

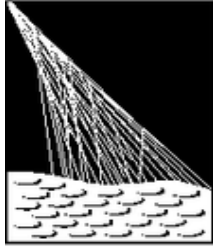
***L'Osservatorio Pierre Auger:
attività locale e richieste per il 2022***

Image:
S.Saffi

R. Assiro, G. Cataldi, M.R. Coluccia, F. Convenga, A. Corvaglia, P. Creti, F. de Palma, Epicoco, G. Fiore, A. Innocente, G. Mancarella, D.Martello, A. Miccoli, A. Nucita, L.Perrone, C. Pinto, F. Ricciardi, G. Rispoli, P. Savina, V. Scherini

The Pierre Auger Observatory

about 400 members, 17 countries



PIERRE
AUGER
OBSERVATORY

Surface detector

an array of 1660 Cherenkov stations on a 1.5 km hexagonal grid ($\sim 3000 \text{ km}^2$)

Fluorescence detector

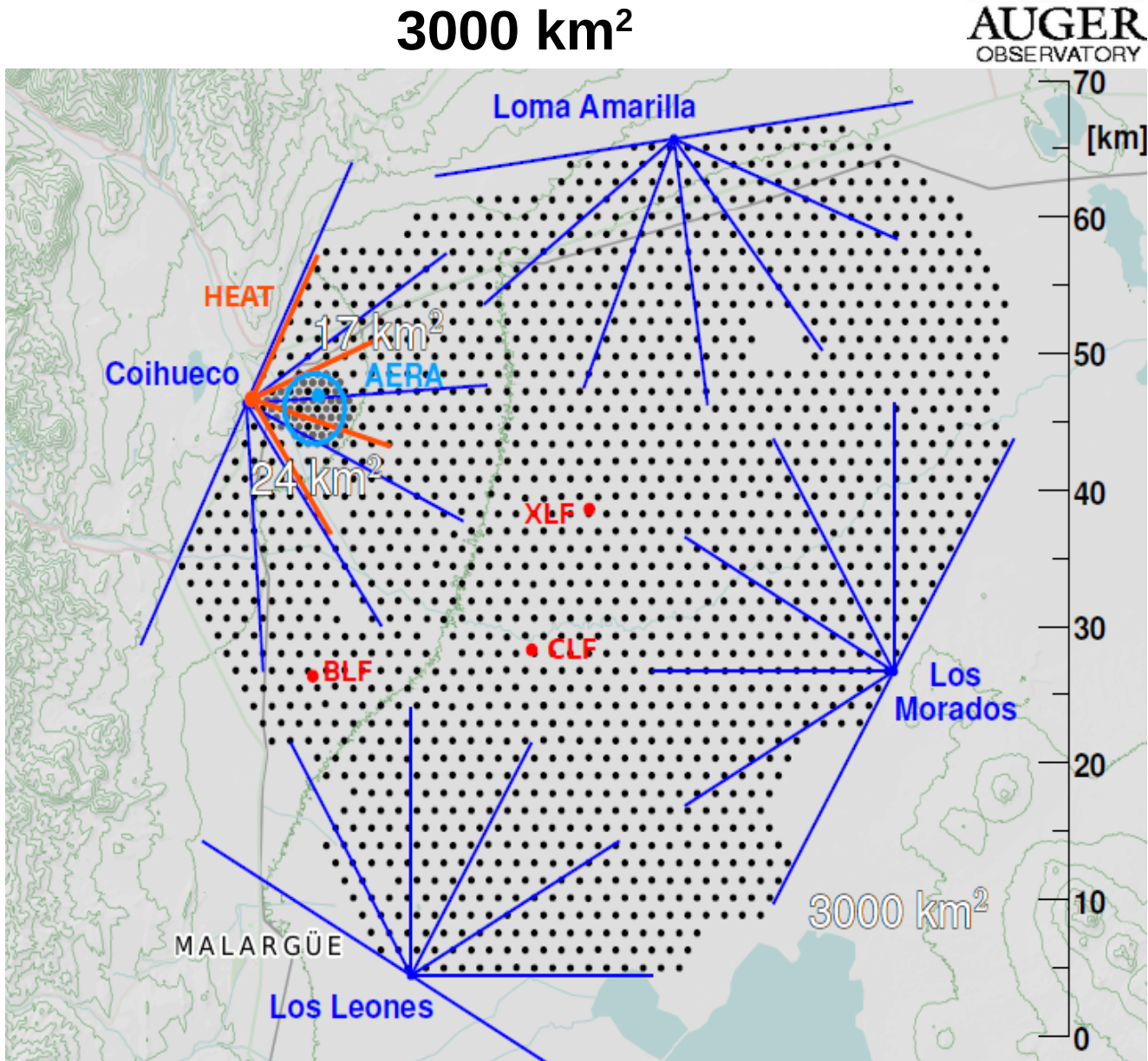
4+1 buildings overlooking the array (24+3 telescopes)

Radio detector

153 Radio Antenna $\rightarrow$ AERA

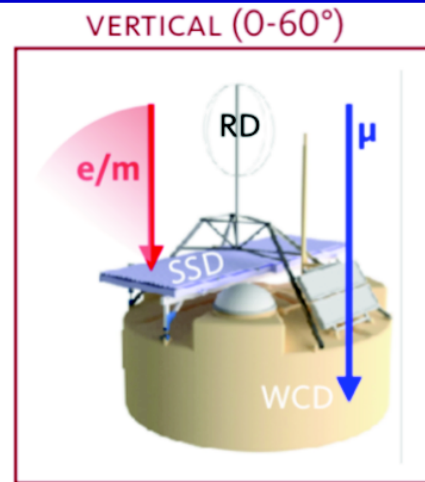
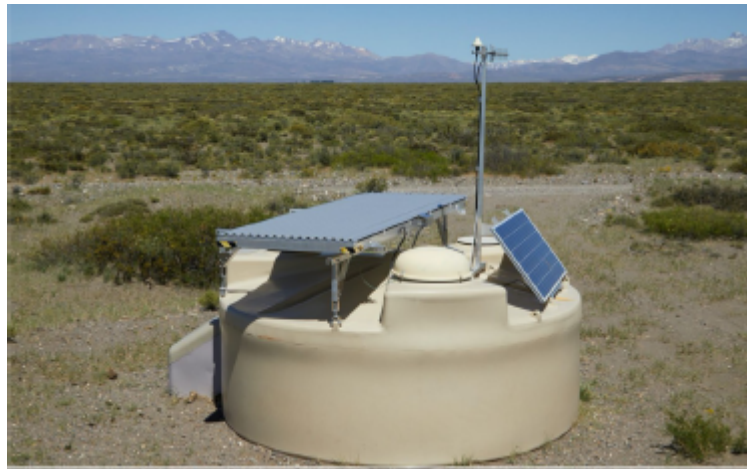
Low energy extensions

- Dense array (24 km^2) plus muon detectors $\rightarrow$ UMD
- 3 further high elevation FD telescopes $\rightarrow$ HEAT



The Pierre Auger Observatory Upgrade: AugerPrime

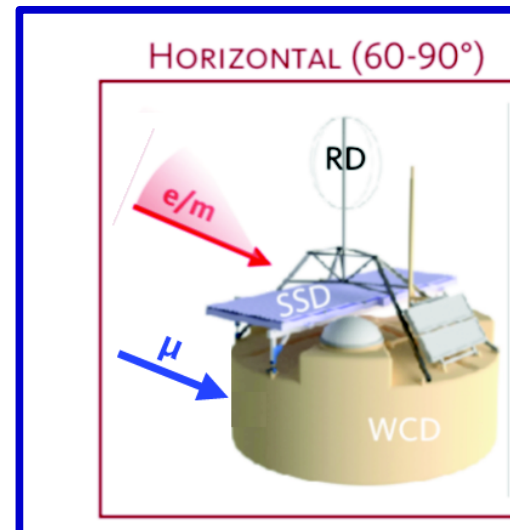
Scintillatori SSD



Caso scientifico:

Migliorare la qualità delle misure di composizione (astronomia alle altissime energia, fisica adronica)

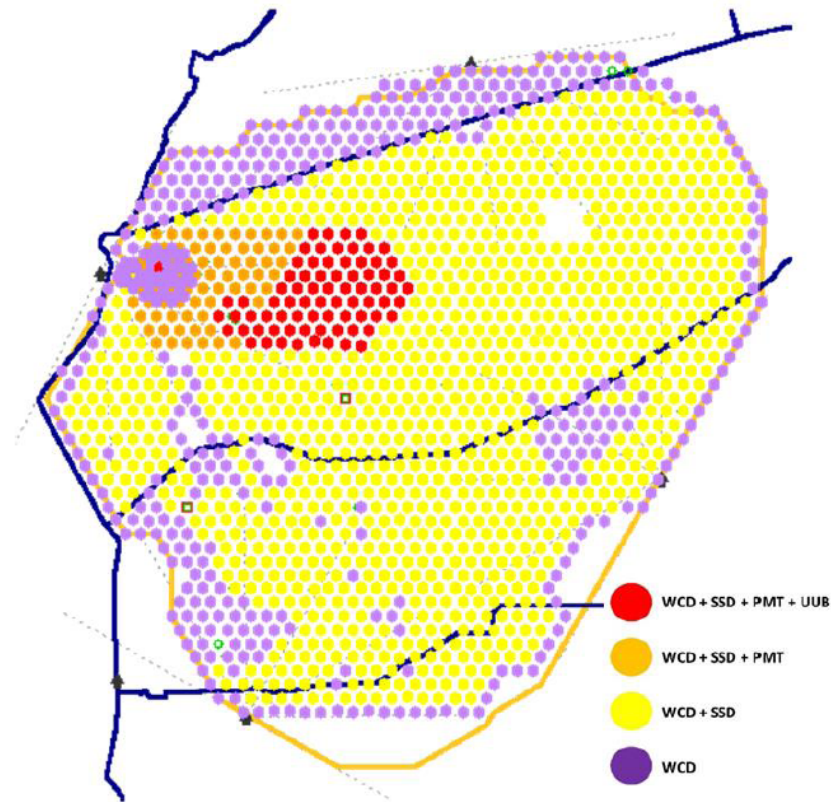
Radio Antenne



Rivelatori di muoni underground

+ elettronica veloce
+ estensione range dinamico

SSD Deployment: status in june 2021



Around 1400 out of the total number of Auger surface detectors will be instrumented with SSD.

The remaining detectors will be used either as spares or on specific parts of the experimental region (e.g. on doublets that are detectors located few meters apart, or in the 750m sub-array where the SDs are more densely spaced).

The full array will contain the upgraded electronics and will be fully functional in trigger capabilities.

- circa 1220 posizionati nel campo
- circa 150 with PMT
- circa 80 con la nuova elettronica UUB

G. Cataldi @ICRC2021

Impatto del COVID...

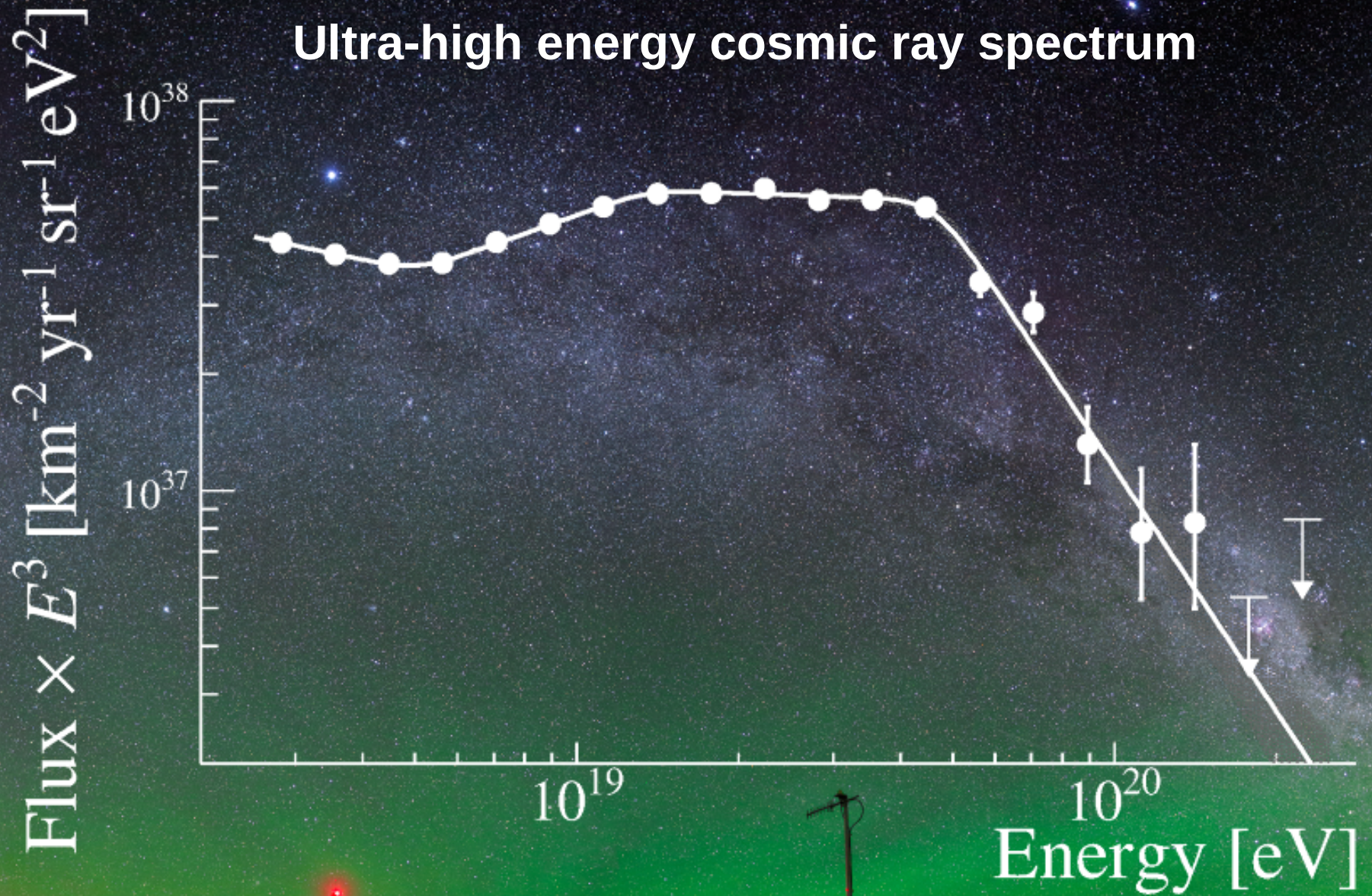
- Meeting di collaborazione online (ormai per 4 volte)
- Turni di presa dati FD da remoto
- Manutenzione e installazione detector piu' complicata
- Produzione della UUB un po' ritardata
- Viaggi di tecnici in situ bloccati, con conseguenze che dovremo affrontare appena possibile viaggiare.



TURNI FD: il lockdown ha richiesto uno sforzo a chi gestisce le stanze ai accesso remoto. 1 turno a Febbraio e uno a Luglio (in corso) nella nostra control room remota di Lecce

TURNI SD: SD dal 1 al 15 Aprile fatto da Lecce

Ultra-high energy cosmic ray spectrum



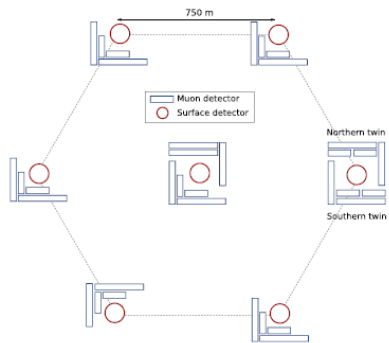
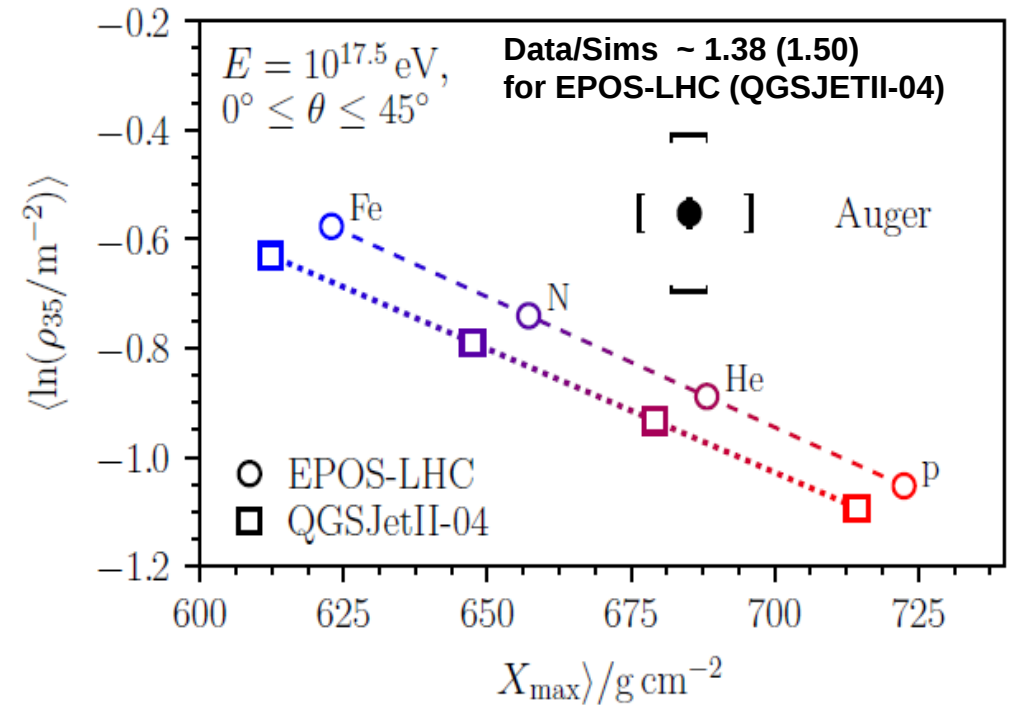
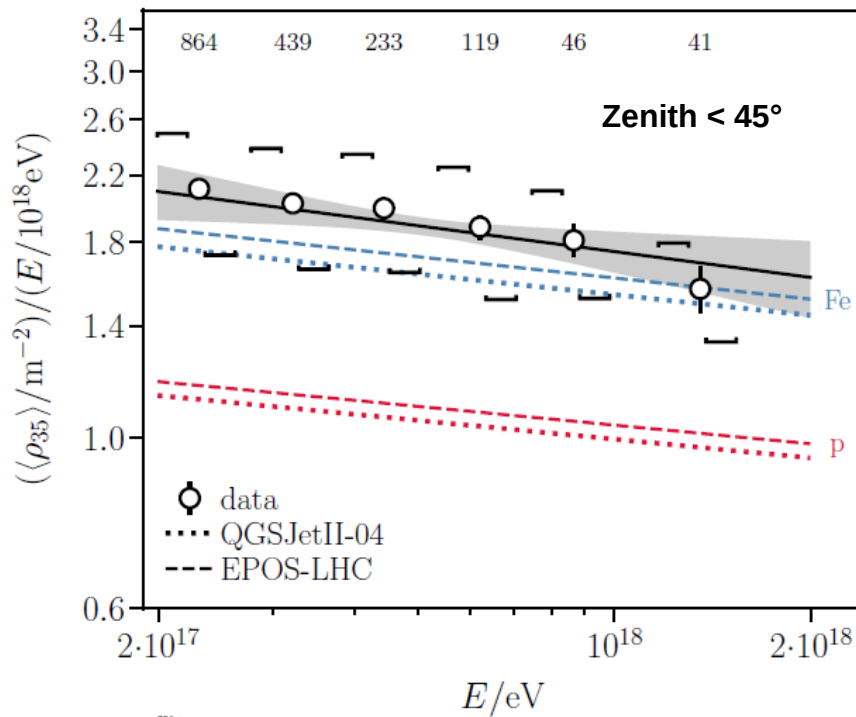
Auger Collaboration PRD 2020 arXiv 2008.06486

