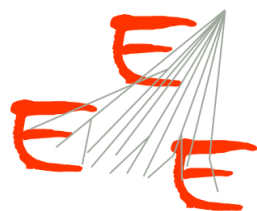




MUSEO
STORICO DELLA FISICA
E
CENTRO
STUDI E RICERCHE
ENRICO FERMI



Extreme
Energy
Events
Science inside Schools

Muon flux measurements underground Status update

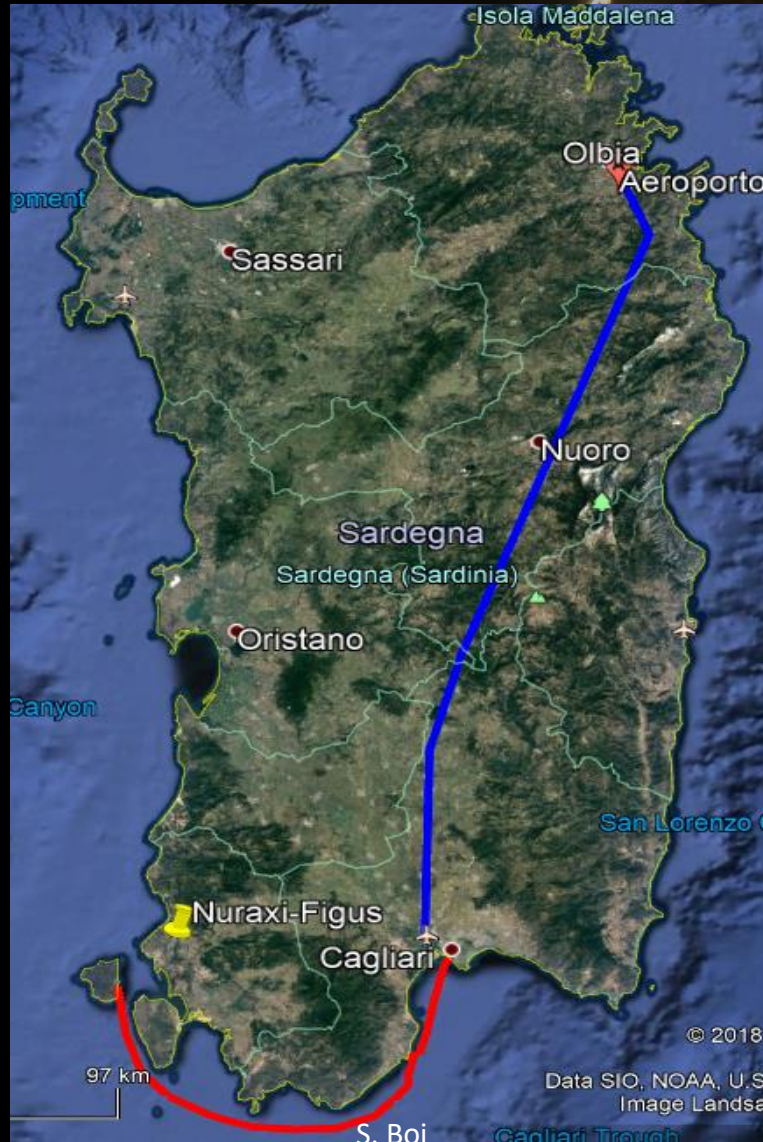
Stefano Boi

Centro Fermi
INFN Cagliari
Università degli Studi di Cagliari

Torino, March 9th, 2019



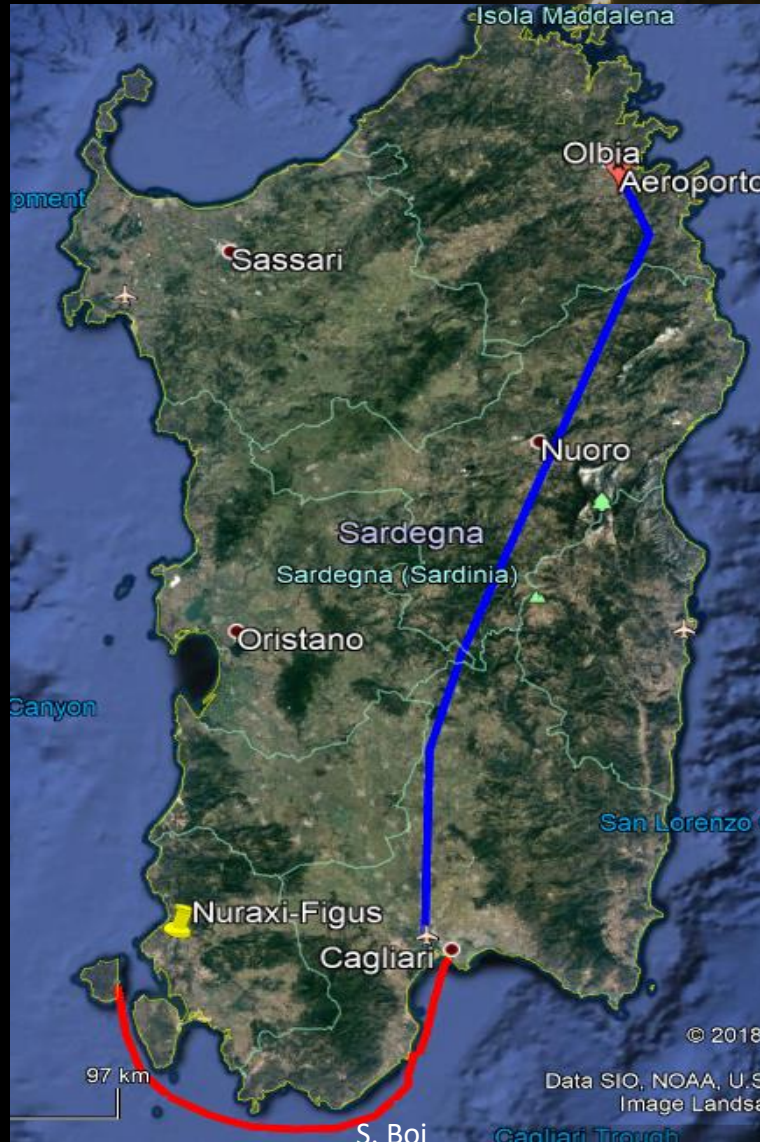
Travelling with Cosmic Box



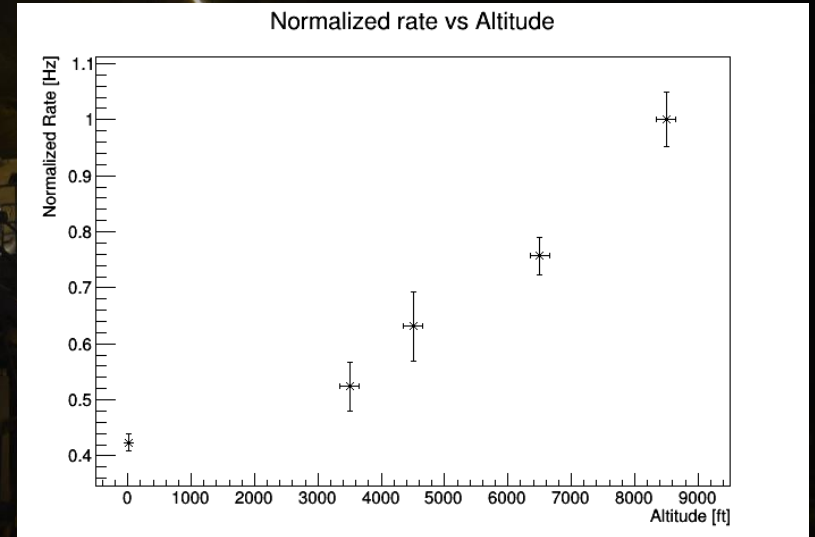
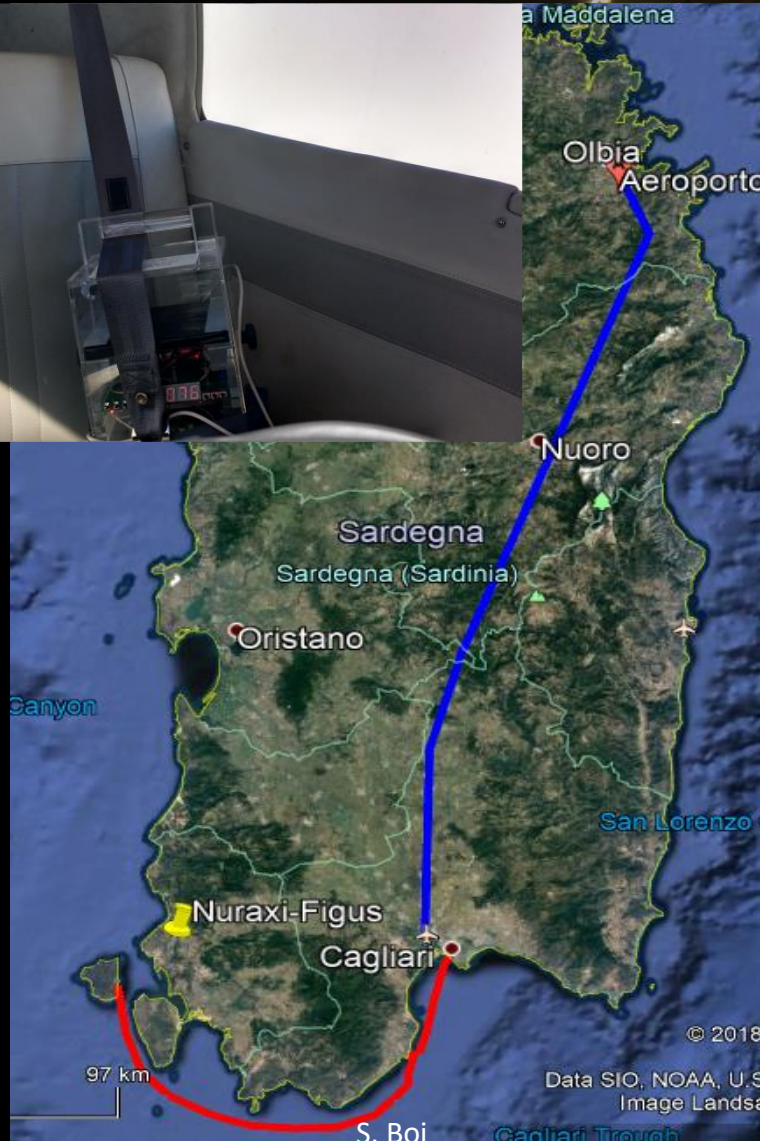
Travelling with Cosmic Box



08/03/2019



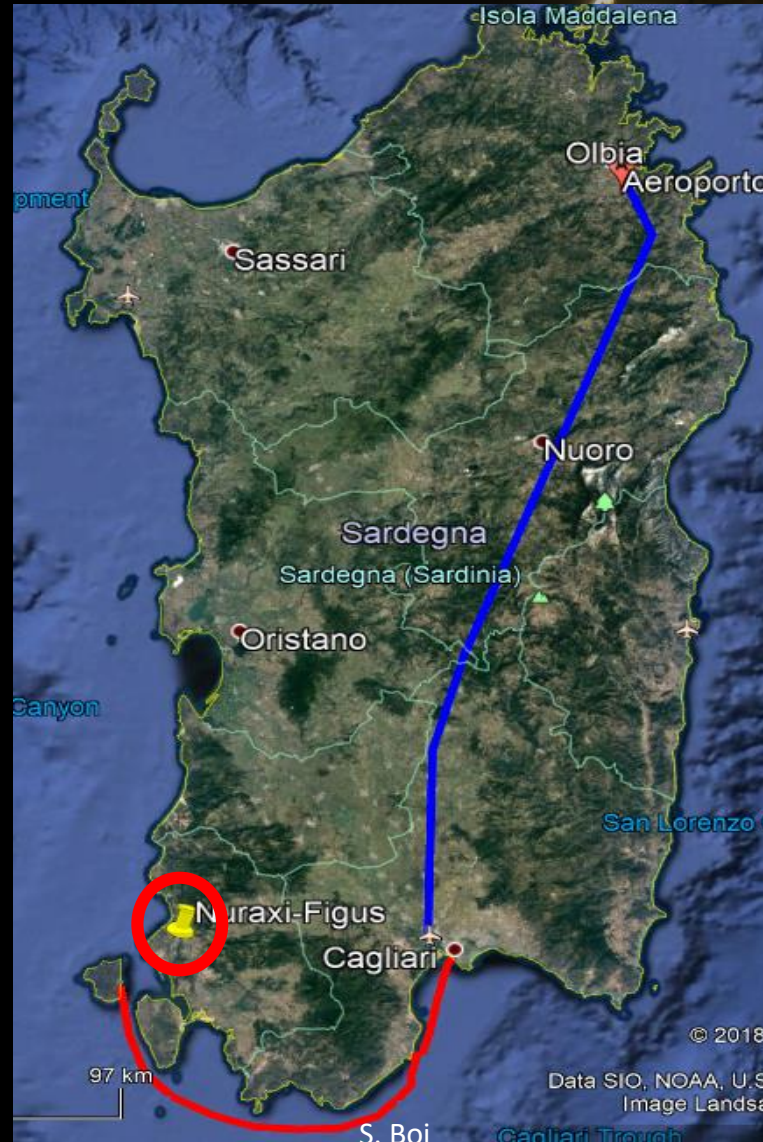
Travelling with Cosmic Box



08/03/2019



What's next?



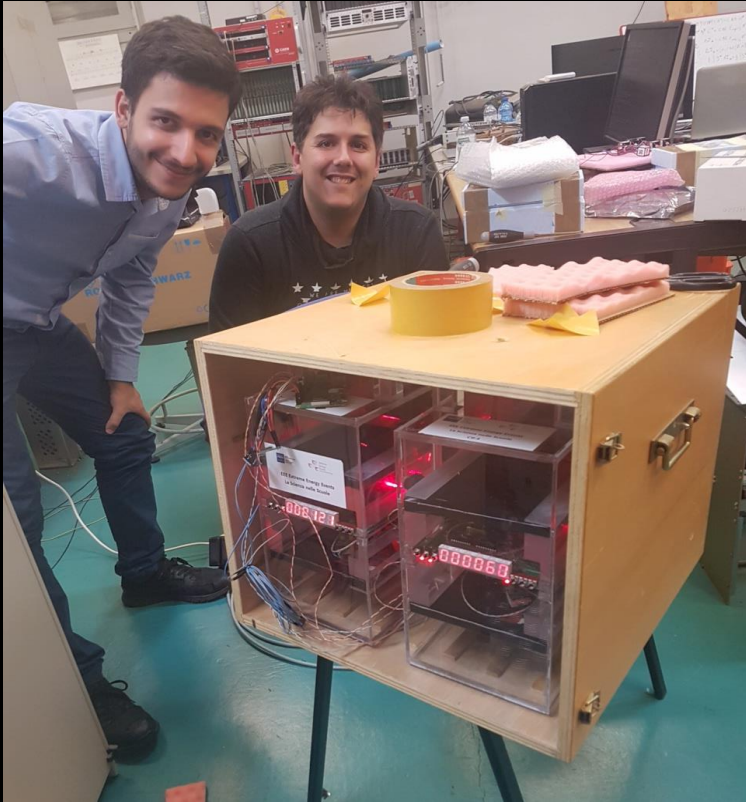
Why measurements underground?

