ULTRA-HIGH ENERGY NEUTRINO LIMITS FROM THE PIERRE AUGER OBSERVATORY

Olivier Deligny, CNRS/IN2P3 - IPN Orsay
for the Auger collaboration

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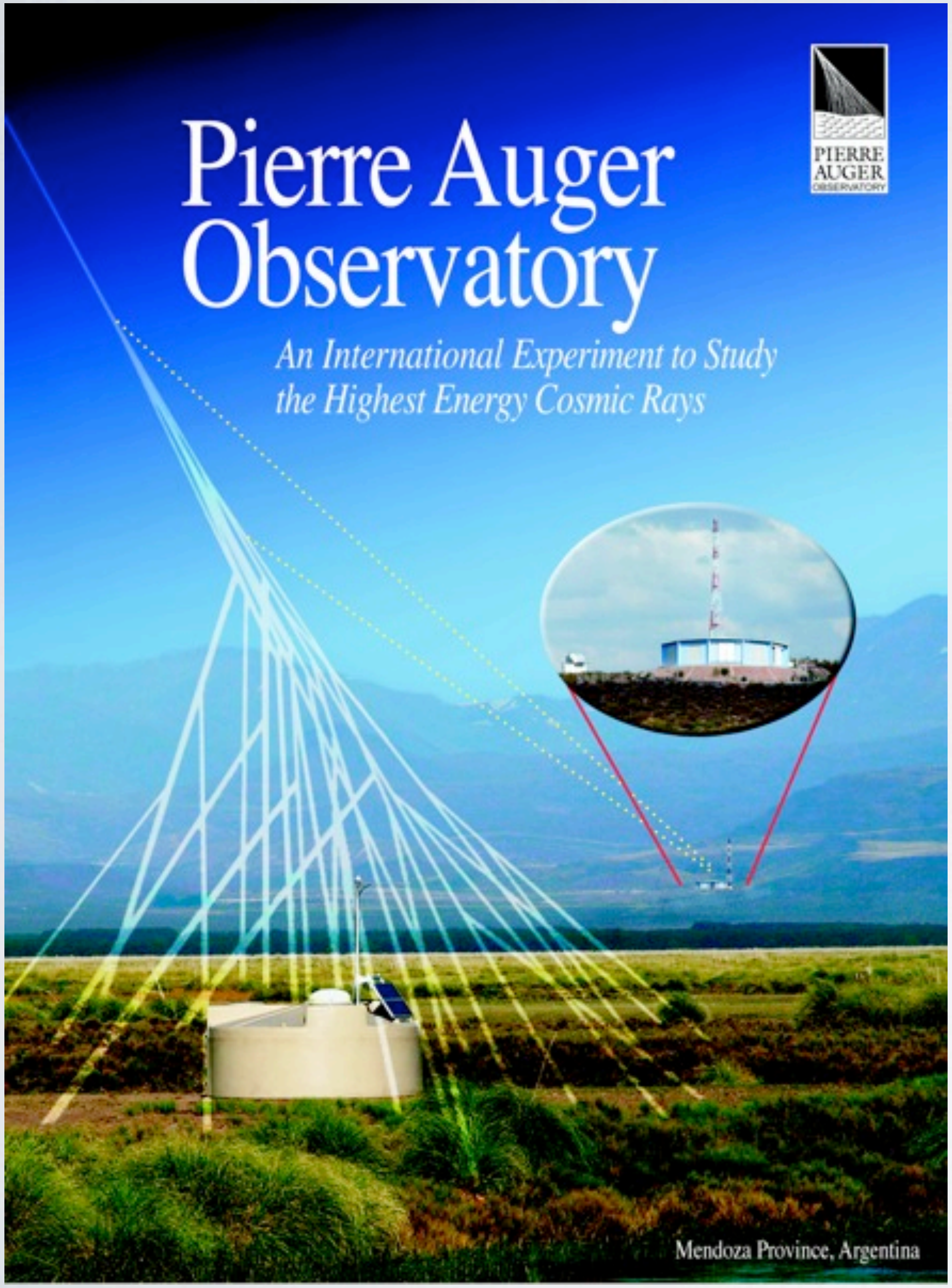
UHE NEUTRINOS

In the EeV range, neutrinos are expected to be produced :
- in the same sources where UHECRs are thought to be accelerated
- during the propagation of UHECRs through the CMB (if the UHECRs above the spectrum cut-off contain a significant fraction of protons)

Neutrinos propagate in straight line over cosmological distances (point back to the source (or GZK interaction point...))

The Pierre Auger Observatory is sensitive to UHE neutrinos through horizontal air showers in the EeV energy range

THE PIERRE AUGER OBSERVATORY



A *hybrid* detector:

Surface Detector Array of 1600 water tanks sampling the lateral profile of the Extensive Air Showers

Air Fluorescence Detector of 4 Telescopes sampling the longitudinal profile of the EAS

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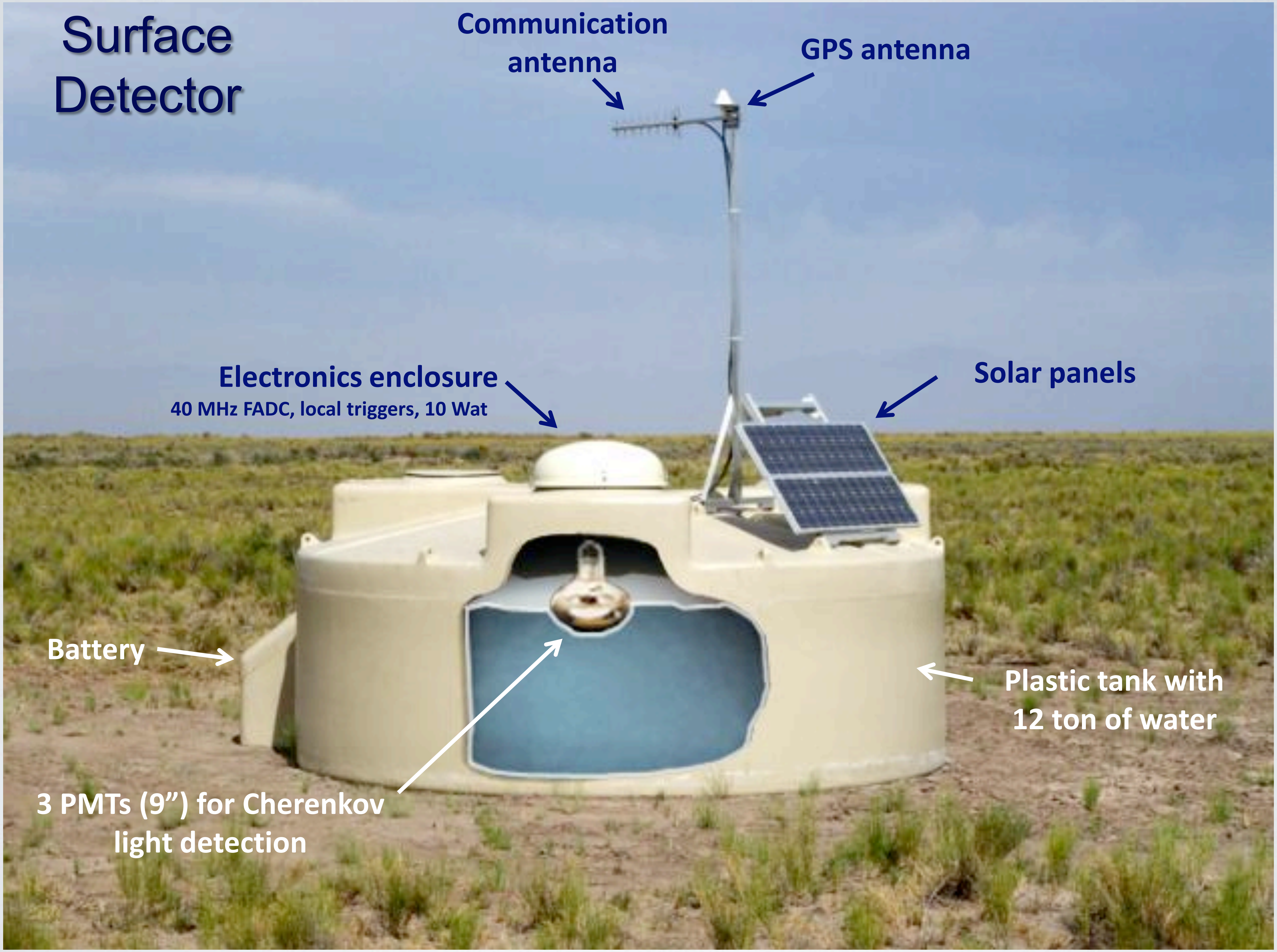
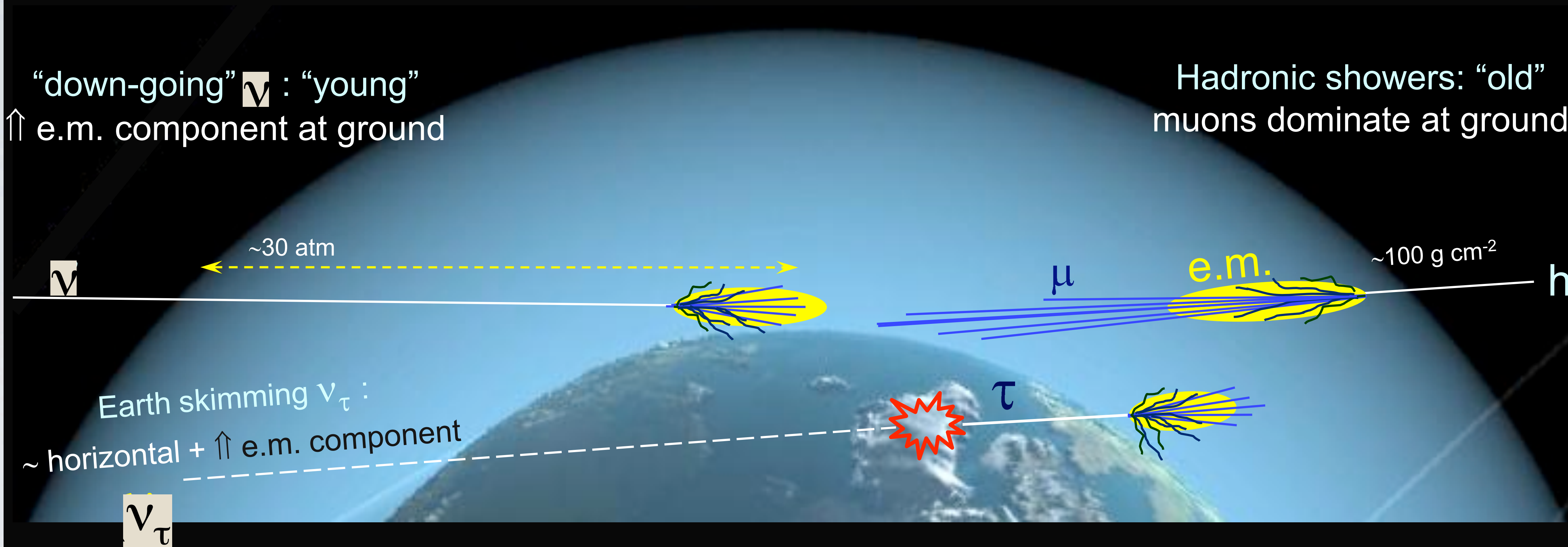
This allows cross-calibration to be performed on set of showers detected at the same time by both detectors

