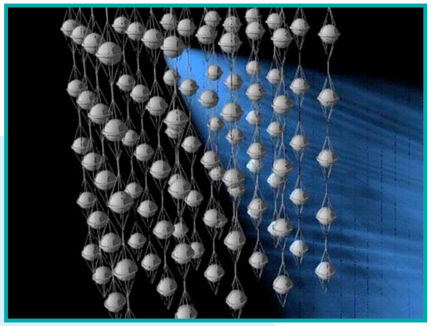



IceCube and IceTop, status

Albrecht Karle
University of Wisconsin-Madison
IceCube collaboration

IceCube

Aspen
April, 2007

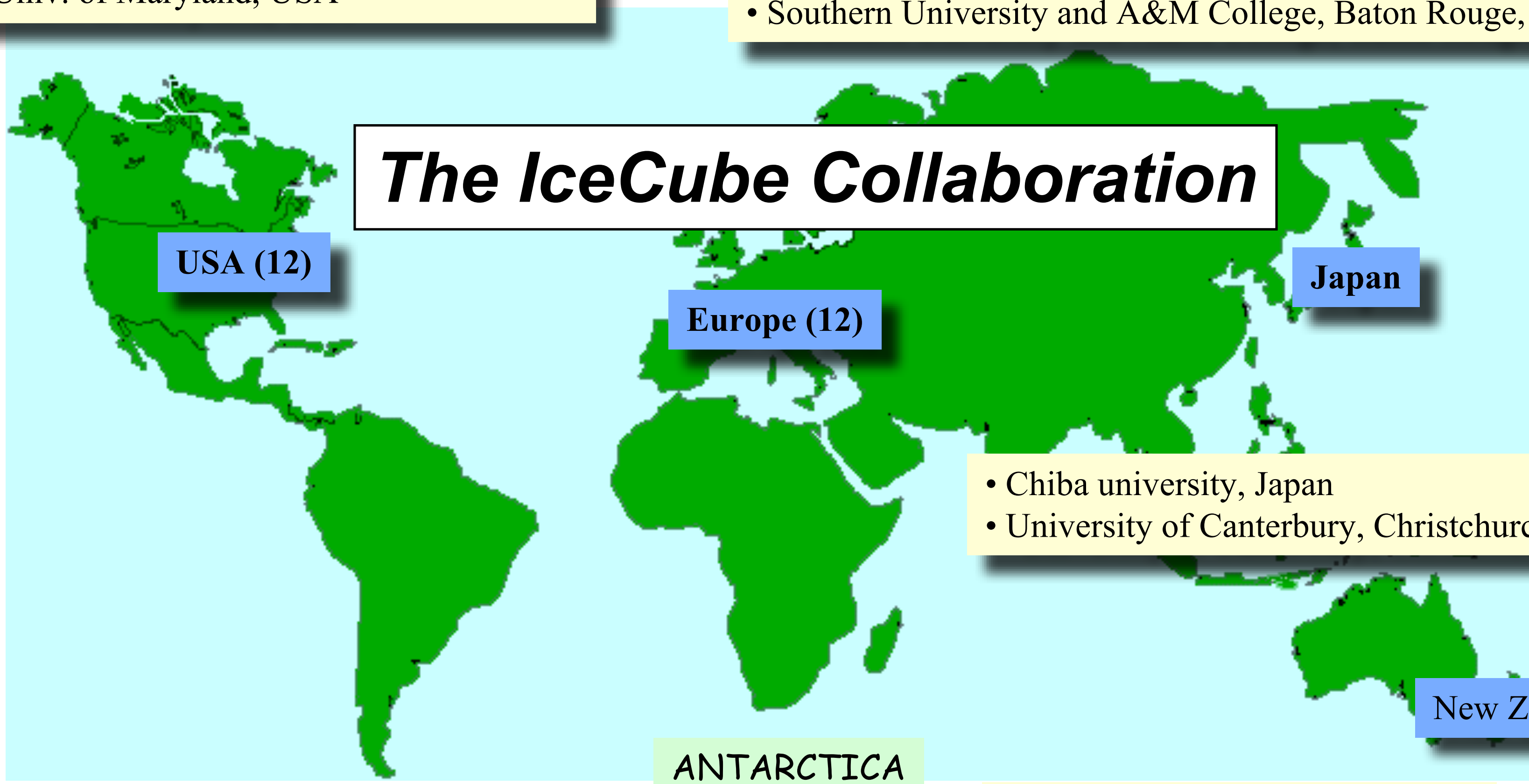
Outline

- Introduction
- AMANDA results
- IceCube construction
- Calibration techniques and some data
- Coincidence events: IceCube-IceTop and remarks on composition
- Thoughts on R&D for future high energy detector extension

The IceCube Collaboration

- Bartol Research Institute, Delaware, USA
- Univ. of Alabama, USA
- Pennsylvania State University, USA
- UC Berkeley, USA
- Clark-Atlanta University, USA
- Univ. of Maryland, USA

- IAS, Princeton, USA
- University of Wisconsin-Madison, USA
- University of Wisconsin-River Falls, USA
- LBNL, Berkeley, USA
- University of Kansas, USA
- Southern University and A&M College, Baton Rouge, USA



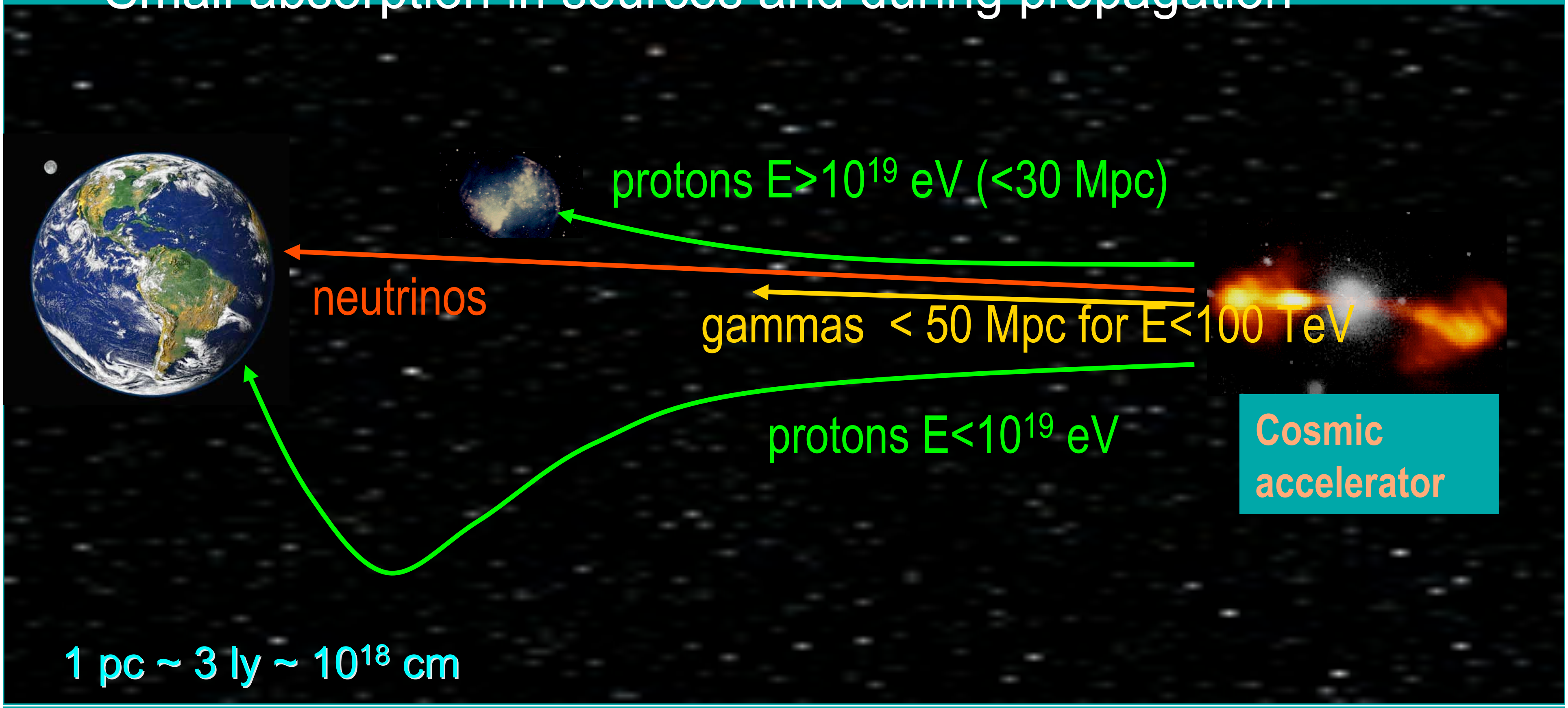
- Chiba university, Japan
- University of Canterbury, Christchurch, NZ

- Universite Libre de Bruxelles, Belgium
- Vrije Universiteit Brussel, Belgium
- Université de Mons-Hainaut, Belgium
- Universität Mainz, Germany
- DESY-Zeuthen, Germany
- Universität Dortmund, Germany

- Universität Wuppertal, Germany
- Uppsala university, Sweden
- Stockholm university, Sweden
- Imperial College, London, UK
- Oxford university, UK
- Utrecht,university, Netherlands

Messengers from the Universe

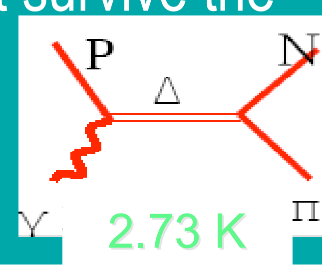
- Straight line propagation to point back to sources
- Small absorption in sources and during propagation



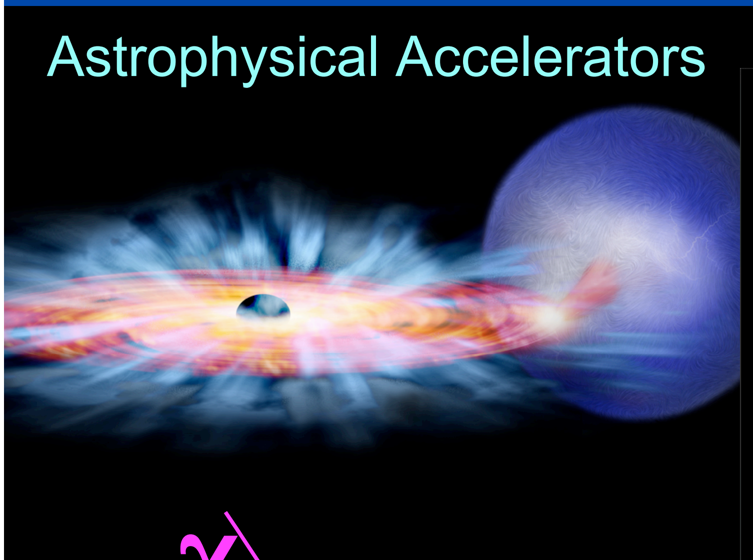
Photons: absorbed on dust and radiation. For E > 100 TeV do not survive the journey from the Galactic Centre

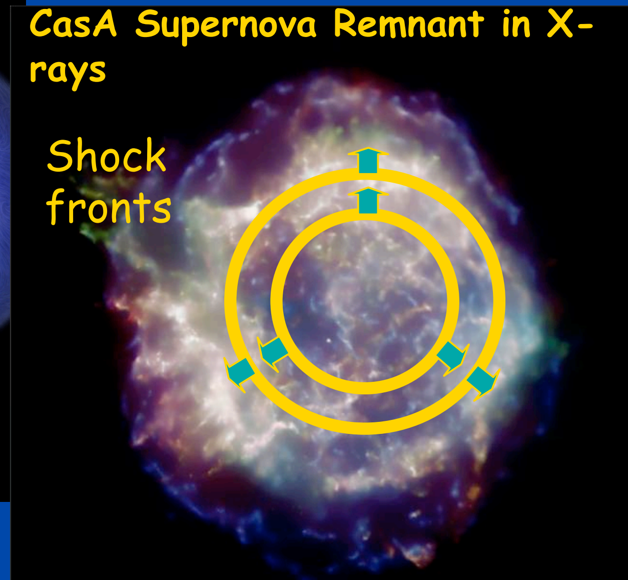
Protons/nuclei: deviated by magnetic fields,GZK cutoff

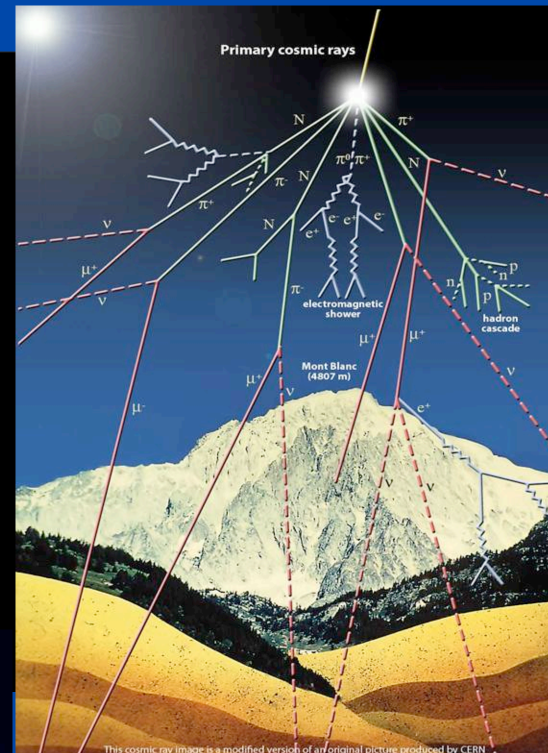
Neutrons: decay



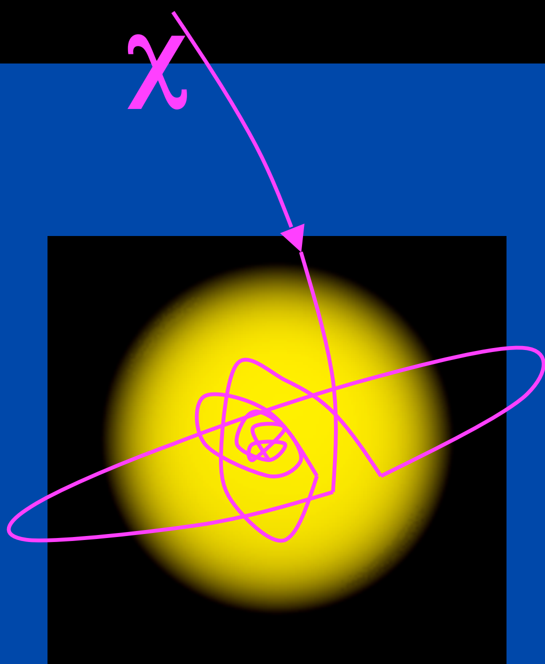
Neutrino sources @ > 100 GeV







Cosmic Rays on atmosphere and on ISM



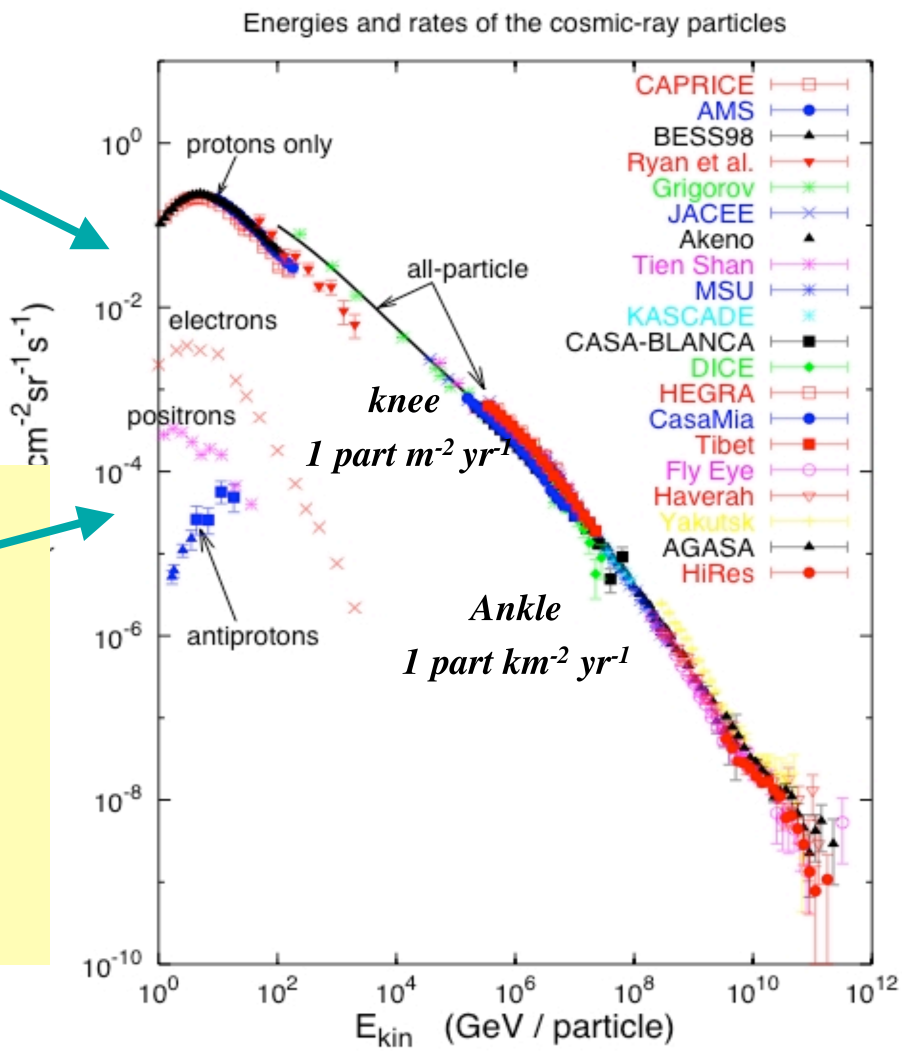
DM annihilation

Sources

Cosmic rays

Candidate sources:

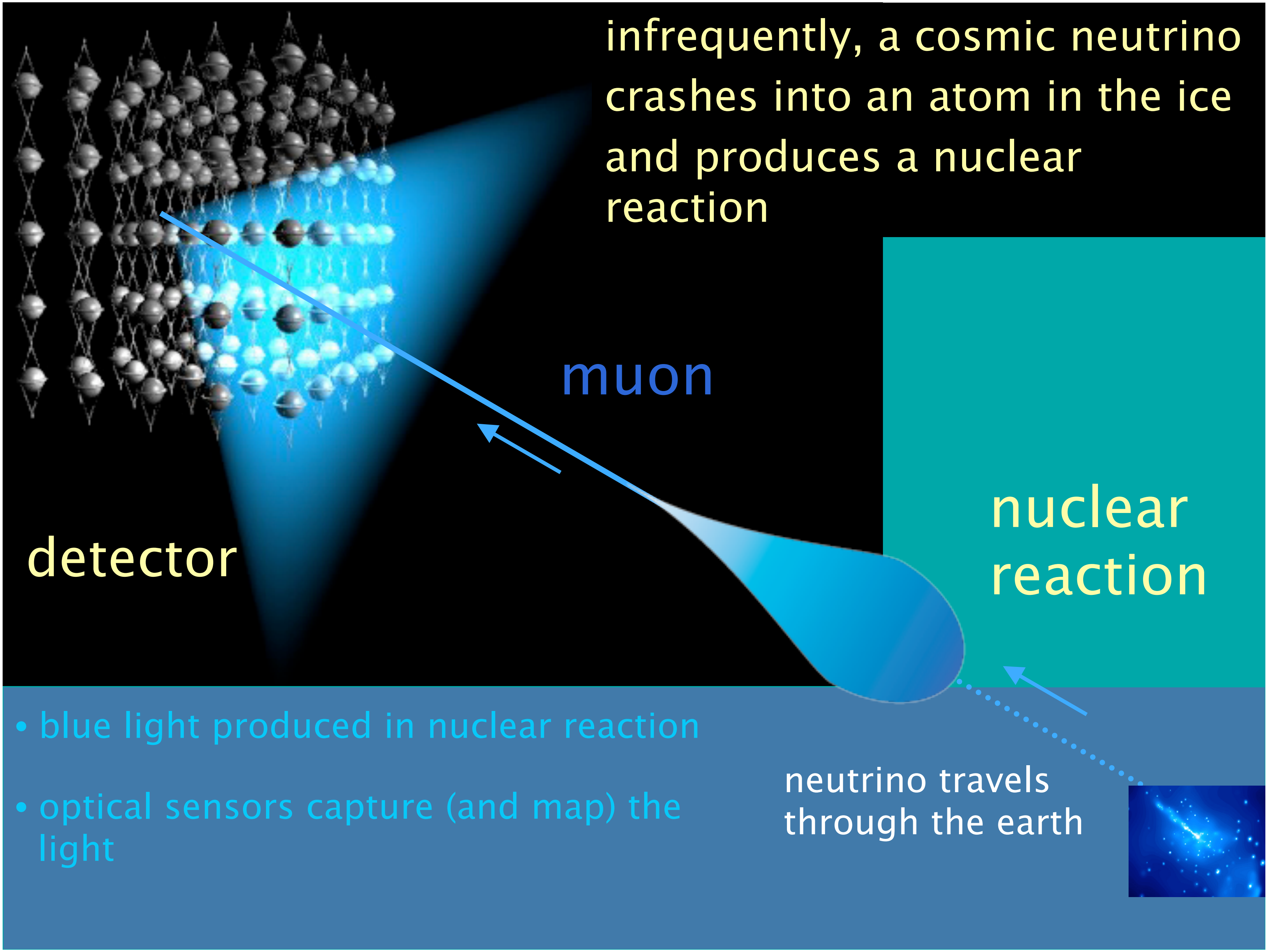
- SN remnants, μQuasars
- Active Galactic Nuclei
- Gamma Ray Bursts
- Dark Matter
- Exotics



