UNIVERSITY *of* DELAWARE

Possibilities for a Surface Veto

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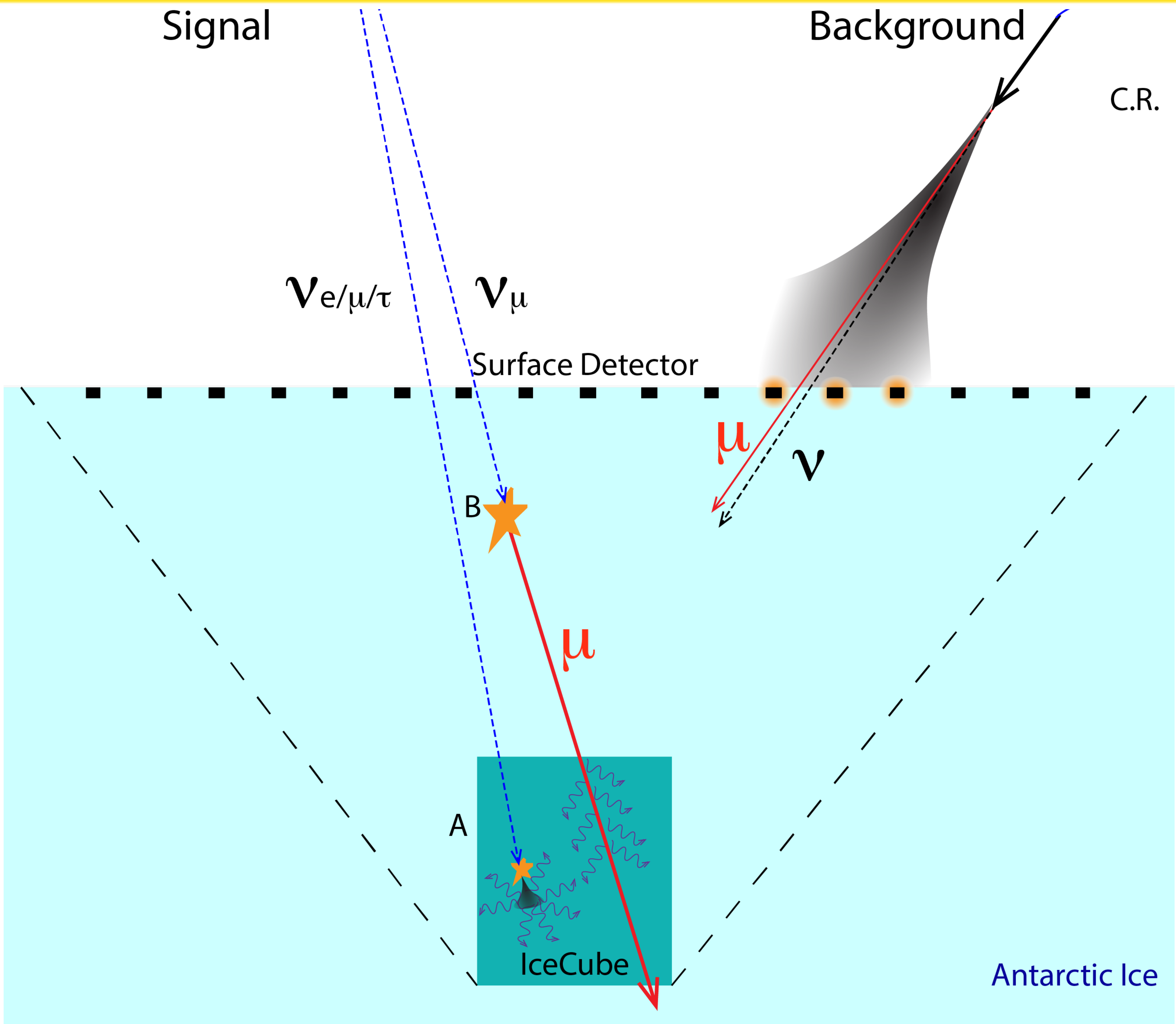
ICECUBE

Outline

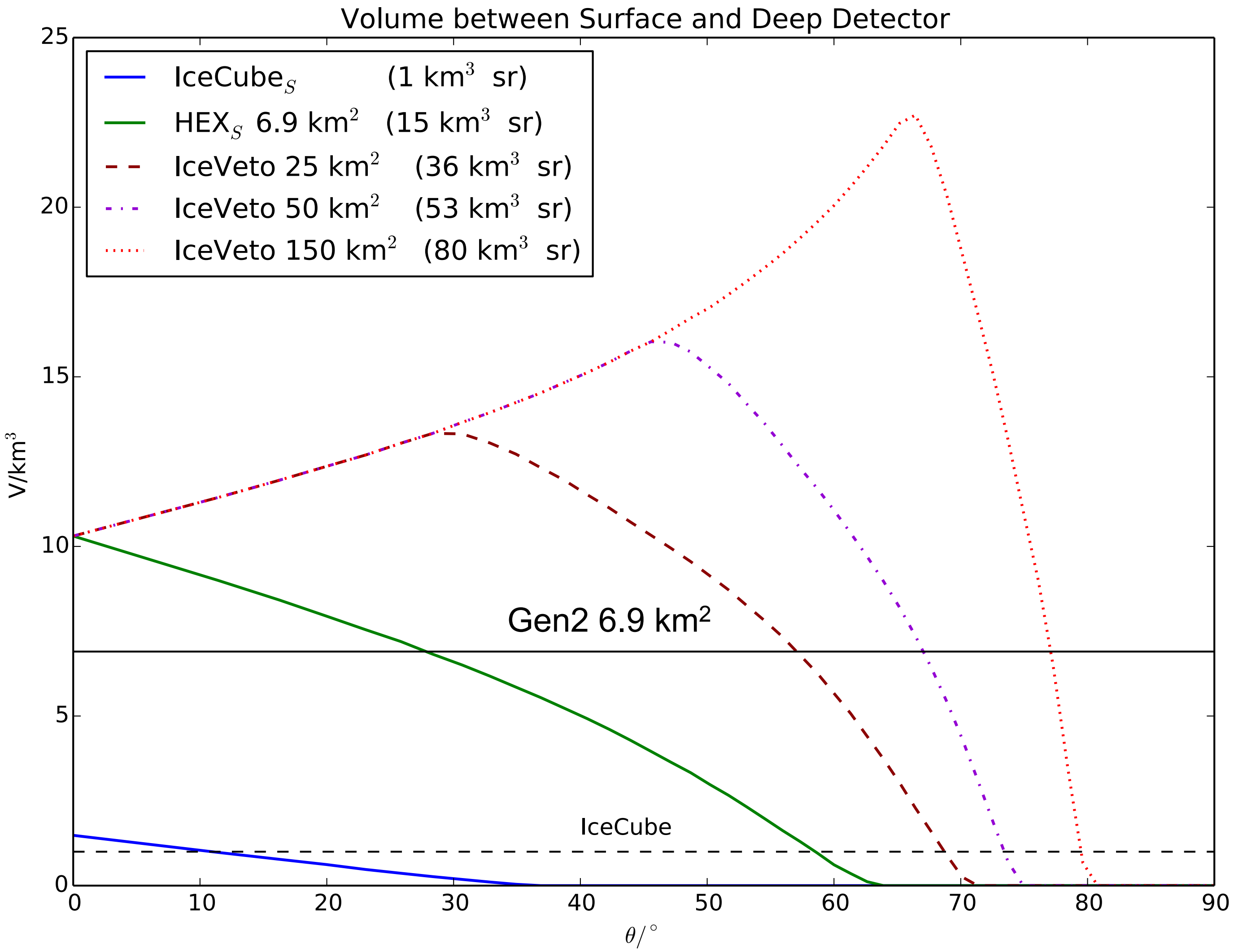
- Veto generalities
- Some CORSIKA simulation results
- How to calculate (muon passing) rates…
- Where should we place detectors for veto R&D?

Surface Veto Concept



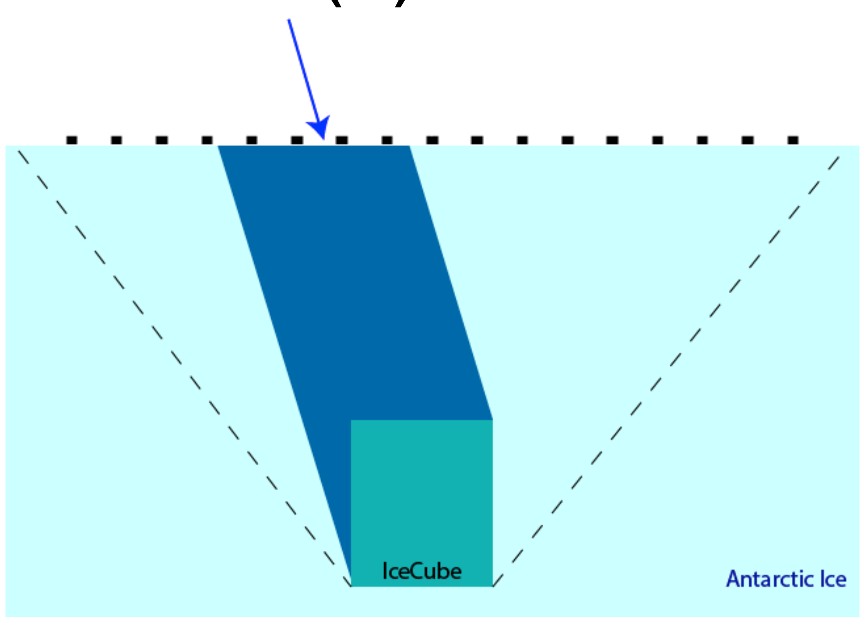
Calculating Rates

$$N = \int_{E_0}^{\infty} \int_{\Omega} \Phi(E) p_s(\theta, E) \frac{\rho_{ice} V(\theta)}{\lambda_{int}} \Delta t d\Omega dE$$



The volume determines it

V(θ)



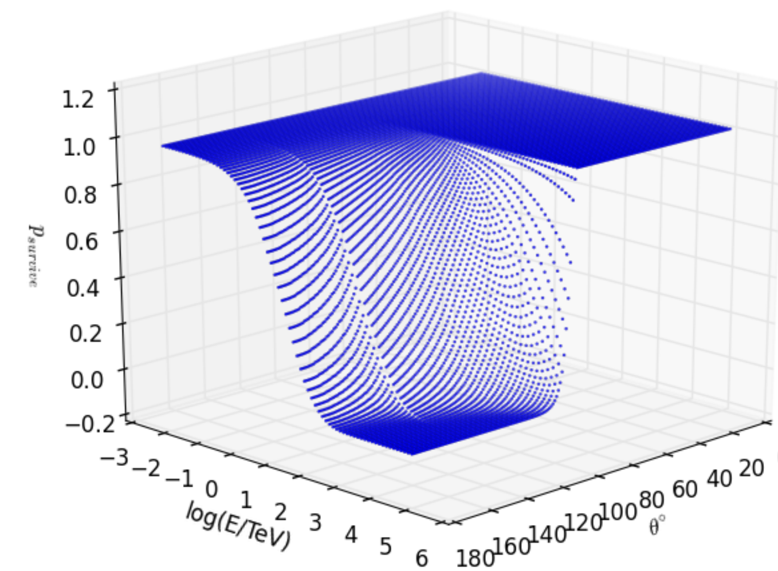
(IceCube/HEX area not included, it is independent)

- Note how small IceCube surface is!
- Gen2 grows linearly with area, veto quadratically. IceVeto 150 is larger than Gen2 6.9 km^2 + surface by x5.3.
- IceVeto 150 is roughly comparable to Gen2

This is the opposite of a detailed simulation!

