The Abdus Salam International Centre for Theoretical Physics

2246-6

Workshop on Cosmic Rays and Cosmic Neutrinos: Looking at the Neutrino Sky

20 - 24 June 2011

UHE neutrino searches with the Pierre Auger Observatory

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UHE Neutrino searches with the Pierre Auger Observatory

Javier Tiffenberg[1] for the Pierre Auger Collaboration[2]

20 de junio de 2011

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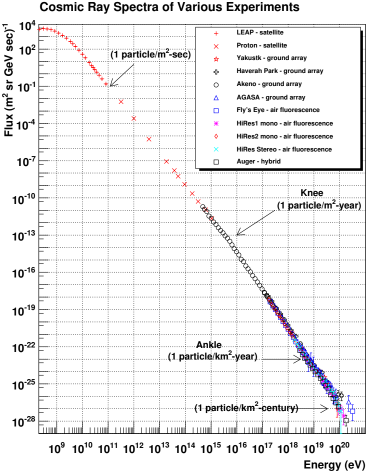
[2]Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina

Cosmic rays



CM energy

E_{lab}[eV]	E_{CM}[TeV]	Exp
10^{14}	0.8	SPS
10^{15}	2	Tevatr.
10^{16}	7	LHC
10^{17}	14	LHC?

Primary objective of the Pierre Auger Observatory

- **Energy:** Cutoff at the highest energies? Ankle?
  - Phys. Lett. B 685 (2010)
  - Phys. Rev. Lett 101 (2008)
- **Arrival direction:** Which are the UHECRs sources? Is the UHECR flux isotropic?
  - Astropart. Phys. 34 (2010)
  - Astropart. Phys. 29 (2008)
- **Mass composition:** Is the UHECR flux proton/iron-dominated?
  - Phys. Rev. Lett 104 (2010)

- **Neutrino and photon detection!**
  - Astropart. Phys. 31 (2009)
  - Phys. Rev. D 79 (2009)

The Observatory has also the capability to detect UHE ν and γ.

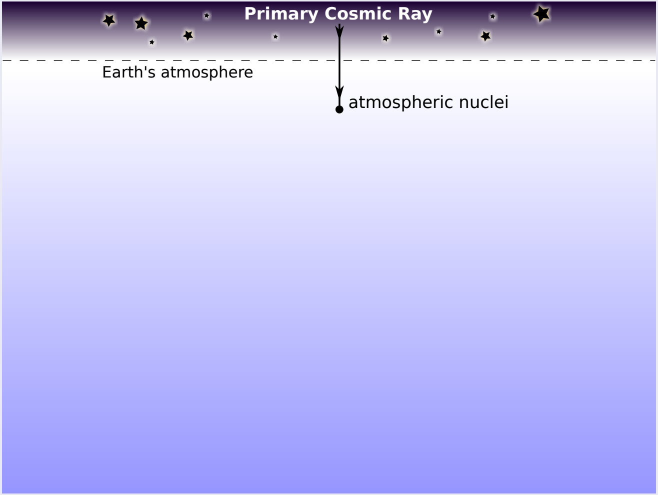
Origin of the UHEν

- Astrophysical Neutrinos
  - Neutrinos are expected as a product of pion decays produced in hadronic interactions of cosmic rays with radiation or matter near the astrophysical sources (AGNs, etc)
- Cosmogenic neutrinos
  - GZK neutrinos: produced by high-energy interactions of cosmic rays with the microwave background.
- New physic and "top-down" scenarios
  - Decay of ultra massive objects (topological defects, super heavy dark matter, Z burst..): harder spectrum & usually high ν and γ fluxes predicted.

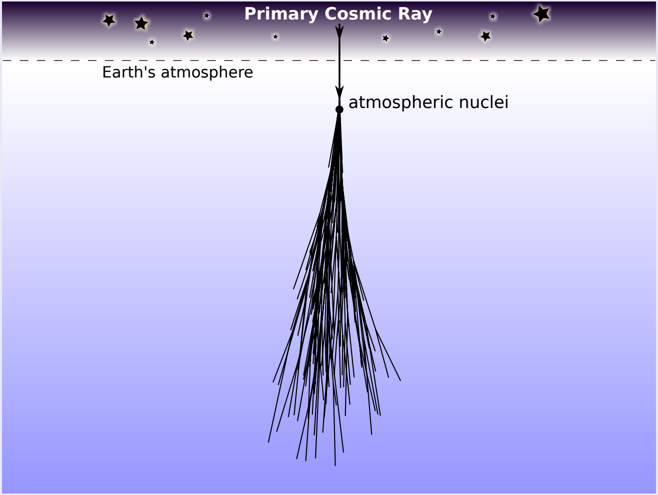
Neutrino astronomy

You know the advantages! (also the challenges involved!)

Extensive air showers



Extensive air showers



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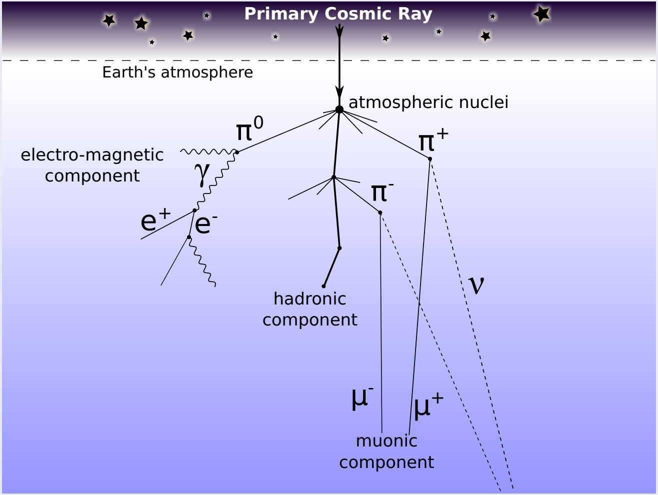

