

# icebound



# neutrinos

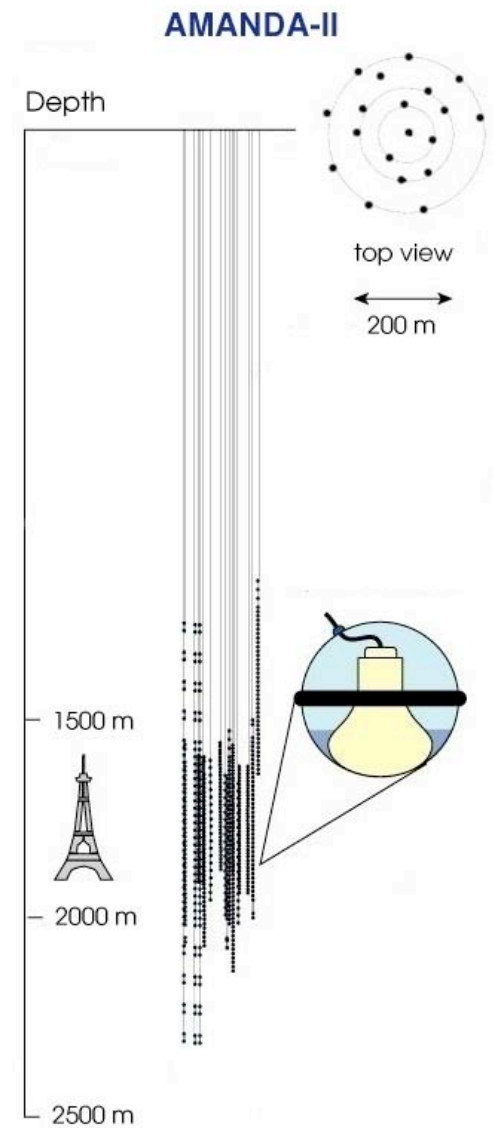
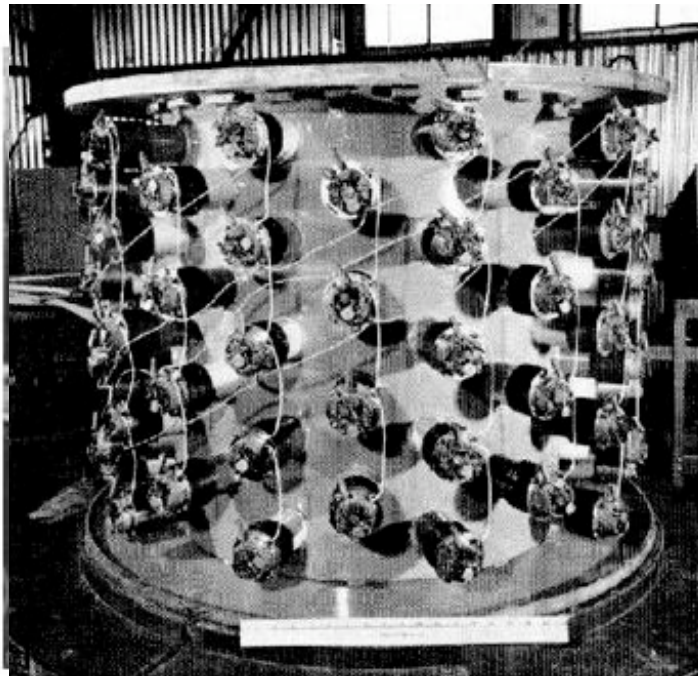
Francis Halzen

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

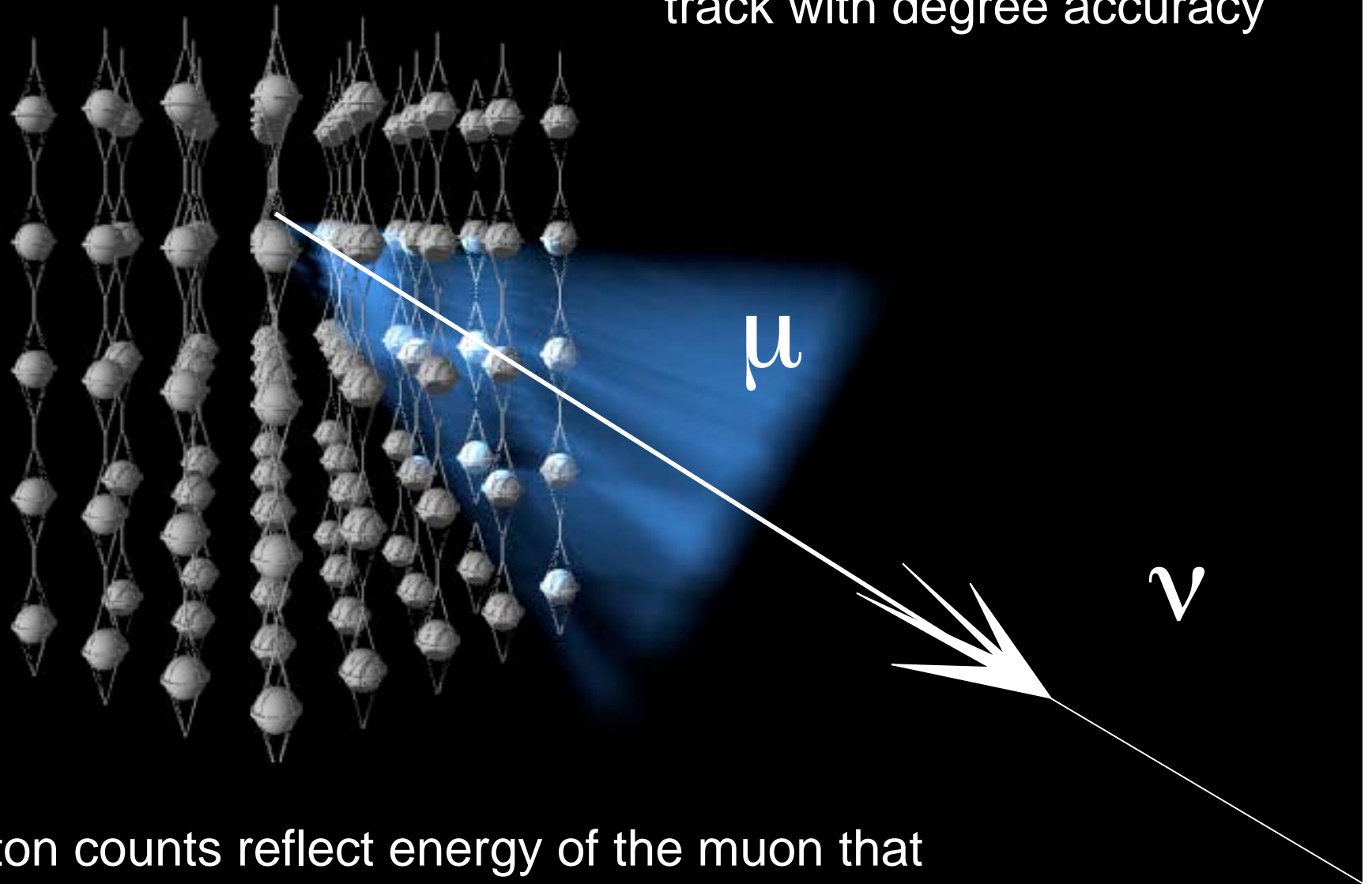
# neutrinos from the cosmos

- neutrino astronomy
- kilometer-scale detectors
  - AMANDA: proof of concept
  - IceCube: bigger and better
- direct and indirect dm search
- AMANDA limits
- the contained event detector

# Kilometer-Scale Neutrino Detectors



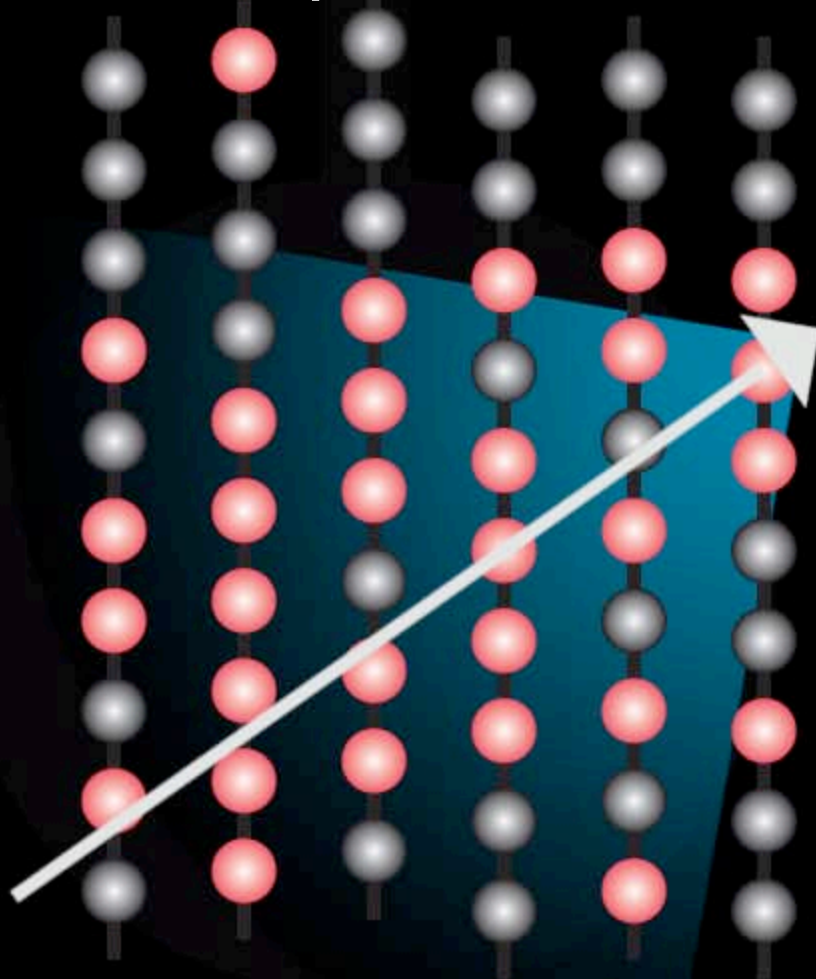
- nanosecond timing allows likelihood reconstruction of the track with degree accuracy



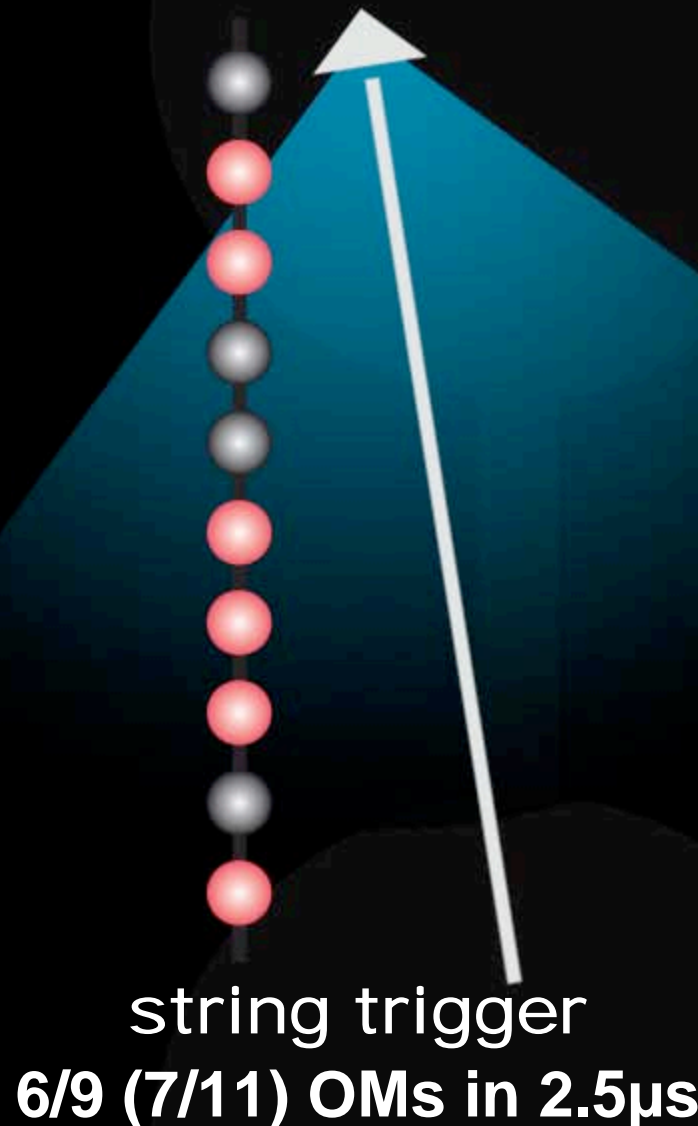
- photon counts reflect energy of the muon that loses energy catastrophically (bremsstrahlung,...)

