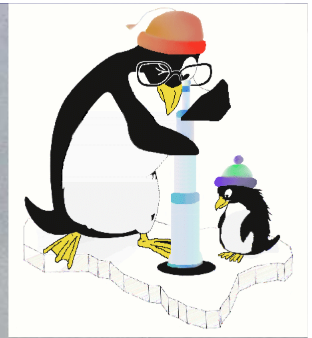


Kyoto 2005

UHE Neutrino Astronomy

Shigeru Yoshida

Chiba University

http://www.ppl.phys.chiba-u.jp/~syoshida/

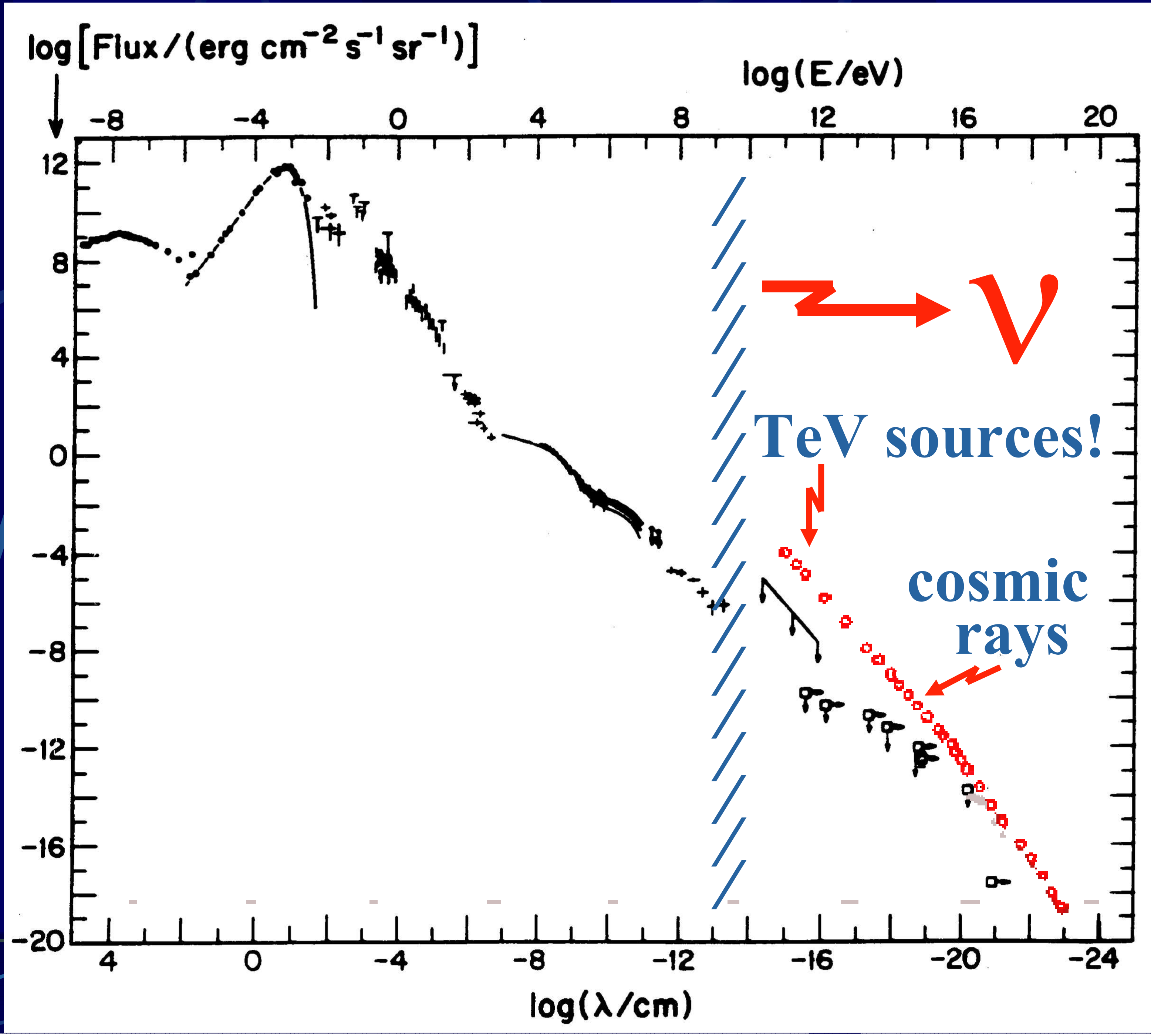
Kyoto 2005

Outline

- HE ν emission – What it can tell
- Theoretical Bound of ν fluxes
- Extremely High-Energy ν generation
- Cosmic ν detection – the current status
- IceCube : reachable to EHE ν universe
- Charged particle astronomy?

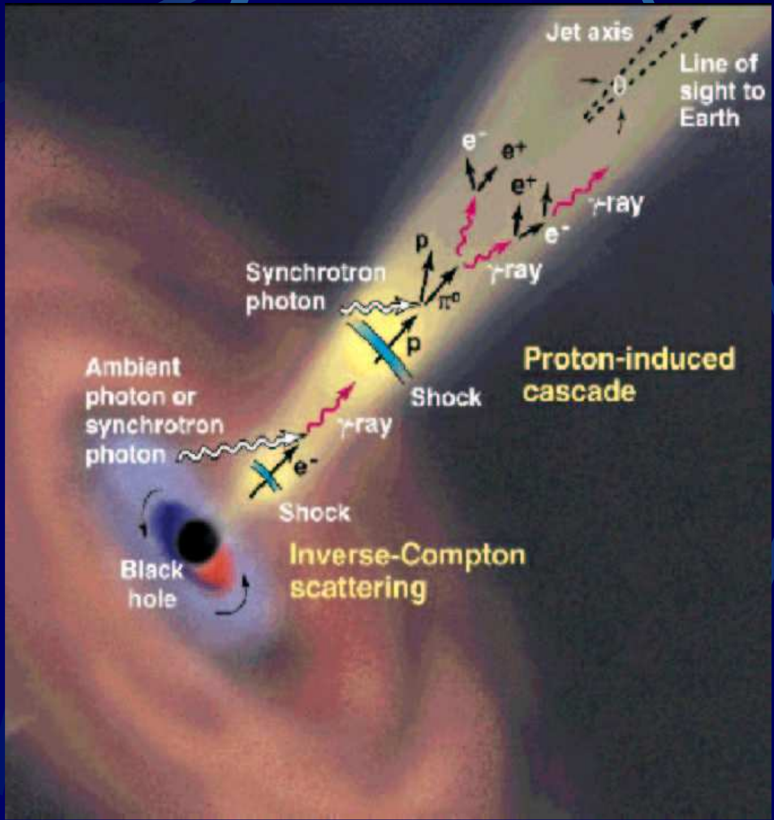
Chiba University 千葉大学

IceCube



log[Flux/(erg cm^{-2} s^{-1} sr^{-1})]
log(E/eV)
-8 -4 0 4 8 12 16 20
12 8 4 0 -4 -8 -12 -16 -20
4 0 -4 -8 -12 -16 -20 -24
log(λ/cm)
ν
TeV sources!
cosmic rays

Physics motivation



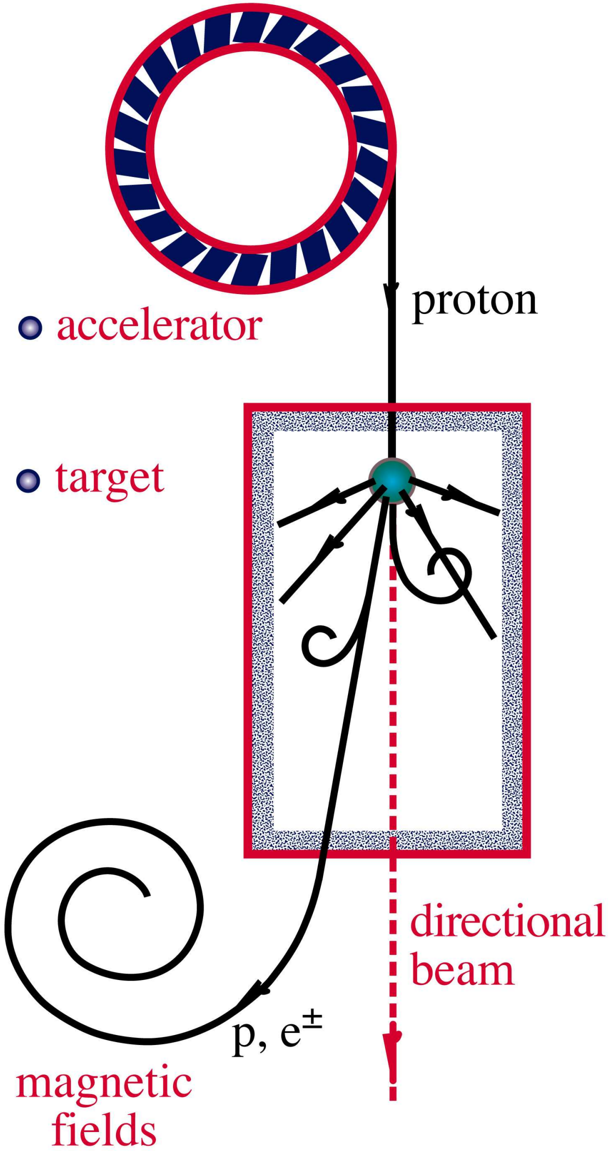
- origin and acceleration of cosmic rays
- understand cosmic cataclysms
- find new kind of objects?

- neutrino properties (ν_τ , cross sections ..)

- dark matter (neutralino annihilation)

  - *tests of relativitiy ....*
  - *search for big bang relics ...*
  - *effects of extra dimension etc. ...*

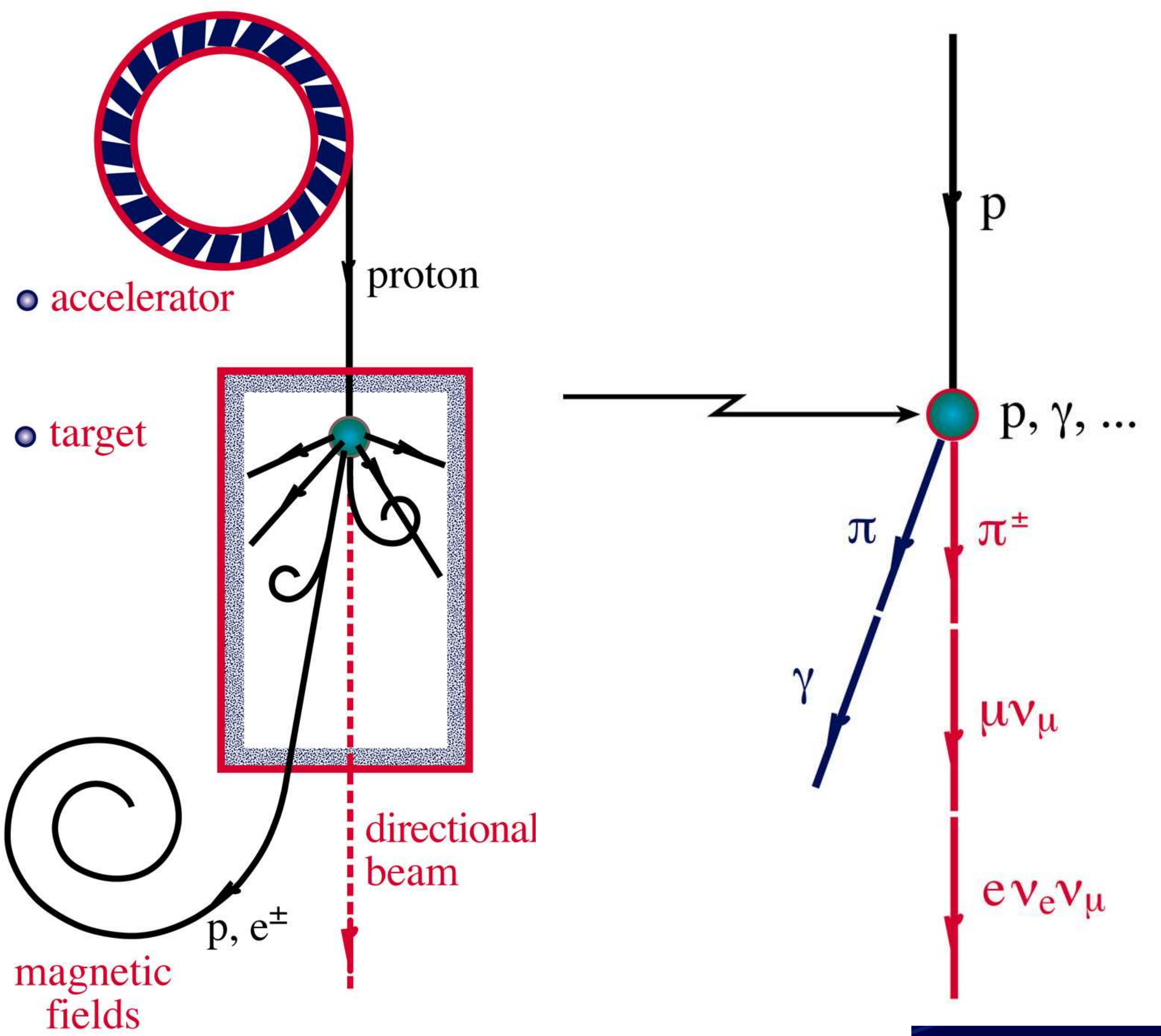
NEUTRINO BEAMS: HEAVEN & EARTH



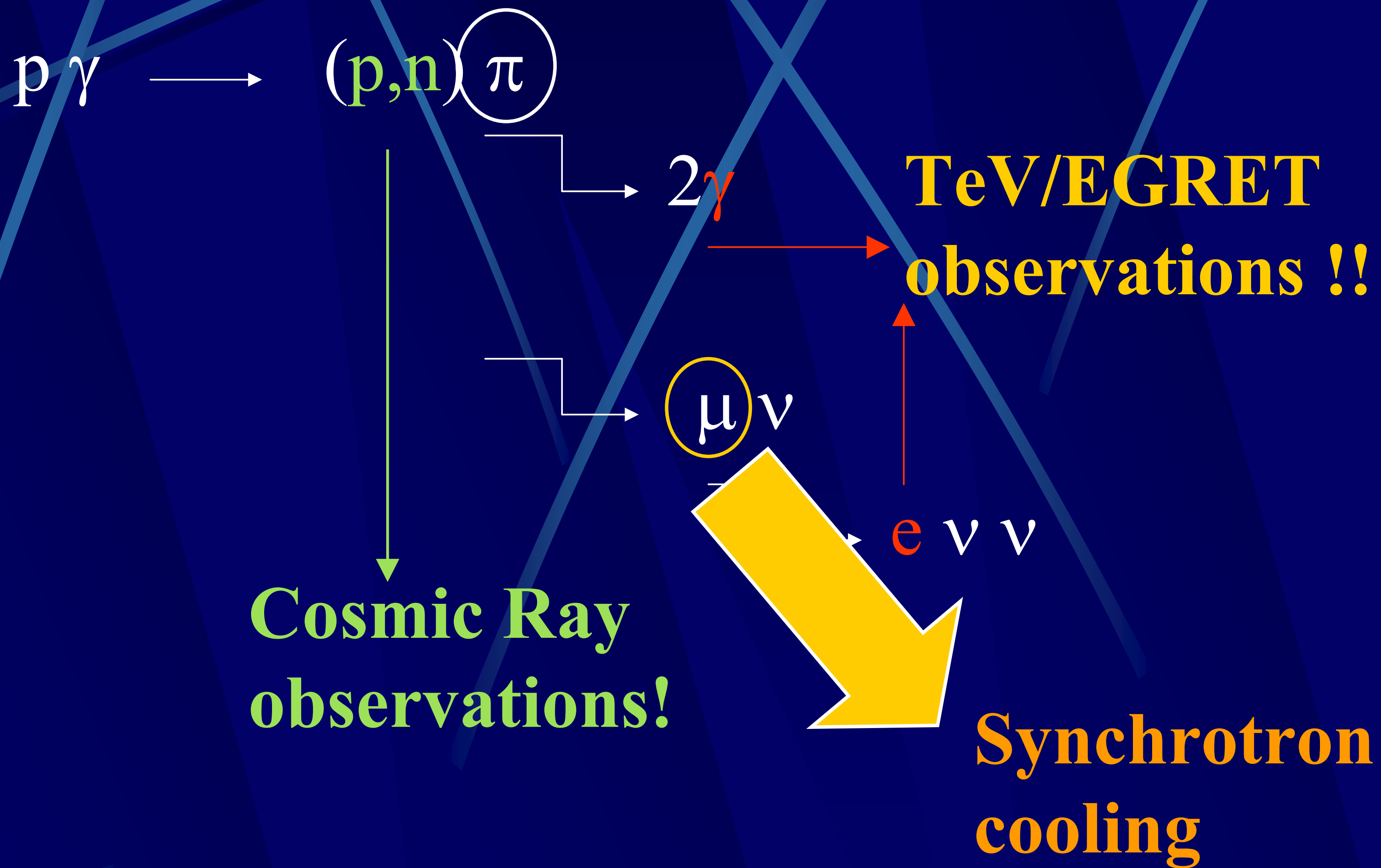
black hole

radiation
enveloping
black hole

NEUTRINO BEAMS: HEAVEN & EARTH

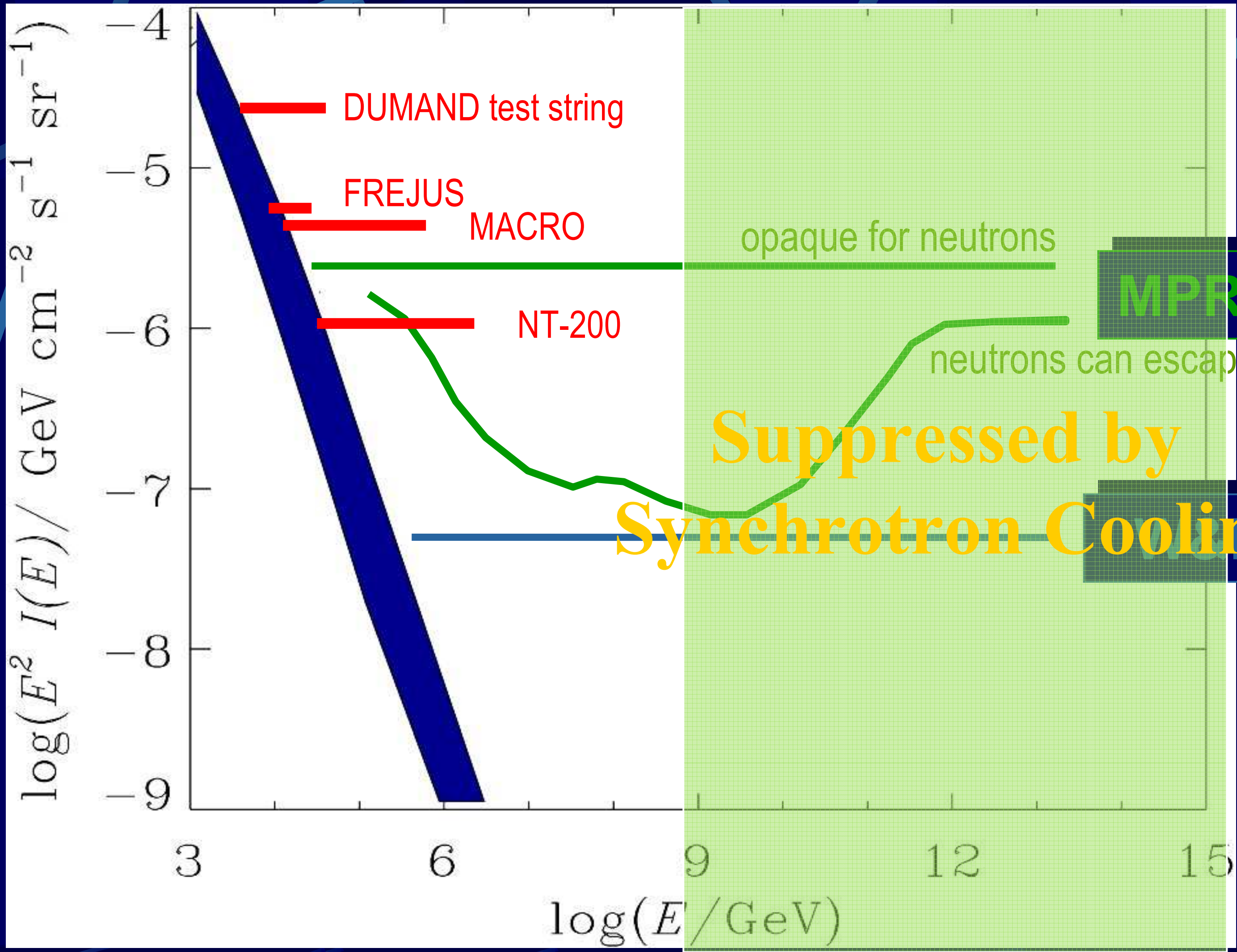


You cannot expect too many ν!



