Introduction to IceCube Deep Core: Design, Schedule and Capabilities

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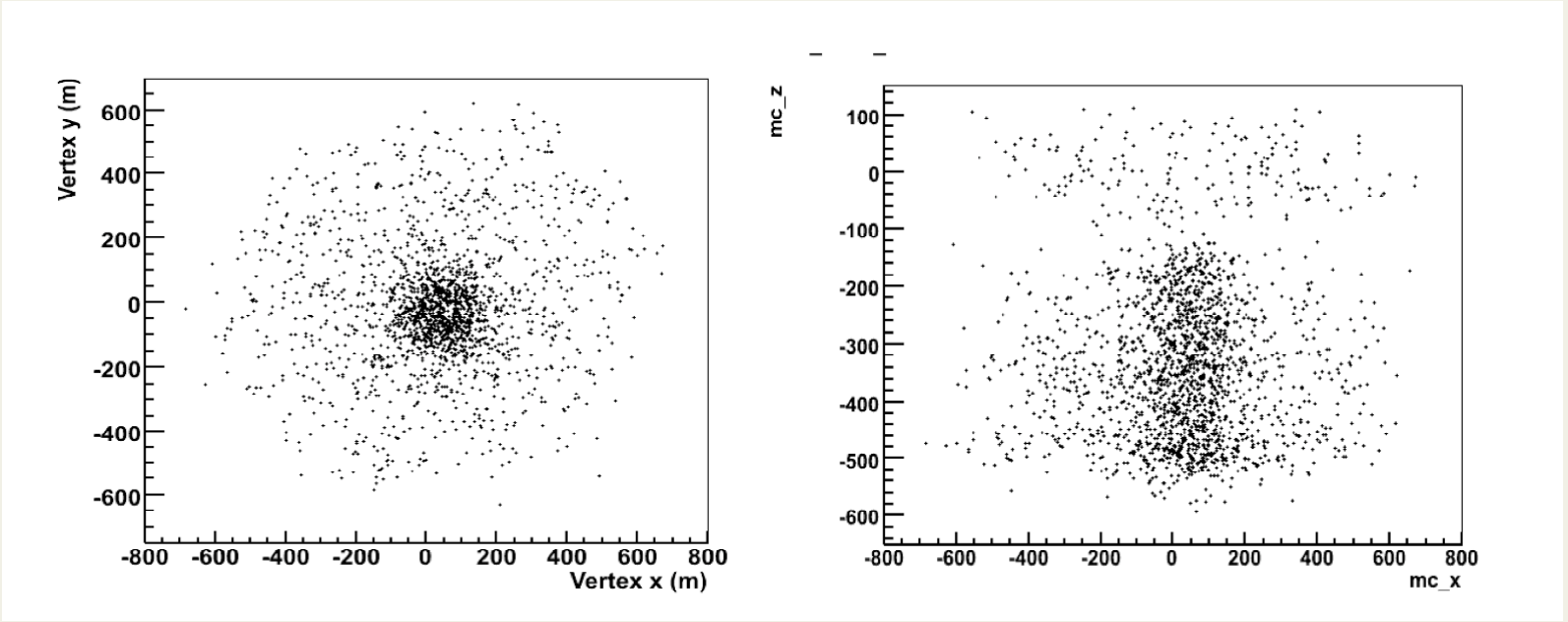
Partly based from Doug Cowen's Venice talk

Deep Core proposal

1. Deploy six strings at the centre of IceCube in order to increase IceCube low energy sensitivity.
2. Instrument the lower part of the detector with denser DOM spacing and use outer and top part of IceCube modules as veto for atmospheric muons.

Increased sensitivity

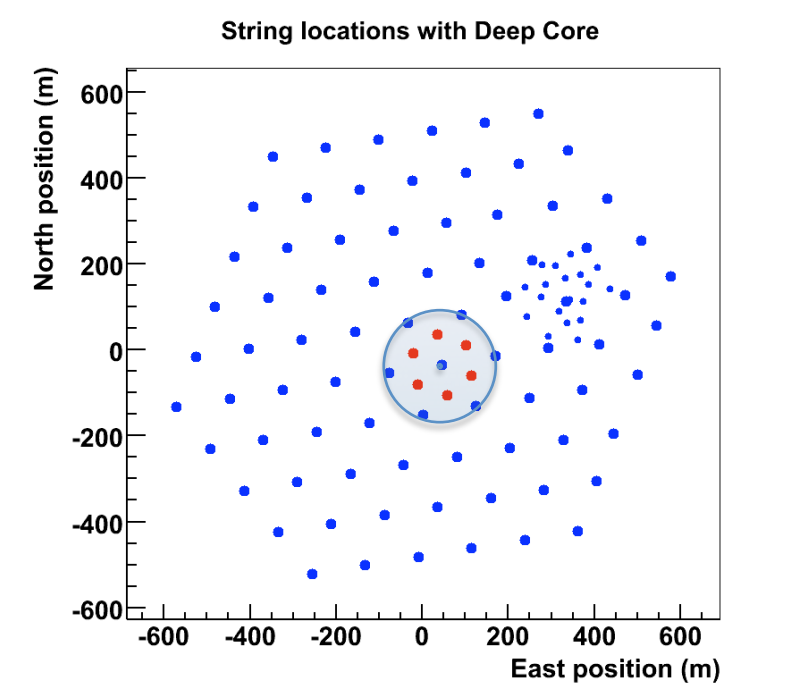
- The extra six strings strongly improves the sensitivity for low energy neutrinos.

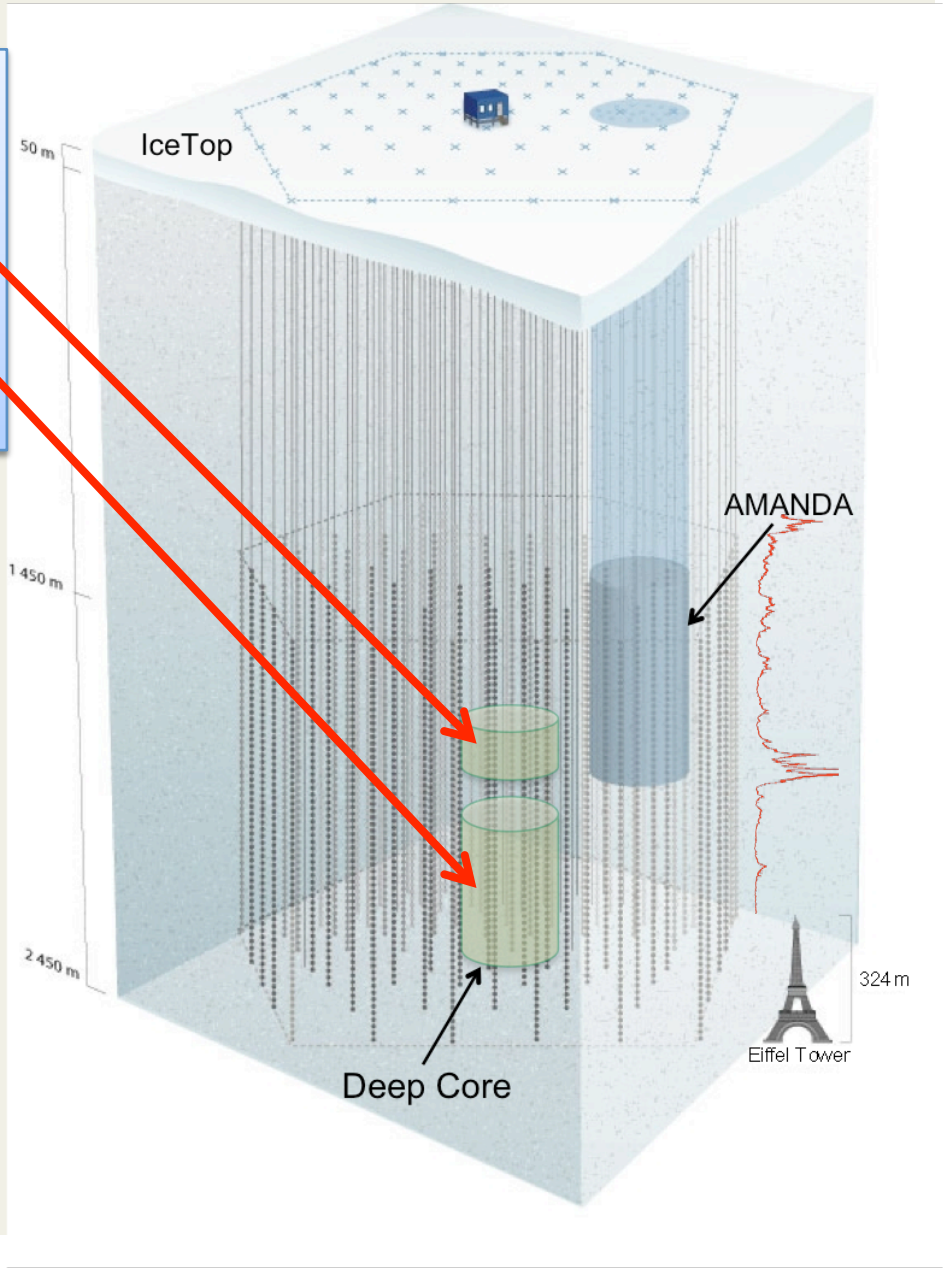


Interaction points for 100 GeV neutrinos from Wimp annihilations in the Sun

Deep Core

- Six new special strings located at the centre of IceCube
  - 10 Doms above dust layer with 10 m spacing
  - 50 DOMs below dust layer with 7 m spacing
- New PMTs with 40% higher QE!