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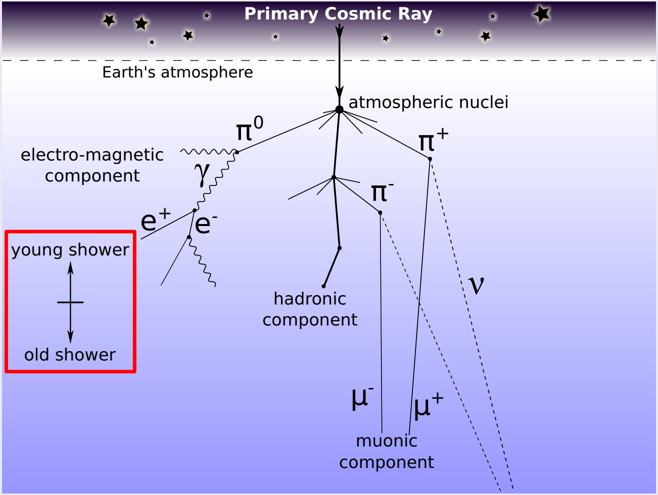

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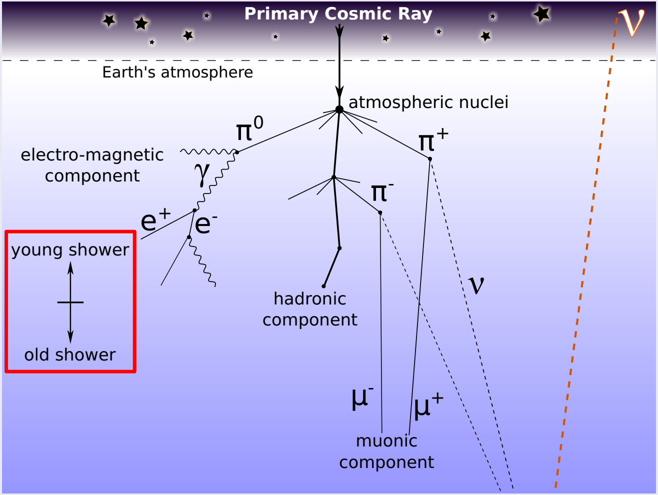
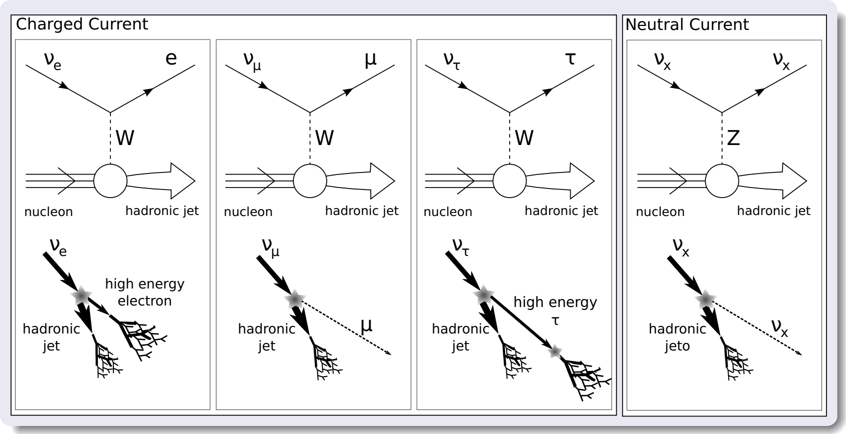
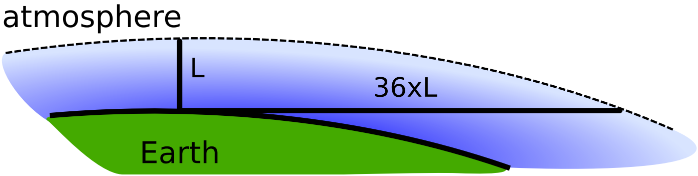


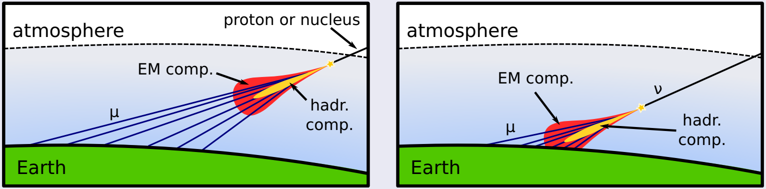
Atmospheric showers initiated by neutrinos



Identification of neutrino induced showers



High zenith angle showers



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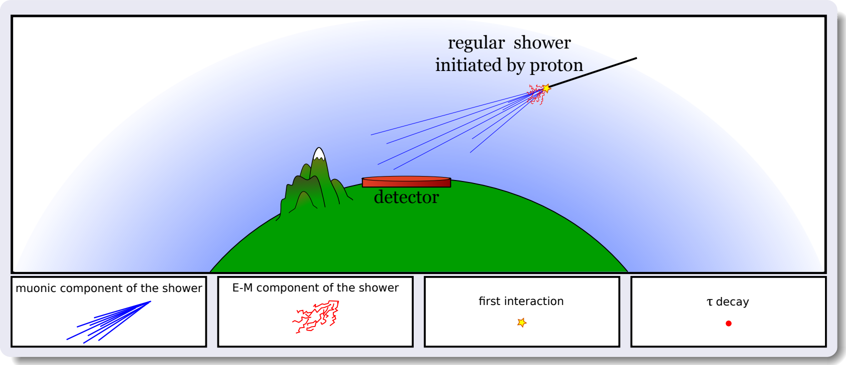

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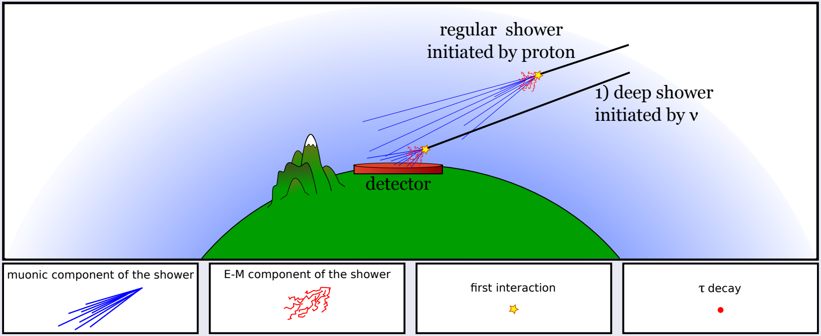

