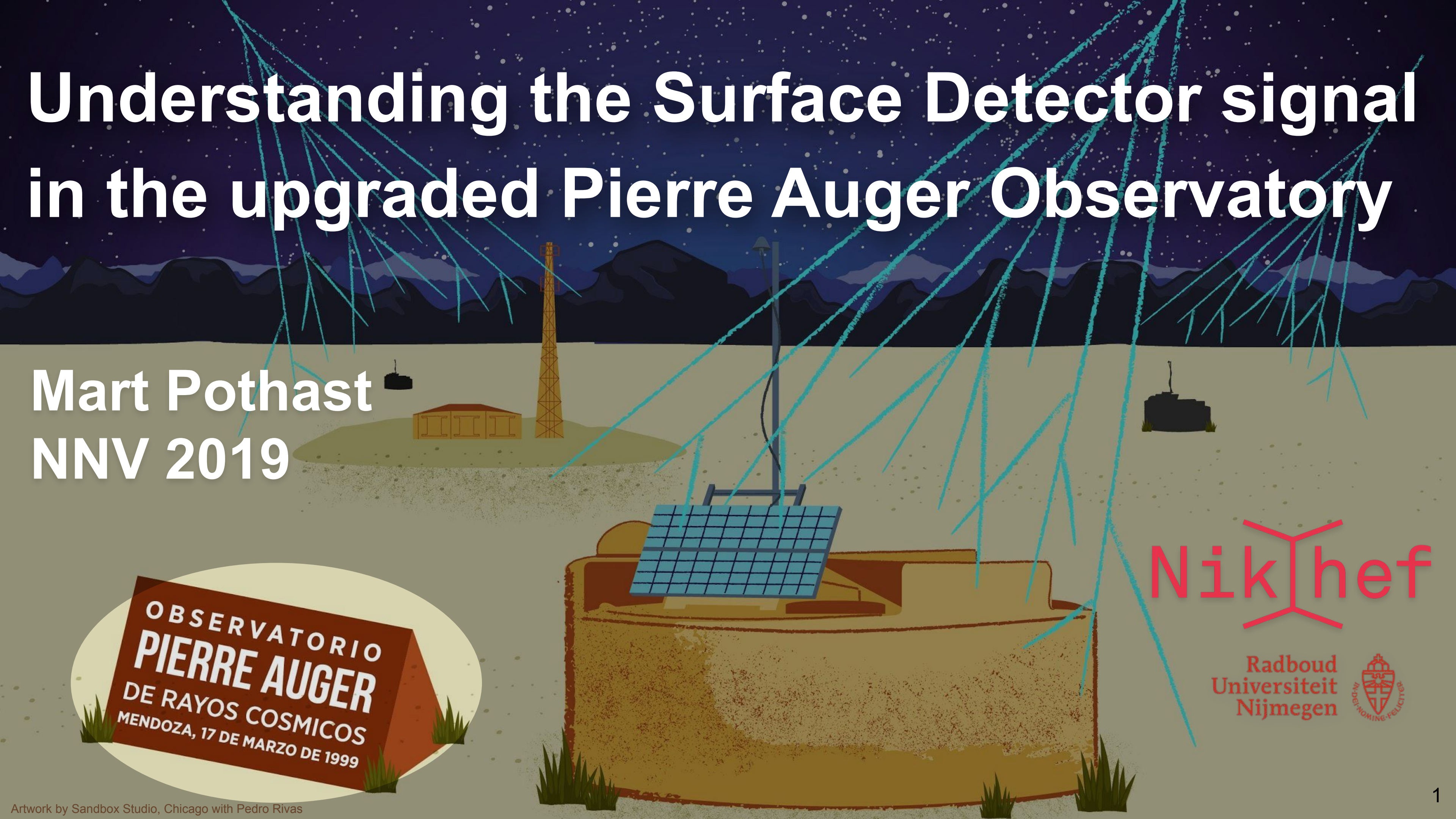
Understanding the Surface Detector signal in the upgraded Pierre Auger Observatory

