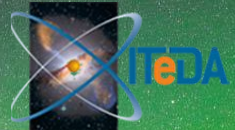# Measurement of the Cosmic Ray Spectrum with the SD433

Gabriel Brichetto Orquera
gabriel.brichetto@iteda.cnea.gov.ar

DDAp/DDEIT - HIRSAP Meeting 2023
Nov 22nd 2023

The SD433

Nested within the SD1500 and the SD750
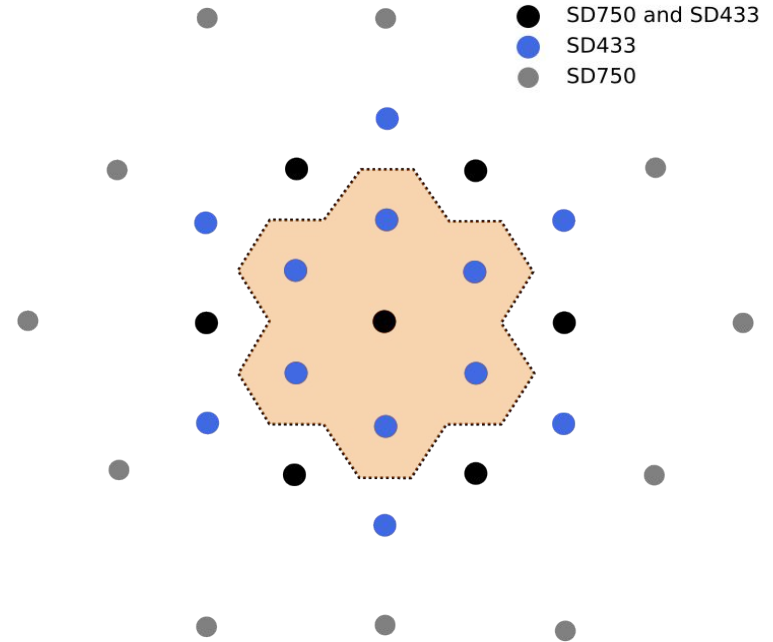
Densest array of Auger SD
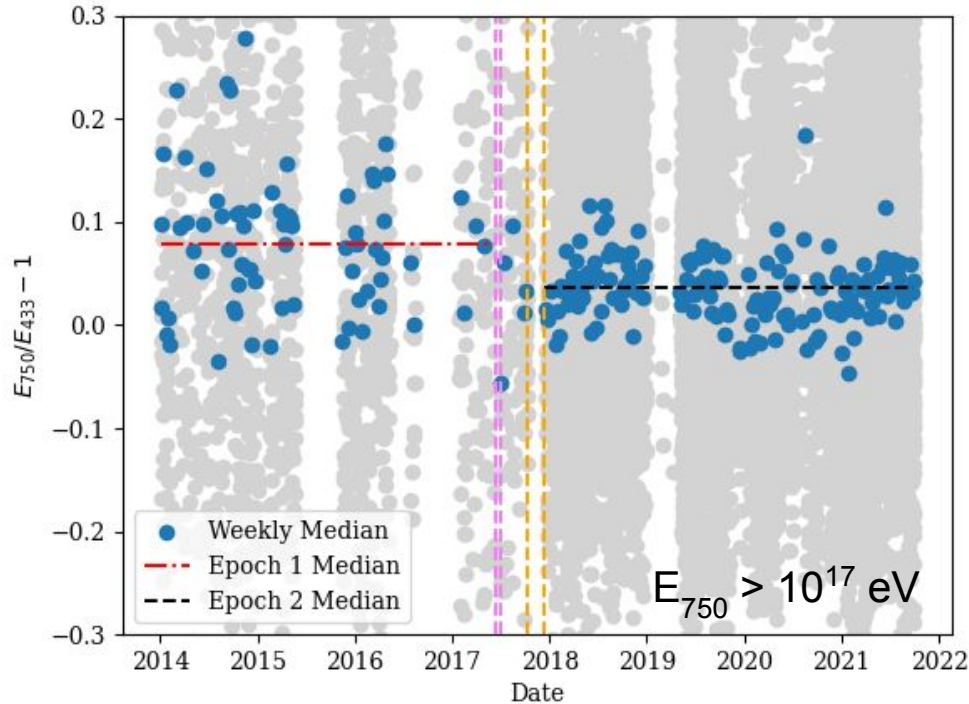
19 WCD