- It is a study of muon flux attenuation (same process of altitude measurements, but with different materials)
- Many studies of muon flux underground
- It could be an interesting information for the particular experimental site (Nuraxi Figus - Seruci mine complex)

Why Nuraxi Figus - Seruci?

- Nuraxi Figus – Seruci is a coal mine with more than 30 km of galleries
- No more extractions – alternative (also scientific) activities in progress
- Electric power (almost!) stable
- Possibility to access both by car and by elevator
- Staff support is available (technicians, safety, geologists, engineers,...)
- INFN (*Istituto Nazionale di Fisica Nucleare*) is present: **ARIA project**

Experimental setup



- 3 cosmic box enclosed in a wooden box
- 1 Raspberry Pi for DAQ
- 1 UPS for backup



ASTRO

- Scintillator based detector (equipped with SiPM) enclosed in a waterproof suitcase
- Integrate backup battery
- Stand-alone DAQ

Schools involved

Cagliari:

- Liceo Scientifico «A. Pacinotti» 5 students + 3 teachers
- Liceo Scientifico «Alberti» 1 student

Cinisello Balsamo (Mi):

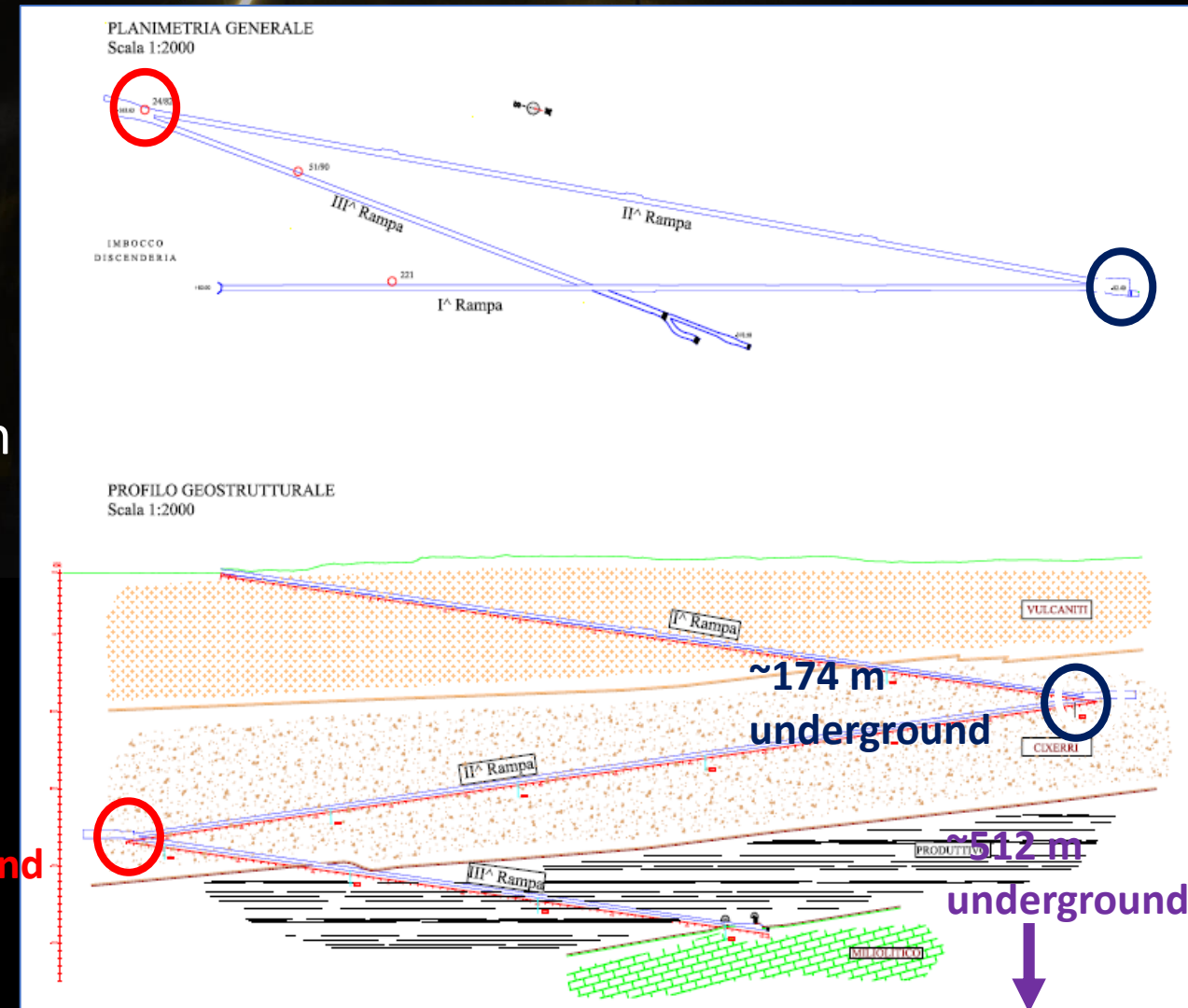
- Liceo «G. Casiraghi» 2 students + 1 teacher



Status of measurements

- 1 measurement outside
 - ~48 minutes of acquisition
- 3 measurements underground
 - 174 m ~71.5 hours ~ 3 days of acquisition
 - 339 m ~ 214.3 hours ~ 9 days of acquisition
 - 512 m ~ 1510 hours ~ 62 days of acquisition

~339 m
underground





Poisson distribution

Poisson distribution regulate **rare events** ($P \ll 1$). Process should have a constant rate λ and a large number of events ($N \gg 1$)

Probability (P) to have n events in a fixed time interval:

$$P(n, t) = e^{-\mu} \frac{\mu^n}{n!}, \text{ with } \mu = \lambda t$$

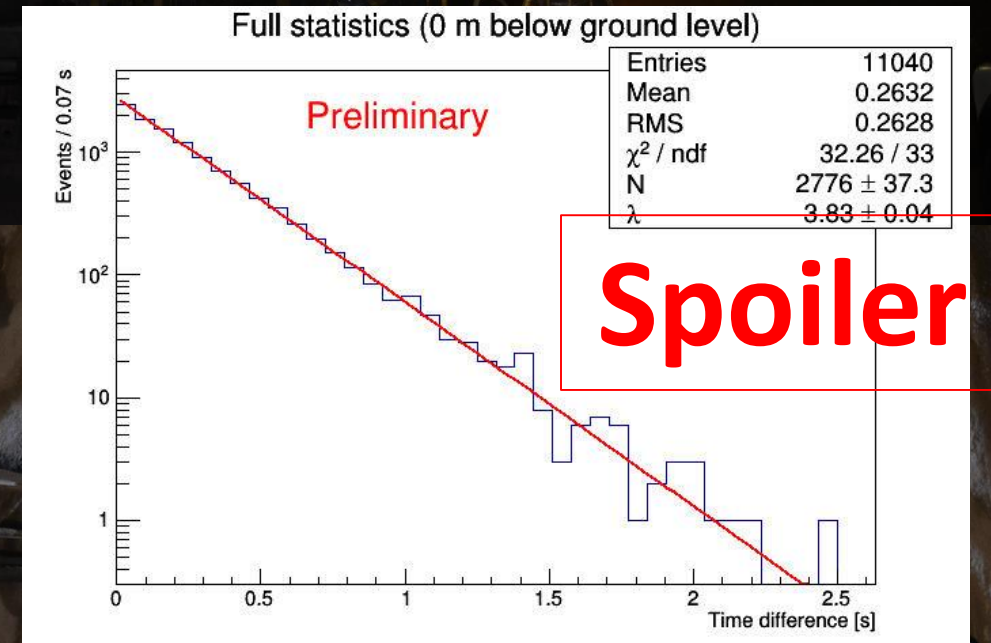
In Example:

- Number of calls received by a call center in a day
- Number of muons detected by a Cosmic Box 500 meters underground

Poisson distribution

Time difference distribution $\sim e^{-\lambda t}$

This imply that two events next two each others are more probable than with long time difference

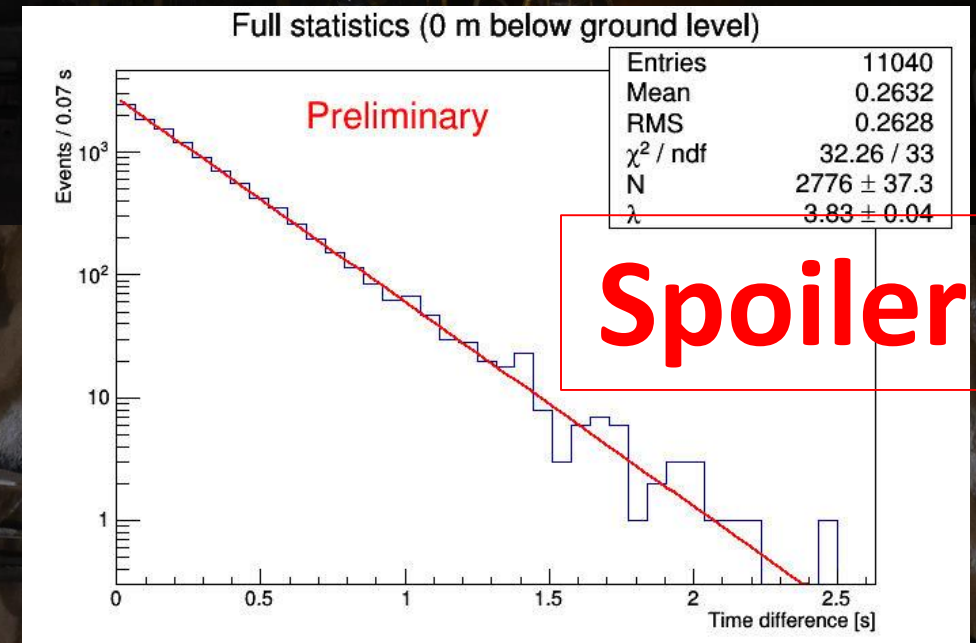


Poisson distribution

Time difference distribution $\sim e^{-\lambda t}$

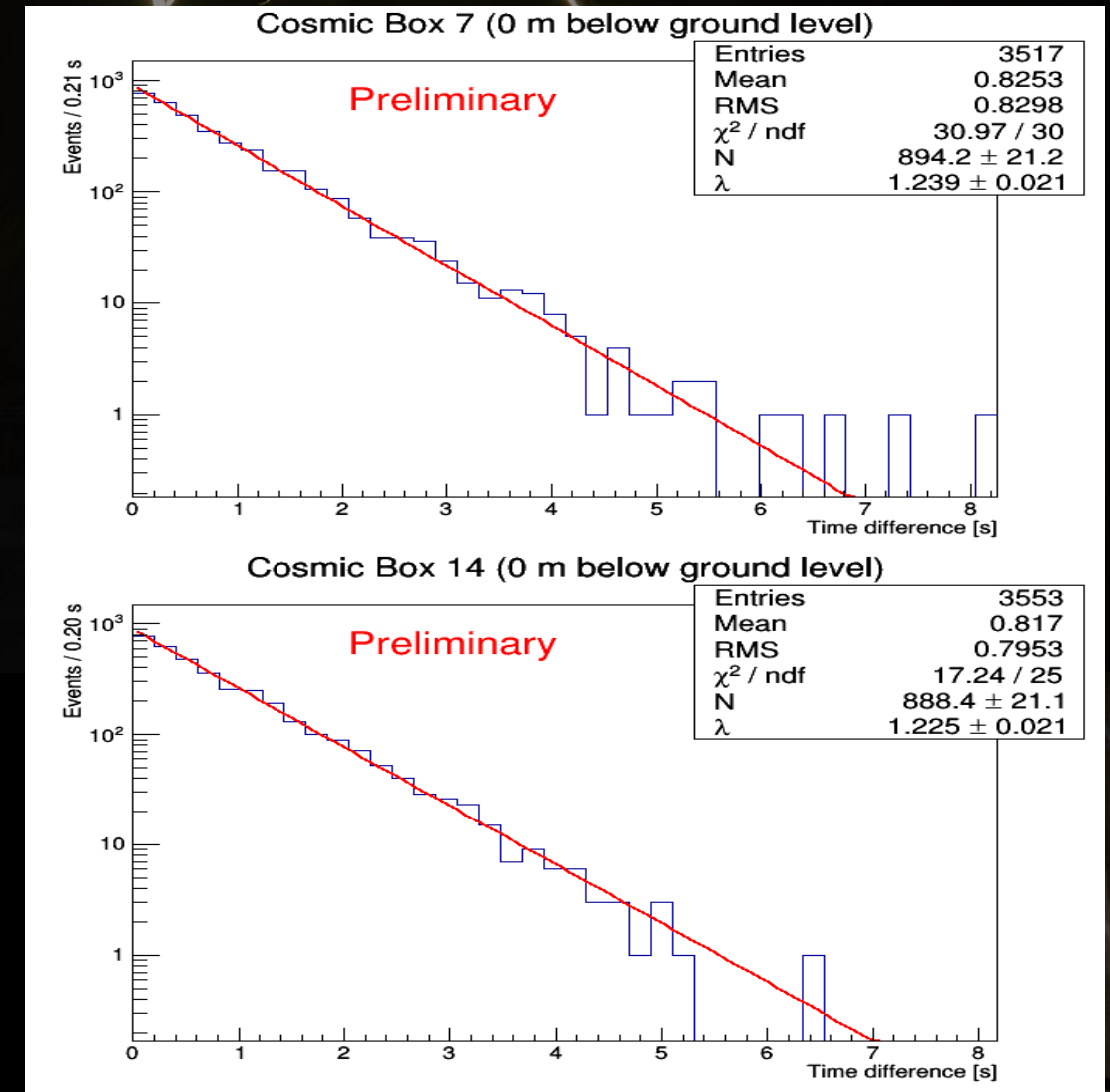
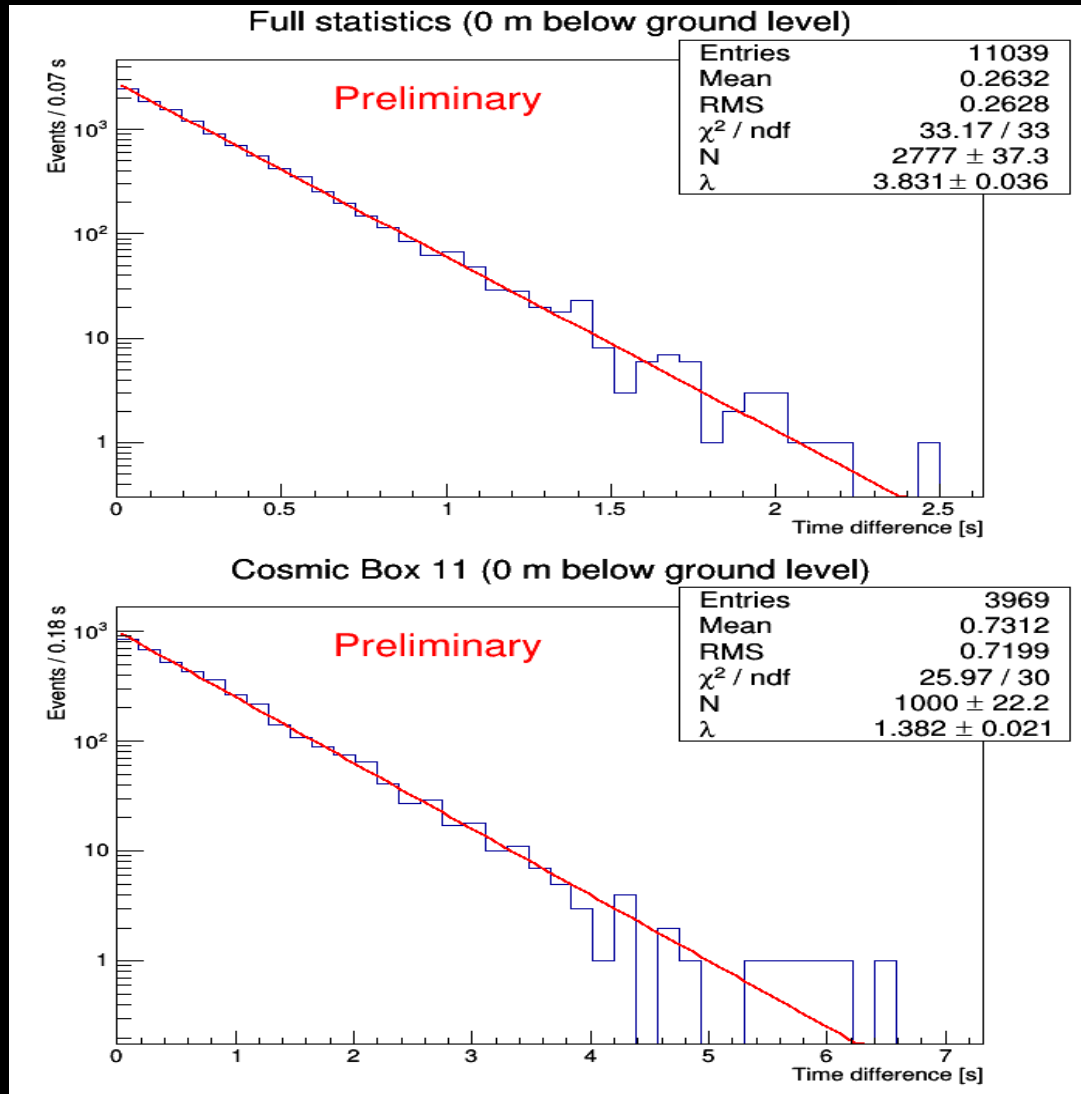
This imply that two events next two each others are more probable than with long time difference

