# On extensions of IceTop to Veto Air Showers for Neutrino Astronomy with IceCube

IPA, May 4th 2015



Dr. Jan Auffenberg

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# Content

Part 1:

- Why an extended surface array as veto for CR

Part 2:

- An alternative technical solution: Air Cherenkov detectors.

- Where do **high-energy cosmic-rays** come from?

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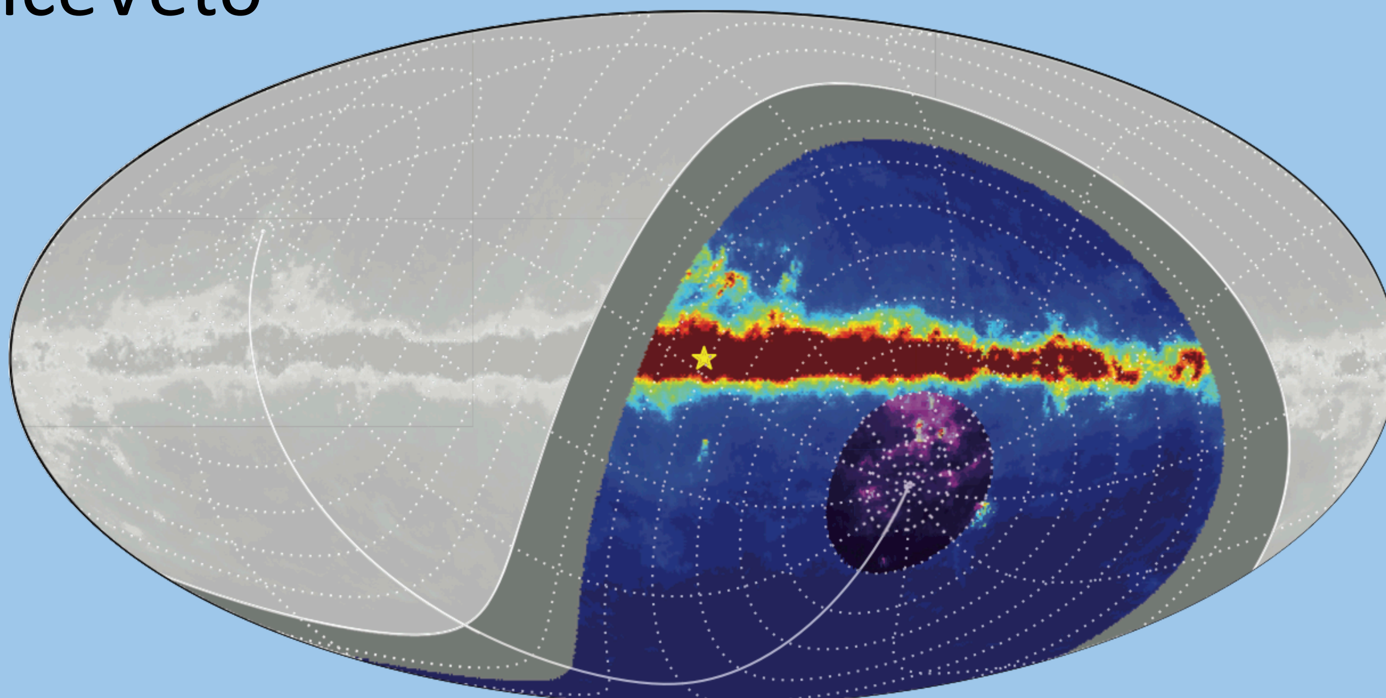
  - Why



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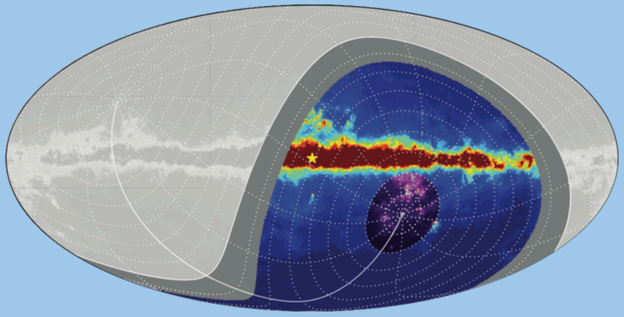
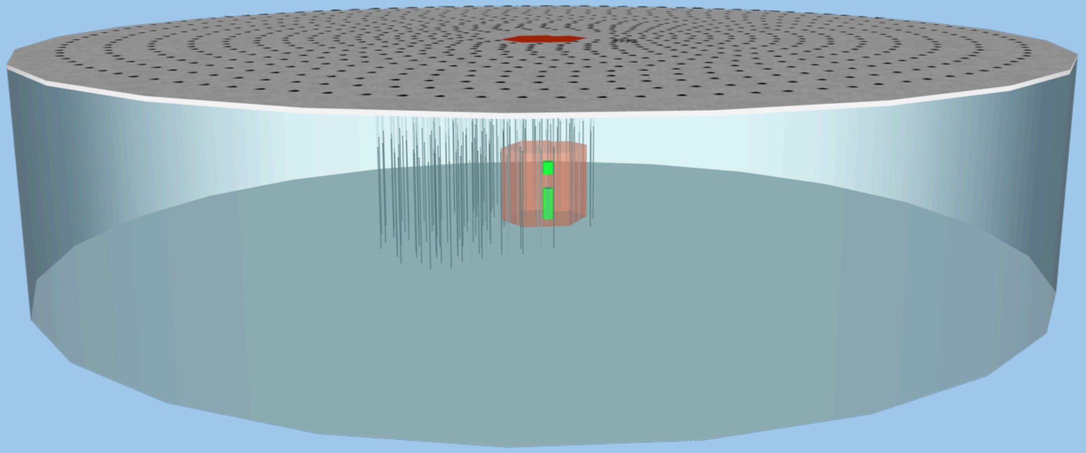
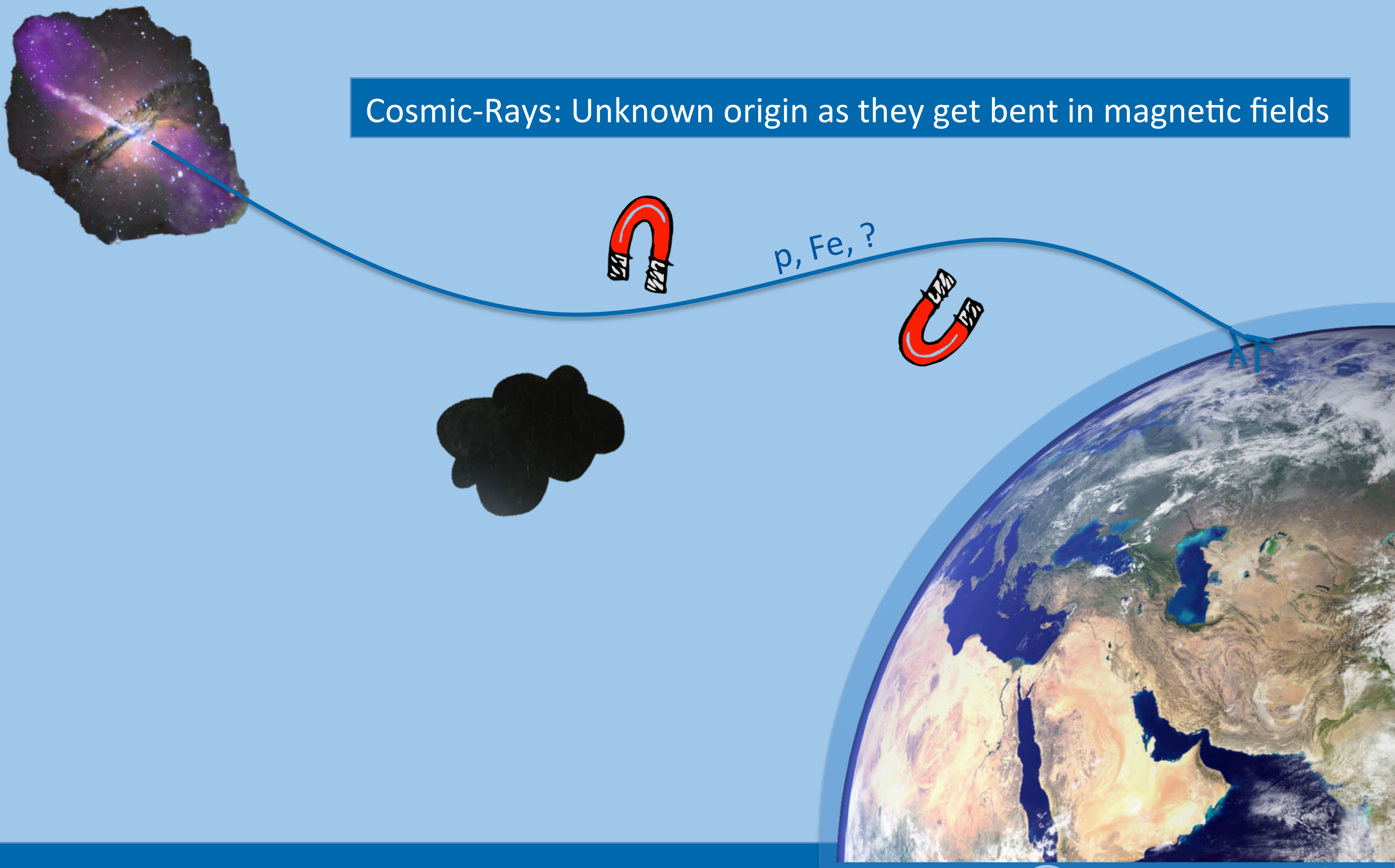




# Why astrophysical neutrino search?

Cosmic-Rays: Unknown origin as they get bent in magnetic fields



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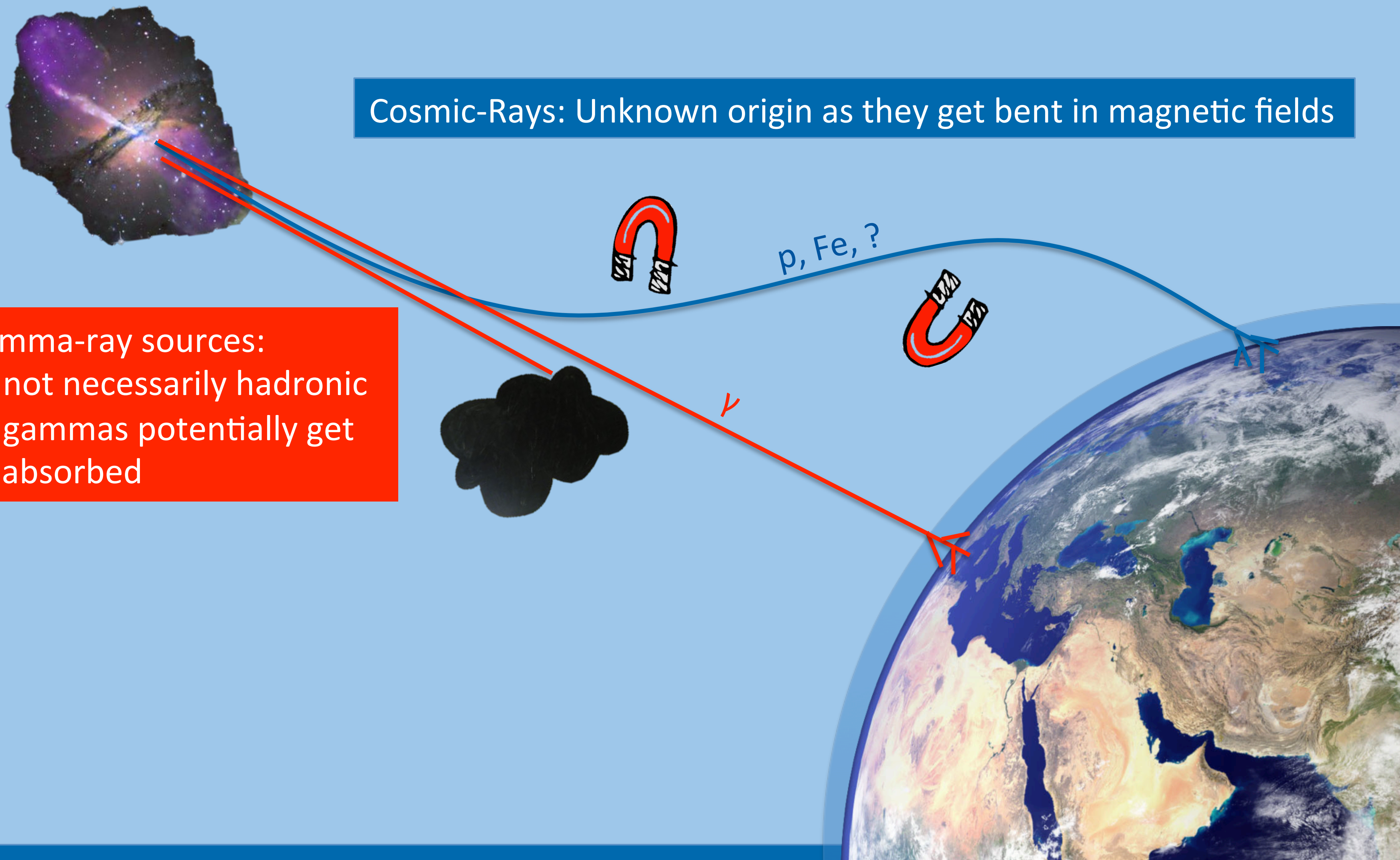
- not necessarily hadronic
- gammas potentially get absorbed



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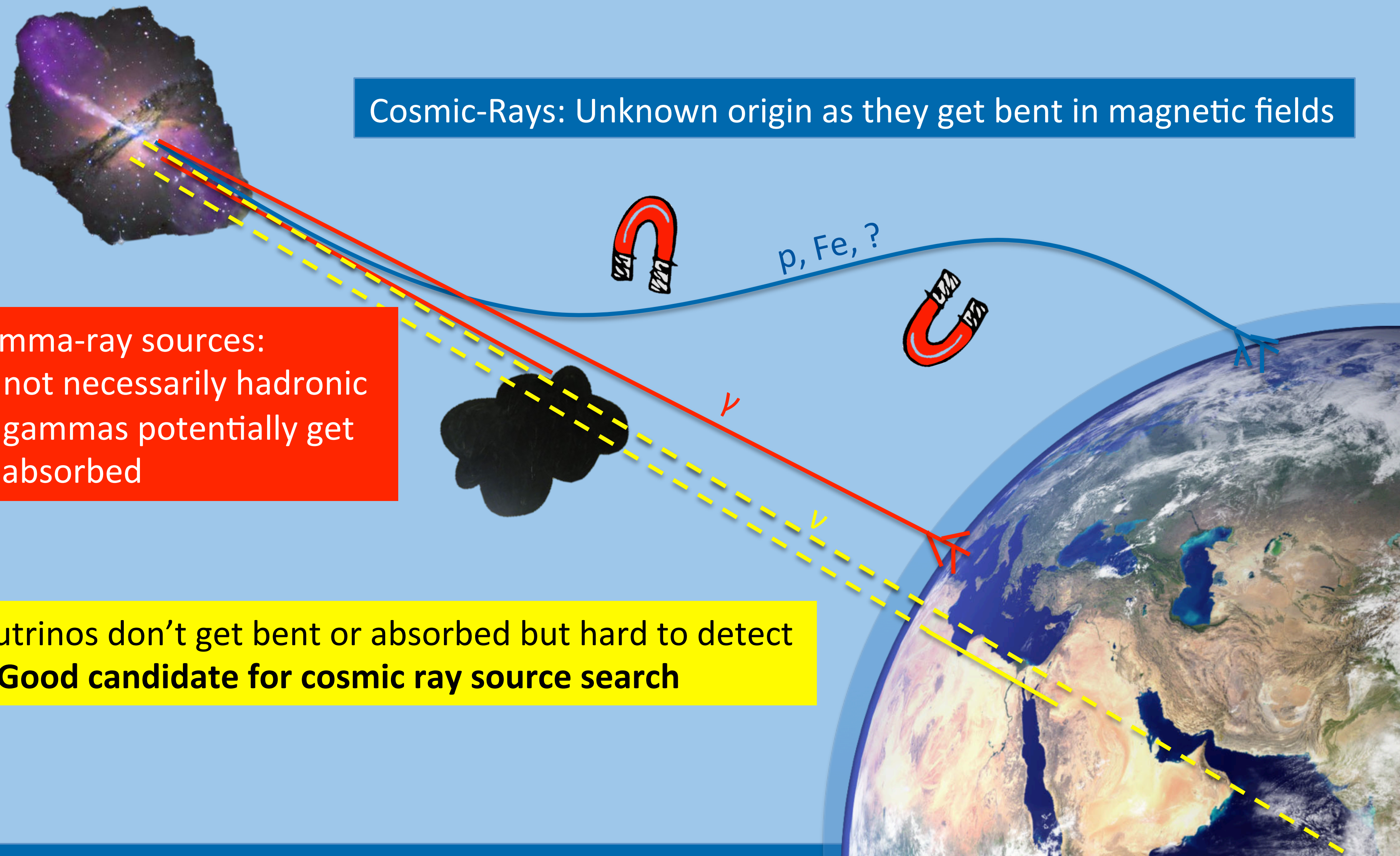


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- **Good candidate for cosmic ray source search**

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ICECUBE

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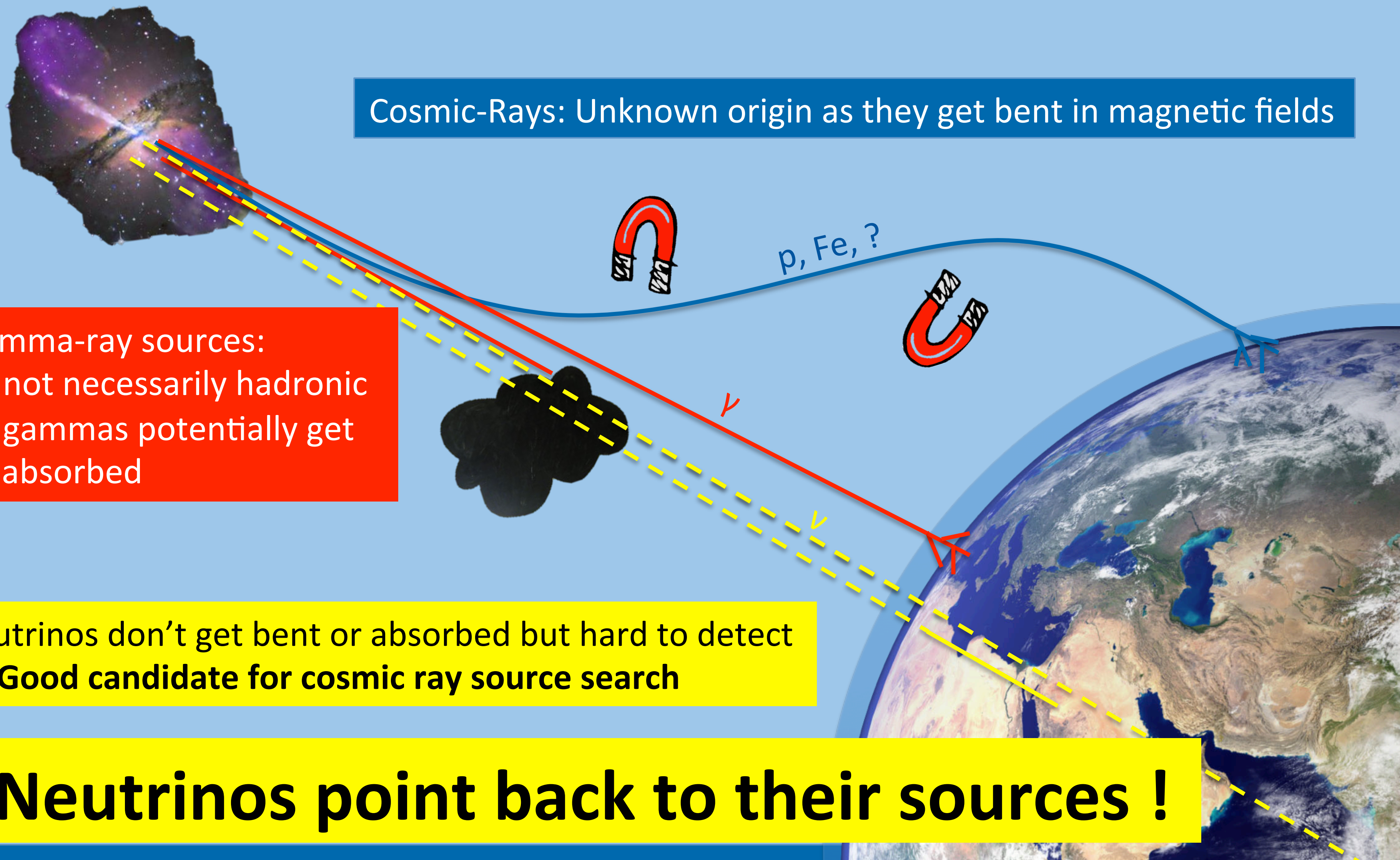