- Started off with a very old neutrino cross-section (should be ok though)
- Roughly estimated survival probability across the Earth using the Preliminary Earth Model
- Ignored effects due to muon energy loss.

- **What matters is not the absolute numbers you will see but the relation between them**



Different fluxes considered. All in $GeV^{-1}cm^{-2}sr^{-1}s^{-1}$.

Power law flux	$1 \times 10^{-8}\left(\frac{E}{GeV}\right)^{-2}$
HESE three year	$1.5 \times 10^{-8}\left(\frac{E}{100\,TeV}\right)^{-0.3}\left(\frac{E}{GeV}\right)^{-2}$
1 TeV paper	$2.06 \times 10^{-18}\left(\frac{E}{10^5\,GeV}\right)^{-2.46}$
HESE flux with a cutoff	$1 \times 10^{-8}\left(\frac{E}{GeV}\right)^{-2} e^{-E/1.9PeV}$
Steep power law flux	$7 \times 10^{-5}\left(\frac{E}{GeV}\right)^{-2.7}$

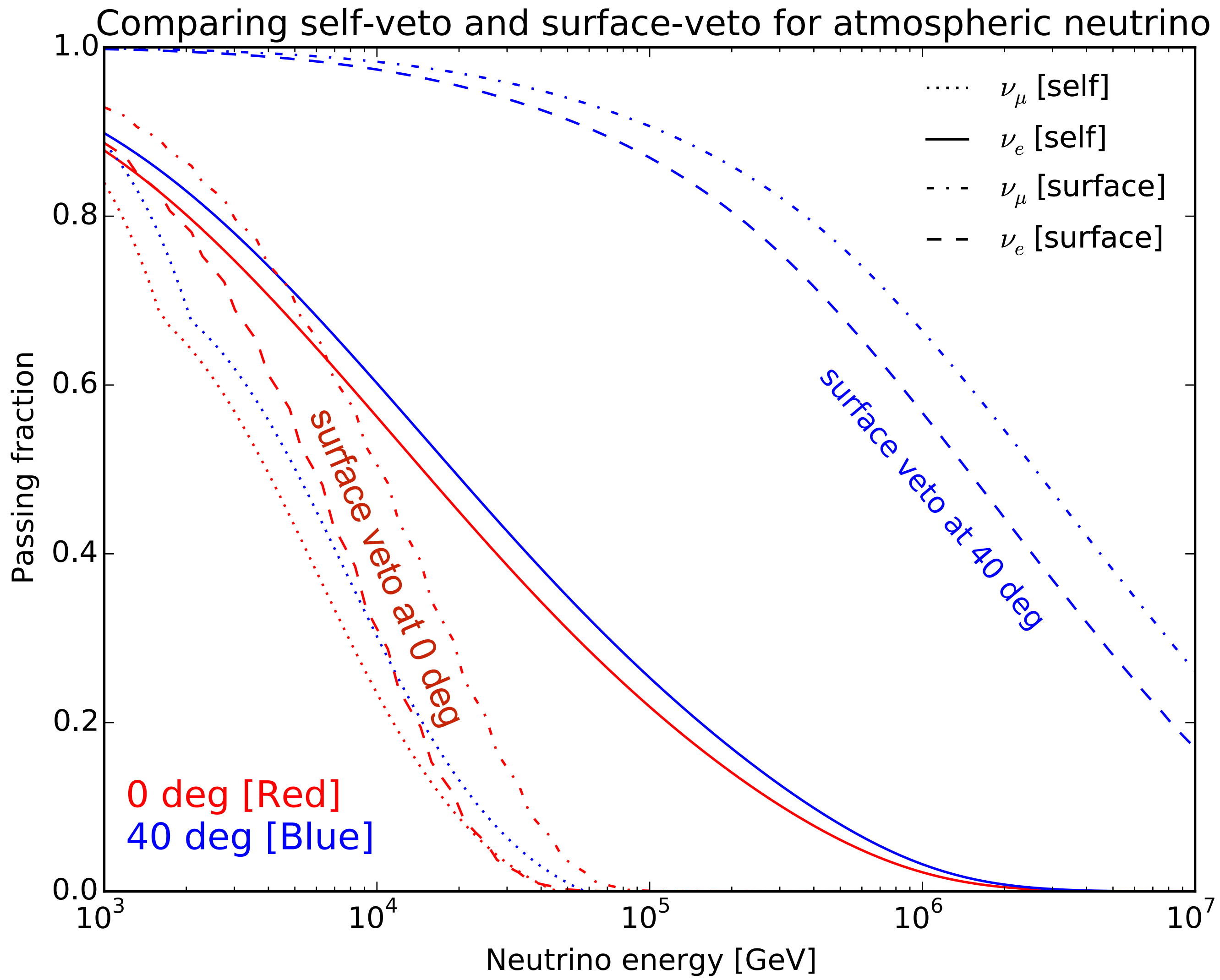
Rates from 1 TeV Paper Flux

All rates are above 100 TeV and all directions unless stated.

	CC	NC	tracks (CC/3)
IceCube	7.6	3.0	2.5
IceCube	0.1	0	0.1
NextGen contained	52.5	20.9	17.5
NextGen contained ($\theta < 80°$)	27.7	11.1	9.2
IceVeto	20.7	0	20.7
NextGen (surface vetoed)	3.6	0	3.6
NextGen (E > 30 TeV)	9.4	0	9.4
NextGen (E > 15 TeV)	15.9	0	15.9
NextGen (E > 10 TeV)	22.5	0	22.5

Low-energy surface veto tracks in ORANGE

Atmospheric neutrino case
(Case A: contained events)



- At small angles it seems to be better than the self-veto. (Never mind the solid angle “detail”)
- The self-veto will degrade with increased string spacing. Right?

- Then a surface veto for atmospheric neutrinos seems a necessity for NextGen contained.

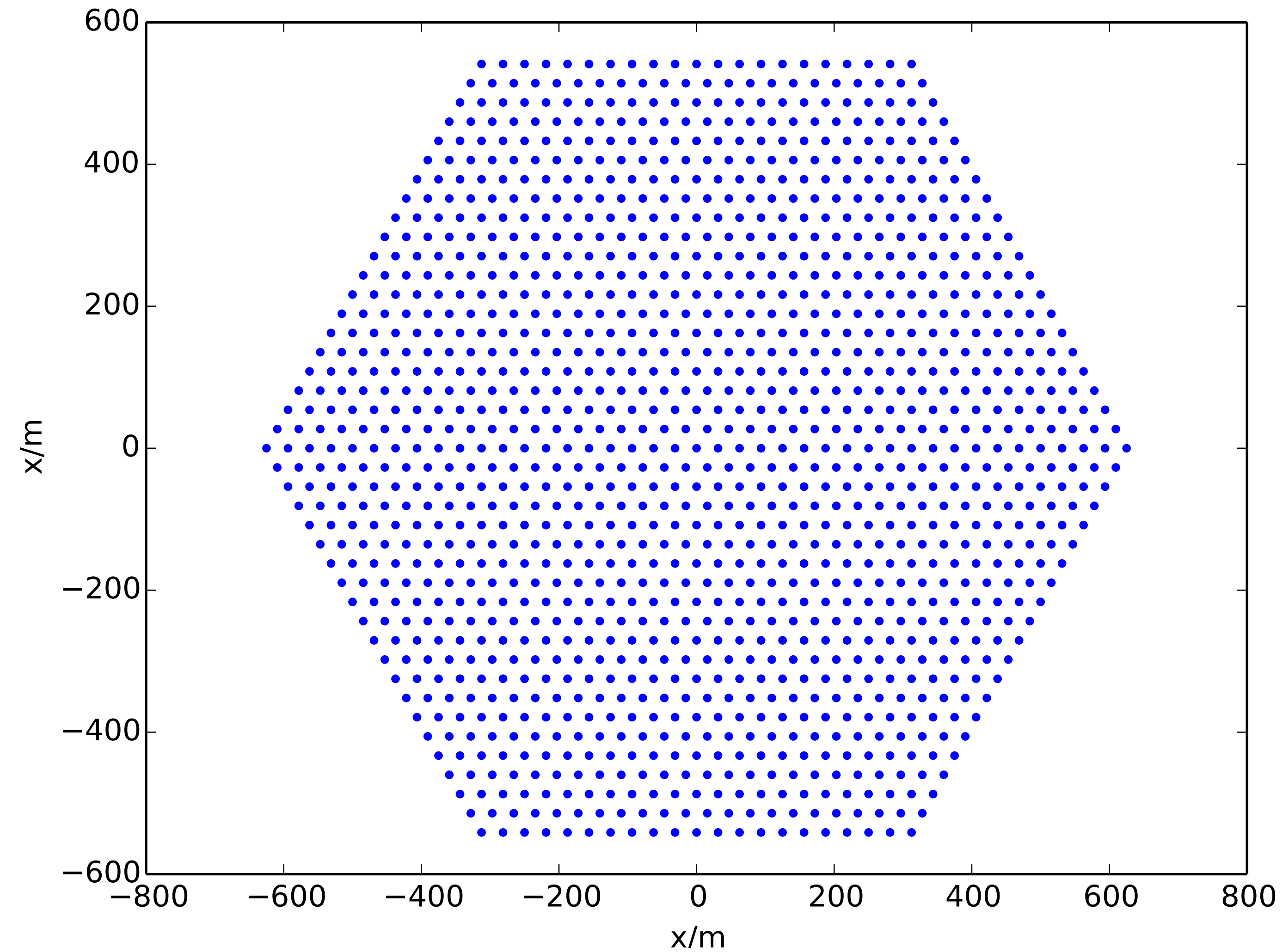
- There seem to be three possibilities:
  1. NextGen contained events with a surface veto (case A).
  2. high-energy array like IceVeto (case B)
     but with higher threshold than I considered?
  3. low-energy array to look for CC ν_μ tracks (case B).

