A Surface Array to Study Astrophysical Neutrinos with IceCube-Gen2

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for the IceCube-Gen2 Collaboration

IceCube

Take Home Message

- A surface array on top of an Antarctic neutrino detector can be used to identify neutrinos of astrophysical origin.
- Such an array could double the number of “track” events.
- Plans for a next generation detector, IceCube-Gen2, include a surface array.
- We are working on determining the optimum characteristics for the array.

The IceCube Collaboration

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Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines & Technology
Southern University and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
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University of Delaware
University of Kansas
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Yale University

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Technische Universität München
Technische Universität Dortmund
Universität Mainz
Universität Wuppertal

Université de Genève, Switzerland

University of Adelaide, Australia

University of Canterbury, New Zealand

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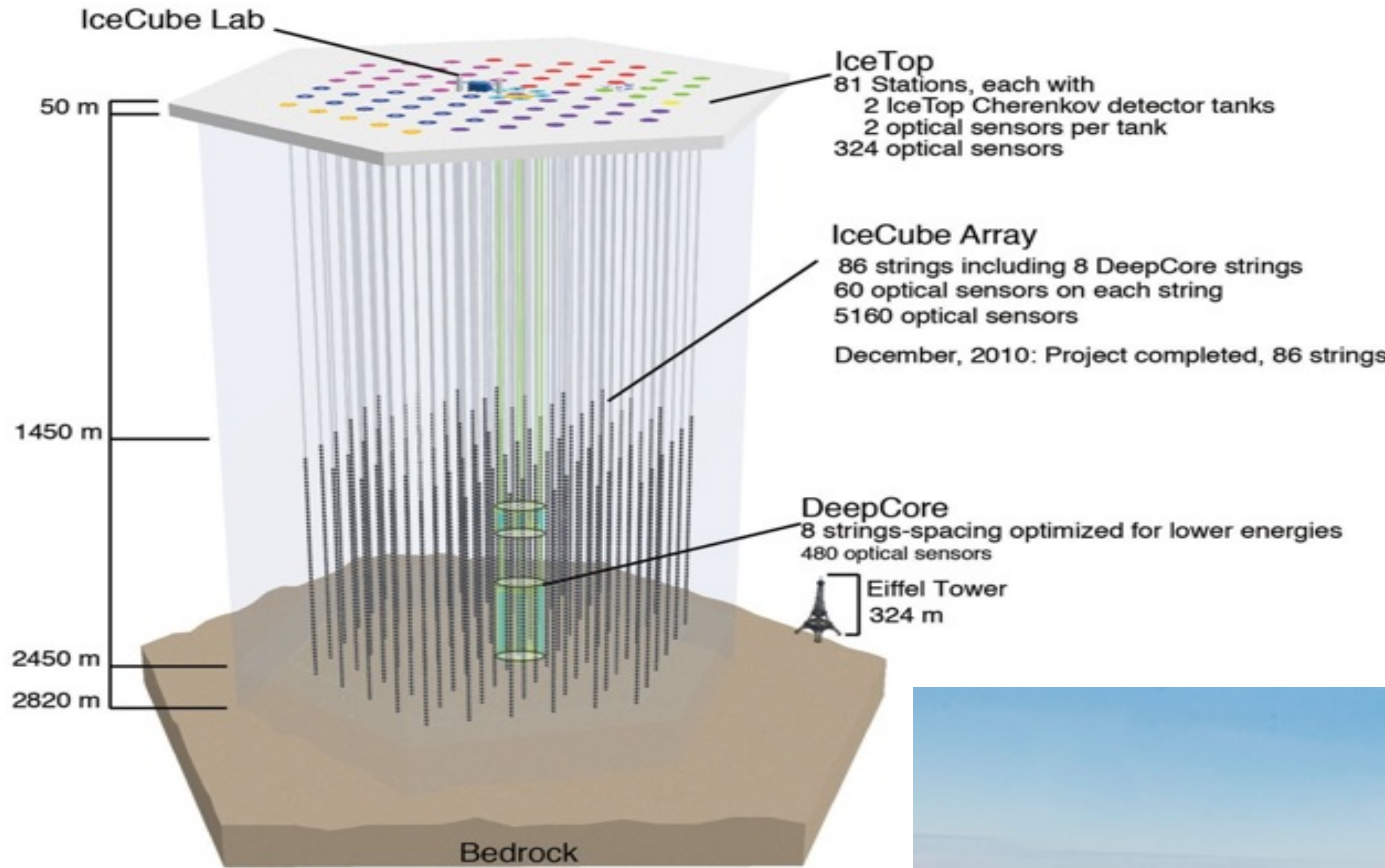
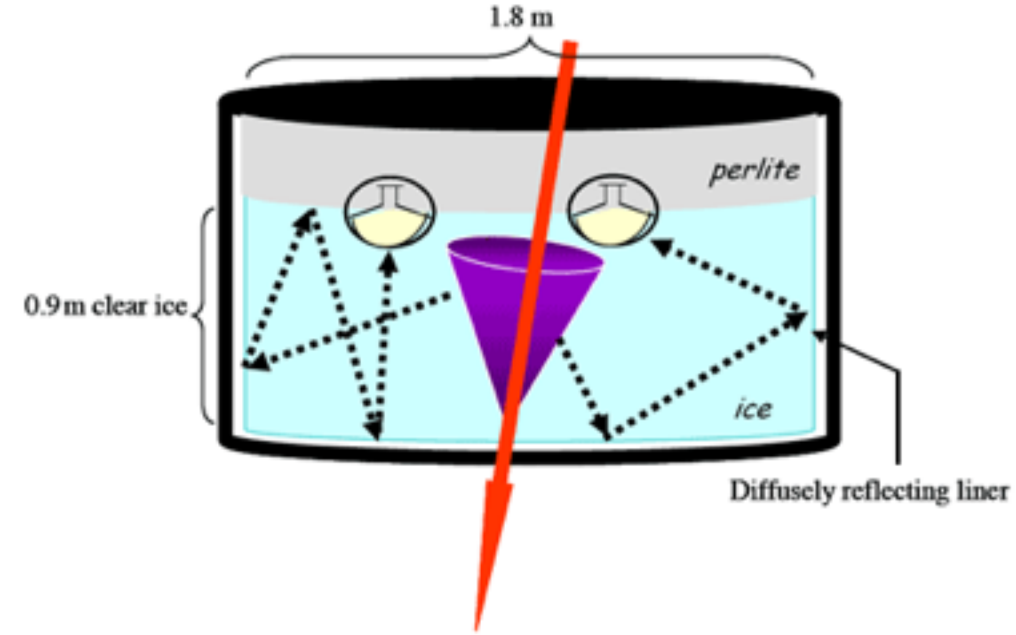
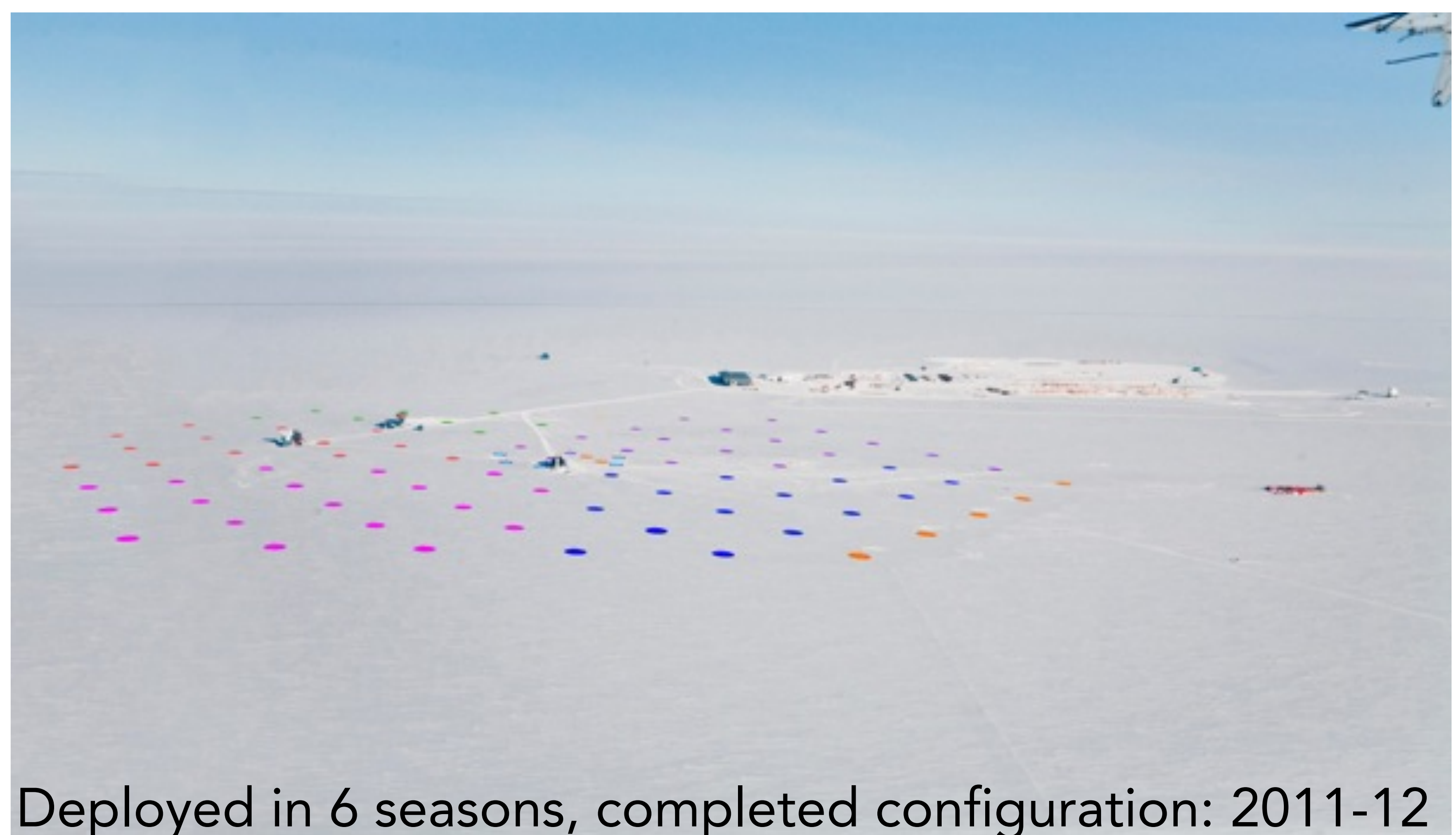
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