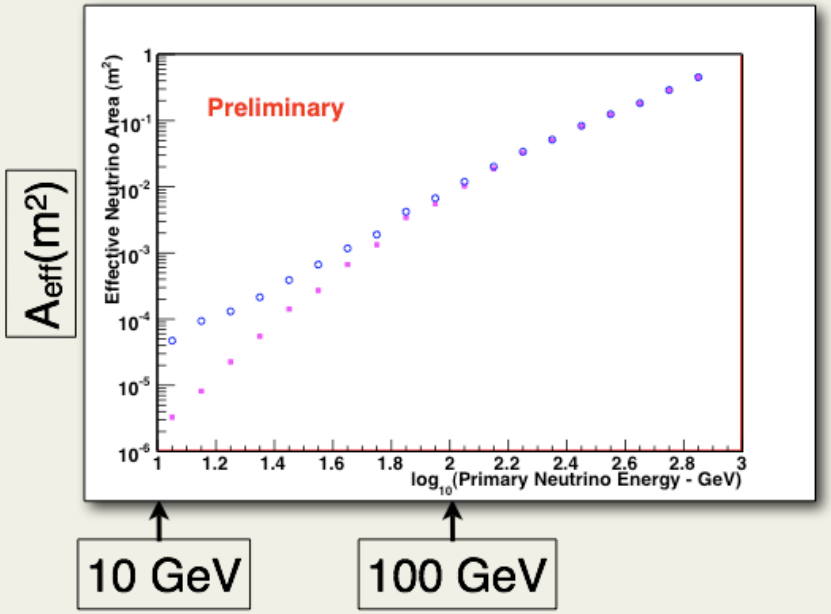


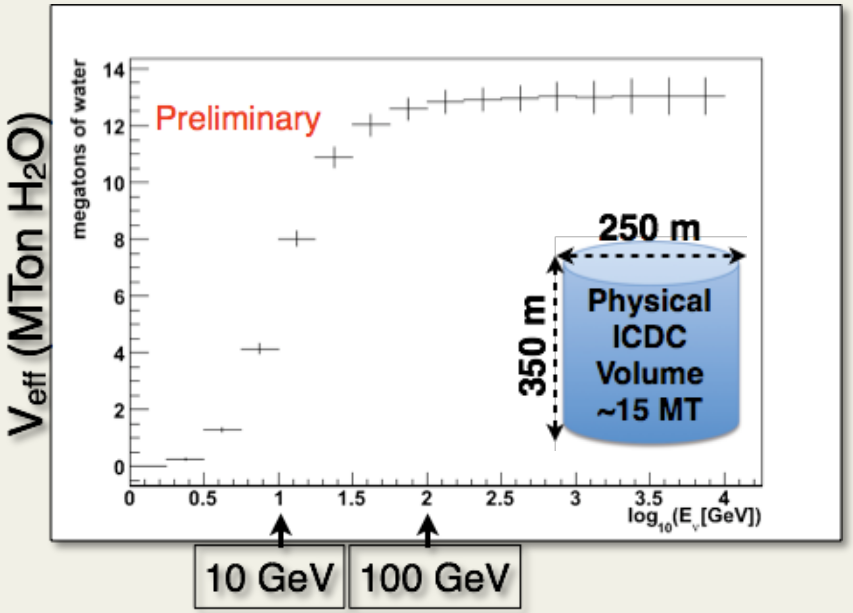
Deep Core

- Geometry
  - In total 13 (6 Deep Core and 7 Standard Icecube) strings with in average 72 m distance instead of 125m.
  - The 6 Deep core strings have 50 DOMs with 7 m spacing (instead of 17 m) below the dust layer at 2050 m and 10 DOMs with 10 m spacing above the dust layer.
- The 6 Deep Core strings have PMTs with Higher Quantum efficiency (≈40% higher)
- The ice below dust layer has the clearest ice (λ_{eff}~ 40-50m) in IceCube.

Effective areas and volumes

A_{eff}: For down going muon neutrinos following E^{-2} spectrum that trigger the detector ("SMT4", no reconstruction efficiencies included yet!)

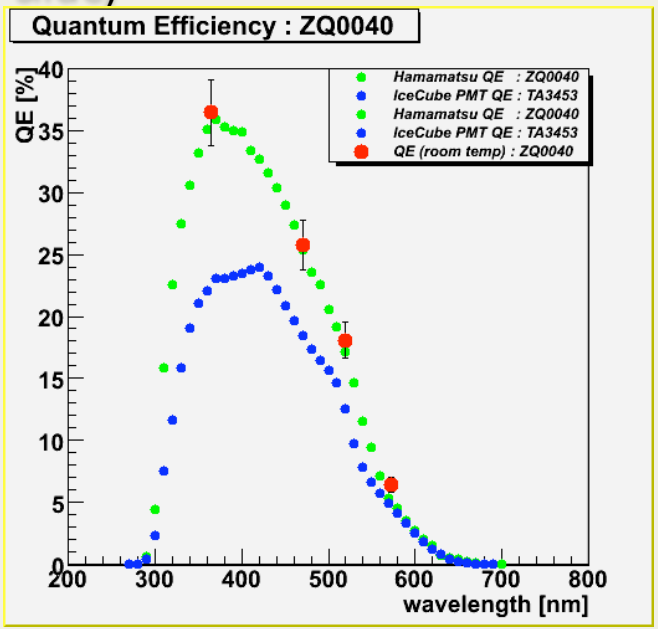


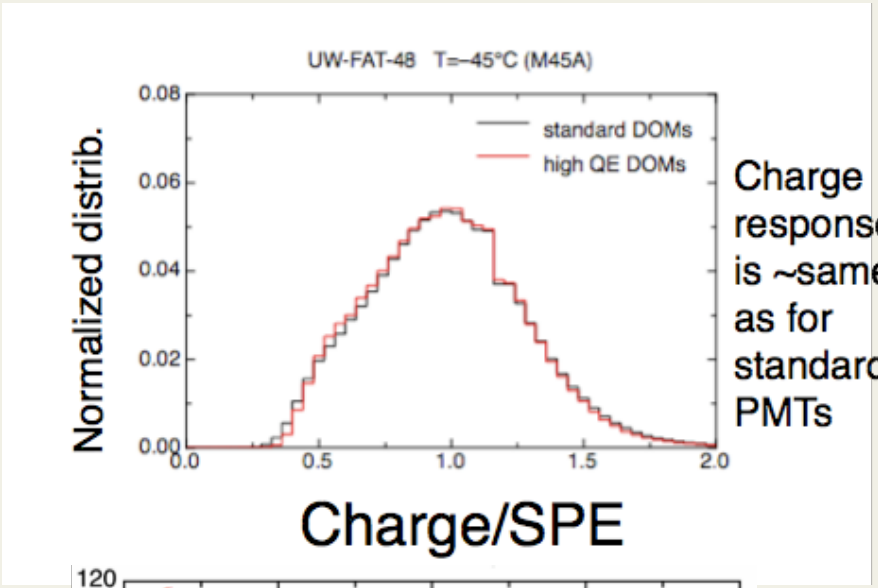


V_{eff}: For contained down going muon neutrinos that interact in the fiducial volume and trigger the detector ("SMT4", no reconstruction efficiencies included yet!)

