Characterization of the Piedicastello Tunnels as a Potential Underground Laboratory for Astroparticle Physics in Trento, Italy

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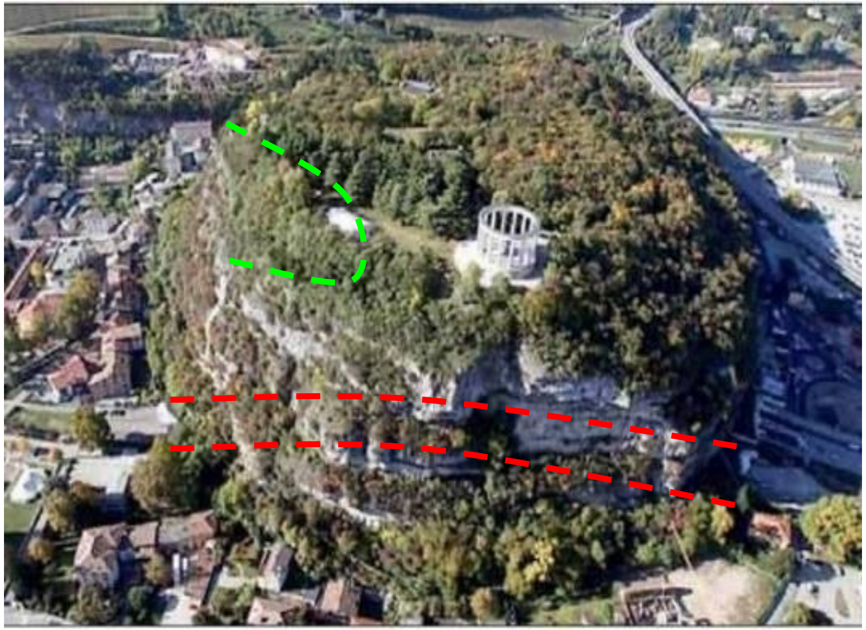
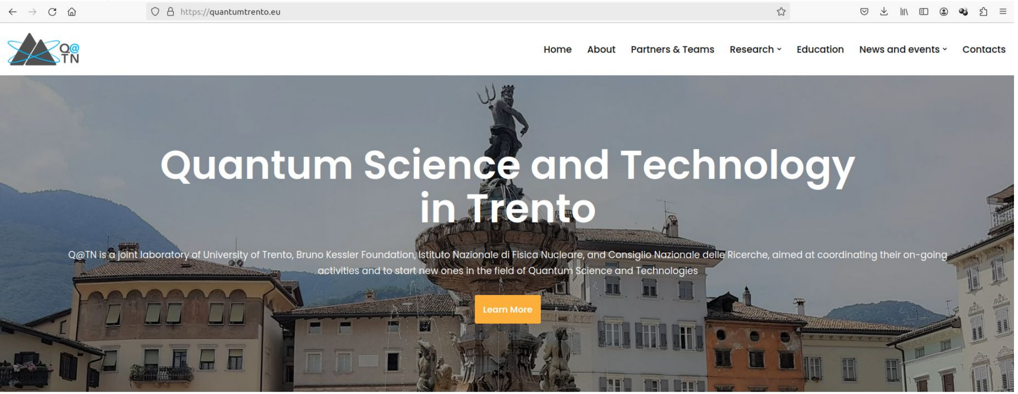
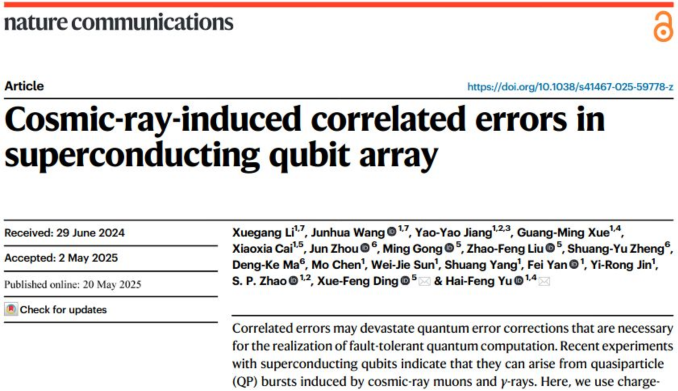


TIFPA Istituto Nazionale di Fisica Nucleare

Why a shallow underground laboratory in Trento?





