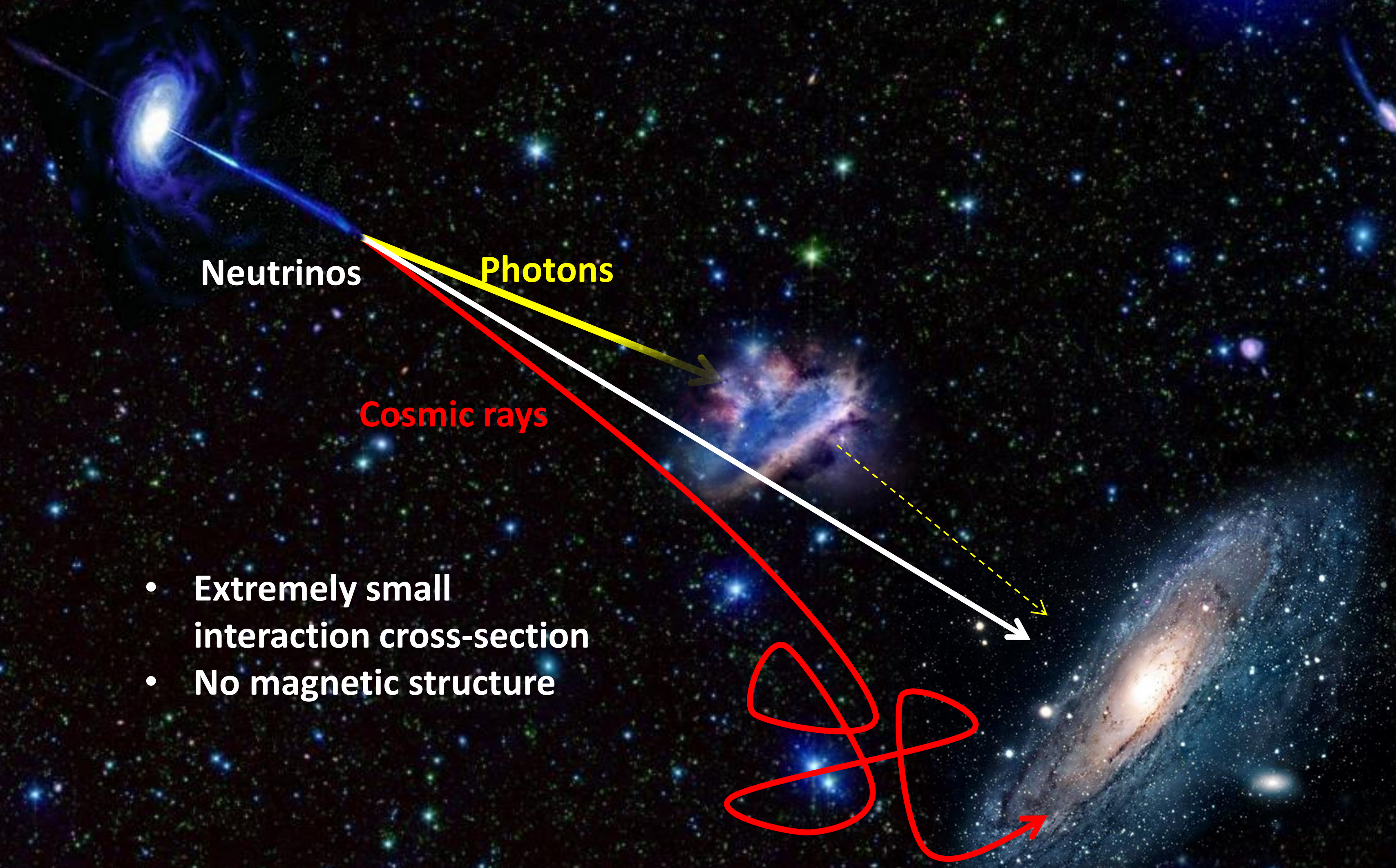
Search for cosmic neutrinos at the South Pole with IceCube & ARA

Thomas Meures

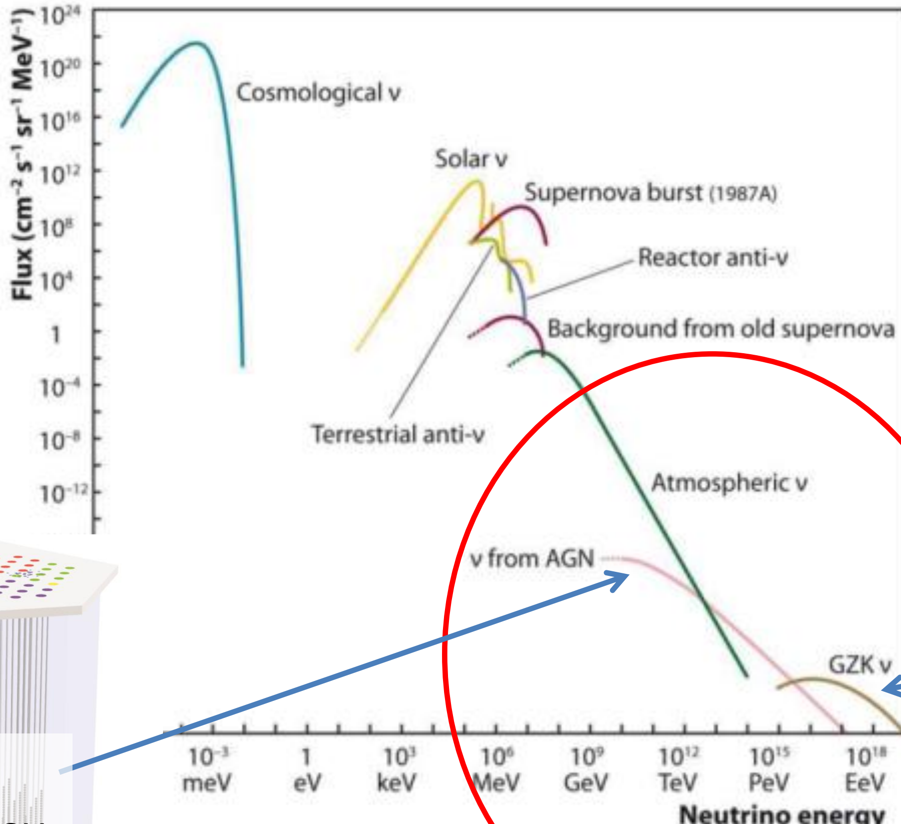
for the Belgian IceCube/ARA groups

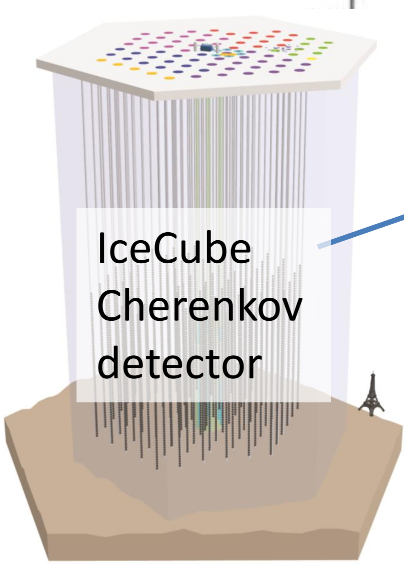
What makes neutrinos an interesting messenger in the universe



- Extremely small interaction cross-section
- No magnetic structure

What we expect



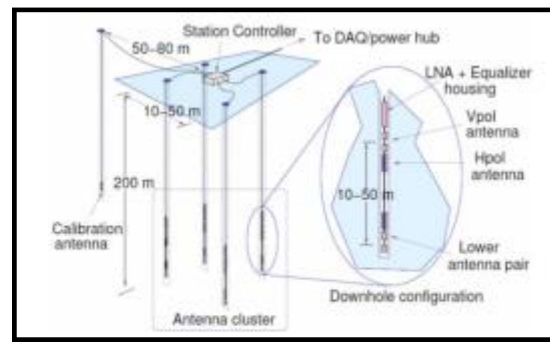


Typical production of cosmic neutrinos:

$$p + \gamma \rightarrow \pi^+ + n$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$
$$n \rightarrow p + e^- + \bar{\nu}_e$$

