Study of ultra-low level gamma radiation/radioactivity (inside an UGL) and its consequences

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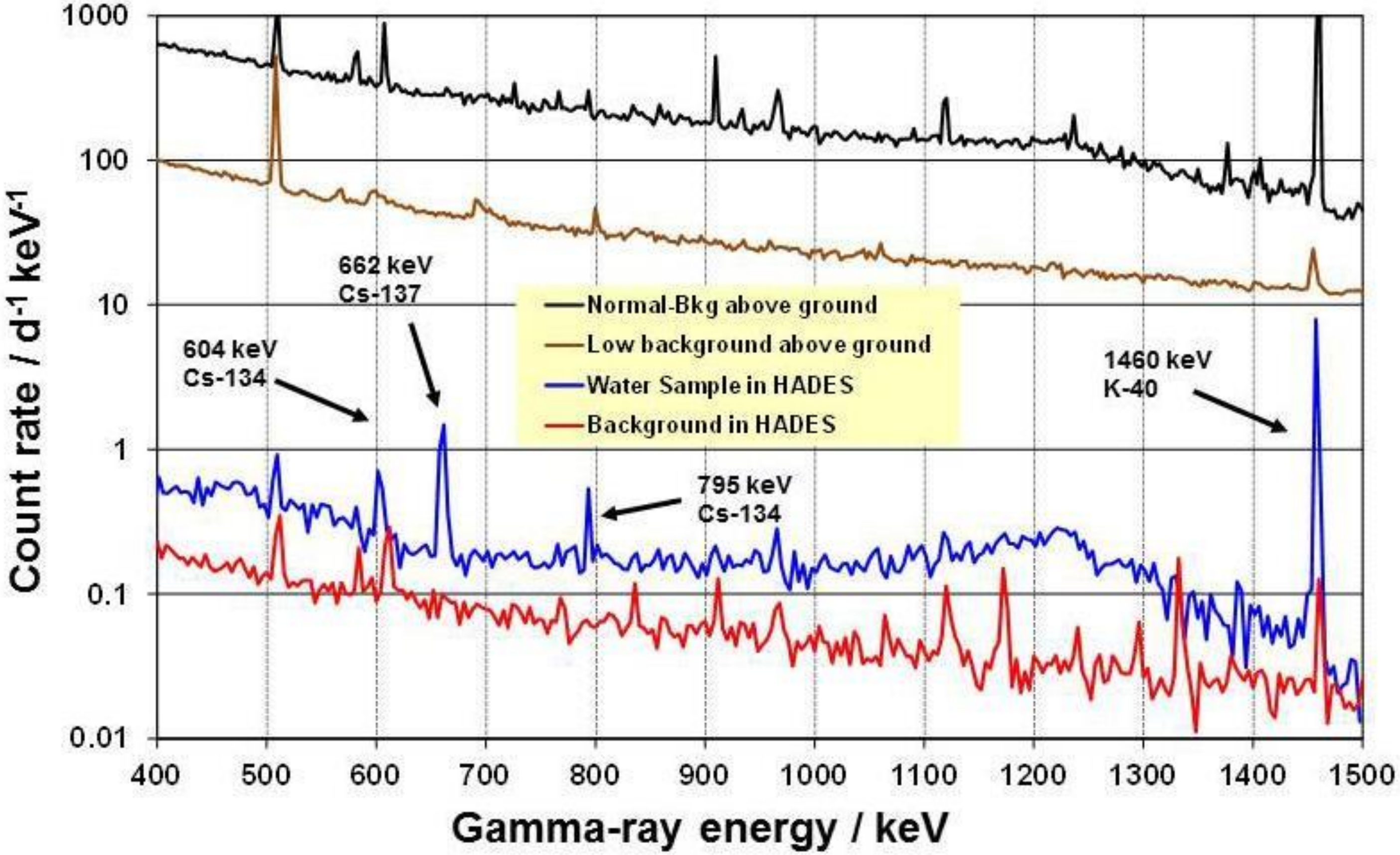
Background for gamma ray spectroscopy

- In the deep underground the secondary cosmic ray flux is significantly lower compare to that on the Earth surface.