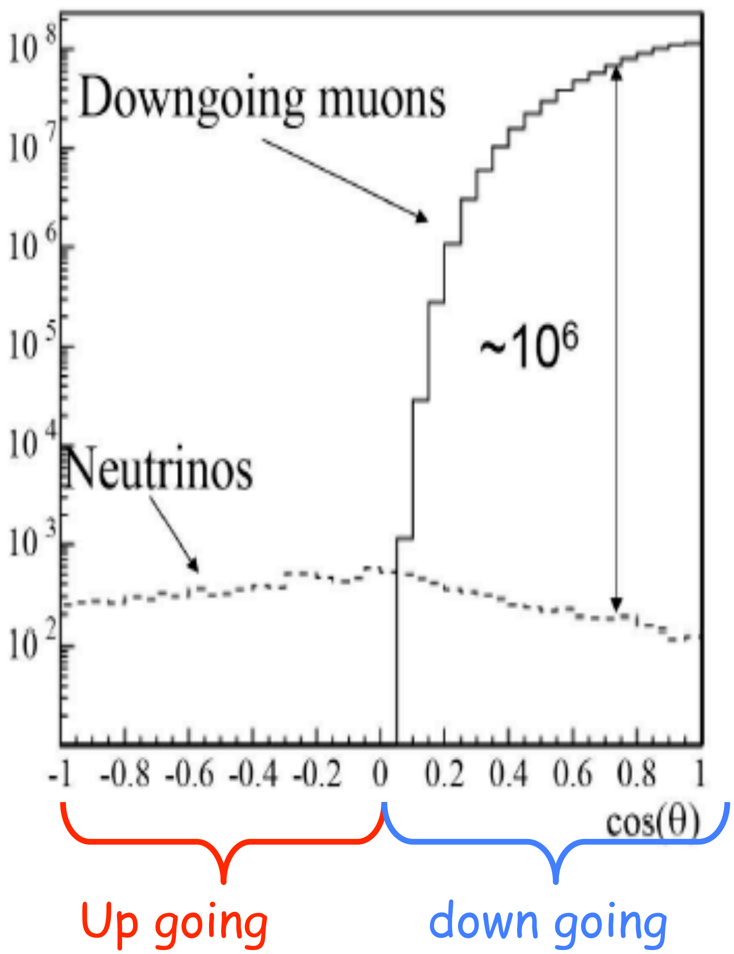
Guaranteed sources:

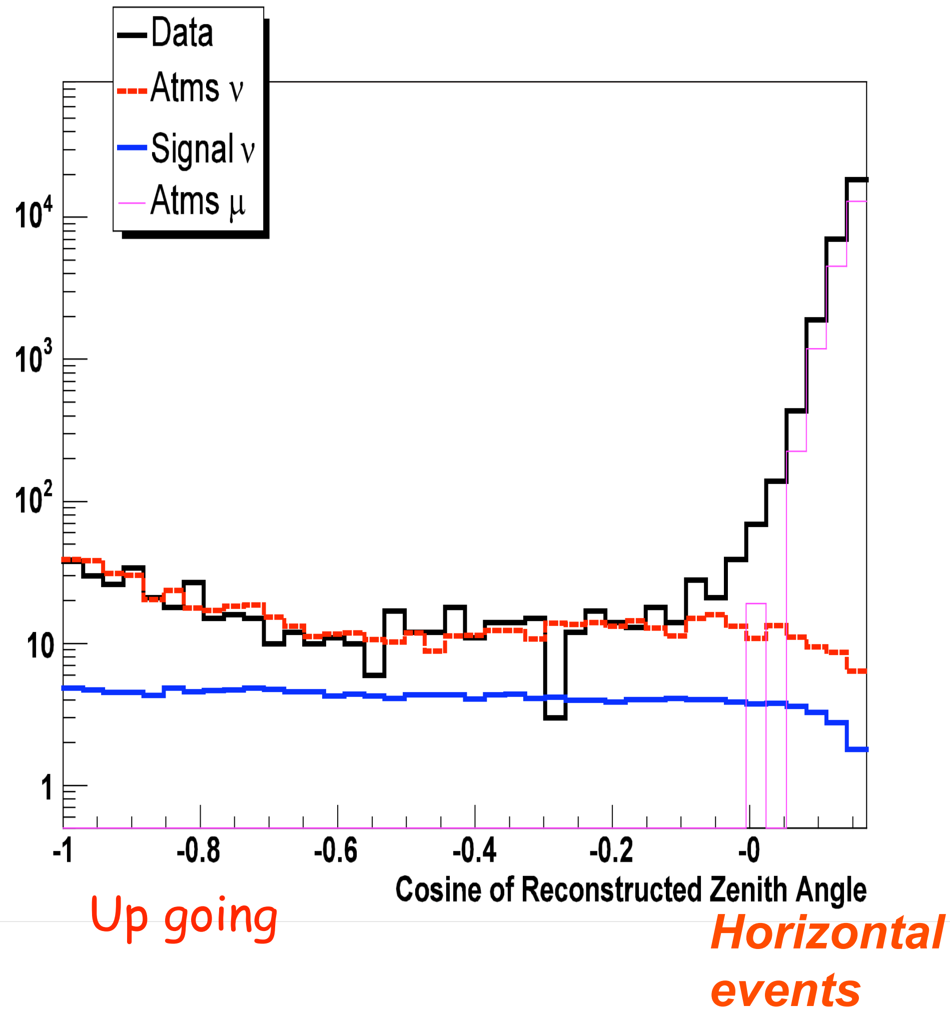
- Atmospheric neutrinos
- Galactic plane:
  CR interacting with ISM, concentrated on the disk
- Starburst galaxies
- GZK
  $p\,\gamma \rightarrow \Delta^+ \rightarrow n\,\pi^+ \;(p\,\pi^0)$

A. Karle


infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction
muon
detector
nuclear reaction
• blue light produced in nuclear reaction
• optical sensors capture (and map) the light
neutrino travels through the earth

Down/up going events





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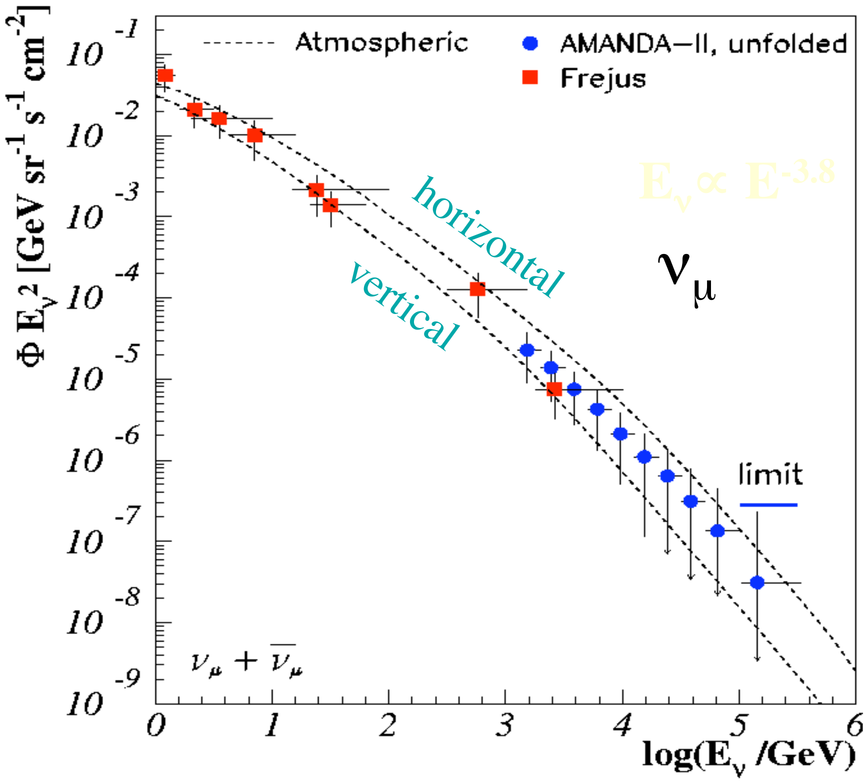
Atmospheric neutrinos

Atmospheric neutrinos is the background for cosmic neutrinos but in the same time an important calibration tool.



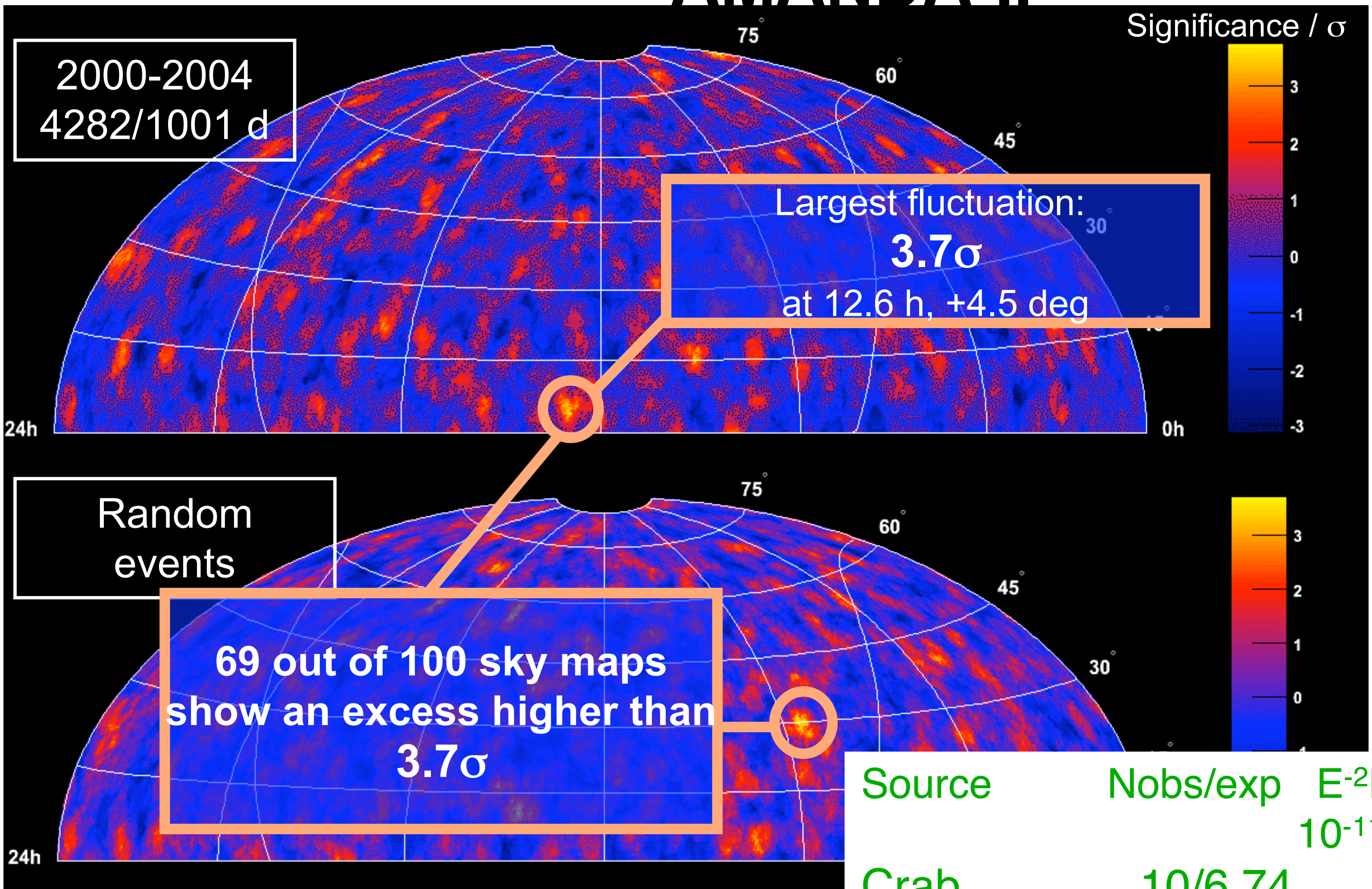
Neutrinos up to a few 100 TeV have been observed in AMANDA

Spectrum can be used to search for E^{-2} component

Limit on diffuse E^{-2} ν_μ flux (100 -300 TeV): $E^2\Phi_{\nu_\mu}(E) < 2.9 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

A. Karle UW Madison

5 years of point-like source searches with AMANDA-II

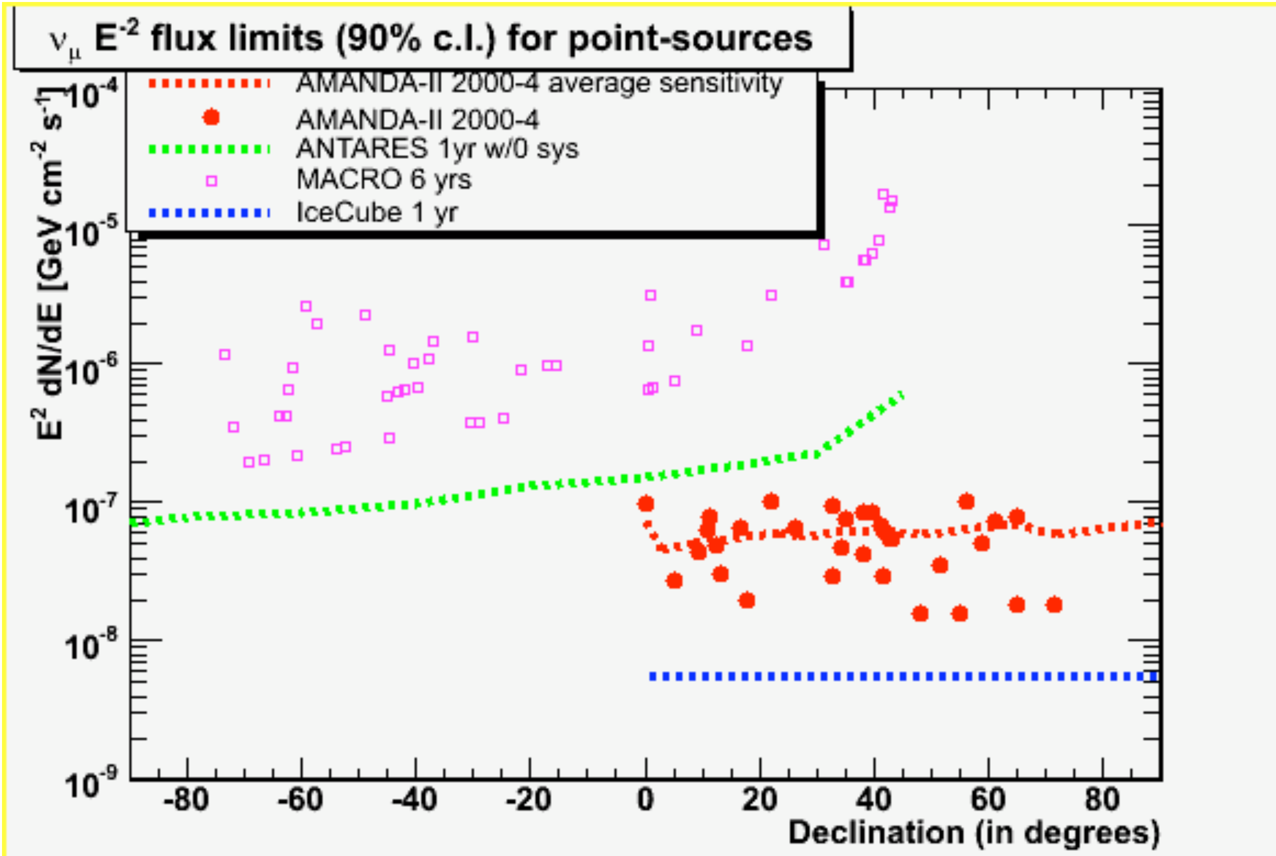


Source	Nobs/exp	E^{-2}Limit(90%cl) 10^{-11} TeV^{-1} cm^{-2} s^{-1}
Crab	10/6.74	17.8
Mrk 501	8/6.39	14.7
LSI +61 303	5/4.81	12.6
1ES 1959+650	5/4.77	13.5

astro-ph/0611063
Submitted to Phys Rev D

A. Karle

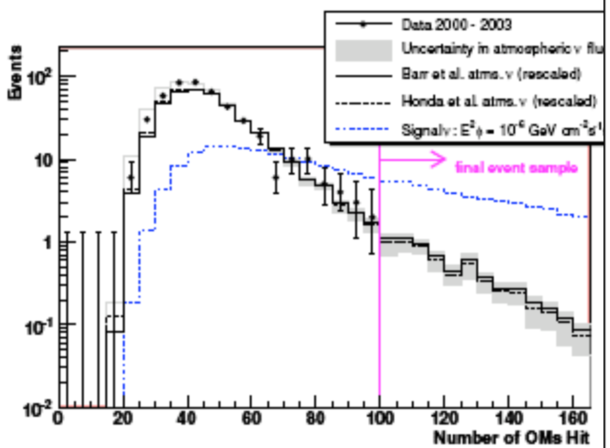
Summary of results for point-like source searches

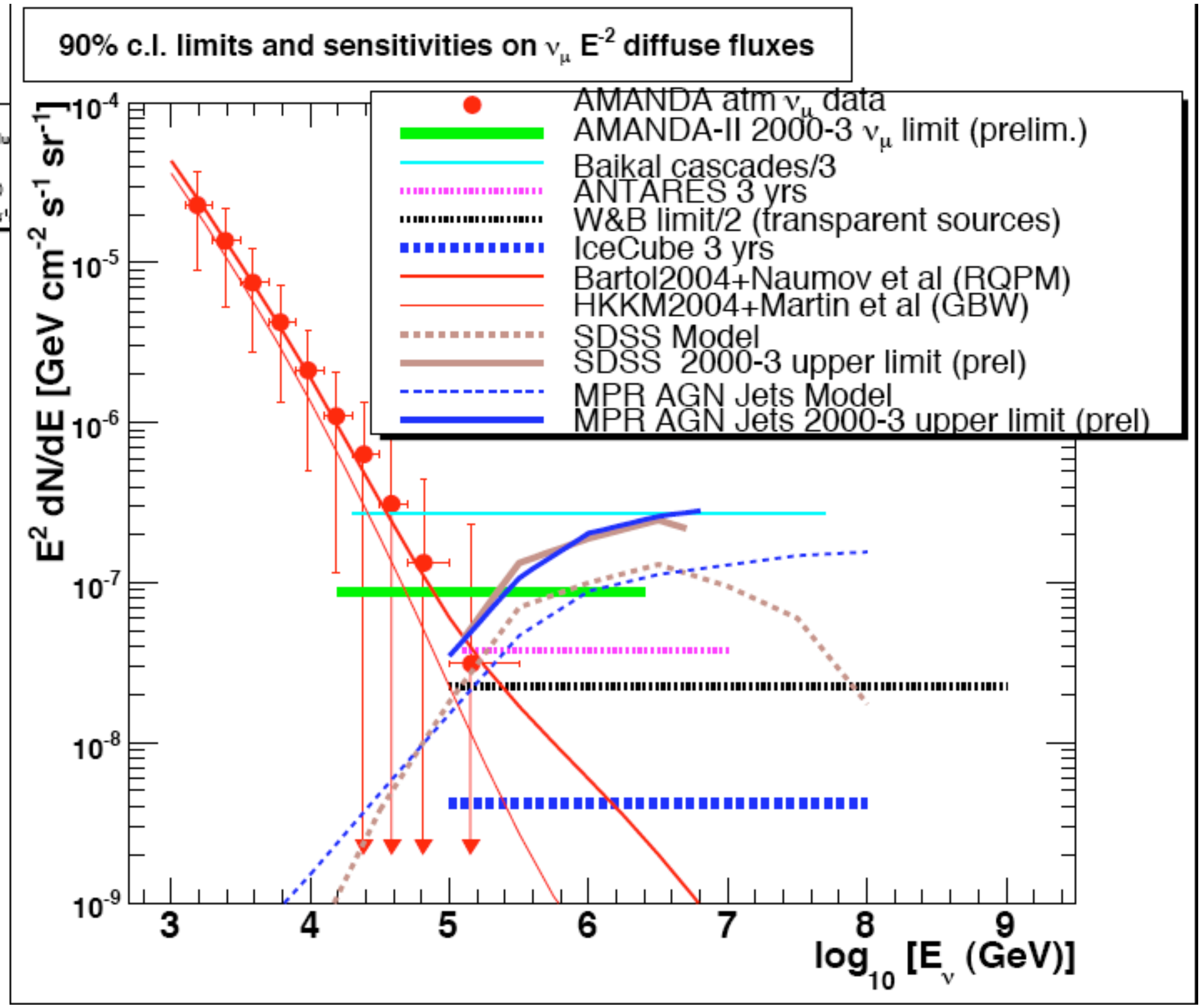


AMANDA
1000 atm ν/yr
1 deg cones $\Rightarrow$ 2 /yr

IceCube
50000 atm ν /yr
1 deg $\Rightarrow$15 /yr

Looking for diffuse fluxes





AMANDA-II is about a factor of 4 from W&B

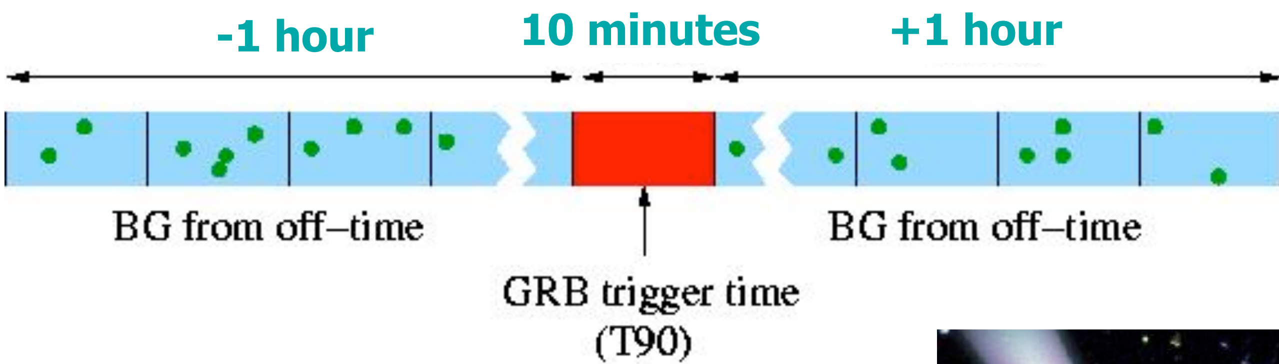
1st IceCube EHE studies:

10^5 - 10^{11} GeV

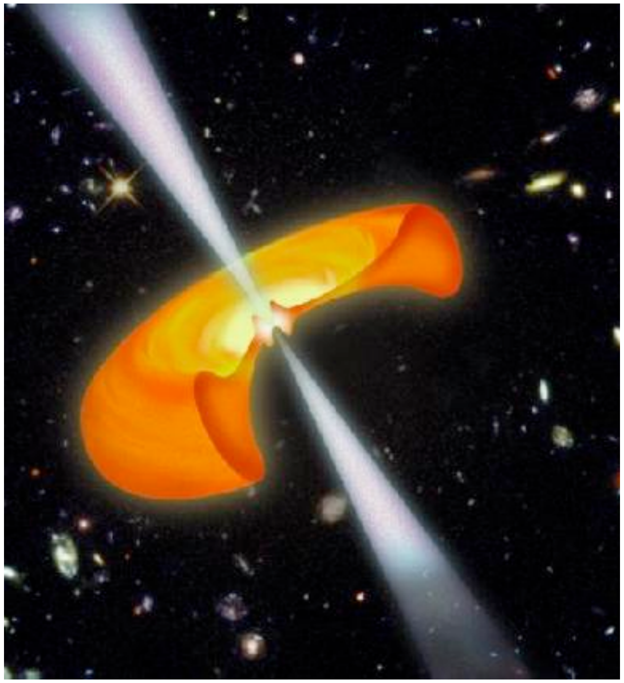
0.7 ν events

0.03 atm μs

Search for Neutrinos from GRBs

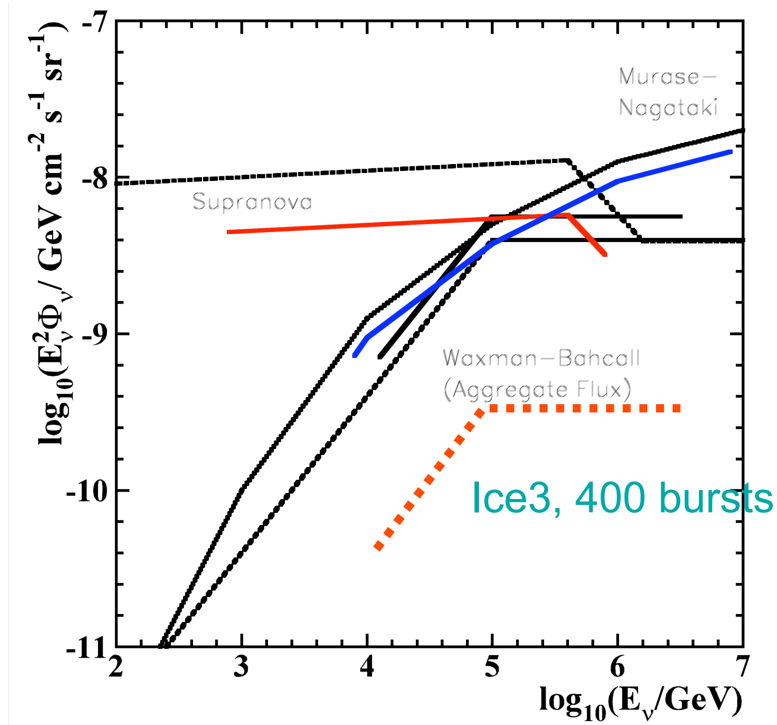


- Short duration (~T90) reduces background dramatically.
- Measure background during off time



Observations 1997-2003

Year	N_{Bursts}	N_{BG}	N_{Obs}
1997	78	0.06	0
1998	94	0.20	0
1999	96	0.20	0
2000	87	1.02	0
2001	16	0.07	0
2002	22	0.08	0
2003	26	0.13	0
Total	**419**	**1.74**	**0**



Combined Event Upper Limit: 1.10

Waxman & Bahcall fireball
Prediction constrained to: 1.3
MRF(Razzaque et al.) = 0.46
Most optimistic models excluded

ICECUBE + SWIFT, GLAST,….:
factor of 20 to 40 improvement in sensitivity:
Background events ∝ sqr(angular resolution) of trigger

AMANDA-II ⇒ ICECUBE

NIMA 524, (2004)

AMANDA-II

- 677 OM on19 strings
- 200 m diameter, 400 m tall
- Years >=2000
- Trigger rate 80 Hz
- Ang res for μs (2π): **1.5º - 2.5º**
- Energy res for cascades (2π) : 0.1-0.2 in $\log_{10}$[E/TeV]

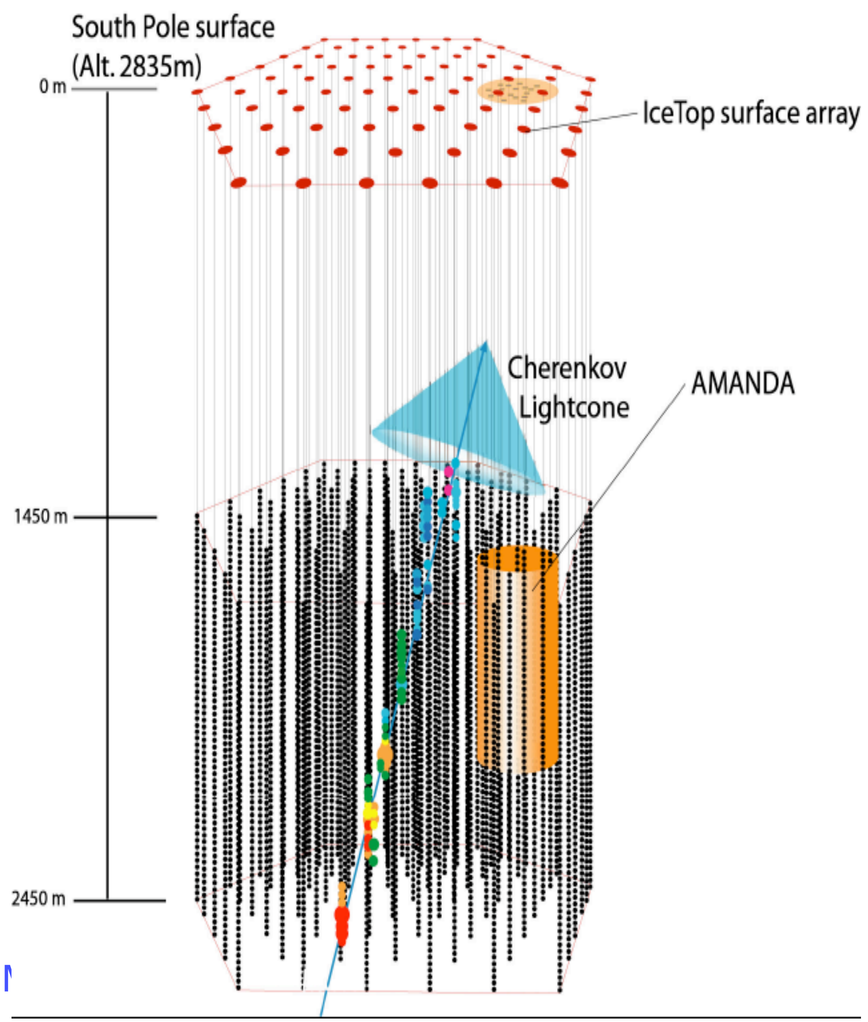
IceCube

- 1 Gton instrumented volume
- 60 DOMs/string 1450-2450 m deep
- 4800 sensors / km3

  Angular res: <0.7°

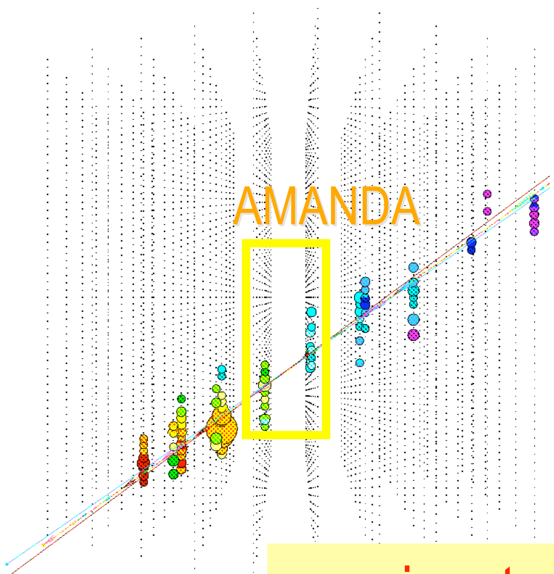
IceTop air shower array

- pair of surface frozen water tanks at 10m (2m diameter)
- each contains 2 DOMs

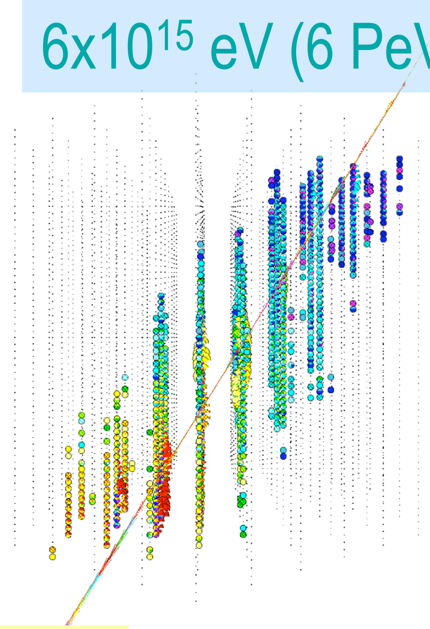


To observe E>PeV we need km3!

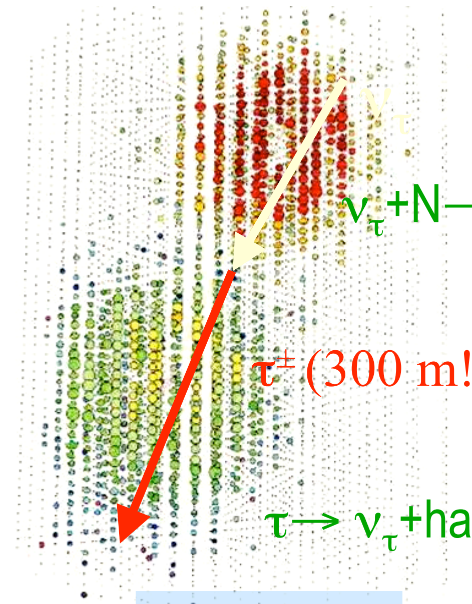
10^{13} eV (10 TeV)



6×10^{15} eV (6 PeV)



ν_μ signature



Multi-PeV

ν_τ signature

EHE muons look like infinite cascades
Composite events: Double Bang
τ–identification, decay range (O(100m) for E>1 PeV)

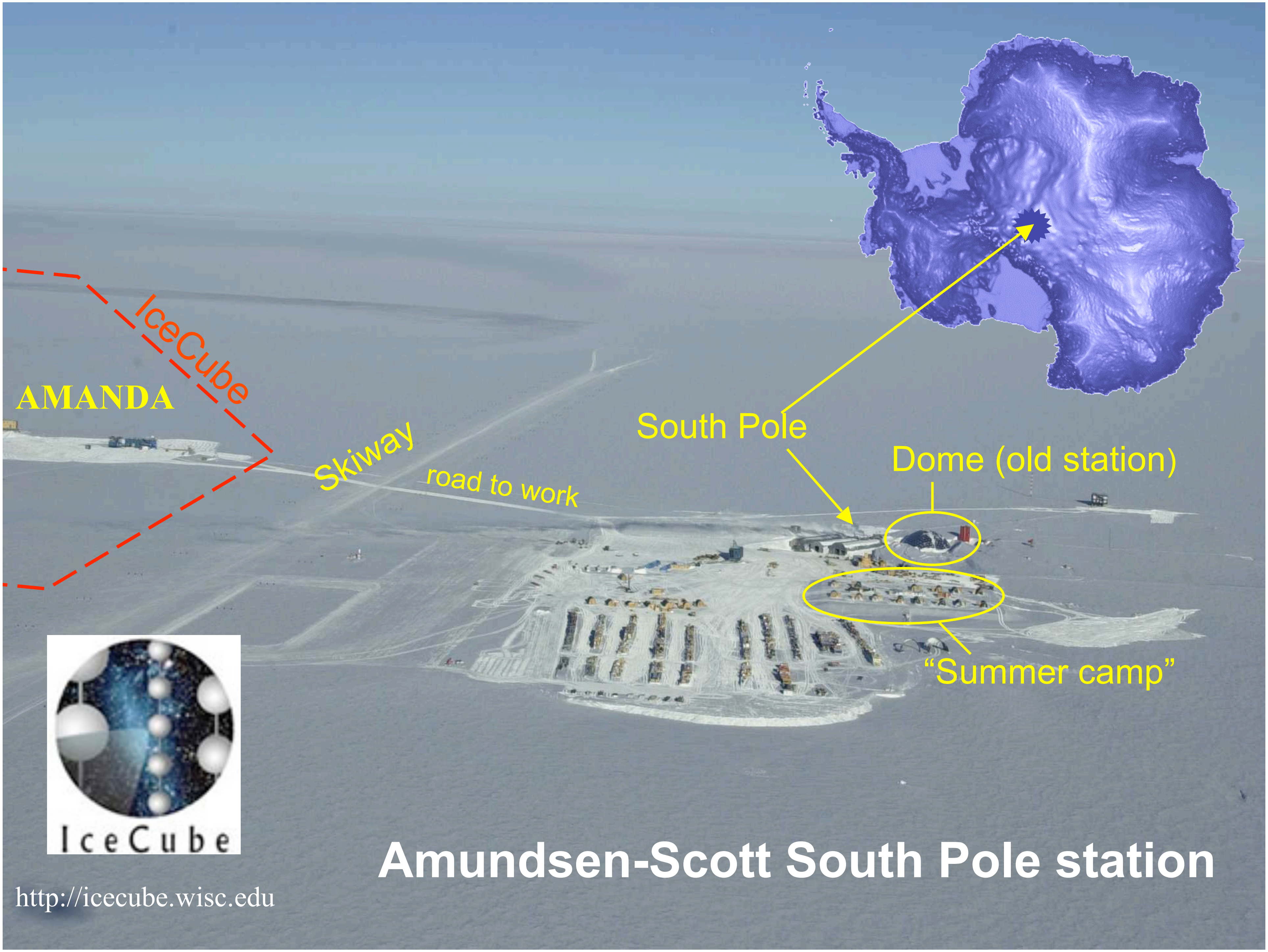
DOM (Digital Optical Module)

PMT: 10 inch Hamamatsu
Power consumption: 3 W
Digitize at 300 Mhz (and 40 MHz)
Dynamic range 200pe/15 nsec

Send all data to surface over copper
Two sensors/twisted pair.
Flasherboard with 12 LEDs
Local HV

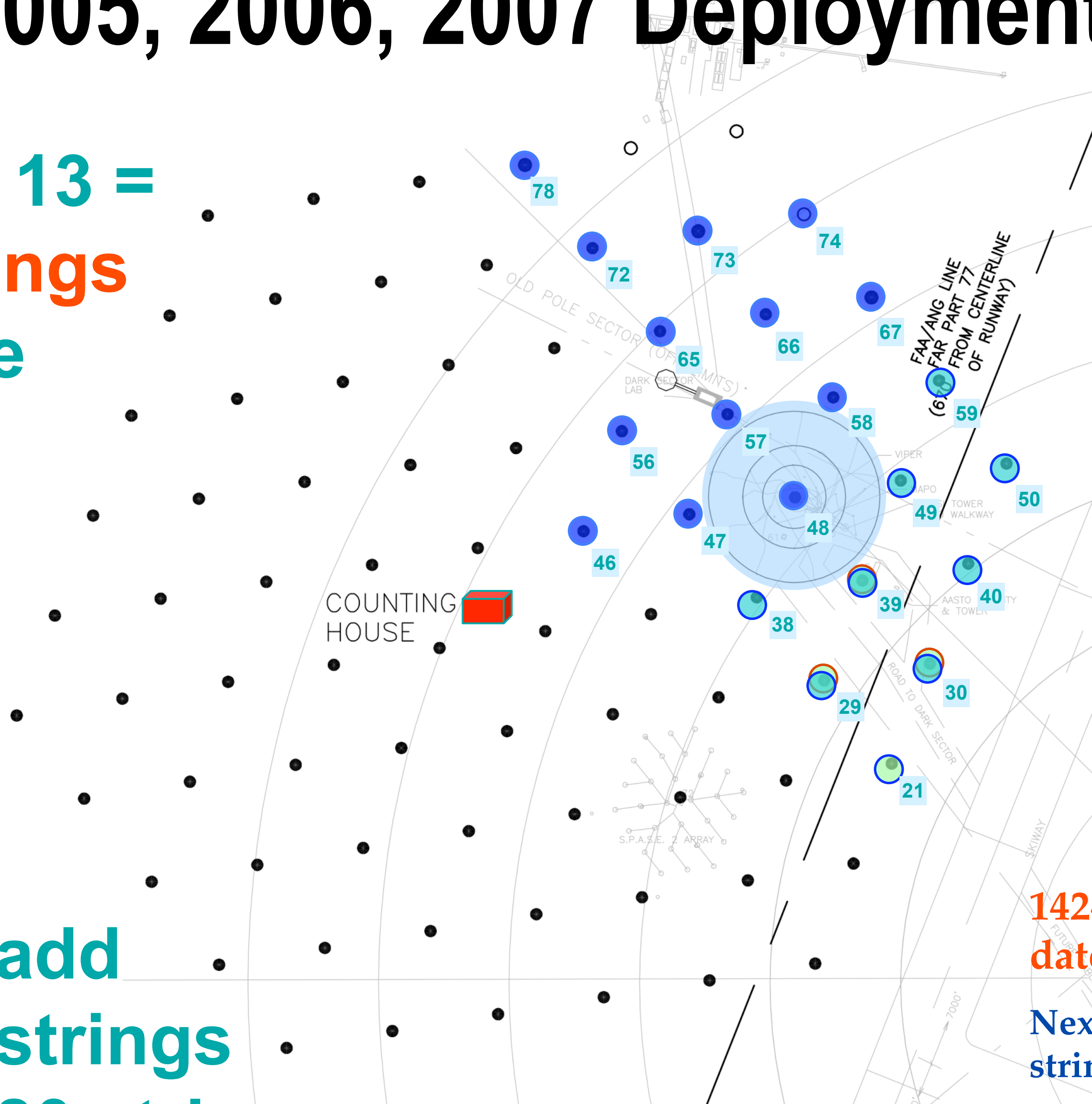
Clock stability: $10^{-10} \approx 0.1$ nsec / sec
Synchronized to GPS time every ≈ 10 sec
at a precision of rms = 2 nsec (design goal 5 nsec)

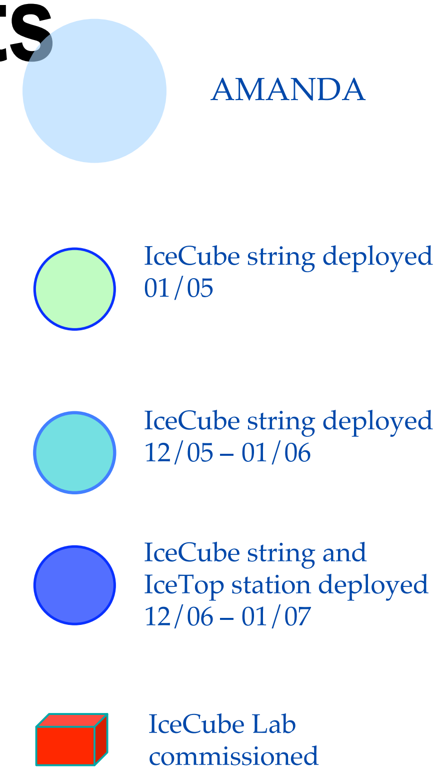
ladison


IceCube
AMANDA
Skiway
road to work
South Pole
Dome (old station)
"Summer camp"
IceCube
Amundsen-Scott South Pole station
http://icecube.wisc.edu

