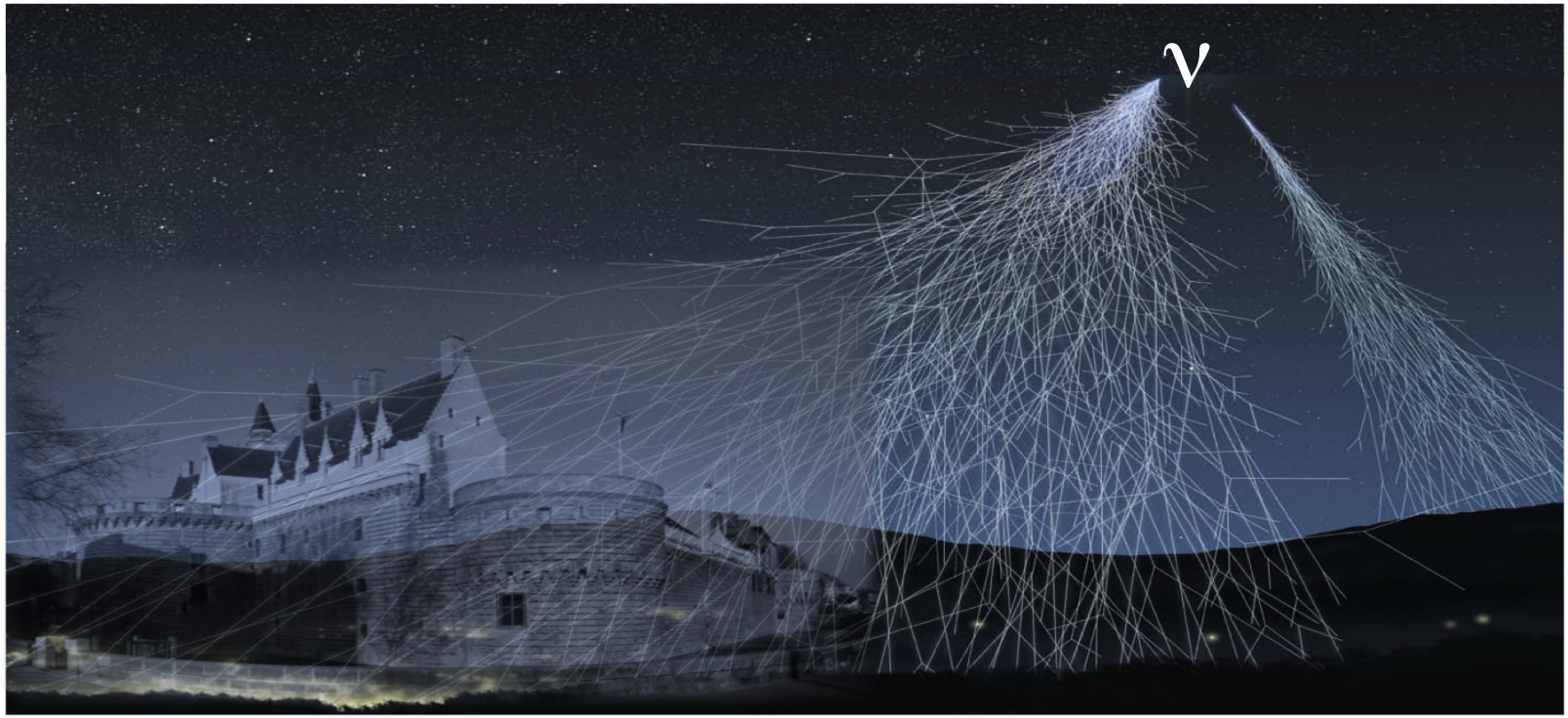
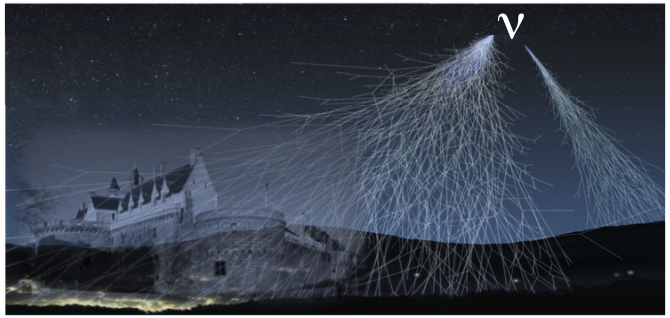


Limits on the diffuse flux of UHE neutrinos using the Pierre Auger Observatory

Sergio Pastor
(IFIC Valencia)
for the Pierre Auger Collaboration

4th International workshop on Acoustic and Radio EeV Neutrino detection Activities
Nantes, June 29 - July 2, 2010

Outline



★ **Particle showers induced by UHE neutrinos** at the Surface Detector array of the Pierre Auger Observatory

★ Types of neutrino-induced showers:

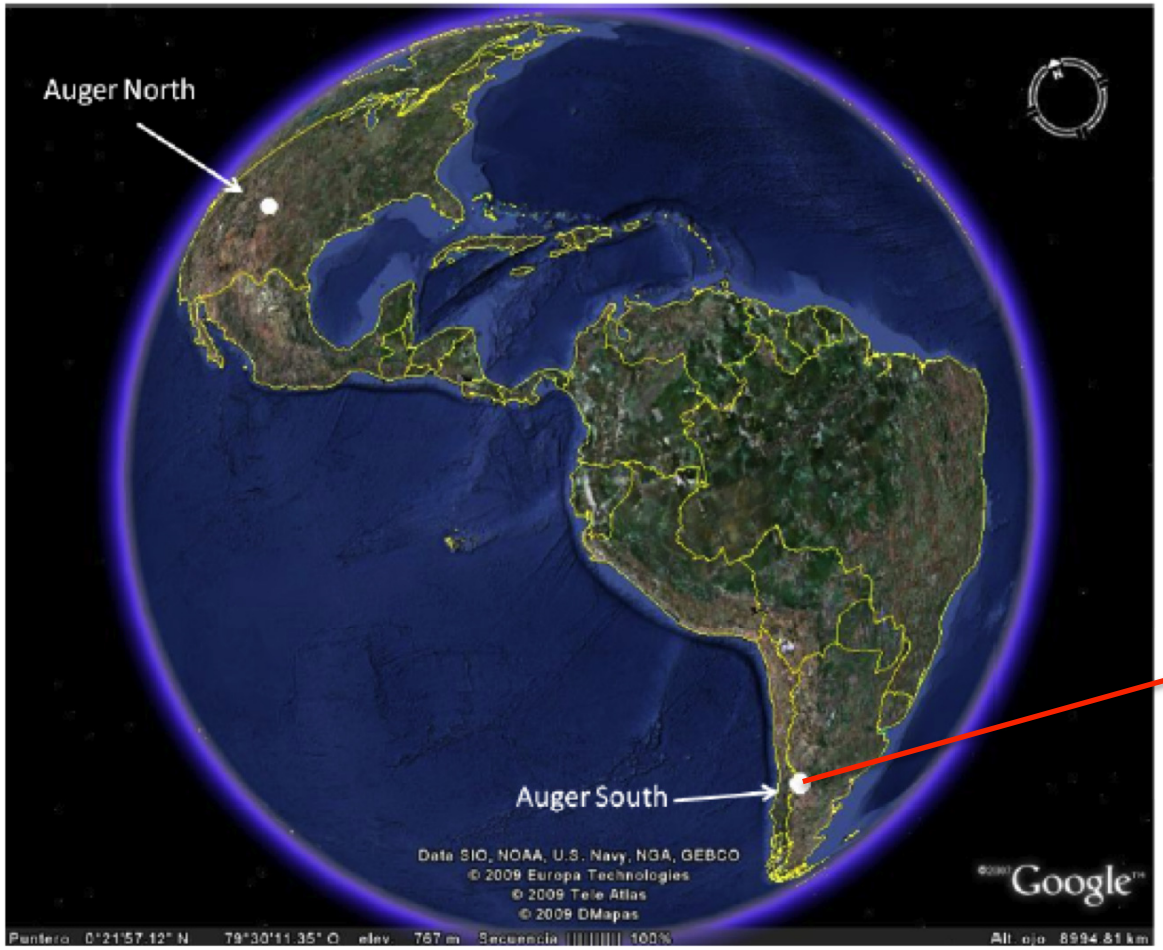
Up-going (tau neutrinos) & **Down-going** (all ν flavours)

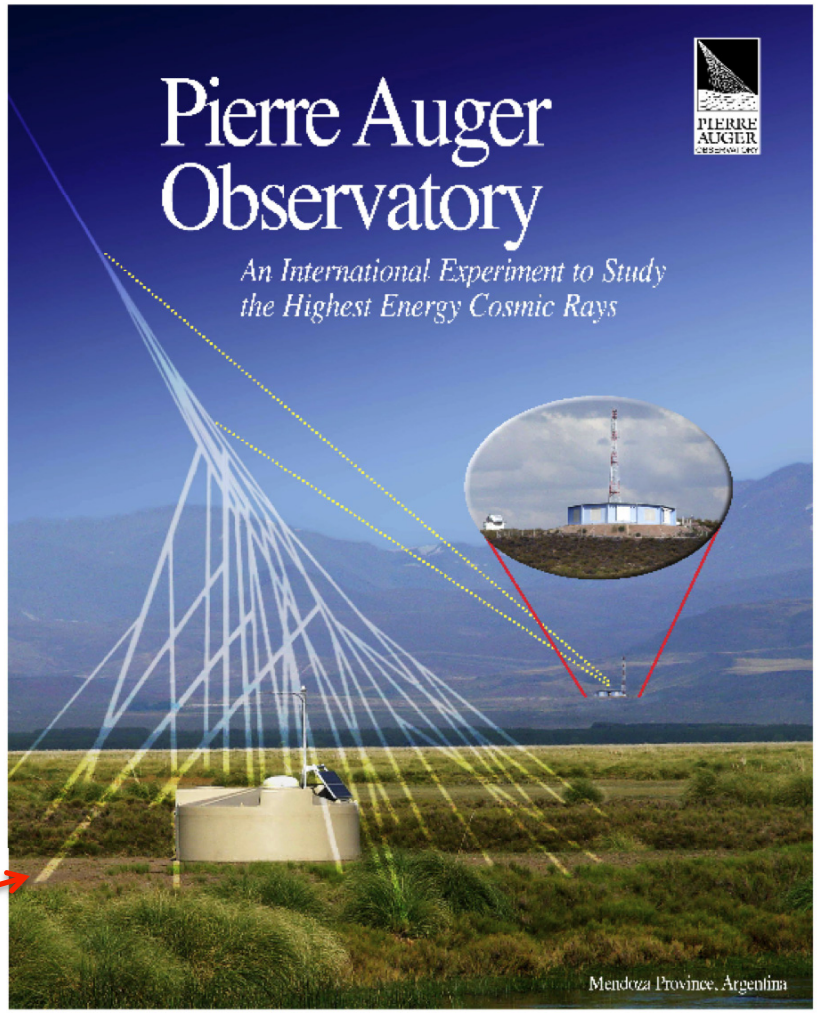
★ Identifying neutrino candidates at Auger

★ Analysis of data and results

★ **Limits on the diffuse flux of UHE neutrinos**

The Pierre Auger Observatory in Argentina





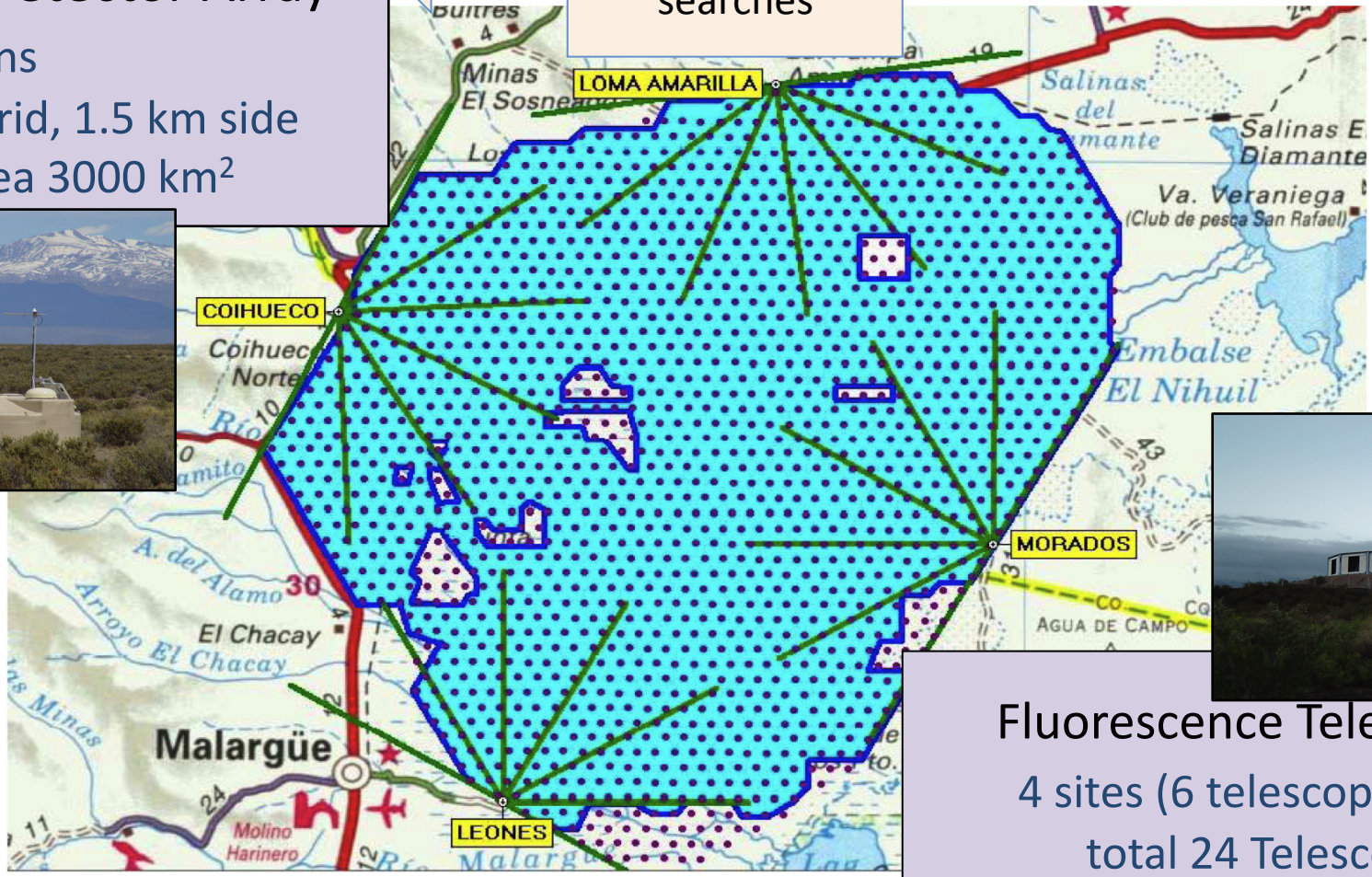
Located in the Mendoza province. Office building in **Malargüe**

