From AMANDA to PINGU: an on-going journey

Elisa Resconi, TU Munich
for the IceCube Collaboration (which includes PINGU).
I acknowledge useful discussion with A. Palazzo, D. Franco, A. Meregaglia

Catania, LNS. Date: 6.12.2012

Content

- AMANDA as first low energy extension (>100 GeV)
- IceCube/DeepCore: the present (~50 GeV - PeV)
- IceCube/DeepCore/PINGU: the future ? (~1 GeV - PeV)
- Ideas for sensitivity calculations (work on-going)

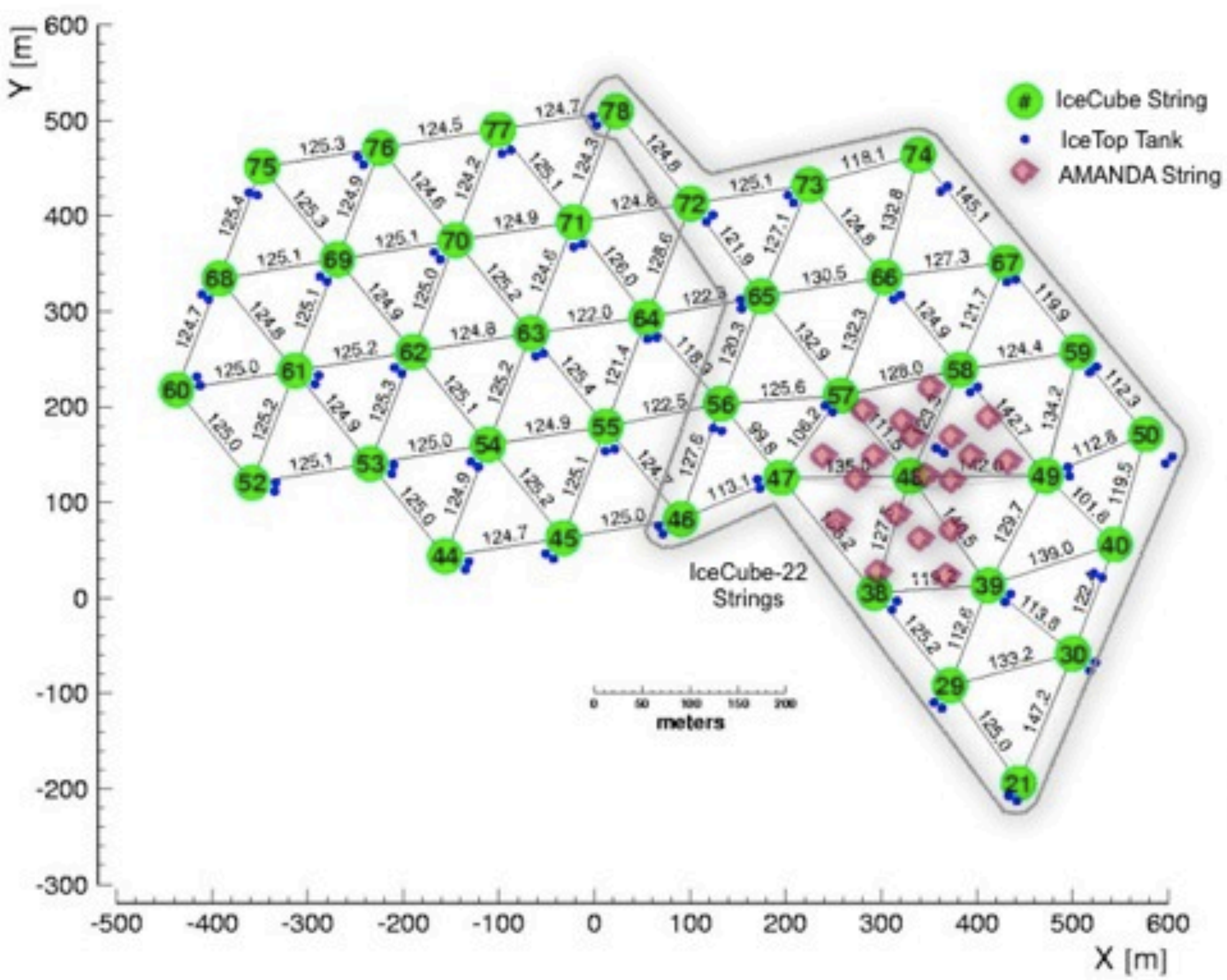
WARNING: IN THIS PRESENTATION VARIOUS ICECUBE NON-OFFICIAL PLOTS ARE USED FOR ILLUSTRATION PURPOSE. THEY ARE NOT MEANT TO BE CIRCULATED TO A LARGER GROUP.

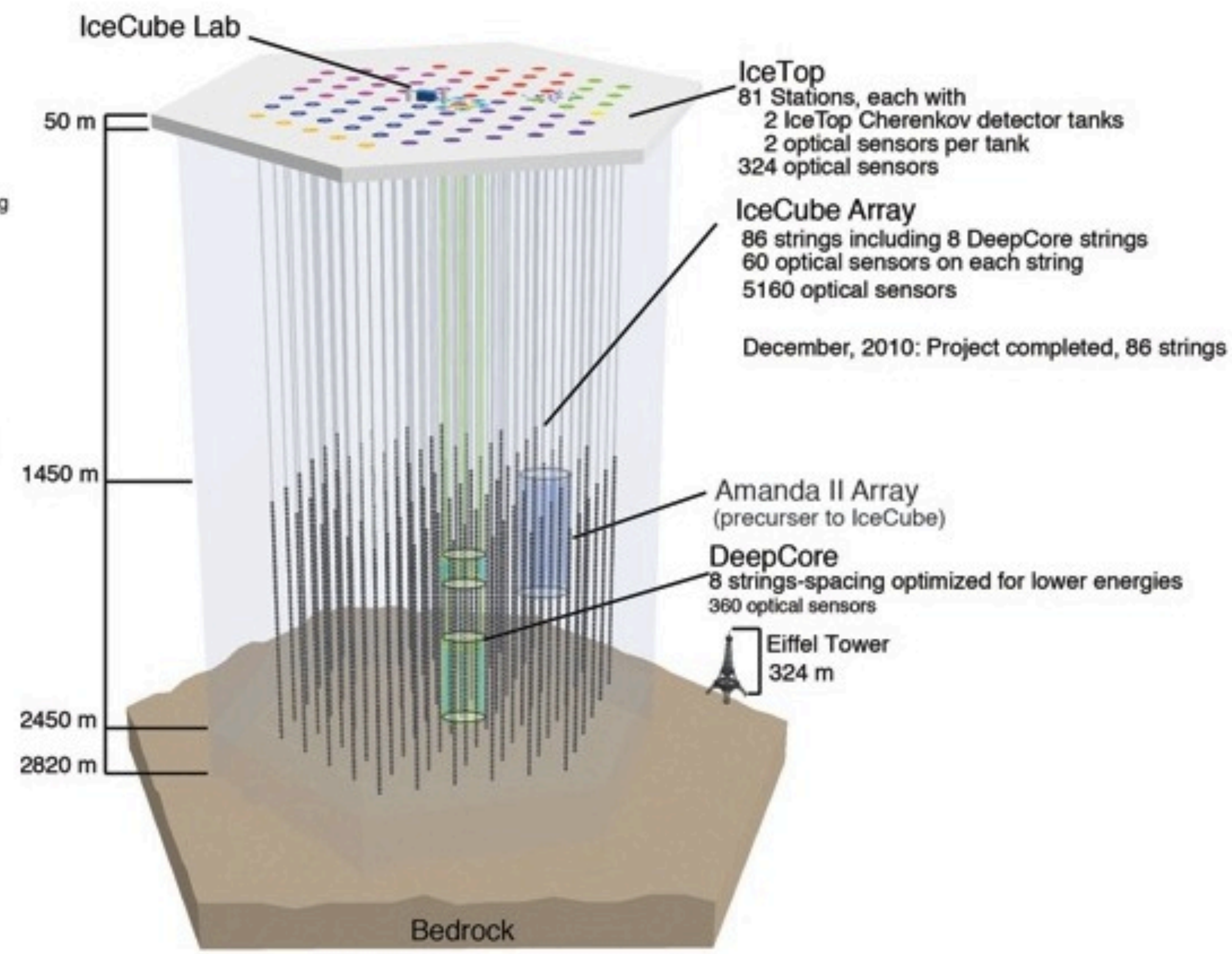
AMANDA as first low energy extension

- First IceCube strings impact on AMANDA reconstruction
- Effective area
- Containment
- Impact on point source
- Impact on dark matter searches

AMANDA as first low energy extension

19 strings with a total of 677 Optical Modules (OMs)





AMANDA as first low energy extension

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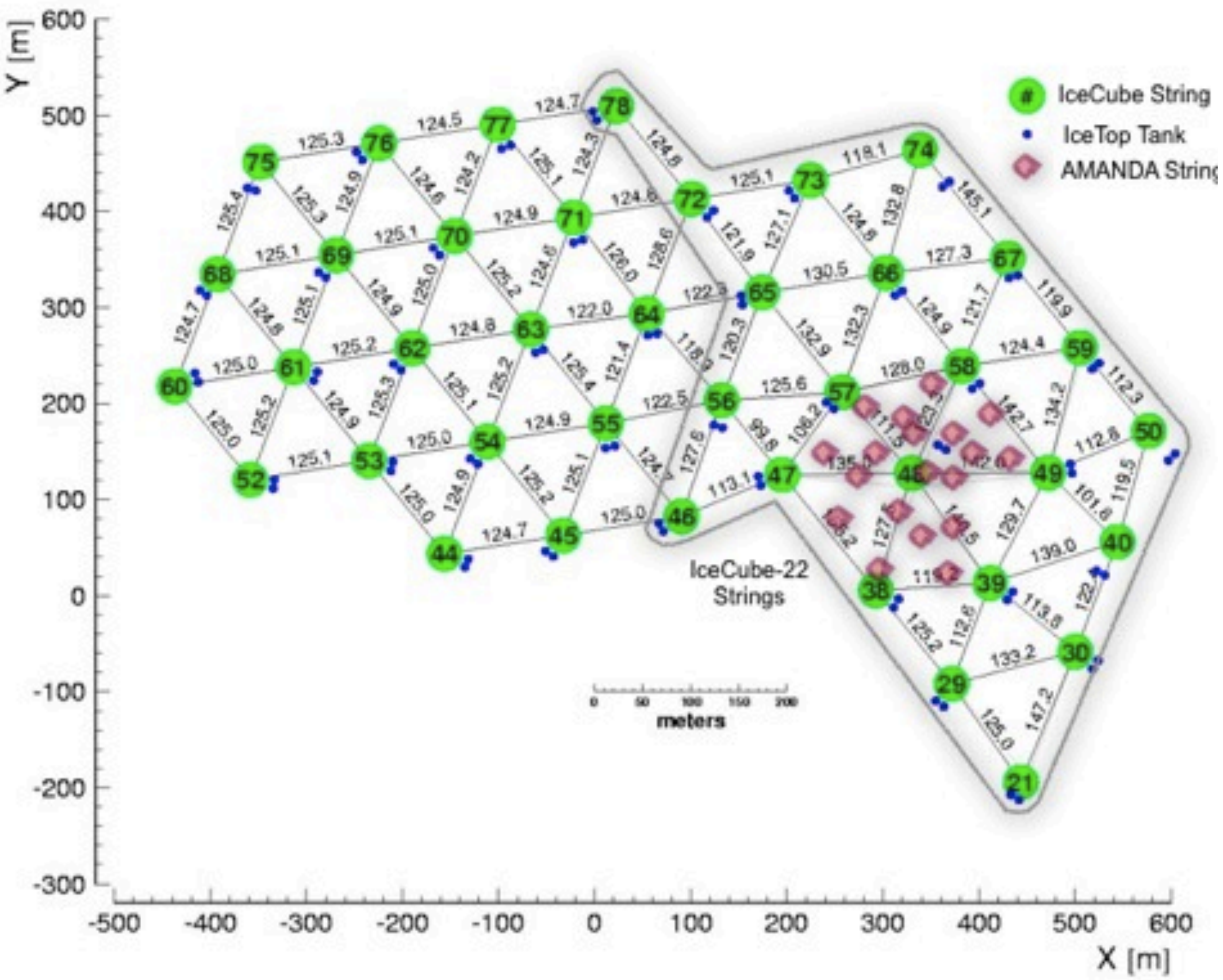
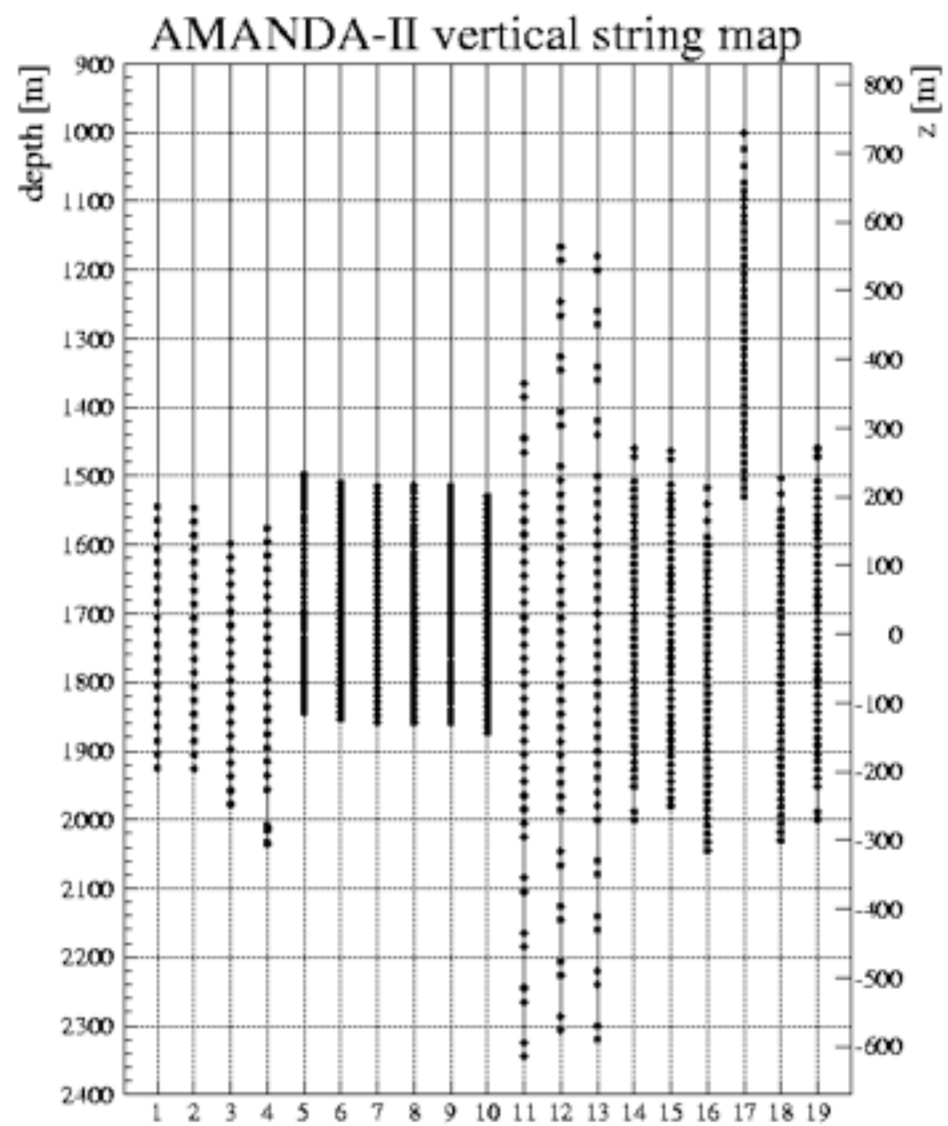
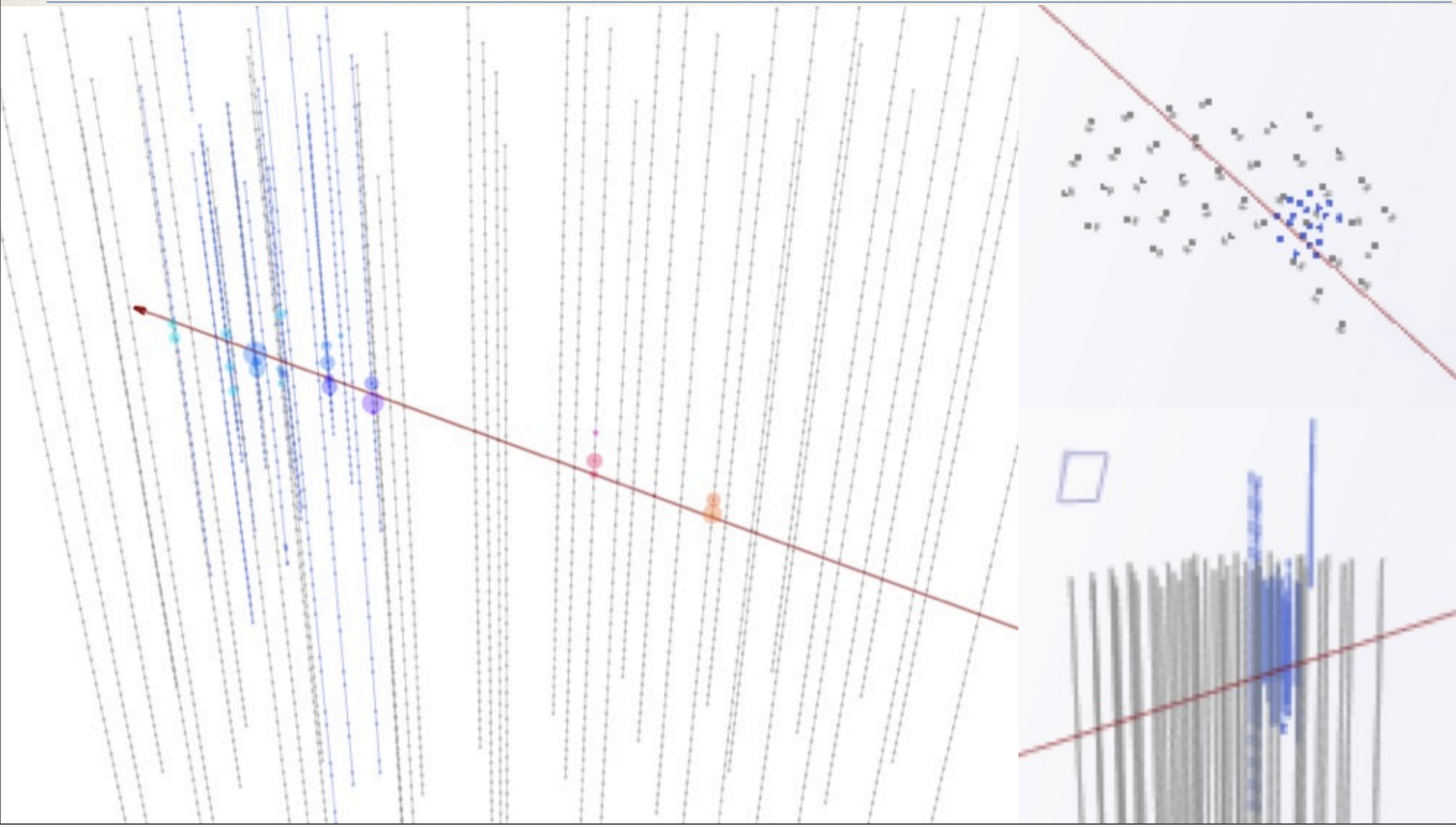




AMANDA into IceCube (2006-2008)



