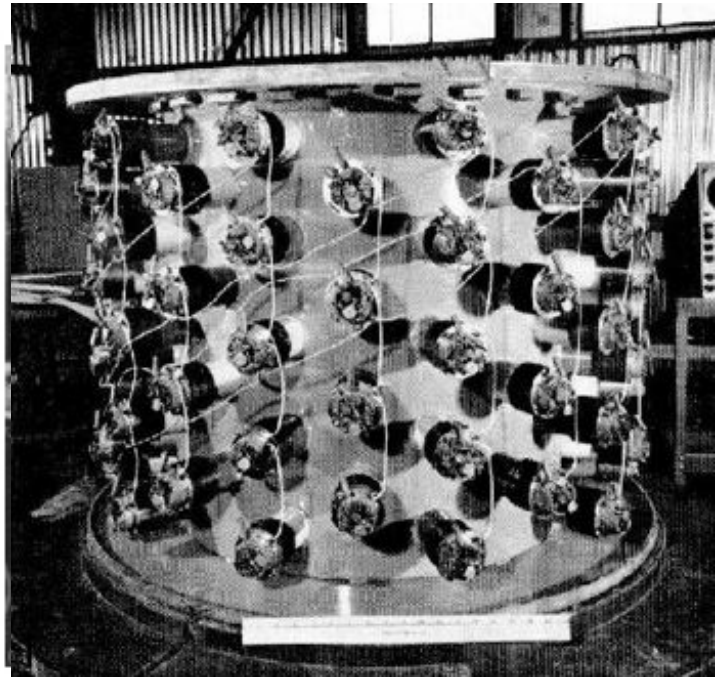
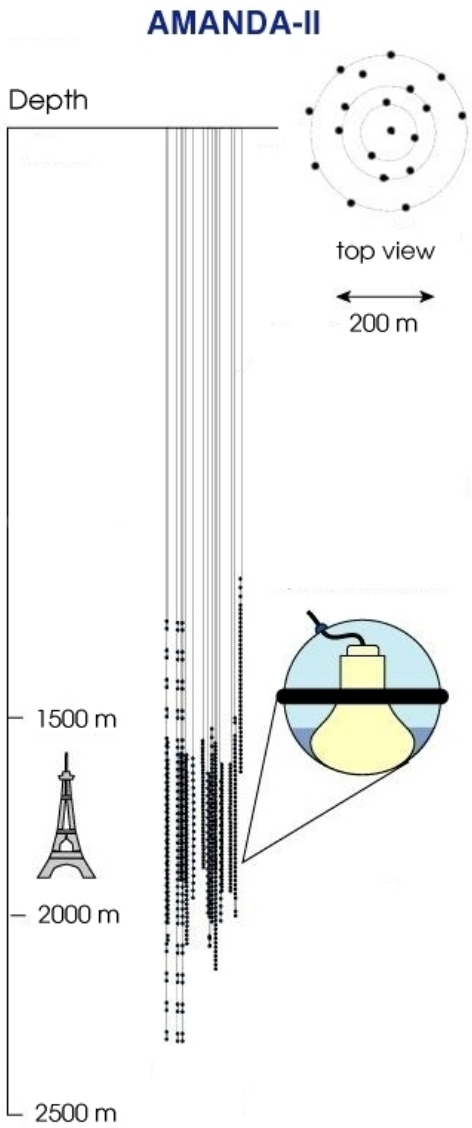
icebound neutrinos

Francis Halzen

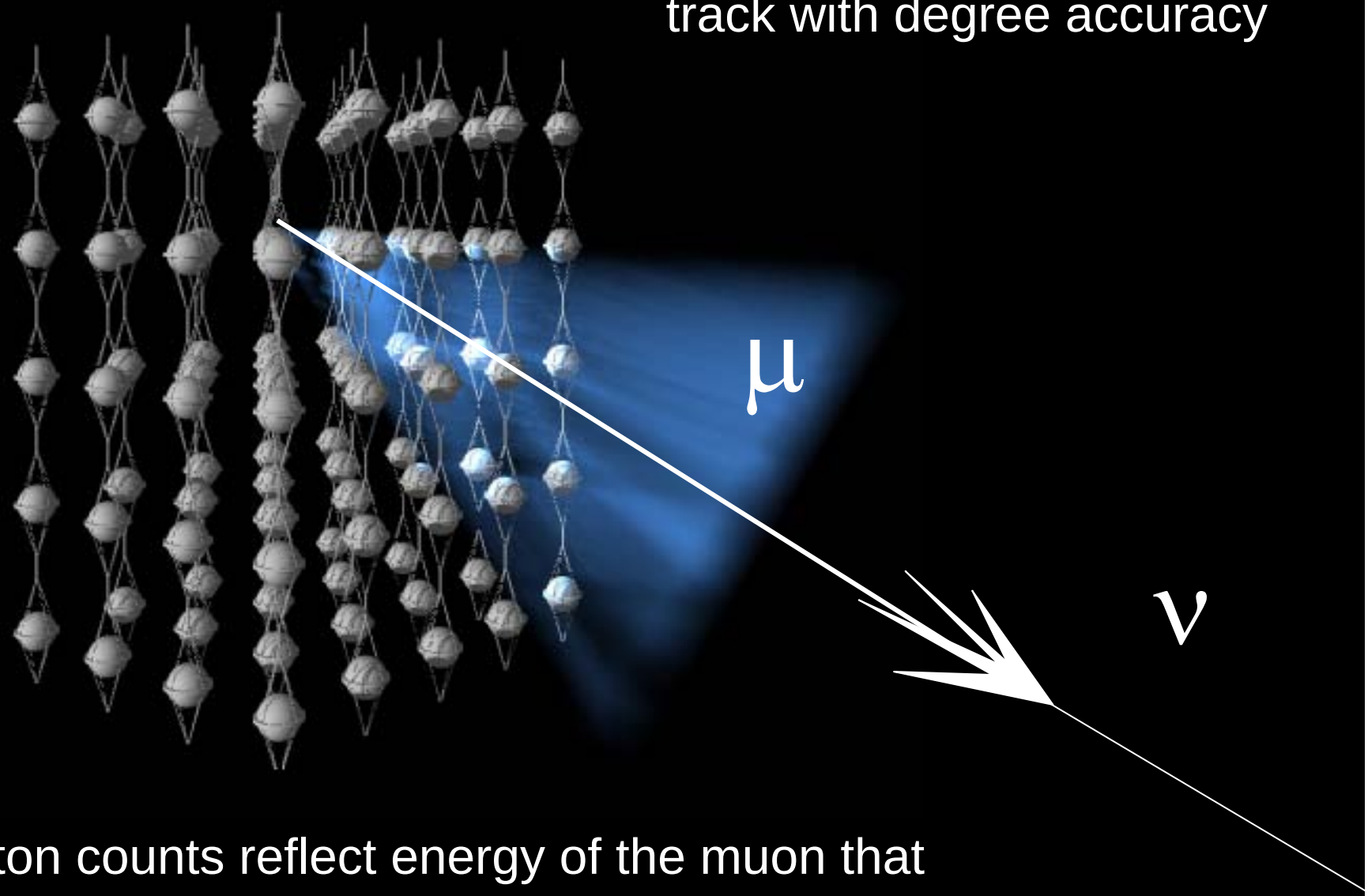
University of Wisconsin
http://icecube.wisc.edu

Kilometer-Scale Neutrino Detectors



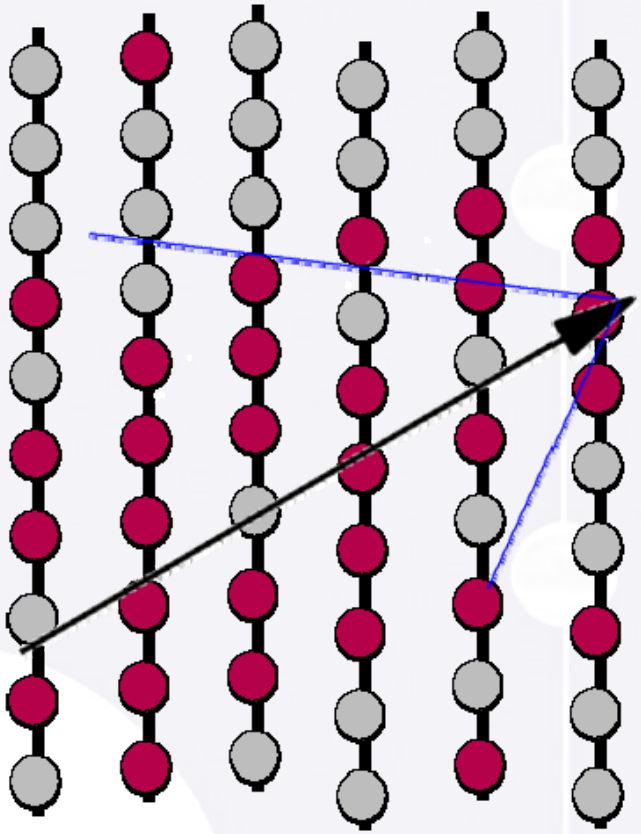


- nanosecond timing allows likelihood reconstruction of the track with degree accuracy



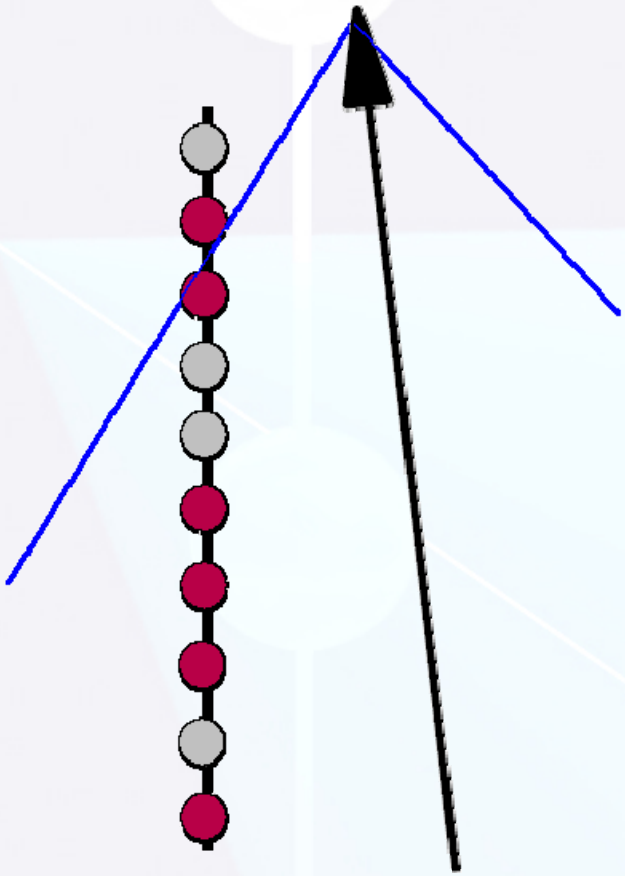
- photon counts reflect energy of the muon that loses energy catastrophically (bremsstrahlung,…)

DAQ trigger



multiplicity trigger

24 OMs in 2.5μs



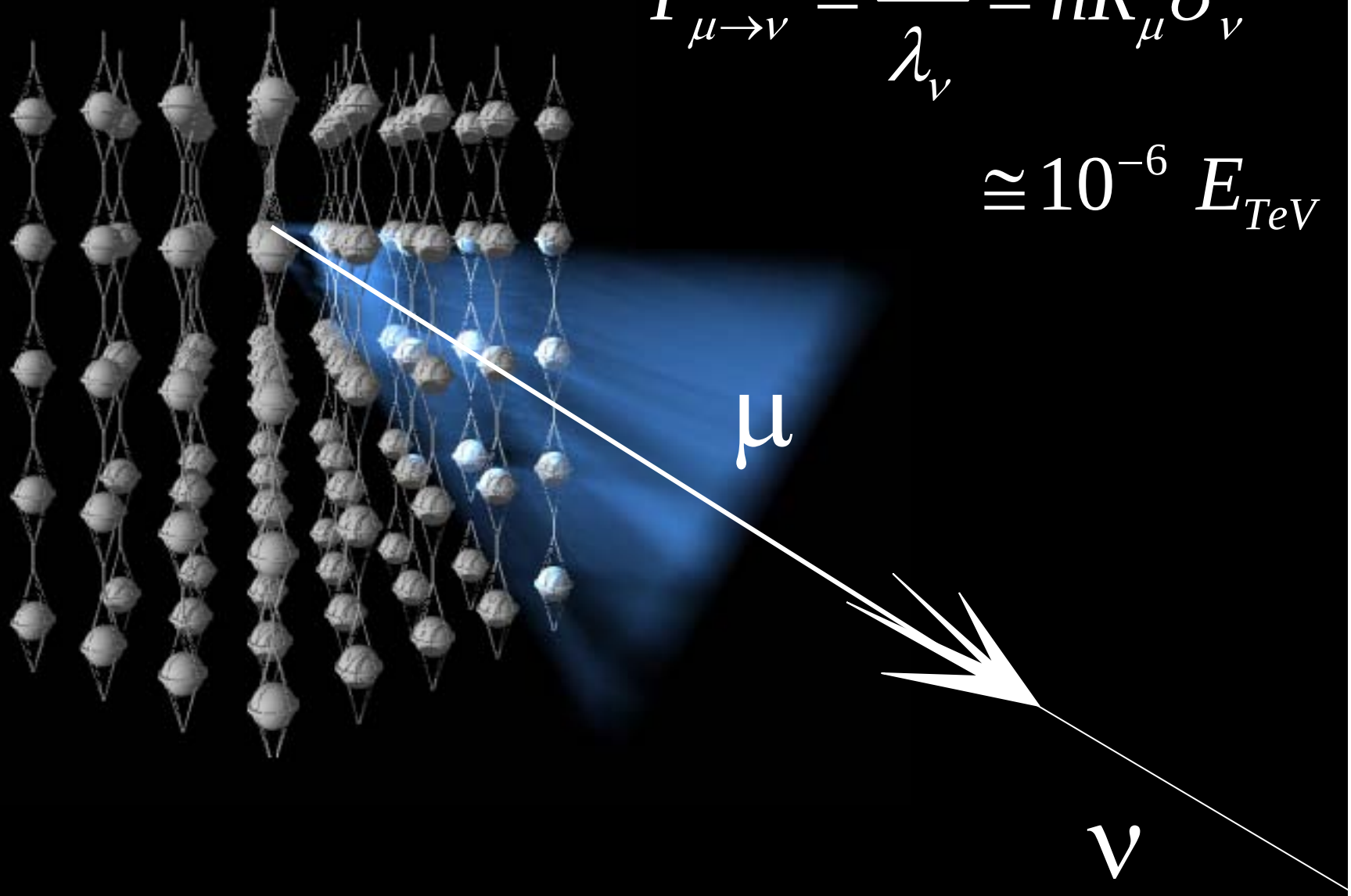
string trigger

6/9 (7/11) OMs in 2.5μs

detection method

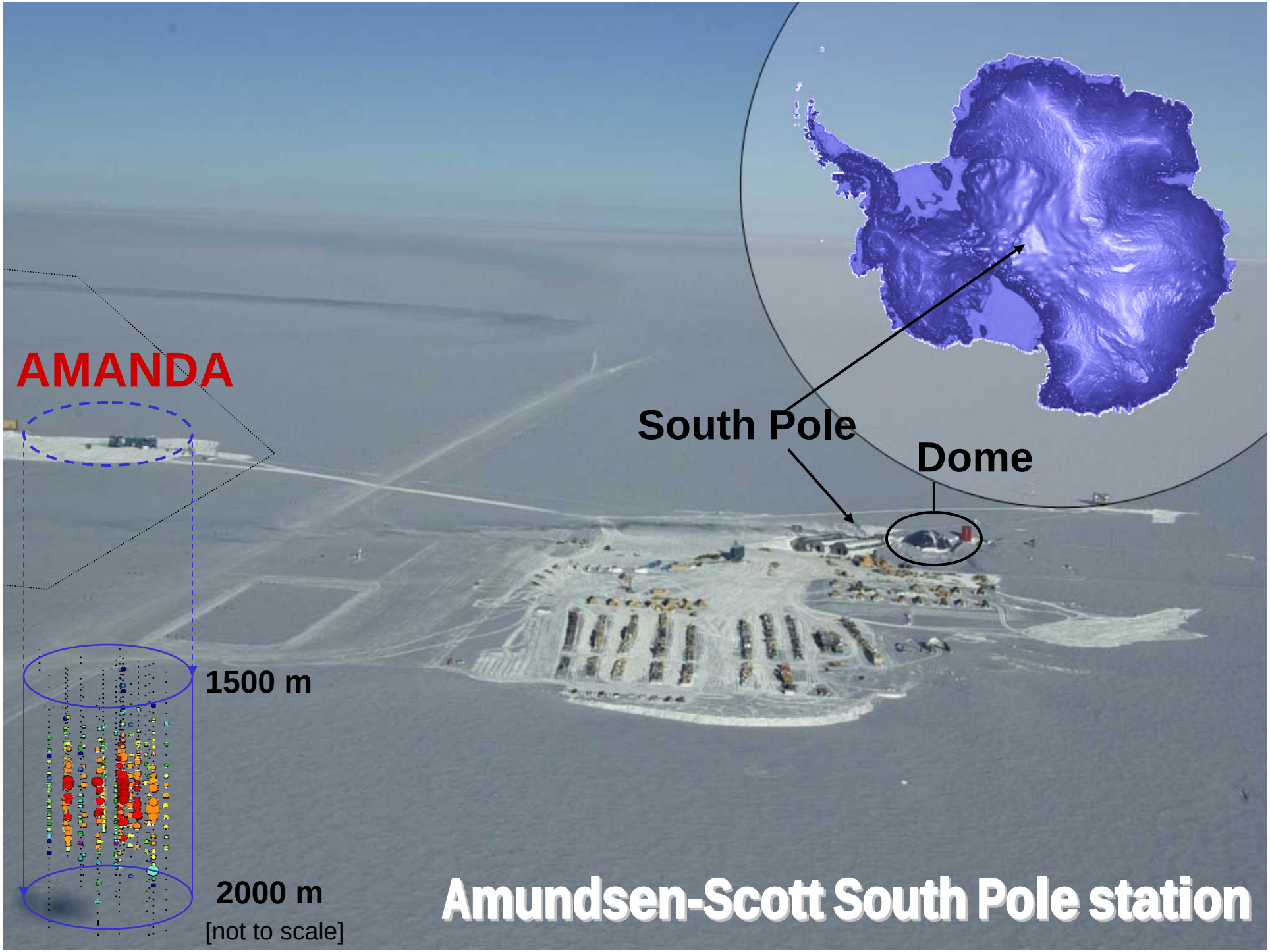
$$P_{\mu\to\nu} = \frac{\lambda_\mu}{\lambda_\nu} = nR_\mu\sigma_\nu$$

$$\cong 10^{-6}\ E_{TeV}$$



unfortunately, detecting a neutrino is difficult !

