DEASA array: A simulation study of the secondary particles in air shower using CORSIKA code

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CORSIKA 8 workshop, 11 july -15 july 2022, MPI for Nuclear Physics in Heidelberg.
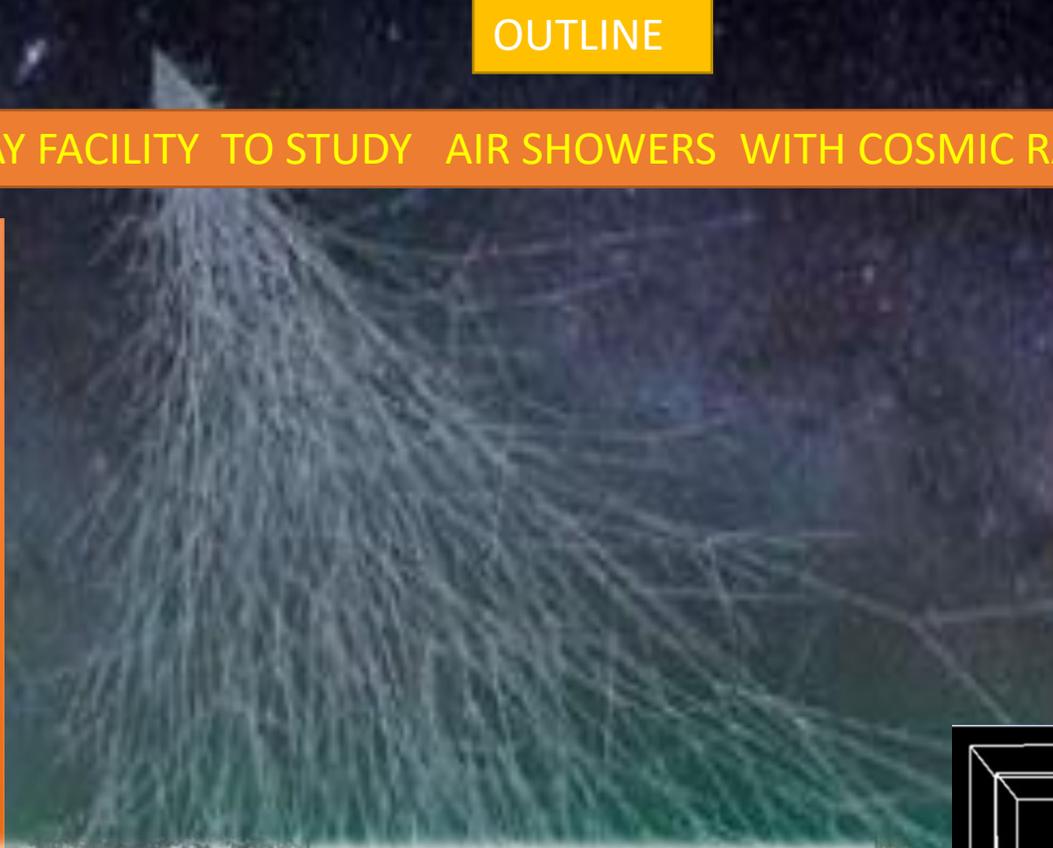
STUDENTS
Ph.D.'s awarded : 02
PhD's enrolled : 01
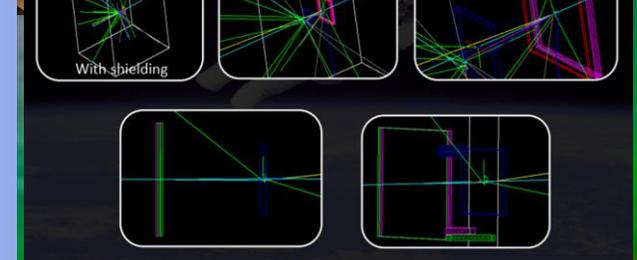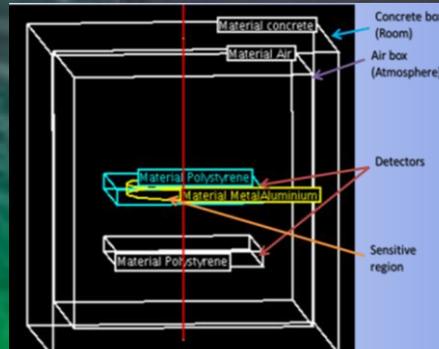M.Phil.'s : 05
M.Sc. : 19
UGRA : 06
Internship : 04

DEASA: ARRAY FACILITY TO STUDY AIR SHOWERS WITH COSMIC RAY LAB., OOTY

OBJECTIVES OF DEASA:

1. Shower rates based on different triggers: 4-fold,8 fold.
2. Shower rate variations with atmospheric pressure and temperature .
3. MC based studies in Geant4 and CORSIKA :
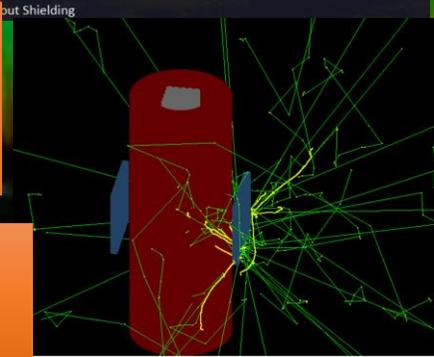
- SPACE PHYSICS.
- HADRONTHERAPY.
- MUON TOMOGRAPHY.

