The Auger Observatory and UHE neutrinos

- Why UHE neutrinos ?
- What is the Pierre Auger Observatory ?
- How can it see UHE neutrinos ?
- How to discriminate them ?
- Upper bounds to fluxes

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Auger Collaboration

possible sources of UHE neutrinos

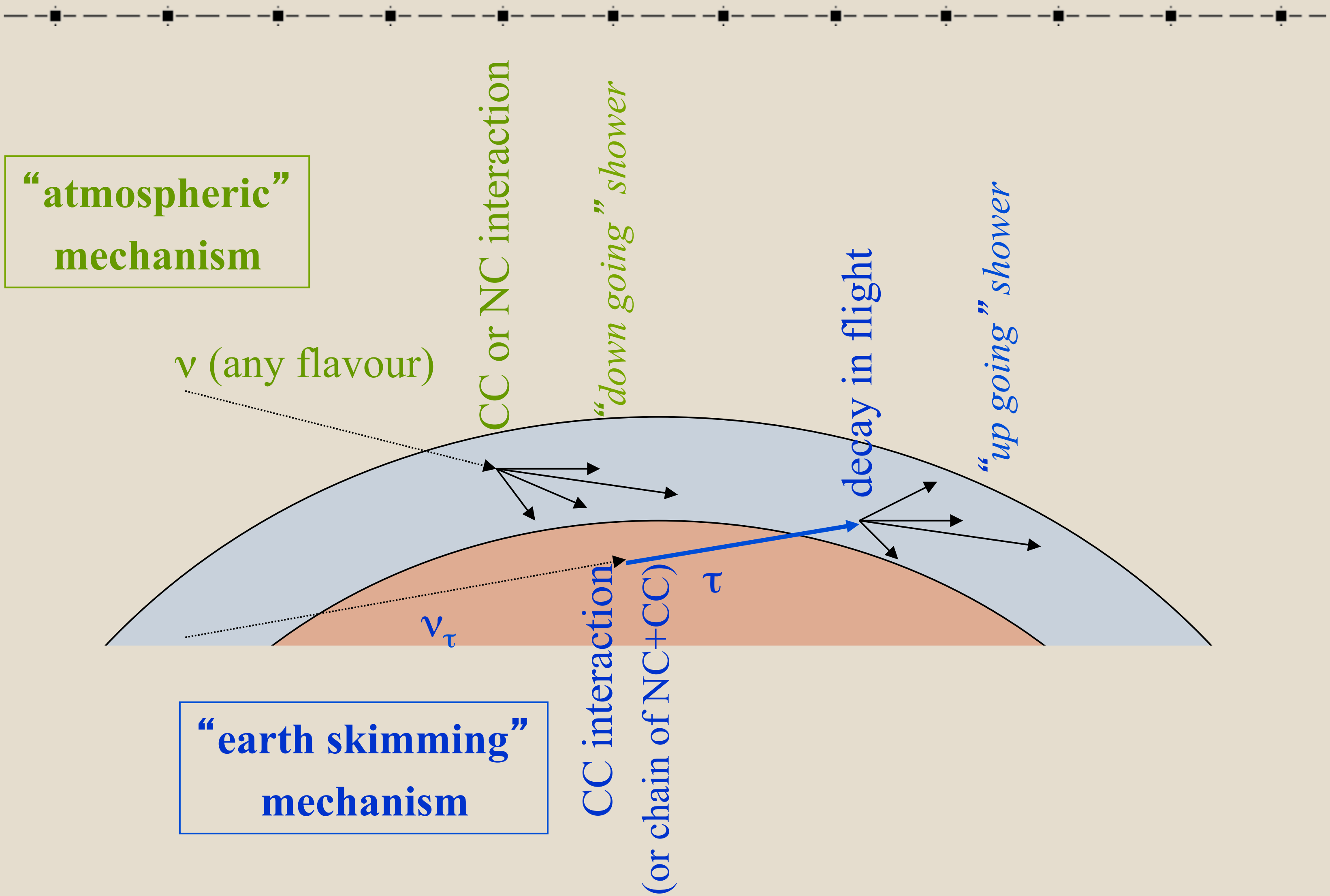
• interaction of accelerated particles with nucleons/photons in the source region or with the CMBR during propagation (GZK effect): *relatively soft spectrum*

• decay of ultra massive objects (scale of Grand Unification ?)
harder spectrum expected
UHE photons and neutrinos are a signature of top-down scenarii

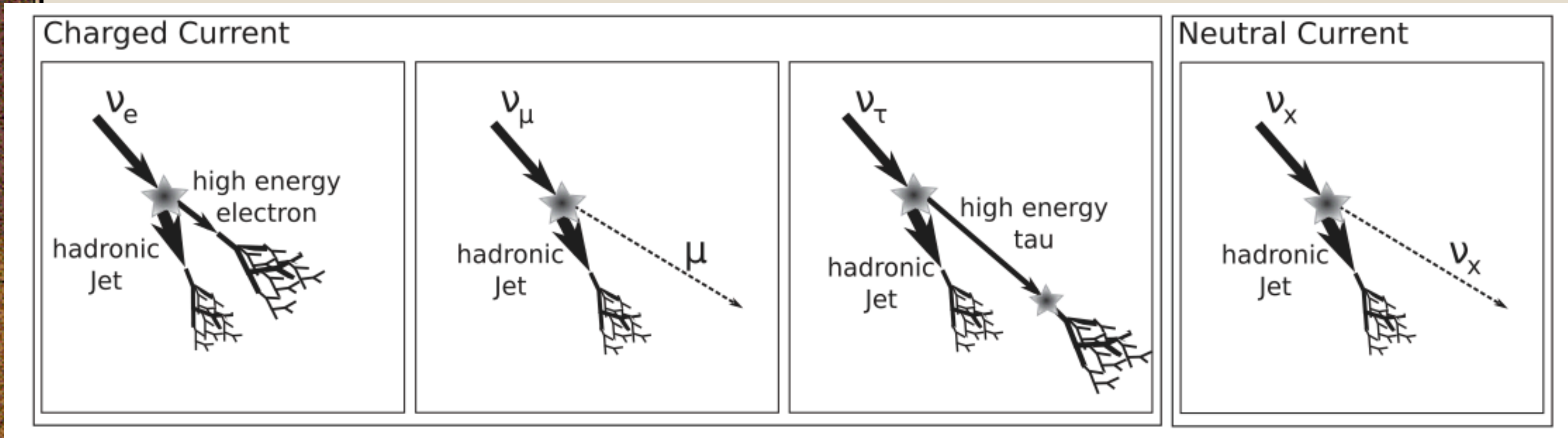
ν's propagate in straight line over cosmological distances
→ *point back to the source (or GZK interaction point …)*
but: low probability to produce an atmospheric shower

possible interesting byproducts of the Auger Observatory
(confirm GZK mechanism and test "exotic" models)