- Theoretically it is possible to measure ultra-low level gamma radiation/radioactivity inside a laboratory underground.

- Joint Research Centre (JRC) under European Commission operates a laboratory for ultralow-level radioactivity measurements inside the 225 m deep underground laboratory HADES, located at the premises of the Belgian Nuclear Research Centre (Belgium).



1000
100
10
1
0.1
0.01
Count rate / d-1 keV-1
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Gamma-ray energy / keV
662 keV
Cs-137
604 keV
Cs-134
795 keV
Cs-134
1460 keV
K-40
Normal-Bkg above ground
Low background above ground
Water Sample in HADES
Background in HADES

Challenges

- All materials contain traces of radioactive nuclides.

- To bring down the intrinsic background of the detector set-up.

- To achieve low level background shielding materials have to be purer.
  - Old lead bricks (^{210}Pb has a half life of 22 years), fresh copper for shielding.

- Ultra-Low Background (ULB) Coaxial High purity Ge detectors. ULB HPGe detectors can reach sensitivities on the order of 10 – 100 µBq /kg (*1 becquerel = 1 radioactive decay per second = 2.703x10^{-11} Ci.*)

Science goals

- Non-linear processes (vacuum polarization effects) of QED
- Geological studies of Radon activity
- Radioactive waste management
- Rare nuclear/particle decays
- Effects of radiations on living cells and their mutations

Studies of non-linear processes of Quantum Electrodynamics

- *QED* admits nonlinear processes like scattering of photons by photons

- The root of the non-classical nonlinear effects in *QED* is vacuum polarization, a consequence of *QED*

- Non-linear processes - Scattering of light by light, Delbruck scattering, photon splitting, Coalescence of photons, Multiphoton Compton scattering, Unruh effect etc.

ARTICLES
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nature physics
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Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC

ATLAS Collaboration†

Light-by-light scattering ($\gamma\gamma \rightarrow \gamma\gamma$) is a quantum-mechanical process that is forbidden in the classical theory of electrodynamics. This reaction is accessible at the Large Hadron Collider thanks to the large electromagnetic field strengths generated by ultra-relativistic colliding lead ions. Using 480 μb^{-1} of lead–lead collision data recorded at a centre-of-mass energy per nucleon pair of 5.02 TeV by the ATLAS detector, here we report evidence for light-by-light scattering. A total of 13 candidate events were observed with an expected background of 2.6 ± 0.7 events. After background subtraction and analysis corrections, the fiducial cross-section of the process $Pb + Pb (\gamma\gamma) \rightarrow Pb^{(*)} + Pb^{(*)}\gamma\gamma$, for photon transverse energy $E_T > 3$ GeV, photon absolute pseudorapidity $|\eta| < 2.4$, diphoton invariant mass greater than 6 GeV, diphoton transverse momentum lower than 2 GeV and diphoton acoplanarity below 0.01, is measured to be 70 ± 24 (stat.) ±17 (syst.) nb, which is in agreement with the standard model predictions.