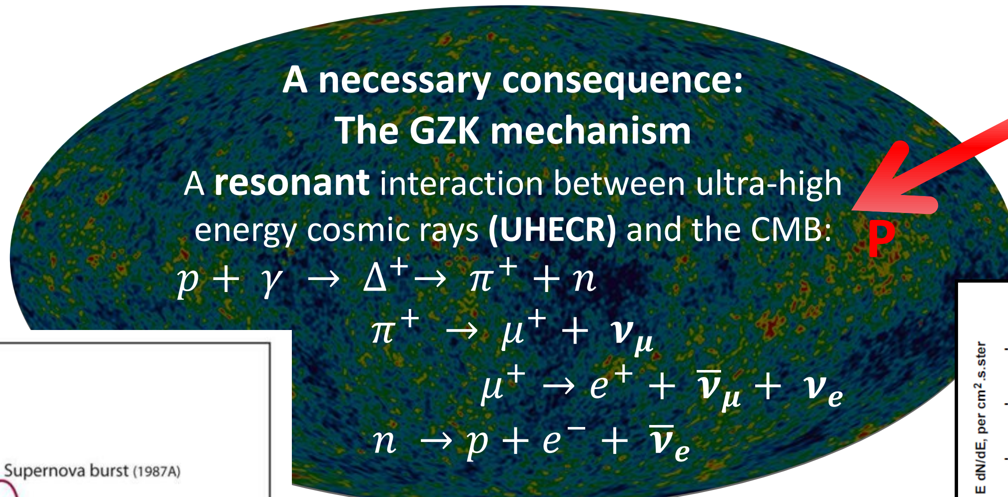
ARA: Radio detector



The Askaryan Radio Array

Main purpose: Looking for GZK neutrinos

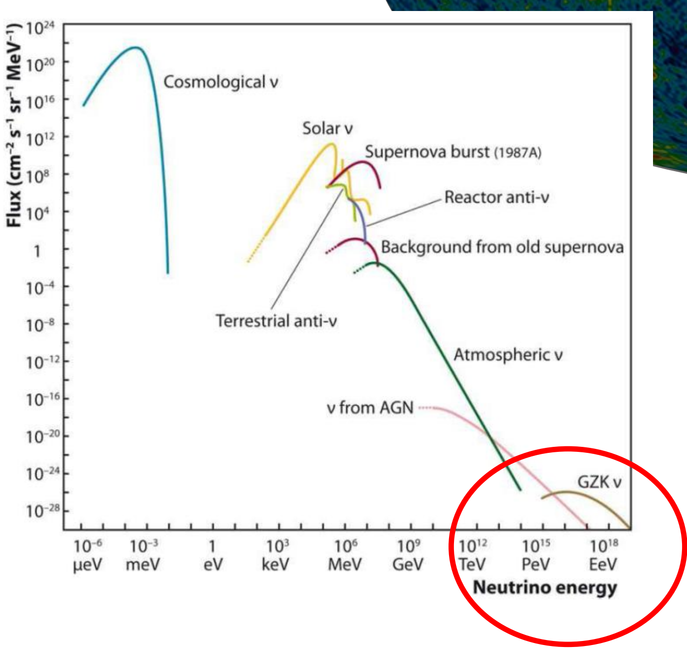
Cosmic Microwave Background radiation
discovered by Penzias & Wilson (1965)



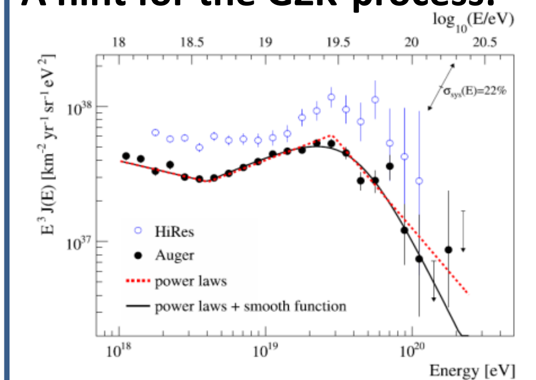
A necessary consequence:
The GZK mechanism

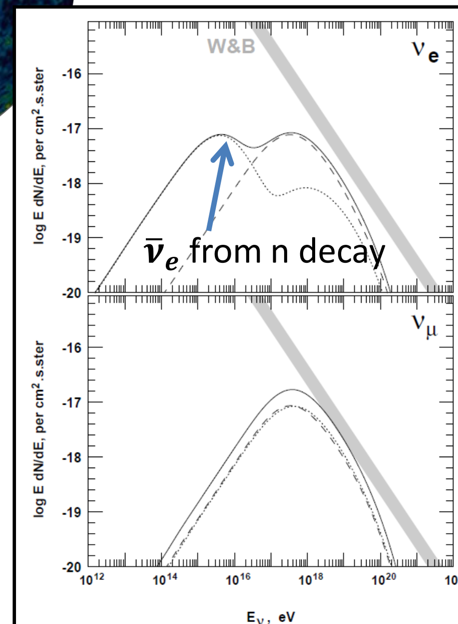
A **resonant** interaction between ultra-high energy cosmic rays **(UHECR)** and the CMB: **p**

$$p + \gamma \rightarrow \Delta^+ \rightarrow \pi^+ + n$$
$$\pi^+ \rightarrow \mu^+ + \boldsymbol{\nu_\mu}$$
$$\mu^+ \rightarrow e^+ + \boldsymbol{\bar{\nu}_\mu} + \boldsymbol{\nu_e}$$
$$n \rightarrow p + e^- + \boldsymbol{\bar{\nu}_e}$$

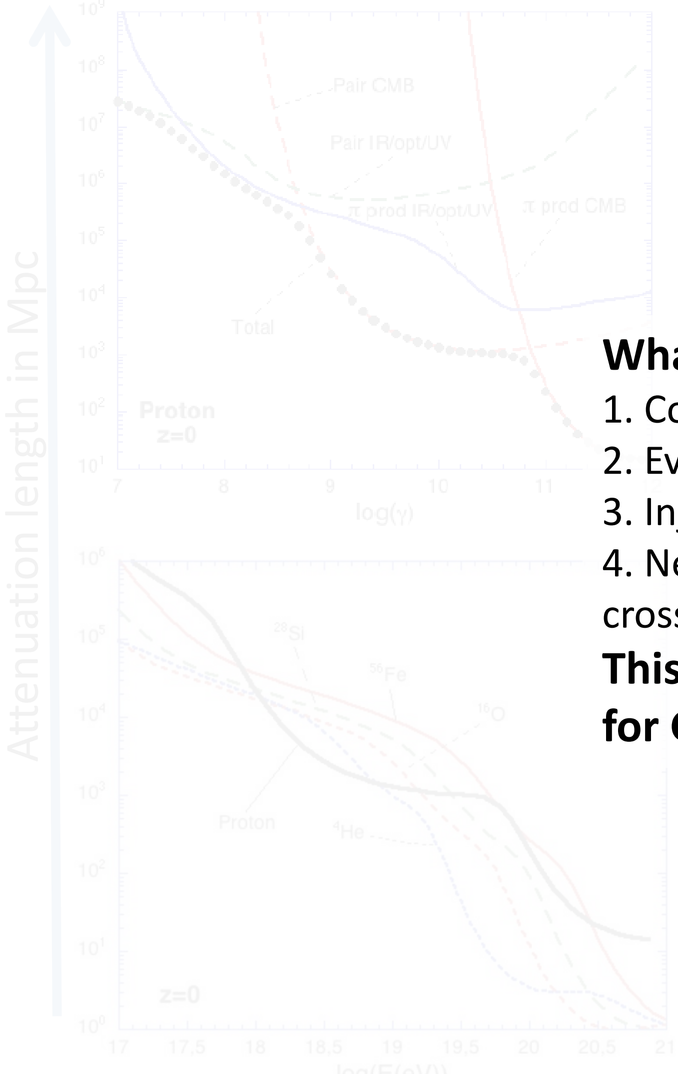


A hint for the GZK-process:





Summary – GZK neutrinos

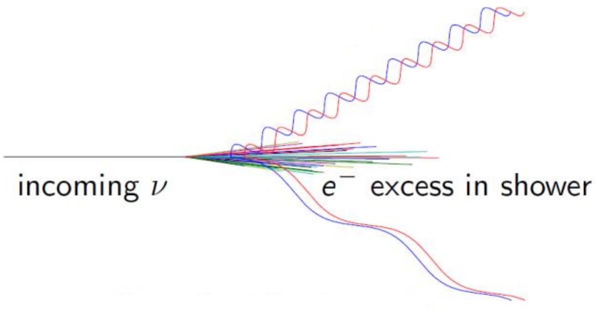


What does the GZK-flux shape depend on:

1. Composition of UHECR
2. Evolution of sources (redshift distr.)
3. Injection Spectrum: Acceleration mechanisms
4. New physics (Top down models, Neutrino cross sections, etc. …)

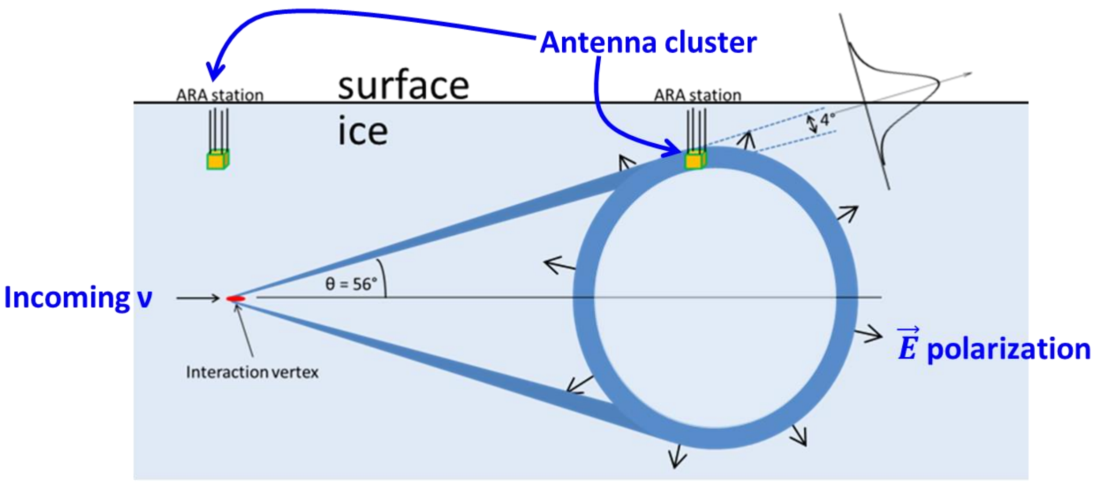
This is what we can constrain, by looking for GZK-neutrinos

Detecting νs via the Askaryan effect in ice

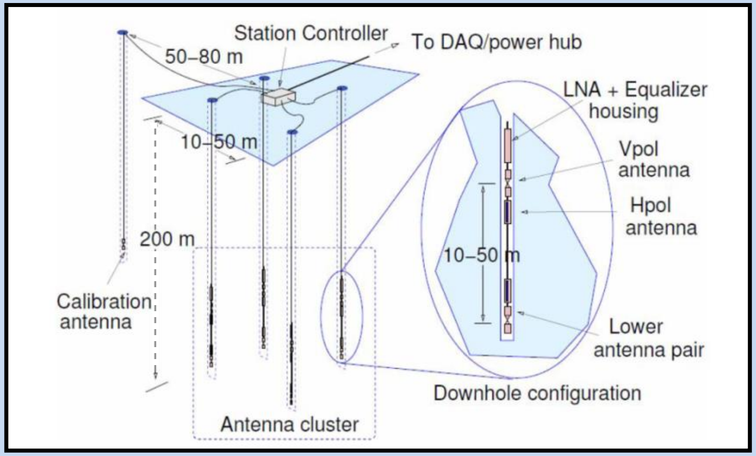


- Neutrinos produce particle cascades in the ice
- If the energy is high enough, a significant negative charge excess (~20%) is built up through:
  - Compton scattering
  - Delta-rays

- This is one of the few possibilities to detect GZK-neutrinos cost effectively
- **For most other techniques the attenuation length for the used signal is too short**



The ARA setup

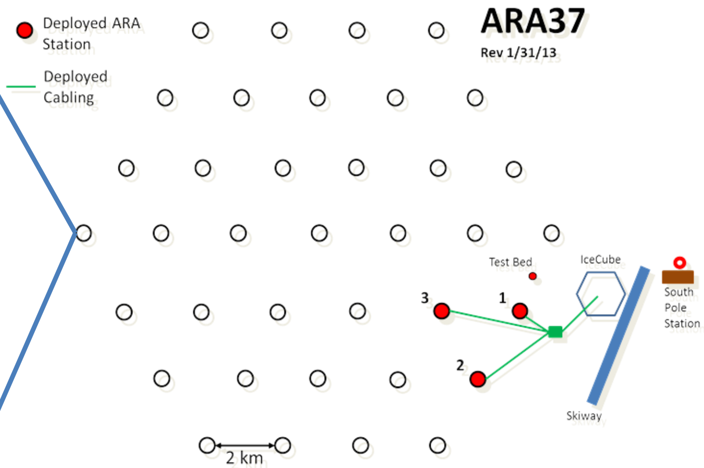


One station:

- **Measurement system:**
  - 4 holes, 20 m spacing
  - 16 antennas, 150 MHz – 800 MHz
    (8 horizontally polarized., 8 vertically pol.)
- **Calibration system:**
  - 2 holes, ~40 m distant
  - 4 pulsing antennas (2 h-pol., 2 v-pol.)

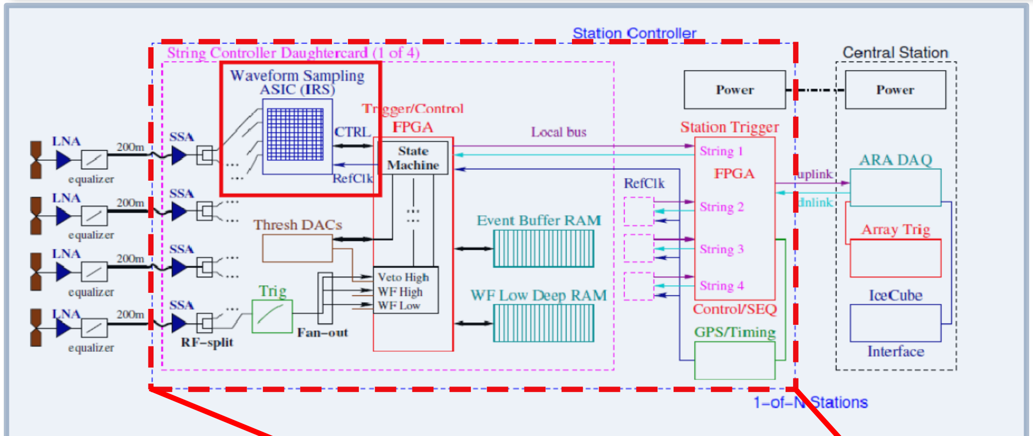
Each station is an autonomous detector!