Approximately 300 physicists from 45 institutions in 12 countries

The IceCube Detector





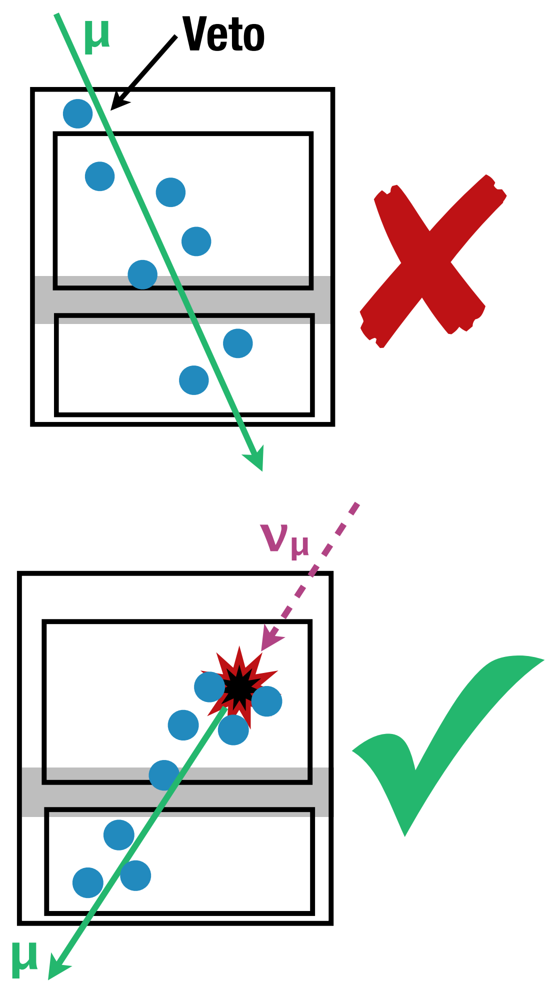


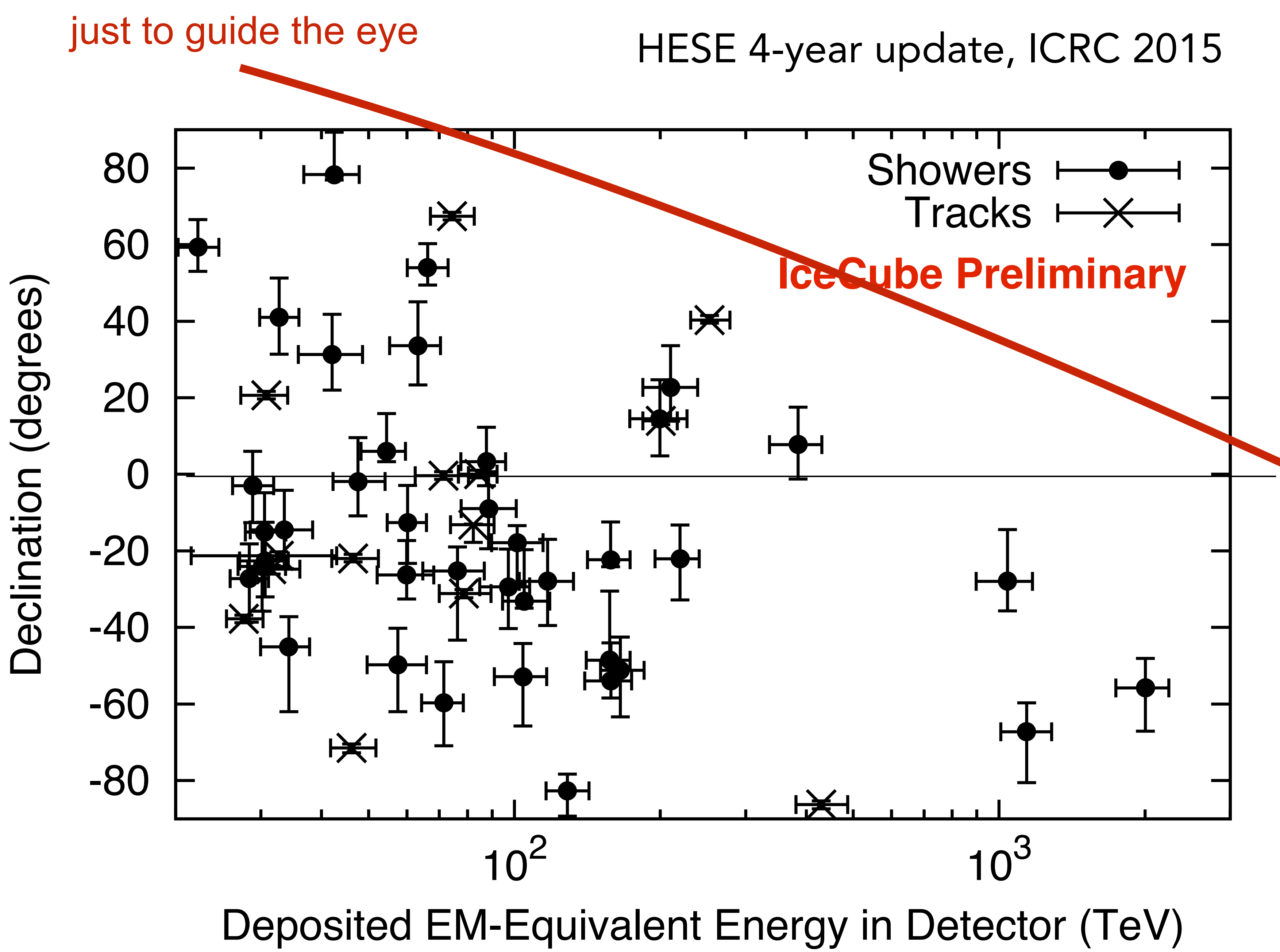
High-Energy Starting Events

Science 342 (2013) 1242856

PRL 113.101101 (2014)

HESE 4-year update, ICRC 2015

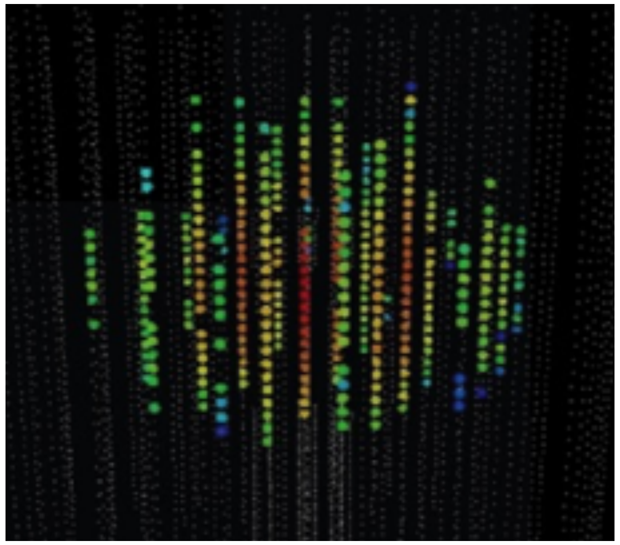




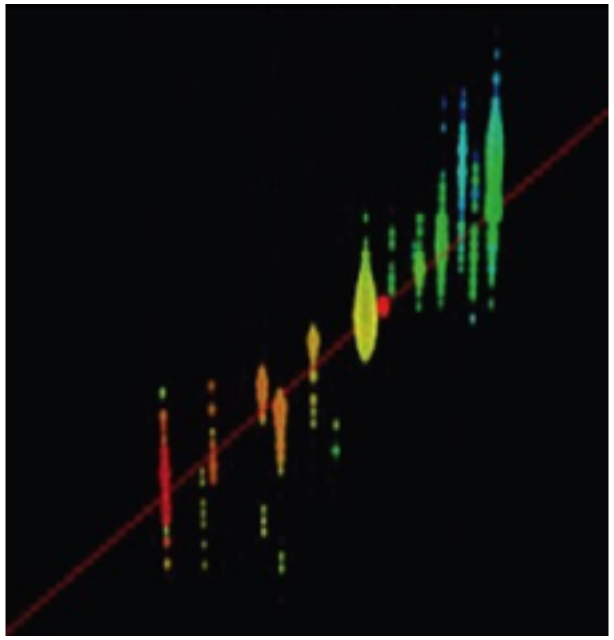
High-energy events are absorbed in the earth.

