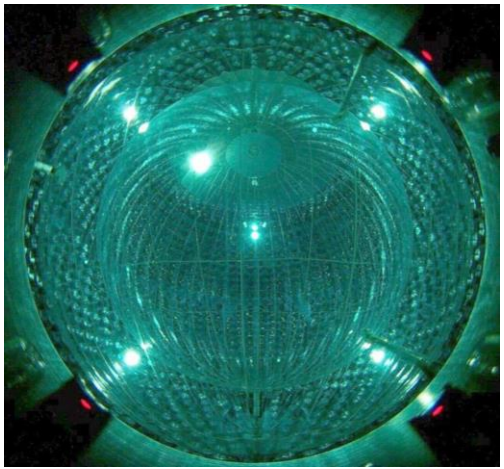
Bedretto: A New Underground Laboratory for Fundamental Physics

A. Kavner on behalf of Penning, Baudis, and Sores-Santos Groups

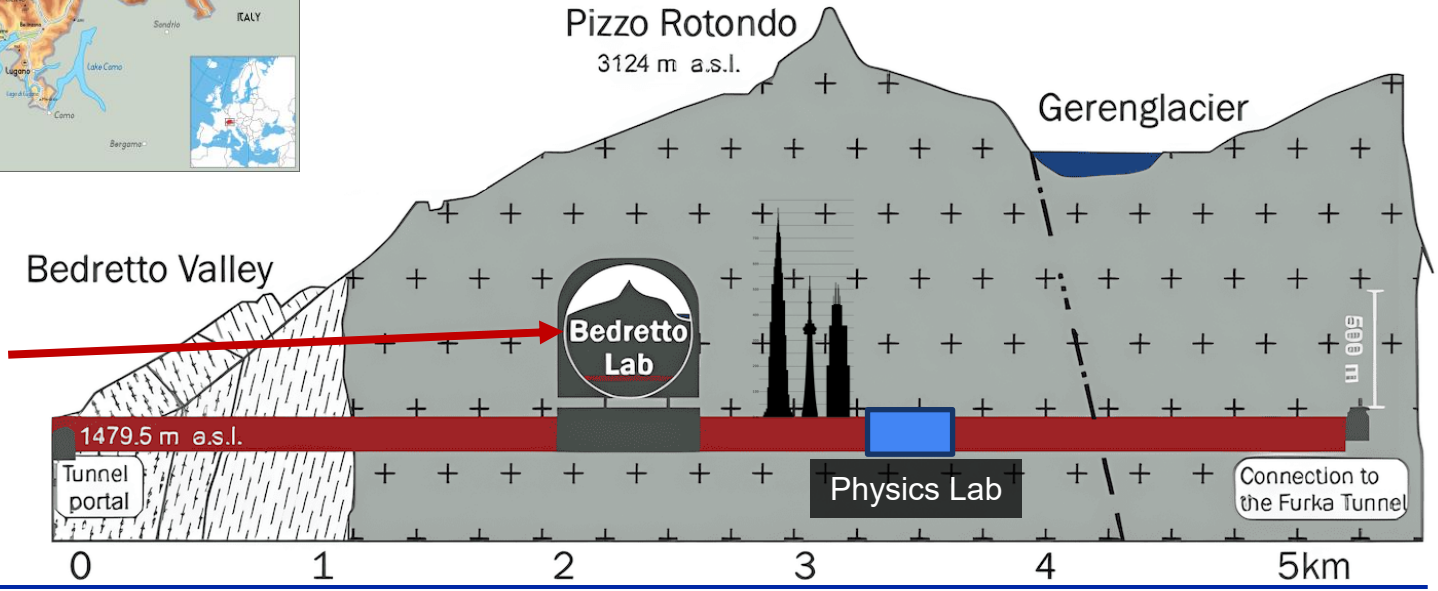

CallioLab
Boulby
SNOlab
SURF
Modane
Canfranc
LGNS
Baksan
Yemilab
Kamioka
Jinping
SUPL
Greenland
United States
Mexico
Venezuela
Colombia
Peru
Brazil
Bolivia
Chile
Argentina
Atlantic Ocean
South Pacific Ocean
South Atlantic Ocean
Indian Ocean
Russia
Ukraine
Kazakhstan
Mongolia
South Korea
Pakistan
India
Saudi Arabia
Libya
Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
Kenya
DRC
Tanzania
Angola
Namibia
Botswana
Madagascar
South Africa
Indonesia
Papua New Guinea
Australia
New Zealand
There are about 10 Deep Underground Labs

- Critical infrastructure for:
  - Dark matter
  - Neutrinos: $0\upsilon\beta\beta$, δ_{CP}, Solar-υ, etc.
  - Rare decay physics
  - Nuclear / environmental monitoring
  - Quantum sensing / computing
- Deep lab space is a hot commodity!
  - Limitations for R&D stage experiments



- 5.2 km tunnel connecting the Furka train tunnel and Bedretto valley
- 1650 m of rock overburden under peak
- Less than 2 hours from Zurich, Bern, and Geneva
- Geosciences laboratory established in 2019

Existing geosciences lab



Newly excavated lab space in 2025

2025 Lab Expansion

2025 Lab Expansion

3500 Meters in the Mountain

2025 Background Characterization Campaign

- Wholistic campaign to measure backgrounds from:
  - Cosmic-ray muons
  - Neutrons
  - Gamma-rays
  - Radon
  - Vibrations
  - EMI
- Work summarized: https://arxiv.org/abs/2512.14815

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  - Cosmic-ray muons
  - Neutrons
  - Gamma-rays
  - Radon
  - Vibrations
  - EMI
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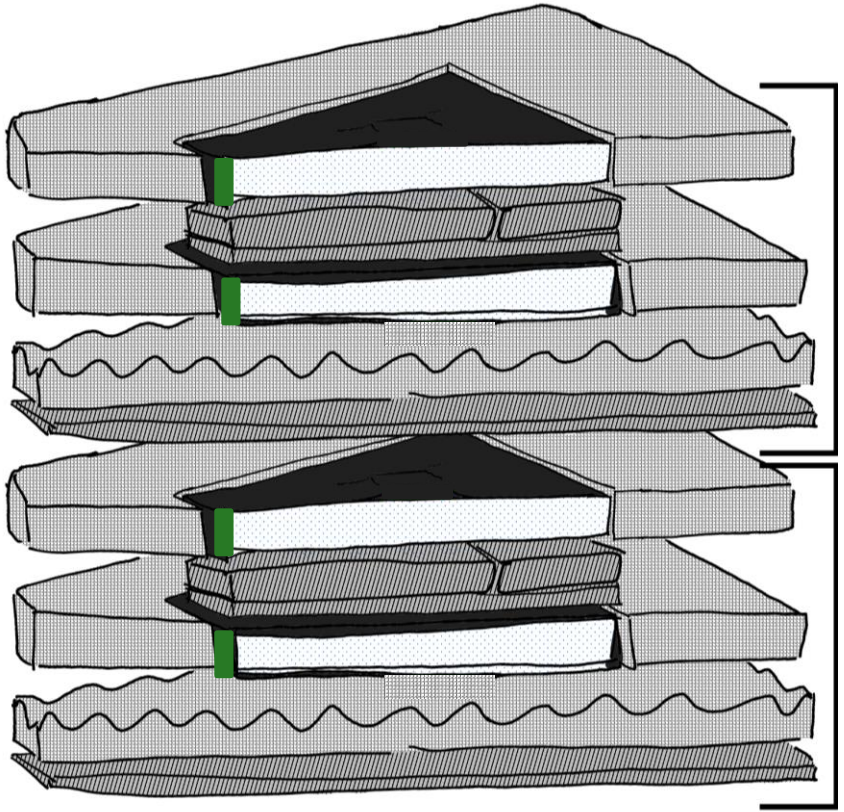
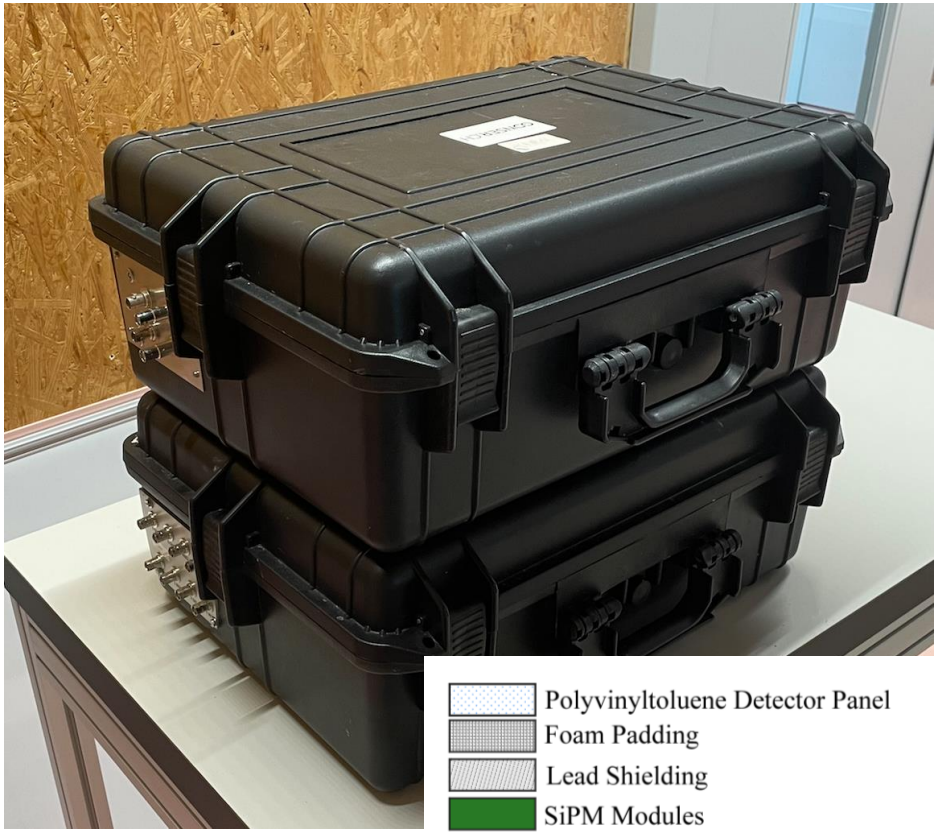
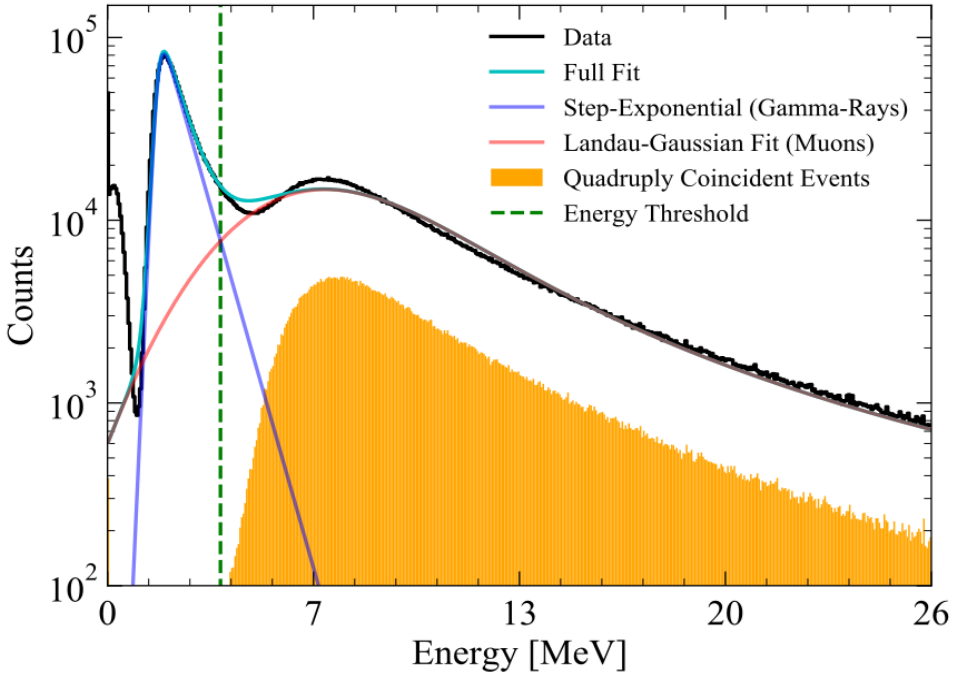
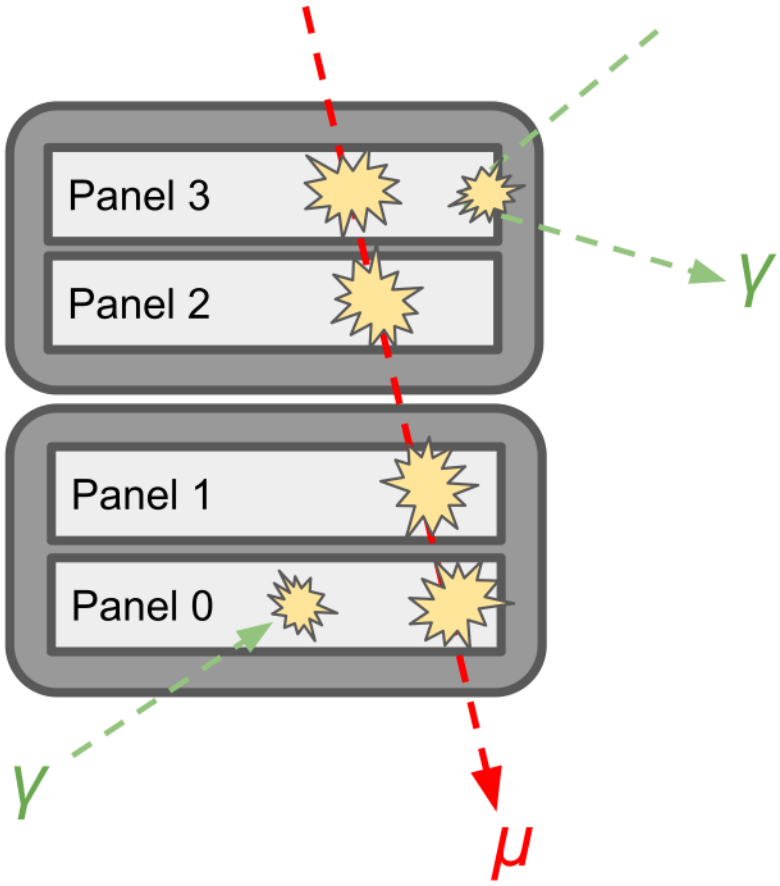
Muon Telescope