AMANDA+IC22/IC40 energy range

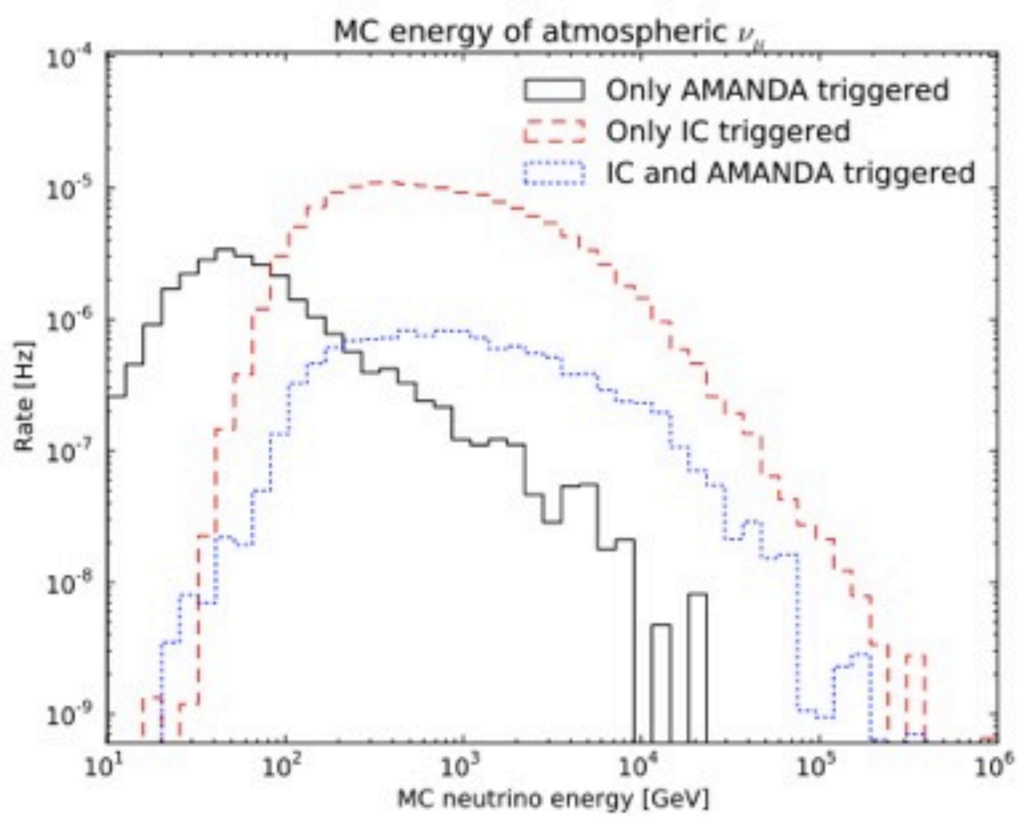
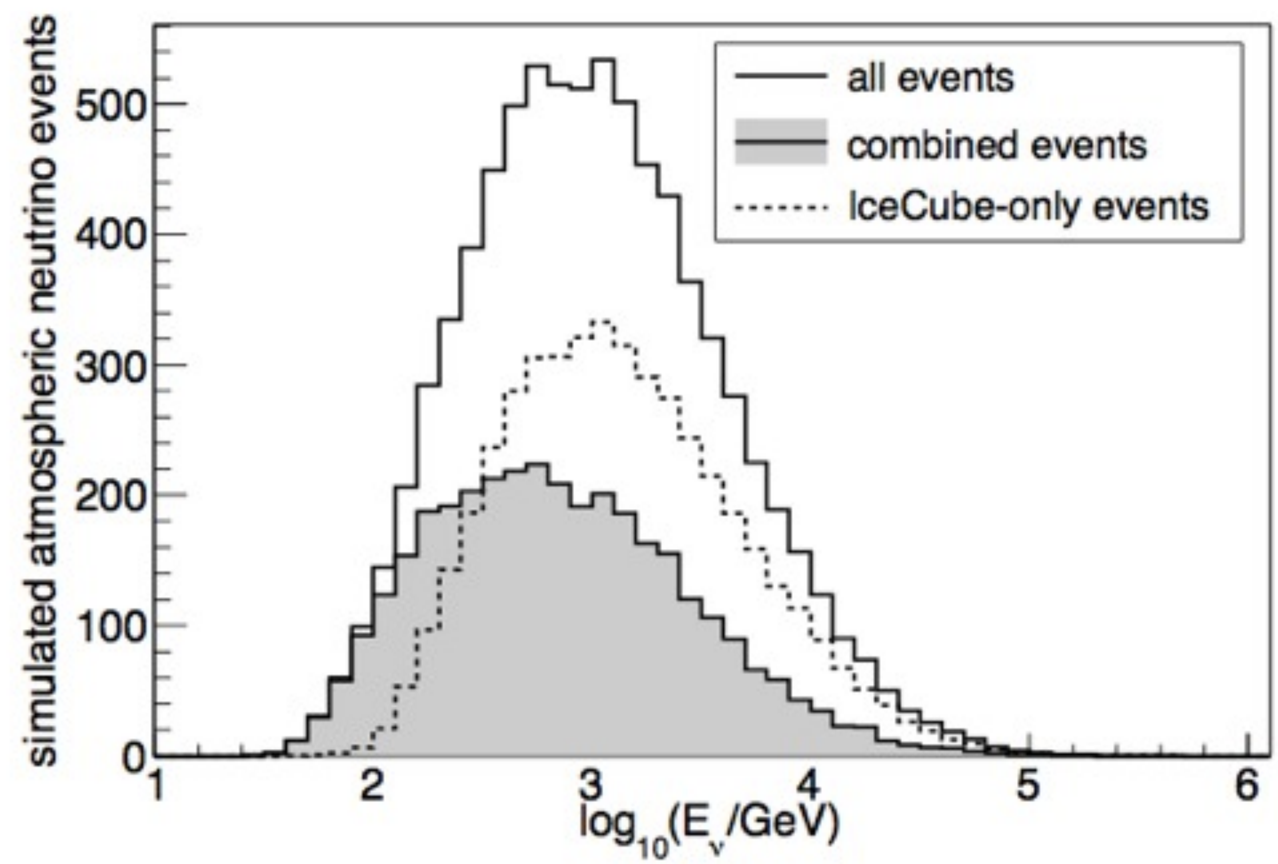


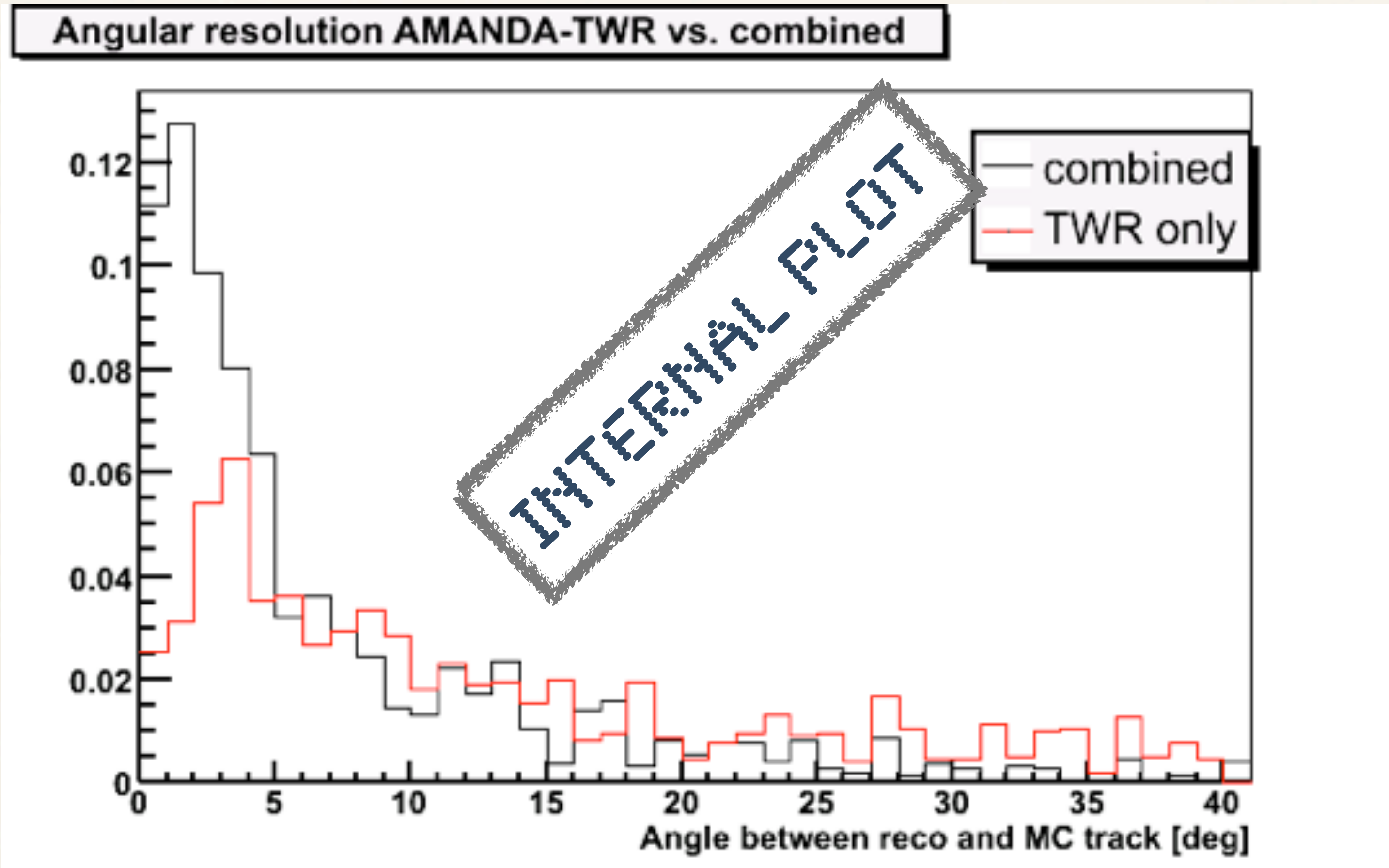
FIG. 2. Monte Carlo neutrino energy distribution at final level of Analysis B, of the events triggering only AMANDA–II (full line), only IceCube (dashed line) or both detectors (dotted line).



AMANDA+IC22, The IceCube Coll. , arXiv: 1210.3273, accepted in ApJ

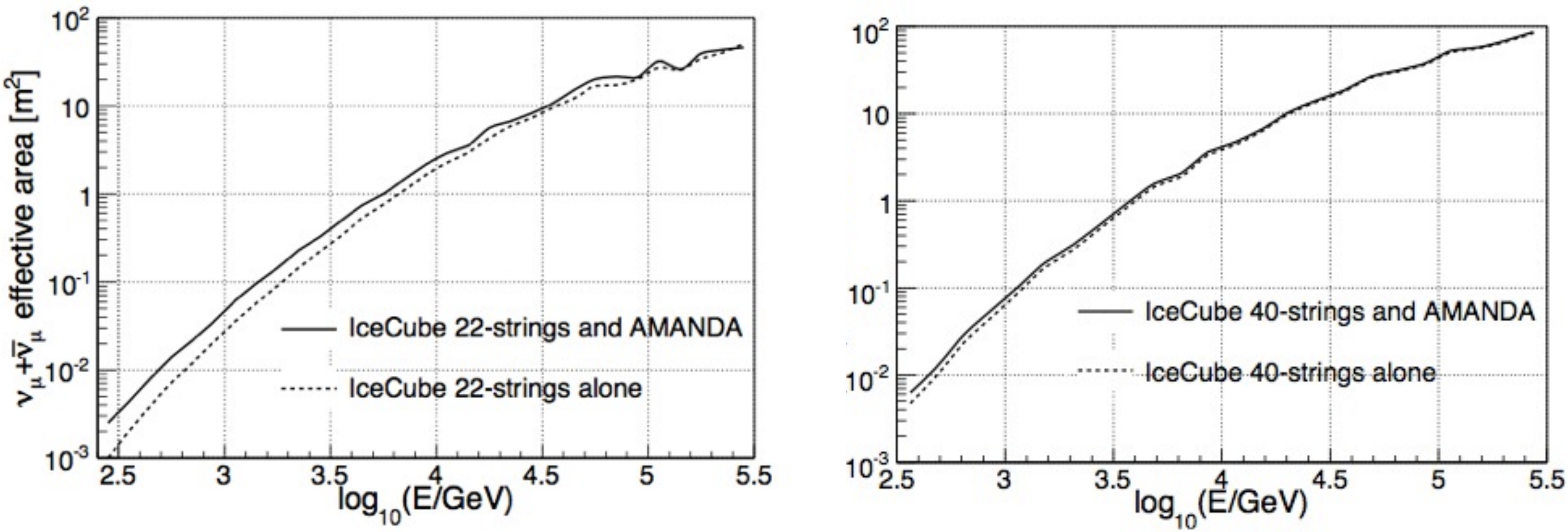
The IceCube Coll., PRD85 (2012) 042002, arXiv:1112.1840.pdf

AMANDA+IC22/IC40 reconstruction

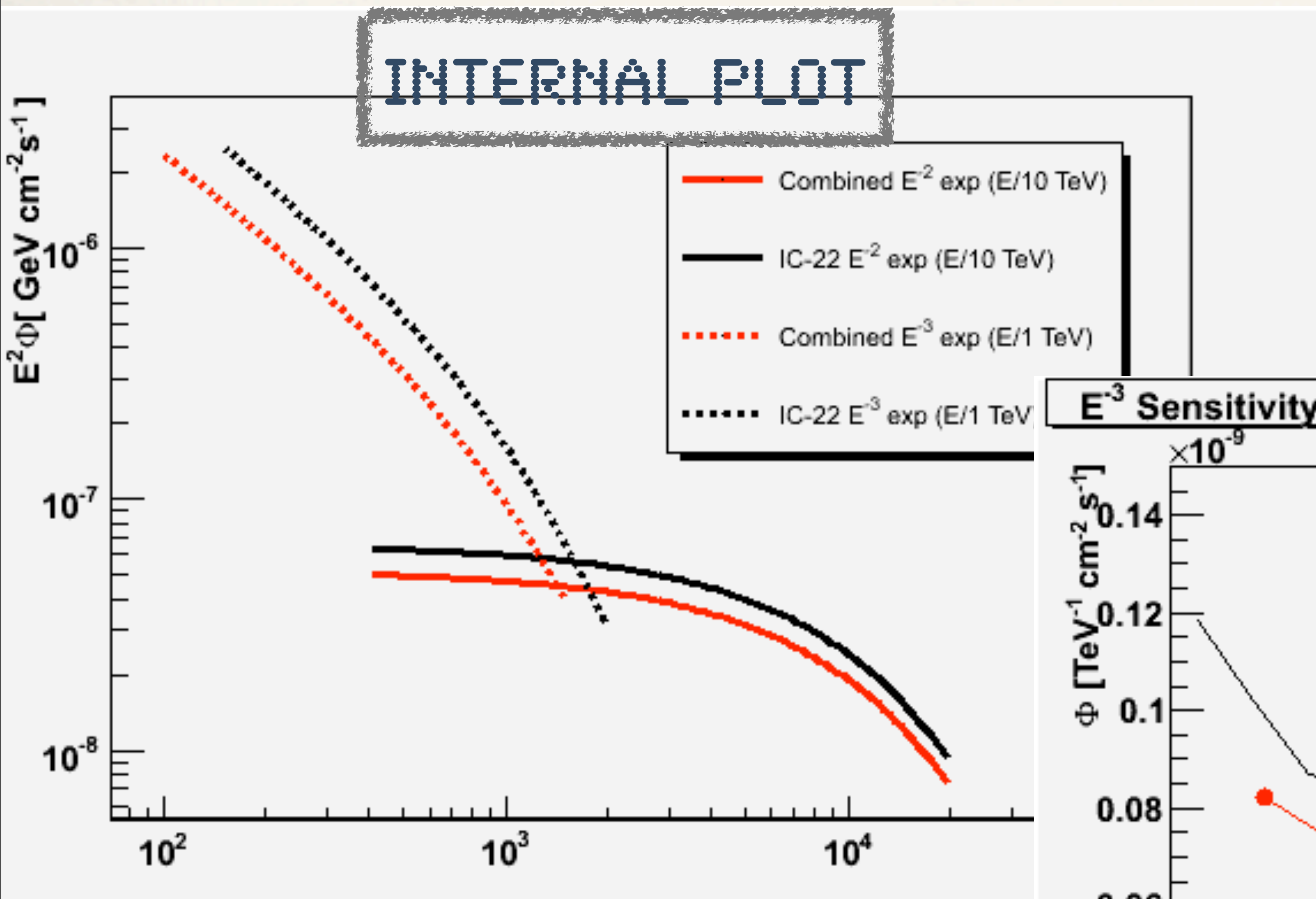
- The longer lever arm of the IceCube first strings had an impact
- 

AMANDA+IC22/IC40 effective area

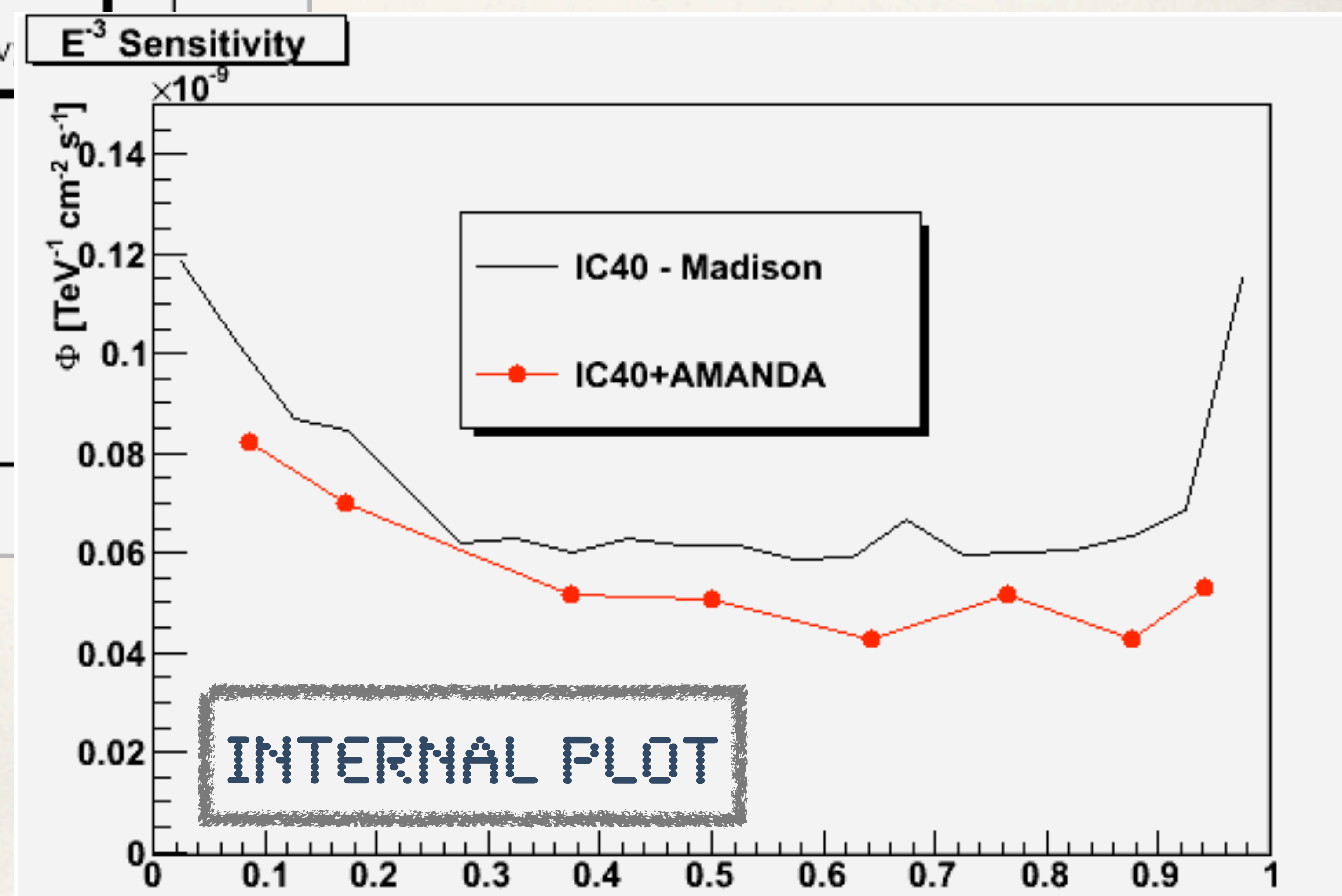
The IceCube Coll. , arXiv:1210.3273, accepted in ApJ