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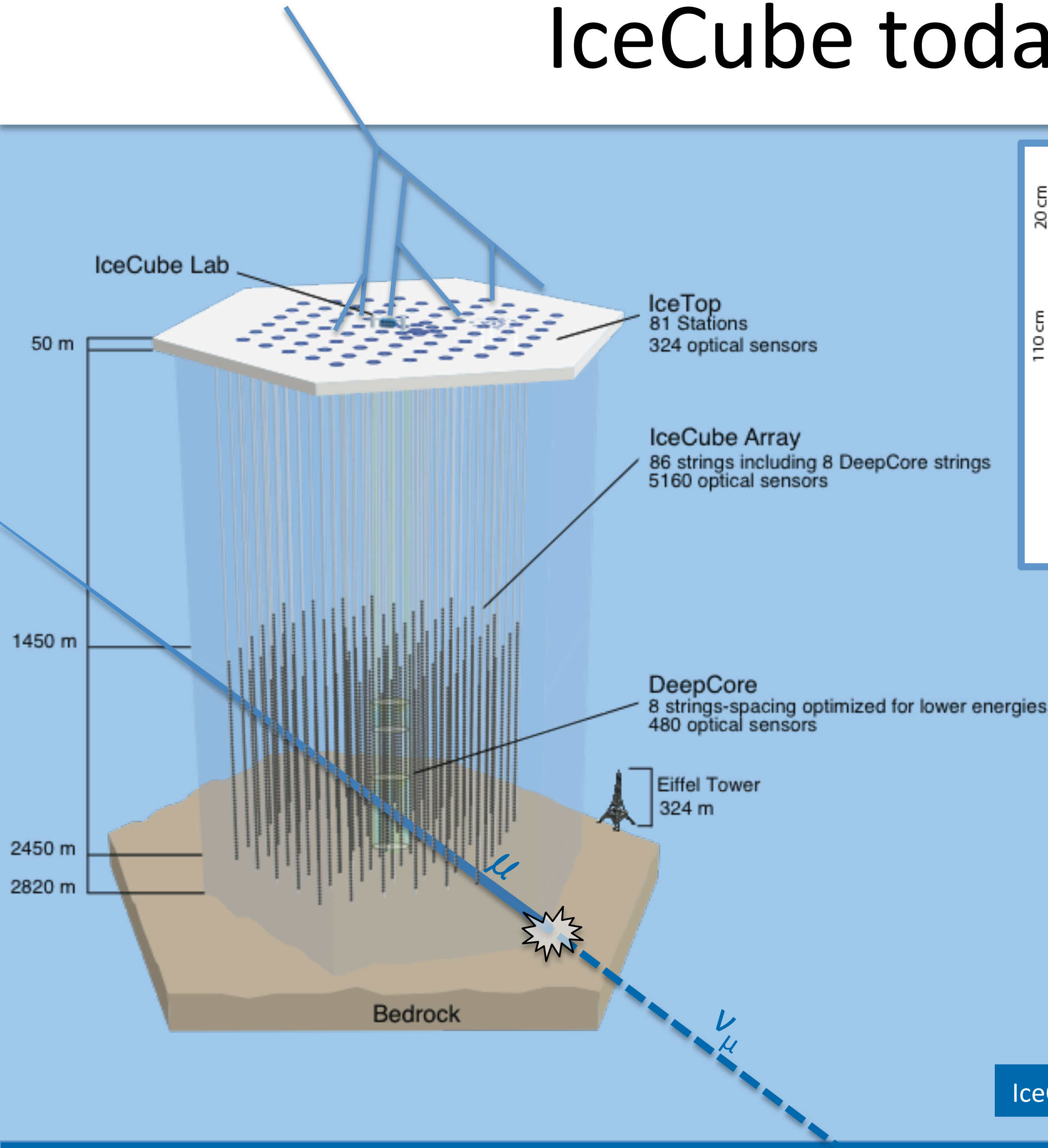
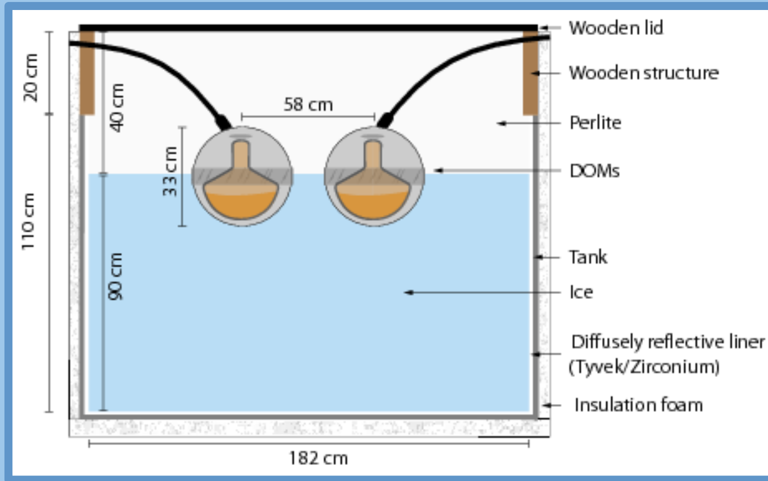
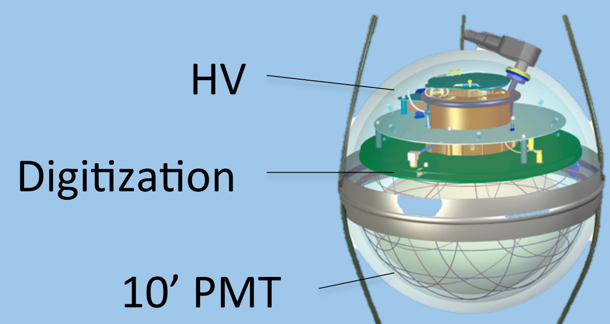
**Neutrinos point back to their sources !**

# IceCube today




IceCube et al. Nucl. Inst. Meth. A 618 (2010) 139-152

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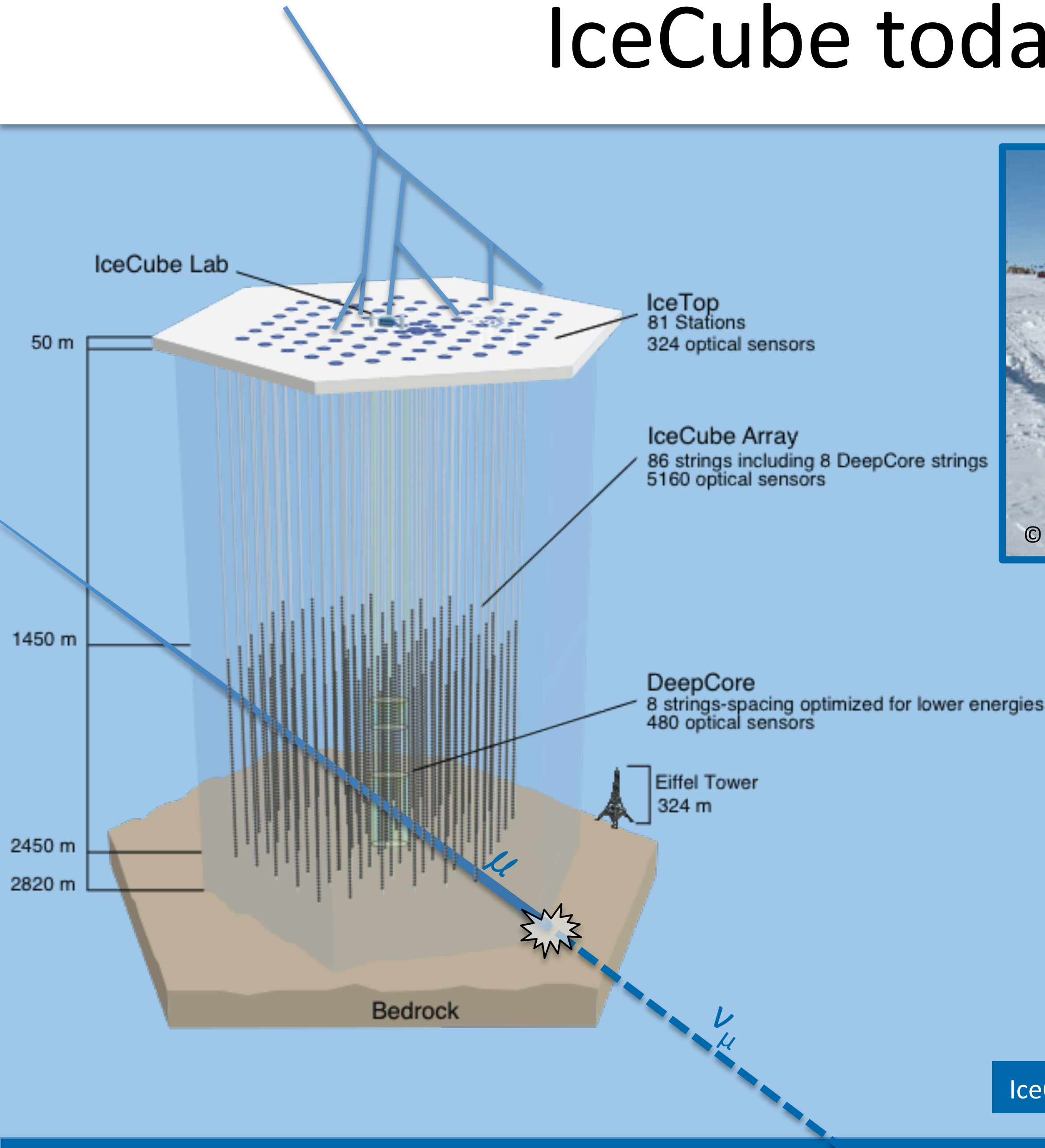



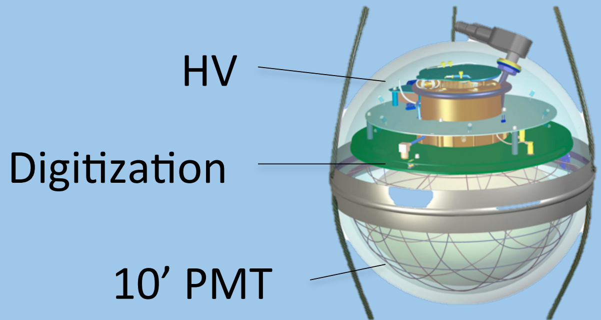


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# Observed Neutrino Signatures

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Neutral Current /Electron
Neutrino
so called “**shower**”

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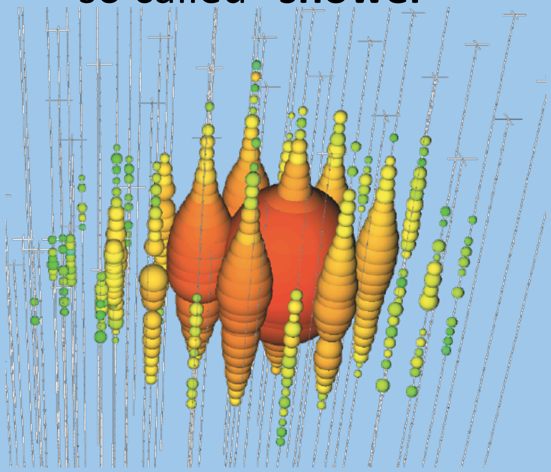

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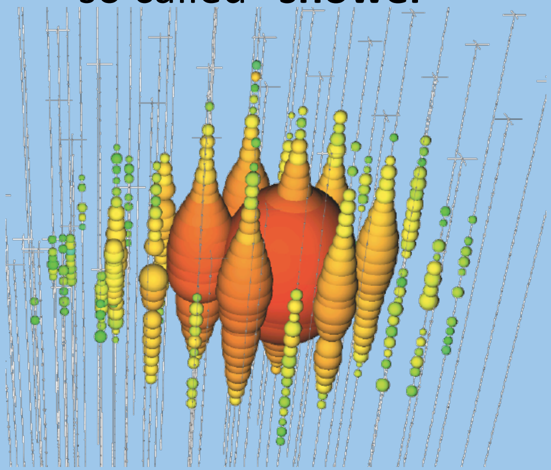

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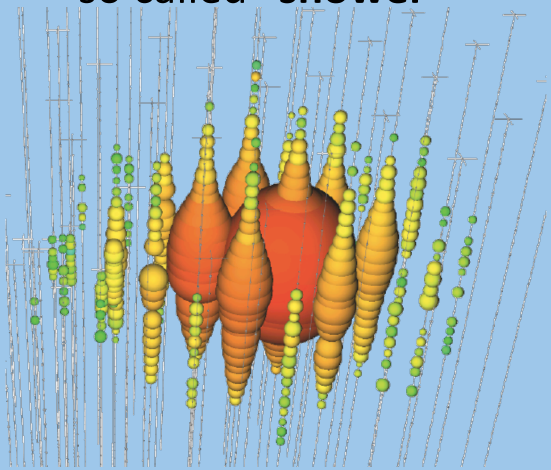

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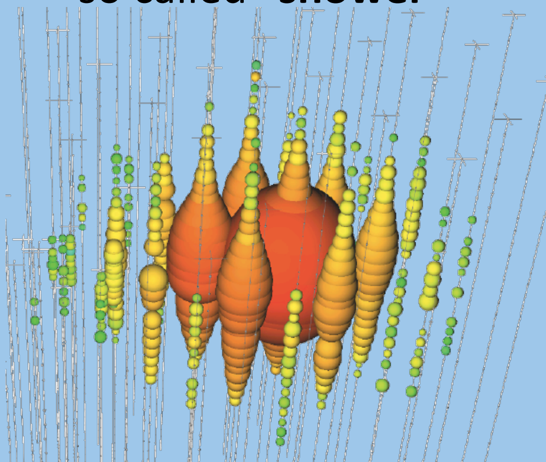

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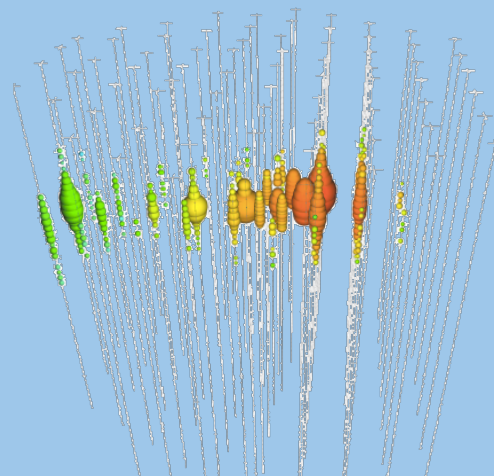

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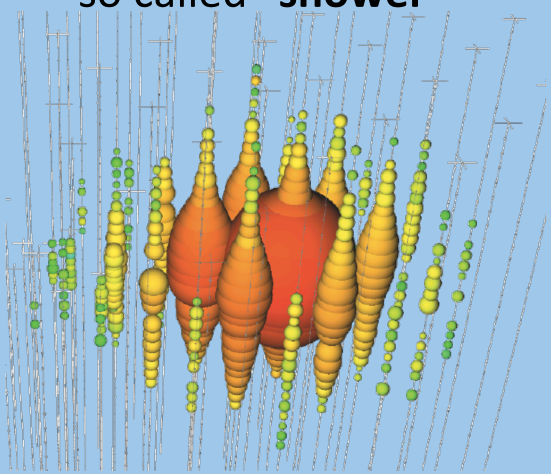

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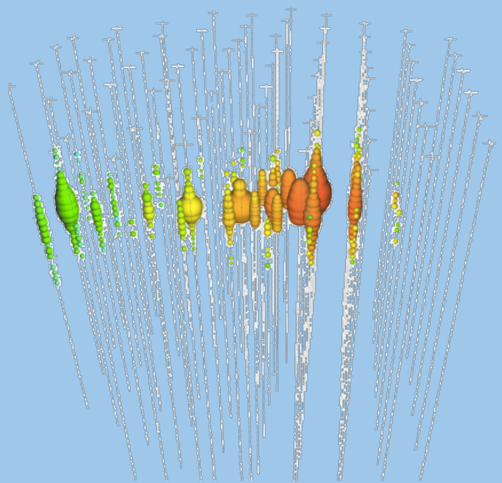

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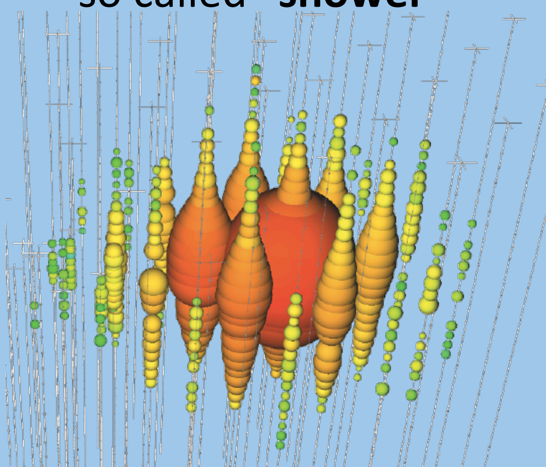

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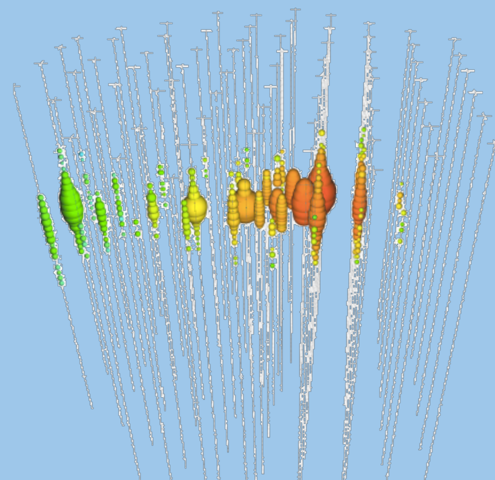

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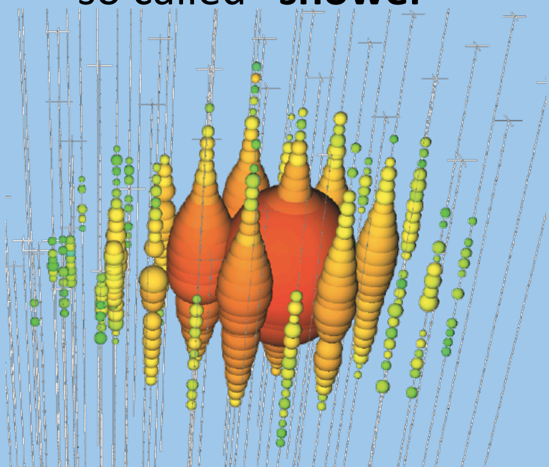

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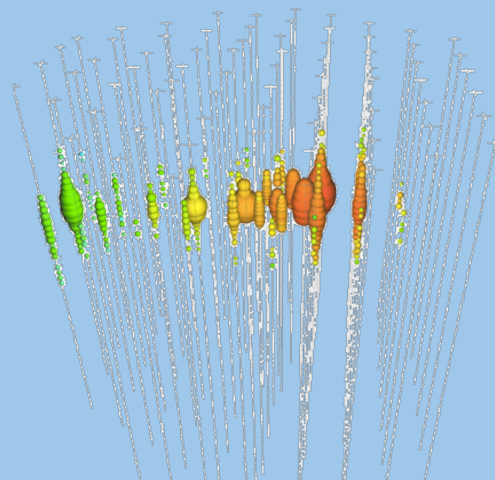