Bad luck never comes alone!!!

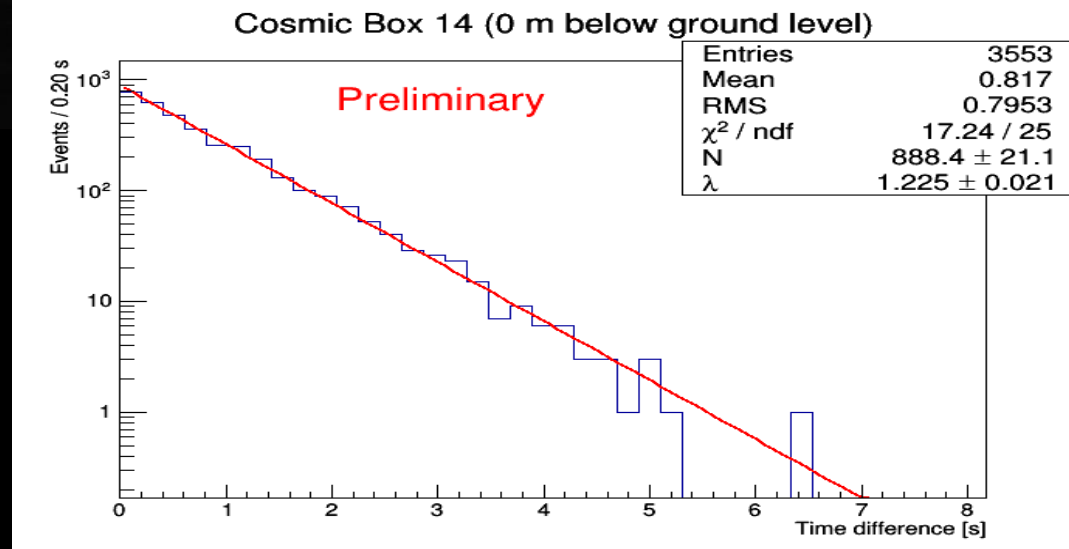
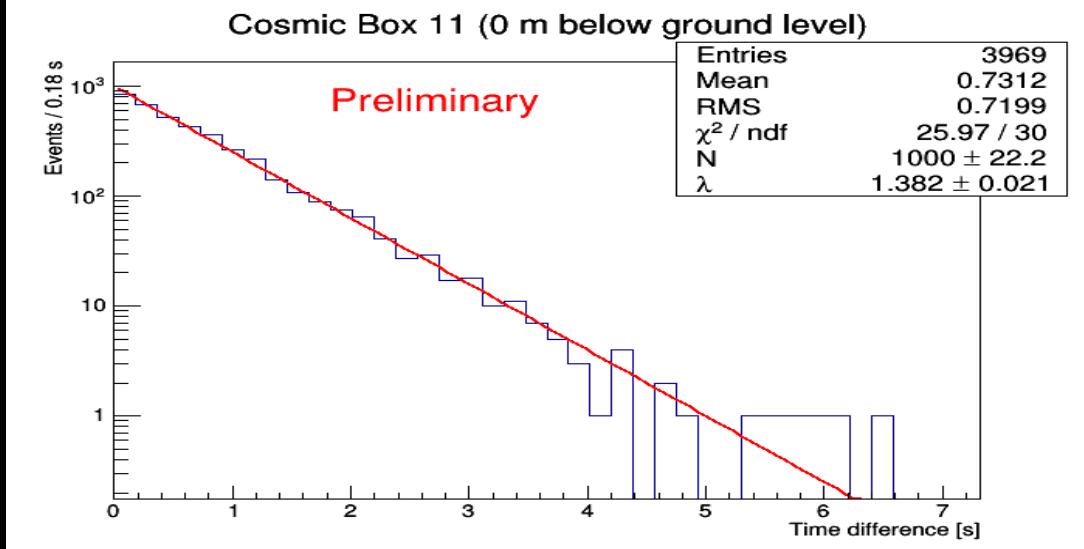
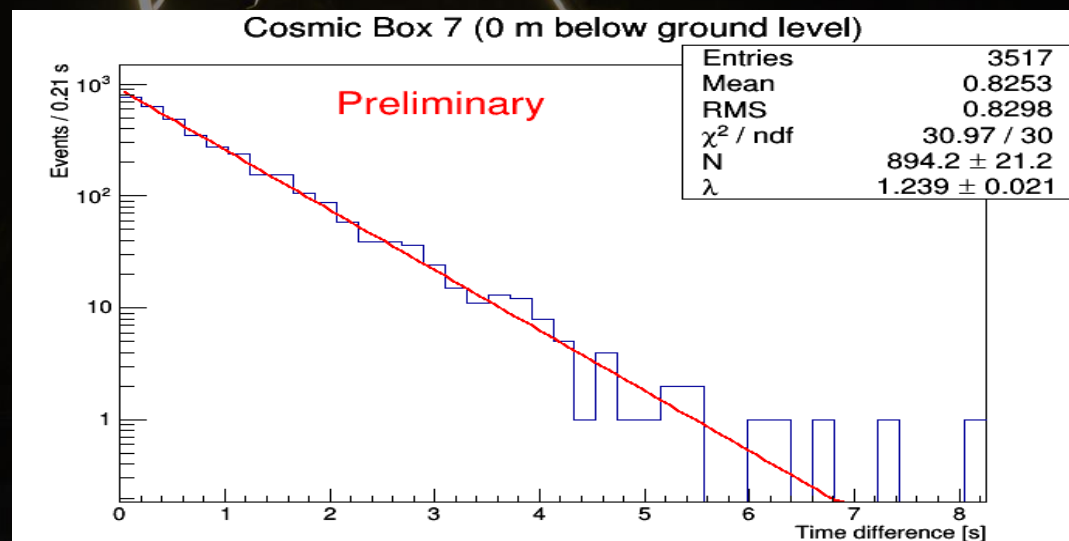
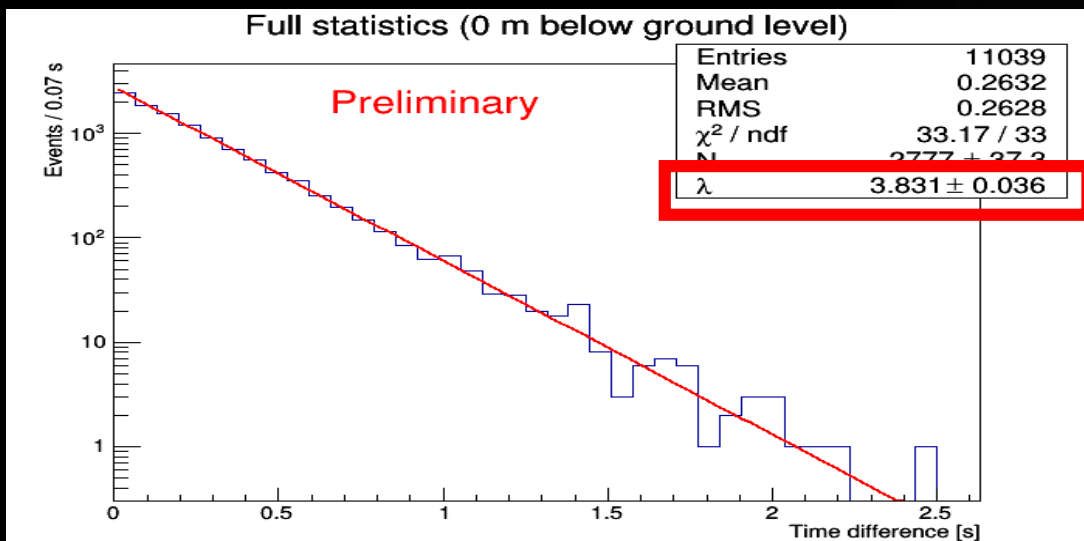