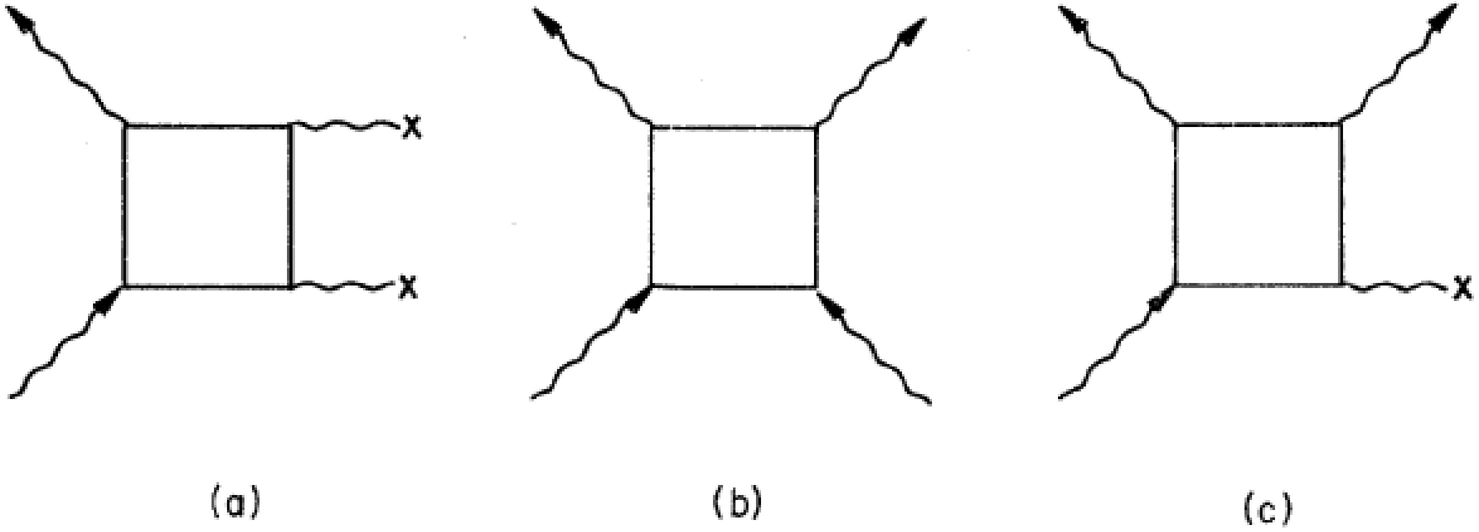


FIG. 1. Feynman diagrams for (a) Delbrück scattering, (b) the scattering of light by light, and (c) the photon-splitting process.

- NSF sponsored project (2003?)
- Award # 9631330 - U.S.-India Collaborative Research: Elastic Scattering and Pair Production of 1.115 MeV photons
  - Delbruck contribution in the elastic scattering of 1.115-MeV photons, PRA 71, 032724, 2005,
  - Delbruck scattering of 1.115 MeV photons, Rad Phys. and Chem. 75, 2252-2257, 2006
  - Examining the scaling behavior of Delbruck scattering in experimental data, Phys. Rev. C **84**, 034614 (2011)
  - Astrophysical applications of Delbr¨uck scattering:Dust scattered gamma radiation from gamma ray bursts, Radiation Physics and Chemistry 95 (2014) 326–328

- Prof. Indranil Mazumdar (TIFR)

Geological Study on Radon activity

- Lung cancer is one of the commonest cancers and cause of cancer related deaths all over the world. It accounts for 13 (6.9) per cent of all new cancer cases and 19 (9.3) per cent of cancer related deaths worldwide (India). (Indian J Med Res 141, January 2015, pp 5-7, Editorial)