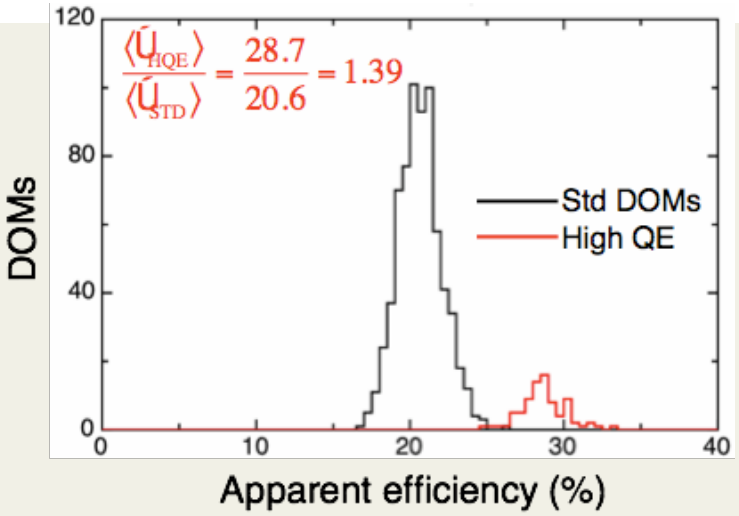
High QE PMT

- New photo cathode material
- No other hardware difference compared with IceCube's standard PMTs
- Lab measurements show about 40% improvement in QE
- In situ measurements have thus far validated lab measurements (see next slide)





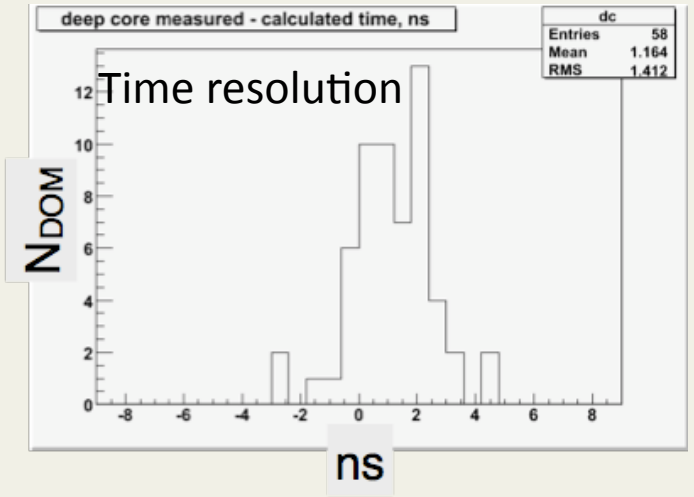
Charge response is ~same as for standard PMTs



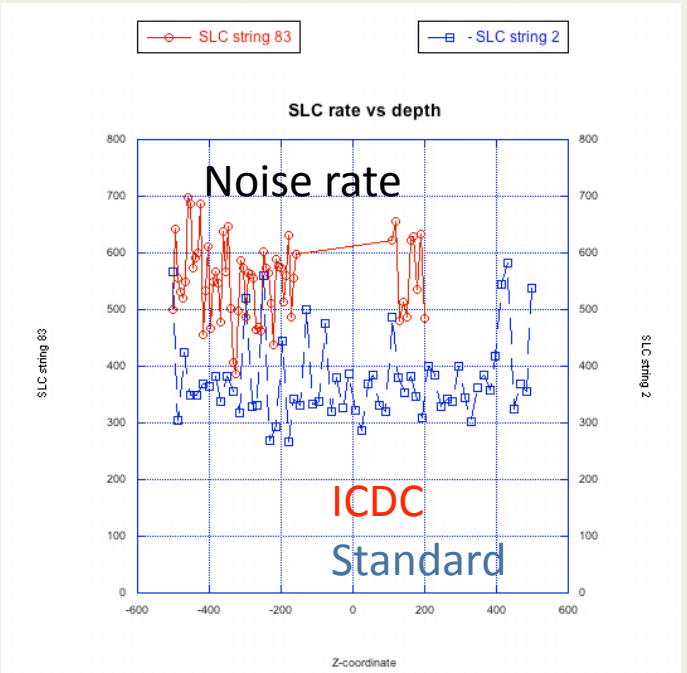
Performance in situ of HQE DOMs

The first Deep Core string with 60 HQE DOMs was deployed January 2009

Behaves as expected



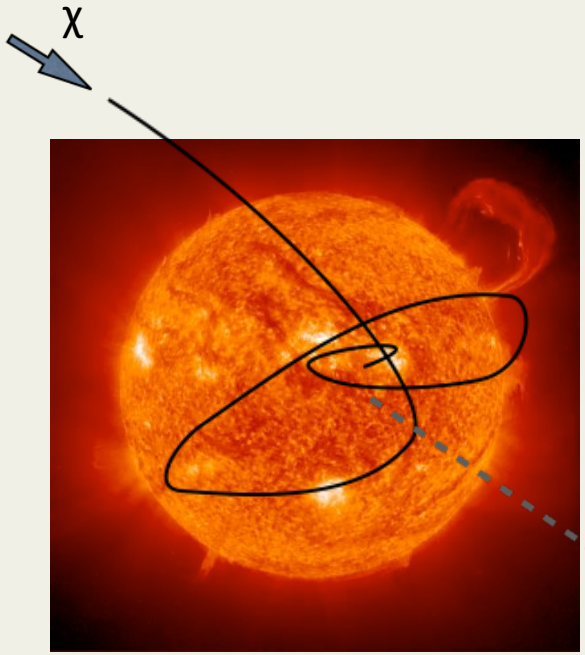
Preliminary data!!
String 2 noise rate 376 Hz
String 83 Deep core 552 Hz
Ratio 1.45



Scientific goals

- Improve sensitivity for low mass Wimp search
- Low energy electron-neutrinos, τ-neutrinos, cascades
- Neutrino oscillations
- Observation of neutrino sources in the southern hemisphere

WIMPs



$$\chi\chi \rightarrow \begin{matrix} q\bar{q} \\ l\bar{l} \\ W^{\pm},Z,H \end{matrix} \rightarrow \cdots \rightarrow \nu_{\mu}$$

Indirect detection from WIMP-WIMP annihilation in the

- Earth's core
- Solar core
- Galactic center

Indirect vs. direct searches:
- longer cosmological integration time
- sensitive to lower $\bar{v}_{WIMP}$

ν_{μ}

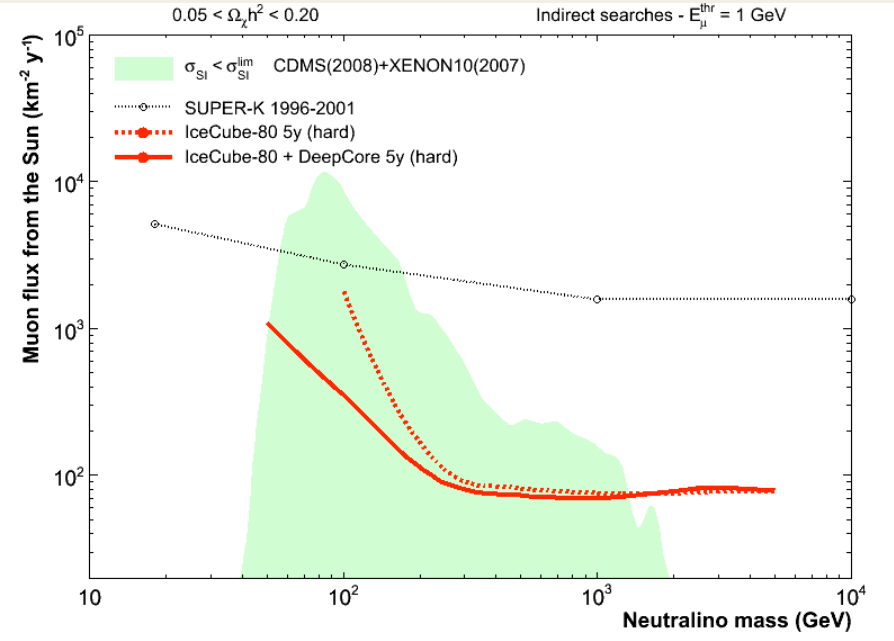
$\chi\chi \rightarrow \bar{b}b(\tau^{+}\tau^{-}) \rightarrow \nu$ soft E_{ν} spectrum