Area of the Observatory (approx. 3000 km^2)

Surface Detector Array

1660 stations
triangular grid, 1.5 km side
effective area 3000 km^2

UHE neutrino searches

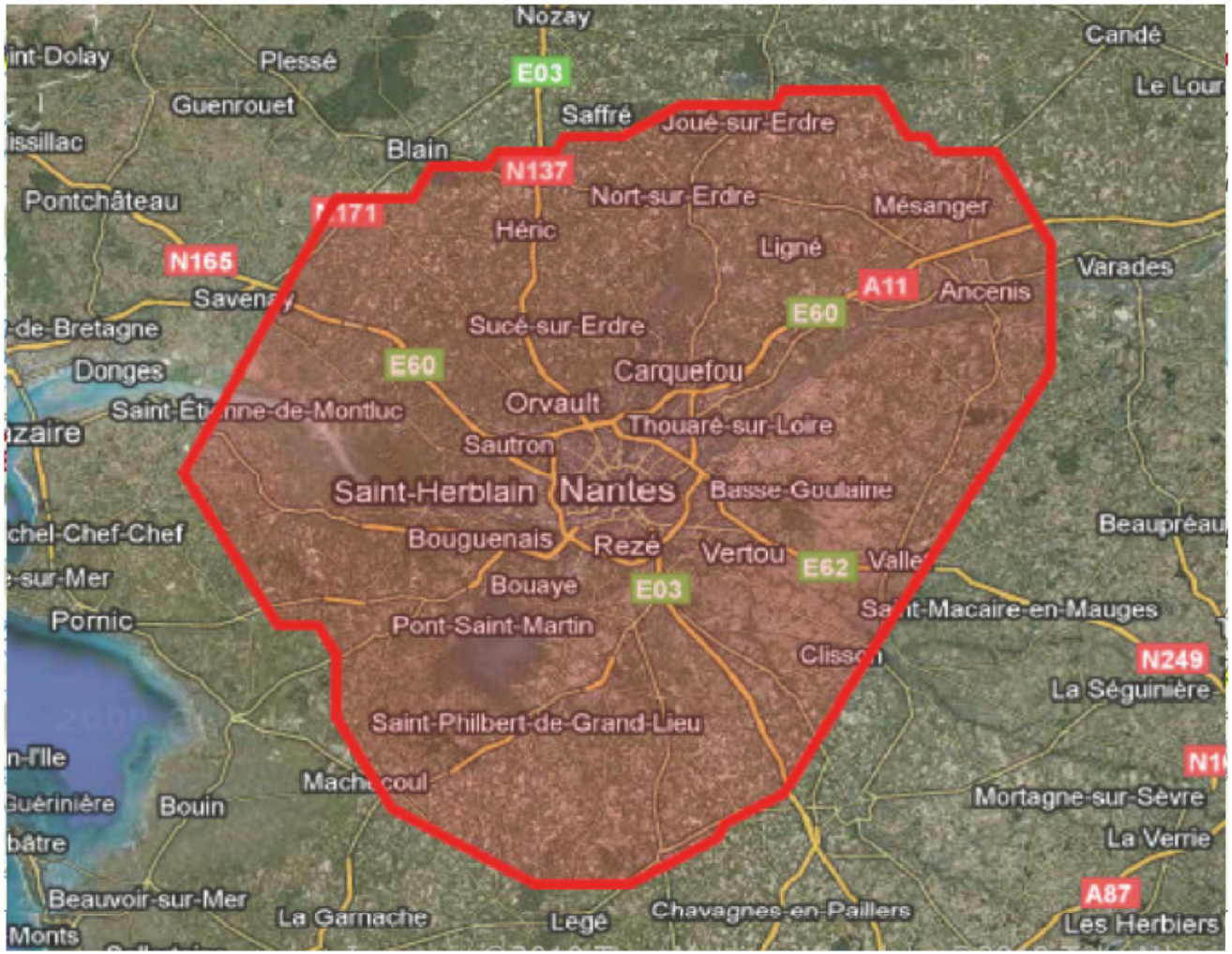


Fluorescence Telescopes

4 sites (6 telescopes each)
total 24 Telescopes

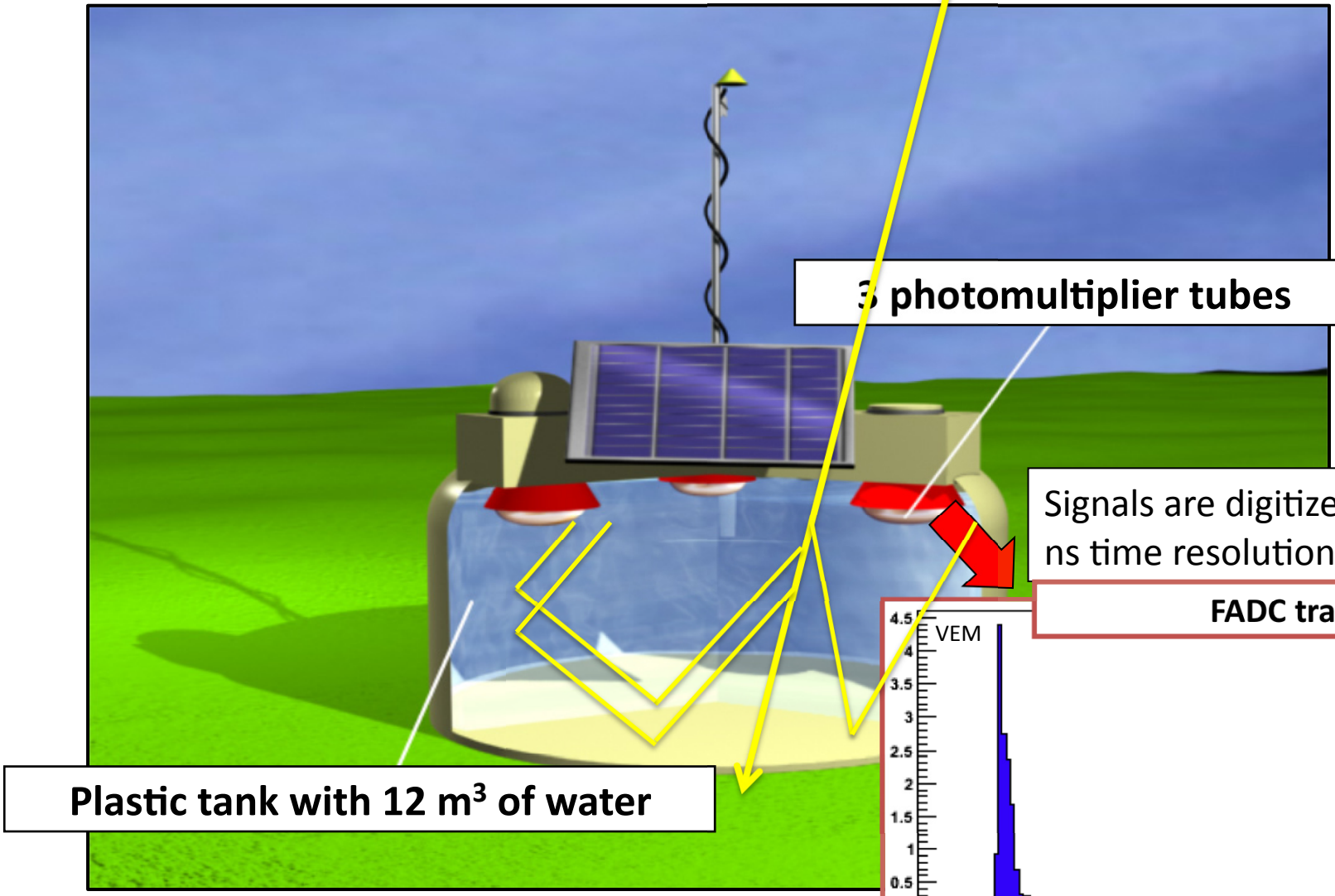
Observatory completed in June 2008

Area of the Observatory (approx. 3000 km^2)



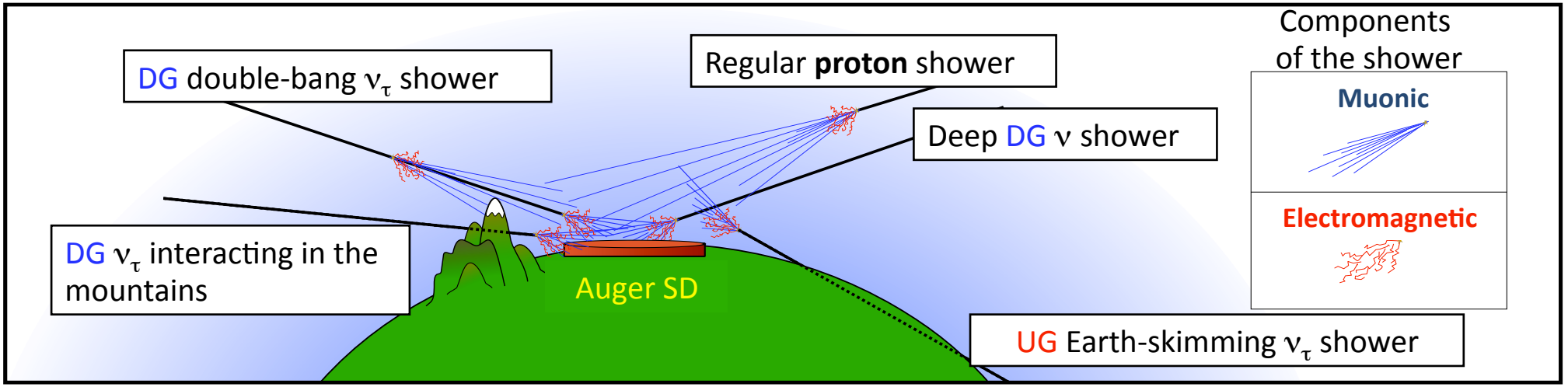
http://auger.colostate.edu/ED

SD station


3 photomultiplier tubes
Signals are digitized with 25 ns time resolution
FADC trace
VEM
t (ns)
Plastic tank with 12 m³ of water

UHE neutrino-induced showers

Types: Up-Going & Down-Going



UG: Earth-skimming tau neutrinos

↑ τ's travel large distances in the Earth not losing too much energy before decaying close to the detector

↑ ↓ Sensitivity to ν_τ CC channel

↓ Small solid angle: ≈ 90-95°

↑ Dense mass target (Earth crust)