You cannot expect too high energies

Theoretical bounds



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

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

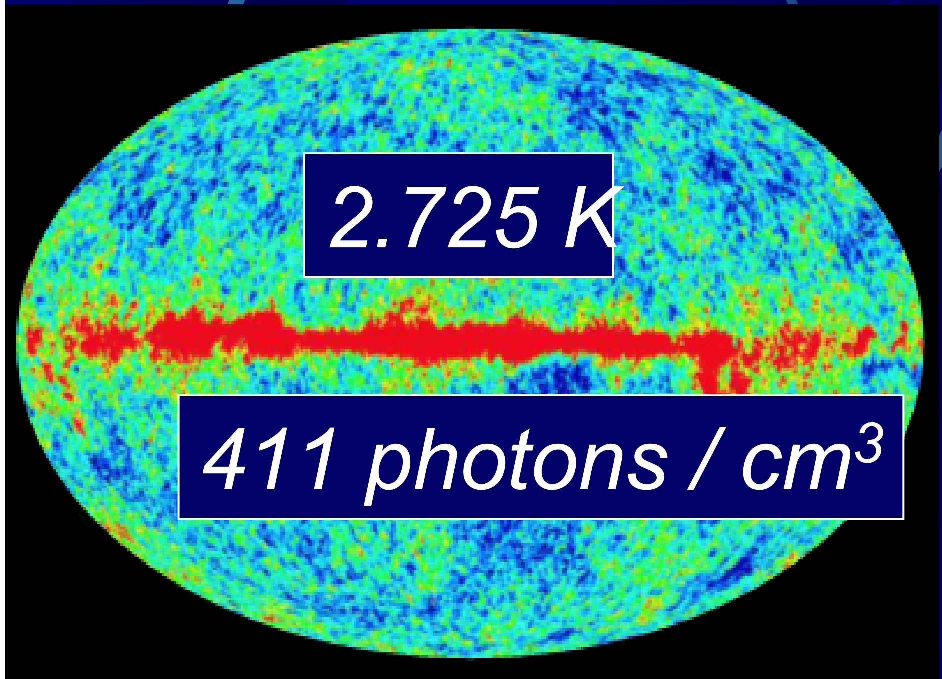
EHE(Extremely HE) ν

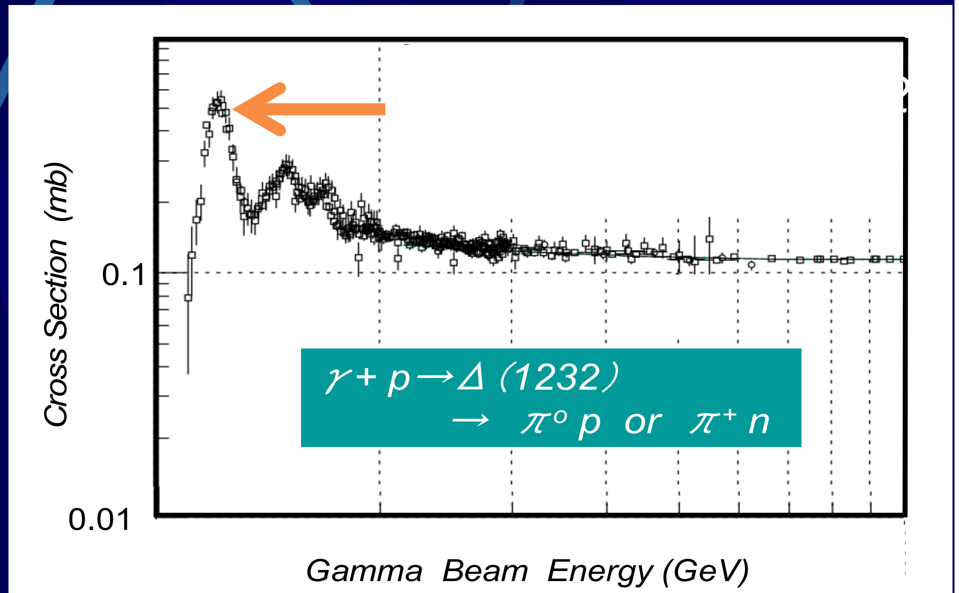
Synchrotron cooling of μ …
Production sites with low B

→ **Intergalactic space!!**

- **GZK Production**
- Z-burst
- Topological Defects/Super heavy Massive particles

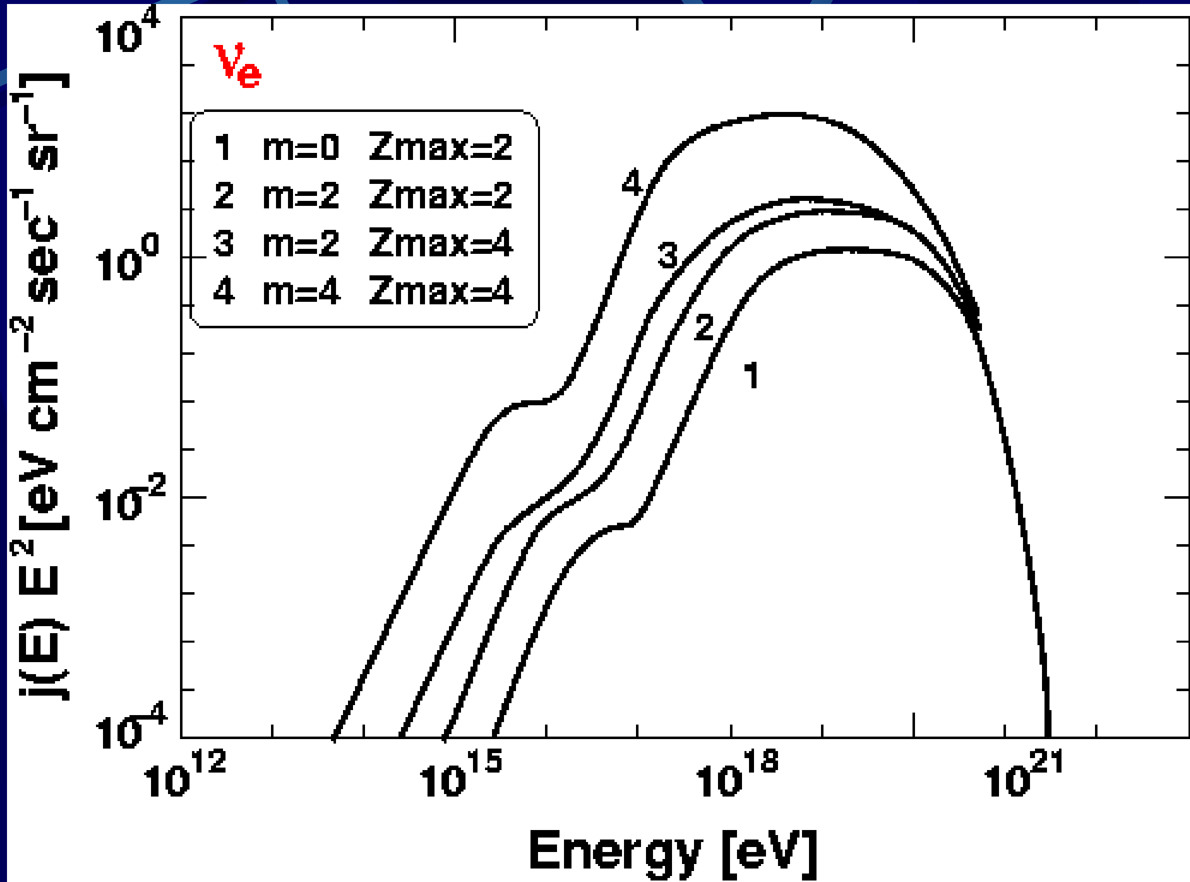
GZK Neutrino Production





→ Conventional Mechanism of EHE neutrinos!!

GZK ν fluxes (EeV~ZeV!)



Yoshida and Teshima 1993

Yoshida, Dai, Jui, Sommers 1997

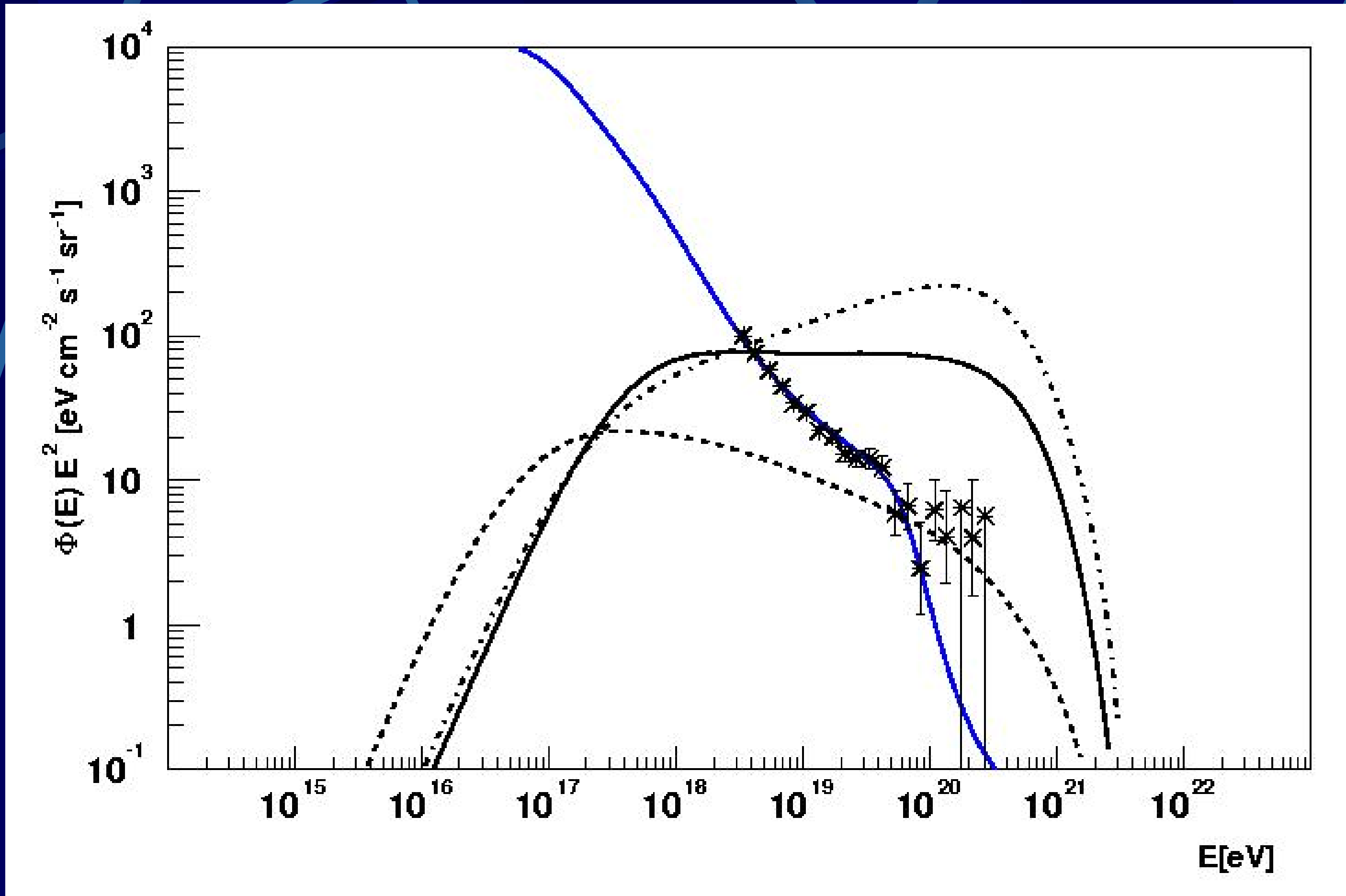
Parameters involved in calculation. Predicted fluxes.

Parameters		Orientative order of magnitude
γ	spectral injection index	[1-3]
m	activity evolution index	[3-5]
z_{max}	z of formation of sources	[1-4]
Ω_M	density of matter	[0.2-1]
H_o	Hubble constant	[50-80 Km/s/Mpc]
B	intergalactic magnetic field	[B≤1nG]
$\eta_L \rho_L / \eta_o \rho_o$	local enhancement	[?]
E_{max}	maximum acceleration energy in source	[E_{max} >4 10^{20} eV]

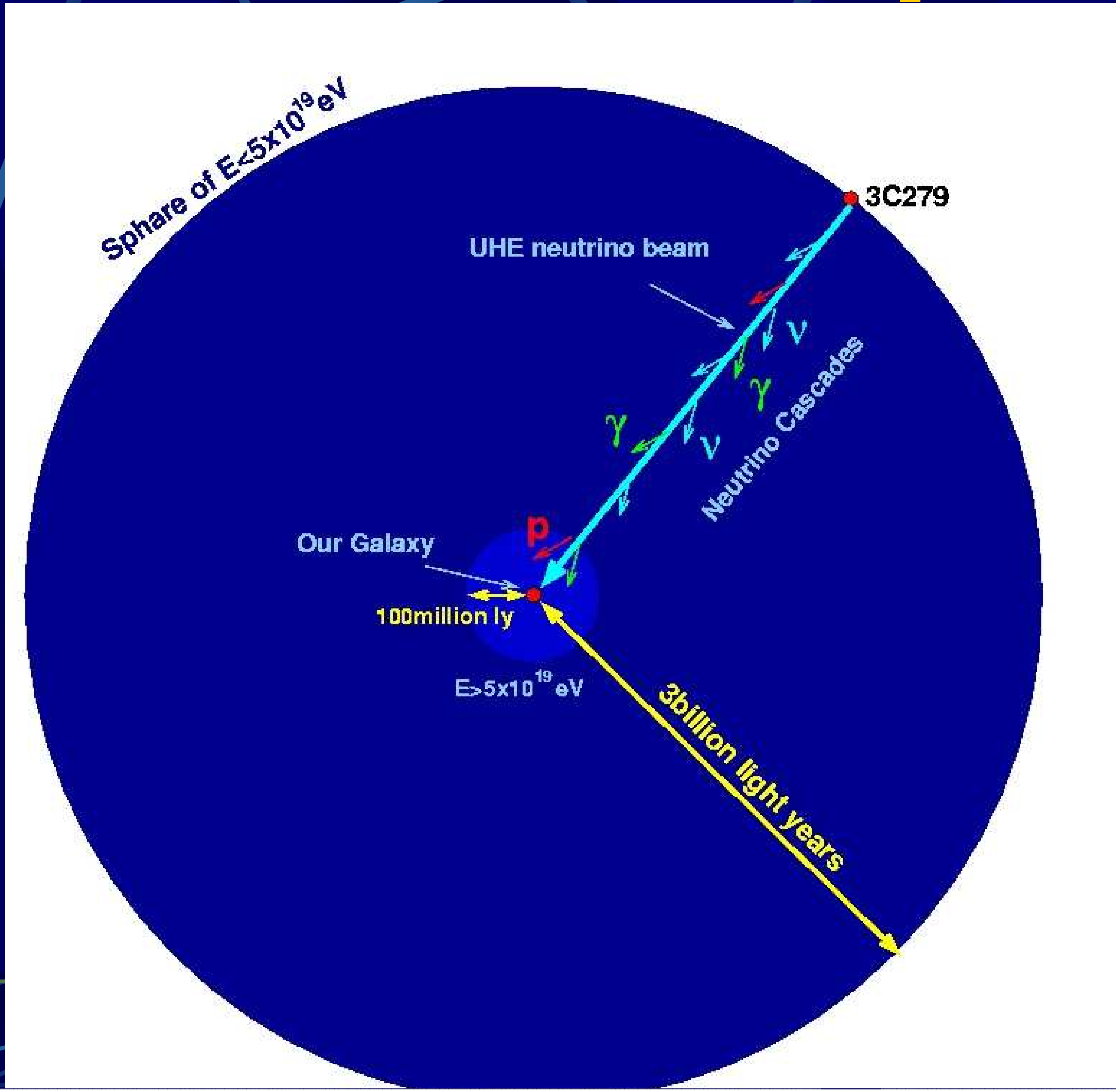
(Diego González-Díaz, Ricardo Vázquez, Enrique Zas 2003)

(Diego González-Díaz, Ricardo Vázquez, Enrique Zas 2003)

CR and ν fluxes for different models

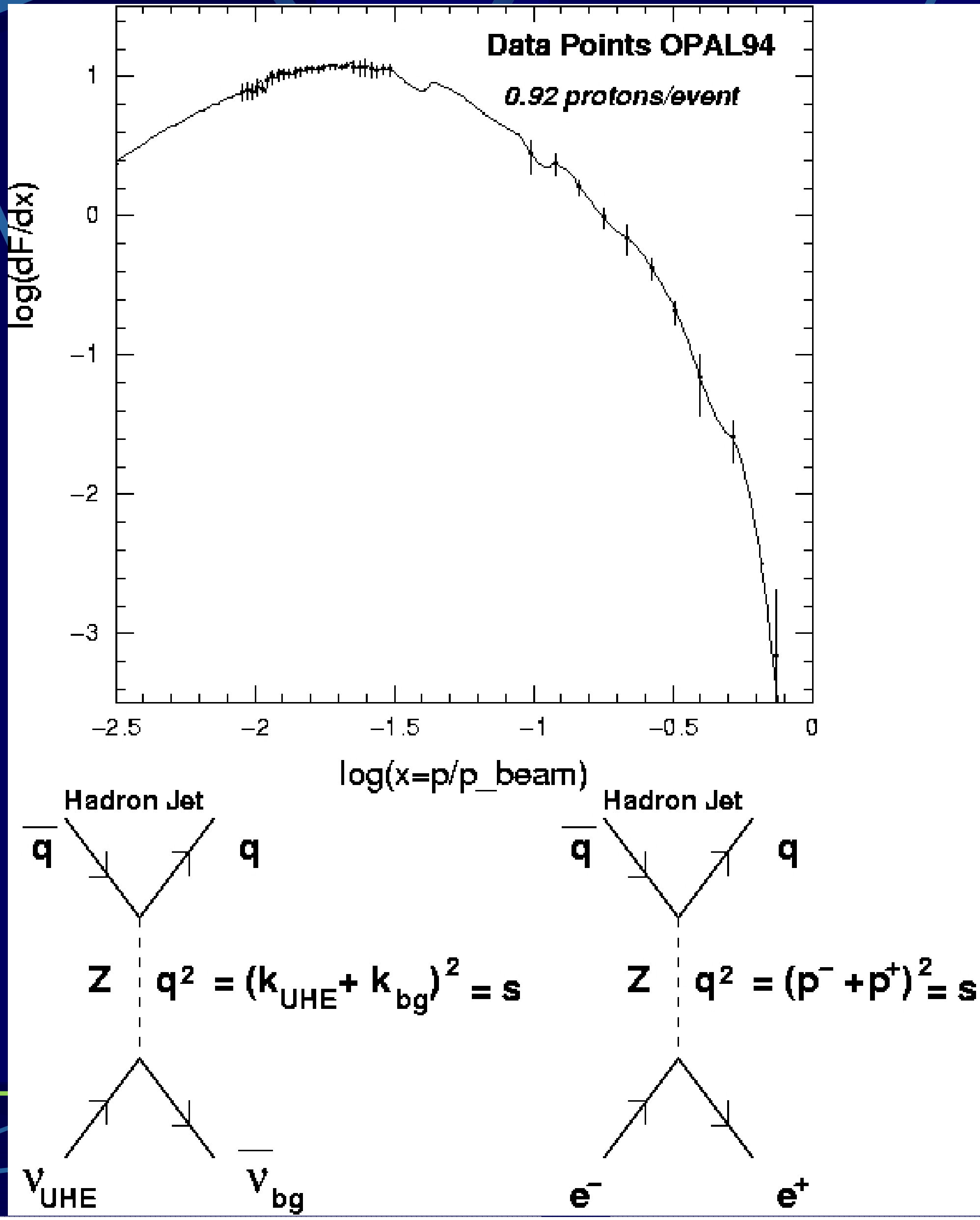


Z-bursts Concept

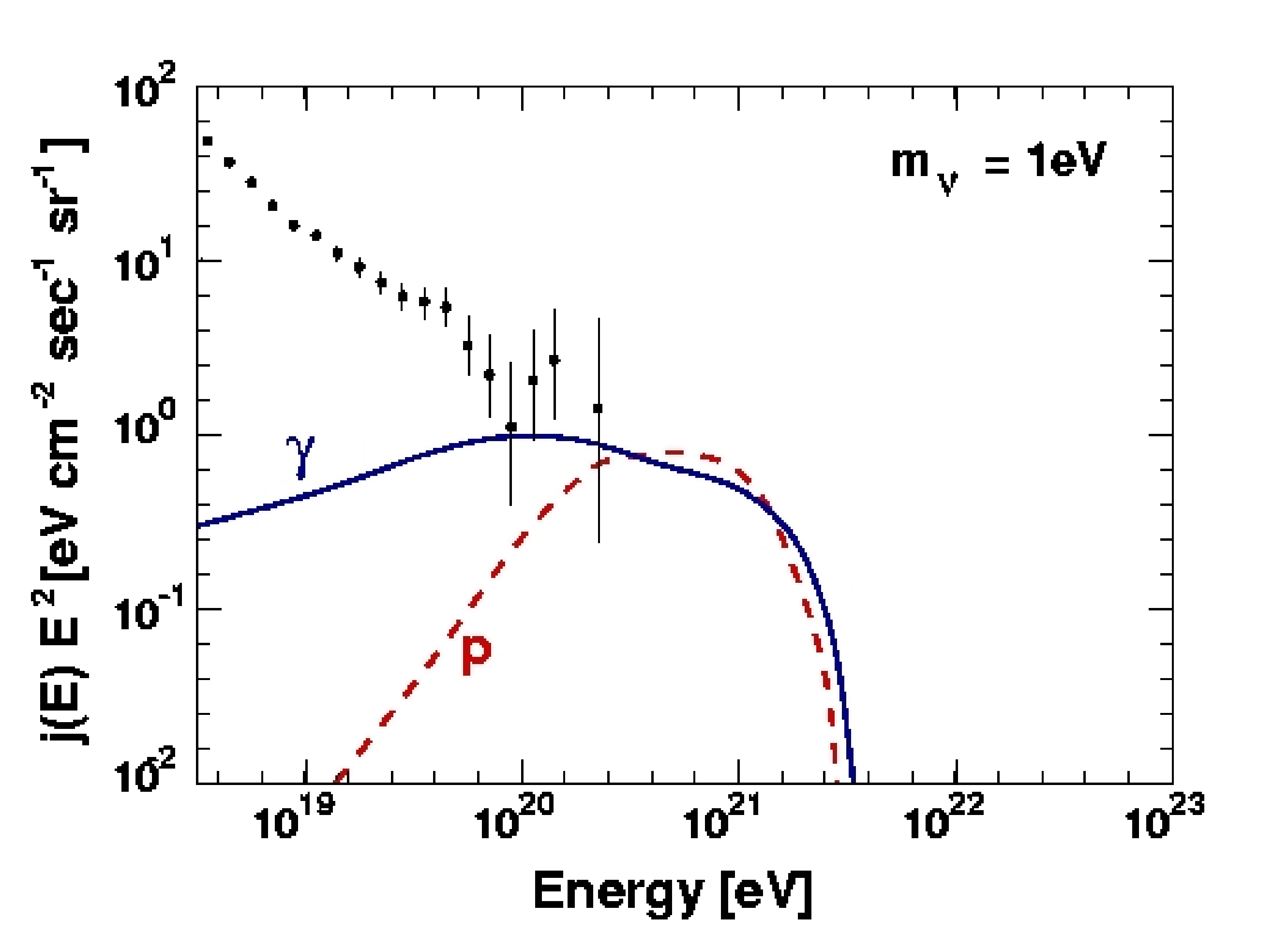


It is the “standard” particle physics

$\nu\nu \rightarrow p, \pi^{+}, \pi^{-}. \pi_{0}..$

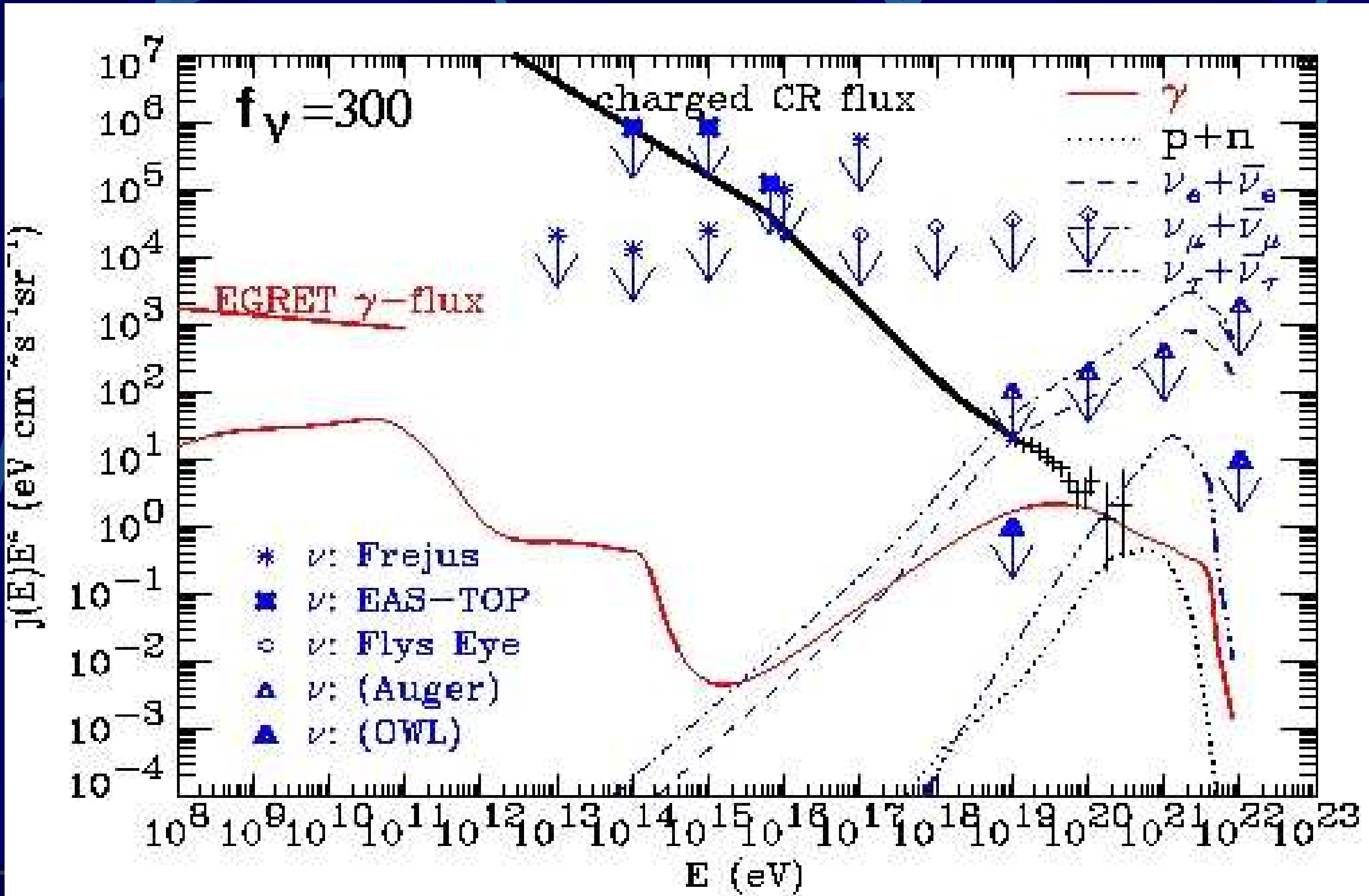


CRs extending to superEHEs!