AMANDA+IC22/IC40 sensitivity to soft-spectra point source

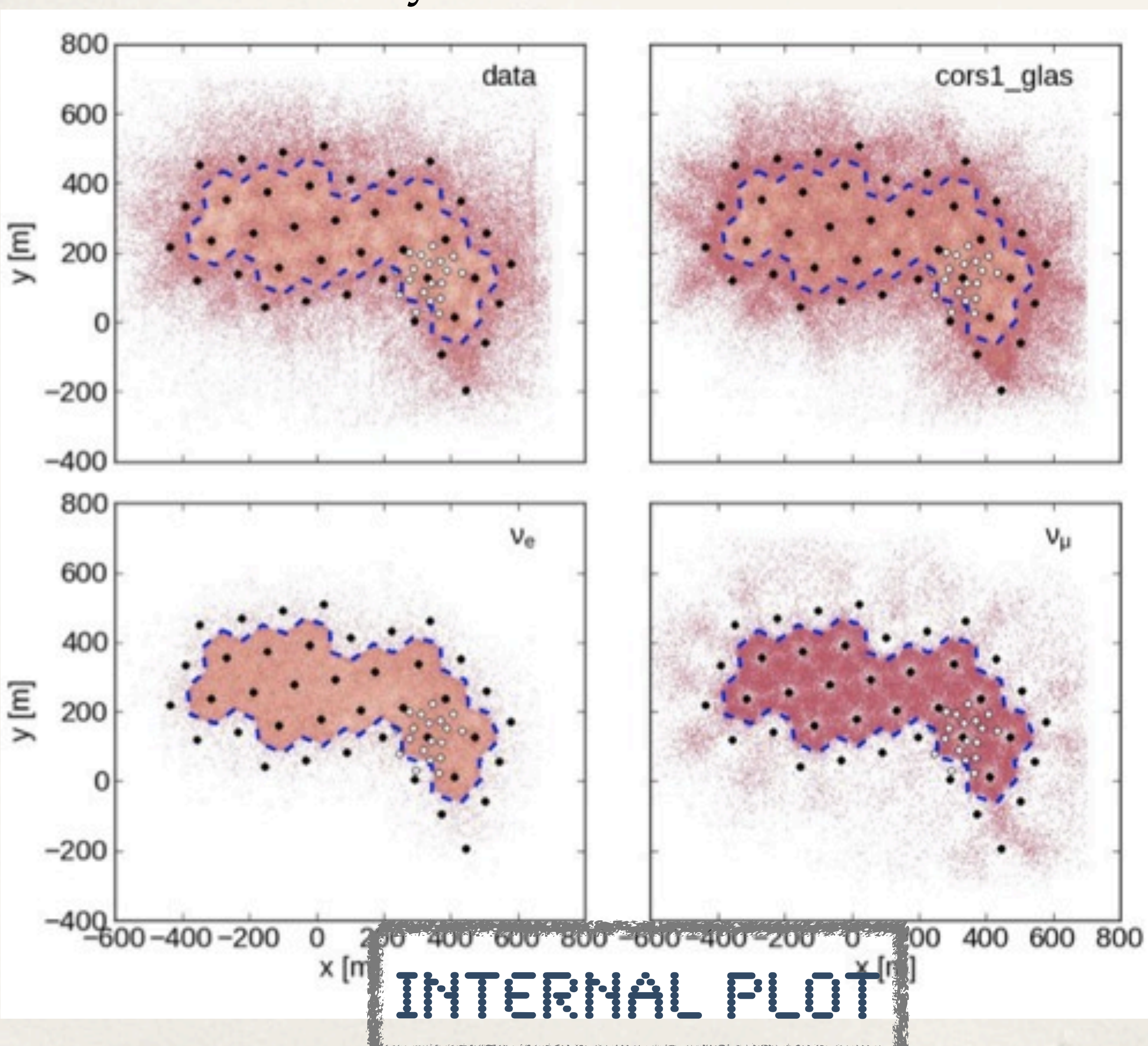


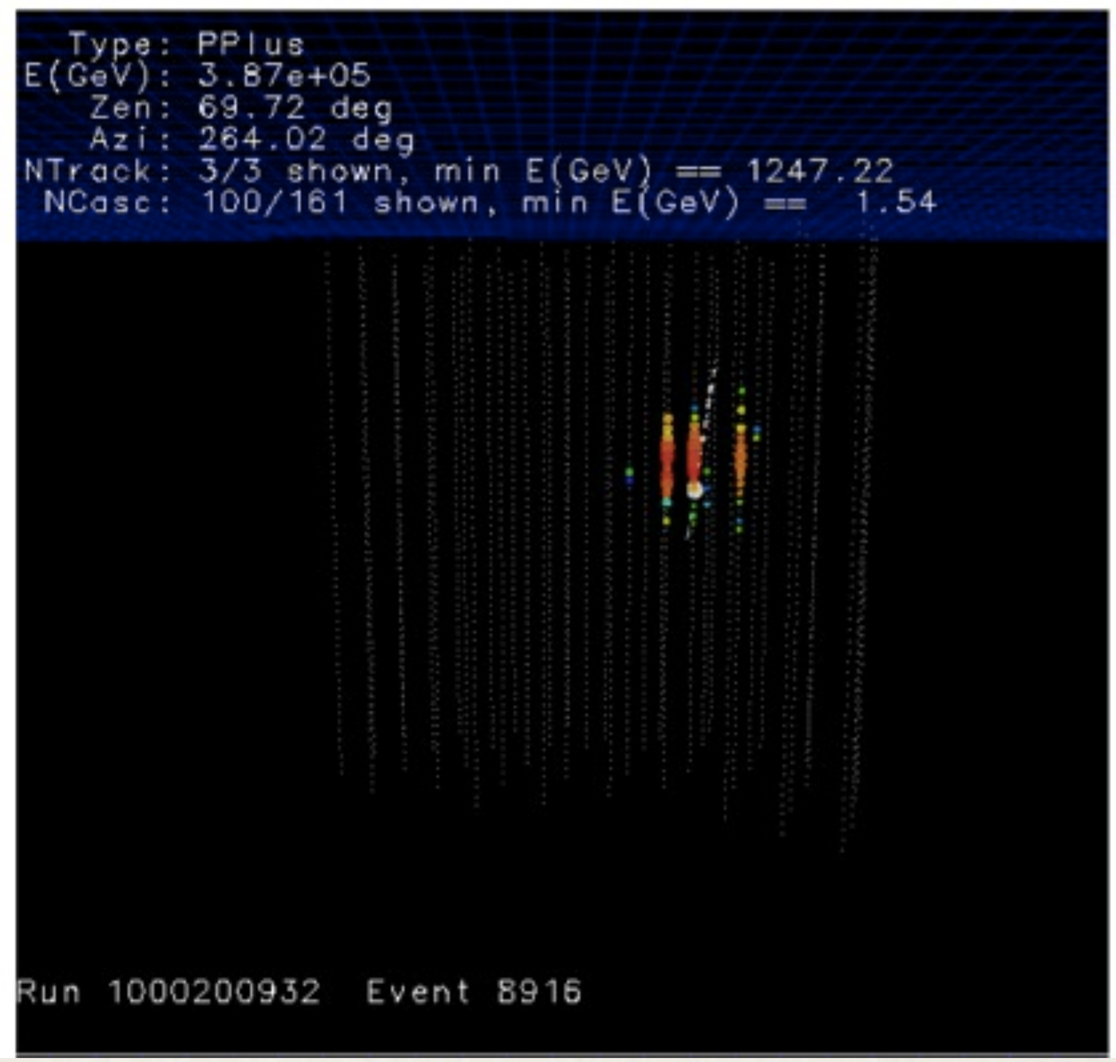
Final results and official plot in:
The IceCube Coll.
arXiv:1210.3273, accepted in ApJ
ADD WIMPS



Fighting atmospheric background by **containment**

- Example: Extensive study on the atmospheric background rejection vs containment for cascade analysis (in this case no AMANDA included), IC40 cascades analysis





surviving Corsika event

AMANDA+IC: lessons learned

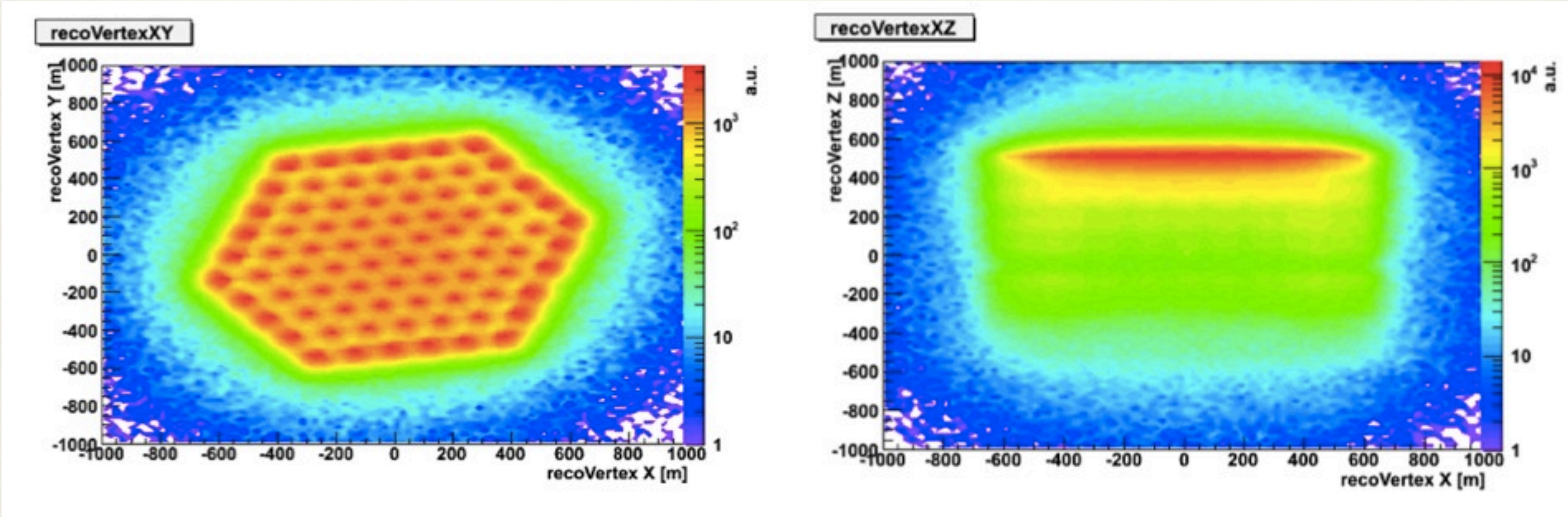
- A neutrino telescope based on different matrixes operates at a larger energy region respect one fix geometry
- Significant effect on reconstruction, background rejection hence sensitivity
- First profound study of containment
- Seeds for DeepCore
- ...

DeepCore

- Rejection of atmospheric background
- The reconstruction of neutrinos
- Electron neutrinos
- Muon neutrino disappearance
- Atmospheric neutrino oscillation
- Systematic uncertainties

DeepCore: Rejection of atmospheric background

Corsika background (IC80) reconstructed vertex



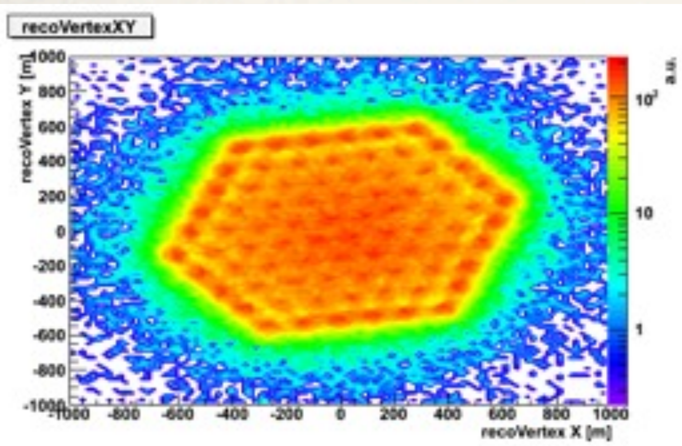
from DeepCore design study meeting in Stockholm, 2008

DeepCore: Rejection of atmospheric background

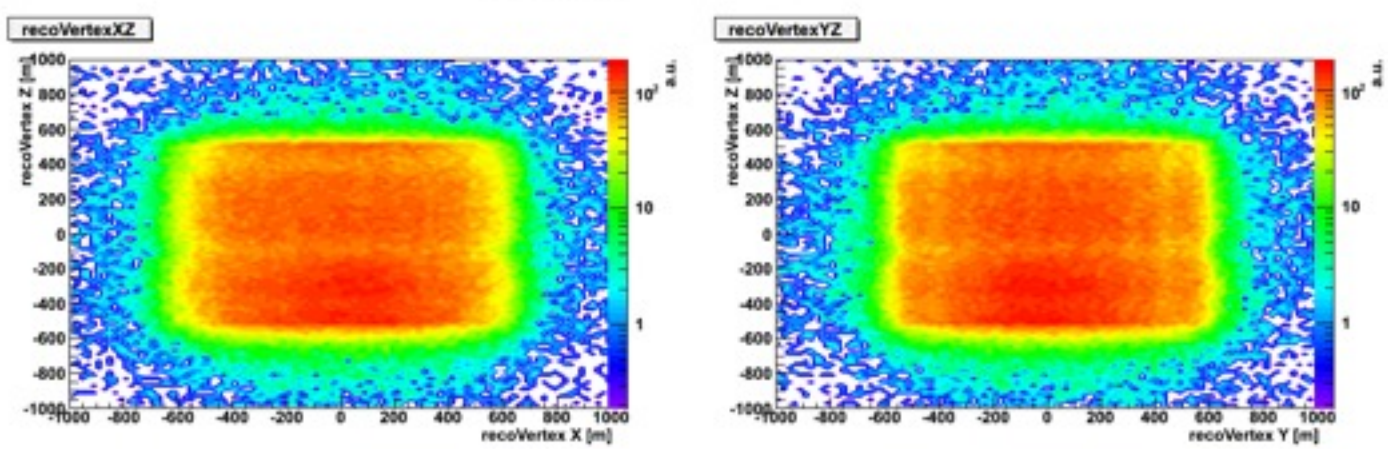
IC80 + 12 strings DeepCore

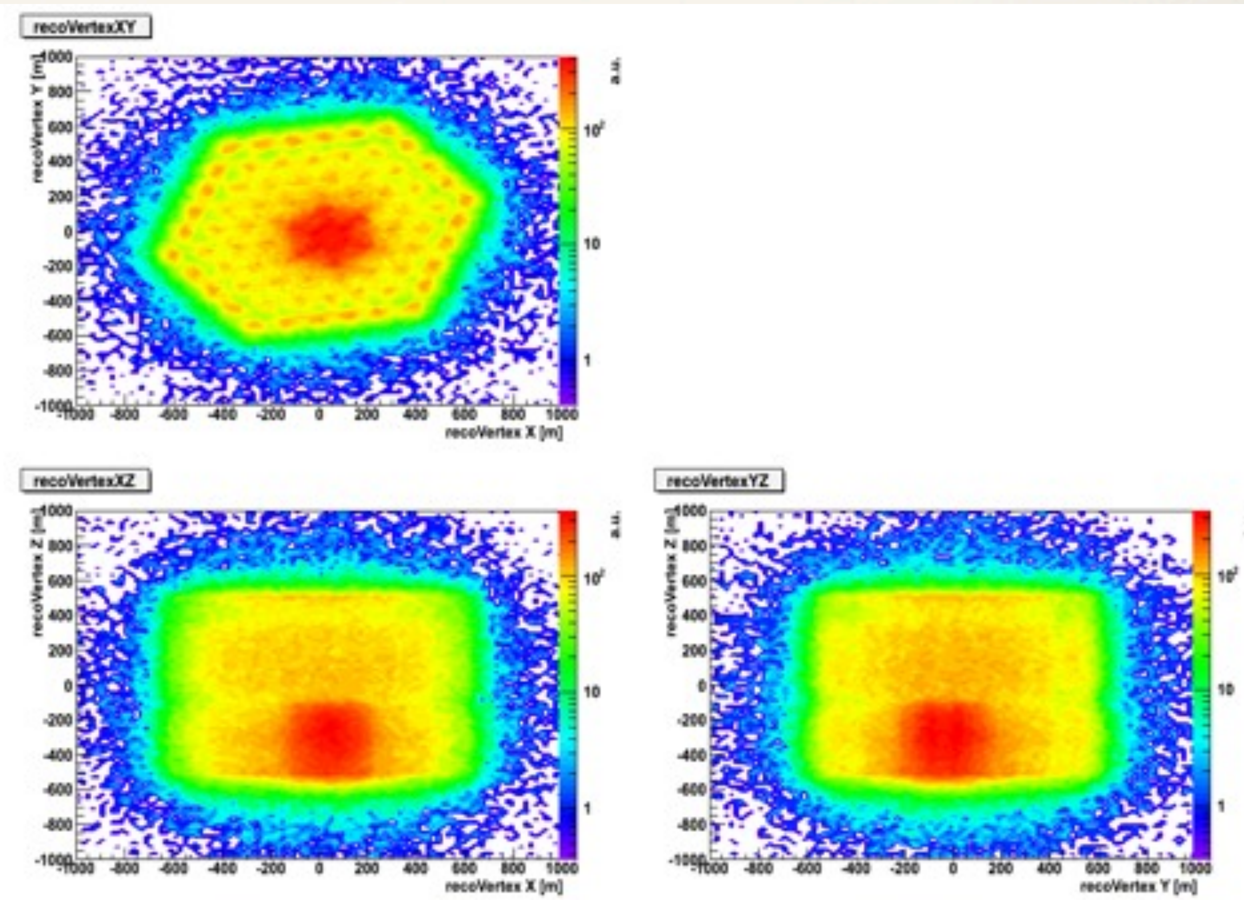
IC80 ν - vertex

ν - vertex



- MonteCarlo simulation
- 4π neutrino simulation
- E [5 GeV – 50 TeV]
- E $^{-2}$ spectrum

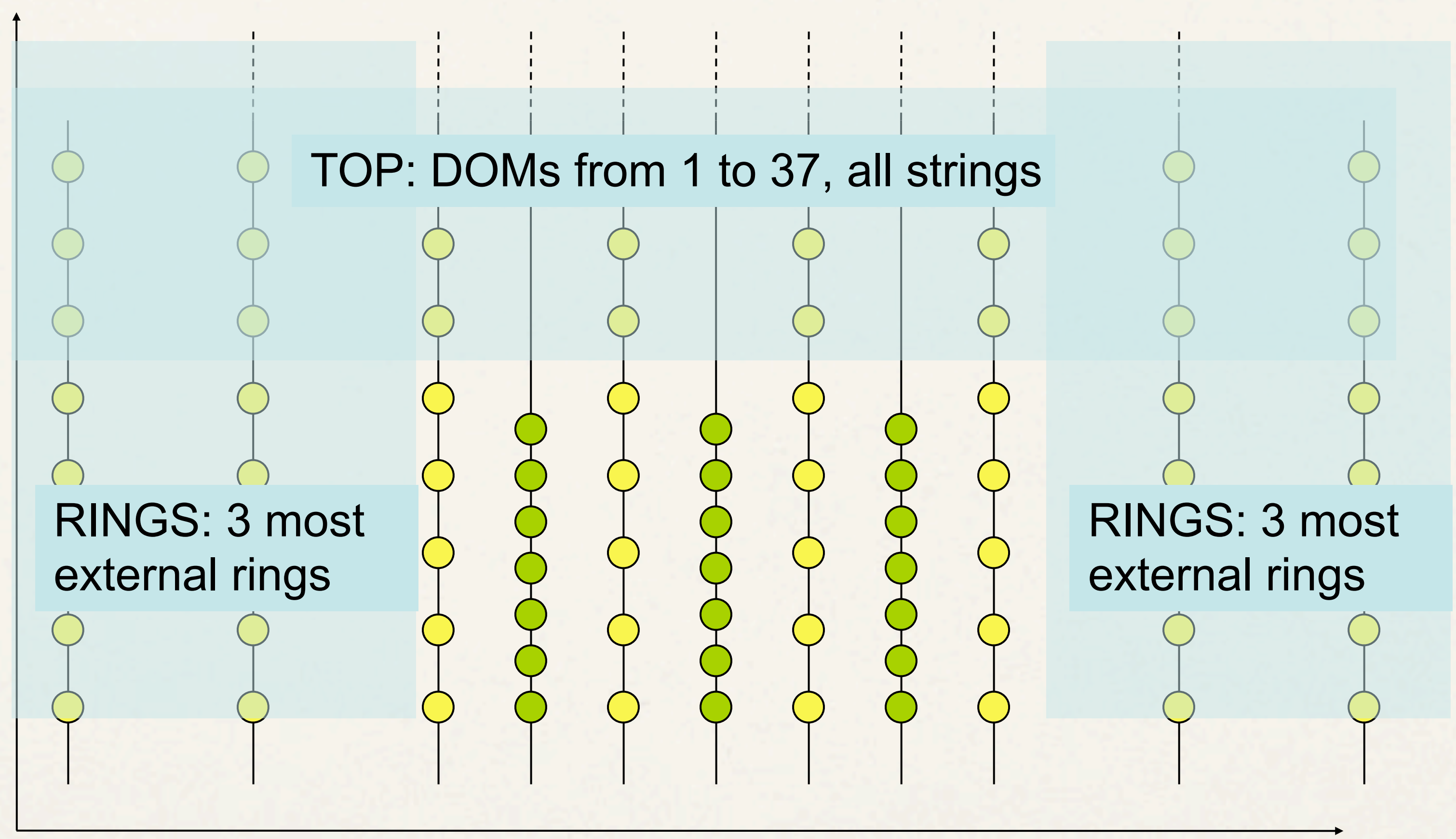




from DeepCore design study meeting in Stockholm, 2008

DeepCore: Rejection of atmospheric background

Containment cuts: enough for the reduction of the first 3 - 4 order of magnitude atmospheric background

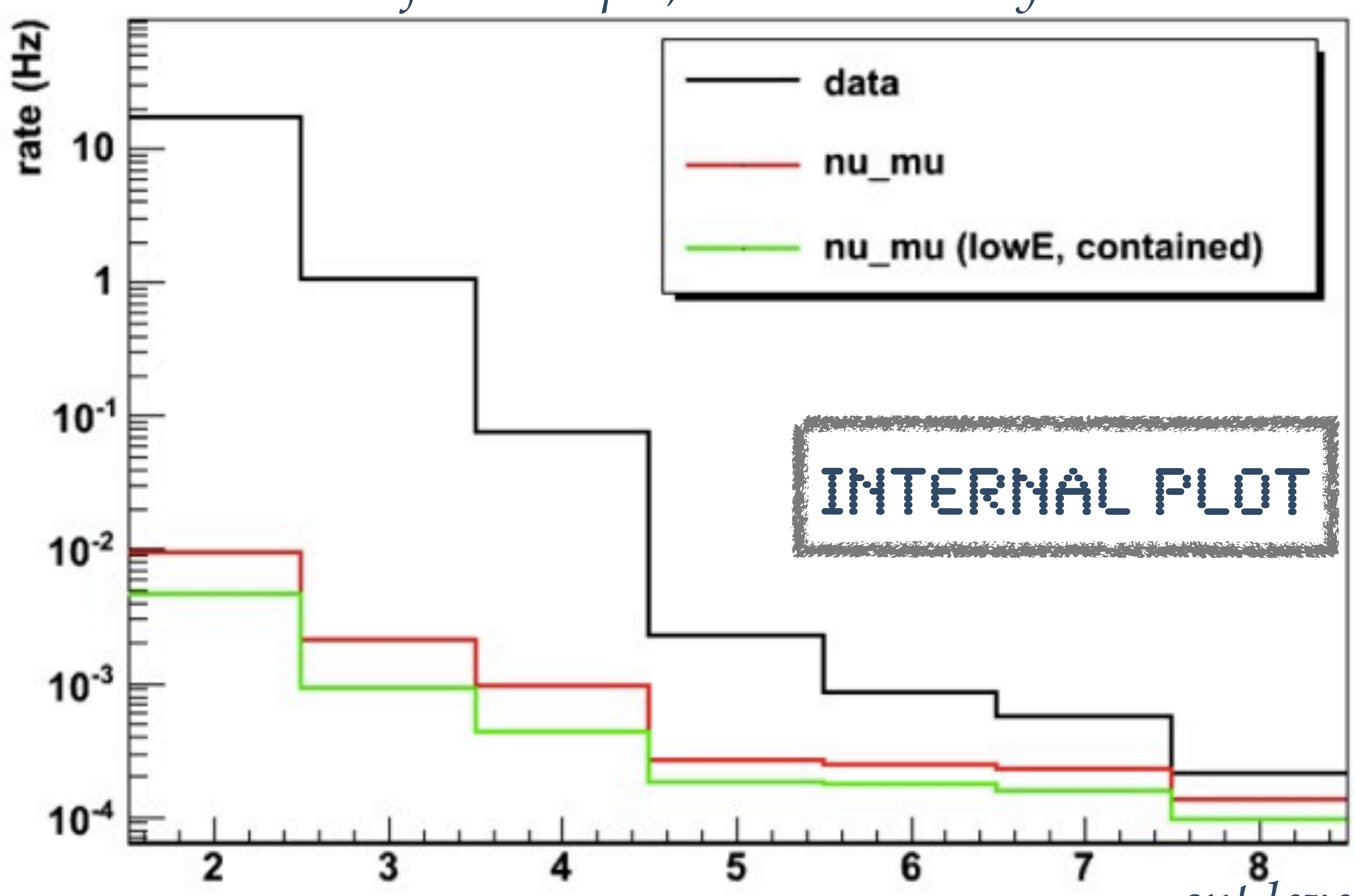


from DeepCore design study meeting in Stockholm, 2008

DeepCore: Rejection of atmospheric background

Containment cuts: reduction of the first 3 - 4 order of magnitude atmospheric background.
Various study performed in this direction, new variables at mature stage.

