IceCube - Astrophysik mit kosmischen Neutrinos am Südpol

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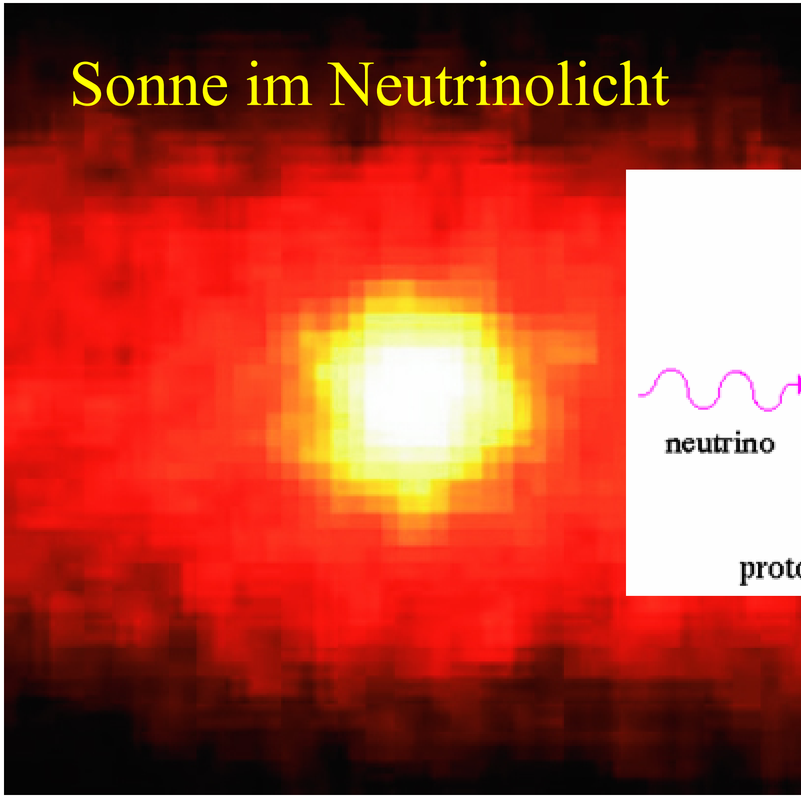
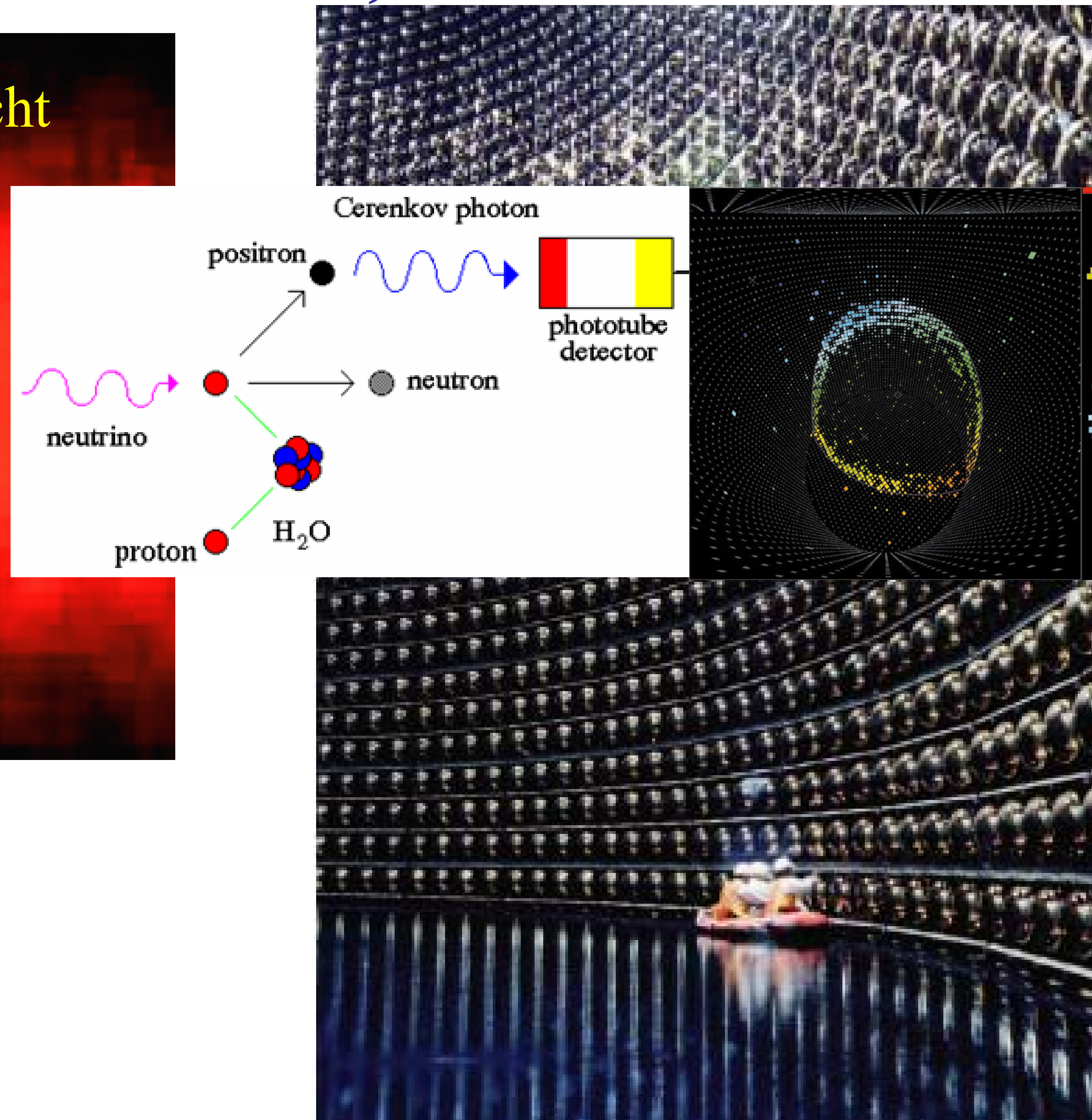
kosmische Neutrinos, die wir kennen:

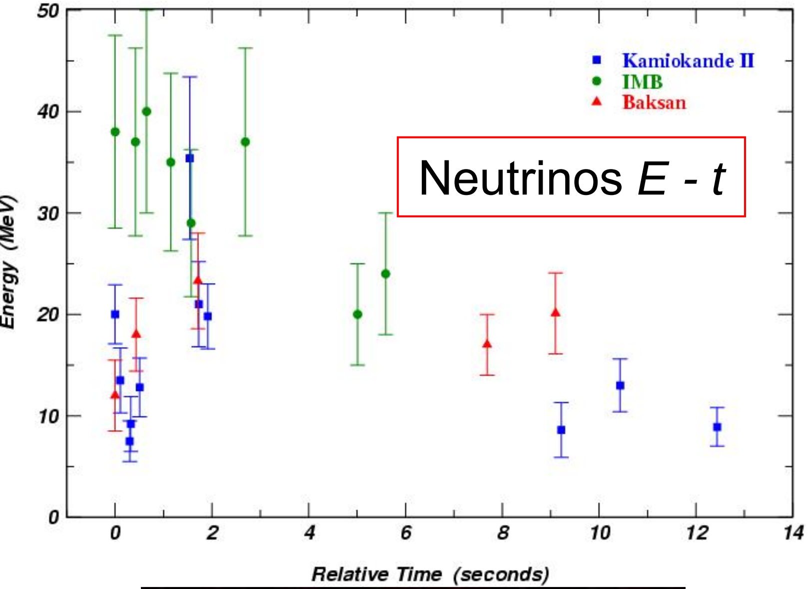


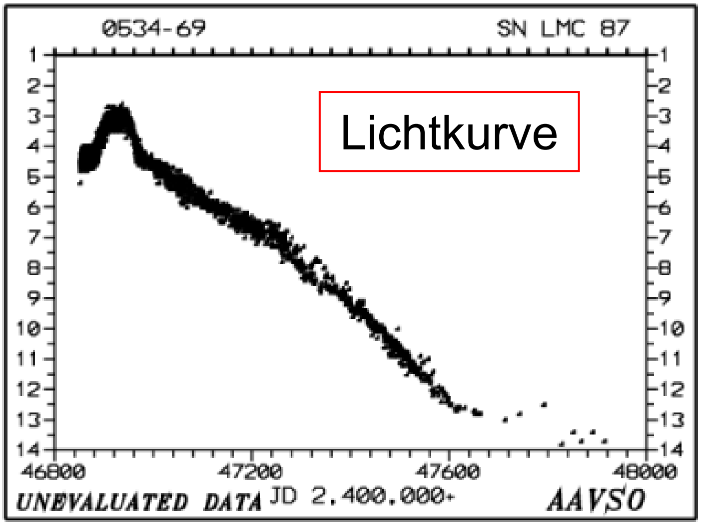


kosmische Neutrinos, die wir kennen:

Supernova-Neutrinos

Supernova SN1987A



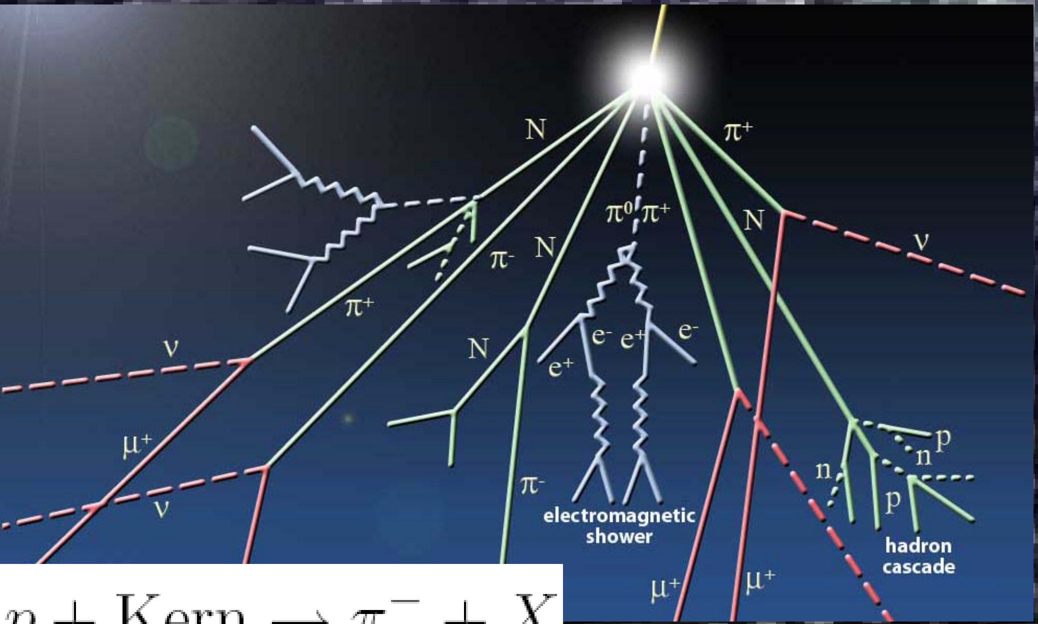


Supernova-Alarm auch aus dem Südpoleis

(siehe später)

... kosmische Neutrinos, die wir kennen:

Atmosphärische Neutrinos



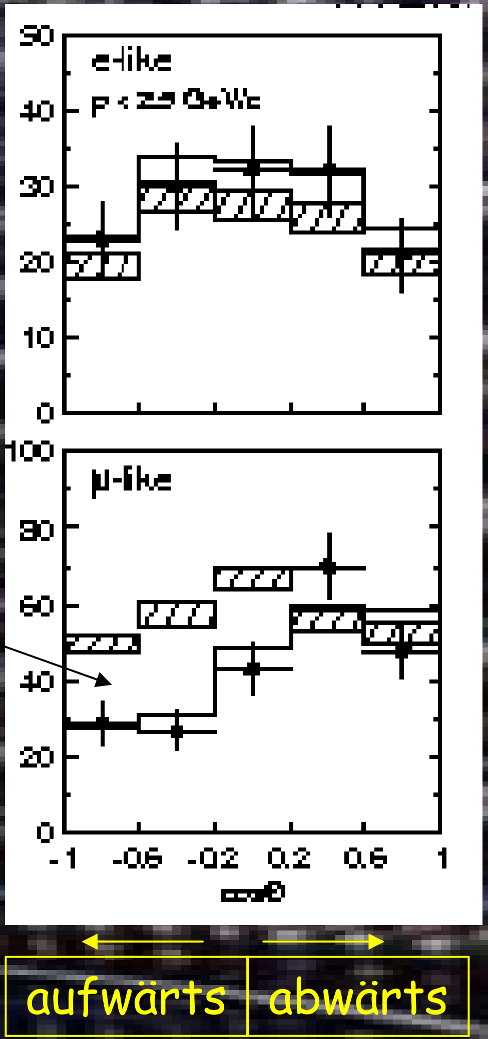
$$p + \mathrm{Kern} \rightarrow \pi^- + X$$

↓

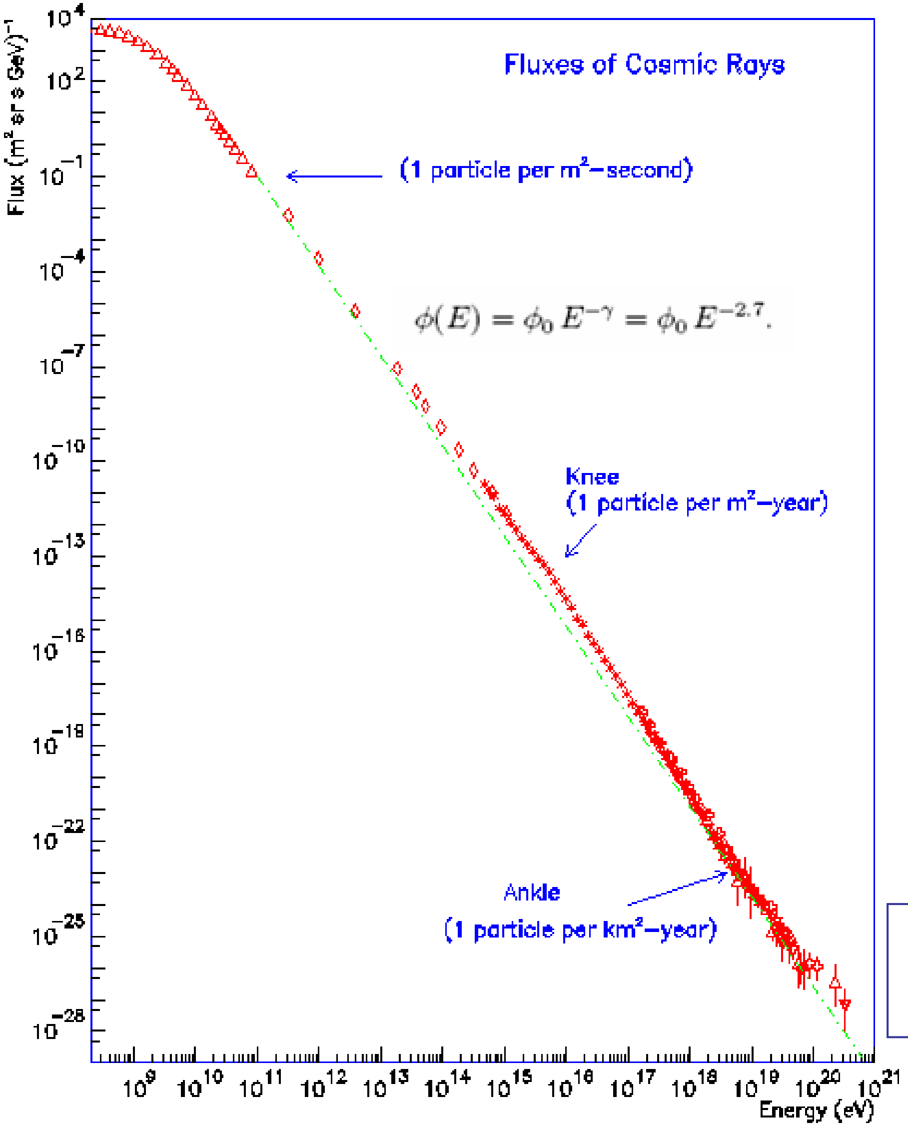
$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

↓

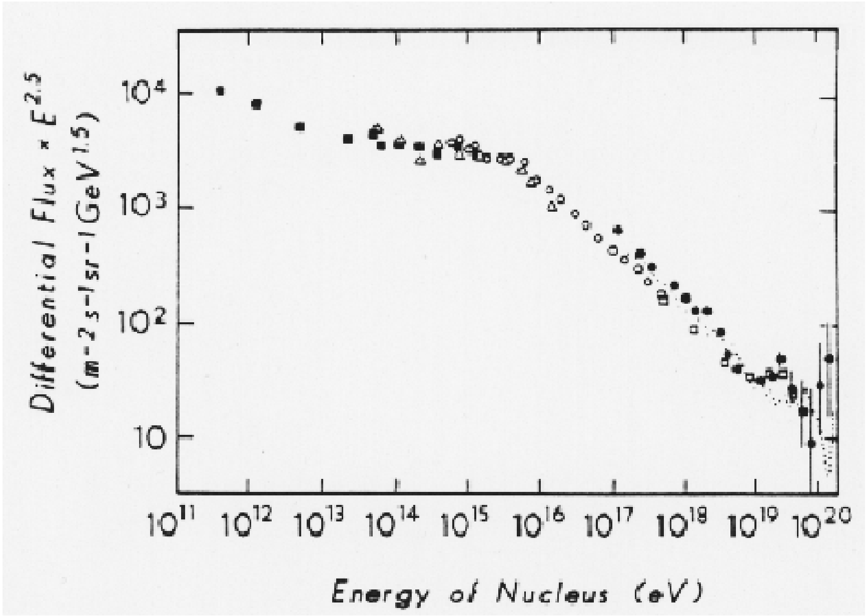
$$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$$



Geladene kosmischen Strahlung

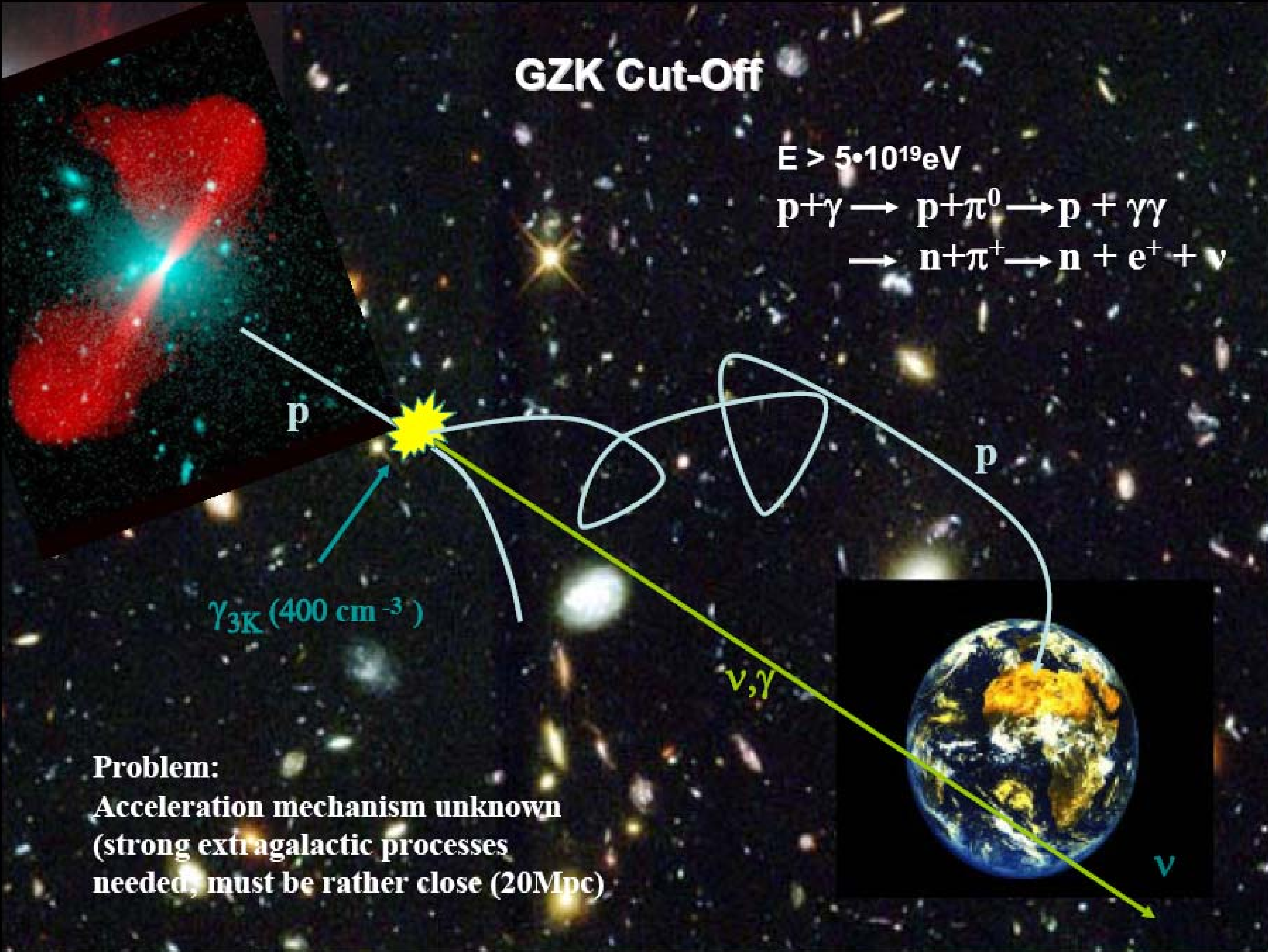


PeV EeV ZeV



$$I_N(E) \approx 1.8\, E^{-\alpha}\, \frac{\text{nucleons}}{\text{cm}^2\ \text{s}\ \text{sr}\ \text{GeV}}$$

