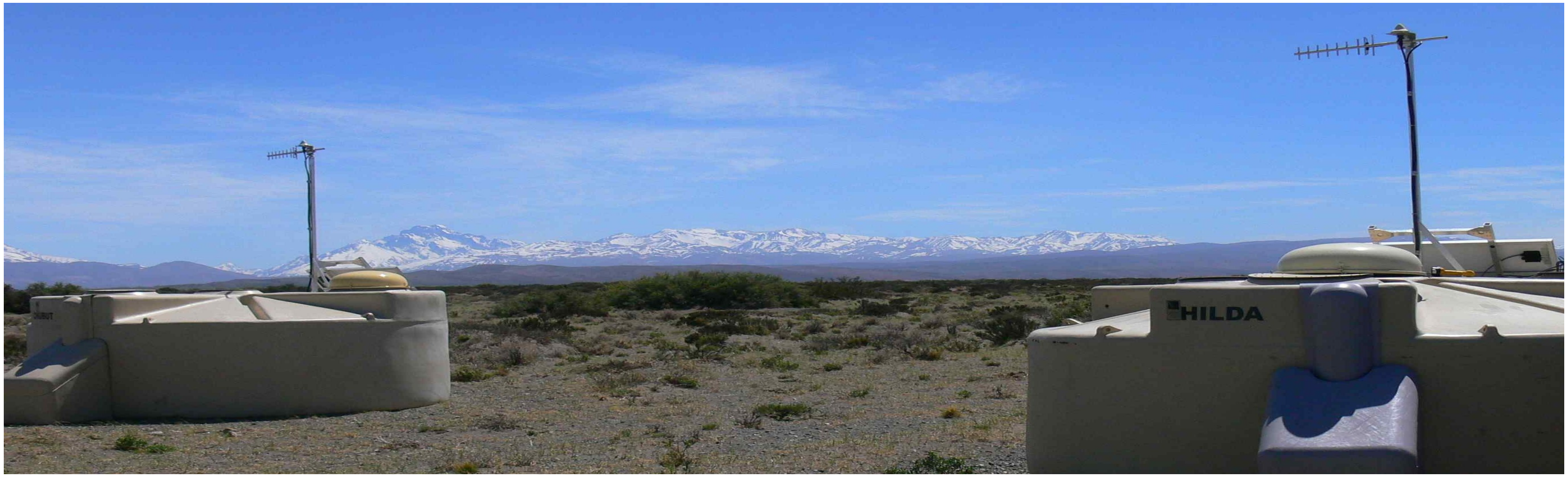


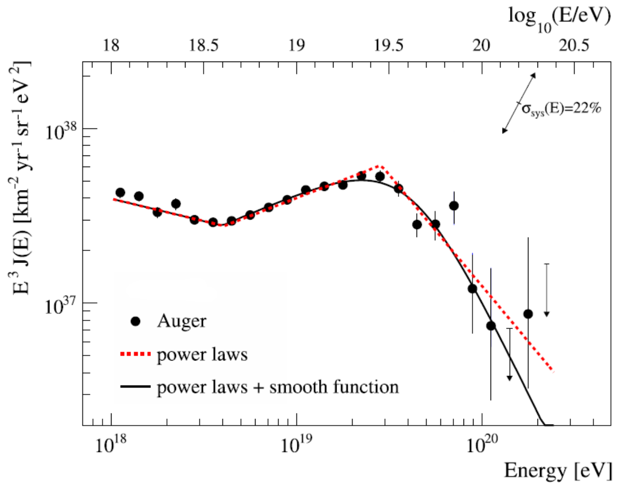
Limits on UHE neutrino flux from the Pierre Auger Observatory

Simone Maldera[1]
for the Pierre Auger Collaboration

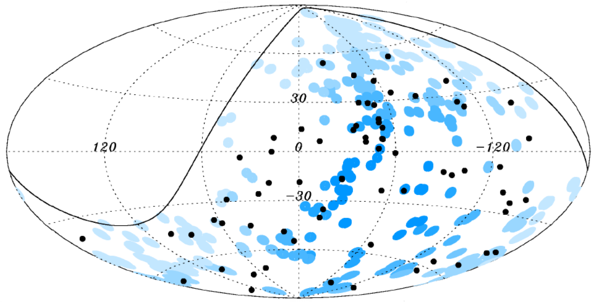
[1] *INAF-Osservatorio Astrofisico Torino and INFN*

Goals of the Pierre Auger Observatory:

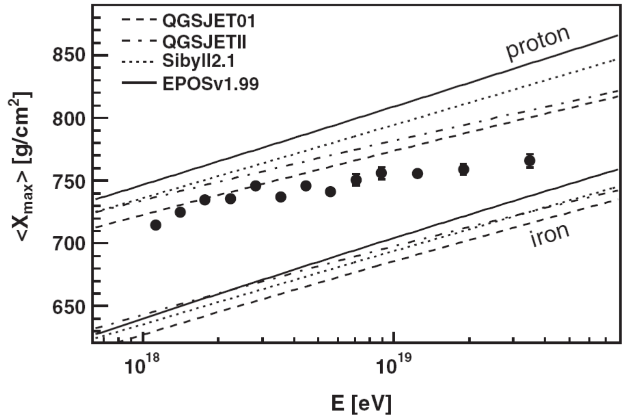
"Measure the properties of Ultra High Energy Cosmic Rays (E > 10^{18}eV) with unprecedented statistics and accuracy"



Energy
Cutoff at the highest energies?
Ankle?



Direction
Is the UHECR flux isotropic ?
Which are the UHECRs sources?



Mass composition
Is the UHECR flux proton/iron-dominated?

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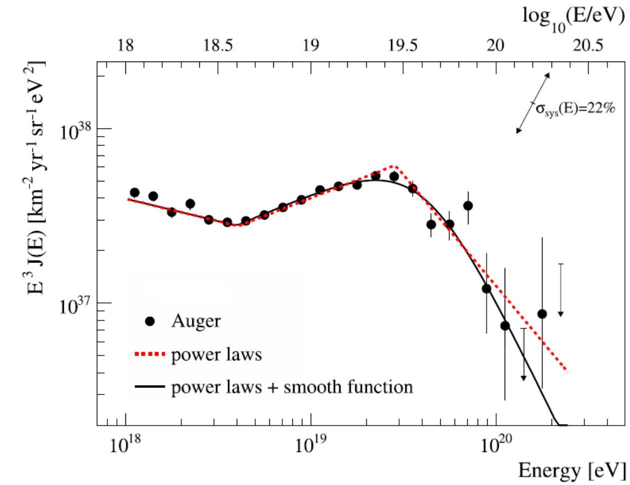

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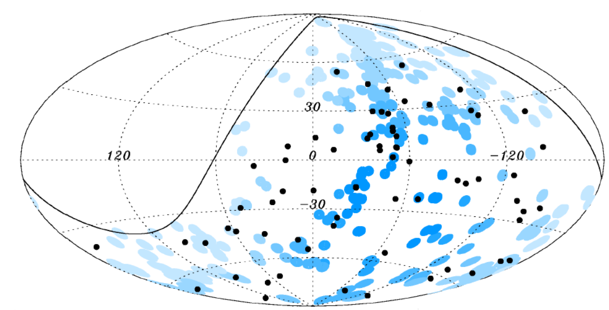

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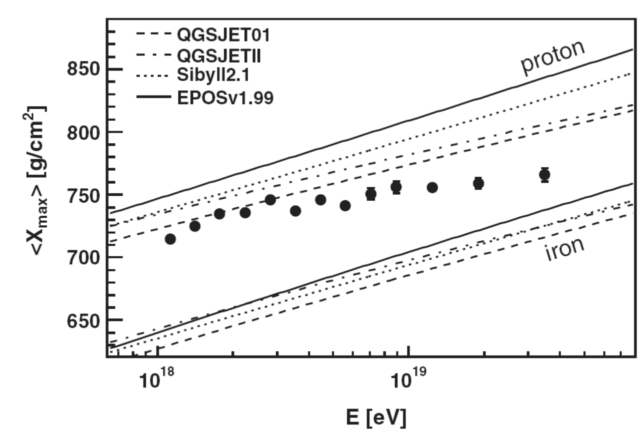


ν (and γ) detection capability

Sources of UHE neutrinos

Astrophysical neutrinos

product of pion decays produced in hadronic interactions of cosmic rays with radiation or matter near the astrophysical sources

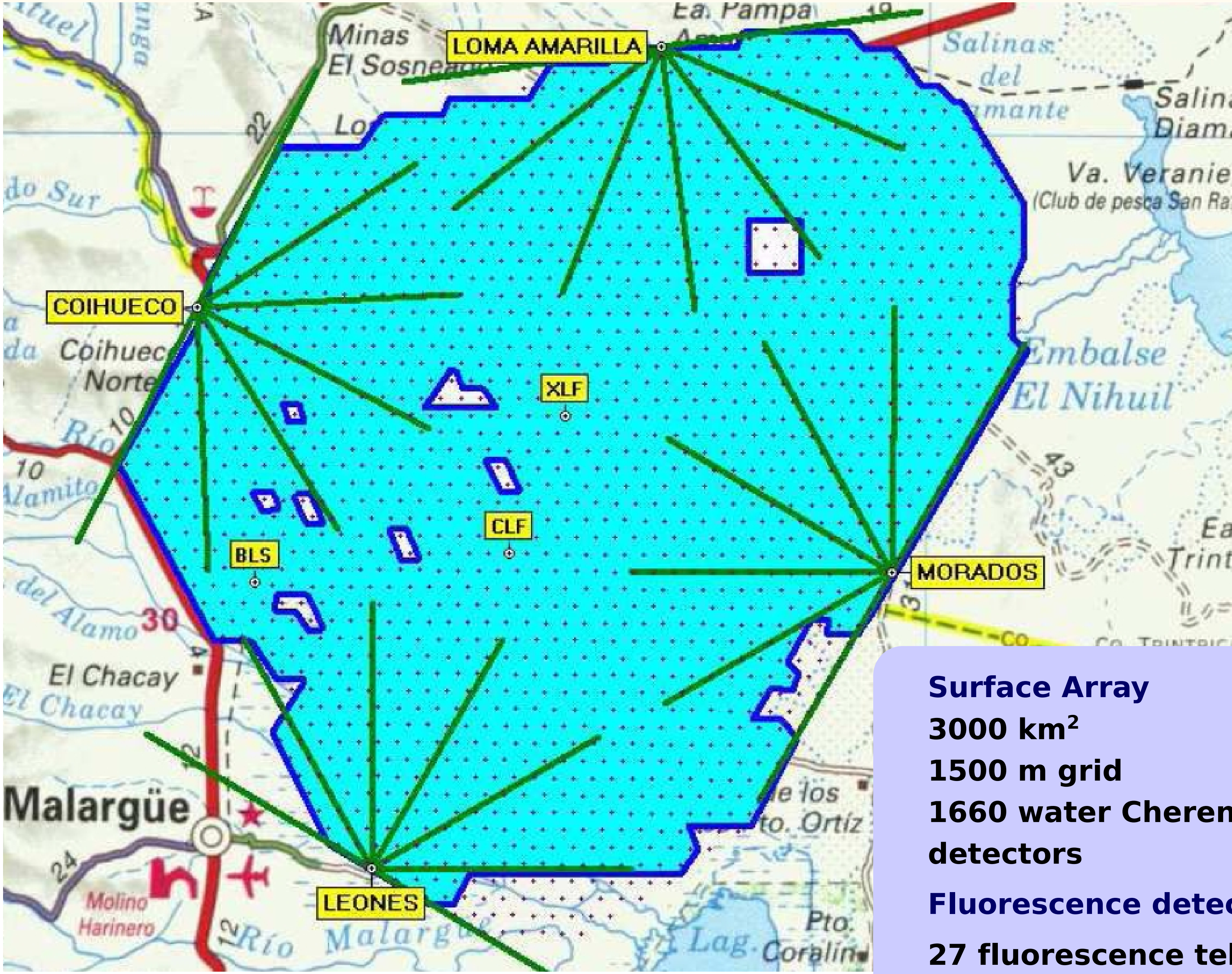
Cosmogenic neutrinos

produced by high-energy cosmic rays interactions with the microwave background.