for example, IC79 DC study



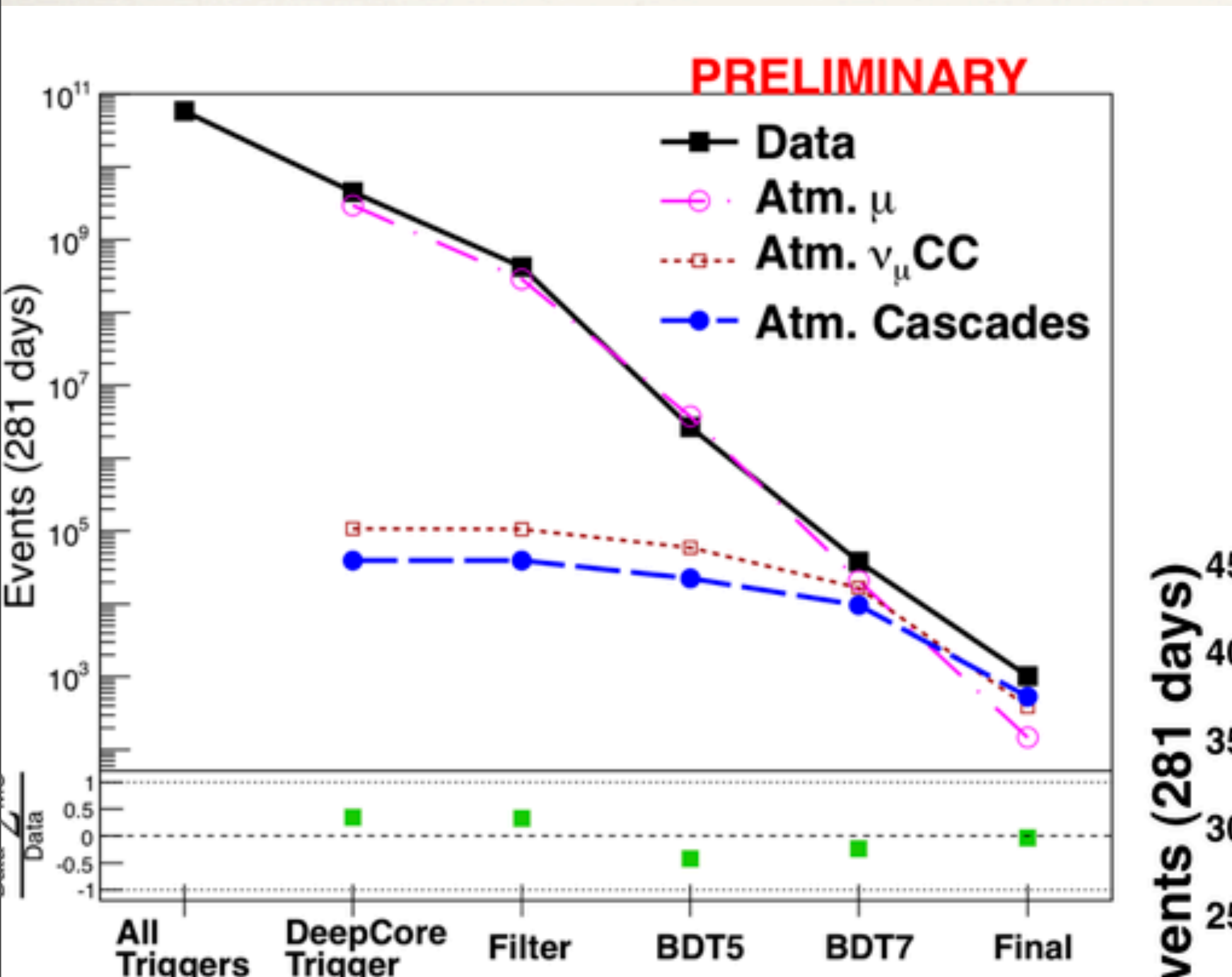
cut level

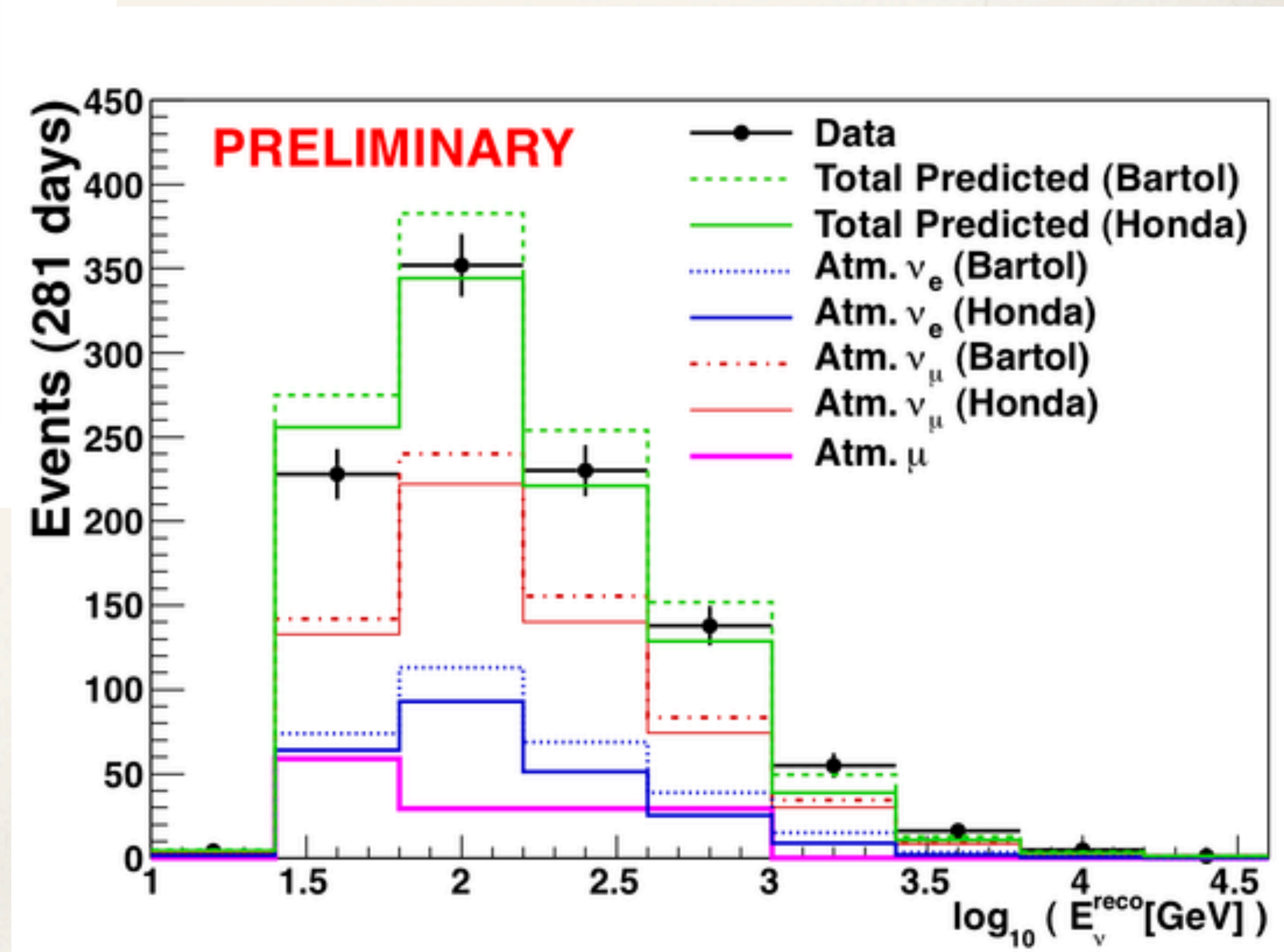
Up to L5,
with containment only
(nearly)

DeepCore: reconstruction

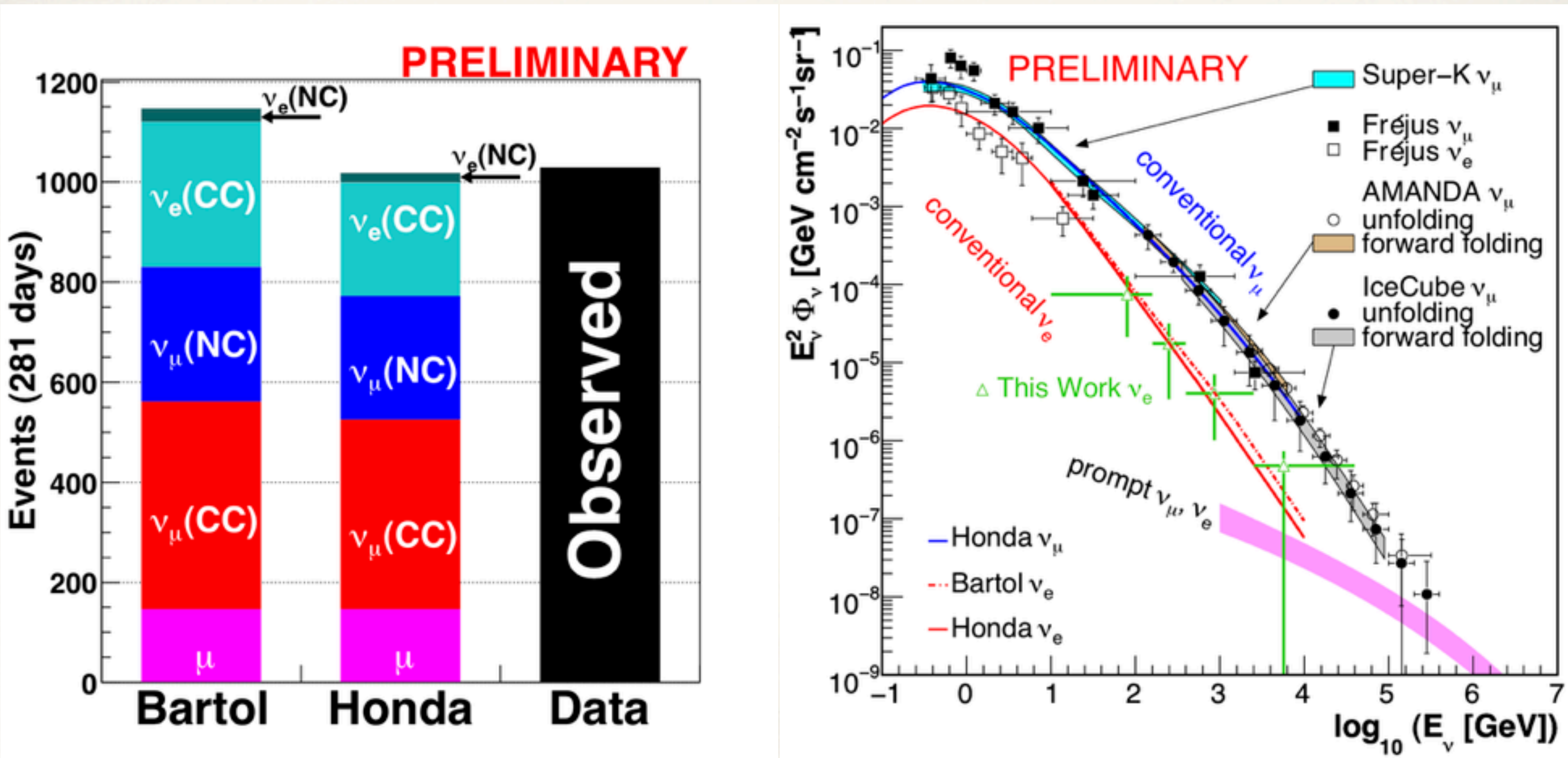
- Dedicated algorithm developed for the identification of starting tracks (finiteReco).
- First hit is interpreted as interaction vertex.
- Used information from hit and no-hit DOMs, likelihood ratio approach.
- No cascades at the interaction vertex identified.
- The last O(10) atmospheric background rejected via reconstruction, quality parameter, entering in the fiducial volume of DC.
- Signal efficiency in DC: ~10-15% for a high pure sample.

DeepCore: electron neutrinos





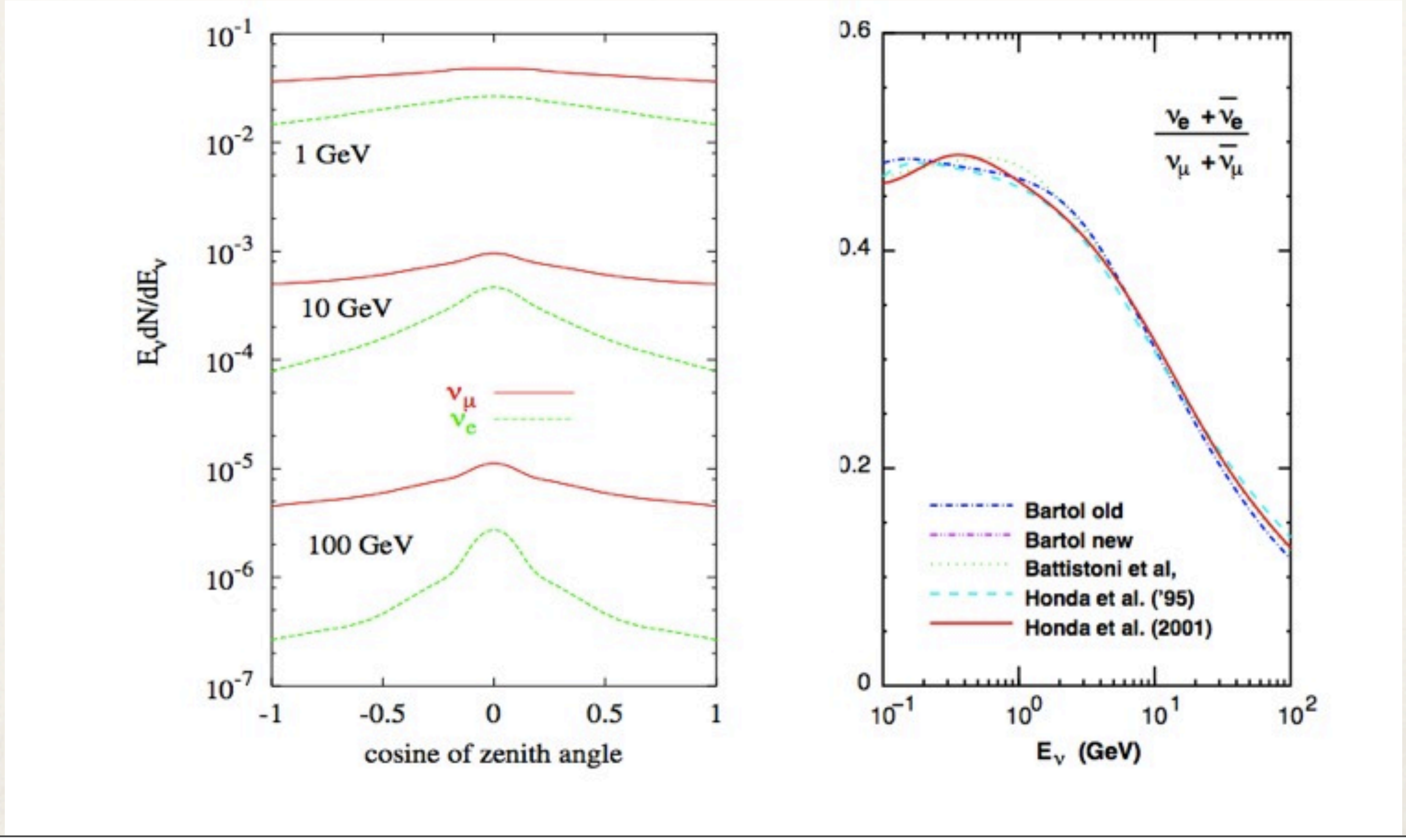
DeepCore: electron neutrinos



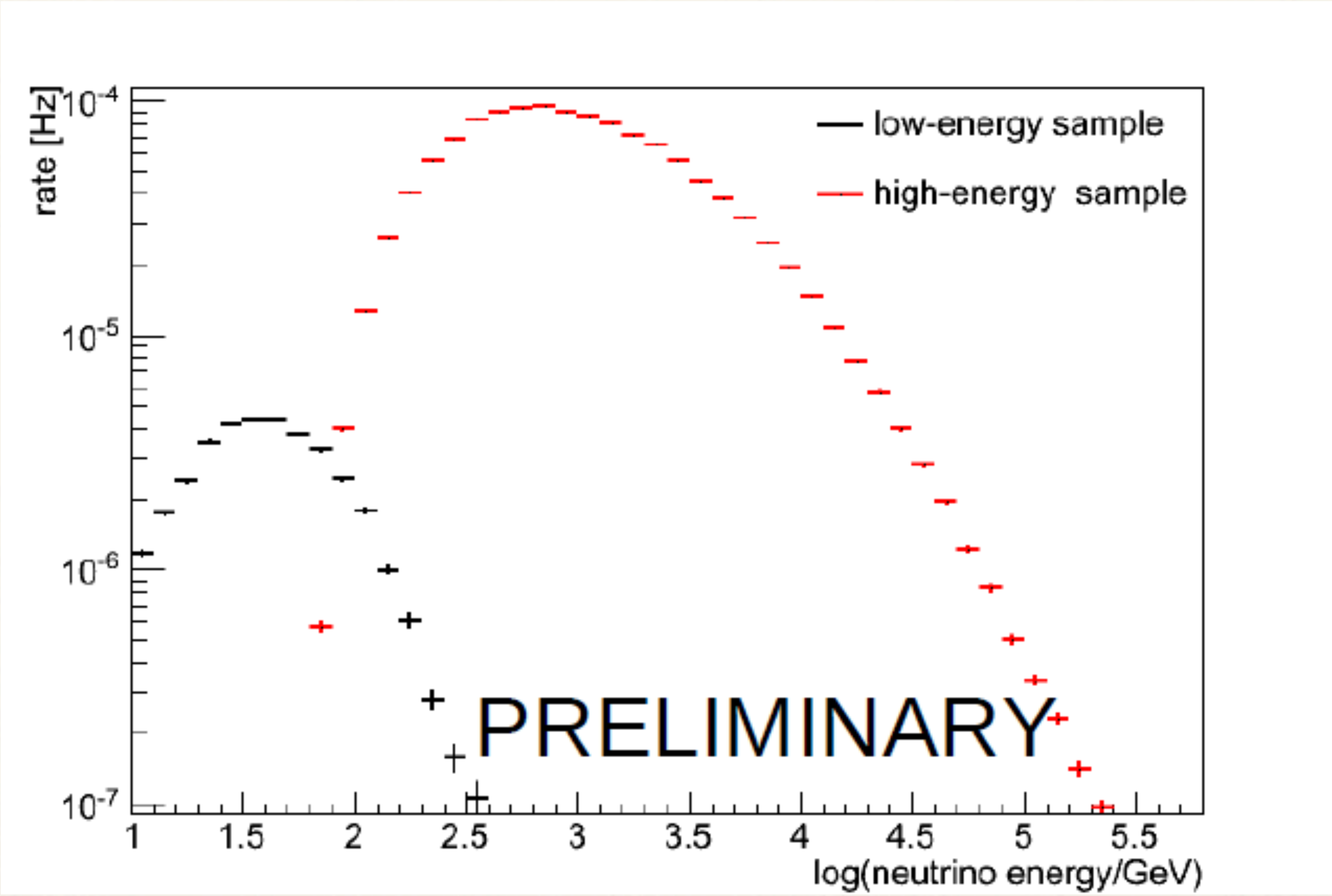
DeepCore: electron neutrinos

as a reminder for PINGU/ORCA:
at lower energy electron neutrinos are more !!!