DAQ

DAQ PC

Detectors

SPACE PHYSICS: the shielding from GCRs.

With shielding

out Shielding

HADRON THERAPY: dose deposition in Bragg peak for different organs in phantoms.

MUON TOMOGRAPHY: study muon scanning of radioactive containers.

Dayalbagh Educational Air Shower Array

- 171 m above sea level
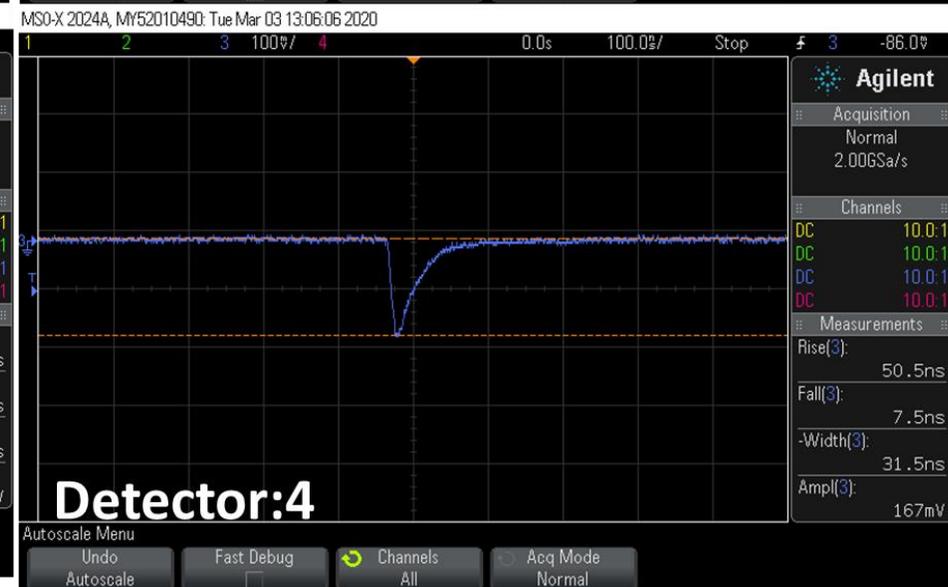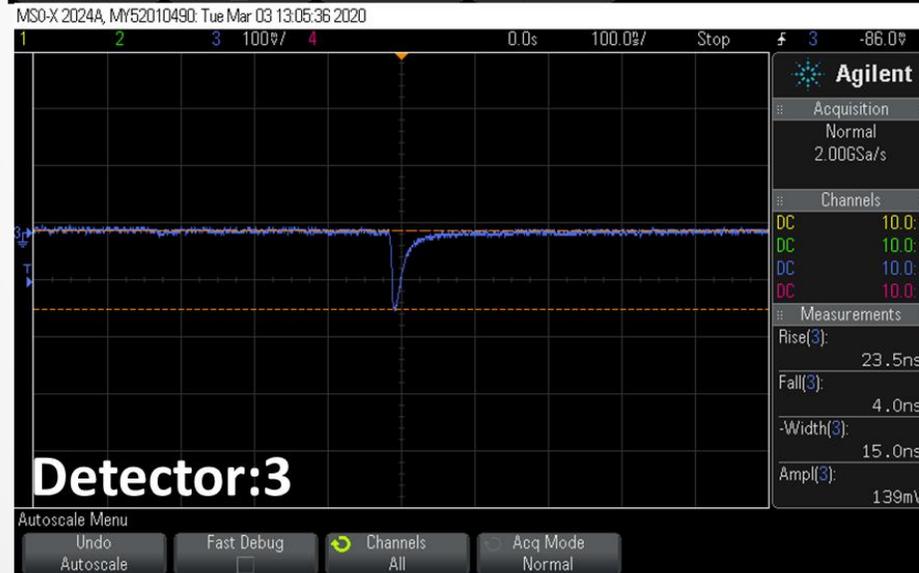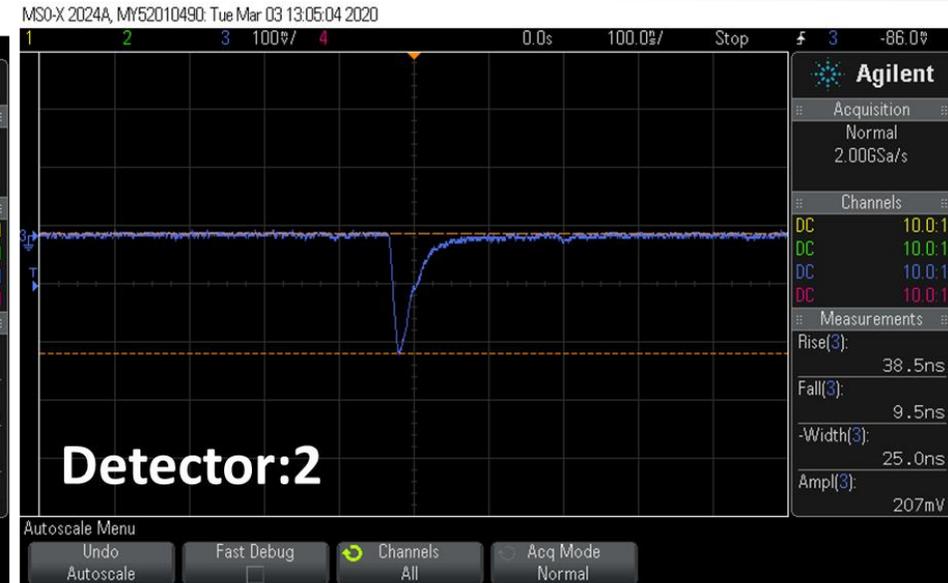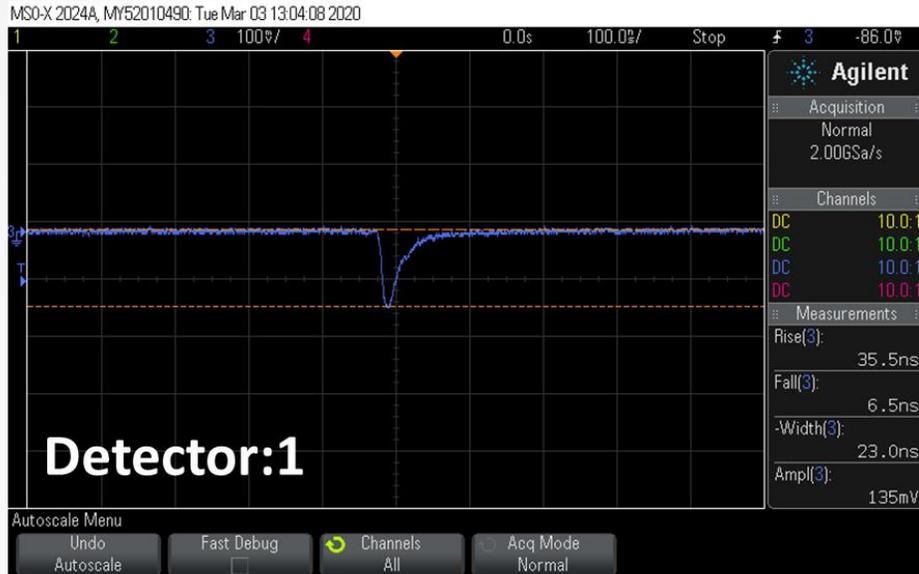- Area of DEASA is 260 m^2.
- 100x 100 cm^2 and 2 cm thick.