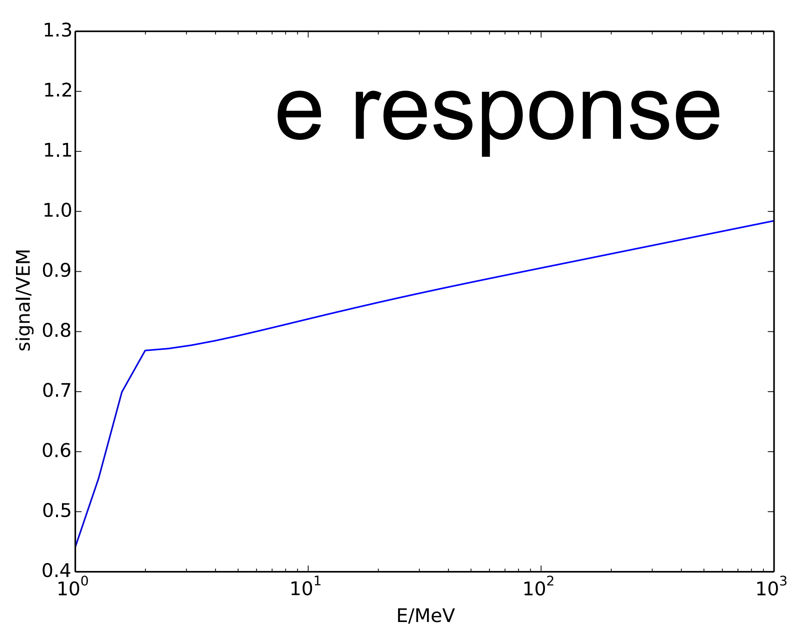
- I am considering #3:
  - How low in energy is it possible to go?
  - What is the background rate?
  - Are there any “irreducible” backgrounds?
  - What detector spacing should we use for a given E_{min}?
  - What detector size should we use for a given E_{min}?

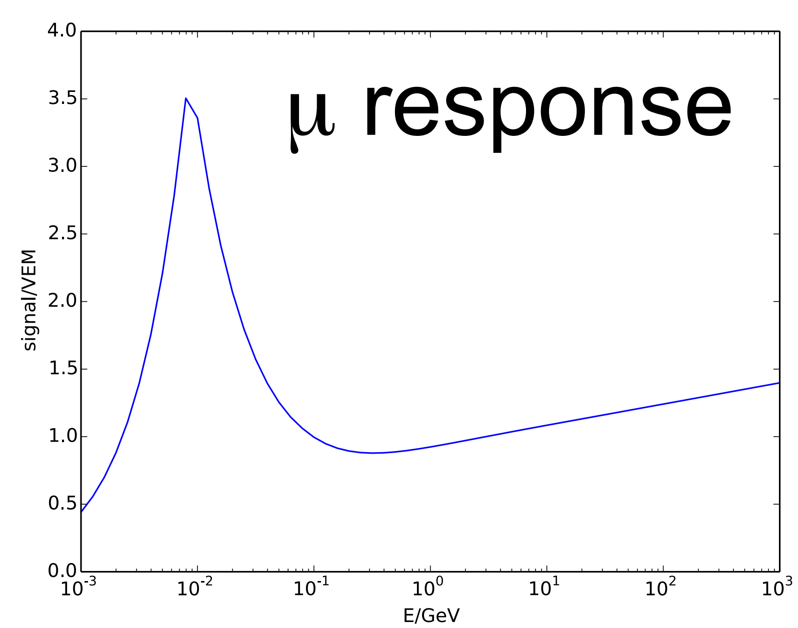
  - The difficult one…
    required passing rate < 10^{-5} at very low energies? too extreme?
    This is what should be studied with R&D on IceTop area.

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







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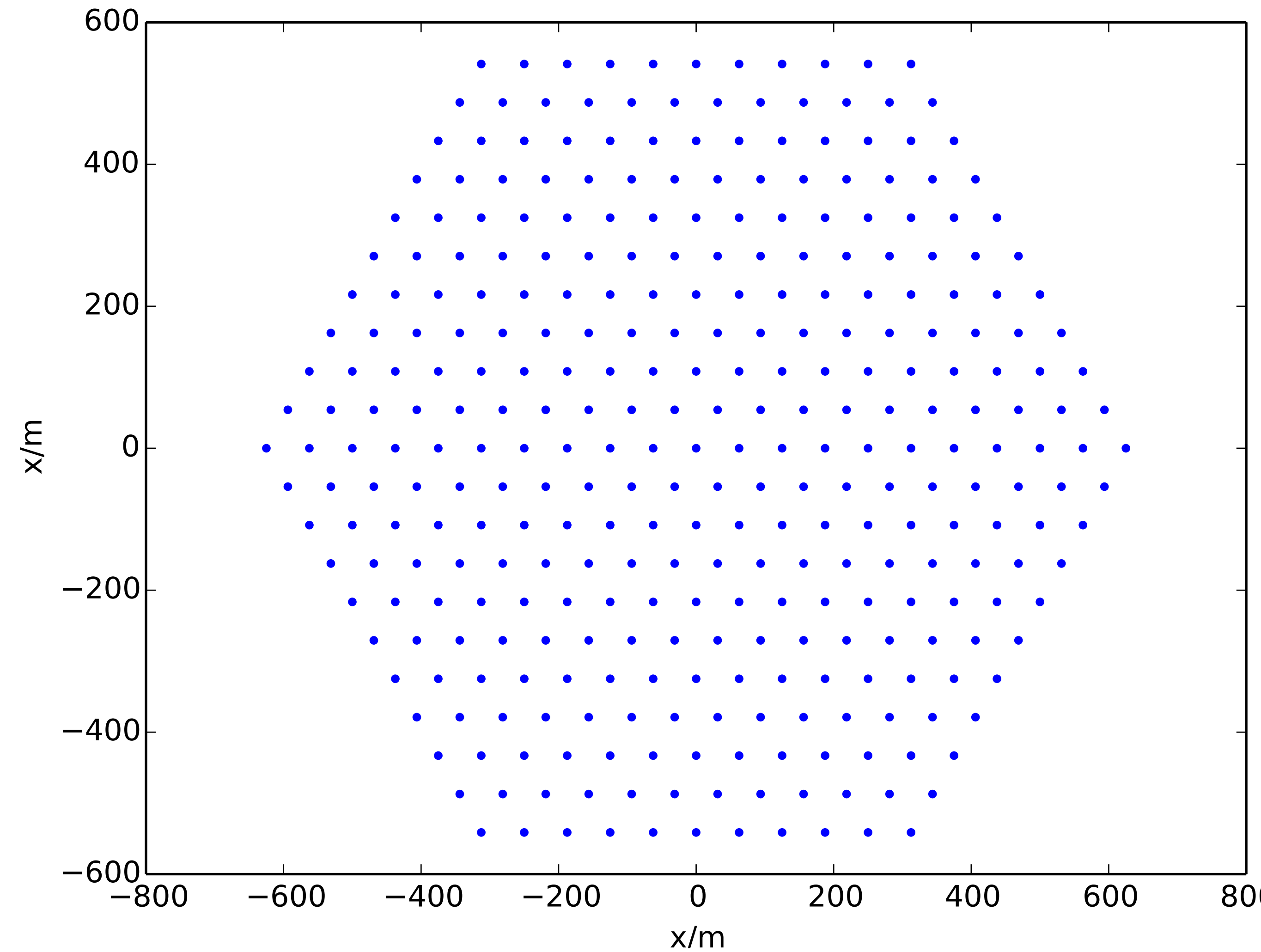

