Fission Gamma Rays

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I. VECC activities at Jaduguda Underground Science Lab (JUSL)

Search for high energy gamma rays in Nuclear Fission

- Physics motivation
- What have we done and the results

II. Proposed activities at the (proposed) new Underground Lab

Research program that we are going to propose is somewhat outcome of JUSL expt.....

Fundamental physics related to nuclear phenomena

Jaduguda Underground Science Laboratory (JUSL)

- The lab is at the 555 meters depth level of an Uranium mine.

- It is a small cavern of approximately 4.5 m length x 4.5 m width x 2.2 m average height.

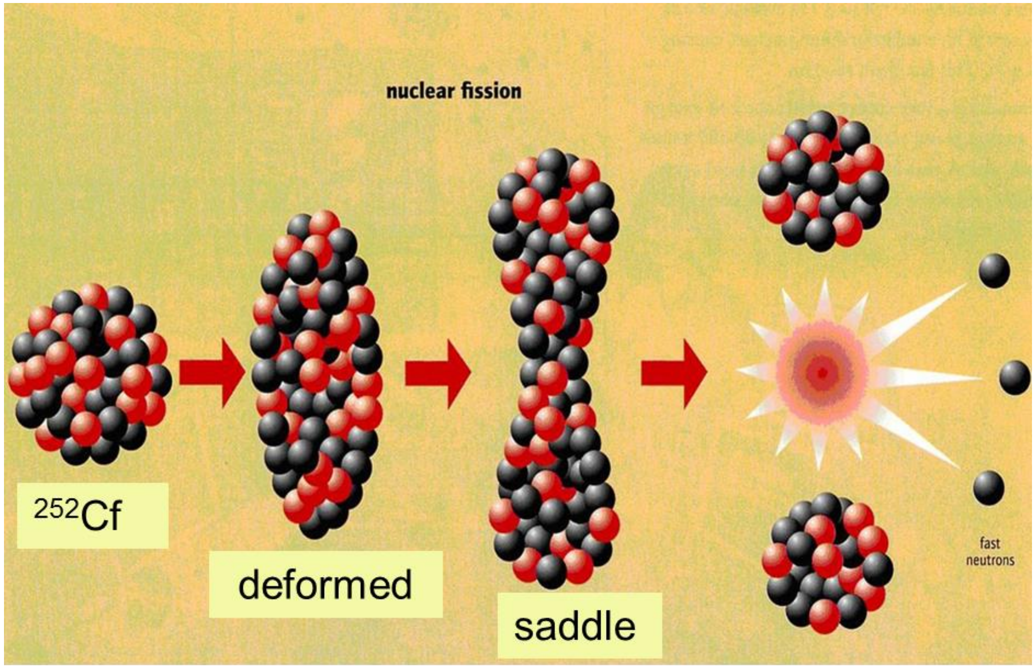
- The lab is basically an abandoned cavern located deep within the innards of a uranium mine.

This new laboratory at UCIL is the first of its kind in the country after closure of a 2.3 km-deep lab at Kolar gold mine in early 1992.

Cosmic reduction factor measured by VECC scientists at the underground lab = 2.4×10^4

Scientific motivation of the JUSL experiment

Nuclear fission process, discovered about 80 years ago, has fascinated science as well as history of mankind !



Fission reaction ; Q Value and energy balance

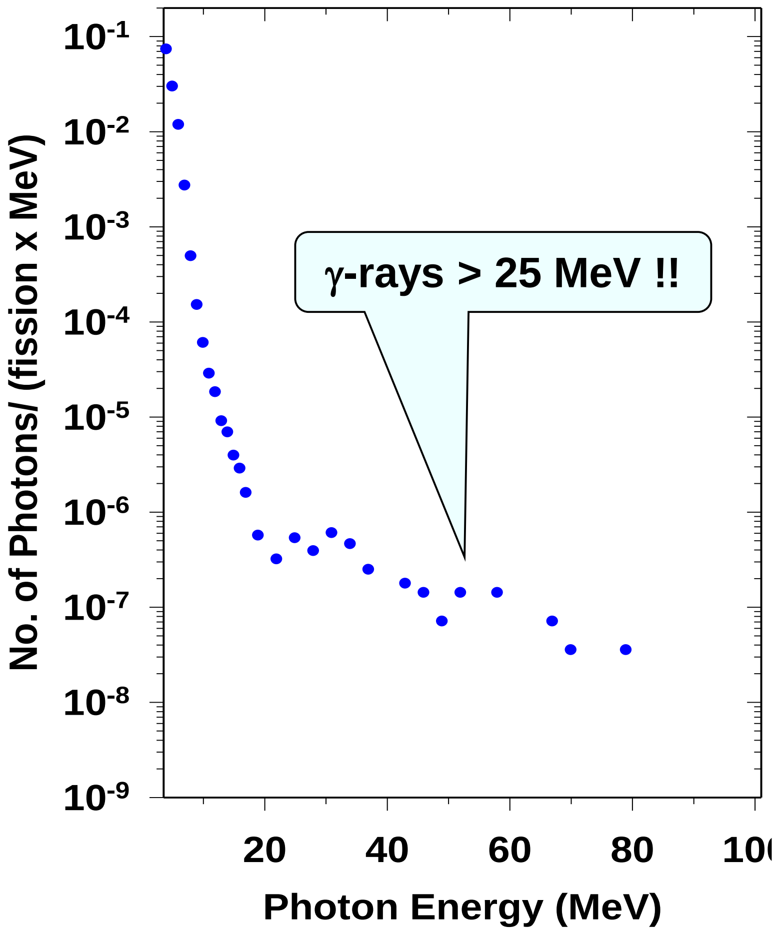
	Energy (MeV)
Kinetic energy of Fission fragments	170
Inst Gamma rays	7
KE of neutrons	5
β from FPs	7
γ from FPs	6
Neutrinos	10
Total (appx)	200

Energy release ~ 200 MeV per fission

Recently several experiments claimed to measure high energy γ rays (E_γ > 25 MeV) in spontaneous fission of ^{252}Cf which is unexpected.

High energy γ-ray spectra in ^{252}Cf fission

The claim of the observation of gamma rays > 25 MeV in fission is one of the fundamental and debated problems of nuclear fission physics



Measurement @ VECC

Deepak Pandit et al, Phys. Lett. B 690, 473 (2010)

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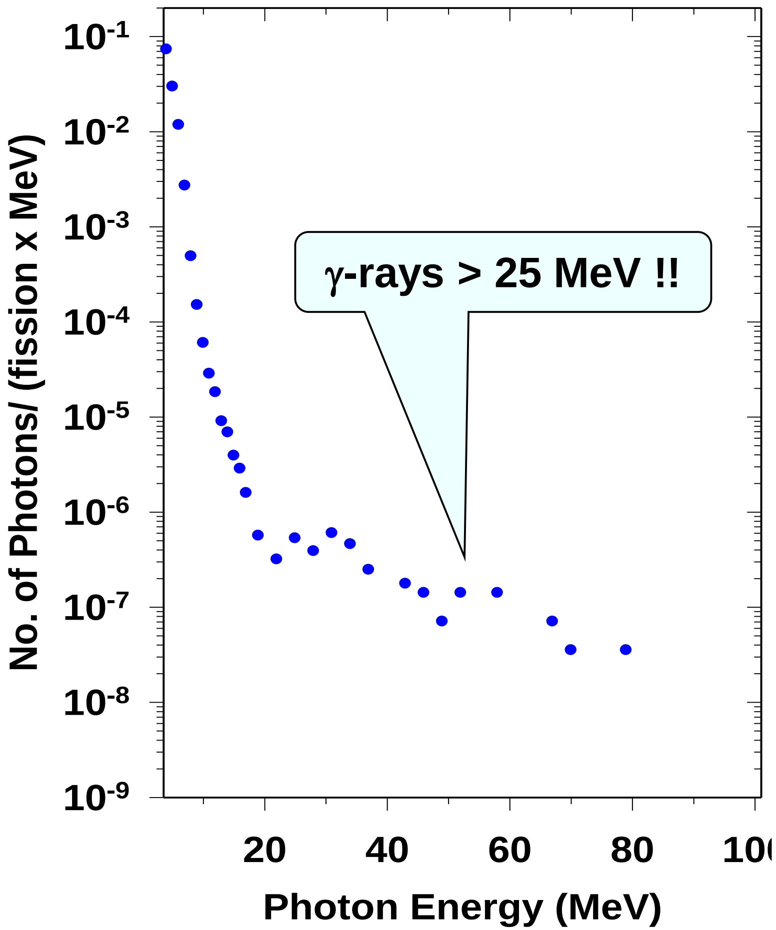

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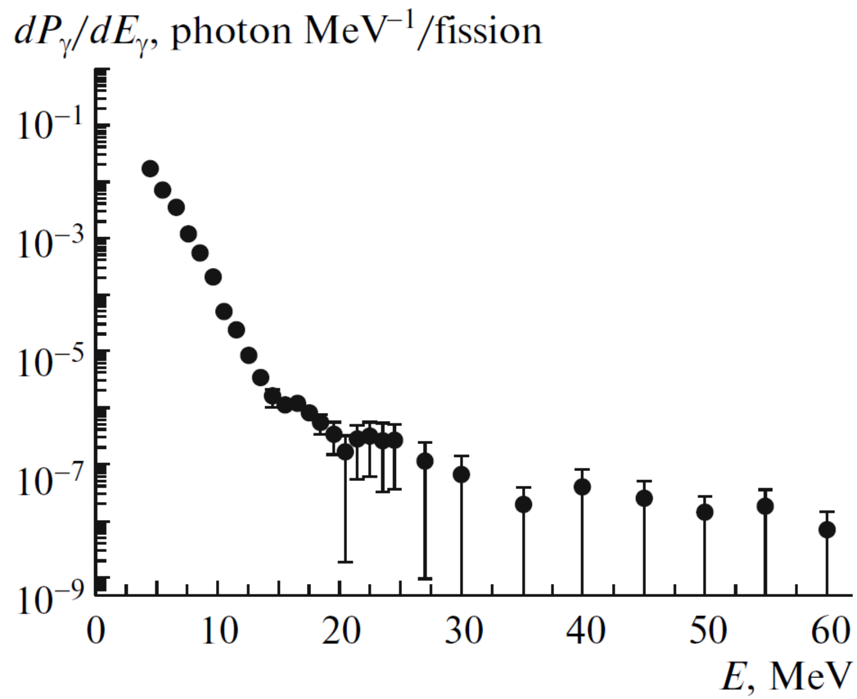
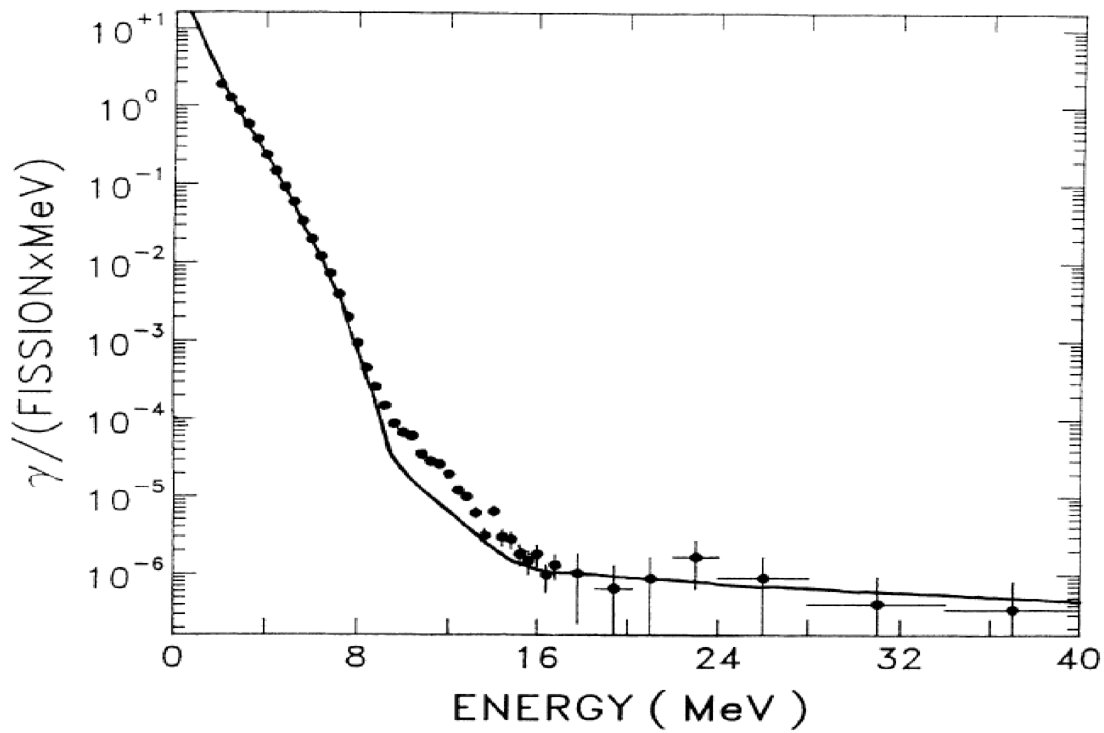