THE AUGER OBSERVATORY: *SURFACE DETECTOR*



NEUTRINO-INDUCED SHOWERS



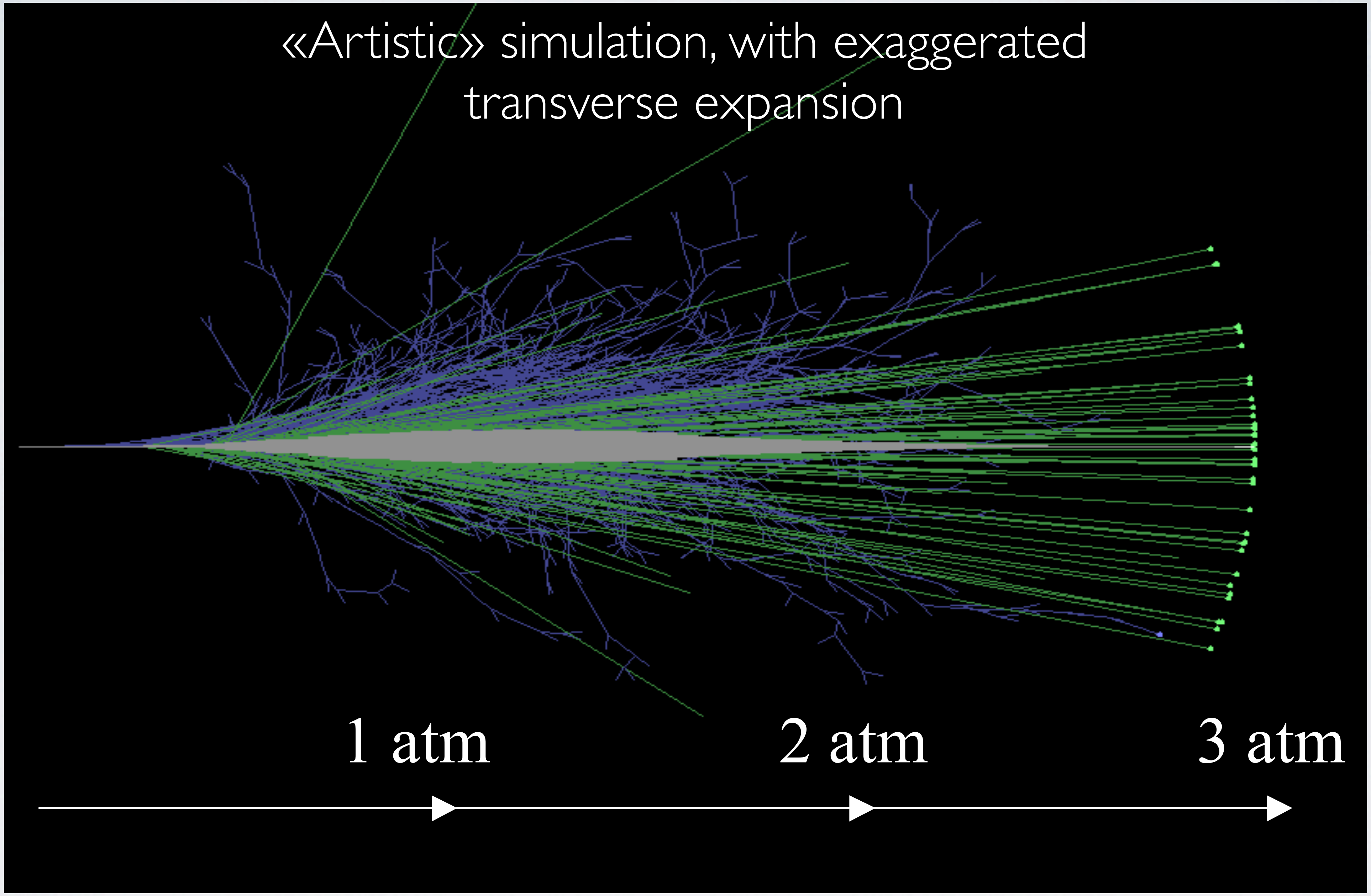
"down going" neutrinos

- ↑ Sensitivity to ALL ν flavours
- ↑ Sensitive to ALL interaction channels (CC & NC)
- ↑ Large solid angle (60° → 90°)
- ↓ Dilute mass target (air)

"Earth skimming" tau neutrinos

- ↑ ν_τ travels long distances in the Earth without losing too much E before decay
- ↓ Sensitivity to ν_τ CC channel
- ↓ Small solid angle (few degrees)
- ↑ Dense mass target (Earth crust)