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Cosmic-ray-induced correlated errors in superconducting qubit array

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Check for updates

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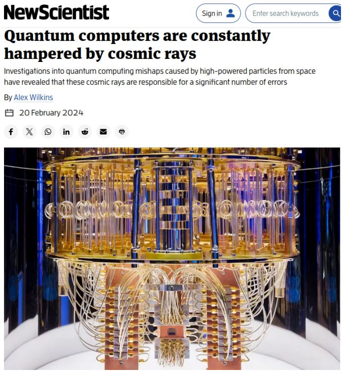
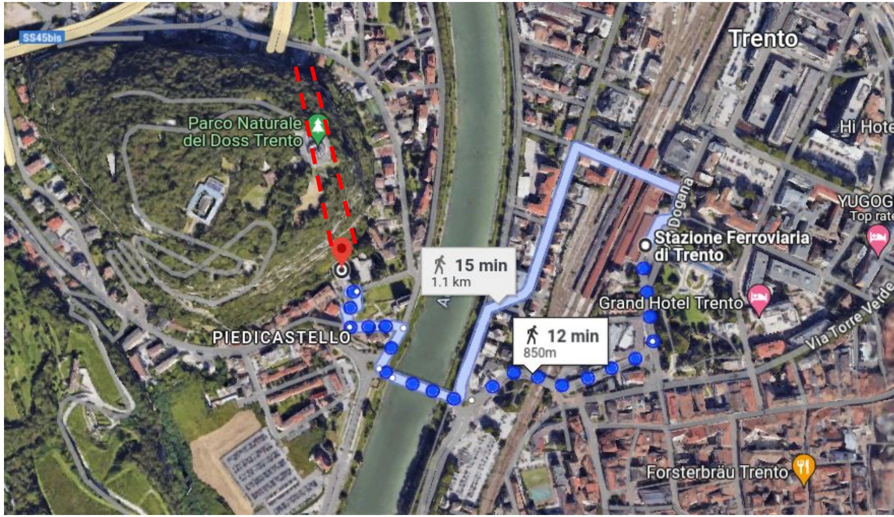
Correlated errors may devastate quantum error corrections that are necessary for the realization of fault-tolerant quantum computation. Recent experiments with superconducting qubits indicate that they can arise from quasiparticle (QP) bursts induced by cosmic-ray muons and γ-rays. Here, we use charge-



+ ultra-low level γ -ray spectroscopy, ultra-pure material development, astroparticle physics and nuclear astrophysics

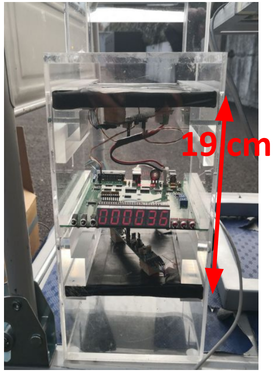
Piedicastello "Doss Trento" Tunnels:

- former bypass tunnels of the Freeway (until 2007)
- 2 x 300m long, 2 entrances for side, 6000 m^2
- now host exhibitions of Trentino Historical Museum
- located 12 minutes on foot from the railway station
- dry, equipped with: electric power, internet, WC
- 100 meters of limestone overburden, of interest for experiments requiring low muon background



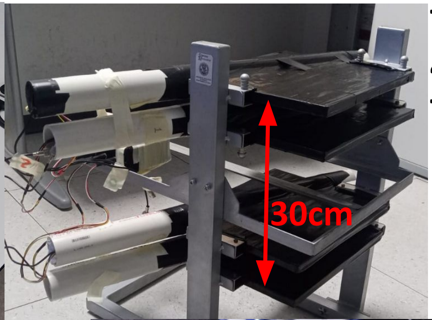
Portable detectors for muon flux measurements
(EJ-200 plastic scintillators)