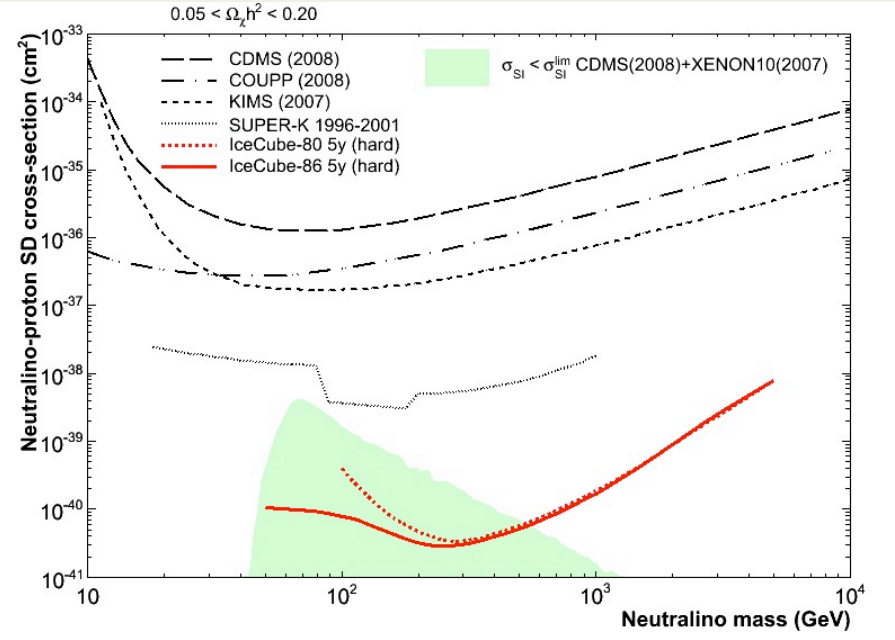
$\chi\chi \rightarrow W^{+}W^{-} \rightarrow \nu$ hard E_{ν} spectrum

Deep Core WIMP sensitivity

Muon flux and Spin dependent x-sec*

An early simulation of a 6 Deep Core strings with 40 standard DOMs spaced 10 m showed a strong increase of Deep Core sensitivity for low mass Wimps





With more efficient Deep Core and exposure 365 days a year we will have better sensitivity

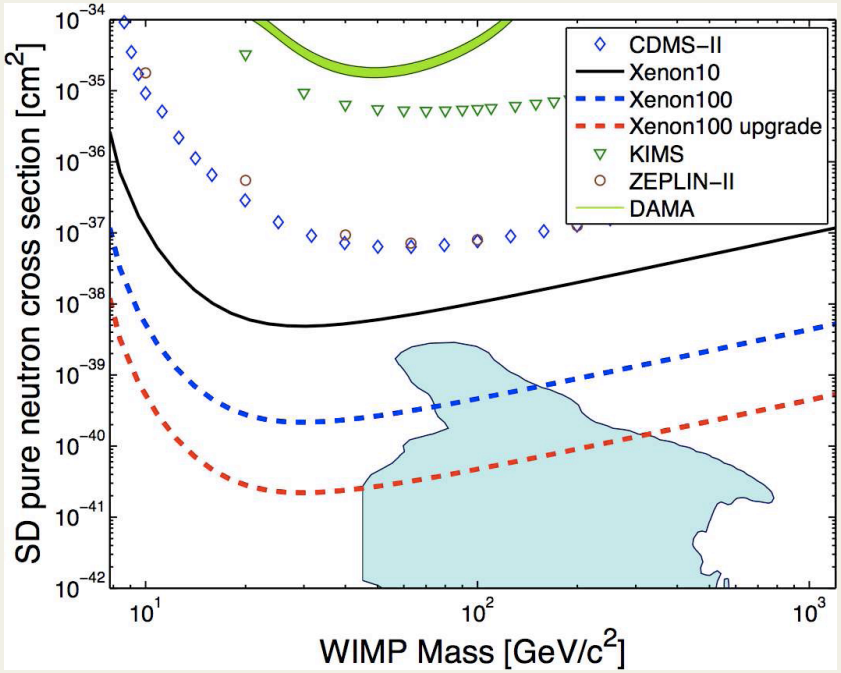
* Assuming equilibrium between capture and annihilation rates in the Sun.

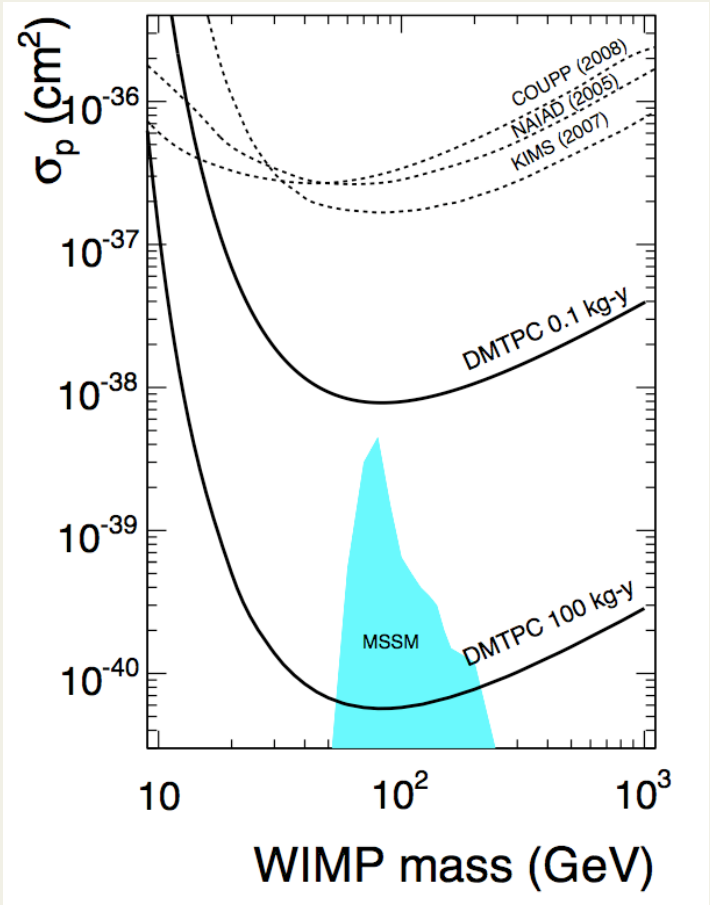
Deep Core and Wimps

- Higher sensitivity for low mass WIMPs
  - Shorter spacing between strings and DOMs
  - Higher Quantum efficiency DOMs
  - Possibility to observe neutrinos when the sun is above the horizon by vetoing down going atm muons (this is most efficient for low mass Wimps)
  - Possible to search for Wimp annihilations in the galactic centre.

