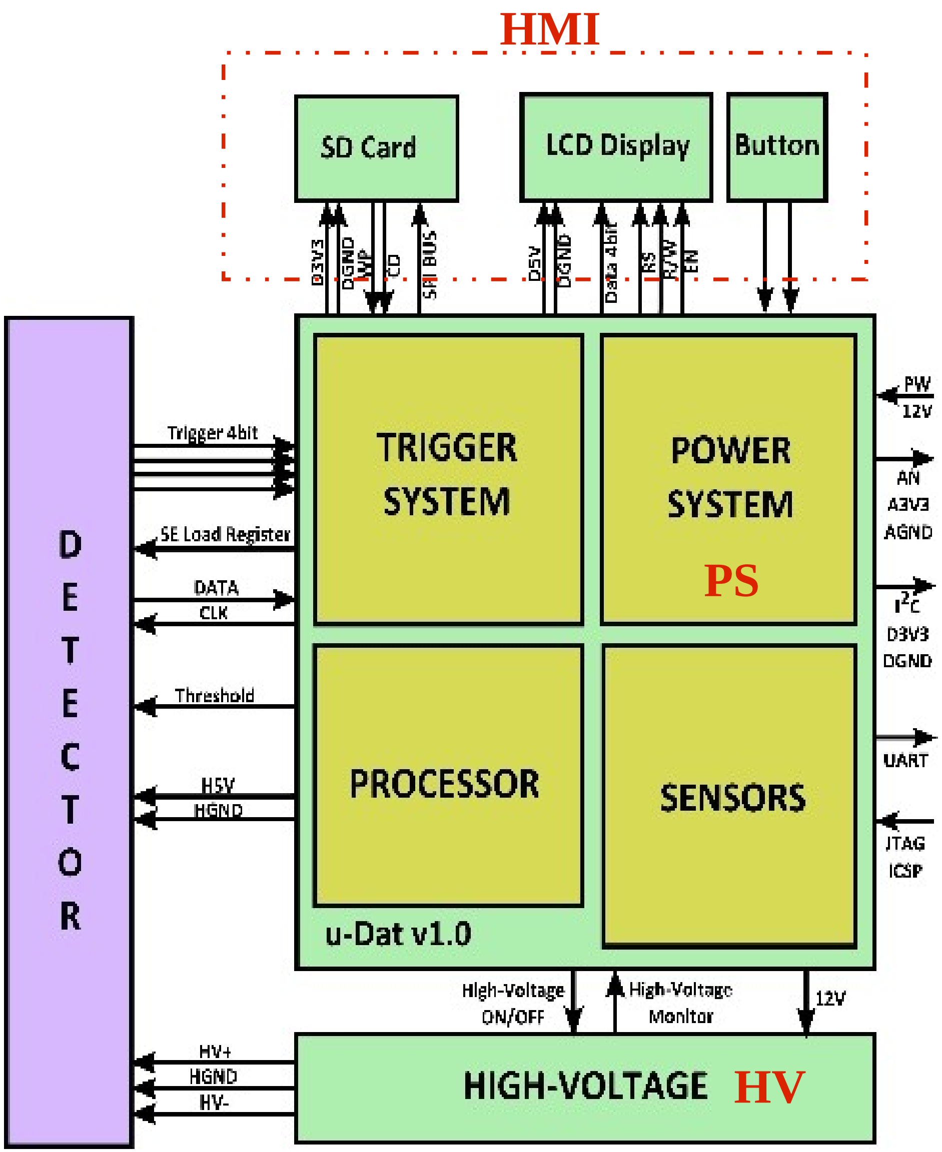




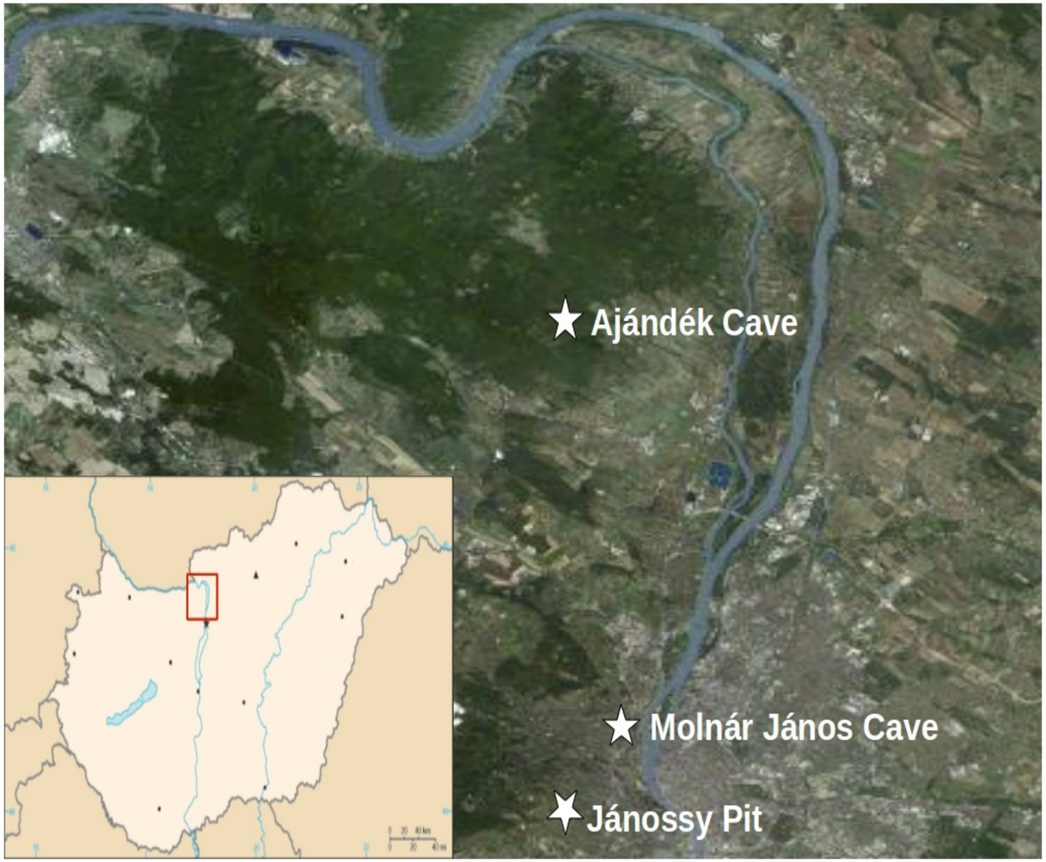
- 16 channels per electronic
  (10 electronics per chamber)
- Analog amplification
  with commercial logic ICs
  (CD4001 and CD4069)
- Discrimination →
  1 bit per channel
- Local storage
  in a shift register (74HCT165)
- Serial readout
- All electronics can be put into one chain

Integrated Data Acquisition System

- PIC32 based DAQ
- All functions are integrated
  into a common system plan
- Small unit: placed between the middle CCC layers
- **Main functions:**
  - Low Voltage, Power System (PS)
  - High Voltage:
    - 1000-1050 V for sense wires
    - -600 V for field wires and cathode
  - Trigger System
  - Detector Data Handling
  - Environmental Control
  - HMI for maintance and data storage
- **Total power consumption:**
  - 380 mA at 12 V: **power < 5 W !!!**
  - Complete unit can operate
    for more than 5 days with a 50 Ah battery

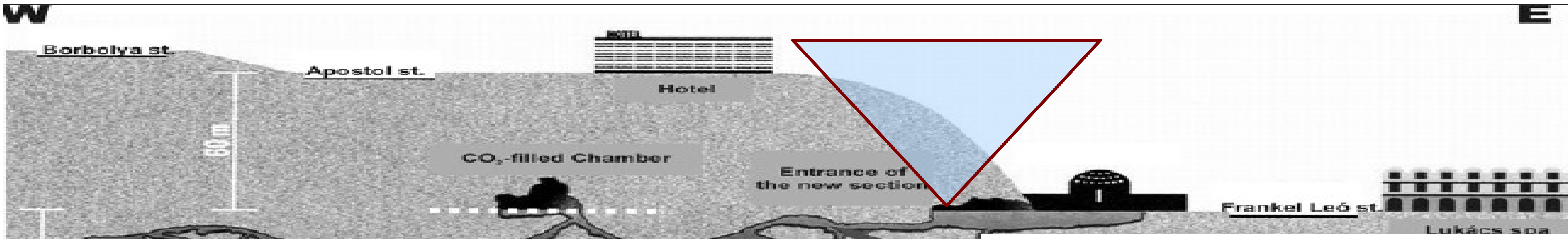


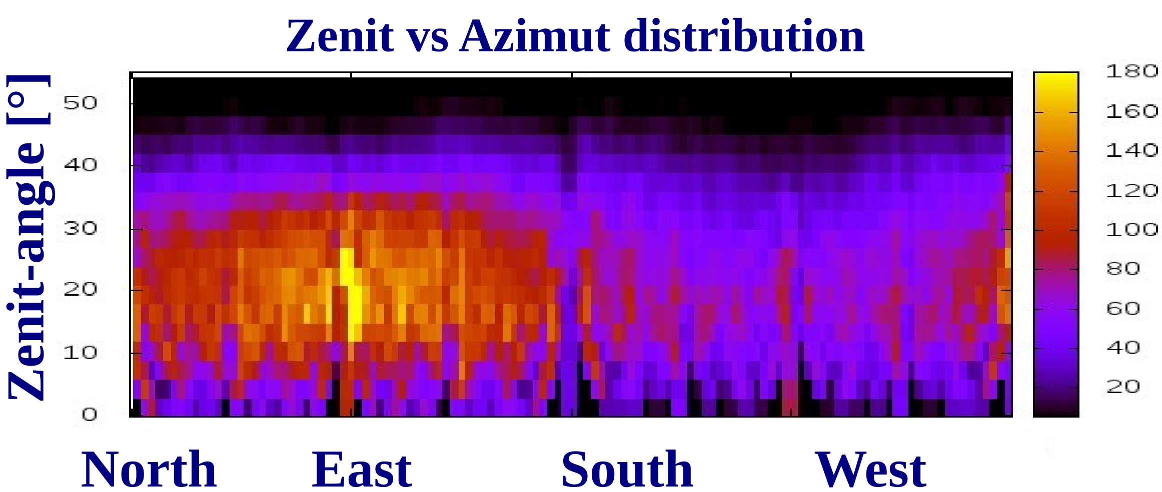
III. Fieldwork: Natural Caves and Artificial Pits

