TAUP2003

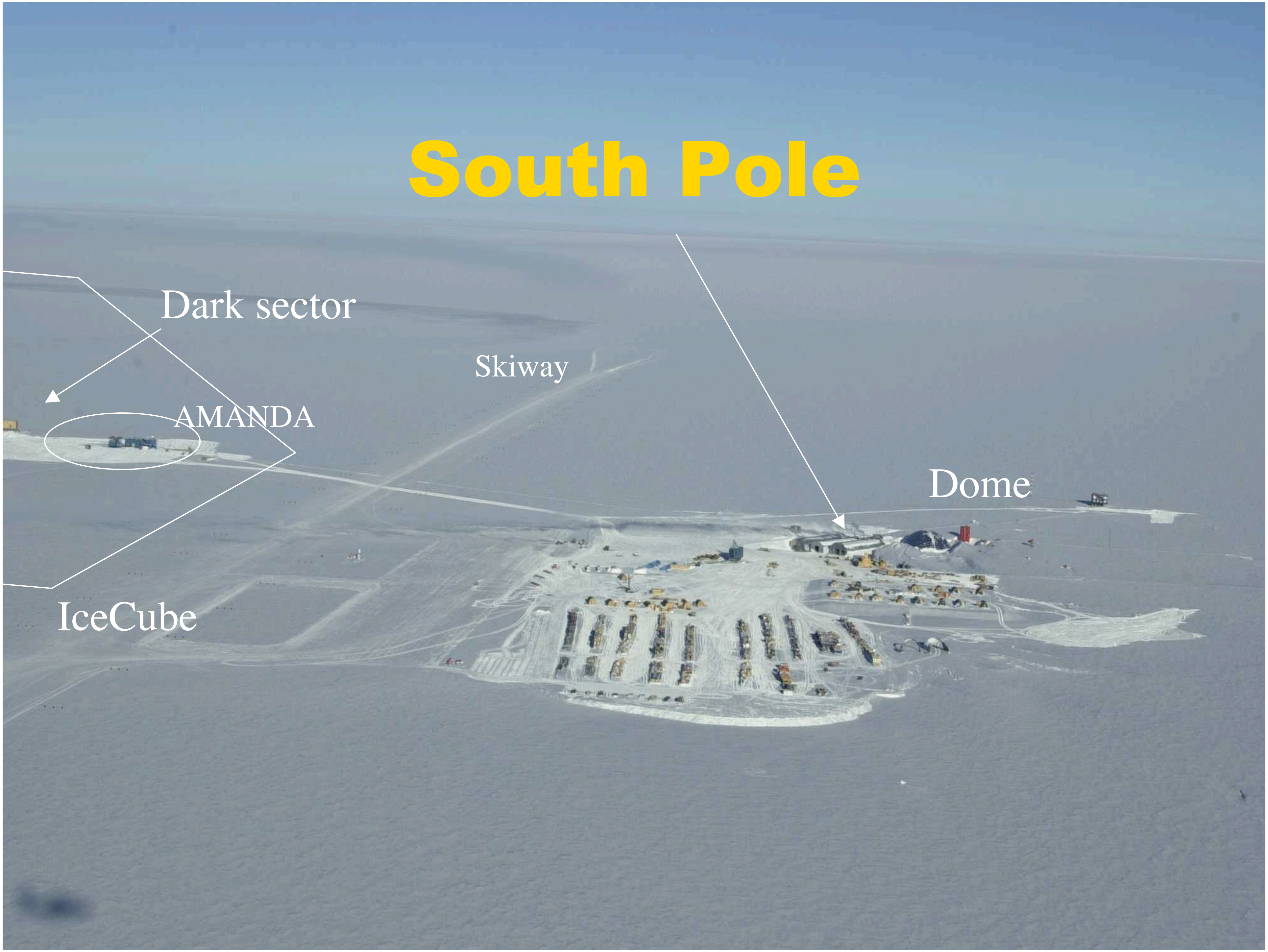
The IceCube Neutrino Telescope

- Project overview and Status
- EHE Physics Example: Detection of GZK neutrinos

Shigeru Yoshida, Chiba University

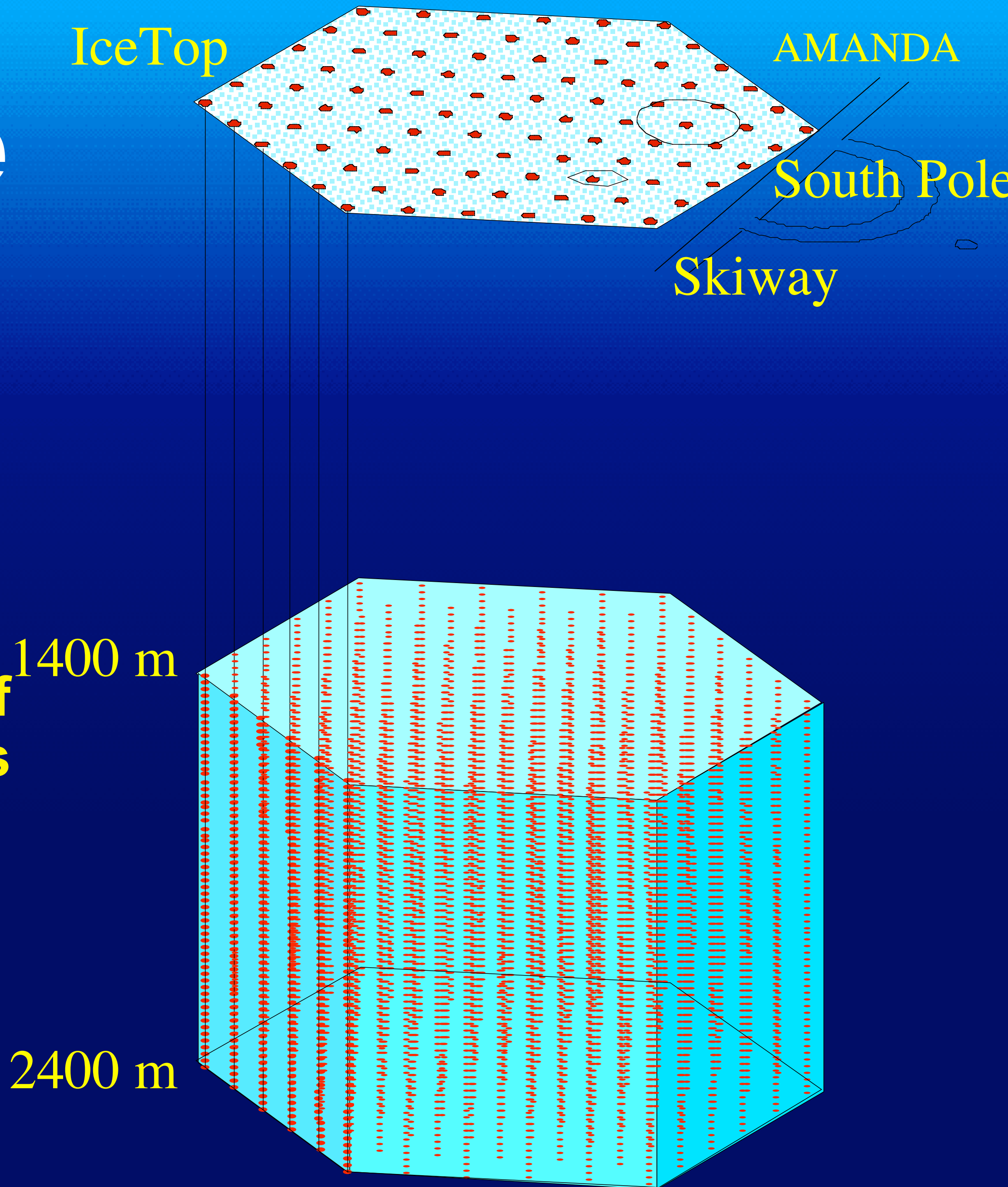
The IceCube collaboration

- Chiba University, Chiba, Japan
- Clark Atlanta University, Atlanta, GA
- DESY-Zeuthen, Zeuthen, Germany
- Imperial College, UK
- Institute for Advanced Study, Princeton, NJ
- Lawrence Berkeley National Laboratory, Berkeley, CA
- Pennsylvania State University, Philadelphia, PA
- South Pole Station, Antarctica
- Southern University and A & M College, Baton Rouge, LA
- Stockholm Universitet, Stockholm, Sweden
- Universität, Mainz, Germany
- Universität Wuppertal, Wuppertal, Germany
- Université Libre de Bruxeelles, Bruxelles, Belgium
- Université de Mons-Hainaut, Mons, Belgium
- University of Alabama, Tuscaloosa, AL
- University of California-Barkeley, Berkeley, CA
- University of Delaware, Newark, DE
- University of Kansas, Lawrence, KS
- University of Maryland, College Park, MD
- University of Wisconsin-Madison, Madison, WI
- University of Wisconsi-RiverFalls, River Falls, WI
- Universidad Simon Bolivar, Caracas, Venezuela
- Uppsala Universitet, Uppsala, Sweden
- Vriie Universiteit Brussel, Brussels, Belgium


South Pole
Dark sector
Skiway
AMANDA
Dome
IceCube

IceCube

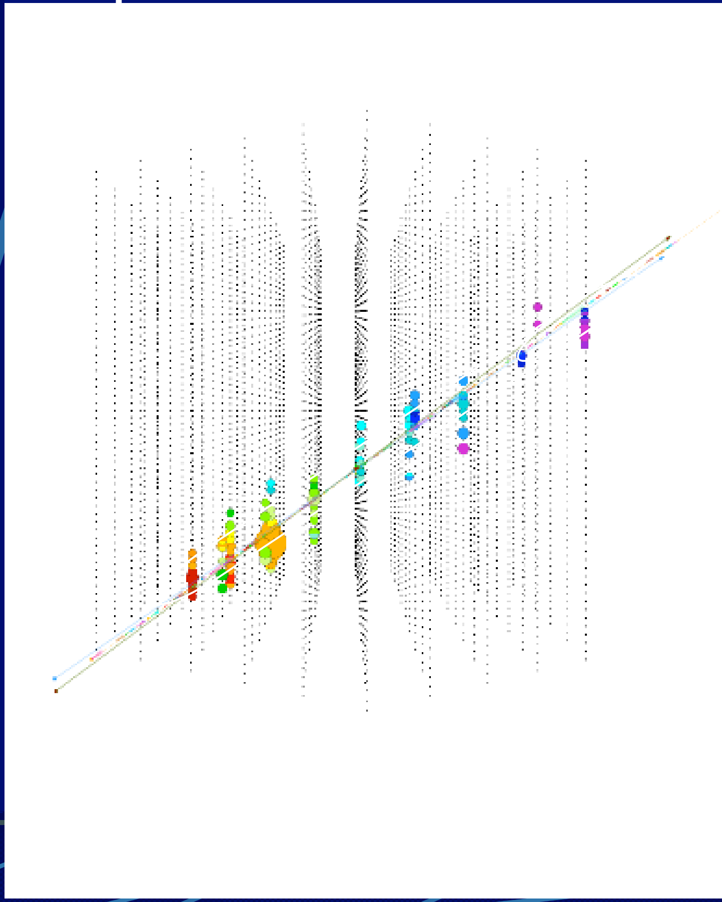
- 80 Strings
- 4800 PMT
- Instrumented volume: 1 km3 (1 Gt)
- IceCube is designed to detect neutrinos of all flavors at energies from 10^7 eV (SN) to 10^{20} eV



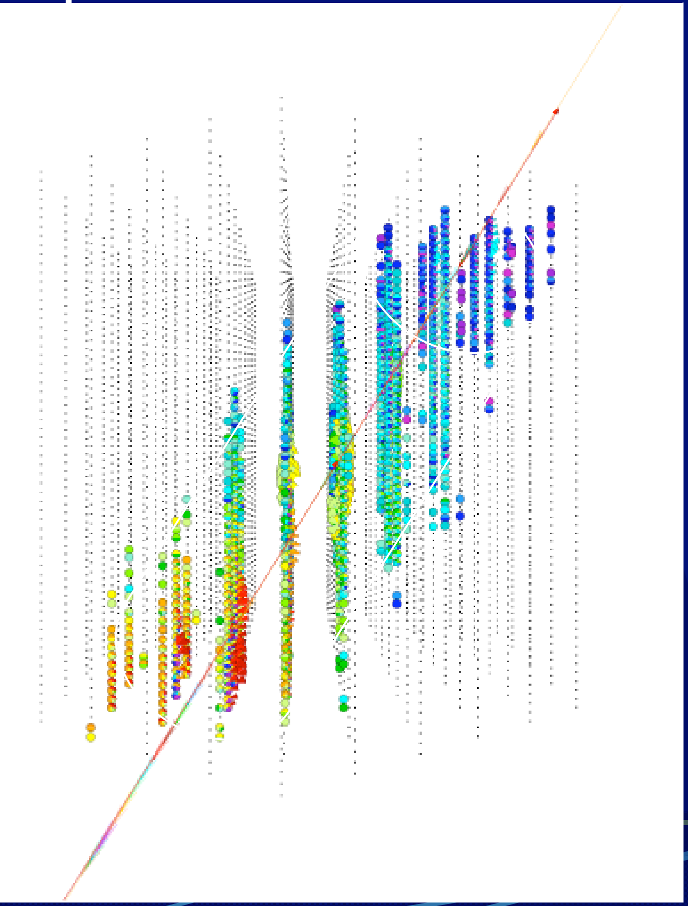
How our events look like

The typical light cylinder generated by a muon of 100 GeV is 20 m, 1PeV 400 m, 1EeV it is about 600 to 700 m.