neutrino induced showers



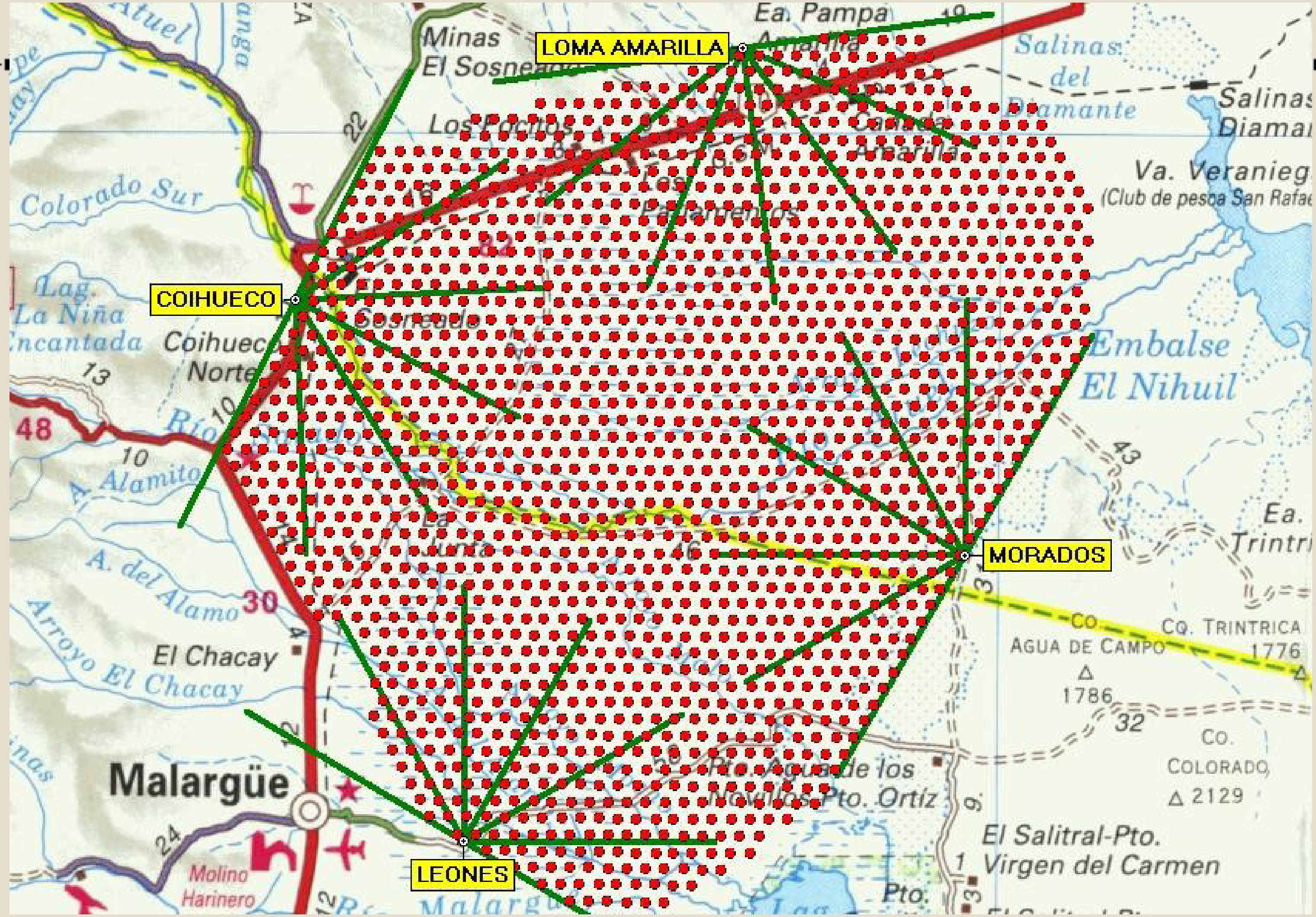
“down going” showers



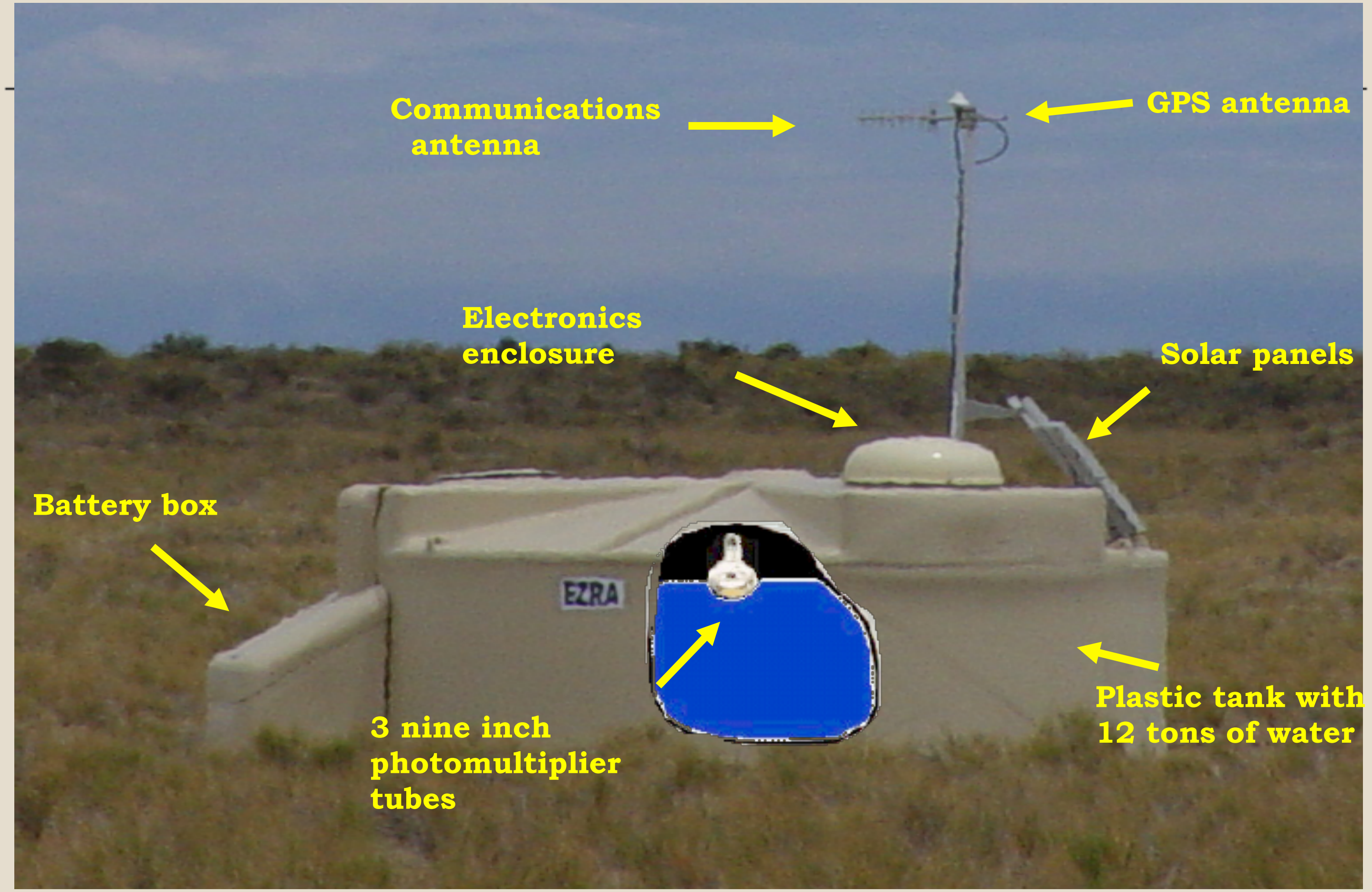
« visible » energy : variable fraction of neutrino energy

the Pierre Auger Observatory

1600 surface detectors + 4x6 fluorescence telescopes



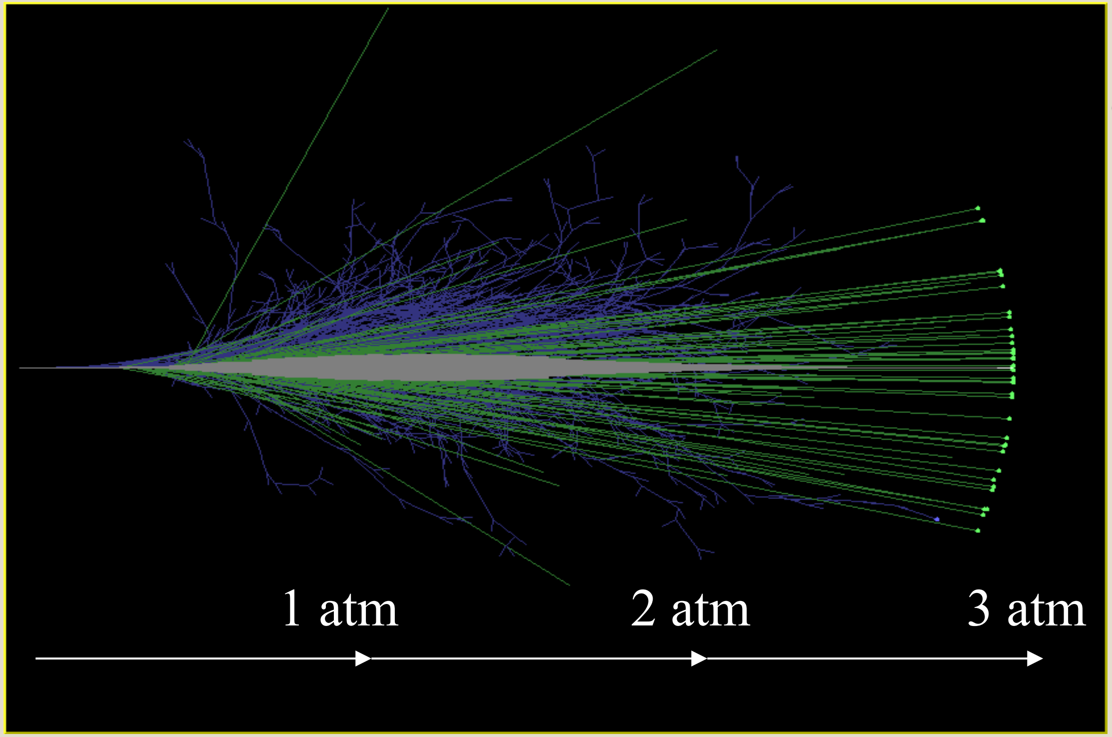
Auger surface array: water Cherenkov tanks



fluorescence data not yet used in this study (less statistics)

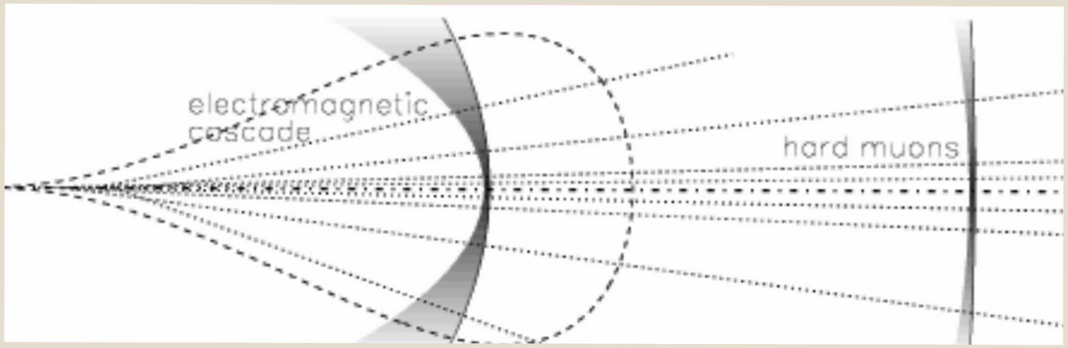
atmospheric shower development

electromagnetic cascade + muons (from hadronic cascade)