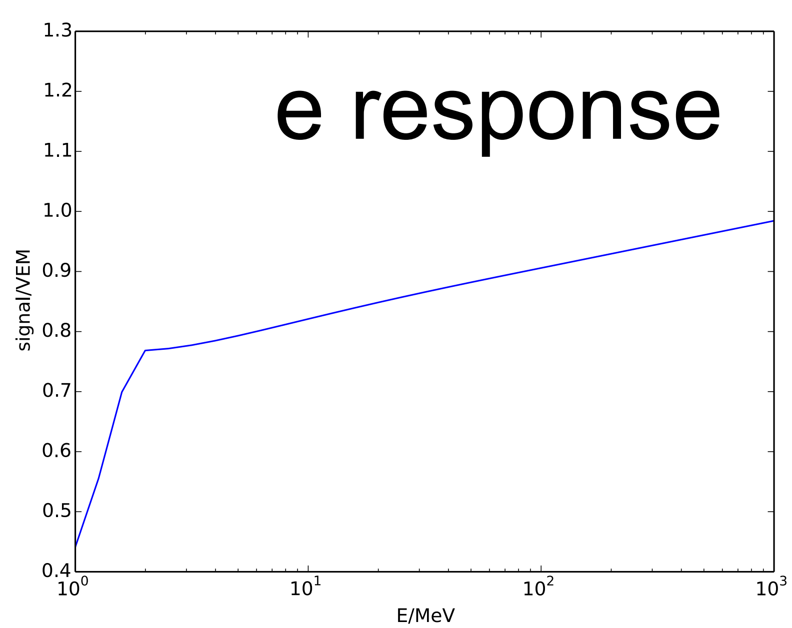

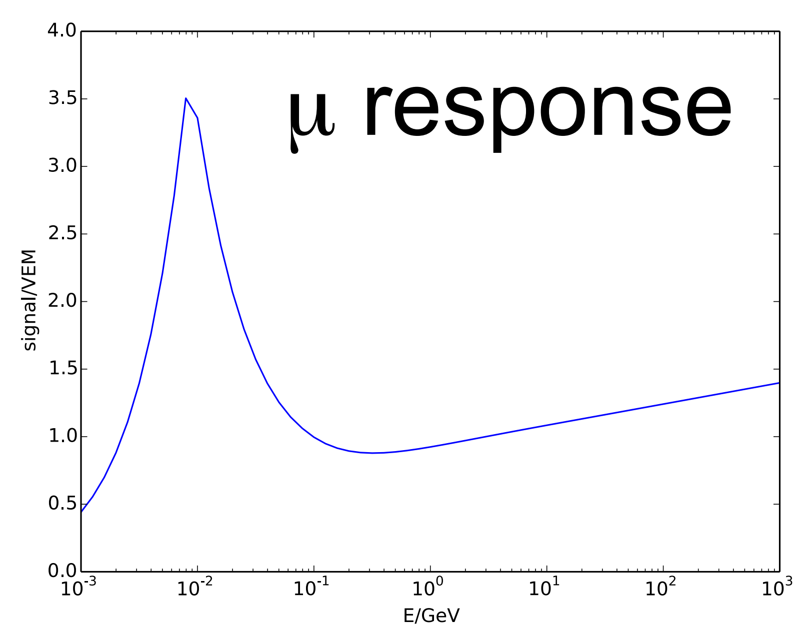

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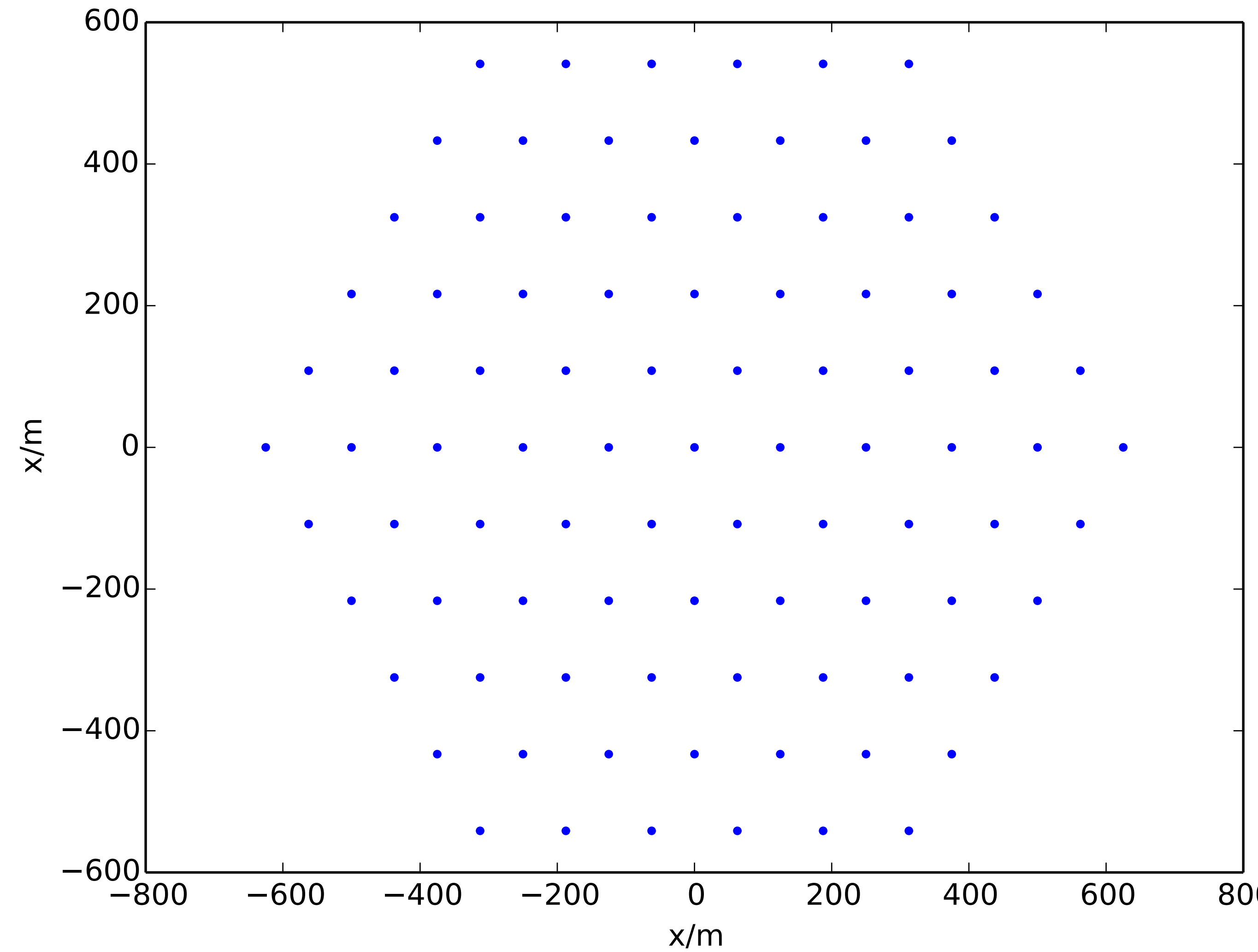