Eremin et al; Bulletin of the Russian Academy of Sciences (2011)

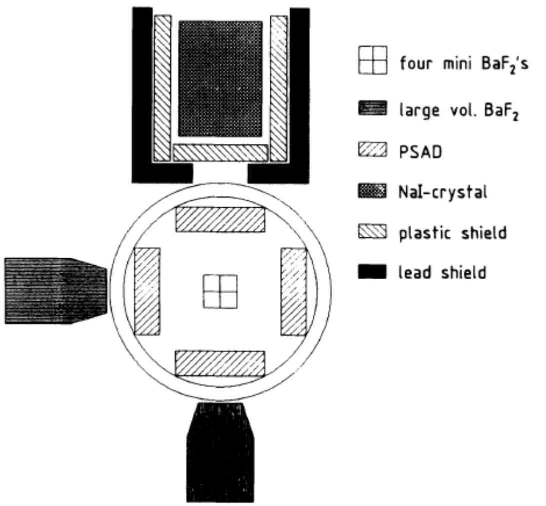
Kasagi et al; J. Phys. Soc. Japan 58, 620 (1989)

High energy γ-ray spectra in ^{252}Cf fission

All these recent experiments were triggered after the first convincing report came from KVI, Groningen



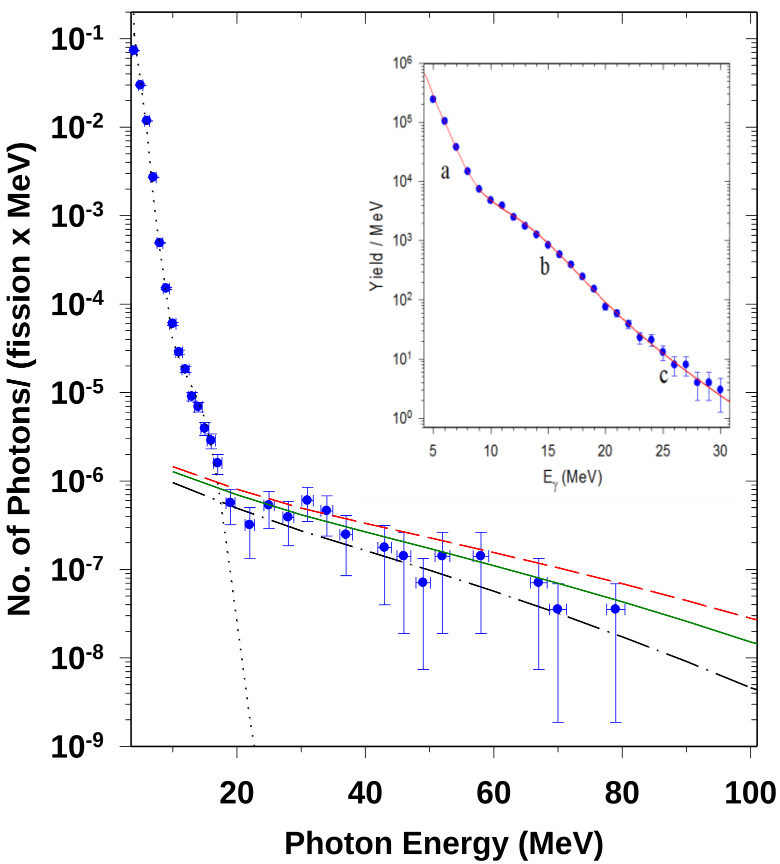
The γ spectrum measured in coincidence with fission



H. van der Ploeg. et al, Phys. Rev. Lett. 92, 3145 (1992)

Kasagi, Hama, Yoshida & Sakuri, Koyoto Conf 1988 (J. Phys. Soc. Japan 58, 620 (1989)

Origin of γ-rays in fission

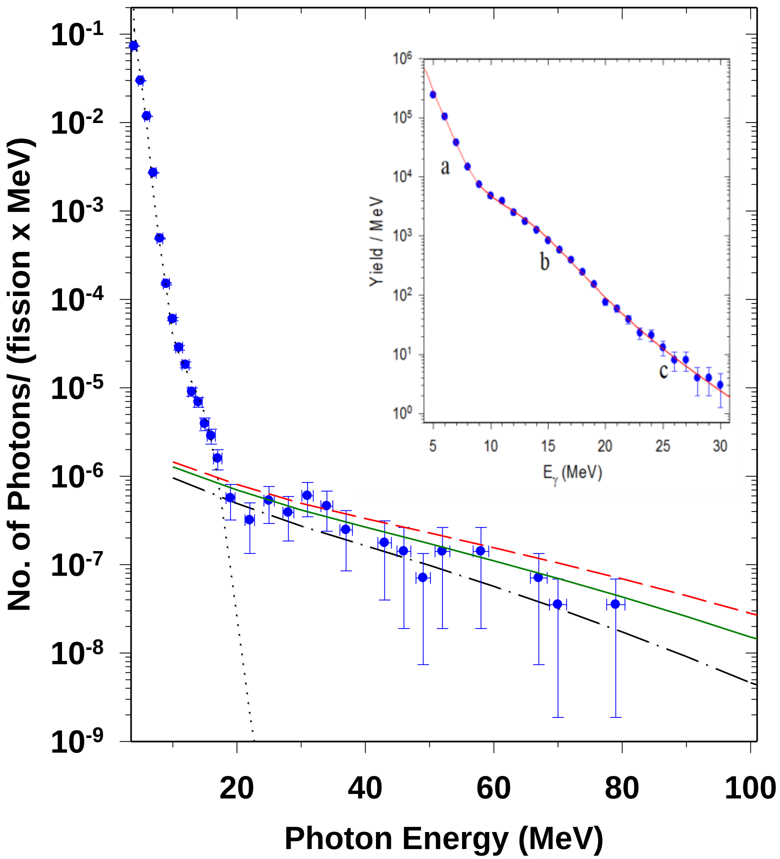


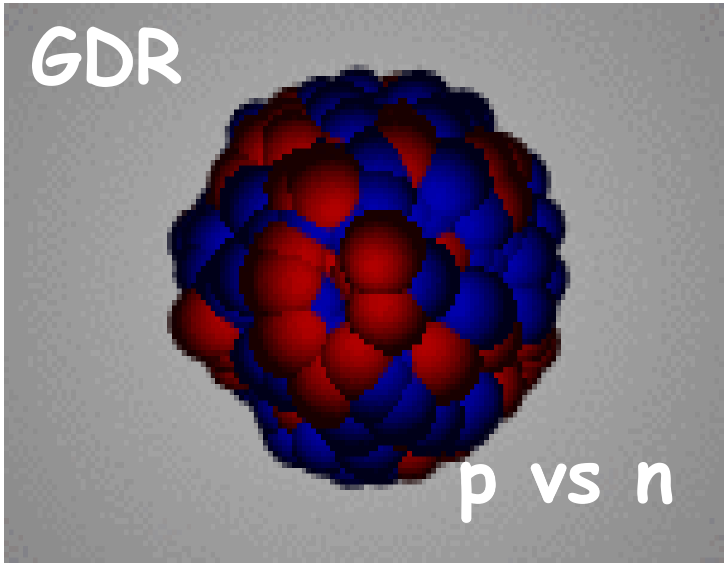
a: Statistical - γ rays (< 8 MeV)

b: GDR - γ rays (8 – 20 MeV)

c: **?? (> 25 MeV)**

Origin of γ-rays in fission





GDR: Giant Dipole Resonance is a small amplitude, high frequency collective mode of excitation in nuclei.

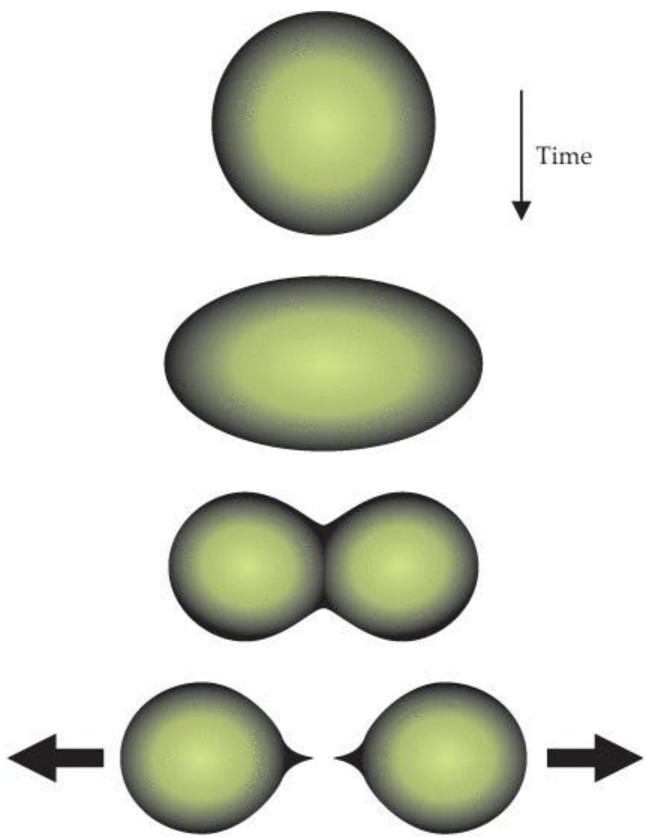
a: Statistical - γ rays (< 8 MeV)

b: GDR - γ rays (8 – 20 MeV)

c: **?? (> 25 MeV)**

Origin of γ-rays in fission

One can expect bremsstrahlung emission in fission, since two charged particles are separated and accelerated in a very short time period



Bremsstrahlung : "braking radiation" or "deceleration radiation" produced by the deaccleration of a charged particle when deflected by another charged particle

Accelerated charged fission fragments in the Coulomb field emits bremsstrahlung radiation.

Nucleus-nucleus coherent bremsstrahlung photons are emitted in fission

And there exists theories..

