
XIX International Workshop on Neutrino Telescopes Feb 18 - 26 2021

# Ultra-high energy multi-messenger activities at the Pierre Auger Observatory

**Viviana Scherini* for the Pierre Auger Collaboration****

*** INFN Lecce, Italy**

**** http://www.auger.org/archive/authors_2021_02.html**

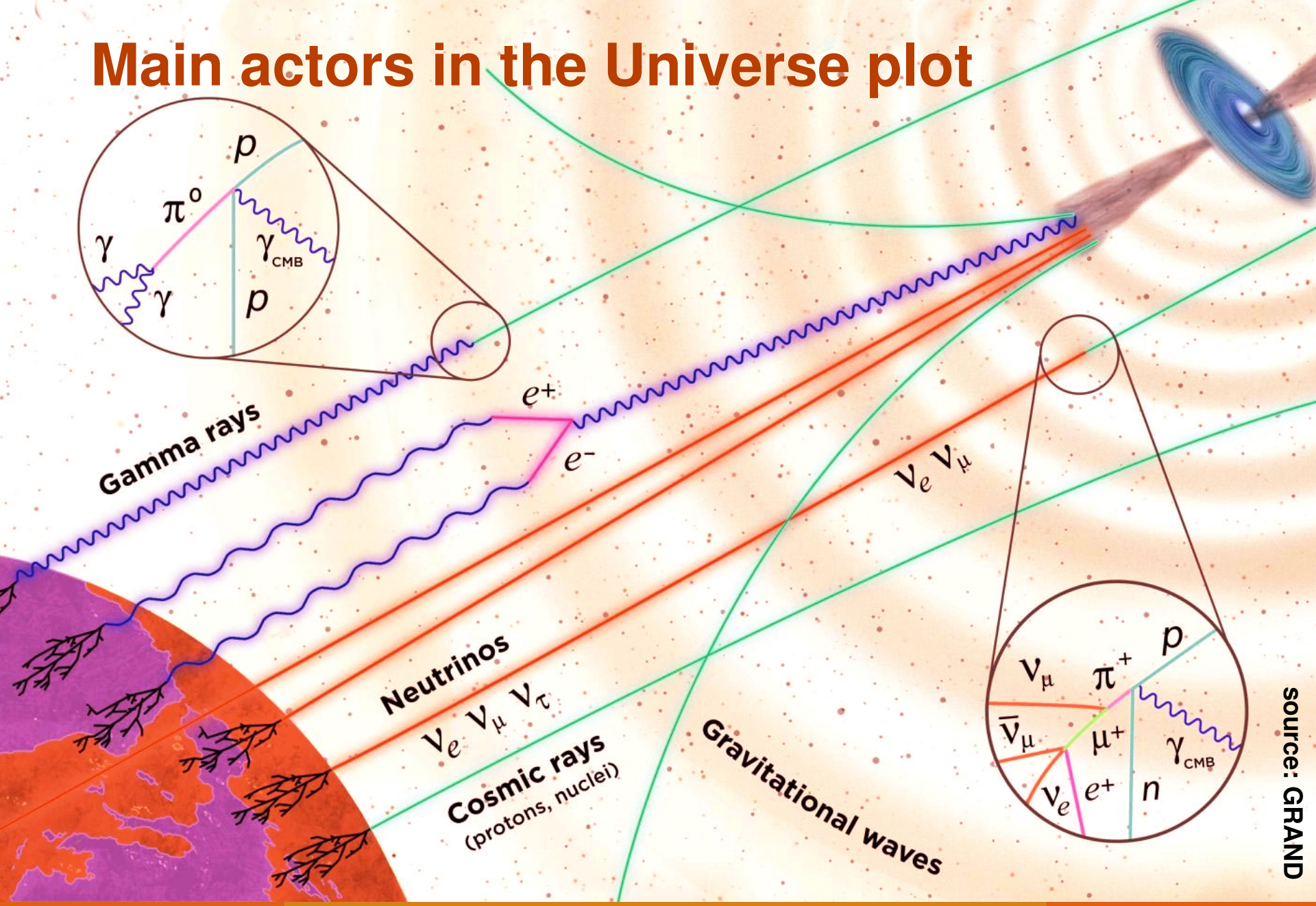
# Outline

- Multi-messenger astronomy at the highest energies
- The Pierre Auger Observatory
- Search for photons and neutrinos:
  - detection channels
  - data selection
  - exposure
  - diffuse limits
- Targeted studies photons and neutrinos
  - GC - TXS0506+056

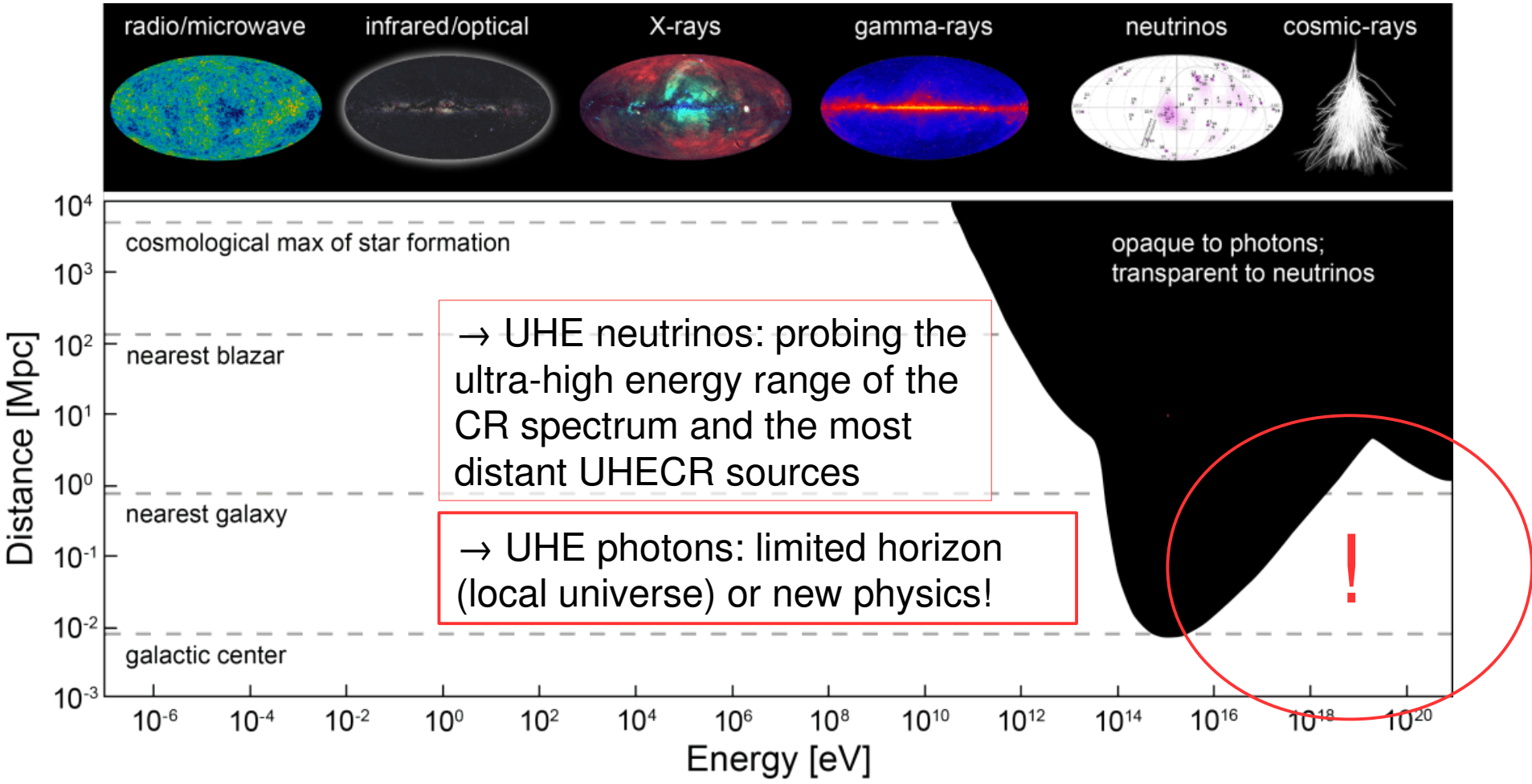
→ see next talk by M. Schimp about follow-up GW observations