E_μ=10 TeV ≈ 90 hits



E_μ=6 PeV ≈ 1000 hits

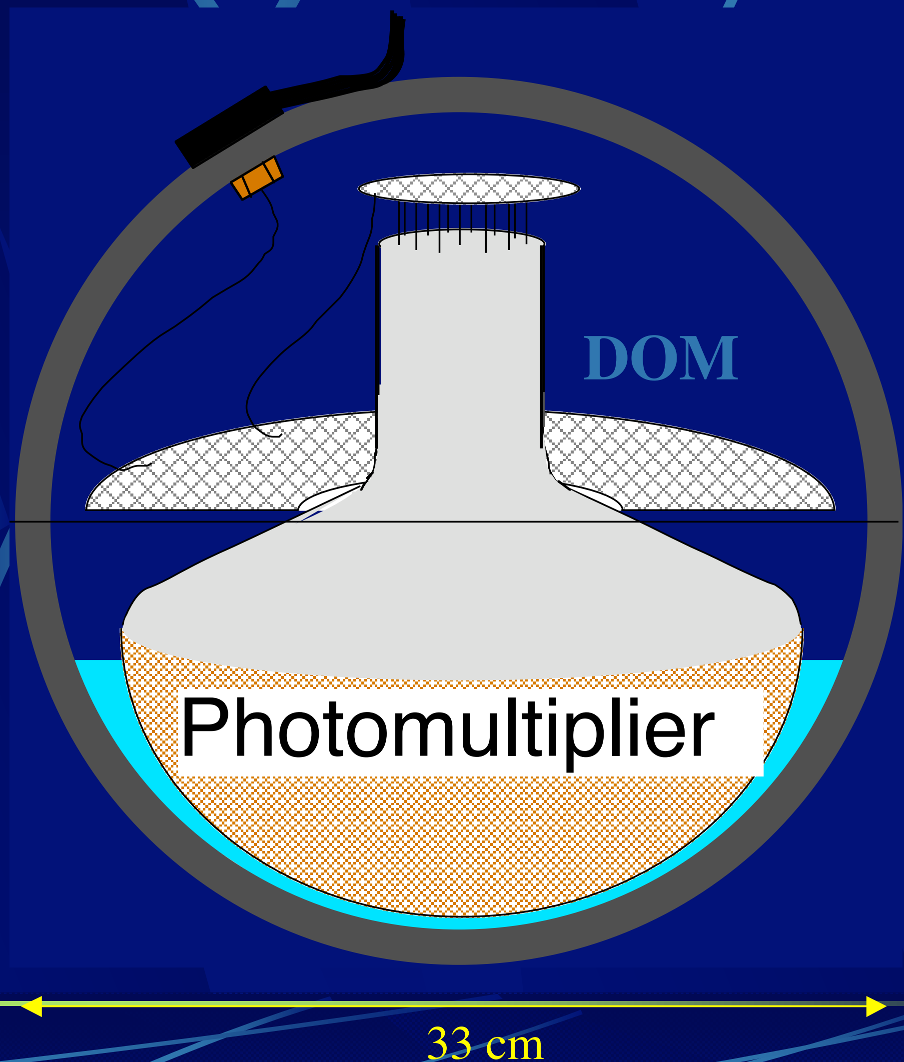


DAQ design: Digital Optical Module - PMT pulses are digitized in the Ice

Design parameters:

- Time resolution:≤ 5 nsec (system level)
- Dynamic range: 200 photoelectrons/15 nsec
- (Integrated dynamic range: > 2000 photoelectrons)

  (1.p.e. /10ns ~ 160μA 10^7G ~8mV 50 Ω) 4V saturation→500p.e.
- Digitization depth: 4 μsec.
- Noise rate in situ: ≤500 Hz
- Tube trig.rate by muons 20Hz

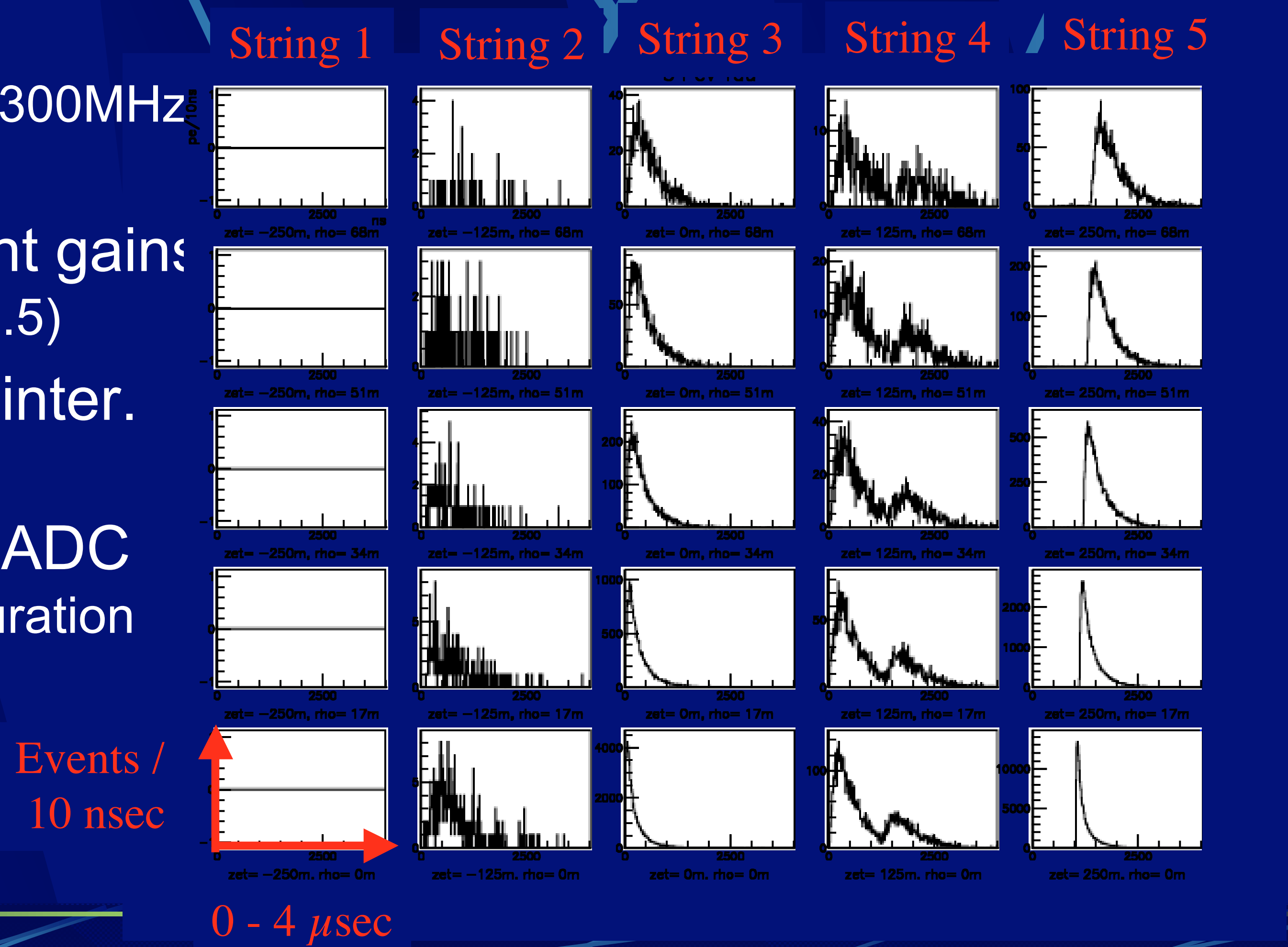


Capture Waveform information (MC)

ν_τ

E=10 PeV

- ATWD 300MHz
  14 bits.
- 3 different gains
  (x15 x3 x0.5)
- Capture inter.
  426nsec
- 10 bits FADC
  for long duration pulse.



Photomultiplier:

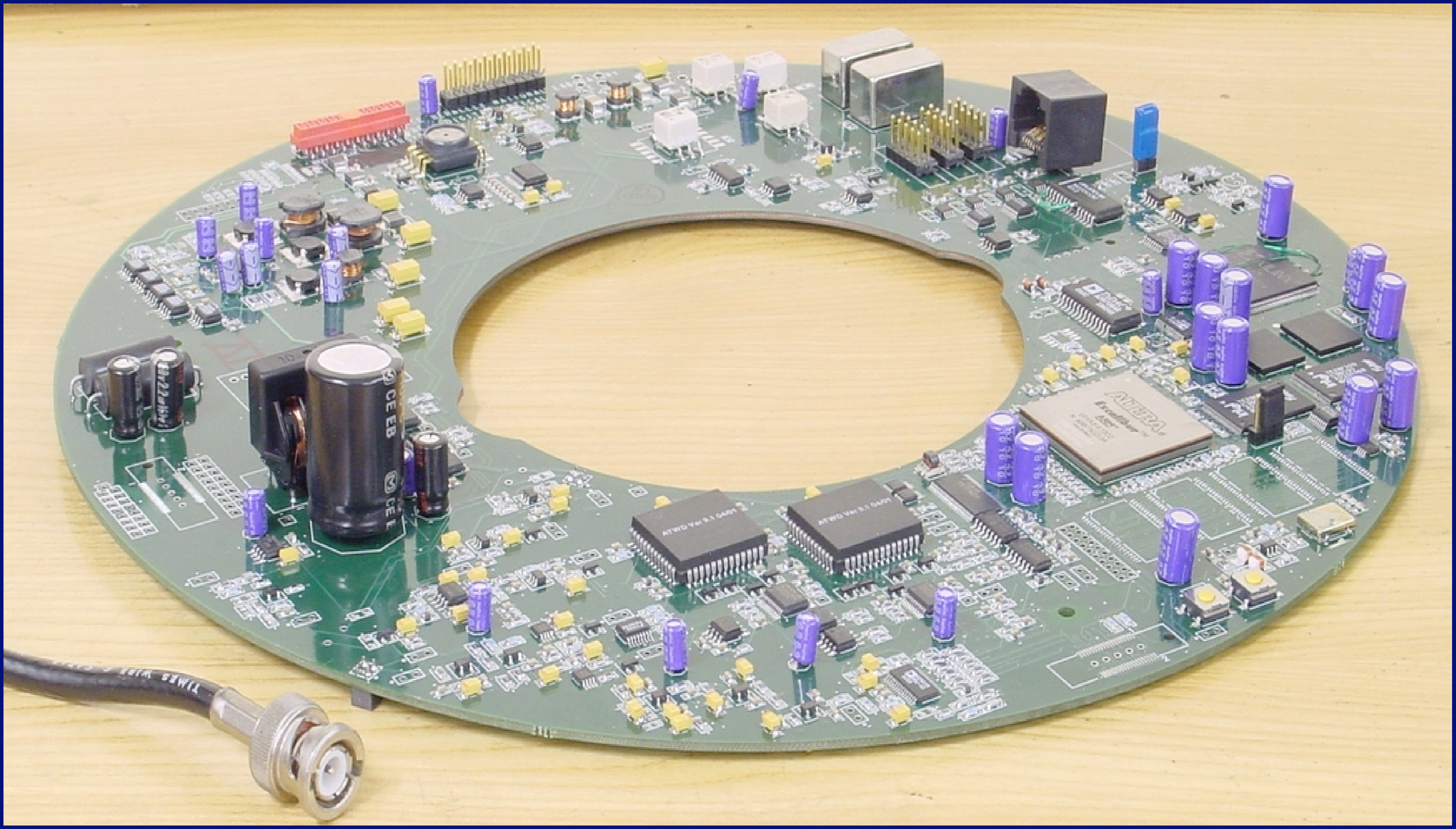
Hamamatsu R7081-02

(10", 10-stage, 1E+08 gain)