DG: ν's interacting deep in the atmosphere

↑ Sensitivity to ALL ν flavours

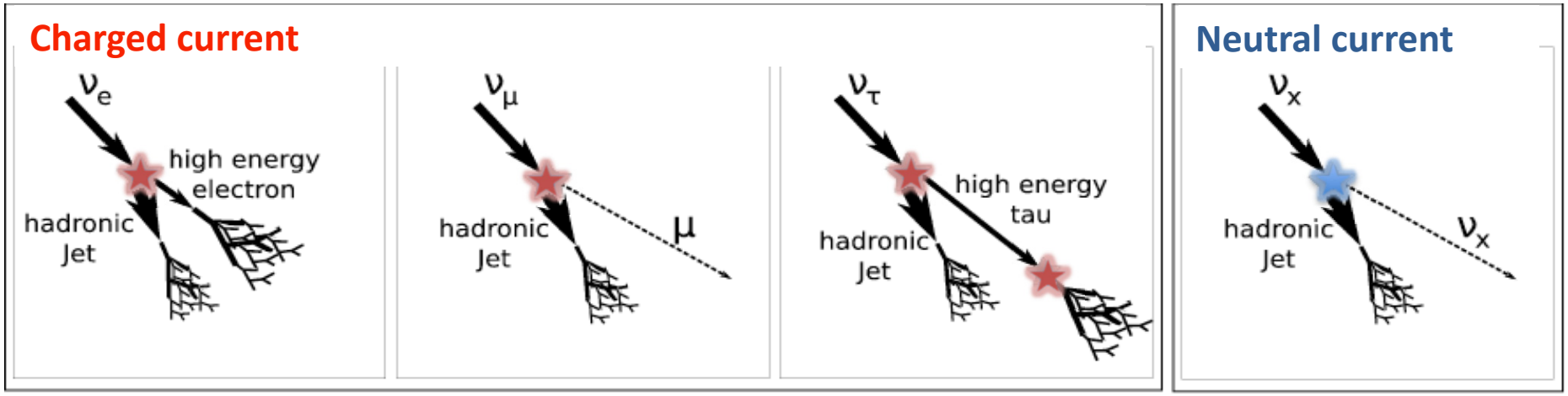
↑ Sensitivity to ALL weak interaction channels CC & NC

↑ Large solid angle: 60° → ≈ 90°

↓ Dilute mass target (air)

UHE neutrino-induced showers

Interaction channels



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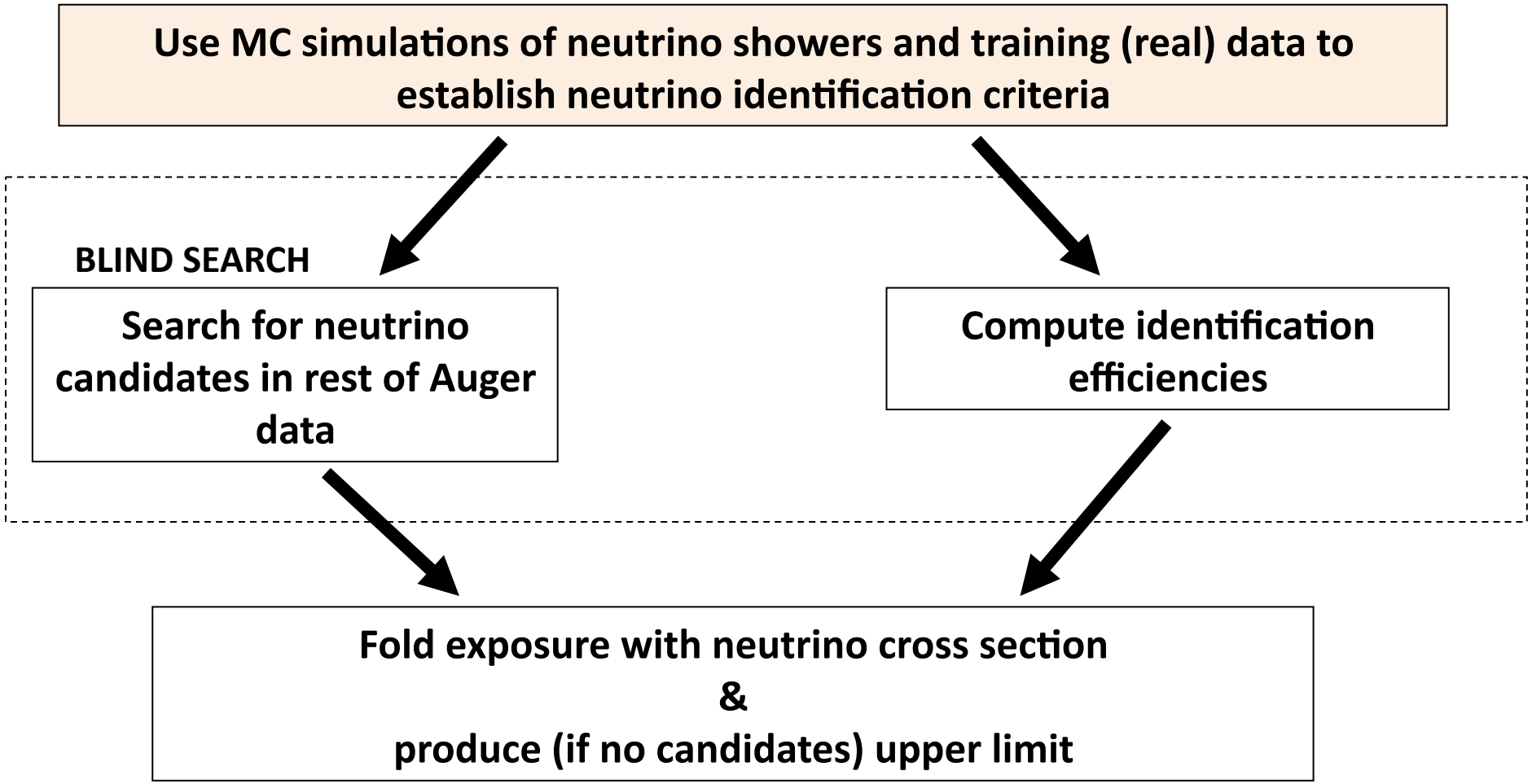
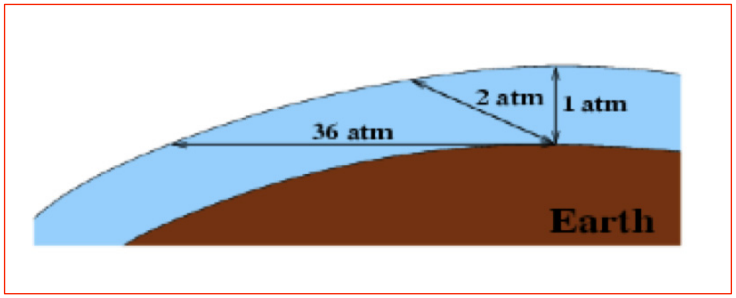
↓ Dilute mass target (air)

UHE Neutrino-searches in Auger



Identifying neutrino showers with the Auger SD

Look for INCLINED & DEEP showers

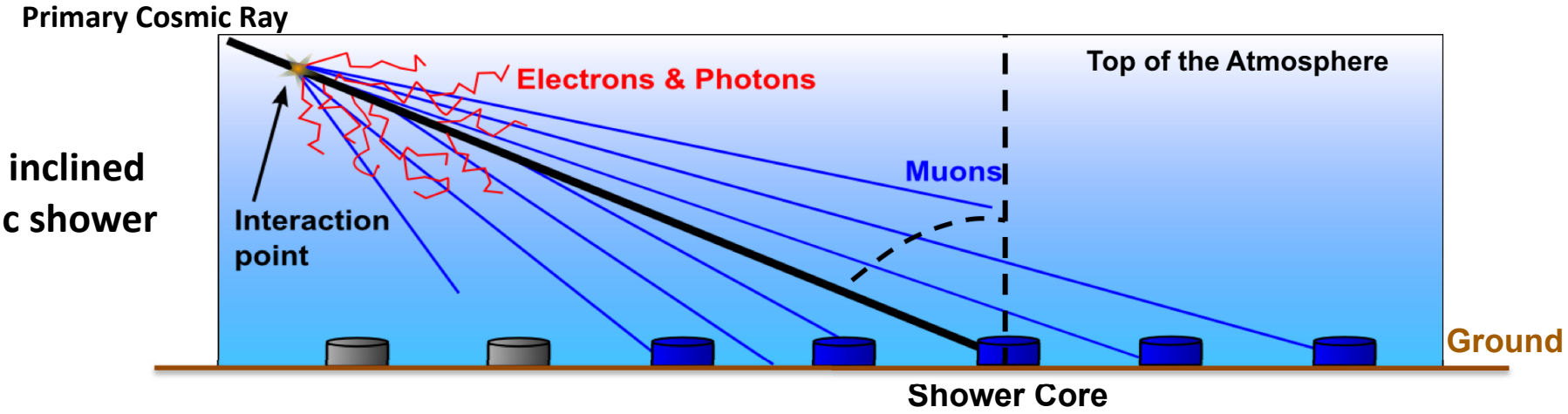


Atmosphere @ Auger site

Vertical ≈ 880 g cm^{-2}

Horizontal ≈ 32000 g cm^{-2}

Regular inclined hadronic shower



OLD shower (develops far from the detector): Electromagnetic (EM) component absorbed in the atmosphere: only muons survive. Small EM halo (≈15 %) mainly due to μ decay close to the ground.

Identifying neutrino showers with the Auger SD

Look for INCLINED & DEEP showers

Basis of identification: broad signals in the early region of an inclined shower

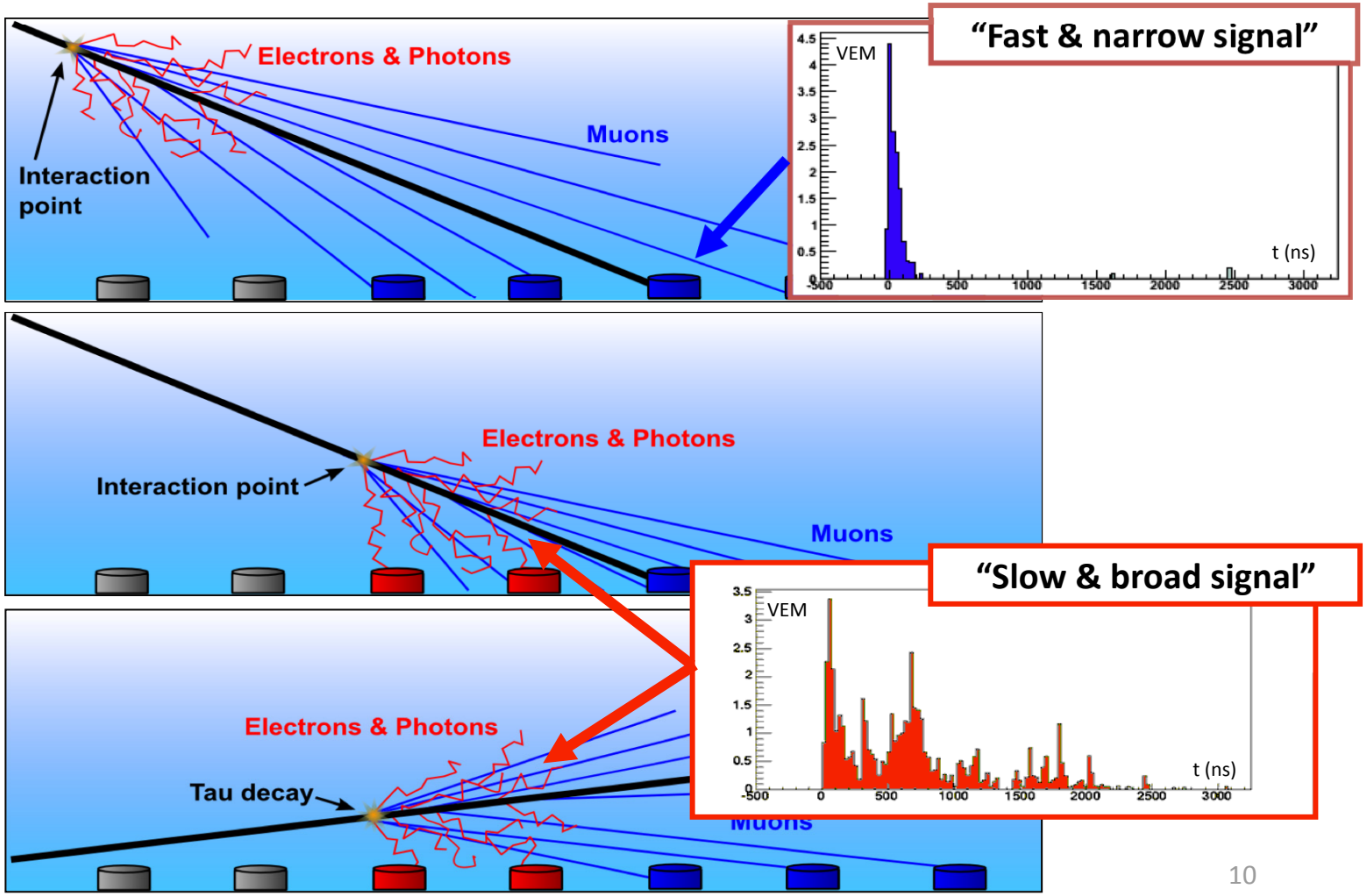
Regular hadronic shower

(OLD shower)

Deep DOWNGOING neutrino shower

Neutrinos can interact at any atm. depth (YOUNG showers)

