AMANDA/IceCube
Statut et perspectives vers les très hautes énergies

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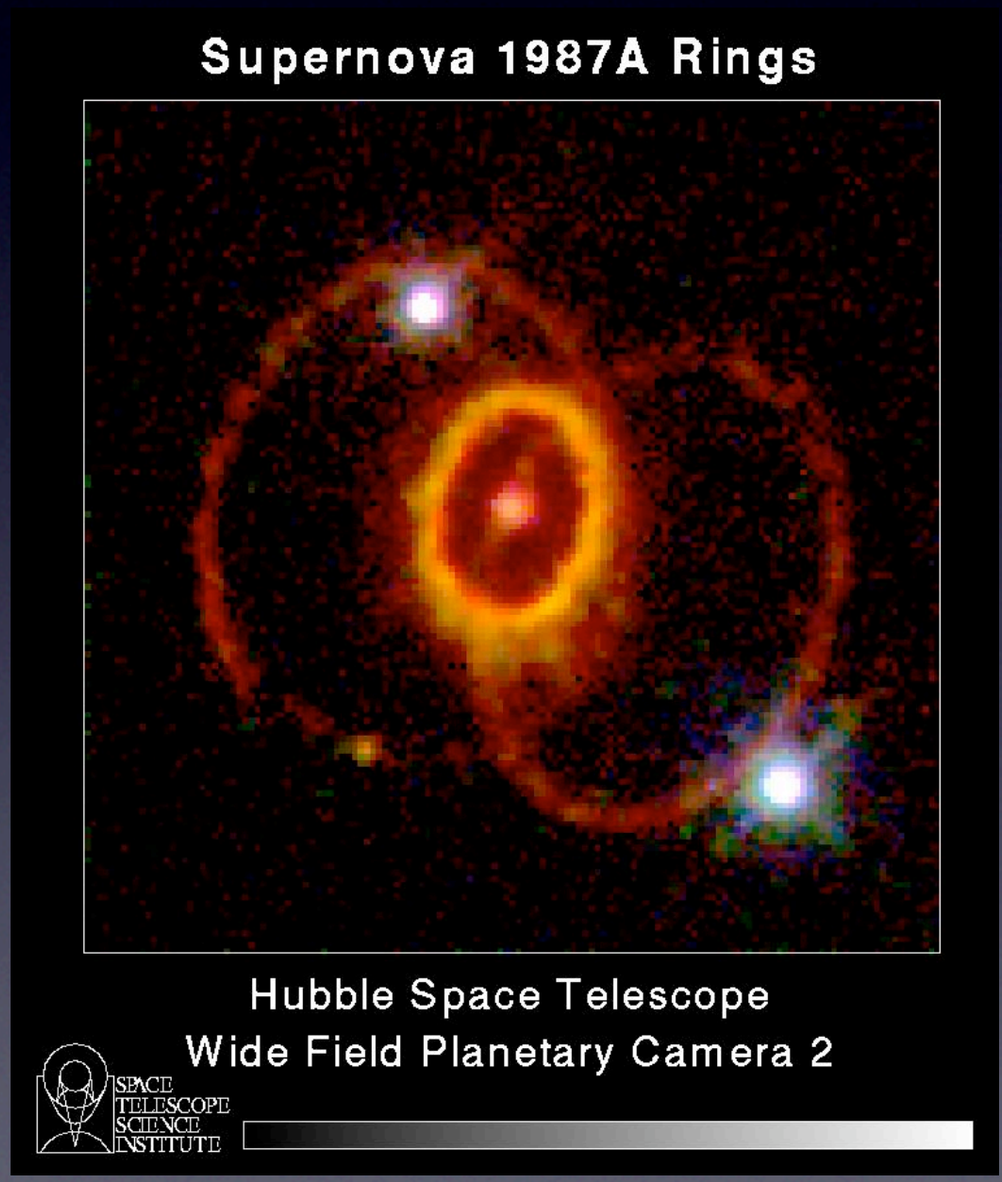
Astrophysical Neutrinos

First Observation

- First observation: SN 1987A
  - Kamiokande II
    7.5-36 MeV
  - IMB (Irvine-Michigan-Brookhaven)
    20-40 MeV
  - 20 events in total, ~20h before the optical detection
- First generation of high-energy neutrino detectors (mid-90s):
  - NESTOR, ANTARES, NT-200 (Baikal)
  - AMANDA
    Use of ice proposed by
    F. Halzen, J. Learned, T. Stanev, AIP Conf. 198 (1989) 39

K. Hirata et al., Phys. Rev. Lett. 58 (1987) 1490
R.M. Bionta et al., Phys. Rev. Lett. 58 (1987) 1494

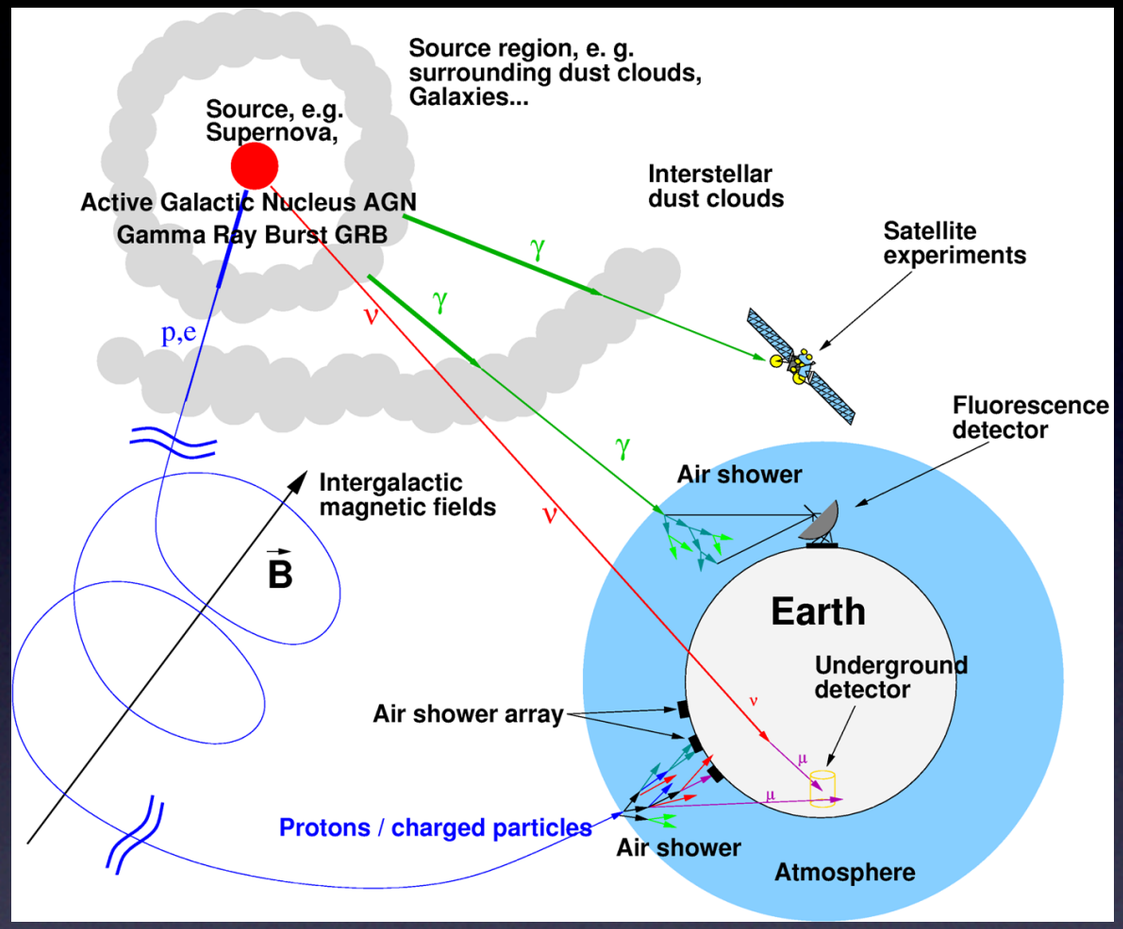


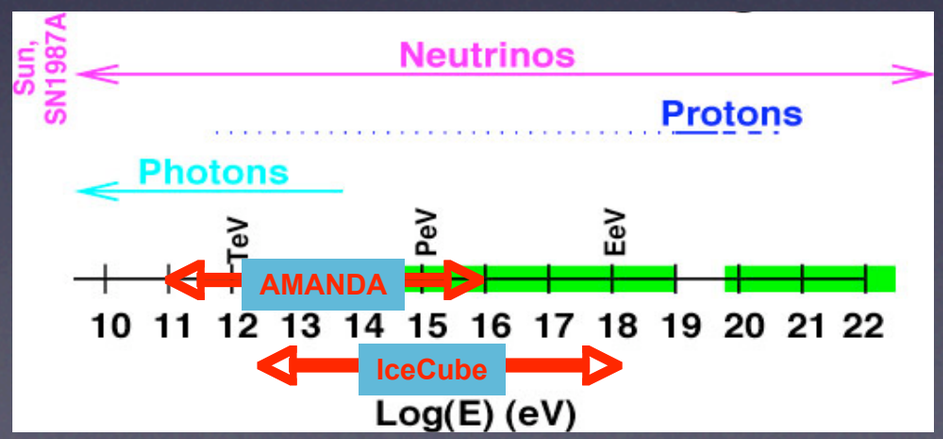
Production

$$p + p \rightarrow \pi + ...$$
$$\rightarrow \mu^+ + \nu_\mu$$
$$\rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$

$$p + \gamma \rightarrow n + \pi^+$$
(CMB)
$$\rightarrow \mu^+ + \nu_\mu$$
$$\rightarrow p + e^- + \overline{\nu_e}$$

$$p + \gamma \rightarrow p + \pi^0$$
$$\rightarrow \gamma + \gamma$$

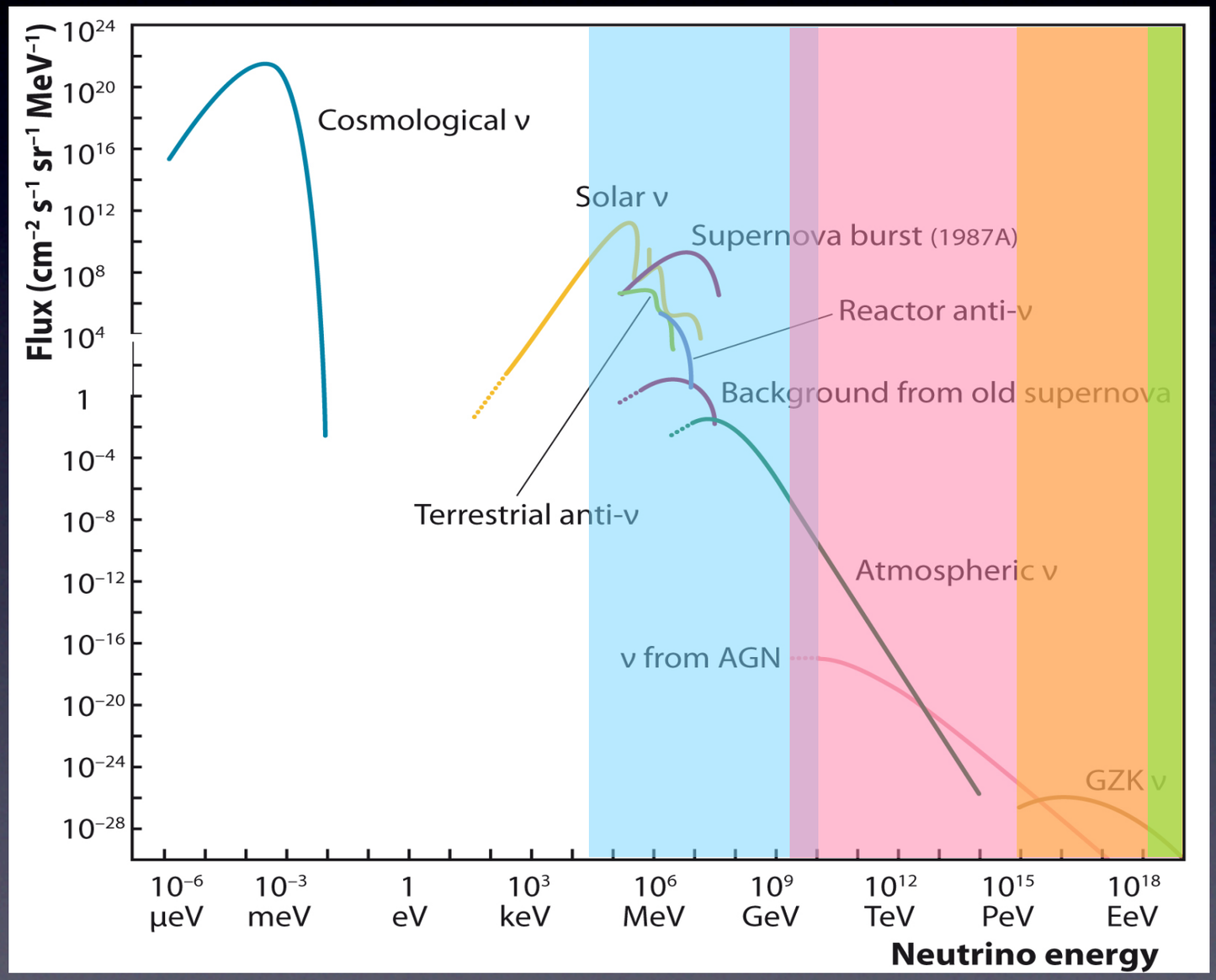




- Hadronic processes
- Possible sources: GRBs, AGNs, SNRs...
- No absorption, no deflection

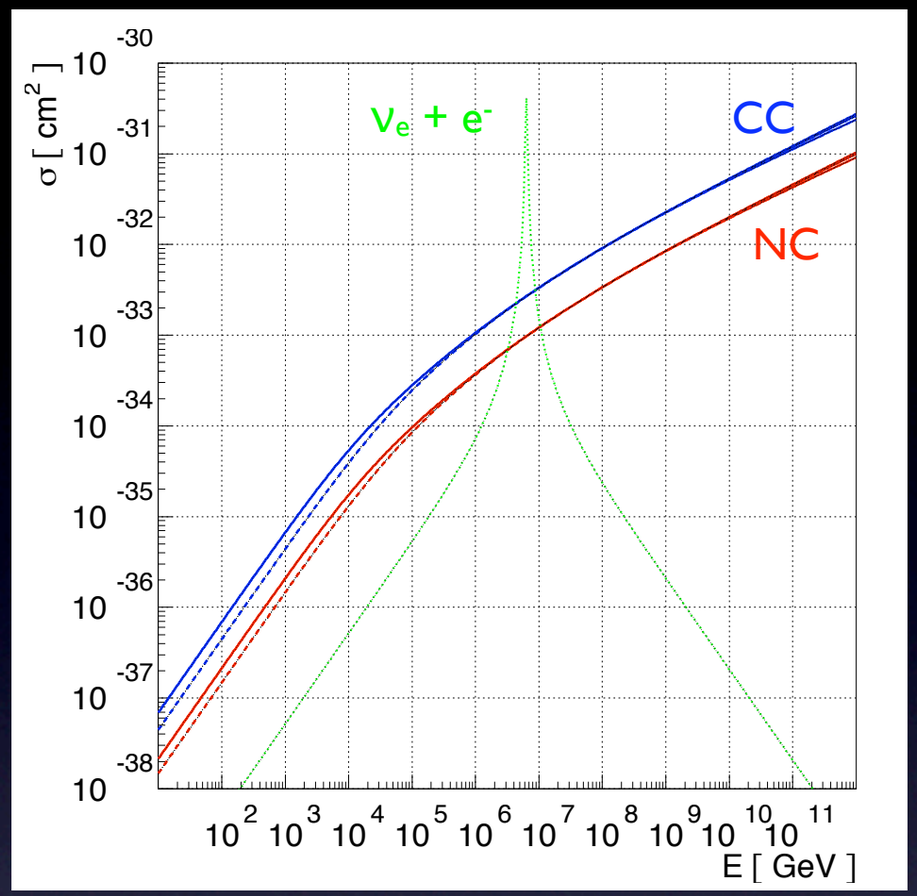
Spectrum

- Different techniques
  - Underground
  - Under water/ice
  - Radio/acoustic
  - Air showers

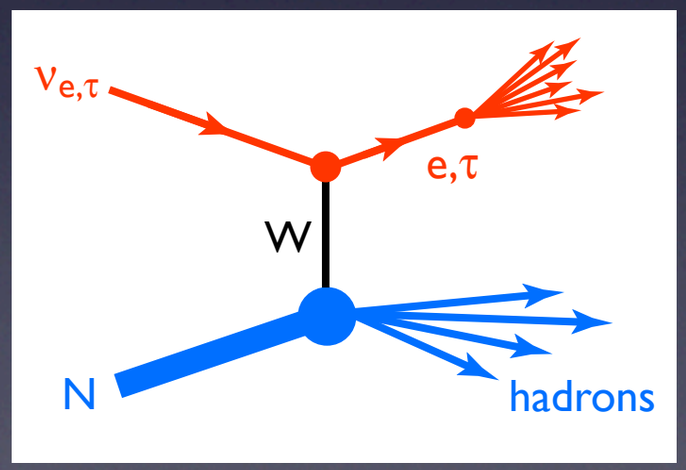


Interactions

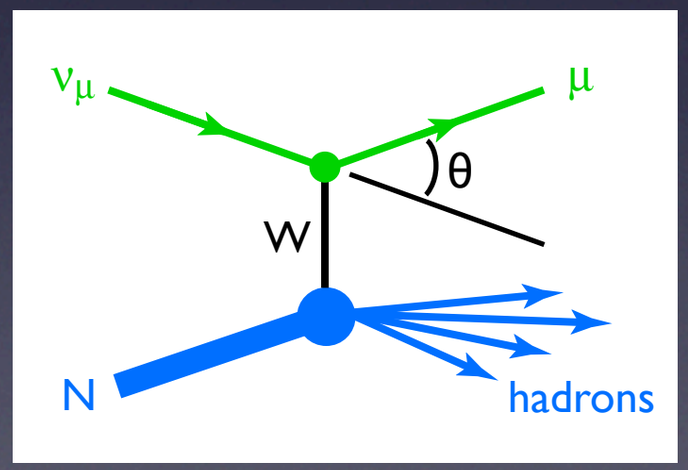
- Two modes of interaction:
  - Neutral Current (NC)
  - Charged Current (CC)
- Interaction cross sections:
  - Very low !
  - Increase with energy