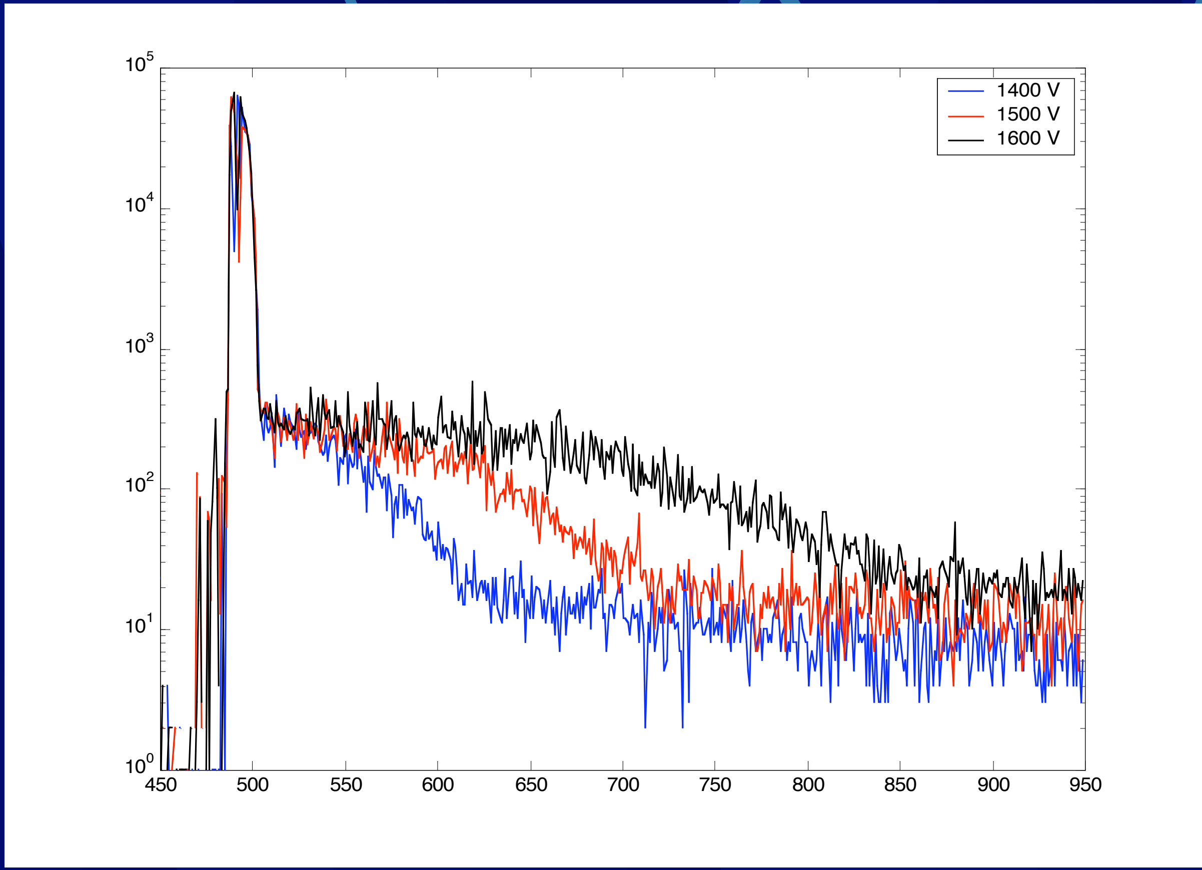
- Selection criteria (@ -40 °C)
  - Noise < 300 Hz (SN, bandwidth)
  - Gain > 5E7 at 2kV (nom. 1E7 + margin)
  - P/V > 2.0 (Charge res.; *in-situ* gain calibration)

- Notes:
  - Only Hamamatsu PMT meets excellent low noise rates!
  - Tested three flavors of R7081.

Digital Optical Module (DOM) Main Board Test Card

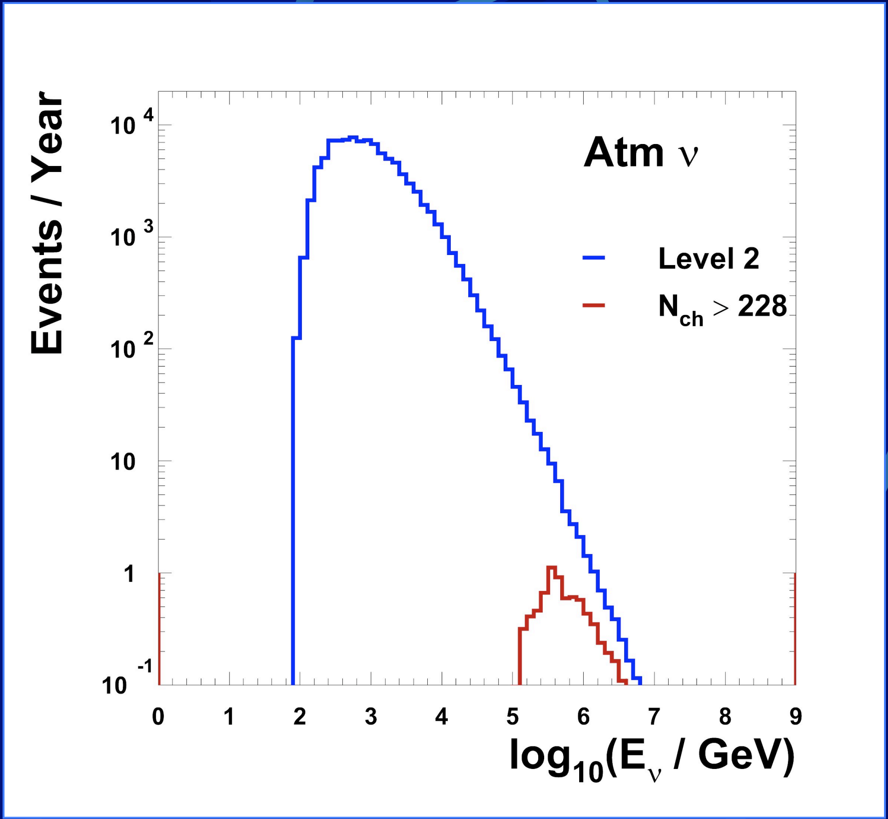


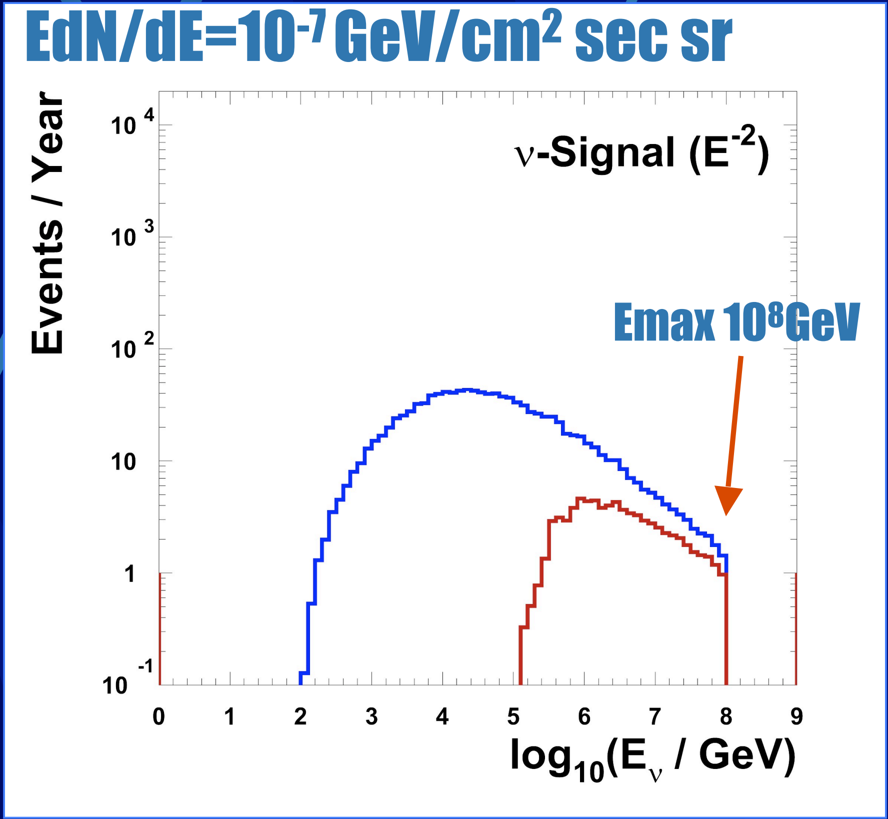
SPE Discriminator Scan – PMT Pulses Input (71DB)