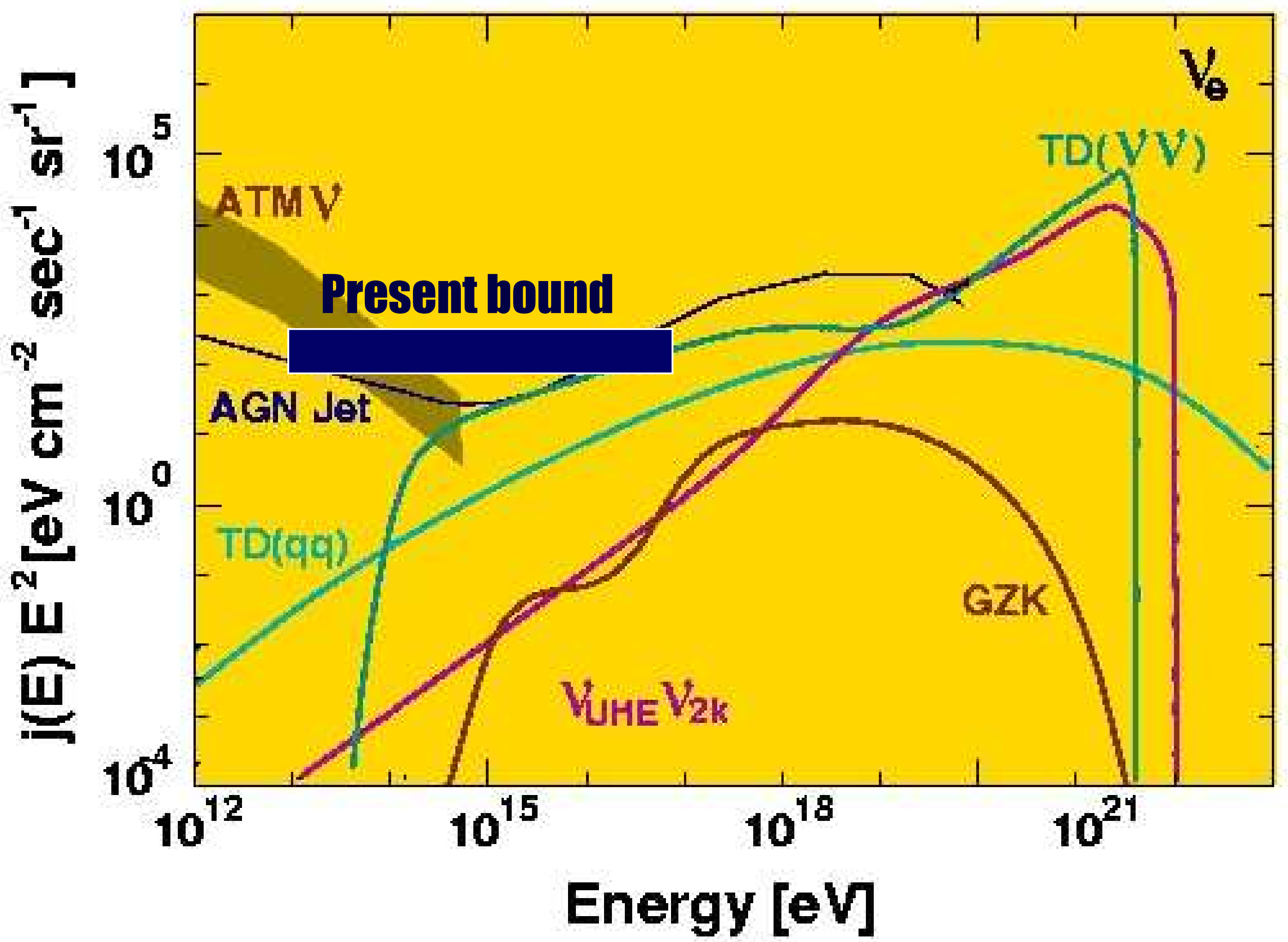
(Yoshida, Sigl, Lee 1998)

Z-burst constraints



(Yoshida, Sigl, Lee 1998)

EHE Neutrino Fluxes

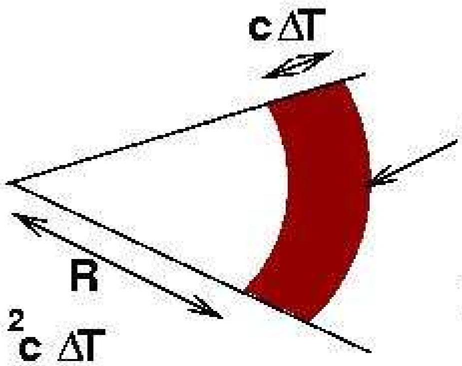


Where the source of (Extremely)-high energy ν?

My $100 goes to **GZK**

My $1 goes to **GRB**

GRBs might be a solution........



$R = \Gamma^2 c\, \Delta T$

Lorents Factor of the plasma bulk
$\Gamma \sim 100\text{–}1000$

Observed MeVγ's Energy Density $U_{rad} = \eta \dfrac{E_{total}}{4\pi R^2 \Gamma^2 c\, T_{GRB}}$
@ the shock rest frame

E_{total} : total energy of a GRB $\sim 10^{53}$ erg

η : Efficiency to the energy transfer to γ

Fraction of energies going into pions

$f = \dfrac{t_{esc}}{t_{p\gamma}}$

$t_{esc} = \Gamma \Delta T$

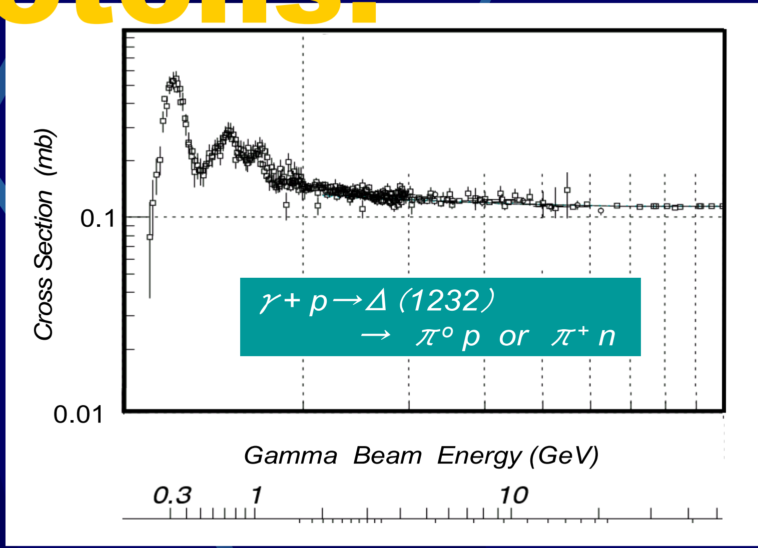
$t_{p\gamma}^{-1} = \dfrac{U_{rad}}{c k_{break}} \sigma_{res} \dfrac{\Delta s}{s - m_p^2} \varepsilon$ @ the shock rest frame

$k_{break}^{obs} = \Gamma k_{break} \sim 1$ MeV $\quad \varepsilon \sim 0.2$

$$f = 0.8 \left(\frac{\eta}{1.00}\right)\left(\frac{E_{total}}{10^{53}\text{erg}}\right)\left(\frac{\Gamma}{300}\right)^{-4}\left(\frac{\Delta T}{10\text{ ms}}\right)^{-1}\left(\frac{T_{GRB}}{10\text{ s}}\right)^{-1}\left(\frac{k_{break}^{obs}}{1\text{MeV}}\right)^{-1}$$

(E)HE ν generation needs target photons!

Δ resonance in the photopion production



$E_p\ E_\gamma \sim 0.25\ \Gamma^2\ [\mathrm{GeV}^2]$

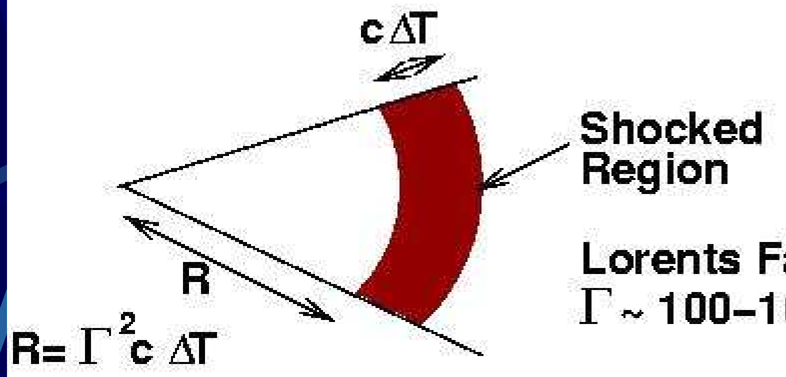
$\Gamma \sim 300$, $E_\gamma \sim$ MeV $\longrightarrow$ $E_p \sim 10^{16}$ eV ~ 10 PeV

$\Gamma \sim 300$, $E_\gamma \sim$ eV $\longrightarrow$ $E_p > 10^{20}$ eV ~ 1 ZeV

$E_\gamma \sim$ eV ?? **Proton-synchrotron model**

(Totani 1998)

Proton–synch might be a solution.......



Lorents Factor of the plasma bulk

$\Gamma \sim 100\text{–}1000$

Observed MeVγ's Energy Density $U_{rad} = \eta \dfrac{E_{total}}{4\pi R^2 \Gamma^2 c\, T_{GRB}}$
@ the shock rest frame

E_{total} : total energy of a GRB $\sim 10^{56}$ erg

η : Efficiency to the energy transfer to γ ~Me/Mp

Fraction of energies going into pions

$$f = \frac{t_{esc}}{t_{p\gamma}} \qquad t_{esc} = \Gamma \Delta T$$

$$t_{p\gamma}^{-1} = \frac{U_{rad}}{c\, k_{break}} \sigma_{res} \frac{\Delta s}{s - m_p^2} \varepsilon$$

@ the shock rest frame

$$k_{break}^{obs} = \Gamma k_{break} \sim 1\ \text{eV} \qquad \varepsilon \sim 0.2$$

$$f = 0.1 \left(\frac{\eta}{5\times10^{-4}}\right)\left(\frac{E_{total}}{10^{56}\text{erg}}\right)\left(\frac{\Gamma}{300}\right)^{-5}\left(\frac{\Delta T}{10\ \text{s}}\right)^{-1}\left(\frac{T_{GRB}}{10\ \text{s}}\right)^{-1}\left(\frac{k_{break}^{obs}}{1\text{eV}}\right)^{-1}$$

Energy limit!

Life is not so easy...

Synchrotron cooling supresses the intensity? Yes!!

$$\varepsilon_{syn} = \frac{t_{syn}}{\tau} \qquad \tau = \tau_{rest}\left(\frac{E_{obs}}{m\Gamma}\right) \qquad t_{syn}^{-1} = \frac{4}{3} U_{mag}\sigma_t \frac{m_e^2}{m^3}\left(\frac{E_{obs}}{m\Gamma}\right)$$

$$U_{mag} = \xi_B U_{rad} \quad \text{(equipartition)}$$

$$\varepsilon_{syn}^{\mu} = 2\text{x}10^{-9}\left(\frac{E_{total}}{10^{56}\text{erg}}\right)^{-1}\left(\frac{\Gamma}{300}\right)^{8}\left(\frac{\Delta T}{10\text{ s}}\right)^{3}\left(\frac{E\nu}{4\text{x}10^{21}\text{eV}}\right)^{-2}\xi_B^{-1} \qquad \varepsilon_{syn}^{\pi} = 3.4\text{x}10^{2}\,\varepsilon_{syn}^{\mu} \ll 1$$

$$\varepsilon_{syn} \sim 1 \longrightarrow E_{\nu} = 10^{19}\text{ eV}\left(\frac{\Gamma}{300}\right)^{4} \sim E_{GZK}\ !!$$

(Highly biased) conclusion ☺

- Cosmic neutrinos come from …….

GRBs $E_\nu \sim$ PeV

+

GZK + GRBs(p-synch) $E_\nu >$ EeV

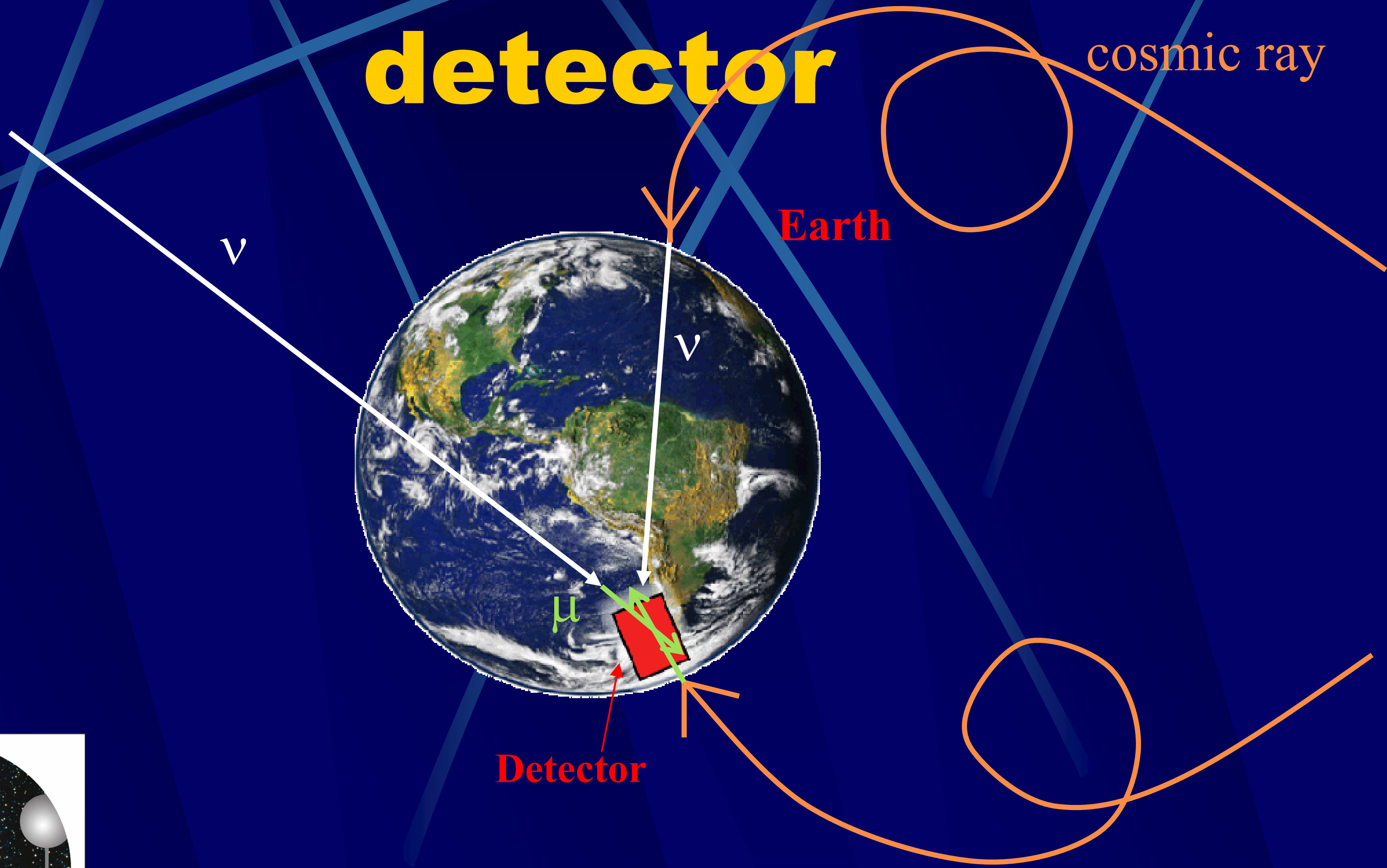
All "diffusive/background" fluxes

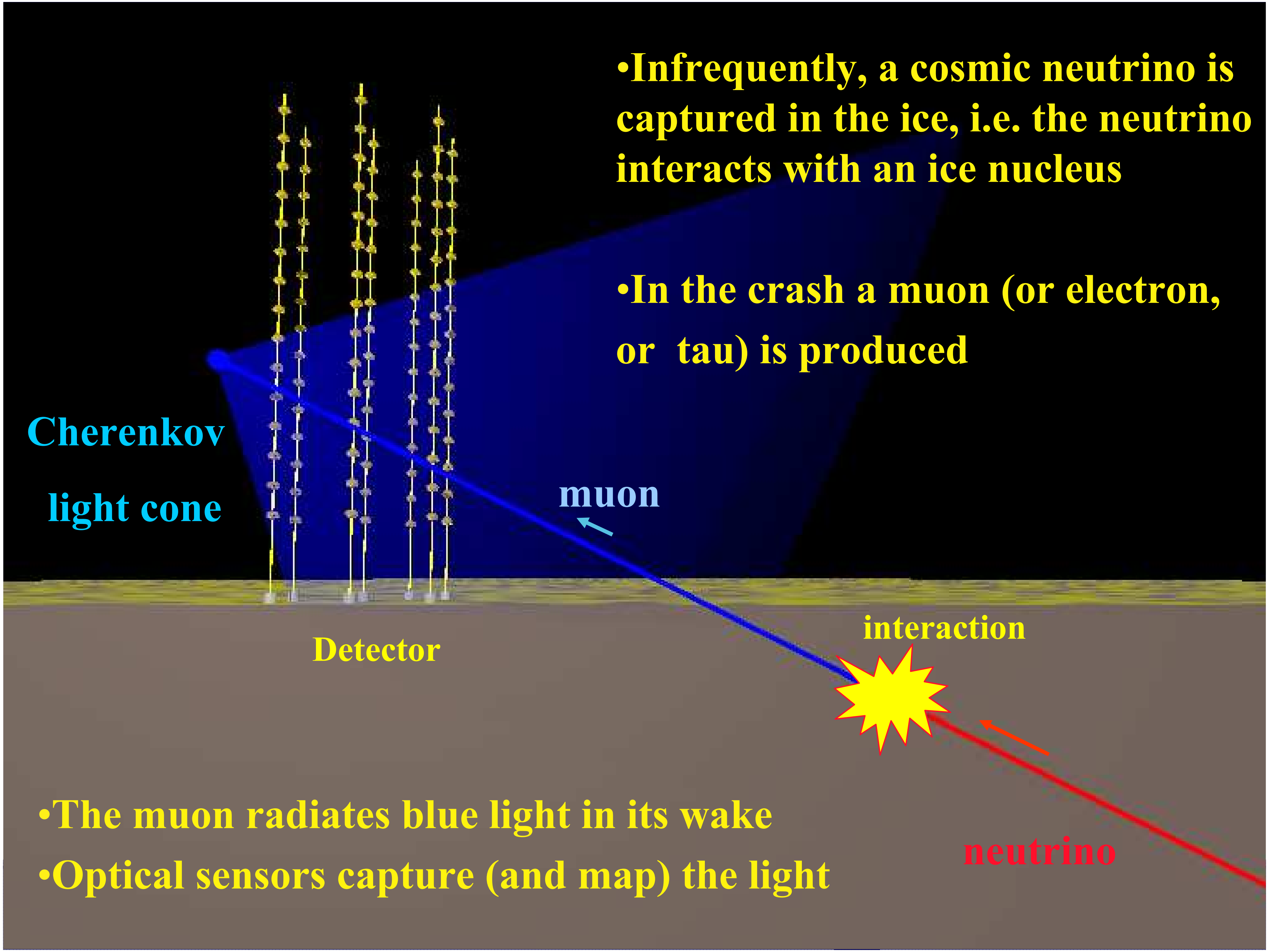
Kyoto 2003

Cosmic ν detection

Neutrino Telescopes – ANTARES, IceCube etc.