- AugerPrime: upgrade of the Pierre Auger Observatory

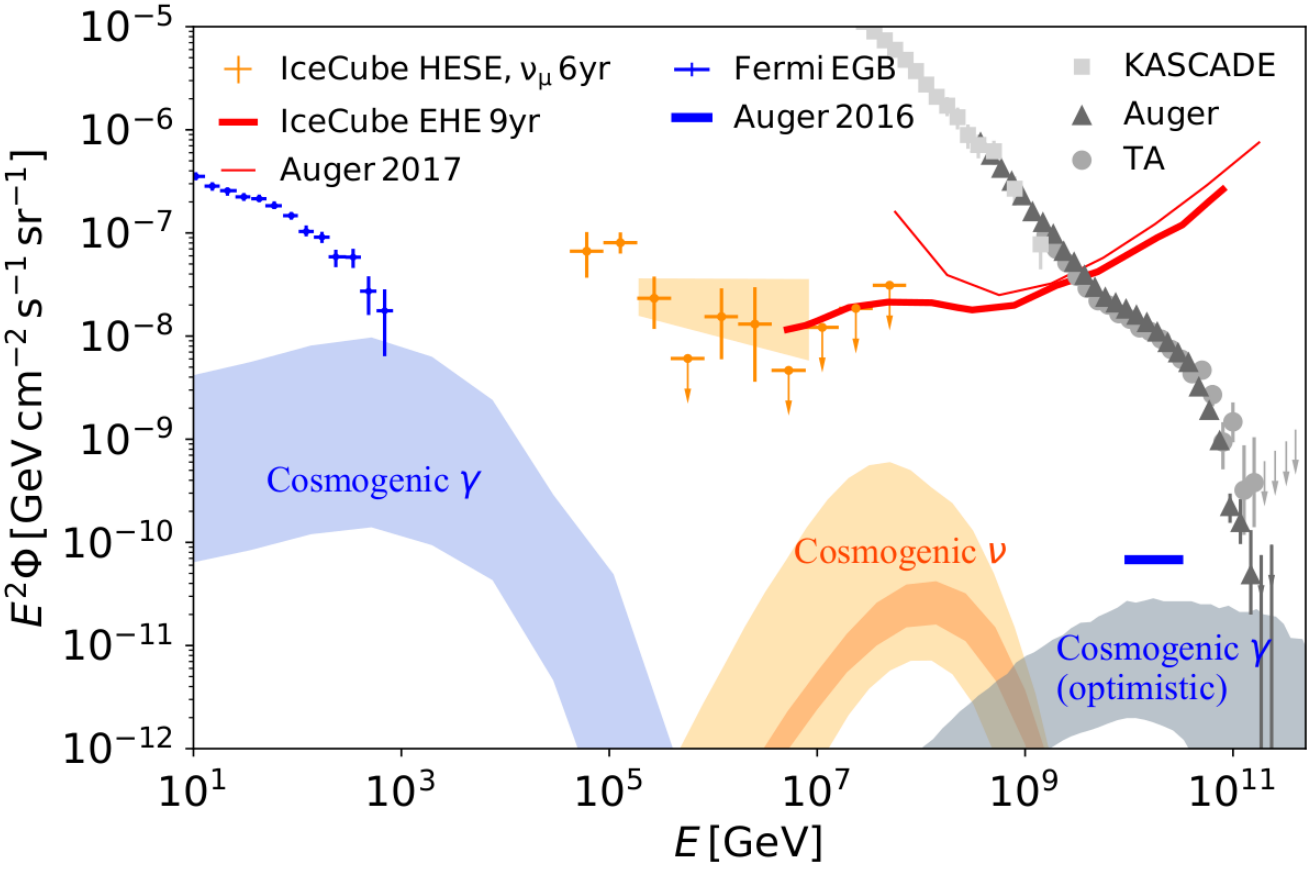
# Main actors in the Universe plot



# The multi-wavelenght panorama



# Probing the origin of UHECRs

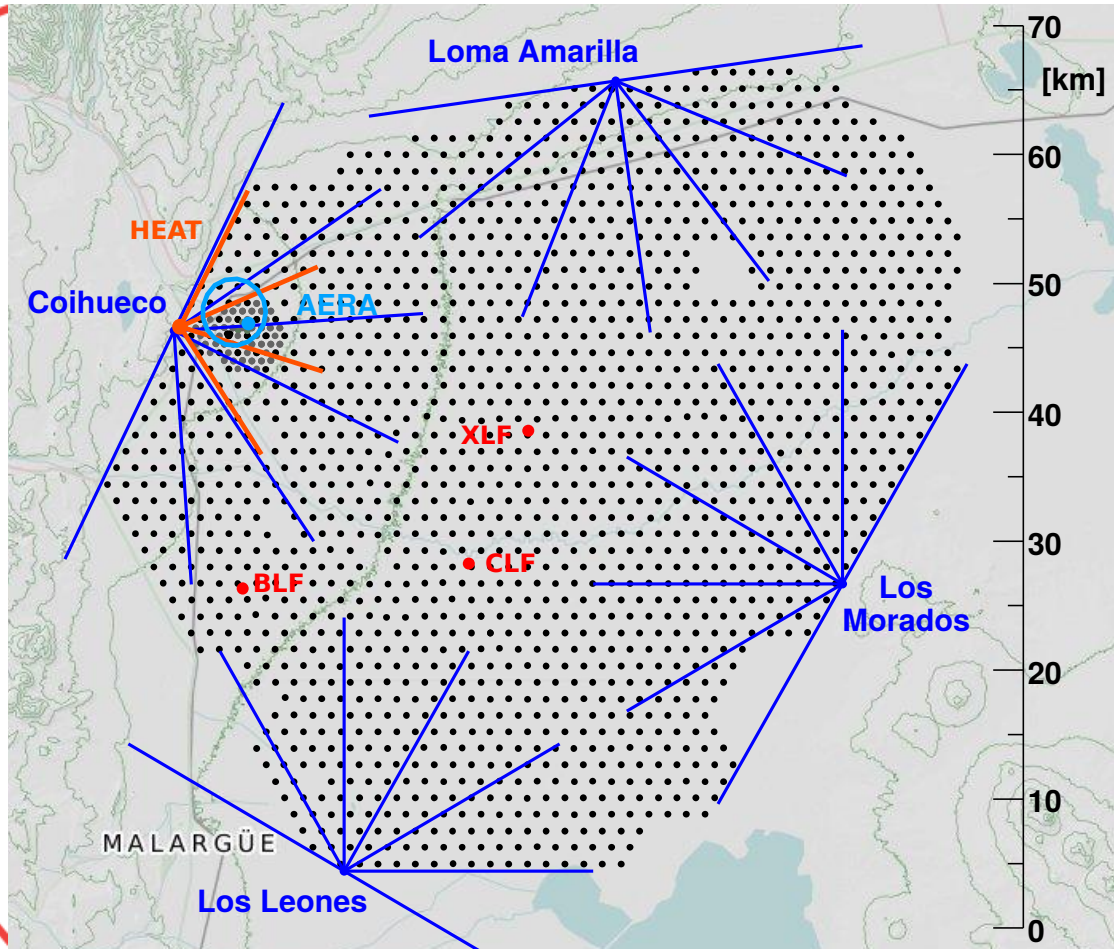



Maximum rigidity and/or propagation scenario: cosmogenic neutrinos and photons → GZK

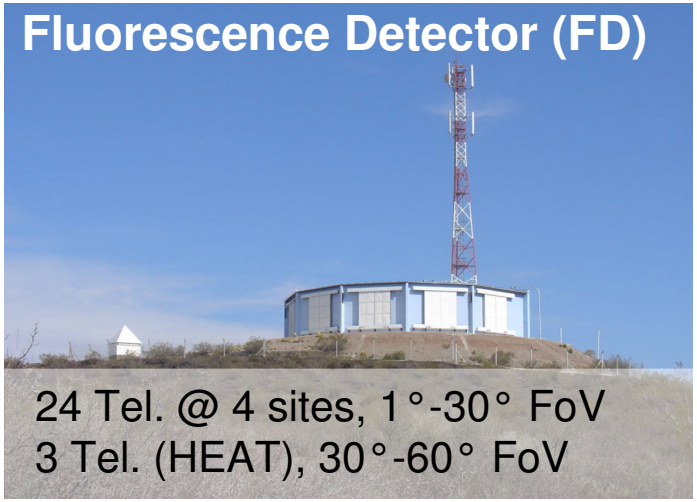
Hadronic acceleration in the sources → probe properties and evolution