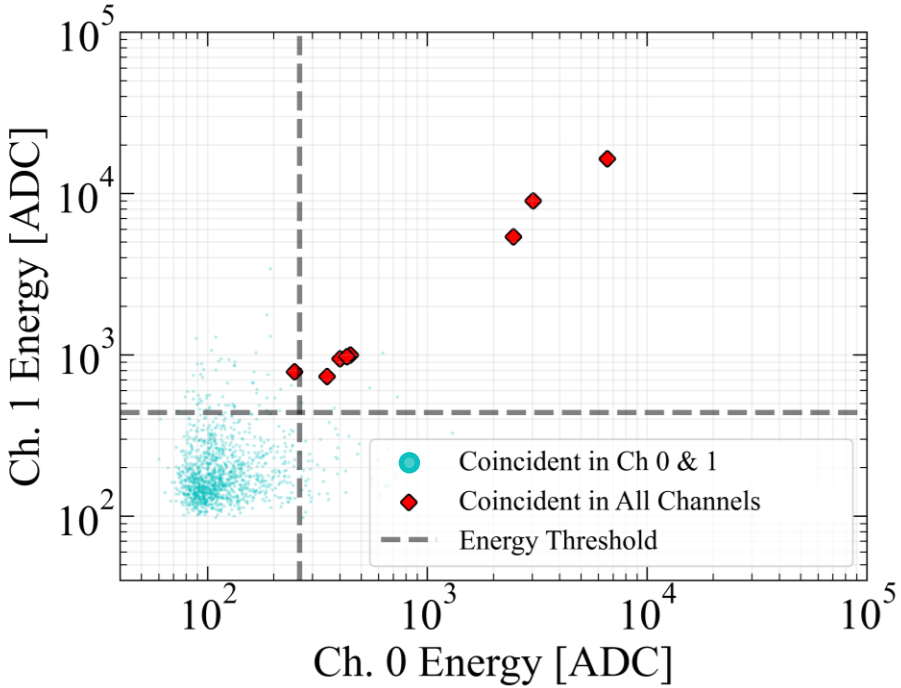


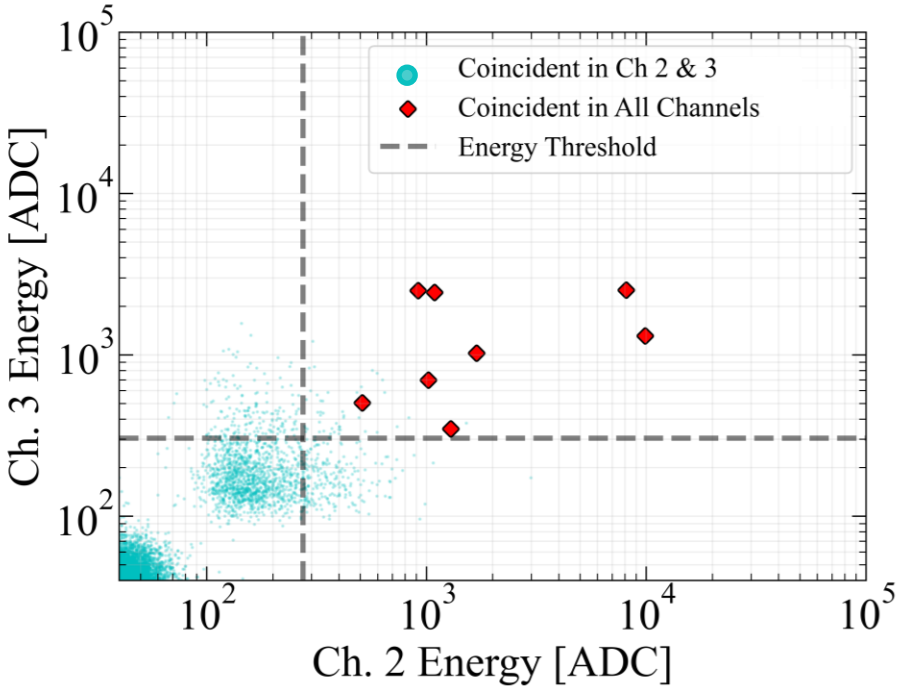
- Above ground measurements found a detection efficiency of 28%, validated with Geant4





- 3 weeks of live-time
- 8 Measured muon events: 7 above all channel thresholds, 1 corner clip