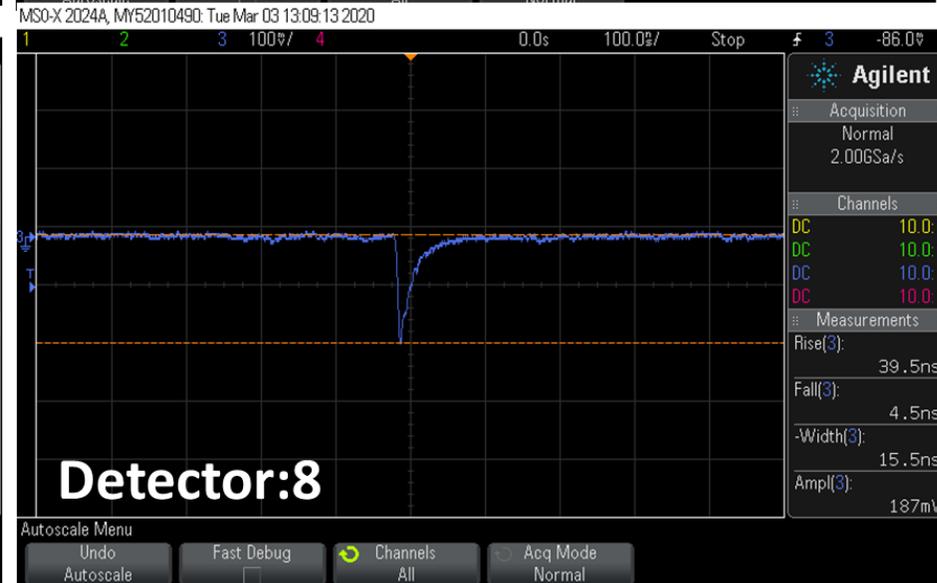# OBJECTIVES

SHOWER ATTRIBUTES
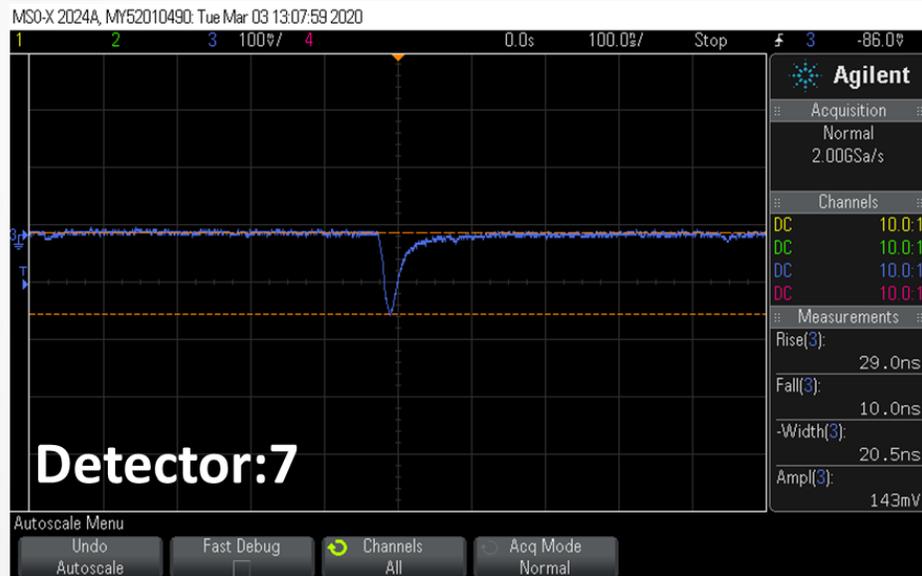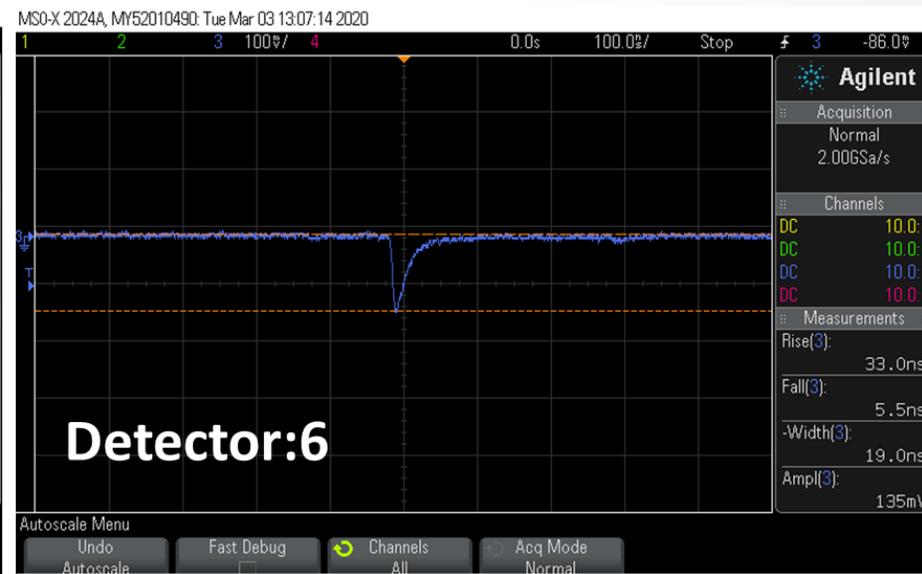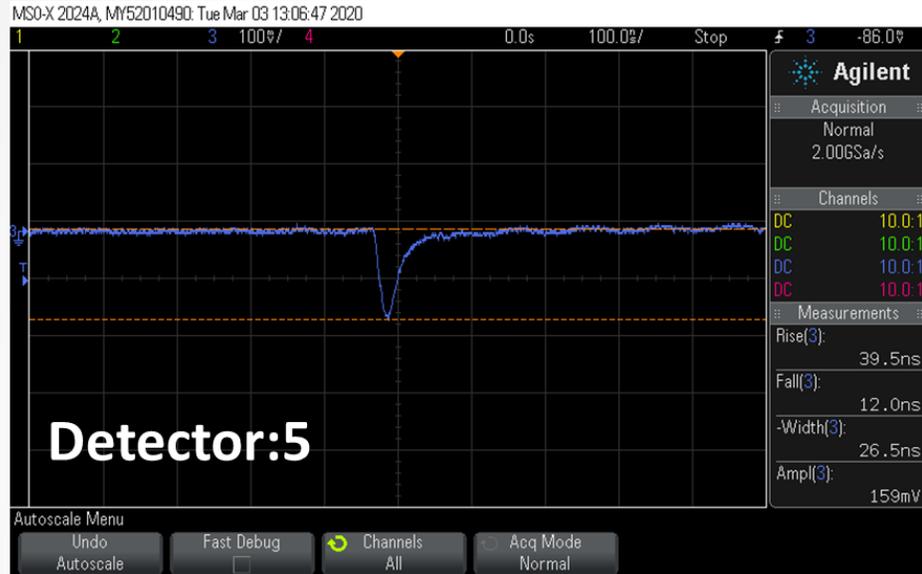
- BASED ON MACHINE LEARNING
- NEURAL NETWORK