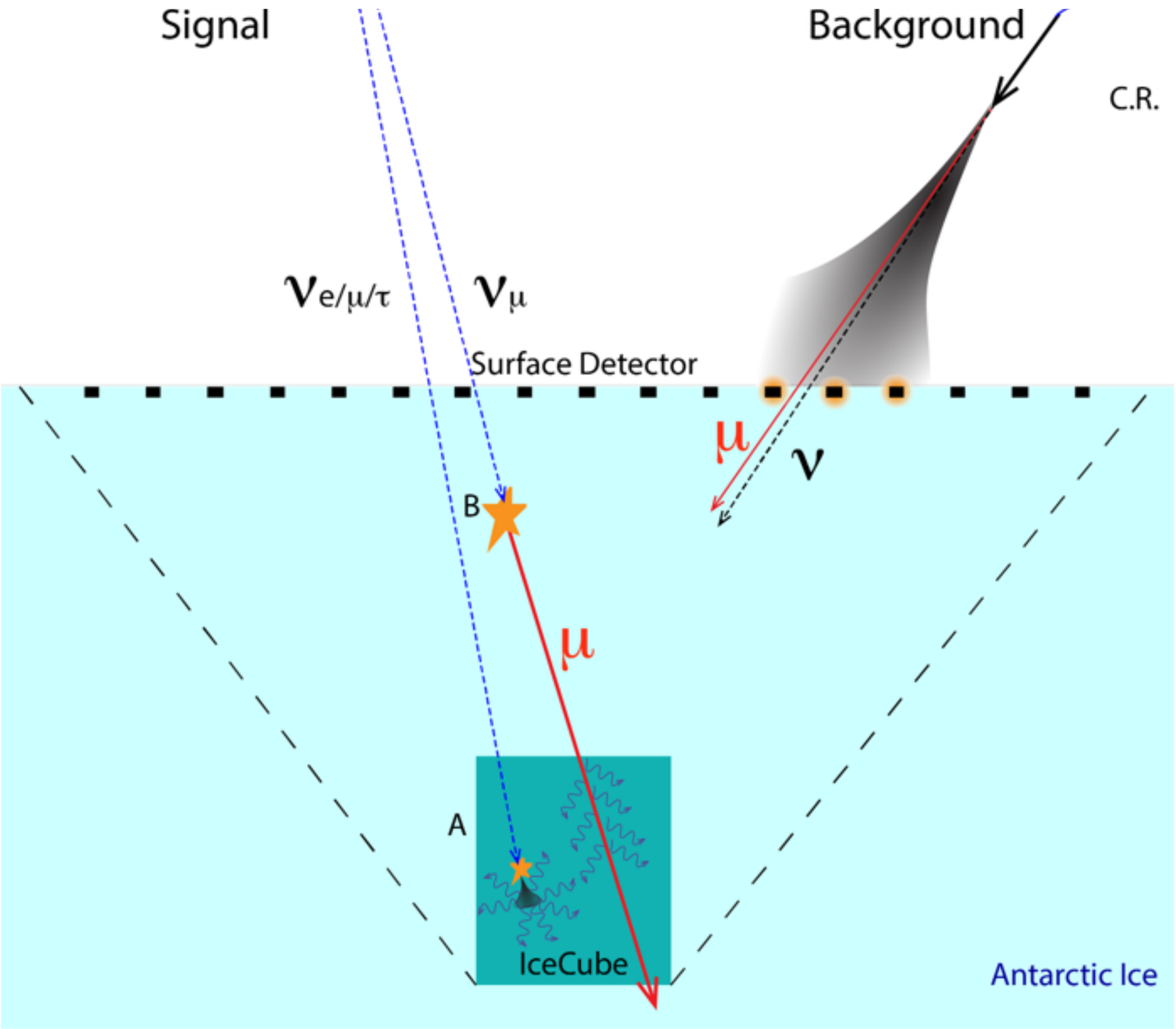
Surface Veto Concept

A. Cascades
~ 15° angular res.

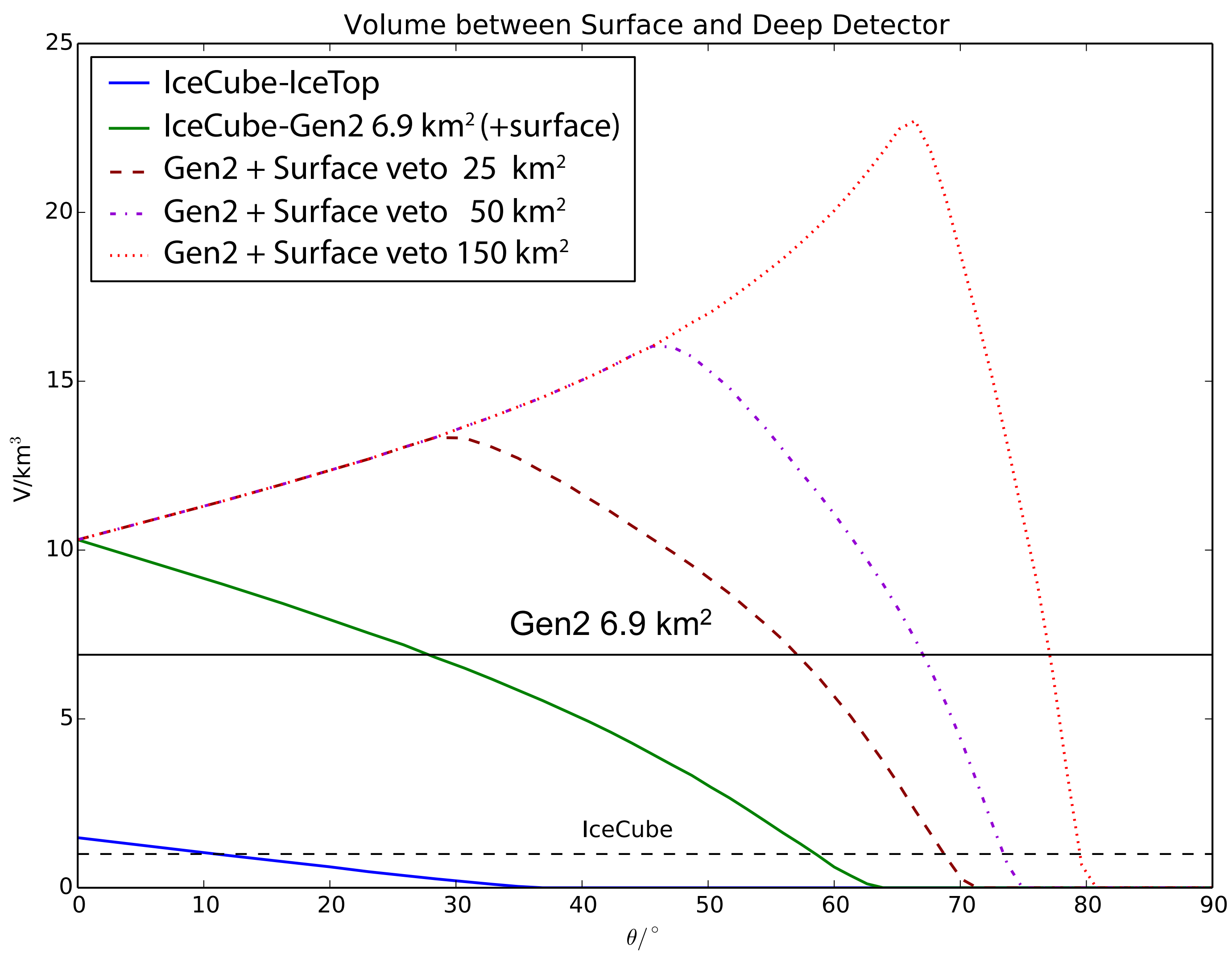


A. Tracks
< 1° angular res.

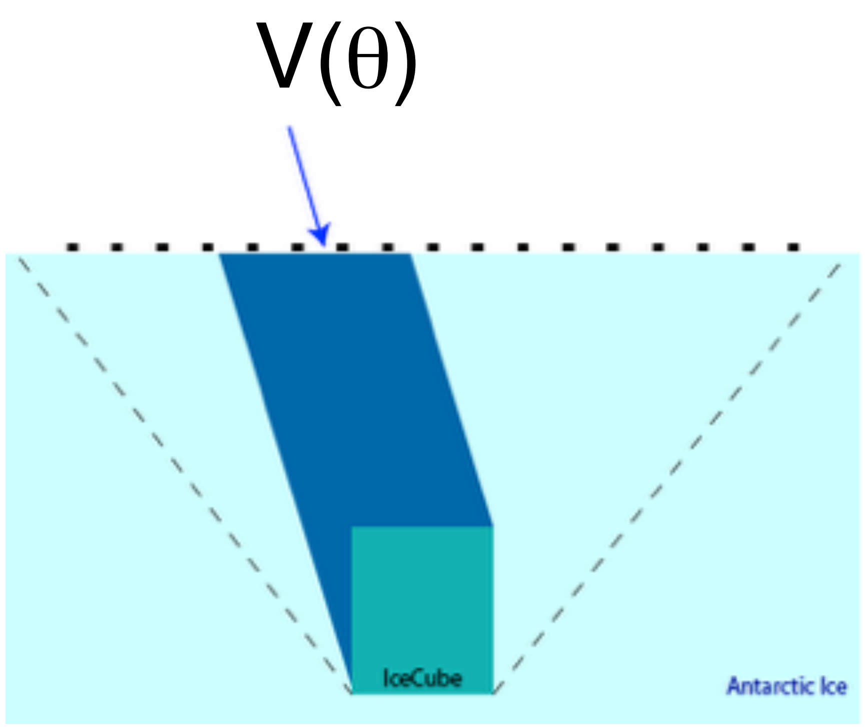




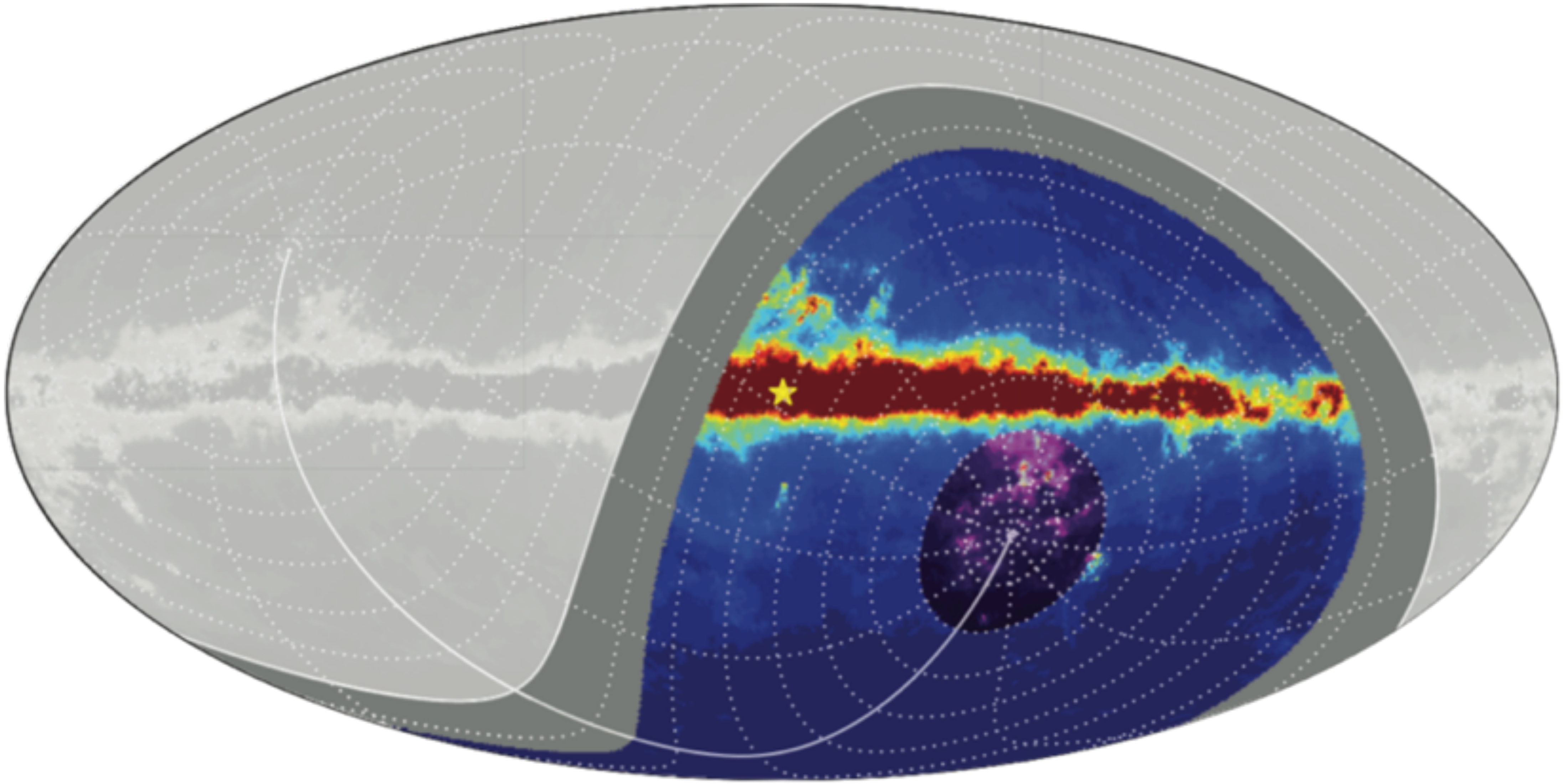
Increasing the Track Rate



The volume determines the rate



- HESE analysis sacrifices a fraction of the volume for veto (~40%).
- Relative to starting events (**naively counting**), the volume for astrophysical $\nu_\mu \longrightarrow$ tracks increases by:
  - ~×2.5 in the vertical direction (> ×3.5 when one includes gain in fiducial volume).
  - ~×4 in the direction of the galactic center at zenith angle 61°(or ~×7).
  - ~×2 integrated over the entire sky.