# DAQ trigger

**multiplicity trigger**  
24 OMs in 2.5 $\mu$ s

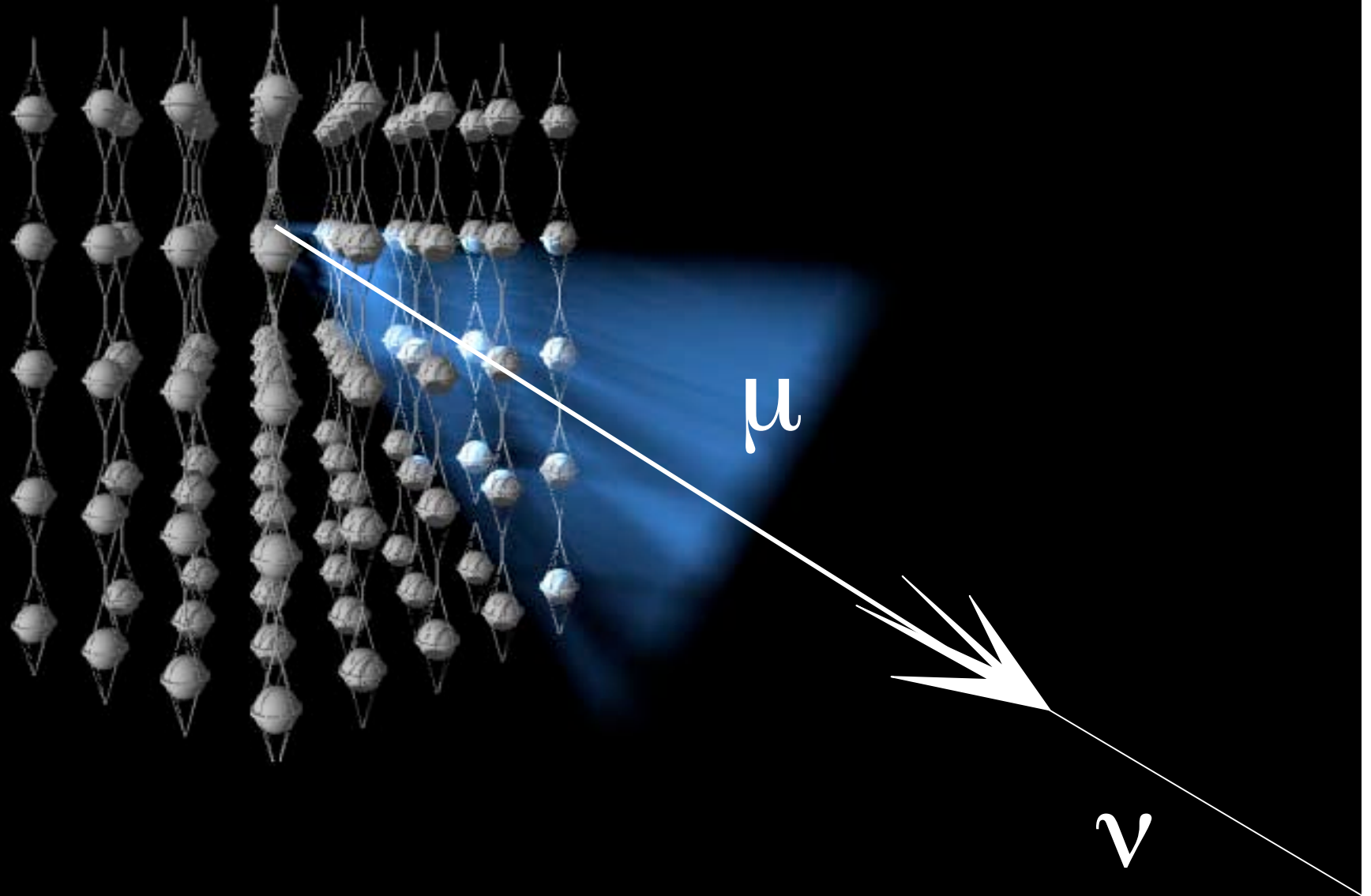


**multiplicity trigger**  
24 OMs in 2.5 $\mu$ s



**string trigger**  
6/9 (7/11) OMs in 2.5 $\mu$ s

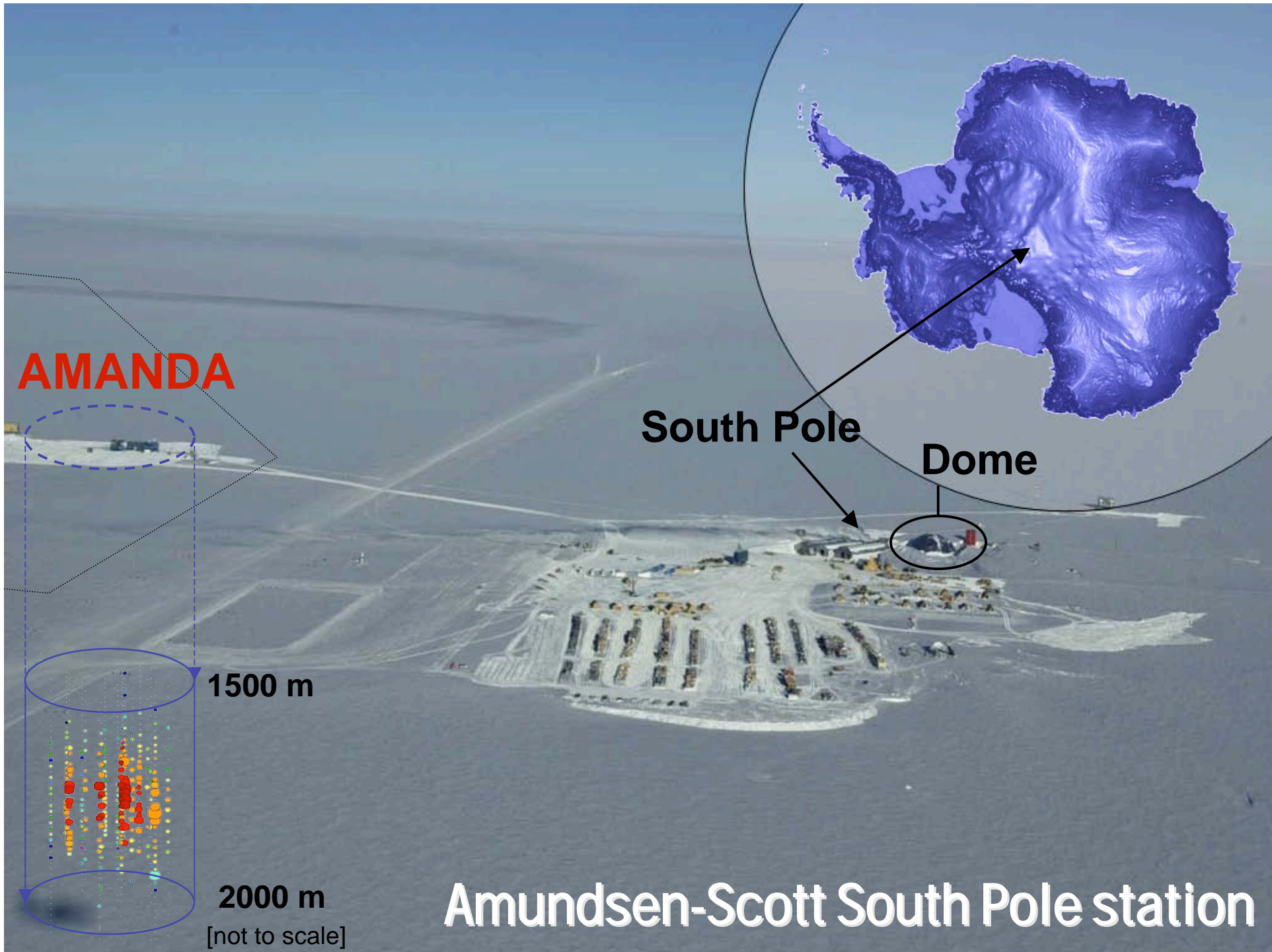
# detection method



unfortunately, detecting a neutrino is difficult !

AMANDA: proof of concept



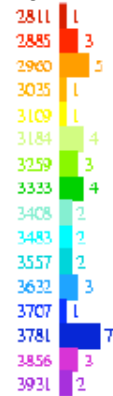


# AMANDA Event Signatures: Muons

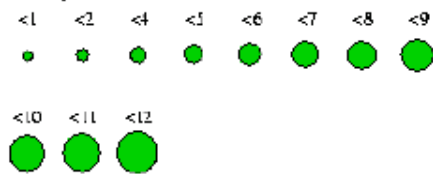
**muon neutrino interaction → track**



Color displays: LE Primary Channels



Size displays: ADC



Size scaling: Lin

No external geometry file is opened.  
 Detector: amanda-b-10, 10strings, 302 modules  
 Data file: /home/itsbosada/amanda\_events/strict19.f2k  
 File contains 19 events.  
 Displaying data event 1197960 from run 0  
 Recorded y/ty: 1997/285  
 18132.0091381 seconds past midnight.  
 Before cuts: 44 hits, 44 OMs  
 After cuts: 44 hits, 44 OMs  
 Antineutrino

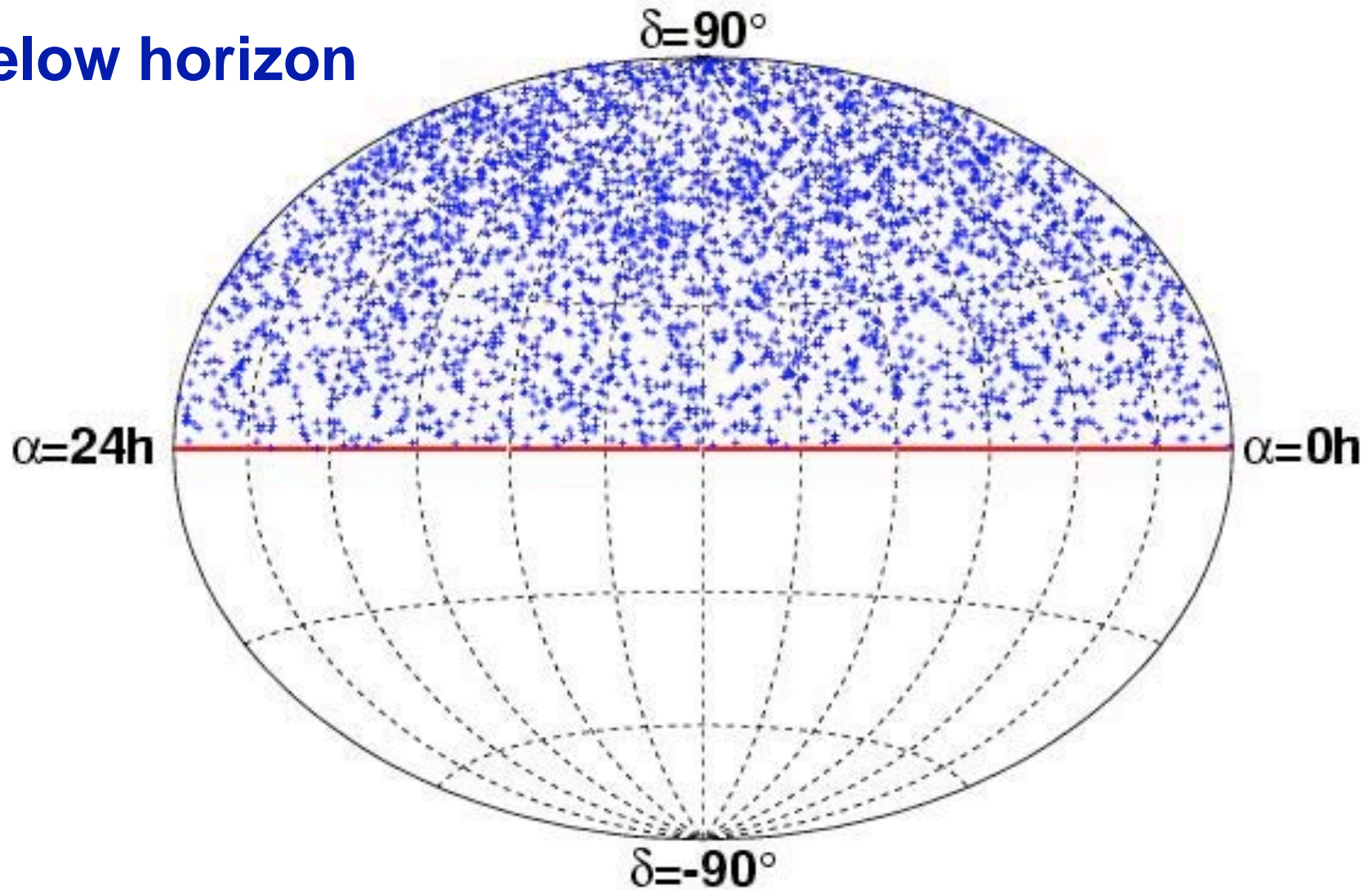
	x	y	z
Vertex pos :	12.4	-16.1	6.8 m
Direction :	0.03970	0.41614	0.90844
Length :	Inf m		
Energy :	? GeV		
Time :	3205.100000 ns		
Zenith :	155.3°		
Azimuth :	264.6°		