ATMOSPHERIC SHOWER DEVELOPMENT

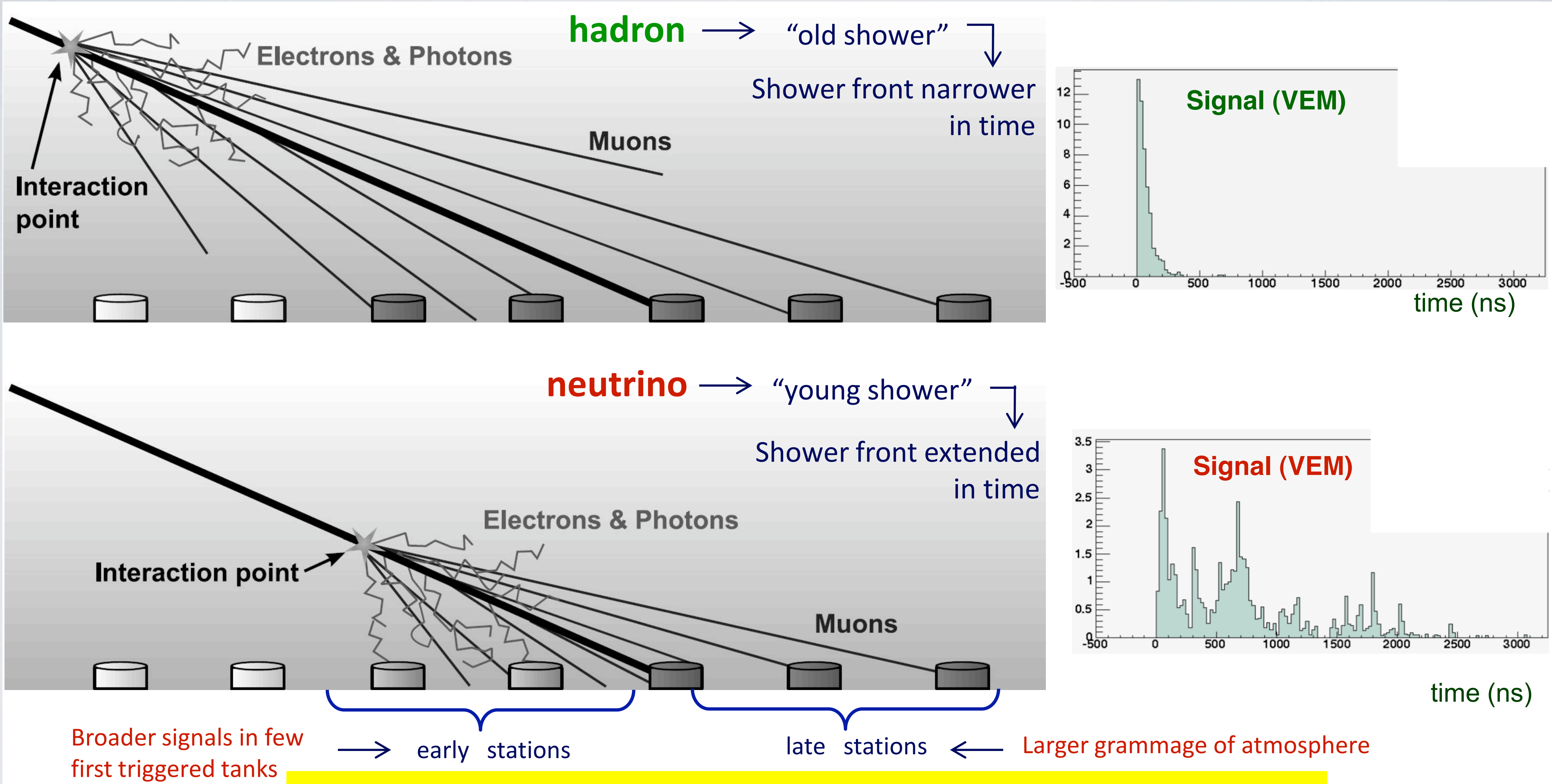


Evolution of the shower front shape:

curved and thick when *young*

flatter and thin when *old*

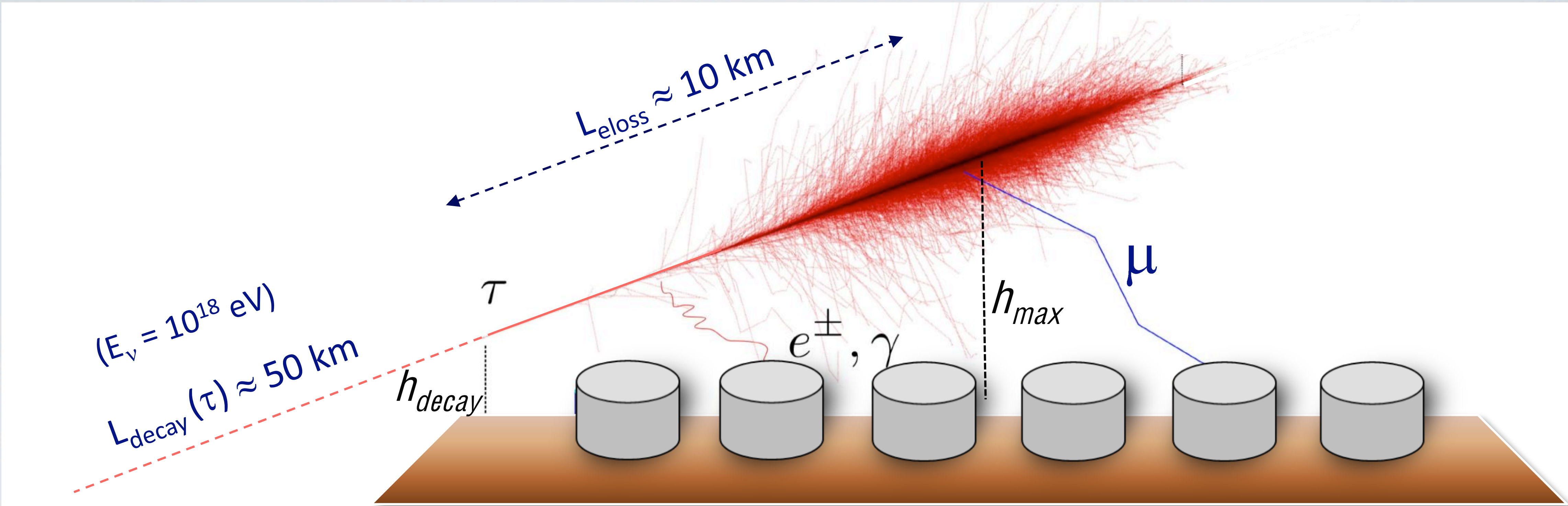
DOWN-GOING NEUTRINO FEATURES



<u>Distinguishable signature :</u>

inclined shower showing a *young* behaviour mainly in the early part of the shower

