Underground Physics at CUP

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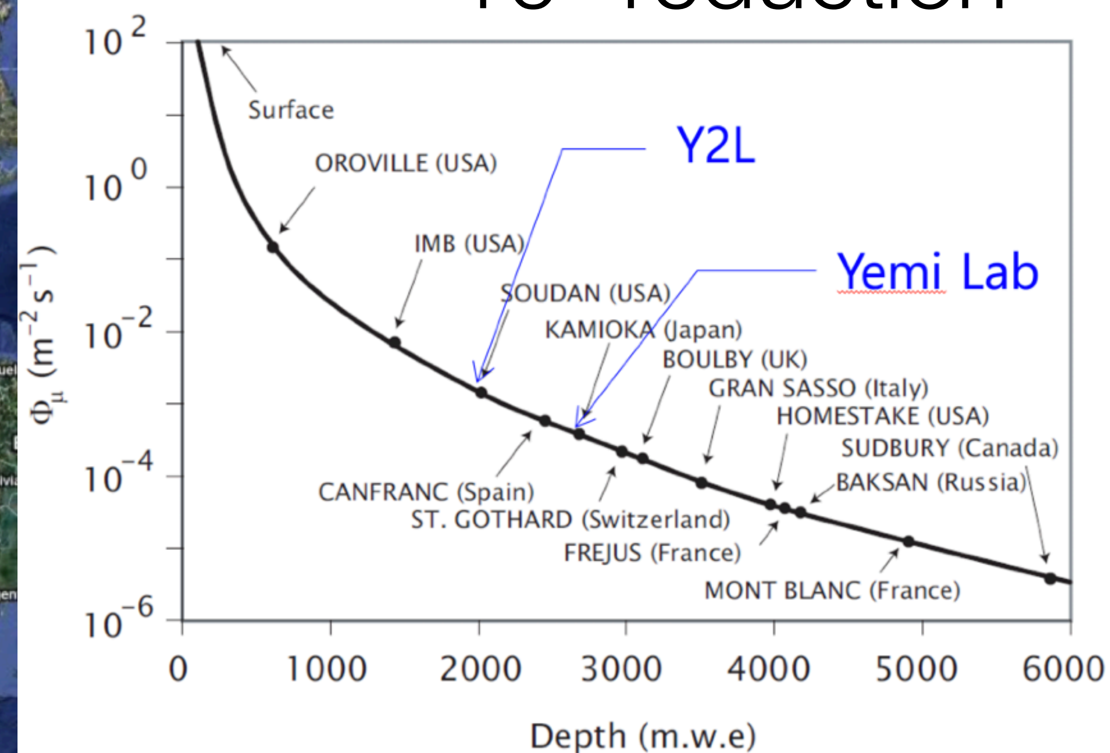
Why deep underground laboratory for rare event searches?

- Dark matter and neutrinoless double beta which we are interested in are occurring with very low probability
- Requirements to achieve the best signal-to-background ratio
  - **Low backgrounds**
    - **Underground, shielding against external radiation, low radioactive material, good radiopurity**
  - **Low energy threshold, good energy resolution**

