MUON FLUX MEASUREMENT UNDERGROUND WITH THE EEE COSMIC BOX

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WHY MEASUREMENT UNDERGROUND

- Natural extension of altitude measurement
- Well known sites
- Abundance of data of underground measurement
- Real and handy example of attenuation phenomena

THE NURAXI FIGUS - SERUCI MINE COMPLEX

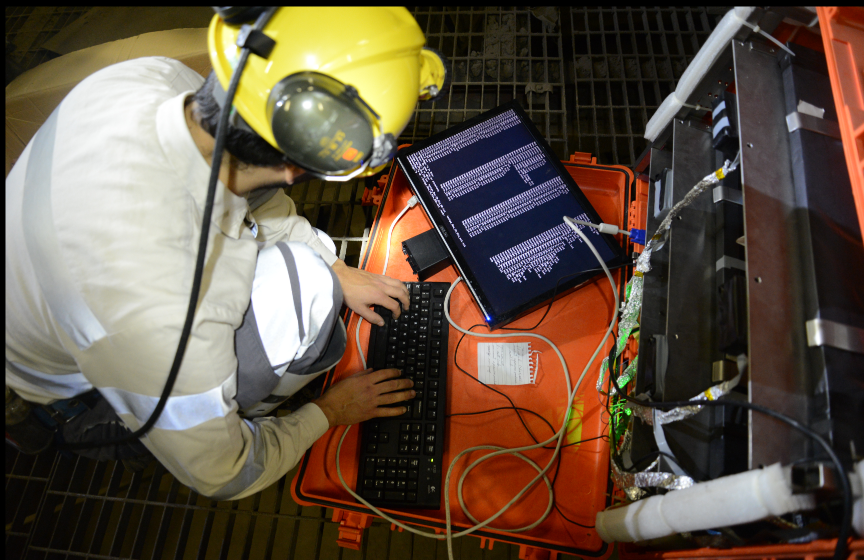
- Why here?
  - Active mine, no more extractions
  - Winze
  - Electric current steady supply
  - Staff availability : project ARIA
  - Well studied and safe enviroment

THE DETECTORS

- Cosmic Box
  - Box of two 15x15 cm^2 plastic scintillators (spread 12cm)
  - Three detectors connected with Raspberry PC
  - Each event on a CB time tagged
  - Possibility to add the statistics of the three detectors
  - Arduino start signal
- ASTRO
  - 8 scintillators with single SiPM (4 long 60x8 cm, 4 short 15x8 cm)
  - Several coincidence combination (2 scintillator or more)
  - FPGA system control
  - Hardware temperature correction
  - Photo-electron Calibration
  - Transportable in sealed box
  - Weather station and GPS
  - 20 h autonomy with battery and switch in case of no normal power

C.Cicalò,S.Boi,G.Serri

UNDERGROUND MEASUREMENT



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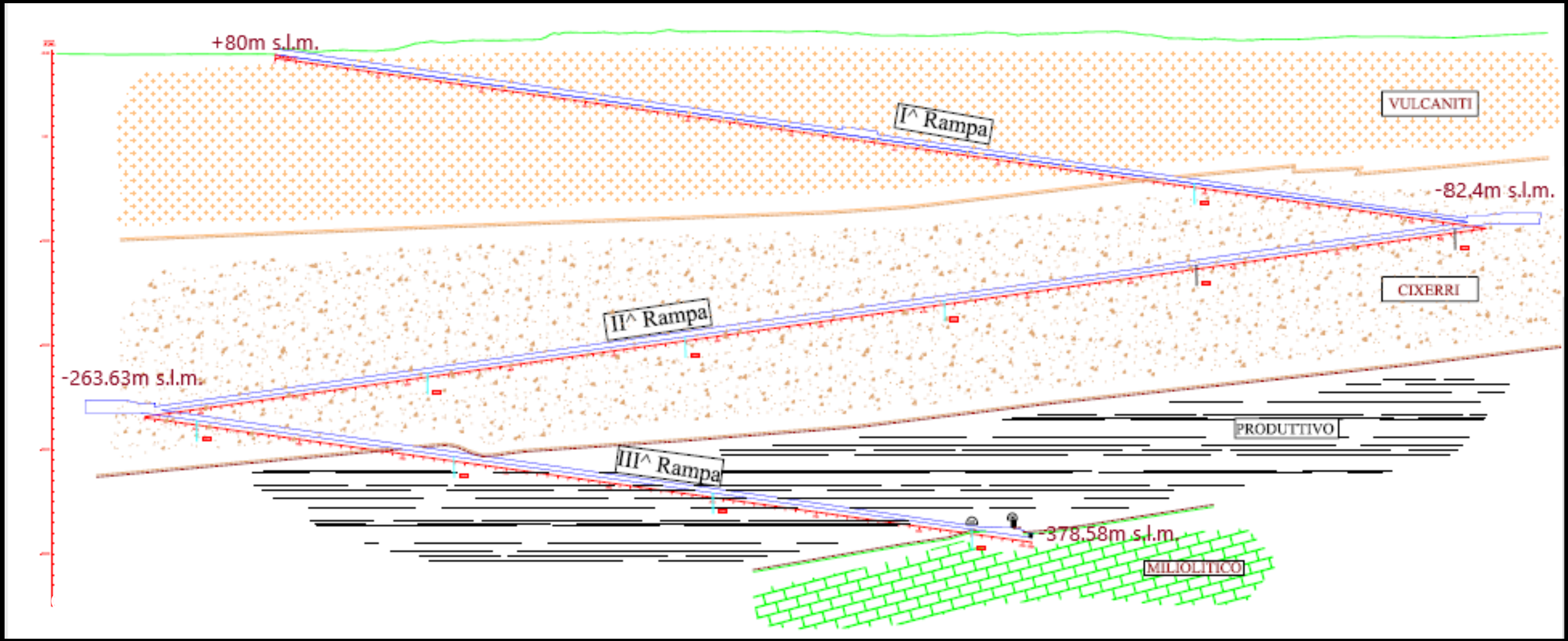
THE MEASUREMENTS

- We selected three depths:
  - Surface (+100 m above sea level A.S.L.) out of the mine entrance
  - \- 174 m (-78 m A.S.L.)
  - \- 339 m (-259 m A.S.L.)
  - \- 500m (-397 m A.S.L.)



DEVELOPING AN EXPERIMENT: TIME ESTIMATION

How much time does the measurement require?

- Domusnovas measurement
- Comparison and projection of existing models

PREVIOUS MEASUREMENT

STEFANO BOI, ALICE MULLIRI, CORRADO CICALO'

- S.Giovanni cave --> Domusnovas (40 km west of Cagliari). APR 2018
- Two Cosmic Box
- Outside the cave: R=1.38Hz
- Inside the cave(100 m of limestone d≈2.1g/cm^3): R=3.9e-3

PREVIOUS PROJECTIONS IN DOMUSNOVAS

Depth in m (standard rock)	Acquisition days	$\frac{\sqrt{n}}{n}$
100	1	0.05
	3	0.03
	7	0.02
200	1	0.08
	2	0.055
	7	0.03
	15	0.02
300	1	0.13
	2	0.089
	7	0.047
	15	0.032
400	1	0.2
	2	0.14
	7	0.074
	15	0.05
500	1	0.48
	7	0.18
	15	0.12
	20	0.1

COMPARISON ON EXPECTED RATE

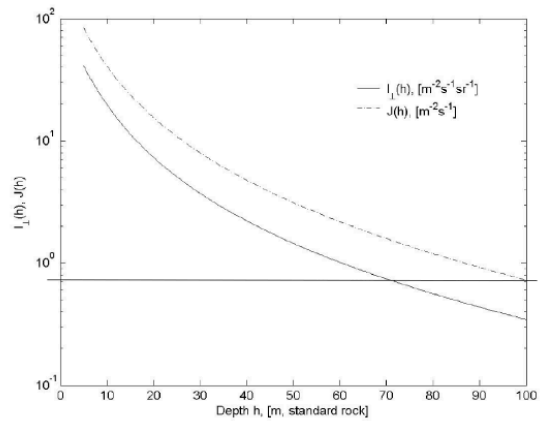


Figura: Muon flux as a function of standard rock depth (Cosmic muon flux at shallow depths underground. L.N.Bogdanova, M.G.Gavrilov, V.N. Kornoukhov, A.S.Starostin).