Auger Collaboration PRL 2020 arXiv 2008.06488

Editor
suggestion

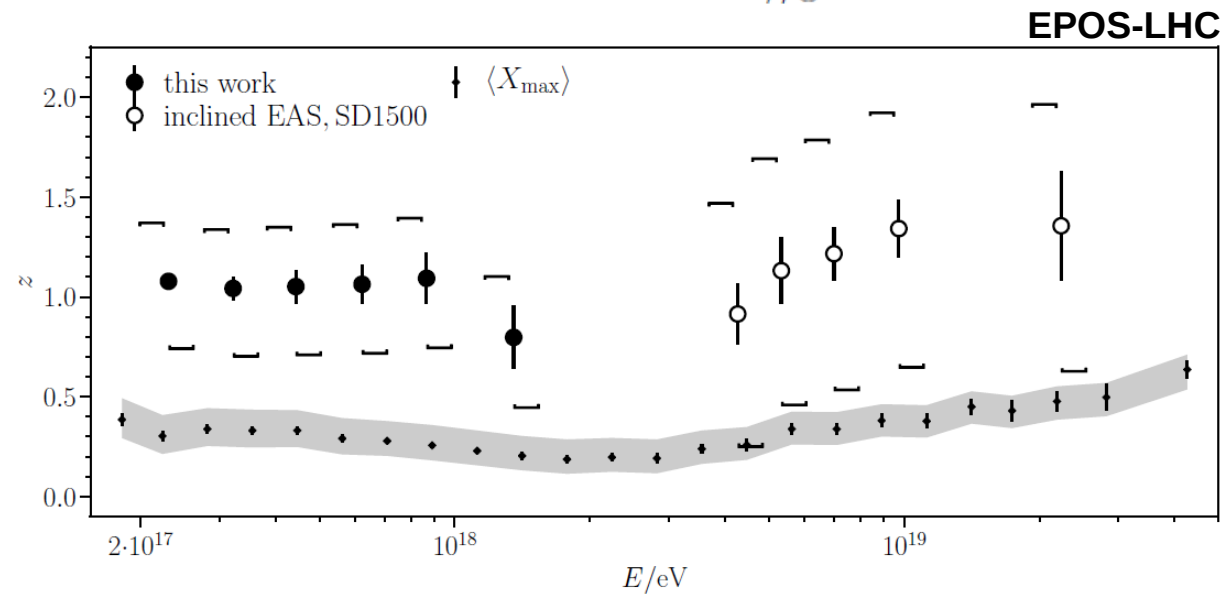
Measurement of muon density and impact on models

Eur. Phys J. C (2020) 80:751: first direct measurement of muon number with UMD at Auger



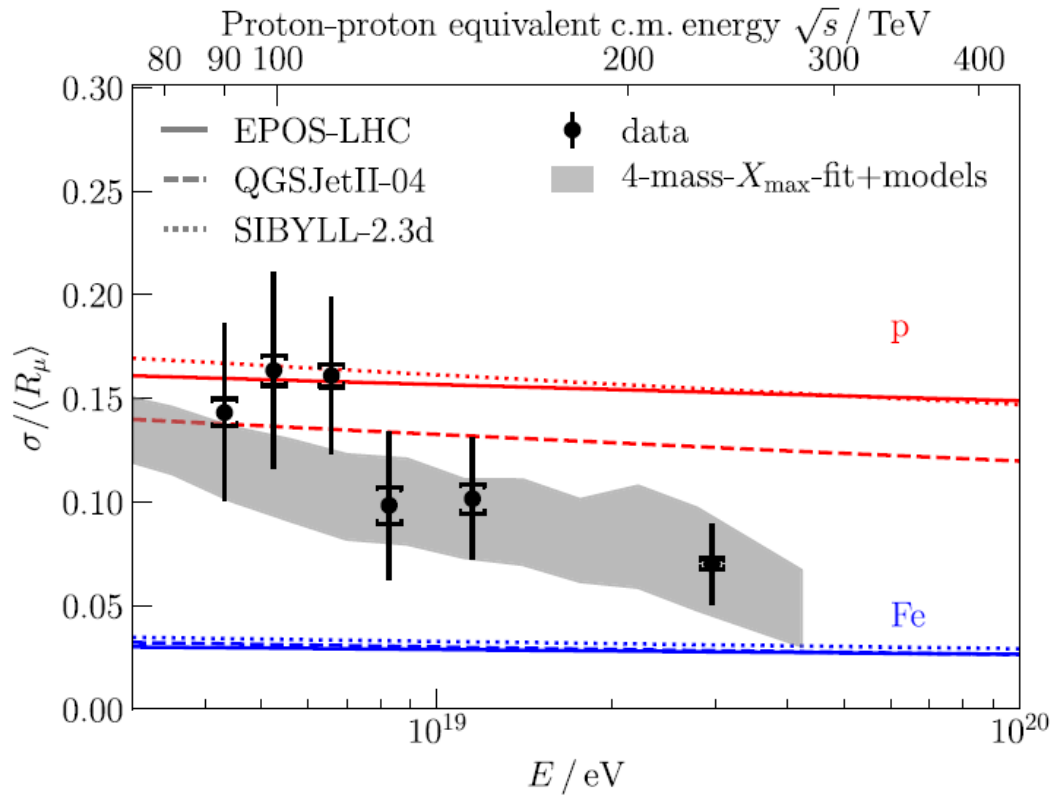
$$z = \frac{\langle \ln x \rangle - \langle \ln x \rangle_p}{\langle \ln x \rangle_{\text{Fe}} - \langle \ln x \rangle_p}$$

Models in tension with data on a wide energy range



Measurement of muon number fluctuations

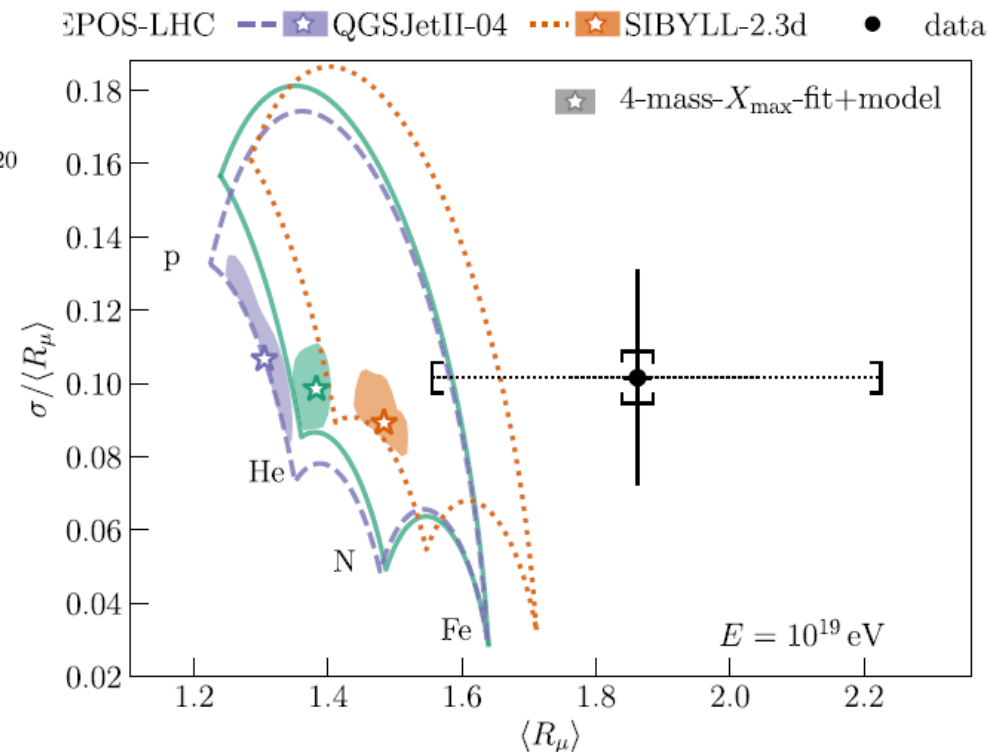
PHYSICAL REVIEW LETTERS 126, 152002 (2021)



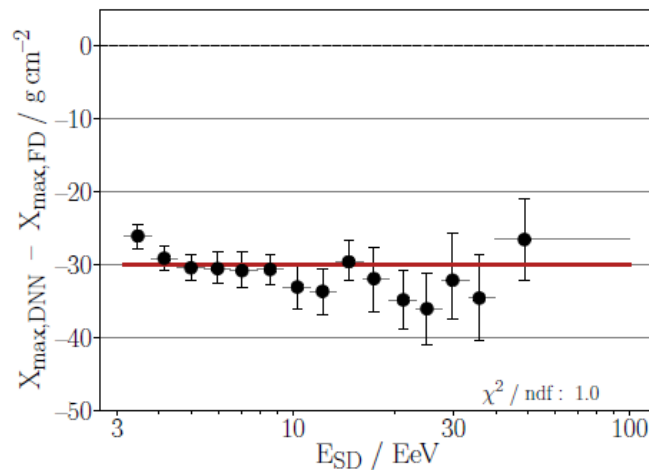
Fluctuations are within the expectations of the models

Any change to model should reproduce a higher number of muons without changing fluctuations

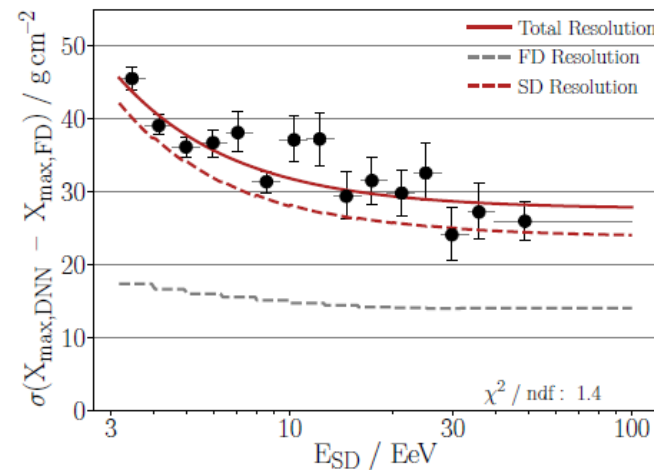
This points to a small effect occurring at any stage of the shower development rather than a sizable difference at the first interaction



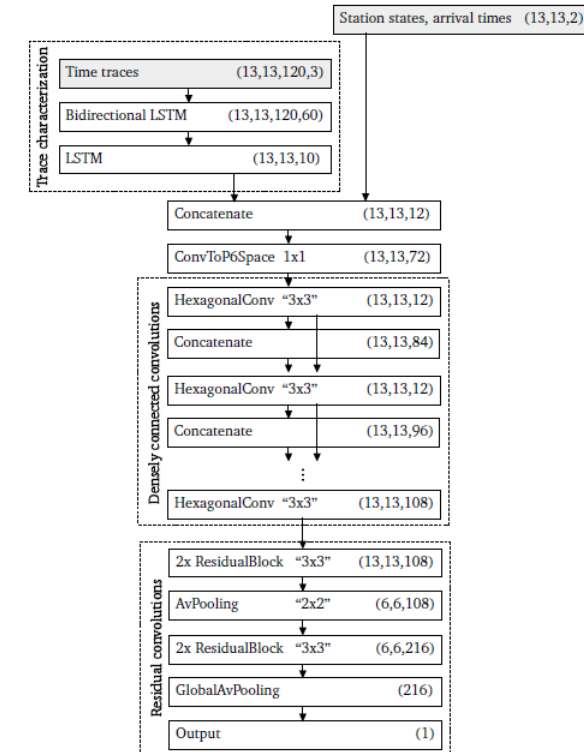
Deep-Learning based Reconstruction of the Shower Maximum $X_{\max}$ using the Water-Cherenkov Detectors of the Pierre Auger Observatory



(a) Bias



(b) Resolution



**Architettura della
rete neurale per
misurare $X_{\max}$**

Figure 12: (a) Energy-dependent bias of the deep neural network with respect to the reconstruction of the fluorescence detector. (b) Energy-dependent resolution of the deep neural network with respect to the reconstruction of the fluorescence detector.

Deep Learning e NN applicate alle misure di composizione
AugerPrime permetterà di validarle e capire l'origine dei bias

Multi-messenger Astronomy



Multi-Messenger Physics With the Pierre Auger Observatory

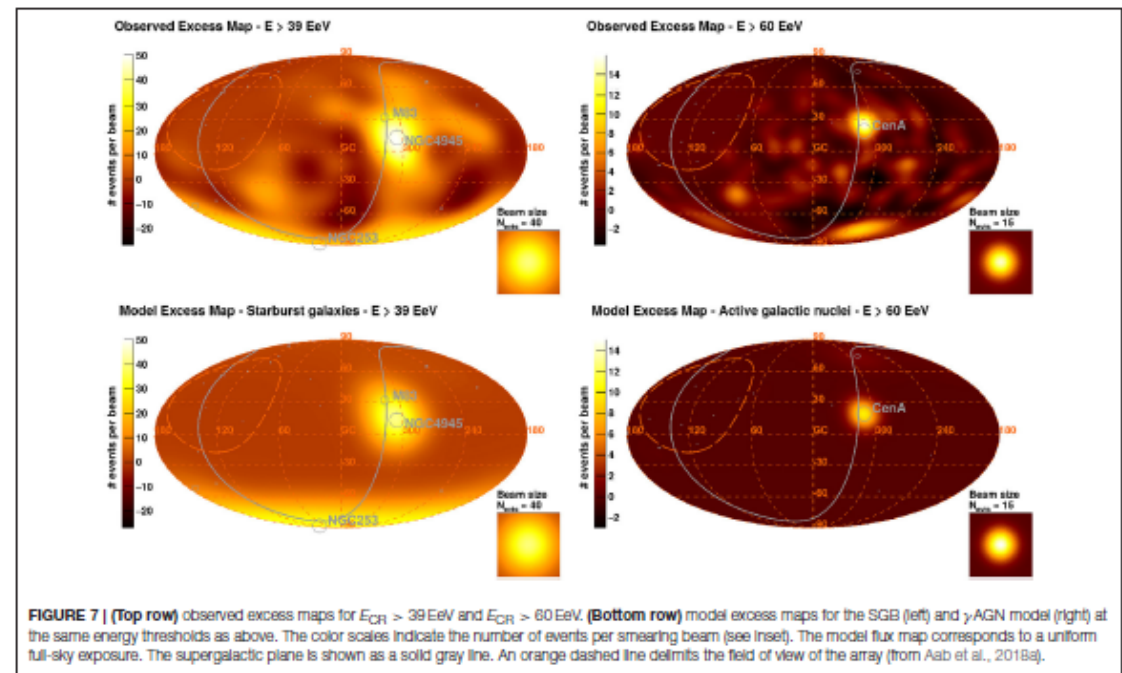
Karl-Heinz Kampert¹, Miguel Alejandro Mostafa²,
Enrique Zas³ and The Pierre Auger Collaboration^{4*}

Ricerca di fotoni, neutrini (anche con radio detection), neutroni, raggi cosmici, GW in coincidenza tra apparati operativi sul pianeta

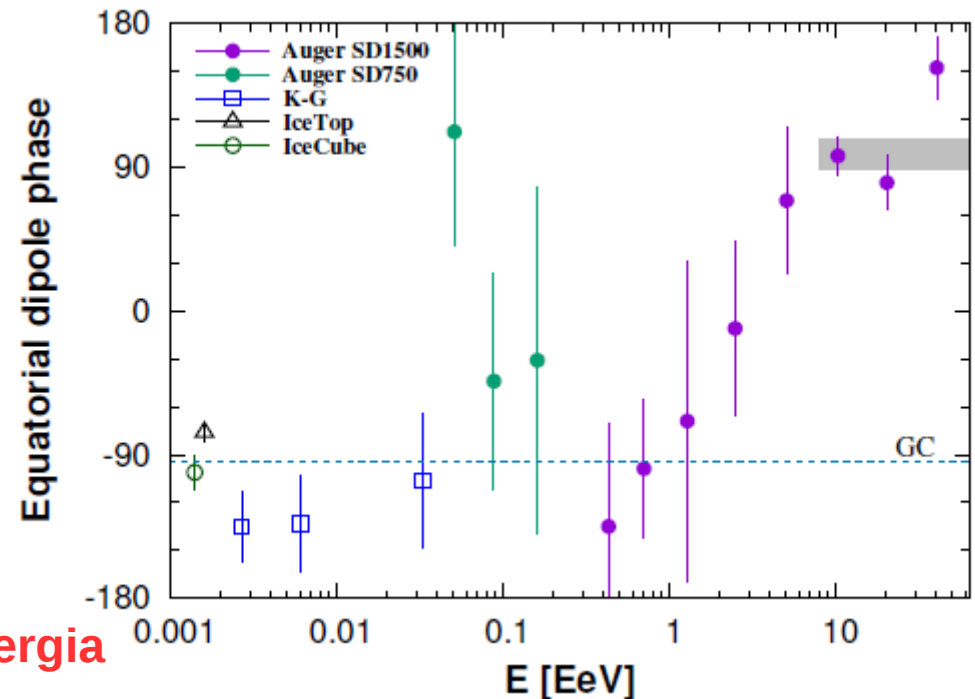
Studio delle anisotropie nella direzione di arrivo → Anisotropie a larga scala ad alta energia ($E > 8$ EeV)

- Risultato di science 2017 confermato e rafforzato (da 5.2 a 6 sigma)

Natura extragalattica dei RC di altissima energia



Astrophys. J. 891 (2020) 142



Pierre Auger Observatory Open Data

February 2021 release



The Pierre Auger 2021 Open Data is the public release of 10% of the Pierre Auger Observatory data presented at the [36th International Cosmic Ray Conference](#) held in 2019 in Madison, USA, following the [Auger collaboration open data policy](#).

This website hosts [the datasets for download](#). An [online event display](#) is available to explore the released events, and example [analysis codes](#) are provided. See below for a brief overview of the [Pierre Auger Observatory](#) and of the [Auger Open Data](#).