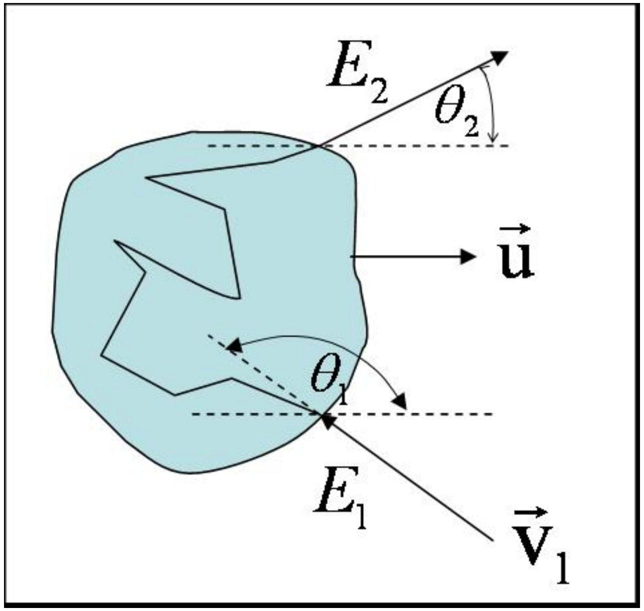
$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{array}{l} p + \pi^0 \\ n + \pi^+ \end{array}$$

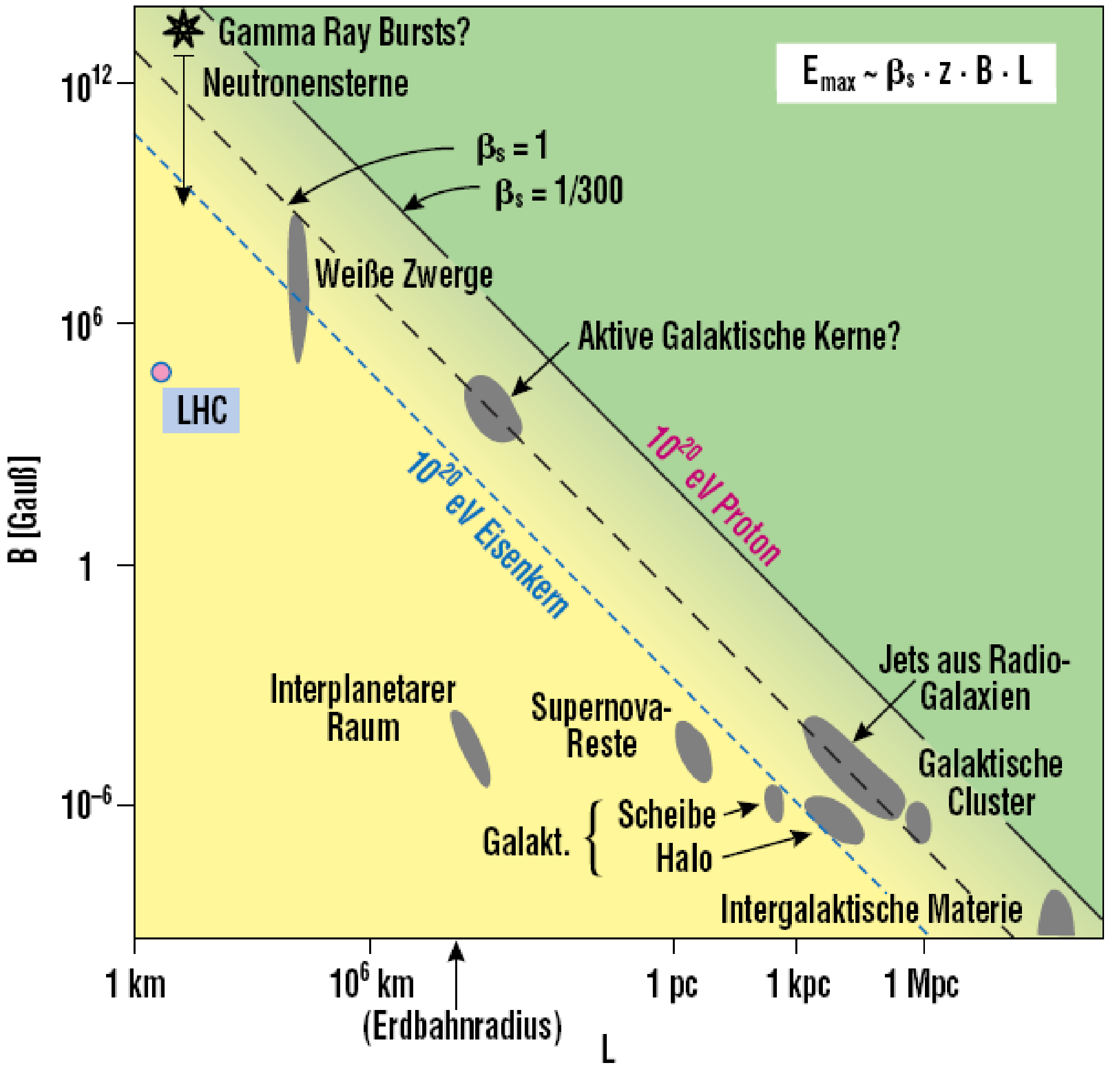

GZK Cut-Off
E > 5•10^19eV
p+γ ⟶ p+π^0 ⟶ p + γγ
⟶ n+π^+ ⟶ n + e^+ + ν
p
p
γ3K (400 cm -3)
ν,γ
ν
Problem:
Acceleration mechanism unknown
(strong extragalactic processes
needed, must be rather close (20Mpc)

Hillas-Diagramm

Fragen:

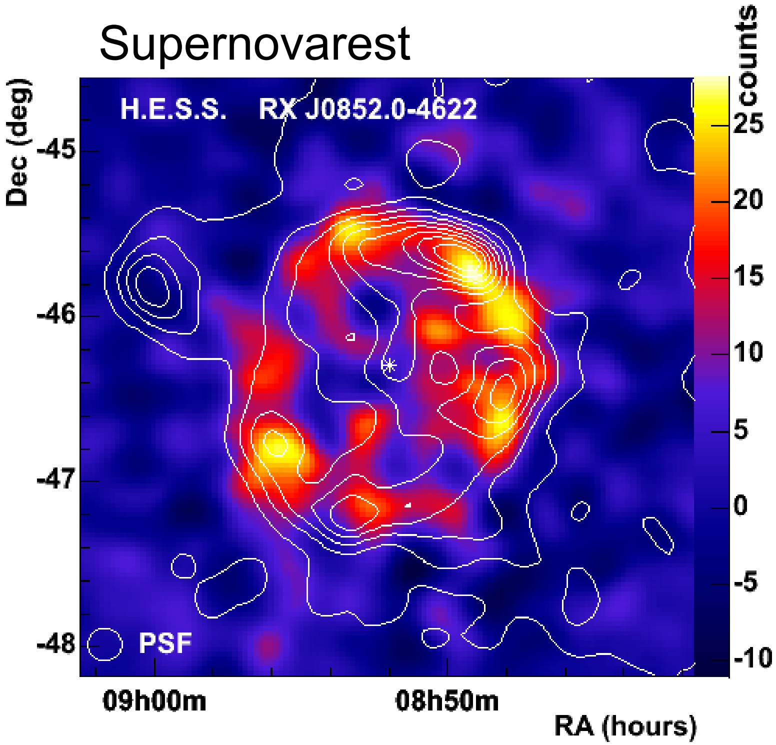
- Wo werden die hohen Energien erzeugt?
- Wo herrschen die dafür notwendigen Bedingungen: *B·L*

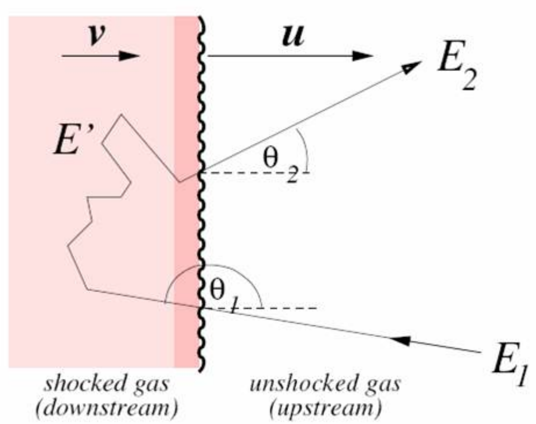


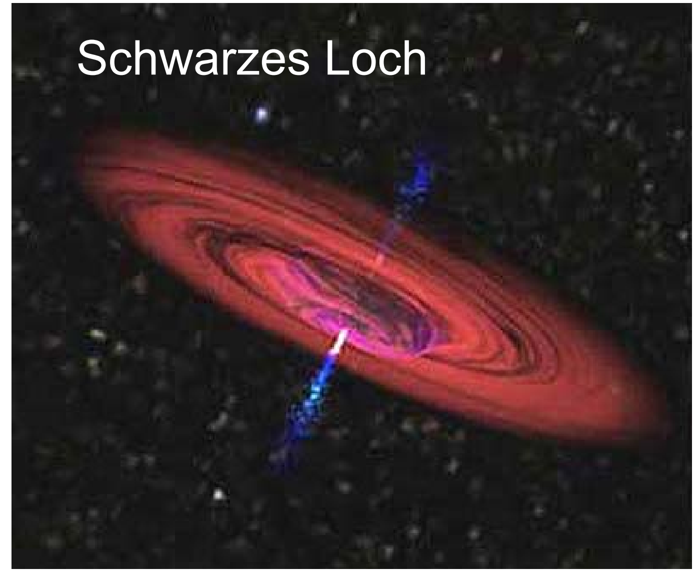


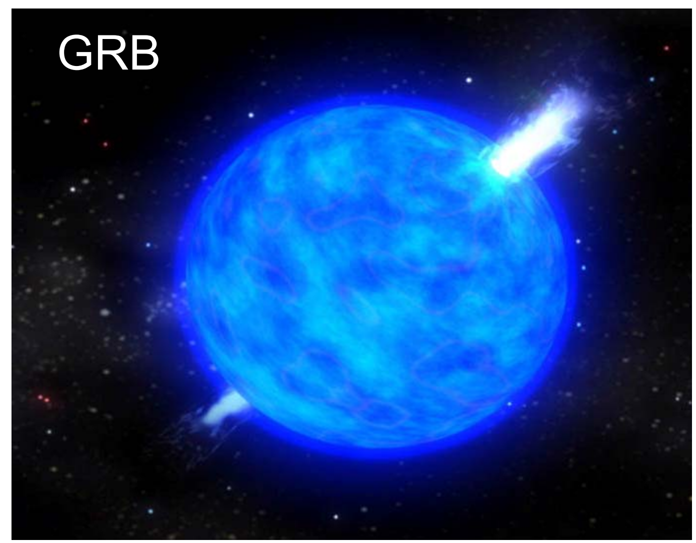
Kosmische Beschleuniger

Supernovarest

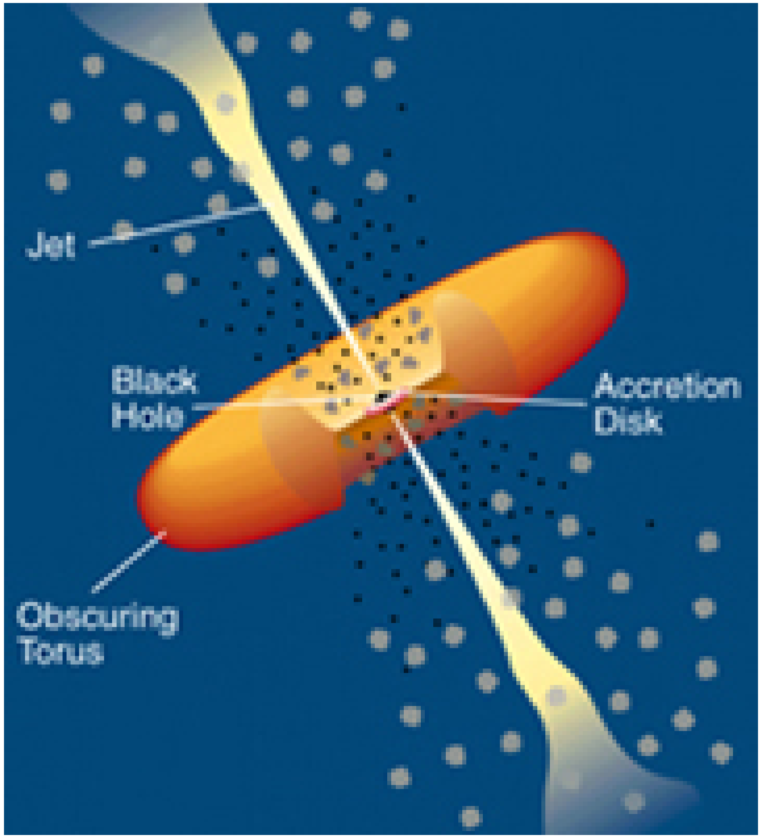








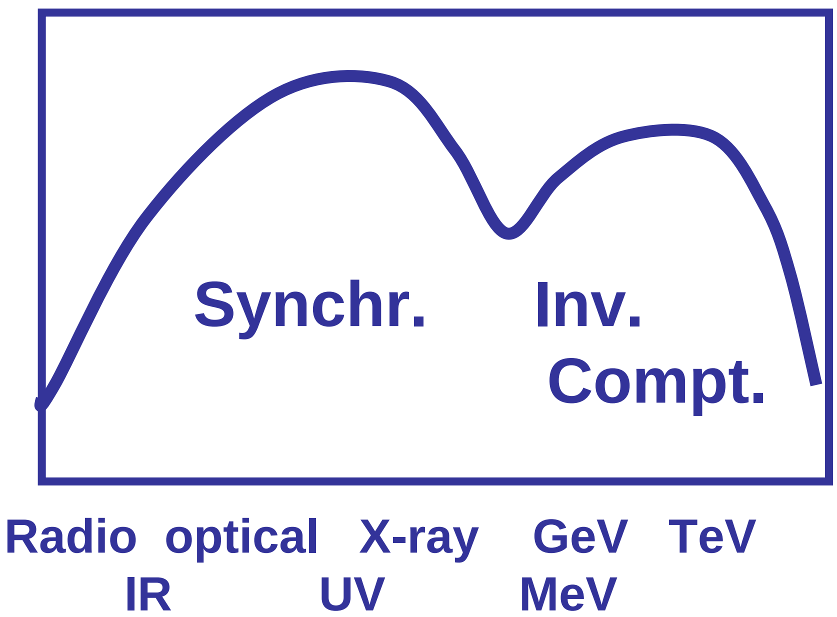
Aktive Galaktische Kerne

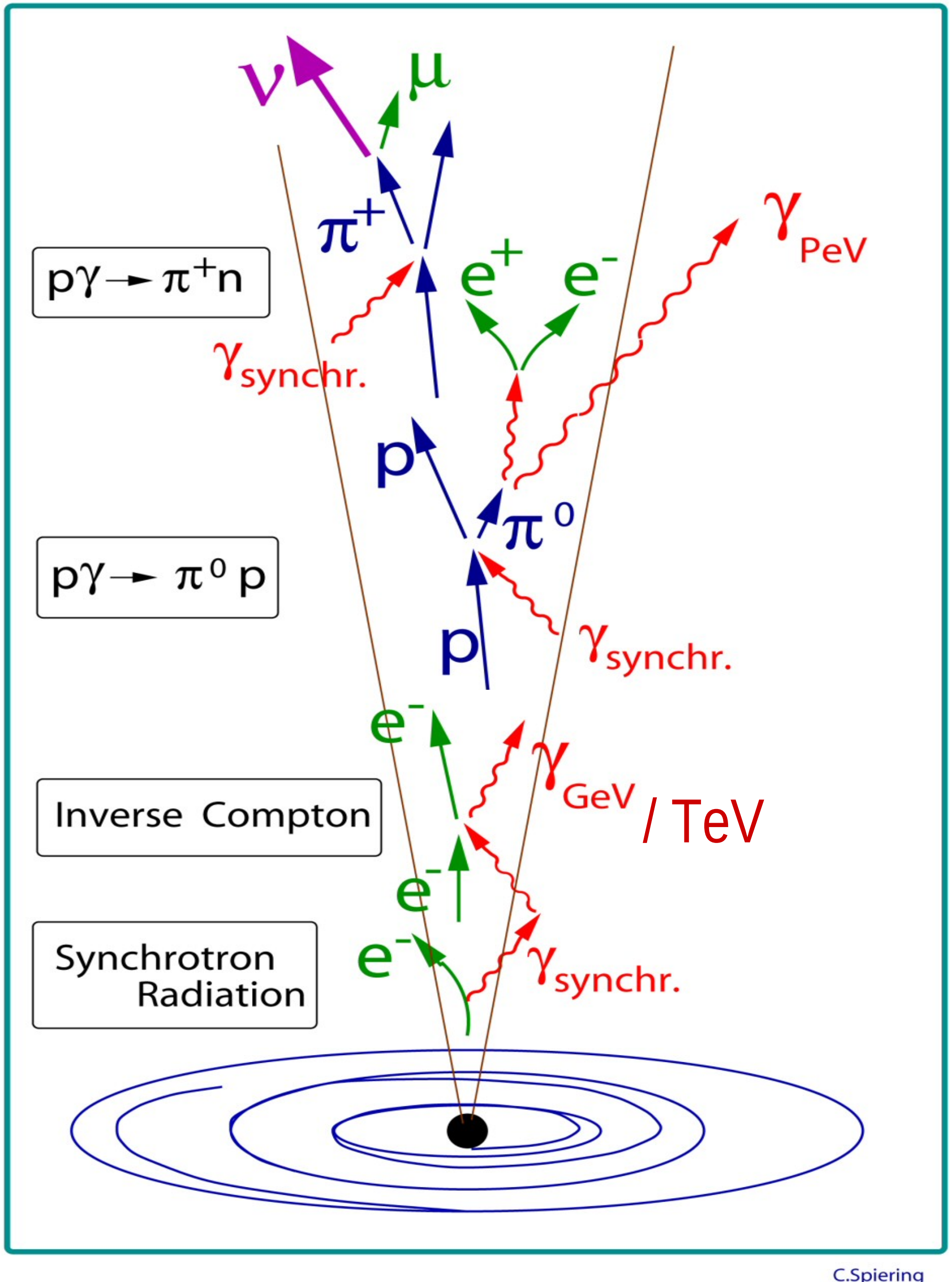


The first image is a Hubble Heritage image of M87, while the second one is a schematic diagram of an AGN

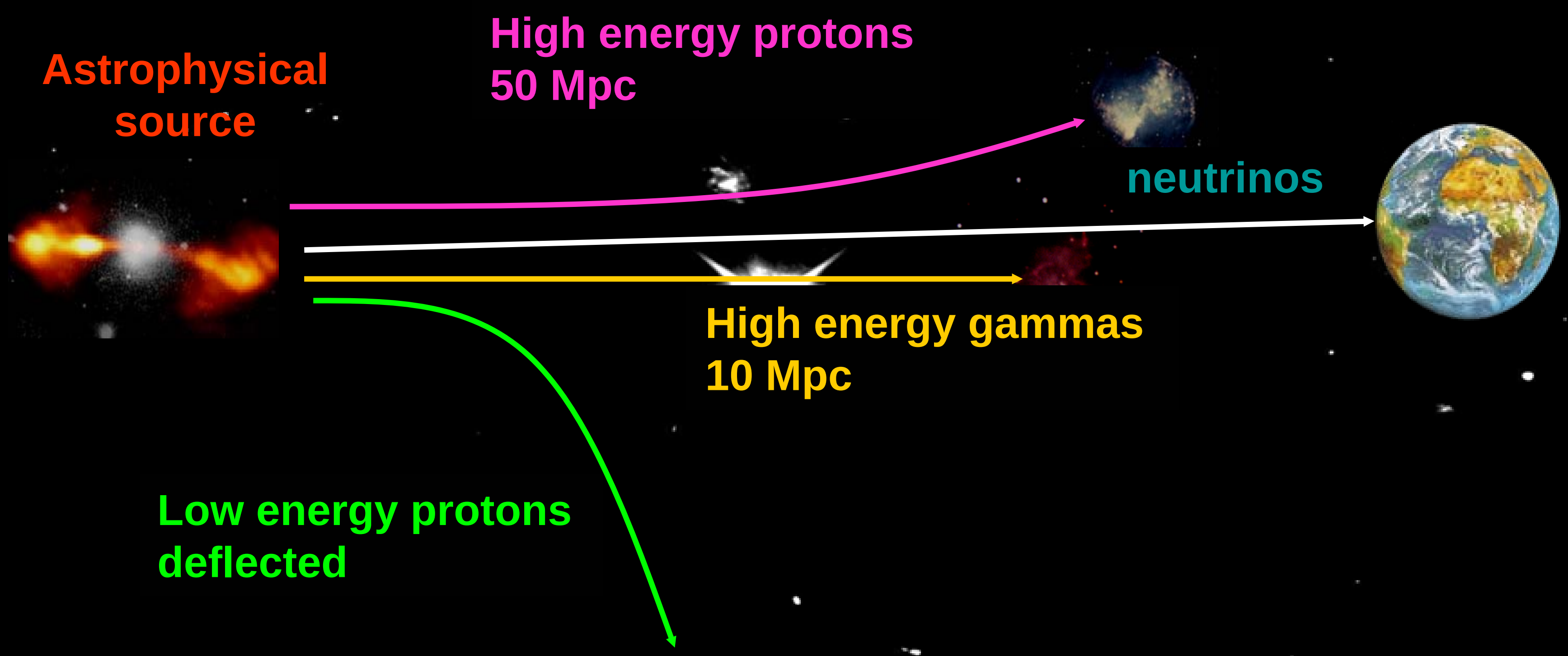
Particle Generation in AGN Jets

The electromagnetic spectrum of the TeV Gamma-sources known until now

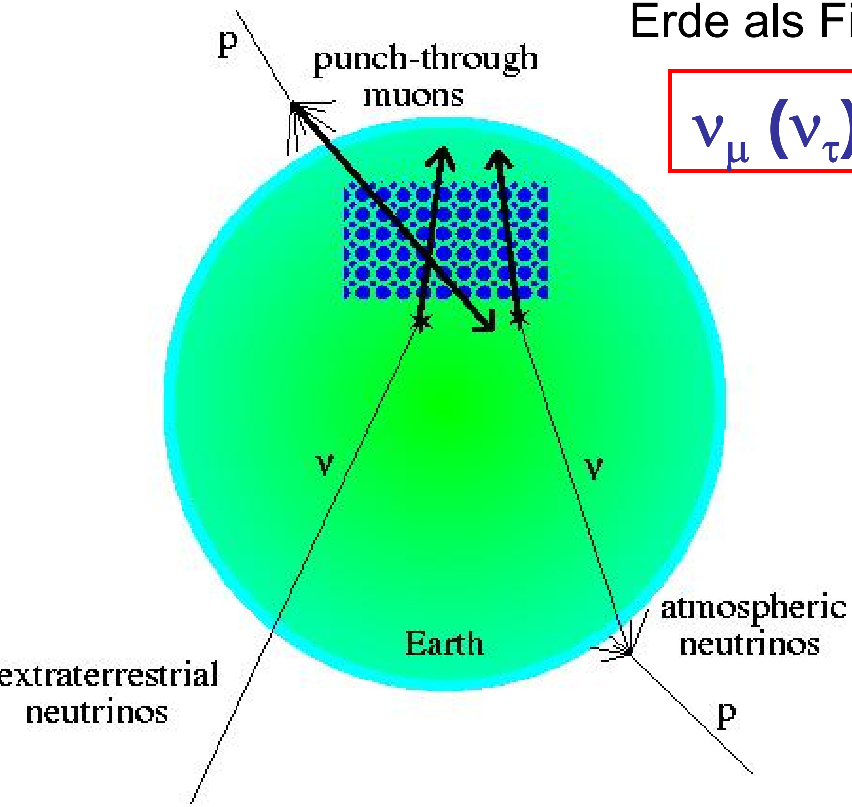




Warum Neutrinos?