~1.1 km² of effective area

Measurement of the spectrum

Full efficiency threshold at 6.3×10^{16} eV

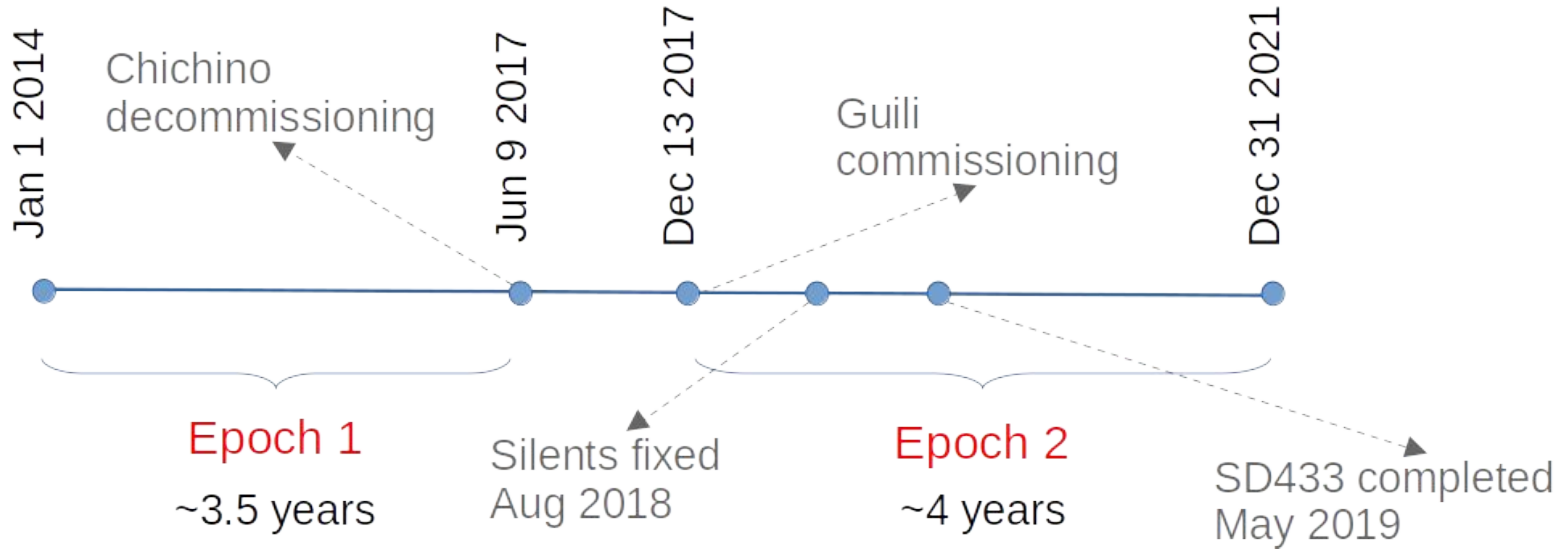First characterization of the 2nd knee with Auger SD