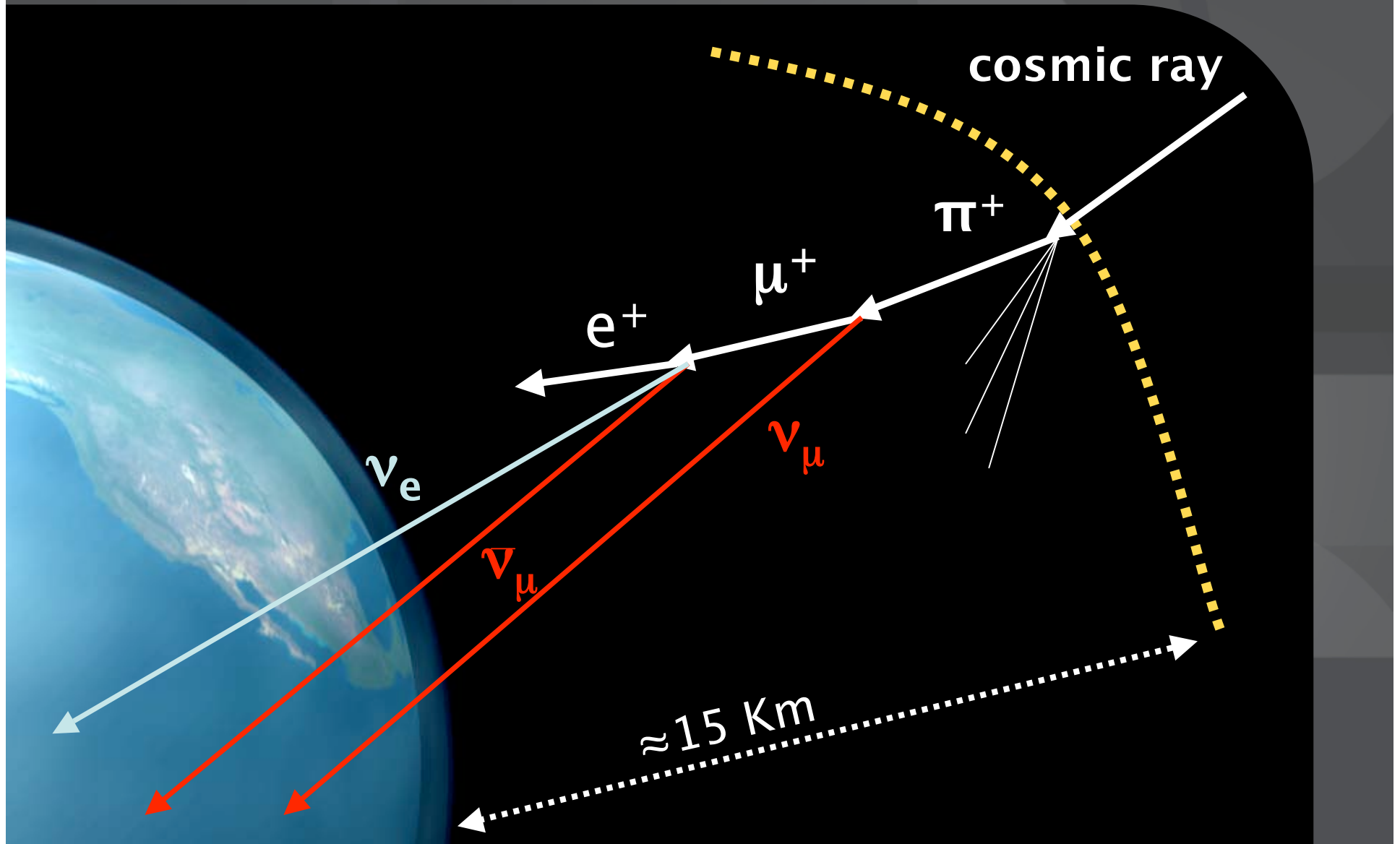
# AMANDA skyplot 2000-2003

3369 events

below horizon



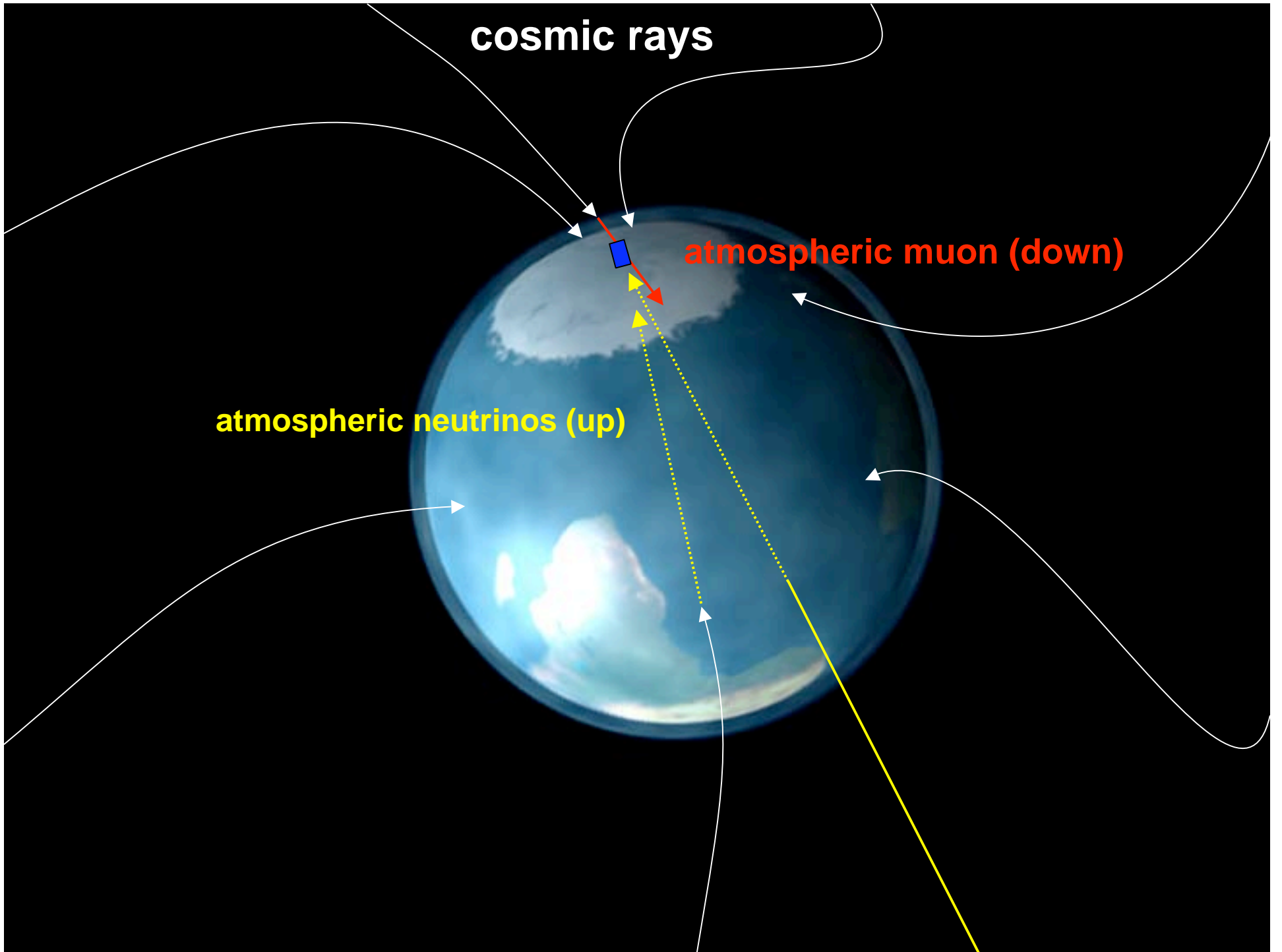
# atmospheric neutrinos



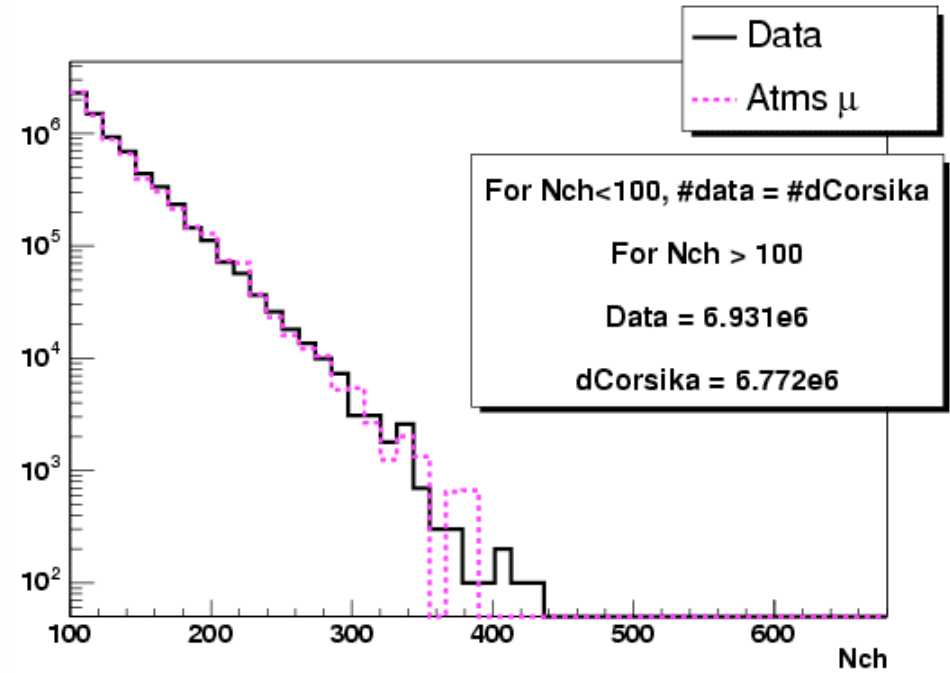
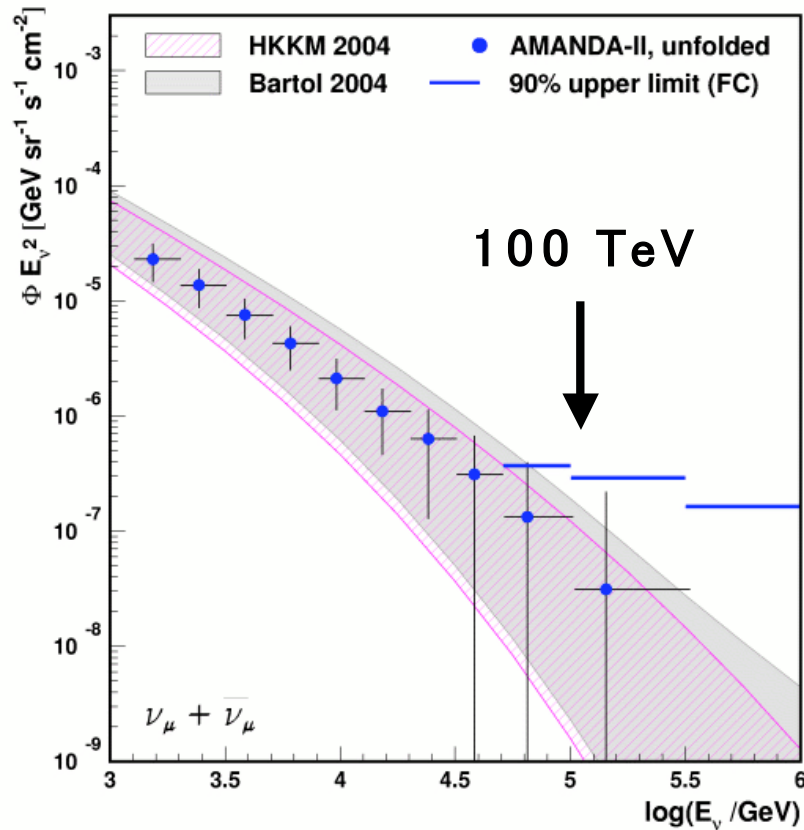
**cosmic rays**

**atmospheric muon (down)**

**atmospheric neutrinos (up)**



# calibration on cosmic ray neutrinos and muons

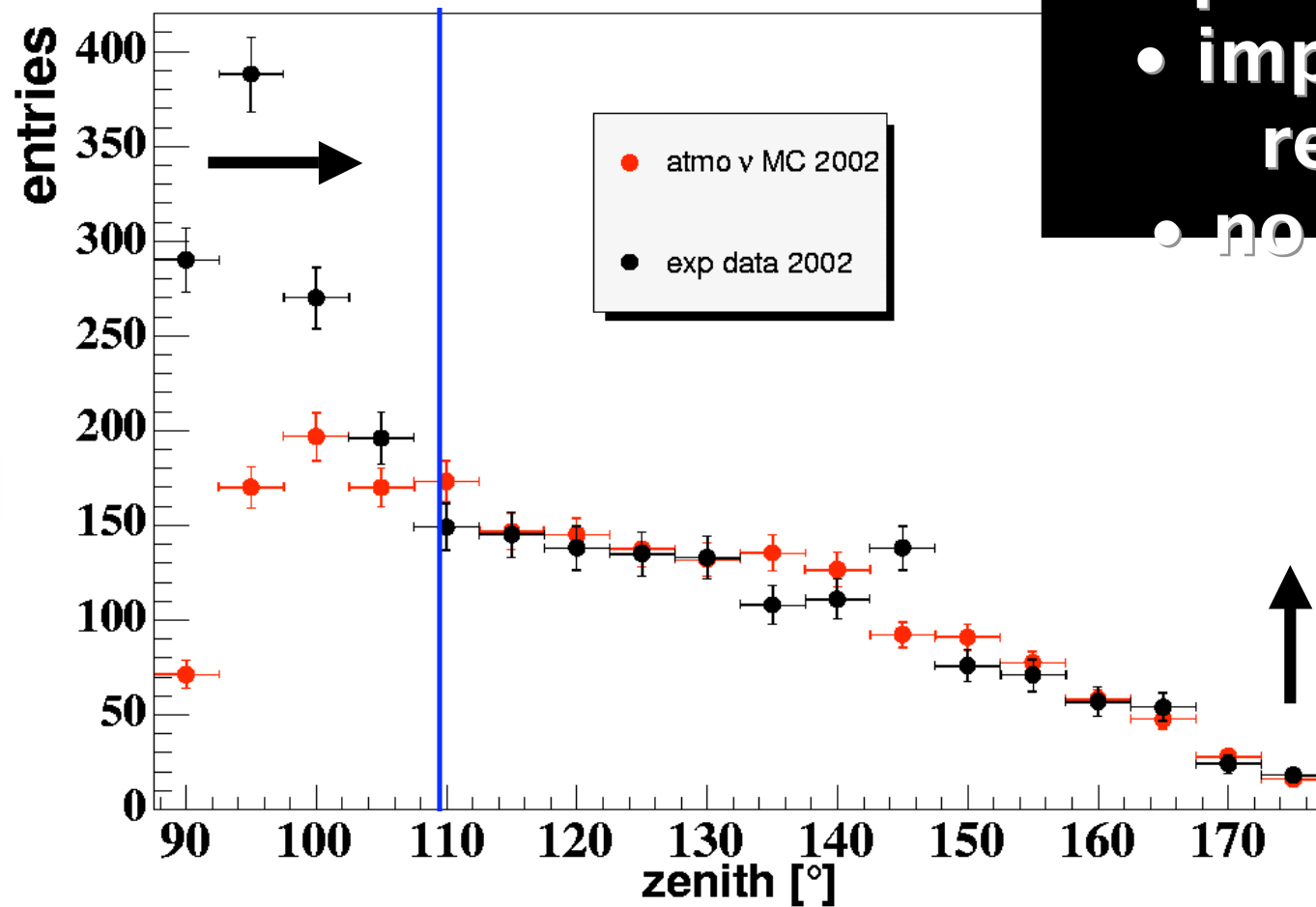


**inverted analysis: use atmospheric muons to benchmark MC**

- atmospheric  $\nu_\mu$  spectrum

# 2002 analysis

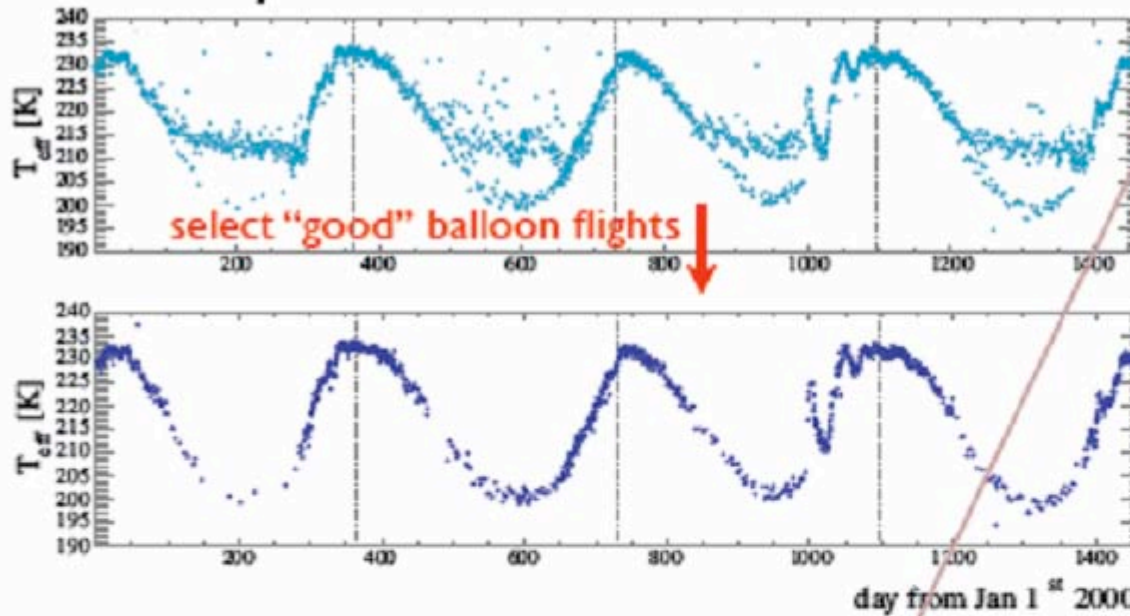
zenith distribution



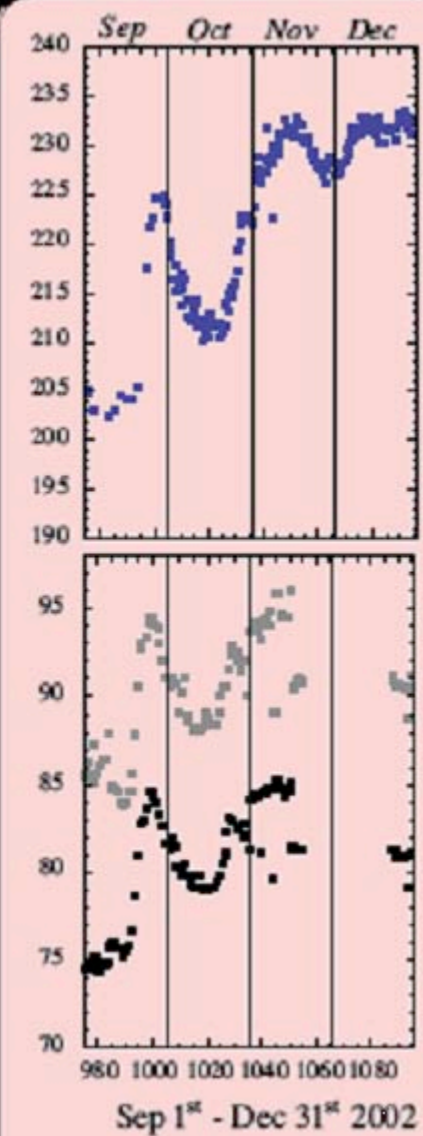
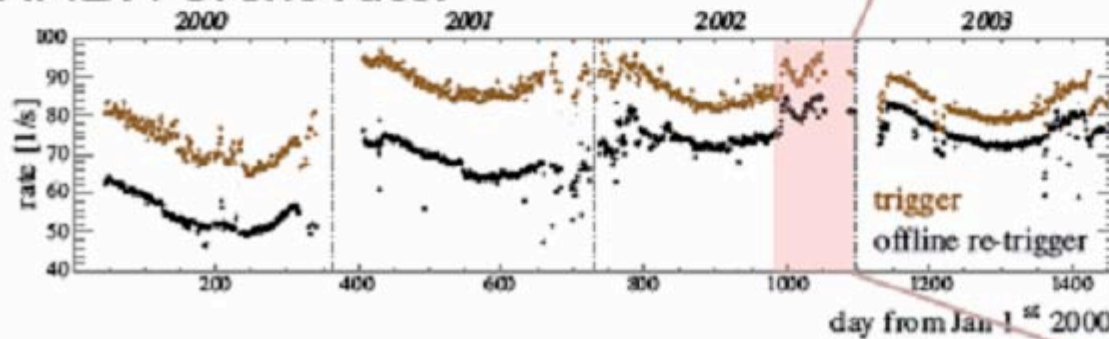
→ 10 events  
per day:  
• improved  
reco  
• no cuts !

# 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 ~ 1500–2000 m	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 <sup>3</sup>	Instrumented Volume ~ 1 km <sup>3</sup>

IceCube is both larger and technologically superior



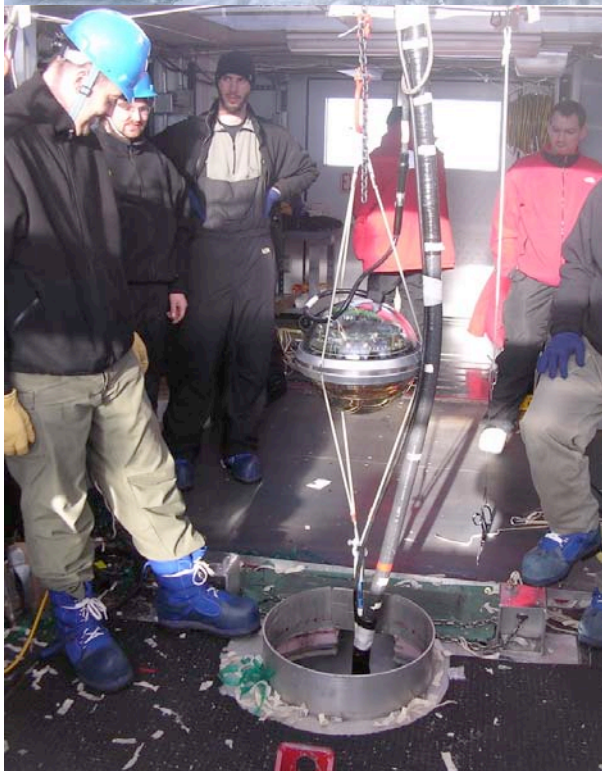
# IceCube drilling: 2 to 4.8 megawatt



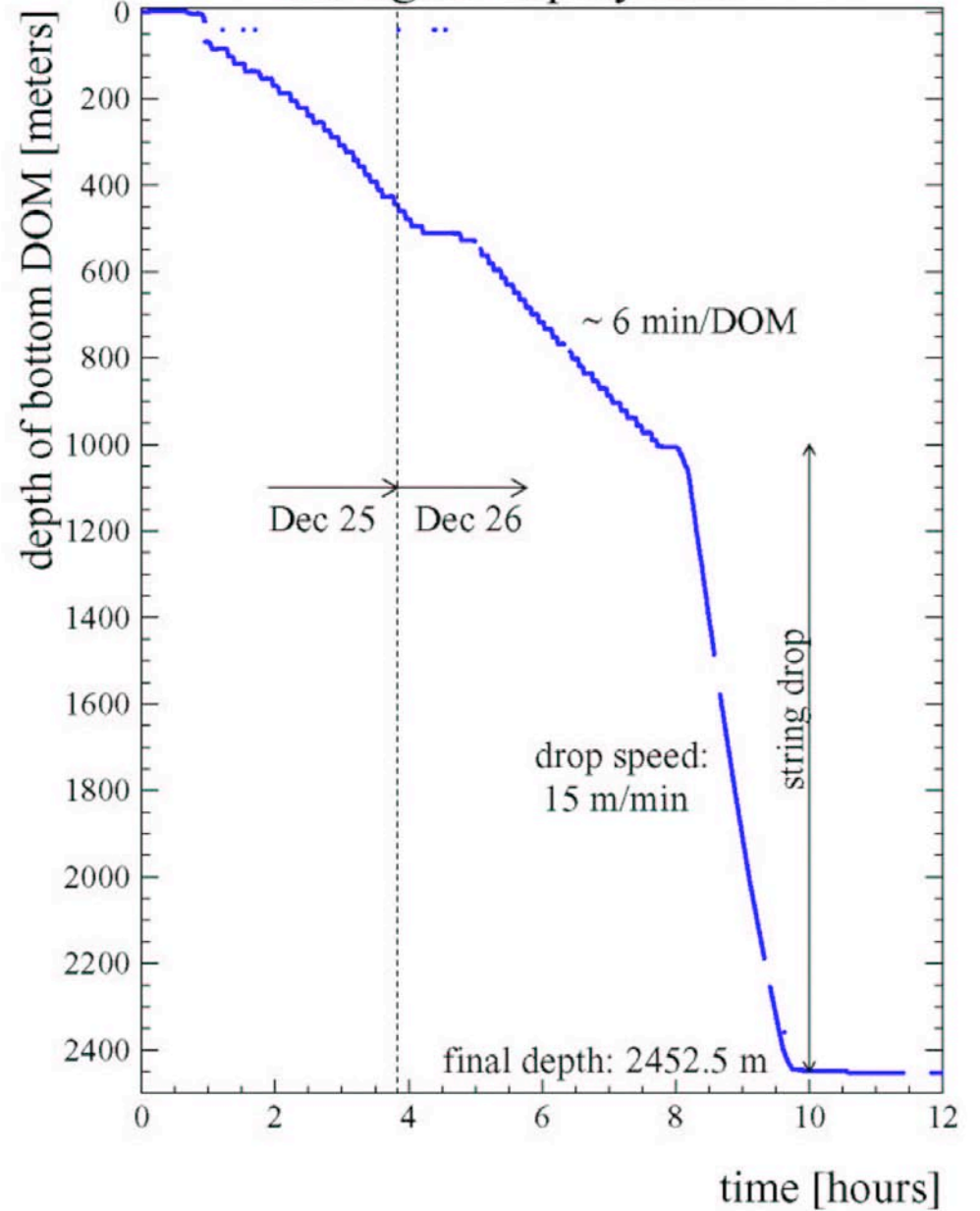
- 1 million pounds of cargo
- C-130 planes: > 50 flights