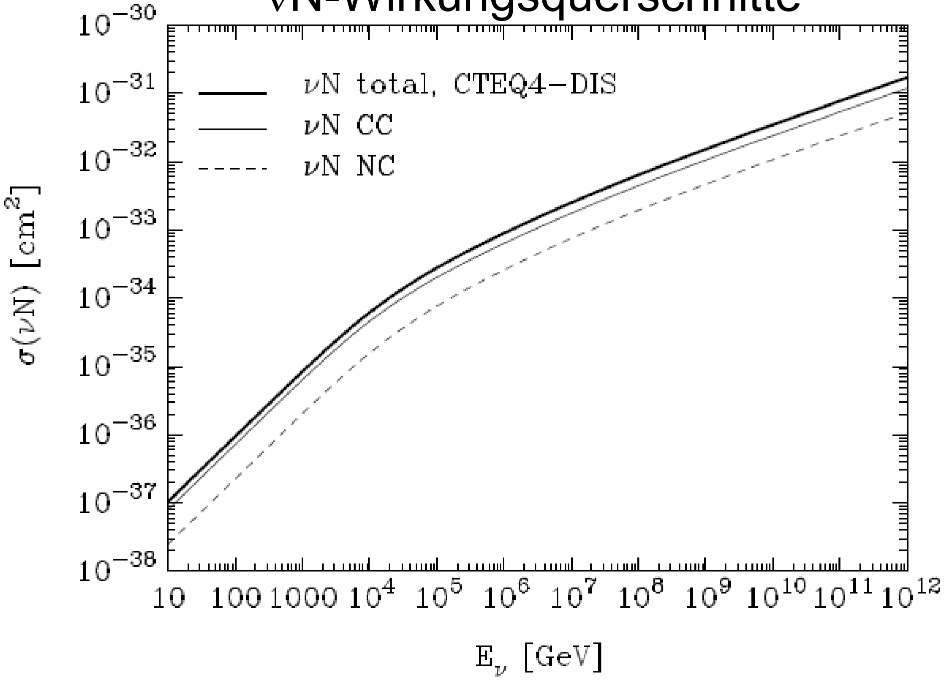
Nachweis hochenergetischer Neutrinos



Erde als Filter: Methode für ν_μ und geeignet

$$\nu_\mu\ (\nu_\tau) \rightarrow \mu + X$$

νN-Wirkungsquerschnitte

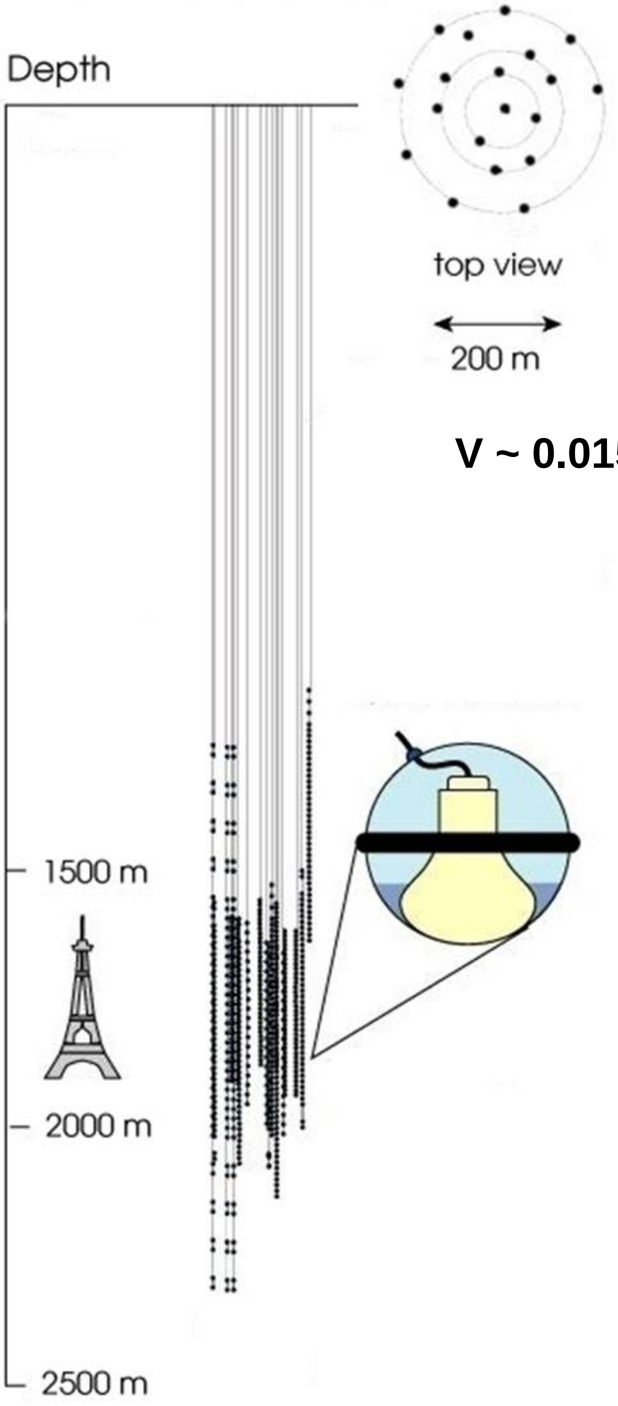


E_ν [GeV]	10^3	10^6	10^9
$\sigma_{tot}(\nu N)$ [cm^2]	$8.4 \cdot 10^{-36}$	$8.9 \cdot 10^{-34}$	$1.5 \cdot 10^{-32}$
$\rho\Lambda$ [km w.e.]	$2.0 \cdot 10^6$	$1.9 \cdot 10^4$	$1.1 \cdot 10^3$

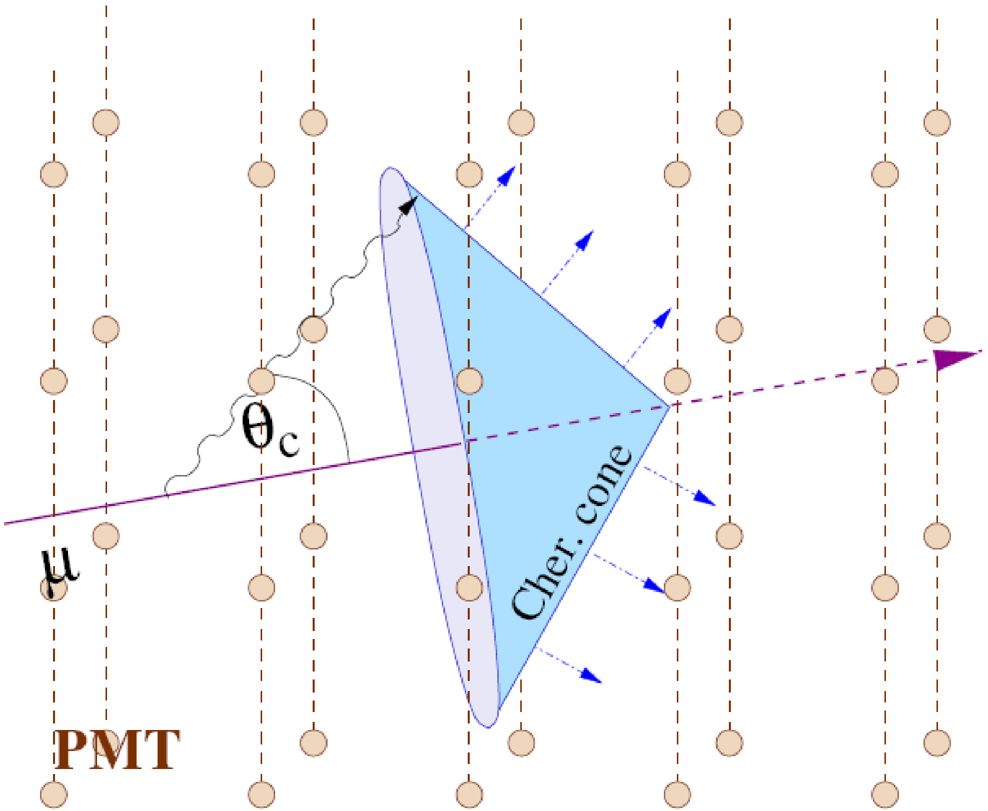
AMANDA-II

Construction: 1995-2000 - 19 strings, 677 OMs

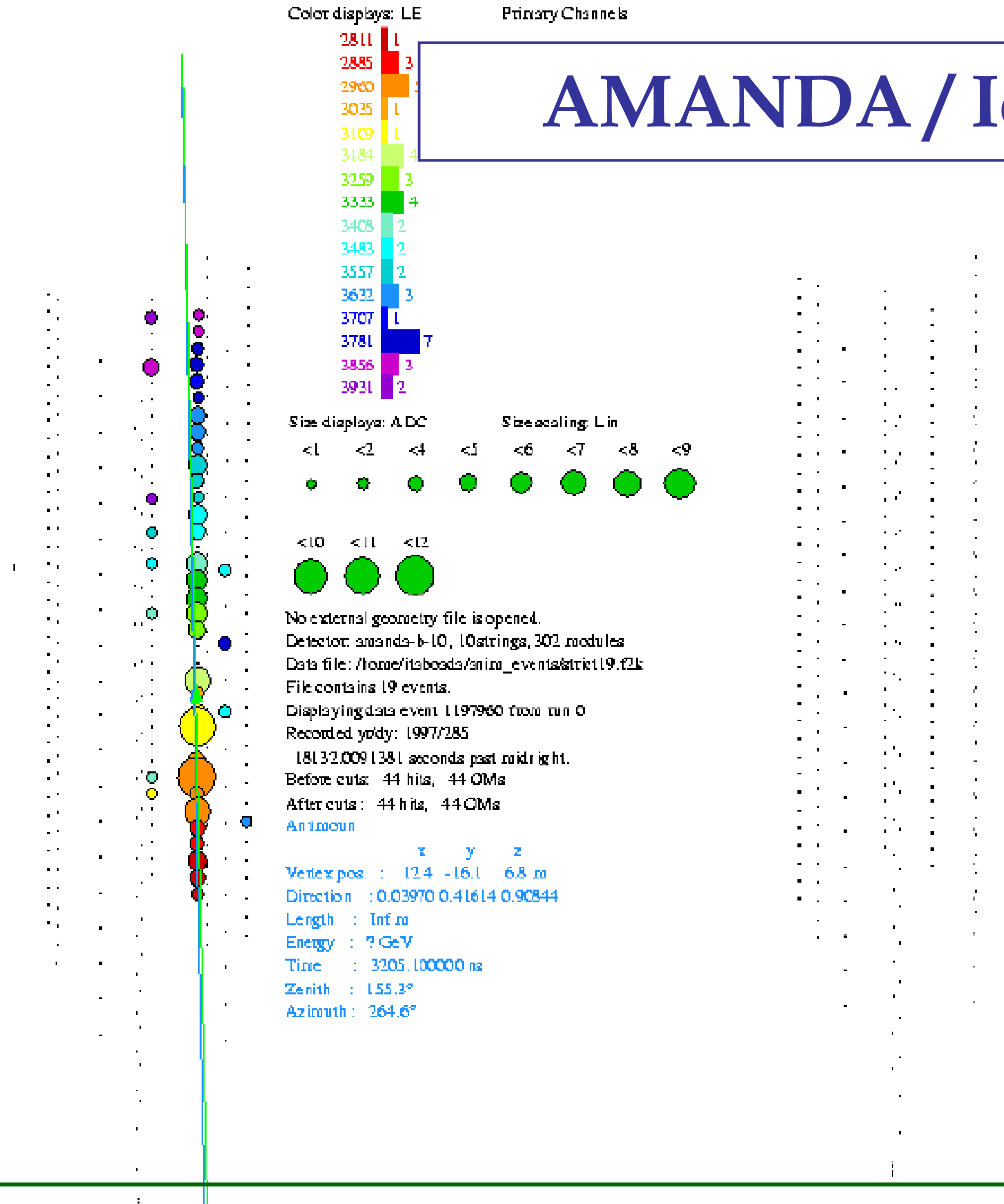
Prototyp von IceCube (V= 1 km³)



V ~ 0.015 km³



AMANDA / IceCube

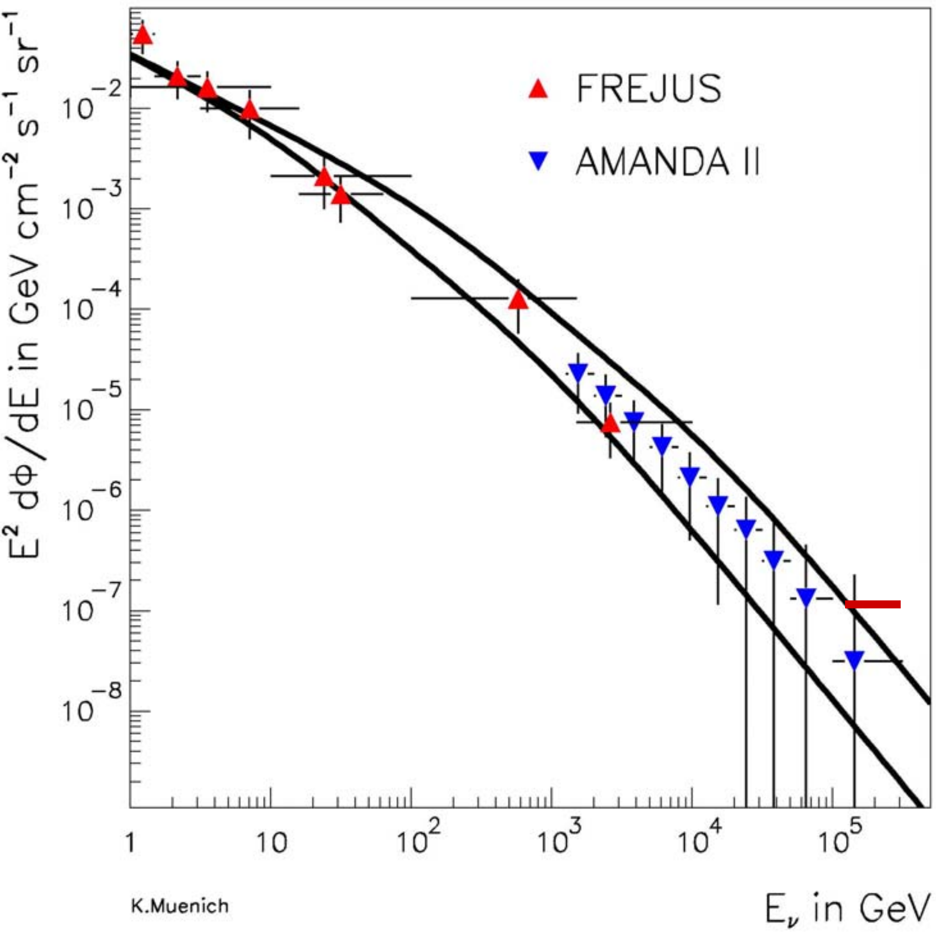


$\nu_\mu + N \rightarrow \mu + X \Rightarrow$ high energy μ above C-threshold in ice

AMANDA-Physik

- Atmospheric neutrinos
- **Point source searches**
- Gamma-ray bursts
- Dark Matter, WIMPs
- Galactic plane
- Diffuse extra-terrestrial search
- Supernovae
- Monopoles
- Cosmic ray composition
- Searches for new physics

Atmospheric neutrinos



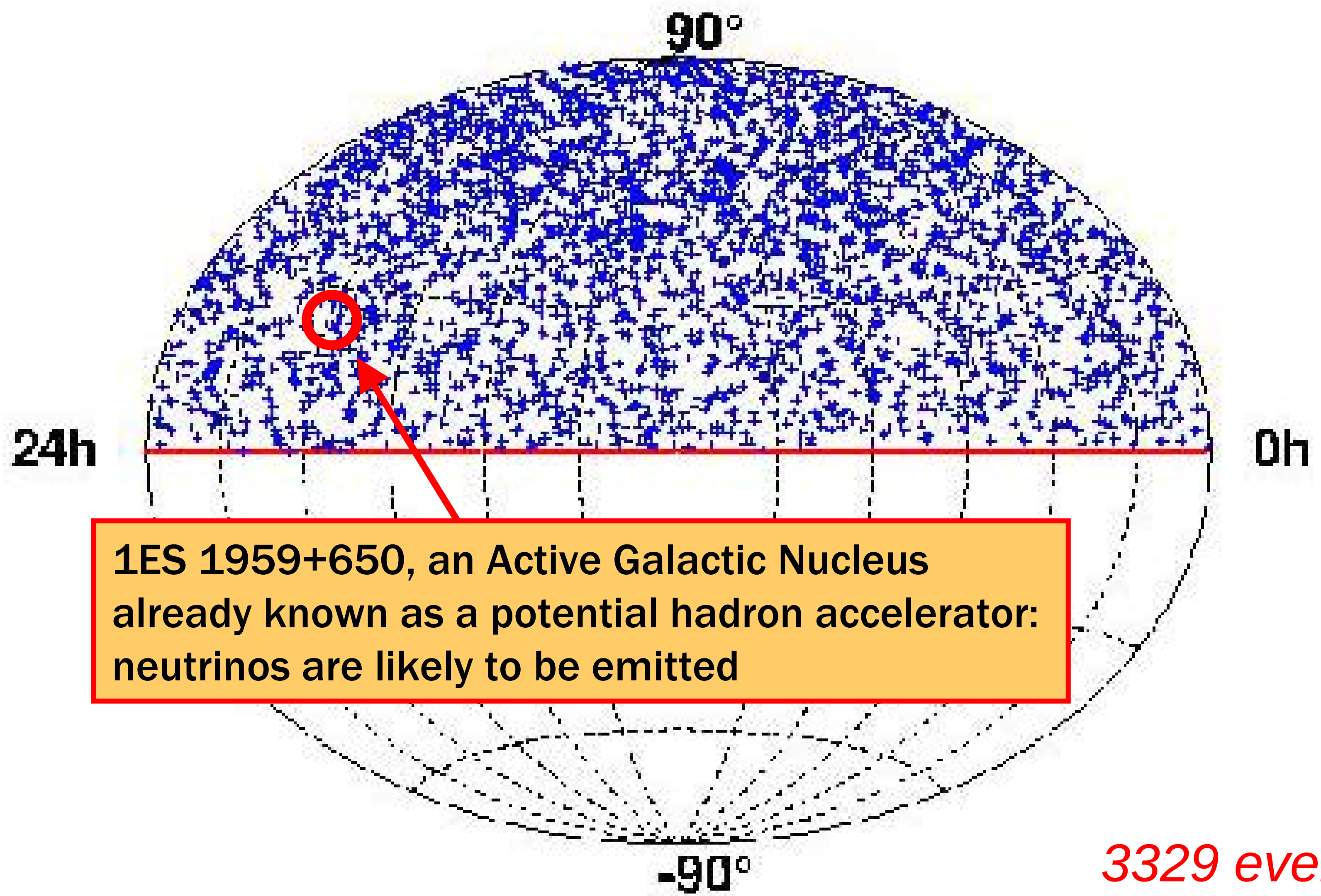
Measurement extracted with a regularised unfolding technique

Limit on diffuse E^{-2} ν_μ flux (100-300 TeV):

$$E^2\Phi_{\nu_\mu}(E) < 2.6\cdot 10^{-7}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$$