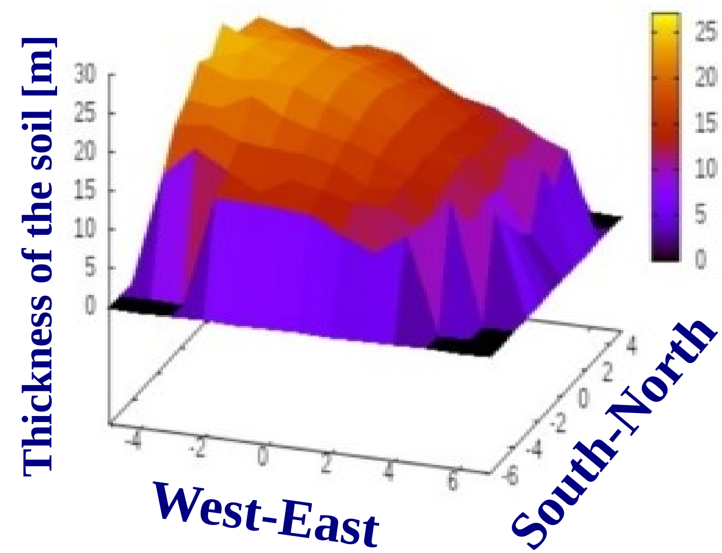


- **Lab (0 m):** > 100 days, > 100 M muon events
- **Molnár János Cave (-45 m):** 77 days, 1.1 M muon events
- **Kőbánya Tunnel Sys. (-20 m):** 30 days, 500 k muon events
- **Jánossy Pit (-10, -20, -30 m):** 30 days, 4 M muon events
- **Ajándék Cave (-60 m):** 50 days, 170 k muon tracks

Detector Tests in the Molnár János Cave



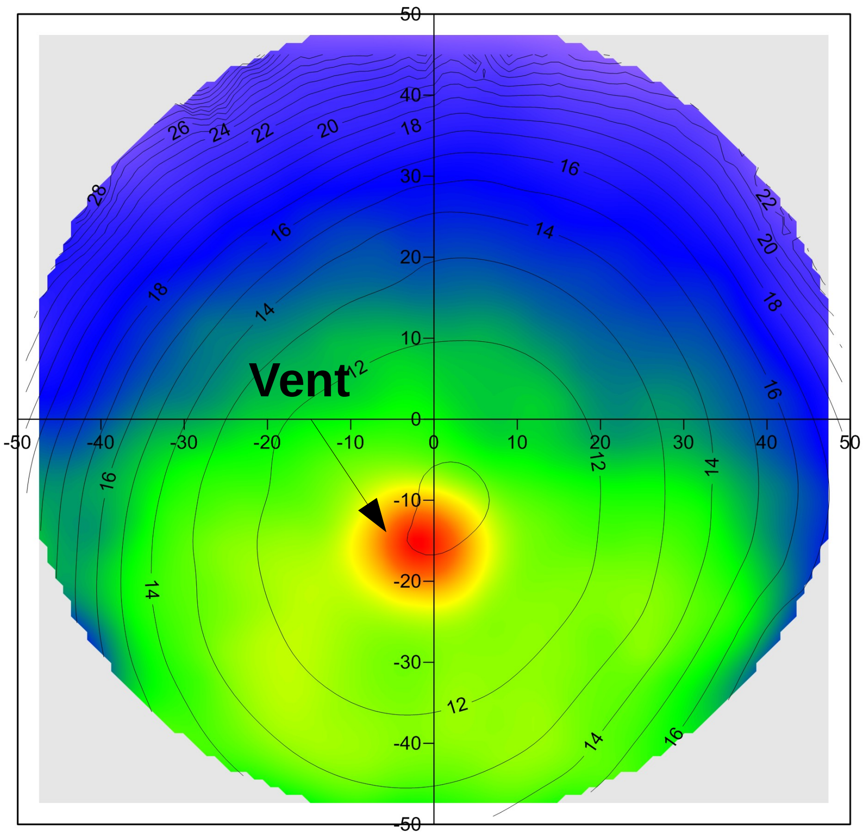


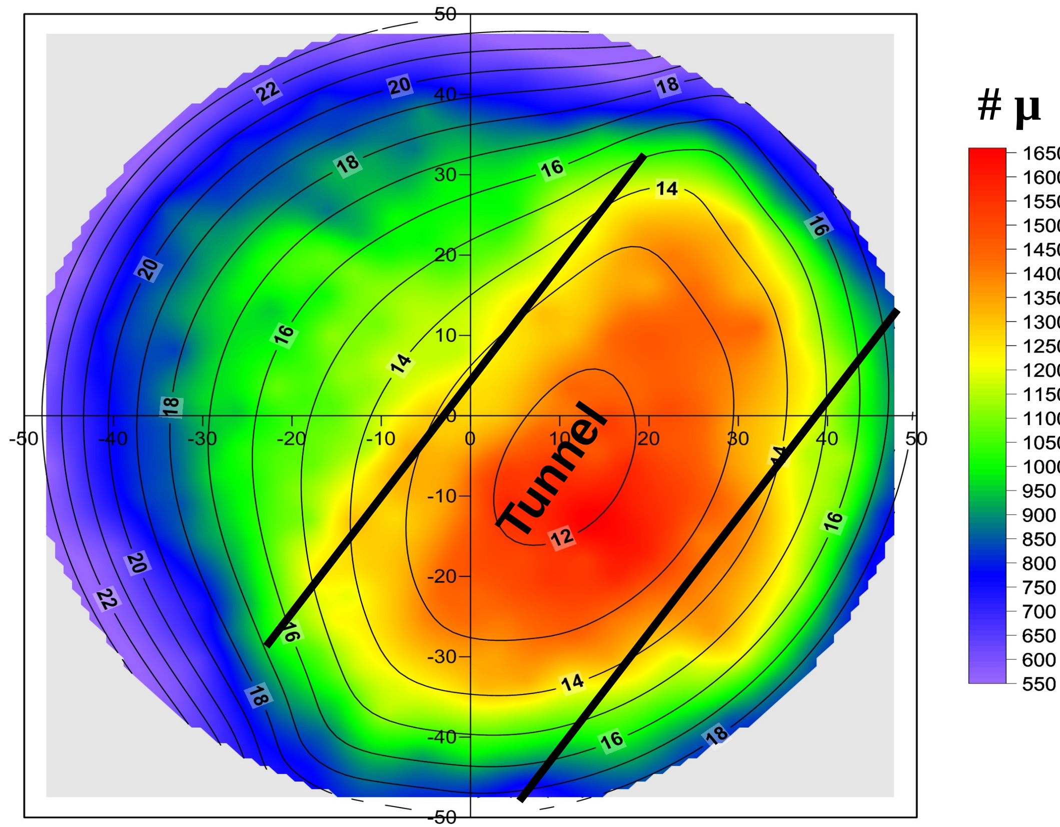


- Motivation: detector calibration under a well mapped hill and its relief reconstruction
- Measurements at 20-50 meter-rock-equivalent: 18 days with 850 k events
- Zenit-Azimut angle distribution and relief reconstruction both show the correlation between the amount of material above the detector and muon yield

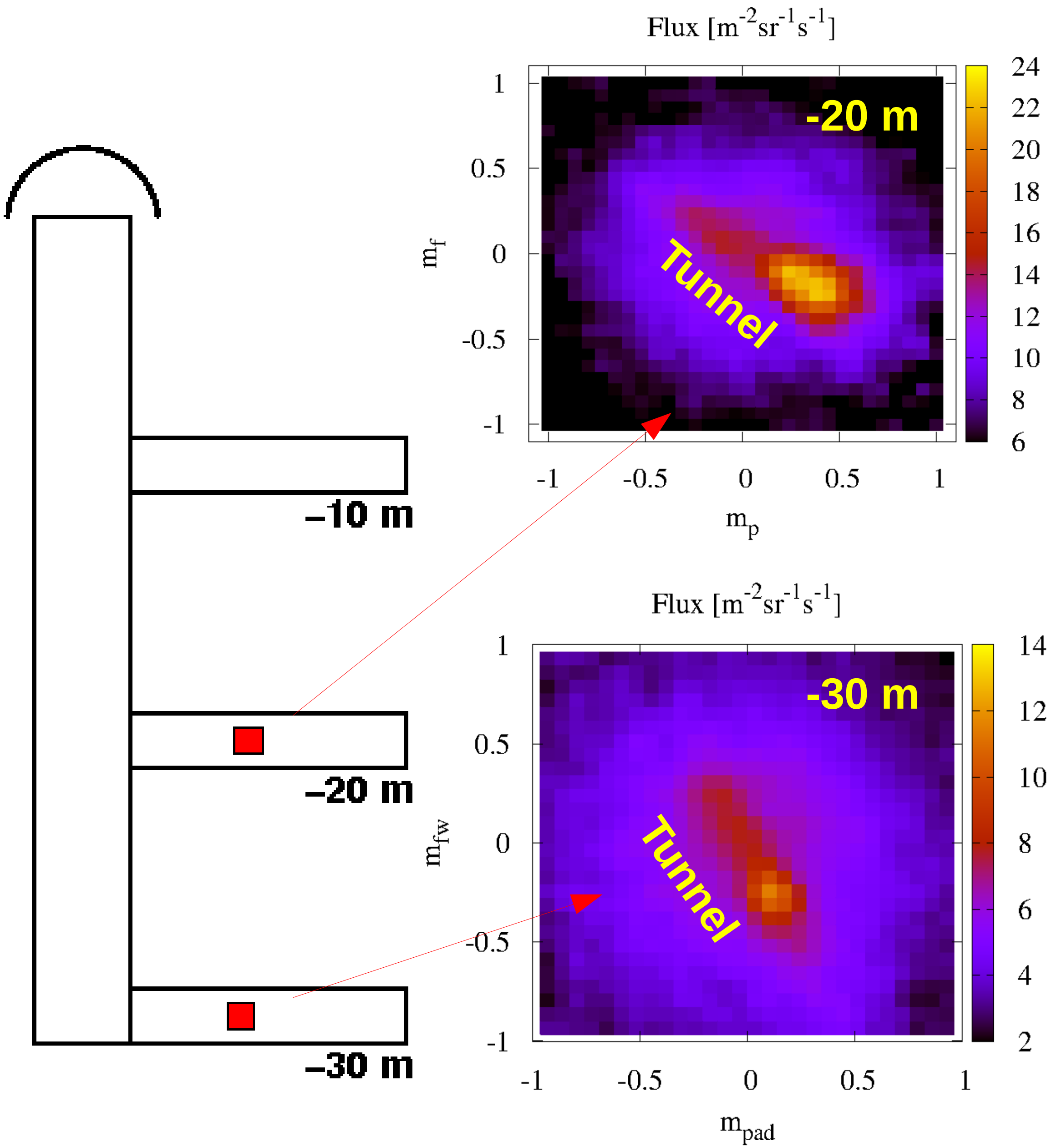
Detector Tests in Kőbánya Tunnel System

- Motivation: detect the sharply differences with relatively small size (1-2 m) in rock thickness
- Measurements at 10-20 m depths: 1-2 week with 200k - 500k muon tracks
- Measured muon flux correlates with the transversed material: the muon telescope could detect the sharply differences in soil thickness (e.g. the vents, the walls of tunnels)!