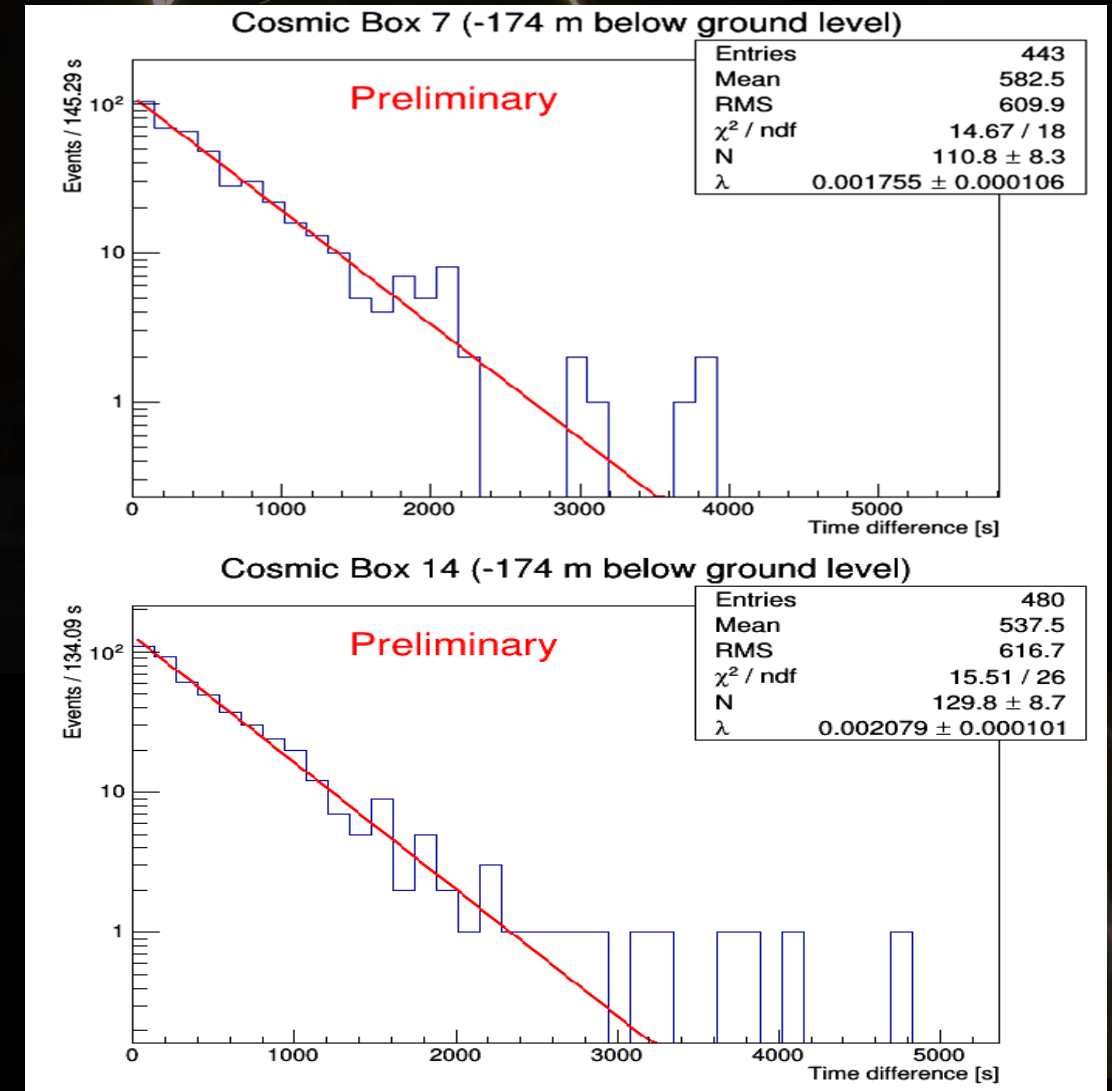
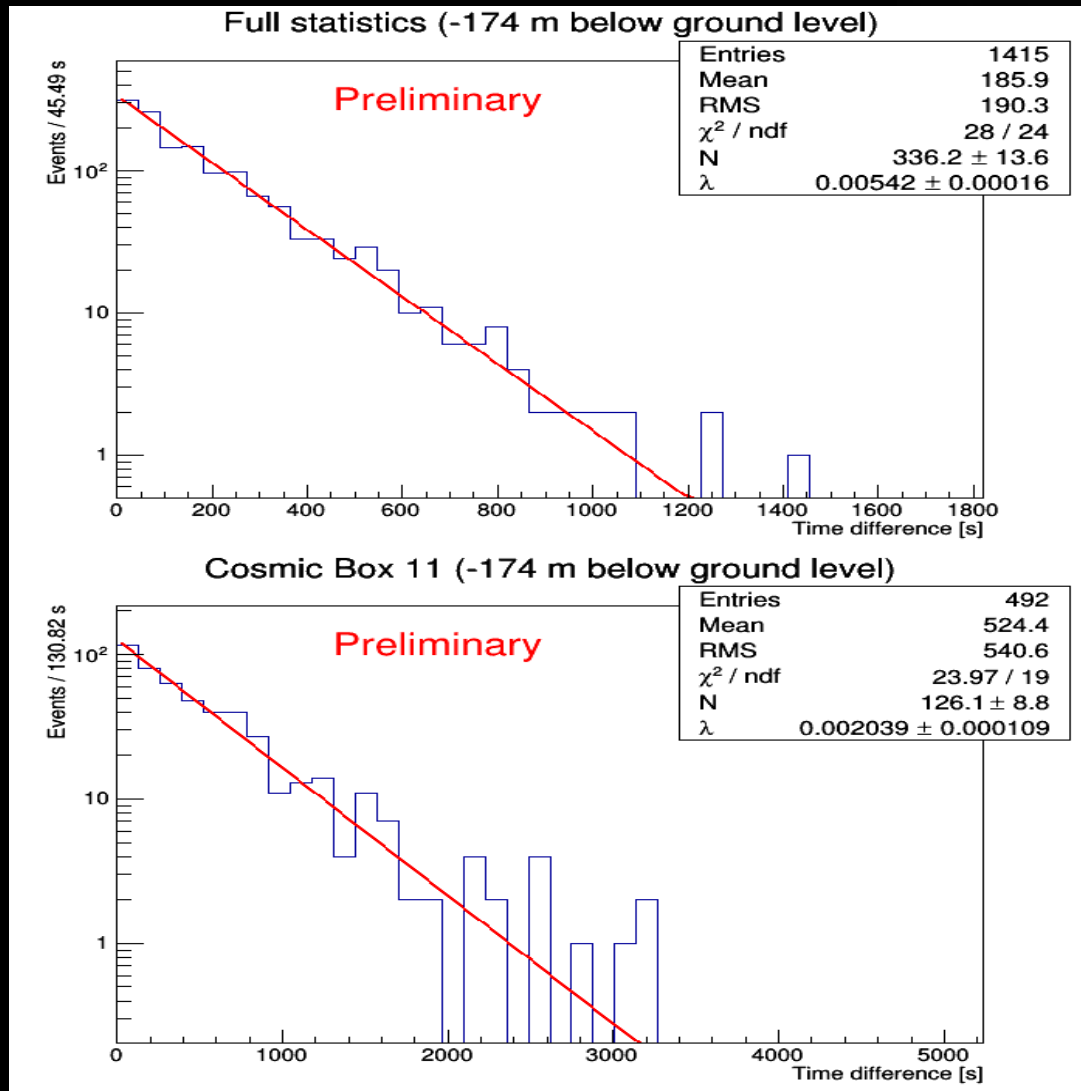
A few results – Ground level



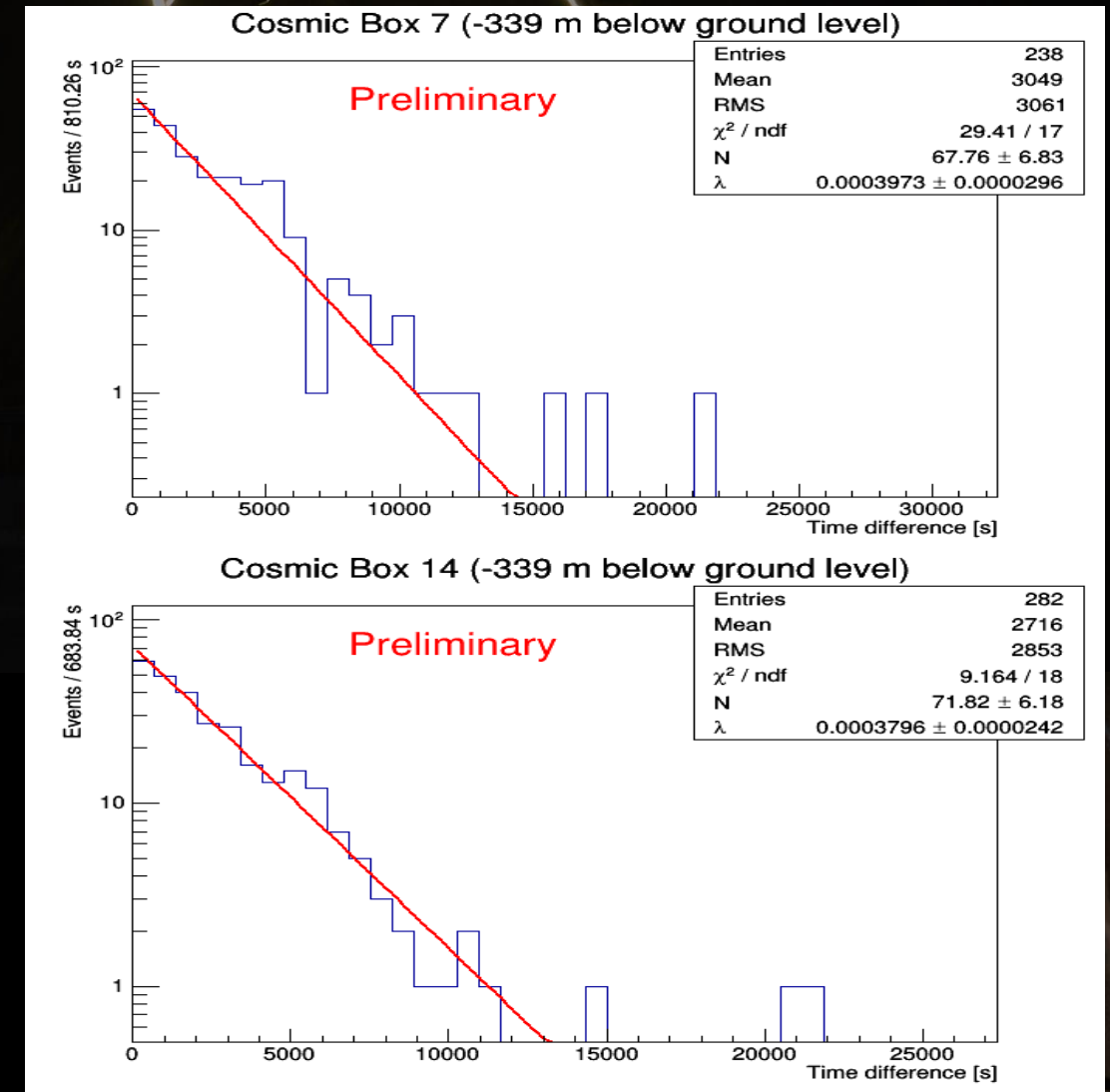
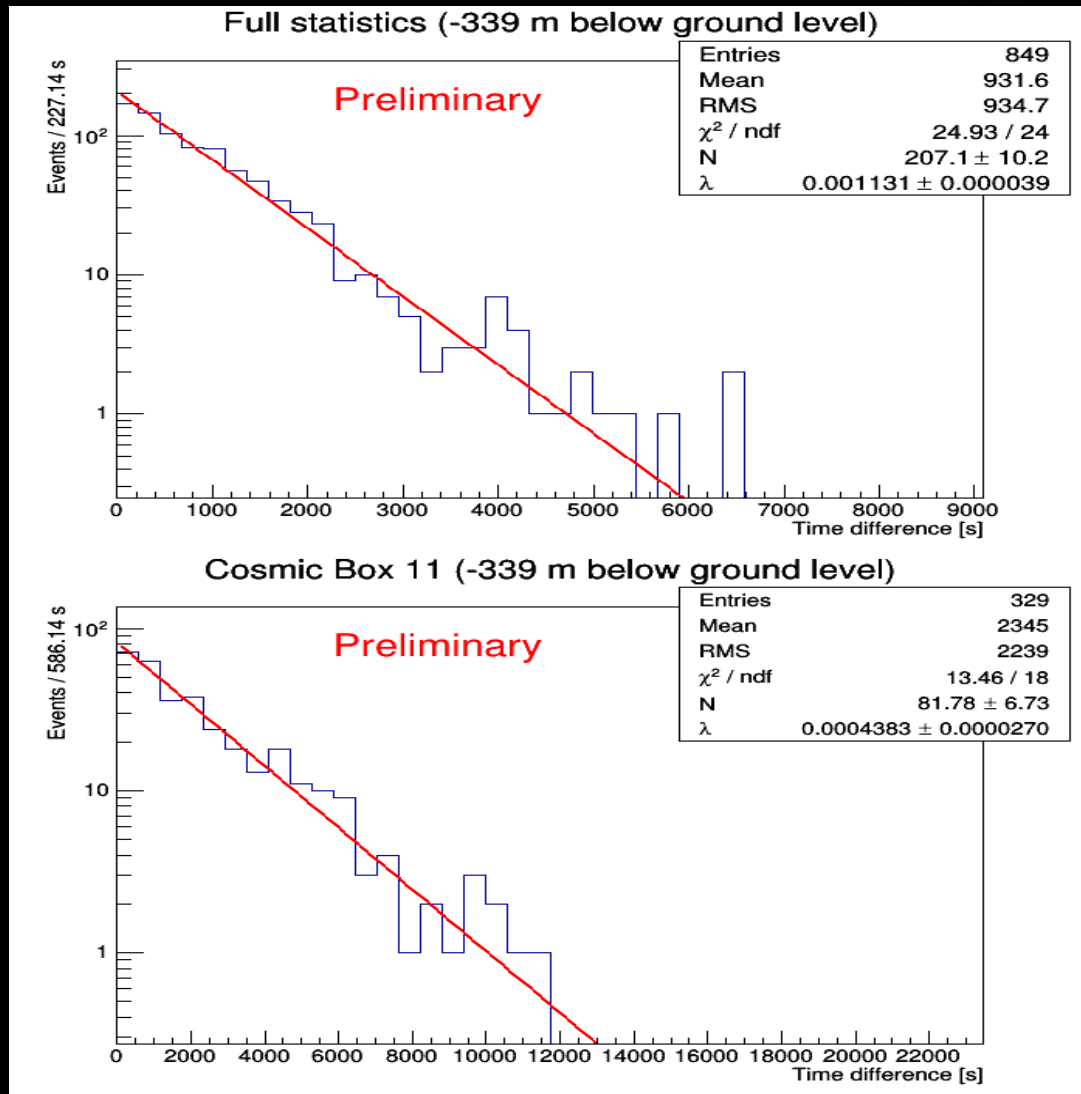
A few results – Ground level