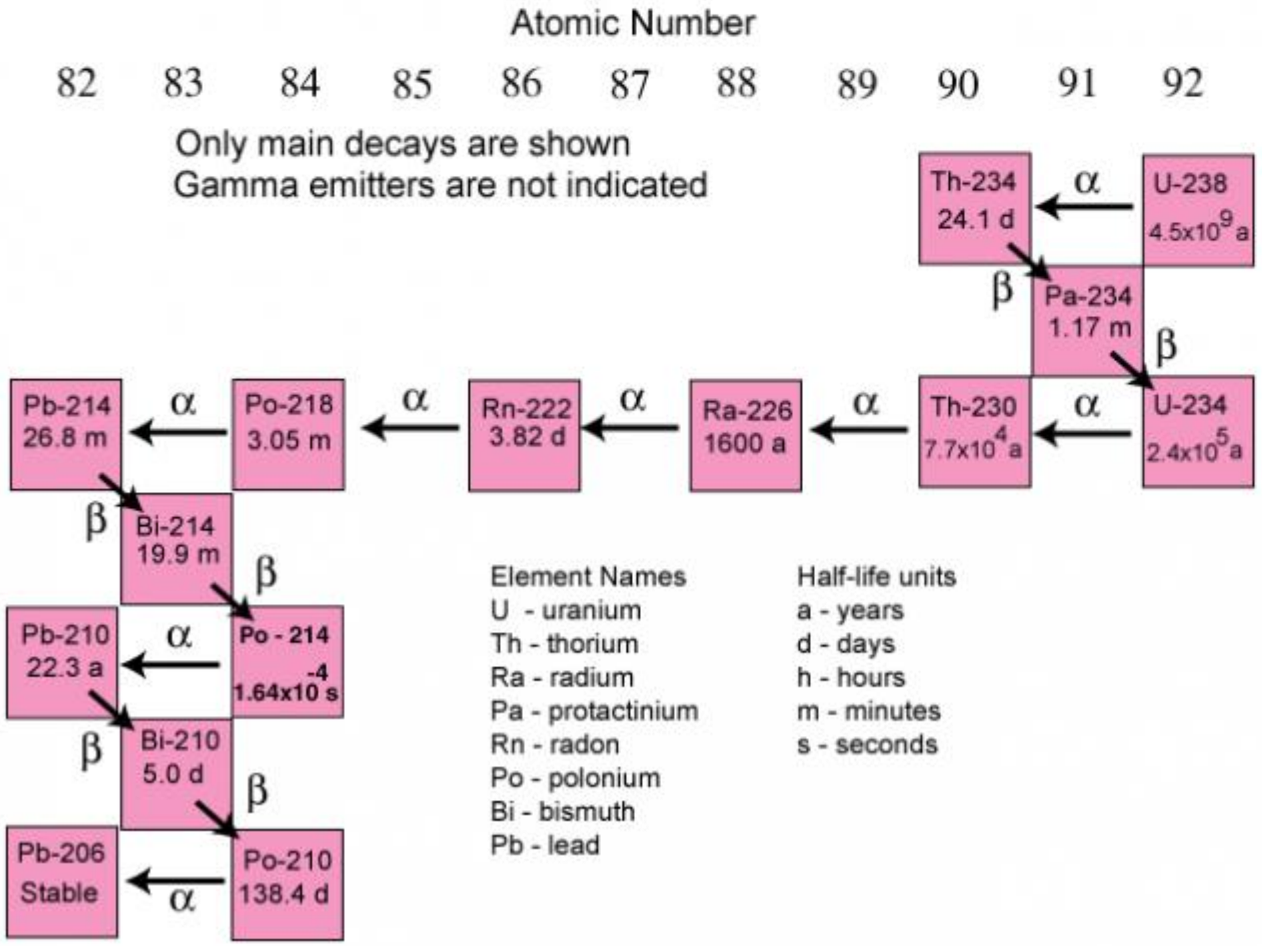
- The time trends of lung cancer show a significant rise in Delhi, Chennai and Bengaluru in both sexes.

