Simulation Studies for a Surface Veto Array to Identify Astrophysical Neutrinos at the South Pole

The IceCube-Gen2 Collaboration

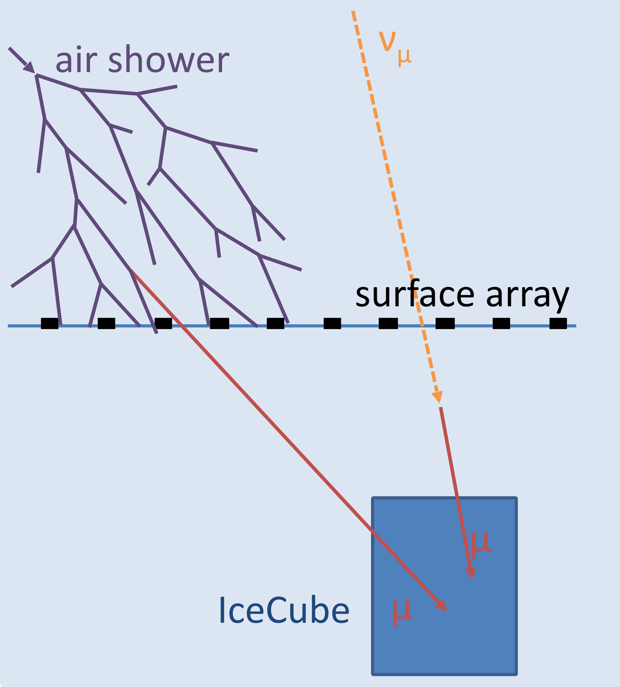
Corresponding authors: Sebastian Euler[1], Javier Gonzalez[2], Ben Roberts[3]

[1]Dept. of Physics and Astronomy, Uppsala University, Sweden

[2]Bartol Research Institute, University of Delaware, USA

[3]Dept. of Physics and Astronomy, Canterbury University, Christchurch, New Zealand

A Surface Veto for IceCube

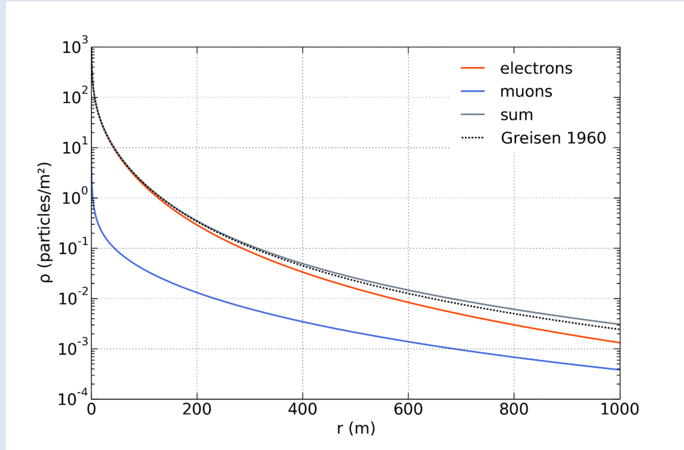


Crucial in the IceCube detection of astrophysical neutrinos is the reduction of background by veto techniques, either by using the outer layers of the detector [1], or with an array on the surface to tag particles of atmospheric origin by detecting the accompanying air shower. We follow two strategies:

- Fast simulations based on lateral distribution functions.
- Detailed CORSIKA [2] simulations.

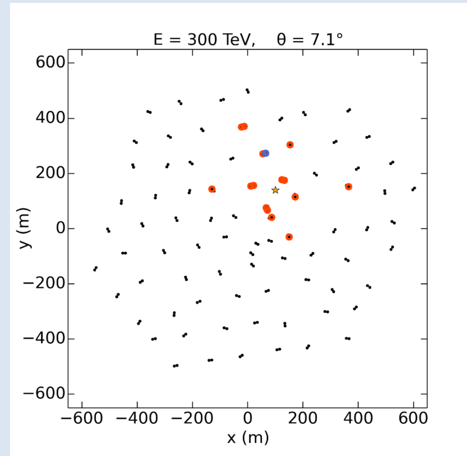
LDF-based Monte Carlo simulation

The basis of the simulations are lateral distribution functions (LDFs) [3,4], describing the particle density of the electromagnetic and muonic components of air showers of a given energy. The LDFs are evaluated at the positions of simulated detector stations, and the Poisson probability for a "hit" is calculated. 10 000 showers are simulated at each point in the (θ, E) parameter space . The array is "triggered" by a shower if at least one hit is detected.