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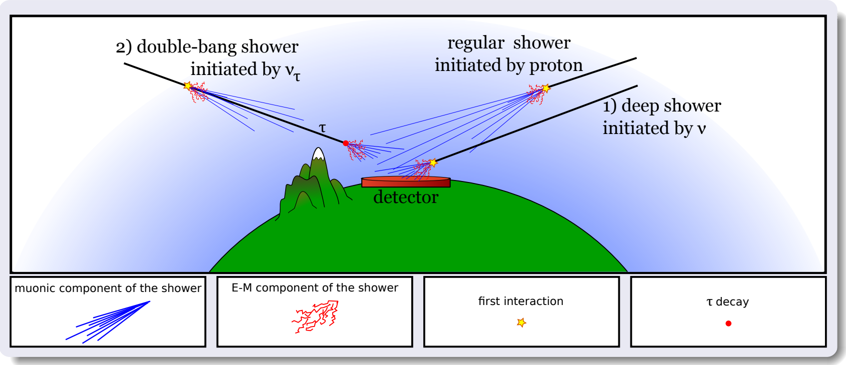

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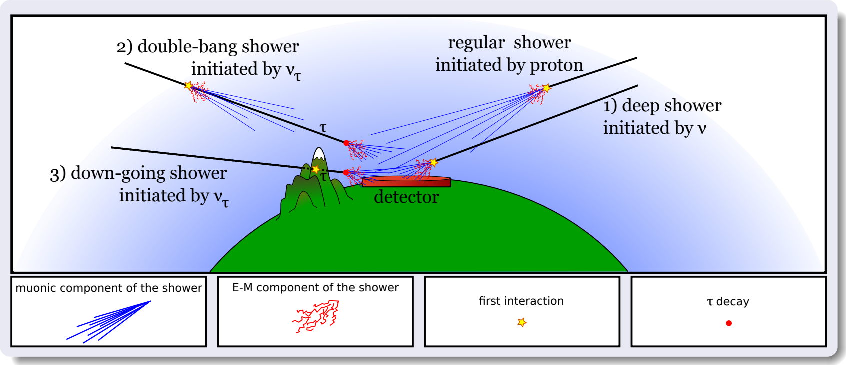

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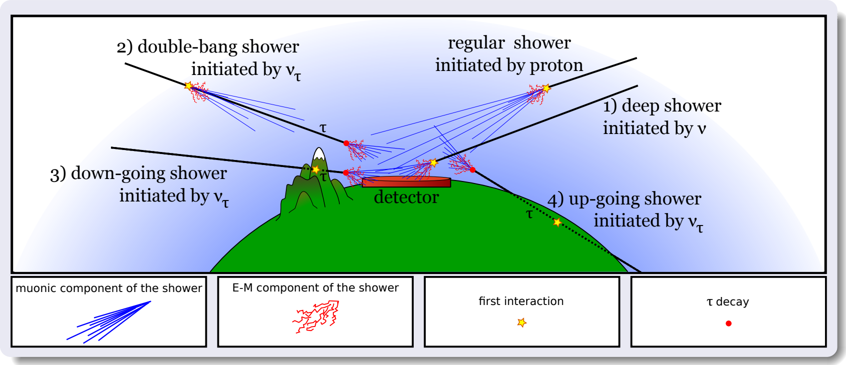

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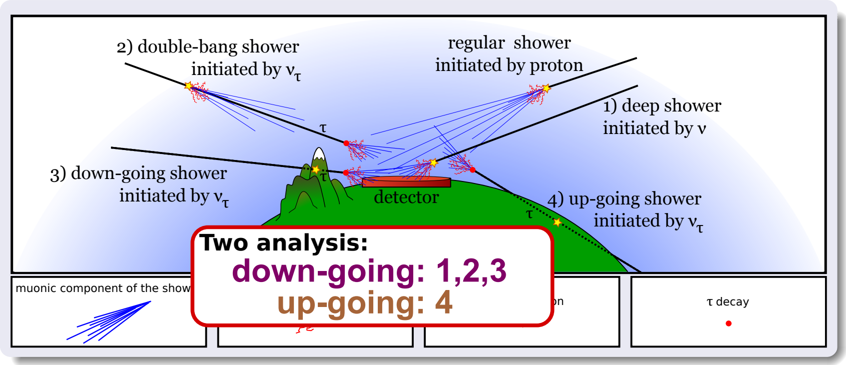
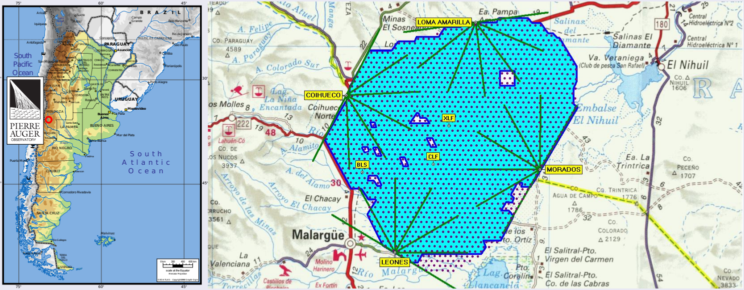
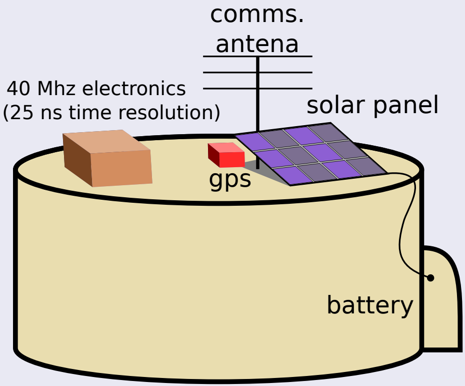


Pierre Auger Observatory



- hybrid detector.
  - Surface Detector (SD): ∼1600 stations over 3000 km^2.
  - Fluorescence Detector (FD): 4 eyes, 24 telescopes.
- construction completed in June 2008.