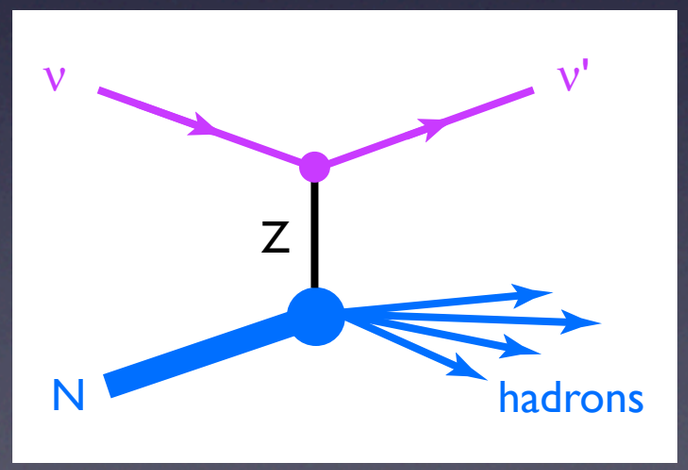
Cross sections



CC



CC

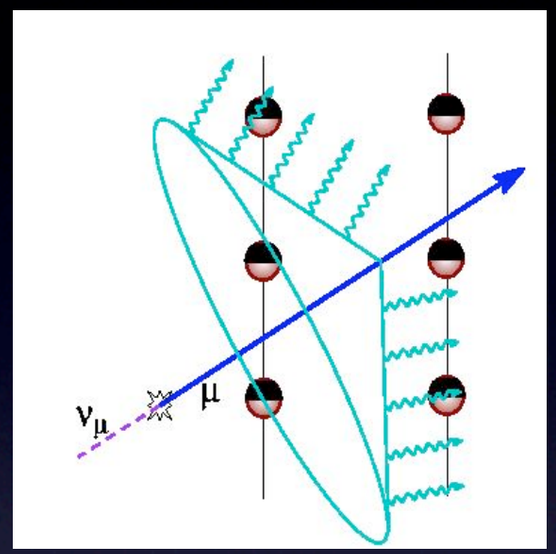


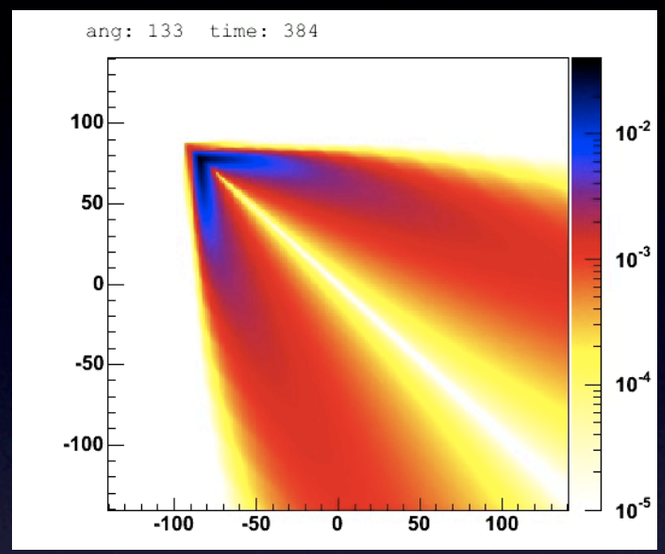
NC

$$\langle\theta\rangle \leq \frac{1.5^o}{\sqrt{E_\nu(\mathrm{TeV})}}$$

Signatures

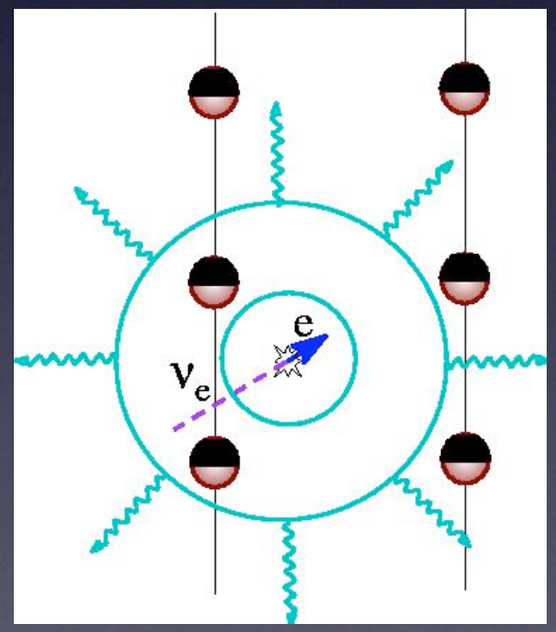
- Muon tracks : O(1 km)
  - angular resolution ✔ ~0.5-1°
  - energy resolution ✘ ~0.3 (in log(E))

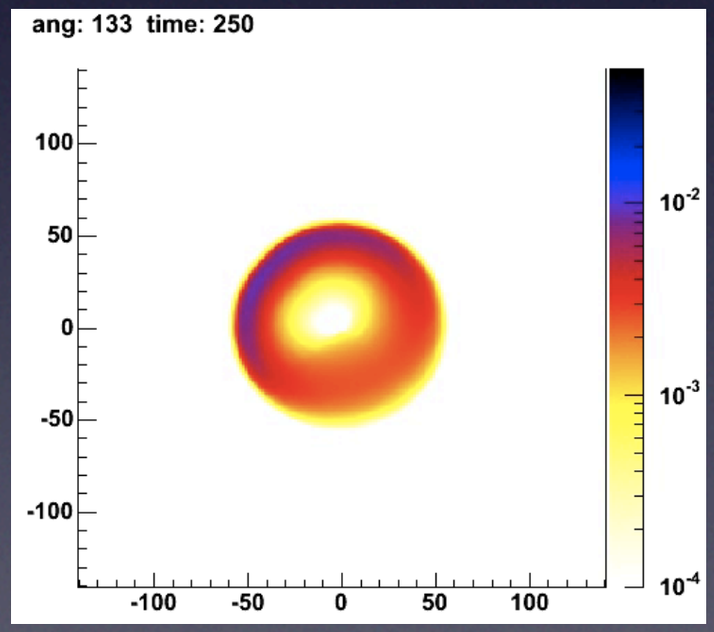




- Cascades : O(10 m)
  - energy resolution ✔ ~30 % (in E)
  - angular resolution ✘ ~25°

(Numbers given at 10 TeV)





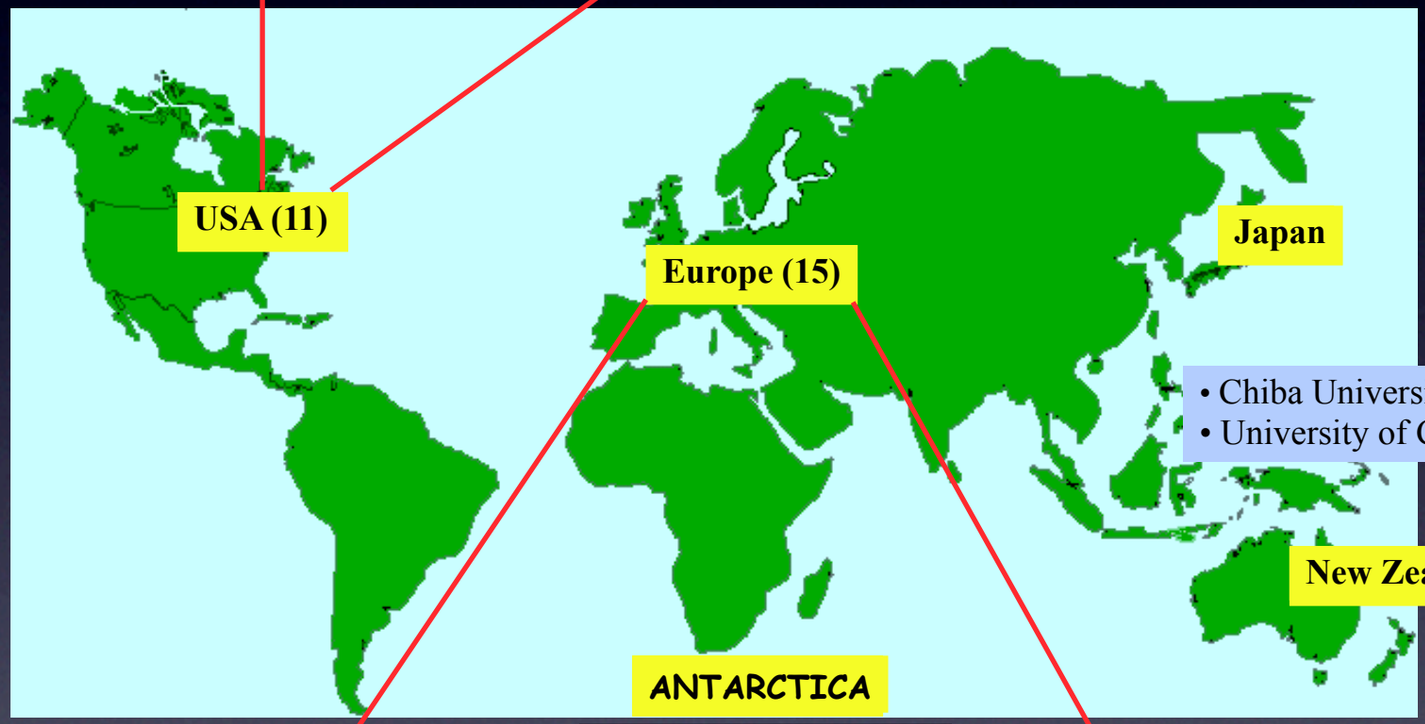
Photonics simulations.
Homogeneous ice.

AMANDA / IceCube

The Collaboration:
29 Institutions - ~250 Scientists

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

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

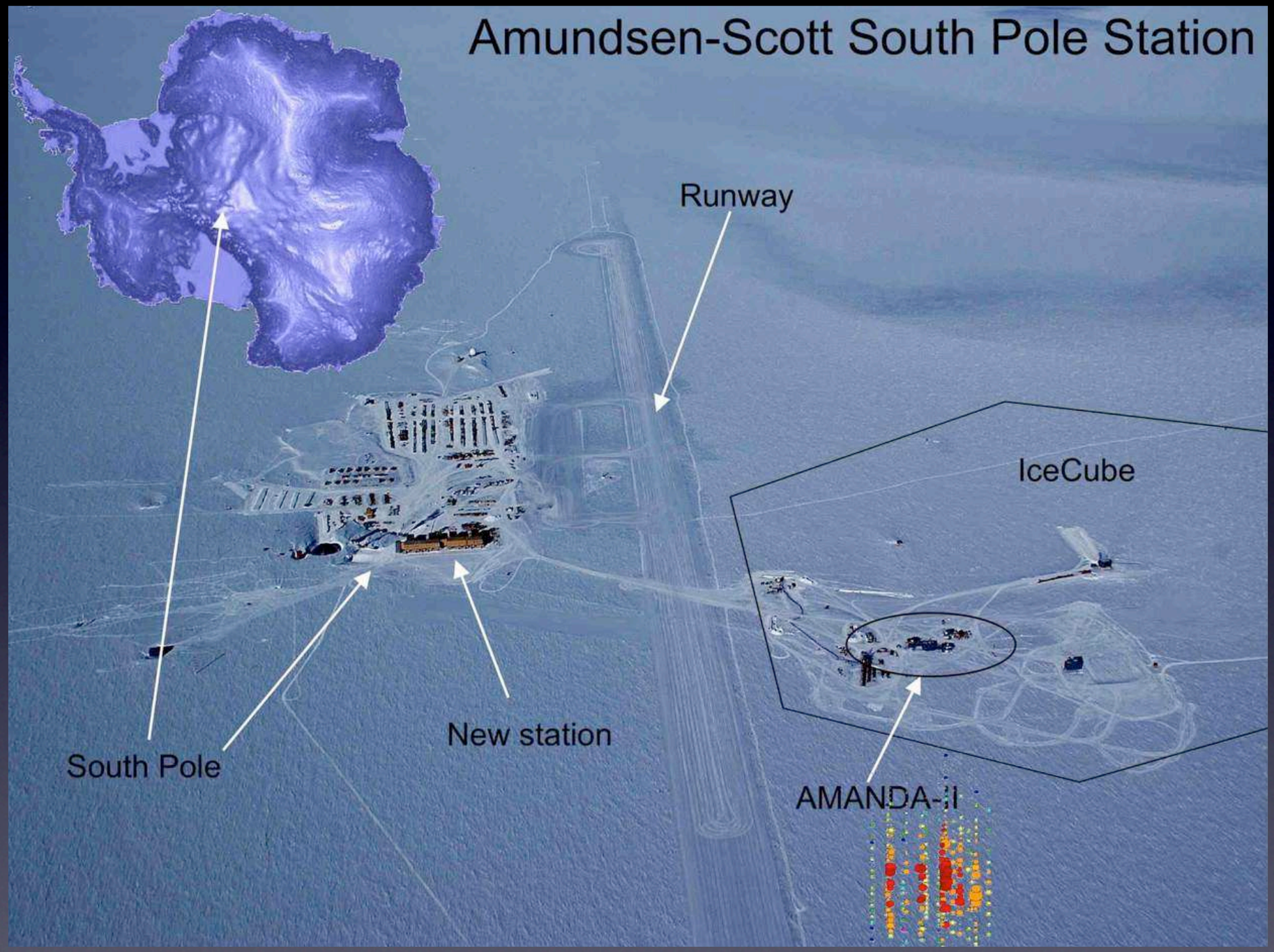


- Chiba University, Japan
- University of Canterbury, Christchurch, NZ

Amundsen-Scott Station

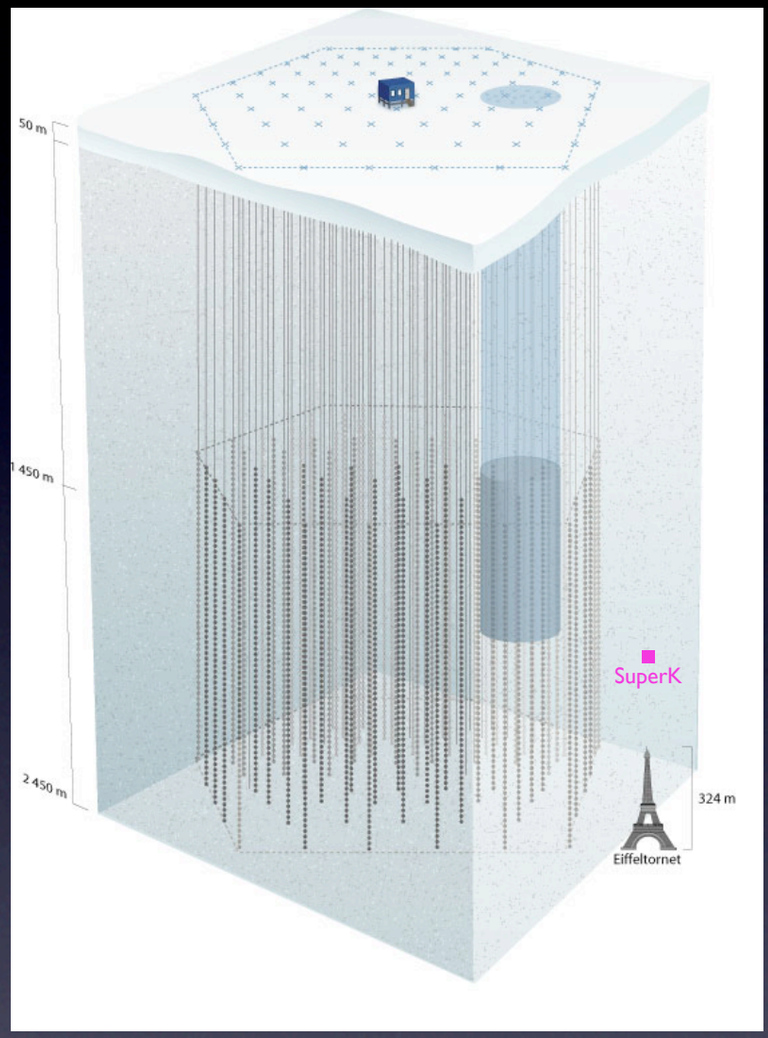
- Universite Libre de Bruxelles, Belgium
- Vrije Universiteit Brussel, Belgium
- Université de Mons-Hainaut, Belgium
- Universiteit Gent, Belgium
- Humboldt Universität, Germany
- Universität Mainz, Germany
- DESY Zeuthen, Germany
- Universität Dortmund, Germany

- Universität Wuppertal, Germany
- MPI Heidelberg, Germany
- RWTH Aachen
- Uppsala university, Sweden
- Stockholm university, Sweden
- Oxford university, UK
- Utrecht university, Netherlands


Amundsen-Scott South Pole Station
Runway
IceCube
South Pole
New station
AMANDA-II

AMANDA/IceCube

- AMANDA
  - ∅ 200 m, 500 m high (0.02 km^3)
  - 677 OMs on 19 strings (2000+)
  - Horizontal spacing: ~60 m
  - Vertical spacing: ~12 m
- InIce = IceCube - IceTop
  - 1 km^3
  - 4800 DOMs on 80 strings (2011)
  - Horizontal spacing: ~125 m
  - Vertical spacing: ~17 m
- AMANDA as a low-energy subdetector of IceCube
  - IceCube threshold: 100 GeV
  - 30 GeV with AMANDA

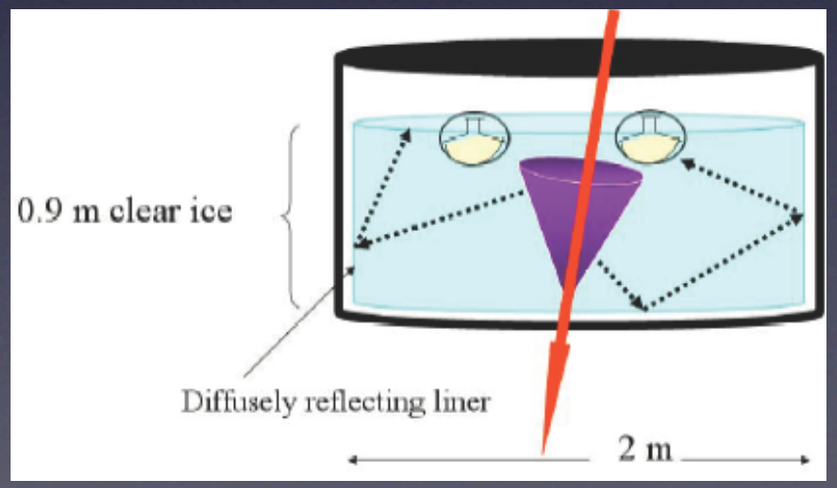


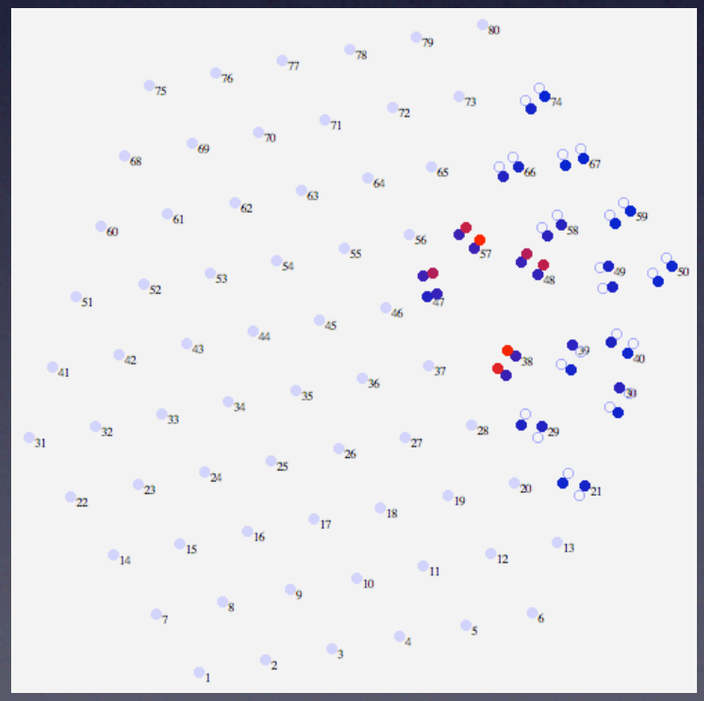
1450 m

2450 m

IceTop

- Air shower detection at E > 300 GeV
- 160 tanks with 2 DOMs each
- Altitude : 2830 m
- Present : 26 stations
- Planned for next year : 40 stations