1 Cosmic-Box from EEE collaboration
(https://eee.centrofermi.it/en)
$15x15cm^2$ h=19cm "Telescope"
2x $3x3mm^2$ SiPM NUV3S-P / pad



all the DAQs require a 4-fold coincidence

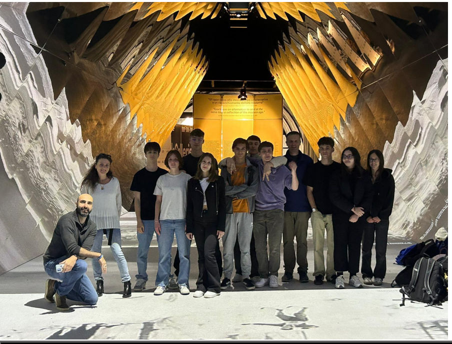
2 Developed by INFN-TIFPA: $30x25cm^2$



TIFPA0 "Telescope"
4 pads $30x25cm^2$
Tot. Distance Pad1-4 = 30cm
1 PMT 30CW5 Sens-Tech / pad
BKG: < 2 eventi/h

TIFPA1 "Flat"
(wide acceptance)
2 stacked pads $30x25cm^2$
2 x SiPM $3x3mm^2$/pad
BKG: < 2 eventi/h

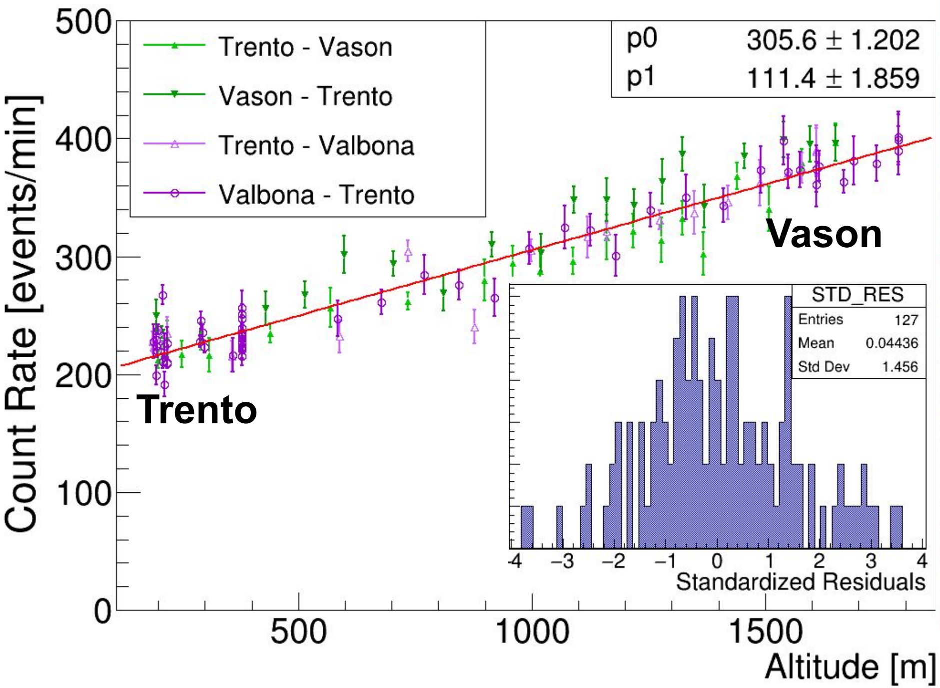
High school students were engaged in the muon flux measurements:



Students from Da Vinci Liceo in Trento, Italy:
H. Ait Aissa, N. Avi, E. Baldi, G. Bonetti, E. Bonomi, C. Caramelle, M. D'Angelo, A. Decarli, S. Devigili, M. Franceschini, K. Ndria, T. Oss Emer, D. Paternoster, E. Pregnolato, E. Potrich, G. Verrocchio.
Teachers: S. Bimbi, M. Rossi