Water Cherenkov detectors: autonomous units



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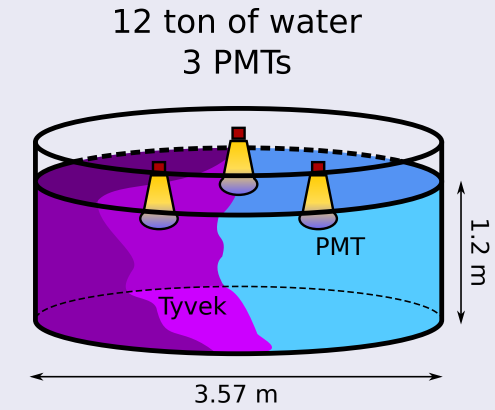
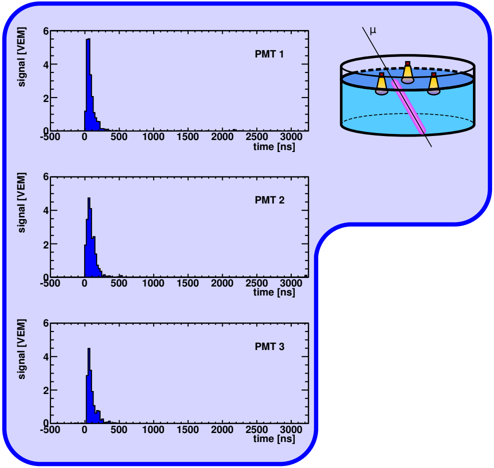


Signals produced by muons / EM component



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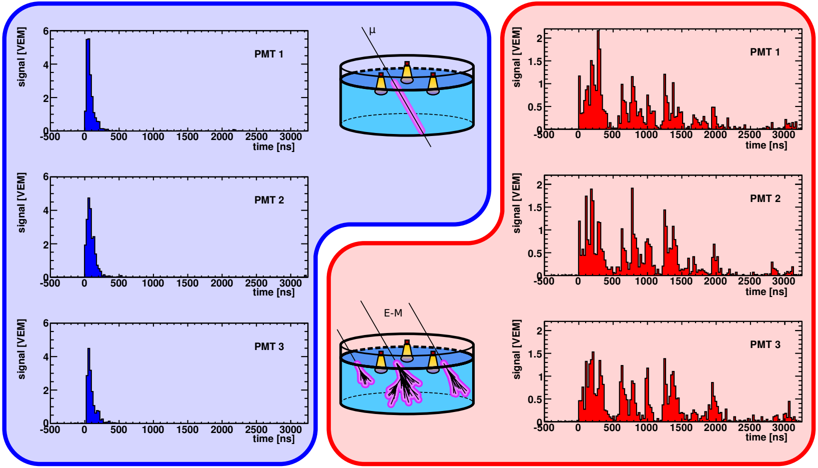
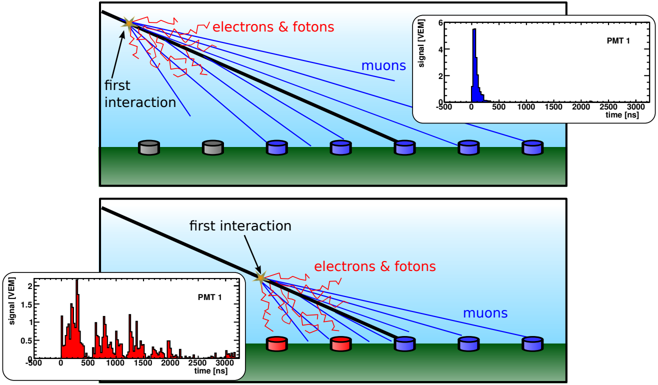


Identification basis



SIGNATURE

inclined shower with significant electromagnetic content, in the **early** part of the shower.

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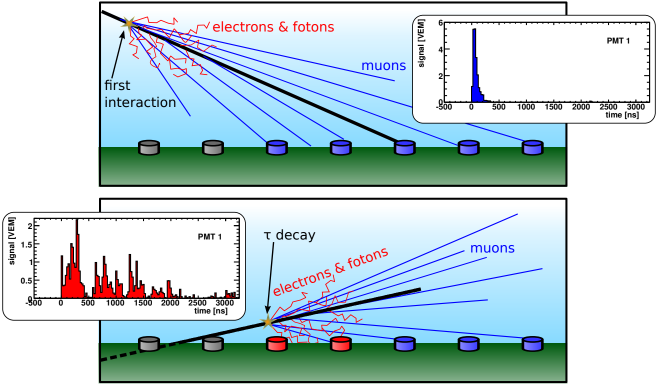

SIGNATURE

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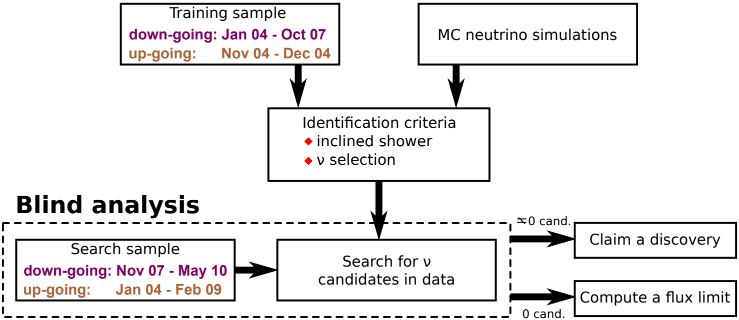
General neutrino search strategy

down-going & up-going

Two analysis, same approach



General neutrino search strategy

down-going & **up-going**

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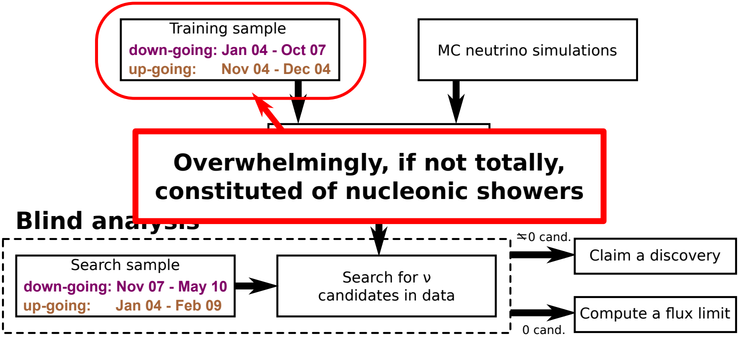

