Enhanced sensitivity to astrophysical neutrinos with a surface veto array above IceCube

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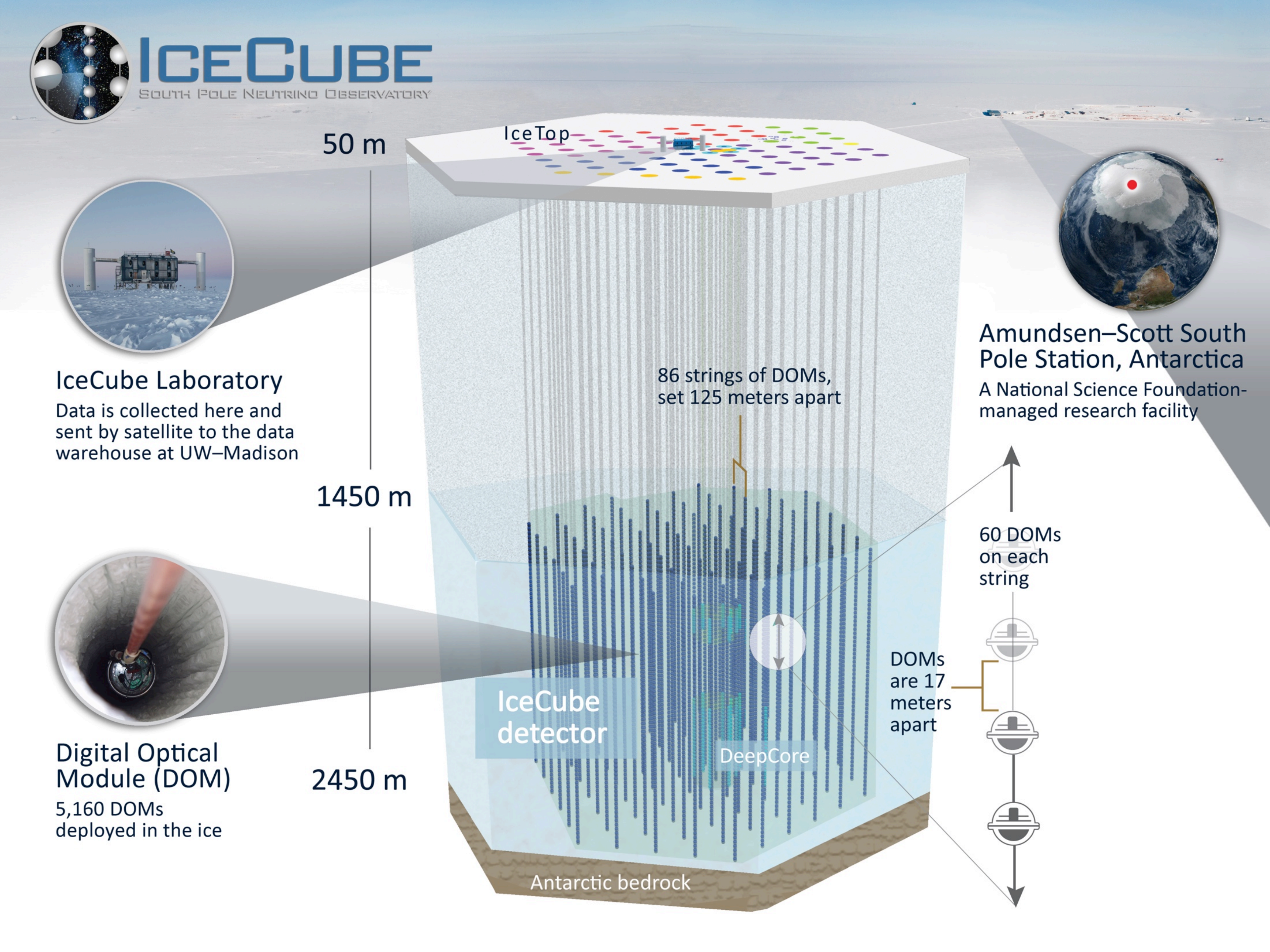
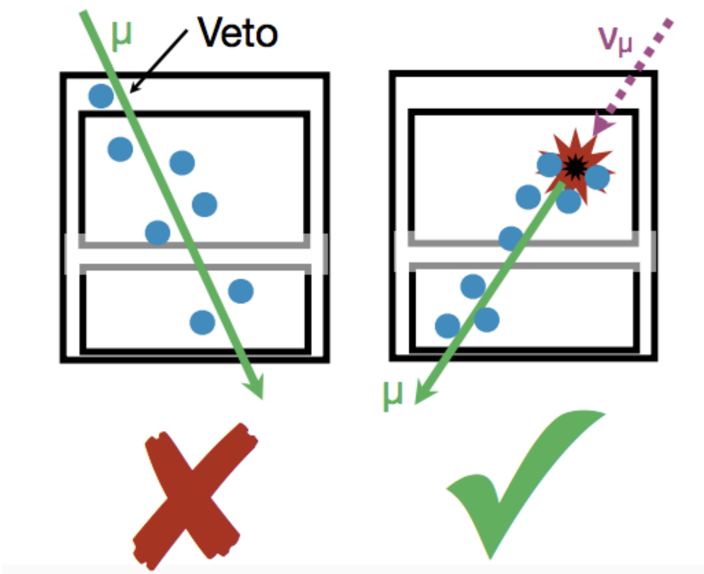
TeV Particle Astrophysics 2015

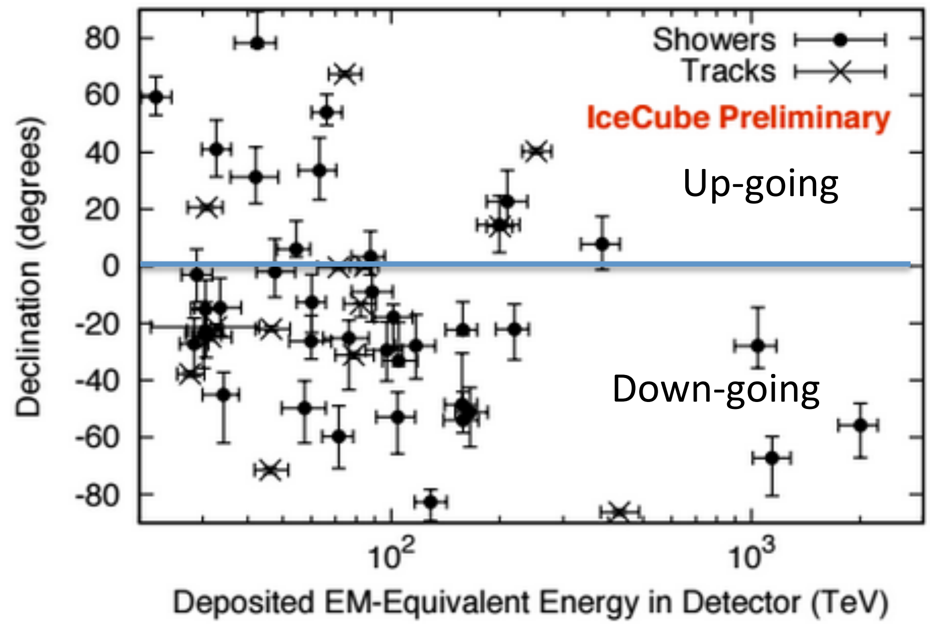
Kashiwa, Japan


ICECUBE
South Pole Neutrino Observatory
IceTop
50 m
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
Antarctic bedrock

The astrophysical neutrino flux

Science 342 (2013) 1242856
PRL 113.101101 (2014)
PoS(ICRC2015)1081





- High energy neutrinos are absorbed in the earth
- Above 10 TeV neutrino energy we expect as many down-going neutrinos as up-going
- Most down-going neutrinos are rejected by the self-veto since they interact above instrumented volume
- A surface veto array could help detect twice as many neutrinos as IceCube alone

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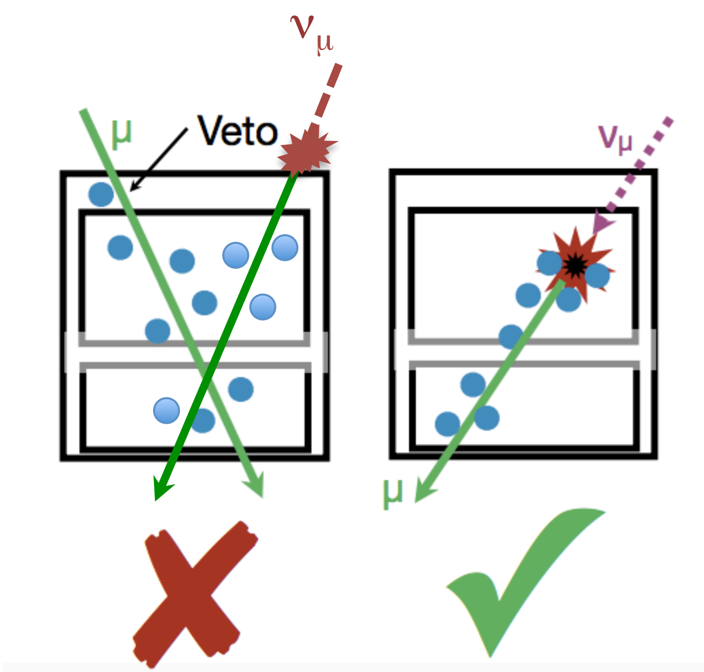