Preliminary test: outdoor μ flux

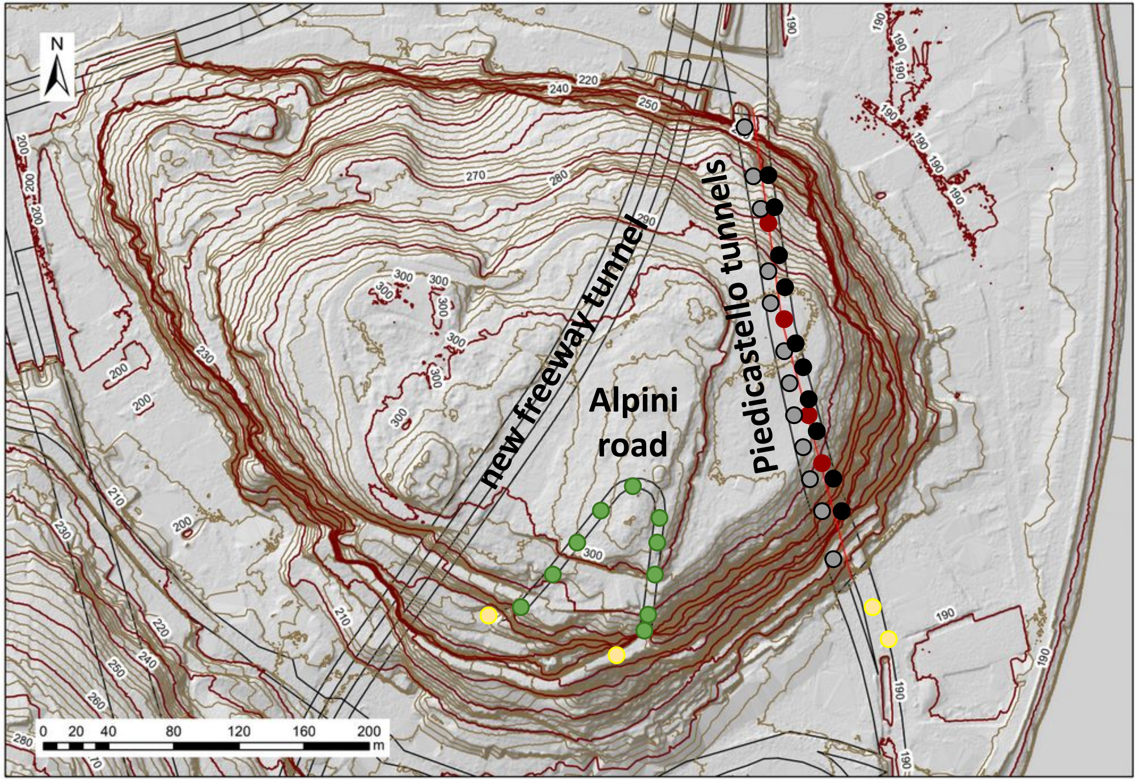
Muon flux measured by TIFPA1 detector inside a vehicle (both uphill and downhill)



Piedicastello tunnels 200m

Test the stability of the counting rate: better than 5% within the same measurement session.

Underground measurements



total: 40 locations of measurement taken in 7 days (afternoon march-april)

Daily Calibrations:
2 measurements at begin and 2 at the end of each day taken in 2 fixed locations near the tunnel entrance (yellow points)

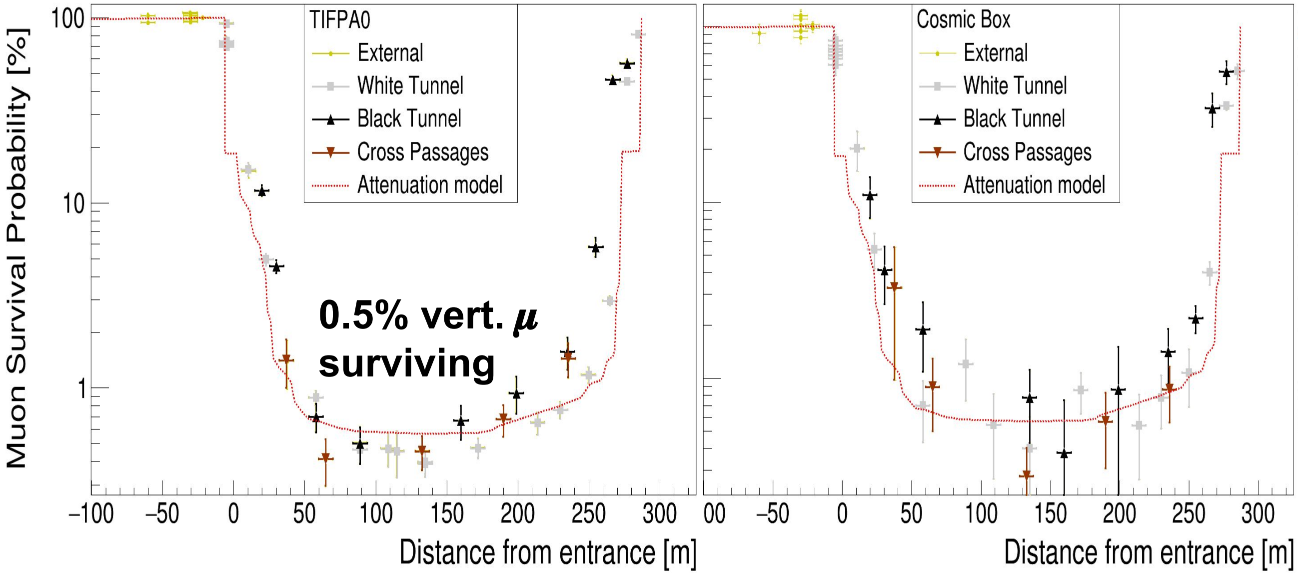
Random coincidence background <6 x 10^{-4}Hz
In the deepest part of the tunnel the pads of TIFPA0 and TIFPA1 were horizontally displaced (0 counts measured in ½ hour)