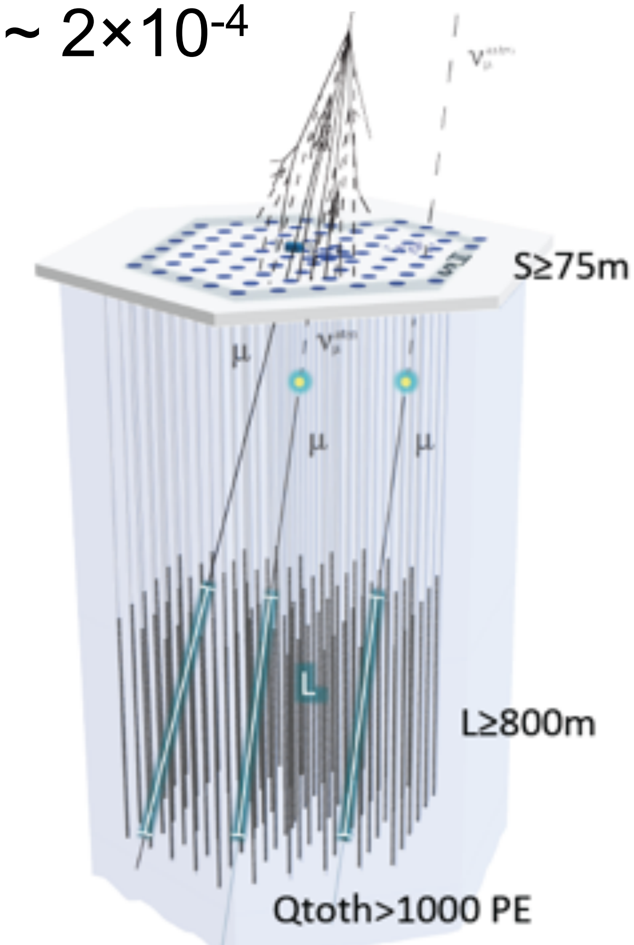


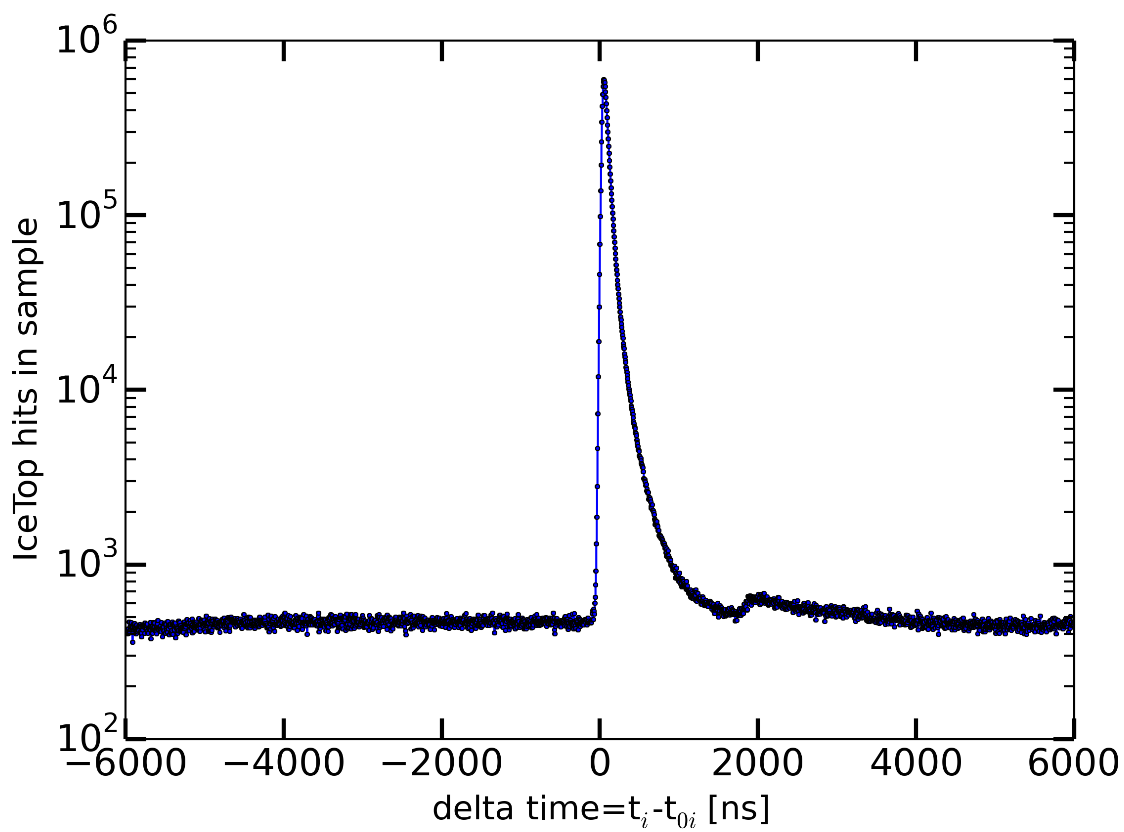
Tracks from astrophysical neutrinos in one year:

	up-going			down-going		
	1 TeV	10 TeV	100 TeV	1 TeV	10 TeV	100 TeV
E^{-2}	110	44	11	80	44	18
$E^{-2.3}$	220	60	9	160	57	13
$E^{-2.7}$	740	110	7	590	100	10
ν_{Atmos}	15000	500	5	10500	350	5