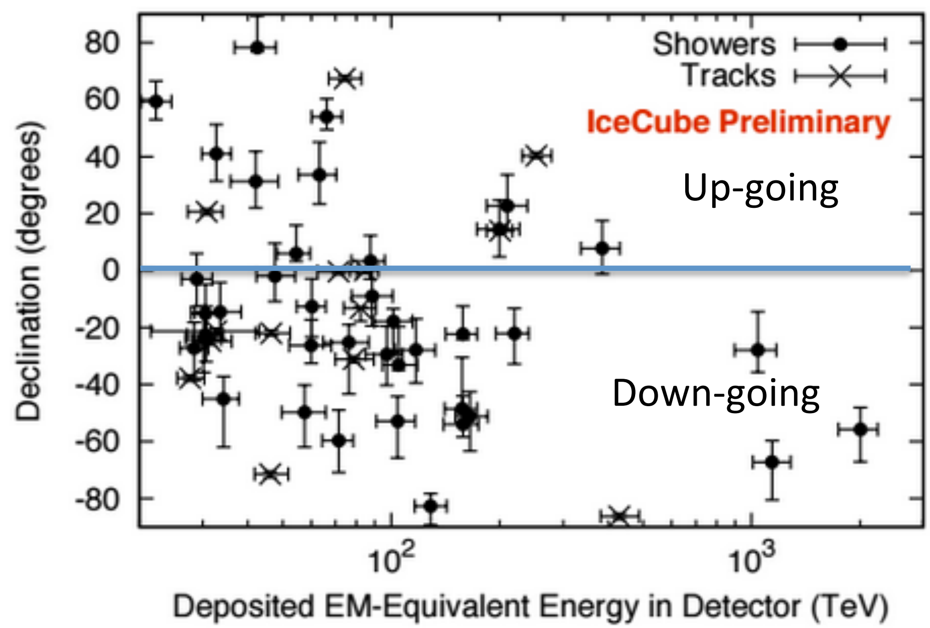

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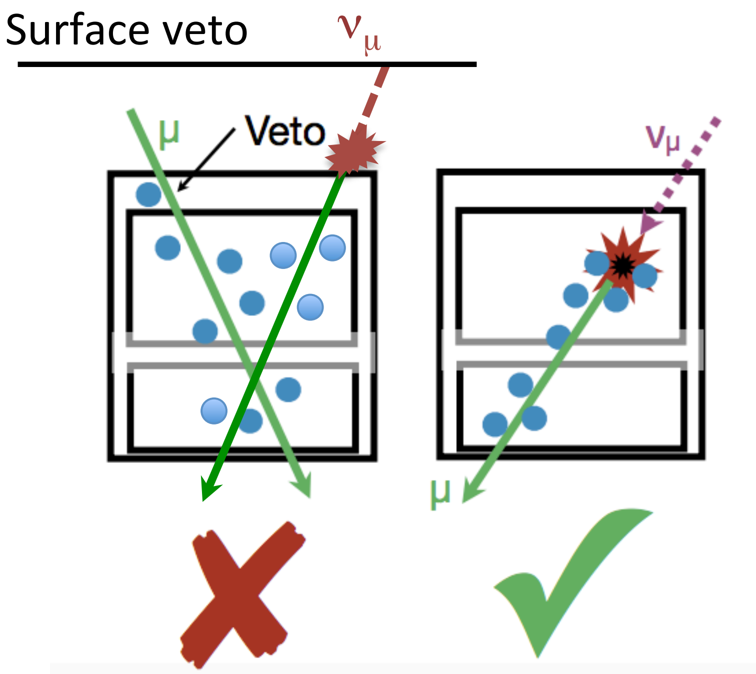

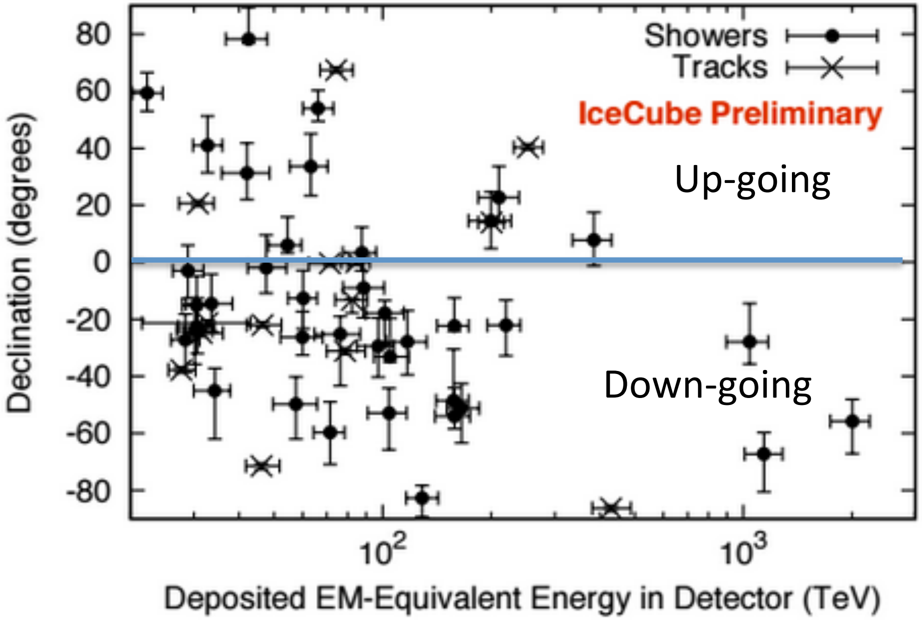

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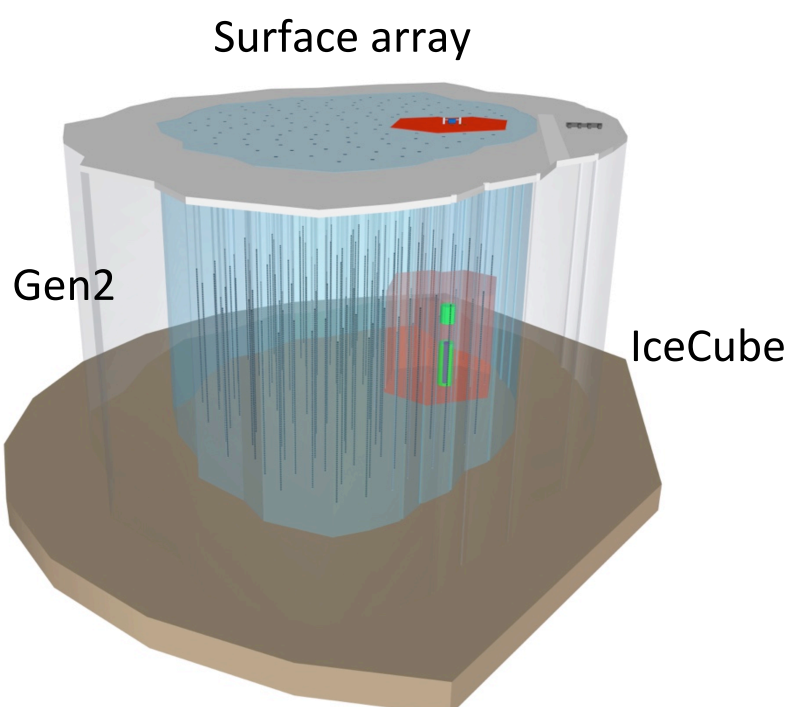
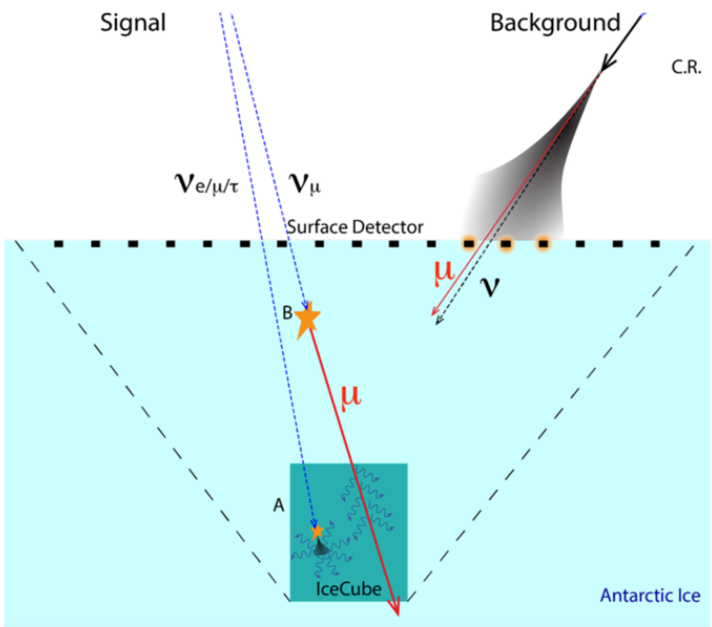
An extended surface array

White paper:
arxiv.org/abs/1412.5106

- IceCube is planning an extension array including a low energy infill, a high energy in-ice array, a radio component and a surface array
- Multiple efforts are currently underway to design a surface array able to serve as veto for the in-ice detector [PoS(ICRC2015): 1070,1156]
- This talk focuses specifically on one of these analysis