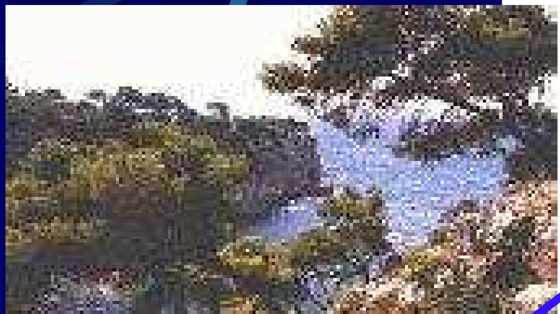
How to build a ν detector




•Infrequently, a cosmic neutrino is captured in the ice, i.e. the neutrino interacts with an ice nucleus
•In the crash a muon (or electron, or tau) is produced
Cherenkov light cone
muon
Detector
interaction
•The muon radiates blue light in its wake
•Optical sensors capture (and map) the light
neutrino

Optical Cherenkov Neutrino Telescope Projects

ANTARES
La-Seyne-sur-Mer, France



NEMO
Catania, Italy

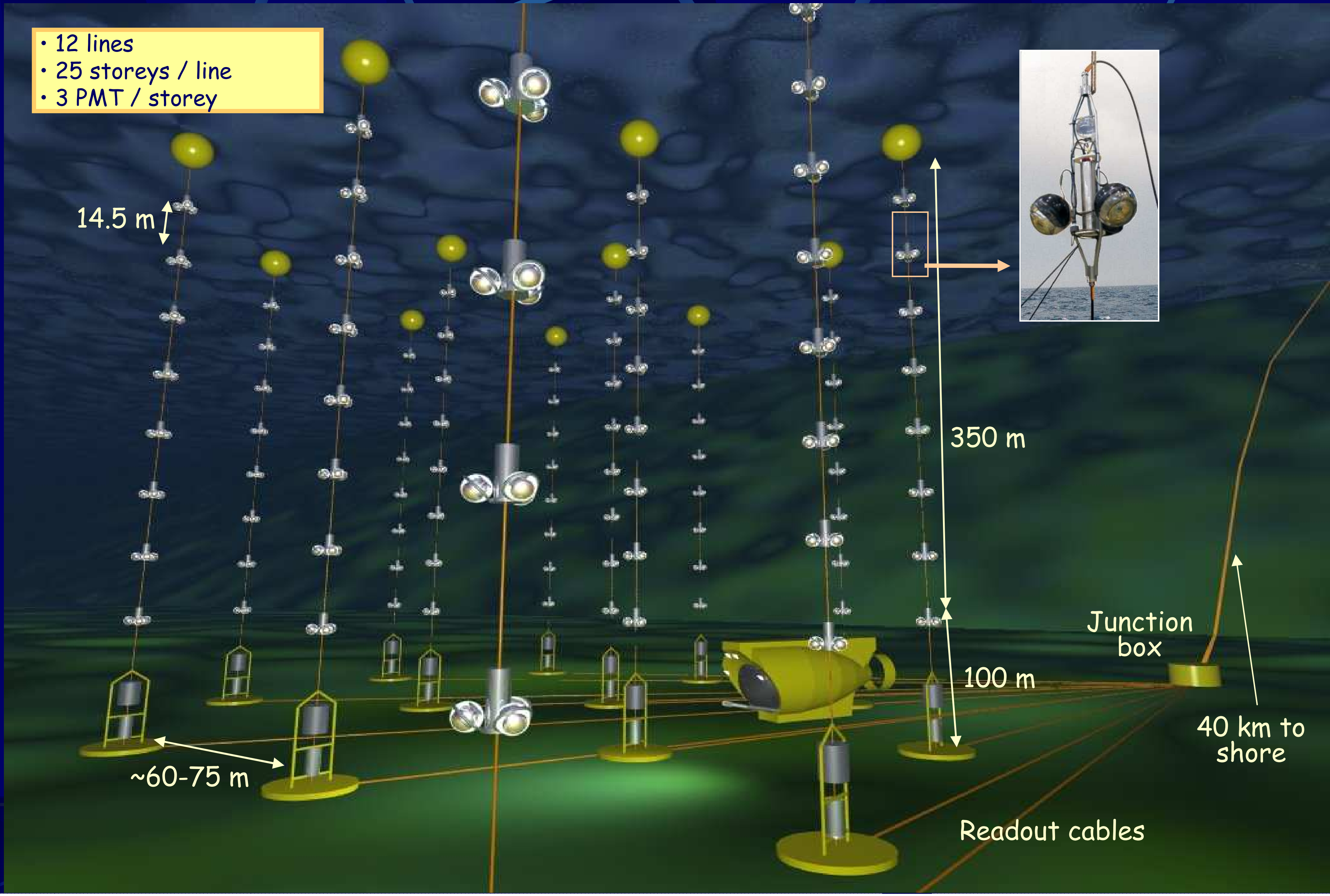
NESTOR
Pylos, Greece

BAIKAL
Russia

DUMAND
Hawaii
(cancelled 1995)

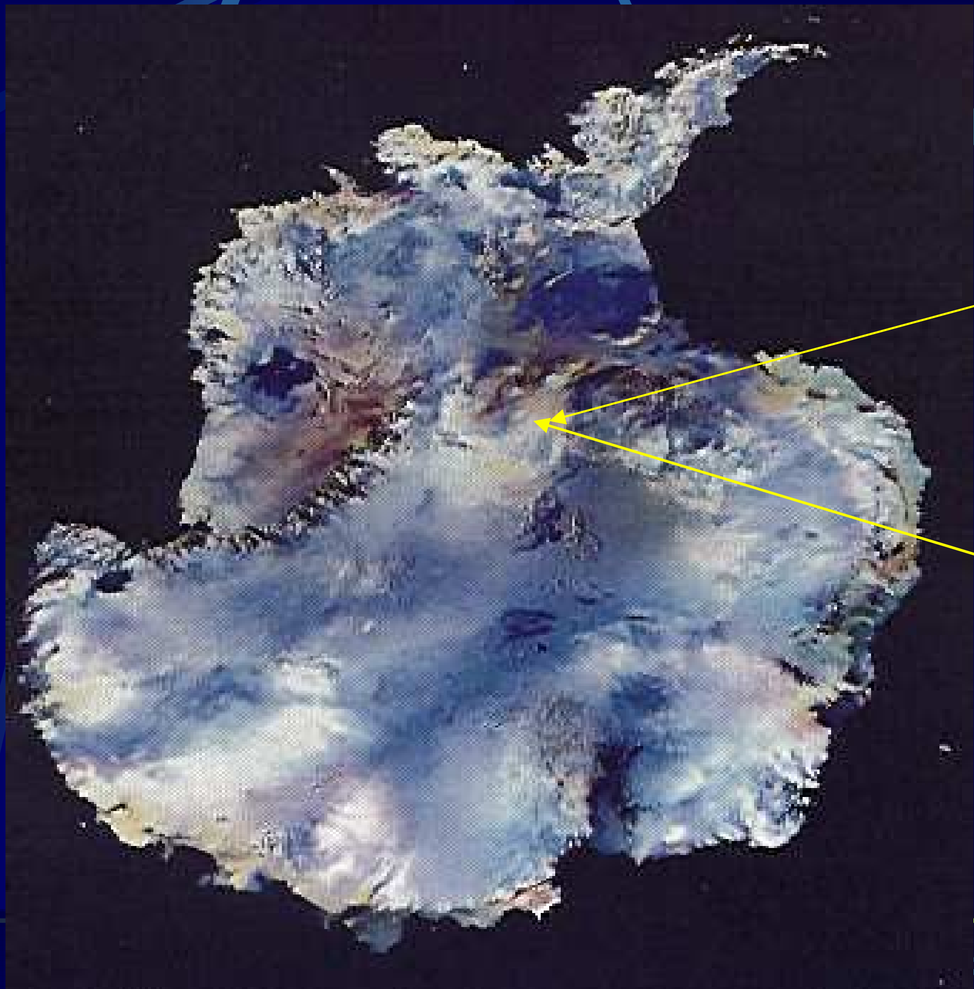
IceCube, South Pole, Antarctica

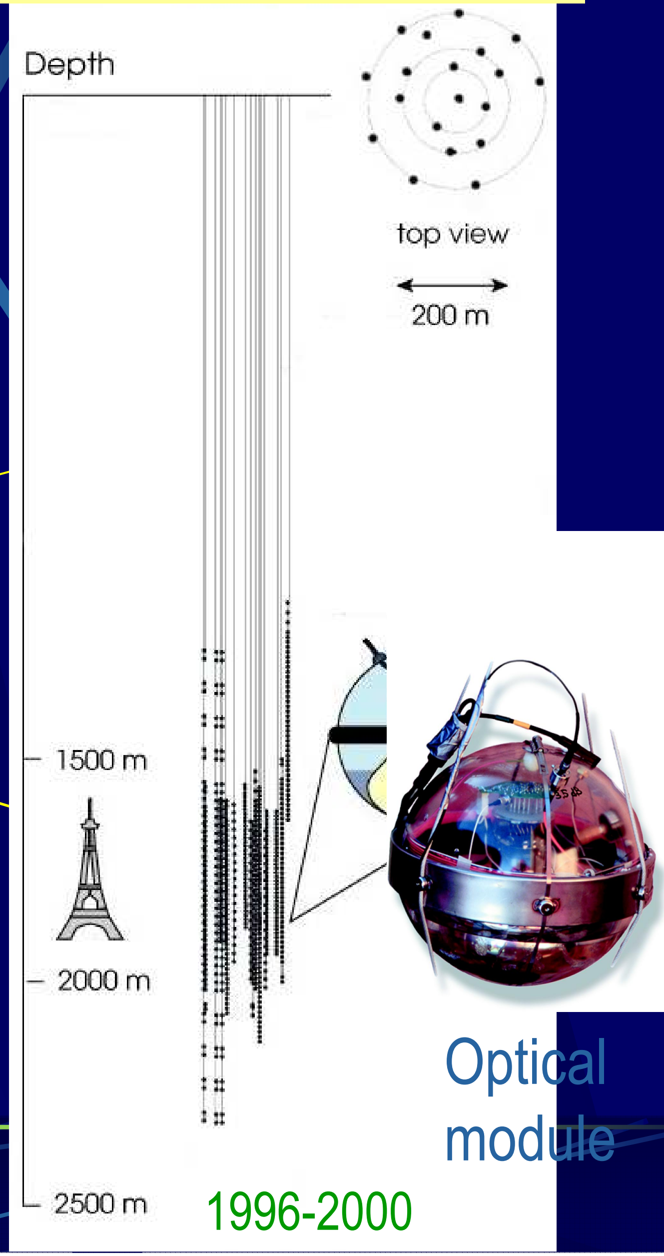
ANTARES Layout



AMANDA II Detector

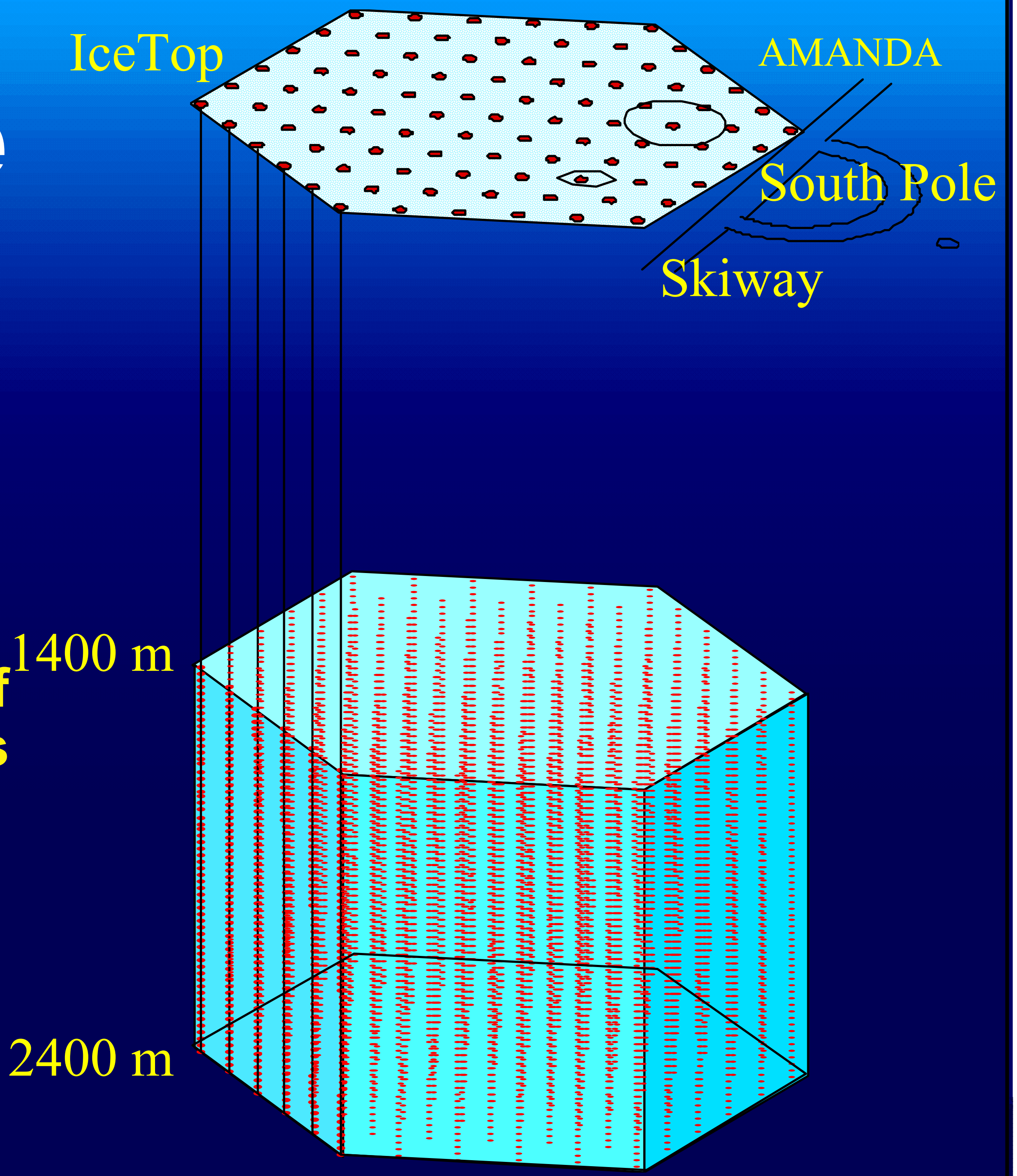
Amundsen-Scott Station South Pole



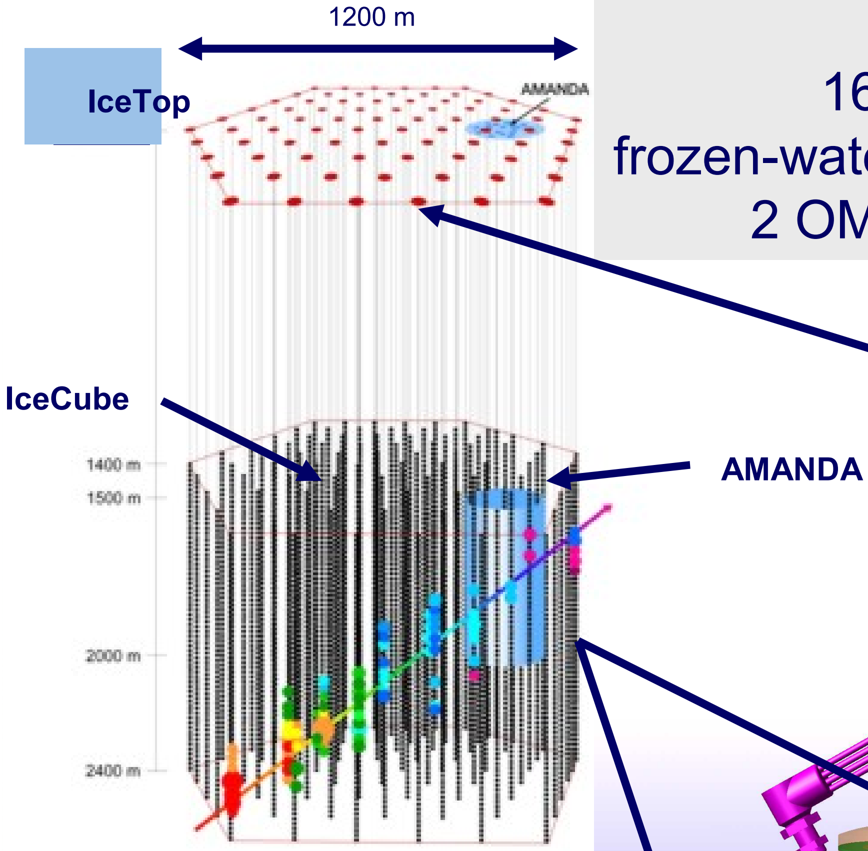


IceCube

- 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



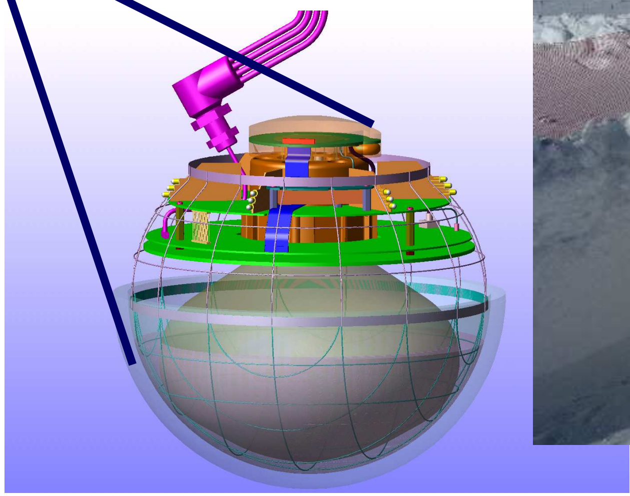
IceCube



IceTop
160 tanks
frozen-water tanks
2 OMs / tank

<u>First year deployment (Jan 2005)</u>
4 IceCube strings (240 OMs)
8 IceTop Tanks (16 OMs)

IceCube
80 strings
60 OMs/string
17 m vertical spacing
125 m between strings



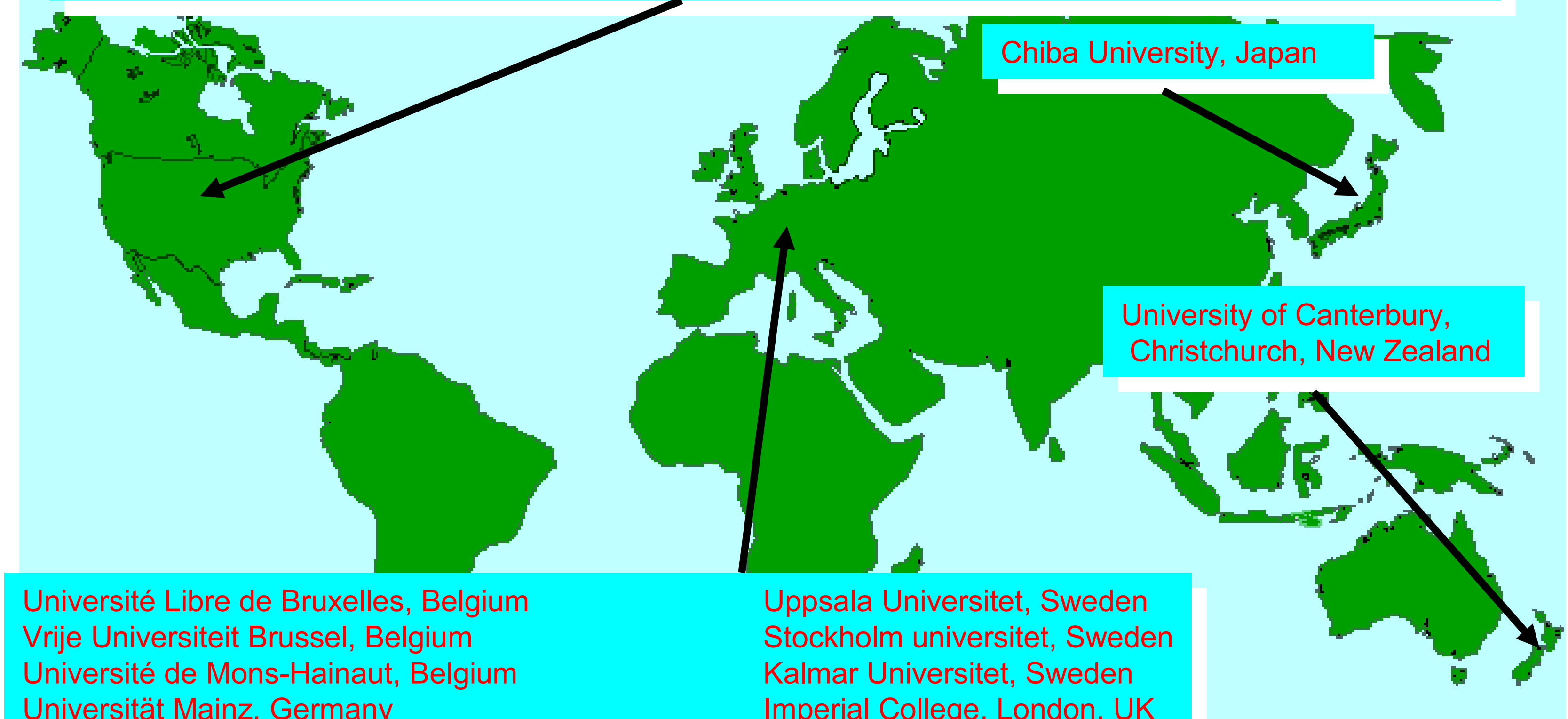
10" Hamamatsu R-7081

IceTop Tank deployed in 2004

Who are we ?

