

neutrino “astronomy”



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university of wisconsin
<http://icecube.wisc.edu>



Science

5 January 2007 | \$10

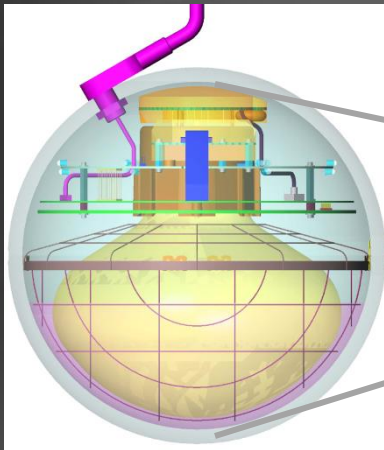
CATCHING
Cosmic Clues

AAAS

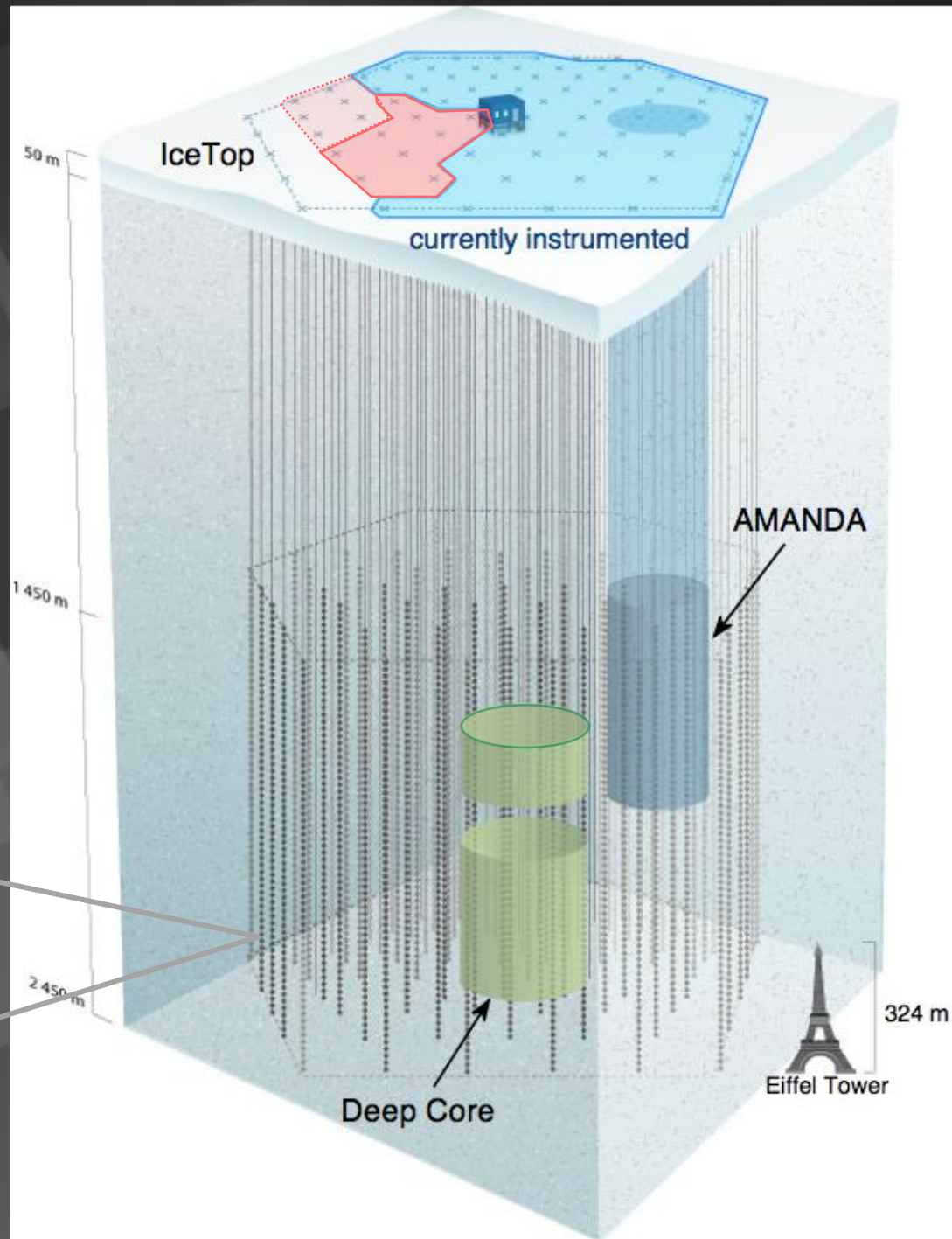
- IceCube and DeepCore complete and operating
- analysis of first year of DeepCore data in progress
- atmospheric neutrinos in IceCube

IceCube / Deep Core

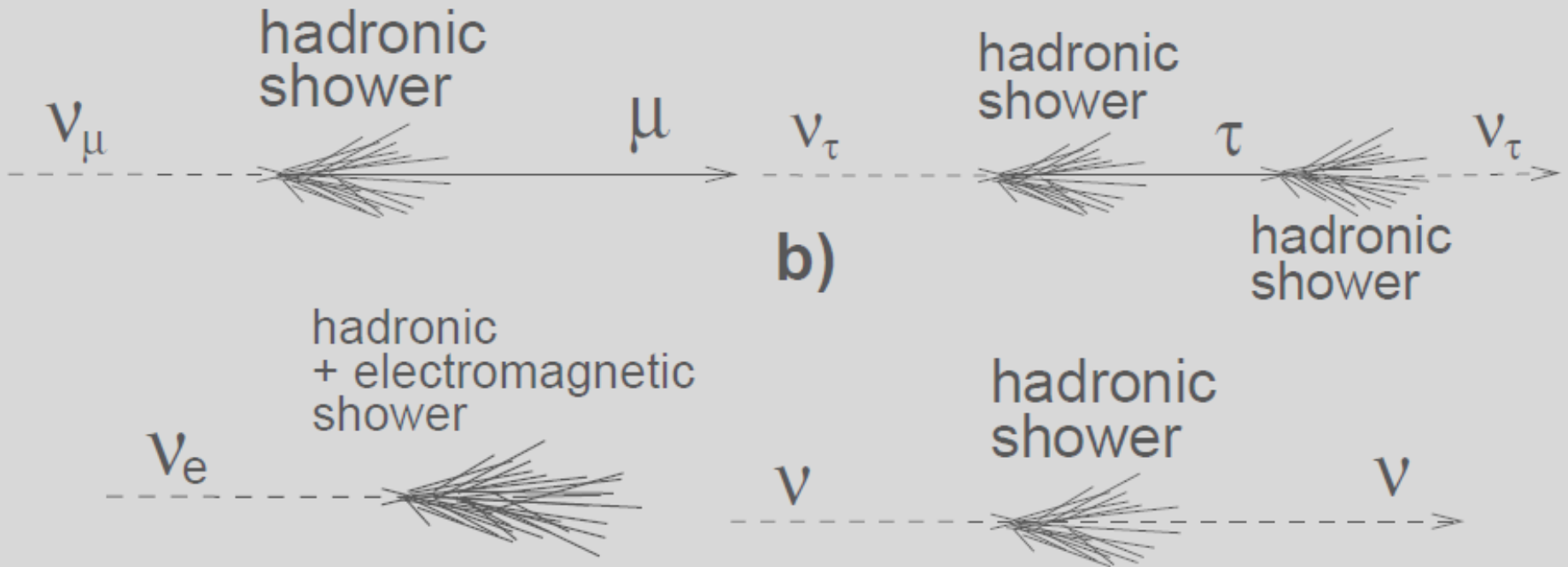
- 5320 optical modules on 86 strings (+ IceTop)
- detects ~ 220 neutrinos and 1.7×10^8 muons per day
- threshold 10 GeV
- angular resolution < 1 degree



Digital Optical Module (DOM)

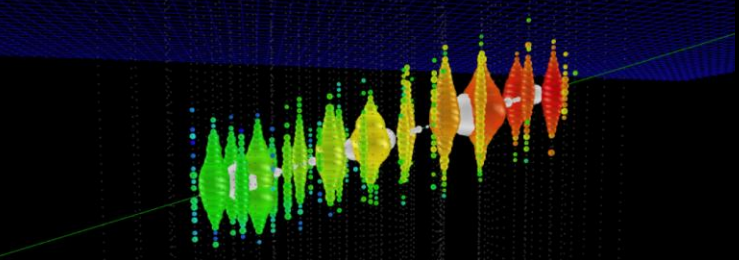


neutrino flavors

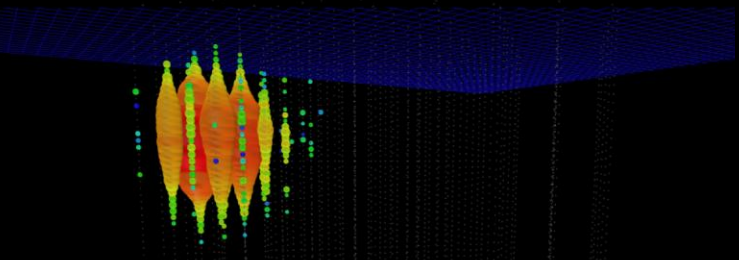


tracks and cascades

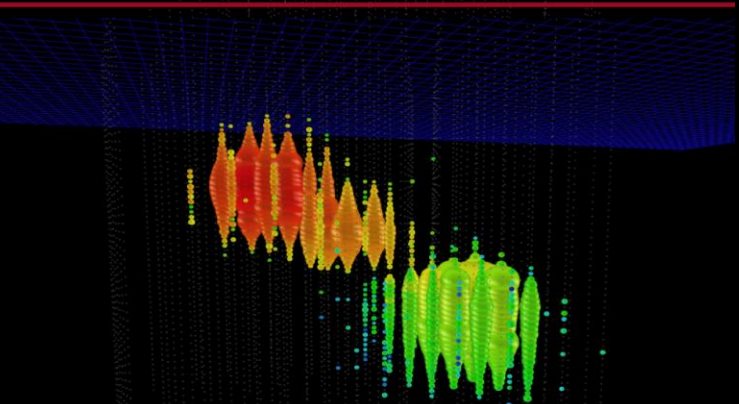
Type: NuMu
(GeV): 4.31e+06
Zen: 73.23 deg
Azi: 349.46 deg



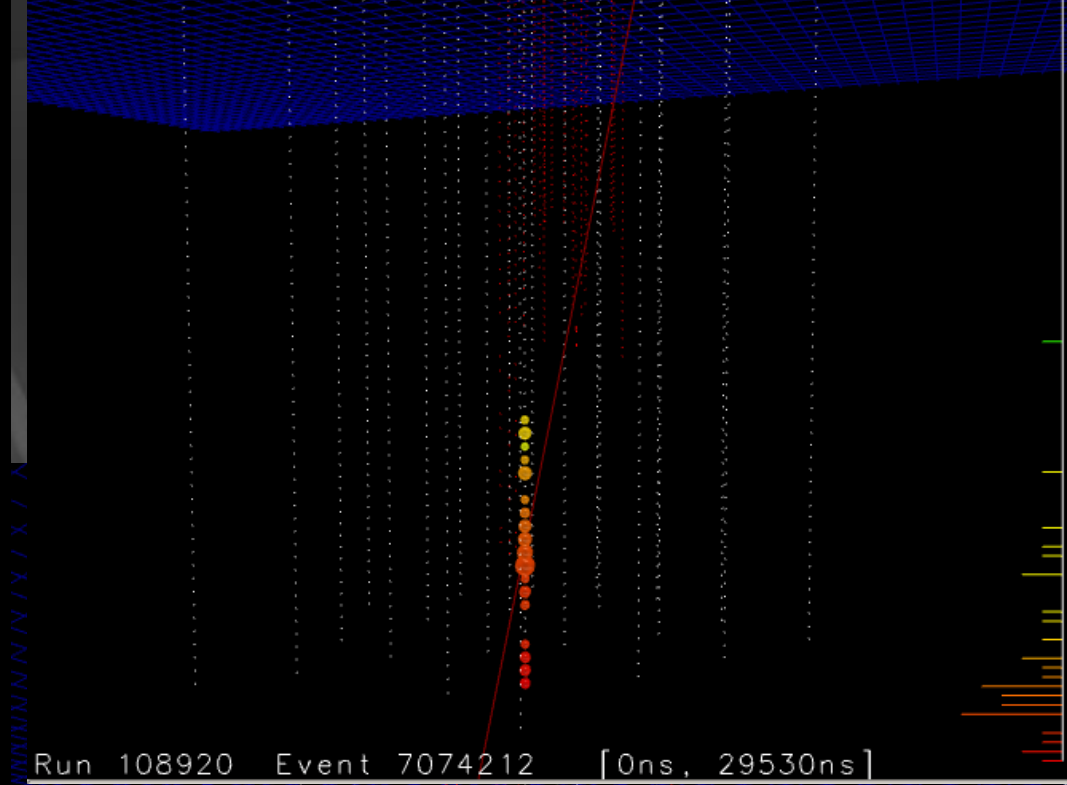
muon



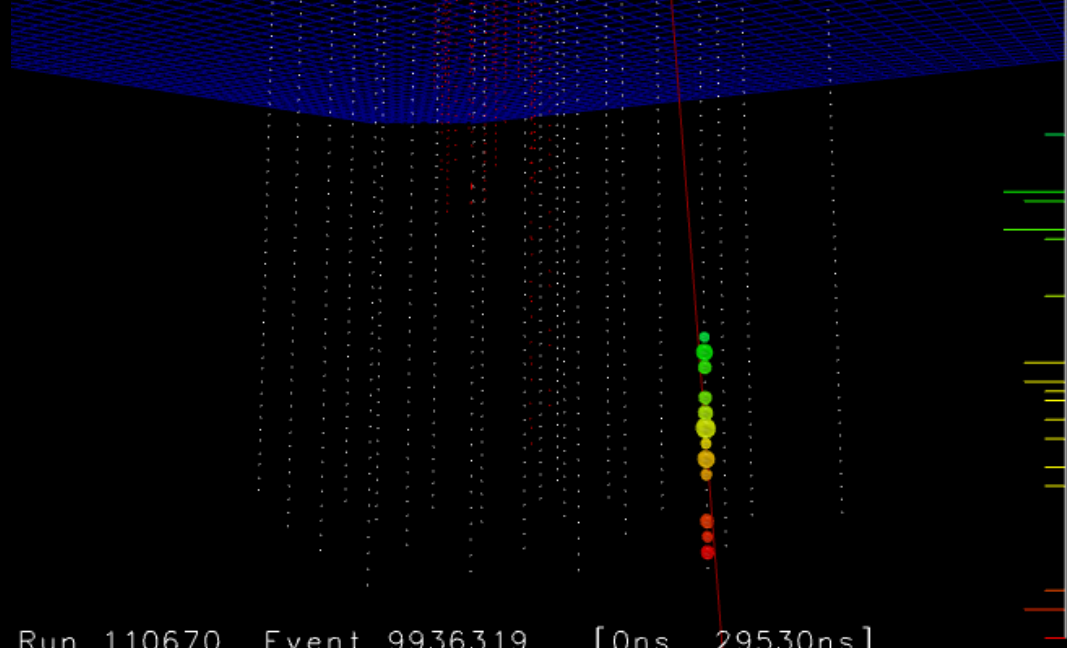
electron



tau



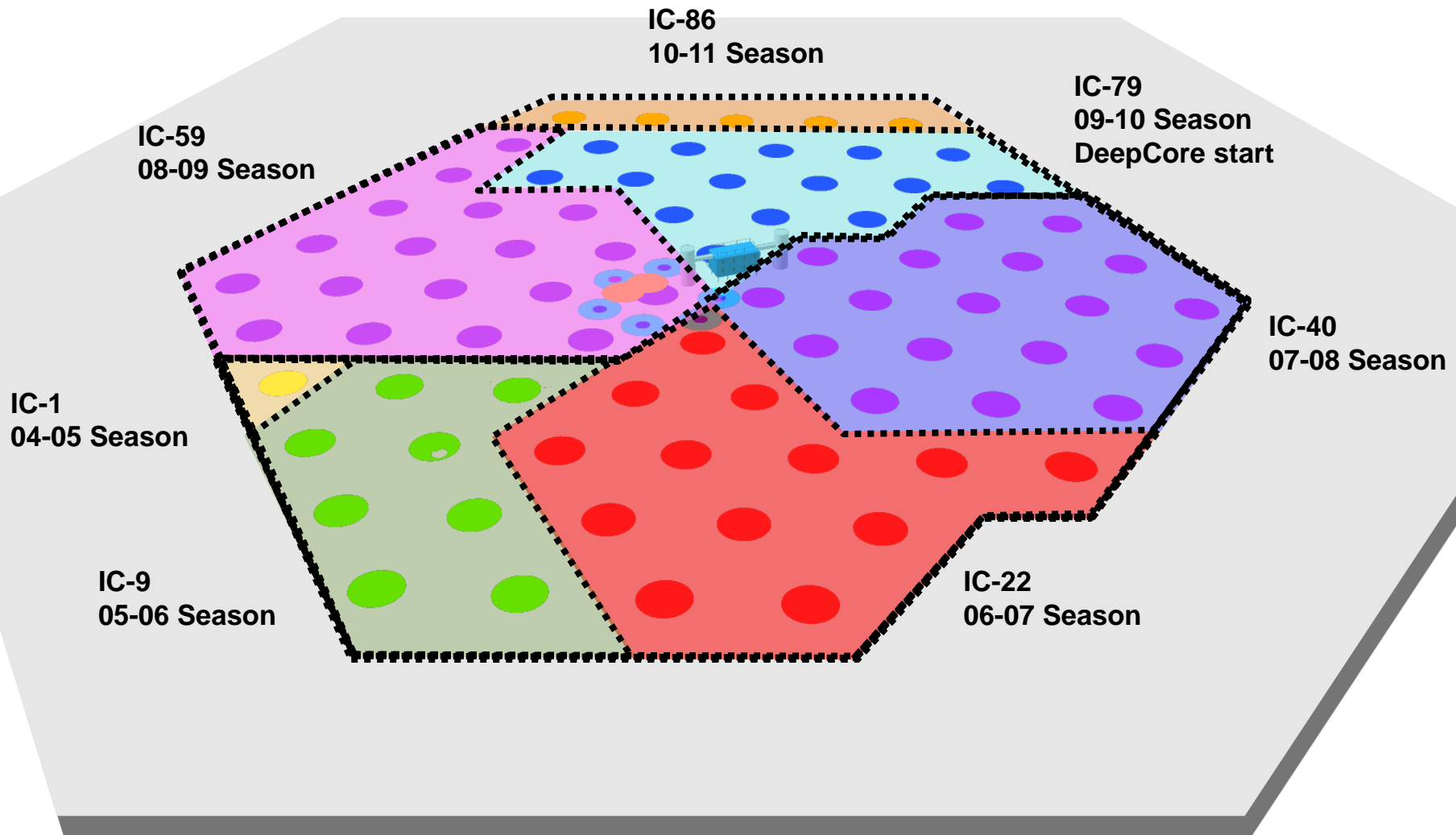
Run 108920 Event 7074212 [0ns, 29530ns]