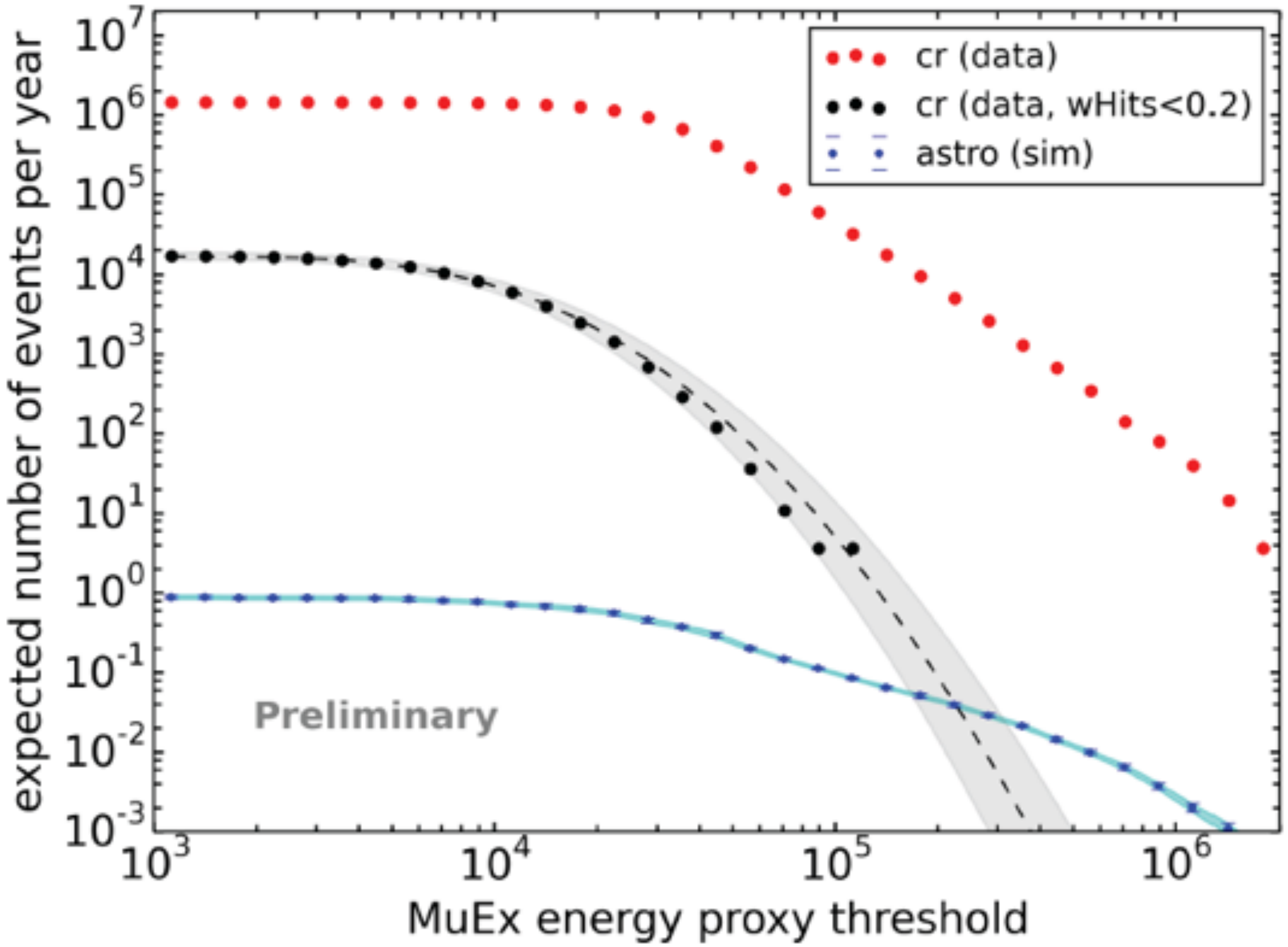
IceTop as Veto

Fill factor ~ 2×10^{-4}



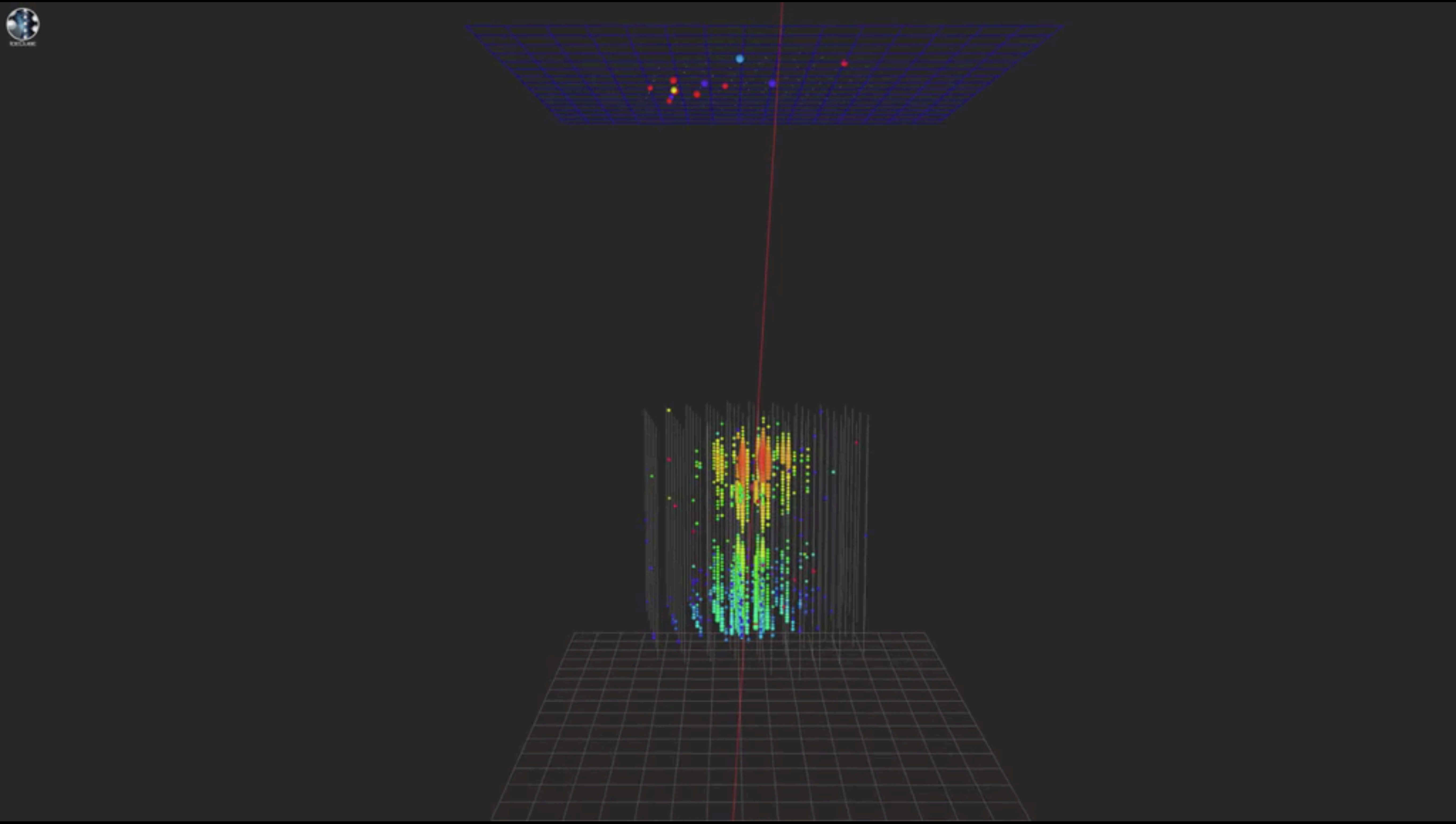


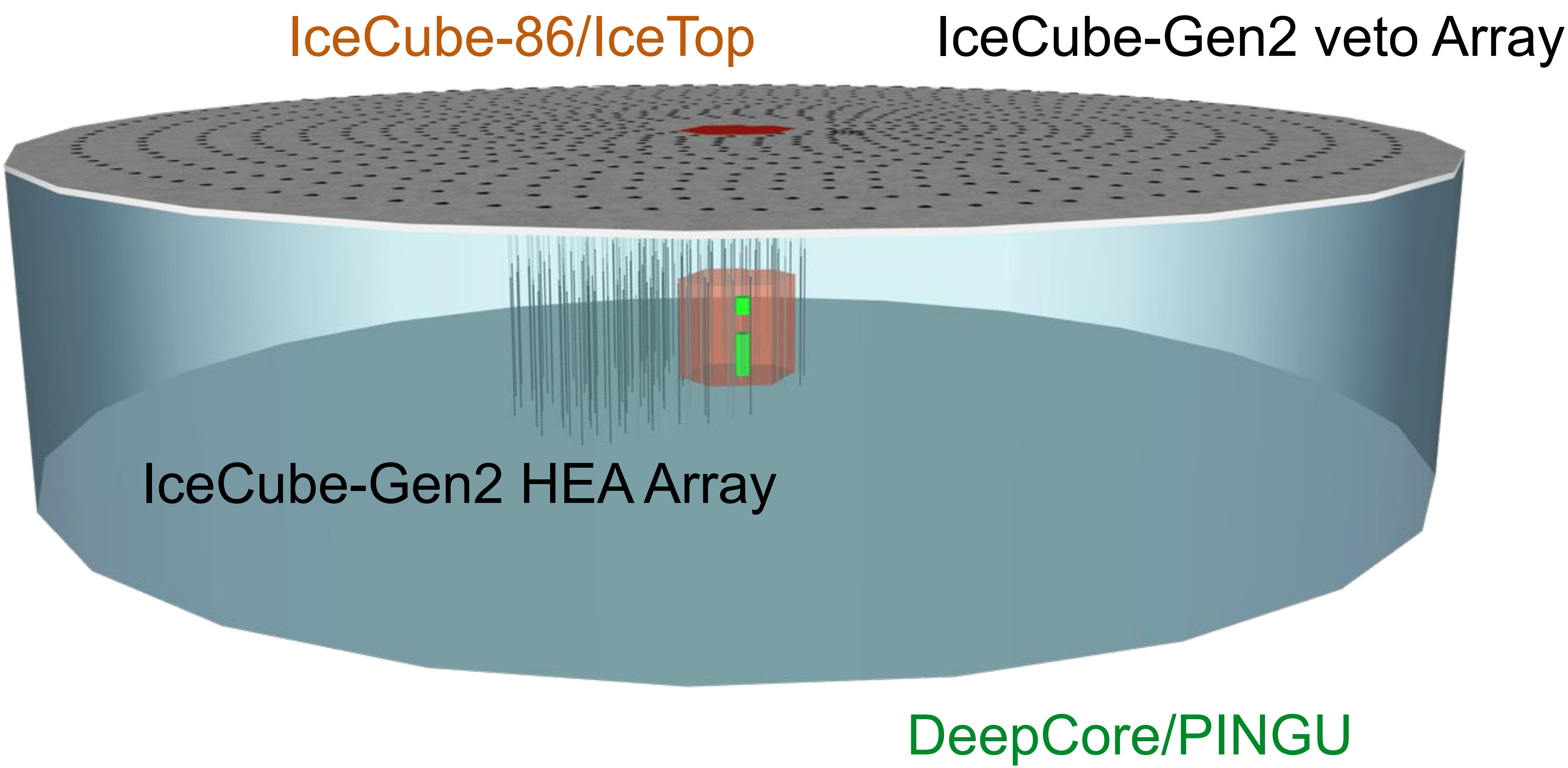
D. Tosi, K. Jero et al. (IceCube coll.) ICRC 2015



- Training sample
  102 days of data between 2012 and 2014
- Q_{toth}>1000 PE, L > 800 m, S > 75 m
- MuEx energy proxy is NOT energy, it is proportional.
- 0.1 event per year expected

Most Probably a Neutrino

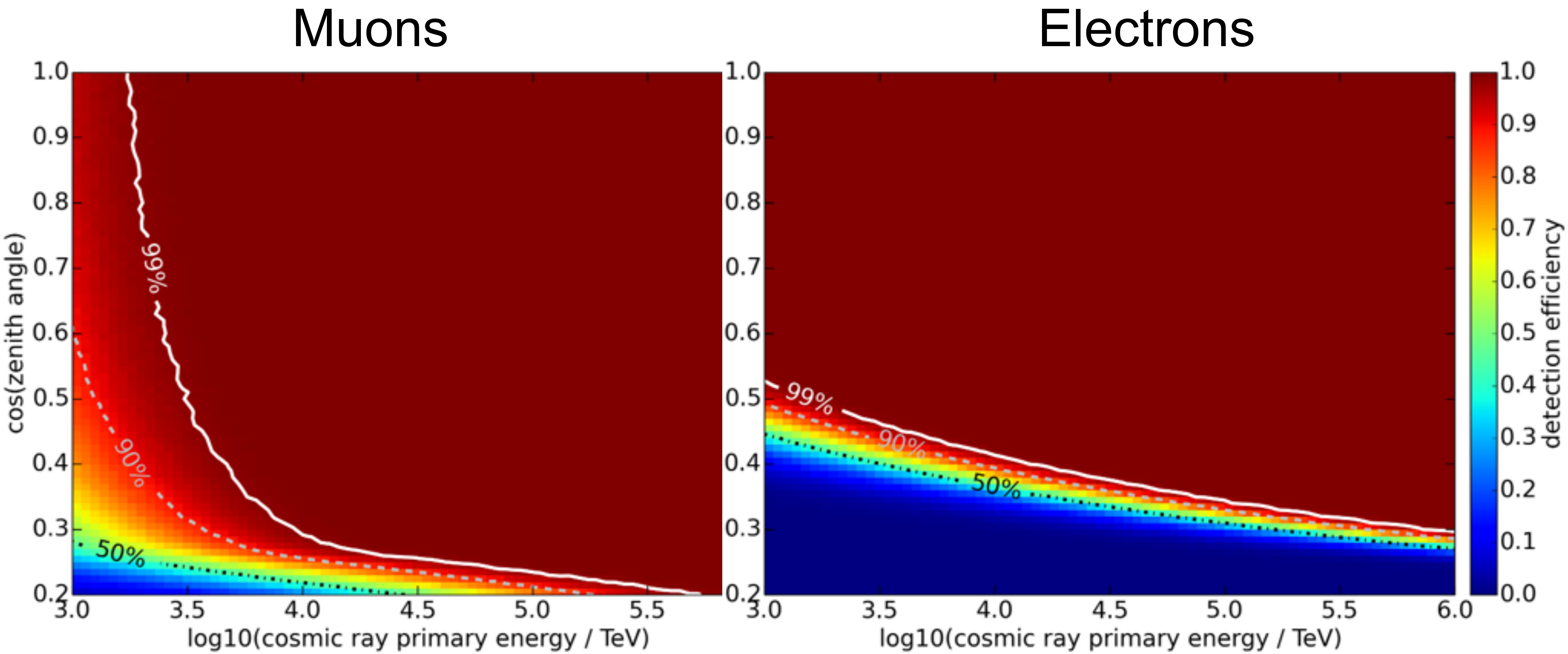




(schematic view)

