IceCube-Gen2

Upgrading IceCube to higher and lower energies

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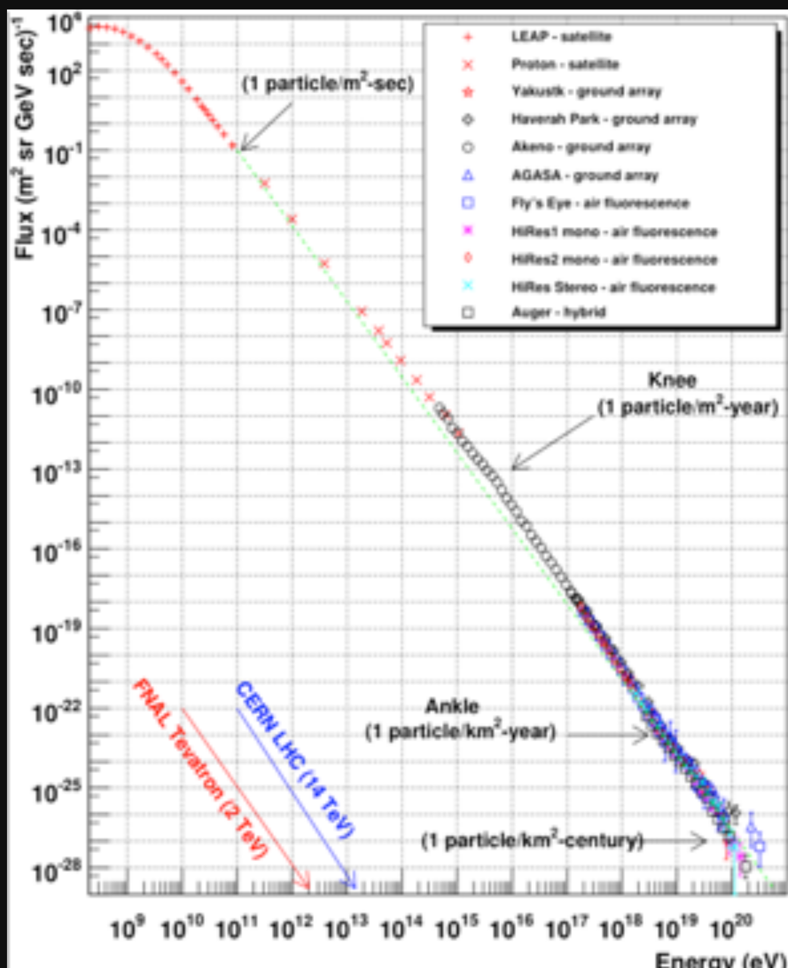
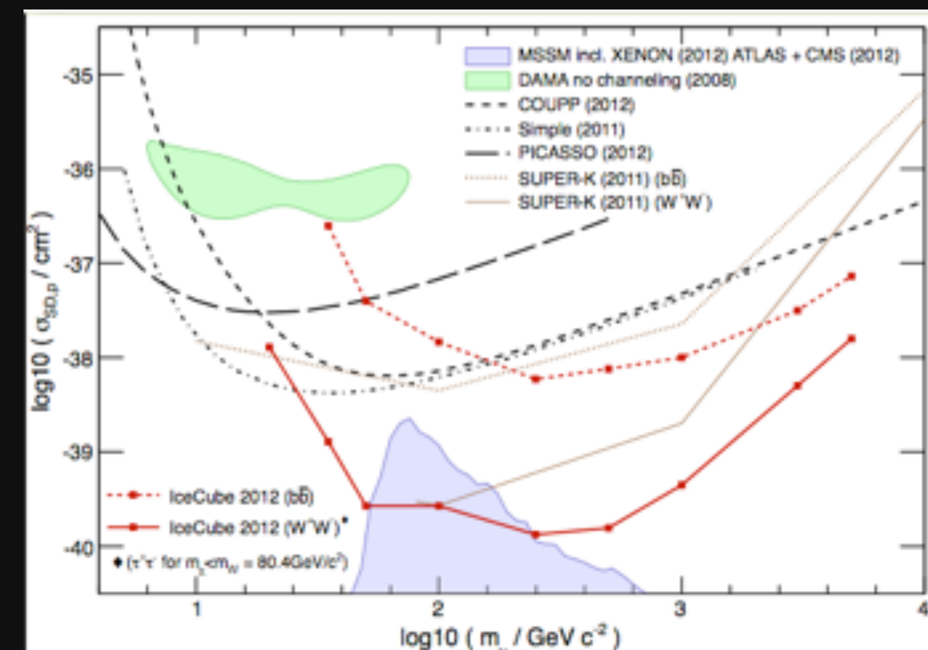
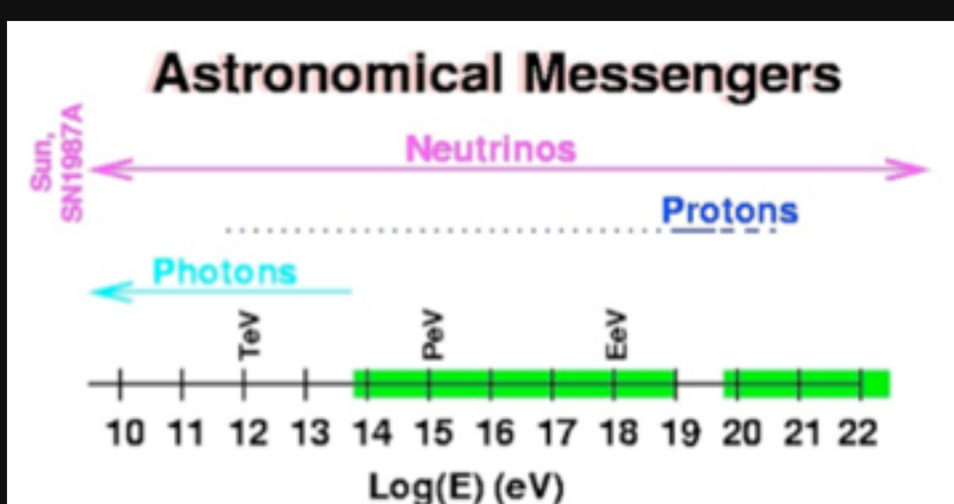
IceCube Physics

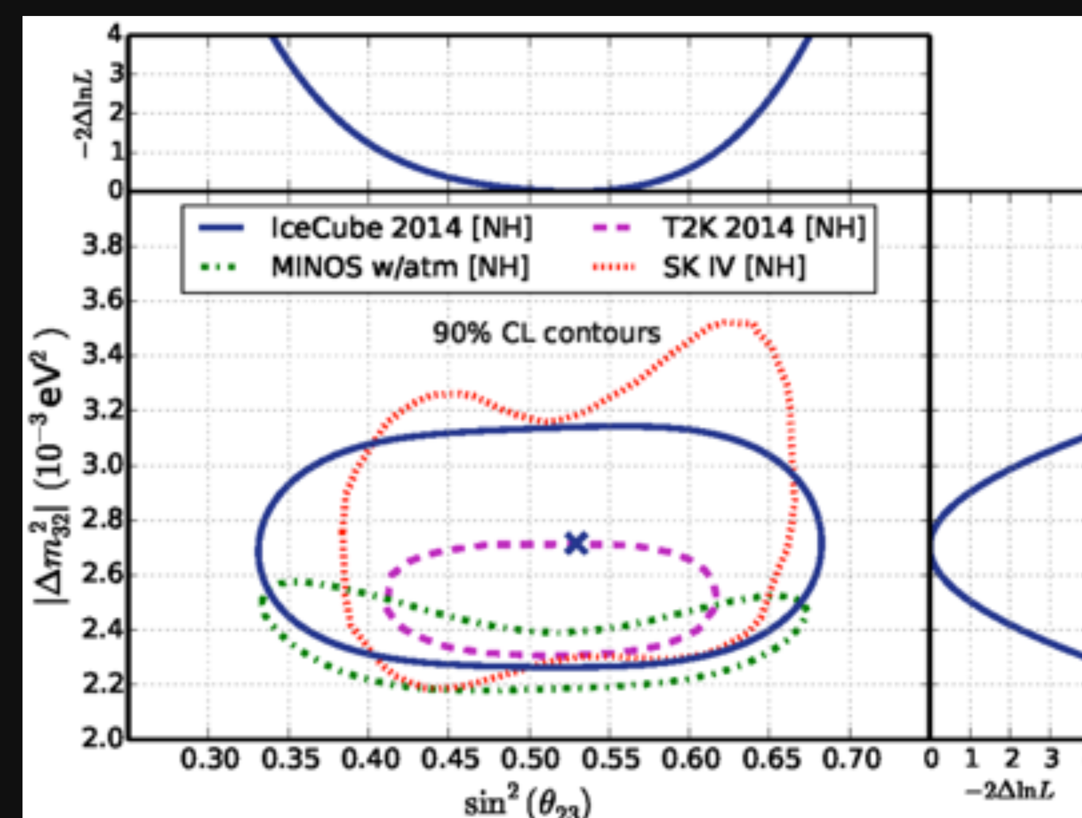
Sources of high-energy cosmic rays, new astronomical window, probe low-mass WIMP DM, neutrino oscillations





see previous talk by C. Weaver





IceCube-Gen2 Infrastructure

A "next generation IceCube" detector

- **PINGU ("Precision IceCube Next Generation Upgrade")**
  - Scale: 40 strings, extending DeepCore
  - Physics goals: neutrino mass ordering, neutrino physics, dark matter
- **High-Energy In-Ice Component**
  - Scale: O(100) strings, O(10km^3)
  - Physics goals: identify astrophysical sources of neutrinos and cosmic rays, neutrino and particle physics, BSM
  - Surface component like IceTop
- **A large surface extension for vetoing downgoing bkg**
  - Several km larger than the detector
  - Optimal size and density under investigation

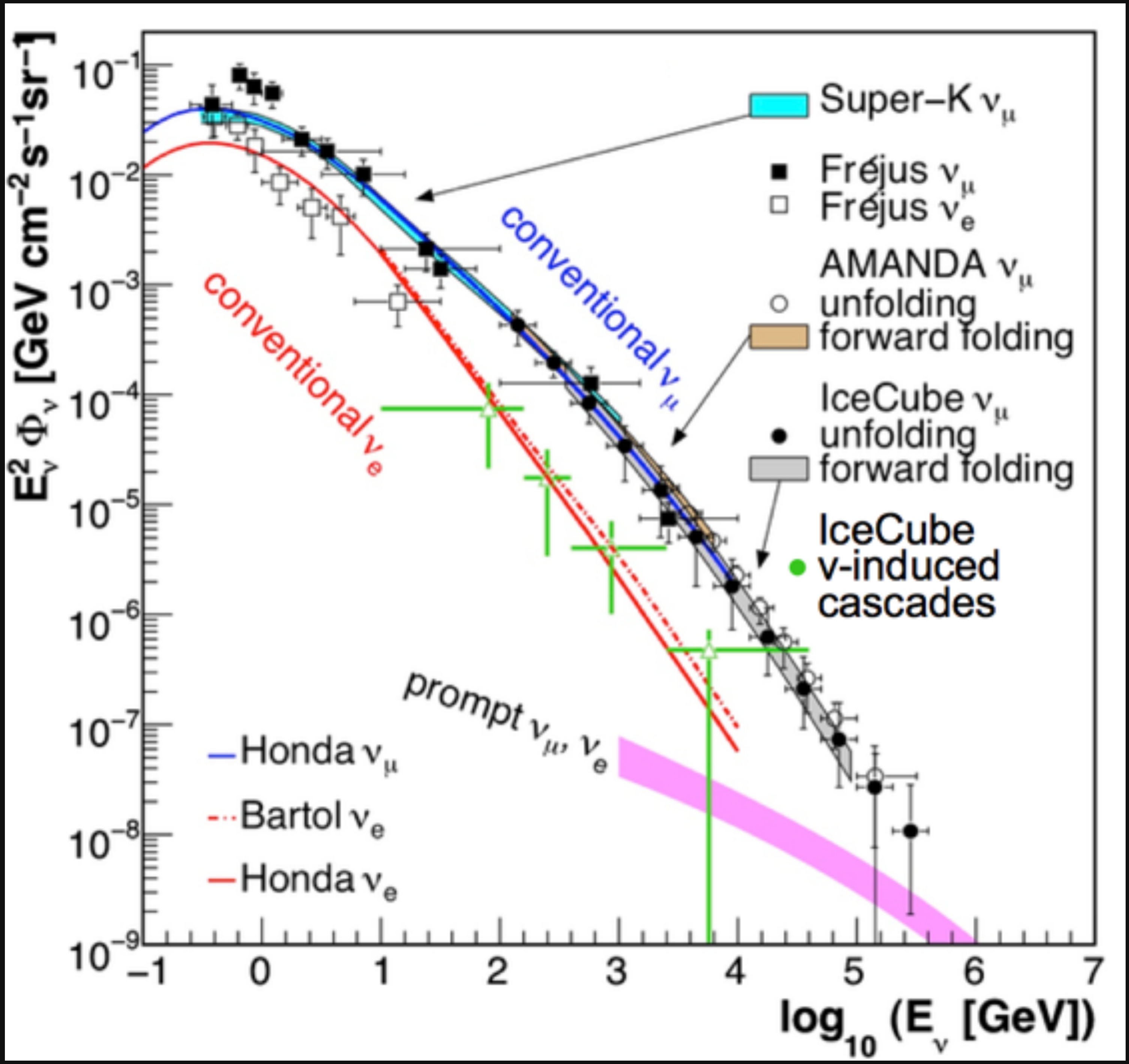
PINGU Low-Energy Extension

PINGU would lower neutrino energy threshold to a few GeV

- **Baseline geometry:**
  - Add 40 new strings interleaved with existing DeepCore strings
  - 60 (updated) DOMs on each string
    - also evaluate impact of more DOMs/string
- **Use technology very similar to that used with IceCube (drill, digital optical module, …)**
- **Would take 2-3 seasons to deploy**
- **Could be taking data as early as 2020**