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

Univ. of Alabama, USA
Clark-Atlanta University, USA
Univ. of Maryland, USA
IAS, Princeton, USA
University of Kansas, USA
Southern Univ. and A&M College, Baton Rouge



Chiba University, Japan

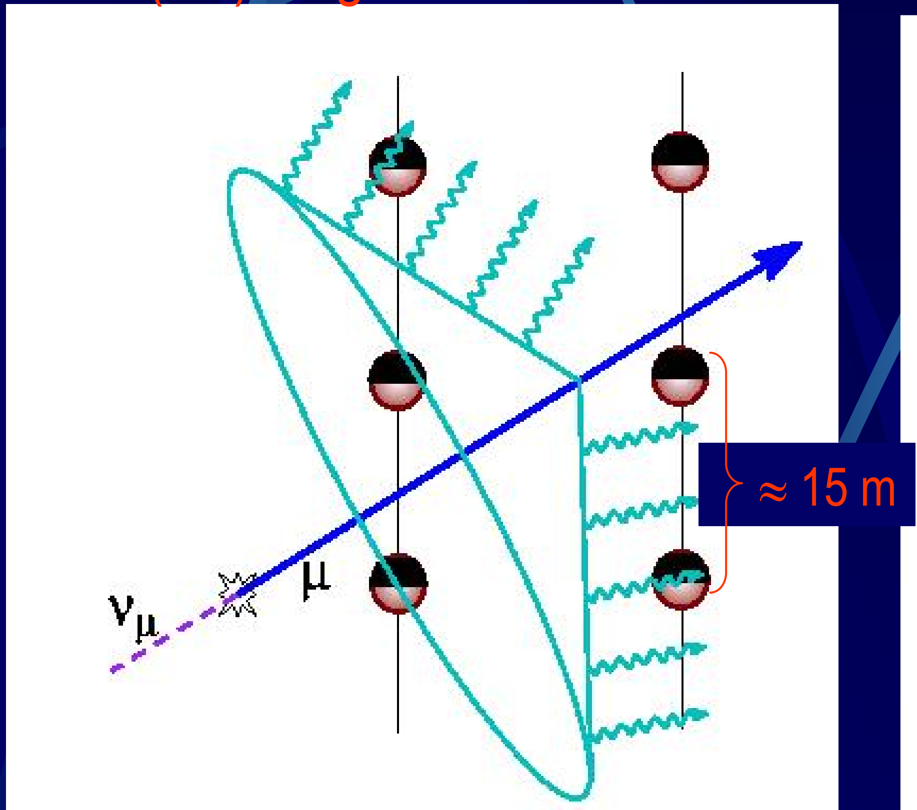
University of Canterbury,
Christchurch, New Zealand

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

Uppsala Universitet, Sweden
Stockholm universitet, Sweden
Kalmar Universitet, Sweden
Imperial College, London, UK
University of Oxford, UK
Utrecht University, Utrecht, NL

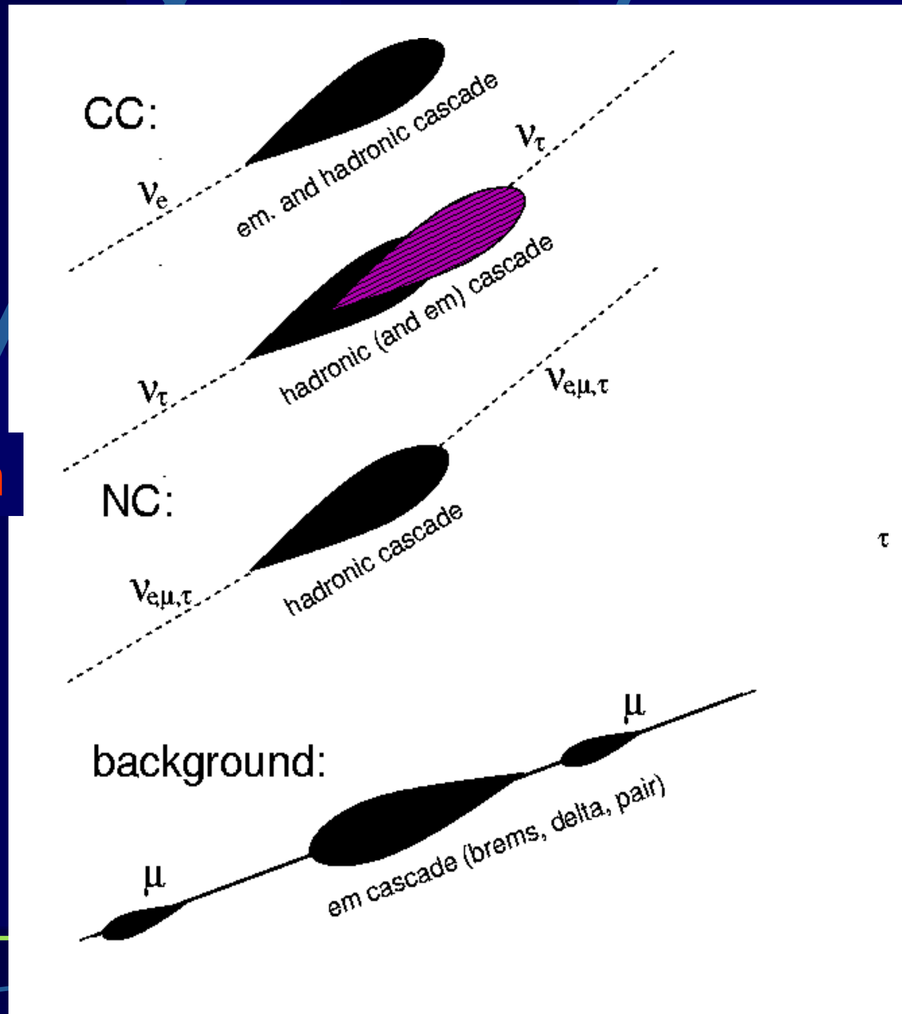
Detection of ν_e, ν_μ, ν_τ

O(km) long muon tracks

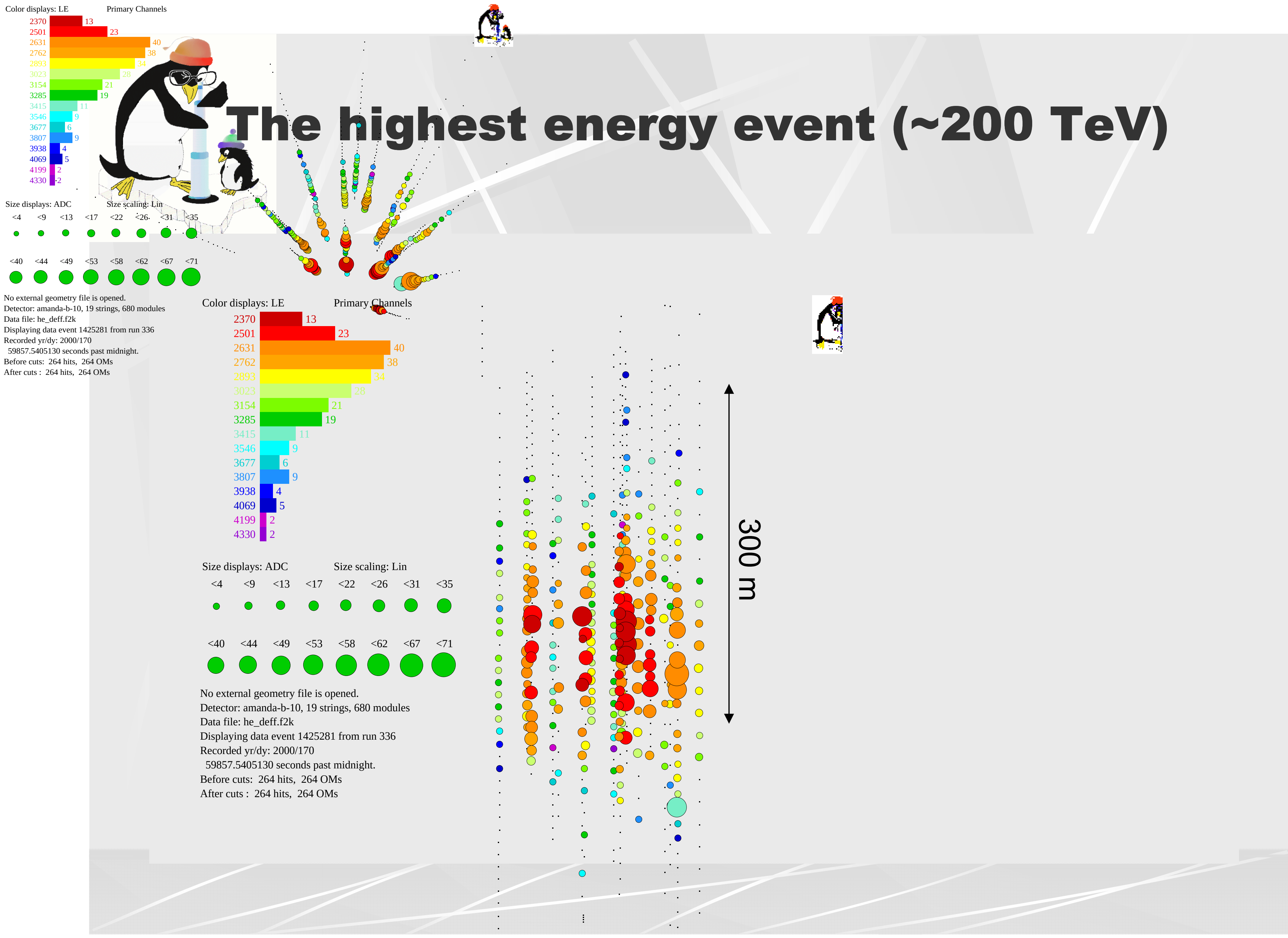


direction determination
by cherenkov light timing

Electromagnetic and hadronic cascades



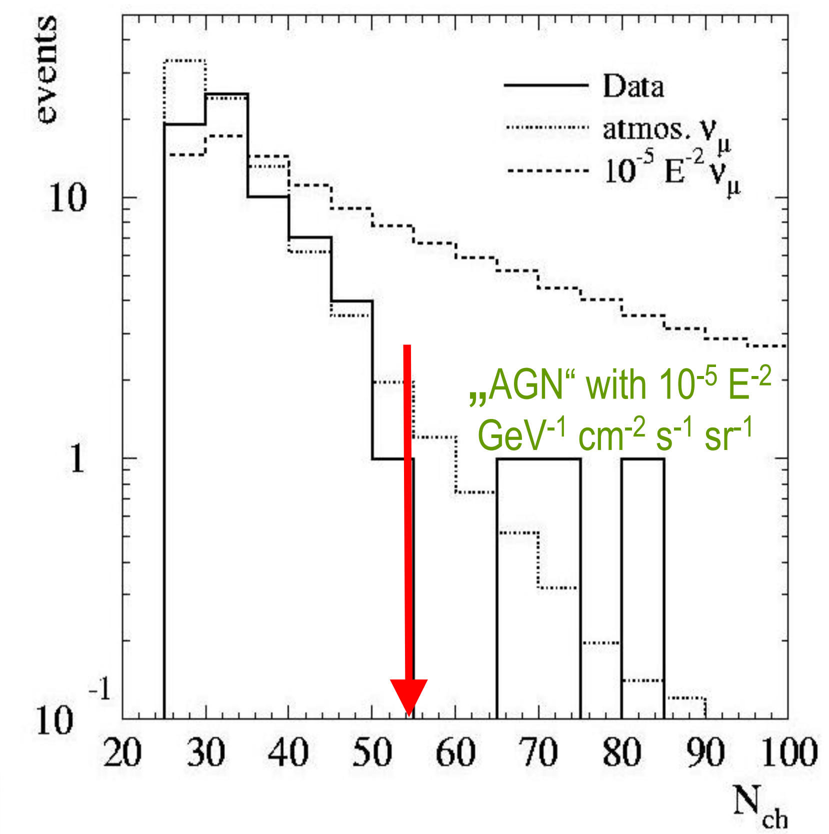
The highest energy event (~200 TeV)



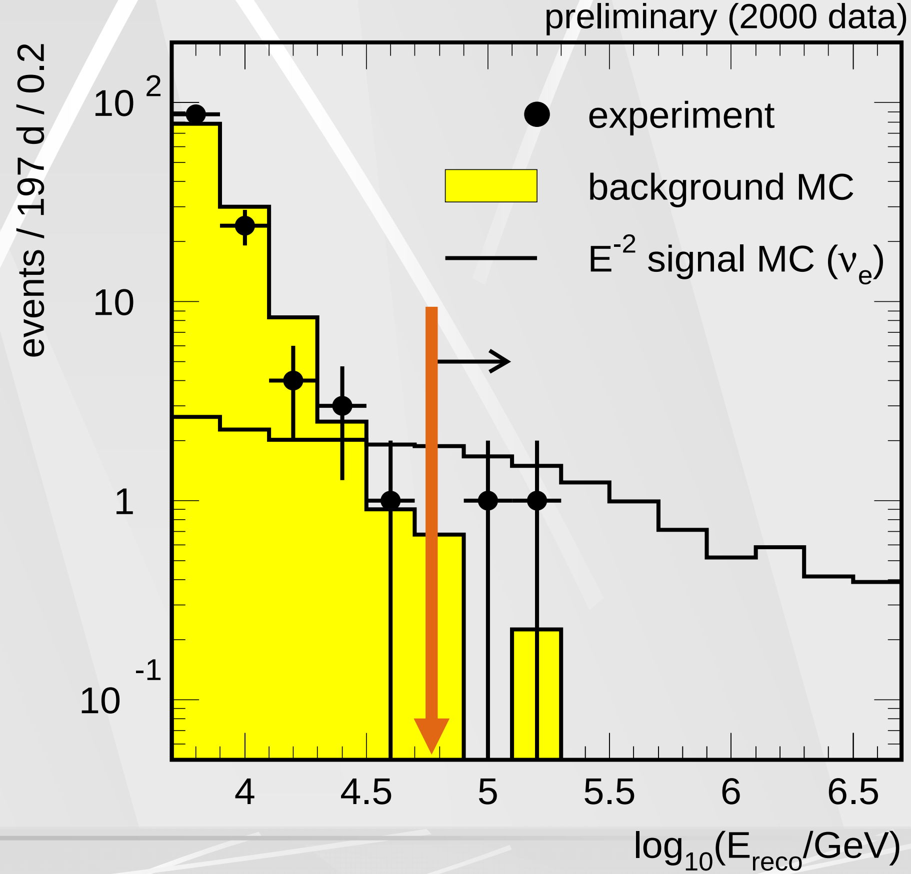
Excess of cosmic neutrinos? Not yet ...

.. for now use number of hit channels as energy variable ...

muon neutrinos (1997 B10-data)
accepted by PRL



cascades (2000 data)



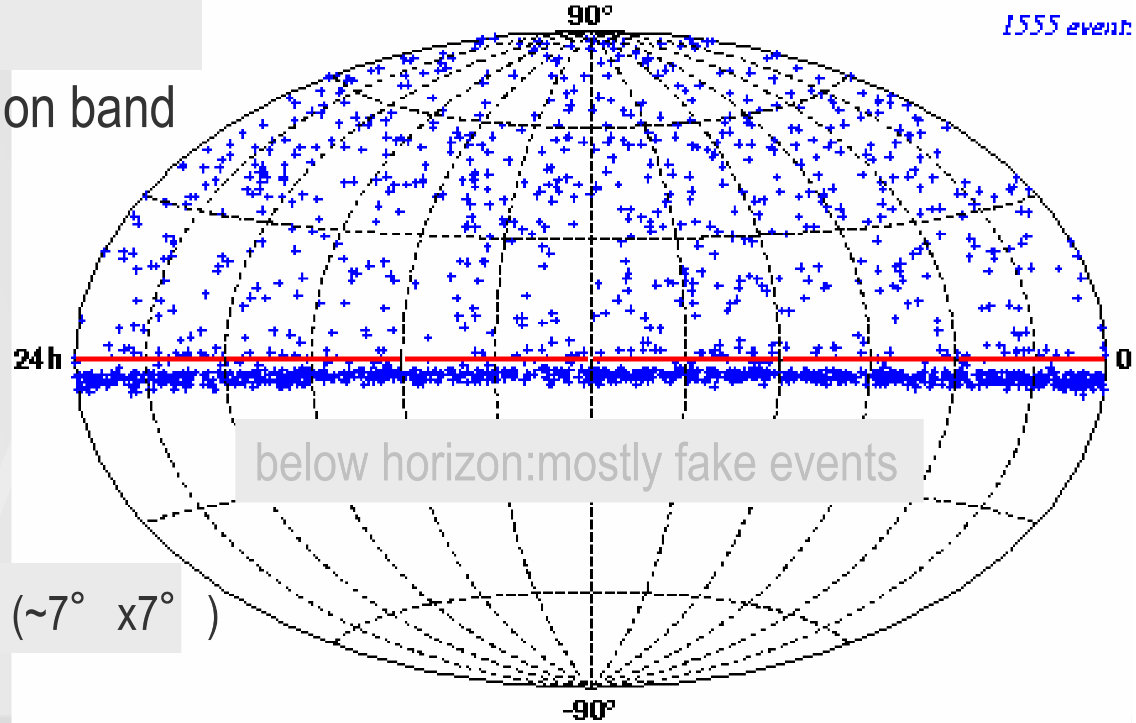
cuts determined by MC – blind analyses !

Point source search in AMANDA II

Search for excess events in sky bins for up-going tracks

PRELIMINARY

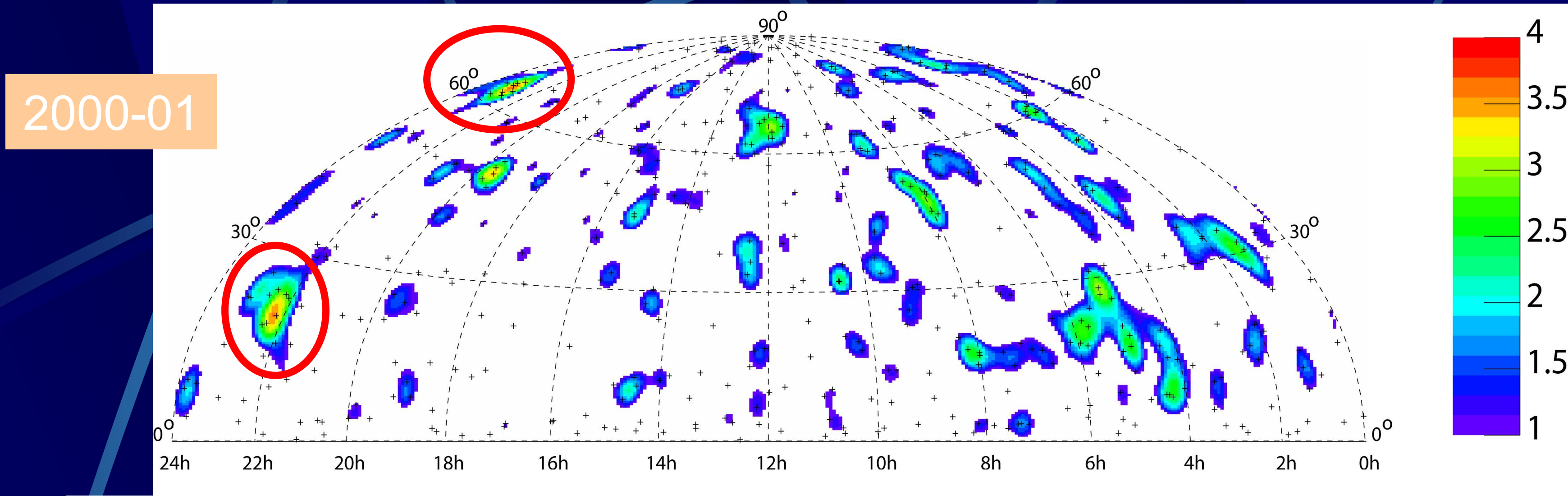
- 697 events observed above horizon
- 3% non-neutrino background for θ > 5°
- cuts optimized in each declination band

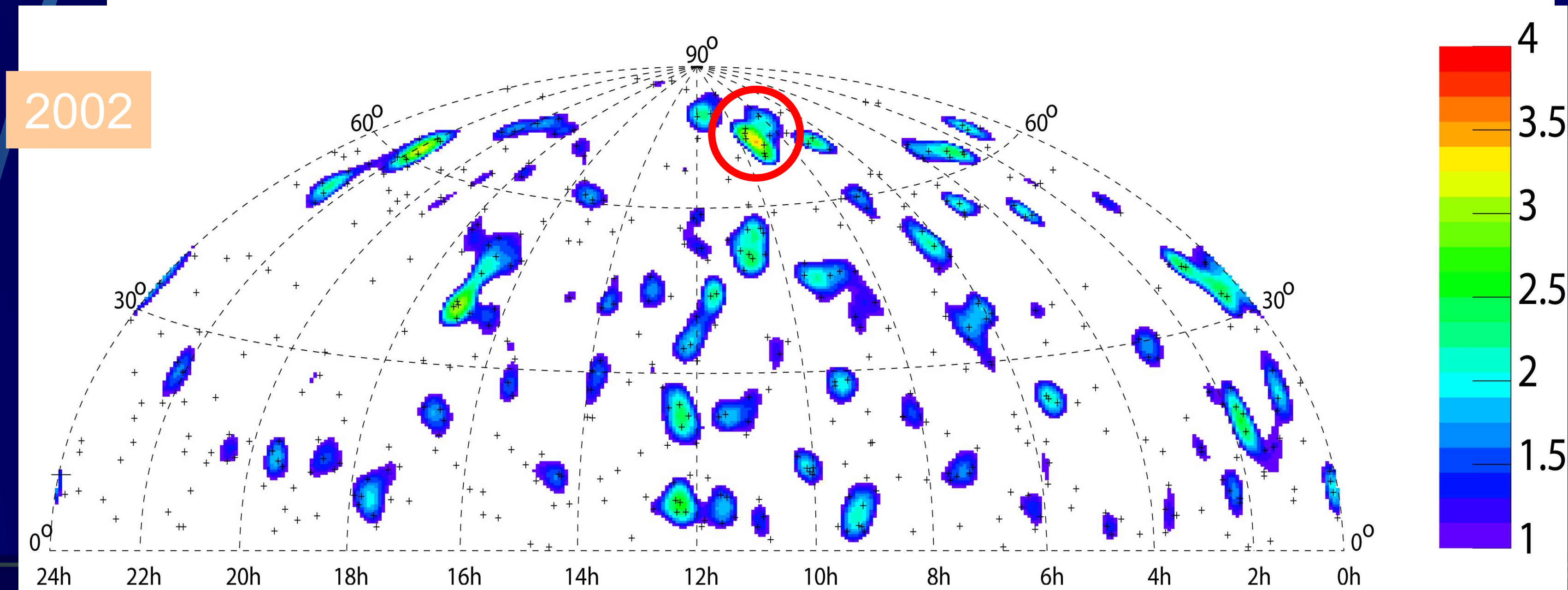


- sky subdivided into 300 bins (~7° x7°)

no clustering observed - no evidence for extraterrestrial neutrinos ...