Mart Pothast
NNV 2019



Artwork by Sandbox Studio, Chicago with Pedro Rivas

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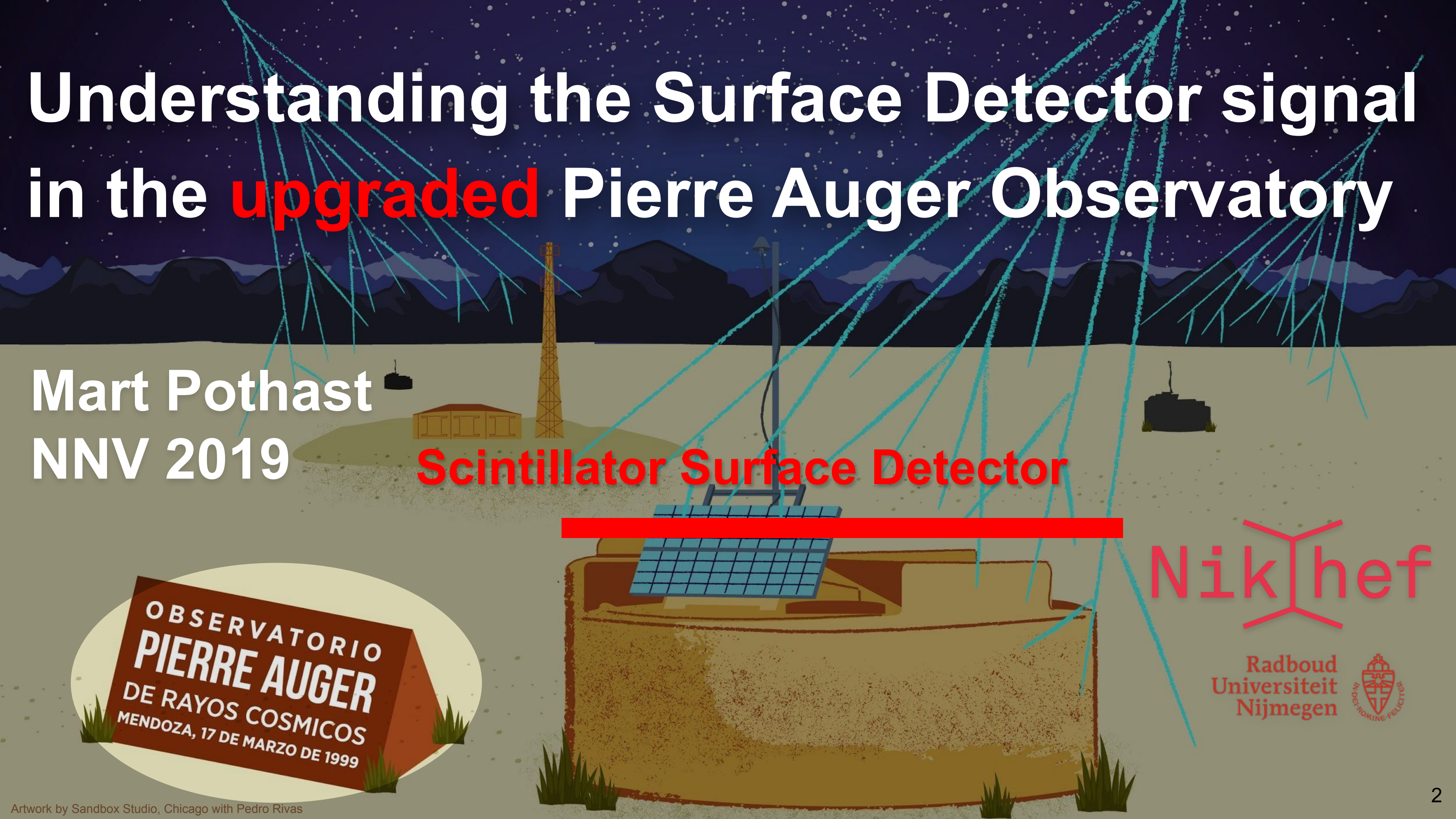
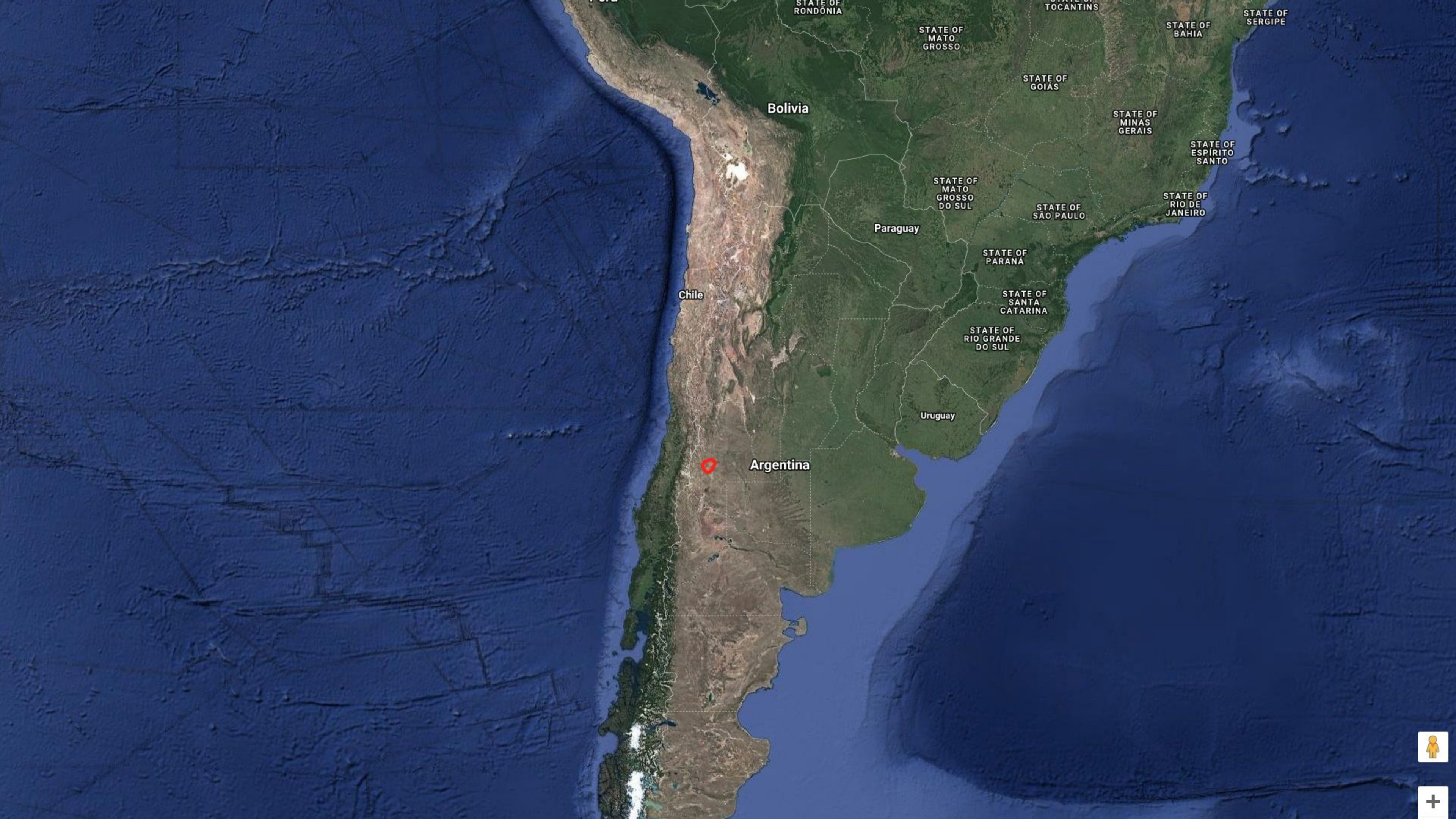
Scintillator Surface Detector