Photon emission probability due to pure Coulomb acceleration of the fission fragments can be calculated

The bremsstrahlung photon emission probability is coherent sum of the vector potentials of the two charged fragments:

Just text book stuff
J. D. Jackson

$$\frac{d^2 I}{d\omega\, d\Omega} = 2 \mid \mathbf{A}_1(\omega) + \mathbf{A}_2(\omega) \mid^2$$

A(ω) : vector potential in the frequency space
n: unit vector along the radiation axis

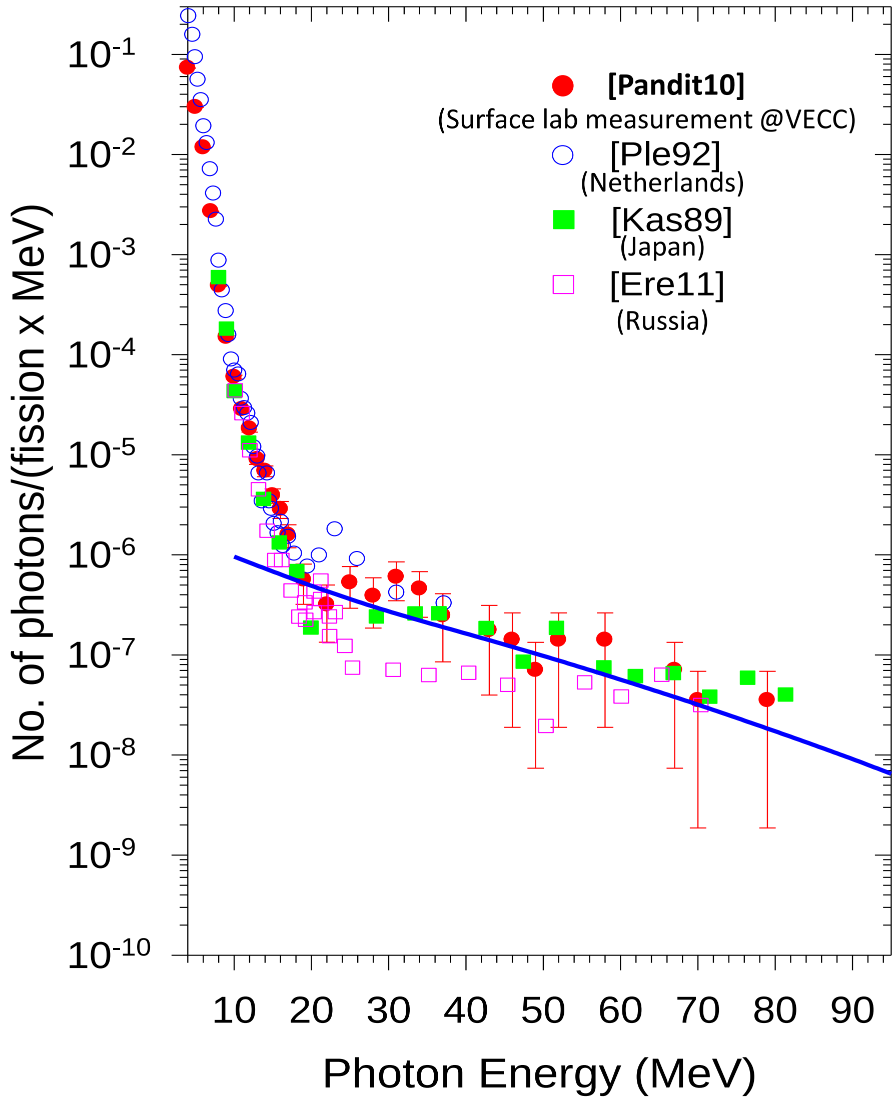
$$\mathbf{A}_i(\omega) = \left(\frac{1}{\sqrt{2\pi}}\right)\left(\frac{c}{4\pi}\right)^{\frac{1}{2}}\left(\frac{1}{c}\right)\int_{-\infty}^{\infty} dt \left[\frac{\hat{\mathbf{n}} \times [(\hat{\mathbf{n}} - \boldsymbol{\beta}_i) \times \dot{\boldsymbol{\beta}}_i]}{(1 - \boldsymbol{\beta}_i \cdot \hat{\mathbf{n}})^2}\right] q_i e^{-\imath\omega[t - \hat{\mathbf{n}}\cdot\mathbf{r}_i(t)/c]}$$

- Motion of the fragments can be determined by solving the equation for the two particles under the influence of a repulsive coulomb potential

$$\frac{1}{2}\mu\dot{r}^2 + \frac{k}{r} = E$$

μ is the reduced mass
$k = z_1 z_2 e^2$
$\dot{r}$ is the relative velocity
E is the energy of the system

Coherent bremsstrahlung



Deepak Pandit et. al, Phys. Lett. B 690, 473 (2010)

Apparently data is explained by model!

Thus, the general understanding is....

Coherent Bremsstrahlung photons are emitted in spontaneous fission of ^{252}Cf

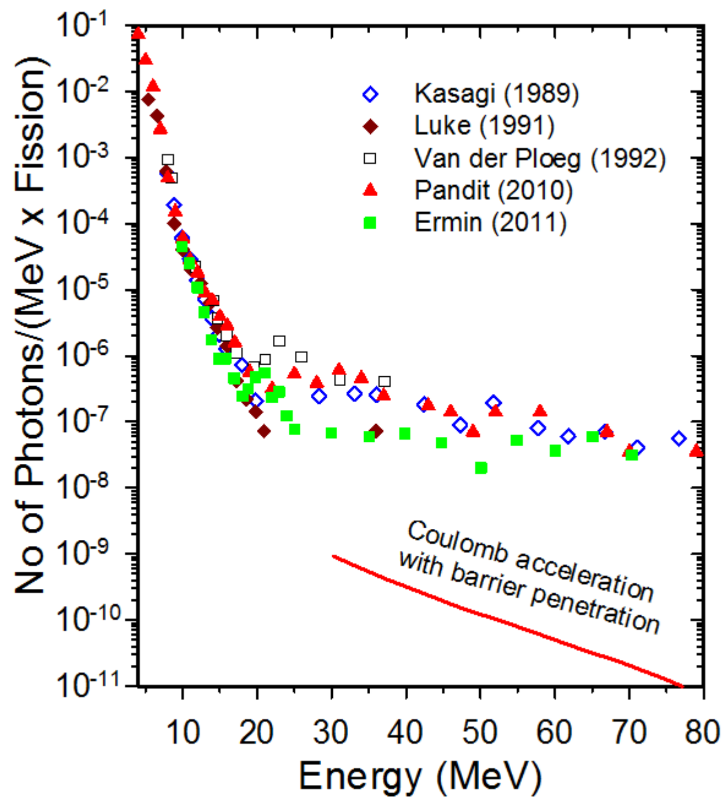
But there is one problem here which is not accepted by fission community !!

Fission school of thought

High energy γ-rays (E_γ > 25 MeV) resulting from spontaneous fission of ^{252}Cf is unexpected!

- The γ emission takes away the kinetic energy of the fission fragments that would lead the fragments into a classically forbidden region. This reduces the photon emission probability.

Reduced tunnelling probability will set an upper limit of photon emission:



The measured event rate is orders of magnitude higher than expected !

Our school of thought

- The possibility of observing high energy γ rays during the fission of Cf is indeed intriguing !

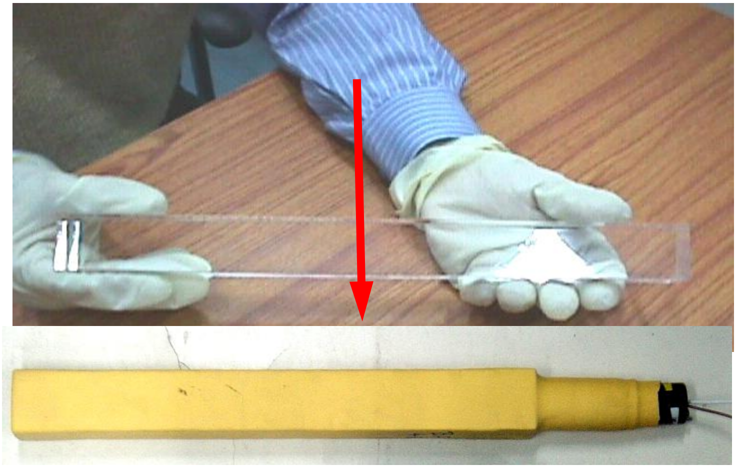
Cosmic rays can be major source of background

- VECC experimental program at Jaduguda Underground Science Lab was undertaken to search for high energy γ rays in a low cosmic background environment.

Detectors

Large Area Modular BaF_2 Detector Array (LAMBDA) developed at VECC

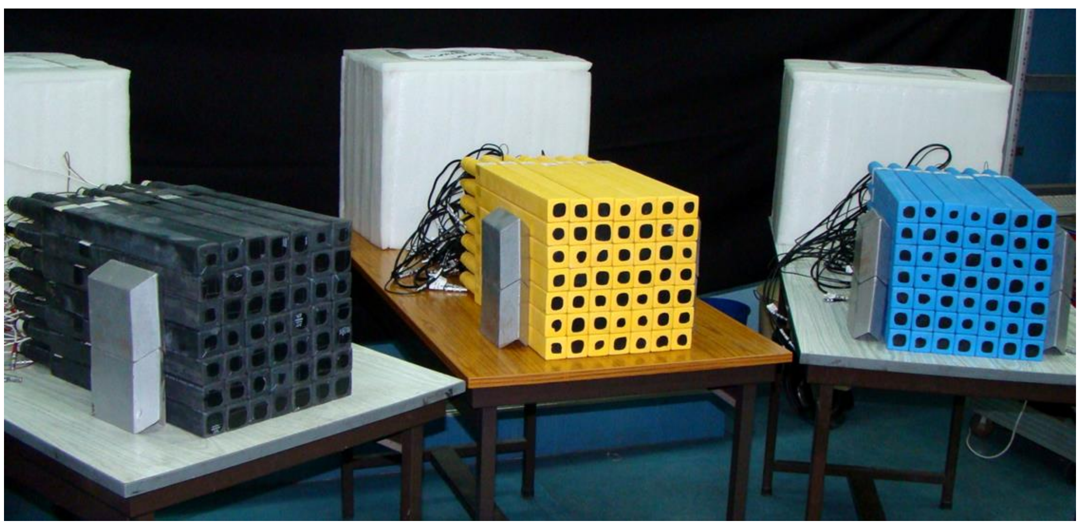
NIM A 582, 603 (2007)



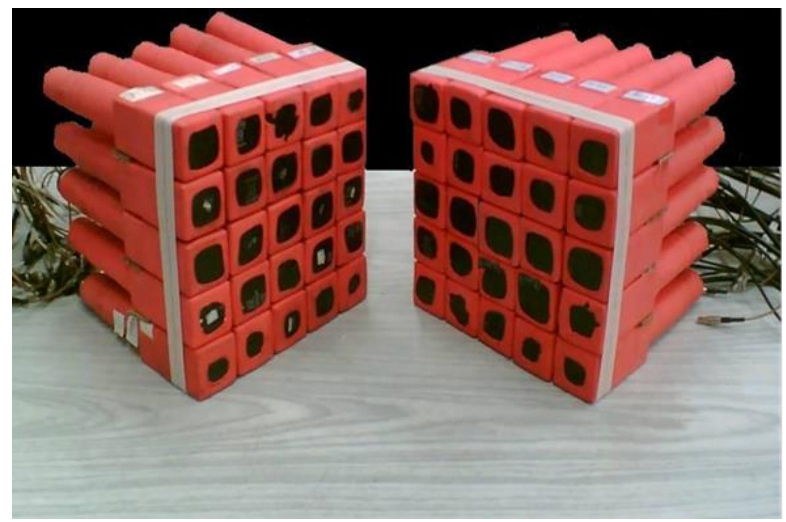
BaF_2 detector:

Dimension: 3.5 cm x 3.5 cm x 35 cm
3.5 cm x 3.5 cm x 5 cm

Min. ionizing muons deposit 6.6 MeV/cm in BaF_2 crystals i.e., 23.1 MeV/detector when incident vertically

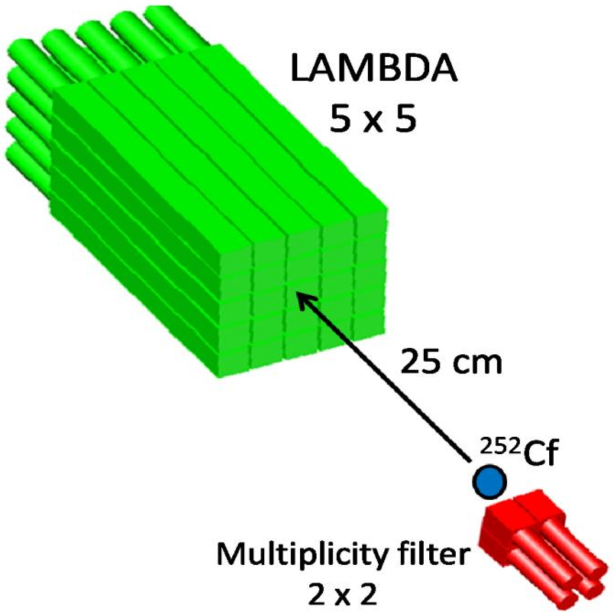


LAMBDA



Multiplicity filter

Measurement at Jaduguda Underground Laboratory

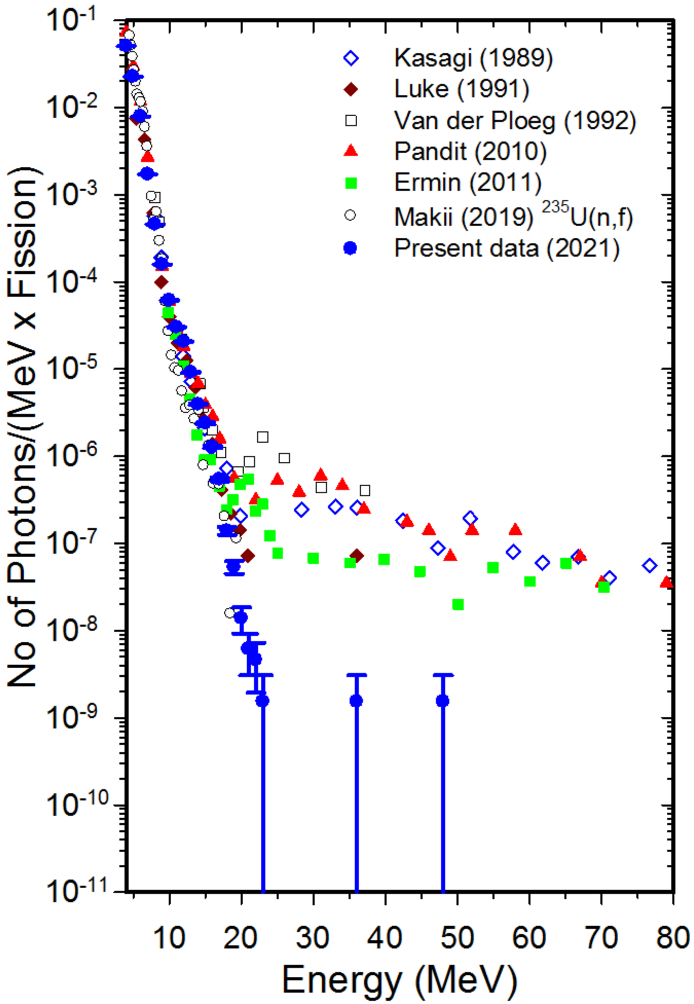


High energy γ-rays were measured in coincidence with the prompt γ-rays in order to establish a correlation (photons/fission) between the high energy γ-rays and the fission process.