"artistic" simulation

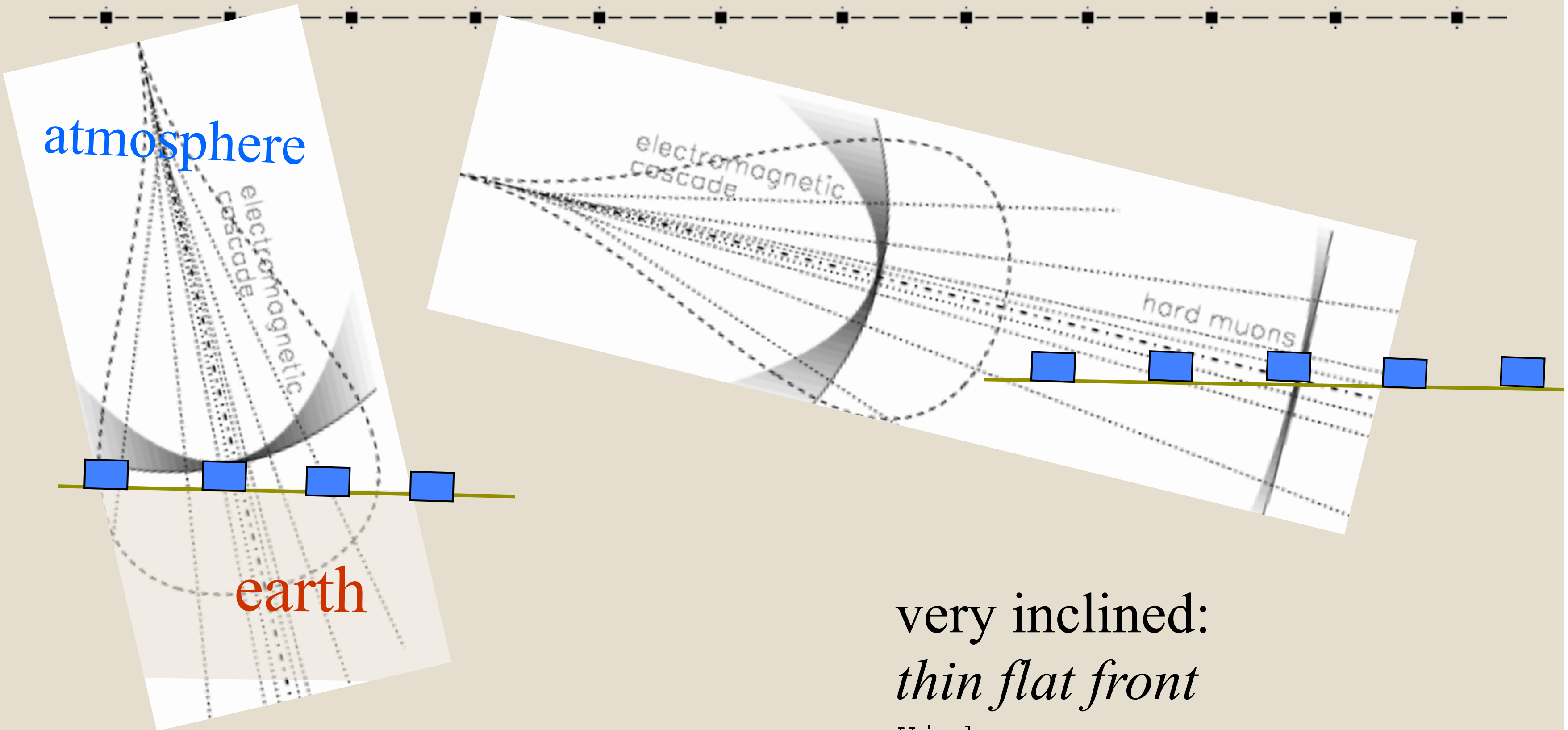
(exaggeration of transverse expansion)



evolution of shower front shape:

- curved and thick when "young"
- flatter and thin when "old"

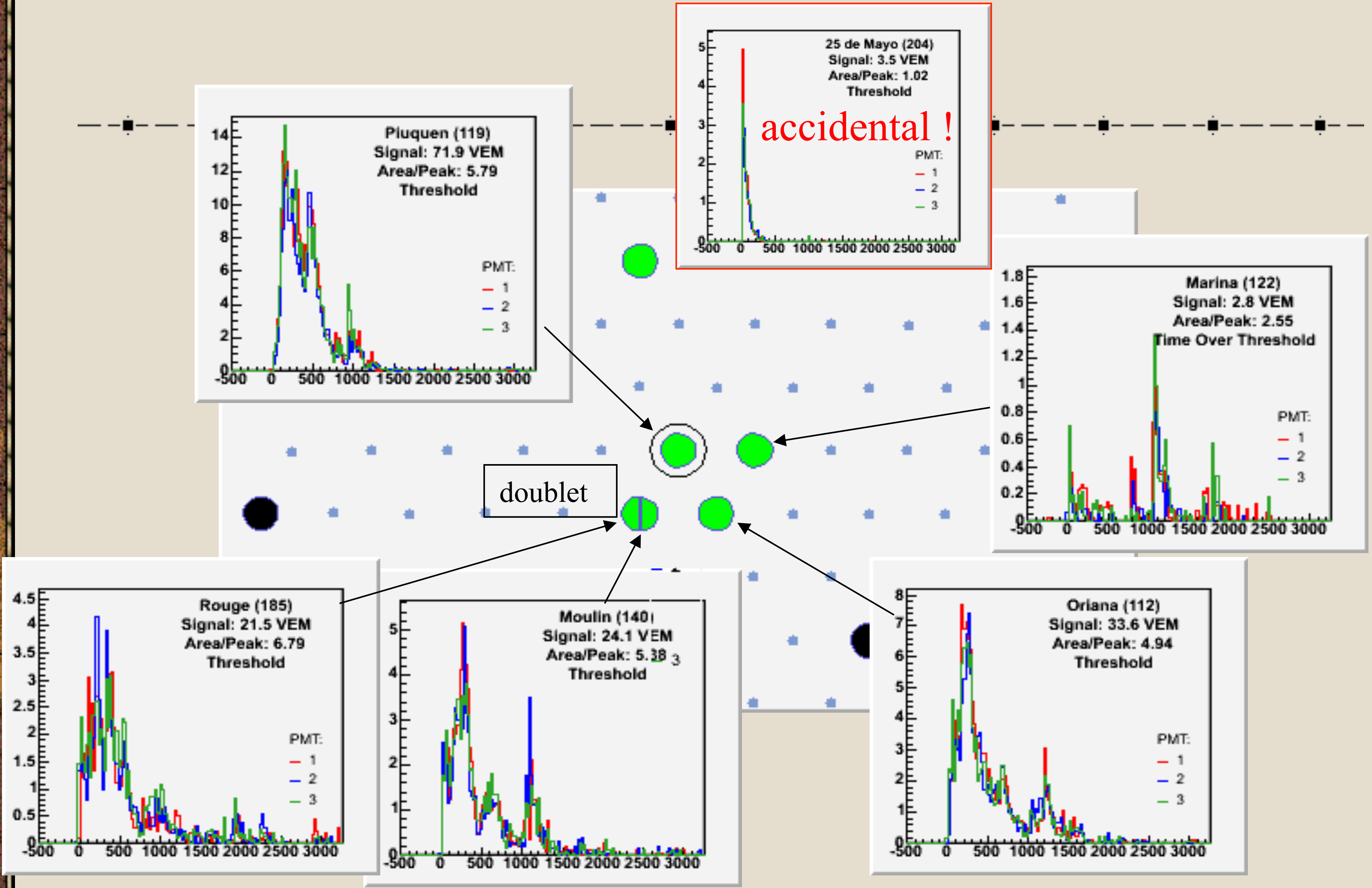
“normal” (nucleic) showers



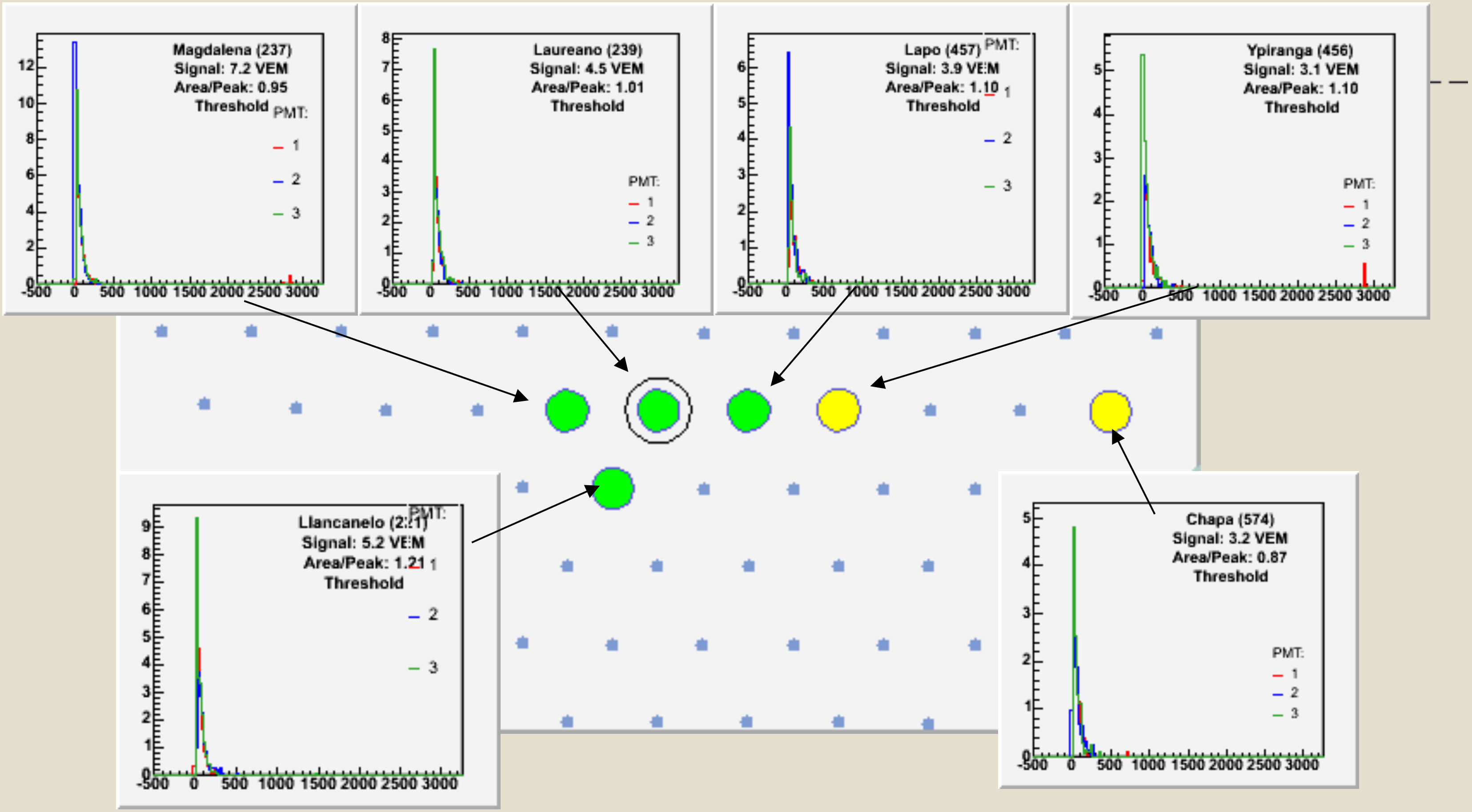
nearly vertical:
thick curved front
muons + electromagnetic

very inclined:
thin flat front
High energy muons

a real vertical event (20 deg)



a real horizontal event (80 deg)