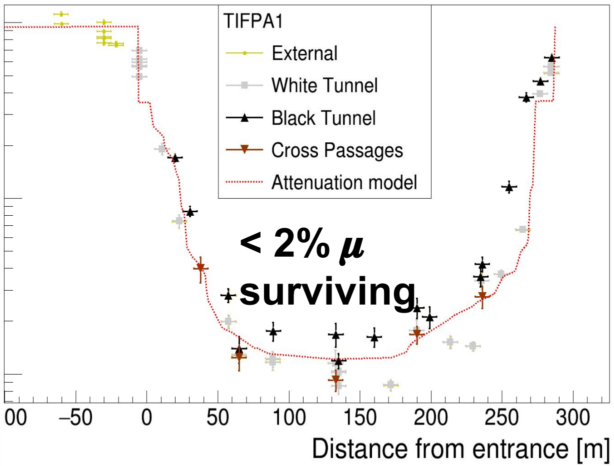
Red points are the measurements taken in the four “cross passages“ connecting the two (White and Black) tunnels.

10 measurements were acquired inside the tunnel of the “Alpini road” (green points, 50m overburden)

Comparison of measurements by different detectors

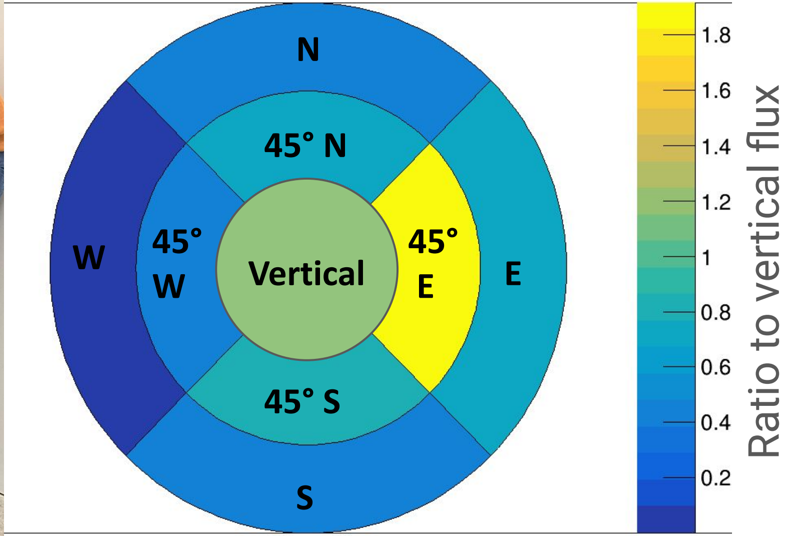
Cosmic-Box FoV is similar to the TIFPA0 FoV
(but the rates were 1/10 due to smaller size)