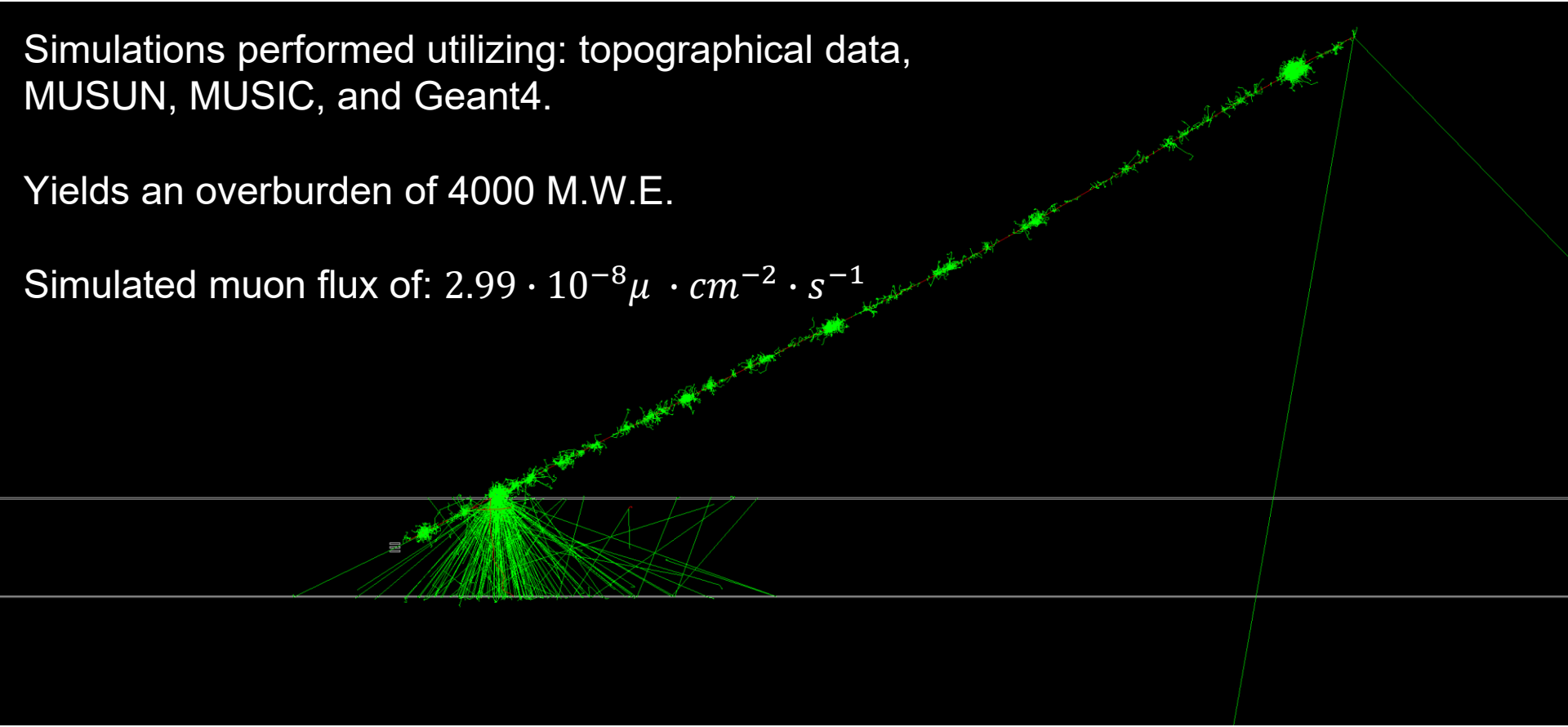


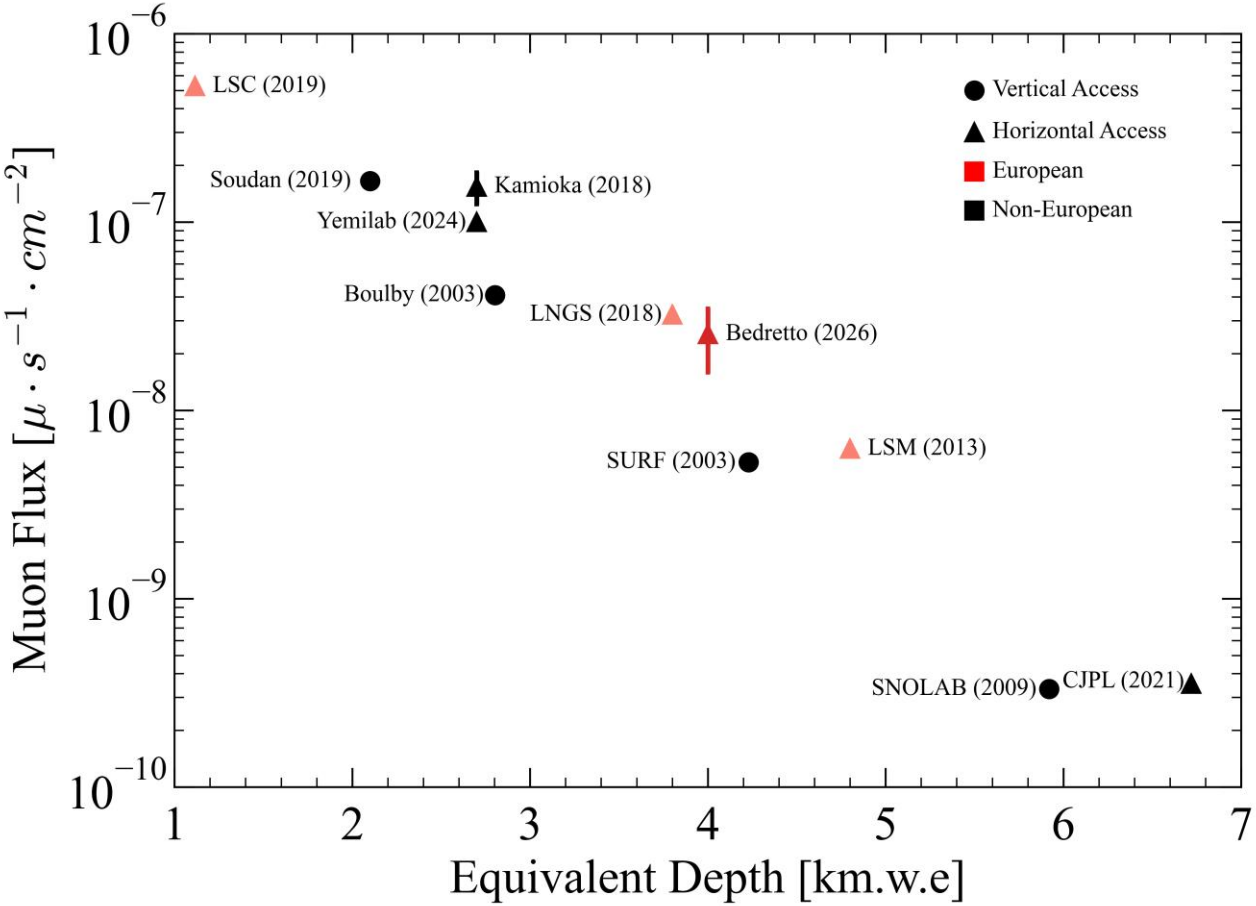


Simulations performed utilizing: topographical data, MUSUN, MUSIC, and Geant4.

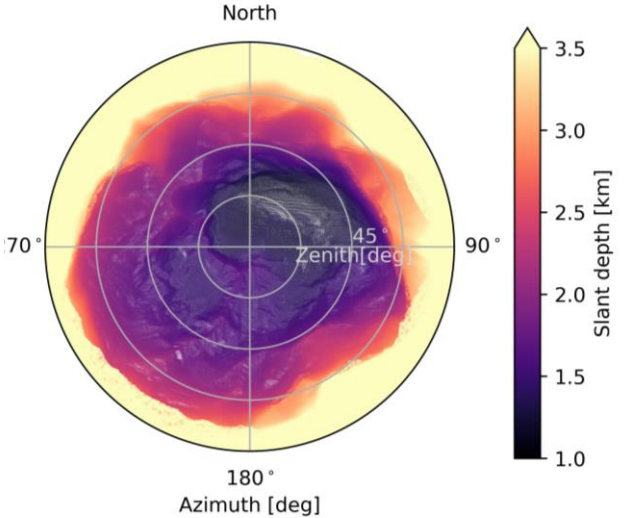
Yields an overburden of 4000 M.W.E.

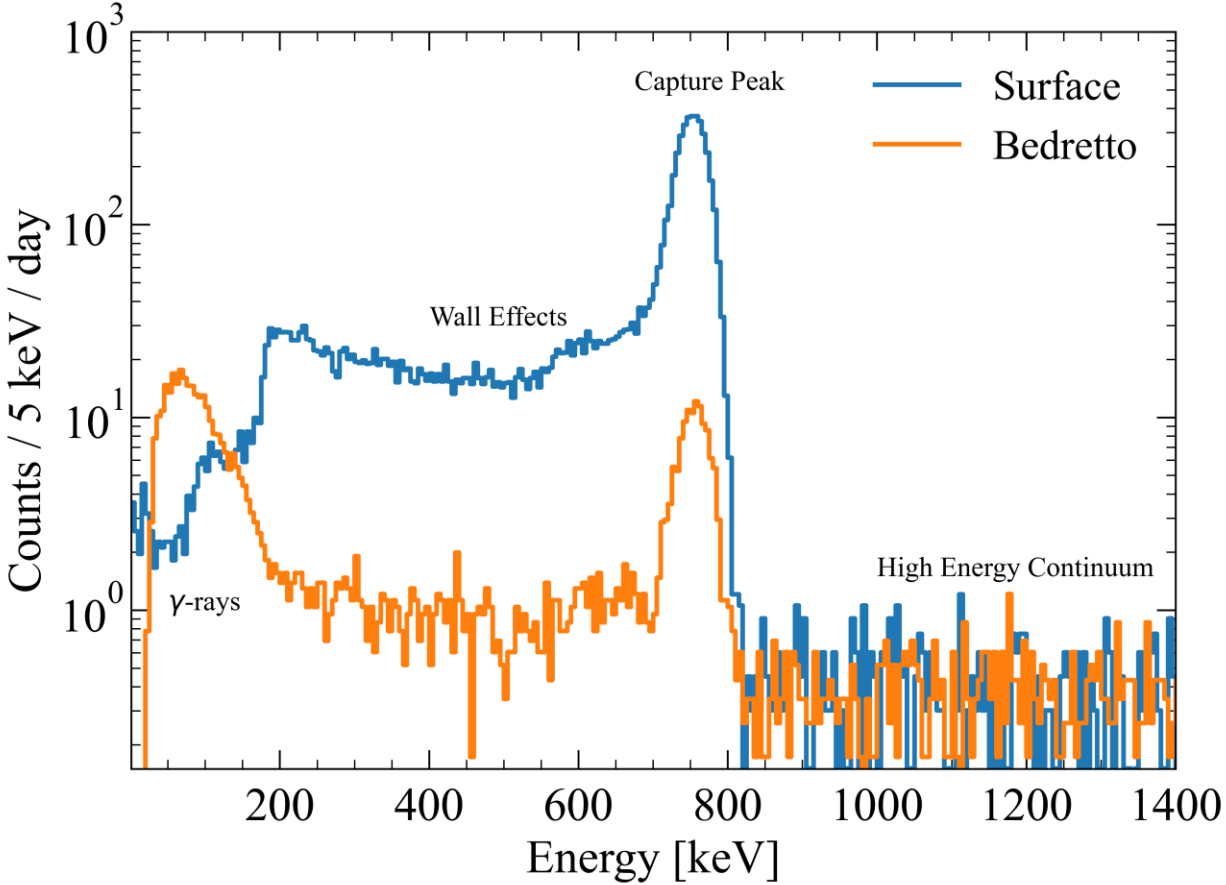
Simulated muon flux of: $2.99 \cdot 10^{-8} \mu \cdot cm^{-2} \cdot s^{-1}$

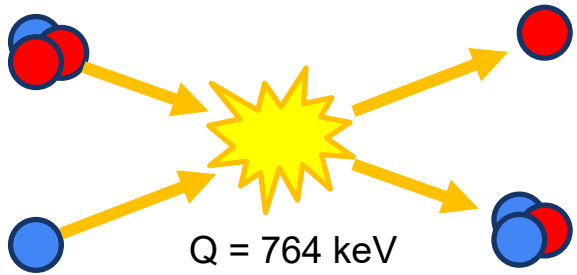




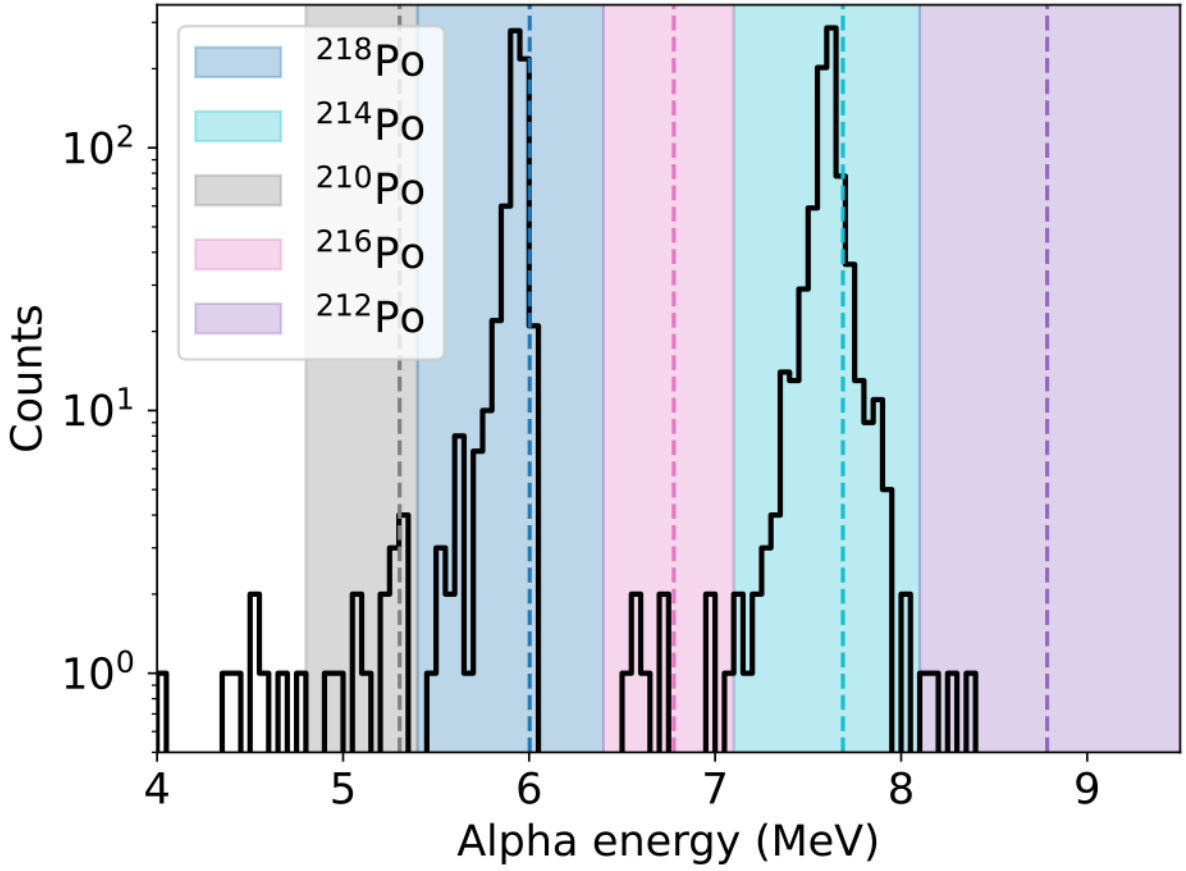
- Muon flux of: $2.54 \pm 0.95 \cdot 10^{-8} \mu \cdot cm^{-2} \cdot s^{-1}$
- Uncertainties: statistical, simulation, & assembly variation