Run 110670 Event 9936319 [0ns, 29530ns]



completed December 18, 2010

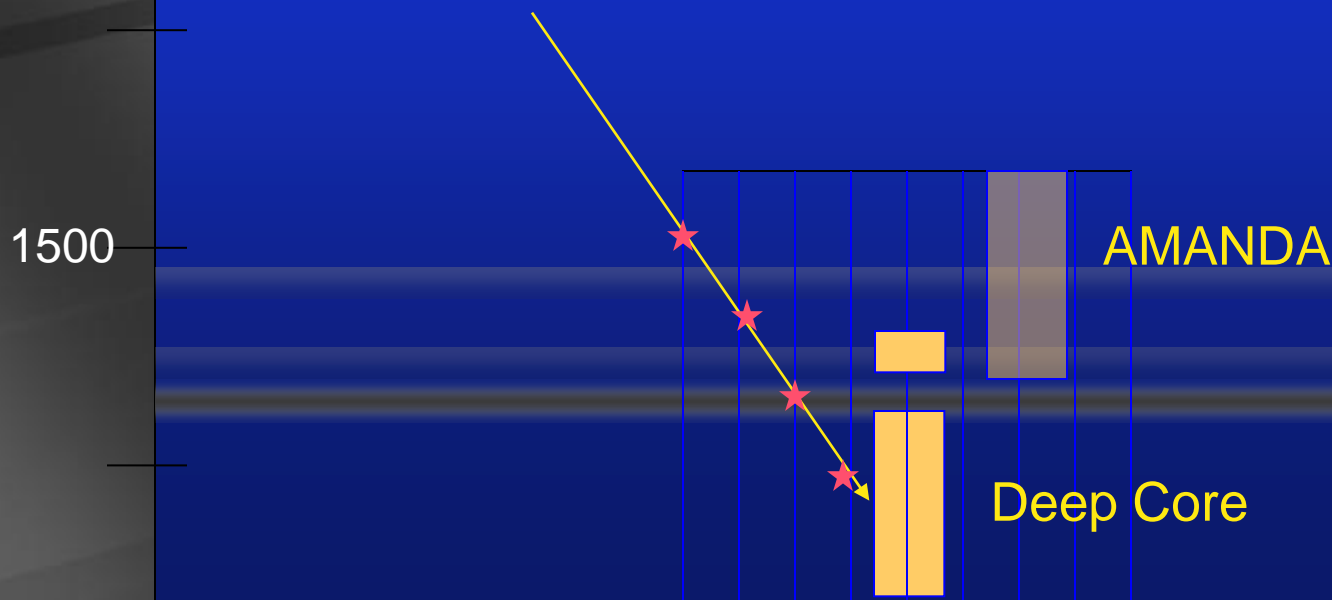


DeepCore



low energy core for IceCube

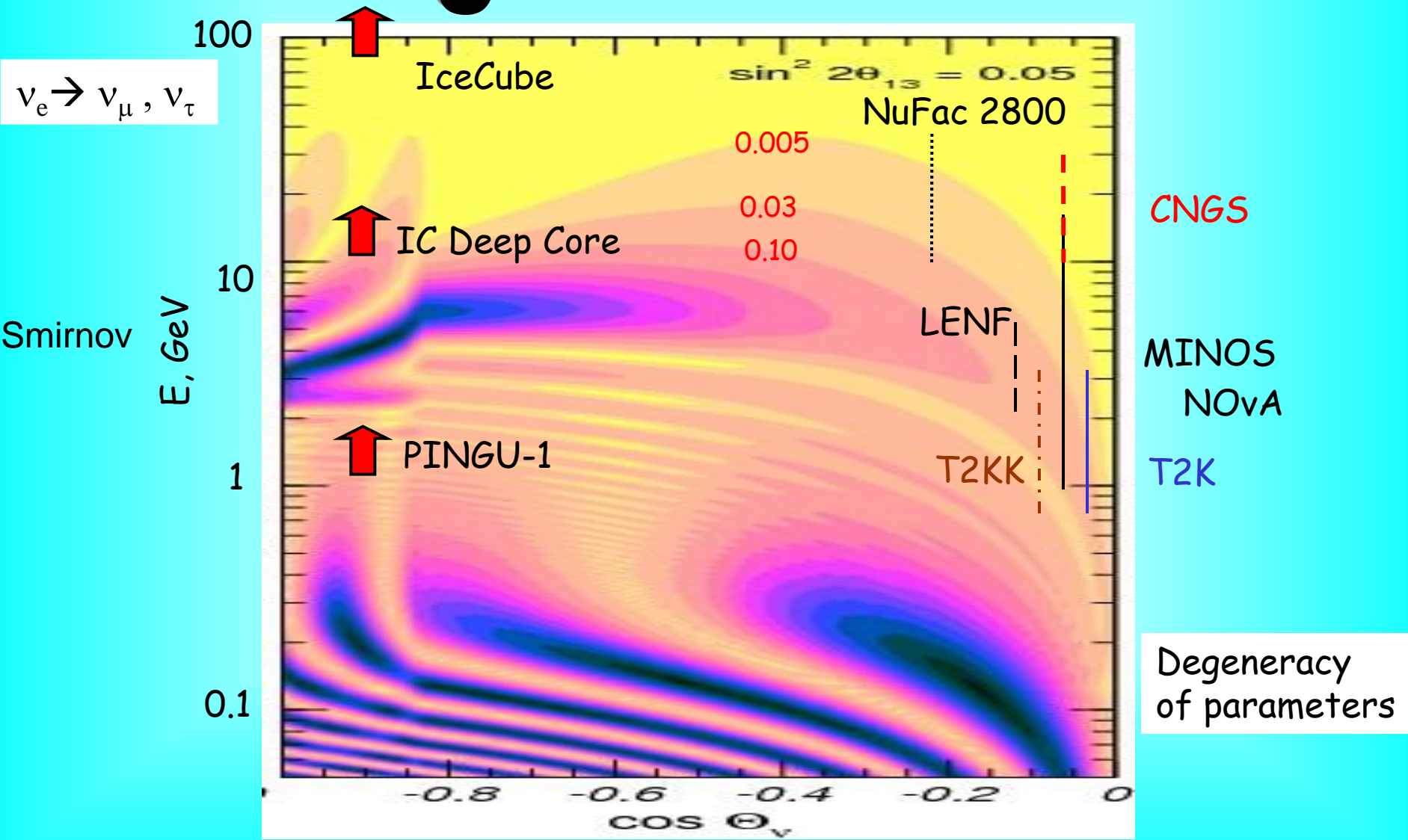
- concept: contained vertex with no hits in outer “veto” region is a candidate for a downward neutrino.
- scattering length 47m
- absorption length 220m



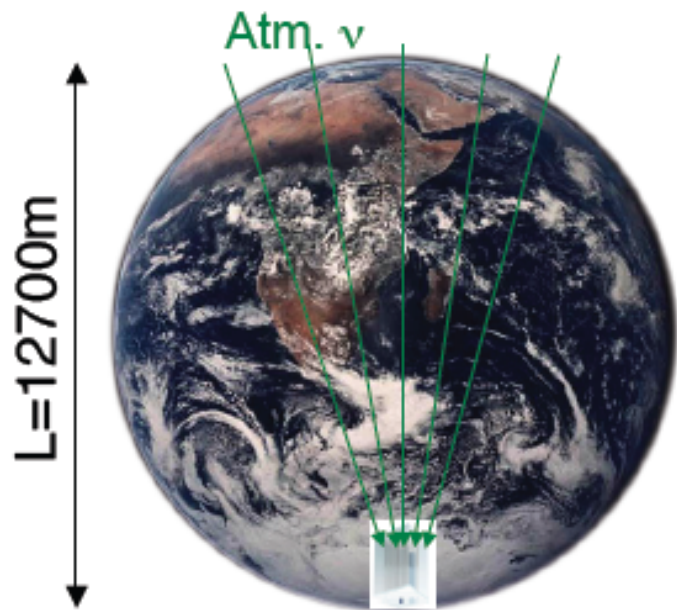
$$n_{strings} \times height \times (\pi \lambda_{scatt}^2) \approx ten \text{ Mton}$$

Oscillograms

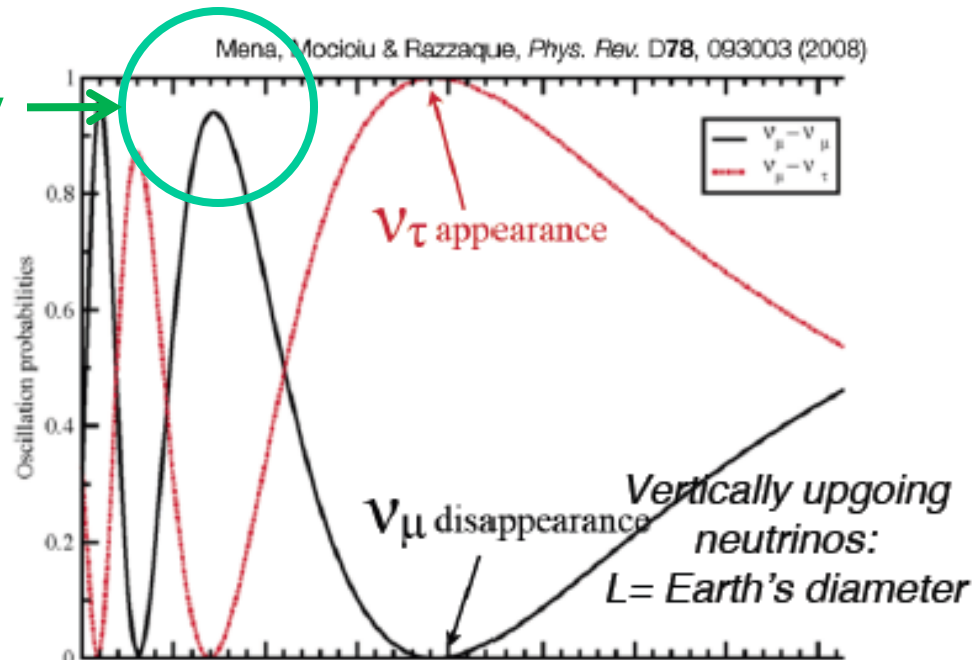
contours of constant oscillation probability in energy- nadir (or zenith) angle plane



Neutrino Oscillations with DeepCore

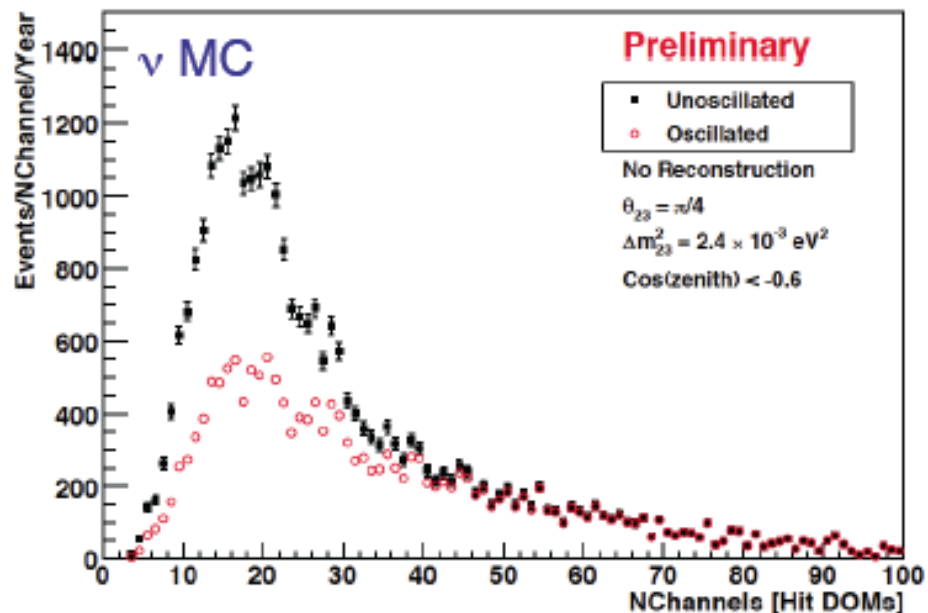


hierarchy →

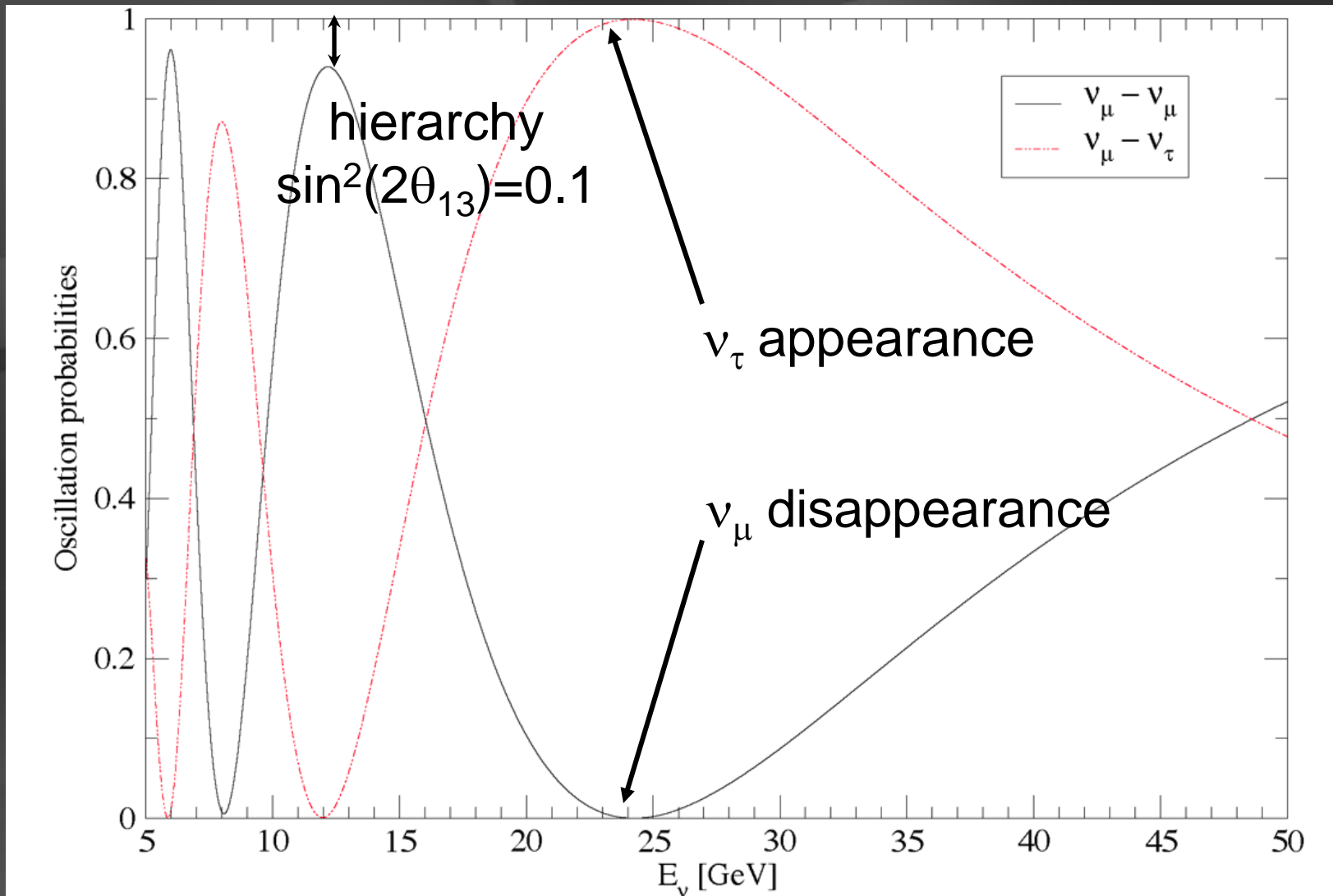


ν_μ disappearance MC

- 3-flavor oscillations
- signal simulation only
- lifetime= 1 year IC79



neutrino oscillations in Deep Core



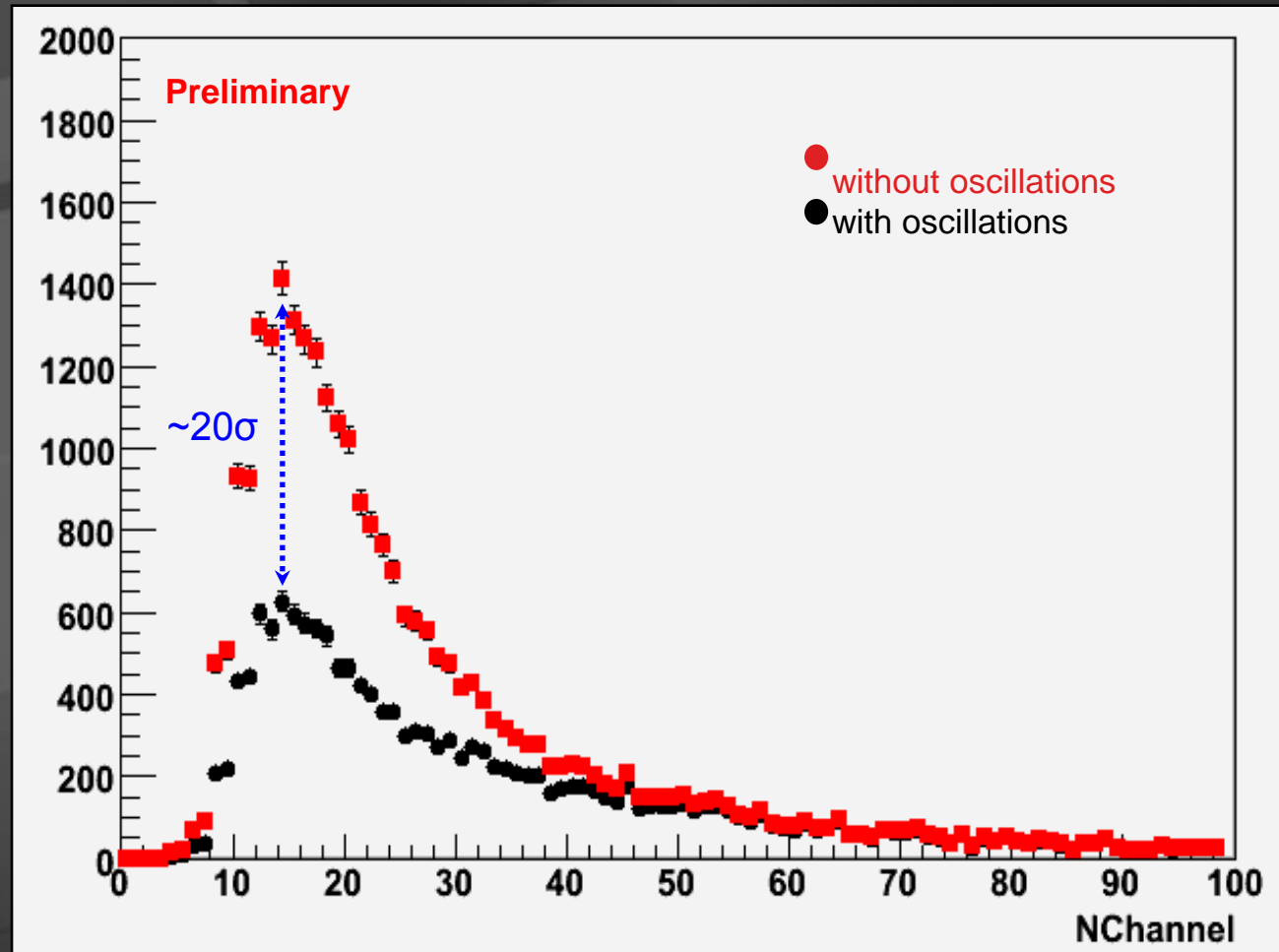
resonance in effective θ_{13} angle traversing the Earth diameter at 10 GeV