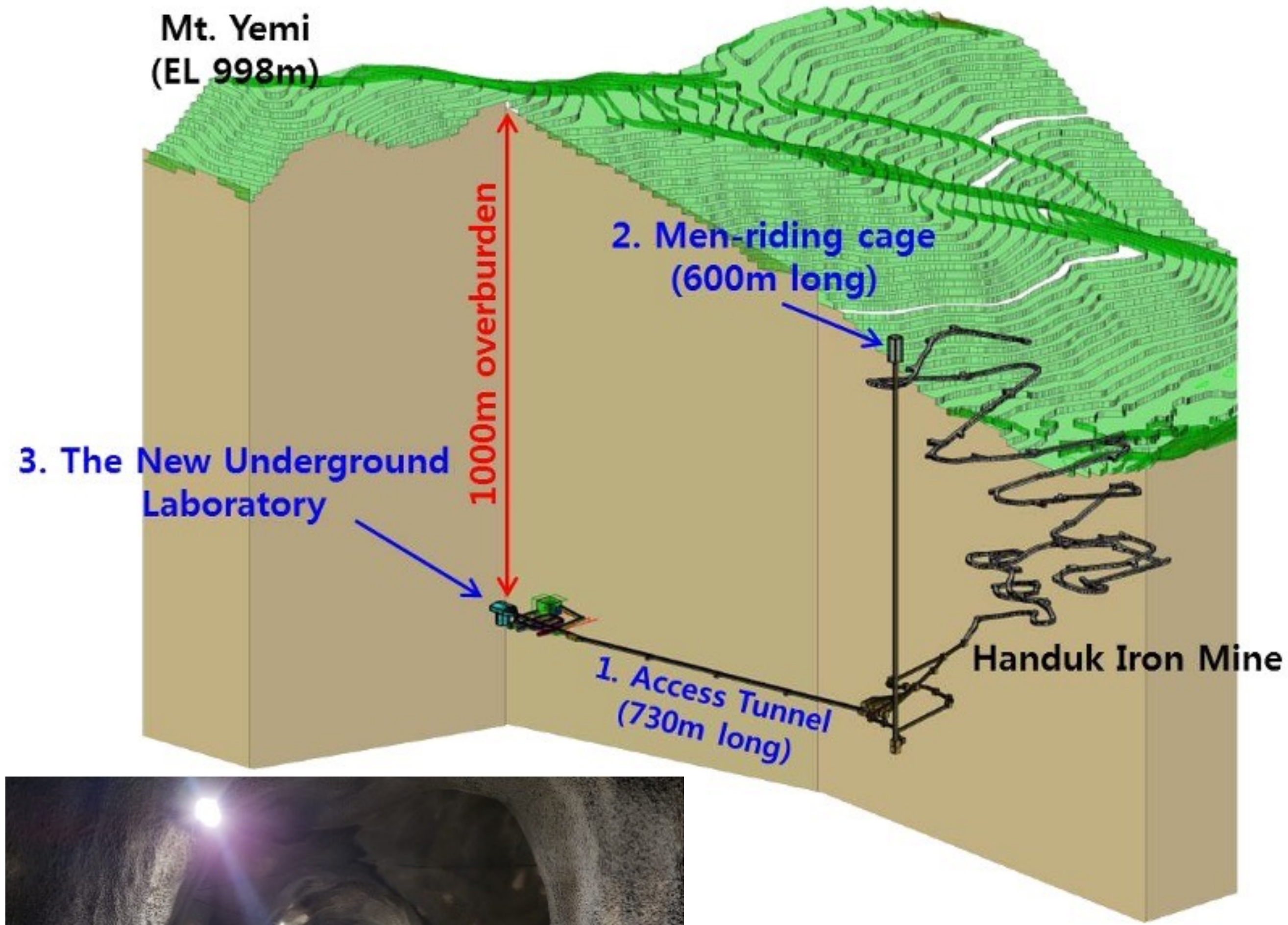
    ➔ low-temperature detector
  - **Topological background discrimination ➔ PSD**