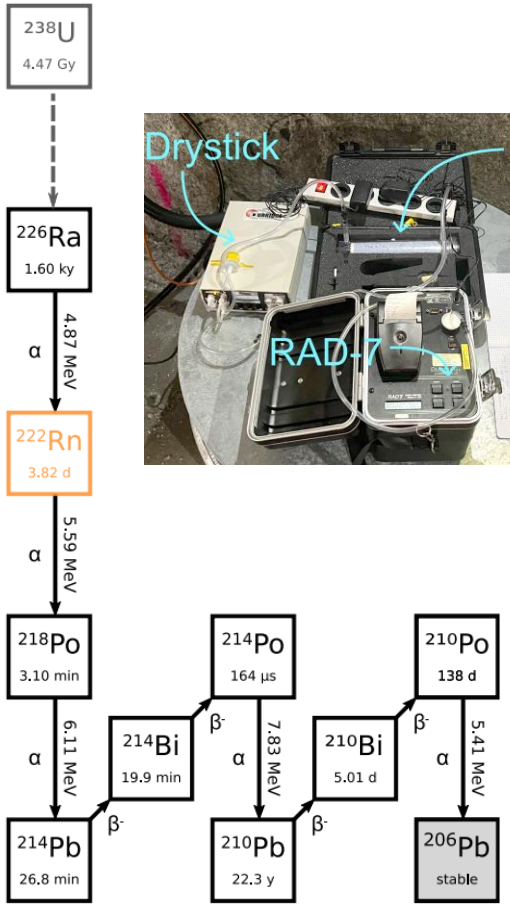




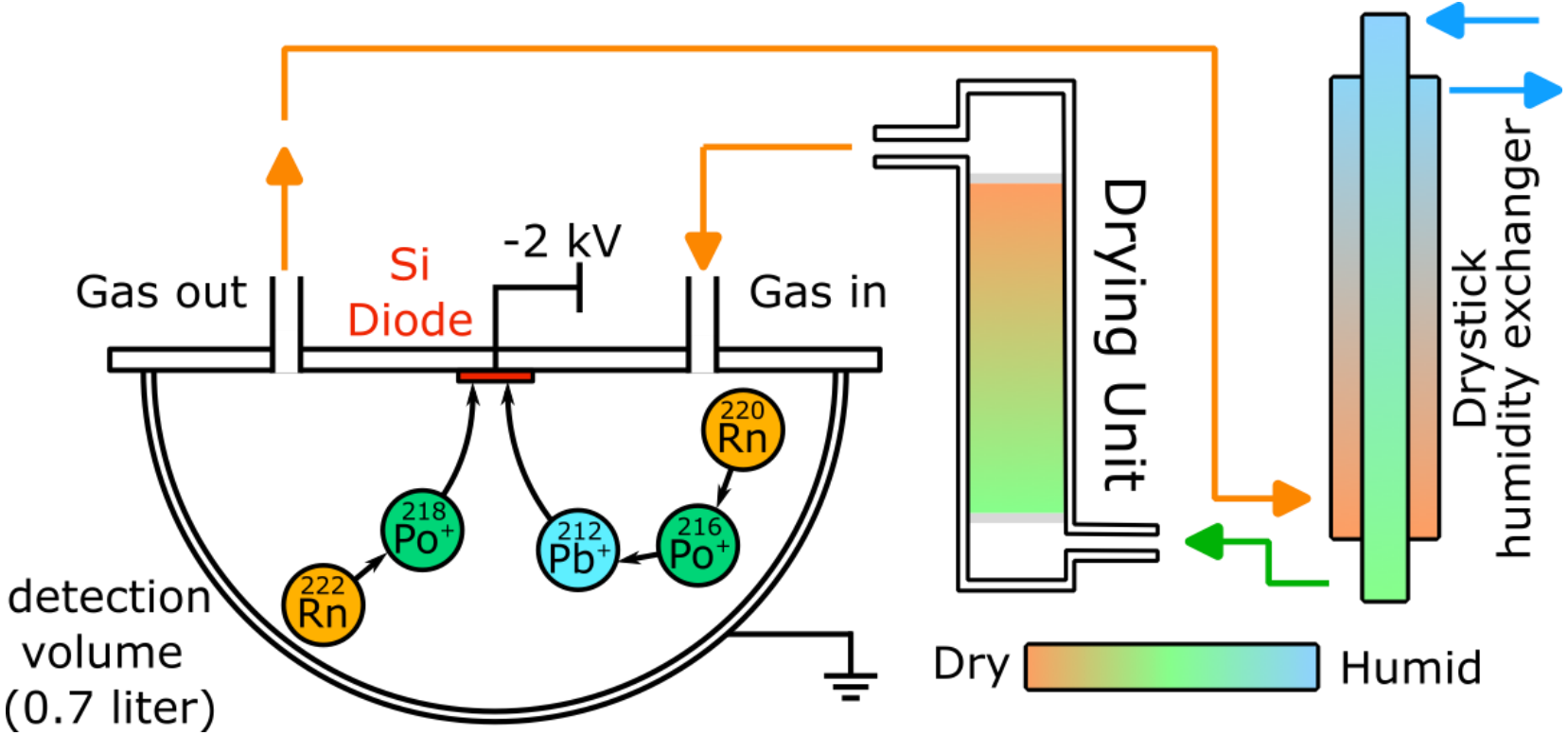


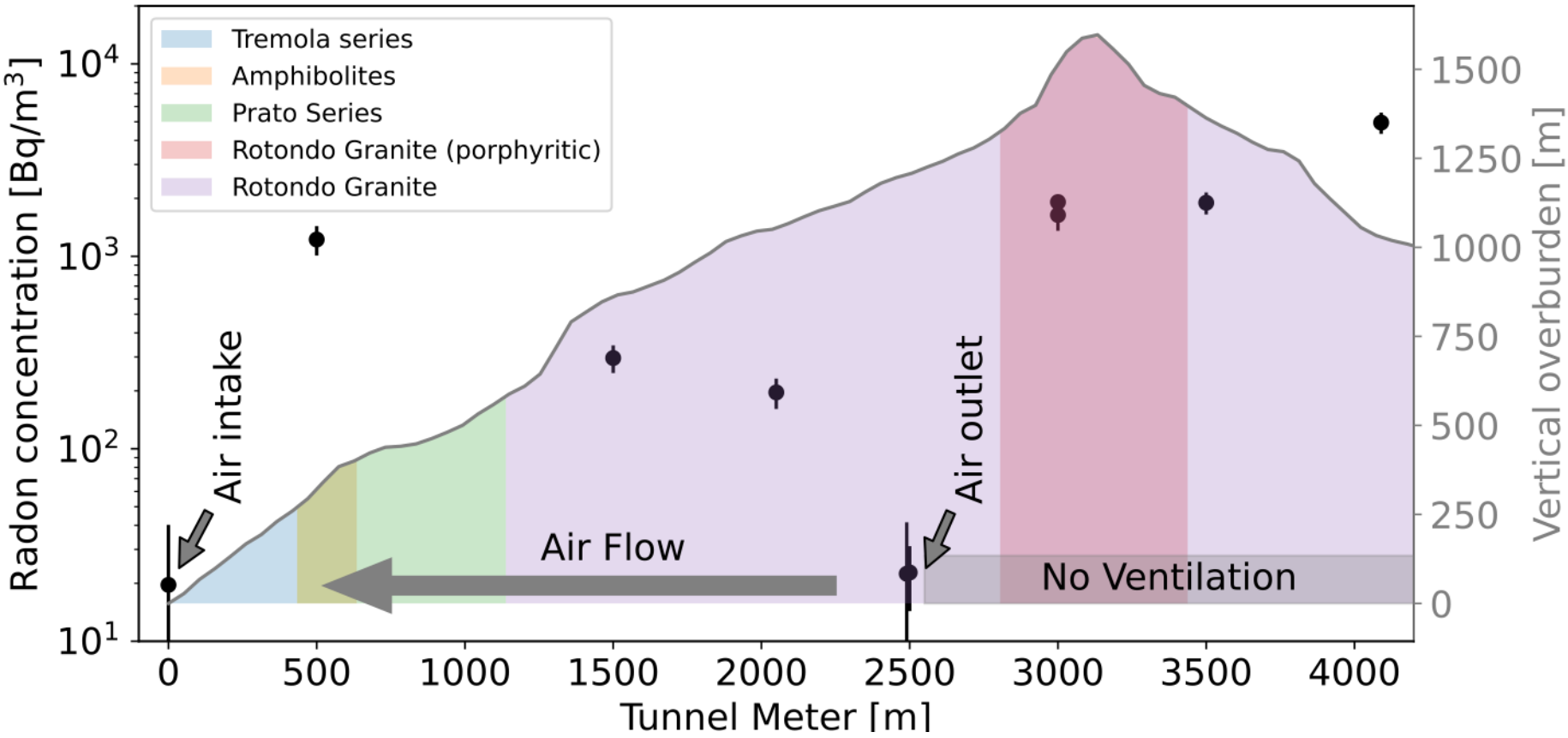
- Factor of 100 reduction from surface flux
- We assume the fast flux scales similarly
- Fast flux measurement in Summer 2026!


218Po
214Po
210Po
216Po
212Po
Counts
10^2
10^1
10^0
4
5
6
7
8
9
Alpha energy (MeV)

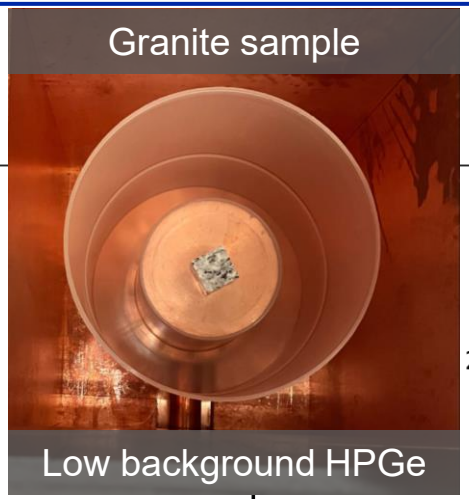

238U
4.47 Gy
226Ra
1.60 ky
α
4.87 MeV
222Rn
3.82 d
α
5.59 MeV
218Po
3.10 min
α
6.11 MeV
214Pb
26.8 min
β-
214Bi
19.9 min
β-
214Po
164 µs
α
7.83 MeV
210Pb
22.3 y
β-
210Bi
5.01 d
β-
210Po
138 d
α
5.41 MeV
206Pb
stable

Drystick
Drying Unit
RAD-7

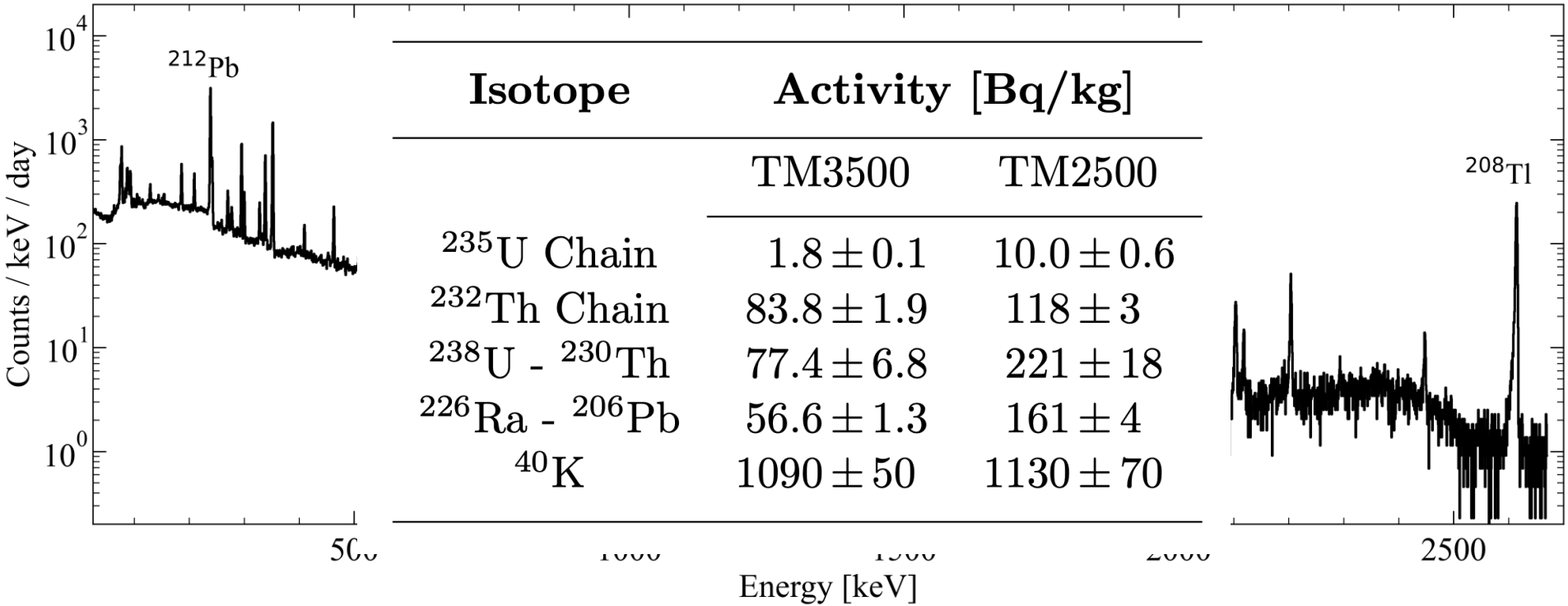

Gas out
Si Diode
-2 kV
Gas in
220 Rn
218 Po+
212 Pb+
216 Po+
222 Rn
detection volume (0.7 liter)
Drying Unit
Drystick humidity exchanger
Dry
Humid