"Top-down" models

Decay of ultra massive objects (topological defects, super heavy dark matter, Z burst…): harder spectrum and high fluxes predicted.

Auger: a hybrid detector

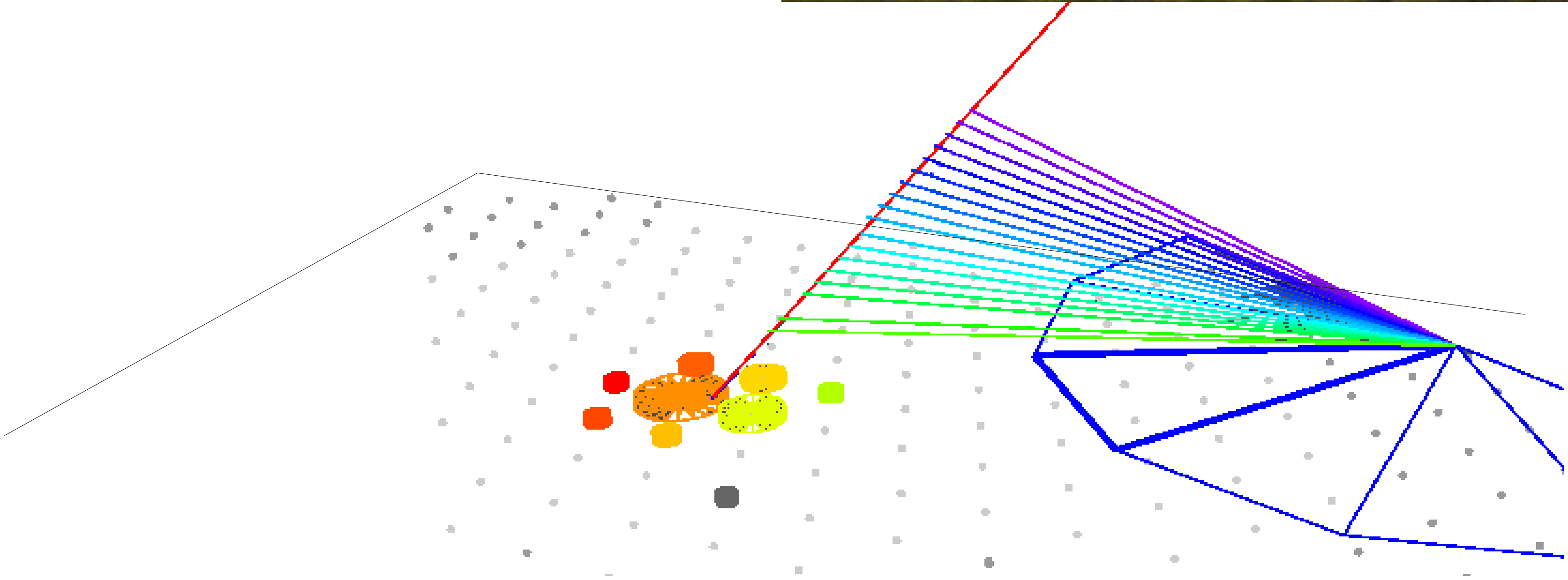


Surface Array
3000 km²
1500 m grid
1660 water Cherenkov detectors

Fluorescence detector

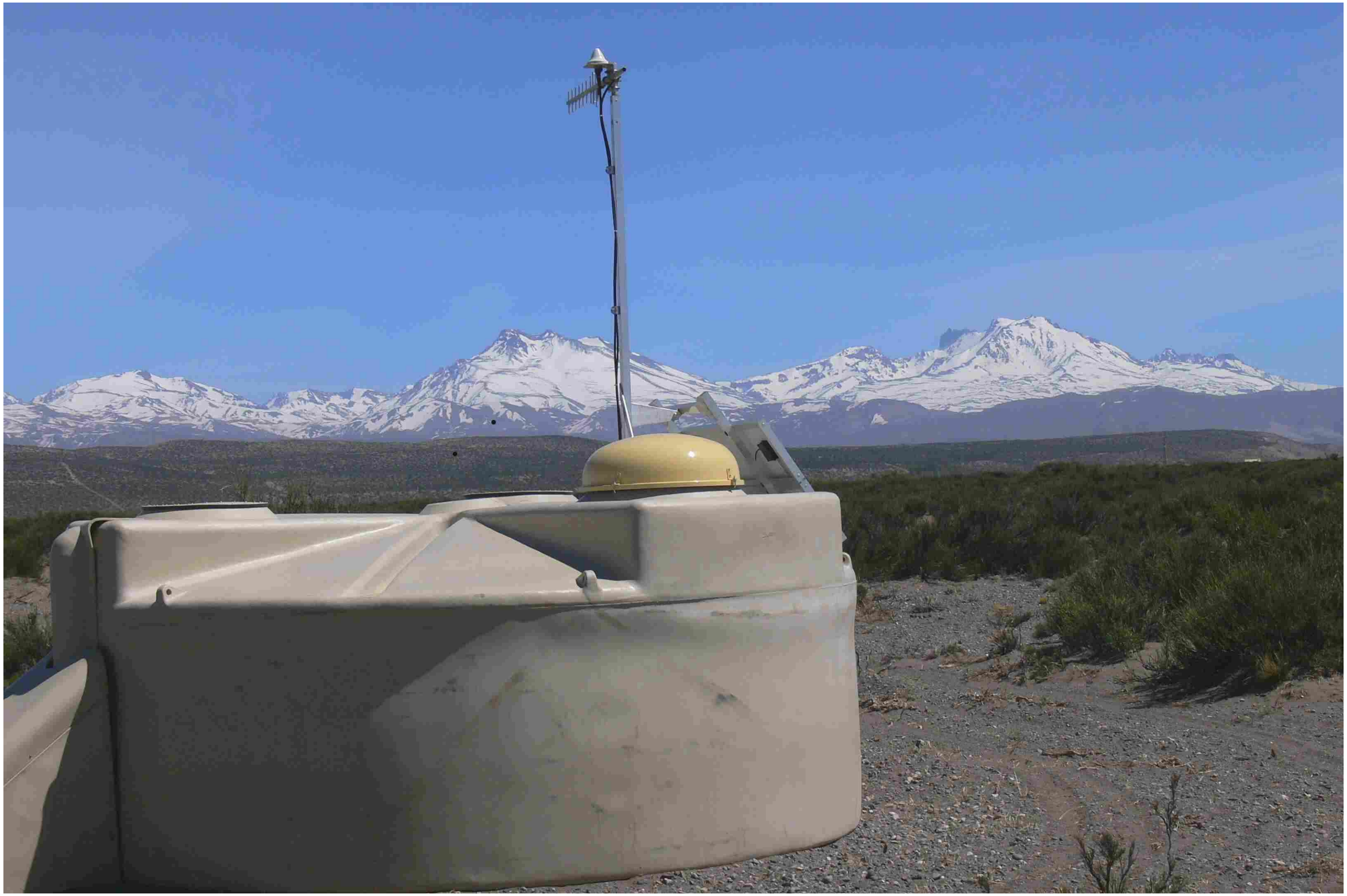
27 fluorescence telescopes

Auger: a hybrid detector

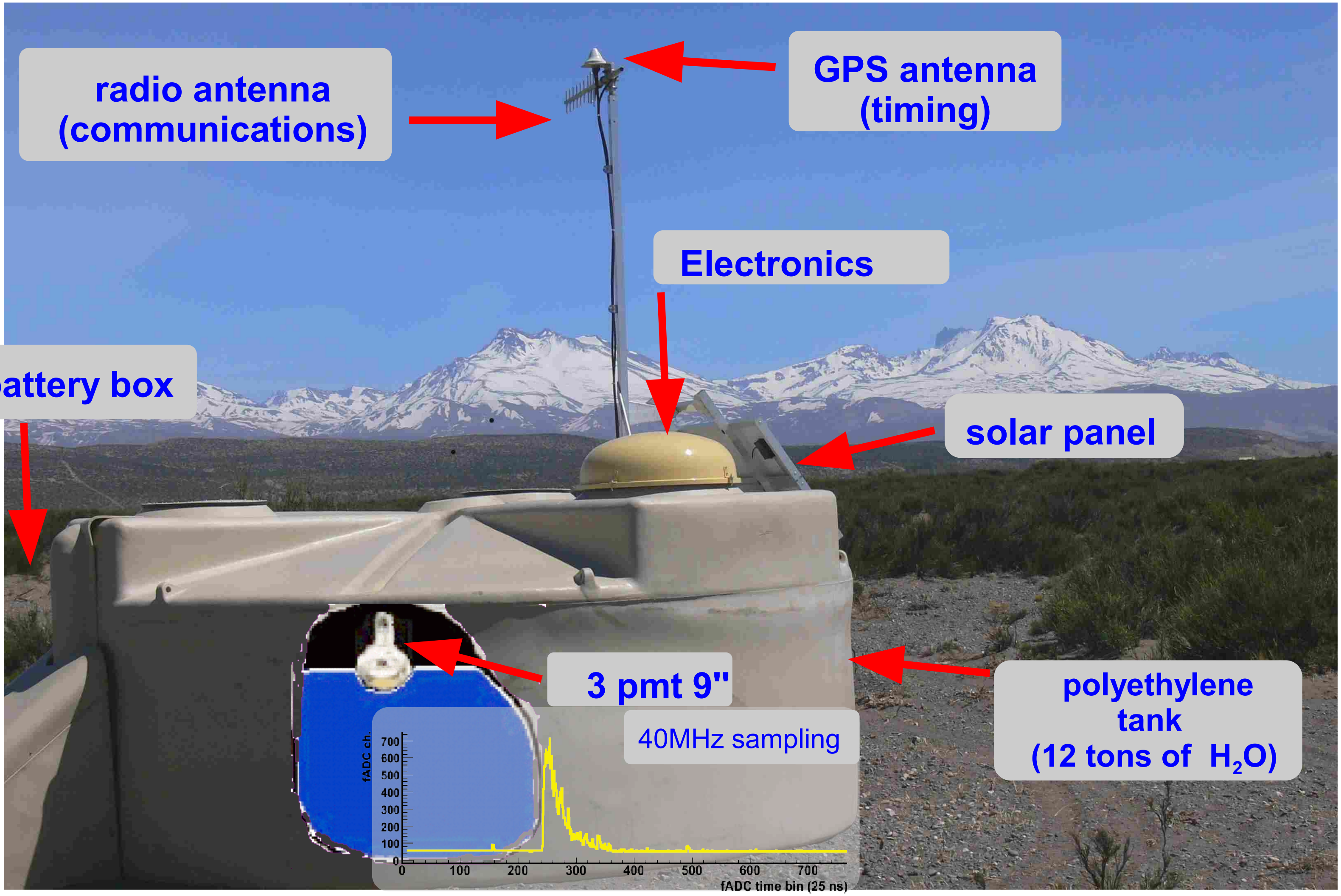


event 3022201 θ=42° E=7.7 10^{18} eV

Surface detector

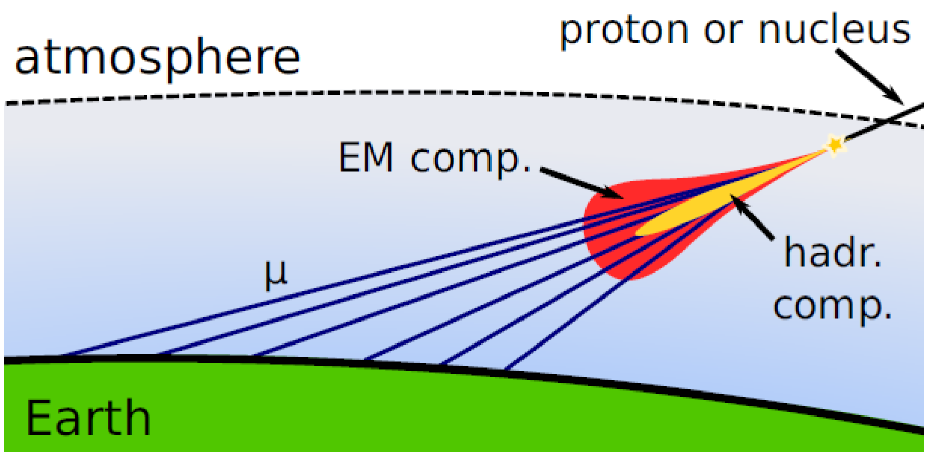


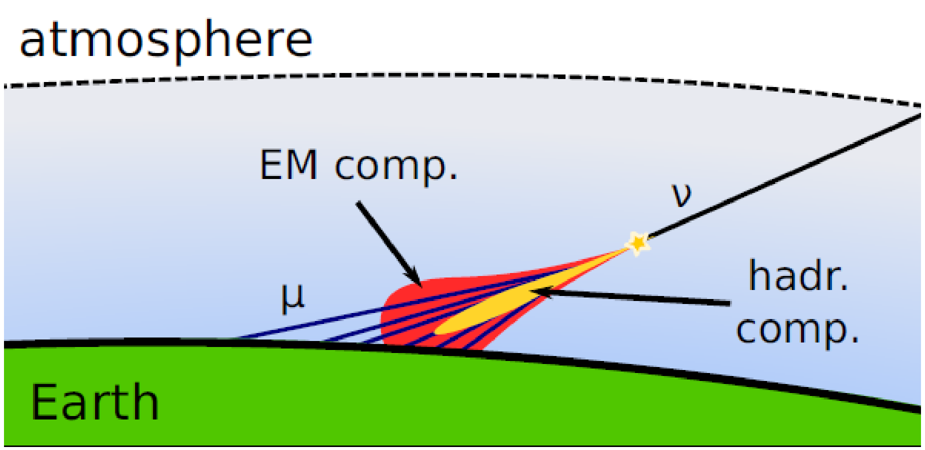
Surface detector



Identification of neutrino induced showers

Discrimination power enhanced looking at very inclined showers





Cosmic ray showers:

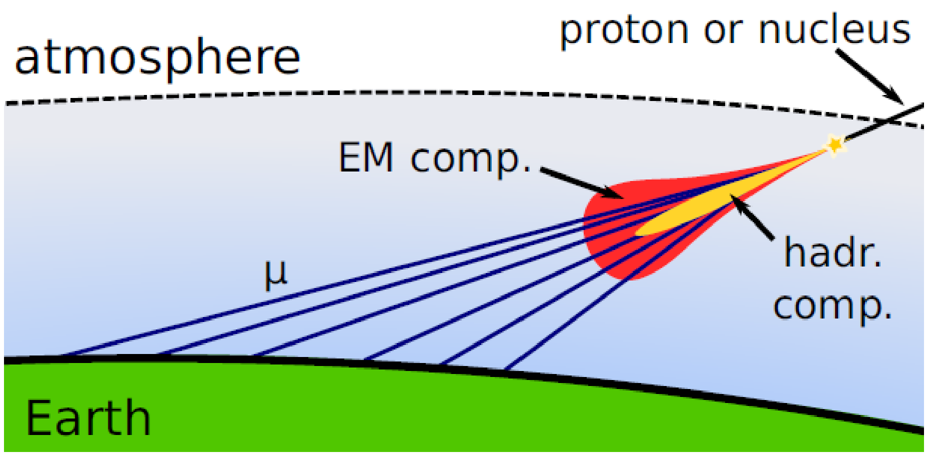
- interact higher in the atmosphere
