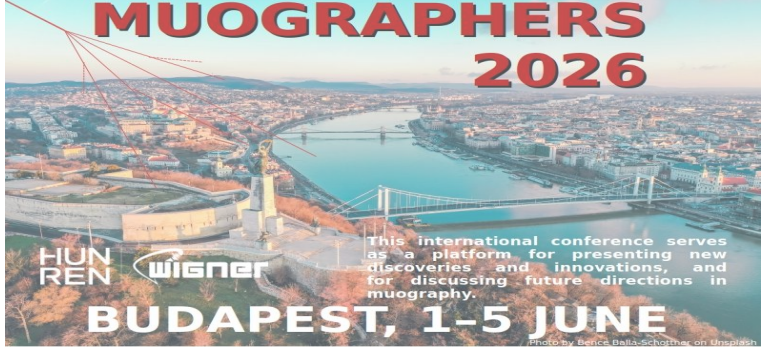

Tracking upgrades and results of cavity imaging in more than 200 m depth

Gabor Nyitrai
UCLouvain
INFN, UNINA*

Co-authors: G. Saracino, L Cimmino, D. Iacopini, L. Repola, G. Anzelmo, M. Letizia, F. Ambrosino

Università degli Studi di Napoli Federico II
ITALKALI
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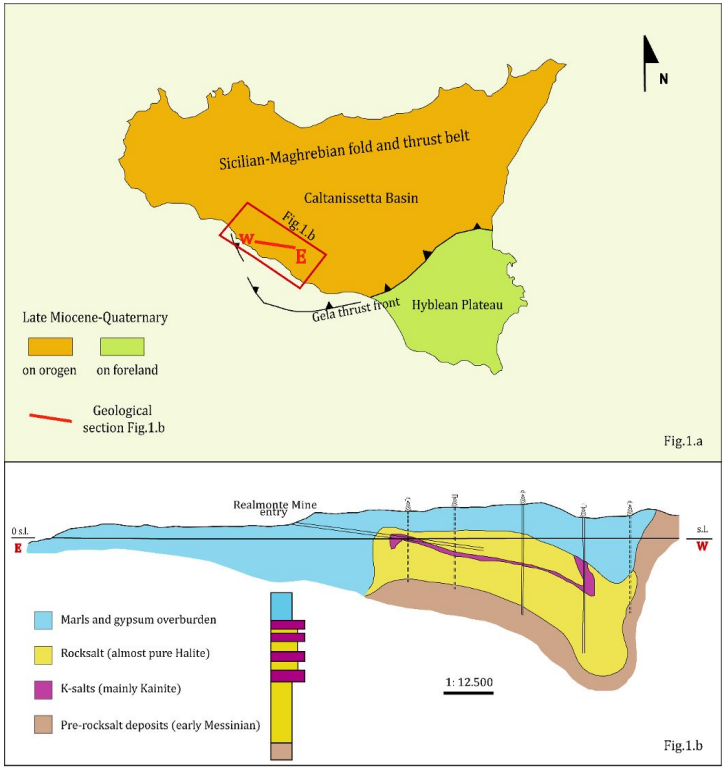
Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

Outlook

- ➢ Geological description of the target salt mine and the aim of measurements
- ➢ Summary of the detector setup and tracking upgrades
- ➢ Results of cavity imaging validation in >200 m depth

Target: Italkali salt mine in Realmonte, Sicily

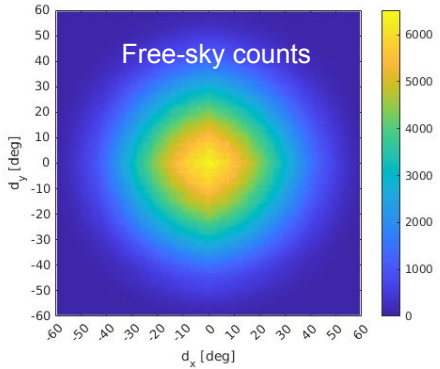
- Active salt mine, mainly halite extraction
- Possible UHS (underground hydrogen storage) for EU green energy targets
- Muography can help mapping and monitoring structural integrity
- First step: Validation by measuring a known tunnel from the lower tunnel level

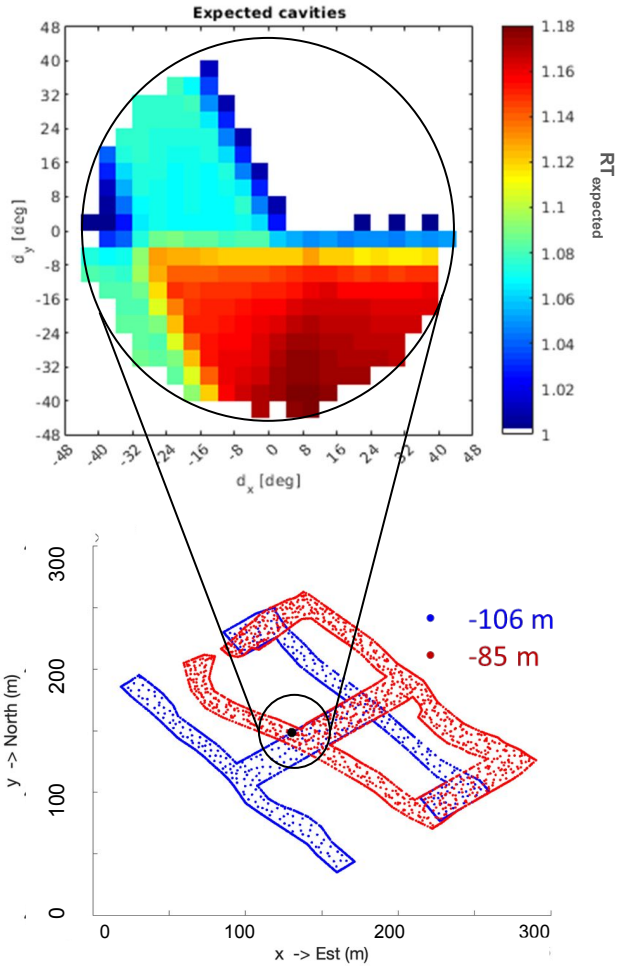


Expected results

- The detector is located at level -106 m ASL at 203 m underground
- A gallery at -85 m ASL level has been chosen for imaging
- Expected cavity map shows muon rate increase compared to bulk material assumption.
- 2 month free-sky data for Transmission imaging (<1°res.)