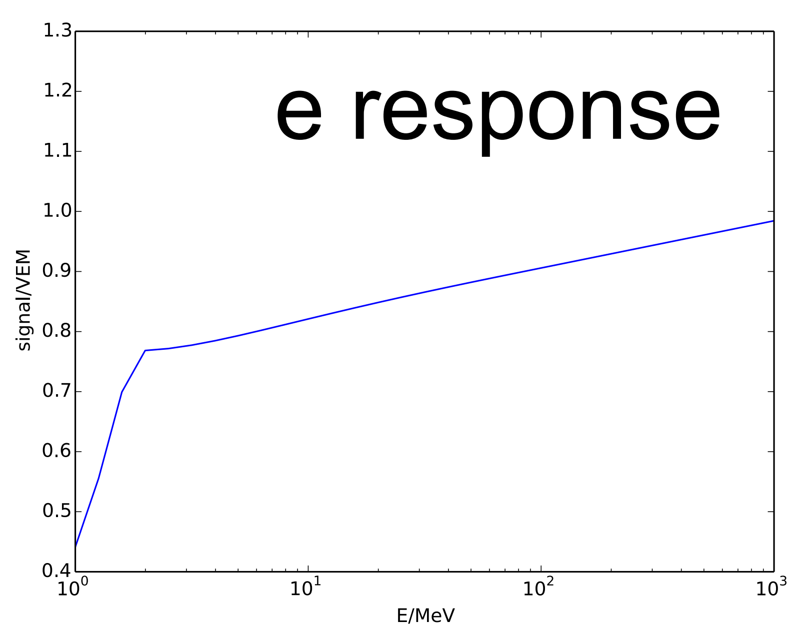

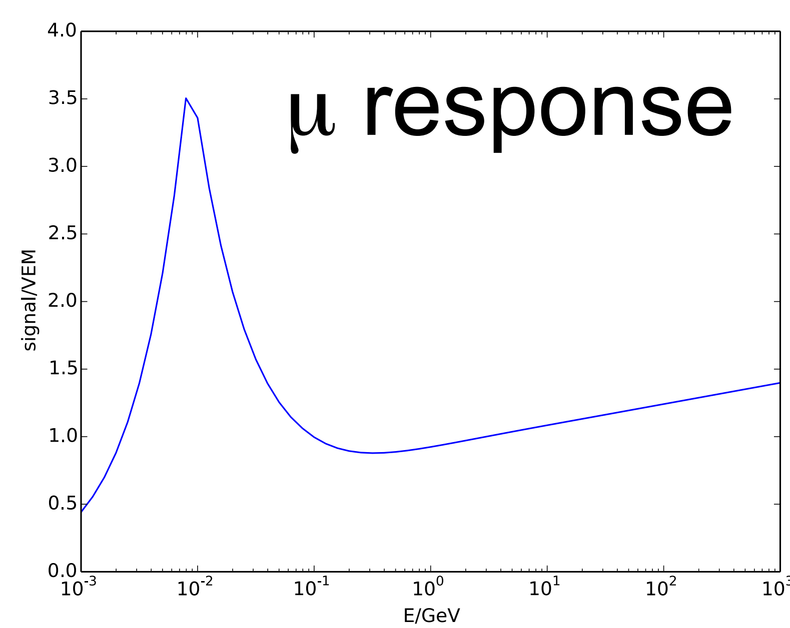

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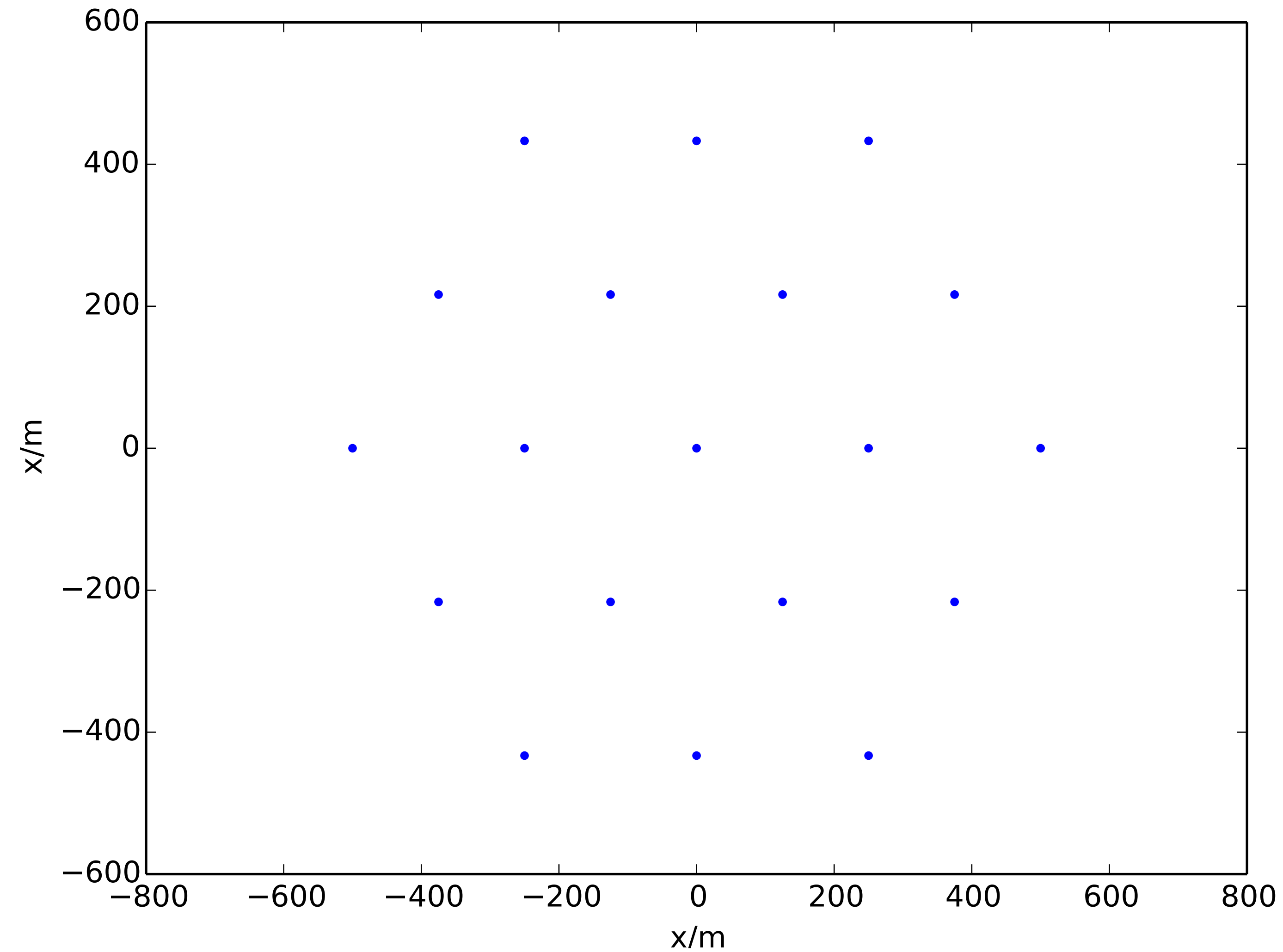
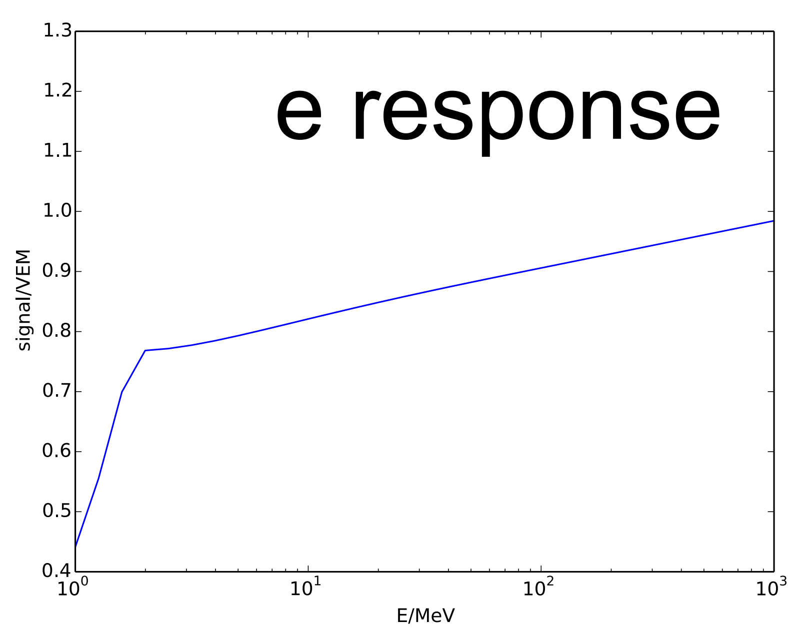
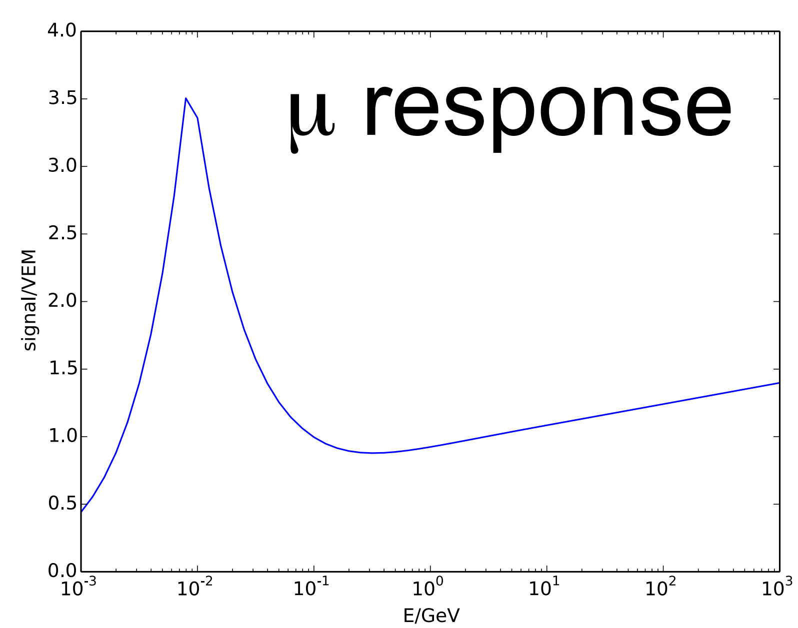
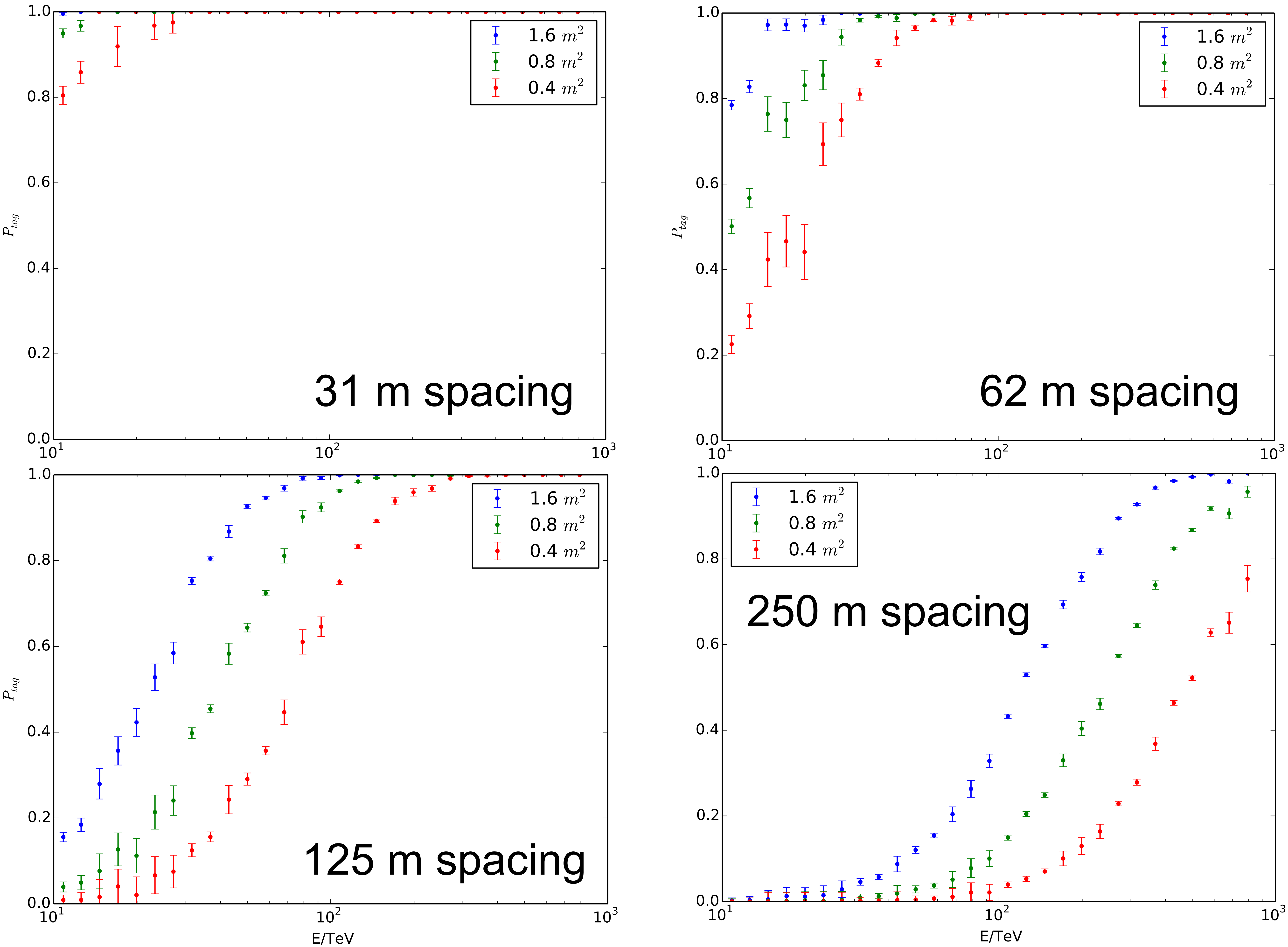







31 m spacing
62 m spacing
125 m spacing
250 m spacing
1.6 m^2
0.8 m^2
0.4 m^2
P_{tag}
E/TeV

Some Extreme Showers

Assuming λ_{had} ~ 70 g/cm2

Plots of efficiency versus slant depth of first interaction would have been here…

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

Estimating Background Rates...

Lepton rates:

$$r(E_l,\theta) = \int R_l(E_l, A, E, \theta) p_{\text{pass}}(E,\theta) dE$$

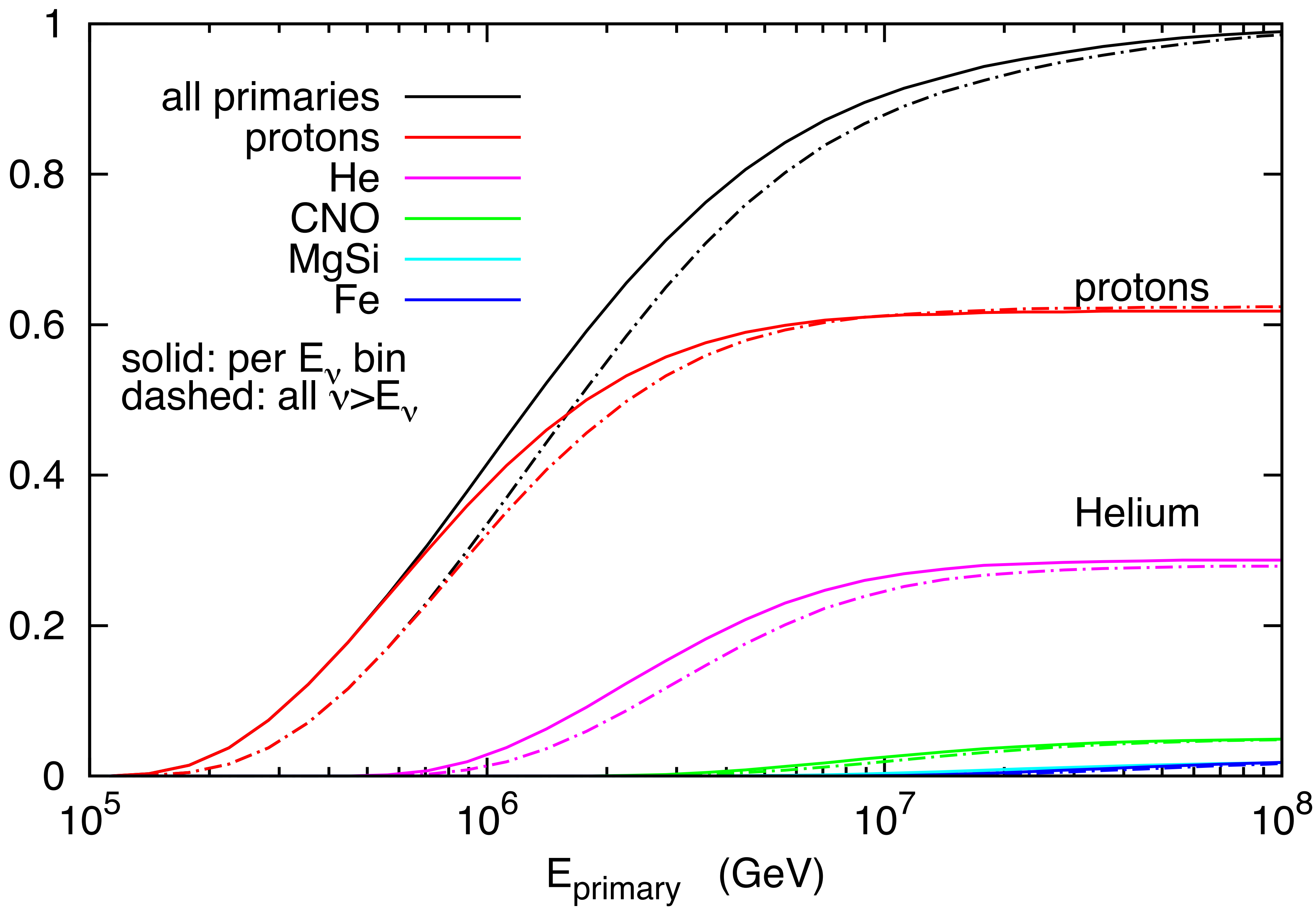
$$= \int \frac{dN_l(E_l, A, E, \theta)}{dE_l} \phi_N(A, E) p_{\text{pass}}(E,\theta) dE$$