- almost only muons at ground

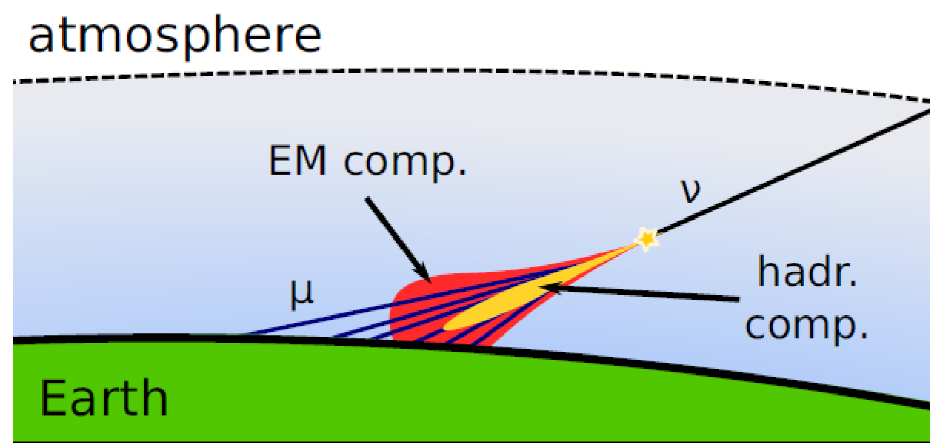
Neutrino induced shower:

- likely to interact near the ground
- large E.M component at ground (specially in the *early* region)

Identification of neutrino induced showers

Discrimination power enhanced looking at very inclined showers





Cosmic ray showers:

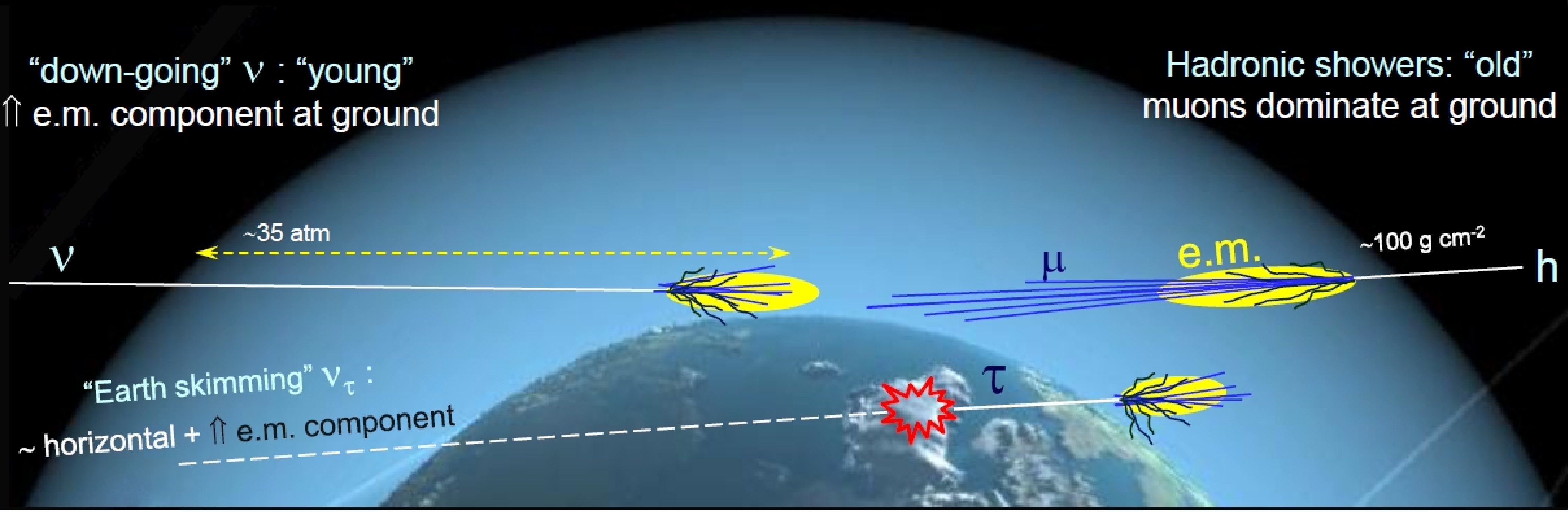
- interact higher in the atmosphere
- almost only muons

Neutrino induced shower:

- likely to interact near the ground

Neutrino ⟺ young (deep) inclined shower

Two main channels:



Earth–skimming

Sensitivity only to ν_τ

Sensitivity to CC channel

Small solid angle (90º –95º)

Dense mass target (Earth crust)

Down-going

Sensitivity to ALL flavours

Sensitive to ALL interaction channels (CC & NC)

Larger solid angle (75º - 90º)

Low density target (air)