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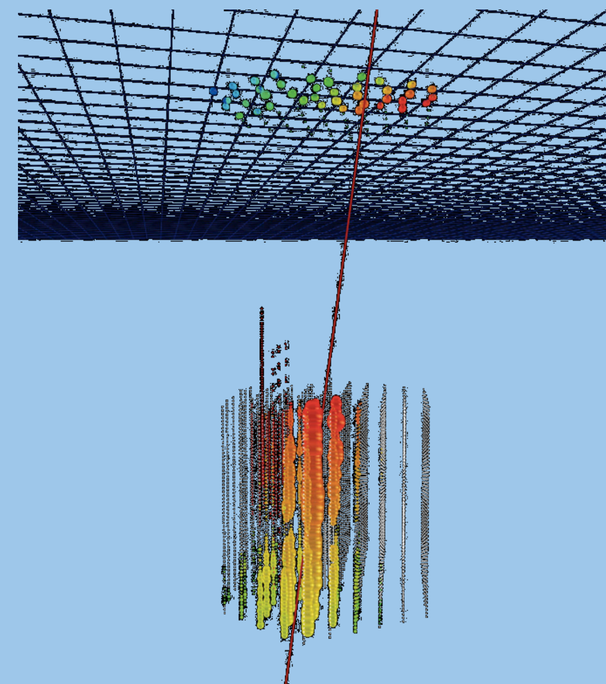
**Cosmic-Ray background**



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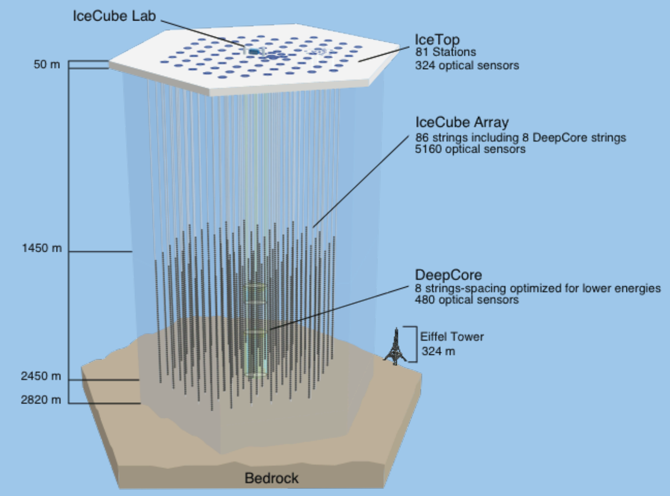
# IceCube Results: Starting Events



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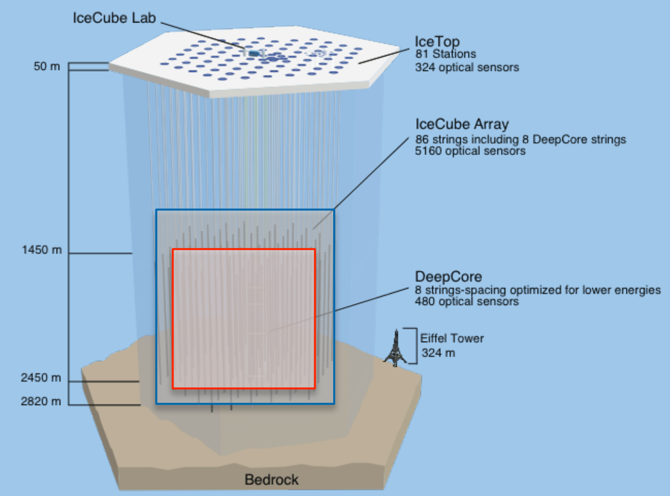

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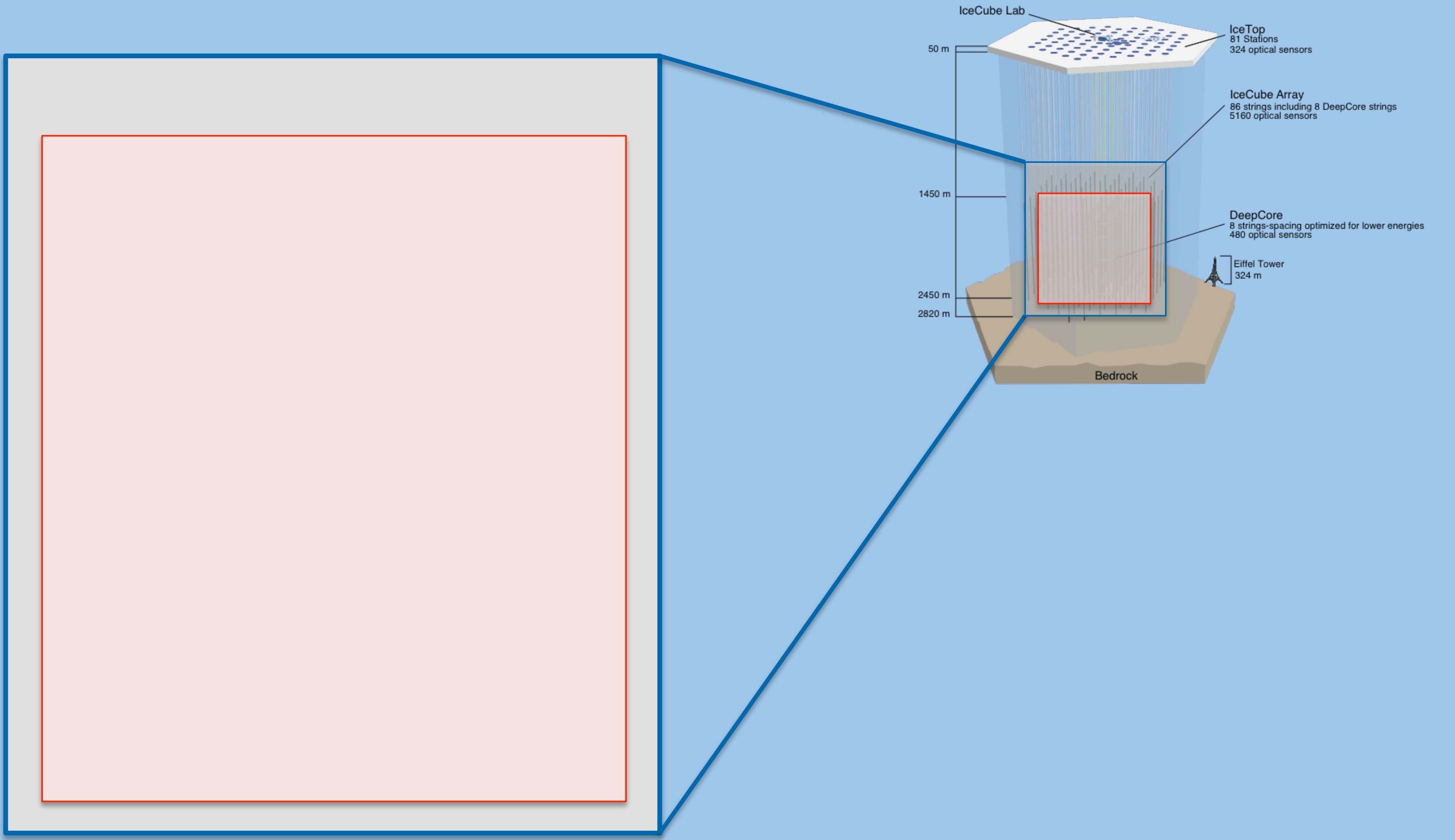

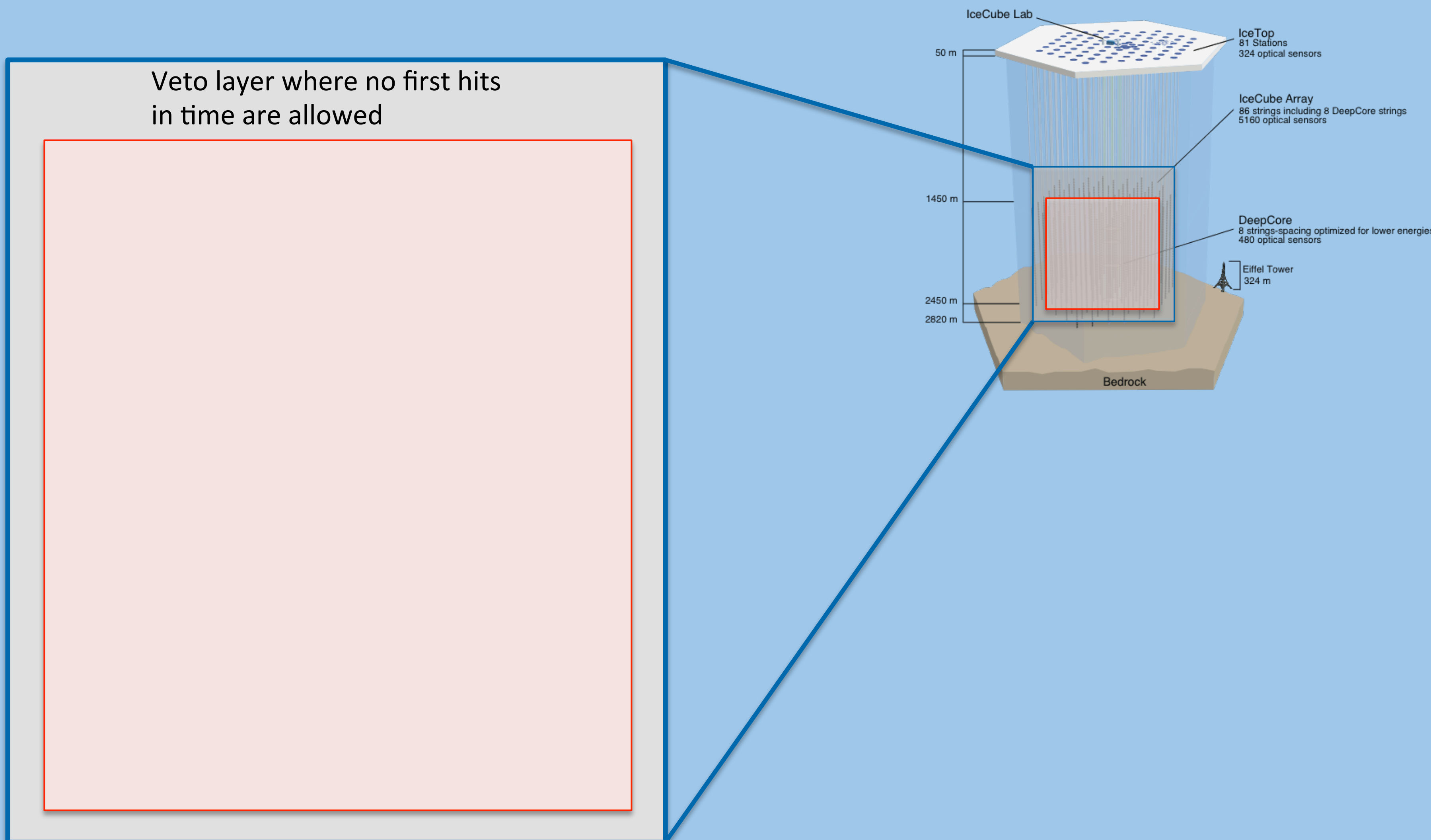
Veto layer where no first hits
in time are allowed
IceCube Lab
50 m
IceTop
81 Stations
324 optical sensors
IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors
1450 m
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
2450 m
2820 m
Bedrock

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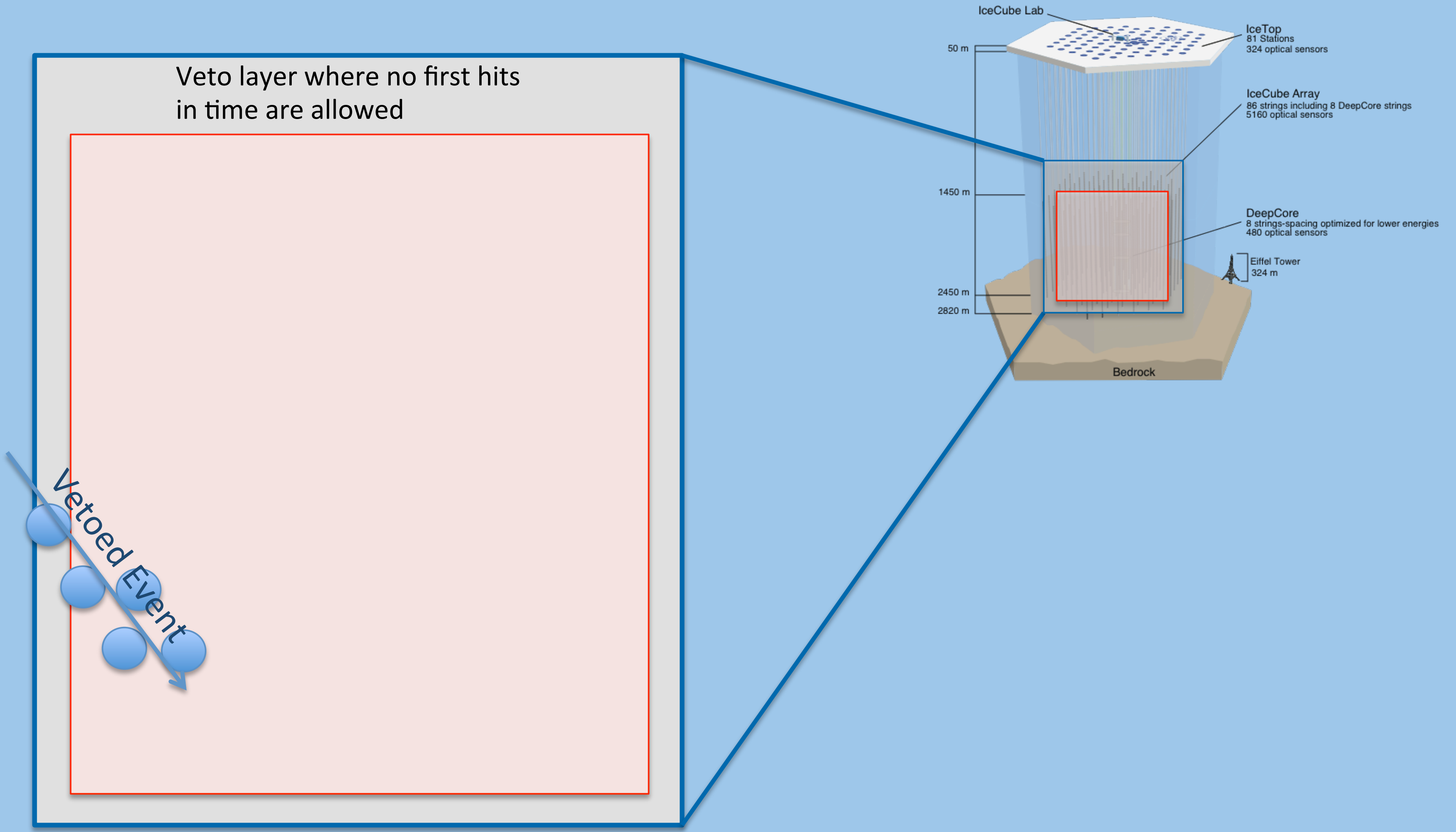

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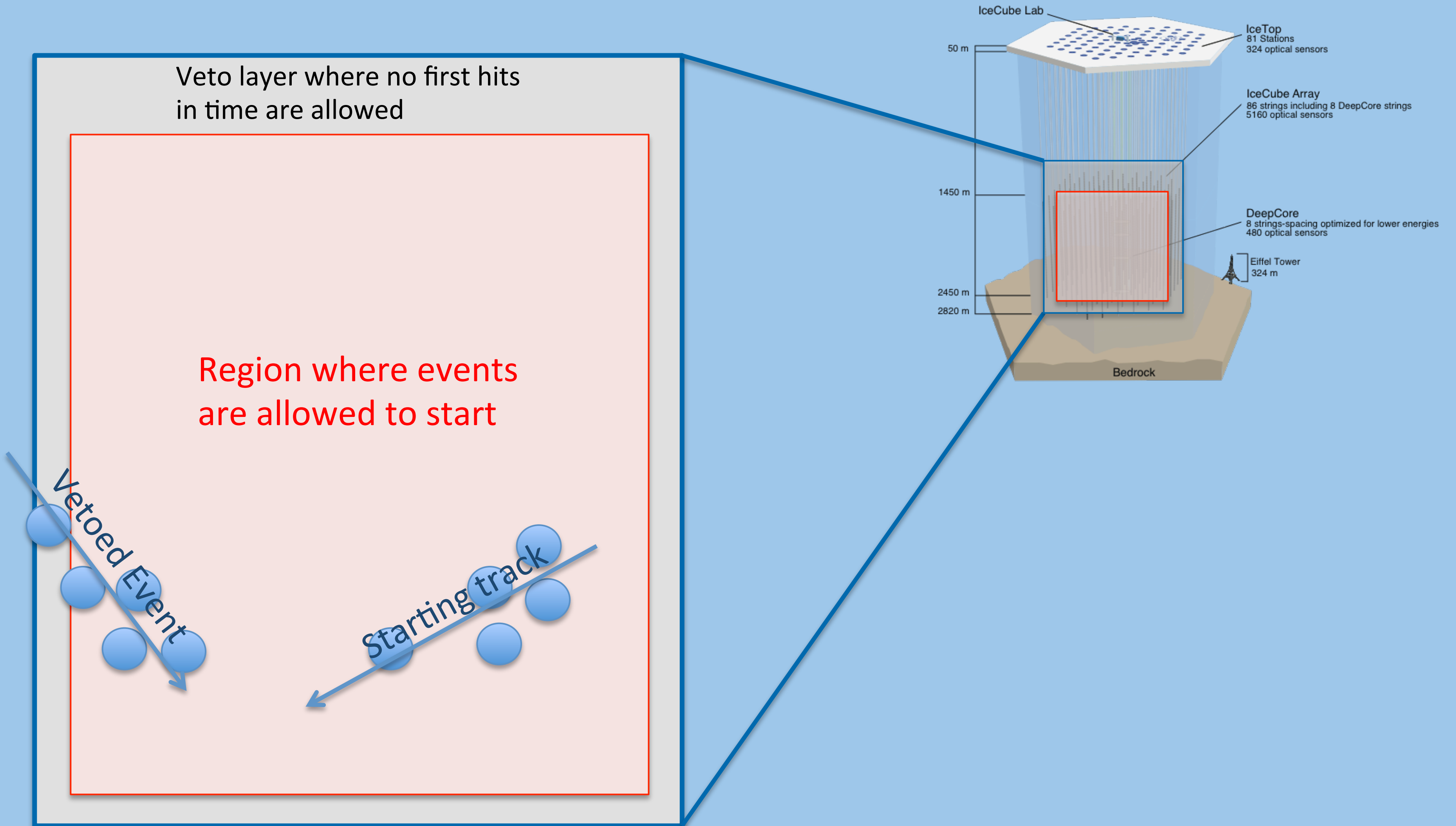