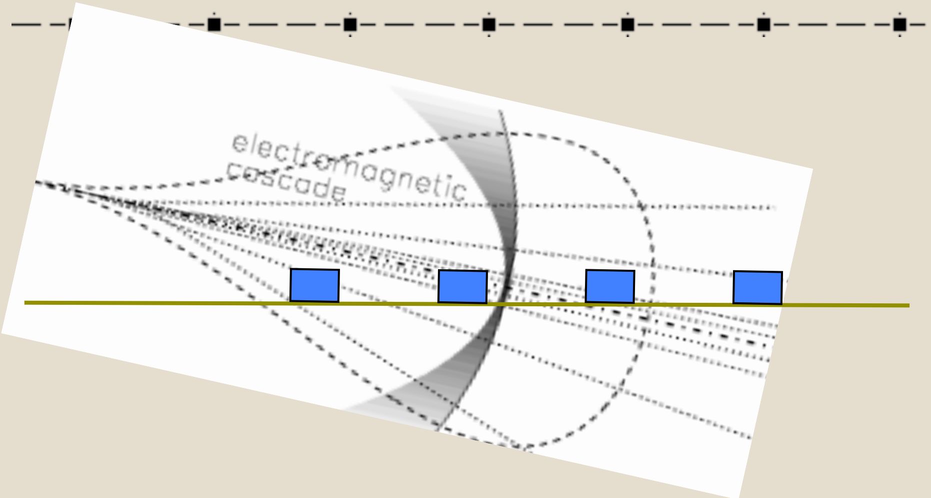


"single" peaks : fast rise + exp. light decay ($\tau \sim 70$ ns)

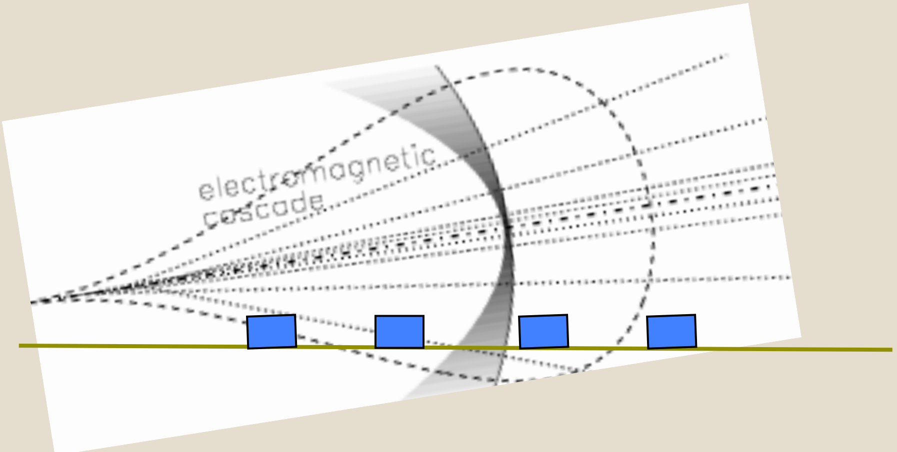
accidental background signals are similar

neutrino showers

(distinguishable if almost horizontal)



downgoing (all flavours)
(direct ν interaction in atmosphere)

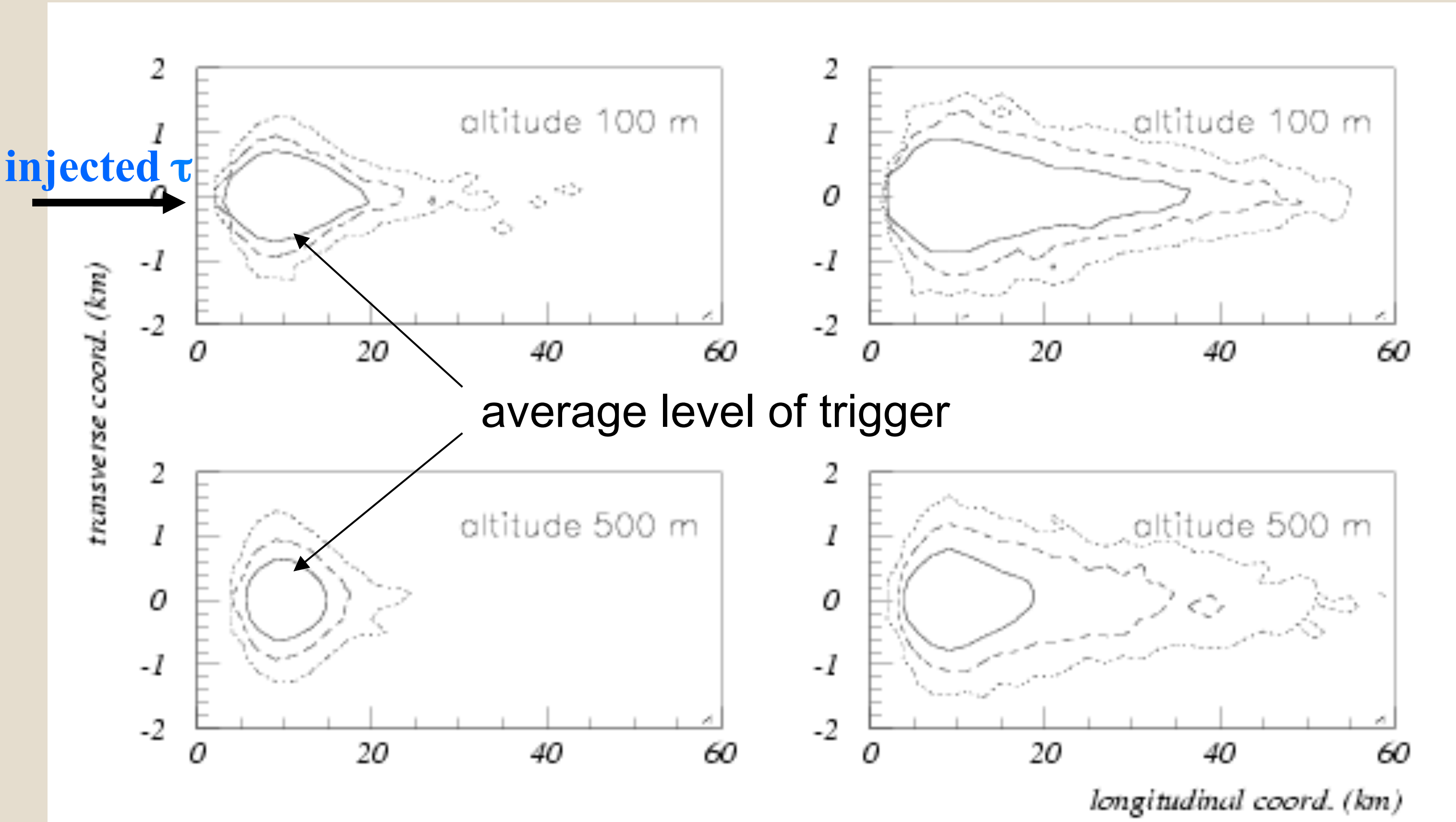


upgoing
($\nu_\tau \rightarrow \tau$ in earth
τ decay in flight)

