ICECUBE

IceCube Canada - current status and future long range planning

GENTWO
Next Generation IceCube Project

IPP Town Hall
Edmonton AB Canada
June 14, 2015

Darren R Grant

PRECISION ICECUBE NEXT GENERATION UPGRADE

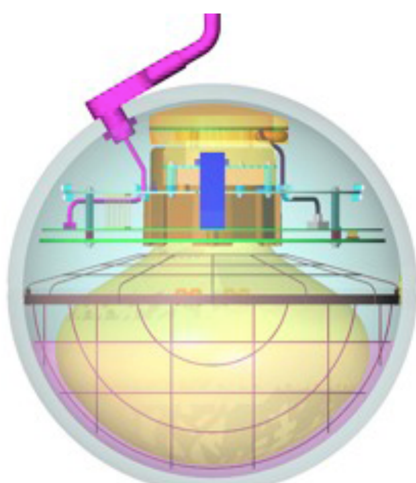
UNIVERSITY OF ALBERTA
UNIVERSITY OF TORONTO

The IceCube Neutrino Observatory

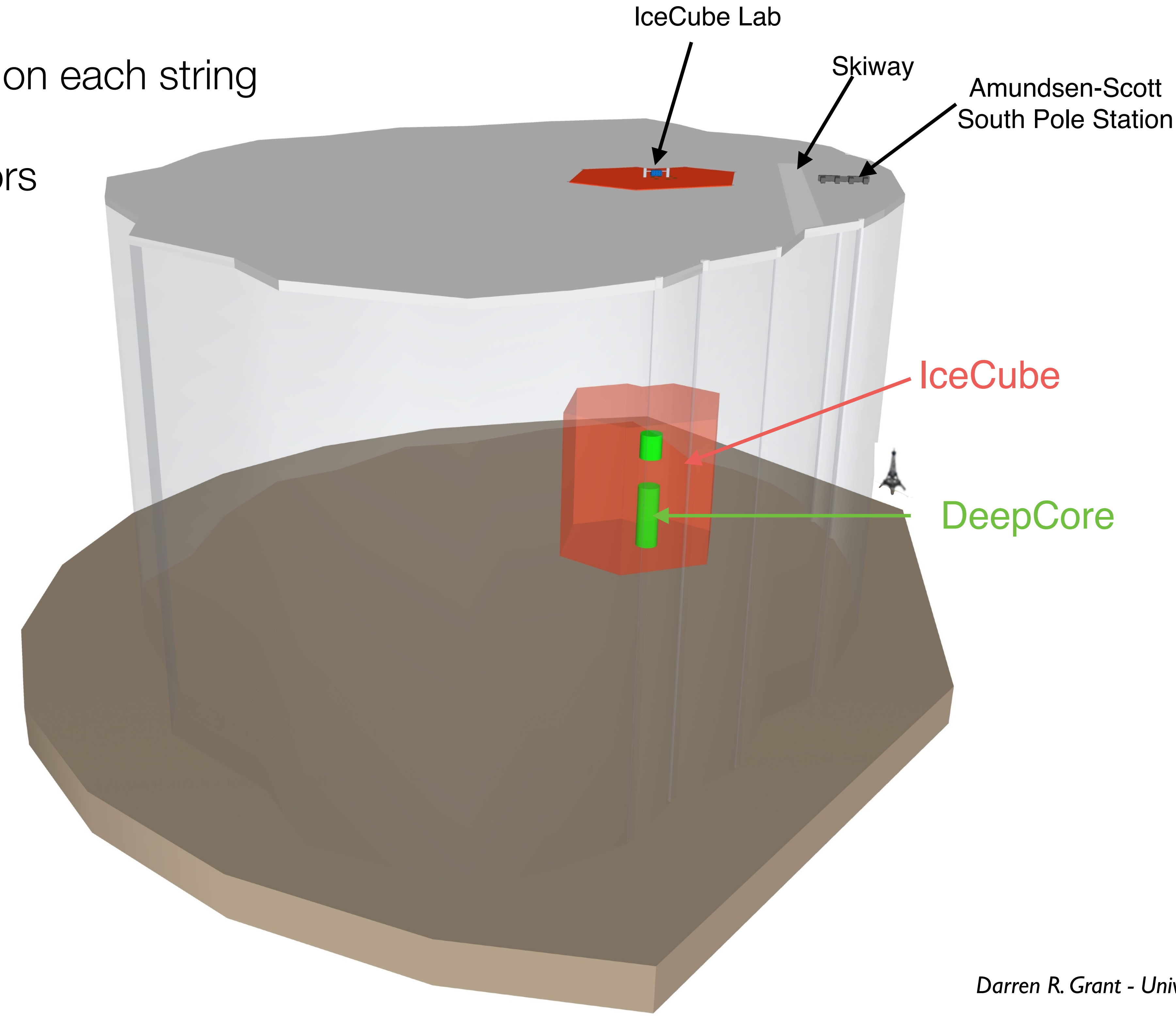
IceCube Array
86 total strings, including 8 DeepCore strings

60 optical sensors on each string

5160 optical sensors



Digital Optical Module



Darren R. Grant - University of Alberta

The IceCube Neutrino Observatory - Canadian activities

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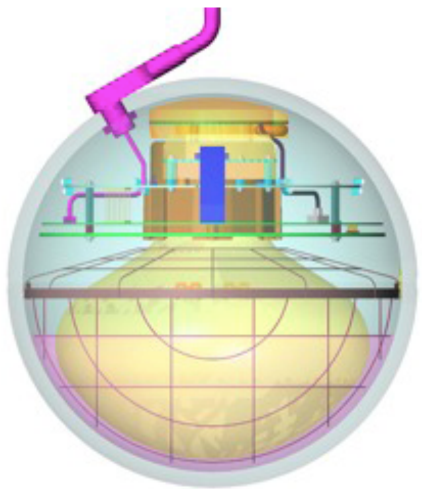

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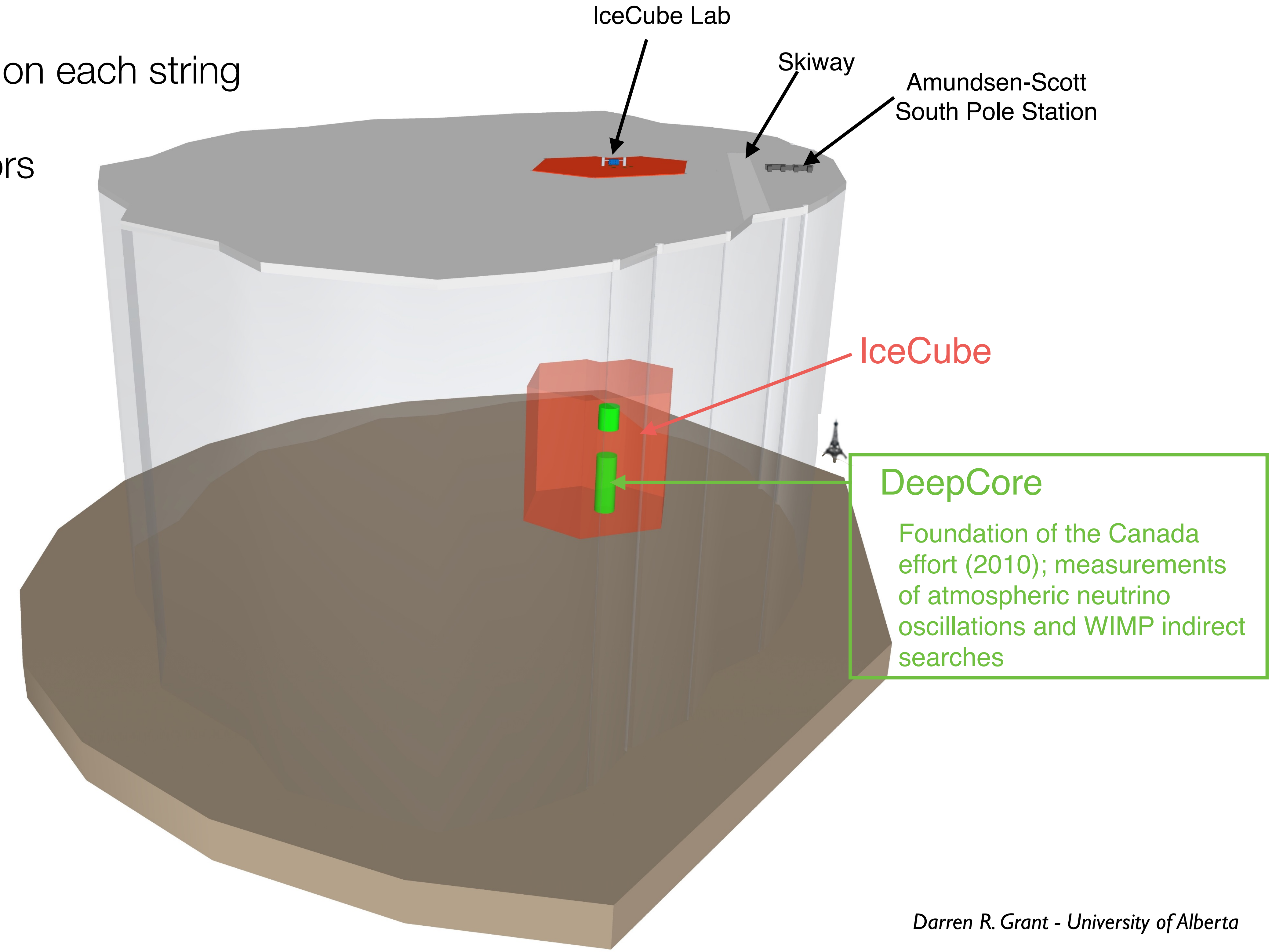

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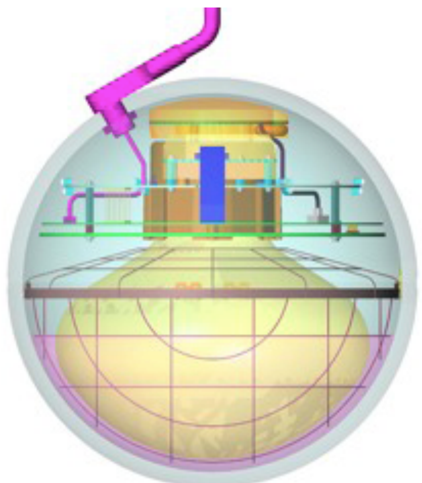

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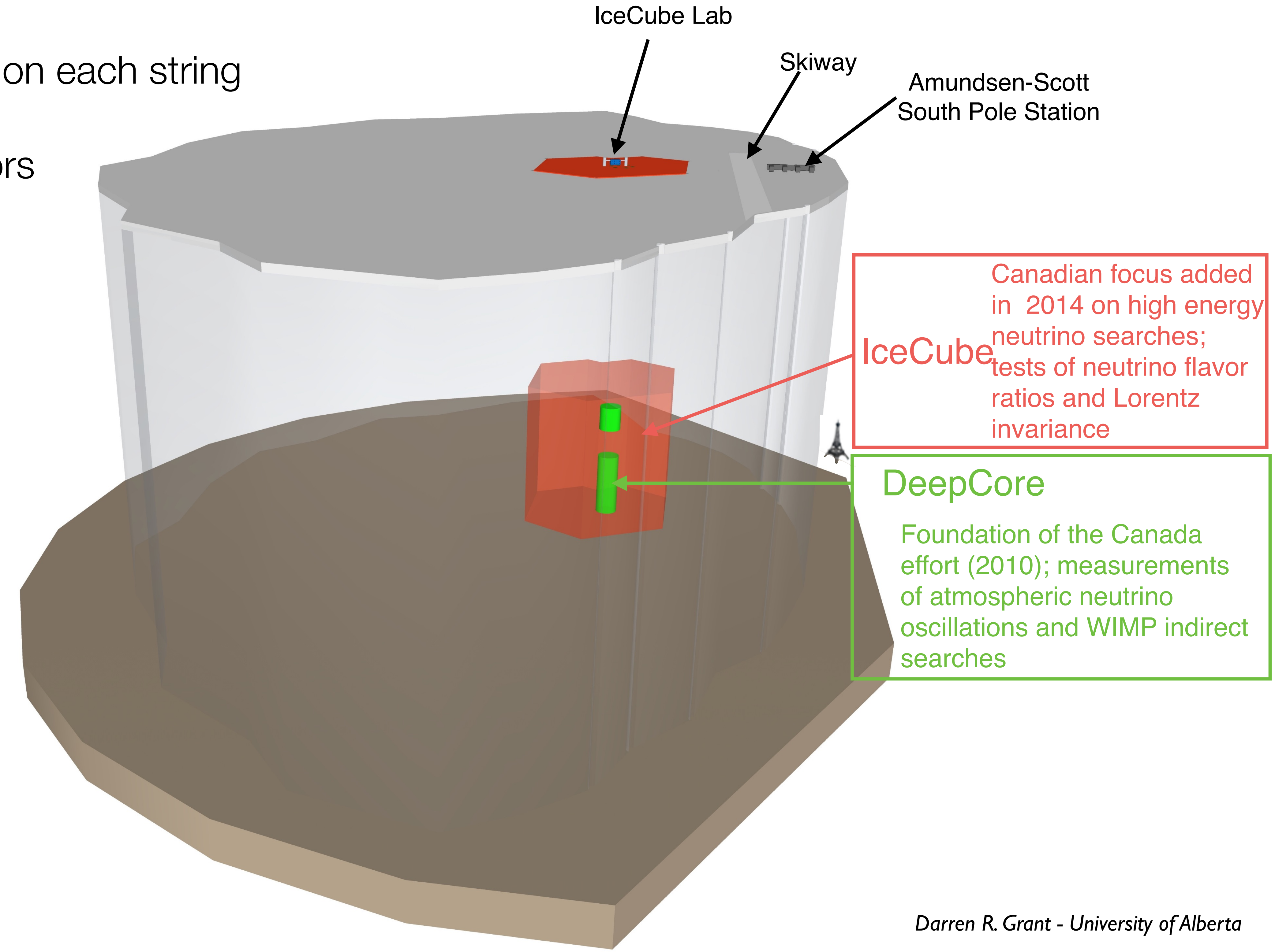
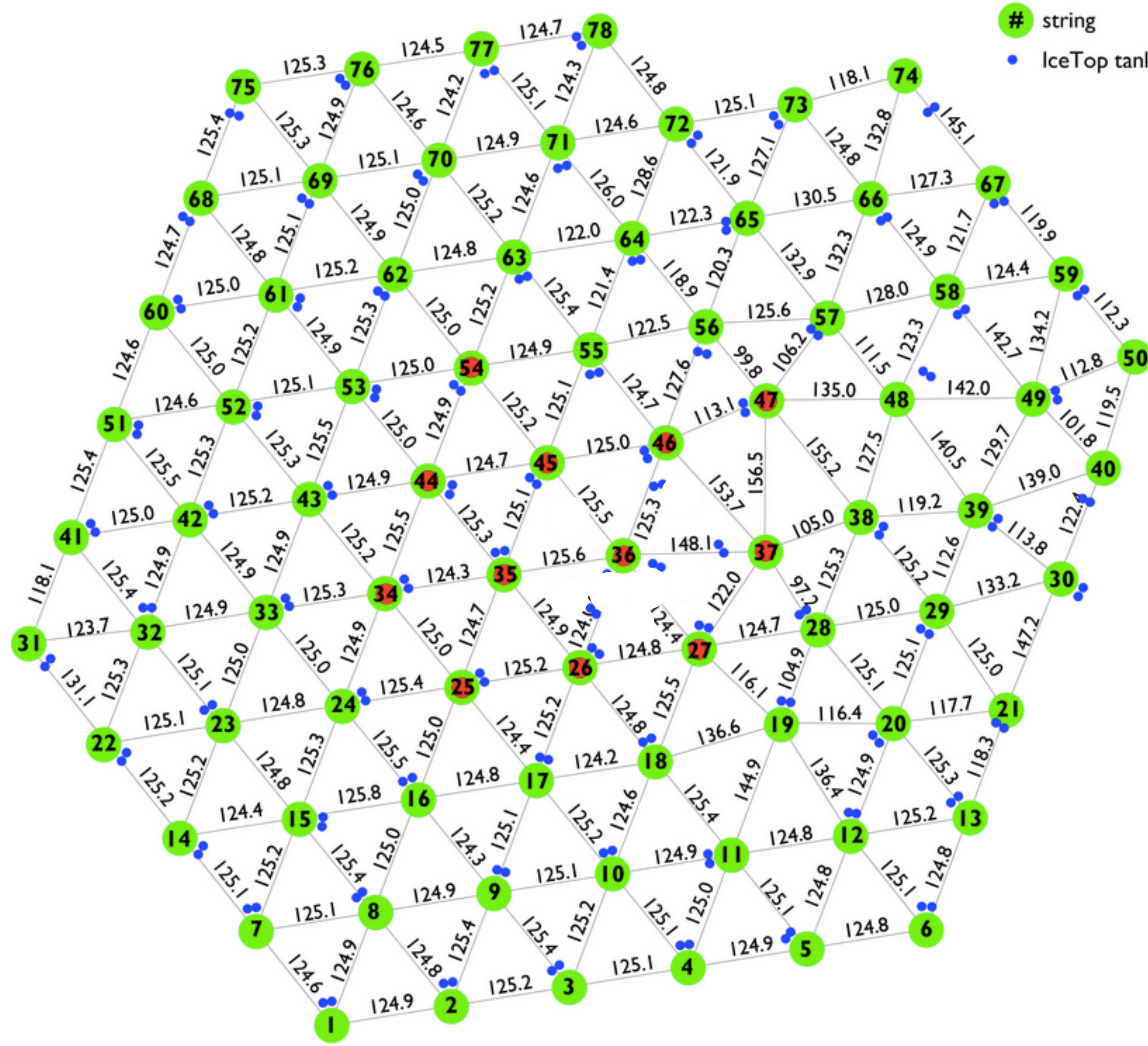
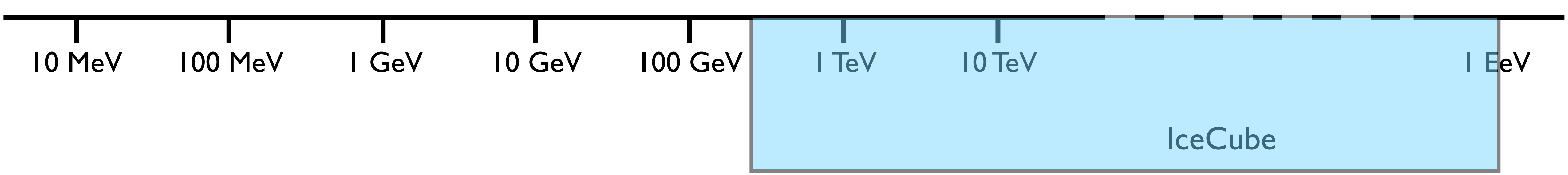