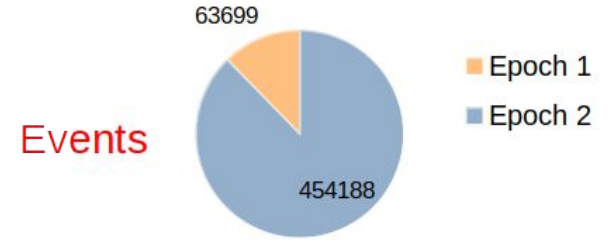● SD750 and SD433
● SD433
● SD750

Event-by-event bias

Shift in the energy ratio in 2017

Difference related to repositioning of two WCDs

$Bias_{Epoch1} = 0.07$

$Bias_{Epoch2} = 0.03$

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SD433 Epochs

Events

63699 — Epoch 1
454188 — Epoch 2

Jan 1 2014

Chichino decommissioning

Jun 9 2017

Dec 13 2017

Guili commissioning

Dec 31 2021

Epoch 1
~3.5 years

Silents fixed Aug 2018

Epoch 2
~4 years

SD433 completed May 2019

Epoch 2 finishes when the first UUB is deployed

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SD433 Spectrum Unfolding
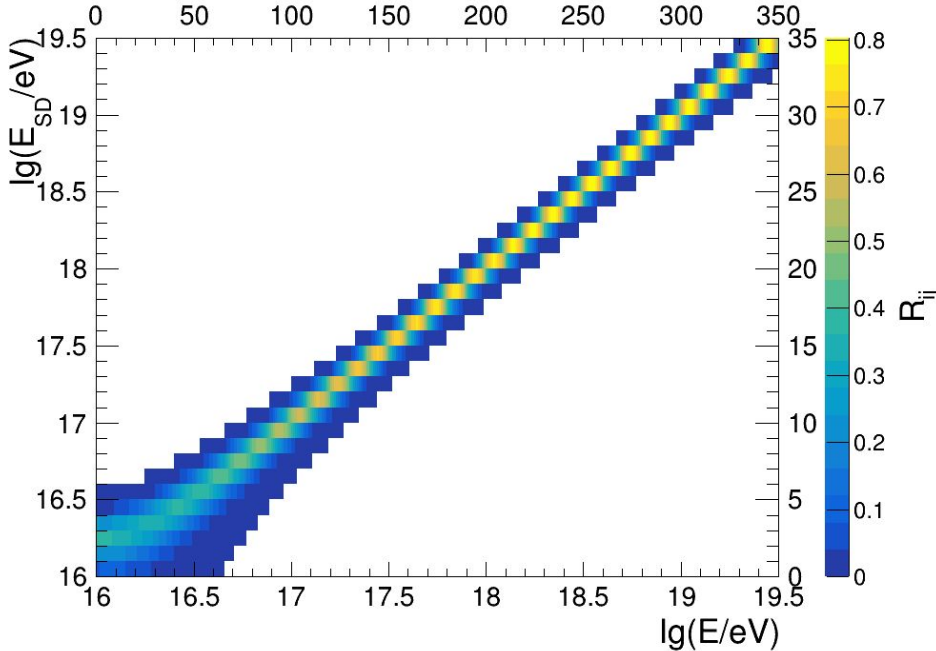
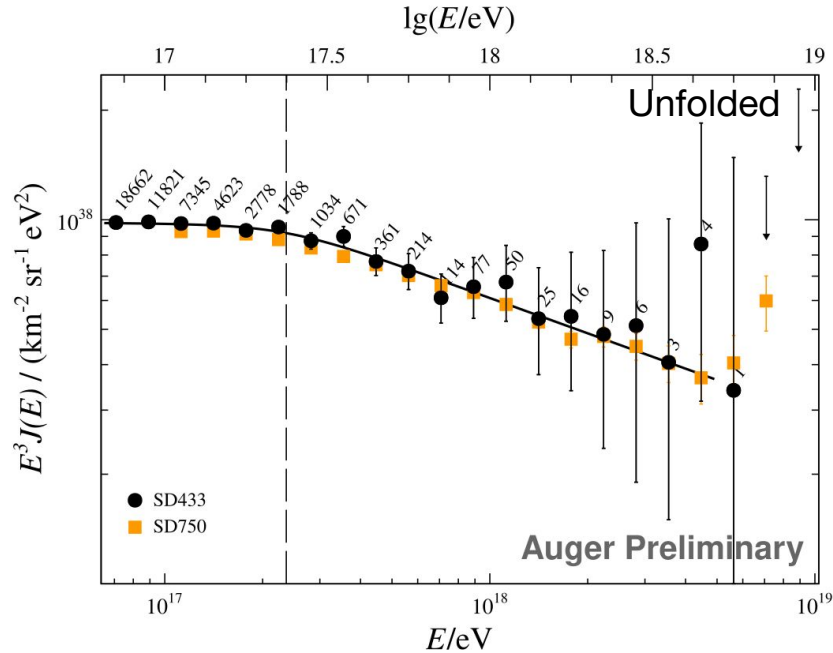Forward folding procedure like other Auger SD arrays

Implemented in the spectrum fit

Correction factors for the spectrum less than 10%

$$R_{ij} = \int_{\Delta E_r} dE_r \, r(E_r | E_t, \sigma(E_t)) \varepsilon(E_t)$$
$$\Delta E_{true} \ll \Delta E_{rec}$$