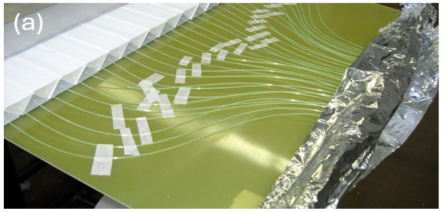
$$RT(\hat{d}) = \frac{T_M(\hat{d})}{T_E(\hat{d})} \qquad T_E(\hat{d}) = \frac{\int_{E_{min}(X)}^{\infty} \Phi(\theta, E) dE}{\int_{E_0}^{\infty} \Phi(\theta, E) dE}$$



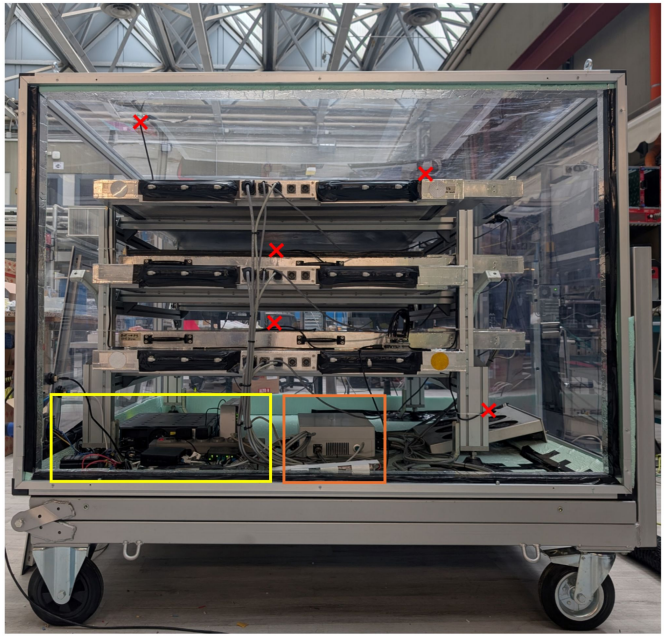


2025 Sci. Rep. 15, 34147

MURAY detector



- 1 m^2 triangular scintillator detector system
- 3 detection plane (3 X + 3 Y)
- 15 yo system upgraded
- Hermetic box and AC, tiltable 23°
- Orange: Master RPi unit
  Yellow: auxiliary (DAQ, UPS, smart switches, NAS)
- X Temperature sensors



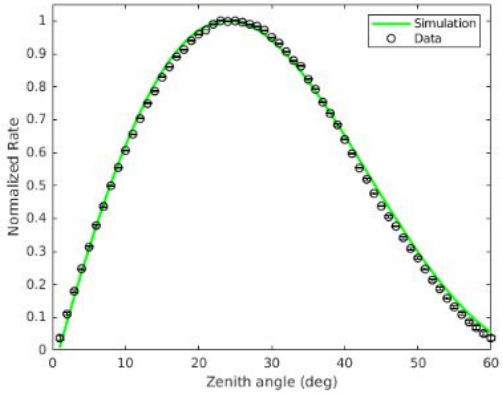
Instruments 2026, 10(2), 27

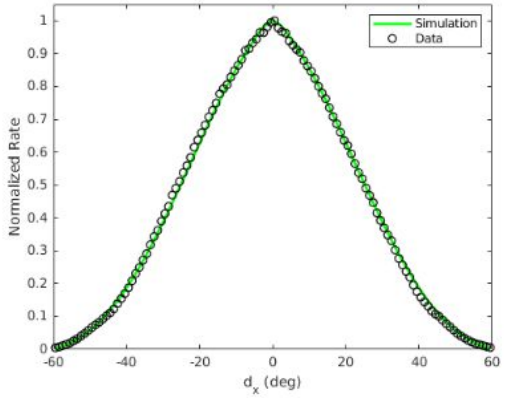
Detector performance

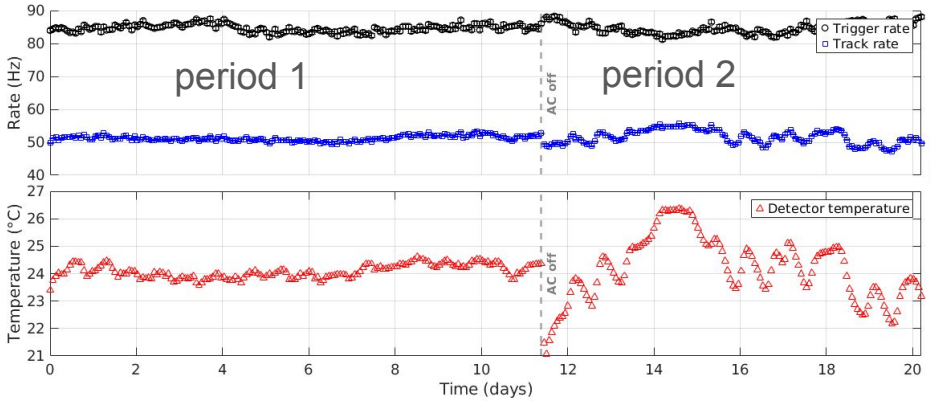
- Open sky meas. and exp. fits
- Open sky temp. fluct.
  effect cancelled with AC
  no AC test still produce ok

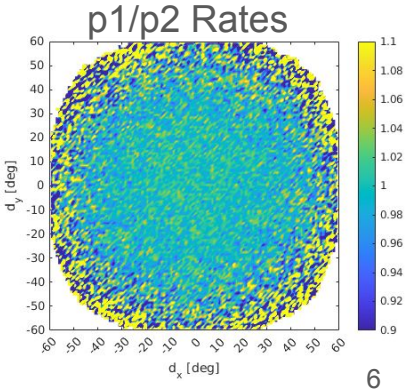
New developments eg:

Hamamatsu SiPMs, new DAQ,
Acquisition and performance monitoring,
Automatic download, filter, and alert scripts for raw data,
New tracking software