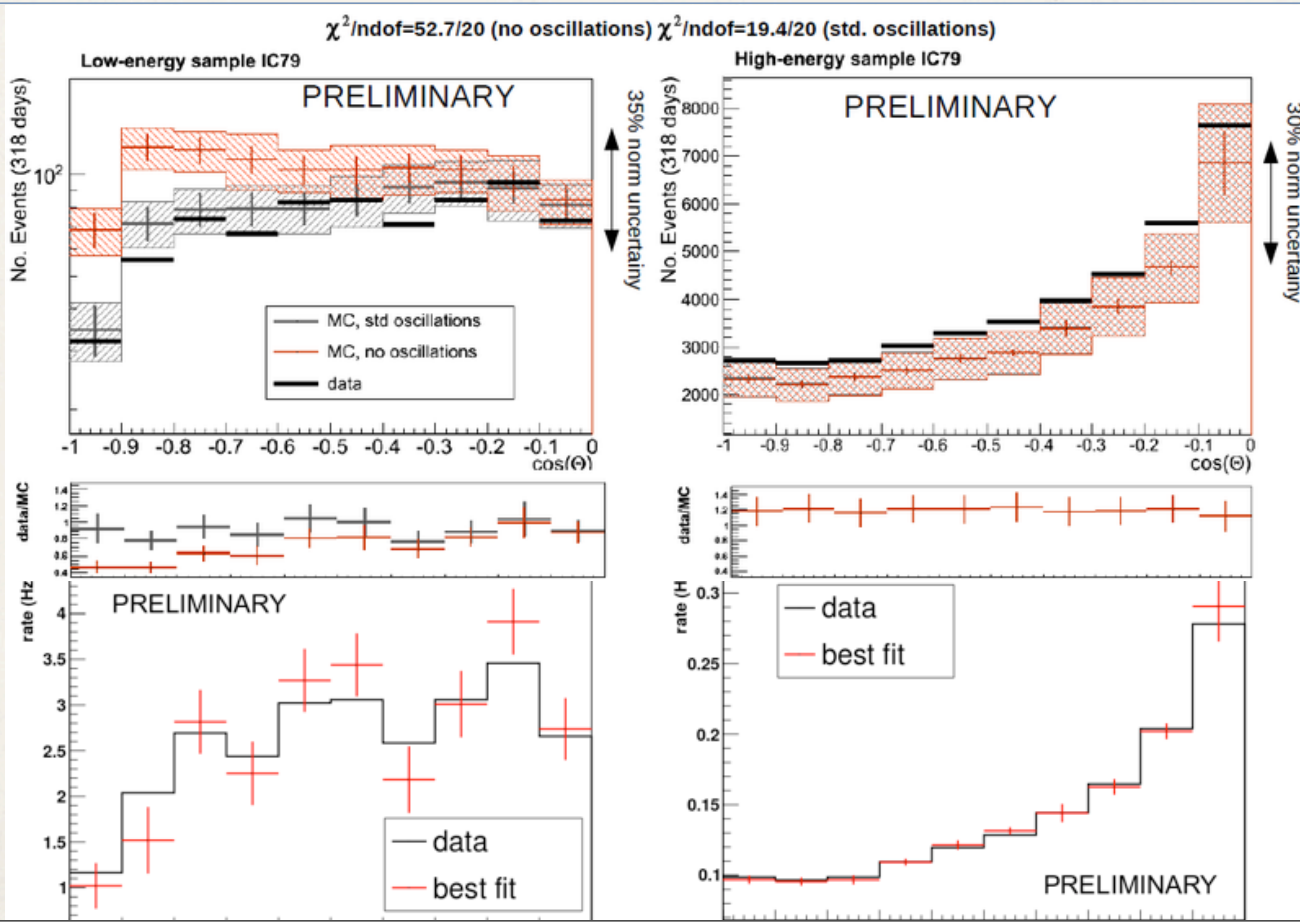
T.K. Gaisser and M. Honda, arxiv.org/pdf/hep-ph/0203272v2.pdf



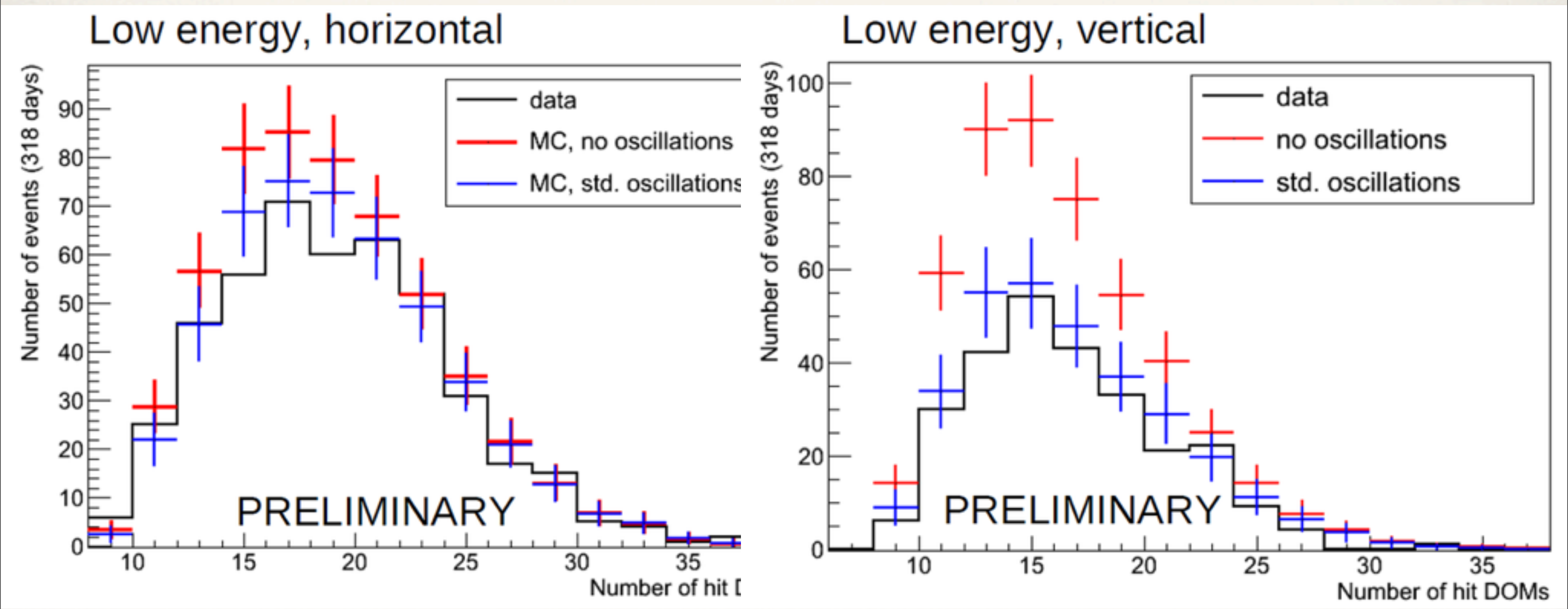
DeepCore: muon neutrino disappearance



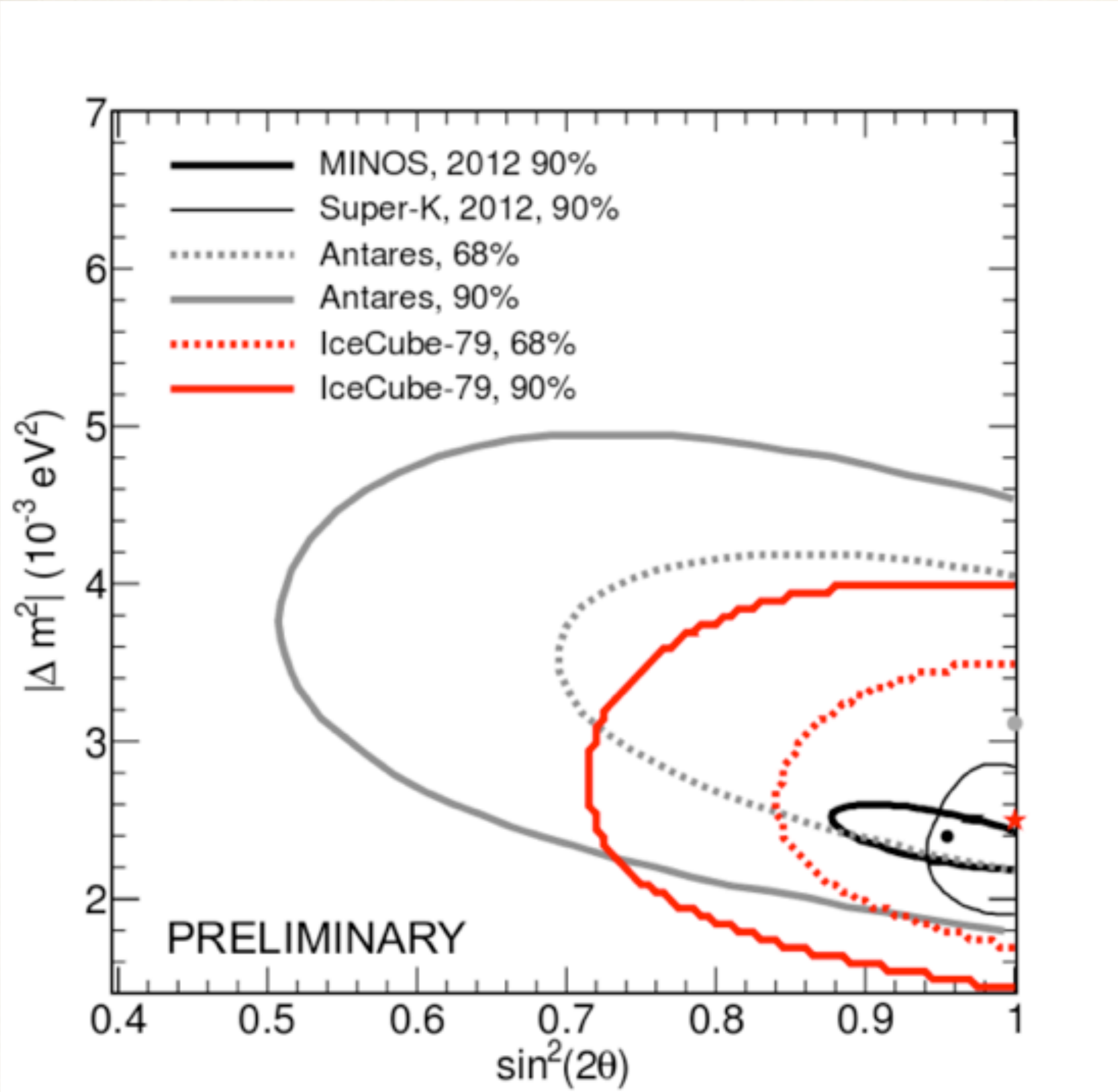
DeepCore: muon neutrino disappearance

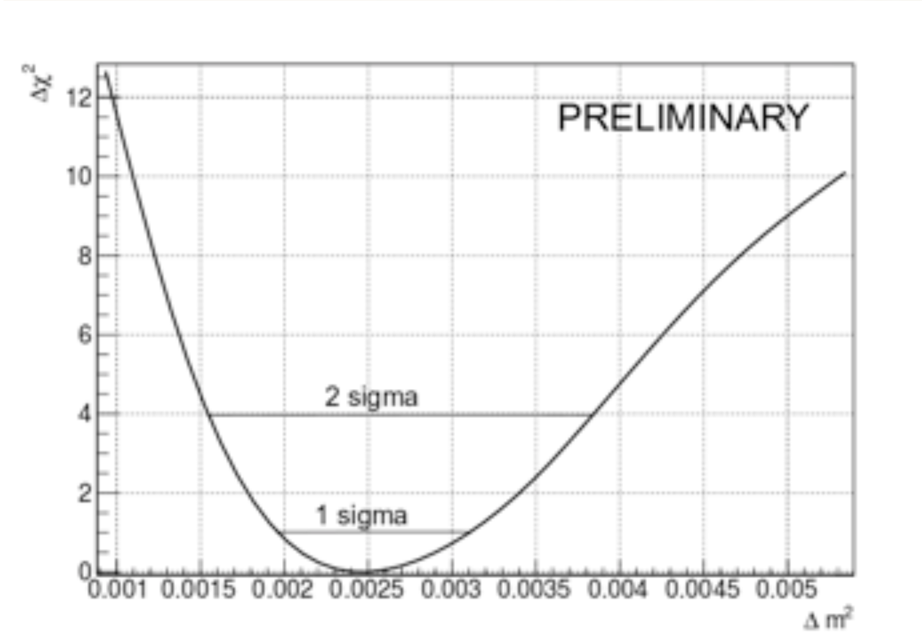


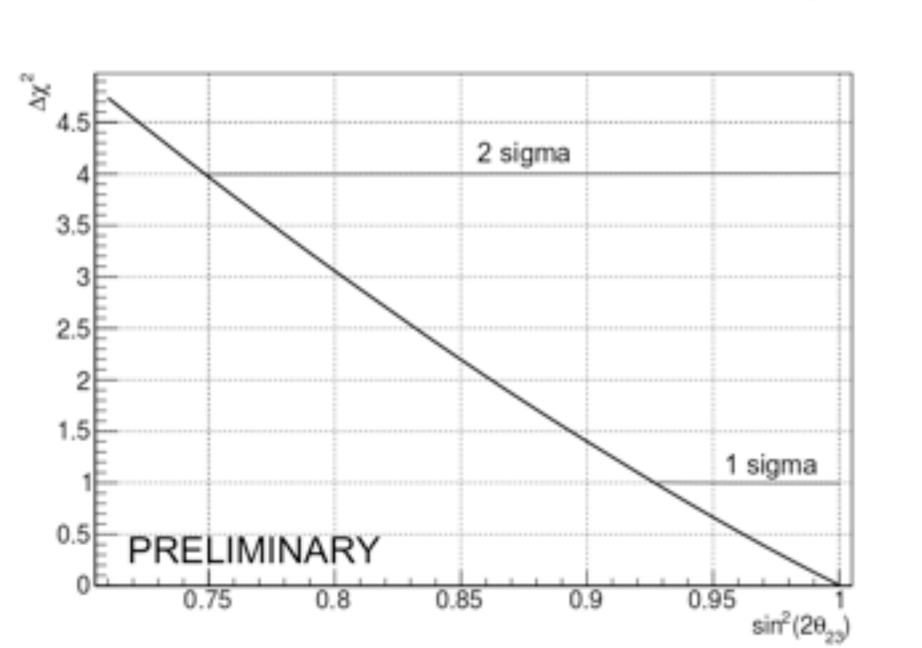
DeepCore: muon neutrino disappearance



DeepCore: atmospheric neutrino oscillation

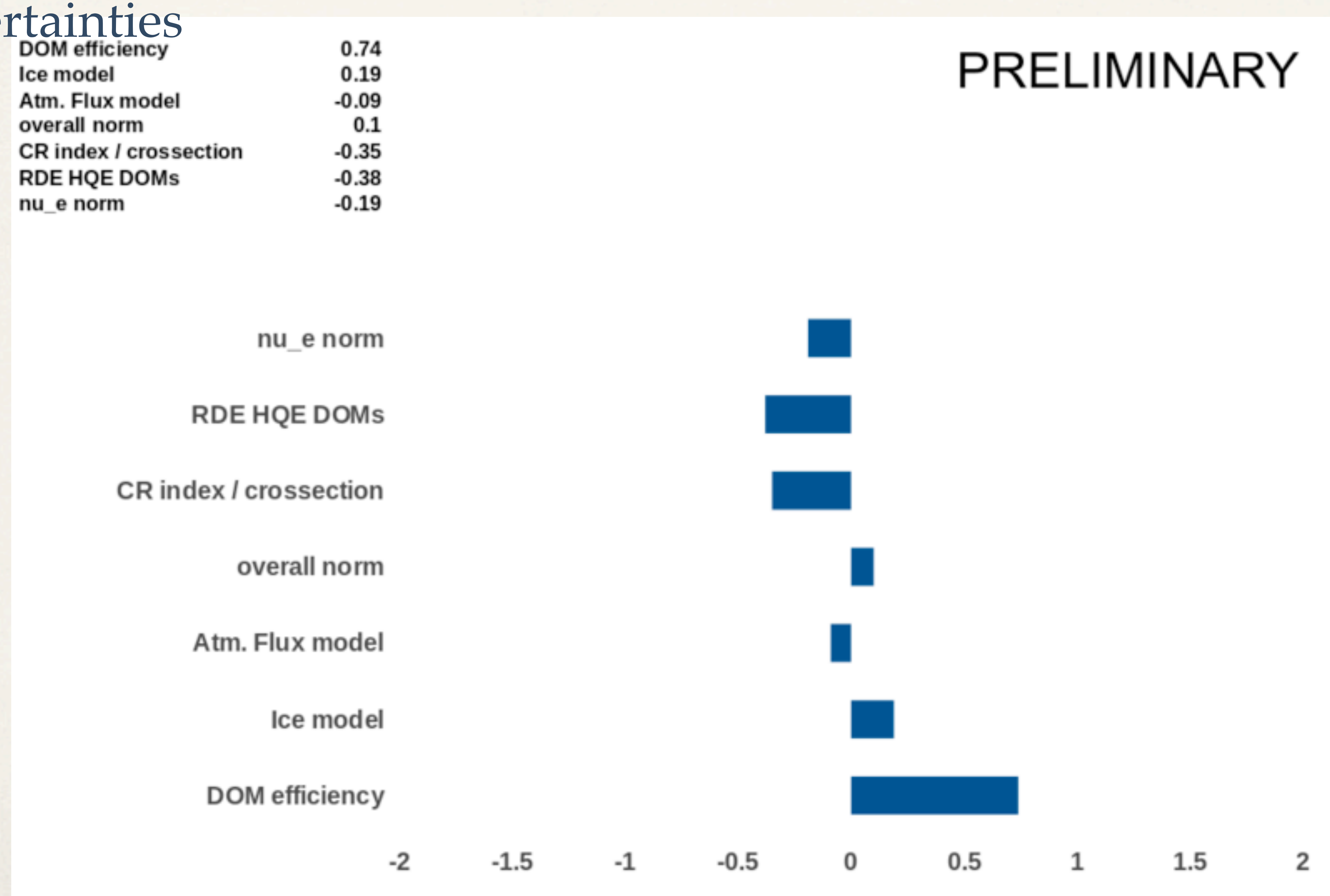






DeepCore: atmospheric neutrino oscillation

uncertainties



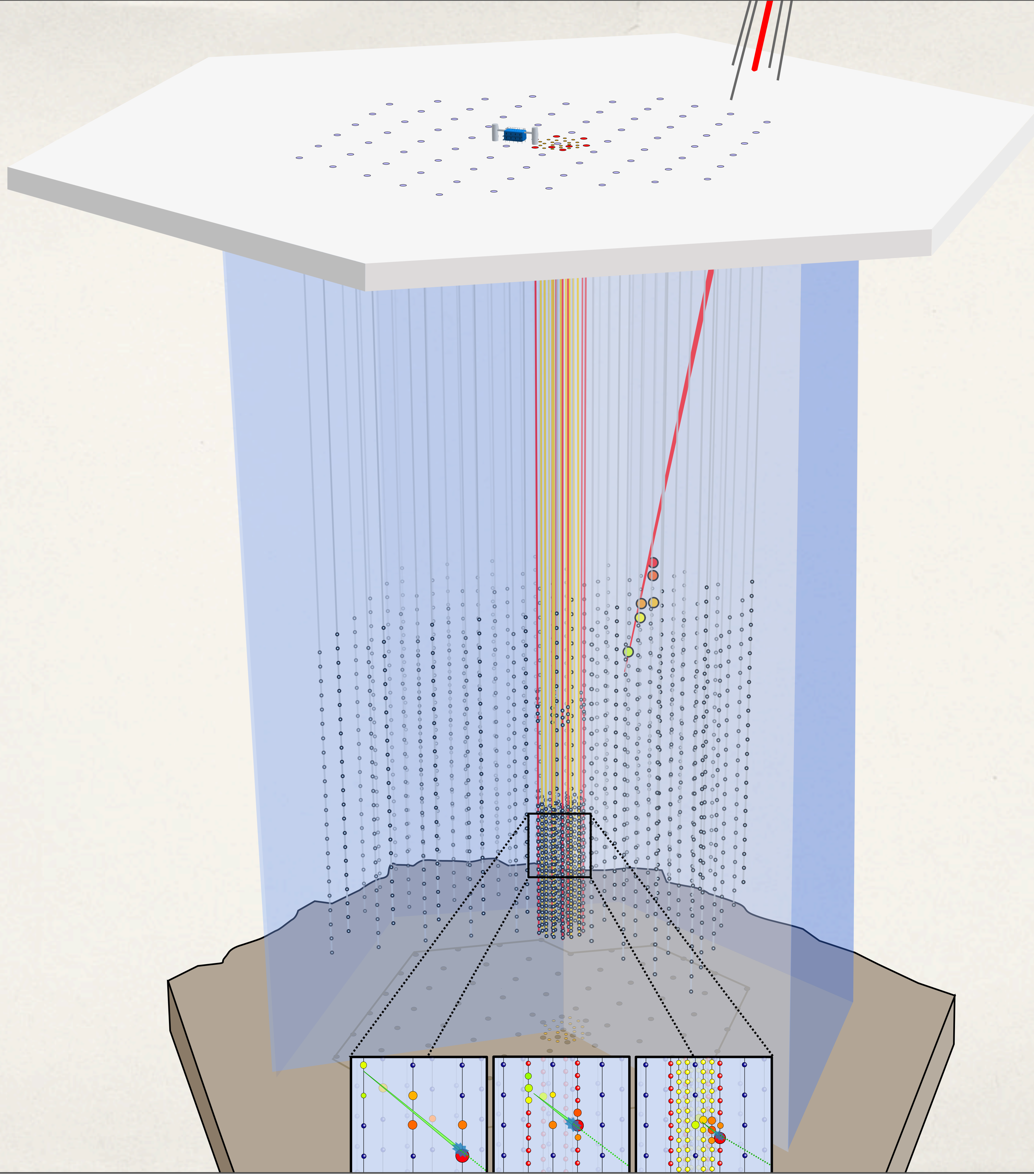
DeepCore: lessons learned

- Atmospheric background fight by **containment and reconstruction.**
- Electron neutrinos detected.
- Muon neutrinos disappearance -> oscillation analysis with high significance but not that high precision yet. More in the pipe-line.
- Not mentioned here: WIMPs search also for neutrinos above the horizon
- How to propagate and make diagnostic of systematic uncertainties: one strategy completely implemented.
- Test on full simulation chain for assessment of single systematic uncertainty on-going, important exercise for PINGU too.