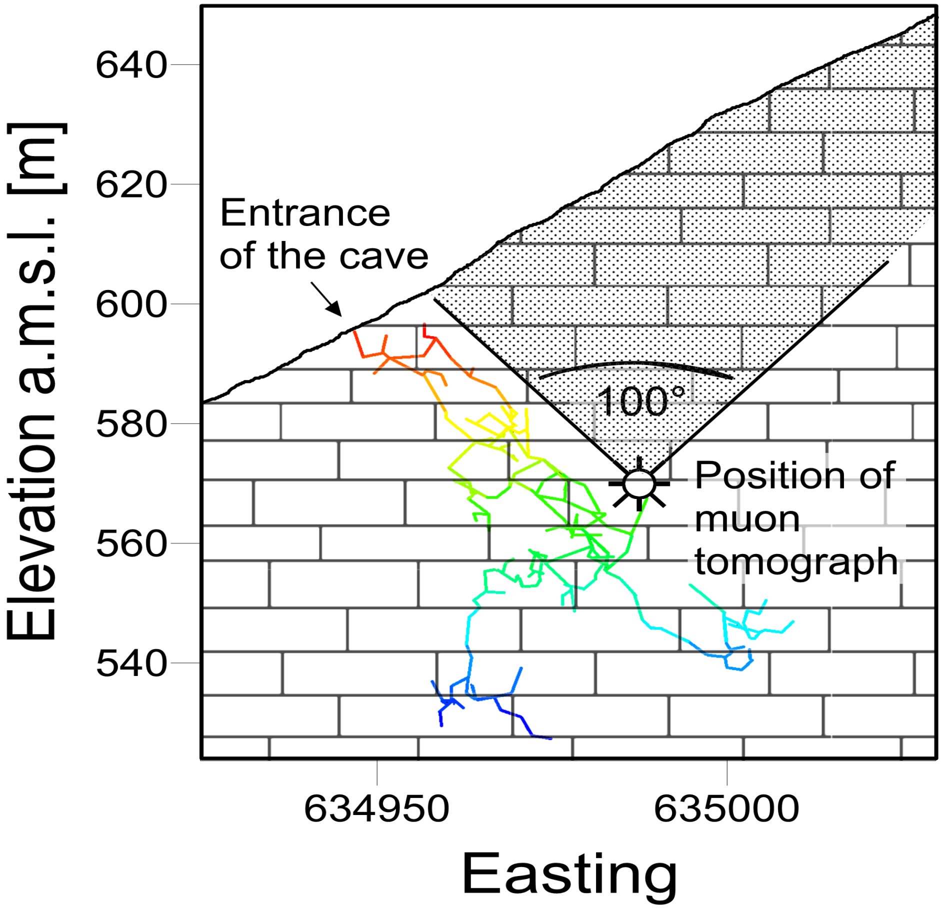
Tunnel Detection in the Jánossy Pit



- Motivation: detect the underground tunnel structures
- Measurements at 10 m, 20 m, and 30 m depths: 3-5 days with 100k-200k muon tracks
- Measured muon flux clearly shows the ,,image" of the tunnels

Search for Cavities in the Ajándék Cave

- Natural cave system
  close to Pilis mountain, Hungary
- Search for unknown natural caverns or chambers at scale 2-4 m
- Time of data taking: 50 days
- The gas and 3 power supply batteries were deposited at the cave entrance, and were connected with 100 m long cable and tube



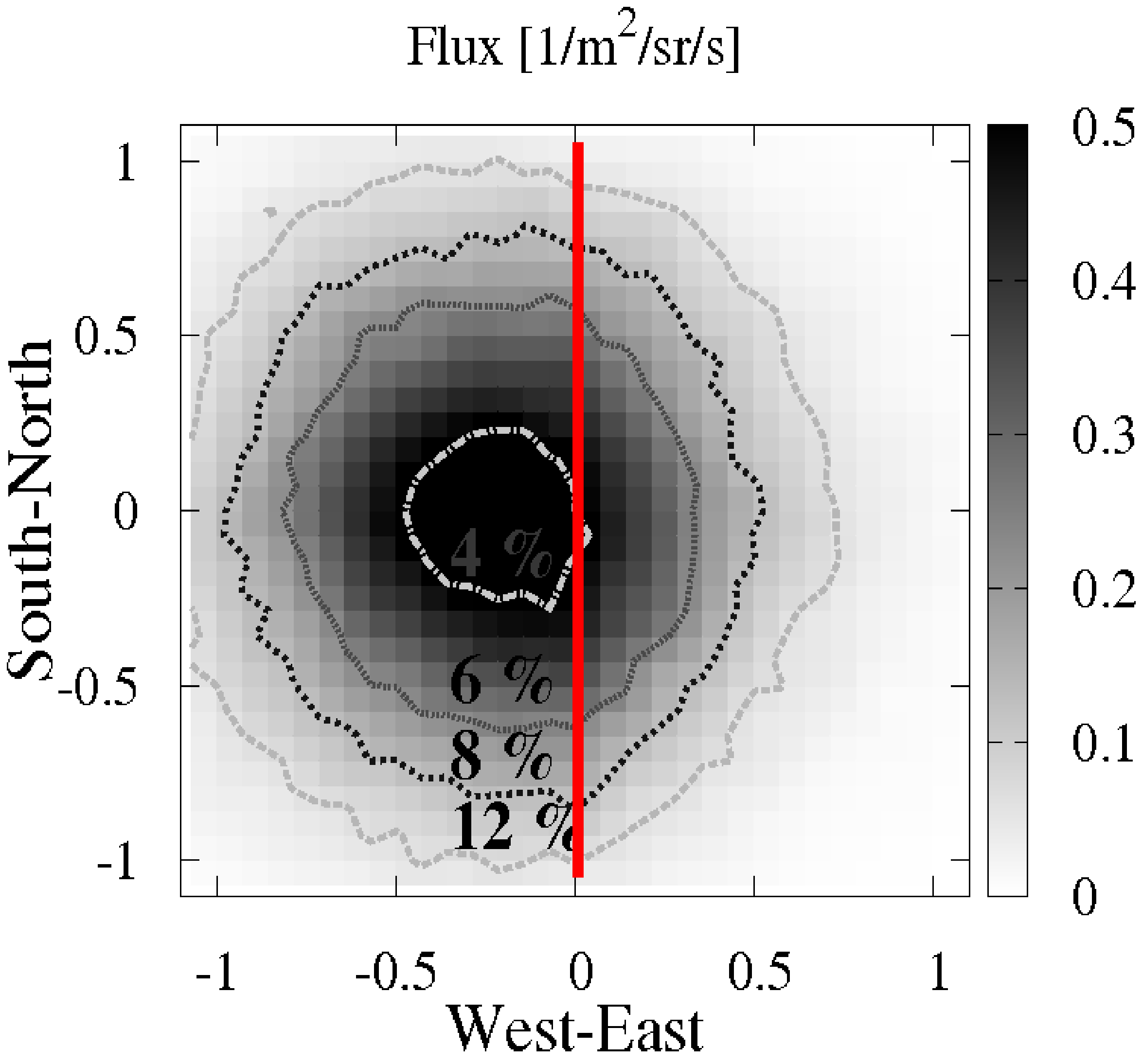
Deployment at the entrance of the Ajándék Cave

- Cave entrance: batteries and gass bottles (detector before deployment)

Deployment in the Ajándék Cave

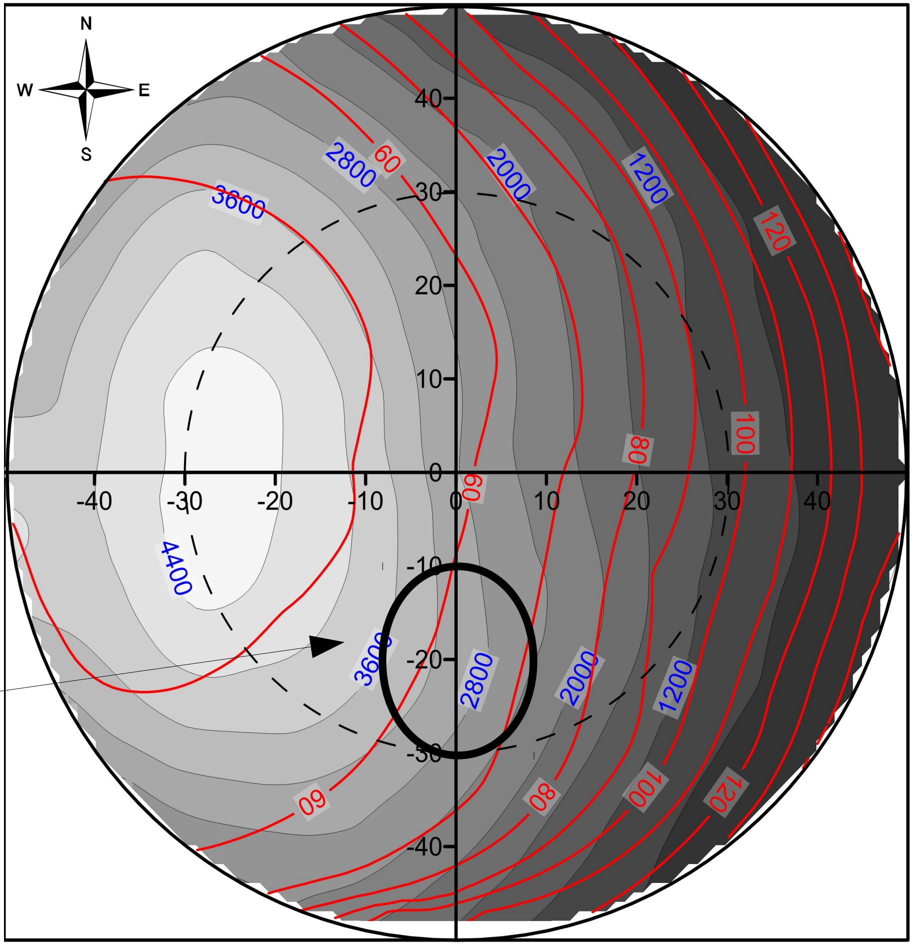
Measured Muon flux in the Ajandek Cave

- During the 50 days of data taking: 170 k muon tracks (60m underground)
- Flux with pixel-by-pixel statistical error
- Main yield is shifted to the Western direction