SHOWER RATES

- TRIGGER BASED 3,4 -FOLD
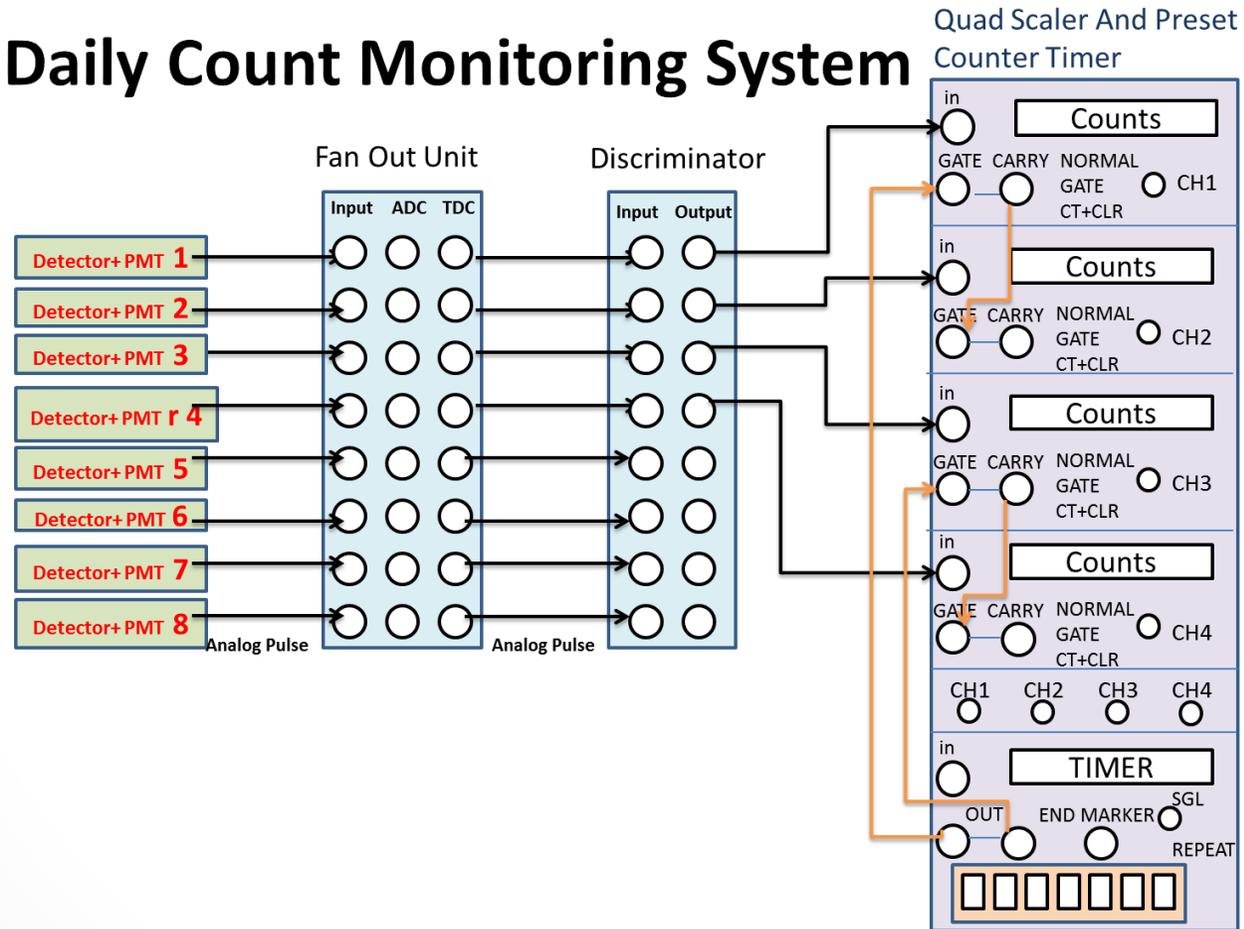- TRIGGER BASED 8-FOLD