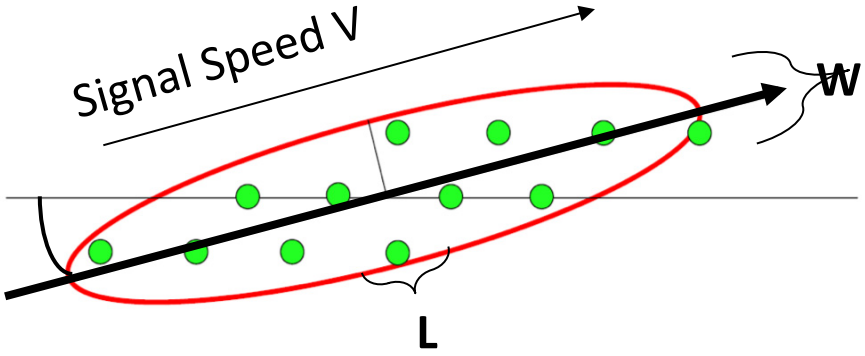
Deep UPGOING neutrino shower



Inclined events: selection & quality cuts

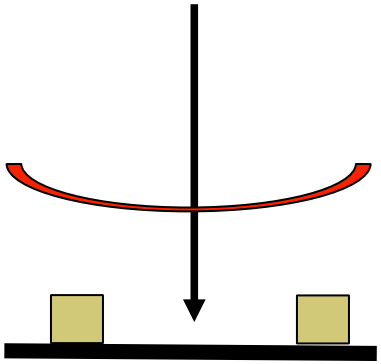
We reconstruct the events and select the inclined ones

- $\theta_{rec} > 75°$
- **"Speed of propagation of signal"** along the footprint very close to speed of light (<V> < 0.313 m ns^{-1})



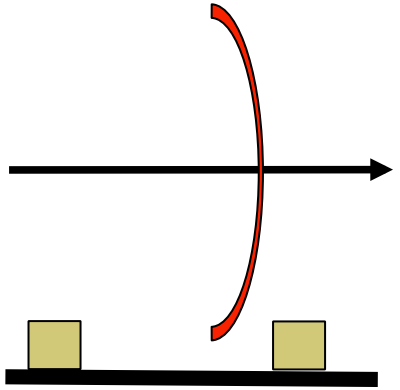
vertical shower

<V> >> c



horizontal shower

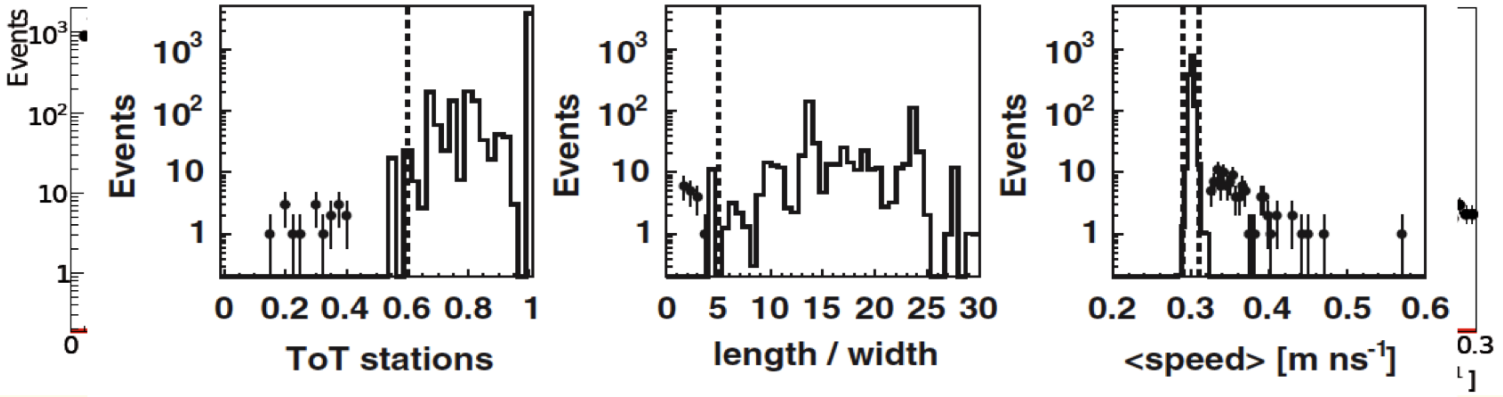
<V> ≈ c = 0.3 m ns^{-1}



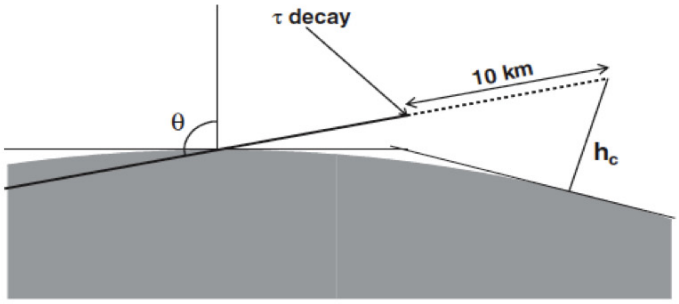
Quality cuts for ν identification:

- RMS[*signal speed*] / <*signal speed*> < 0.08
- Shape (Elongated Footprint): **L/W > 3 (DG) or > 5 (UG)**
- **3 (UG) / 4 (DG)** or more stations with **local trigger**

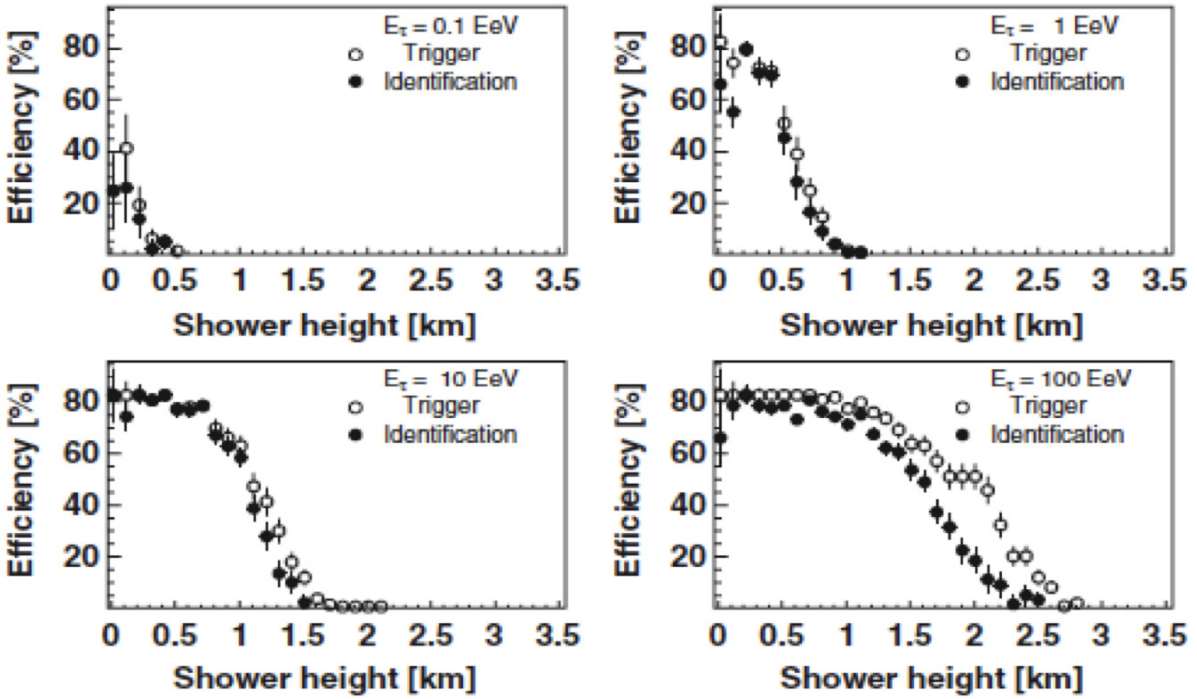
UG: variables and trigger+ tau identification



Discrimination **very inclined showers** (E^{-2} ν_τ flux) and **real events (training data, < 1%)**



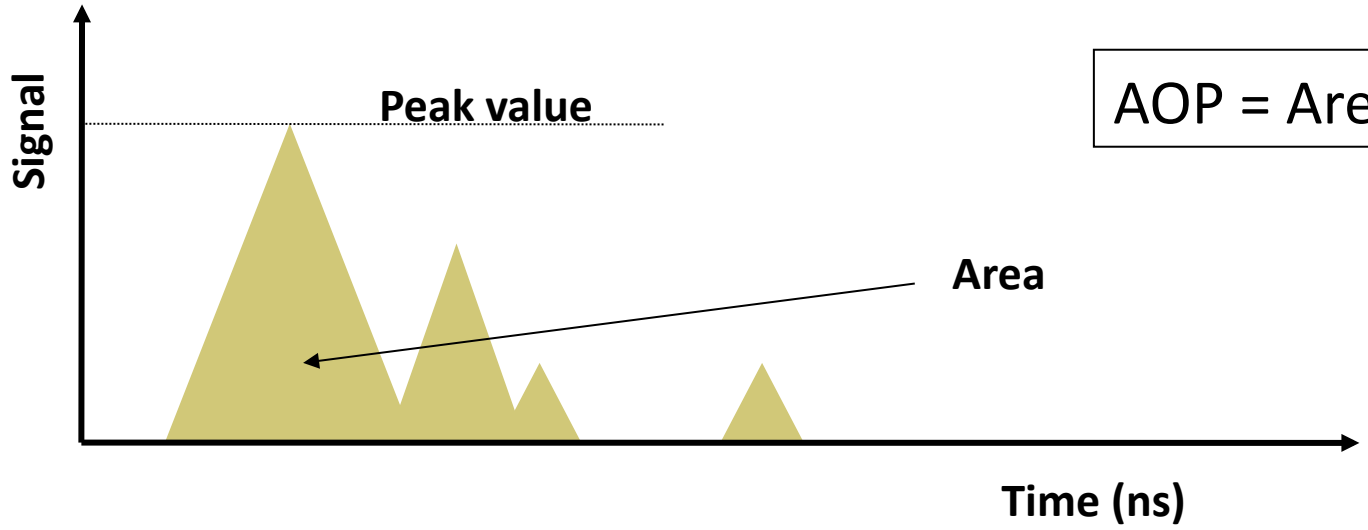
Trigger (o) and identification (•) efficiency as a function of h_c



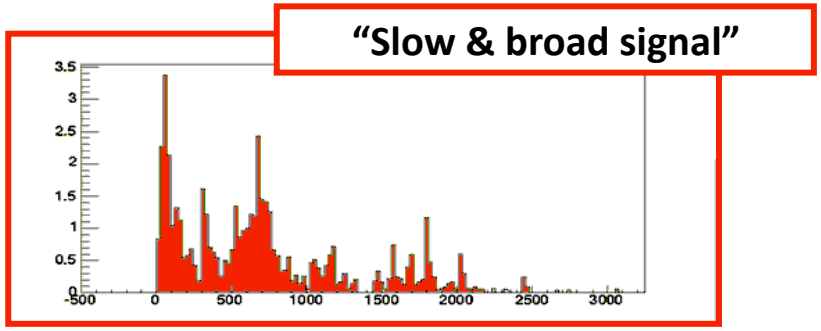
Pierre Auger Coll., PRL 100 (2008) 211101; PRD 79 (2009) 102001

Looking for broad signals: Area Over Peak (AOP)

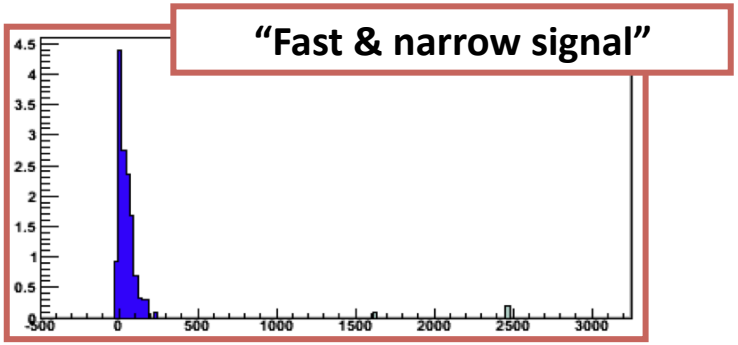
FADC trace



AOP = Area/Peak



Large AOP (> 3)

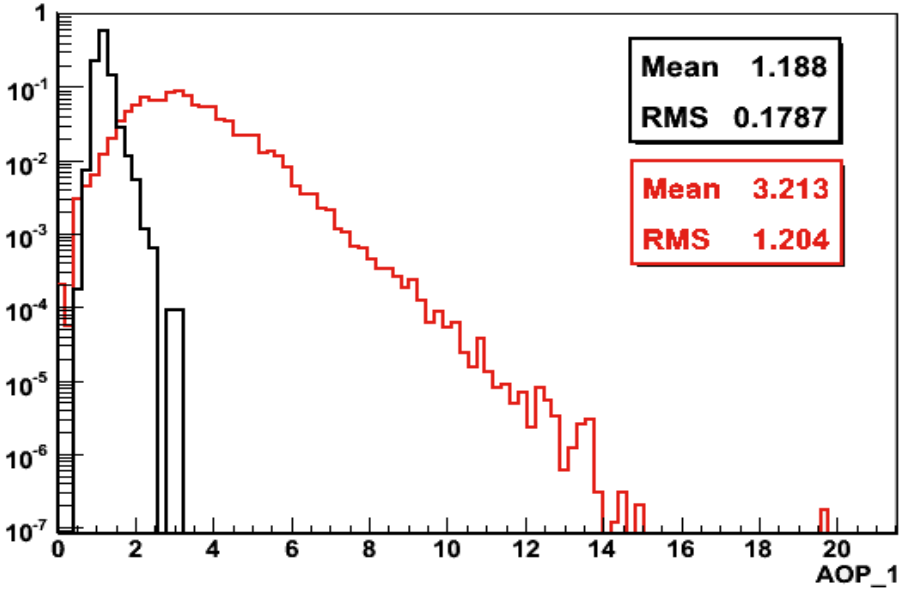


Small AOP (~ 1)