Other WIMP experiments

Spin dependent x-sec

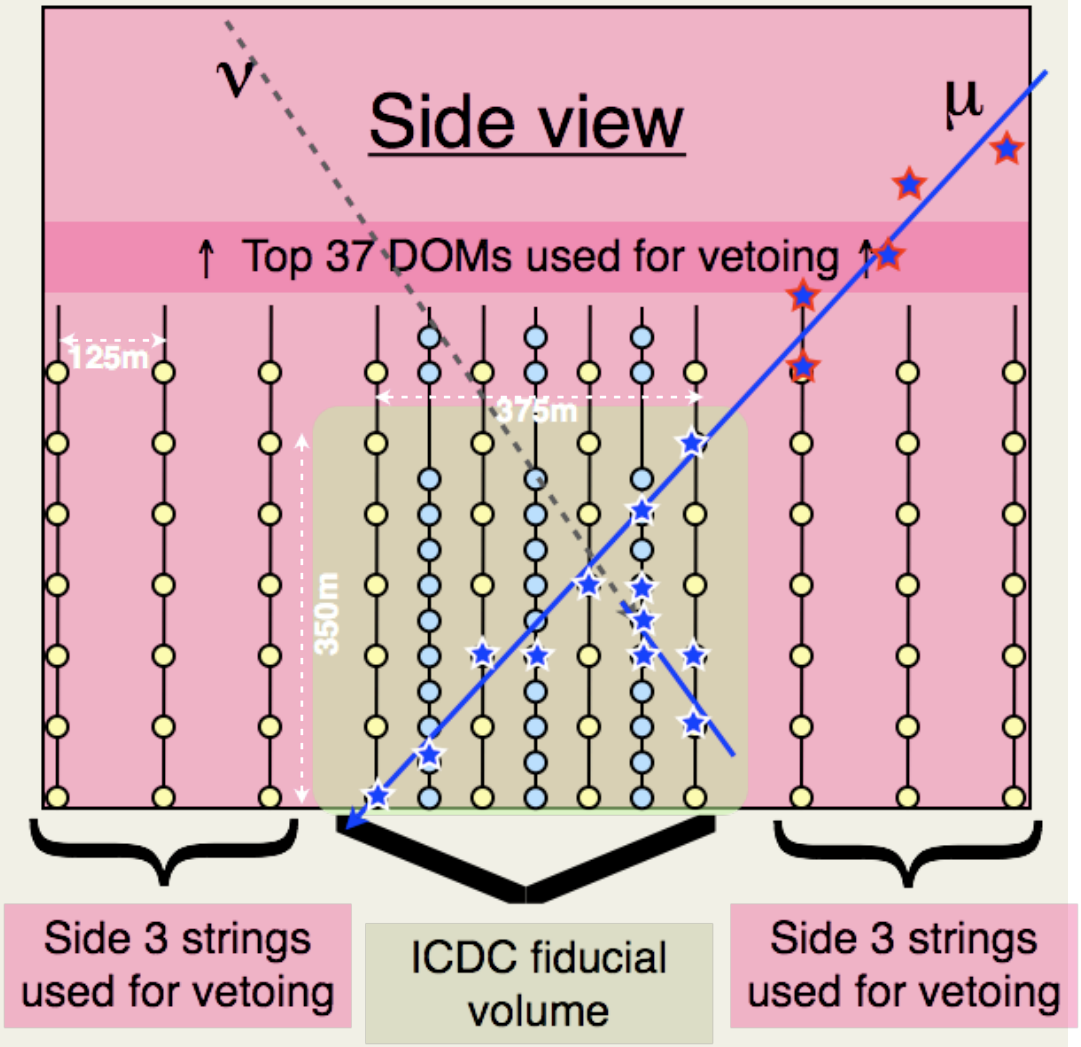




Assuming no back ground events, Xenon100 upgrade might reach similar sensitivity after 2012 and a new DMTPC sometime far in future in DUSEL lab?

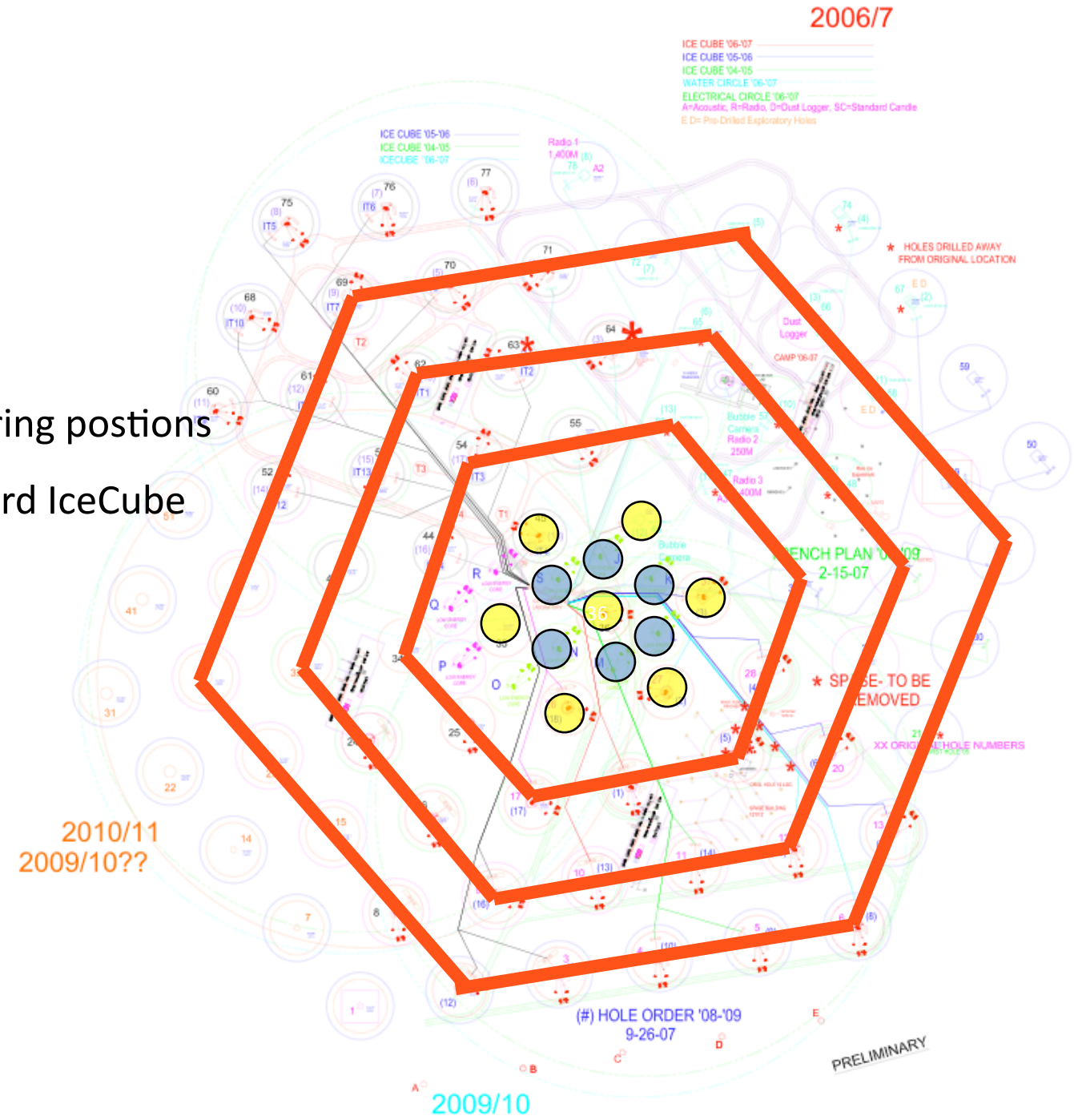
ICDC veto for atmospheric muons

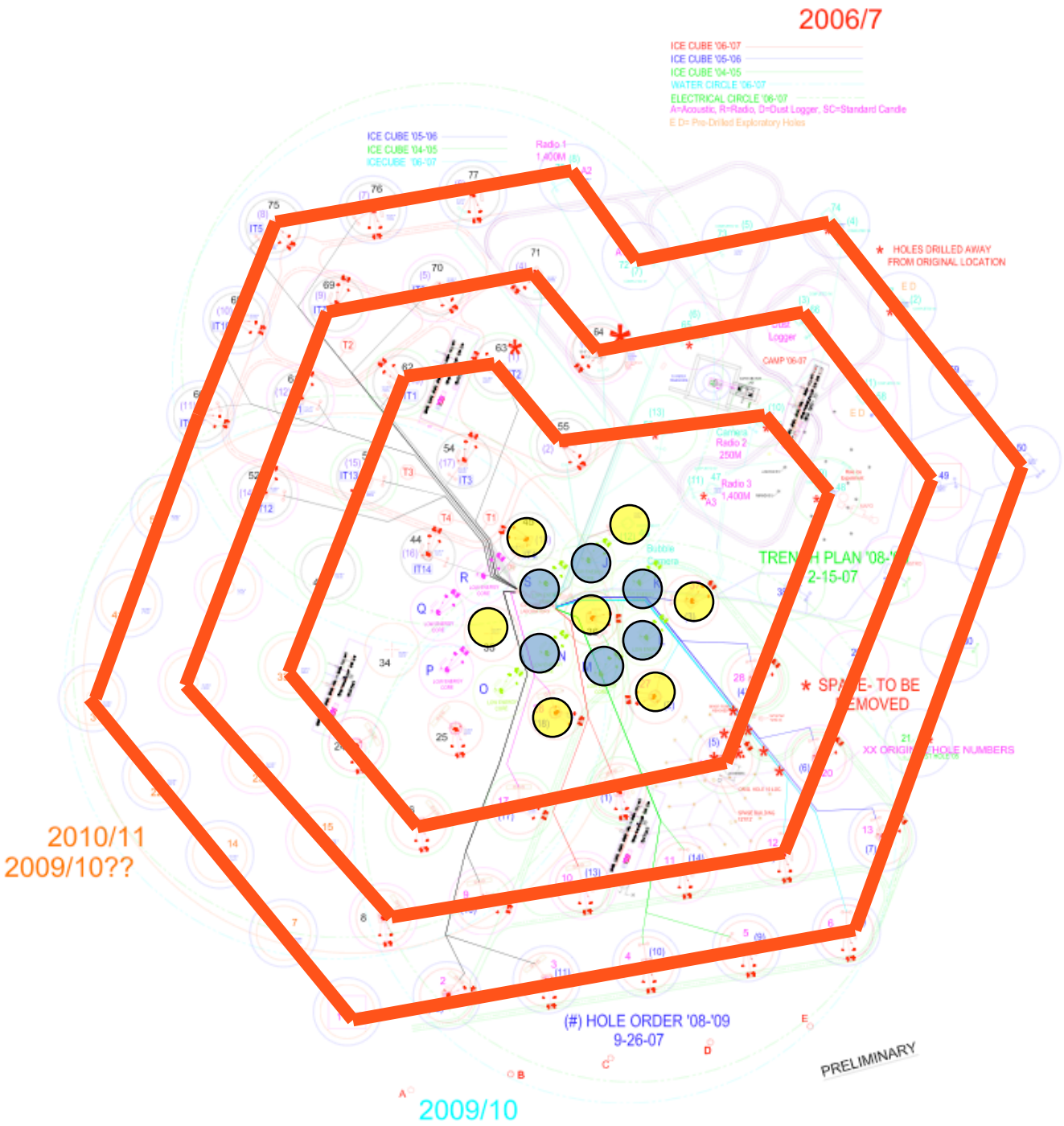
- Use the outer IceCube strings for veto atmospheric muons.
- Ratio atm-μ/atm-ν 10^6
- Three lines of IceCube strings needed for >10^6 rejection.