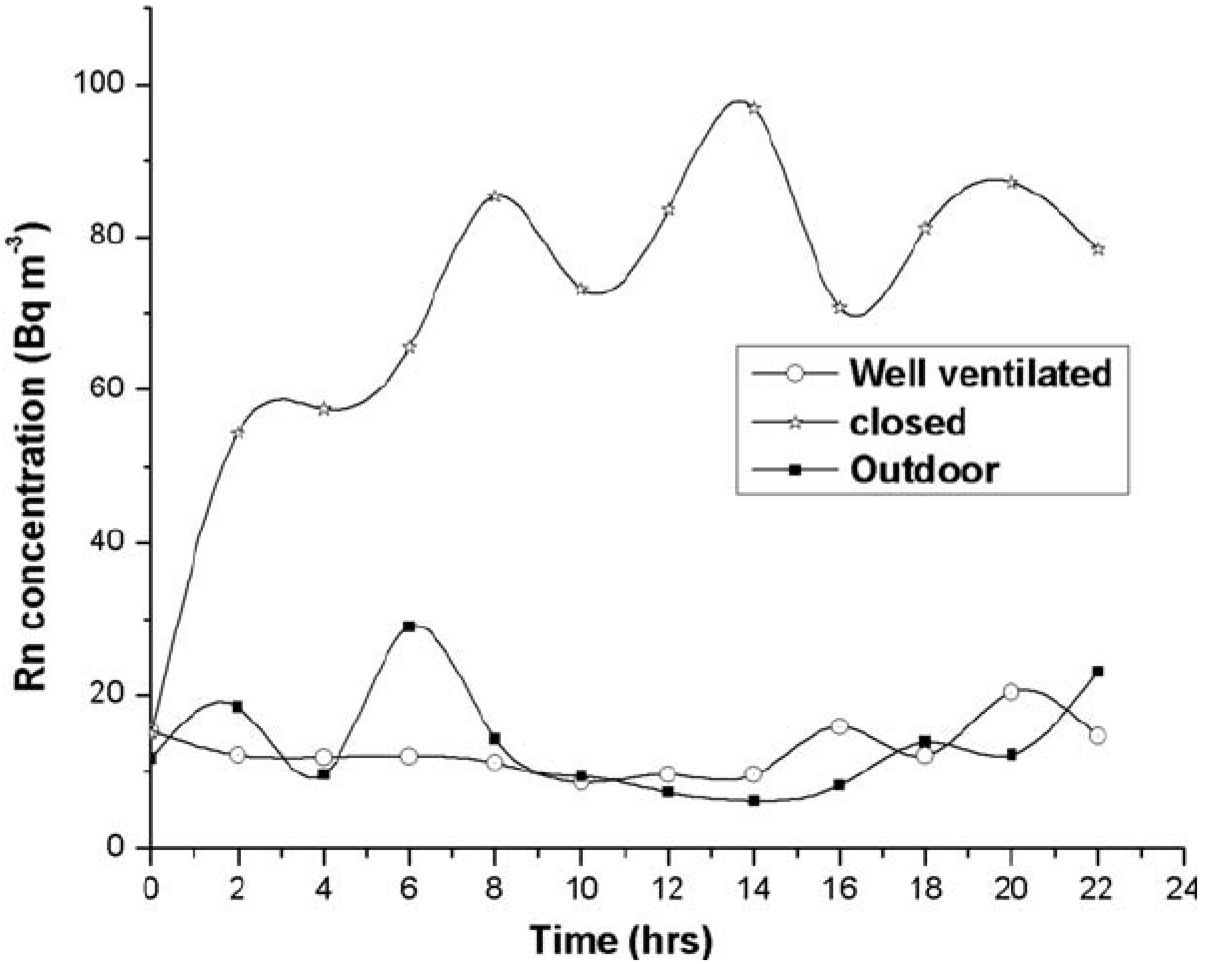
- Radon is the number one cause of lung cancer among non-smokers.

Radon

- It is a radioactive gas arising from the uranium (^{238}U) decay series
- a colorless, odorless, and tasteless, not detectable by human senses alone.
- Where did uranium come from?
    - The Earth's uranium had been thought to be produced in one or more supernovae over 6 billion years ago. Some uranium may be formed in the merger of neutron stars.
    - Later, Uranium became enriched in the continental crust.