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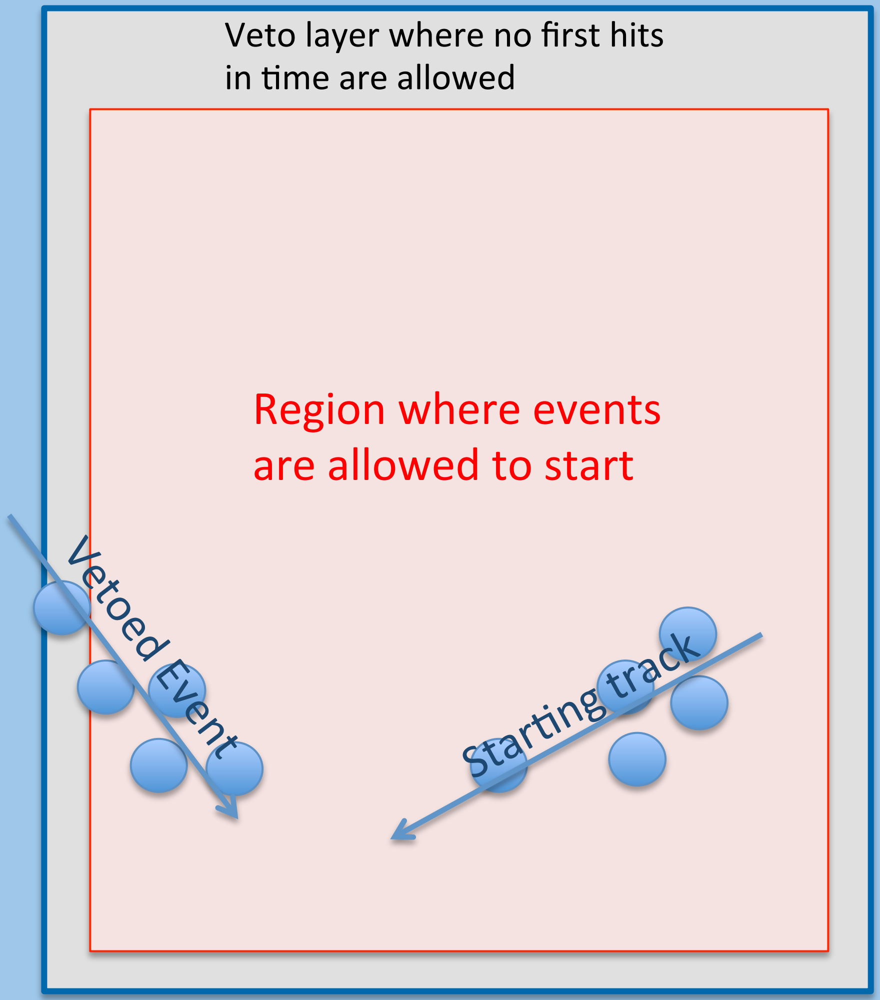


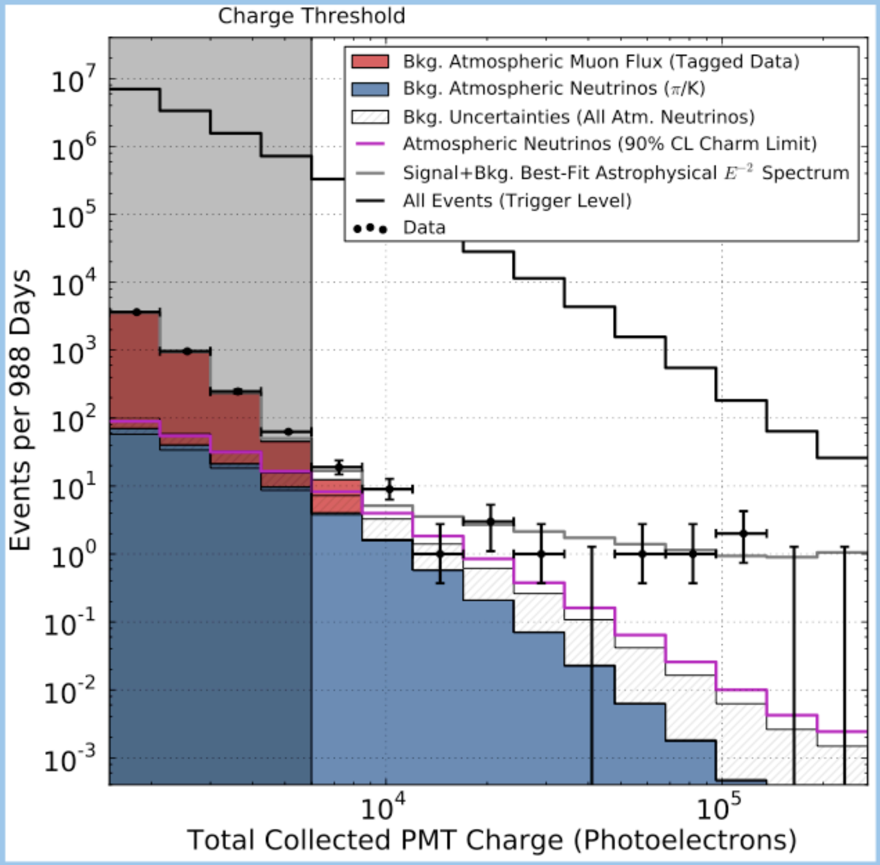




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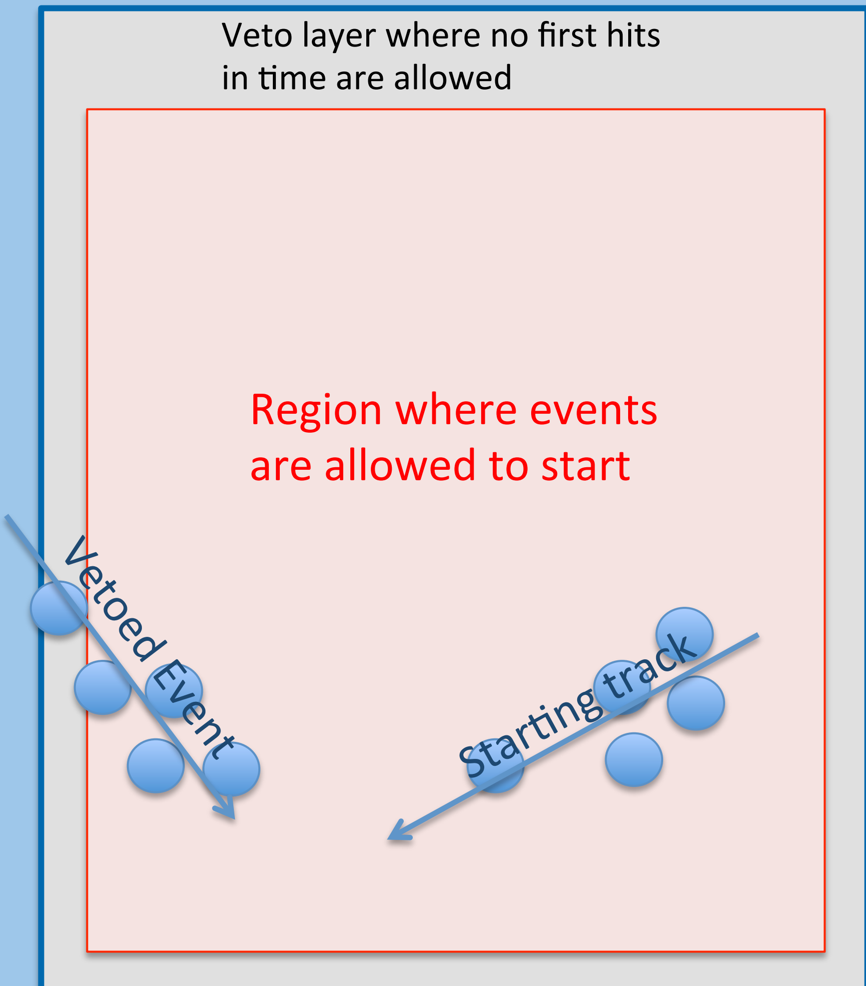
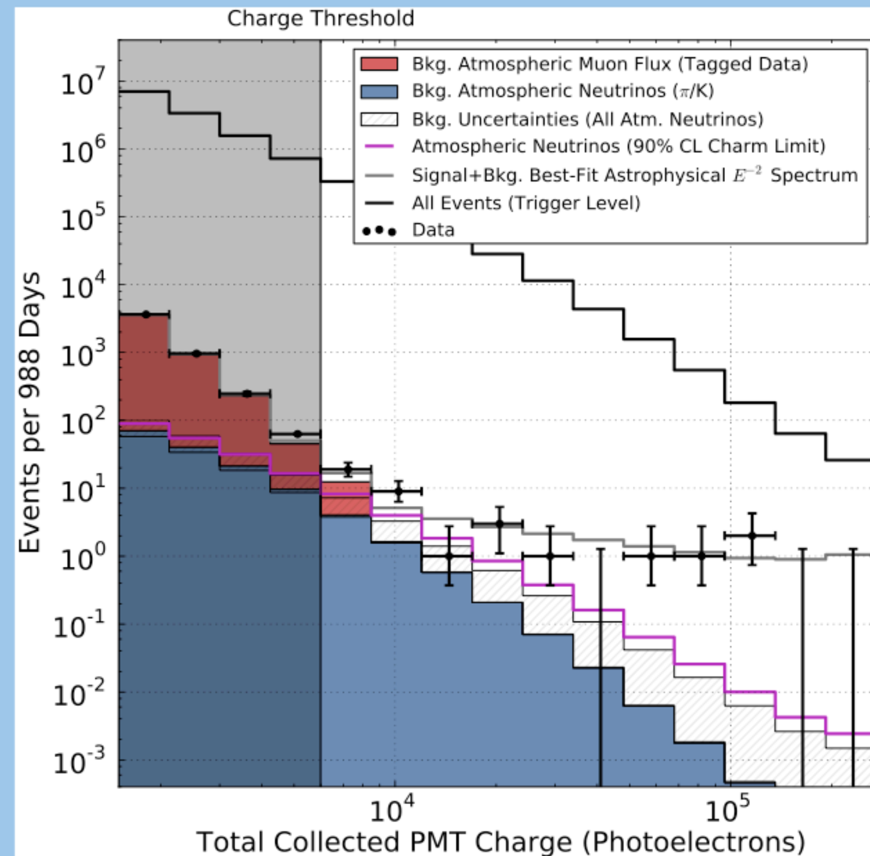
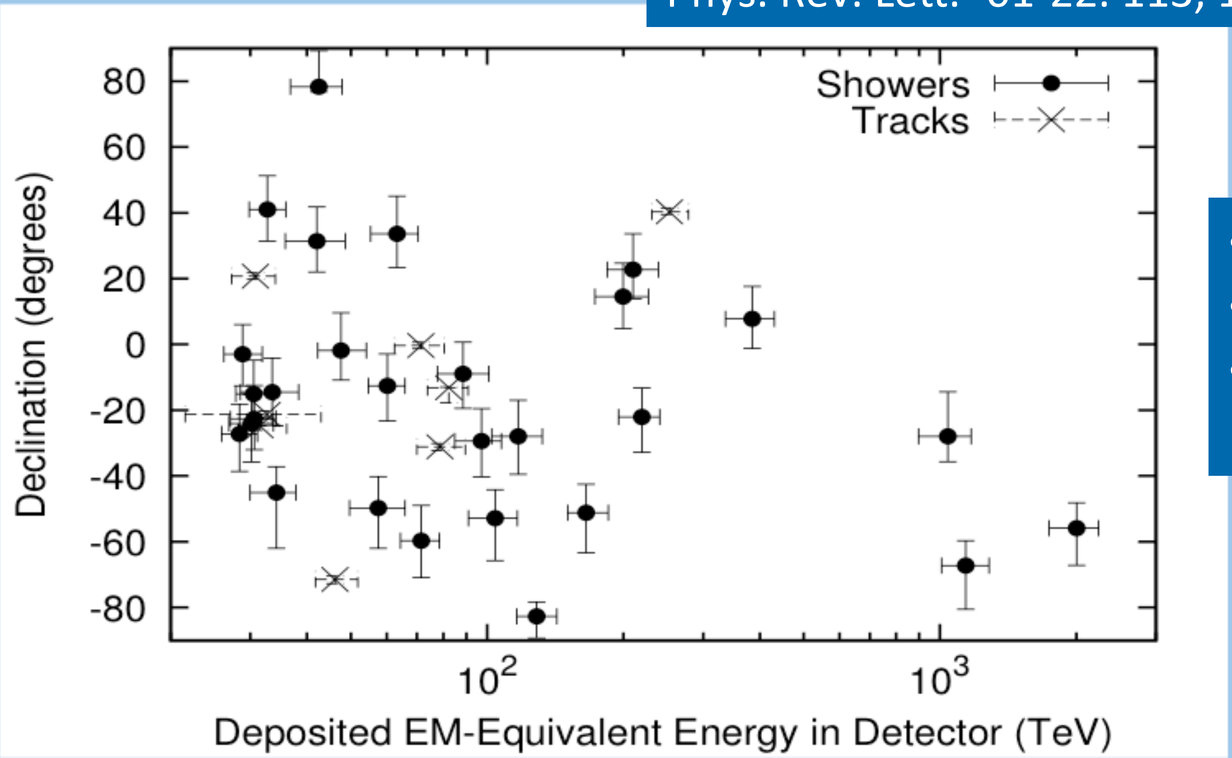



- null hypothesis rejected with 5.7σ after three years of data taking

# Where do the neutrinos come from?

Phys. Rev. Lett. -01-22. 113, 101101 (2014)




- showers don't point
- only few tracks
- PeV neutrinos only from the southern sky

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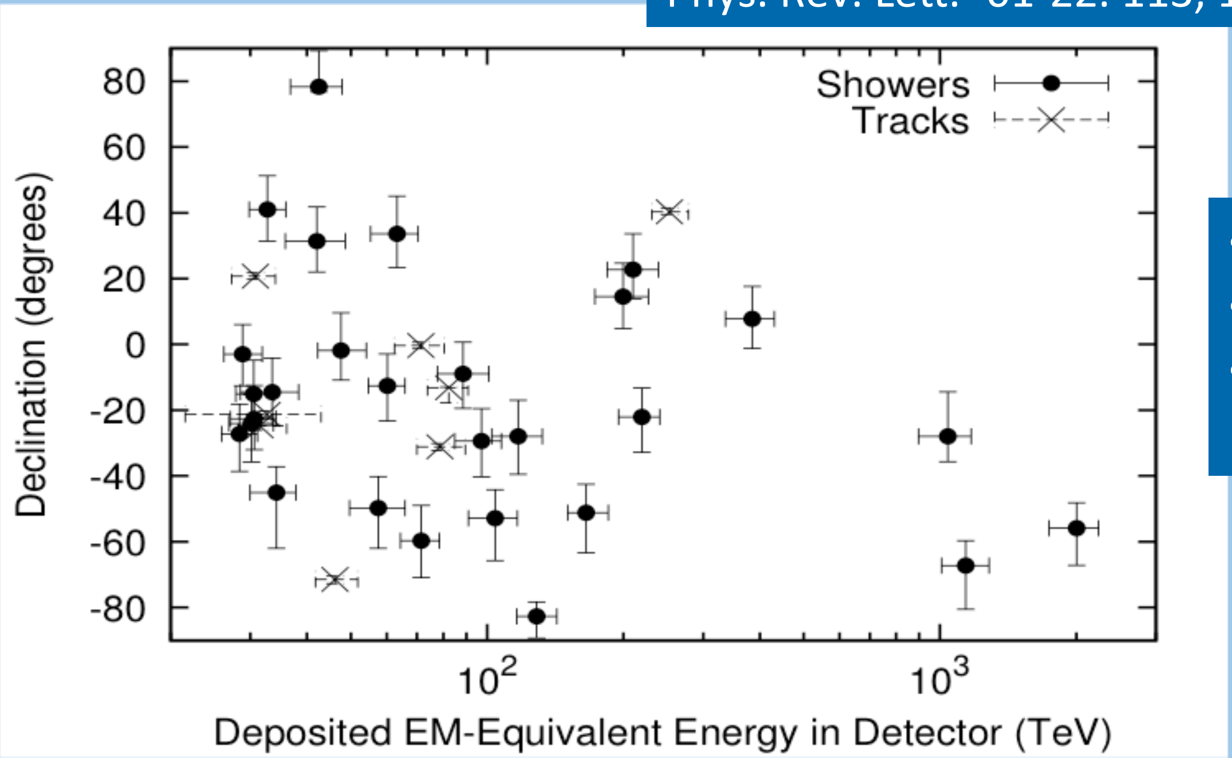


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We need more high energy tracks e.g. from the southern sky!

# The future extension: IceVeto

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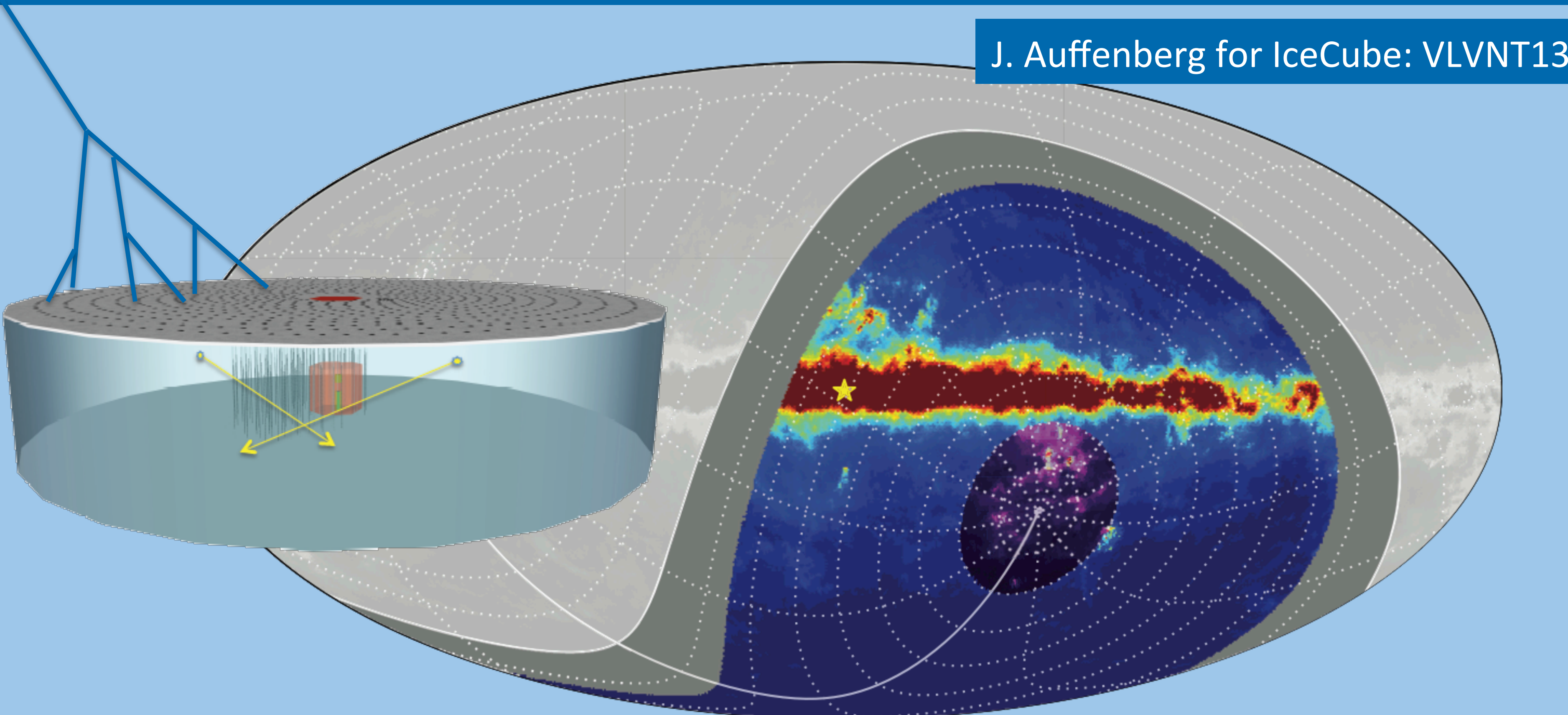
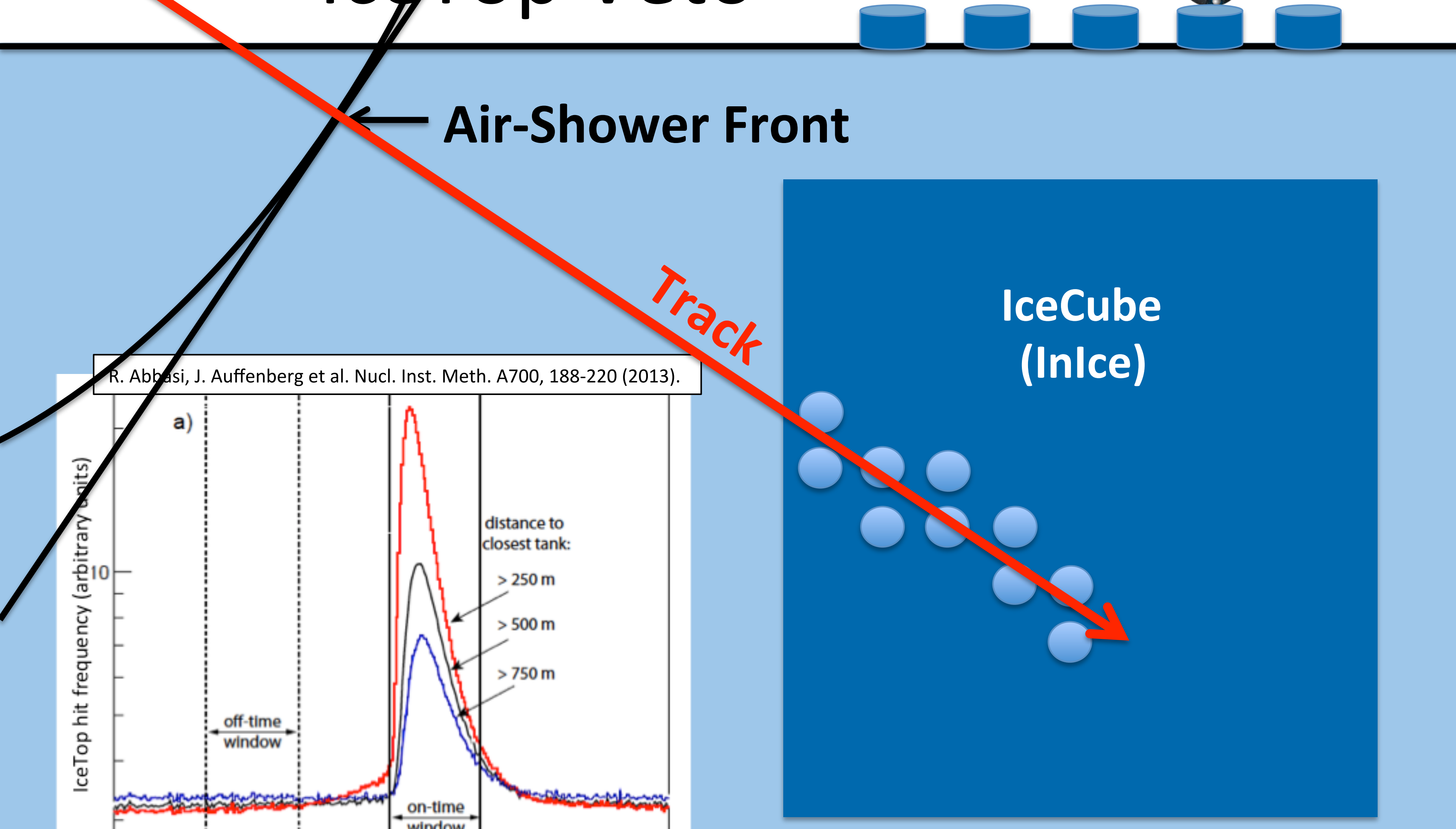
J. Auffenberg for IceCube: VLVNT13