The big reel for the hotwater drill

Energy Spectrum Diffuse Search

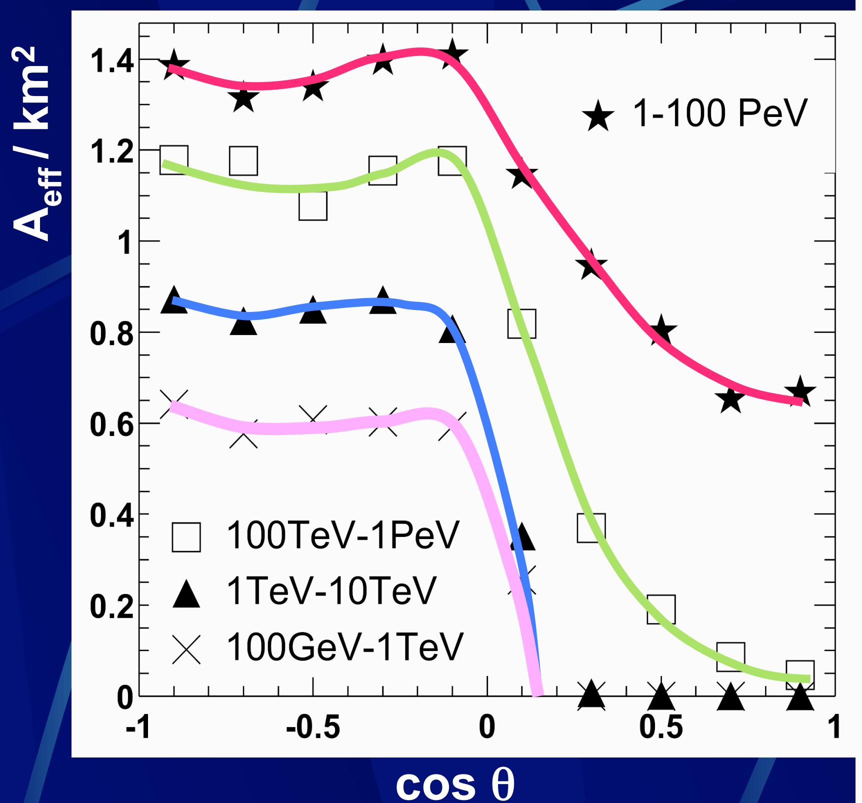


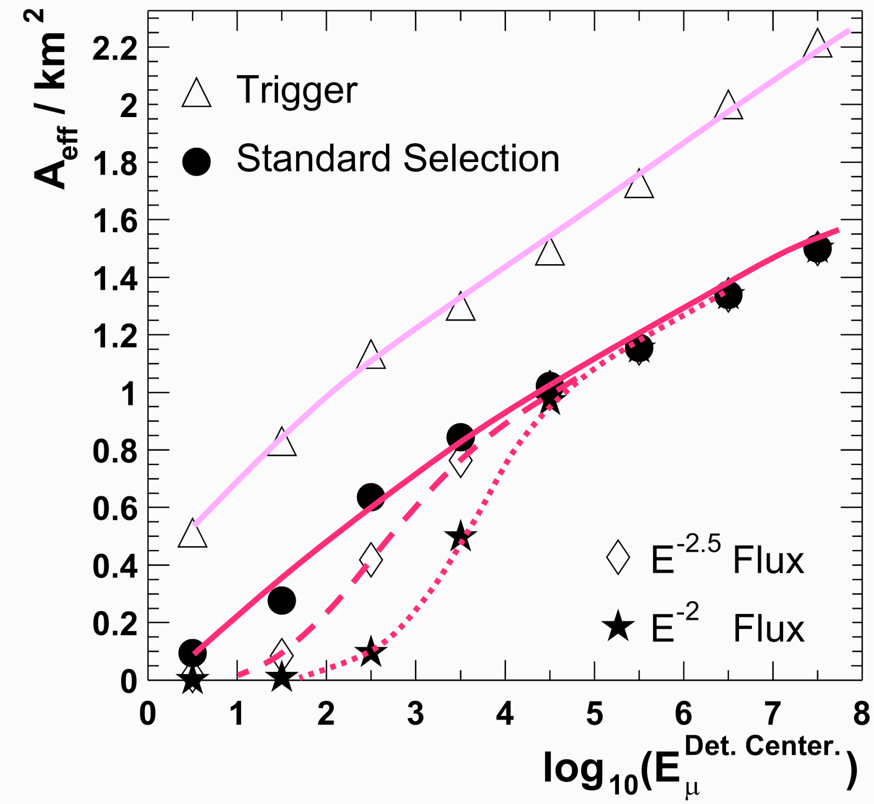


Blue: after downgoing muon rejection

Red: after cut on N_{hit} to improve sensitivity

Effective area of IceCube



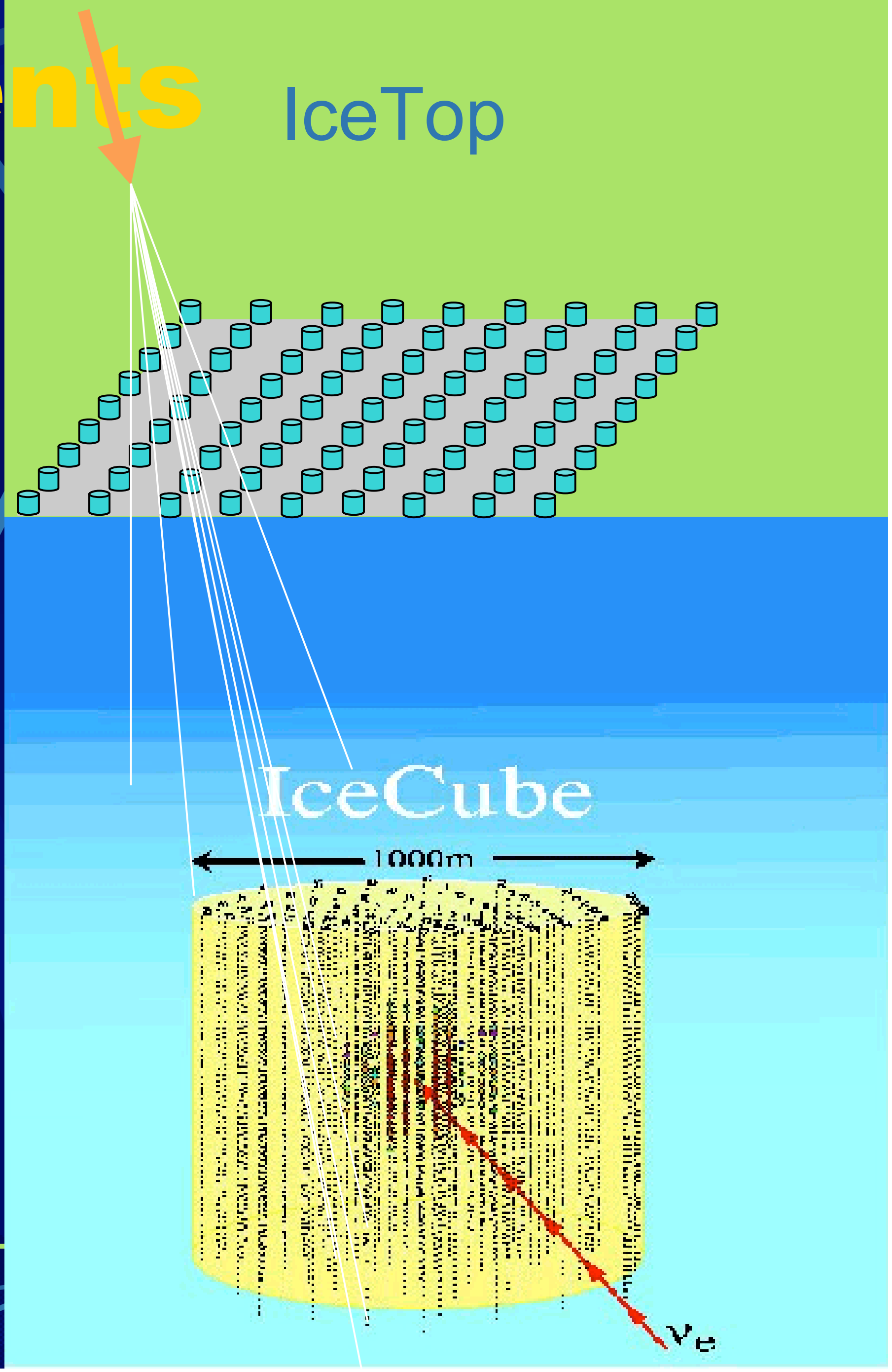


Effective area vs. zenith angle after rejection of background from downgoing atmospheric muons

Note: Should be further improved by utilizing waveform information

Coincident events

- Energy range:
  - ~3 x 10^{14} -- 10^{18} eV
- Two functions
  - veto and calibration
  - cosmic-ray physics
  - few to thousands of muons per event
- Measure:
  - Shower size at surface
  - High energy muon component in ice
- Large solid angle
  - One IceTop station per hole
  - ~ 0.5 sr for C-R physics with "contained" trajectories
  - Larger aperture as veto

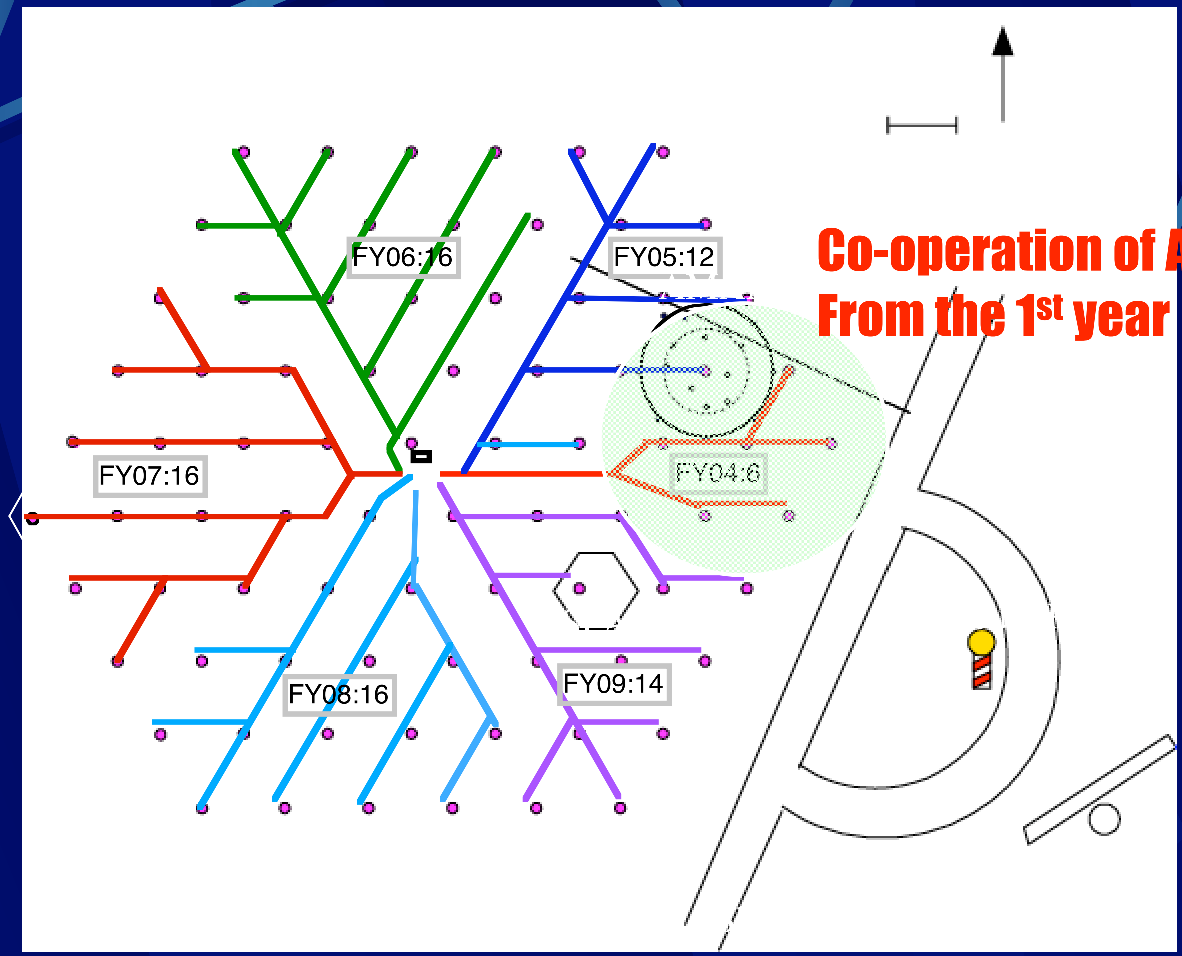


In three years operation…

- $E^2 dN\nu/dE \sim 10^{-8}$ GeV/cm^2 s sr (diffuse)
- $E^2 dN\nu/dE \sim 7\times10^{-9}$ GeV/cm^2 s (Point source)
- 200 bursts in coincidence (GRBs – WB flux)