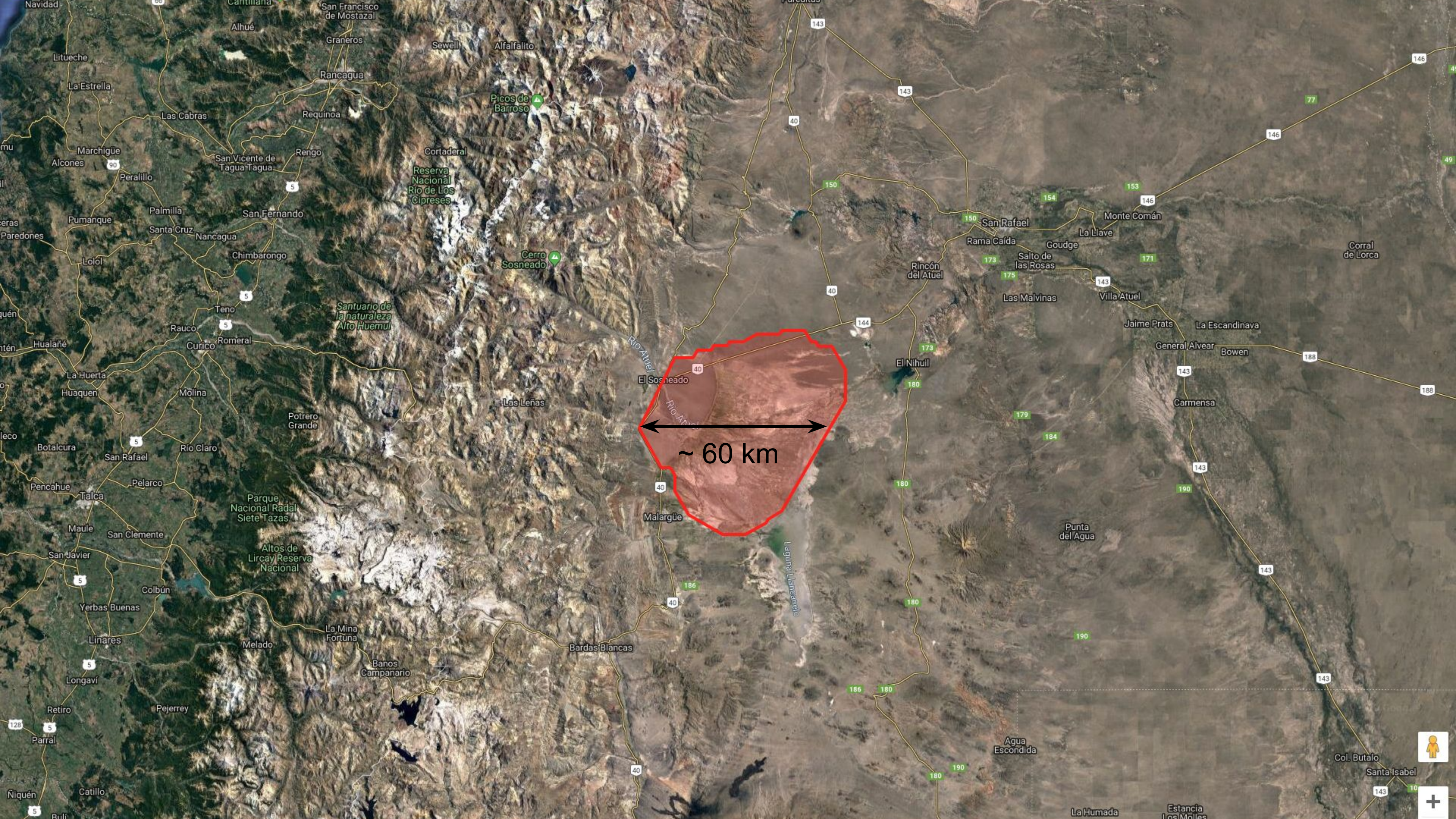
Nikhef
Radboud Universiteit Nijmegen

Artwork by Sandbox Studio, Chicago with Pedro Rivas


Lunteren
Pierre Auger Observatory
Google

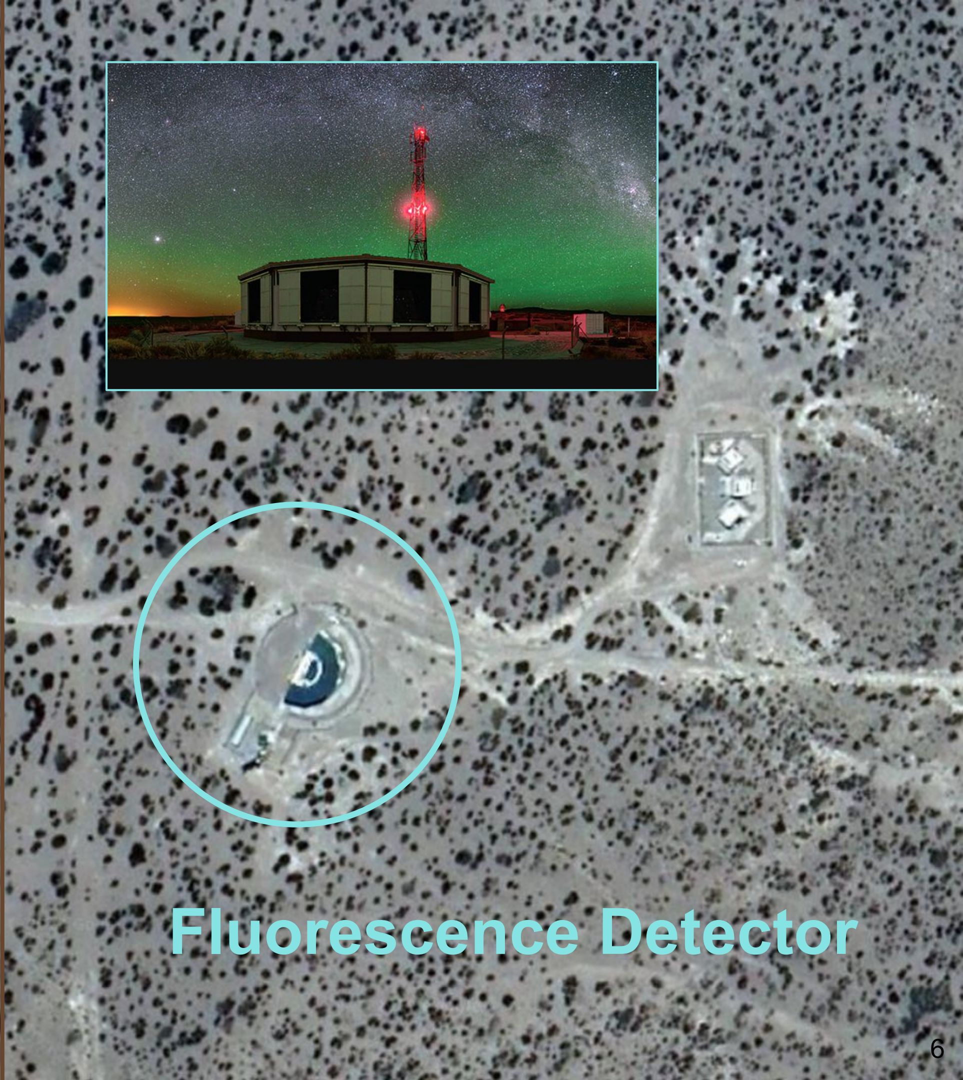


RONDÔNIA
TOCANTINS
STATE OF SERGIPE
STATE OF MATO GROSSO
STATE OF BAHIA
STATE OF GOIÁS
Bolivia
STATE OF MINAS GERAIS
STATE OF ESPÍRITO SANTO
STATE OF MATO GROSSO DO SUL
STATE OF SÃO PAULO
STATE OF RIO DE JANEIRO
Paraguay
STATE OF PARANÁ
Chile
STATE OF SANTA CATARINA
STATE OF RIO GRANDE DO SUL
Uruguay
Argentina