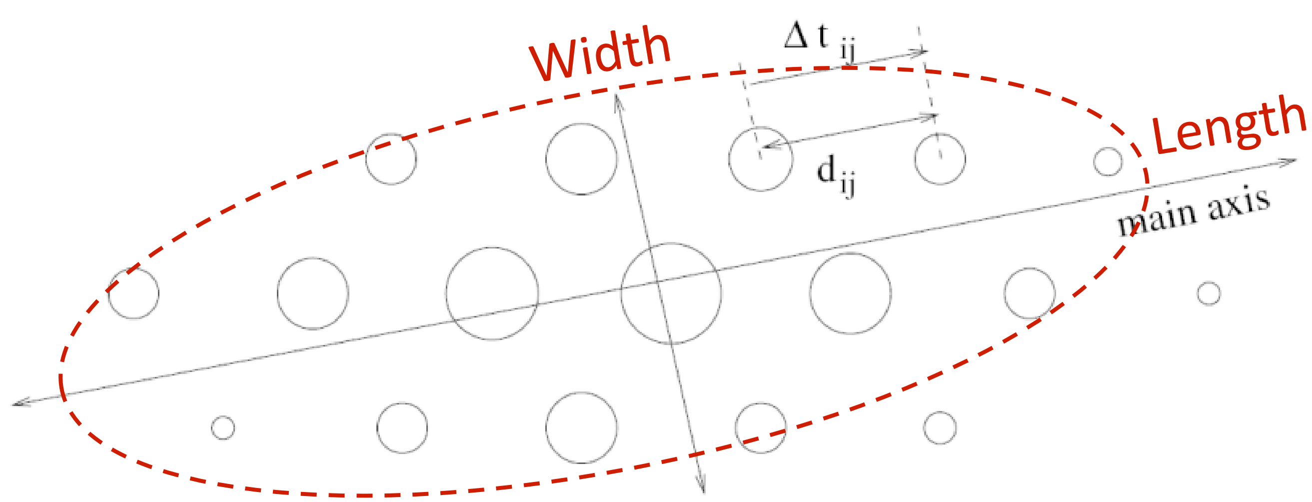
EARTH-SKIMMING TAU-NEUTRINO FEATURES



broad signals in time

- "ToT triggers" large
- "L/W" big
- "<signal speed>" $\sim c$

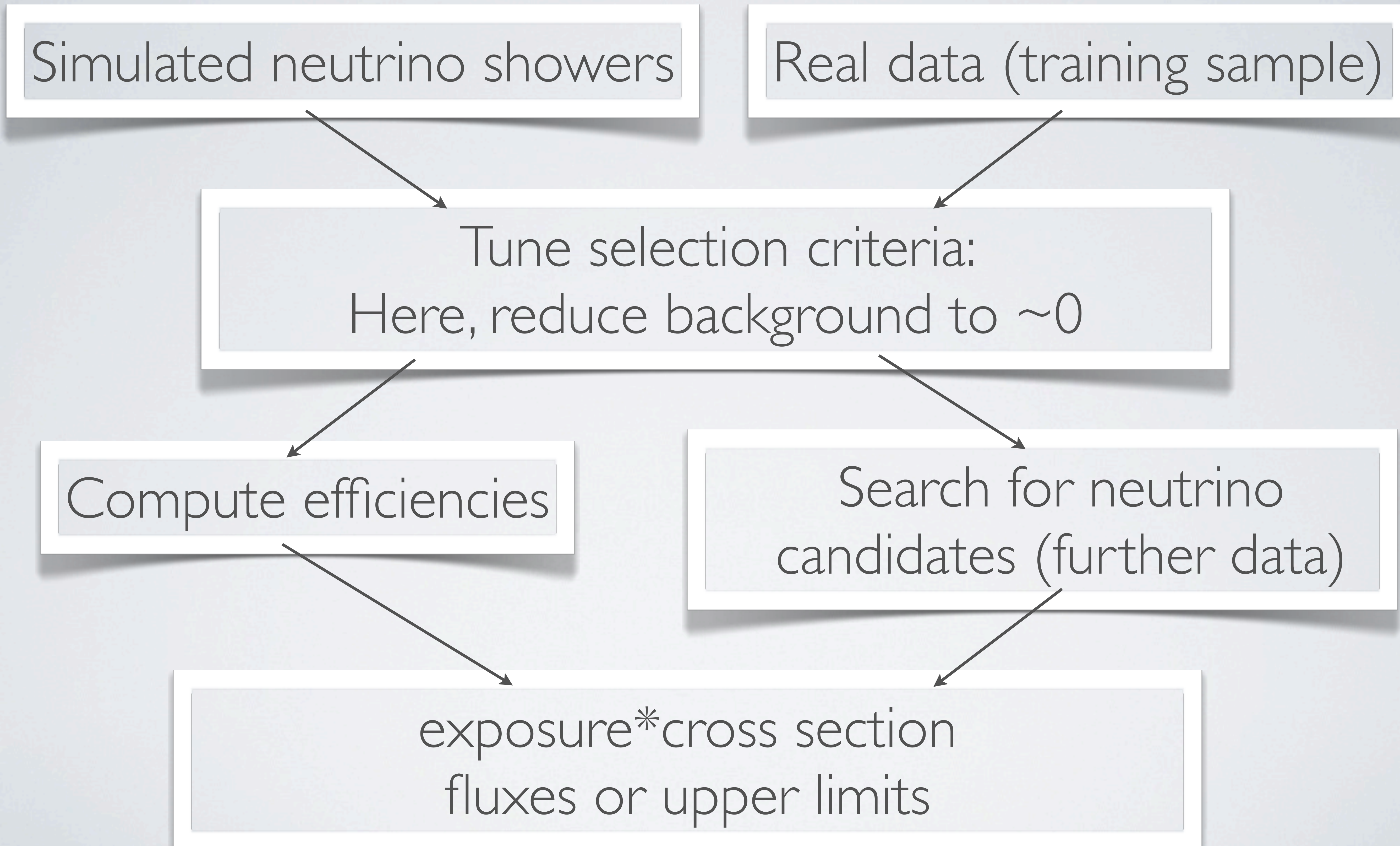
horizontal shower



Distinguishable signature :

almost horizontal and *young* shower

STRATEGY TO OBTAIN FLUXES/UPPER LIMITS



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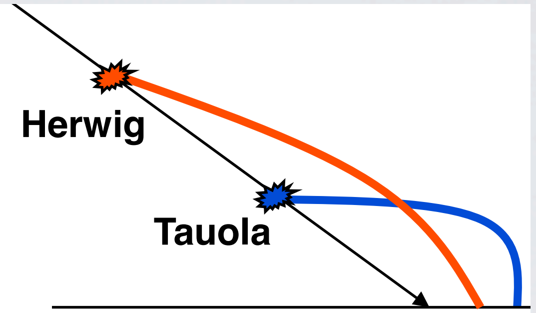
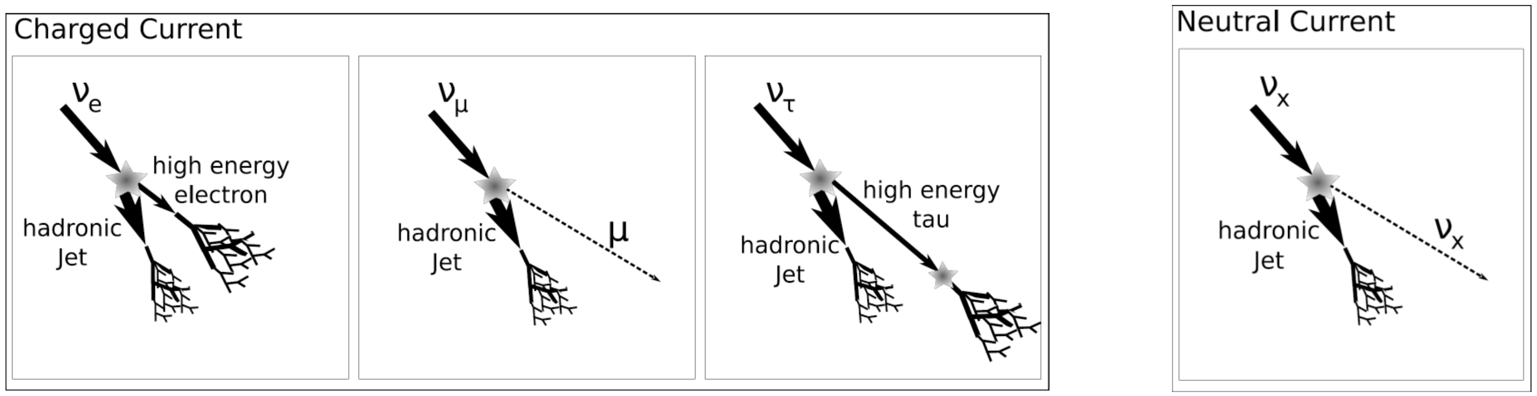
NEUTRINO SIMULATION CHAINS

- First interaction: HERWIG
- Tau decay: TAUOLA
- Shower development: AIRES 2.8.0 + QGSjetII.03
- Detector simulation: AUGER Offline
- All flavours (ν_e , ν_μ , ν_τ) and channels (NC & CC):





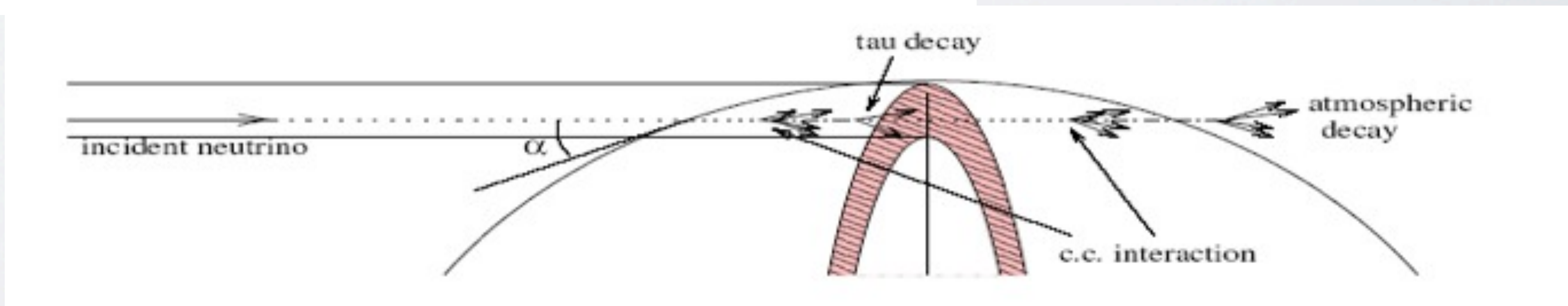
~ 150.000 showers ~ 200.000 showers ~ 150.000 showers

DOWN-GOING

Parameters of simulations:

- Energy: E = 10^{16} eV – 10^{20} eV
- Zenith: $\theta_{down\text{-}going}$ = 75° – 89° (6 bins in sec(θ))
- Depth of 1st interaction: X_{inj} = 0 – 8000 g cm^{-2} (slanted from ground)

EARTH SKIMMING :