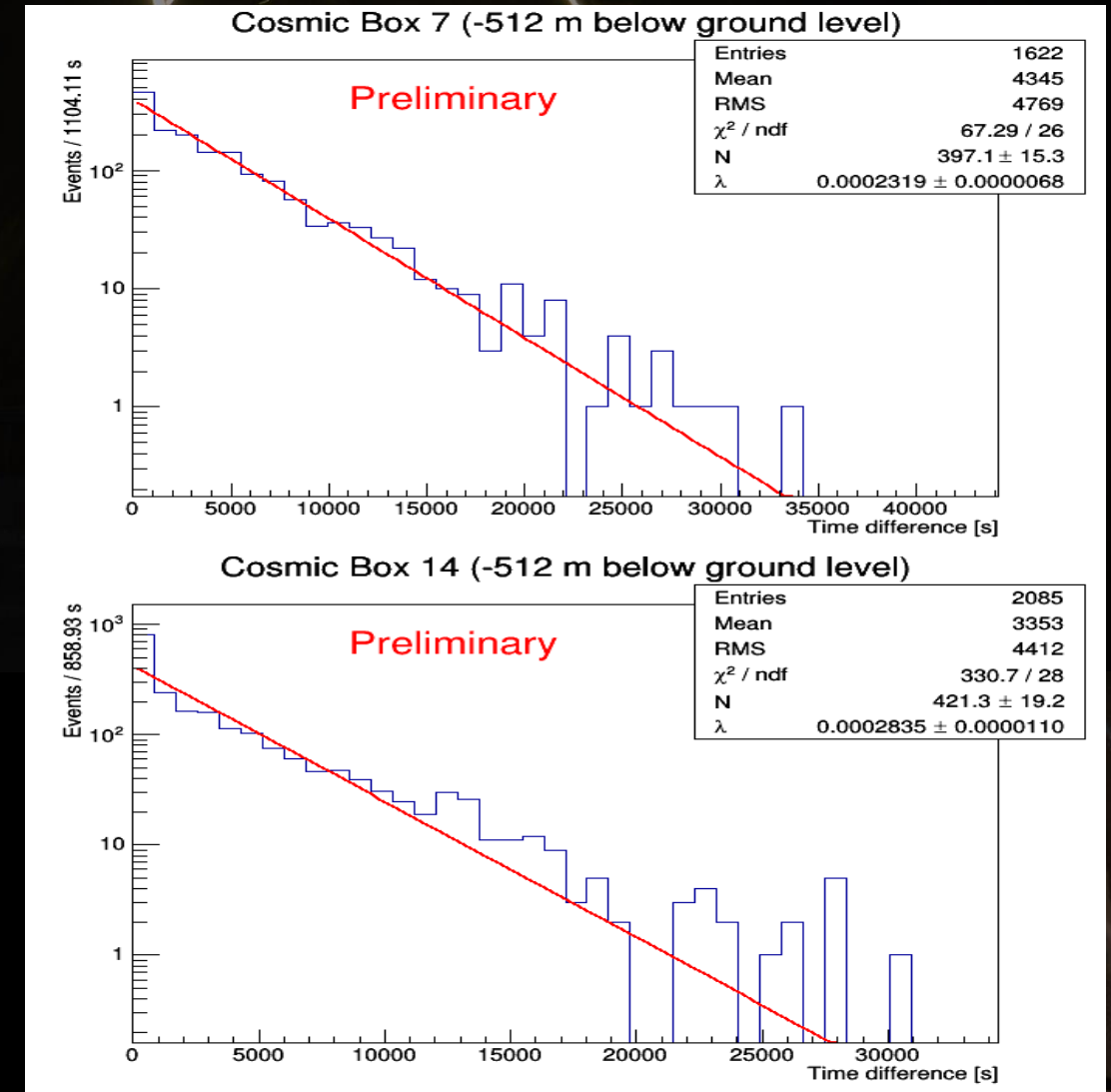
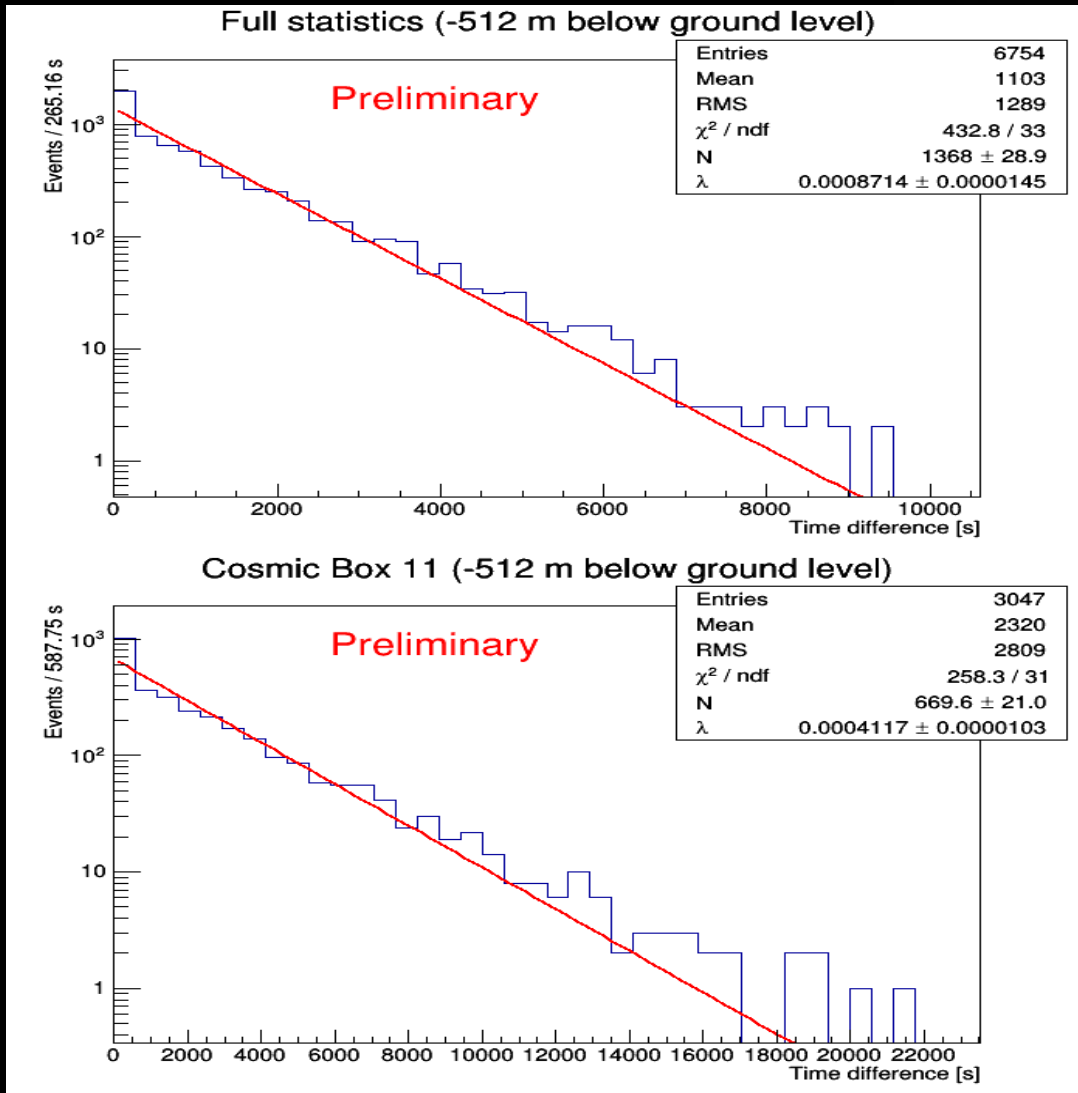
A few results @ 174 meters



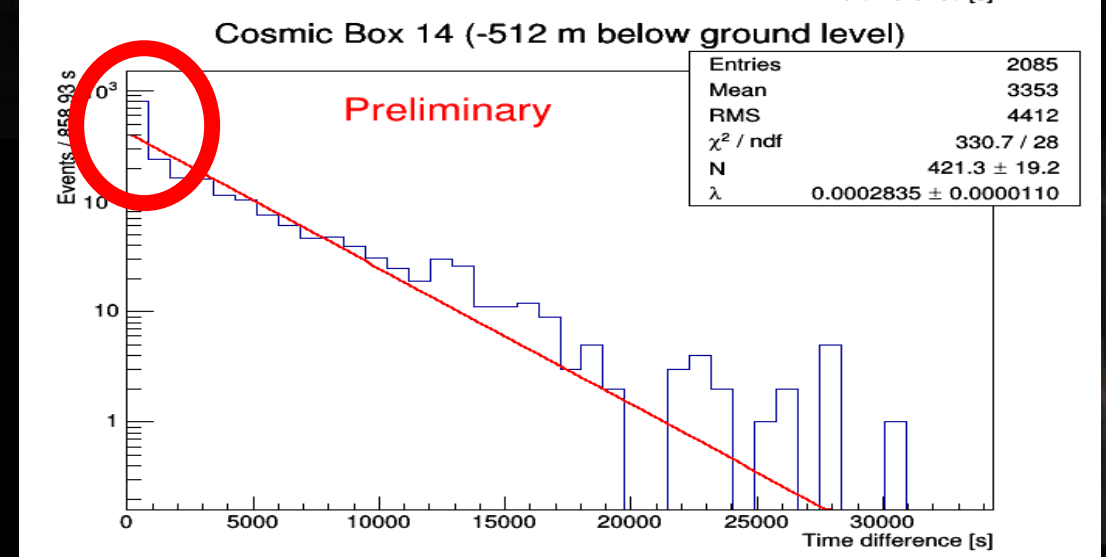
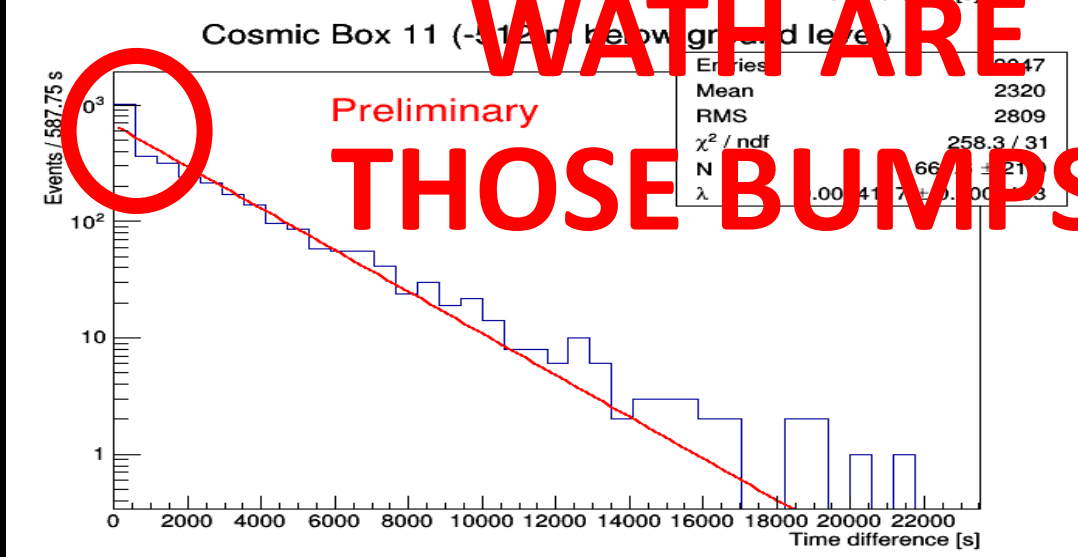
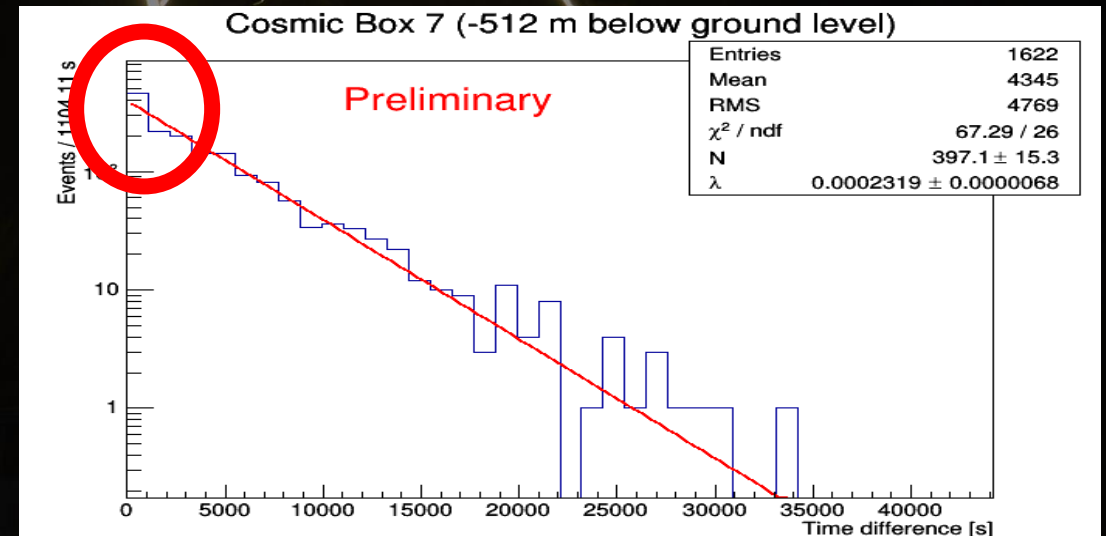
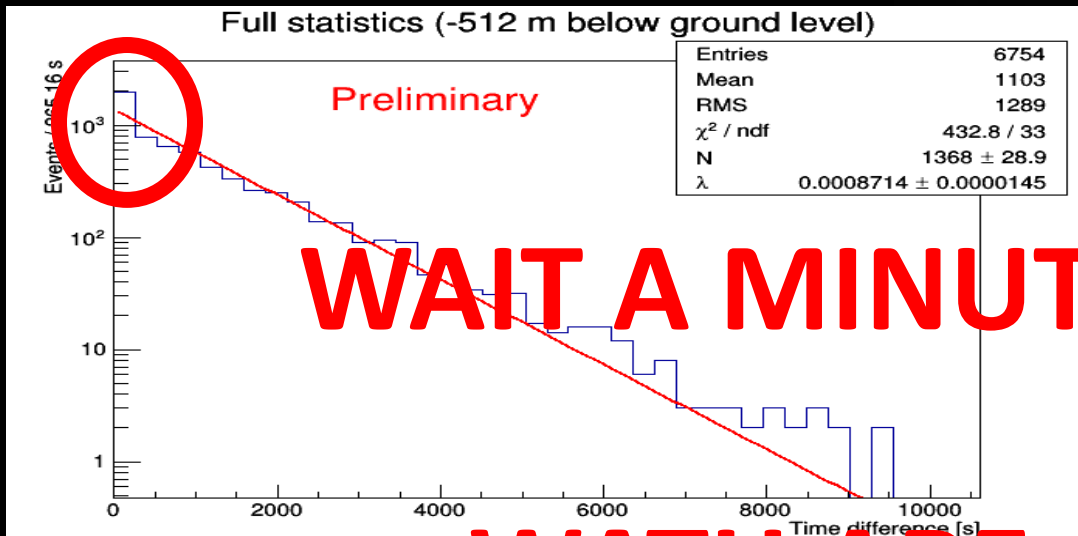
A few results @ 339 meters



A few results @ 512 meters



A few results @ 512 meters

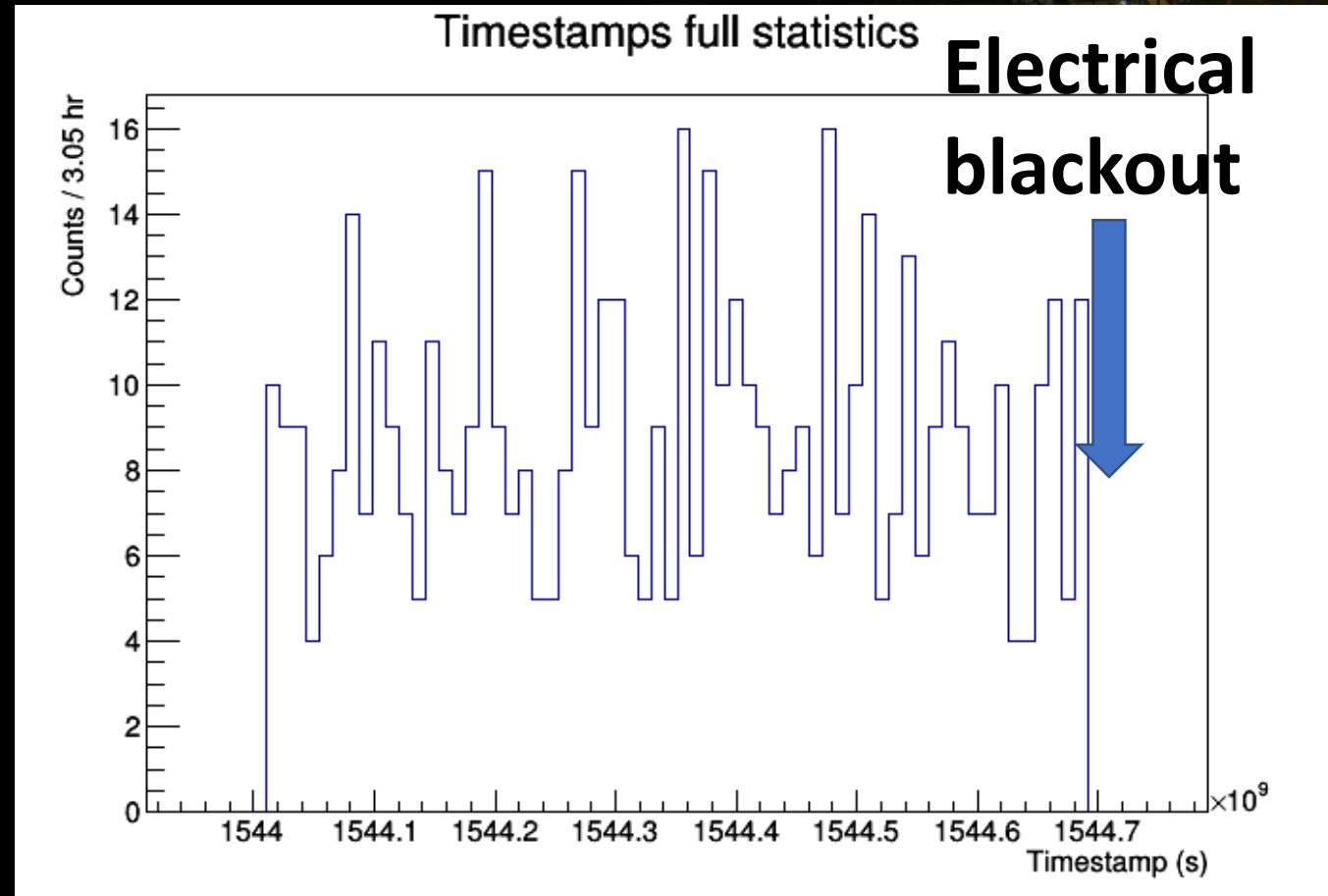


WAIT A MINUTE!