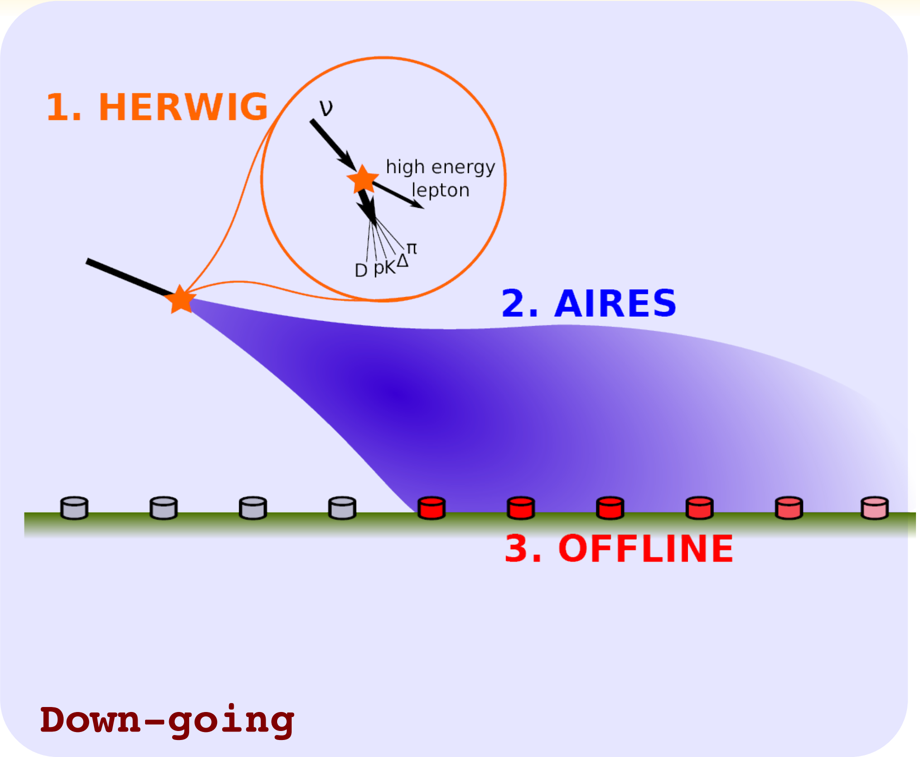
Neutrinos search strategy

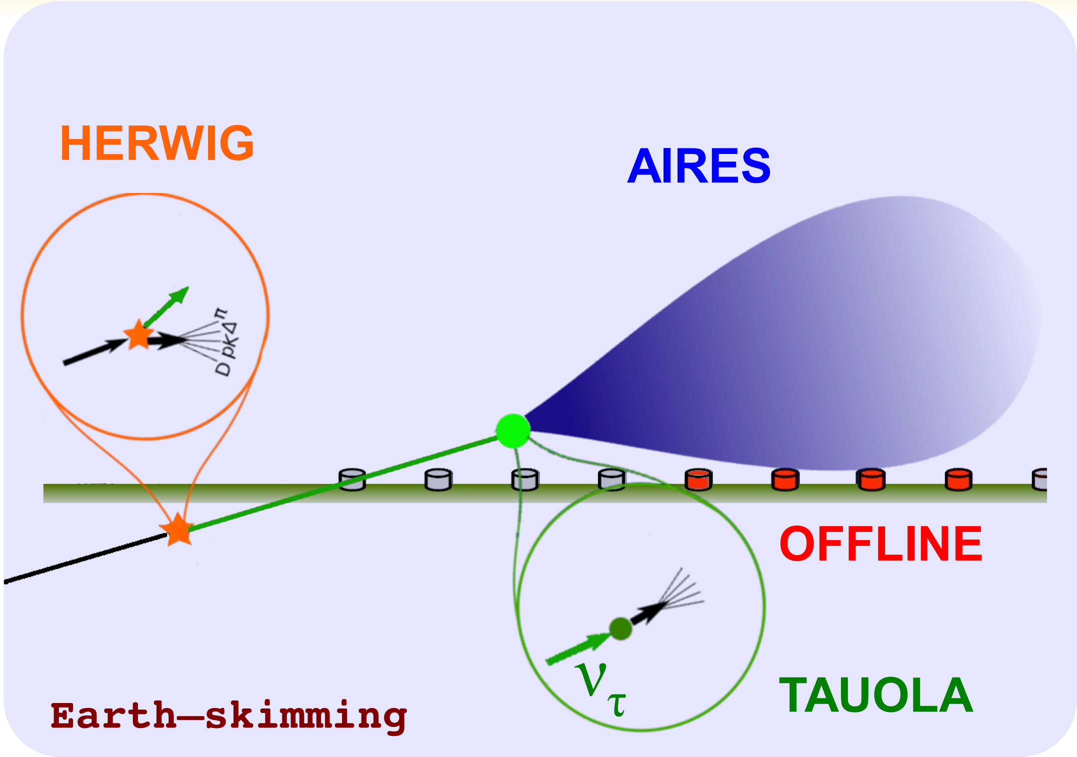
- simulation of ν showers
- Definition of ν selection cuts
  (background from uhecr showers from "training data")
- compute ν identification efficiency
- search for ν candidates in data
  (search sample)

Candidates found → **Claim a discovery**

zero candidates → **Compute upper limit on the flux**

Simulation of neutrino induced showers





Simulation of ν-nucleon interactions using HERWIG

in the case of ν_τ CC interactions

Tau decay → TAUOLA

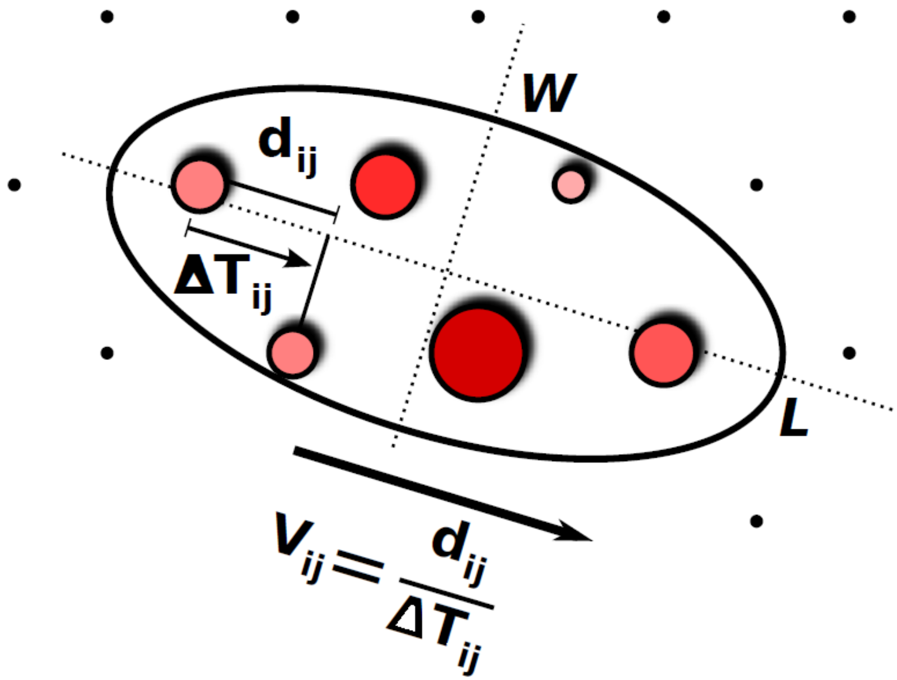
Simulation of the induced air shower with AIRES

Auger Offline package used to simulate the response of the SD detector

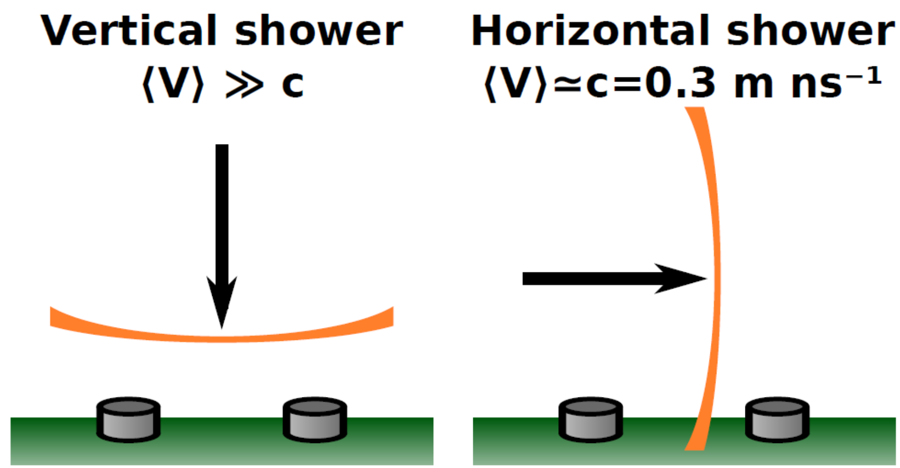
- GEANT4 simulation of Cerenkov light
- PMT signals
- local station and global trigger conditions

Select large zenith showers:

Elongated footprint on ground



Signal speed ~ c



Earth–skimming ν_τ

L/W >5

$0.29 \text{ m ns}^{-1} < \bar{V} < 0.31 \text{ m ns}^{-1}$

RMS(V) < 0.08

$90^\circ < \theta < 95^\circ$

Down-going neutrinos

L/W >3

$\bar{V} < 0.313 \text{ m ns}^{-1}$

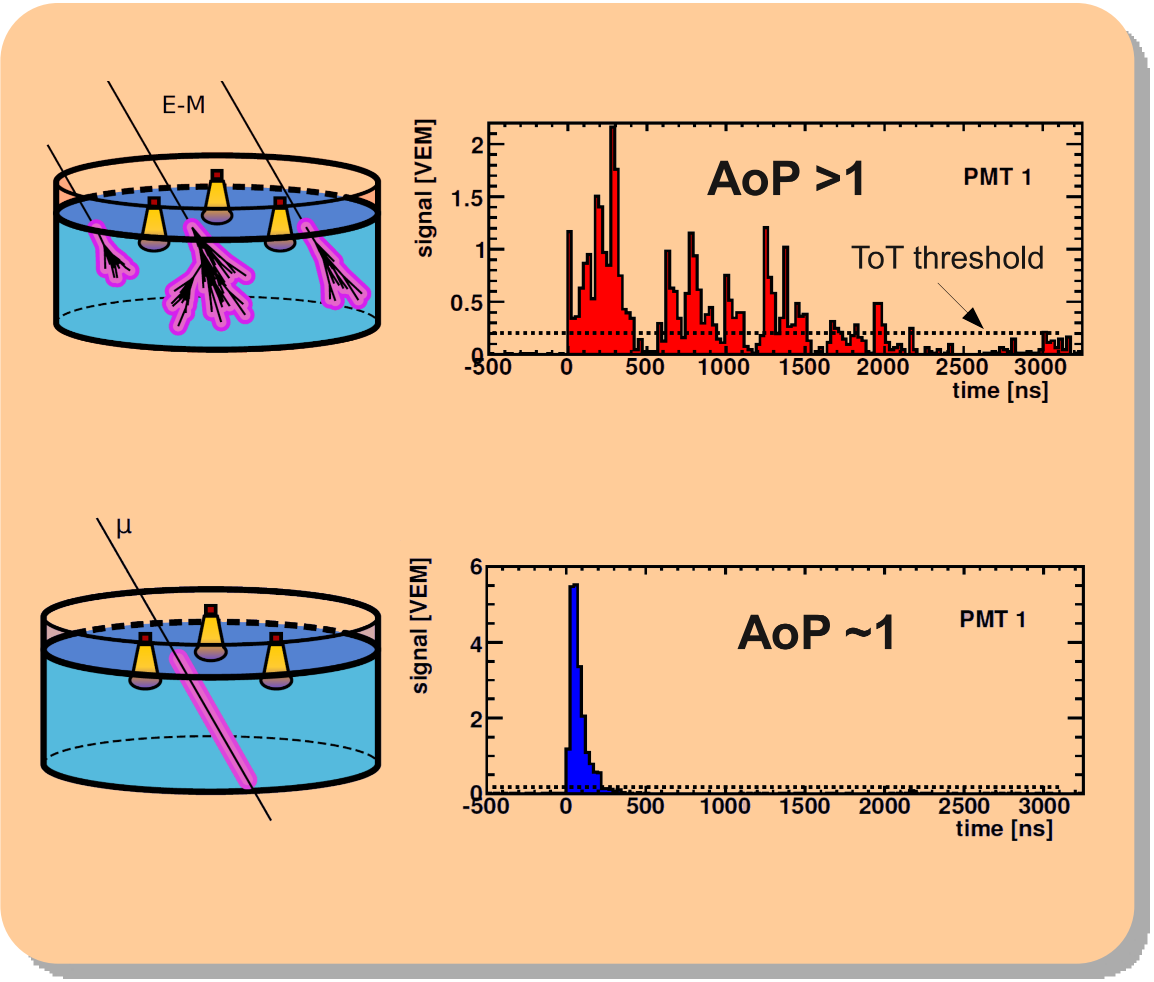
$\sigma_V / \bar{V} < 0.08$

$\theta_{rec} > 75^\circ$

$75^\circ < \theta < 90^\circ$

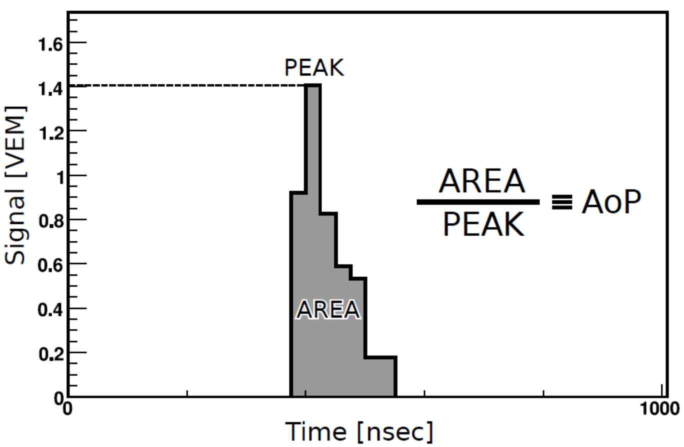
Select deep showers: large E.M. component at ground

Electromagnetic rich showers give a signal broader in time



2 discriminating variables:

- Area over Peak (AoP)