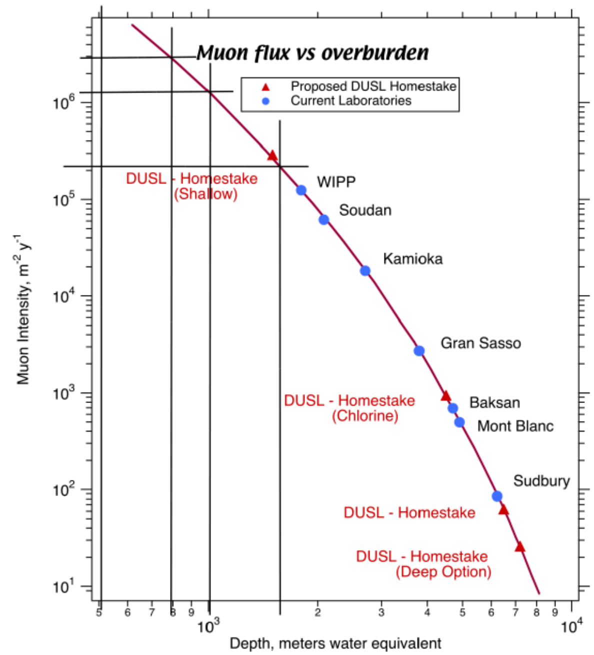
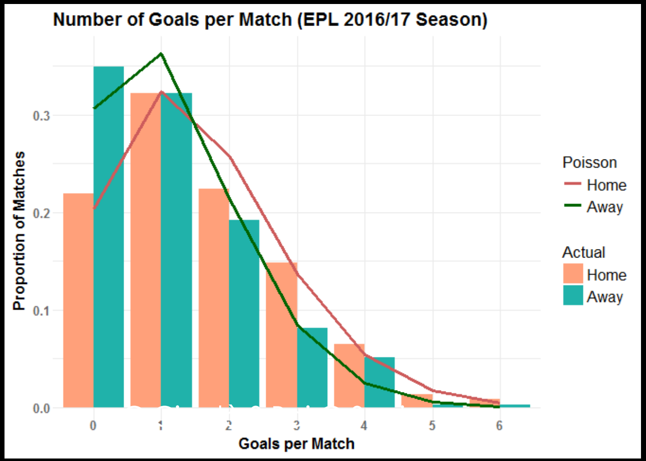


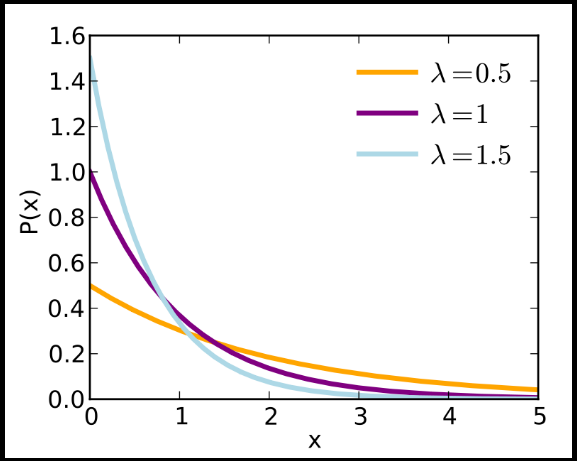
Figura: Muon flux as a function of depth in equivalent m of water measured in various experiments (V. Diwan et all J. (2003). Megaton Modular Multi-Purpose Neutrino Detector for a Program of Physics in the Homestake DUSEL).

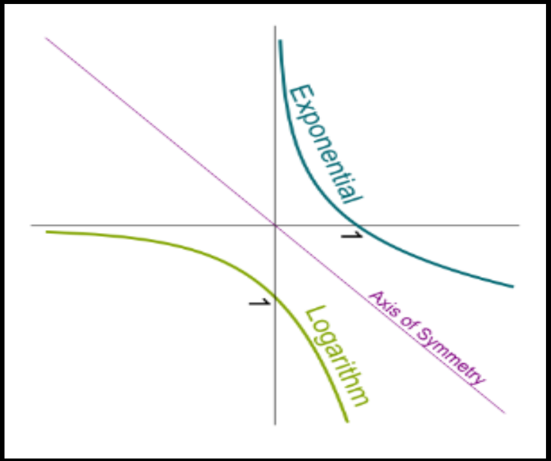
FIRST RESULTS OF ONGOING MEASUREMENTS

POISSON DISTRIBUTION

- Rare events $(n \gg 1, p \ll 1)$
- Number of events in finite and constant time interval
  $P(n) = e^{-\mu}\frac{\mu^n}{n!}$ Poisson distribution, $\mu = \lambda t$
- Probability of having one event in dt: $dP = P_{(0,t)} = \lambda dt$
- Probability of 0 events: $P_{(0,t)} = e^{-\lambda t}$
- Probability density distribution $q(t) = \frac{dP}{dt} = \lambda e^{-\lambda t}$: negative exponential (more likely a little time separation than a long one)