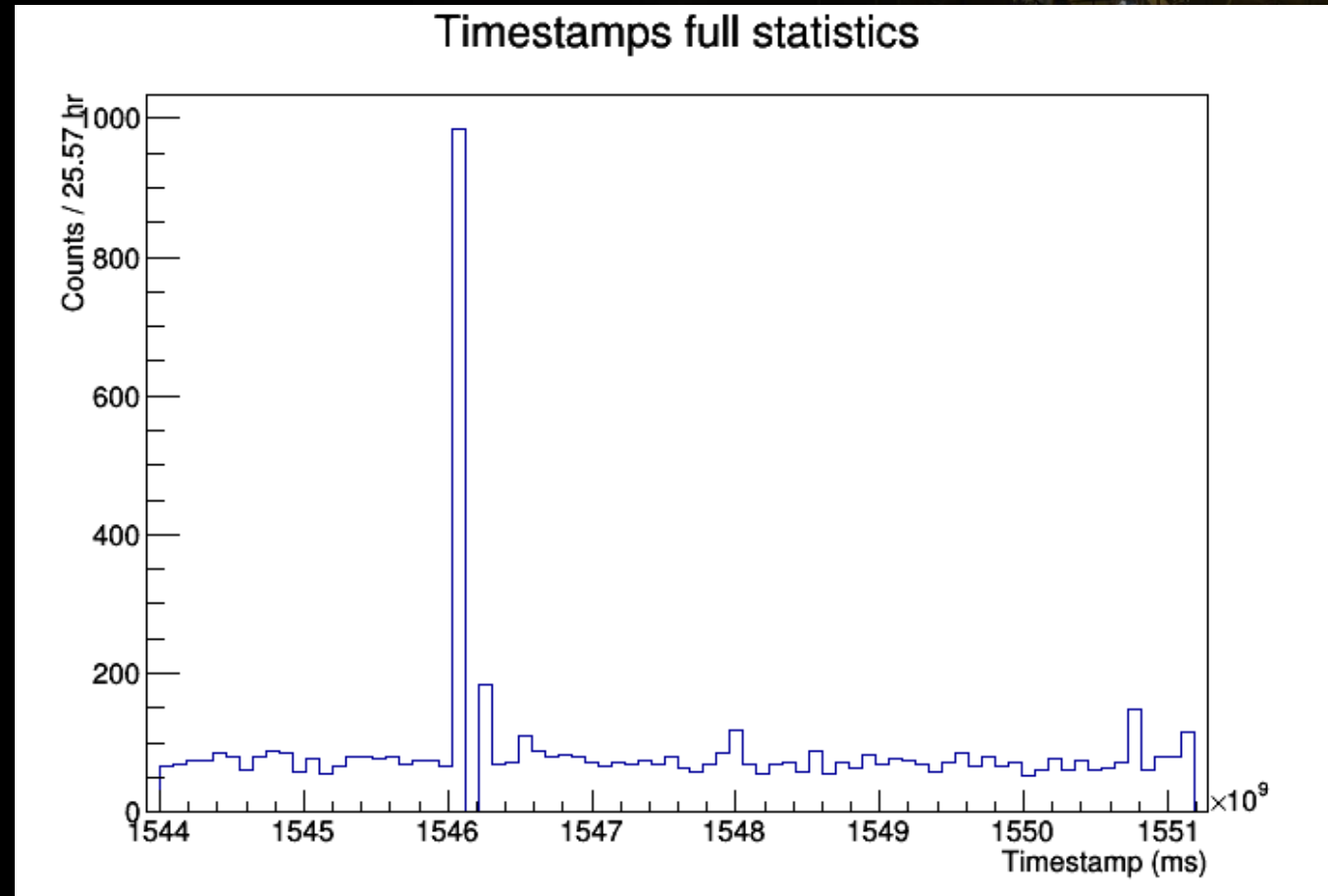
WATH ARE
THOSE BUMPS?

Timestamps @ 512 meters

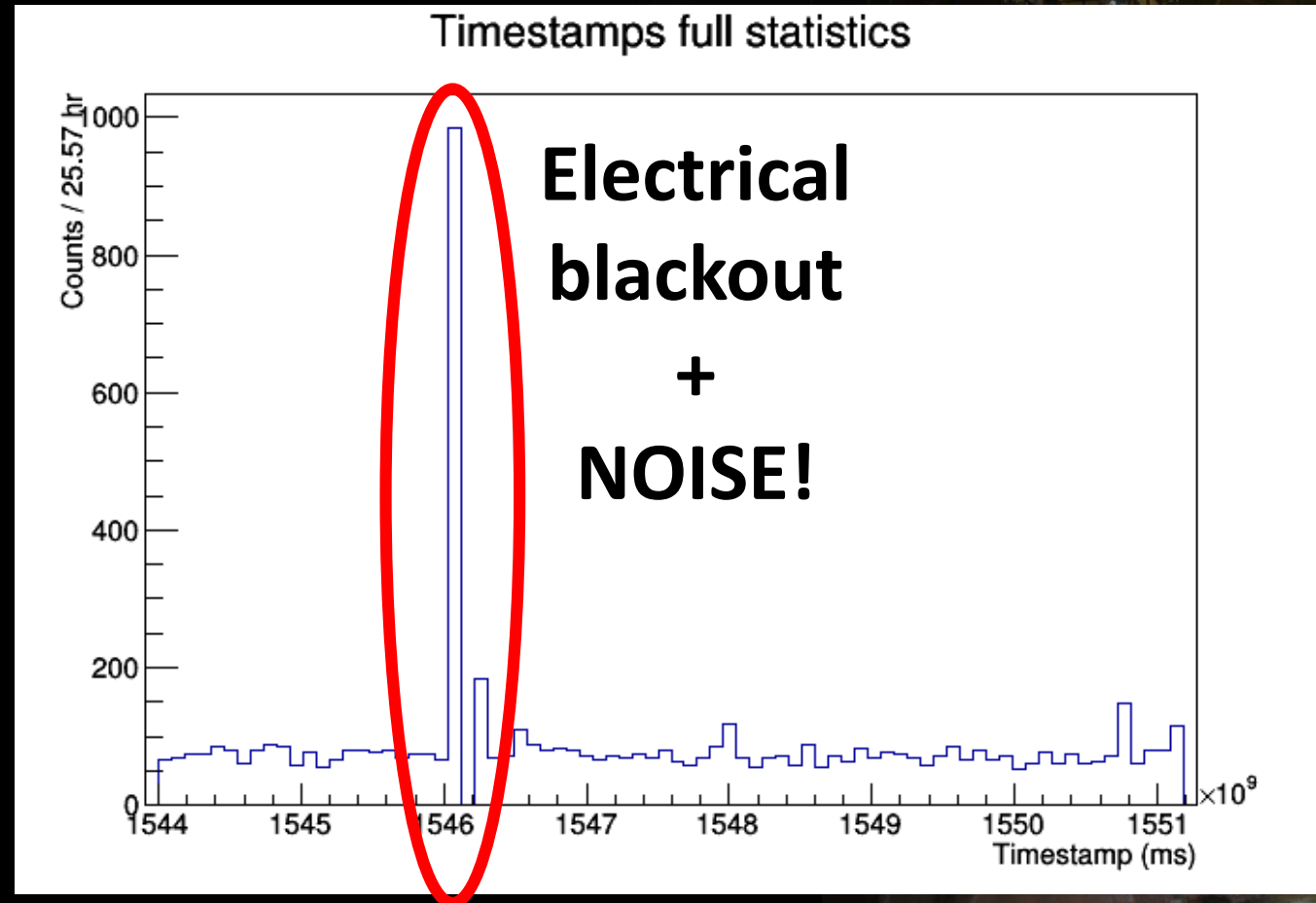
From 2018-12-05 to 2018-12-13



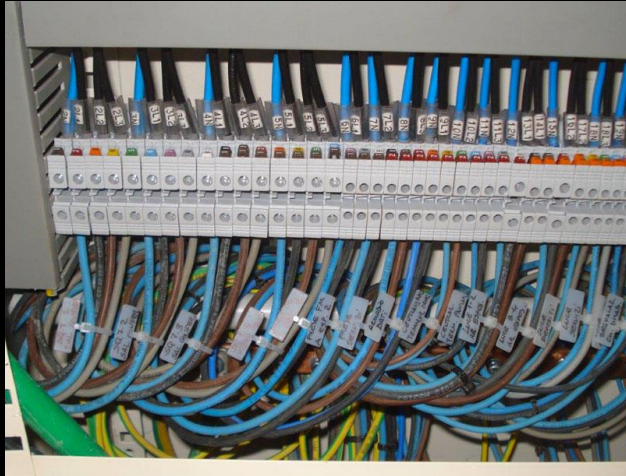
Timestamps @ 512 meters From 2018-12-5 to 2019-12-6



Timestamps @ 512 meters From 2018-12-5 to 2019-12-6



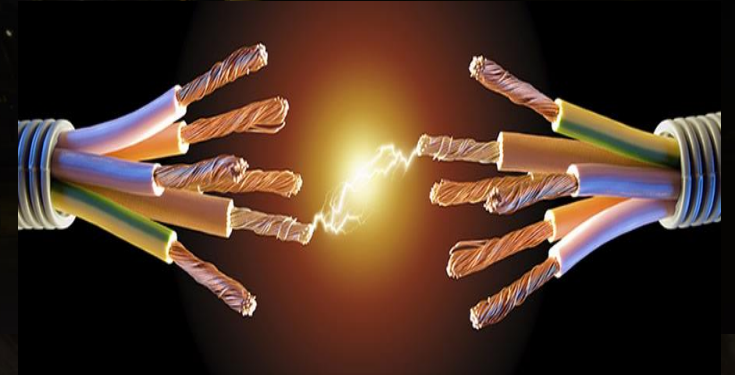
Problems during acquisition @ 512 meters underground



+



=



⇒DAQ STOP

Problems @ 512 meters

- A few mice cut electrical wires causing a blackout
- DAQ started again without any problem
- A second blackout occurred in 2018-12-31 with electromagnetic noise detected by Cosmic Boxes
- Other noise was detected by the Cosmic Boxes during next days

Problems @ 512 meters

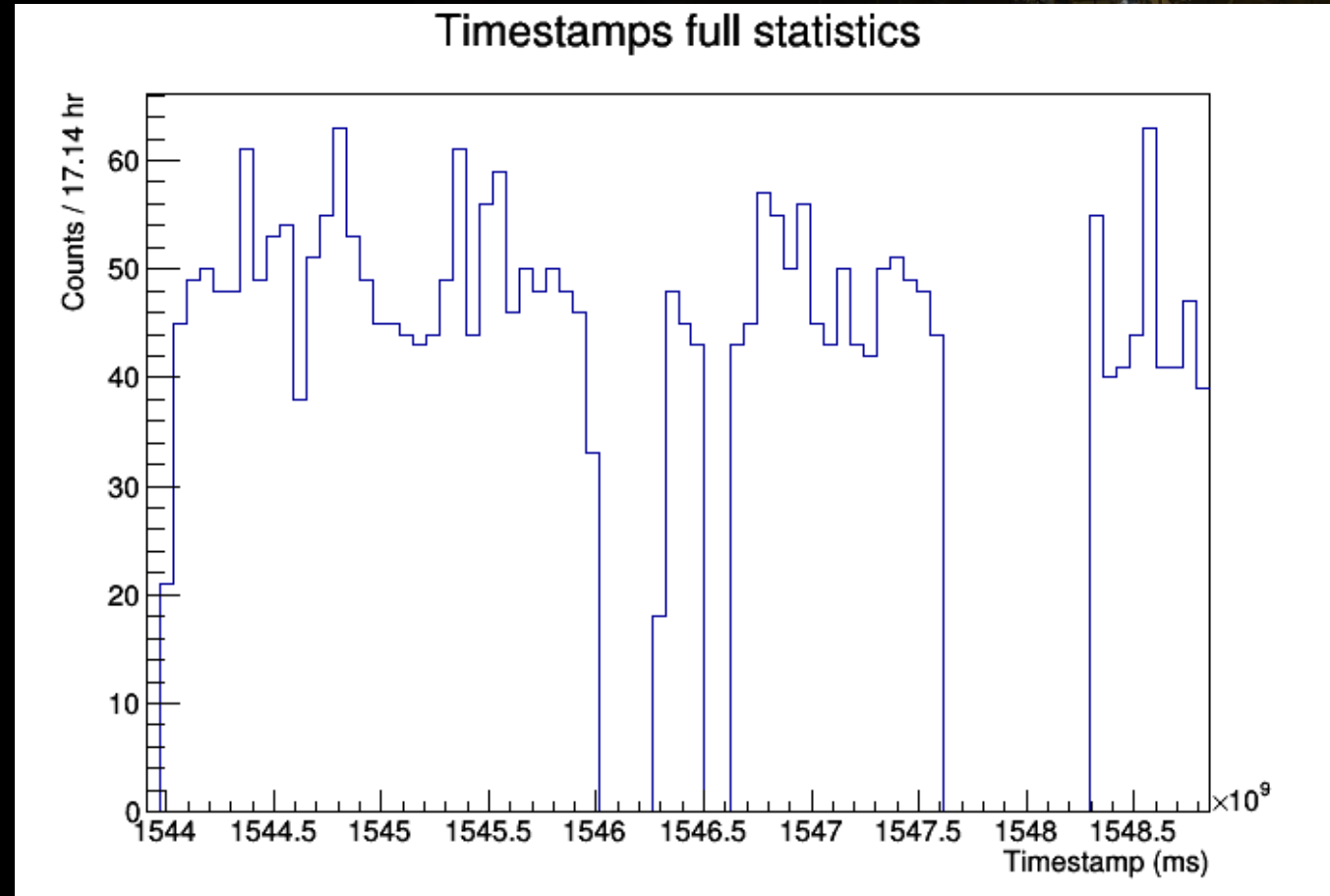
The background of the slide is a dark, dimly lit tunnel. In the upper right, several workers in reflective safety gear are visible, working on a structure. A white vehicle is parked further down the tunnel. The overall atmosphere is industrial and somewhat mysterious due to the low lighting.