Tremola series
Amphibolites
Prato Series
Rotondo Granite (porphyritic)
Rotondo Granite
Radon concentration [Bq/m³]
10^4
10^3
10^2
10^1
Air intake
Air outlet
Air Flow
No Ventilation
0
500
1000
1500
2000
2500
3000
3500
4000
Tunnel Meter [m]
1500
1250
1000
750
500
250
0
Vertical overburden [m]

Granite Gamma-Ray Counting



Granite Gamma-Ray Counting



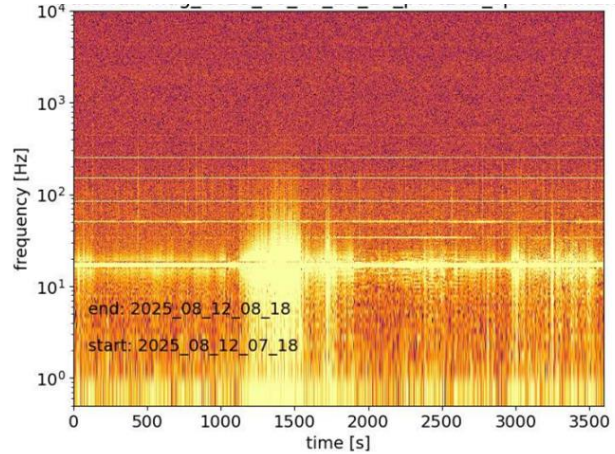
Isotope	Activity [Bq/kg]	
	TM3500	TM2500
^{235}U Chain	1.8 ± 0.1	10.0 ± 0.6
^{232}Th Chain	83.8 ± 1.9	118 ± 3
^{238}U - ^{230}Th	77.4 ± 6.8	221 ± 18
^{226}Ra - ^{206}Pb	56.6 ± 1.3	161 ± 4
^{40}K	1090 ± 50	1130 ± 70

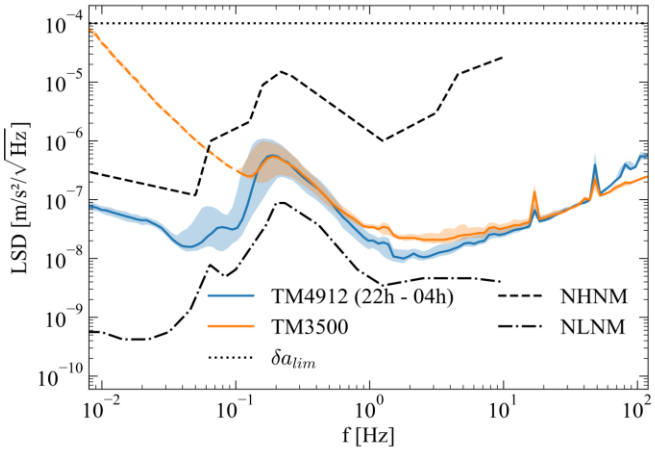
Electromagnetic

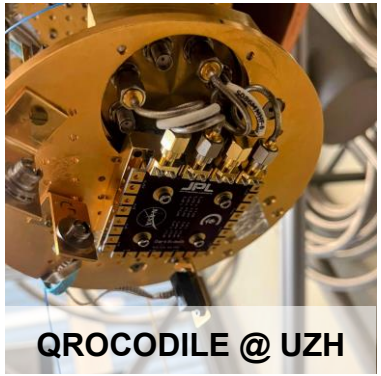
- 3-axis magnetic backgrounds
  - With and without zero-Gaus Chamber
- Exceeds requirement for atomic interferometry
  - < 100 nT / $\sqrt{Hz}$

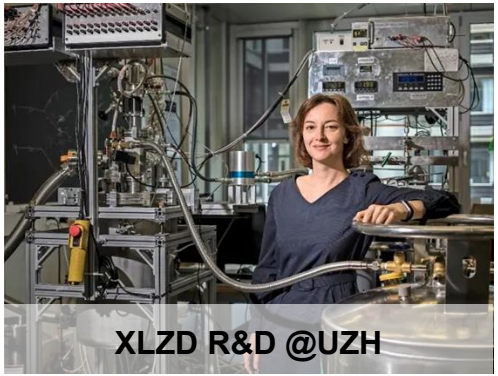
Vibrational

- Very low seismic backgrounds
  - Consistent within geological noise models
- Amongst lowest vibration in the world!

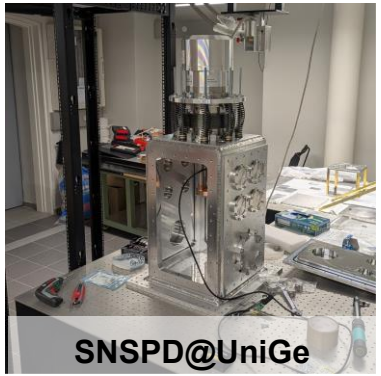




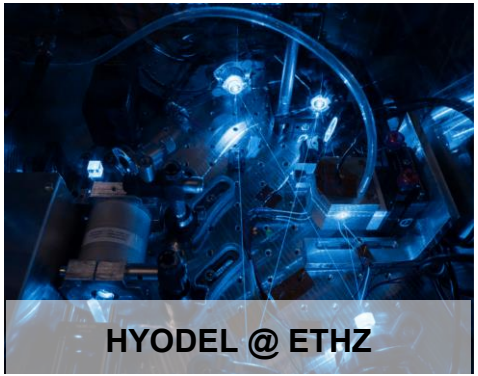

QROCODILE @ UZH

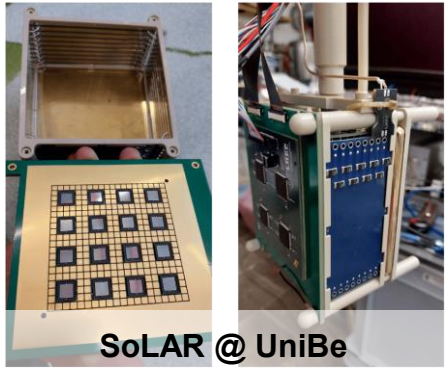

XLZD R&D @UZH

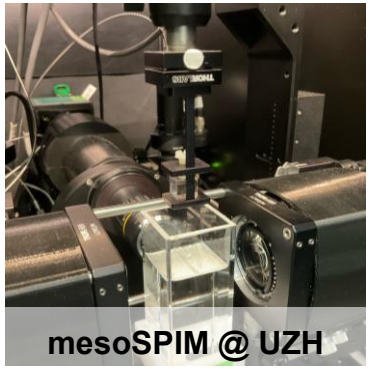

MuonTomo@UniGe


SNSPD@UniGe


GW @ UZH


HYODEL @ ETHZ


SoLAR @ UniBe


mesoSPIM @ UZH

Lab Expansion Plans

Equipment and Cost

Electric Supply	**CHF 700'000**
- 16kV Cable, 2'000m	
- 16kV Switch and 250kVA Transformer	
- 400V Switch cabinet	
Ventilation / HVAC	**CHF 200'000**
- Booster fan	
- Air duct dm 500mm, 1'000m	
- HVAC System, Filters	
- air supply for laminar flow	
Other Equipment, planing and permits	**CHF 200'000**
- Lighting, power sockets, cables	
- Voice and data communication, radio	
- Safety systems	
- planing and permits	
Total	**CHF 1'100'000**

Auftraggeber: ETH, Bedretto Lab
Projektverfasser: buntech
Plan Nr.
Format A3
Index: V1.0 | Erstellt / Vis: 22.01.2026 / Bun | Geprüft / Vis: | Freigabe / Vis:
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Bedretto Underground Laboratory (BULGG)

Technical equipment für operation and safety

Overview Paper is Out!

- BedrettoLab for Physics promises a new ultra-low background UG research facility in central Europe
  - Convenient: Easily reachable, horizontal access
  - Background mitigation schemes implemented in the design phase
  - Plans for first phase of the lab can be realized within few years only

Characterisation of the Bedretto Underground Site for Fundamental Physics Experiments

Björn Penning[a,1], Nicolas Angelides[1], Laura Baudis[1], Harvey Birch[1], Abigail Flowers[1], Florian Jörg[b,1], Alexander Kavner[c,1], Marcelle Soares-Santos[1], Aravind Remesan Sreekala[1], Johannes Wüthrich[1], Guandi Zhao[1,3], Chiara Capelli[1], John Clinton[6], Jose Cuenca García [1], Paolo Crivelli[3], Domenico Giardini[2], Evangelos-Leonidas Gkougkousis[1], Yacine Haddad[5], Marian Hertrich[2], Rebecca Hochreutener[2], Luisa Hötzsch[1], Philippe Jetzer[1], Ben Kilminster[1], Boris Korzh[4], Frédérick Massin[6], Knut Dundas Morå[1], Margherita Noia[1], Francesco Piastra[1], Christian Regenfus[3], Federico Sanchez[4], Steven Schramm[4], Francesco Riva[4], Serhan Tufanli[5], Michele Weber[5], Stefan Wiemer[2], Mathilde Wimez[2]

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[3]Departement Physik, ETH Zürich, Otto-Stern-Weg 1, Zürich, 8093, Switzerland
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the date of receipt and acceptance should be inserted later

Abstract Underground laboratories provide the ultra-low background and low-vibration environments essential for rare-event searches, gravitational-wave detection, and quantum-sensing technologies. We report a comprehensive environmental characterisation of the Bedretto tunnel in Ticino, Switzerland, a site offering horizontal access, excellent infrastructure, and the potential to be Europe's second-deepest and quietest underground laboratory. At the prospective physics site, located beneath an overburden exceeding 1400 m, we measure the cosmic-muon, γ-ray, and neutron fluxes, as well as the radon concentration, magnetic-field spectrum, and seismic backgrounds. The muon flux is suppressed by six orders of magnitude relative to the surface, consistent with an effective depth of about 4000 metre water equivalent, gamma-ray and neutron measurements reflect the local geology and guide shielding requirements for future particle and nuclear physics experiments. Magnetic and seismic noise levels are found to be exceptionally low, meeting or exceeding the criteria for next-generation atom-interferometric gravitational-wave detectors. These results establish the site as a highly competitive, accessible deep-underground location for fundamental-physics experiments.