IceCube

- 78 Strings
  - 125m string spacing
  - 17m DOM spacing

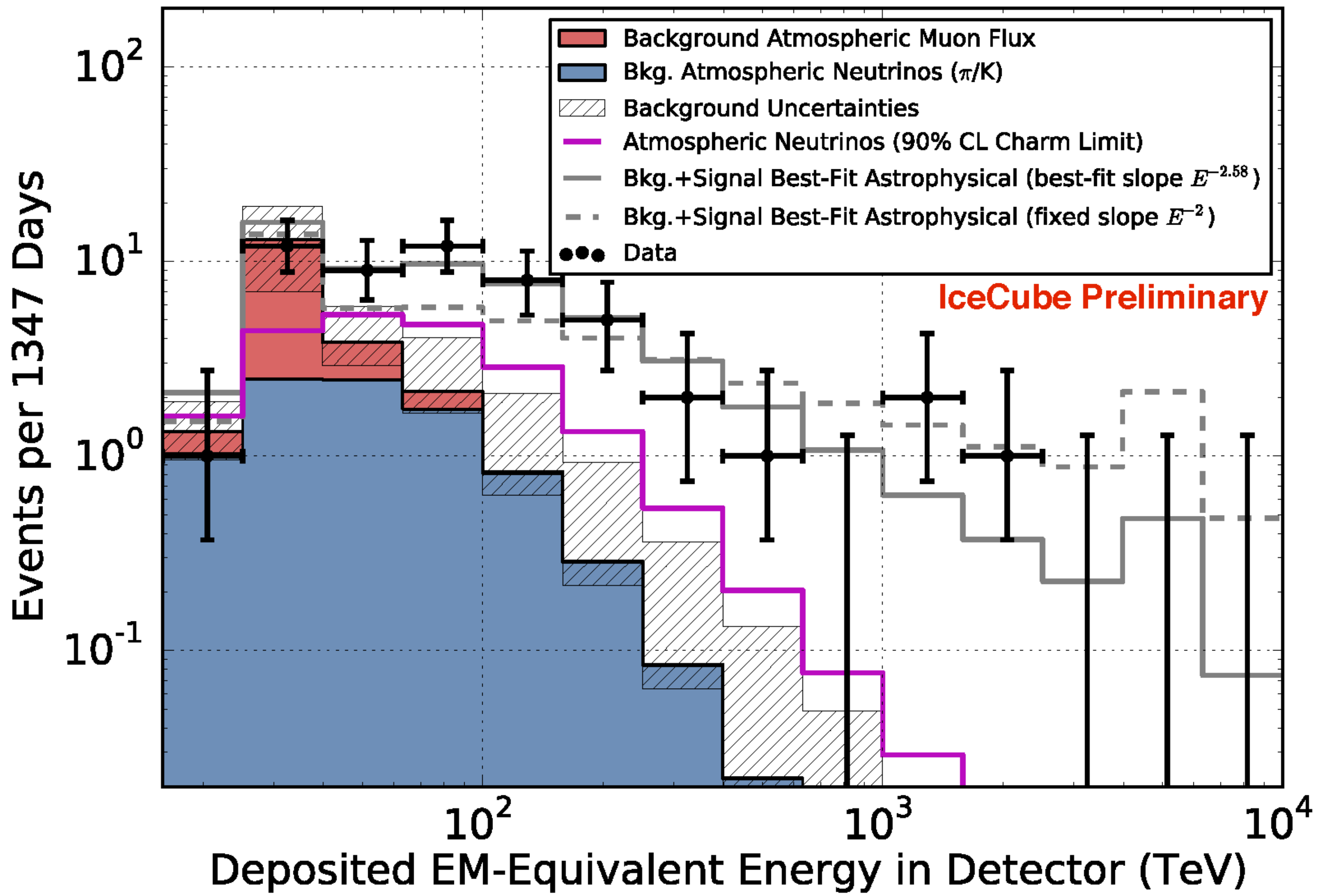


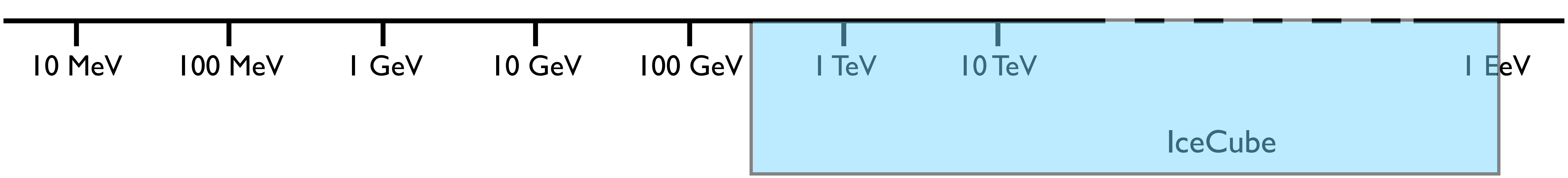


IceCube

High Energy Neutrino Searches

C. Kopper/ **C. Weaver** - UofA

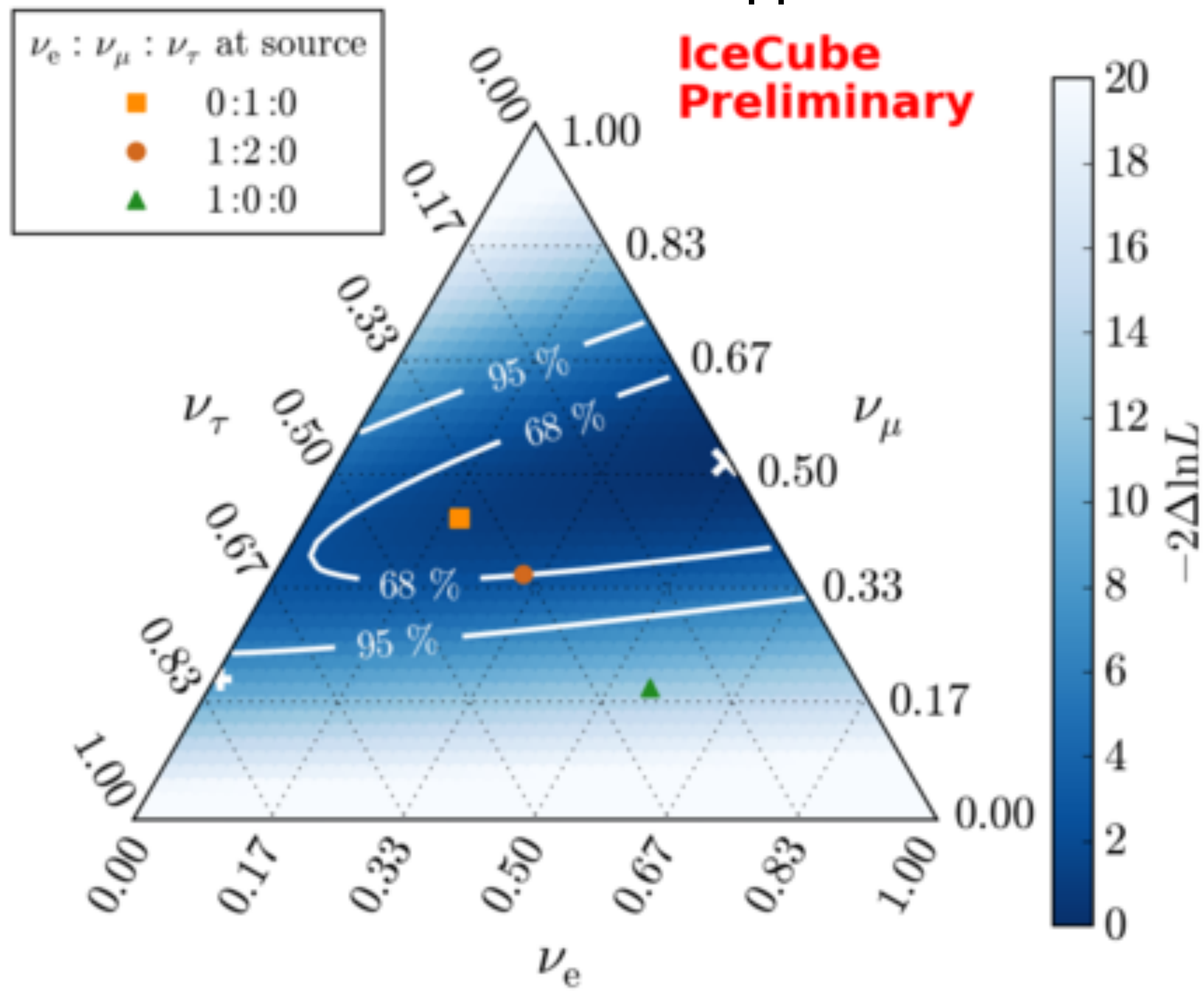


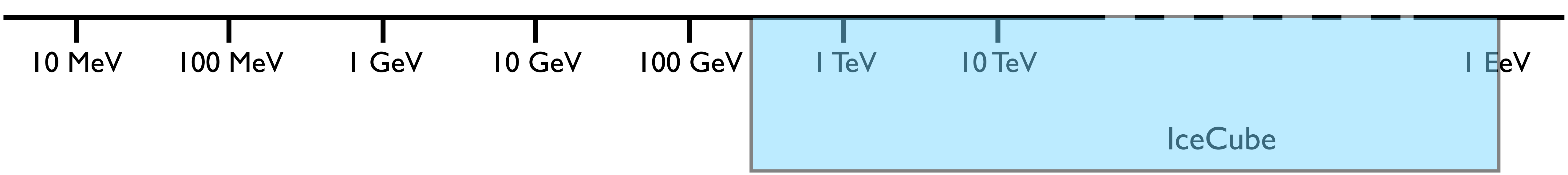


IceCube

Tests of neutrino flavour ratio

C. Kopper/ **C. Weaver** - UofA





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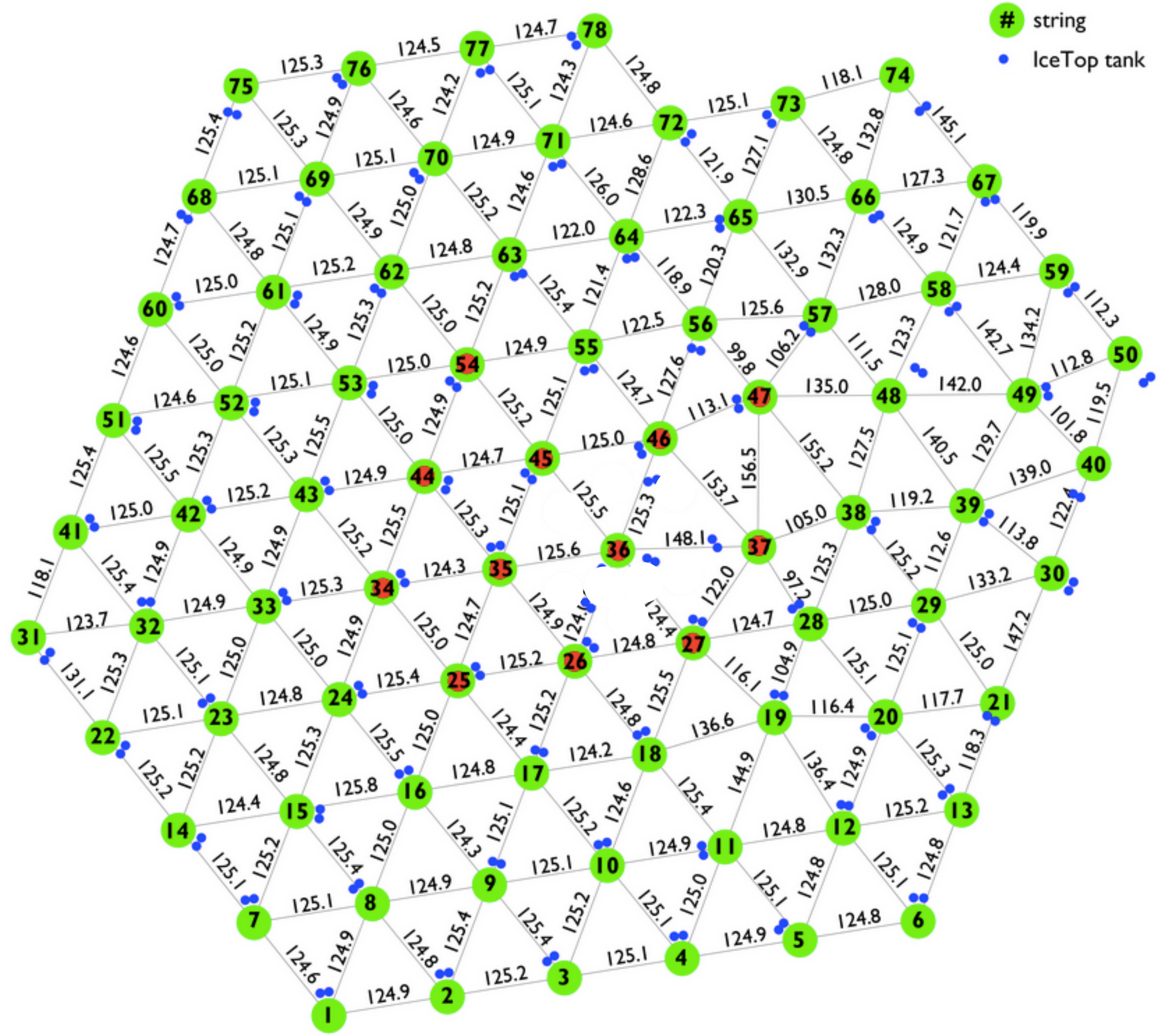

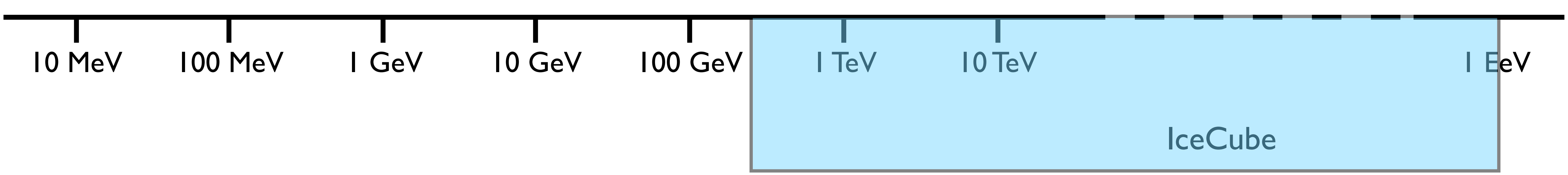

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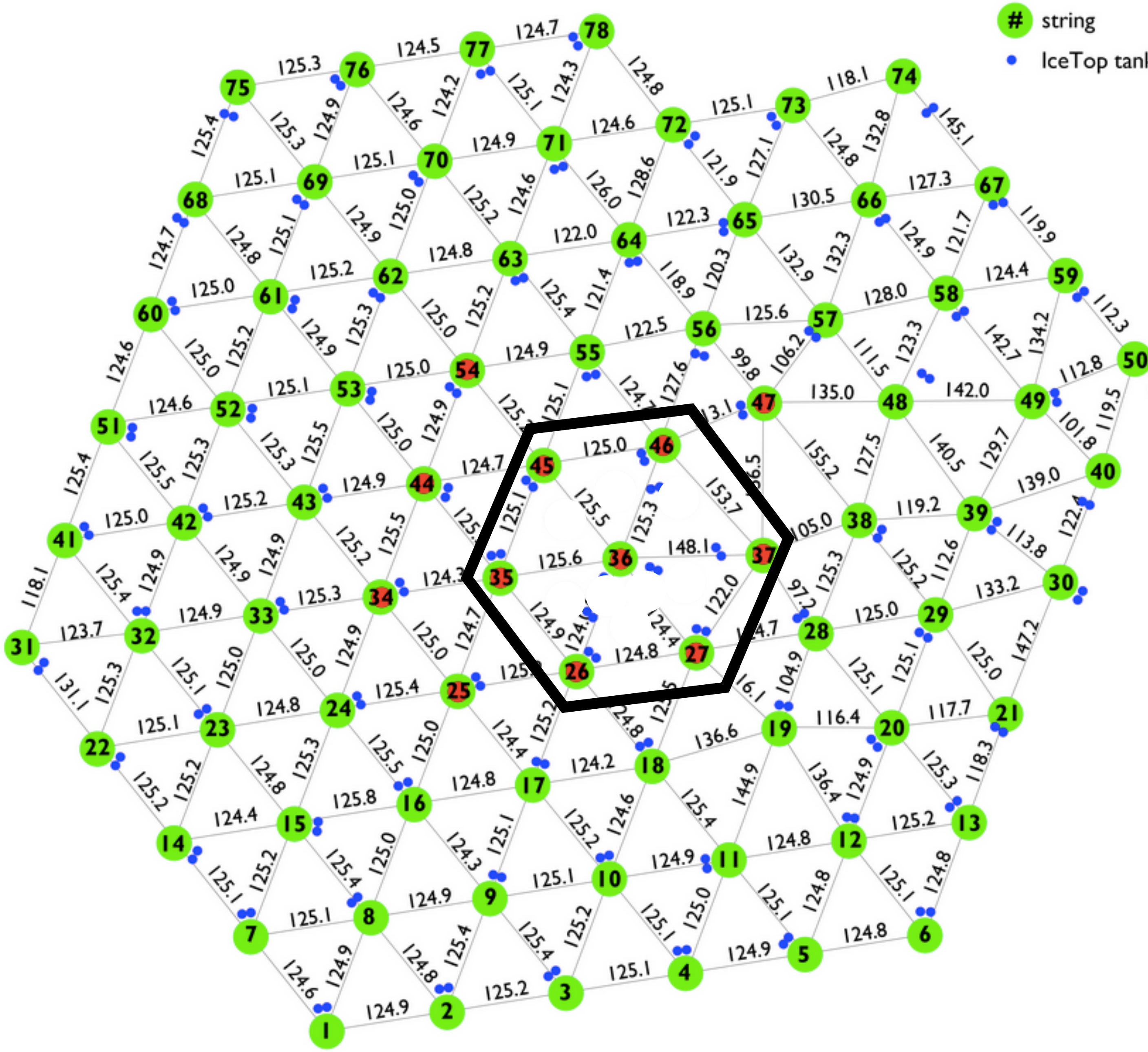