- A few mice cut electrical wires causing a blackout
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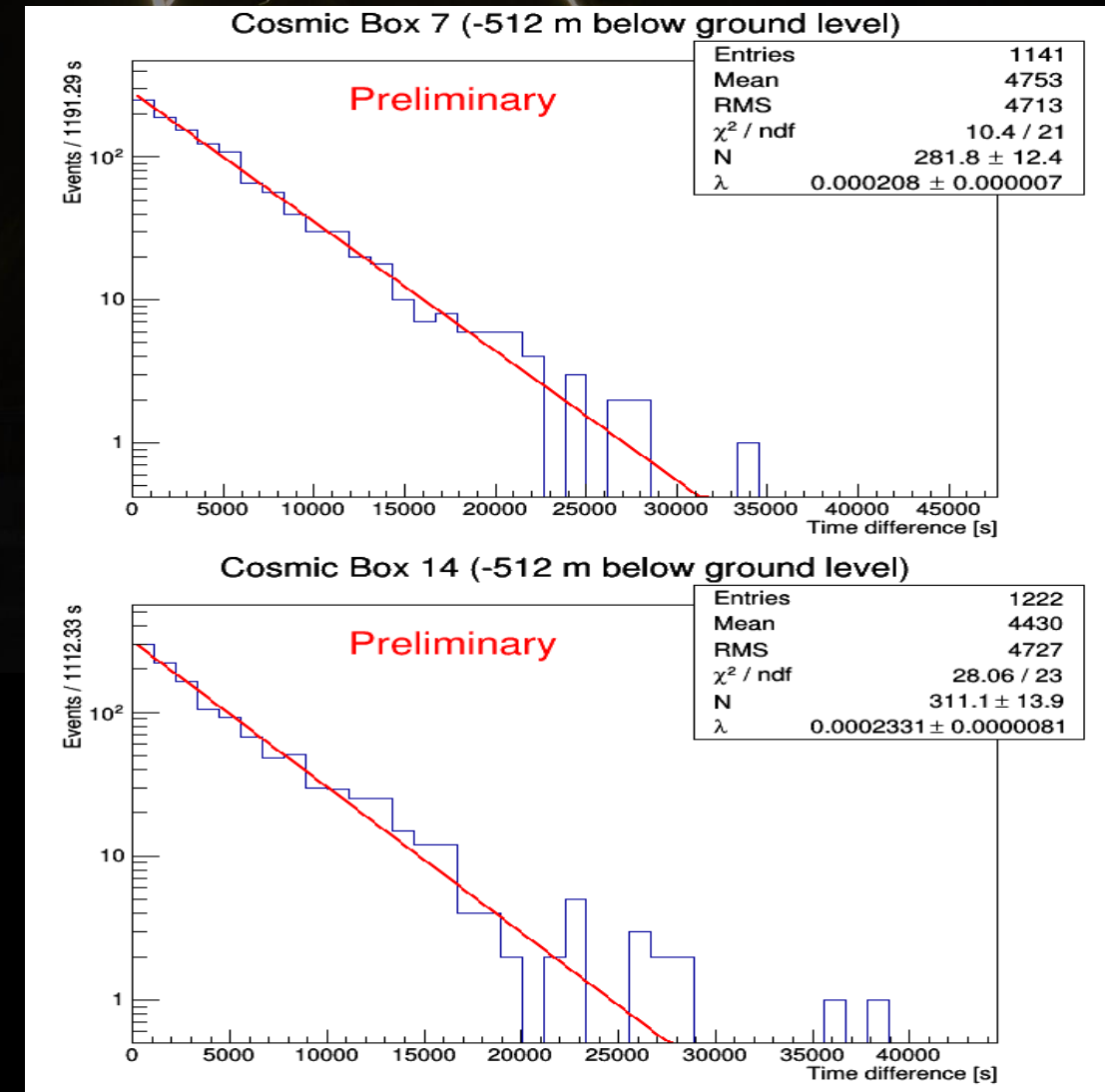
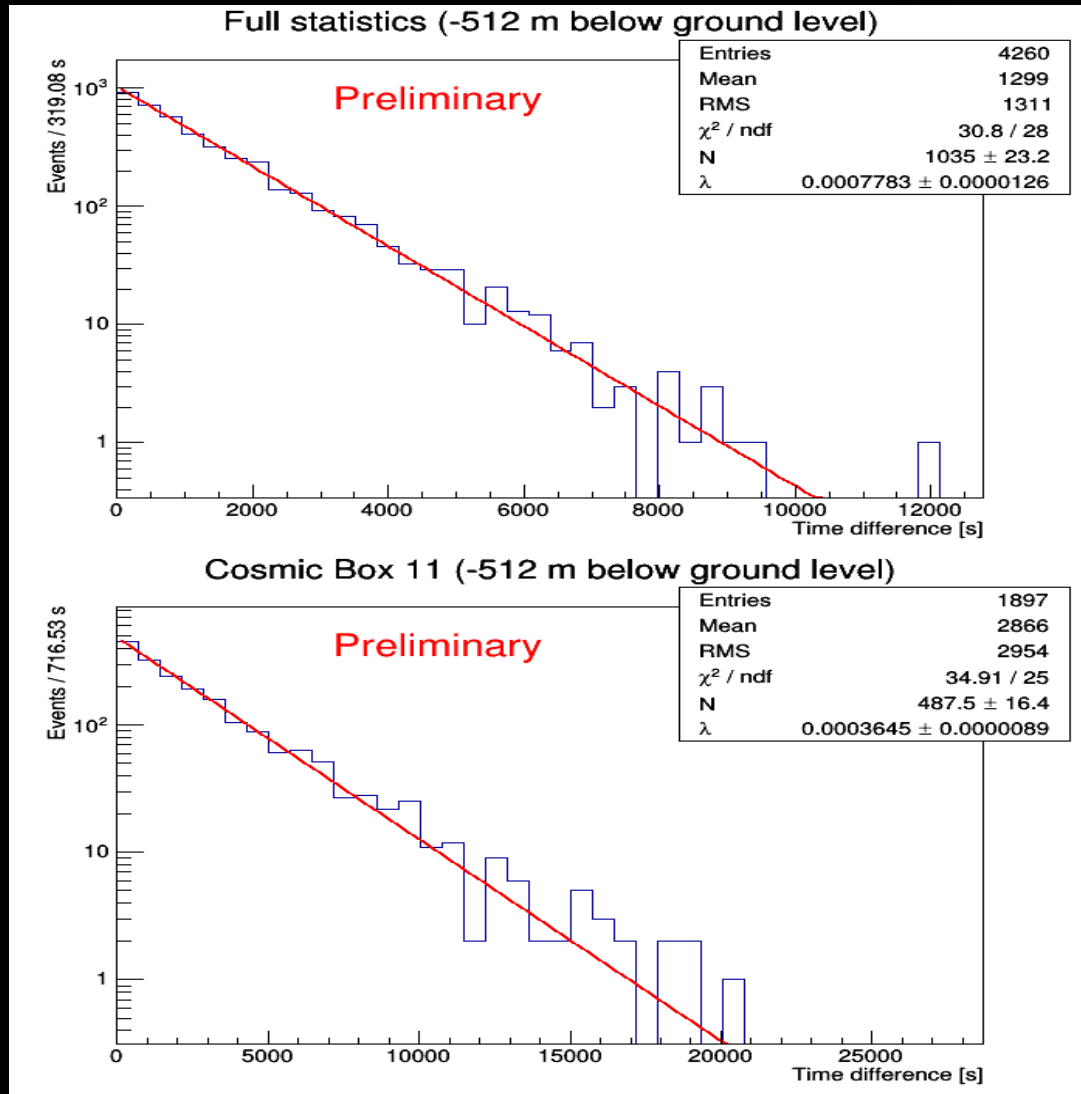
Don't panic: we can just remove noisy data

The background of the slide is a dark, dimly lit tunnel. In the upper right, several workers in reflective safety gear are visible, working on a structure. A white vehicle is parked further down the tunnel. The overall atmosphere is industrial and somewhat mysterious due to the low lighting.