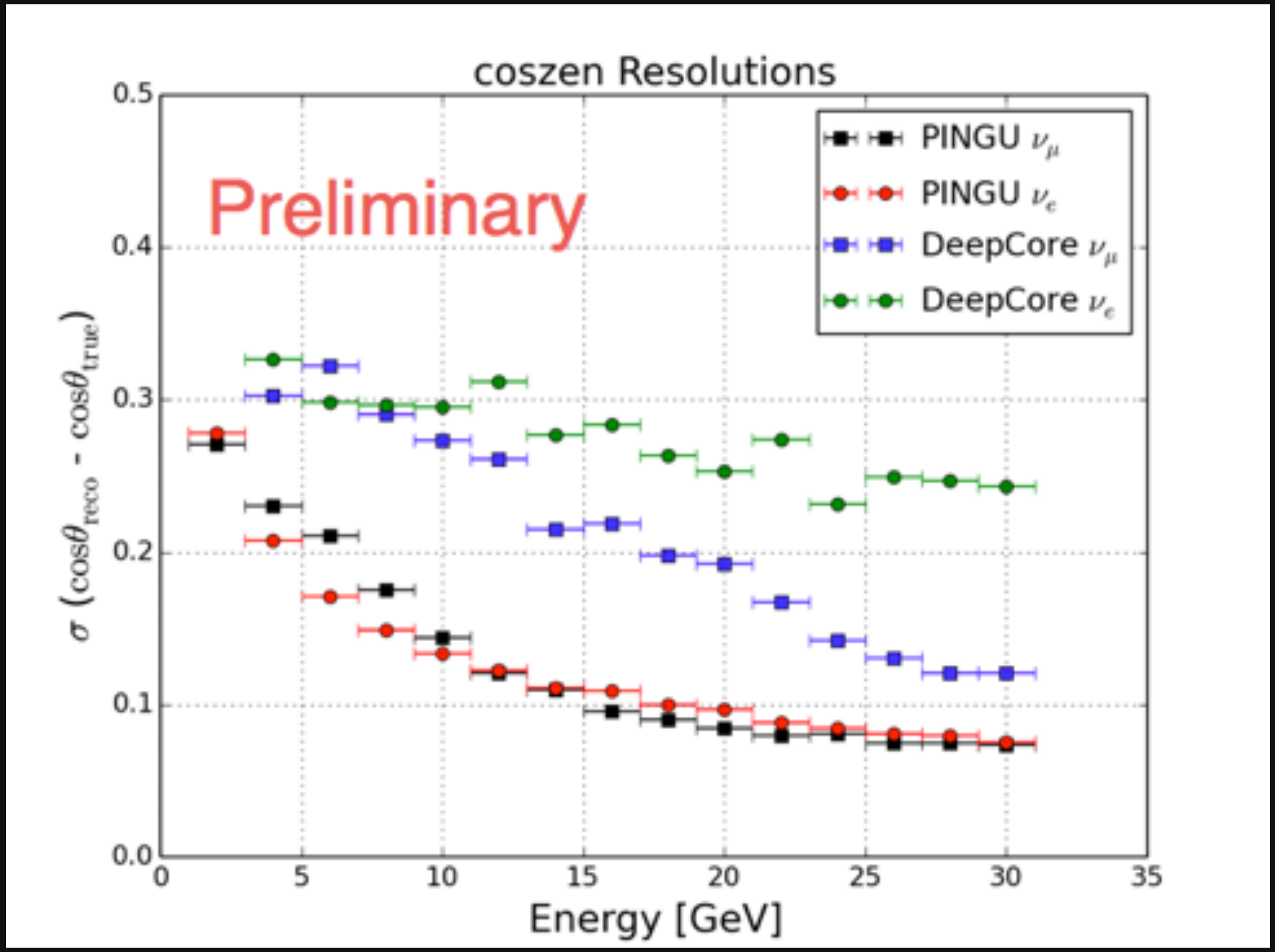
Atmospheric Neutrino Signal

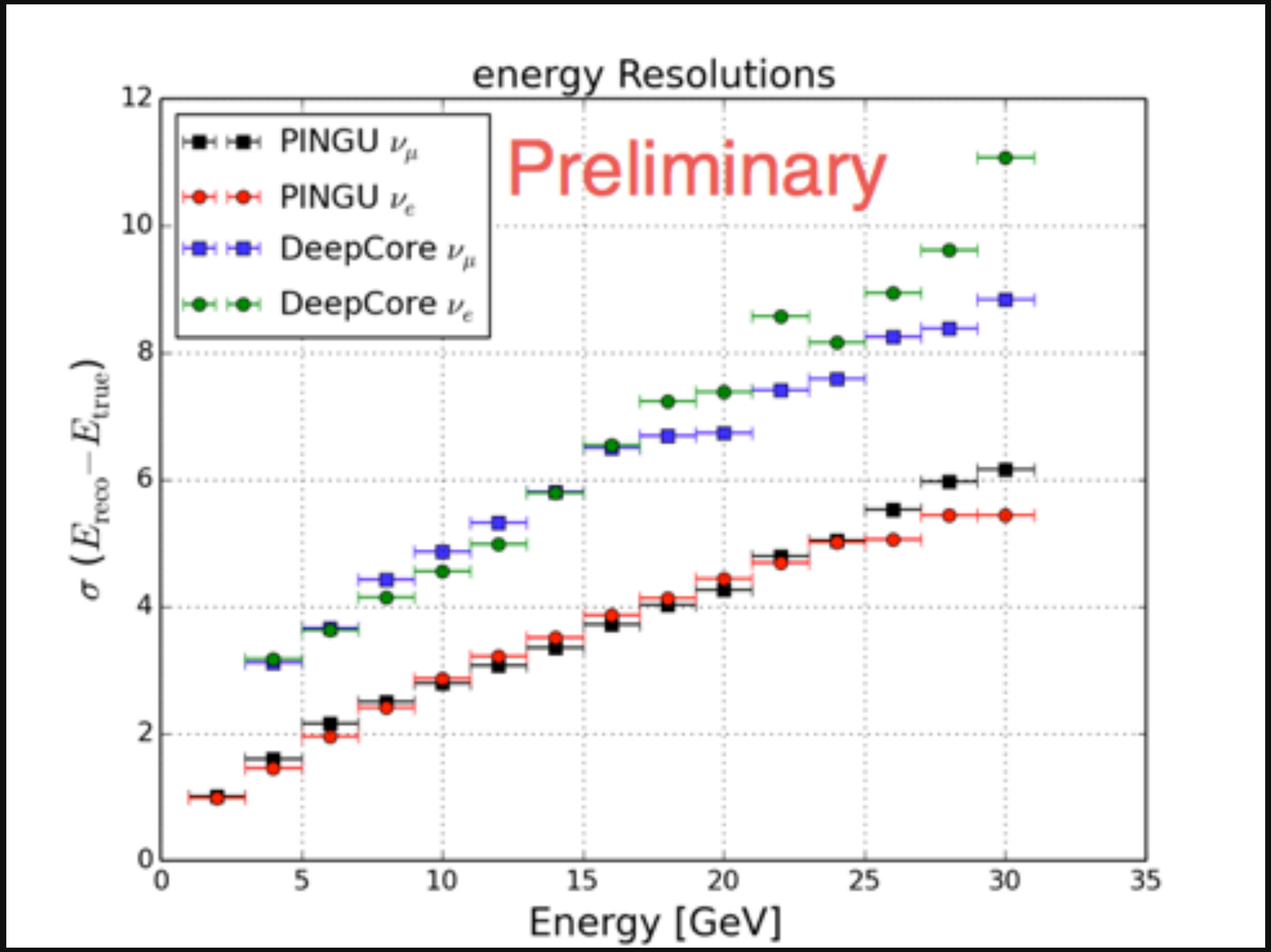
number of events expected in PINGU/year		
	triggers detector	pass baseline analysis
ν_e CC	52k	26k
ν_μ CC	86k	35k
ν_τ CC	6.4k	2.7k
ν_x NC	17k	7.9k



PINGU Event Reconstruction

For baseline geometry (40 strings, 60 DOMs/string)





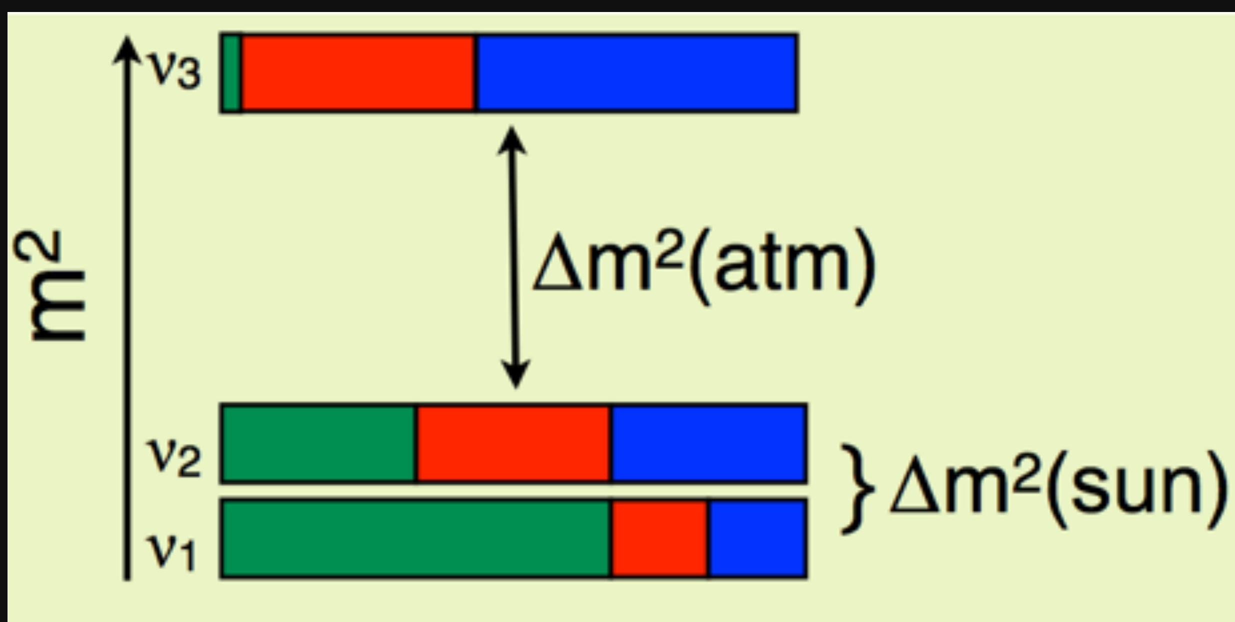
+ "particle ID" (track vs. cascade)

(noise not fully simulated, but noise removal algorithms are very efficient: small impact on the resolutions)

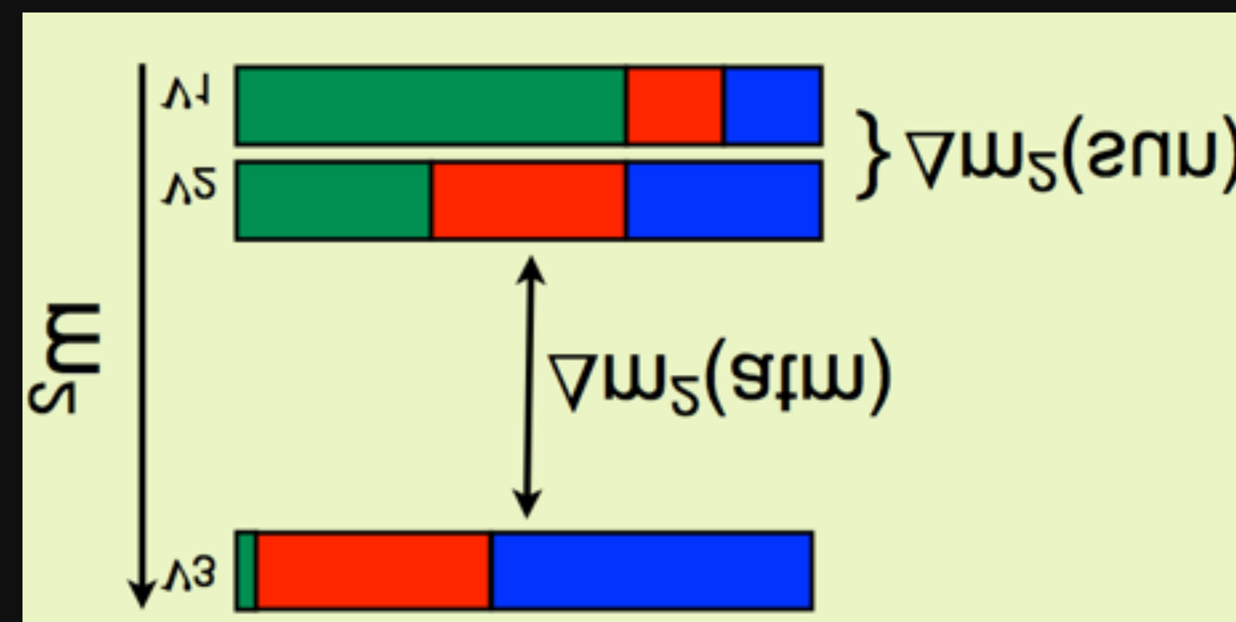
Neutrino Mass Ordering (Hierarchy)

Main goal of PINGU - in addition to better sensitivity to oscillations, WIMPS, …

“normal”



“inverted”

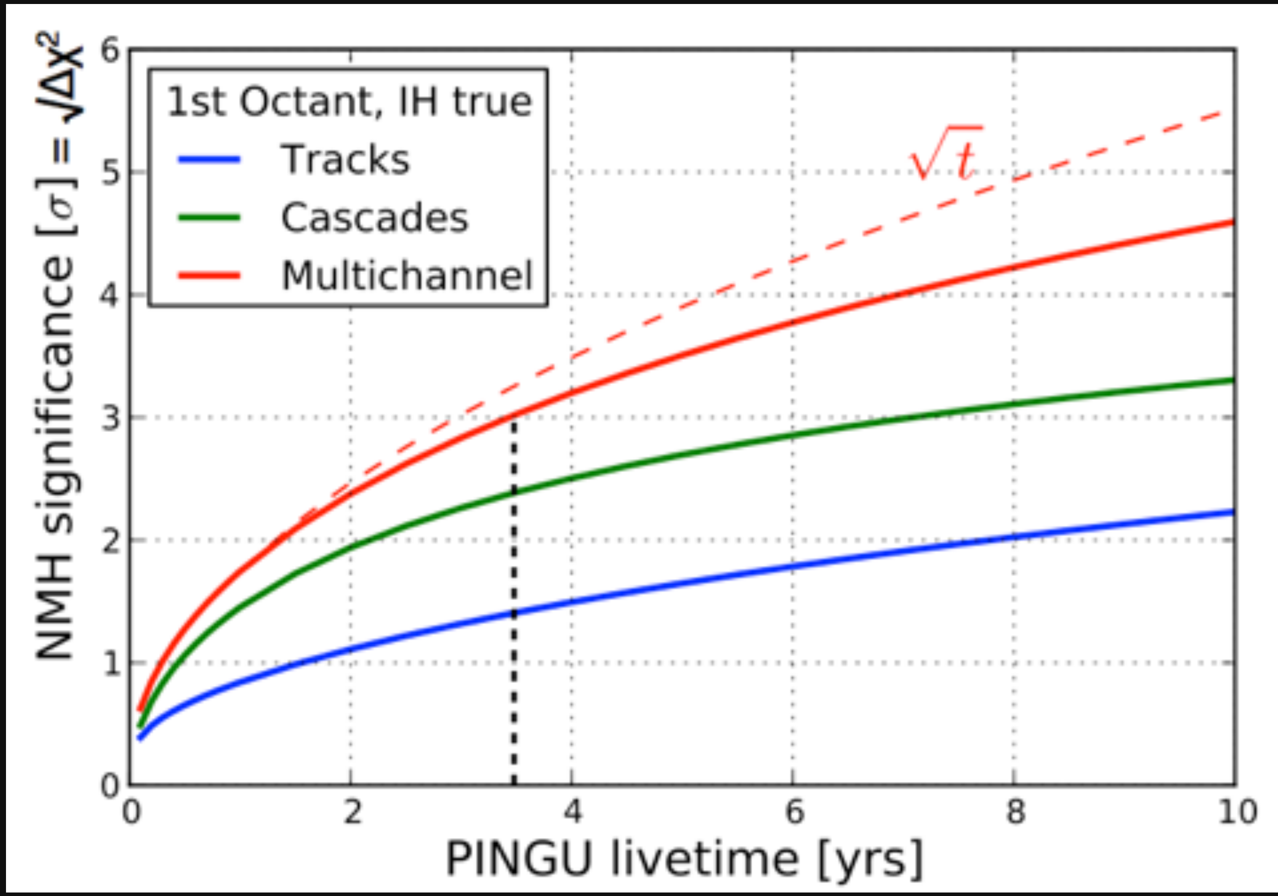


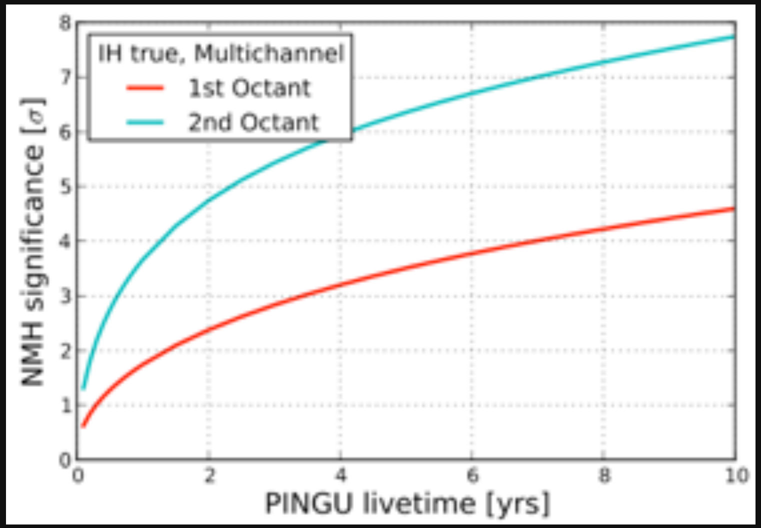
- **mass ordering is an unknown parameter in the neutrino sector**
- **can be determined as neutrinos pass through matter**
  - ν oscillation probability is enhanced if ordering is <u>normal</u>
  - $\bar{\nu}$ oscillation probability is enhanced if ordering is <u>inverted</u>