Mountain Relief above the Ajándék Cave

- Muon flux vs thickness of the rock: show correlation
- Possible cavern around -25 deg zenith angle at the North-South axis



G. G. Barnaföldi et al.: NIM A 689 (2012) 60
L. Oláh et al.: Geoscientific Instruments, Methods and Data Systems 2 (2012) 781

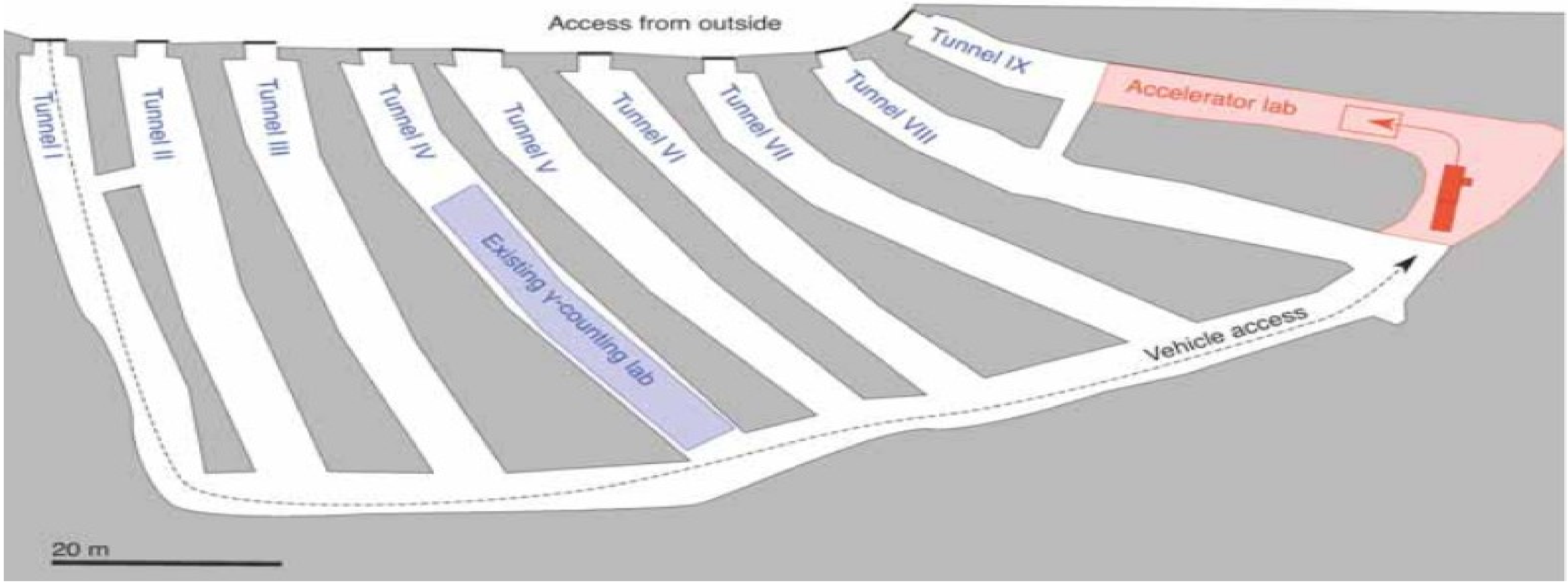
IV. Measurements in Felsenkeller, Dresden

Motivation of the Measurements

- Underground accelerator for astrophysical research at Felsenkeller tunnel system

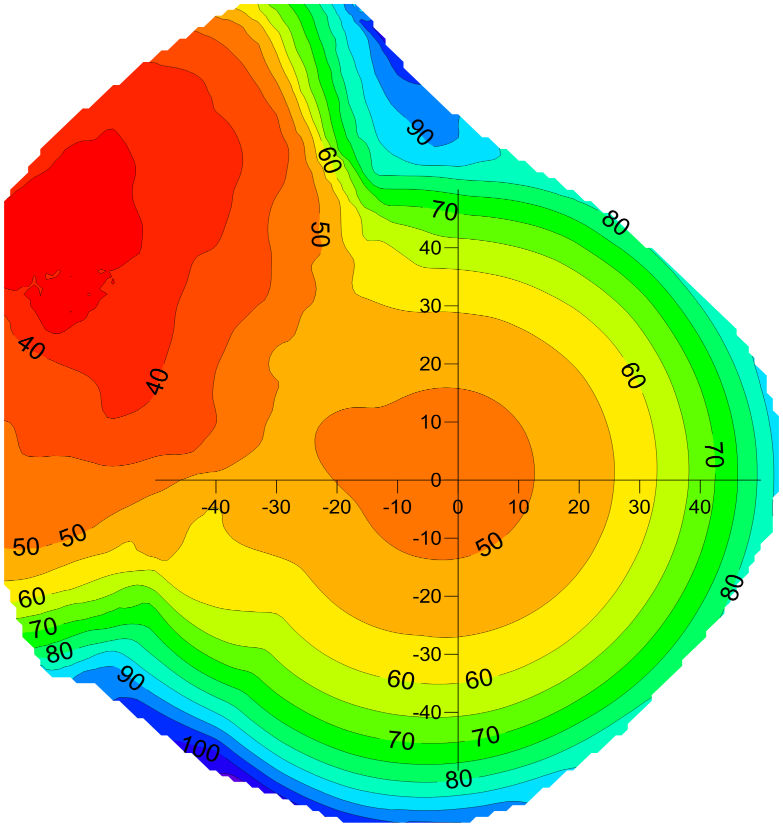
  T. Szücs, D. Bemmerer, T. Cowan and K. Zuber:
  Journal of Physics: Conference Series 337 (2012) 012032

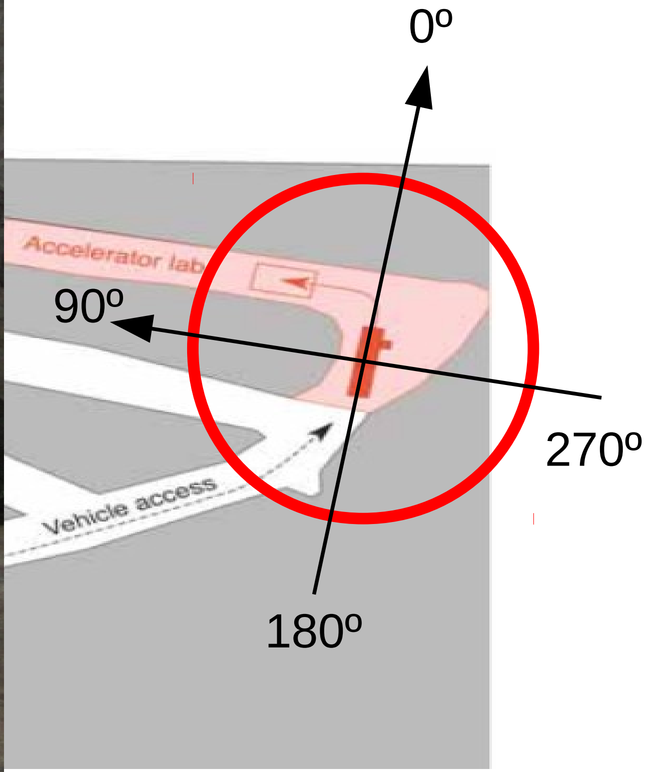
- **Aim:**
  measure the background,
  which caused by cosmic muons and electron showers



The Program

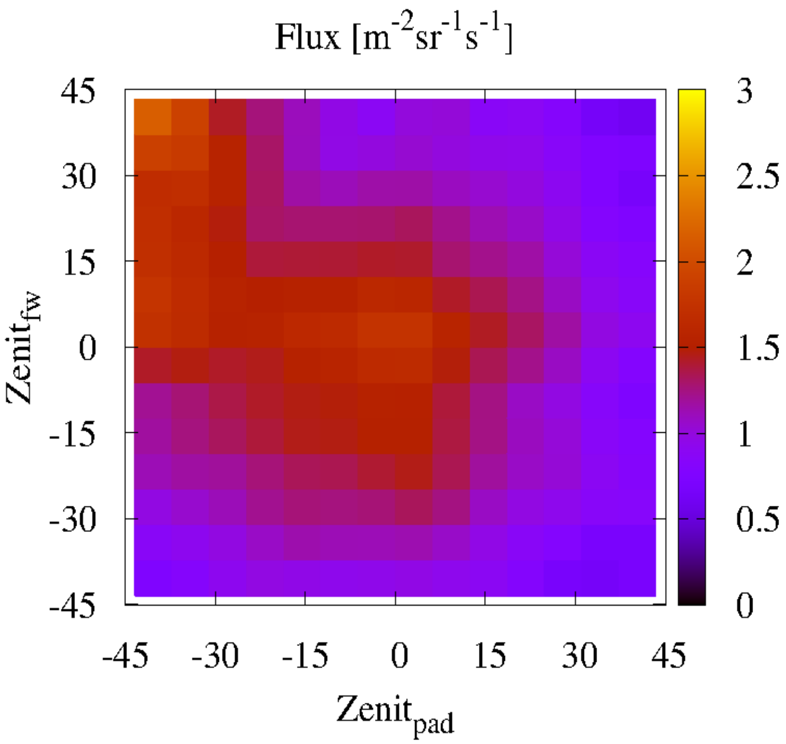
- 2π scan of muon flux by 1 + 4 (tilted with 45°) measurements
- Fix detector position during the meas.: 350° to the magnetic North
- Rock thickness also have been measured by laser scanning total station