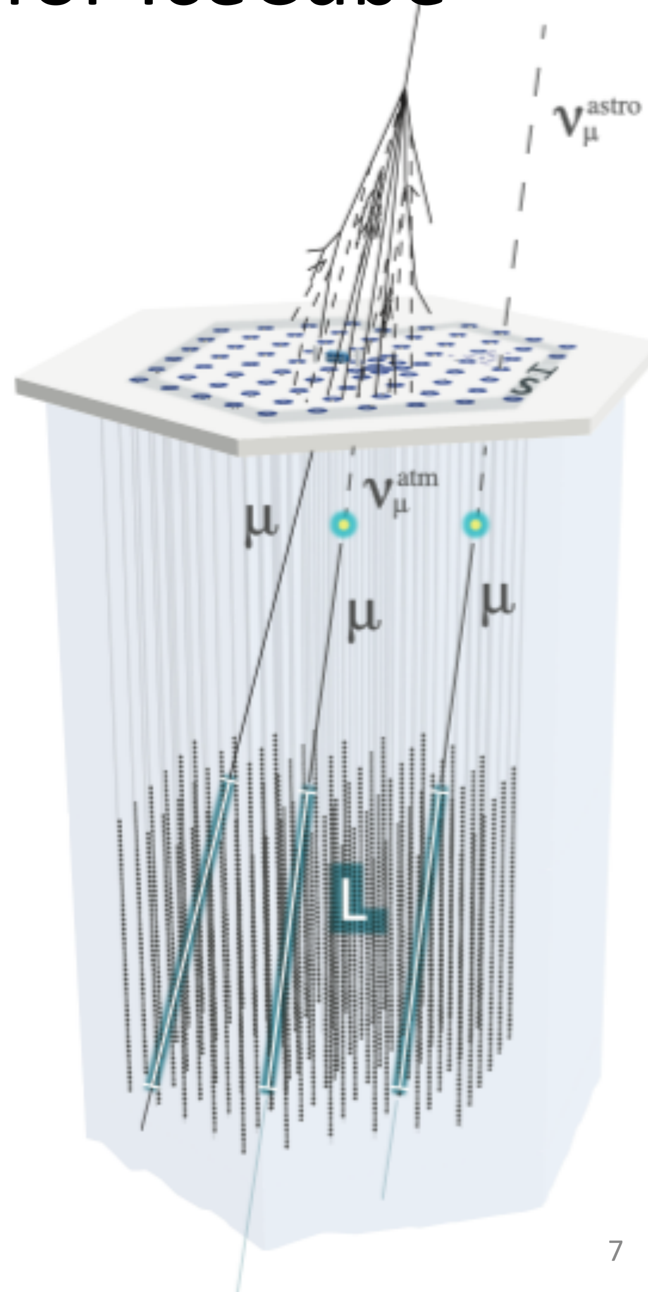




Performance of IceTop as veto for IceCube

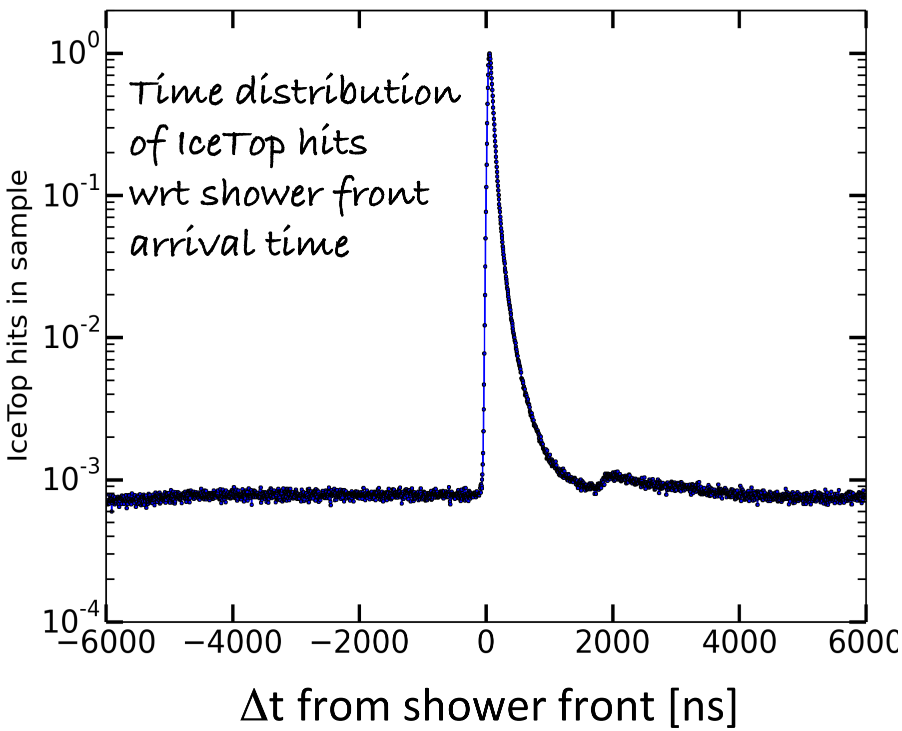
- IceTop is an array of tanks, equipped with DOMs, which was designed primarily to study cosmic ray physics
- This analysis aims to study its efficiency as veto, as a reference point for the design of a future surface array
- Select near vertical tracks:
  - Number of pe recorded in detector> 1000
  - Track length > 800 m
  - Surface intersection point inside IceTop border by 75 m

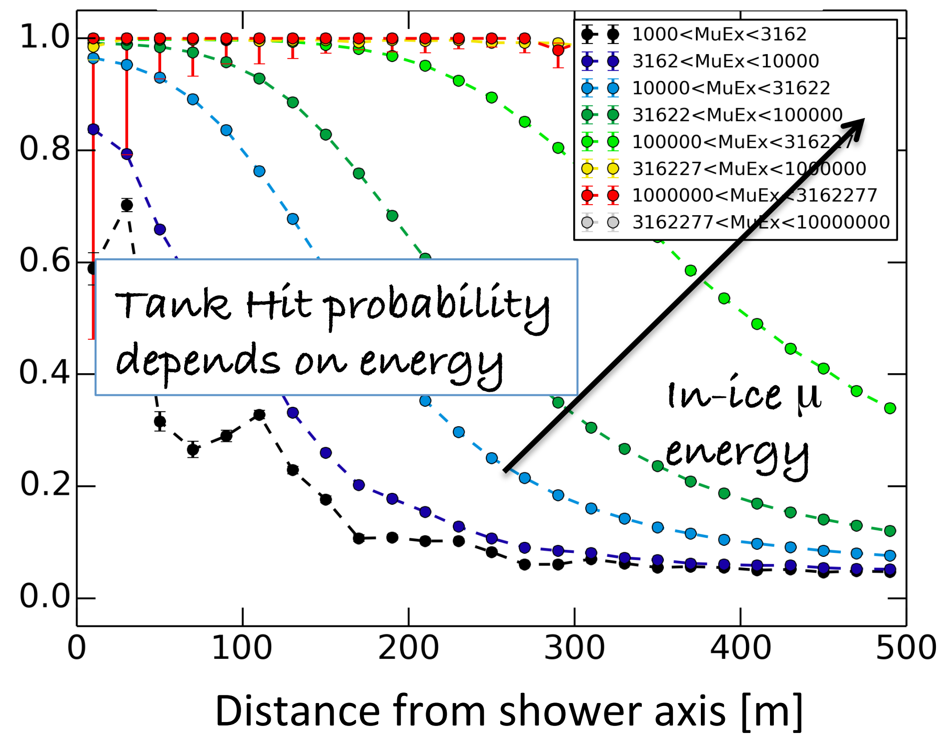
  ➔ CR showers, atm ν, astro ν
- Use IceTop information to separate astro ν from the rest



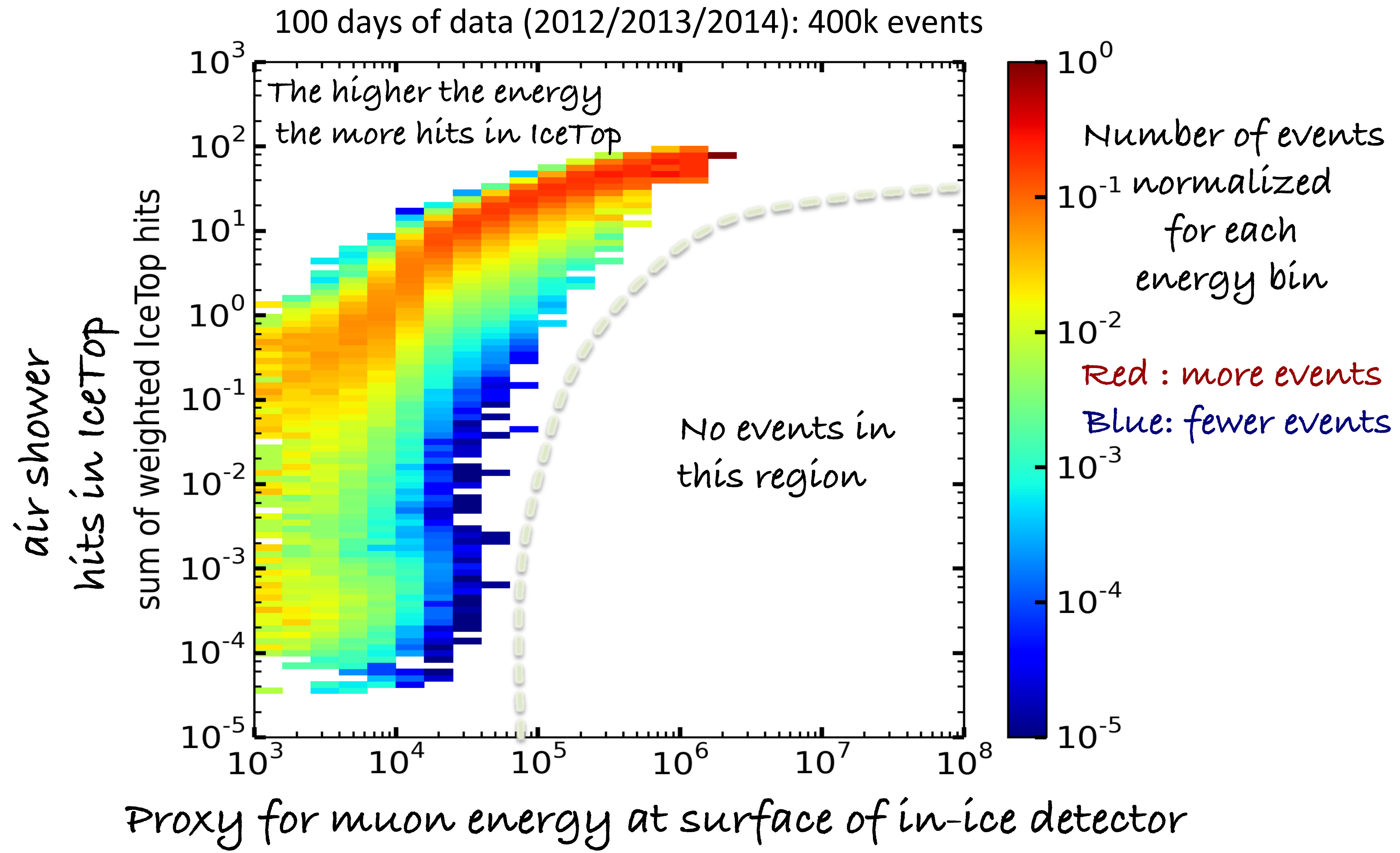
Weighting IceTop hits

- An IceTop hit is more likely to be correlated to a CR shower if close in time to the shower front and close in space to the shower axis
- For each event, every IT hit recorded gets two weights
- Each event gets a global weight given by the sum of hits (“sum of weighted IceTop hits”): this is used as cut variable





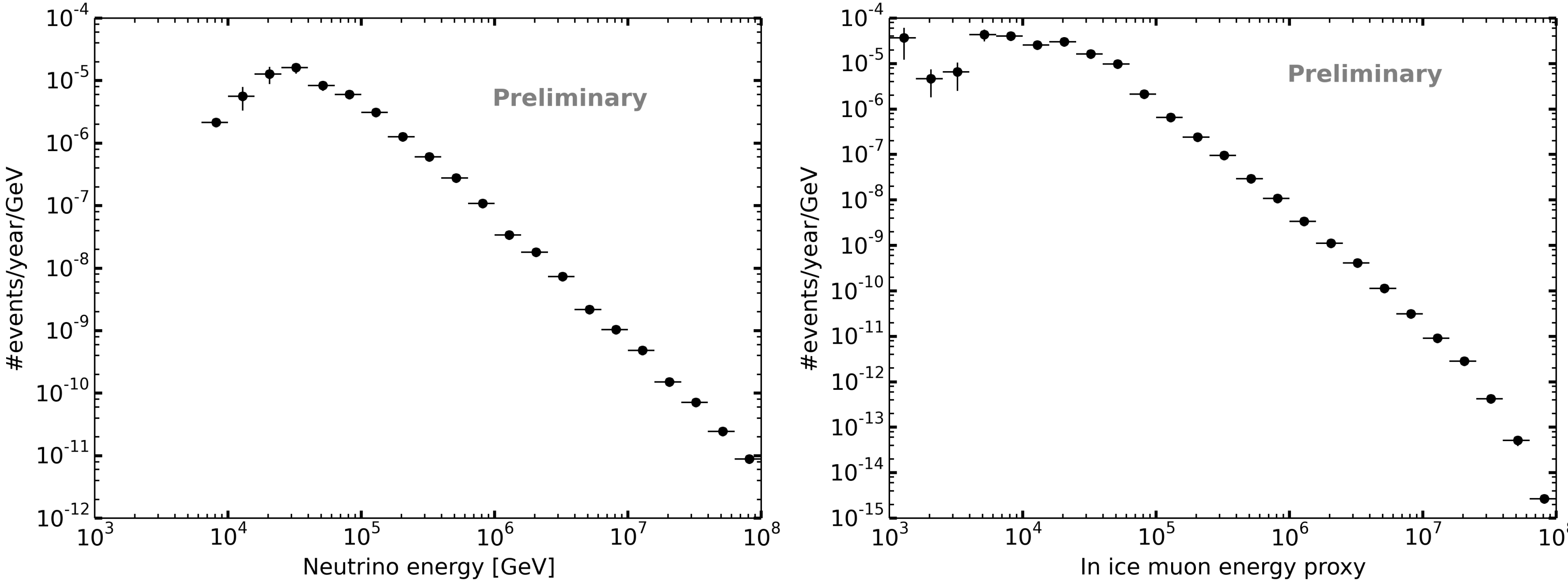
IceTop signal vs in-ice muon energy



Simulation of neutrino signal

- Simulation of neutrino with energy range from 10^2 to 10^9 GeV and zenith angle from 0 to 180 deg processed through same cuts as data
- Weighted to flux model from PoS(ICRCR2014)1064 to determine rates