Datasets

[the complete released datasets](#)
[and their complementary data](#)



Visualize

[an online look at the released](#)
[pseudo raw data](#)



Analyze

[example analysis codes in](#)
[online python notebooks to run](#)
[on the datasets](#)

The Open Data

The February 2021 release

10% of data used for physics results presented at ICRC2019

Aim: re-use by a wider community

including professional and citizen scientists and
in world-wide educational & outreach initiatives

Close-to-raw data & higher level
reconstructed information

Surface and Fluorescence Detectors

JSON and summary CSV files

Event visualization tools

Python code for data analysis

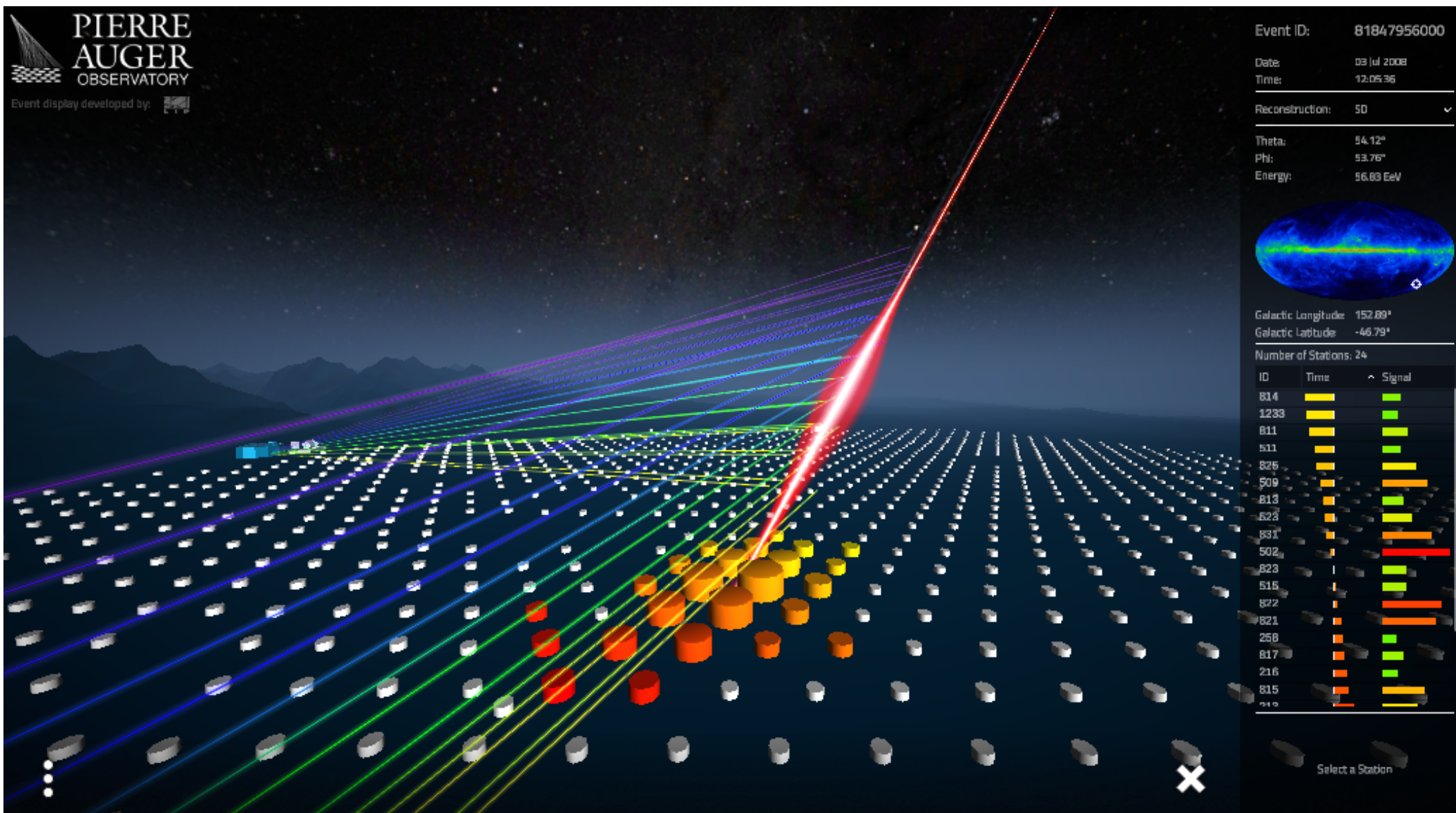


<https://opendata.auger.org>

DOI:10.5281/zenodo.4487613

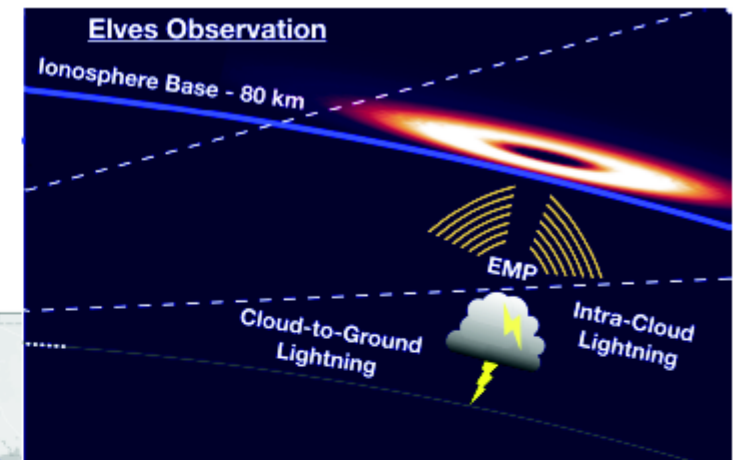
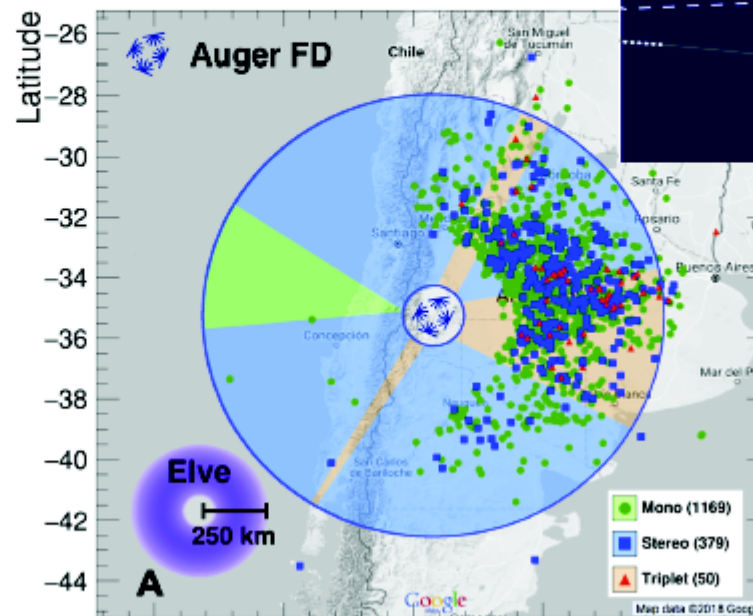
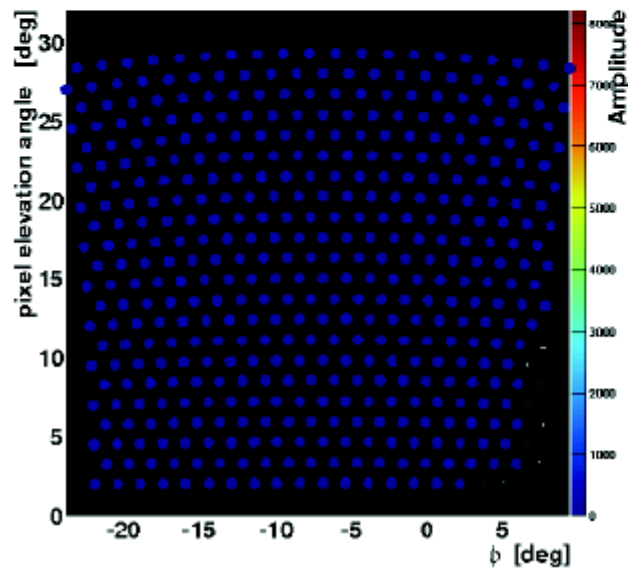
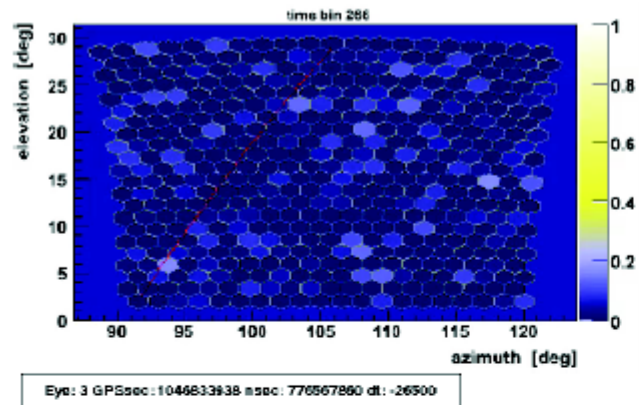
V. Scherini@ICRC2021

Visualization



Ricerca interdisciplinare: Osservazioni di elfi

Earth Space Sci. 7 (2020) e2019EA000582



1600 elves observed

Short article to
appear in EOS News

High-level publications of correlation with super bolts in preparation

Gruppo Auger di Lecce: anagrafica e percentuali

Ricercatori					
	Nome	Età	Contratto	Qualifica	Aff. %
1	Cataldi Gabriella		Dipendente	Ricercatore	CSN II 95
2	Convenga Fabio		Associato	Dottorando	CSN II 100
3	De Palma Francesco		Associato	Ricercatore B Tempo Determinato Tipo B	CSN II 60
4	De Vito Emanuele		Associato	Dottorando	CSN II 100
5	Epicoco Italo		Associato	Ricercatore Universitario	CSN II 60
6	Mancarella Giovanni		Associato	Prof. Ordinario	CSN II 100
7	Martello Daniele		Associato	Prof. Ordinario	CSN II 95
8	Nucita Achille		Associato	Ricercatore Confermato (Ricercatore)	CSN II 50
9	Perrone Lorenzo		Associato	Prof. Associato	CSN II 80
10	Savina Pierpaolo		Associato	Dottorando	CSN II 100
11	Scherini Viviana		Associato	Assegnista	CSN II 100
Numero Totale Ricercatori				11	FTE: 9.40

Tecnologi					
	Nome	Età	Contratto	Qualifica	Aff. %
1	Coluccia Maria Rita		Dipendente	Tecnologo	CSN II 80
2	Creti Pietro		Dipendente	Primo Tecnologo	CSN II 20

Anagrafica
2020



2021

1 Dottorando
(E. De Vito)

1 Laureato Magistrale
(C. Cardellini)

- 1 fisico al 100% (Pierpaolo Savina)
- 1 fisico al 100% (Fabio Convenga)

1 Laureando Magistrale
(M. Conte)

Ritocchi alle percentuali in fase di definizione

1 Laureando Triennale
(R. Rizzo)

Il gruppo di Lecce: responsabilità

Science/Detector

Responsabilità per l'infrastruttura di produzione a Lecce per conto di Auger (G. Cataldi)

Referente per il calcolo di Auger al CNAF (G. Cataldi)

Official readers in vari Editorial Boards (G. Cataldi, V.Scherini, L. Perrone)

Chair del Production readiness committee per AugerPrime Radio detector, subsystem Mechanics (G. Cataldi)

Task leader per SSD (D. Martello)

Istituzionali

Chair del Collaboration board (L. Perrone)

Membro del Publication Committee (L. Perrone)

Il gruppo di Lecce: partecipazione a conferenze

2020

G. Cataldi	ICHEP (On-Line)	Luglio 2020
L. Perrone	SIF (On-Line)	Settembre 2020
E. De Vito	SIF (On-Line)	Settembre 2020

2021

P. Savina	Madison (On- Line)	Febbraio 2021
F. Convenga	TIPP 2021 (On-line)	Maggio 2021
V. Scherini	NeuTel (On-line)	Marzo 2021
V. Scherini	ICRC (On- Line)	Luglio 2021
G. Cataldi	ICRC (On- Line)	Luglio 2021
P. Savina	ICRC (On- Line)	Luglio 2021
F. Convenga	SIF2021 (On-line)	Settembre 2021

Attività di analisi svolta a Lecce

Performance del rivelatore ibrido

calibrazioni, on-time e data quality

Misura dello spettro energetico

spettro ibrido in particolare (misura di ankle e soppressione)

Open data

Messa a punto dei tool e interazione con task di analisi

AugerPrime

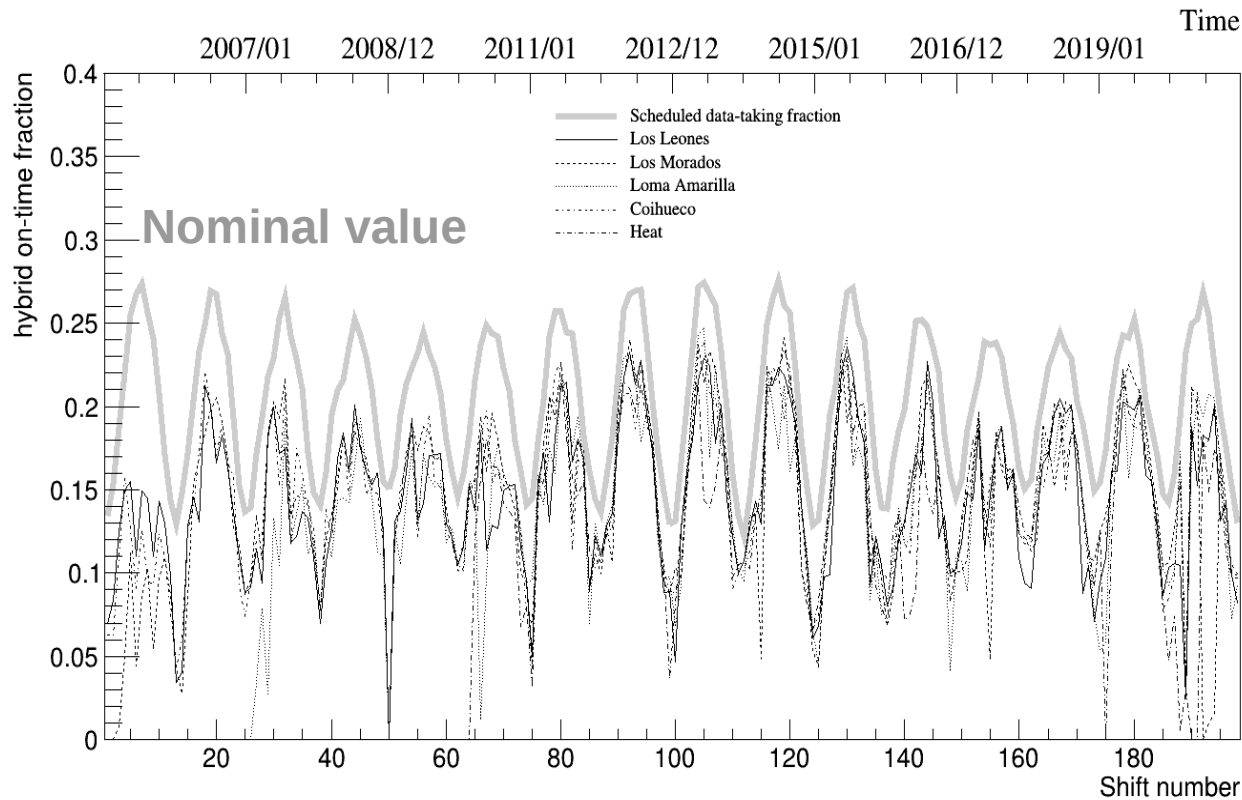
Studio della performance, prime analisi sui dati raccolti

Ricerca di fotoni primari con tecniche di ricostruzione basate sul modello di “universalità”

Ricerca di neutrini con il rivelatore di fluorescenza

Multi-messenger

Performance e long term per il rivelatore ibrido



Hybrid detector ontime

Influenced by:

- Telescope status
- Wheather conditions
- Connection to SD

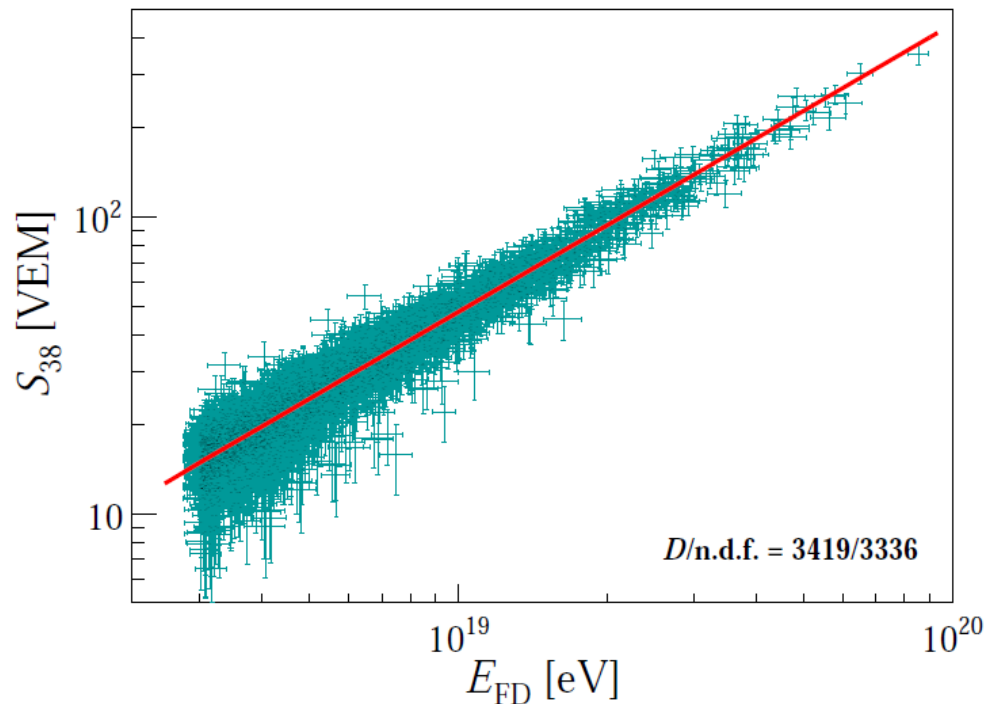
Updated to March 2021

Produzione e controllo di qualità dei dati ibridi dell'osservatorio.