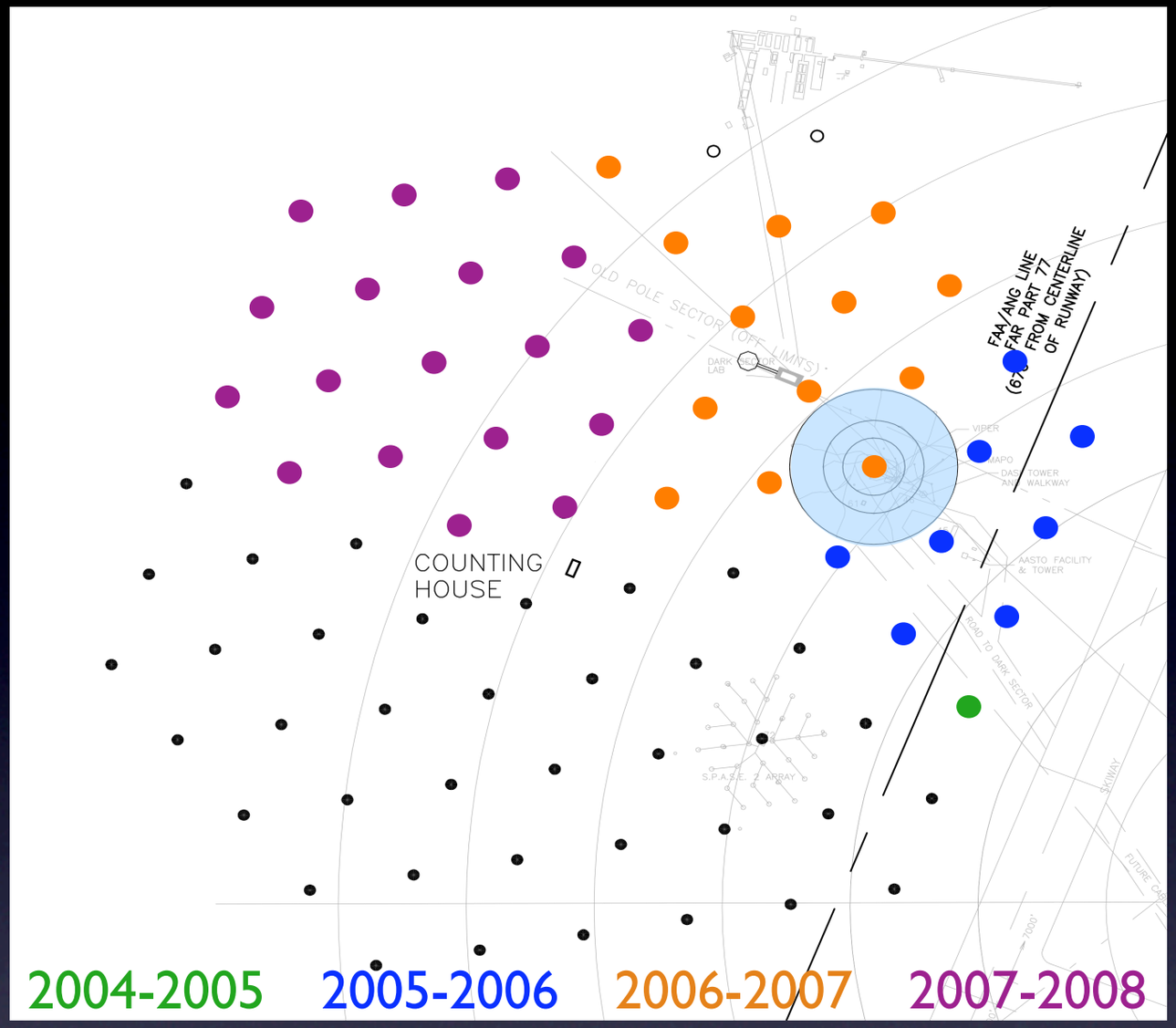




Air shower seen by IceTop

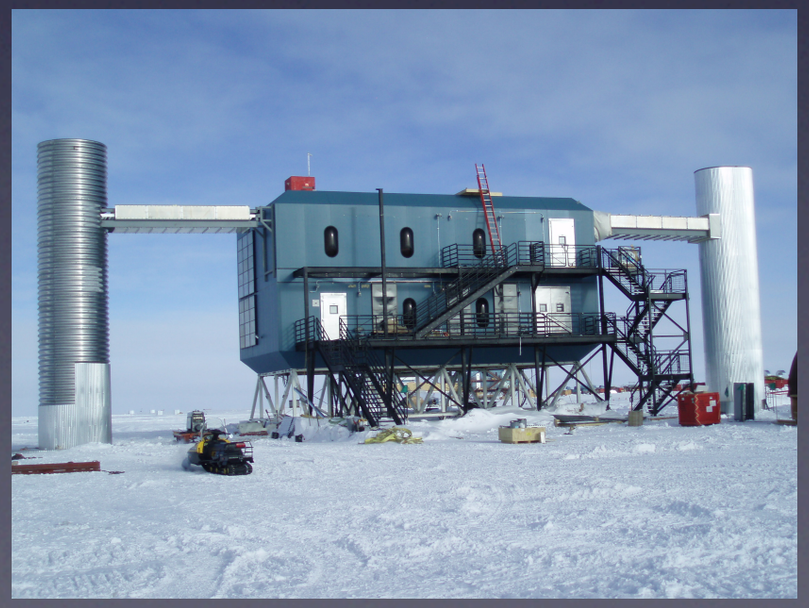
Status

- 2004/2005 - 1 string
- 2005/2006 - 8 strings
- 2006/2007 - 13 strings
- 2007/2008 - 14-18 strings ?
- Present:
  - 22 strings = 1320 DOMs
  - 0.3 km^3 instrumented



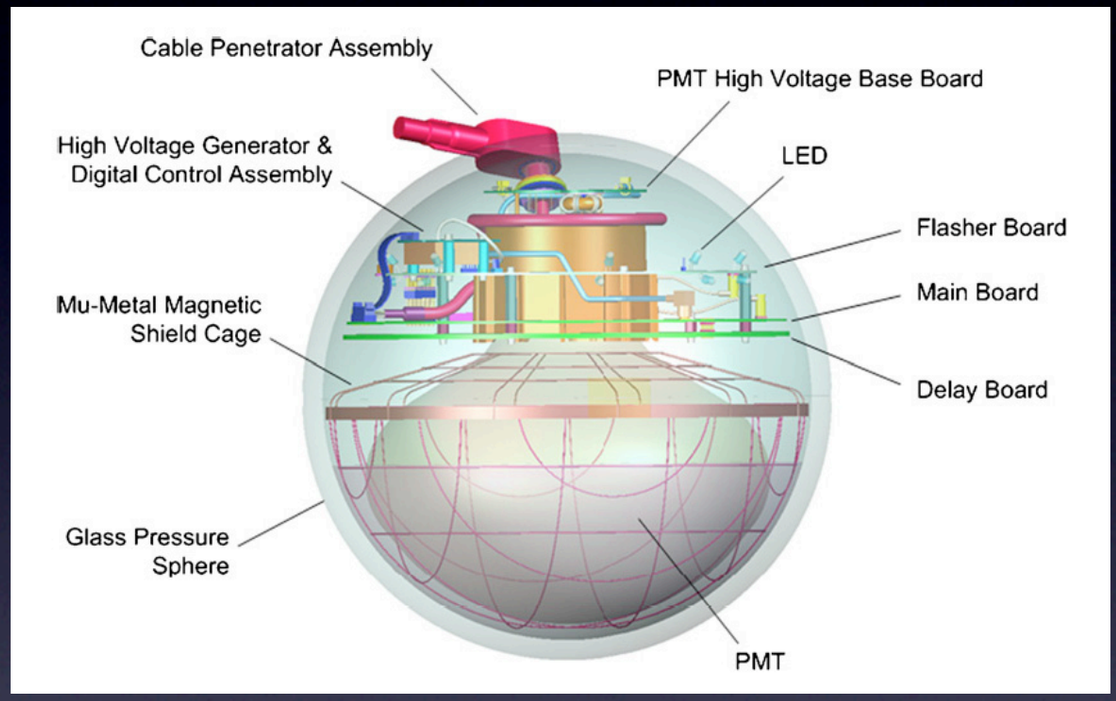
99.5 % of the DOMs take data

IceCube Lab. and Data Center Commissionned in January 07



Digital Optical Module

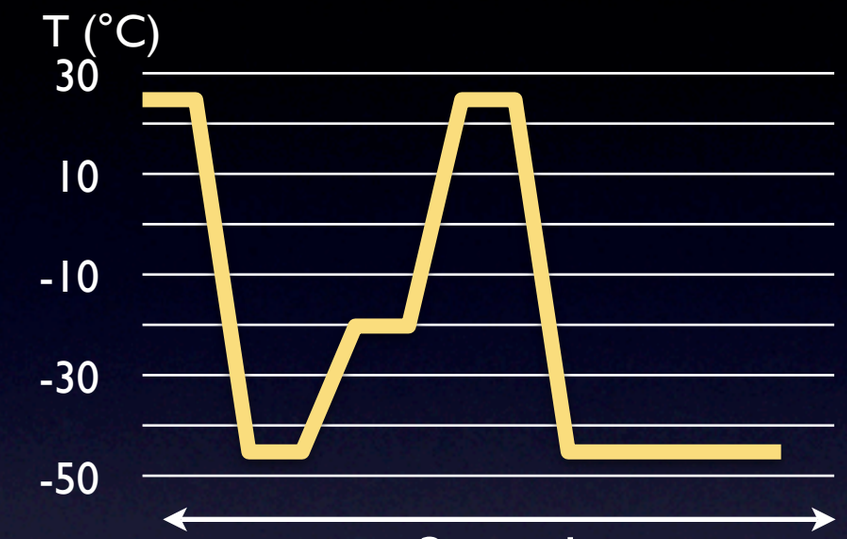
- 10” PMT
- Main board (2 ATWD, fADC)
- Flasher board
- Dead time < 1%
- Resolution ≤ 2 ns
- Low intrinsic noise (~300 Hz)
- Low consumption (~5 W/DOM)
- “Golden DOMs”: 2D sensitivity scan + absolute calibration

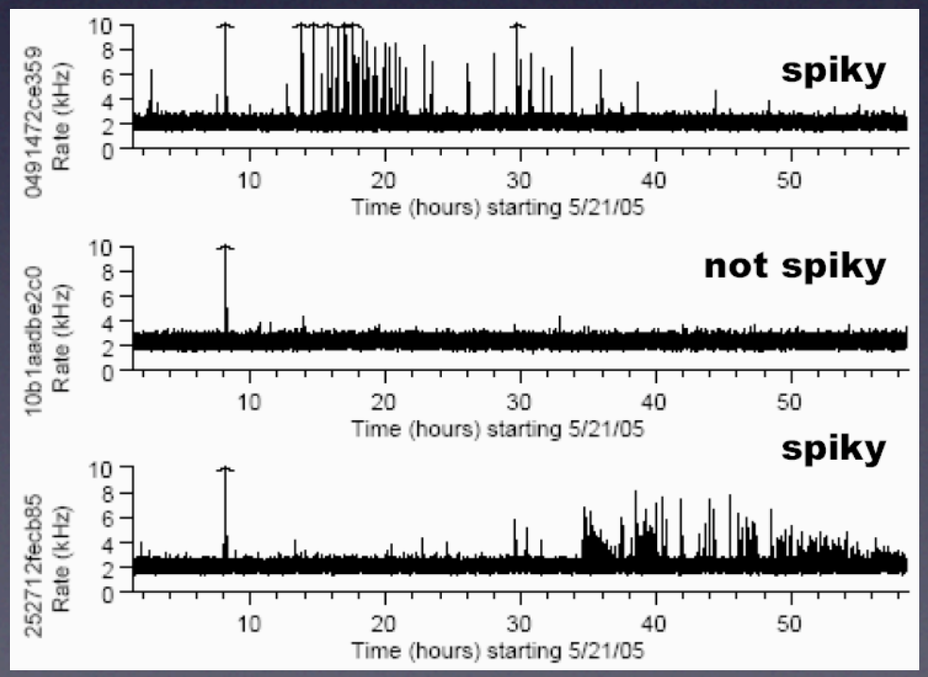


Production sites: Madison, Stockholm/Uppsala, Zeuthen

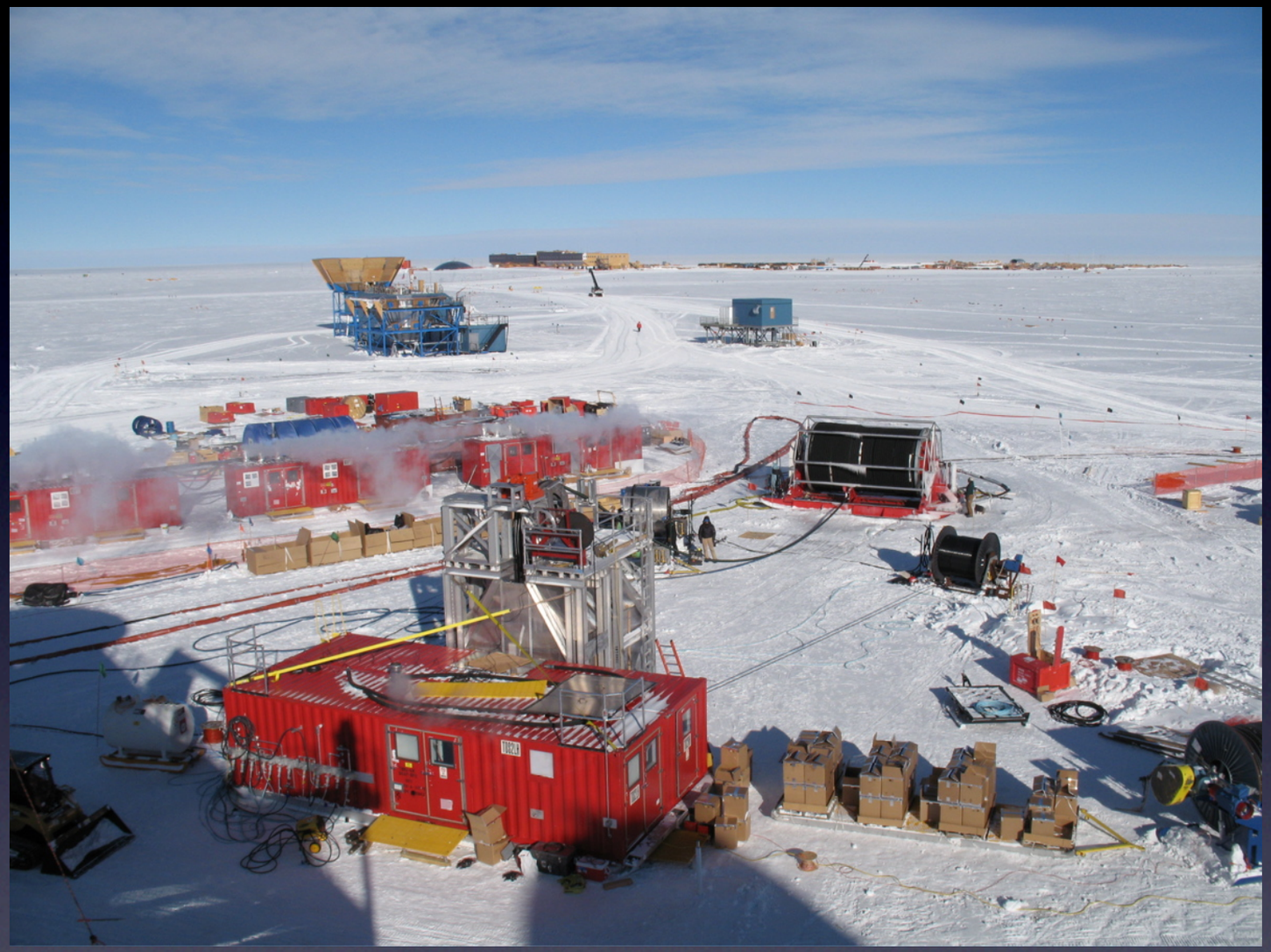
Final Acceptance Testing

- All modules are tested in a dark freezer
- Systematic tests of electronics
- Calibration
- Time resolution
- Optical sensitivity
- ~99% of DOMs pass the tests



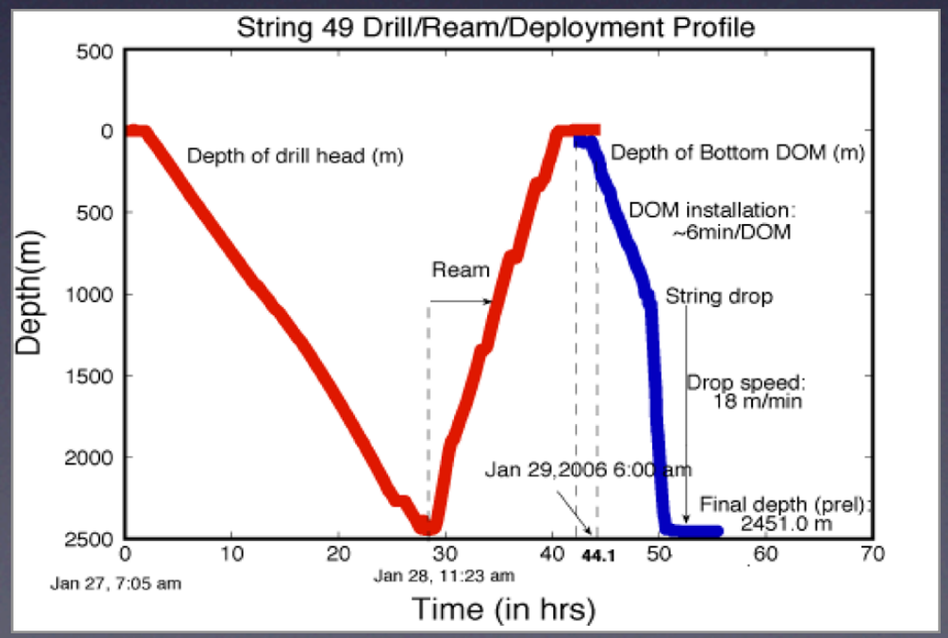


Drilling & Installation



- Hot water drill
- 5 MW hot water generator

- Drilling: ~40 h
- String installation: ~10 h

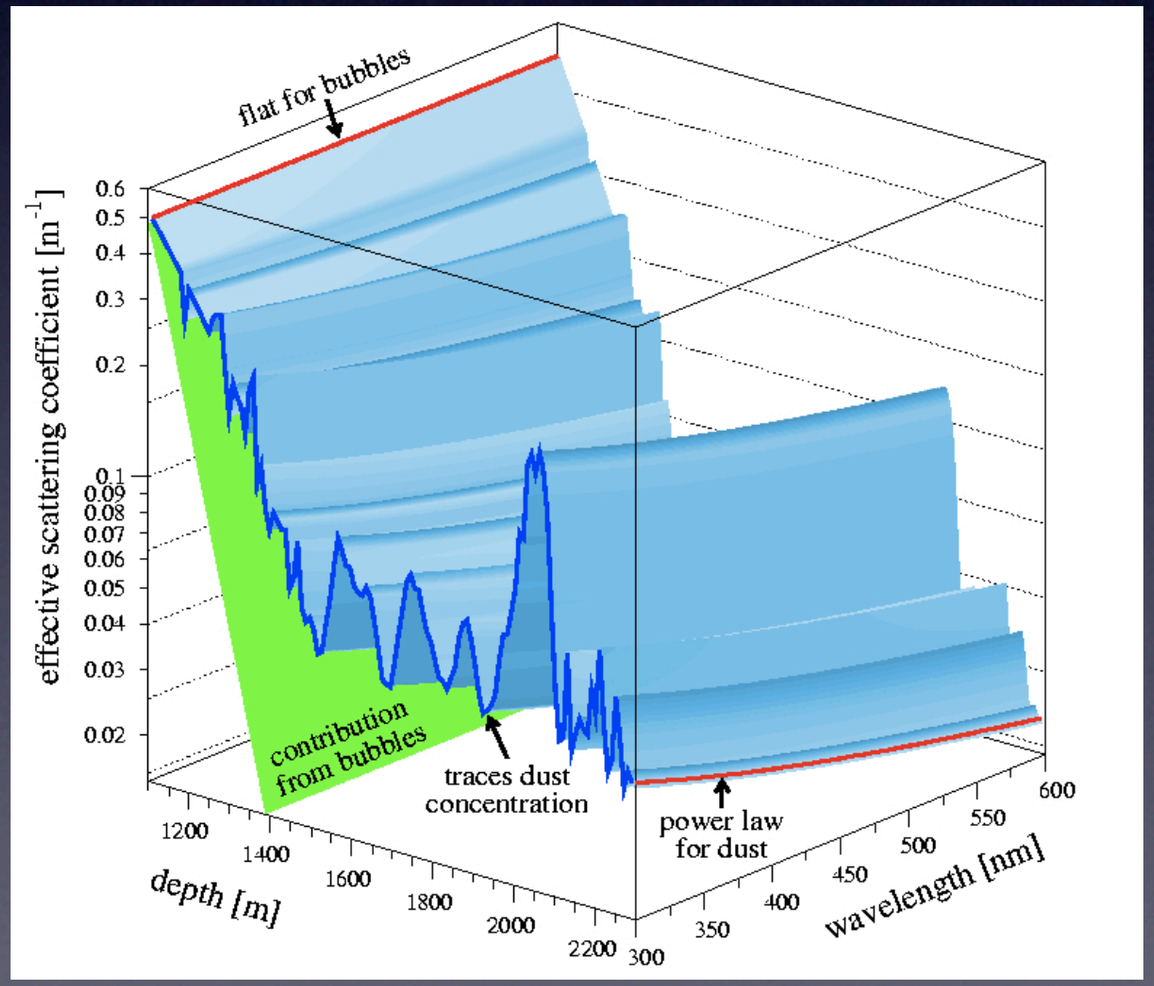


Ice Properties

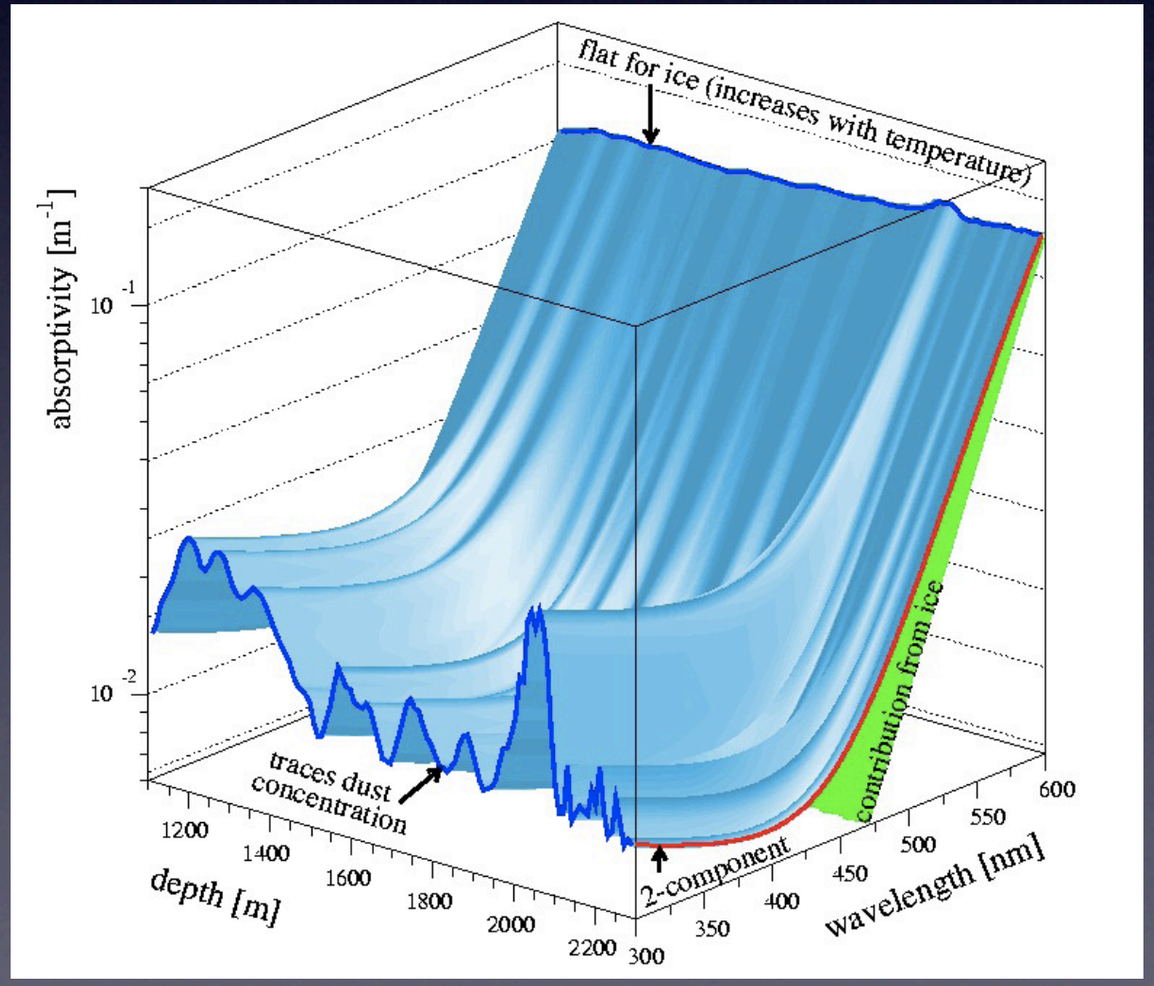
- Absorption length: ~110 m ⇨ Effective volume
- Scattering length: ~20 m ⇨ Angular resolution