Estimated Sensitivity

Significance including all systematics and basic particle ID

- **1.8σ in first year of data (first octant)**
- **Reach 3σ in roughly 3.5 years**
    - (does not include livetime from partially built detector)



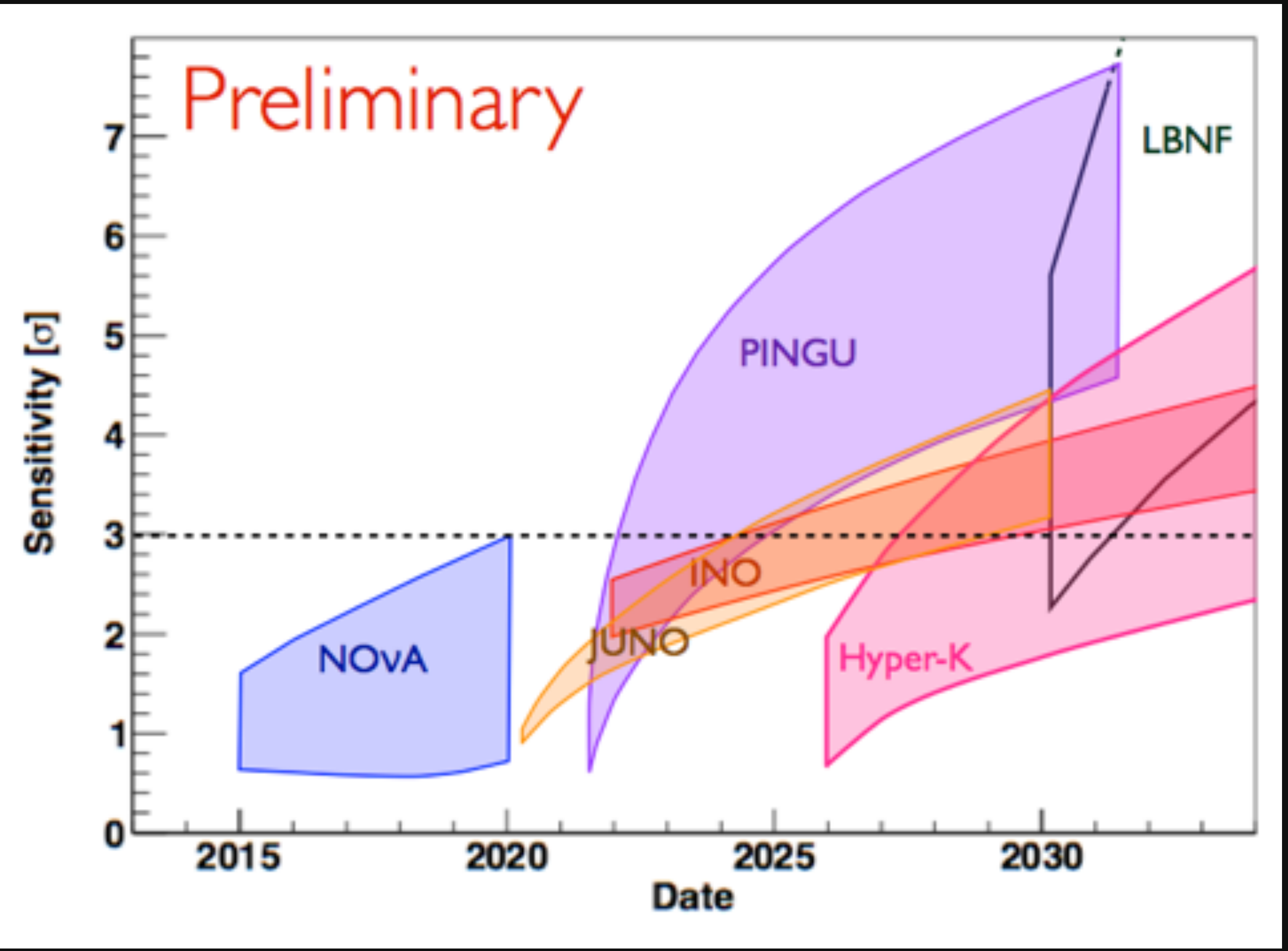


The Neutrino Mass Ordering Landscape

Several current or planned experiments will have sensitivity to the neutrino mass ordering in the next 10-15 years

- **Width indicate main uncertainties**
- **PINGU timeline based on aggressive but feasible schedule**

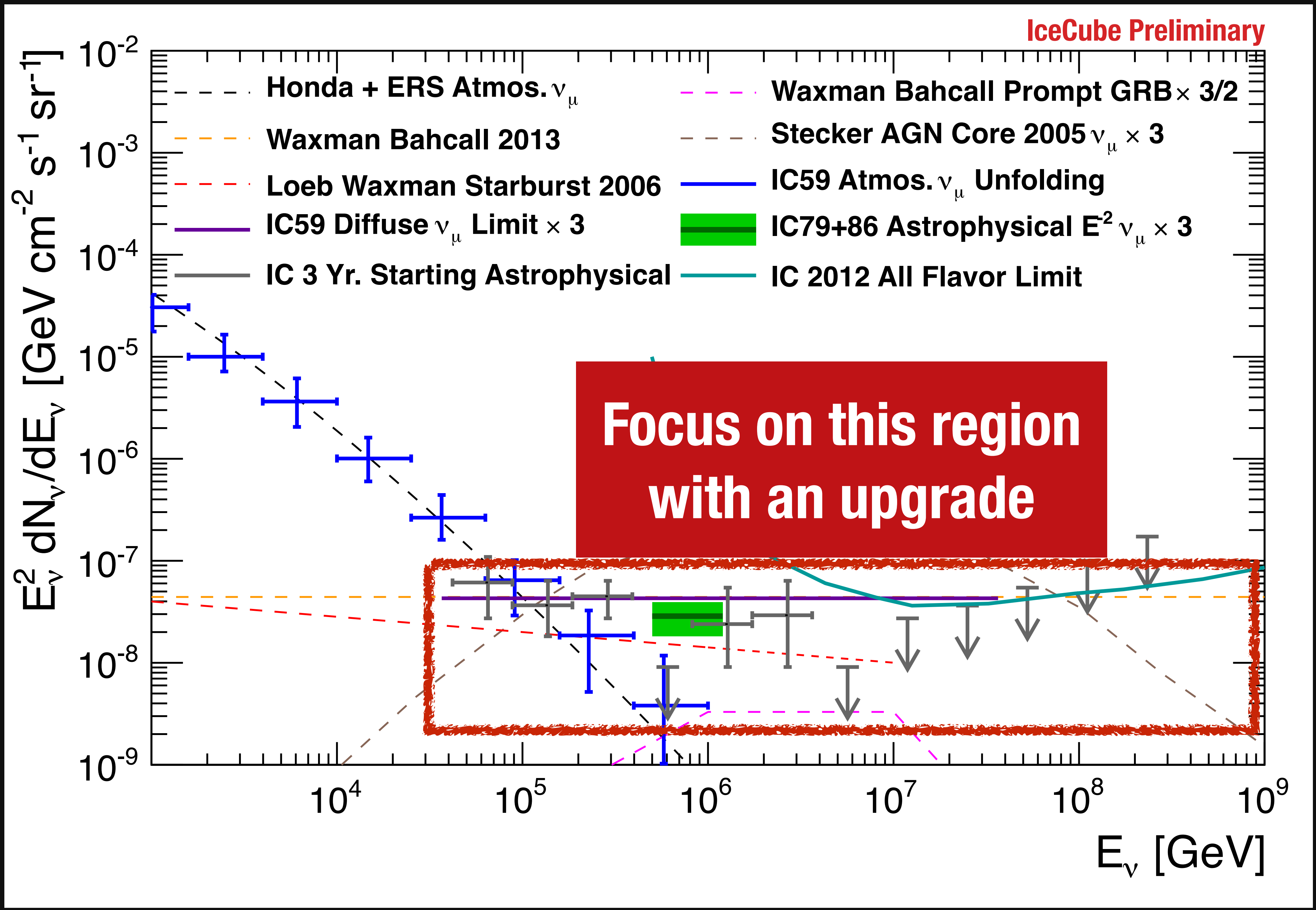
after Blennow et al., arXiv:131.1822



note: median outcome shown - large fluctuations possible

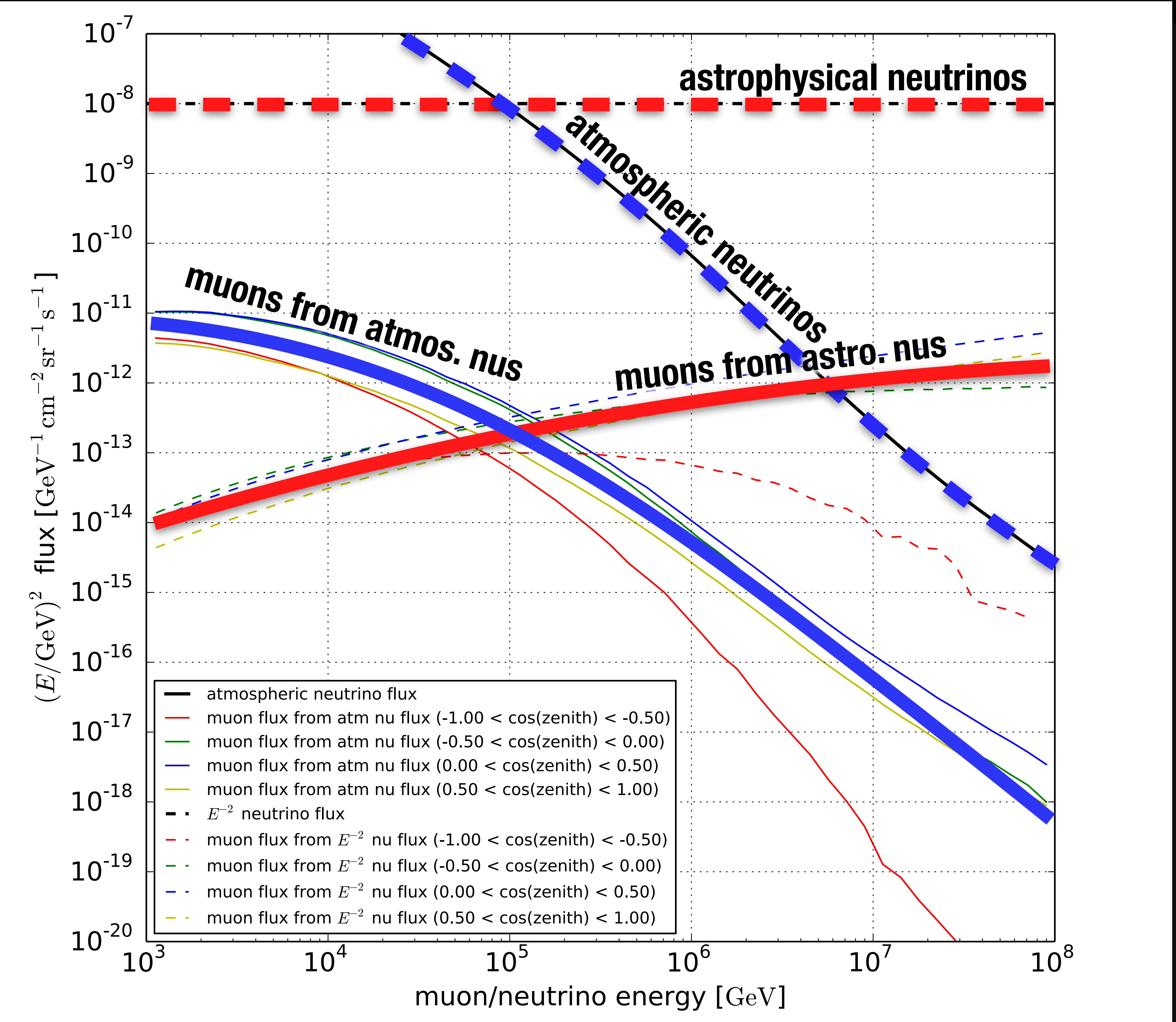
Astrophysical Neutrinos

Best-fit spectral index between 60TeV and 2PeV (per flavour) is about $E^{-2.3\pm0.3}$ - looks more complicated below 60TeV