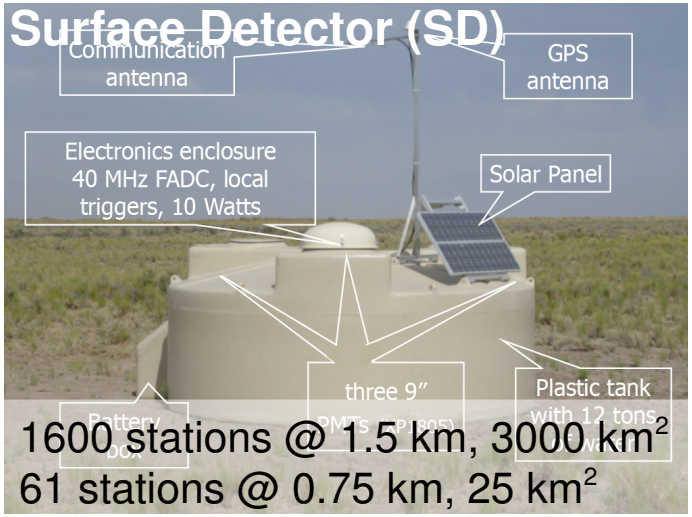
New physics? SHDM, LIV

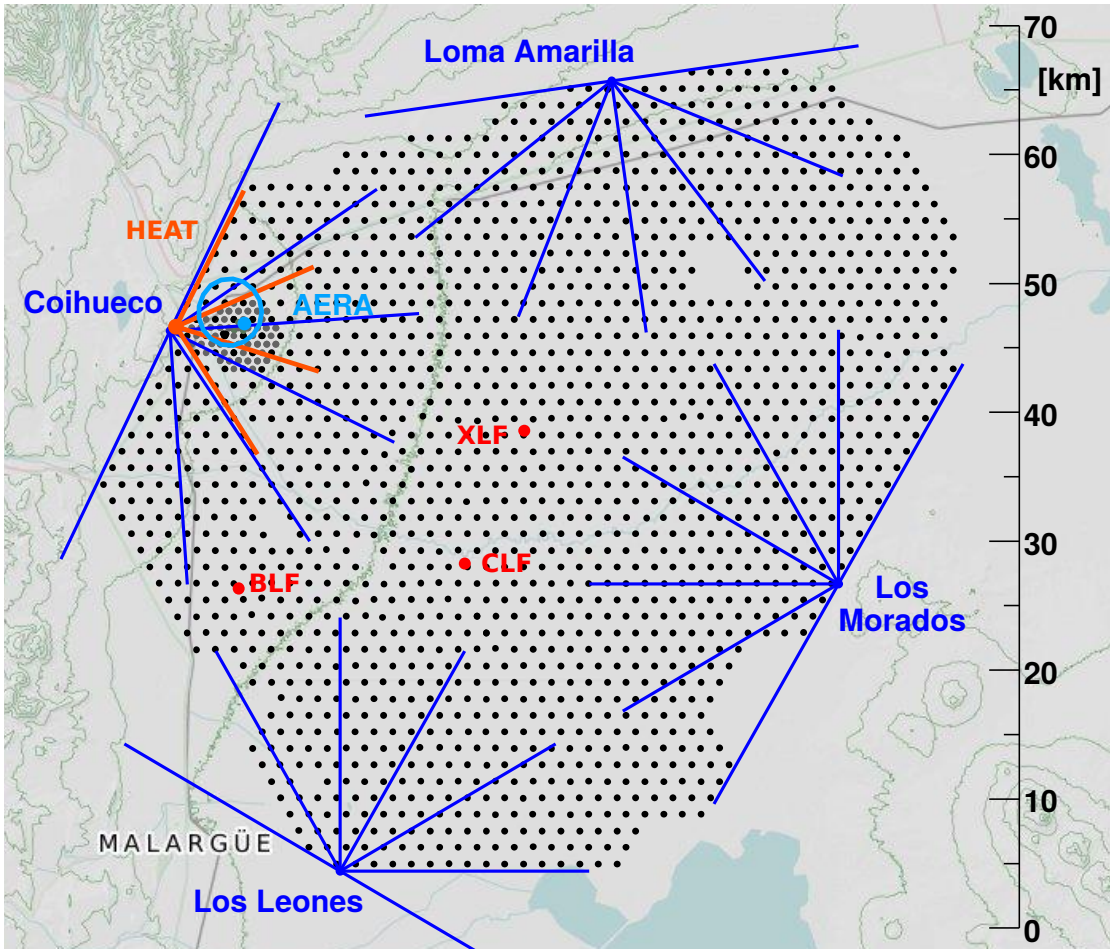
# The Pierre Auger Observatory

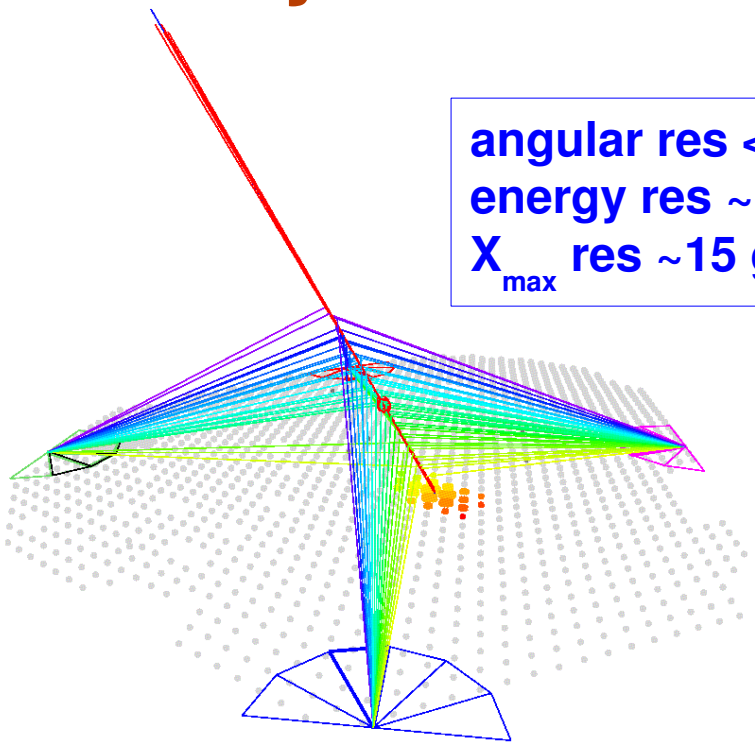
# The Pierre Auger Observatory



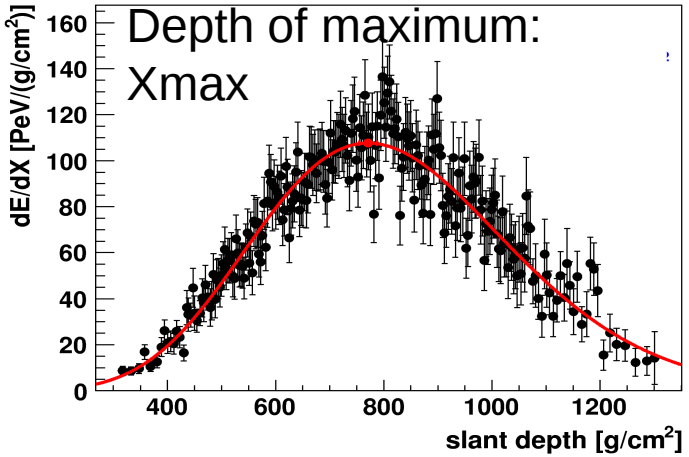



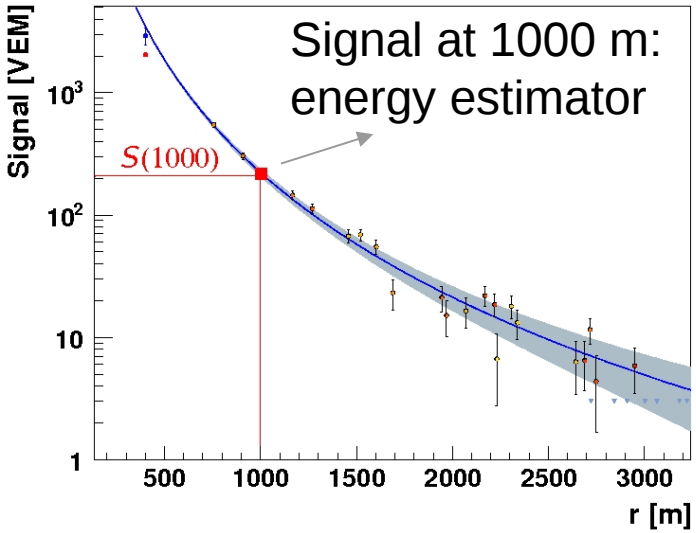



# The hybrid concept



**angular res <1°**
**energy res ~ 8 %**
**$X_{max}$ res ~15 g cm$^{-2}$**



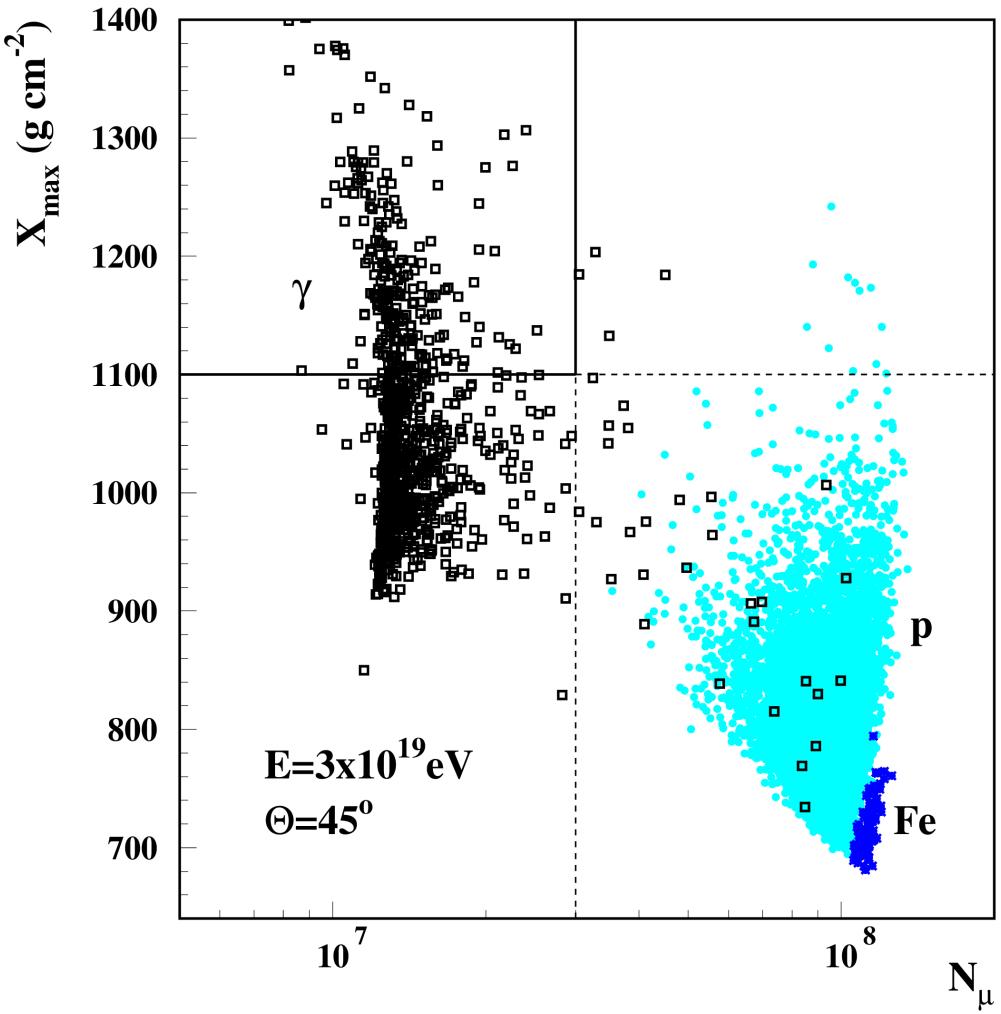




**Longitudinal profile**
FD - calorimetric measurement
- duty cycle 15%

**Density of particles at the ground**
SD - duty cycle ~ 100%

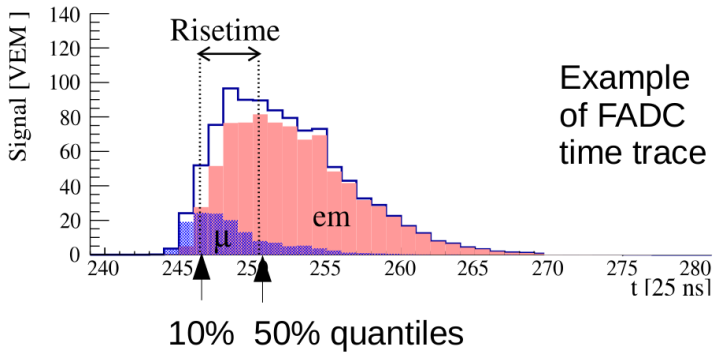
Use the energy scale provided by FD to calibrate the entire SD data sample

# UHE Photon induced cascades




Photon EAS distintive signature:
→ delayed shower developement
→ smaller muon content

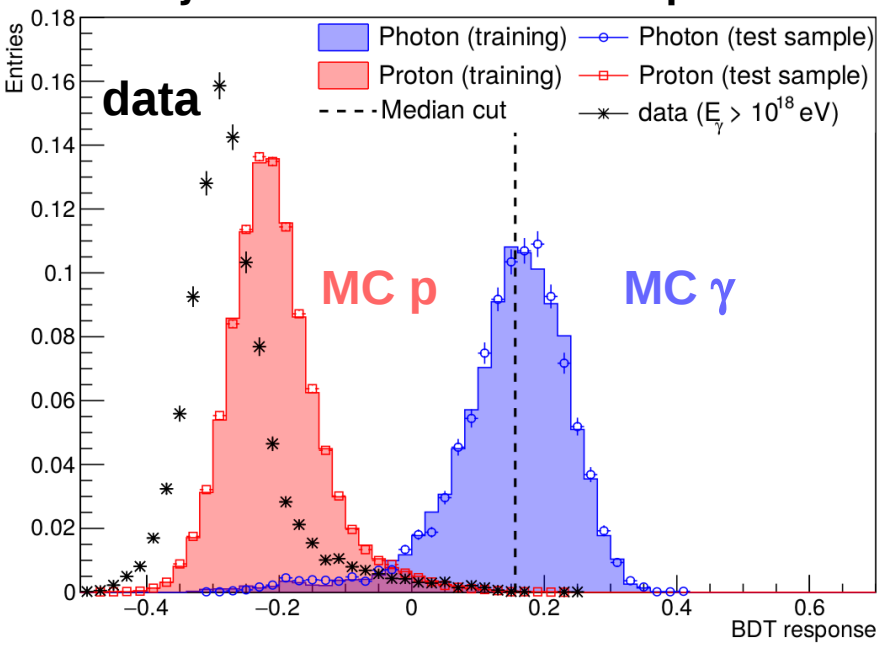
observable characteristics:
- larger <Xmax>
- steeper LDF
- smaller footprint
- broader signal