2005, 2006, 2007 Deployments

1+ 9 + 13 =
22 strings
to date





2008: add
14-18 strings
2011: 80 strings

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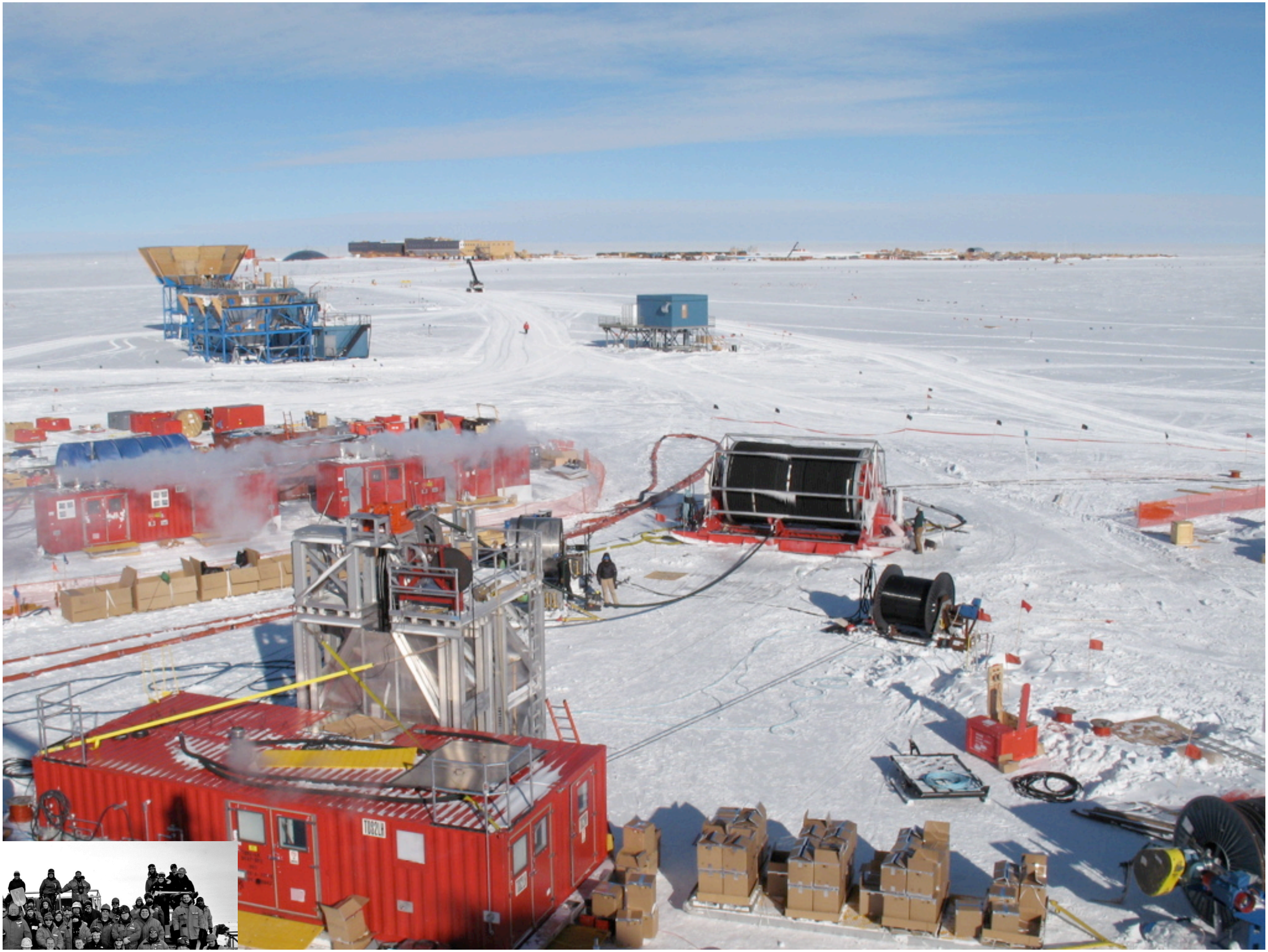
1424 DOMs deployed to date

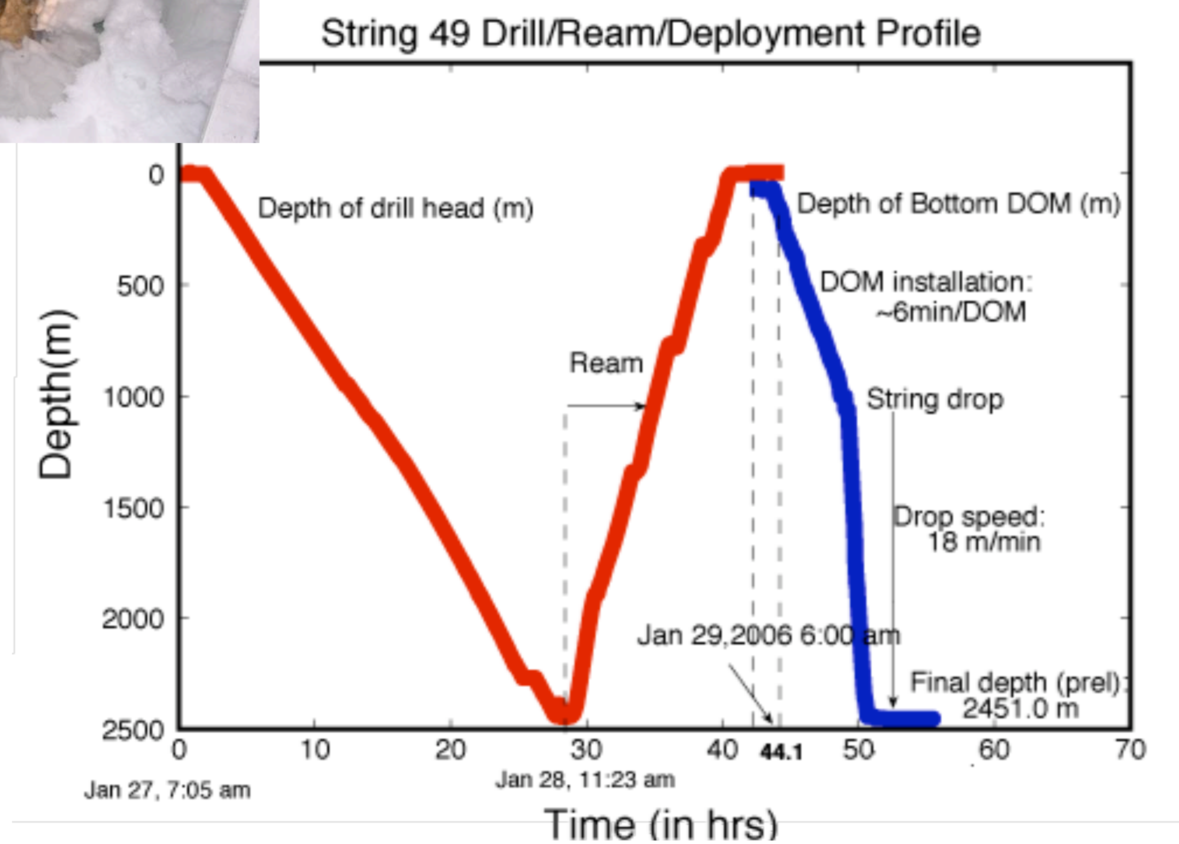
Next year looking for 14 to 18 strings.

Want to achieve steady state of >= 14 strings / season.

Arial view of drill camp



Drilling experience



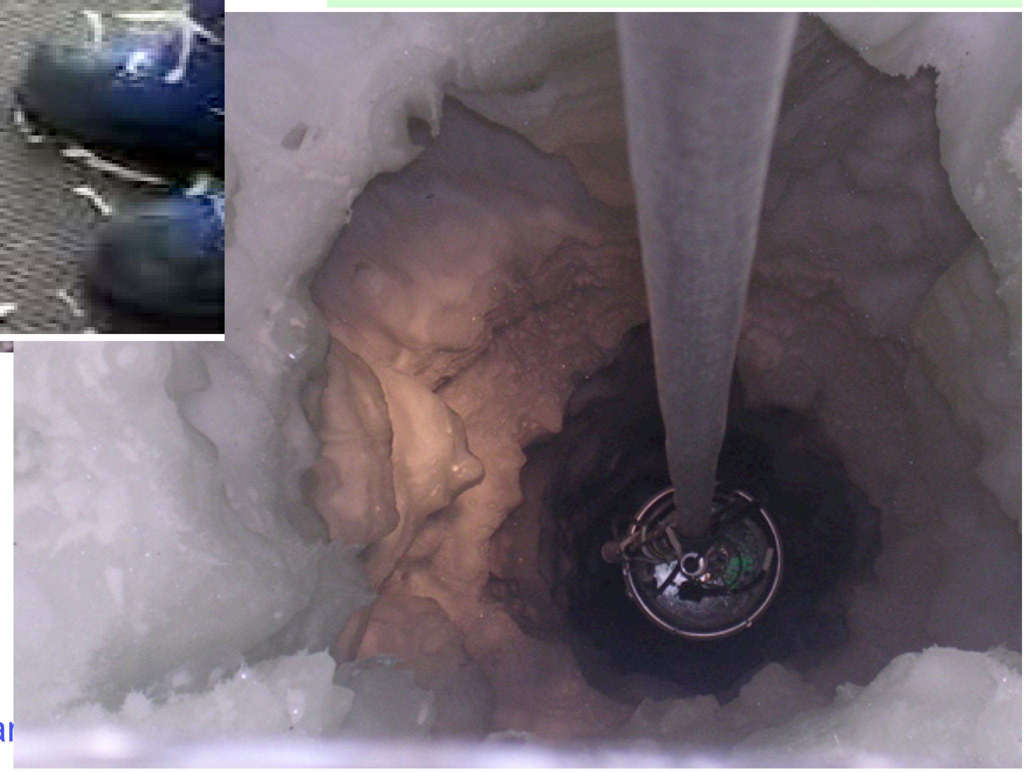
AMANDA drilling (1950m) 90 hrs
deployment: 18 hrs
IceCube drilling (2450m) 40 hrs
deployment: 10 hours
5MW x 30 hrs = 0.56 TJ!

First string installation

DOM being deployed in the ice

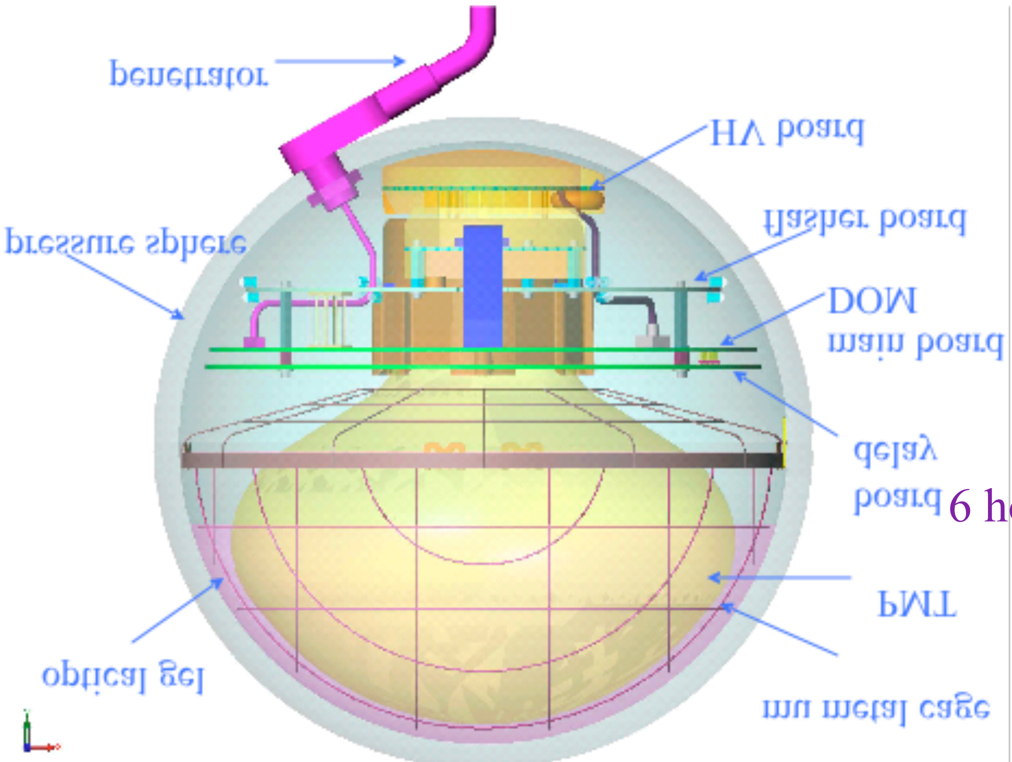
String installation very successful.

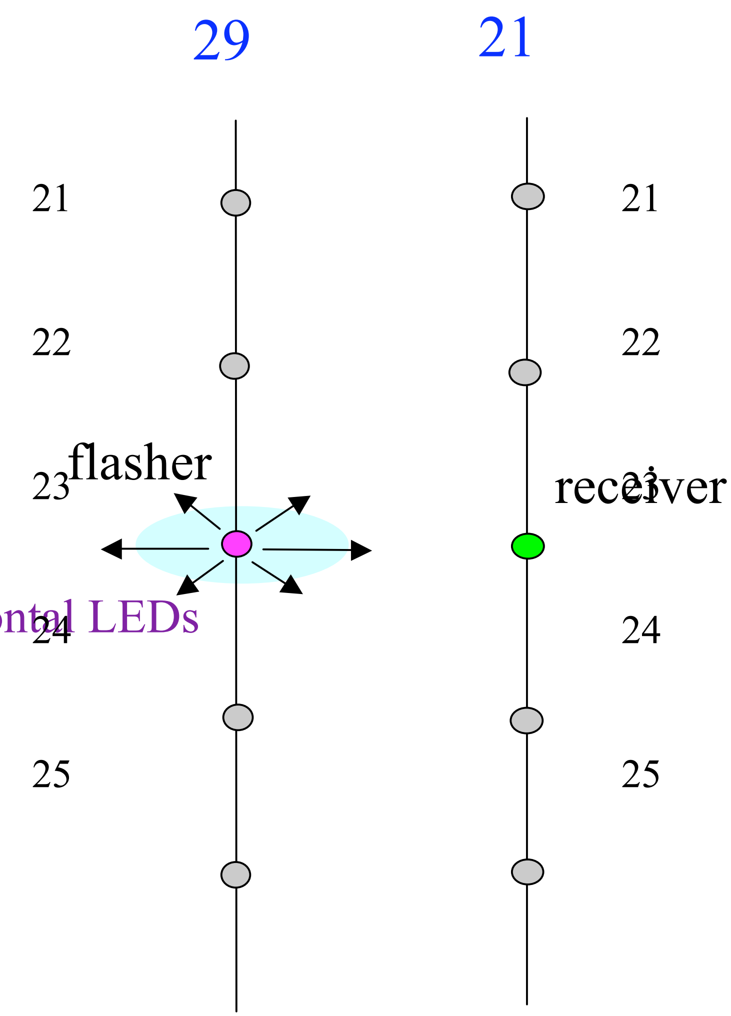
Installation time: ≈16 hours
Time allocated: ≈35h



LED Orientation

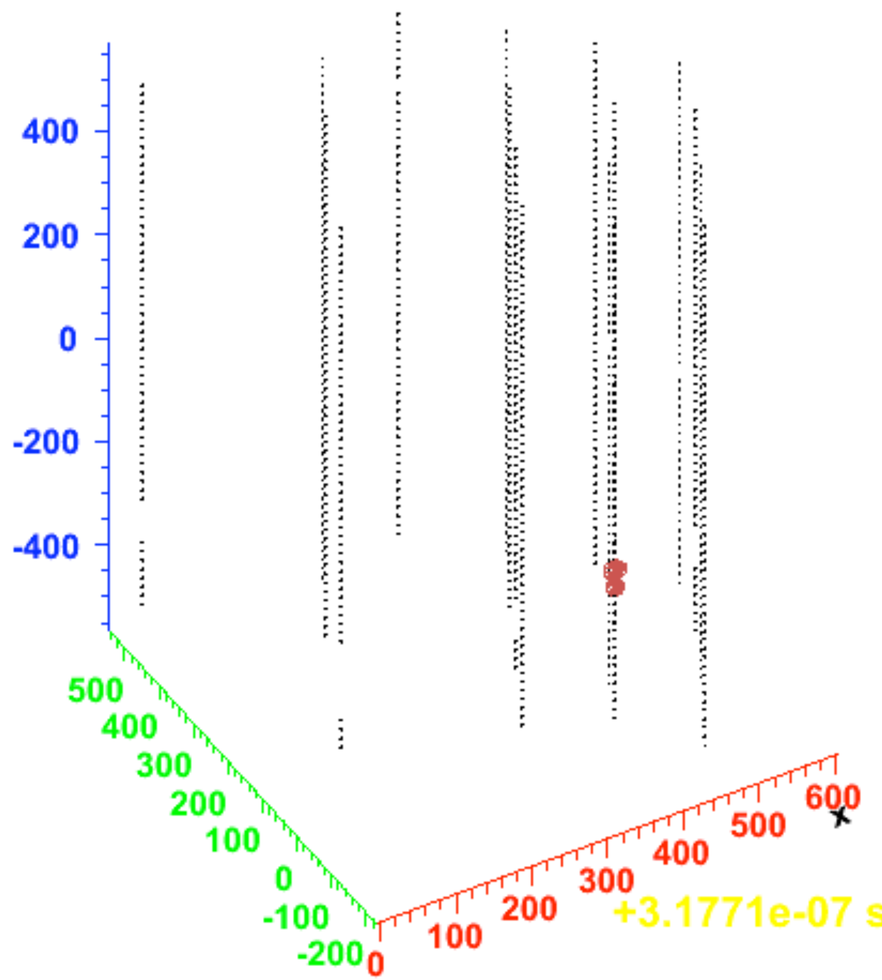
TESTDAQ01 25527 – 25532
(single LED RUNs)





Flasher event taken last month

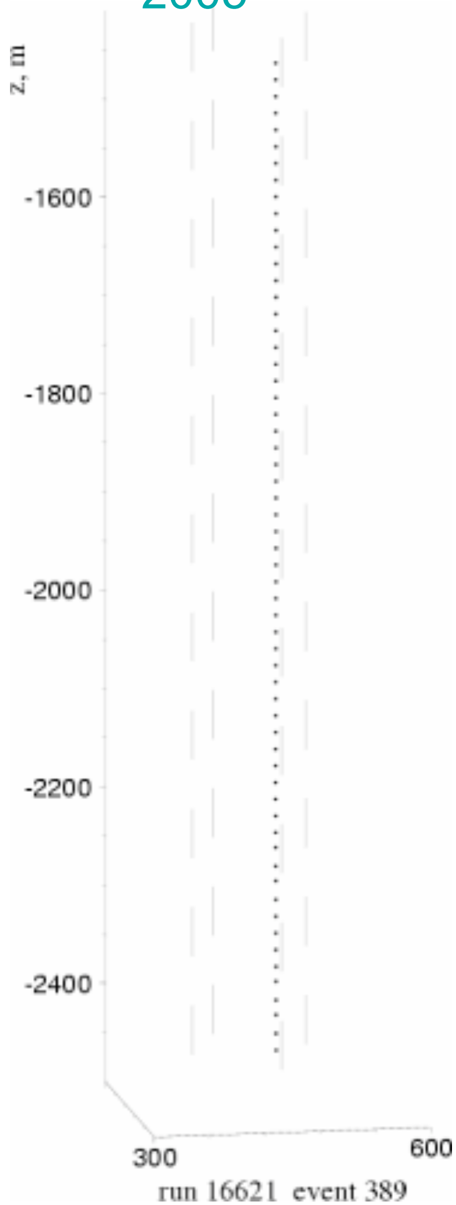
- DOM on string 49 flashing
- 300 DOMs see it (1 at 600 m)