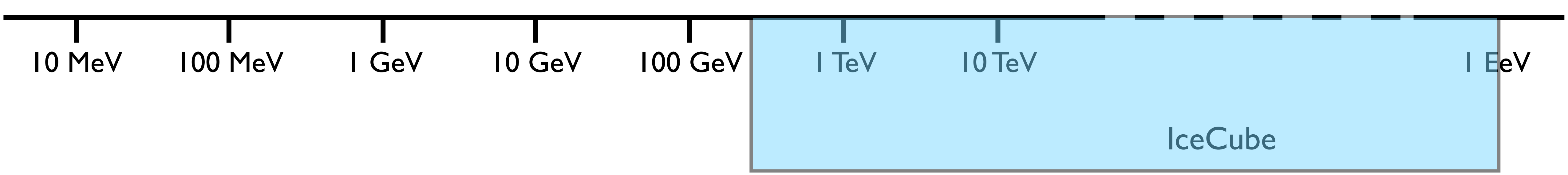

IceCube

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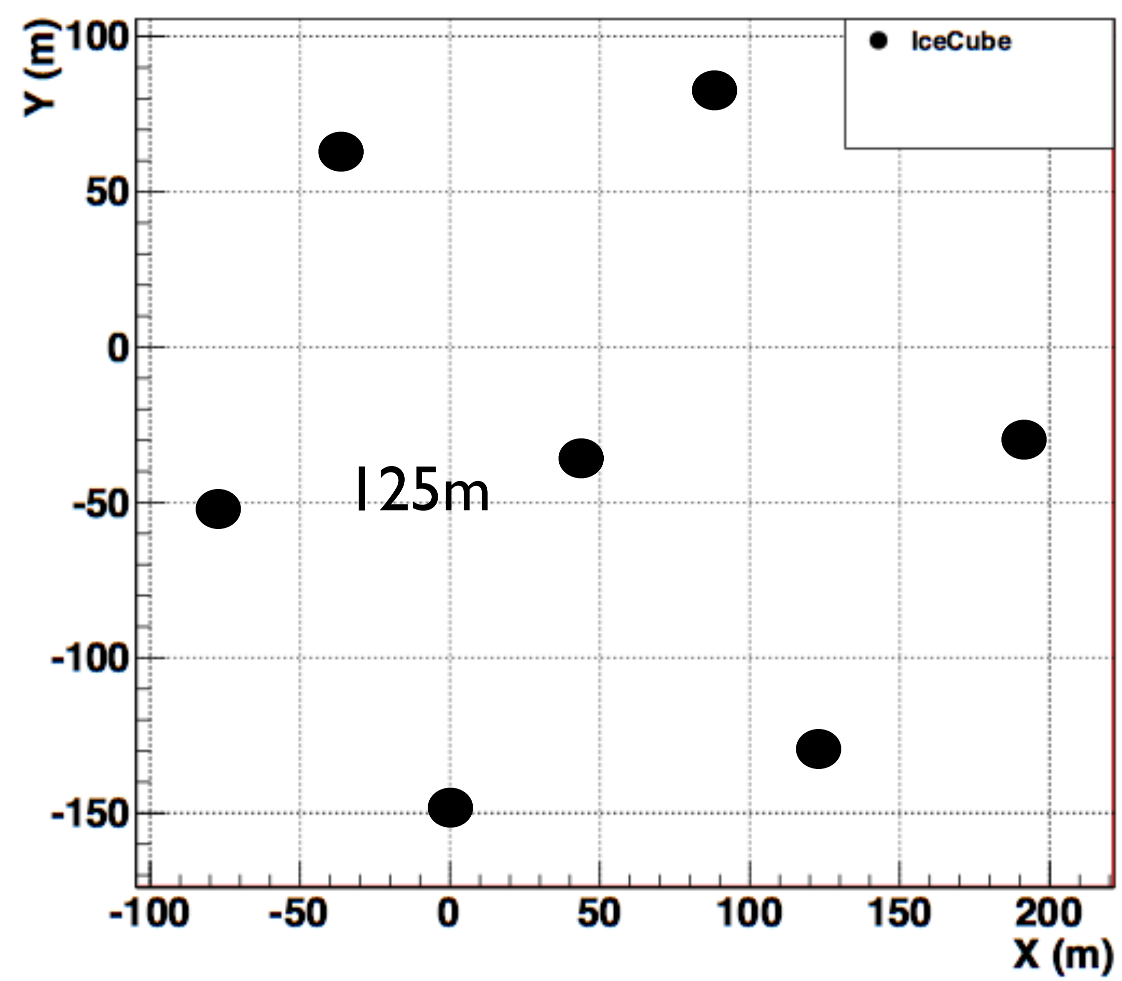
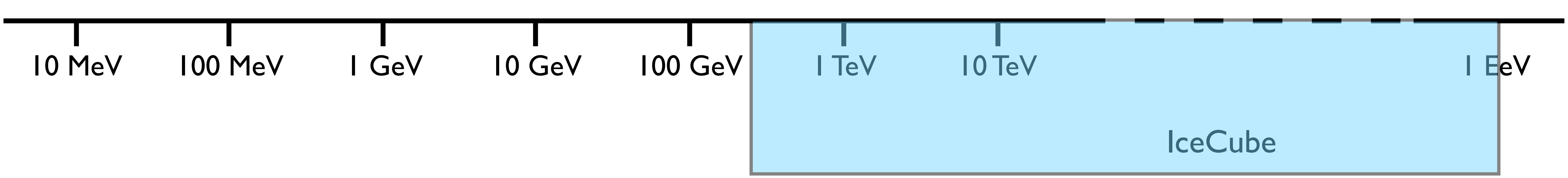
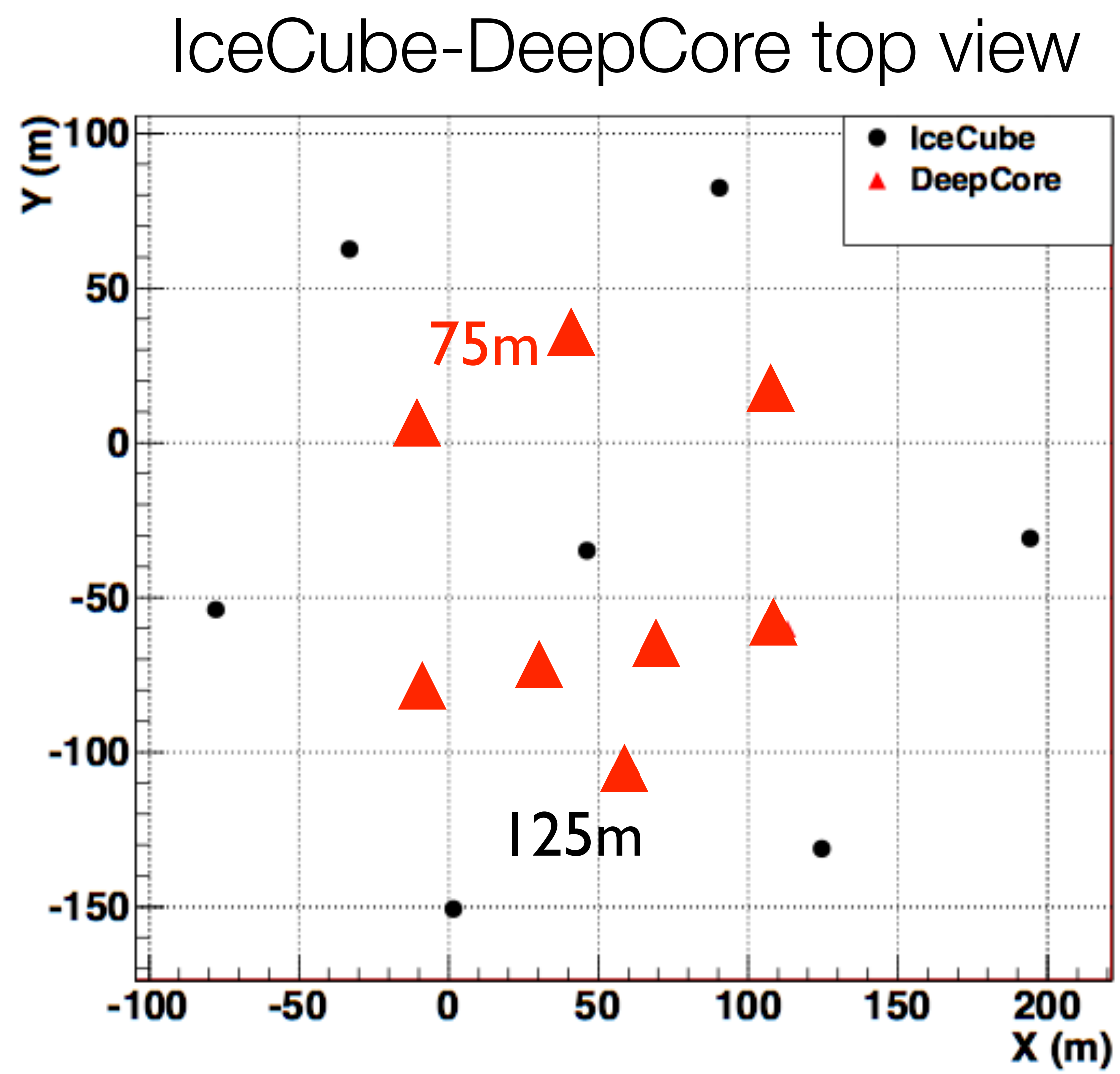
IceCube top view

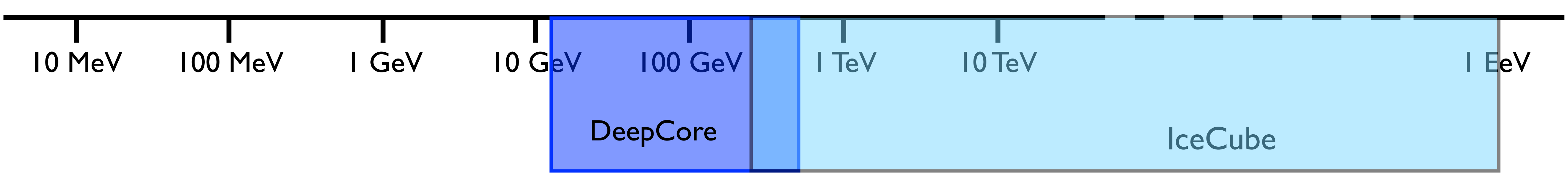




IceCube-DeepCore

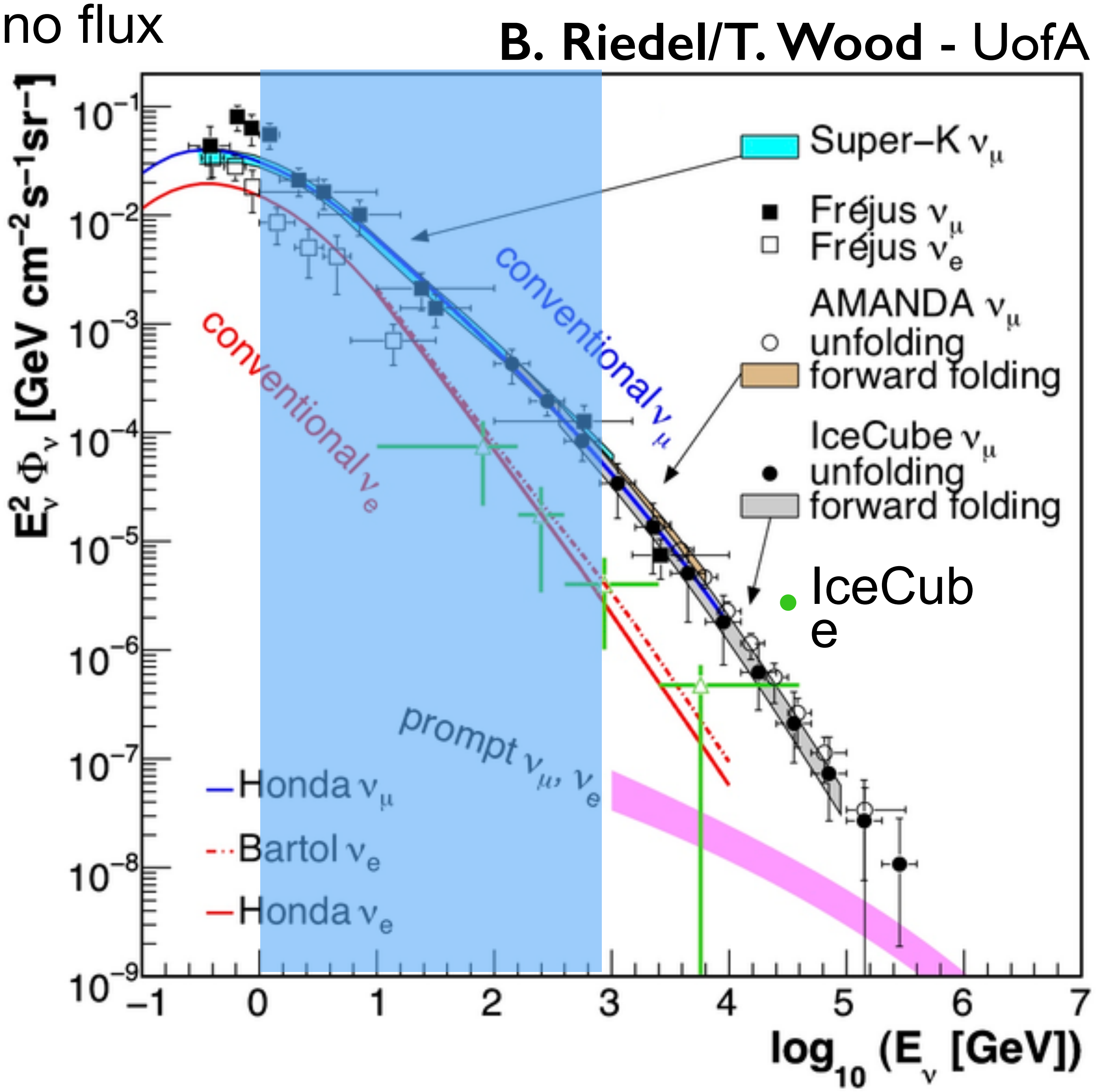
- 78 Strings
    - 125m string spacing
    - 17m DOM spacing
- Add 8 strings
    - 75m string spacing
    - 7m DOM spacing

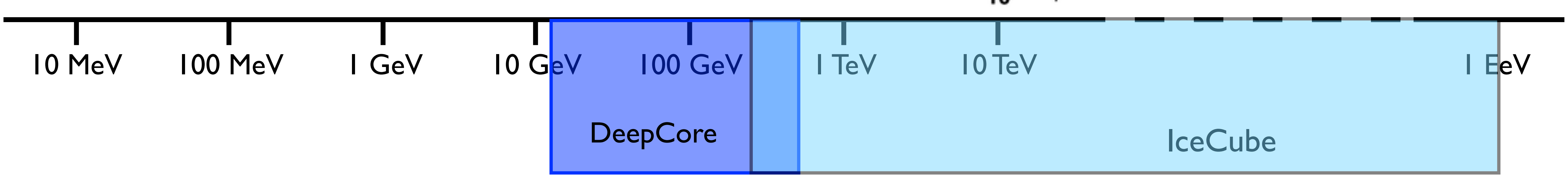




IceCube-DeepCore

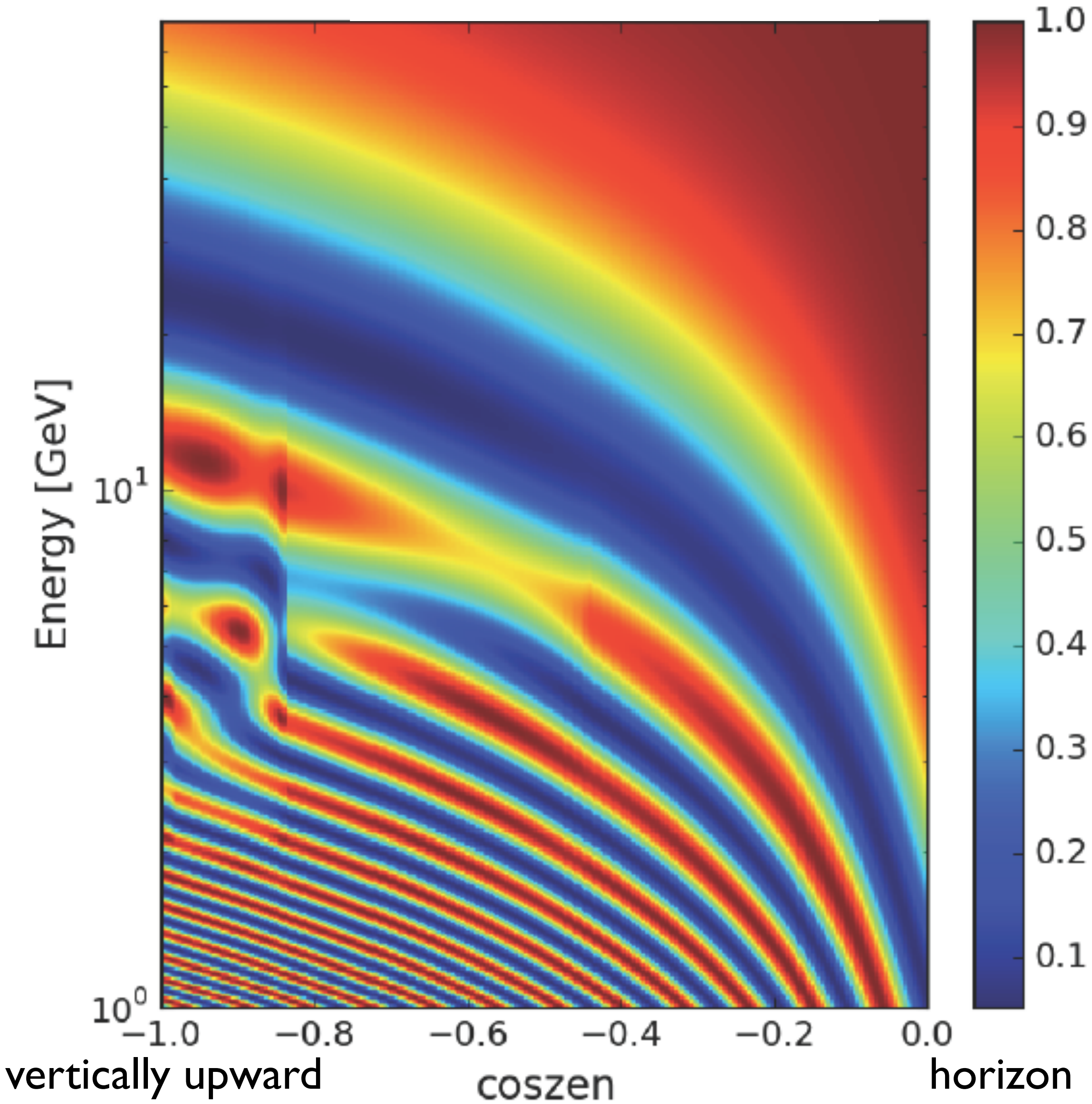
Atmospheric neutrino flux

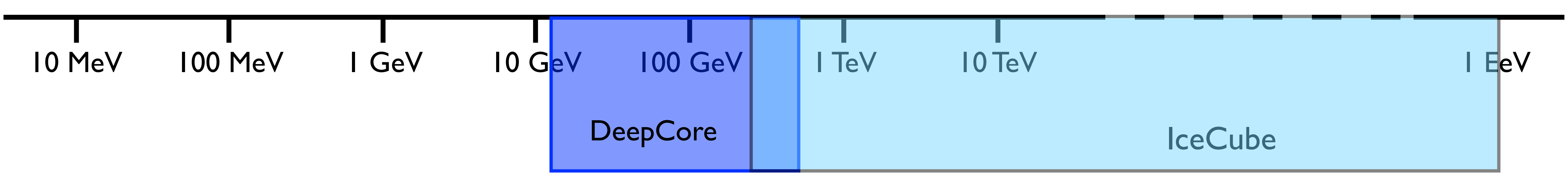




IceCube-DeepCore

Atmospheric neutrino oscillations **S. Nowicki**/C. Krauss - UofA/ K. Clark UofT





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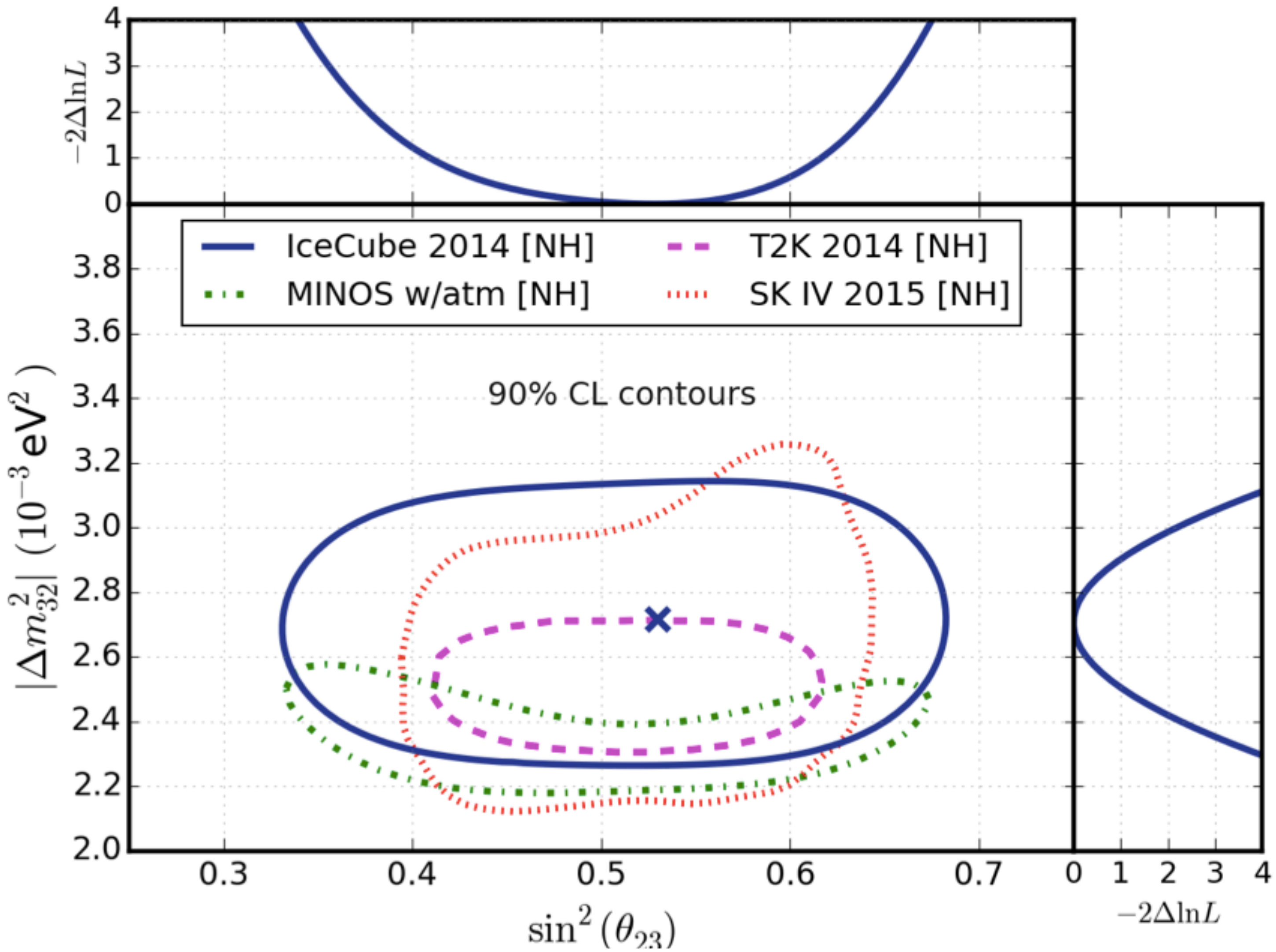