Includes 33% systematic uncertainty

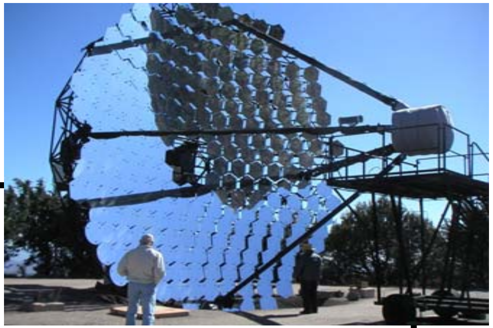
AMANDA skyplot 2000-2003

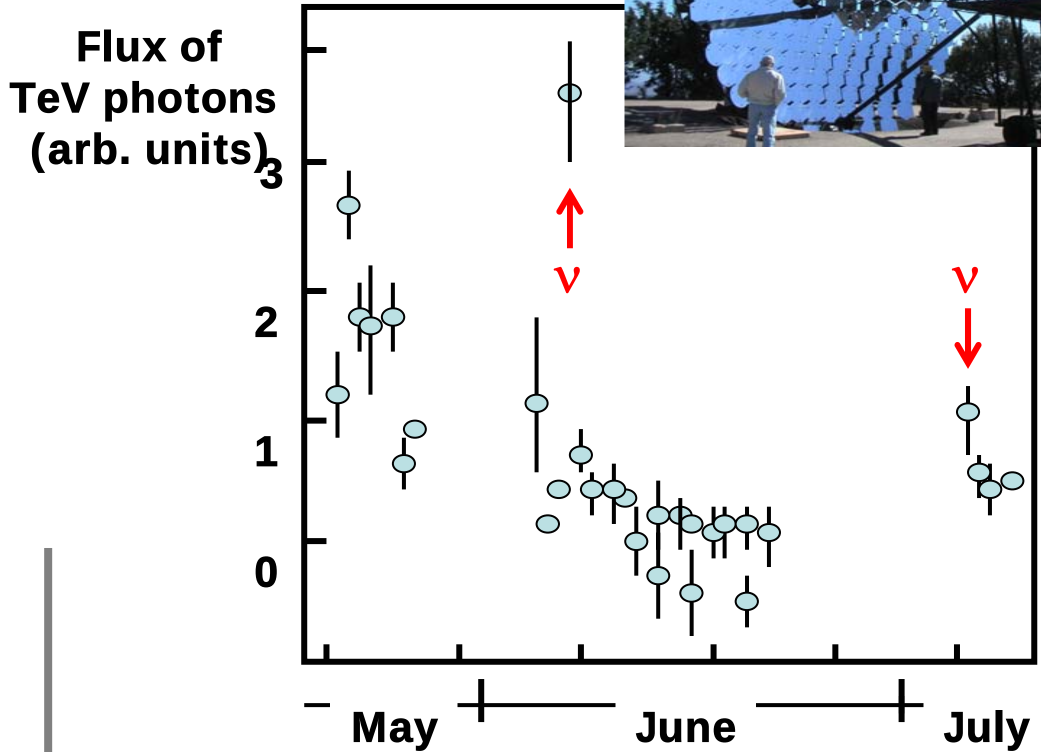


1ES 1959+650, an Active Galactic Nucleus already known as a potential hadron accelerator: neutrinos are likely to be emitted

3329 events

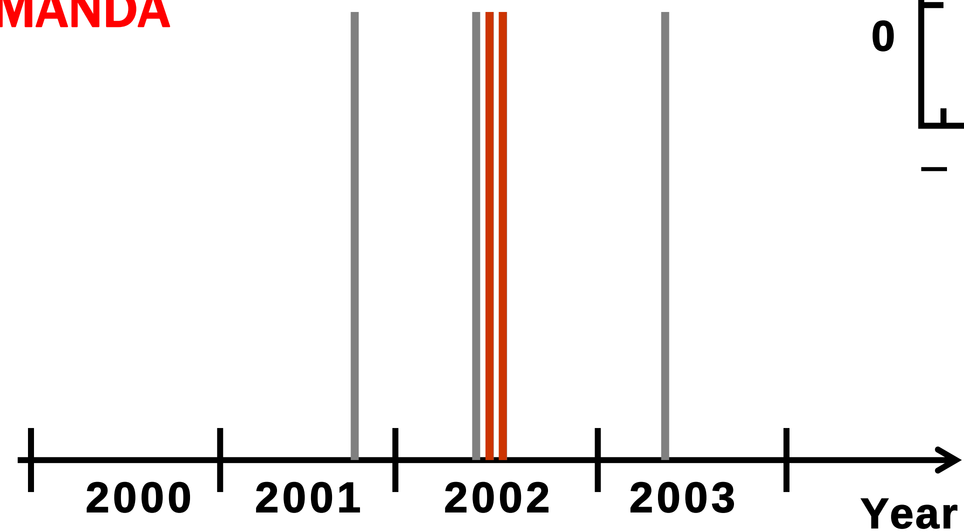
Did we see already the first signal ?





Gamma-rays detected by a TeV gamma telescope

Arrival time of the neutrinos from the direction of ES1959+650 detected by AMANDA



SNEWS – SuperNova Early Warning System

Reaktionen von MeV-Neutrinos aus einem **Supernova-Burst in unserer Galaxis** würden die Rauschraten aller Photomultiplier für 5 -10 Sekunden um einige Hertz nach oben treiben.

alle 50 Jahre?

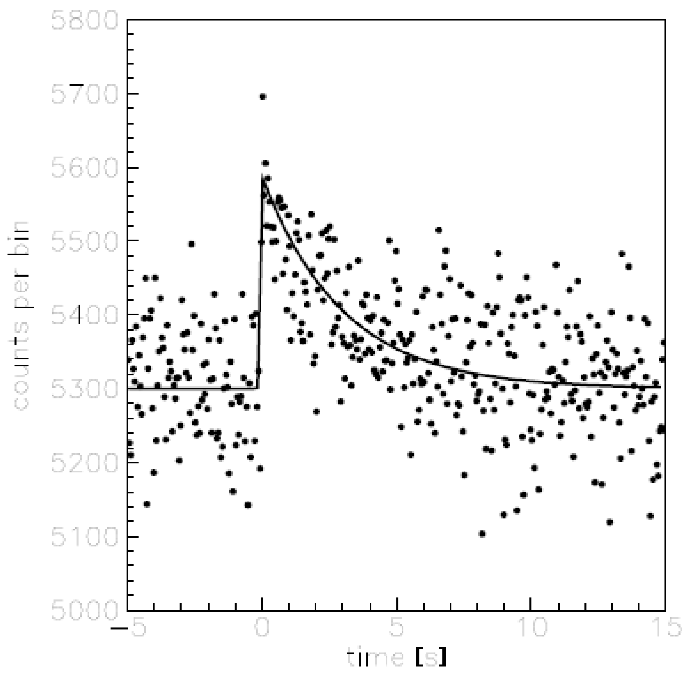


Fig. 5. Simulated counting rates for a supernova in the center of our galaxy, for the AMANDA detector.

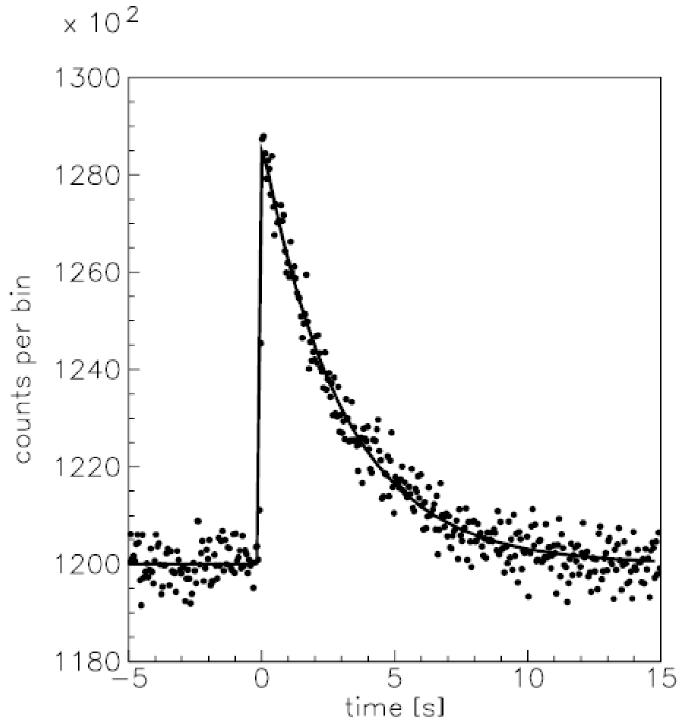
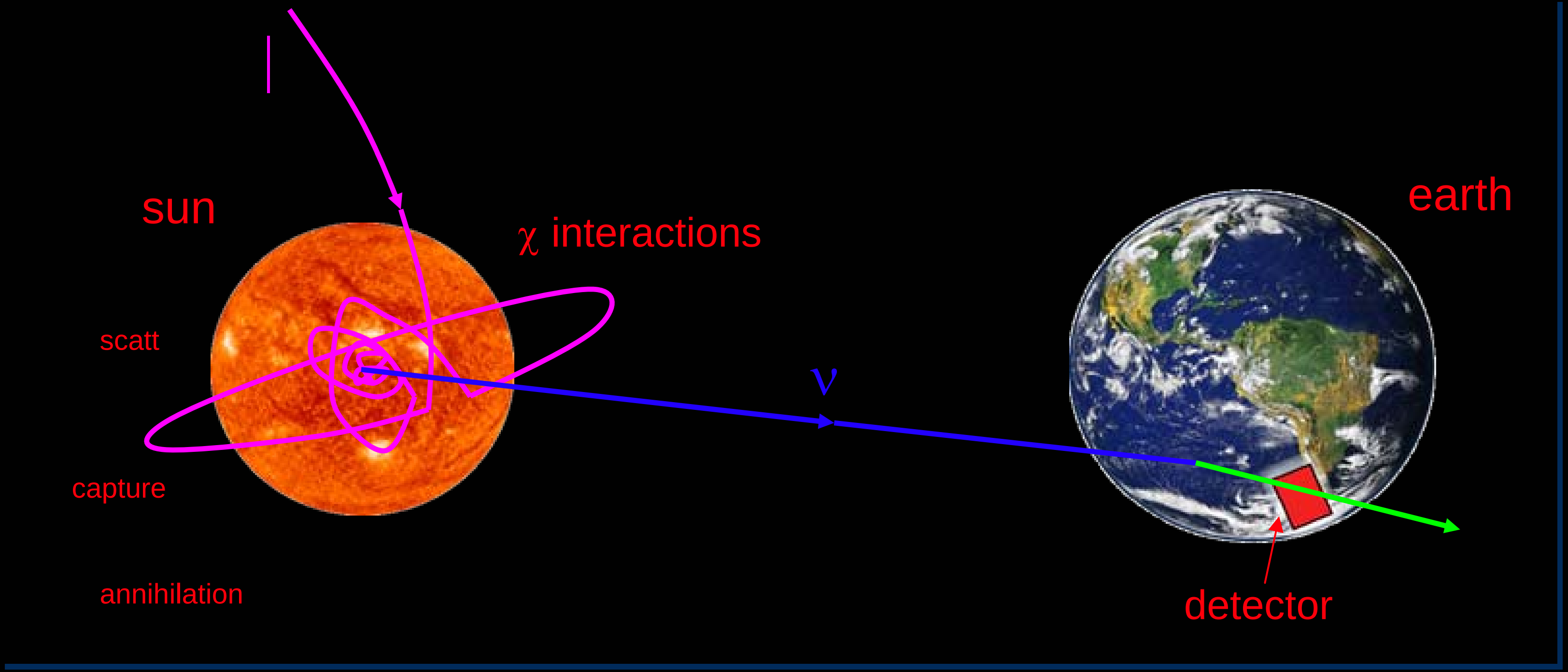


Fig. 6. Simulated counting rates for a supernova in the center of our galaxy, for the IceCube detector.

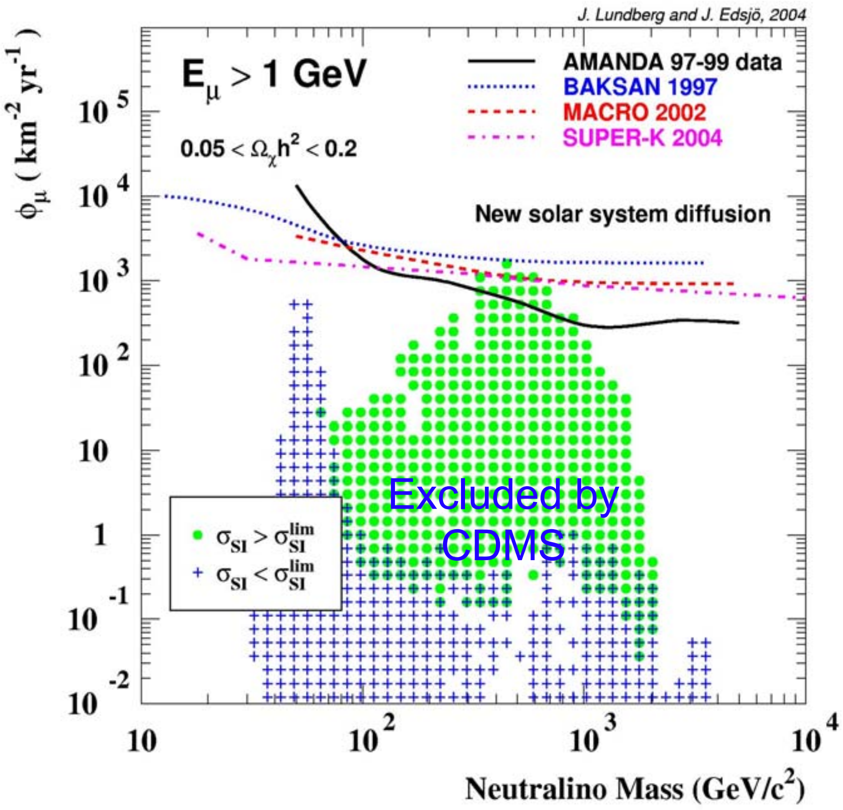
Dunkle Materie



$$\chi\chi \rightarrow \begin{pmatrix} q\bar{q} \\ l\,\bar{l} \\ W^{\pm}, Z^{0}, H \end{pmatrix} \rightarrow \ldots \rightarrow \nu_{\mu}$$

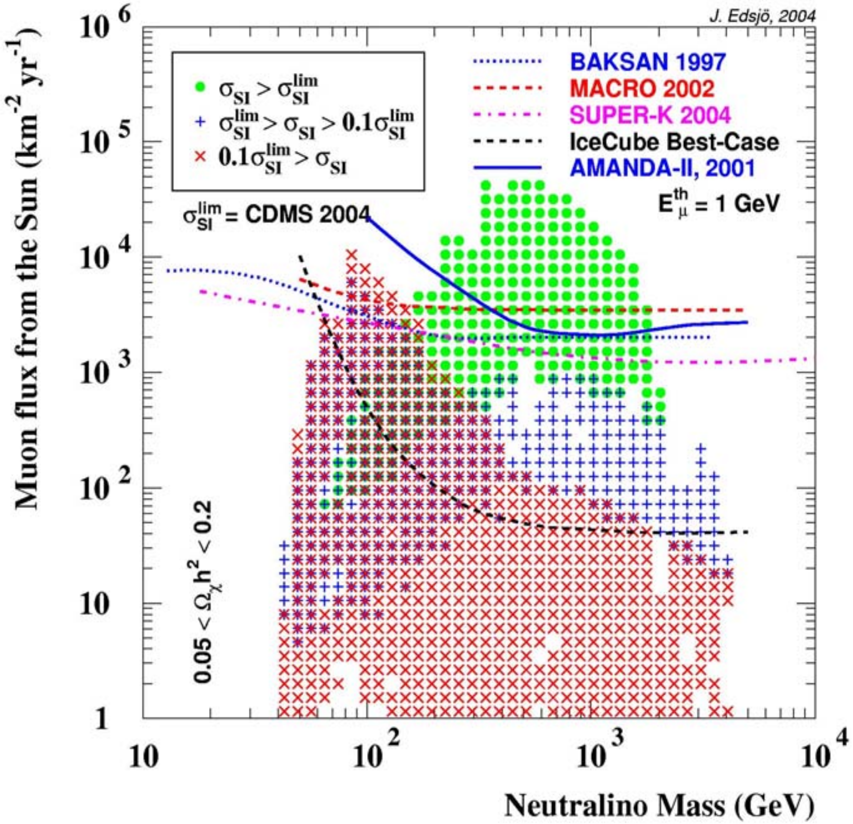
Dunkle Materie

ERDE:

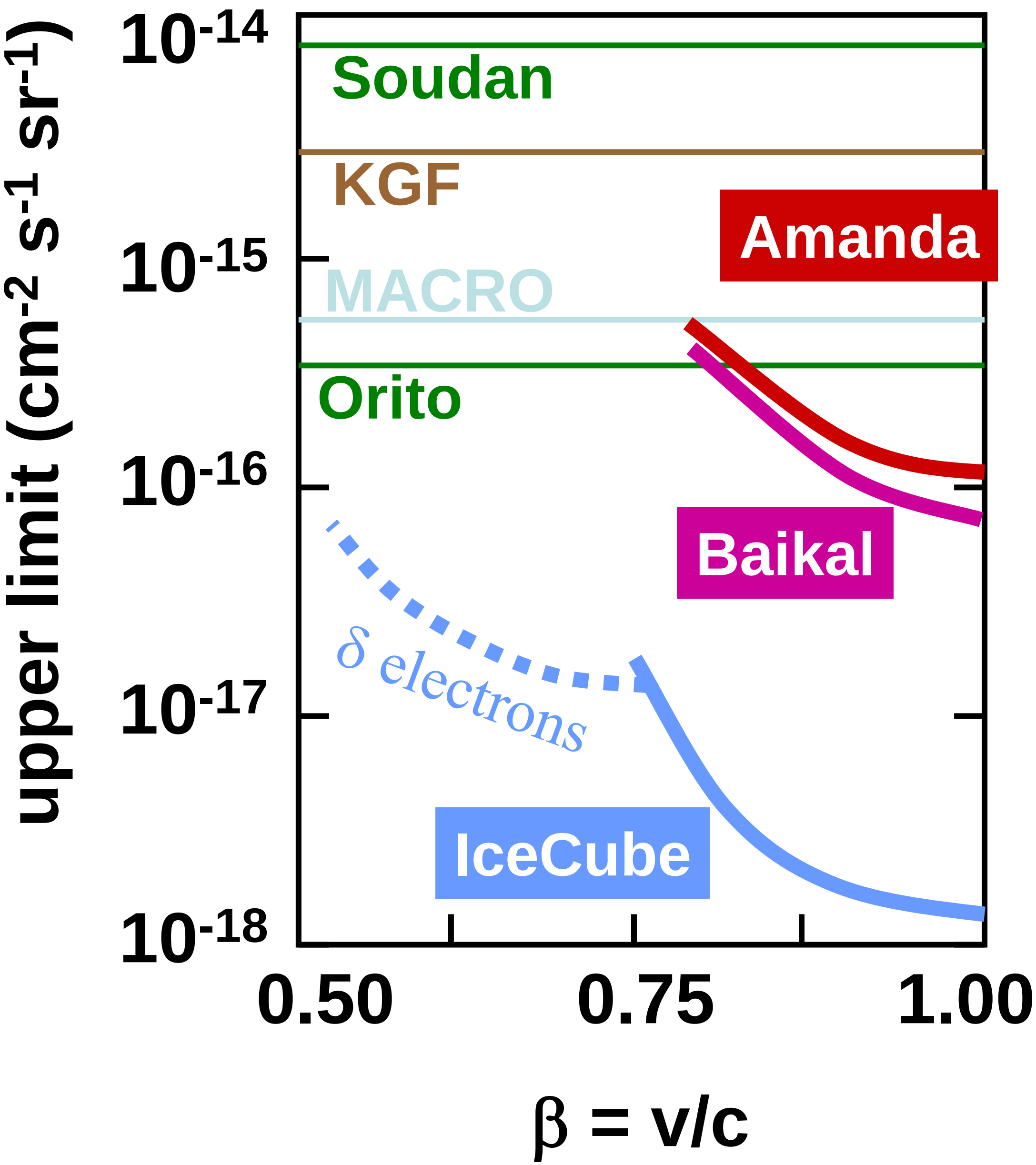


Ref. CDMS:
D.S. Akerib et al., Phys. Rev. Lett., 93, 211301 (2004)

Sonne:



Methode beschrieben in: D. Hubert et al., ICRC 2005, Pune, astro-ph/0509330



Relativistic Magnetic Monopoles

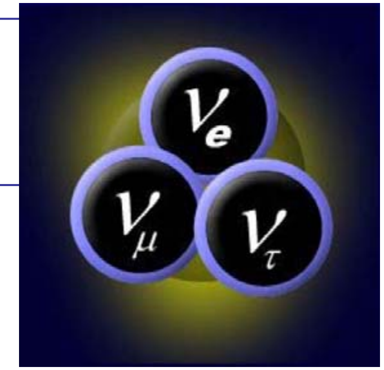
Cherenkov-Light ∝ $n^2 \cdot (g/e)^2$

$n = 1.33$

$(g/e) = {}^{137}/_{2}$

≈ 8300

Cascades inside detector

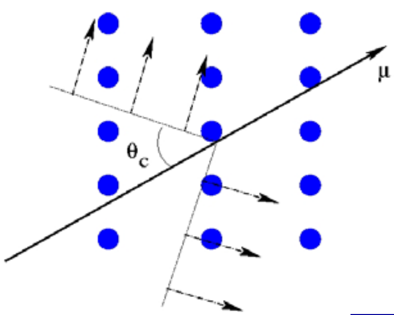


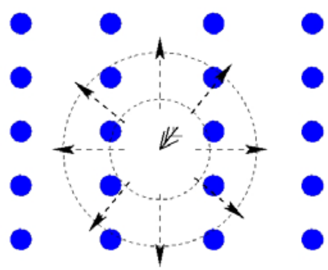
Sensitive to all 3 flavors

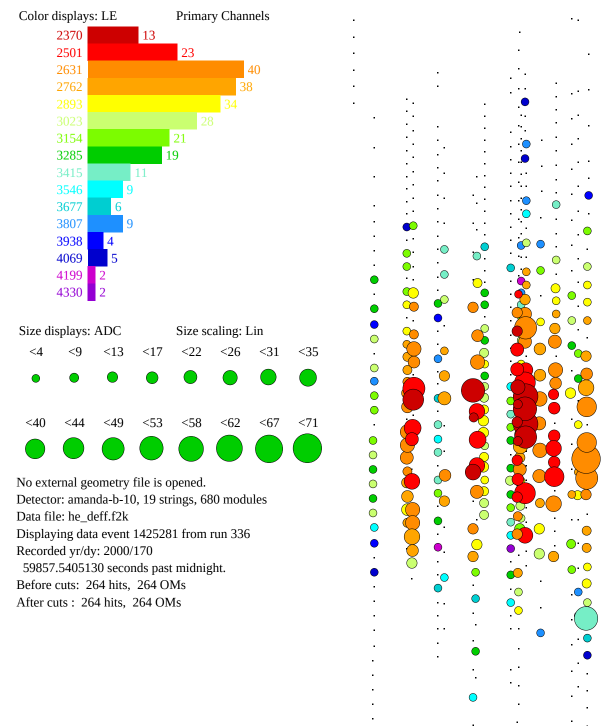
- **CC electron and tau neutrino interaction:**
- $\nu_{(e,\tau,)}$ **+ N → (e, τ) + X**