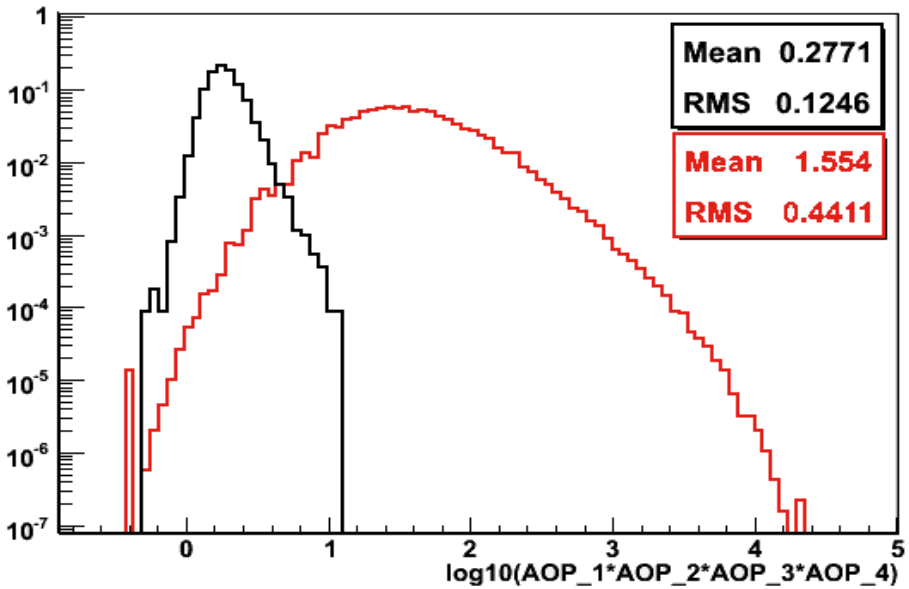
DG: Broad signals in early stations

Inclined real events vs. simulations of deep neutrino showers

Training data 1 Jan 2004 – 31 Oct 2007 (black) and ν showers (red)



Area Over Peak of the first station

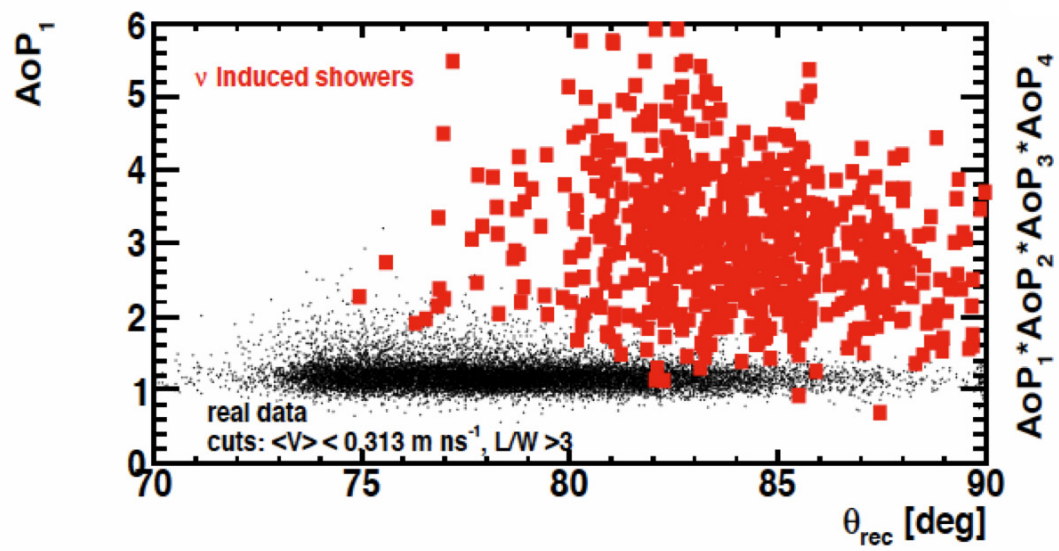


AOP Product of the first four stations

DG: Broad signals in early stations

Inclined real events vs. simulations of deep neutrino showers

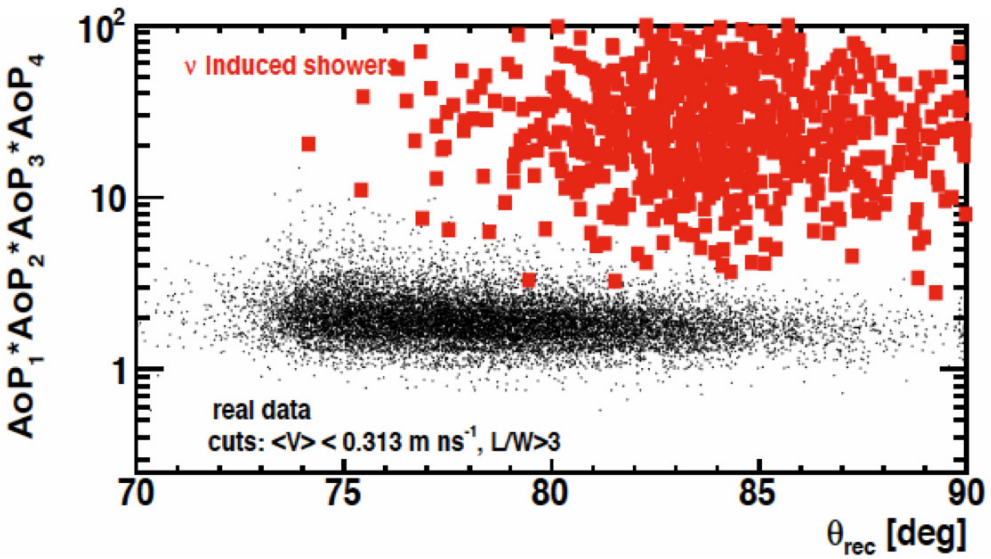
Training data 1 Jan 2004 – 31 Oct 2007 (black) and ν showers (red)



Area Over Peak of the first station

vs

reconstructed zenith angle



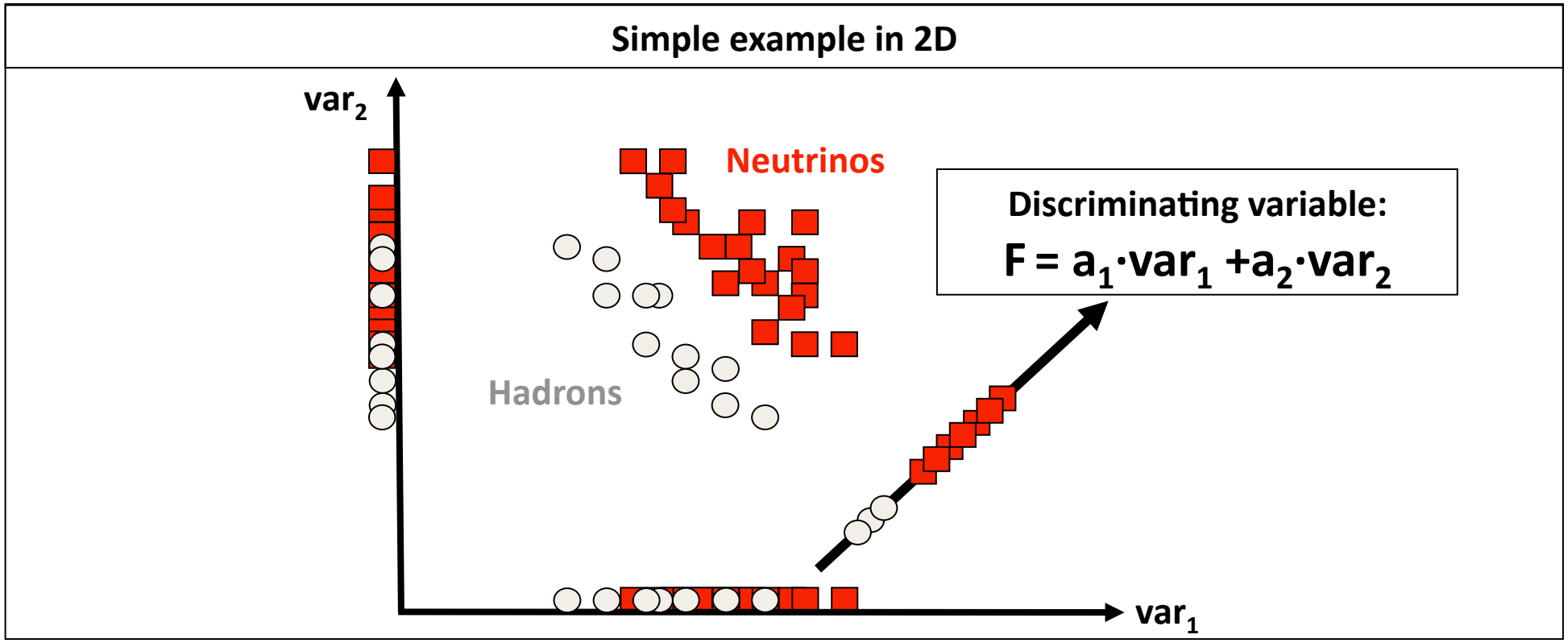
AOP Product of the first four stations

vs

reconstructed zenith angle

DG: Fisher Discriminant method

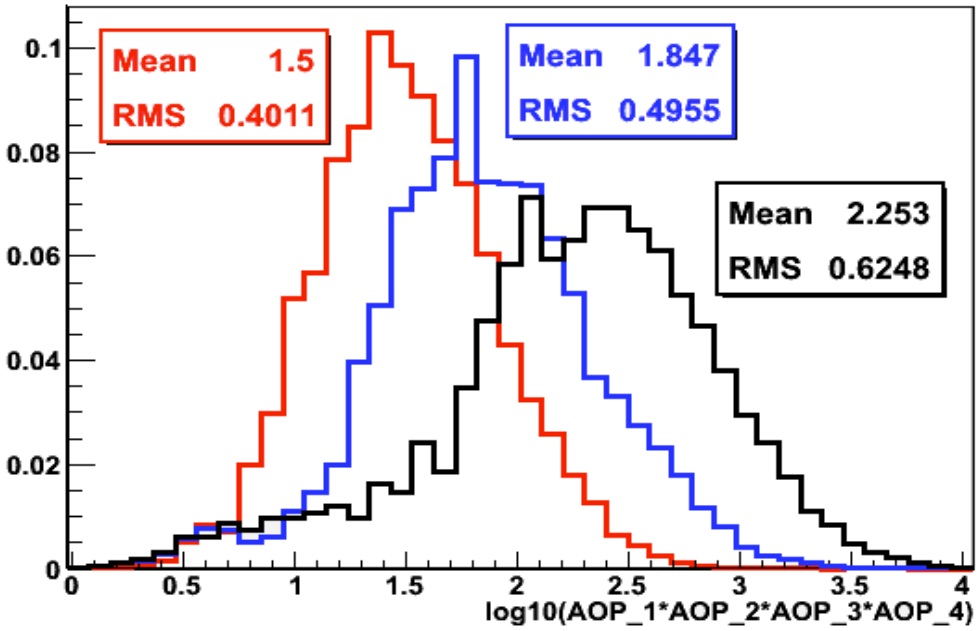
- **Standard procedure to separate two classes of events.**
  - In our case hadronic & simulated Neutrino showers.
- **Simple idea**:
  - Find the line so that hadronic & Neutrino showers are well separated.