Thanks for all the help to Diego R. and Ezequiel

SD433 Spectrum

$$J(E) = J_0 \left(\frac{E}{10^{17}\,\mathrm{eV}} \right)^{-\gamma_0} \left[1 + \left(\frac{E}{E_{01}} \right)^{\frac{1}{\omega_{01}}} \right]^{(\gamma_0 - \gamma_1)\omega_{01}}$$
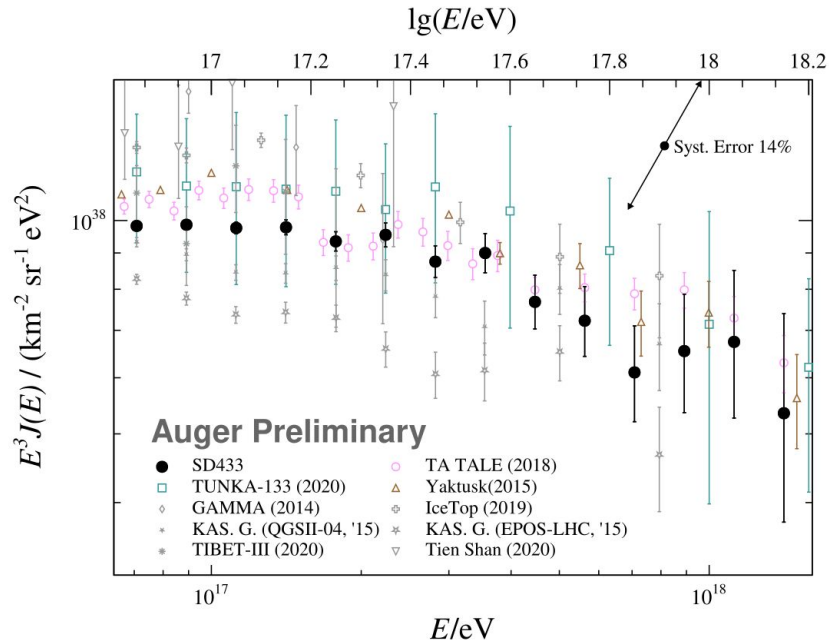
- Broken power law with soft transitions spectrum
- Unfolding procedure considering SD433 energy resolution and bias
- Second knee measurement

$E_{01}/10^{17}\,\mathrm{eV}$	γ_0	γ_1
$2.30 \pm 0.50 \pm 0.35$	$3.00 \pm 0.05 \pm 0.10$	$3.32 \pm 0.08 \pm 0.10$
	Value $\pm\sigma_{\mathrm{stat}} \pm \sigma_{\mathrm{syst}}$	

$$\omega_{01} = 0.25 \ (\text{fixed})$$

- Good agreement between SD433 and SD750 spectra

Comparison with other spectra

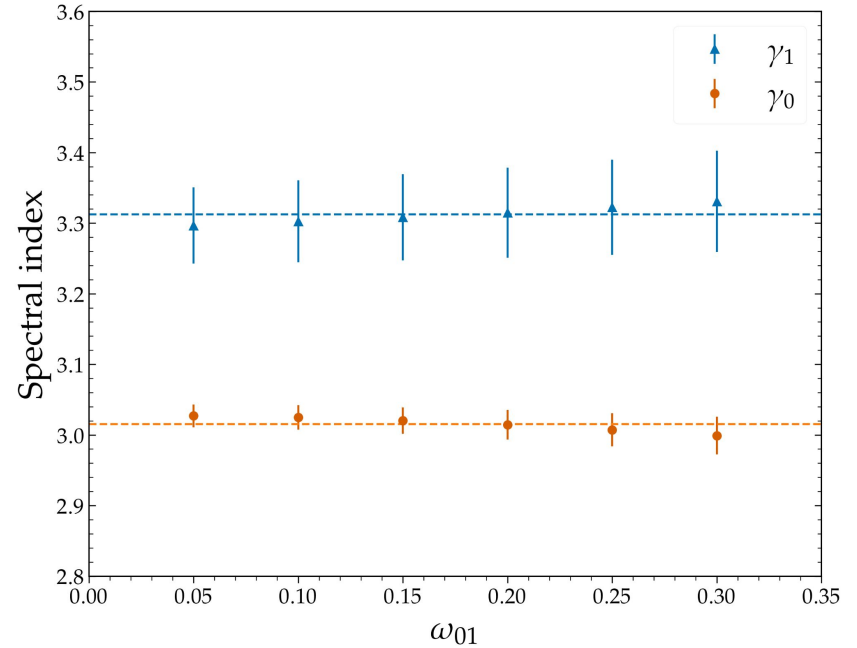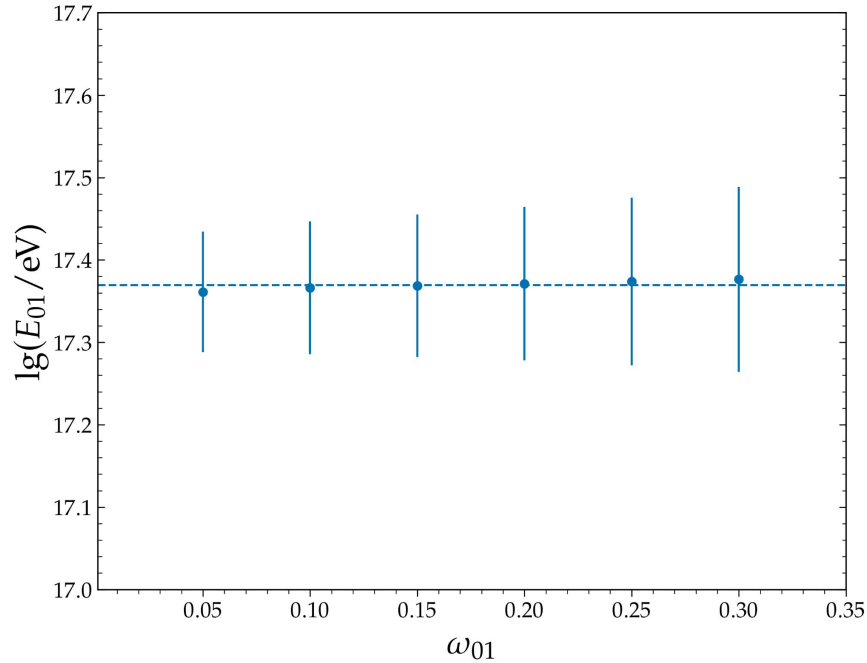**SD433 flux consistent with other spectra within systematics**