**Open the southern sky for E < 100 TeV Neutrino induced muon tracks by vetoing signals with coincident air showers**

# IceTop Veto




J. Auffenberg for IceCube: ICRC13 ID 0373

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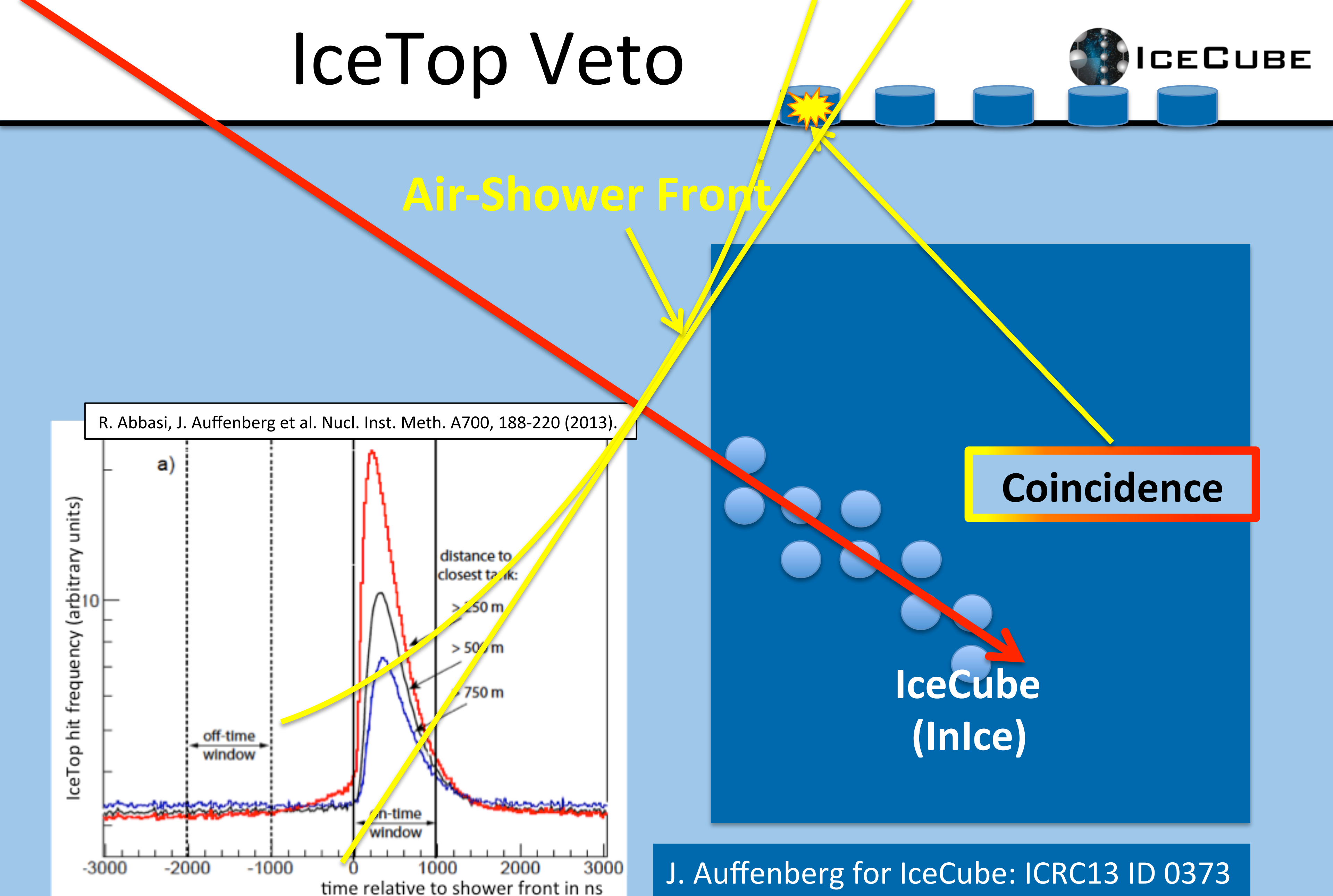


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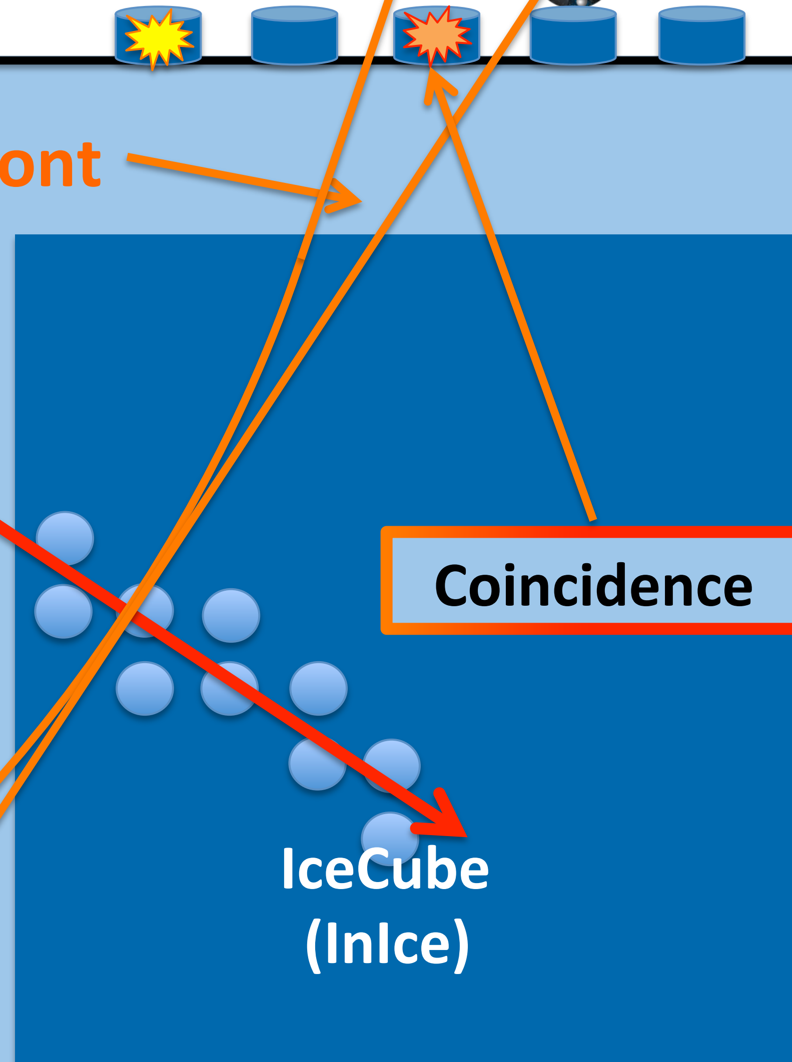
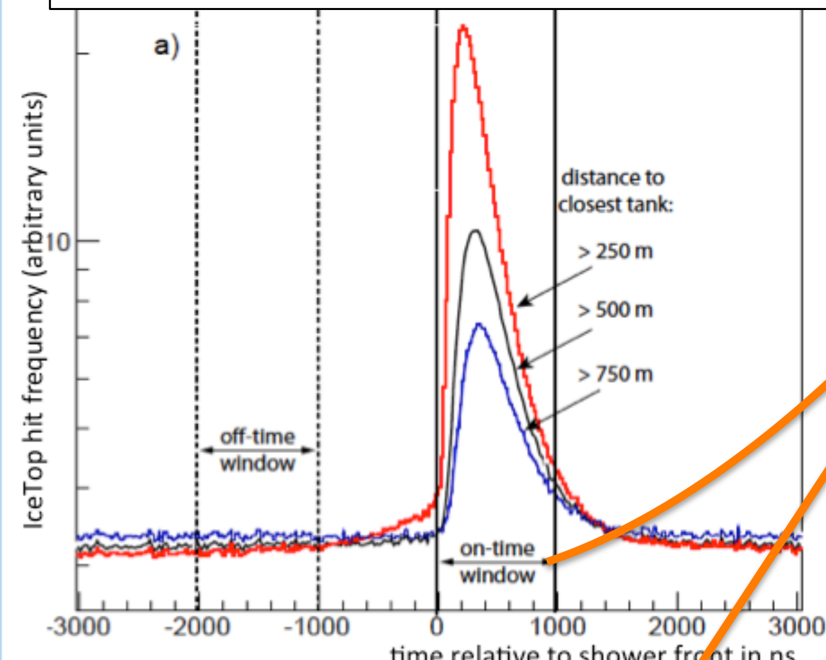
# IceTop Veto

Air-Shower Front




R. Abbasi, J. Auffenberg et al. Nucl. Inst. Meth. A700, 188-220 (2013).

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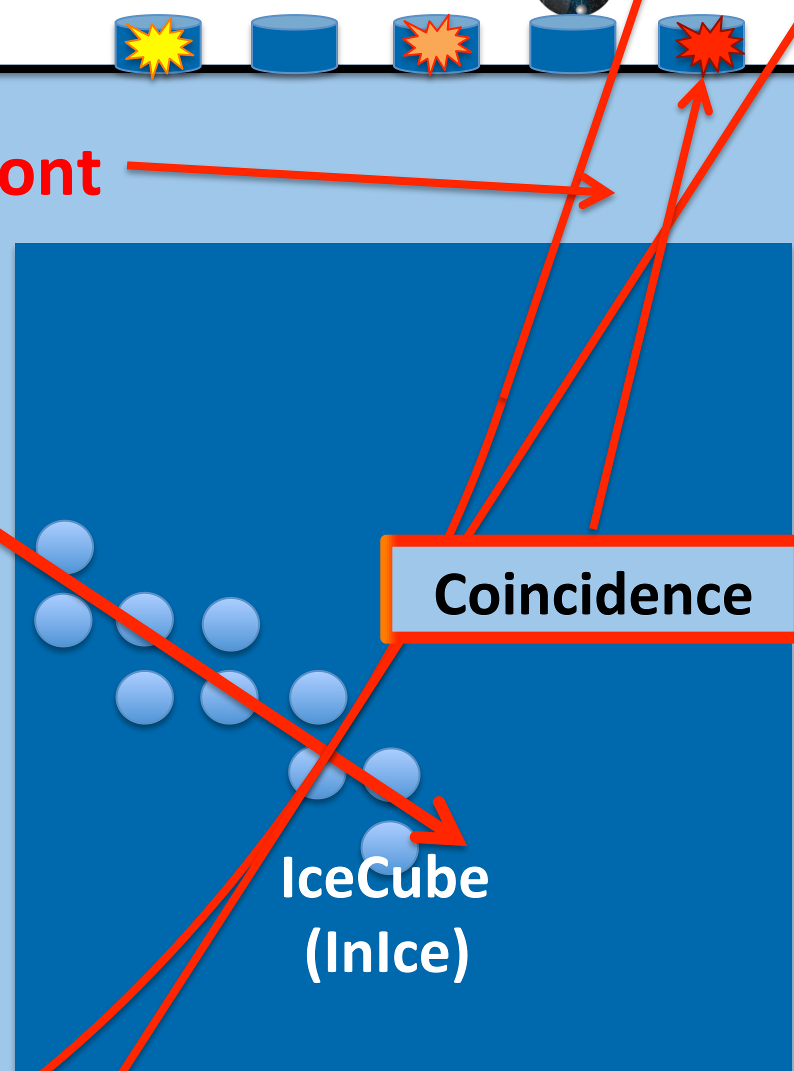


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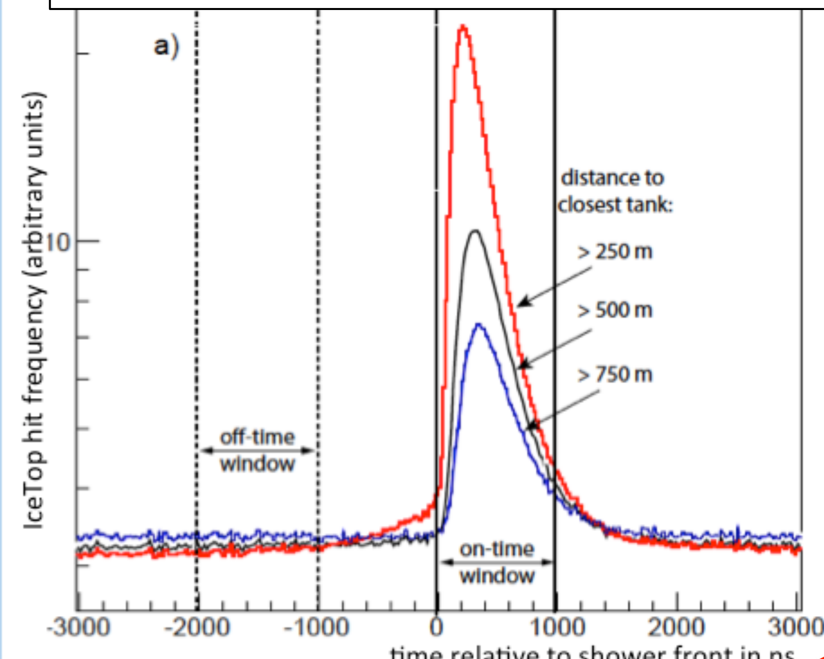


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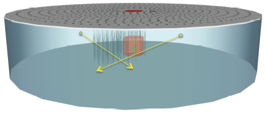
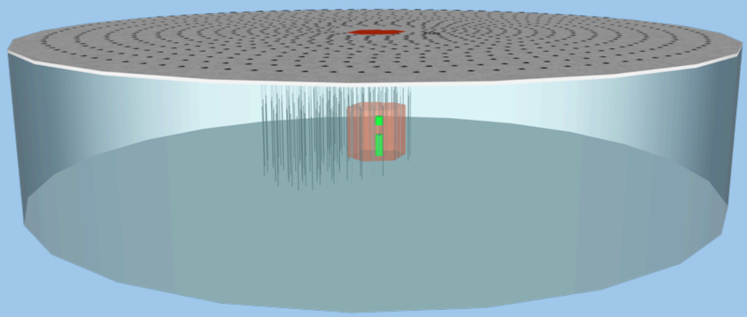
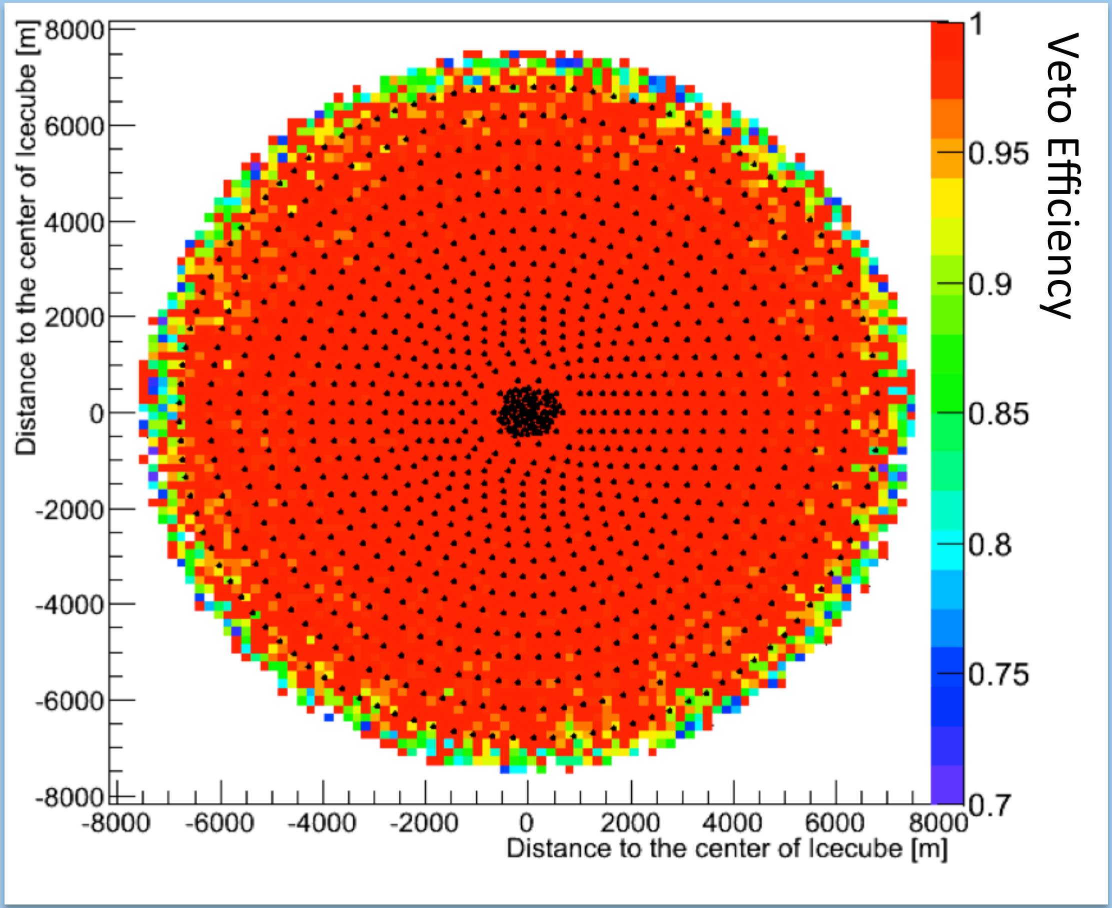


# IceVeto Simulation



- **943 additional modules on surface**
- **99.999% Veto efficiency For PE > 4000**




IceVeto is a sub-PeV cosmic-ray energy veto with $10^{-4}$ rejection power!