Deep underground laboratories in the world

~ 10^5 reduction

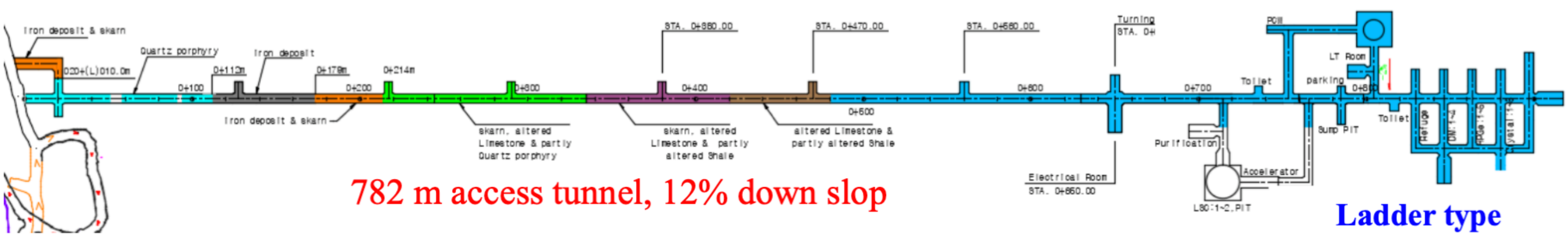


Yemilab: a new underground laboratory



Top view of the Yemilab tunnels

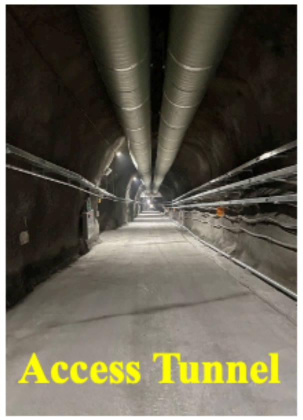
AMoRE Hall

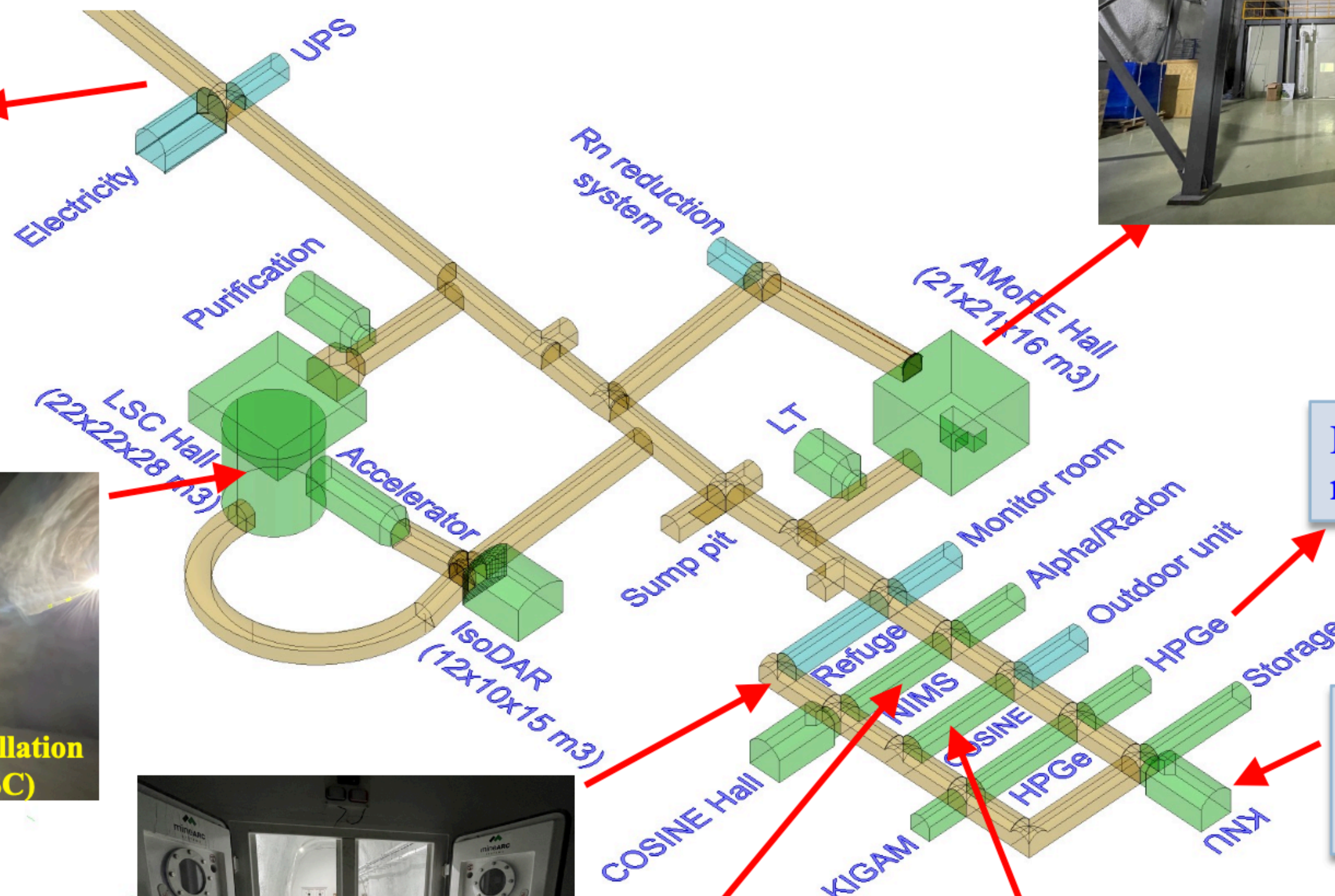


782 m access tunnel, 12% down slop

Ladder type experimental area

Experimental area of Yemilab





KAERI radiation measurement

Kyungpook National University : CPT conservation

IBS Supercomputing facility (https://www.ibs.re.kr/rsc/)