→ **Grazie a Fulvio e Antonio per il supporto al calcolo**

Calibration with the FD energy scale

Auger Collaboration PRD 2020 arXiv 2008.06486



Energy resolution

SD: < 20% (zenith < 60° and $E > 2.5$ EeV)

Hybrid: 7-8 % Hybrid (zenith < 60°)
[ICRC 2019]

Important to account for
resolution effects in the SD-based
spectra

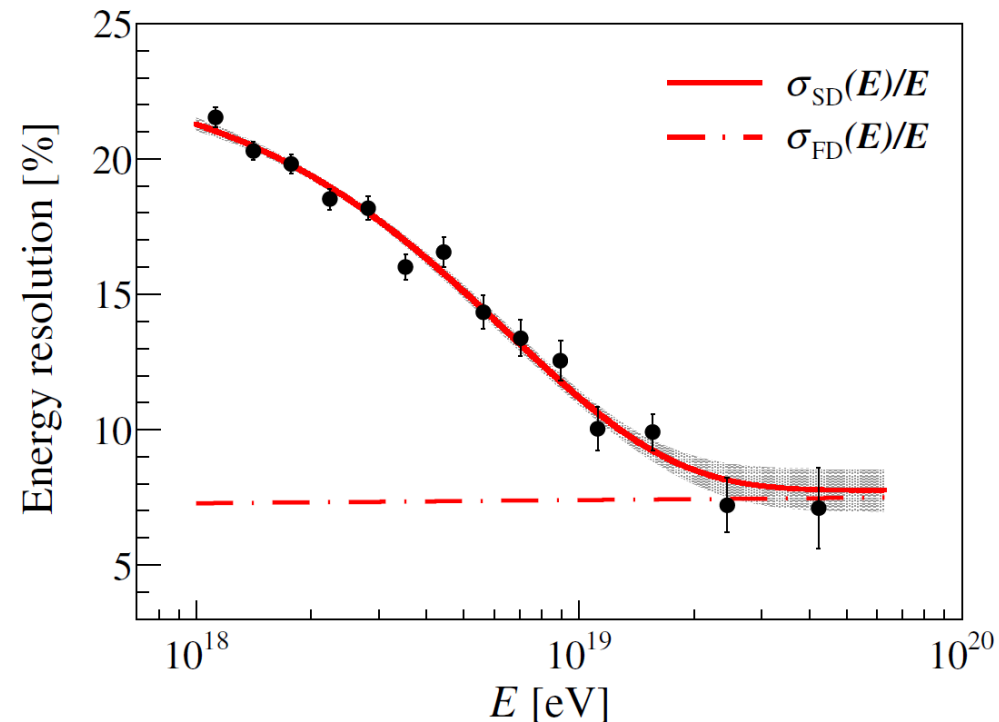
Energy scale uncertainty

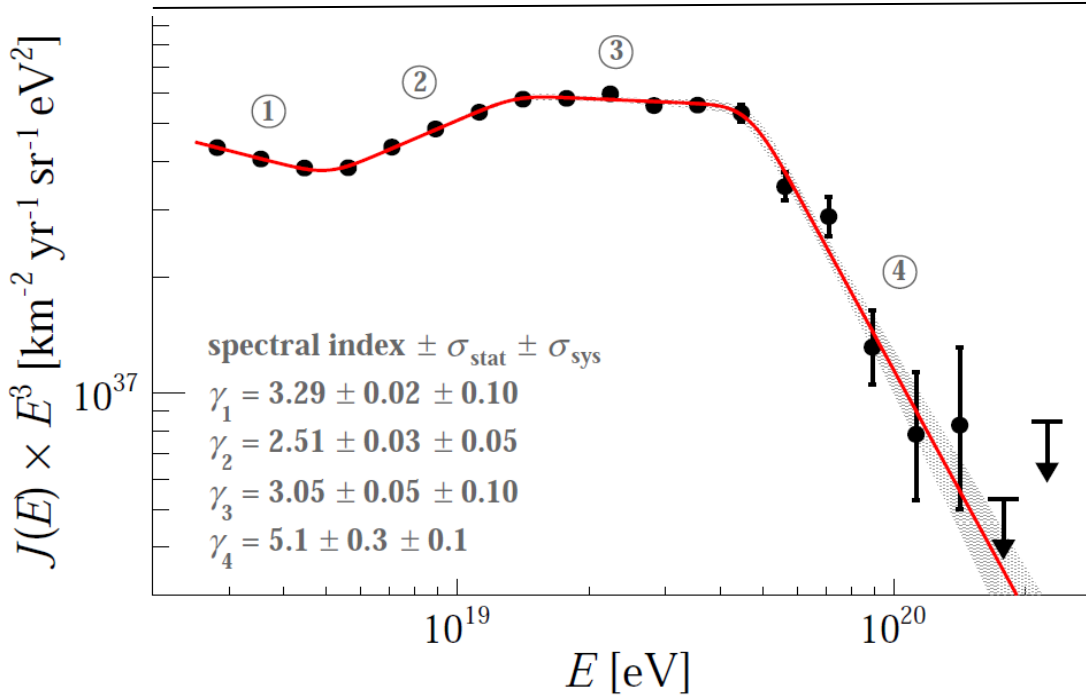
Systematic uncertainty in the energy scale

ICRC 2013

Fluorescence yield	3.6%
Atmosphere	3.4% – 6.2%
FD calibration	9.9%
FD profile recon.	6.5% – 5.6%
Invisible energy	3% – 1.5%
Stability of energy scale	5%
TOTAL	14%

Auger Collaboration PRD 2020 arXiv 2008.06486





Data sample:

215030 events

1/1/2004 – 31/8/2018

Exposure:

60400 km² sr y

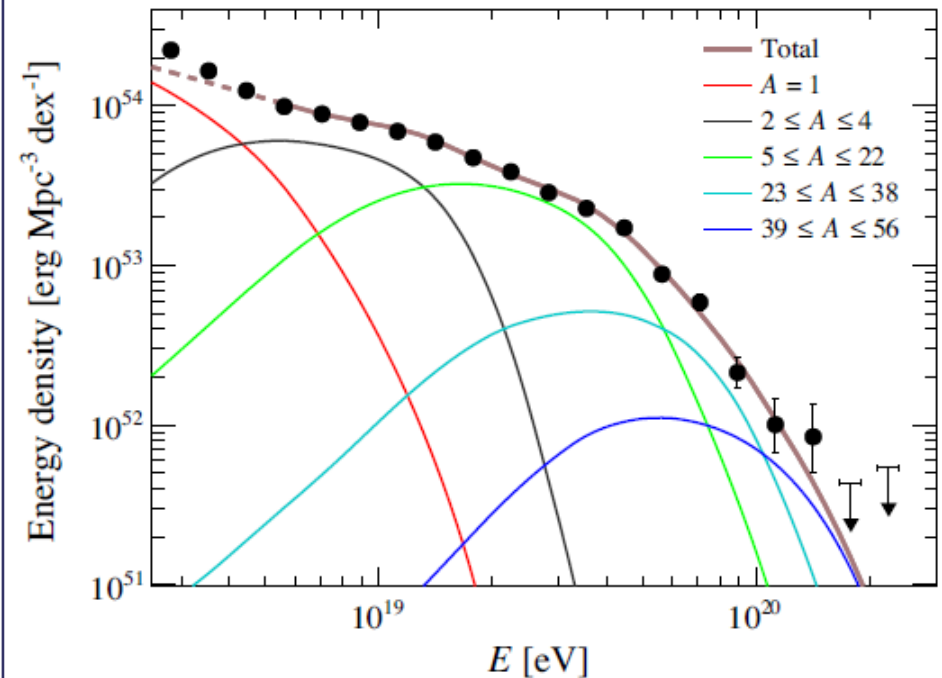
Steepening at $\sim 5 \cdot 10^{19}$ eV confirmed

Ankle at $\sim 5 \cdot 10^{18}$ eV confirmed

New feature at $\sim 10^{19}$ eV identified

**No evidence of dependence
on declination**

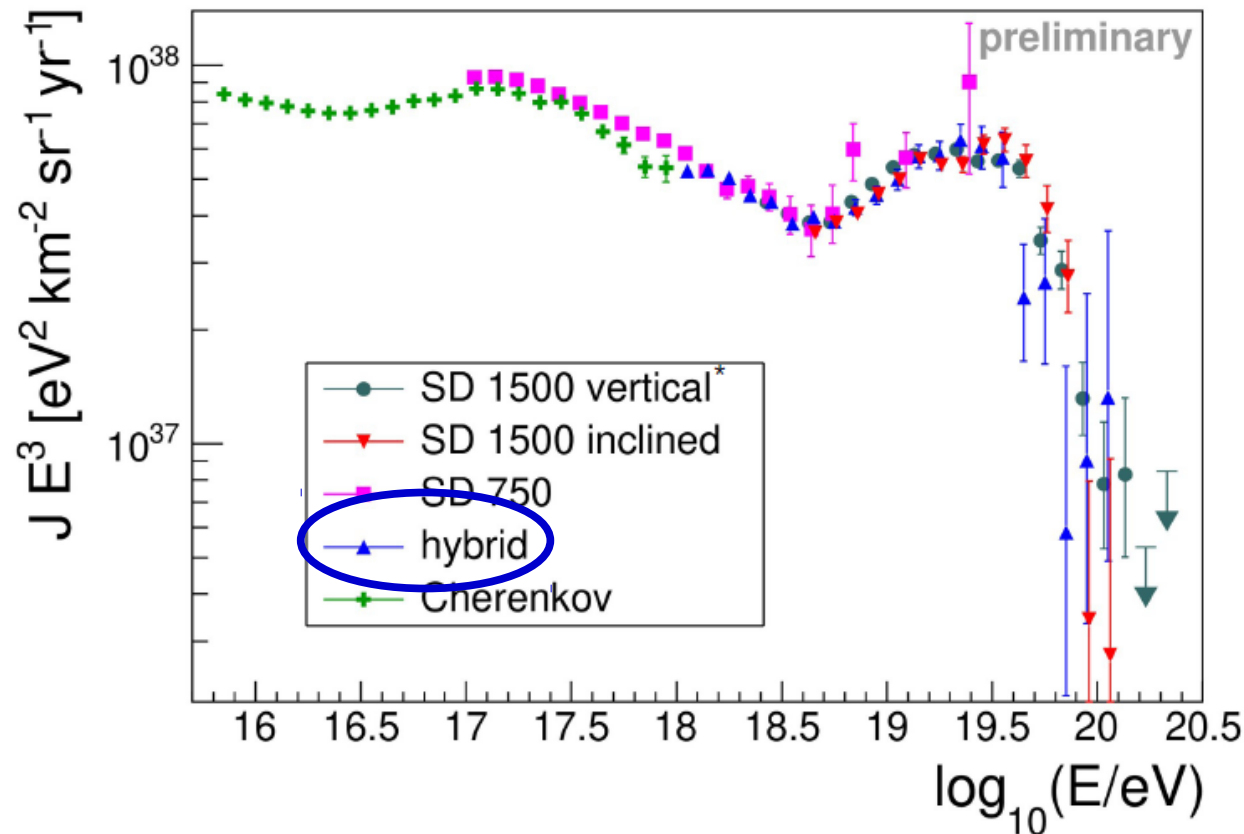
Astrophysical implications



Interplay of heavier primaries as
the energy increases

Spettro energetico con eventi ibridi

@ ICRC 2021



normalization shifts after comb.:

SD 1500 m	<1 %
SD 750 m	-2 %
SD 1500 m inclined	+5 %
Hybrid	<1 %
Cherenkov	+7 %

Esposizione del detector valutata in modo realistico sulla base di ontime, atmosfera ed efficienza di ricostruzione

Demanding dal punto di vista del calcolo gestito al CNAF

(il nostro gruppo si occupa del calcolo per l'intera collaborazione italiana)

Ricerca di fotoni primari con tecniche di Universalità

Tesi di dottorato di Pierpaolo Savina

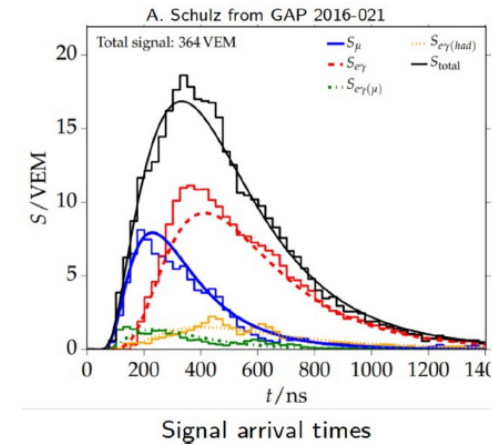
Sviluppo di un metodo basato sul concetto di “universalità”
[sistema complesso di particelle secondarie descritto da pochi parametri]

Four universal components can be identified:

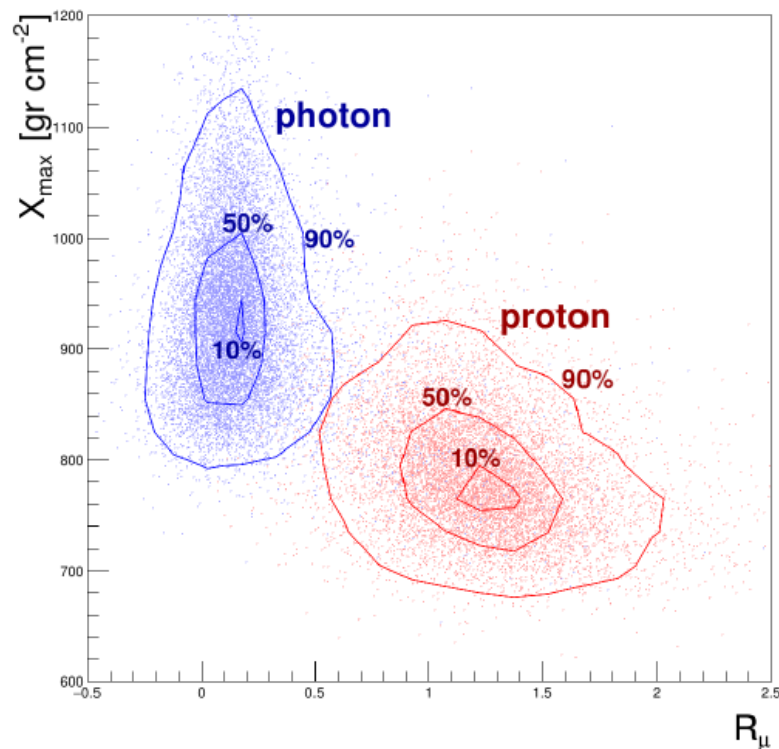
- muons (μ);
- e.m. particles from high energy pions;
- e.m. particles the muons;
- e.m. particles from low energy hadrons;

$$S(r, \Delta X, E, \theta, \psi) = \sum_i (1 + (R_\mu - 1)\alpha_i) S_i \quad (1)$$

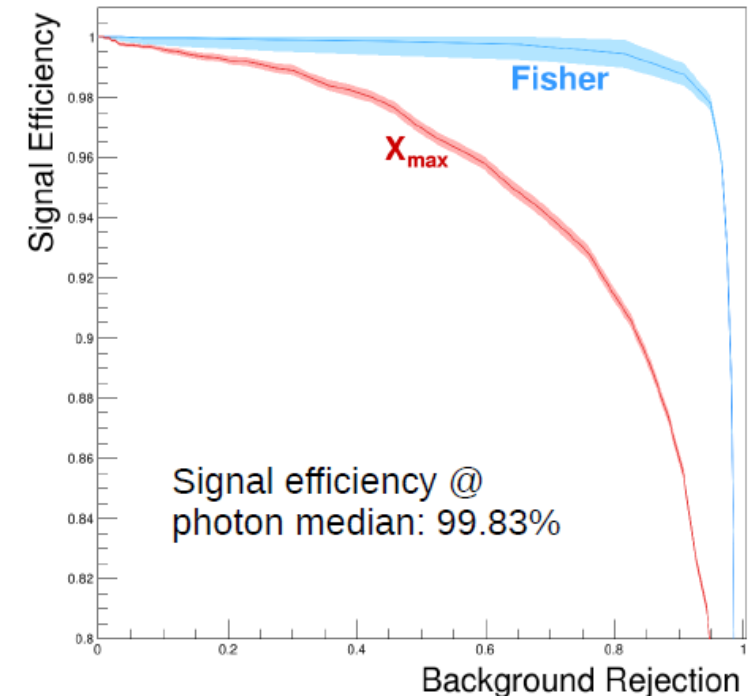
$$R_\mu = \frac{S_\mu}{S_{\mu}^{\text{ref}}} \quad \frac{S_\mu}{S_{\mu}^{\text{ref}}} = \alpha_i \frac{S_i}{S_i^{\text{ref}}}$$



@ ICRC 2019



Miglioramento
della
separazione
tra
adroni (rossi)
e **fotoni** (blu)



Ricerca di neutrini astrofisici con il rivelatore di fluorescenza

Ricerca motivata dall'osservazione di due eventi sospetti (neutrini?) da parte dell'esperimento ANITA (Antartide)

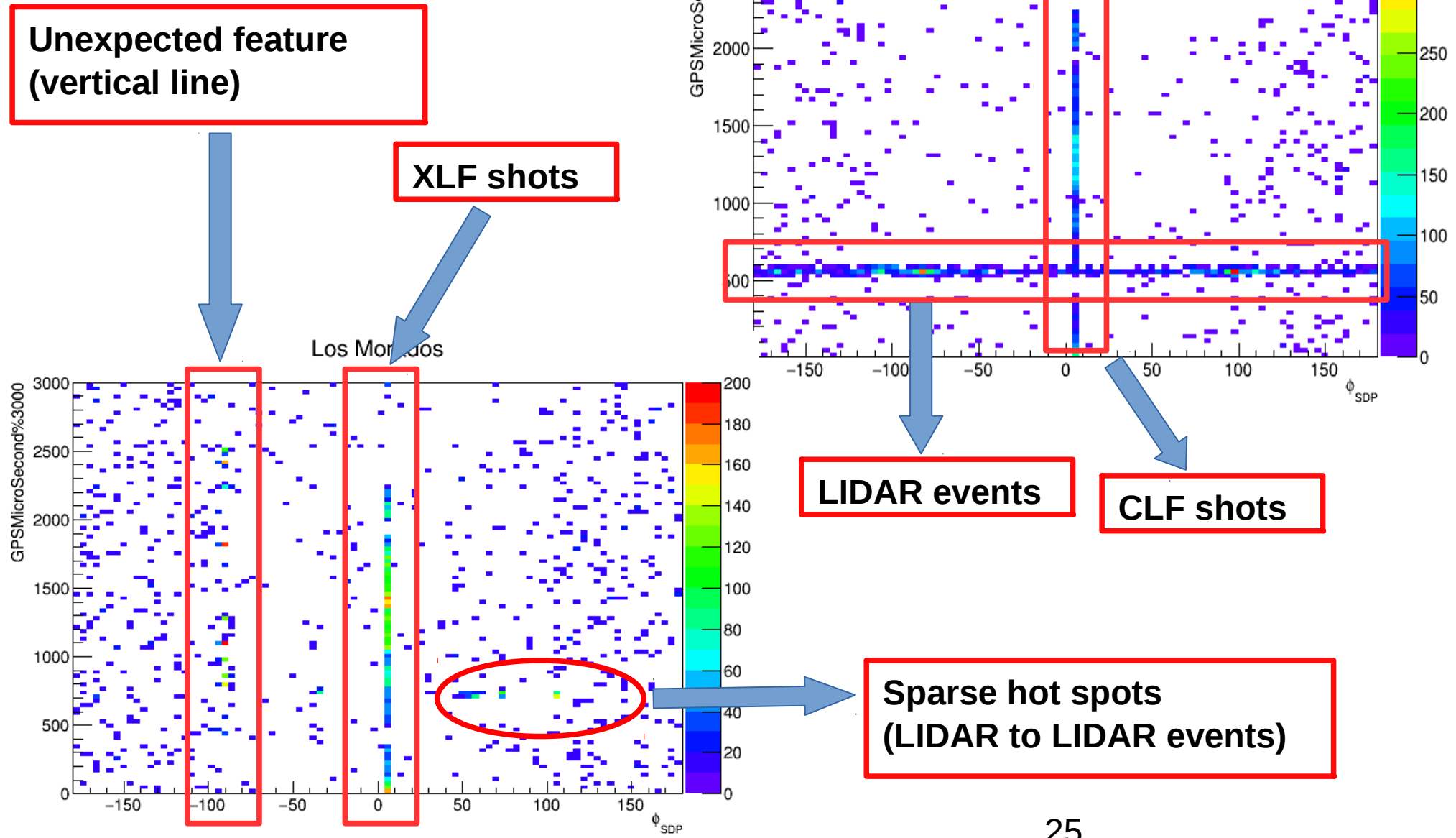
- Ricerca di sciami upward-going (sciami indotti dal decadimento dei tau generati per corrente carica dalla propagazione di neutrini nella roccia)
- Ricerca delicata a causa del background (Laser, fulmini, inefficienze strumentali)

Working group dedicato nel task dei Multi-messenger: obiettivo confutare (o confermare) l'osservazione di ANITA in tempi molto rapidi

Gruppo di Lecce impegnato nell'analisi dei dati, ed in particolare nella reiezione del background

Exemplary plots: burn sample

Los Leones



Event AugerId=11274648000

Lecce Reconstruction (only Coihueco), downward mode favored
Inclined event ($\sim 80^\circ$) passing over Coihueco and landing behind Loma Amarilla