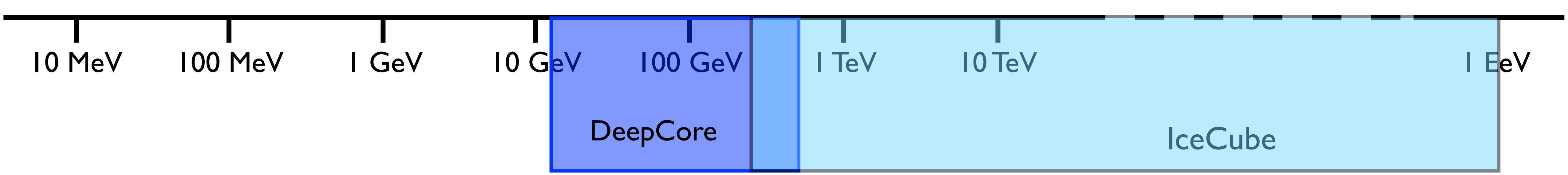

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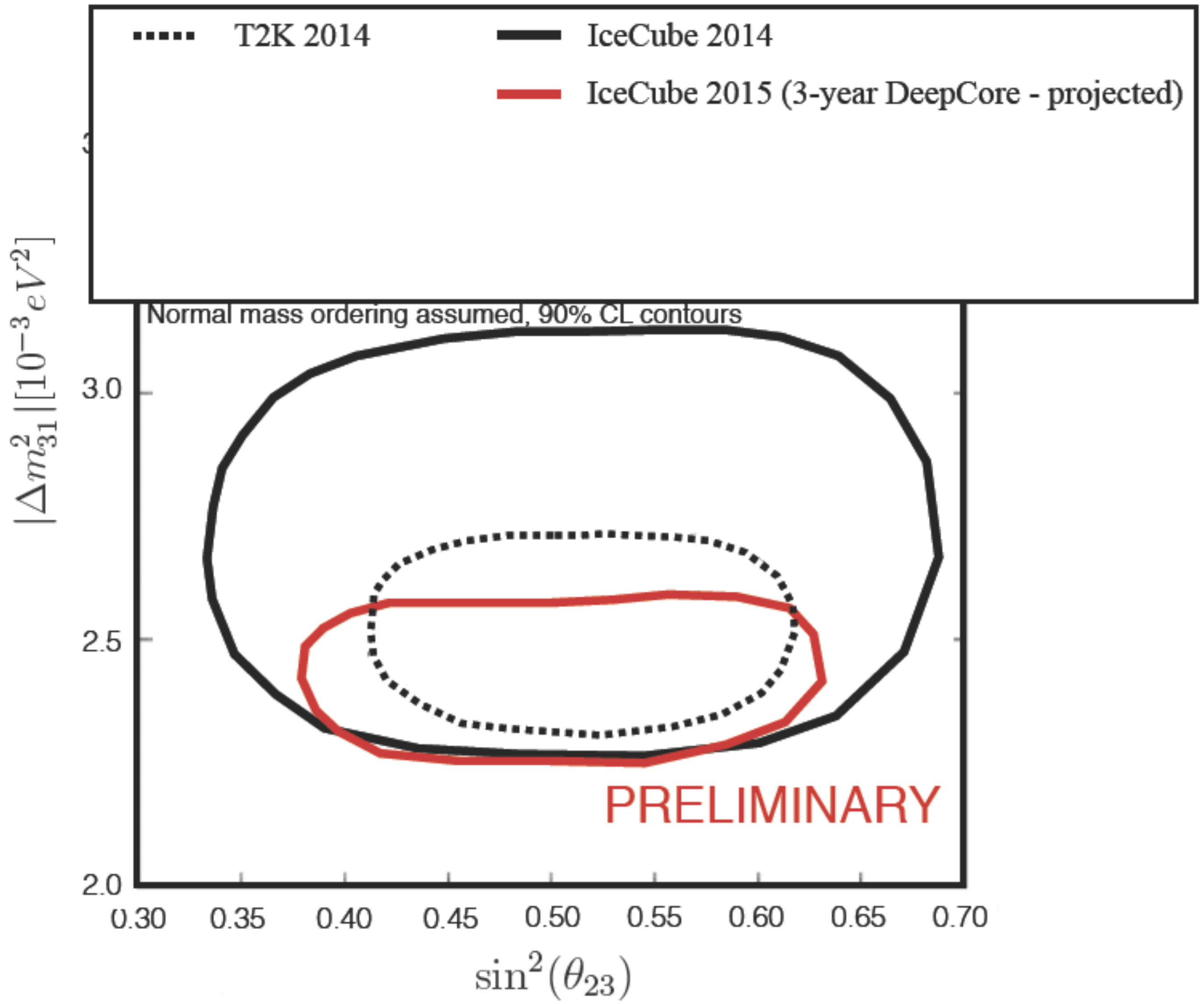
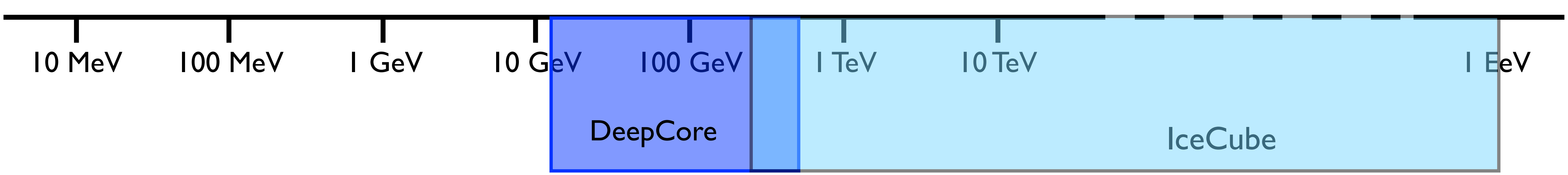




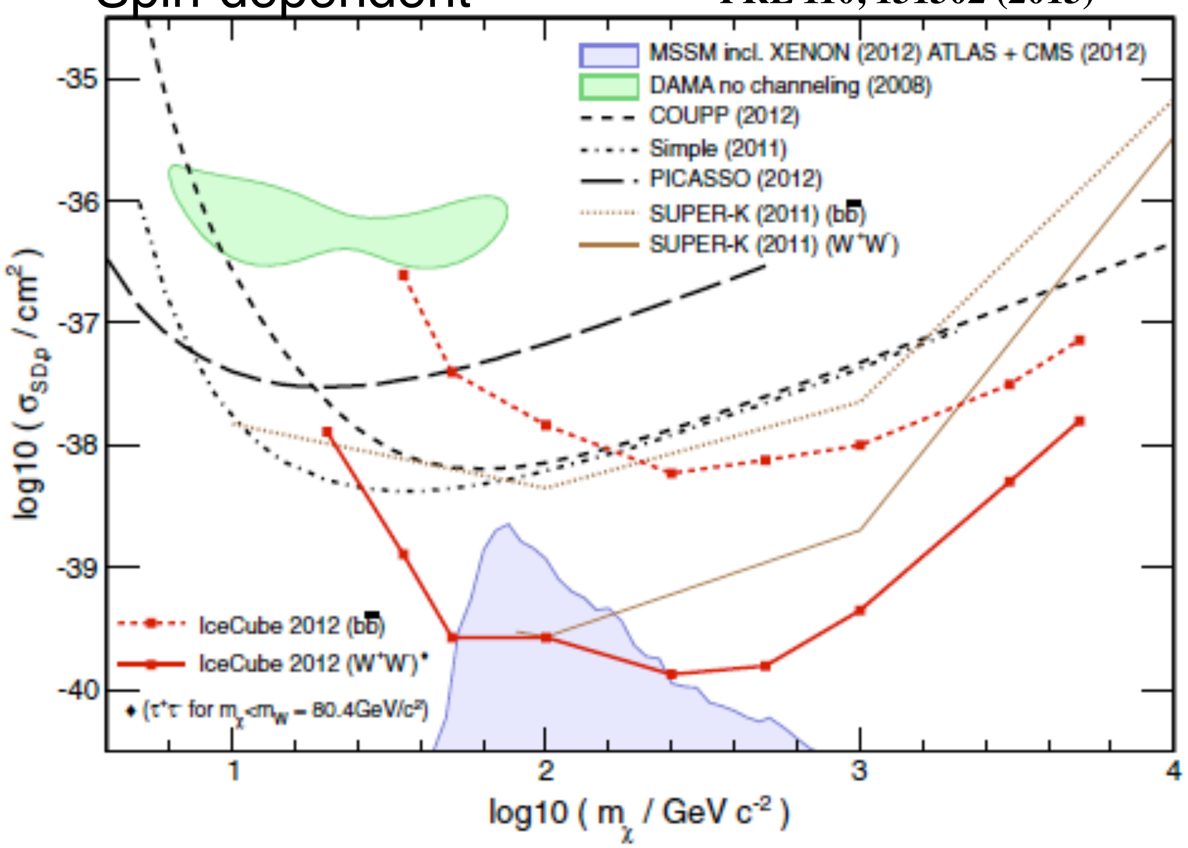
IceCube-DeepCore

Indirect dark matter searches

R. Moore - UofA/ K. Clark UofT

Spin-dependent

PRL 110, 131302 (2013)



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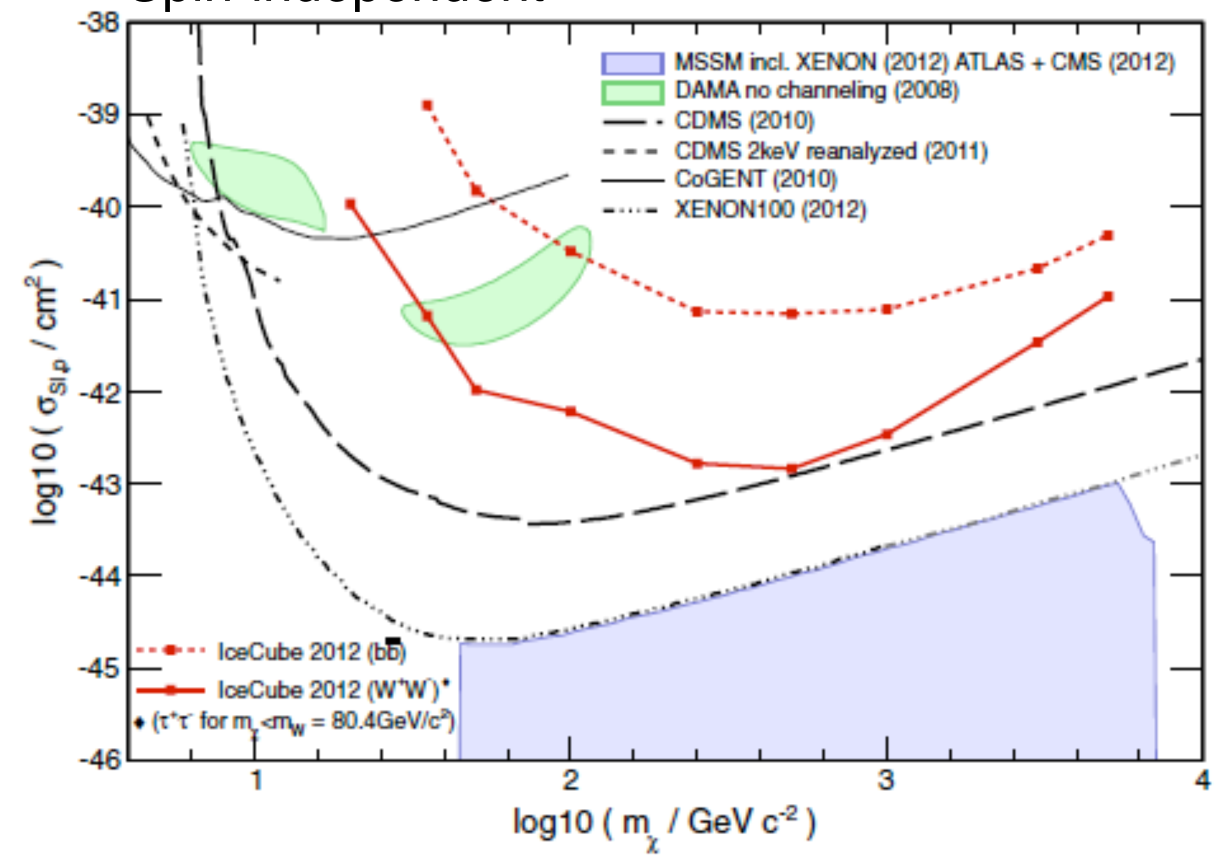

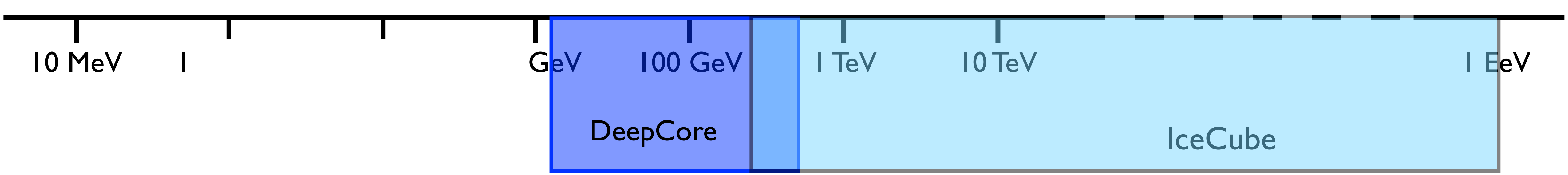

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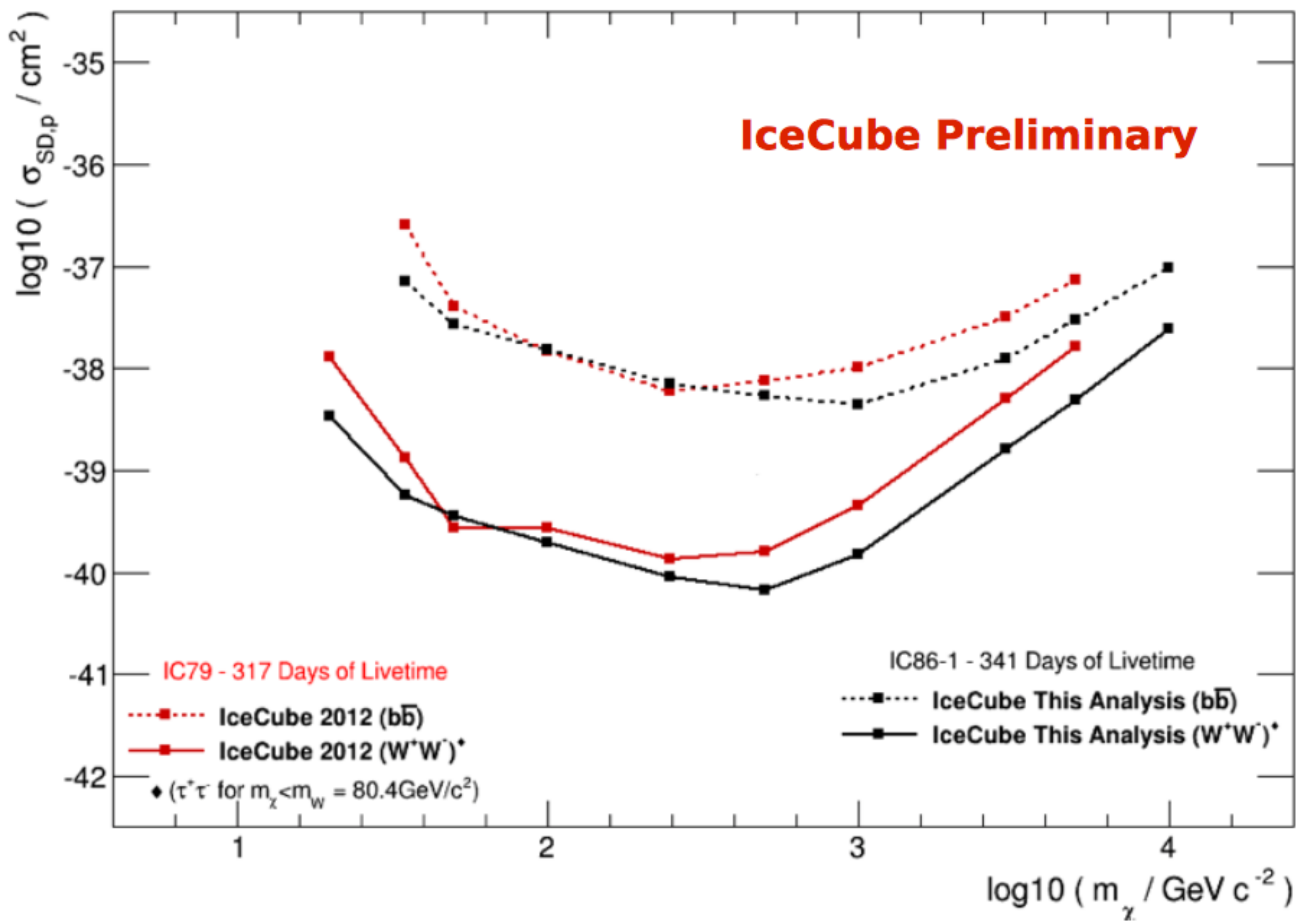
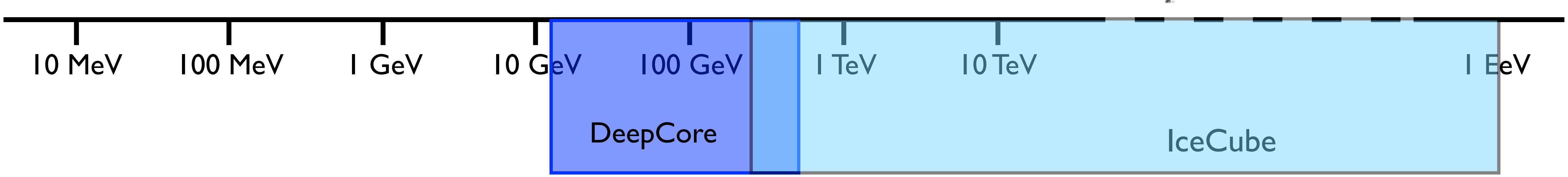
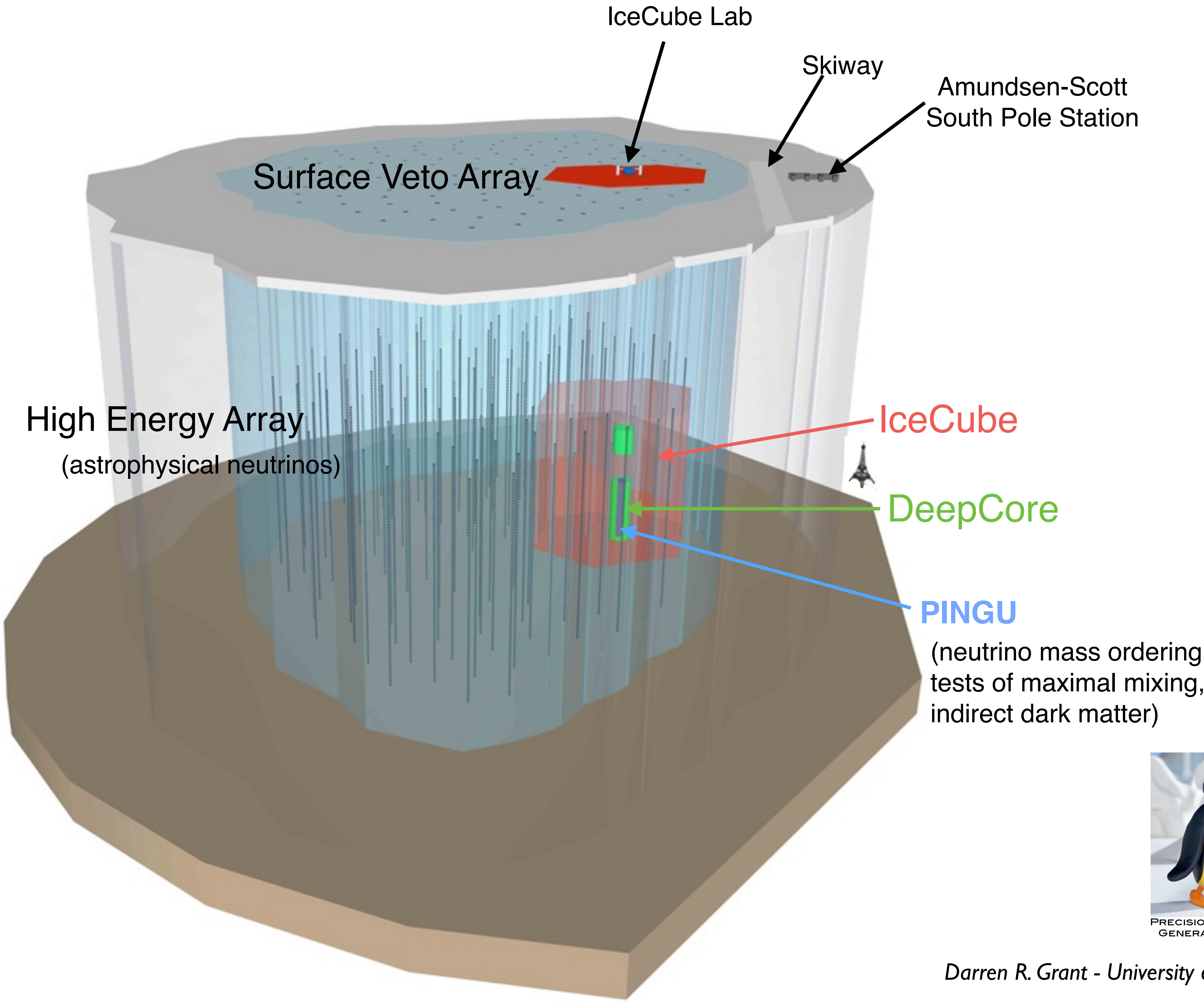




The IceCube Neutrino Observatory - Generation 2 (Gen2)