For 5σ detection

Construction: 11/2004-01/2009



Co-operation of AMANDA-IceCube
From the 1st year

Next season: Buildup of the Drill and IceTop prototypes

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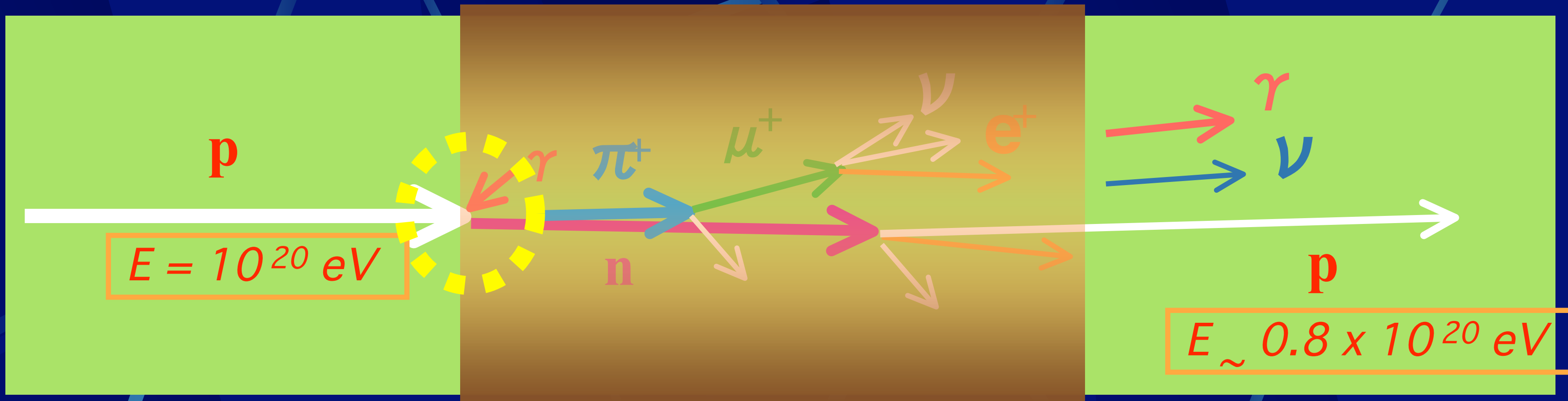
Project status

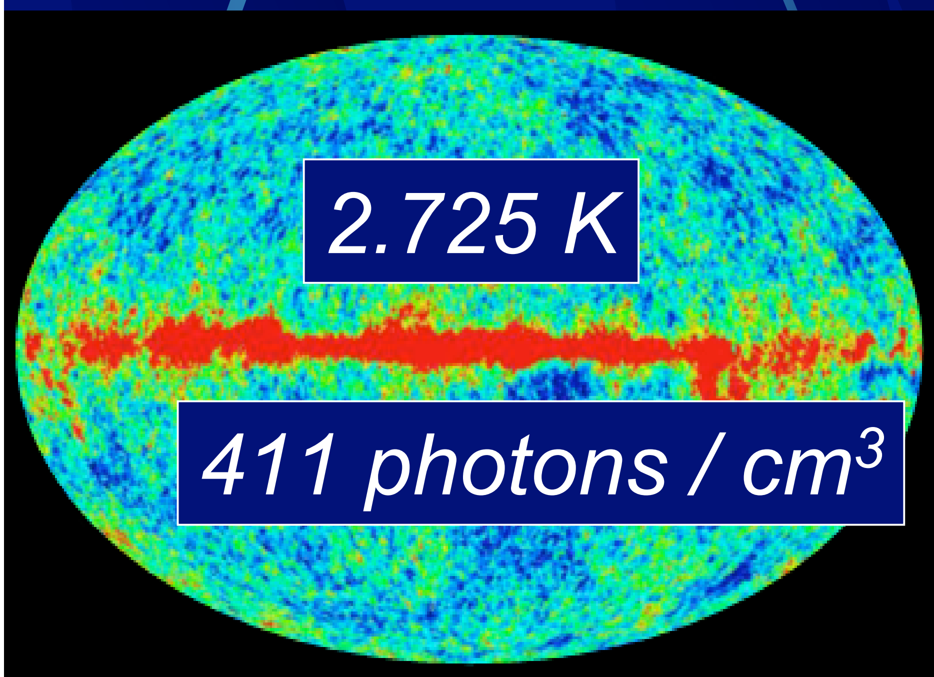
- Startup phase has been approved by the U.S. NSB and funds have been allocated.
- 100 DOMs are produced and being tested this year.
- Assembling of the drill/IceTop prototypes is carried out at the pole this season.
- Full Construction start in 04/05; takes 6 years to complete.
- Then 16 strings per season, increased rate may be possible.

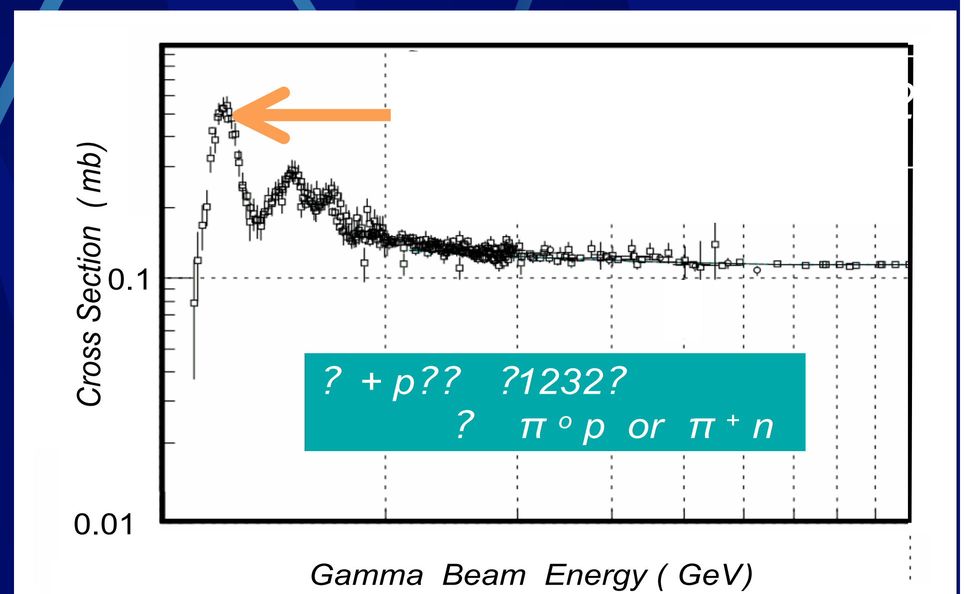
GZK EHEν detection

- What is the GZK mechanism?
- EHE $\nu/\mu/\tau$ Propagation in the Earth
- Expected intensities at the IceCube depth
- Atmospheric μ – background
- Event rate

GZK Neutrino Production

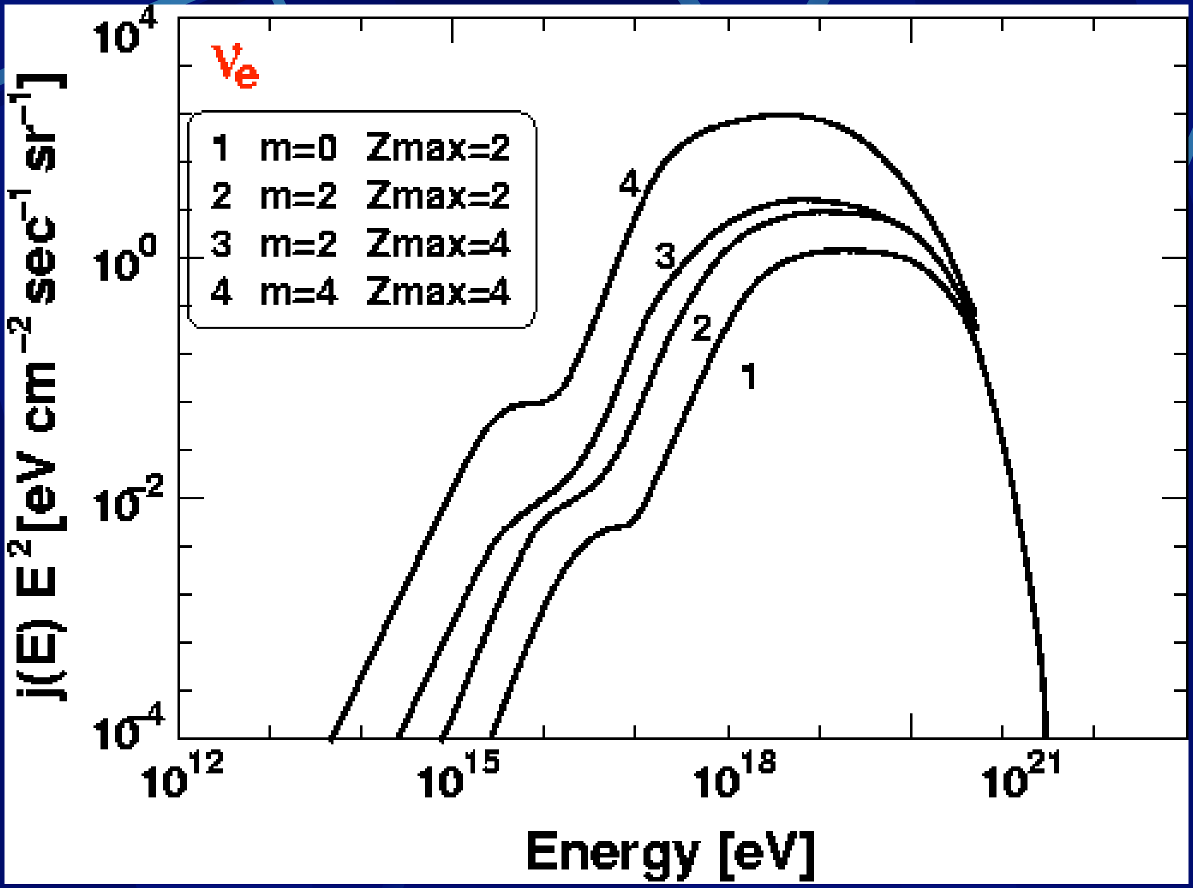






→ Conventional Mechanism of EHE neutrinos!!