examples of ground spots

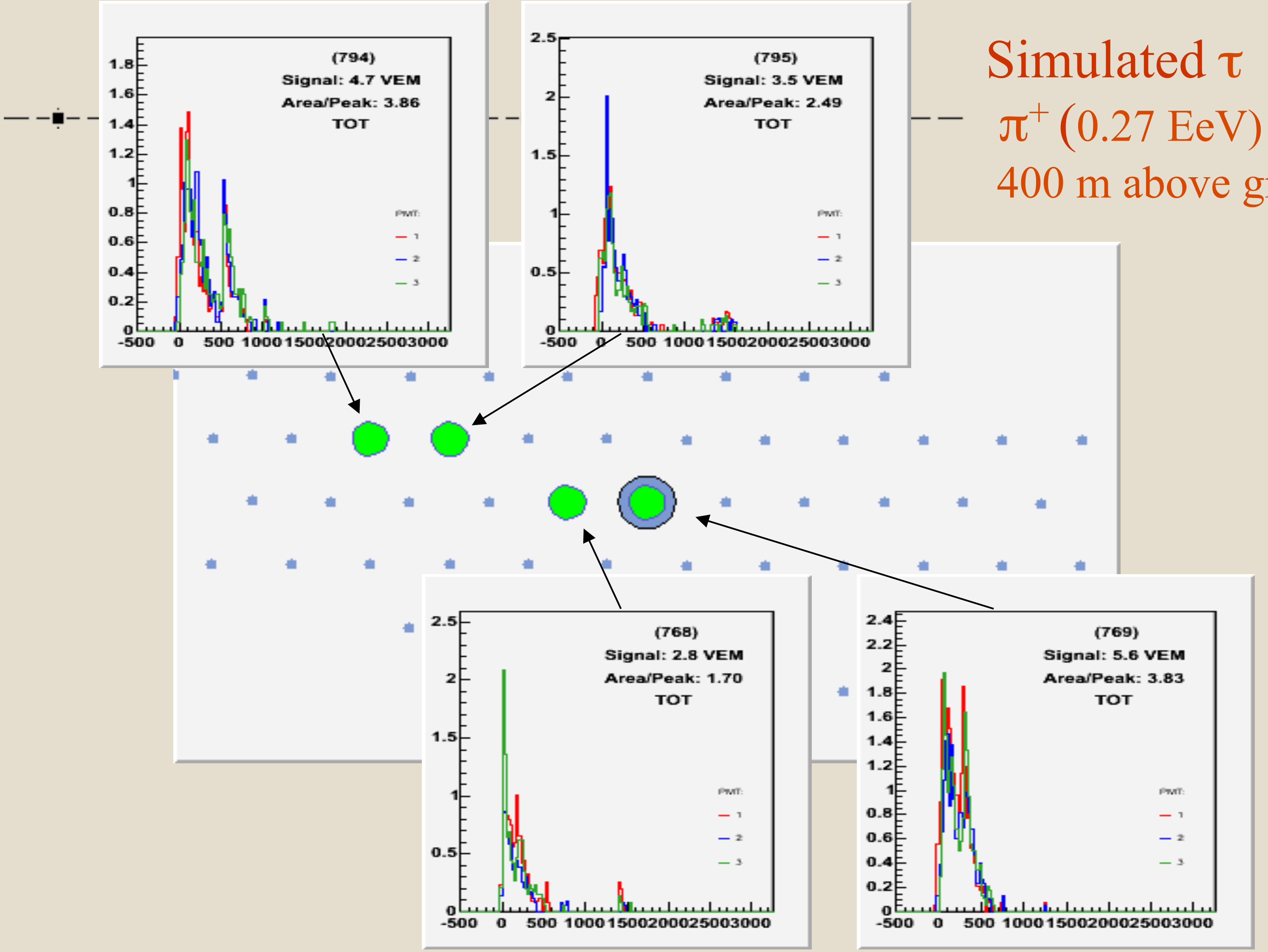
decay of an horizontal τ of 1 EeV

$e\nu\nu$ (almost pure e.m. cascade) $\pi\nu$ (hadronic+e.m. cascade)



simulated neutrino event (1)

Simulated $\tau \longrightarrow$
π^{+} (0.27 EeV) ν
400 m above ground

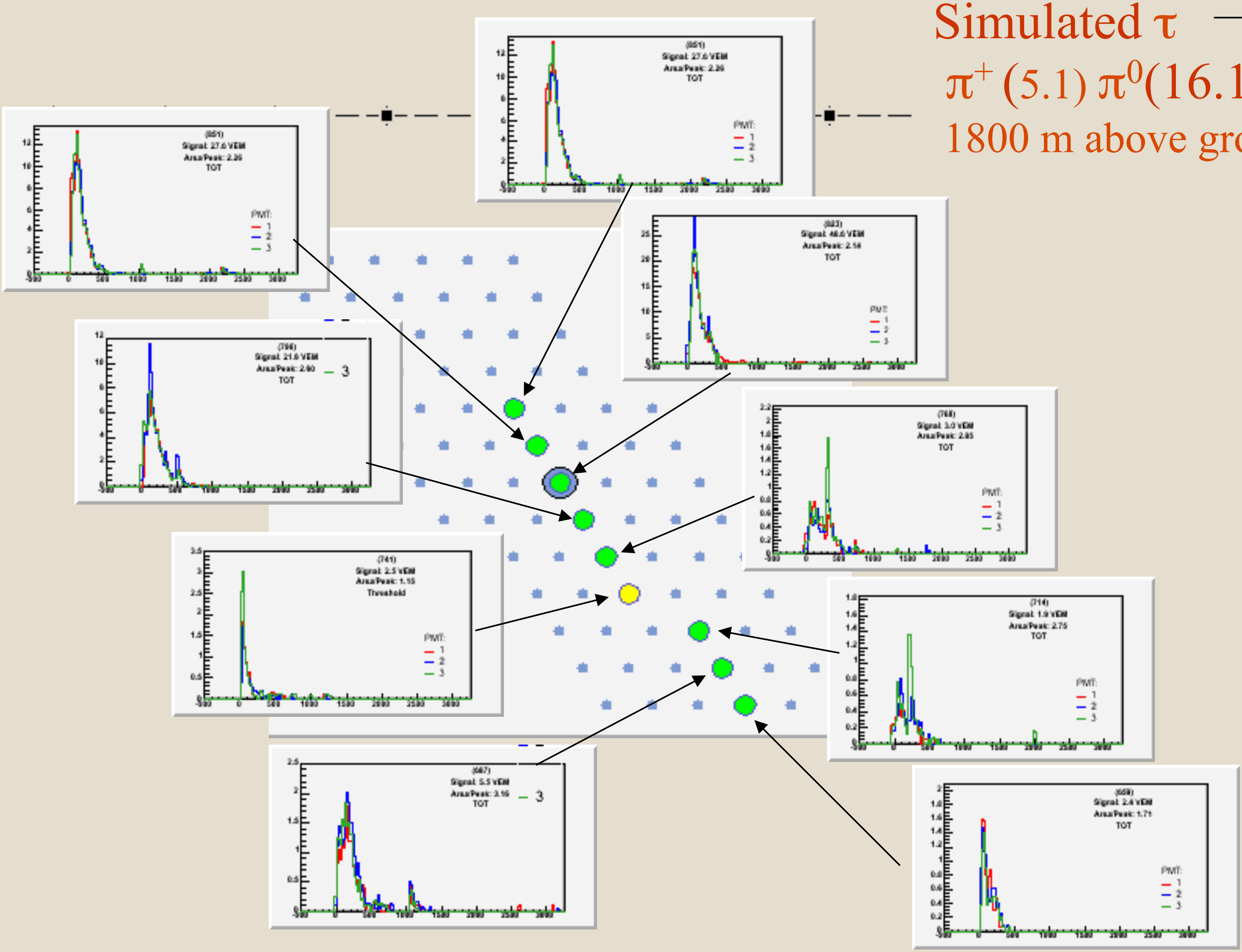


simulated neutrino event (2)

Simulated $\tau \longrightarrow$

$\pi^+ (5.1)\ \pi^0 (16.1)\ \nu$

1800 m above ground

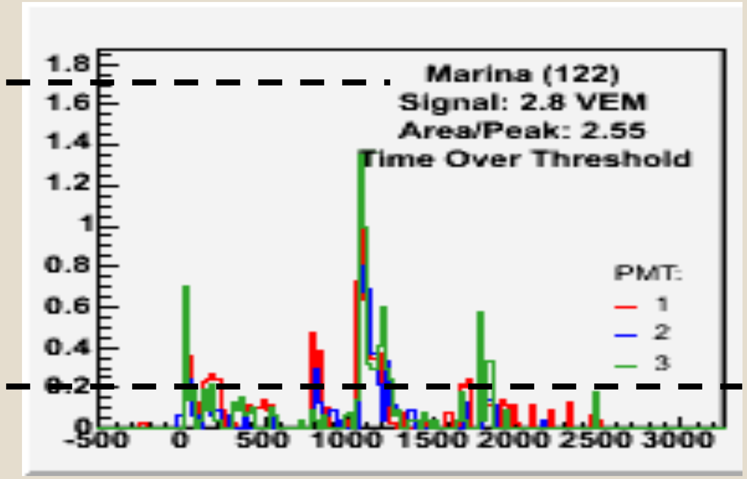


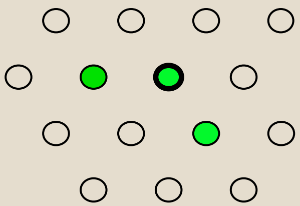
characterization of "young" showers
(trigger + offline analysis)

online local triggers (one tank):

• **threshold:** one slot above *Th*
(detection of peaks)

• **time over threshold**: *N* slots within 3 μs above *th*
(detection of broad signals)





global trigger condition:
at least 3 "T.o.T" stations in a compact configuration (one "central" + two neighbours)

offline: "FADC trace cleaning" (removing accidental signals)
computing AOP (Area/Peak) (normalized to 1 for single particle signals)

characterization of horizontal showers ("footprint" analysis)

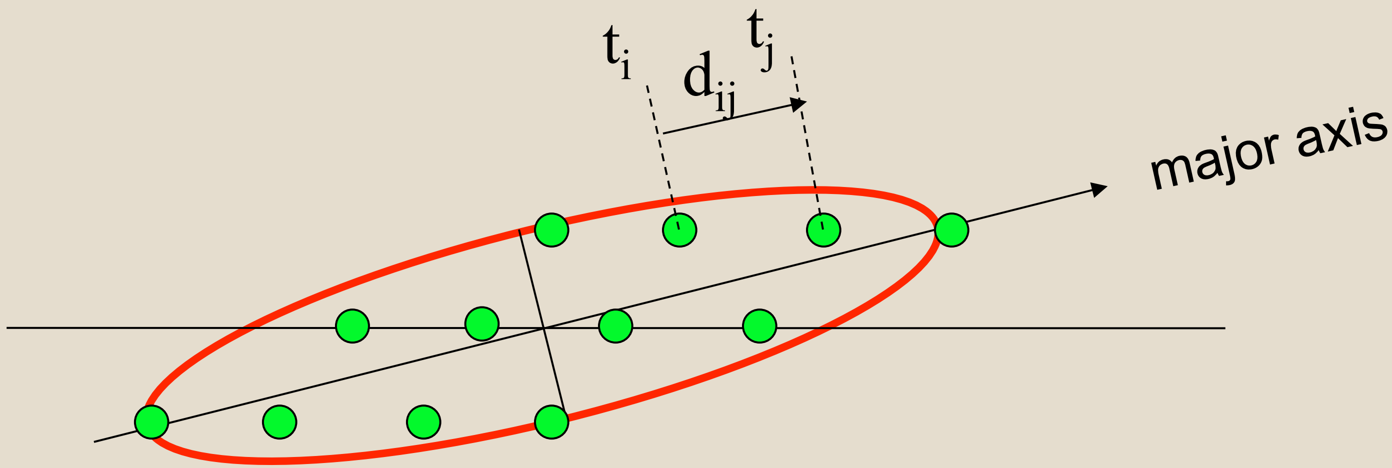
variables defined from the footprint

(in any configuration, even aligned)