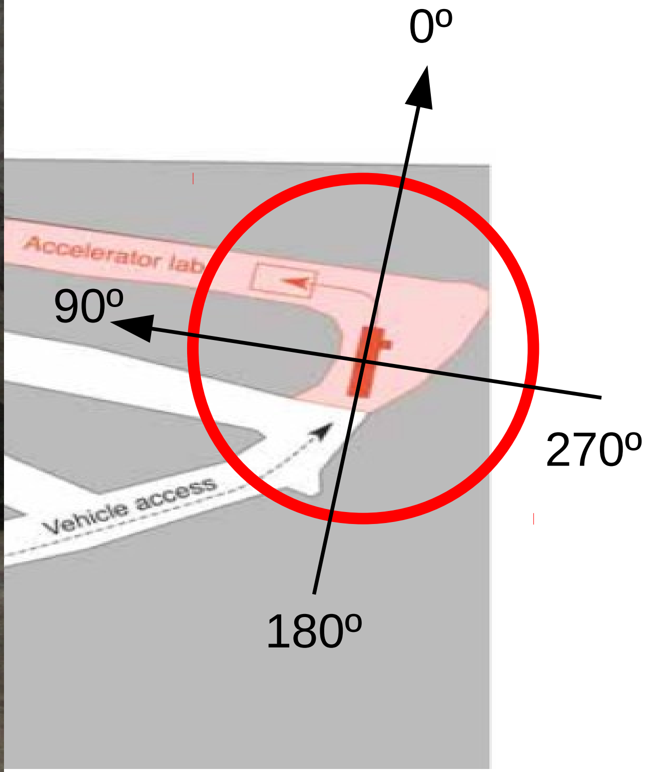




Measurements in horizontal detector position

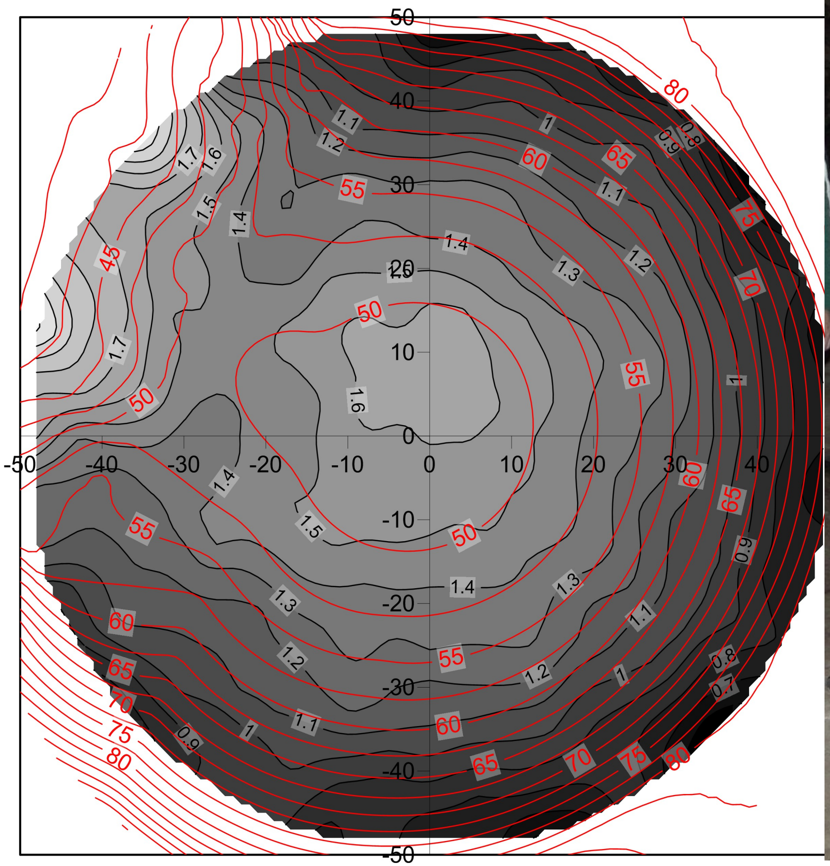
- Azimuth 0º and zenith 0º:
  107008 tracks have been collected during 10 days
- Vertical flux: ~ 1.6 $m^{-2}sr^{-1}s^{-1}$

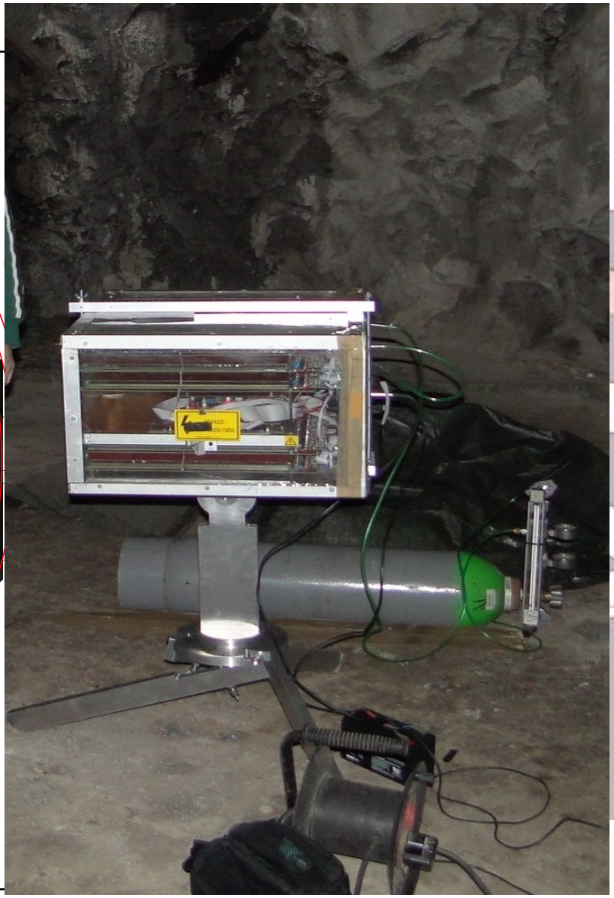


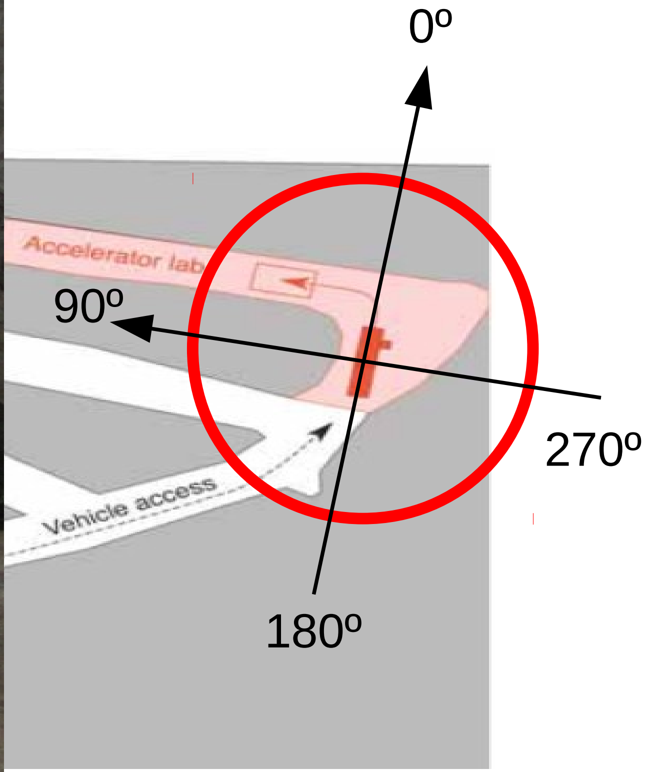


Measurements in horizontal detector position

- Azimuth 0º and zenith 0º:
  107008 tracks have been collected during 10 days
- Vertical flux: ~ 1.6 $m^{-2}sr^{-1}s^{-1}$
- Correlation between the measured flux and rock thickness