PINGU
(Precision IceCube Next Generation Upgrade) or Neutrino Mass Hierarchy using Atmospheric Neutrinos

E. Kh. Akhmedov, Soebur Razzaque, and A. Yu. Smirnov http://arxiv.org/pdf/1205.7071**v5**.pdf

- Hardware
- Atmospheric background rejection by containment
- Reconstruction of the signal (Sirin)
- Neutrino mass hierarchy
- Uncertainties
- Approaching sensitivity calculation



PINGU: Hardware

IceCube legacy hardware with various modifications

Minimize cost and risk:

- Simplify Design of DOM electronics
- Simplify Design of Down Hole Cables
- Streamline Deployment
- Use freeze-in proven components from IC
- Work on-going on the break-outs of the cable

Cable cost: ~50% less expensive then IC cables

angular acceptance	as in IC
sensitivity	high QE DOMs (like DC)
timing resolution	as in IC
dynamic range	as in IC (or less)
dark noise	as in IC (HQE)
data rate expected	as in IC
DOM spacing	under study: 6-17 m
# DOM / string	60-80
# Strings	16-20 (unless requested more)
Depth/Environment	as in IC

PINGU: Hardware

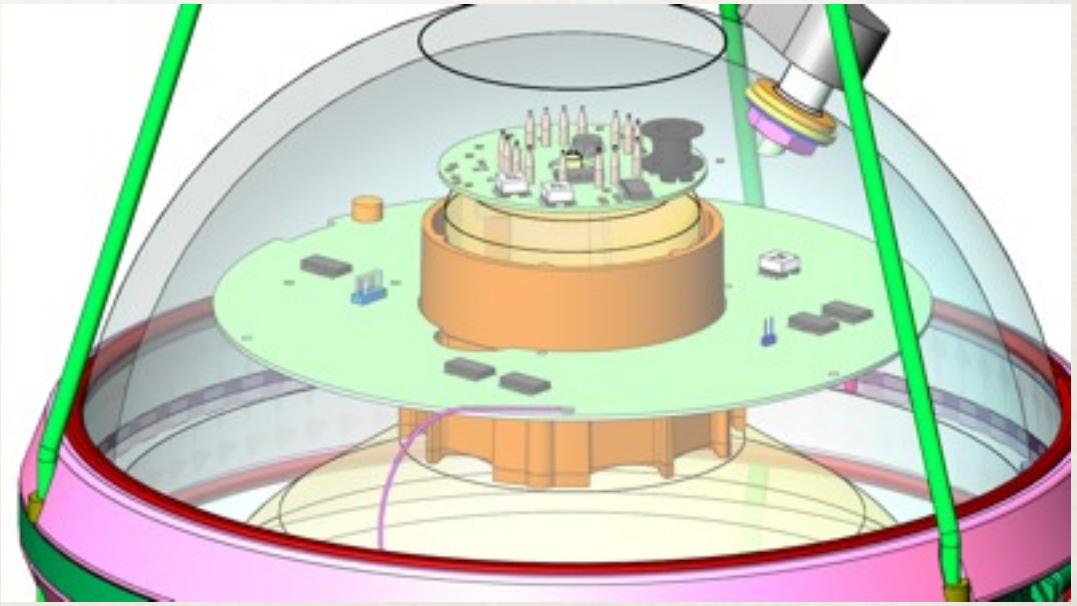
PINGU DOM = **PDOM**

Minimize cost and risk:

- Reduce (50%) power consumption for each single PDOM
- Parts kept: sphere, penetrator, PMT, collar, gel, harness, HV generator and base, quad cable technology
- Parts under new development: digitizer (ADC), circuitry, flasher (LED), FPGA logic, power supply
- Upgrade (partly already planned for IceCube): DAQ (and few others I don't know …)
- prototyping on-going

PDOM cost: ~30% less expensive then IC cables

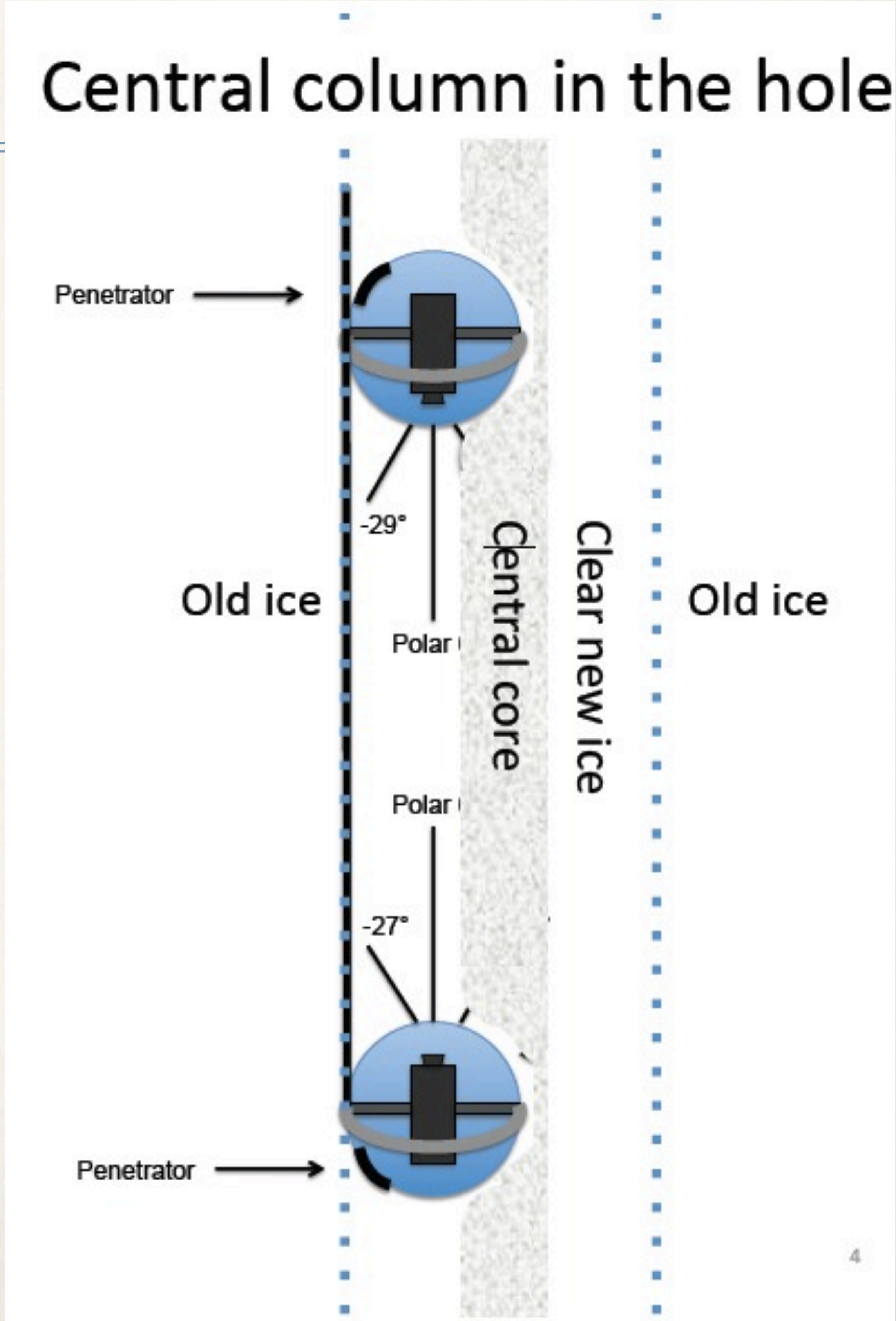
also alternative designs under study



PINGU: the hole ice

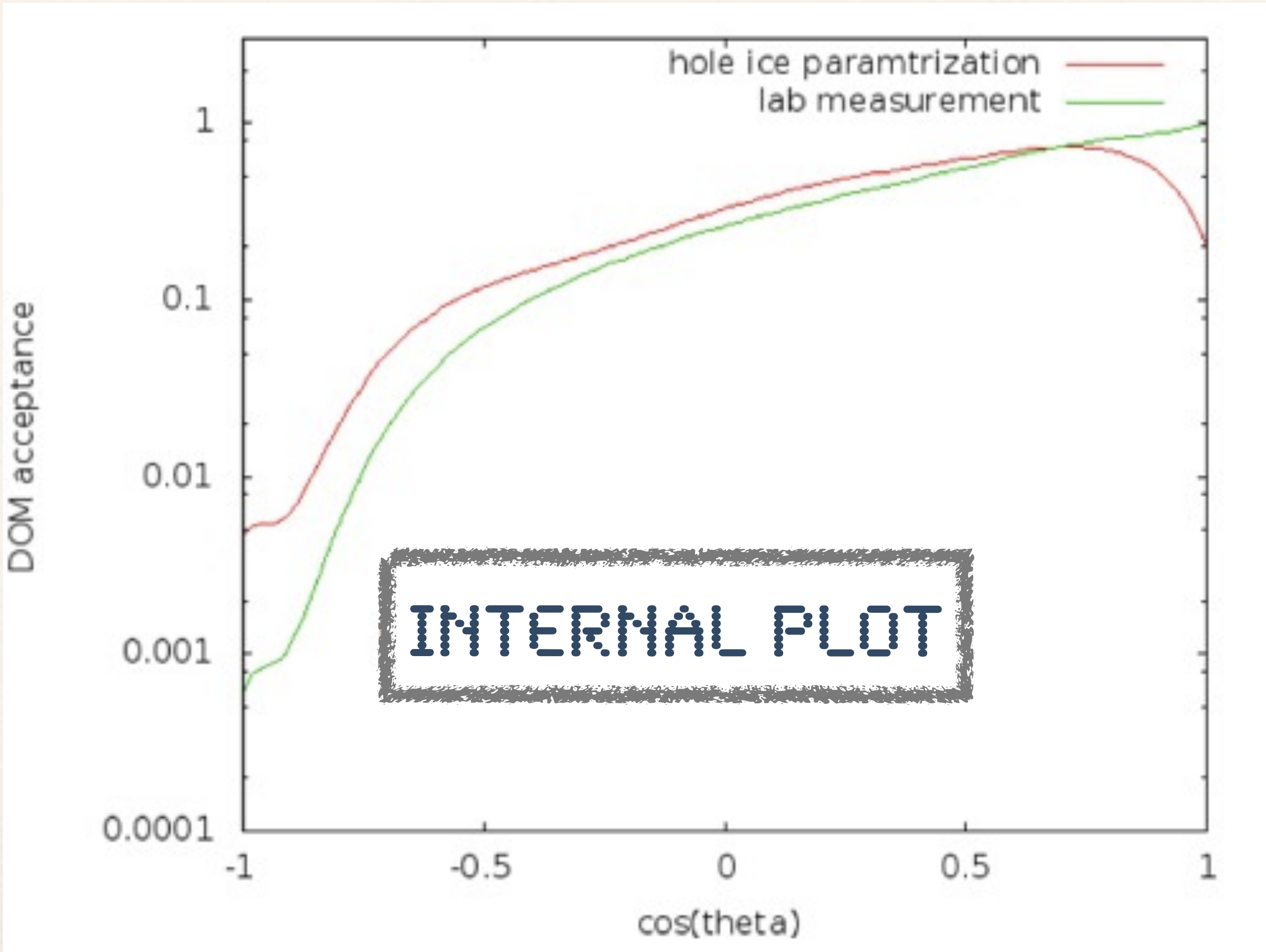
The water in the IceCube drilled holes was not degassed, natural refreezing process allowed.

Air bobbles trapped into a central core.



PINGU: the hole ice

In IceCube, hole ice is modeled in simulation by changing DOM angular acceptance. This works good enough for the moment (tested on oscillation analysis for example).



PINGU: the hole ice, calibration

But for PINGU, we want and we can do BETTER!

Ideas under study:
- add degassing / filtering stage
- addition of clean / degassed water to the hole after drilling
- control the refreezing

Improve in-situ calibration: improve LED-flasher system
Minimum pulse width 7ns -> 1ns

~5° -> 1° aim accuracy

30° FWHM beam -> 1° or diffuse beam

~30% uncertainty in brightness -> brightness measured with photodiode (under study)

PINGU: possible time-line

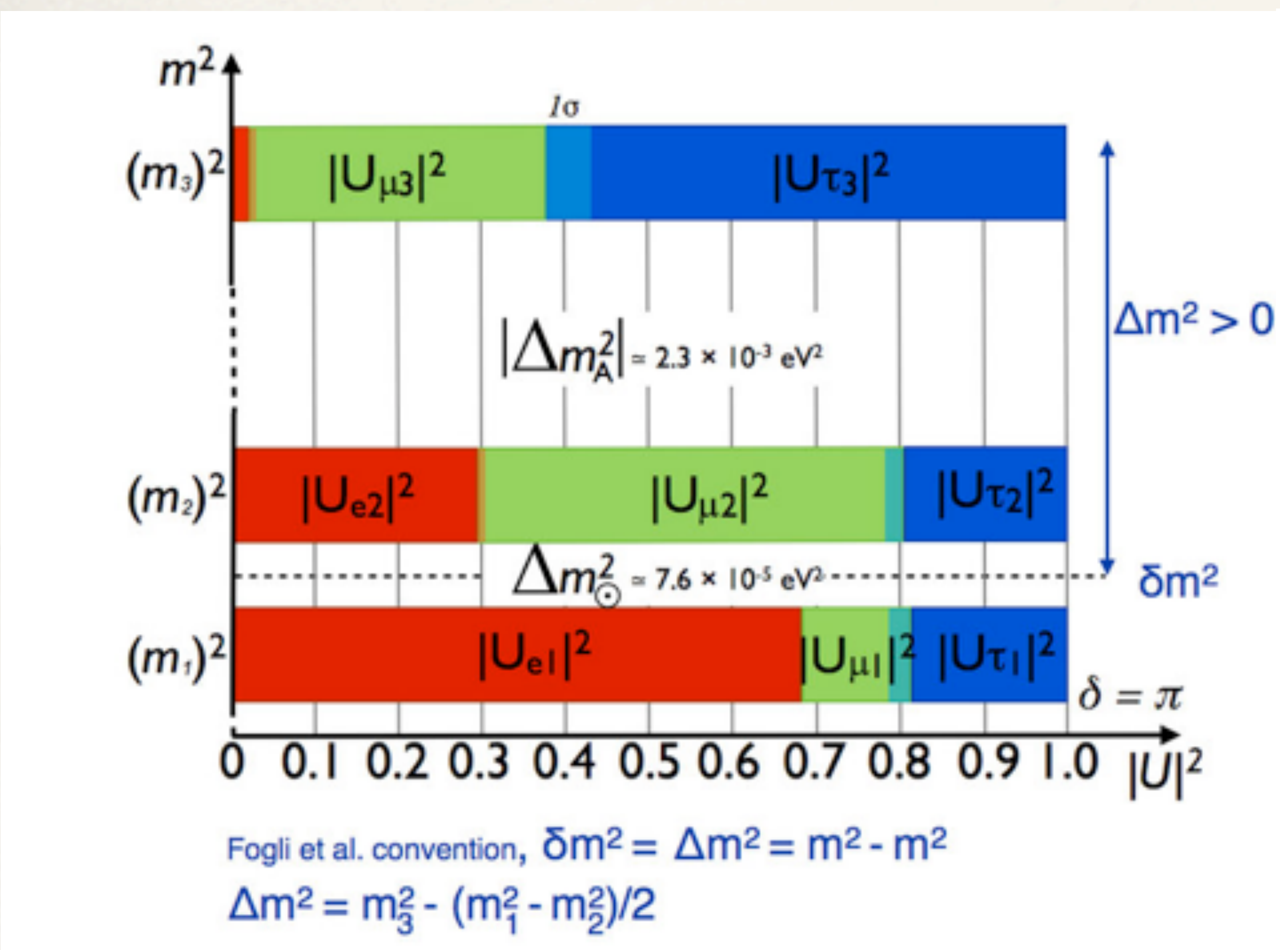
- Fall 2012, LOI preparation, submission
- Fall 2013, Proposal to various funding agences submission
- Mar, April 2014, Proposal approval (!)
- May 2014, Begin “pre-spending”
- Summer 2014 -> Mar 2015 Procurement
- Sept 2015, Ship to pole 1
- Winter ‘15-’16 Deploy season 1
- Sept 2016, Ship to pole 2
- Winter ‘16- ’17 Deploy season 2

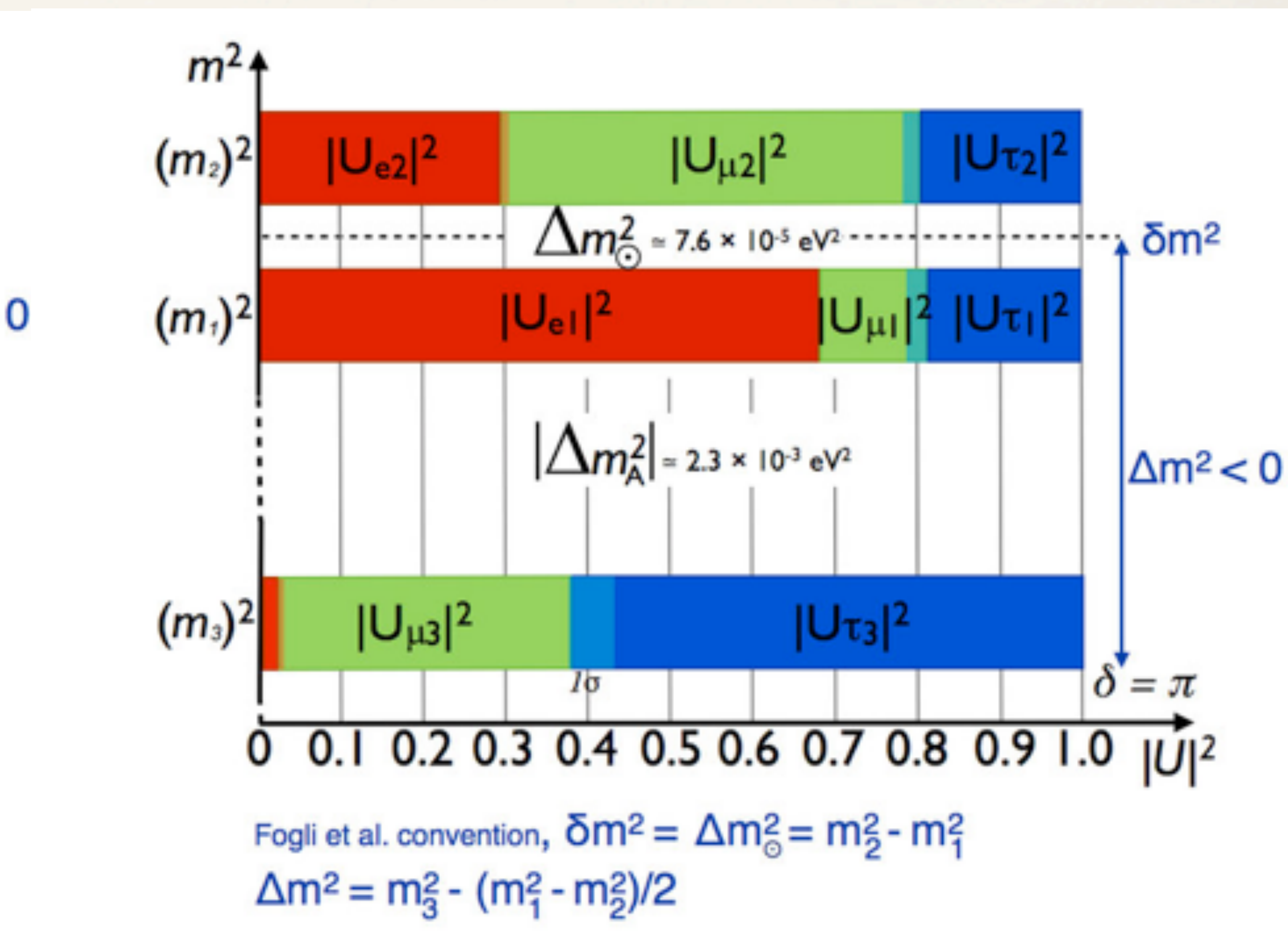
Atmospheric neutrino mixing

convenient convention (Fogli et al., http://arxiv.org/abs/hep-ph/0506083)

$\Delta m^2 = |m_3^2 - (m_1^2 + m_2^2)/2|$ $\qquad$ $\delta m^2 = m_2^2 - m_1^2 > 0$