- 37 antenna stations planned
- 3 stations deployed at the current date (two currently operating)



- Stations spaced by 2 km
  → **Maximizing effective volume by avoiding overlap**
- Antennas deployed in a depth of 200 m
  → **Minimizing the effect of "ray tracing" due to the changing index of refraction in the ice**

The ARA data acquisition



- Band + notch filter, to limit the LNA input to **"our"** signal
- **L**ow **N**oise **A**mplifier to enhance the signal for the data acquisition system
- RF over fiber link for loss-less transmission

Surface antennas

In-ice Antennas

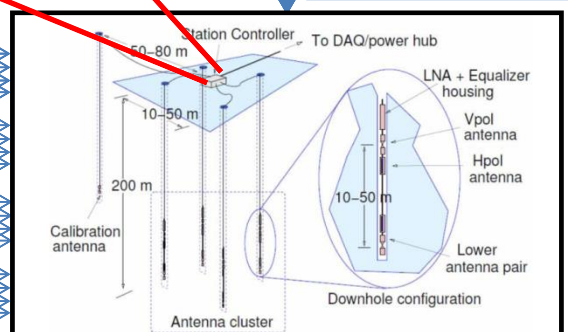
V-pol

H-pol

Notch filter

Low noise amplifier

RF over fiber link



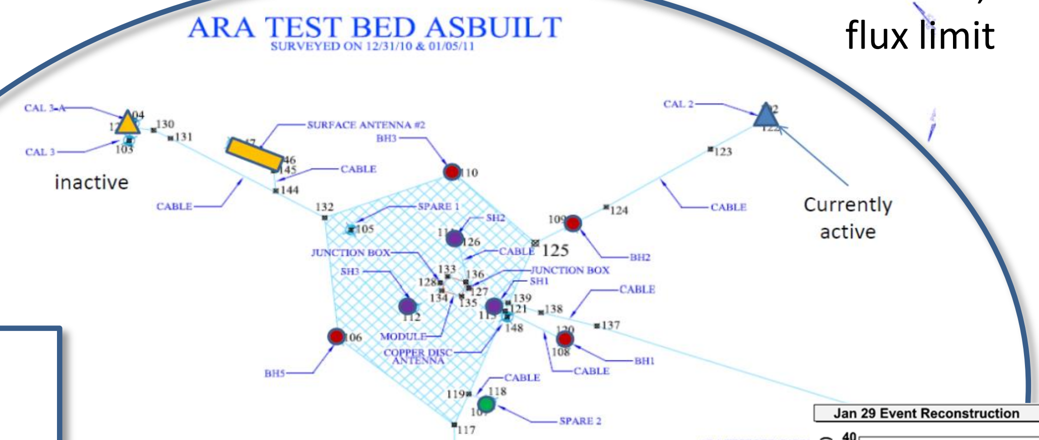
Current results

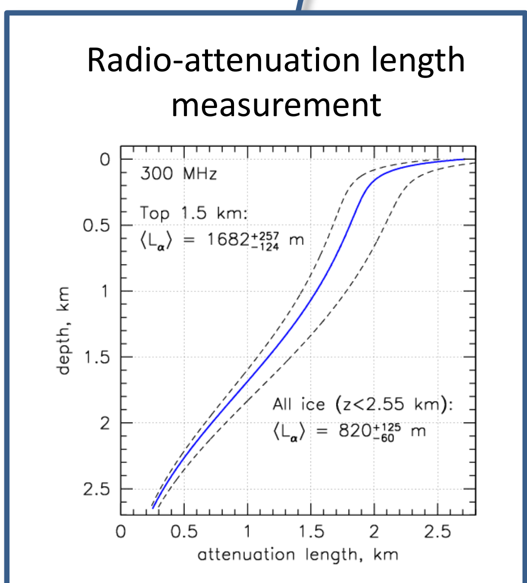
From the testbed

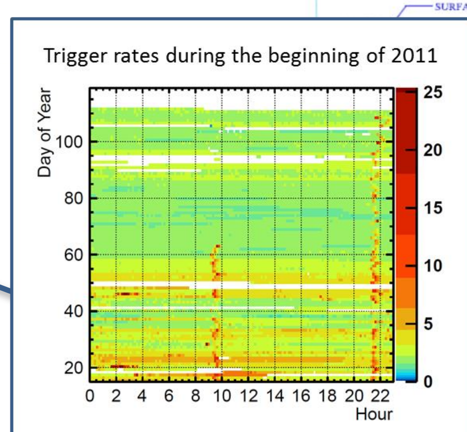
- Attenuation length measured
- Reconstruction resolution < 0.5°
- Dominantly triggering on thermal noise

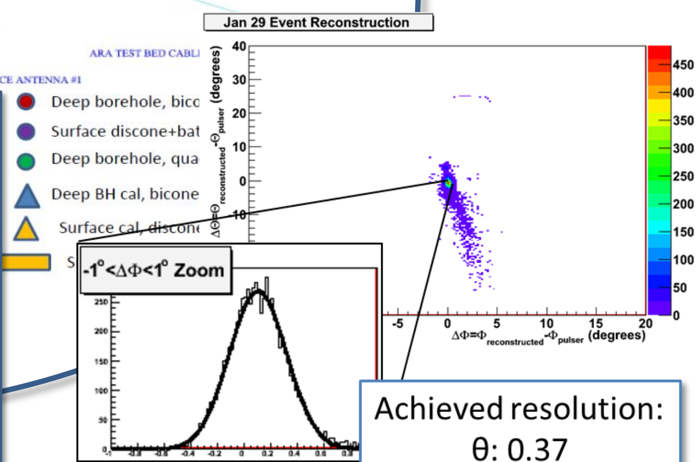
Currently pogressing:

- Various data analysis from the testbed, to calculate a neutrino flux limit









Achieved resolution:
θ: 0.37
ϕ: 0.17

ARA analysis strategy and sensitivity

Particle background:

- No other particles carry high enough energies, to produce dense enough particle showers in the ice

Radio background:

- Thermal noise of ice/antennas
- Continuous wave sources (mostly communication transmitters)

Other challenges:

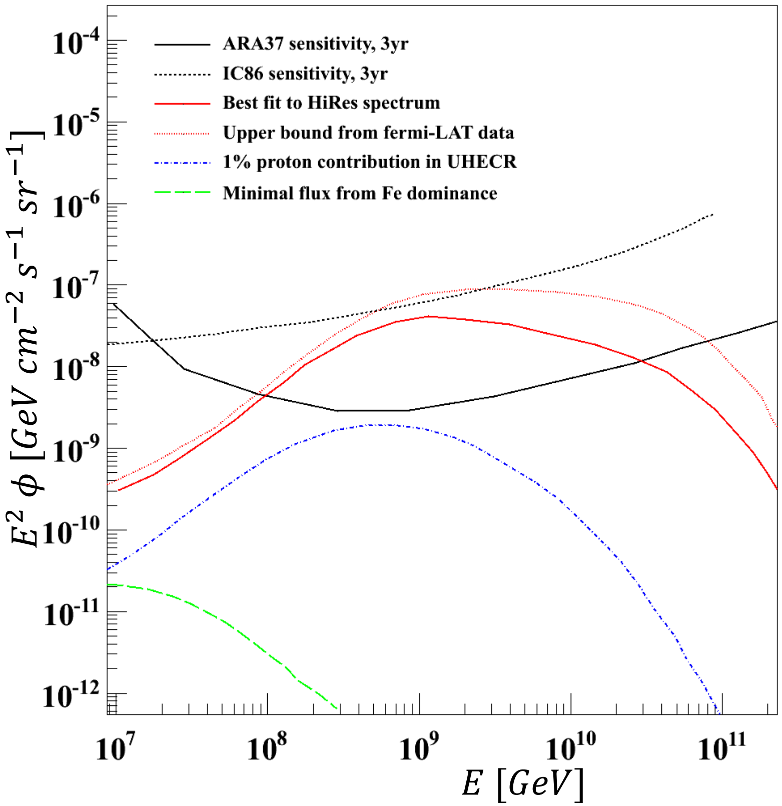
- Detector calibration/understanding

Time line:

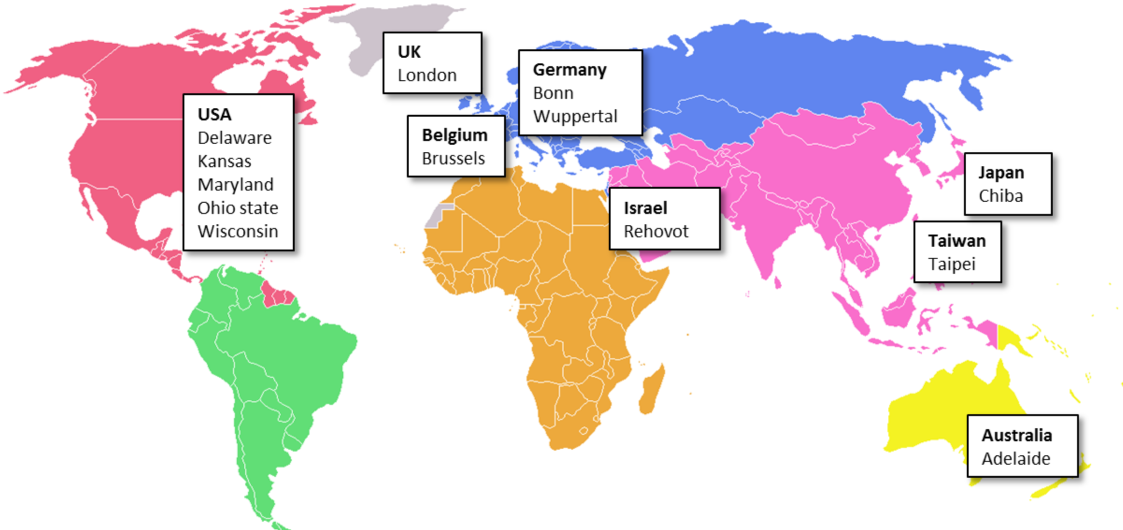
2010/2011: ARA prototype: "testbed"
2011/2012: deployment: ARA station 1
2012/2013: deployment: ARA station 2, 3
2013/2014: no deployment