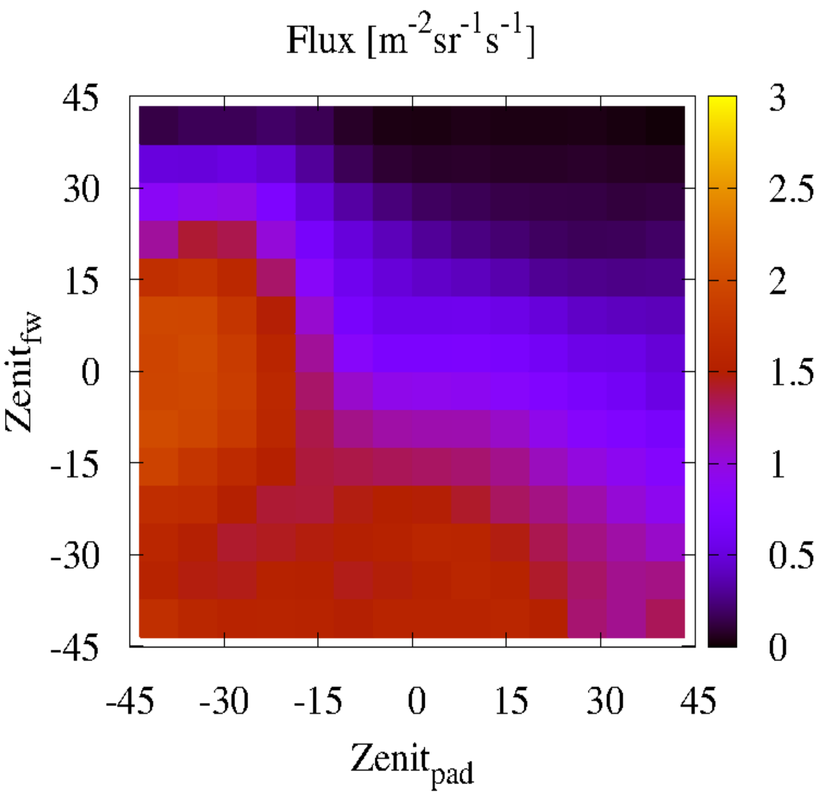


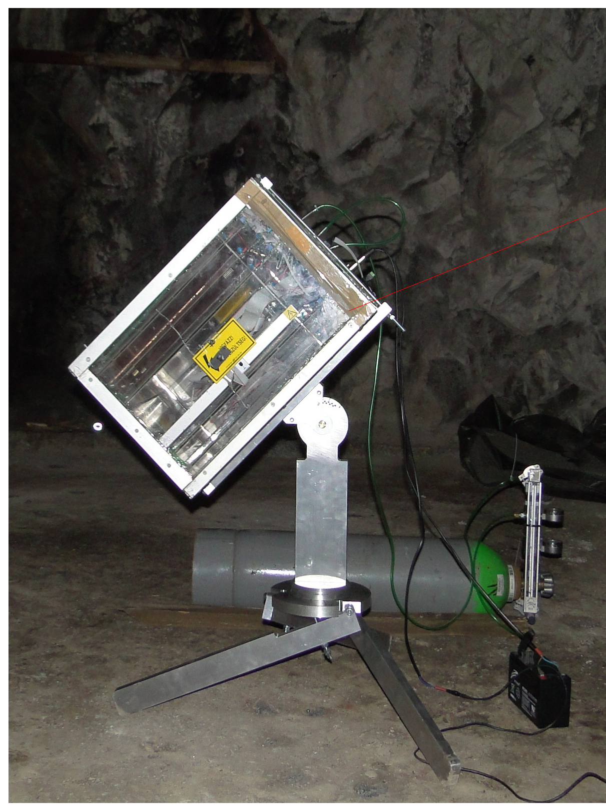


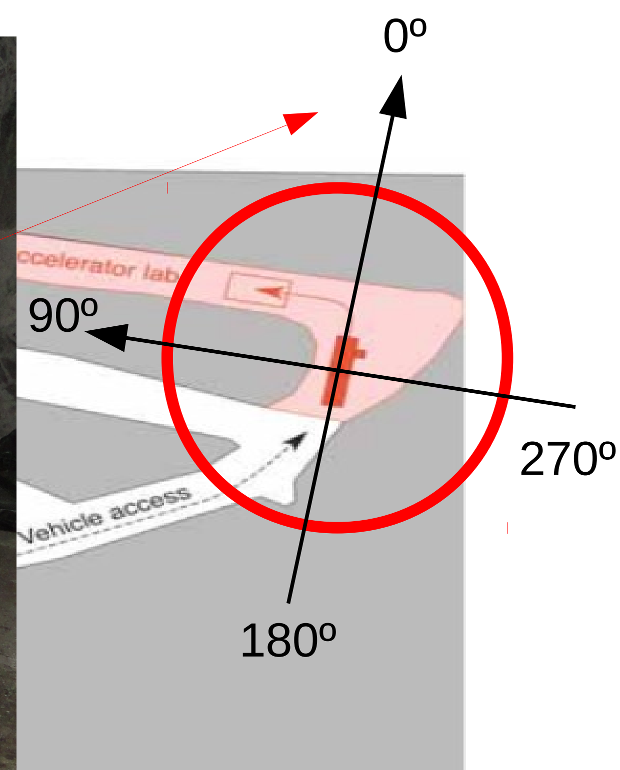


Measurements in tilted position I.

- Azimuth 0º and zenith 45º:
  56627 tracks have been collected during 7 days 5.5 hours

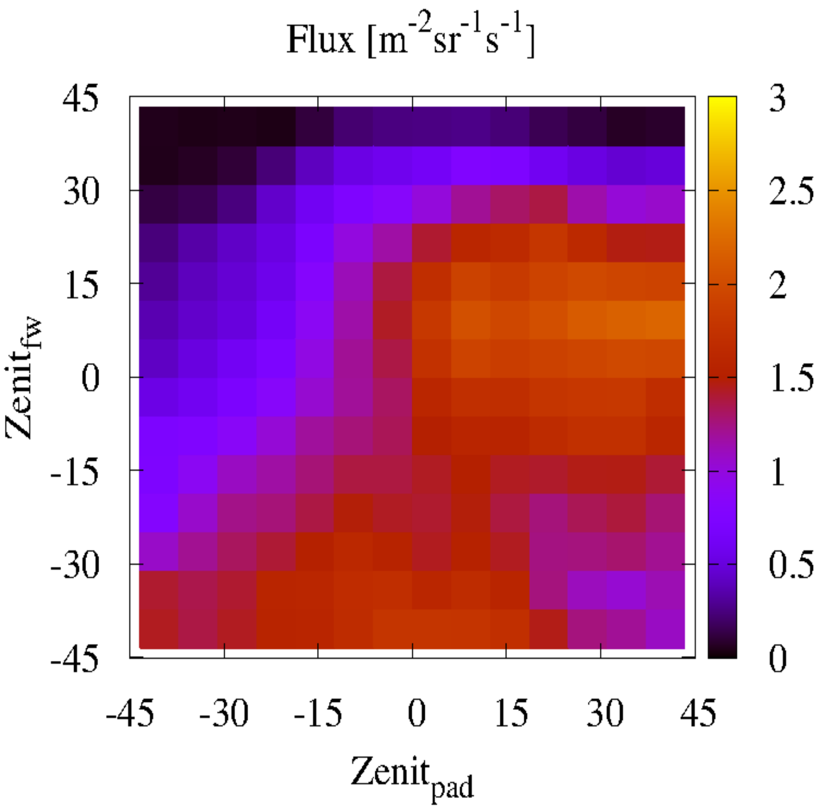


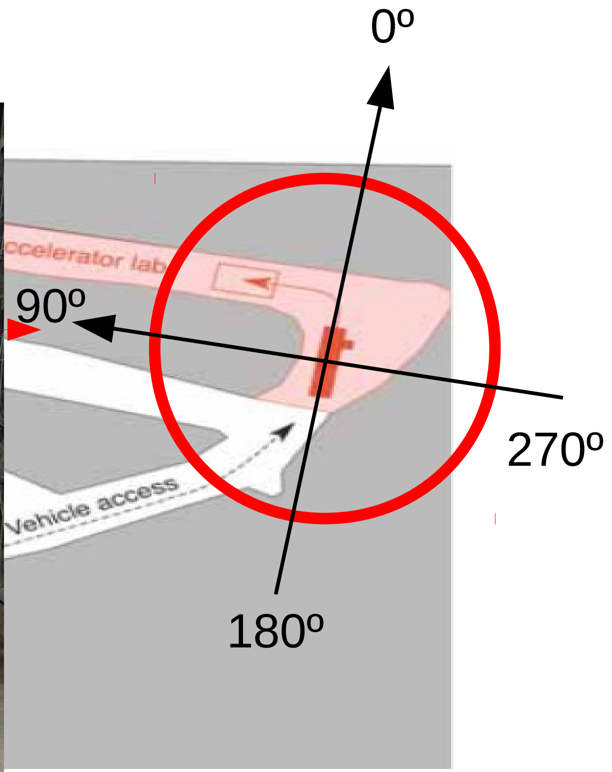




Measurements in tilted position II.

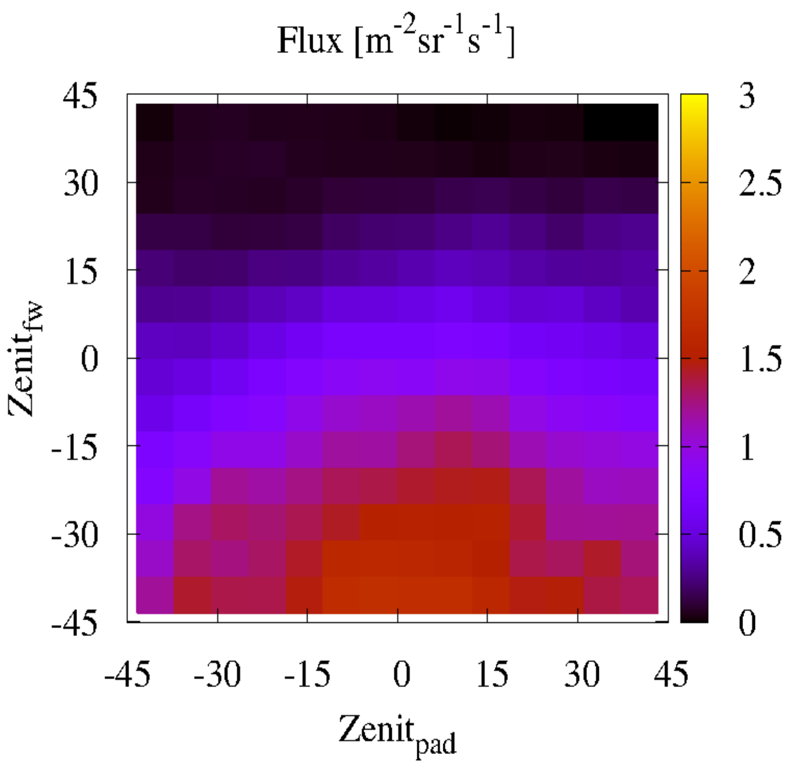
- Azimuth 90º and zenith 45º:
  39807 tracks have been collected during 3 days 17.3 hours

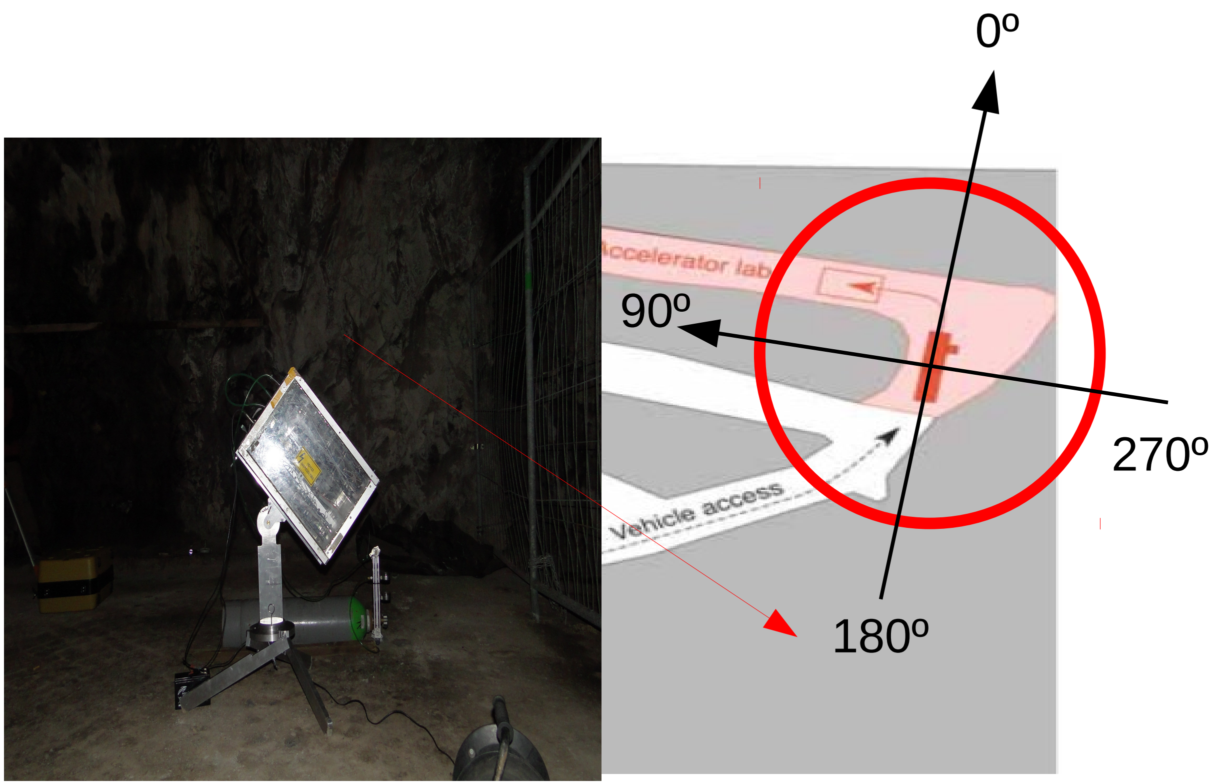




Measurements in tilted position III.