Effective data collection for 38 days in γ-γ coincidence mode

Background: 38 days without ^{252}Cf source

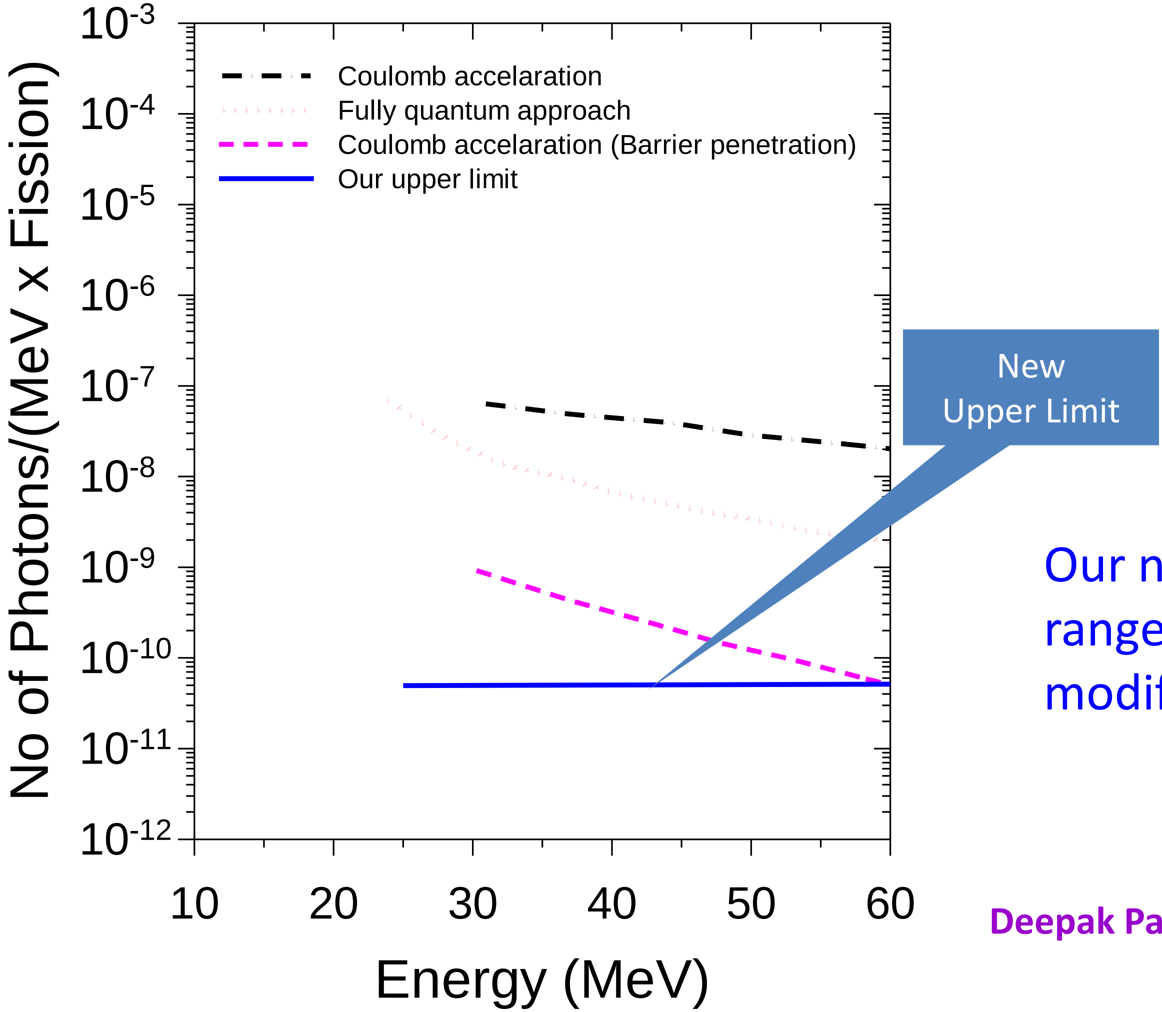
Measured γ- ray spectra for photon emission



- ❑ Total fission events detected: 2.5 x 10^{10}
- ❑ Only two events observed > 25 MeV
- ❑ Observed Coherent Bremsstrahlung emission probability is 2 orders of magnitude smaller than the previous measurements.

Deepak Pandit et al; Physics Letters B 823, 136760 (2021)

No theory can explain our new data



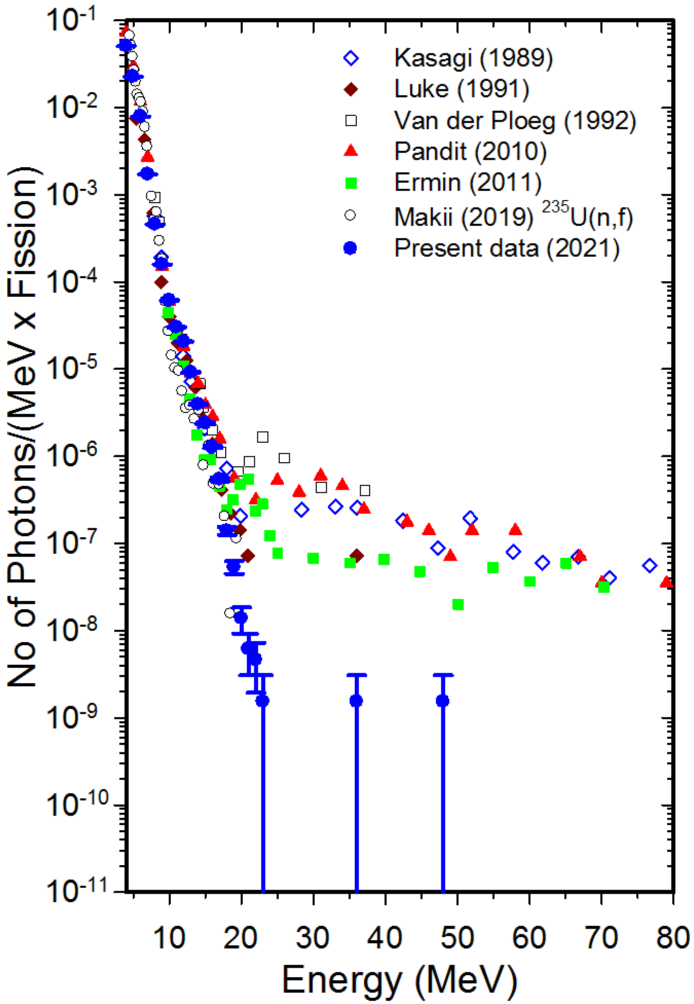
Upper limit for the production of γ-rays at 95 % confidence level

Our new upper limit in the energy range 25-50 MeV pointing towards the modification of the existing theories.

Deepak Pandit et al; Physics Letters B 823, 136760 (2021)

Modifications of existing theories or a new theory is indeed important to understand whether coherent bremsstrahlung of fission fragments in the Coulomb field exists or not

Measured γ- ray spectra for photon emission



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Deepak Pandit et al; Physics Letters B 823, 136760 (2021)

Discrimination between cosmic μ & high energy γ

Underground lab is not devoid of high energy background !

0.0	0.0	0.0	34.9	0.0
0.0	0.9	10.3	36.9	0.0
0.0	0.0	6.2	32.1	0.0
0.0	2.4	35.4	20.0	0.0
0.0	0.0	28.9	4.5	0.4

Cosmic track

29.9	31.0	30.9	34.6	13.9
34.8	31.7	41.4	36.5	34.9
8.4	34.6	31.6	11.6	29.1
28.8	34.2	13.6	12.0	31.3
27.7	28.5	27.1	7.1	17.6

Cosmic track

29.4	30.5	30.4	0.0	7.1
5.2	17.2	9.8	15.6	1.1
4.9	20.8	31.0	0.0	0.0
1.3	12.6	34.5	3.6	0.0
0.0	20.5	1.4	2.4	0.0

Cosmic track

0.0	1.9	30.2	0.0	0.0
0.0	1.7	4.1	8.7	0.0
0.0	0.0	1.8	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

γ-cluster

Cosmogenic background:

- Using the high granularity of the LAMBDA array, muon events can be efficiently identified as muons produce track in the detector whereas the high-energy γ rays produce cluster.
- For the 2 events that we have observed, highest energy deposit was in the outer detector, thus the measured energy may not be precise.

2 events that we identify as bremsstrahlung emission is not unambiguous

How to get rid of the ambiguity?

I. Requirement of well equipped underground lab

- ❑ Measurement of fission fragment K.E. + Eγ

To carry out such experiments with radioactive sources, the requirement is a cavern about 6 meter x 6 meter x 3 meter.

....that can accommodate vacuum chamber, pumps etc.

II. Requirement of underground accelerator facility

- ❑ Accelerator facility is best suitable for such experiments

JUSL Experiment:

(with radioactive sources)

Arrival: 20^{th} January, 2020

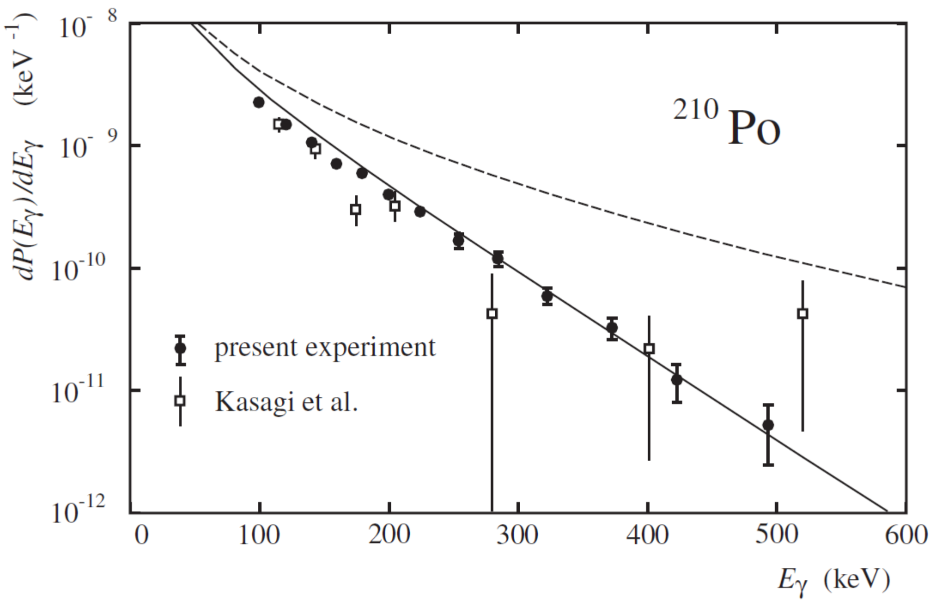
Departure: 23^{rd} July, 2021

- ❑ In beam experiments reduce the data taking time significantly (factor of ~10) thereby reducing the random coincidences

Bremsstrahlung in α decay

JUSL experiment advocates to reexamine the mechanism of bremsstrahlung emission in the Coulomb field of nucleus

Interestingly, bremsstrahlung emission in alpha decay has been experimentally measured and also theoretically explained.