New string postions

Standard IceCube




2006/7
ICE CUBE '06-'07
ICE CUBE '05-'06
ICE CUBE '04-'05
WATER CIRCLE '06-'07
ELECTRICAL CIRCLE '06-'07
A=Acoustic, R=Radio, D=Dust Logger, SC=Standard Candle
E D= Pre-Drilled Exploratory Holes
ICE CUBE '05-'06
ICE CUBE '04-'05
ICECUBE '06-'07
Radio 1
1,400M
HOLES DRILLED AWAY
FROM ORIGINAL LOCATION
CAMP '06-'07
Camera
Radio 2
250M
Radio 3
1,400M
TRENCH PLAN '08-'
2-15-07
SPARE- TO BE
REMOVED
XX ORIGINAL HOLE NUMBERS
2010/11
2009/10??
(#) HOLE ORDER '08-'09
9-26-07
PRELIMINARY
2009/10

Preliminary ICDC veto algorithms

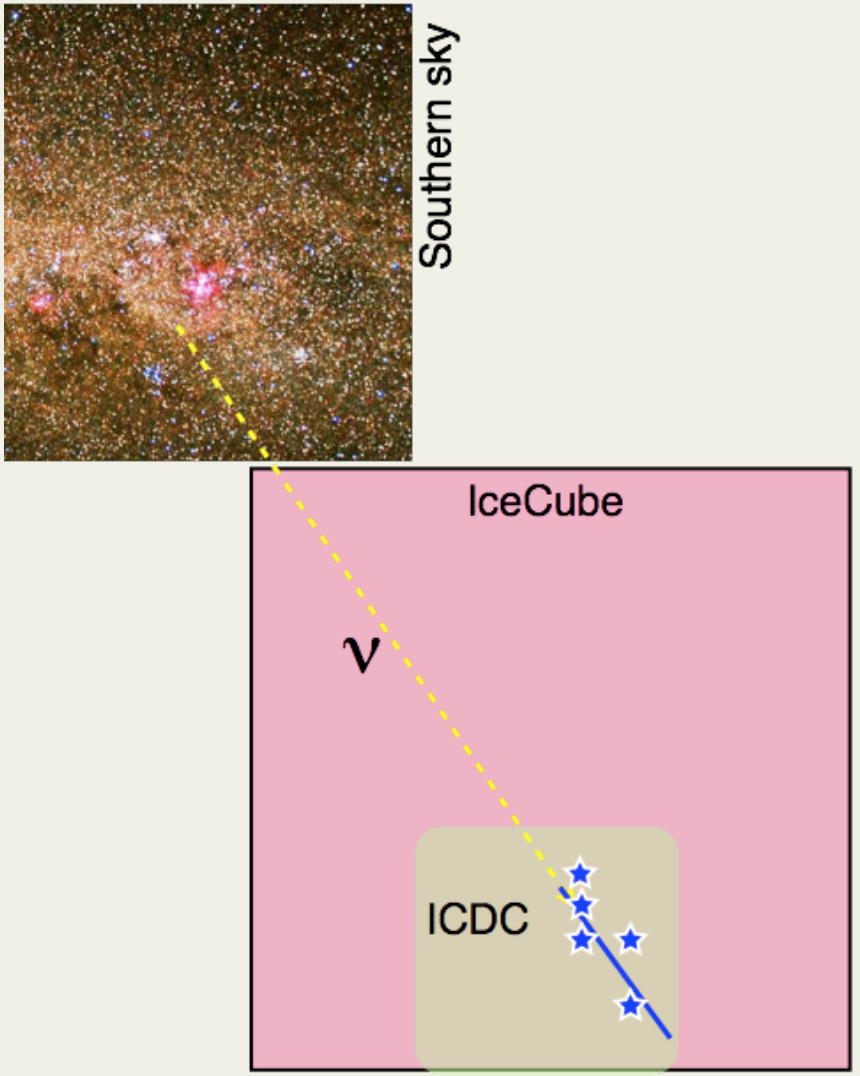
- On line
  - Find event's light intensity weighted centre of gravity and start time
    - $V = |\bar{r}_{COG} - \bar{r}_{DOM}|/(t_{COG} - t_{DOM})$
  - If too many hits give v≈c => veto event
    - Gives ≈ 5 $10^{-4\ in}$ rejection with ≈ 90% signal left

Preliminary ICDC veto algorithms

- Offline algorithm (preliminary)
  - Hit kept only if close in (r,t) with another hit
  - Calculate weight $w(r_{ICDC})$ for each hit
    - more distant hits get higher weight
    - require small summed weight
    - Gives 10^4 rejection of cosmic-rays
- Next require event "vertex" in V_{ICDC}
  - Gives 10^6 rejection (with low signal efficiency)
    - This rejection factor brings us close to 1:1 ratio of (cosmic-ray background):(atmospheric neutrinos)
- Work in progress!!

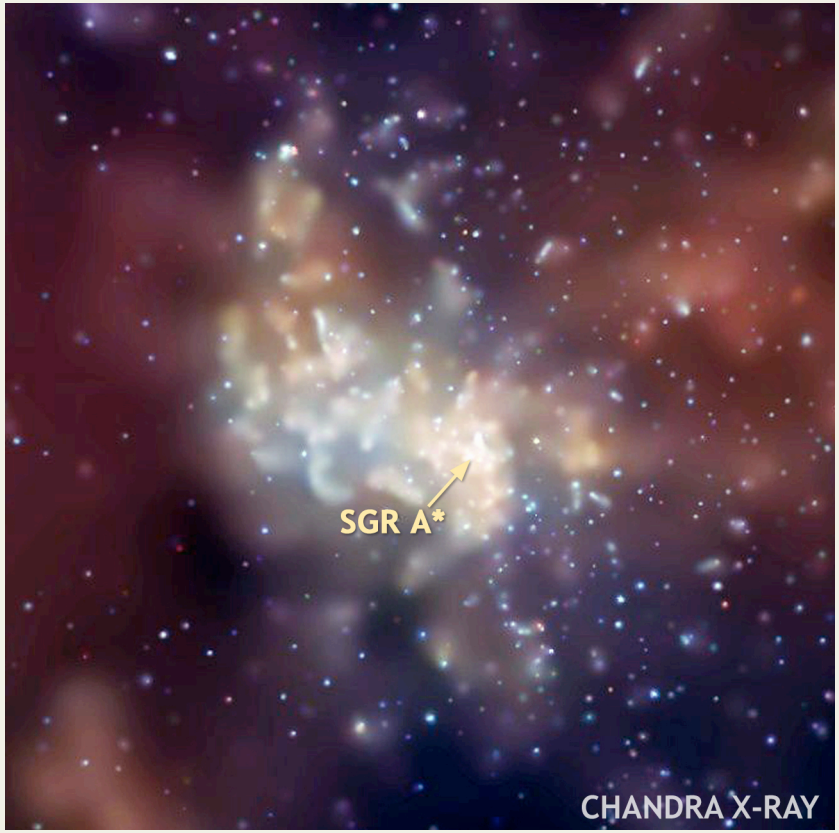
Southern hemisphere

- Potential sources:
  - AGN, PWNe, SNR, GRBs
- Enabled by vetoing capability
  - Thus far, all neutrino telescopes have only tried to look down
  - Focus on tracks that start in the ICDC fiducial volume
  - Will need specialized reconstruction algorithms to handle starting cascade (and use it for energy estimation) as well as fully contained tracks
- Work in progress...