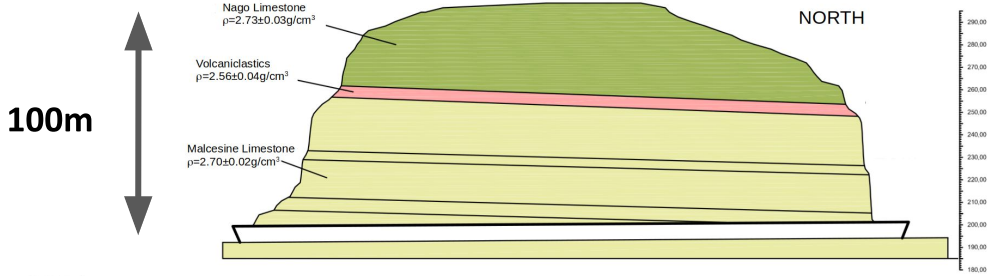
TIFPA1 is "Flat"/wide acceptance it is able to detect inclined muons arriving from the the relatively thin east cliff of the Doss Trento hill

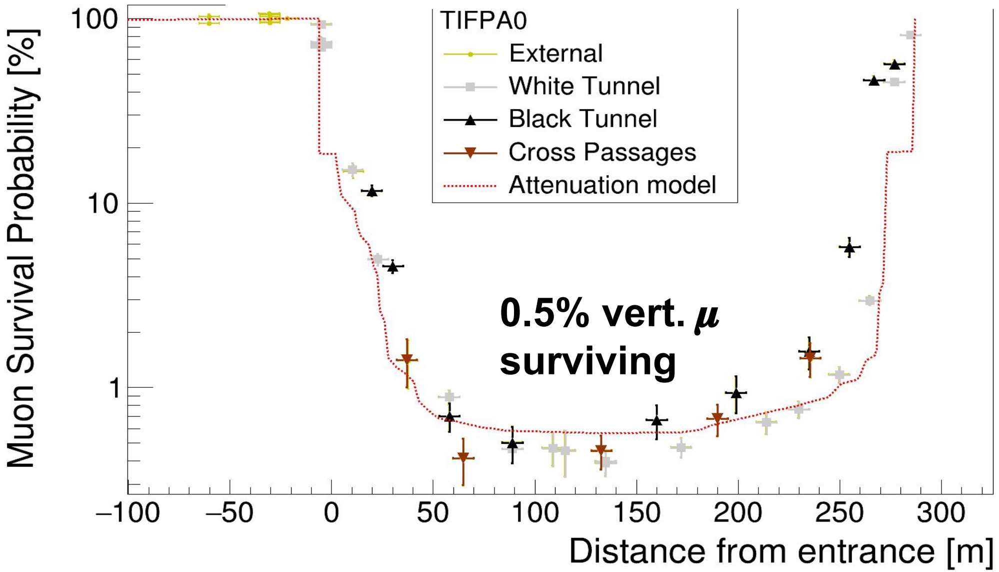
Angular distribution of μ at the center of the White tunnel (TIFPA0 detector)

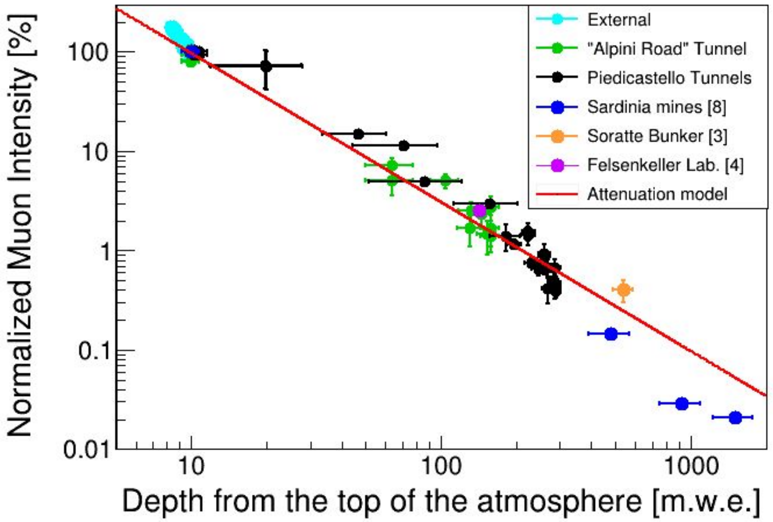


Data was collected in the center of the White tunnel by tilting the TIFPA0 detector at 45° and 90° with respect to zenith, pointing it towards the four cardinal directions. The rate measured by tilting the detector ~45° towards the east direction is twice the vertical one because of the relatively thin east cliff of the Doss Trento hill

Vertical μ flux (TIFPA0 detector)





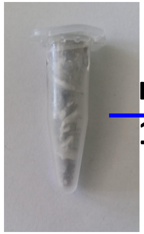


Attenuation model:
for "vertical" muons, a single power-law with spectral index -3/2 (red line) provides a raw but simple attenuation model in this depth range.