DOWN-GOING SELECTION CUTS

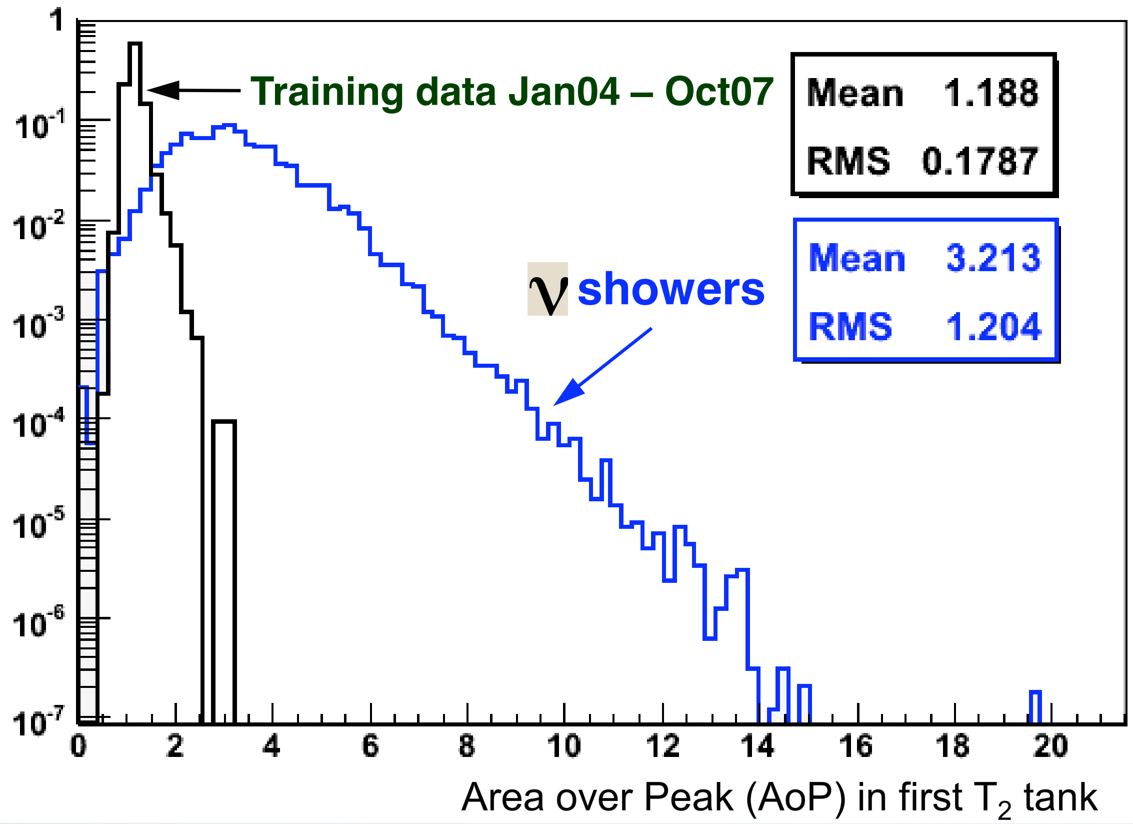
Inclined selection
➢ $\theta_{rec} > 75^o$
➢ *<signal speed>* < 0.313
Quality cuts
➢ <signal speed> relative error < 0.08
➢ L/W > 3

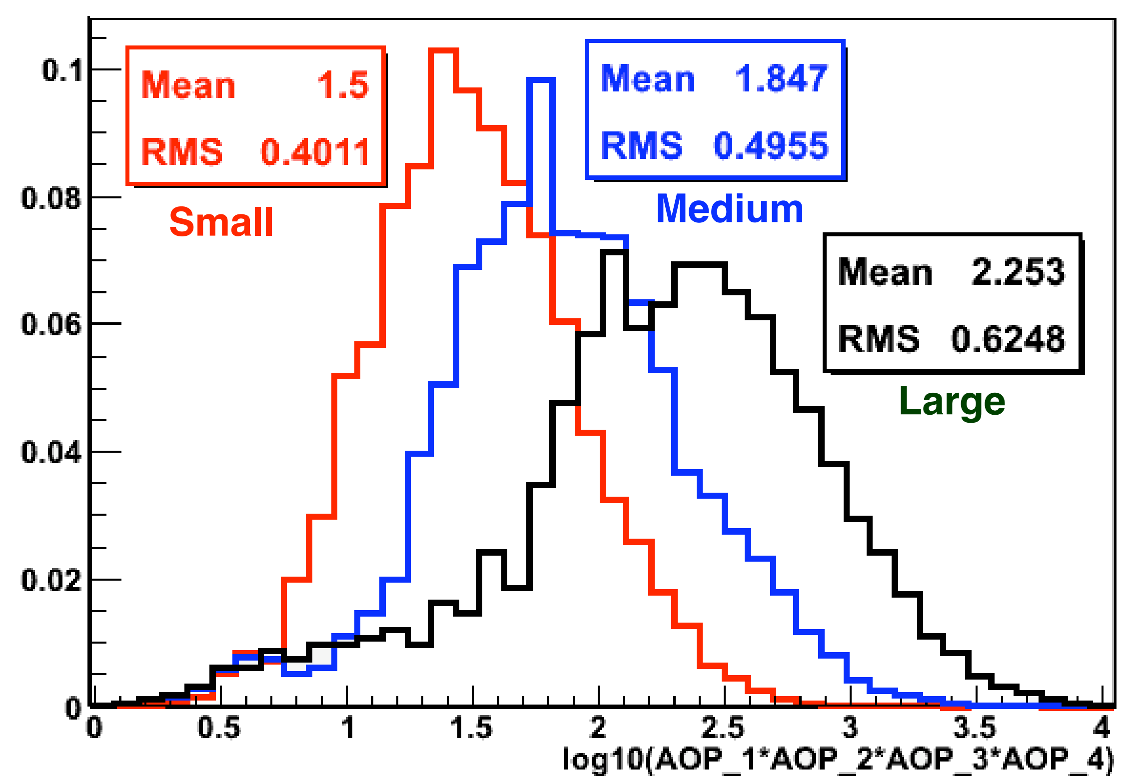
"Fisher" analysis →

- First 4 AoP (**A**rea **o**ver **P**eak)
- First 4 $(AoP)^2$
- Product of the first 4 AoP
- <Early AoP> – <Late AoP>