The Uranium-238 Decay Chain





There is no known safe level of exposure to radon

EPA (US) recommends homes be fixed if the radon level is 150 Bq/m^3 or more.,

SCIENTIFIC REPORTS
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Radon exposure is rising steadily within the modern North American residential environment, and is increasingly uniform across seasons

Fintan K. T. Stanley[1], Jesse L. Irvine[1], Weston R. Jacques[1], Shilpa R. Salgia[1], Daniel G. Innes[2], Brandy D. Winquist[3], David Torr[4], Darren R. Brenner[5] & Aaron A. Goodarzi[1*]

Human-made buildings can artificially concentrate radioactive radon gas of geologic origin, exposing occupants to harmful alpha particle radiation emissions that damage DNA and increase lung cancer risk. We examined how North American residential radon exposure varies by modern environmental design, occupant behaviour and season. 11,727 residential buildings were radon-tested using multiple

Radioactive waste management.

- Characterizing very low level radioactive waste
- High-level and intermediate-level radioactive waste
  - High-level radioactive waste can remain radioactive from thousands to hundreds of thousands of years. The internationally accepted solution for its safe and secure long term management is geological disposal in a facility several hundred meters underground.

  - Monitoring from different depth level, characterizing rocks etc.

Exploring for rare nuclear decays.

- Low background offers to observe rare nuclear decay processes not visible on the Earth surface based laboratories.

- The background spectrum in deep underground itself can be interesting

- Passive (low cost) solid-state nuclear track detectors (transparent sheet of overhead projector) may be installed to search for rare decays

Understanding the effects of radiations on living cells and their mutations etc.

- All living organisms are daily exposed to radiation.
- Ionizing radiation can affect cells through direct and indirect action, causing DNA damage as well as mutations.
- The effects of high radiation as a biological extreme have historically been, and continue to be, extensively researched in the fields of radiation biology and astrobiology (Frontiers: doi: 10.3389/fspas.2020.00050)
- High doses of ionizing radiation produce clinically detectable harm in an exposed individual (for instance Prise et al Radiat. Res. 156, 572–576 (2001).

- the absence of radiation as an extreme has received relatively limited attention
- its effects on life remaining unclear

- The currently accepted model of the radiation dose-damage relationship for organisms is the linear no-threshold (LNT) model
    - a positive linear correlation between dose and damage
- Hormesis model -damage at high doses but beneficial stimulation of growth at low doses.
- Experiments to date have not yet been able to conclusively validate or dismiss either of these models.

TABLE 1 | Average annual effective dose of public due to natural background exposure [based on data from UNSCEAR (3)] and BEIR (4).

Source of exposure	World average (mSv)	Typical range (mSv)	Remark
Cosmic radiation	0.39 (0.16%)	0.3–1.0	Depends on altitude, includes cosmogenic radionuclides
External terrestrial radiation	0.48 (0.20%)	0.3–1.0	Depends on soil and building material
Inhalation of air	1.26 (0.52%)	0.2–10	Mainly from radon, depends on indoor accumulation
Ingestion of food and water	0.29 (0.12%)	0.2–1.0	Depends on food and drinking water composition, includes K-40
Total (natural)	2.40	1.0–13	Depends strongly on the geographical site

1 Sv (Sievert) = 1 joule/kg

- The genetic effects of radiation are expressed in their immediate or remote offspring

- The genetic effects of radiation are monitored through the study of certain endpoints
  - visible chromosome abnormalities,
  - proteins with altered conformations,
  - congenital malformations,
  - premature death etc.

- Ionizing radiation could have affected the evolution of life on Earth (Astropart. Phys. 53, 186 (2014)
- Understanding the role of background radiation is important for improving our knowledge about life evolution on Earth and about the health effects of low dose ionizing radiation exposure.
- Mutations induced from natural background radiation
- Exploration of changes in living organisms exposed to ultra-low radioactivity

- Life on Earth extends into deep subsurface and extreme environments.

- the influence of deepunderground conditions on life have been derived from experiments carried out in underground laboratories (ULs).