- For atmospheric neutrino veto:
  - leptons are neutrinos (obviously)
  - response is given by Elbert's yield
- For atmospheric muon veto:
  - response uses Elbert's yield but is more complicated (bundle identification efficiency and muon energy resolution)

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

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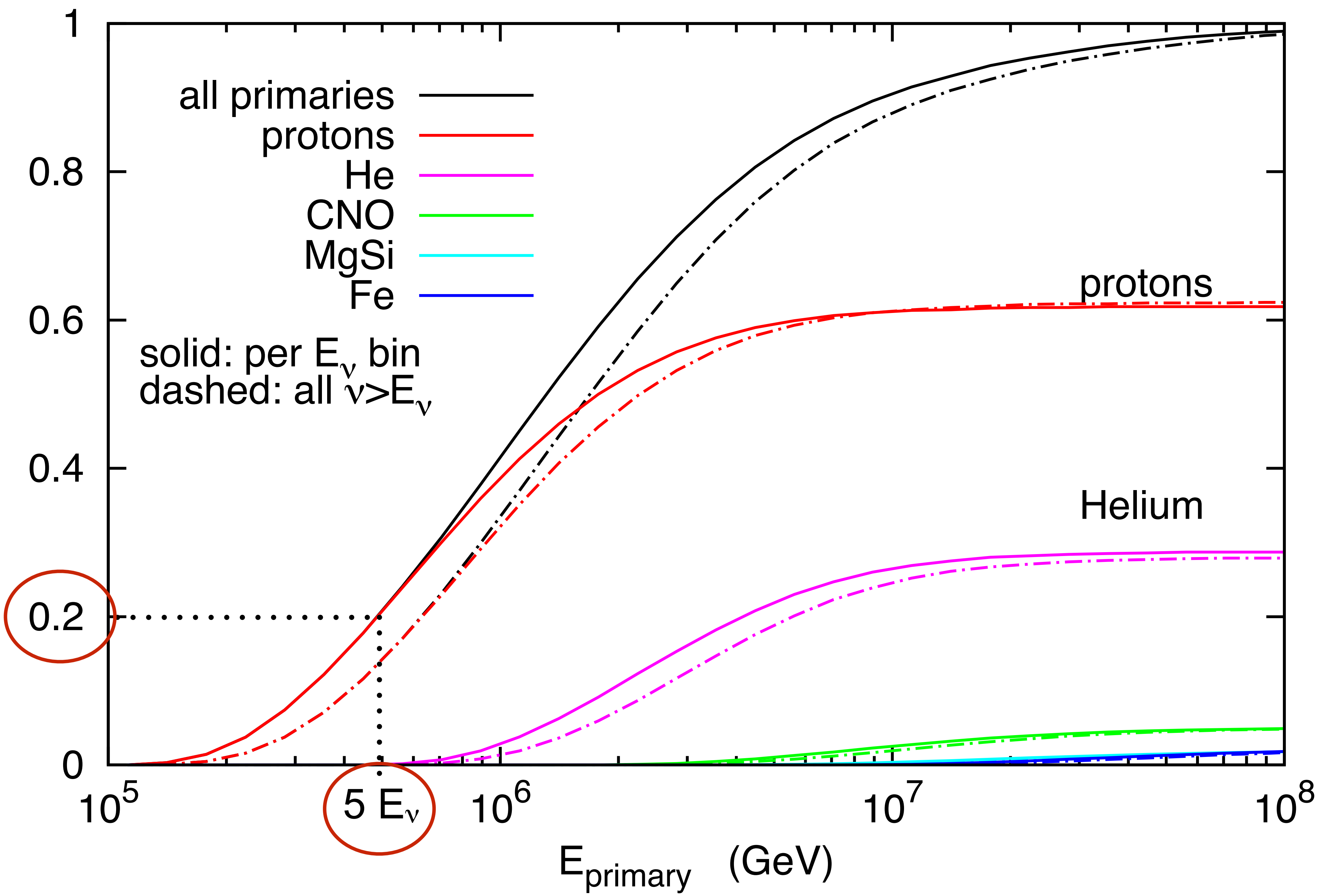

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20% are produced by primaries with E < 5 E_ν

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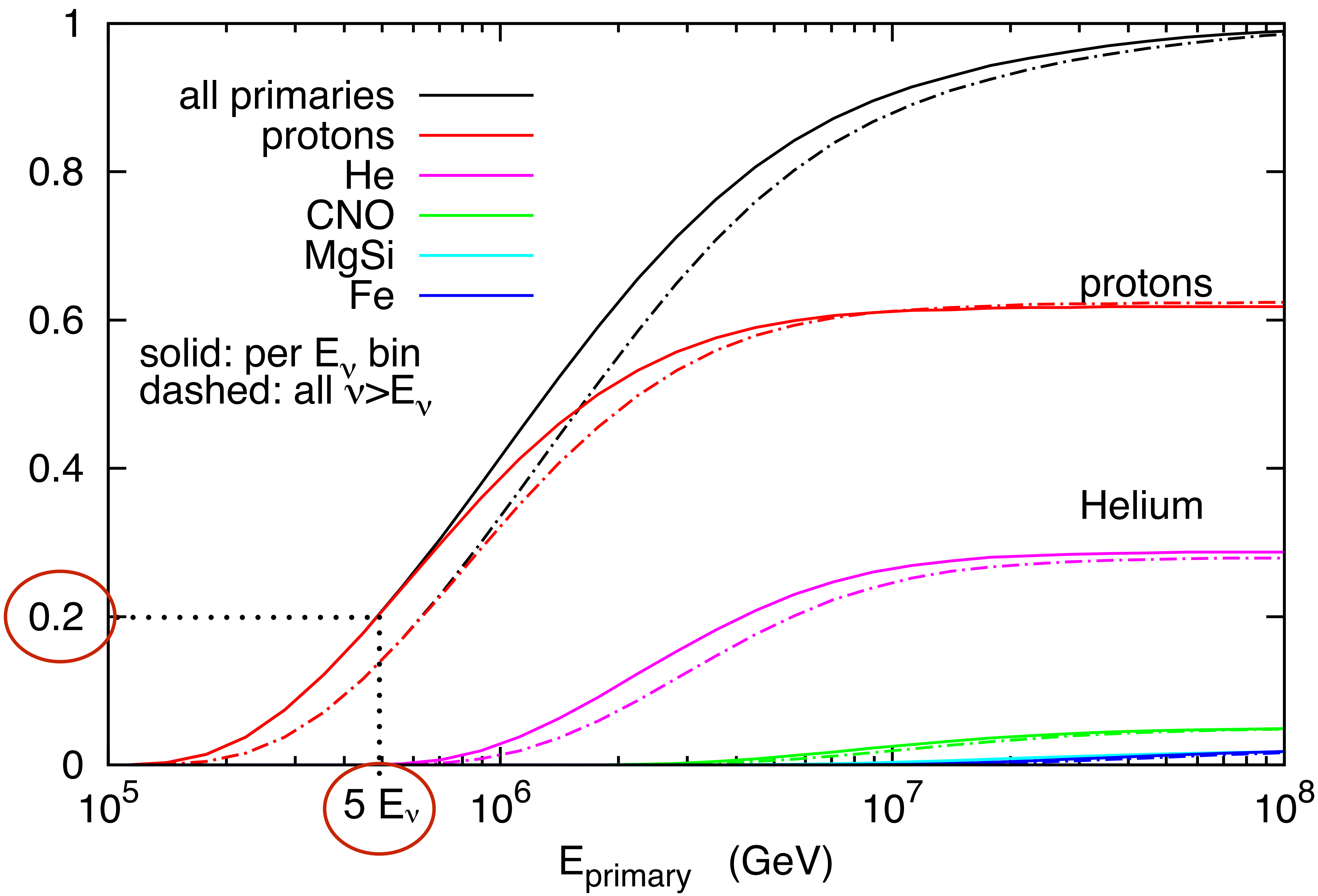

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Imagine now we want a veto efficiency of 99.99%

ICRC-2007 paper 0328, Bai et al.