- **NC neutrino interaction:**

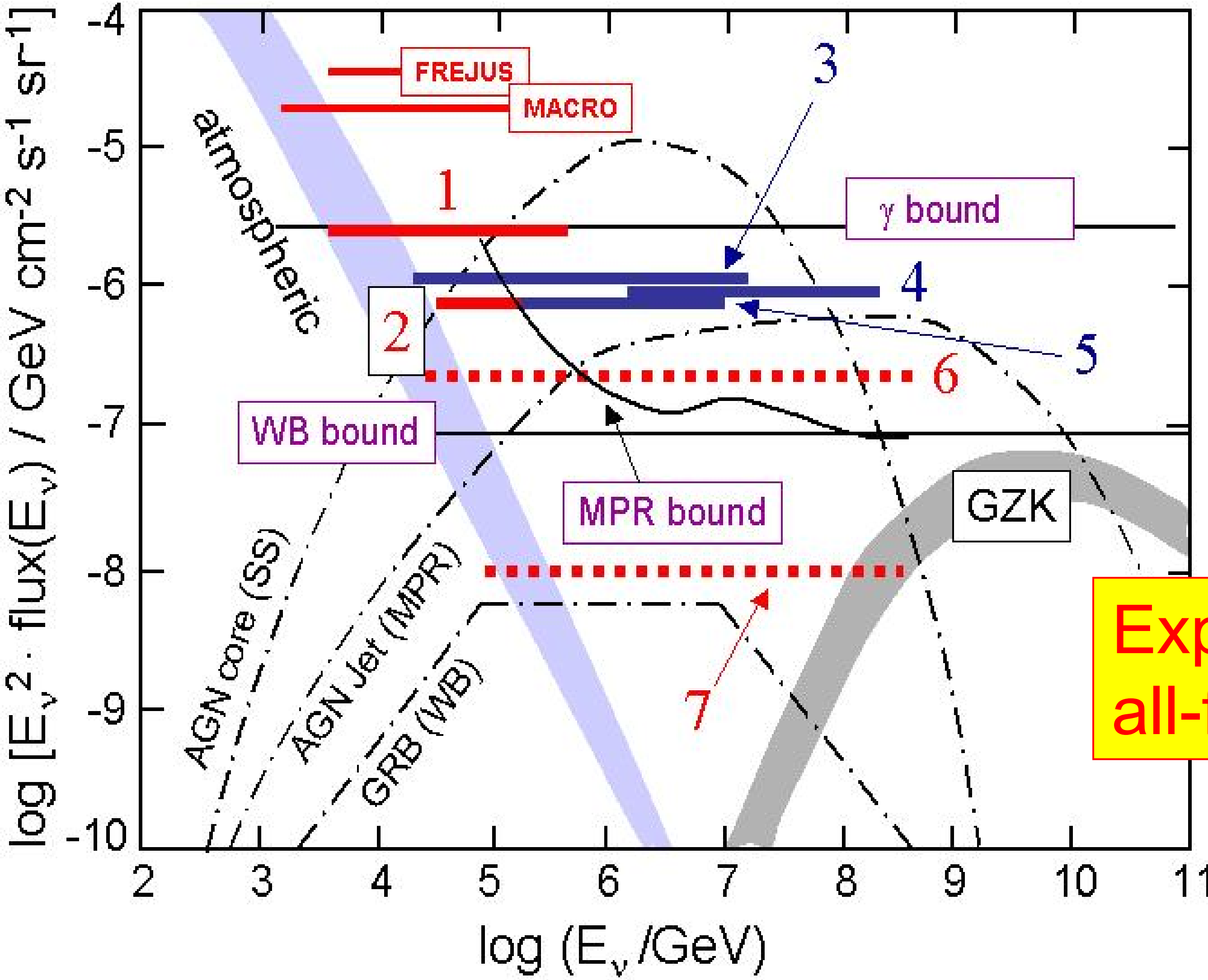
  ν_x **+ N →** ν_x **+ X**







$E^2\,\Phi_{all-\nu} < 0.6 \cdot 10^{-6}\ \mathrm{GeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}}$



Experimental all-flavor limits

1: Amanda-B10, muons
2: Amanda-II, muons
3: Baikal all flavor
4: Amanda all flavor UHE
5: Amanda cascades

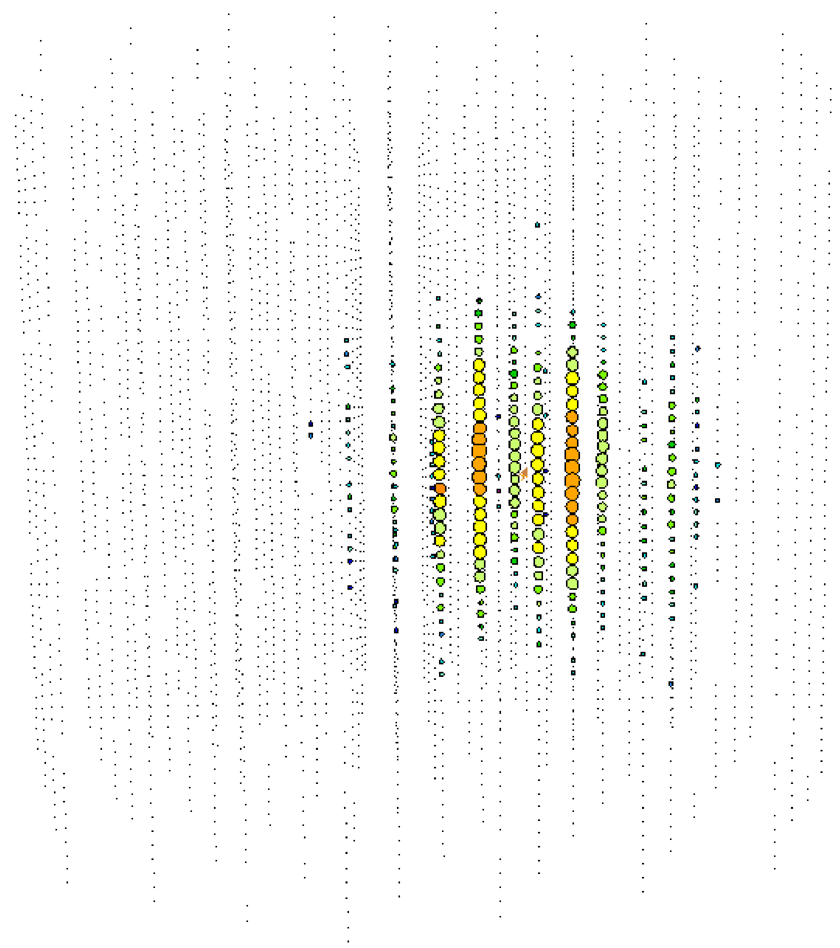
Expected:
6: Amanda-II, 4 years
7: IceCube 3 years

Cascade event

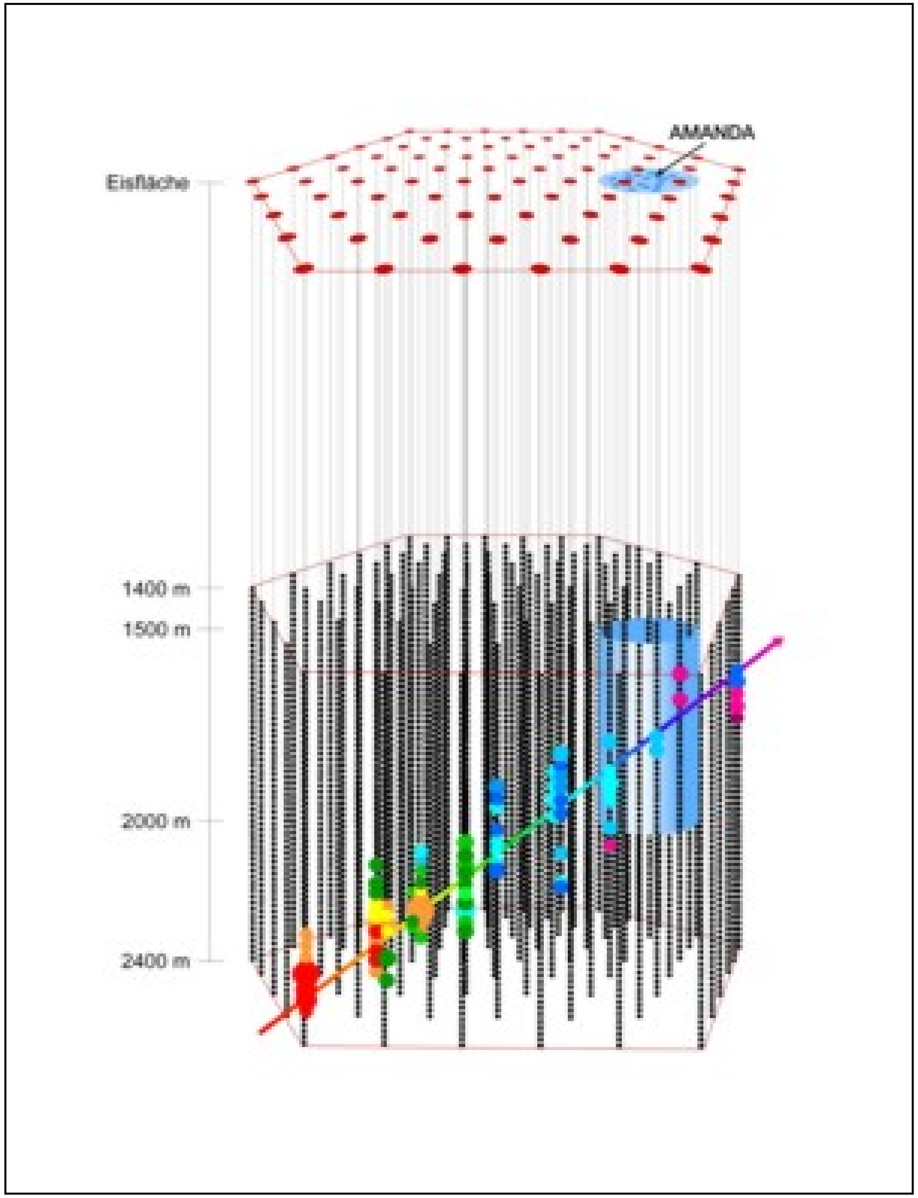
Energy = 375 TeV

ν_e **+ N --> e- + X**

- The length of the actual cascade, ≈ 10 m, is small compared to the spacing of sensors
- ==> ≈ roughly spherical density distribution of light
- 1 PeV ≈ 500 m diameter
- Local energy deposition = good energy resolution of neutrino energy



- 80 Strings
- 4800 PMTs
- Instrumented Volume: 1 km^3
- Installation: 2005-2011



IceCube

- 80 Strings
- 4800 PMTs
- Instrumented Volume: 1 km^3
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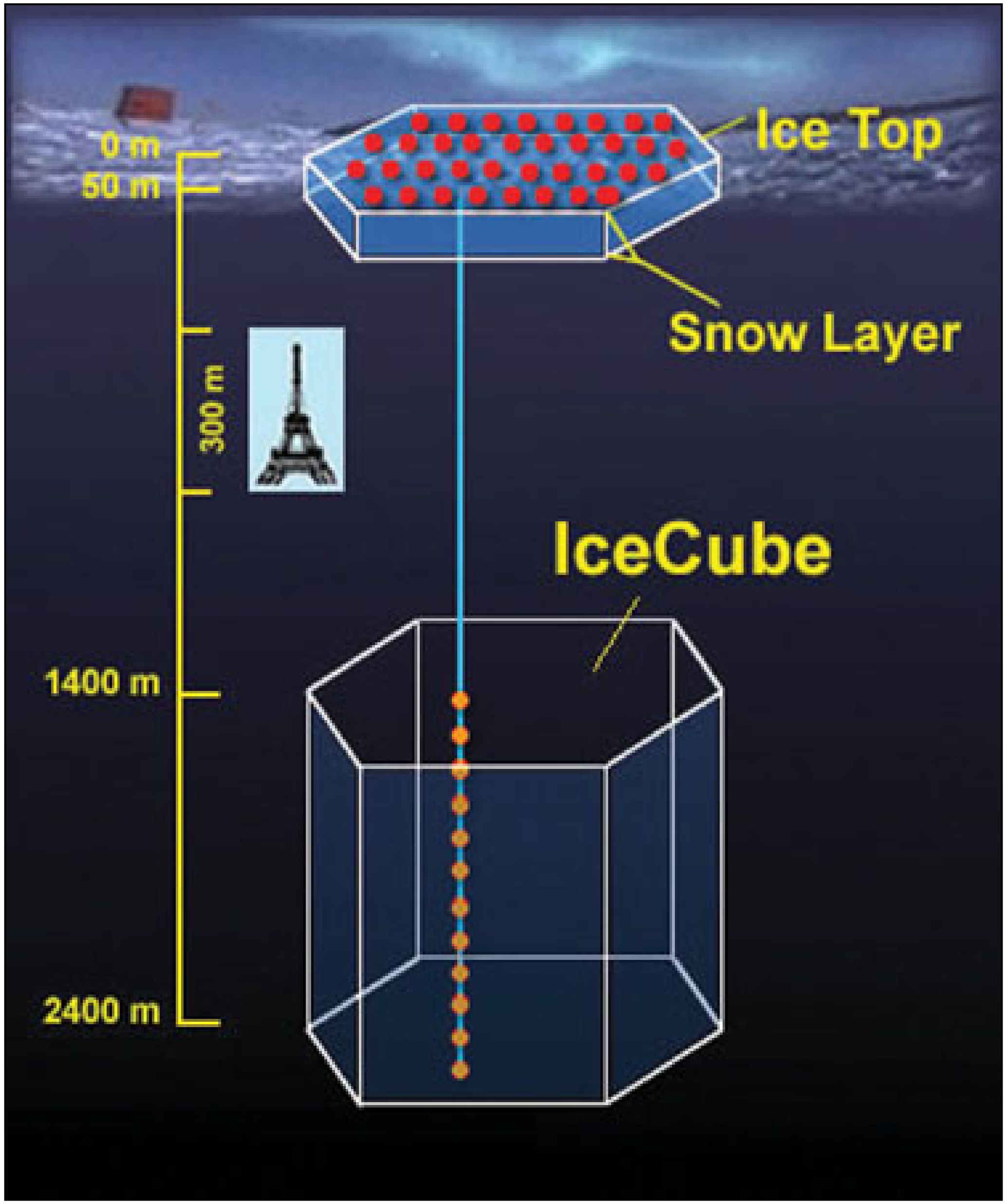
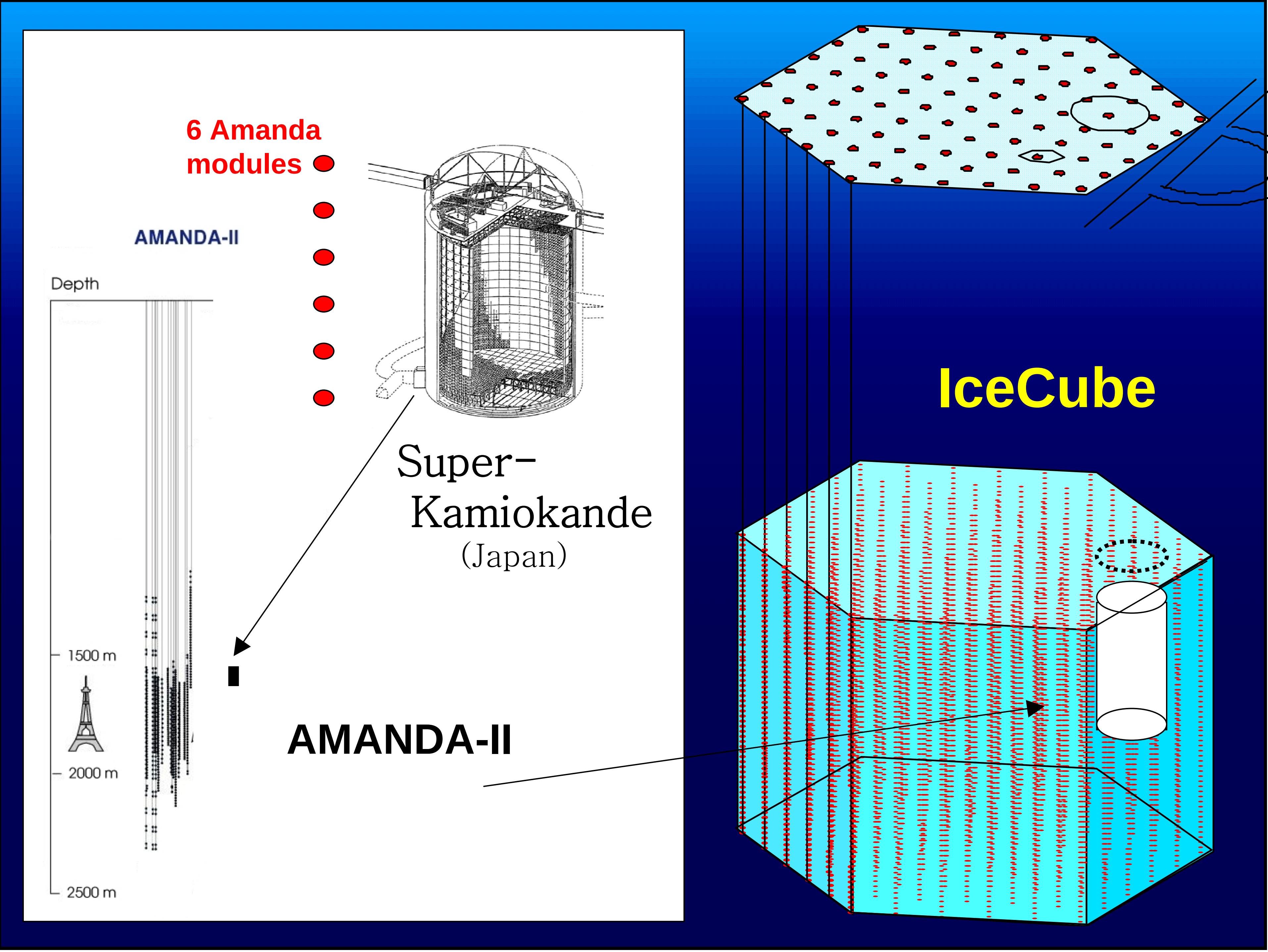
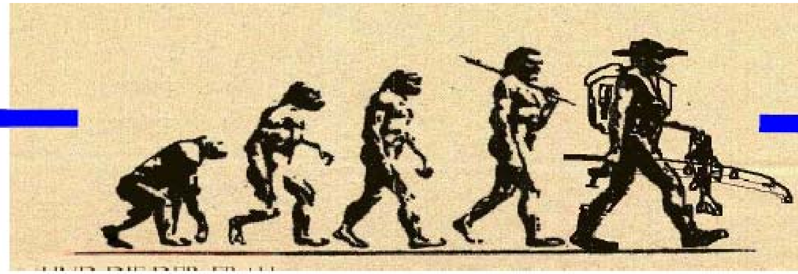



6 Amanda modules
AMANDA-II
Depth
1500 m
2000 m
2500 m
Super-Kamiokande
(Japan)
AMANDA-II
IceCube

Von AMANDA zu IceCube

Amanda



IceCube

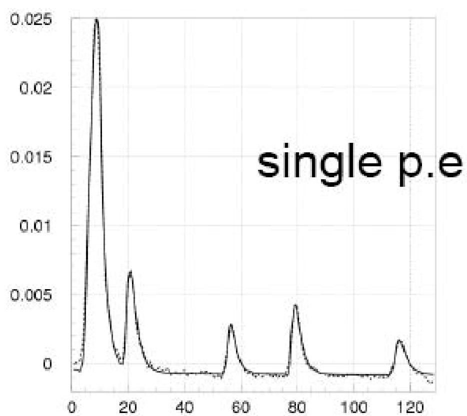
Optical Module

8” PMT

Digital Optical Module

10” PMT
+Main Board
+flasher

Trigger, Digitalisation, HV



Digitized Waveform

Surface

- res. temp. ~4-8 ns
- 32 µs/trigger
- bruit: ~1kHz

DOM

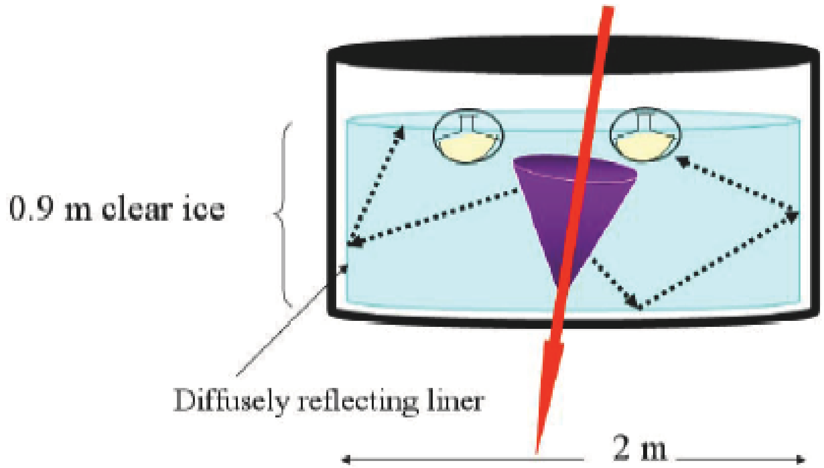
- res. temp.<2ns
- 400ns & 6.4µs/trigger
- 3 gains
- bruit ~700Hz