(values given at 400 nm)

Scattering



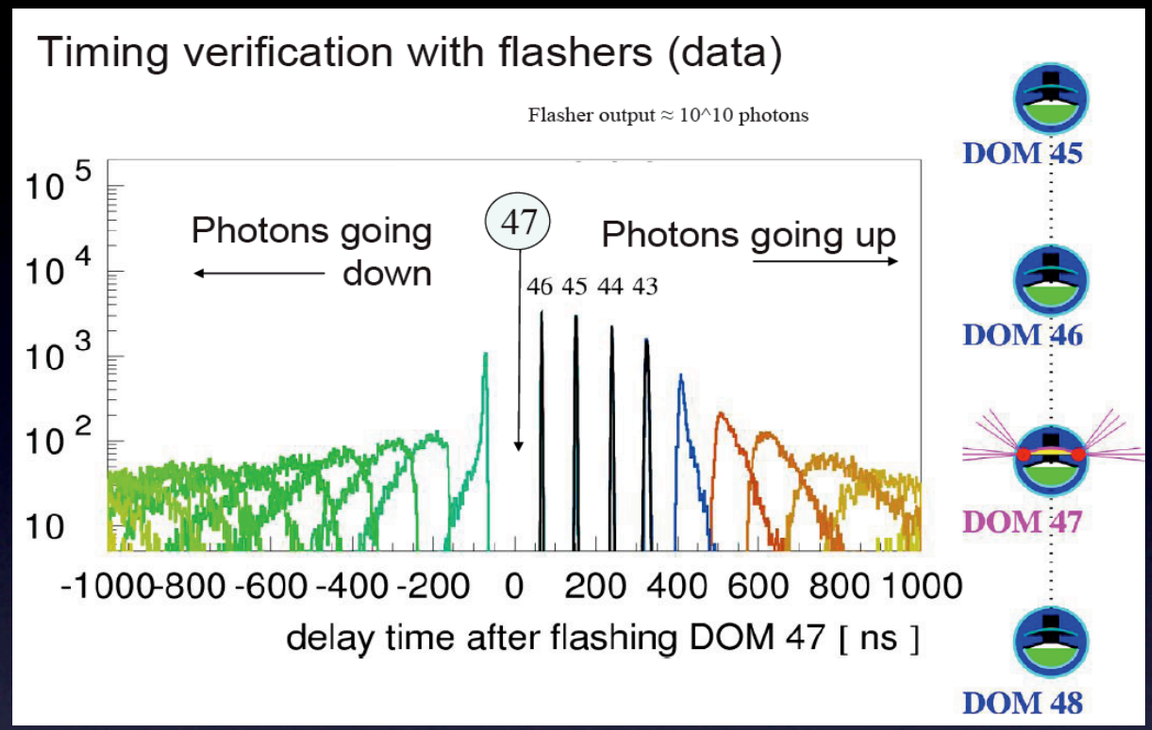
Absorption

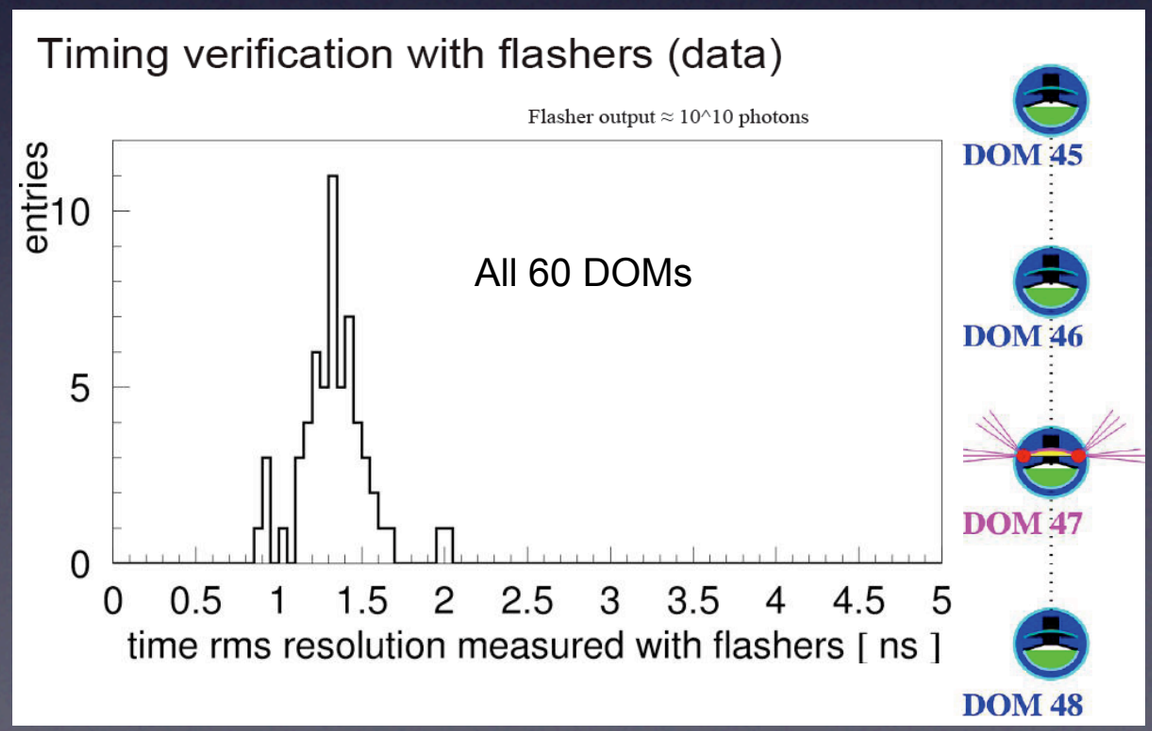


Time Resolution

- Use of flashers
  - One DOM flashes
  - Other DOMs receive

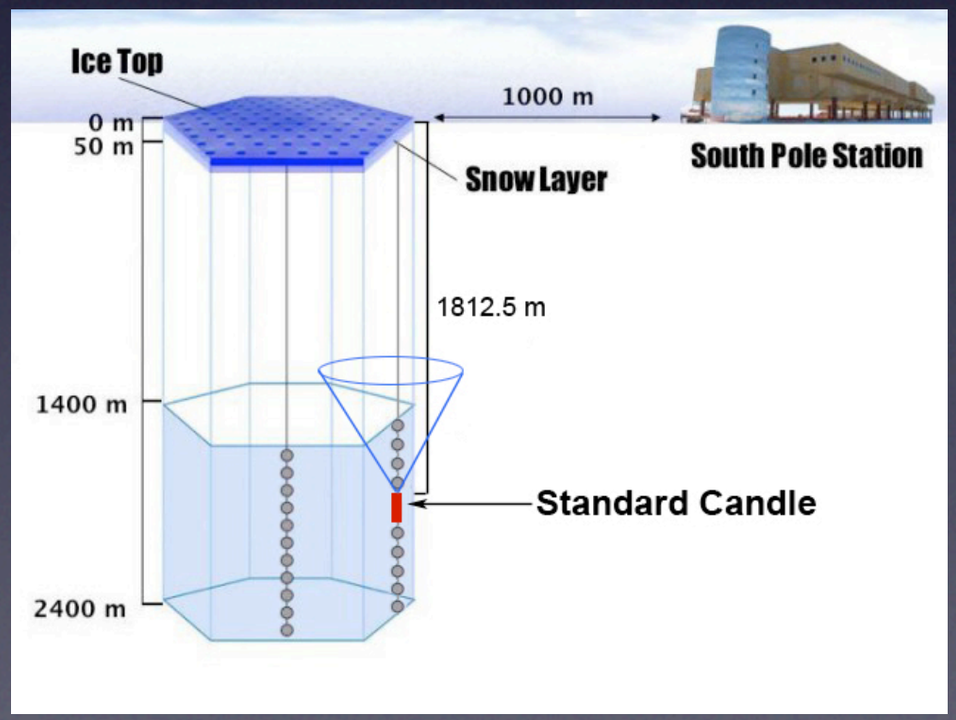
Resolution = ~1.5 ns



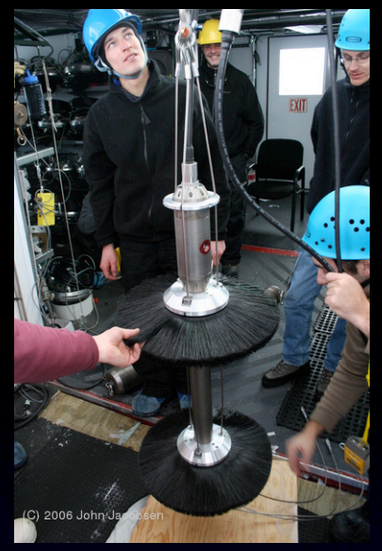


Standard Candle

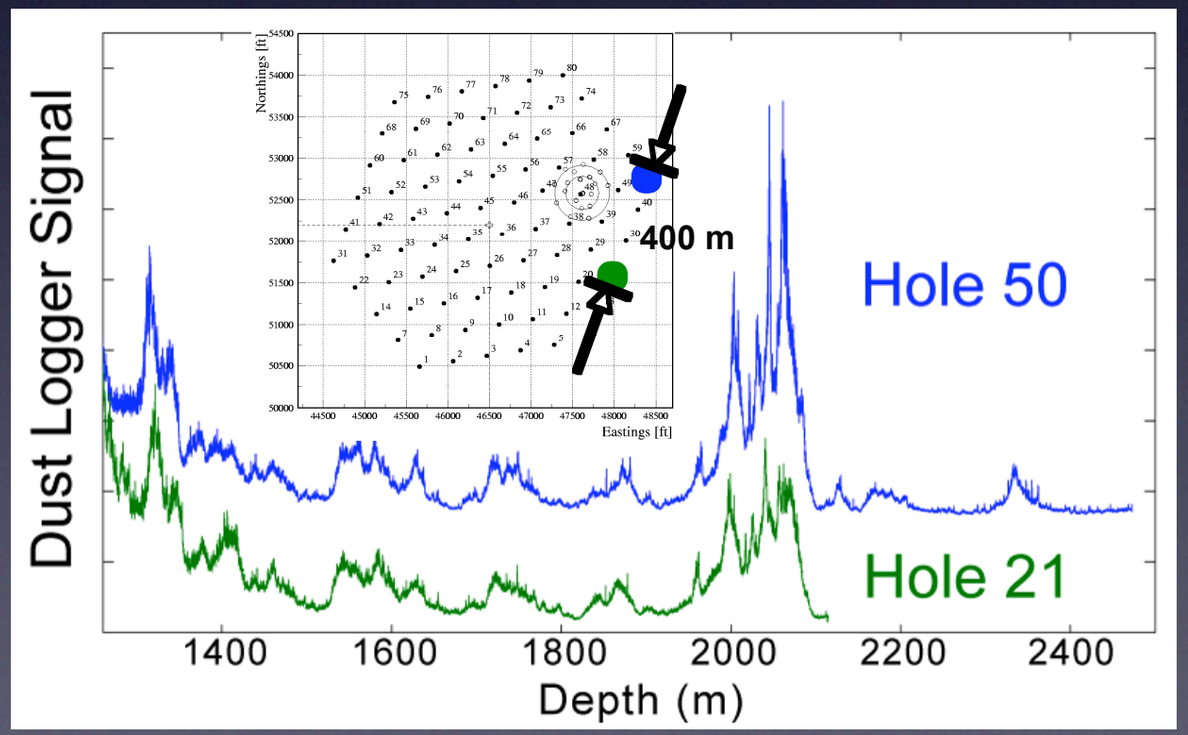
- Calibrated light source
- Absolute intensity known with high precision
- With “Golden DOMs” ⇨ good calibration

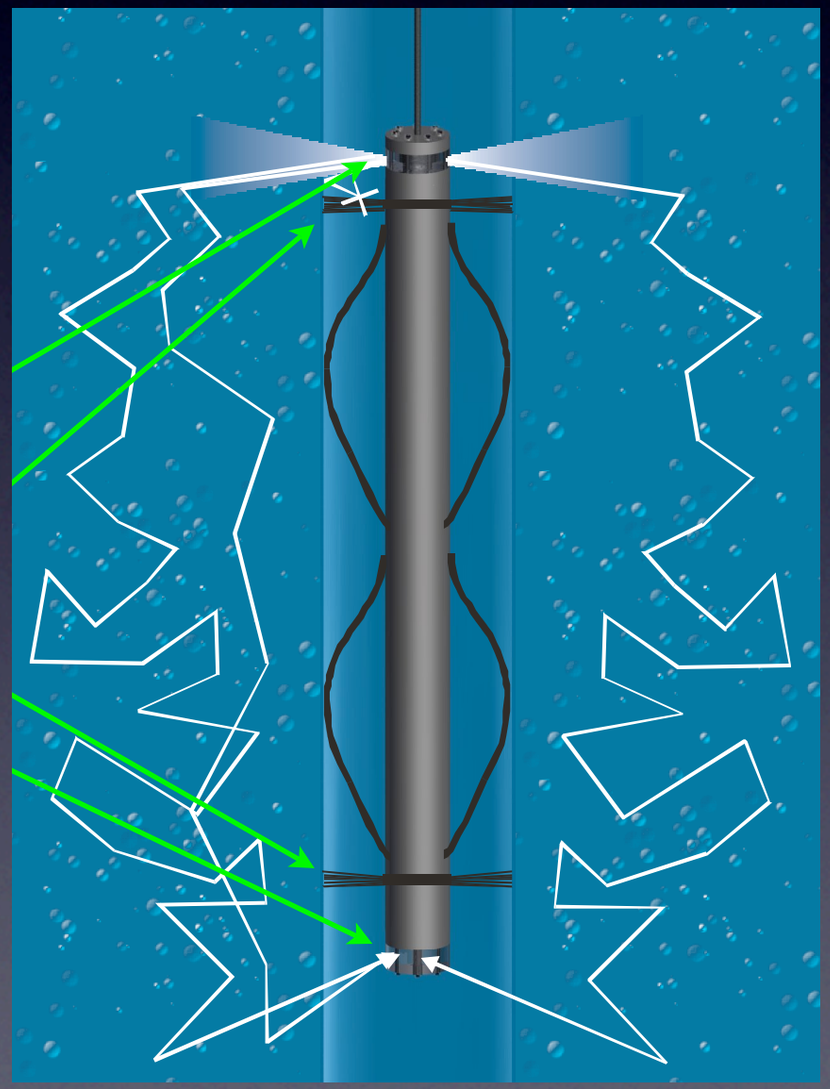


Dust logger



- Measurement of diffused light vs. depth
- Resolution < 1 cm
- Scan duration: ~4 h



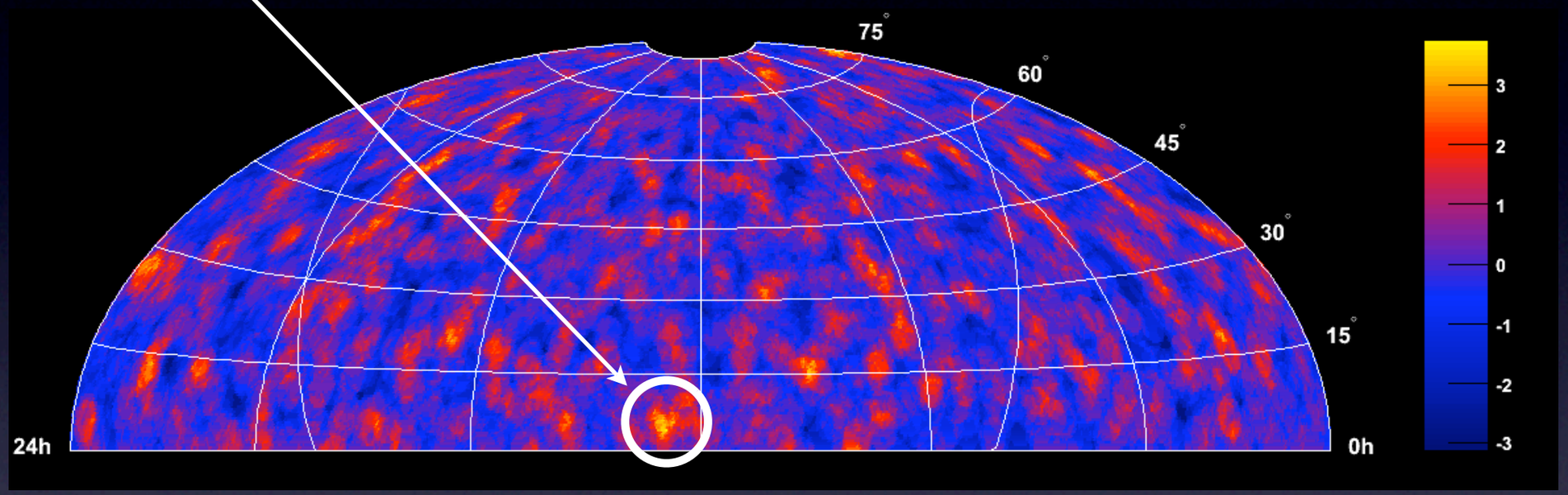


Some Results

AMANDA: Point Sources

M. Ackermann

Compatible with 3EG J1236+0457 ??