Grid Search Results





Mrk 421 sensitivity (AMANDA)

Low state:

can be compared to our best upper limit (sensitivity shown here)

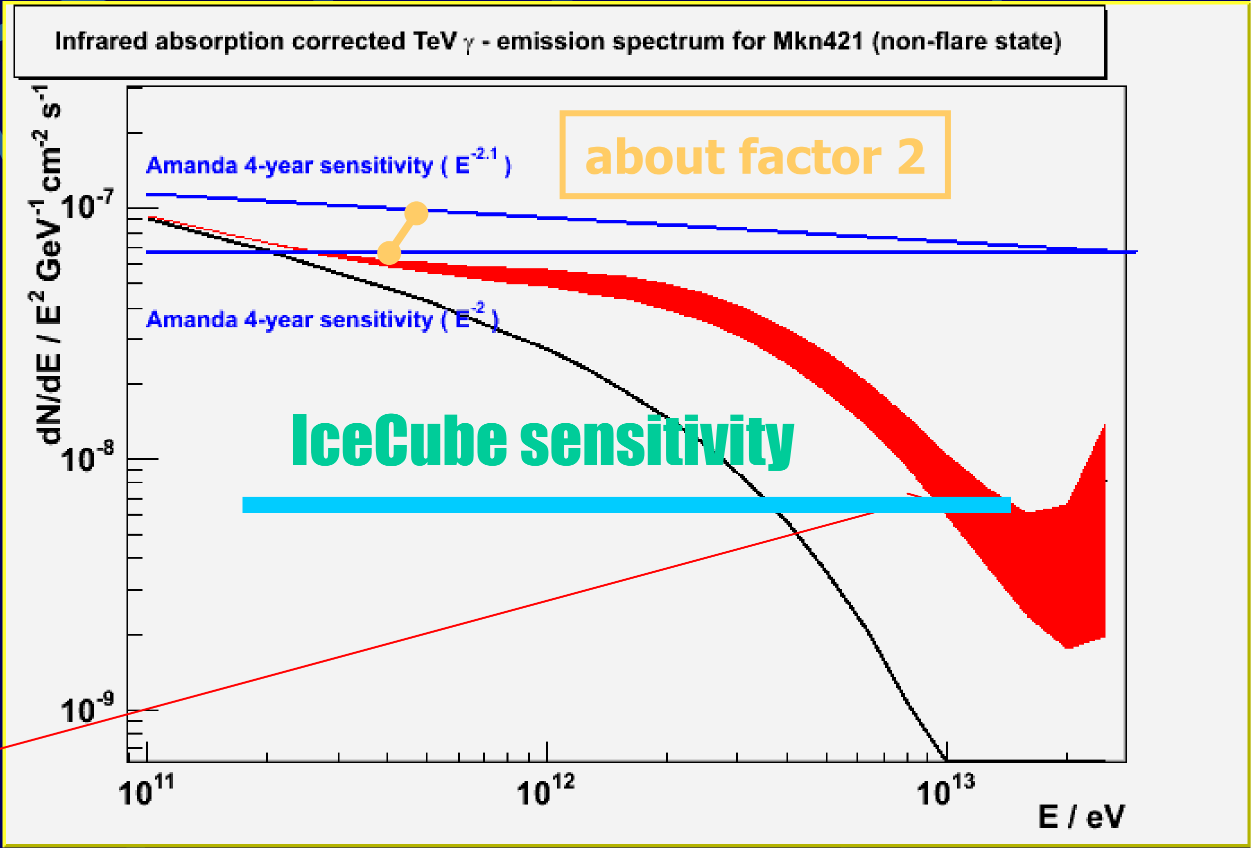
— Fit of the measured spectrum from HEGRA (Low)

Allowed range for the emitted flux

AMANDA sensitivity

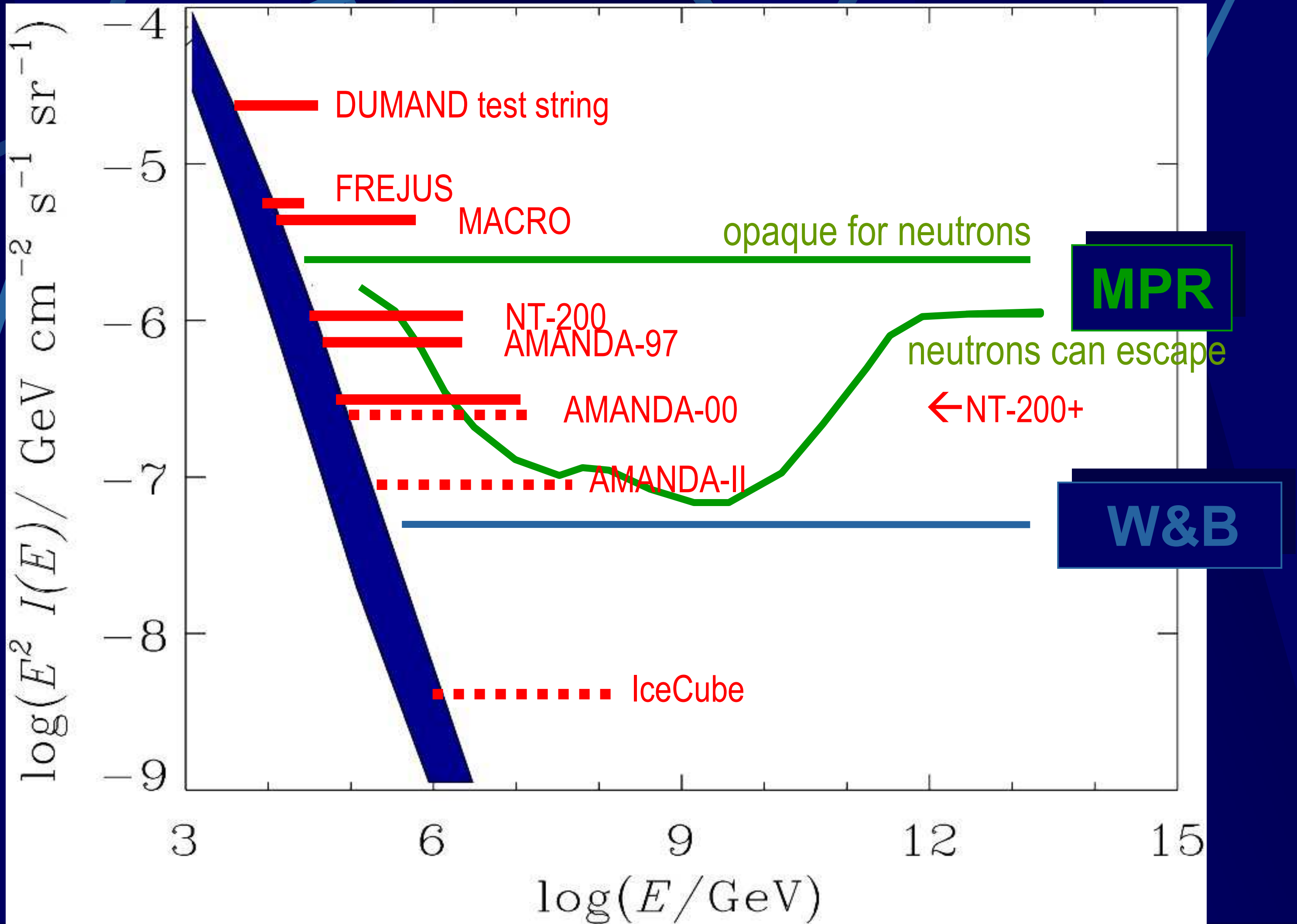
Correction for extra-galactic γ absorption¶:

TeV γ-ray spectra are modified by red-shift dependent absorption by intergalactic IR-UV background



¶O.C.De Jager & F.W.Stecker, Astrophy.J. 566 (2002), 738-743

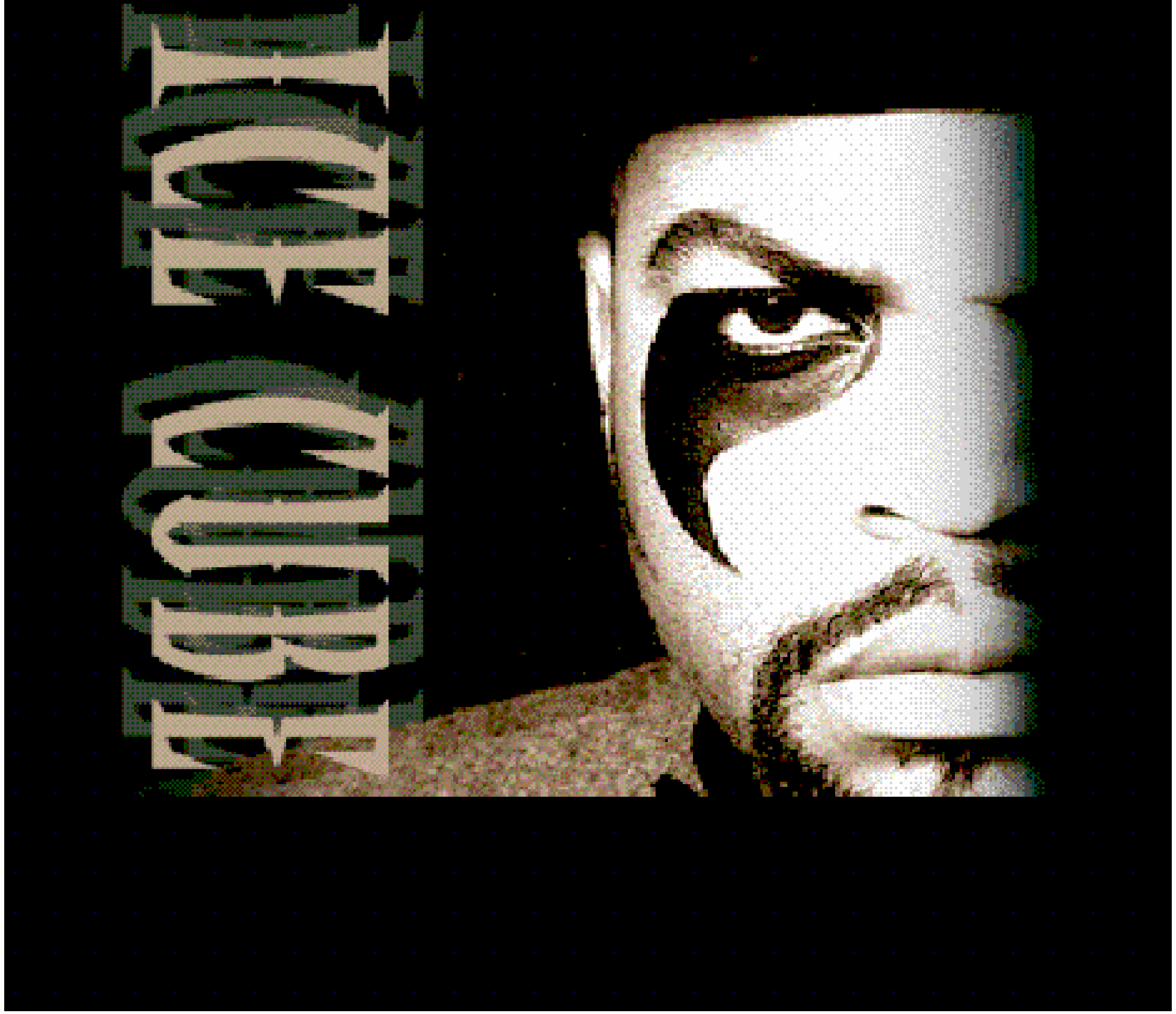
Theoretical bounds and future



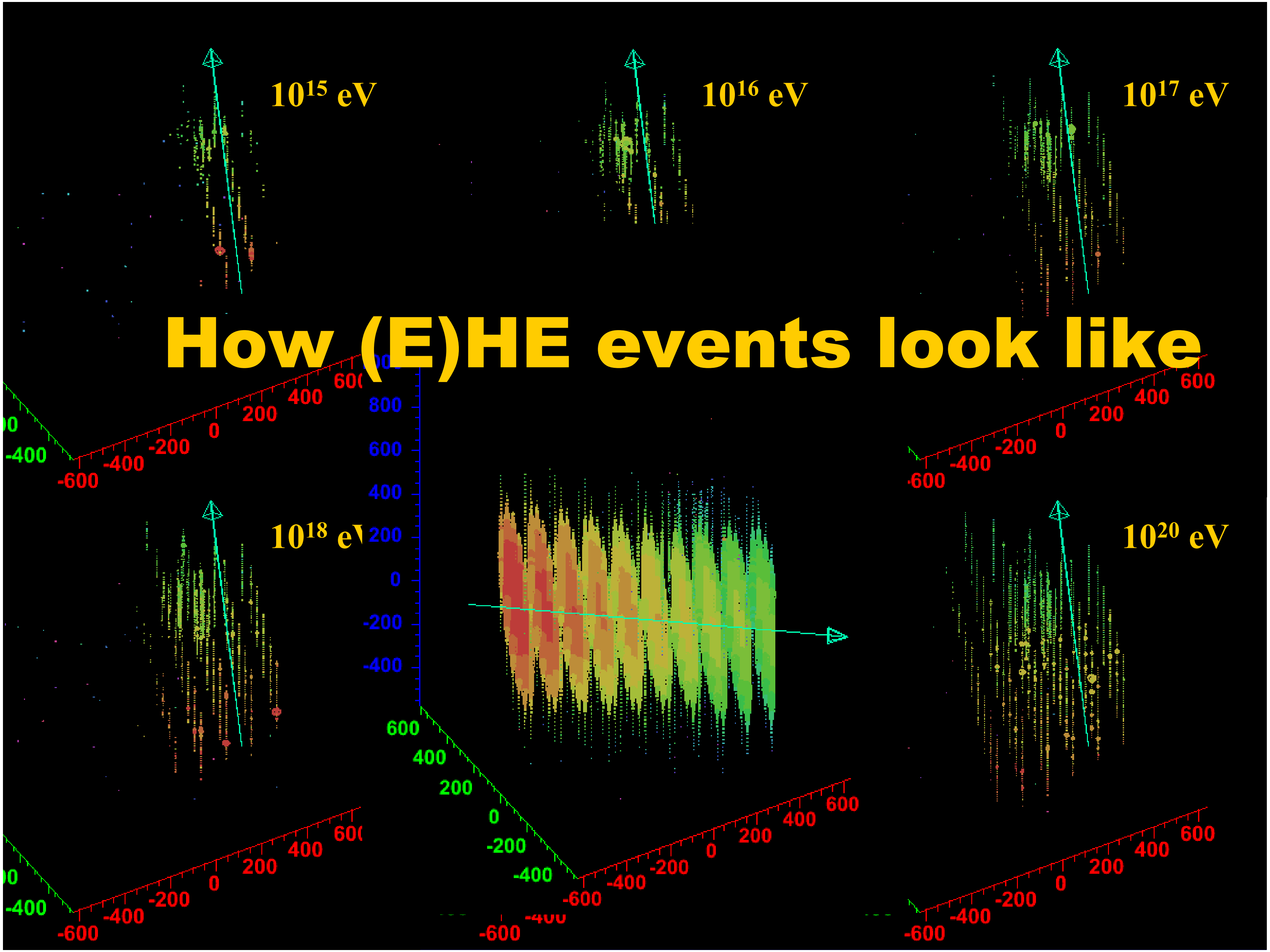
Mannheim, Protheroe and Rachen (2000) – Waxman, Bahcall (1999)

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

GIGA-ton detector!!

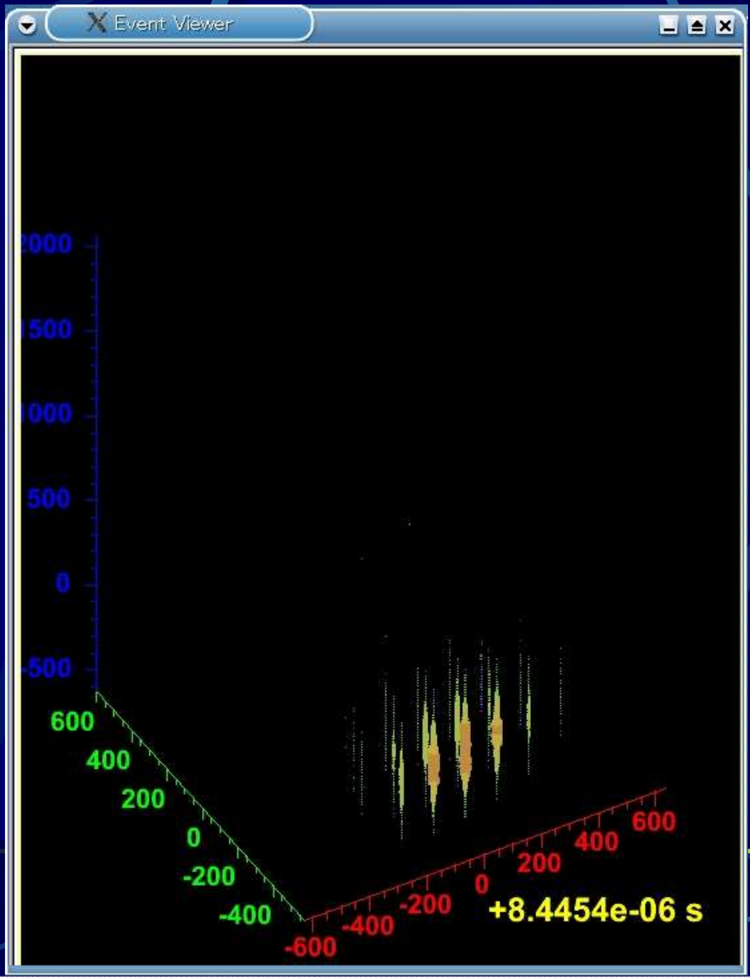


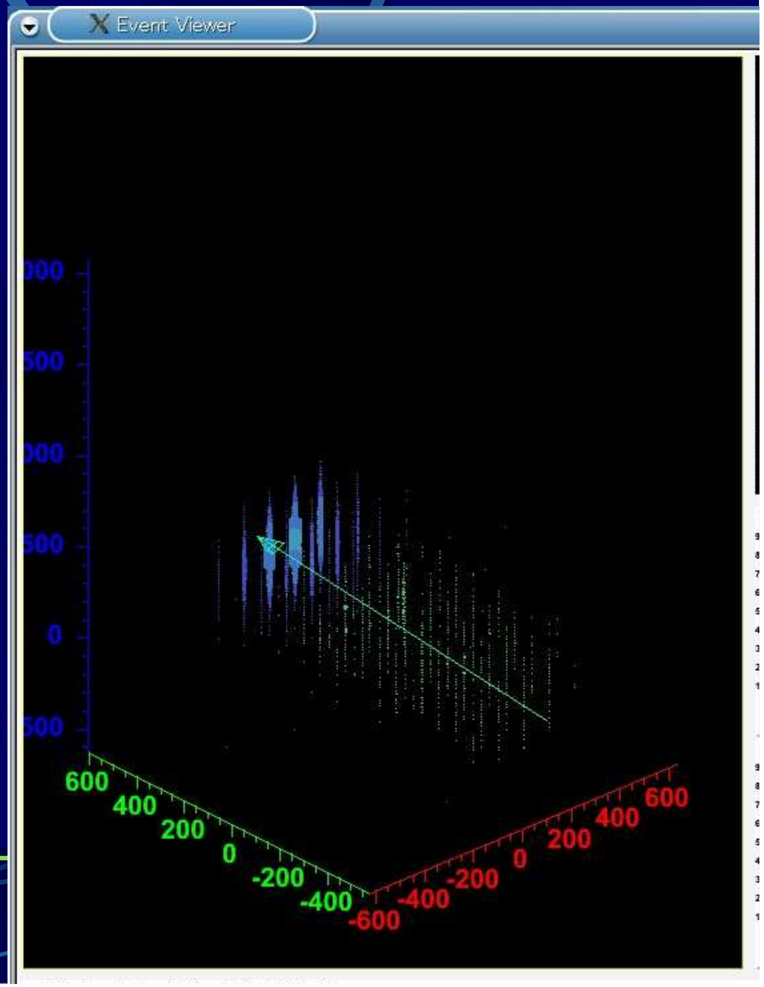
How (E)HE events look like



EHE MC Event examples

300 PeV taus





EHE (EeV or even higher) Neutrino Events

Arriving Extremely Horizontally

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

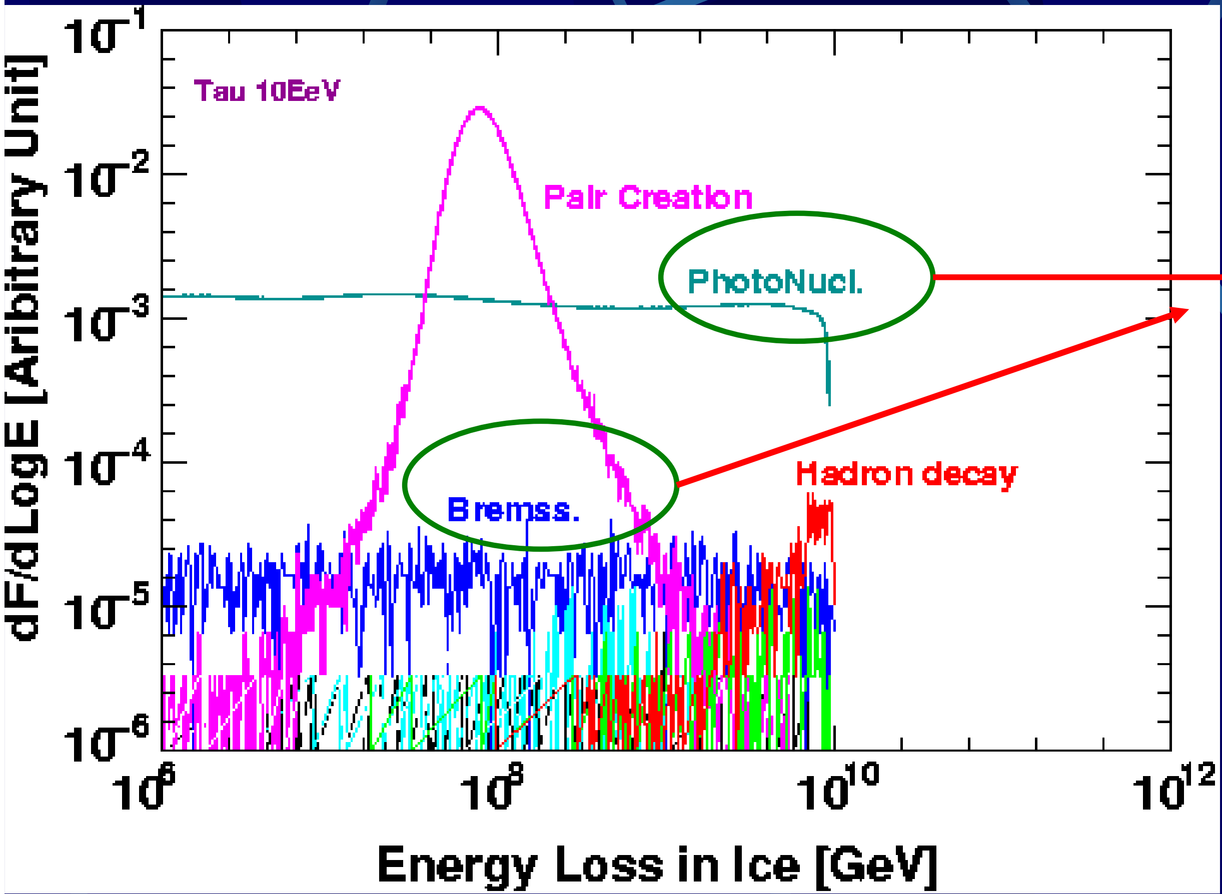
$$(\sigma\rho N_A)^{-1} \sim 600\ (\sigma/10^{-32}\mathrm{cm}^2)^{-1}(\rho/2.6\mathrm{g\ cm}^{-3})^{-1}\ [\mathrm{km}]$$

Involving the interactions generating electromagnetic/hadron cascades

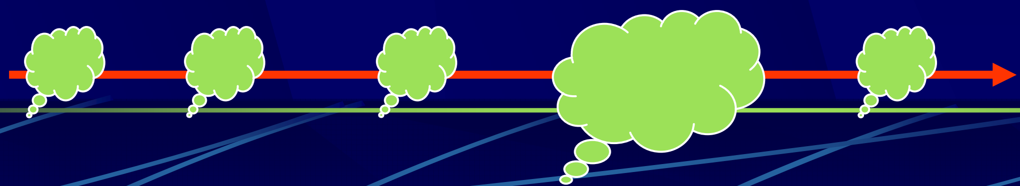
$$\mu N \longrightarrow \mu X\ e^+e^-$$

Energy loss profile in UHE/EHE

By JULIeT



Stochastic Loss
Initiating high energy
Cascades!