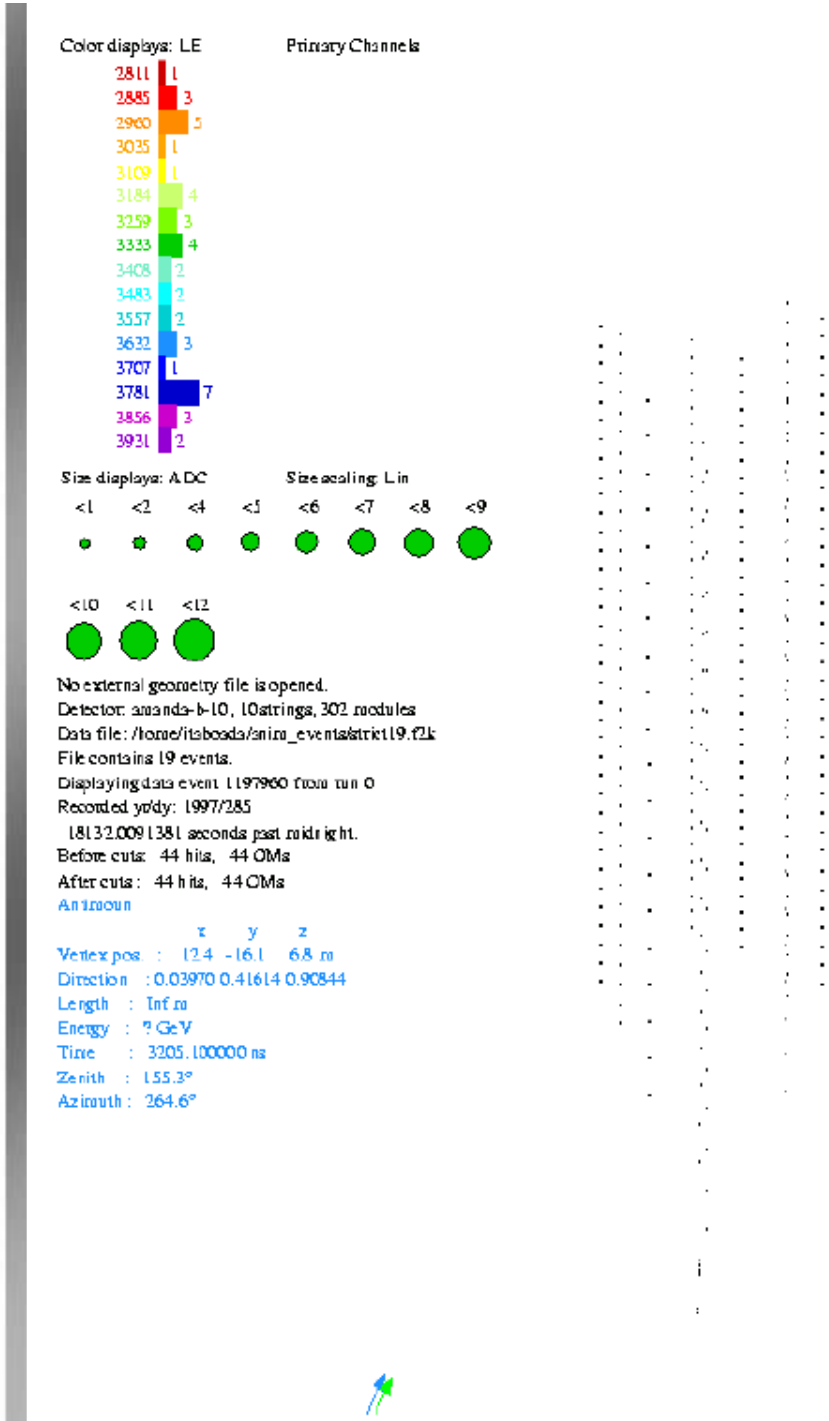
AMANDA: proof of concept


AMANDA
South Pole
Dome
1500 m
2000 m
[not to scale]
Amundsen-Scott South Pole station