Keywords underground laboratory, gravitational waves, dark matter, rare event searches, radiopurity, radio assay, atom interferometry, neutrinoless double beta decay

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1 Introduction

Underground laboratories provide uniquely background-free environments and are indispensable tools to understand fundamental physics processes. The massive rock overburden shields effectively even from the highest energetic cosmic rays, they are seismically very quiet since most vibrations travel at the surface and are attenuated quickly at depth, and Newtonian noise is reduced by the very large mass of rock surrounding the laboratory. Examples of underground experiments include rare-event searches such as the search for dark matter and neutrinoless double beta decay, rare-decay nuclear physics measurements, low-background material assay, environmental monitoring, and optimal sensitivity and stability of quantum sensors. Furthermore, the stable, low-background, and low-vibration environment offered by underground locations is highly beneficial for gravitational wave detection. Several major deep underground

Thanks!

Backup Slides

Stage 0

- Background measurements
- ARGUS (4k Quantum sensing)
- Detailed Muon tomography
- Astrobiology
- Space Exploration

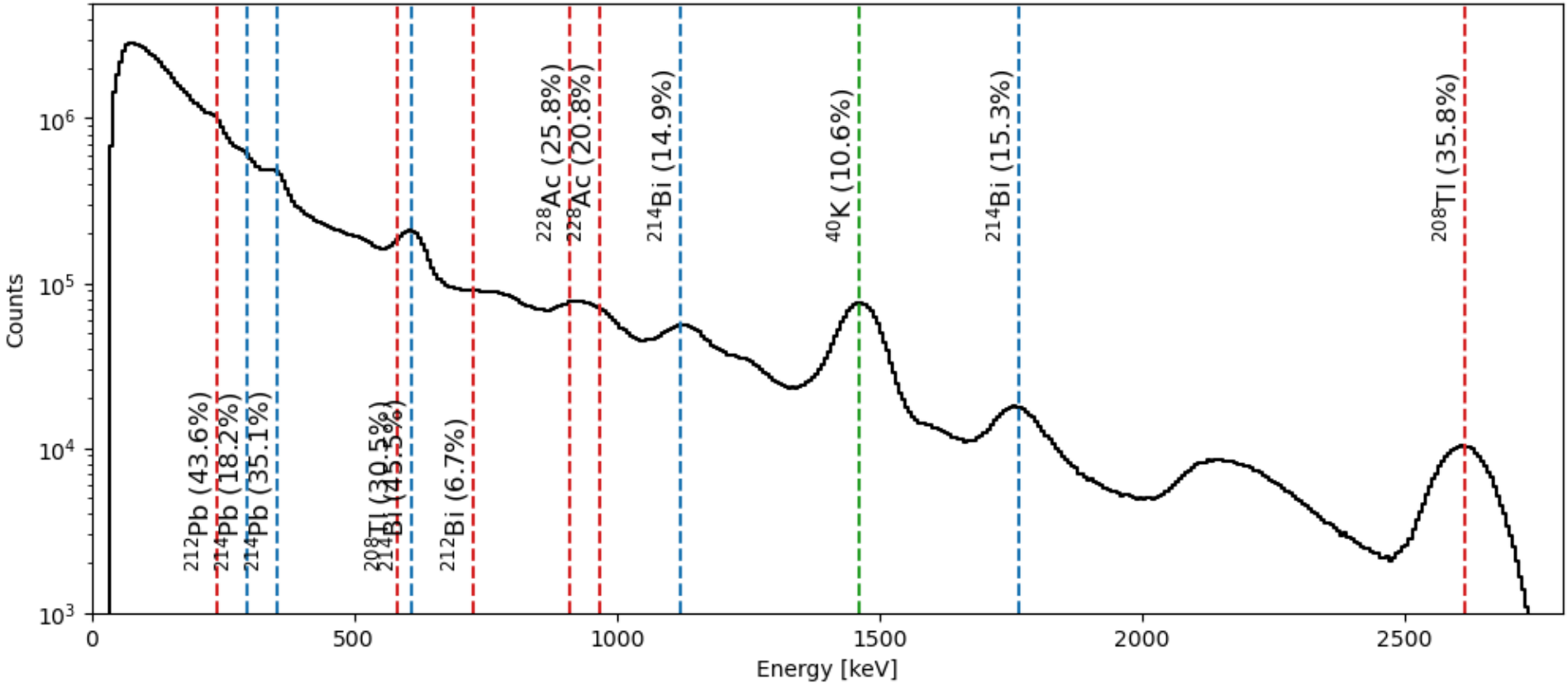
Stage 1

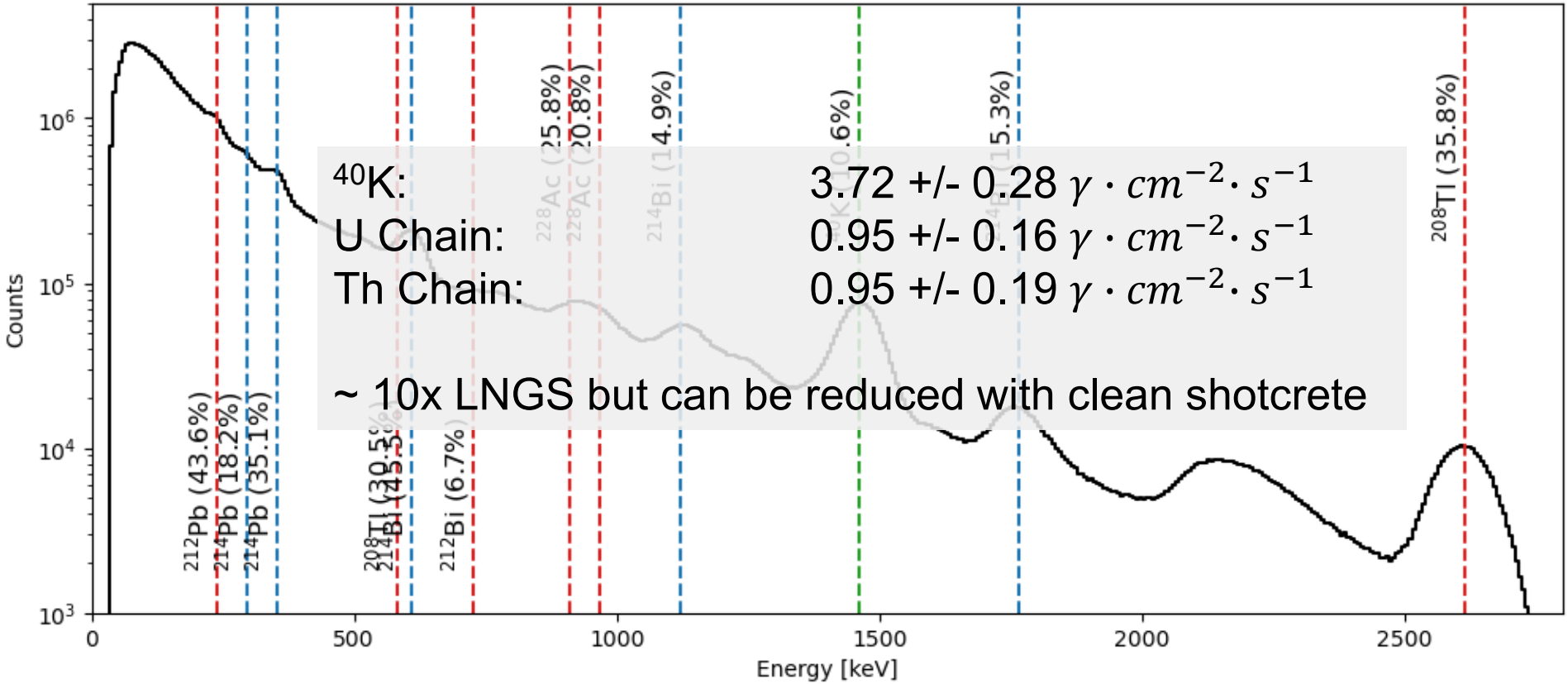
- HPGe Counter
- mK Quantum Sensing
- Small TPC test-setups
- SoLAr
- Astrobiology
- Space Exploration
- Radionuclide Monitoring

Stage 2

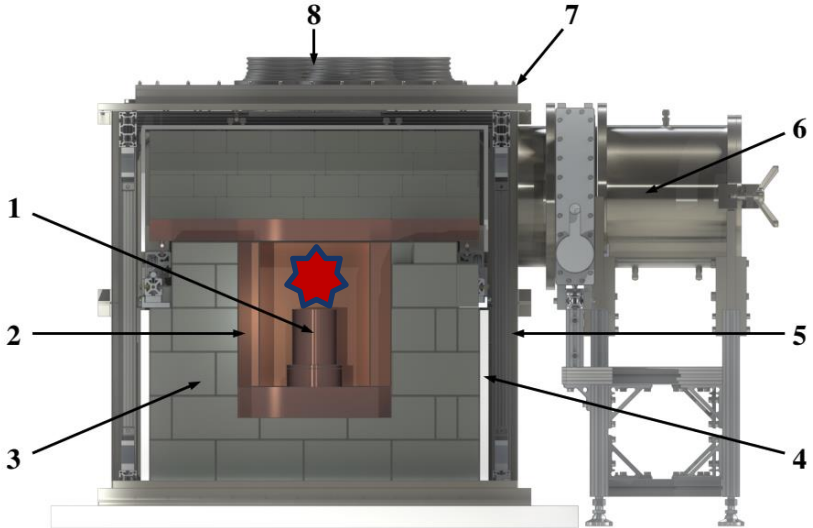
- HPGe Counter
- mK Quantum Sensing
- LXe full scale demonstrator
- Grav. waves R&D
- Atom Interferometry
- Astrobiology
- Space Exploration
- Radionuclide Monitoring

In-Situ Gamma Flux



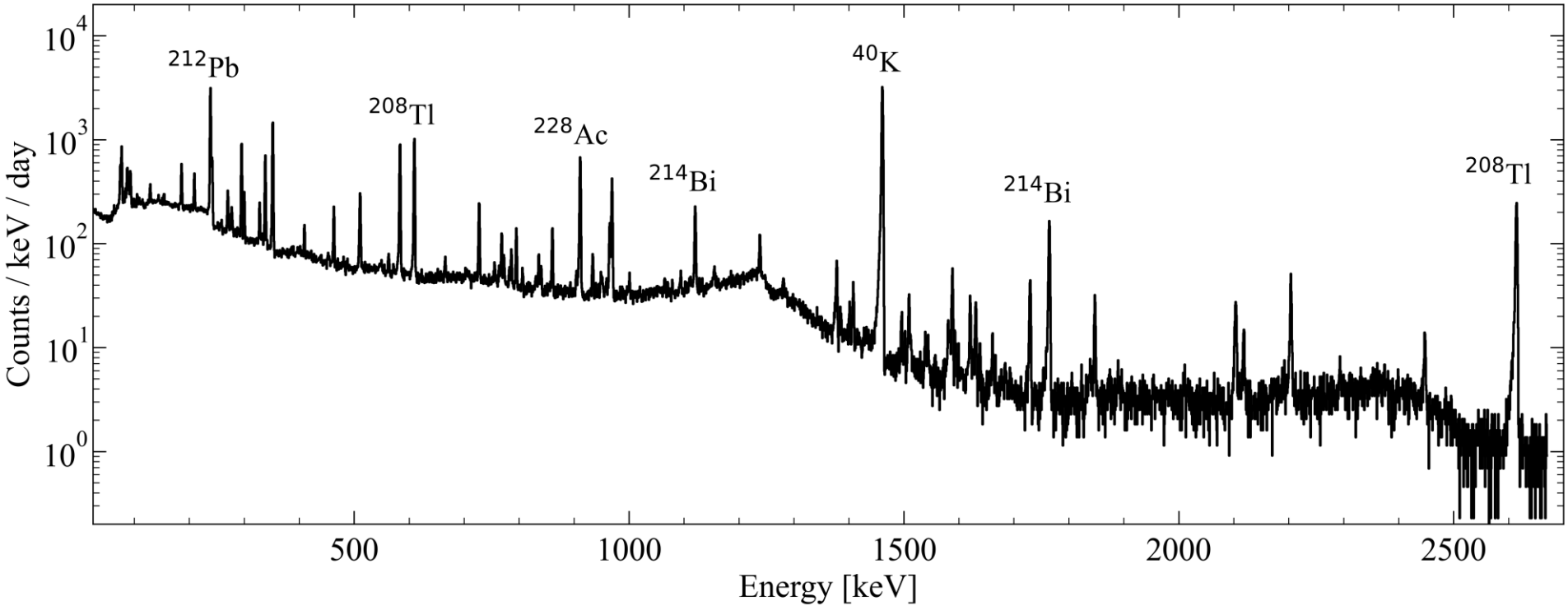

^{40}K:
3.72 +/- 0.28 $\gamma \cdot cm^{-2} \cdot s^{-1}$
U Chain:
0.95 +/- 0.16 $\gamma \cdot cm^{-2} \cdot s^{-1}$
Th Chain:
0.95 +/- 0.19 $\gamma \cdot cm^{-2} \cdot s^{-1}$
~ 10x LNGS but can be reduced with clean shotcrete
Counts
Energy [keV]
^{212}Pb (43.6%)
^{214}Pb (18.2%)
^{214}Pb (35.1%)
^{212}Bi (6.7%)
^{208}Tl (35.8%)