Differential flux

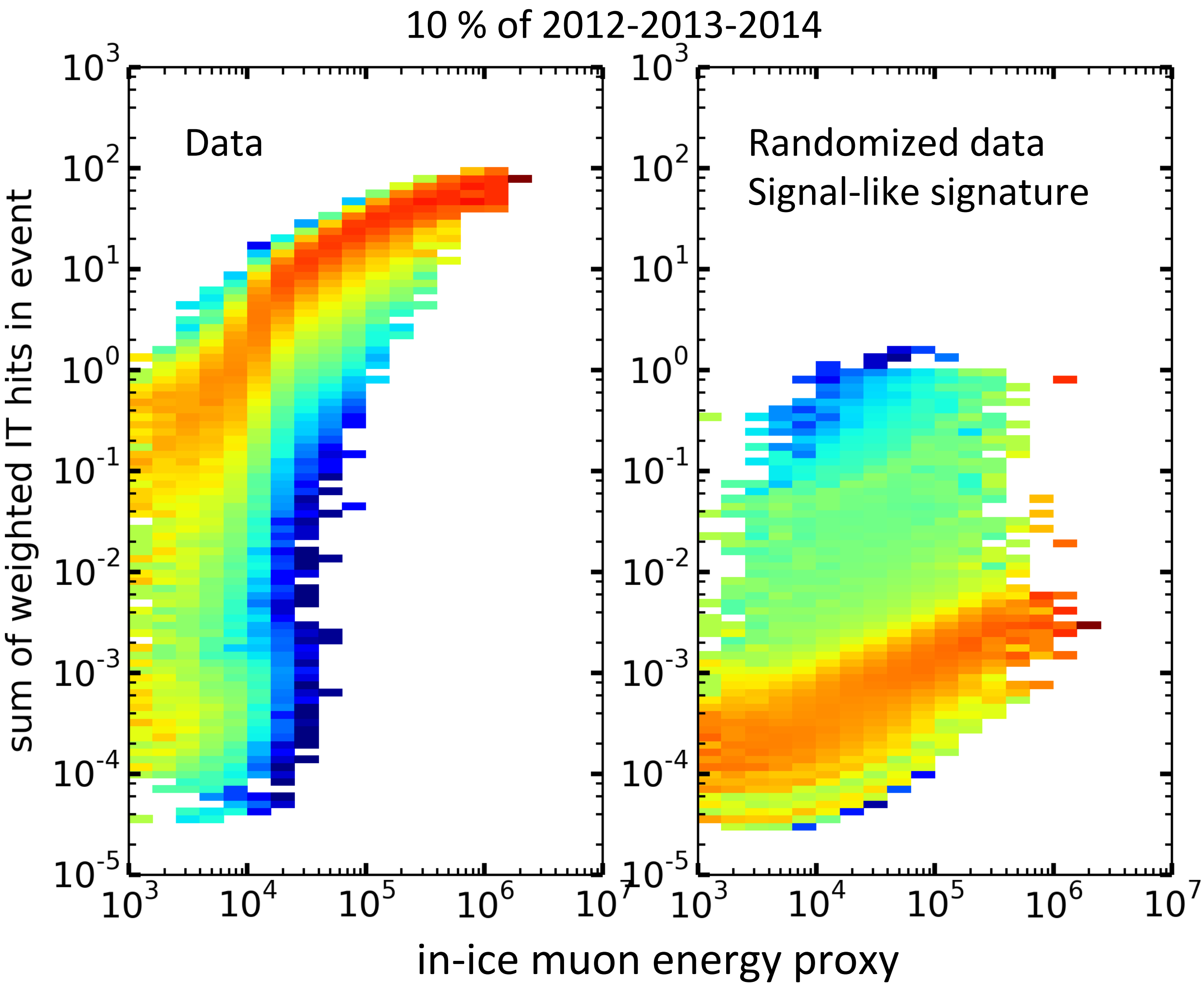


- Since neutrinos won't have hits in IceTop, IceTop hits in data are replaced by random noise hits to simulate noise
  →noise-grafted neutrino-like sample

$$\Phi_\nu = \phi \times \left(\frac{E}{100\,\mathrm{TeV}}\right)^{-\gamma}$$

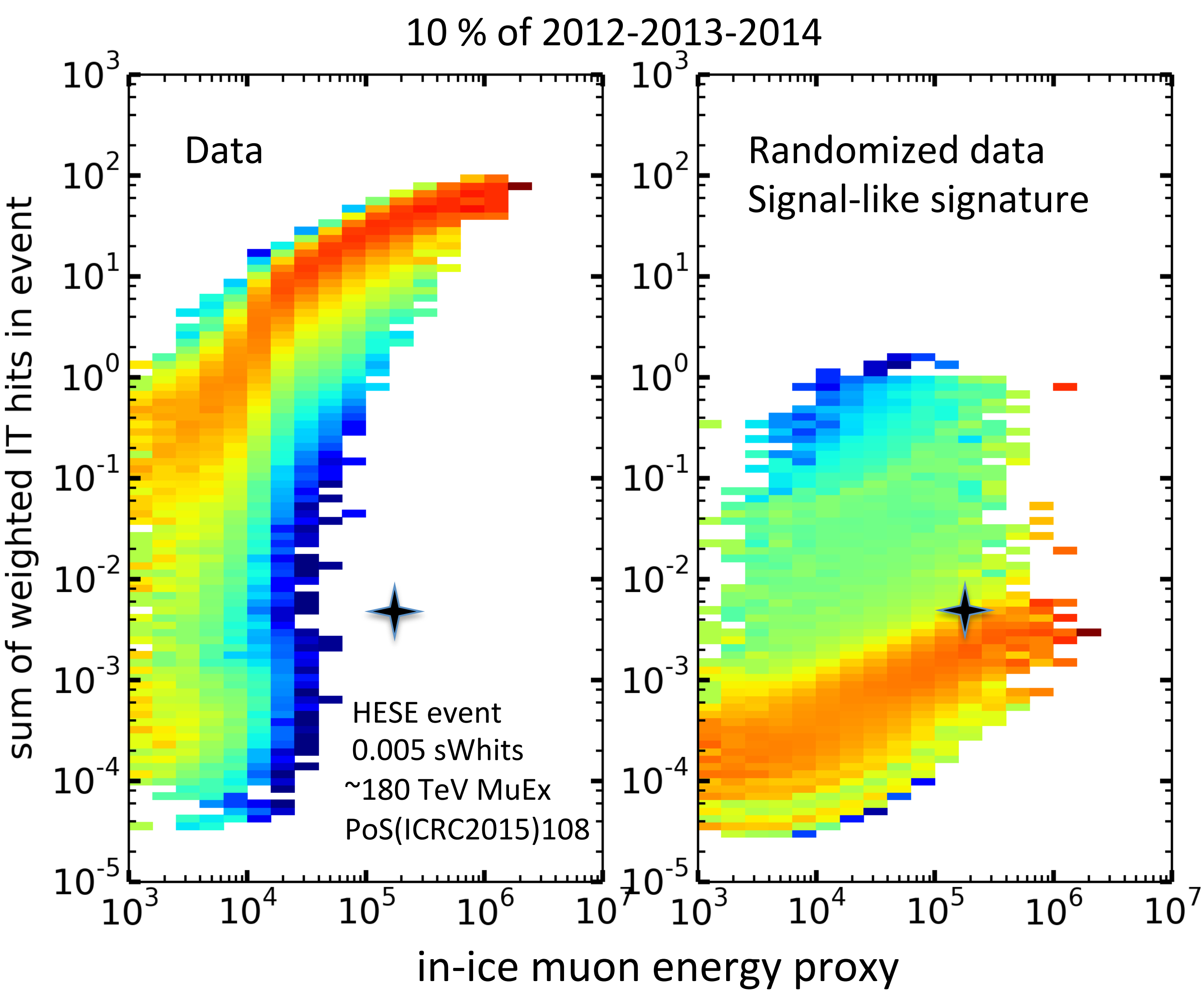
	GlobalFit (ICRC) PoS(ICRC2015)1064
ϕ	1/3*7e-18 $\mathrm{GeV^{-1}s^{-1}sr^{-1}cm^{-2}}$
γ	-2.49

Data vs randomized data



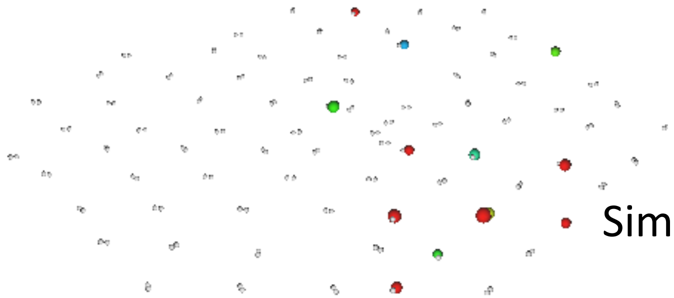
Red : more events
Blue: fewer events

Data vs randomized data

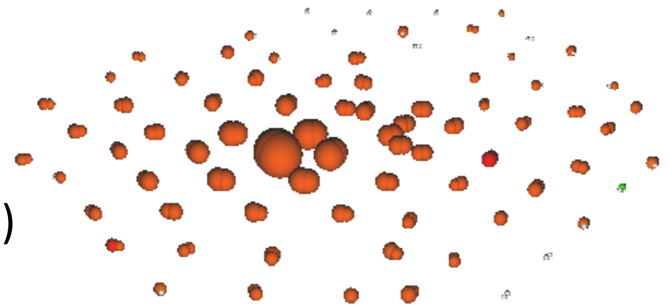


Red : more events
Blue: fewer events

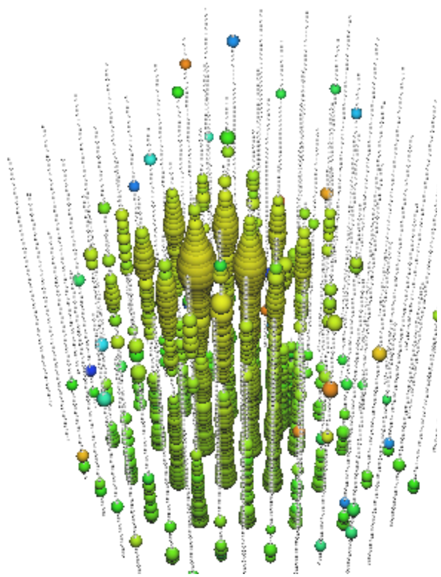
The neutrino candidate vs a typical shower