AMANDA Event Signatures: Muons

muon neutrino interaction → track

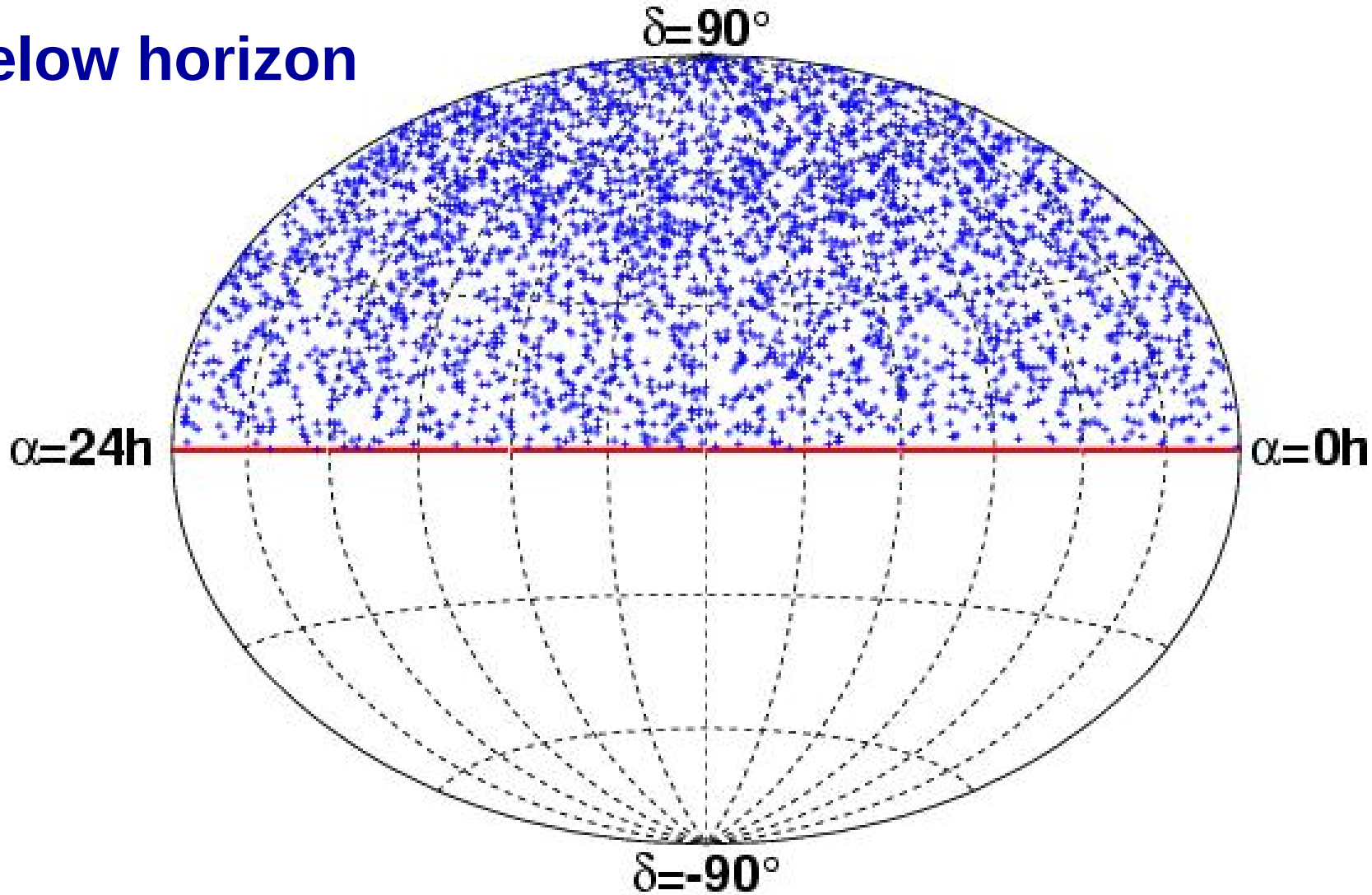
$$\nu_\mu + N \rightarrow \mu + X$$

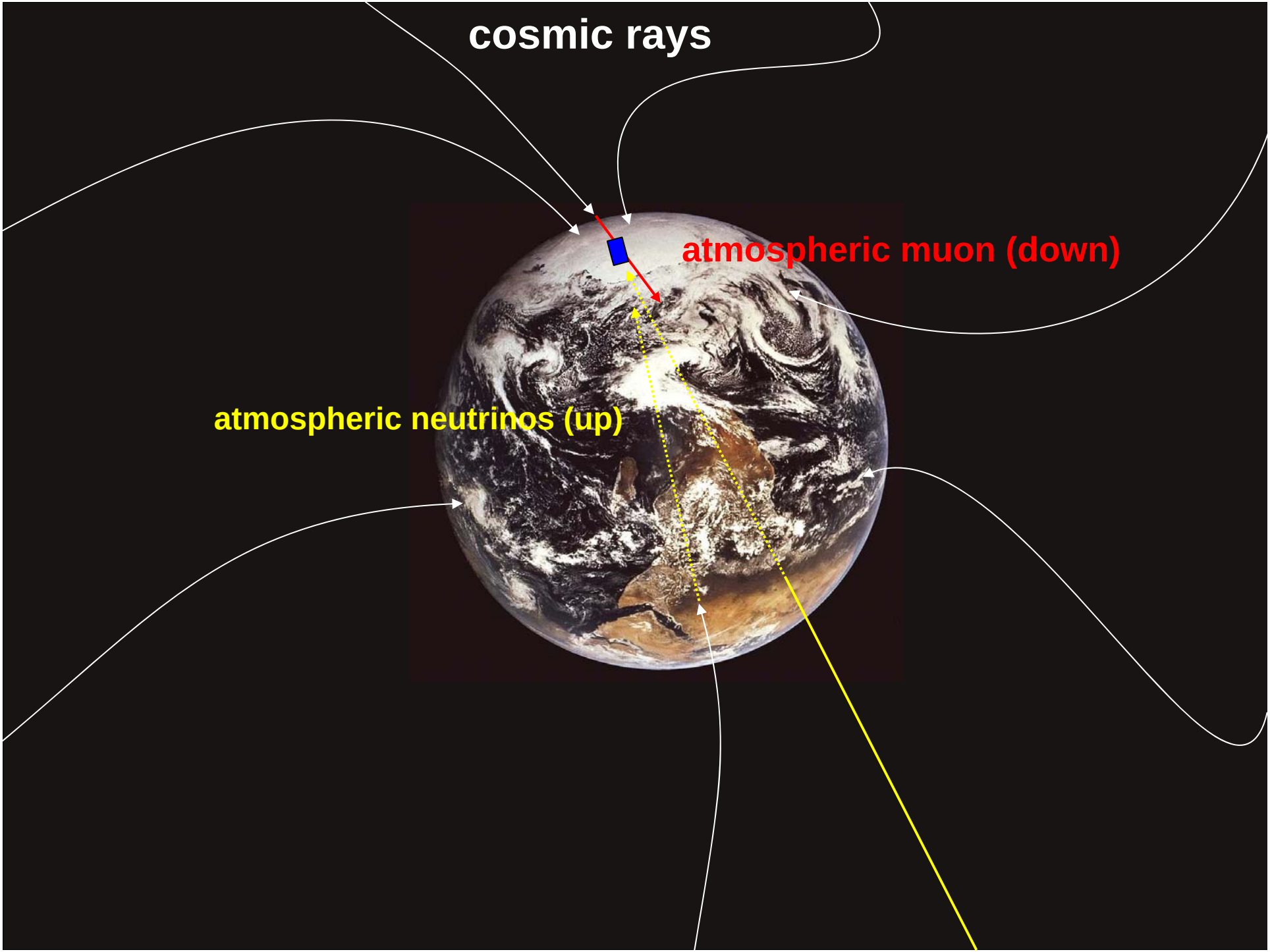


AMANDA skyplot 2000-2003

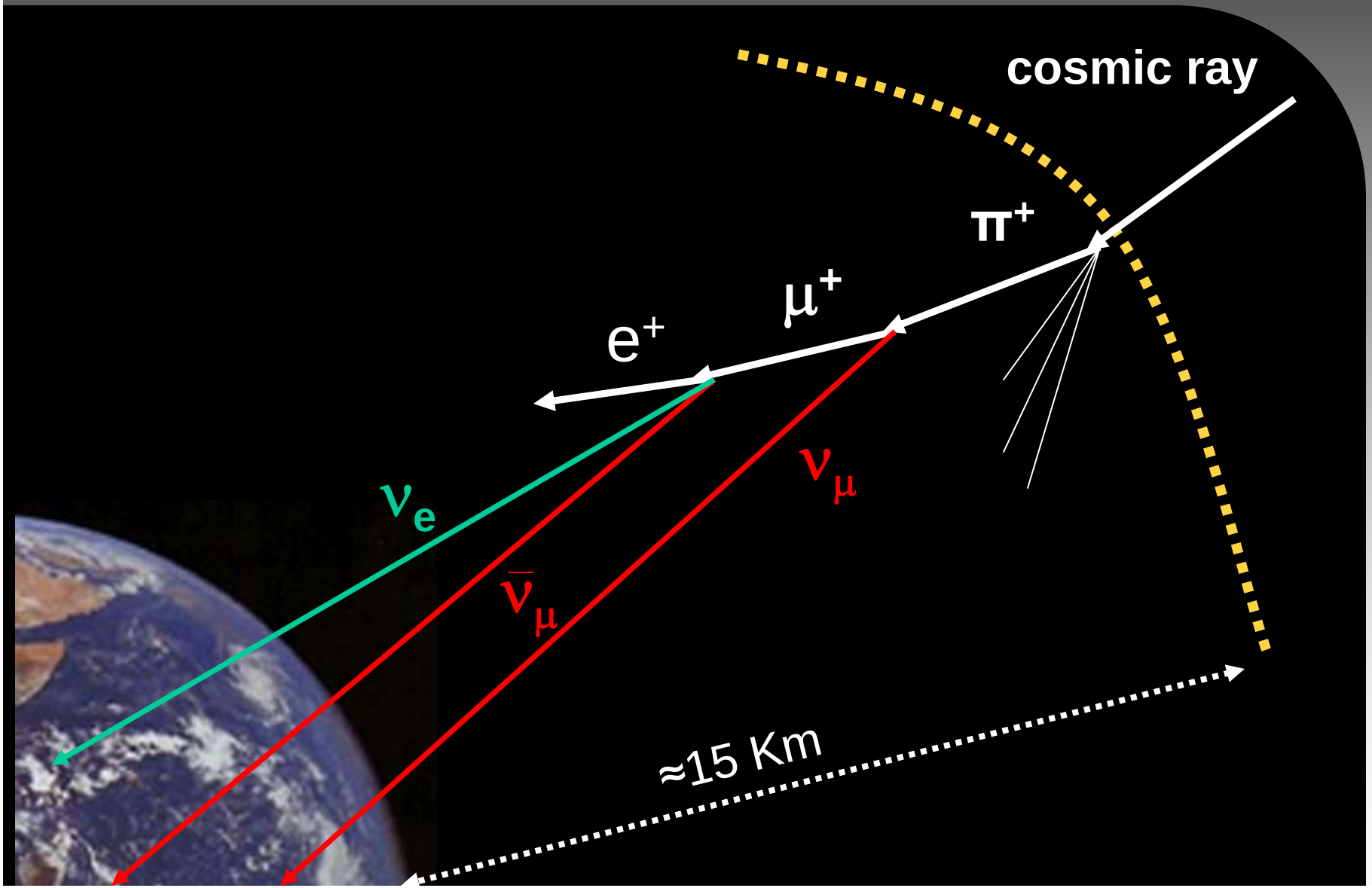
3369 events

below horizon

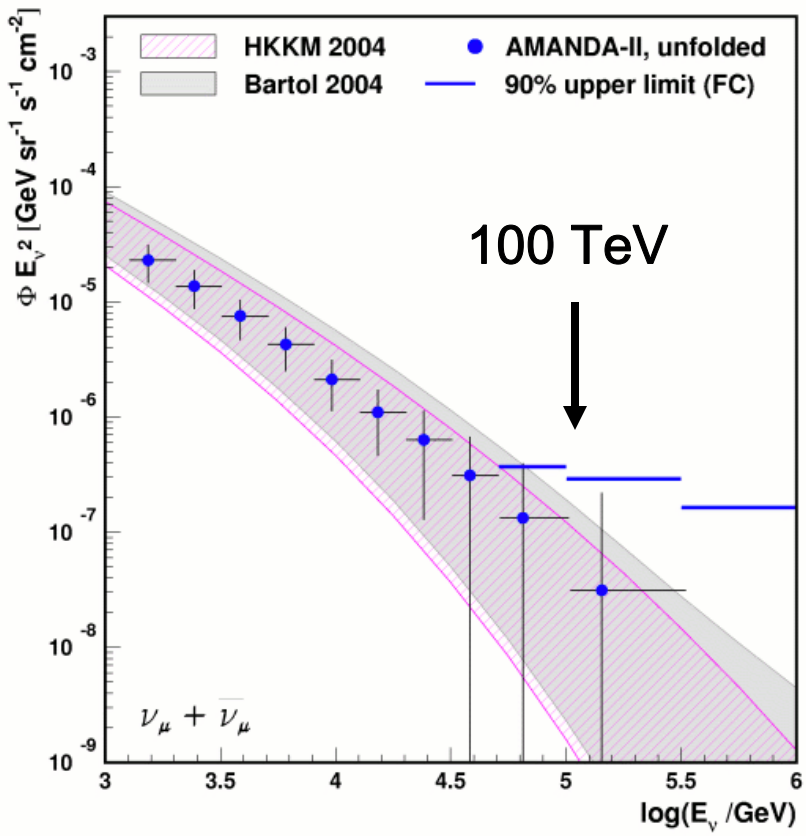


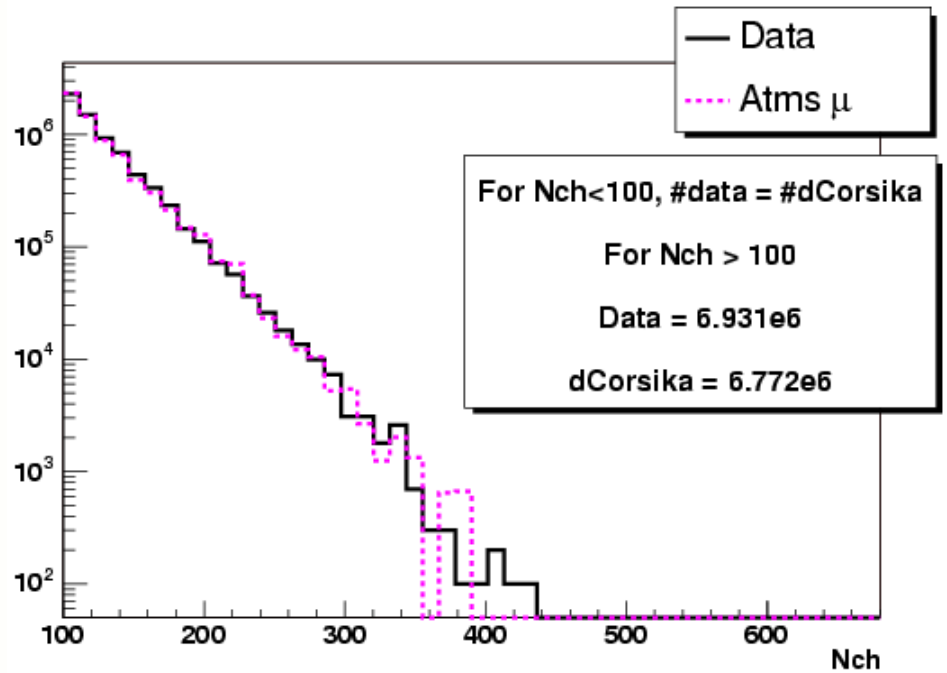

cosmic rays
atmospheric muon (down)
atmospheric neutrinos (up)

atmospheric neutrinos



calibration on cosmic ray neutrinos and muons



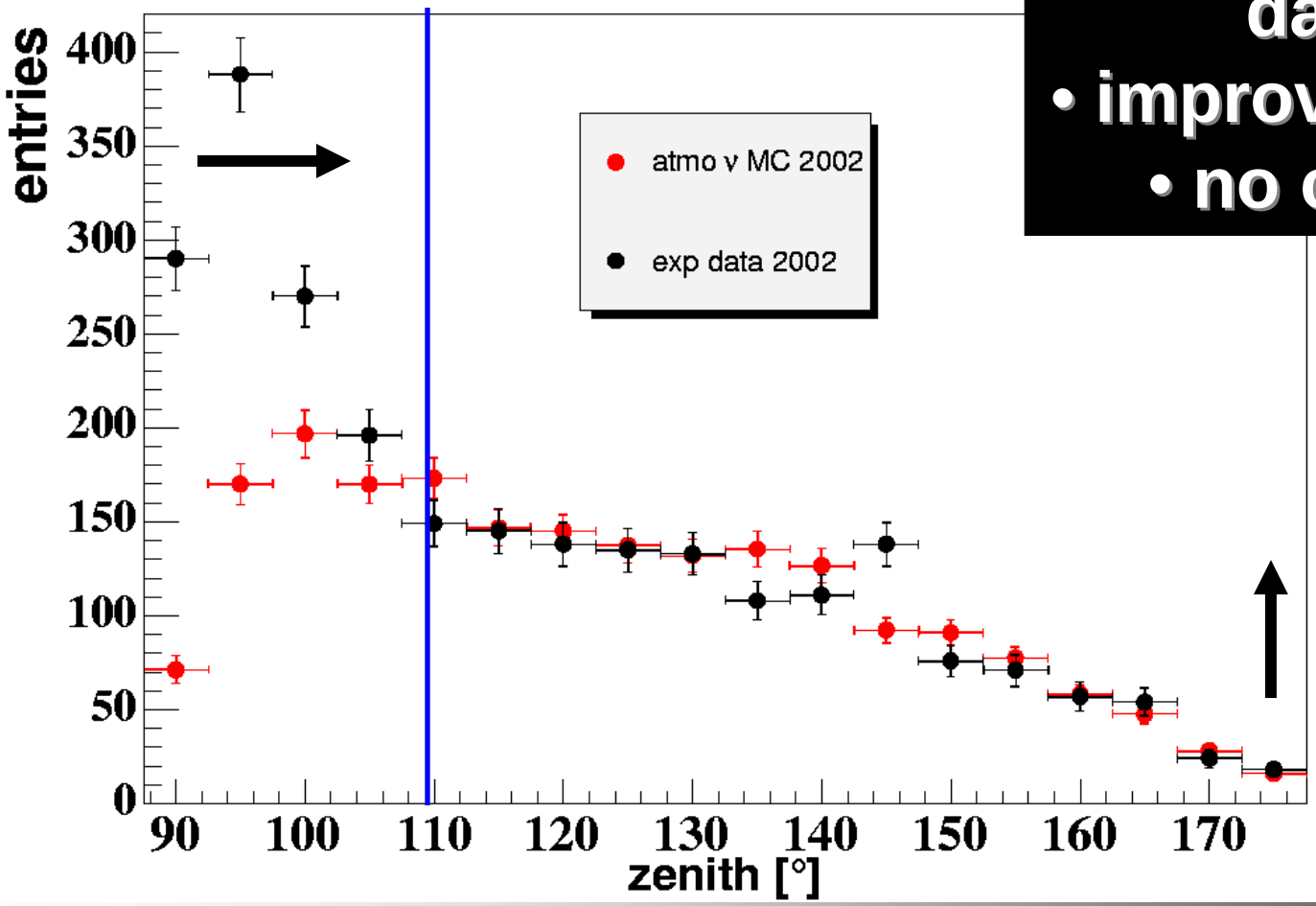


inverted analysis: use atmospheric muons to benchmark MC

- atmospheric ν_μ spectrum

2002 analysis

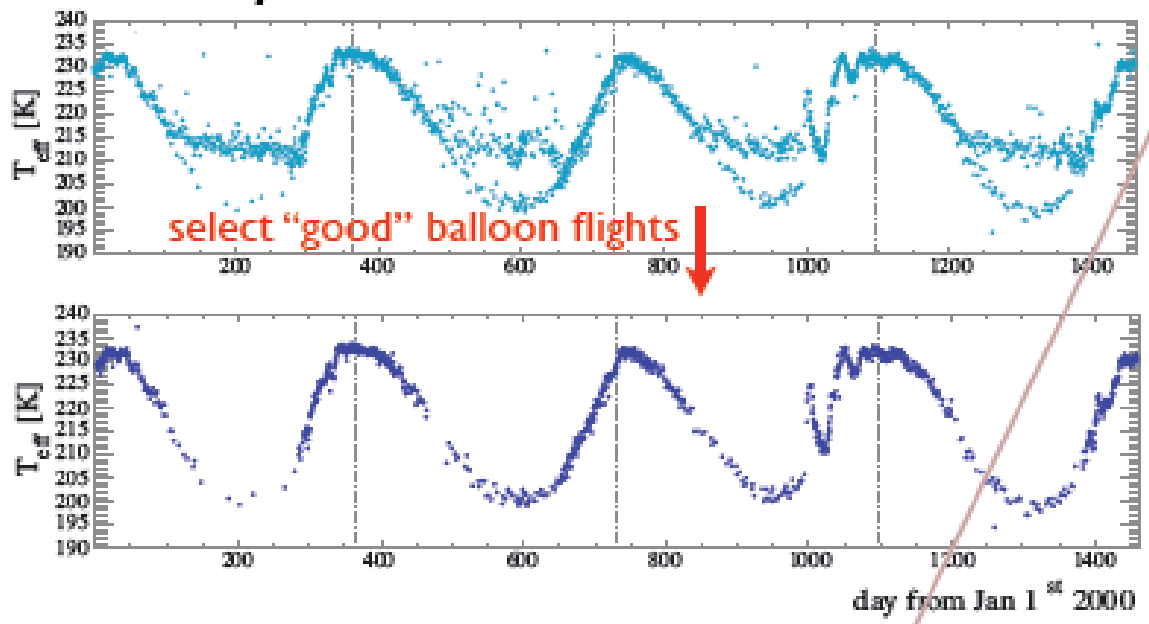
zenith distribution



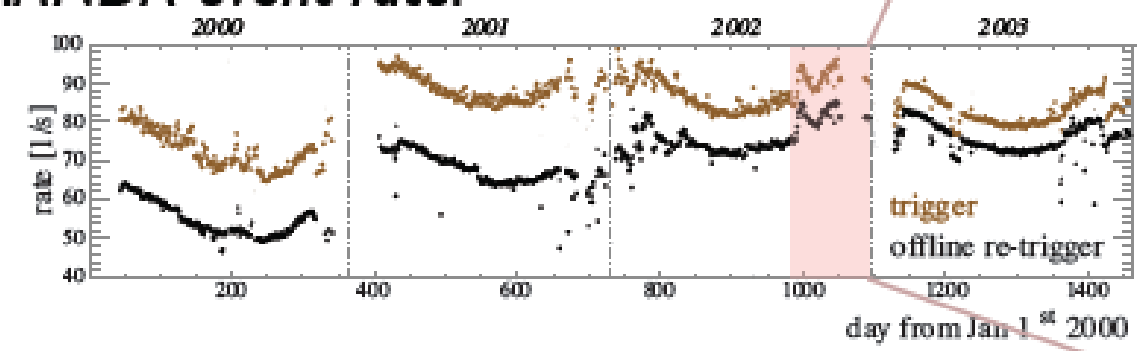
→10 events per day:
- improved reco
- no cuts !

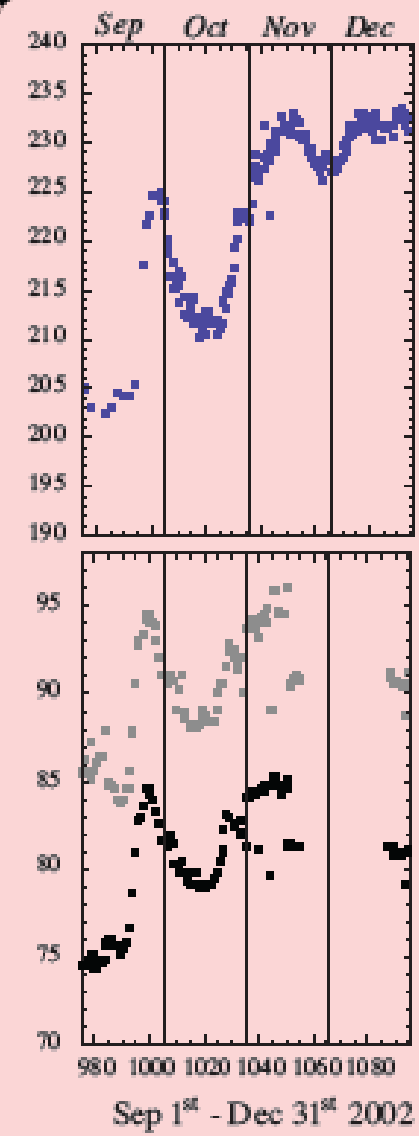
Effective Atmospheric Temperature Over The South Pole

effective temperature:



AMANDA event rate:





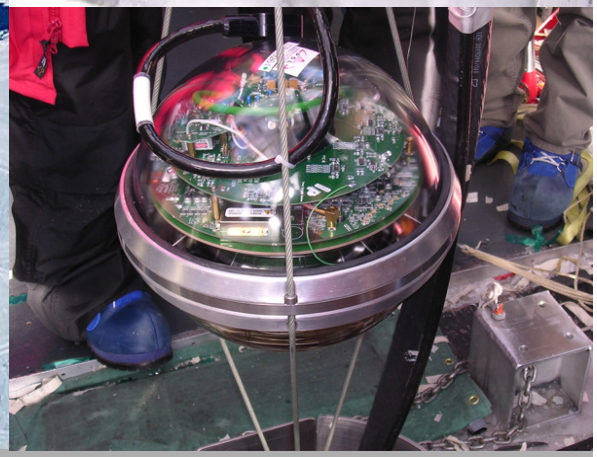
icecube

AMANDA vs. IceCube

2 megawatt drilling	4.8 megawatt drilling
Analog signals to surface	In-ice signal digitization
ADC/TDC	Full Waveform recording
Saturation for multiple p.e. signals	Larger dynamic range
1 ms deadtime	No deadtime
Hardware Trigger	Software Trigger
Depth ~ 1500-2000m	Depth 1450-2450 m
String spacing Vertical: 10-20 m Horizontal: 55-75 m	String Spacing Vertical: 17 m Horizontal: 125 m
Instrumented Volume .015 km^3	Instrumented Volume ~ 1 km^3

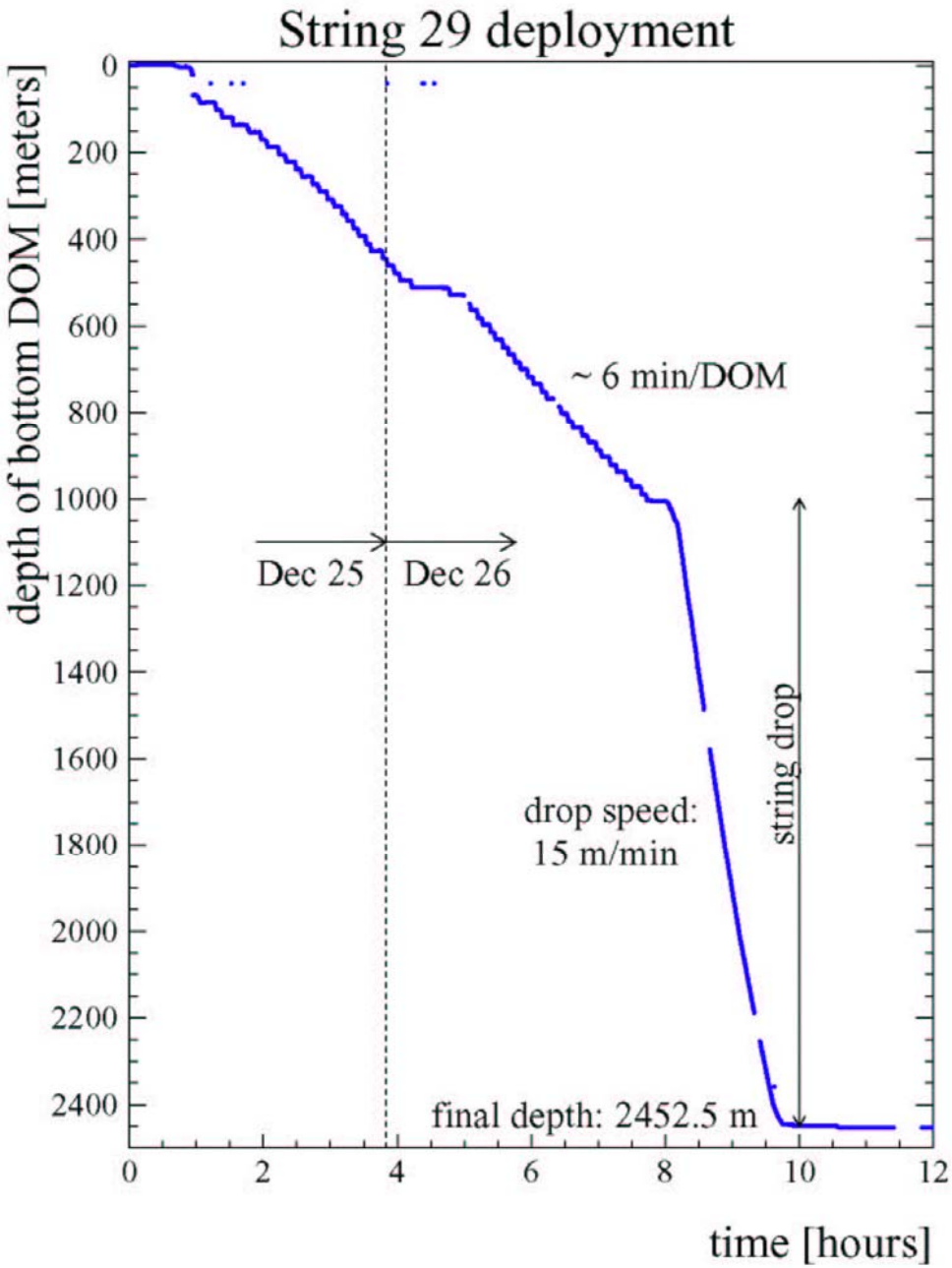
IceCube is both larger and technologically superior