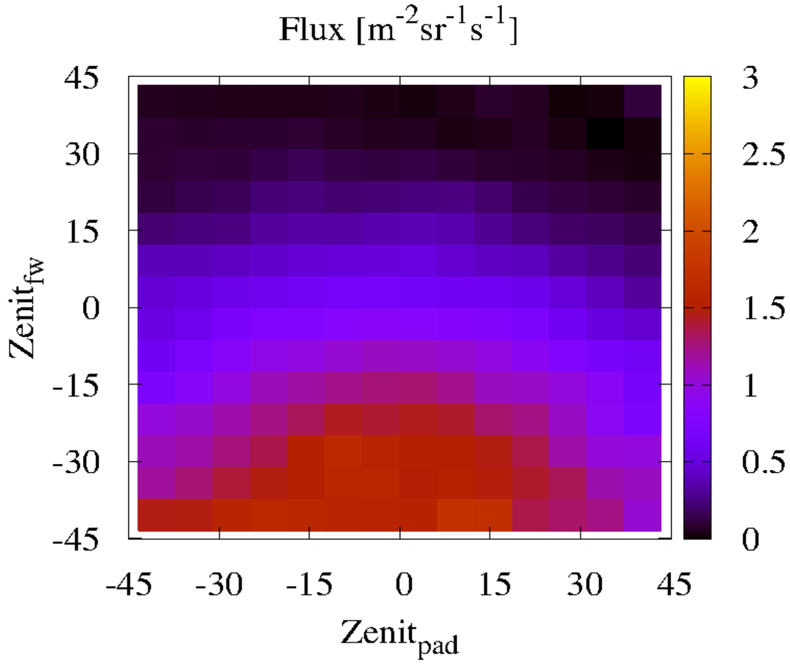
- Azimuth 180º and zenith 45º:
  19344 tracks have been collected during 3 days 4 hours

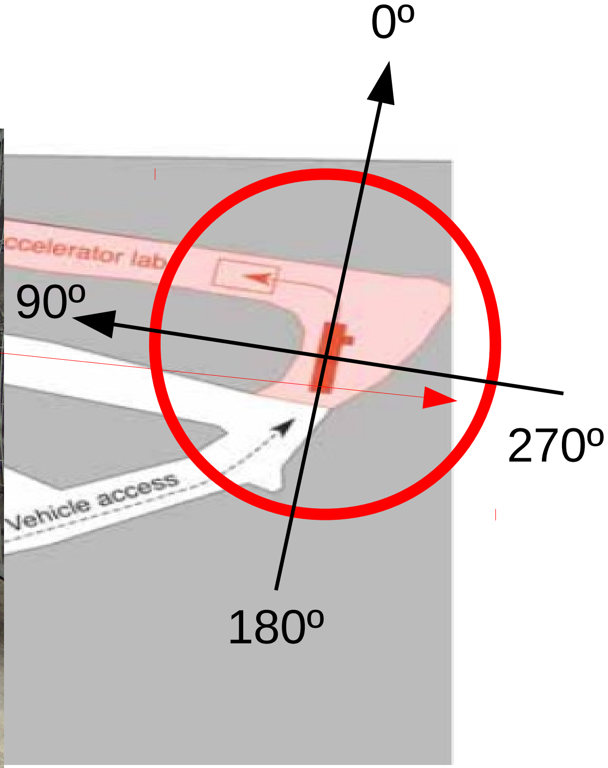




Measurements in tilted position IV.

- Azimuth 270º and zenith 45º:
  22928 tracks have been collected during 3 days 21 hours

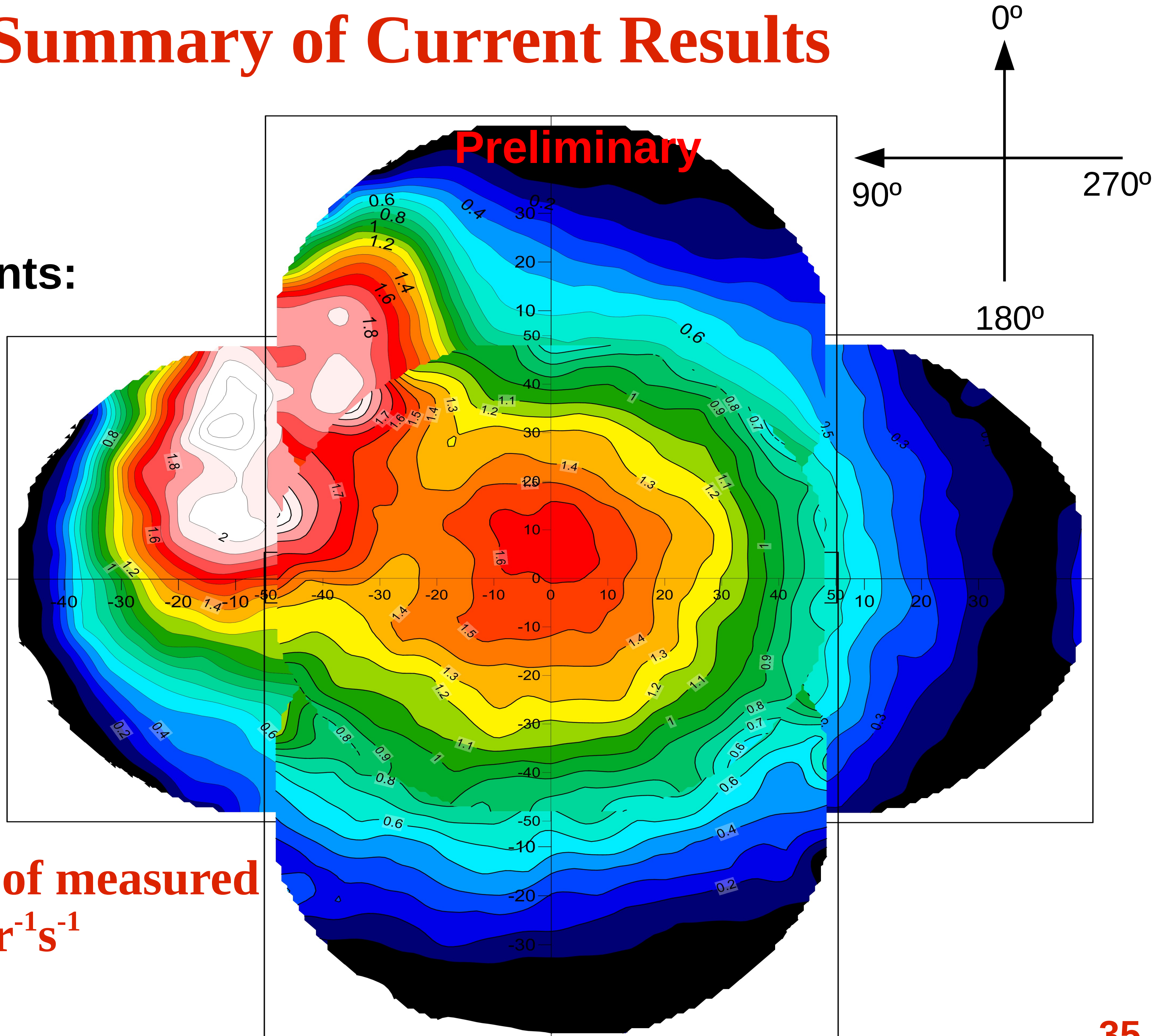




Summary of Current Results

Total time of measurements:
28 days

Total number of tracks:
245600



The maximum of measured flux is ~ 2 $m^{-2}sr^{-1}s^{-1}$

Summary

- **REGARD Group's Muontelescope:**
  - Mobile (< 15 kg, 51 x 46 x 32 cm^3) and power efficient (< 5 W)
  - Precision: 1.5 mm spatial and 10 mrad angular resolution
  - Cost efficient CCC technology (total cost 2000-3000 €)
  - Integrated DAQ + HV + LV + Trigger System + HMI
- **Measurements in Natural Caves:**
  - MWPC-based tracking telescope can work in high humidity conditions
  - Relief reconstruction has been done above the Molnár János Cave, Kőbánya tunnel system, and tunnels have been detected in the Jánossy Pit
  - 50 days of data taking in the Ajándék Cave:
- **Muon flux measurements have been done in Felsenkeller, Dresden**
  - The maximum of measured flux is ~ 2 $m^{-2}sr^{-1}s^{-1}$

Thanks for Your Attention!