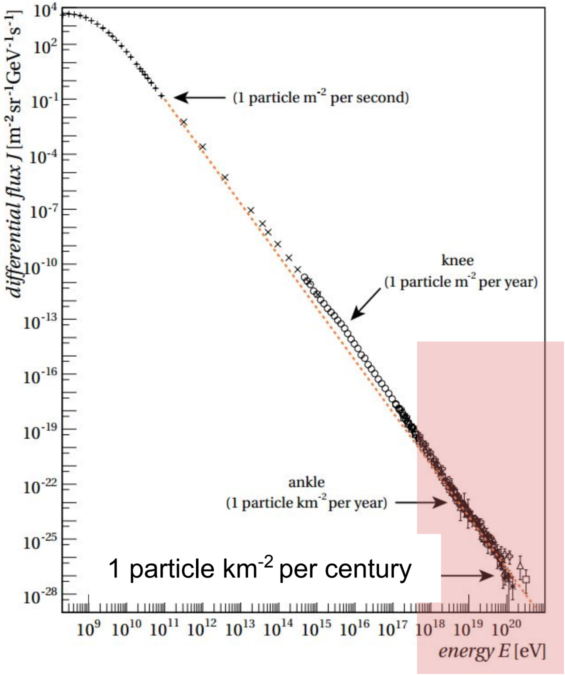


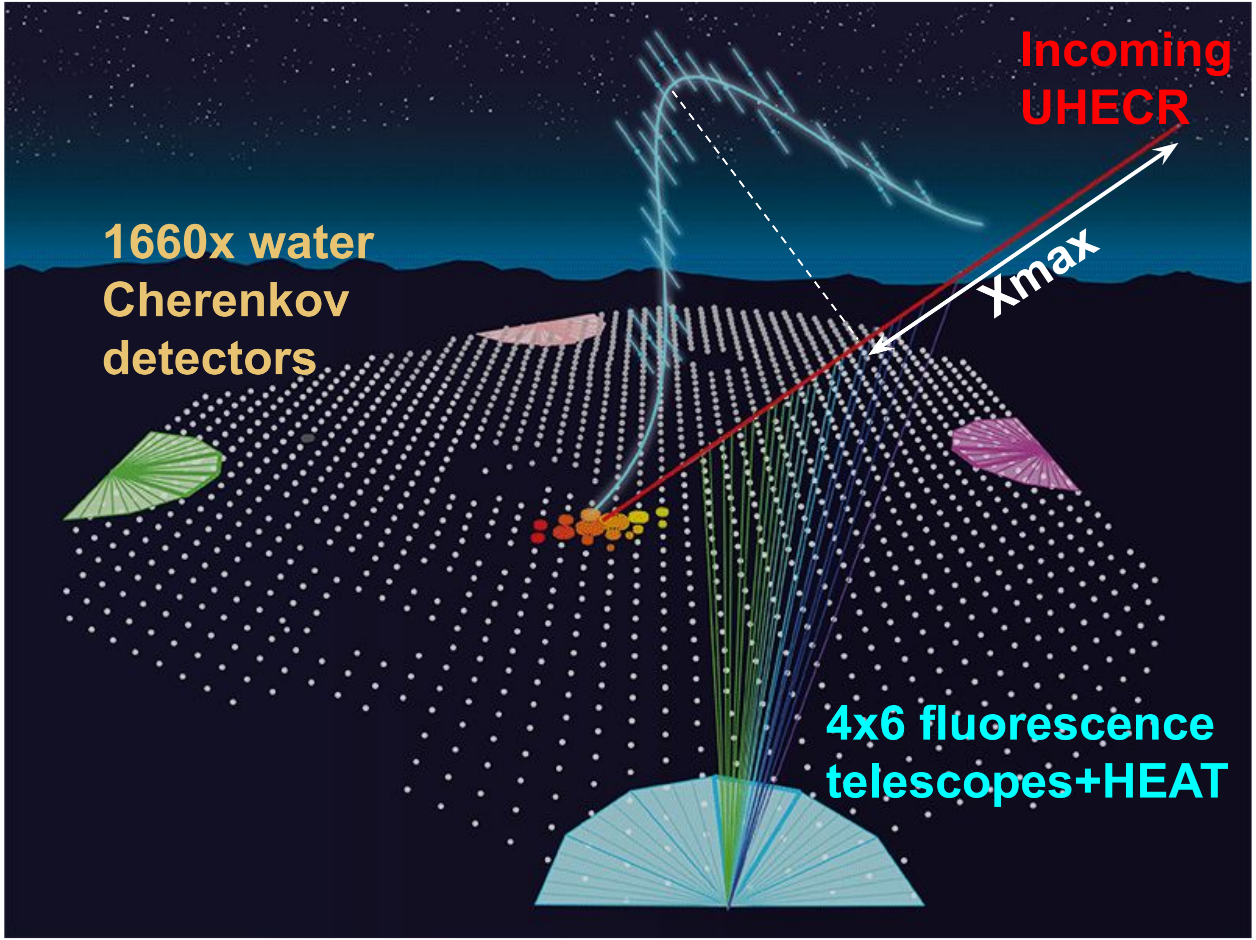
~ 60 km
El Sosneado
Malargüe
Río Atuel
Las Leñas
El Nihuil
San Rafael
Rama Caída
Monte Comán
La Llave
Goudge
Salto de las Rosas
Rincón del Atuel
Las Malvinas
Villa Atuel
Jaime Prats
La Escandinava
General Alvear
Bowen
Carmensa
Corral de Lorca
Punta del Agua
Agua Escondida
La Humada
Col. Butalo
Santa Isabel
Bardas Blancas
Laguna Llancanelo
Cerro Sosneado
Picos de Barroso
Sewell
Alfalfalito
Cortaderal
Reserva Nacional Río de Los Cipreses
Santuario de la naturaleza Alto Huemul
Parque Nacional Radal Siete Tazas
Altos de Lircay Reserva Nacional
Potrero Grande
La Mina Fortuna
Banos Campanario
Melado
Pejerrey
Rancagua
Graneros
Alhué
San Francisco de Mostazal
Requínoa
Rengo
San Vicente de Tagua Tagua
Las Cabras
Litueche
La Estrella
Marchigüe
Alcones
Peralillo
Palmilla
Pumanque
Santa Cruz
Nancagua
San Fernando
Chimbarongo
Paredones
Lolol
Teno
Rauco
Romeral
Curicó
Hualañé
La Huerta
Huaquen
Molina
Botalcura
San Rafael
Río Claro
Pencahue
Talca
Pelarco
Maule
San Clemente
San Javier
Colbún
Yerbas Buenas
Linares
Longaví
Retiro
Parral
Catillo
Ñiquén
Navidad


Surface Detector


Fluorescence Detector

We measure extensive air showers from ultra high energy cosmic rays

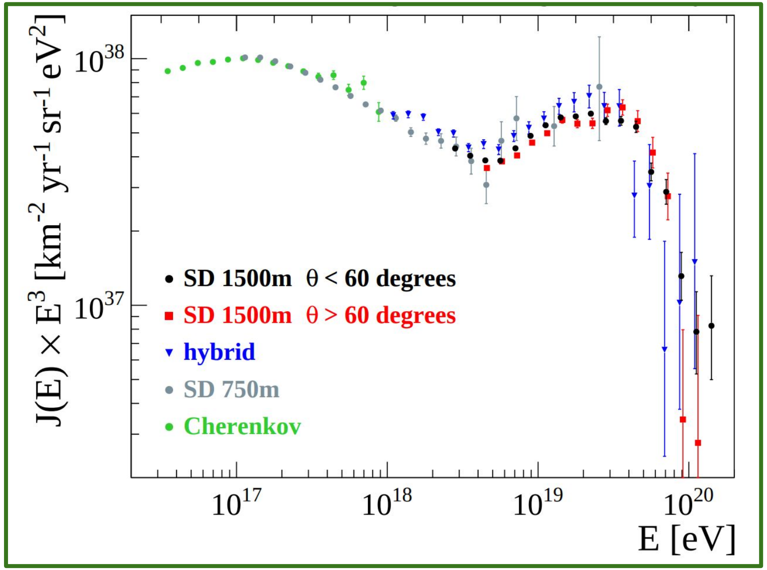




Some results from the Pierre Auger Observatory

Spectrum

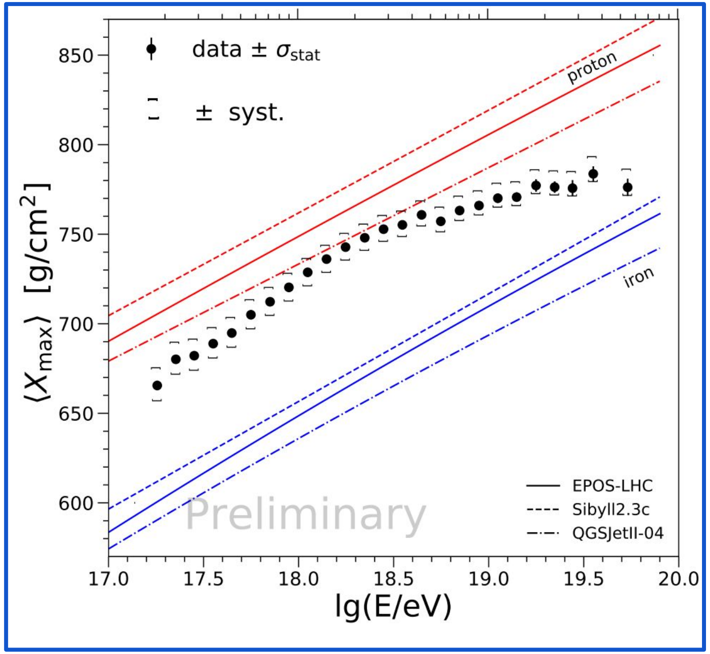
Features with high precision: ankle, cutoff



V.Verzi [Pierre Auger Coll.], PoS(ICRC2019) 450.