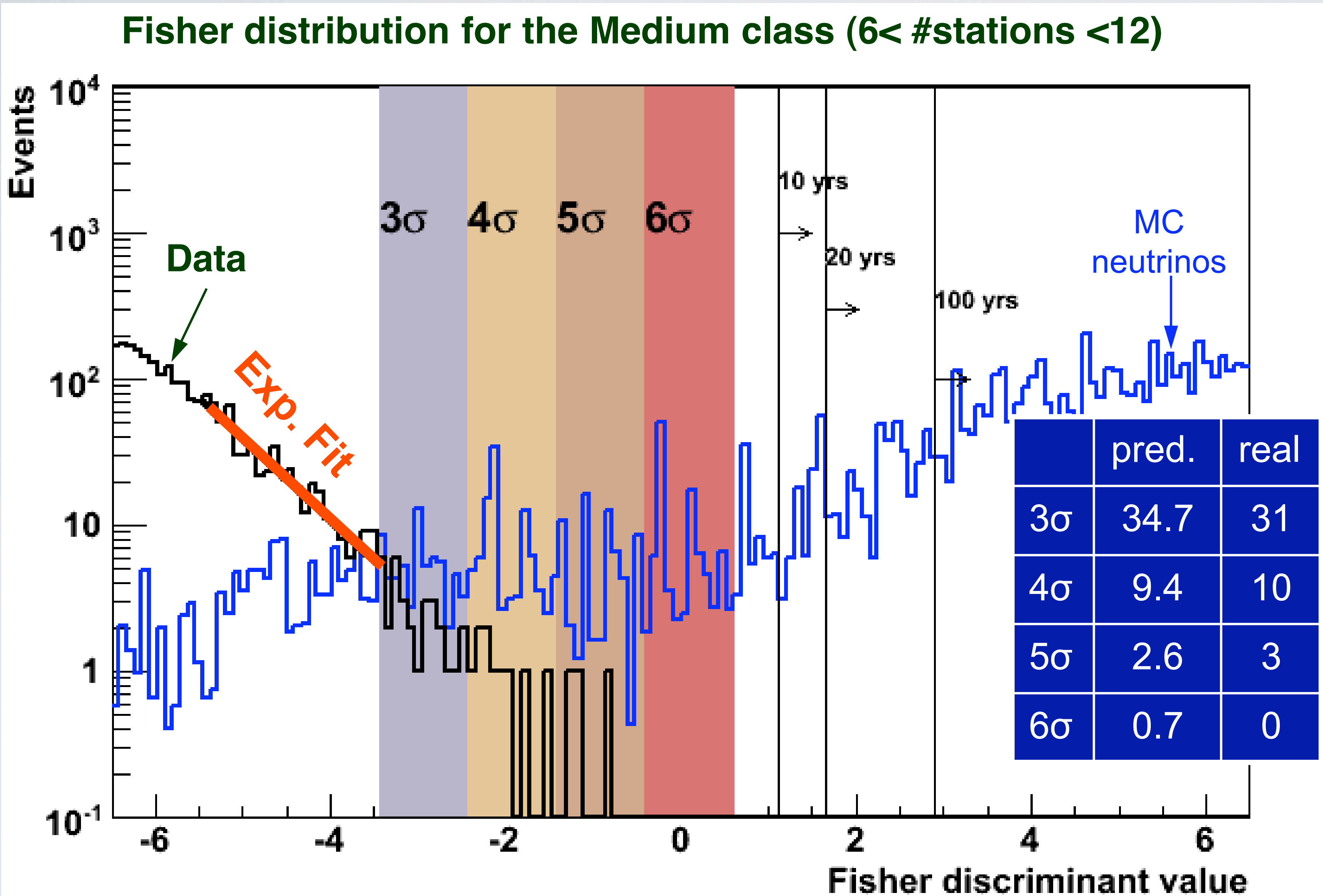
3 classes

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





FISHER CUT



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

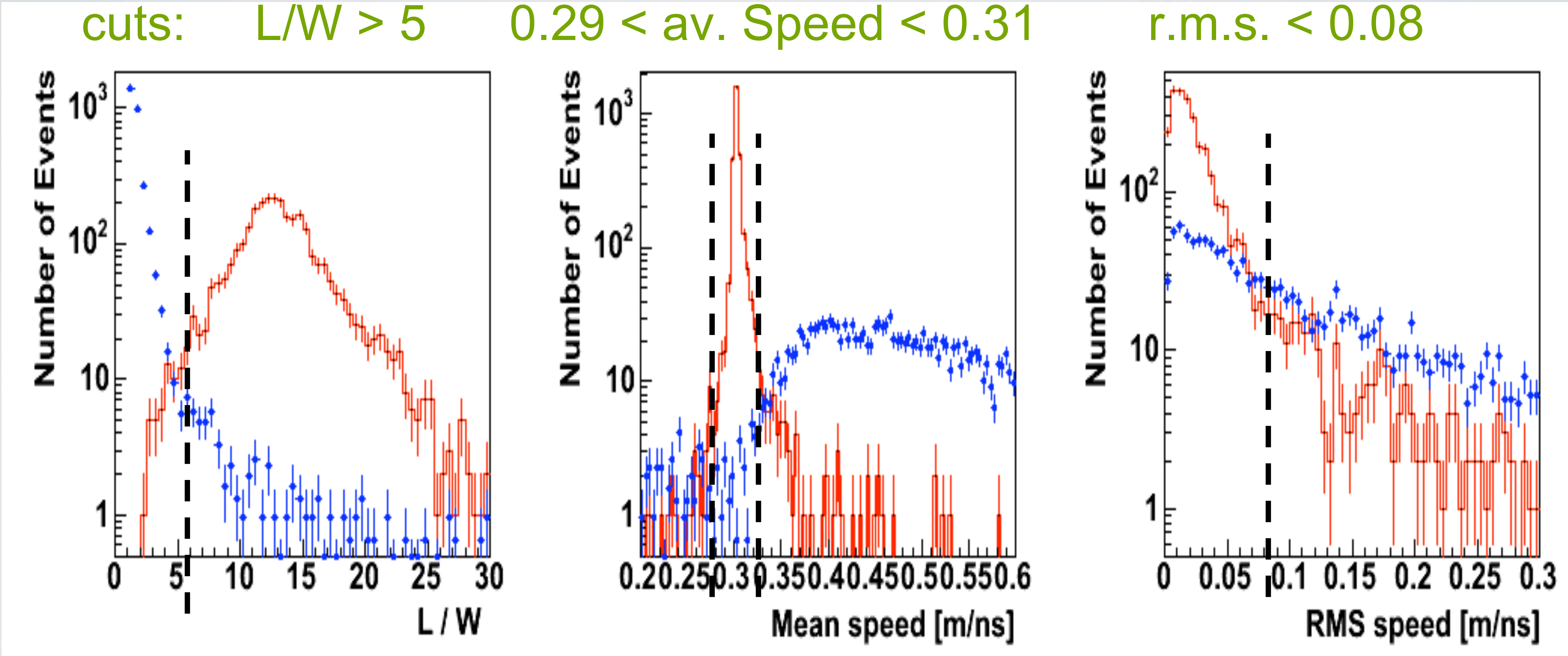
Very good separation between the wo event categories

Selection done on the basis of a single cut on the Fisher value

<u>Choosing the cut :</u>

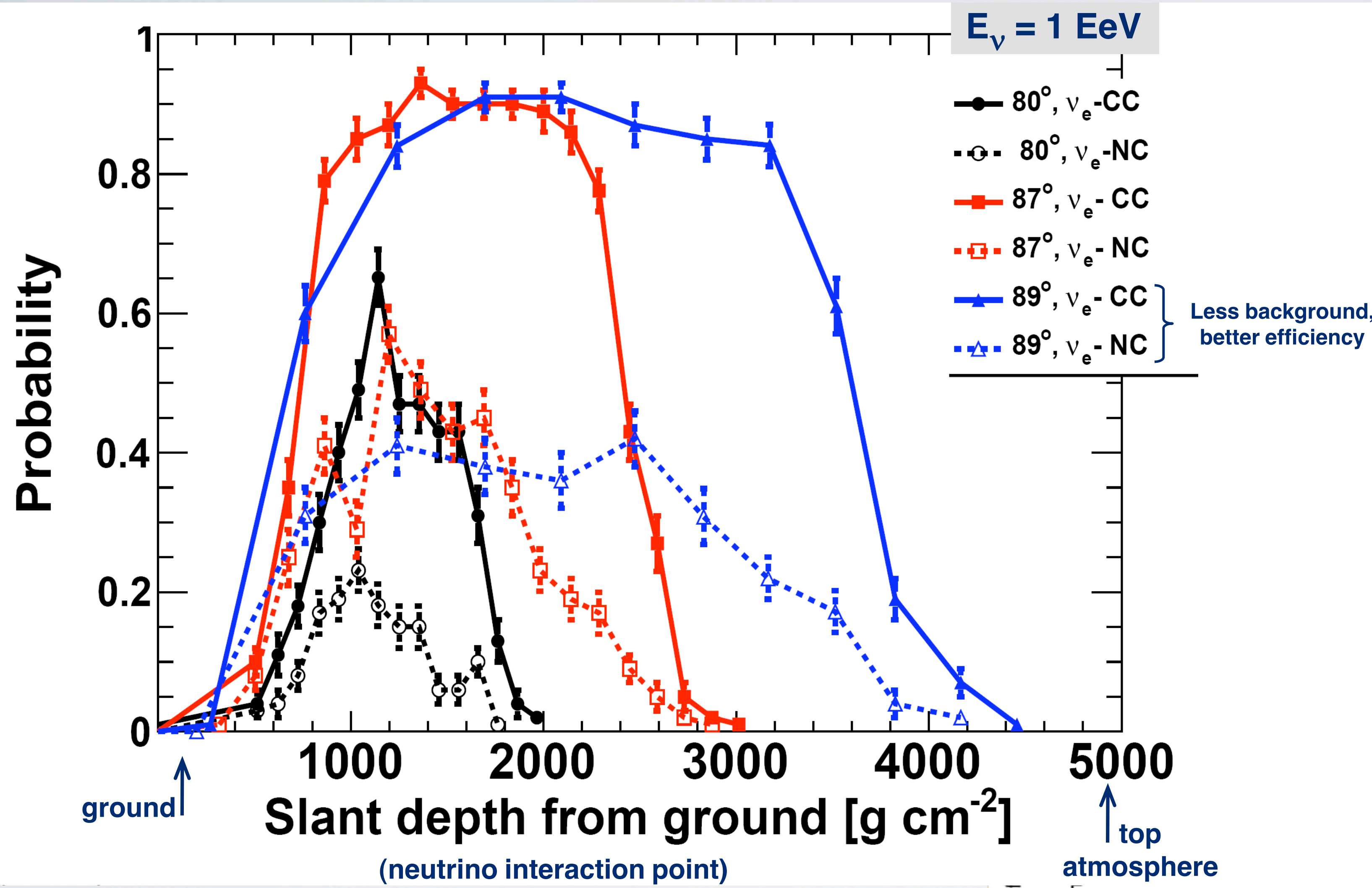
i/ Fit the data with an exponential to extrapolate the behaviour of the Fisher distribution
ii/ Rescale up the extrapolated data tail to 20 years of Auger data taking
iii/ Choose the cut such that the expected background is < 1 event per 20 years