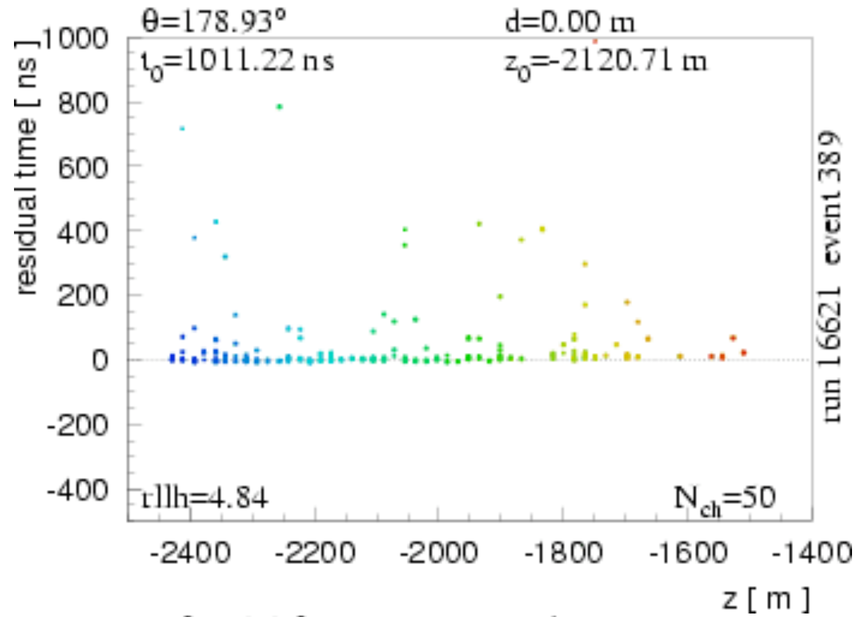


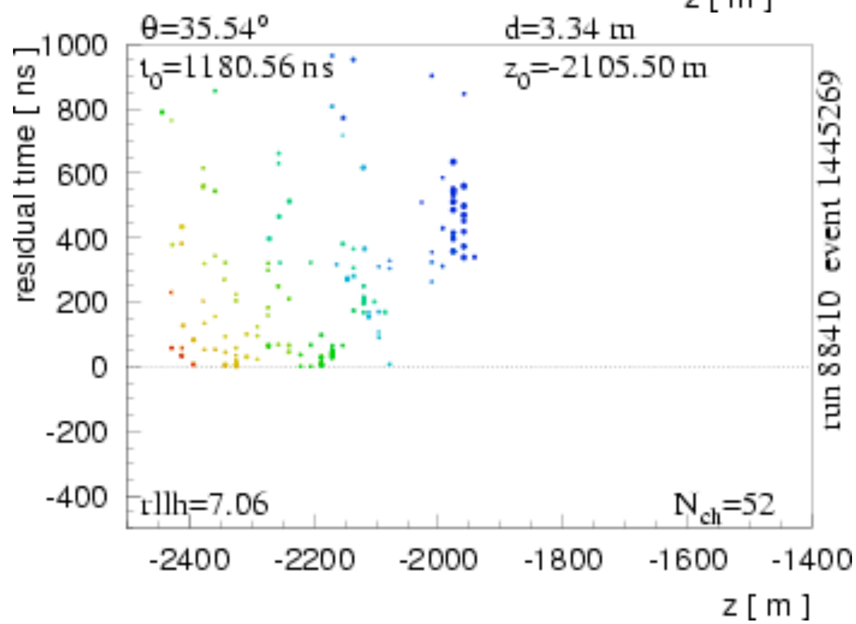
Flashing DOM:
29-15

Upgoing muon events

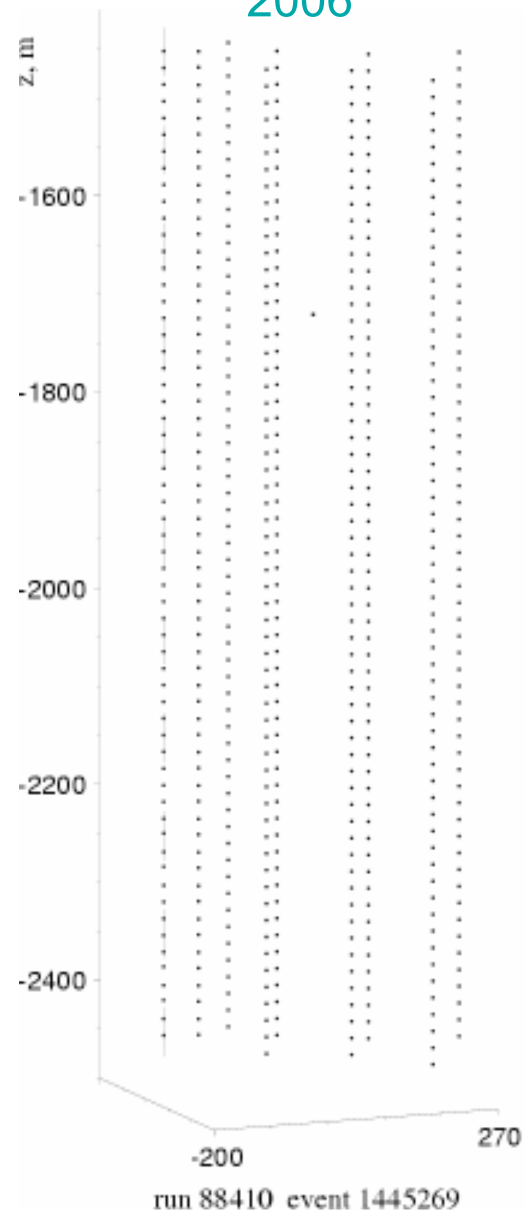
2005







2006



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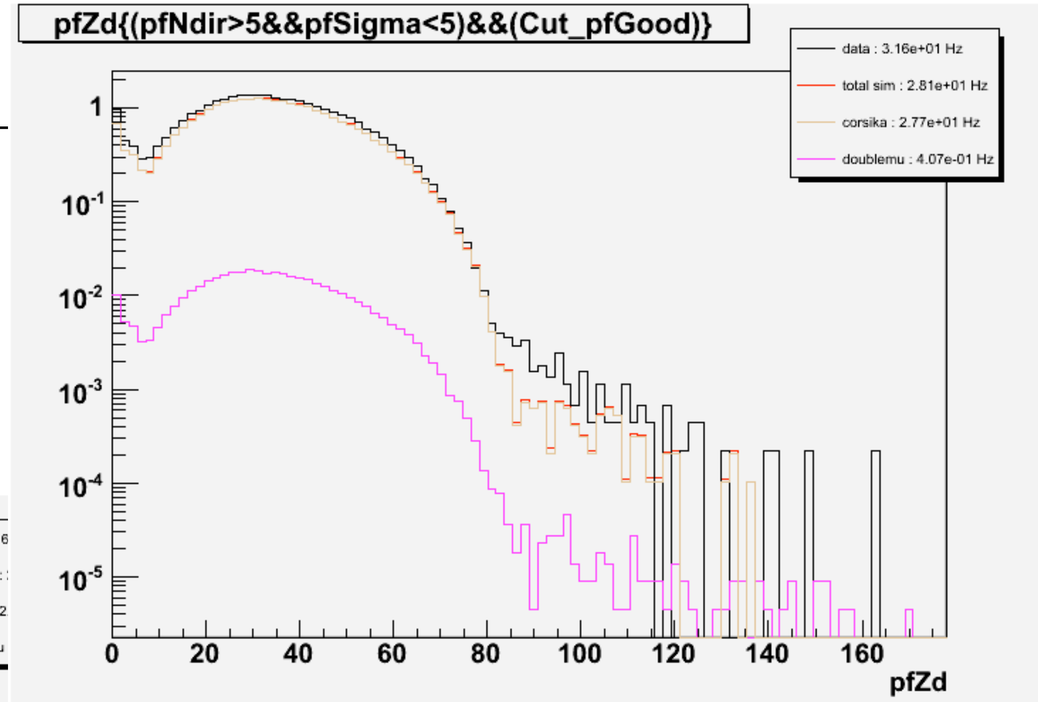
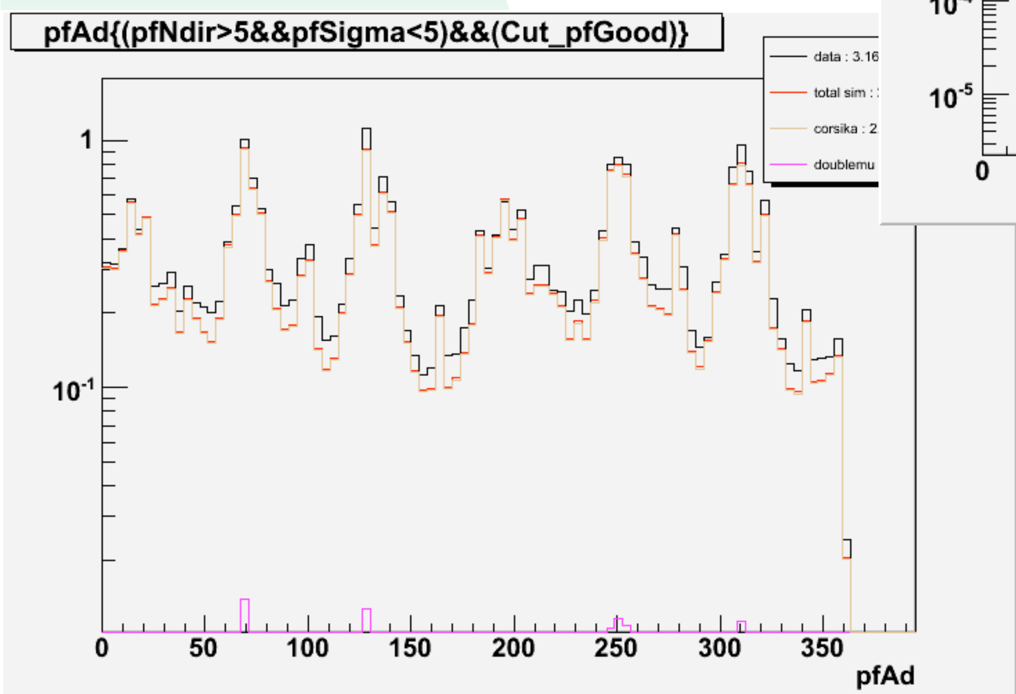
9 string array

Zenith and azimuth distributions

For downgoing muons.

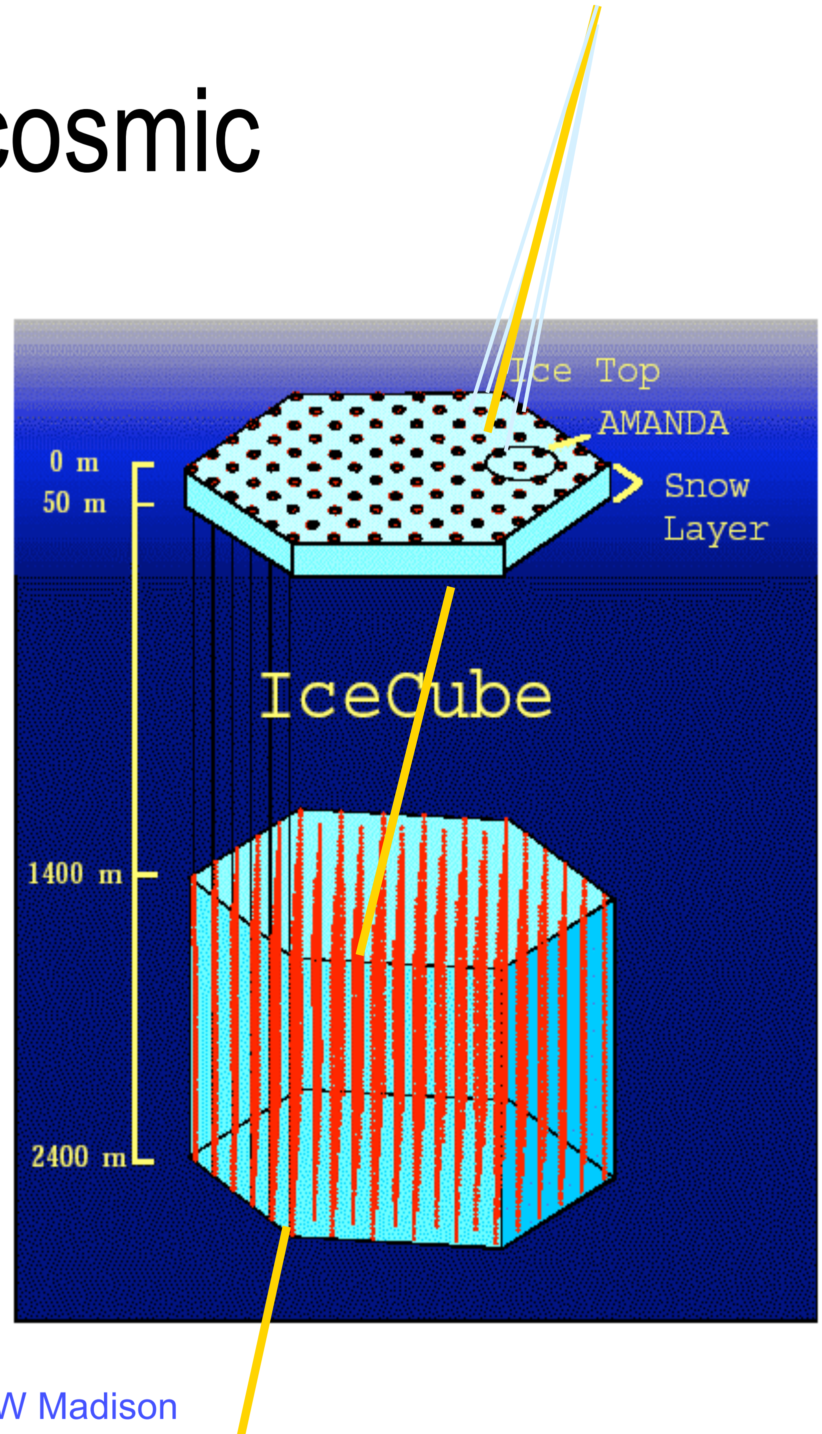
Data are compared to MC.

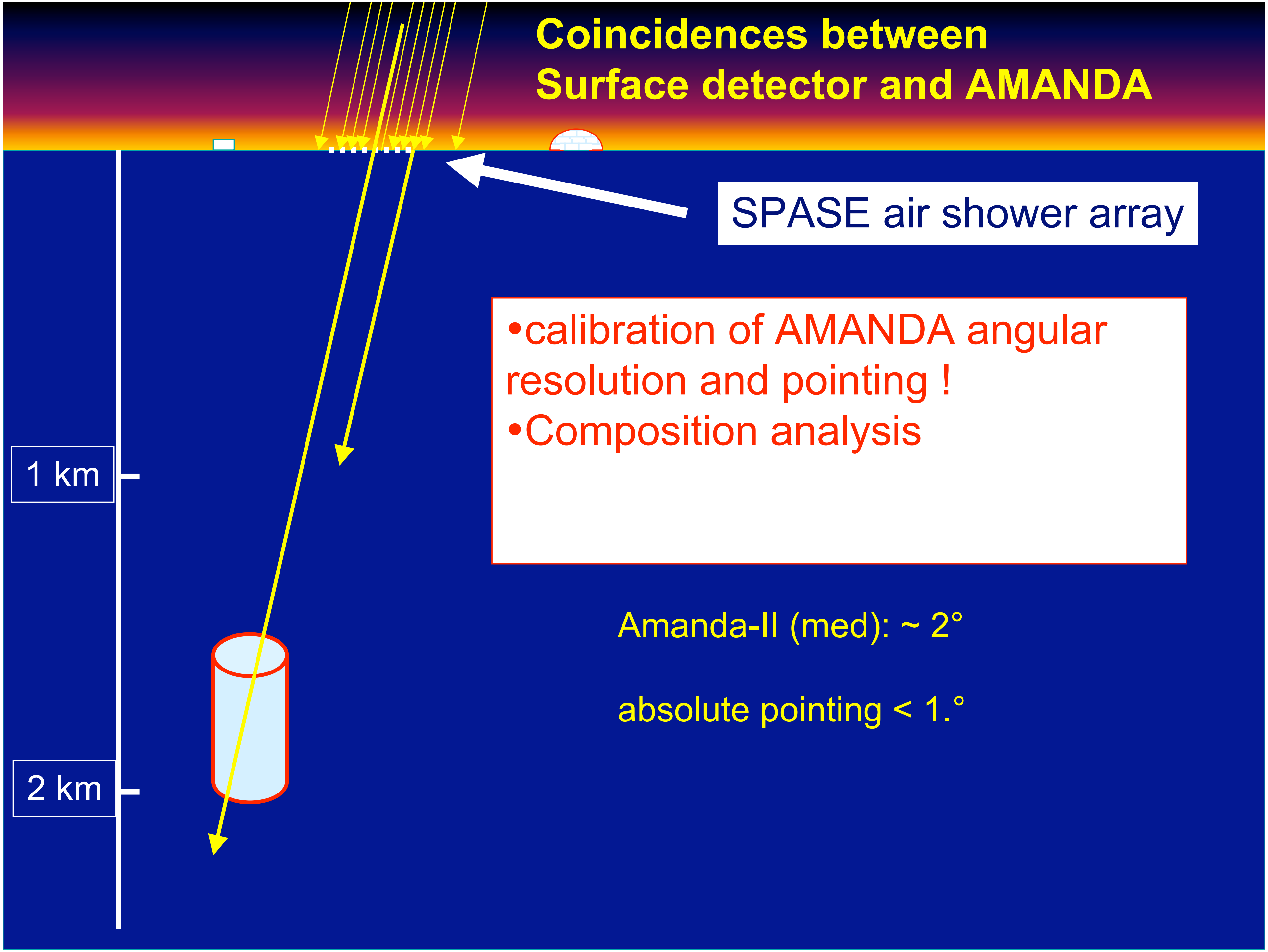




A few comments on cosmic rays

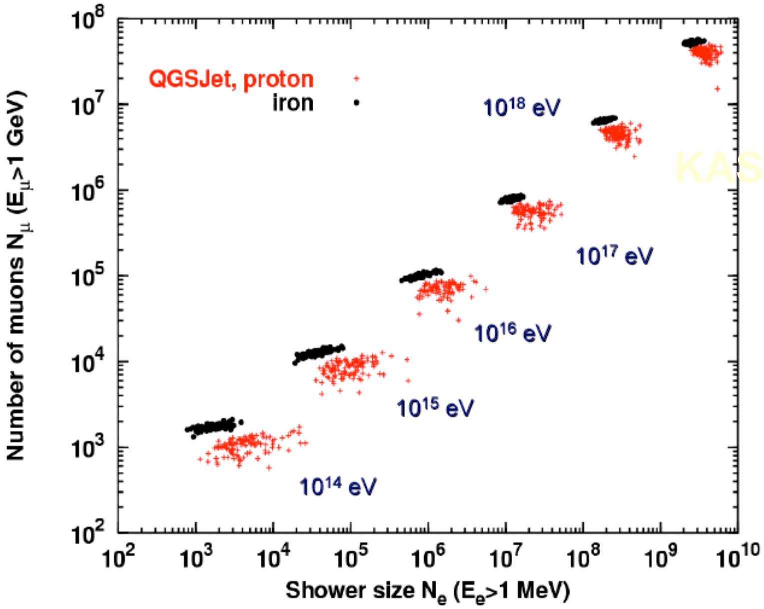
- Cosmic ray airshowers:
- We measure
  - the electromagnetic component at surface
  - the muonic (hadronic origin) component in the deep ice.
- Goal:
  - measure total energy accurately
  - Measure mass composition





Coincidences between
Surface detector and AMANDA
SPASE air shower array
•calibration of AMANDA angular resolution and pointing !
•Composition analysis
Amanda-II (med): ~ 2°
absolute pointing < 1.°
1 km
2 km

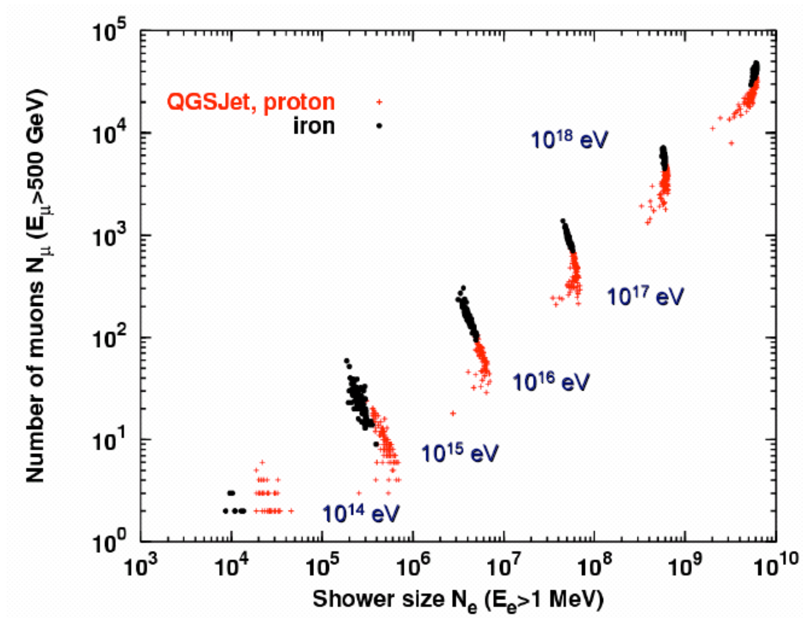
Muon / electron ratio reflects nuclear composition of primaries