muon neutrino disappearance

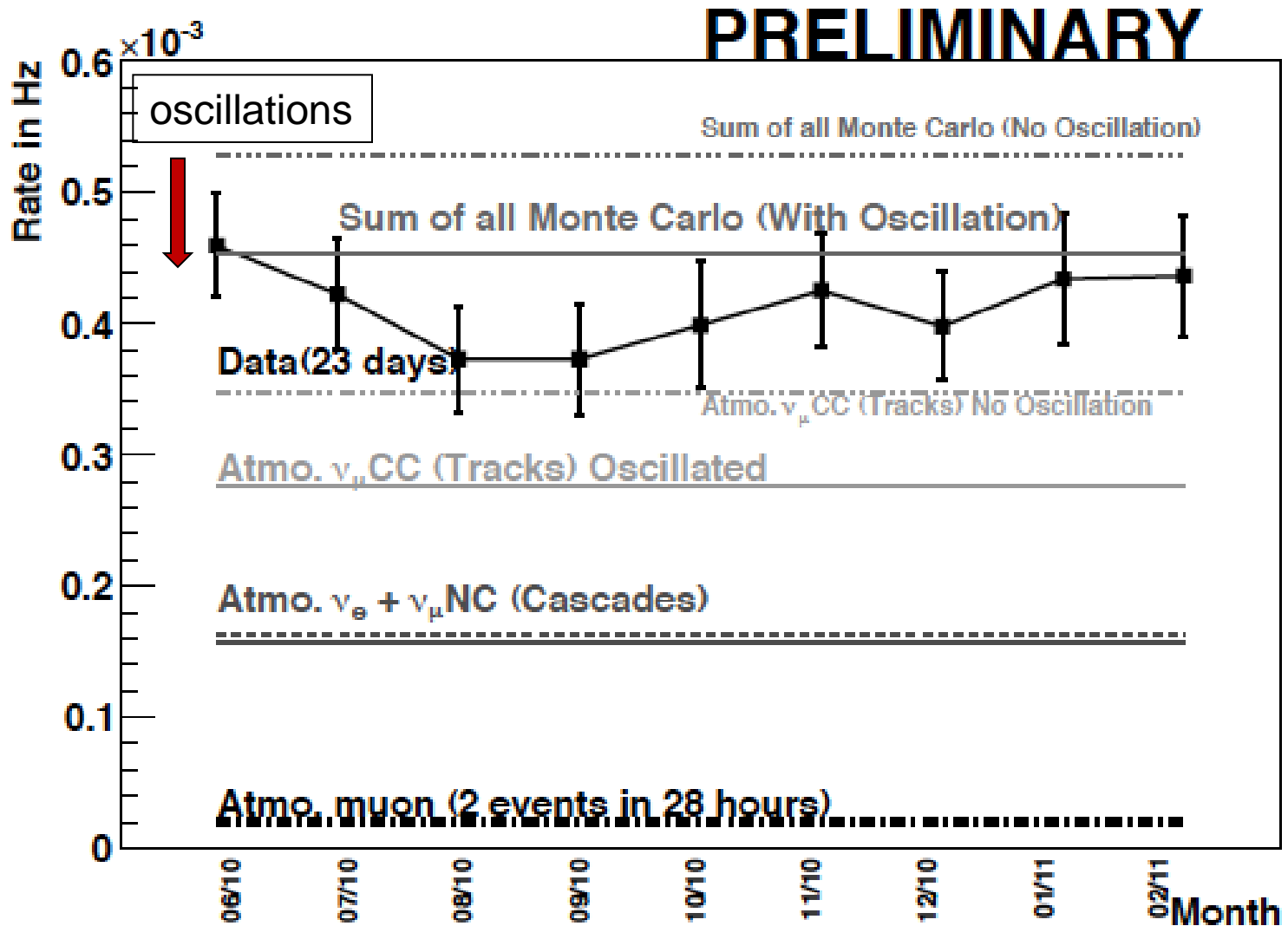
full detector simulation of 3-flavor oscillations

- 1 year DC
 - no bg assumed
 - $\cos(\theta) < -0.6$

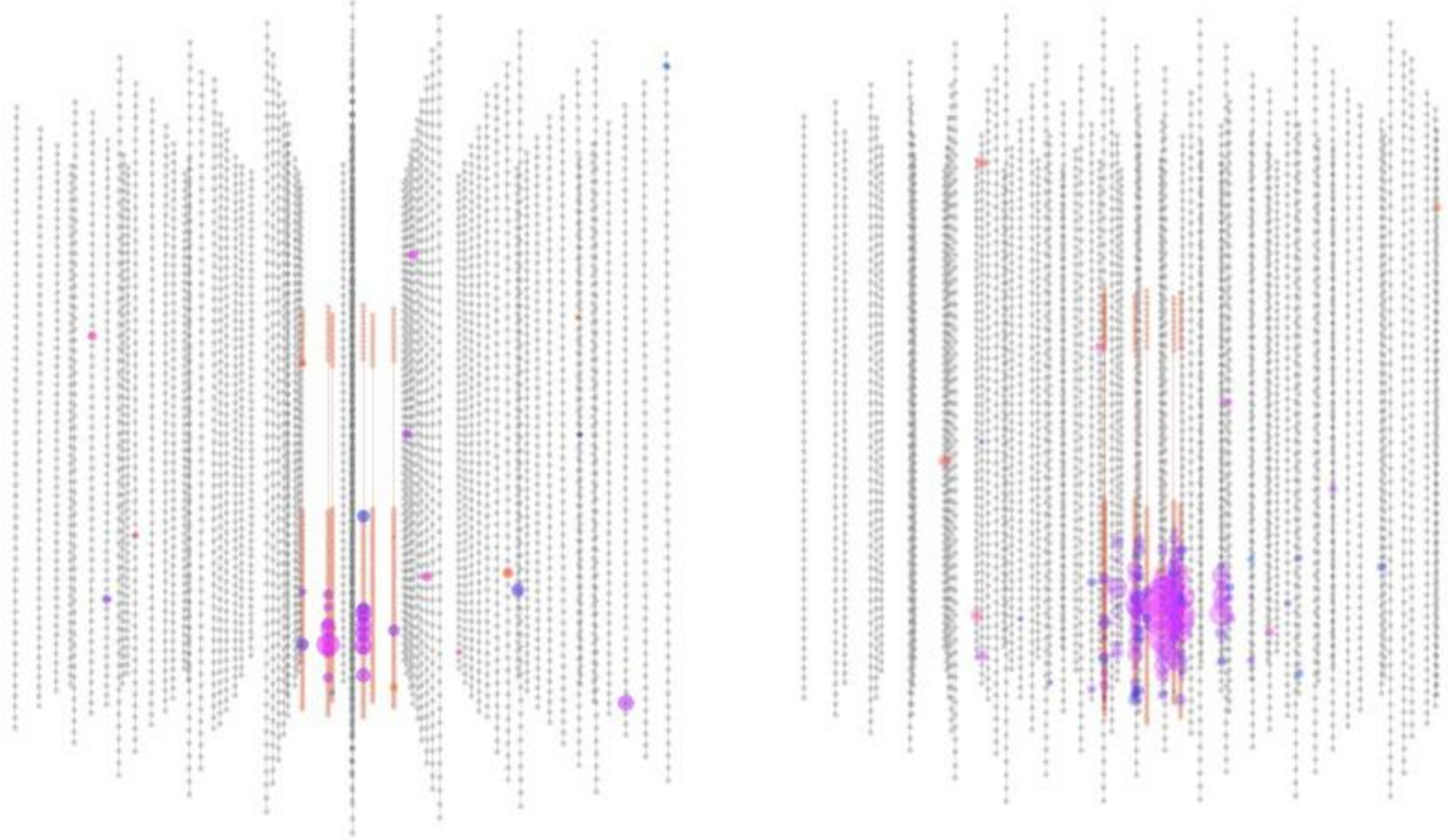
number of hit DOM used as simple energy estimator



cascades in IC79 DeepCore (one tenth of data only!)



DeepCore cascade events

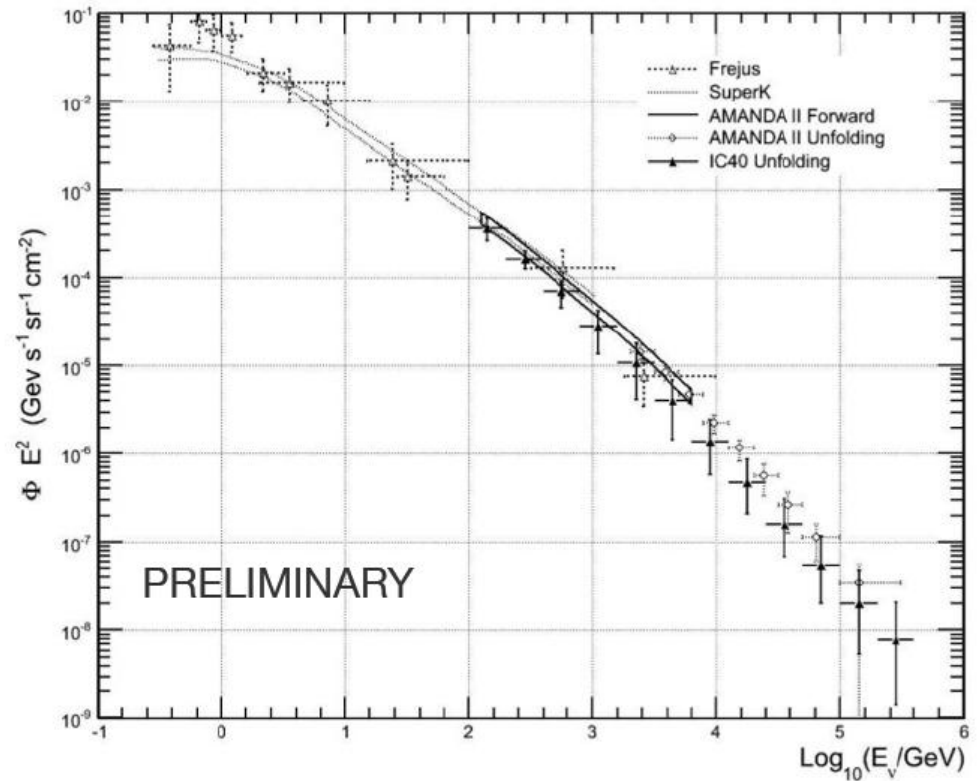
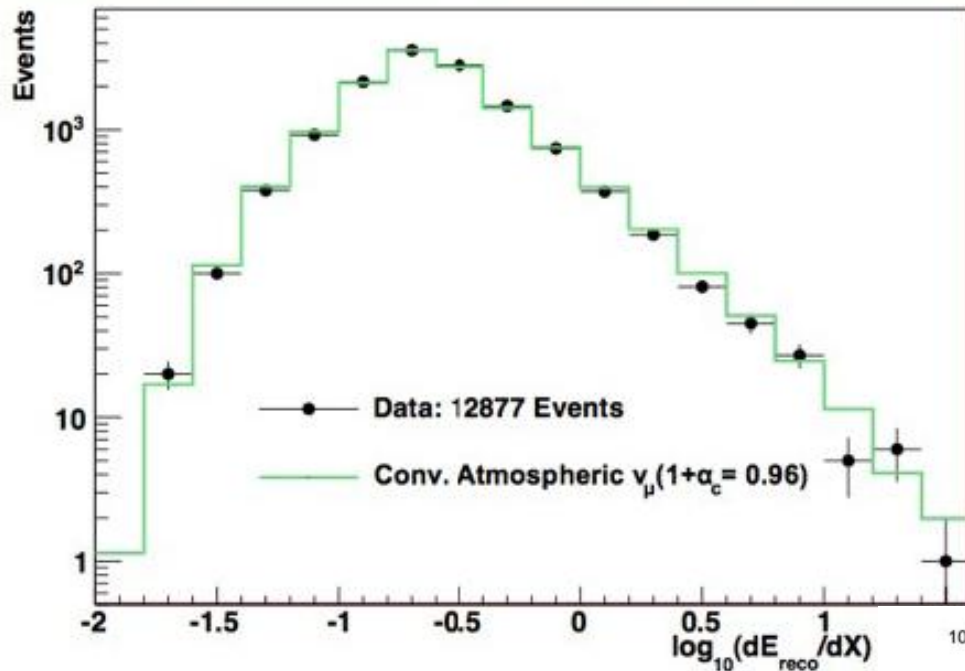


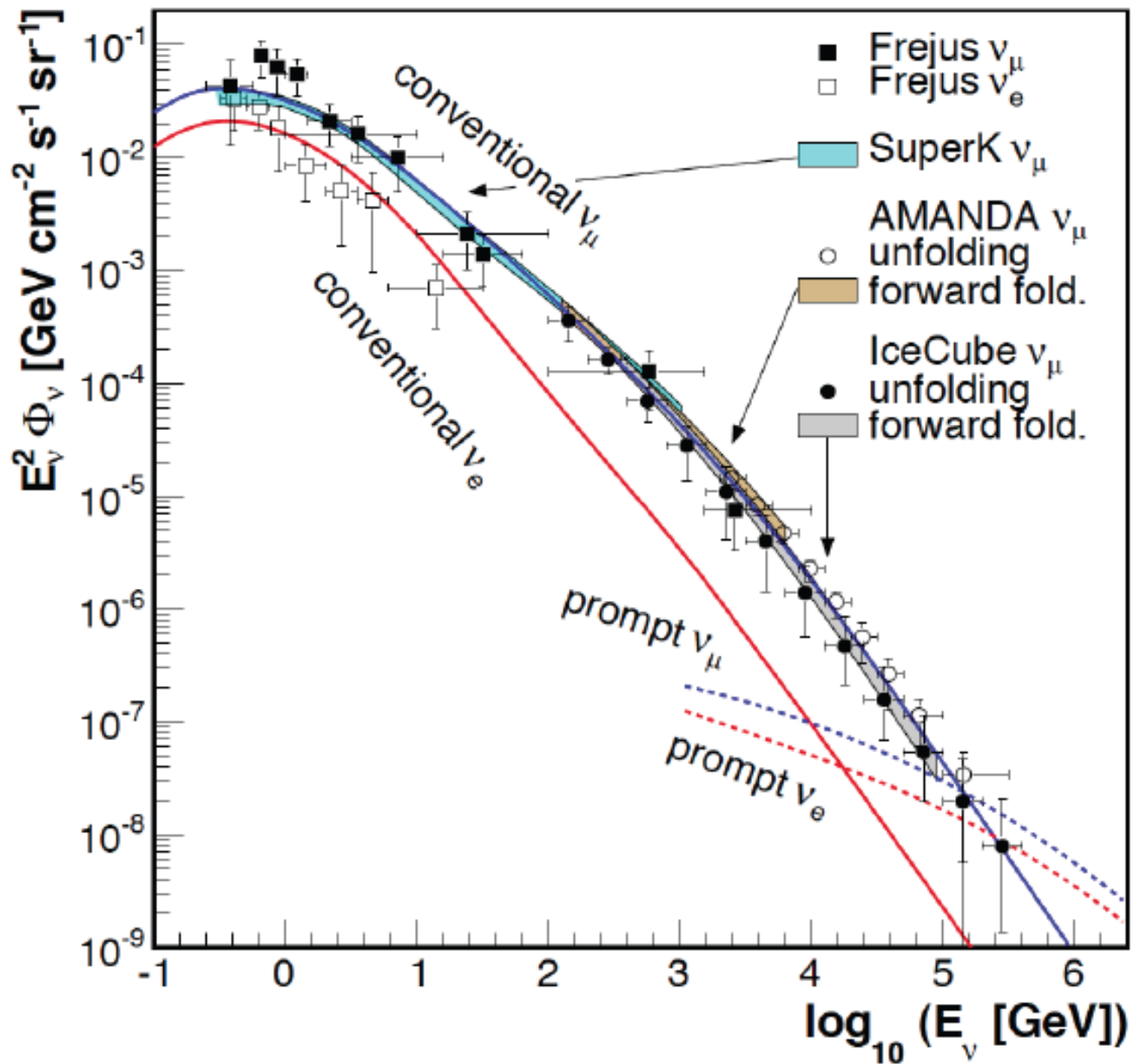
atmospheric neutrinos in IceCube

... on to IceCube science

we measure the flux of atmospheric muons and neutrinos at higher energies and with better statistics than previous experiments. Any deviations from what is expected is new neutrino physics or new astrophysics. We just look for surprises.