Note: The oscillations convert ν_e, ν_μ to ν_e,ν_μ, ν_τ



Yoshida and Teshima 1993

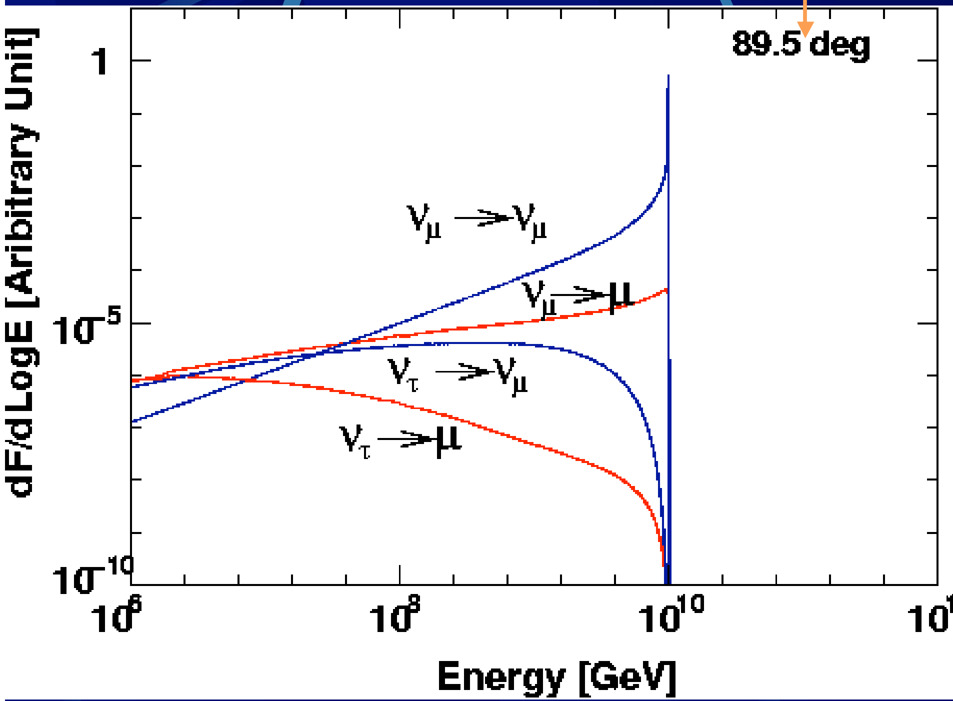
Yoshida, Dai, Jui, Sommers 1997

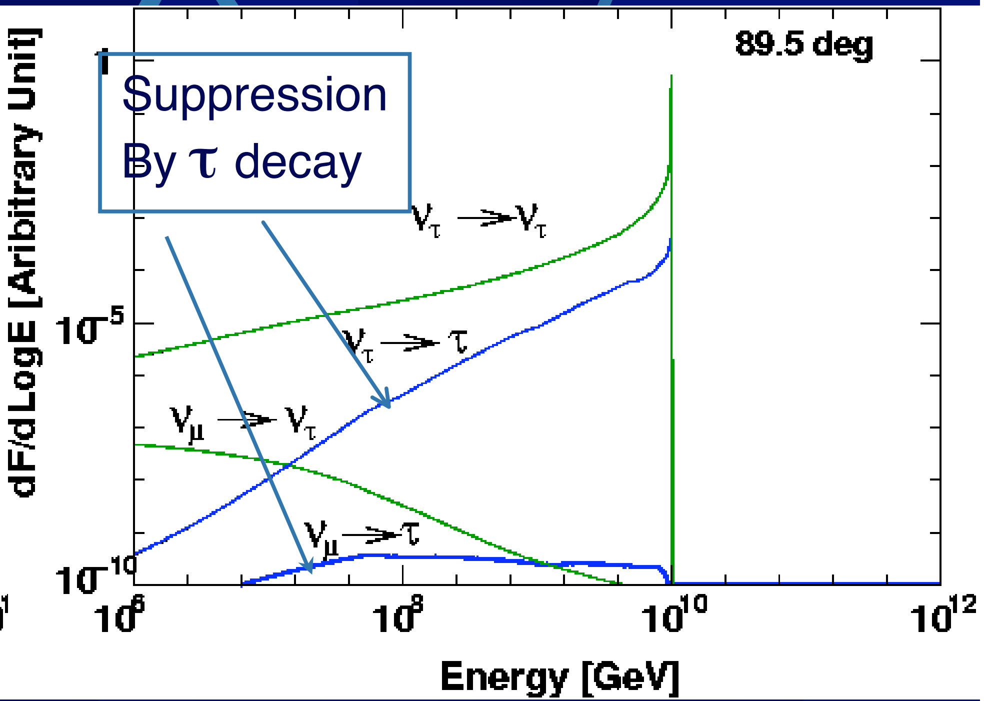
Products

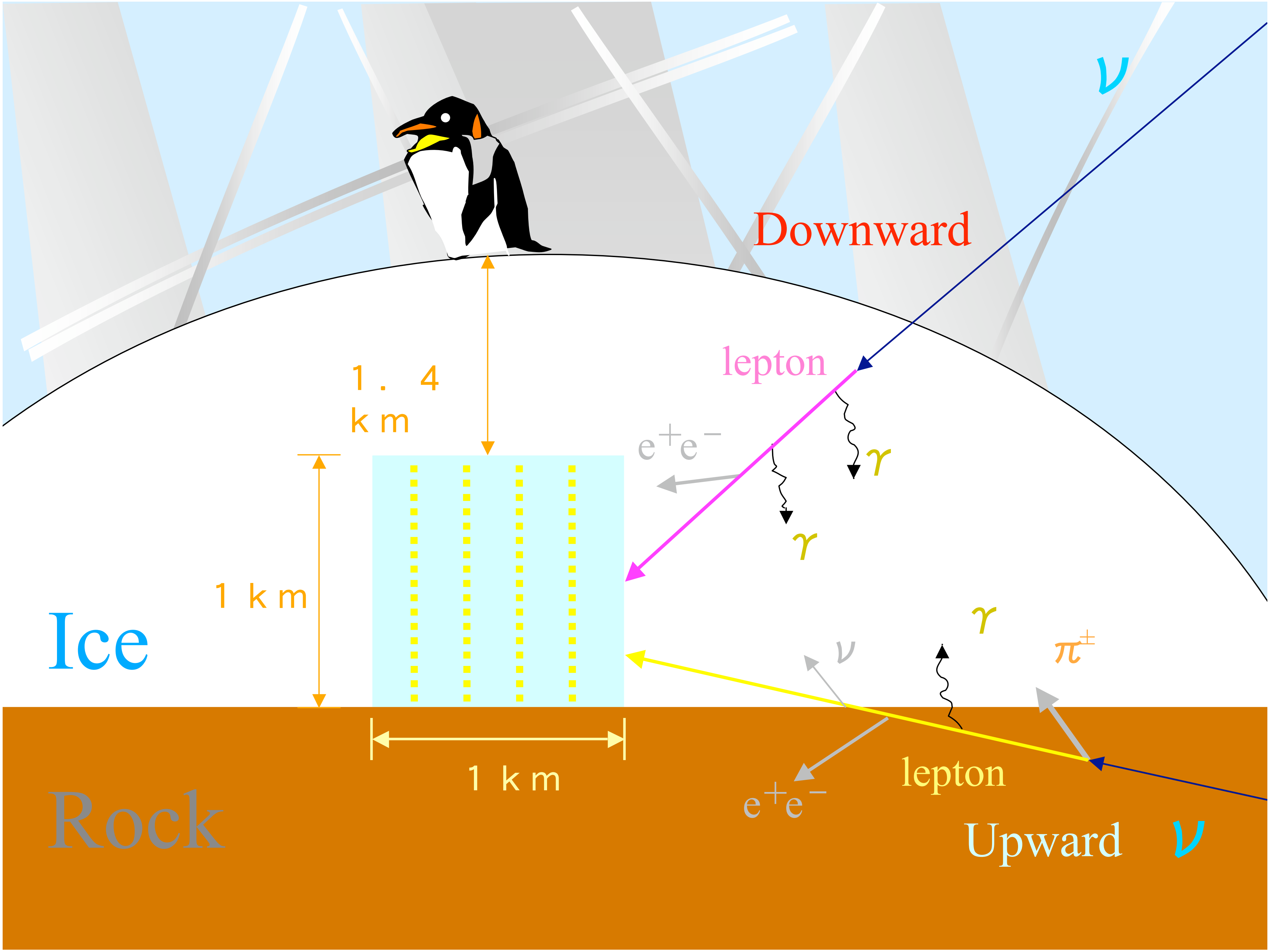
Incoming	ν_e	ν_μ	ν_τ	e/γ	μ	τ	π
ν_e				Weak			Weak
ν_μ					Weak		Weak
ν_τ						Weak	Weak
e/γ				Cascades			
μ	Decay	Decay Weak		Pair/decay Bremss	Pair	Pair	PhotoNucl.
τ	Decay	Decay	Decay Weak	Pair Bremss Decay	Decay Pair	Pair	Decay PhotoNucl.
π							Cascades

Muon(Neutrinos) from ν_μ ν_τ | Tau(Neutrinos) from ν_μ ν_τ

Nadir Angle



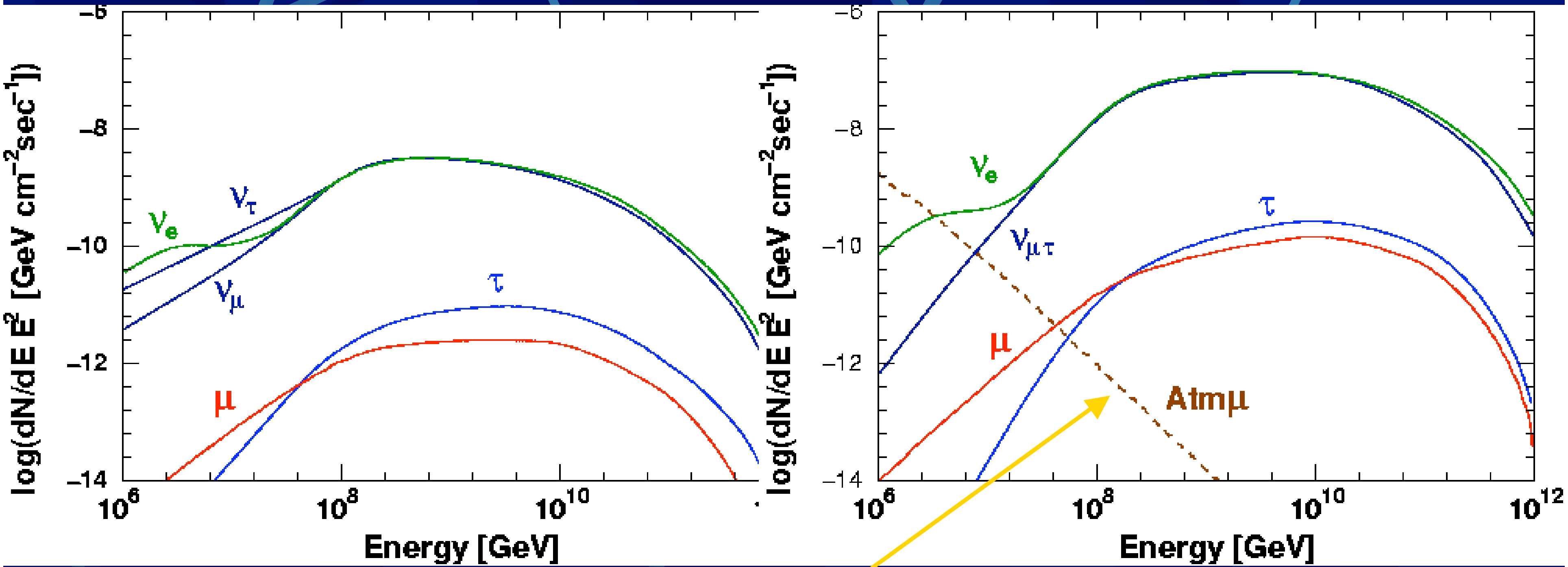




ν
Downward
lepton
1．4
km
e+e−
γ
γ
γ
1 km
Ice
ν
π±
lepton
e+e−
1 km
Rock
Upward ν

Upward-going

Downward going!!

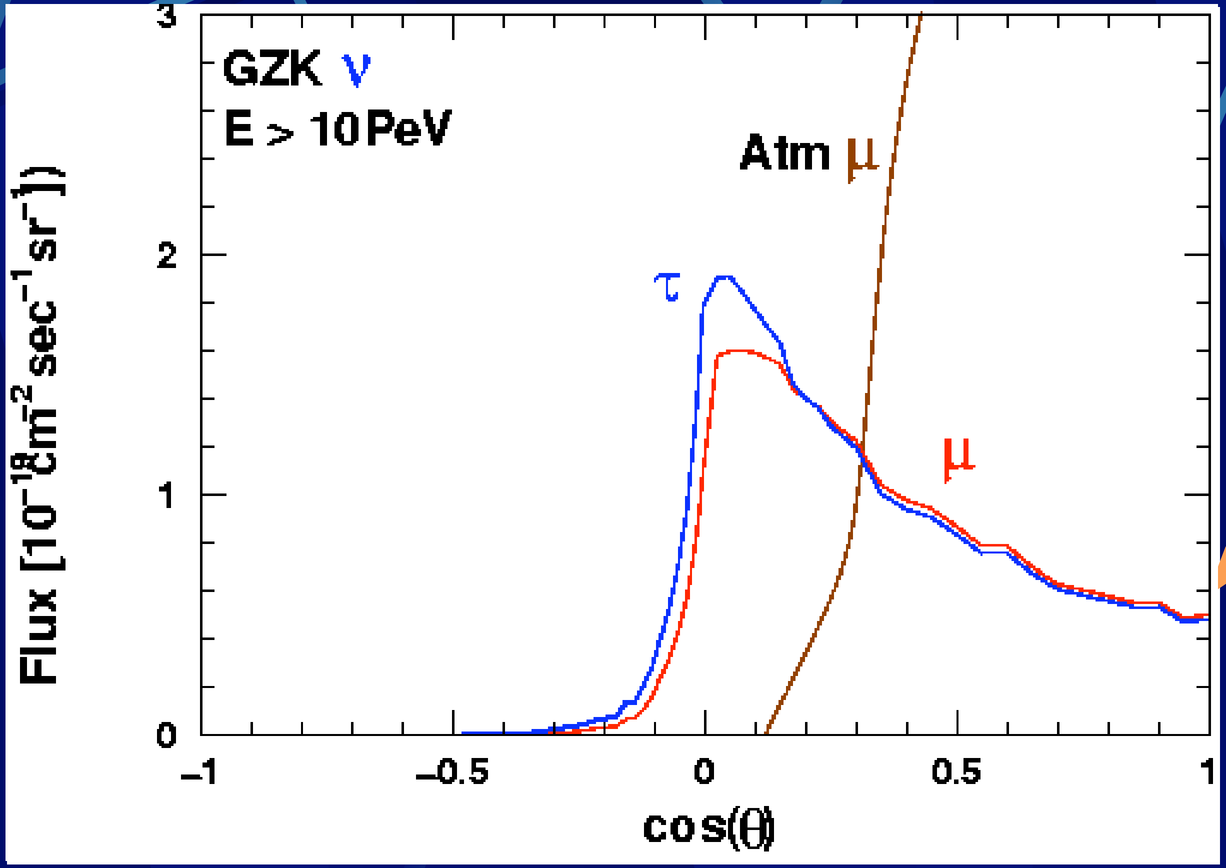


Atmospheric muon! – a major backgrond

But so steep spectrum

Down-going events dominate...