Composition

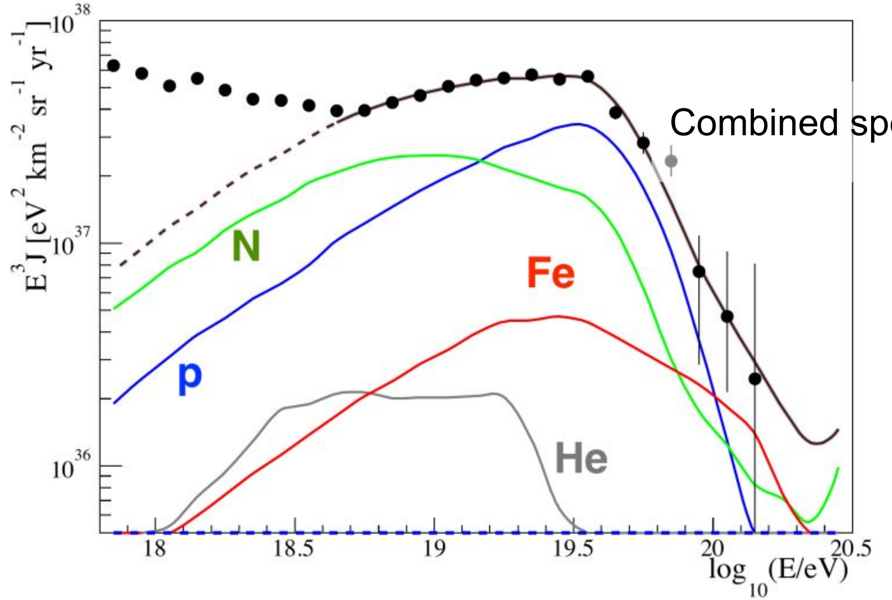
Heavier at higher energy



A.Yushkov [Pierre Auger Coll.], PoS(ICRC2019) 482.

Amazing! But...

Do we have this… or this



Combined spectrum+Xmax fit

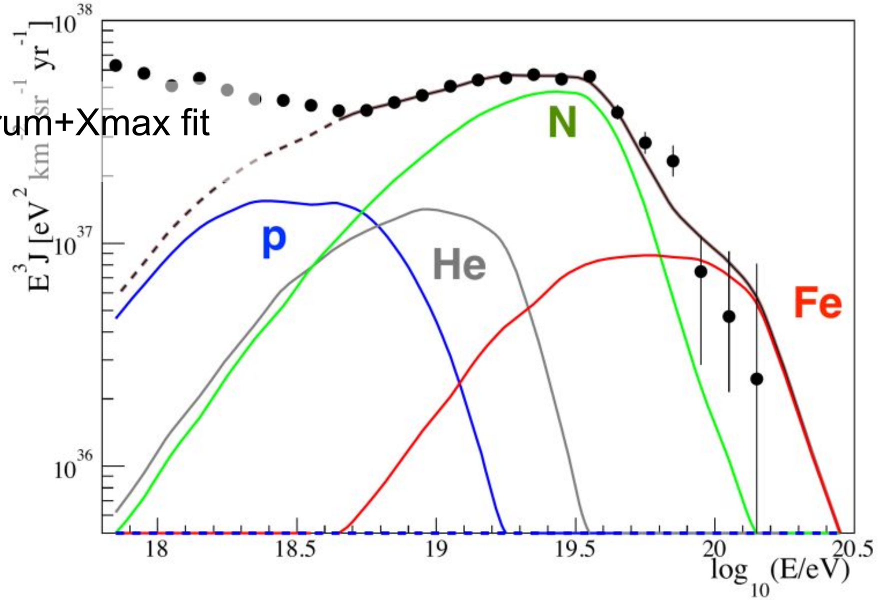


Photo-disintegration scenario
Cutoff due to propagation effects

Maximum rigidity scenario
Cutoff due to power of sources

Need to know composition at highest energy

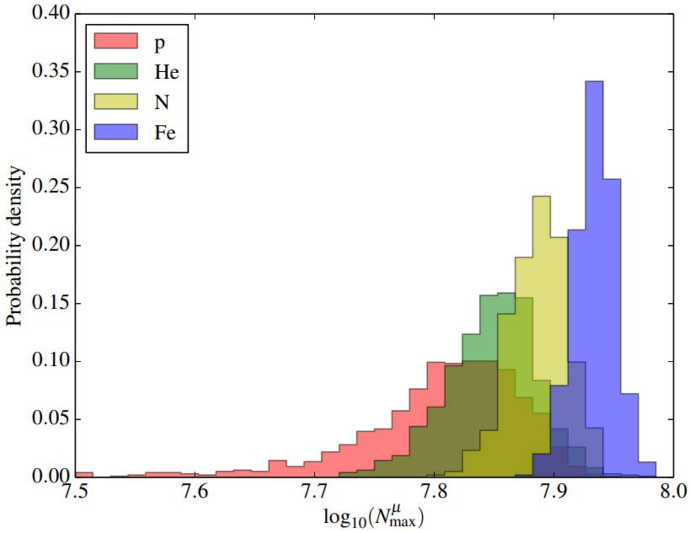
Time to upgrade!

Fluorescence Detector ~ 10% duty cycle

Surface Detector ~ 100%

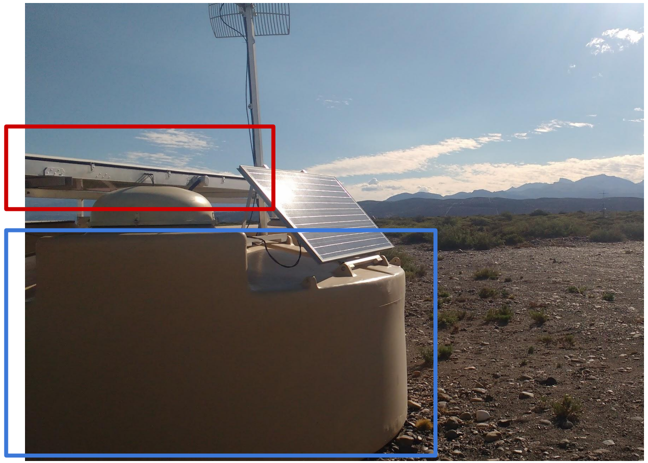
Number of muons is a good mass discriminator

Other upgrades also planned:
UMD, ***Radio****, extend fluorescence cycle, electronics*



How? -> Add a new detector

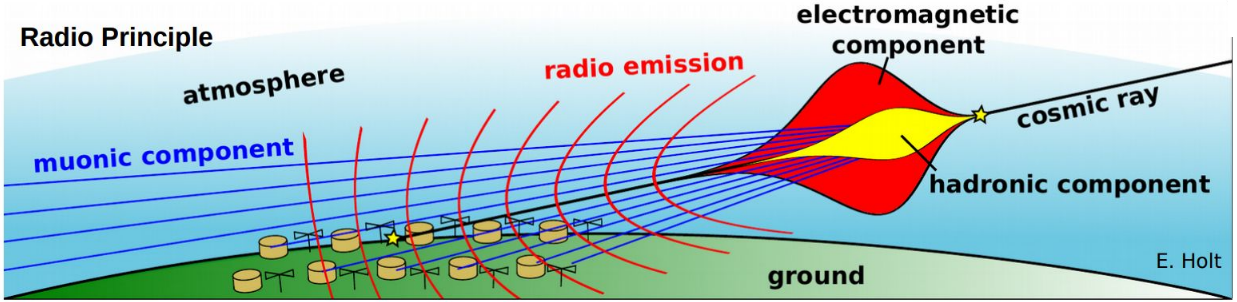
NEW: Scintillator Surface Detector
OLD: Water Cherenkov Detector (still important!)