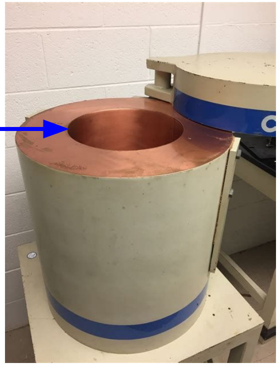
Nucl.Instrum.Meth.A 1072 (2025) 170163

HPGe spectroscopy of a rock sample from Doss Trento

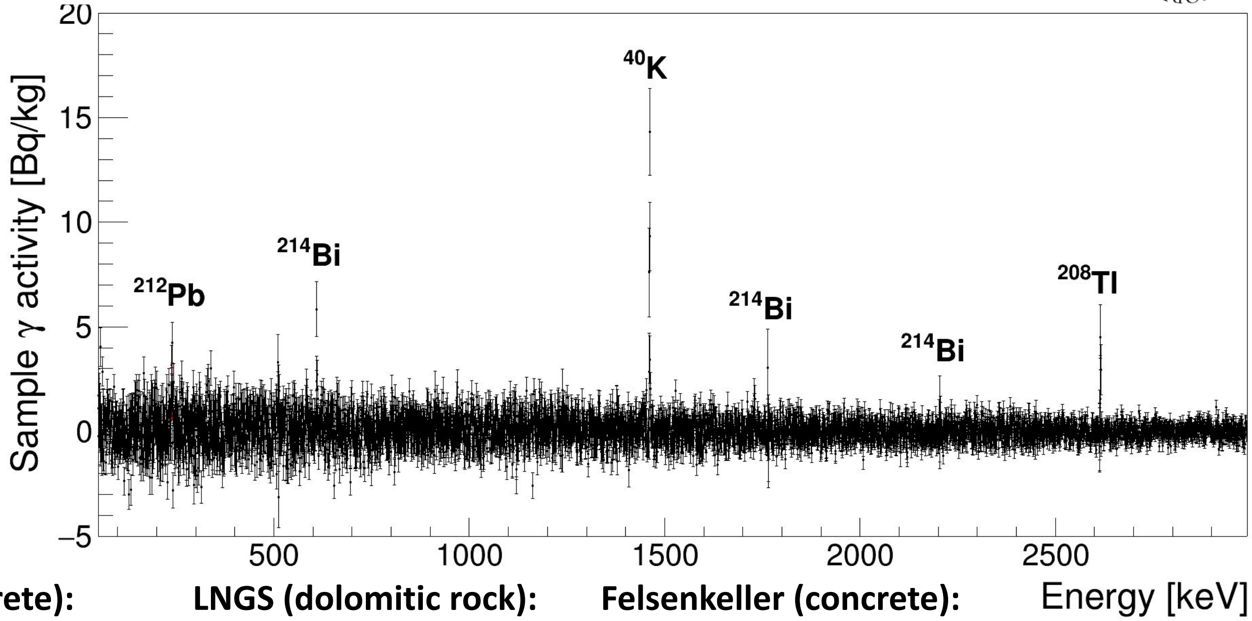
Collected a 2.4g sample made by:
45% rocks from 3 layers of Doss Trento
30% rocks from same layer of the tunnel
25% painting + concrete inside the tunnel



measured
10days HPGe



compared with bkg
5d+5d (empty vial)



Doss Trento:
^{40}K: 210±25 Bq/kg
^{238}U: 12±3 Bq/kg
^{232}Th: 9±2 Bq/kg

LNGS (concrete):
^{40}K: 70±2 Bq/kg
^{238}U: 9.5±0.3 Bq/kg
^{232}Th: 3.7±0.2 Bq/kg