EARTH-SKIMMING SELECTION CUTS



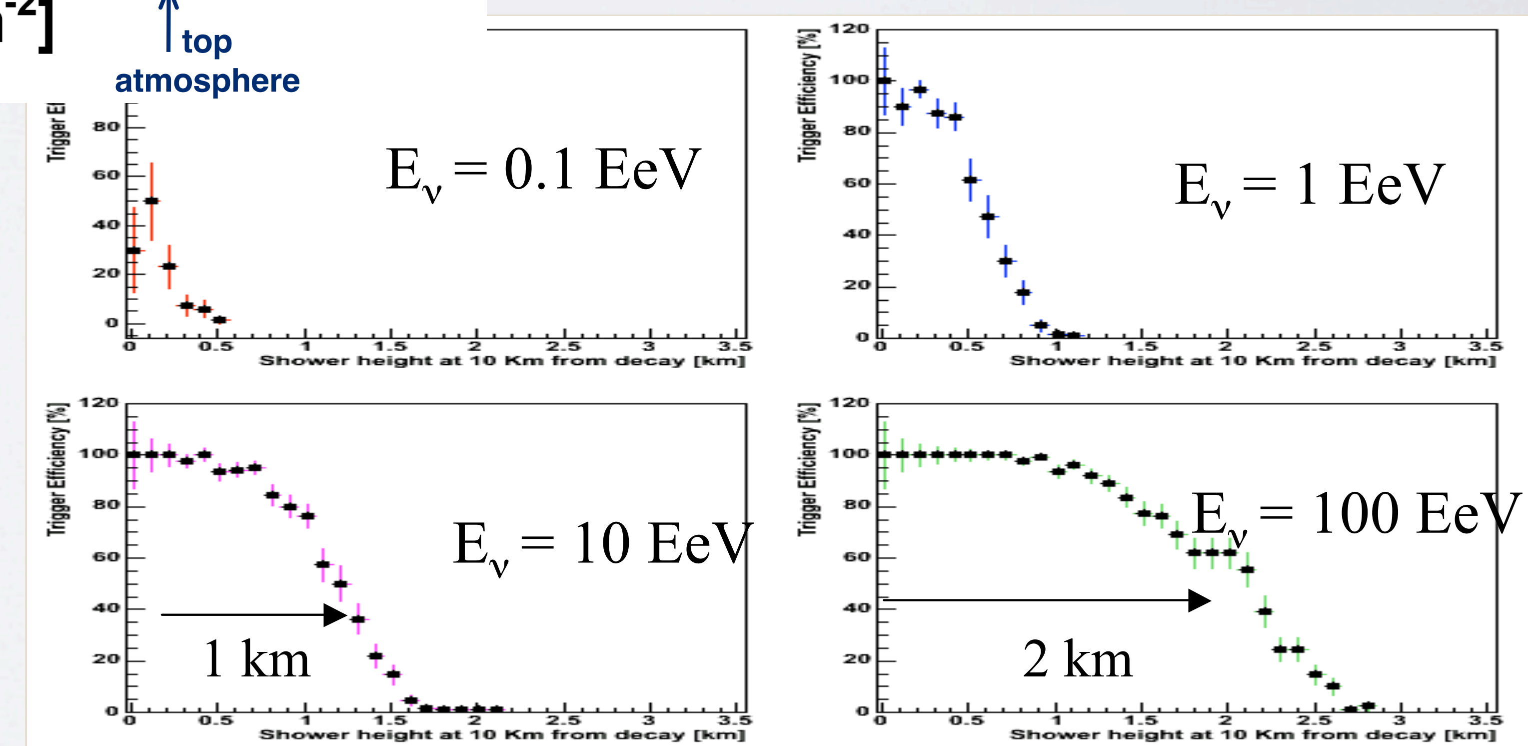
Amongst young showers, search for *long shaped* configurations compatible with a front moving *horizontally* at speed of light

SELECTION EFFICIENCIES



DOWN-GOING

EARTH SKIMMING :



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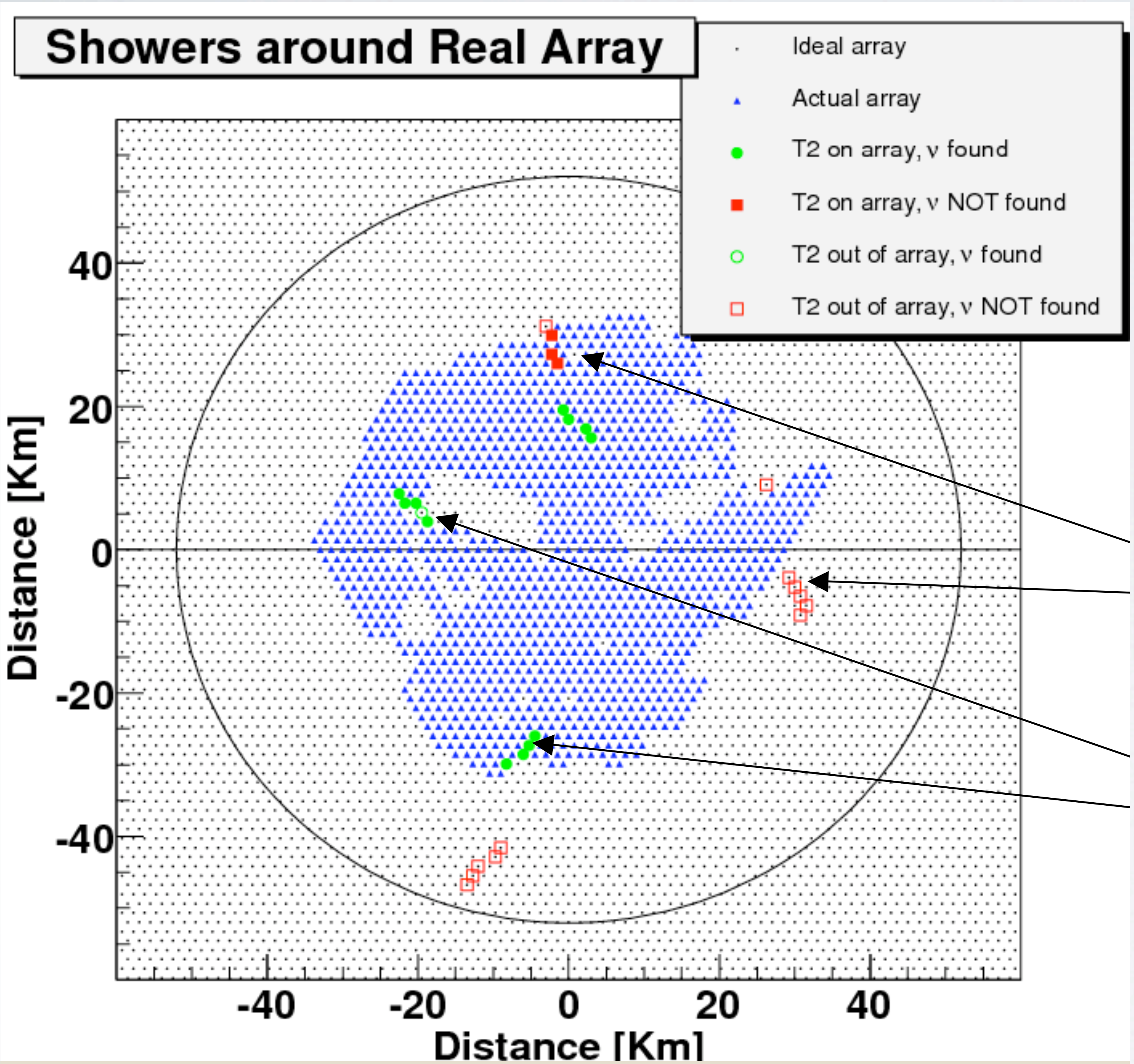
APERTURE CALCULATION



«moving footprint» method: throw simulated showers at random on real array configurations

not triggering

triggering

MAIN SYSTEMATIC UNCERTAINTIES

- **cross section** of neutrinos (Cooper-Sarkar, Sarkar 08) ~ 10 %
- **simulations** (hadronic model, thinning, software) ~ 20 %
- **topography** (Andes mountains, Pacific Ocean) ~ 15 %