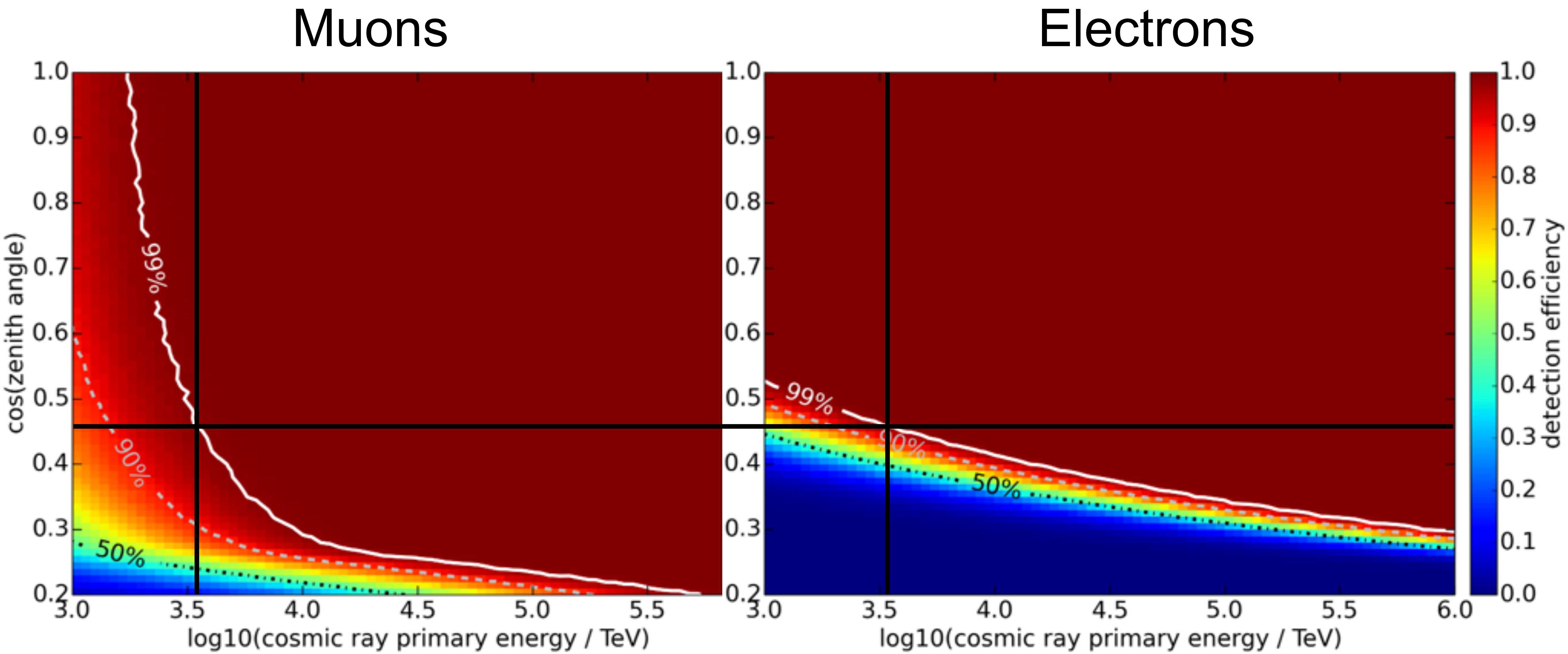
- Technology to use is still not decided. Some being considered.
  - Tanks (a la IceTop)
  - ice bags (ICRC2013 ID 0373)
  - Scintillator slabs
  - Air Cherenkov

EAS Detection Efficiency



- Toy MC using average lateral distributions

EAS Detection Efficiency

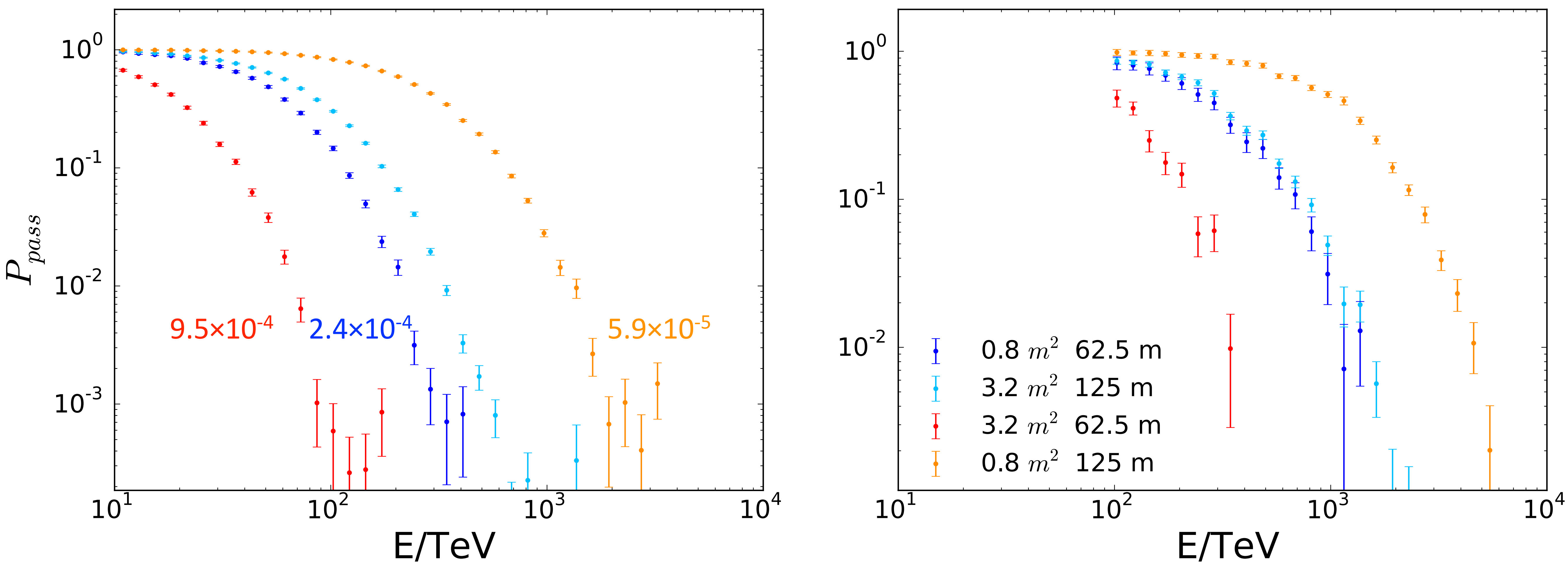


- Toy MC using average lateral distributions
- Two regions:
  - $\theta \lesssim 60°$: EM component dominates.
  - $\theta \gtrsim 60°$: muon component dominates.
- EM partly absorbed in snow
- Efficiency shown up to 99% only.

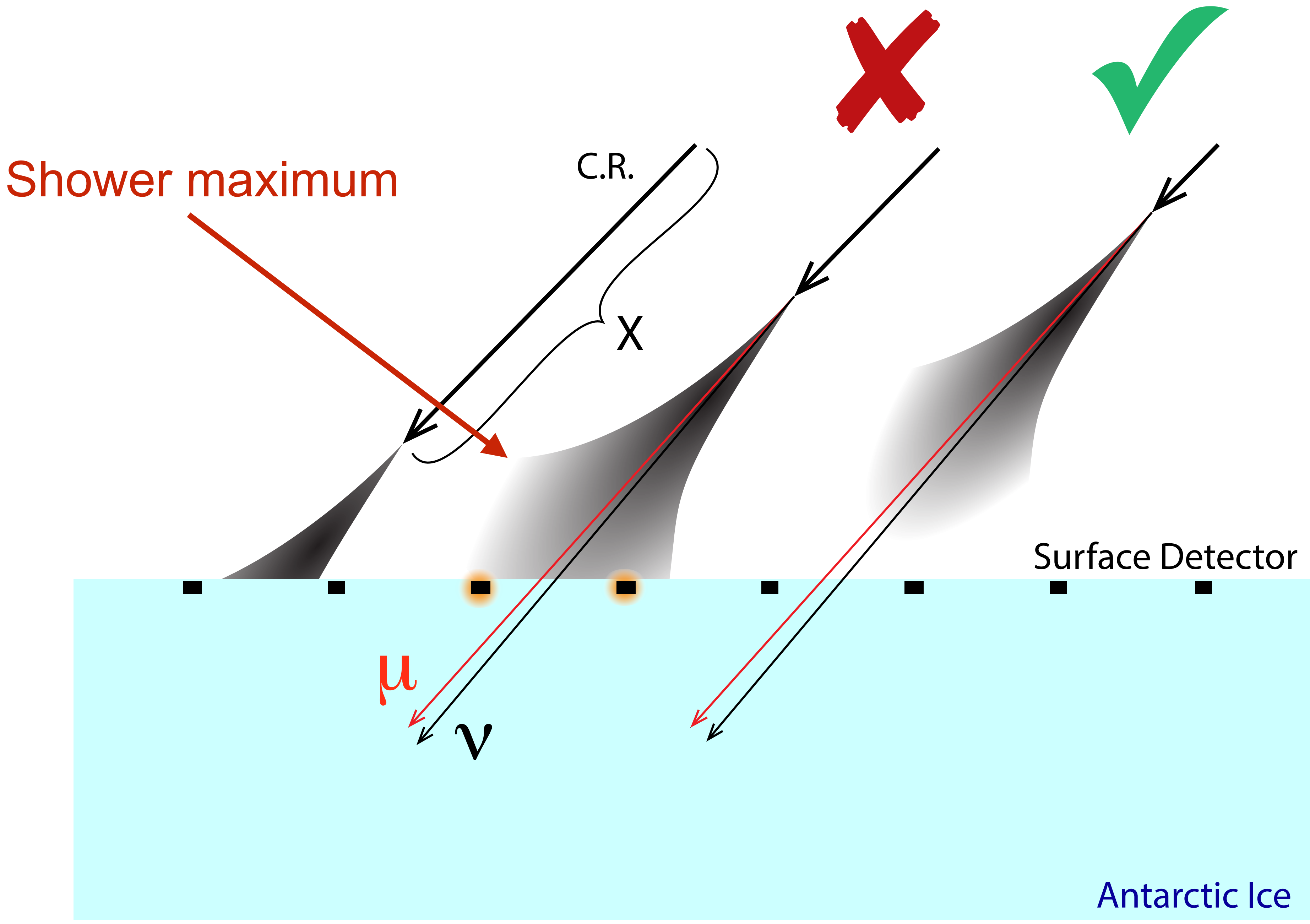
EAS Detection Efficiency II

$p_{pass} = 1 - Eff$

0° 55°



- CORSIKA simulations without snow (Sibyll 2.1).
- Triangular arrays of 1 cm polystyrene scintillation detectors.
- Efficiency roughly scales with fill factor
- Fill factor ~10^{-3} reaches 10^{-3} passing fraction at ~100 TeV
- threshold is larger by about a factor of 4 at 55°.