Neutrino and Muon Fluxes

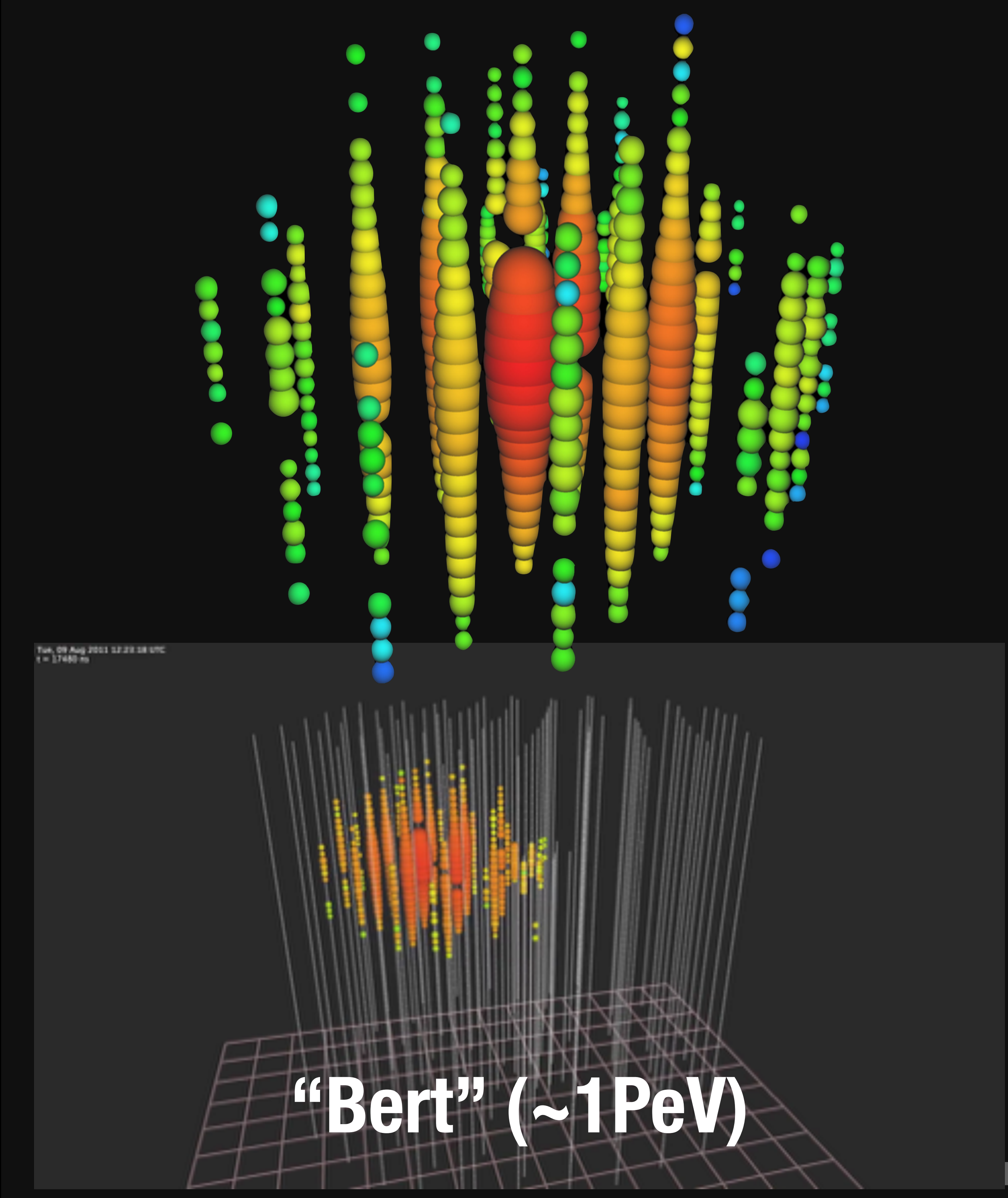
Signal region begins to dominate above ~80TeV - detector should be efficient above ~30TeV



String Density

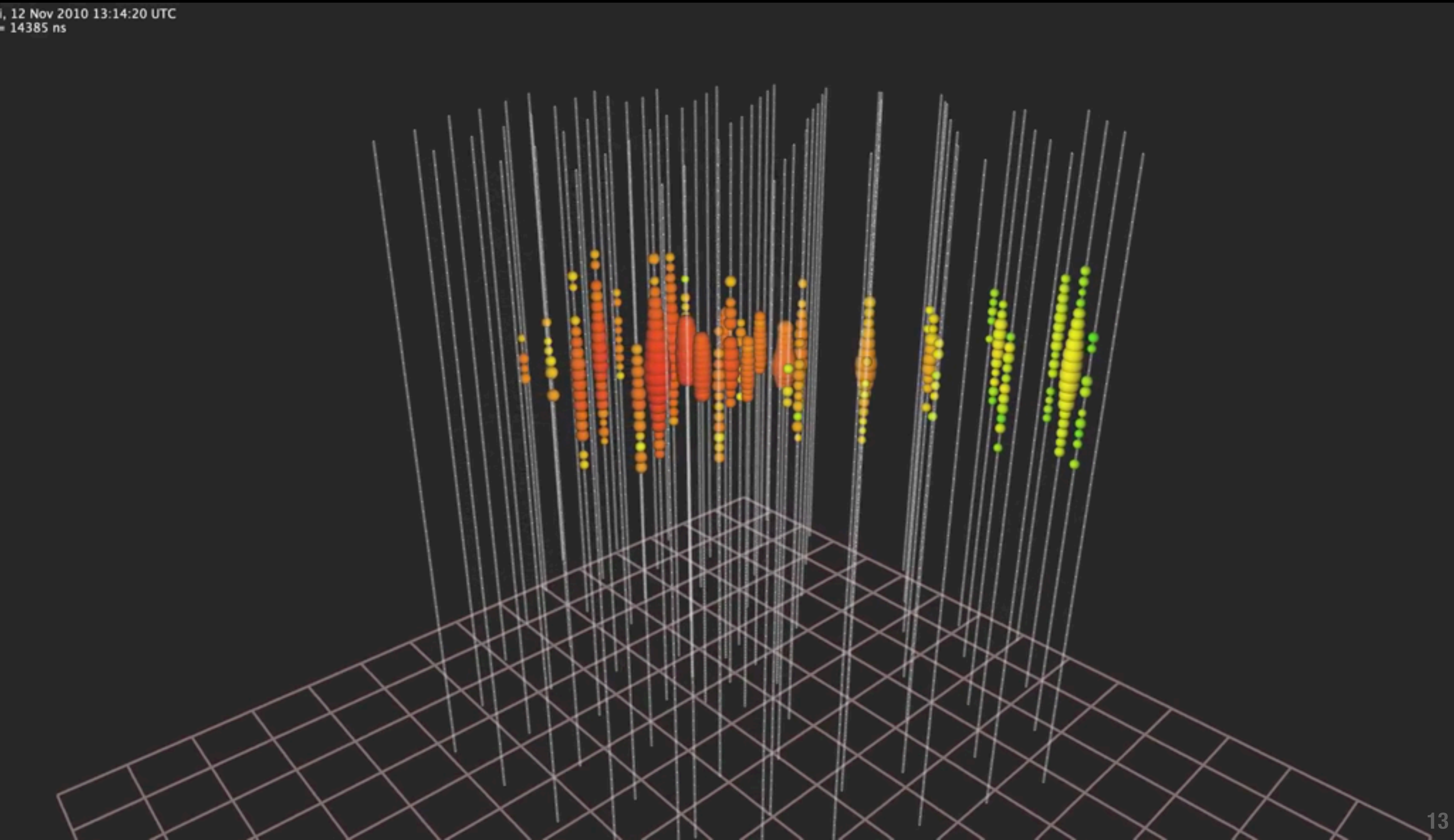
How well would we reconstruct events with fewer strings?

- **Analyzed the event with only a subset of the IceCube strings (20 strings, spacing 250m)**
- **Result:**
  - angular resolution: 30°
  - energy resolution: 10%
- **We can work with fewer strings!**



String Density

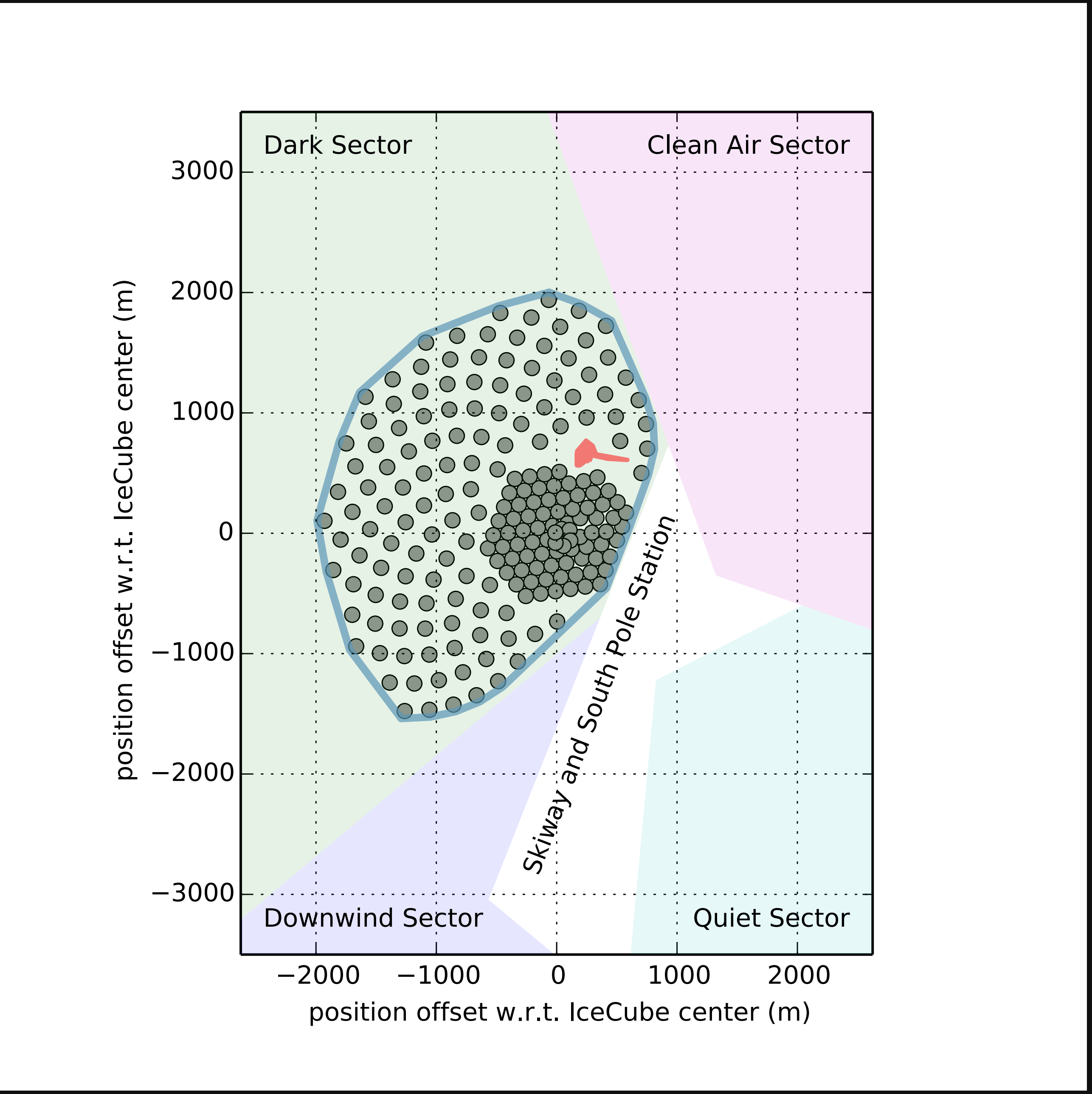
Similar story for high-energy tracks - we don't need as many "layers" of strings to observe this one



Deploy More Strings!

Baseline idea: extend from IceCube

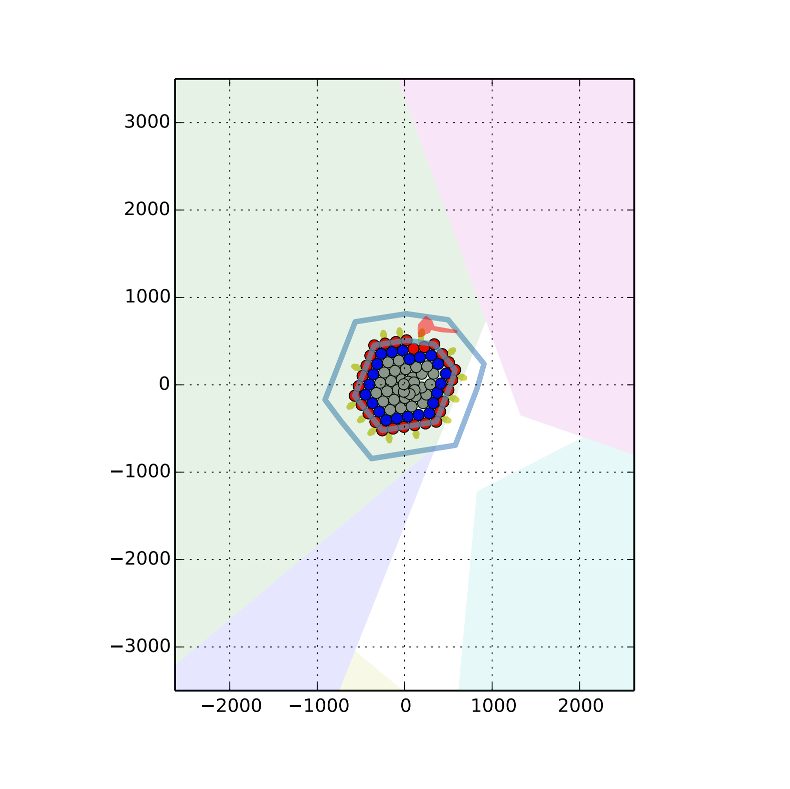
- **“Strawman" detector shown here:**
  - 120 strings in addition to IceCube
  - average spacing of 240m
  - volume: ~10 km^3
  - string length: ~1.3km



Geometries - Strawman Designs

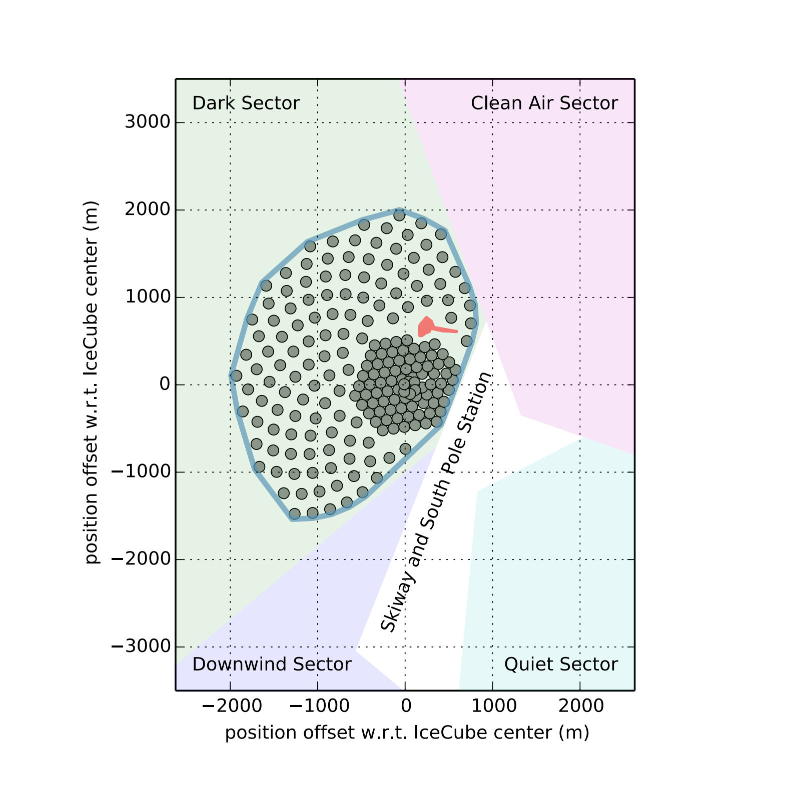
All upgrades also include PINGU low-energy strings (not shown) — these use the current IceCube technology (1x large PMT modules)