IceCube drilling: 2 to 4.8 megawatt

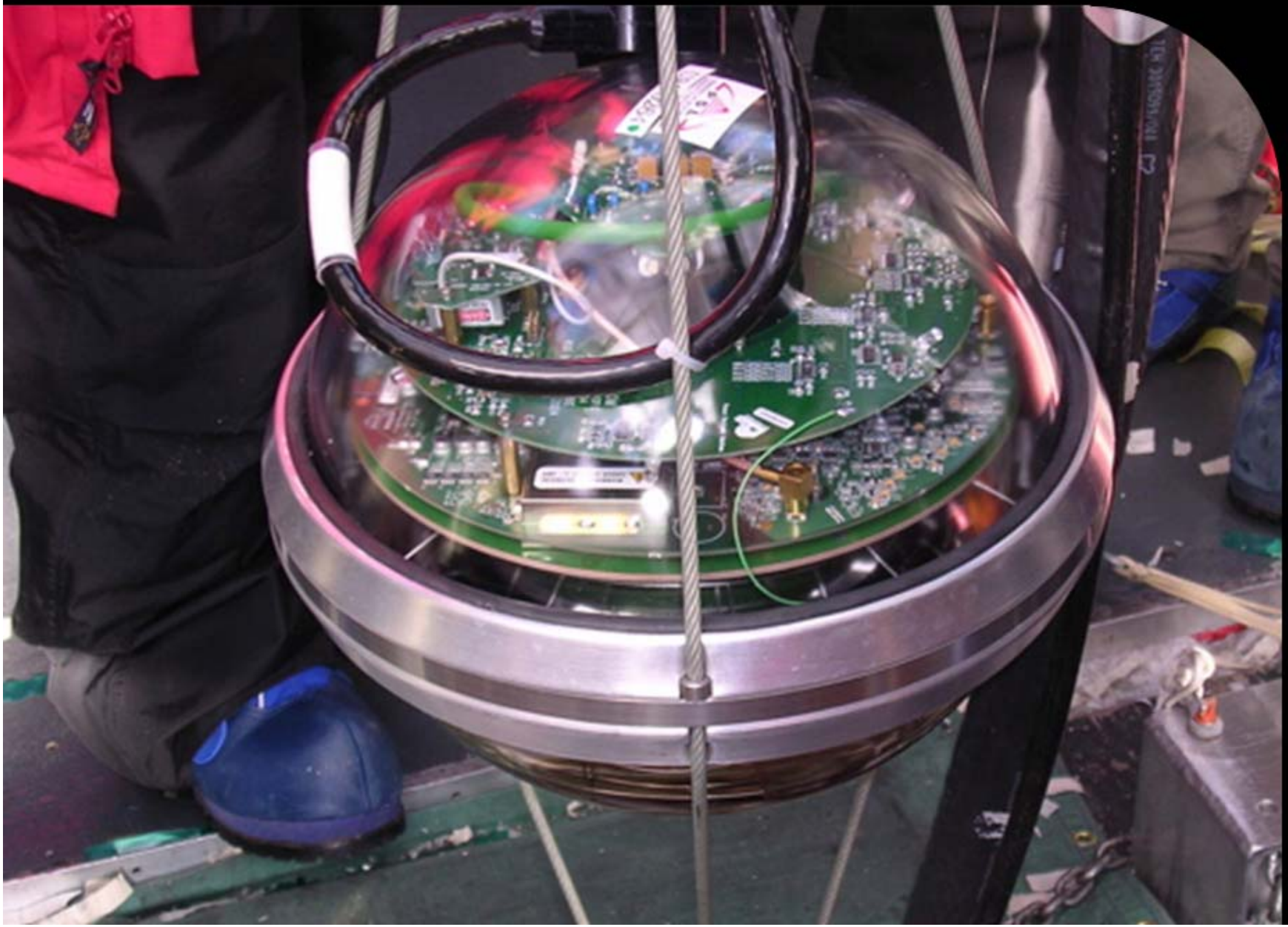


- 1 million pounds of cargo
- C-130 planes: > 50 flights

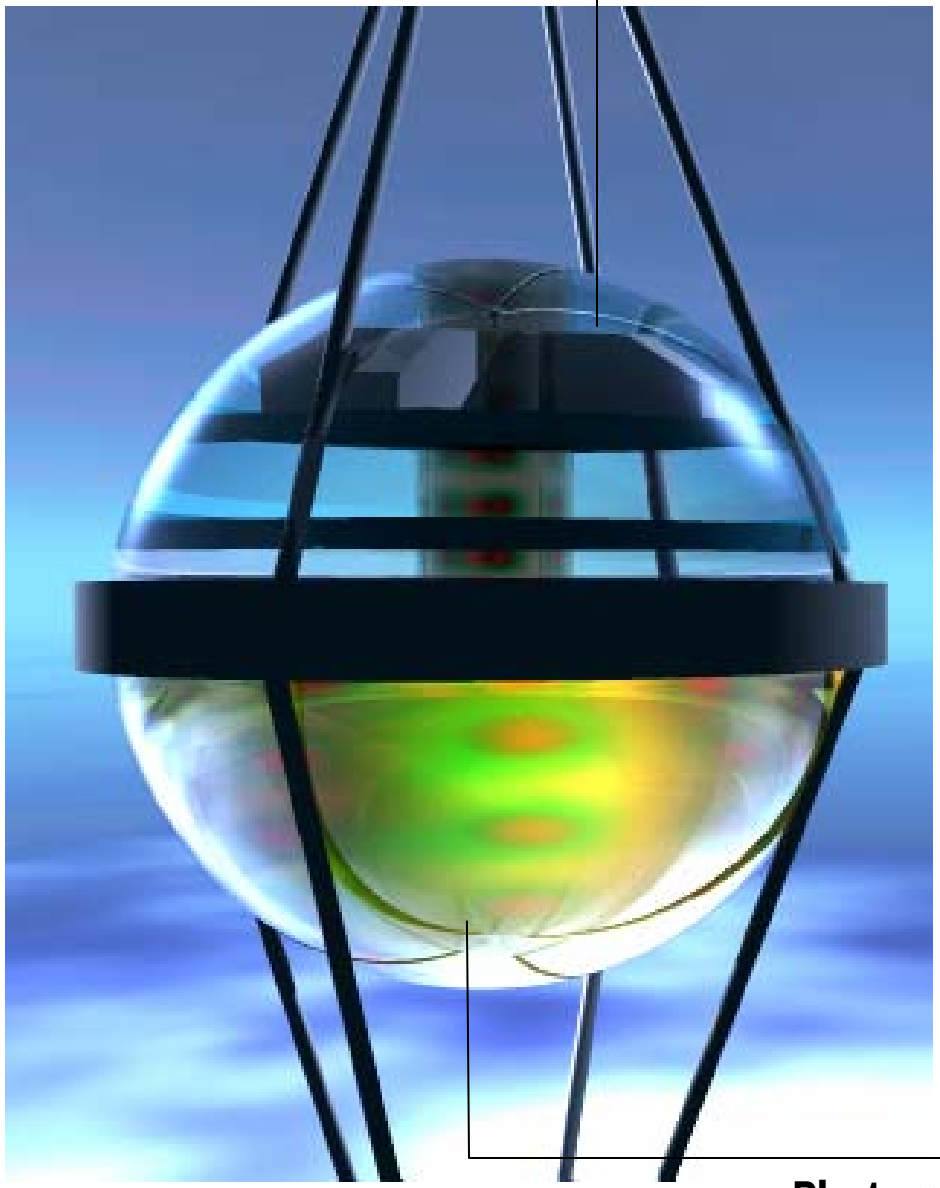
String cable 2500 m Weight ~6 tons

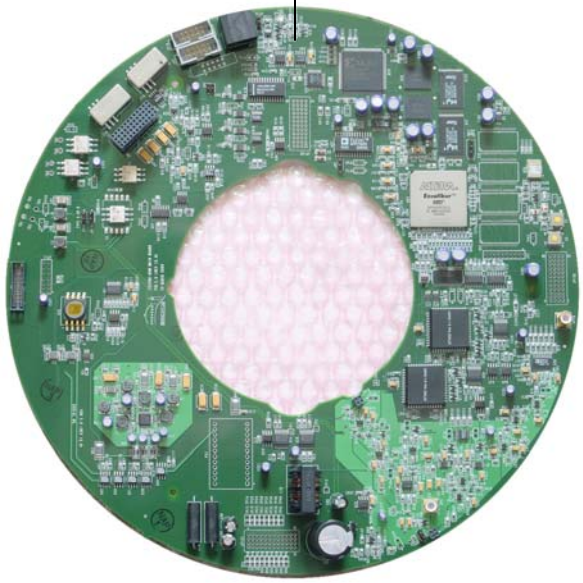


optical sensor



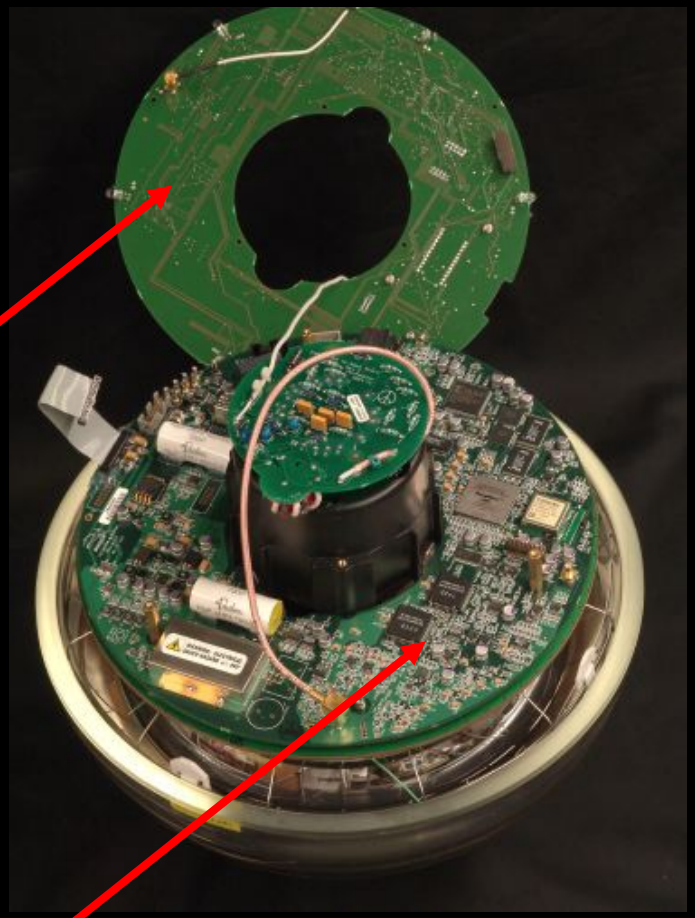
Digital Optical Module

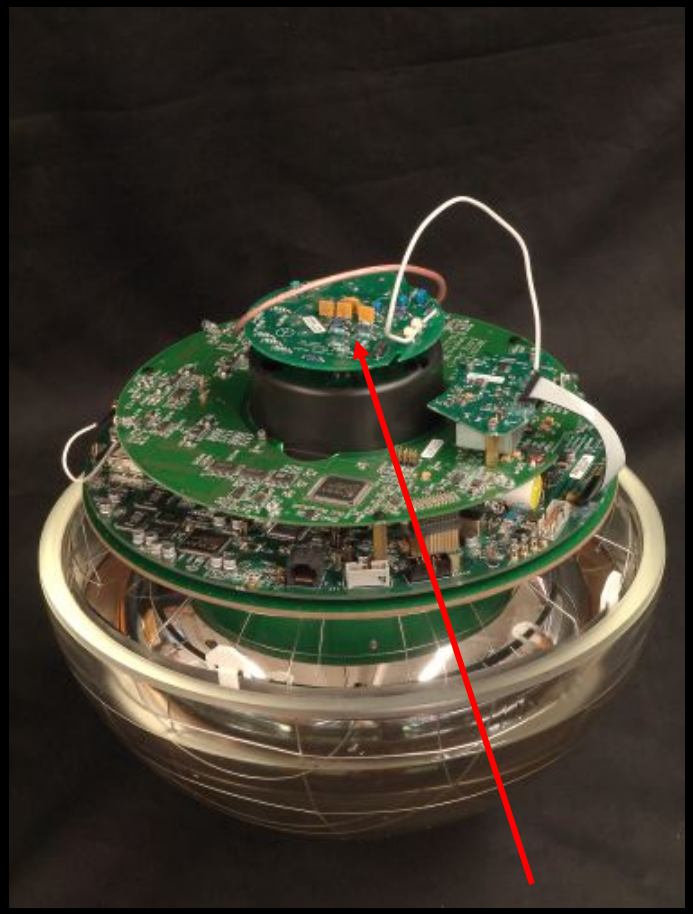




Photomultiplier Tube

Digital Optical Module



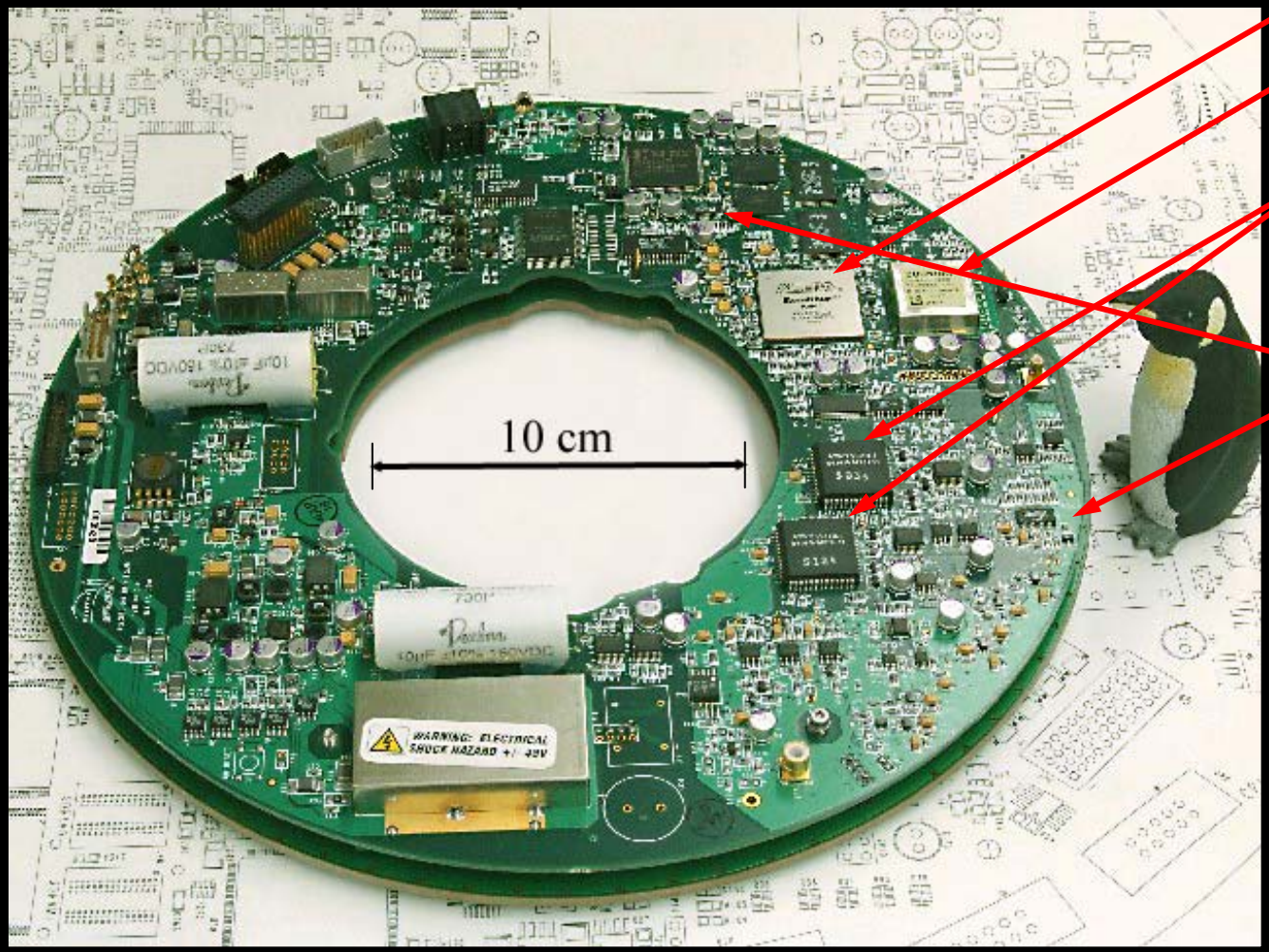


LED flasher board

main board

HV board

Digital Optical Module Mainboard



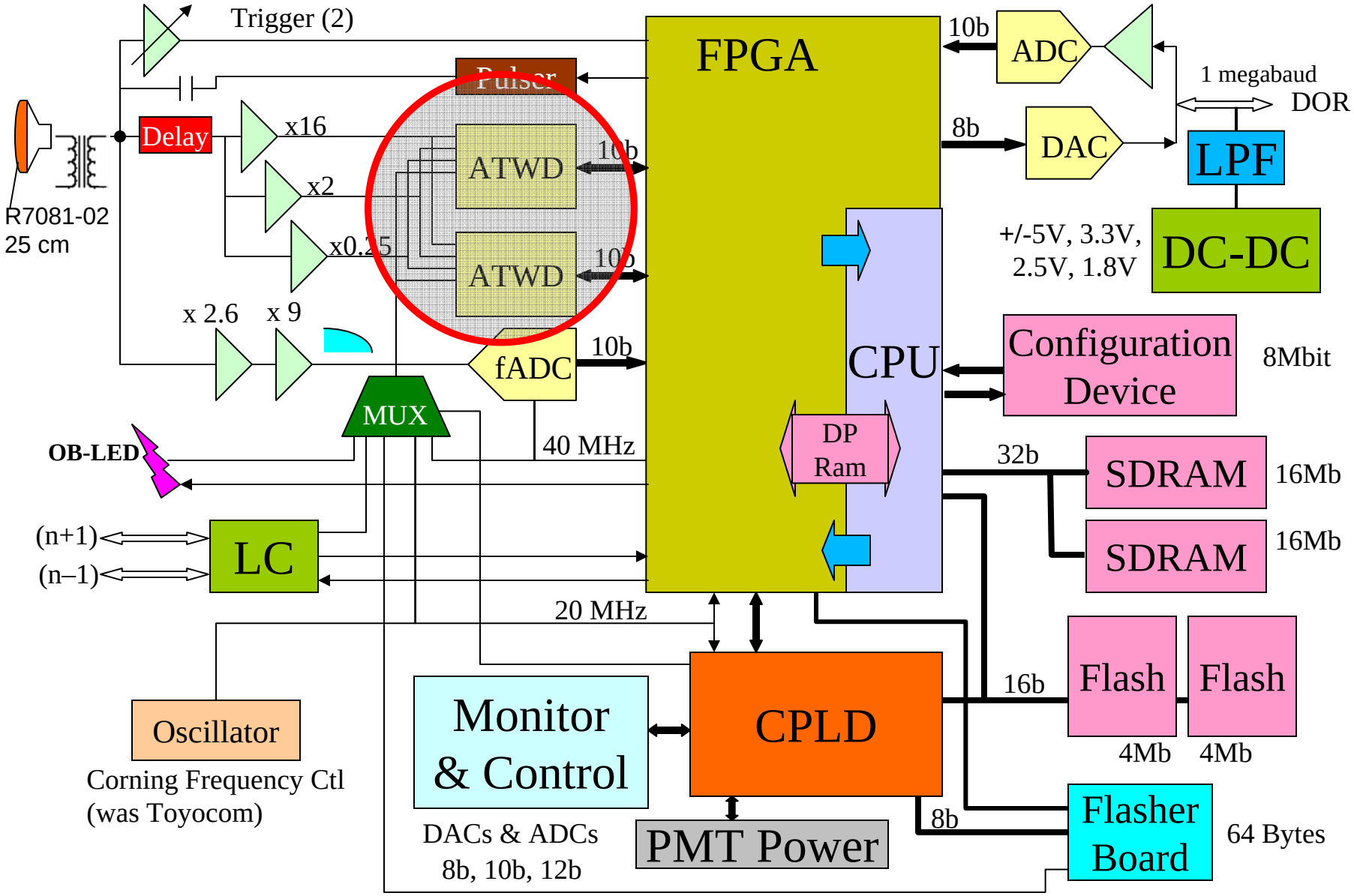
CPU+FPGA

20 MHz osc

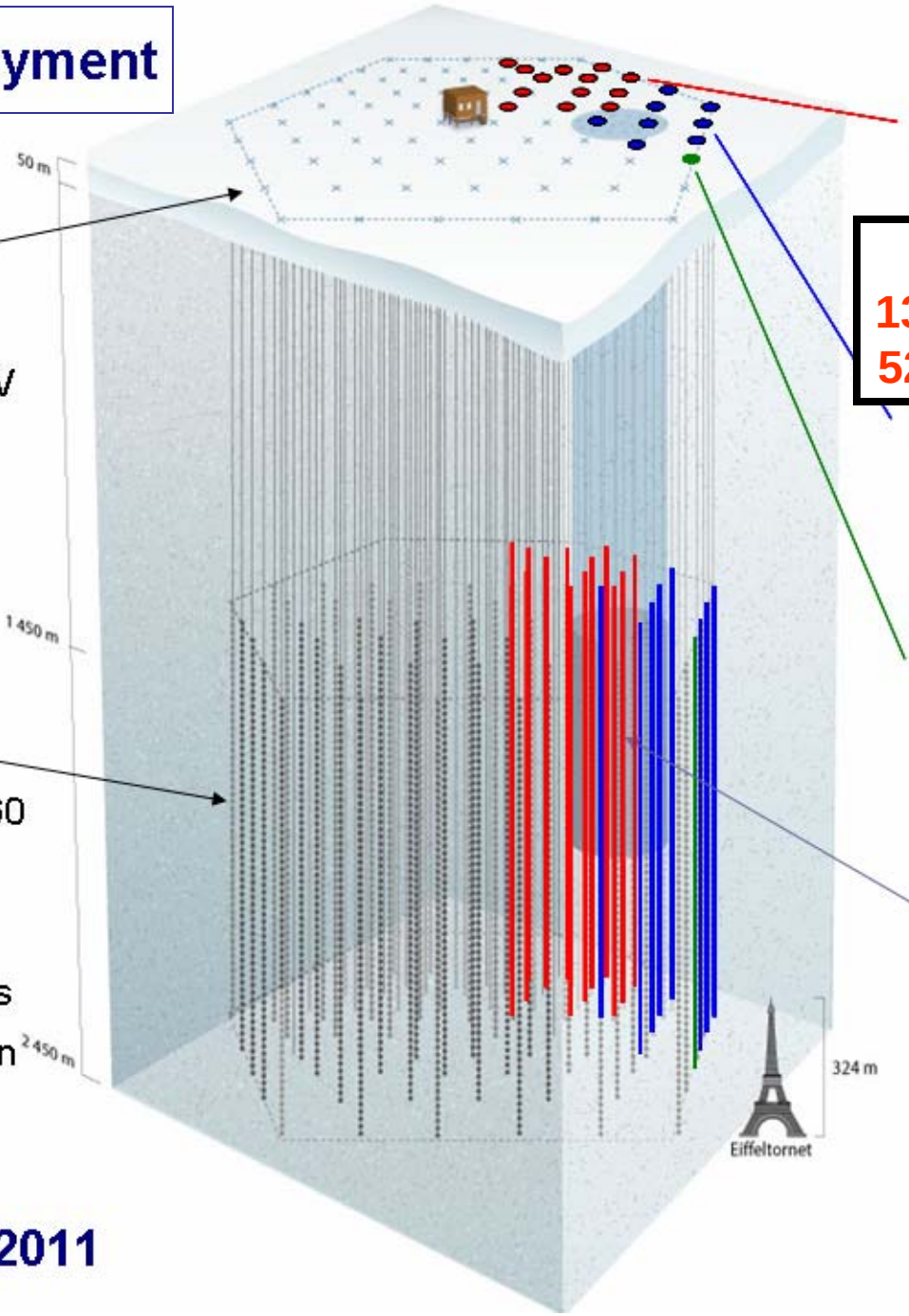
2 ATWDs

Fast ADC: waveform and COMM

DOM MB Block diagram



IceCube Deployment



IceTop

Air shower detector

Threshold ~ 300 TeV

InIce