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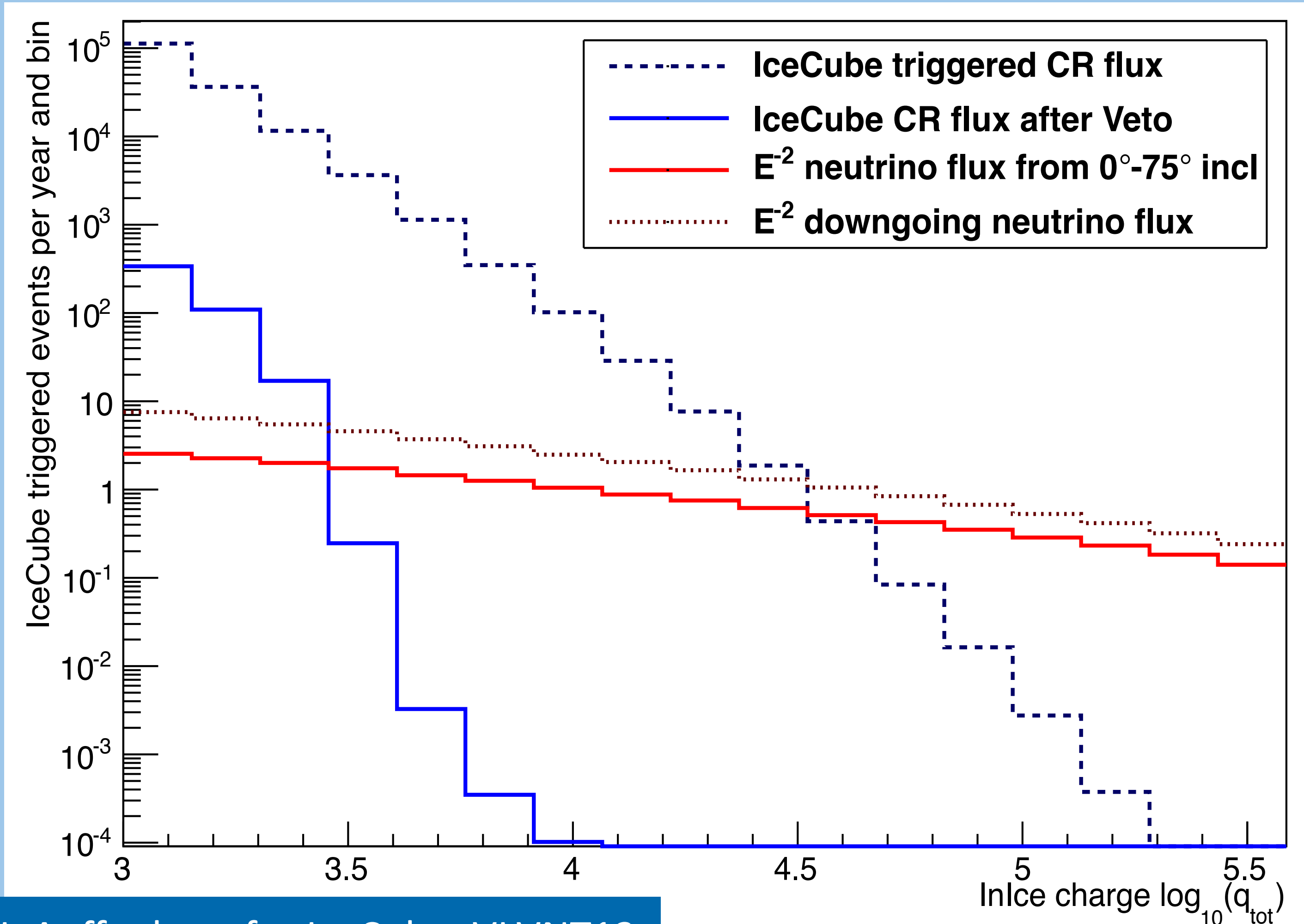
# IceVeto Performance

Veto efficiency and neutrino flux calculated **based on real data**.




J. Auffenberg for IceCube: VLVNT13

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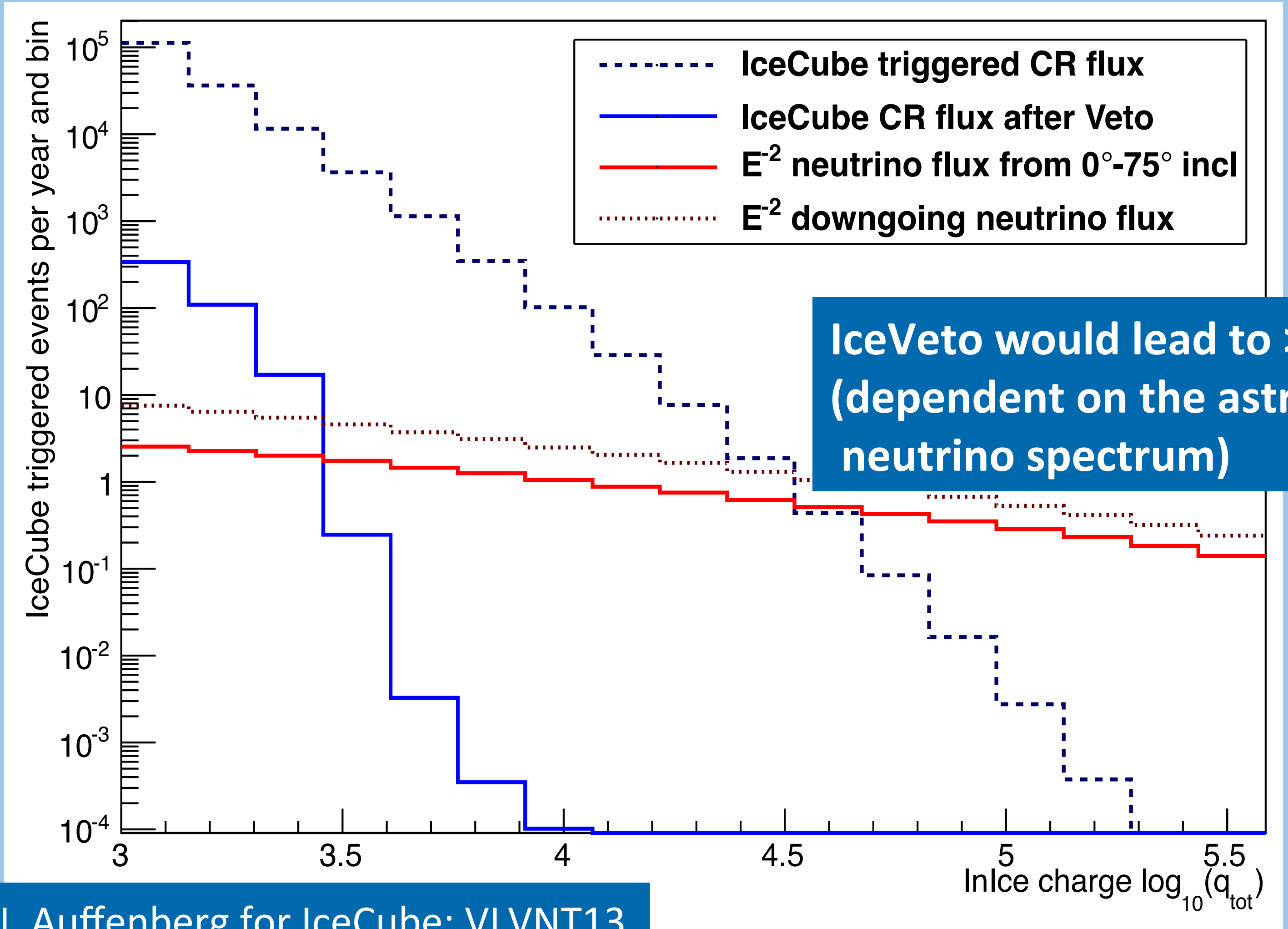


**IceVeto would lead to >10 tracks per year (dependent on the astrophysical neutrino spectrum)**

J. Auffenberg for IceCube: VLVNT13

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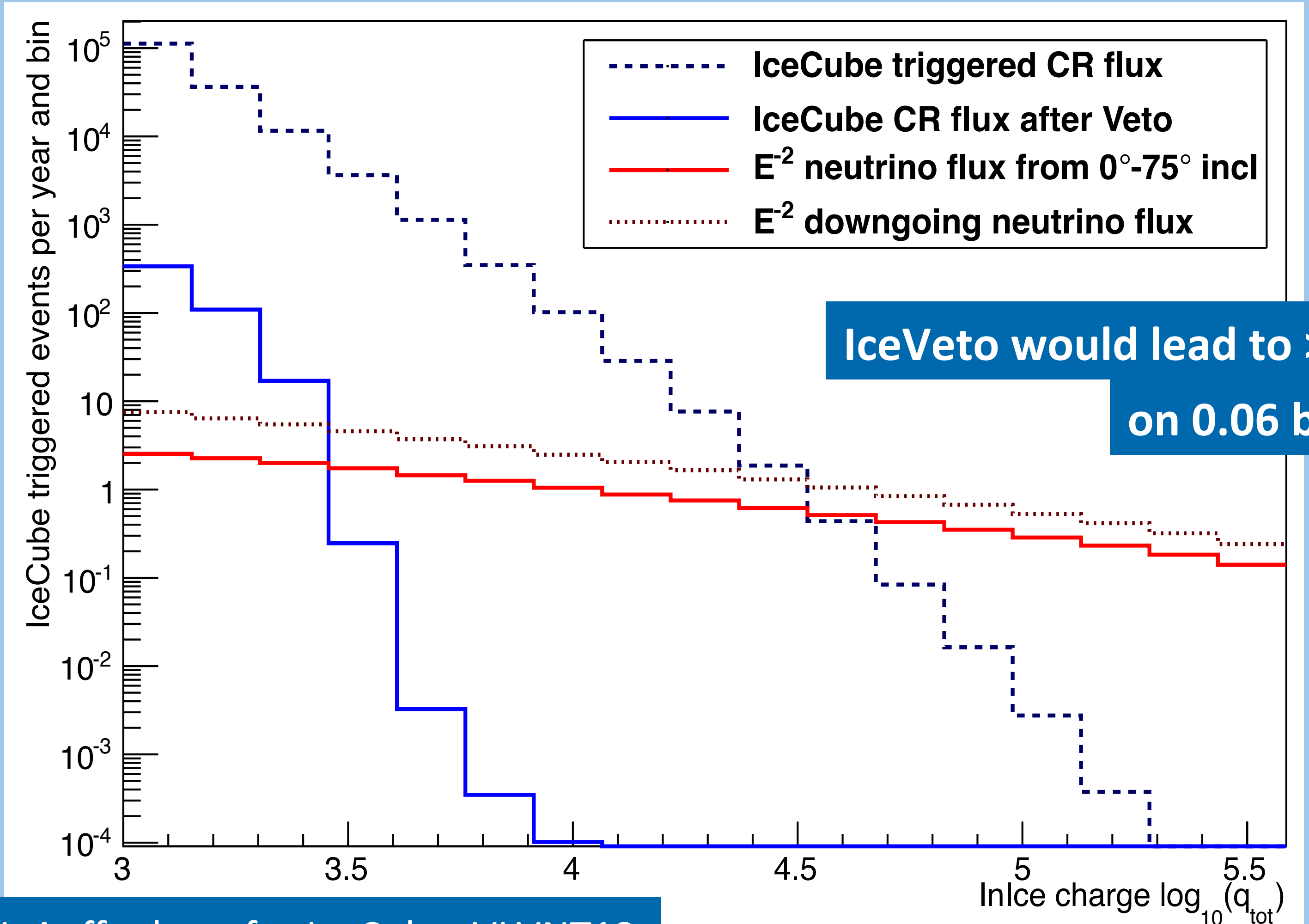


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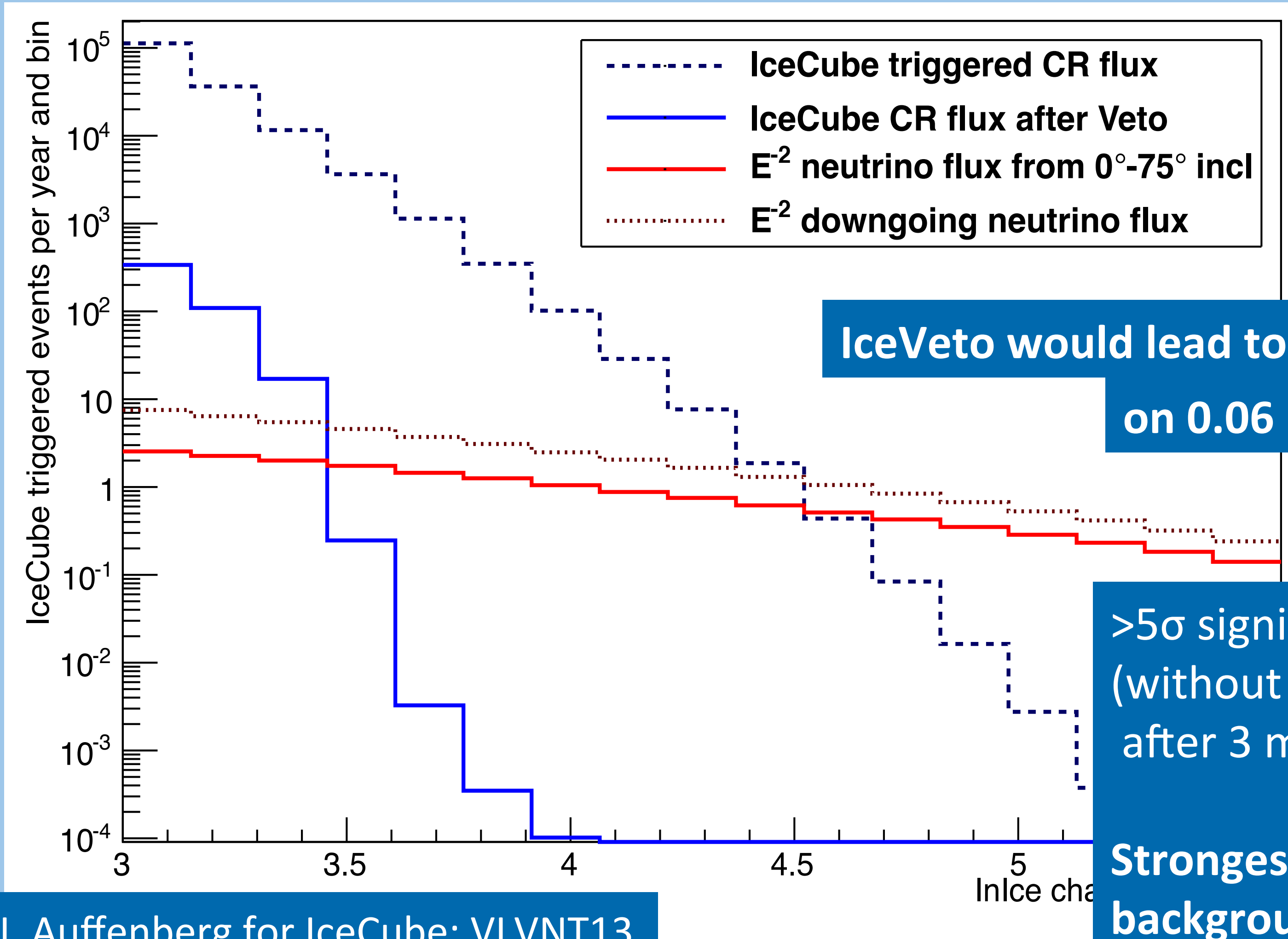


**IceVeto would lead to >10 tracks per year on 0.06 background events!**

>5σ significance (without systematic errors) after 3 month!

**Strongest argument remains background free pointing**

J. Auffenberg for IceCube: VLVNT13

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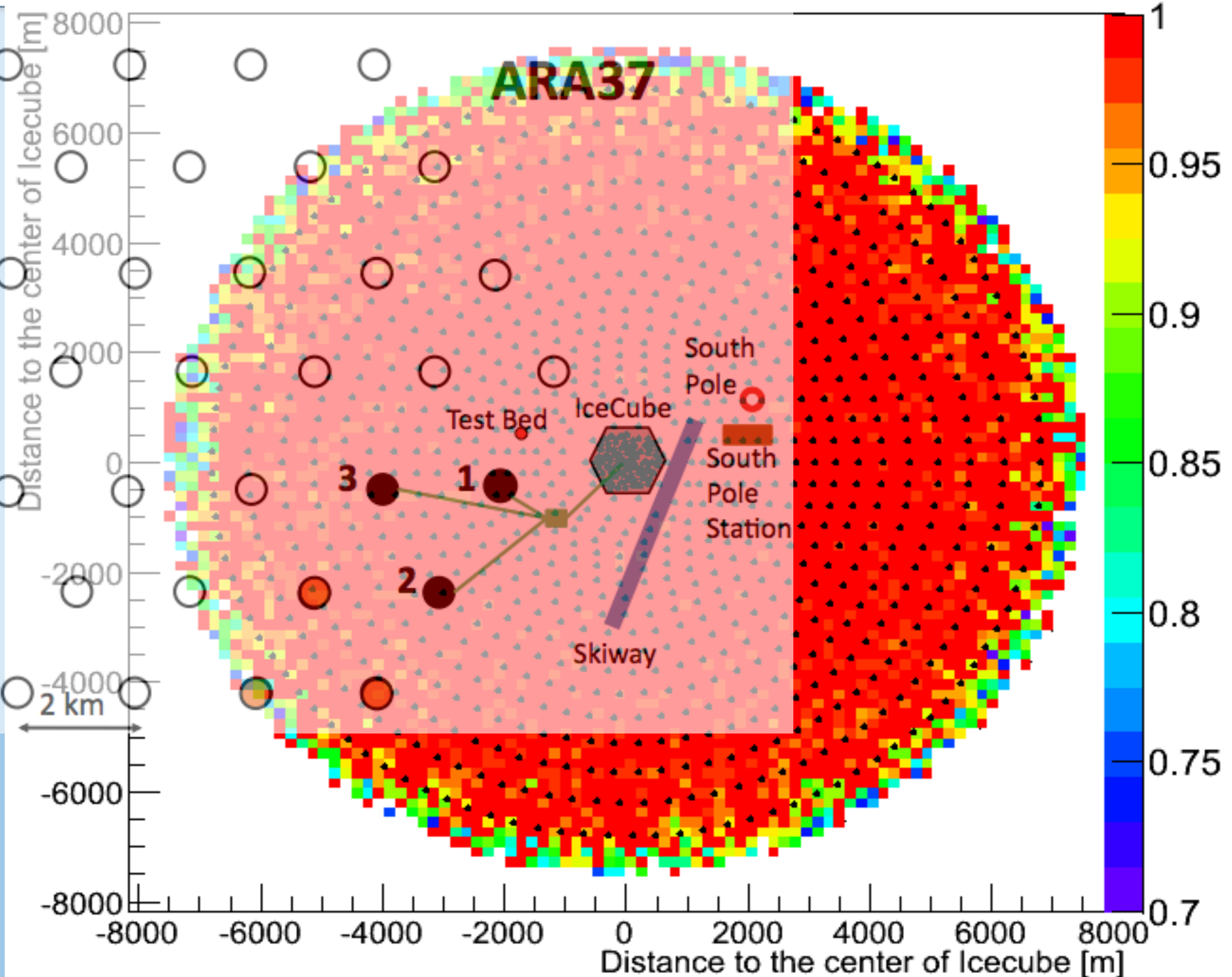
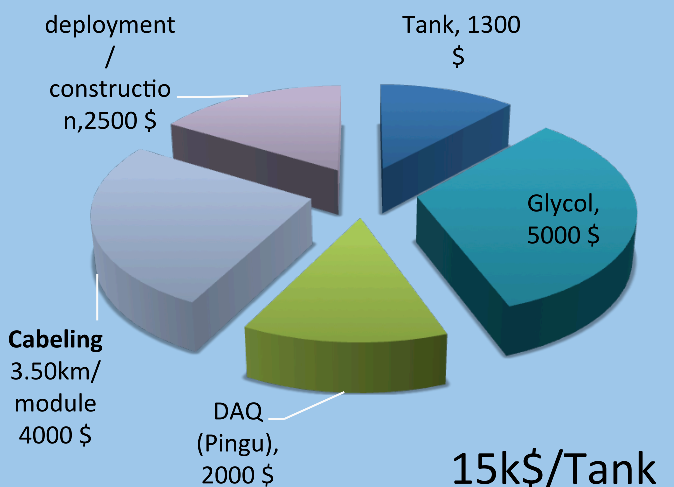
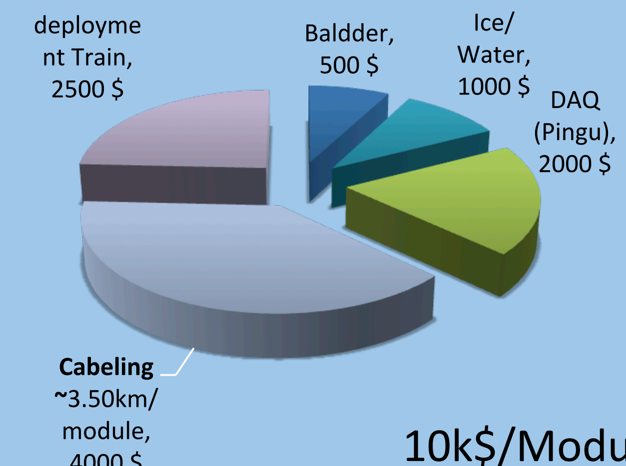