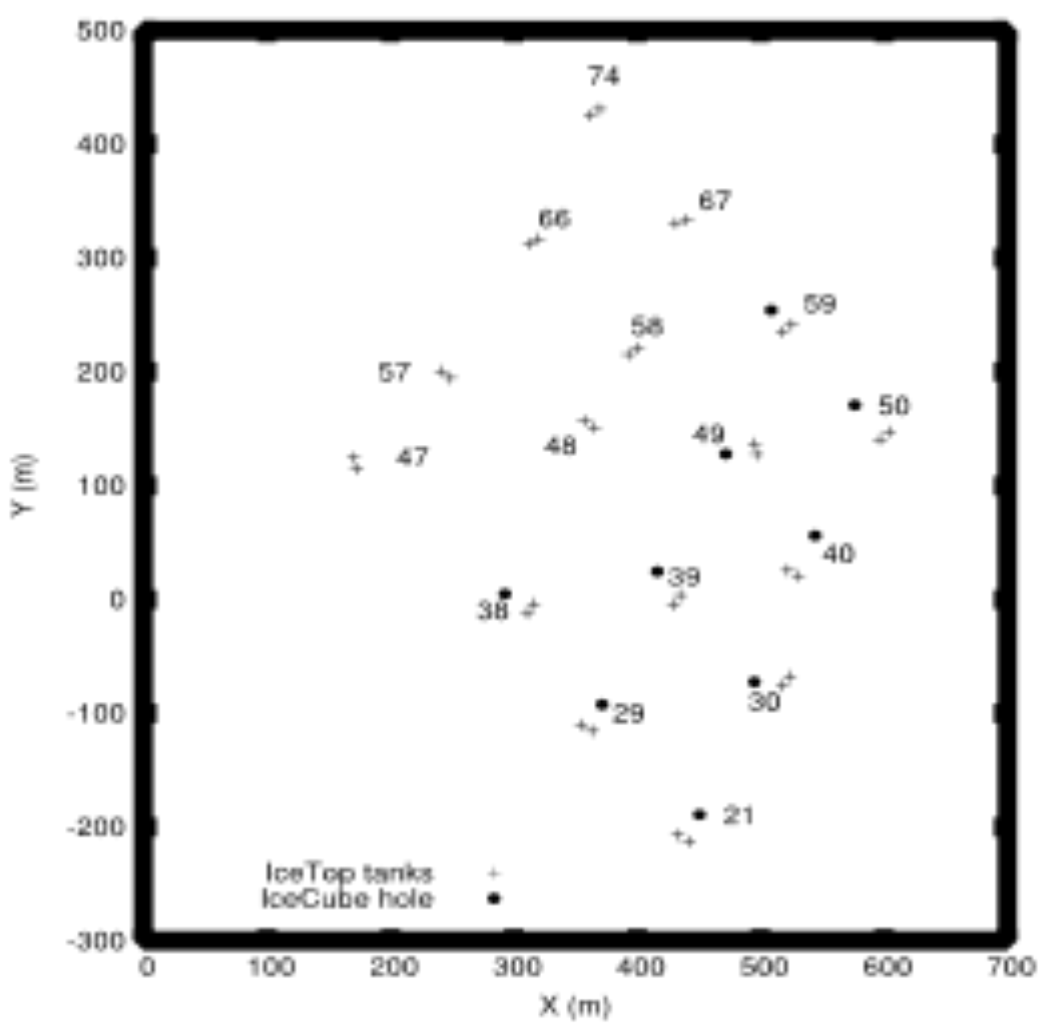


Figure 1: Surface map of IceCube in 2006. Two tanks (+) are separated from each other by 10 m at each station. Each tank has one high-gain and one low-gain DOM.

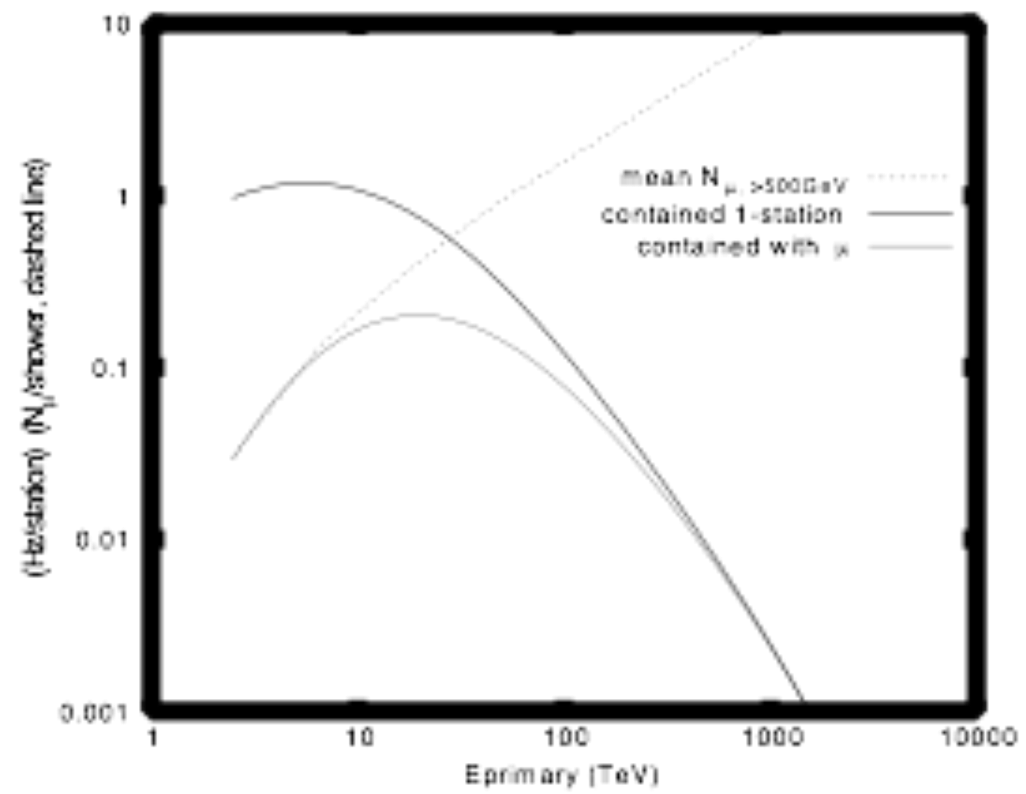
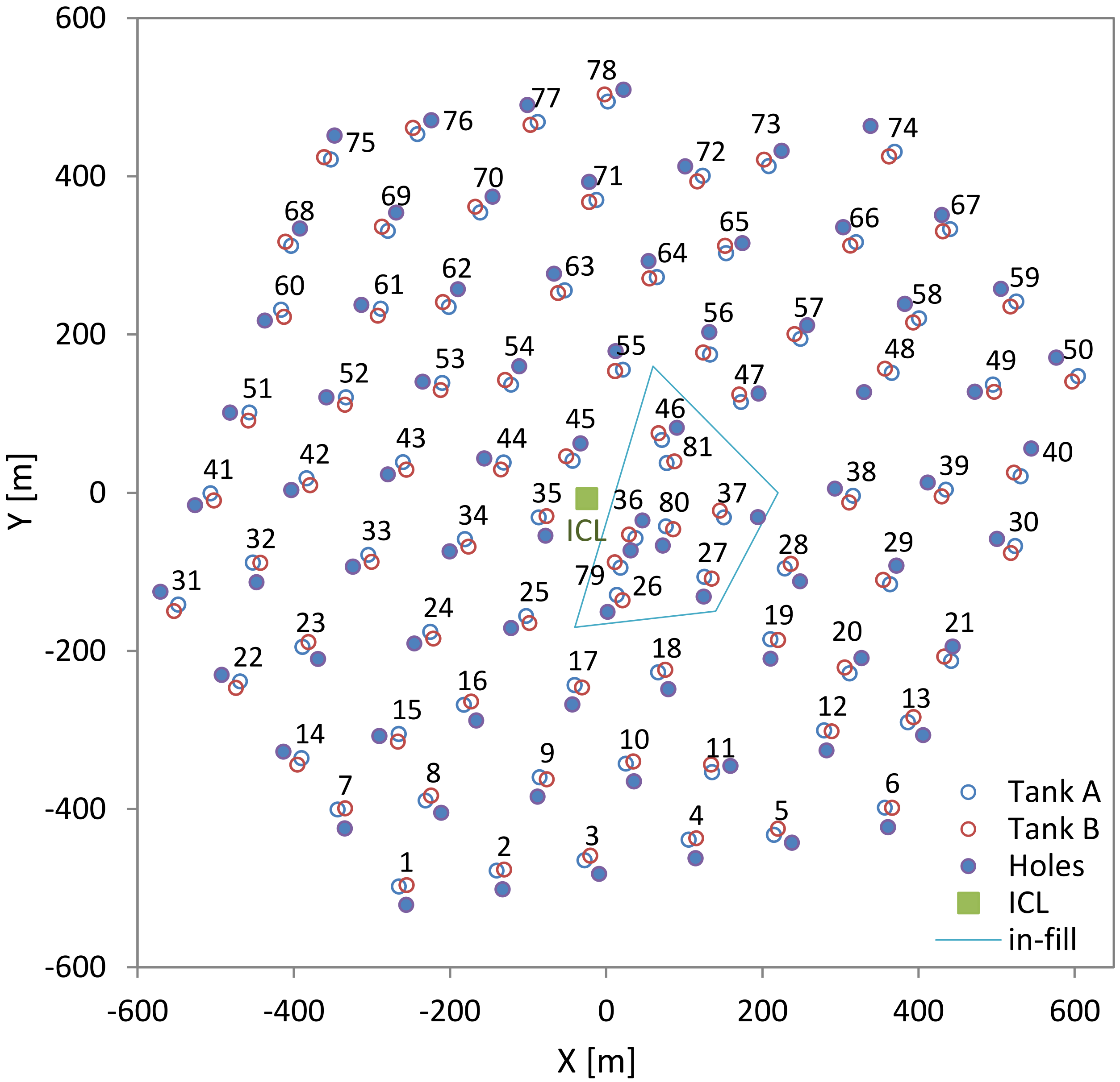
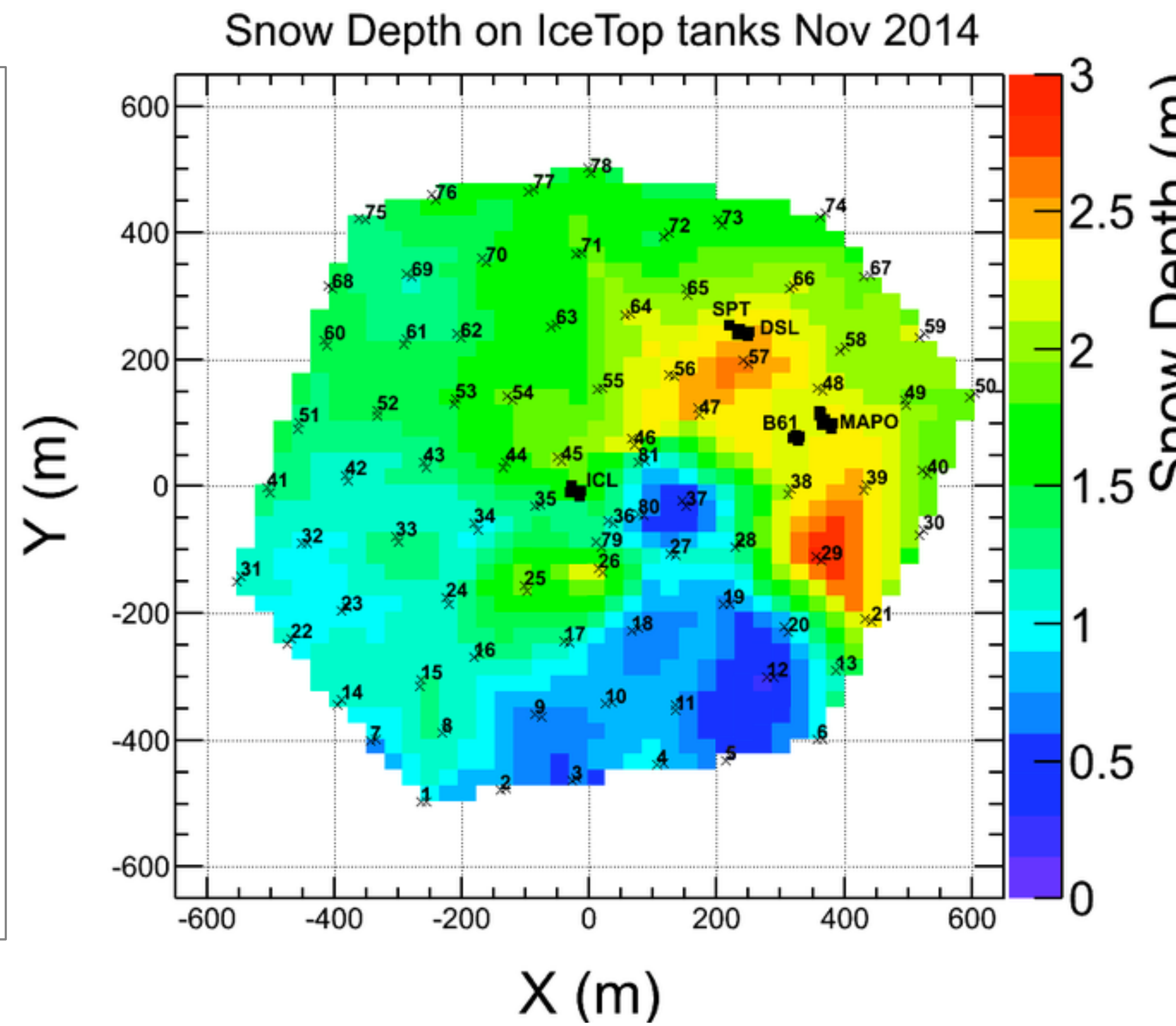