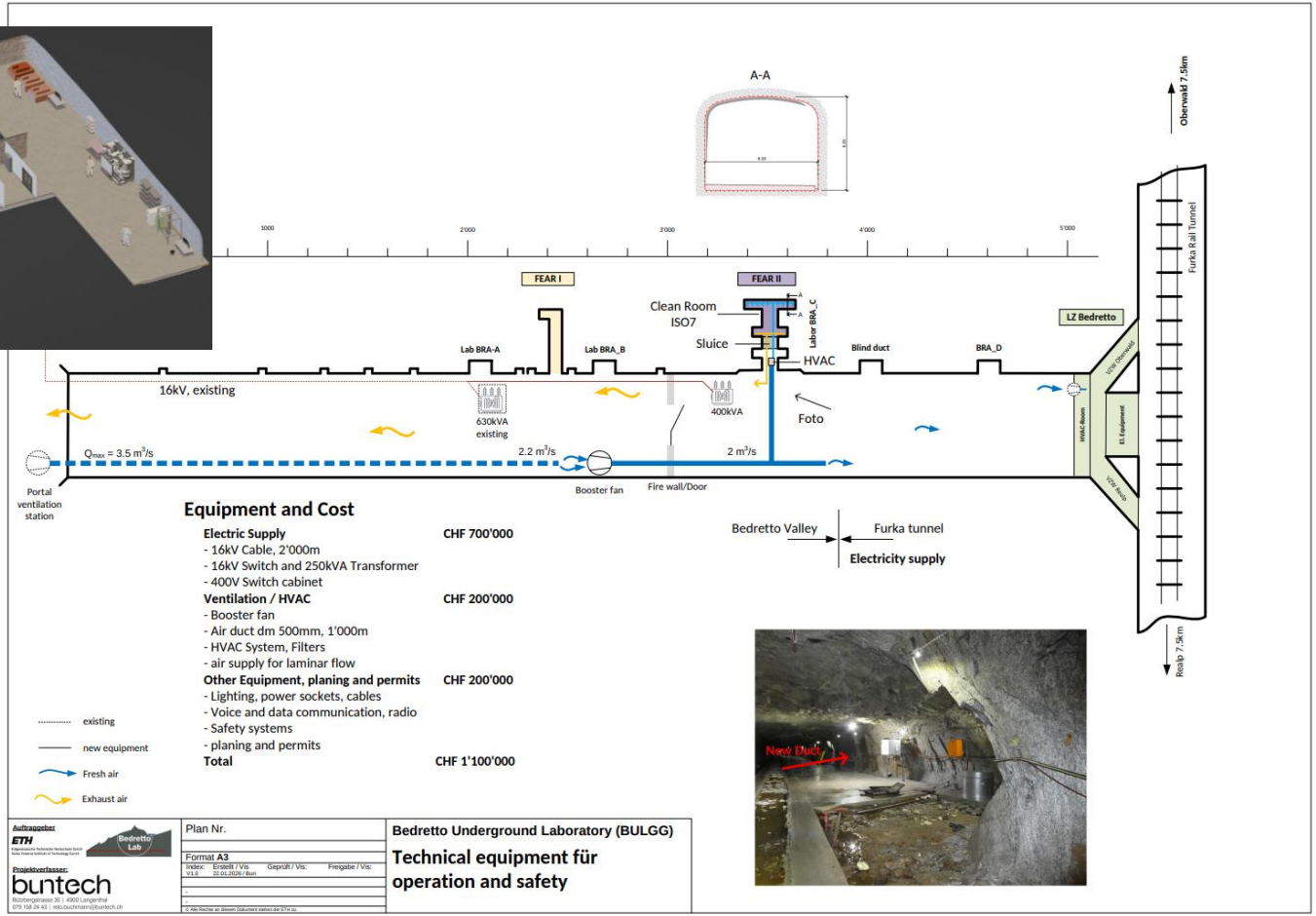
Bedretto Granite Assay



1) HPGe crystal 2) low background copper 3) lead shield
4) HDPE 5) Load lock 6) load lock 7) Glove port 8) view port

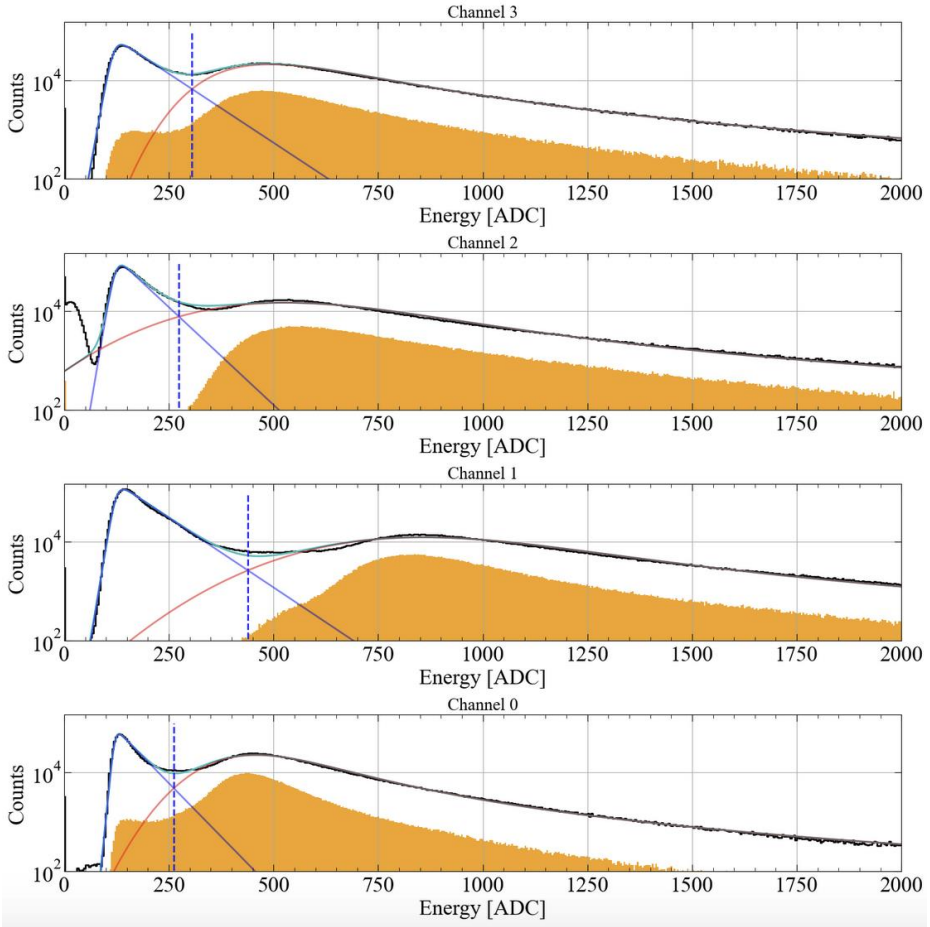
Granite Counting



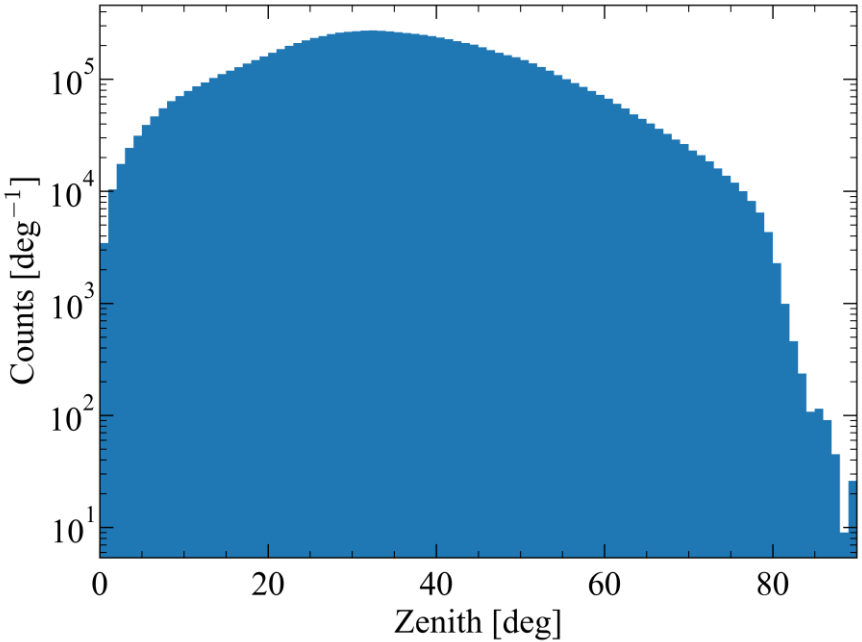

A-A
Oberwald 7.5km
Furka Rail Tunnel
Realp 7.5km
FEAR I
FEAR II
Clean Room ISO7
Sluice
HVAC
Lab BRA-A
Lab BRA_B
Labor BRA_C
Blind duct
BRA_D
LZ Bedretto
16kV, existing
630kVA existing
400kVA
Foto
Q_{max} = 3.5 m³/s
2.2 m³/s
2 m³/s
Portal ventilation station
Booster fan
Fire wall/Door
Bedretto Valley
Furka tunnel
Electricity supply
existing
new equipment
Fresh air
Exhaust air
Equipment and Cost
Electric Supply CHF 700'000
- 16kV Cable, 2'000m
- 16kV Switch and 250kVA Transformer
- 400V Switch cabinet
Ventilation / HVAC CHF 200'000
- Booster fan
- Air duct dm 500mm, 1'000m
- HVAC System, Filters
- air supply for laminar flow
Other Equipment, planing and permits CHF 200'000
- Lighting, power sockets, cables
- Voice and data communication, radio
- Safety systems
- planing and permits
Total CHF 1'100'000
Auftraggeber
ETH
Bedretto Lab
Projektverfasser:
buntech
Plan Nr.
Format A3
Bedretto Underground Laboratory (BULGG)
Technical equipment für operation and safety