planned 80 strings of 60 optical modules each

17 m between modules

125 m string separation

2006-2007:

13 strings deployed

22 strings
1320 digital modules
52 surface detectors

2005-2006: 8 strings

2004-2005 : 1 string

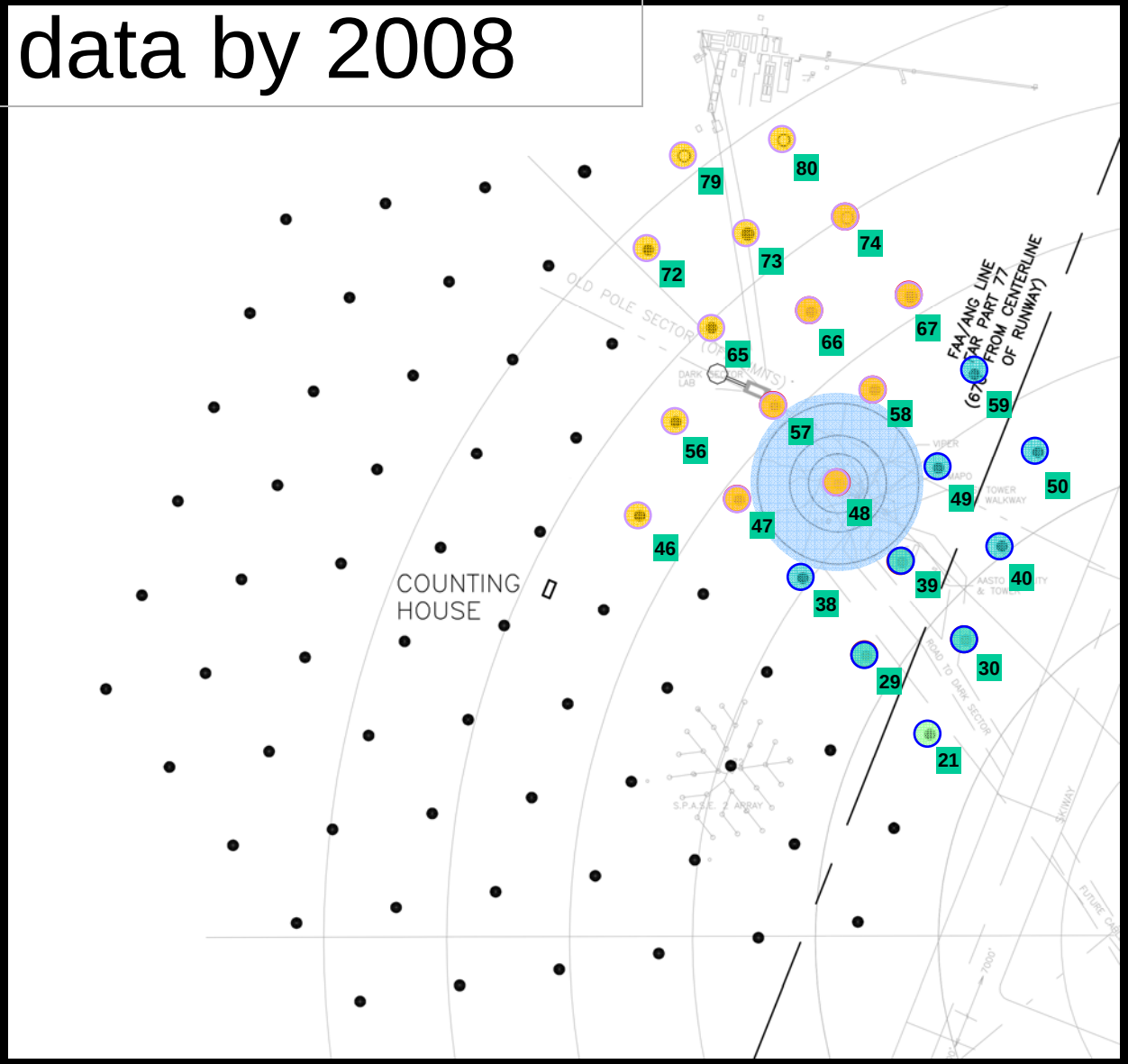
First data in 2005
first upgoing muon:
July 18, 2005

AMANDA
19 strings
677 modules

Completion by 2011

a km squared year data by 2008

2005, 2006, 2007 deployments



AMANDA

IceCube string and IceTop station deployed 01/05

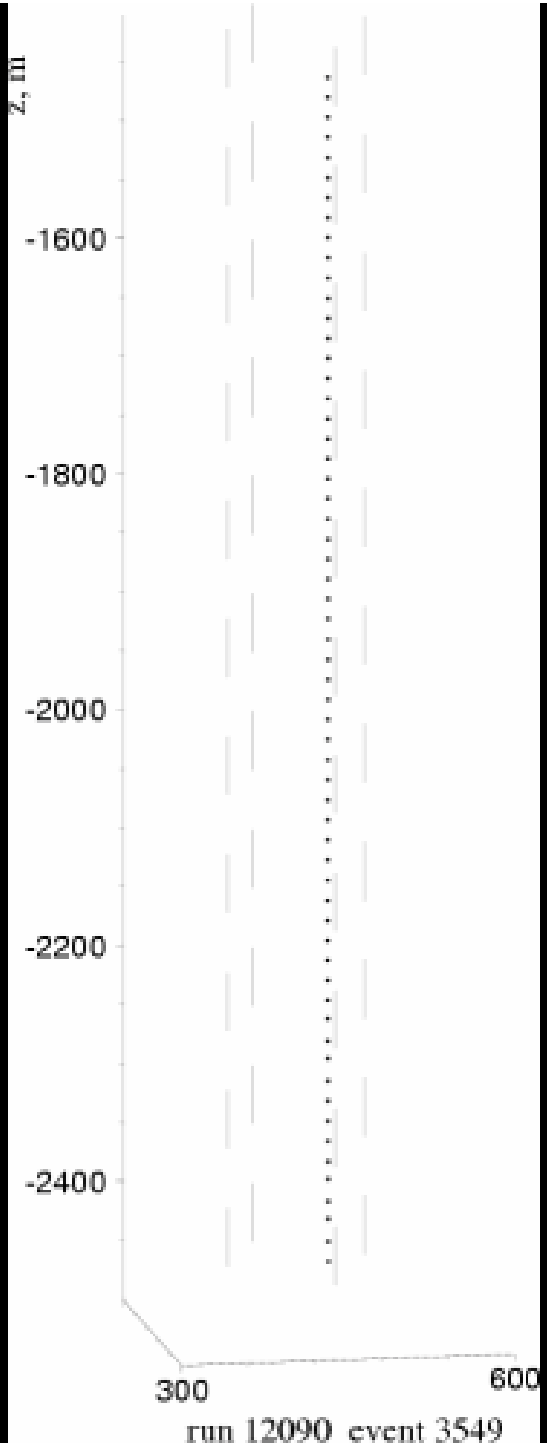
IceCube string and IceTop station deployed 12/05 – 01/06

IceTop station only 2006

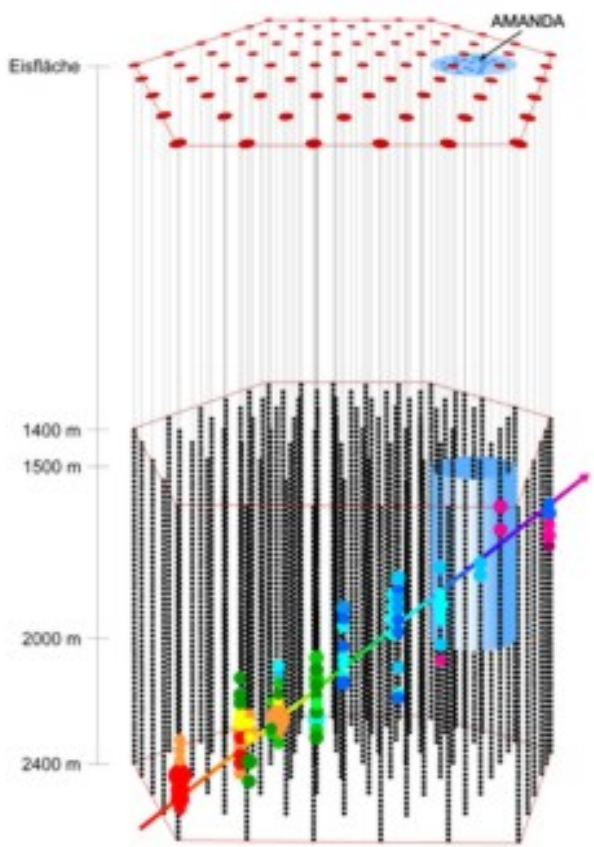
IceCube string and IceTop station to be deployed 12/06 – 01/07

- 604 DOMs deployed to date
- Want to achieve steady state of 14 strings / season.