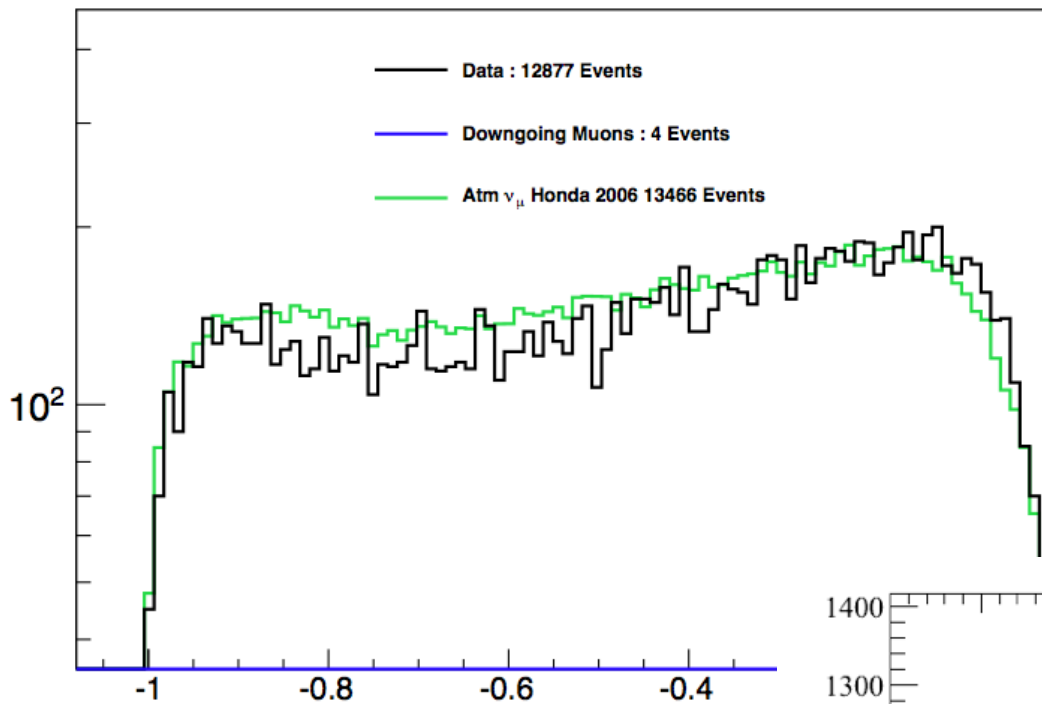
IceCube-40 atmospheric neutrino spectrum





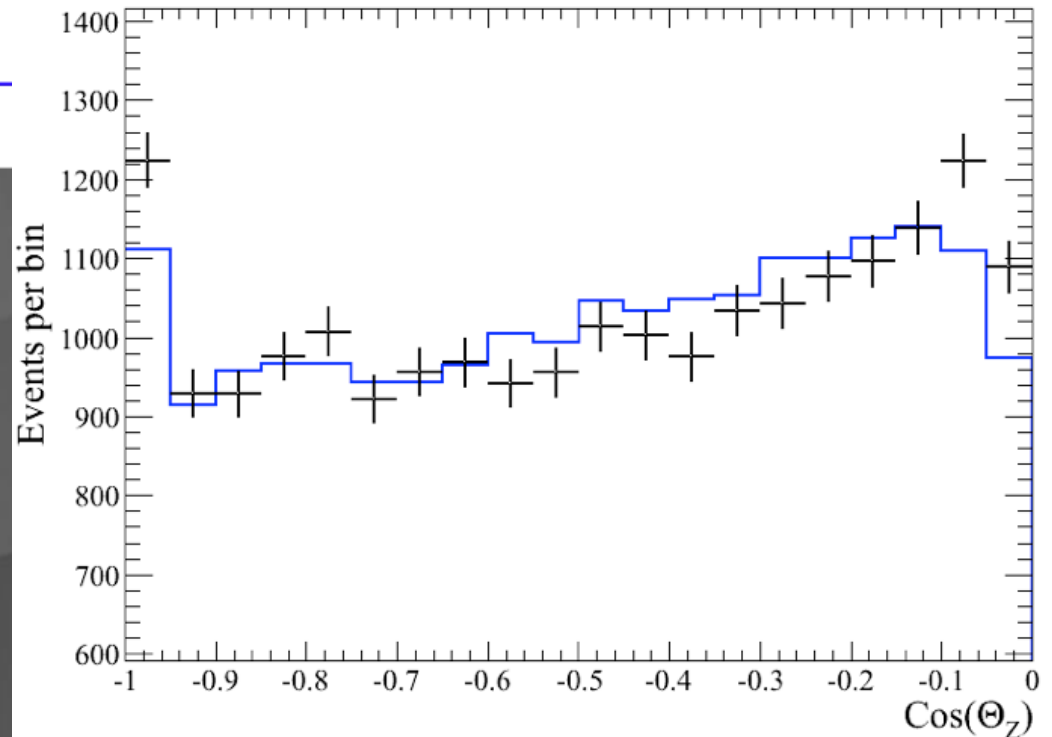
atmospheric neutrino spectrum to >100 TeV

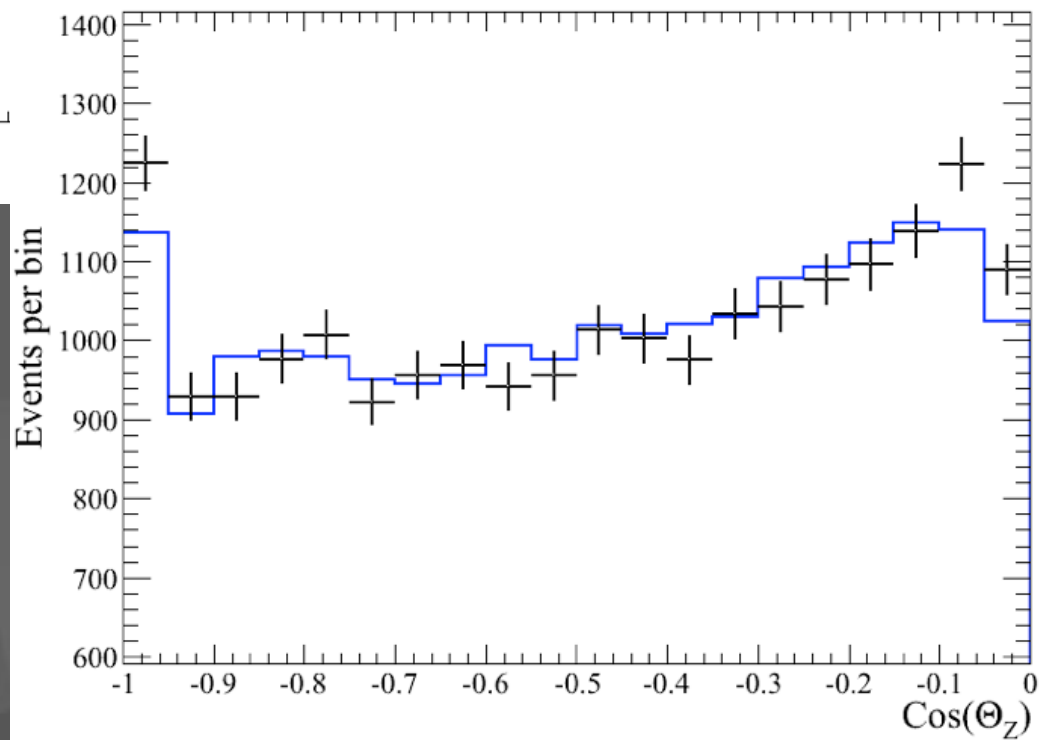
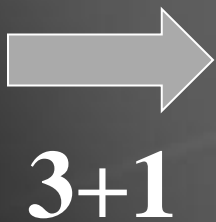
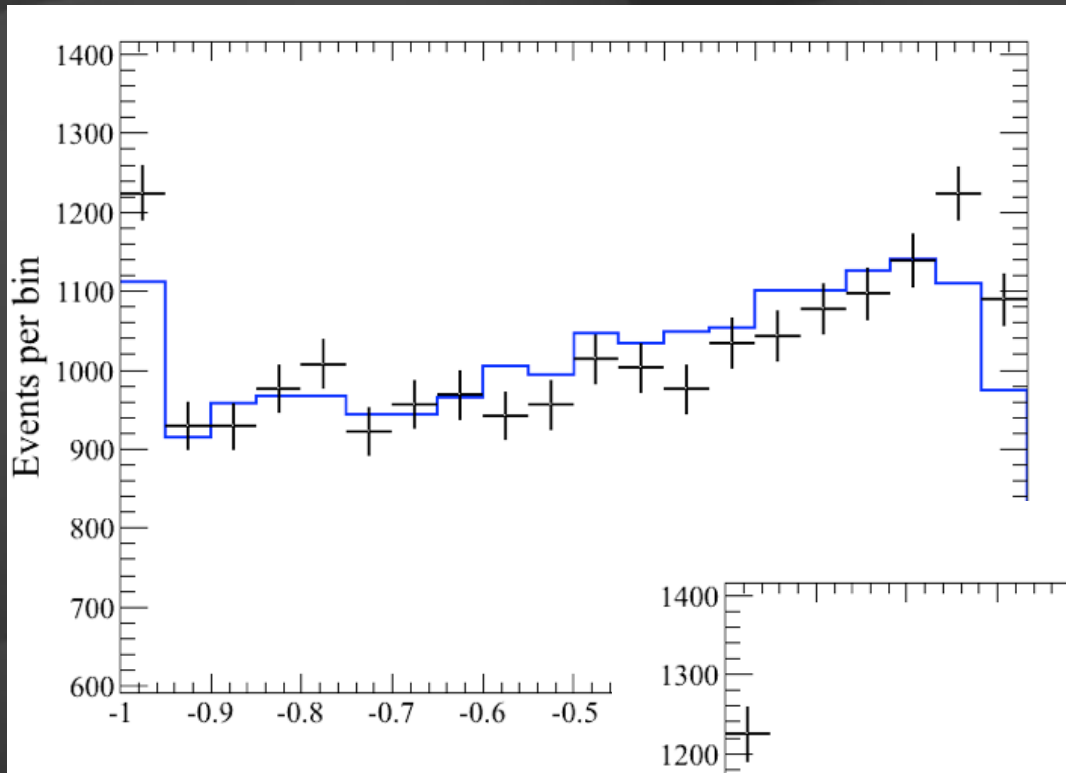
375.5 days IC40



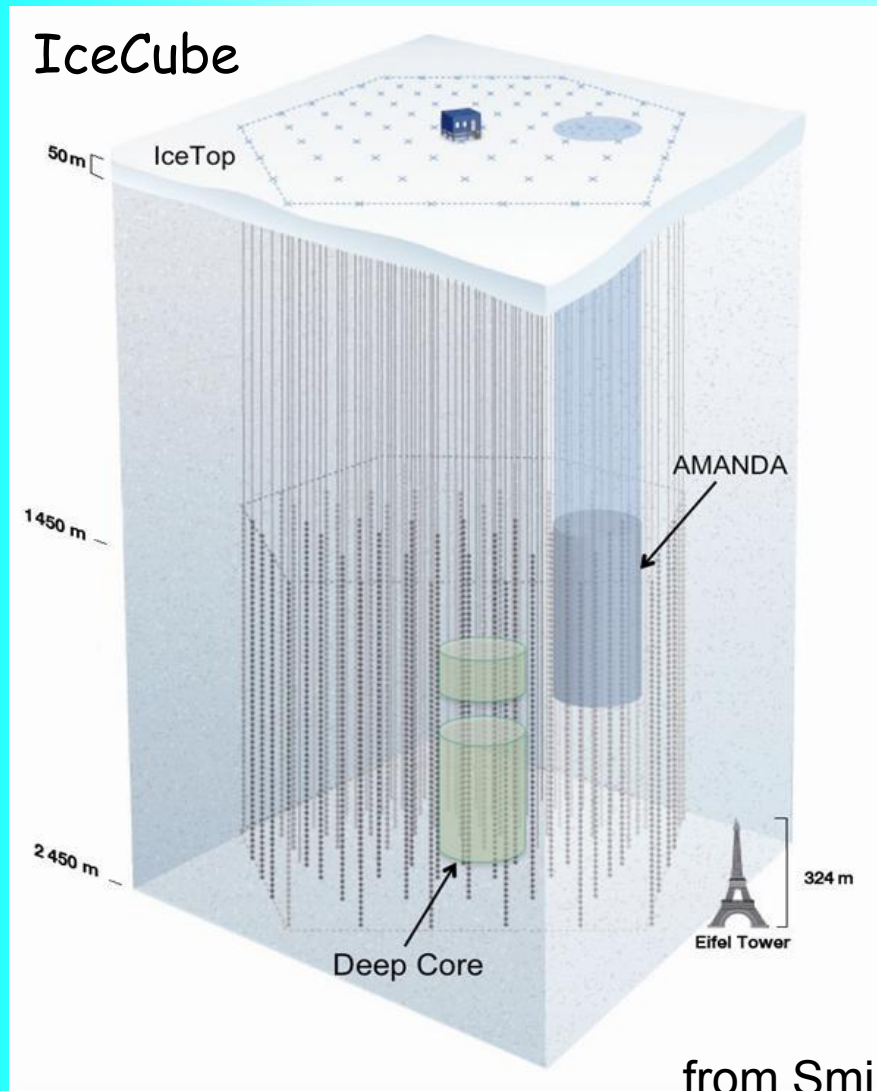
zenith angle
two analyses

matter effect
of eV sterile ν 's ?





Looking for sterile in ice



*H Nunokawa O L G Peres
R Zukanovich-Funchal
Phys. Lett B562 (2003) 279*

$\nu_\mu - \nu_s$ oscillations with $\Delta m^2 \sim 1 \text{ eV}^2$
are enhanced in matter of the
Earth in energy range 0.5 - few TeV

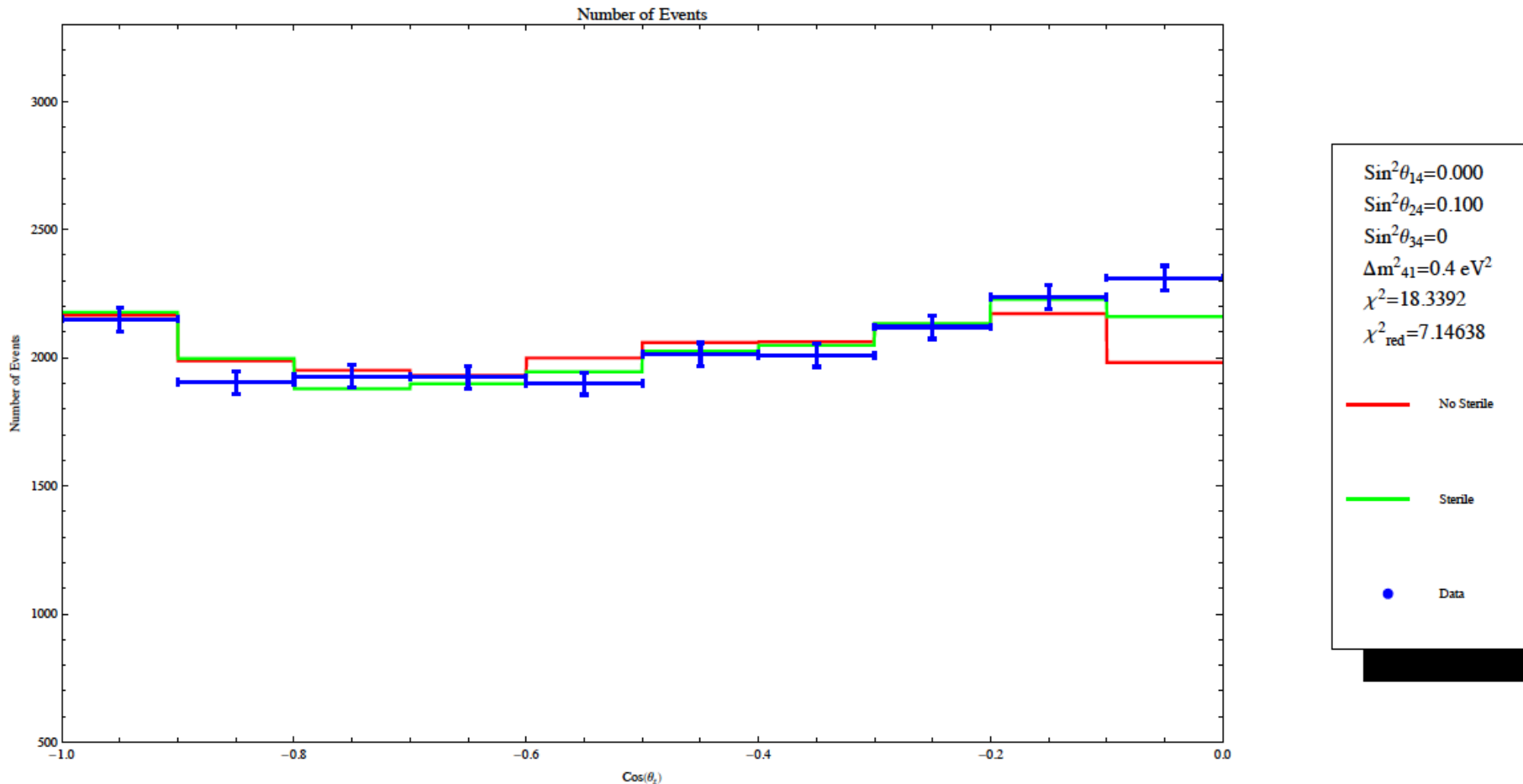
This distorts the energy spectrum
and zenith angle distribution of the
atmospheric muon neutrinos