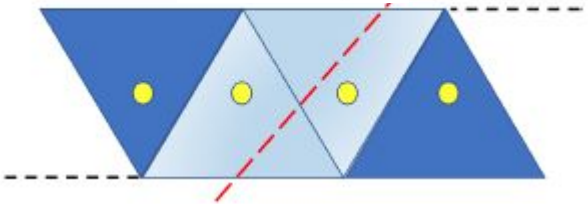






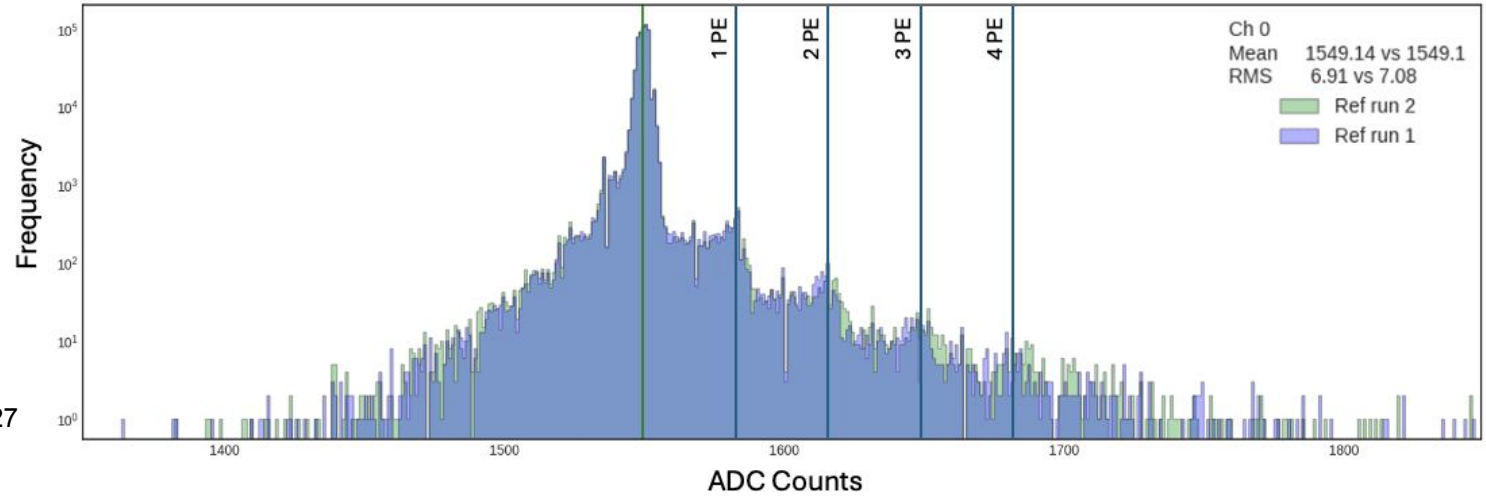
Tracking

$$x_{cluster} = \frac{\sum_{strips} x_i E_i}{\sum_{strips} E_i}$$



M. D'Errico 2022 PhD Thesis

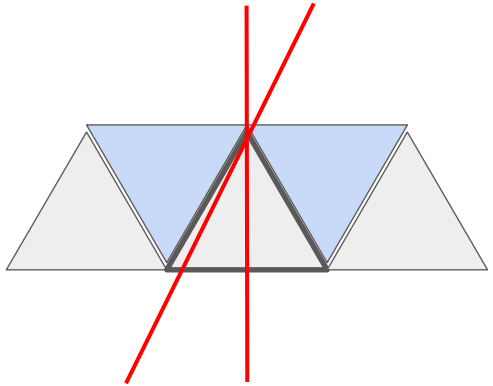
- Raw data: ADC units of deposited energy
- Preliminary checks and calibrations:
  Dark rate, dead time, photoelectron (PE) value for converting ADC to energy
- Clustering: adjacent fired strips total energy above threshold, hit position by weighting with energy

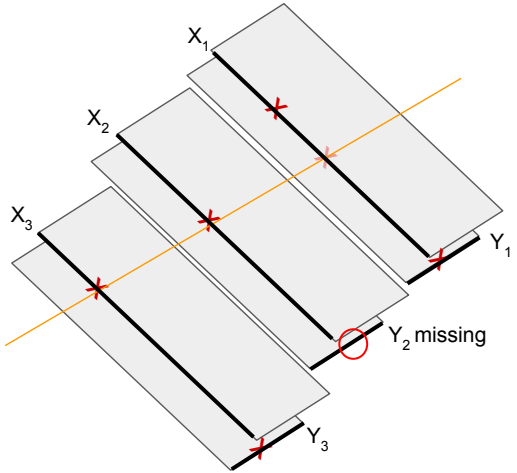


Instruments 2026, 10(2), 27

Tracking upgrades

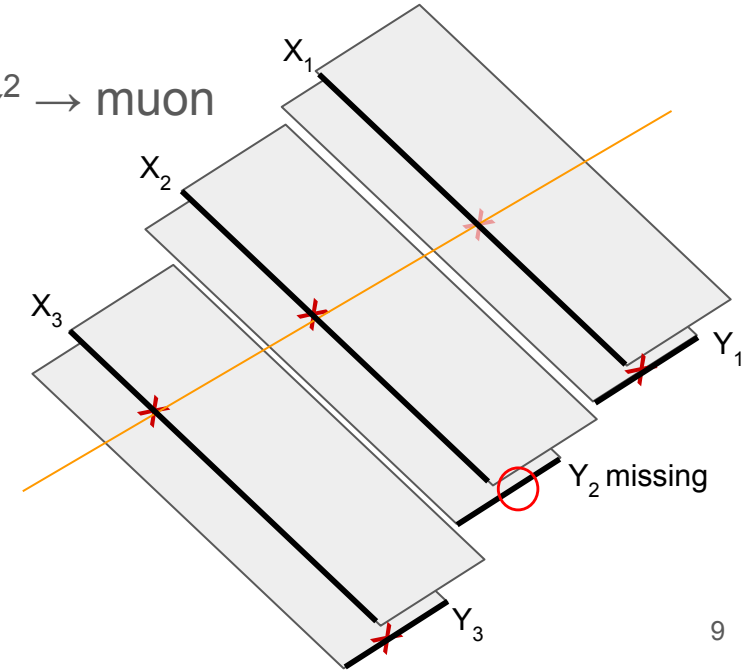
- Single-strip cluster position ambiguity
  Can be corrected with randomization or iterative track angle correction
- Combinatorial search between clusters for better χ^2
- Track condition allowing for 5-point tracks (out of 6)