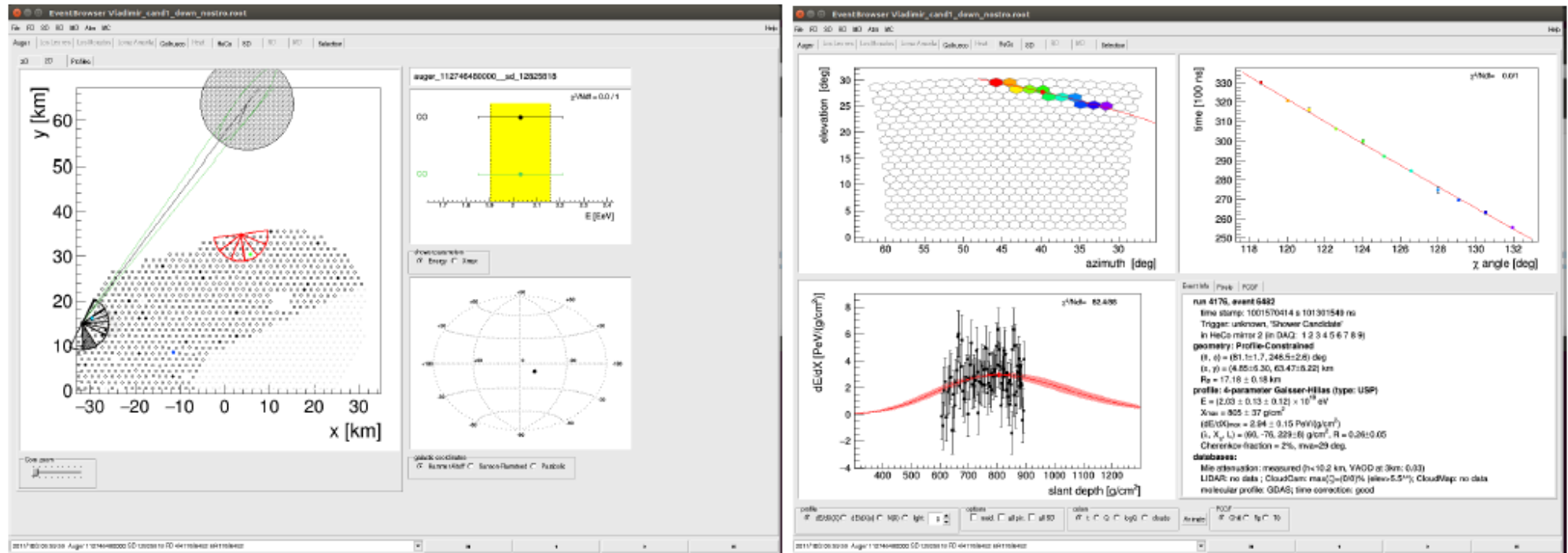
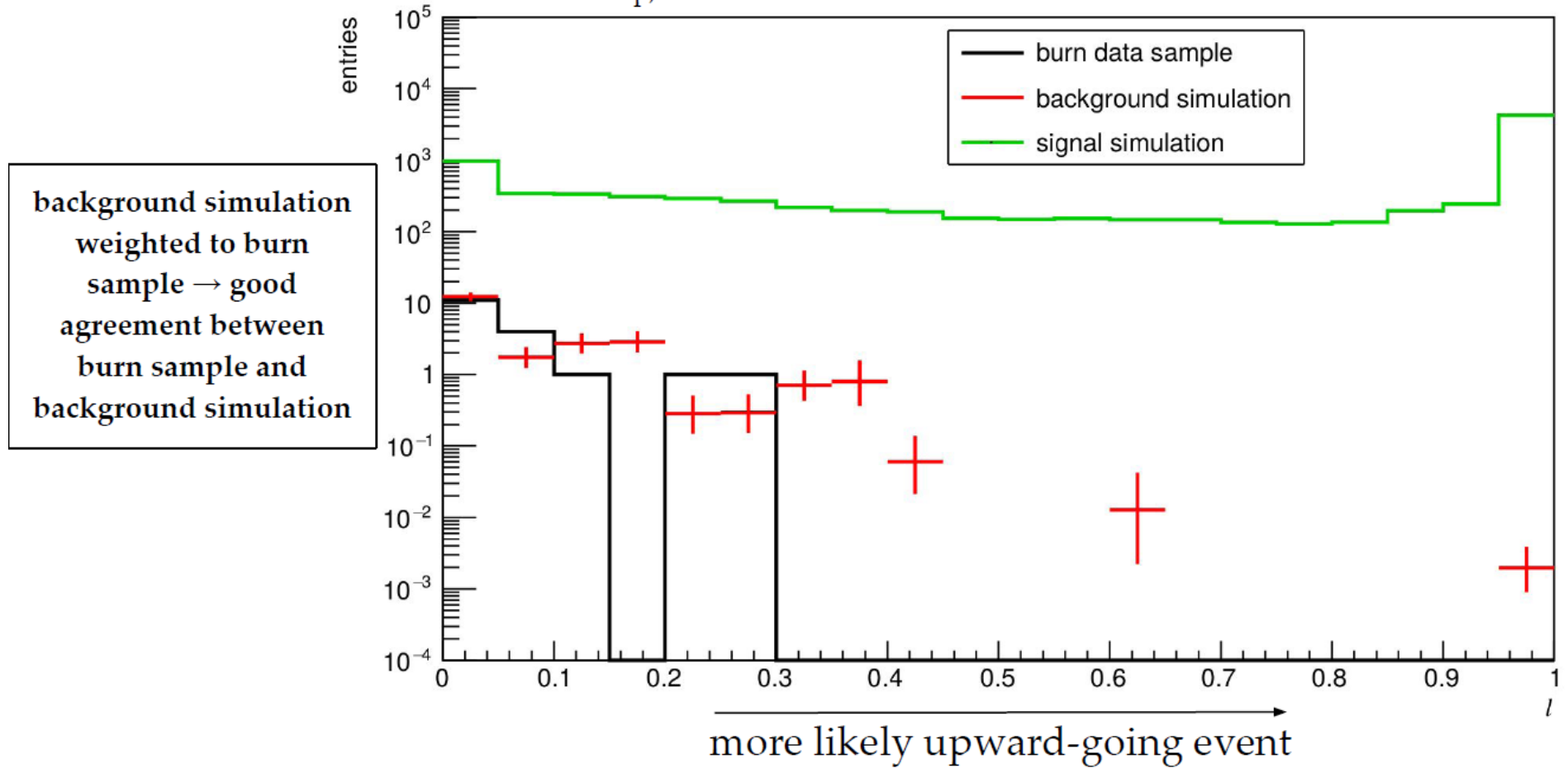


Figure 2: AugerId=11274648000, reconstructed core (left) and camera/profile view (right), according to HECO reconstruction

Discriminazione segnale-fondo sul burnt sample

@ICRC 2021

- Variable $l = \text{atan}(-2\log(L_{\text{down}}/L_{\text{up,down}})/50)/(\pi/2)$ defined between 0 and 1



Blind analysis with a burn sample of 10% of data.

Unblinding agreed 3 week, ago. Lecce and Prague responsible for it

Summary report after the opening of the data box for the FD search of upward-going events

J. Blazek, E. De Vito, V. Novotný, L. Perrone
and the entire group if the document will be approved

June 30, 2021

Stay tuned, results will be presented at ICRC 2021 (just few days ahead now)

Attività di costruzione e analisi legate all'upgrade, svolte a Lecce

Meccanica

Assemblaggio dei moduli, allestimento di una stazione di test con RPC, test dei PMTs
Test di uniformità e misura del MIP: **Completato**

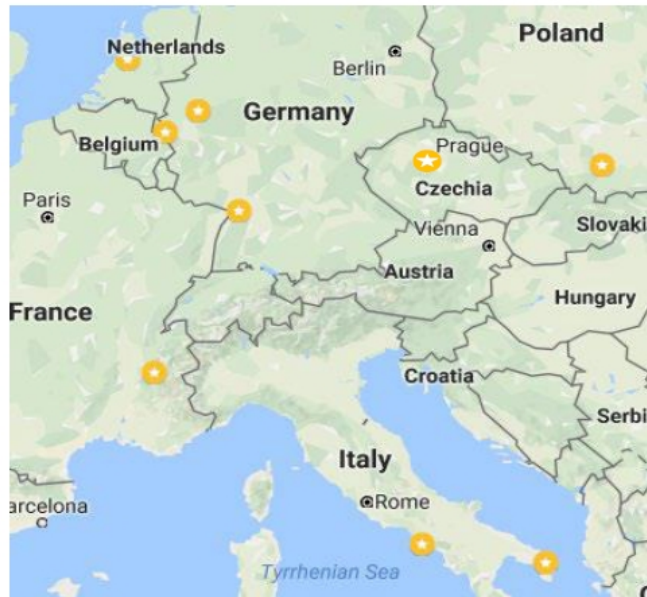
Elettronica

Messa a punto del front-end. Analisi.
Sistema operativo e tool di monitoring
Terza versione della UUB in fase di produzione interamente da SITAEI

Avviato un lavoro di analisi a livello di detector

performance di SSD e di WCD in combinazione con la nuova elettronica

SSD Production



SSD assembly and testing

NIKHEF Nijmegen

RWTH Aachen

LPSC Grenoble

IFJ PAN Kraków

KIT Karlsruhe

INFN Lecce

PMT testing

Bergische Universität Wuppertal

INFN Napoli

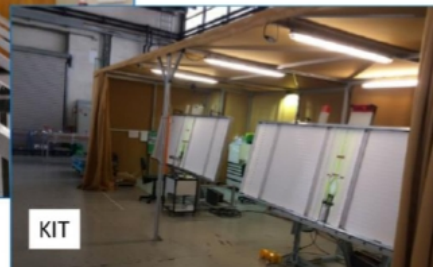
UUB testing (electronics)

Prague

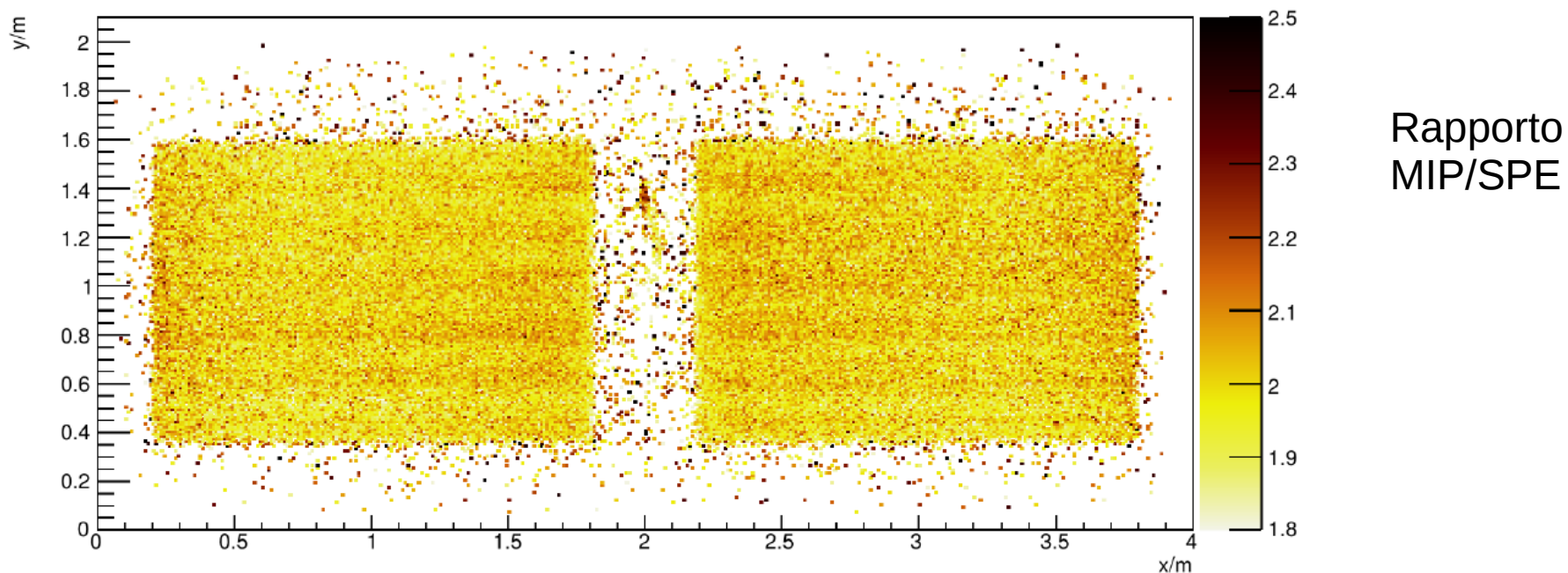
Other institutions are helping in the procurement and preparation of the parts.



The large-scale production of the 1518 detectors is now completed

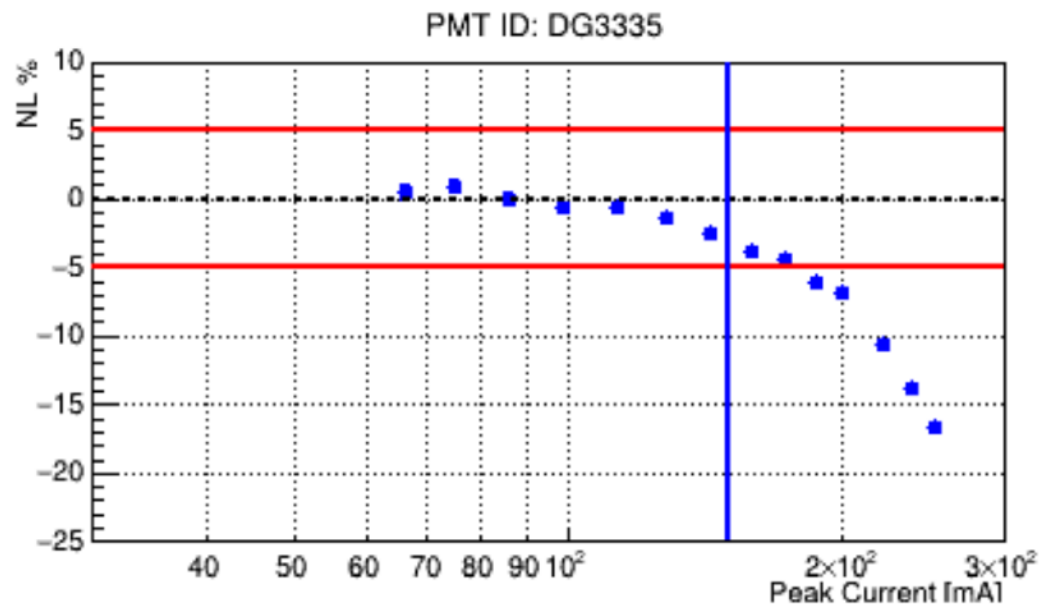


Uniformità della risposta del detector (misurata utilizzando un setup esterno per la misura di muoni)

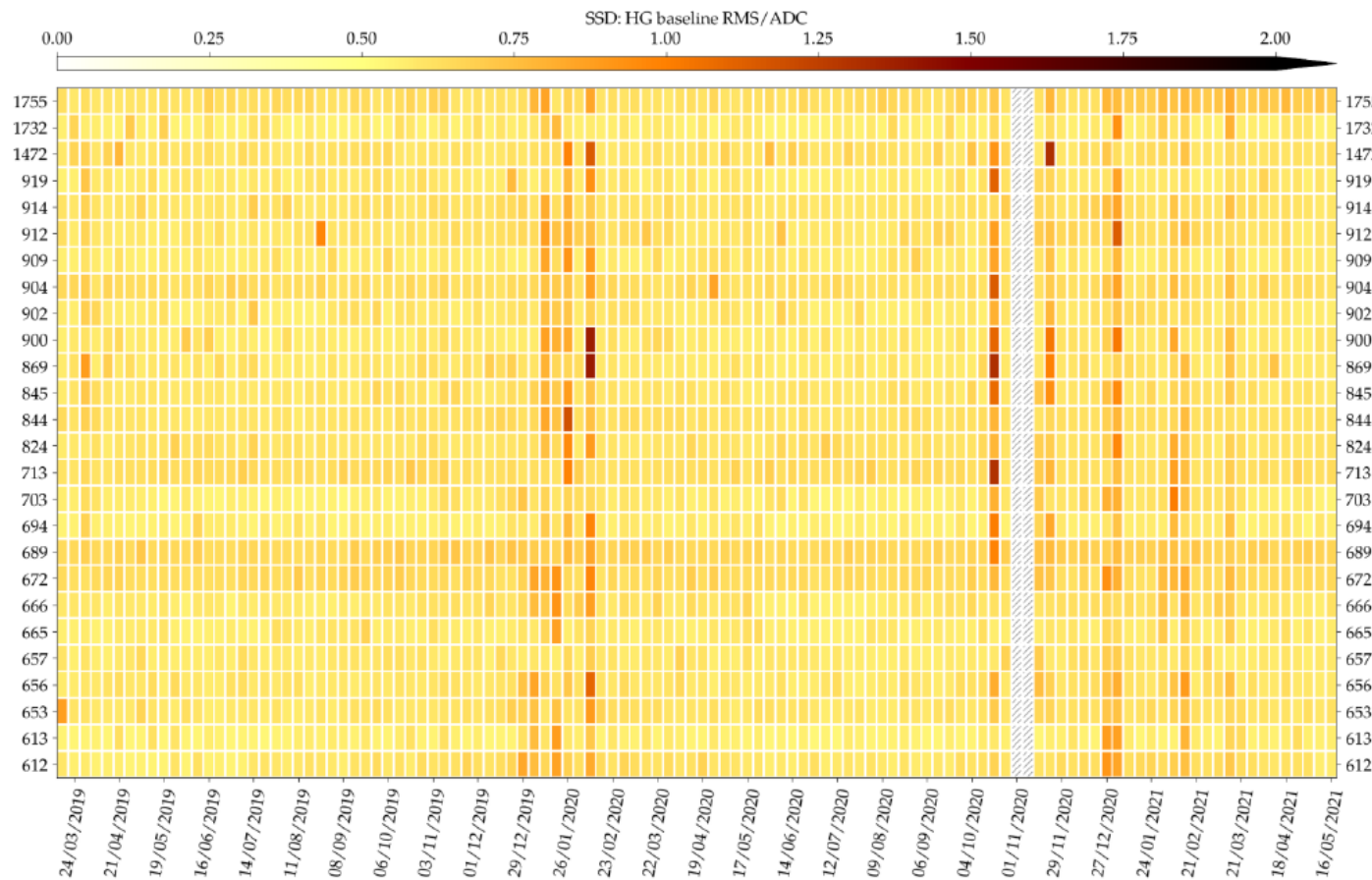


Linearità

< 5% fino a 150 mA



G. Cataldi @ ICRC2021



Stabilità di SSD

RMS

ADC counts vs time
(Vecchia elettronica)

G. Cataldi @ ICRC2021

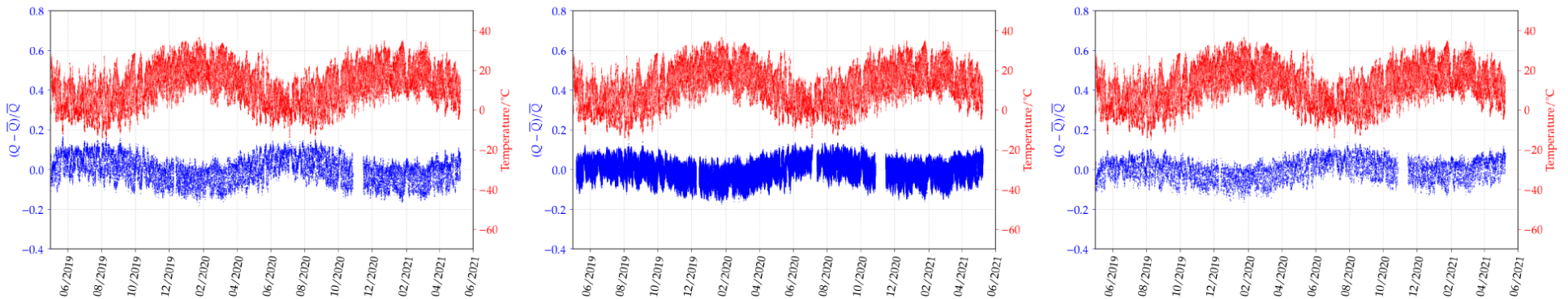
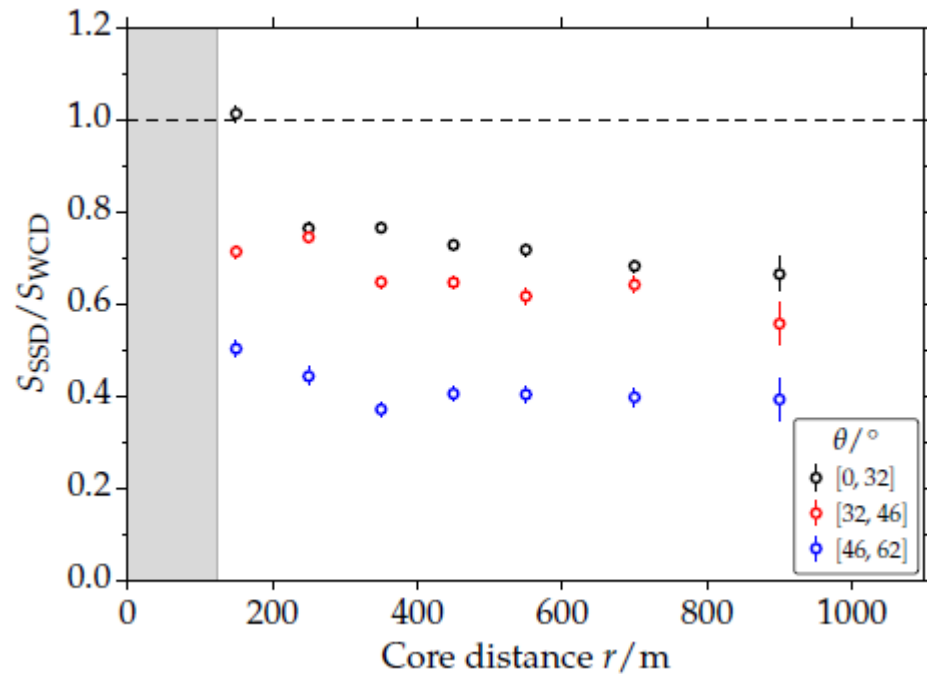


Figure 5: Evolution of the oscillation around an average MIP value (in blue) and evolution of the temperature (in red) for 3 SSDs of the Array.