string trigger on IceCube string



IceCube



• in the next 10 years IceCube will observe

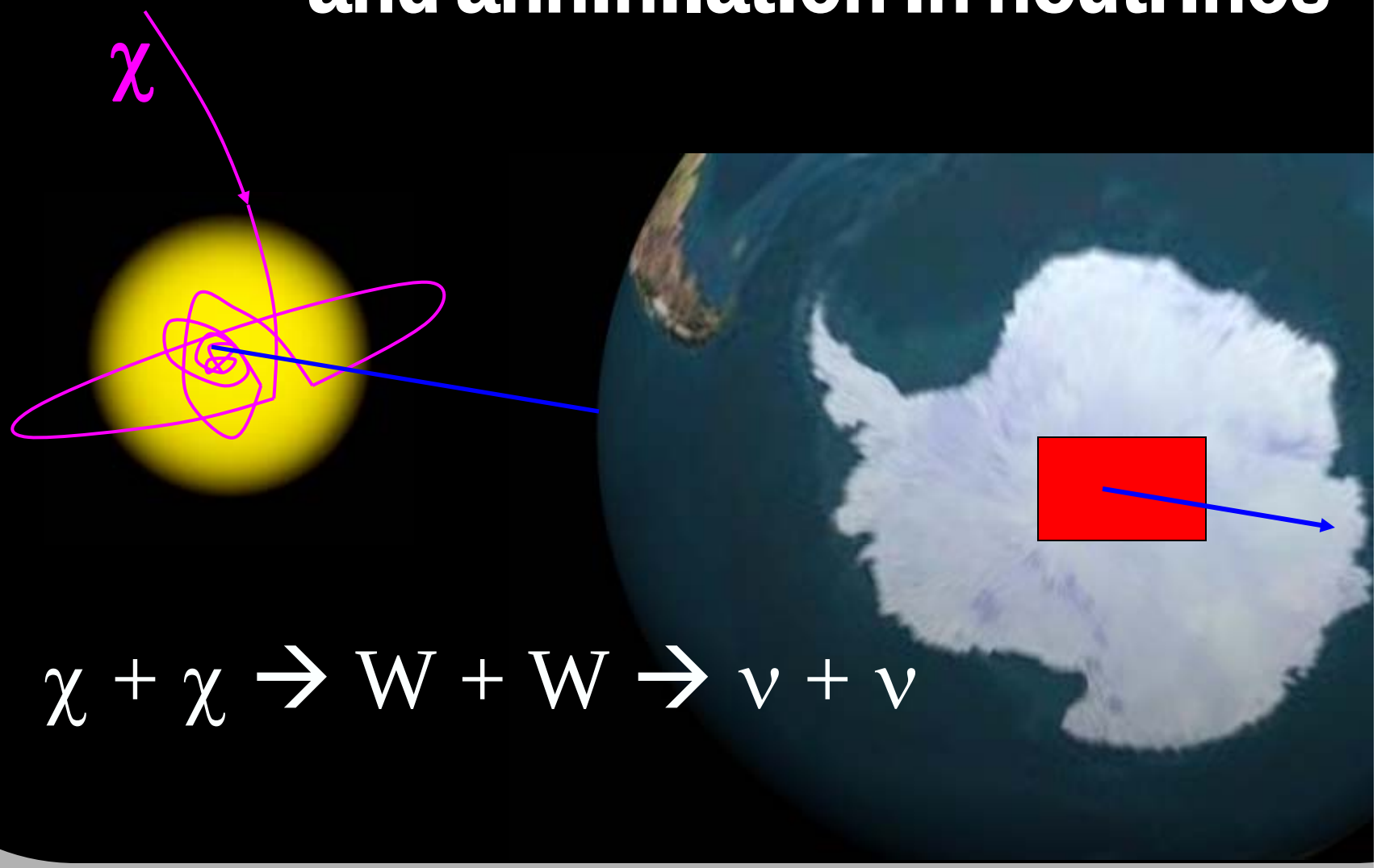
~ 10^6 neutrinos with energies 0.1—1,000 TeV
~ 10 neutrinos with energy > 10^6 TeV

made in the interactions of cosmic rays with the Earth's atmosphere and microwave photons.

• with m~0.01 eV and E~100 TeV the gamma factor of the neutrino is

$$\gamma = \frac{E_\nu}{m_\nu} \approx 10^{16}$$

WIMP capture in the sun and annihilation in neutrinos



$$\chi + \chi \rightarrow W + W \rightarrow \nu + \nu$$

indirect dark matter detection

- indirect rates are dictated by the interaction cross section of WIMPS with hydrogen.
- in the neutrino case there is a direct connection between theory and observation and the background is understood.

indirect dark matter detection

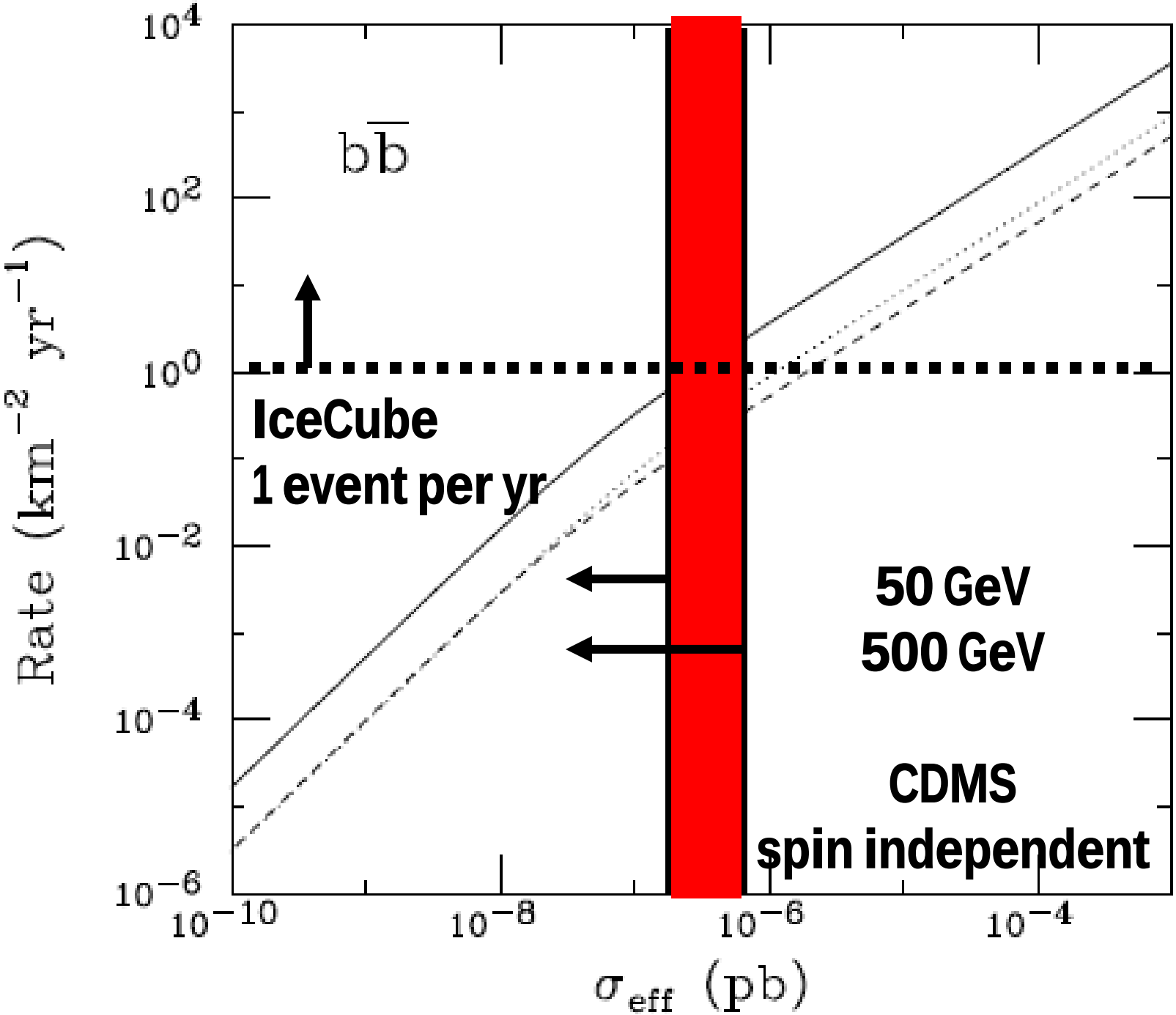
- indirect detection is especially sensitive to heavy WIMPS (good sensitivity of neutrino telescopes)

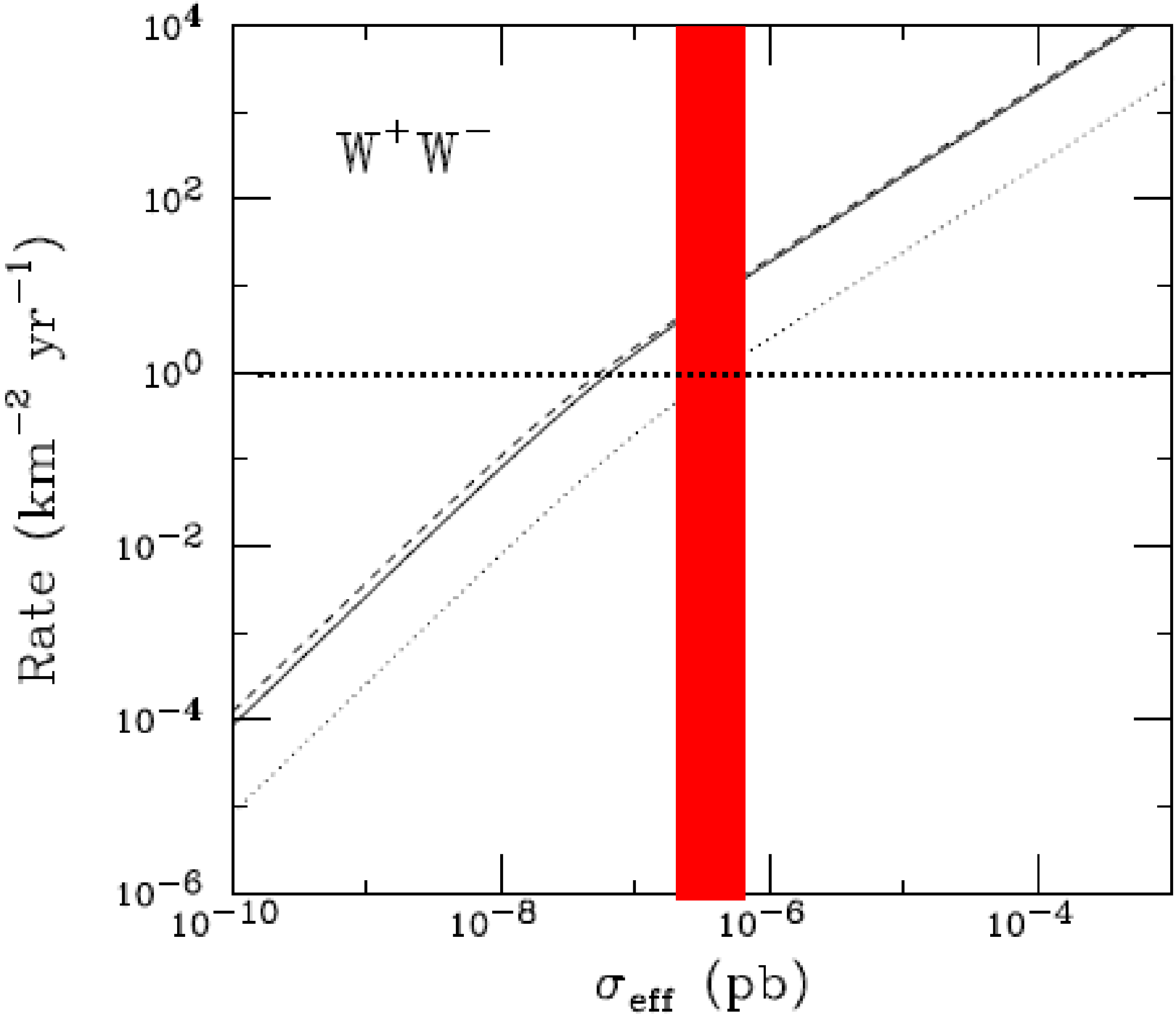
- indirect detection is especially sensitive to spin independent WIMP interactions (squark- and W- exchange in s, t channel)

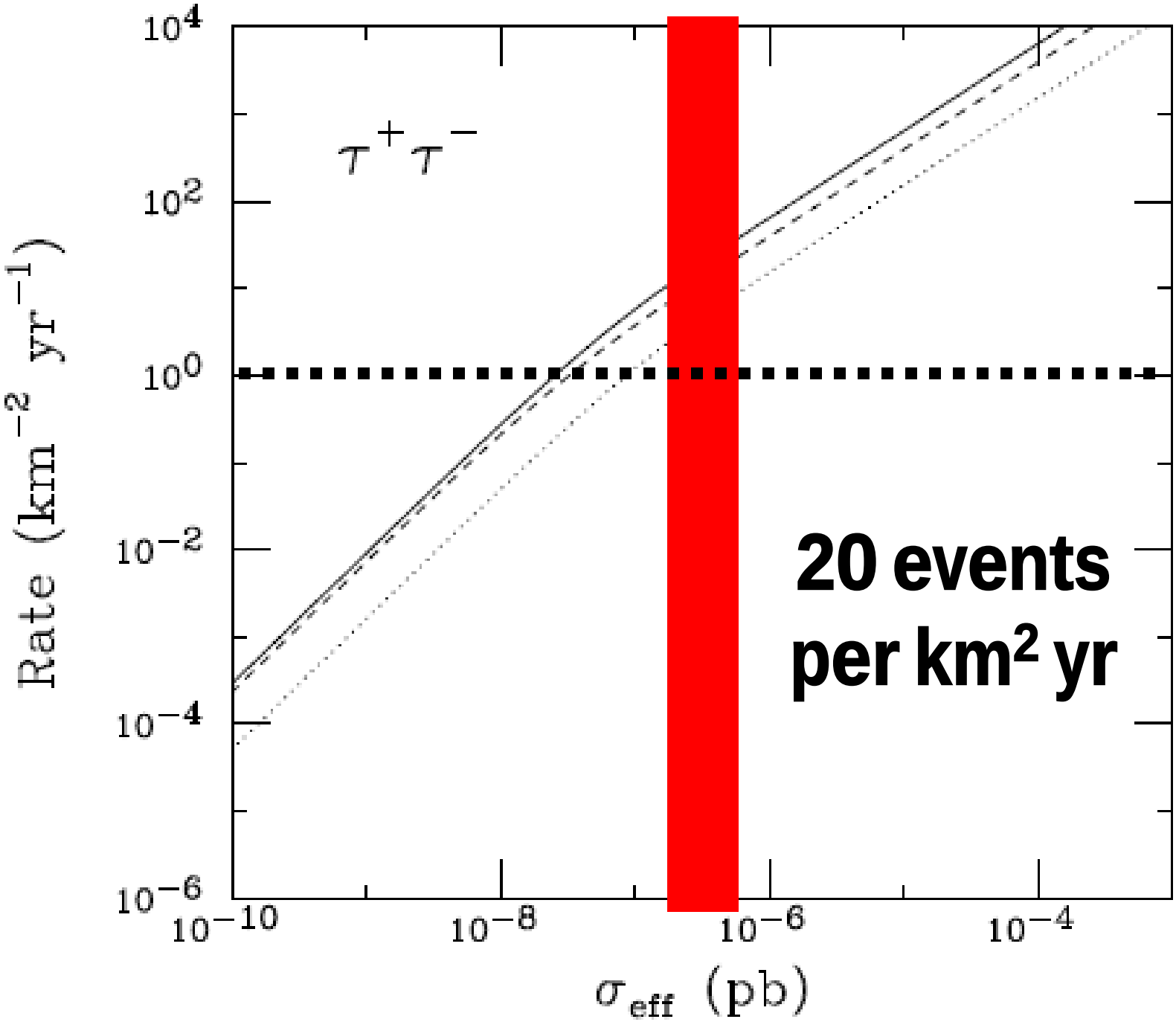
indirect dark matter detection

- direct and indirect strategies complementary
- strategies for DM detection using AMANDA + IceCube
- models with >> 1000 IceCube events per year that are not ruled out by CDMS x100 !