# Photons: HYB and SD data selection

Pierre Auger Collab., PoS ICRC2019 398

## Hybrid selection: BDT response

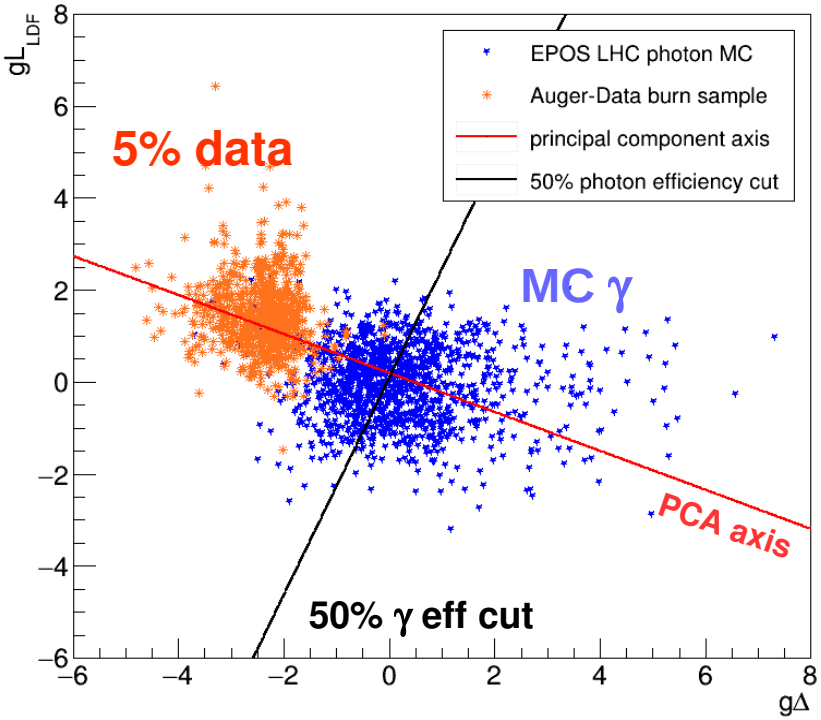



Maximum of shower development: $X_{max}$

Distance weighted signal: $S_b$

Number of triggered stations: $N_{stations}$

## SD selection: PCA transformed

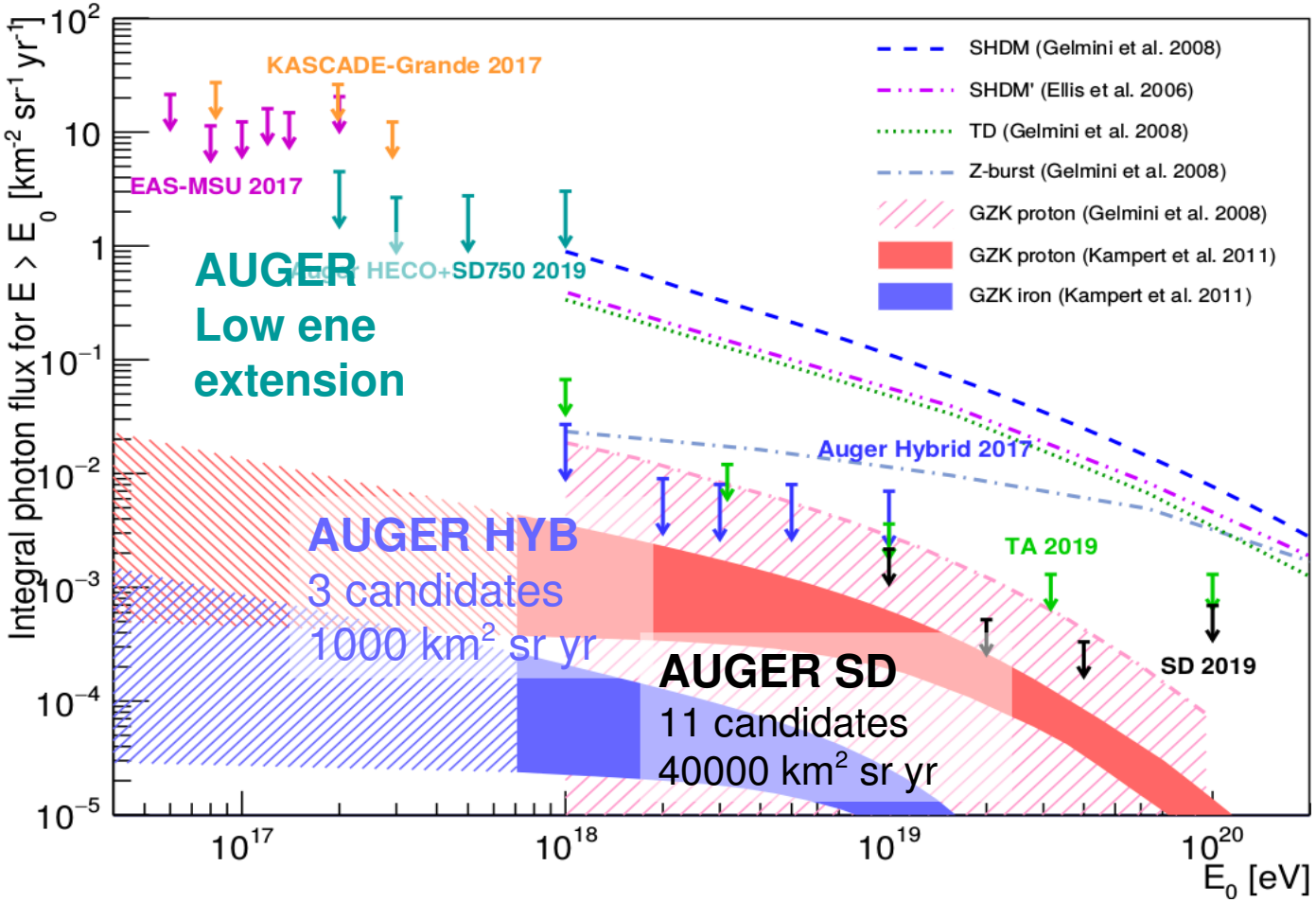



deviation from data <LDF>: $gL_{LDF}$

rise-time rel. event-wise quantity: $g_\Delta$

# Photon diffuse flux upper limits

**Pierre Auger Collab., PoS ICRC2019 398**



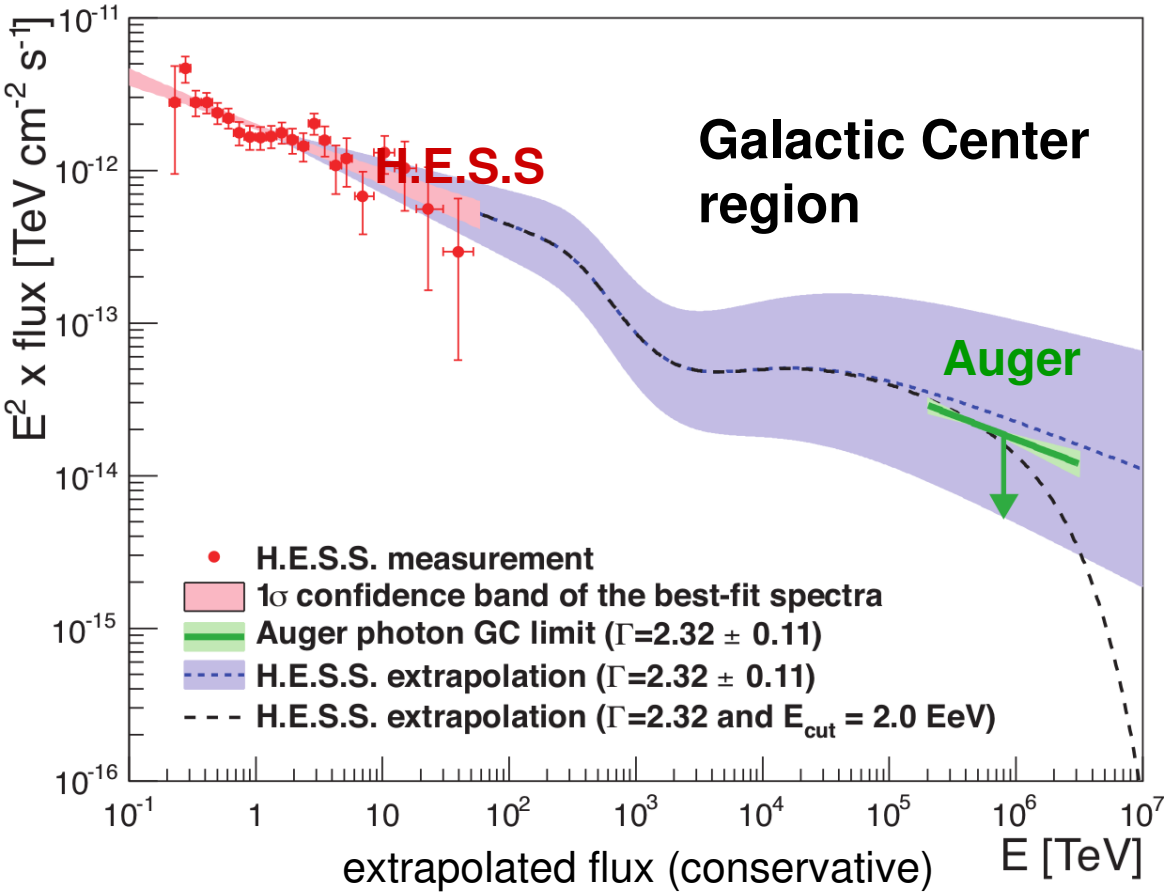

→ most top-down models disfavoured

→ constraining cosmogenic γ predictions

The SD analysis can be run in real-time and monitor the sky in the zenith angle band 30° – 60°

# Targeted searches

**Pierre Auger Coll., ApJL 837: L25 (2017)**




- focus on **12 target sets** (364 candidates sources)
- stacked analysis

→ complement targeted neutron searches

**NO evidence for *nearby* photon-emitting *steady* sources in the EeV range**

→ PS limits constrain the continuation of measured TeV fluxes to EeV energies

# UHE neutrinos: detection channels

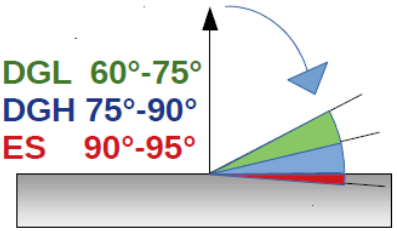
## Earth-skimming (ES):
upward going τ neutrinos CC
zenith angle 90° ÷ 95°

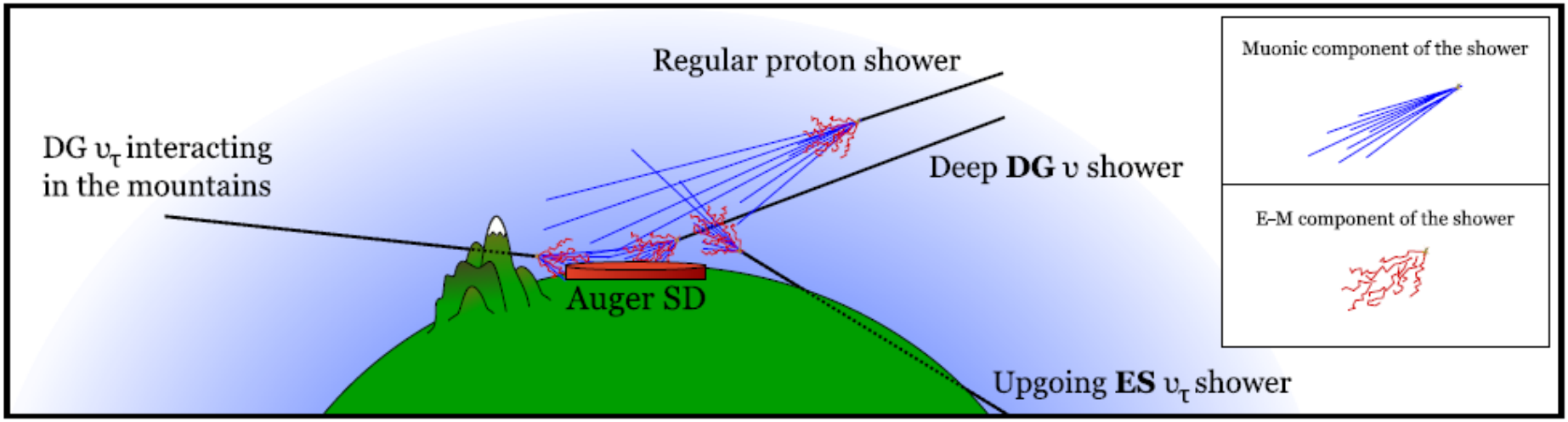
τ can emerge from the Earth crust and decay close to the detector