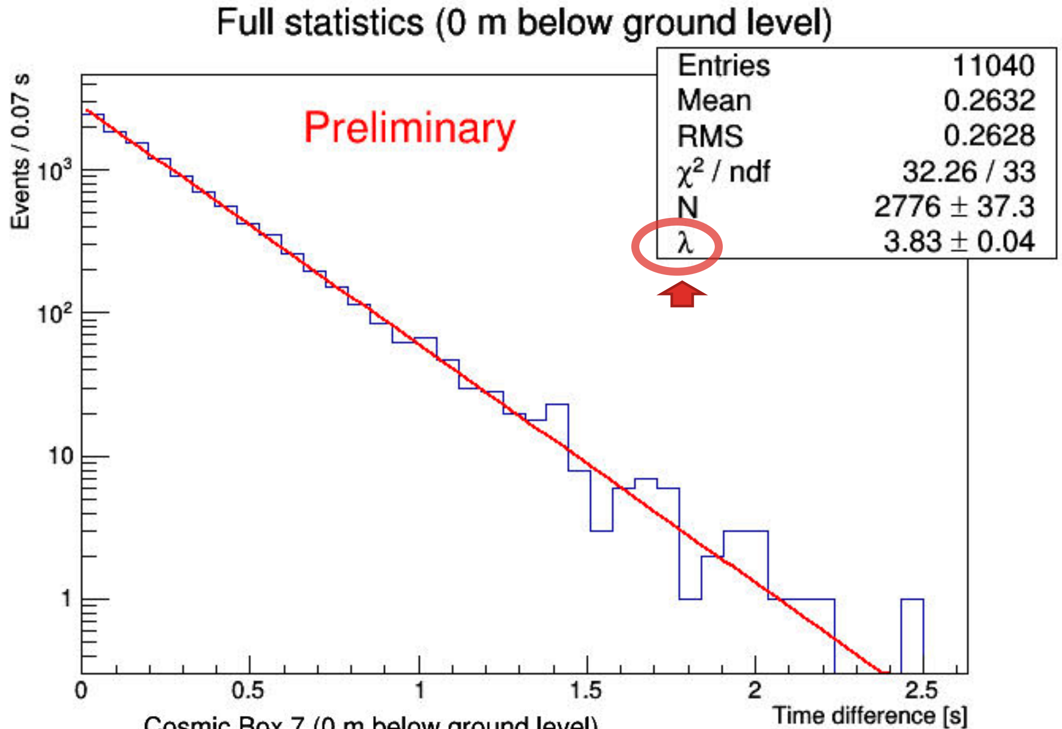


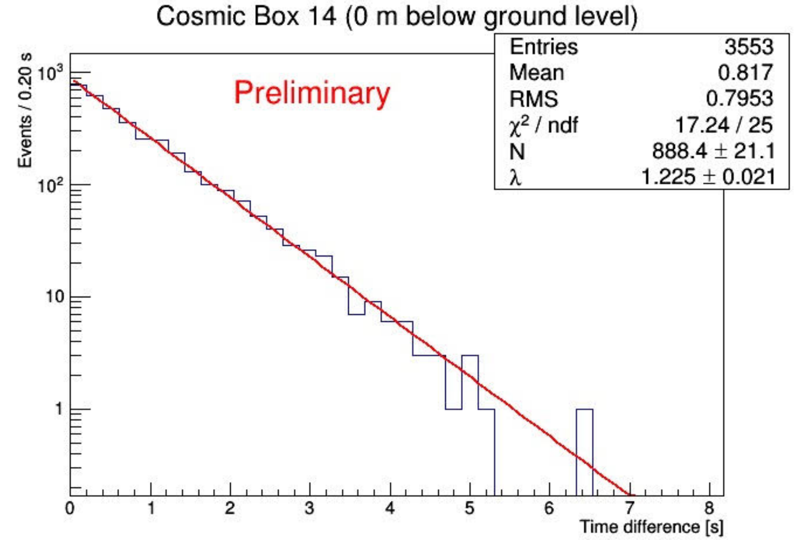


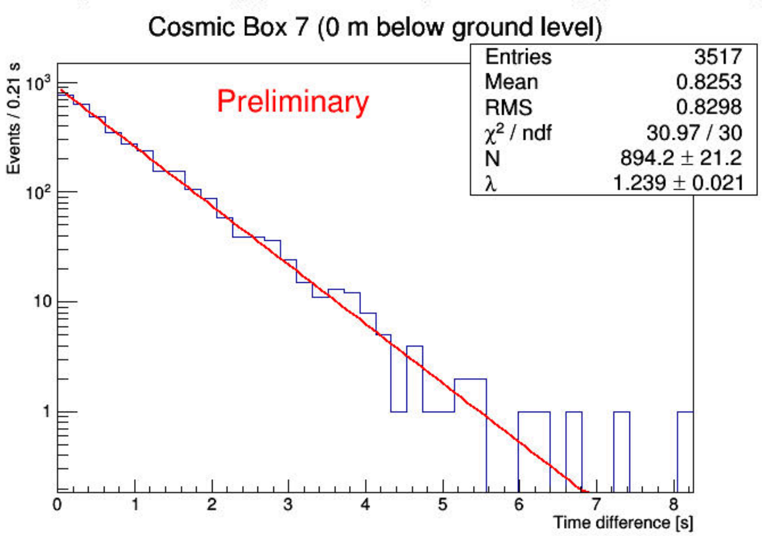


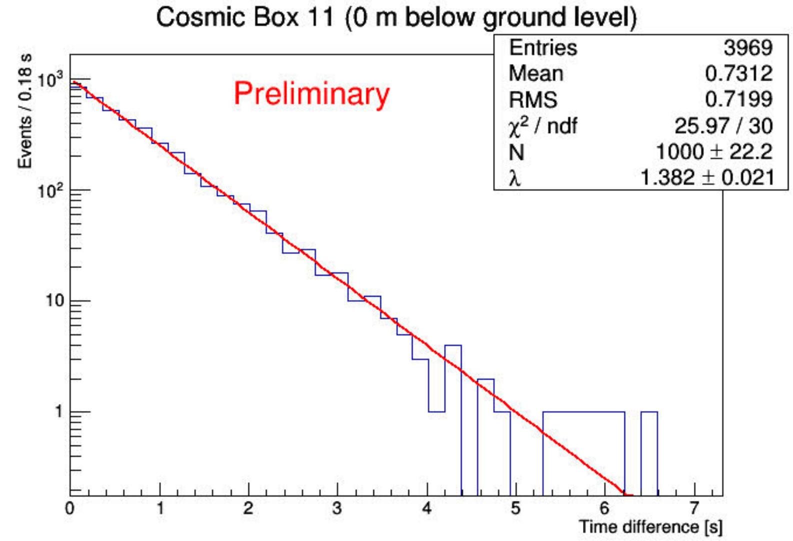
Outside the mine…
Acquisition time 2902s