String cable 2500 m Weight ~6 tons



String 29 deployment



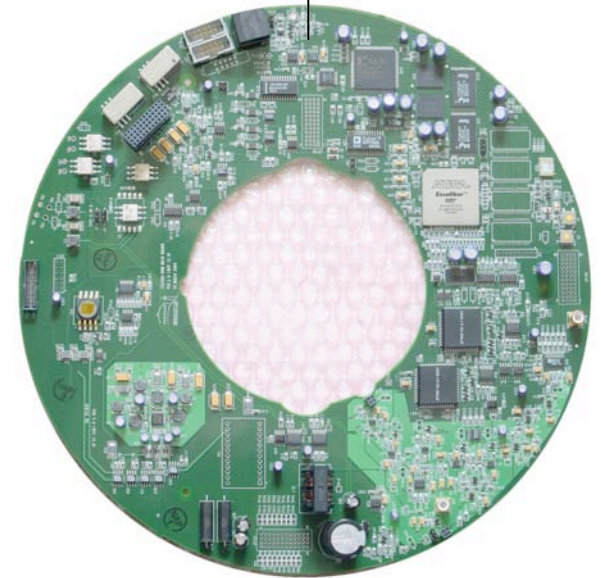
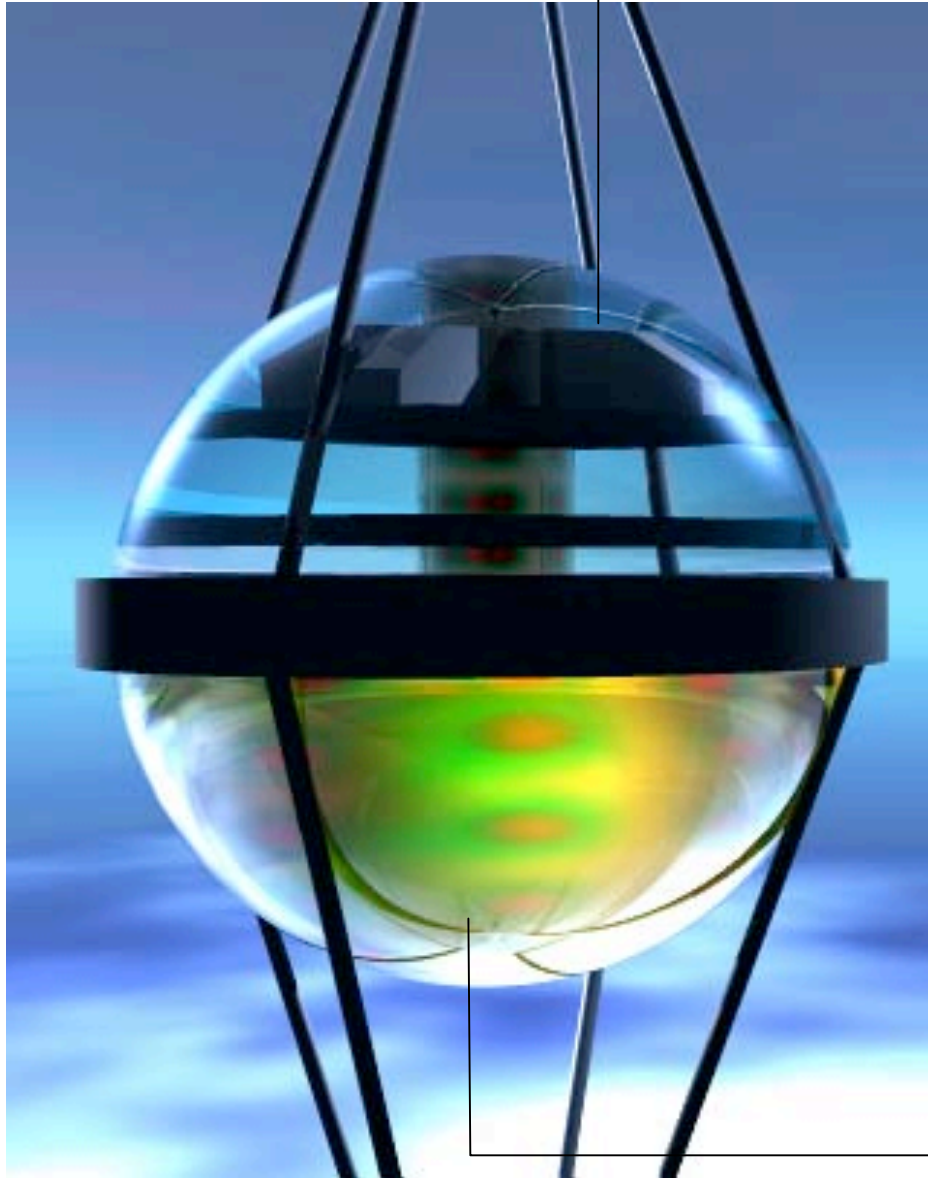