The second knee in the cosmic ray spectrum observed with the surface detector of the Pierre Auger Observatory

Gabriel Brichetto Orquera[a,b,*] for the Pierre Auger Collaboration[c]
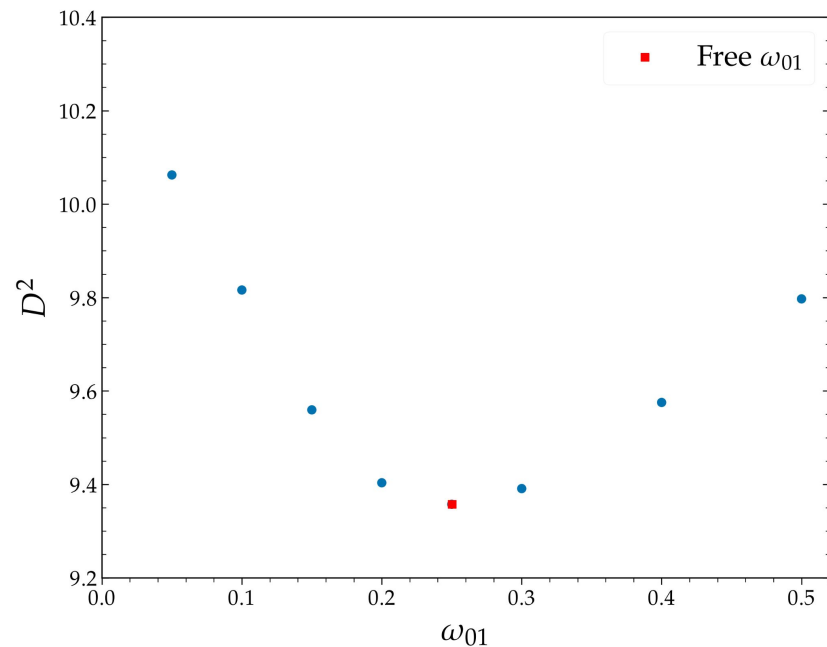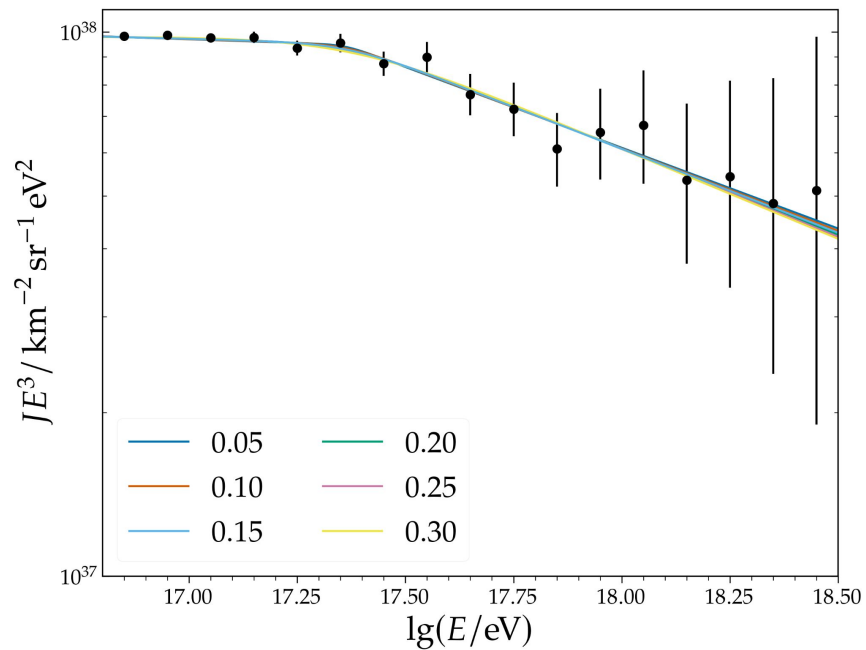
PoS(ICRC2023)398