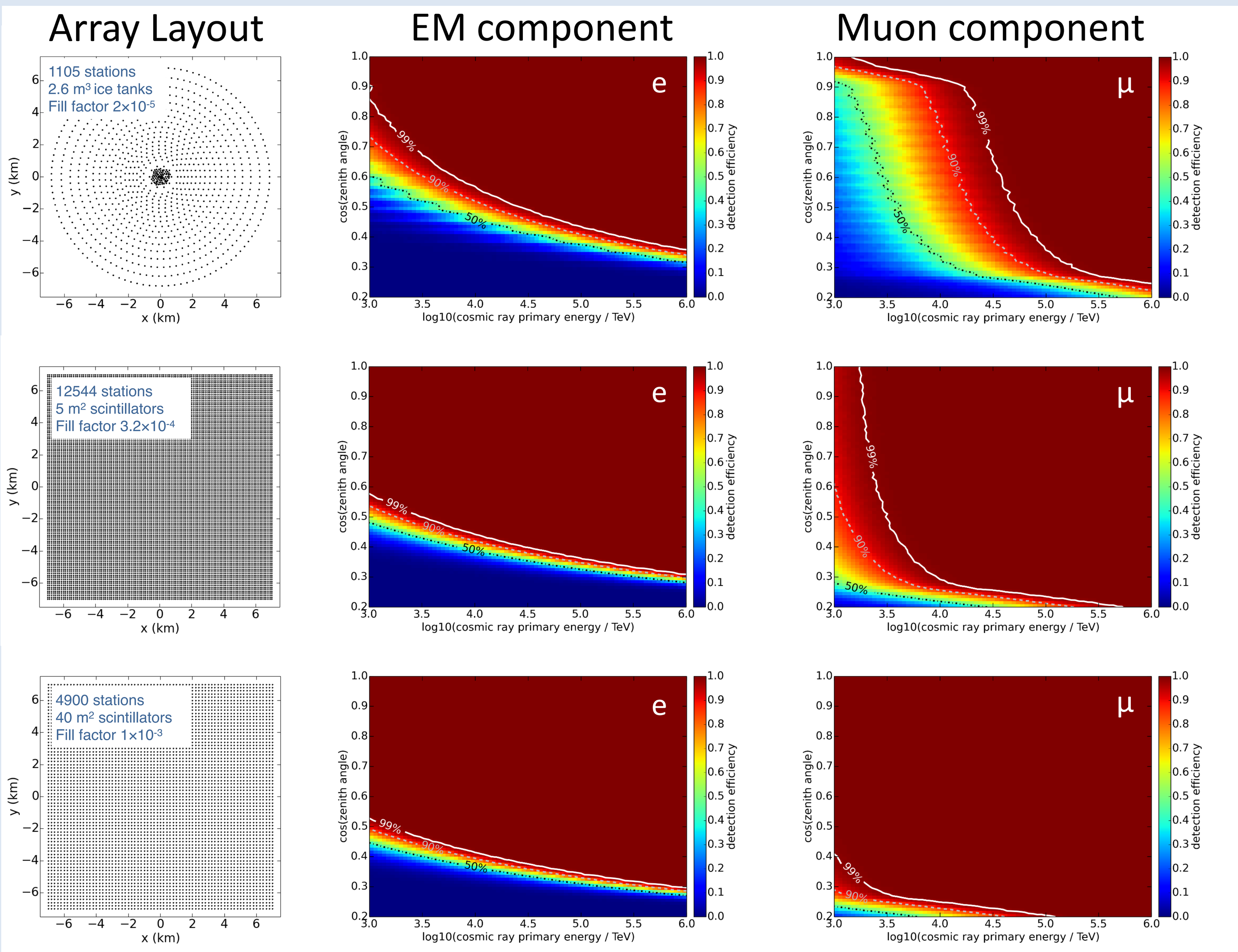
▲ Example LDFs (near-vertical, E_{prim} = 300 TeV)

The approach takes into account the atmospheric depth varying with inclination, the size of the detector station and its apparent change with inclination, but assumes pure proton primaries. This approach relies on average air shower properties and thus by construction ignores extreme air showers, even though they become important for a high-efficiency veto.



IceTop footprint of the same shower. ▶
Orange: electron hits, blue: muon hit.

Results from the LDF-based simulation



▲ detection efficiencies, obtained with the LDF-based Monte Carlo simulation for three geometries.

Three different array configurations are studied:

- IceVeto, an extension of the existing IceTop array, 943 additional IceTop-like tanks.
- 125 m rectangular grid array with 5 m² scintillators at each station.
- 200 m array with very large 40 m² scintillators.

All geometries cover the elevation of the Galactic Center (θ = 61˚).