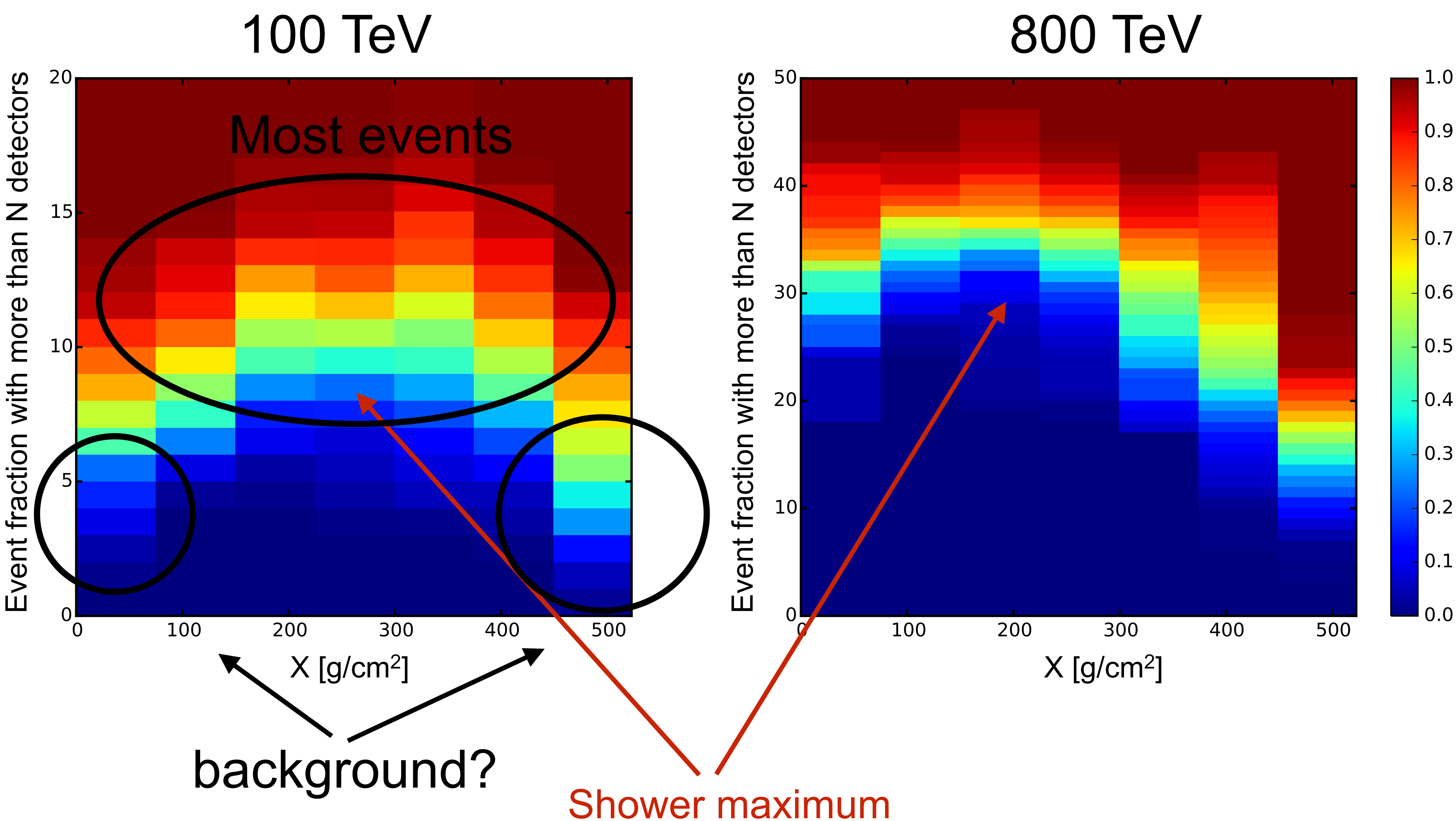


South Pole atmospheric depth: 680 g/cm^2

Assuming λ_{had} ~ 70 g/cm2

Depth	Survival Probability
70	0.37
140	0.14
210	0.05
280	0.02
350	0.007
420	0.0025
490	0.001

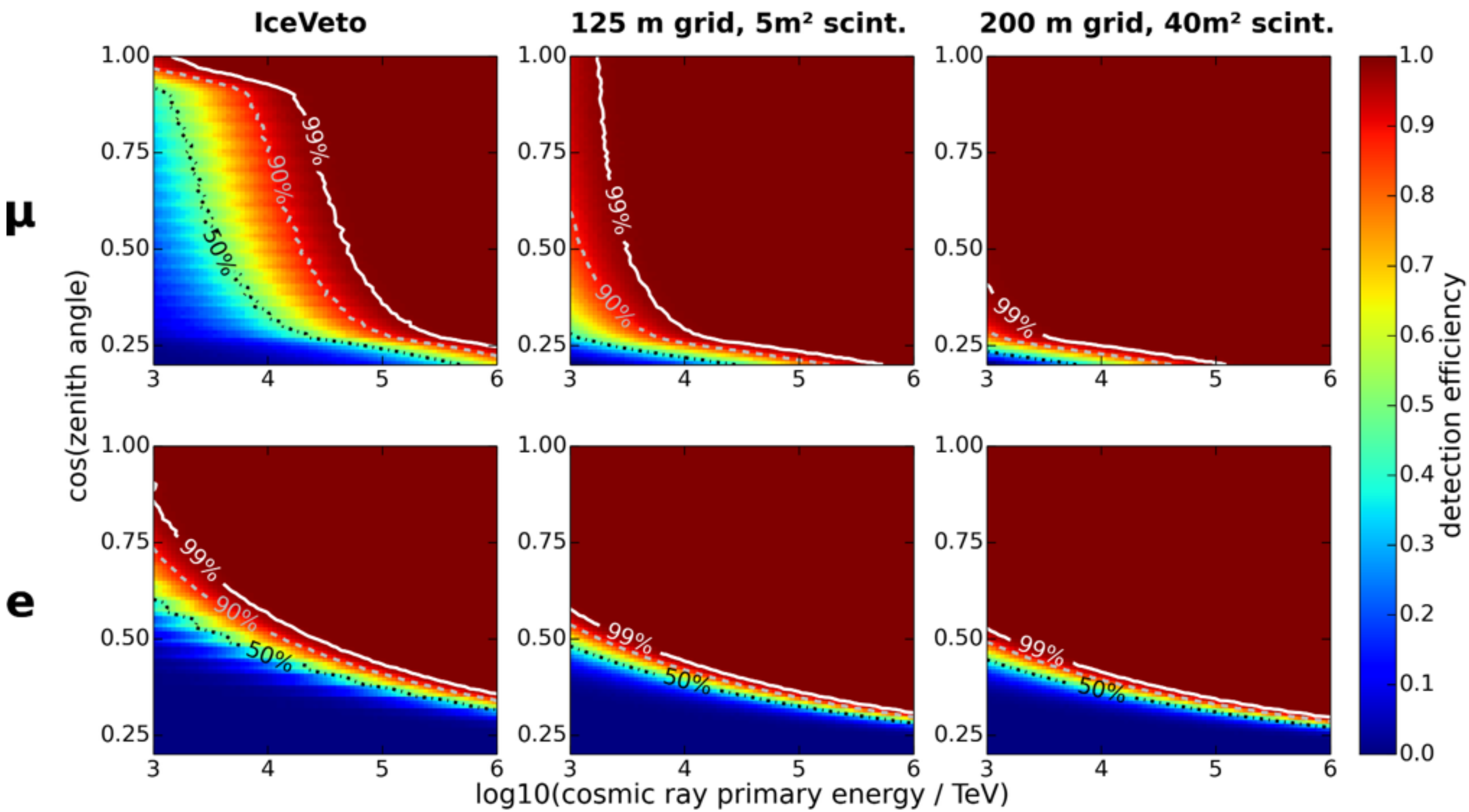
Depth Dependence

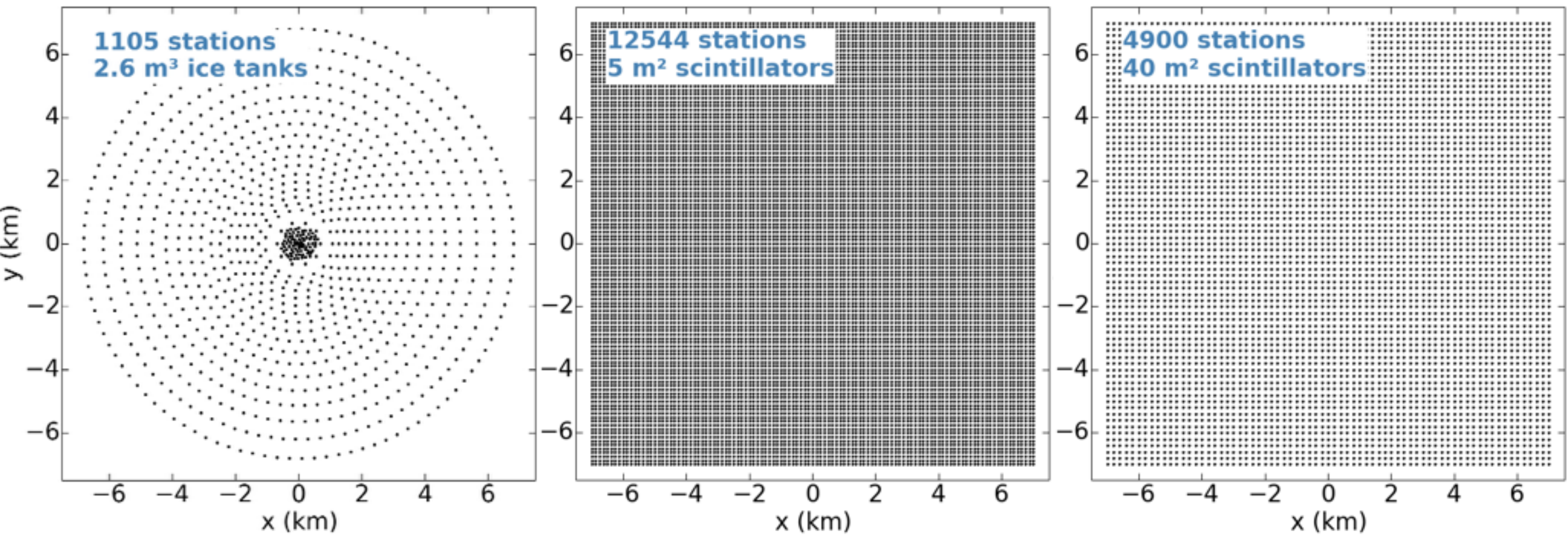


Summary

- A surface array on top of an Antarctic neutrino detector can be used to identify neutrinos of astrophysical origin.
- Such an array could double the number of track events, which have the best angular resolution.
- Plans for a next generation detector, IceCube-Gen2, include a surface array.
- We are working on determining the optimum characteristics for the array.
- Passing fraction on the order of 10^{-3} at primary energies ~100 TeV seem attainable with fill fraction ~10^{-3} (400 TeV at 55°)
- Need further studies around p_{pass}~10^{-4} to p_{pass}~10^{-6}
- More realistic layouts will be considered... we'll keep you posted

Extra


IceVeto
125 m grid, 5m² scint.
200 m grid, 40m² scint.
μ
e
cos(zenith angle)
log10(cosmic ray primary energy / TeV)
detection efficiency
1.00
0.75
0.50
0.25
3
4
5
6
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
99%
90%
50%