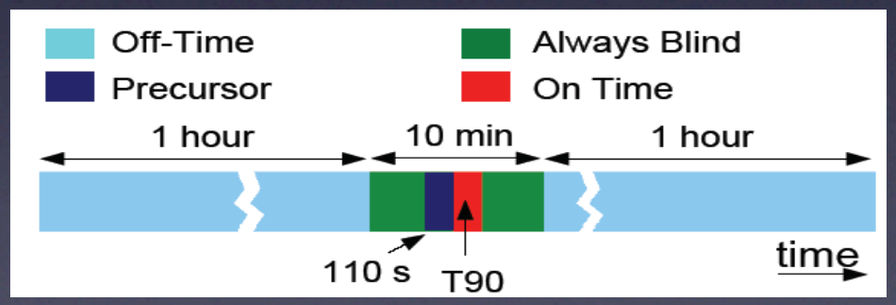


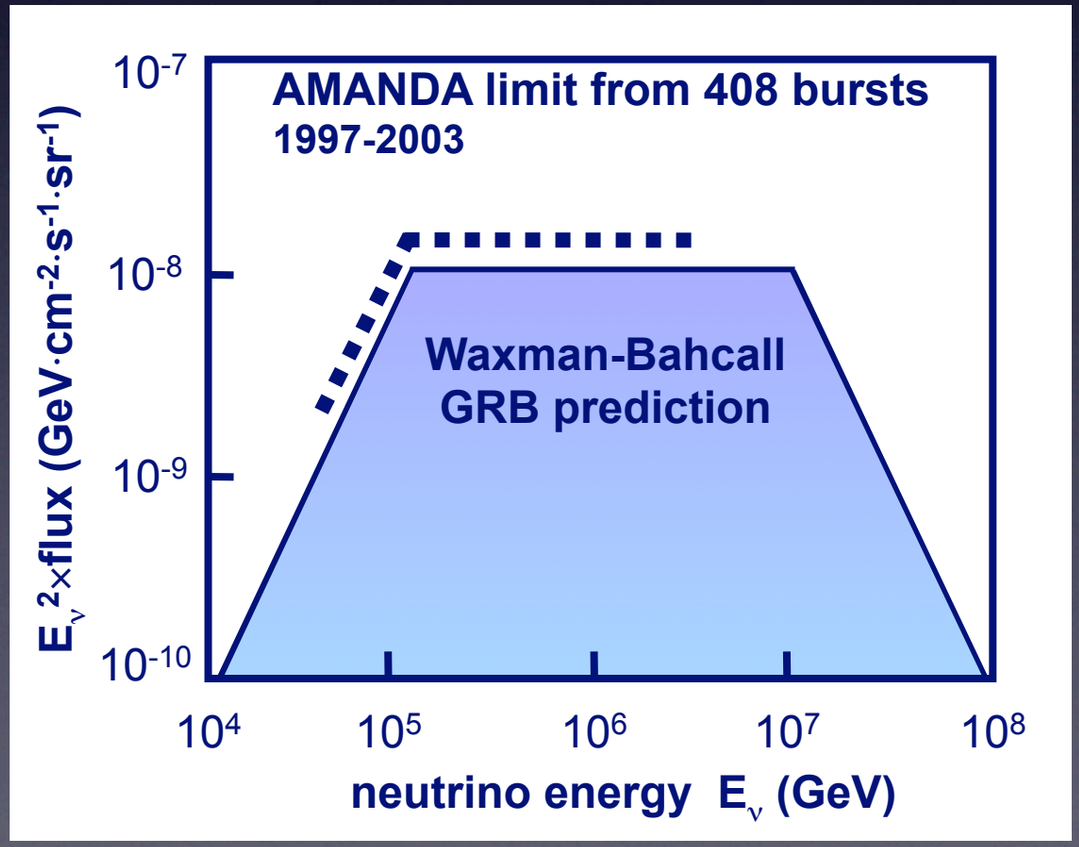
- Significance map 2000-2004 (~1000 days, 4282 ν events)
- Largest excess with a selection of 33 candidate sources: Crab with N_{obs} = 10, N_{bg} = 6.7 (1.5 σ)
- Scan: best significance : ~3.7 σ ⇨ No significant excess !

AMANDA: Gamma-Ray Bursts

I. Taboada

- Check for coincidences with BATSE, IPN, SWIFT
- 6 years of AMANDA-II data
- Close to WB within a factor 2
- IceCube will test WB within a few months !

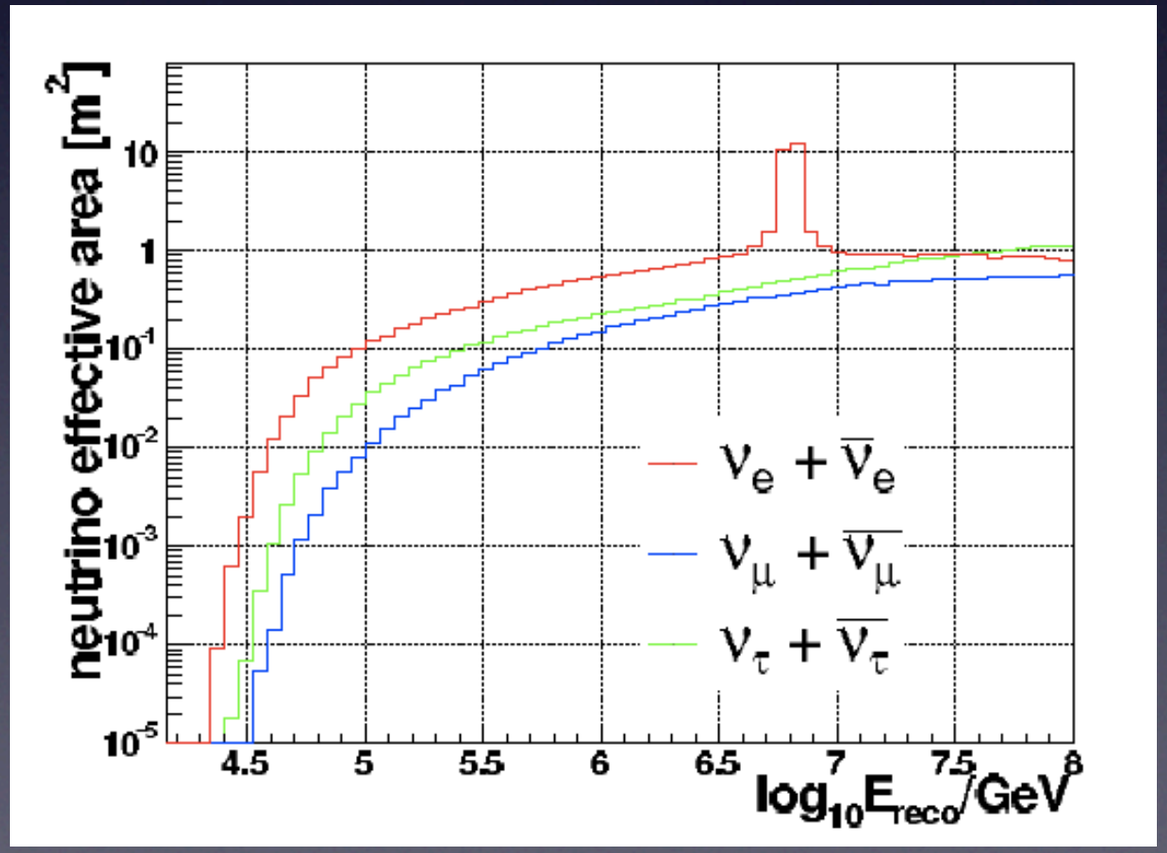


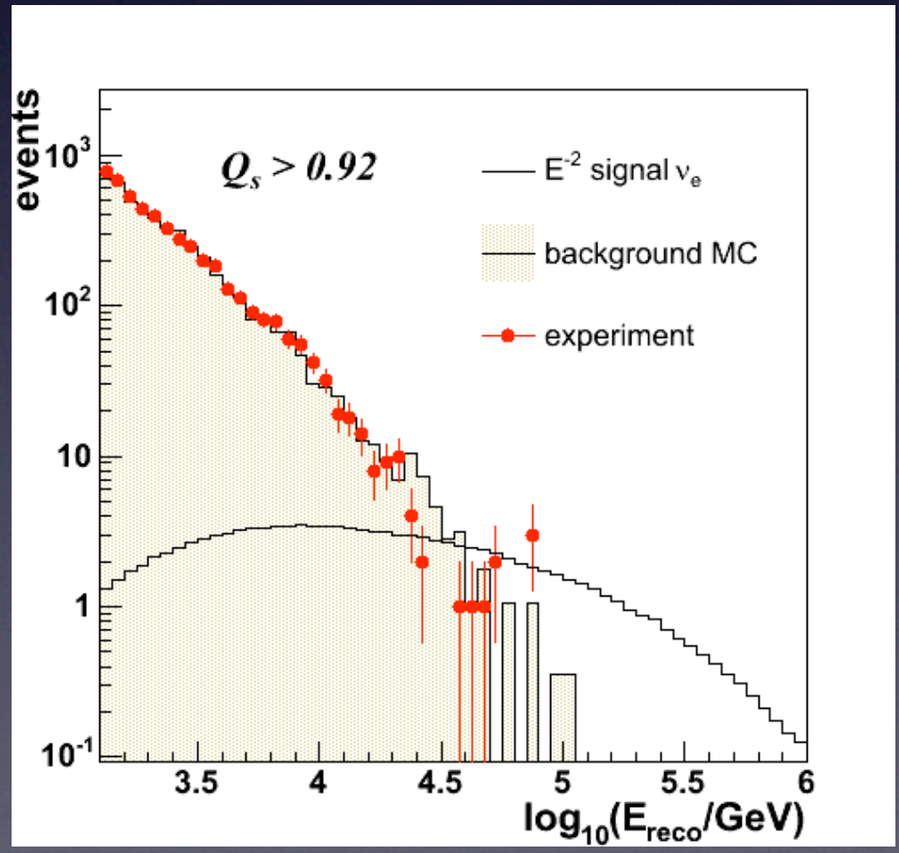


AMANDA: Cascades

O. Tarasova

- Data taken from 2000 to 2004 (1000.1 days)
- Diffuse analysis - 4π acceptance
- All flavors
- 6 events pass the cuts : compatible with the background from atmospheric muons

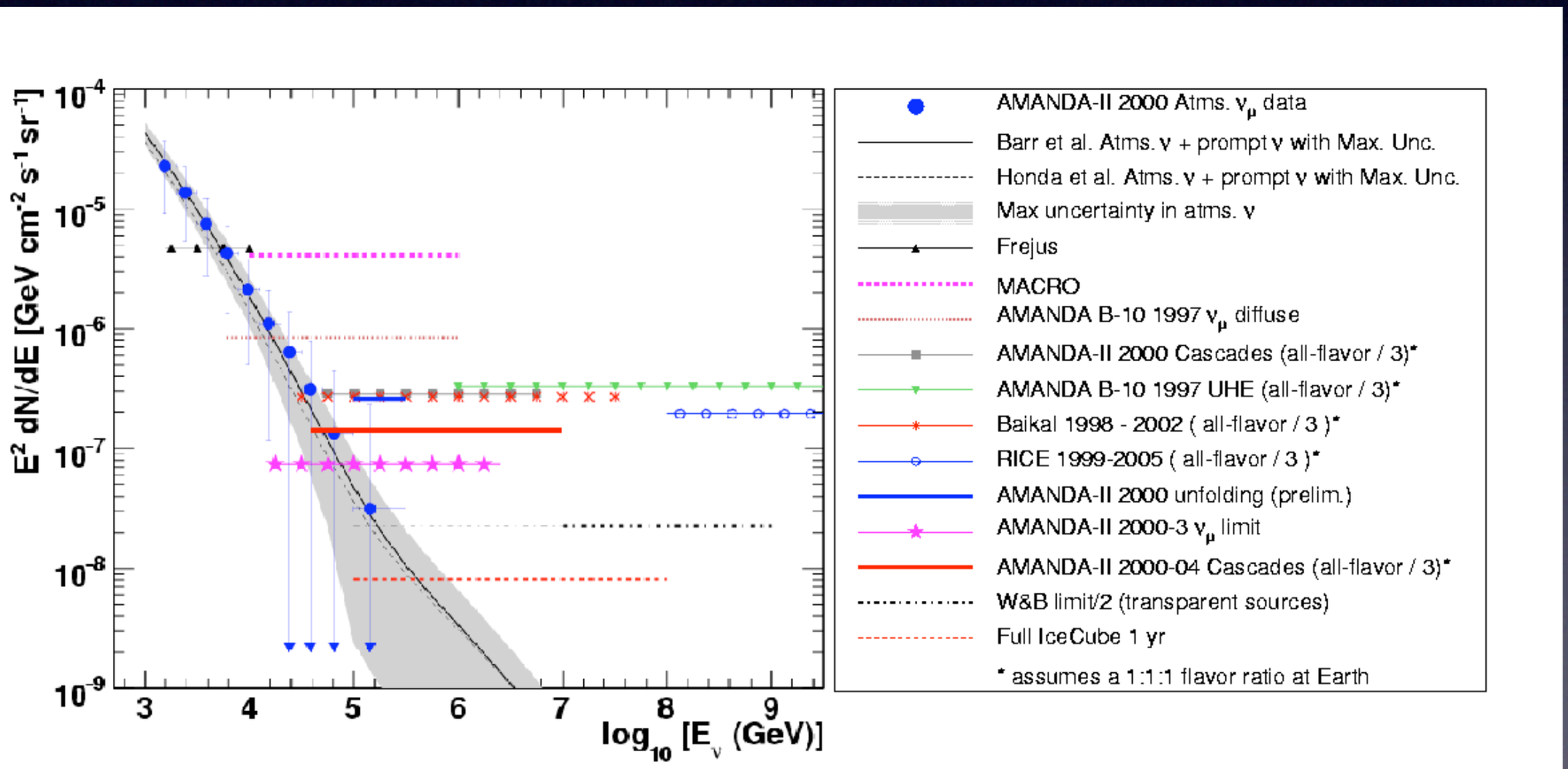




AMANDA: Cascades (2)

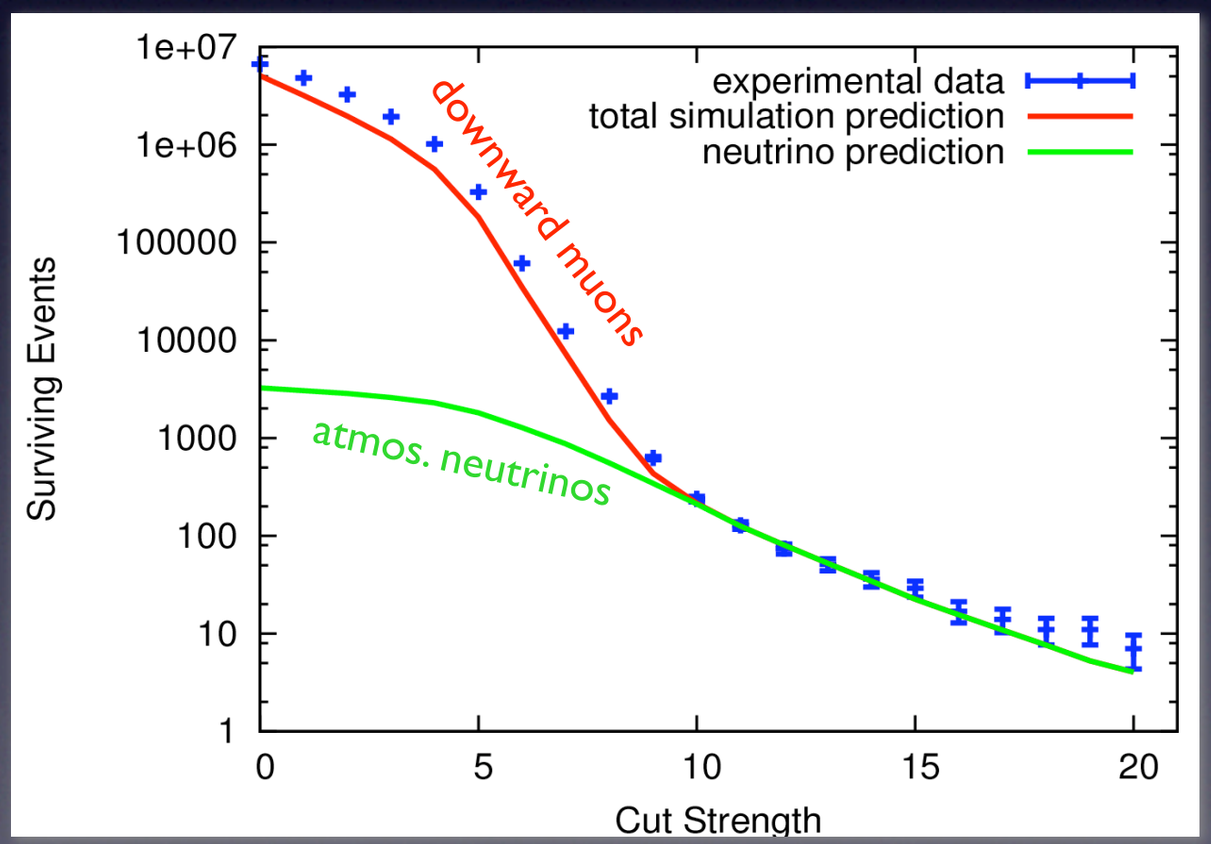
O. Tarasova

- Limit in the range 40 PeV - 9 TeV : 3.96×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}
- Best upper limit on the diffuse all-flavor neutrino flux for cascade events

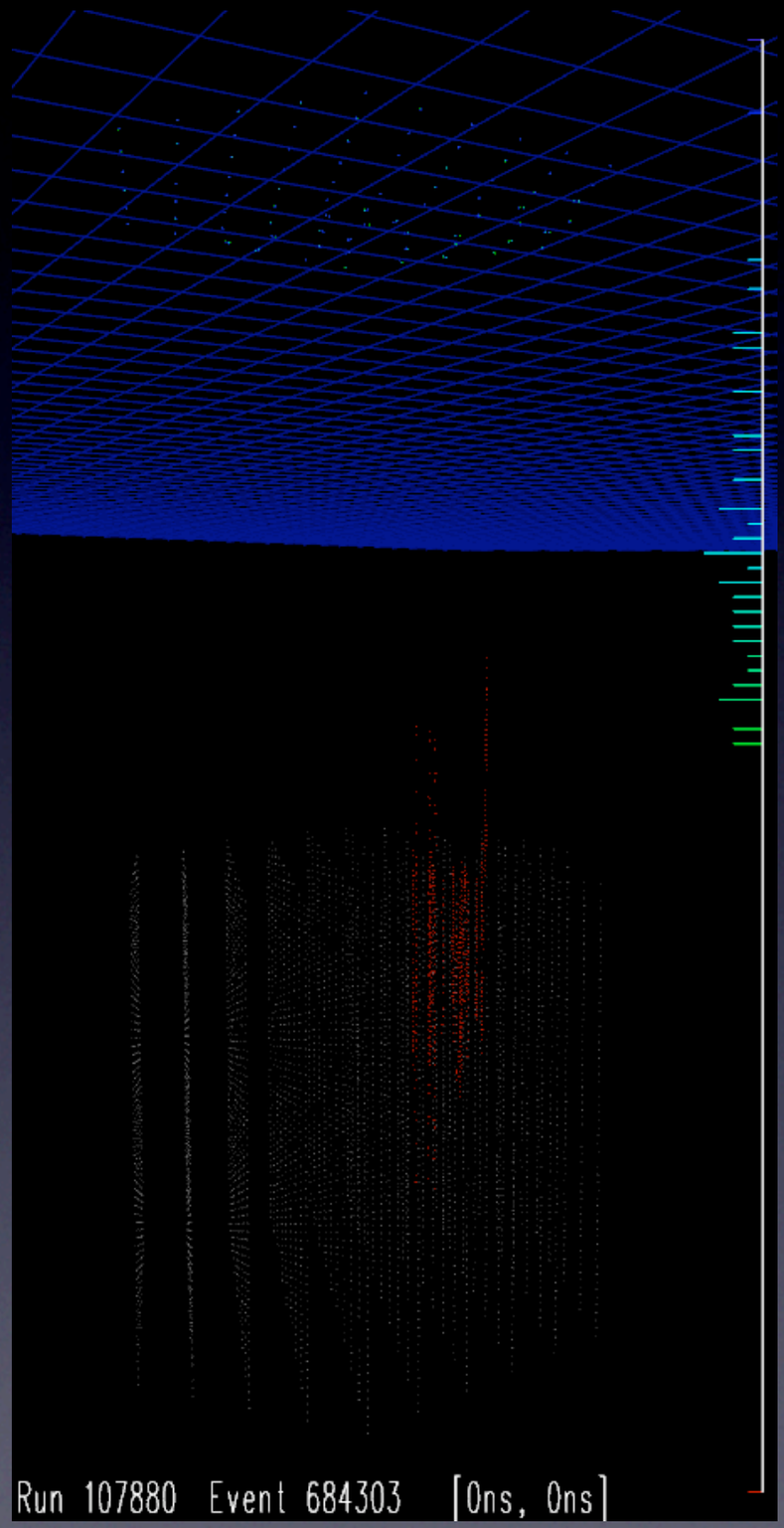


IceCube

- Atmospheric neutrinos with IC-9 (137.4 days)
- Analyses of IC-22 data are on-going



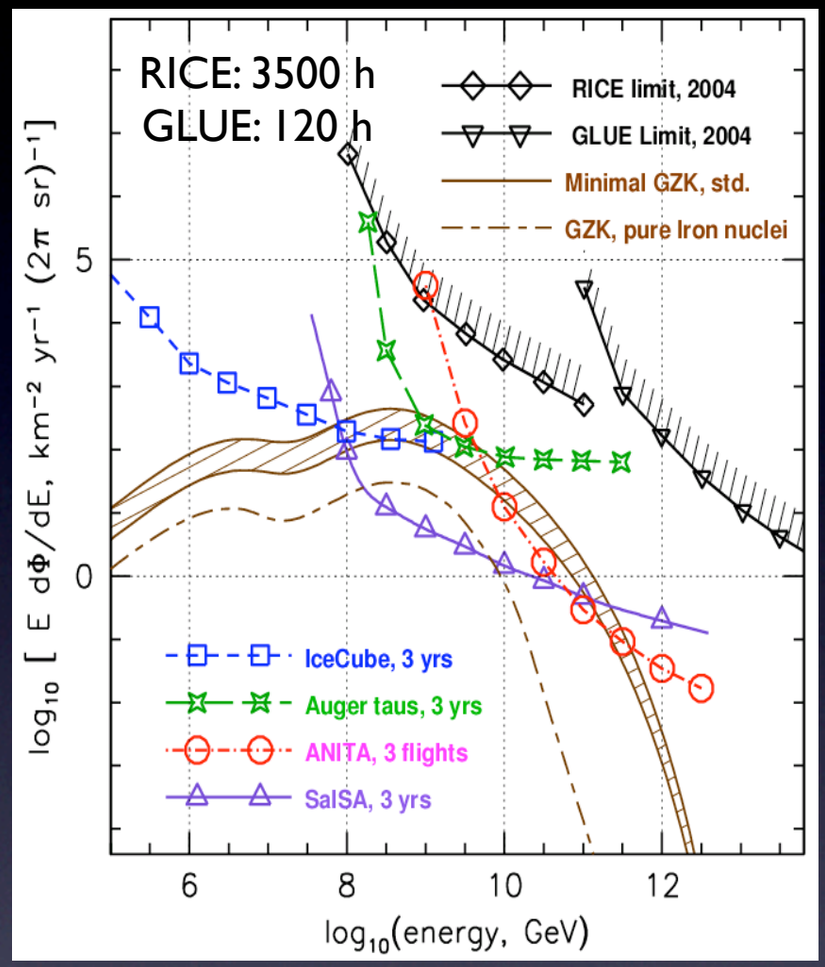
arXiv:0705.1781



Towards Very High Energies...