Large funding from Taiwan, Japan
U.S. funding uncertain due to budget cuts

Continuous wave rejection
+ Thermal noise rejection
+ reconstruction quality
determine the neutrino sensitivity



The ARA collaboration



ARA Belgium

PhD student

Thomas Meures

Postdoc

Aongus O Murchadha

Professor

Kael Hanson

Engineer

Yifan Yang

Technician

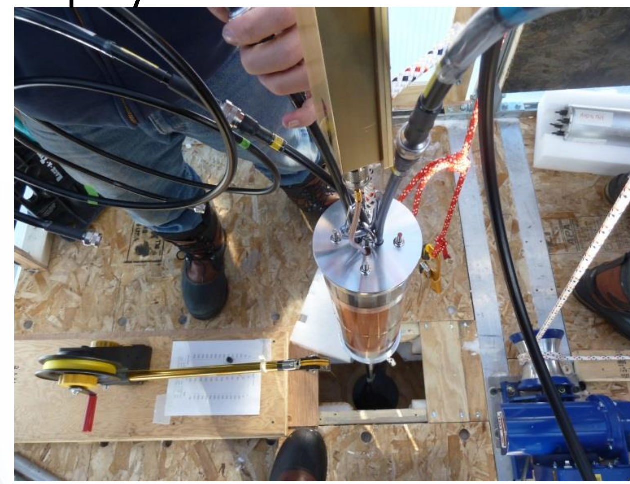
Michael Korntheuer

ARA South Pole activities

2012 - 2013

Drilling

Deployment



Commissioning

2 new stations :
12 holes drilled
48 antennas deployed

The IceCube detector

A 1km^3 neutrino detector (~1Gton)

- 5160 Photomultipliers inside **D**igital **O**ptical **M**odules (**DOM**s) on 86 strings
- 162 **IceTop** tanks (equipped with two **DOM**s each): for air shower detection
- Infill array **Deepcore**: 8 denser strings: Optimized for lower energies

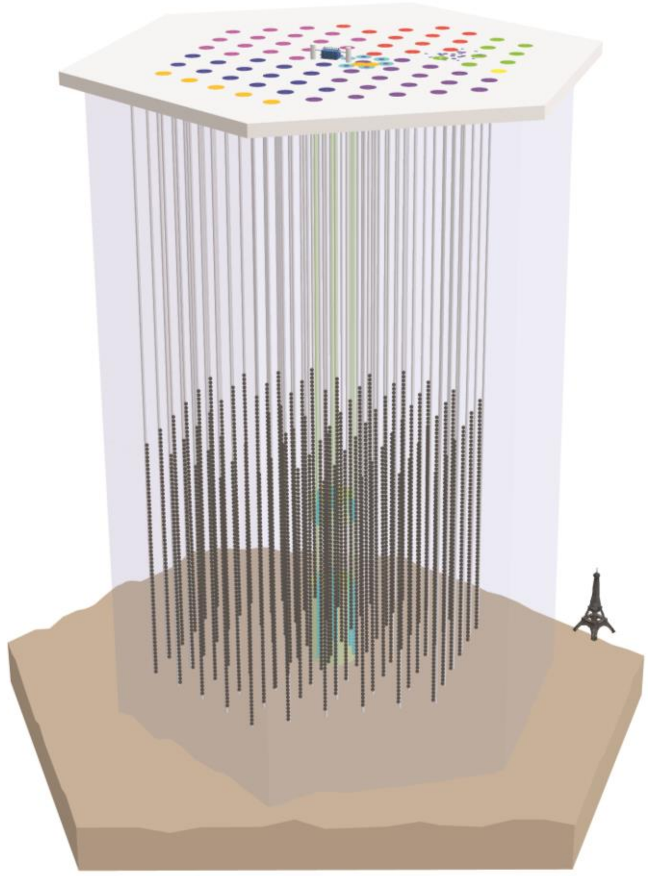
IceCube Belgium: 30 people from

Vrije Universiteit Brussel

ULB UNIVERSITÉ LIBRE DE BRUXELLES

UNIVERSITEIT GENT

UMONS Université de Mons



Event signatures in IceCube

From secondary particles

Three neutrino flavours

- ν_μ
- ν_e
- ν_τ

Interaction via

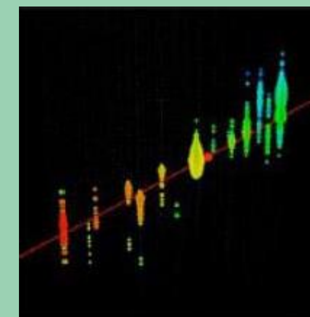
Charged current
$\nu_\mu + N \rightarrow \mu + X$

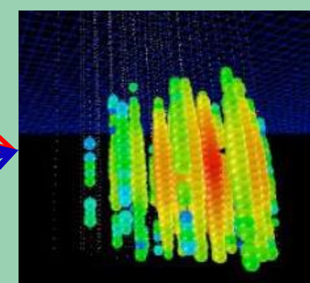
Charged current

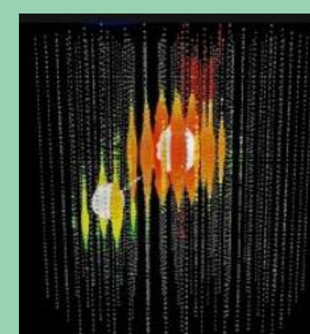
Neutral current
$\nu_x + N \rightarrow \nu_x + X$

Charged current
$\nu_\tau + N \rightarrow \tau + X$

Detector signature



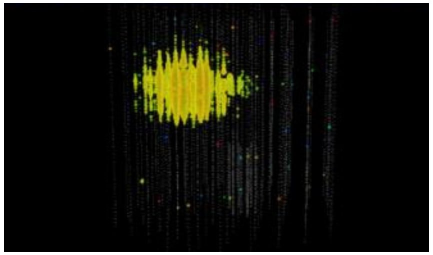




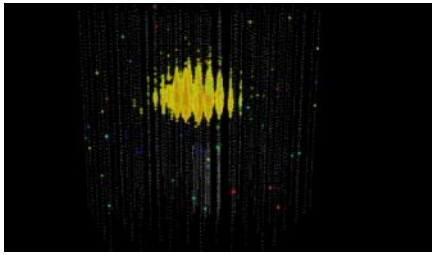
IceCube High-energy neutrino search

Extremely High Energy (EHE)-analysis

- Neutrino search with 662 days of data (2010 – 2012)
- Optimized for EeV (10^{18}eV) neutrino energies
  → sensitive above 1PeV
- The result: two neutrinos found
- **Could they be atmospheric neutrinos:**
  → $\mathbf{2.8\sigma}$ exclusion