DG: Fisher variables

Three sets of events:

Small	4 to 6 stations
Medium	7 to 11 stations
Large	12 or more stations

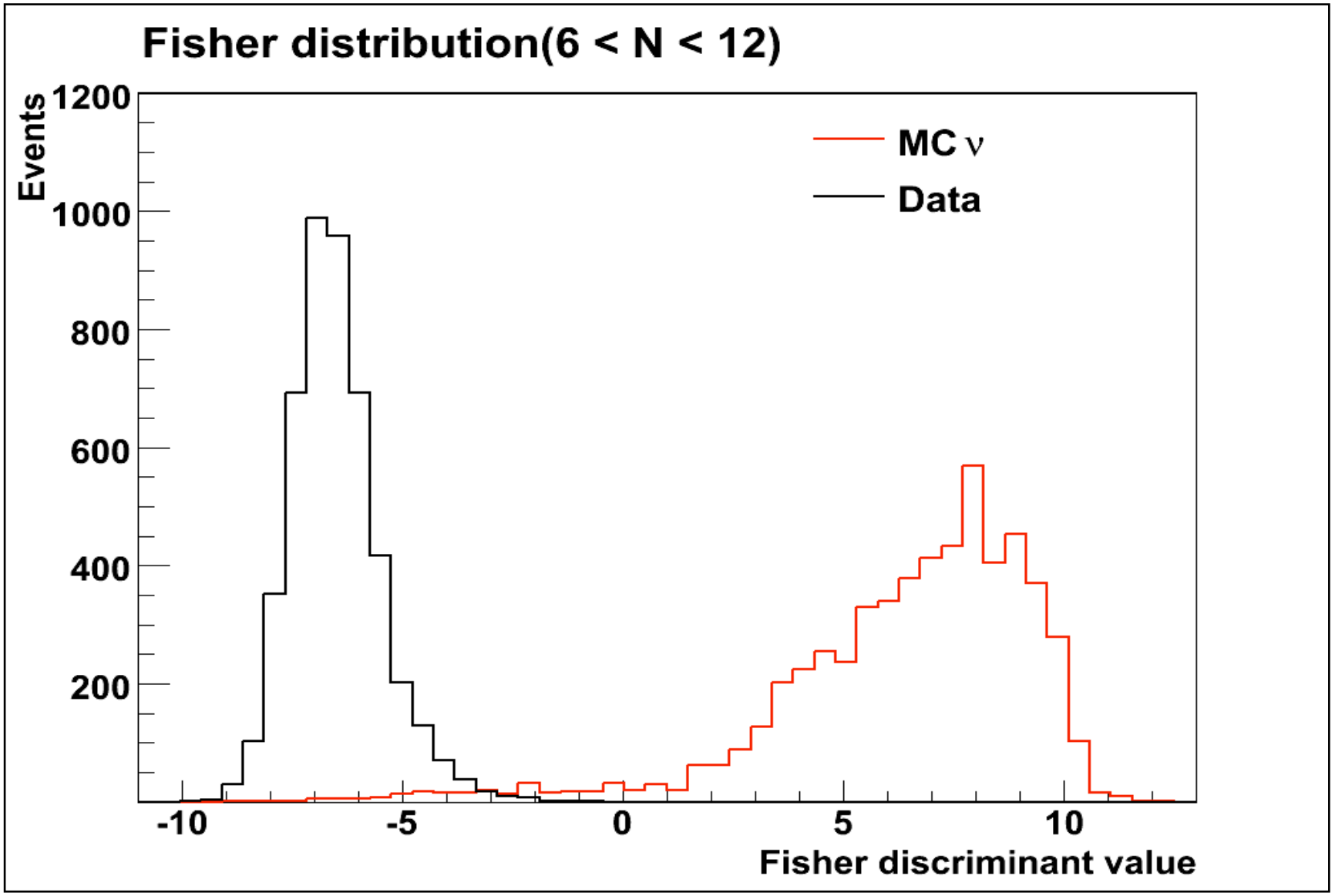


10 Fisher variables:

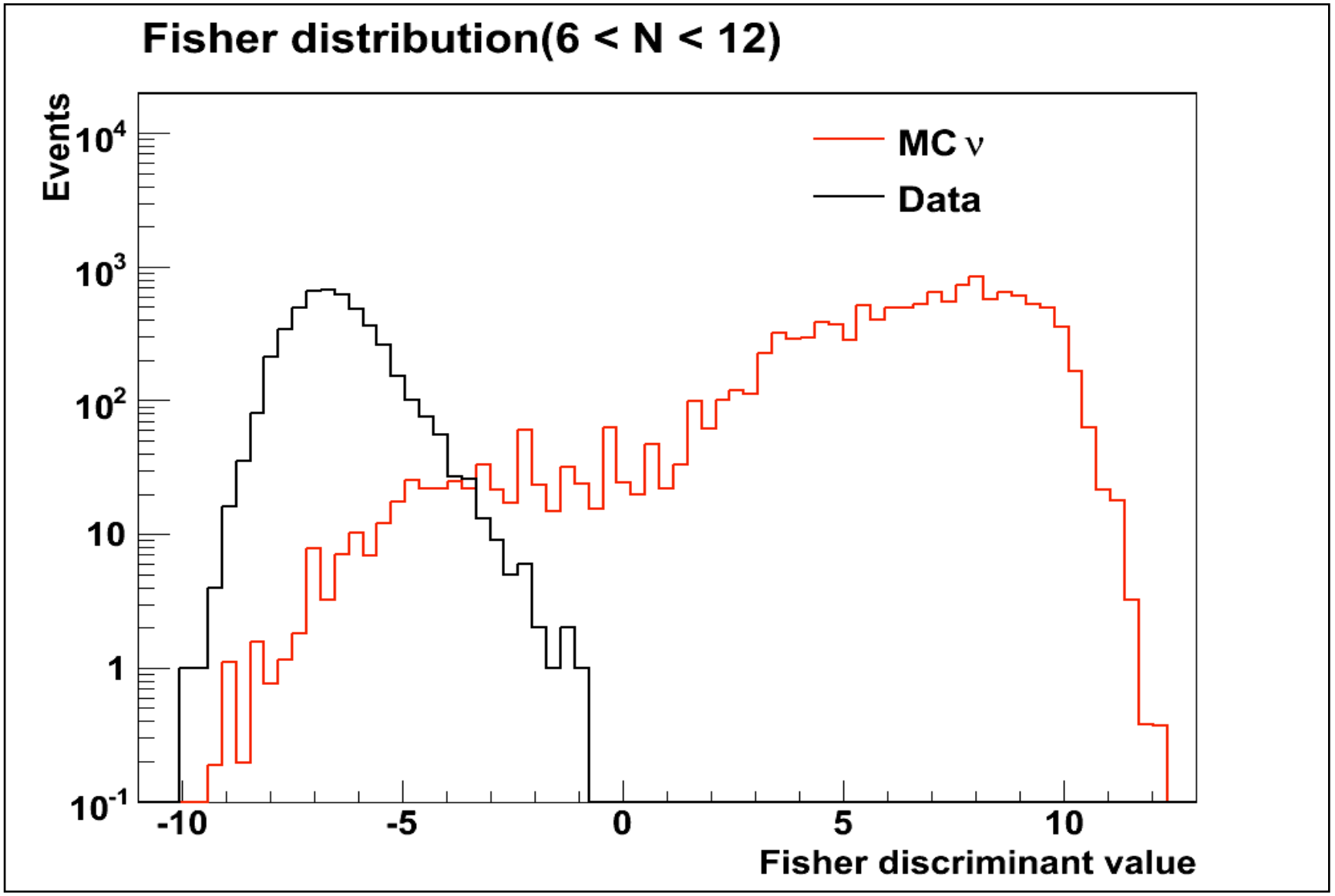
- First 4 AOPs
- First 4 $(AOPs)^2$.
- Product of the first 4 AOPs.
- An asymmetry parameter : Mean[*early AOP*] - Mean[*late AOP*].

IMPORTANT: **Auger data 1 Jan 2004-31 Oct 2007 used to train the Fisher method**
data 1 Nov 2007-28 Feb 2009 used to search for UHE neutrinos (limit)

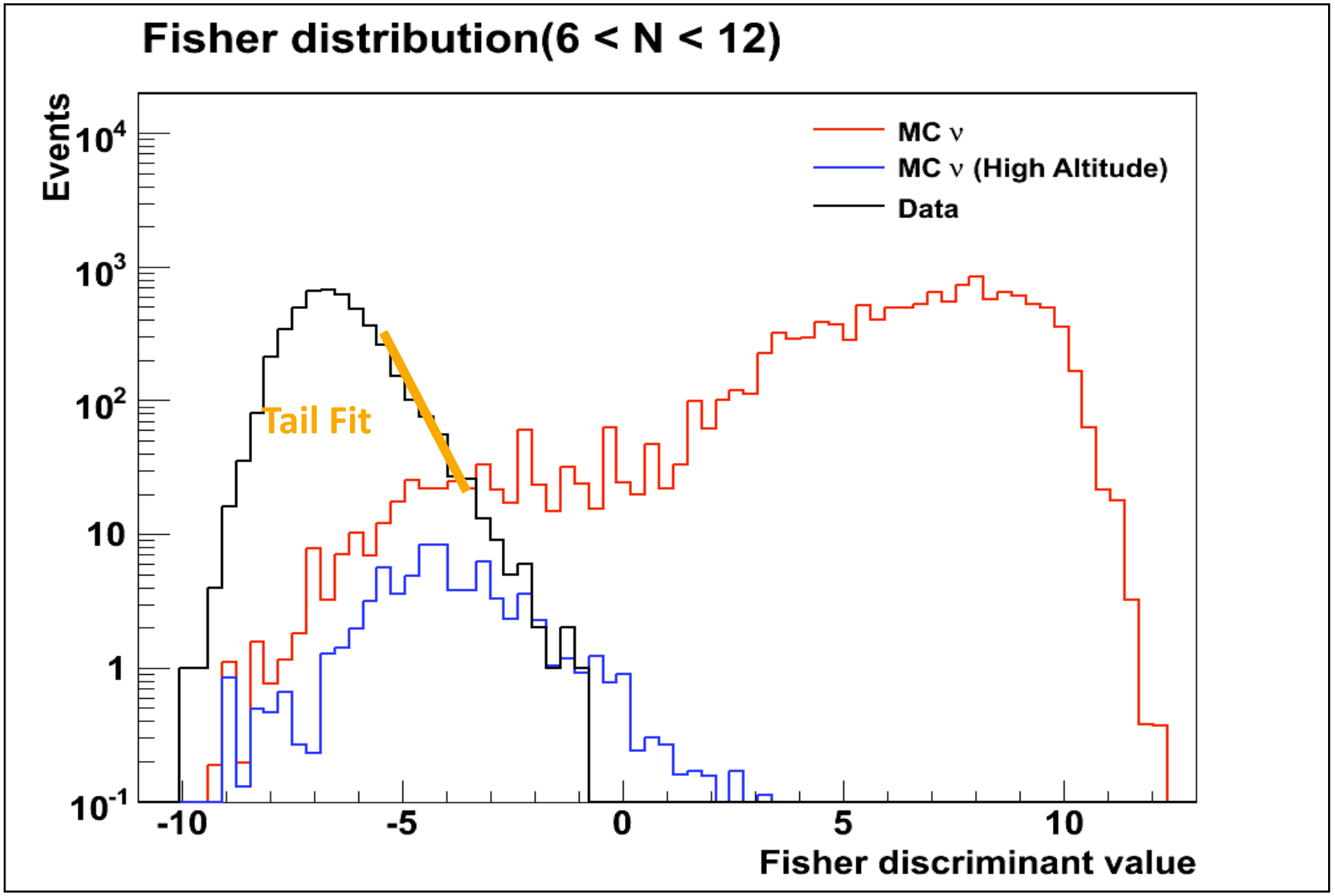
DG: Fisher results (training data)



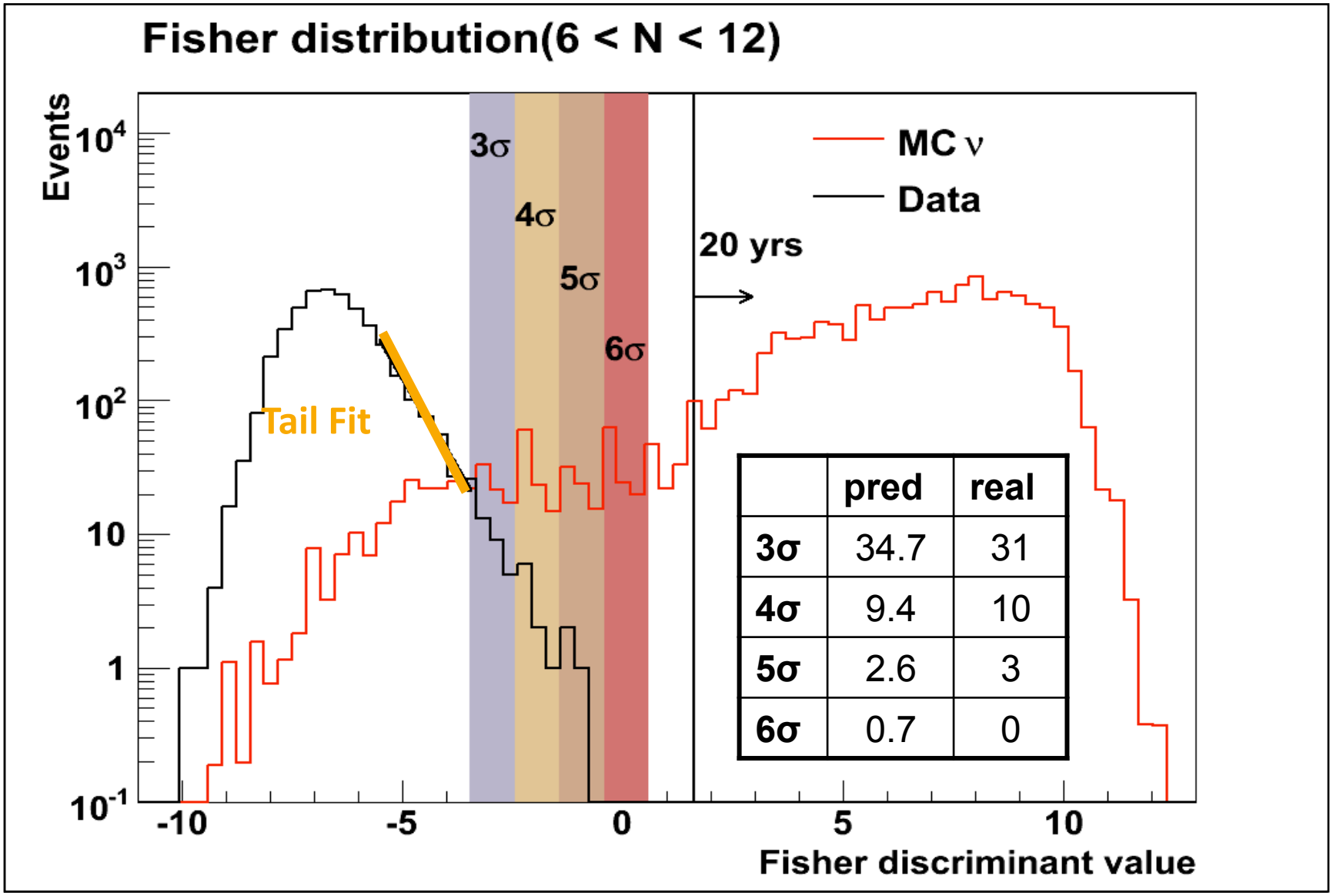
DG: Fisher results (training data)