The black hole in the Milky Way

- Mass 3-4 million times the Sun
- Had probably a strong flare 300 years ago
- Next one?
- Deep Core 24/7.

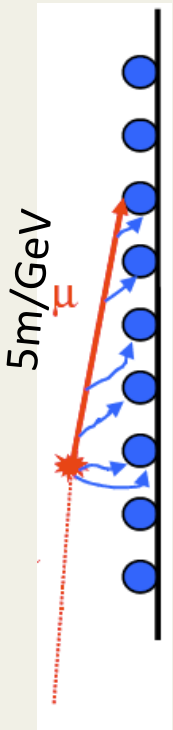


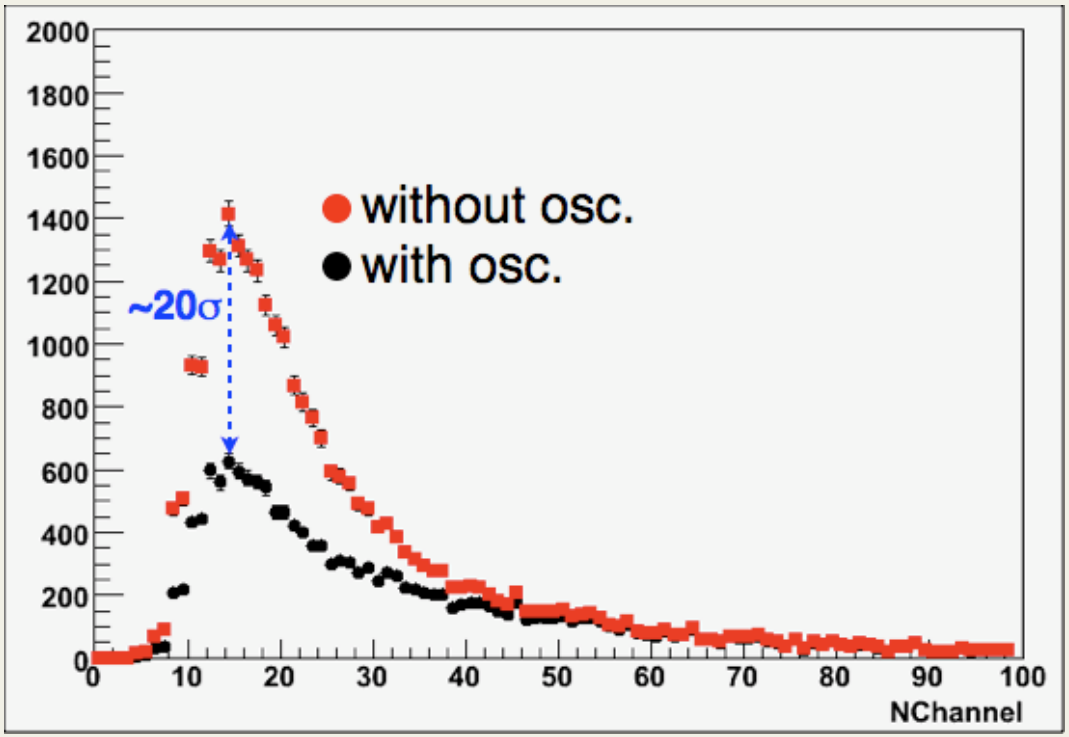
ICDC & ν Oscillations

- To be sensitive to $\Delta m^2(\text{atm}) \sim 10^{-3}$, require $L(\text{km})/E(\text{GeV}) \sim 10^3$
- Atmospheric neutrinos, with $L \sim 10^4$ km, can be used by IceCube.....
  - but only if IceCube has sensitivity to $E_\nu \sim 10$ GeV

Neutrino oscillations and ν_μ disappearance

Effect is simplest to measure for vertically upgoing ν_μ-induced μ (analysis already underway w/IceCube)