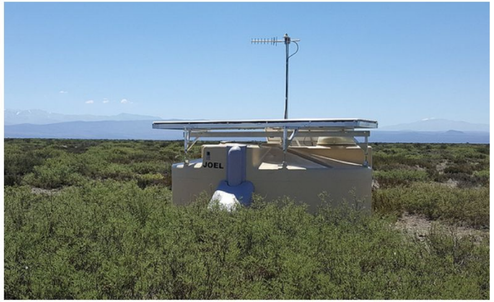
By the way

SSD only works for vertical showers

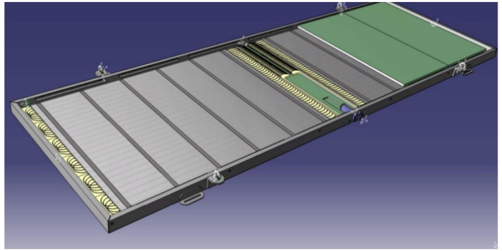
For inclined showers we will have **radio**



Scintillator Surface Detector (SSD)

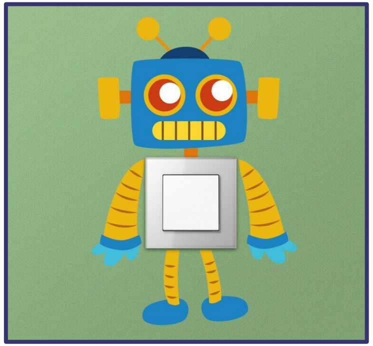


SSD has a different response to the particle content than the Water Cherenkov Detector (WCD):
Can use this difference to resolve the signal from muons and from electromagnetic particles. Always need good old WCD.

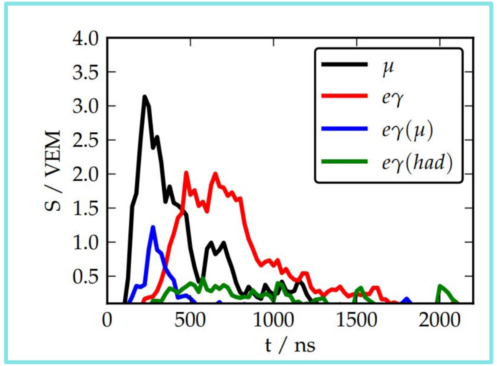


Matrix inversion

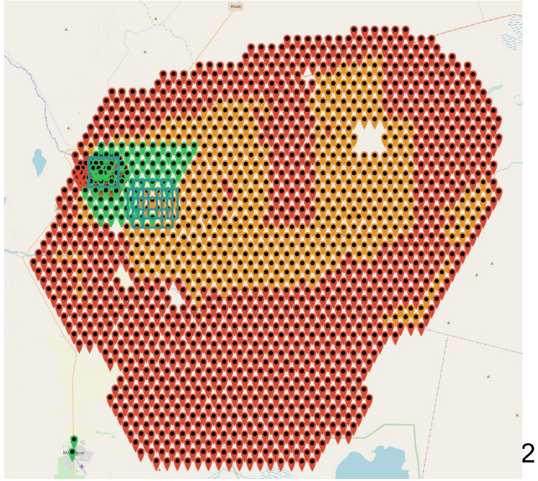
$$\begin{pmatrix} S_{\mathrm{SSD}} \\ S_{\mathrm{WCD}} \end{pmatrix} = \begin{pmatrix} \lambda\, \mathcal{A}_{\mathrm{SSD}} & \mathcal{A}_{\mathrm{SSD}} \\ \beta\, \mathcal{A}_{\mathrm{WCD}} & \mathcal{A}_{\mathrm{WCD}} \end{pmatrix} \begin{pmatrix} \mathcal{F}_{\mathrm{em}} \\ \mathcal{F}_{\mu} \end{pmatrix}$$



Shower universality



Deep learning

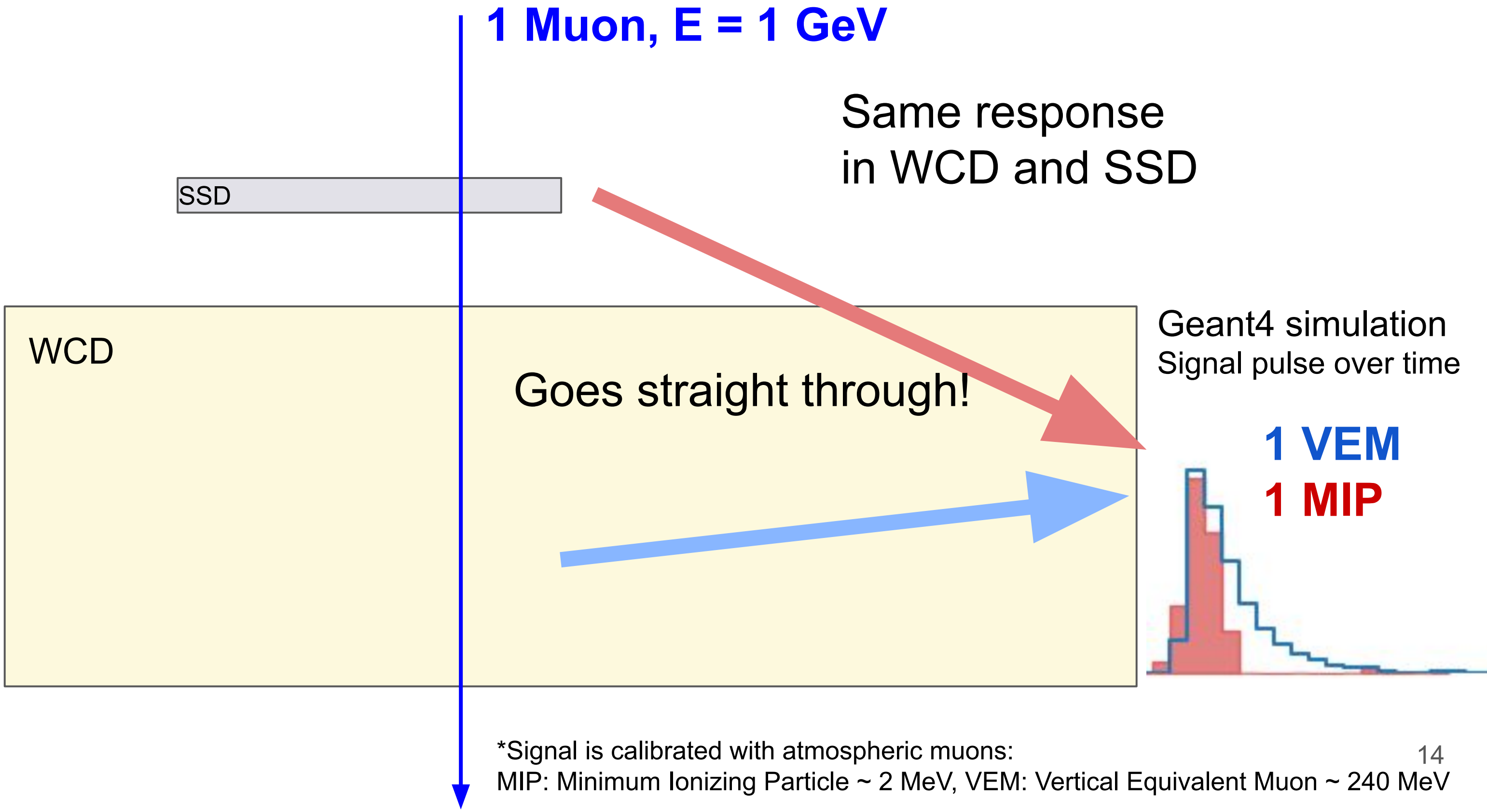


If we apply our *deep neural matrix inversion universality* algorithm on the raw signal, do we understand why it does (not) work?