Qualitatively, two distinct regimes for a surface veto:

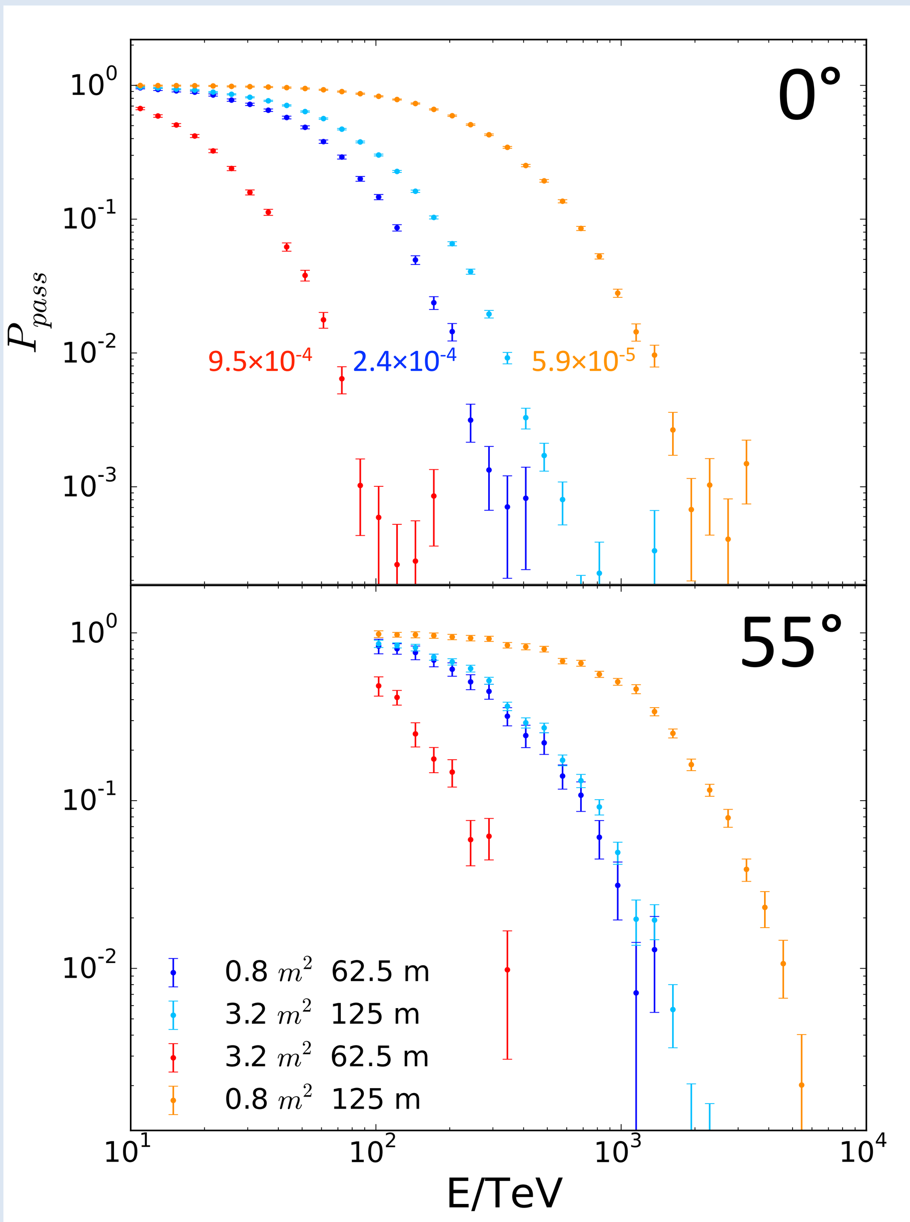
- **Vertical case**: Detection efficiency is larger for **EM component**
- **Inclined case:** Detection efficiency is larger for **muon component** as the large atmospheric depth causes the EM component to die out.

(The 99% lines cross at about $10^{3.5}$ TeV and cos(θ)≈0.5 in the case of the 125 m array.)

IceVeto geometry becomes efficient from muons at primary energies above 10 PeV. A higher instrumentation density shifts the distributions toward lower energies. Only the 200 m grid array with the largest collection area is more than 99% efficient over almost the whole parameter space.

In the future we plan to update this simulation with more recent LDFs [5,6].

Air Shower Passing Fraction



($P_{pass} = 1 - P_{det}$)
fill factors marked in color

CORSIKA simulations

Using CORSIKA and Sibyll 2.1.
Detector: Regular triangular grid array of scintillation detectors 1 cm thick.
Considering various array spacings and detector areas.

Vertical case (0°):

- threshold determined by the sensitivity to the EM component,
- it depends on the snow accumulation.
- Thresholds as low as 100 TeV seem attainable with a fill factor of 10^{-3}, and reasonable array spacing and size.