- High-performance computing facility is required to support simulations
- 75% of Aleph is allocated to the center for climate physics, and 25% of it can be used for other research centers like us
- Others are general-purpose computing systems and used for research centers

	Aleph	Olaf	Jepyc	Jepyc-rtx	HQ2	Hqmem
Process type	CPU	CPU/ GPU	CPU/ GPU	CPU/ GPU	CPU	CPU
CPU type	Xeon Scalable 6148	Xeon Gold 6230	EPYC 7401	Xeon Gold 6126	Xeon E5-2690	Xeon E5-2650
Node	472	5	20	1	28	4
Cores	18,880	520	1920	48	712	80
core/ node	40	104	96	48	28/24	20
GPU type		V100	1080Ti	2080Ti		
GPU		40	40	8		
gpu/ node		8	2	8		
Memory	89,856 GB	3840 GB	1280 GB	48 GB	2368 GB	1024 GB
memory/ node	192 GB	768 GB	64 GB	48 GB	64/128 GB	256 GB
Storage and file system	Aleph storage, Olaf storage	Olaf storage				

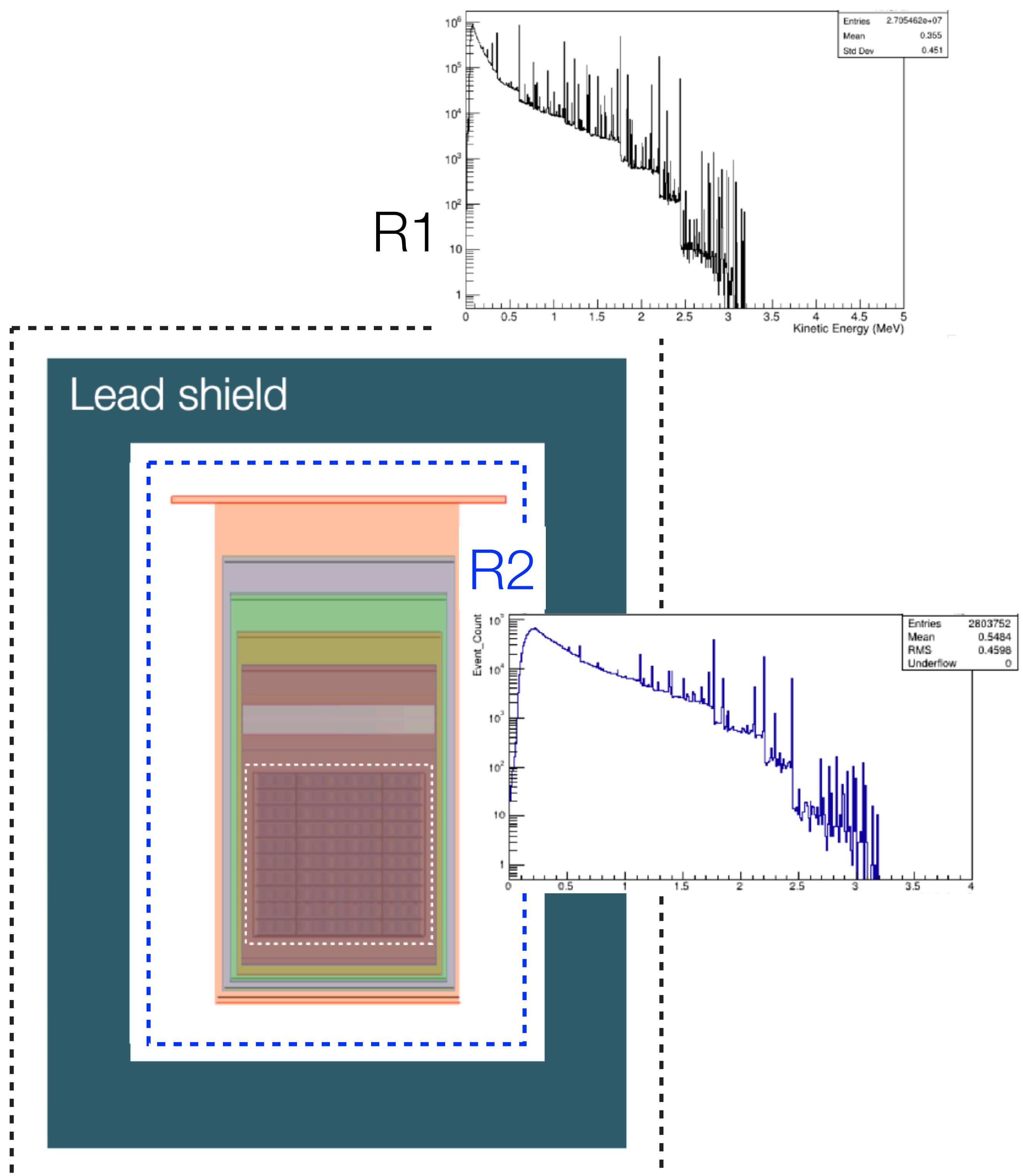
		Olaf storage	Aleph storage
Parallel file sytem	Type	lustre	lustre
	Capacity	2.3 PB	8 PB
Long-term file storage system	Type	SpectraLogic T950	ibm TL4500
	Capacity	4 PB	10 PB
		Aleph, Olaf, Jepyc,HQ2	Aleph