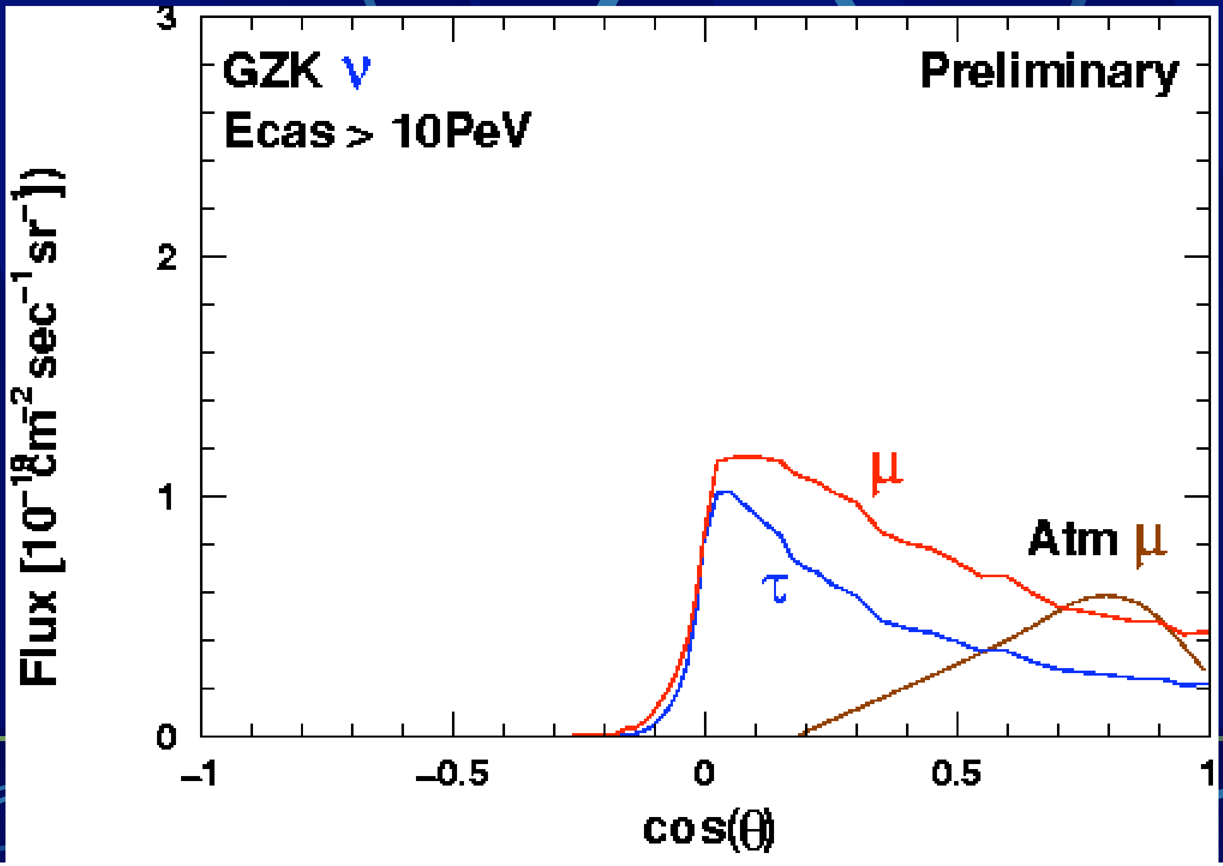
Atmospheric μ is strongly attenuated...



1400 m

Flux as a function of energy deposit in km^3

- $dE/dX \sim \beta E \longrightarrow \Delta E \sim \Delta X b E$



Intensity of EHE μ and τ

[cm^{-2} sec^{-1}]

GZK m=4 Zmax=4		Iμ(E>10PeV)	Iτ(E>10PeV)	RATE [/yr/km^2]
Down		**5.90 10^{-19}**	**5.97 10^{-19}**	0.37
Up		3.91 10^{-20}	6.63 10^{-20}	0.03
		Iμ(E>10PeV) **Energy Deposit**	Iτ(E>10PeV) **Energy Deposit**	
Down		**4.75 10^{-19}**	**2.94 10^{-19}**	0.24
m=7 Zmax=5**Down**		**7.21 10^{-17}**	**4.83 10^{-17}**	37.9
Atm μ		1.74 10^{-19}		0.05

Conclusion

IceCube has great capability for TeV-PeV ν-induced muons taking advantage of long range in the clear ice.

For EHE ν like the GZK....

τ/μ appeared in 10 PeV- EeV are our prime target on GZK ν detection.

1/100-1/500 of primary ν intensity!

Downward τ and μ make main contributions in PeV -EeV

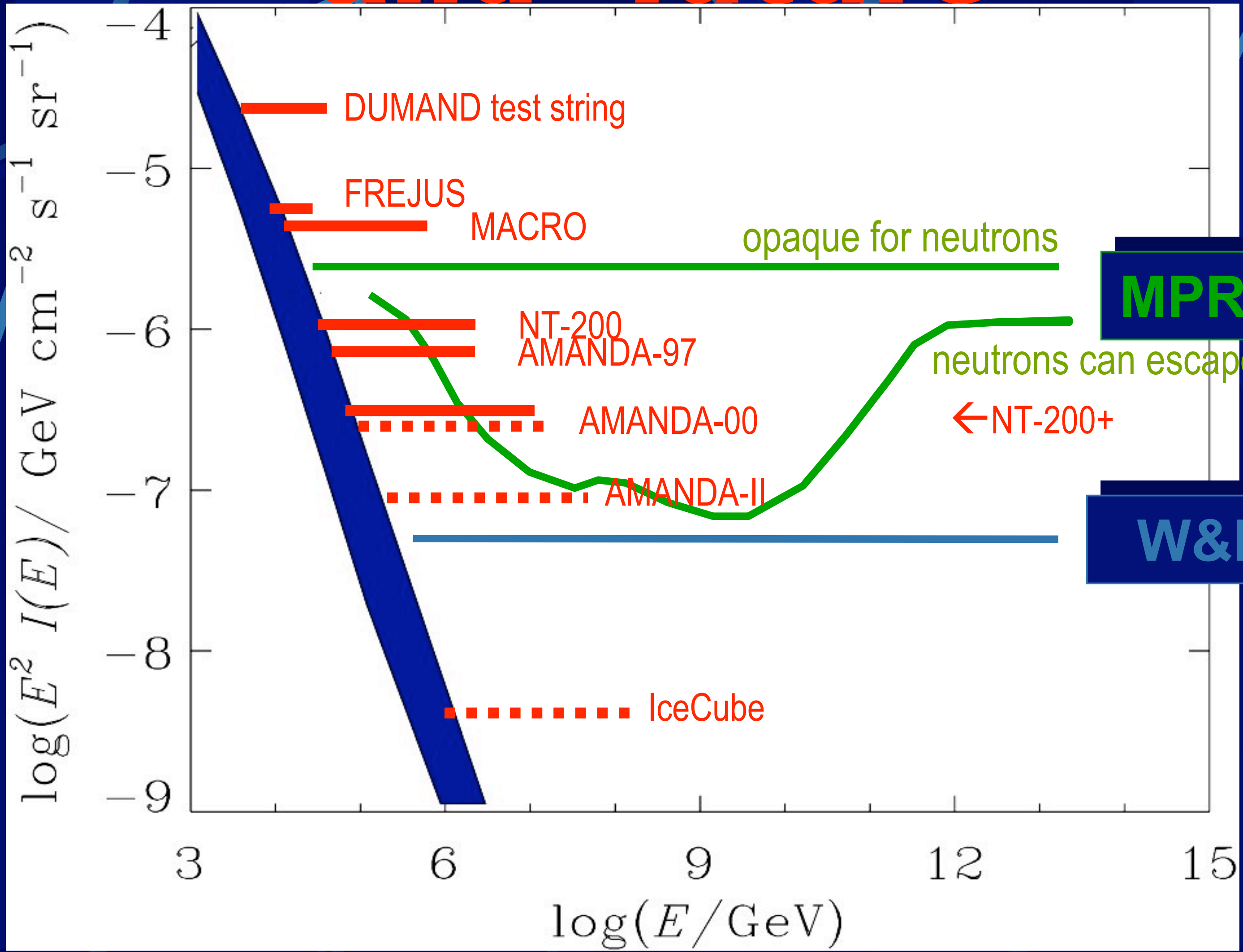
Energy Estimation would be a key for the bg reduction
Because atmospheric μ spectrum ~ $E^{-3.7}$

GZK ν is DETECTABLE by IceCube

0.2-40 events/year (BG 0.05 events/year)

- Backup slides

Theoretical bounds and future



Mannheim, Protheroe and Rachen (2000) – Waxman, Bahcall (1999)

↪ derived from known limits on extragalactic protons + γ-ray flux

UHE (EeV or even higher) Neutrino Events

Arriving Extremely Horizontally

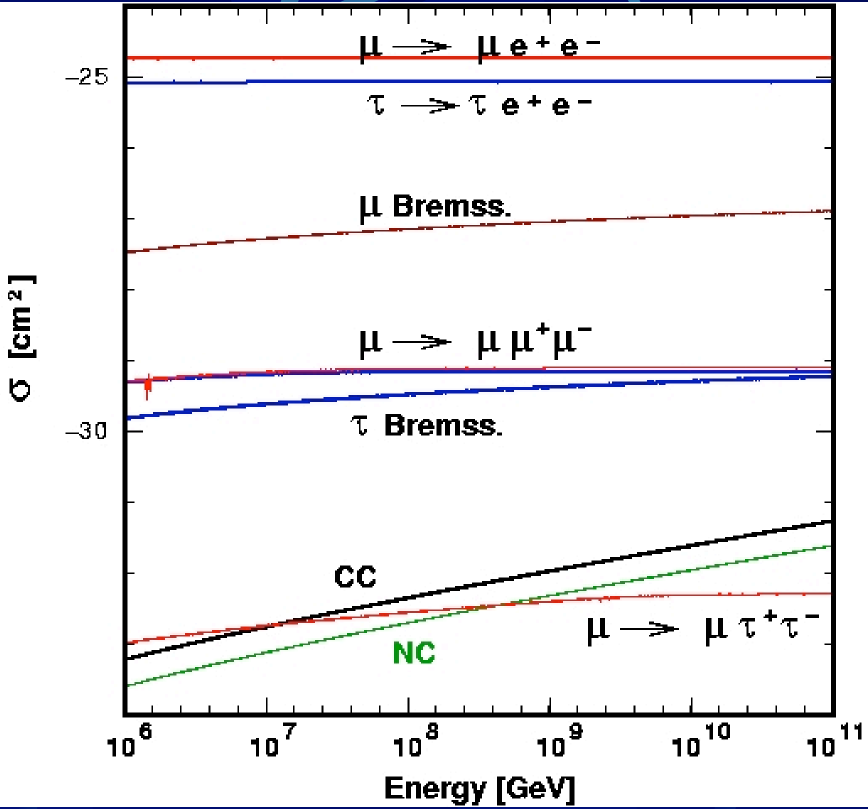
- **Needs Detailed Estimation**
- **Limited Solid Angle Window**