The IceCube Collaboration

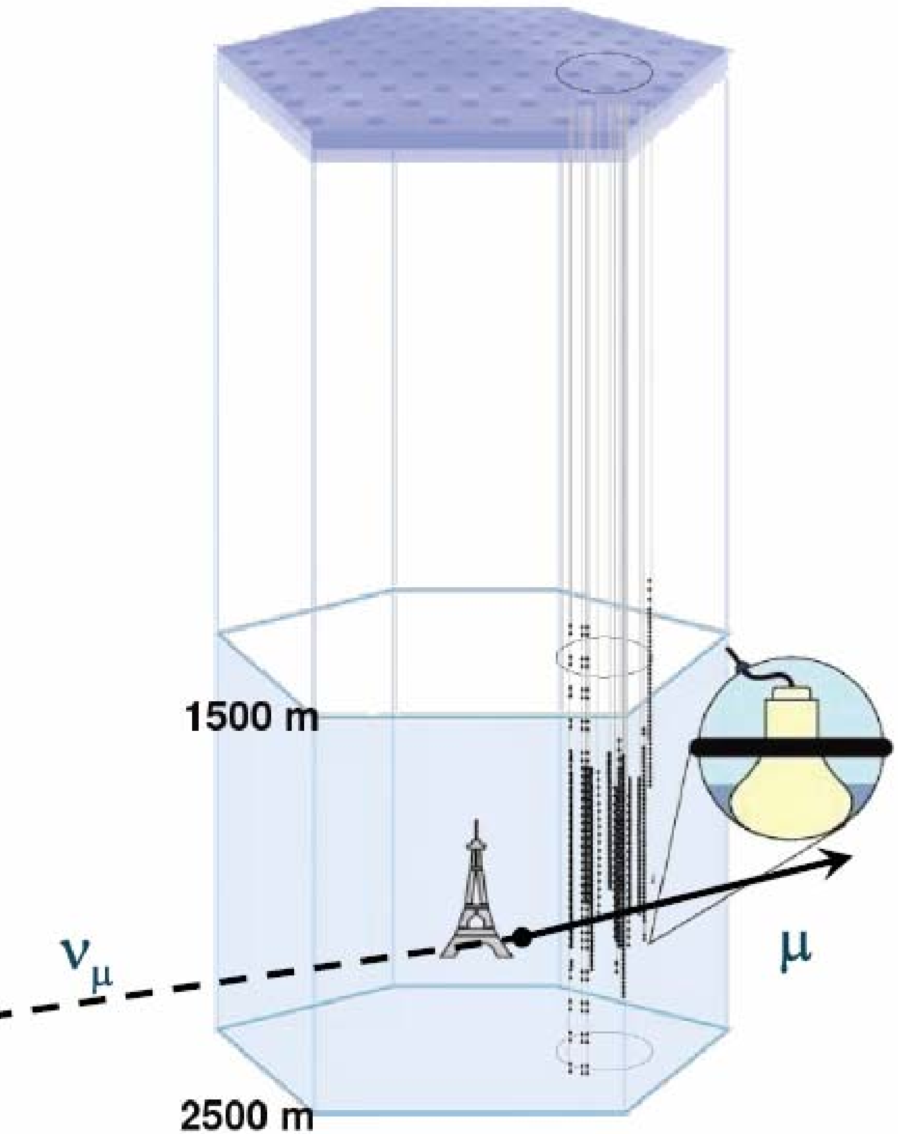
IceCube and AMANDA collaborations merged, March 2005

Cherenkov tank arrays: IceTop

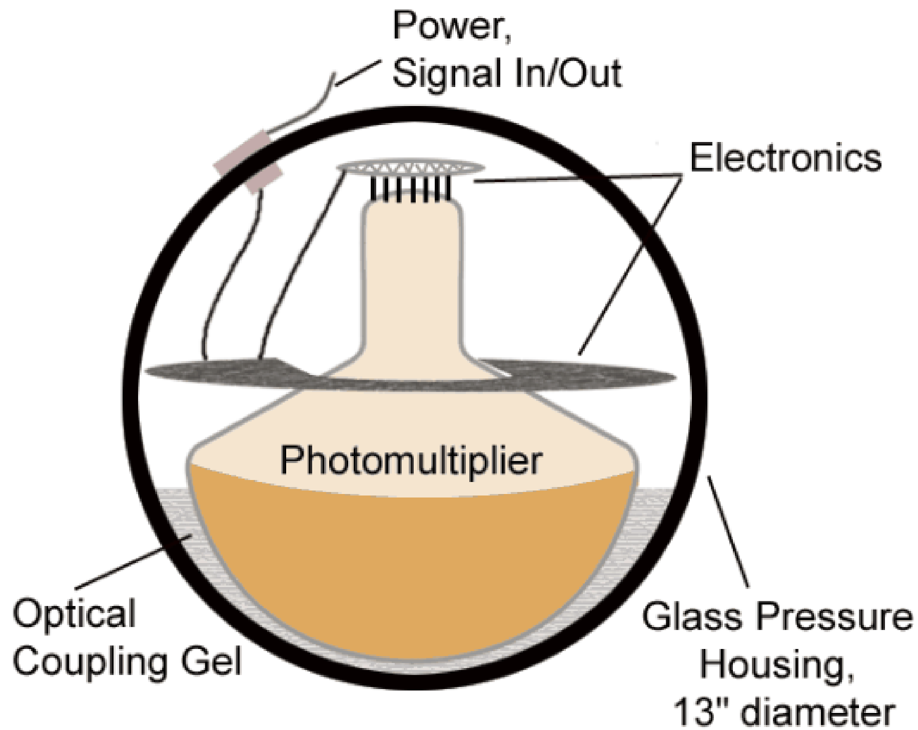
- Southpole, Antarctica
- 1 km²
- 80 Stations x 2 x 3.14 m² = 503 m²
- E > 0.3 PeV
- slightly larger than K-GRANDE



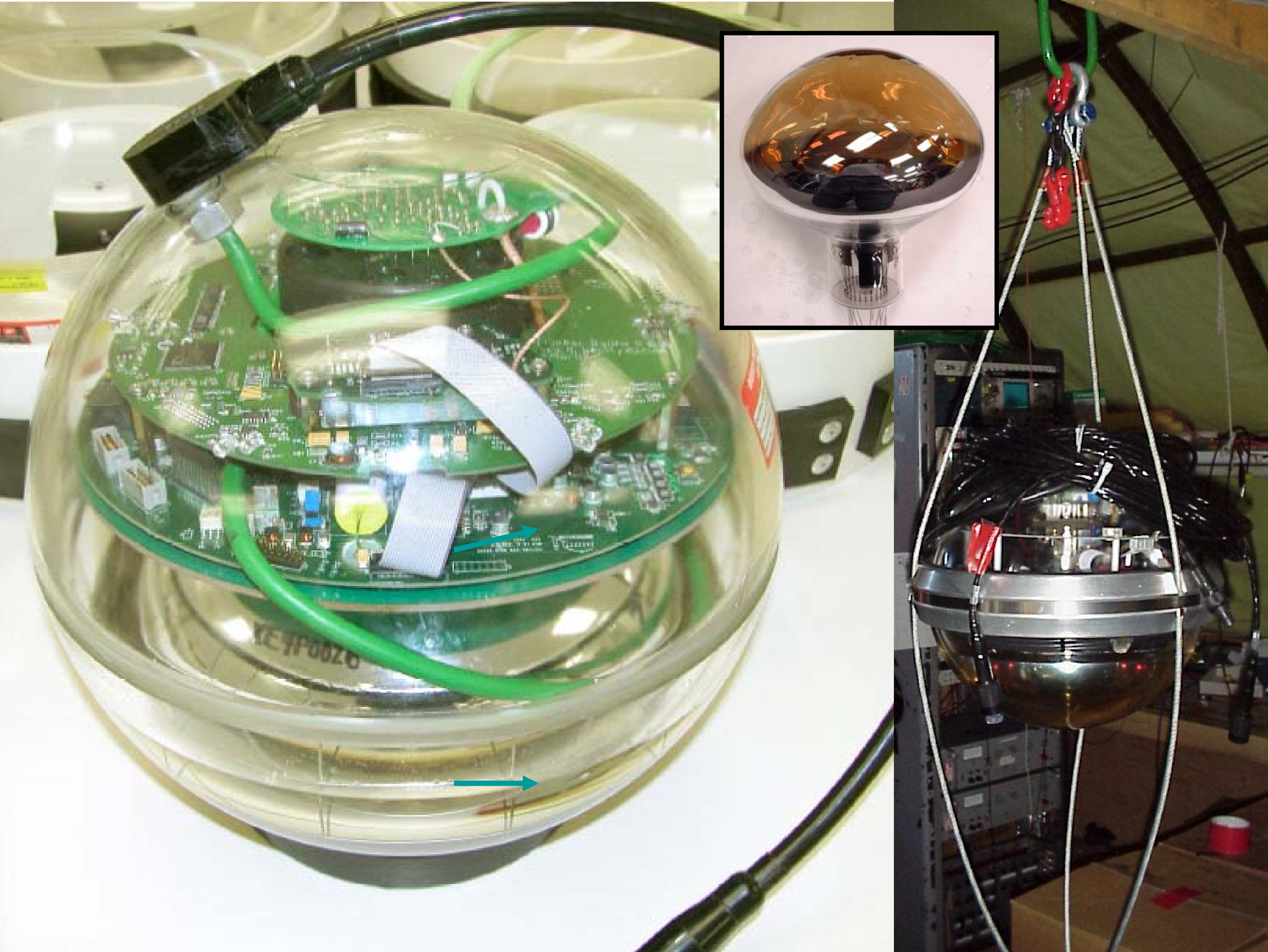
IceCube: DOM



1500 m
2500 m
ν_μ
μ

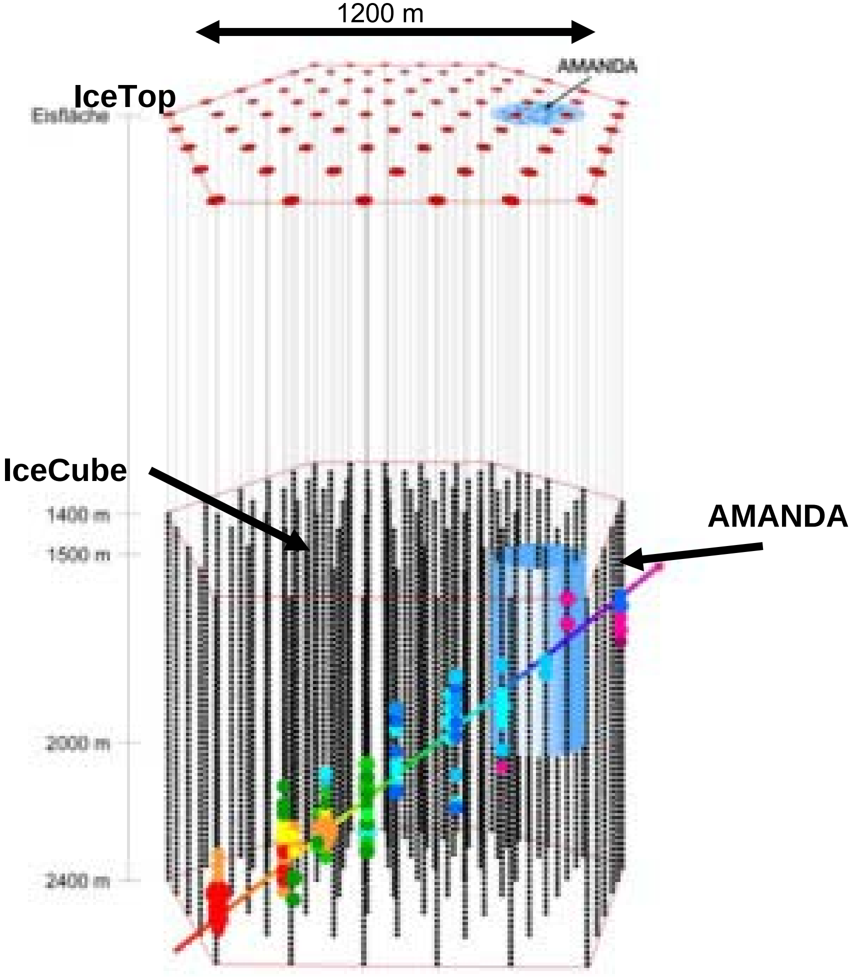


Power,
Signal In/Out
Electronics
Photomultiplier
Optical
Coupling Gel
Glass Pressure
Housing,
13" diameter



Track Reconstruction in Low Noise Environment

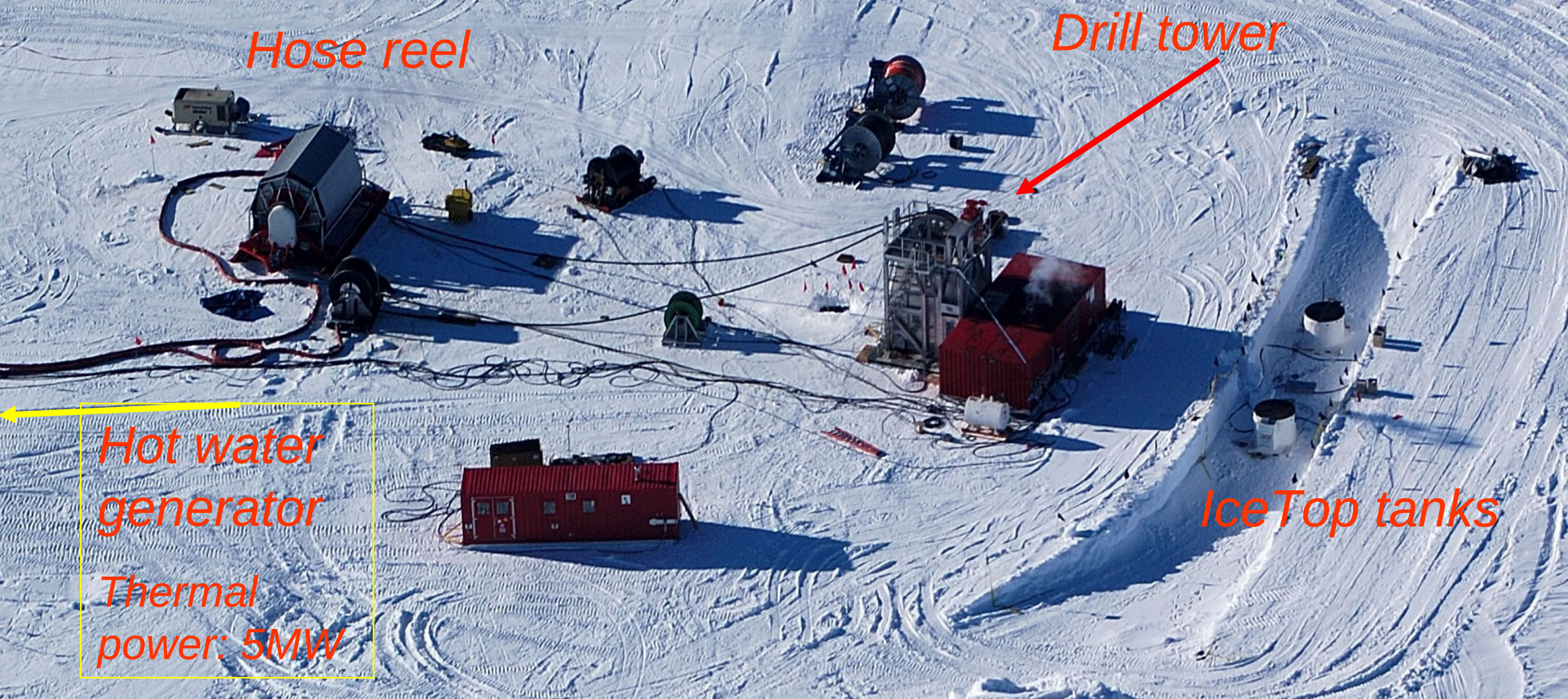
- Typical event: 30 - 100 PMT fired
- Track length: 0.5 - 1.5 km
- Flight time: ≈4 μsecs
- Accidental noise pulses:
  10 p.e. / 5000 PMT / 4 μsec



Season 2005-06

- Highly successful season!
- First string deployed December 25th
- Eighth string deployed January 29th (9 total)
- Dust logger and standard candle
- 12 IceTop stations deployed (16 total)
- First events already reconstructed

A view from last season

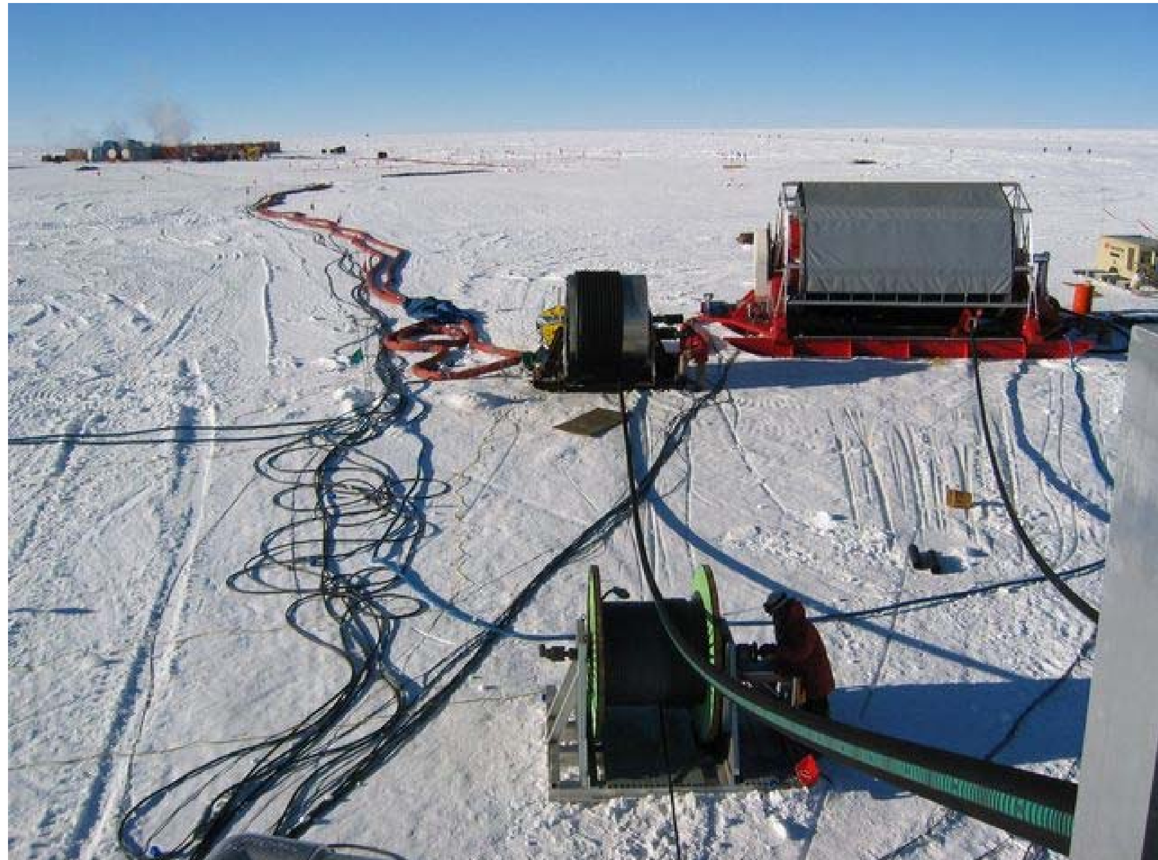


Working time: Nov. - mid-Feb

Plan: deploy 14 strings/season

Completion: 2011

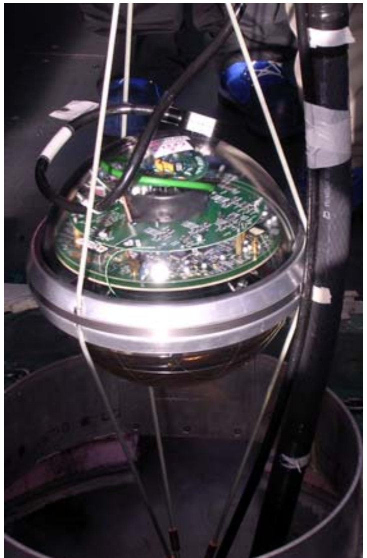
Hot Water Drilling

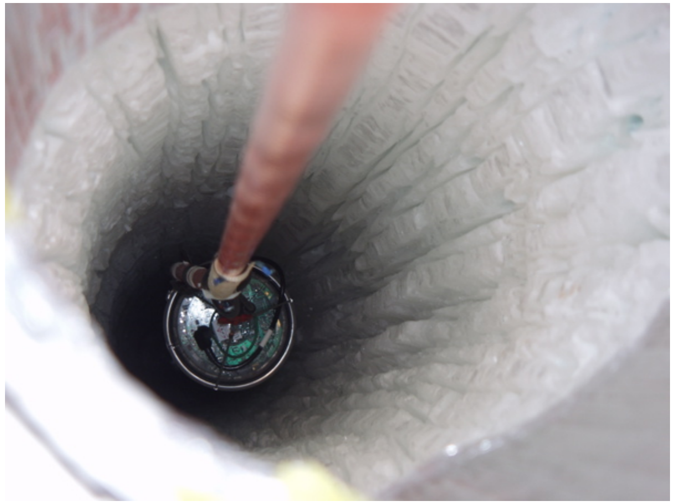


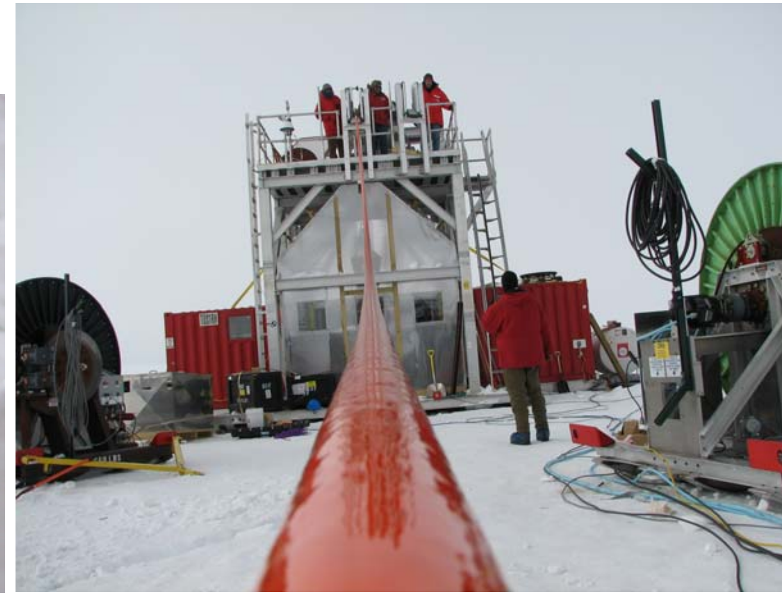
IceCube EHWD significant operation – entire drill camp setup, including generators, heater plants, fuel systems, and support workshops. This camp doesn't move during the season.