# optical sensor





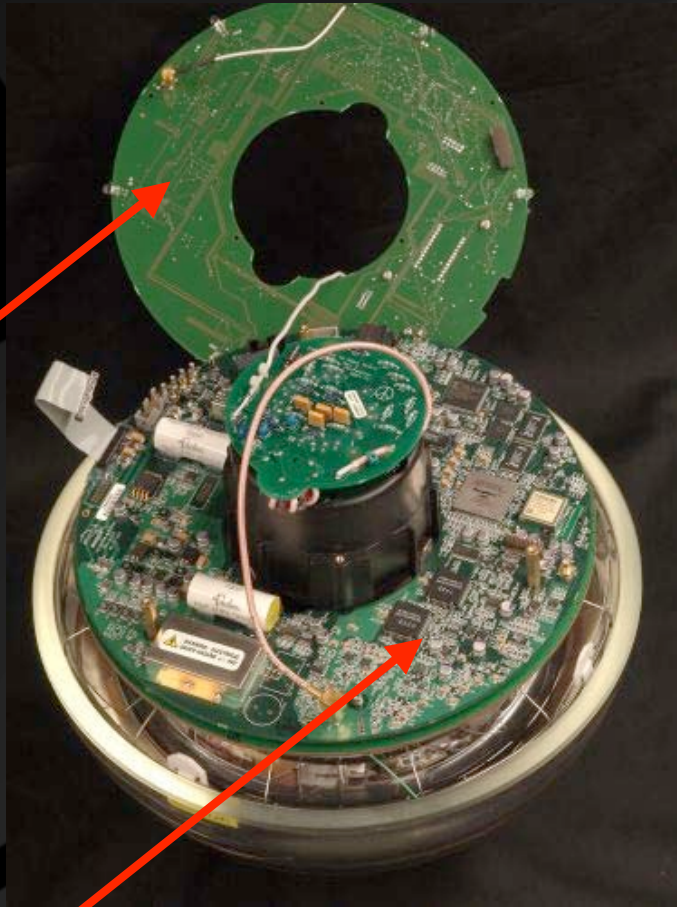
Digital Optical Module



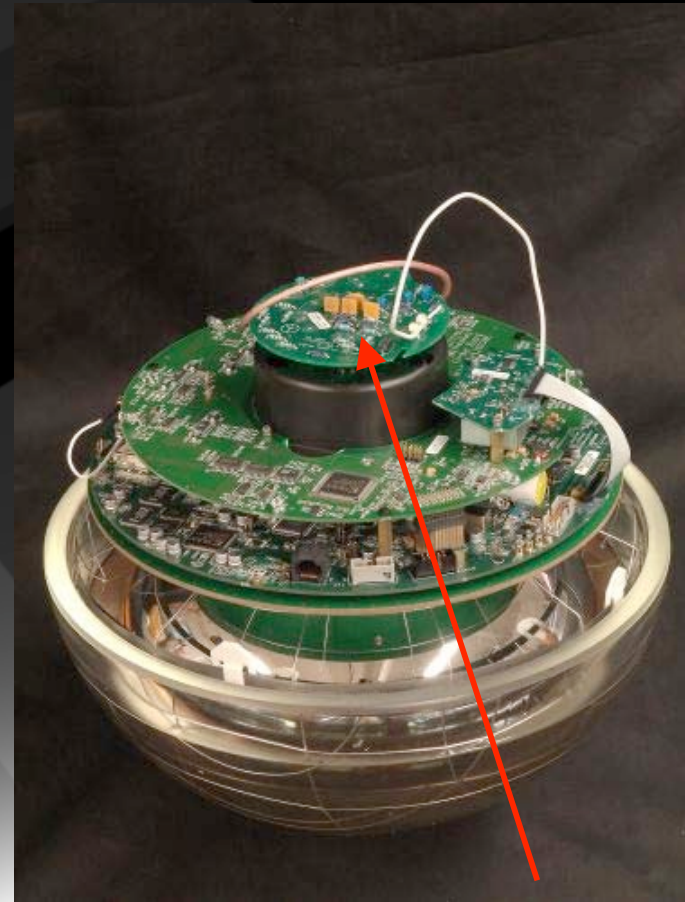
Photomultiplier Tube

# Digital Optical Module

LED  
flasher  
board

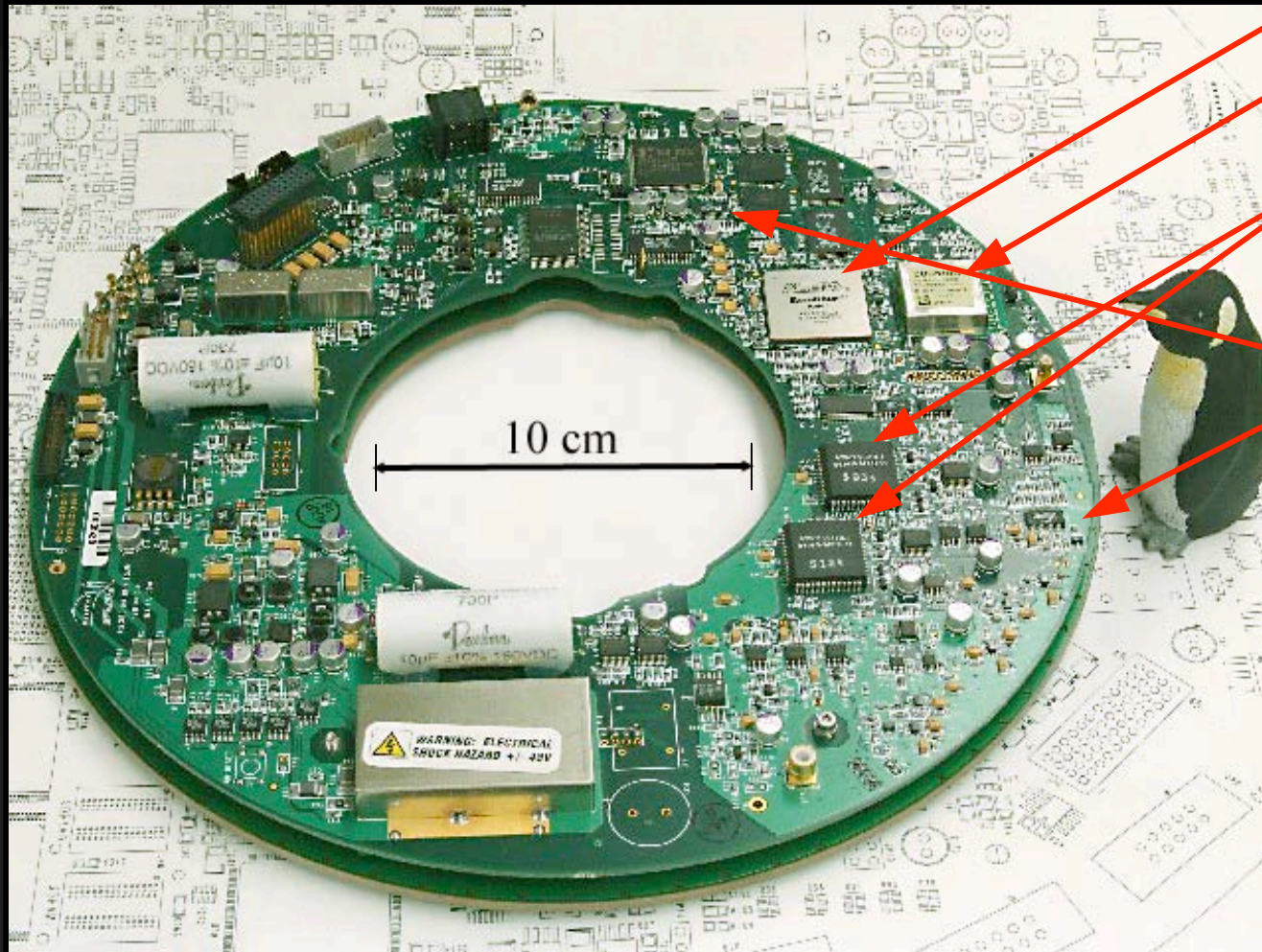


main  
board



HV board

# Digital Optical Module Mainboard

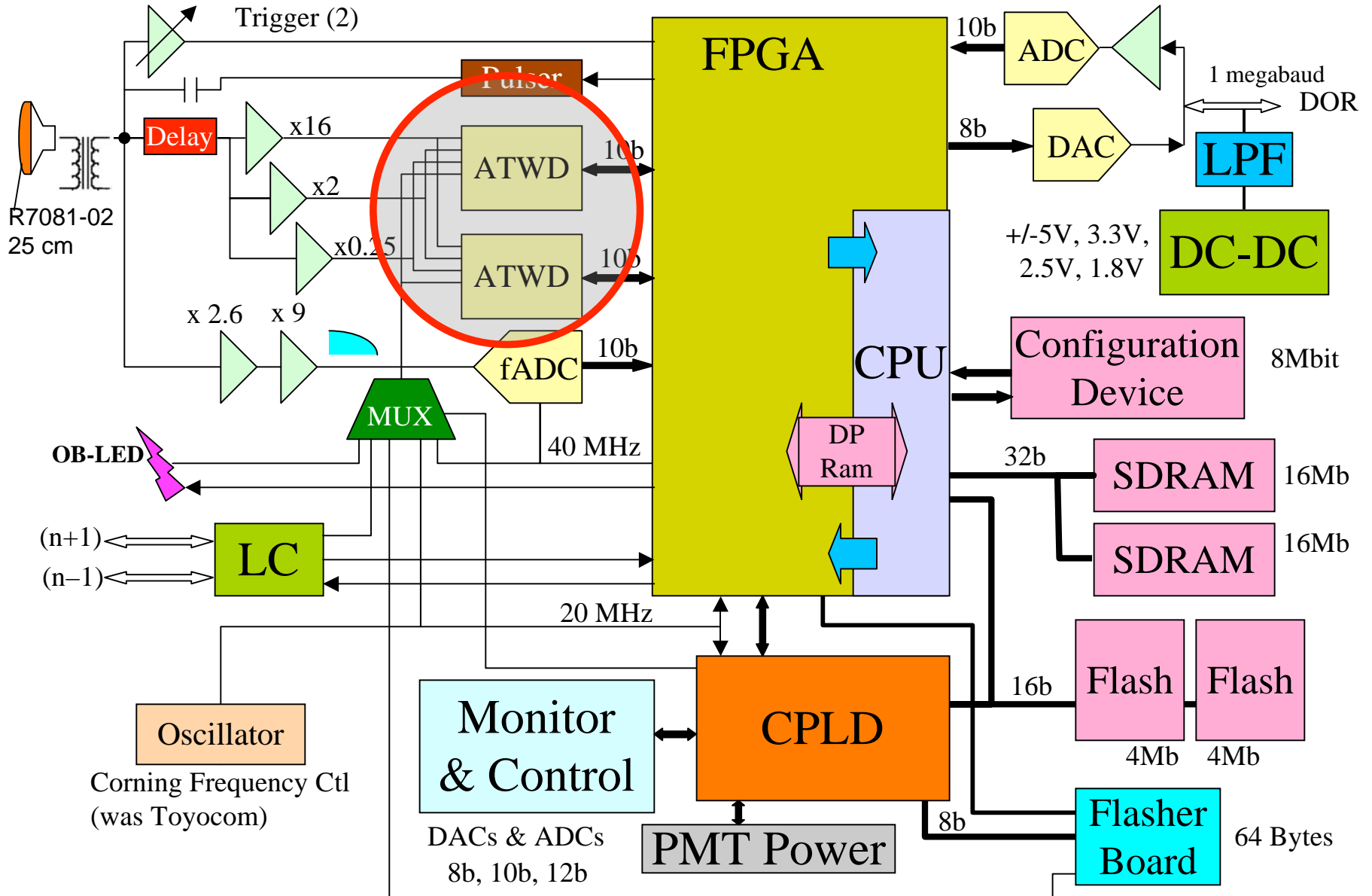


**CPU+FPGA**  
**20 MHz osc**

**2 ATWDs**

**Fast ADC:**  
**waveform**  
**and COMM**

# DOM MB Block diagram



# IceCube Deployment

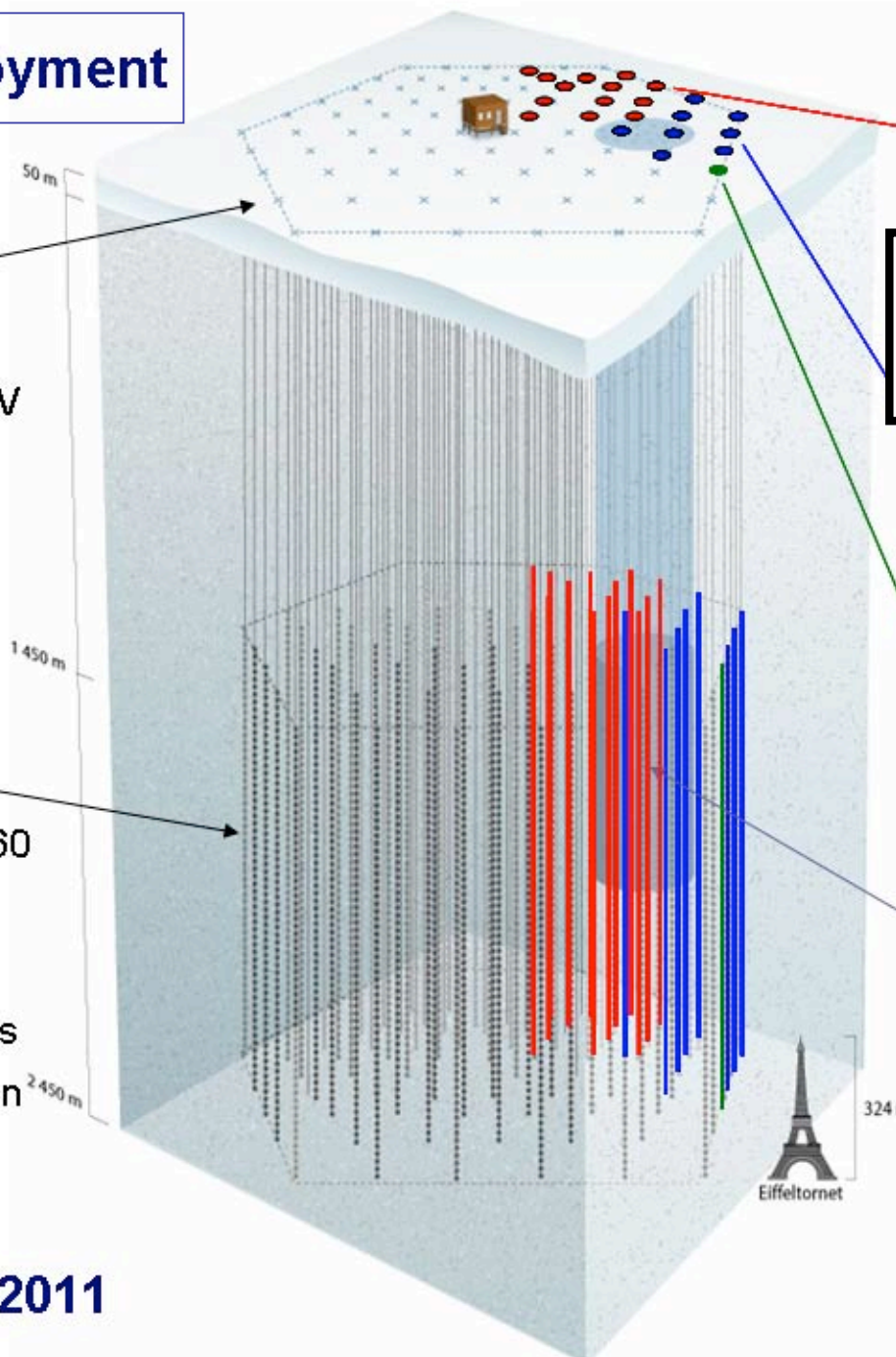
## IceTop

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

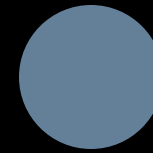
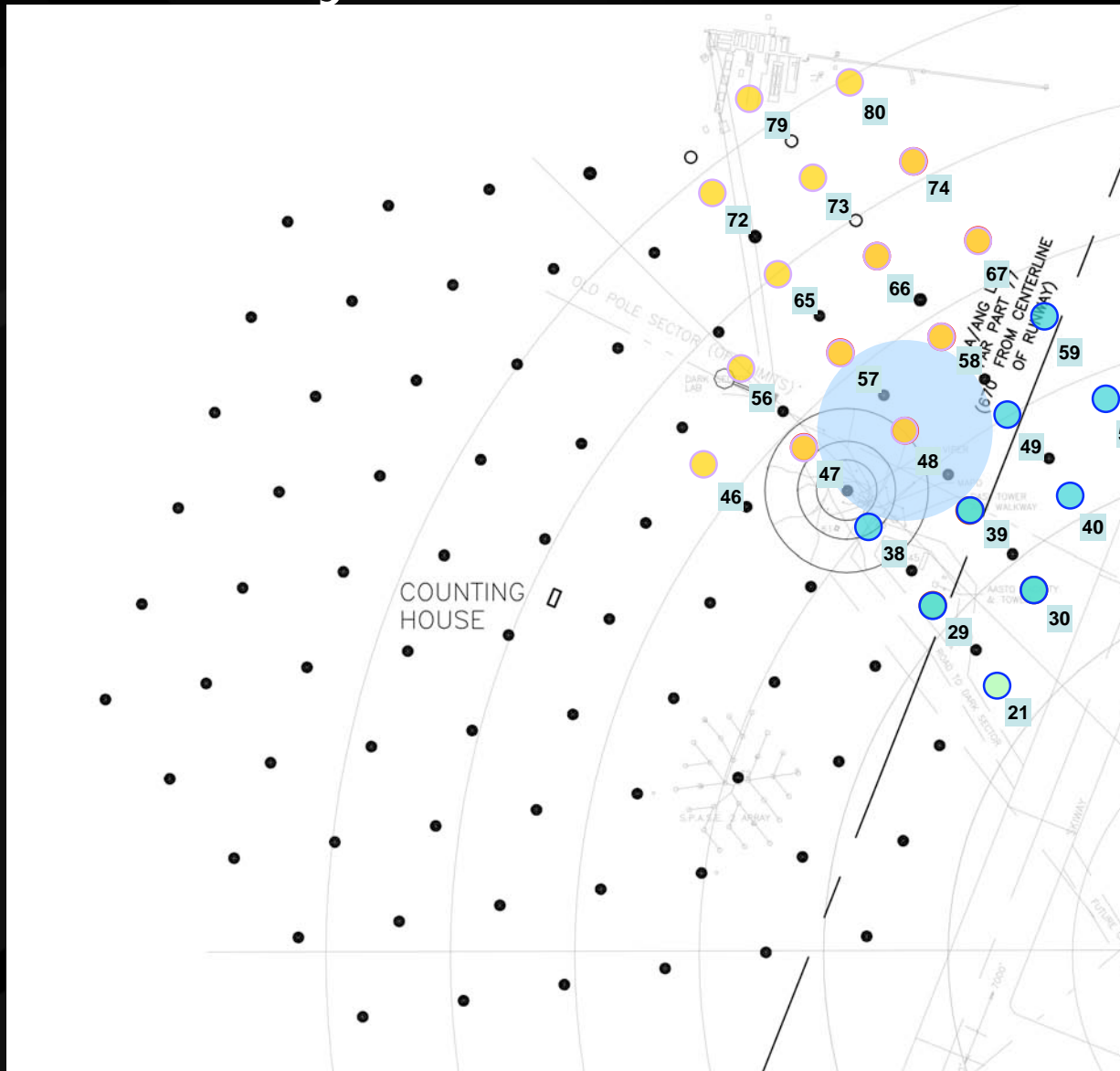
*First data in 2005*  
*first upgoing muon:*  
*July 18, 2005*

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

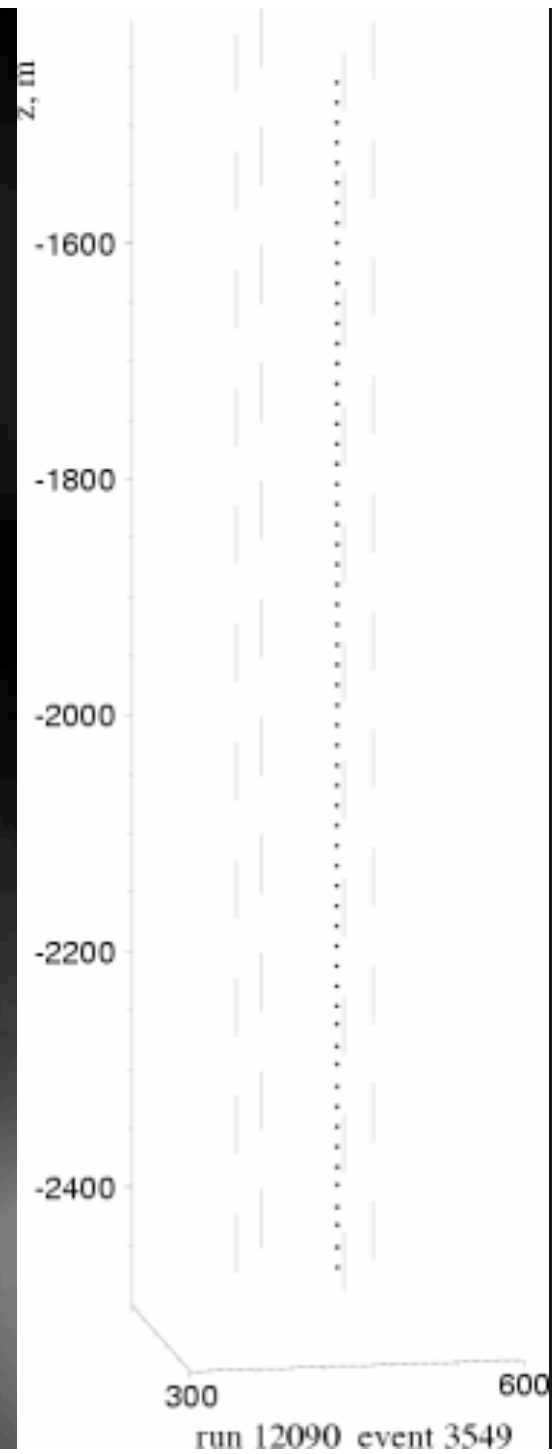


IceCube string and  
IceTop station to  
be deployed 12/06  
– 01/07

•604 DOMs deployed  
to date

•Want to achieve  
steady state of 14  
strings / season.

string trigger on  
IceCube string



# IceCube

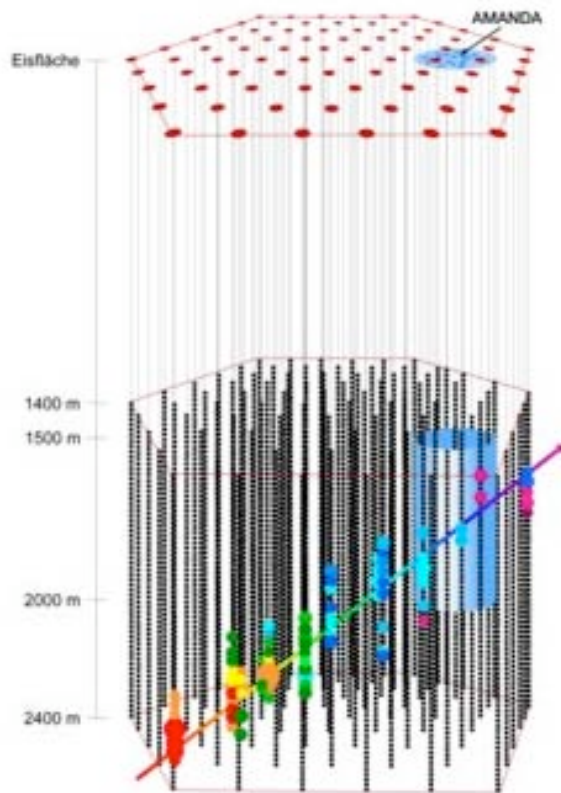
- in the next 10 years IceCube will observe

$\sim 10^6$  neutrinos with energies 0.1—1,000 TeV  
 $\sim 10$  neutrinos with energy  $> 10^6$  TeV

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

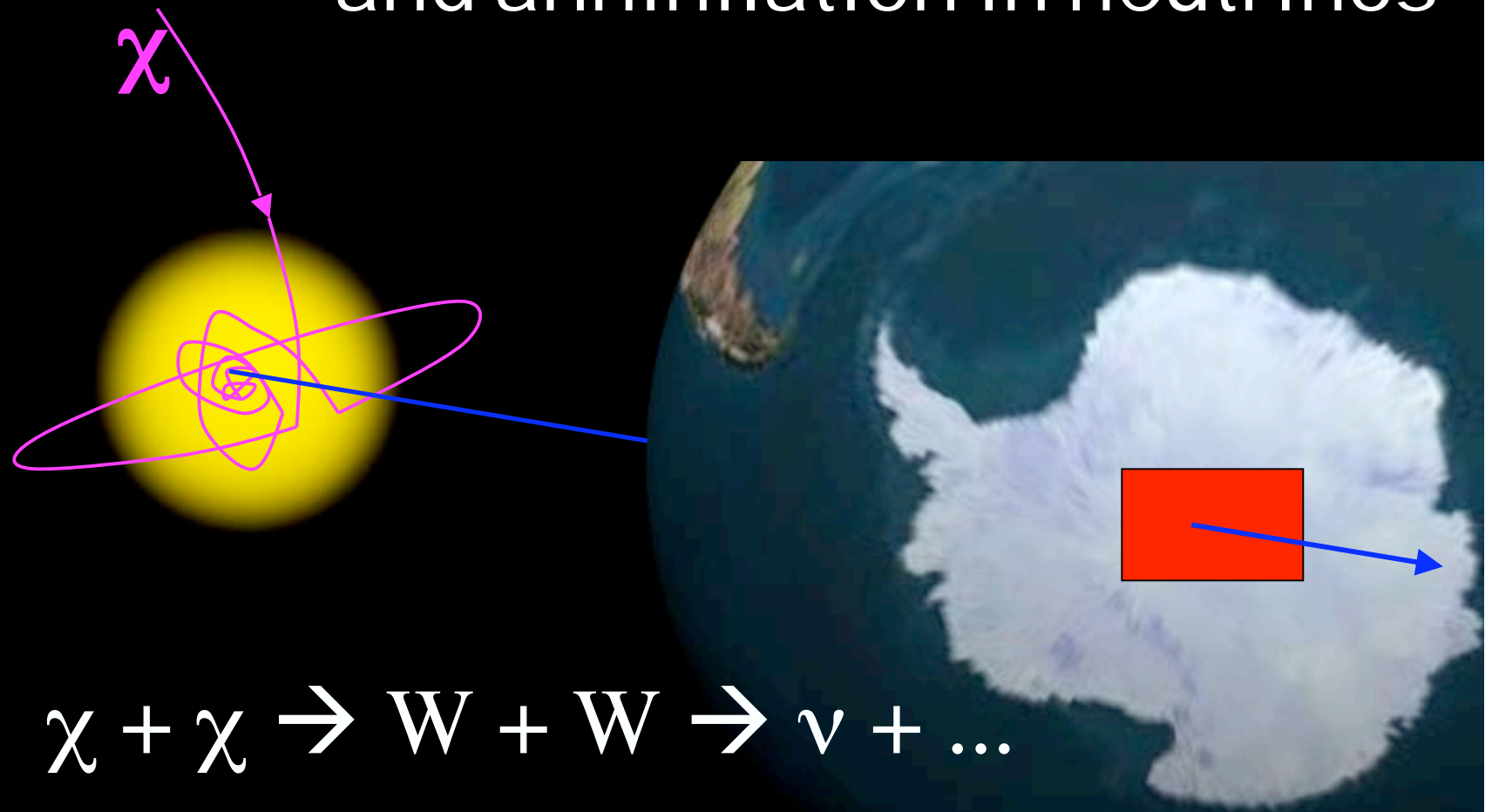
- with  $m \sim 0.01$  eV and  $E \sim 100$  TeV the gamma factor of the neutrino is