Major concerns in simulating underground physics

- How to estimate ultra-low backgrounds with shielding configuration without consuming a lot of CPU time

Gammas from rock

- Underground rock gamma simulation through thick lead shield layers
  - Using two reference gamma spectra outside and inside the lead shield (R1 and R2), the simulation time for ~3 years of gamma events resulting from the decay of ^{238}U underground rock can **be reduced by ~10^4 times** compared to simulating the ^{238}U decay from within the rock



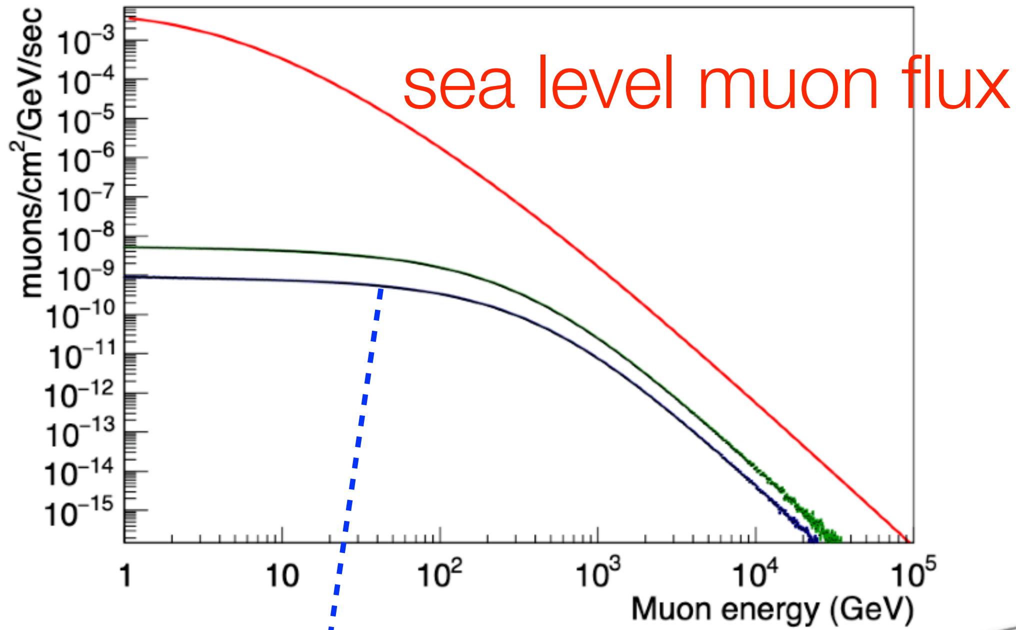
Muon simulation

- Physics lists (+ v4.9.6.p04)
  - QGSP_BERT_HP
  - G4ThermalNeutrons used for neutrons with energies below 20 MeV
- We calculated the underground muon flux by parameterizing the average energy loss of a muon traveling a distance X through a mountain, assuming standard rock density