Bert: 1.04 ± 0.16 PeV



Ernie: 1.14 ± 0.17 PeV

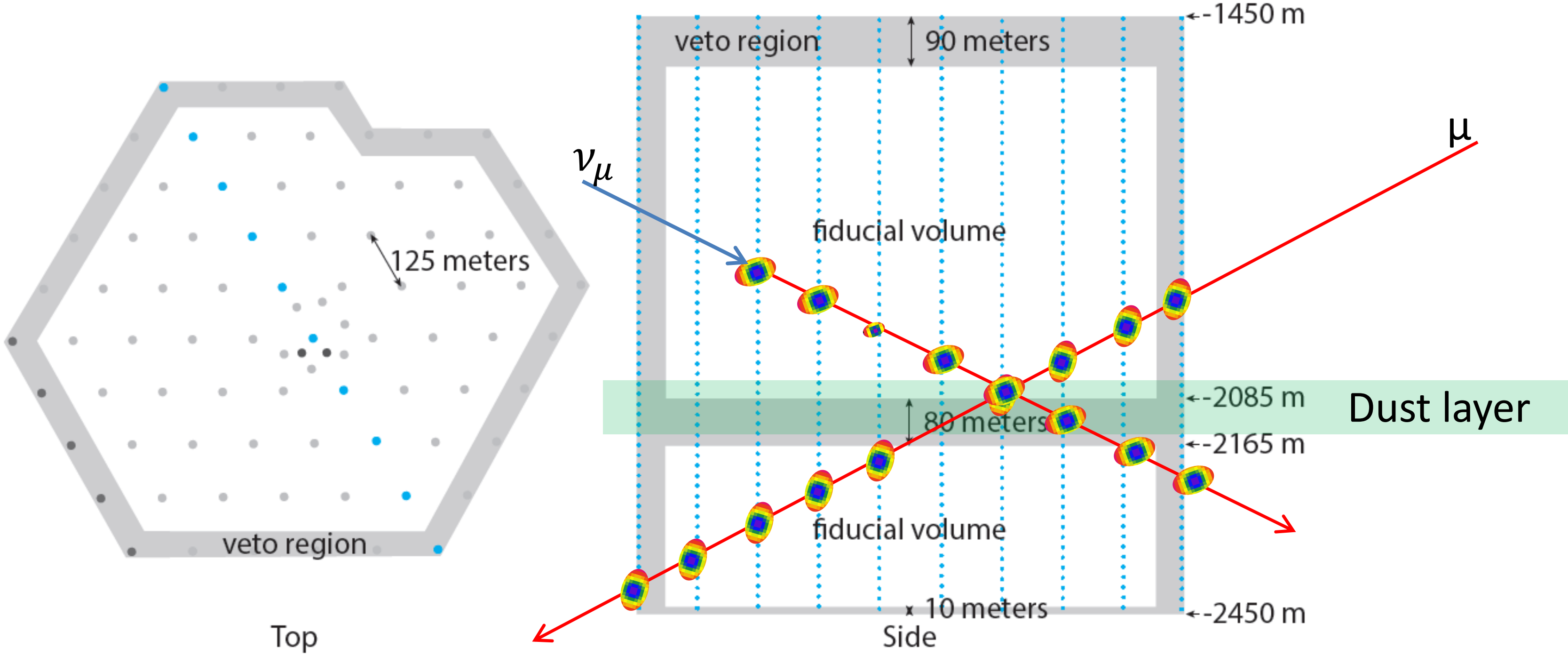
Highest energetic neutrinos ever observed!

Start a different search on the same dataset, to be more sensitive to a bit lower energies

IceCube HESE analysis

High **E**nergy **S**tarting **E**vent search:

- Main background is atmospheric muons: 3kHz
- Define outer regions of the detector as a veto
- **Require:**
  - Minimum 6000 photo-electrons seen in the **DOM**s
  - **First photons are not** in the veto region



HESE search details & results

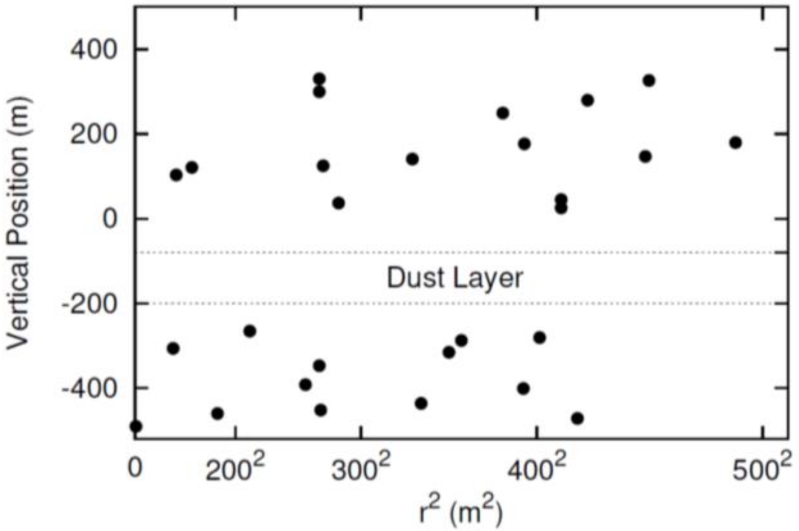
- Veto efficiency can be obtained purely from analysis of real data
  → Atmospheric muons are used to calibrate veto + cuts

Expectations:

- Passing atmospheric muons: 6 ± 3.4 events per 662 days
- Atmospheric neutrinos (including earlier IceCube results): $4.6_{-1.2}^{+3.7}$

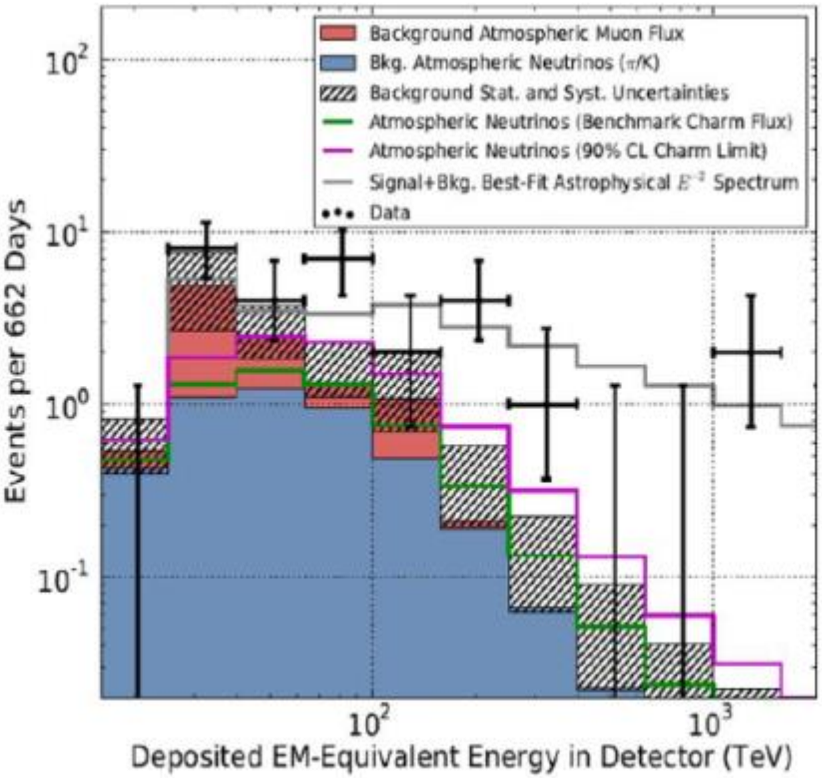
Observed: 26 events with energies between 30 – 300TeV + 2 previous events