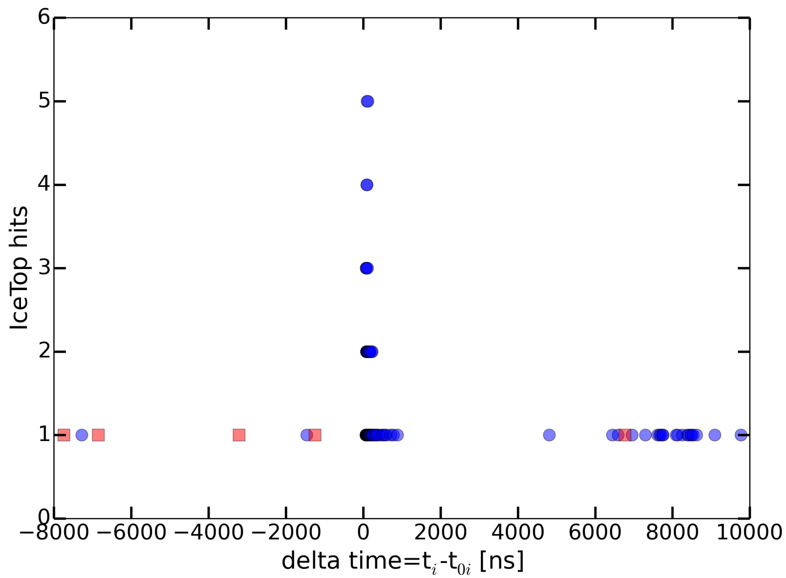


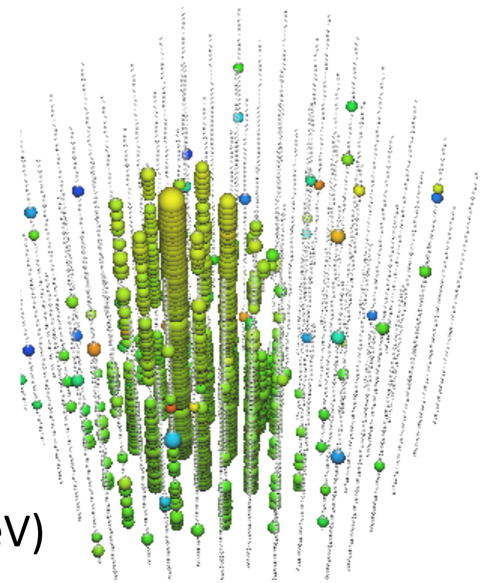
- Similar zenith angle (3 degrees)



Many more IceTop hits



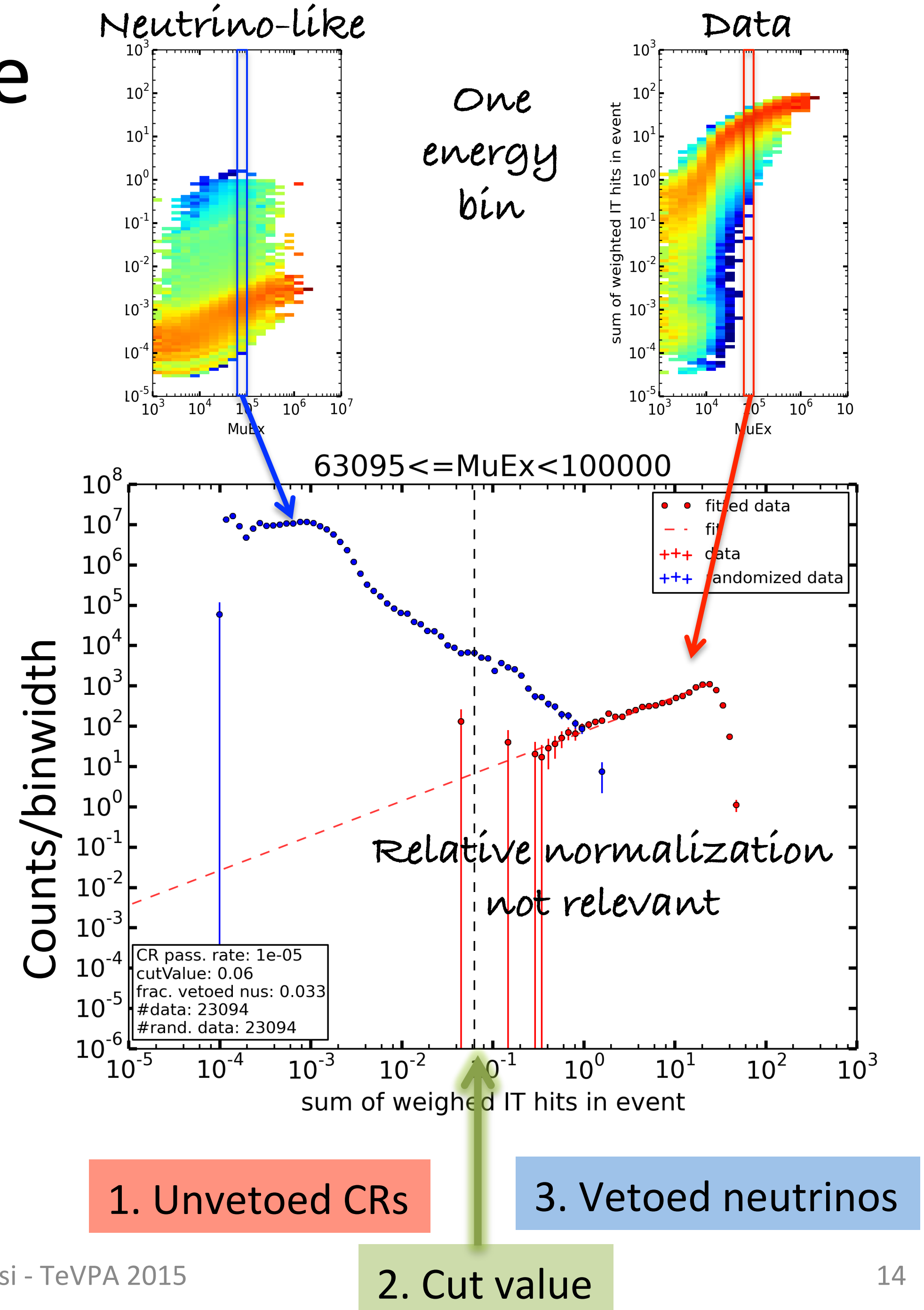




Similar in-ice muon energy proxy (180 TeV)

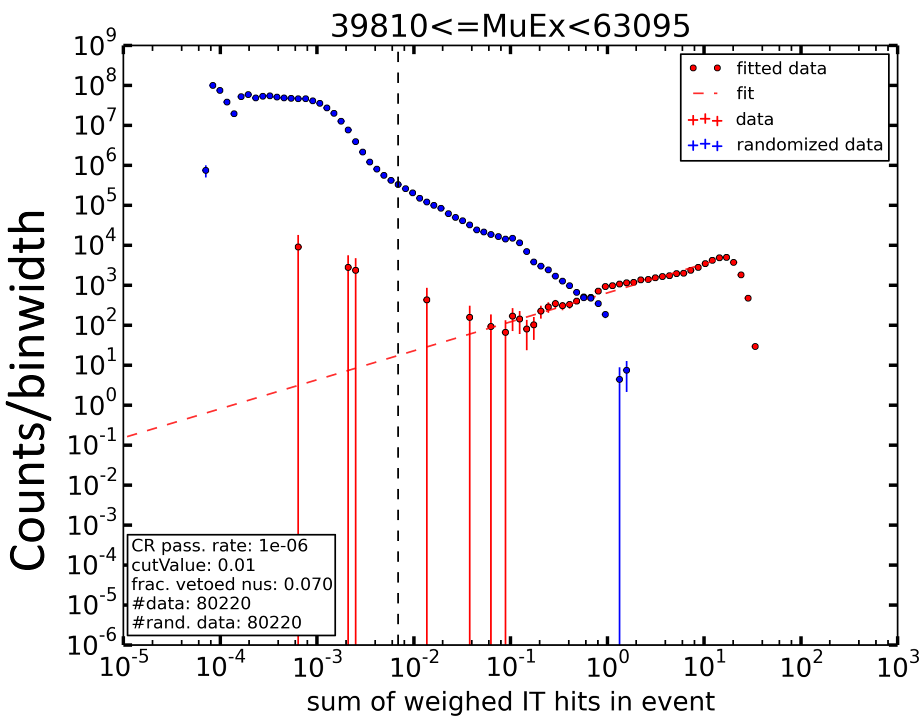
Where to draw the line

1. Assume power law distribution for CR (just because it looks like)
2. Establish desired rejection: R= 99.999%
3. Establish cut such that fit leaves to the left (1-R) of the total CR
   ➔ Everything to the right of cut line is vetoed
4. The fraction of neutrinos accidentally vetoed are to the right of cut line (in this example energy slice, 3.3% neutrinos are lost)