- Time over threshold

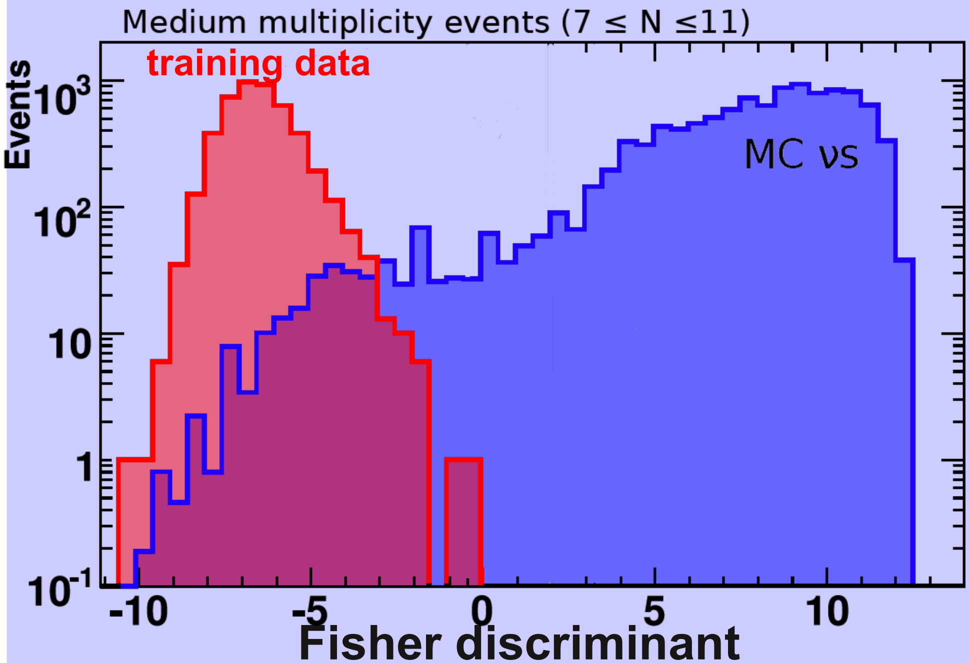
13 bins above 0.2 VEM in a 13 μs Window (after off-line removal of isolated peak → accidental muon)

Select deep showers: 2 different approaches

Down-going

Multivariate Fisher analysis

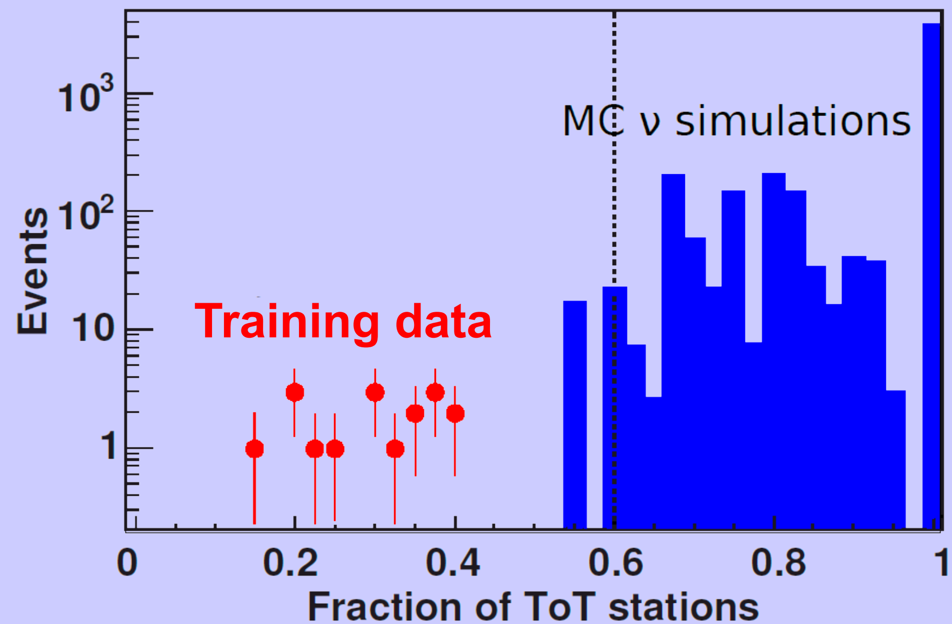
- AoP of first 4 stations
- asym: <early AoP> < late AoP>
- AoP^2 (first 4 stations)
- $\prod AoP_i$ (first 4 stations)



Training data: 1 Jan 2004–31 Oct 2007

Earth–skimming

Cut on fraction of ToT stations with high AoP (>1.4)



Training data: 1 Nov 2004–31 Dec 2004

Select deep showers: 2 different approaches

Down-going

Multivariate Fisher analysis

- AoP of first 4 stations
- asym: <early AoP> < late AoP>
- AoP^2 (first 4 stations)
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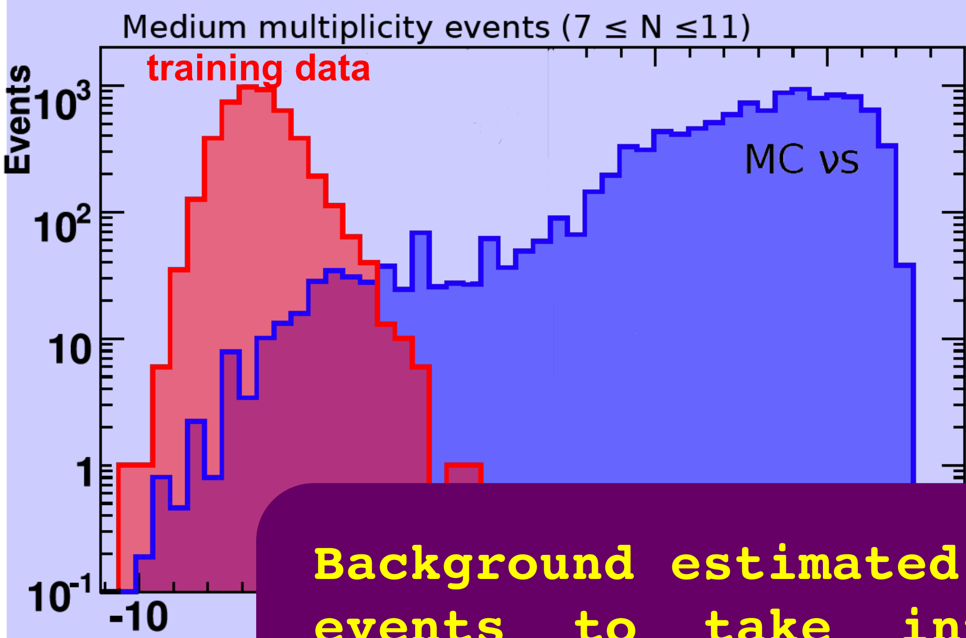
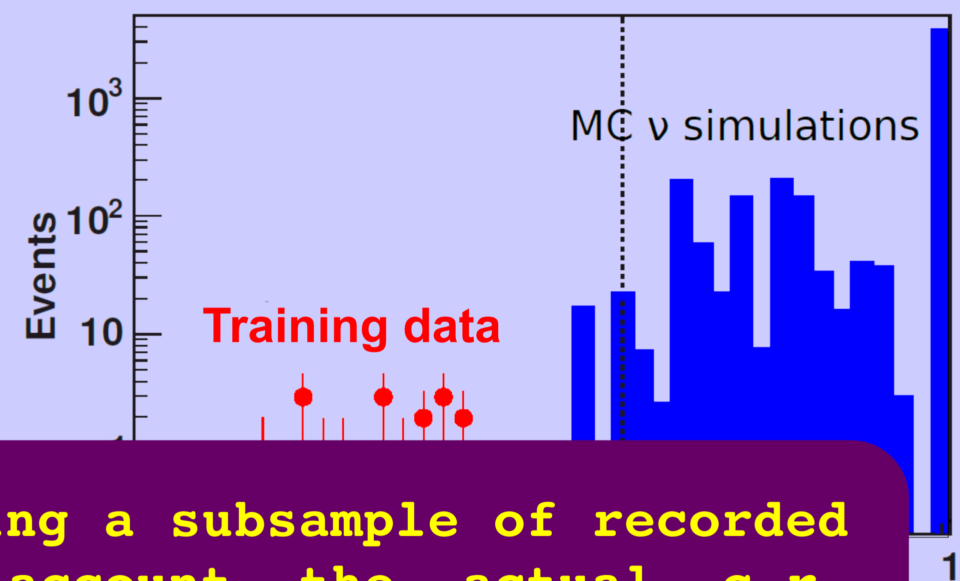


Training

Earth–skimming

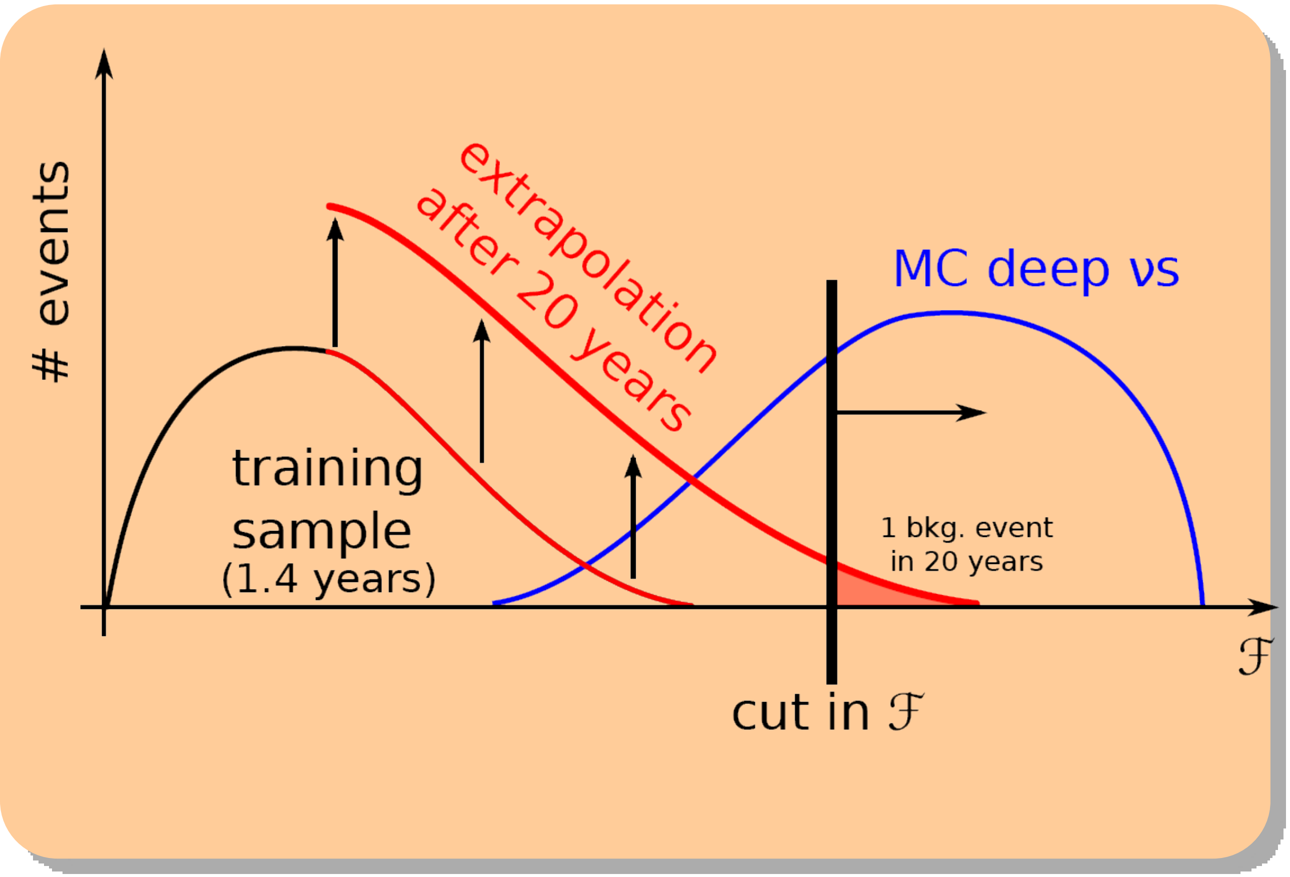
Cut on fraction of ToT stations with high AoP (>1.4)