DISTRIBUTION OF TIME DIFFERENCE BETWEEN TWO SUBSEQUENT EVENTS



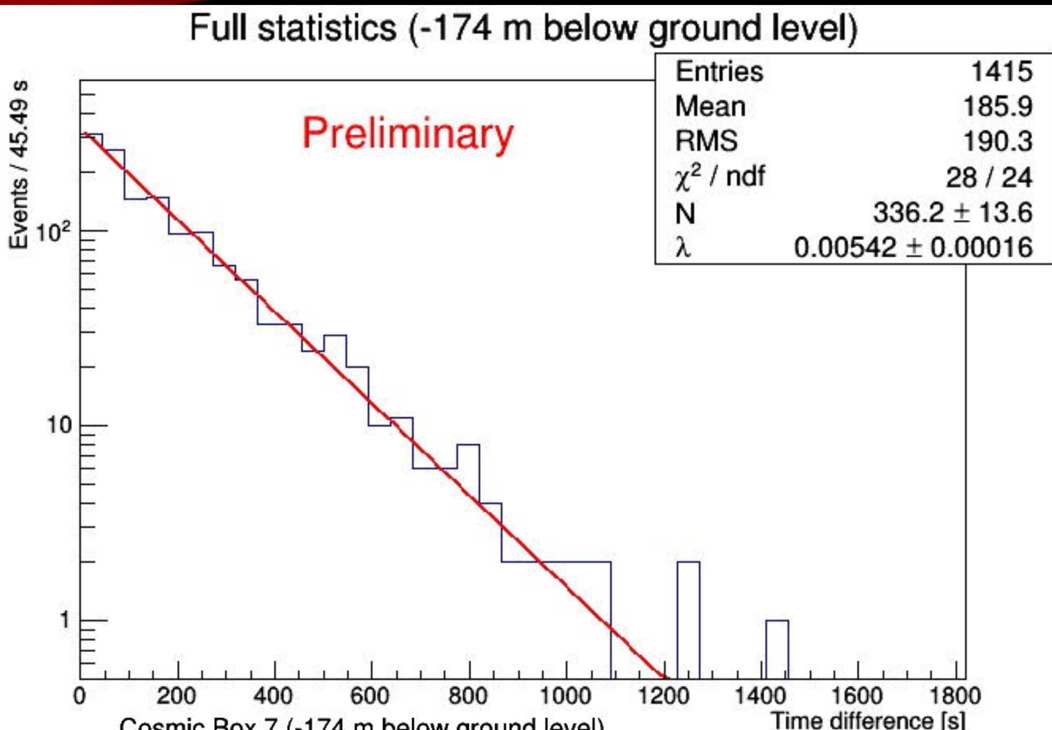


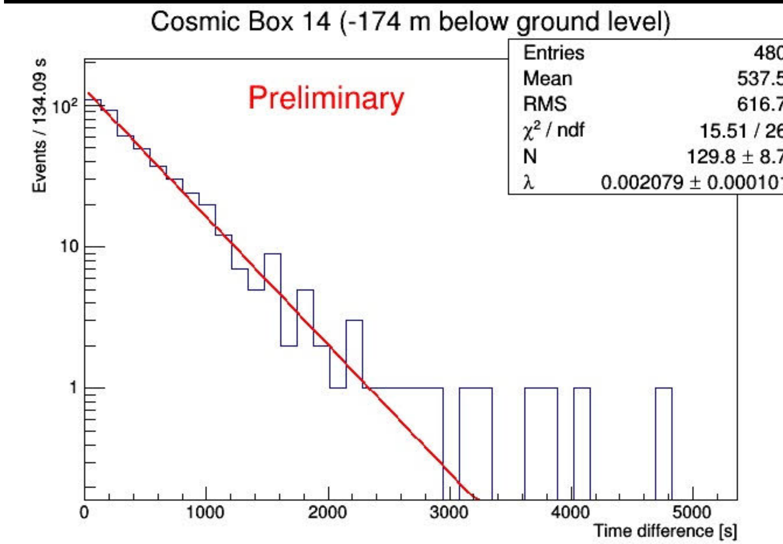


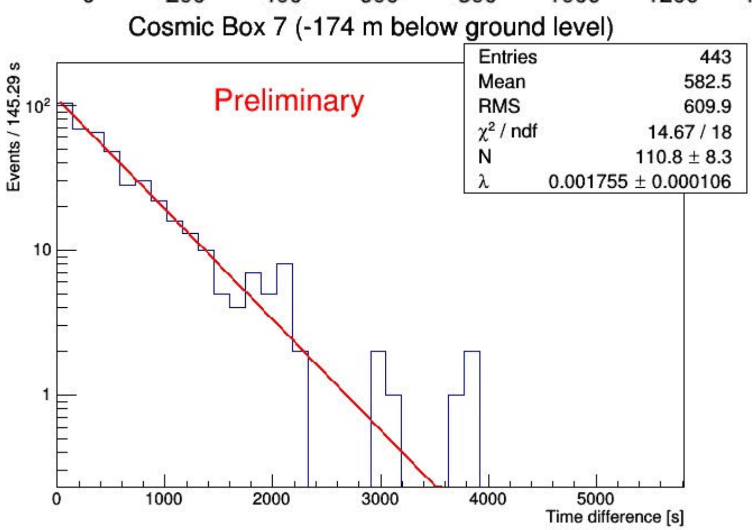


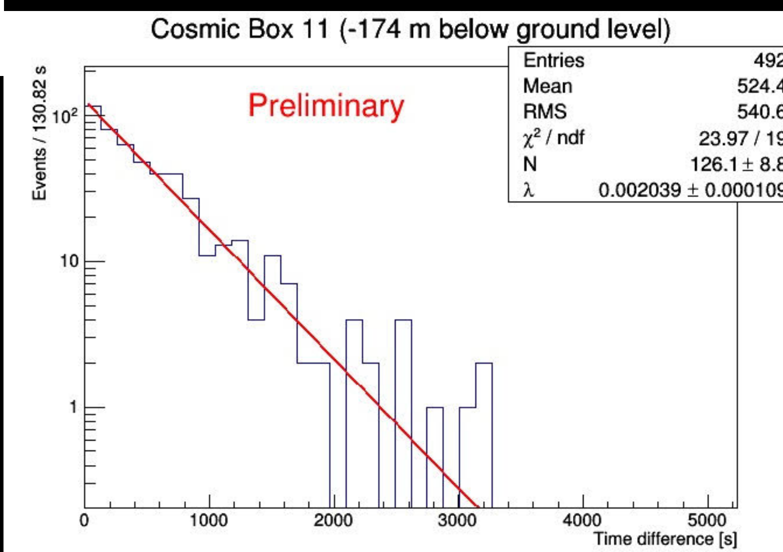
First level inside the mine..
Acquisition time 72hr=259200s