Papenbrock and Bertsch,
Phys. Rev. Lett. 80, 4141 (1998)

J. Kasagi et al., Phys. Rev. Lett. 79, 371 (1997)
Phys. Rev. Lett. 85, 3062 (2000)
H. Boie et al., Phys. Rev. Lett 99, 022505 (2007)

We propose to

Search for gamma rays in α decay

at the underground laboratory

Summary

- **Nature of the experiment:** Stand alone (with radioactive source) or low energy accelerator based *Nuclear Physics Experiments*

- **Scientific goals:** Address fundamental physics related to unsolved problem in nuclear fission and alpha decay.

- **Approximate requirements of the experiment:**
  - A cavern about 6 meter x 6 meter x 3 meter
  - A high current low energy accelerator

May be considered as a proposal for DAY ONE experiment ☺

Back up slides

Cosmic tracks

Total fission events detected: 2.5 x 10^{10}

Only two events observed > 25 MeV

0.0	0.0	0.0	34.9	0.0
0.0	0.9	10.3	36.9	0.0
0.0	0.0	6.2	32.1	0.0
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Cosmic track

29.9	31.0	30.9	34.6	13.9
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Cosmic track

29.4	30.5	30.4	0.0	7.1
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Cosmic track

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0.0	0.0	1.8	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

γ-cluster

- **Background run:** 26 events in raw data. All the events produced track, with energy > 187 MeV & identified as cosmic muons.

- **^{252}Cf run:** 29 events in raw data. 27 events were identified as cosmic muons owing to their hit pattern.

- Highest energy deposit in both the cases was in the outer detector, thus the energy deposit may not be the precise.

If the experiment would have been carried out at surface laboratory the background would have been ~ 46,000 !

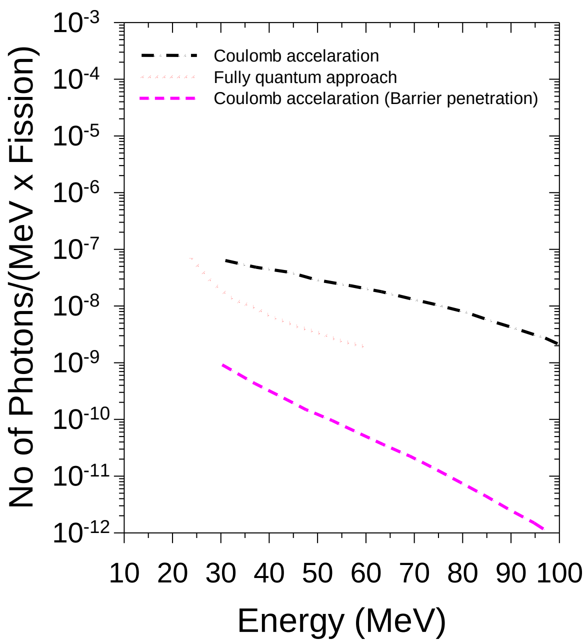
Controversies summarized!

- In few experiments, the high energy γ rays were observed and theoretically attributed to coherent bremsstrahlung of fission fragments in the Coulomb field.

Ploeg et al; Phys. Rev. Lett. 92, 3145 (1992)
Pandit et al; Phys. Lett. B 690, 473 (2010)
Kasagi et al; J. Phys. Soc. Japan 58, 620 (1989)

- In few other experiments, the high energy γ rays were not detected. Only an upper bound was determined.

Luke et. al, Phys. Rev. C 44, 1549 (1991)
Varlachev et al; JETP Letters, 82, 390 (2005)
Pokotilovskii et al, Sov. J. Nucl Phys 52, 599 (1990)
Experiments in pipe line: Nishio et al Japan EPJ Web of Conferences 146, 04036 (2017)
V.M. Datar et al DAE Symp on Nucl Phys 1990



- The calculations in different models differ by several orders of magnitude.

The emission probability is calculated in terms of the transition matrix element of the fission fragments from the state before photon emission to the state after photon emission considering spherically symmetric wave functions.

Concluding remarks

An amazing experience, we thoroughly enjoyed in performing the First Physics experiment in the lab ☺

Arrival: 20th January, 2020
Departure: 23rd July, 2021

- Effective data taking time was considerably less ☹

Experiment in the time of corona…..

- The lab require facilities to monitor the experiment from outside
- Development of a well equipped laboratory at the surface may be required

JUSL is a good lab for low background measurement, however, require few more infrastructural development

Acknowledgements

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Satyajit Saha, A. K. Mohanty*

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Bhabha Atomic Research Centre, Mumbai

Thanks to HPU, VECC, & SINP (S. Chattopadhyay, M.K Sharan, N.K. Mondal)

Sumit Som, VECC ; S. Basu, BARC

In the QM approach, nuclear shape is specified in terms of smoothly joined portions of three quadratic surfaces of revolution: two spheroids connected by a hyperboloidal neck.

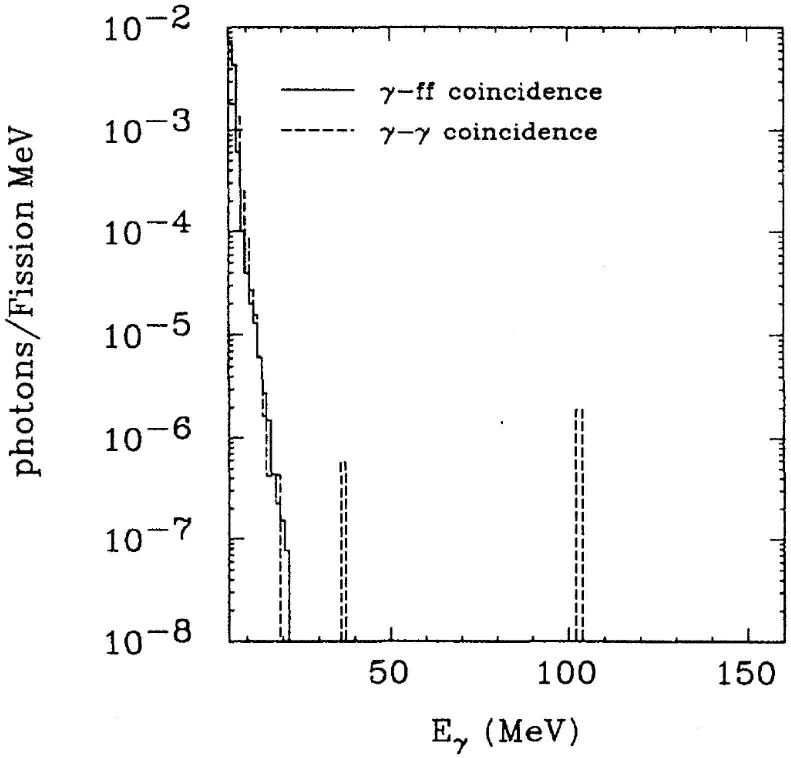
Next the interaction potential (Coulomb + nuclear) is generated between the fragments with respect to the shape and the distance between them.

The photon emission probability is calculated in terms of the transition matrix element of the fission fragments from the state before photon emission to the state after photon emission considering spherically symmetric approximation of the fissioning system.

The wave functions of the fissioning system required for the calculation are obtained from the interaction potential between the emitted fragment and residual nucleus satisfying appropriate boundary conditions.

Fission school of thought

The experimental program undertaken at the Washington University provides interesting info.



Luke et. al, Phys. Rev. C 44, 1549 (1991)

Two separate techniques:
γ- γ trigger
Fission- γ trigger

Not observed when measured with the detection of fission fragments

Nuclear Inst. and Methods in Physics Research, A 994 (2021) 165083

Table 2
Summary of results.

Site/Level	Muon flux cm^{-2} s^{-1} sr^{-1}
SINP lab, Kolkata (Sea Level)	$(8.22 \pm .01(stat) \pm .49(syst)) \times 10^{-3}$
UCIL surface lab (~2 m w.e.)	$(5.02 \pm .18(stat) \pm .31(syst)) \times 10^{-3}$
UCIL 555 m ((1554 ± 45) m w.e.)	$(2.79 \pm .13(stat) \pm .20(syst) \times 10^{-7})$

Measurements of gamma ray, cosmic muon and residual neutron background fluxes for rare event search experiments at an underground laboratory

Sayan Ghosh*, Shubham Dutta, Naba Kumar Mondal, Satyajit Saha

Saha Institute of Nuclear Physics - HBNI, I/AF Bidhan Nagar, Kolkata 700064, India.

arXiv:2106.12980v1 [astro-ph.IM]