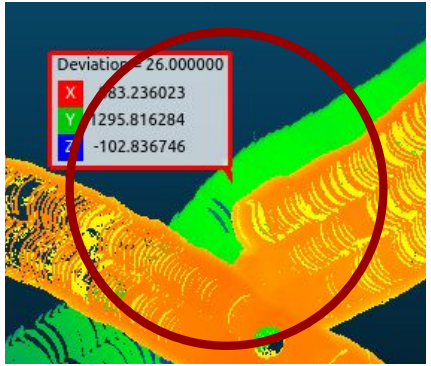
Tracking upgrades

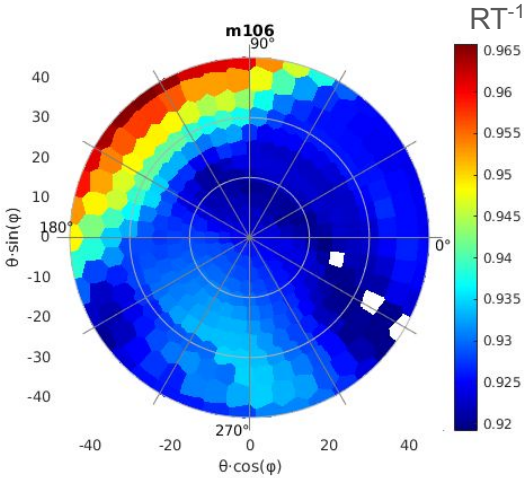
- 5-point track meaning: if one track hit is lost because of efficiency, we can still recover the track
- Hypothesis
  If one projection already has 3 point and low χ^2 → muon
  Other plane's two point → 3D track
- Lower track quality but:
- **Higher statistics**
- **Efficiency estimation**

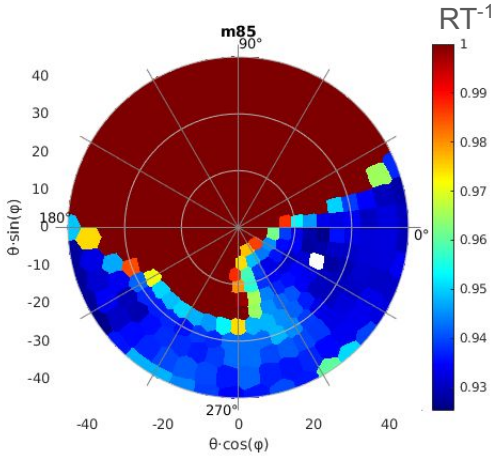


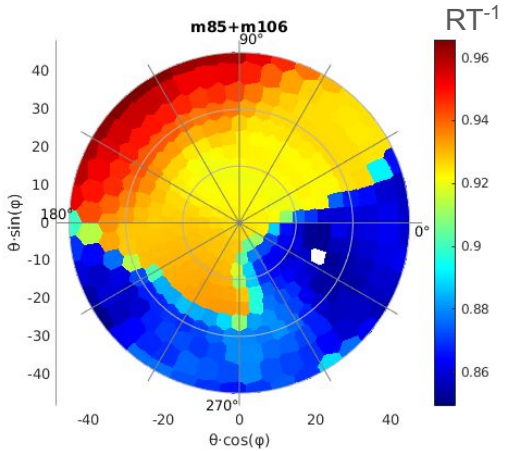
New scan survey by L.Repola et al

- Detector placed at -106 gallery (green)
- View cone intersects -85 gallery (yellow)
- First underground position >130 days of live time
- Color plots show new expected effect of galleries