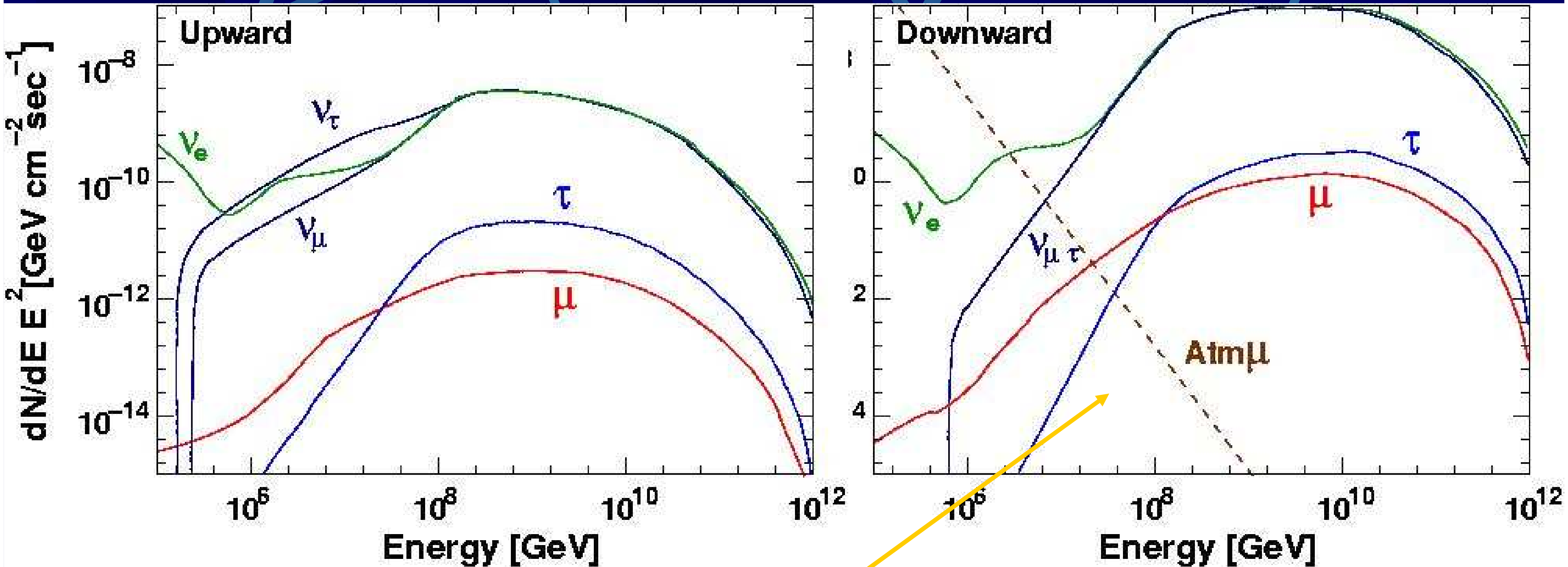
Products

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

GZK spectrum @ IceCube depth

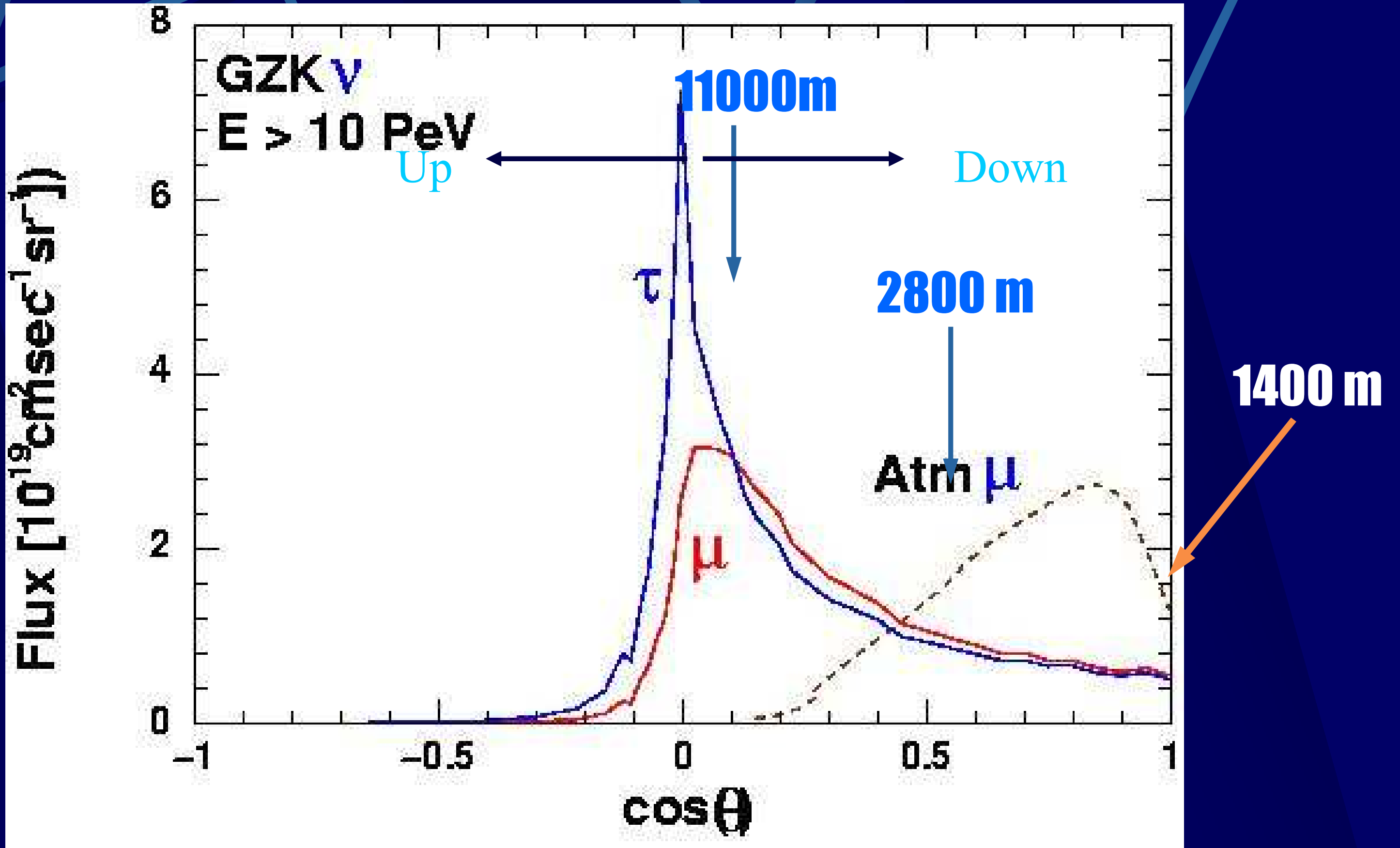
Upward-going **Downward going!!**

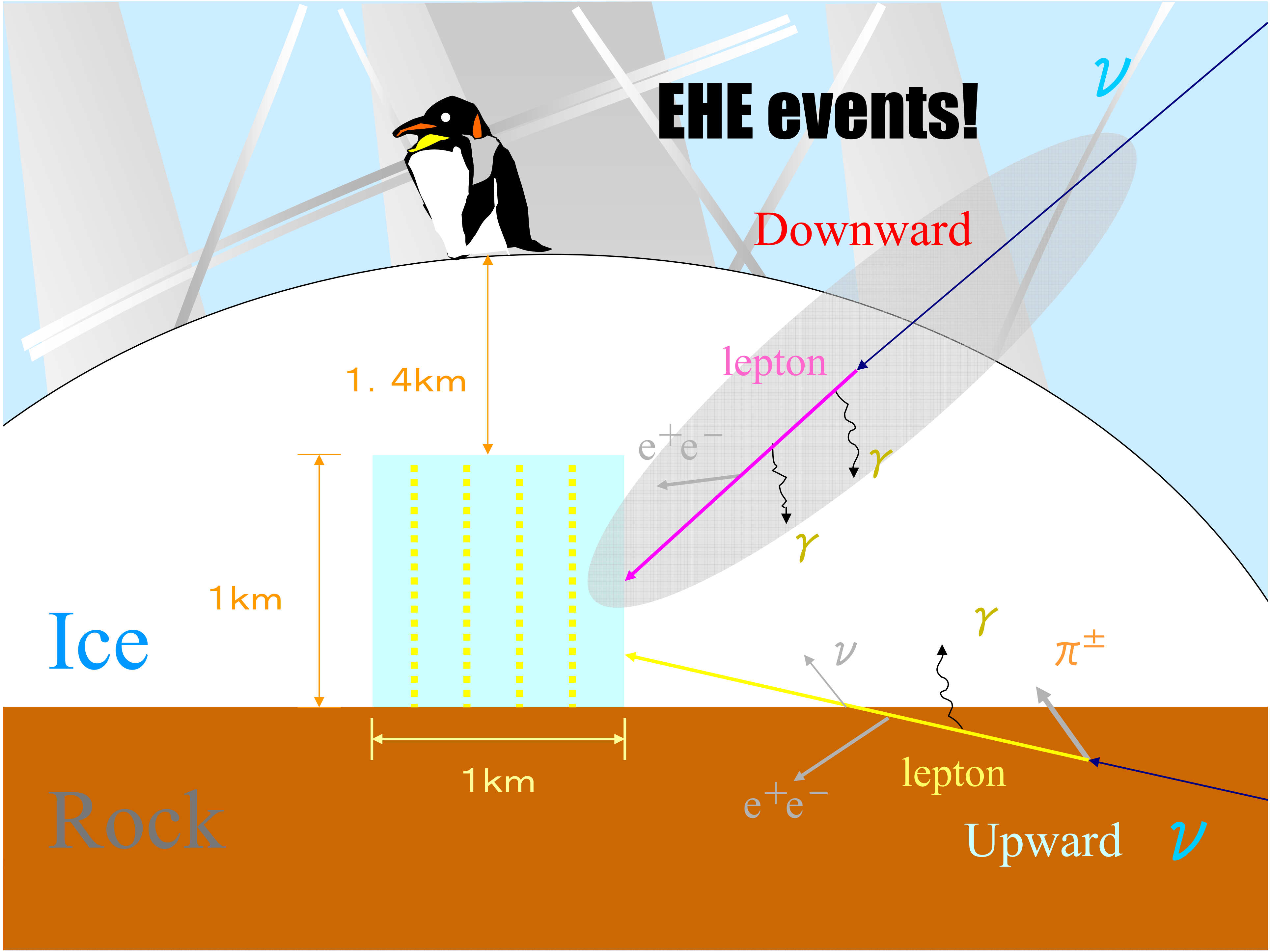


Atmospheric muon! – a major backgrond
But so steep spectrum

Down-going events dominate...

Atmospheric μ is attenuated faster...

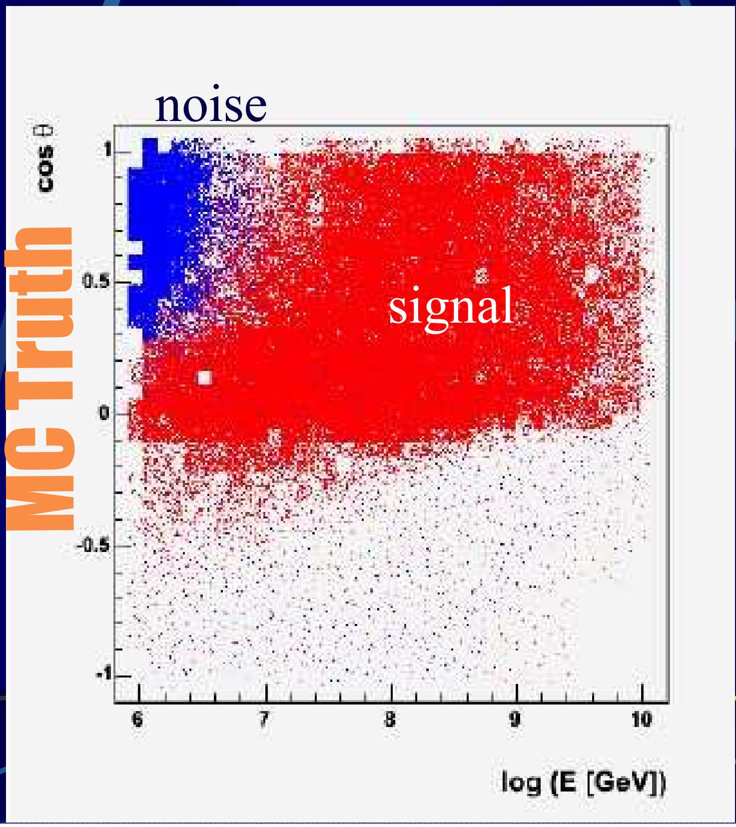


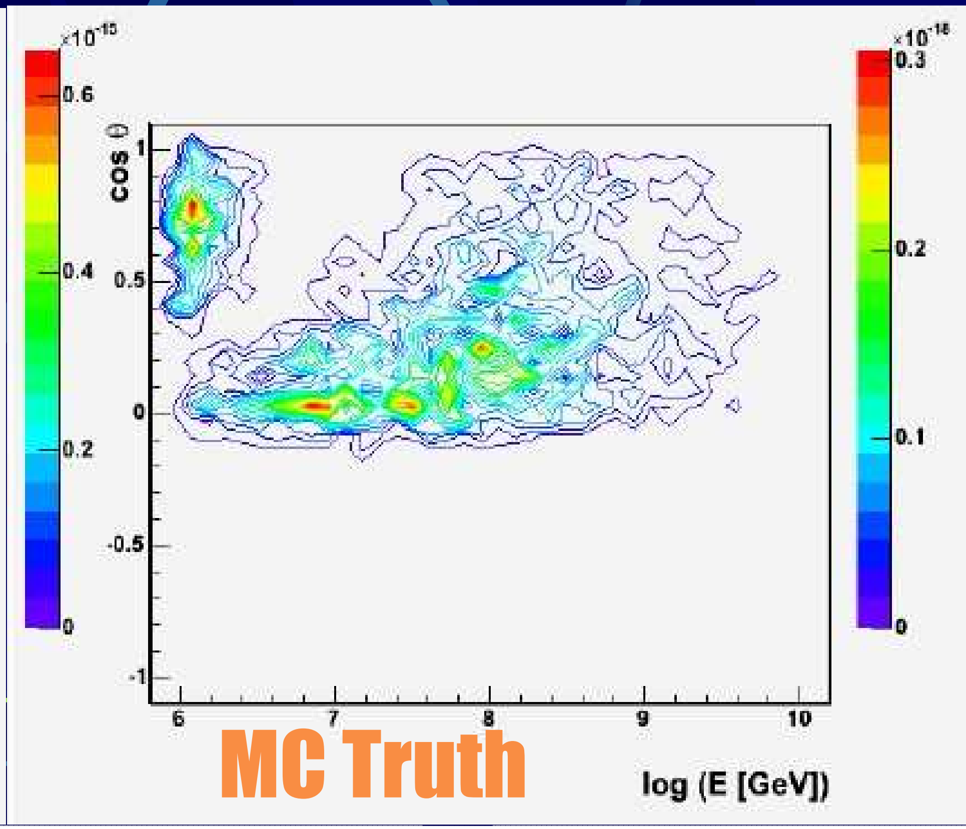


EHE events!
ν
Downward
lepton
1．4km
e+e−
γ
γ
1km
Ice
γ
ν
π±
1km
lepton
e+e−
Rock
Upward
ν

Signal(GZK) Vs Atm μ

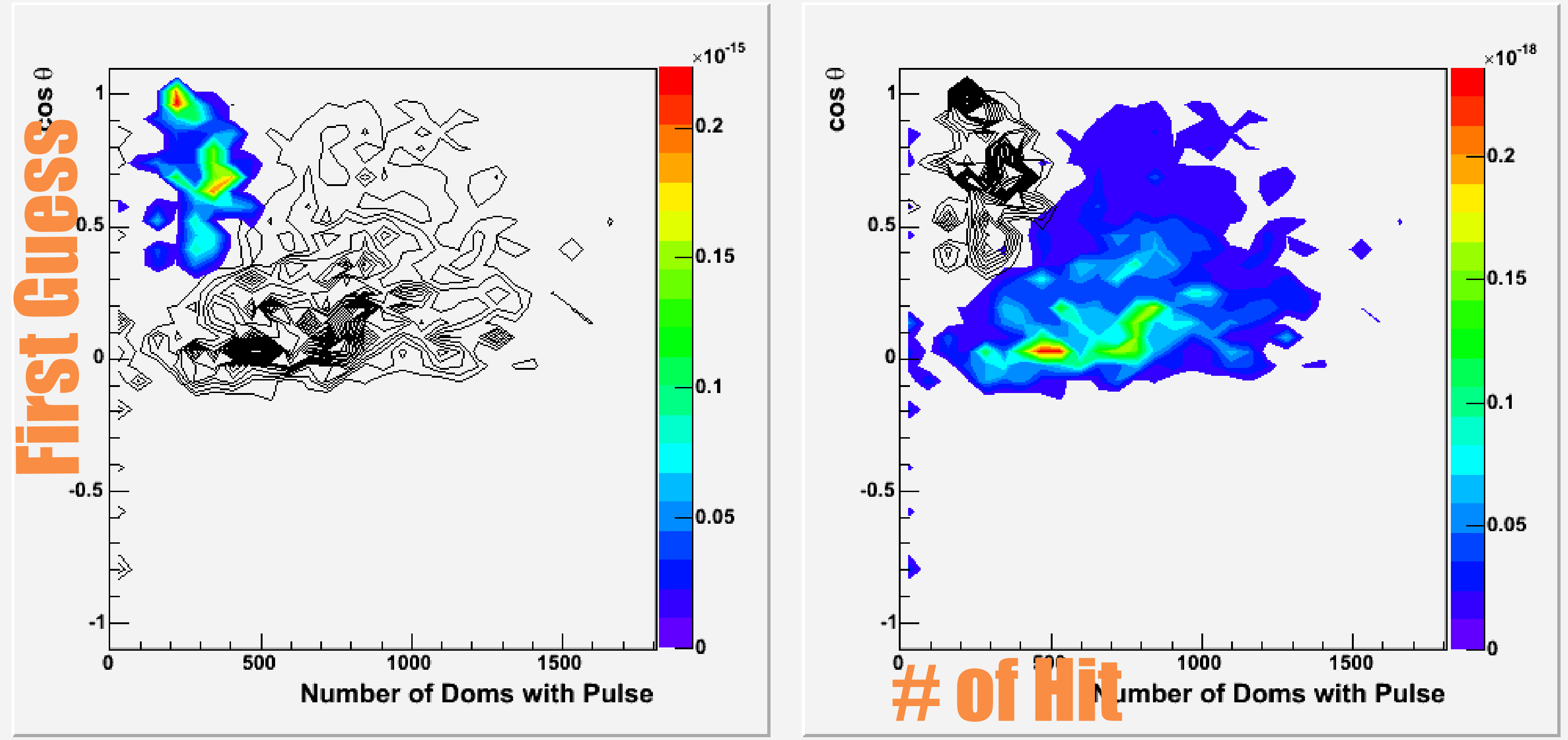
Very Preliminary





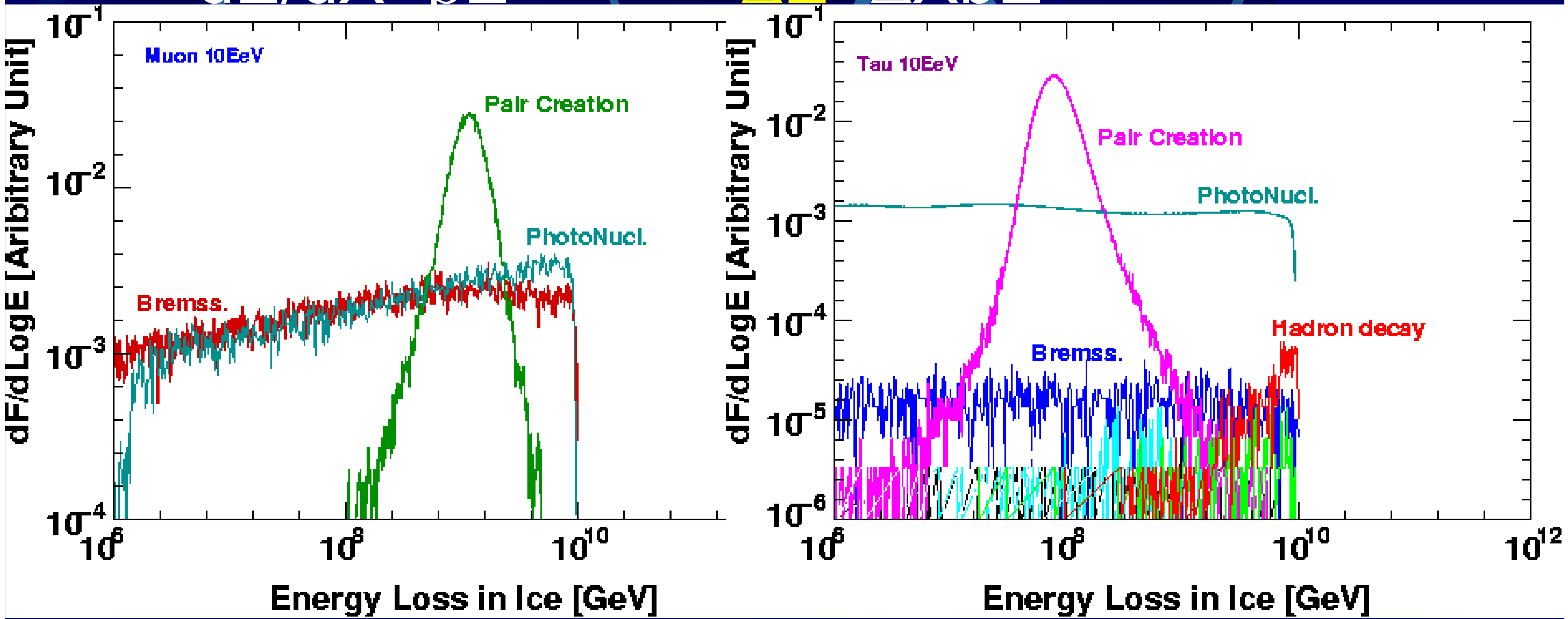
Signal(GZK) Vs Atm μ

Very Preliminary



We MEASURE energy deposit in km^3

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



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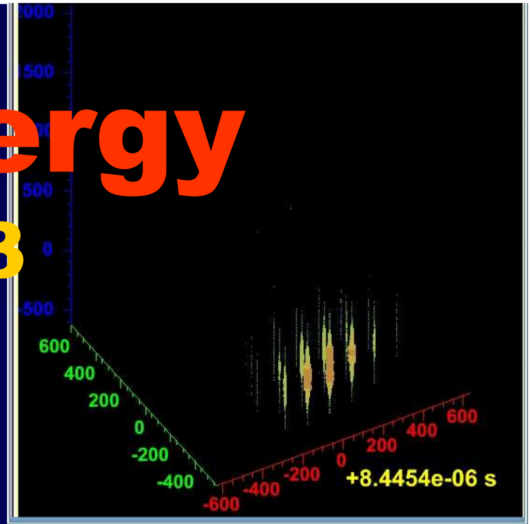
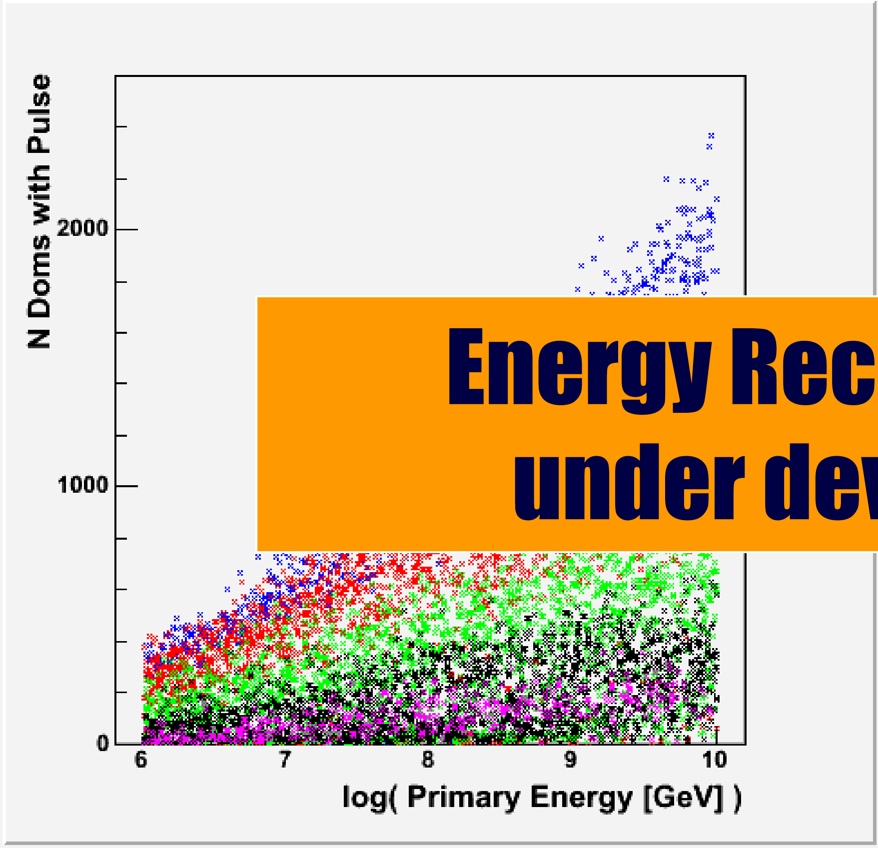
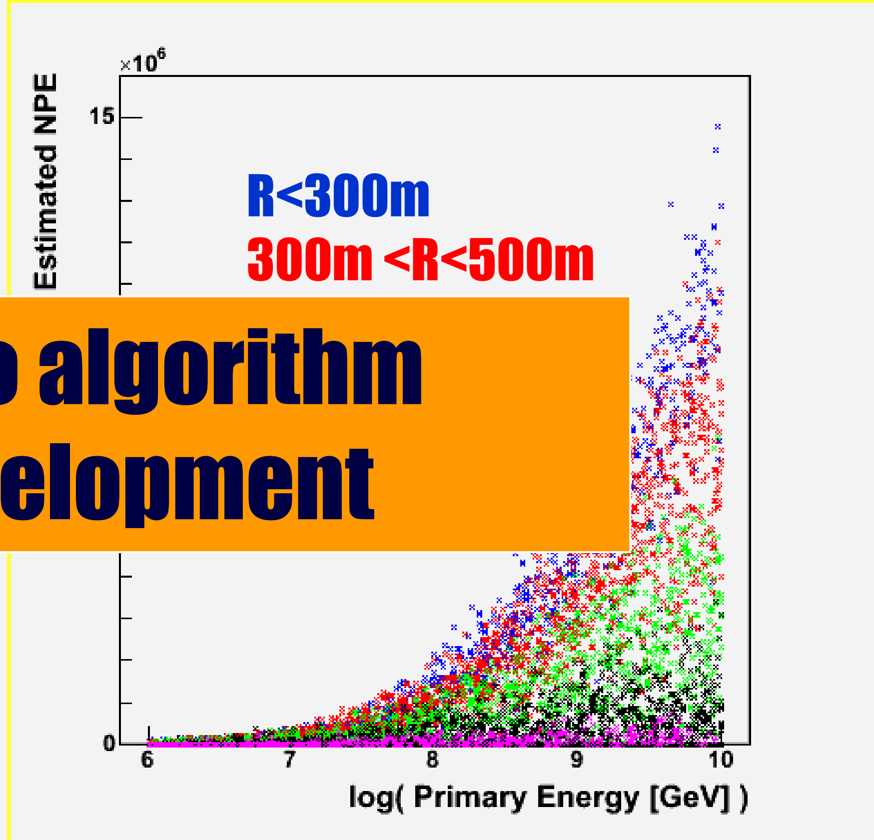