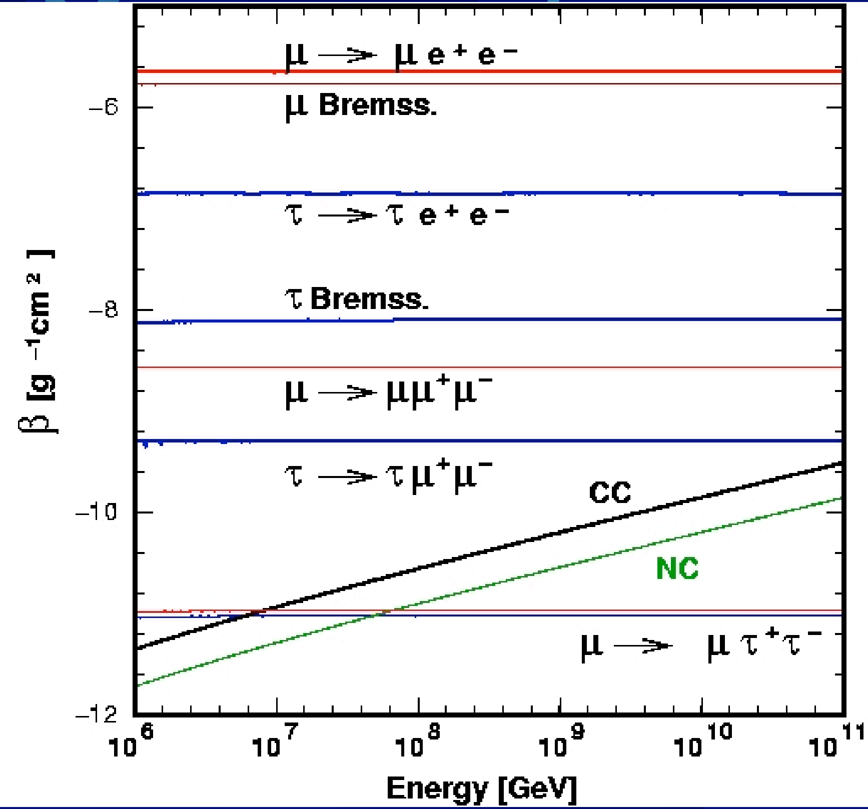
$$(\sigma\rho N_A)^{-1} \sim 600\ (\sigma/10^{-32}\mathrm{cm}^2)^{-1}(\rho/2.6\mathrm{g\ cm}^{-3})^{-1}\ [\mathrm{km}]$$

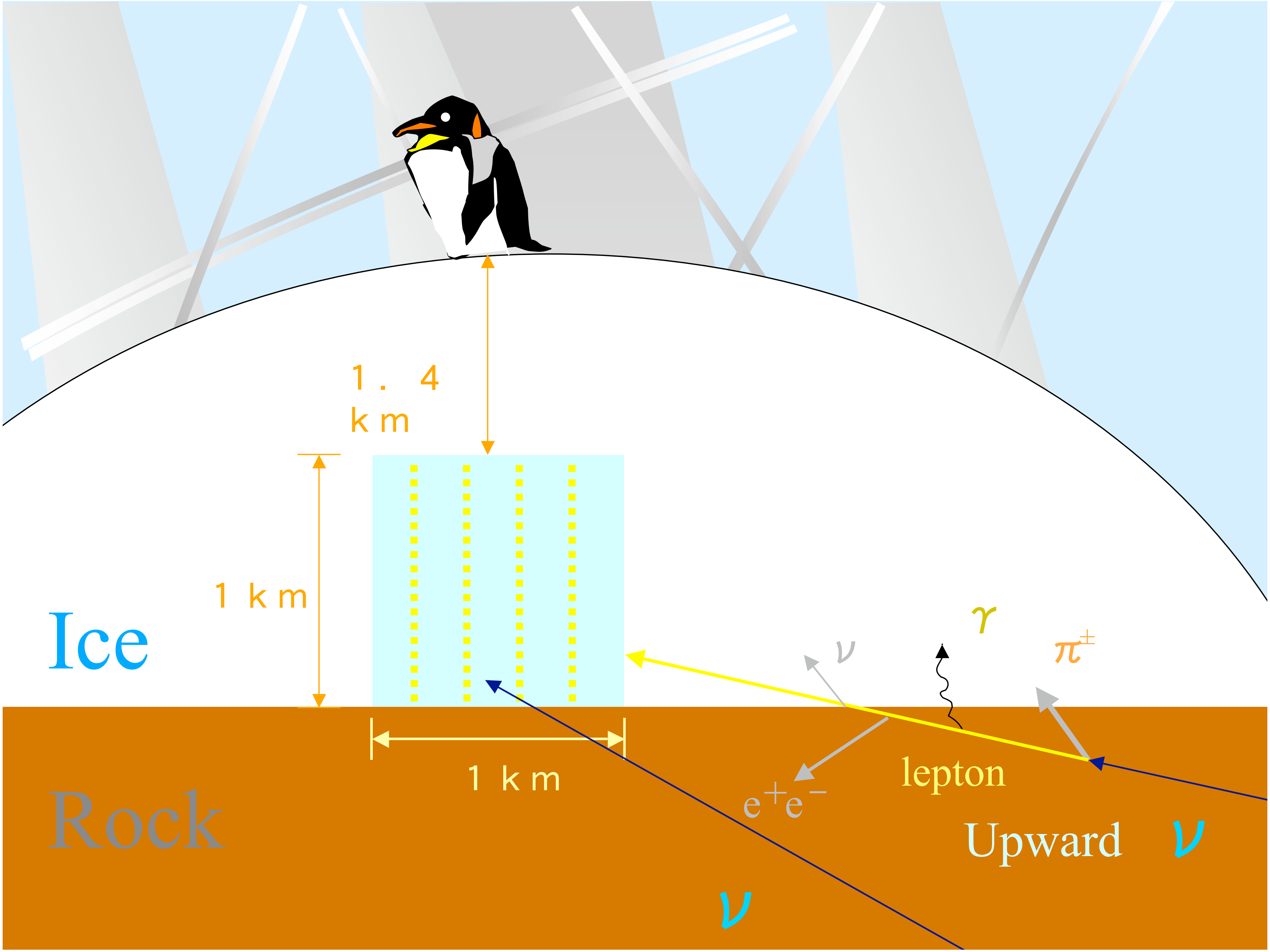
Involving the interactions generating electromagnetic/hadron cascades

$$\mu N \longrightarrow \mu X\ e^+e^-$$

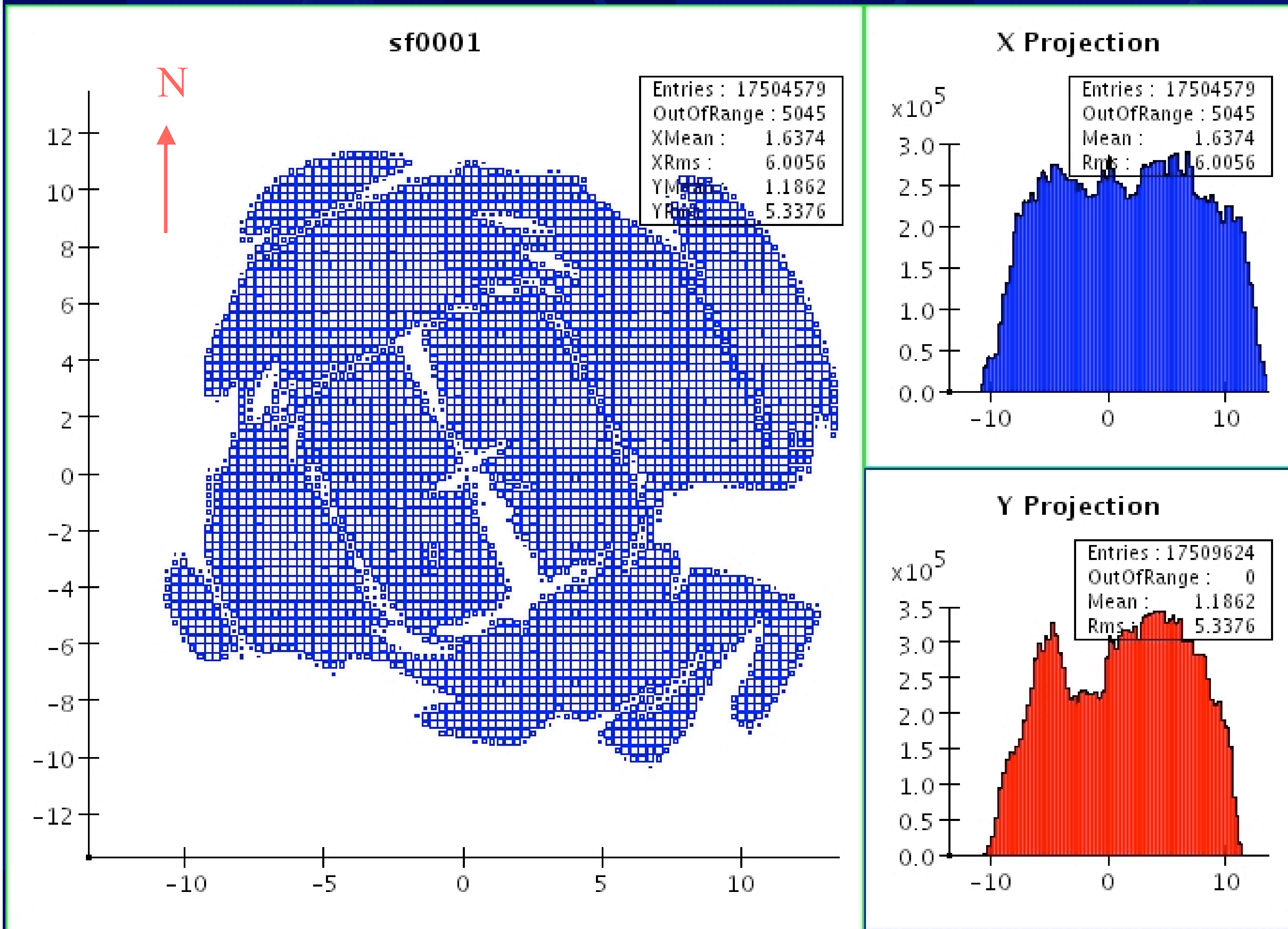
τ/μ propagation in Earth







１．４
ｋｍ
１ｋｍ
Ice
Rock
１ｋｍ
γ
ν
π±
lepton
e+e−
Upward ν
ν


sf0001
N
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OutOfRange : 5045
XMean : 1.6374
XRms : 6.0056
1.1862
5.3376
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-10
-5
0
5
10
X Projection
x10^5
Entries : 17504579
OutOfRange : 5045
Mean : 1.6374
6.0056
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-10
0
10
Y Projection
x10^5
Entries : 17509624
OutOfRange : 0
Mean : 1.1862
5.3376
3.5
3.0
2.5
2.0
1.5
1.0
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0.0
-10
0
10