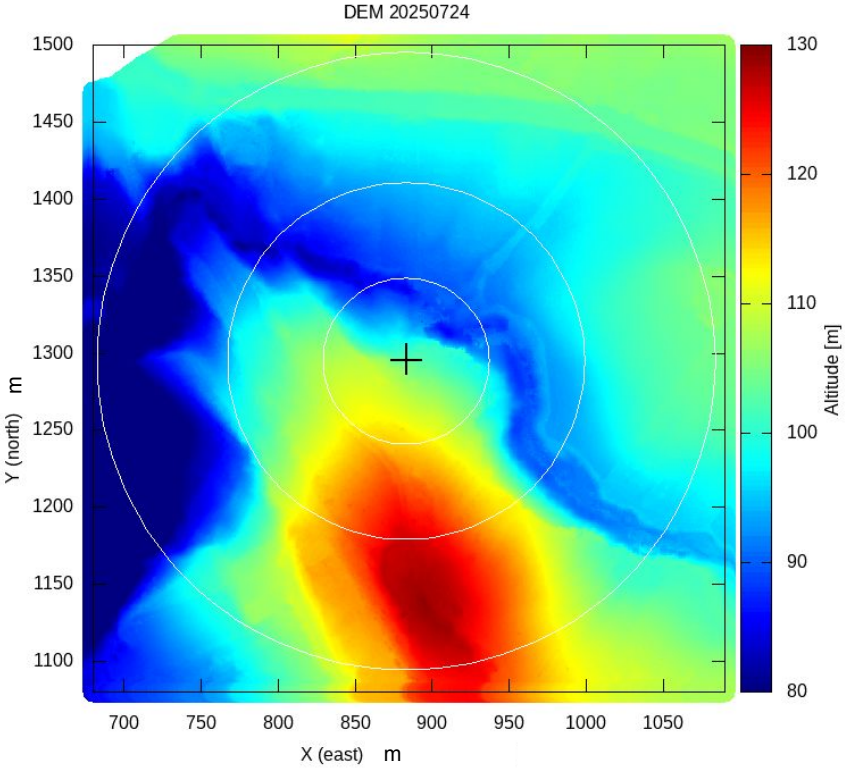






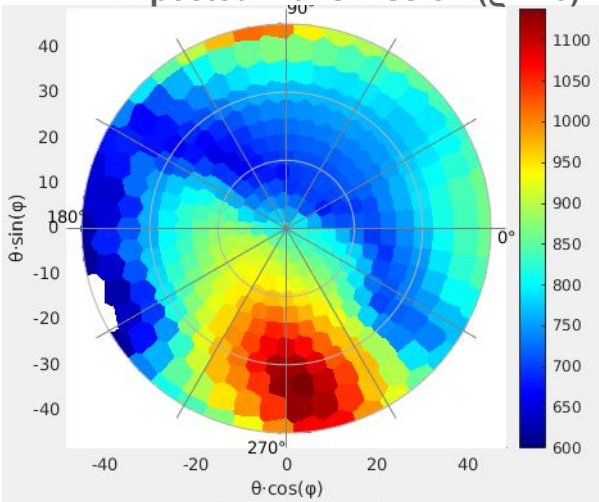


Topography vs Data

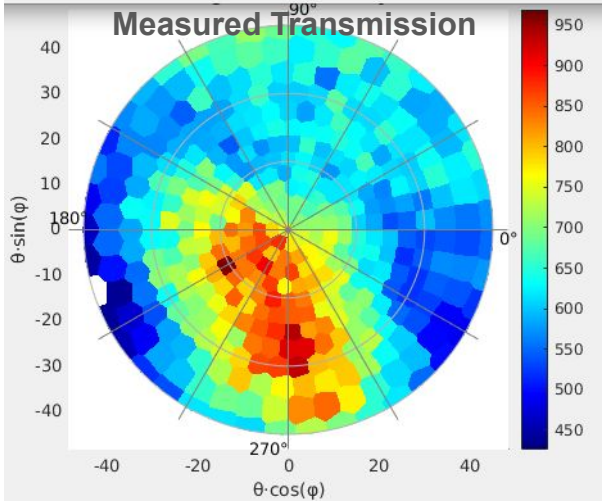


L*ϱ ~ Transmission^{-1}

Expected Transmission (ϱ=2.3)



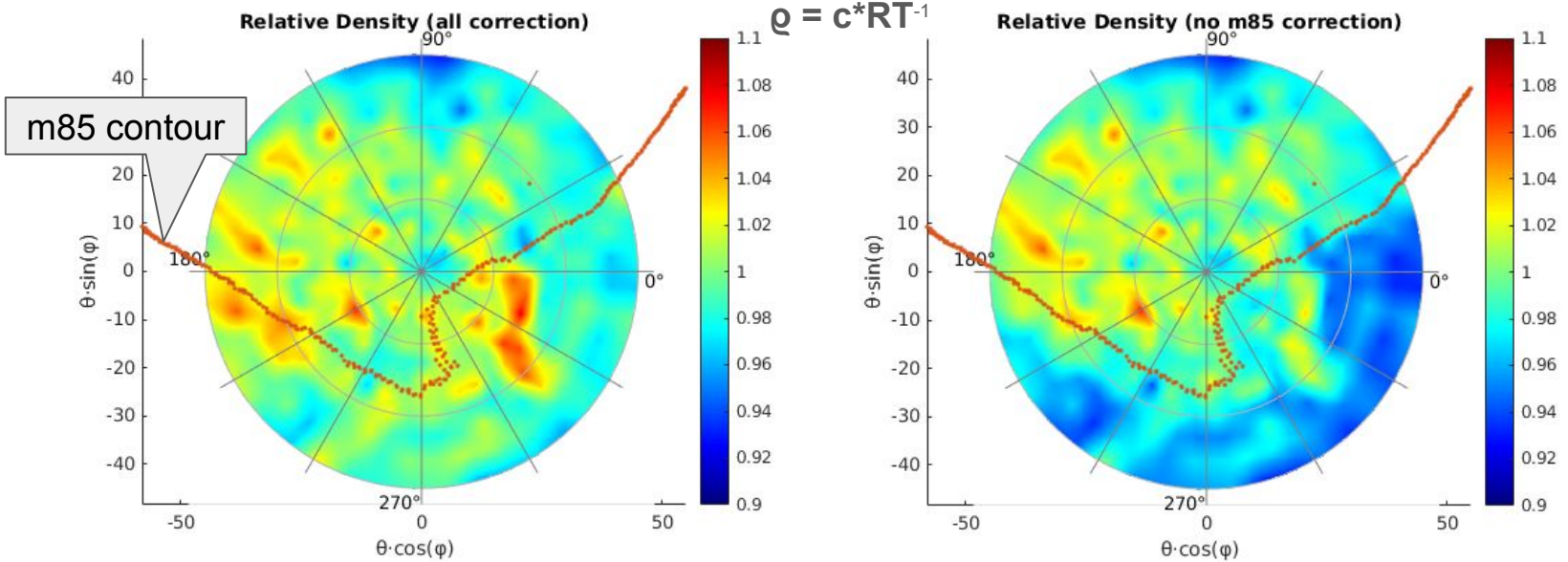
Measured Transmission



Results

Relative Transmission should be constant 1 in every direction if expectation is perfect

Right: effect of topography and -106 gallery subtracted, blue corresponds to -85 gallery



Conclusions

- ➢ Density-length variation at 2–3% validated at >200 m depths
  (6–7 m cavity over 200–300 m rock length)
- ➢ High-resolution subsurface imaging:
  structural integrity monitoring possible
- ➢ Upgraded MURAY detector has stable performance
  in deep underground and open sky environments