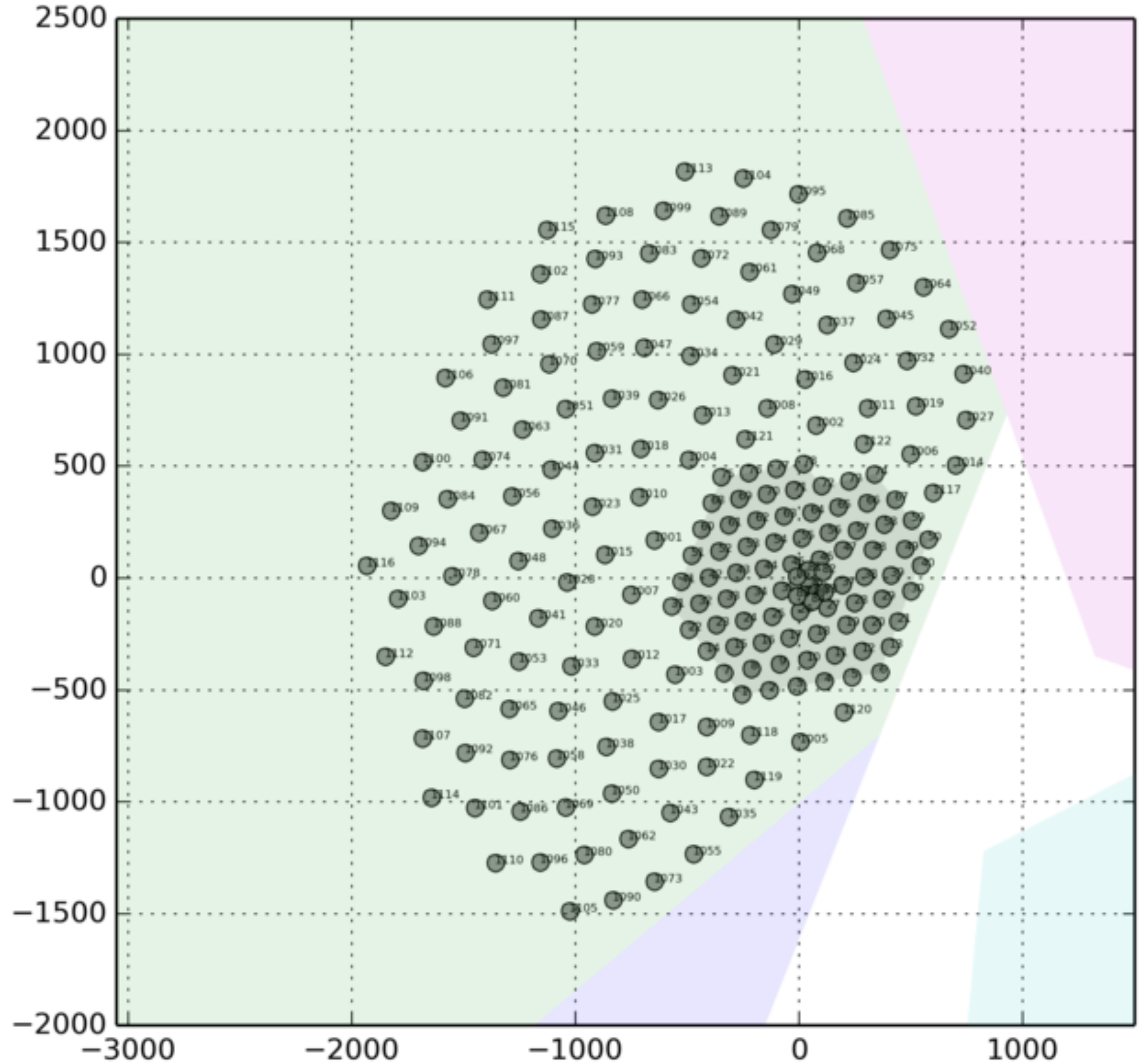
GENTWO
Next Generation IceCube Project

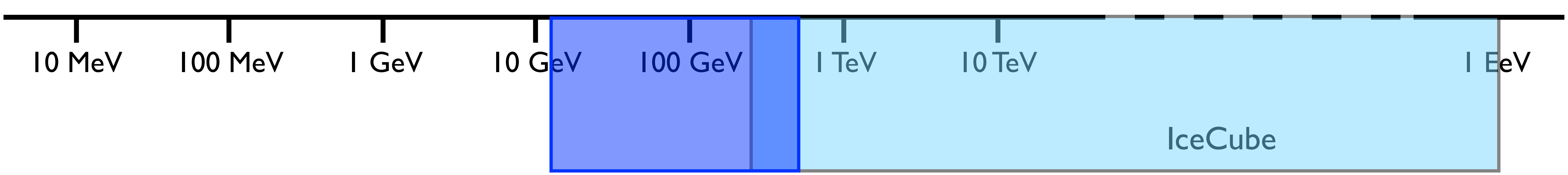


IceCube-Gen2

the High Energy Array (goal of 10x sensitivity to high energy neutrinos)

- ~120 new strings
  - up to 250m string spacing
  - 80 modules/string at 17m spacing





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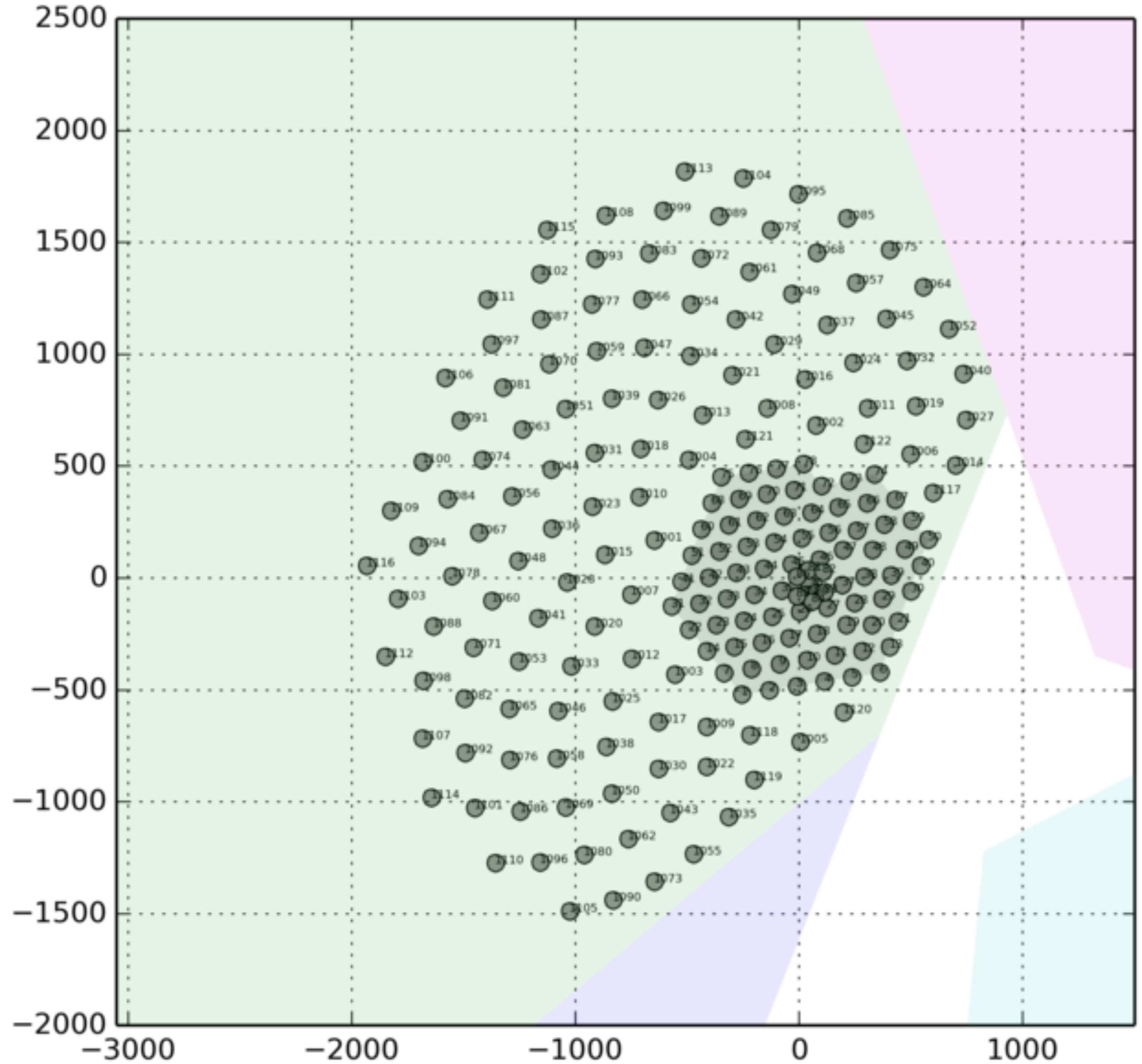
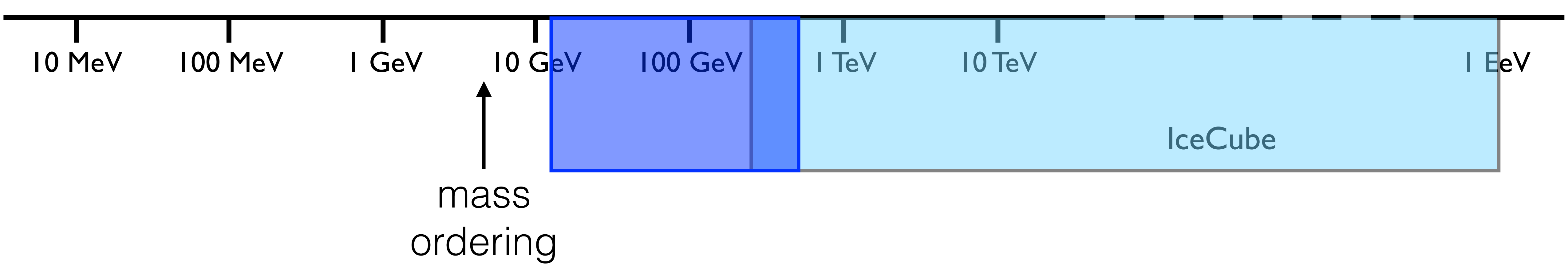
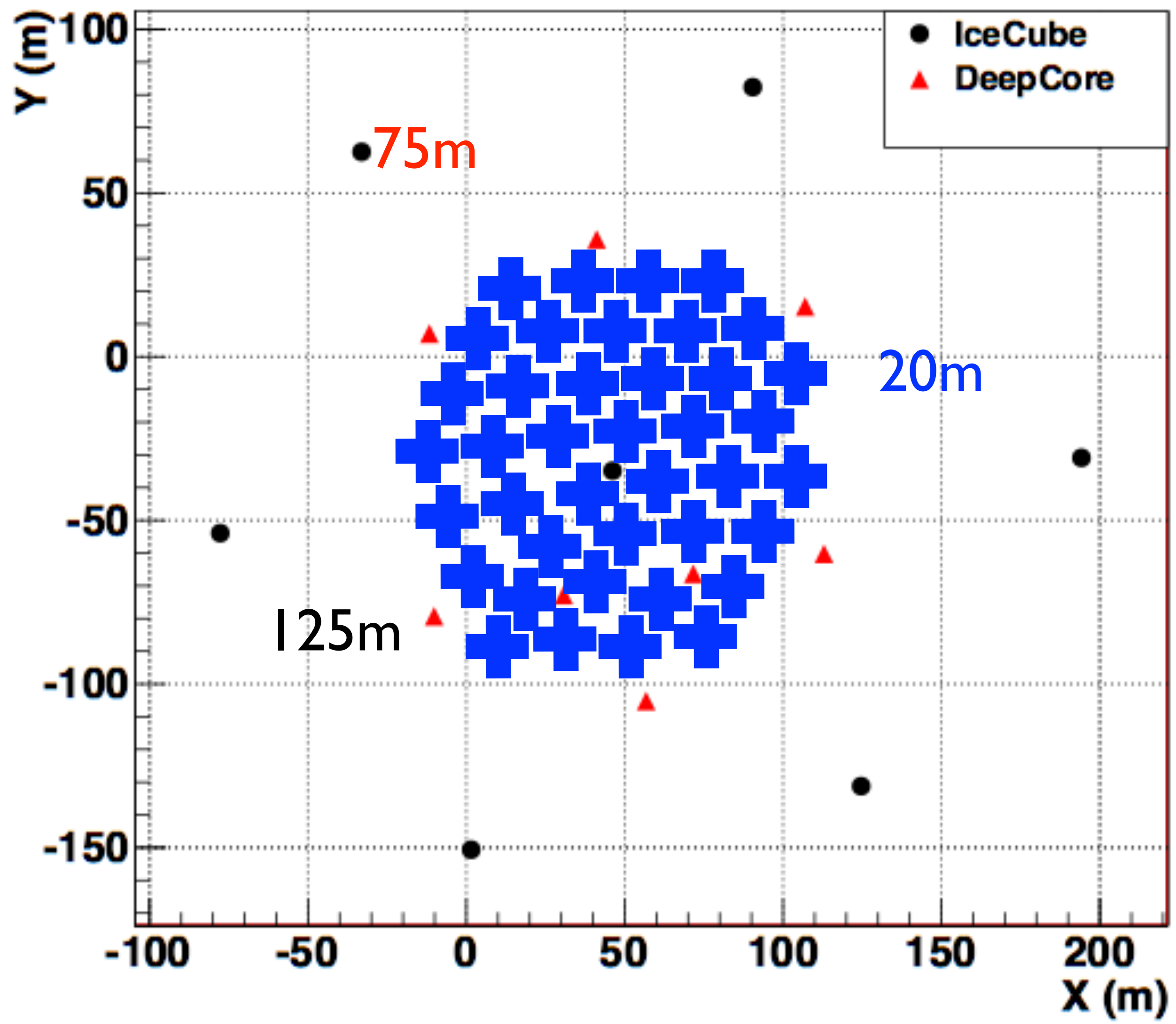


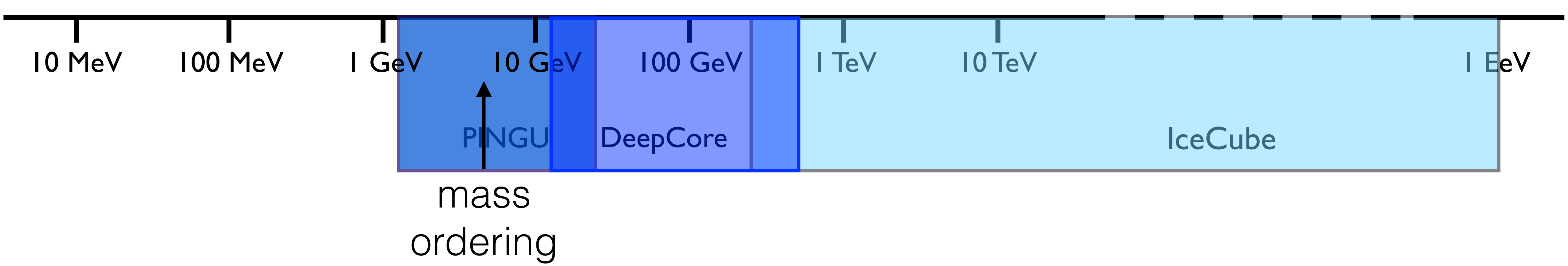


IceCube-Gen2

- Add 40 strings (baseline target)
  - ~20m string spacing
  - 3-5m DOM spacing
  - ~15x higher photocathode density

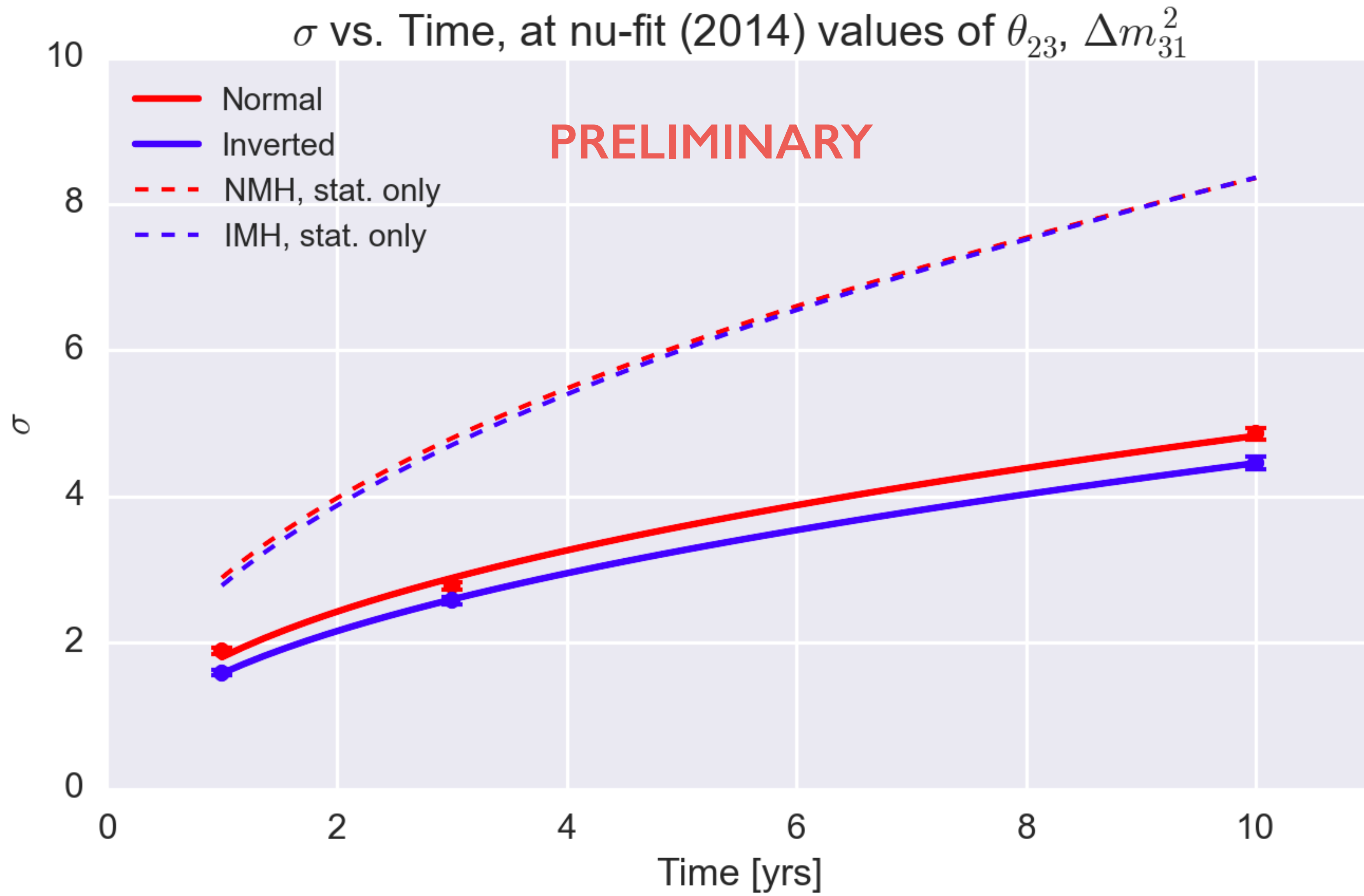
IceCube-DeepCore-PINGU top view

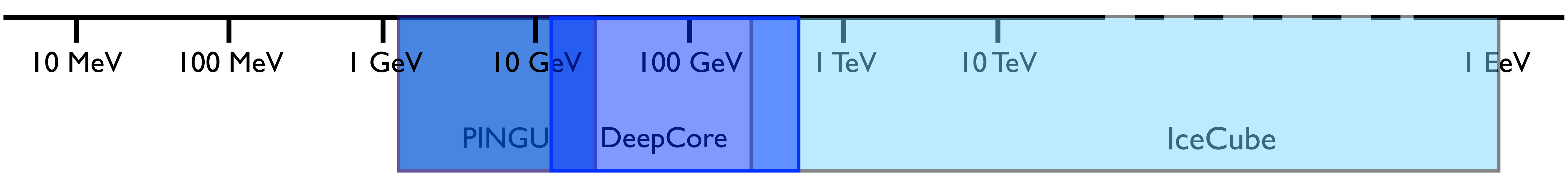




IceCube-Gen2

PINGU sensitivity to the neutrino mass ordering (3 sigma in 3-4 years)