DG: Fisher results (training data)

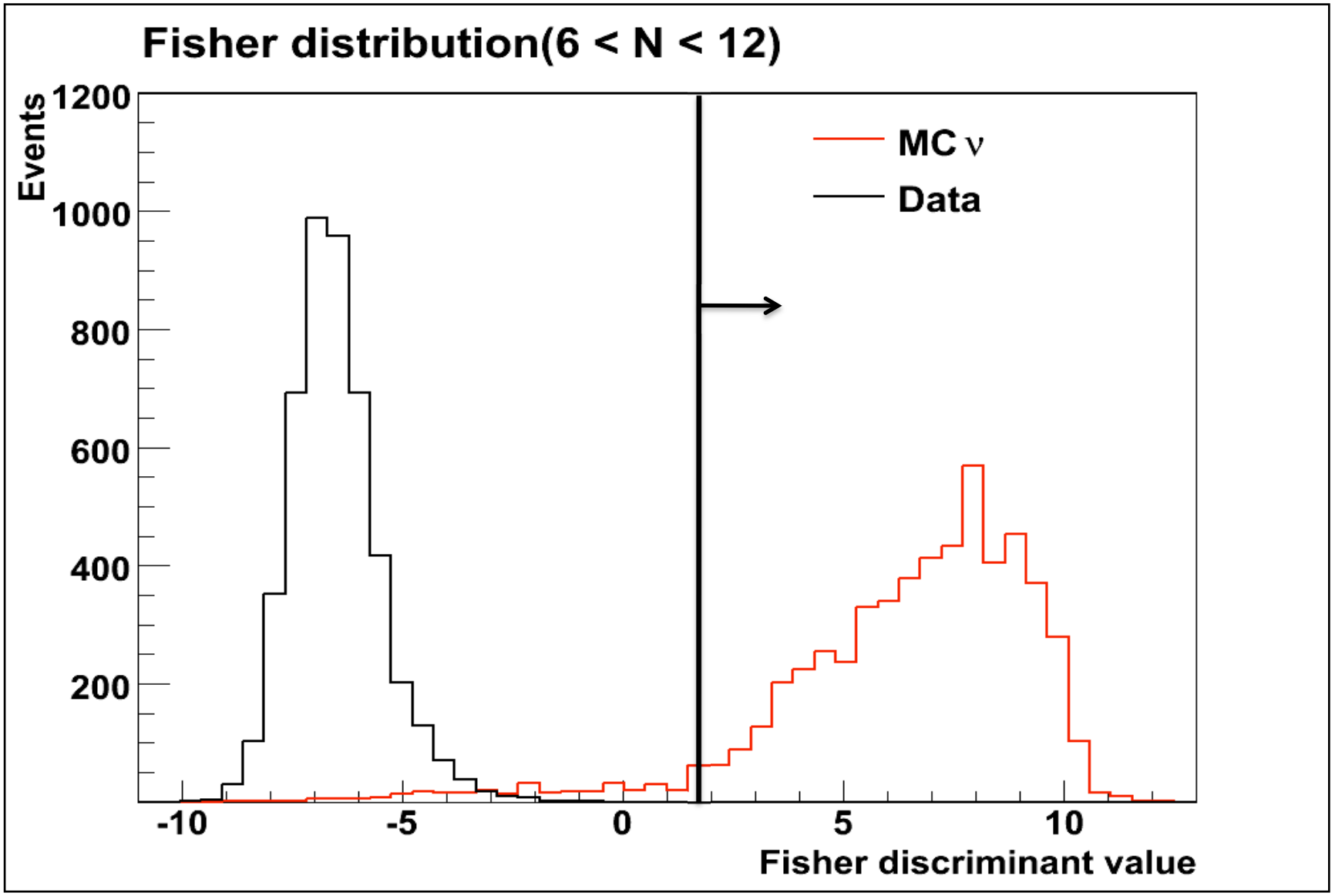


DG: Fisher results (training data)

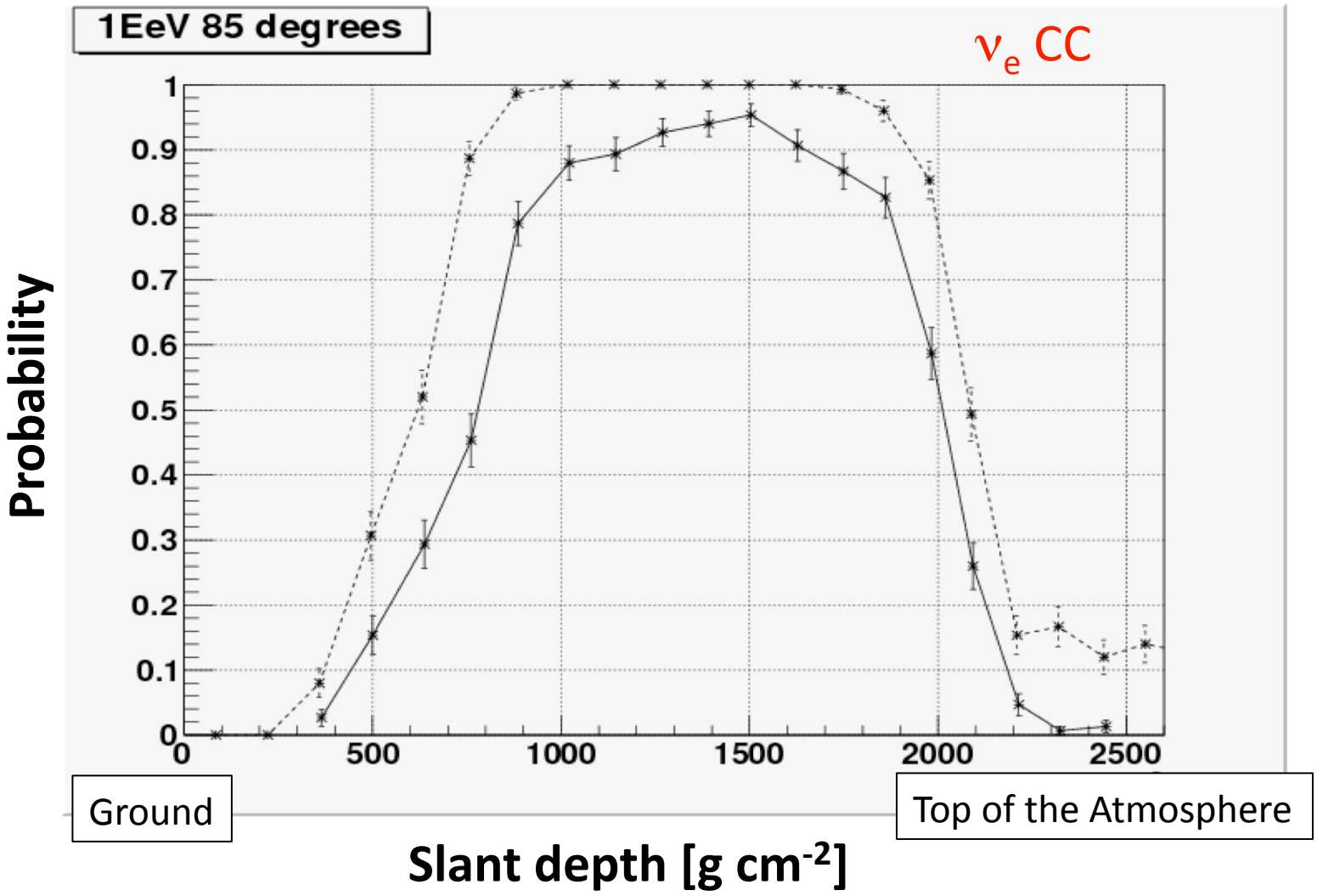


	pred	real
3σ	34.7	31
4σ	9.4	10
5σ	2.6	3
6σ	0.7	0

DG: Fisher results (training data)