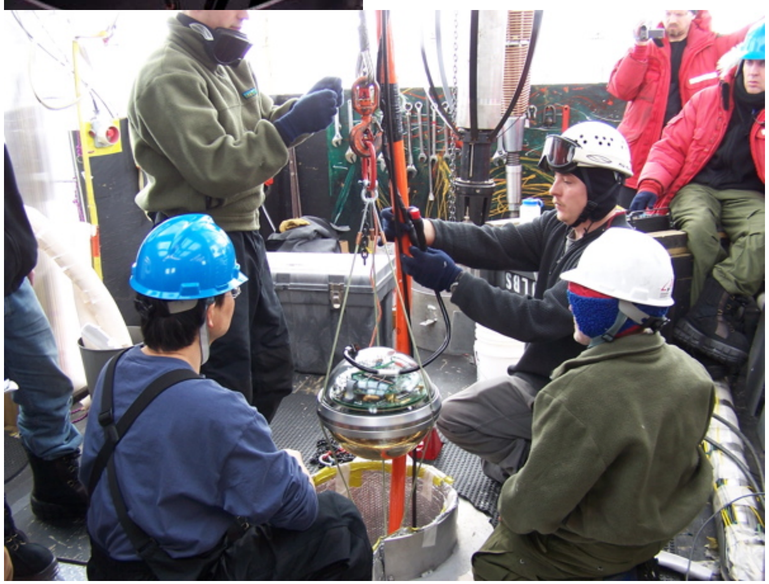
2 drill towers connect to central plants and leapfrog over holes.

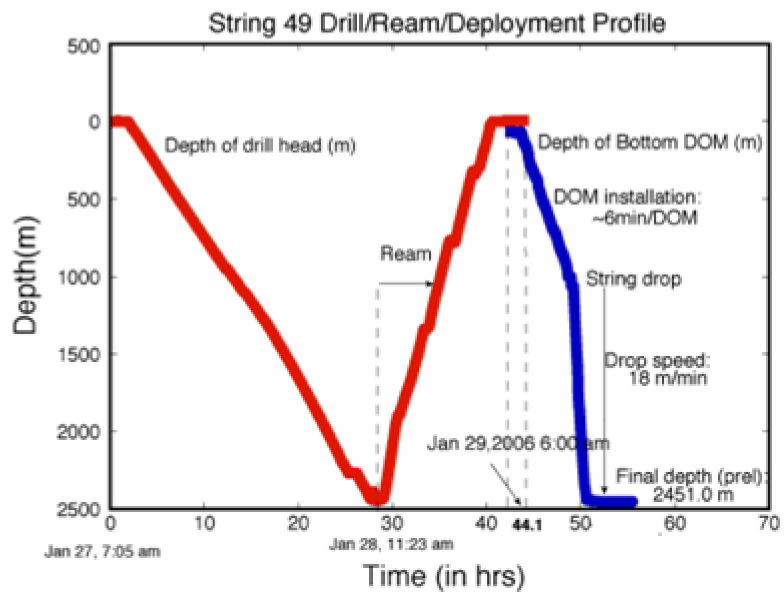
Deployment





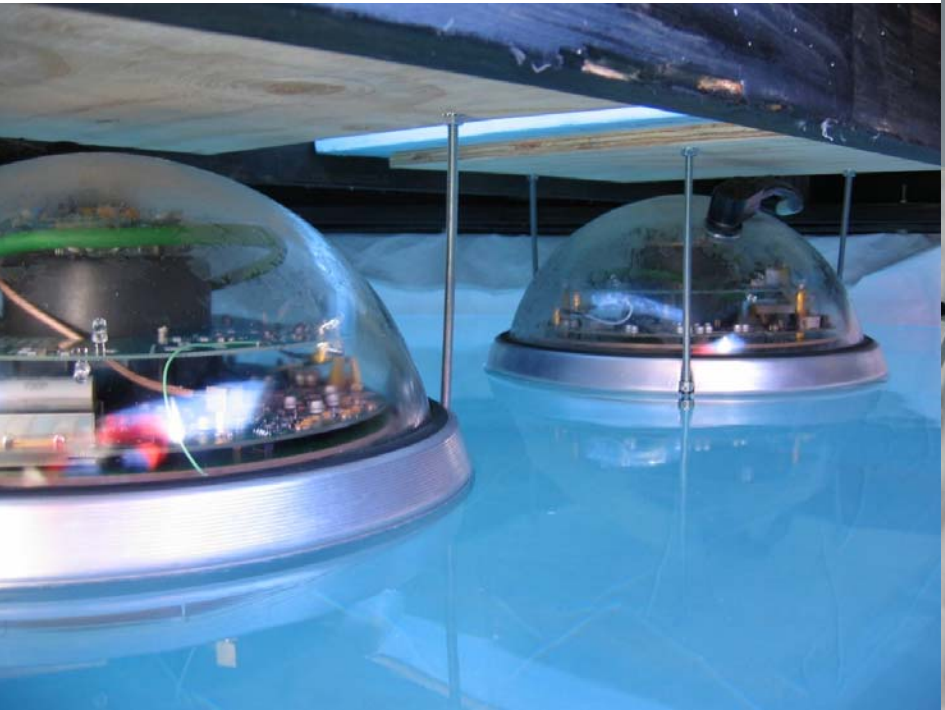




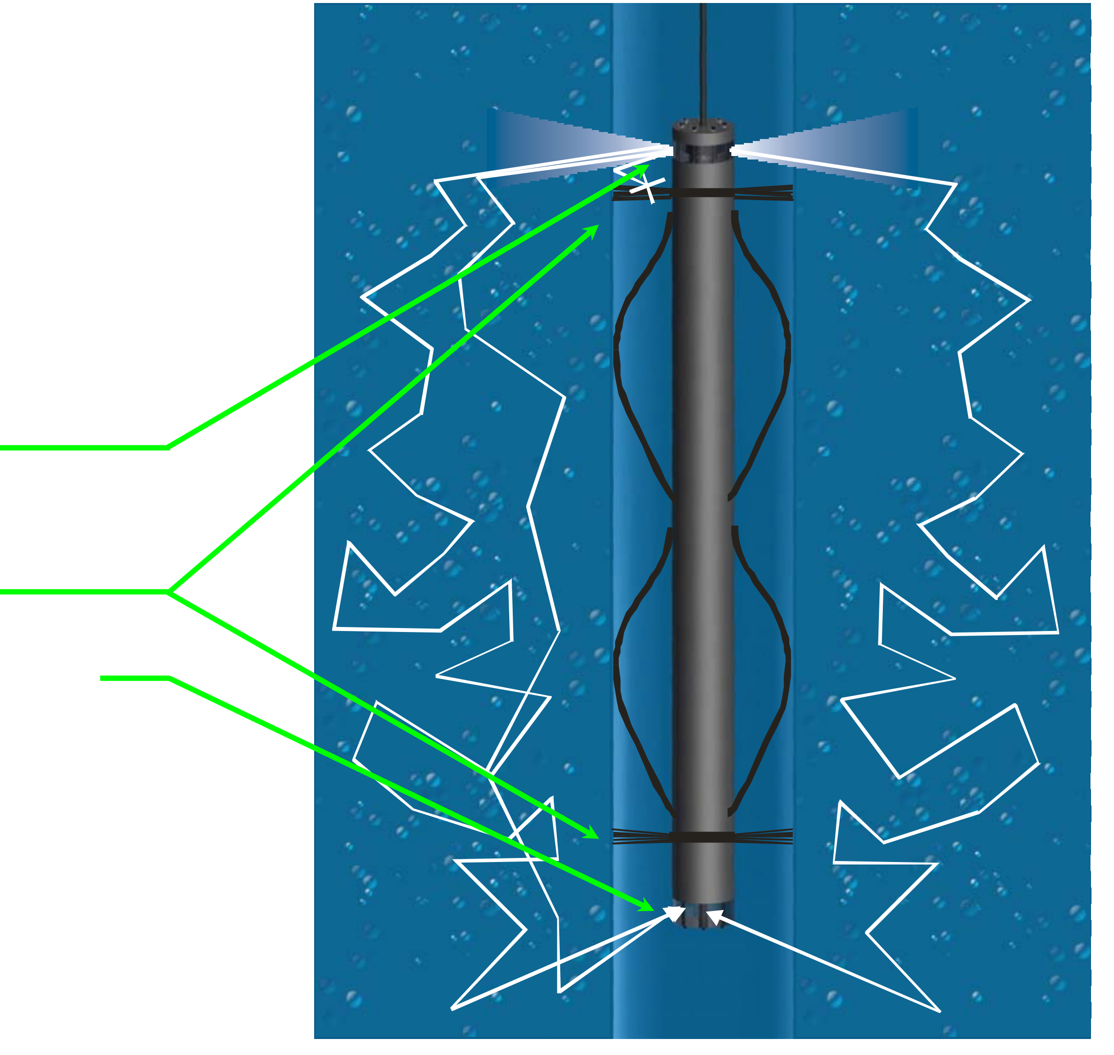


99% of 604 DOMs survive deployment and freeze-in

Ice Top

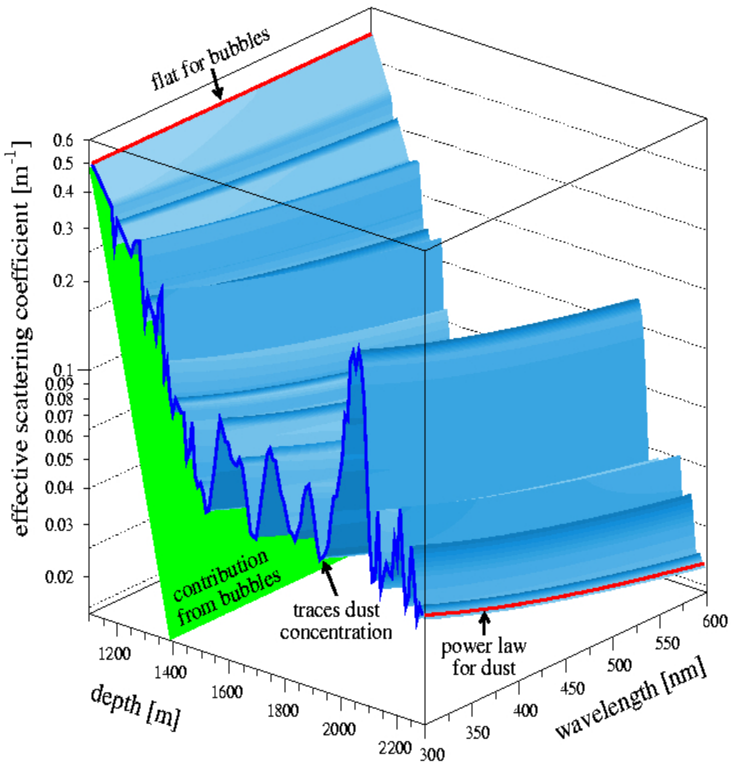


Dust logger

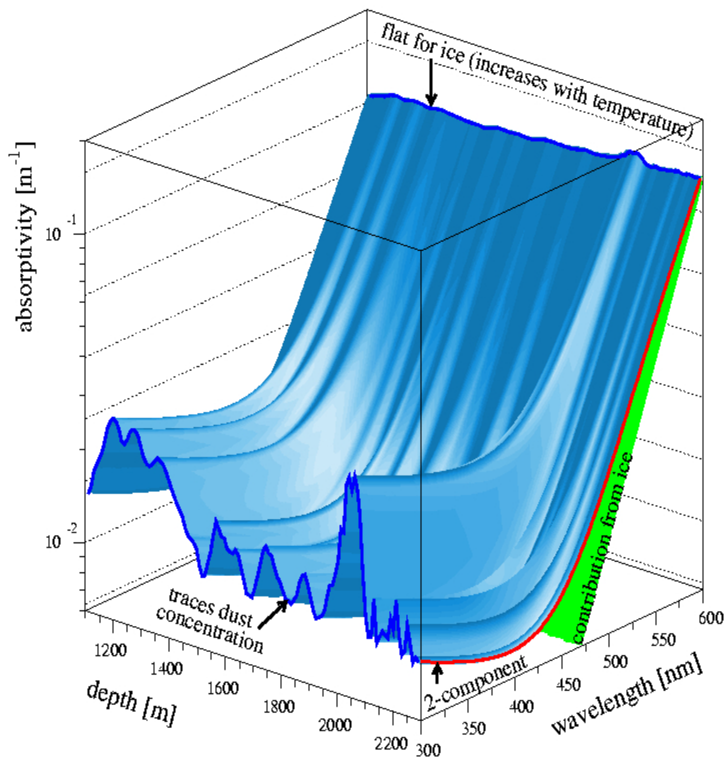


Diffusion/Absorption

Absorptionslänge : ~110 m
Diffusionslänge: ~20 m
(λ = 400 nm)

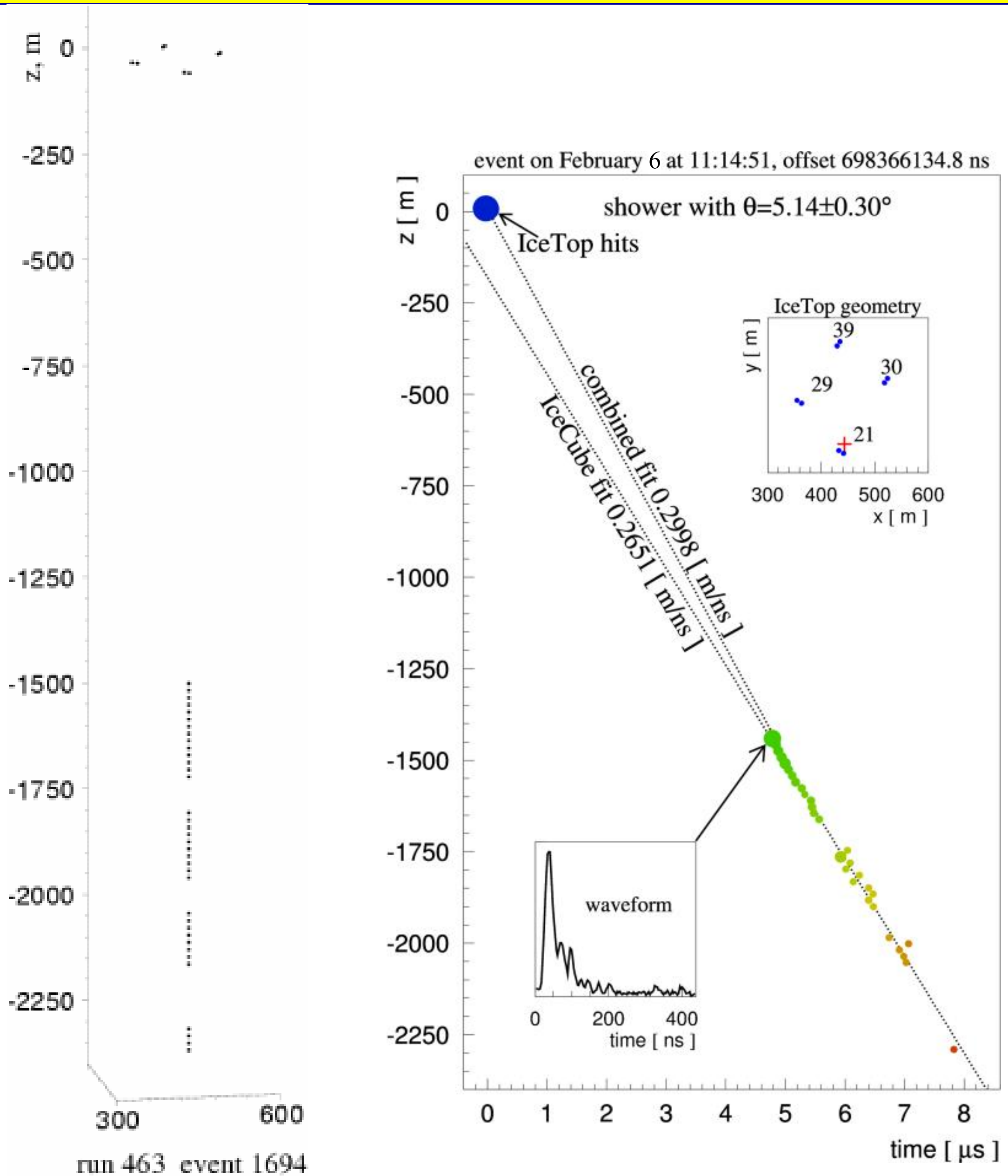


Diffusion



Absorption

The first muon – IceTop shower coincident event

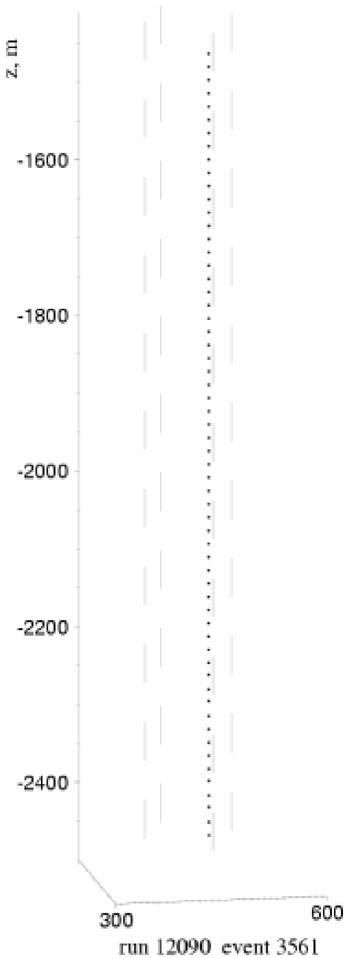


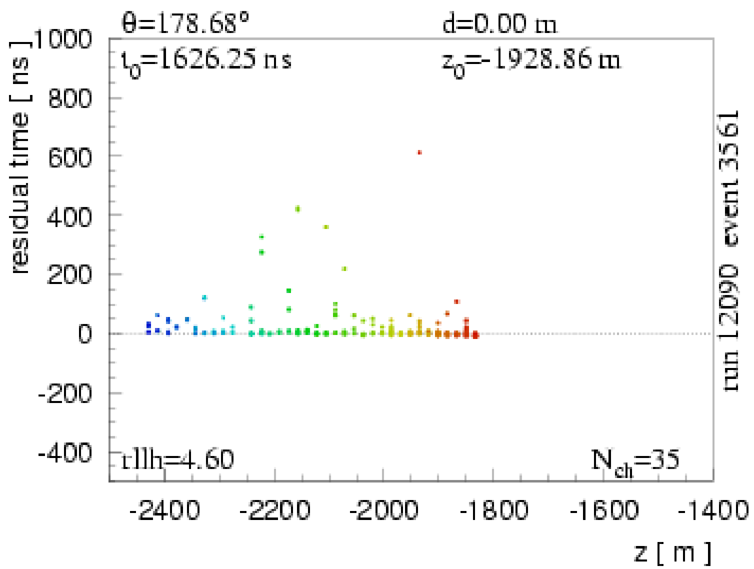
January 23
First runs with the four IceTop stations (8 tanks) taken

January 29 1:31
First IceCube string deployed

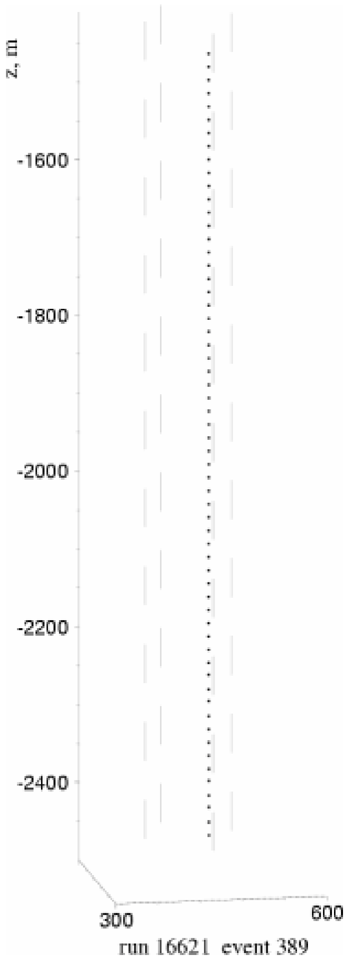
February 9
First shower/muon coincidence events found

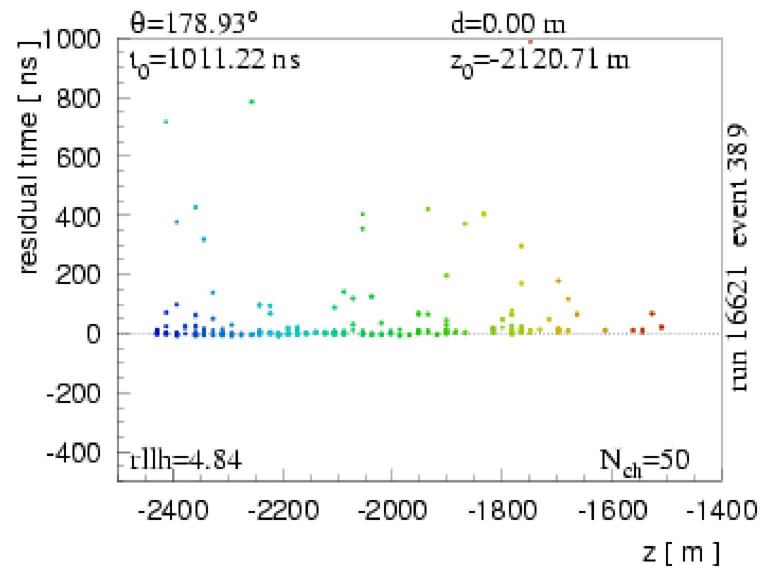
Upgoing neutrino-induced muon in IC-1, number 1