IceCube



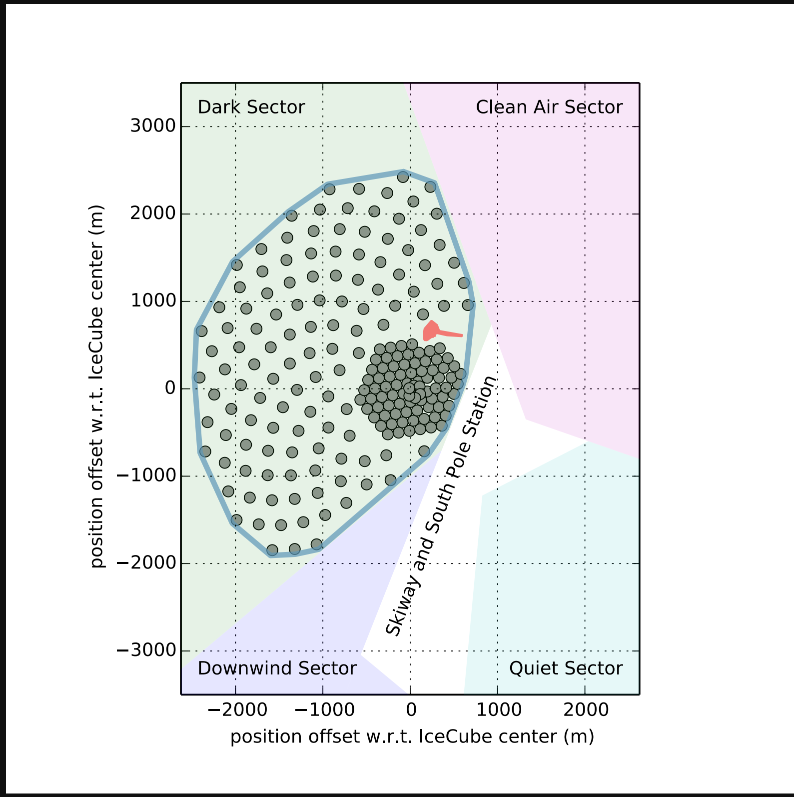
top area (+60m border): 0.9km^2
volume: 1.2 km^3
strings: IC86
spacing: ~125m

"Sunflower" 240m



top area (+60m border): km^2
volume: 9.7 km^3
strings: IC86+120
spacing: ~240m

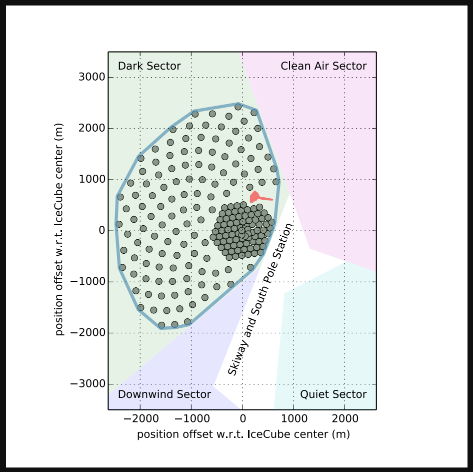
"Sunflower" 300m

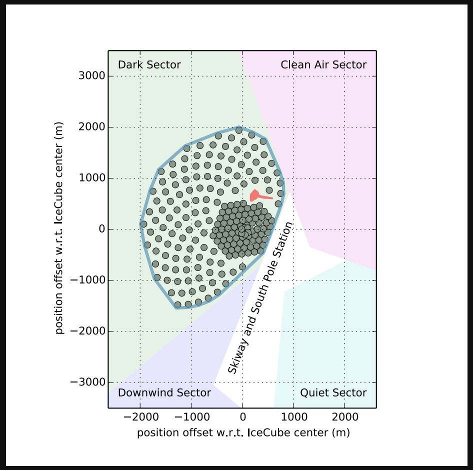


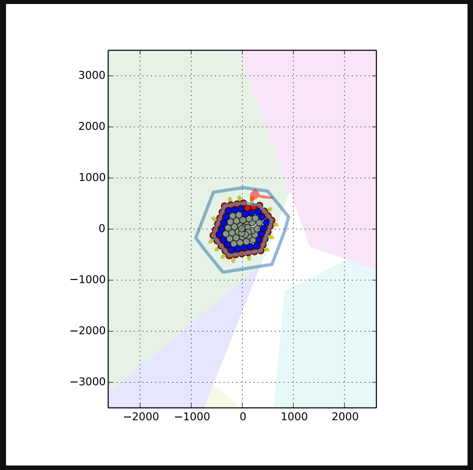
top area (+60m border): km^2
volume: 14.2 km^3
strings: IC86+120
spacing: ~300m

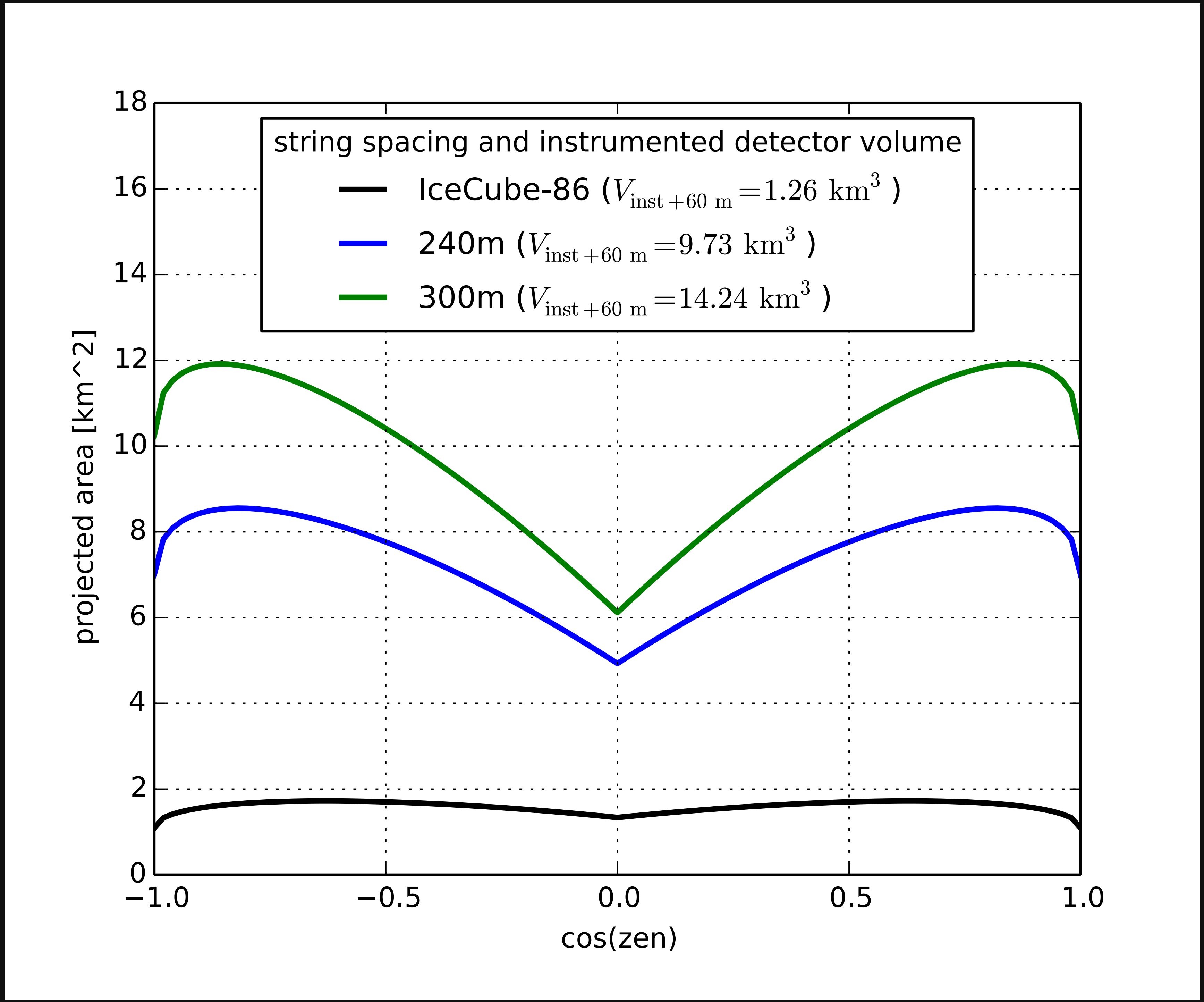
Geometries - Strawman Designs

Increase in volume and projected area - However: the sparser the array the more you (potentially) lose in track quality!





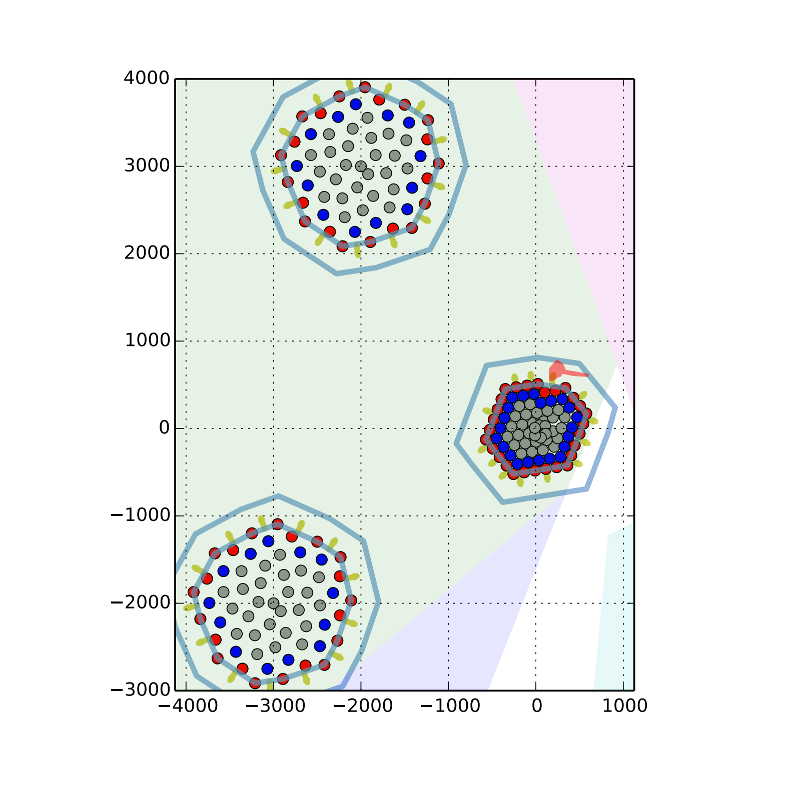




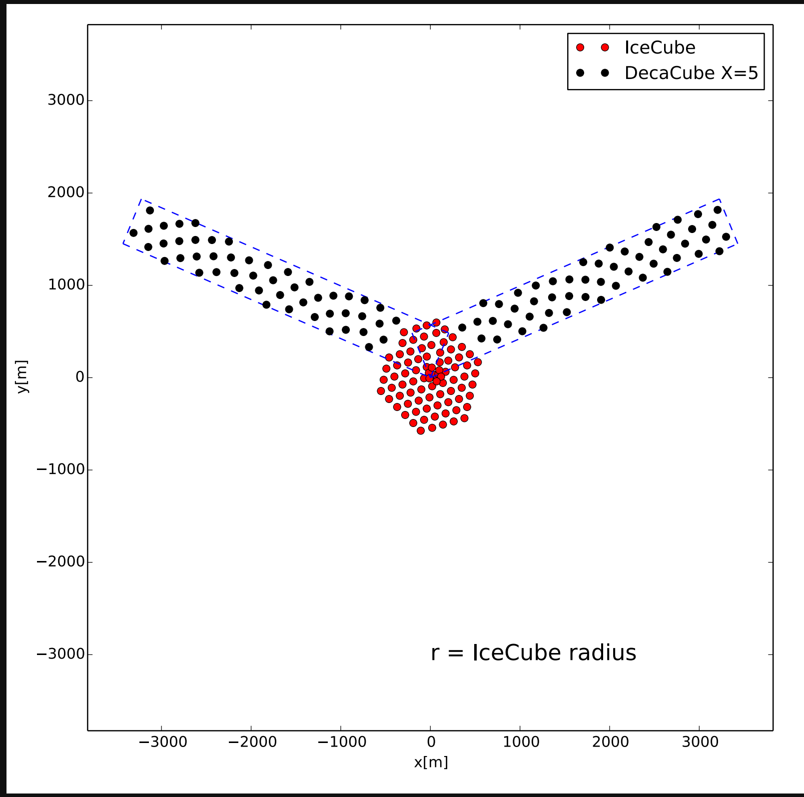
Geometries - Even More Ideas

Or maybe these? We are still optimizing for the best design!

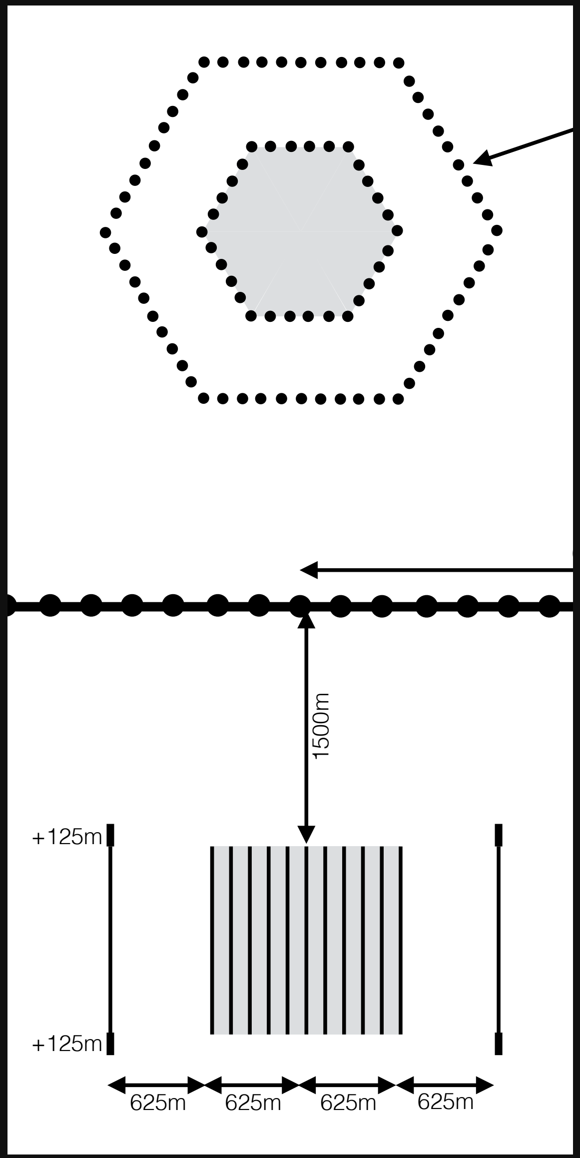
Two Clusters



"Bunny Ears"?



"Wall of Strings"?

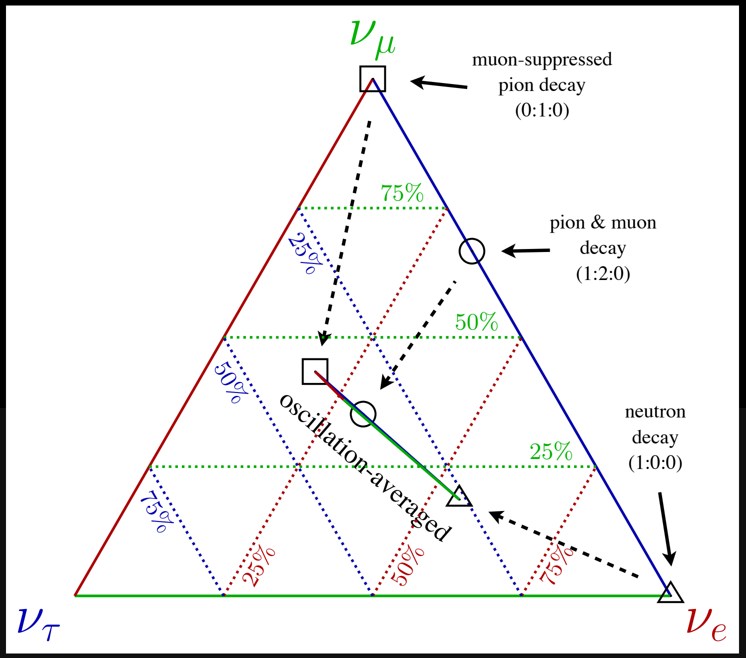


or something totally different?