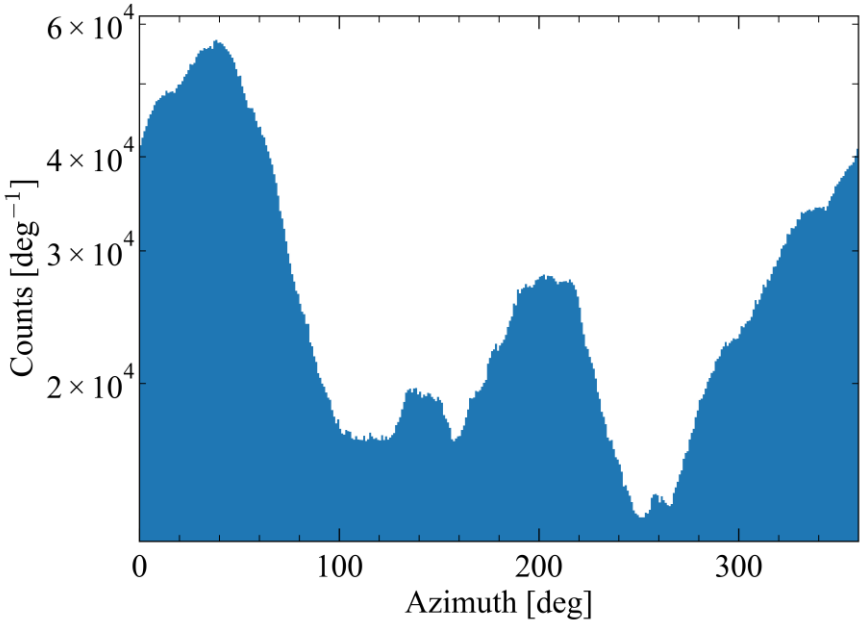
New Duct

Muon Quad Channel

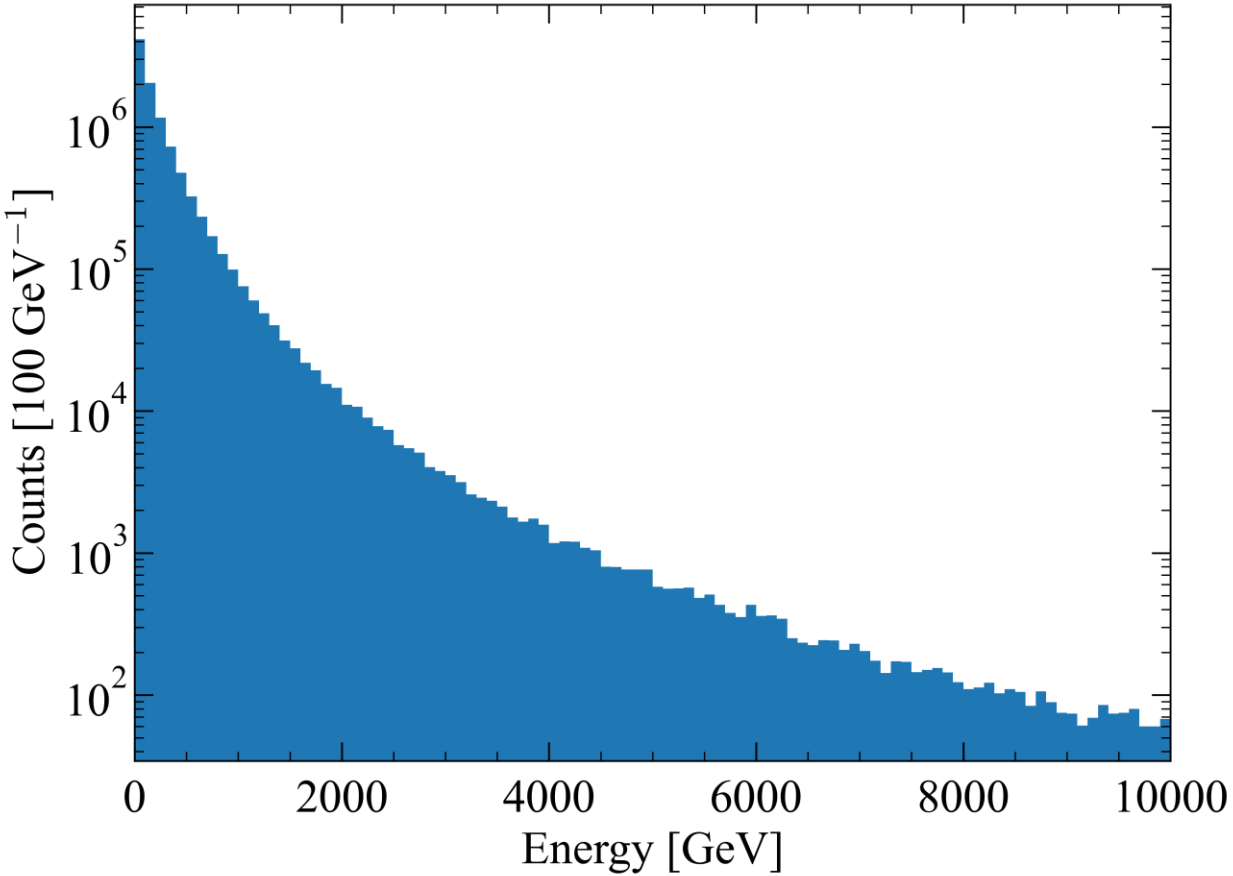


Muon Simulations

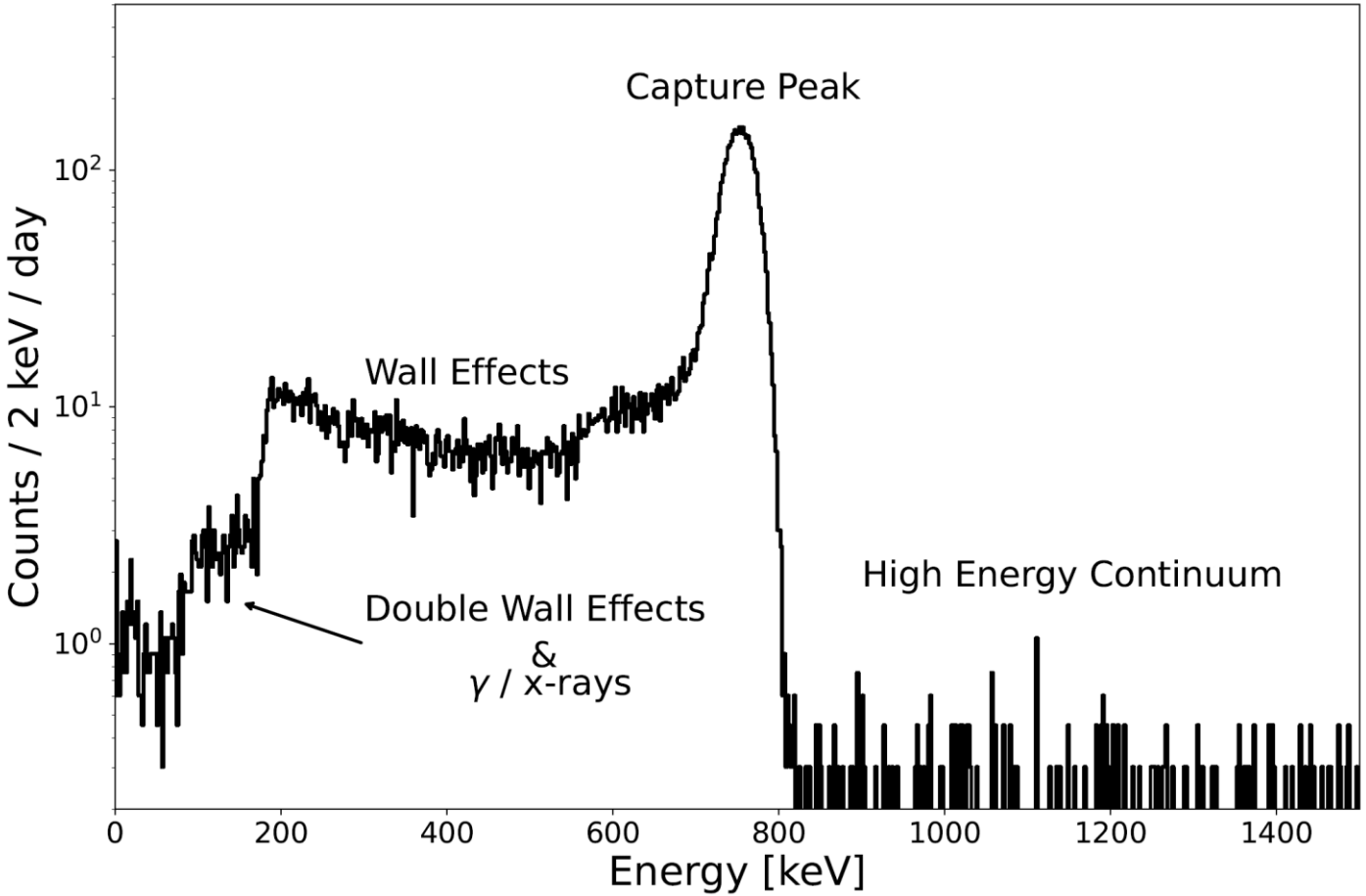




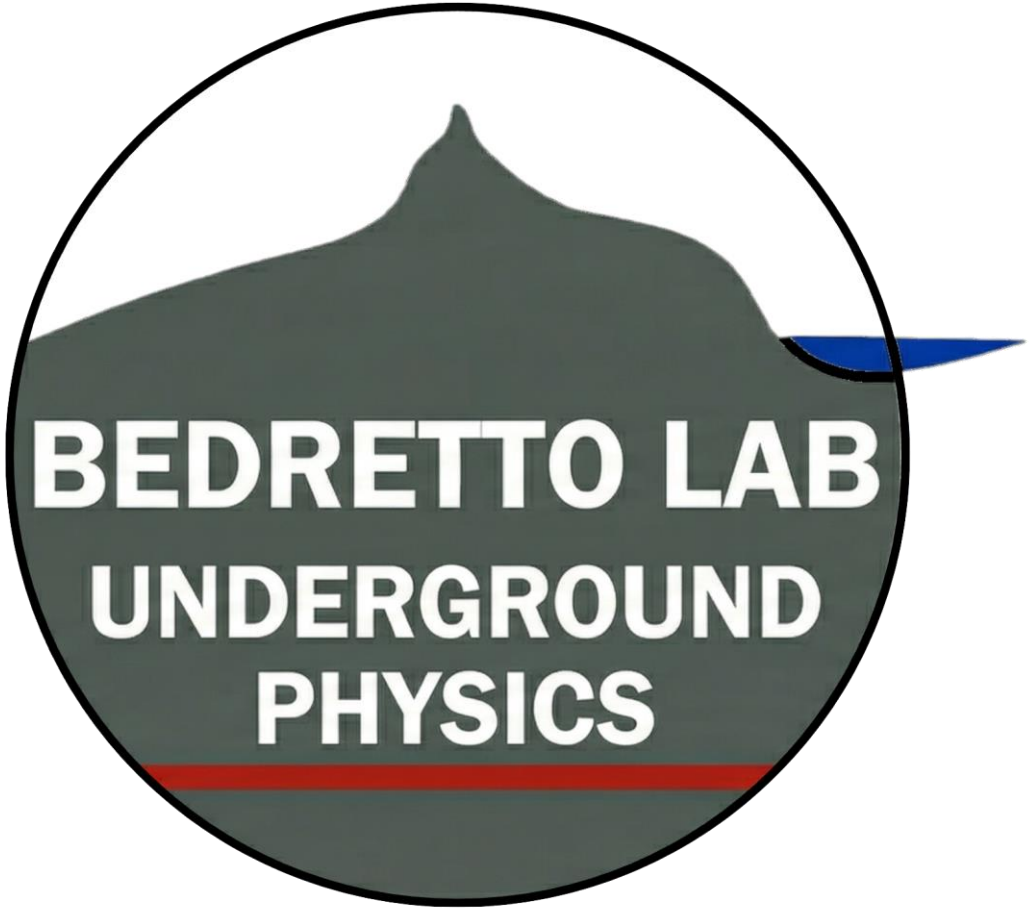
Muon Simulations



Neutron Spectal Features



- Wholistic measurement of backgrounds from:
  - Muons, gamma rays, neutrons, radon, vibrations, and EMI


BEDRETTO LAB
UNDERGROUND
PHYSICS