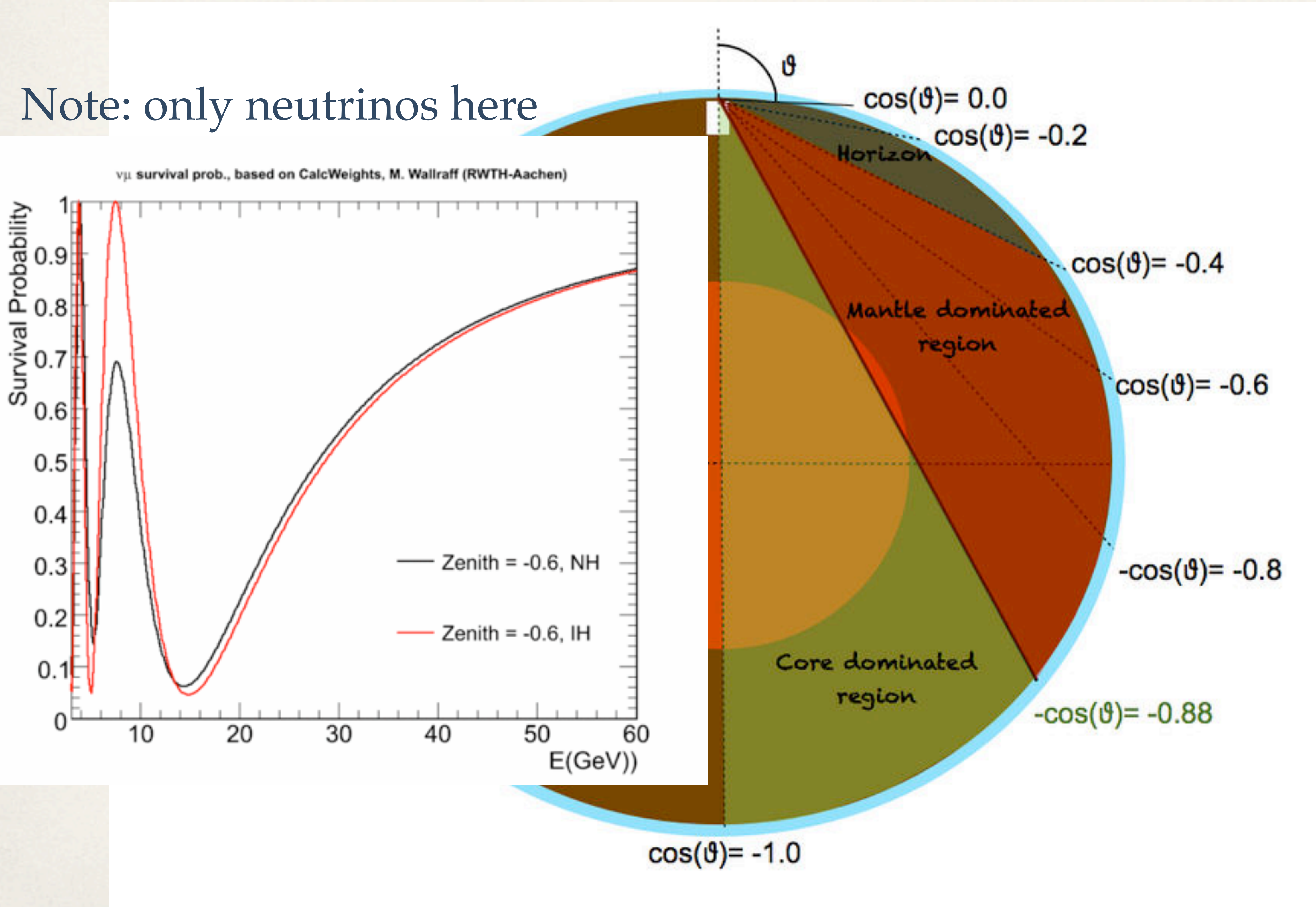
to invert the hierarchy: $+\Delta m^2 \rightarrow -\Delta m^2$



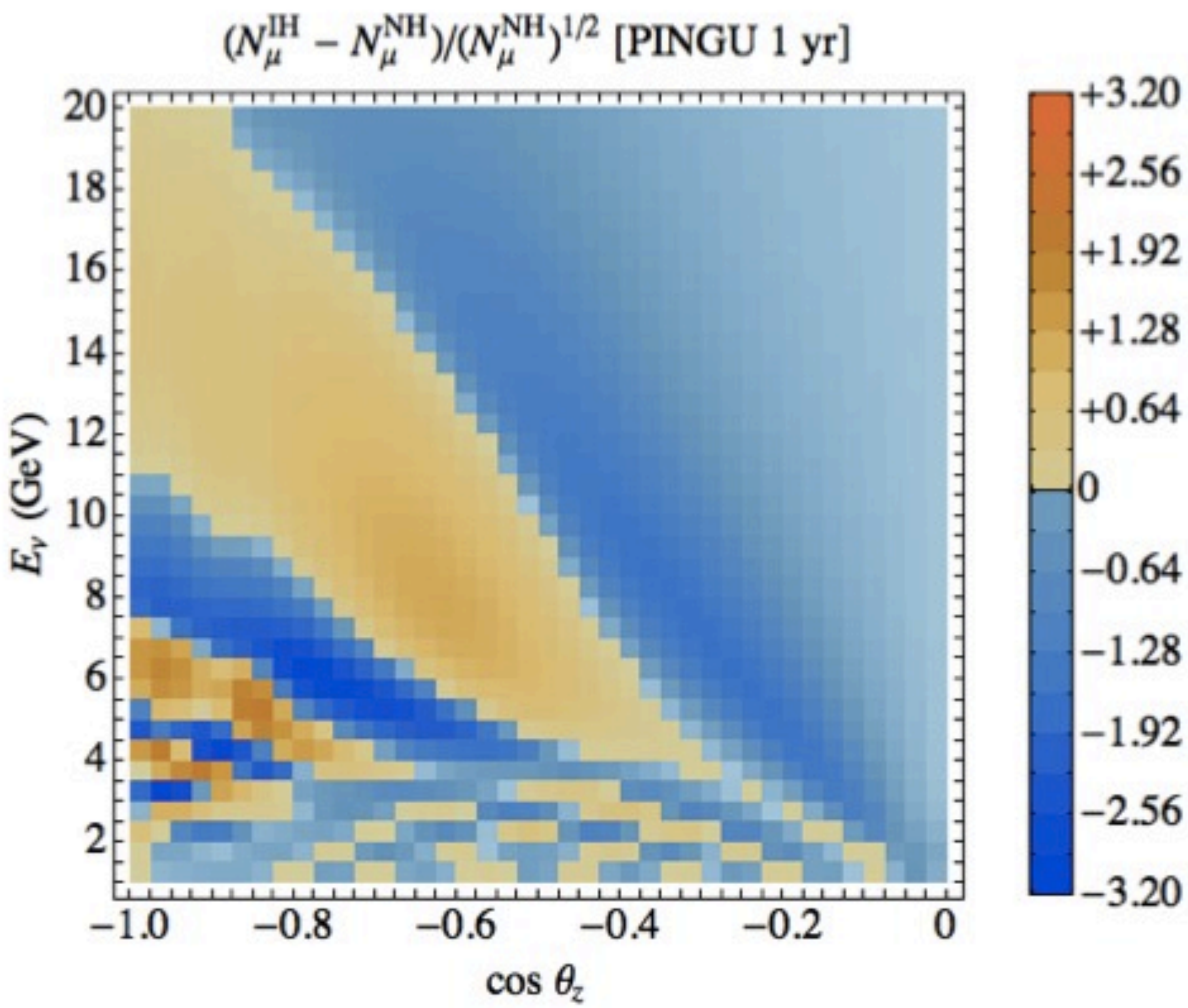


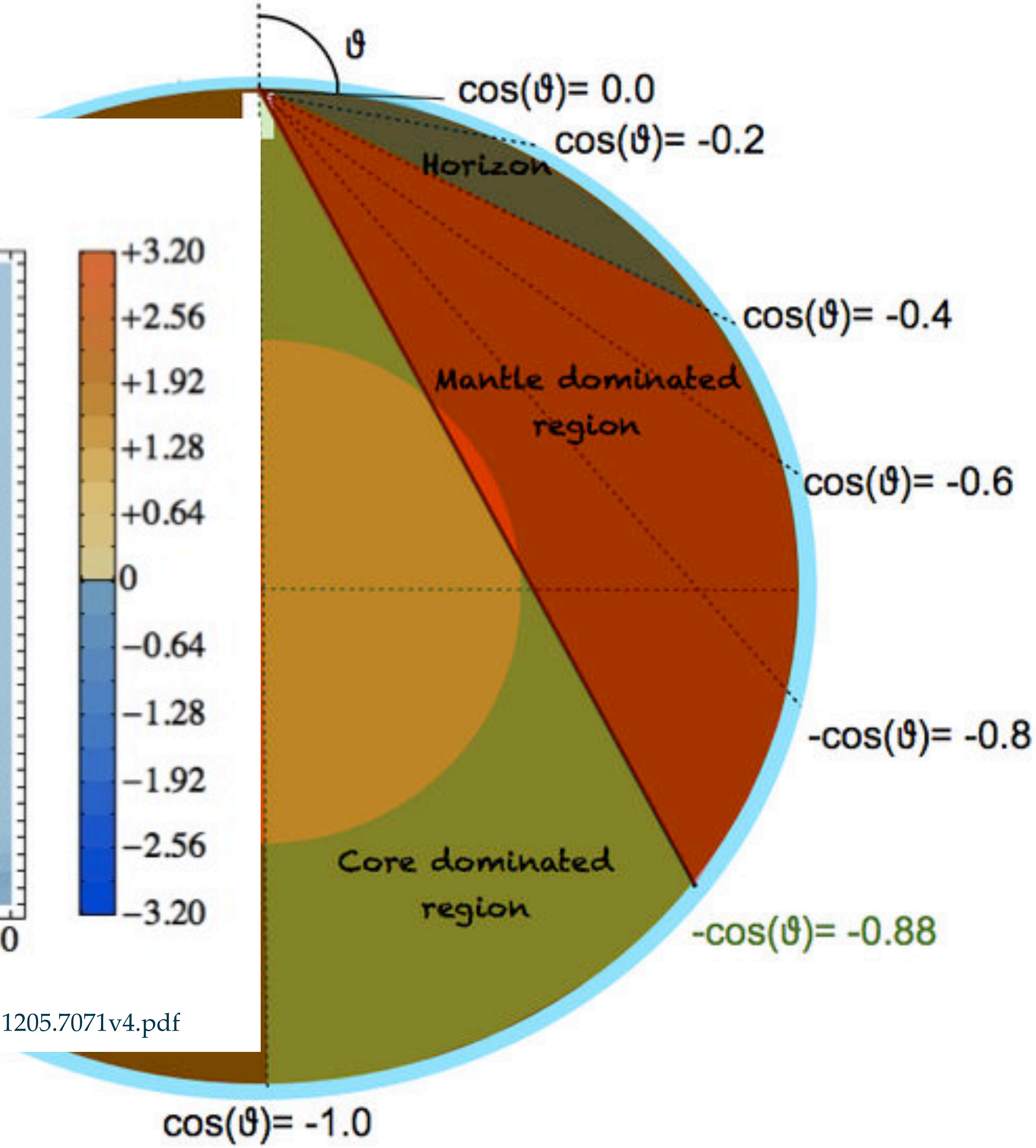
Atmospheric neutrino oscillation

Note: only neutrinos here



Atmospheric neutrino oscillation





E. Akhmedov,, S. Razzaque, and A. Smirnov, http://arxiv.org/pdf/1205.7071v4.pdf

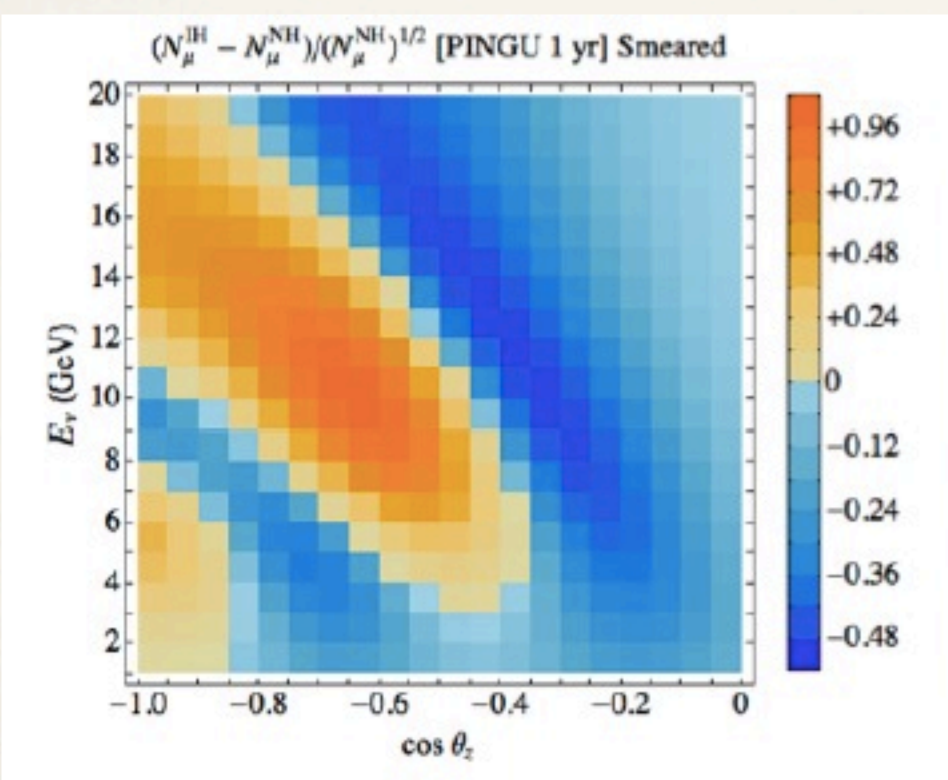
NMH on atmospheric neutrinos: where-is-the-signal?

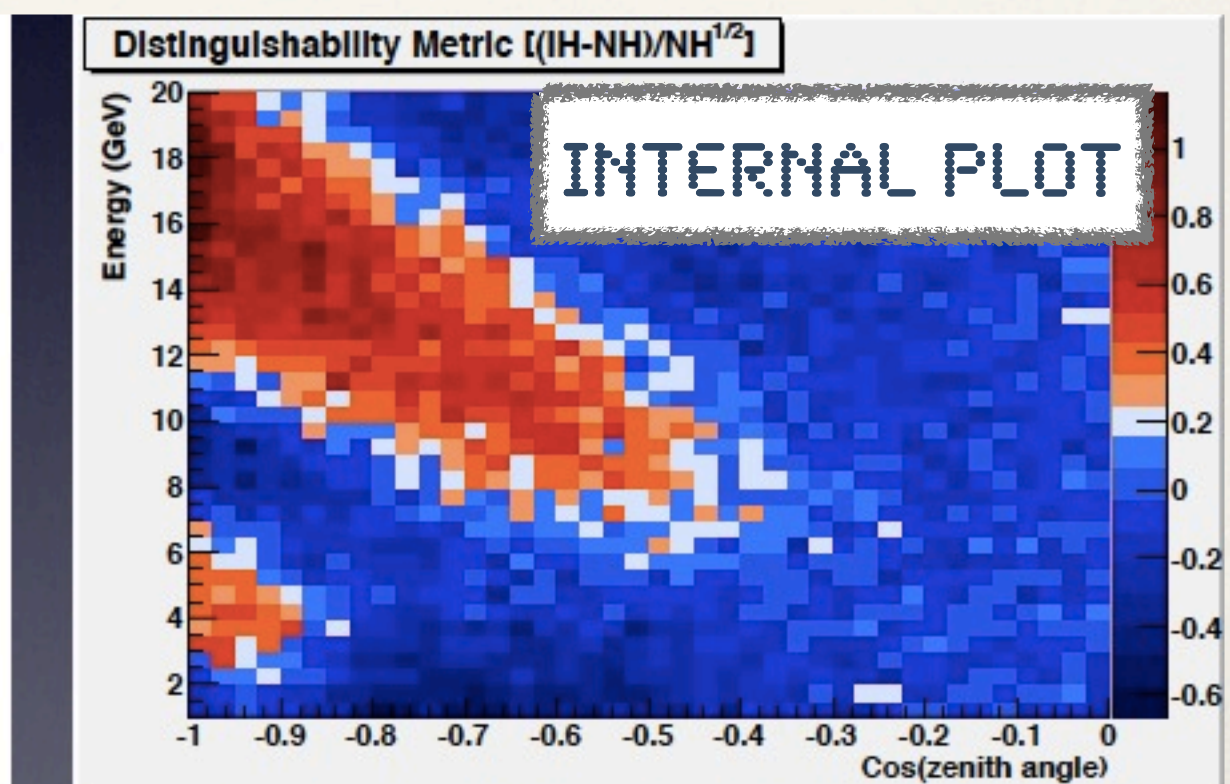
From the figures above to real case one needs to consider:

- background contamination: using IceCube & DeepCore as veto atmospheric muons should not be a problem. But mainly electron neutrinos and tau neutrinos will be in the sample.
- use topology of the events for separation -> need of new reconstruction (see Sirin's talk)
- resolutions of reconstructed events
- systematic uncertainties

NMH on atmospheric neutrinos: where-is-the-signal?

From the figures above to real case one needs to consider:
- resolutions of reconstructed events (2 GeV, 11.25 deg)





Sensitivity calculation: one path (work on-going)

It is nothing else then an oscillation analysis with an extra sign

STEP 1: Define the input parameters

- Zenith distribution of atmospheric neutrinos in the signal region
- Energy distribution of atmospheric neutrinos in the signal region
- Consider the use of off-signal region (DeepCore, IceCube streams) for possible mitigation and self-constrain of uncertainties

- List of uncertainties

Uncertainties

From other experiments		PINGU specific	
Primary CR flux (AMS, BESS, …)	M. Sajjad Athar, M. Honda et al., http://arxiv.org/abs/1210.5154	DOM efficiency	improved in-situ calibrations
Geomagnetic field, interaction model	M. Sajjad Athar, M. Honda et al., http://arxiv.org/abs/1210.5154	Ice optical properties	hole ice water purification
Atmospheric neutrinos zenith, energy, composition	M. Sajjad Athar, M. Honda et al., http://arxiv.org/abs/1210.5154	Background?	electron neutrinos?, see reconstruction
Earth Profile (PREM, …)	under study		
Neutrino Interaction cross section	starting with GENIE under study		
Mixing parameters	degeneracies		
CP violation	probably not a bit problem		

Sensitivity calculation: one path (work on-going)

STEP 2: Define the analysis strategy

- reconstruction (see Sirin's talk)
- background rejection (see Sirin's talk)

Fitting procedure: various approaches to be compared. Using both zenith and energy distributions, construct the $\Delta\chi^2$ between the NH and IH case. What to fit?

1) fit ($\pm \Delta m^2$, $\sin^2 2\Theta$), all the other mixing param marginalized
2) fit $\pm \Delta m^2$ all the other mixing param marginalized, uncertainties treated as nuisance parameters
3) fix the Δm^2 value to the best fit value (like all the others) and fit the sign only

Sensitivity calculation: one path (work on-going)

STEP 3: Propagate the uncertainties

various approaches to be compared.
- covariance matrix approach
- pull / nuisance minimization
- full MonteCarlo approach (test impact of non gaussian uncertainties)

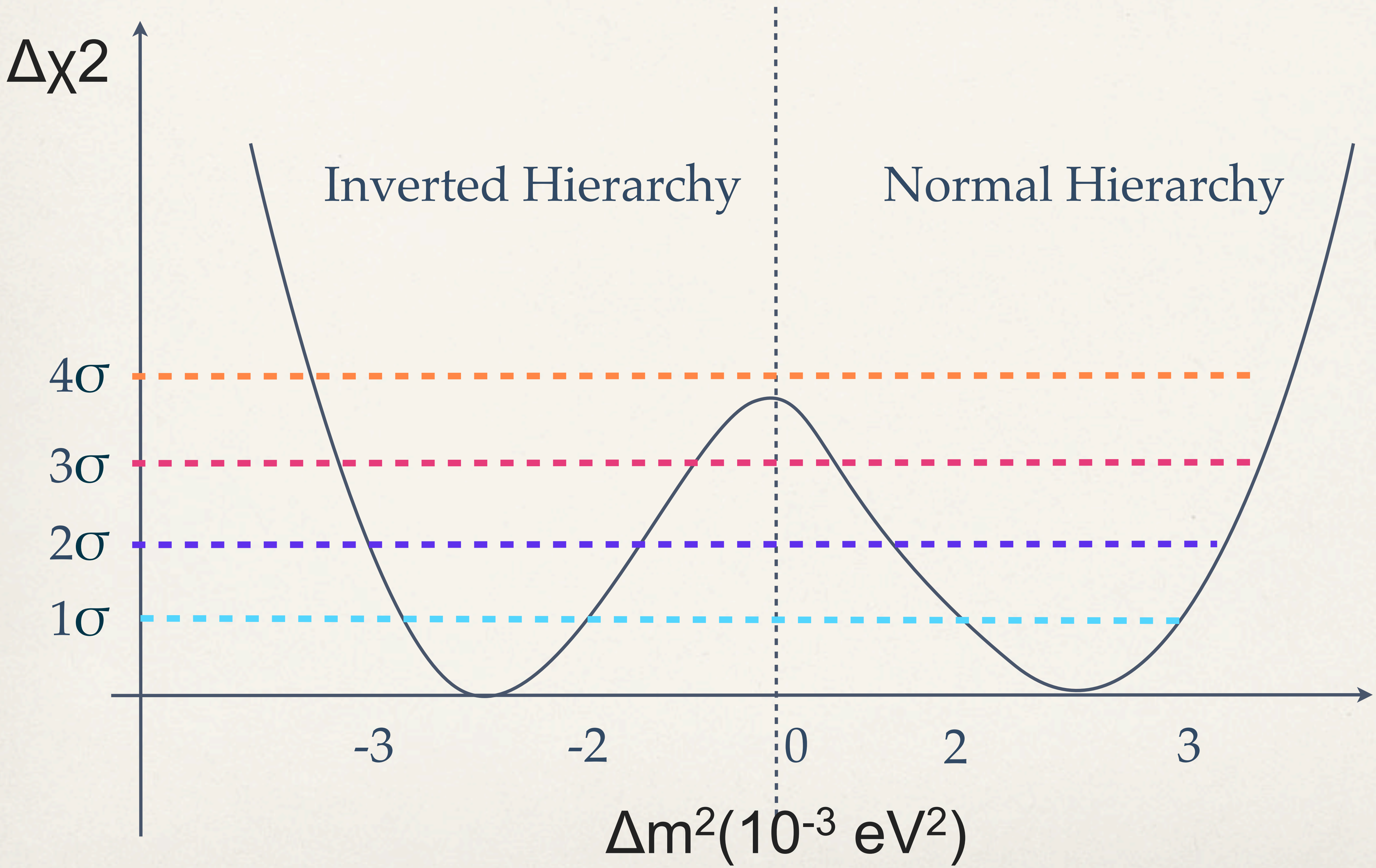
STEP 4: Generate N pseudo-experiments to build up the test statistics

STEP 5: Visualize the sensitivity, dependencies vs uncertainties (degeneracies) and possible progression vs life time.