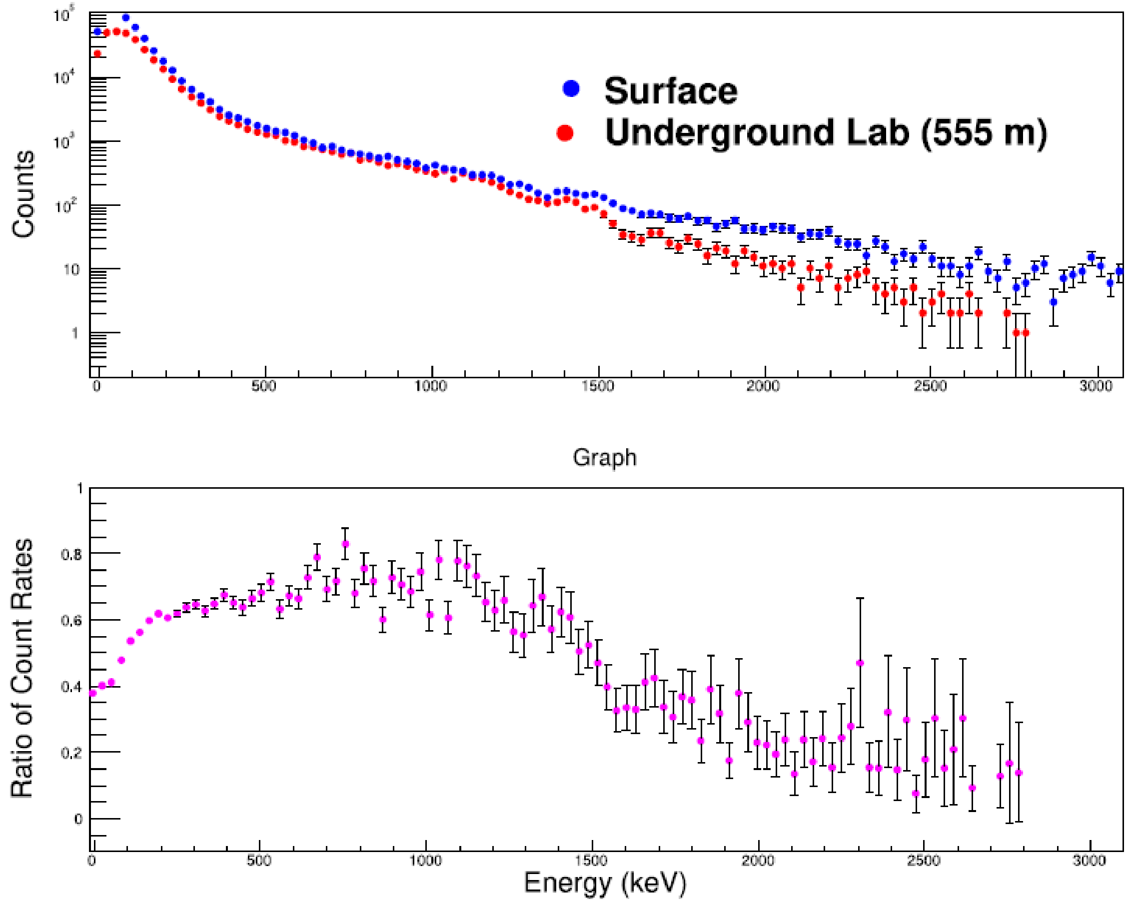
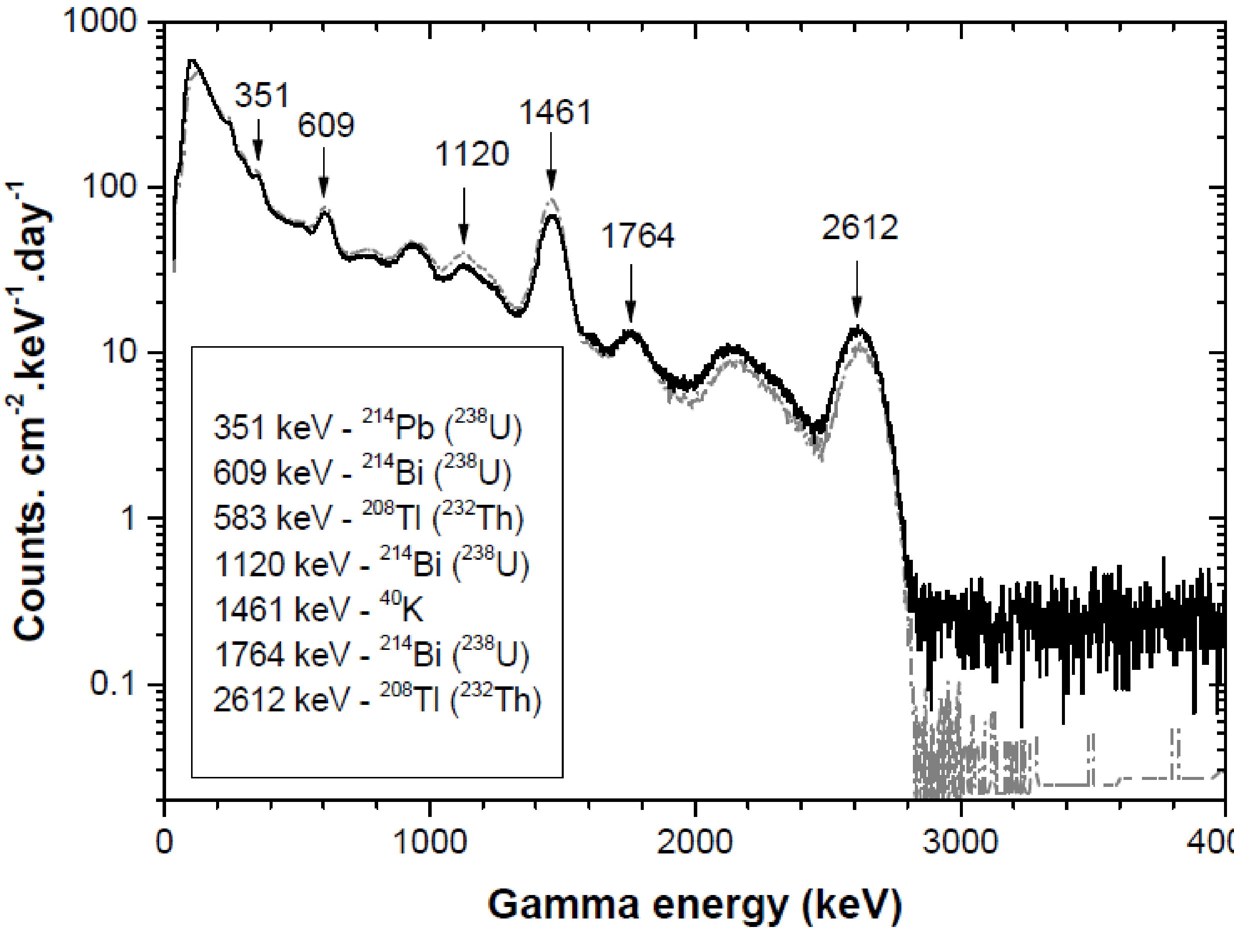


Fig. 6. (Color online) Radioactive spectrum, measured with the CdTe detector, at the surface, and the underground lab. The ratio of the background rates at the underground lab to the surface is shown in the bottom part of the figure.

Nuclear Inst. and Methods in Physics Research, A 994 (2021) 165083

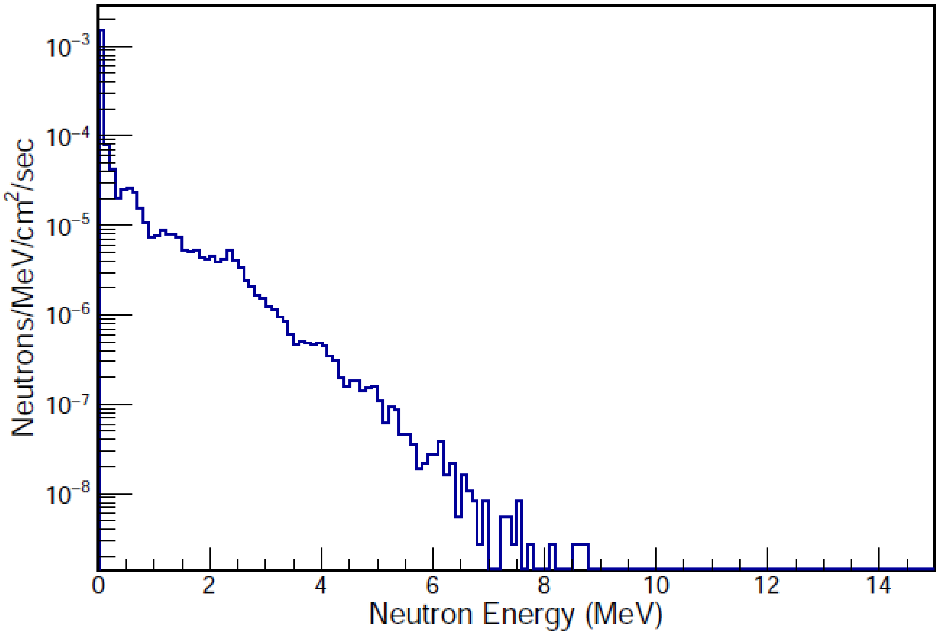
This γ-ray background has been measured using a CdTe detector both at the surface and underground site. The gamma flux at the underground site has been measured to be $\sim$1.2 $cm^{-2}s^{-1}$. These rates depend upon



Range of E_γ (MeV)	Count rate at UG $(cm^{-2}.sec^{-1})$
0 – 0.3	0.9028(32)
0.31 – 0.5	0.2146(15)
0.51 – 1.0	0.2796(18)
1.01 – 1.5	0.2177(16)
1.51 – 2.0	0.06858(89)
2.01 – 2.5	0.0333(6)
2.51 – 3.0	0.02095(49)
3.01 – 4.6	$1.06(35) \times 10^{-4}$

Figure 1: Gamma ray spectra measured using CsI(Tl) detector at the underground laboratory (grey line) and at the surface laboratory (black line).

Sayan Ghosh et al : arXiv:2106.12980v1 [astro-ph.IM]



Flux was measured using pressurized ^4He detector manufactured by Arktis Radiation Detectors, Switzerland

Total flux of radiogenic neutrons as measured at the underground site:

$$(1.61 \pm 0.03) \times 10^{-4}\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$$

Figure 12: Simulated energy spectrum of radiogenic neutrons falling on the detector placed inside the laboratory.

Sayan Ghosh et al : arXiv:2106.12980v1 [astro-ph.IM]

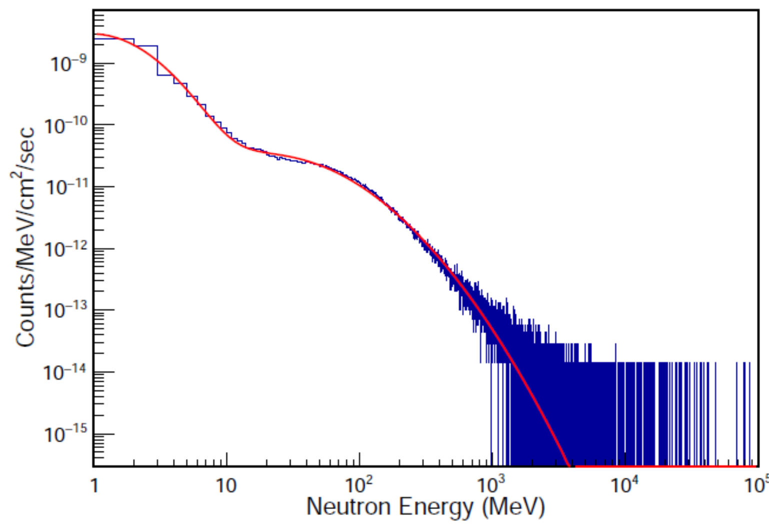
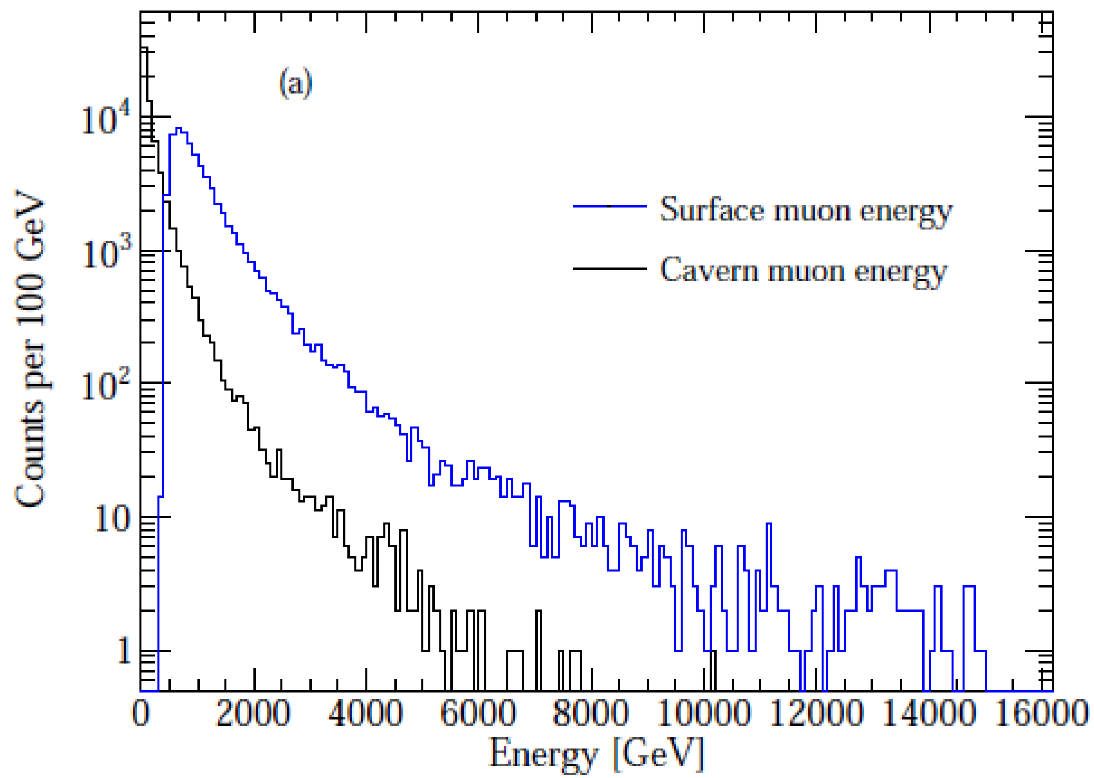


Figure 14: Energy spectrum of cosmogenic neutron in the laboratory volume. The fit function (red) is the same as that given in [37, 38].