Basic Facts

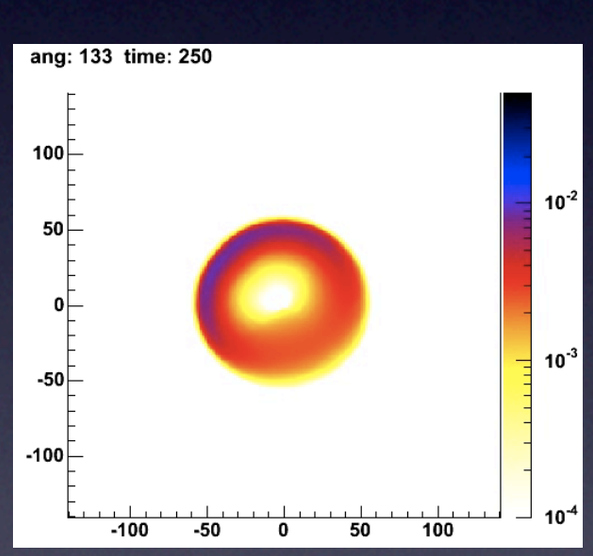
- Possible sources:
  - AGNs
  - GZK (1.5-3 GZK events in 3 years, IC-80)
  - Exotic processes...
- At E > 40 TeV
  - The Earth is opaque to neutrinos
  - IceCube looks for neutrinos coming from the top
  - Light input is significantly higher



In the following:
ν_e with E > ~100 PeV

IceCube Simulation

- Emission of Cherenkov light in the ice is done by "Photonics"
- Cascades are considered as point sources of light
  - OK for low energies
  - Bad for VHE
- LPM is not taken into account

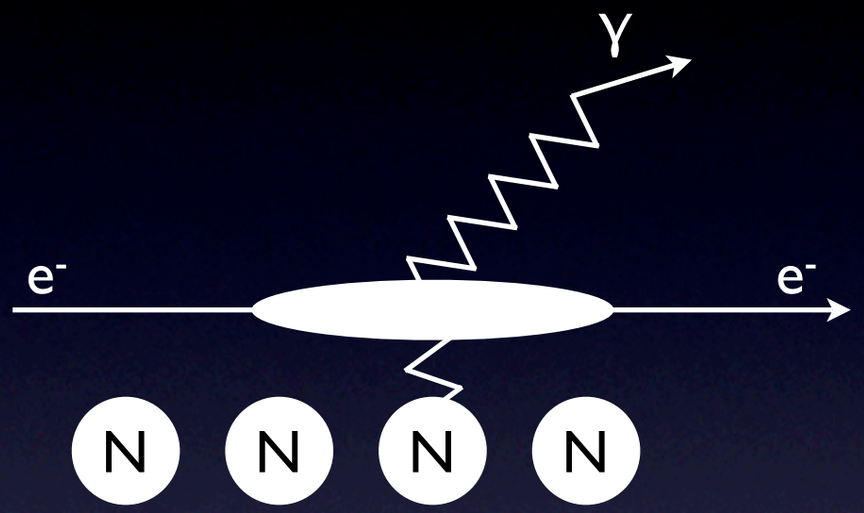


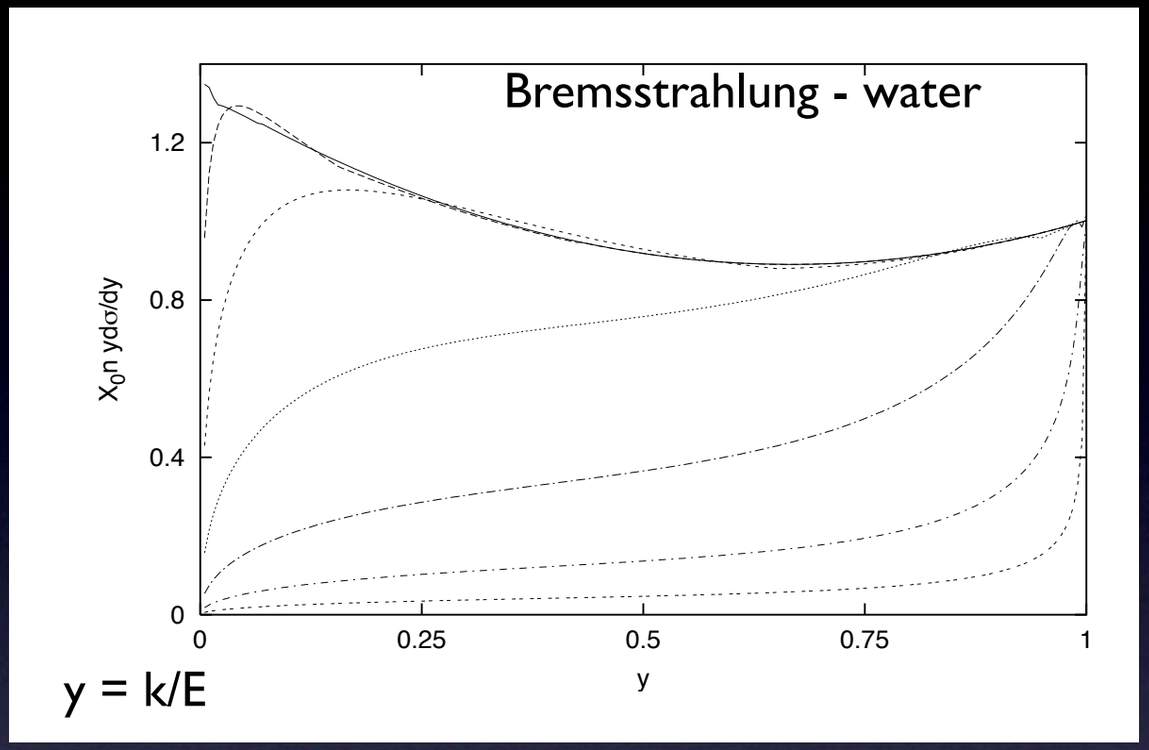
Longer cascades

Better angular resolution !?

Simulation needs to be improved !

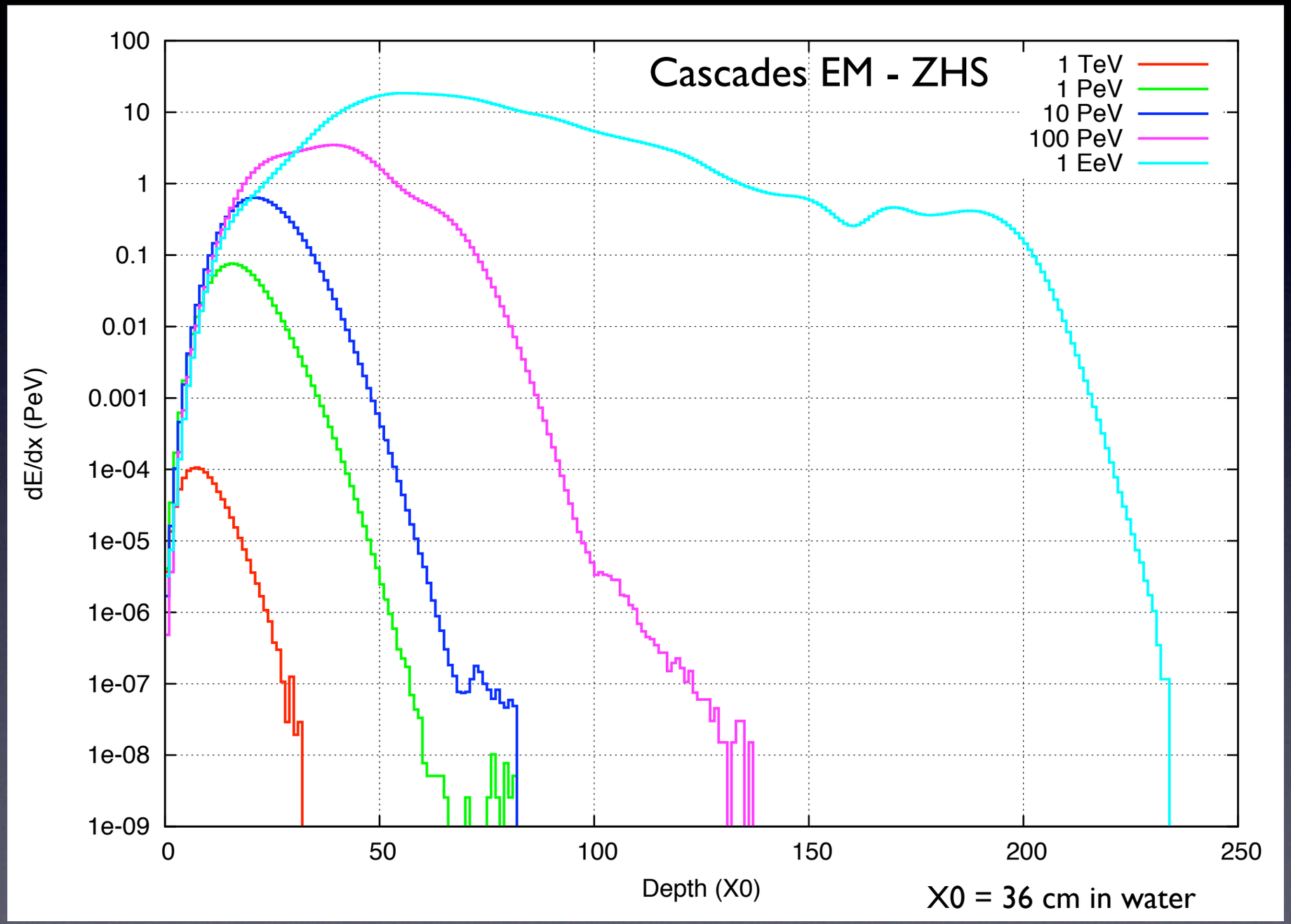
The LPM Effect





- Landau-Pomeranchuk-Migdal
- Multiple Coulomb scattering by atoms in a dense medium
- Reduction of pair production and bremsstrahlung cross-sections
- Result: cascades are longer ! More fluctuations !
- E_{EM} > ~20 PeV and $E_{HAD.}$ > ~10 EeV

The LPM effect



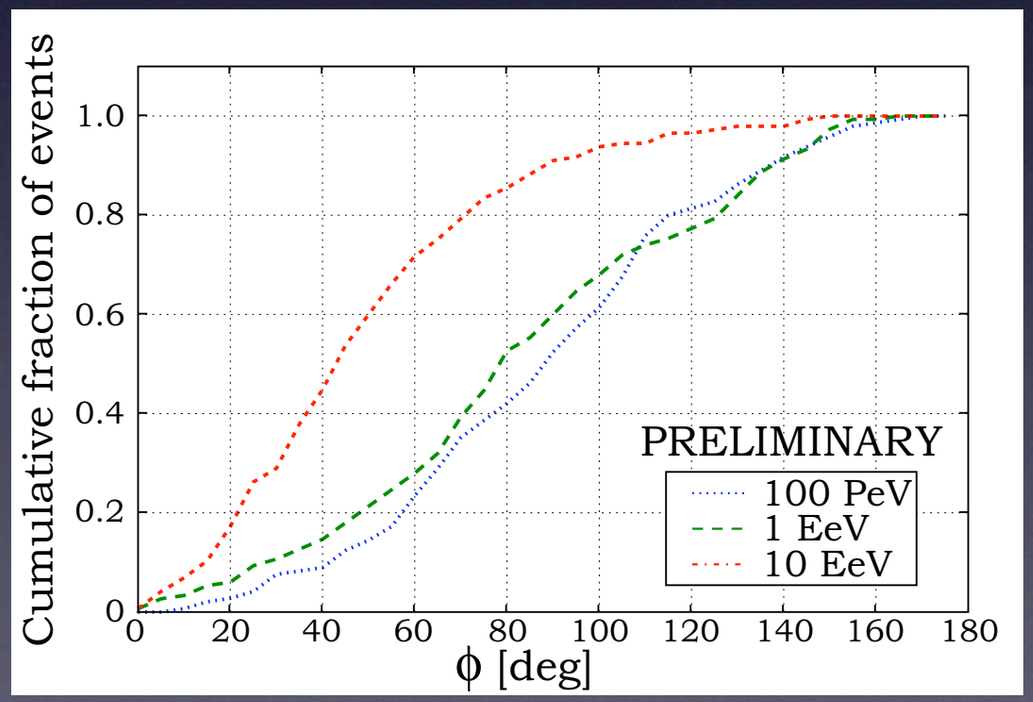
Longer cascades

Better angular resolution ?

A First Attempt

B. Voigt

- Using parameterisations of cross section with a fast hybrid approach
- Using a muon track reconstruction algorithm
- At 1 EeV, ~5% of the cascades reconstructed with a precision < 20°
- At 10 EeV, ~20% of the cascades reconstructed with a precision < 20°



30th ICRC Proceedings, arXiv:711.0553

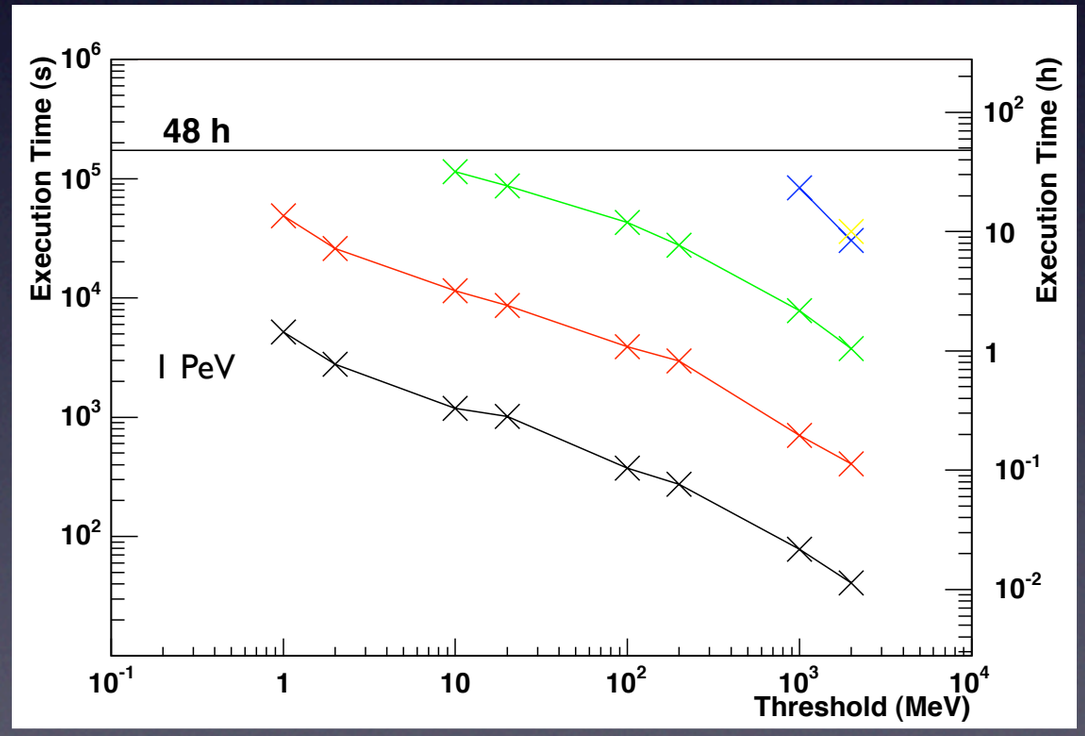
We need something more accurate !

Simulation Packages

- "Low Energy" simulation packages
  - GEANT4
    - E < O(TeV) for EM processes
    - E < ~20 TeV for Had. processes
    - LPM effect for pair-production is not included
  - FLUKA
    - E < O(PeV) for EM processes
    - E < 20 TeV for Had. processes (10 PeV with DPMJET)
    - LPM effect for pair-production is not included
- Other solutions: ZHS or CORSIKA !

ZHS

- Developed by E. Zas, F. Halzen & T. Stanev (Phys. Rev. D, 45, 362) and maintained by E. Zas and J. Alvarez-Muñiz
- LPM effect included for bremsstrahlung and pair production
- Output: longitudinal profile, radial profile, track length
- Execution times similar to those obtained with GEANT
- EM processes only !