Risultati del “preproduction array”

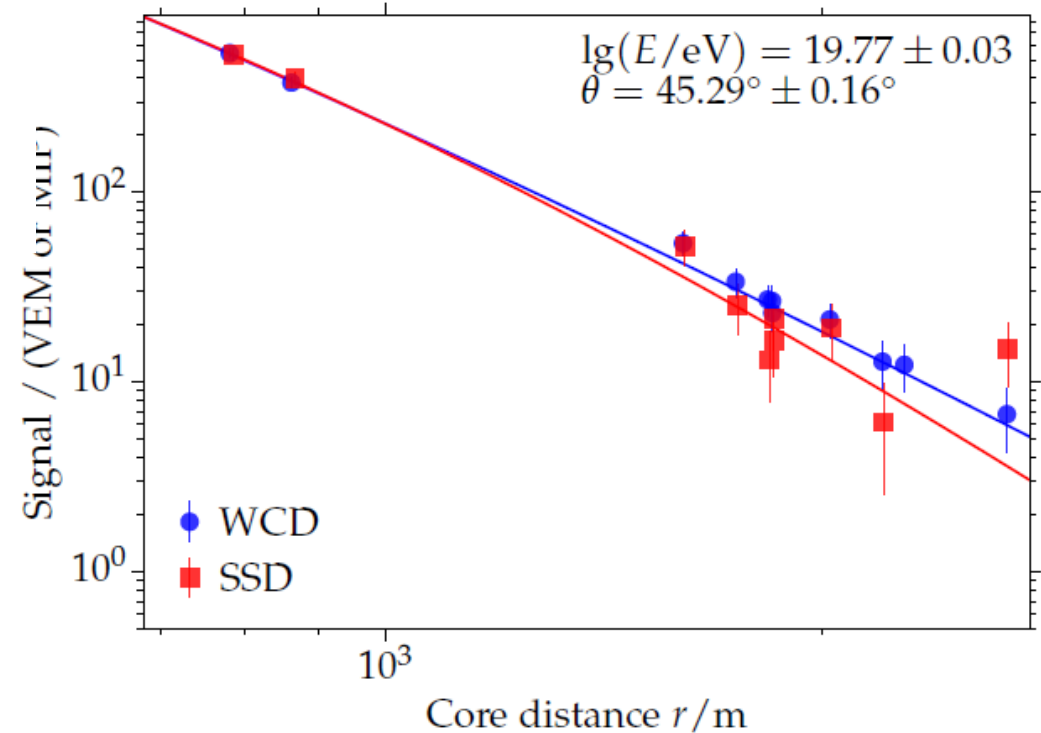
@ ICRC2019

76 Stazioni SD con SSD (120 km²) collegate alla vecchia elettronica
[1 PMT di SD disconnesso]



Diversità del profilo dovuta alla diversa “sensibilità” dei detector a parte elettromagnetica e muonica

Parte muonica (a cui e' piu' sensibile SD)
domina per sciami inclinati



High Energy Event

Event 57111829 :-)

Time (UTC): 2020/2/7 05:44:16

Time (GPS): 1265089474 s 370057000 ns

Trigger: 3TOT & 4C1; 6T5 5T5

Stations: 10 (Acc: 1, Bad: 84)

Full reconstruction (4.5)

$E = (3.31 \pm 0.10 \pm 0.09) \times 10^{18}$ eV

$(\theta, \phi) = (31.6 \pm 0.2, 273.3 \pm 0.4)$ deg

$(x, y) = (-20.79 \pm 0.02, 14.05 \pm 0.01)$ km

$S_{1000} = 163.5 \pm 4.6 (\pm 4.2)$ VEM

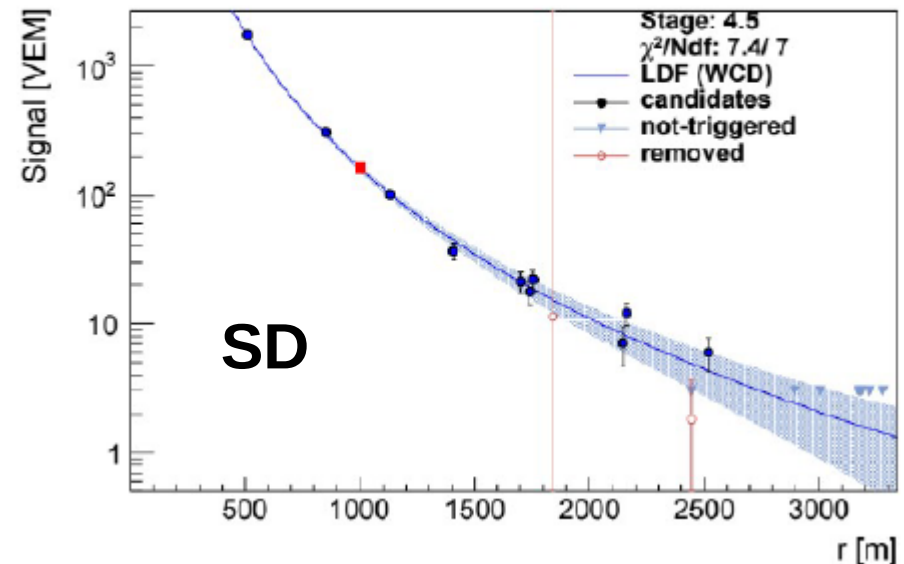
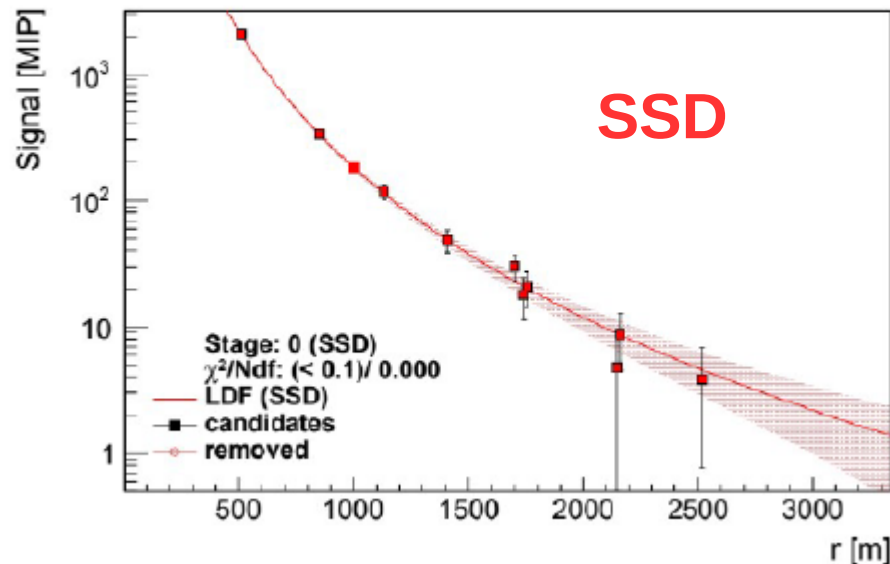
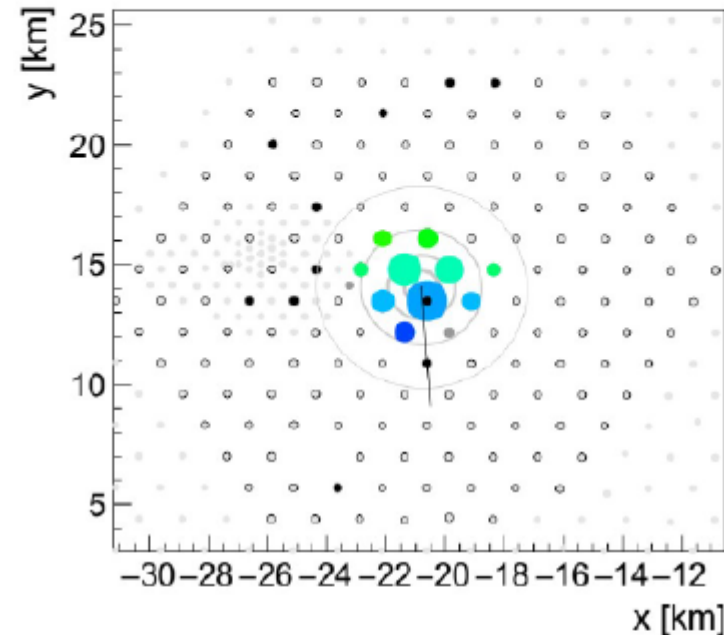
$\beta = -2.36 (\pm 0.17)$, $\gamma = 0.10$, $r_{\text{opt}} = 910$ m

radius = 8.25 ± 0.37 km

Monitoring

average stations age: 14.6 yr

$T = 16.3^\circ\text{C}$; $T(\text{day}) = 19.2^\circ\text{C}$



Upgrade: elettronica di Front-End: attività a Lecce



UUB petalinux system final version (1.00.0 - Mar 2020)

Prague, March 2020



Image.ub

UUB Petalinux image file content

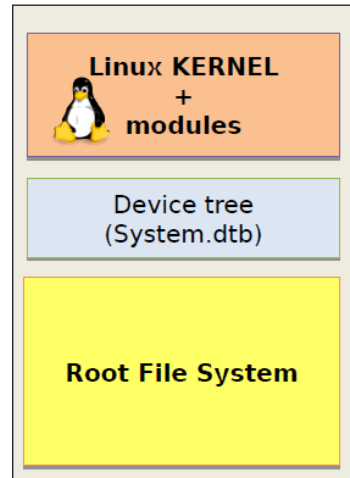


Image.ub size: **18Mb**

Most important improvements on last petalinux version

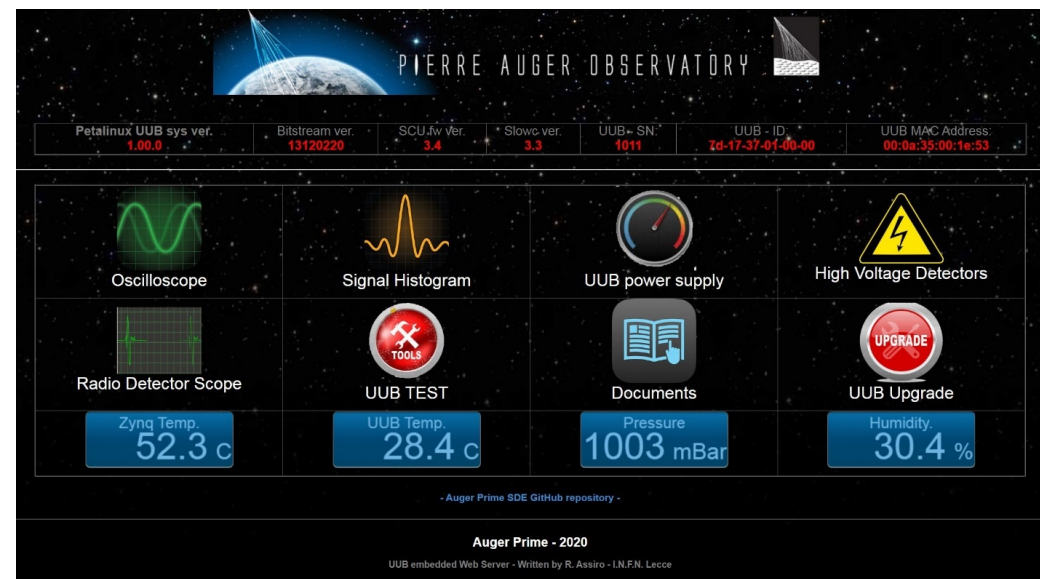
- 1) FSBL modification for Radio Detector group (SPI-1 interfaces)
- 2) Device tree file external from petalinux image (for future modifications)
- 3) Implementation of the programs for the test bench in SITAEI
- 4) Control of the ADC failures after the boot
- 5) Watchdog modification for new slow control firmware to avoid bad data on I2C between Zynq and microcontroller
- 6) The UUB repairs the flash memory by itself in case of corrupted booting files (image.ub, bitstream)

Sviluppo applicativi per il test

- A Lecce sviluppato Il sistema operativo PETALINUX. **Stabile e pronto per l'installazione nel campo**

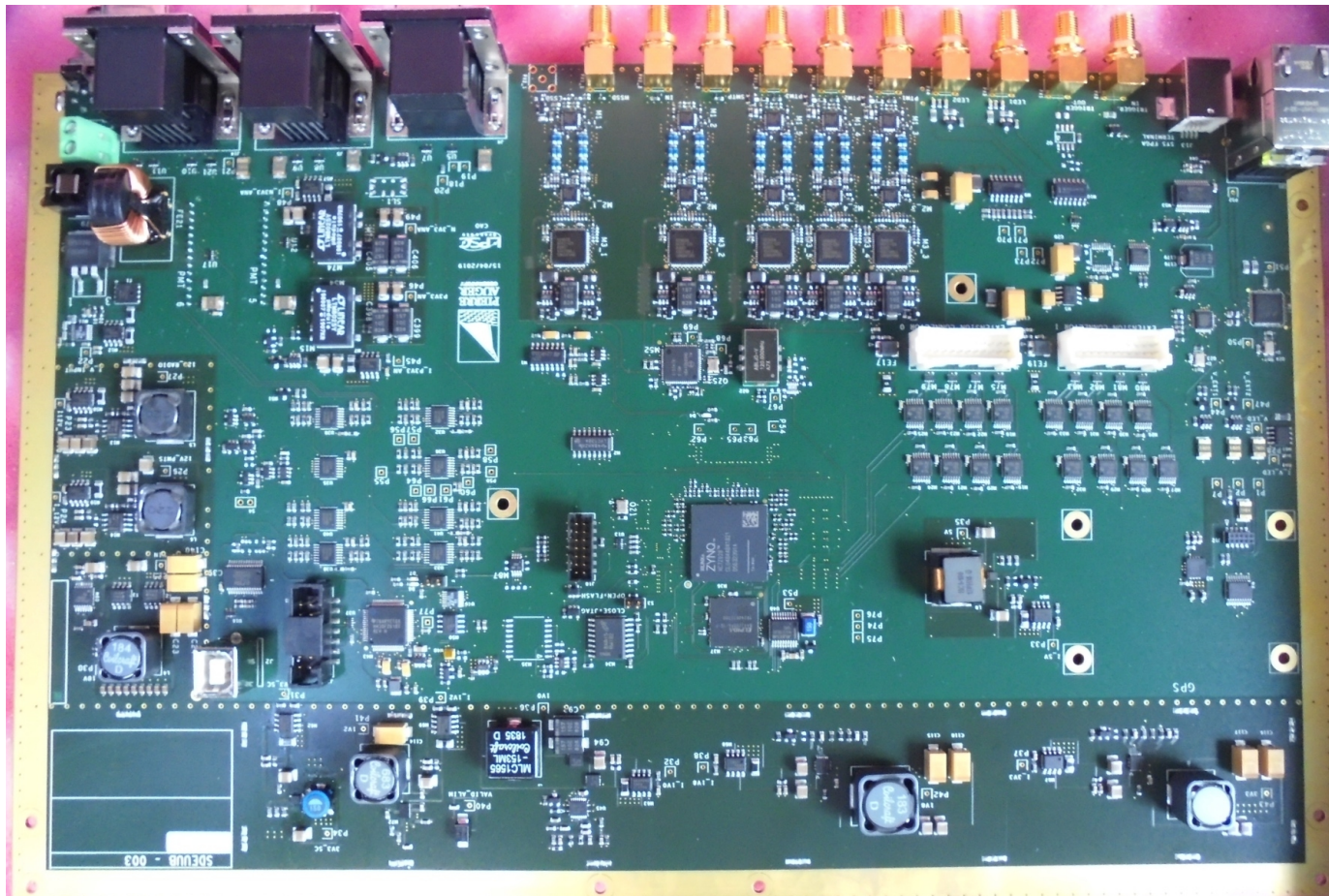
- Contributo a DAQ delle nuove Schede

Tesi di dottorato di Fabio Convenga



Elettronica + Software

UUB v3



Le nuove schede di Elettronica sono Prodote da **SITAEI** A Mola di Bari sotto La supervisione della Sezione di Lecce è essenziale per la validazione della produzione.

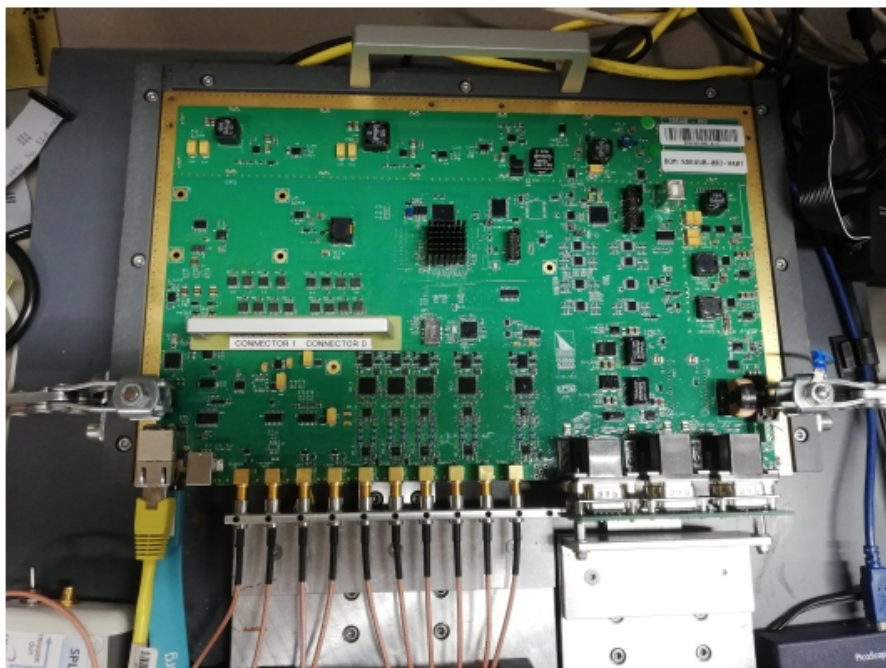
**81 board installate
~ 400 board per fine
agosto a Malargue**

FPGA Xilinx 7020 con un doppio processore ADC a 12 bit, 120 MHz

Design dei 10 canali, filtro antialiasing e contributo all'installazione e configurazione del firmware e del software per il funzionamento della scheda.