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ω_{01} dependence

$$J(E) = J_0 \left(\frac{E}{10^{17}\,\mathrm{eV}} \right)^{-\gamma_0} \left[1 + \left(\frac{E}{E_{01}} \right)^{\frac{1}{\omega_{01}}} \right]^{(\gamma_0 - \gamma_1)\omega_{01}}$$

No impact from the transition width

ω_{01} dependence

$$J(E) = J_0 \left(\frac{E}{10^{17}\,\mathrm{eV}} \right)^{-\gamma_0} \left[1 + \left(\frac{E}{E_{01}} \right)^{\frac{1}{\omega_{01}}} \right]^{(\gamma_0 - \gamma_1)\omega_{01}}$$

Summary and future work

Updated SD433 dataset (Jan 2018 - Dec 2021)

Unfolded SD433 spectrum

Measurement of the 2nd knee (2.30 ± 0.50 stat ± 0.35 syst) x 10^{17} eV with γ_0= 3.00 ± 0.05 stat ± 0.10 syst and γ_1= 3.32 ± 0.08 stat ± 0.10 syst

Further work:

Finish the SD433 spectrum systematics estimation

Combined Auger SD Spectrum

Towards a FAL SD433 Spectrum paper

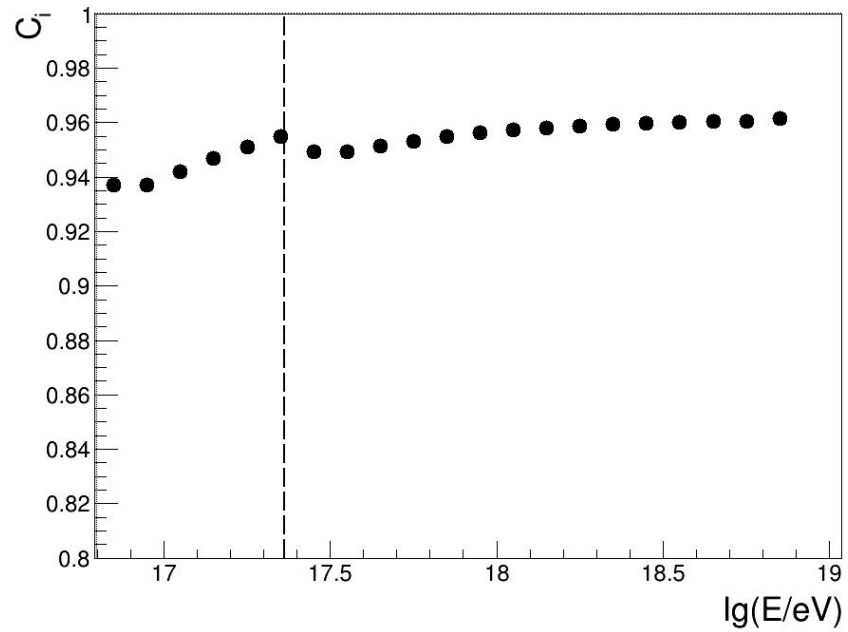**First measurement of the second knee with Auger SD**

Backup

Tank movements

Chichino

| Decommissioning | 98 | 2017-06-09T21:25:05Z |
| Commissioning | 30 | 2017-06-30T20:55:35Z |

Guili

| Decommissioning | 13 | 2017-10-10T00:00:00Z |
| Commissioning | 47 | 2017-12-13T00:00:00Z |

Correction factors

SD750 vs SD433 ratio