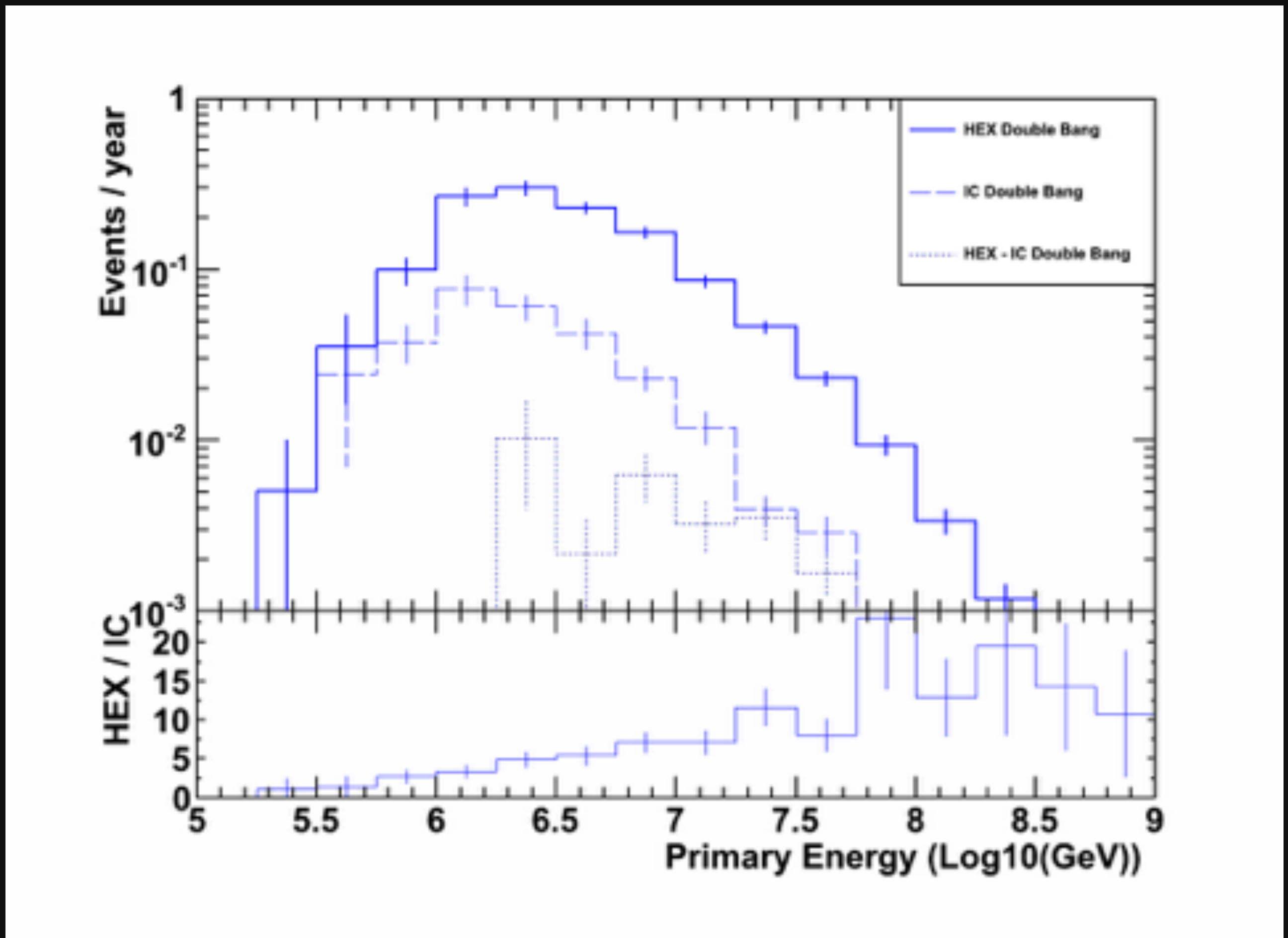
all results/designs shown are preliminary

Sensitivities

We need to optimize the detector to be sensitive to all three neutrino flavours!



- **“starting events” - scale with detector volume - low backgrounds**
  - electron neutrinos
  - tau neutrinos
  - starting tracks
  - neutral current
- **“incoming tracks” - scale with detector area and pointing (for distant sources w/o extension)**



tau neutrino double-bang rate

all results/designs shown are preliminary

Sensitivities - Example: Glashow Events

Larger volumes provide rates higher by an order of magnitude!

Φ_{ν_e} $[\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$	interaction type	pp source IC-86	240m	360m
$1.0 \times 10^{-18}(E/100\,\mathrm{TeV})^{-2.0}$	GR	0.88	7.2	16
	DIS	0.09	0.8	1.6
$1.5 \times 10^{-18}(E/100\,\mathrm{TeV})^{-2.3}$	GR	0.38	3.1	6.8
	DIS	0.04	0.3	0.7
$2.4 \times 10^{-18}(E/100\,\mathrm{TeV})^{-2.7}$	GR	0.12	0.9	2.1
	DIS	0.01	0.1	0.2

Number of Glashow Resonance (from a pp source) events per year with visible energy between 5 and 7 PeV

How Do Point Sources Scale?

In the presence of background (i.e. for incoming muons including lower energies): ≈ sqrt(area)·resolution

- **Expect better resolution from longer lever arm (factor 2 for parts of the sky?)**
- **Larger effective area from larger instrumentation**
- **We know we are not using the best reconstruction**
  - limit is computing power!
- **Aim for overall increase of factor ≥5 for "traditional" PS**

≈

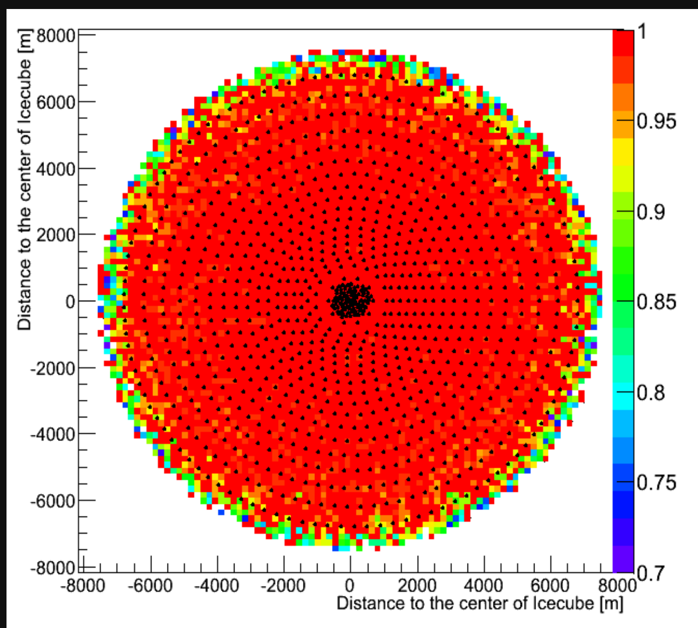
sqrt(area increase)

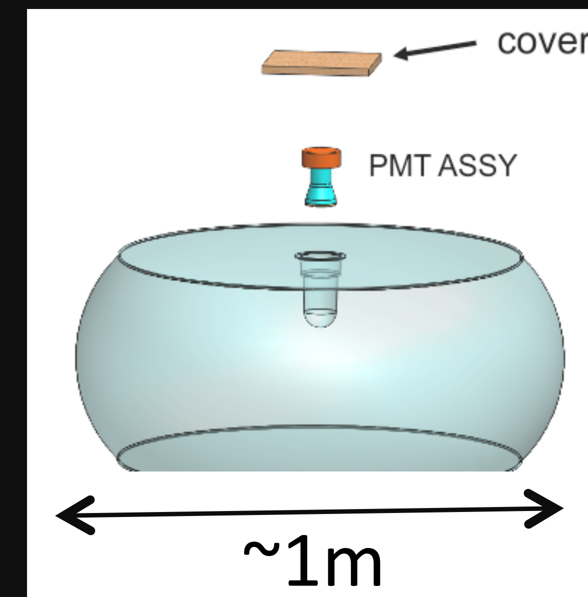
x

resolution increase

Opening Up the Southern Sky (even more)

Expand the surface veto (IceTop-like, air cherenkov, …) to veto CR showers (and thus atmospheric muons and neutrinos)





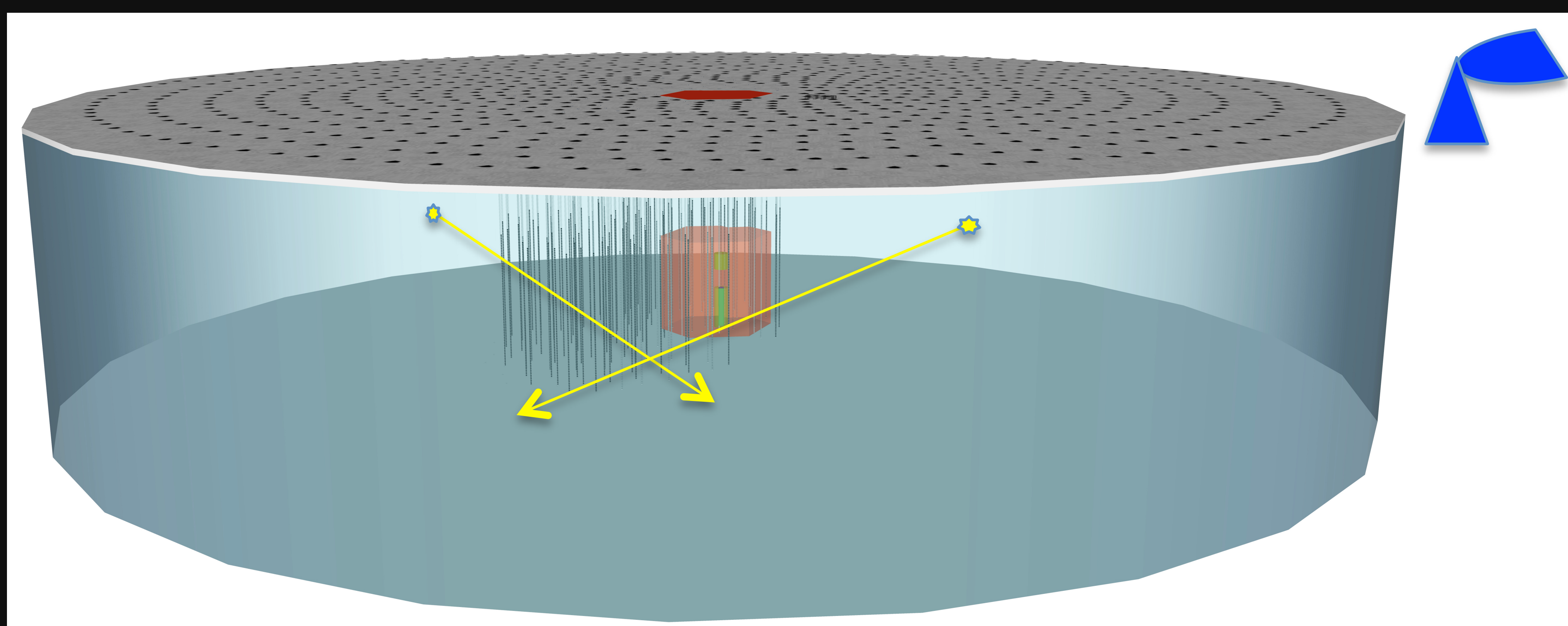


Photo-detection Technology

Baseline: IceCube "DOM" (digital optical module) - simplified using "modern" technology