D. Fargion, Astrophys. J. 570, 909 (2002)
A. Letessier-Selvon, AIP Conf. Proc. 566, 157 (2001)

## Downward Going (DG):
deeply interacting ν all flav. CC & NC
zenith DGL 60°÷75°  DGH 75°÷90°

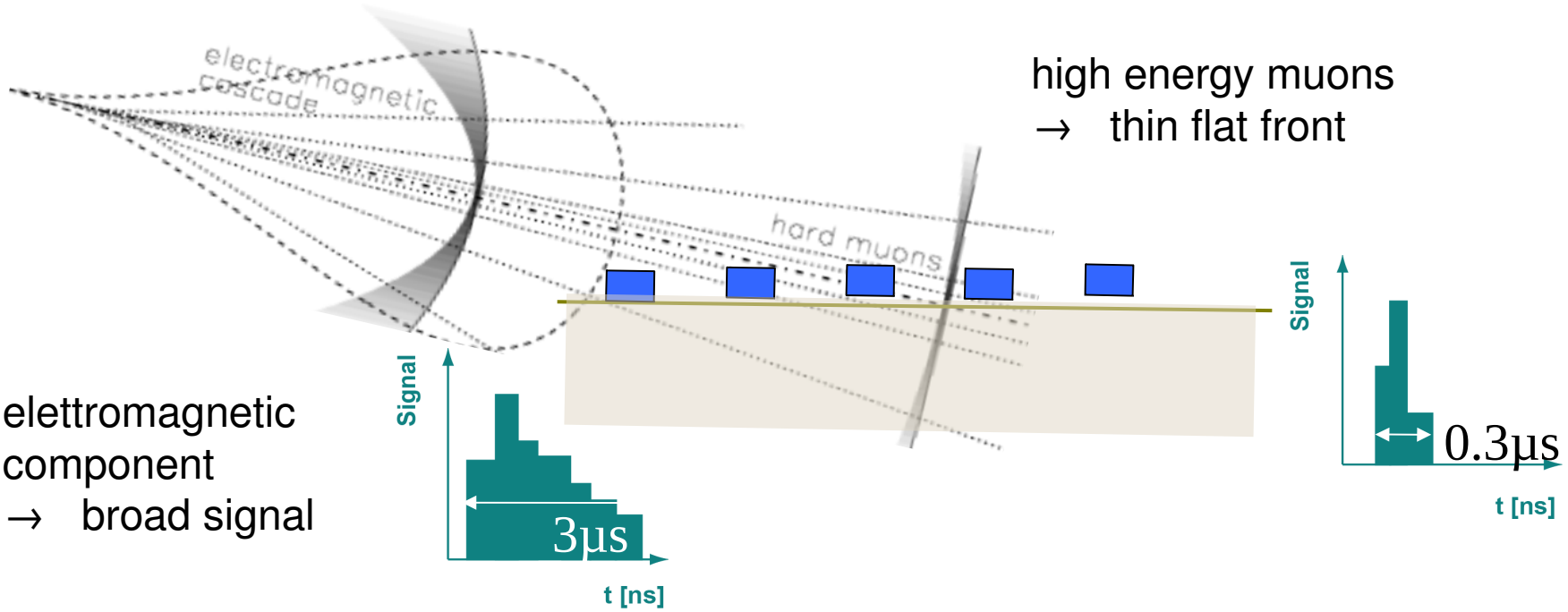
**Sensitivity to ALL ν flavours and ALL interaction channels**



# UHE neutrinos: signature

**neutrino signature:**
**young shower i.e. with large electromagnetic component**
**→ inclined event with slow rising and broad signal**

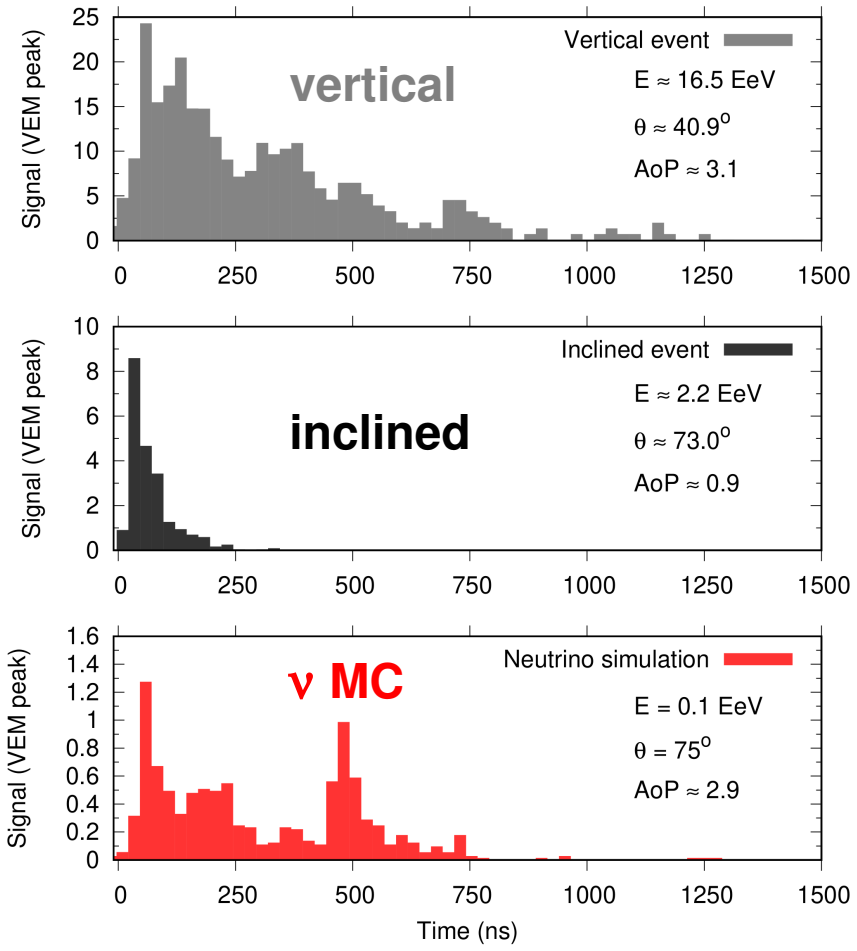


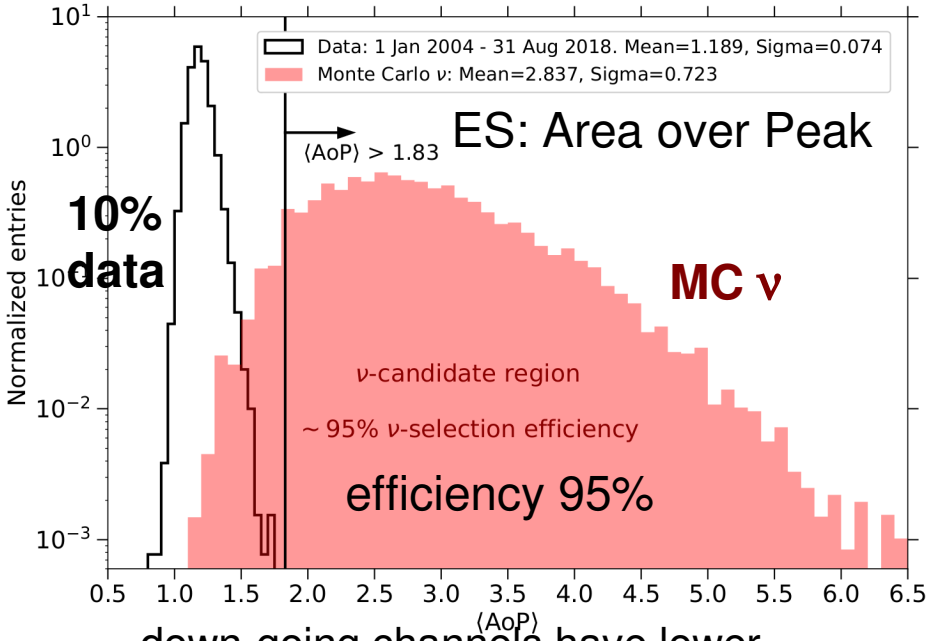

**UHE neutrinos detectable as almost horizontal young showers**

# UHE neutrinos: data selection

**Pierre Auger Coll., JCAP 10 (2019) 022**

- Data 2004 – 2018 14.7 yr of stable operation
  ~10% of the data for background estimation
  → **bkg expected: <1 event in 50 years**
- Selection tuned on the different det. channels

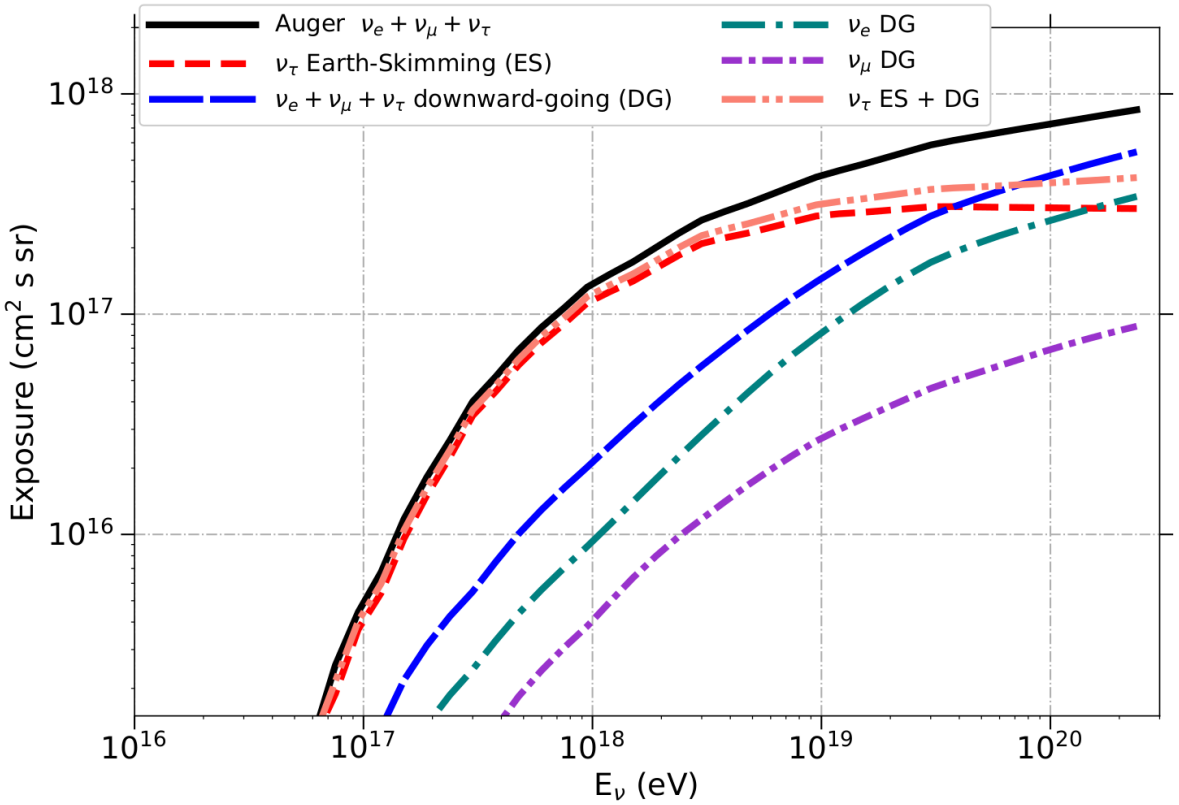


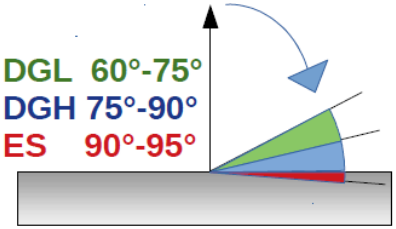




down-going channels have lower ν-selection efficiency (85% and 72%)