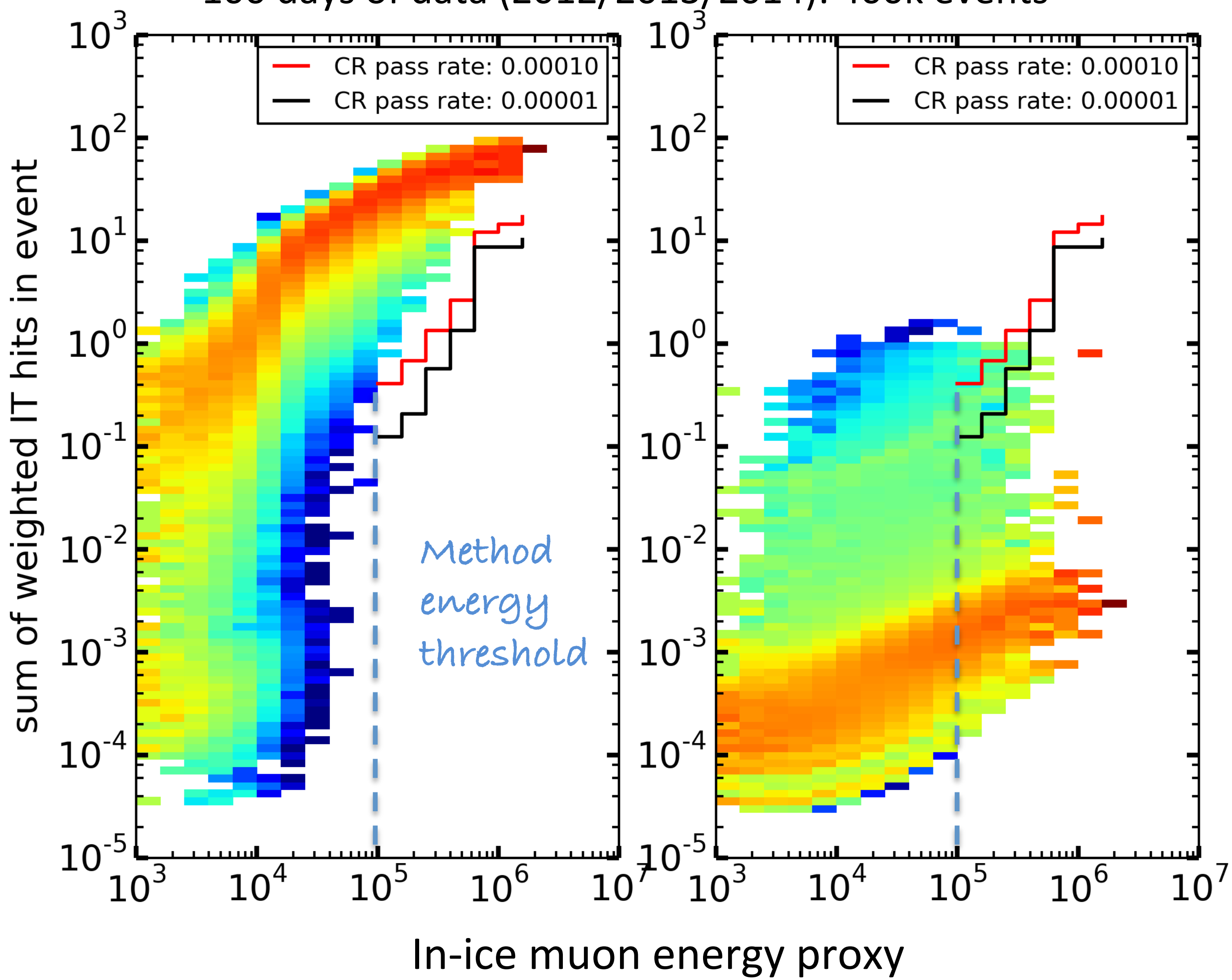
Methods limitations

- Above 60-70 TeV in ice muon energy proxy the method seems to work well
- At lower energies, data shows deviation from power law behavior
- Reasons (under investigation):
  - Small error in the reconstruction timing
  - Single tank hits
  - Neutrinos are naturally mixed in sample