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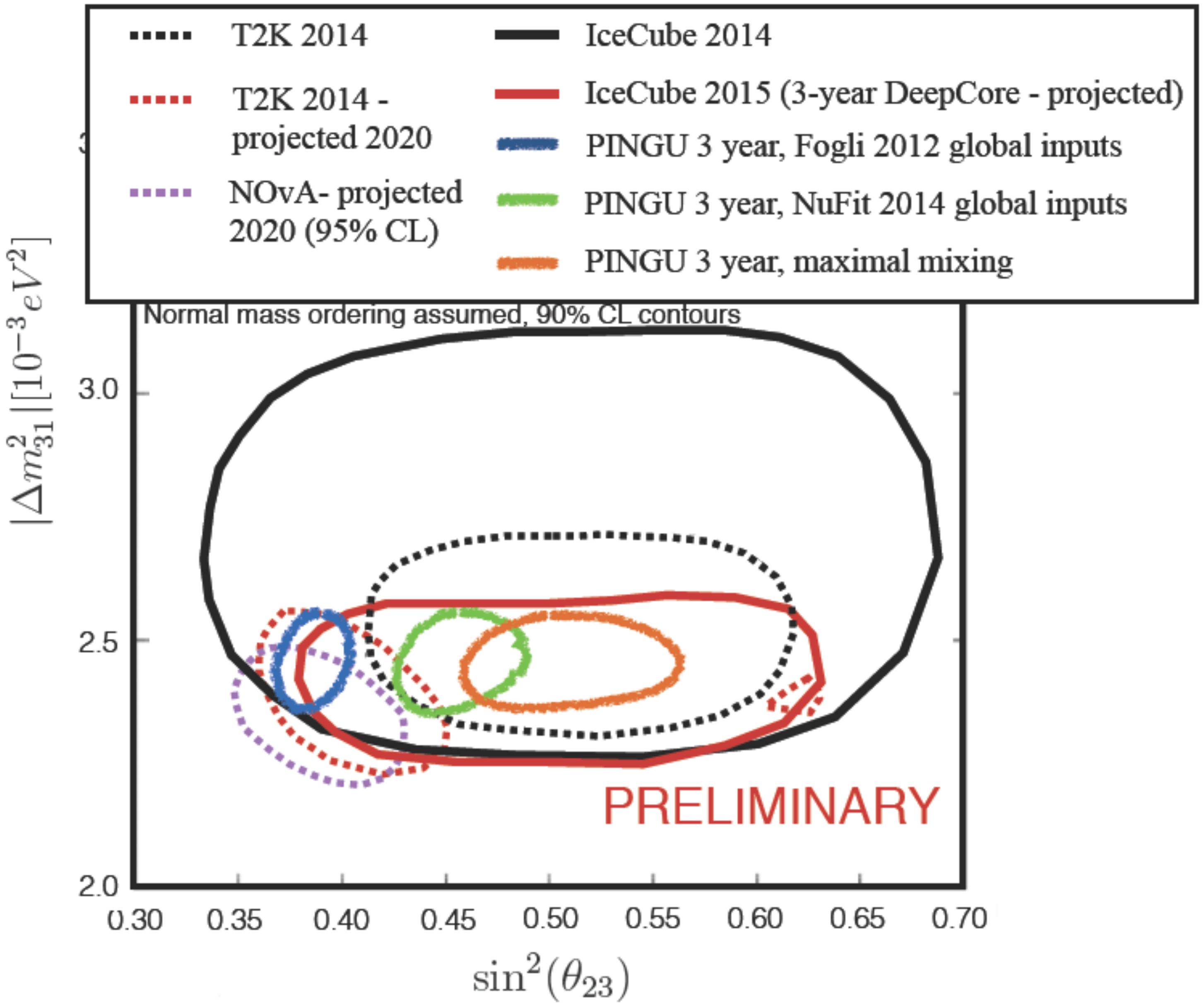
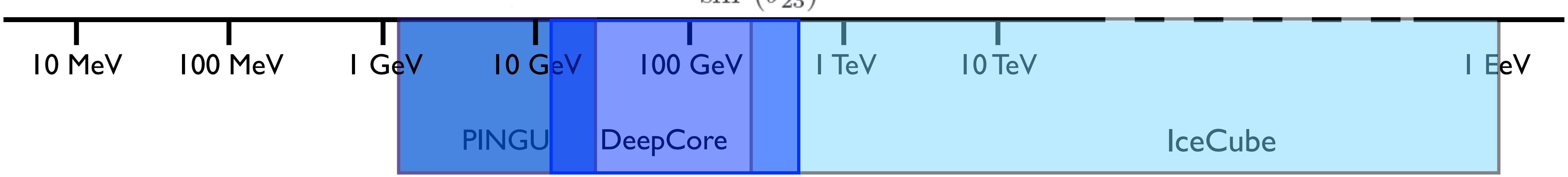




IceCube-Canada Long Range Planning (2017 - 2021)

IceCube-Canada Long Range Planning (2017 - 2021)

1. Physics and other research goals:

- Exploit the full capability of the current IceCube-DeepCore arrays, including leading measurements for:
  - neutrino oscillations
  - dark matter
  - atmospheric neutrino fluxes
  - particle physics at the highest energy sources (including acceleration mechanism)
  - tests of long-baseline vacuum oscillation flavour ratios
  - tests of Lorentz invariance with high energy neutrinos
  - supernova neutrinos
  - beyond standard model searches

- Complete the design of PINGU and the High Energy Array

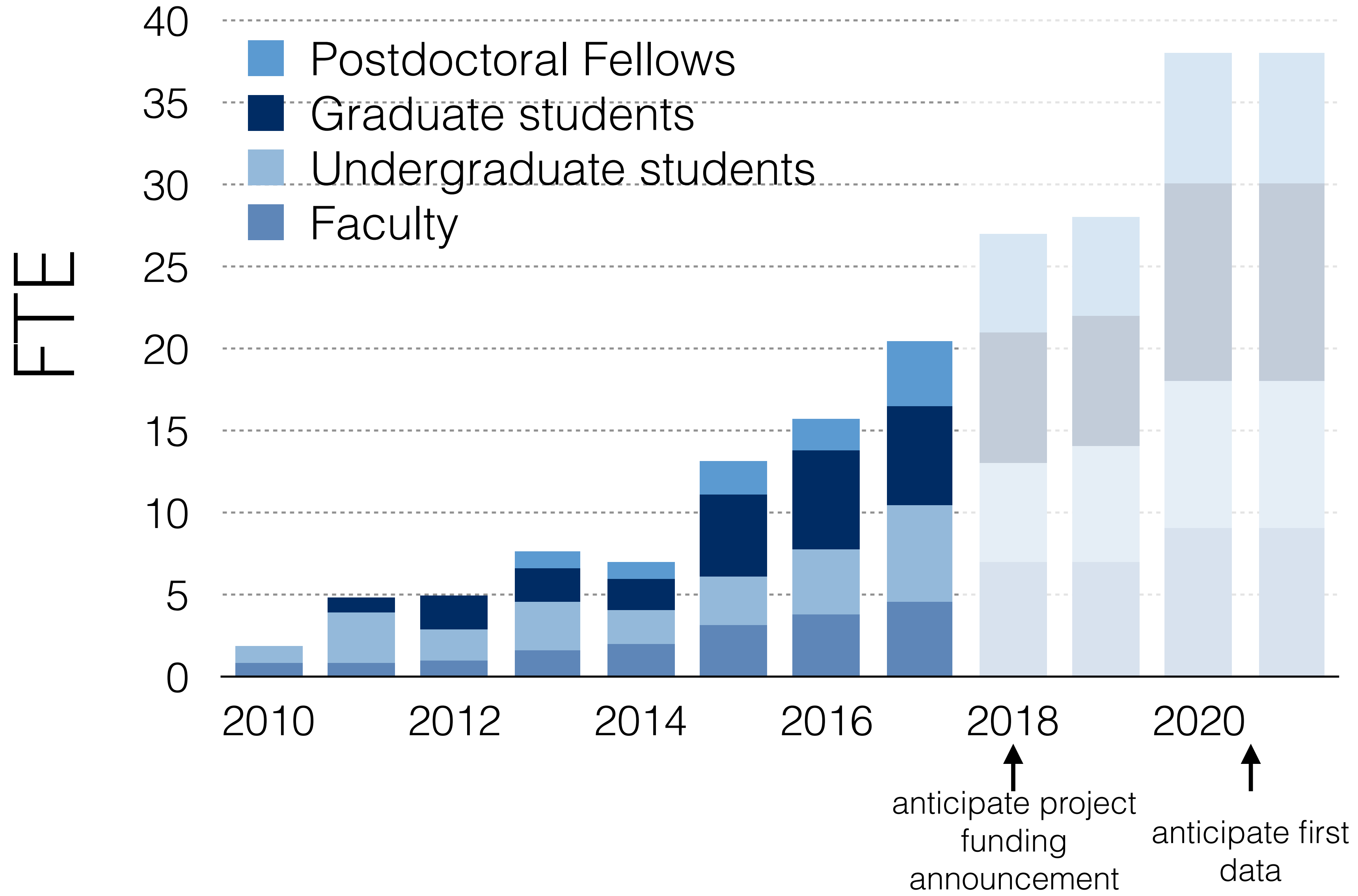
- Complete the design and fabrication of Gen2 optical modules; first deployments 2020/21; first data of new detector arrays.

IceCube-Canada Long Range Planning (2017 - 2021)

2. Expected HQP training:

The IceCube program has proven very popular with students and has attracted scholarship students and a number of students from high-ranking international programs

With an increase in total FTE researchers (currently forecast and anticipated) we expect student (PDF) numbers to increase by 75% (200%) in 2018 and again by 65% (33%) in 2021.



aggressive ramp-up post-2017 assumes successful international Gen2 project funding starting in 2018

IceCube-Canada Long Range Planning (2017 - 2021)

3. Equipment needs:

- Anticipate the need for a large-scale cold test facility for next generation optical modules (and potential water test facility at SNOLAB) (CFI; ~$1.5M, 2017/18)

- Electronics shop time (TRIUMF and UofA) for next generation module design and testing of main boards, calibration systems, front-end DAQ (CFI; ~$3.5M; 2017/19)

- Potential optical module fabrication facility (CFI; ~$1.5M; 2018)

- Photosensor development facility (jointly with TRIUMF) (NSERC/CFI; see Fabrice's talk)

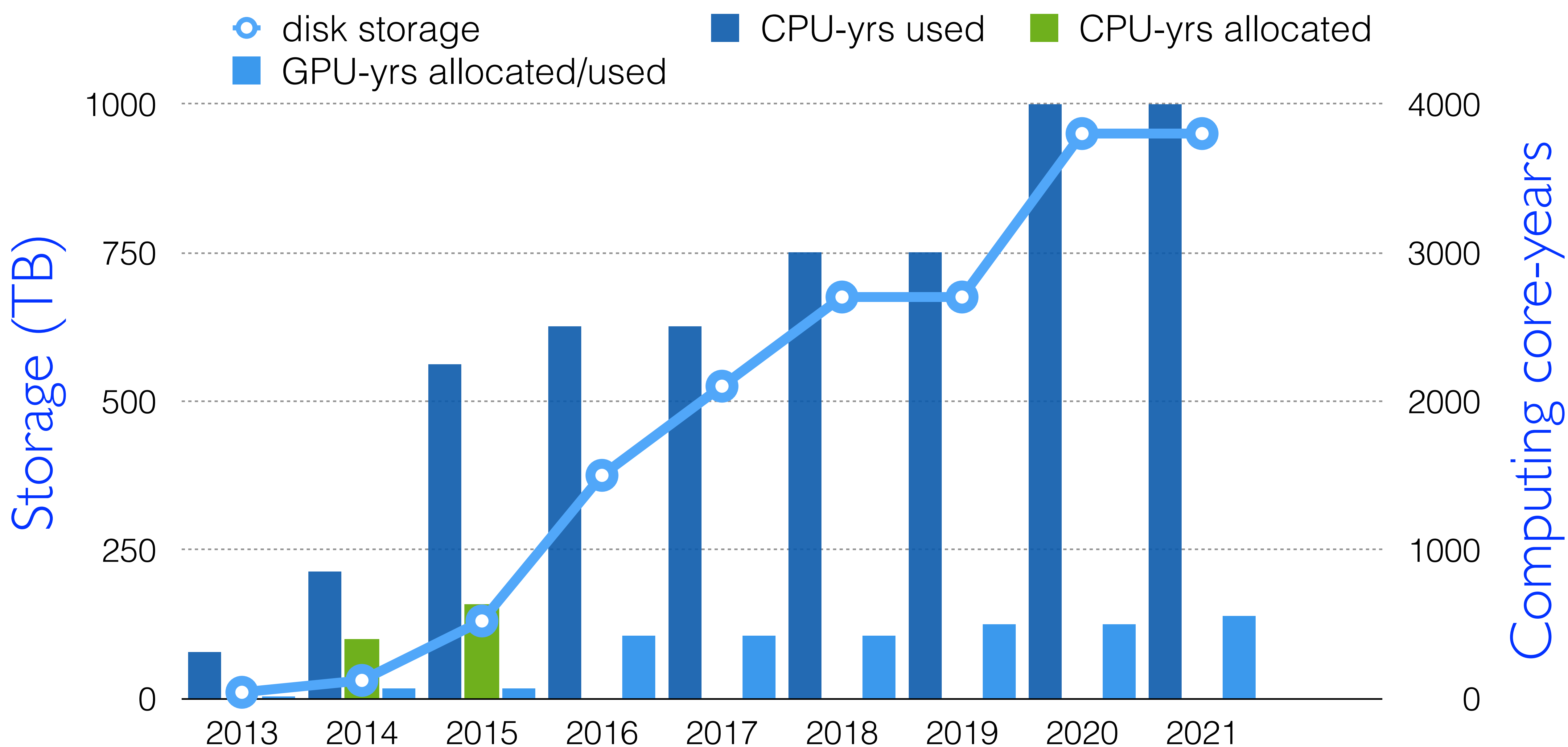
- (plans for request ~30% Gen2 DOMs from CFI)

- total CFI requests planned ~$12M-15M

IceCube-Canada Long Range Planning (2017 - 2021)

4. Computing needs anticipated:

- ~25 TB per user for storage (based on average IceCube analysis sets)
- approximately steady increases in CPU with increase in group size
- large increase of GPU-years (~100x CPU) in 2016 (proposed *illume* cluster - Kopper CFI JELF)



IceCube-Canada Long Range Planning (2017 - 2021)

5. Technical support requirements:

- CPP+ (MRS - Alberta/Toronto) is absolutely vital for the long-term Gen2 plans

- TRIUMF electronics and detector shops are essential to the proposed detector developments during this period

- SNOLAB facilities (space and expertise in low-background counting) are planned for use (calibrations, detector operation/verification, R&D)

IceCube-Canada Long Range Planning (2017 - 2021)

6. Relationships with other projects:

- common elements are being explored with HyperK-Canada. In particular potential design and development of a multi-PMT optical module, simulations, PMT characterization

- planned photosensor development activities have potential overlap with long term SNOLAB program (nEXO, DEAP-50T, SNO++); synergies with Queen's-led CFREF under review

IceCube-Canada Long Range Planning (2017 - 2021)

7. Relationships with international partners (primarily via the IceCube collaboration):

- USA (WIPAC leadership of the IceCube operations including the data/computing facility; new US collaborators joining for Gen2 including Columbia, MIT, Notre Dame)

- Europe (Belgium, Germany - particular overlap with Erlangen and DESY for module development, Sweden;significant increased activity in UK and Denmark for Gen2)

- Japan and S. Korea (Chiba, University of Tokyo, SKKU; collaborating on activities for module development)

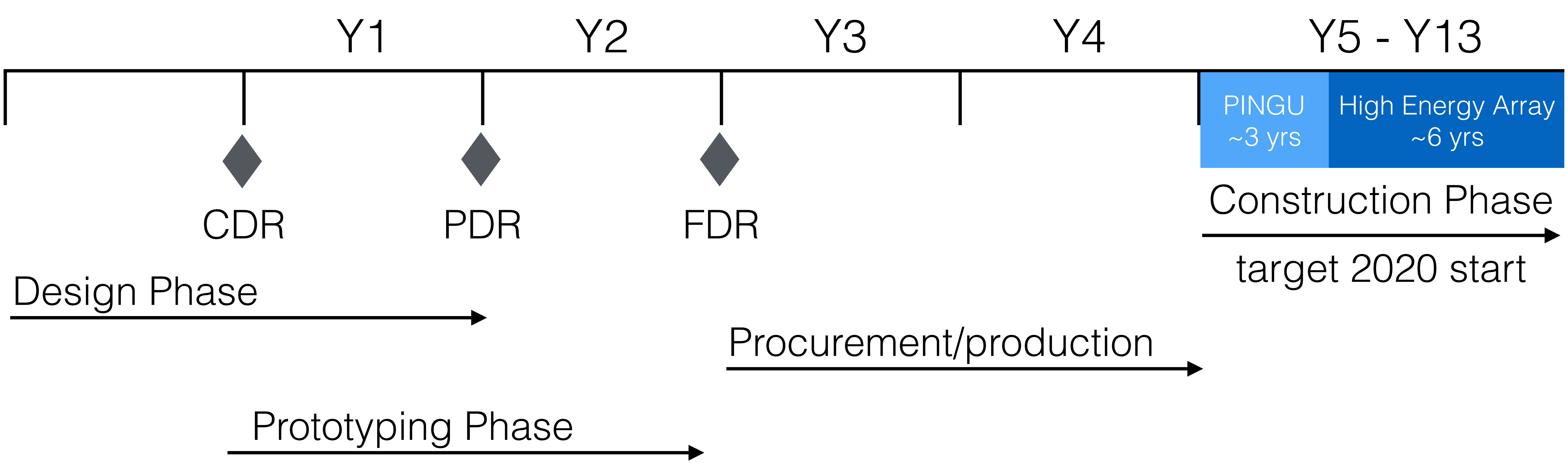
Summary and Outlook

IceCube-Canada has matured into a vibrant program in the past 5 years with established leadership in the core analyses of the project (neutrino oscillations, high energy neutrinos, dark matter)

Canadian researchers currently hold guiding roles in the collaboration, including chair publications committee, co-conveners of the diffuse, the oscillations and PINGU-analysis working groups, co-lead scientist for future upgrades

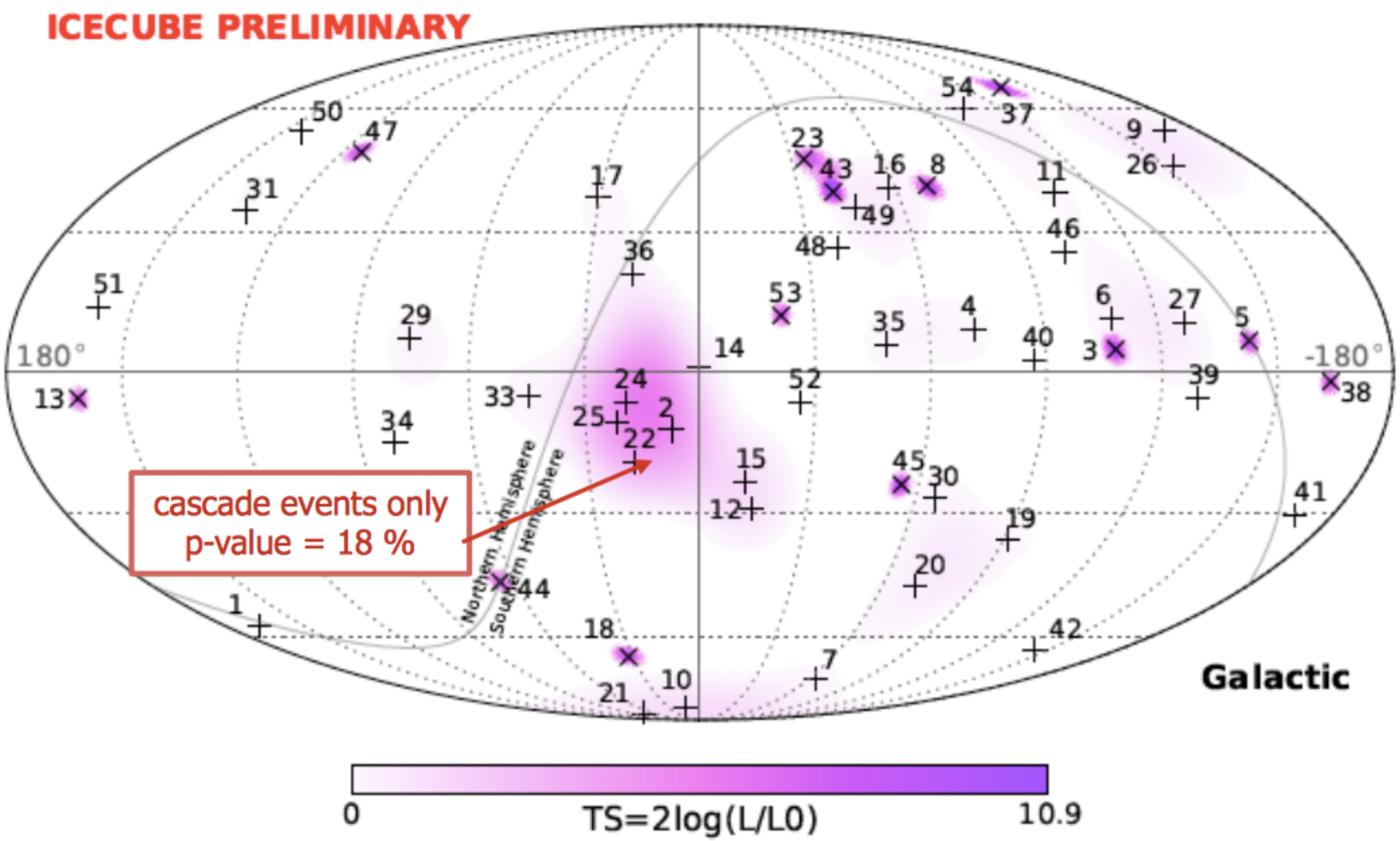
Current projection is the Canadian group will have tripled in size in 2016 (since 2011) with estimates that could see this double again by 2021

Future planning for Gen2 (lead by Canadian researchers) is developing rapidly; current timeline is limited by funding planning.