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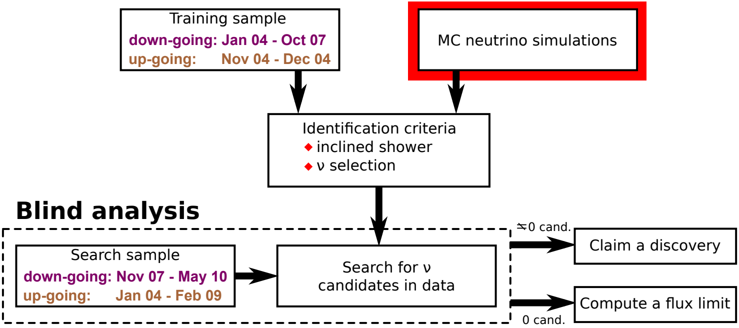
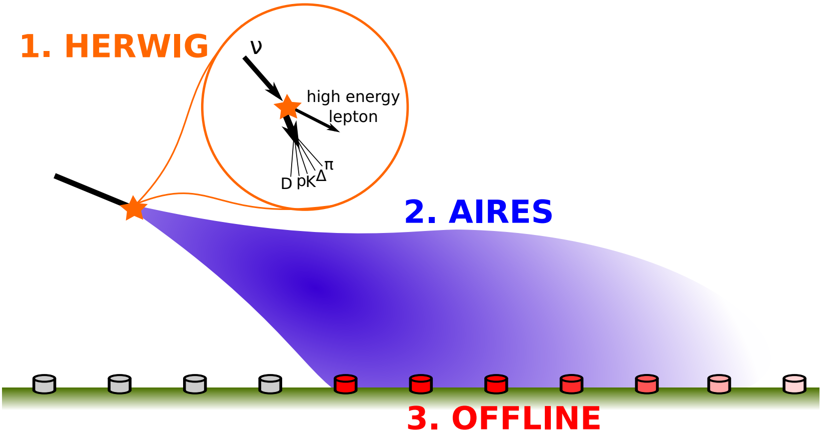


Monte Carlo simulations



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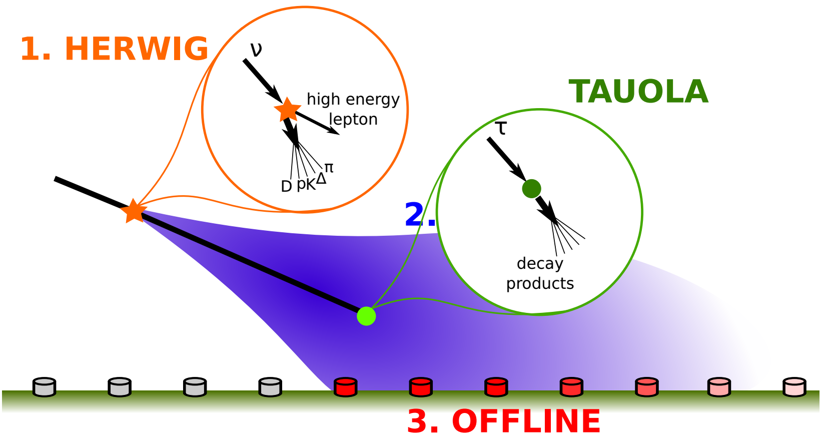

Simulations summary

CC e neutrino & NC all flavours

Energies (EeV): 0.06-0.1-0.3-1-3-10-30

Zenith angle	#Inj. pt.	Max. slant depth (g cm^{-2})
75°	30	2993
80°	30	3066
85°	30	3540
87°	30	4469
88°	30	5683
89°	30	8599

CC tau neutrino in the atmosphere

Energies (EeV): 0.06-0.1-0.3-1-3-10-30

Zenith angle	#Inj. pt.	Max. slant depth (g cm^{-2})
75°	33	3325
80°	48	4866
85°	84	8803
87°	123	12968
88°	165	16570
89°	218	22085

CC tau neutrino in the mountains

Energies (EeV): 0.1-0.3-1-3

Zenith angle	#Inj. pt.	Max. slant depth (g cm^{-2})
89°	20	8015
89.5°	18	7222
89.7°	12	4838

- $\sim$ one million events.
- weighted: $w \propto \cos\theta \sin\theta \, E^{-5/3}$

General neutrino search strategy

down-going & up-going

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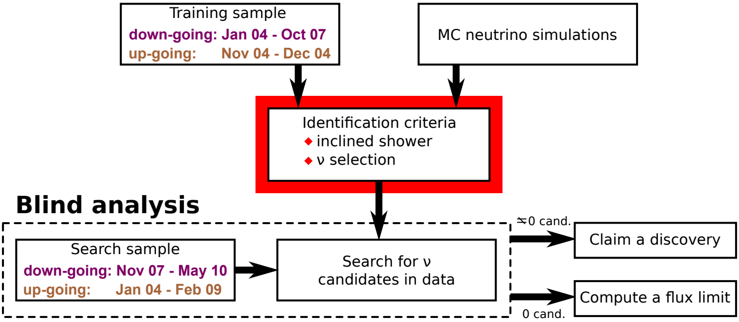
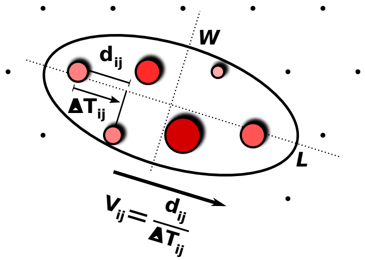
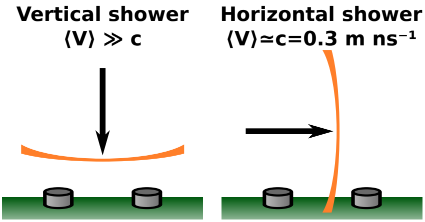


Inclined showers selection





Down-going

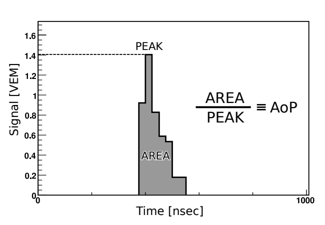
- elongated evt. $L/W \leq 3$
- signal speed $\langle V \rangle \leq 0.314$ m ns^{-1}
- $\langle V \rangle$ rel. err. $\leq 8\,\%$
- **Rec. zenith angle $\theta \geq 75°$**

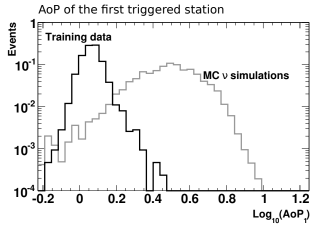
Up-going

- $L/W \leq 5$
- $0.28\,\mathrm{m\,ns}^{-1} \leq \langle V \rangle \leq 0.31\,\mathrm{m\,ns}^{-1}$
- $\mathrm{SD}(\langle V \rangle) \leq 0.08\,\mathrm{m\,ns}^{-1}$