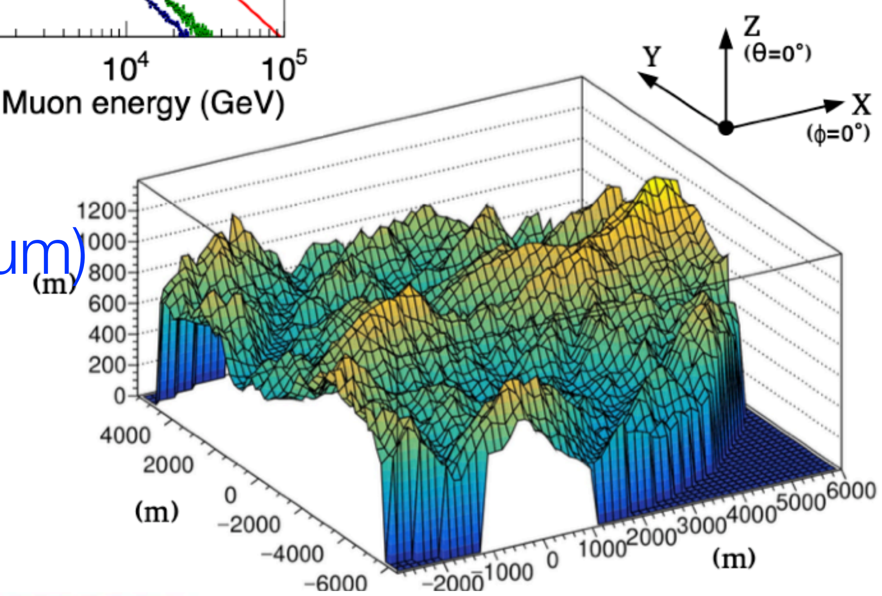
  ➔ This method is efficient and saves CPU time

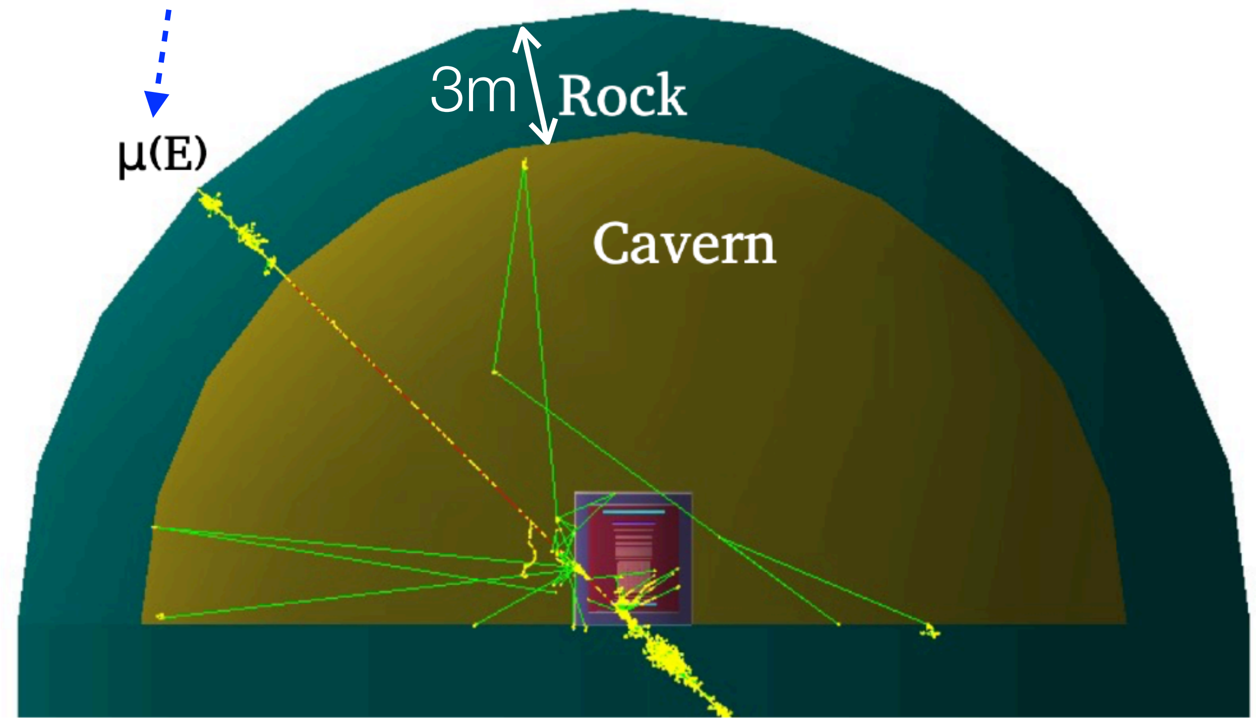
  ➔ But, for accurate muon spectrum underground, simulation of muon interaction with rock is needed: we plan to simulate it and compare the results with MUSIC
- We used the underground muon spectrum to simulate muon events passing through a 3m-thick rock shell and recorded the resulting primary and secondary particles generated by the interaction with the rock