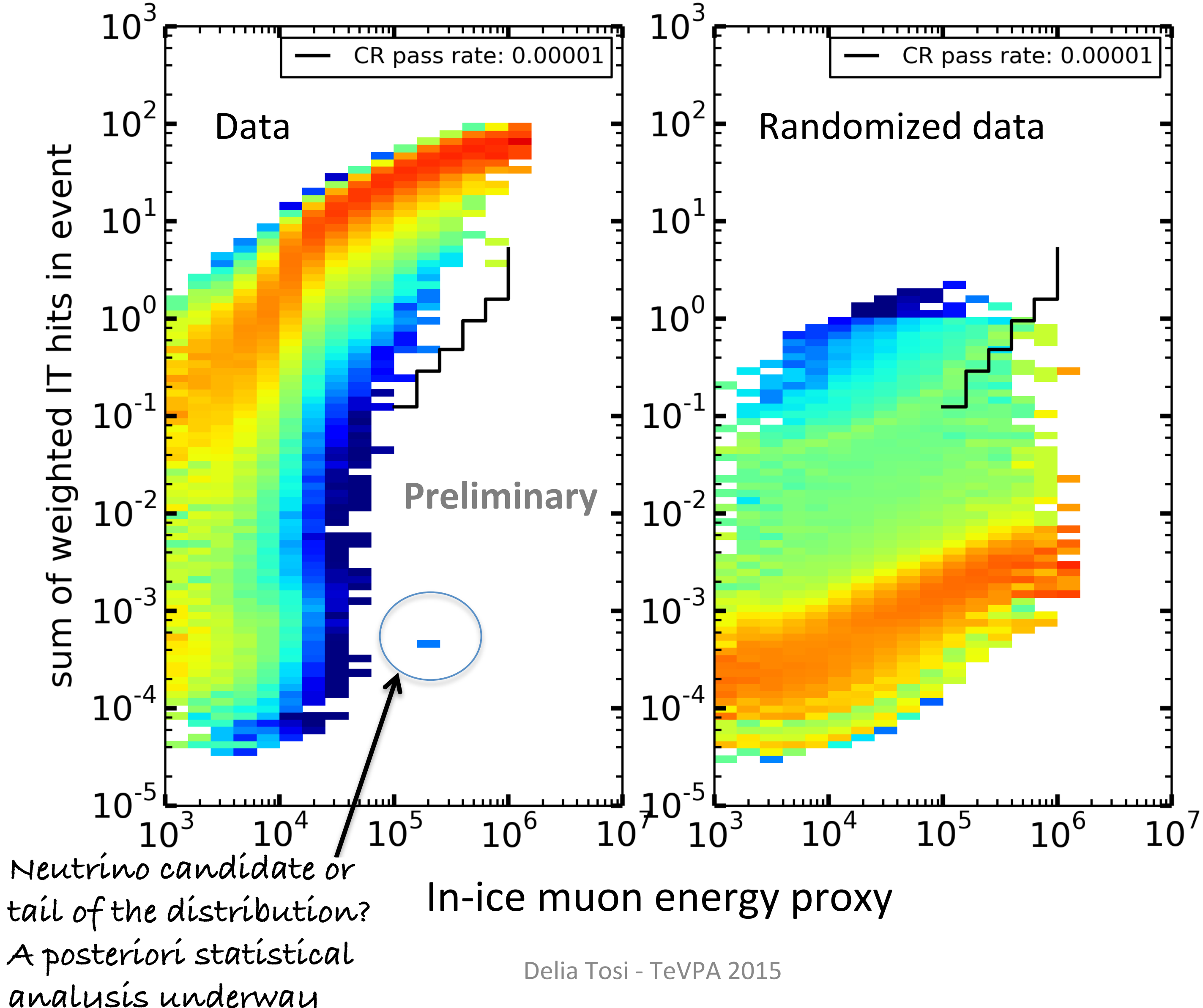
Separation of nu-like/CR populations

100 days of data (2012/2013/2014): 400k events

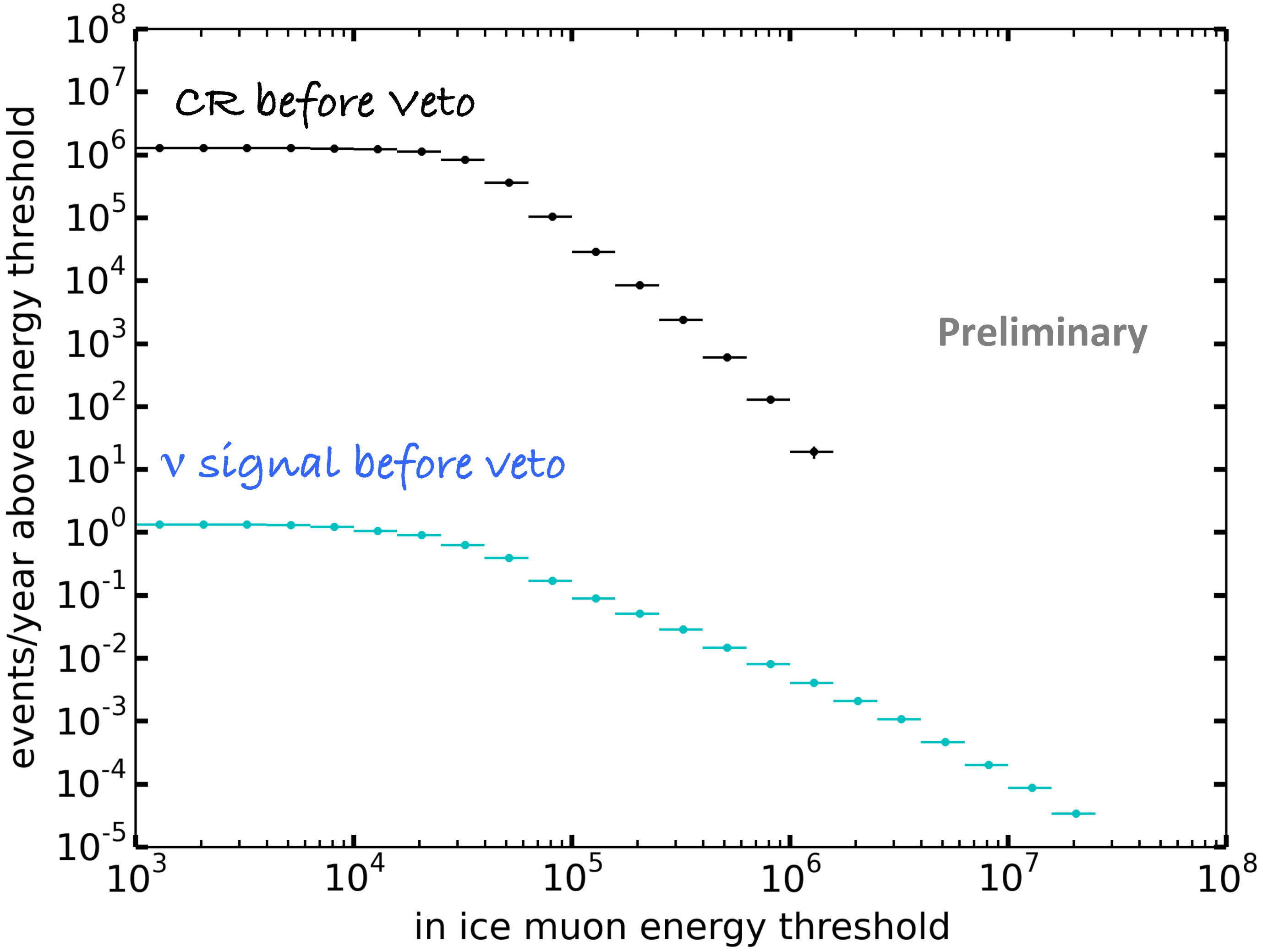


With one year of data

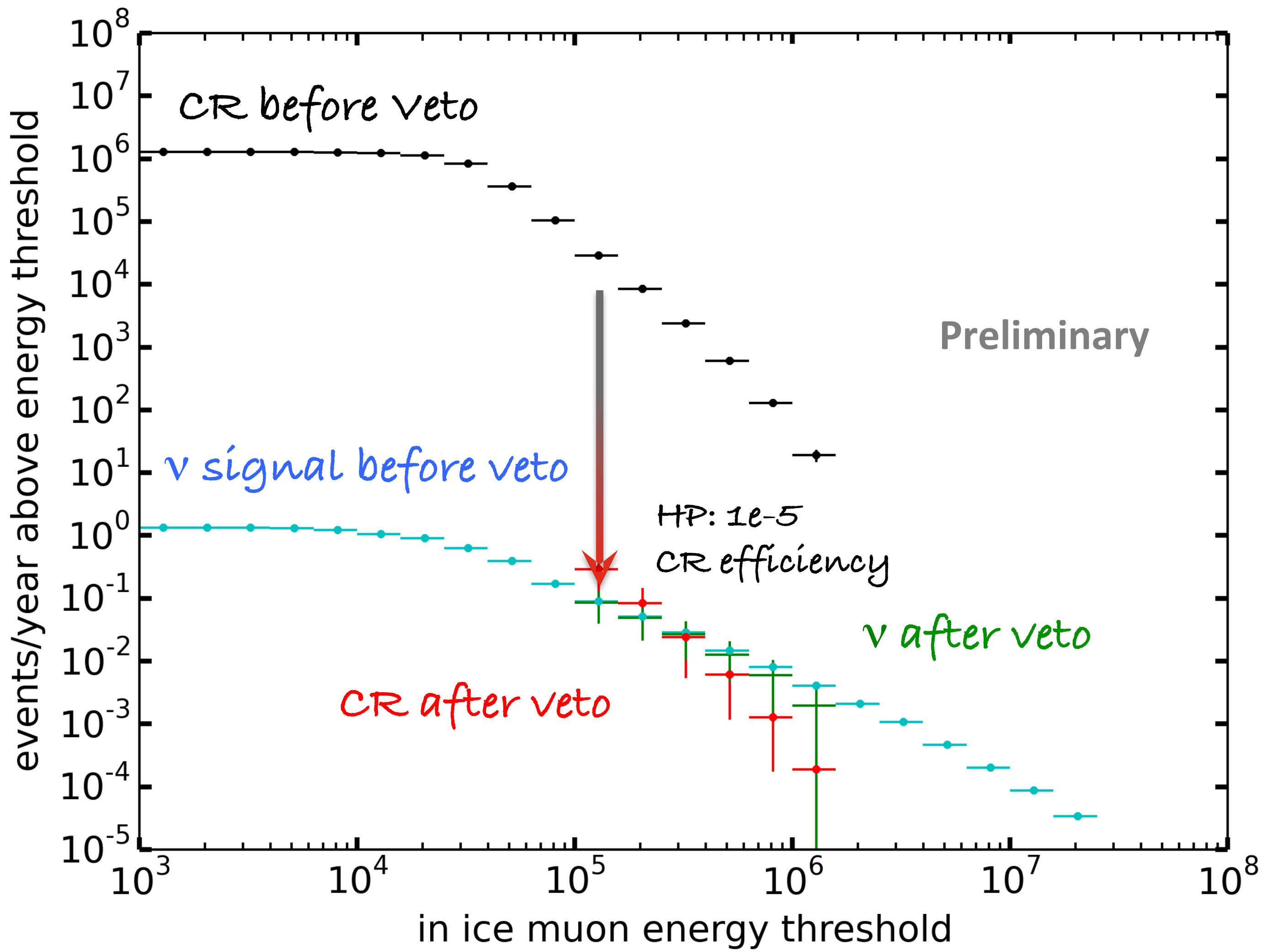
1 year of data (2012): 1.3M events : 30k above 100 TeV , 8.5k above 160 TeV



Signal and background rates



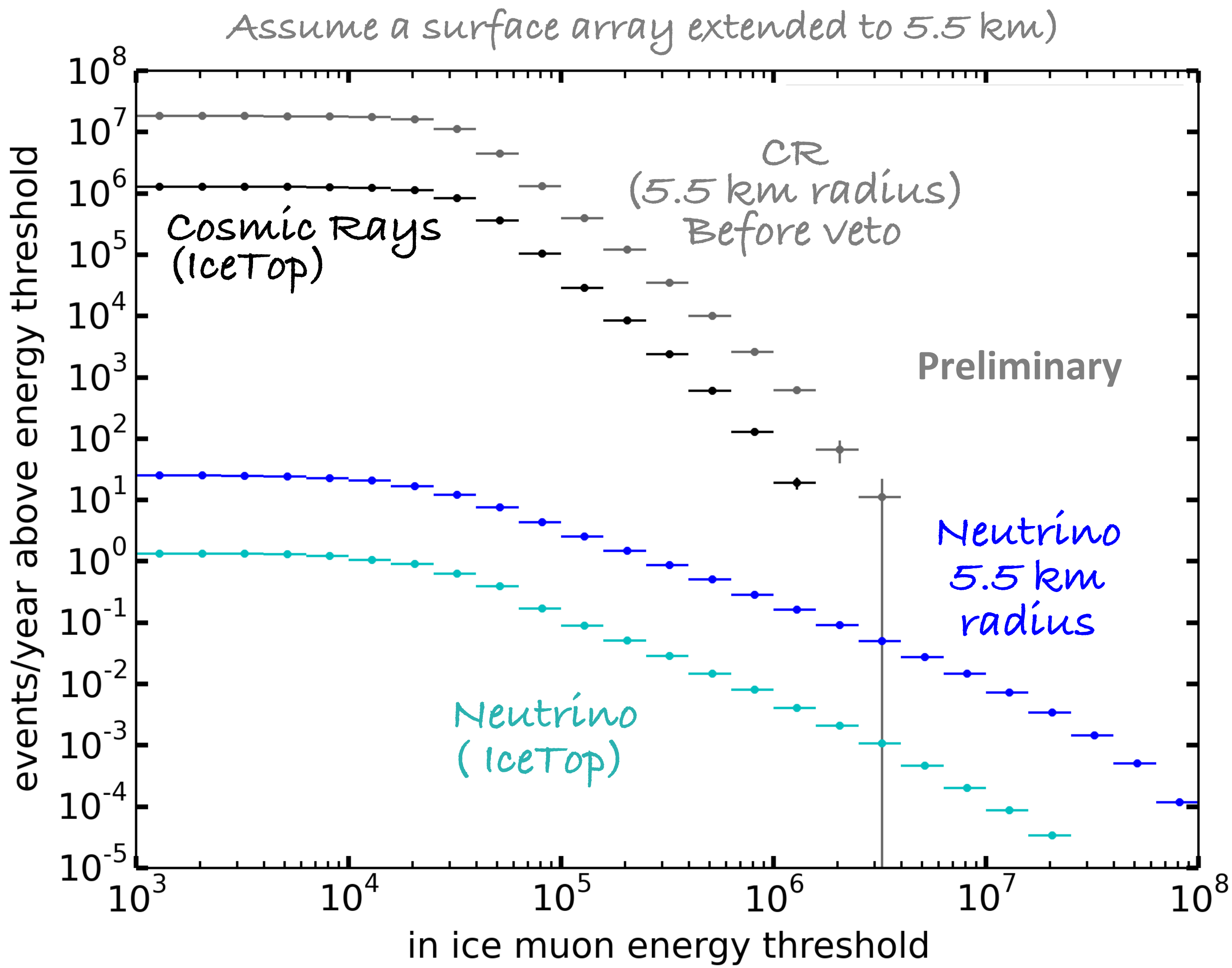
Signal and background rates



Implications for a large surface array

- Remove the containment cuts and accept events up to 5 km from IceTop edges (75 km^2), assuming same rejection efficiency
- Calculate increase in rate over one year for both neutrino simulation and data, and assume same rejection factor
- Simplified approach, not taking into account:
  - For a fixed in-ice muon energy proxy, the average primary energy at larger zenith angles is higher
  - From corsika, the energy threshold of a flat surface detector is higher for large zenith angles
  - CR showers muon/em content depends on zenith

Assume same rejection factor down to 70°



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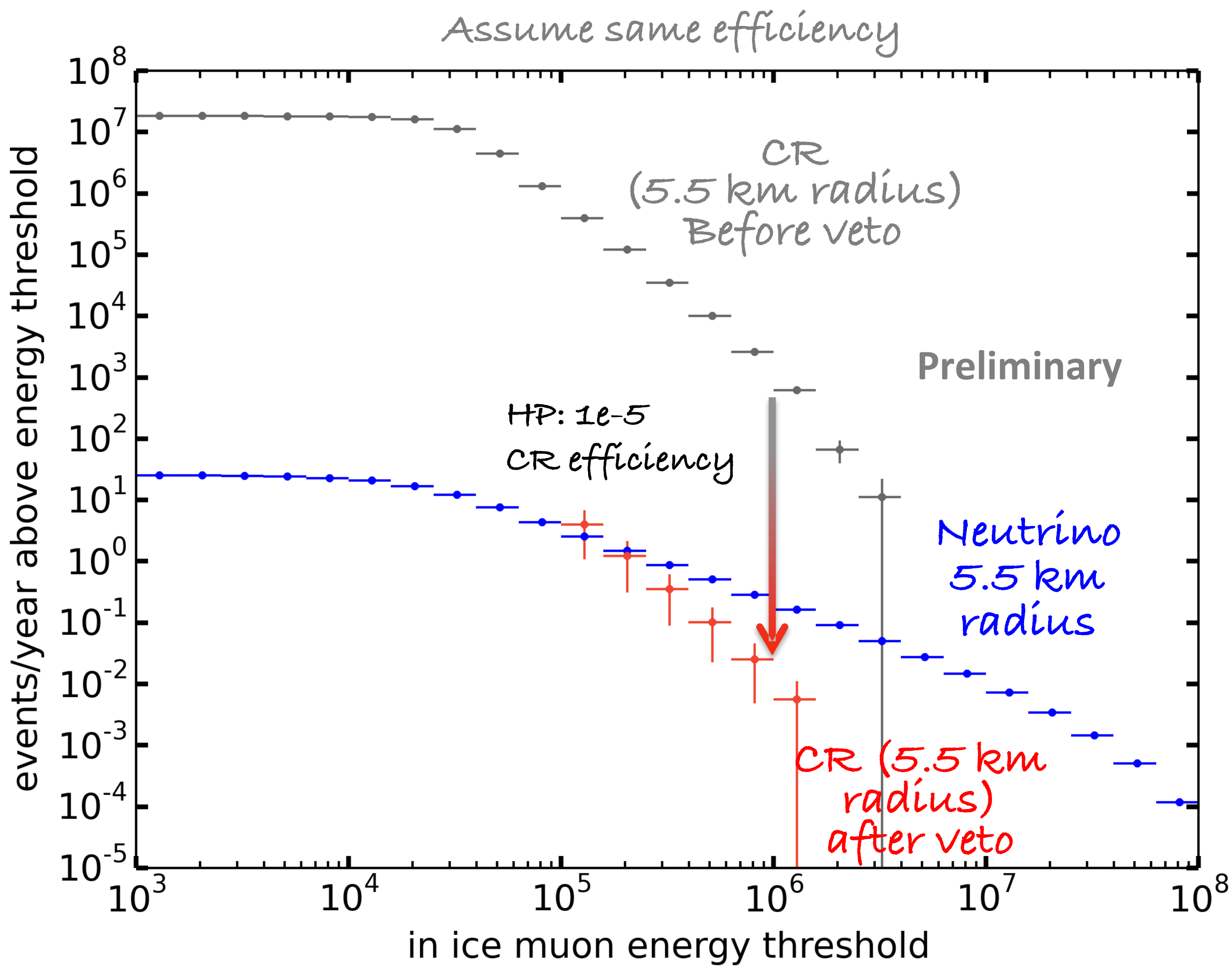