UUB test prima dell'installazione nel campo

@ SITAEI



@ Prague

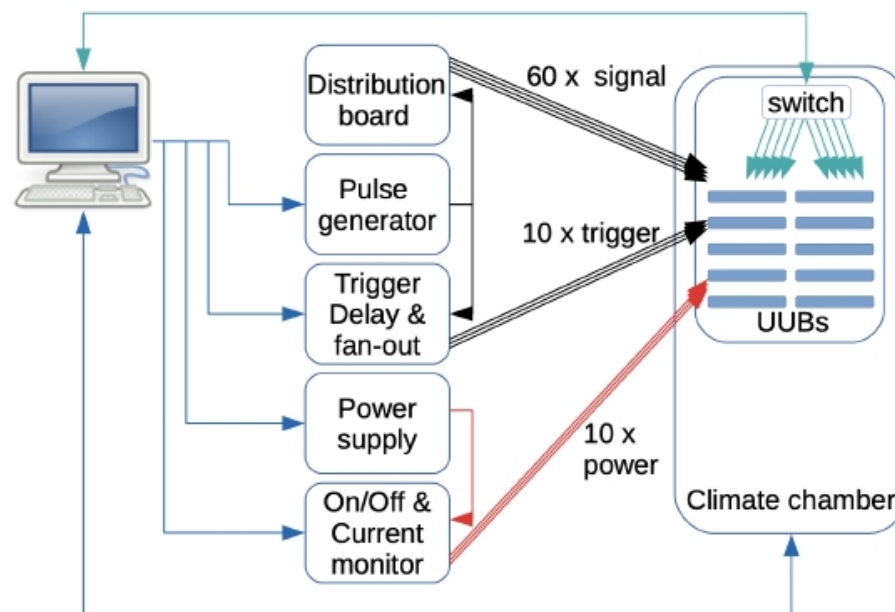


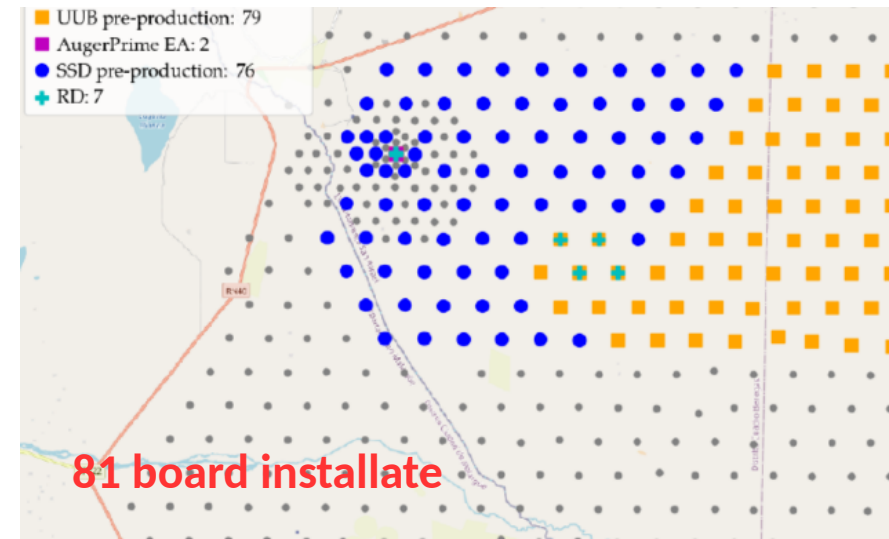
Figure 1: Left: UUB in Manufacturer Test system. Right: ESS Test system description.

@ ICRC 2021

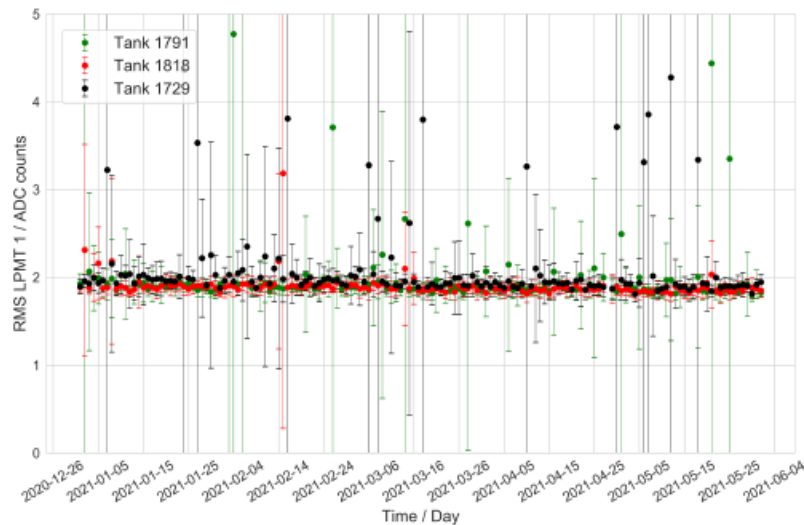
Stabilità temporale della baseline

@ ICRC 2021

RMS HG Channel < 2 ADC counts
(< 0.5 for LG)



LPTM



SSD

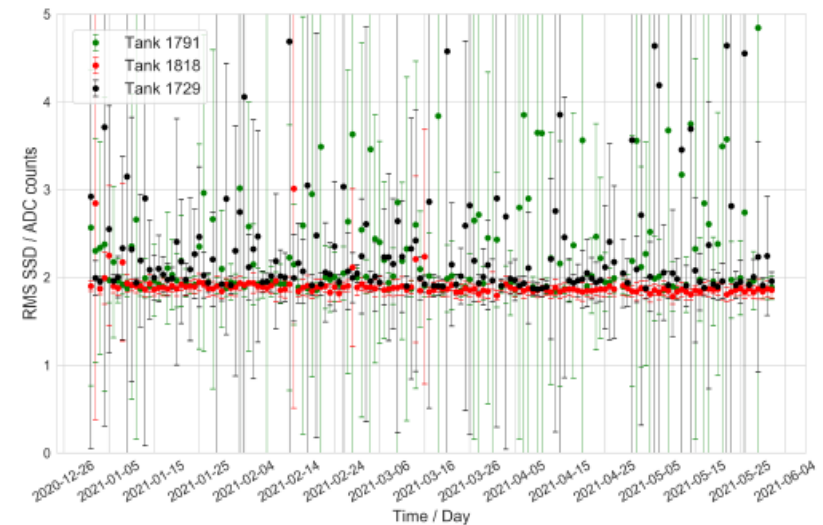
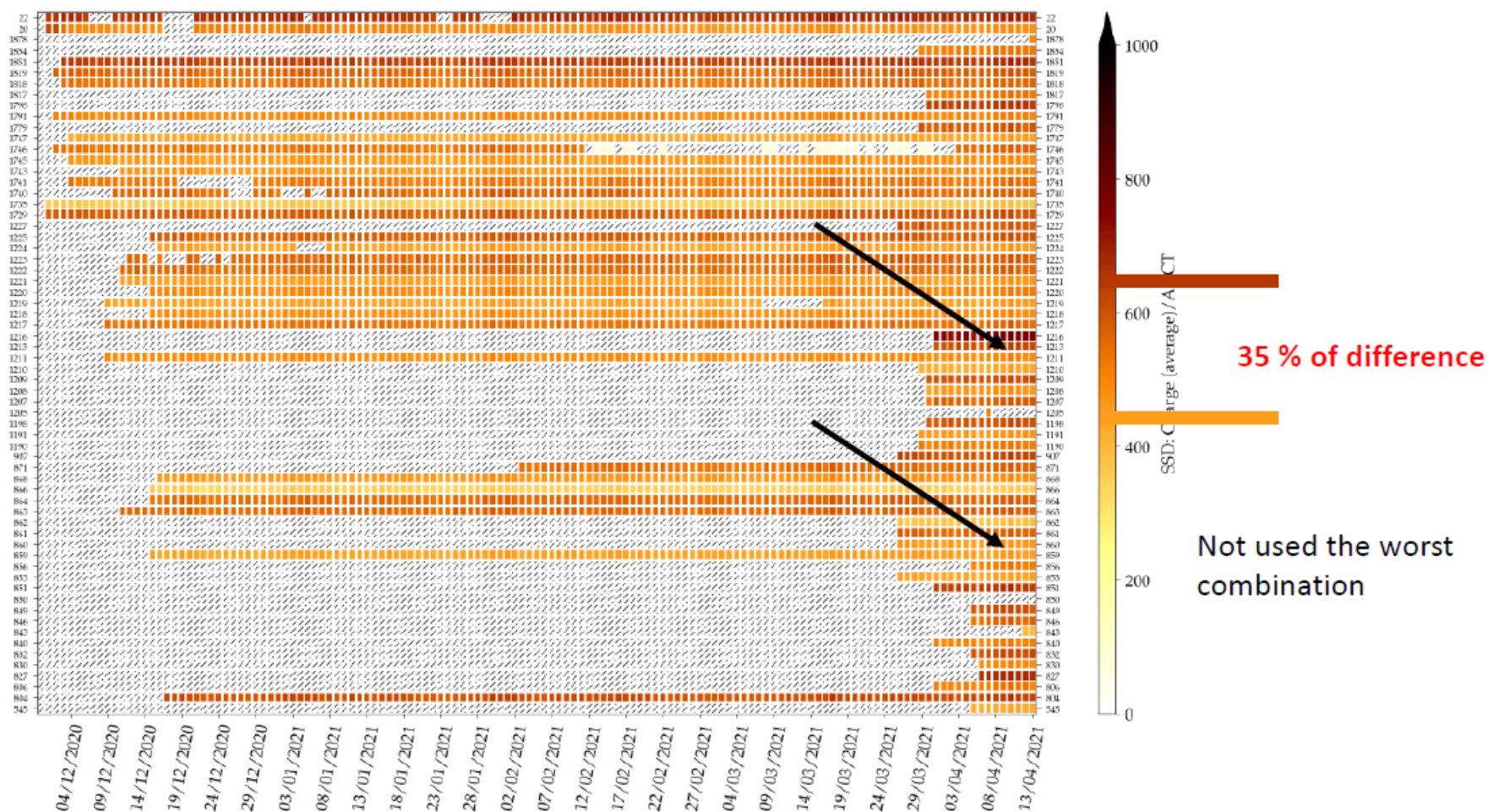


Figure 3: Distribution of the daily mean value of the baseline RMS distribution. The error bar is the RMS of such daily distribution. Left: WCD LPMTs. Right: SSD signals

Calibrazione di SSD con la nuova elettronica:

attività avviata di recente nel gruppo di Lecce

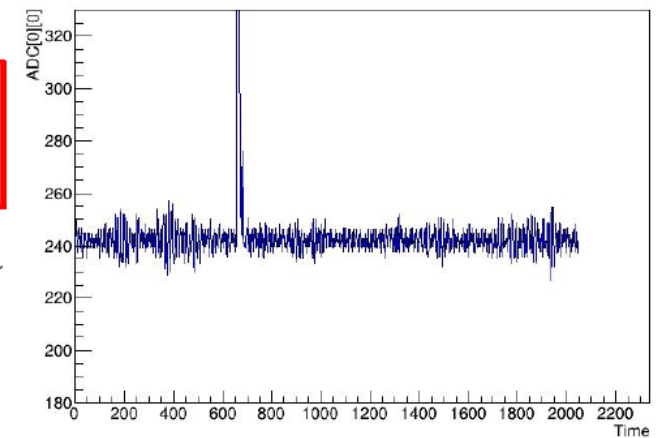
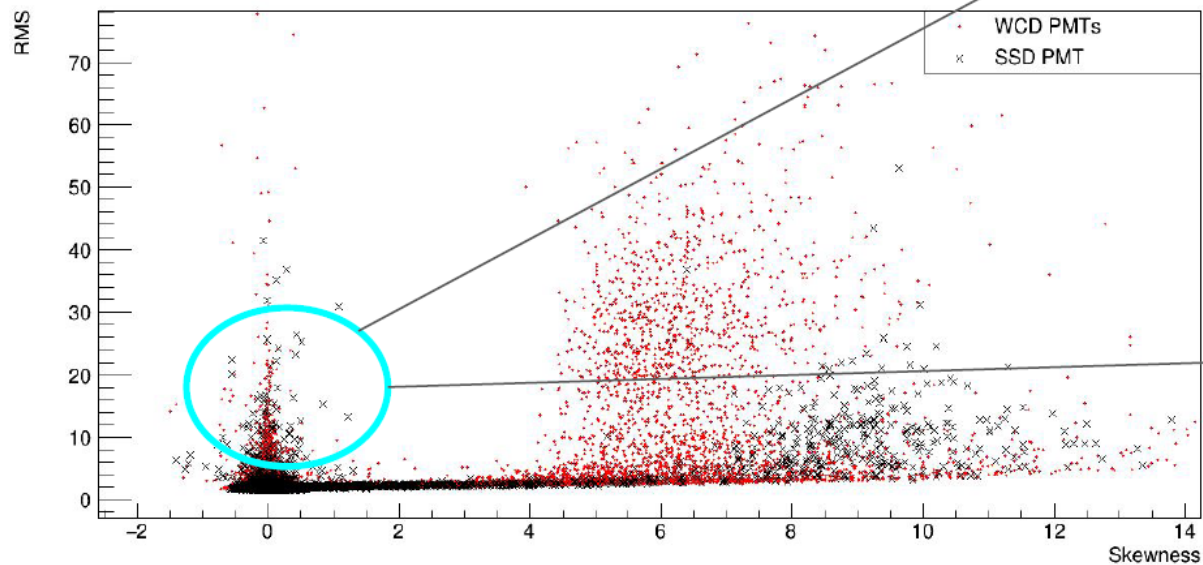


Studio della simmetria della baseline in SSD e WCD, come proxy per possibili patologie del detector (nuova elettronica)

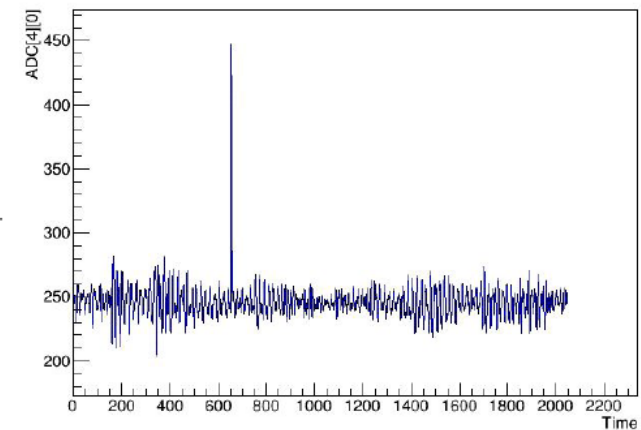
Studying the single bin trigger events, we focused on the Zone one with high RMS values (>3) and low skewness $[-1, 1]$

Symmetrical noise both in WCD and SSD

RMS vs Skewness first 300 bins - SINGLE BIN trigger



WCD



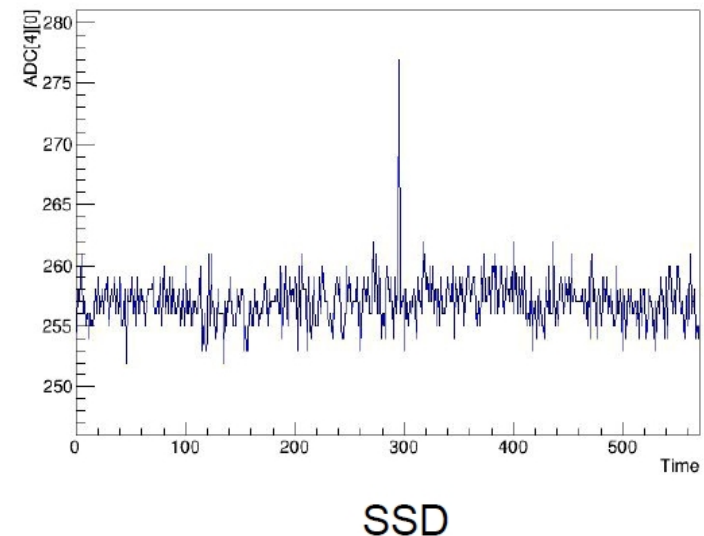
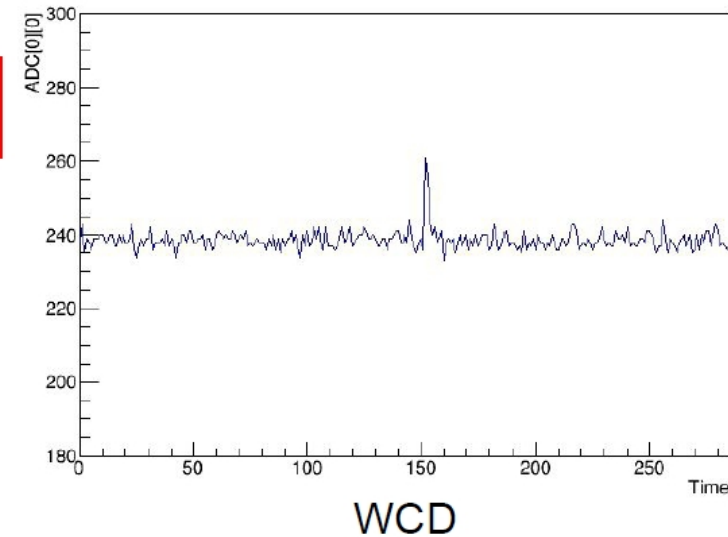
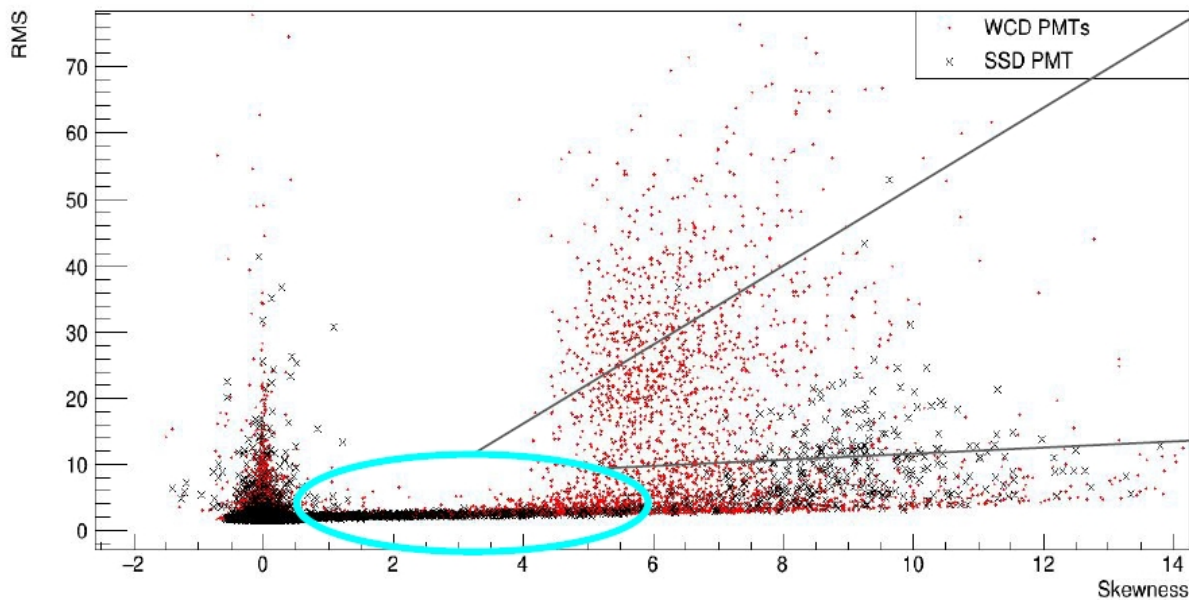
SSD