Calculations of Ralph Engel, presented at Aspen, April, 2005

KASCADE-Grande

- Sea level
- Low-energy muons

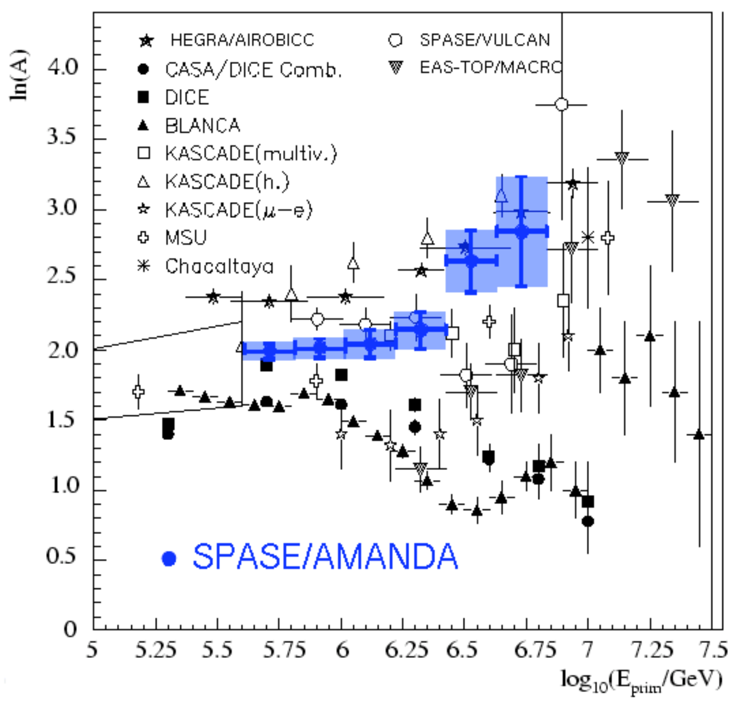


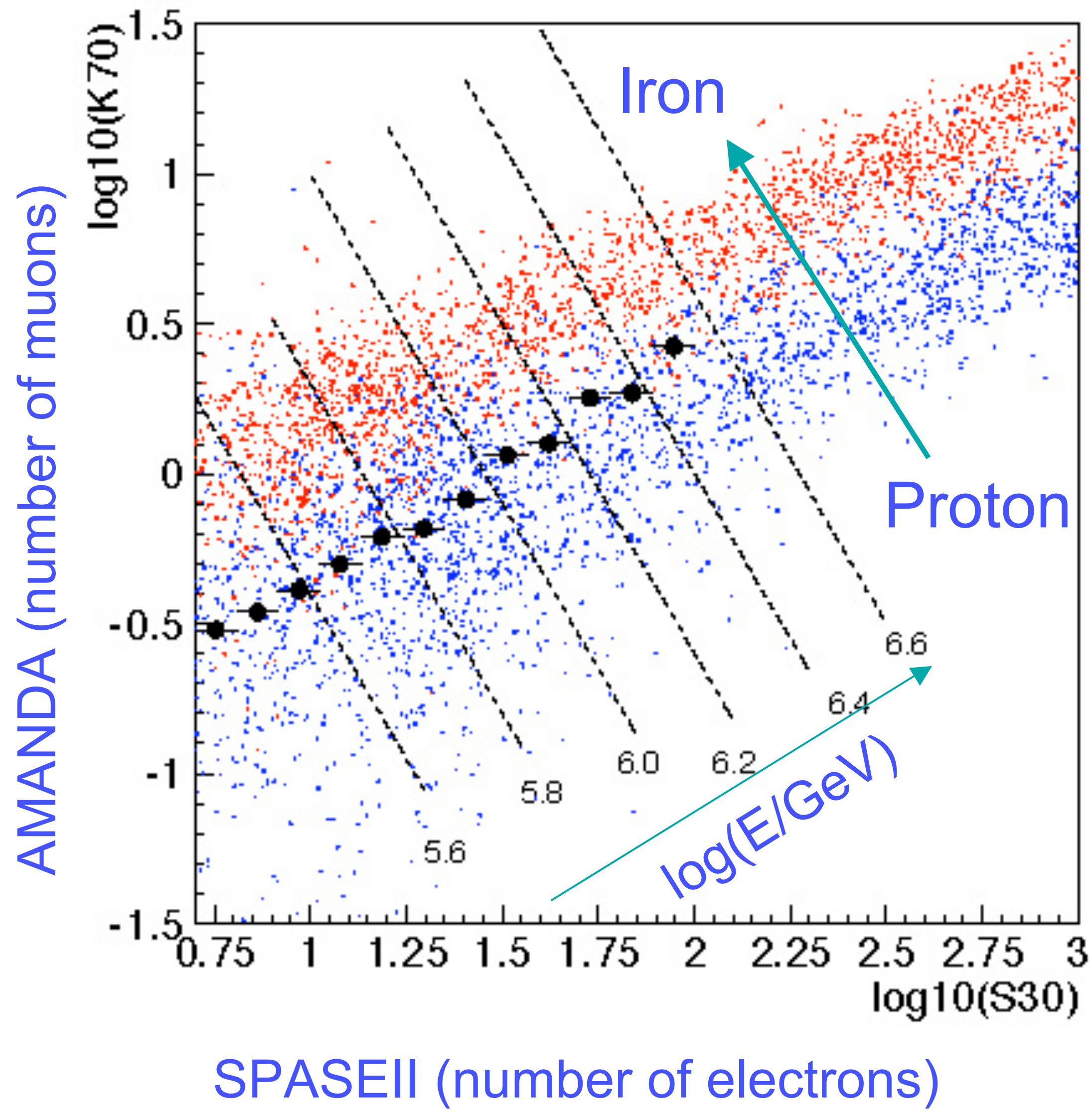
IceCube

- Mountain altitude
- High-energy muons
- Single model

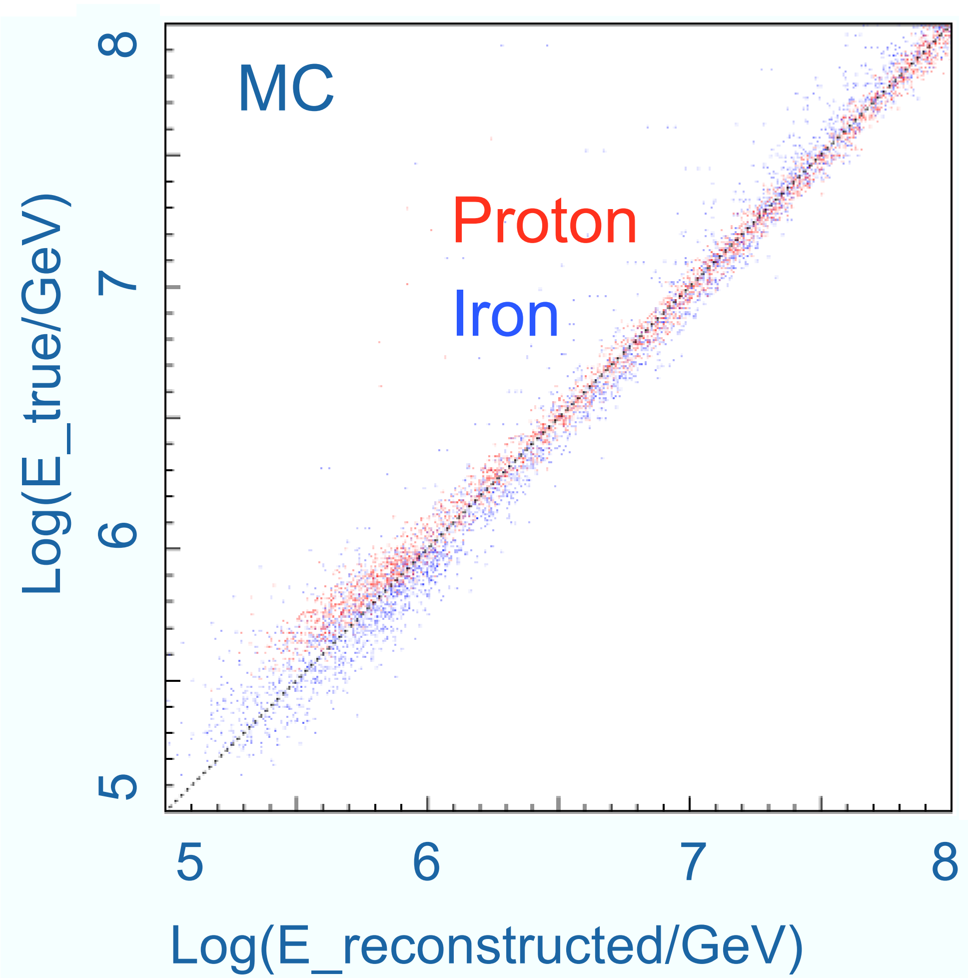
Measuring mass and energy

Results from
SPASE-II and AMANDA





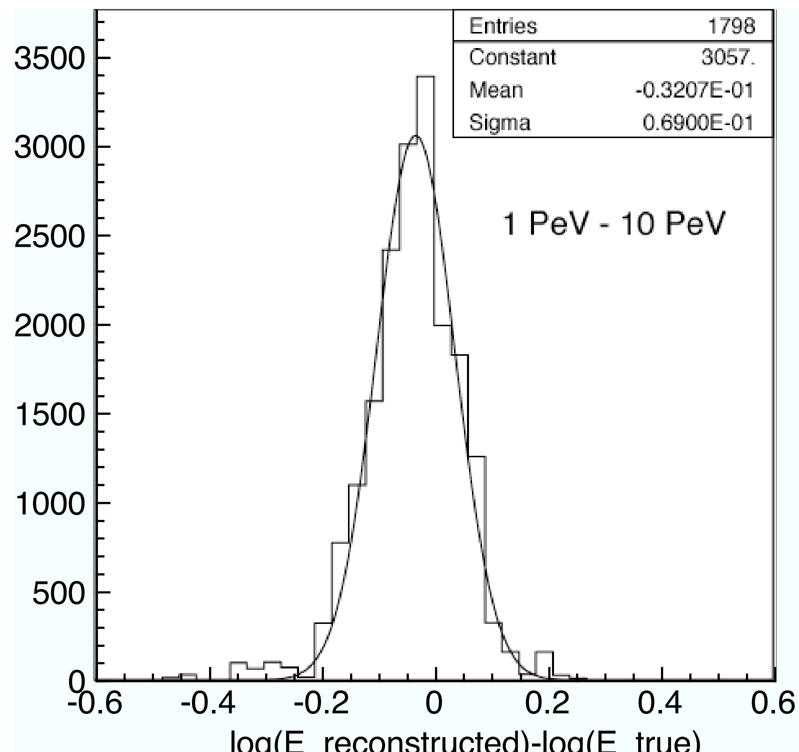
SPASE - AMANDA: Energy resolution of air shower primary

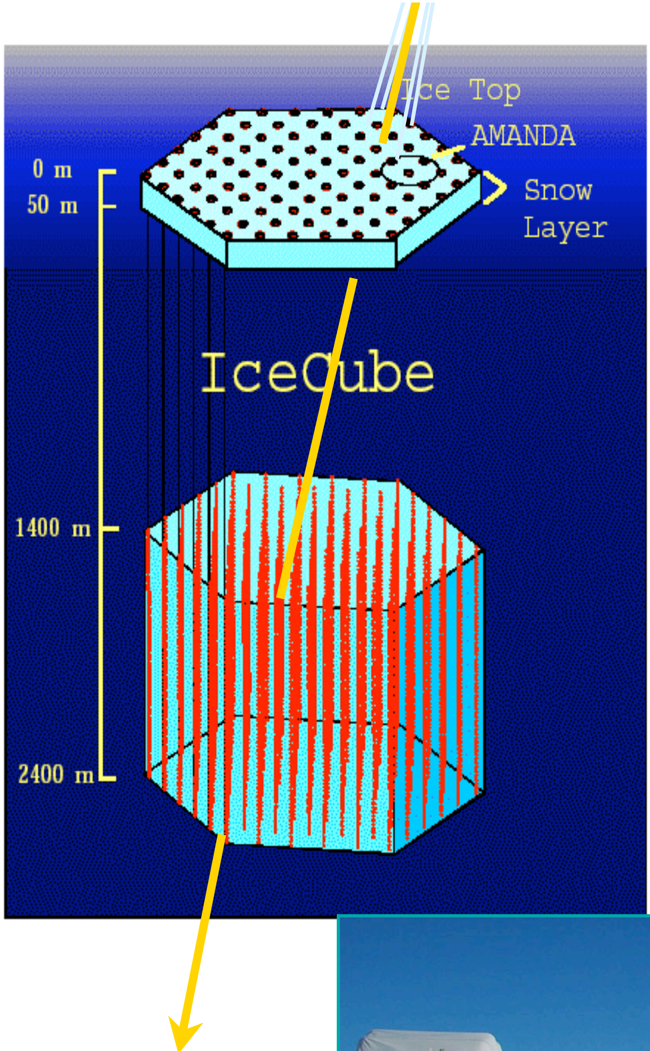


Energy resolution of air shower primary for 1<E/PeV<10:

$\sigma_E \approx 7\% \log(E)$

(Mass independent; based on MC)



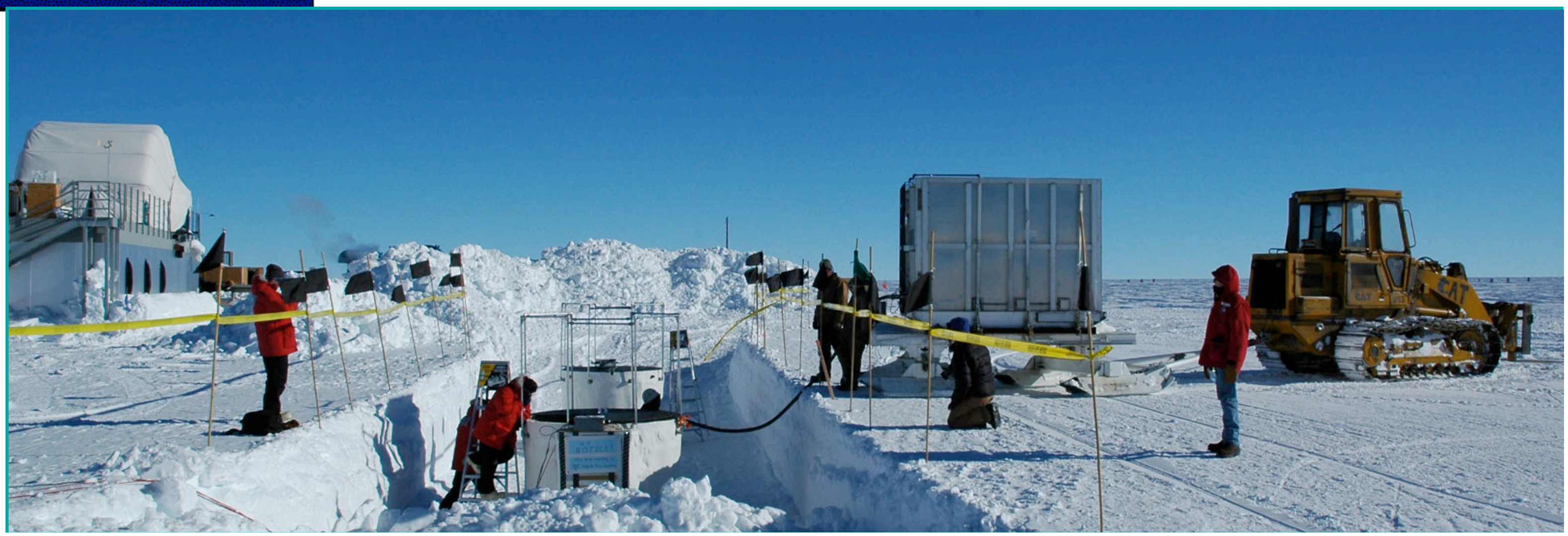


IceCube with IceTop surface array

Area--solid-angle ~ 1/3 $km^2 sr$

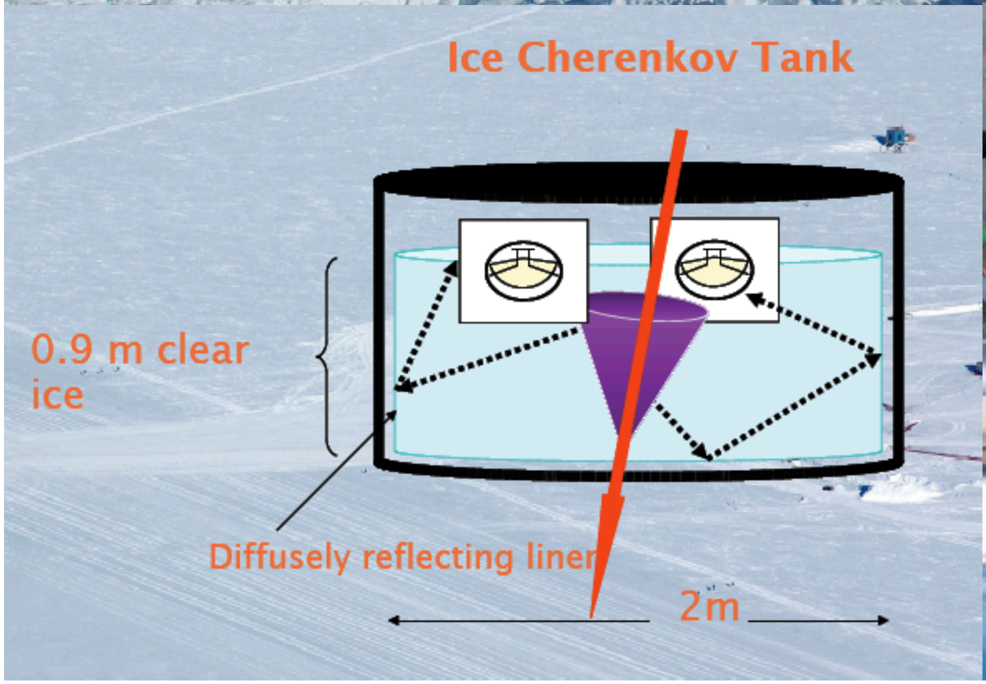
(including angular dependence of EAS trigger)

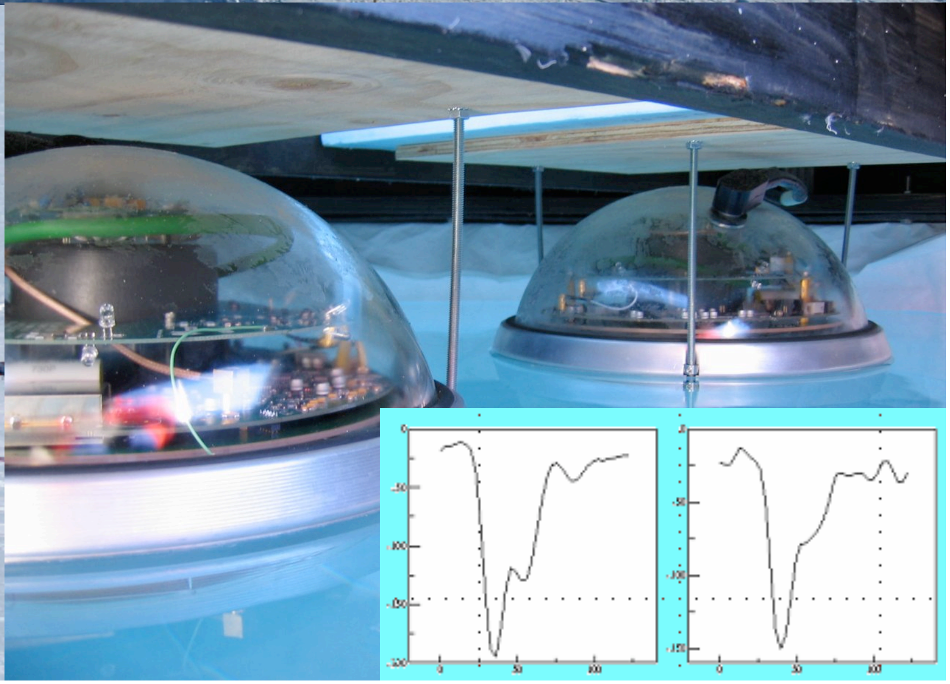
- Calibration
- Veto of HE shower background
- Cosmic Ray/air shower physics up to 10^{18} eV