- *length* L and *width* W

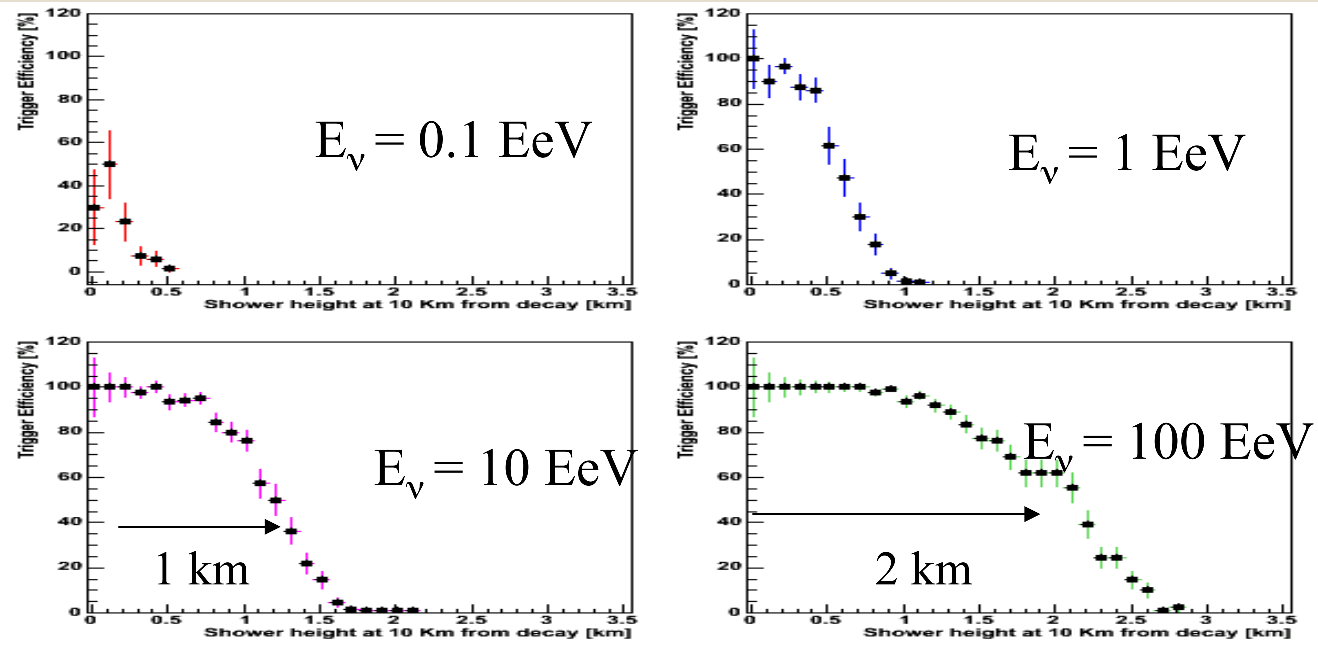
  (major and minor axis of the ellipsoid of inertia)
- *"speed"* for each pair of stations

  (distance/difference of time)



trigger efficiency

example: fraction of quasi-horizontal decaying τ (excluding μνν channel) giving a trigger, as a function of ***altitude***



effective detection volume: slice $(0,h_{max})$

Similar results for down-going showers, with effective slice (h_{min}, h_{max})

Strategy to obtain fluxes or upper bounds

Simulated ν showers

Real data (training sample)

tune selection criteria
here: reduce background to ~ 0

compute efficiencies

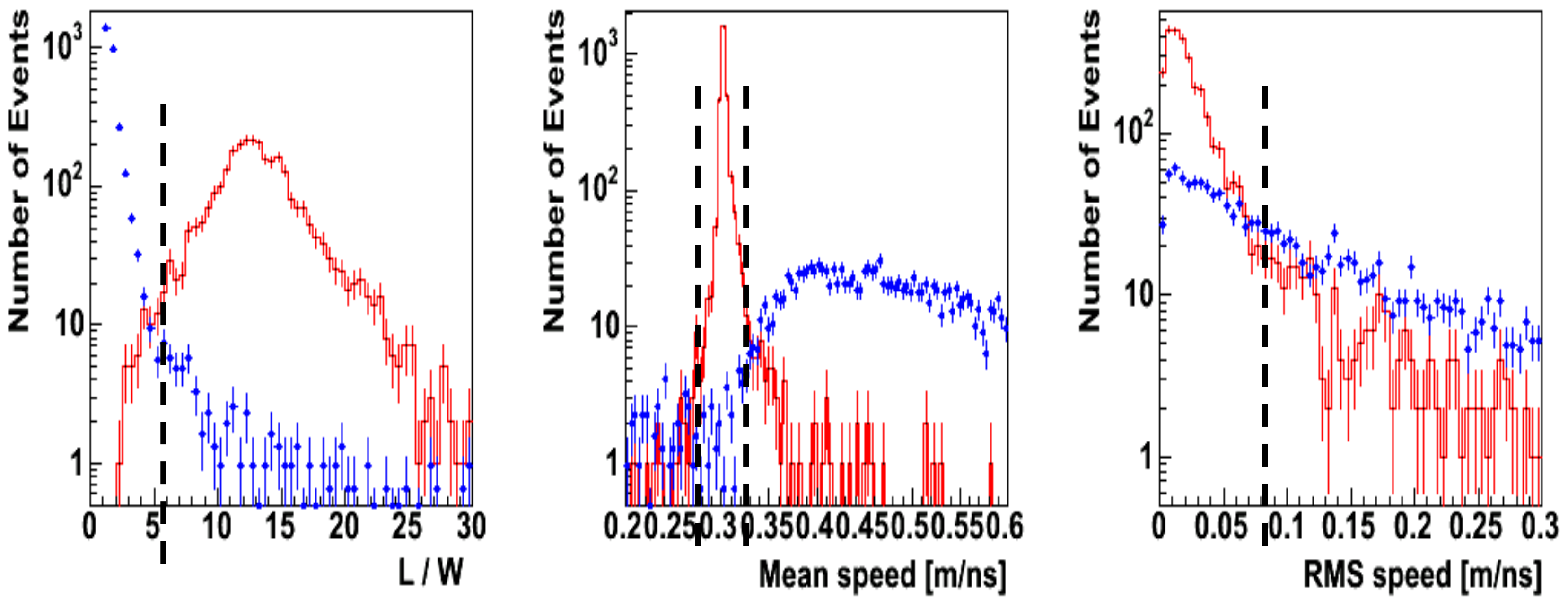
Search for ν candidates
(further data)

exposure * cross section
→ flux or upper bound

ν_τ candidate selection
discriminating variables

amongst "young" showers (ToT trigger + large AOPs):
search for **long shaped** configurations, compatible with a front moving **horizontally** at speed c

cuts: L/W > 5 0.29 < av. Speed < 0.31 r.m.s. < 0.08



down-going ν candidates
1. first selection of inclined events

- 4 or more triggered stations
- mean speed < 0.313 m/ns and rms/mean < 0.08
- θ_{rec} > 75 deg (if aligned stations: assume line direction for ϕ)
- Length/Width > 3
- $|\phi_{ellipse} - \phi_{rec}|$ < 10 deg

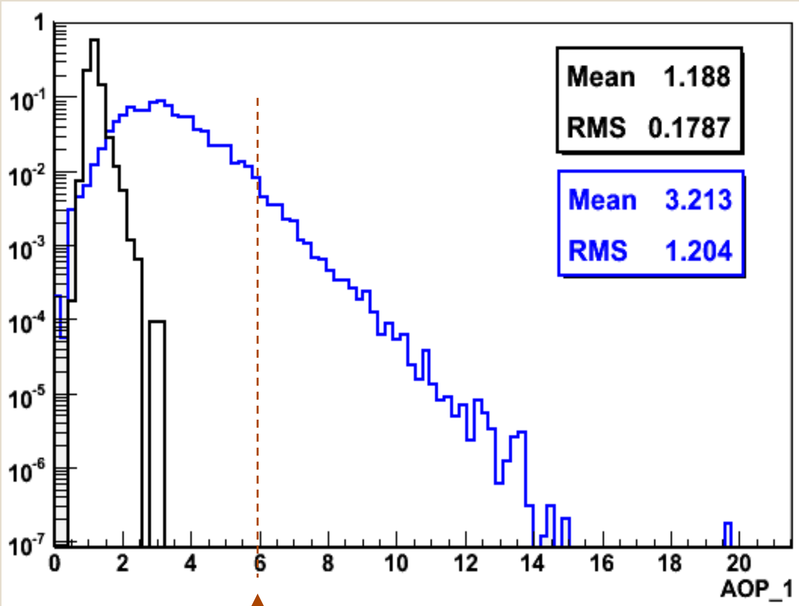
Then: search for broad signals *at least in the first stations (early part of the shower development)*

→ see next slide

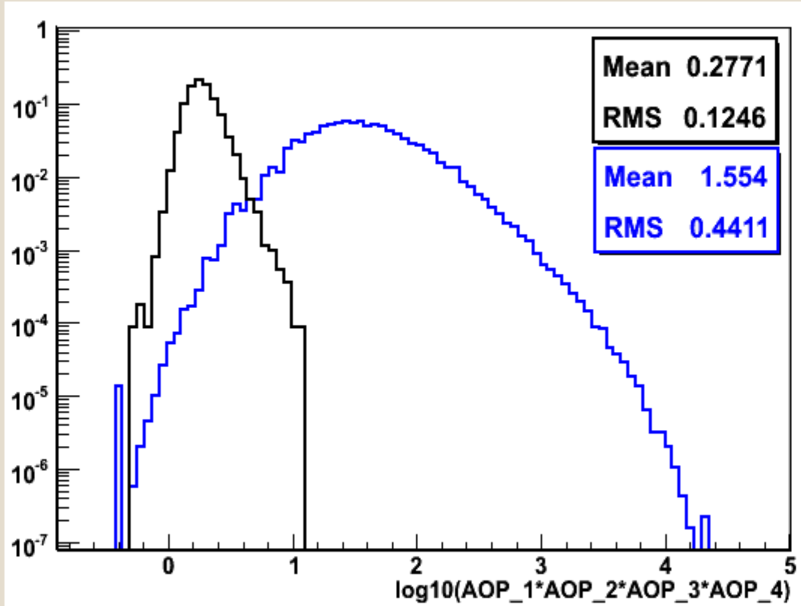
Note: more severe selection needed in the range (75,90) than in (90,95) for up-going ones (more phase space for background)

down-going ν candidate selection
2. discriminating variables for broad signals

AreaOverPeak (1st station)



product of AOPs (4 stations)