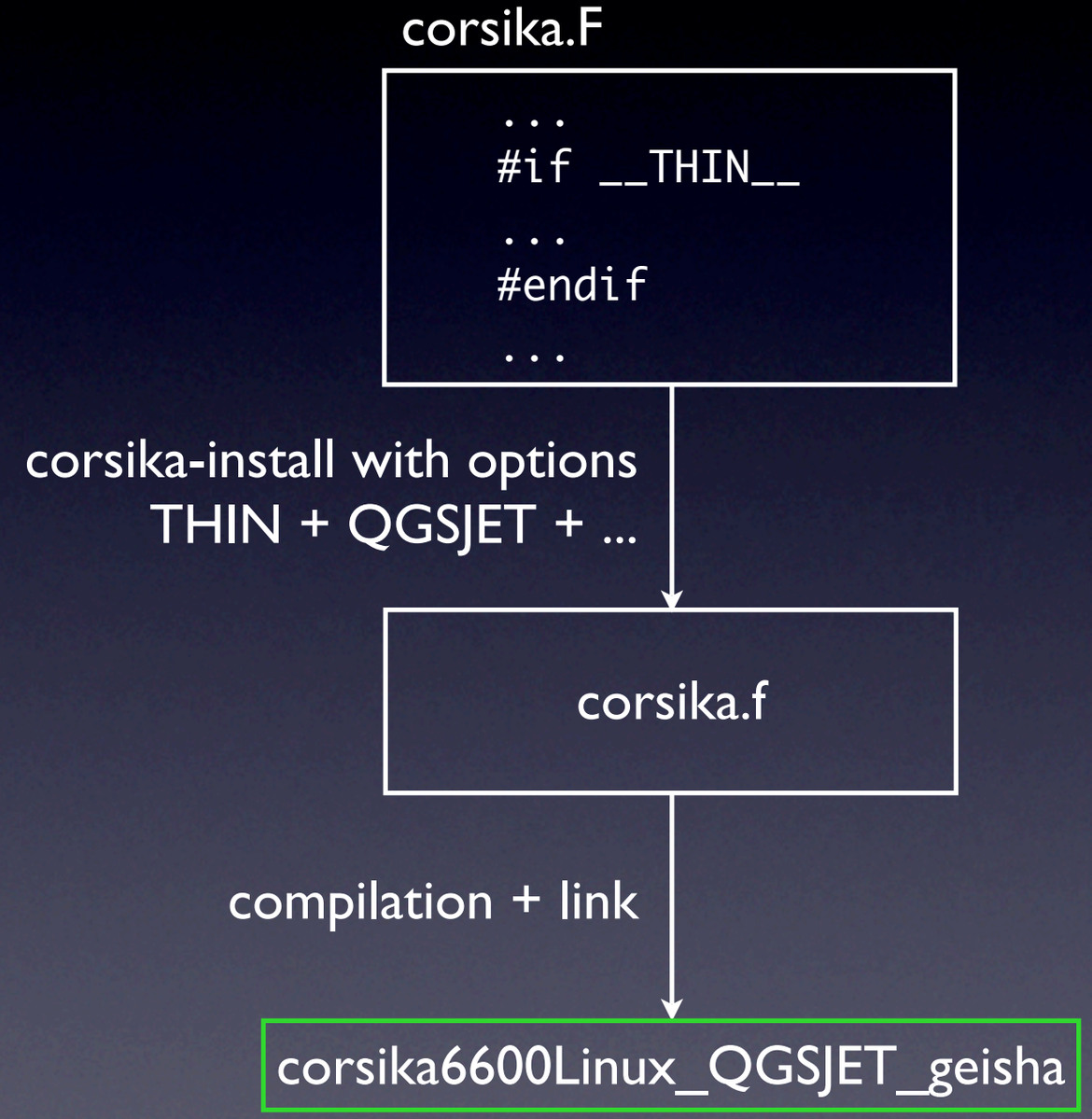


CORSIKA

- LPM included
- Various modules available (EGS4, QGSJET, VENUS, etc.)
- Already used in IceCube for muon background simulation
- Already modified for salt water by T. Sloan (Lancaster University) for the ACoRNE collaboration (arXiv:0704.1025)

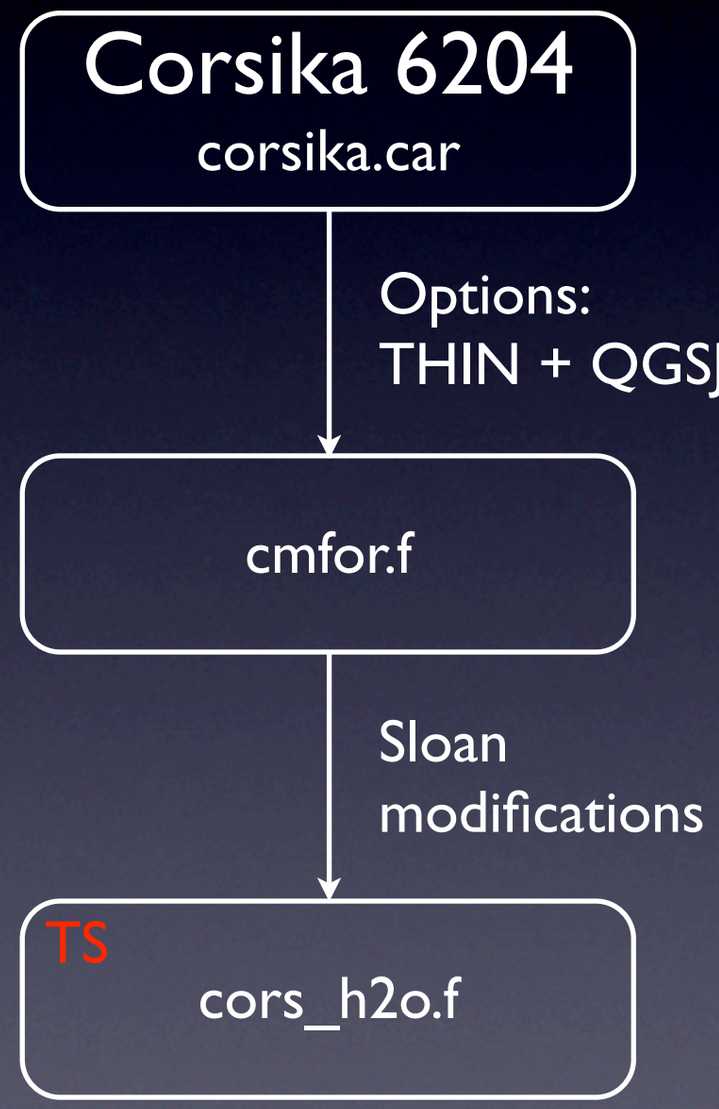
CORSIKA structure

- One master file (src/corsika.F)
- Use of C preprocessor conditions
- Parts of the code are enabled/ disabled by running corsika-install
- Different versions/options can exist in parallel



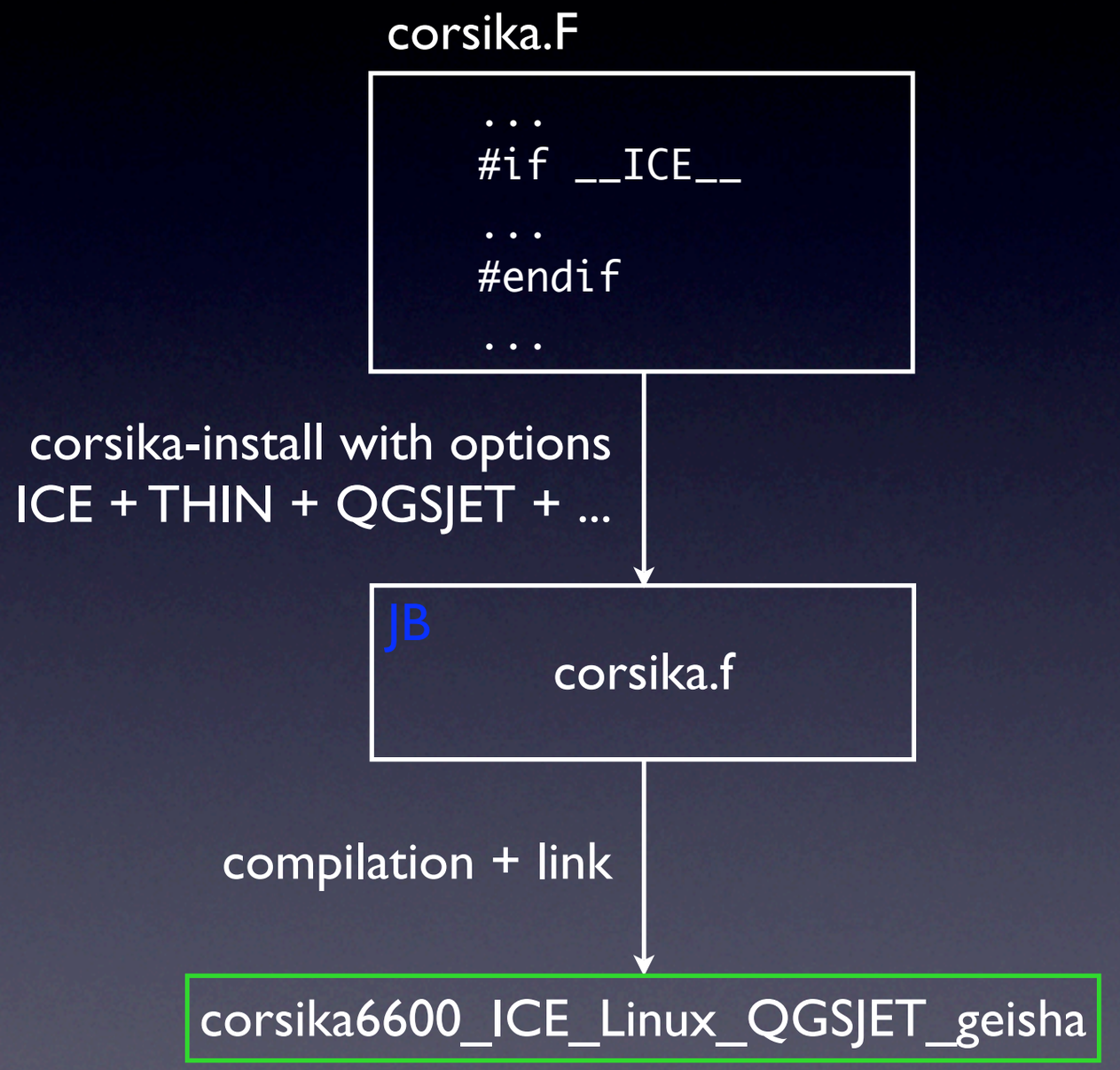
Limitations of Sloan's version

- Old version of CORSIKA (6204)
- Static code: CORSIKA options already chosen for us
- Only QGSJET & GHEISHA
- Fixed size: 20 meters of water



Features of the new version

- Option added to select AIR/SALT WATER/ICE
- All other options are available (*)
- Latest version of CORSIKA (6600)
- Variable size: new datacard entry



* If relevant for ice...

Development

- Modified files:
  - corsika.h.in, corsika.F, configure.in
  - 41 modifications
- Added files:

  run/EGSDAT5_1.ICE,

  run/EGSDAT5_3.ICE,...

  README_ICE, CHANGES_ICE

Features

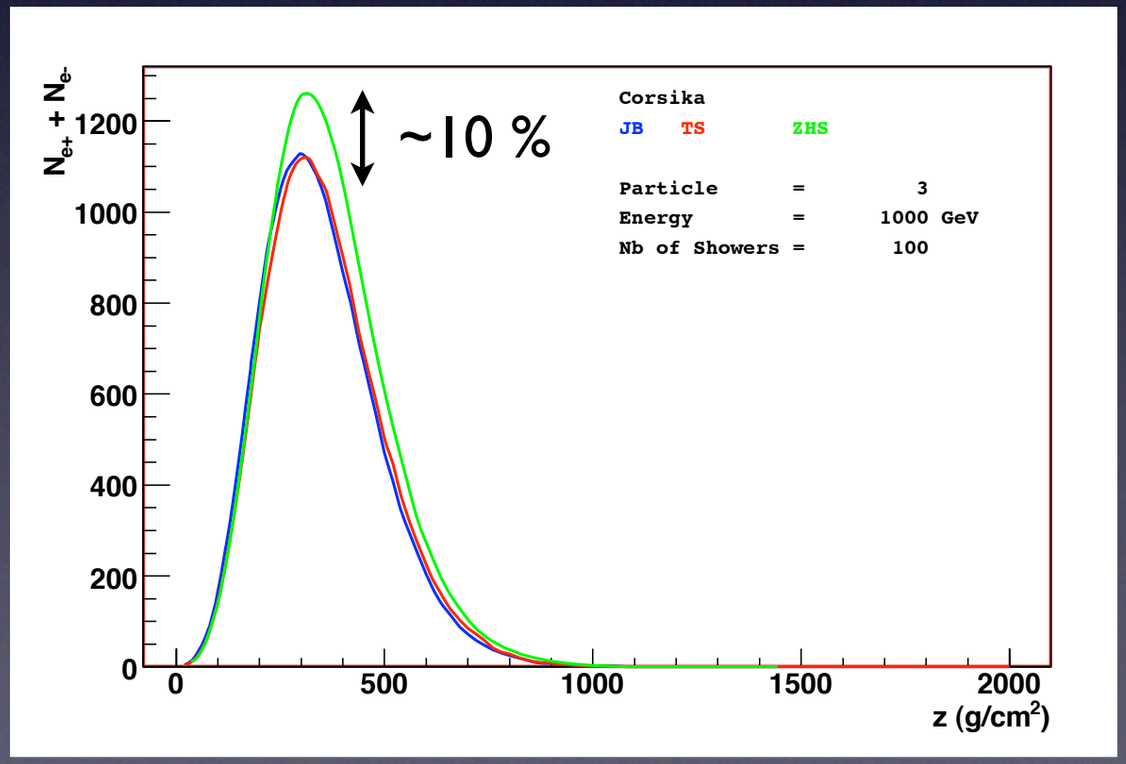
- Configuration option added for ice
- Possibility to have versions ICE/SALT WATER/AIR in parallel
- Possibility to combine options in many different ways
- Possibility to use many different hadronic simulation packages
- New entry in the datacard: possibility to tune the size of the simulated volume (VOLHEI)

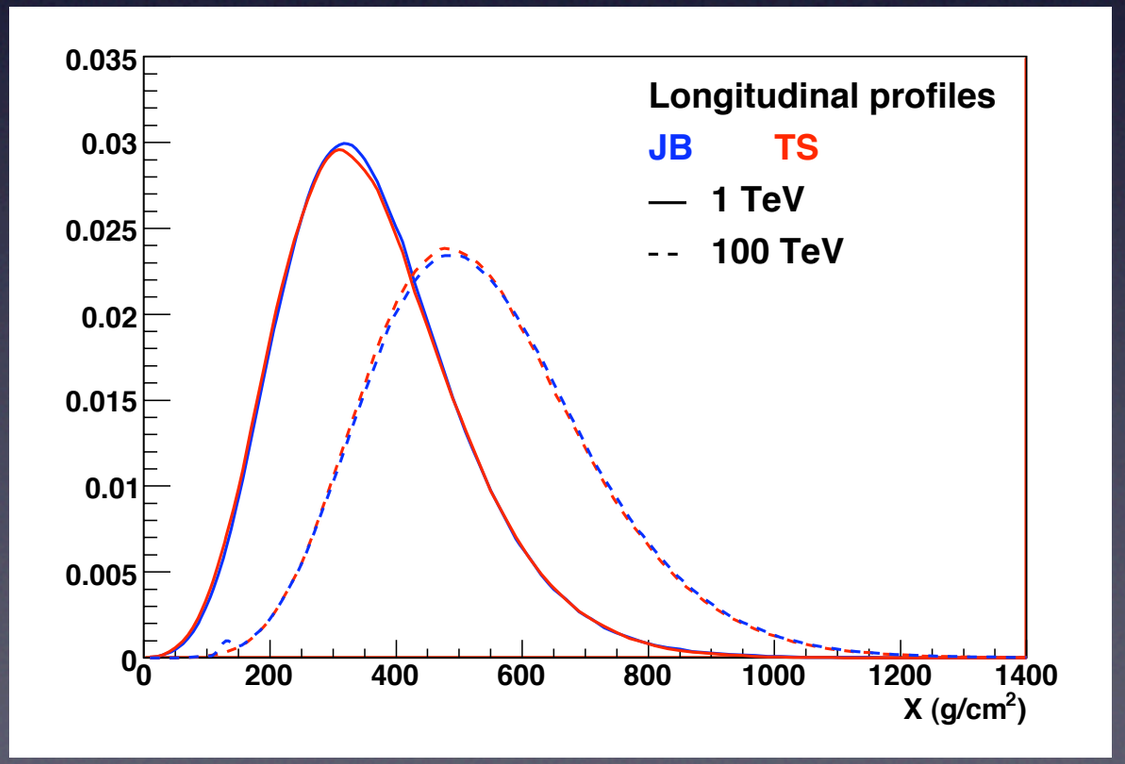
➡ Available on the web:

http://www-zeuthen.desy.de/~bolmont/corsika-ice/

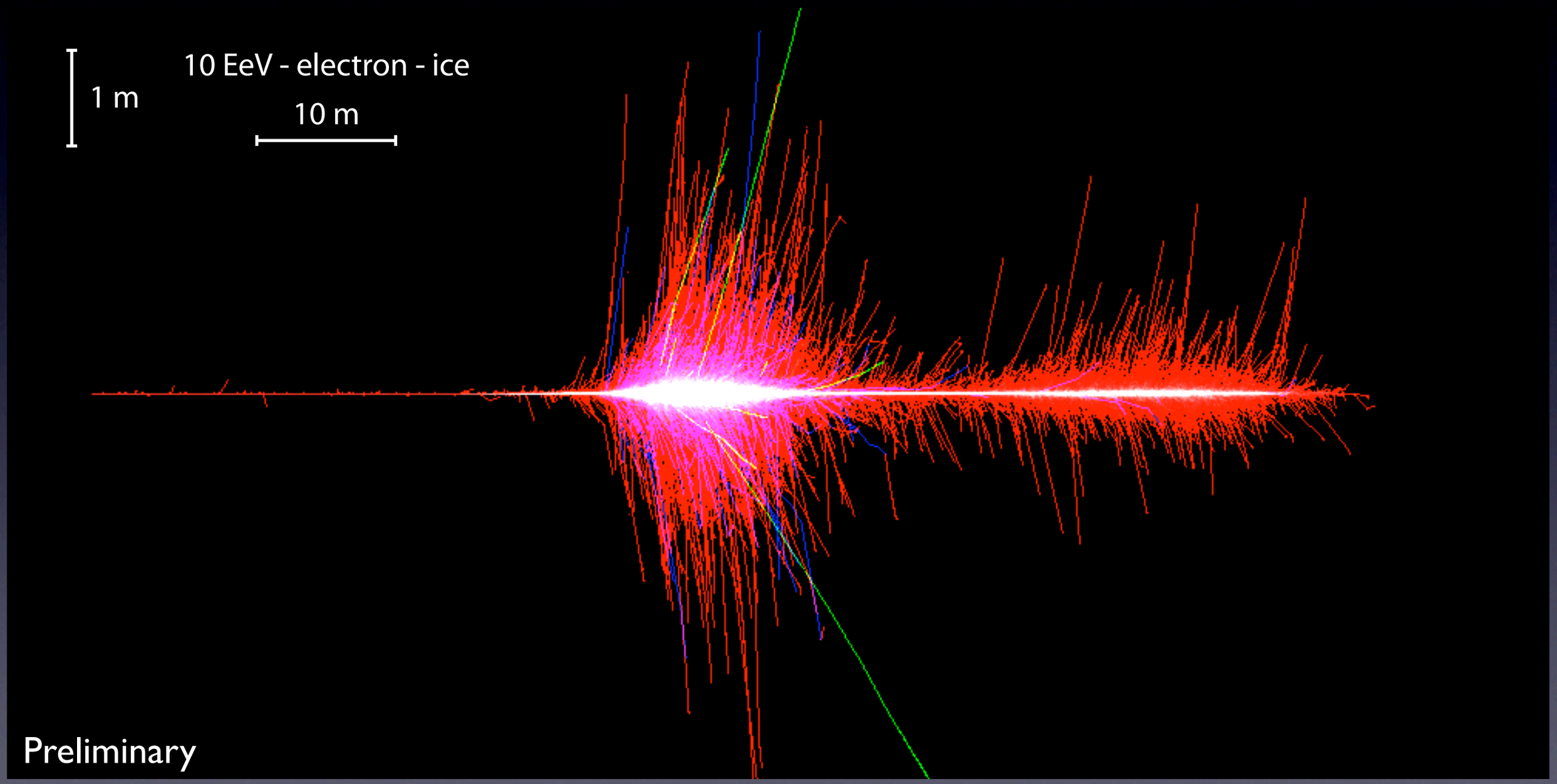
Comparison

- Comparison of longitudinal profiles for energy deposition with Sloan's version and the new version (e-)
- ~10% difference with ZHS already pointed out in the ACoRNE paper
- Comparison with GEANT4 is on-going