→ Inconsistency with Background: 4.1σ



Some more observations

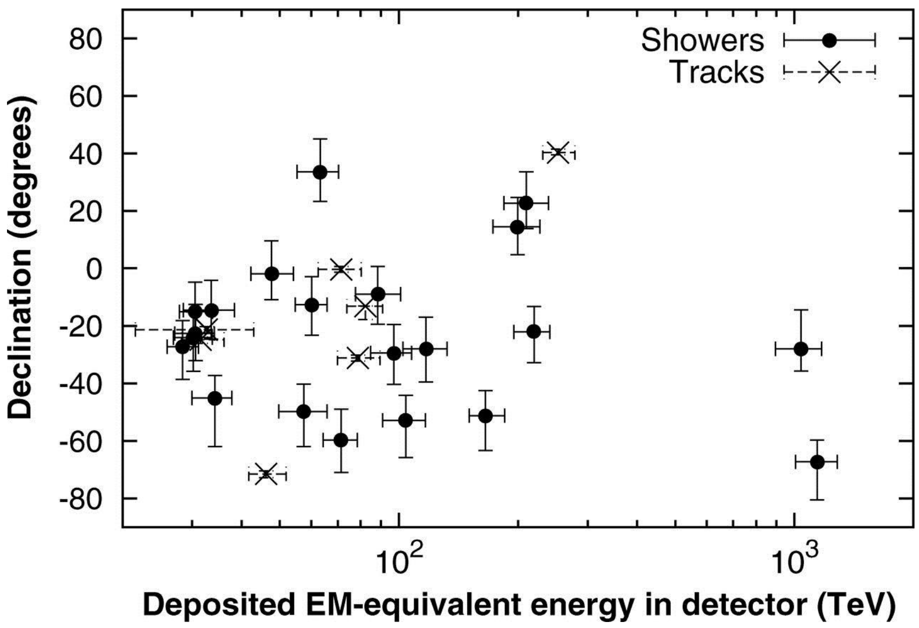
Energy distribution:
Harder than atmospheric expectation
Best fit (with spectral index as fit parameter):
$E^2\Phi = 1.2 \pm 0.4\ 10^{-8} GeV\ cm^{-2}\ s^{-1}\ sr^{-1}$



Some more observations

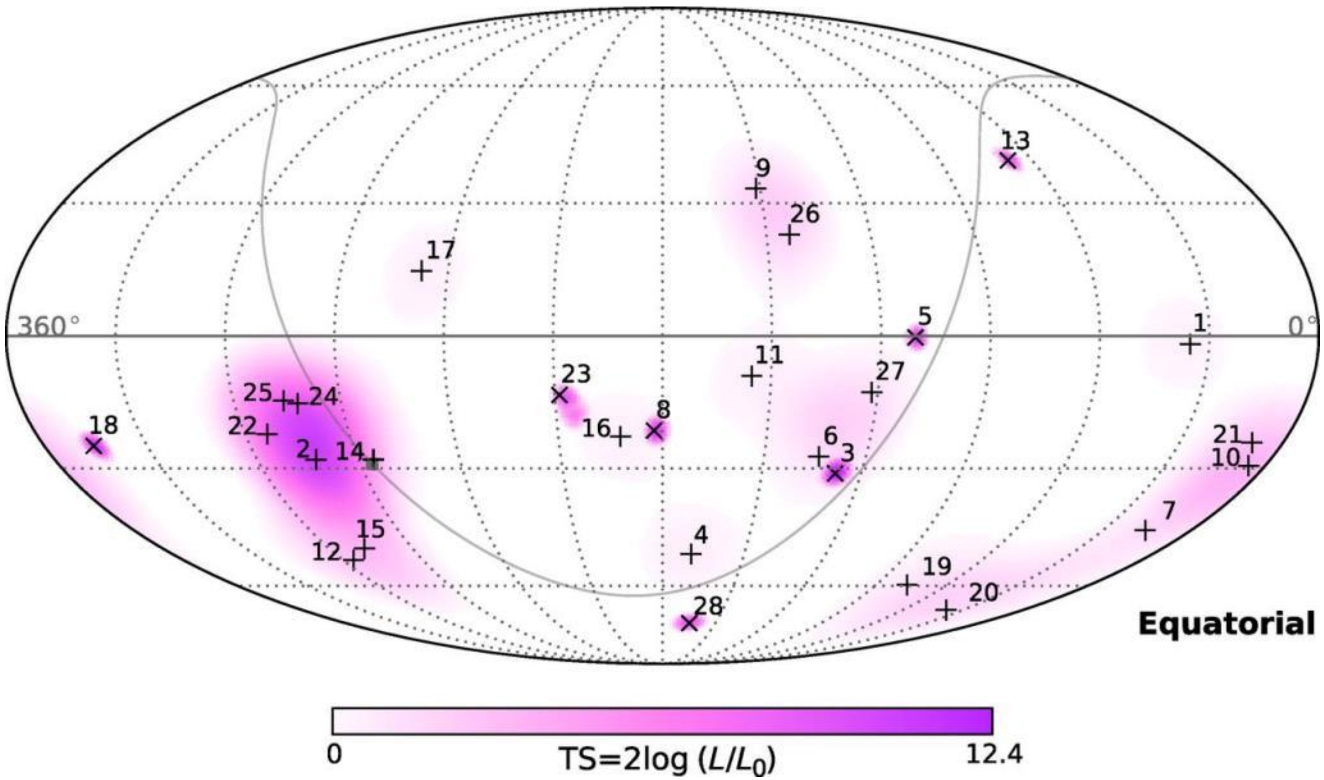
Atmospheric neutrinos are accompanied by muons, if down-going
→ Very good rejection for Southern sky atmospherics from veto cuts

But:
Most observed events come from the southern sky
→ Even less compatible with atmospheric background



Signature	σ directional reco	σ energy reco
Shower	10 -15°	~15%
Track	1°	Lower limit

Can we start neutrino astronomy yet?

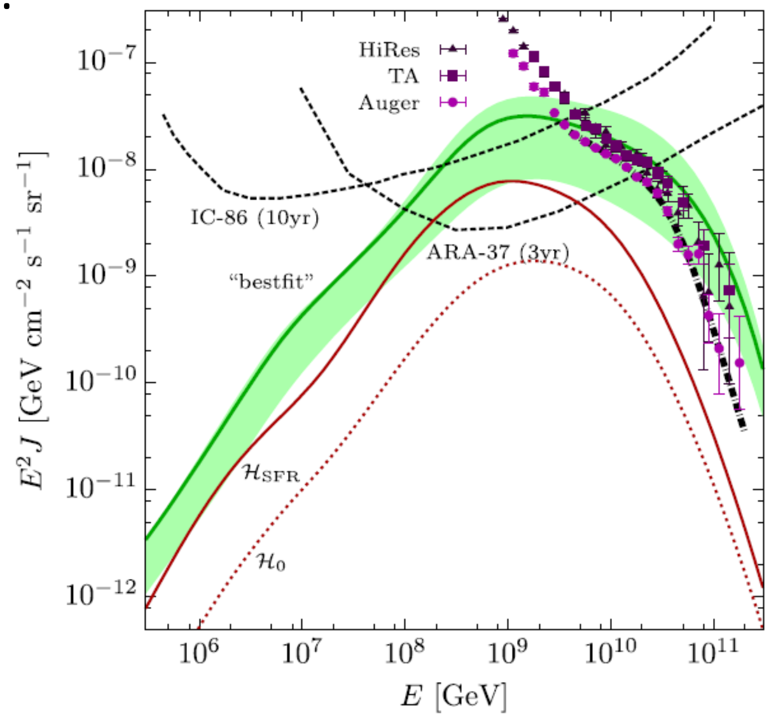


- No significant deviation from an **isotropic source distribution** found yet
- No significant **timing correlation** with catalogued GRBs found yet

Conclusion & Outlook

IceCube:

- Found evidence for high energy cosmic neutrinos, incompatible with atmospheric background by 4.1σ
- So far consistent with isotropic source distribution
- Detecting ~10 to 15 cosmic neutrinos/years with current analysis methods
  → The beginning of neutrino astronomy?
- Didn't find GZK neutrinos



ARA:

- A future detector, still under construction
- Will exceed all current neutrino detectors by ten times in sensitivity for GZK neutrinos

Conclusion & Outlook

At least some parts of the GZK neutrino flux might be difficult to see for IceCube and ARA → Looking for new detection methods

On the feasibility of RADAR detection of high-energy neutrino-induced showers in ice

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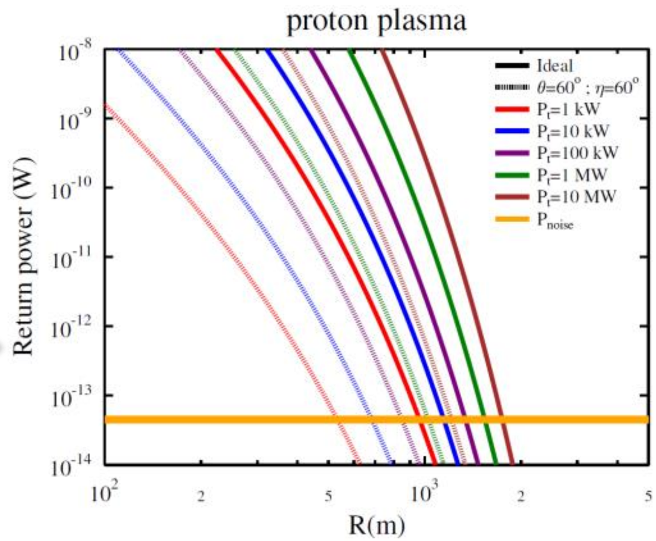
[b] *Université Libre de Bruxelles, Department of Physics, B-1050 Brussels, Belgium*

Can a RADAR signal be bounced of the remnant particle-plasma from a neutrino induced cascade?