Contacts:
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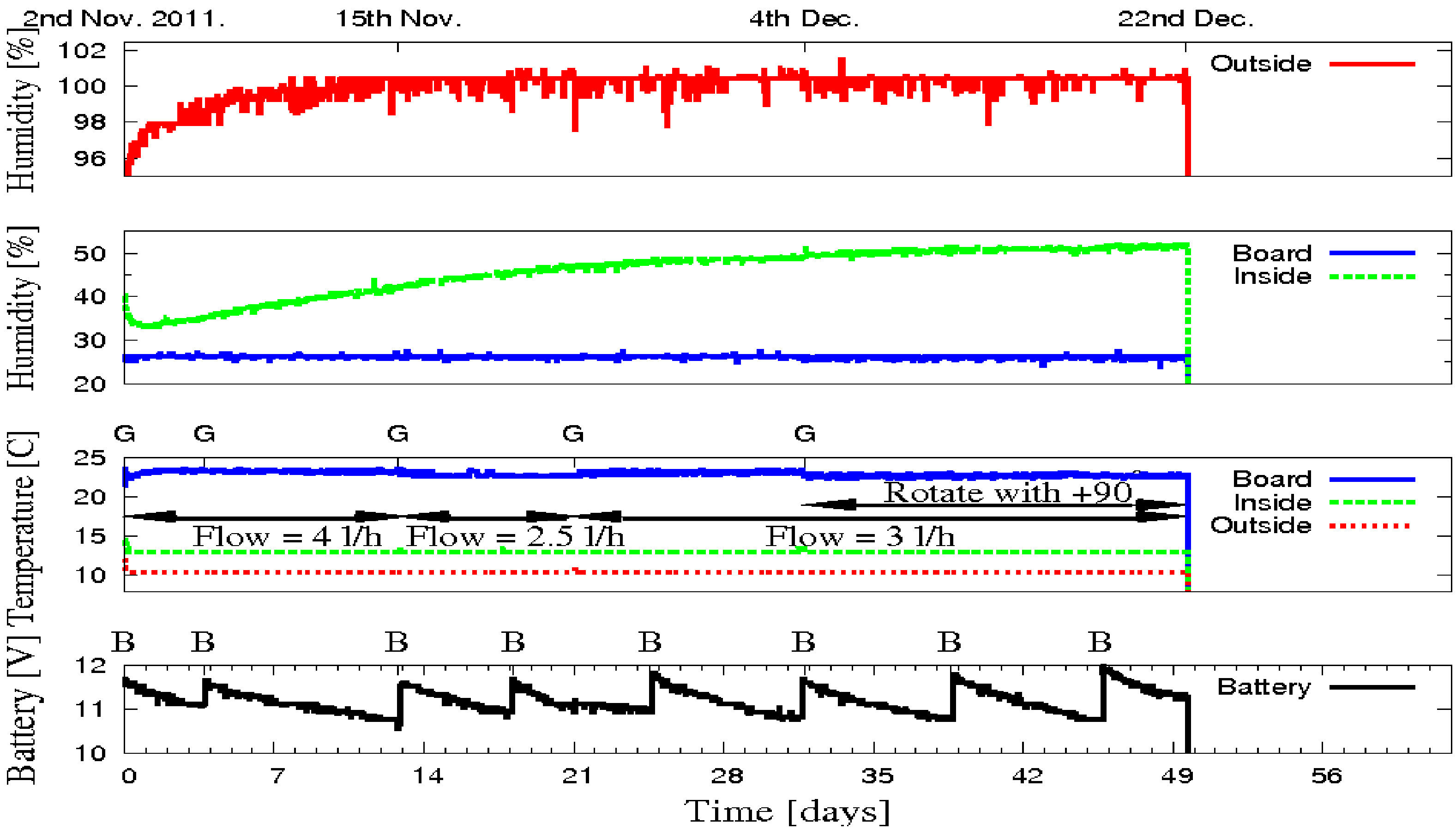
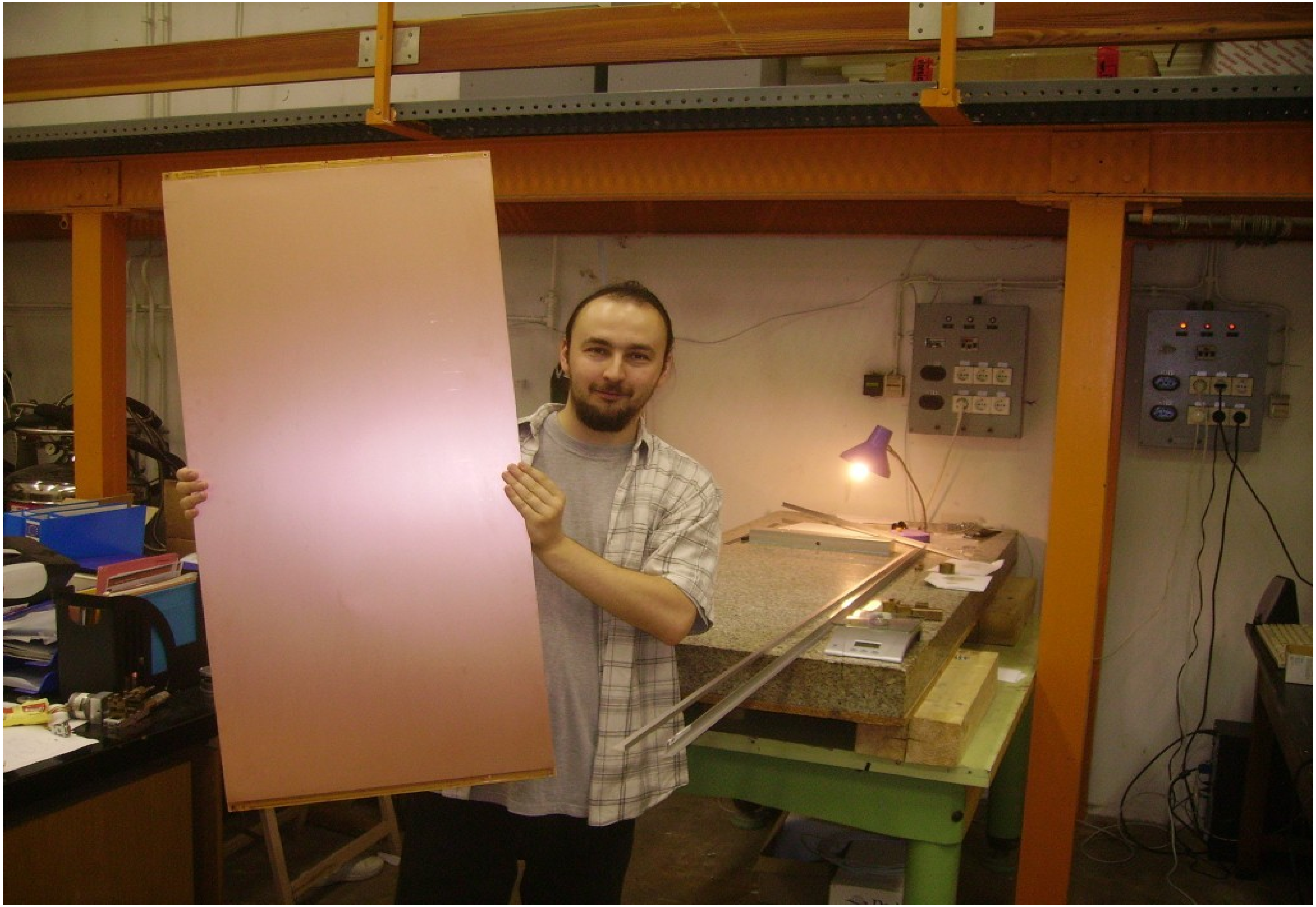
Backup Slides

Environmental Control int Ajándék Cave

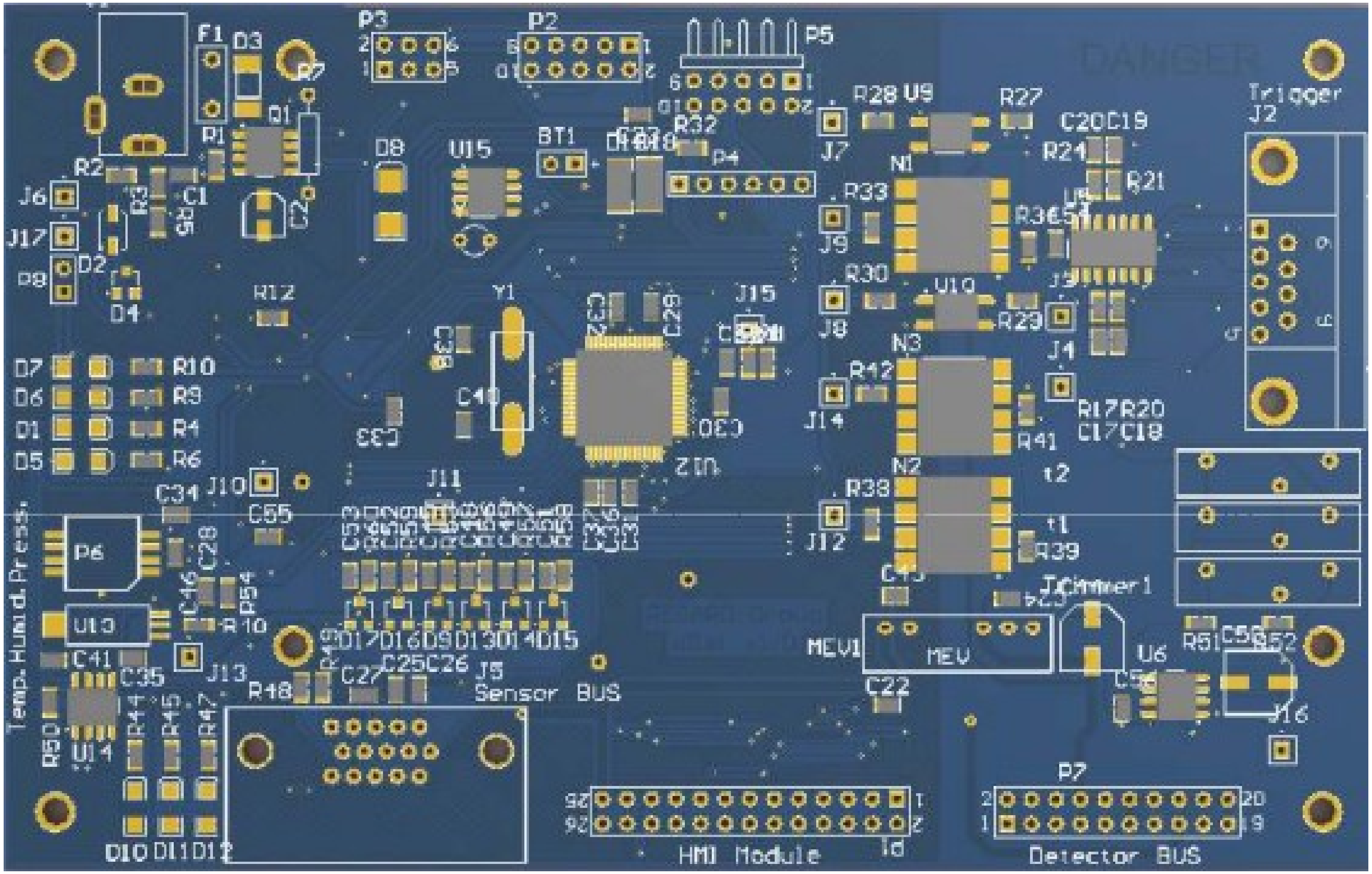
- Enviromental parameters and detector signals were monitored
- Visual control took place regularly on weekly basis
- One 10 l bottle of 150 bar filling is sufficient
  for 20 days of continuous operation with 3 l/h flow.



CCC with 1 m x 0.5 m Sensitive Area



The Board of DAQ



DAQ