-> Need to understand what the signal looks like

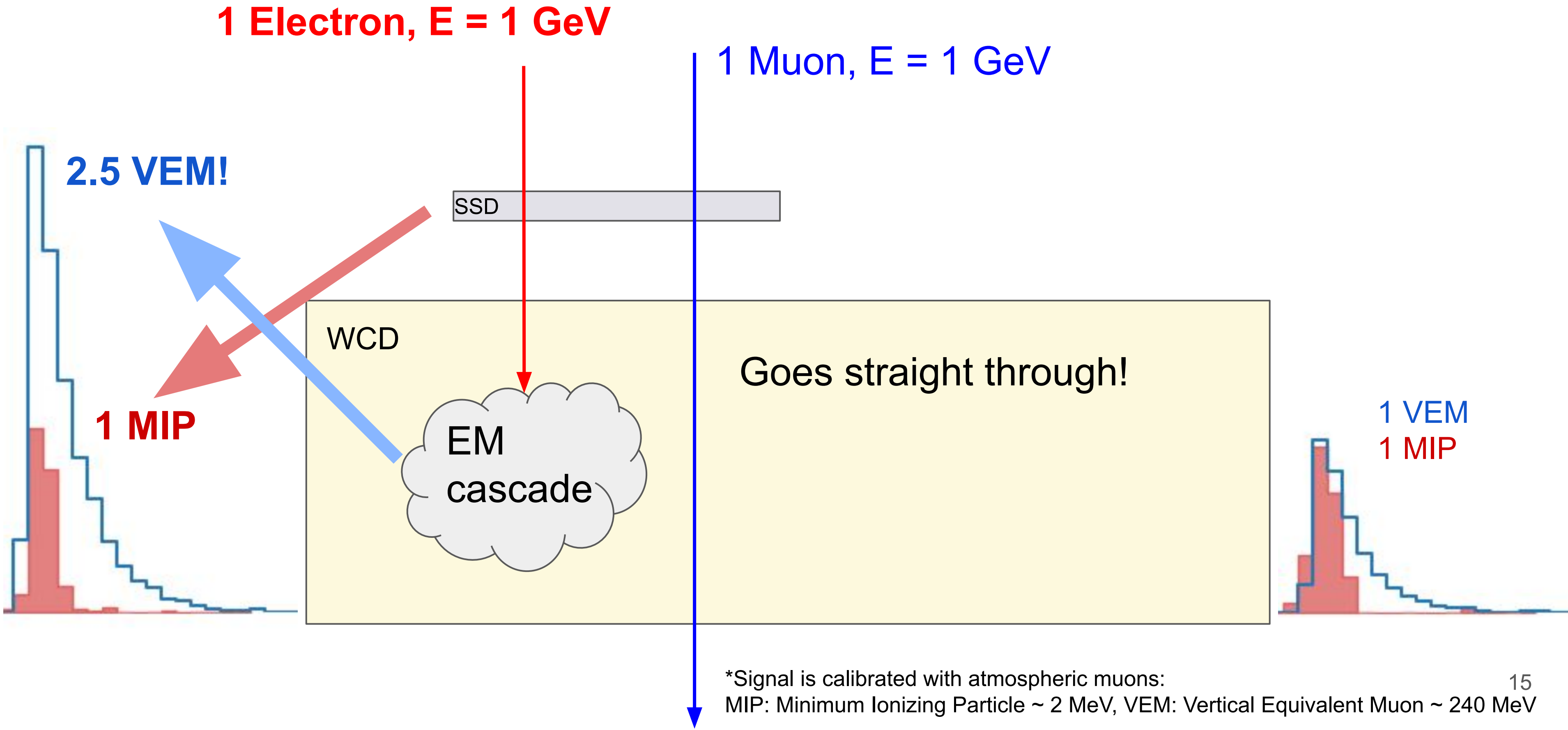
-> **Simulate the signal for 1 particle**, keep it simple (stupid)

What does the signal look like for 1 particle?



*Signal is calibrated with atmospheric muons:
MIP: Minimum Ionizing Particle ~ 2 MeV, VEM: Vertical Equivalent Muon ~ 240 MeV

What does the signal look like for 1 particle?



*Signal is calibrated with atmospheric muons:
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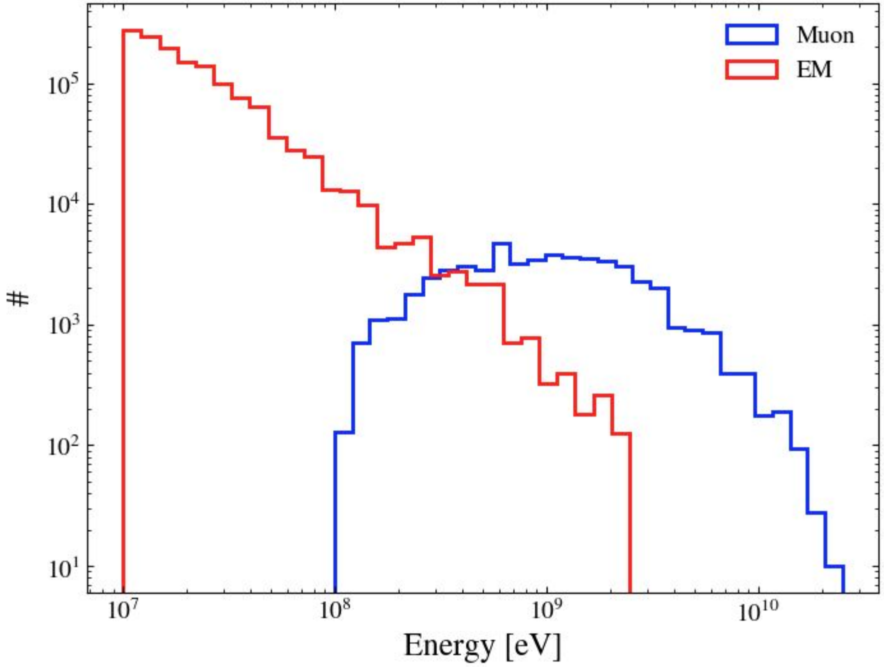
But need to implement the energy spectrum

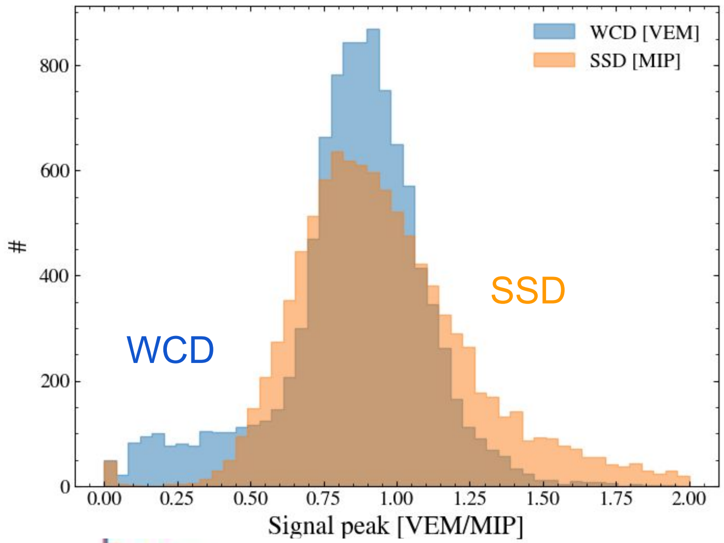
Electrons have on average much lower energy than muons