15k$/Tank



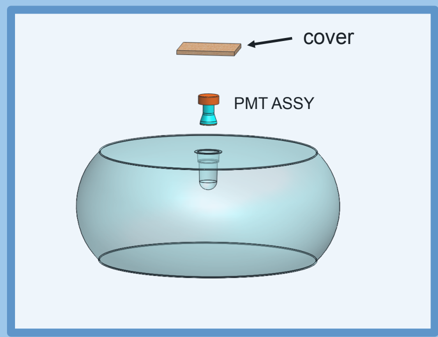

10k$/Module

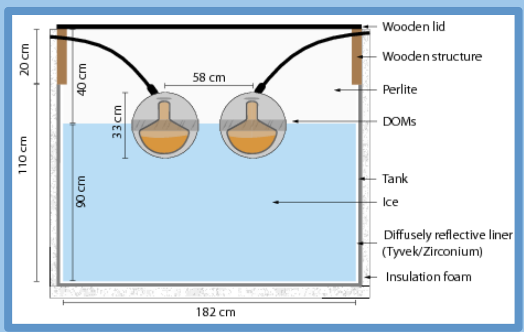
- Tank: $1300 (2007: $1135) or just a bladder ($500)
- Tyvec Liner: $330 (2007: $300)
- Maybe Glyocol instead of Water: $5000 (price at the south pole vs. just south pole water $1000)
- DAQ + PMT: $2000 (PINGU estimate very likely less)
- Cabling (~3.50 km per module): ~$4 000 000
- Deployment $2500 per module or less?

Total: $10000 - $15000 per module

**$ 10 – 20 Million for IceVeto**

**< 1/10 IceCube**



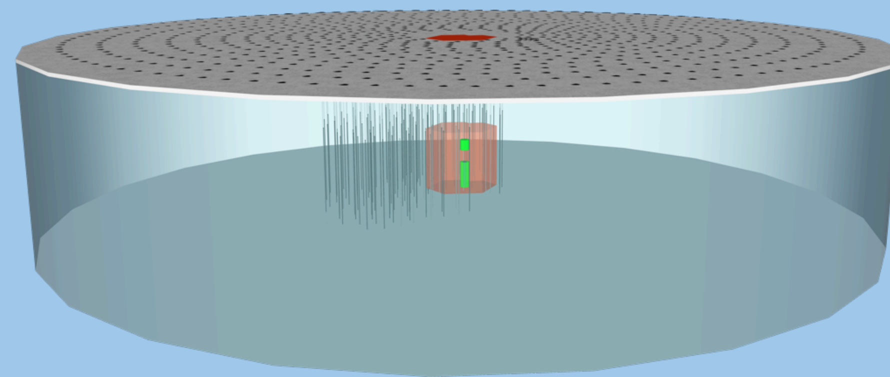



# Part 2: Air Cherenkov telescopes for the veto (IceAct)

# Veto CR to measure astrophysical neutrinos

Requirements:

- extremely good detection efficiency for CR
  - -high duty cycle
  - -low energy threshold



one solution: many surface stations to detect particles on the surface. (limited active volume)

(high duty cycle but high energy threshold)

This idea: Take the atmosphere as active volume and measure the air-Cherenkov light of the air shower.

(low duty cycle but low energy threshold)

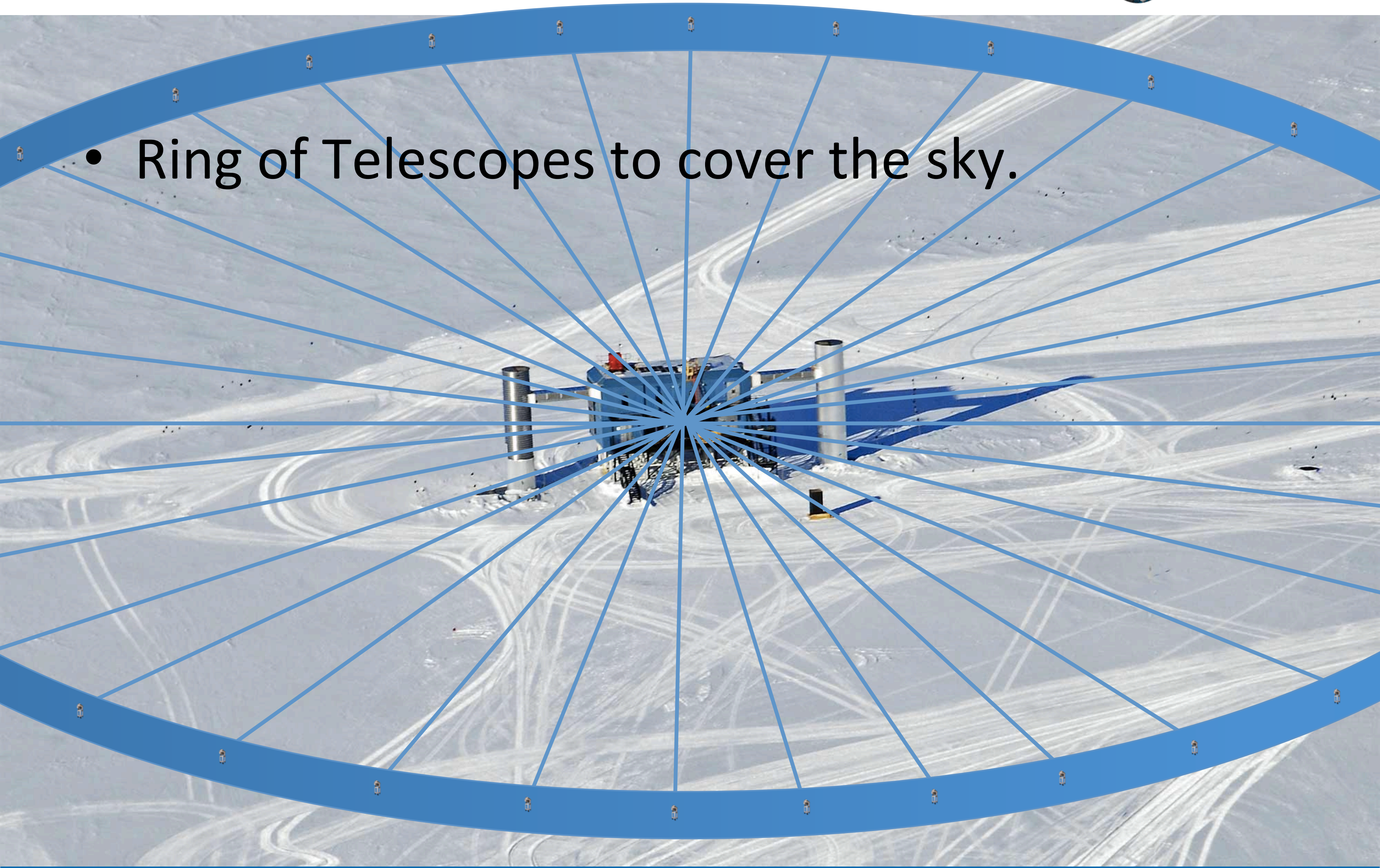
PIERRE AUGER OBSERVATORY

FAMOUS

**Of course the systems could be combined!**

# IceAct

- Ring of Telescopes to cover the sky.



# The geometry of a veto with ACTs

$$\alpha_{vertical} = 180 - 2\alpha_{ws}$$

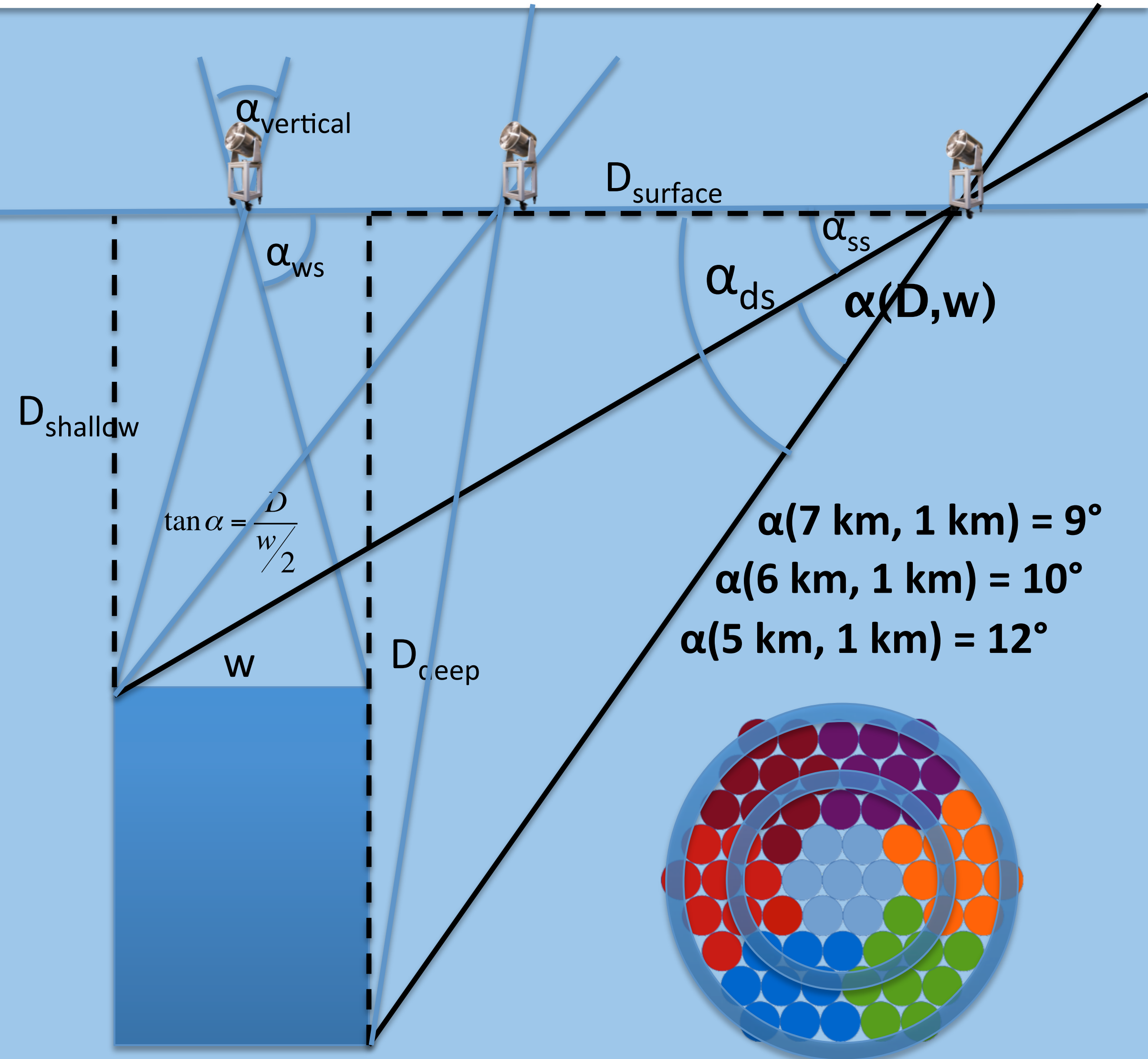
$$\tan\alpha_{ws} = \frac{D_{shallow}}{w/2}$$

$$\boxed{\alpha_{vertical} = 37°}$$

$$\alpha(D,w) = \alpha_{ds} - \alpha_{ss}$$

$$\tan(\alpha_{ss}) = \frac{D_{shallow}}{D_{surface} + w}$$

$$\tan(\alpha_{ds}) = \frac{D_{deep}}{D_{surface}}$$





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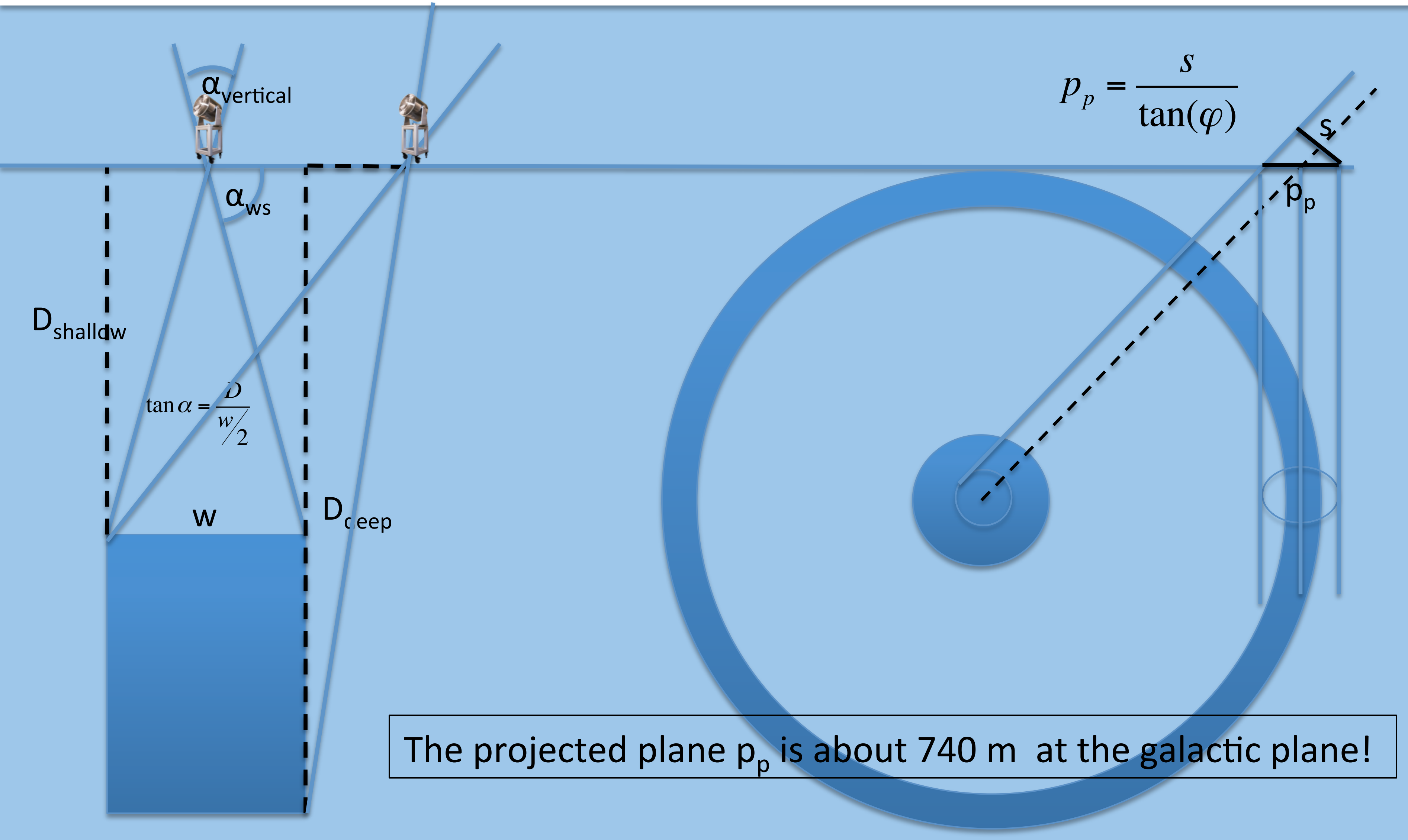
# Projected Cherenkov Cone Size




The projected plane $p_p$ is about 740 m at the galactic plane!



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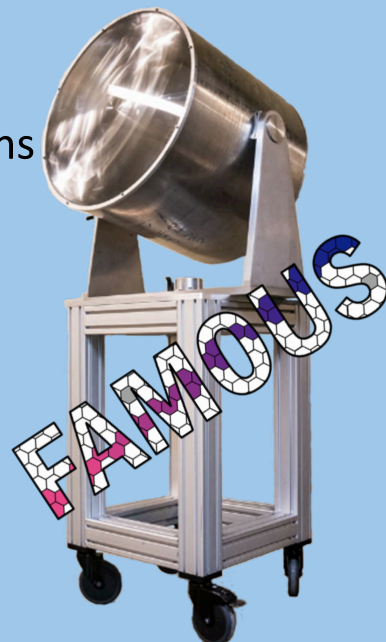
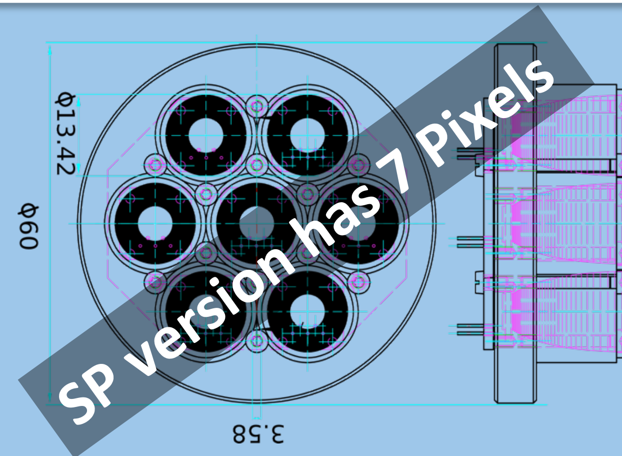
# IceAct Prototypes in Aachen

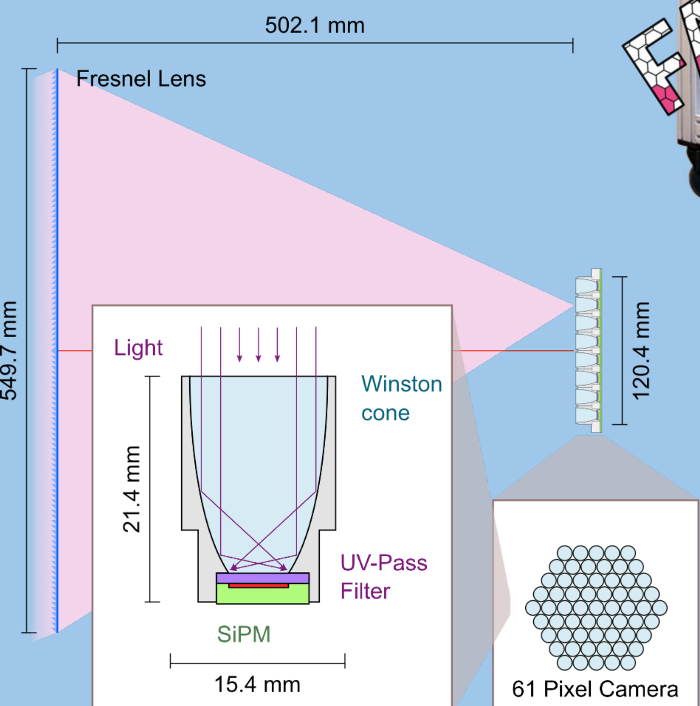
ICECUBE

61 Pixel Prototype Telescope:

- Thin UV transparent UV lens
- Focus length 502.5 mm
- aperture ~f/1
- DRS4 based DAQ
- 12° opening angle