# UHE neutrinos: exposure

**Pierre Auger Coll., JCAP 10 (2019) 022**




$\nu_\tau$ ES sensitivity dominant

Contribution by channel:

ES 79.4%

DGH 17.6%

DGL 3.0%

Contribution by flavour:

$\tau$ 86.1%

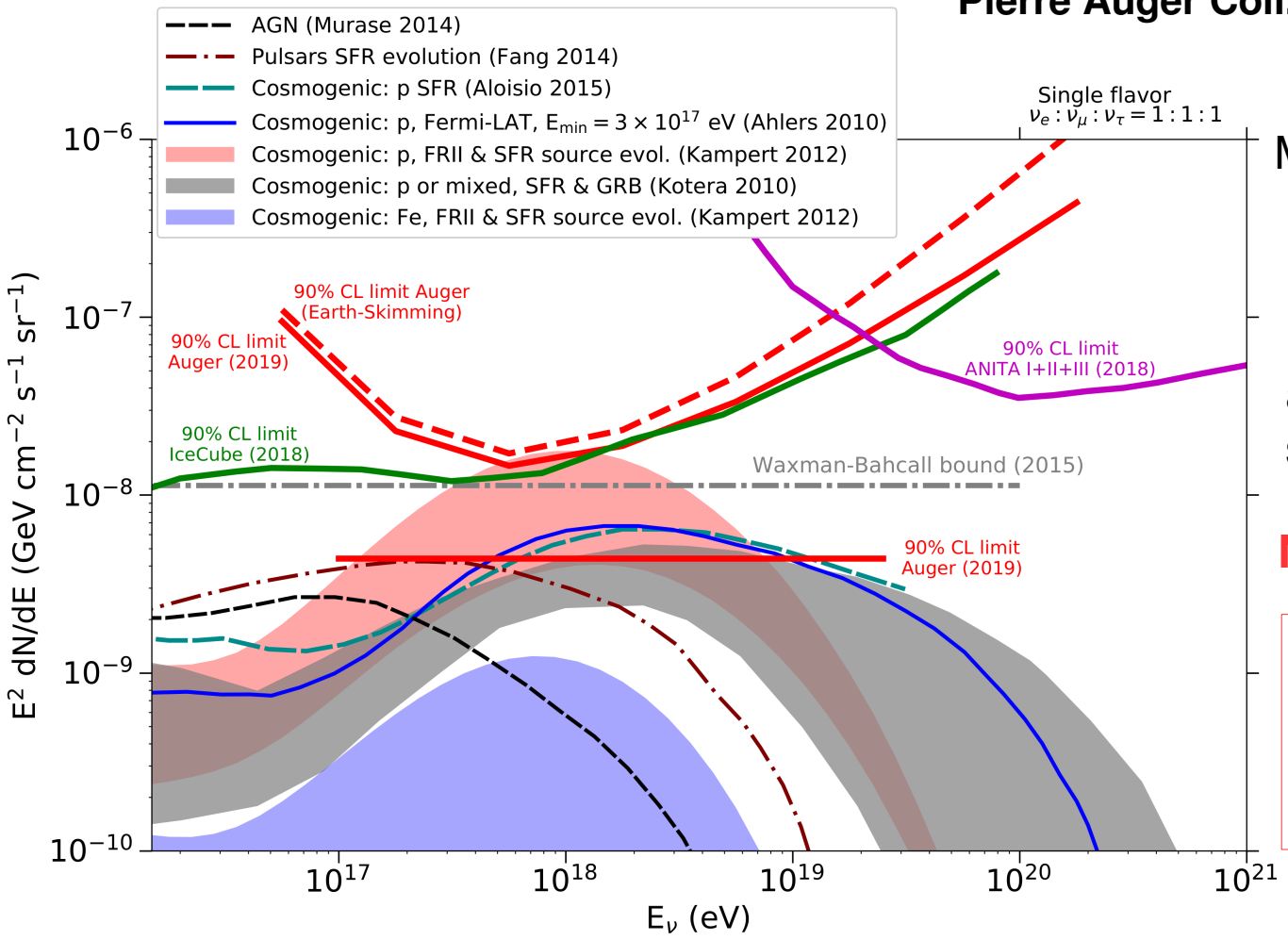
e 10.1%

$\mu$ 3.8%

90% of the events in the range 0.1 - 25 EeV

# UHE neutrinos: diffuse flux limits

**Pierre Auger Coll., JCAP 10 (2019) 022**




Max sensitivity ~ **1 EeV**

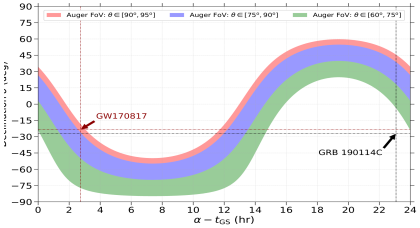
Identification criteria applied “blindly” to the search data set

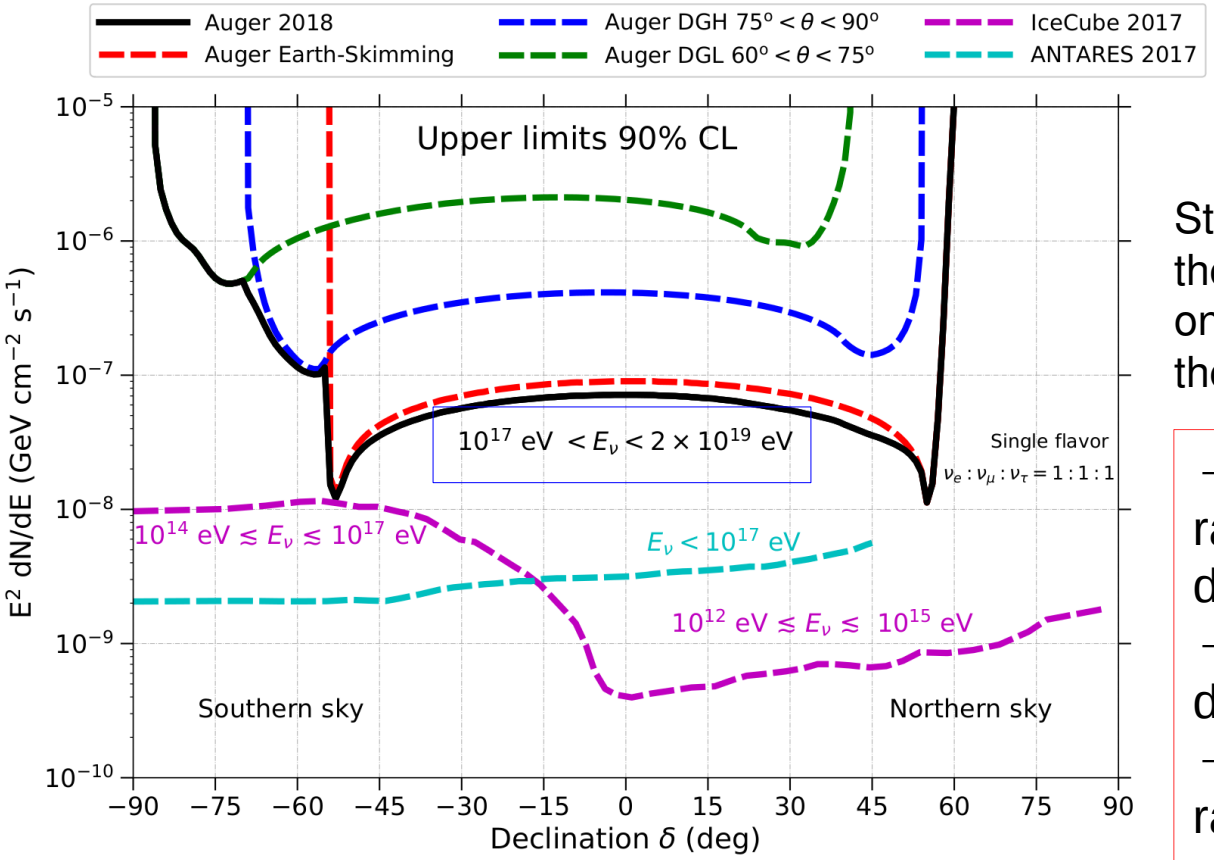
**NO Candidates found**

Integral UL normalization factor
**k ~ 4.4 x $10^{-9}$**
**[GeV cm $^{-2}$ s $^{-1}$ sr $^{-1}$]**

# UHE neutrinos: point like sources limits

**Pierre Auger Coll., JCAP 11 (2019) 004**




Strong dependence on zenith angle: the observation capability depends on where the source is in the FoV of the SD detection channels

→ good sensitivity in the EeV range in a broad range of declinations

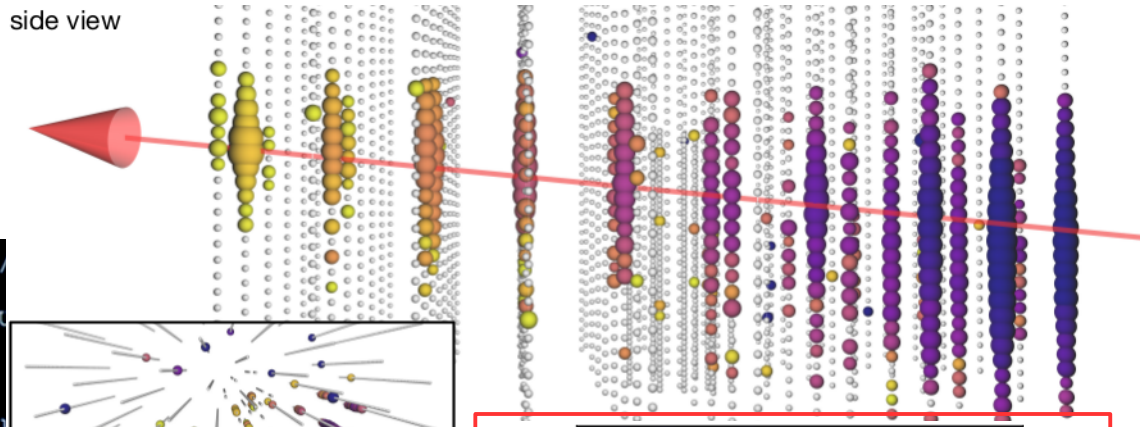
→ Maximum sensitivity at declinations -53° and 55°