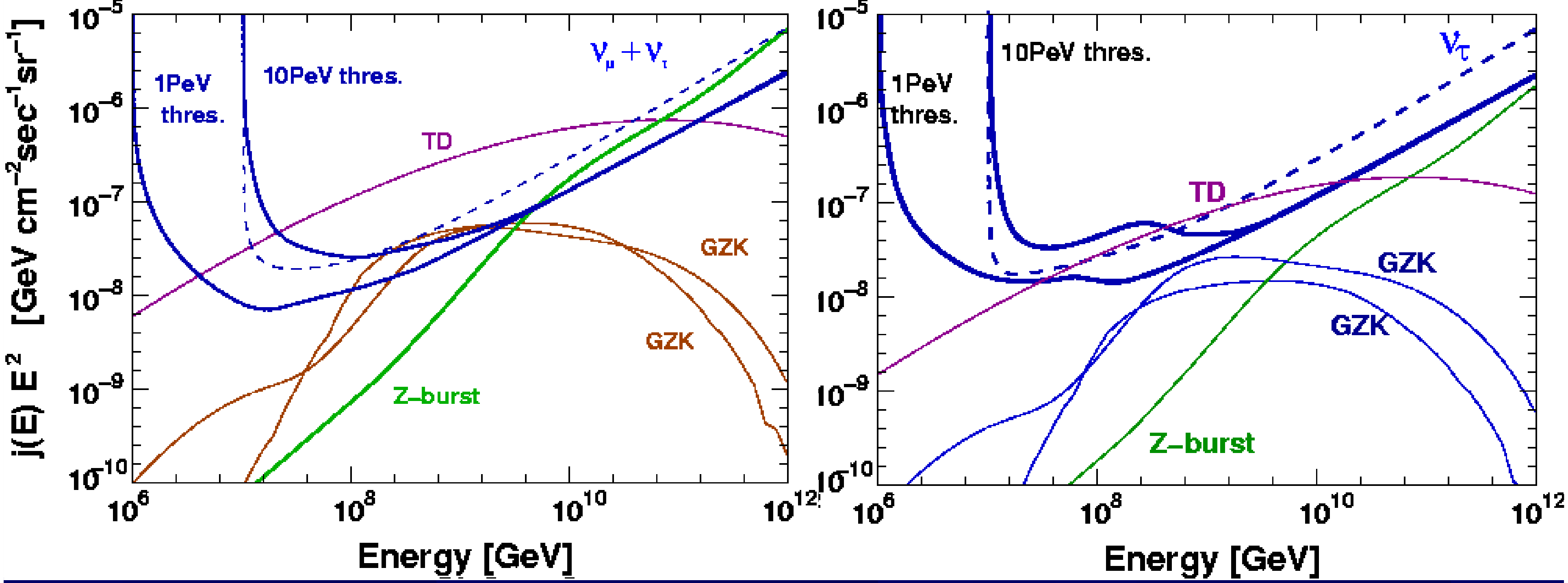


Energy Reco algorithm under development

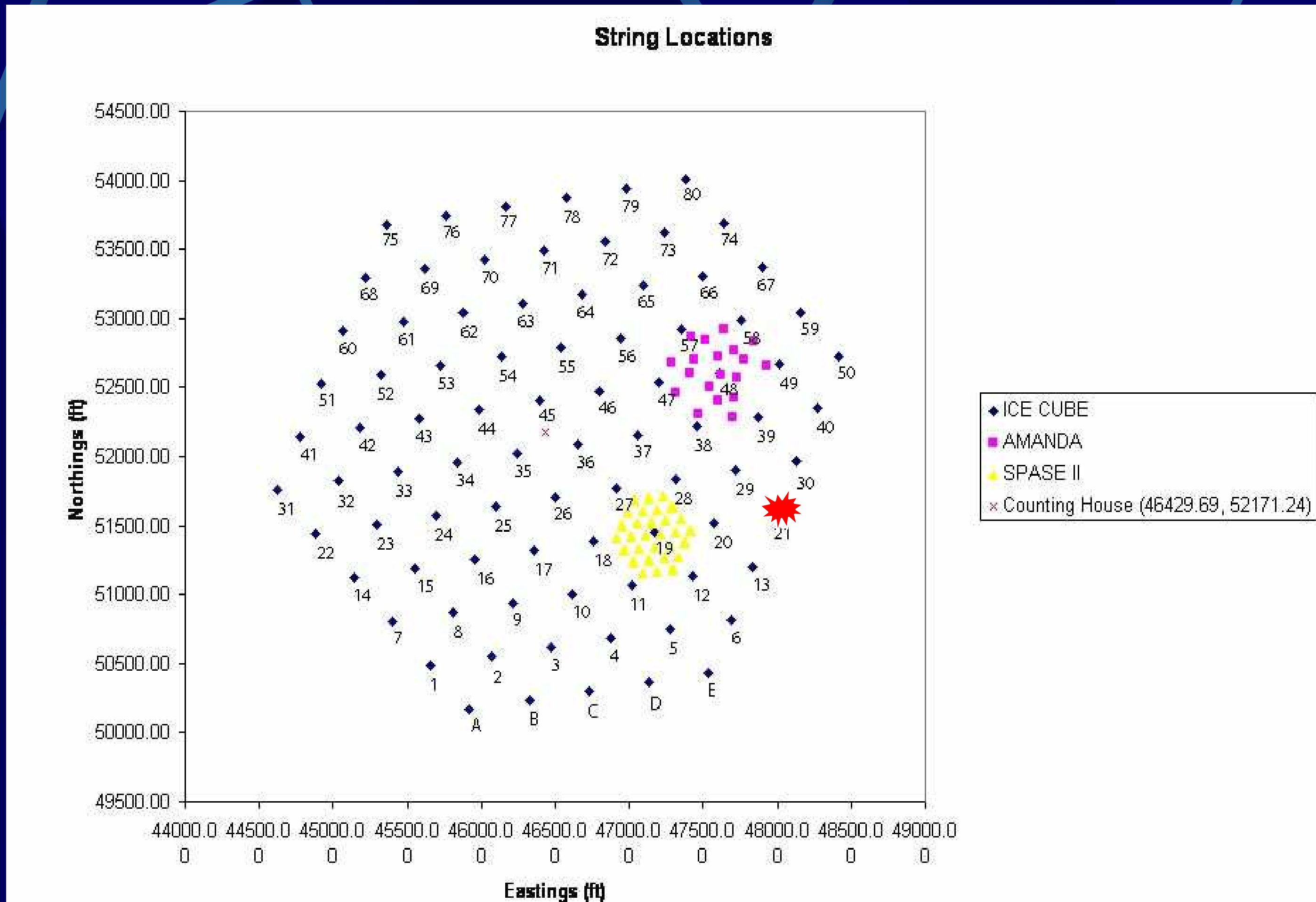
IceCube EHE ν Sensitivity

90% C.L. for 10 year observation

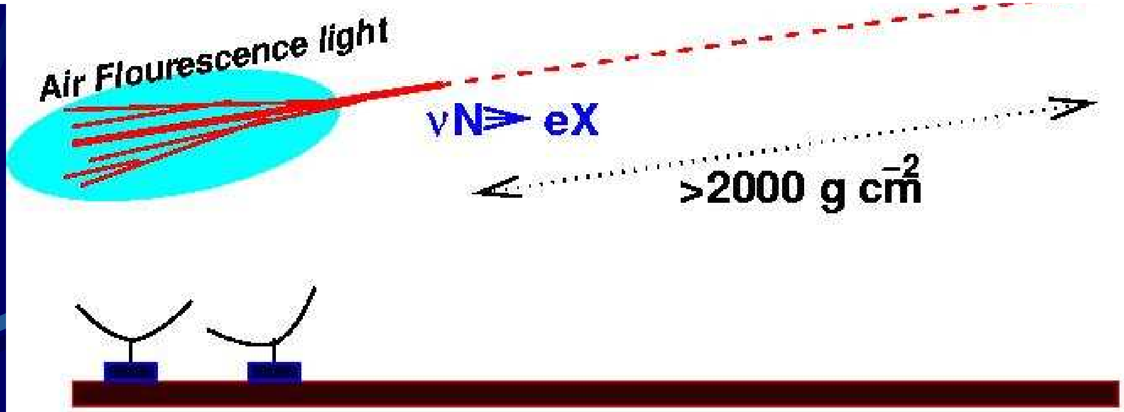
- S.Yoshida, R.Ishibashi, H.Miyamoto, PRD 69 103004 (2004)



IceCube : The Present status



~10 strings will be being deployed now!



Target Volume

$$T(E_e) = \int d\Omega \, (X_\Omega - 2000\text{g}) A(\Omega, E_e)$$

For Monocular Detectoin, analytically

$$\sim 1.1\times10^{5} \left(\frac{h}{8.4\text{km}}\right)\left(\frac{R_{ext}}{8\text{km}}\right)^{4/5}\left(2.7 + \log\left(\frac{E_e}{10\text{EeV}}\right) - \log(S/N)\right)^2$$

$[\text{Km}^2 \text{sr g cm}^{-2}]$

Yoshida et al ApJ (1997)

Effective Aperture

$$D_\nu(E_\nu) = N_a \int dE_e \frac{d\sigma}{dE_e}(E_\nu)\; T(E_e)$$

$$\sim N_a \, \sigma(E_\nu) \, T(E_\nu)$$

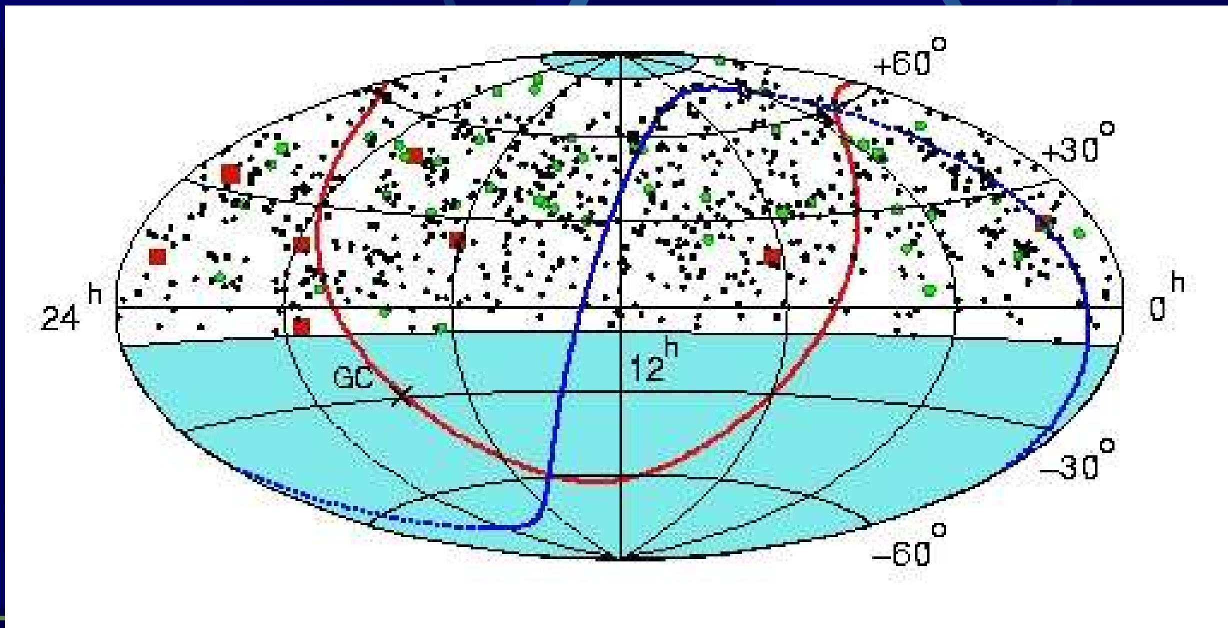
$$\sim 6\times10^{23}\; 2.8\times10^{-32} \left(\frac{E_\nu}{10\text{EeV}}\right)^{0.4} T(E_\nu) \quad [\text{km}^2\text{sr}]$$

$$\sim 1.8\times10^{-3} \left(\frac{E_\nu}{10\text{EeV}}\right)^{0.4} \left(2.7 + \log\left(\frac{E_\nu}{10\text{EeV}}\right) - \log(S/N)\right) \quad [\text{km}^2\text{sr}]$$

~ IceCube

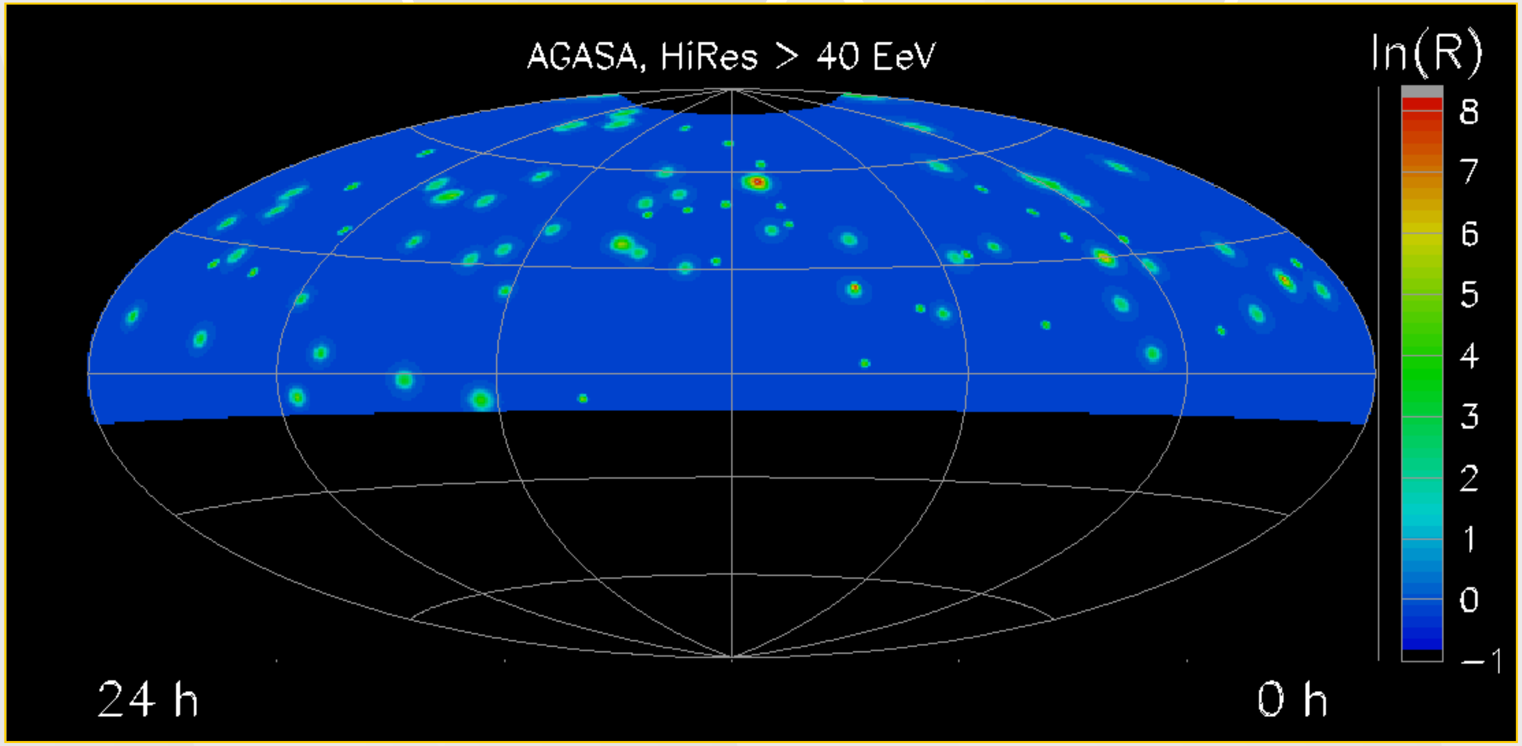
Charged Particle Astronomy?

- E>>10 EeV → $\Delta\ \theta$ ~ a few deg



29th ICRC Pune

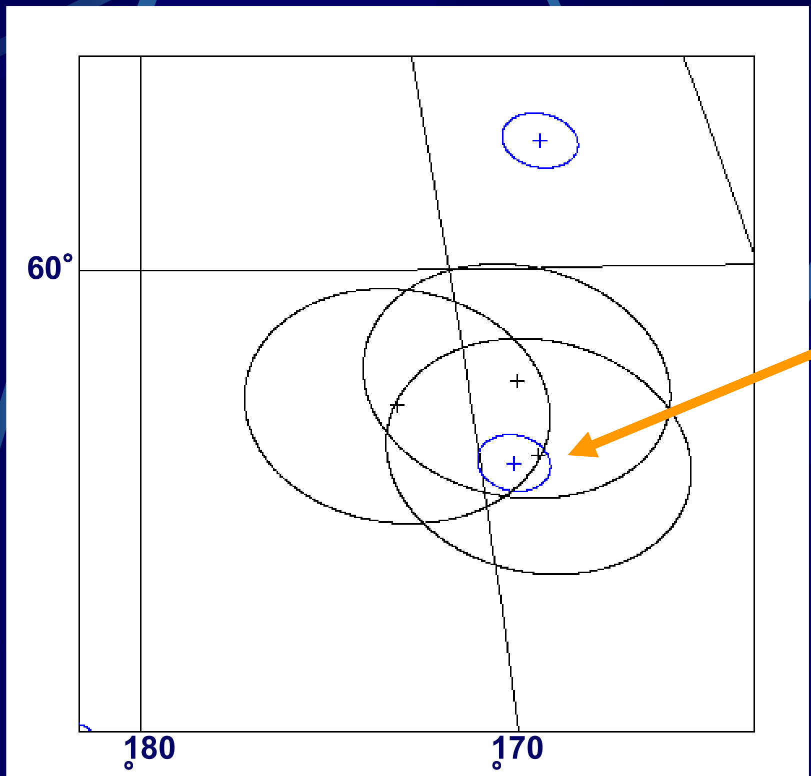
Event cluster > 40 EeV



No significant excess: AGASA's triplet Pch ~0.28

(Westerhoff, this conference)

AGASA triplet story



HiRes stereo event

One event added – BUT below 40 EeV!!

(Westerhoff, this conference)

BL Lac Correlation: New Claim

Most recent claim by Gorbunov is based on published HiRes data.
It uses a 10 EeV threshold, so it is a new claim.

Magnitude	Redshift	6cm Radio Flux	# Obj.	CR Sample	# CRs	Bin Size	# Pairs	Prob.
Catalog: Veron (9th Ed.) BL Lacs			22	AGASA >48 EeV Yakutsk >24 EeV	65	2.5°	8	$< 10^{-4}$
m < 18	z > 0.1 or unknown	$S_{6cm} > 0.17$ Jy		HiRes > 24 EeV	66	2.5°	0	1.00
Catalog: Veron (10th Ed.) BL Lacs correlated with EGRET sources			14	AGASA >48 EeV Yakutsk >24 EeV	65	2.9°	8	10^{-4}
no cut	no cut	no cut		HiRes > 24 EeV	66	2.9°	1	.70
Catalog: Veron (10th Ed.) BL Lacs			156	AGASA > 40 EeV	57	2.5°	12	.02
m < 18	no cut	no cut		HiRes > 40 EeV	27	2.5°	2	.78
Catalog: Veron (10th Ed.) BL Lacs			156	HiRes > 10 EeV	271	0.8°	10	10^{-3}
m < 18	no cut	no cut						

Gorbunov et al., JETP Lett. 80 (2004) 145.

(Finley, this conference)

千葉大学
Chiba University

Future Outlook (of UHECR)

- Auger: 7 x AGASA by 30th ICRC
- HiRes: <2 years STEREO data to be analyzed.

  ~70% more statistics

  “independent” dataset for testing the “BL Lac”
- New observatory in the Northern sky

  Telescope Array

- EHE gamma ray/Neutrino search

EAS detector, IceCube, Rice, ANITA etc.

Summary and outlook

- HE cosmic neutrinos come from

  GZK (100PeV – 100 EeV) $100

  GRB (PeV) GRB-P-synch $10

- Neutrino observatory IceCube provides DATA

  0.1 x IceCube ~2006!

  Strong capability of EHE ν search

- Charged Particle Astronomy (Cluster, BLLac E>10 EeV)

  wait for 2004-5 HiRes data for real test

- 本講演の収録原稿は来年１月まで待ってください。