S Choubey HEP 0712 (2007) 014

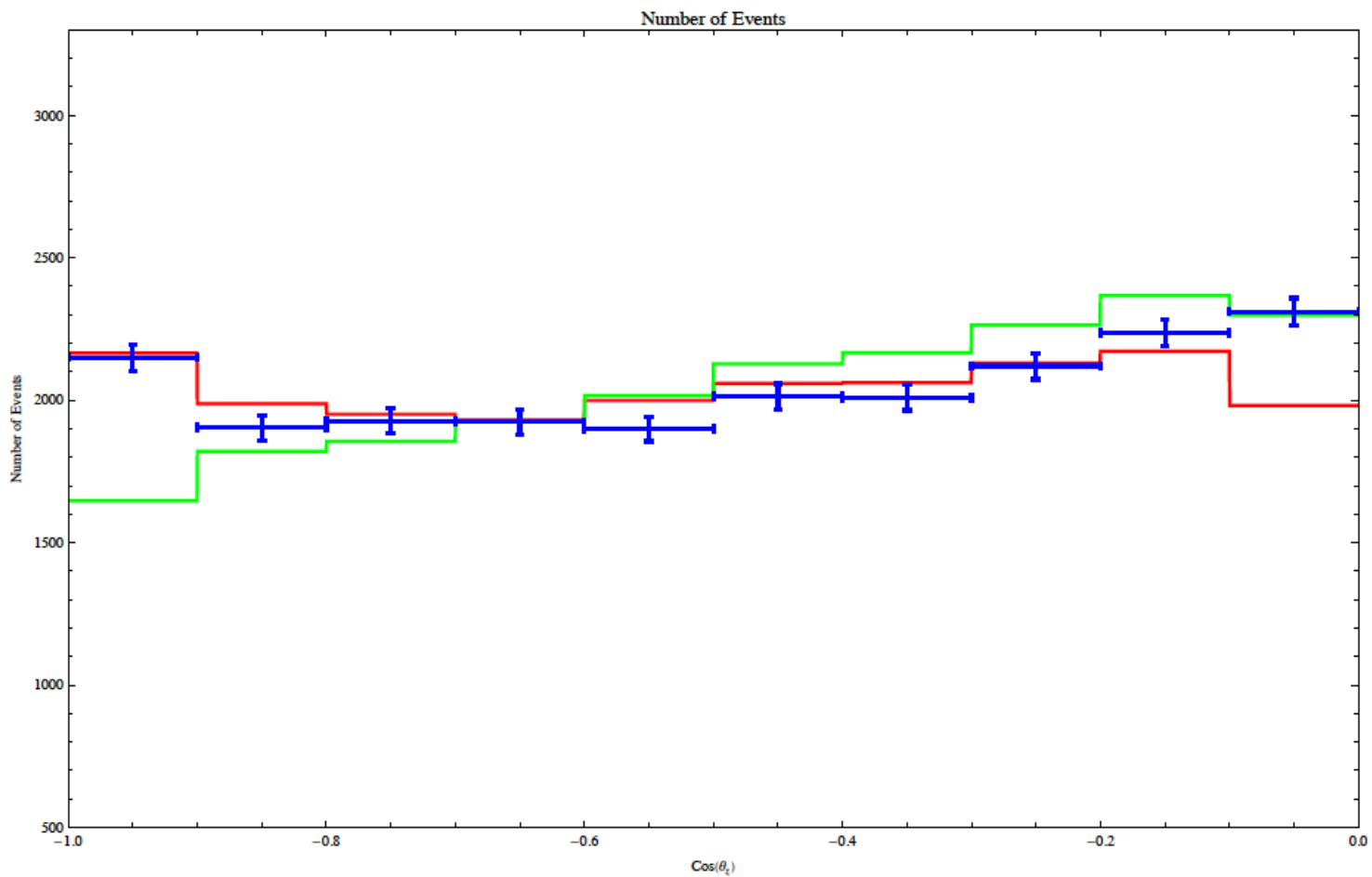
*S Razzaque and AYS,
1104.1390, [hep-ph]*

from Smirnov's talk

number of nu-mu events versus $\cos\theta$ in IceCube 40



$$\Delta m^2 = 0.4 \text{ eV}^2 \text{ and } \sin^2\theta_{34} = 0 \rightarrow 0.5$$

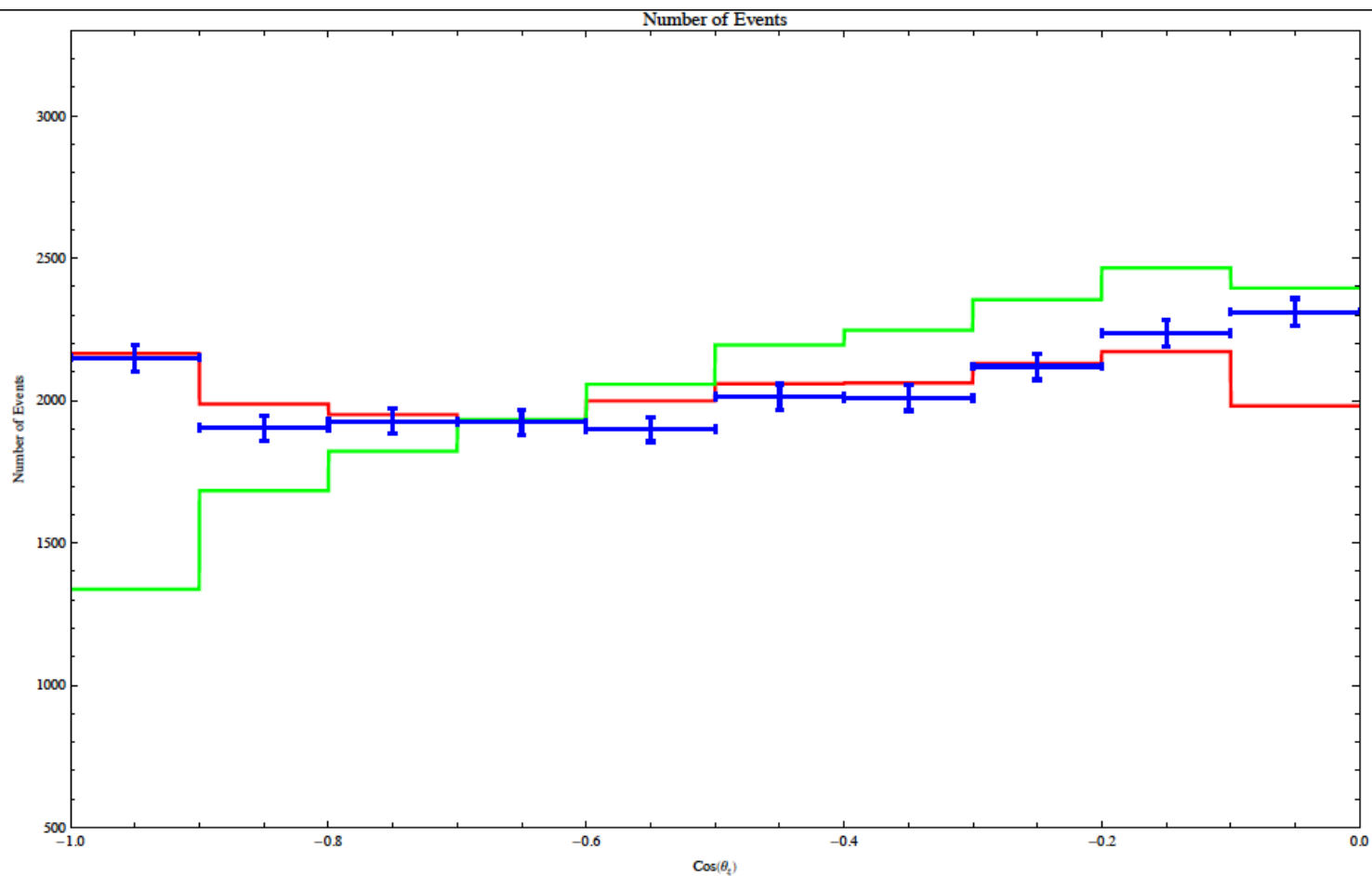


$\text{Sin}^2\theta_{14}=0.000$
 $\text{Sin}^2\theta_{24}=0.100$
 $\text{Sin}^2\theta_{34}=0.0500$
 $\Delta m^2_{41}=0.4 \text{ eV}^2$
 $\chi^2=166.471$
 $\chi^2_{\text{red}}=165.997$

No Sterile

Sterile

Data



$\sin^2\theta_{14}=0.000$

$\sin^2\theta_{24}=0.100$

$\sin^2\theta_{34}=0.100$

$\Delta m^2_{41}=0.4 \text{ eV}^2$

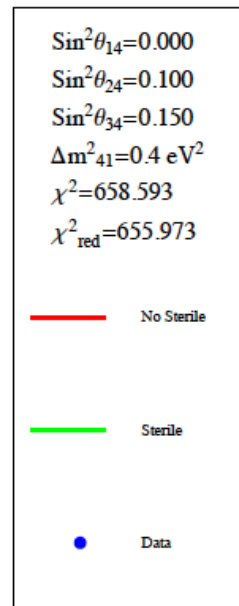
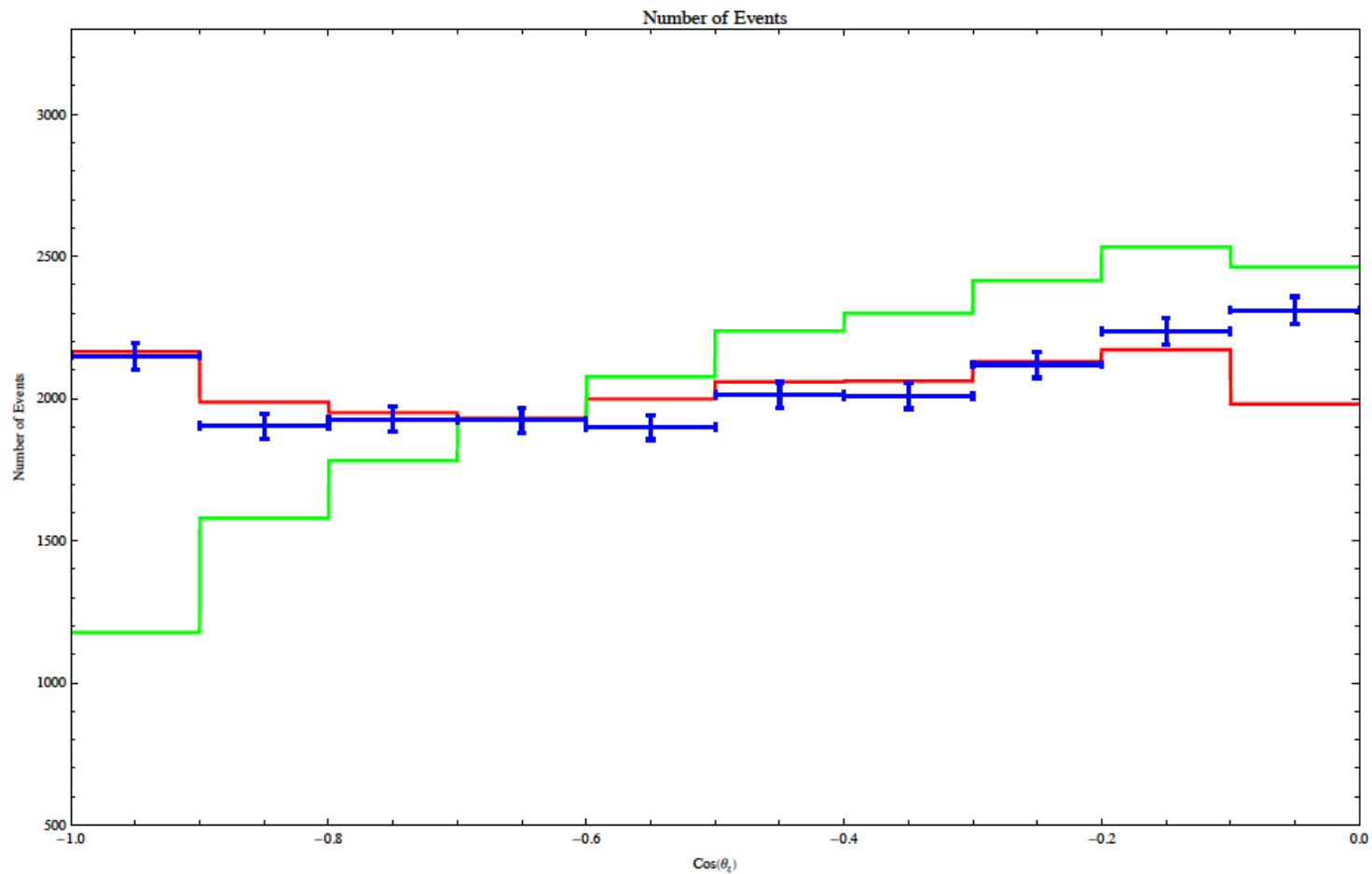
$\chi^2=439.304$

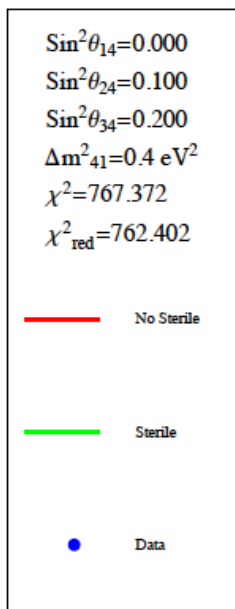
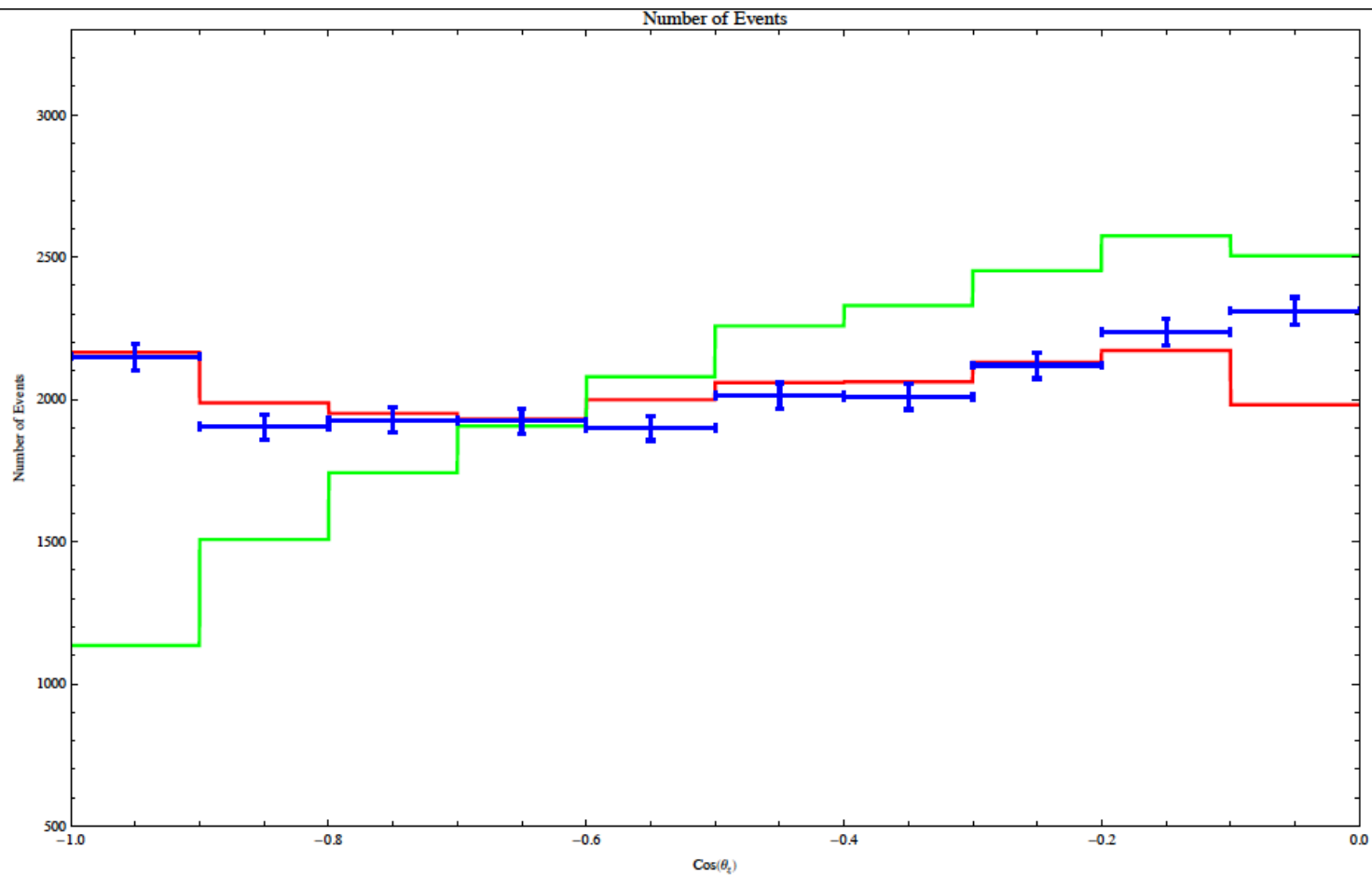
$\chi^2_{\text{red}}=438.764$