- More studies are needed for any conclusive understanding.

frontiers in Public Health

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Check for updates

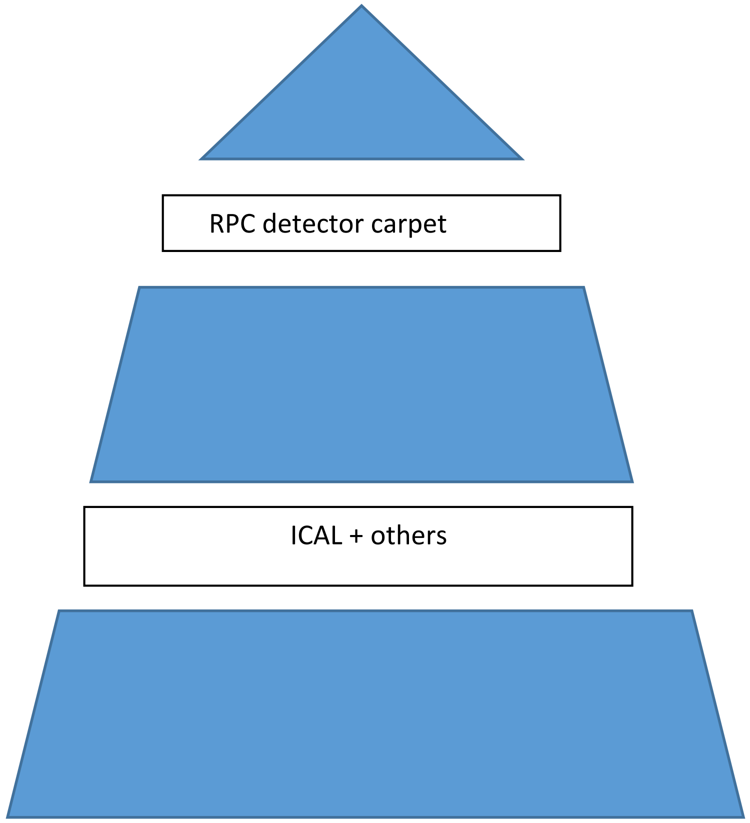
Underground Radiobiology: A Perspective at Gran Sasso National Laboratory

Giuseppe Esposito[1,2], Pasquale Anello[1], Marco Ampollini[1], Emanuela Bortolin[1], Cinzia De Angelis[1], Giulia D'Imperio[2], Valentina Dini[1,2], Cristina Nuccetelli[1,2], Maria Cristina Quattrini[1], Claudia Tomei[2], Aldo Ianni[3], Marco Balata[3], Giuseppe Carinci[4], Maurizio Chiti[4], Oscar Frasciello[4], Giovanni Cenci[5], Francesca Cipressa[5], Alex De Gregorio[5], Antonella Porrazzo[5], Maria Antonella Tabocchini[1,2,6], Luigi Satta[7] and Patrizia Morciano[3]*

- “investigation in DULs can help to understand the molecular mechanisms underlying biological effects observed at very low radiation dose/dose-rate (e.g., adaptive response and bystander effect), their interrelationship, their dependence on radiation type, total dose and dose rate and, even more importantly, their possible role in human health risks.”

Conclusion

- The ultra-low level radioactive environment inside deep underground laboratories can be extremely interesting from basic and applied science.


RPC detector carpet
ICAL + others

- Interest shown by members of our group/collaborators
- Dr. Kabita Sarkar, SVIST, Kolkata
- Dr. T. Sarkar, NBU

Thank you

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Spectrum and charge ratio of vertical cosmic ray muons up to momenta of 2.5 TeV/*c*

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A R T I C L E   I N F O

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Dedicated to the memory of Horst Wachsmuth

A B S T R A C T

The ALEPH detector at LEP has been used to measure the momentum spectrum and charge ratio of vertical cosmic ray muons underground. The sea-level cosmic ray muon spectrum for momenta up to 2.5 TeV/*c* has been obtained by correcting for the overburden of 320 m water equivalent (mwe). The results are compared with Monte Carlo models for air shower development in the atmosphere. From the analysis of the spectrum the total flux and the spectral index of the cosmic ray primaries is inferred. The charge ratio suggests a dominantly light composition of cosmic ray primaries with energies in the energy range between 10^3 and 10^5 GeV.