  ➔ We plan to compare it with FLUKA



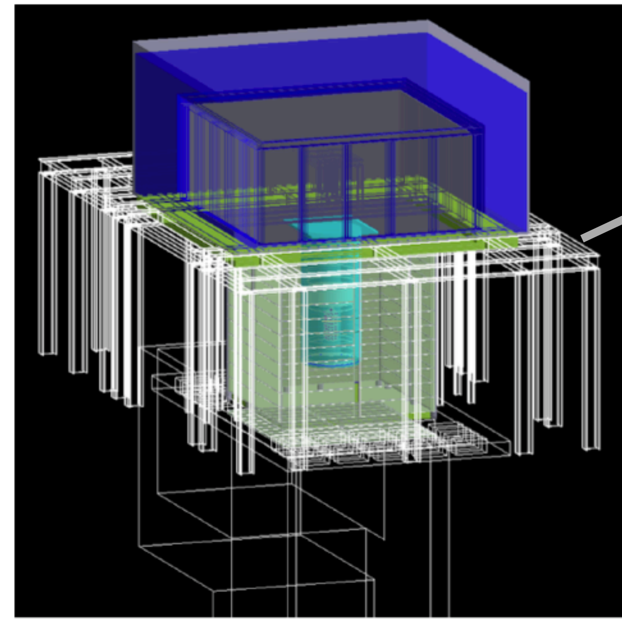
+Yemi mountain contour
(underground muon spectrum)