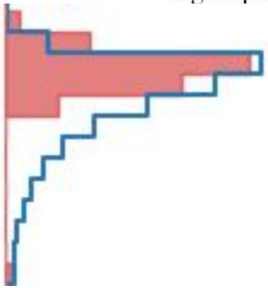


Vertical proton shower E=10^19 eV at 500m from core

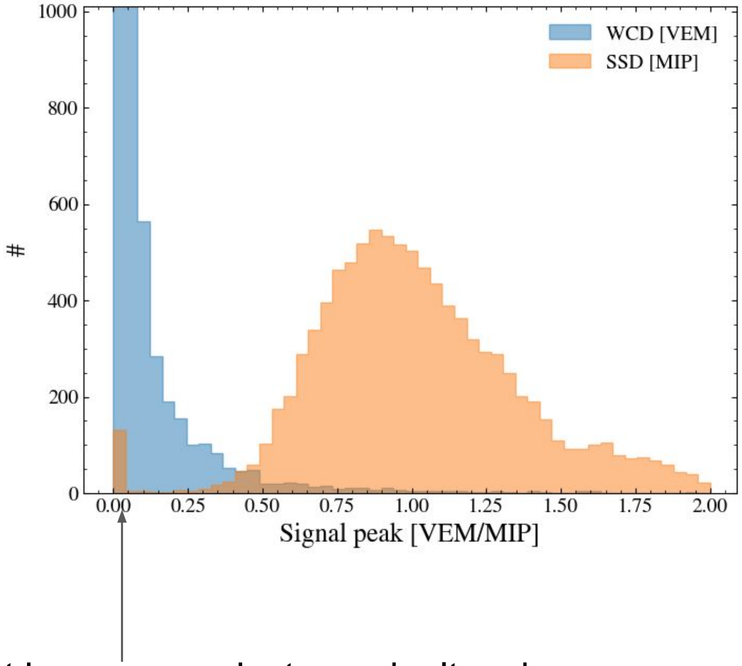
Injecting particles with the spectrum from an EAS:

Muons MIP ~ VEM





Electrons MIP >= VEM



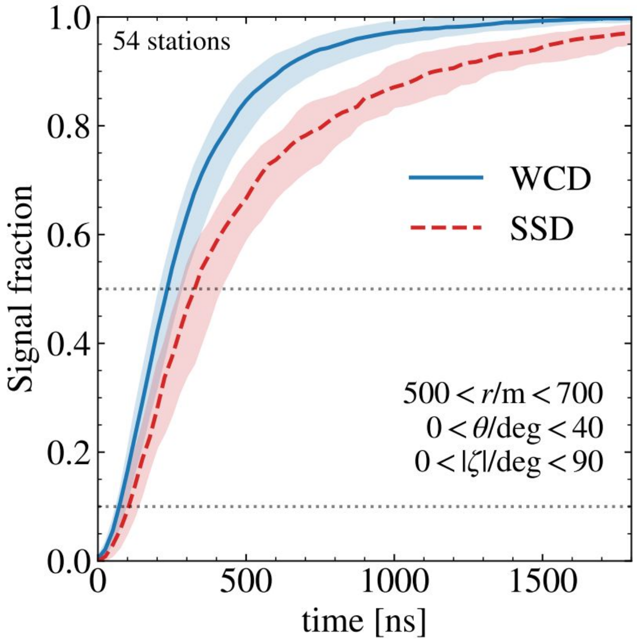
At low energy electrons don't make any signal in WCD

SSD counts particles, irrespective of energy. There are more electrons than muons so the **SSD signal is dominated by electrons.**

WCD is sensitive to high energy particles, these are mostly muons. So the **WCD is on average more sensitive (*than the SSD*) to muons.**

In progress:

Can we see that the response of the WCD/SSD is different in data?



Muons are early, electrons are late

Todo/in progress:

How can a *deep neural matrix inversion universality* algorithm distinguish between signal from muons and electromagnetic particles, with/without SSD?

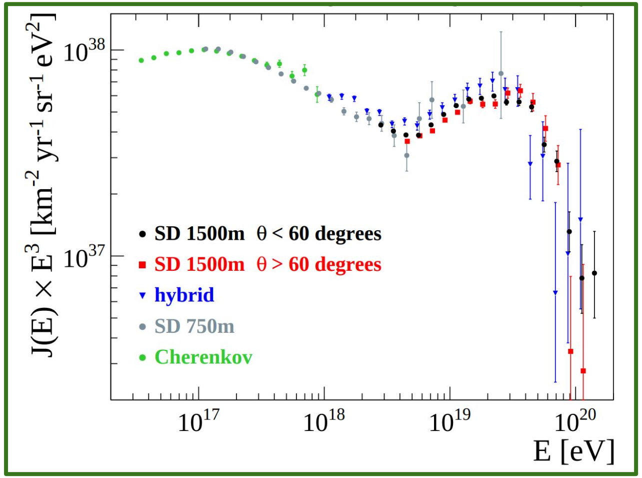
Thank you!

Backup

Results from the Pierre Auger Observatory

Spectrum

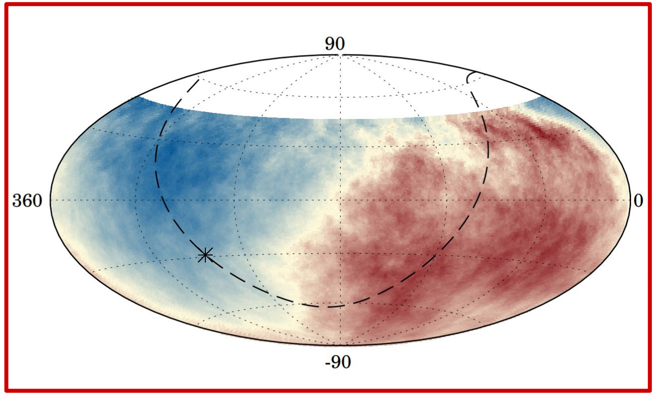
Features with high precision: ankle, cutoff



V.Verzi [Pierre Auger Coll.], PoS(ICRC2019) 450.

Direction

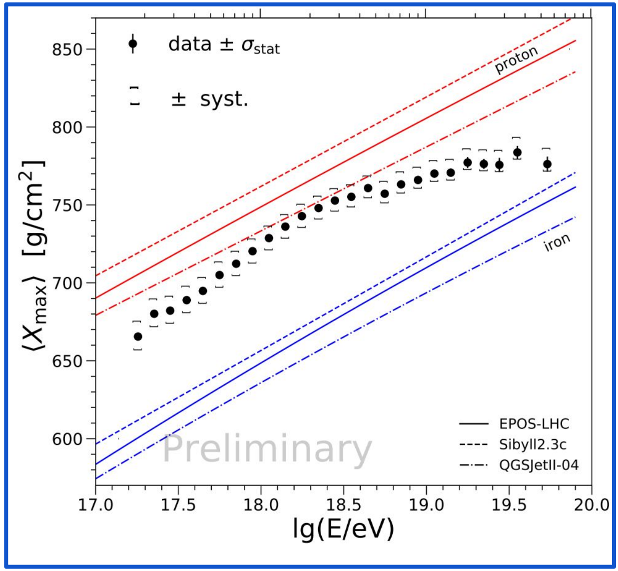
Dipole anisotropy



The Pierre Auger Coll., Science 357 (2017) , 1266.

Composition

Heavier at higher energy



A.Yushkov [Pierre Auger Coll.], PoS(ICRC2019) 482.