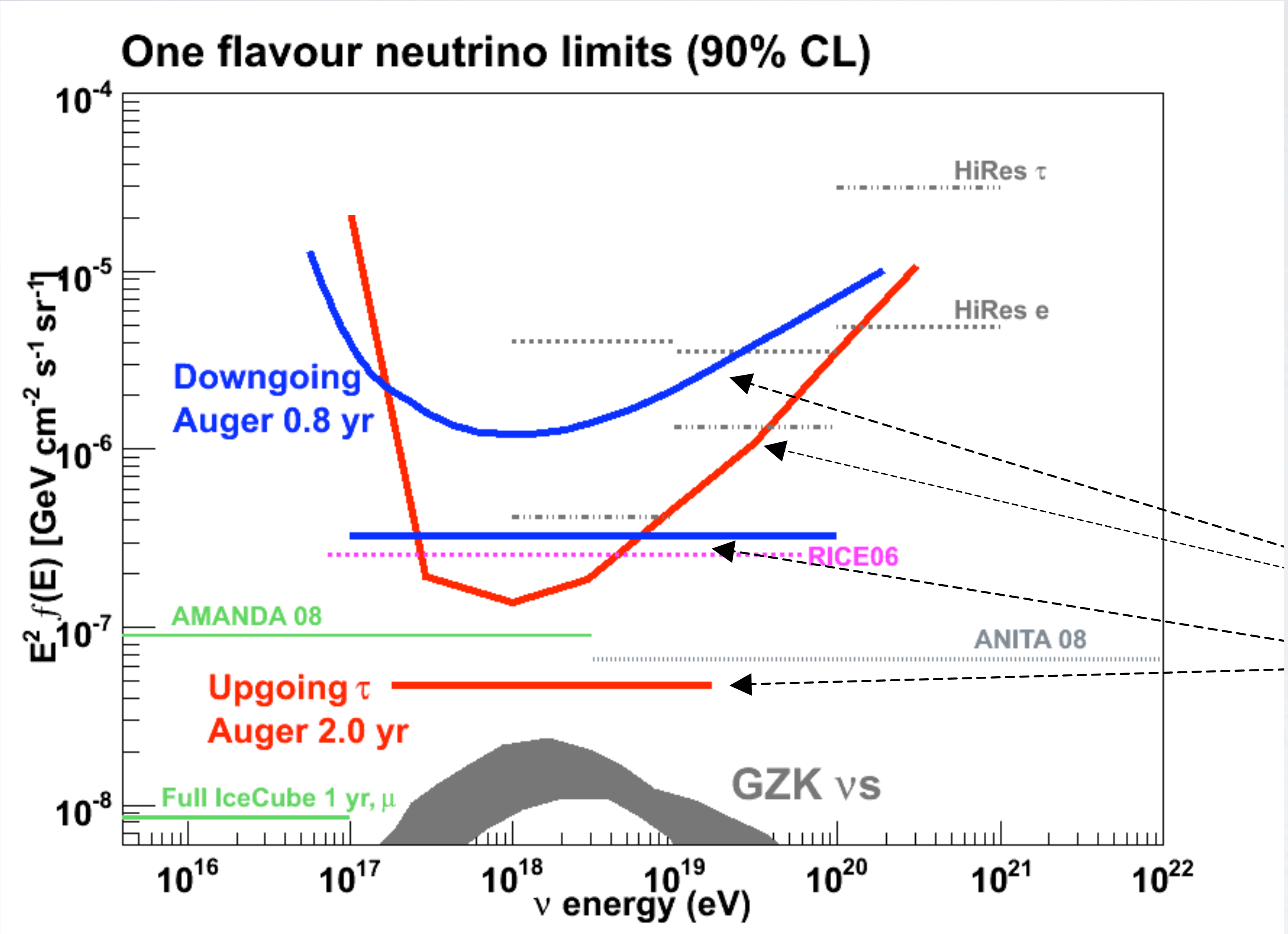
  (*accounted for; fully reliable simulation in progress)*

specific to up-going ν_τ

- **energy loss** of τ in earth $-dE/dx = a + \mathbf{b.E}$ +25% -10%
  - bremsstrahlung + pair production : *well defined*
  - **deep inelastic scattering** in photonuclear processes:

    depends on *structure functions* to be extrapolated in (x,Q^2)
- **τ polarization** (« visible » fraction of decay products) +17% -10%

FLUX LIMITS



NO candidate found

differential sensitivity

integrated limits (assuming a spectrum in 1/E^2)

CONCLUSIONS

The Pierre Auger Observatory is sensitive to UHE neutrinos :
- atmospheric interactions (all flavours)
- earth skimming (tau flavour)

more details on ν_τ analysis in Phys. Rev. D79 (2009) 102001

Simple criteria allow us to reject both the accidental and physical backgrounds without losing too much efficiency for neutrinos (still room for refinements of criteria and extension of acceptance)

Some top-down predictions disfavoured

Approaching the «GZK-predicitons»

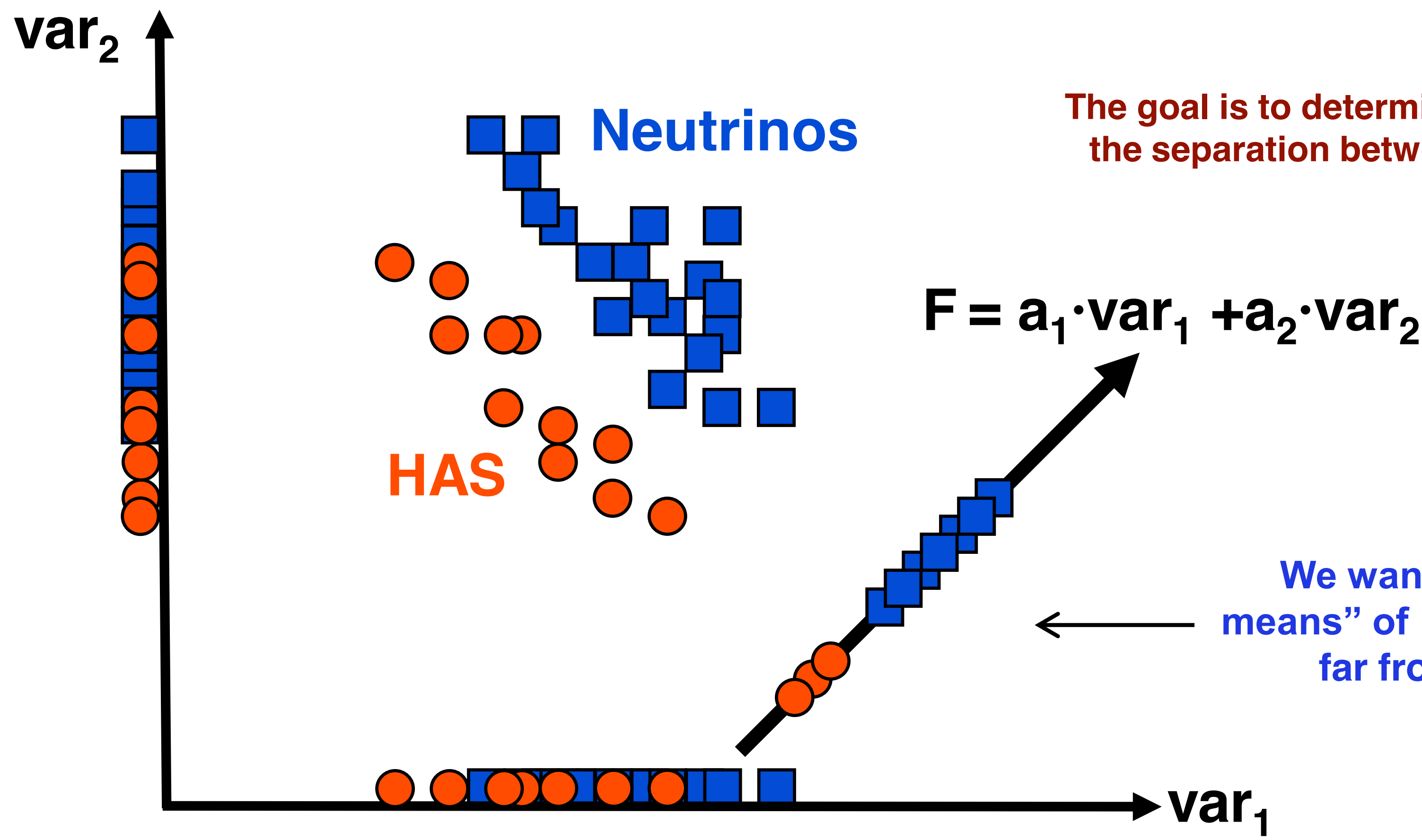
- **Standard procedure to separate two classes of events:** In our case hadronic HAS & simulated neutrinos**.**
- **The goal is to find the projection axis on wich the two classes of events are better separated.**

Only the means and covariances for all variables of the two classes are needed to build R

Maximize R →

$$R = \frac{\left(\langle F\rangle_{HAS} - \langle F\rangle_{\nu}\right)^2}{\sigma_F^2(HAS) + \sigma_F^2(\nu)}$$

Toy example in 2D



The goal is to determine a_i so as to maximize the separation between the event classes.

We want the "projected means" of HAS and neutrinos far from each other