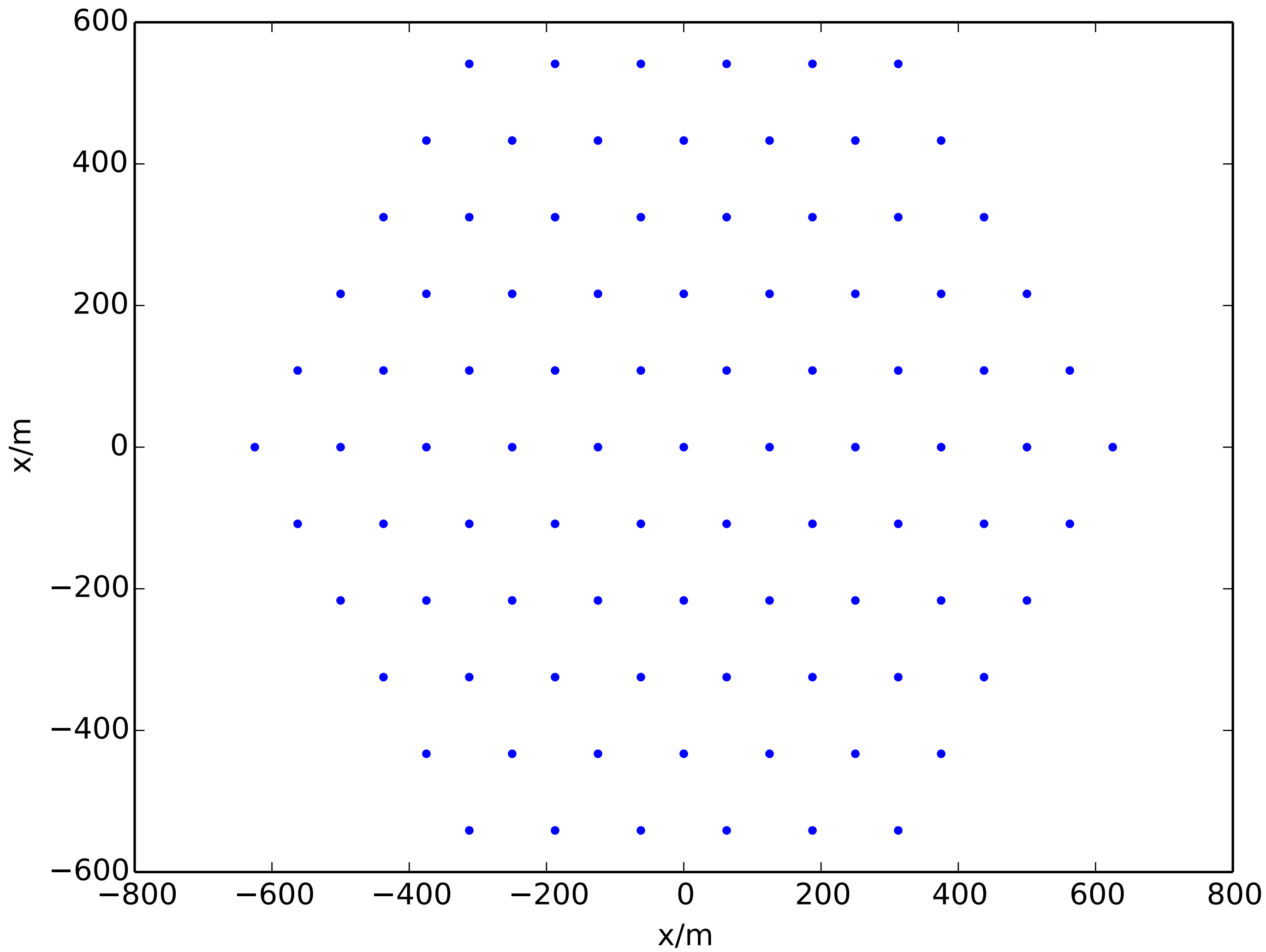
Fill Factor 2×10^{-5}

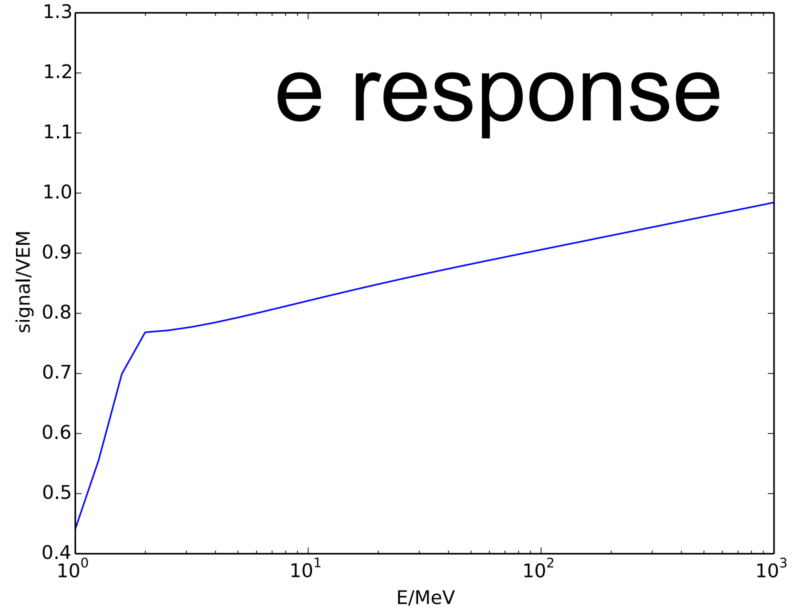
Fill Factor 3.2×10^{-4}

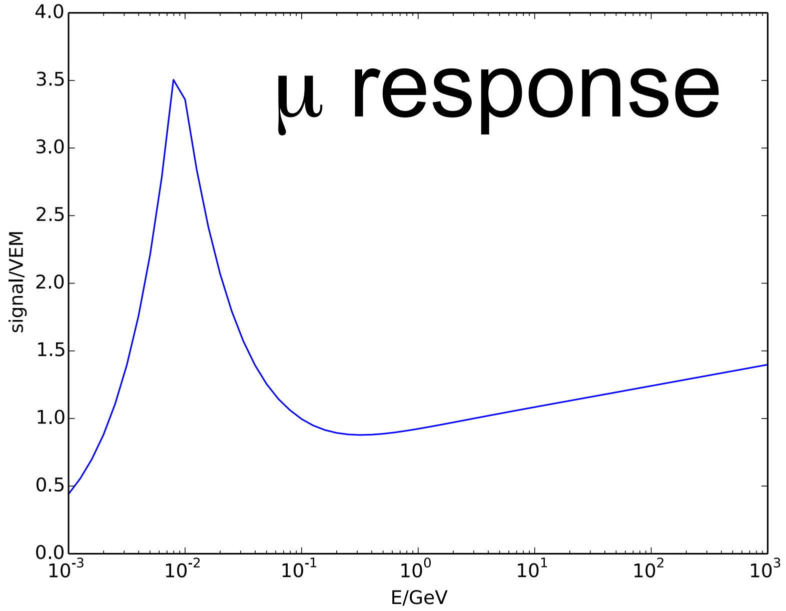
Fill Factor 1×10^{-3}

Simple CORSIKA Simulation

- Performing simple CORSIKA simulations:
  - proton primaries
  - Signals for electron and muon given by Bethe formula
  - Signals normalized to that of a vertical 3 GeV muon (VEM)
  - γ rays are ignored
  - require signal > 0.3 VEM
- Material: 1 cm thick polystyrene
- Considering three different surface areas: 0.4 m2, 0.8 m2, 1.6 m2
- Considering three different layouts. Regular triangular grids: 31.25, 62.5, 125, 250 m



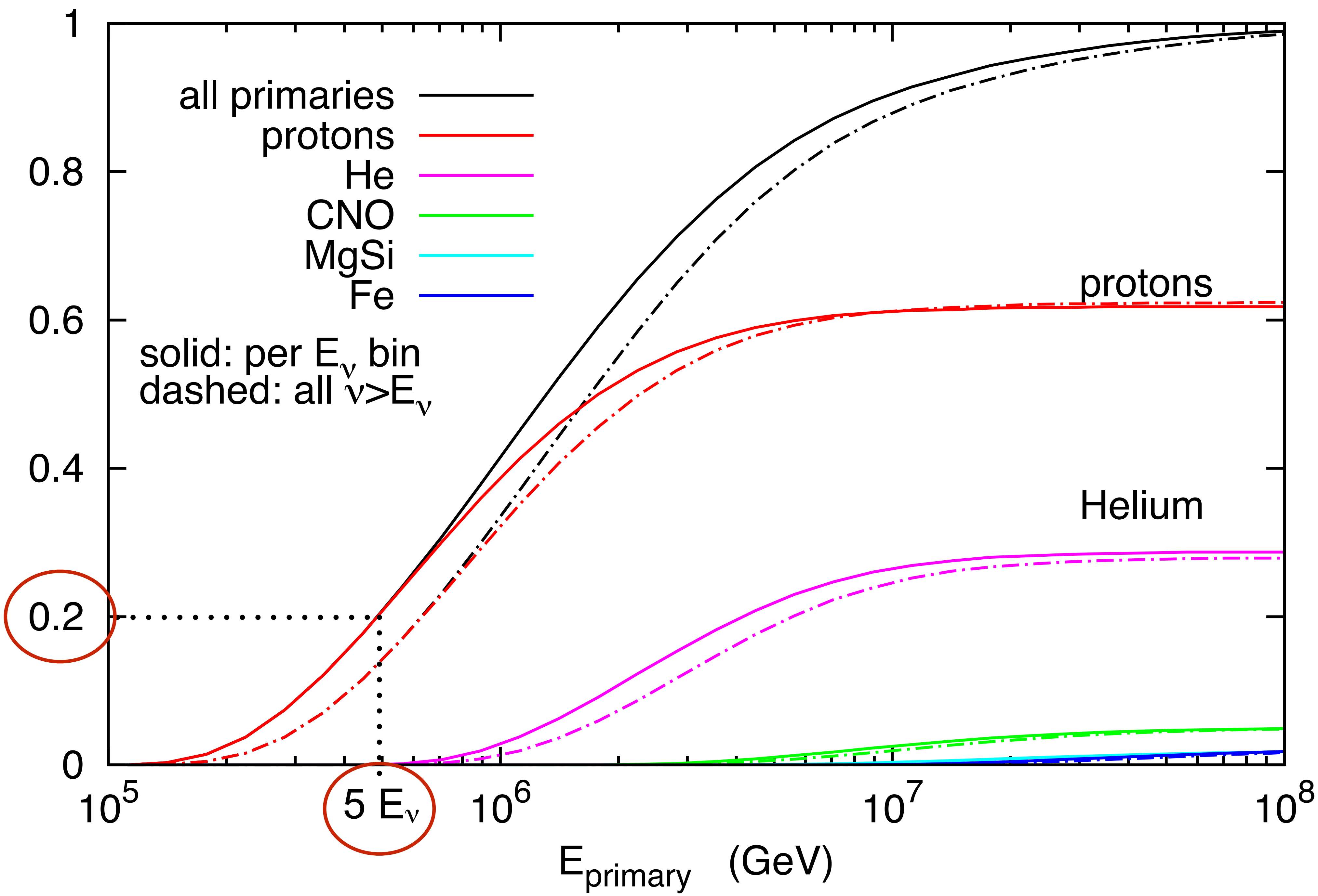




How does the veto work?

Cumulative response for atmospheric 100 TeV ν_μ

assuming H3a spectrum,
parameters for ν_μ yield
from Gaisser, Jero, Karle and van Santen



(Example from the atmospheric neutrino veto)

62% from proton

28% from Helium

10% from heavy nuclei

20% are produced by primaries with E<5 E_ν

Imagine now we want a veto efficiency of 99.99%