Backup slides

IceCube



ICECUBE PRELIMINARY
180°
-180°
Northern Hemisphere
Southern Hemisphere
cascade events only
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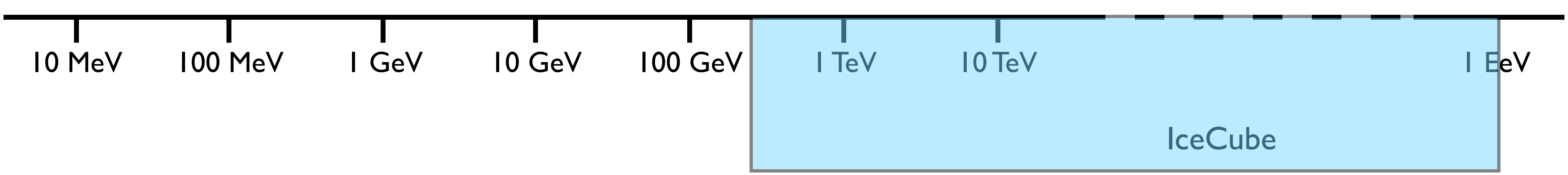
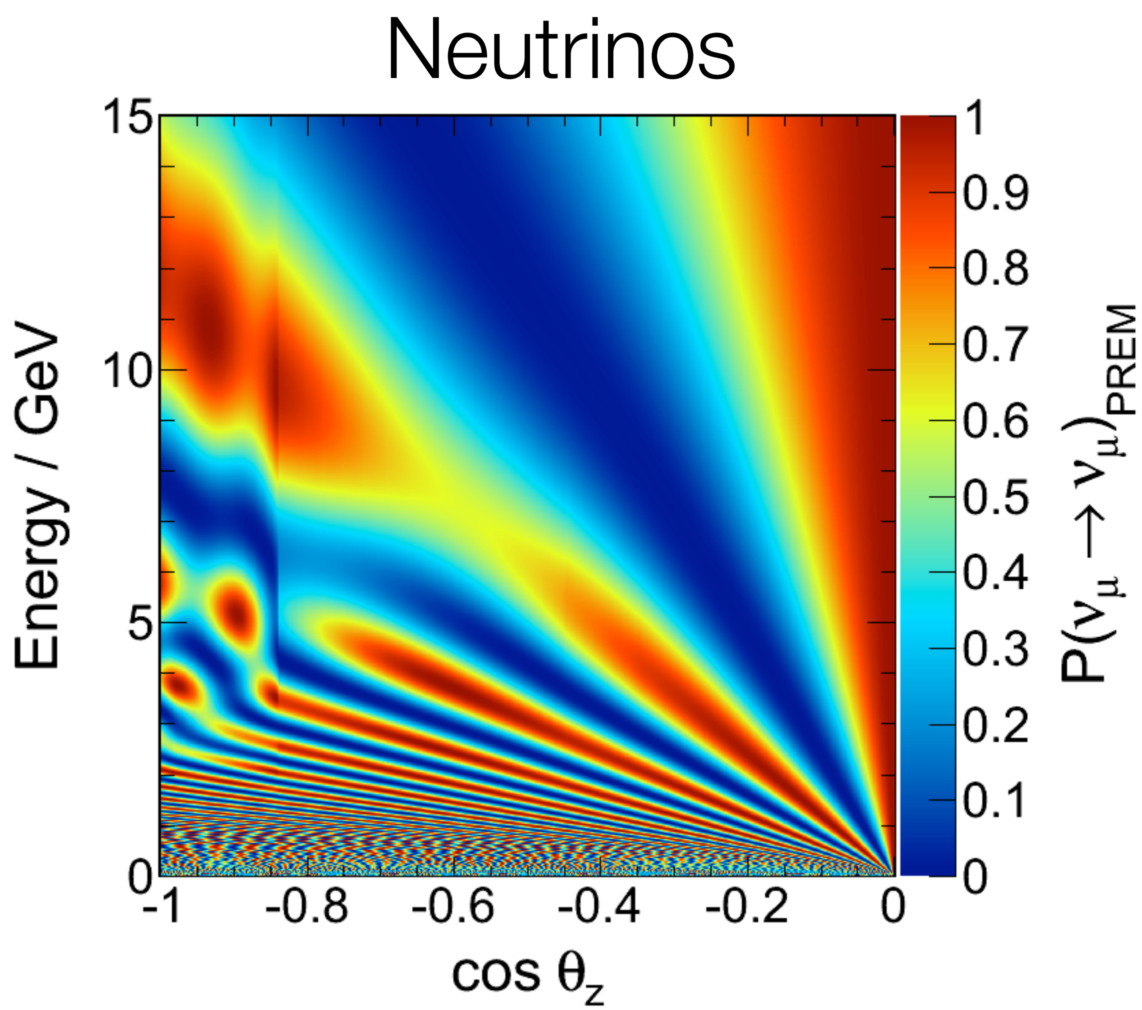
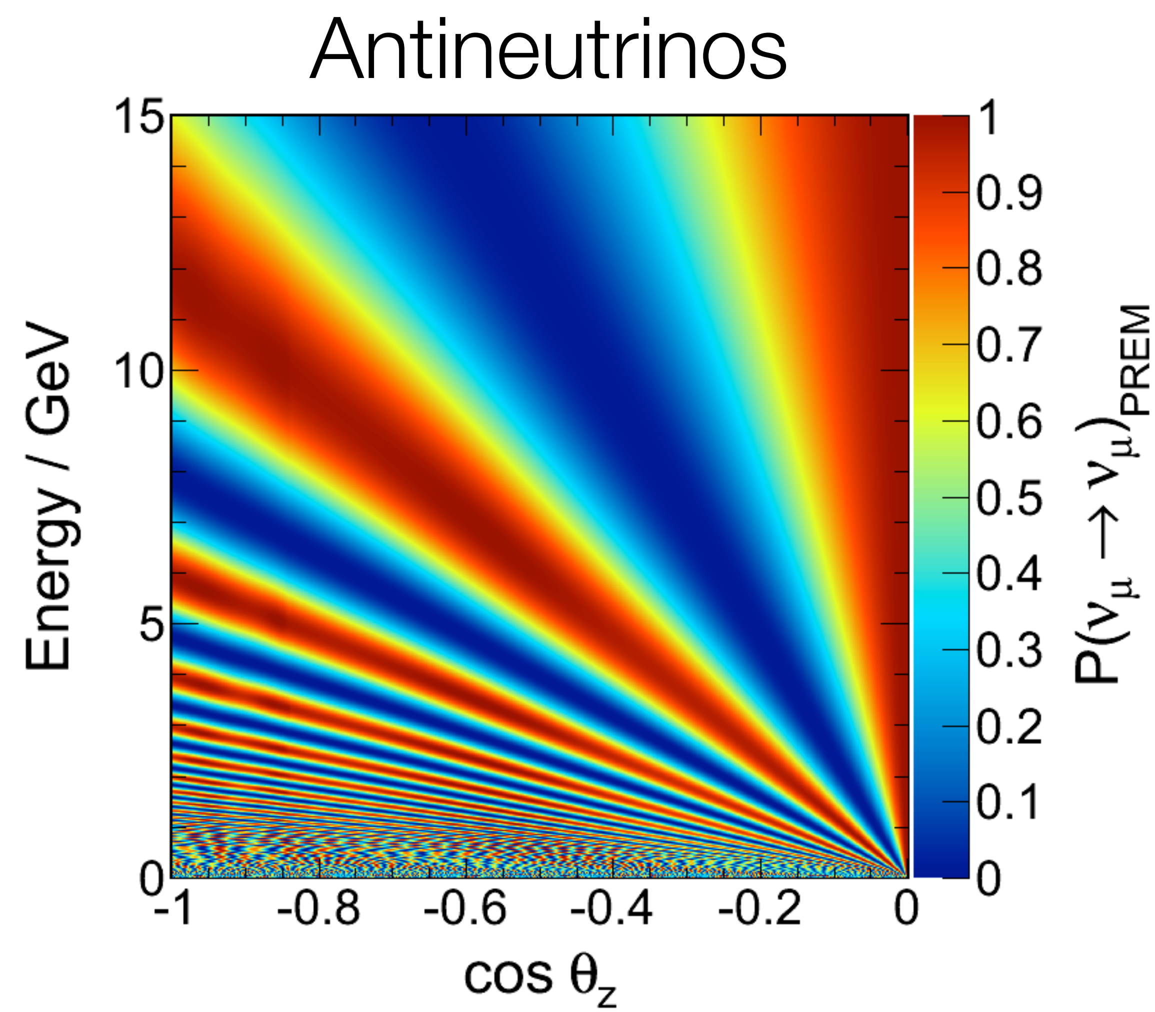


10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
1 EeV
IceCube

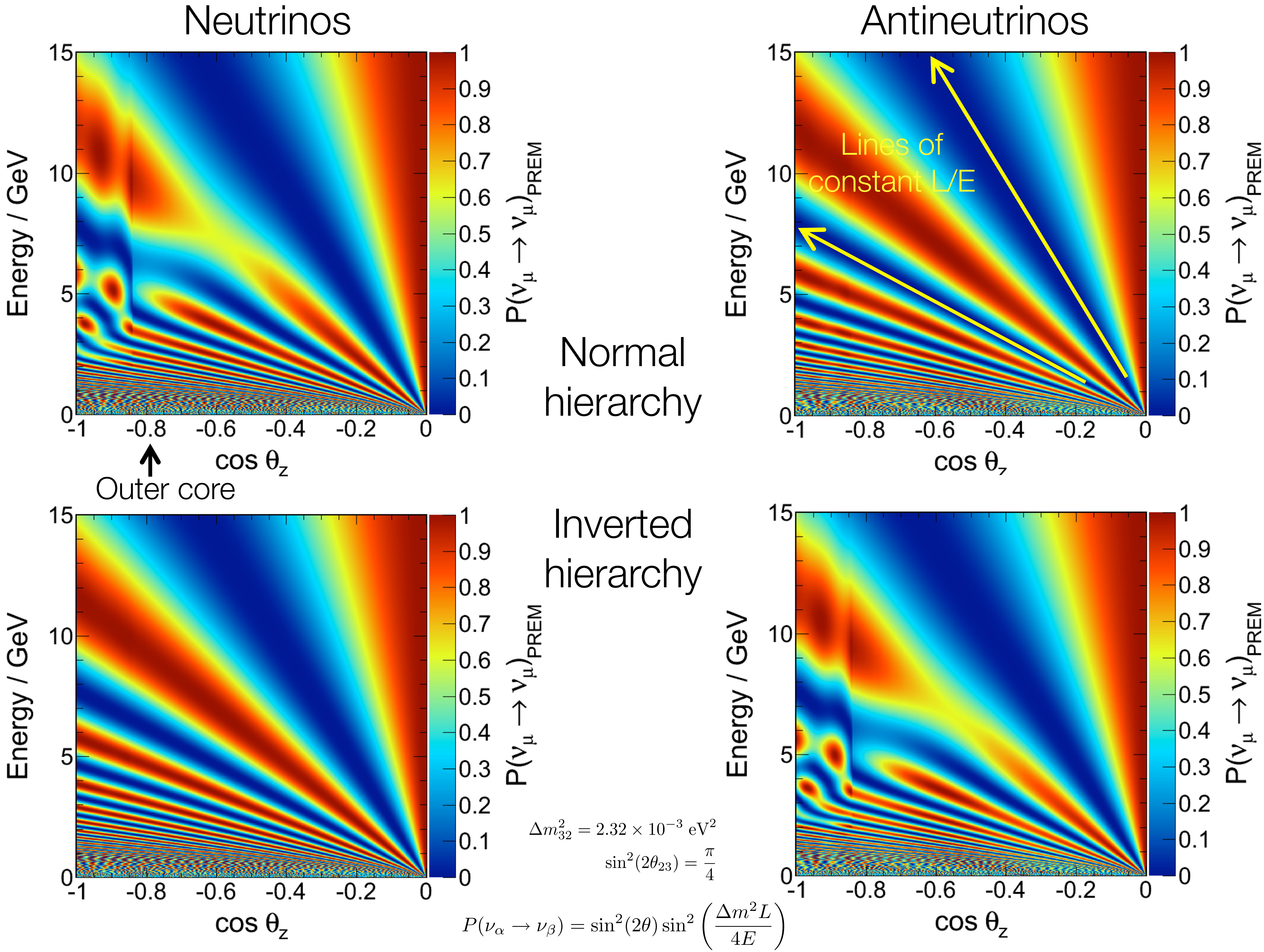


Normal hierarchy



$$\Delta m^2_{32} = 2.32 \times 10^{-3}\ \mathrm{eV}^2$$
$$\sin^2(2\theta_{23}) = \frac{\pi}{4}$$

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$



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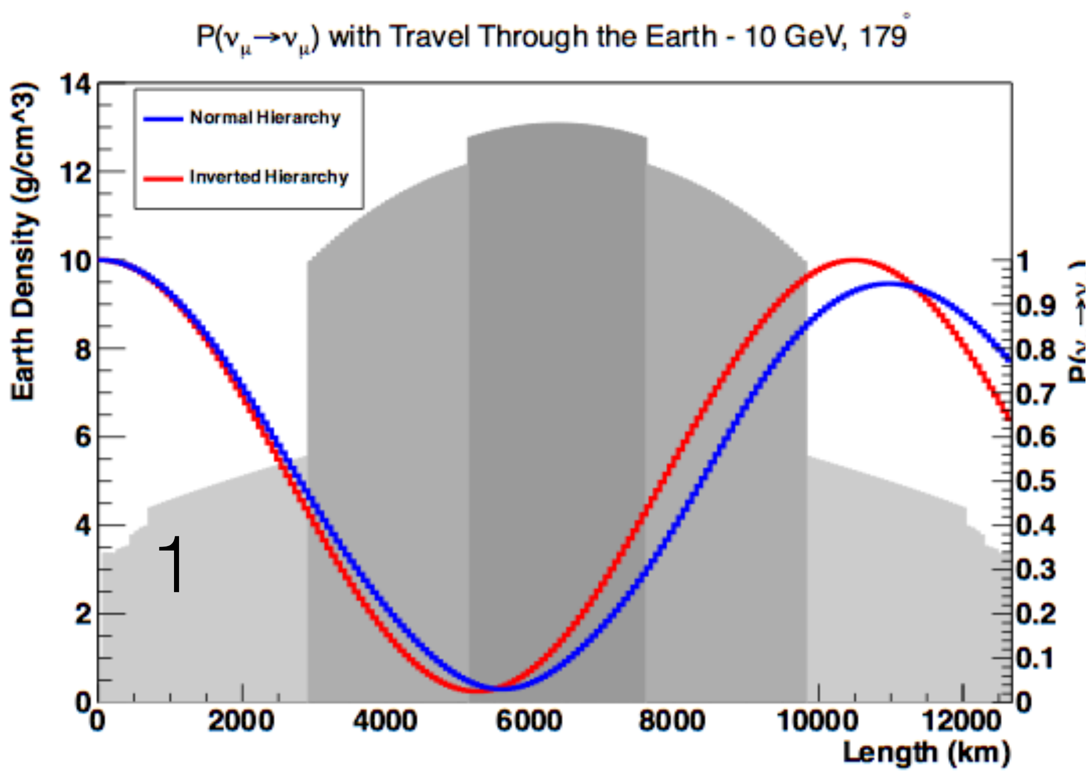
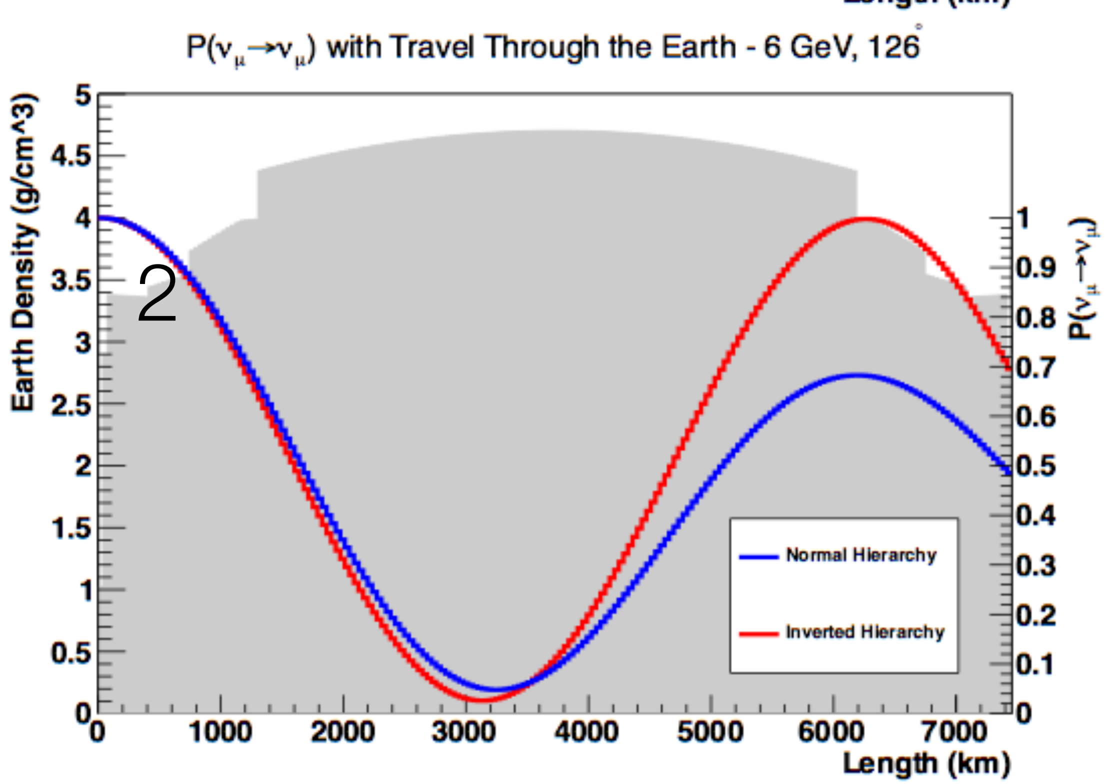
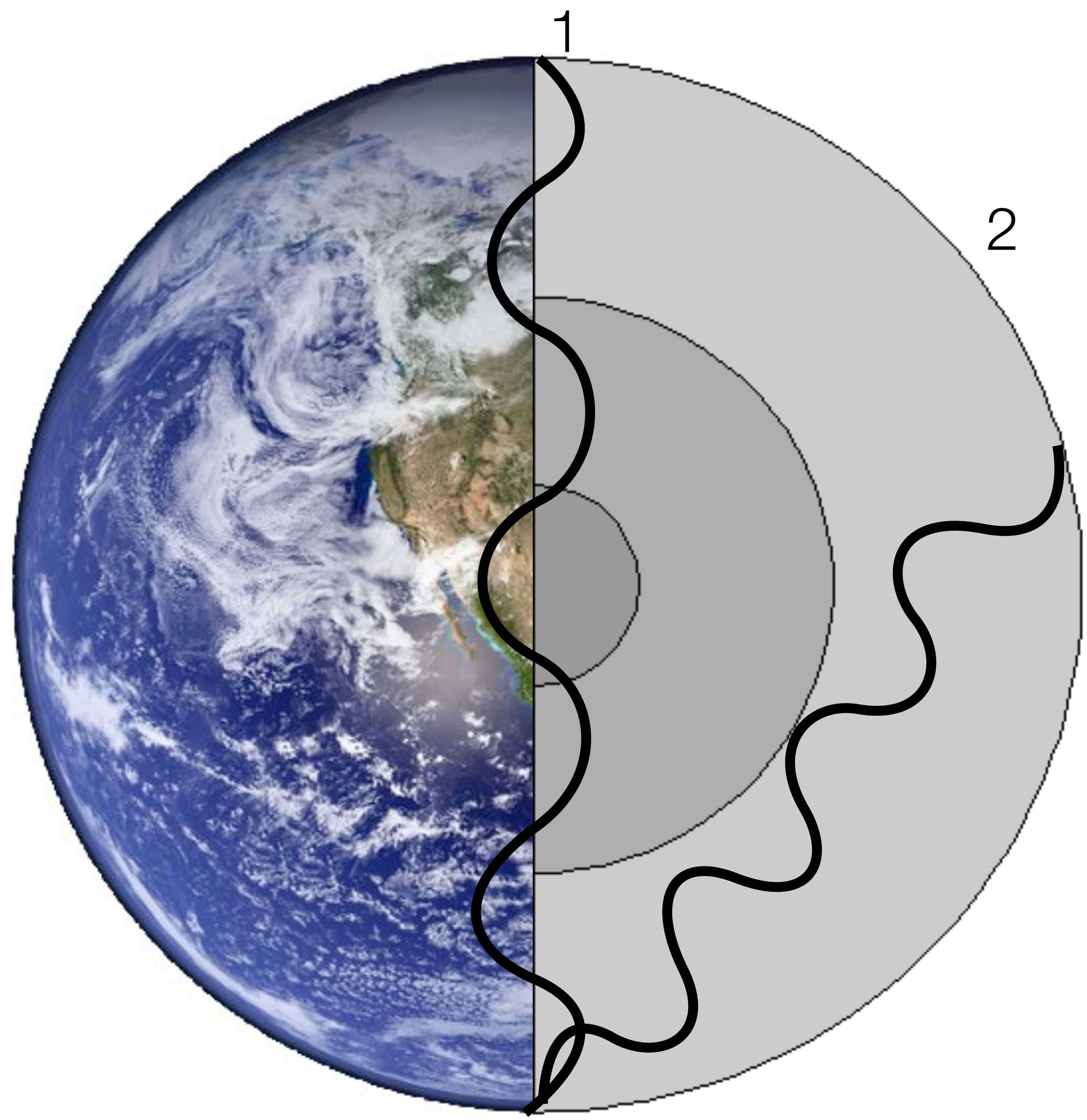
Using atmospheric neutrinos to measure the NMO