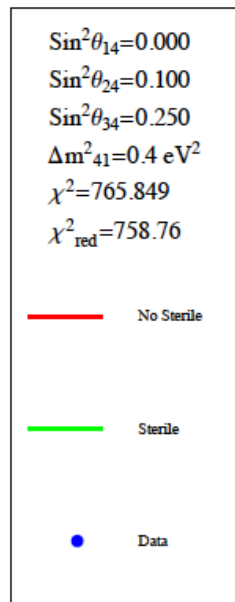
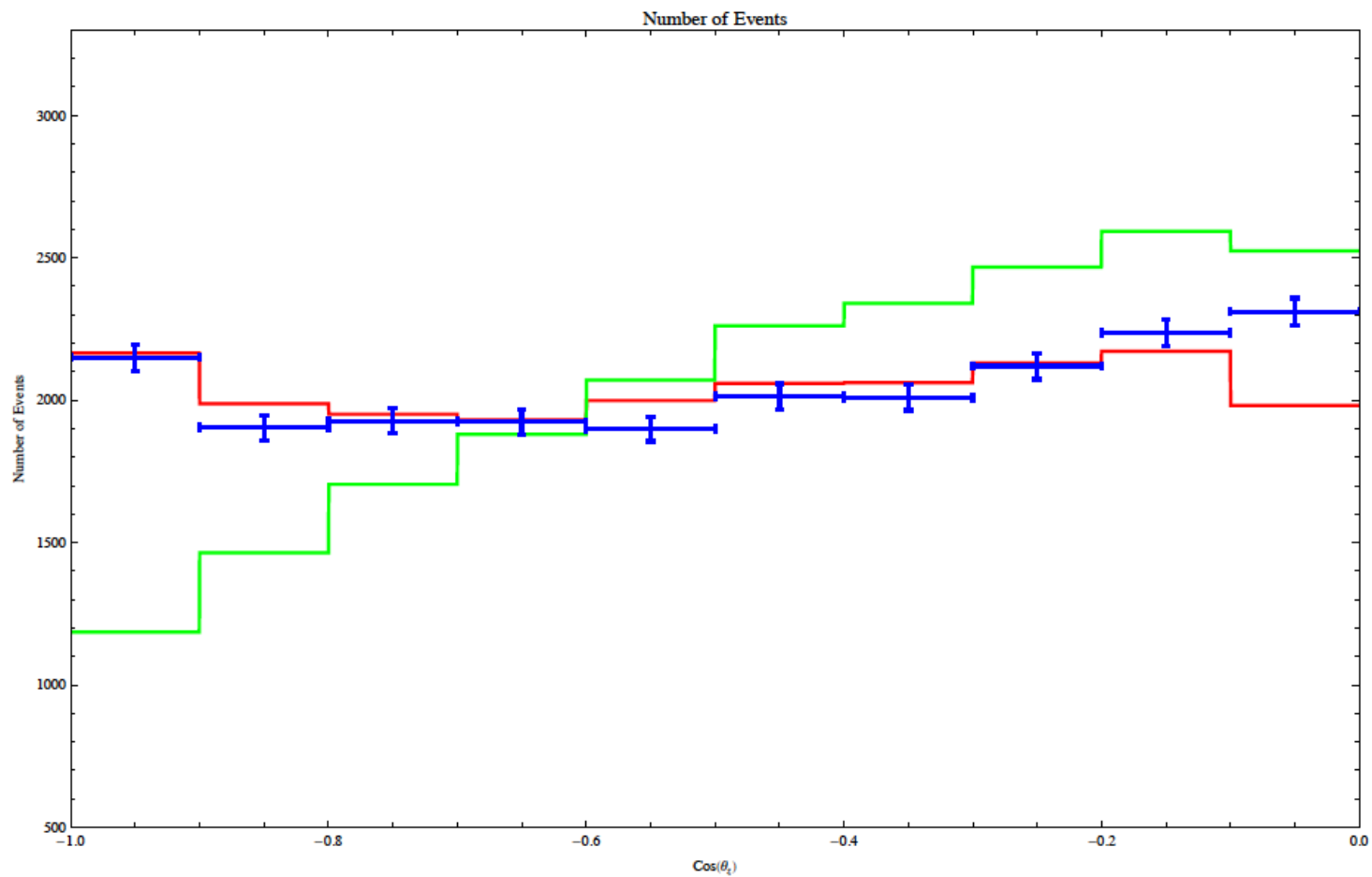
— No Sterile

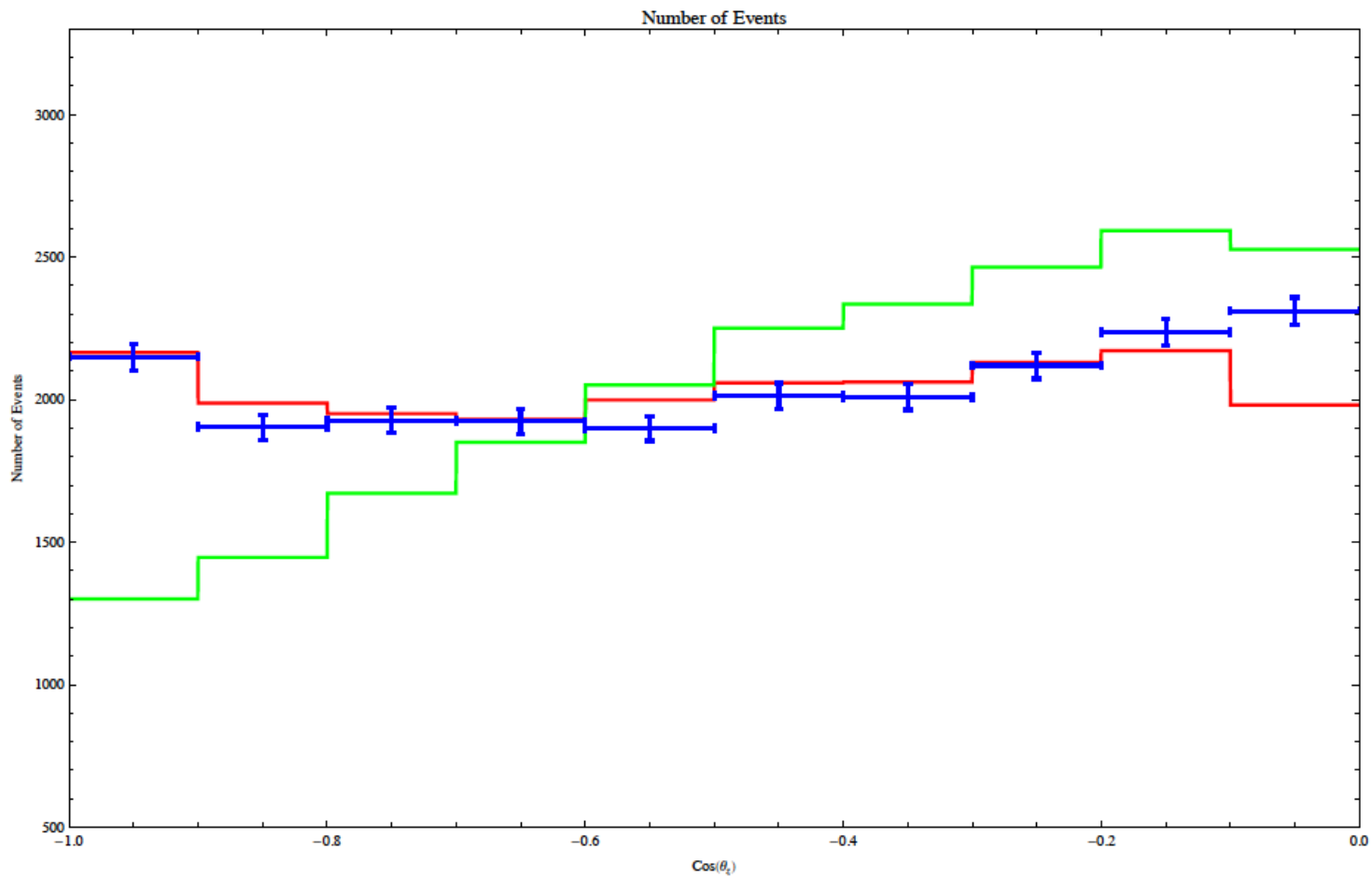
— Sterile

• Data



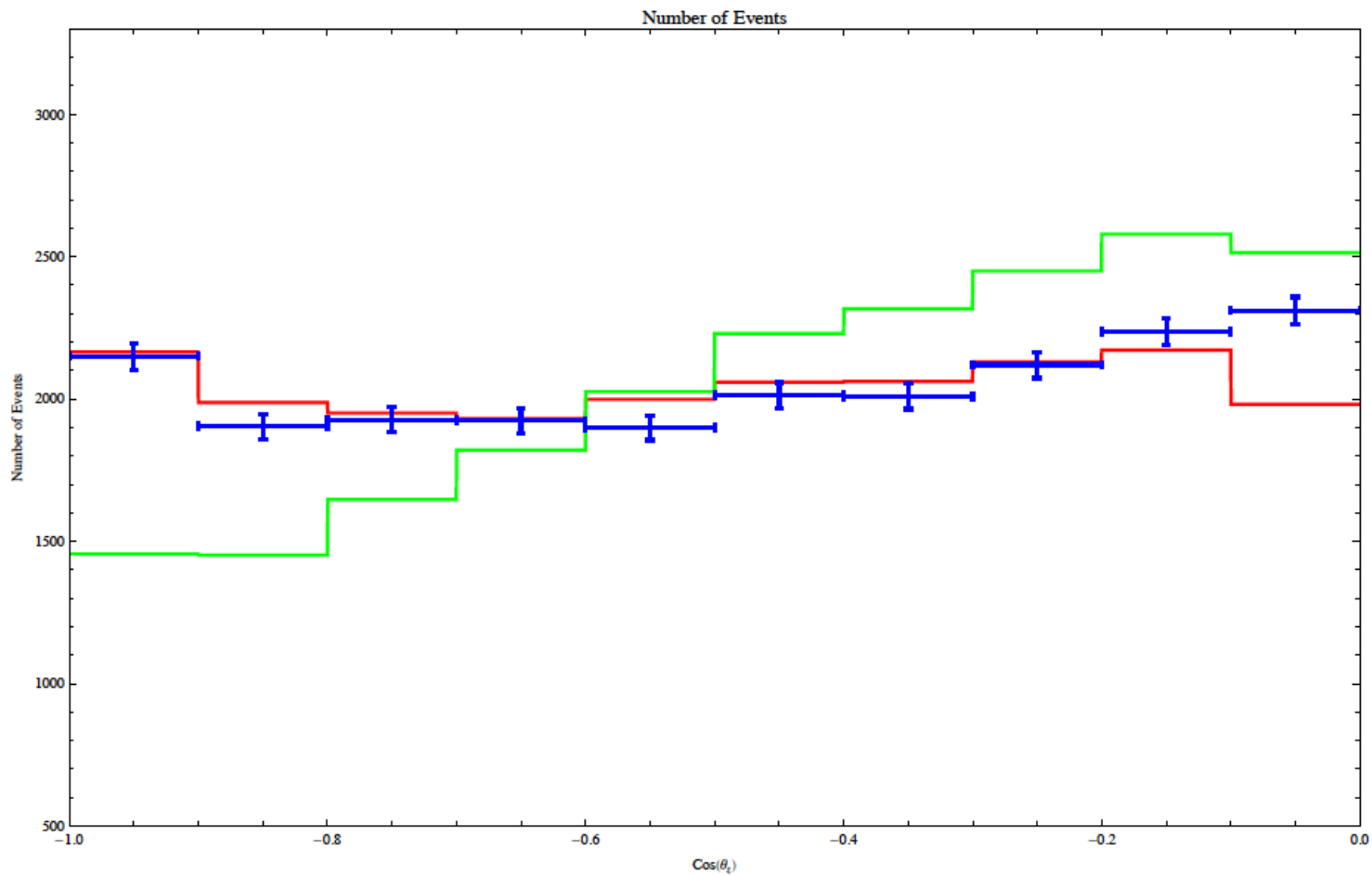






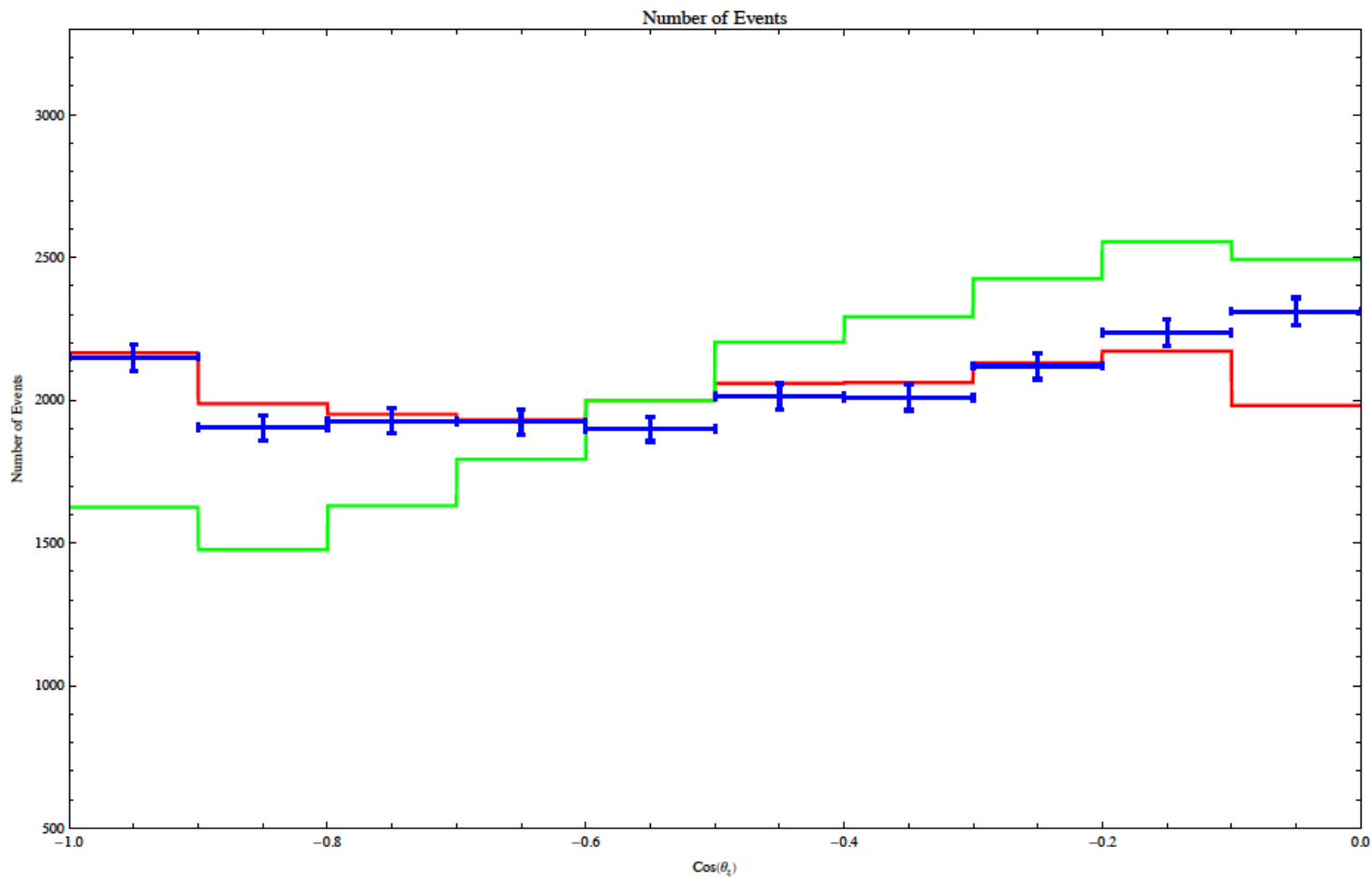
$\text{Sin}^2\theta_{14}=0.000$
 $\text{Sin}^2\theta_{24}=0.100$
 $\text{Sin}^2\theta_{34}=0.300$
 $\Delta m^2_{41}=0.4 \text{ eV}^2$
 $\chi^2=684.279$
 $\chi^2_{\text{red}}=675.718$

- No Sterile
- Sterile
- Data



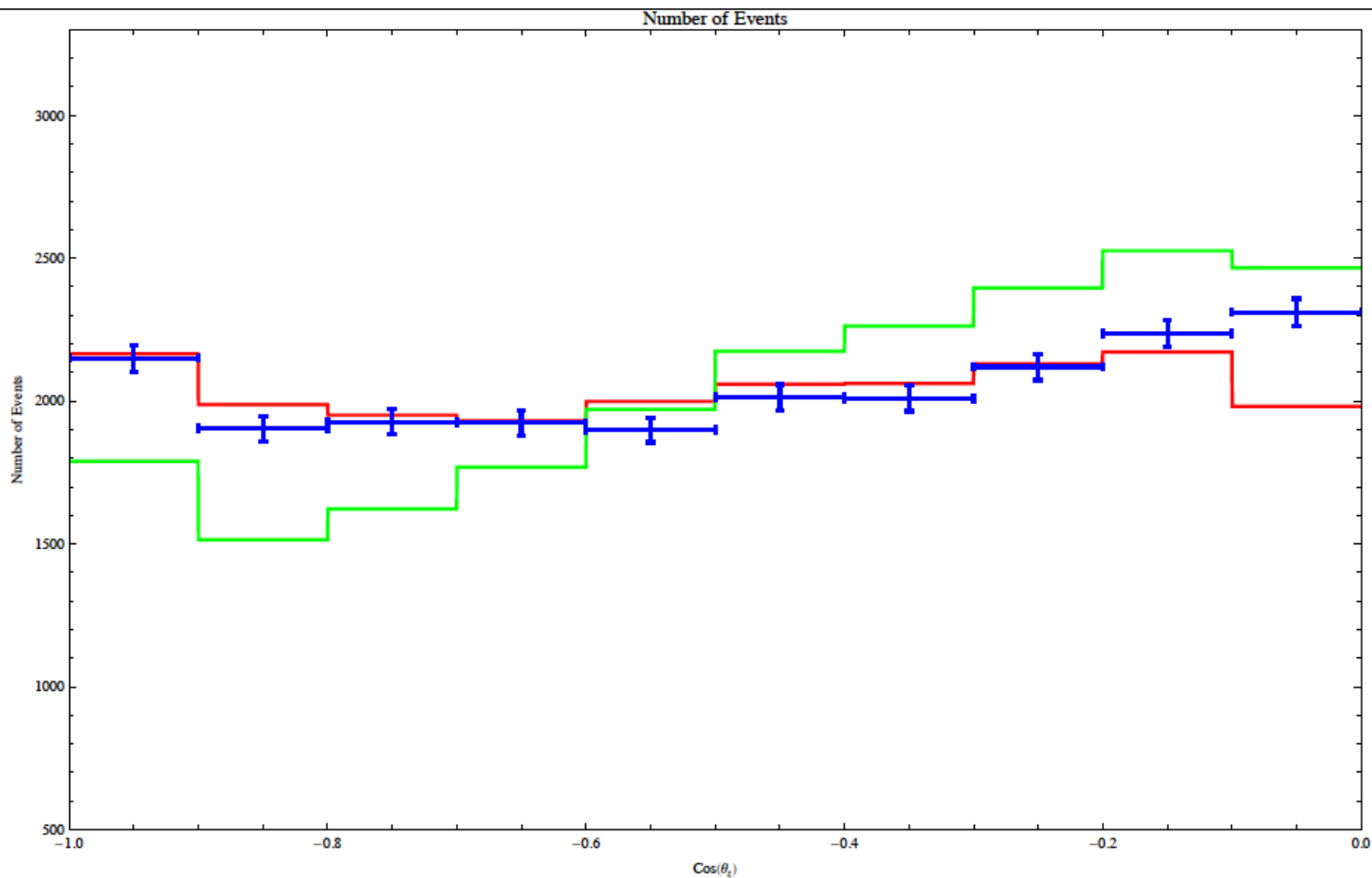
$\sin^2\theta_{14}=0.000$
 $\sin^2\theta_{24}=0.100$
 $\sin^2\theta_{34}=0.350$
 $\Delta m^2_{41}=0.4 \text{ eV}^2$
 $\chi^2=562.921$
 $\chi^2_{\text{red}}=553.932$