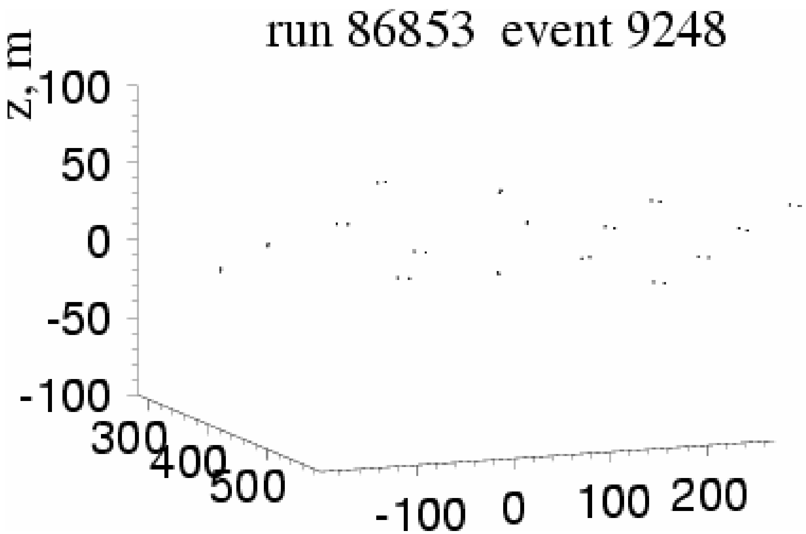


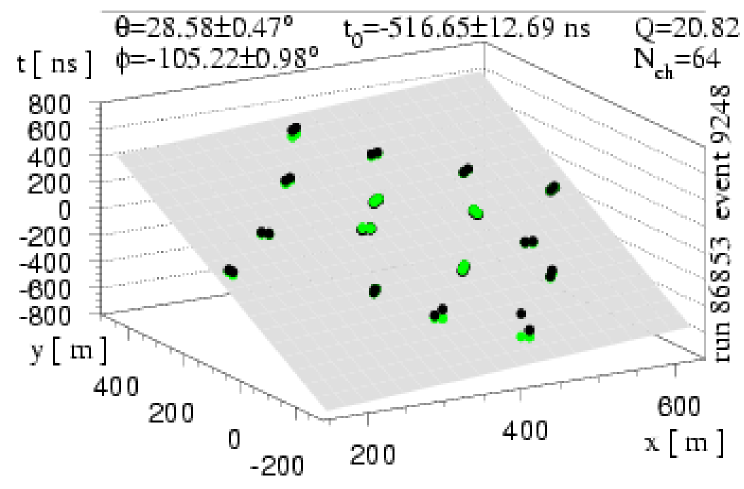
Upgoing neutrino-induced muon in IC-1, number 2



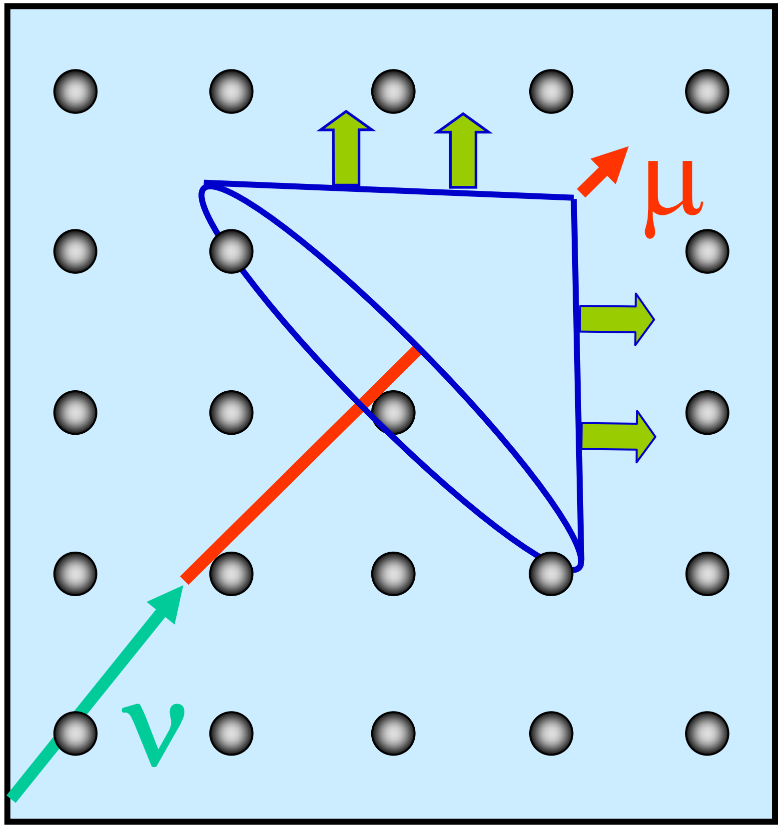


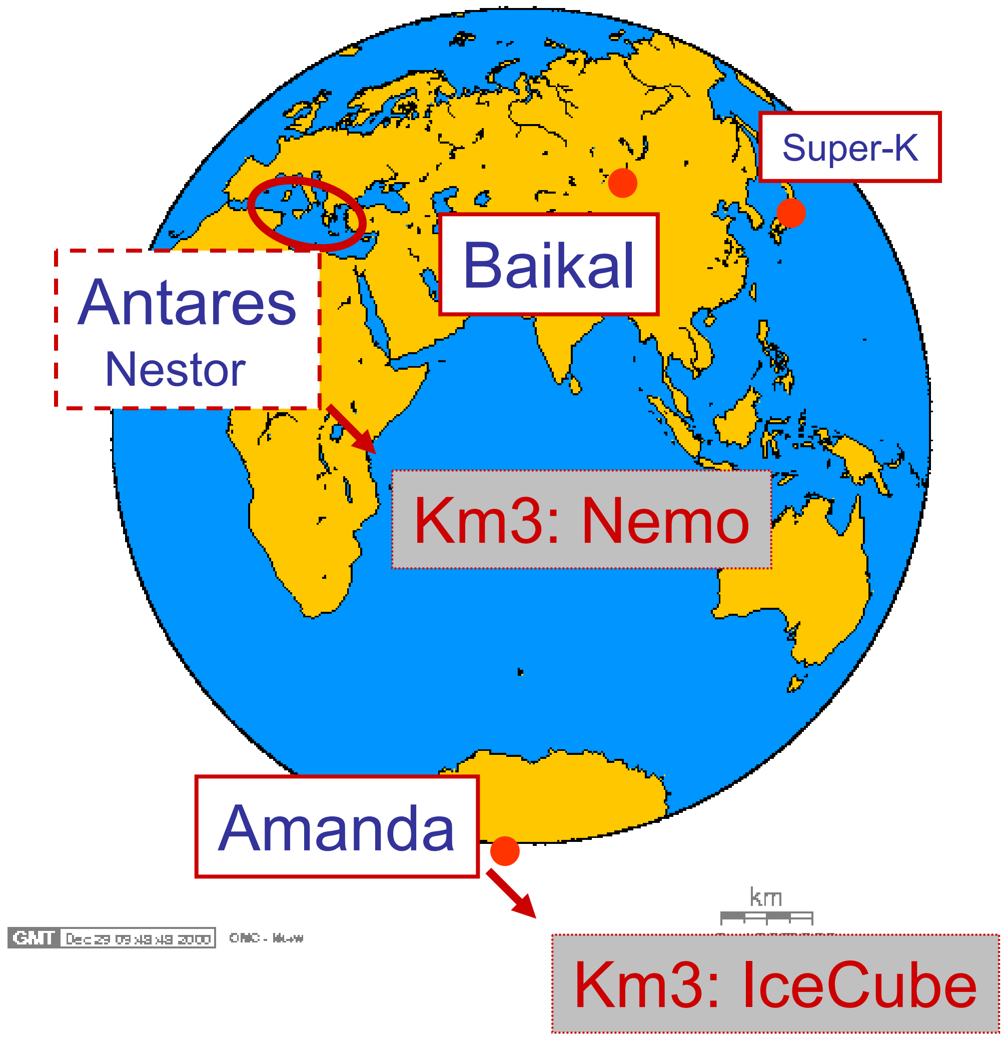
Airshower event in IceTop

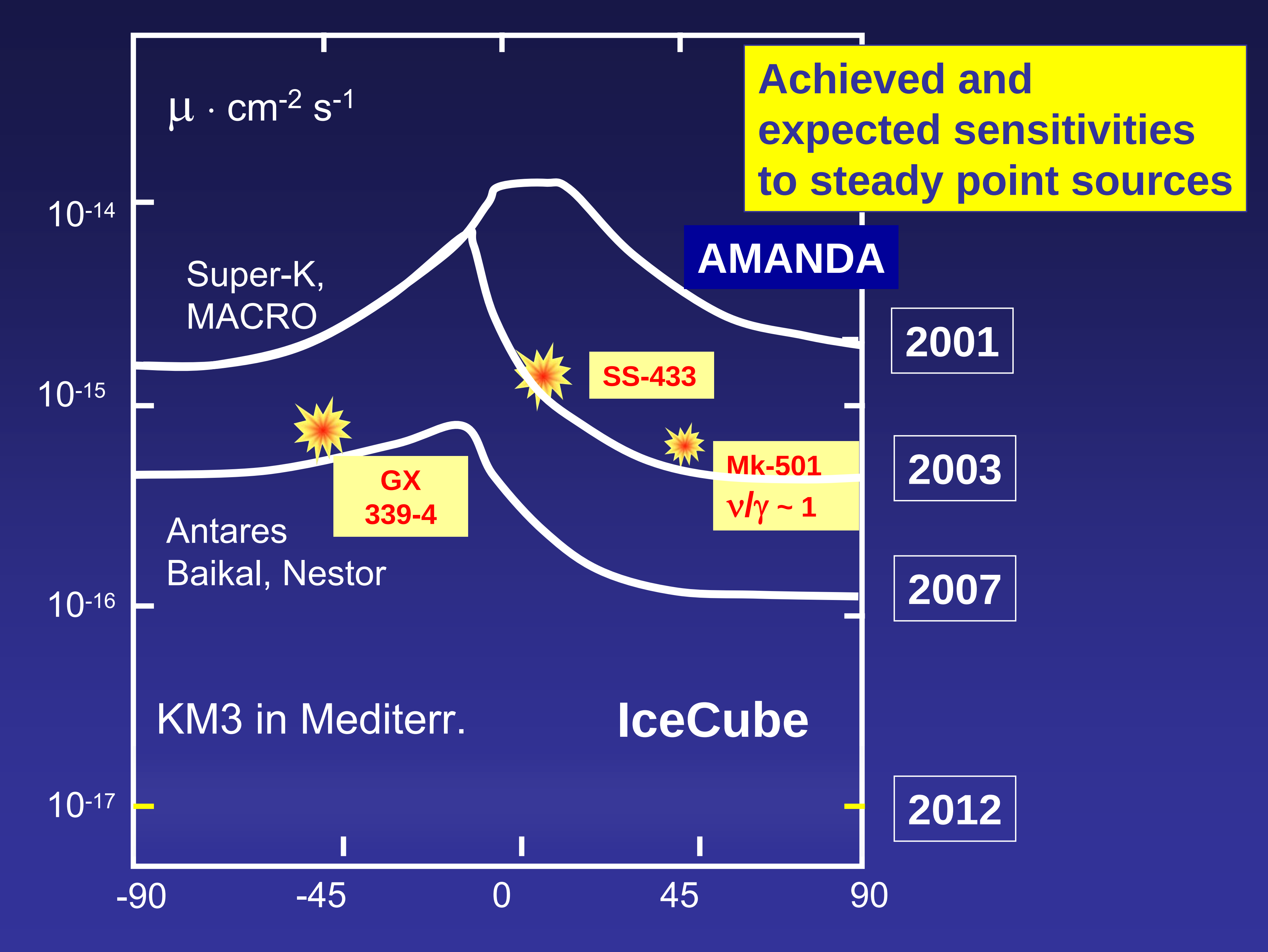




Neutrino Telescopes in Water and Ice

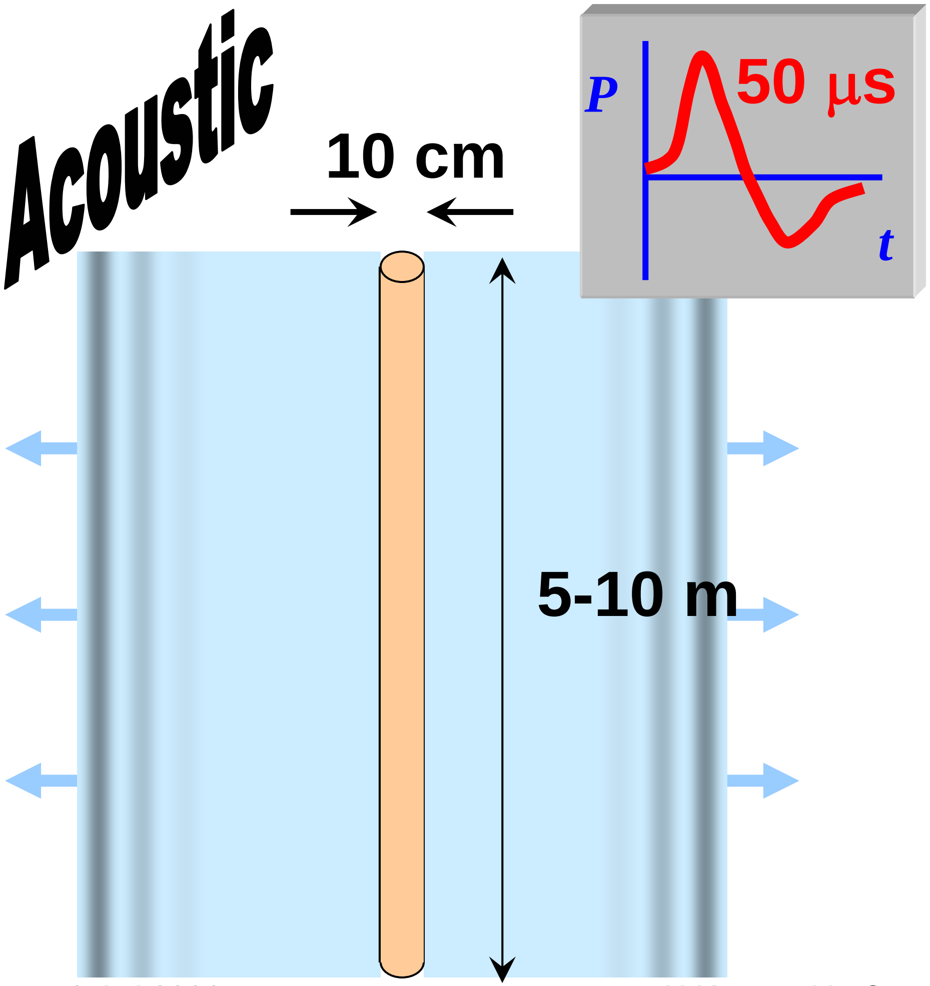




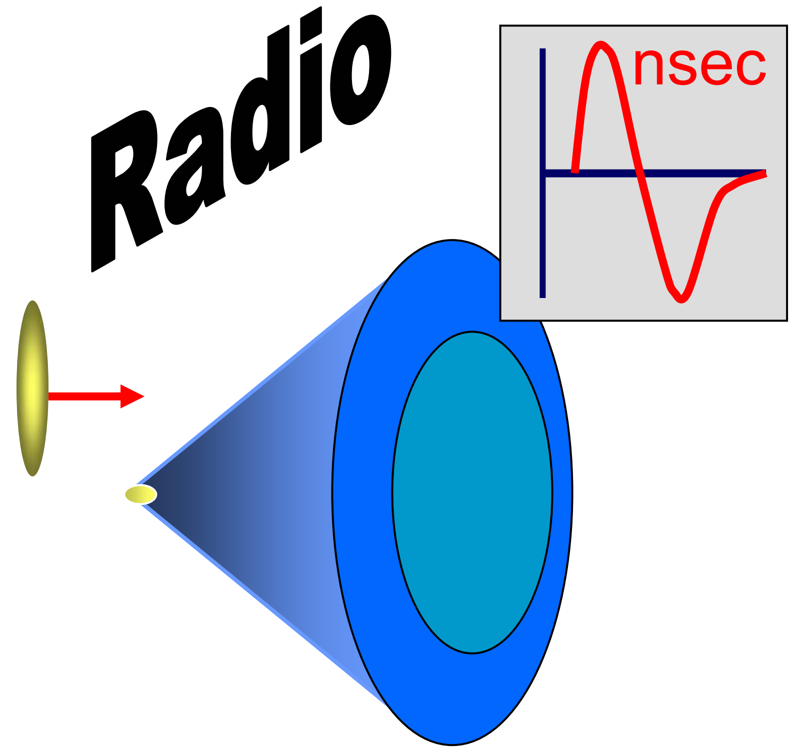


Achieved and expected sensitivities to steady point sources
μ · cm-2 s-1
10-14
10-15
10-16
10-17
Super-K, MACRO
AMANDA
2001
SS-433
GX 339-4
Mk-501 ν/γ ~ 1
2003
Antares Baikal, Nestor
2007
KM3 in Mediterr.
IceCube
2012
-90
-45
0
45
90

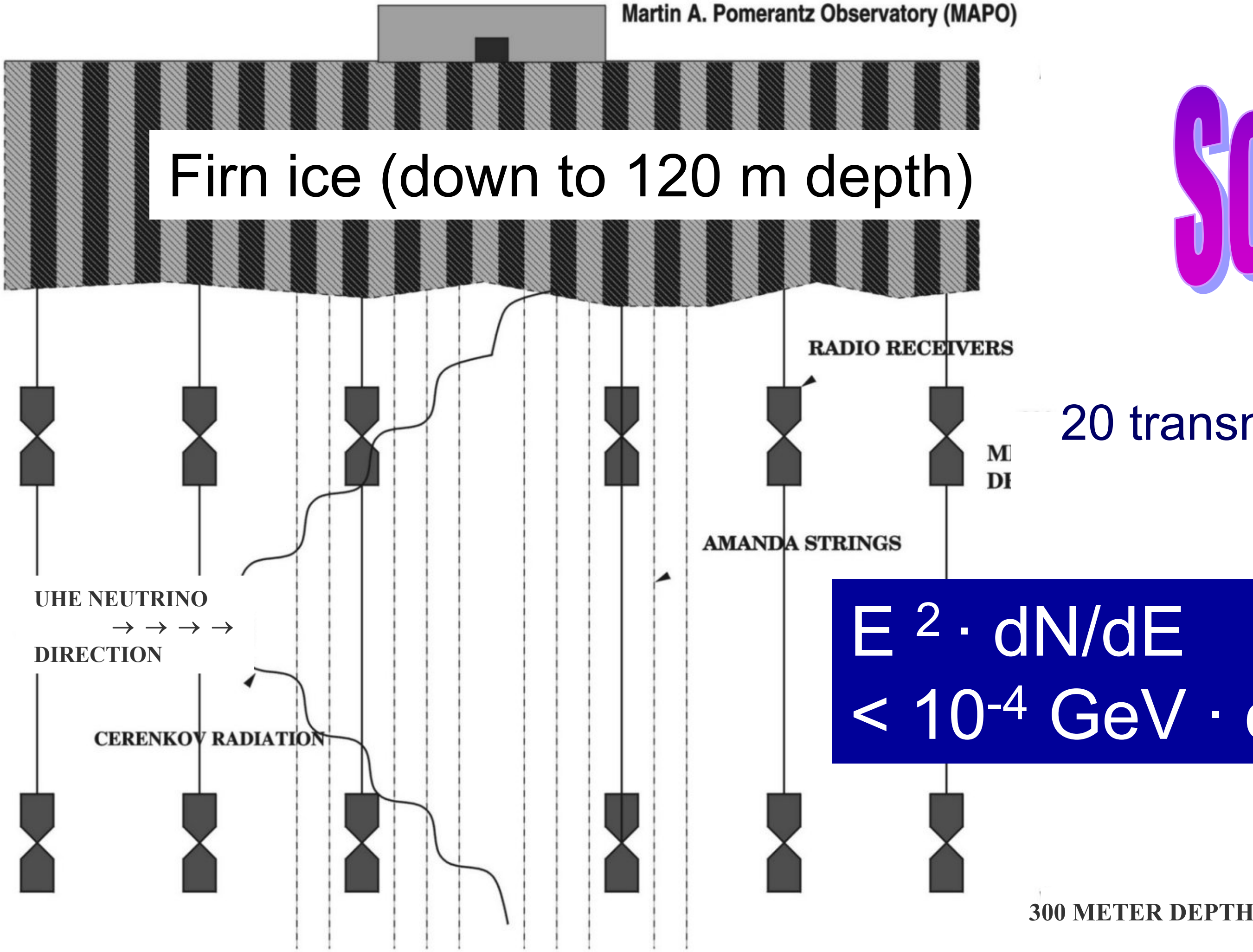
Above 10-100 PeV:
Detection by Acoustic and Radio Waves



attenuation length in ice 1-4 km !!



RICE Radio Ice Cherenkov Experiment



South Pole

20 transmitter + receiver

$E^2 \cdot dN/dE$
$< 10^{-4}$ GeV $\cdot$ cm^{-2} $\cdot$ s^{-1} $\cdot$ sr^{-1}

at 100 PeV

Sehen und Hören: Nutze alle Sinne

Teilchen hören ?!!

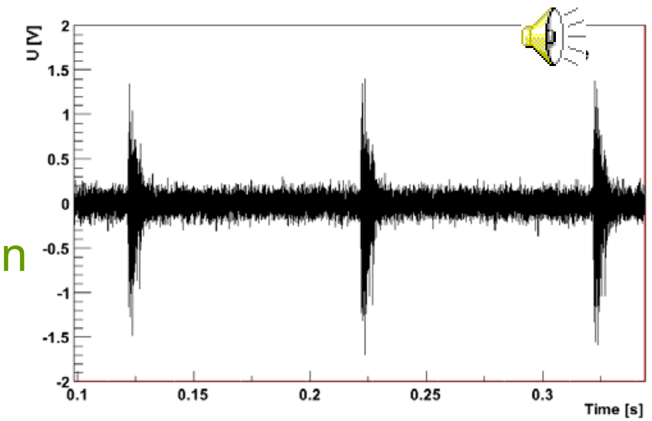
Akustische Sensoren für den IceCube Detektor

Thermoakustisches Modell:

- ➩ Ultrahochenergetische Kaskade
  - ➩ Lokale Erwärmung
    - ➩ Expansion
      - ➩ Schallwelle

Akkustische Sensoren

180 MeV Protonen
TSL, Uppsala



Ende