DISTRIBUTION OF TIME DIFFERENCE BETWEEN TWO SUBSEQUENT EVENTS



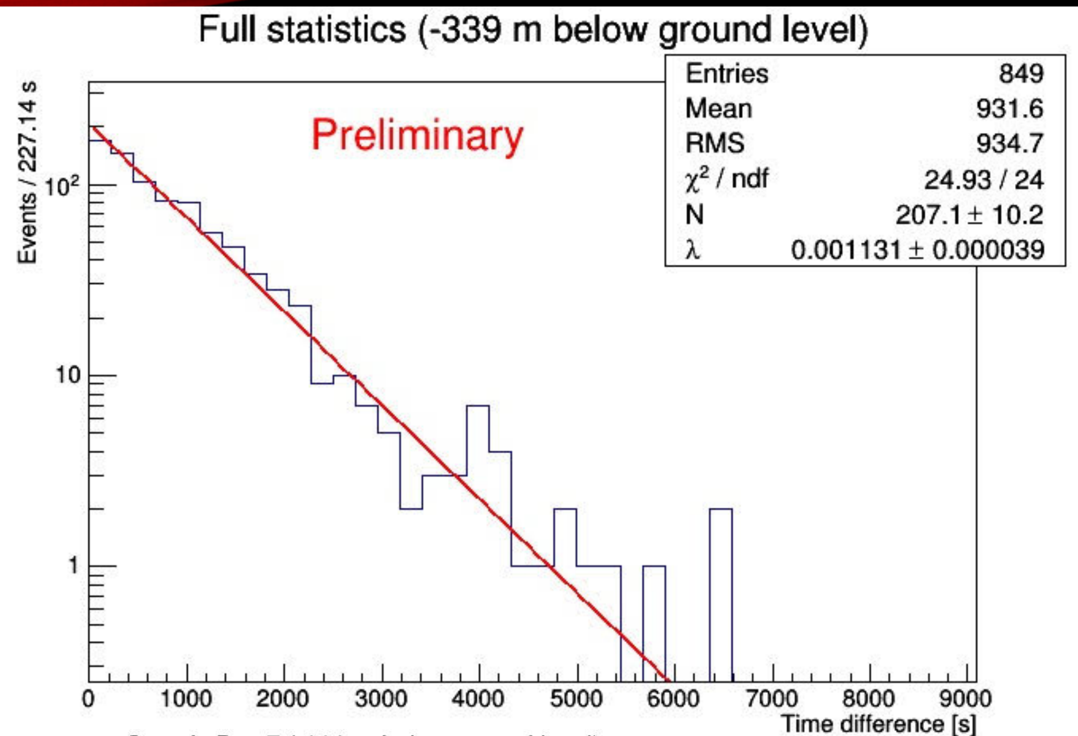


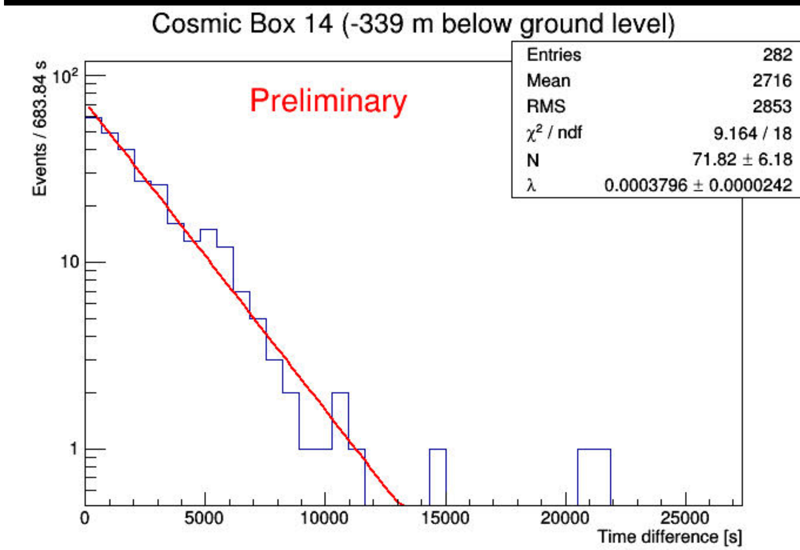


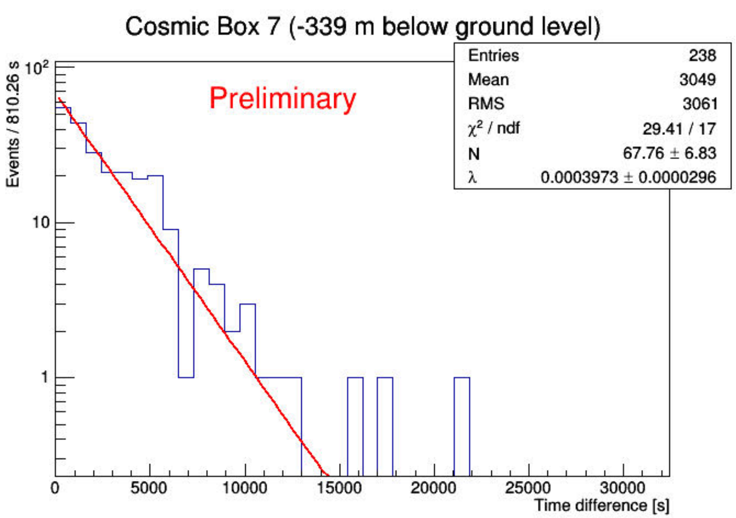


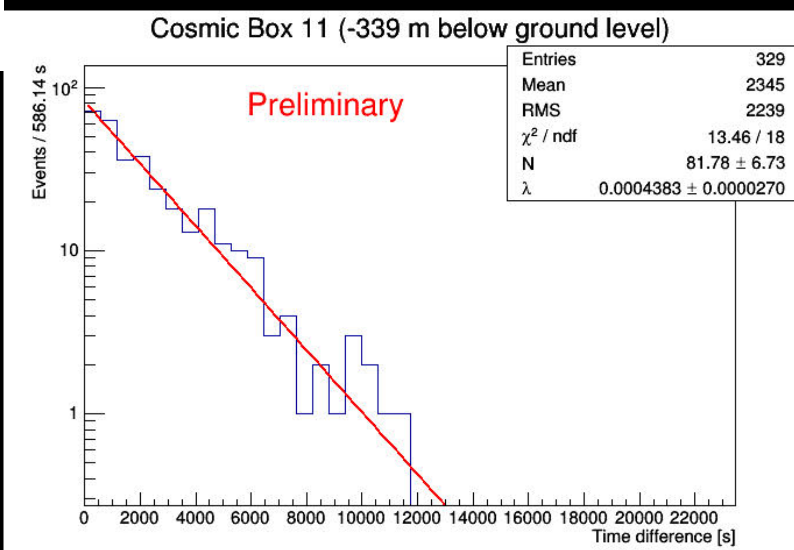
Second level inside the mine..
Acquisition time 9d=$7.7 \cdot 10^5$s