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





# WIMP capture in the sun and annihilation in neutrinos



# 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.

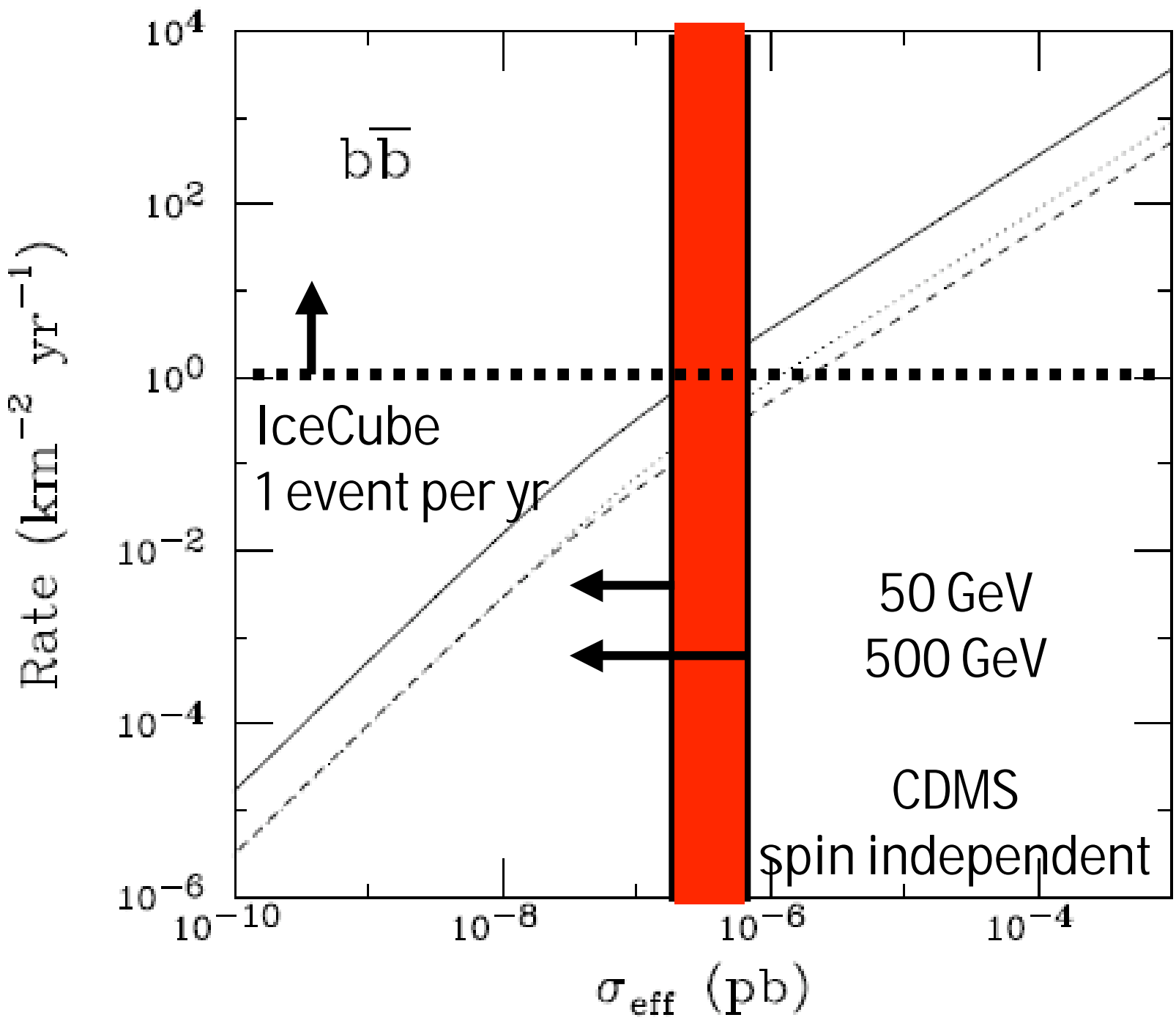
# indirect dark matter detection

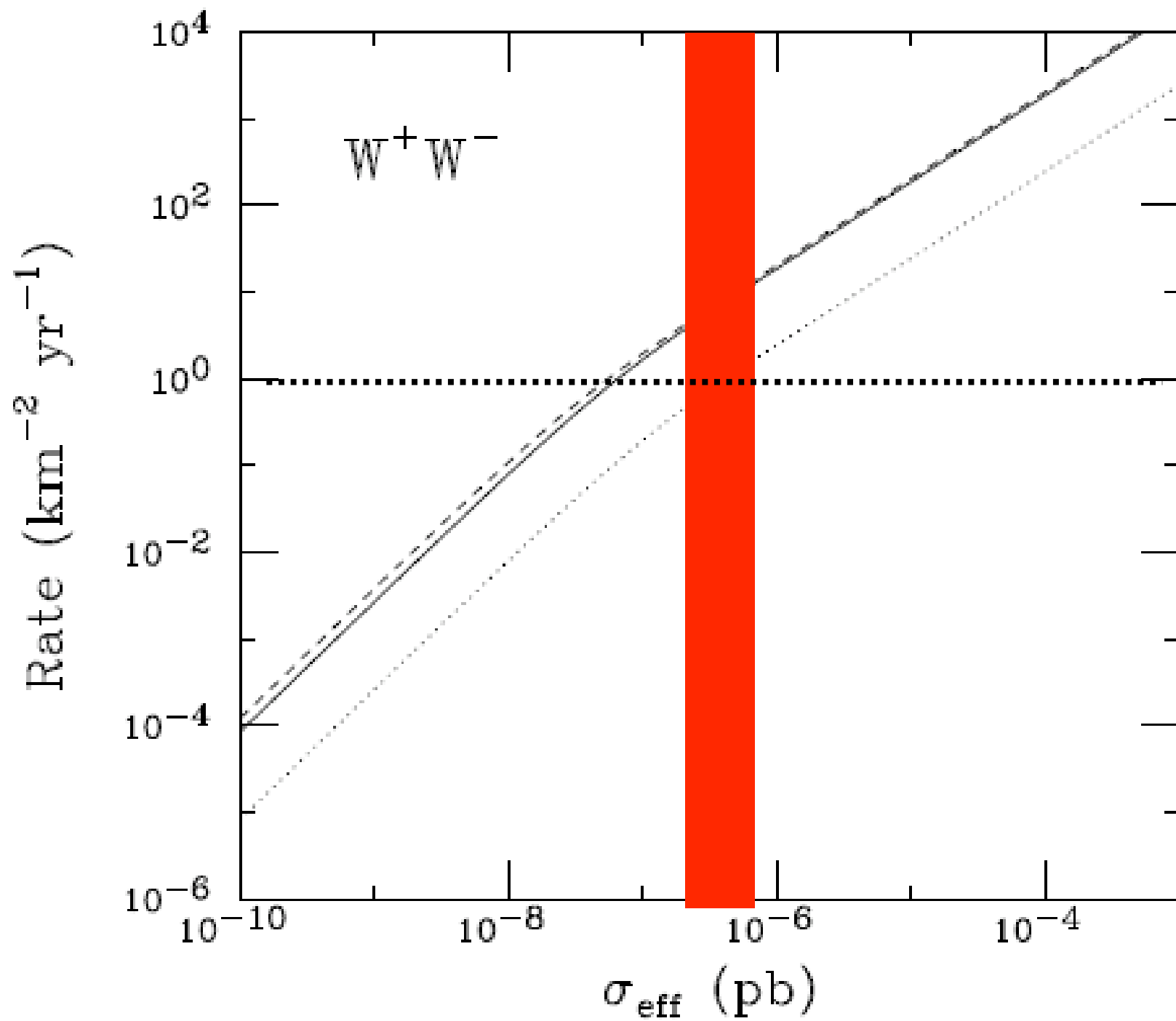
- indirect detection is especially sensitive to heavy WIMPS (good sensitivity of neutrino telescopes)
- indirect detection is especially sensitive to spin dependent WIMP interactions (squark- and W- exchange in s, t channel)

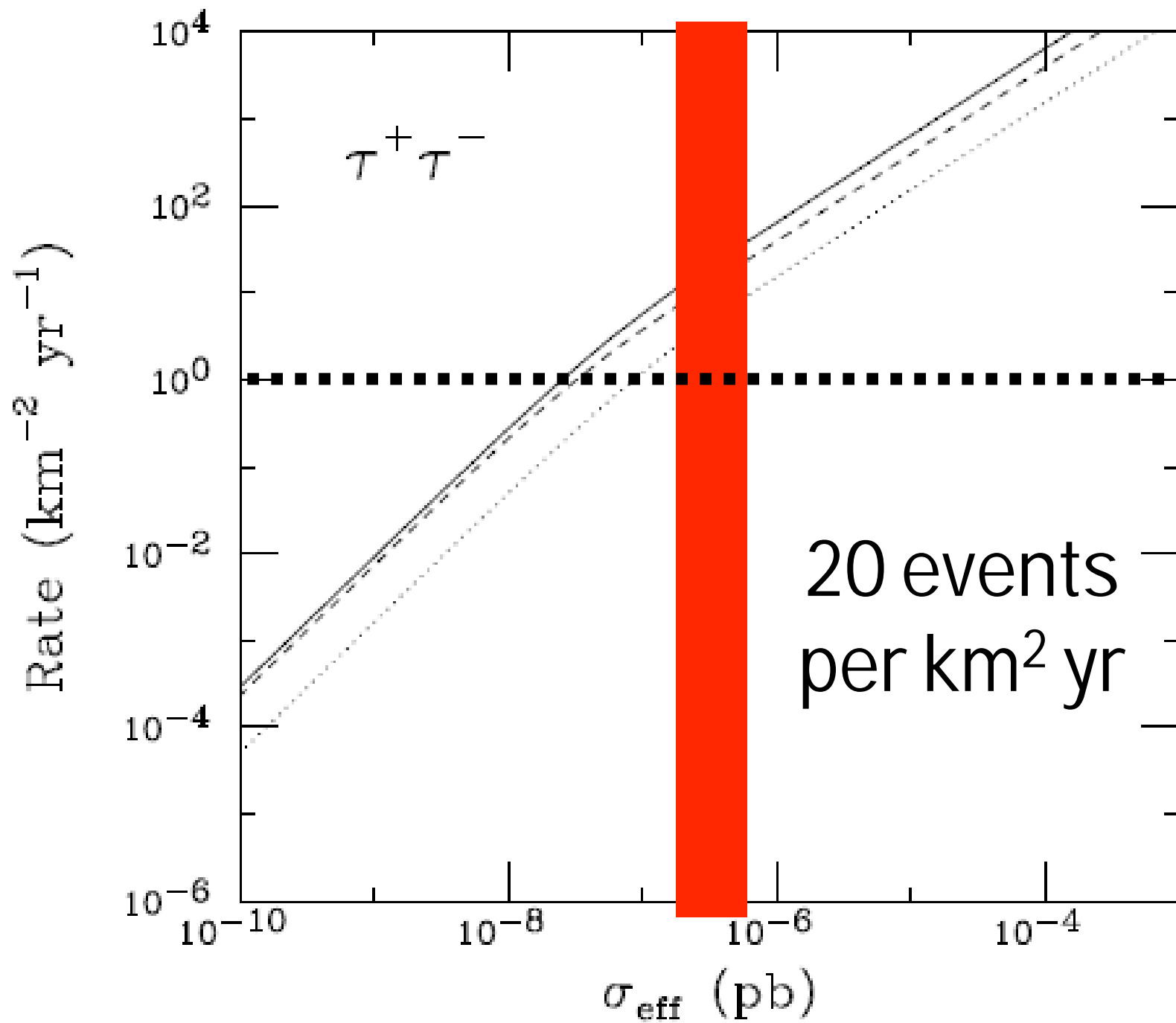
# indirect dark matter detection

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

direct and indirect

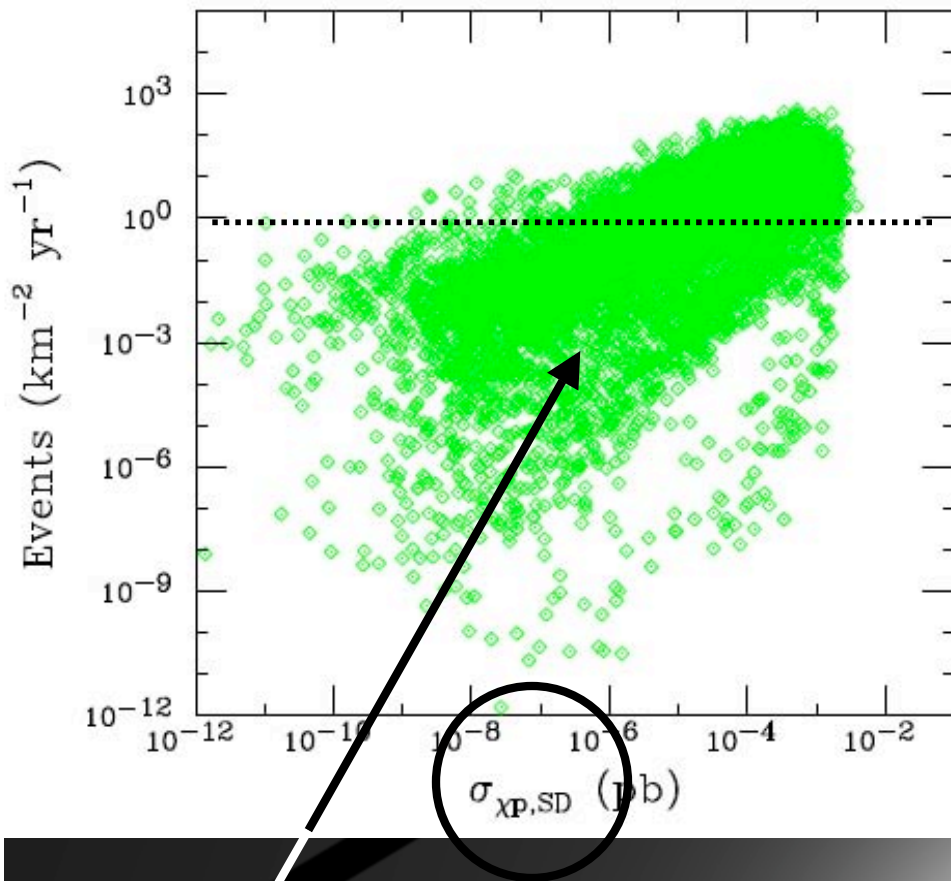




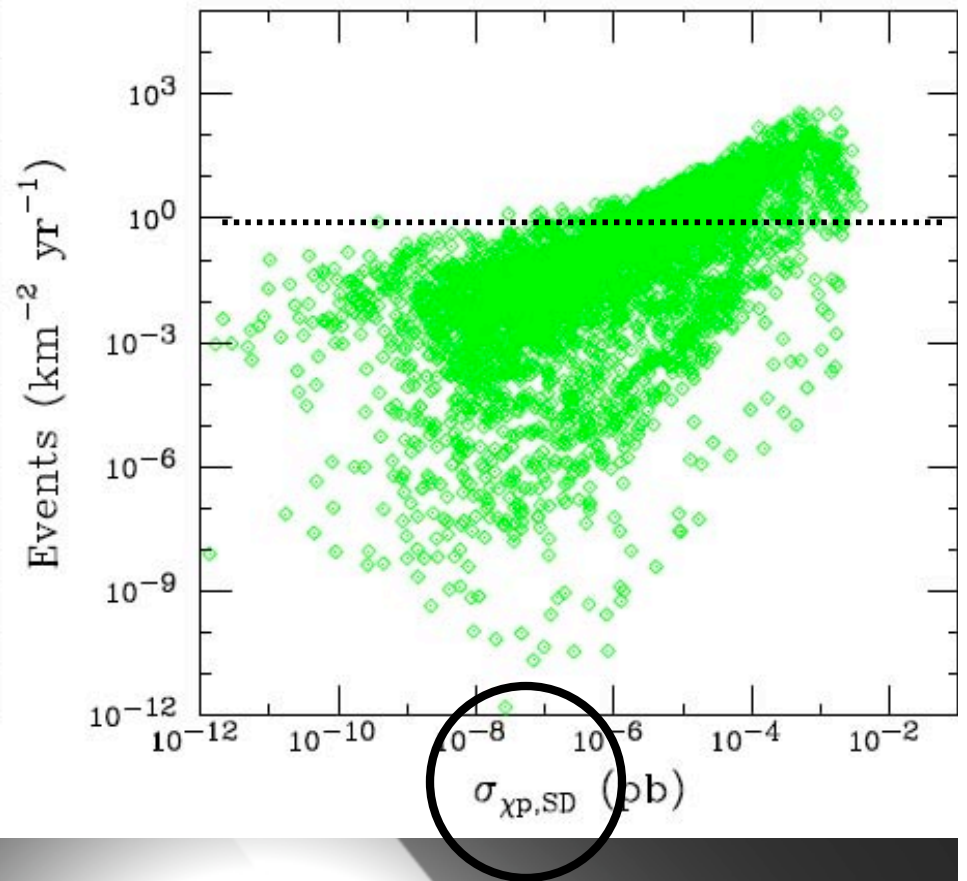




# IceCube: events per km<sup>2</sup> year



not ruled out by CDMS (left)