Pulses from the PMT

Pulses from the PMT

Electronic circuit
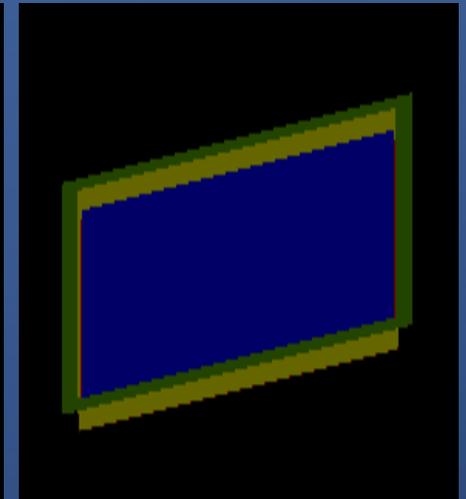

Daily Count Monitoring System

DEASA (during construction)

```cpp
//G4Material* shape3_mat = nist->FindOrBuildMaterial("G4_Al");
G4ThreeVector pos8 = G4ThreeVector(53.84*cm,0*cm,5.08 *cm);

   //detector shape
 G4double shape8_dx = 2.54*cm;
 G4double shape8_dy =51.3*cm;
 G4double shape8_dz  = 0.1*cm;
 G4Box* solidShape8 =
  new G4Box("Shape8",                          //its name
        1*shape8_dx,
      1*shape8_dy, 1*shape8_dz); //its size

 G4LogicalVolume* logicShape8 =
  new G4LogicalVolume(solidShape8,            //its solid
                shape3_mat,                //its material
            "Shape8");              //its name

 new G4PVPlacement(0,                          //no rotation
             pos8,                       //at position
          logicShape8,                  //its logical volume
       "Shape8",                    //its name
        logicWorld,                  //its mother  volume
      false,                     //no boolean operation
    0,                       //copy number
         checkOverlaps);          //overlaps checking
```

Bethe Block Equation

$$-\frac{dE}{dX} = \xi \left\{ \ln\left(\frac{2m_e C^2 \beta^2 \gamma^2}{I}\right) + \ln\left(\frac{\xi}{I}\right) + 0.2 - \beta^2 - \delta(\beta\gamma) \right\}$$

$$\xi = 2\Pi N_A r_e^2 m_e c^2 z^2 \frac{z}{a} \frac{1}{\beta^2} x\rho$$

$2\pi N_A r_e^2 m_e c^2 = 0.1535$ MeVcm^2/g
Where,
$N_A = 6.02 * 10^{23}$
I = mean excitation potential
Z = atomic number of absorbing material
A = atomic mass of absorbing material

Muon and electron is set to as primary in primary generator action.cc class of example B1, energy deposition in one detector for both has been compared by analytically (Bethe Bloch fomula) and by simulation

Analytical results for muon

Analytical results for electron

simulation results for muon

simulation results for electron

CORSIKA: A monte carlo code to simulate extensive air shower

provided by CERN
Used in KASKADE experiment

General program frame handling input, output performing decay of unstable particles and tracking of particles

Hadronic interaction of nuclei with air nuclei at lower energy

COsmic Ray SImulation for KAscade Experiment

Hadronic interaction of nuclei with air nuclei at higher energy

Describes transport and interaction of electron-photon cascade

Input variables

mu$^+$/mu$^-$ Ratio (R)