Conclusions

- The IceCube Collaboration is investigating the possibility to design a large surface array as a veto for a future IceCube Gen2 array
- A first veto analysis shows that with IceTop, not optimized to be a veto, it's possible to achieve rejection factors of at least 1e-4/1e-5 above a muon energy (at surface of detector) threshold of about 150 to 200 TeV
- More improvements to this analysis may be possible
- Preliminary investigations suggest that a large surface veto detector, with a radius of several km, can provide a background free view of a significant fraction of the Southern sky above an energy of about one hundred TeV

Thank you

Auroras seen from Madison Wisconsin – August 201

The IceCube Collaboration

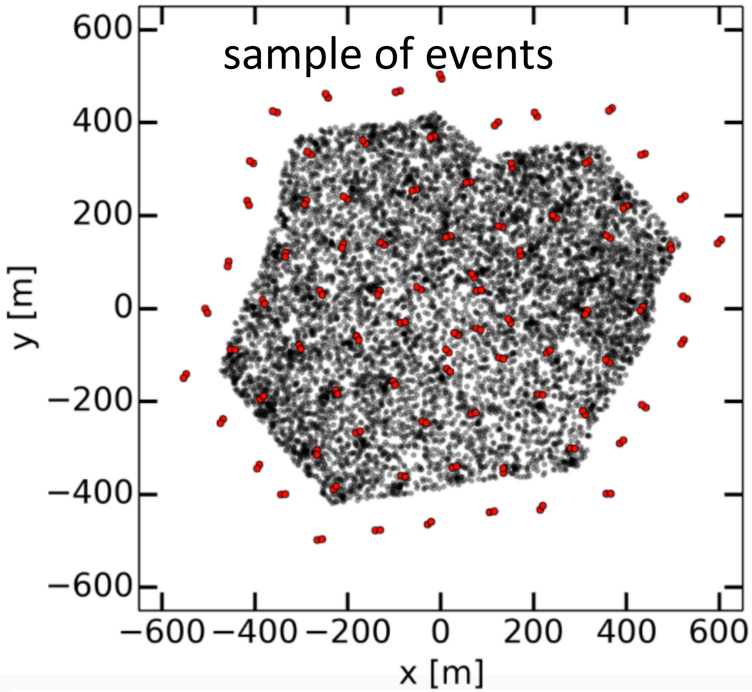
Funding Agencies

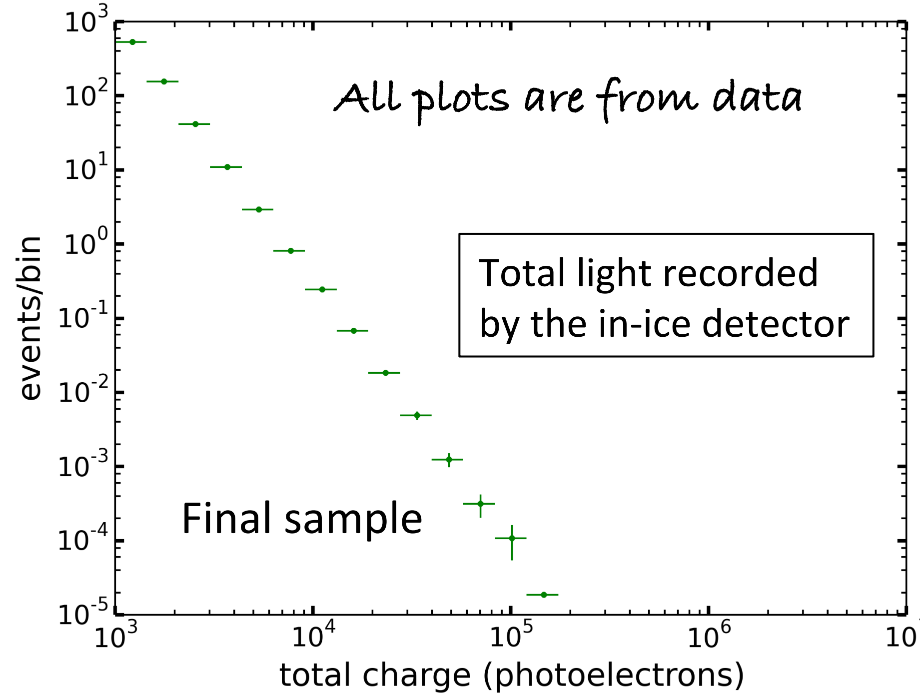
Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

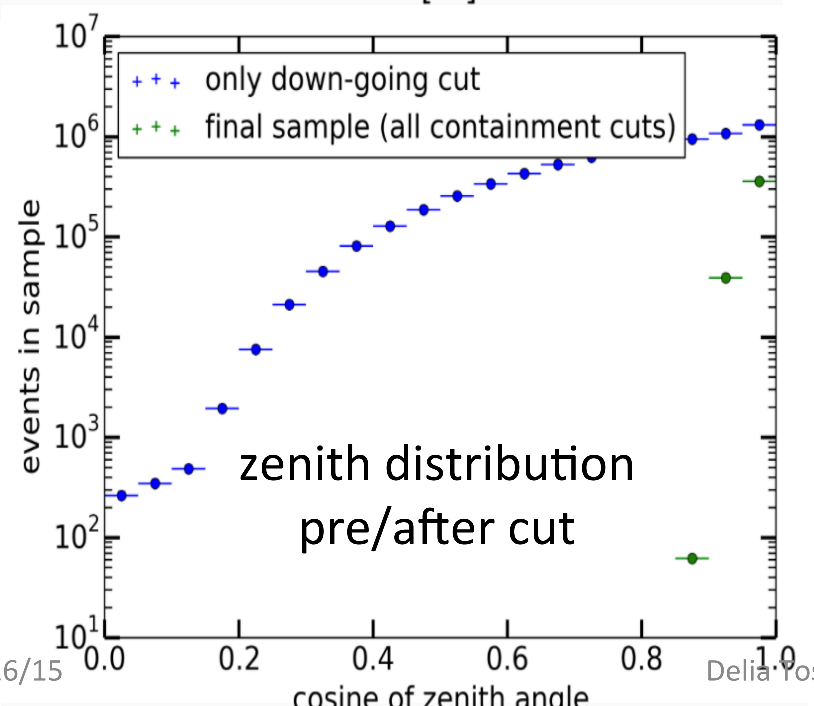
PoS(ICRC2015)1156

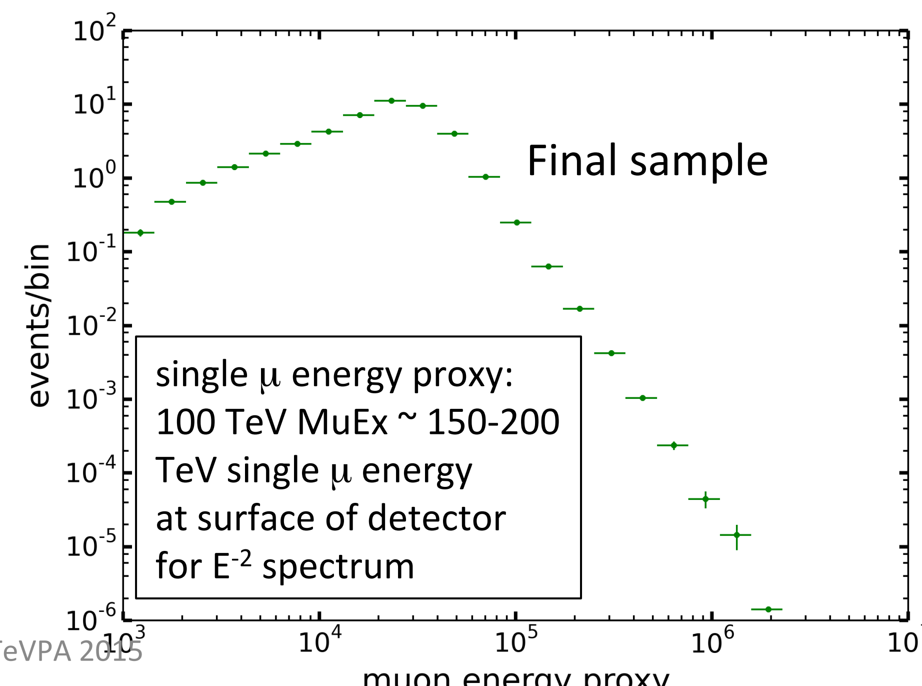
	up-going			down-going		
Neutrino energy	1 TeV	10 TeV	100 TeV	1 TeV	10 TeV	100 TeV
E^{-2}	110	44	11	80	44	18
$E^{-2.3}$	220	60	9	160	57	13
$E^{-2.7}$	740	110	7	590	100	10
ν_{Atmos}	15000	500	5	10500	350	5

Table 1: Number of astrophysical neutrinos expected from the northern and the southern sky above different energy thresholds in IceCube in one year. The estimated event numbers are based on Monte Carlo simulations. The normalization derives from the measured astrophysical flux. Up-going is defined to end 5° above the horizon, the region that is currently used in IceCube diffuse ν_μ analyses. The down-going region is defined from the vertical to 85° declination dominated by muons from air showers without a surface veto. ν_{Atmos} is the expected number of atmospheric neutrinos. No surface veto was applied to the ν_{Atmos}.


sample of events
y [m]
x [m]
600
400
200
0
−200
−400
−600


All plots are from data
Total light recorded by the in-ice detector
Final sample
events/bin
total charge (photoelectrons)


only down-going cut
final sample (all containment cuts)
zenith distribution pre/after cut
events in sample
cosine of zenith angle


Final sample
single μ energy proxy:
100 TeV MuEx ~ 150-200 TeV single μ energy
at surface of detector
for E-2 spectrum
events/bin
muon energy proxy

Signal simulation II: Randomized data

- Since simulations of high energy showers are lengthy and complex, data is used to generate a neutrino-like sample.
- The fixed rate triggers are used to extract the noise frequency of each IceTop DOM on a seasonal basis (summer/winter).
- The IceTop pulses in the final selection are replaced with random hits whose distribution is taken from the above IceTop DOMs noise distribution.
- This distribution is not normalized to any flux but is used as PDF to study cut placement.