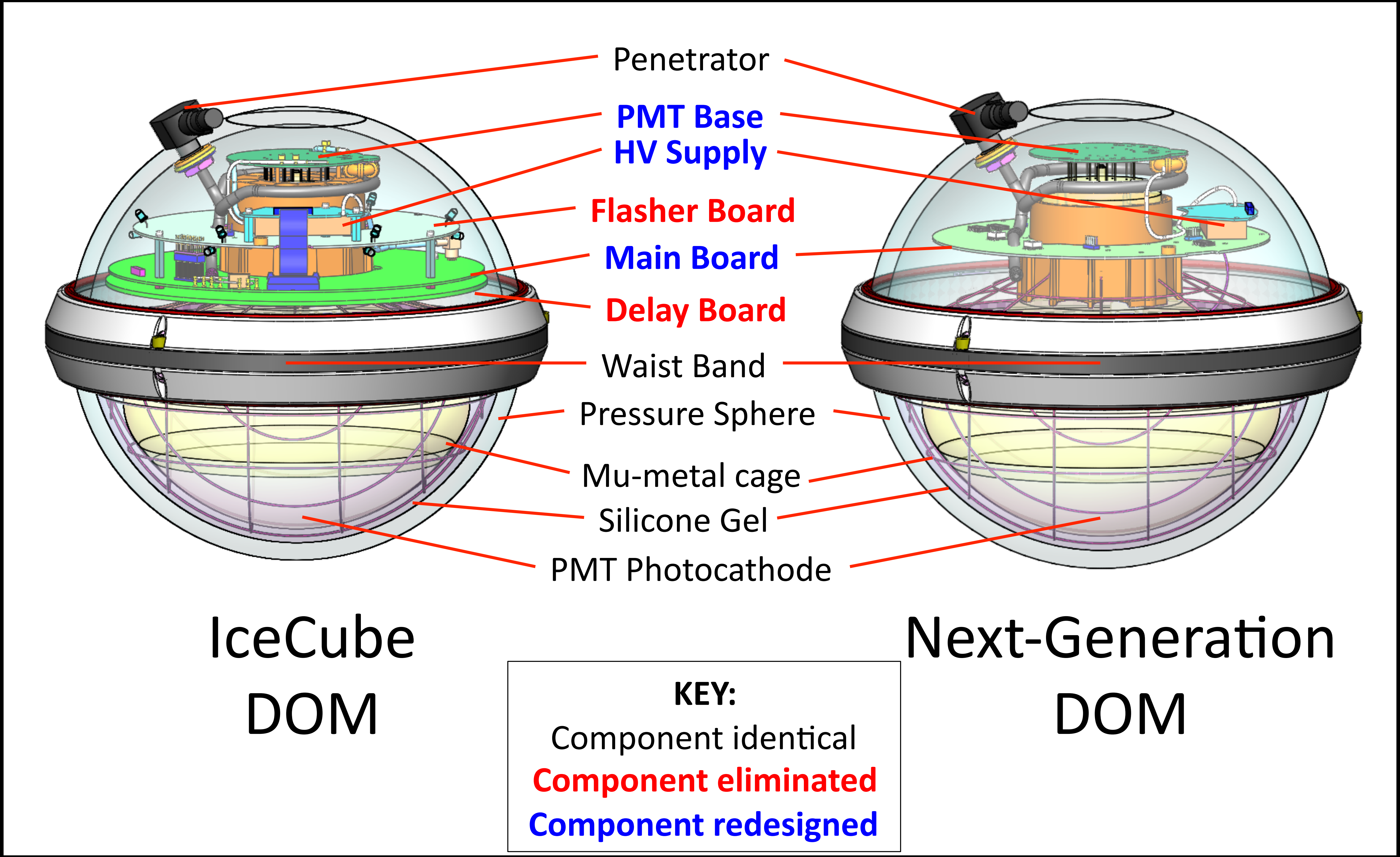
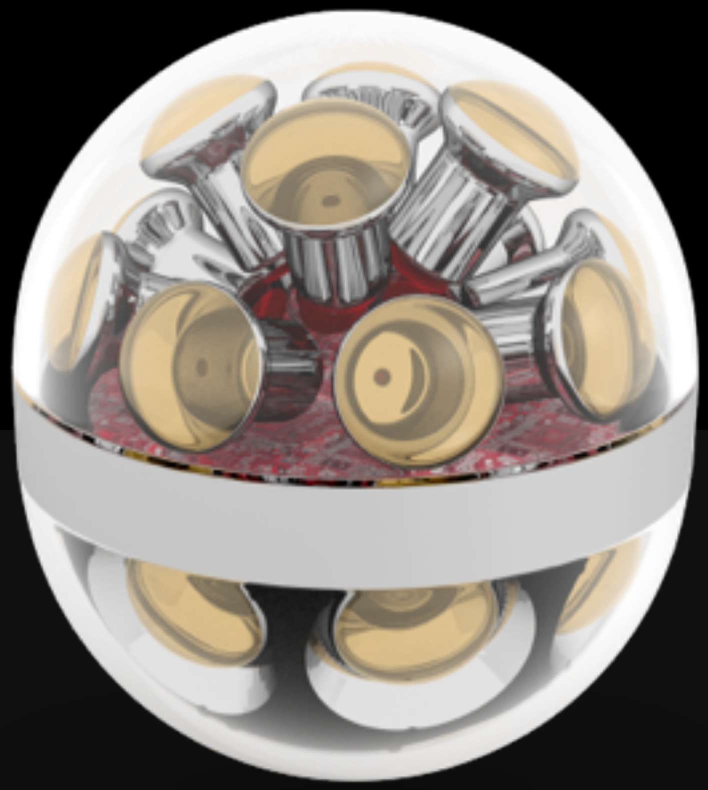
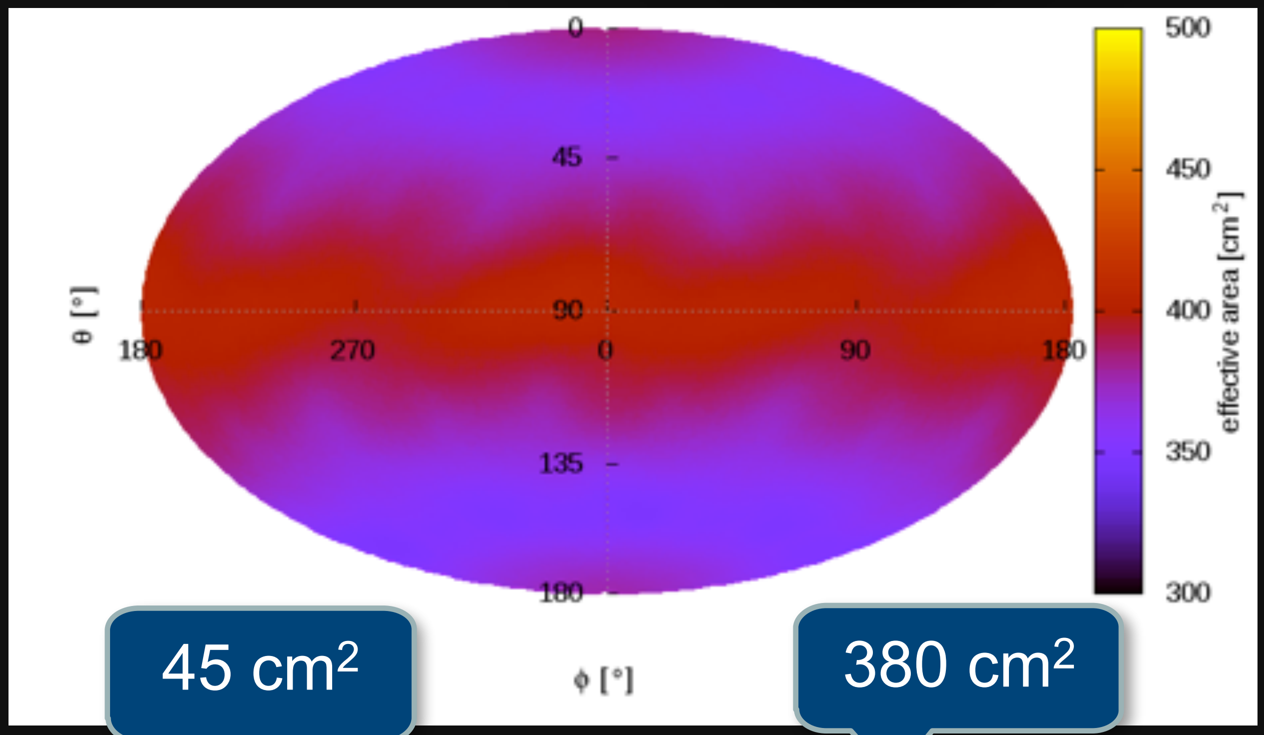


Photo-detection Technology

Alternative: many small PMTs in one module



- 14” diameter pressure vessel
- 24x 3” PMTs (Hamamatsu R12199-02)
- 2x effective area of standard IceCube module
- Full 4π coverage



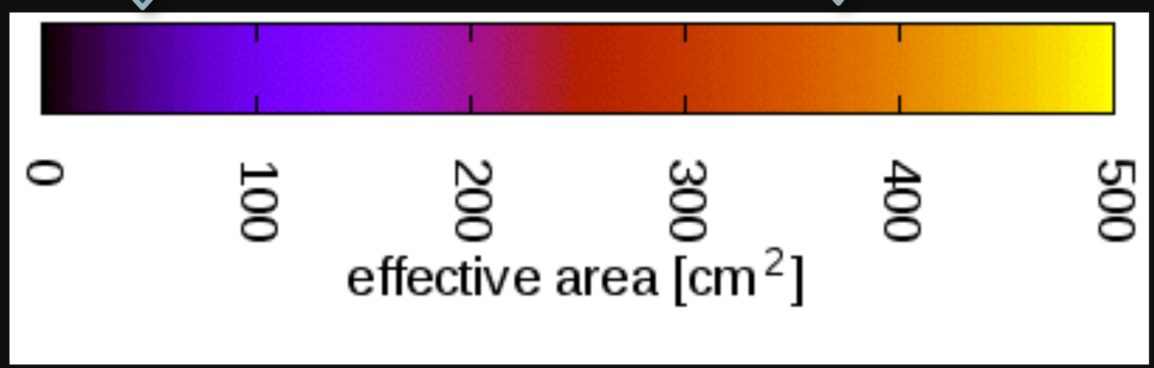
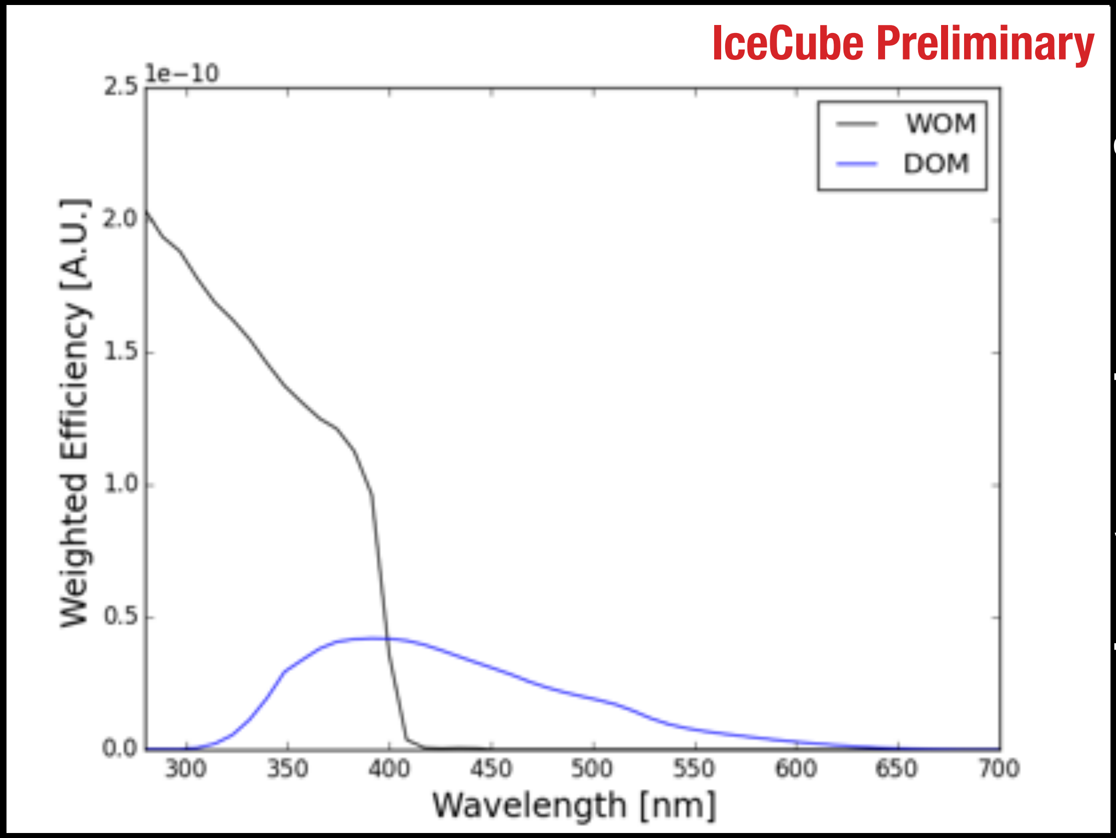


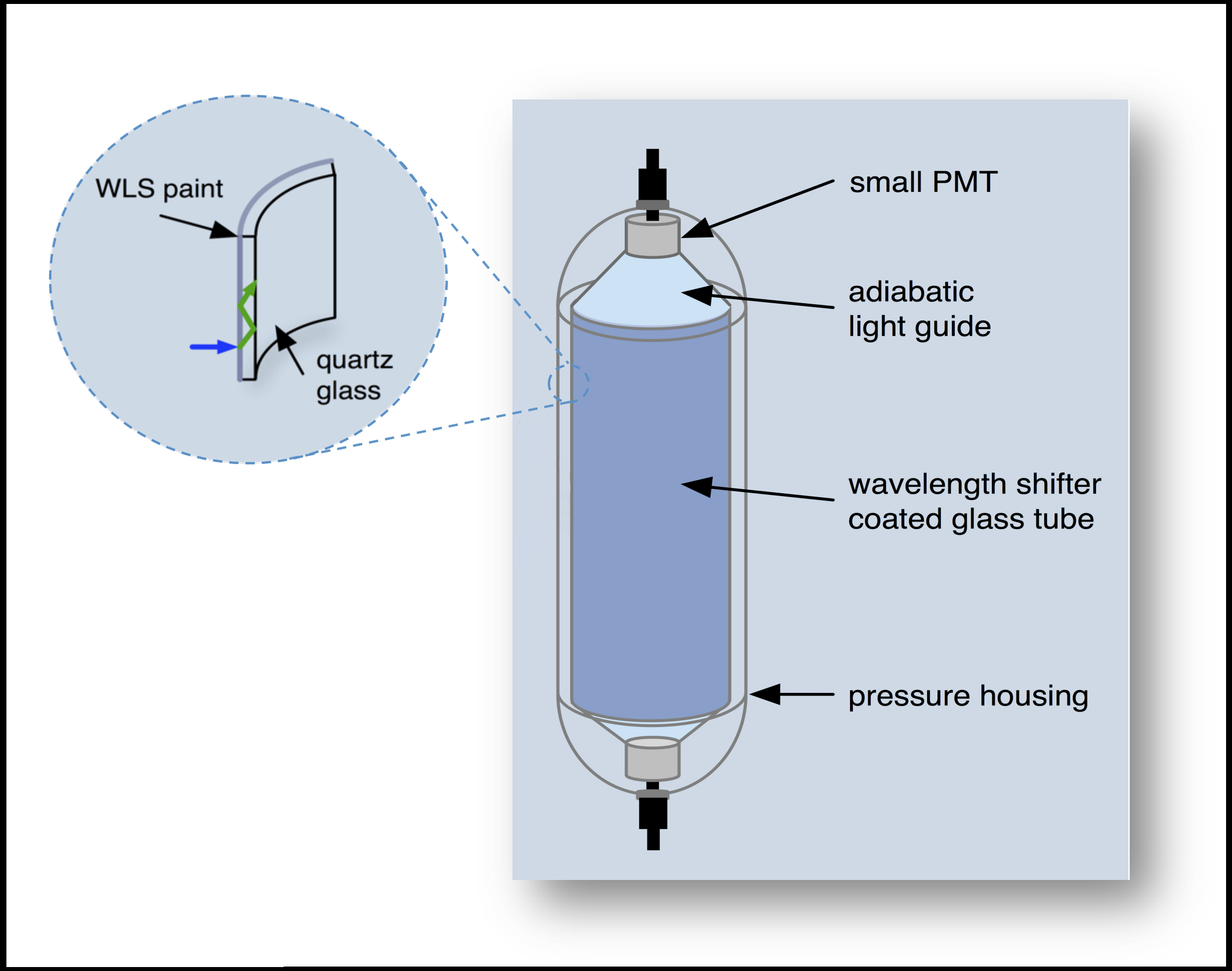
Photo-detection Technology

Alternative: use wavelength-shifters ("WOM")

- large collection area
- better UV sensitivity
- low noise rate
- cost effective



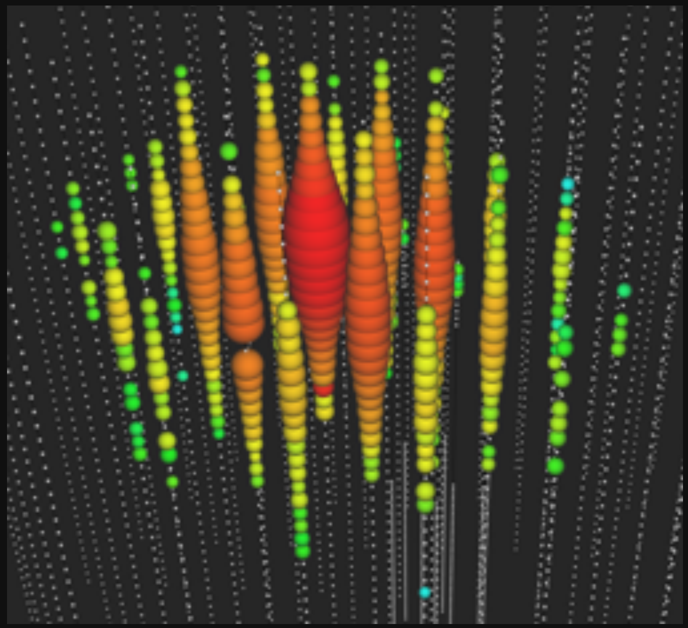
weighted with spectrum, acceptance



Conclusions

Stay tuned!