— No Sterile
— Sterile
• Data



$\text{Sin}^2\theta_{14}=0.000$
 $\text{Sin}^2\theta_{24}=0.100$
 $\text{Sin}^2\theta_{34}=0.400$
 $\Delta m^2_{41}=0.4 \text{ eV}^2$
 $\chi^2=436.643$
 $\chi^2_{\text{red}}=428.396$

— No Sterile
— Sterile
• Data

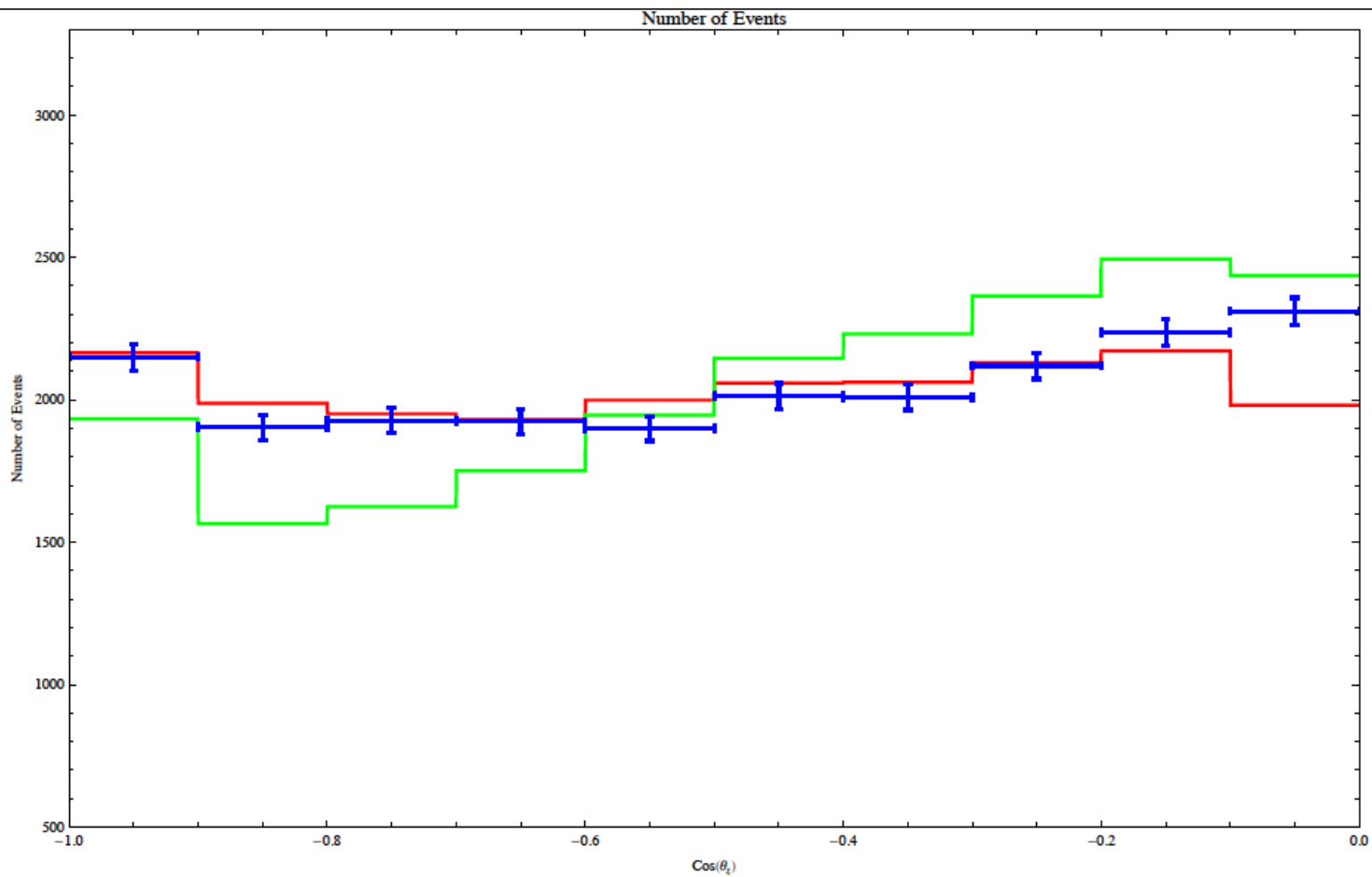


$\sin^2\theta_{14}=0.000$
 $\sin^2\theta_{24}=0.100$
 $\sin^2\theta_{34}=0.450$
 $\Delta m^2_{41}=0.4 \text{ eV}^2$
 $\chi^2=326.895$
 $\chi^2_{\text{red}}=320.294$

— No Sterile

— Sterile

• Data



$\sin^2\theta_{14}=0.000$

$\sin^2\theta_{24}=0.100$

$\sin^2\theta_{34}=0.500$

$\Delta m^2_{41}=0.4 \text{ eV}^2$

$\chi^2=241.386$

$\chi^2_{\text{red}}=236.818$

— No Sterile

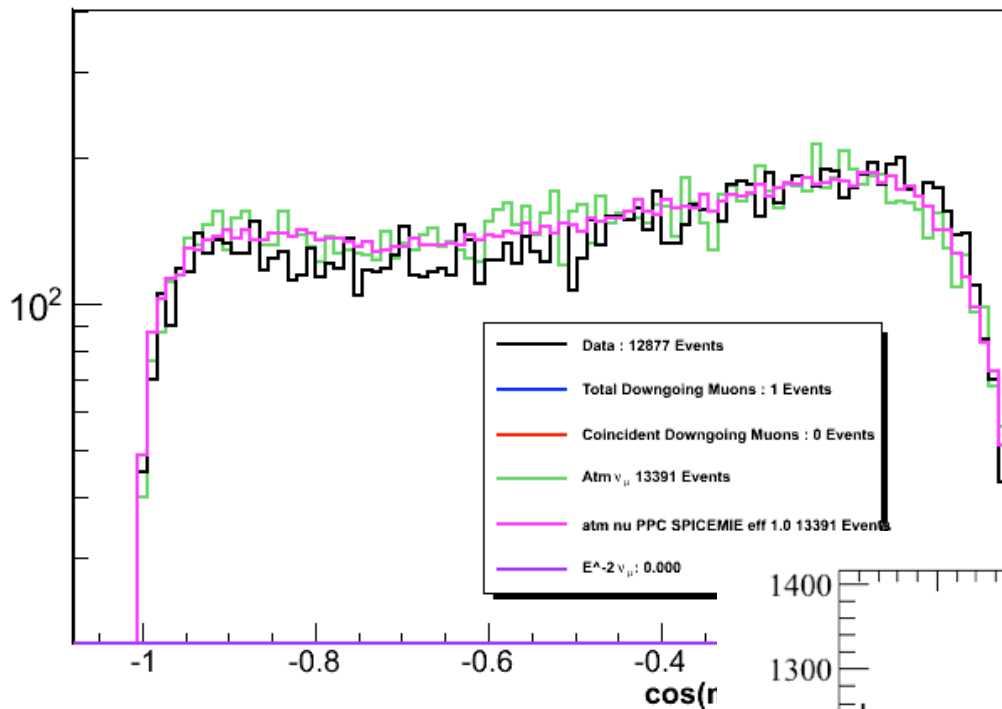
— Sterile

• Data

do not try this at home

The background of the slide is a dark, monochromatic composition of various overlapping geometric shapes. These shapes, including rectangles and squares, are rendered in different shades of gray and are semi-transparent, creating a layered, three-dimensional effect. The shapes are scattered across the frame, with some appearing larger and more prominent than others, all set against a dark, almost black, background.

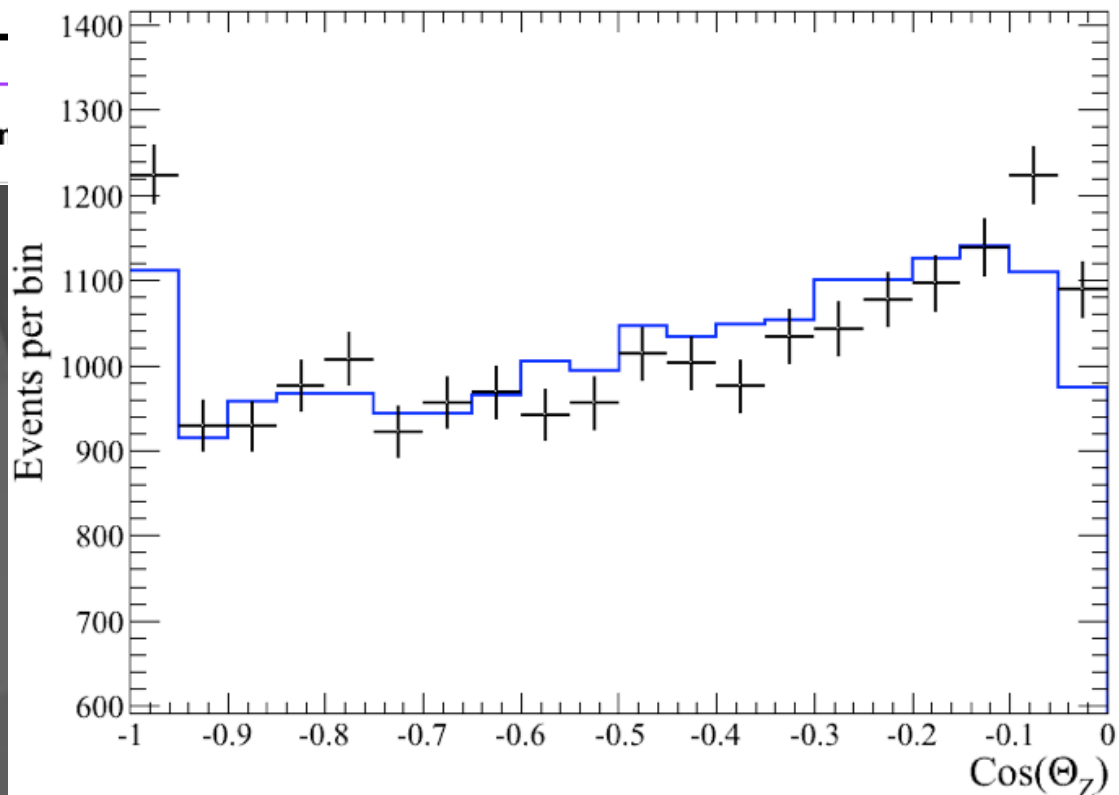
nugenHist



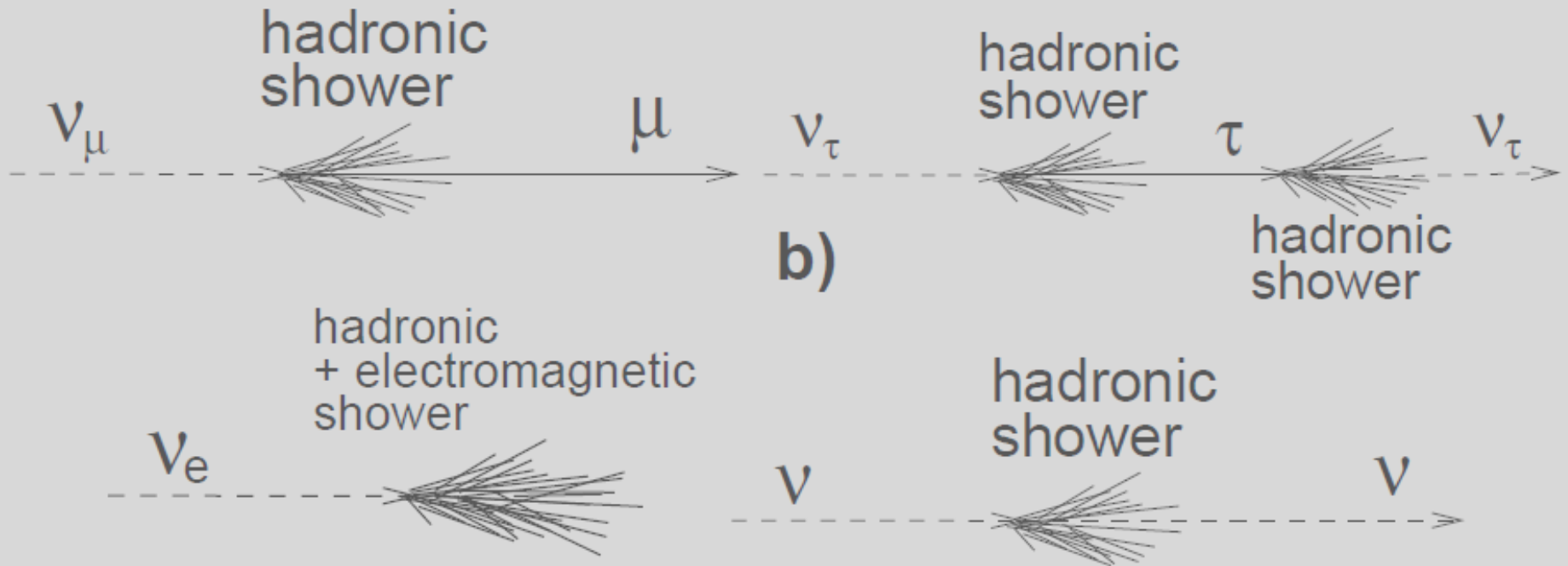
zenith angle
two analyses

SYSTEMATICS !!!

- K/π ratio
- zenith acceptance of modules
- ice
- CR flux, composition
[IceTop helps]

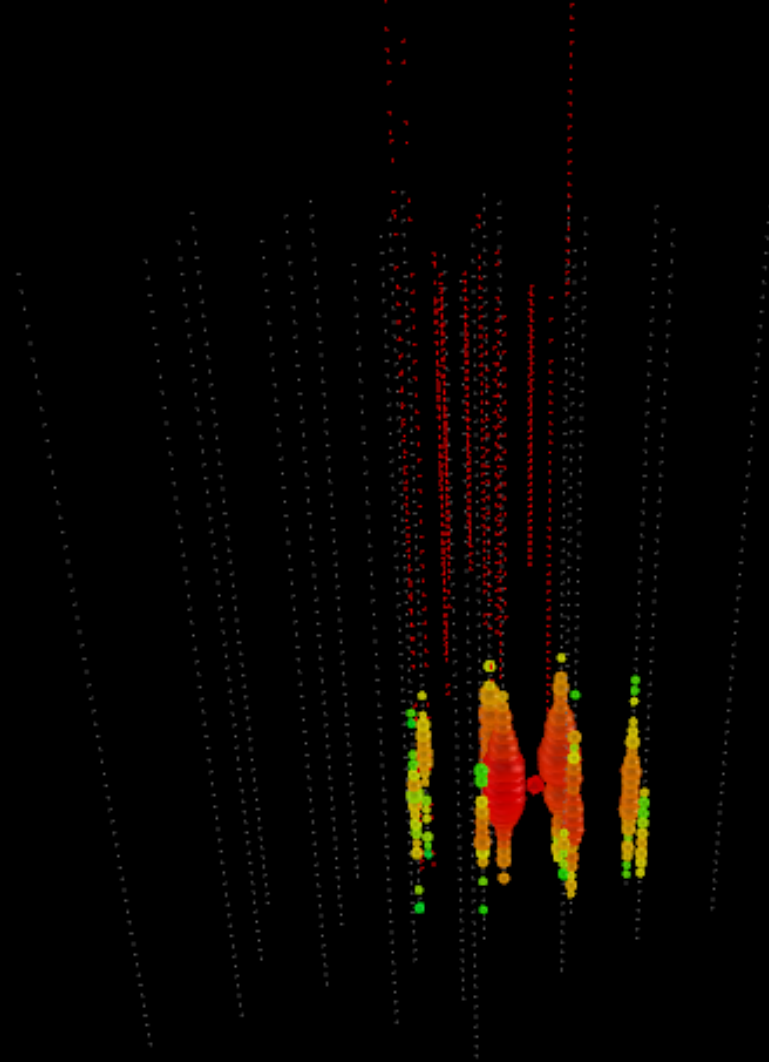


neutrino flavors

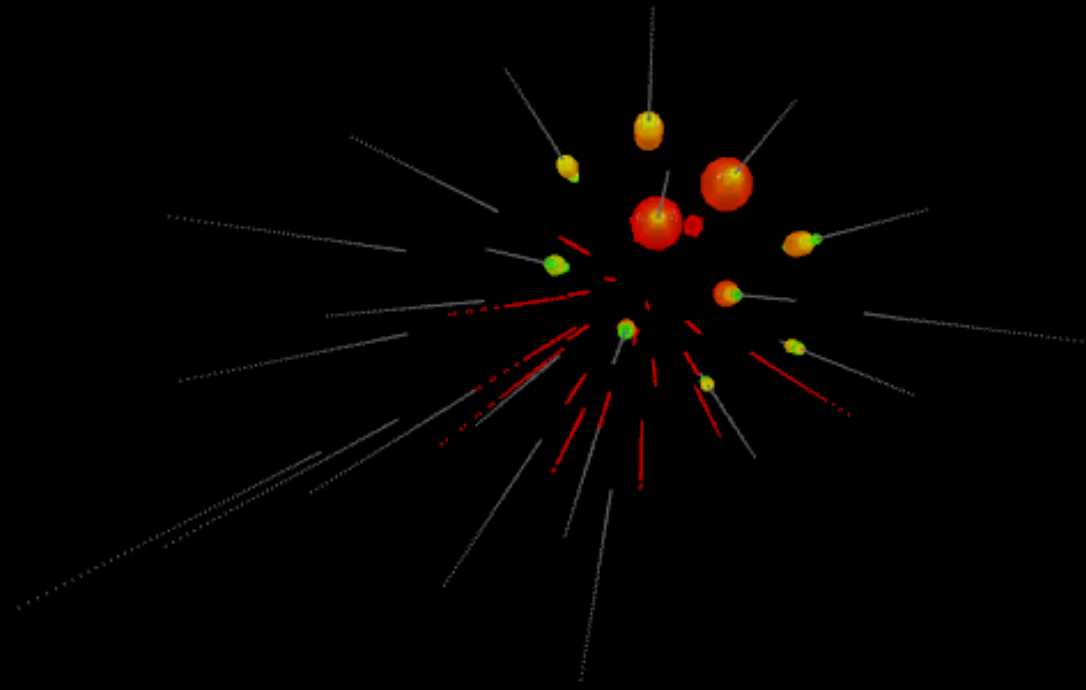


(also ν_e appearance)