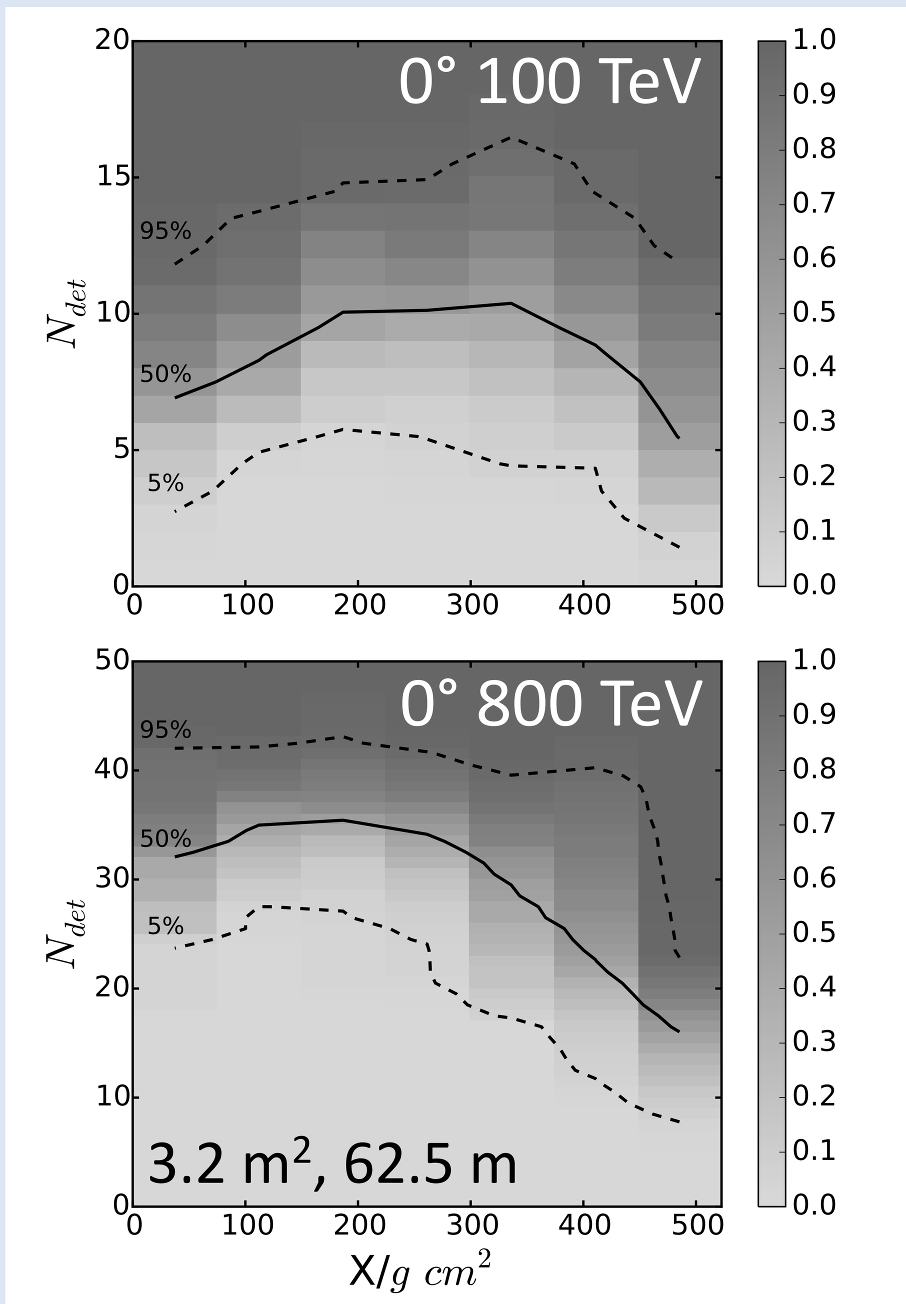
Mildly inclined case (55°):

- threshold starts to depend on the sensitivity to muons,
- threshold is larger by about a factor of 4 at 55˚.

Need to estimate energy at which passing fraction is around 10^{-4} to 10^{-6} [7]
Sensitive to very rare events!

Passing fraction determined mostly by the primary point of first interaction.
Currently studying the effect of the subsequent air shower development.

Dependence on First Interaction Point



[1] M. G. Aartsen et al., Science 342, 1242856 (2013)
[2] D. Heck et al., FZKA Report 6019 (1998)
[3] Thomas K. Gaisser, *Cosmic Rays and Particle Physics*, Cambridge University Press (1991)
[4] K. Greisen, Ann.Rev.Nucl.Sci. 10 (1960) 63-108
[5] IceCube Collaboration, *Surface muons in IceTop*, paper 363, ICRC 2015
[6] IceCube Collaboration, *Studying Cosmic Ray Composition with IceTop using Muon and Electromagnetic Lateral Distributions*, paper 806, ICRC 2015
[6] IceCube Collaboration, *IceTop as Veto for IceCube*, paper 807, Board #261 in this session, ICRC 2015

University of Delaware

Uppsala Universitet