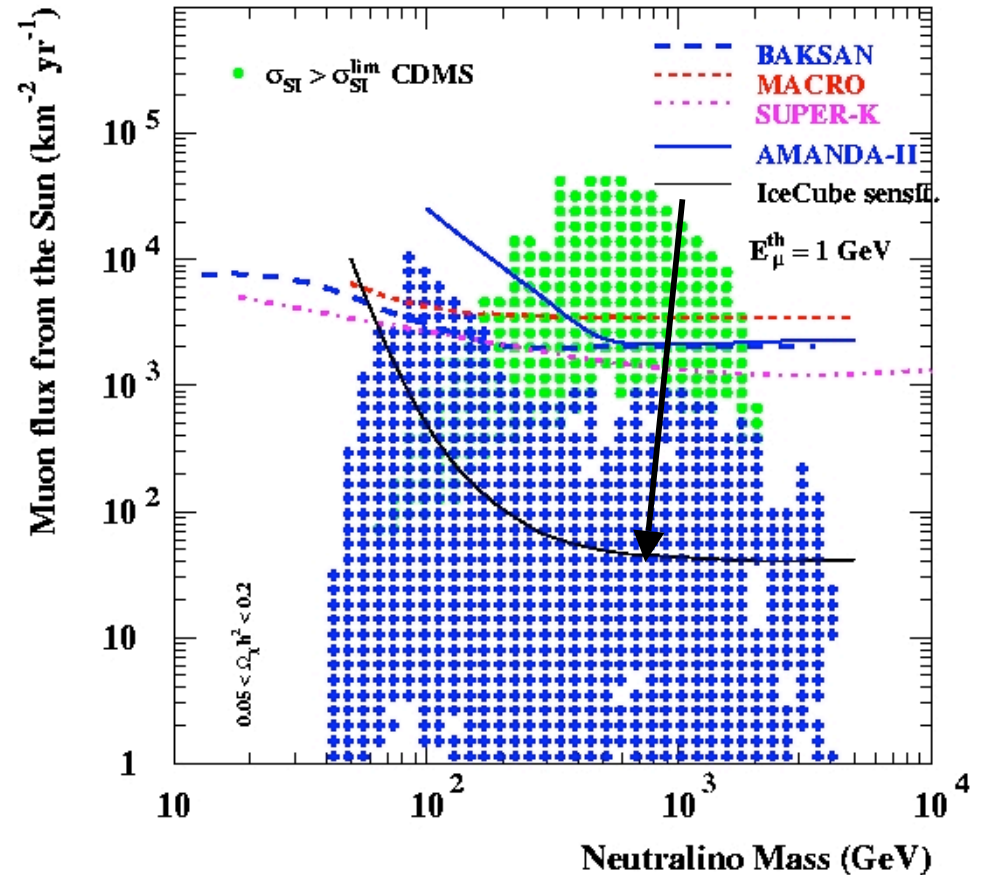
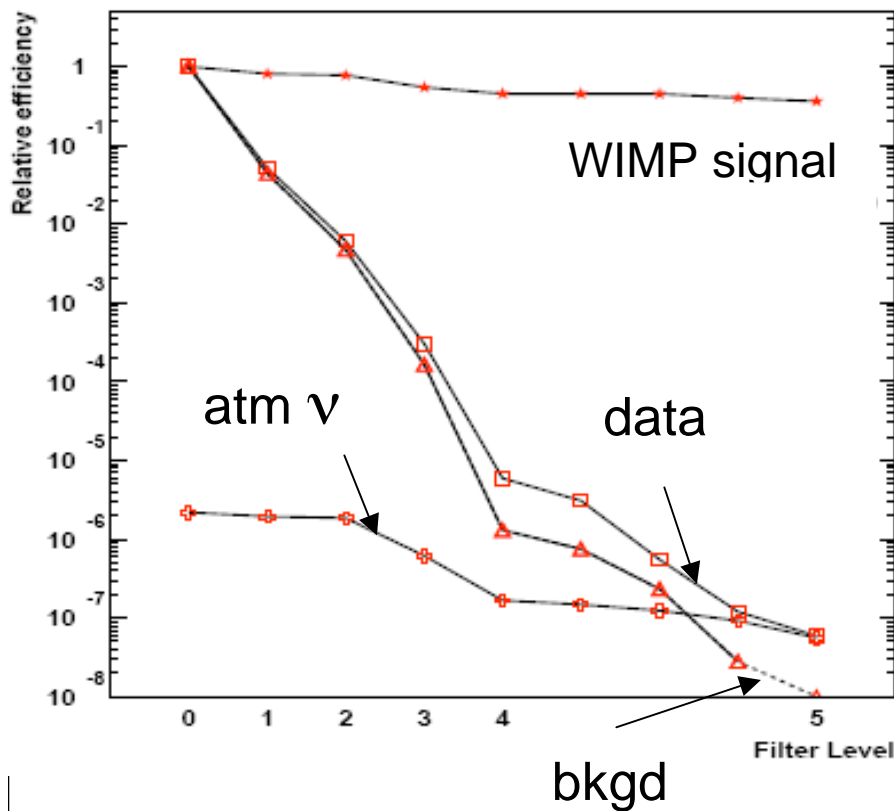
CDMS X 100 (right)

**AMANDA**

# Prospects

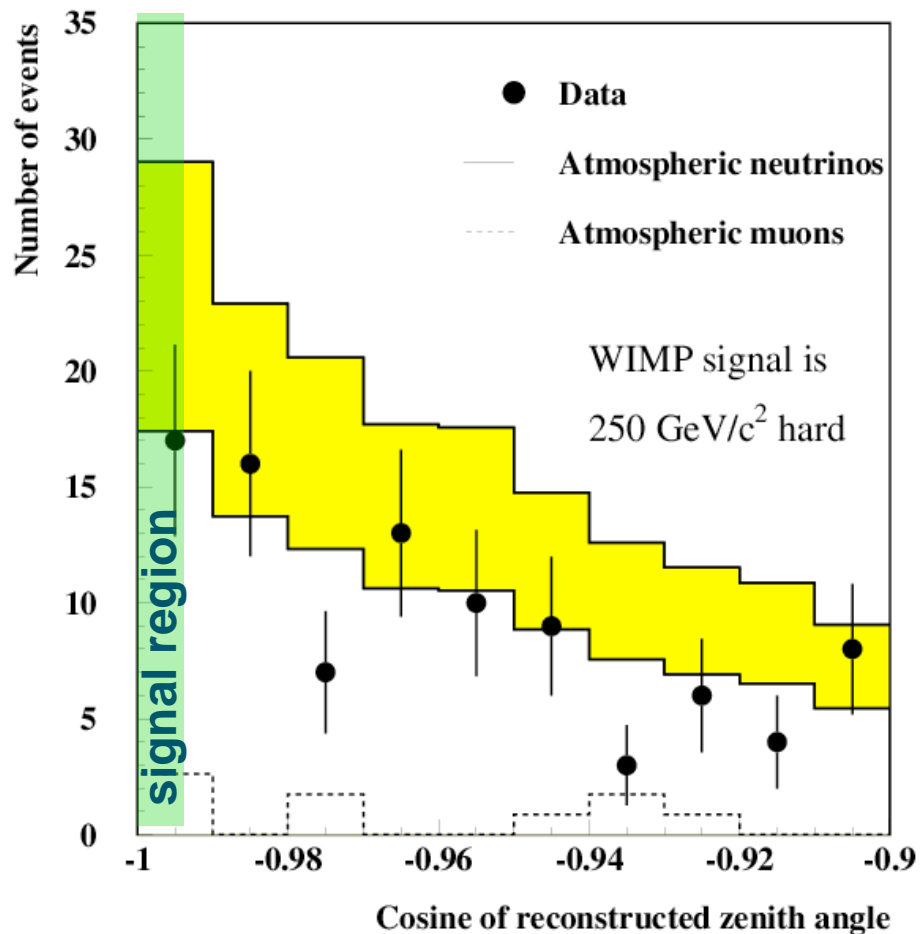
- AMANDA: 144 days only !
- 3 year analysis this summer
- IceCube

Sun

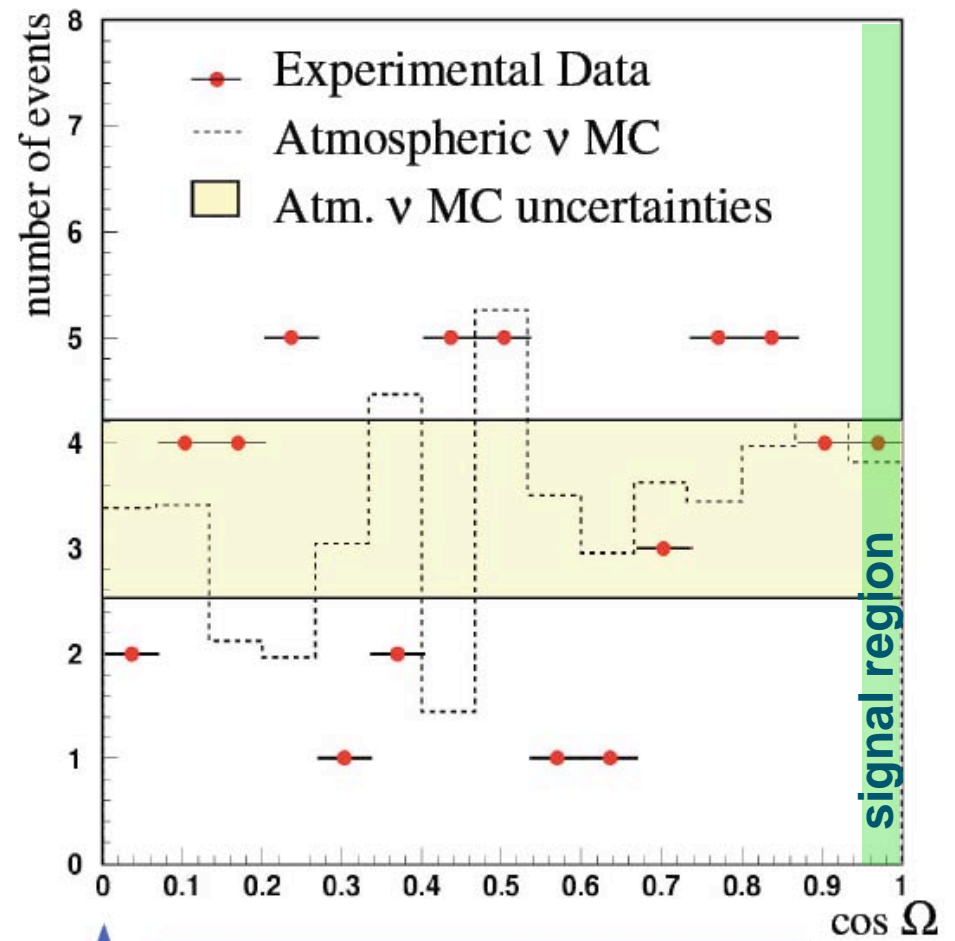


# Data consistent with background

Earth 1997-1999  
(Astropart. Phys. (2006), in Press)



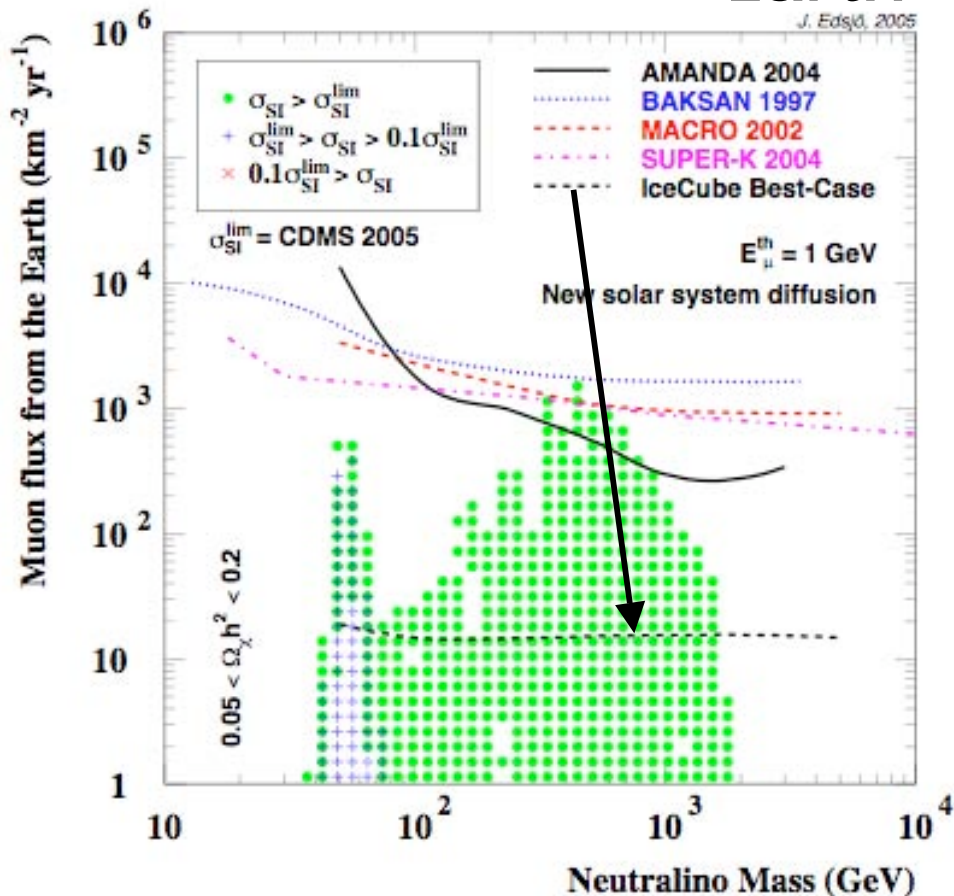
Sun 2001  
(Astropart. Phys. (2006) 459-466)