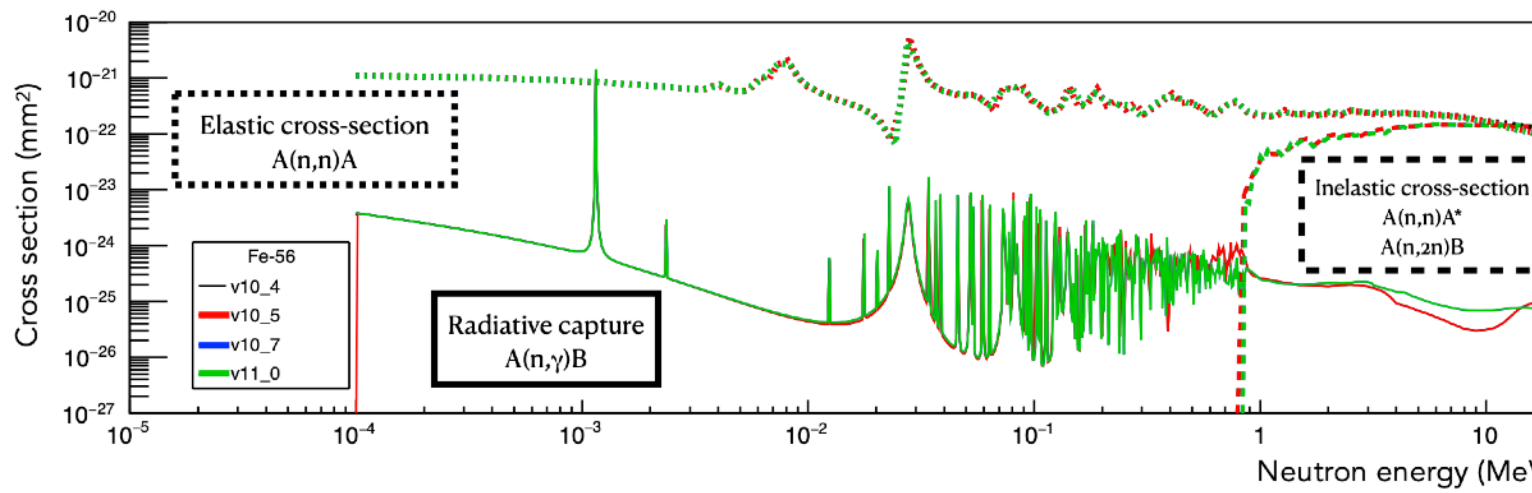
Neutron simulation

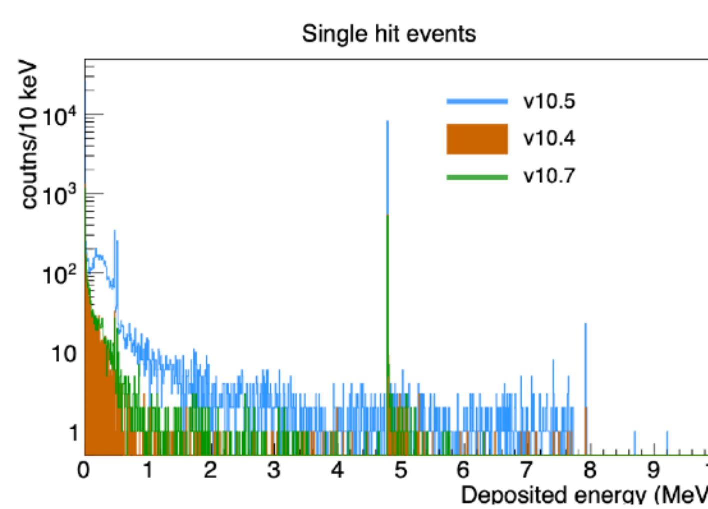
- We simulated underground environmental neutrons and compared results for different genat4 versions
  - v10.4 ➔ 10.5, 10.7, and 11.0
  - G4NDL(+ thermal neutron) data sets were changed
  - G4PARTICLEXS replaced G4NEUTRONXS of 10.5
- (n,γ) process was not correctly simulated in v10.5, but seems to be Okay in the higher versions as well as 10.4

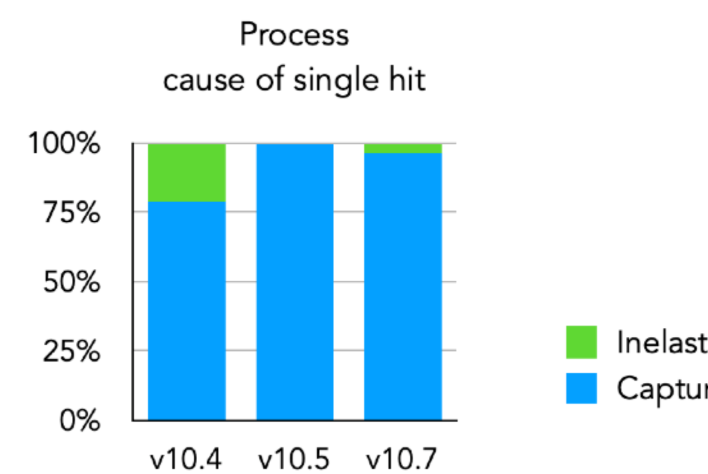


- ~33 tons of steel-wise materials were used for a detector structure frame

➔ γ-rays from the thermal neutron capture by the (n,γ) process in steel-wise materials and copper shields contribute backgrounds in ROI







Summary & Plans

- We have simulated cosmic muons and neutrons/gammas underground in an efficient way that speeds up the simulation time
  - We will compare them with MUSIC/FLUKA
- We are planning a photon simulation for a large scintillation counter of a few kilotons
  - We will be testing GPU-based simulation to increase its speed by using a package of Opticks
- We are also interested in phonon simulation and planning to try applying G4CMP
- We are also interested in lowering the energy threshold below the keV region for rare events search - we need Geant4 simulation of low energy backgrounds