04

Background estimated using a subsample of recorded events to take into account the actual c.r. composition and all possible detector effects

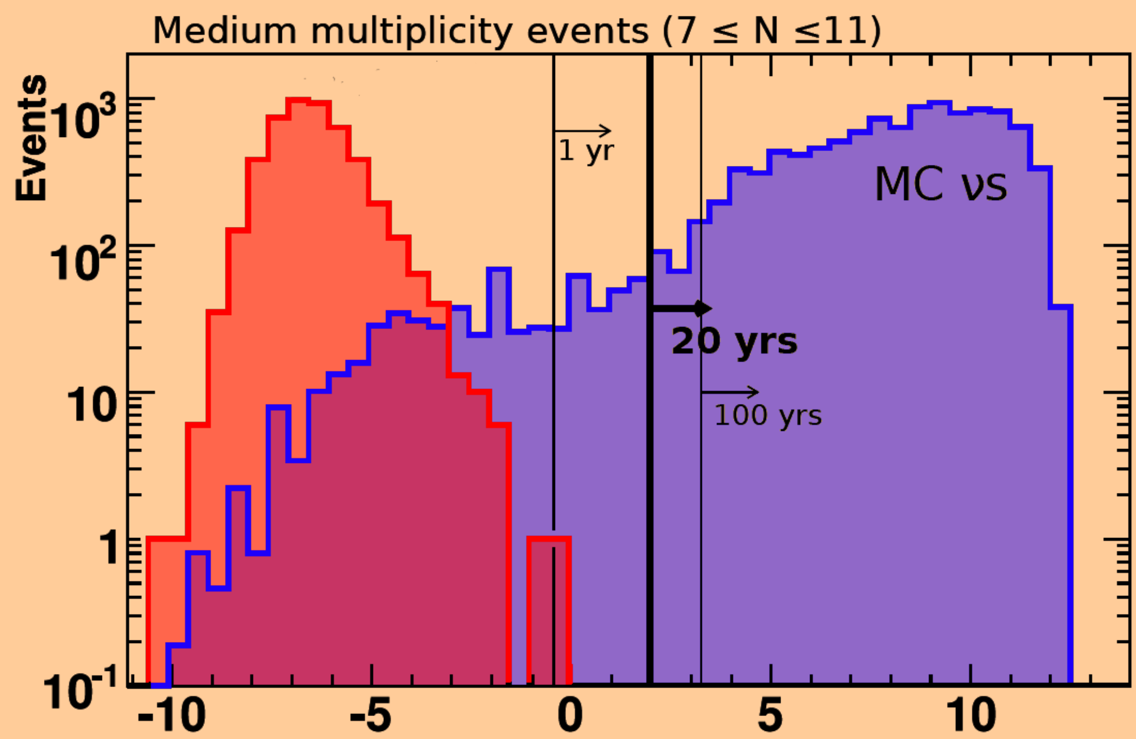
Down-going: estimation of background



Assume an exponential shape for the tail of background distribution of F

extrapolation to find the value of F_cut corresponding to 1 background event in a given time

Down-going: estimation of background



Assume an exponential shape for the tail of background distribution of F

extrapolation to find the value of F_cut corresponding to 1 background event in a given time

F_{cut} fixed to have 1 background event in 20 years

0.1 background events in the search sample (for each multiplicity class)

~10% of ν events rejected

Identification efficiency

Earth–skimming | **down-going**

Detection efficiency depends on:

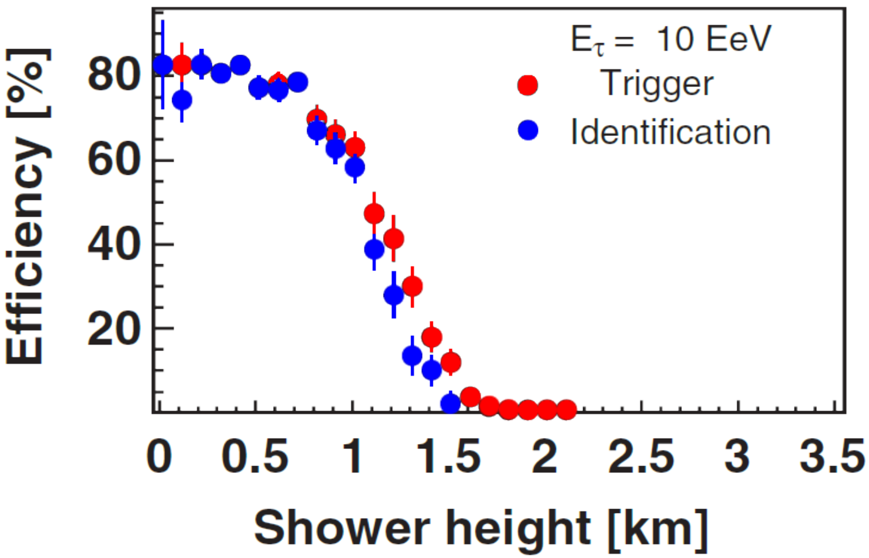
Earth–skimming:

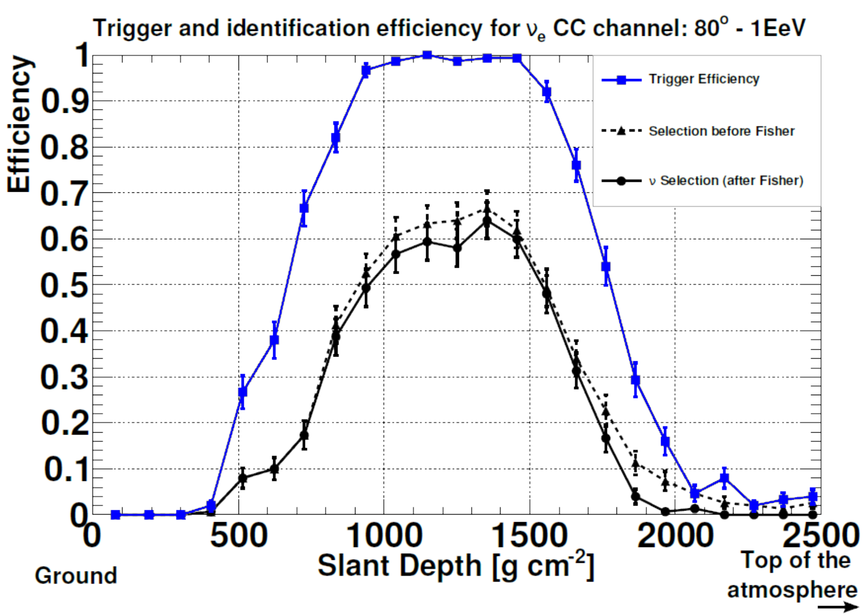
Emerging tau energy

Altitude of the "center of the shower" (hc) above the ground

down-going:

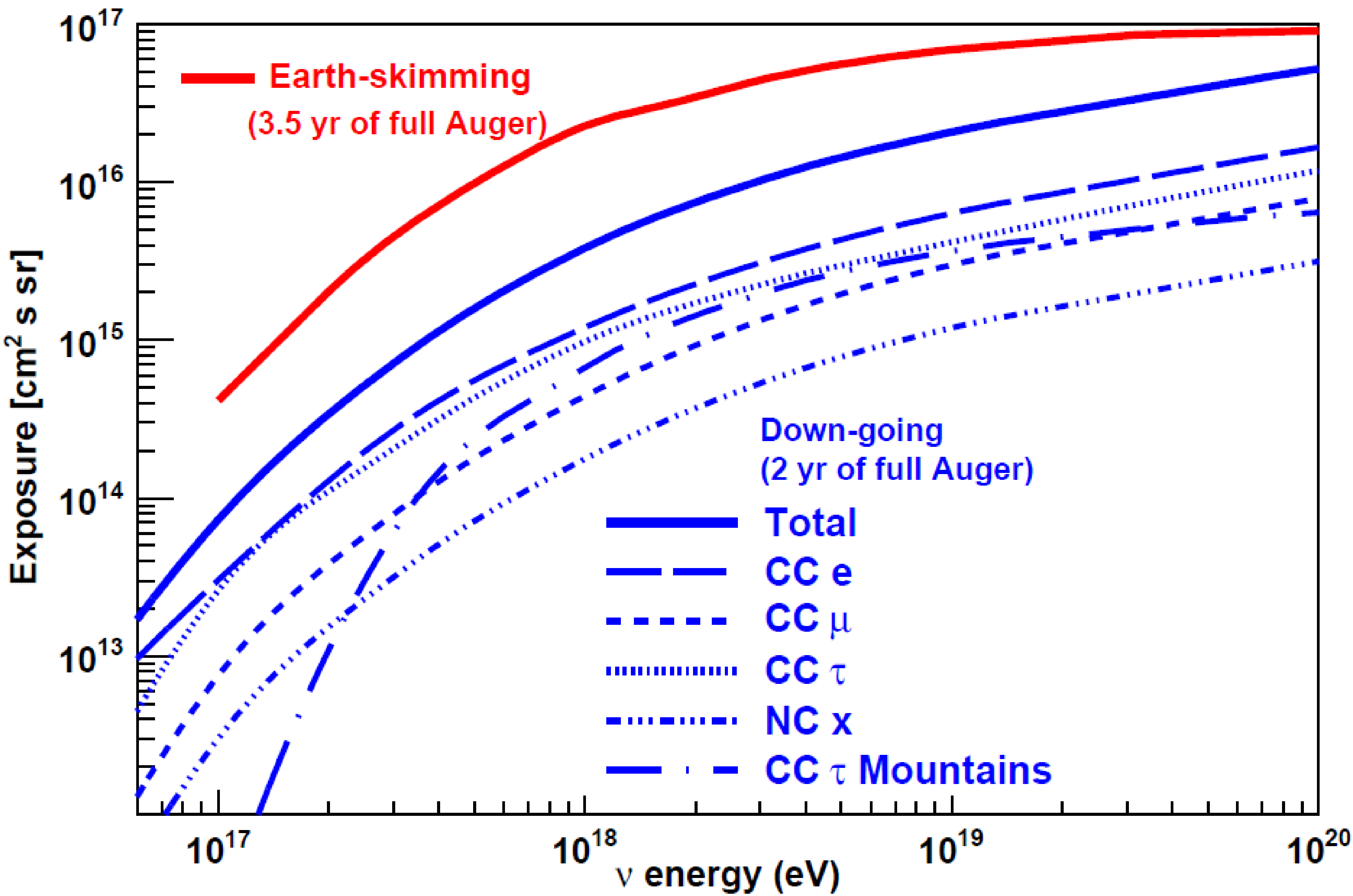
Type of interaction (CC, CN)
Neutrino energy
Zenith angle
Distance from the ground





From the ν identification efficiency and taking into account the time evolution of SD we can compute the exposure

Exposure



Earth-skimming
(3.5 yr of full Auger)
Down-going
(2 yr of full Auger)
Total
CC e
CC μ
CC τ
NC x
CC τ Mountains
Exposure [cm² s sr]
ν energy (eV)
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{17}
10^{18}
10^{19}
10^{20}

Search results

Search sample:

Earth skimming: 1 Jan 2004 – 31 May 2010

Down-going: 1 Nov 2007 – 31 May 2010

Zero candidates found in both analysis

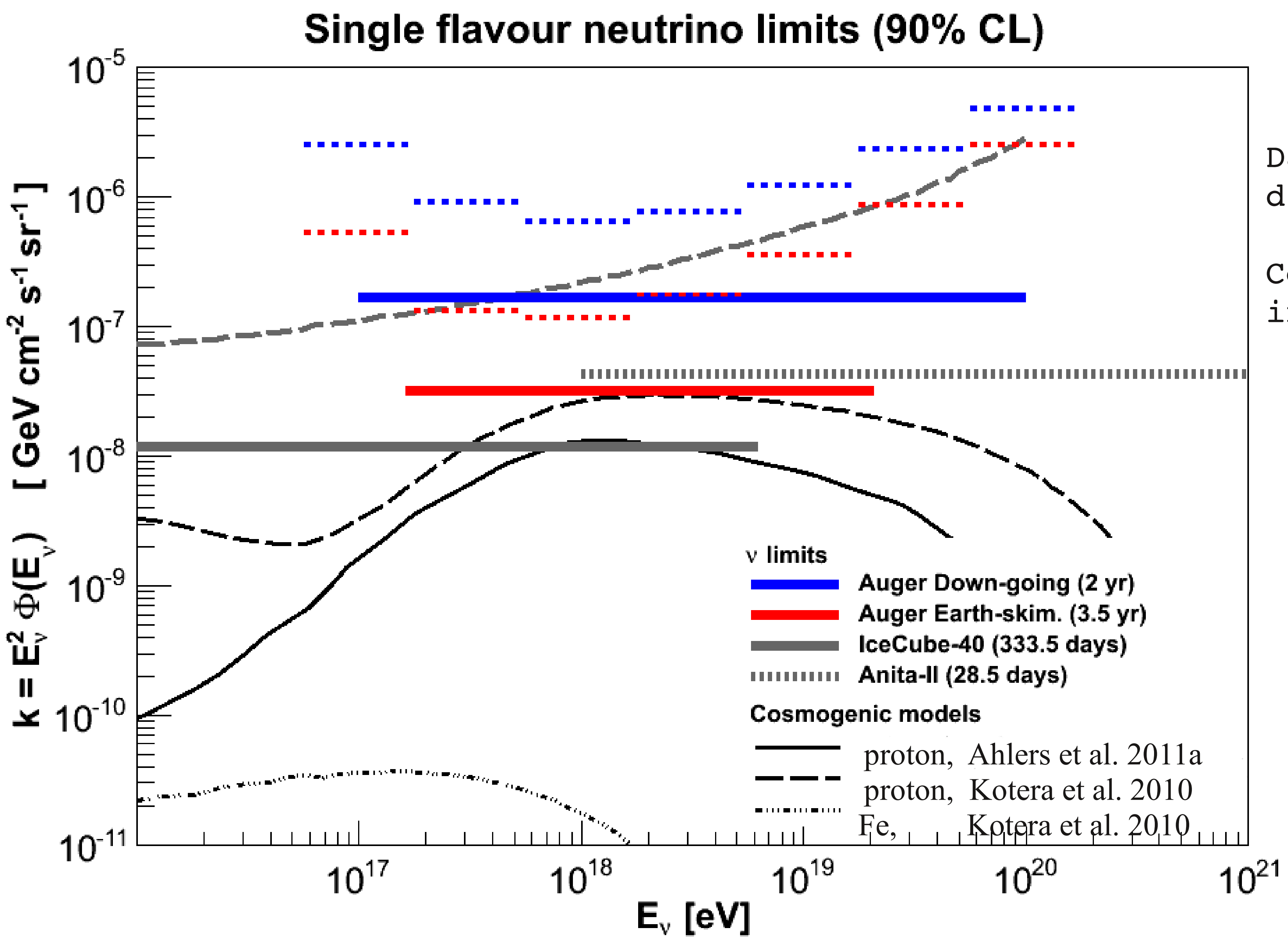
Place an upper limit to the flux

assuming

$$\frac{dN}{dE} \equiv f(E_\nu) = k \cdot E_\nu^{-2}$$

$$k = \frac{N_{\mathrm{up}}}{\int_{E_{\mathrm{min}}}^{E_{\mathrm{max}}} \Phi(E)\ \mathcal{E}(E)\ dE}$$

upper limits to neutrino flux

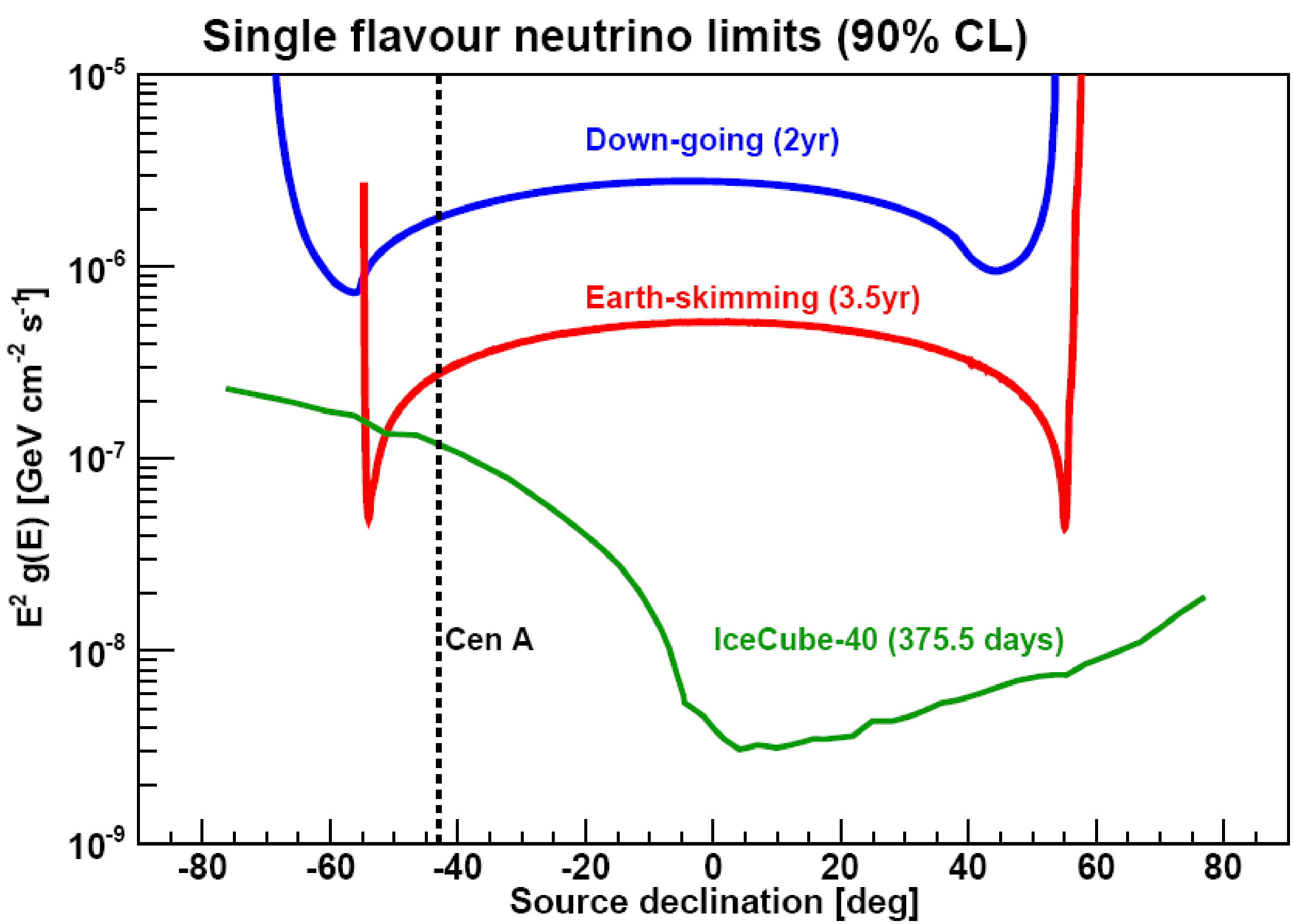


Dashed lines: differential limits

Countinuous lines: integral limits

Directional limits on neutrino flux

Computing the exposure as a function of declination directional limits can be derived

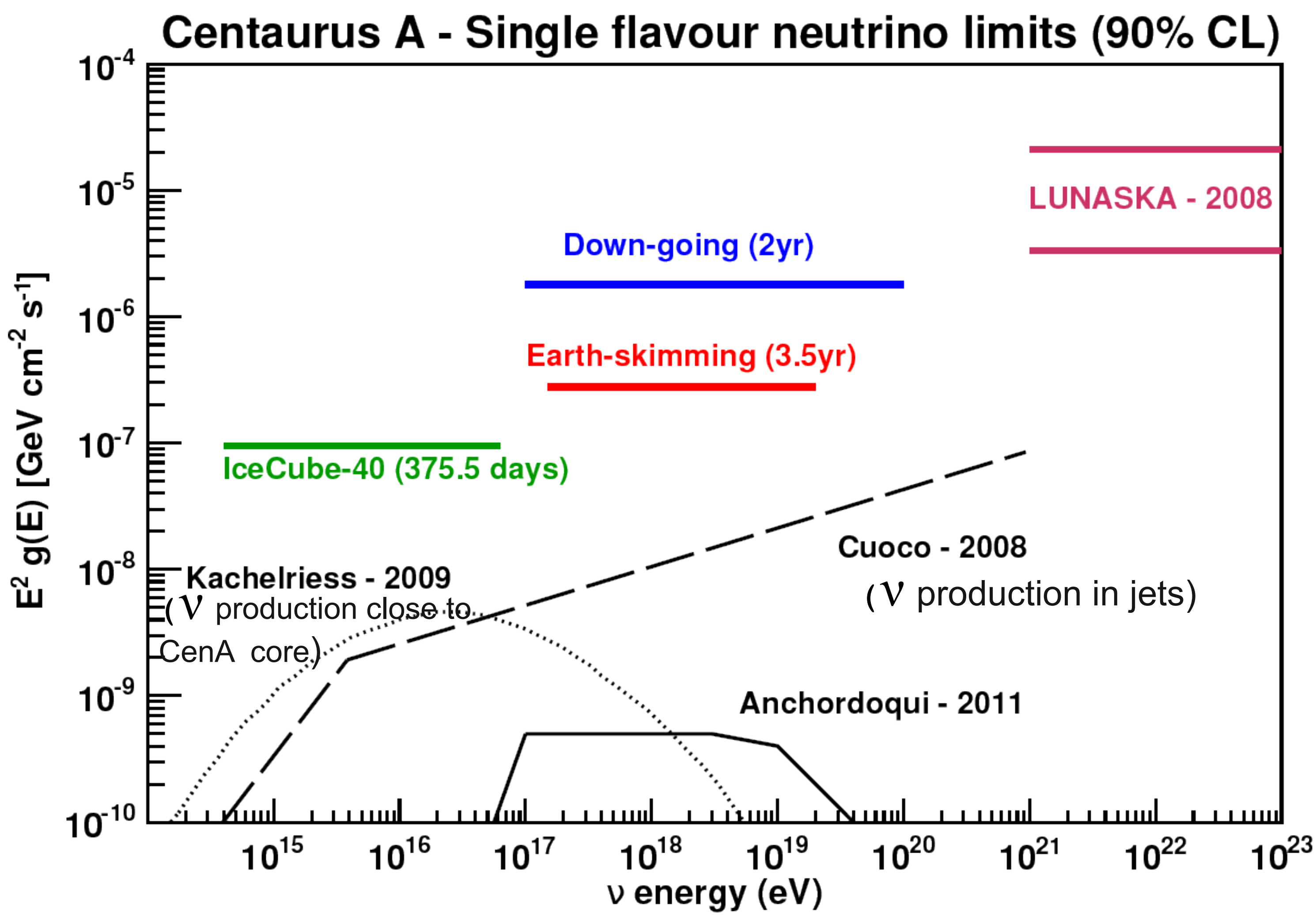


10^{17} eV < E < 10^{20} eV

1.6 10^{17} eV < E < 2 10^{19} eV

Energy range depends on declination Below 10^{17} eV

Neutrino flux limits to Cen A



Conclusions

A method to search for UHE neutrinos using the Surface Detector of the Pierre Auger Observatory have been presented

No candidates have been found in the collected data

Upper limits to UHE neutrino diffuse flux have been placed:

Earth-skimming (sensitive to tau neutrinos)
$k < 3.2\ 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} $1.6\ x10^{17}$ eV < E < $2.0\ x10^{19}$ eV

Down-going (sensitive to all neutrino flavors)
$k < 1.7\ 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1} $1x10^{17}$ eV < E < $1x\ 10^{20}$ eV

The surface detector of the Pierre Auger Observatory is sensitive to potential point sources of UHE neutrinos.