LNGS (dolomitic rock):
^{40}K: 26±2 Bq/kg
^{238}U: 1.8±0.1 Bq/kg
^{232}Th: 1.5±0.1 Bq/kg

(Radioanal Nucl Chem (2013) 295:749)

Felsenkeller (concrete):
(Eur. Phys. J. A (2025) 61)
^{238}U: 16±1 Bq/kg
^{232}Th: 16±2 Bq/kg

Felsenkeller rock is hornblende monzonite
U/Th: 140-170 Bq/kg

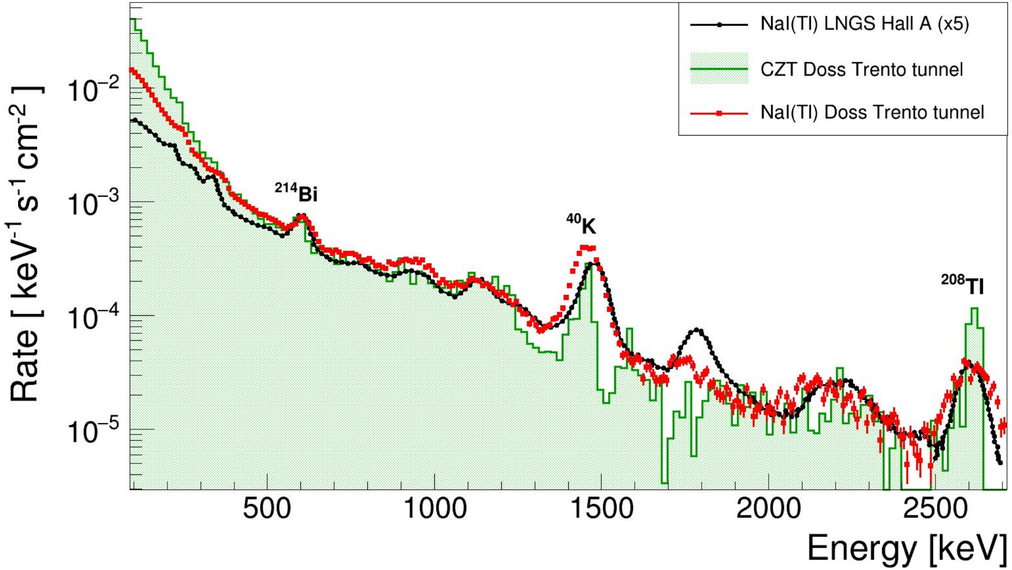
The marly limestone and volcaniclastics layer of Doss Trento are responsible for the higher activity as compared to LNGS.

Characterization of the γ background at the center of the tunnels

Data was collected in the center of the White tunnel and Black tunnel. No significant differences found.

CdZnTe 1500mm^3

NaI(Tl) 3”x3”



Detected a γ flux ≈1.5(s^{-1}cm^{-2})
5 times larger as compared with the one measured with a 3’’x3’’ NaI(Tl) at Gran Sasso LNGS Hall A (NIMA 643 (2011) 36) Relative abundances of ^{40}K ^{232}Th and ^{238}U natural chains similar to LNGS.
The 5x flux agrees with the larger K/U/Th concentrations in the Doss Trento rock as compared to LNGS.
@ Felsenkeller lab. (inside a shield) a factor 2x of the LNGS γ flux was measured (Eur. Phys. J. A (2025) 61)

Characterization of the Piedicastello Tunnels as a Potential Underground Laboratory for Astroparticle Physics in Trento, Italy

2 x 300m long tunnels, 6000 m^2

located 12 minutes on foot from Trento railway station

dry, equipped with: electric power, internet, WC

In the central part of the tunnel:

- 100 m of rock overburden (≈250mwe)
- vertical μ flux ≈0.5% of the external one (≈2000 higher than LNGS)
- γ flux is “only” 5x higher than at the Gran Sasso National Laboratory

Background is similar/better than Felsenkeller Lab. (45m, 140mwe)

Trento could be considered to host a Shallow Underground Laboratory

“Alpini road” Tunnel

“Alpini road” tunnel (overburden < 55m) to reach the top of the Doss Trento by car