Studio della simmetria del baseline in SSD e WCD, come proxy per possibili patologie del detector (nuova elettronica)

Zone two with low RMS values (<3) and higher skewness [1,6]

Small and tight (one or few bins) peaks randomly distributed

RMS vs Skewness first 300 bins - SINGLE BIN trigger

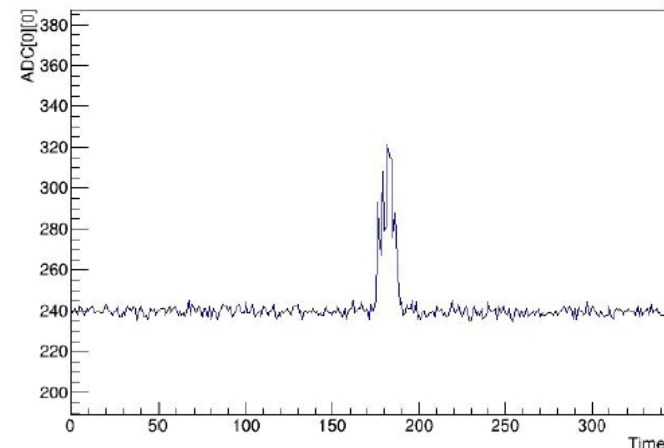
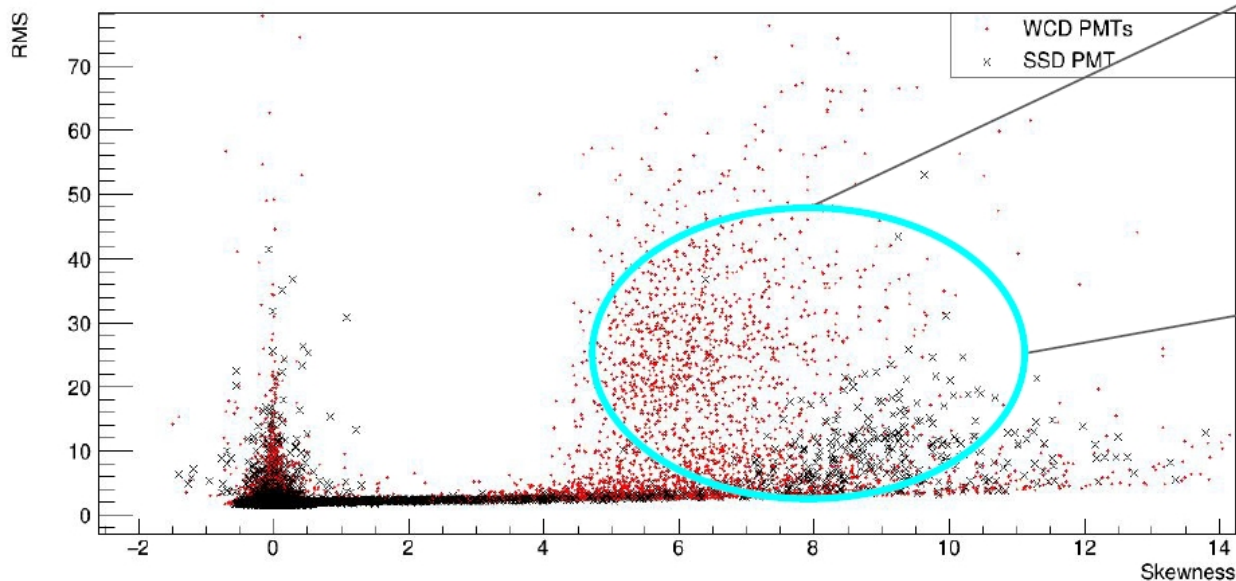


Studio della simmetria del baseline in SSD e WCD, come proxy per possibili patologie del detector (nuova elettronica)

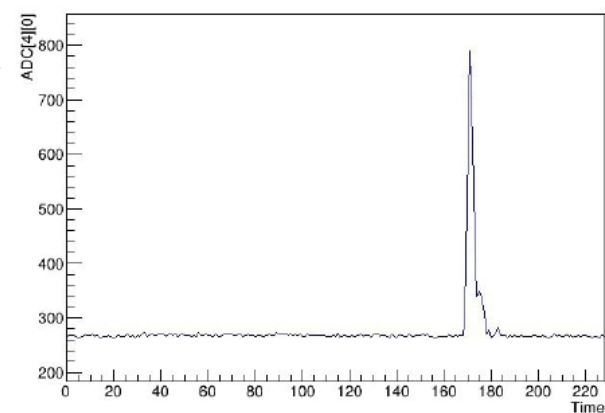
Zone three with high RMS (>3) and high skewness (>6)

Early Peaks that can appear in one or more PMTs

RMS vs Skewness first 300 bins - SINGLE BIN trigger



WCD



SSD

Studio della calibrazione di SSD (nuova elettronica)

SIMULATING THE SLAVE MODE

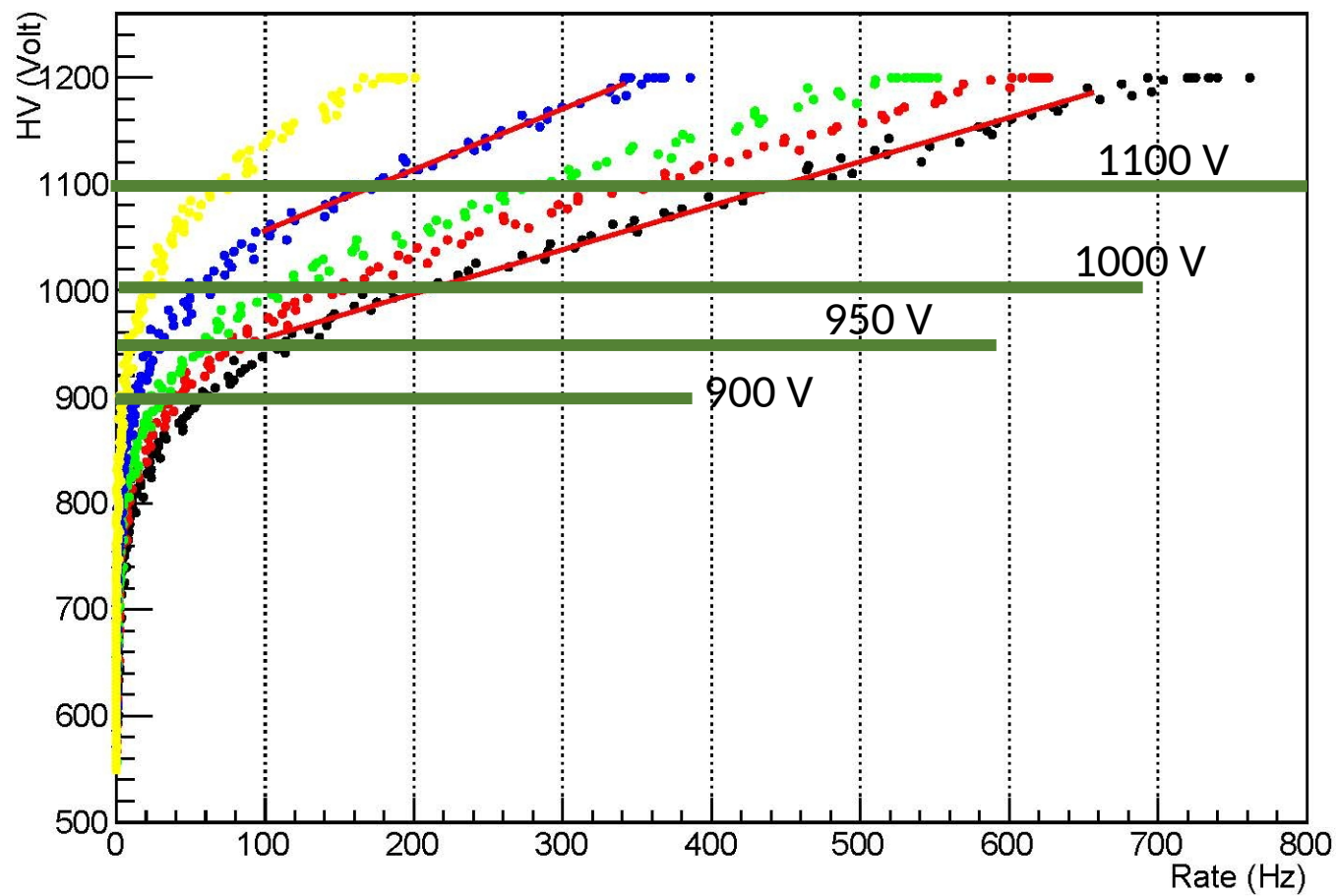
Looking for the MIP position in the SSD

SSD UP – for signal calibration via UUB

SSD DOWN for trigger

→ SSD for Trigger

Using a SSD «for triggering»

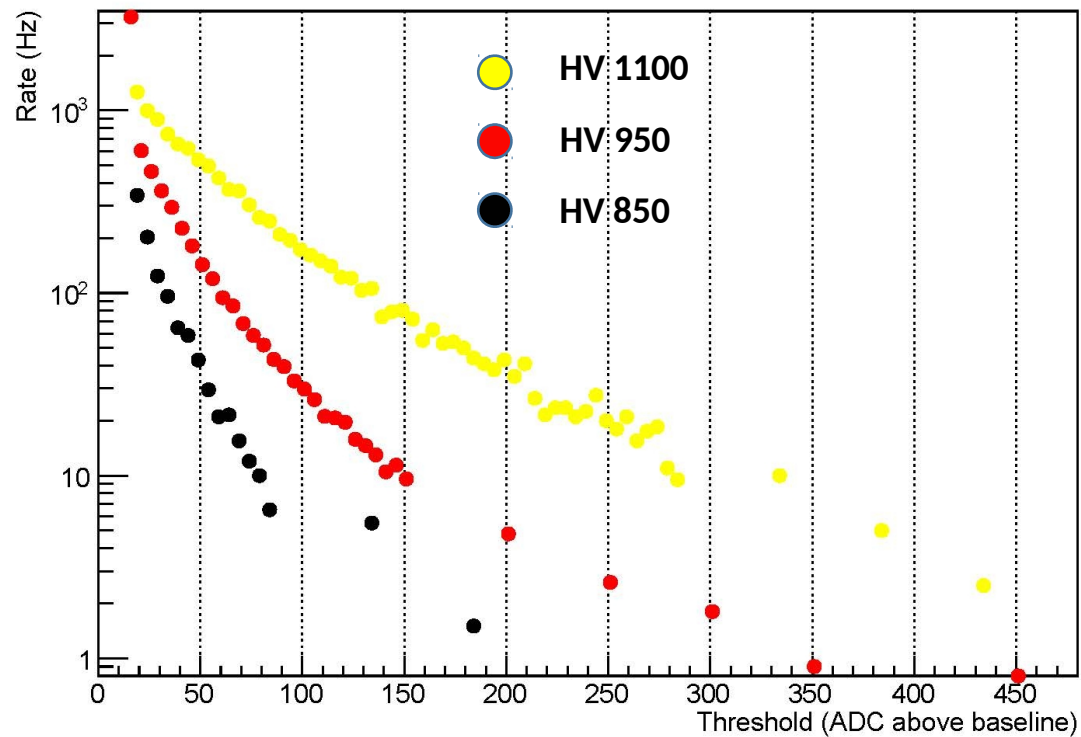


Software rate_dm

HV scan with fixed threshold

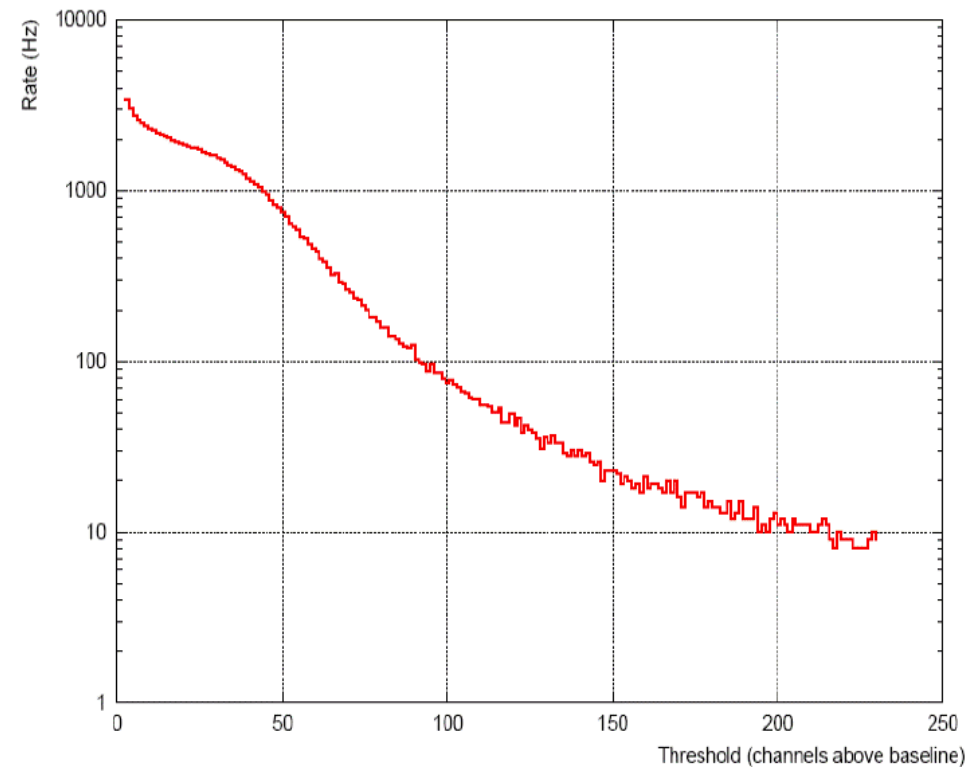
- THR 55 ADC above baseline
- THR 65 ADC
- THR 75 ADC
- THR 100 ADC
- THR 150 ADC

Using the other SSD



- Difference in HV corresponds to diff. in gain
- The single rate curve does not appear as a simple shift.

Using the tank



- 3 fold coincidence very «clean»

Accesso a risorse officina meccanica

Produzione locale terminata.

Per il **2022**

Supporto per il deployment sul campo (gestione eventuali emergenze)

Richieste all'officina
2 mesi/uomo

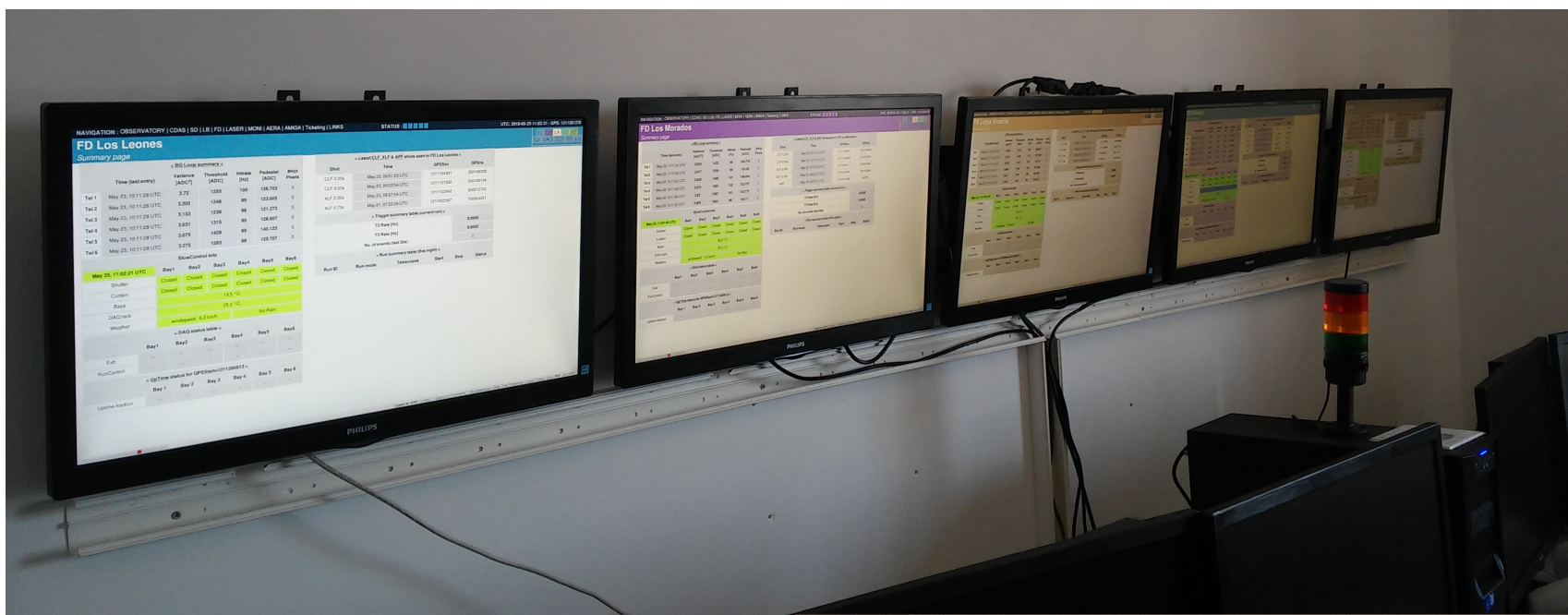
Timeline e accesso a risorse laboratorio di elettronica

2021/2022

- Seguire la produzione e i test associati
- Partecipazione all'installazione dell'elettronica e alla definizione delle procedure di test e verifica del corretto funzionamento delle schede

Richieste al laboratorio
6 mesi/uomo

Control room remota per il rivelatore di fluorescenza



Turni FD remoti eseguiti
- Febbraio 2021
- Luglio 2021 (in corso)

1 Turno SD remoto eseguito
- Aprile 2021

Richieste al servizio calcolo
1 mese/uomo supporto



La farm locale di Lecce utilizzata per la produzione dei dati ibridi utilizzati nelle pubblicazioni dello spettro del 2020 è stata riconosciuta.

Un link con le risorse di calcolo appare nella presentazione a ICRC 2021 sul calcolo per Auger

List of computational resources of the Pierre Auger Collaboration.

VO auger grid resources:

Brazil

- CBPF

Czech Republic

- Prague-LCG2
- Prague_CESNET-LCG2

France

- OBSPM
- IN2P3-CC
- M3PEC
- GRIF

Germany

- RWTH-Aachen
- FZK-LCG2

Italy

- INFN-T1 - CNAF
- INFN-Lecce

Local resources:

Argentina

Australia

- Phoenix HPC, University of Adelaide

Belgium

Brazil

Colombia

Czech Republic

- Institute of Physics of the Czech Academy of Sciences, Prague

France

Germany

- Karlsruhe Institute of Technology:
 - HoreKa
 - ForHLRII (until mid. 2020)

Italy

* INFN-CNAF

* INFN Sezione di Lecce, Local Computing Farm

Mexico

- LARCAD-UNACH
- LNS-BUAP

Outreach

Tutto il gruppo impegnato in varie iniziative (vedi presentazione di Gabriella)

International cosmic day 2020 (remoto)
Varie iniziative con scuole spesso in collegamento
Dalla nostro remote control room

Con “*open data*” l’offerta verso iniziative divulgative potrà
ulteriormente allargarsi.