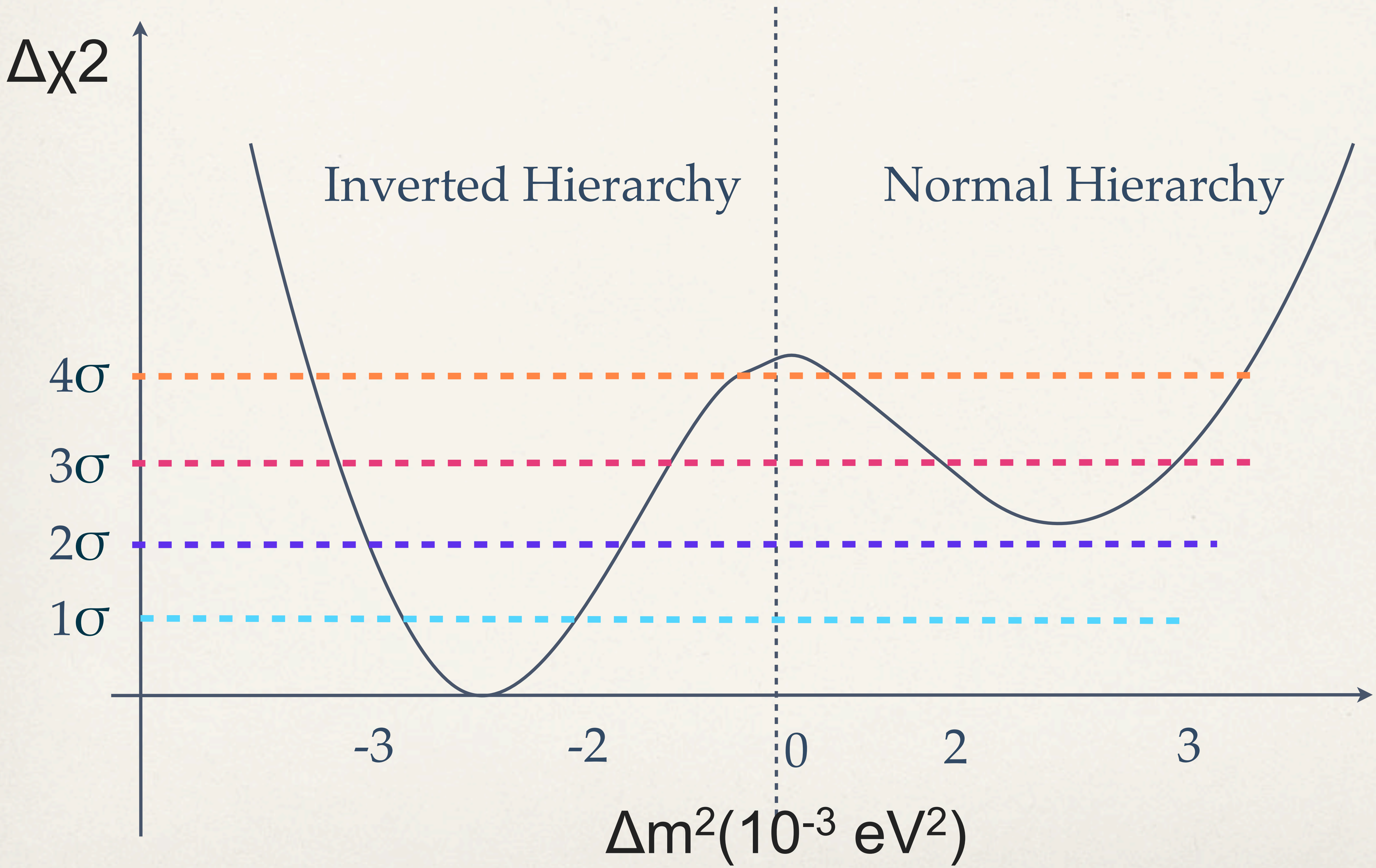
How could look like a sensitivity plot?

this scenario is for an experiment NOT sensitive to NMH

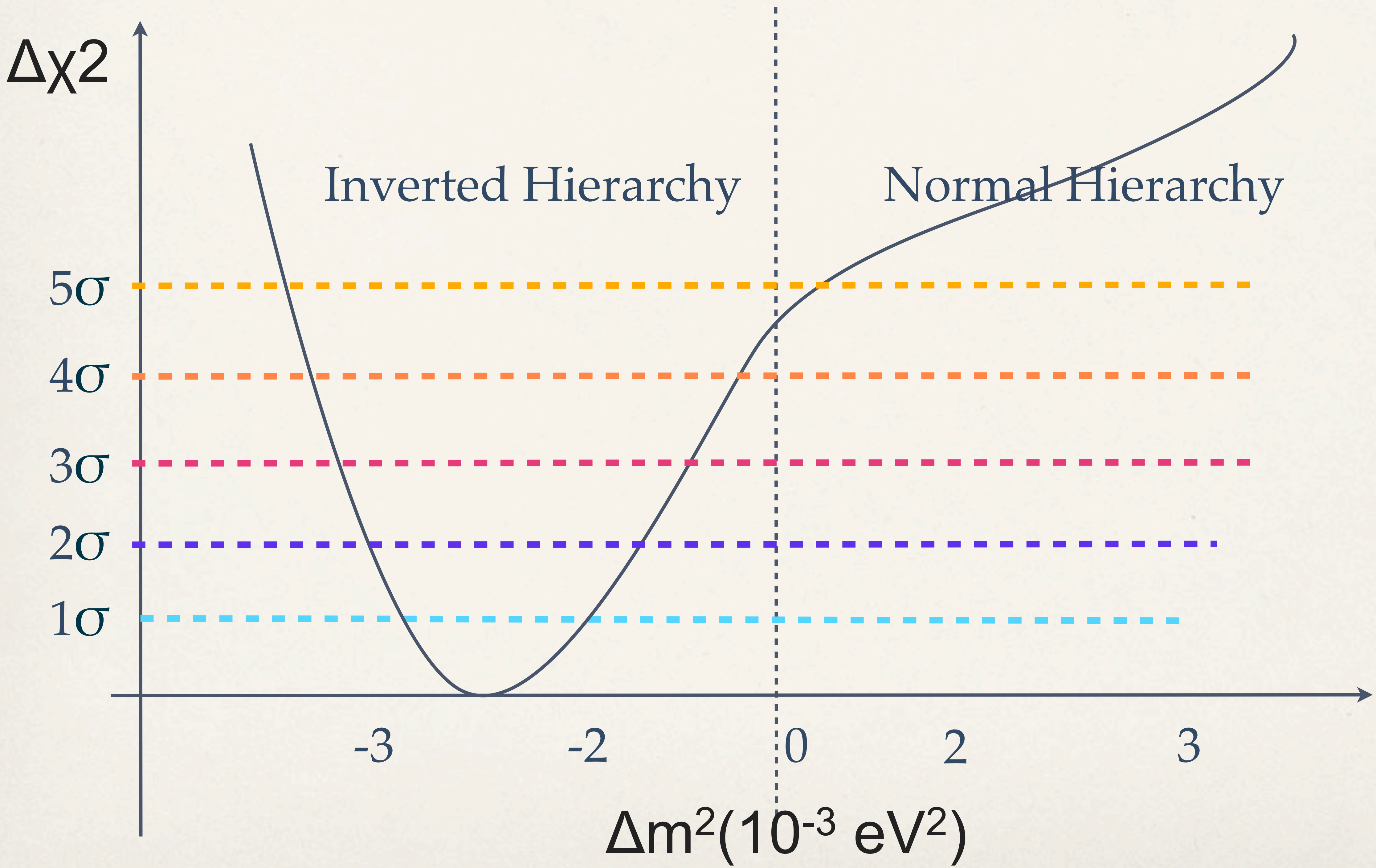
1D representation



this scenario is for an experiment sensitive to NMH indicating IH at 2 sigma level

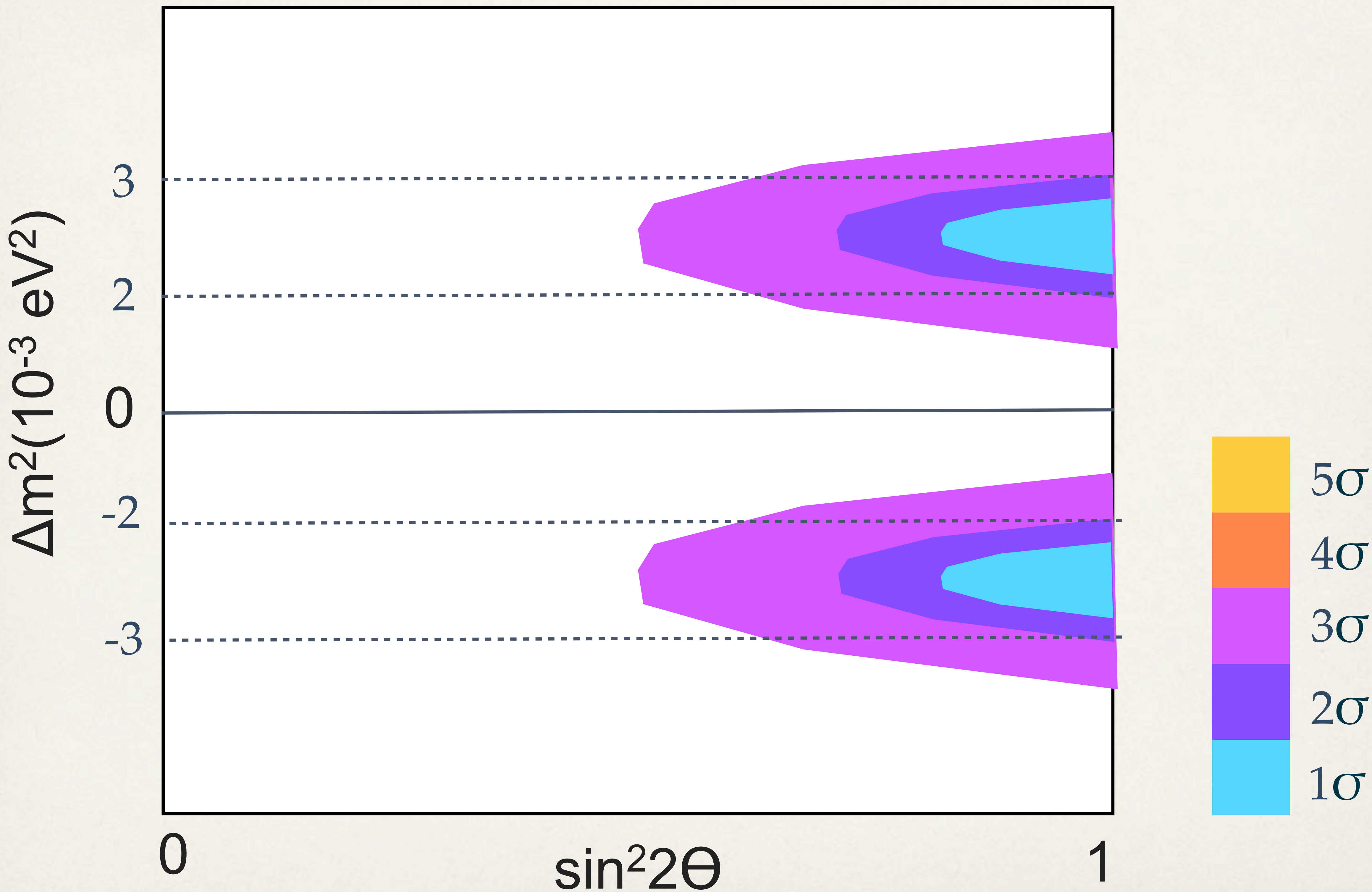


this scenario is for an experiment sensitive to NMH indicating IH at 5 sigma level

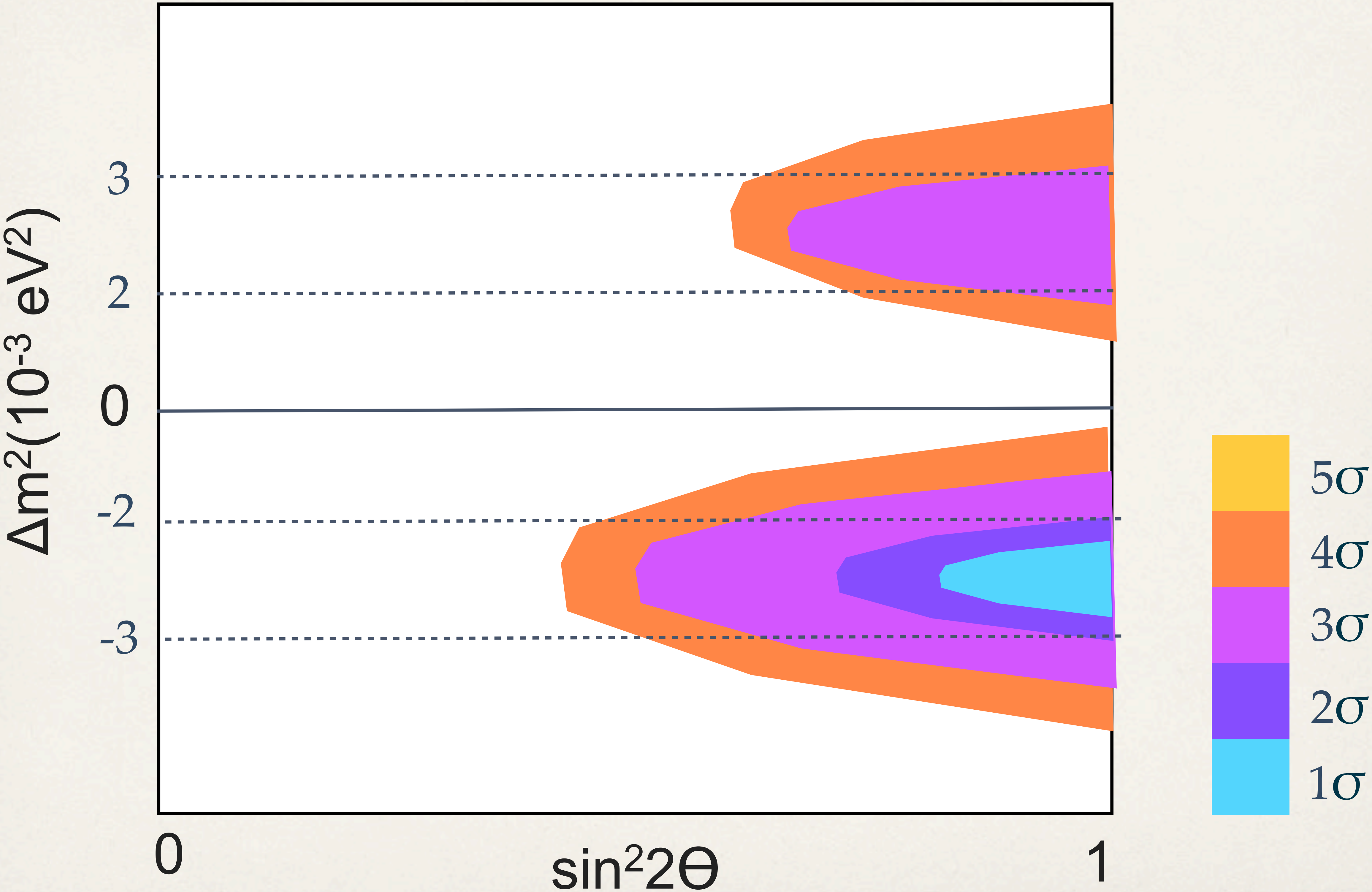


2D representation

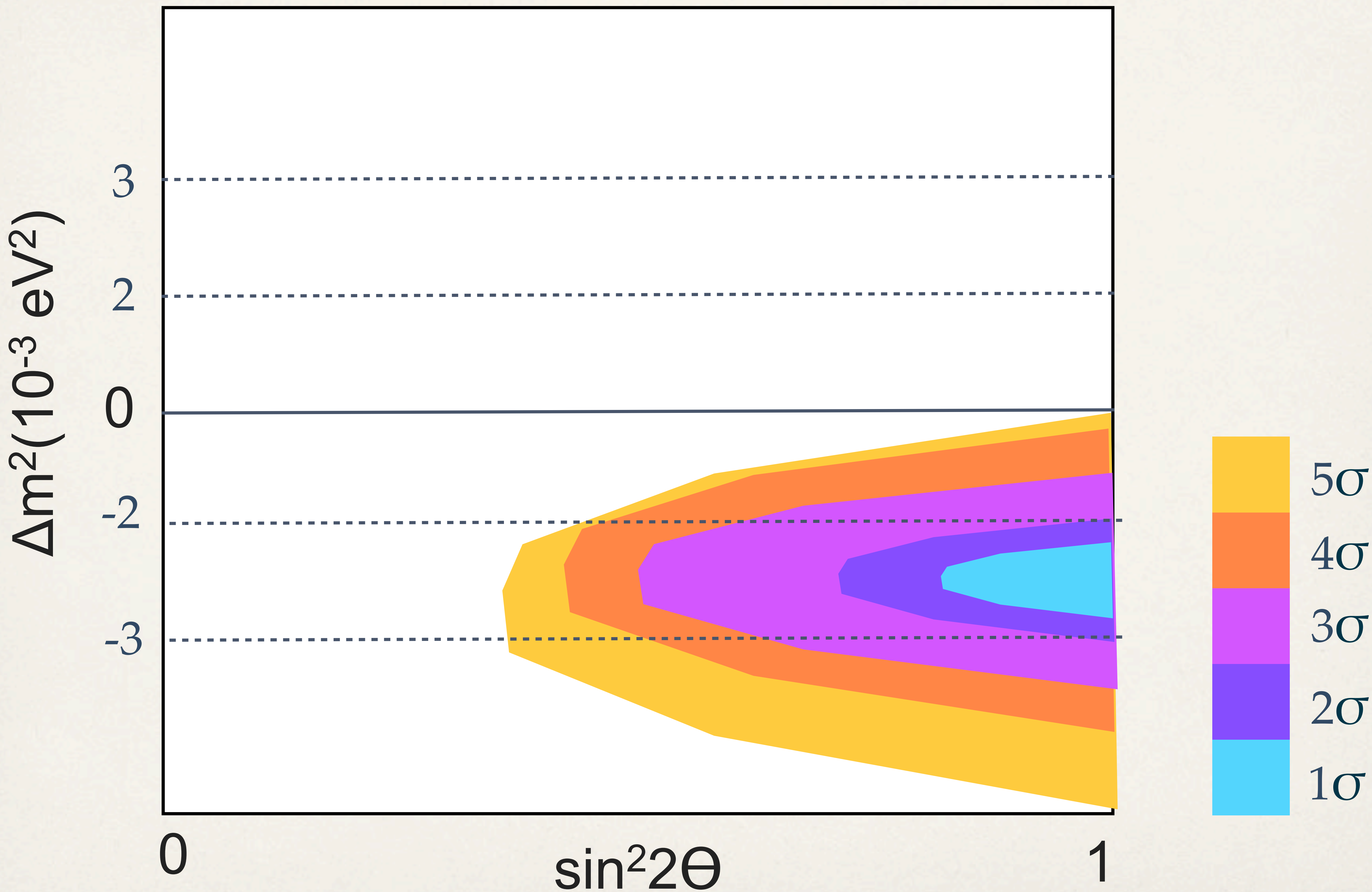
this scenario is for an experiment NOT sensitive to NMH



this scenario is for an experiment sensitive to NMH indicating IH at 2 sigma level



this scenario is for an experiment sensitive to NMH indicating IH at 5 sigma level



Questions to be answered by the sensitivity study

- Role of life-time vs signal efficiency vs volume: optimization to be performed for best (or enough) sensitivity

- Role of uncertainties: do we really need a high precision? the parameter space ($\pm \Delta m^2$, $\sin^2 2\Theta$) is large; for NMH is enough that one of the two regions get disfavored

- Role of degeneracies: to be quantified and carefully study

- Which uncertainties can be mitigated via the use of DeepCore and IceCube off-signal streams?

- and probably much much more ….

Questions to be answered by the sensitivity study

All of this makes the sensitivity study to NMH for PINGU (and ORCA) a large but very exiting project. We are learning a lot!

We hope to have all the full sensitivity / feasibility study this for next Spring / Summer