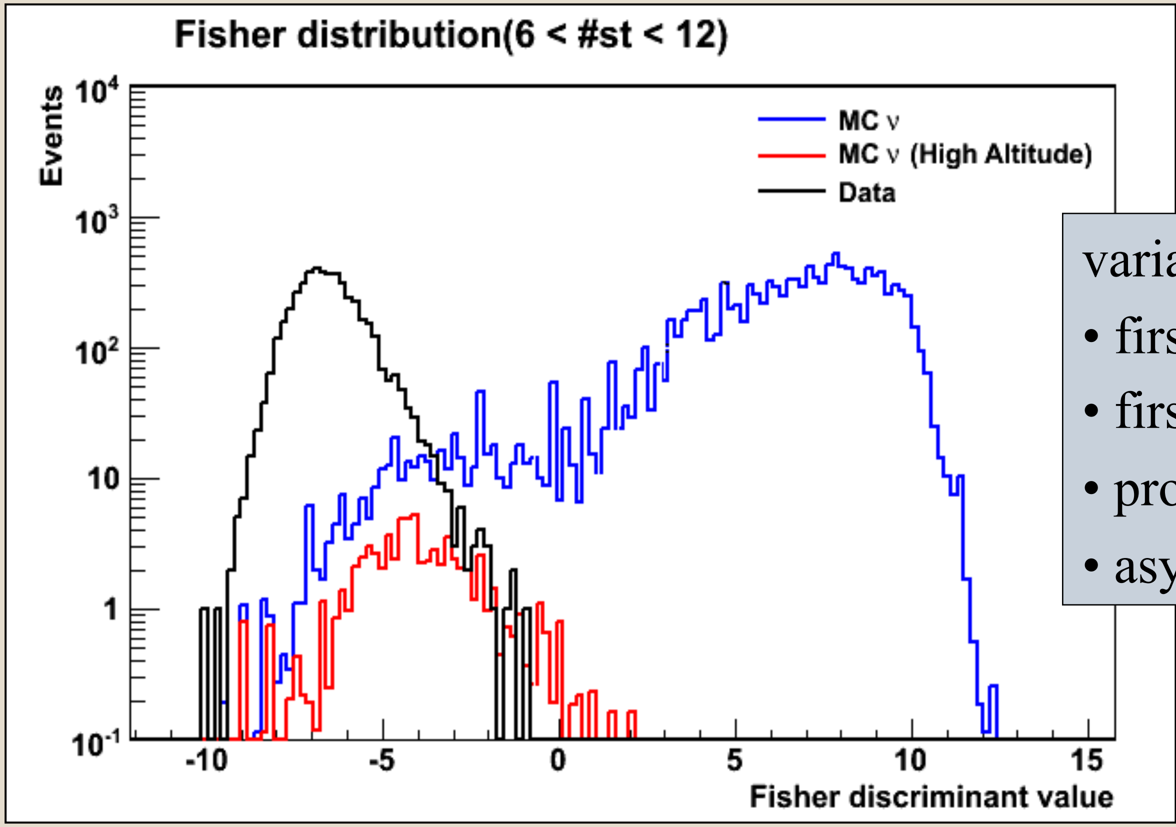


training real data *vs* simulated neutrino showers

large range without overlap

to avoid tails from bad data:
restrict the range of AOP (smooth cut)

down-going ν candidate selection
3. Fisher analysis



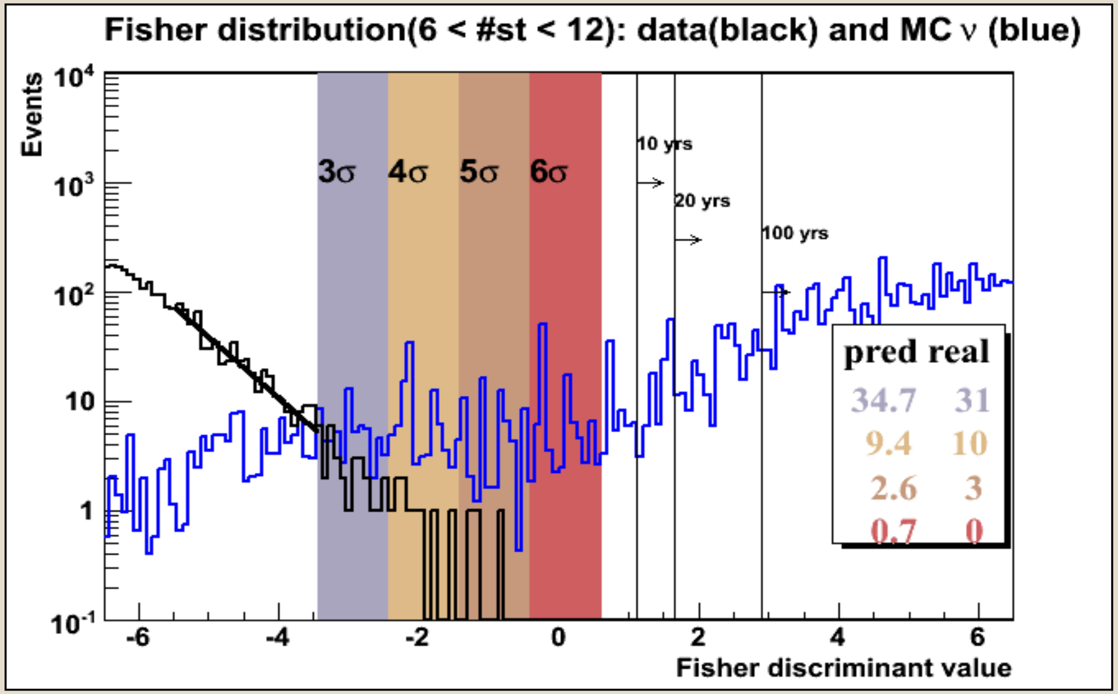
variables:
- first 4 AOPs
- first 4 $(AOP)^2$
- product of 4 AOPs
- asymmetry (early vs late)

low altitude ν showers are well separated from real data

backgrounds

• **physics:** tail of hadronic showers (hard muon interaction) or photon induced showers (delayed by LPM effect): large uncertainties but probably negligible

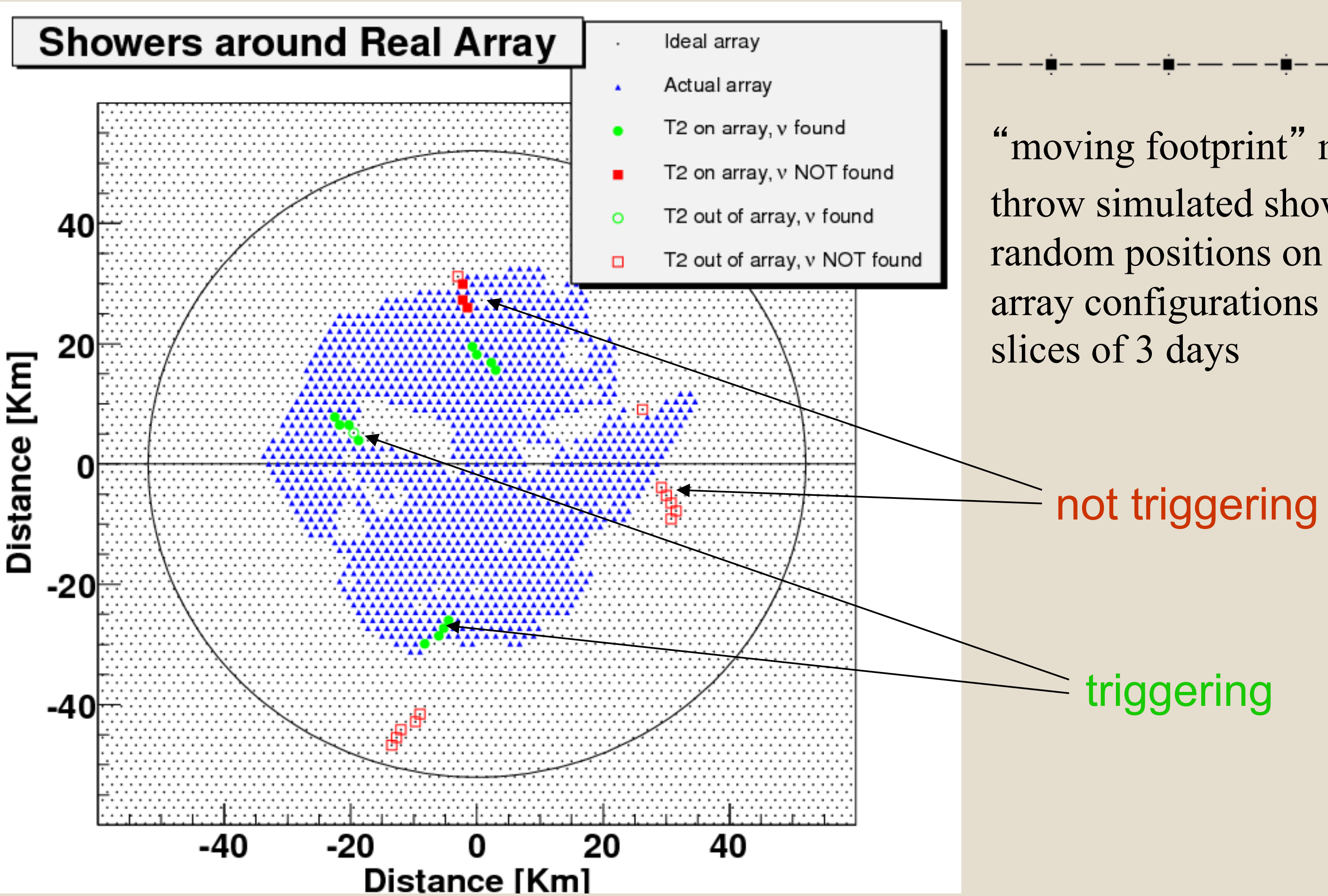
• **detector:** monitoring of PMT response → abnormal shapes may be removed



exponential extrapolation of real background

→ may be reduced to 1 event per 10, 20 or 100 years **without losing much efficiency on neutrinos**

real array aperture calculation
(effective array depending on time)