DISTRIBUTION OF TIME DIFFERENCE BETWEEN TWO SUBSEQUENT EVENTS

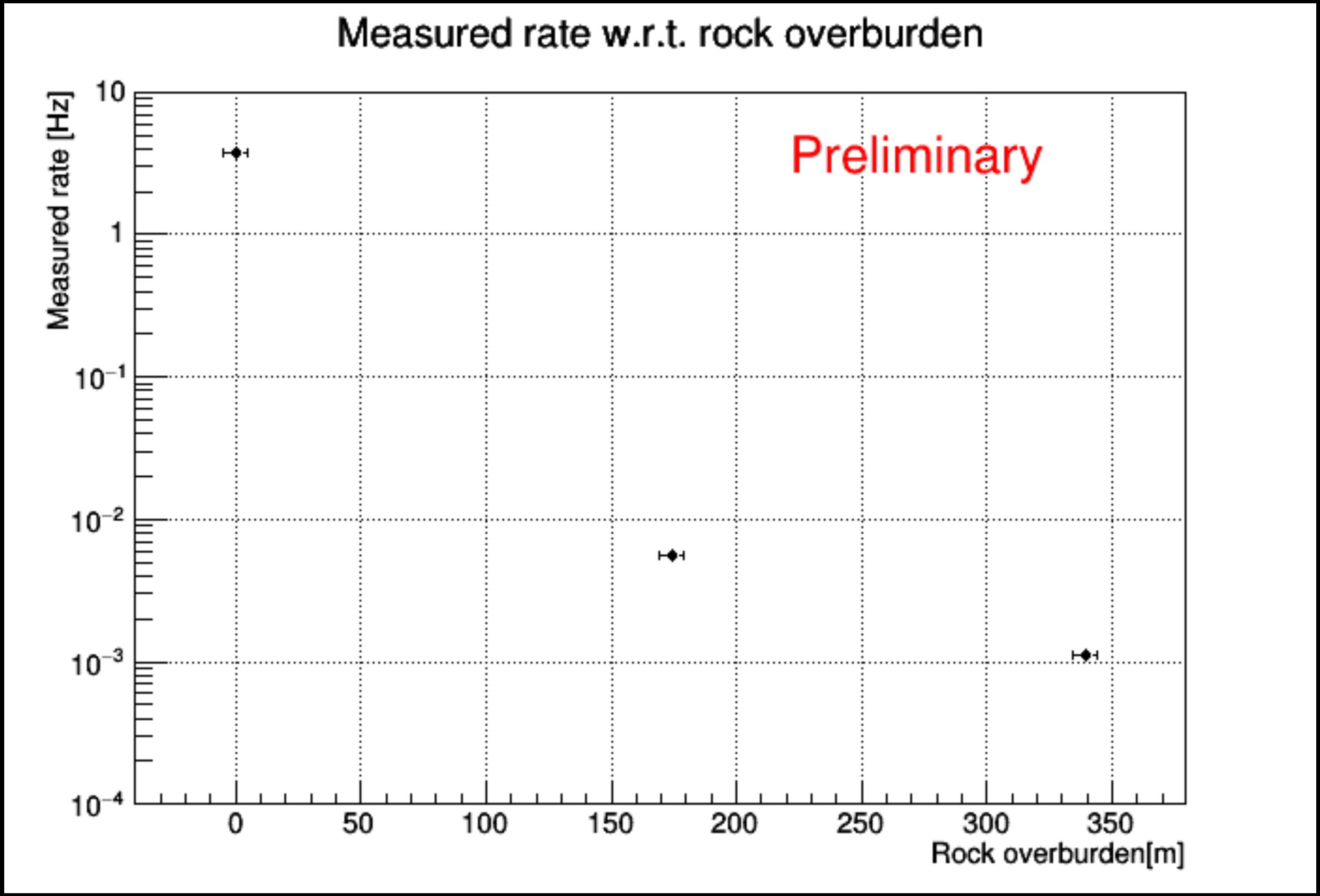








RESULTS: RATE



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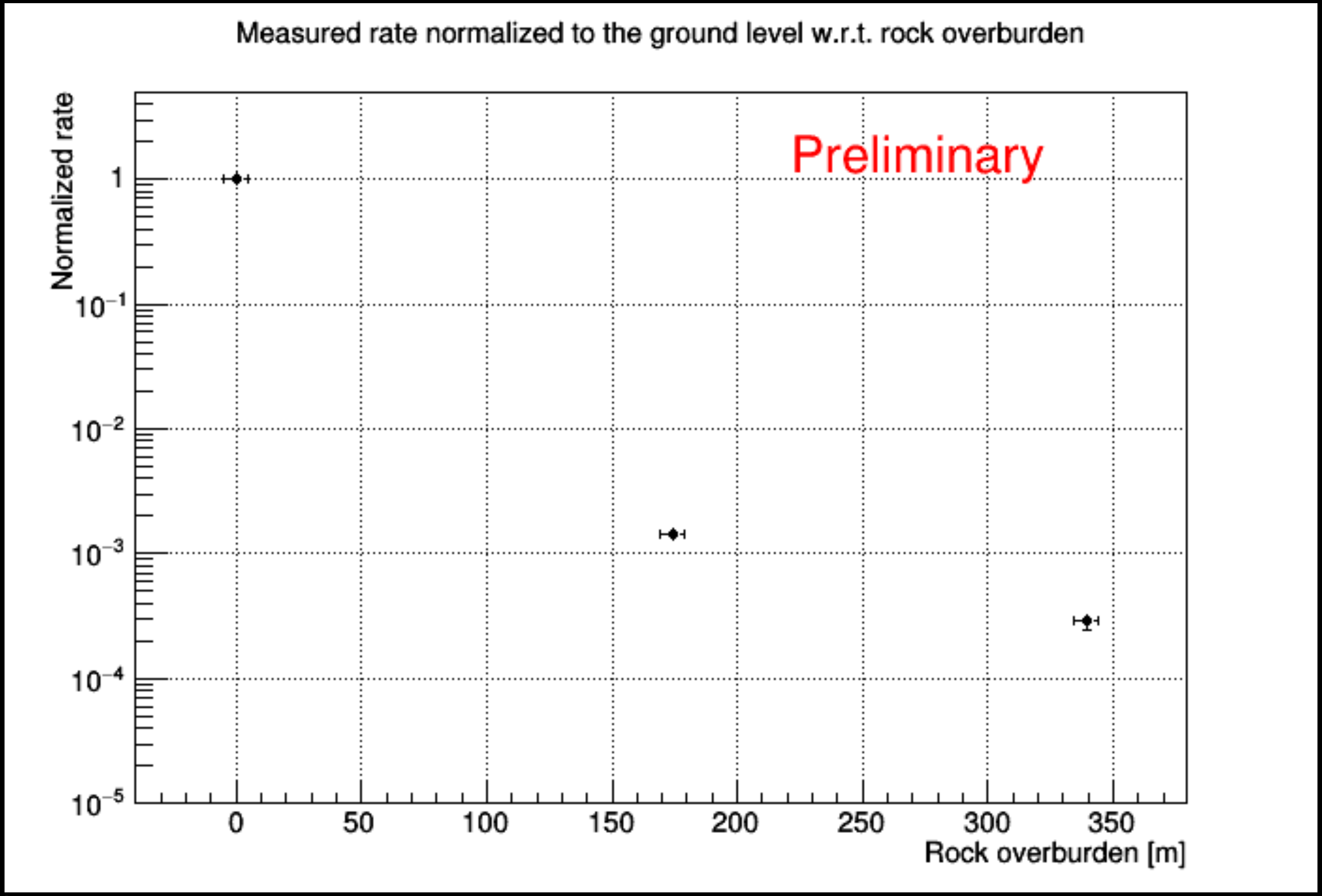
RATE RELATIVE TO THE SURFACE

- R(surf) = (3.80±0.04) Hz
- R(-174m) = (5.49±0.15)·10^{-3} Hz
- R(-339m)=(1.10±0.04) · 10^{-3} Hz

- $\frac{R(-174)}{R(surf)} = (1.44 \pm 0.05) \cdot 10^{-3}$
- $\frac{R(-339)}{R(surf)} = (2.89 \pm 0{,}14) \cdot 10^{-4}$

- Average Rock density in Nuraxi Figus?

NORMALISED RATE



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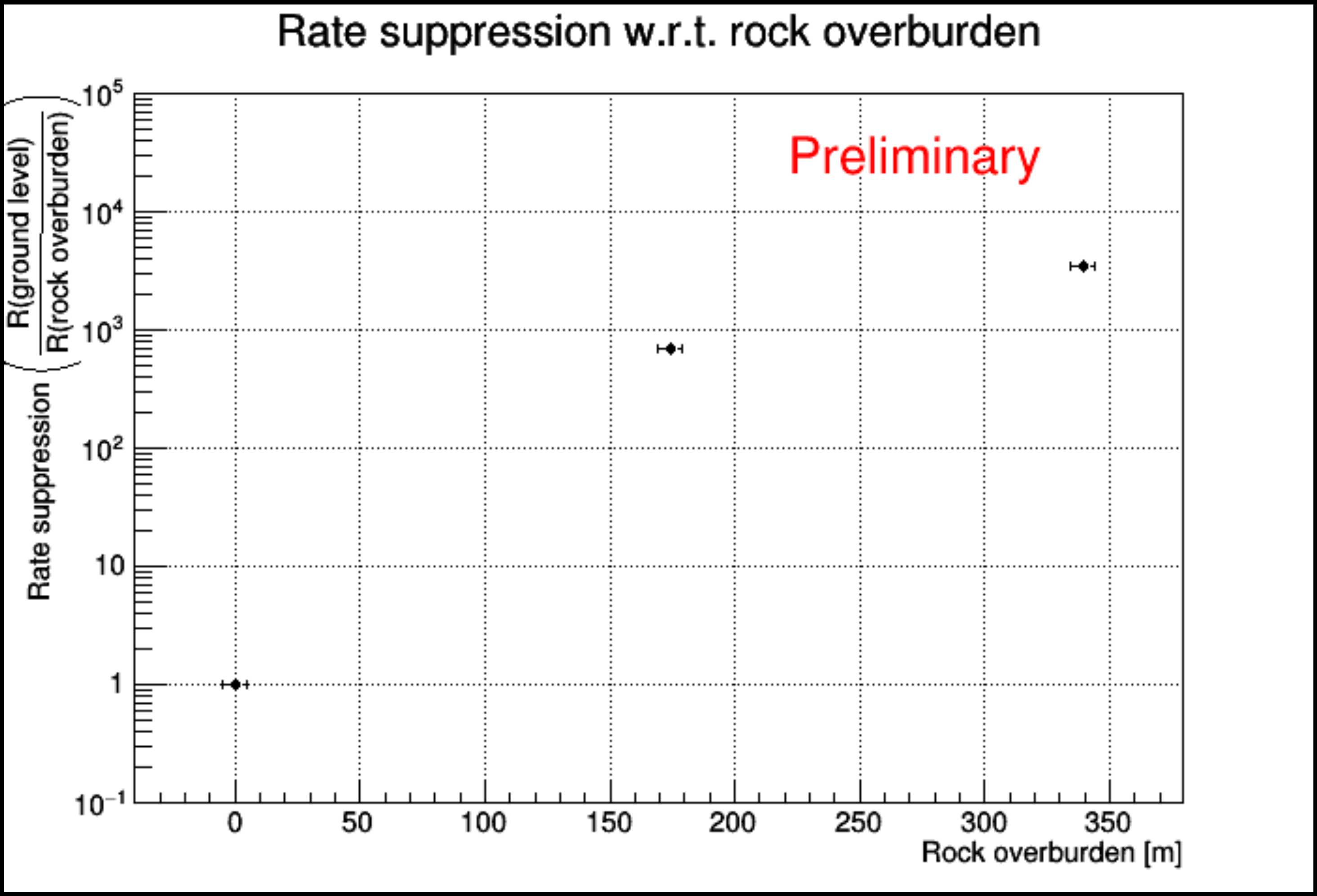
RATE SUPPRESSION