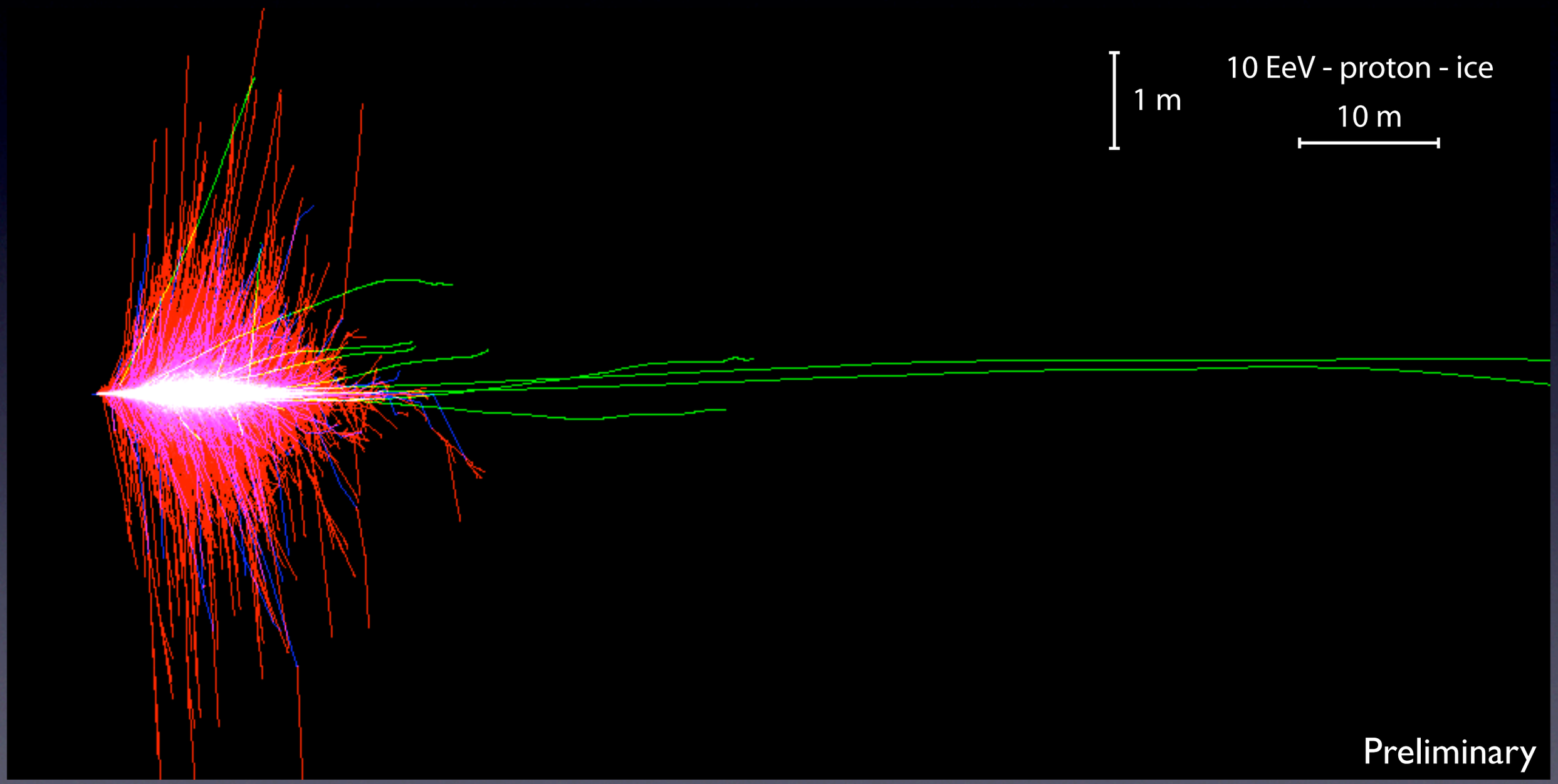




Electron - 10 EeV



Proton - 10 EeV



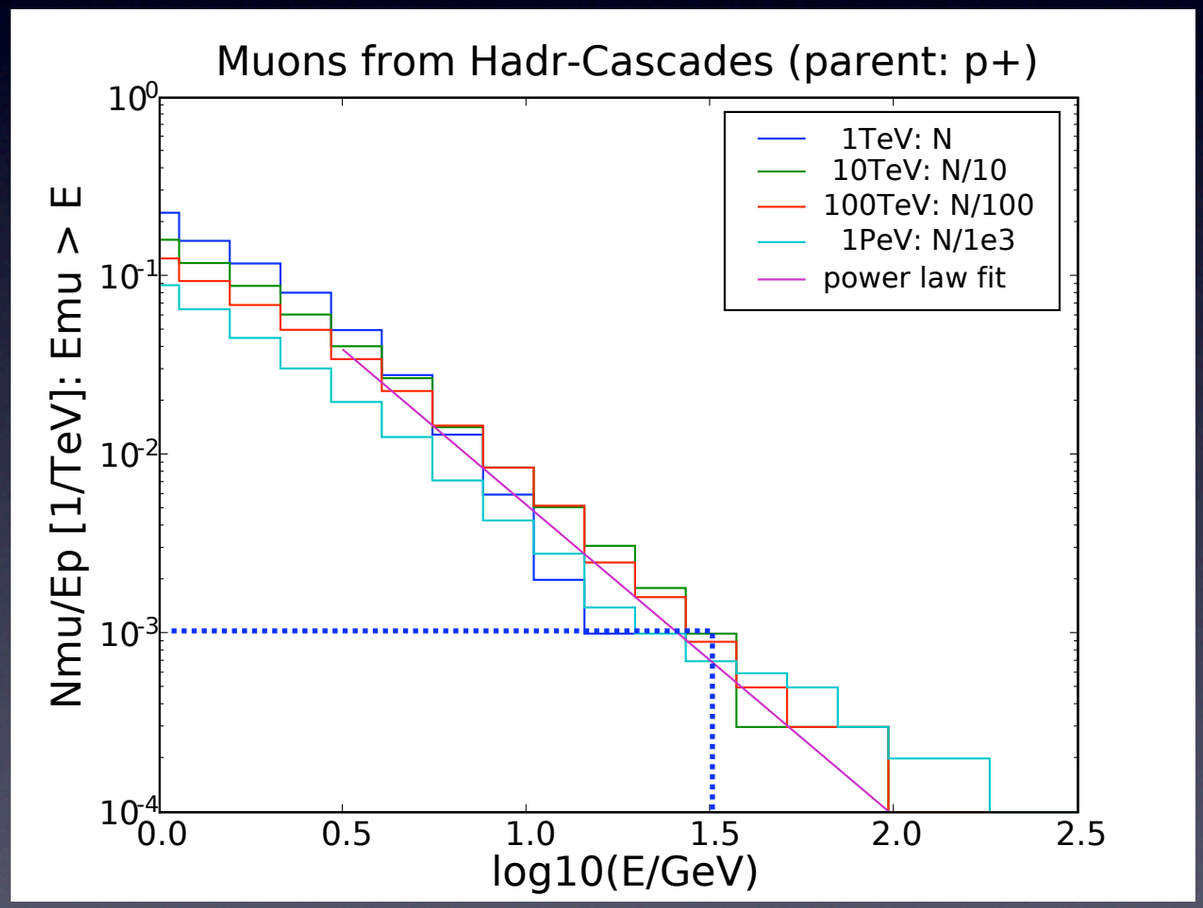
A Possible Application

S. Panknin

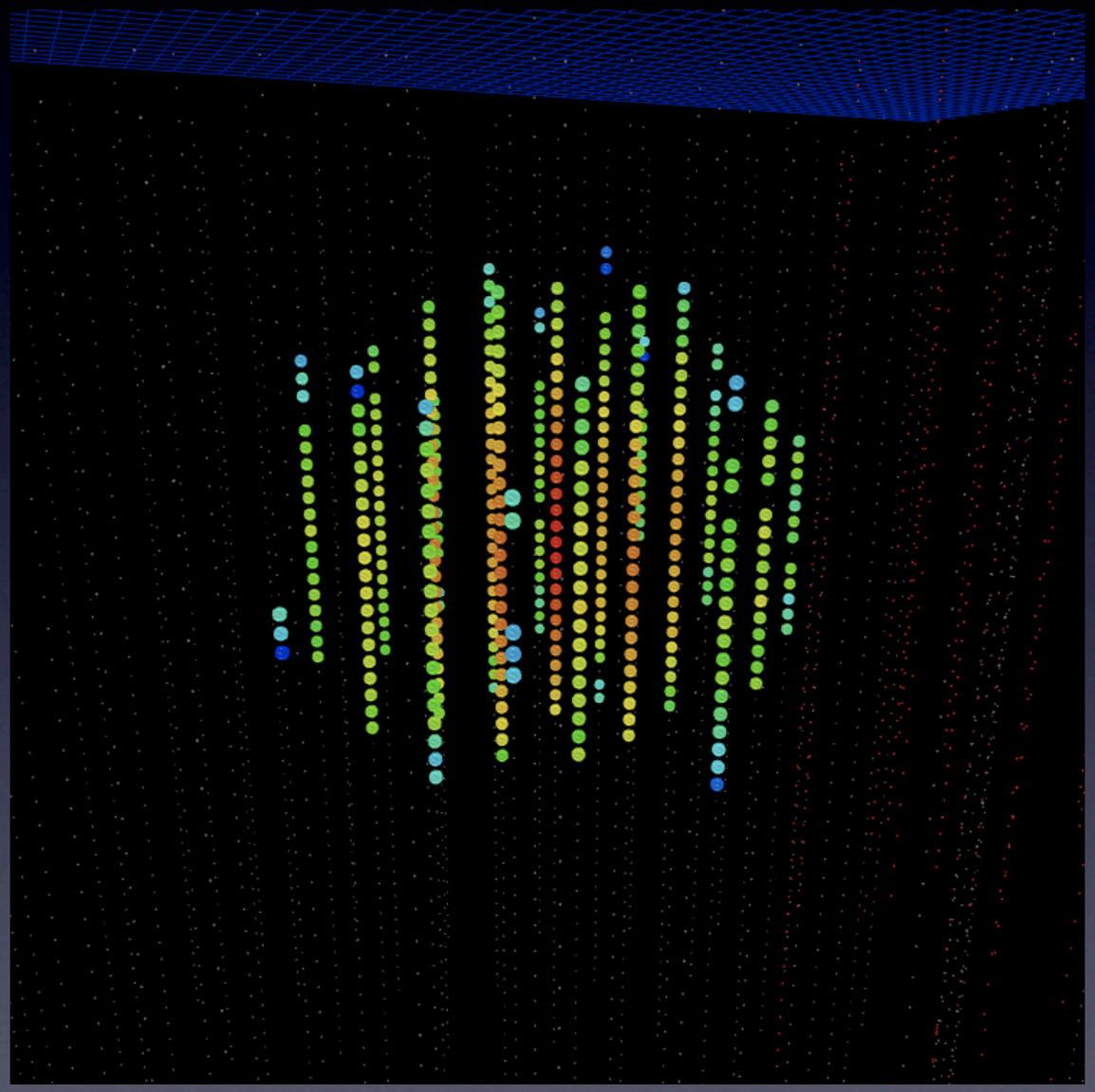
- Is it possible to see the muons going out of a hadronic cascade ?

- Looking for a muon > 30 GeV (~150 m track length)
- 10^{-3} muons per TeV
- So 1 muon > 30 GeV in a PeV cascade

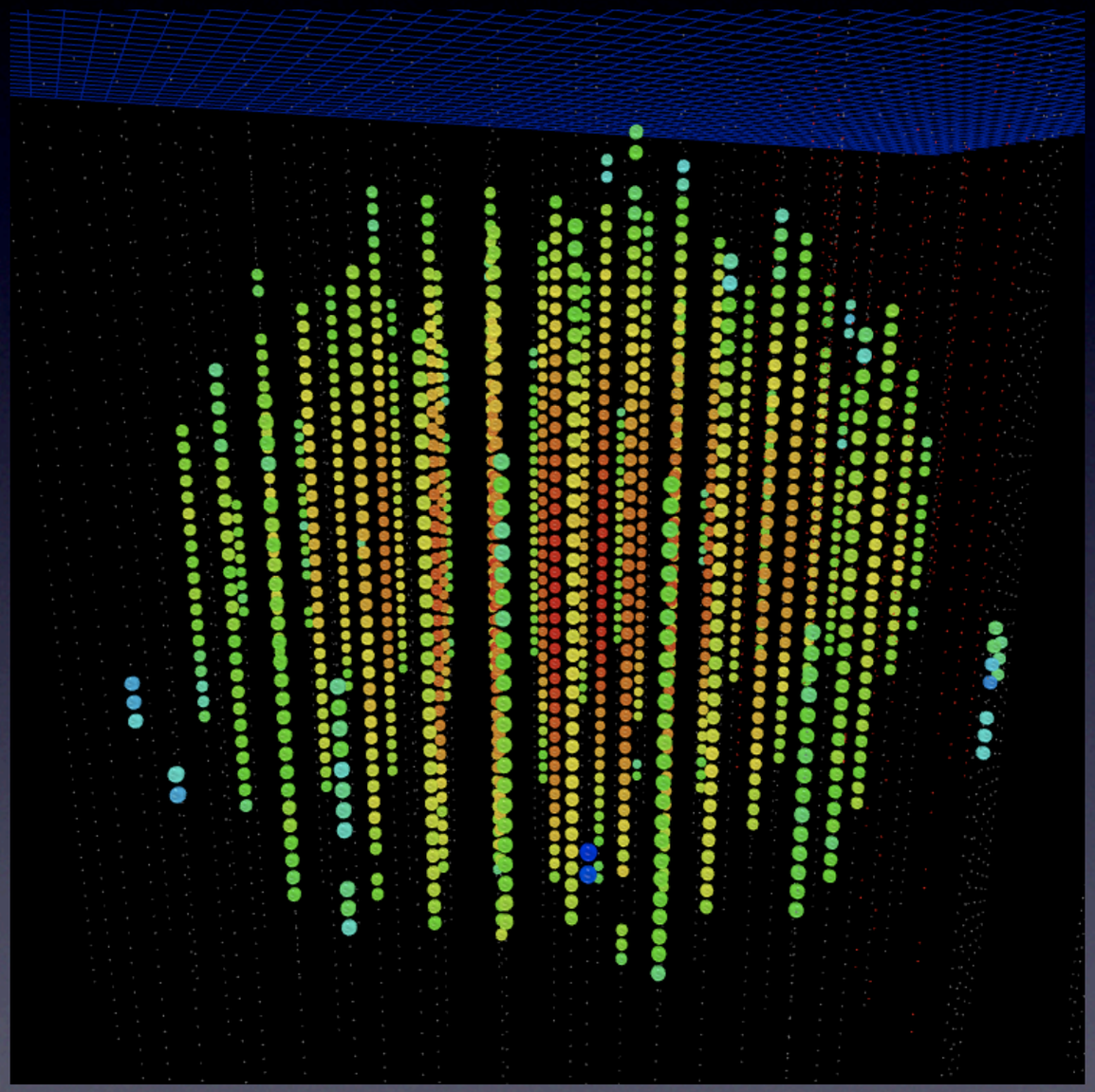
➡ Will be included in the I3 simulation



ν_e Events



7.6 PeV



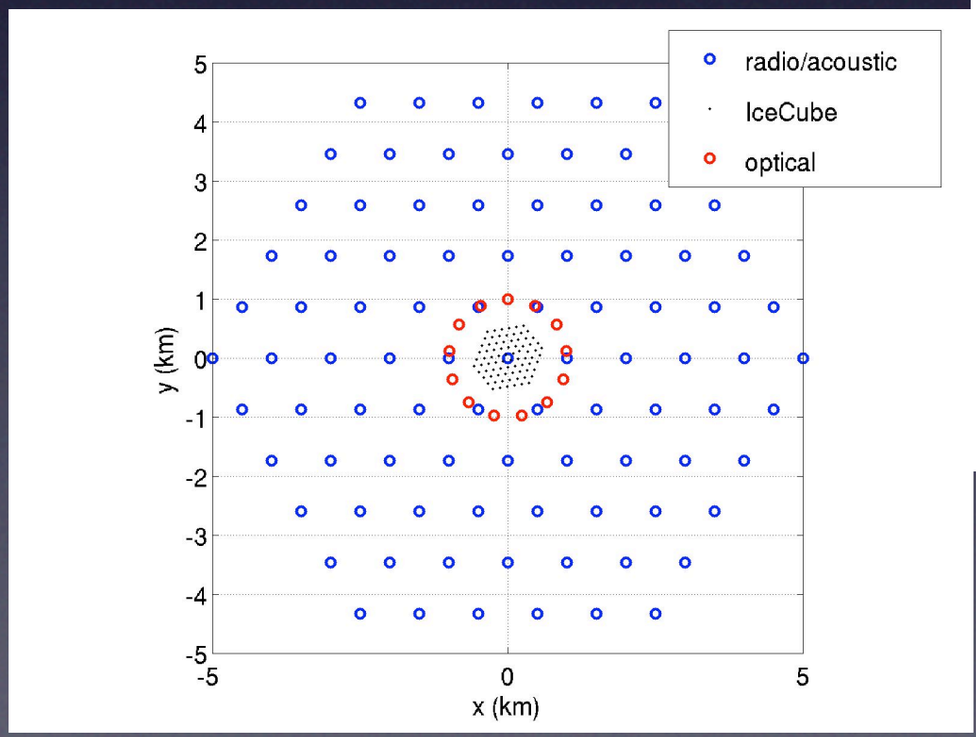
12.5 EeV

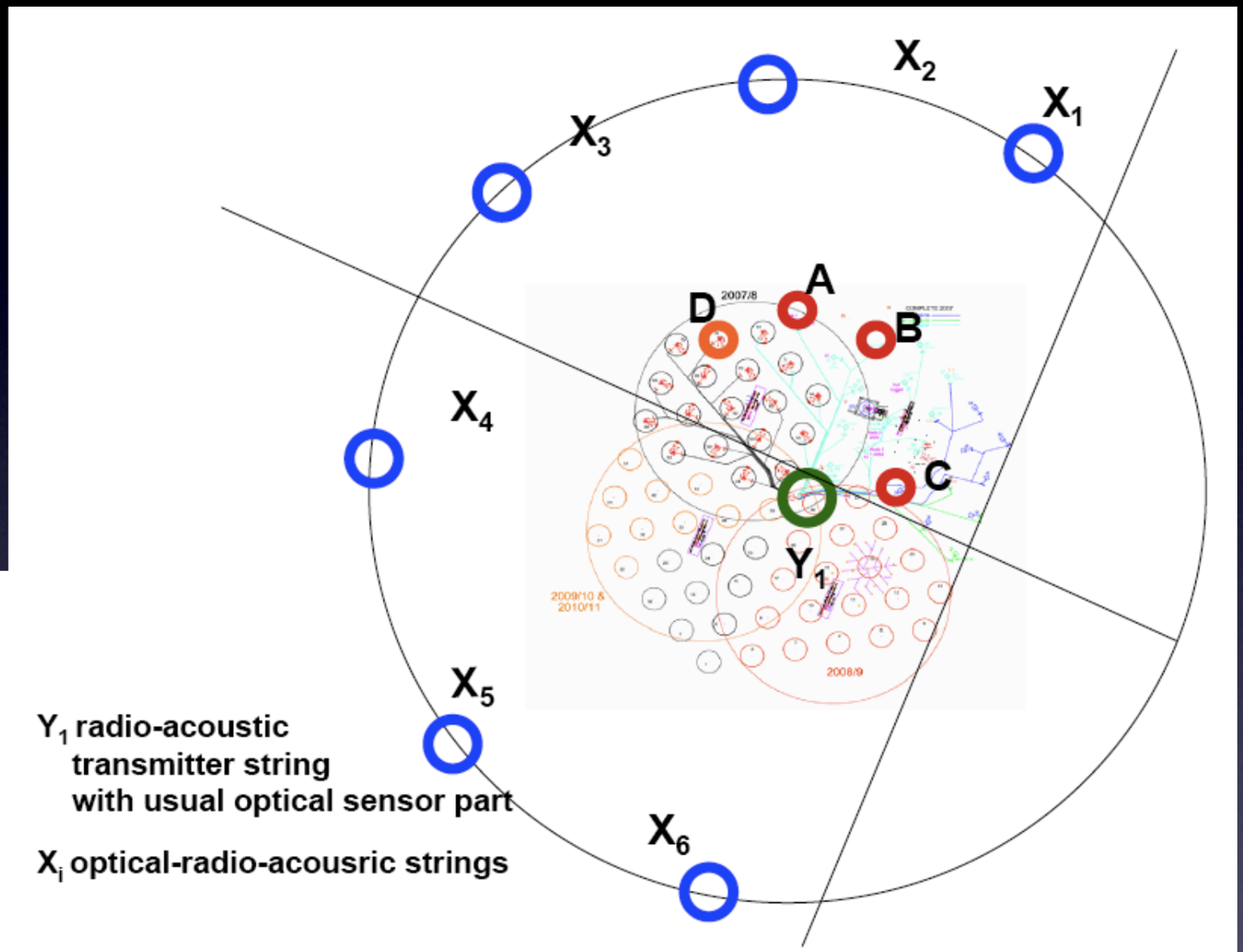
To Do Next !

- Extensive tests and comparisons are on-going with
  - GEANT4 at low energies
  - ZHS
- Systematic study of high energy cascades
- Improvement of the IceCube simulation package
- Information from saturated modules ?
- ...

IceCube High Energy Extension

- Hybrid configuration:
  - Radio
  - Accoustic
  - Optical





Studies have just started !

Conclusions

Conclusions

- AMANDA and IceCube are taking data
- Very good season 2006-2007 with 13 new strings
- 18 strings in season 2007-2008 ?

- IceCube with 22 strings is the biggest neutrino detector in the world
- IC-22 data are being analysed
- Integration of AMANDA and IceCube is on-going
- Work on low/high energy extensions has begun !

Merci !