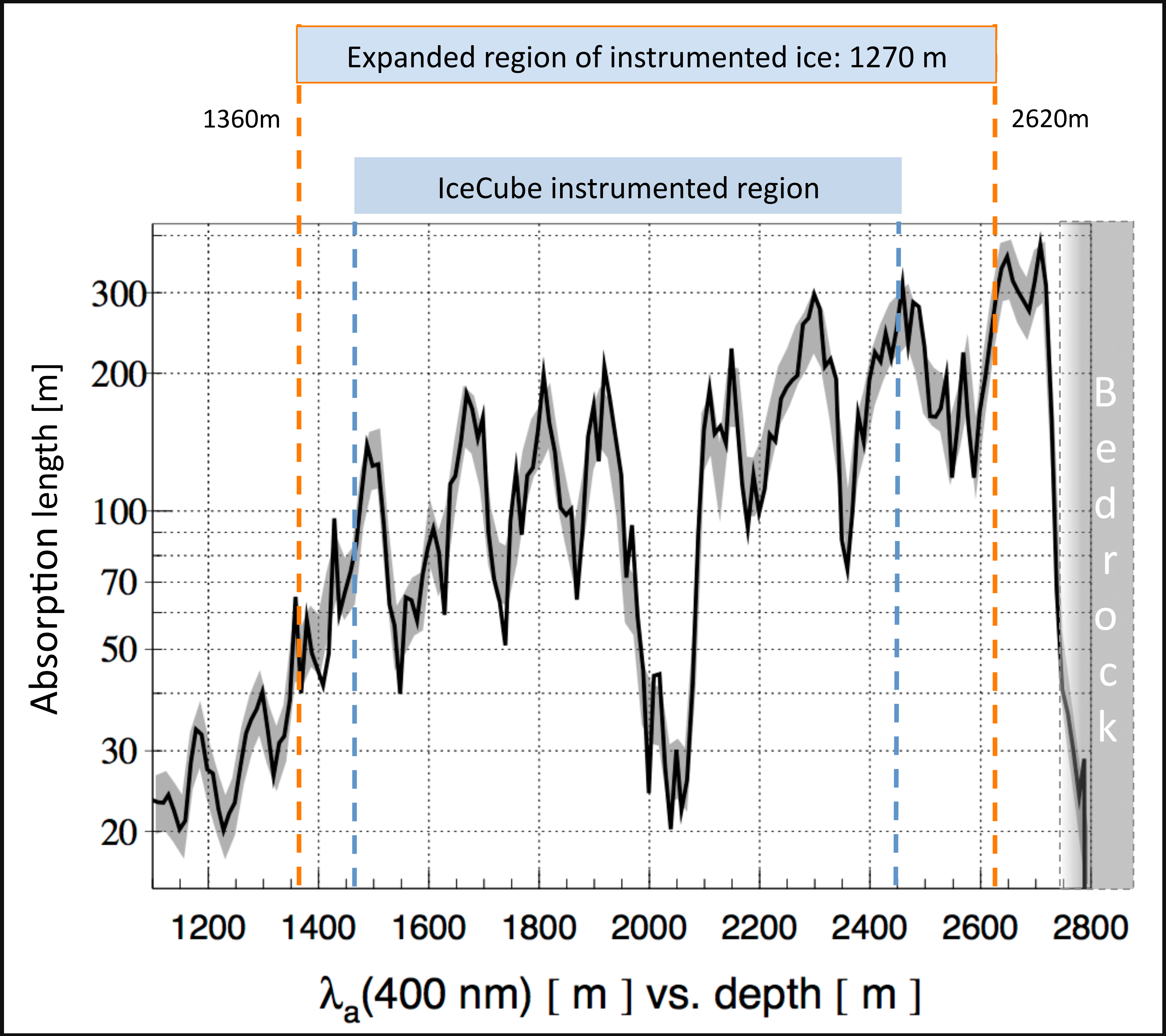
- **We are designing a next-generation detector: "IceCube-Gen2" including PINGU, a high-energy upgrade and a surface veto**
  - We can measure the neutrino mass hierarchy with PINGU (in addition to lots of other physics)
  - A high-energy upgrade with a significantly higher detection rate in all flavours is possible
- **R&D is ongoing**



Backup

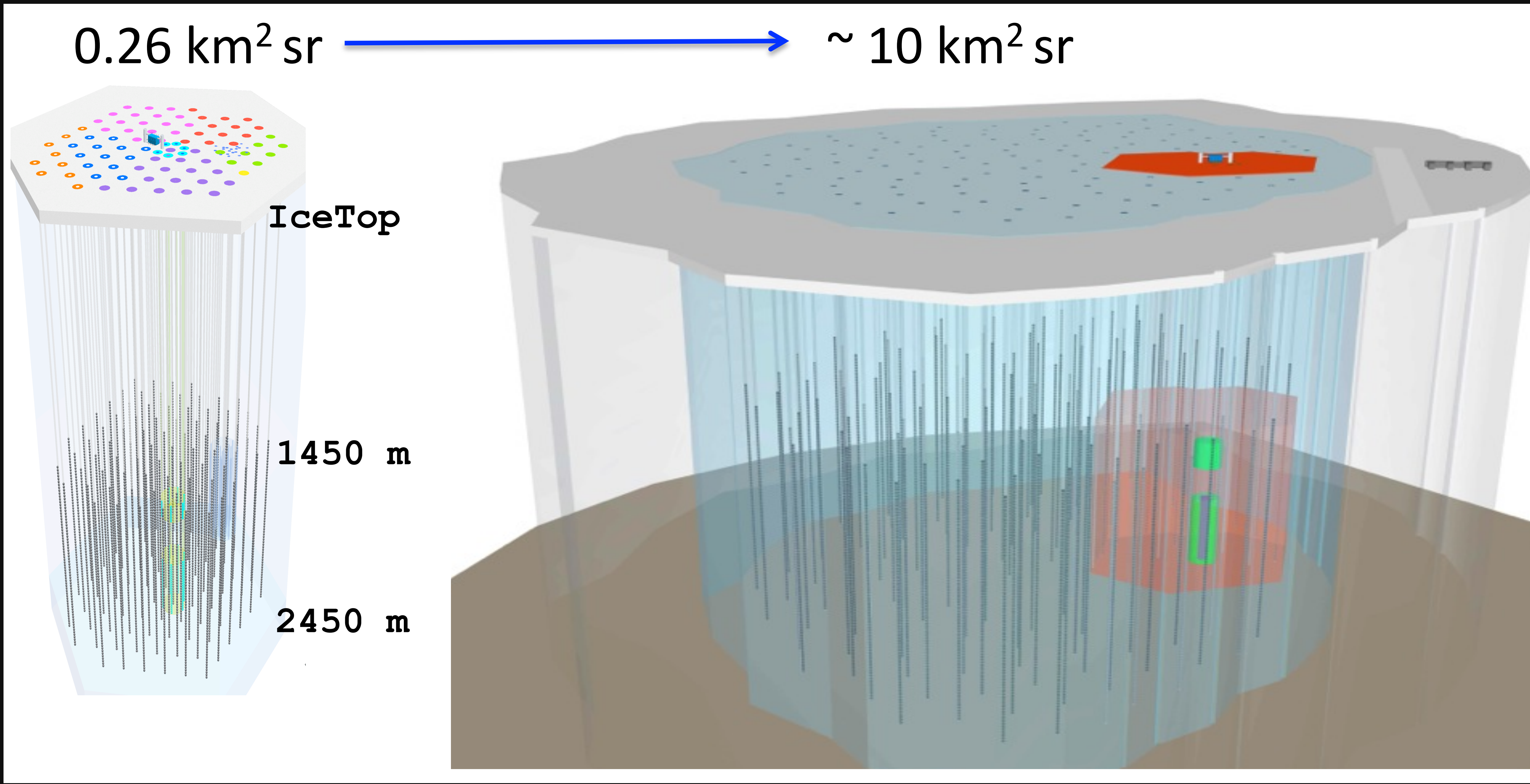
Extended Depth Range

The ice 150m-200m below and ~100m above the current IceCube strings (1km length) is usable!



Aperture For Coincident Events (ν,ɣ,CR)

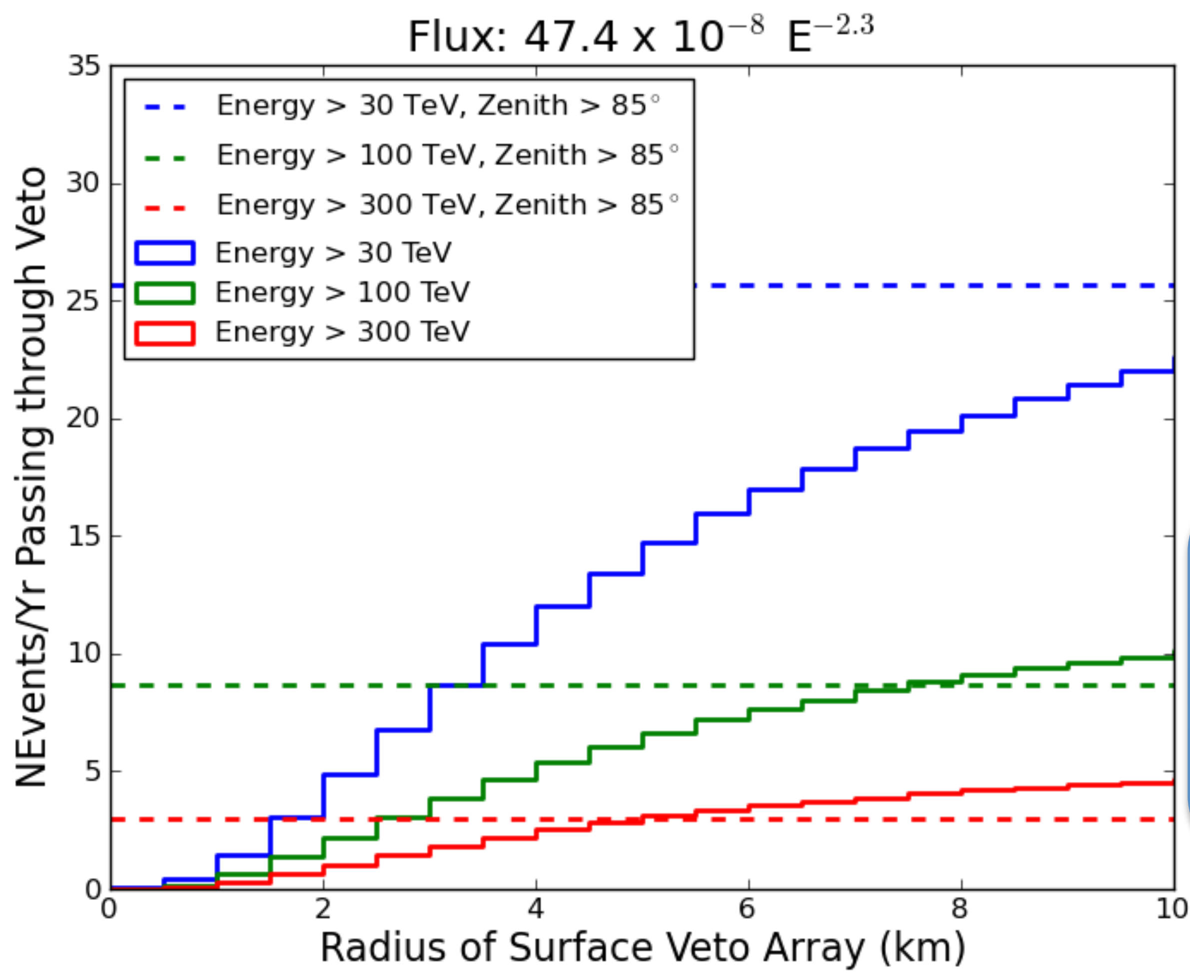
Many more events that go through both surface and in-ice array with an extended detector - great for CR physics and veto!

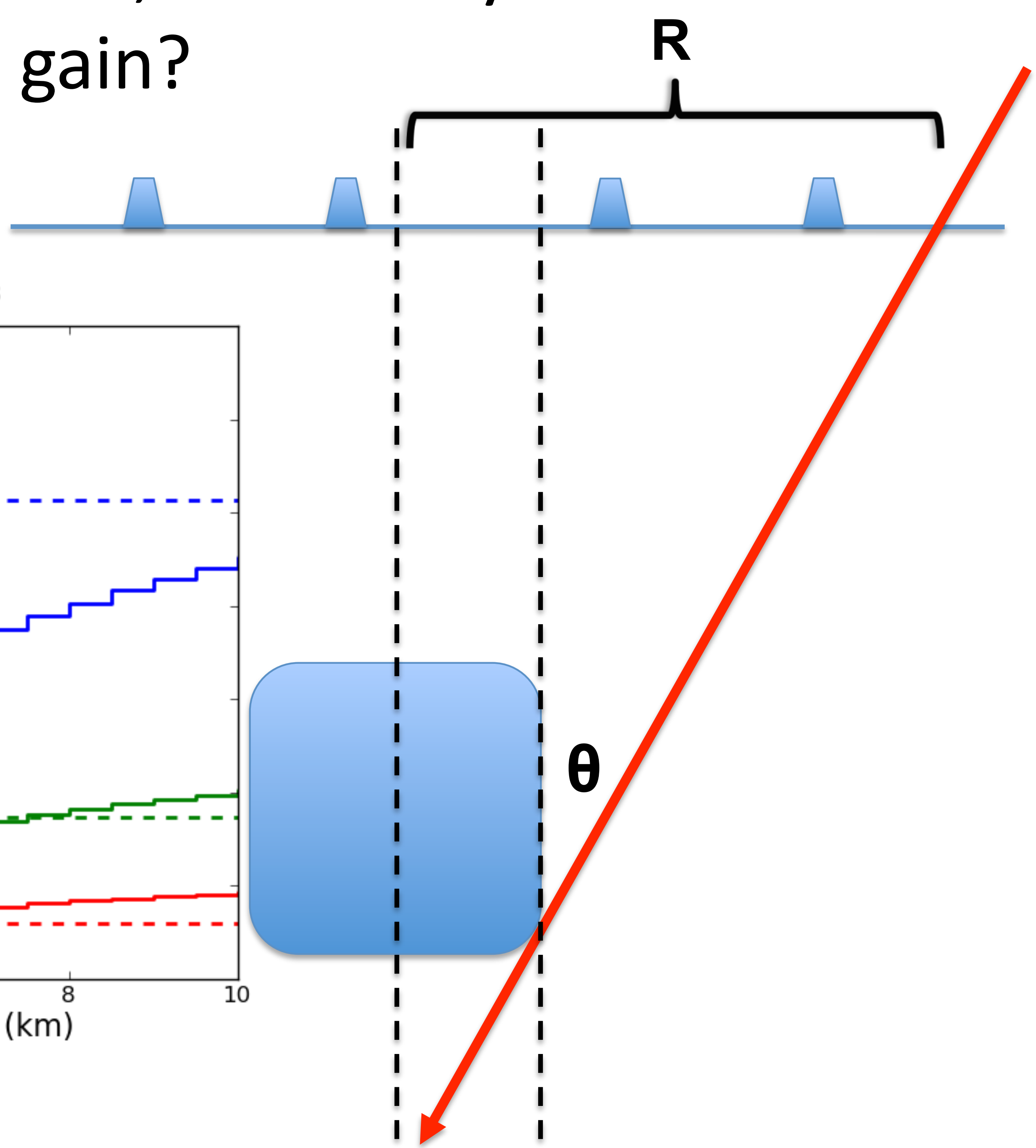


Opening Up the Southern Sky (even more)

If we had a surface veto, how many signal events would gain?

note: IceCube-only





courtesy A. Karle & J. Feintzeig