Young showers selection: discriminating variables

Area Over Peak (AoP)





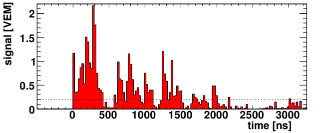
ToT trigger

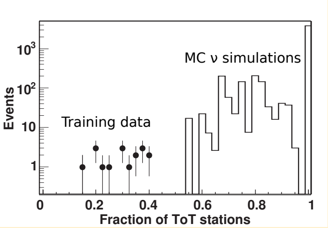
Time over Threshold trigger: ToT

13 bins over 0.2 VEM in a 3 μs window

+

AoP > 1.4





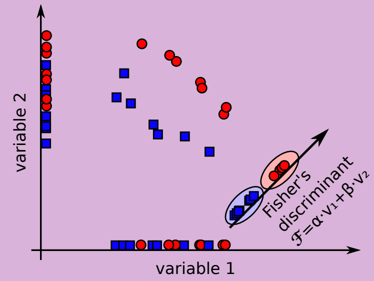
Young showers selection: two different approaches

Down-going

MVA-Analysis: Fisher

10 discriminating variables

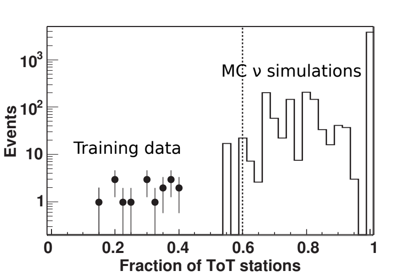
- AoP of first 4 stations.
- Asym par: ⟨early AoP⟩-⟨late AoP⟩
- Non linear transf of them.



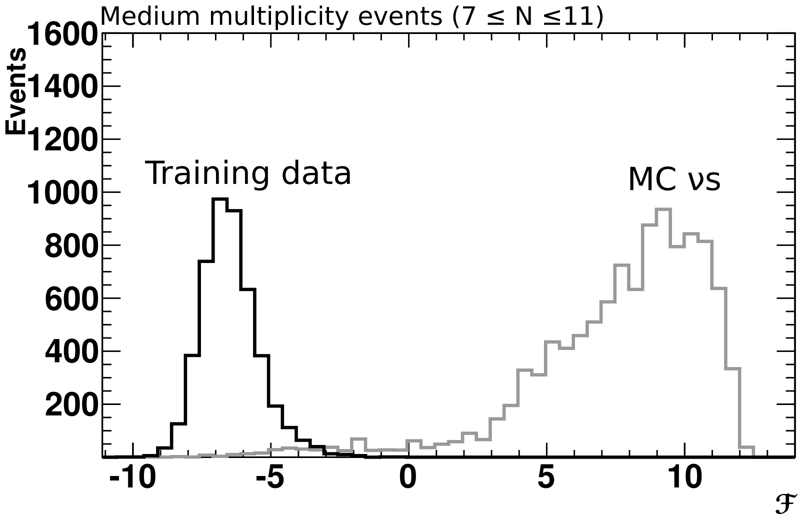
Up-going

Rectangular cut

Percentage of ToT triggered stations (selects broad signals) + high AoP



Down-going: after training



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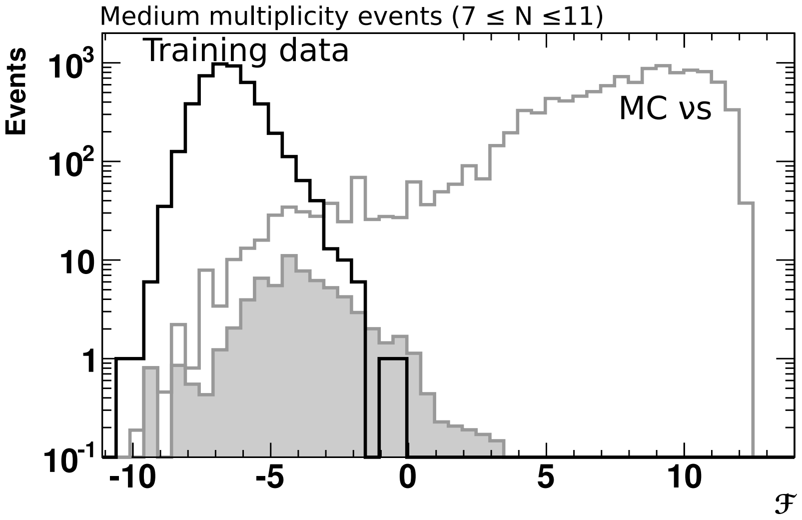

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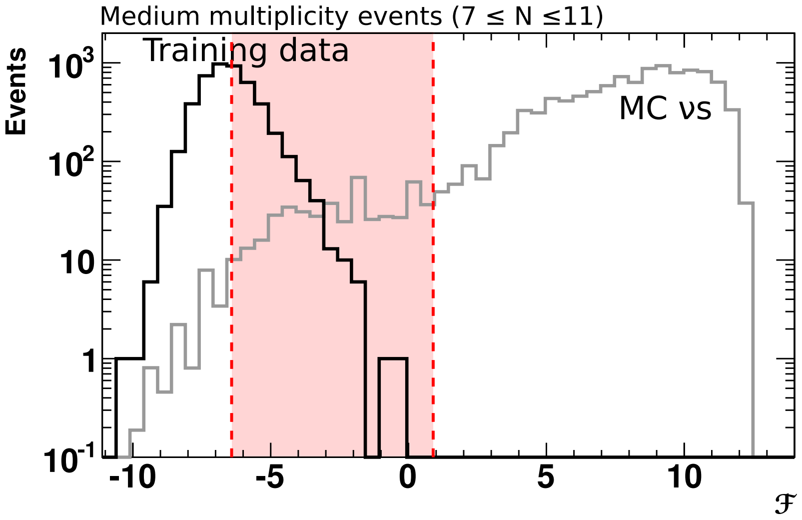
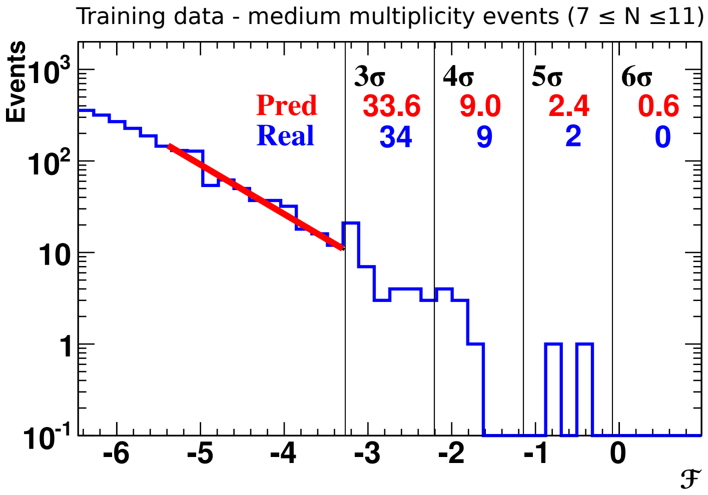