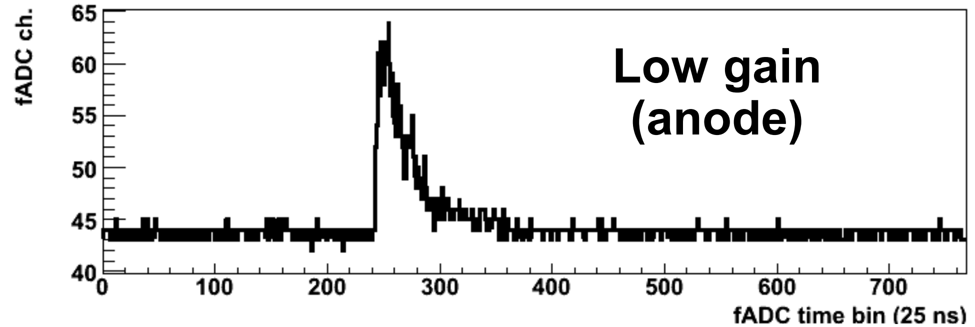
Tanks for your attention

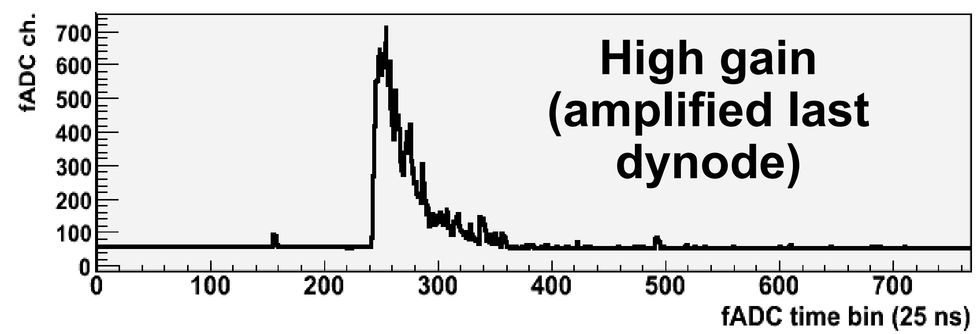
SD signals

3 photomultipliers detect the Cerenkov light emitted in the water

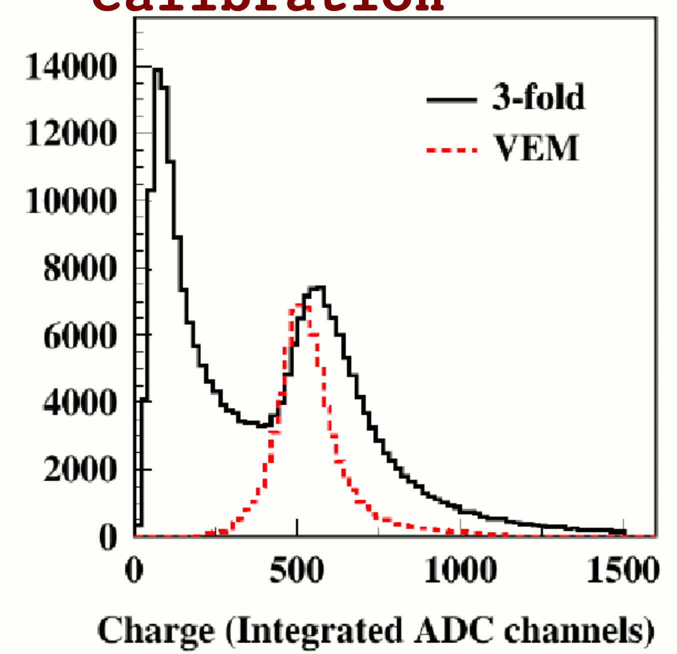
Two signals are extracted from each PMT

ratio ~32





calibration



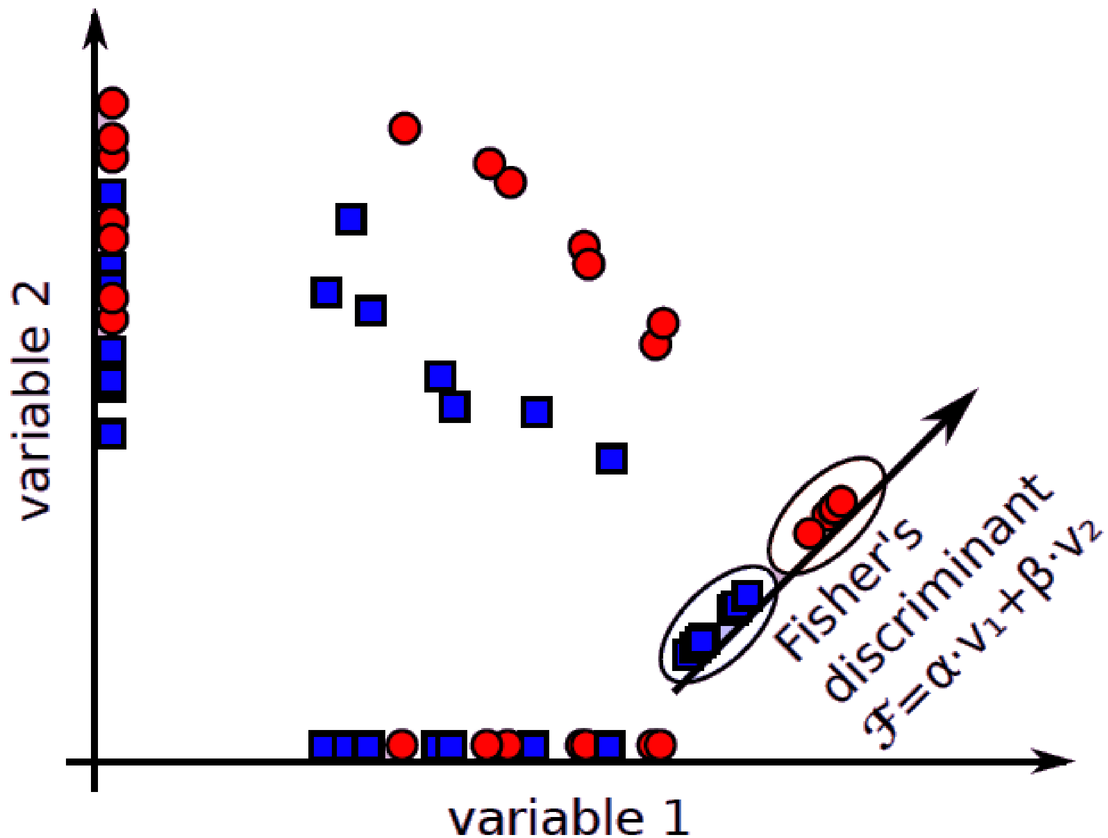
VEM = Vertical Equivalent Muon

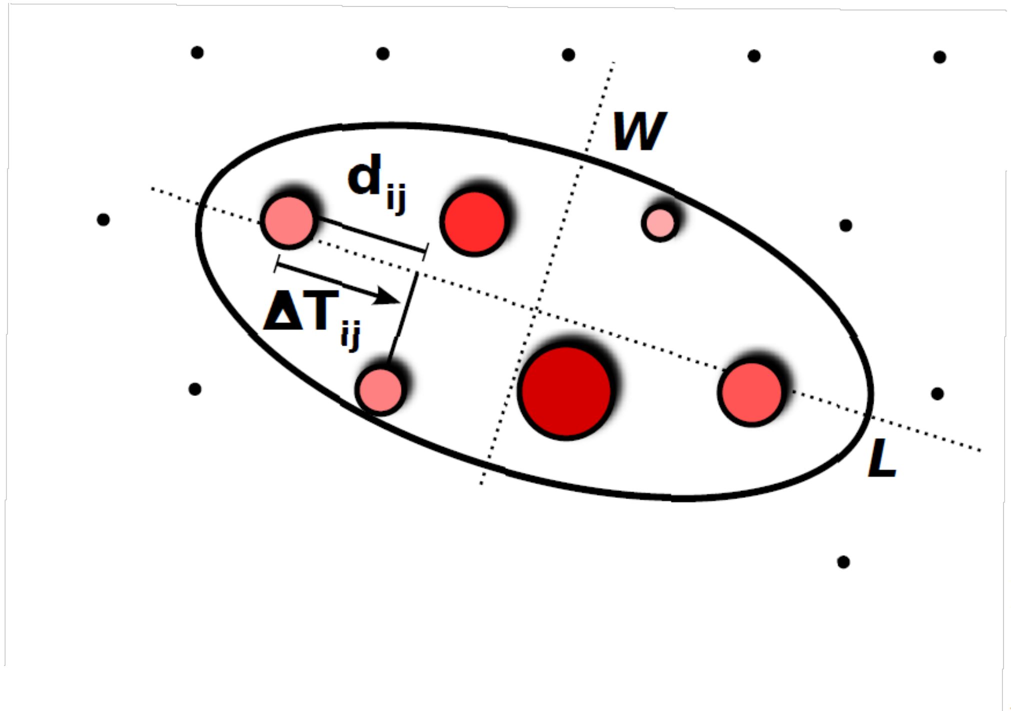
Average charge given by a vertical μ crossing the detector in its center

1 VEM ~ 100 pe/PMT

Multivariate fischer discriminant

Linear combination of observables (F) which optimizes the separation between two data samples





$$S = \Sigma_i s_i$$

$$\langle x \rangle = \frac{\Sigma_i s_i x_i}{S}$$

$$\langle y \rangle = \frac{\Sigma_i s_i y_i}{S}$$

$$I_{xx} = \frac{\Sigma_i s_i (x_i - \langle x \rangle)^2}{S}$$

$$I_{yy} = \frac{\Sigma_i s_i (y_i - \langle y \rangle)^2}{S}$$

$$I_{xy} = I_{yx} = \frac{\Sigma_i^n s_i (x_i - \langle x \rangle)(y_i - \langle y \rangle)}{S}$$

$$L^2 = \frac{I_{xx} + I_{yy} + \sqrt{(I_{xx} - I_{yy})^2 + 4I_{xy}^2}}{2S}$$

$$W^2 = \frac{I_{xx} + I_{yy} - \sqrt{(I_{xx} - I_{yy})^2 + 4I_{xy}^2}}{2S}$$

Sources of uncertainties on exposure

Parameter	Reference (A)	Modification (B)	RD $\frac{\int B - \int A}{(\int B + \int A)/2}$
Interaction generator	HERWIG	PYTHIA	-7 %
		HERWIG++	-7 %
PDF (generation level)	CTEQ06m	CTEQ66	+2 %
		MSTW08nlo	-6 %
		MSTW08nnlo	-7 %
Shower Simulator	AIRES	CORSIKA 6.9	-17 %
Hadronic Model	QGSJETII	QGSJETI	+2 %
		SIBYLL	-2 %
		SIBYLL (E = 0.3 EeV)	-1 %
		SIBYLL (E = 3 EeV)	-2 %
		SIBYLL ($\theta = 85°$)	0 %
		SIBYLL ($\theta = 89°$)	+4 %
Thinning	10^{-6}	10^{-7}	+7 %