"moving footprint" method:

throw simulated showers at random positions on real array configurations per slices of 3 days

main systematic errors

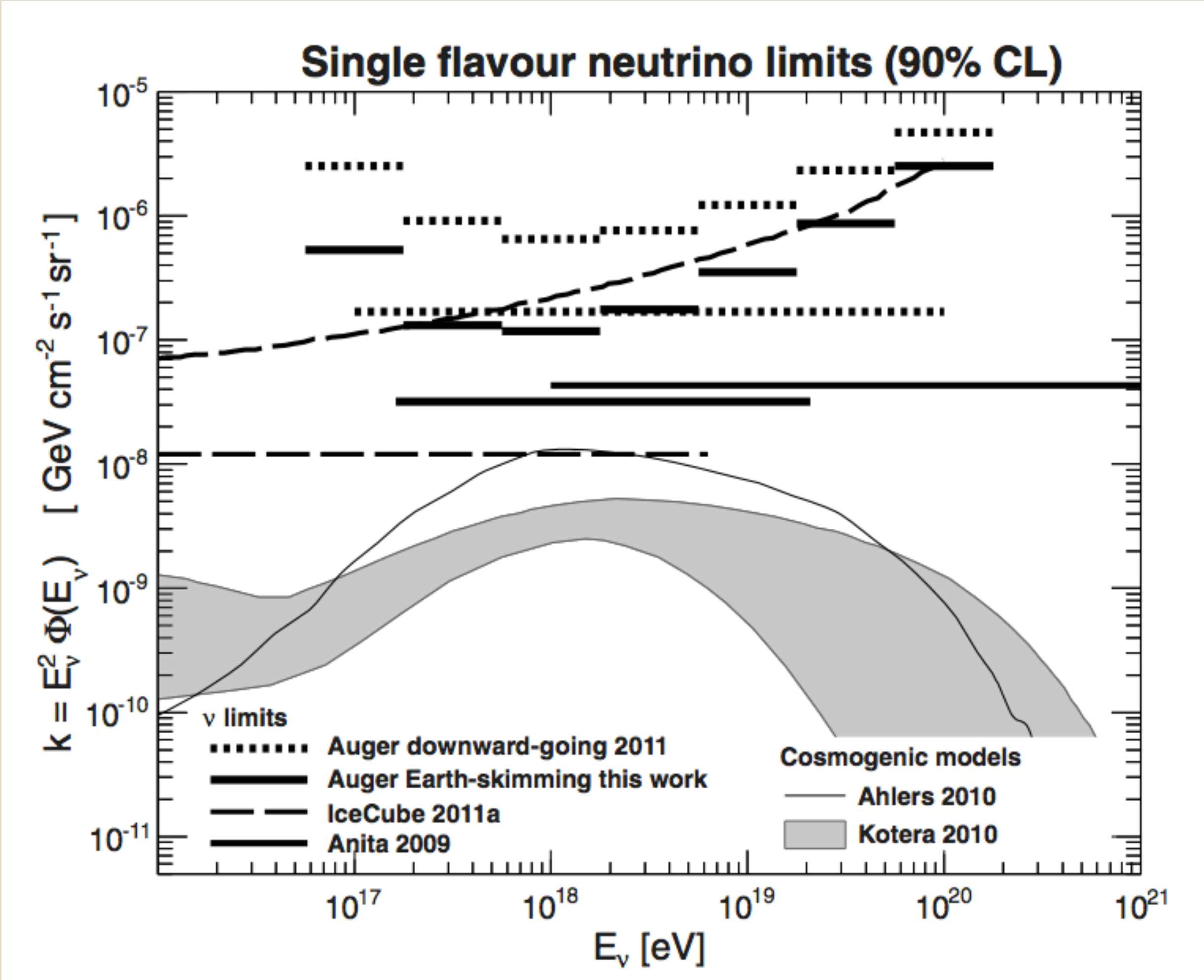
- **cross section** of neutrinos (Cooper-Sarkar, Sarkar 08) ~ 10 %
- **simulations** (hadronic model, thinning, software) ~ 20 %
- **topography** (Andes mountains, Pacific Ocean) ~ 15 %

  (*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%

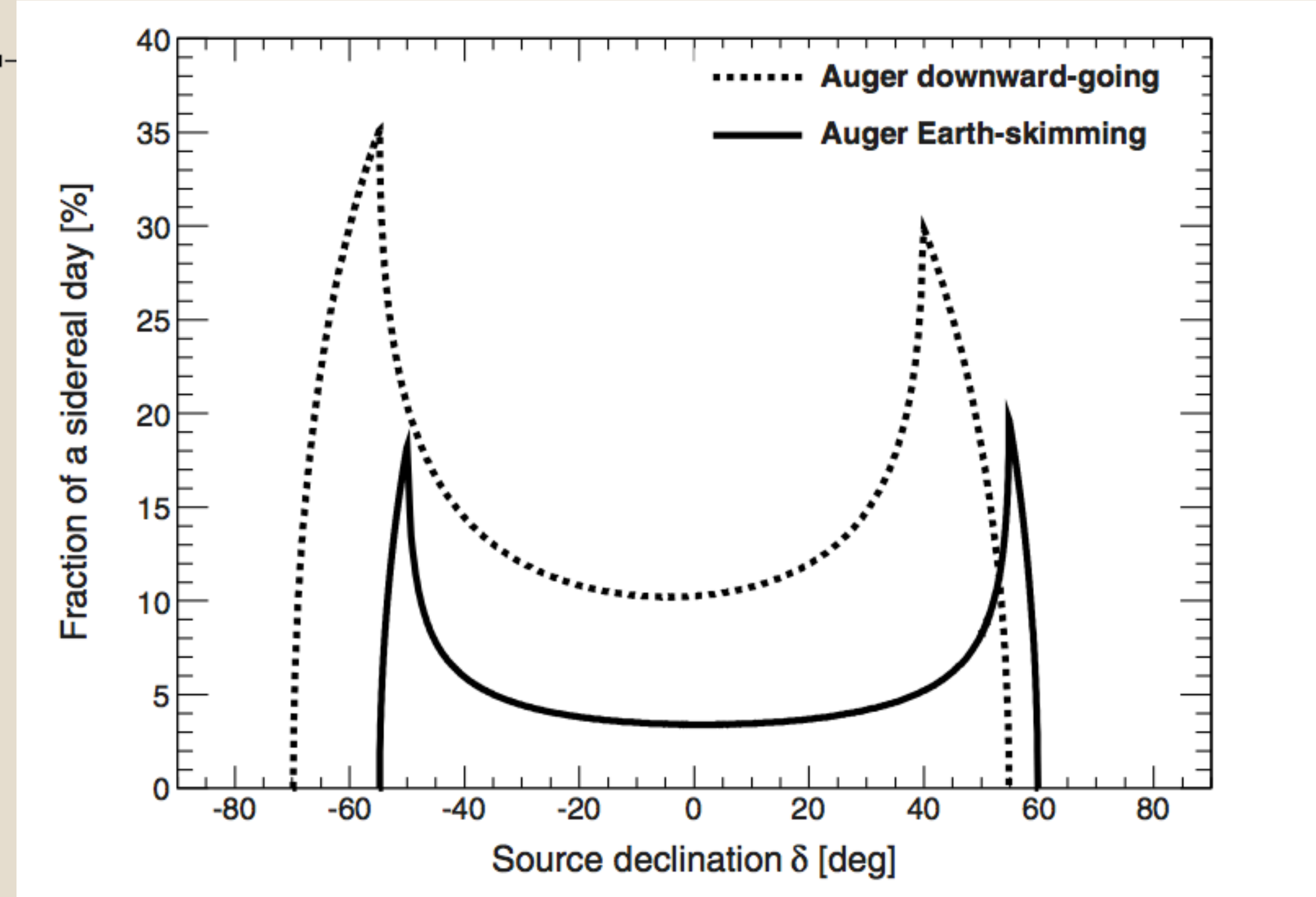
Auger upper bounds
(assuming equal proportions of flavours)



no candidate found

up to mid 2010

differential sensitivity



see Astrophys. Journal Letters 755 (2012) L4

summary and perspectives

- the Pierre Auger Observatory is sensitive to UHE neutrinos
  - atmospheric interactions *(all flavours)*
  - earth skimming *($\nu_\tau \to \tau$ in earth + decay of τ in air)*
- real data are *clean* (or easy to clean up)
- horizontal showers: simple criteria allow to reject both the *accidental* and the *physical* background without losing much efficiency for neutrinos

expected improvement: new triggers (better efficiency at low energy)

- top-down predictions are strongly disfavoured *(confirmation of result on UHE photon flux)*
- we reach GZK predictions: *UHE neutrino discovery or constraining upper bounds expected within a few years*

more details on ν_τ analysis: Phys. Rev. D79 (2009) 102001
results with data up to 2010: Phys. Rev. D84 (2011) 122005