→ complementary energy range: $10^{17} \div 2 \cdot 10^{19}$ eV

# We have a source! TXS0506+056

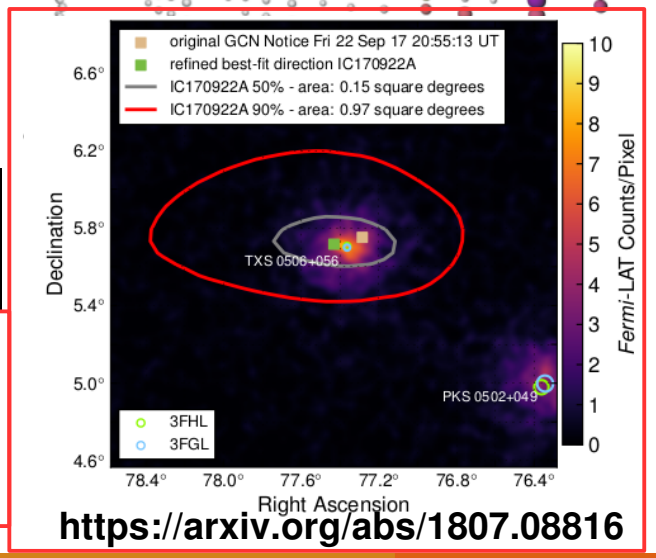
**ICECUBE: Science, Volume 361, Issue 6398, id. eaat1378 (2018)**

**ICECUBE ALERT**
**IC170922A**




```
//////////////////////////////////////////
TITLE:            GCN/AMON NOTICE
NOTICE_DATE:      Fri 22 Sep 17 20:55:13 U
NOTICE_TYPE:      AMON ICECUBE EHE
RUN_NUM:          130033
EVENT_NUM:        50579430
SRC_RA:            77.2853d {+05h 09m 08s}
                   77.5221d {+05h 10m 05s}
                   76.6176d {+05h 06m 28s}
SRC_DEC:           +5.7517d {+05d 45' 06"}
                   +5.7732d {+05d 46' 24"}
                   +5.6888d {+05d 41' 20"}
SRC_ERROR:        14.99 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18018 TJD;   265 DOY;   17/09/22 (yy/mm/dd)
DISCOVERY_TIME:   75270 SOD {20:54:30.43} UT
REVISION:         0
N_EVENTS:         1 [number of neutrinos]
STREAM:           2
DELTA_T:          0.0000 [sec]
SIGMA_T:          0.0000e+00 [dn]
ENERGY :          1.1998e+02 [TeV]
SIGNALNESS:       5.6507e-01 [dn]
CHARGE:           5784.9552 [pe]
```

Fermi flare detection
AGILE – MAGIC..
then x-rays and radio



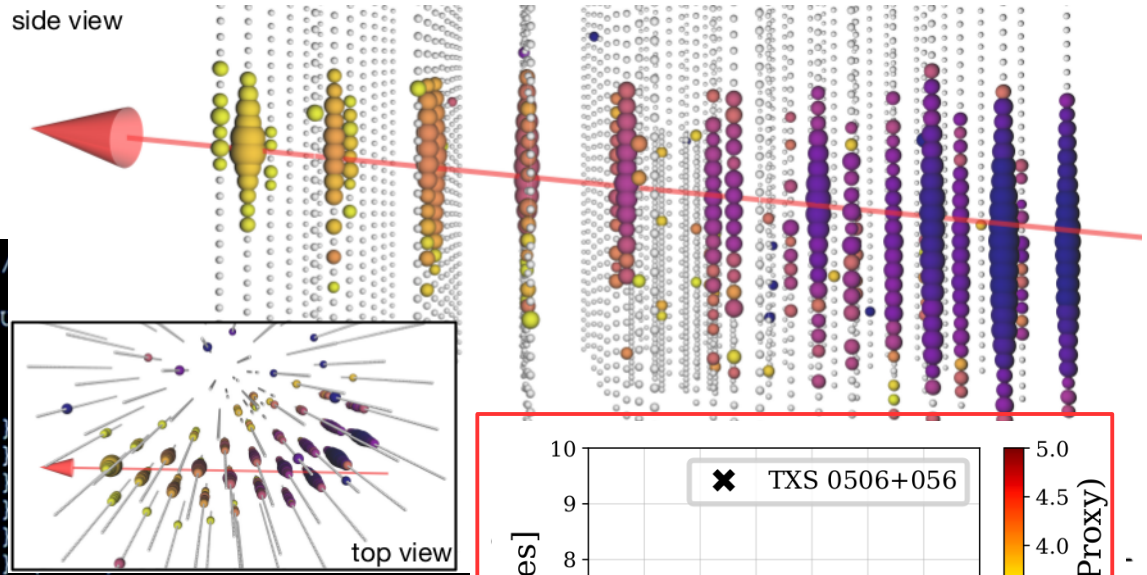

**https://arxiv.org/abs/1807.08816**

# We have a source! TXS0506+056

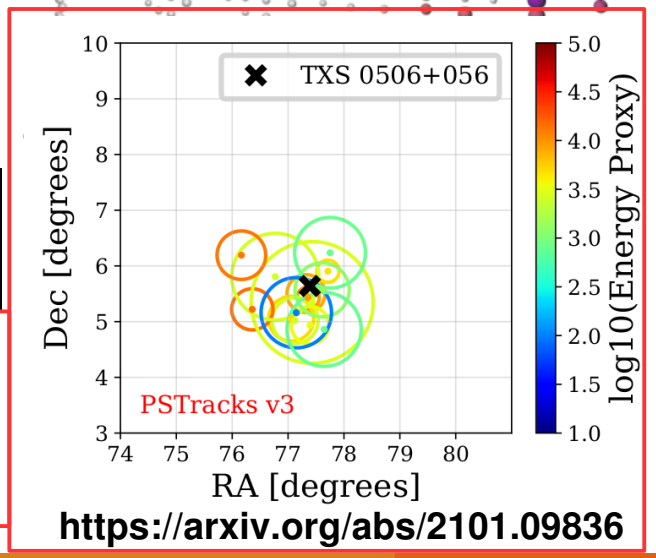
**ICECUBE: Science, Volume 361, Issue 6398, id. eaat1378 (2018)**

**ICECUBE ALERT**
**IC170922A**

```
//////////////////////////////////////////
TITLE:            GCN/AMON NOTICE
NOTICE_DATE:      Fri 22 Sep 17 20:55:13 U
NOTICE_TYPE:      AMON ICECUBE EHE
RUN_NUM:          130033
EVENT_NUM:        50579430
SRC_RA:            77.2853d {+05h 09m 08s}
                   77.5221d {+05h 10m 05s}
                   76.6176d {+05h 06m 28s}
SRC_DEC:           +5.7517d {+05d 45' 06"}
                   +5.7732d {+05d 46' 24"}
                   +5.6888d {+05d 41' 20"}
SRC_ERROR:        14.99 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18018 TJD;   265 DOY;   17/09/22 (yy/mm/dd)
DISCOVERY_TIME:   75270 SOD {20:54:30.43} UT
REVISION:         0
N_EVENTS:         1 [number of neutrinos]
STREAM:           2
DELTA_T:          0.0000 [sec]
SIGMA_T:          0.0000e+00 [dn]
ENERGY :          1.1998e+02 [TeV]
SIGNALNESS:       5.6507e-01 [dn]
CHARGE:           5784.9552 [pe]
```

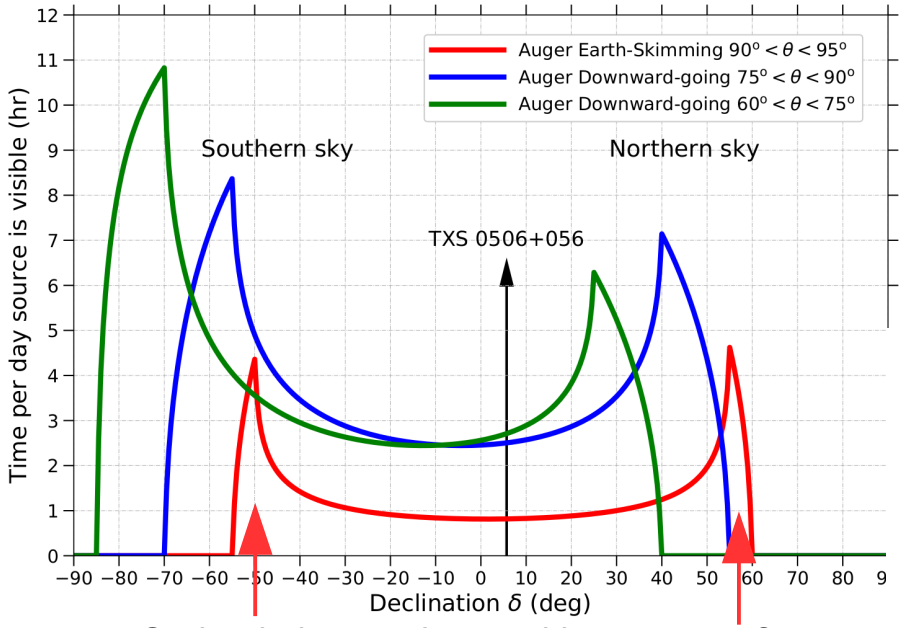



Archival data shows
ν flare in 2014/2015
(~ 3.5 σ level)



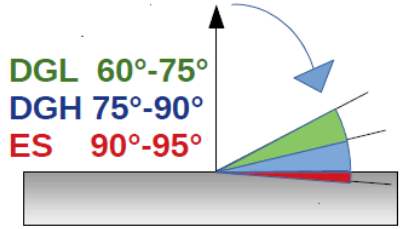

**https://arxiv.org/abs/2101.09836**

# Auger UHE window

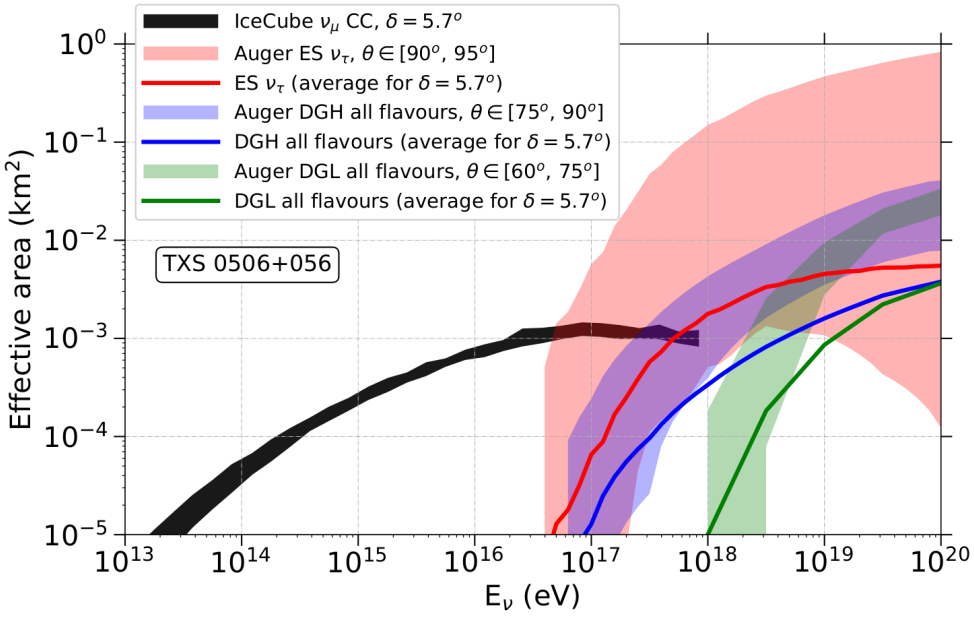



Optimal observation position: source δ in FOV of the Earth-skimming channel (right below the horizon)