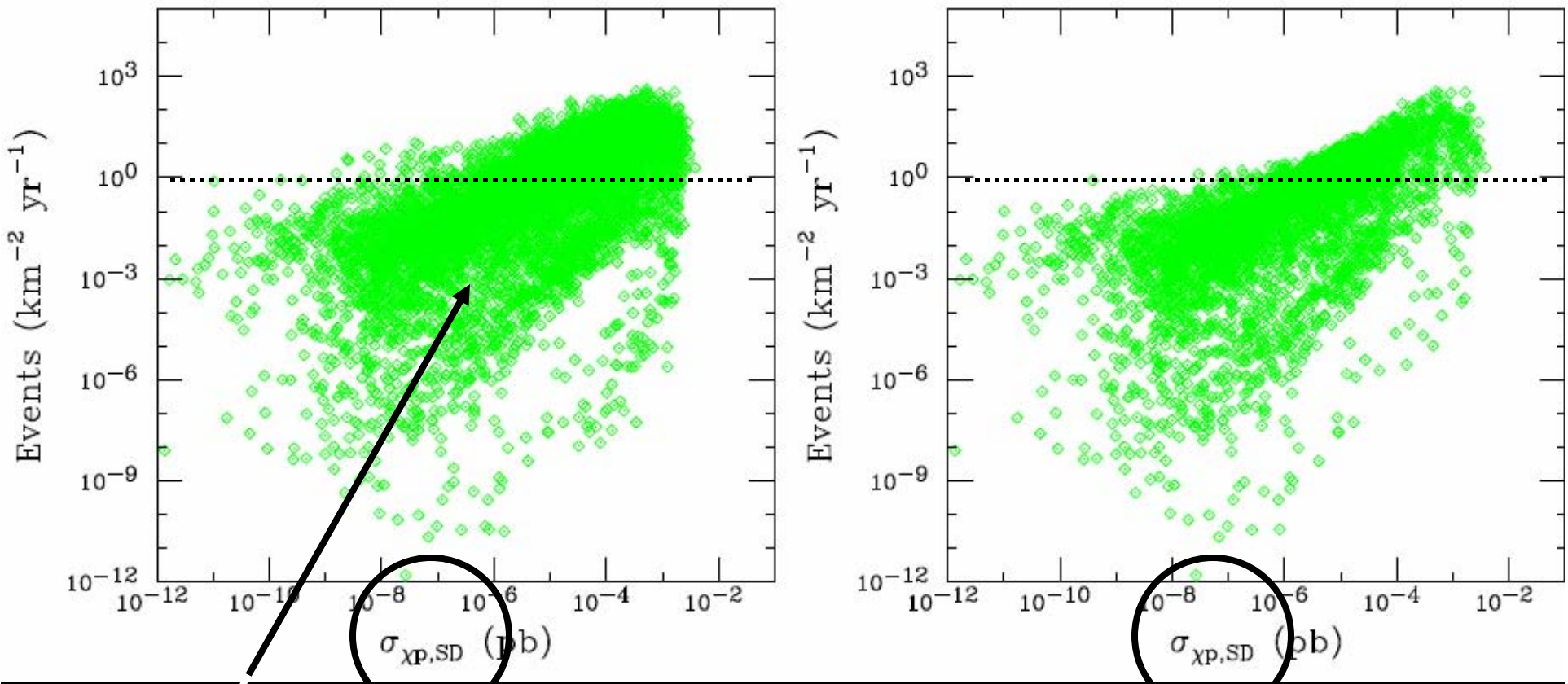
direct and indirect


$b\bar{b}$
IceCube
1 event per yr
50 GeV
500 GeV
CDMS
spin independent
Rate (km^{-2} yr^{-1})
$\sigma_{\rm eff}$ (pb)
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-10}
10^{-8}
10^{-6}
10^{-4}


W^+W^-
Rate (km^{-2} yr^{-1})
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
σ_{eff} (pb)


$\tau^+\tau^-$
20 events
per km^2 yr
Rate (km^{-2} yr^{-1})
$\sigma_{\rm eff}$ (pb)
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

IceCube: events per km^2 year



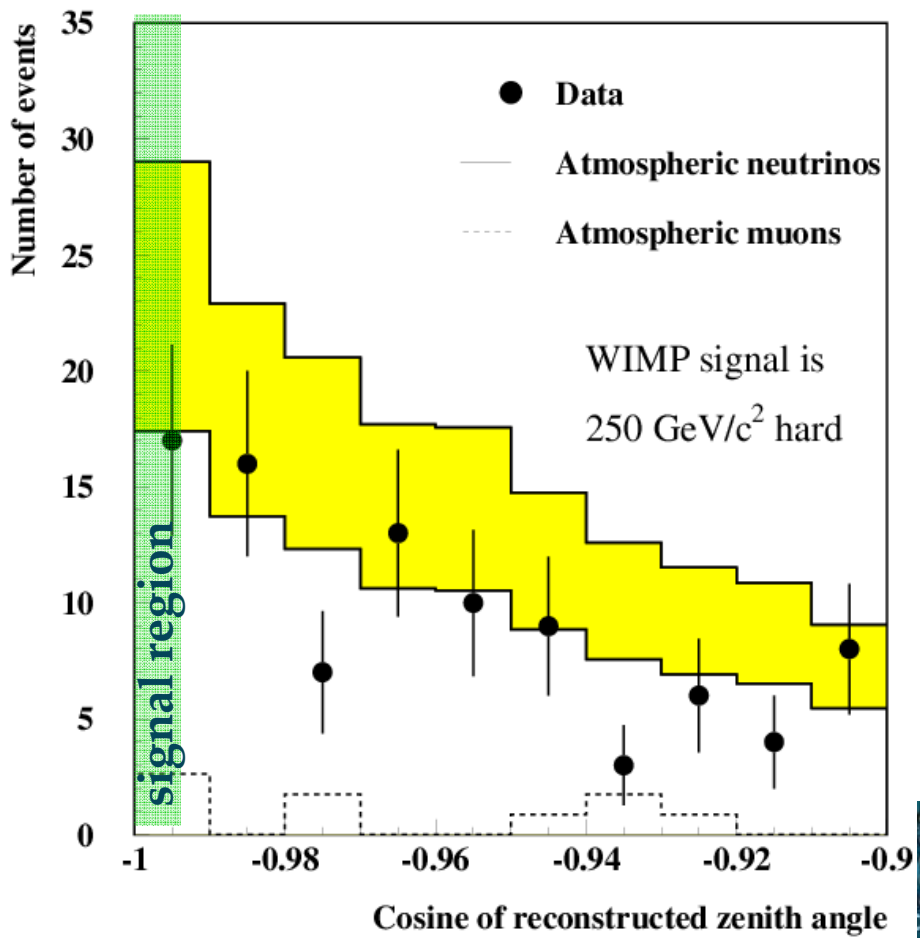
not ruled out by CDMS (left) **CDMS X 100 (right)**

AMANDA

Data consistent with background

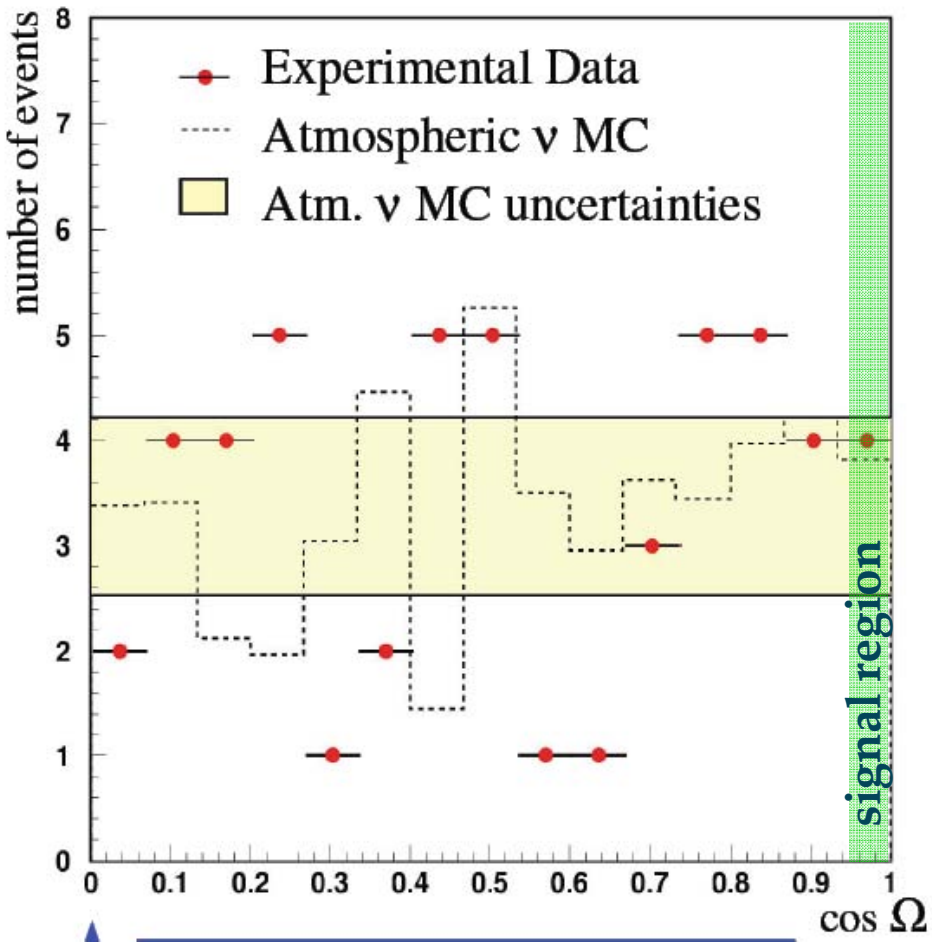
Earth 1997-1999

(Astropart. Phys. (2006), in Press)



Sun 2001

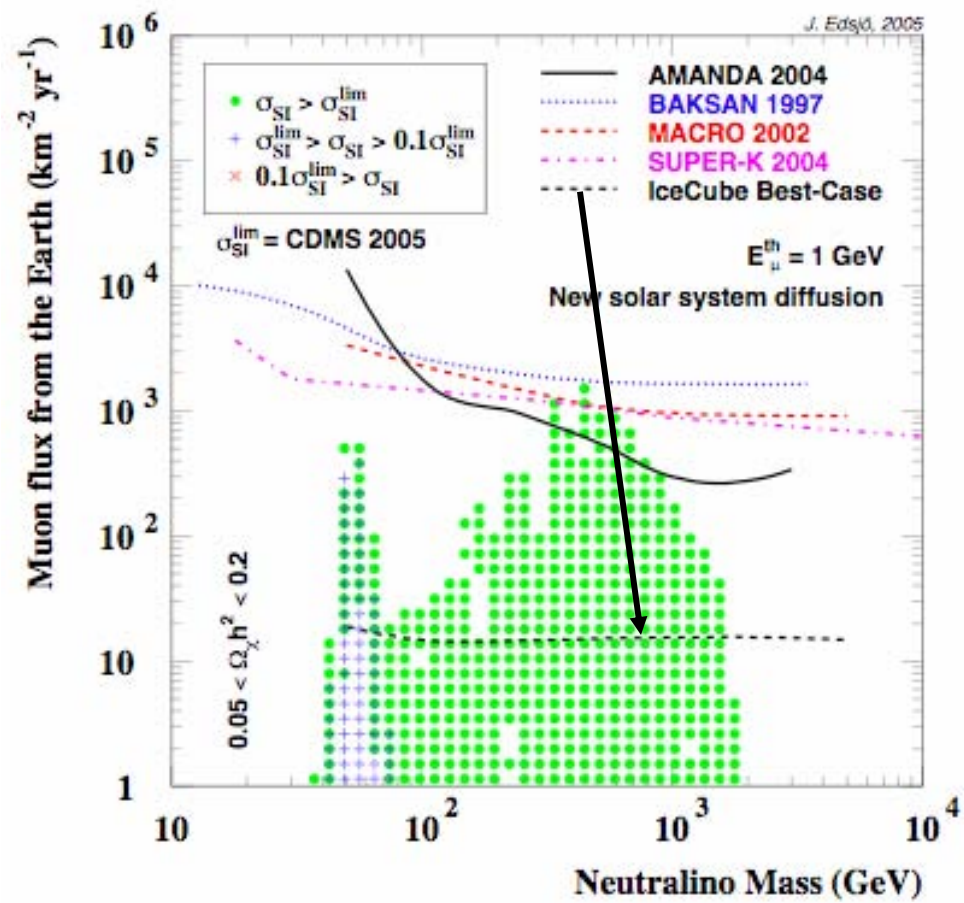
(Astropart. Phys. (2006) 459-466)