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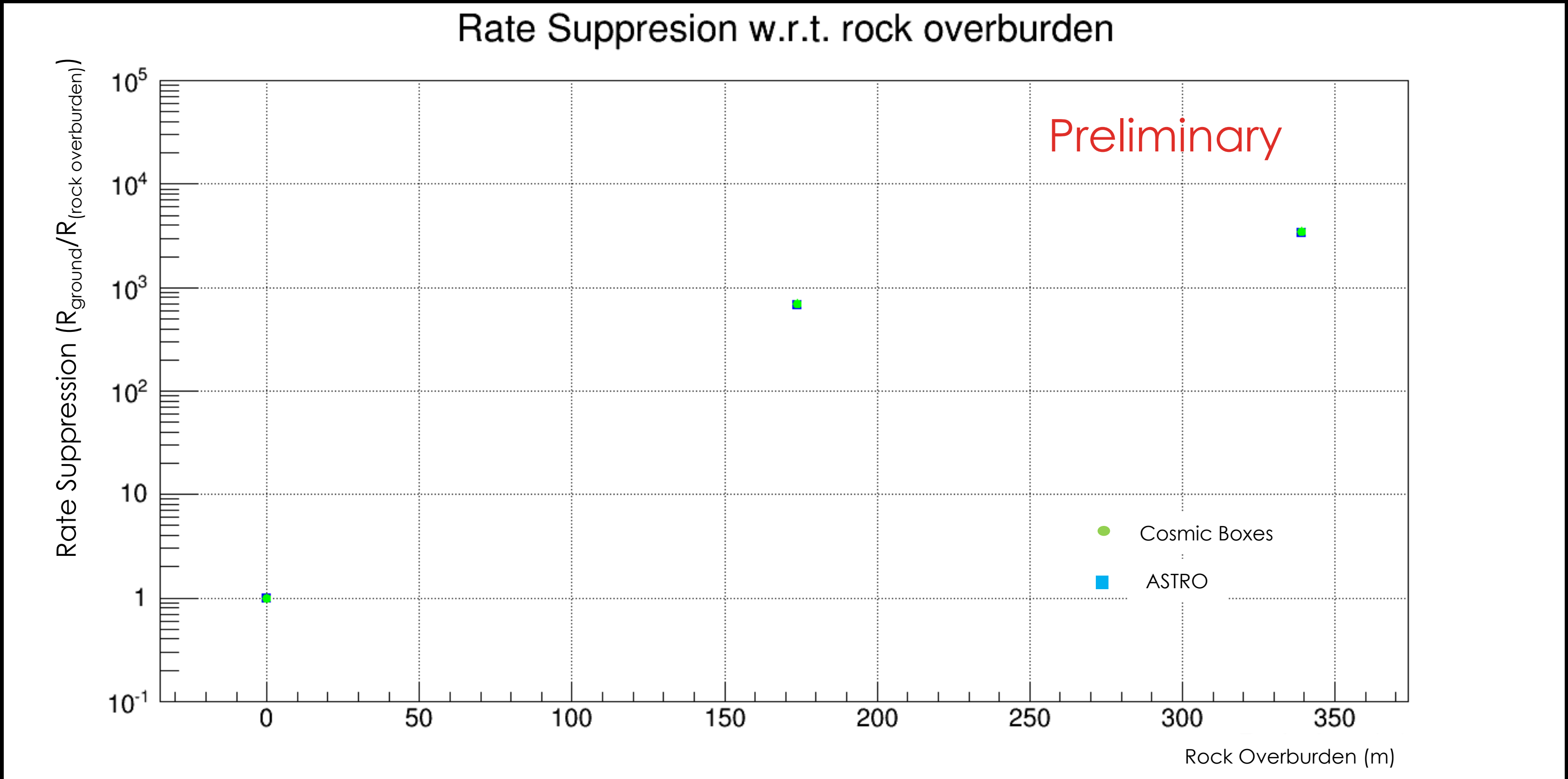
RATE SUPPRESSION



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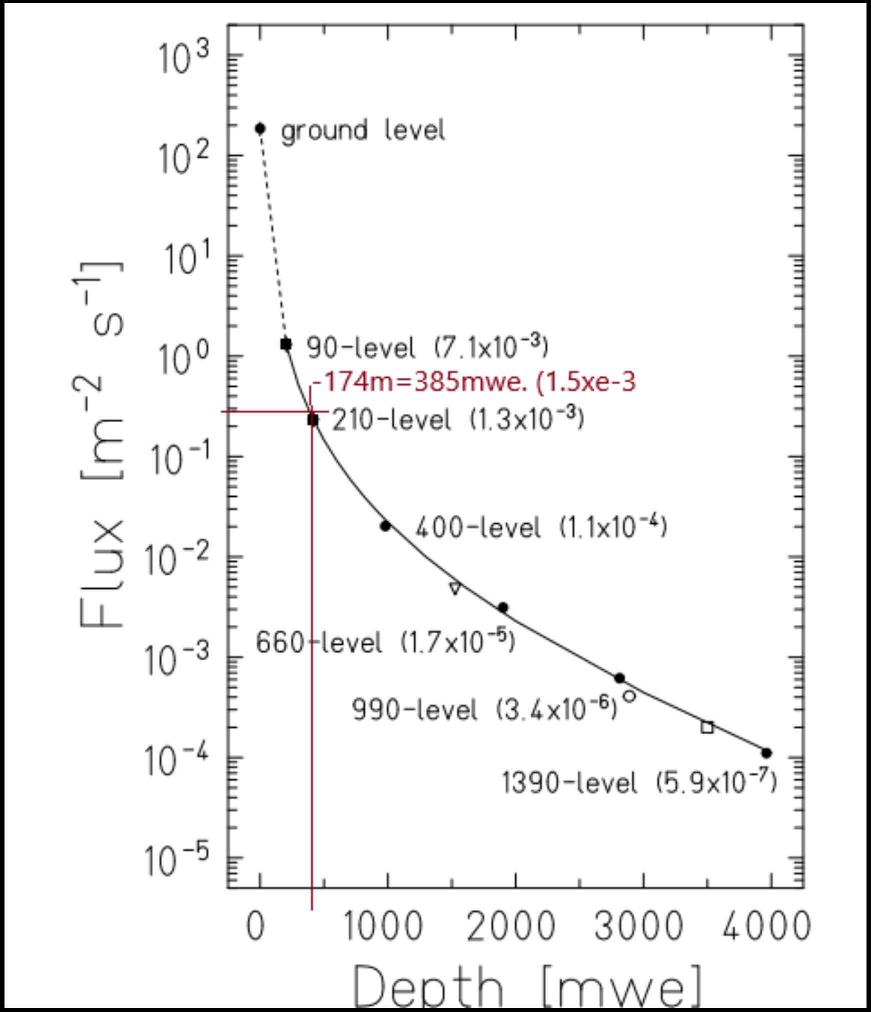
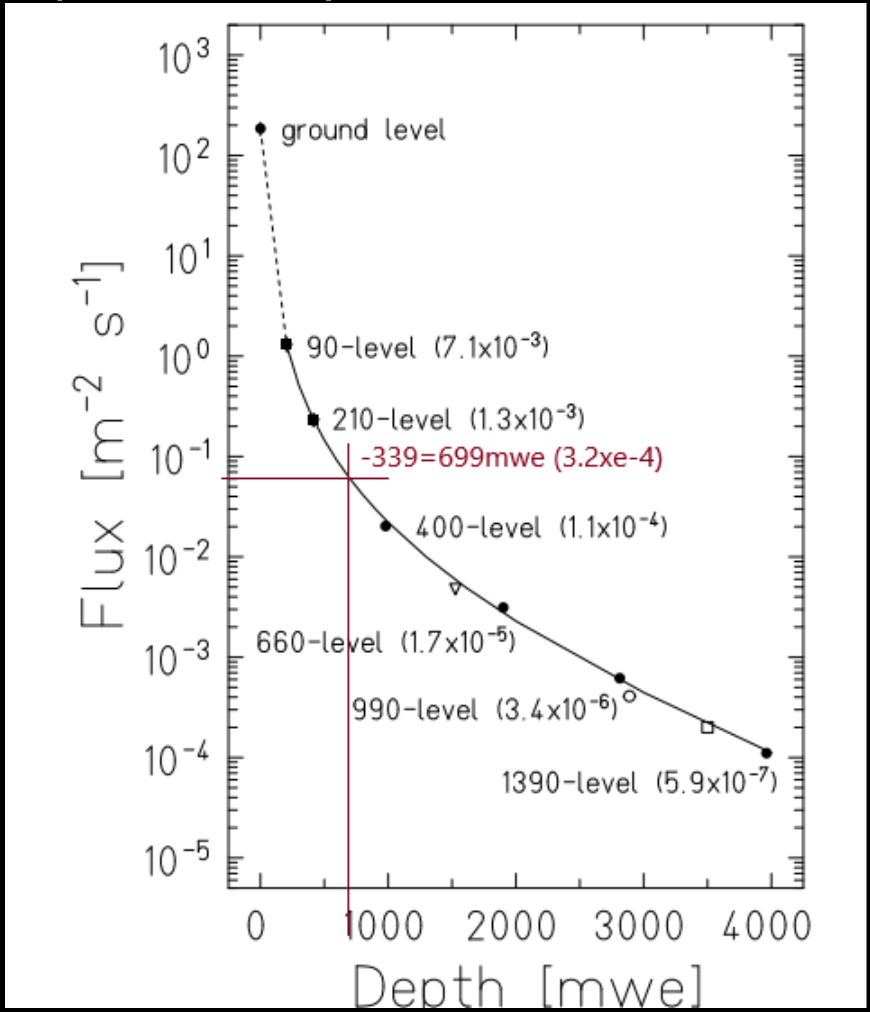
COMPARISON WITH PYHÄSALMI MINE DATA