IceTop tank

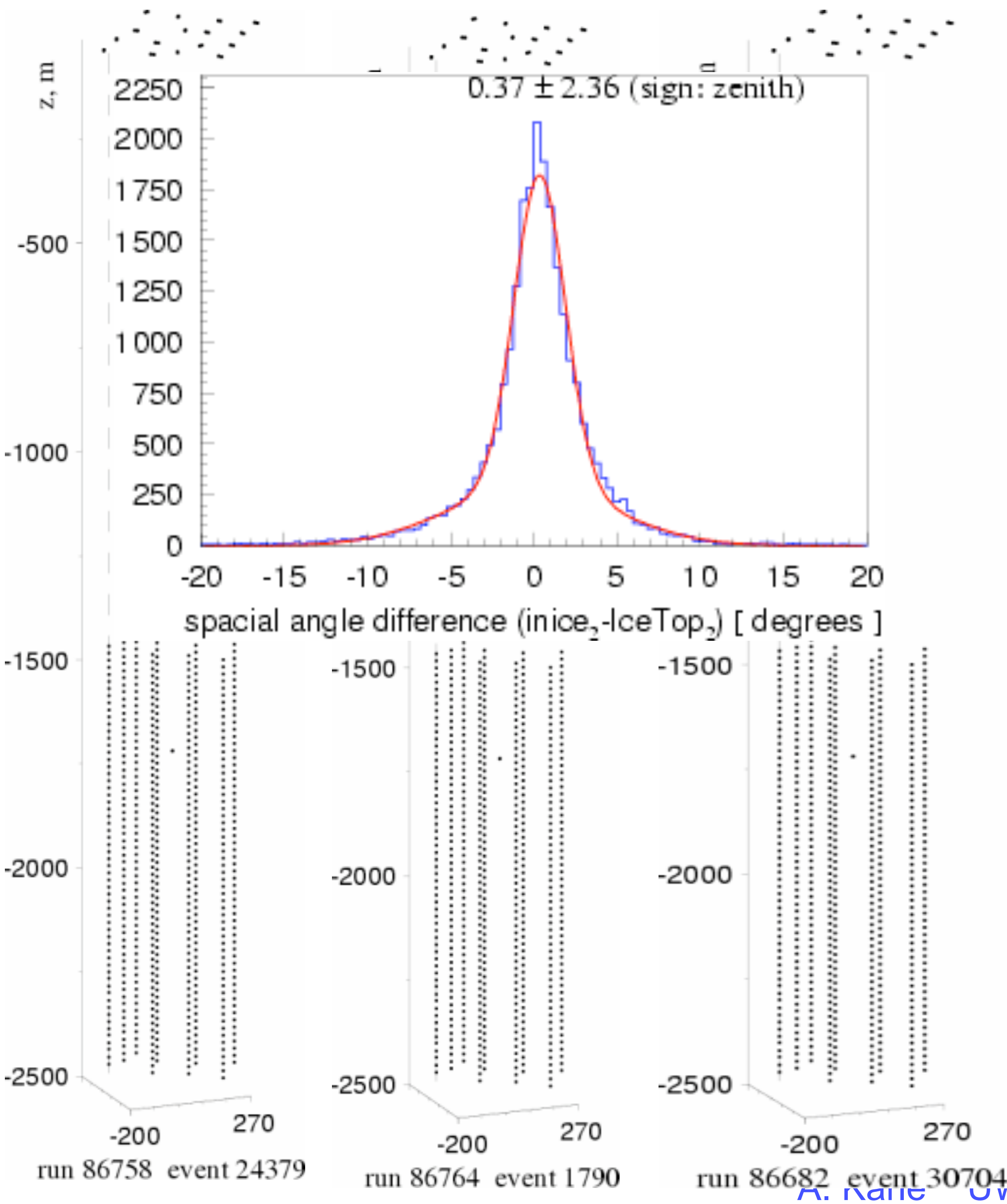
26 stations are built to date

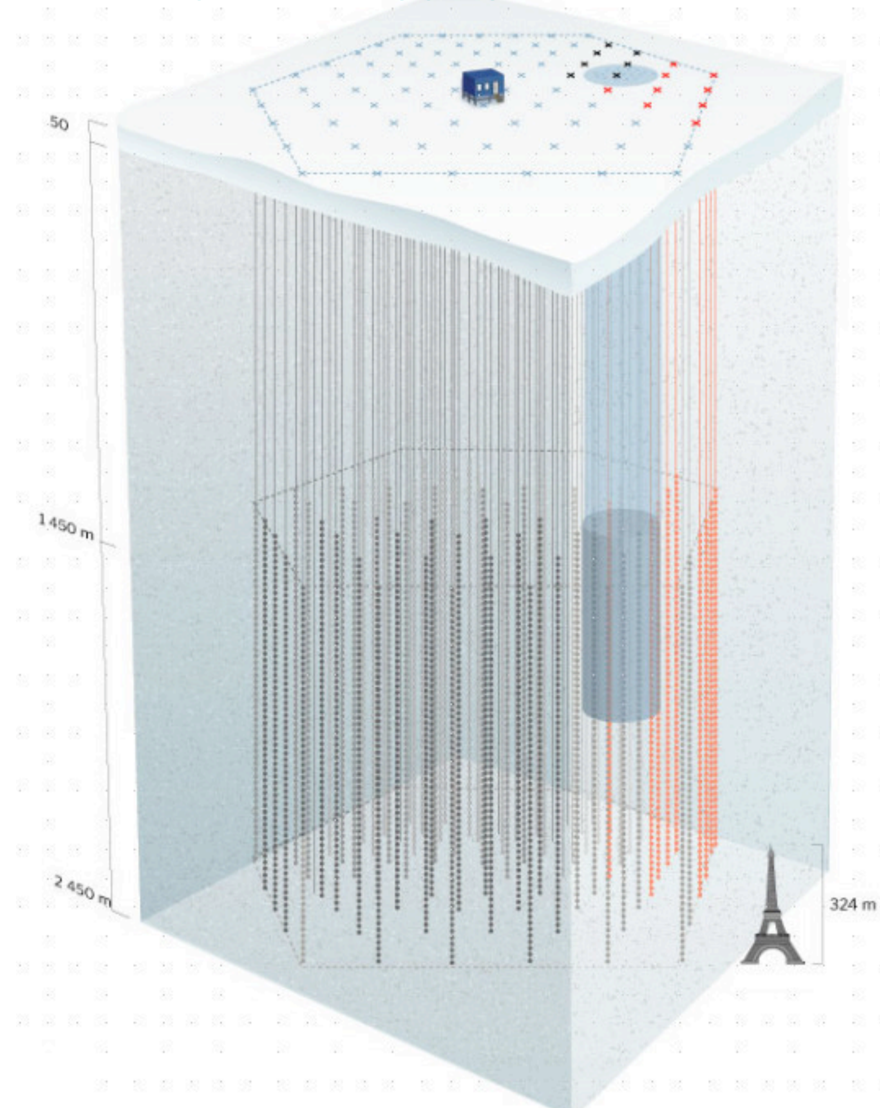




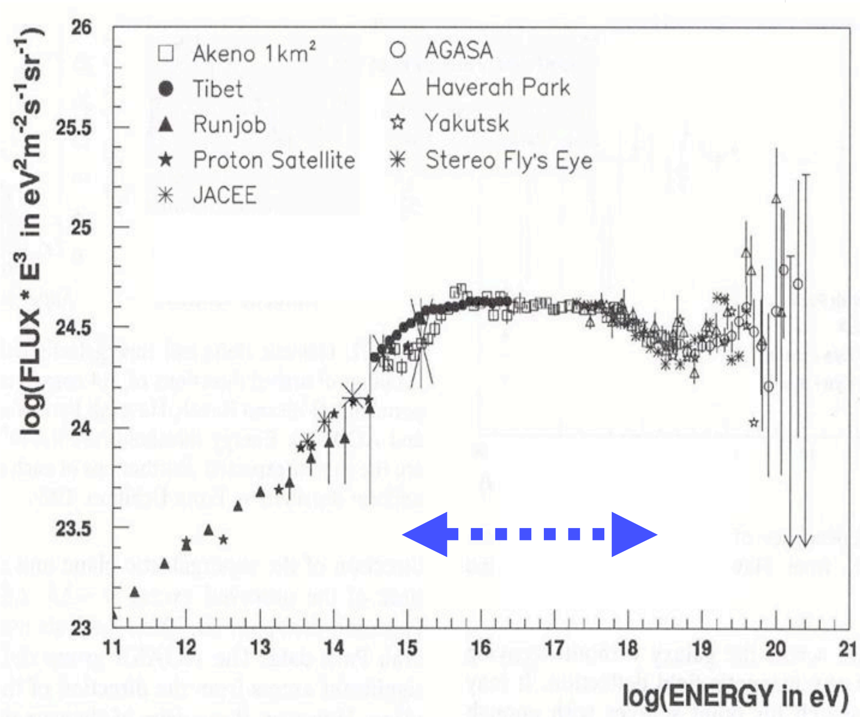
IceTop/in-ice coincident events

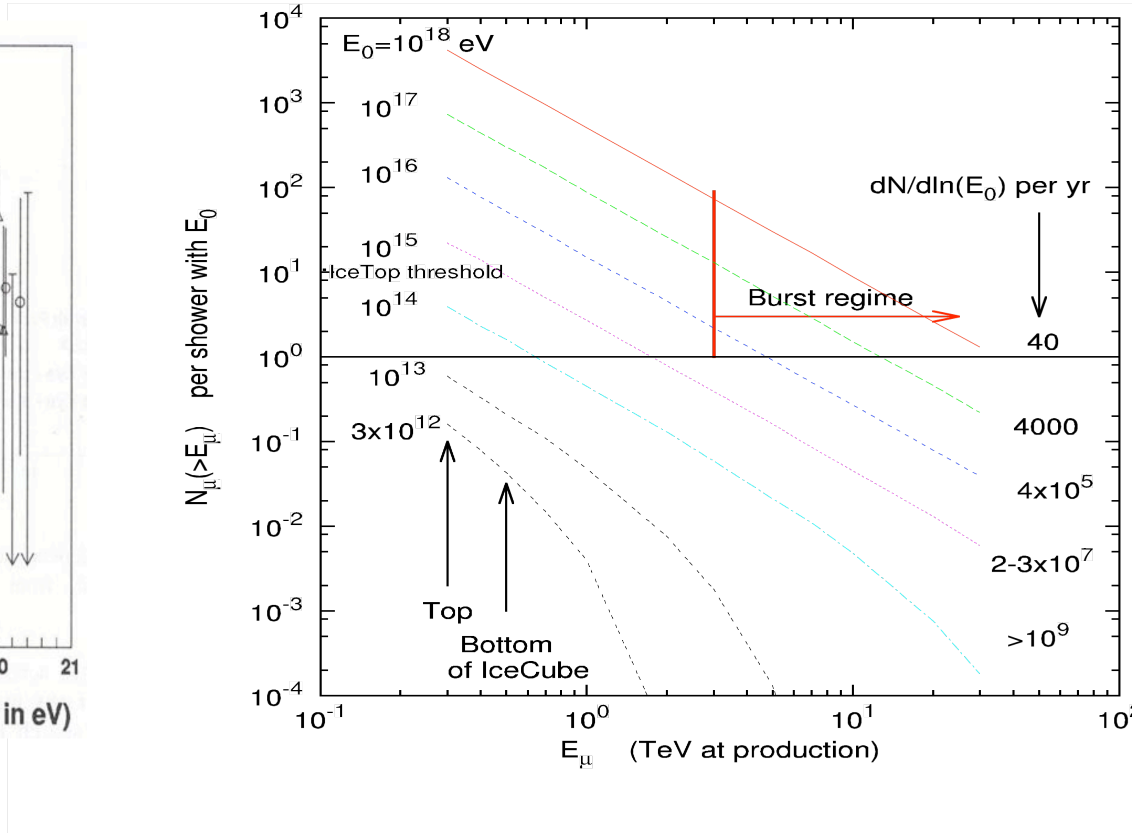
For cosmic-ray physics, calibration & background tagging for IceCube





Reach of IceCube for cosmic rays





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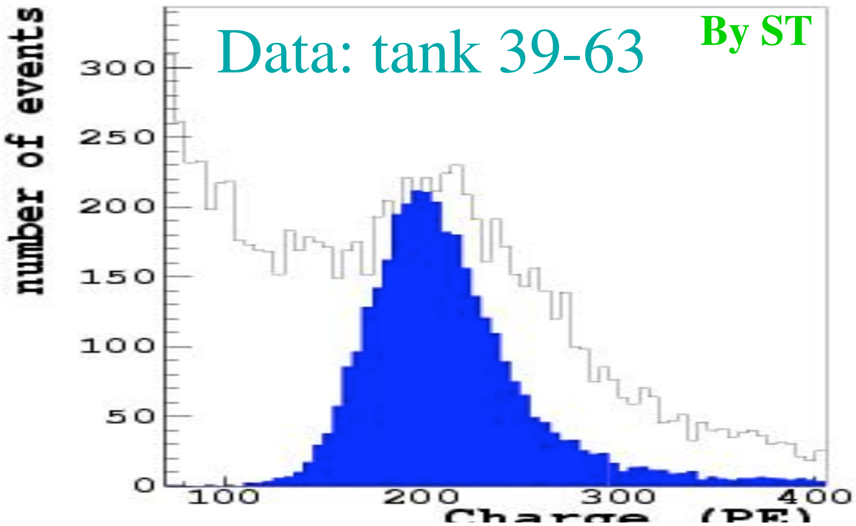
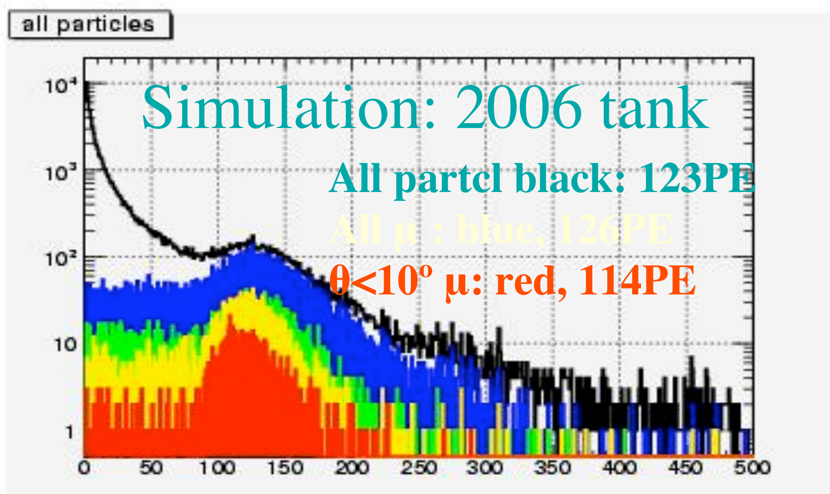
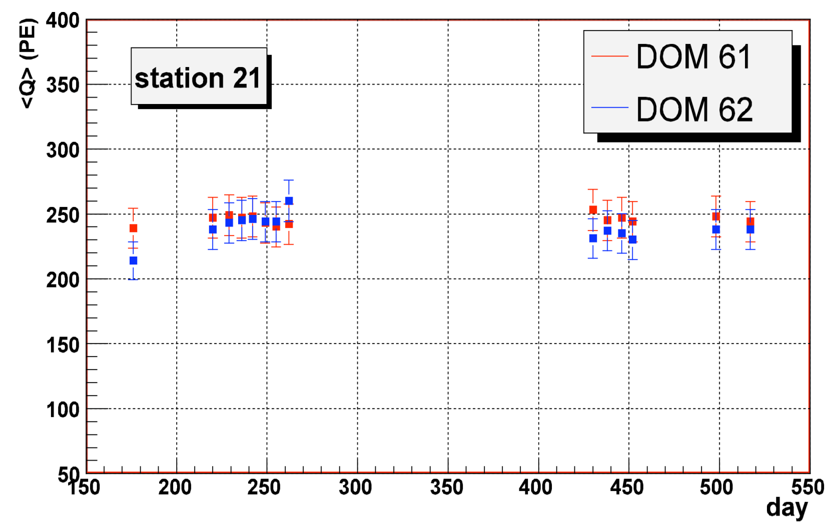
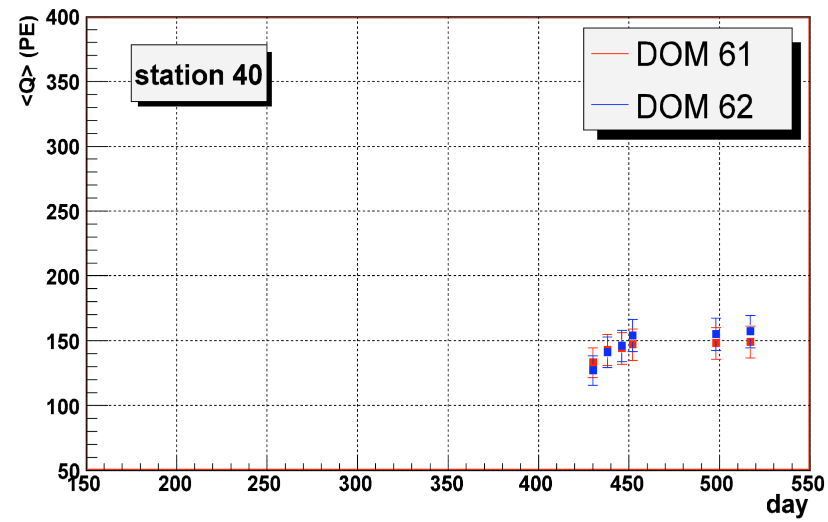
Calibration and monitoring

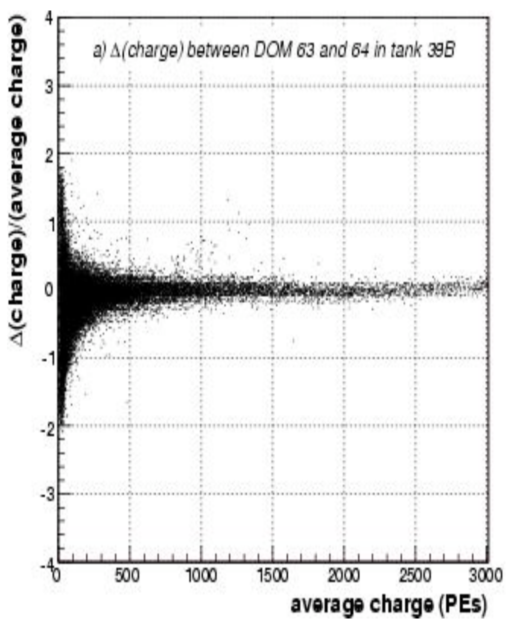


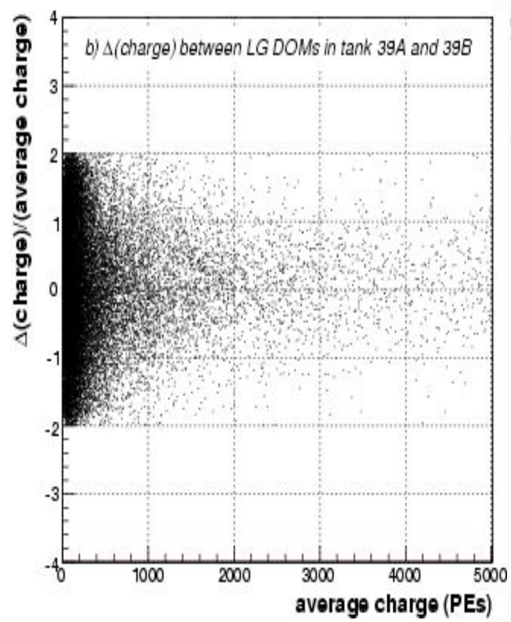


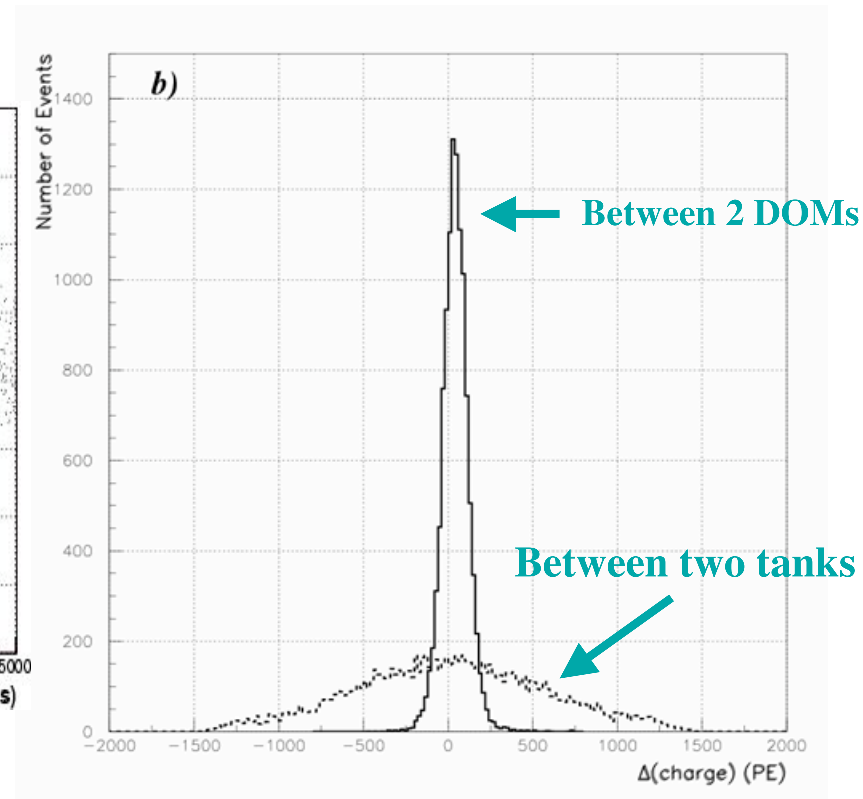




Fluctuations: situation good





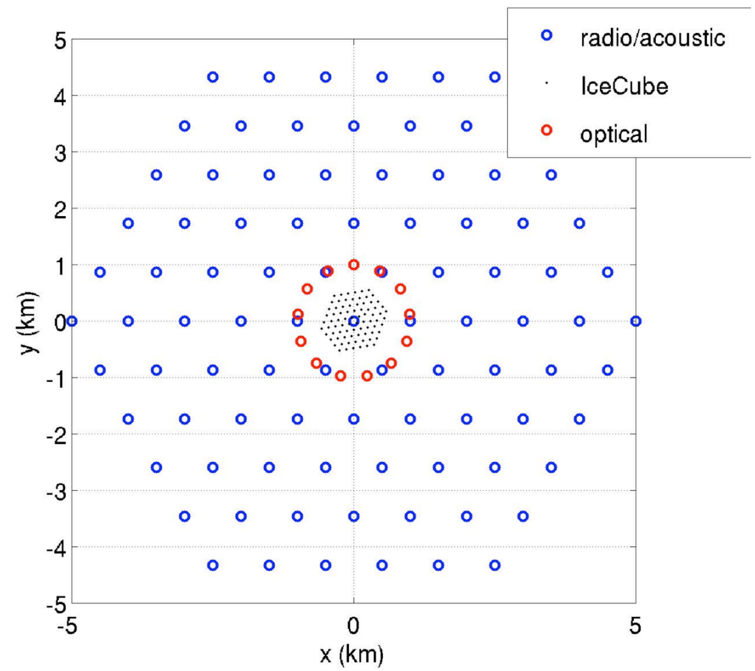


1. Fluctuations in response of a tank to energy deposition is smaller than intrinsic fluctuations in the shower front

2. Using two nearby tanks, we can measure time & density fluctuations and assign the weights in maximum-likelihood fittings for EAS reconstruction.