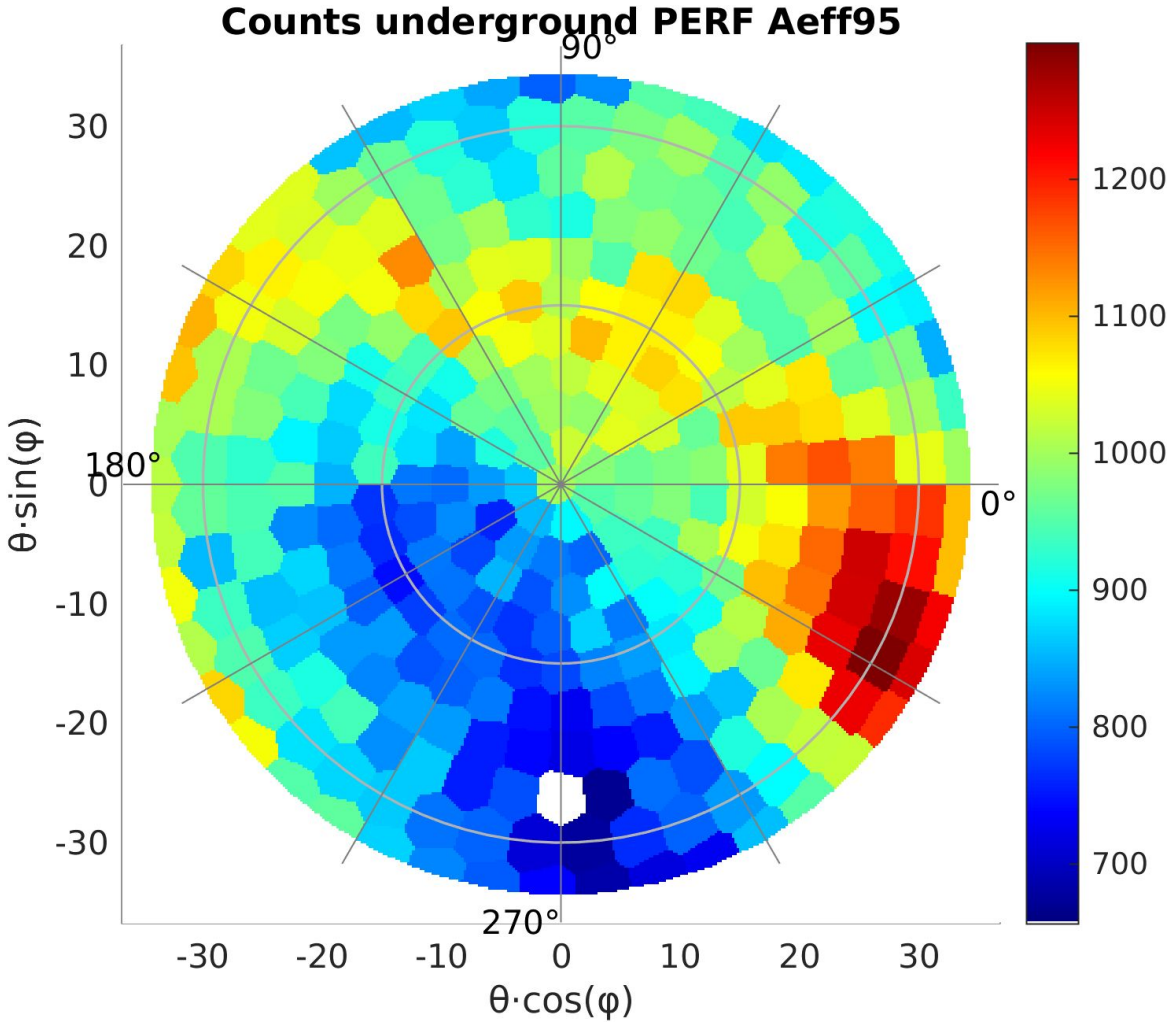
Thank you for your attention!

Backup slides

Track selection

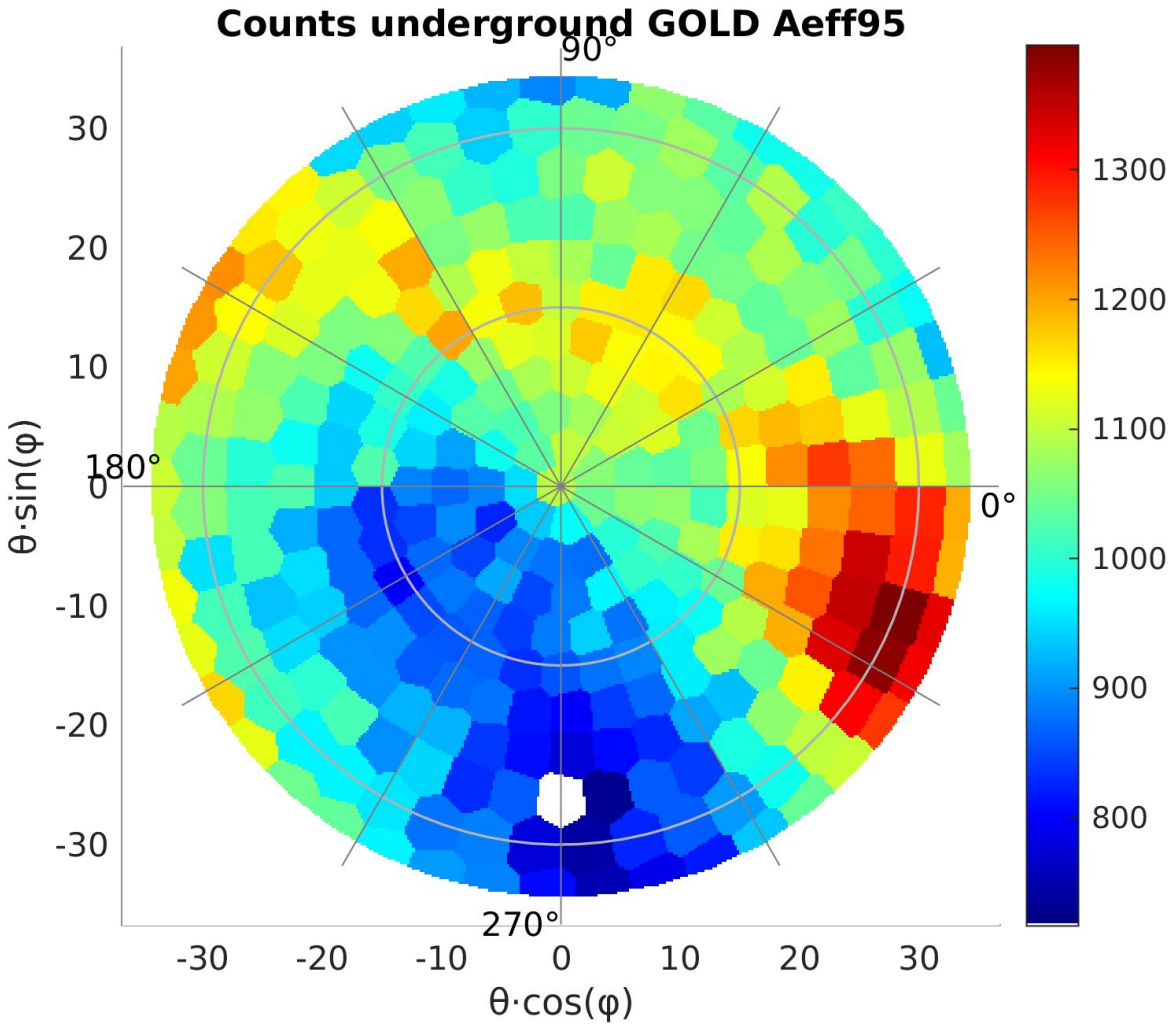
	points	chi2 cut	is combi
Perfect (6-point)	6	5	no
Gold (6-point)	6	5	yes
Good (5-point)	3+2 (top-bottom)	15	yes
Fine (5-point)	3+2 (center+edge)	50	yes

(in case of MURAY, flux made from tracks which are FINE but not the other, can still produce similar muography, can see the cavity etc. Of course the resolution is worse so not to include in final image.)