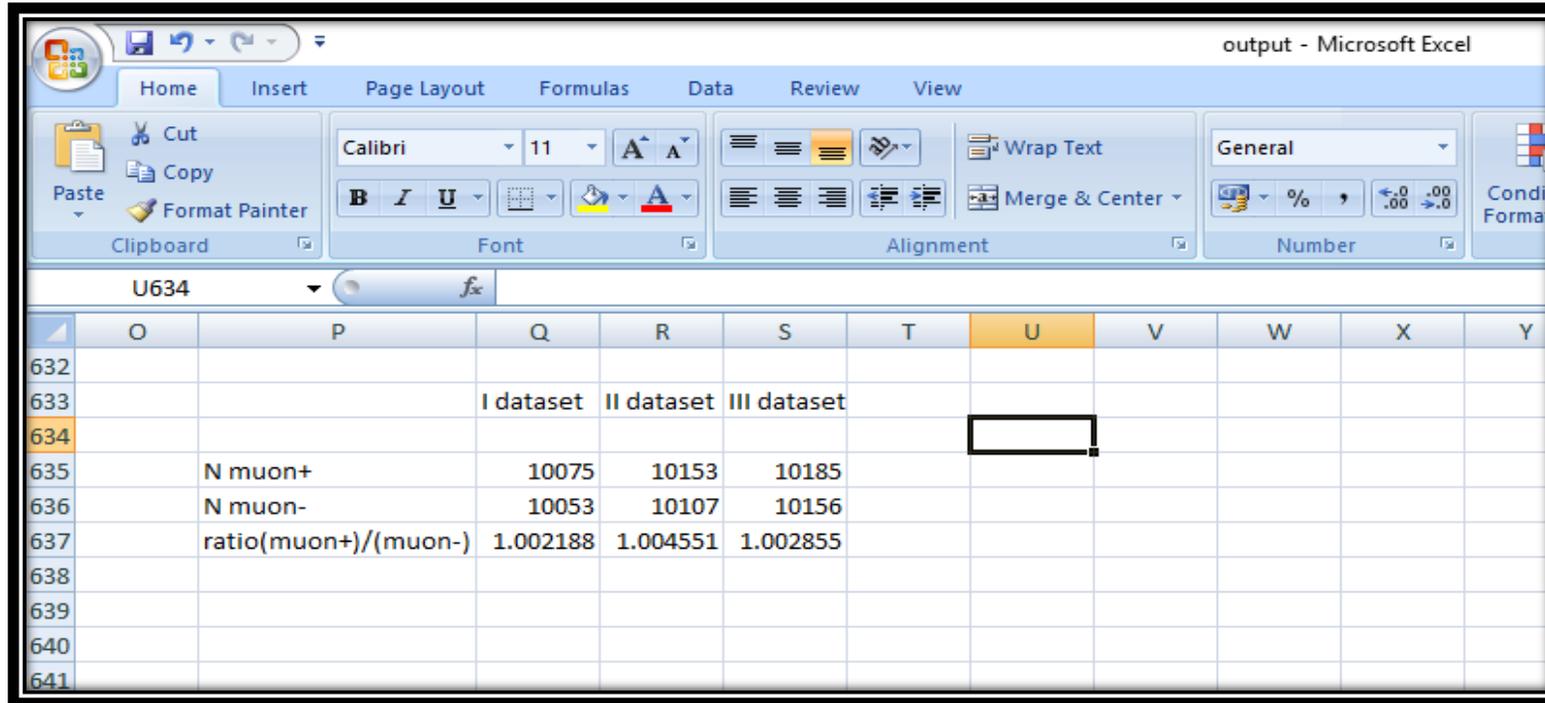|	O	P	Q	R	S	T	U	V	W	X	Y
632											
633			I dataset	II dataset	III dataset						
634											
635		N muon+	10075	10153	10185						
636		N muon-	10053	10107	10156						
637		ratio(muon+)/(muon-)	1.002188	1.004551	1.002855						
638											
639											
640											
641											

❖Output comes in the form of text file which consist the longitudinal parameters as a function of atmospheric depth.
❖With the help of excel spreadsheet , the muon charge ratio as a function of atmospheric depth (g/cm^2) has been determined.
❖For 10^{13-15} ev , simulation is performed.

Number	Energy		
	10^{13} eV	10^{14} eV	10^{15} eV
Number of positive muons	10075	10153	10185
Number of negative muons	10053	10107	10156
Muon charge ratio	1.0021	1.0045	1.0028

Plots for primary particle (proton) having different energies

Space Mission

❑ Space radiation may place the crew at significant risk for radiation sickness, and increased lifetime risk for cancer, central nervous system effects, and degenerative diseases.

❑ Astronauts are exposed to ionizing radiation with effective doses in the range from 50 to 2000 mSv (milli-Sievert).

❑ Although the type of radiation is different, 1 mSv is equivalent to about 3 chest x-rays.

❑ Shielding was studied against GCR (penetrating protons and heavy nuclei), and SEPs (largely medium energy protons).

Radiation in Space

Hierarchy System in Geant4

Initialization in Present simulation

Event Processing in Present simulation

Simulation

With shielding

Without Shielding

Materials for shielding

Aluminium

Polyethylene

Polystyrene

Water

Energy of primary reaching phantom

Intensity

Energy of primaries reaching the phantom
Entries 346
Mean 774.2
RMS 14.36

Al

Energy of primaries reaching the phantom
Entries 382
Mean 781.7
RMS 19.55

Polyethylene

Energy of primaries reaching the phantom
Entries 375
Mean 788
RMS 19.09

Polystyrene

Energy of primaries reaching the phantom
Entries 371
Mean 801.8
RMS 11.12

Water

Energy of primaries reaching the phantom
Entries 990
Mean 995
RMS 0.3177

No Shield

Energy(MeV)

Secondary particles reaching phantom

Intensity

secondary particles reaching the phantom

	300
Entries	1582
Mean	5
RMS	0

Al

secondary particles reaching the phantom

	300
Entries	1959
Mean	5
RMS	0

Polyethylene

secondary particles reaching the phantom

	300
Entries	1899
Mean	5
RMS	0

Polystyrene

secondary particles reaching the phantom

	300
Entries	1854
Mean	5
RMS	0

Water

secondary particles reaching the phantom

	300
Entries	15
Mean	5
RMS	0

No Shield

Energy (MeV)