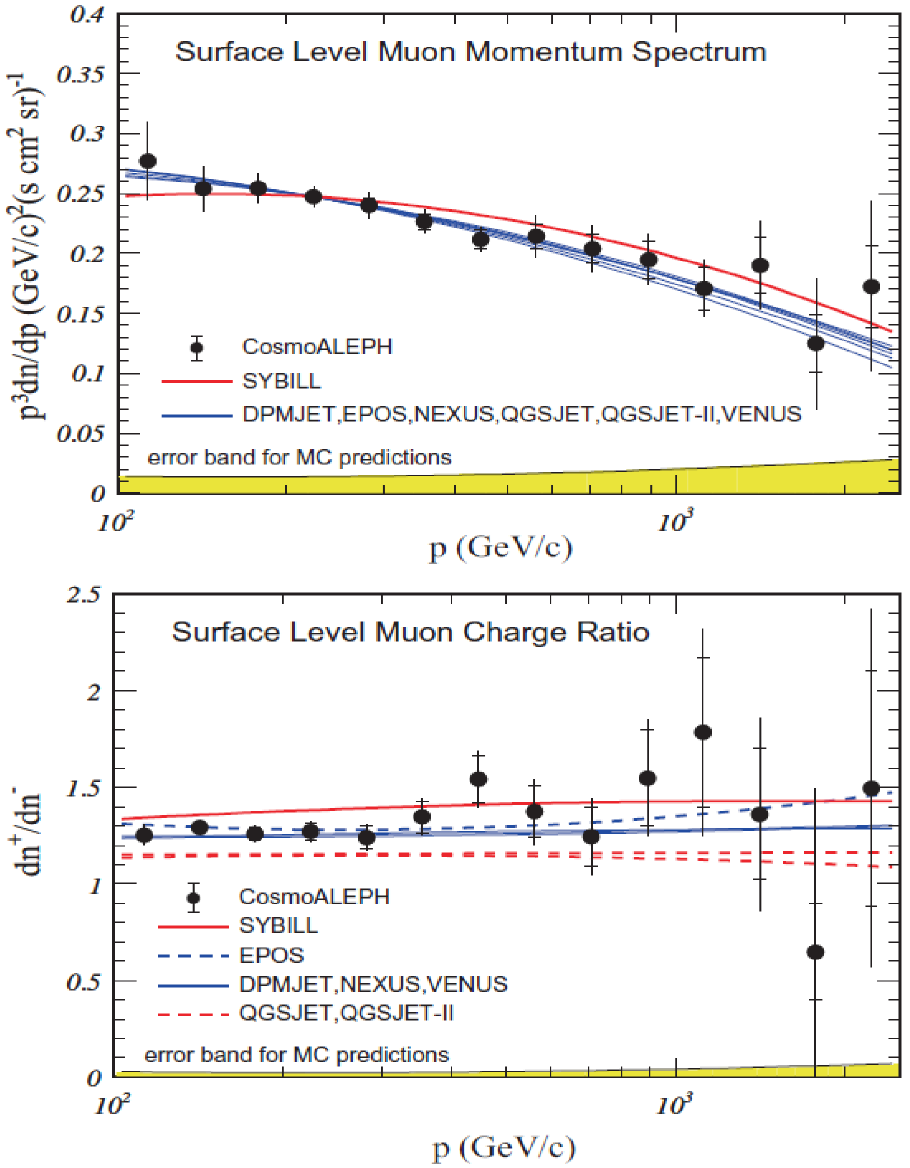

Fig. 3. Measured surface level momentum spectrum and charge ratio compared to best fit Monte Carlo predictions. At the bottom the error bands of the Monte-Carlo curves are indicated. For better visibility the momentum spectrum has been multiplied by p^3.