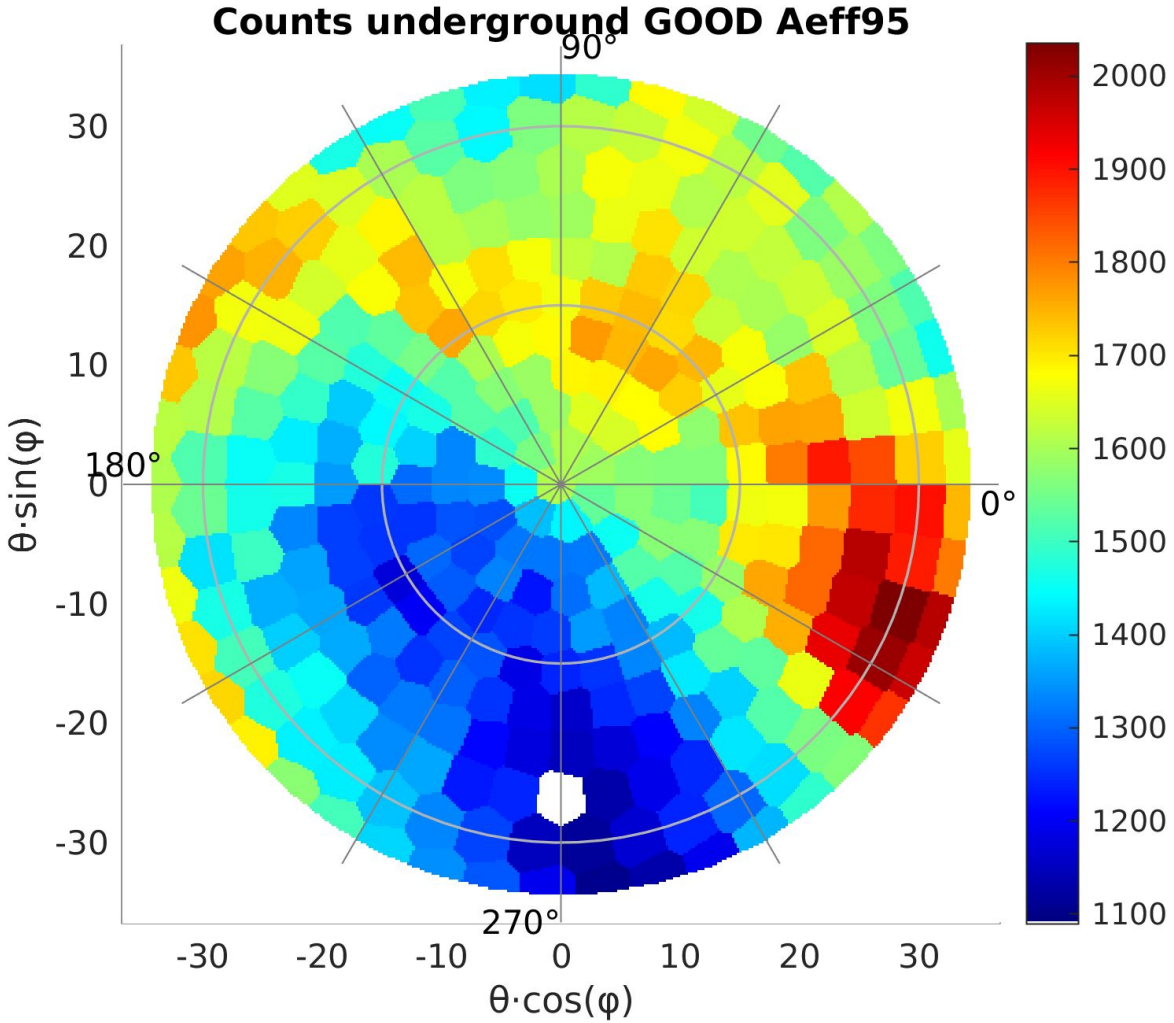


MURAY data
2025

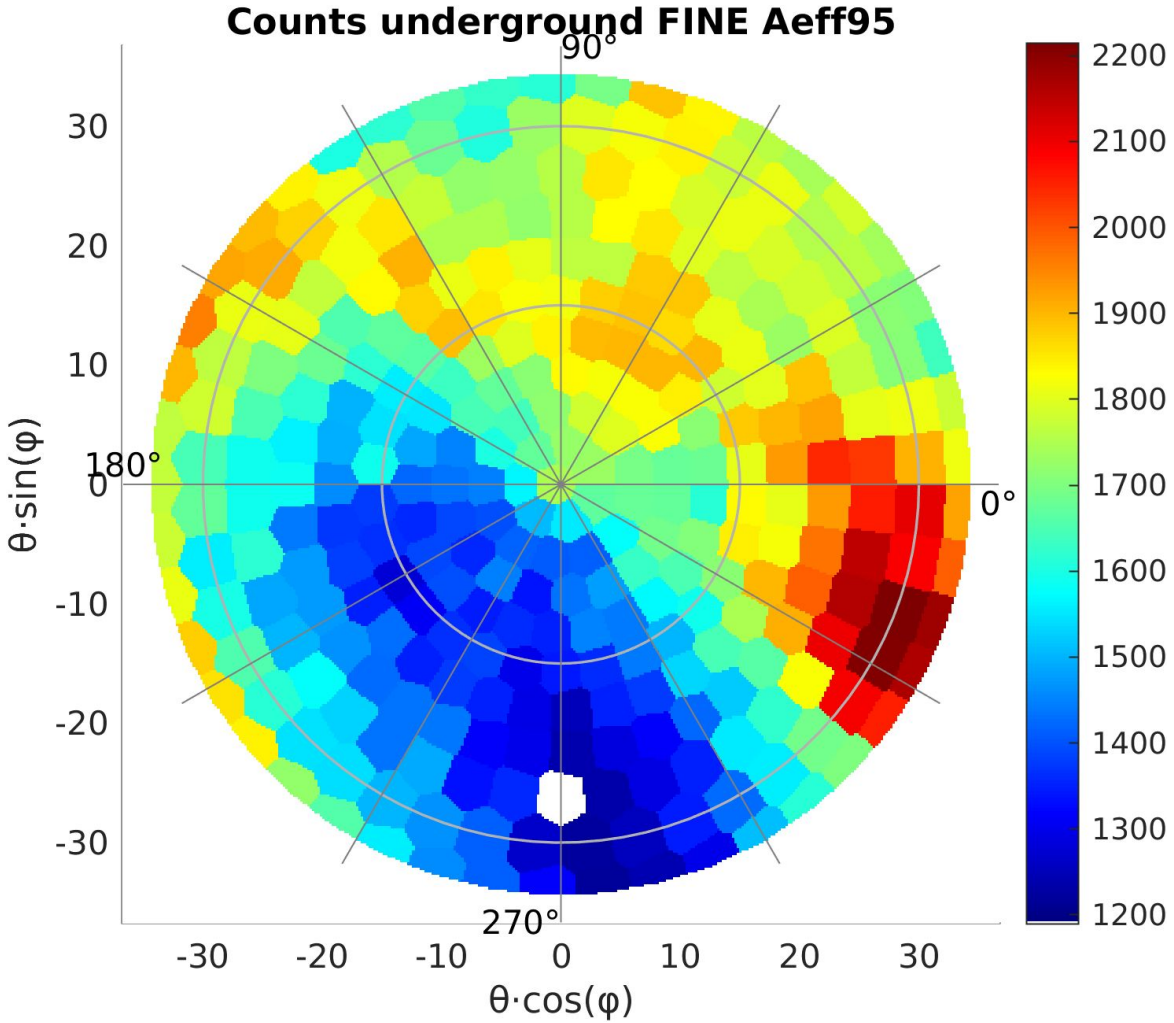
side-note:
adaptive binning
middle solid angles ~9 deg^2