Figure 3: Response function for single station events in IceTop. Only four contained stations (39, 48, 49 and 58) were considered. The dashed line represents the number of muons above 500 GeV at production in a proton shower. The lower curve shows the response function for events with one muon in the deep detector.

These events… what is the air shower size??

(slide from Tom G.)





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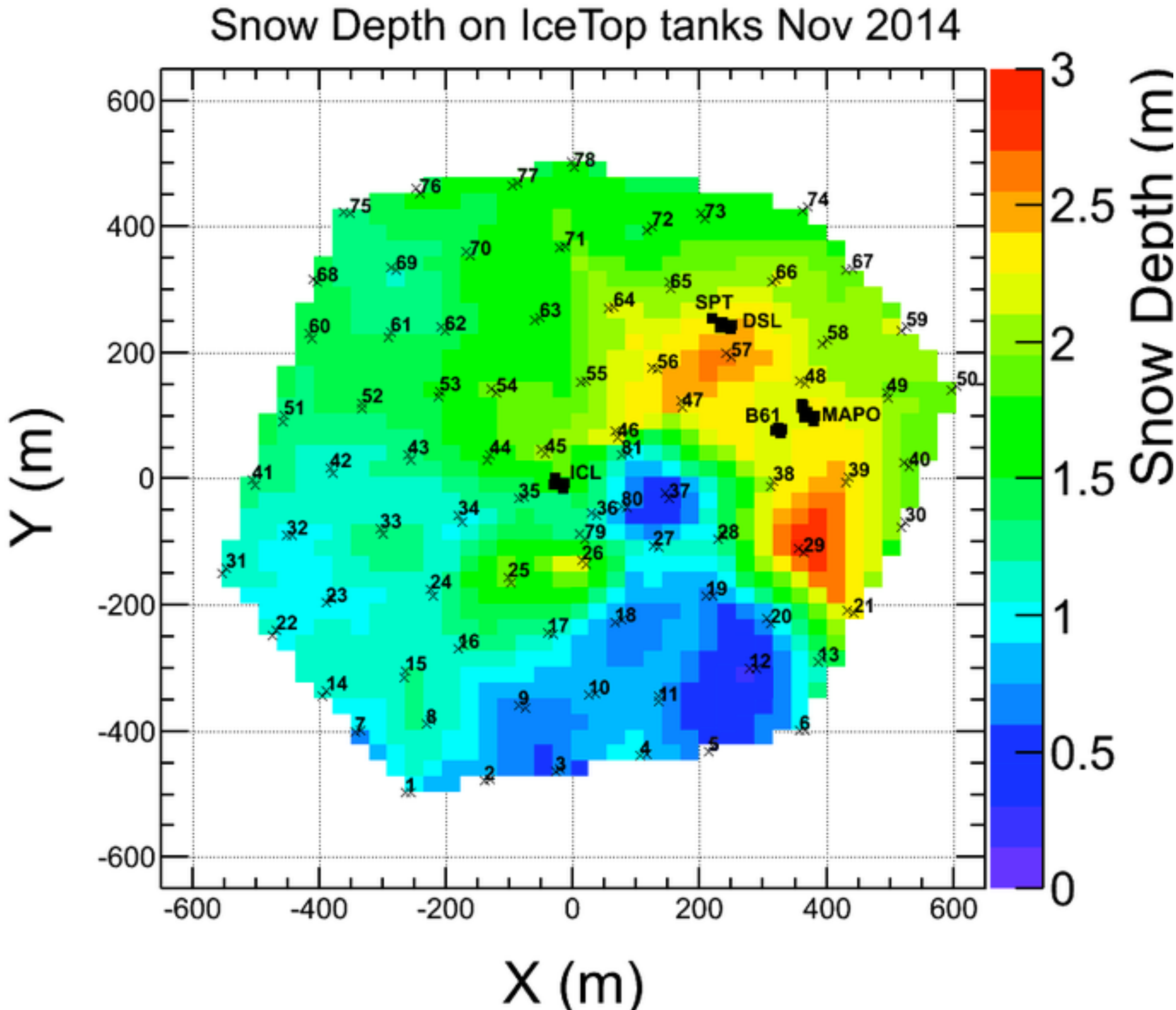
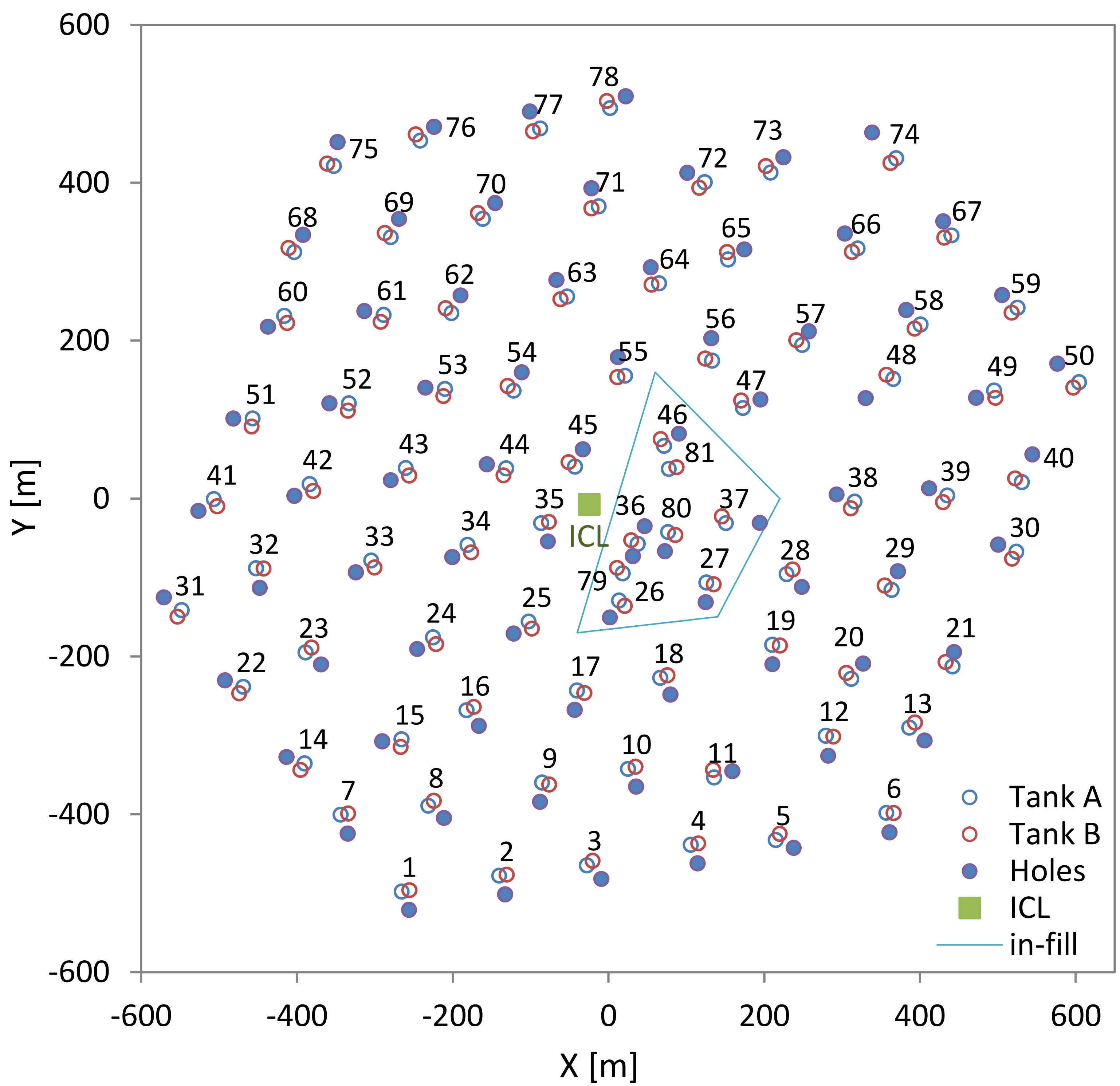


Snow Depth on IceTop tanks Nov 2014
Y (m)
X (m)
Snow Depth (m)
SPT
DSL
B61
MAPO
ICL



(slide from Tom G.)

Summary

- The *folklore* that, to identify astrophysical neutrinos of energy E, we need to veto air showers of energy 10×E or 5×E might be misleading.
- For small passing rates, we might need:
  - to veto primaries of the same energy
  - a denser detector than expected.
- We need to understand extreme, not average, air showers.
- Deep showers are an example of extreme showers.
  Assuming λ=70 g/cm^2, 0.1% of protons survive 490 g/cm^2
  Their footprint might be very small.
- This has implications on where to locate scintillators on IceTop:
  - distances between detectors should be small (<<125 m)
  - Maybe better to start around stations 79, 80, 81
  - May be a good idea to not always place the scintillators on top of IceTop stations