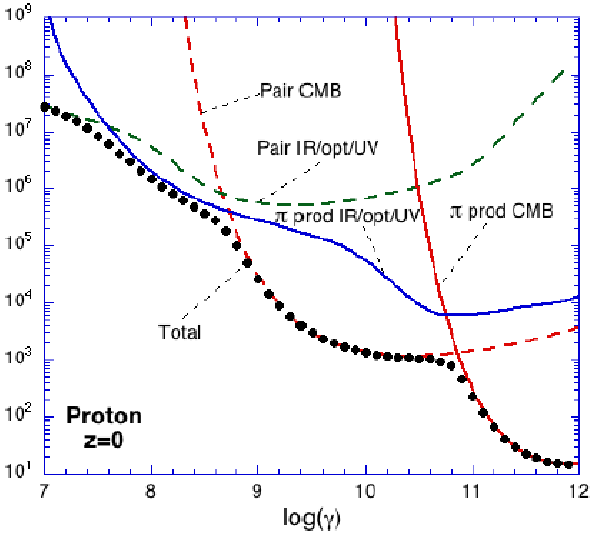
Return power from remnant protons for a primary energy $E_\nu > 20PeV$



BACKUP

Various energy loss mechanisms

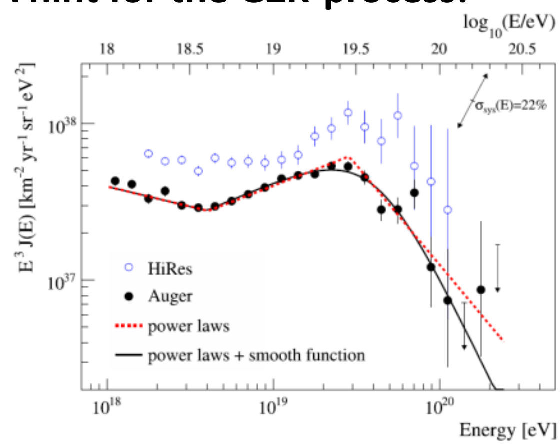
Attenuation length in Mpc



Cutoff for protons through:

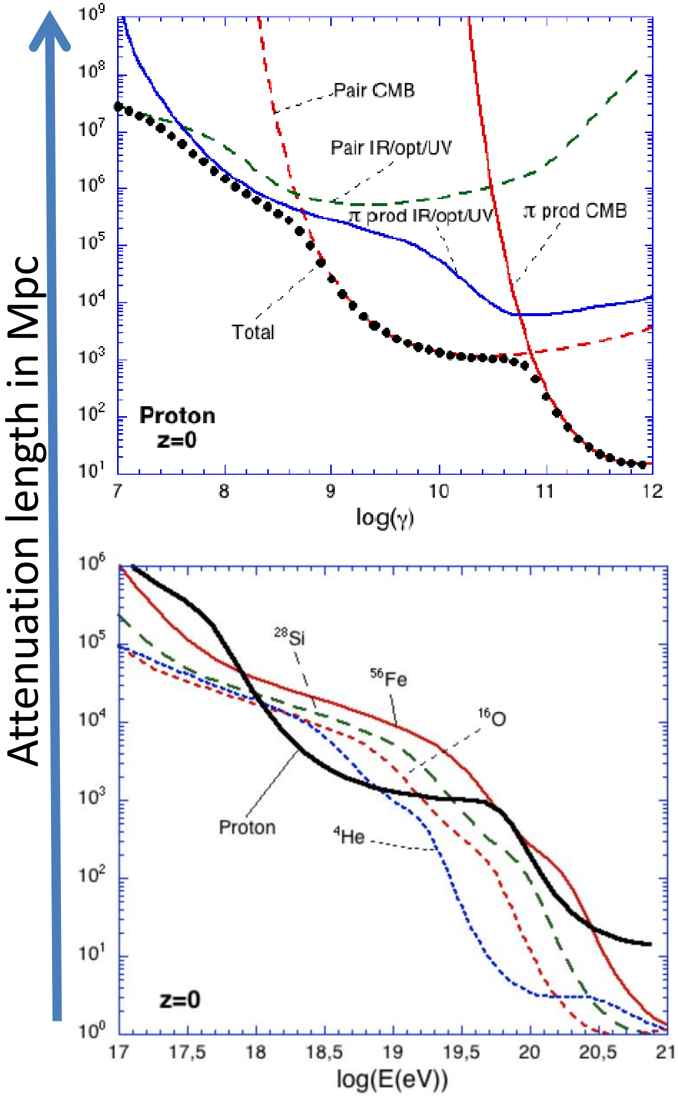
$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

A hint for the GZK-process:



Neutrino Flux

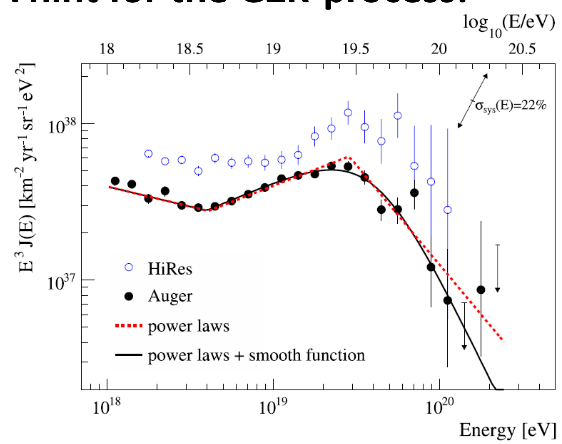
Various energy loss mechanisms



Cutoff for protons through:

$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$

A hint for the GZK-process:

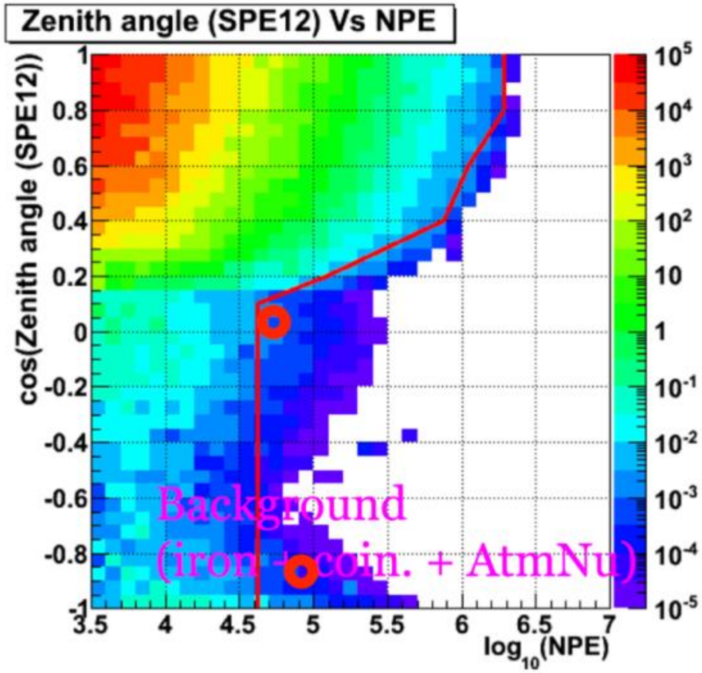


Cutoff for heavy nuclei:

- photo-erosion on CMB (neutrinos from neutron decay)

Neutrino Flux

EHE analysis



HESE charge distribution

Charge distribution:

Fits well the muon background at lower energies

Hatched area includes uncertainties for conventional + prompt atmospheric neutrinos

Q > 6000pe