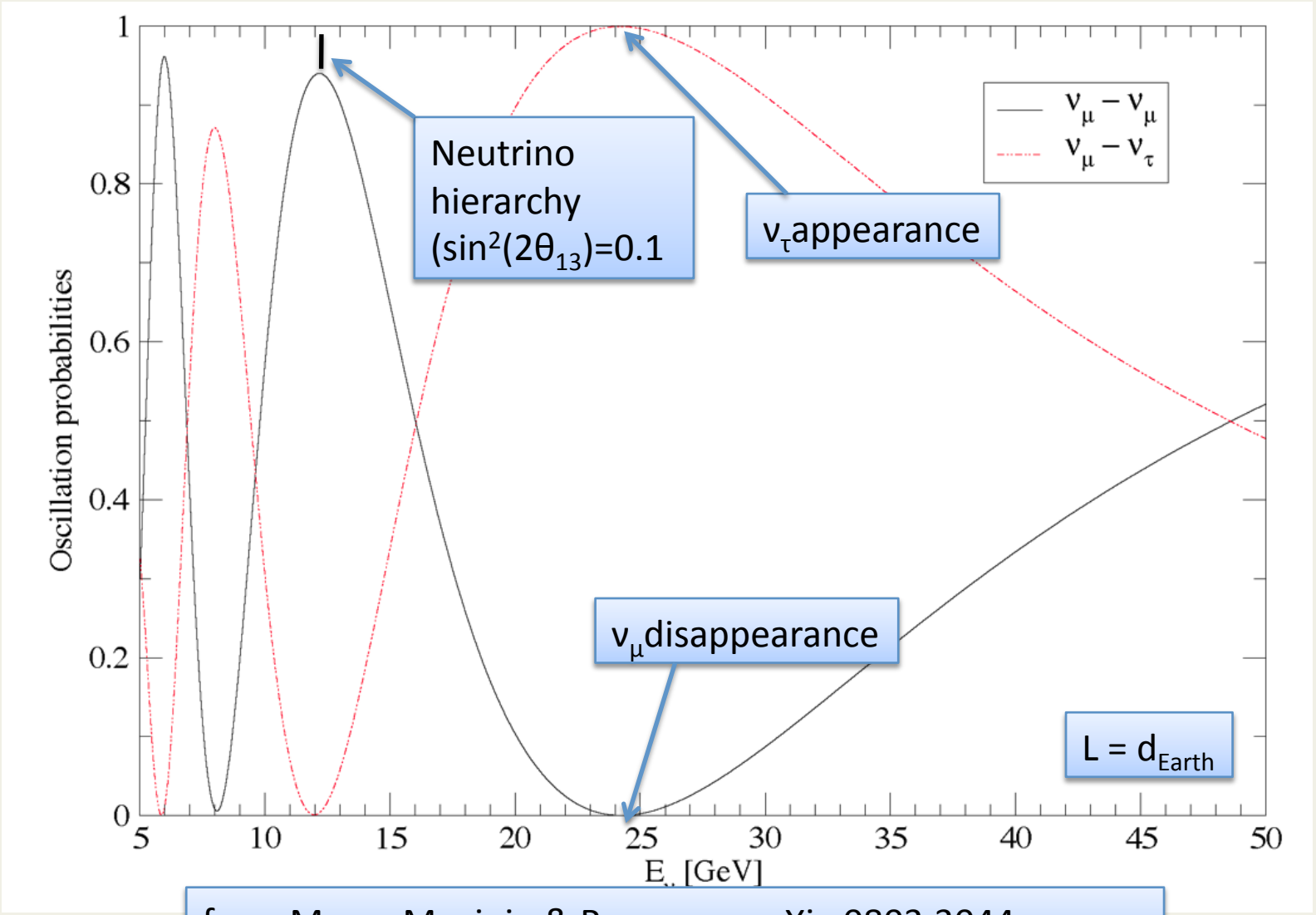




Number of channels hit

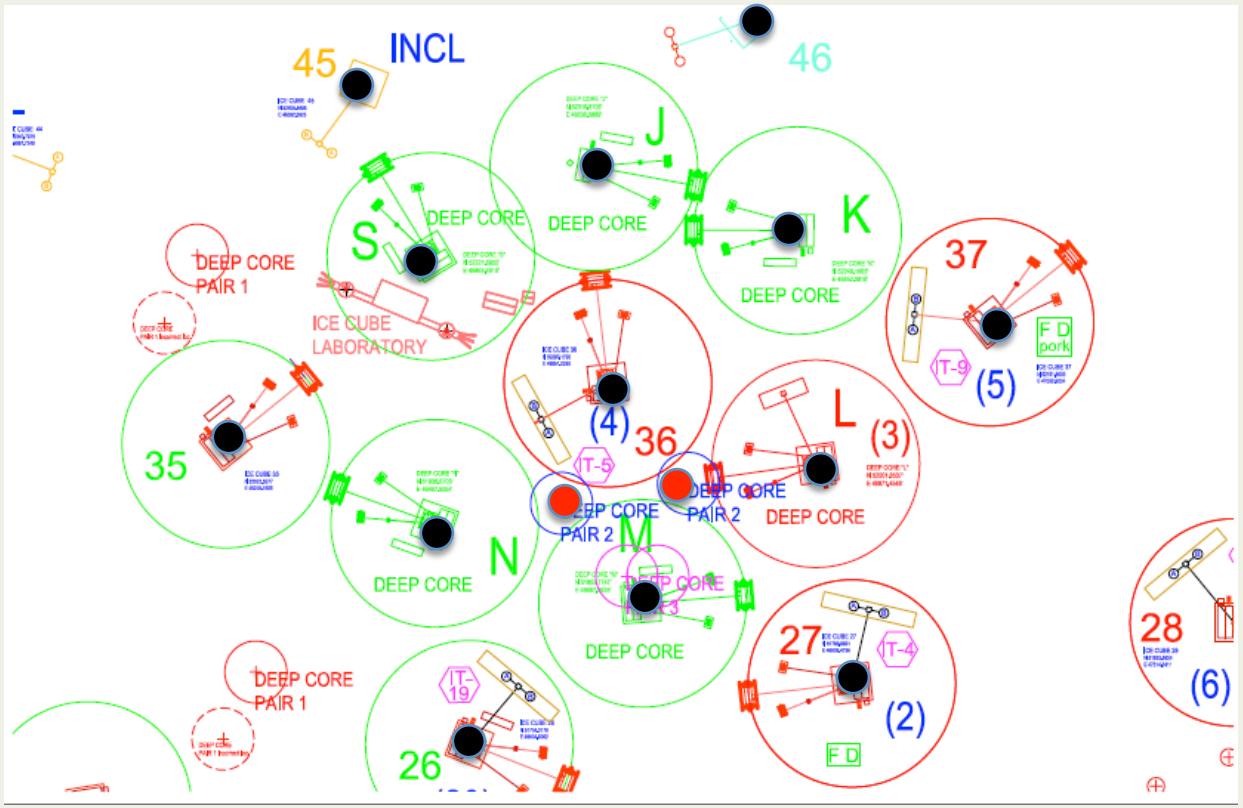
Full 3-ν oscillations
PREM (earth model)
Only at trigger level
Only statistical errors; no systematic
1 yr ICDC
cosΦ < -0.6

Neutrino oscillations



from Mena, Mocioiu & Razzaque, arXiv:0803.3044

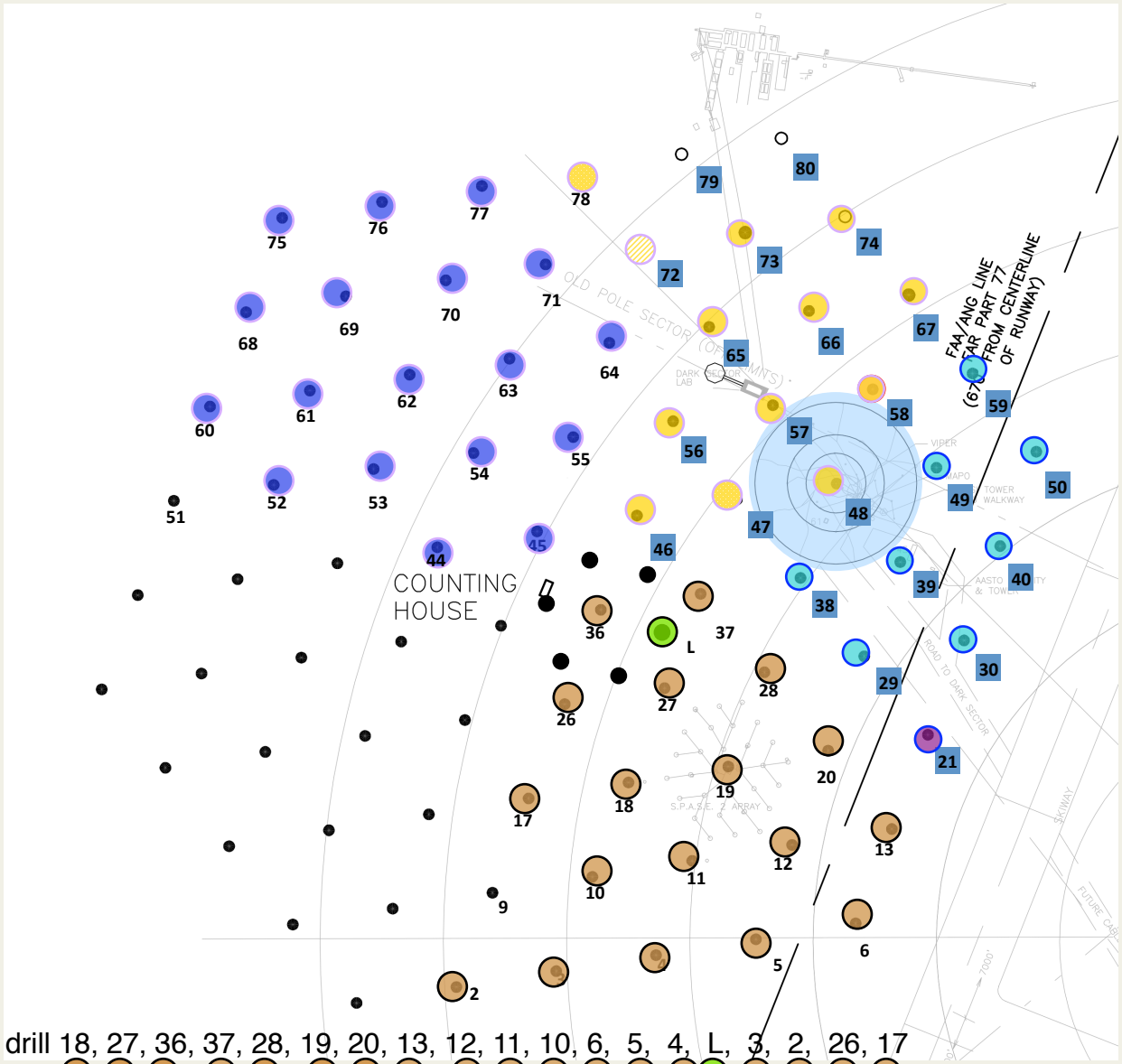
Strings 79 and 80



Deep Core deployment schedule

- The first Deep Core string was deployed January 2009.
- The remaining five strings are planned to be deployed the next season 09/10.
- In the same time the Deep Core will be completely surrounded by three layers of IceCube strings which can be used for vetoing atmospheric muons.
- Running full Deep Core should start March 2010

Deployment status 21/1/09



AMANDA

IceCube string and IceTop station deployed 01/05

IceCube string and IceTop station deployed 12/05 – 01/06

IceCube string deployed 2006/2007

IceCube string with additional acoustic sensors deployed 2006/2007

IceCube string with additional acoustic and radio sensors deployed 2006/2007

Drilling

Deployment 08/09

Deep Core string

Conclusions

- IceCube and IceCube Deep Core can analyze data at much lower E_ν than previously imagined or foreseen
- Improves energy overlap with other experiments
- Expect that veto will be powerful enough to remove most of cosmic-ray background
- Expect energy resolution for all flavors of neutrinos to be sufficient to do interesting neutrino oscillation studies
- This talk has covered only a fraction of the physics potentially opened up by ICDC

Some Deep Core pictures


EIDER