Results

Result	Al	Polyethylene	Polystyrene	Water	No Shielding
Initial energy in shielding	981(MeV), 352(Counts)	991(MeV), 386(Counts)	991(MeV), 379(Counts)	1004(MeV), 375(Counts)	995(MeV), 1007(Counts)
Energy of primary reaching Phantom	762(MeV), 184(Counts)	774(MeV), 197(Counts)	789(MeV), 227(Counts)	796(MeV), 237(Counts)	970(MeV), 999(Counts)
Secondary particles reaching phantom	1572(Counts)	1955(Counts)	1902(Counts)	1858(Counts)	14(Counts)

Galactic Cosmic Energy Spectrum Based Simulation of Total Equivalent Dose in Human Phantom, *Springer International Publishing AG* part of Springer Nature, (2018)

Dose deposition

- **Equivalent dose** :

$$H = QD$$

Here Q = Quality factor, D = absorbed Dose, Q = 10 (for proton).

- **Absorbed dose** :

$$D = \frac{\int_0^\infty f(E)dE}{\rho V}$$

Here ρ is detector density, V is the volume and f(E) is energy distribution function.

Shielding dimensions: 1500*1500*50 cm³	Shielding Material	Density (g/cm3)	Expected dose (Sv)	Calculated dose (sV)
	Al	2.7 g/cm3	130	140
	Polyethylene	0.94	113	117
	Polystyrene	1.04	--	107
	Water	1	--	113

Conclusion

Al is found to be poor shielding material when dose equivalent is concern

With Polyethylene and polystyrene shielding, max no. of secondary produced

Material with high 'H' and low 'Z' content are most efficient in protecting the astronauts.

With Polyethylene, Polystyrene is also examined as potentially useful material & demonstrate important advantages as an alternative to Al

Muon Tomography

- Millions of cargo container enters in India every year but among these containers not even 5% are examined which leads to a risk for the presence of very harmful and dangerous materials being supplied into the country. A need to think about a method by which these containers can be checked without affecting the human life.

- India is increasing its nuclear power plants every year, and this implies a large environmental compliance for these nuclear plants. The nuclear waste from these power plants includes physical, chemical and radioactive characteristics, which requires different approaches to treat them.

- There are certain ways to treat them in a right manner, depends upon the type of nuclear waste.

Muon energy loss, radiation length and scattering angle

- In muon tomography, the muon is used to create a 3D image of the container by passing the muon from the container and detected it before and after it travels through.
- With the help of the tracks of muons, a 3D image is produced that leads us to estimate the material contained inside the container.
- These containers are also need to be observed with the time to estimating the amount of radiation present in it.
- The aim for this study is to apply the method to confirm the presence of any harmful radioactive material without getting affected by it.
- **The analytical results have been given to explain the energy loss and multiple scattering of the muon for different energy.**
- **Radiation length of muon has also been calculated for different type of materials.**

Simulation of cask

Energy (GeV) Energy loss and scattering angle for concrete:

Energy Loss (MeV/c)   σθ (mrad)

Material	Calculated value		Reference value (C. Jewett, 2011)			
	Energy Loss (MeV)	Radiation length (cm)	σθ (mrad)	Energy Loss (MeV)	Radiation length (cm)	σθ (mrad)
			3.65			3.13
Concrete	3.636	10.91	4.17	4.46	11.55	4.06
			4.17			2.09
Iron	13.65	1.52	10.44	14.22	1.76	11.1
			4.68			1.56
Lead	17.98	0.43	18.07	18.55	0.56	20.5
Uranium	27.56	0.21	23.75	28.9	0.32	27.9
			5.01			1.25

Conclusion

- Partially loaded container would give a smaller scattering angle and a fully loaded cask will give the larger scattering angle .

- The nuclear waste is hard to identify and it's not possible to look for all possible scenarios to identify the nuclear waste. Muon tomography has come out to be the best solution for characterizing the nuclear waste.

- We have given an example to show the use and identify the amount of waste.

THANK YOU

Collaborations

Nuclear Electronics Laboratory

Outreach:
Winter Camp, Summer Workshops

Outcomes:
Muon Telescope and Data Acquisition System

DEASA:
(DAYALBAGH Extensive Air Shower Array)

Visitors

Sunil Gupta, Sr. Professor & Head, ,C.R.L., GRAPES-3, Ooty, 2014

Professor Amanda Cooper-Sarkar, Professor of Particle Physics, University of Oxford, Jan 2018

Dr R.C.Verma (CV) Professor Emeritus, Dept. of Physics, Panjab University, Chandigarh, Jan 2017

Atul jain, Scientific OfficerC.R.L., GRAPES-3 Ooty, 2014

Dr. Ambar Chatterjee Former Head, Nuclear Physics Division(Retd.),
Er. Santhi R Ruby, IUAC, New Delhi, Dec 2018