Down-going: estimation of the background due to misclassification



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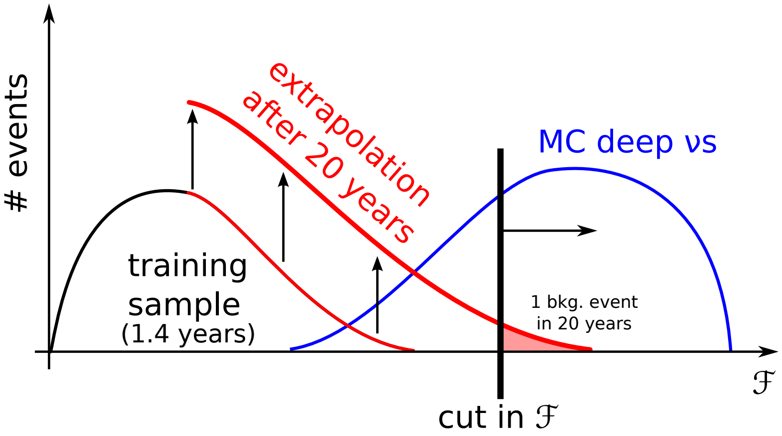

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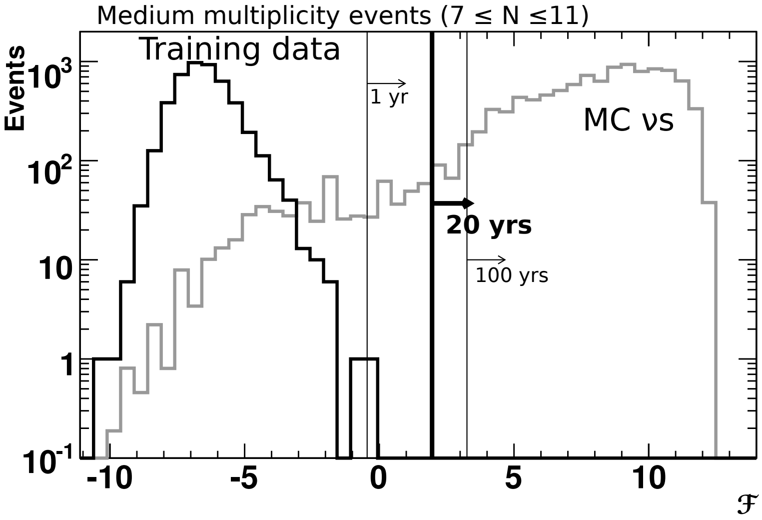
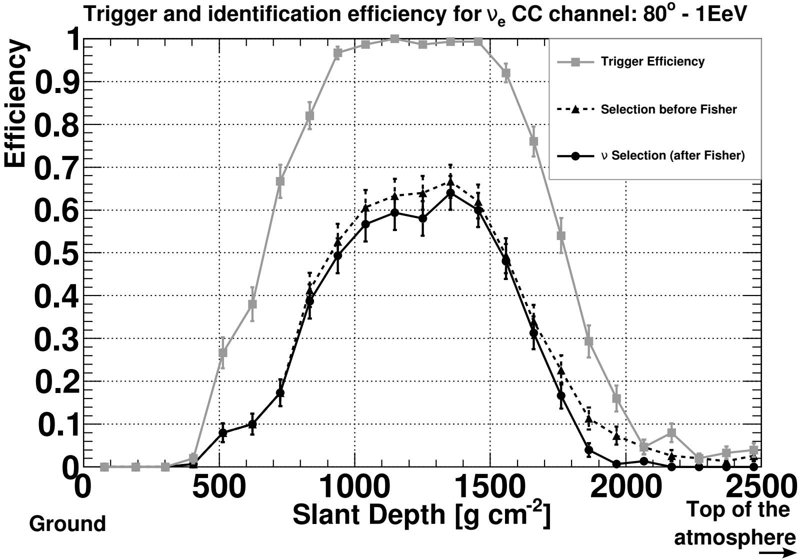


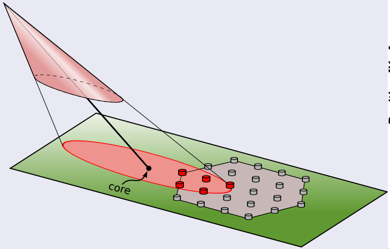
Down-going: identification efficiency

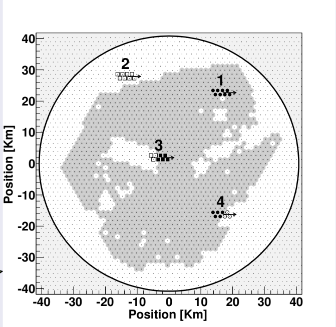


Exposure

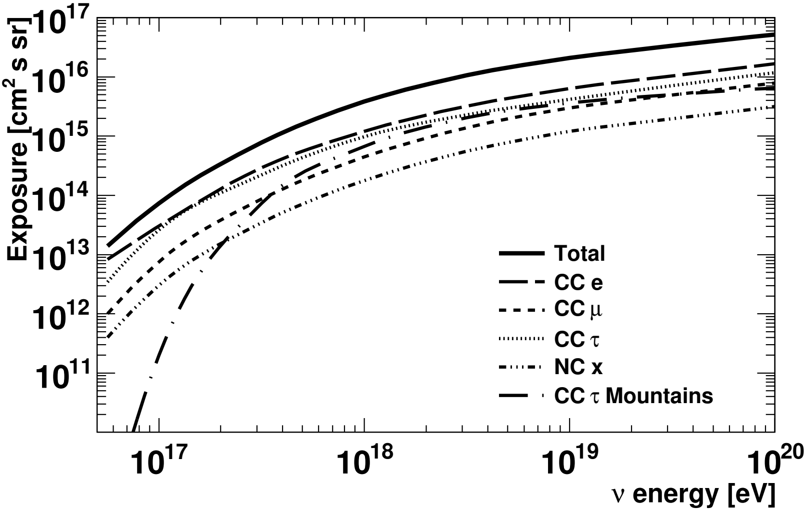
MC ν events are used to compute the exposure of the SD

- we take into account the contribution from showers falling outside the SD.
- that the array configuration varies with time.