growing with theta to
compensate statistics



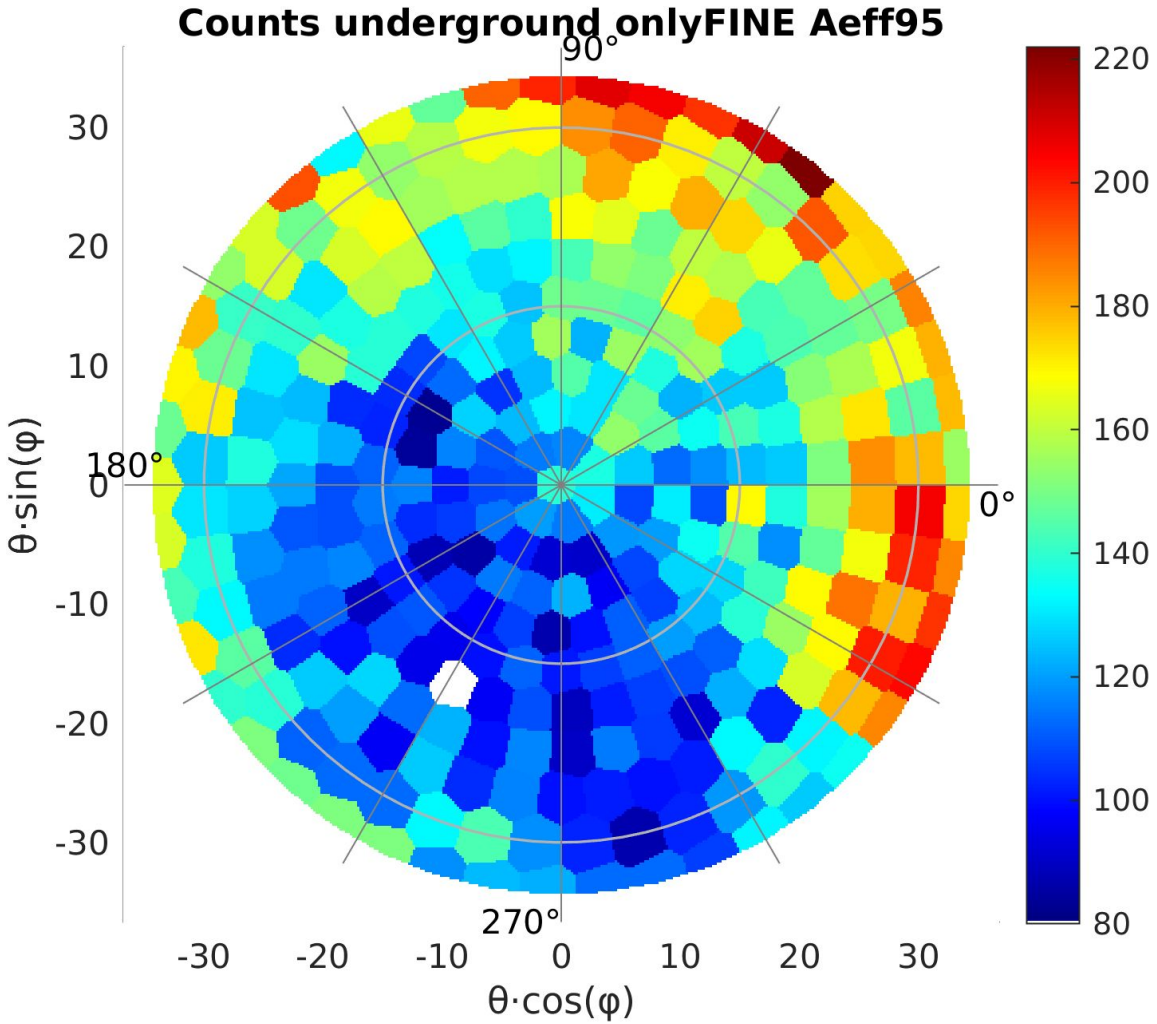
MURAY data
2025



MURAY data
2025



MURAY data
2025



MURAY data
2025