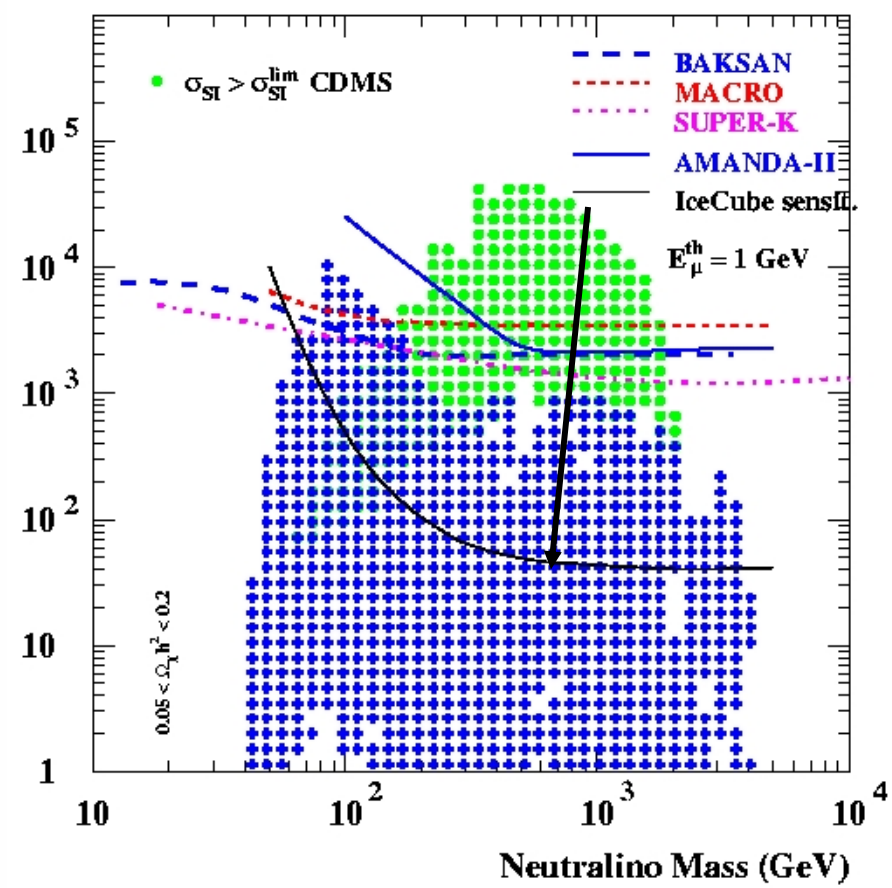
Prospects

- **AMANDA: 144 days only !**
- **3 year analysis this summer**
- **IceCube**

Earth

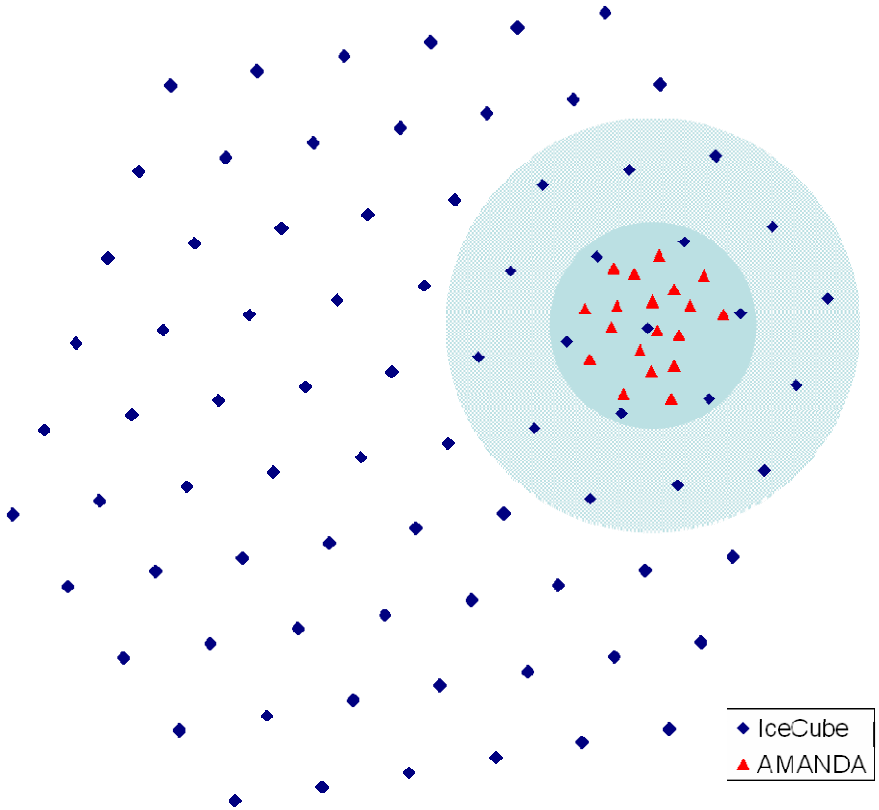


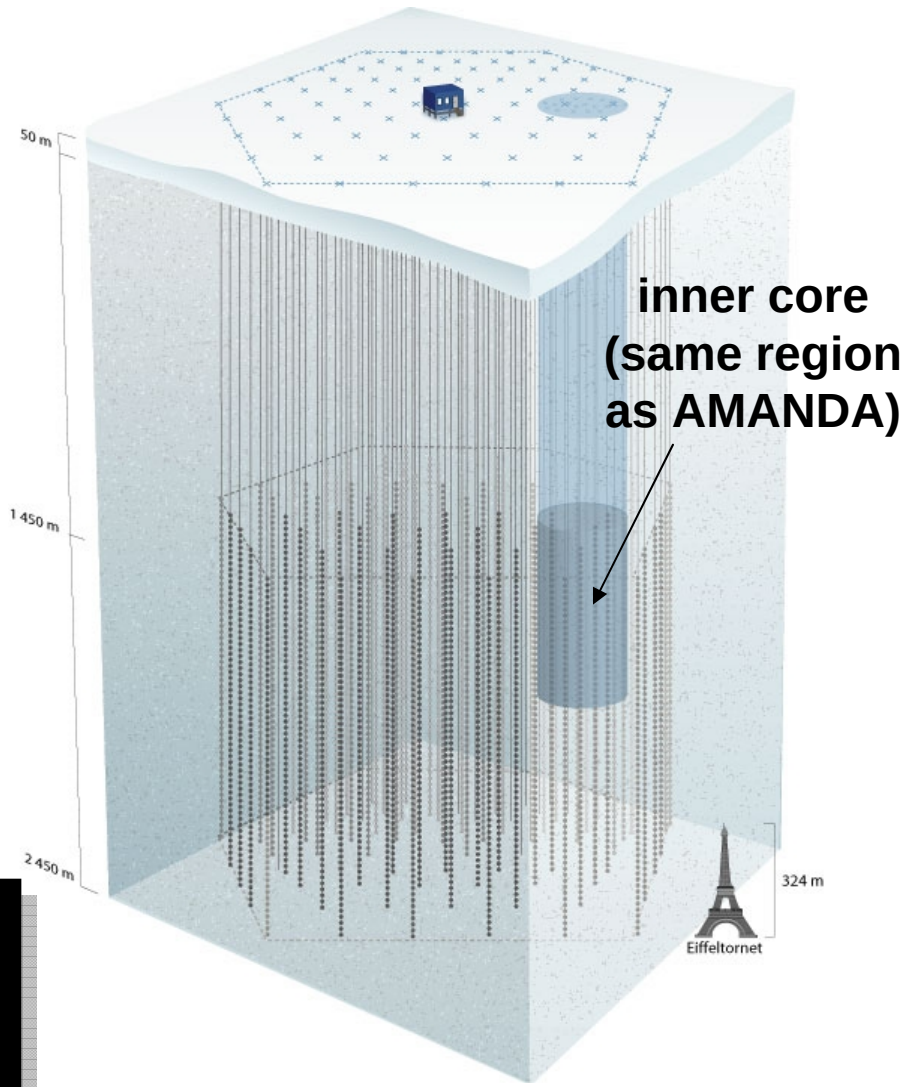
Sun



AMANDA to IceCube

IceCube: inner core detector

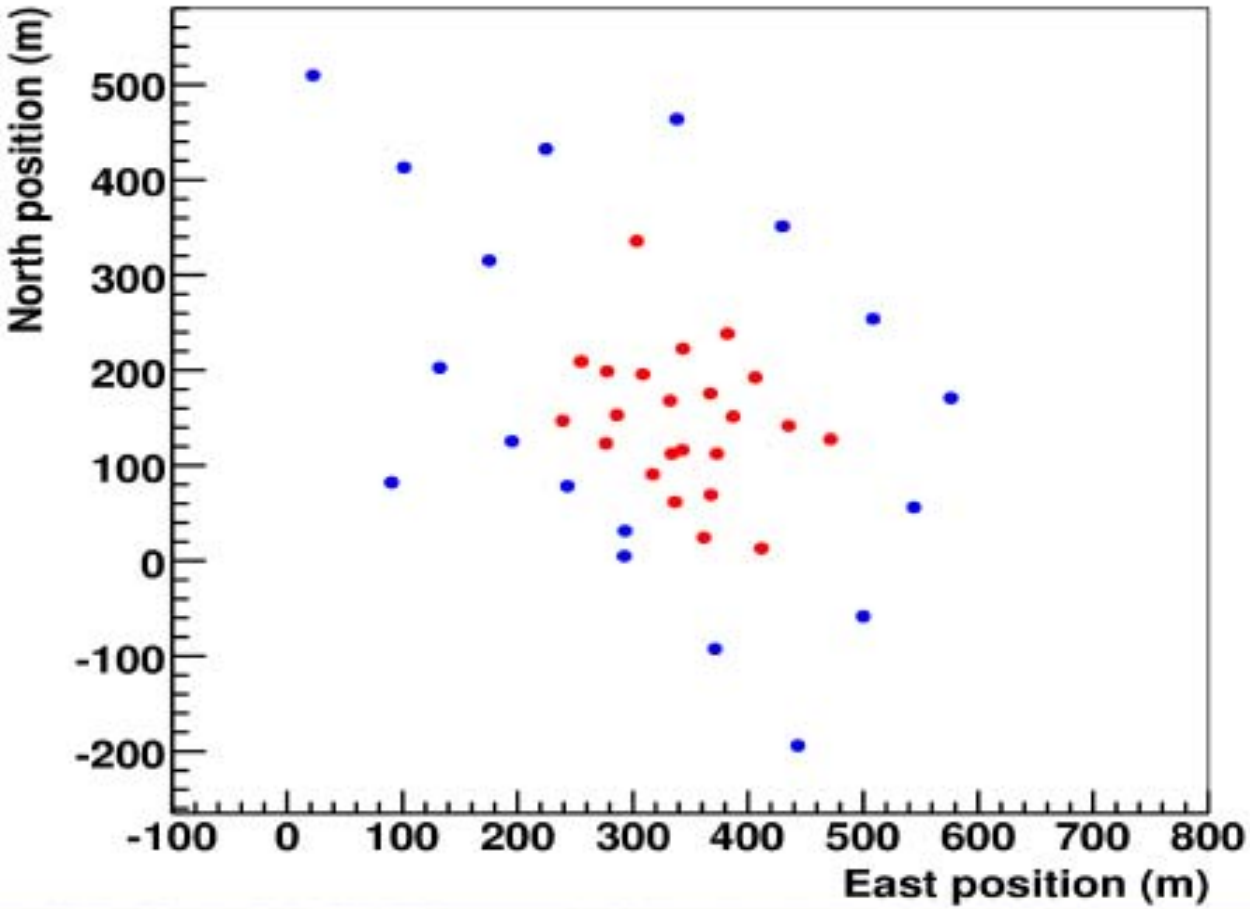




7 IceCube + 18 AMANDA strings
225 DOMs + 540 OMs

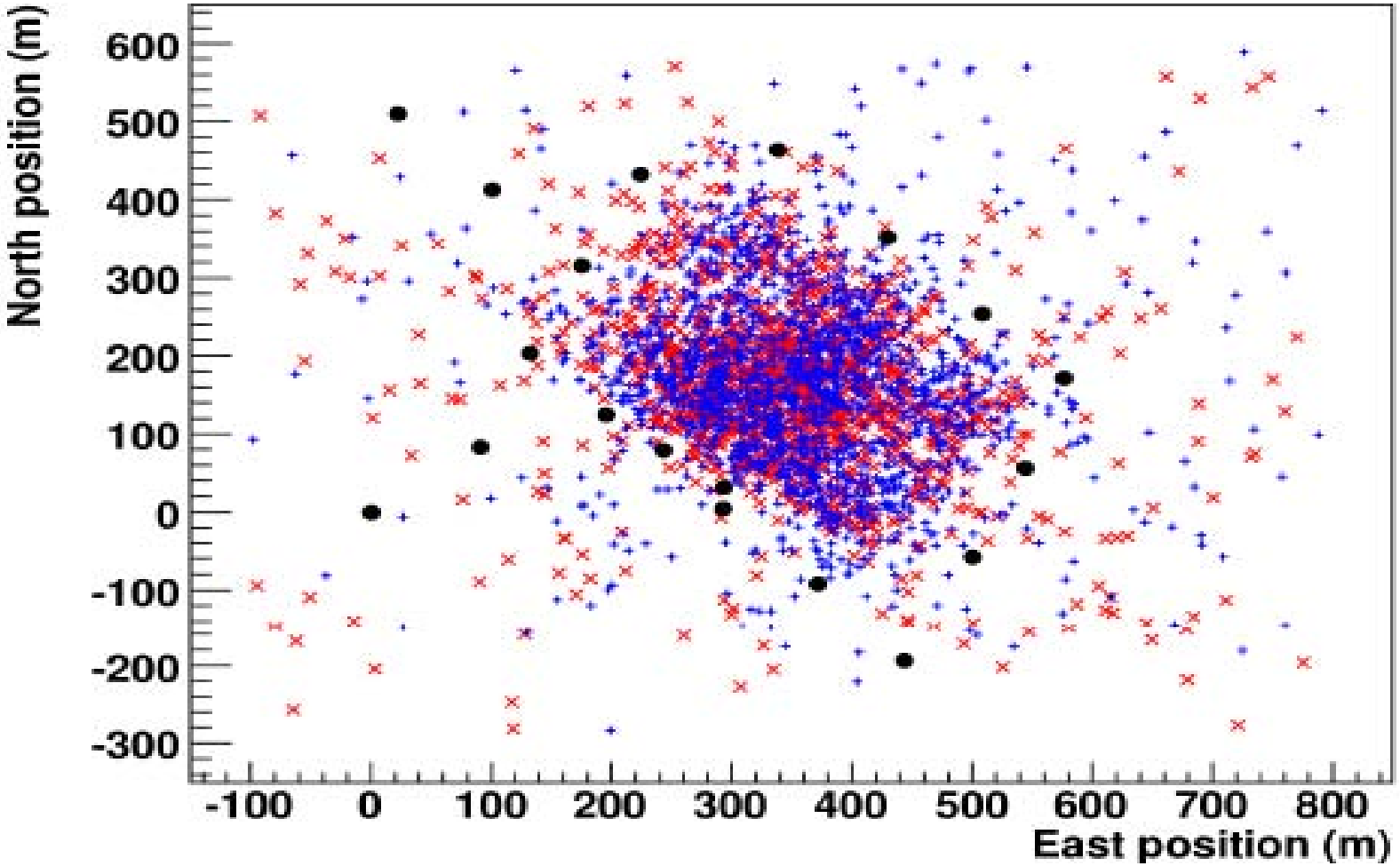
IceCube: the contained event detector

2007 detector: 22 IceCube strings + AMANDA
can be divided in veto and fiducial volume



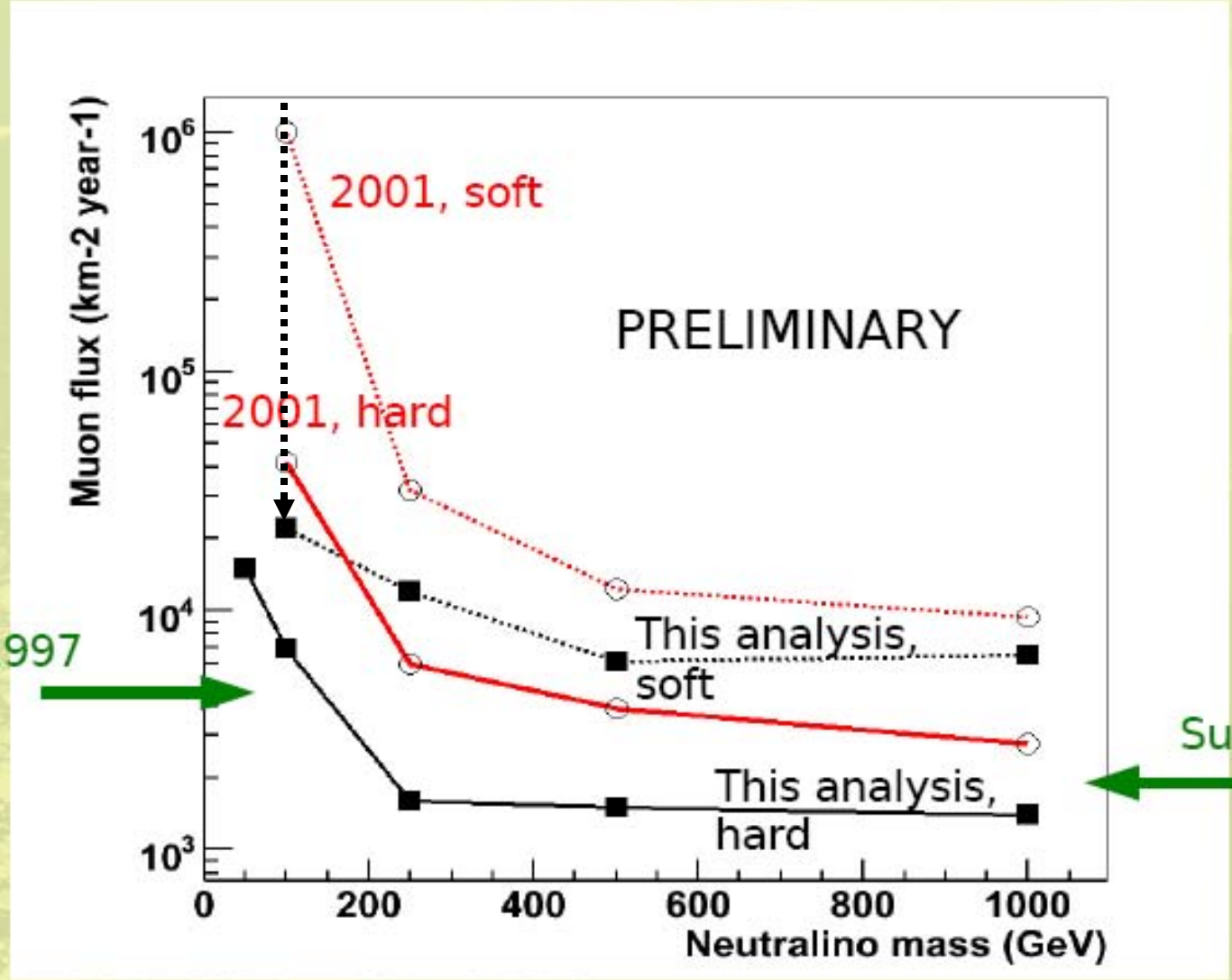
muon vertices of events passing the on-line filter well inside the defined fiducial volume

blue: WIMPS **red: background**



2007 detector: AMANDA → IceCube

Expectation values of sensitivities compared to AMANDA-II 2001 analysis (Y. Minaeva)



Baksan 1997

Super-K 2002

contained event detector

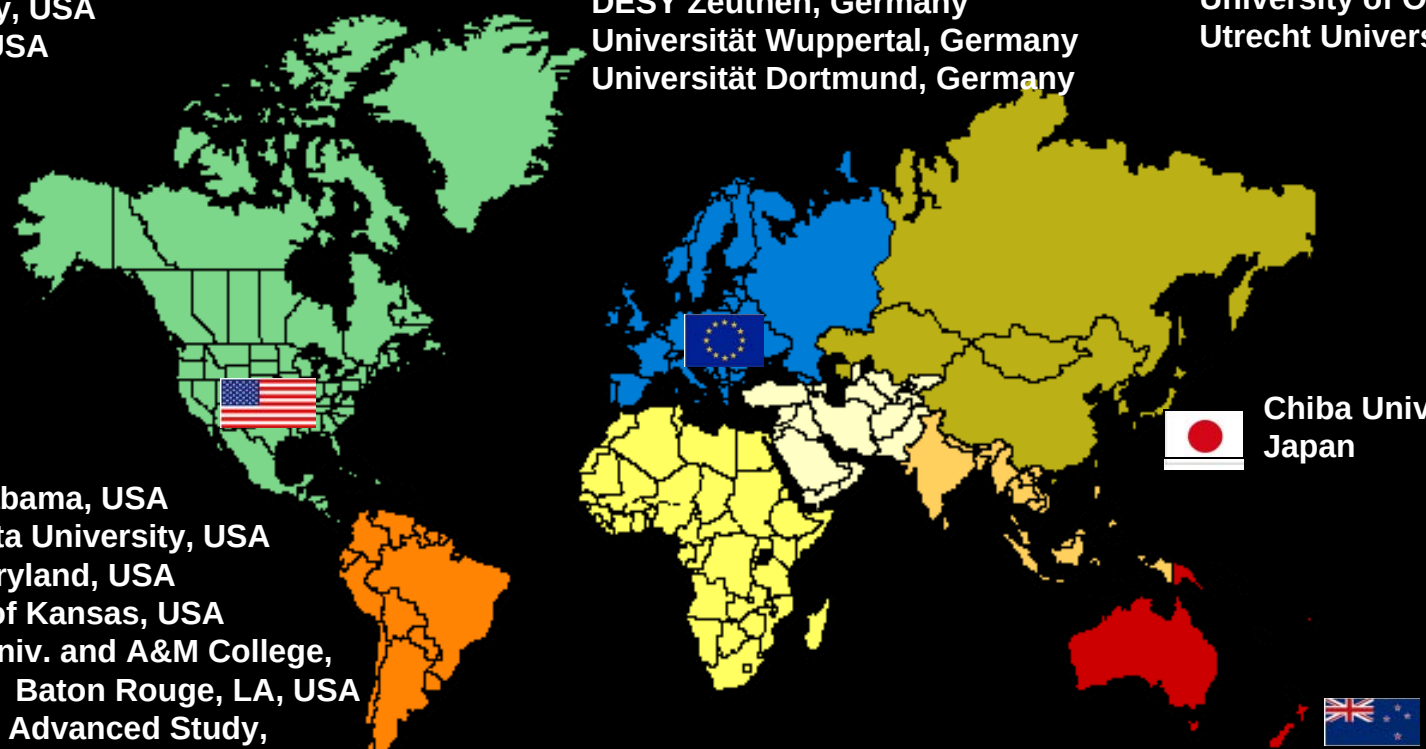
- data taking starts May 15
- 40,000 atmospheric neutrinos by next Christmas
- WIMPs by …

IceCube Collaboration

Bartol Research Inst, Univ of Delaware, USA
Pennsylvania State University, USA
University of Wisconsin-Madison, USA
University of Wisconsin-River Falls, USA
LBNL, Berkeley, USA
UC Berkeley, USA
UC Irvine, USA

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

Humboldt Universität, Germany
MPI, Heidelberg
Uppsala Universitet, Sweden
Stockholm Universitet, Sweden
Kalmar Universitet, Sweden
Imperial College, London, UK
University of Oxford, UK
Utrecht University, Netherlands



Chiba University, Japan

Univ. of Alabama, USA
Clark-Atlanta University, USA
Univ. of Maryland, USA
University of Kansas, USA
Southern Univ. and A&M College, Baton Rouge, LA, USA
Institute for Advanced Study, Princeton, NJ, USA
University of Alaska, Anchorage

University of Canterbury, Christchurch, New Zealand