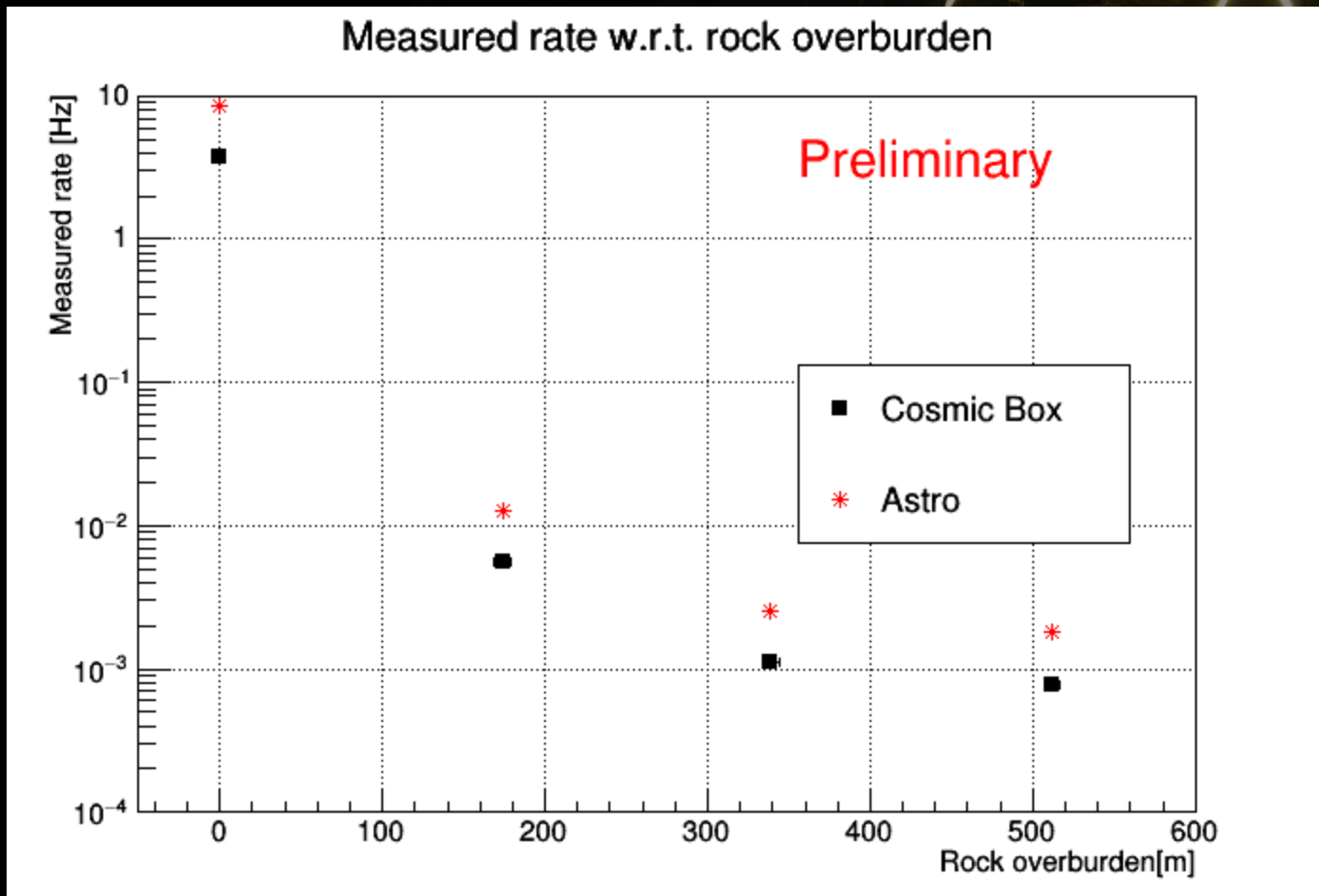
Problems @ 512 meters



A few results @ 512 meters - corrected

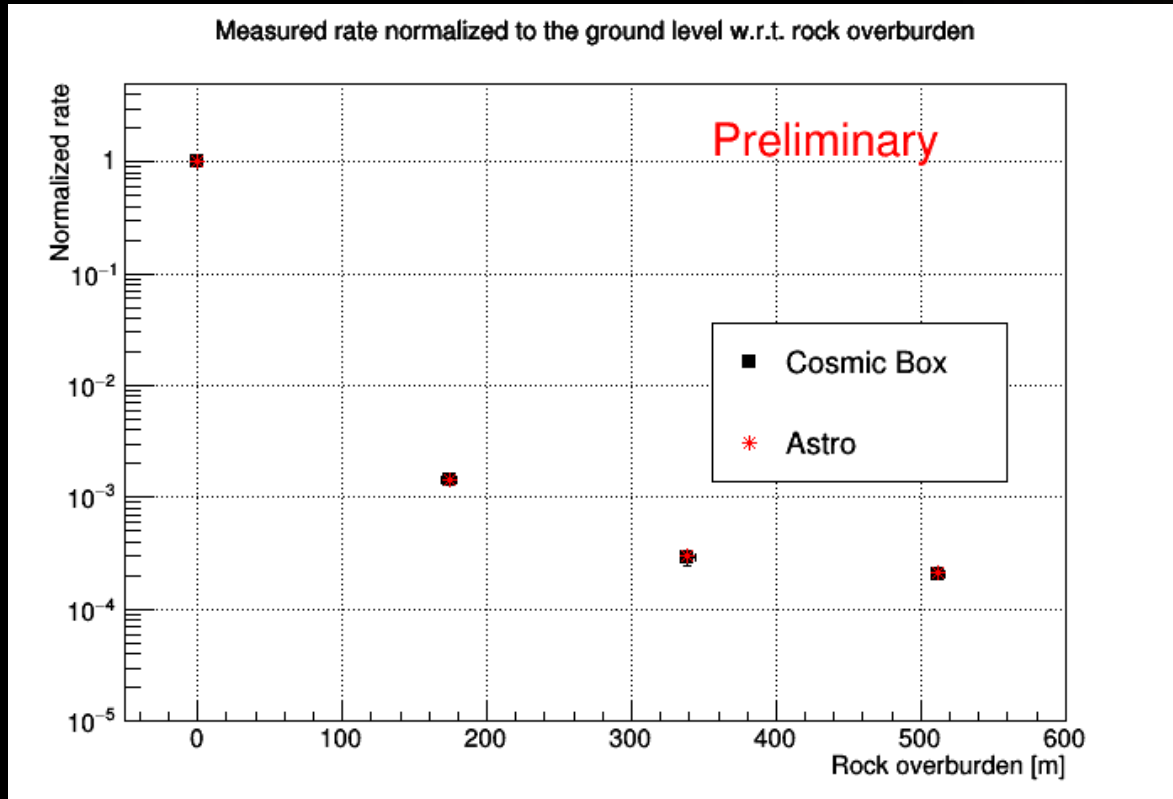


Results

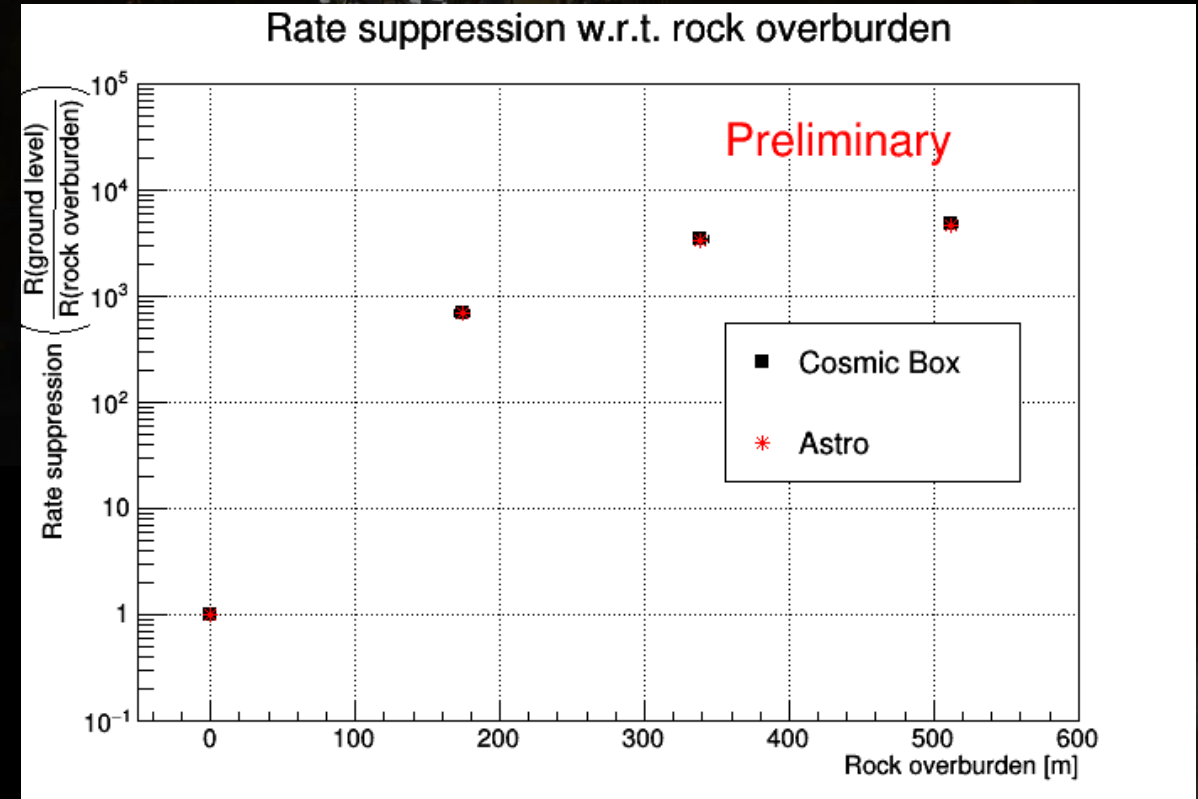


Results

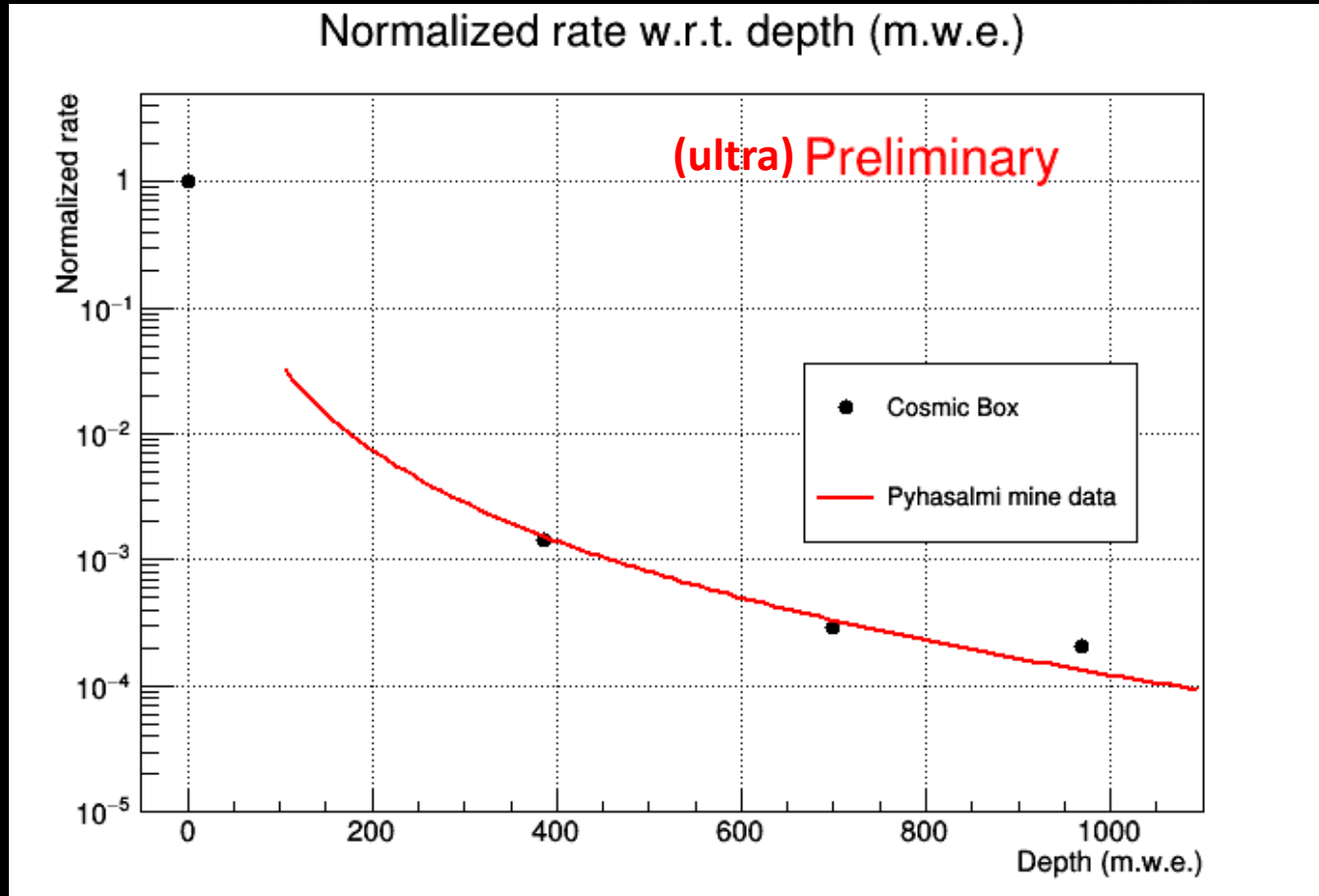
$$R_{in}/R_{out}$$



$$R_{out}/R_{in}$$



Comparison with Pyhäsalmi mine (Finland) measurements



More accurate density uncertainty to be estimated

Conclusions

- Two detectors (CB + Astro) used to measure muon flux underground
- 4 measurements: 0, 174, 339, 512 meters underground
- CB and Astro measurements fully compatible within the errors

To do:

- Other measurements at different depths are scheduled for the next months (set up of next site ongoing)
- Reconstruction of the terrain above measurement sites
- A precise comparison with other experiments
- ...



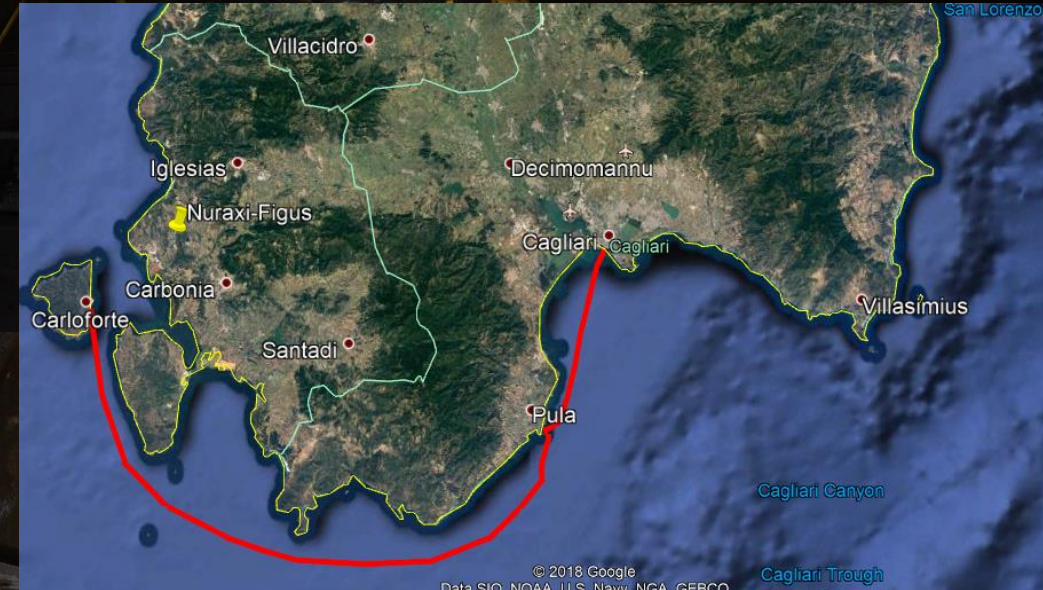
Sailing with Cosmic Box



08/03/2019



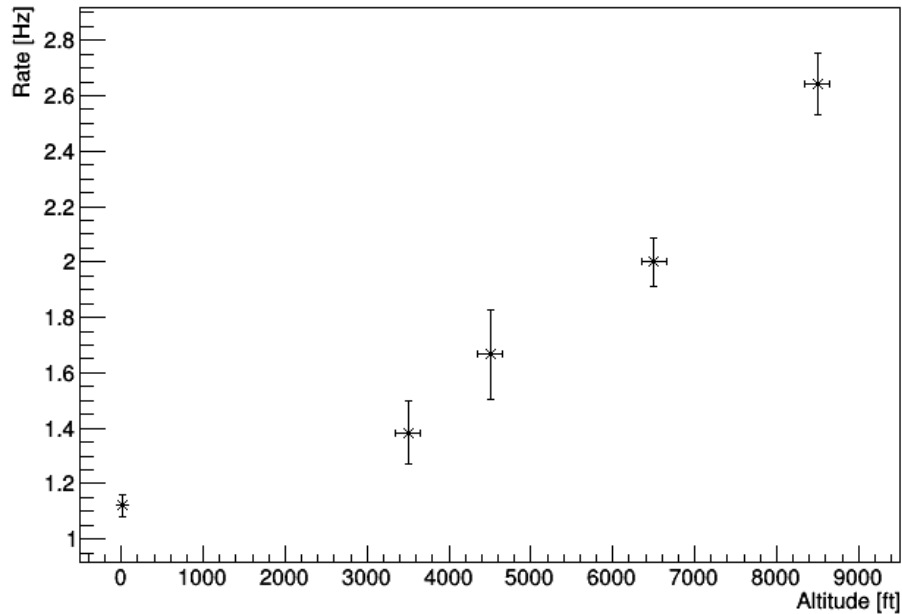
S. Boi



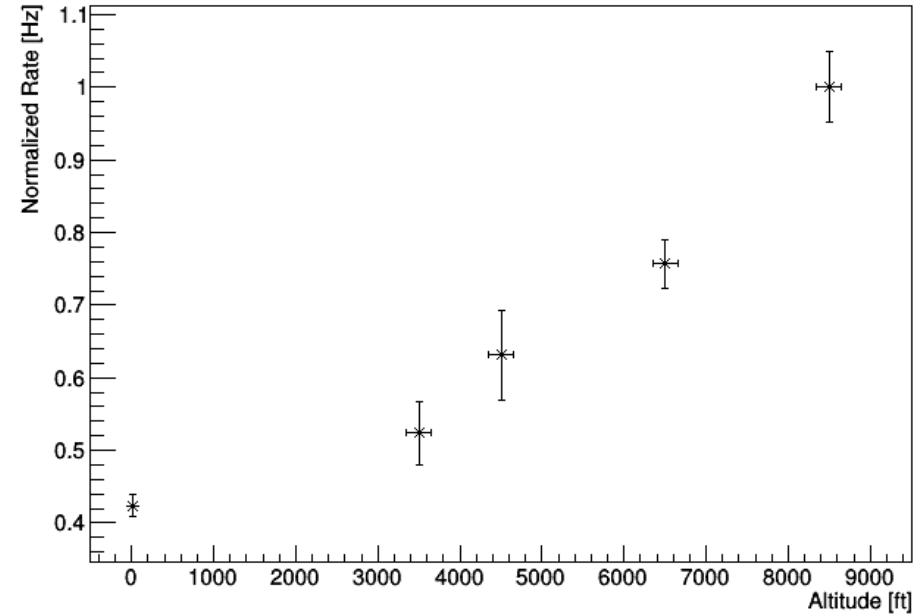
35

In flight with Cosmic Box

Rate vs Altitude



Normalized rate vs Altitude



S. Boi



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Estimate acquisition time: preliminary measurements

S. Giovanni cave in Domusnovas (50 km east of Cagliari):

- two Cosmic Box



Estimate acquisition time: preliminary measurements

- Rate outside: $R = 1,38 \text{ Hz}$
- Rate inside ($\sim 100 \text{ m}$, $d \sim 2,1 \text{ g/cm}^3$) $R = 3,9 \text{ mHz}$
- Rate suppression (inside/outside) $\sim 0,003$



Estimate acquisition time: preliminary measurements

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