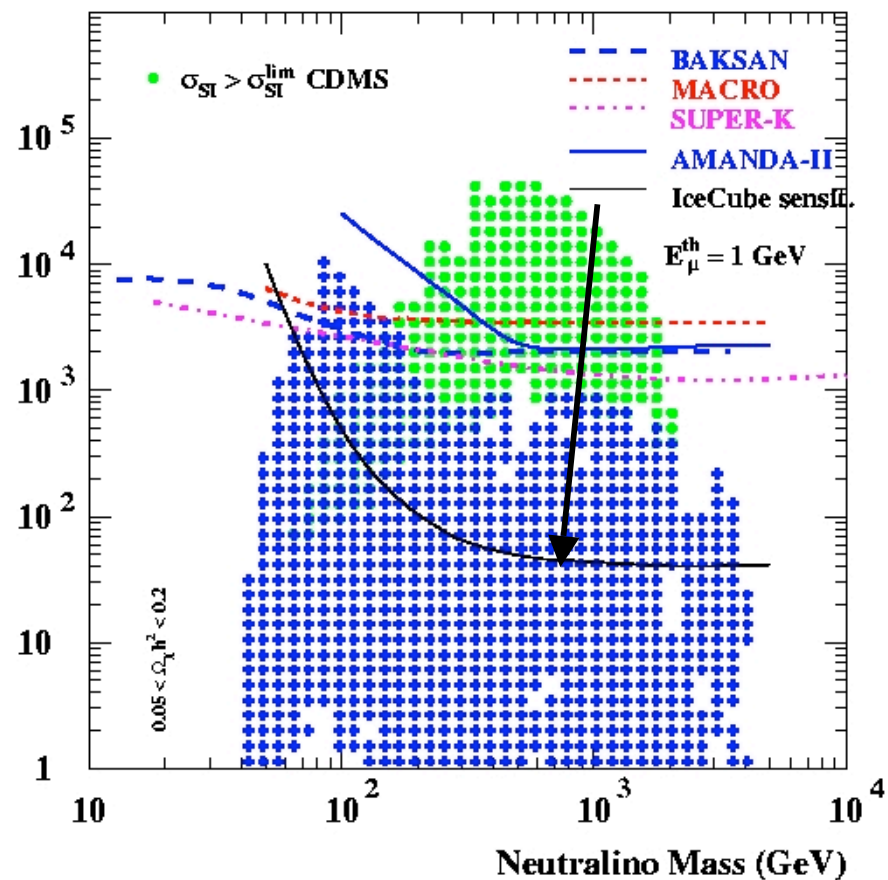
# Prospects

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

Earth

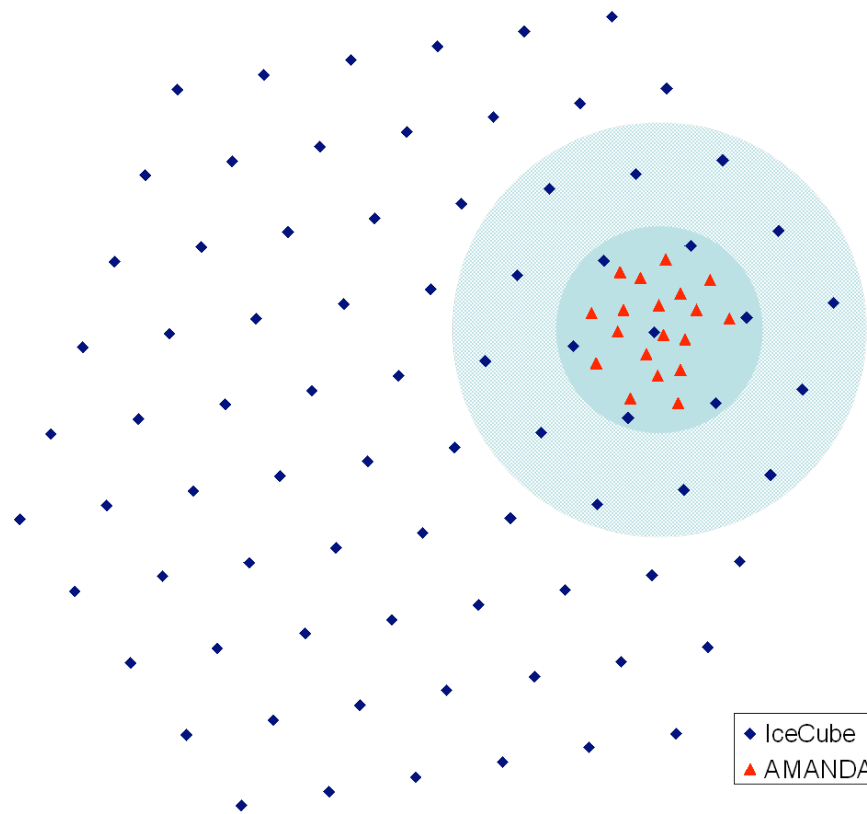


Sun

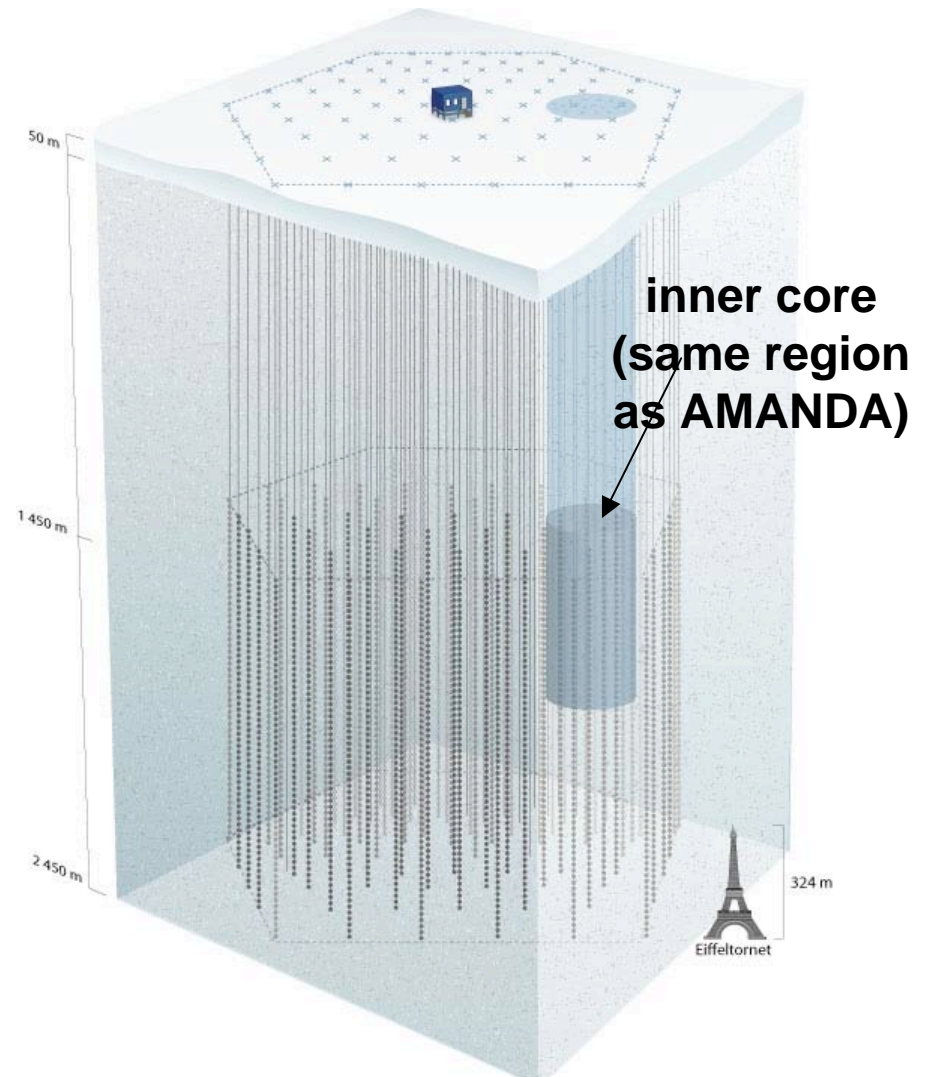


# AMANDA to IceCube

# IceCube: inner core detector

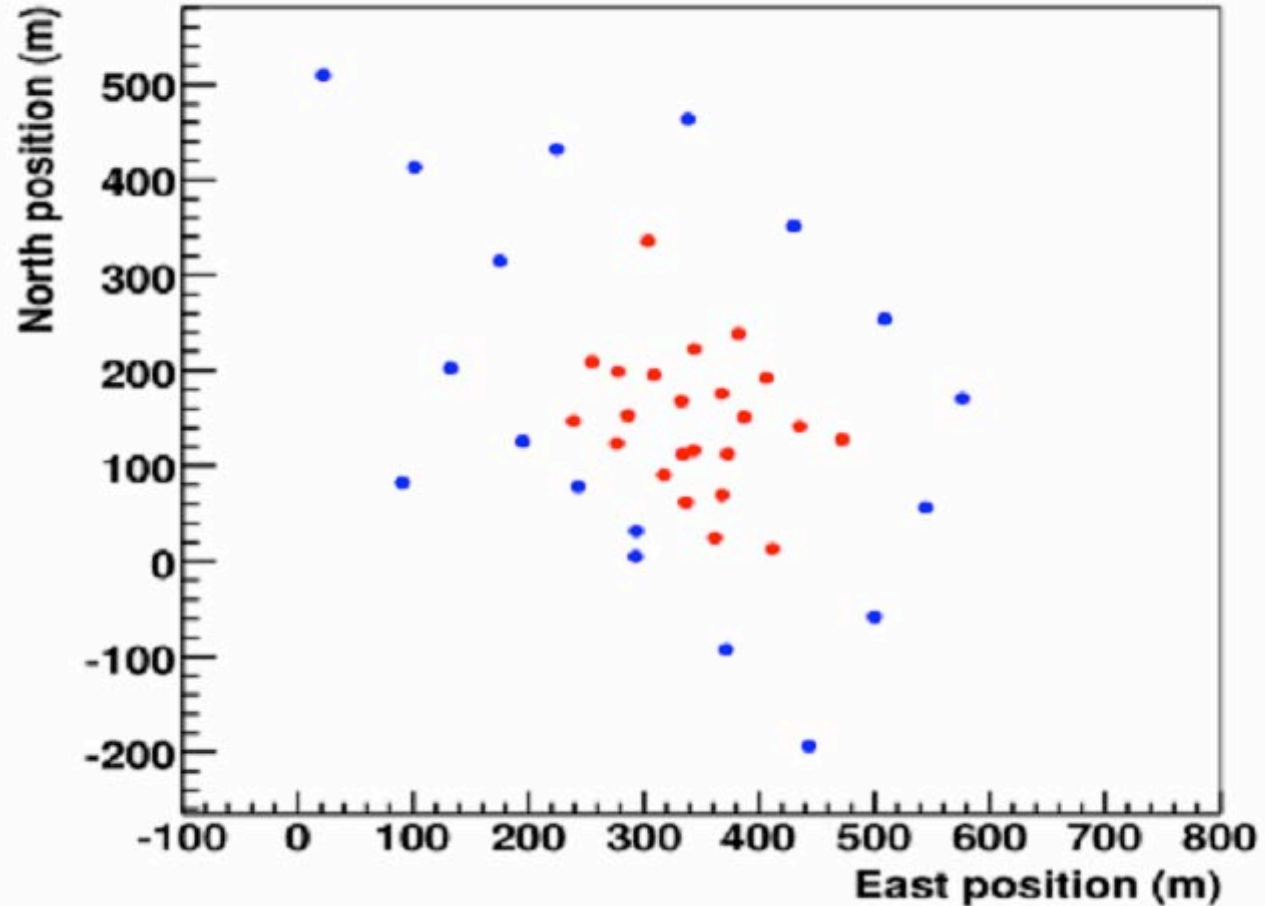


7 IceCube + 18 AMANDA strings  
225 DOMs + 540 OMs



# IceCube: the contained event detector

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

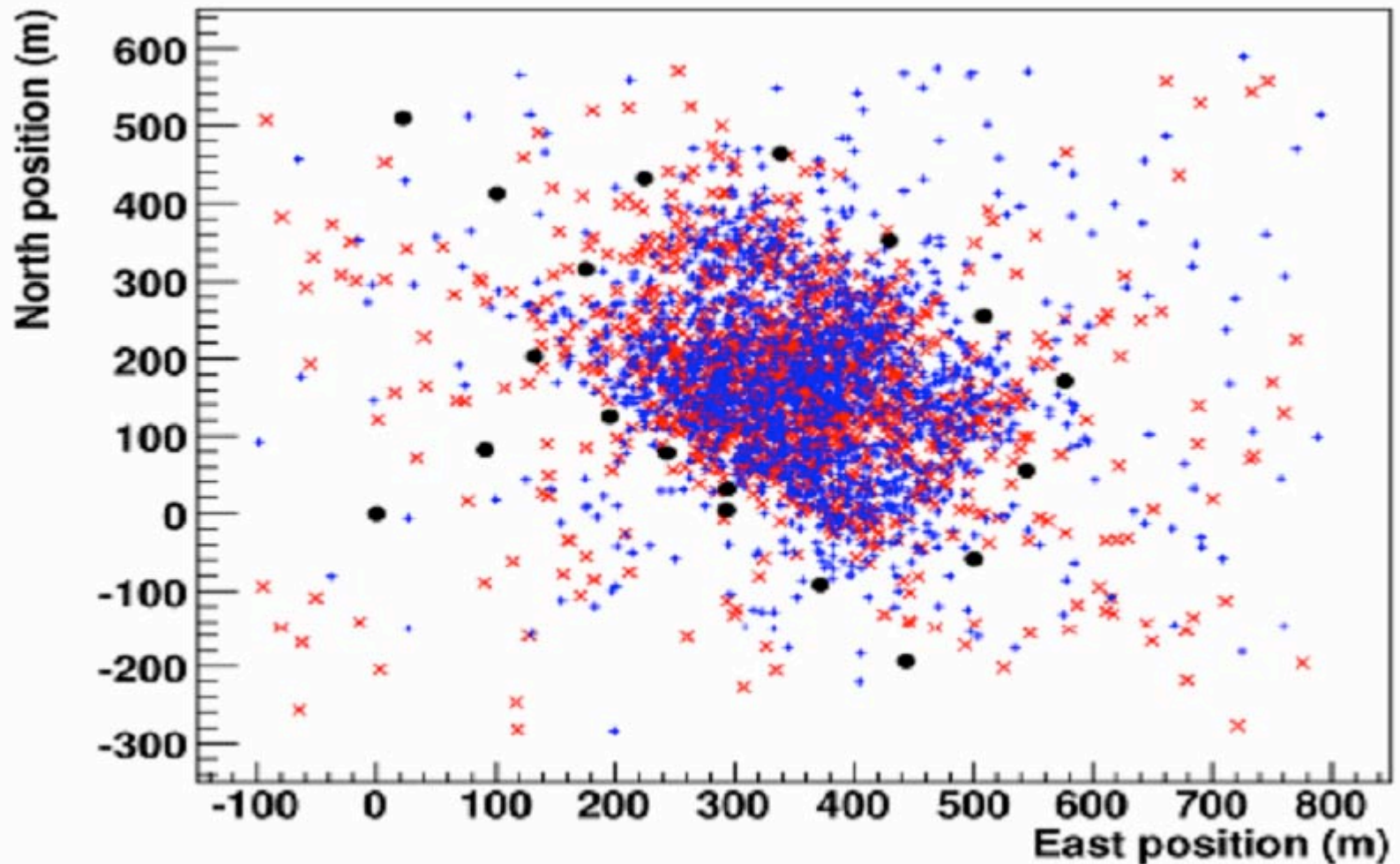




# muon vertices of events passing the on-line filter well inside the defined fiducial volume

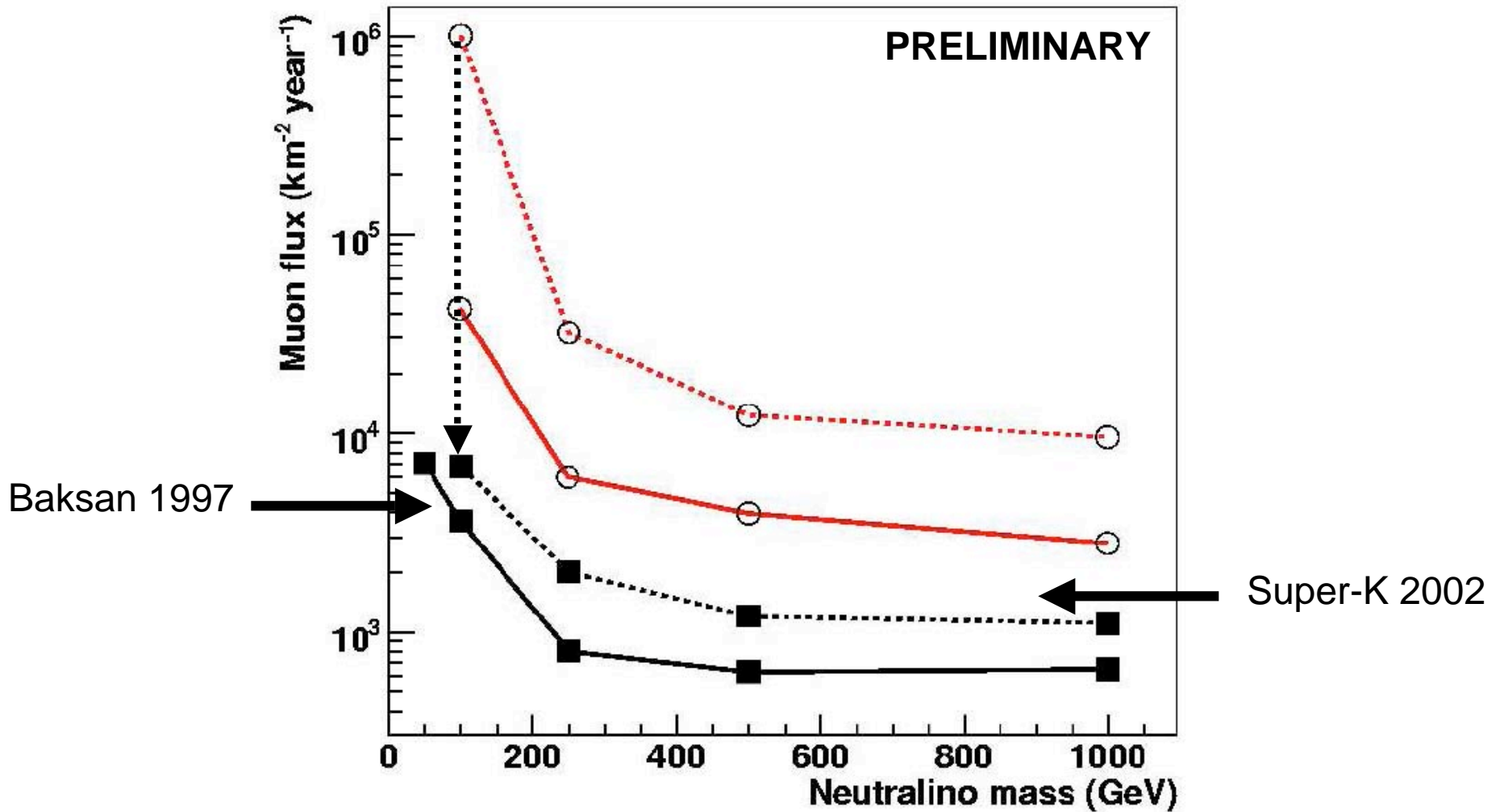
blue: WIMPS

red: background



# 2007 detector: AMANDA → IceCube

atmospheric neutrino flux in the direction of the sun  
for 500 days of data taking in 2007 compared to AMANDA-II 2001 analysis



# contained event detector

- data taking started May 15
- 40,000 atmospheric neutrinos by this Christmas
- WIMPs by ...

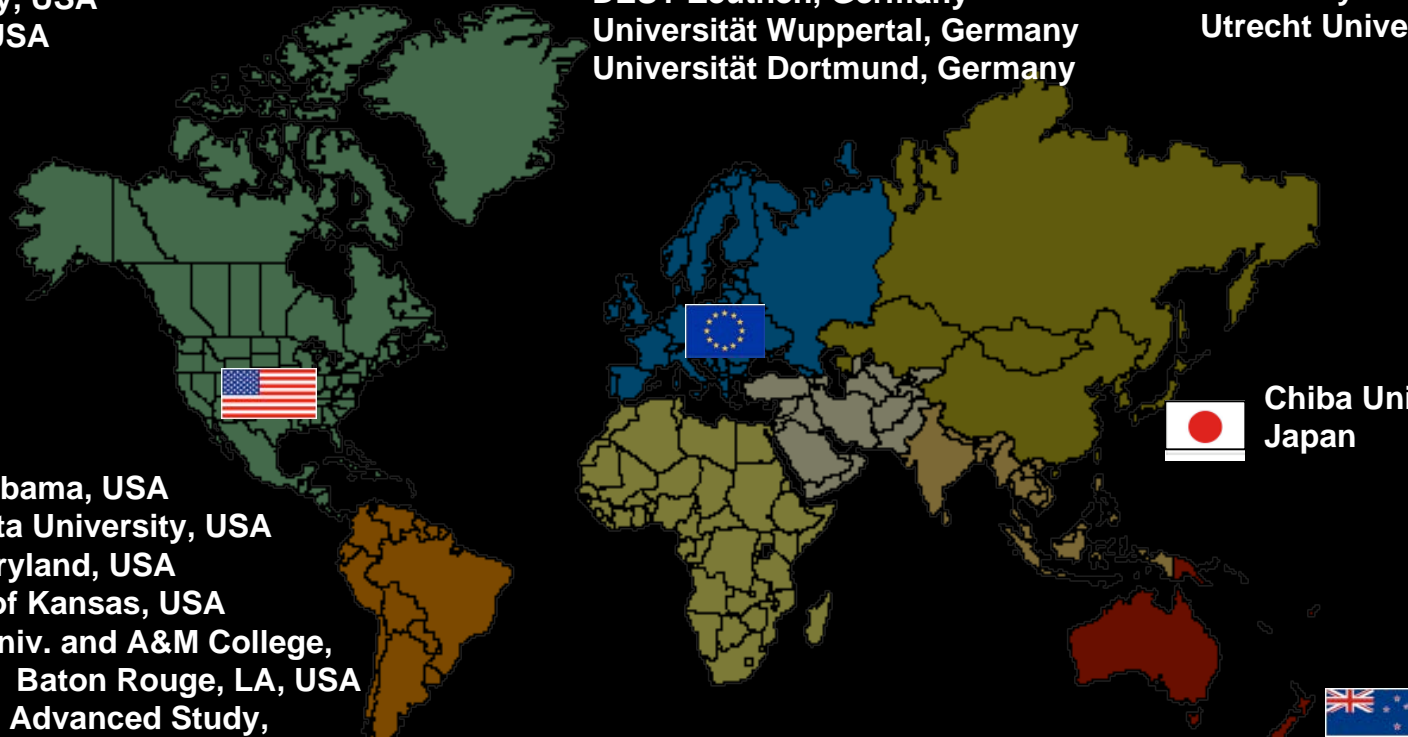
# IceCube Collaboration

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

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

Chiba University,  
Japan