Up to 20% differences in ν_μ survival probabilities for various energies and baselines, depending on the neutrino mass hierarchy







Darren R. Grant - University of Alberta

PINGU and the NMO

- Cannot distinguish ν from $\overline{\nu}$ directly – rely instead on differences in fluxes, cross sections (and kinematics)
- Differences clearly visible in expected atm. muon (ν + $\overline{\nu}$) rate even with 1 year's data
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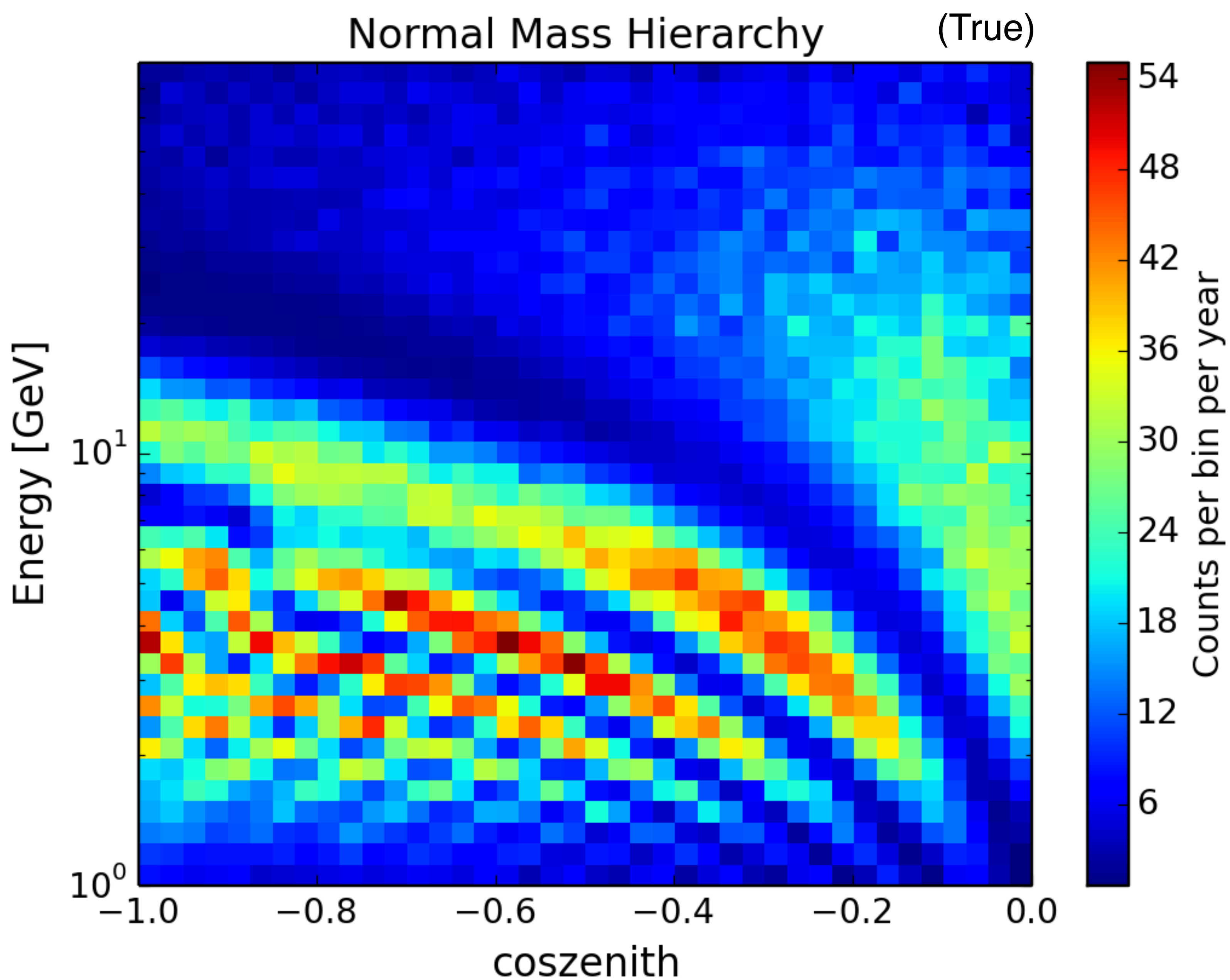

PINGU and the NMO

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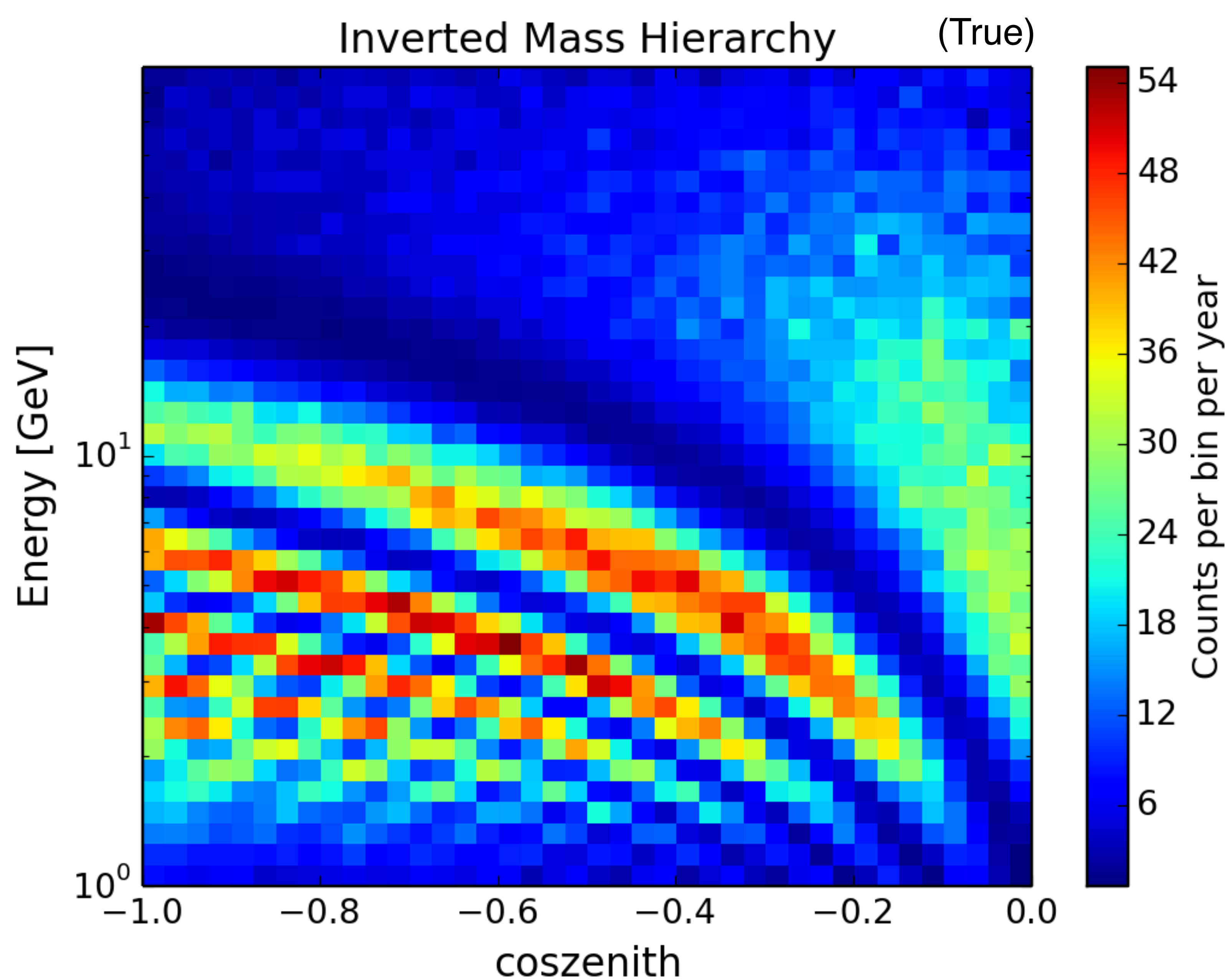
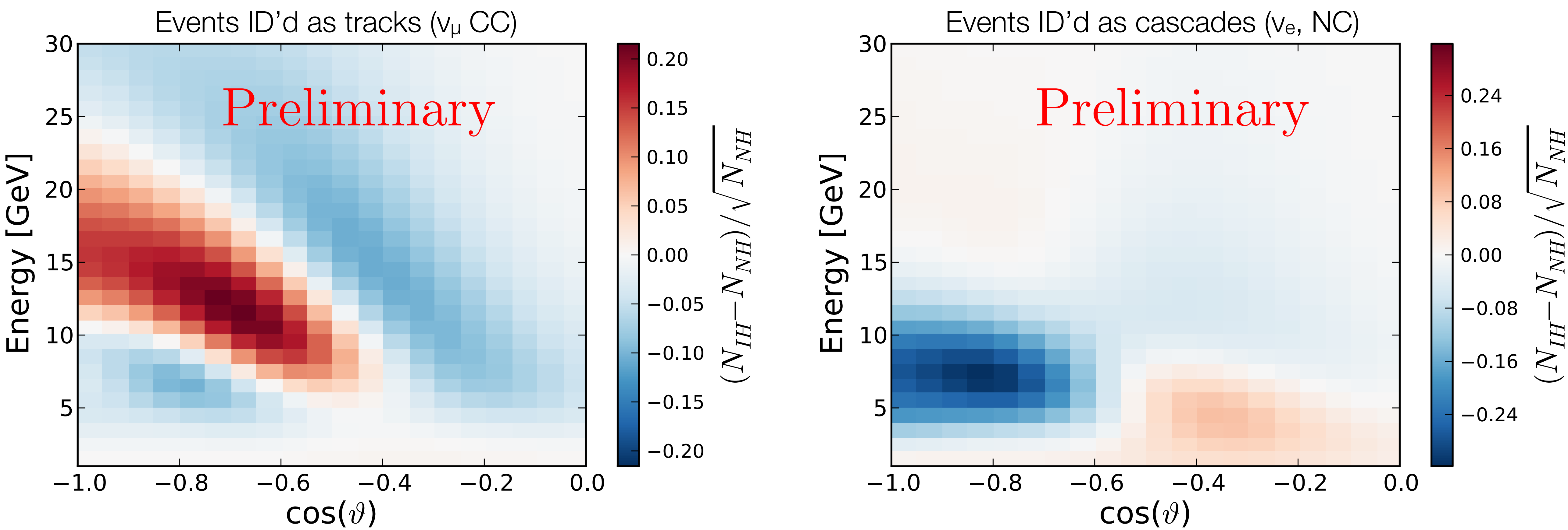


PINGU and the NMO

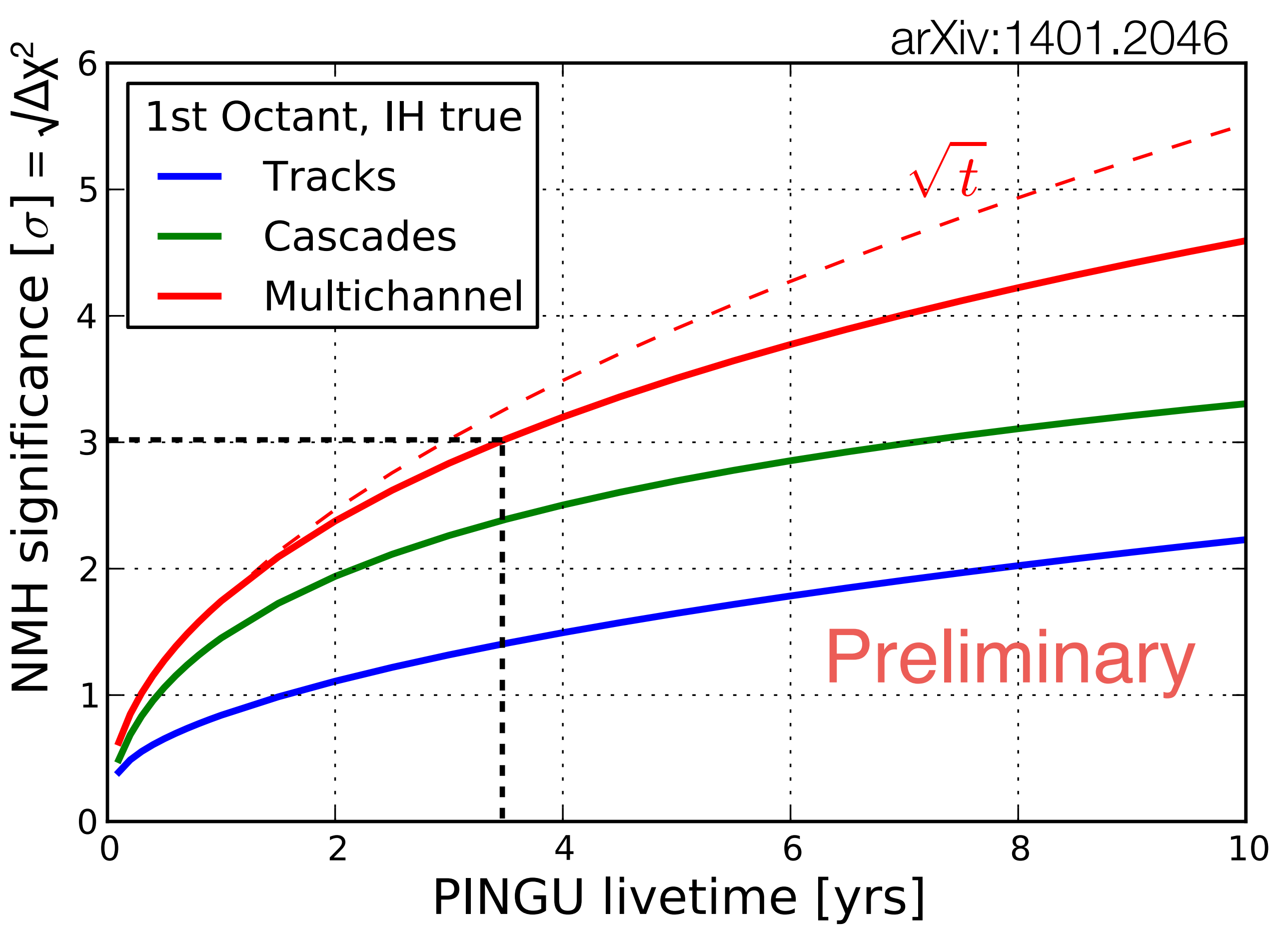
arXiv:1401.2046



- Distinctive (and quite different) hierarchy-dependent signatures are visible in both the track and cascade channels
  - Quantity shown is an illustration of statistical significance per bin (as per Akhmedov et al. arXiv:1205.7071)
  - Full MC for detector efficiency, reconstruction, and particle ID included

PINGU and the NMO - predicted sensitivity

- With baseline geometry, a determination of the mass hierarchy with 3σ significance appears possible with ~3.5 years of data
  - Primary estimate uses parametric detector response model based on simulations
  - Vetted against full Monte Carlo studies with more limited statistics and range of systematics
- Optimization of detector geometry & analysis techniques and more detailed treatment of systematics nearing completion



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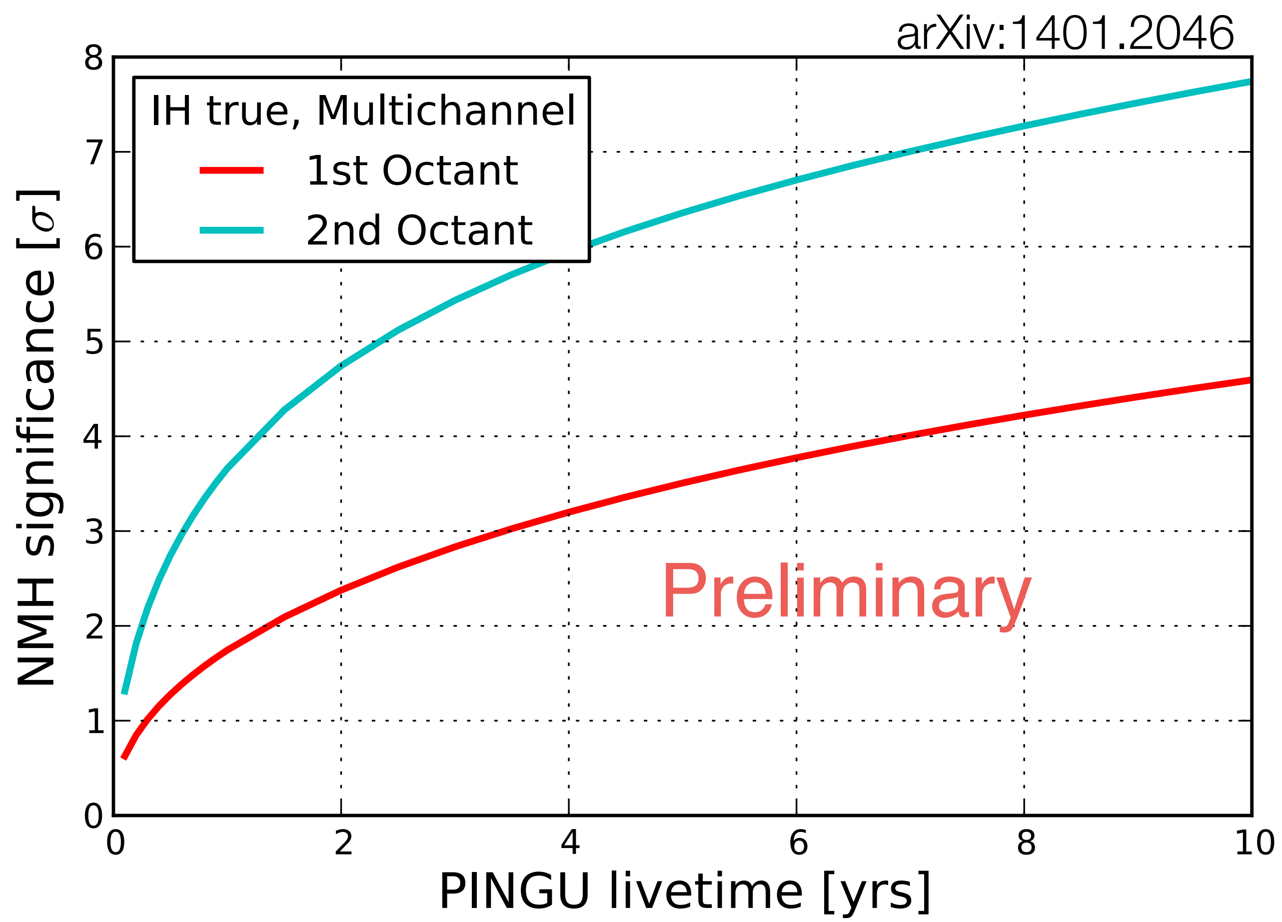

Optimized PINGU and the NMO - predicted sensitivity

- Studies of the PINGU geometries reviewed a very broad maximum for optimizing the signal to the mass hierarchy
- Selected geometry (40 strings, 96 modules per string) optimizes performance as a function of overall estimated cost
- The optimized geometry is remarkably robust to the remaining systematics under study

after Blennow et al., arXiv:1311.1822