The cosmic muon rate at the underground lab at 555 meter was measured to be 2.79×10^{-7} cm^{-2} s^{-1} sr^{-1} [12]. The estimated accidental coincidence rate of the cosmic ray due to the coincidence resolving time between the multiplicity filter and LAMBDA array was 5.0×10^{-8} event/MeV/sec. This corresponds to less than 1 count for the entire duration of the experiment. However, the main source of cosmic



S. Banik et al; JINST 16 (06) (2021) P06022.

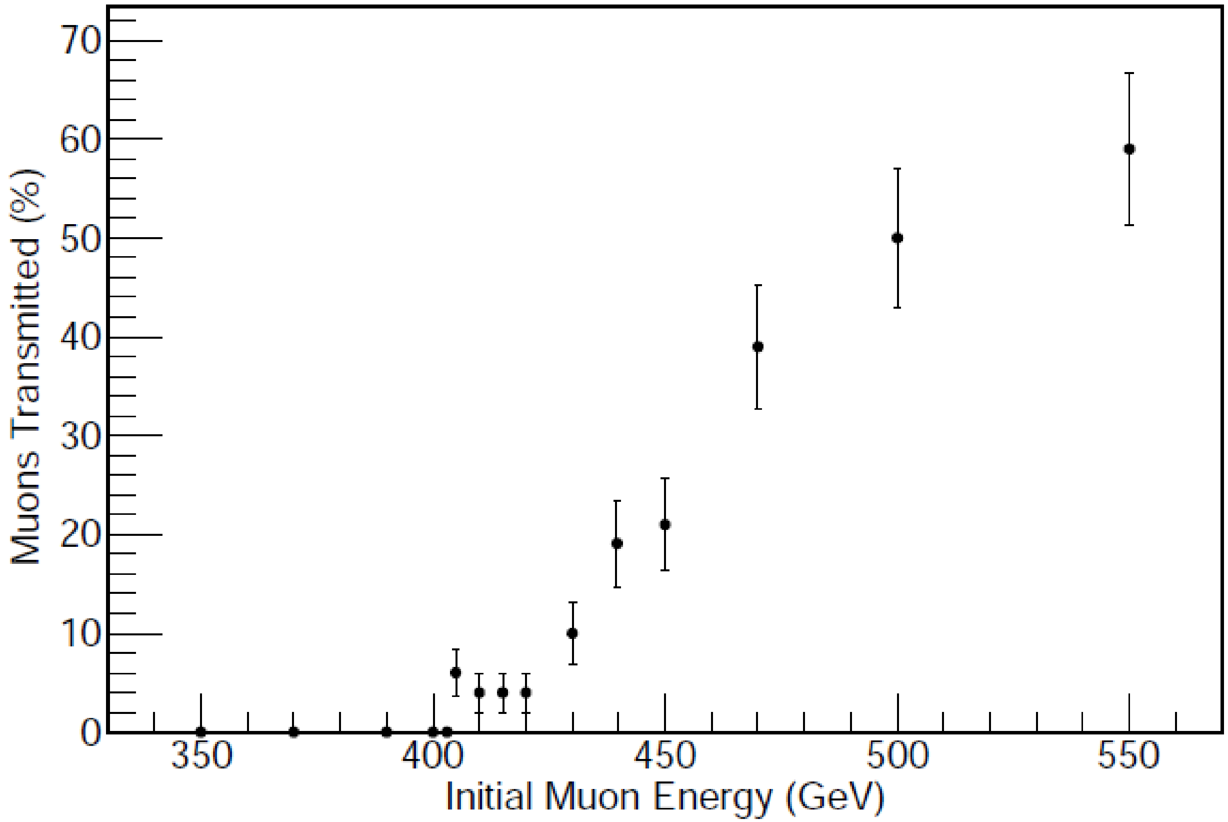
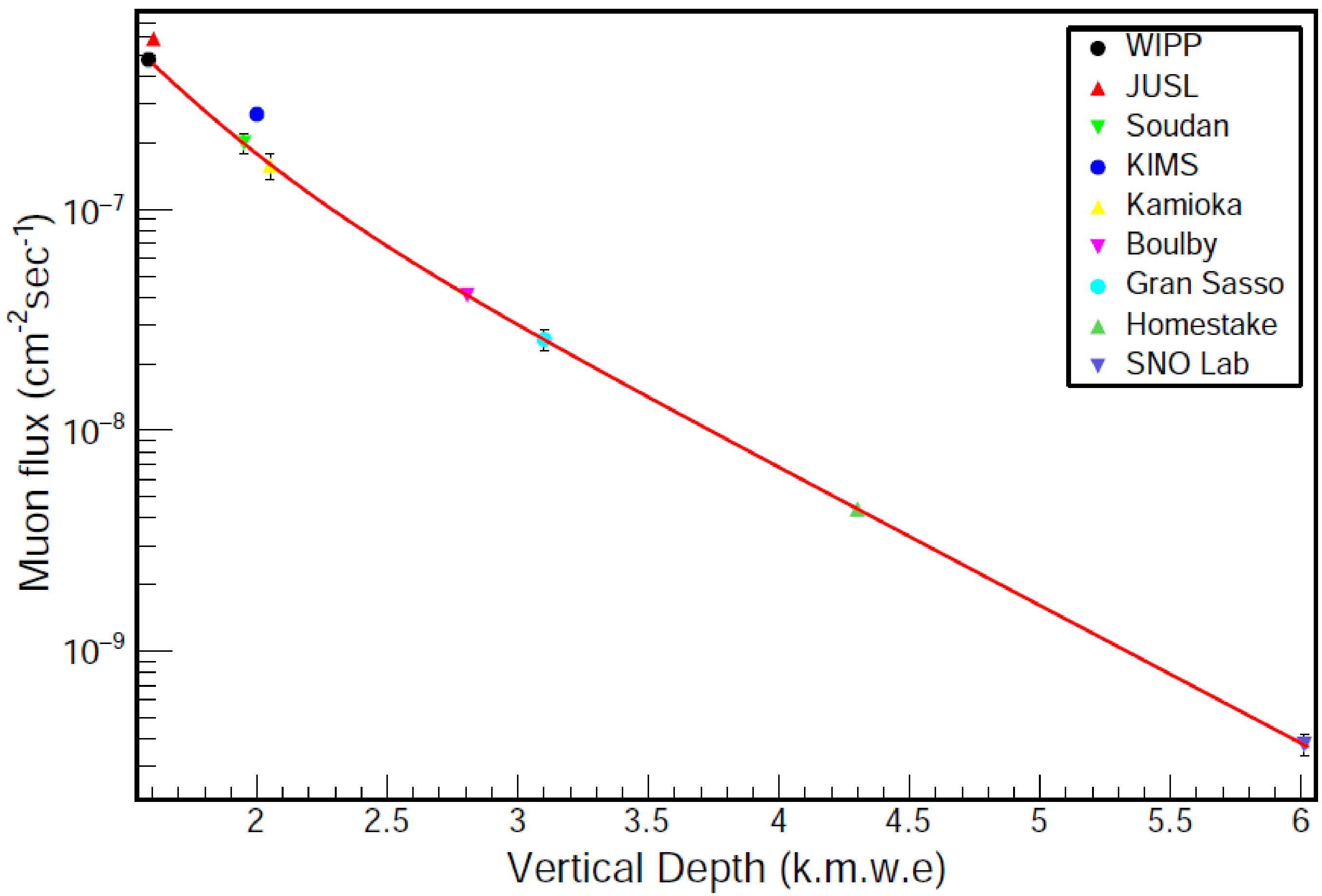


Figure 5: Percentage of mono-energetic muons transmitted through to 555 m underground level.

Sayan Ghosh et al : arXiv:2106.12980v1 [astro-ph.IM]



Sayan Ghosh et al : arXiv:2106.12980v1 [astro-ph.IM]

(WIPP)Waste isolation pilot plant, USA, Soudan: Minnesota, Korea Invisible Mass Search, Boulby: UK, Homestake:Stanford

The gamma ray emission probability was calculated as following. Let N be the total number of events observed between 25-180 MeV. This total number of events depend on the gamma ray emission probability (P_{Eg}) between 25-180 MeV, total number of fission events detected (N_f) and the efficiency of the LAMBDA detector (E_f). Hence,

$$N = N_f * E_f * \int P_E \, dE$$

where the integration limit is from 25 to 180 MeV. The total number of events observed between 25 to 180 MeV was 2. For 95% confidence limit, we take the error 2σ where σ = sqrt(2)=1.414. Therefore, for 95% confidence limit, N = 2 + 2.82 = 4.82.

The total number fission events were measured as $2.5*10^{10}$ from the start trigger of the multiplicity filter having a rate of ~ 7550 events/sec.

The absolute efficiency of the LAMBDA array was calculated from GEANT4 simulation. In the calculation, the gamma ray emission probability was assumed to be constant in the 25-180 MeV energy regions. Thus putting the values we obtain gamma ray emission probability in the 25-180 MeV energy as

$$P_E = 4.82/(2.5*10^{10} * 0.026 * 155) \qquad \int dE = 155 \quad \text{for 25-180 MeV energy range}$$

$$= 4.78 * 10^{-11} \cong 5 * 10^{-11}$$

Fission school of thought

High energy γ-rays (E_γ > 20 MeV) resulting from spontaneous fission of ^{252}Cf is unexpected!

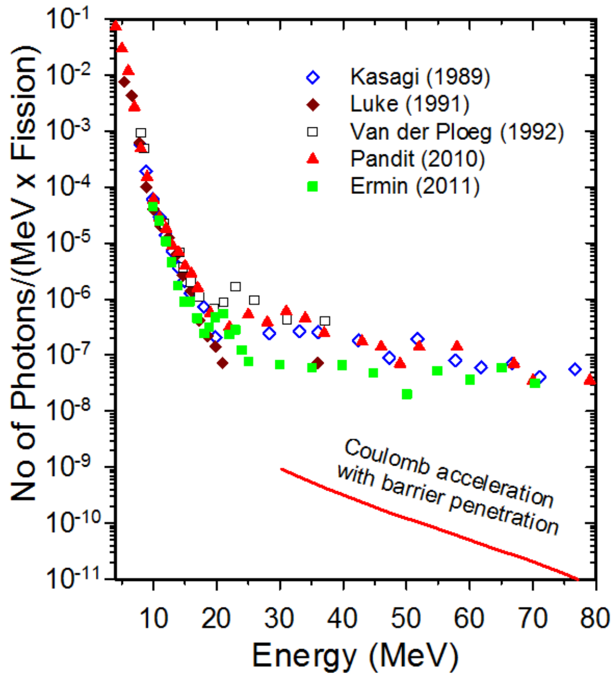
- The γ emission takes away the kinetic energy of the fission fragments that would lead the fragments into a classically forbidden region. This reduces the photon emission probability

Reduced tunnelling probability will set an upper limit of photon emission:

$$P(r) = \frac{1}{1 + e^{2\,S(r)}},$$

where

$$S(r) = \int_r^{r_{\rm CTP}} ds\, \frac{\sqrt{2\,\mu}}{\hbar}\, \sqrt{[V_{\rm Coul}(s) - T(s)]}.$$



The measured event rate is 2 order of magnitude higher than expected !

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Search for high energy γ rays from the spontaneous fission of ^{252}Cf

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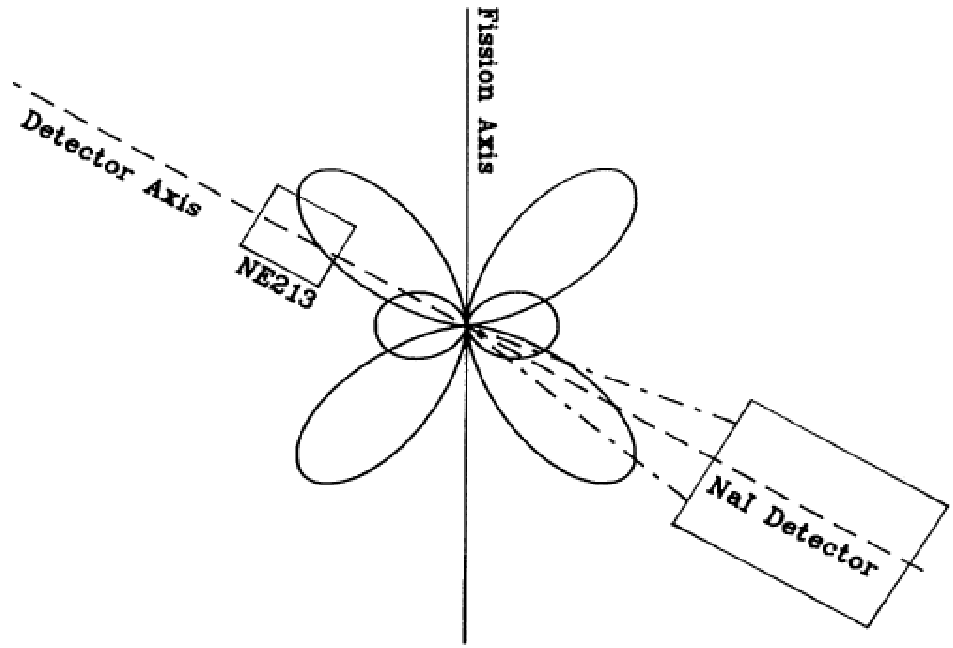
(Received 26 December 1990)



were observed. The source was 50 cm away from a 25.4 cm × 38.1 cm NaI detector which was surrounded by a passive lead shield and an active anticoincidence shield to minimize the cosmic-ray background. The solid-state

Measurement of high-energy prompt gamma-rays from neutron induced fission of U-235

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Abstract. We have developed a new setup to measure prompt γ-rays from the $^{235}U(n_{th}, f)$ reaction. The setup consists of two multi-wire proportional counters (MWPCs) to detect the fission fragments, two $LaBr_3$(Ce) scintillators to measure the γ-rays. The highly efficient setup was installed at the PF1B beam line of the Institut Laue Langevin (ILL). We have successfully measured the γ-ray spectrum up to about 20 MeV for the fist time in neutron-induced fission.