- $(1.55 \pm 0.07) \cdot 10^{-3}$ cfr $(1.44 \pm 0.05) \cdot 10^{-3}$

$(3.2 \pm 0.2) \cdot 10^{-4}$ cfr $(2.89 \pm 0.14) \cdot 10^{-4}$





WHAT ELSE?

In progress: measurement @ mine's deepest level

To be done:

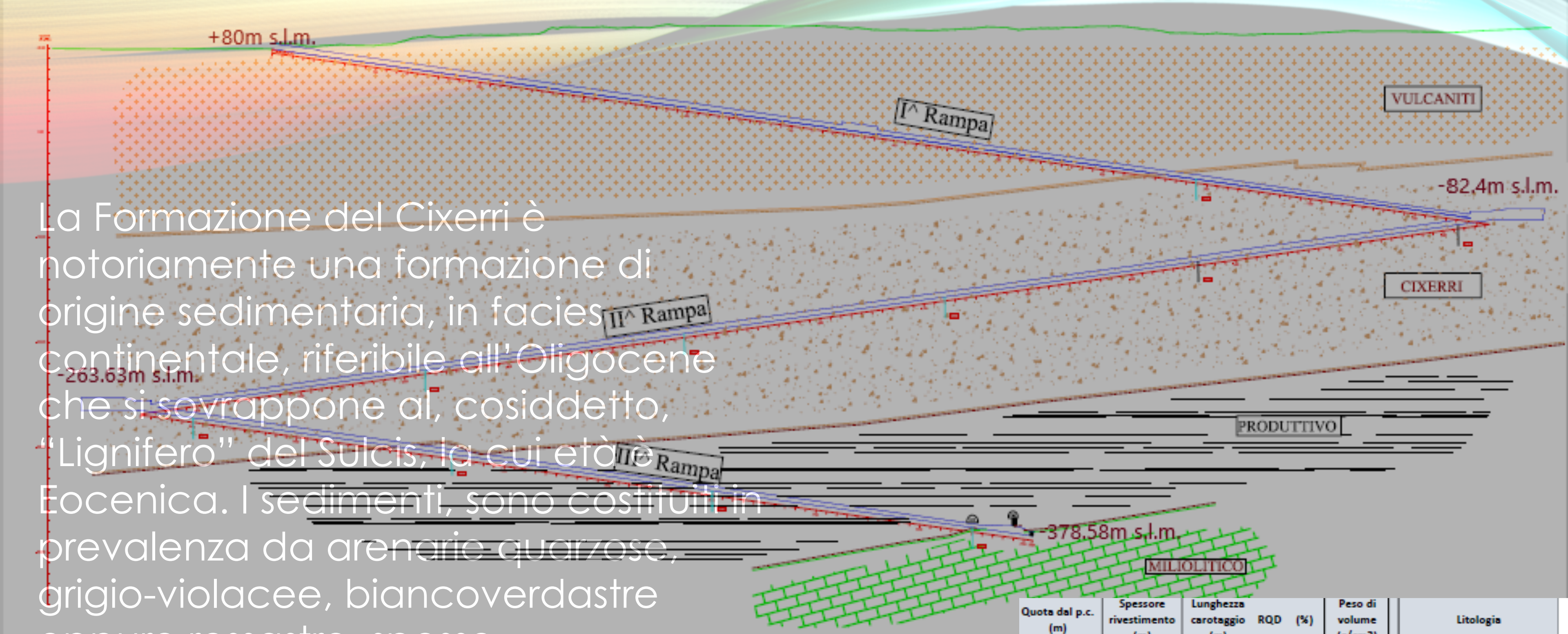
- Precise estimation of the efficiency and acceptance of the CB to measure the absolute flux.
- Refining density profile and precise estimation of rock overburden over detector positioning

ACKNOWLEDGEMENTS

Thanks to Nuraxi Figus mine's personnel

Thanks to INFN Cagliari

BEYOND



La Formazione del Cixerri è notoriamente una formazione di origine sedimentaria, in facies continentale, riferibile all'Oligocene che si sovrappone al, cosiddetto, "Lignifero" del Sulcis, la cui età è Eocenica. I sedimenti, sono costituiti in prevalenza da arenarie quarzose, grigio-violacee, biancoverdastre oppure rossastre, spesso conglomeratiche, a ciottoli di rocce paleozoiche o mesozoiche (soprattutto scisti neri, quarzo, porfidi e calcari del Giurese-Cretaceo). Le arenarie si alternano con marne ed argille siltose violacee o giallo-rossastre, spesso contenenti noduli concrezionari giallastri, ferruginosi, e ben stratificate

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Quota dal p.c. (m)	Spessore rivestimento (m)	Lunghezza carotaggio (m)	RQD (%)	Peso di volume (g/cm3)	Litologia
10.00	0.30	1.50	58	1,249	Ignimbrite cineritica (Unità di acqua sa Canna)
22.00	0.30	1.50	50	1,470	Ignimbrite cineritica (Unità di acqua sa Canna)
30.00	0.30	1.50	88	1,451	Ignimbrite cineritica (Unità di acqua sa Canna)
40.00	0.50	1.50	83	2,203	Ignimbrite competente (Unità di Lenzu)
51.00	0.33	1.50	74	2,03	Microcongl. continentali (Livello detritico)
63.00	0.35	1.50	69	2,37	Ignimbrite competente (Unità di Corona Maria)
75.50	0.46	1.50	67	///	Ignimbrite competente (Unità di Corona Maria)
87.50	0.42	1.50	88	2,16	Arenarie medio-grossolane (Formazione del Cixerri)
99.40	0.23	1.50	100	///	Siltiti ocracee (Formazione del Cixerri)
111.40	0.33	1.50	75	2,298	Arenerie ciottolose grigie (Formazione del Cixerri)
131.00	Frantumi			///	Conglomerati e arenarie (Formazione del Cixerri)
159.00	0.43	1.50	82	2,427	Siltite dura e compatta (Formazione del Cixerri)
207.40	0.52	1.50	78	///	Siltite grigio-verde compatta (Formazione del Cixerri)
255.40	0.33	1.50	65	2,625	Siltite compatta (Formazione del Cixerri)
303.40		1.50	///	///	Argilliti bituminose (Tetto Produttivo)
335.60		1.50	///	///	Carbone (Produttivo)


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