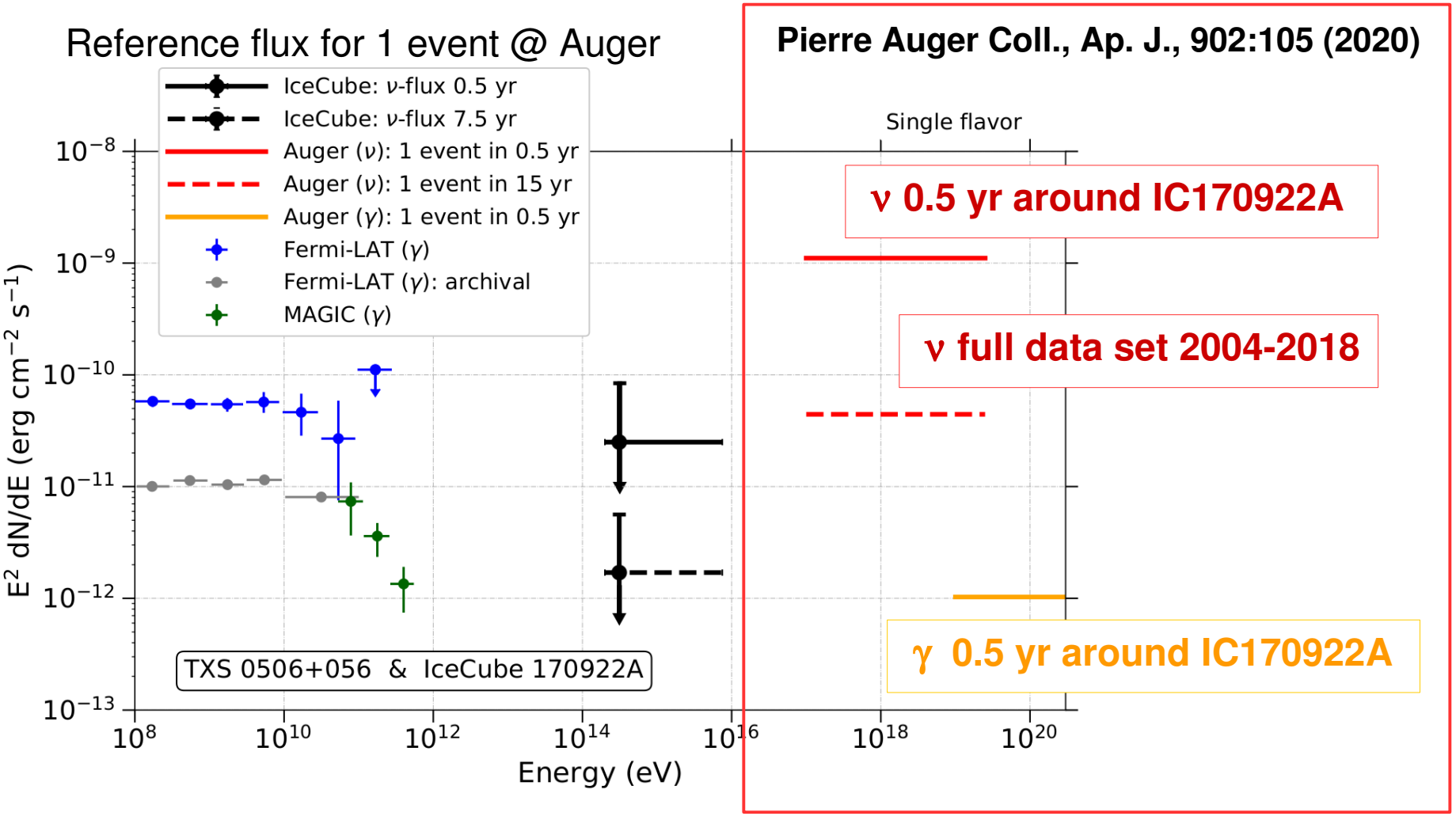
→ complementary to IceCube in the EeV range




TXS0506+056 declination = 5.7°
→ Non optimal sensitivity of the source in all channels

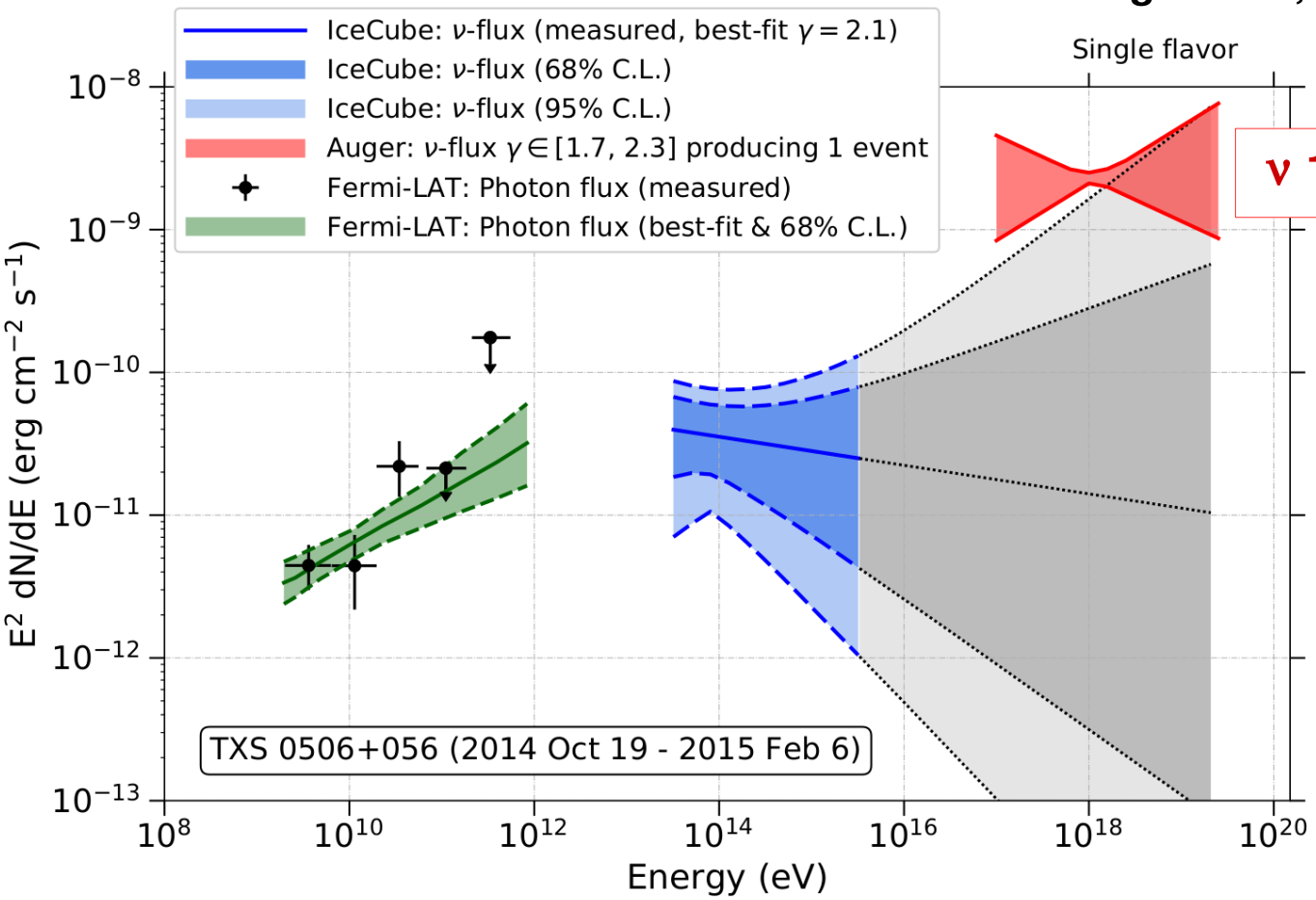


# Auger TXS flux limits



# ν flux producing 1 event @ Auger

**Pierre Auger Coll., Ap. J., 902:105 (2020)**

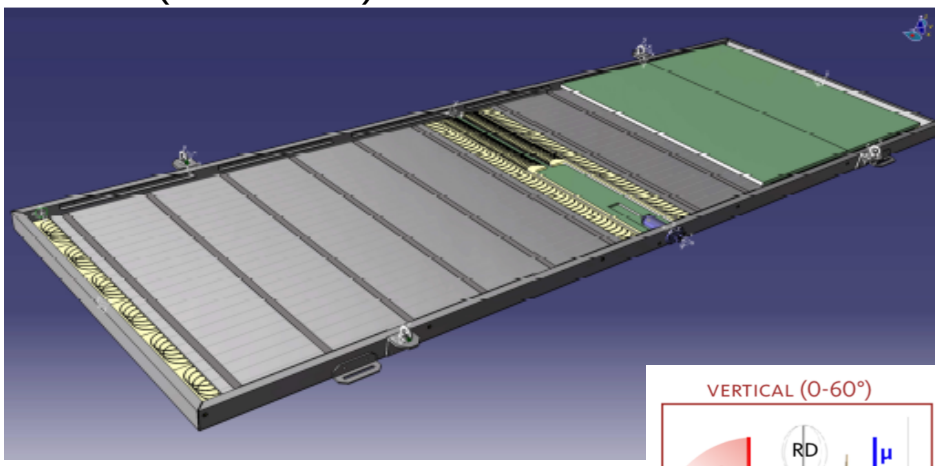


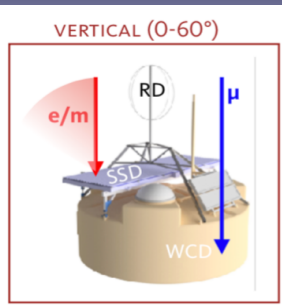

**ν 110 days 2014-2015**

**1-ν observation only if hard (>1.5) spectral index up to EeV range**

# Upgrading the Observatory: AugerPrime

3.8 m$^2$ (1 cm thick) scintillators






Scintillators are sensitive to the electromagnetic content of the shower

**more than 1000 SDD installed!**

- upgraded and faster electronics
- extension of the dynamic range
- underground muon detectors
- radio antennas

→ improve on signal/bkg separation
→ lower detection thresholds for photon/neutrino searches

# Conclusions

Ongoing multi-messenger international effort to combine data from different experiments in complementary energy ranges

The Pierre Auger Observatory is a key detector at UHE energy:
→ Excellent sensitivity to photons and neutrinos in the EeV range
→ stringent diffuse limits in the EeV range
→ constraining exotic scenarios and testing cosmogenic flux predictions *indirect hint on primary CR mass composition*

→ Coverage of a large fraction of the sky with targeted searches
→ no neutrino and photon steady sources found so far
→ limits set on long transients TXS0506+056

**see next talk by Michael Schimp**
about transients including the follow-up searches of Ligo/Virgo mergers

→ Pierre Auger Observatory upgrade will improve on sensitivity

**February 2021 release**

# http://www.auger.org/opendata