electron neutrino



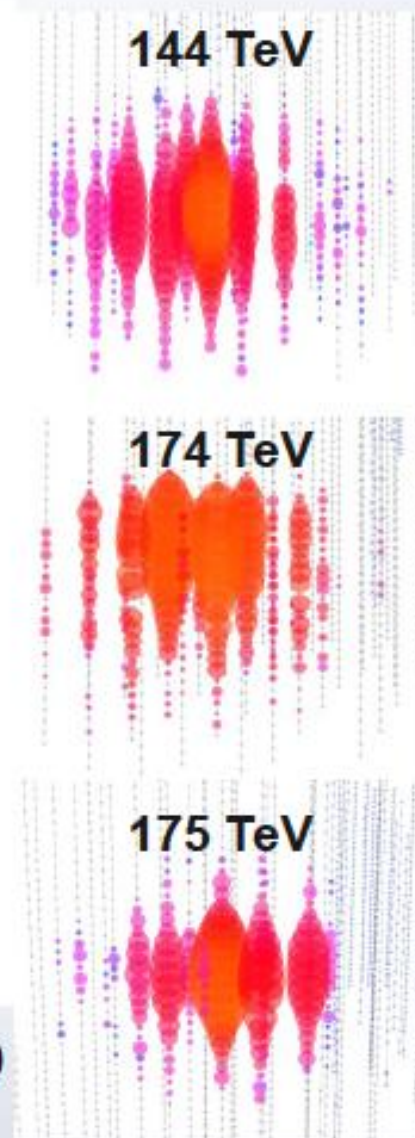
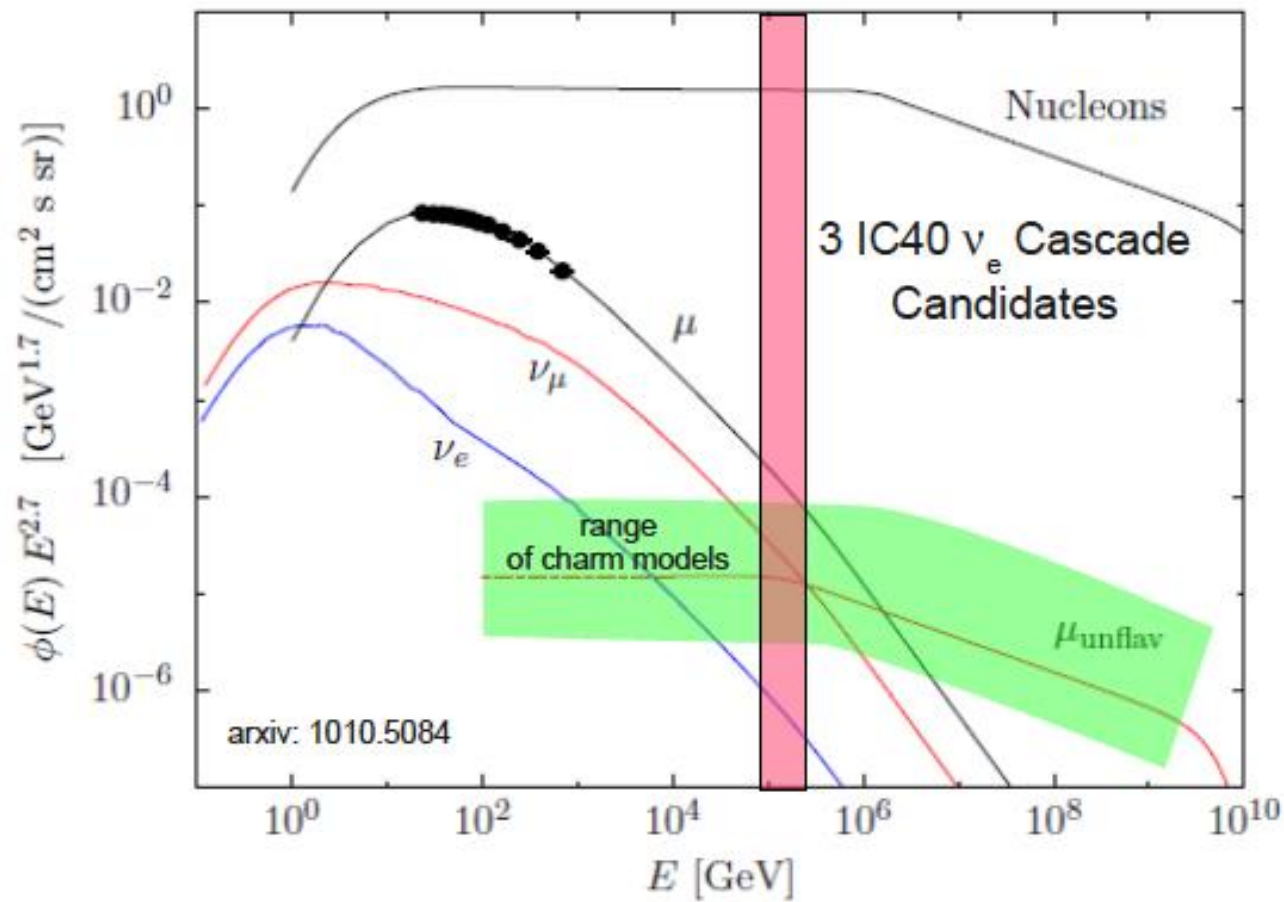
Run 109655 Event 4490744 [0ns, 12349ns]



IceCube 40:

seen: 14 events

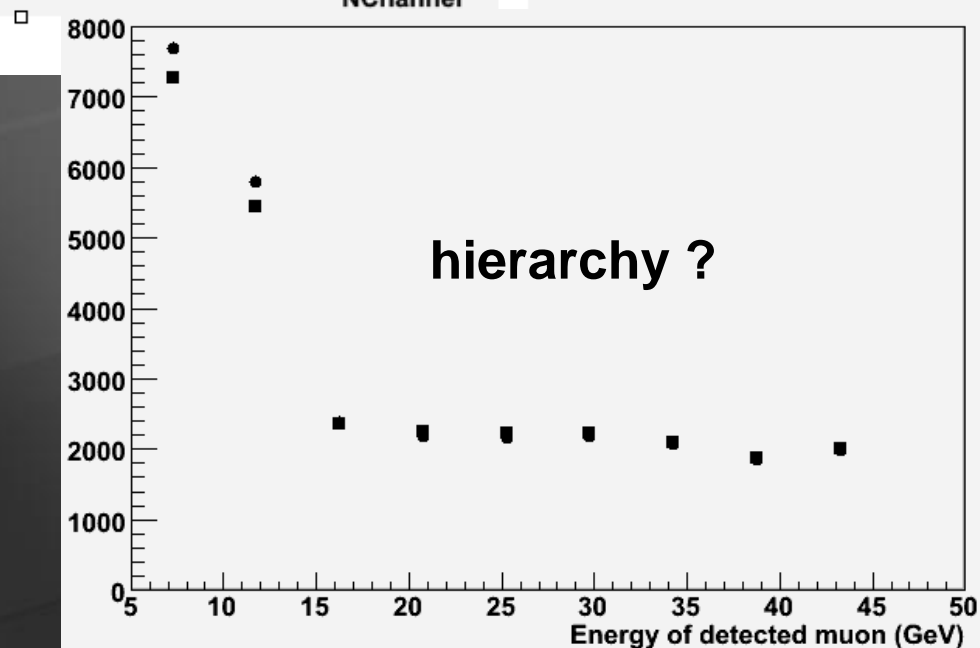
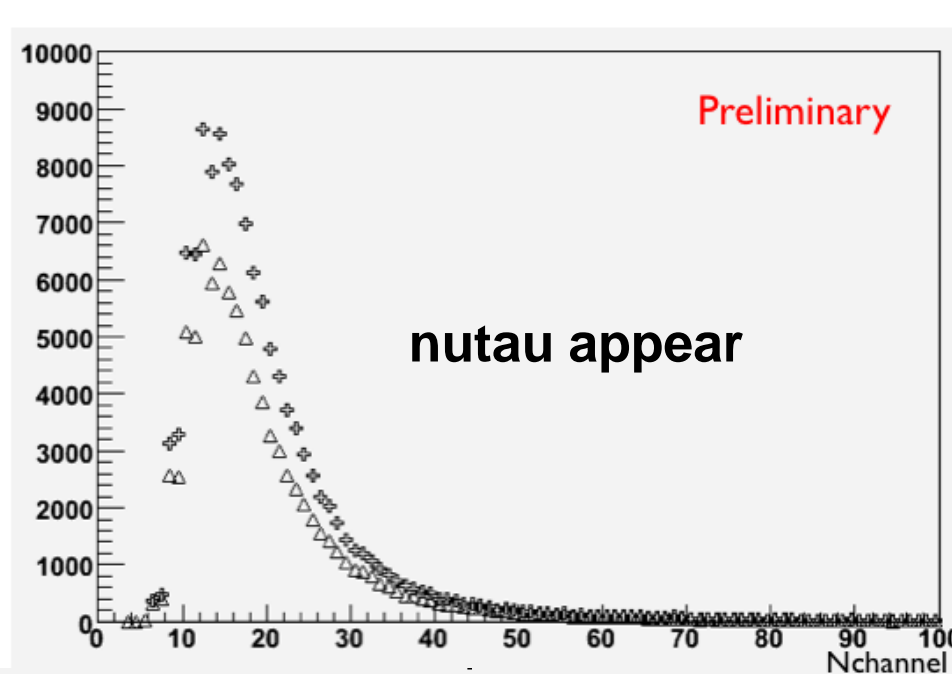
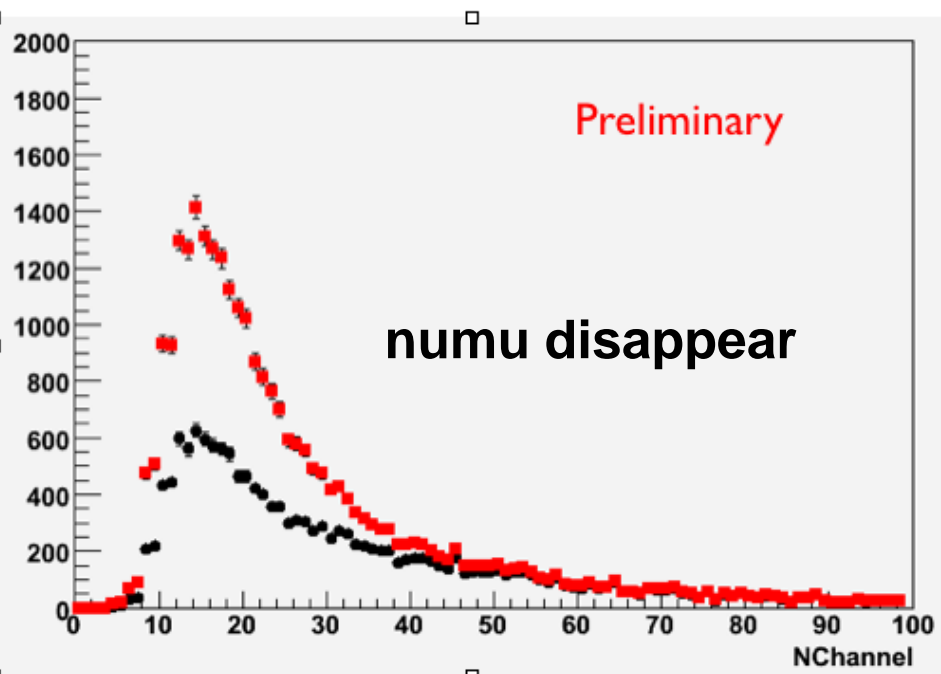
predicted: 3 atmospheric ν and 4 μ background



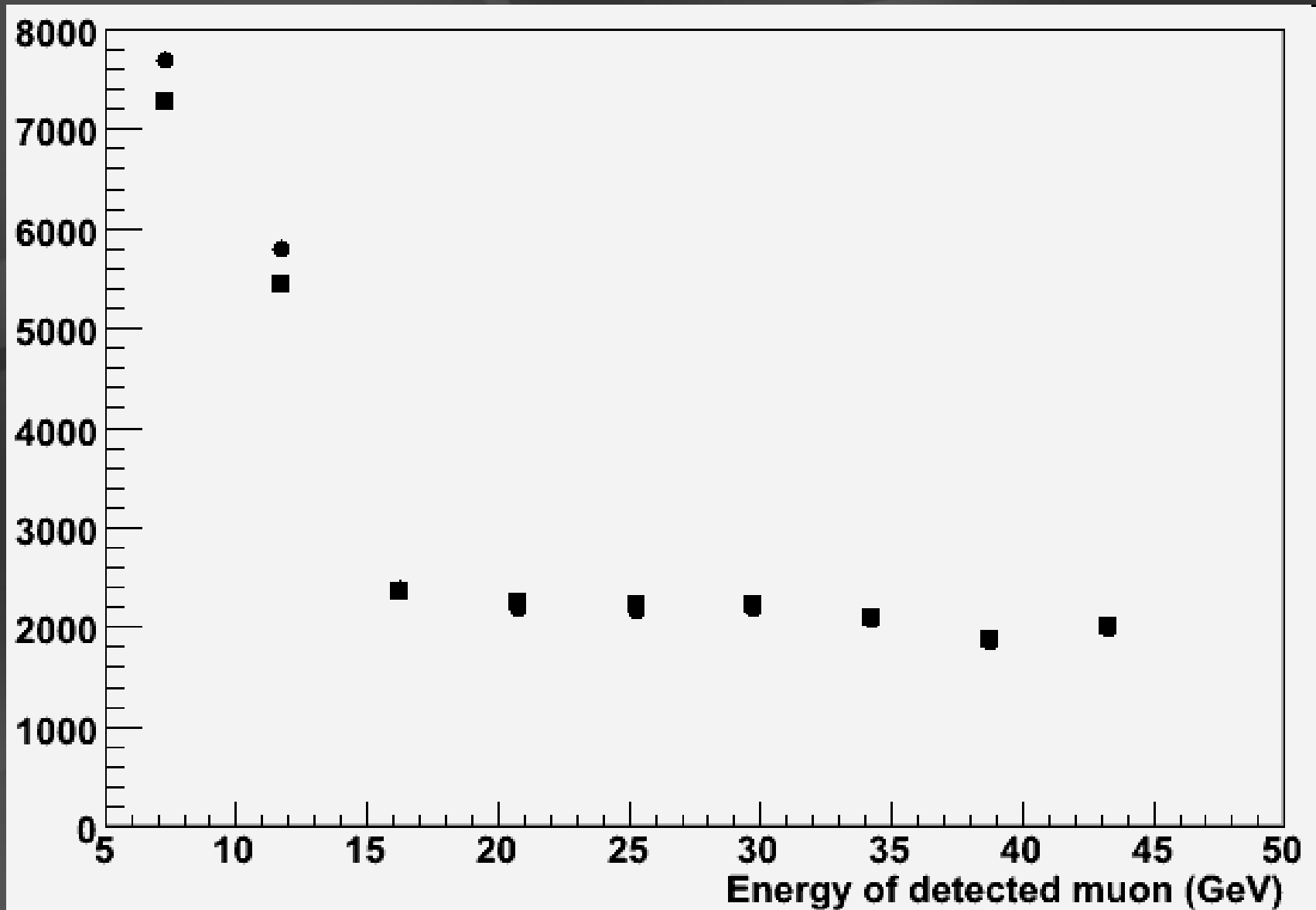
Three strong ν_e candidate events above 100 TeV in IC40 (+1 in IC22)

Conclusions:

- DeepCore has seen cascades (and oscillations)
- IceCube will have something to say about eV sterile neutrinos
- do this at home (webpage with data and effective areas on public webpage after publication— AMANDA and IceCube 40 available)



hierarchy by statistics?



**~ 10 GeV : hierarchy from matter effects
in the Earth near first absorption dip**

$$\sin^2 2\theta_{13}^m = \frac{\sin^2 2\theta_{13}}{\sin^2 2\theta_{13} + \left(\cos 2\theta_{13} \pm \frac{\sqrt{2G_F N_e}}{\Delta_{13}} \right)^2}$$

(mostly) neutrino + antineutrino -

sign Δ_{13} : hierarchy !