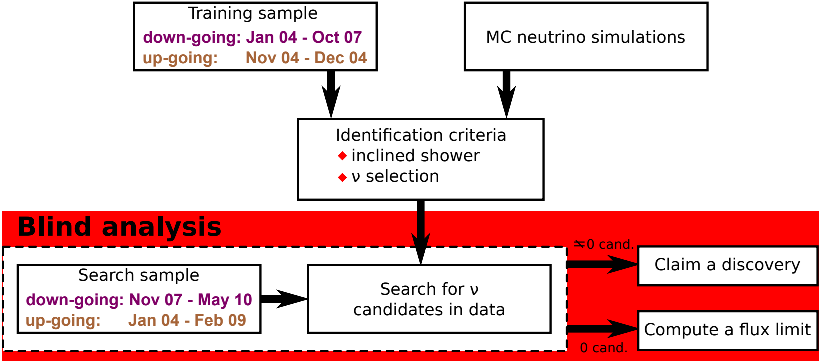
Down-going: exposure for the search period



General neutrino search strategy

down-going & **up-going**

Two analysis, same approach



Opening the box

After unblinding:

0

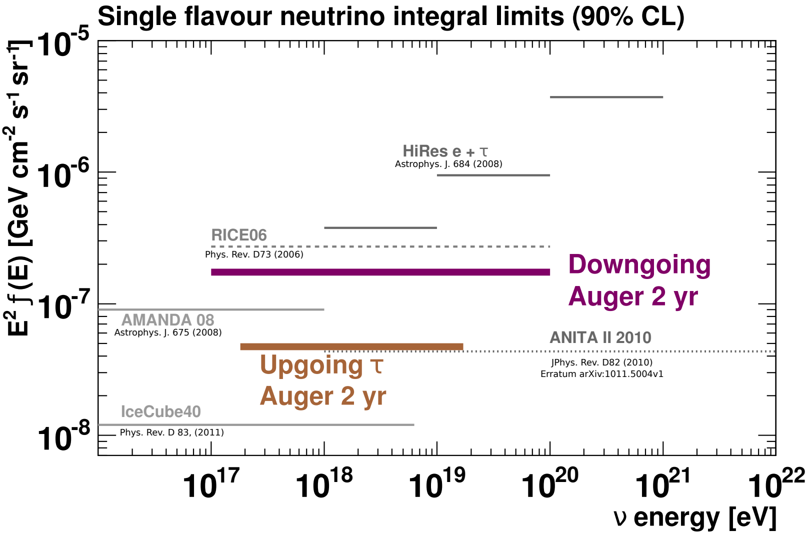
candidates for the search periods.

search periods

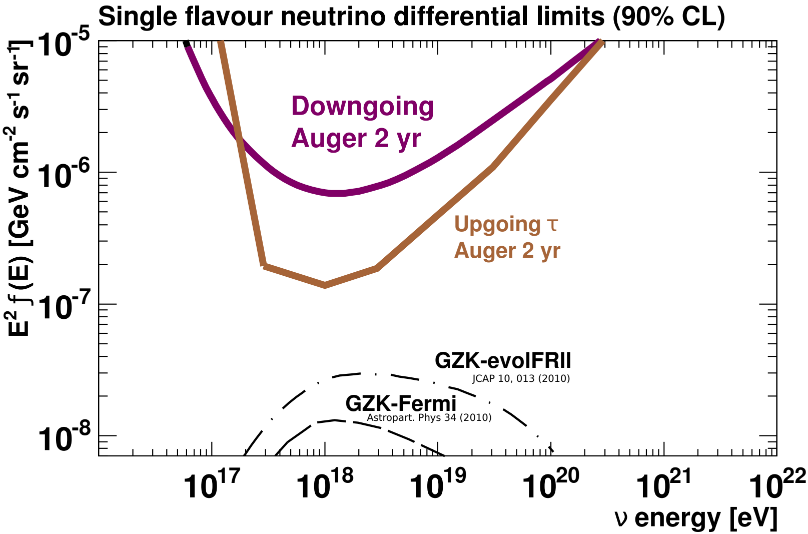
Down-going	:	Nov 07	to	May 10
Up-going	:	Jan 04	to	Feb 09

Both periods are equivalent to 2 yrs. full Auger

Integral limit



Differential limit



Summary

- The Pierre Auger Observatory is sensitive to UHE neutrinos:
  - down-going neutrinos ($\theta \in [75^\circ, 90^\circ]$): all flavours CC & NC.
  - up-going neutrinos ($\theta \in [90^\circ, 95^\circ]$): ν_τ CC.
- Signature: very inclined showers with significant E-M content.
- ZERO neutrino candidate events found in data.
- Maximum sensitivity at the most relevant range for GZK neutrinos (1 EeV).
- Competitive limits on UHE flux.
- Updated limits will be presented at the ICRC2011 (including limits to point-like sources of UHE neutrinos)

BACK UP SLIDES

Systematic uncertainties

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 ($\theta = 85^\circ$)	0 %
		SIBYLL ($\theta = 89^\circ$)	+4 %
Thinning	10^{-6}	10^{-7}	+7 %

Down-going: expected event rate.

Model	N_{exp}
GZK-Fermi	0.12
GZK-evolFRII	0.30
MPR-max	2.08
BBR	0.89
TD-Necklaces	0.84
SHR	8.16

$$N^{\nu}_{\mathrm{exp}} = \int_{E_{\mathrm{min}}}^{E_{\mathrm{max}}} \Phi(E_\nu)\,\mathcal{E}(E_\nu)\,\mathrm{d}E_\nu$$