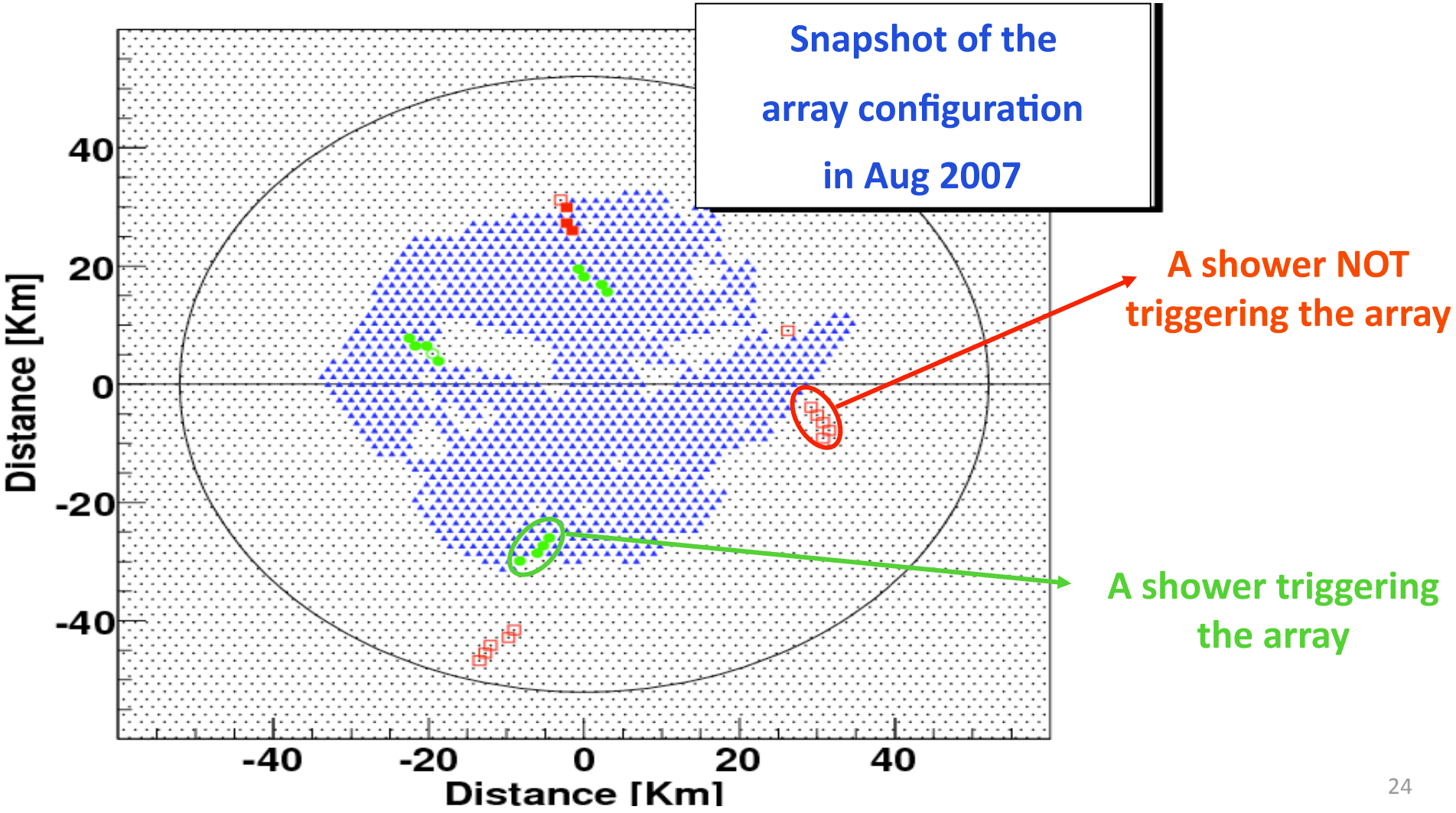


DG: Neutrino identification efficiency

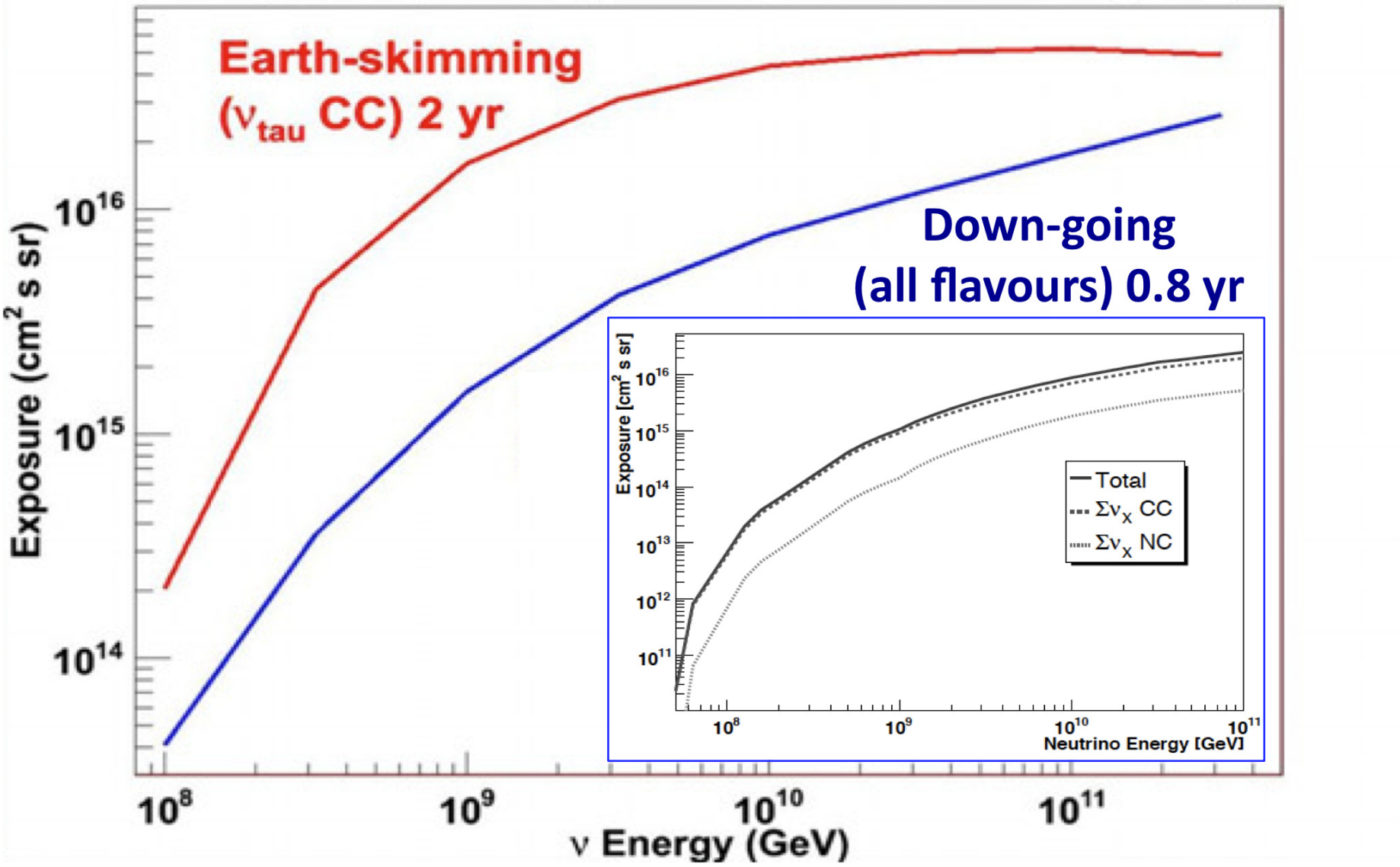


Calculation of the Aperture with the real SD array

The exposure is calculated taking into account that the SD array (continuosly monitored) configuration changes with time



Neutrino Auger Exposure



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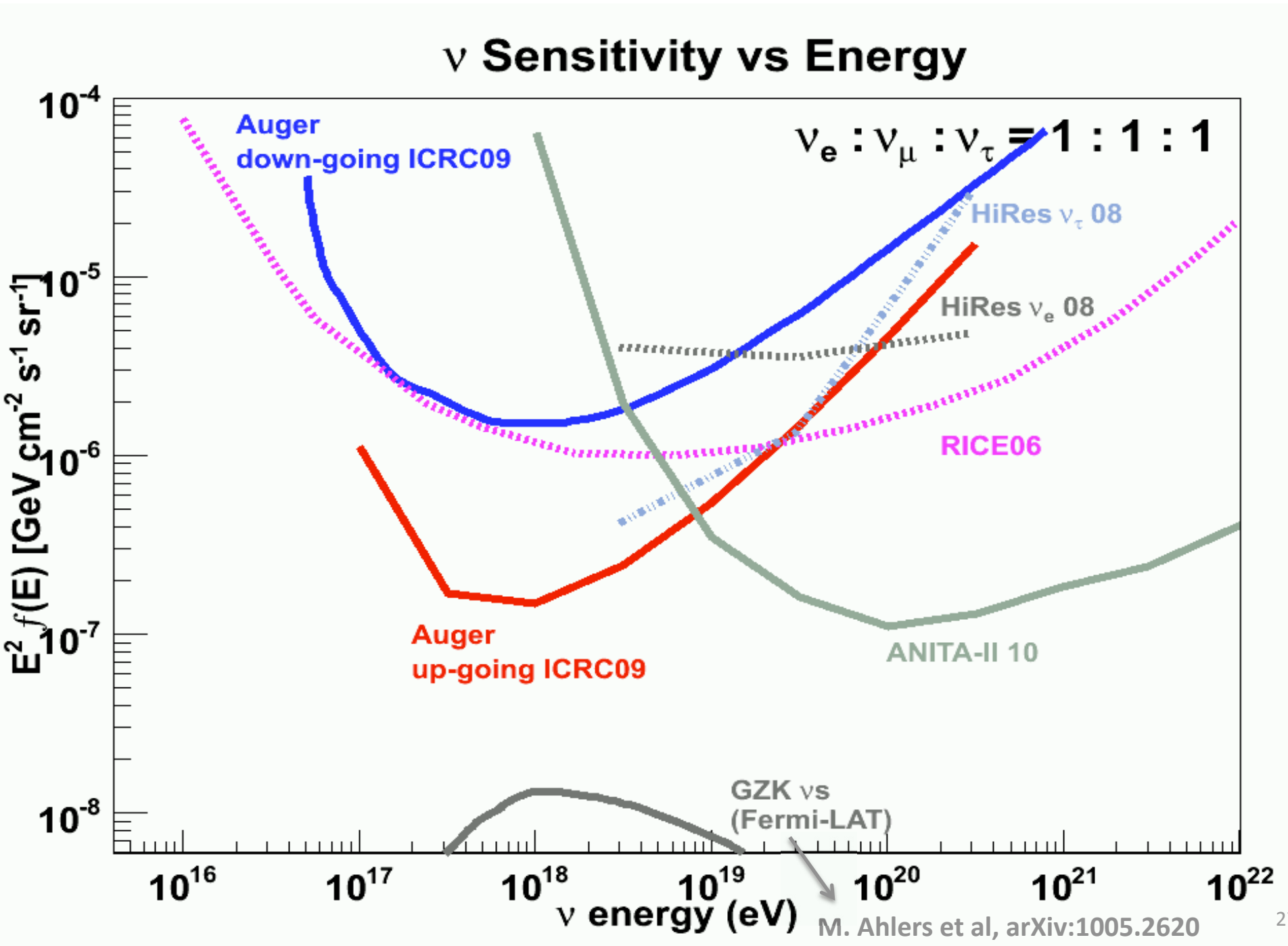
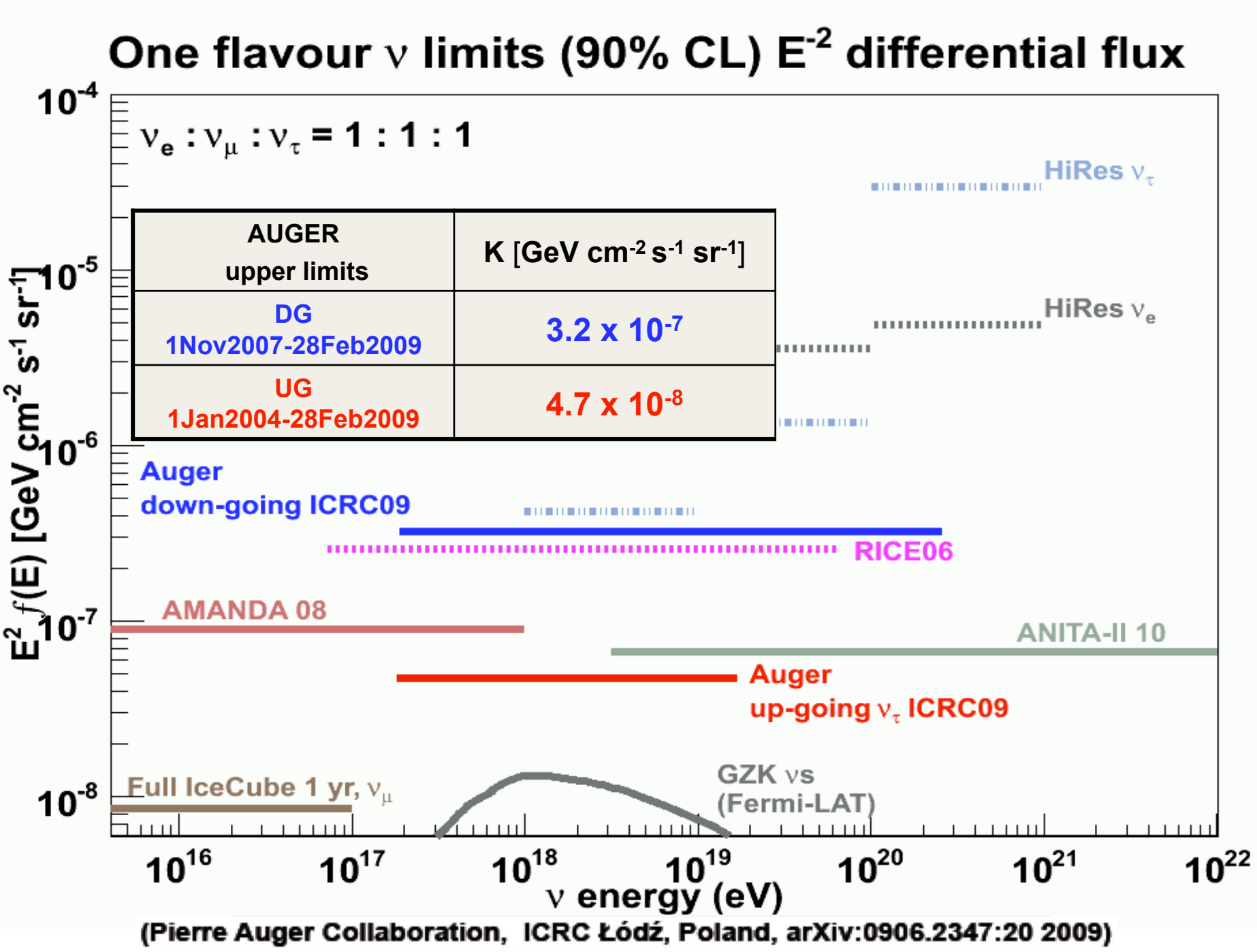
Candidates found for the search period

1 Nov 2007 - 28 Feb 2009 (DG)

1 Jan 2004 - 28 Feb 2009 (UG)

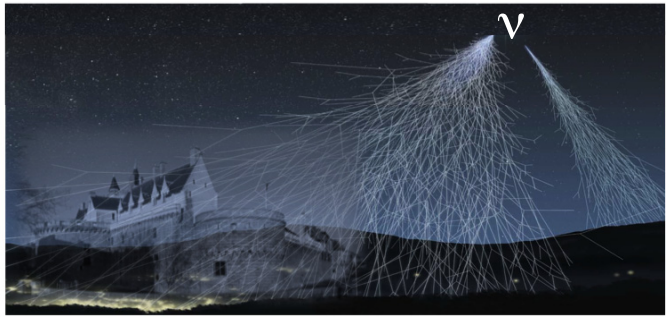


M. Ahlers et al, arXiv:1005.2620


One flavour ν limits (90% CL) E^{-2} differential flux
$\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$
AUGER upper limits
K [GeV cm^{-2} s^{-1} sr^{-1}]
DG 1Nov2007-28Feb2009
3.2 x 10^{-7}
UG 1Jan2004-28Feb2009
4.7 x 10^{-8}
HiRes ν_τ
HiRes ν_e
Auger down-going ICRC09
RICE06
AMANDA 08
ANITA-II 10
Auger up-going ν_τ ICRC09
Full IceCube 1 yr, ν_μ
GZK νs (Fermi-LAT)
$E^2_\nu f(E)$ [GeV cm^{-2} s^{-1} sr^{-1}]
ν energy (eV)
(Pierre Auger Collaboration, ICRC Łódź, Poland, arXiv:0906.2347:20 2009)

PIERRE AUGER OBSERVATORY

Conclusions



★ The Surface Detector of the Pierre Auger Observatory is sensitive to **UHE neutrinos** (max. in the EeV region)

★ Two different channels: **Up-going/Earth-skimming tau neutrinos** & **Down-going**. Key for identification: **inclined showers with EM comp.**

★ **No ν candidates** found in the Auger data set

★ Spectral index dependent limit on the diffuse flux of UHE neutrinos:

UG: $E^2\, dN/dE = 4.7 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

DG: $E^2\, dN/dE = 3.2 \times 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

★ GZK/BZ neutrinos could be tested in 10 years