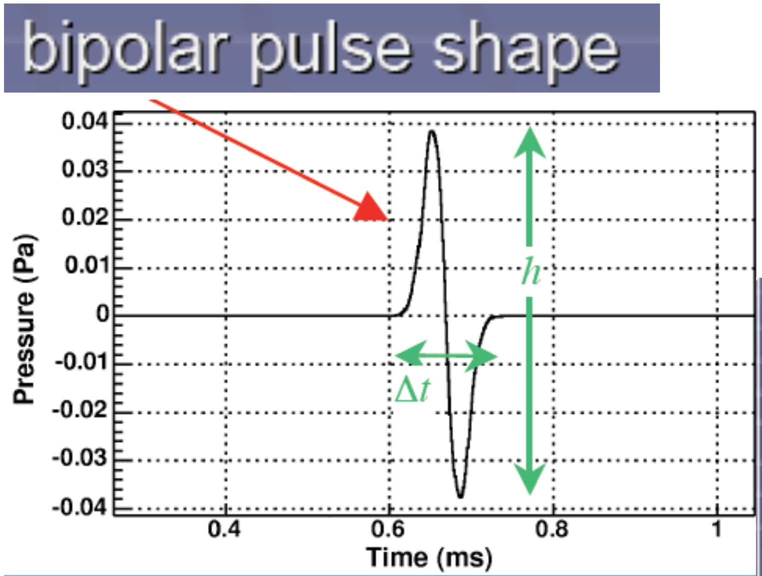
R&D for New Technolgies

- Efforts are underway to develop high energy extensions of IceCube
  - Ice Cherenkov radio detection with goal of future GZK neutrino detection (Rice heritage, but new technology)
  - Acoustic sensor development with goal of future GZK neutrino detection
  - Surface radio detector studies with goal of cosmic ray air shower detection at high energies, extension of IceTop for full zenith coverage.

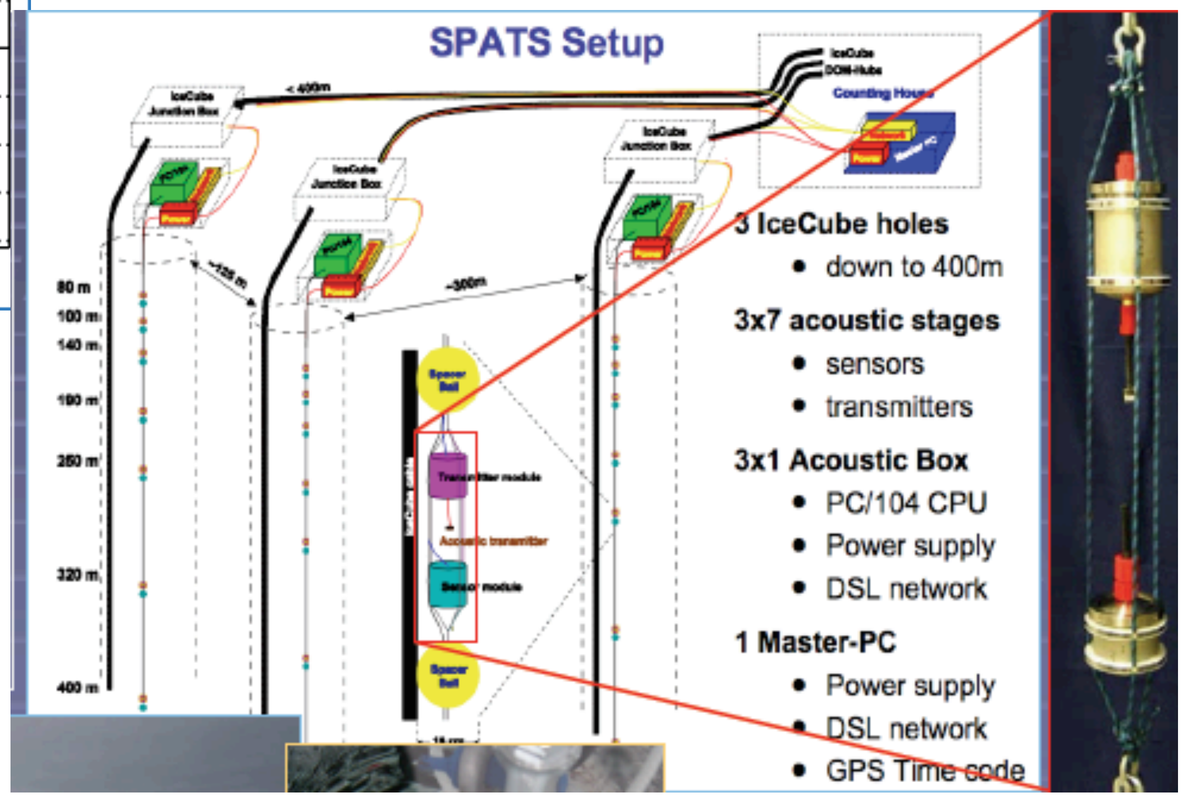


Acoustic R&D

- Fast thermal energy deposition by showers results in a sound pulse
- Signal propagates as a “pancake” perpendicular to the shower axis



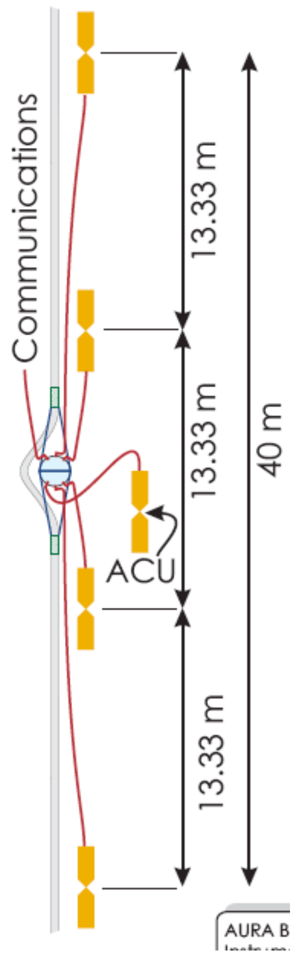
Initial goal:
Measure noise and transmission Properties.



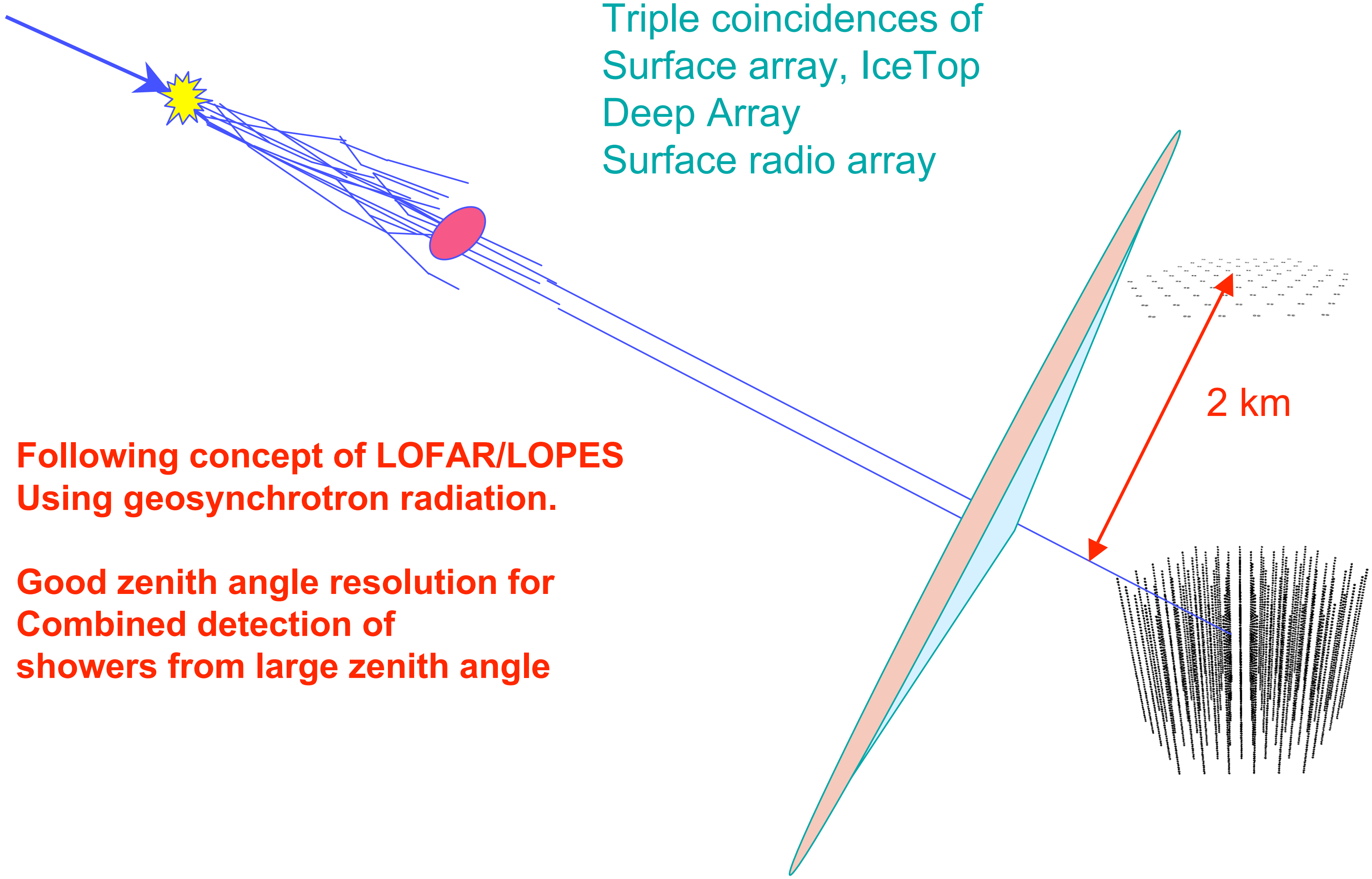
3 test strings deployed this season

Radio ice Cherenkov detectors

Three antenna clusters deployed for R&D.



Starting to think about: Radio/particle shower detection



Following concept of LOFAR/LOPES
Using geosynchrotron radiation.

Good zenith angle resolution for
Combined detection of
showers from large zenith angle

A. Karle UW Madison

Another milestone

ladison

January 21, 2007

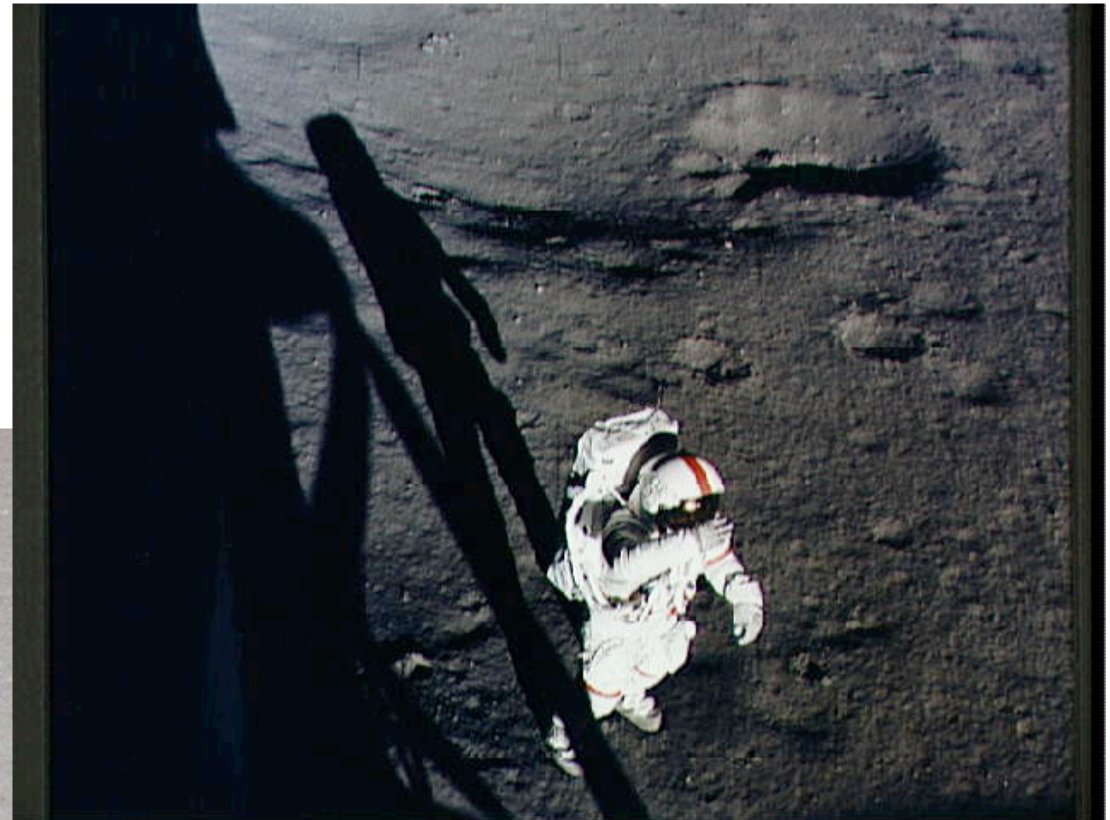
IceCube Golf outing:

Tee-off at South Pole for the 18th hole of IceCube.

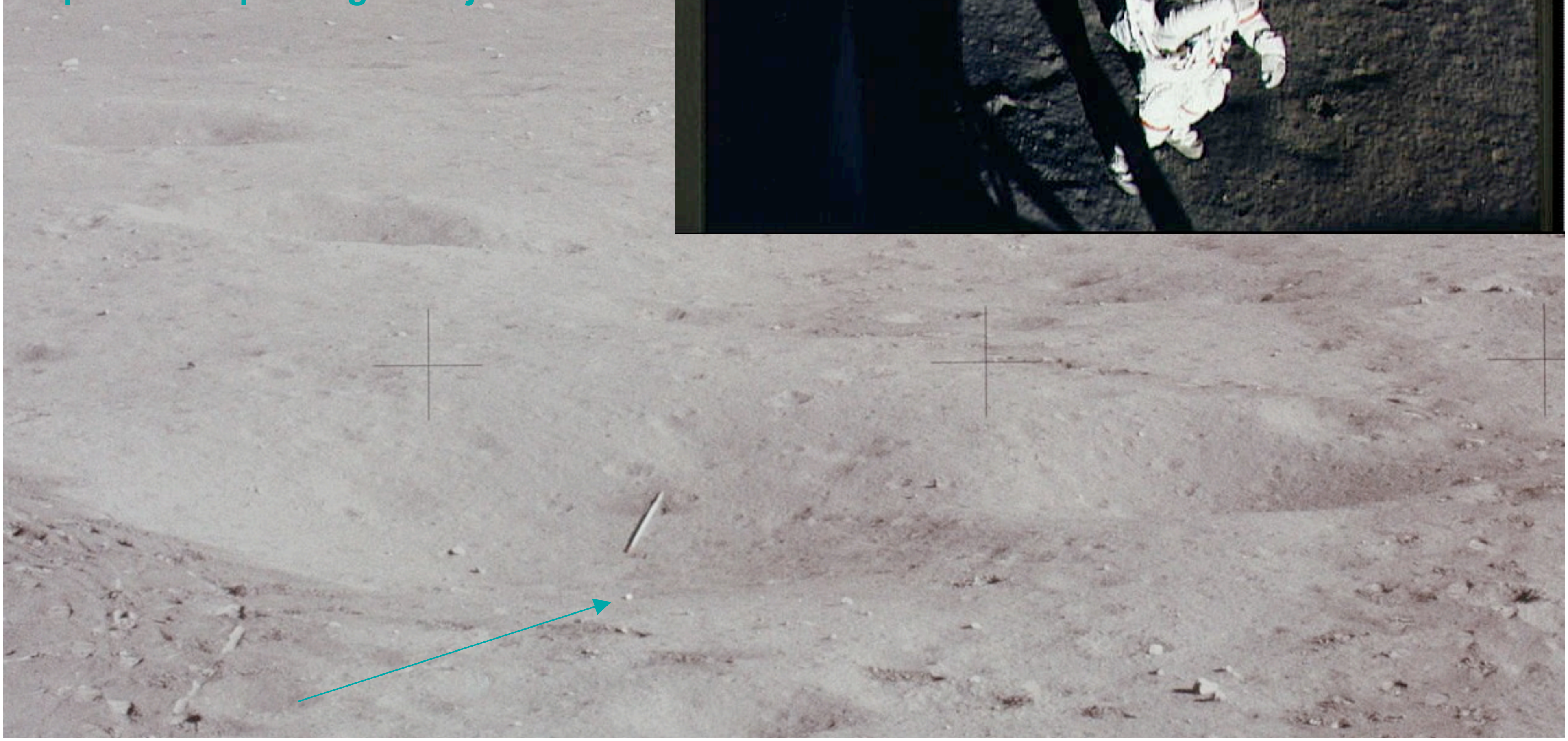
PAR ~10, 1000 yards

Al Shepard, 36 years ago, February 1971

Al Shepard plays golf on the moon.



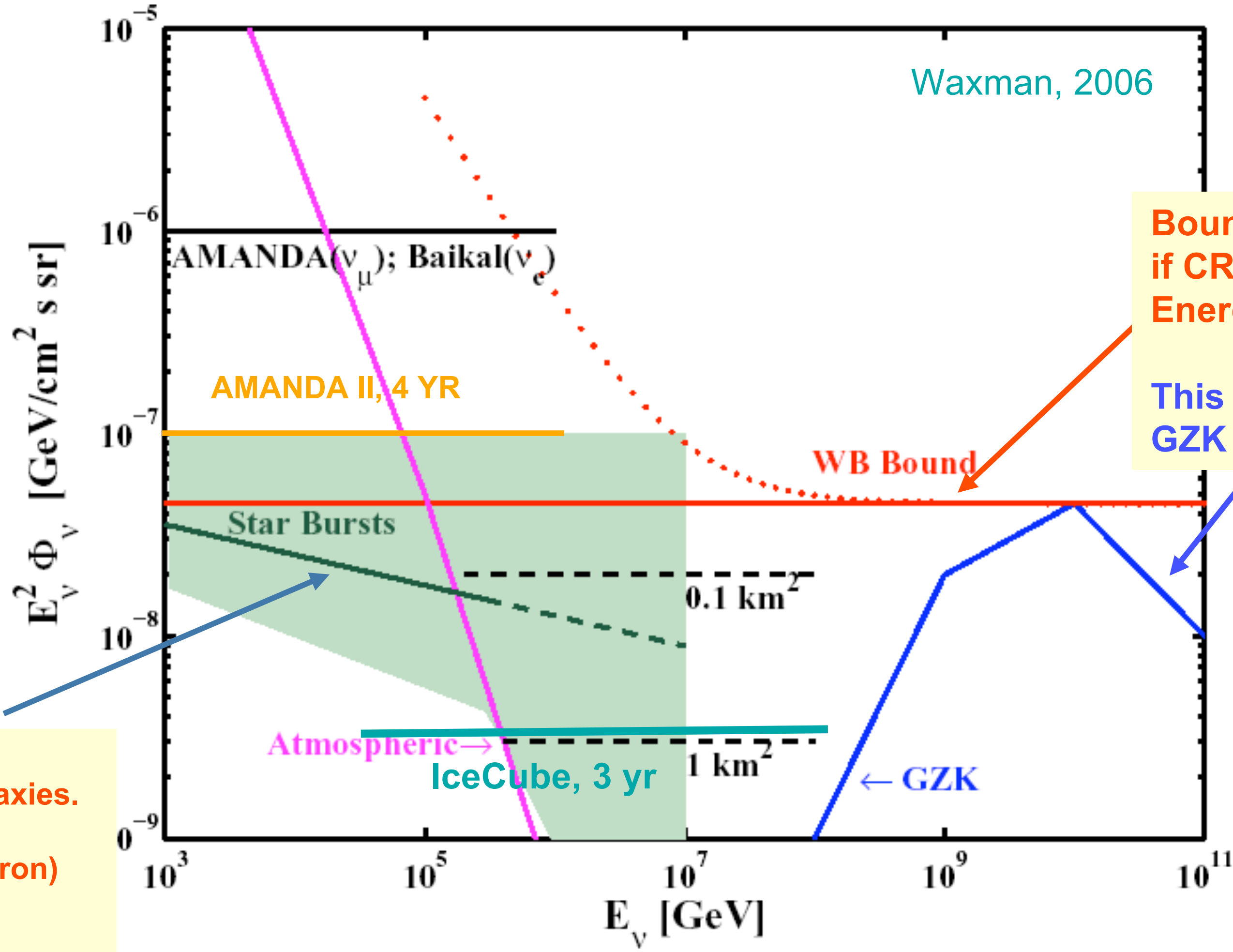
Video clip of this shot at:
http://www.hq.nasa.gov/alsj/frame.html



Conclusions & Outlook

- IceCube will explore the high-energy ν-sky.
  - With a km^2 effective area, IceCube has the potential to observe extra-terrestrial neutrinos.
- We deployed 13 more strings, to a total of 22.
  - More than 99% of the optical sensors survived the extreme conditions of freeze-in and are working well.
  - Timing resolution is < 2 nsec
  - Data are consistent with requirements and with expectations.
- 26 IceTop Cherenkov stations (32 tanks) form sizeable air shower array.
- Taking data with a detector already much larger than AMANDA-II.
- 2007 marks the begin of IceCube science operation.
- Expect to make contributions to Cosmic Ray spectrum measurements from PeV to EeV energies.
- By 2010/11, we plan to have instrumented ~ 1 km^3.

Cosmic rays and neutrino fluxes



Bound = flux
if CR lose
Energy making pions

This is the case for
GZK (guaranteed flux)

CR lose energy
Inside starburst galaxies.

Electrons (synchrotron)
Provide calibration

Waxman, astro/ph
0601695