DOI: 10.1051/epjconf/201714604036

Methodologically:

(I) Measurement of γ in coincidence with low energy γ rays (the γ-γ coincidence technique) [Disadvantage: Can't separate the cosmic gammas]

Kasagi et al; J. Phys. Soc. Japan 58, 620 (1989)
Luke et. al, Phys. Rev. C 44, 1549 (1991)[NE213-NaI]
H. van der Ploeg. et al, Phys. Rev. Lett. 92, 3145 (1992) [BaF2-NaI&BaF2]
Eremin et al; Bulletin of the Russian Academy of Sciences (2011)[Polystyrene organic Scintillator-BGO]

(II) Fission fragments (the γ - *fission* coïncidence technique)

Luke et. al, Phys. Rev. C 44, 1549 (1991)
H. van der Ploeg. et al, Phys. Rev. Lett. 92, 3145 (1992)

(iii) Measurement of high energy γ rays accompanying the induced fission of 235U in a reactor

Varlachev et al; JETP Letters, 82, 390 (2005)

(iv) Direct measurement of γ using large volume scintillators (NaI and BaF2) with anticoincidence protection from the cosmic background

Pokotilovskii et al, Sov. J. Nucl Phys 52, 599 (1990)

Cosmic Reduction Factor Measurement@ JUSL

Detector setup @ JUSL

Electronic setup @ JUSL

EXPERIMENT AT VECC (Surface Lab)

- Detector threshold: above 3 MeV
- Any two detectors in coincidence: 7280/hour

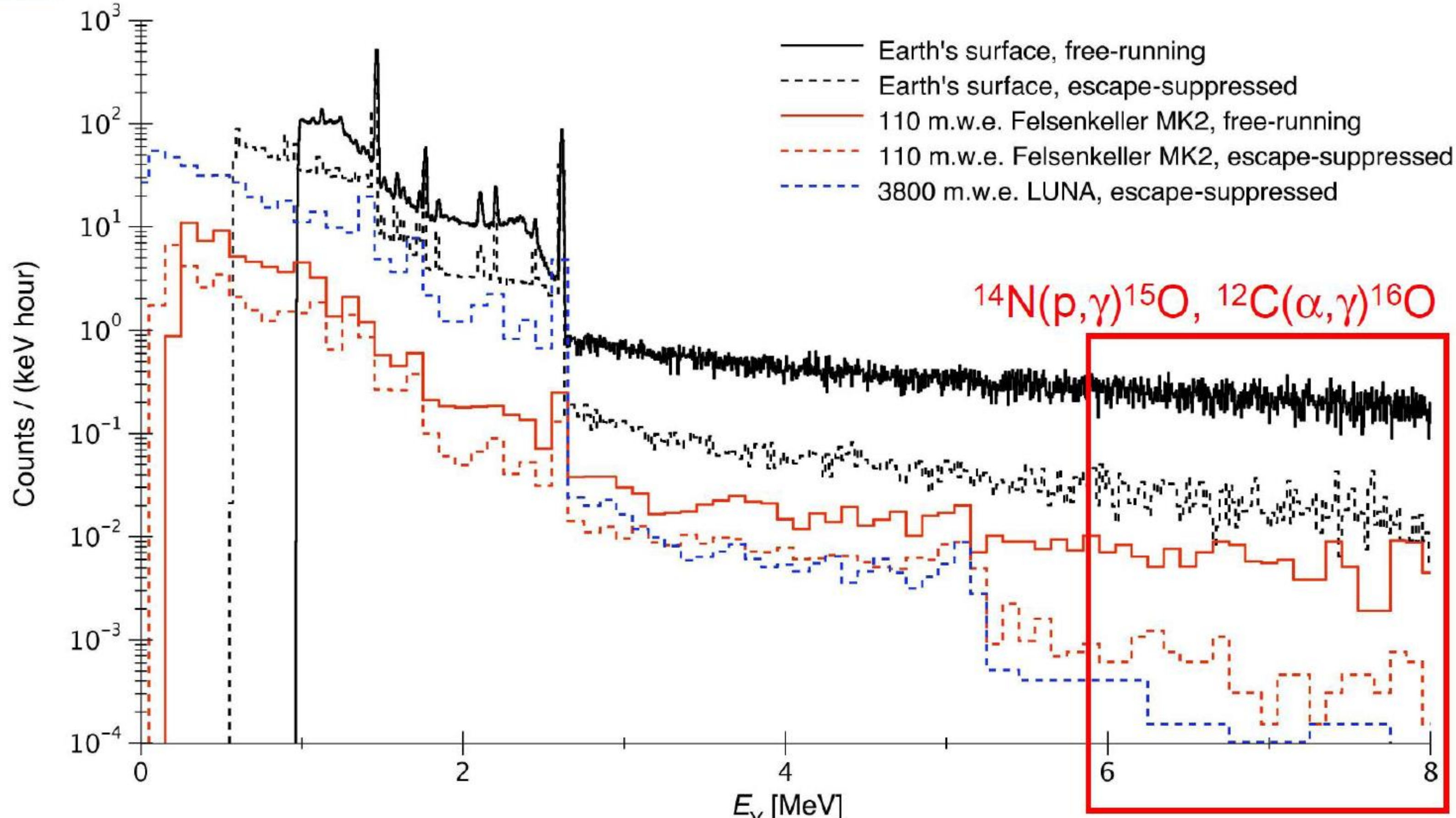
EXPERIMENT AT JUSL (Underground)

- Detector threshold: above 3 MeV
- Trigger Condition: any two detectors out of four
- Run time: 17 hours
- Depth of the underground Lab: 555 meter

RESULTS

- Scalar reading in Surface Lab: 123760 counts
- Scalar reading in Underground Lab: 5 counts

Cosmic reduction factor = 2.4×10^4



Earth's surface, free-running
Earth's surface, escape-suppressed
110 m.w.e. Felsenkeller MK2, free-running
110 m.w.e. Felsenkeller MK2, escape-suppressed
3800 m.w.e. LUNA, escape-suppressed
$^{14}N(p,\gamma)^{15}O$, $^{12}C(\alpha,\gamma)^{16}O$
Counts / (keV hour)
E_γ [MeV]

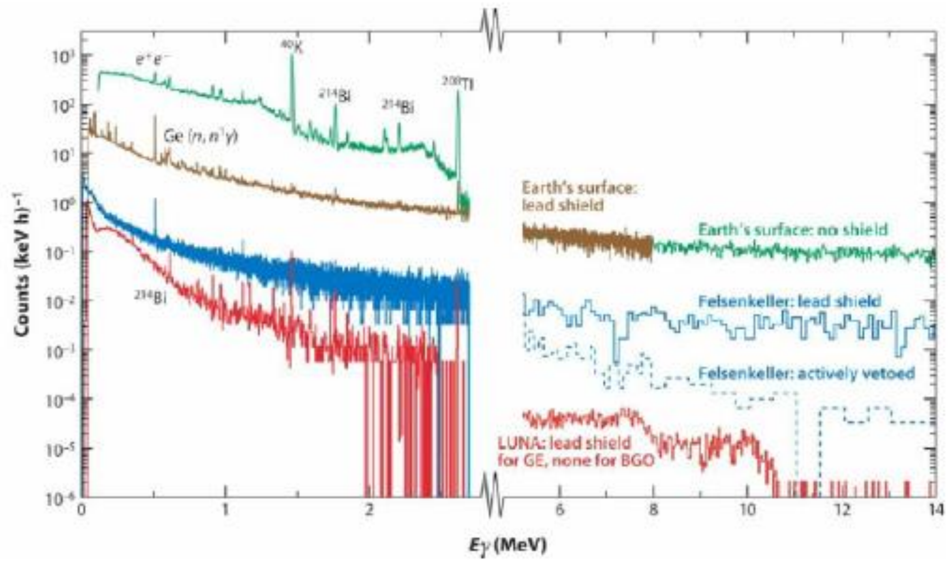
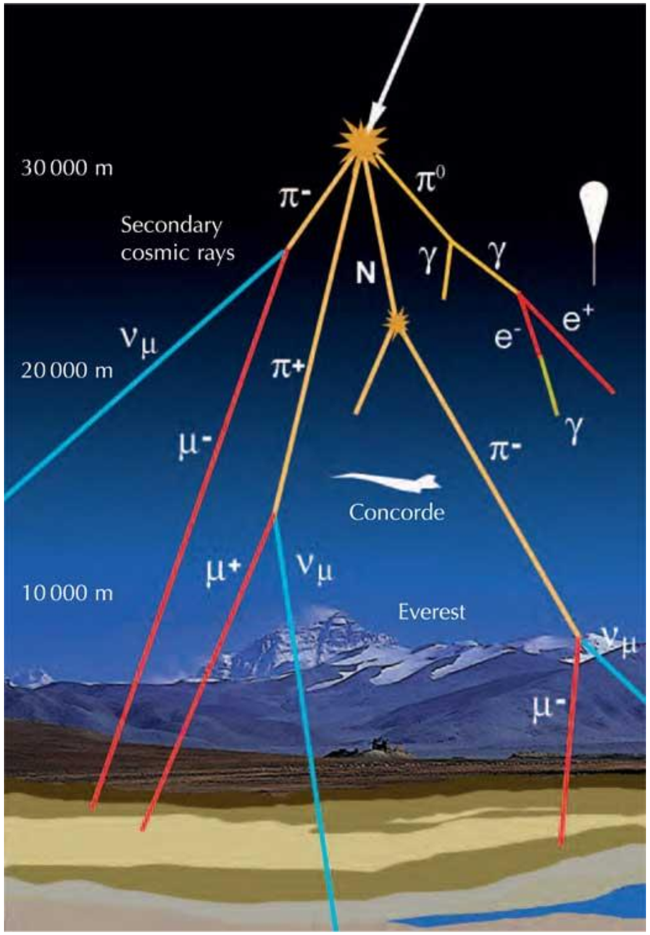


FIG. 1: Laboratory γ-ray background measured with (a) a 100% relative efficiency Ge detector at $E_\gamma <$ 2.7 MeV and (b) a bismuth germanate (BGO) detector (scaled for equal volume with the germanium) for 5.2 MeV $< E_\gamma <$ 14 MeV. The green plot represents the background on Earths surface with no shield while the brown curve represents the same with lead shield. The blue solid curve is the background at 110-mwe (meters water equivalent) underground Felsenkeller laboratory (Dresden, Germany) with lead shield and the blue dashed line indicates actively vetoed spectrum in the Felsenkeller lab. The red curve is the background at 3,800-mwe LUNA lab with lead shield for the Ge detector and no lead shield for the BGO detector [Broggini et al. Ann. Rev. Nucl. Part. Sci. 60, 53(2010)].

Why do physicist need to go at underground ?



- Every moment earth's atmosphere is bombarded by Cosmic Rays. Approx. 90% of them are hydrogen nuclei (protons).
- When a high energy proton strikes an atom at the upper atmosphere, a cascade of other particles are formed
- Muons observed at the surface of the earth and underground sites are mainly produced in the decay of pions.

Mean energy of muons at the ground $\approx$ 4 GeV, count rate $\approx$ 1/min /cm^2

When conducting any low count-rate experiment, like rare and week signals created by dark matter, cosmic muons are the main source of background

Jaduguda Underground Science Laboratory (JUSL)

Elevator takes about 3 minutes to reach the innards of this uranium mine, from where the lab is a short walk.