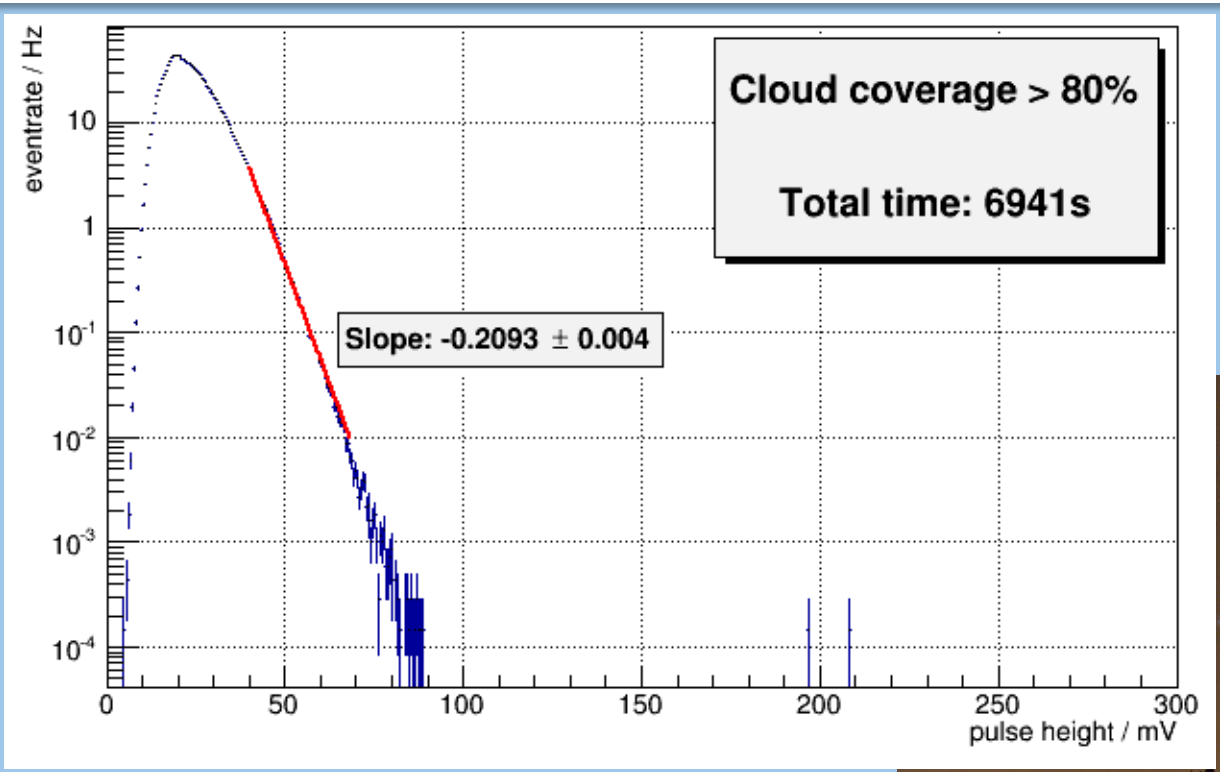

Assuming:

- an acceptable energy threshold (100TeV)
- acceptable duty cycle
- durability in harsh environments

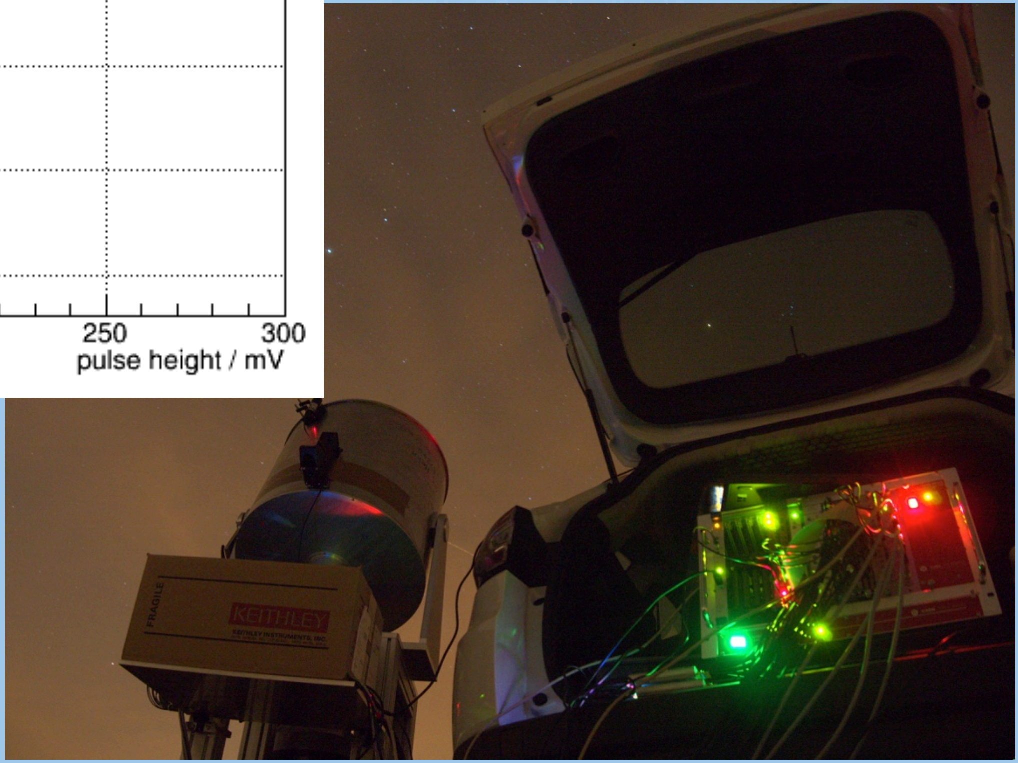
**-interesting in the outer region at 5km and lager?**
**-in combination with stations?**
**-as an infill for source regions?**

**The instrumentation form 5-7km is ~13000 channels**
**;a cost equivalent to ~ 200 61 pixel telescopes**
**Goal: Test run of a prototype at South Pole**

# The IceAct Prototype




Background measurement at a cloudy day



Almost no high pulse signals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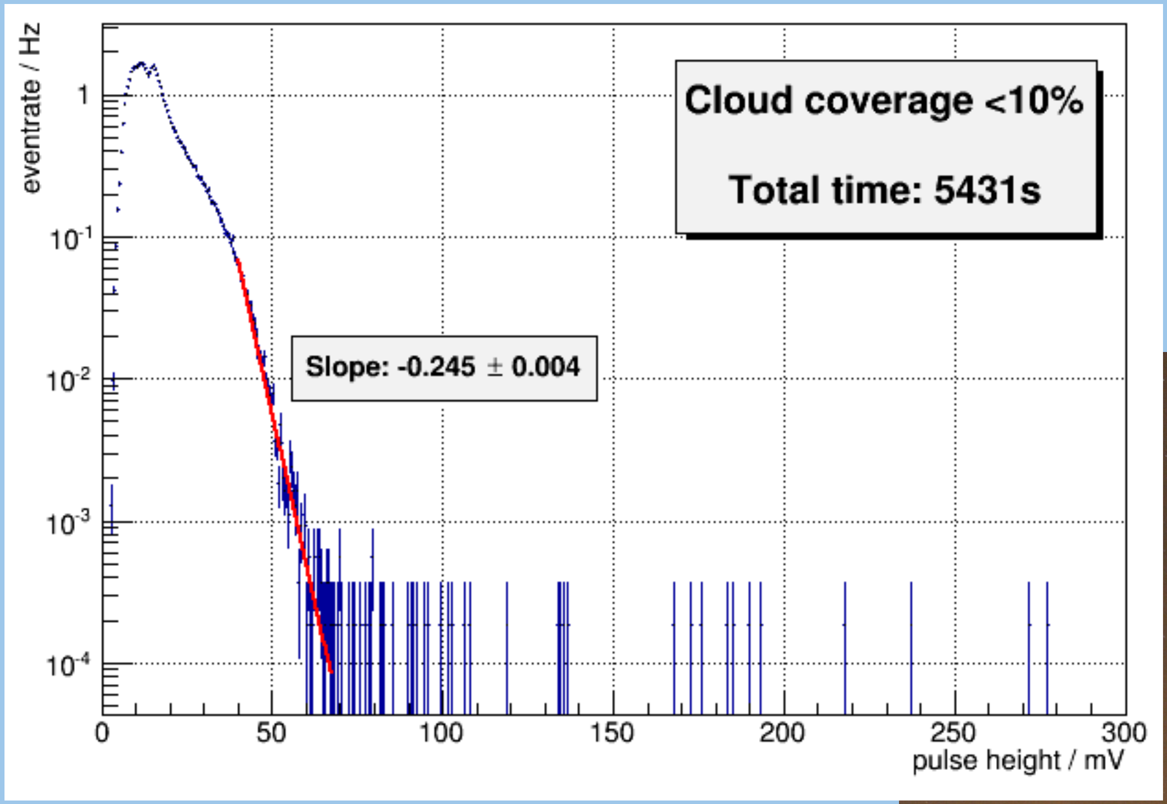
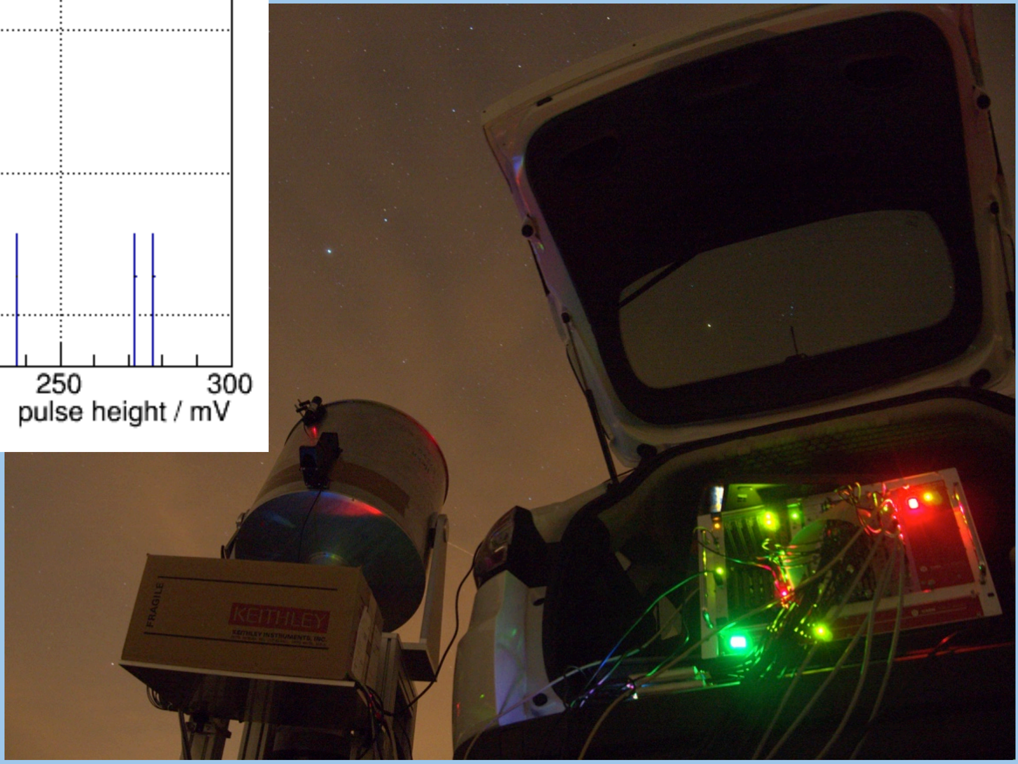
# The IceAct Prototype




Air Cherenkov measurement at a clear day

A lot high pulse signals



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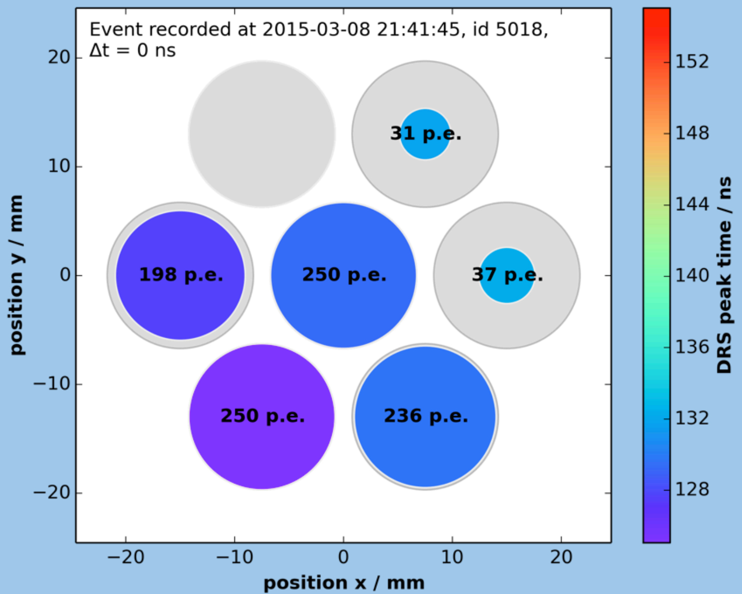
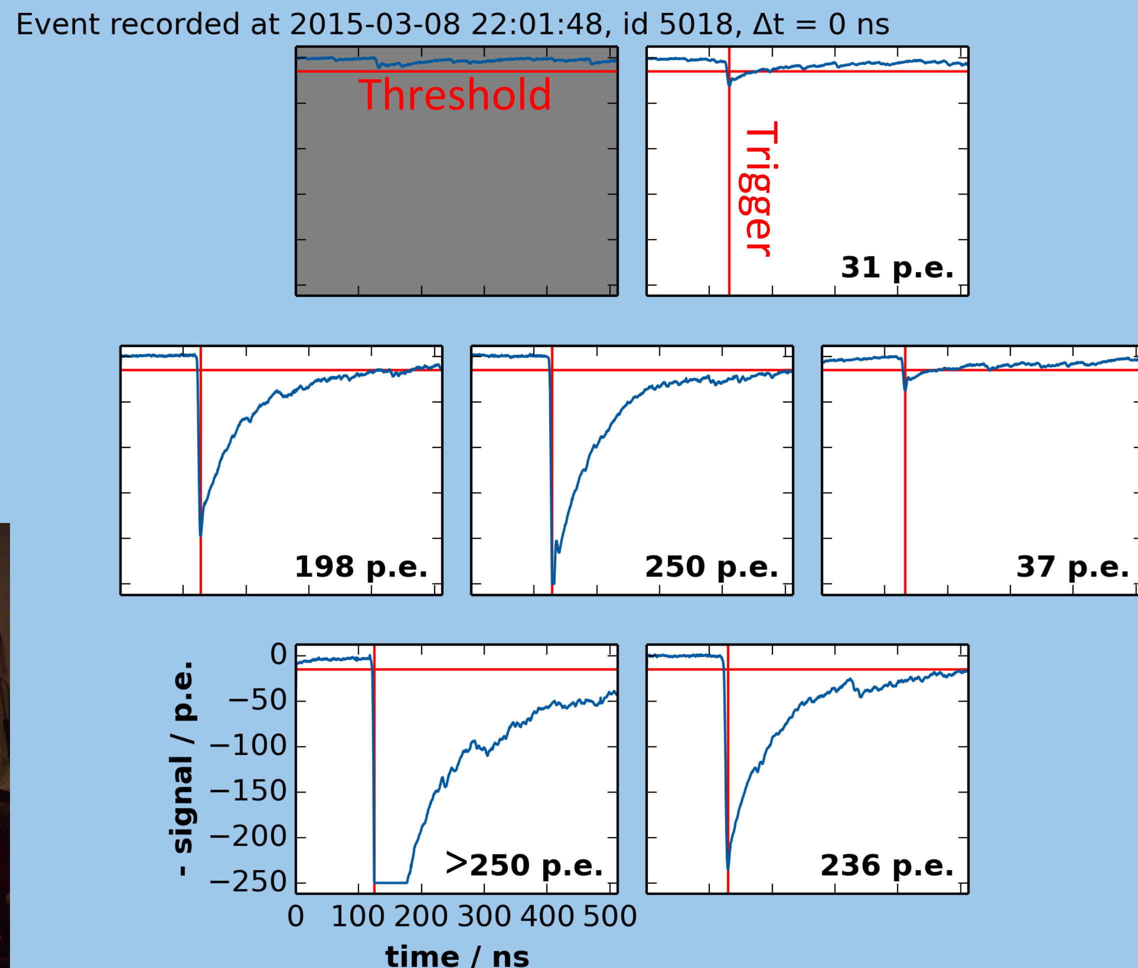
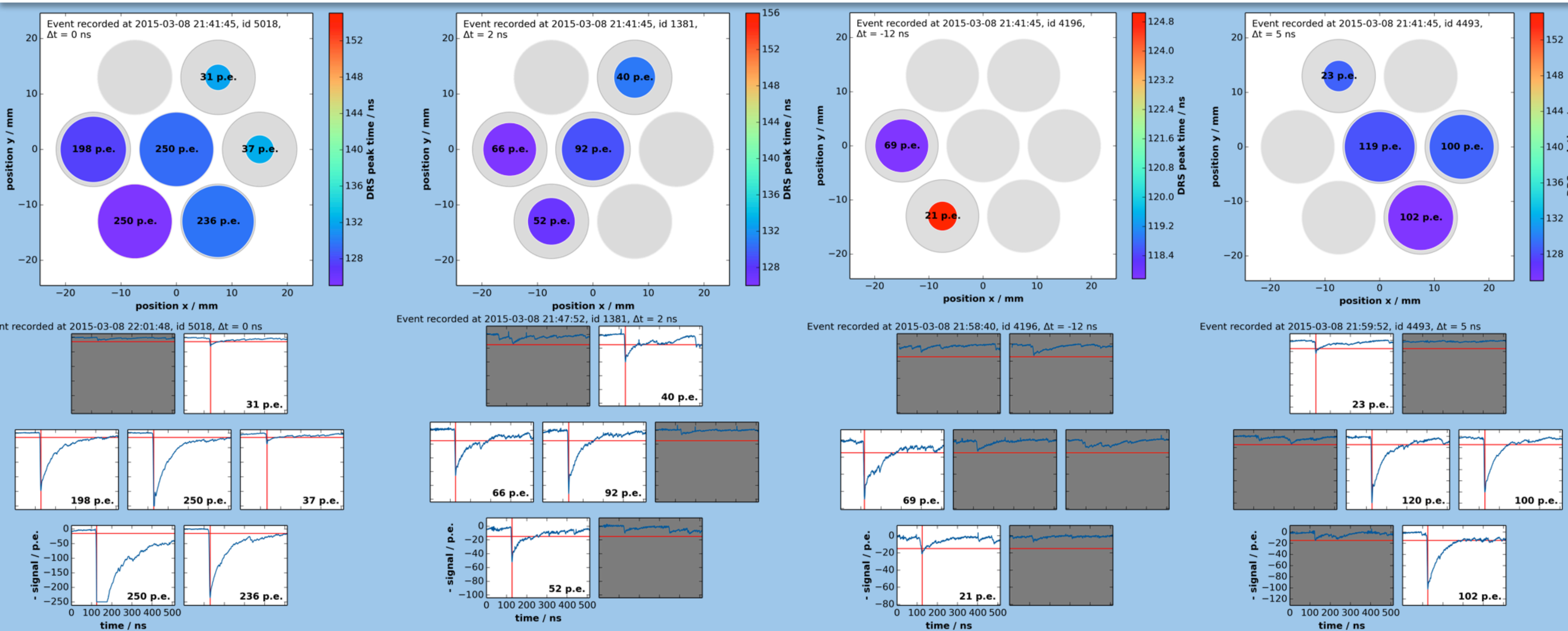
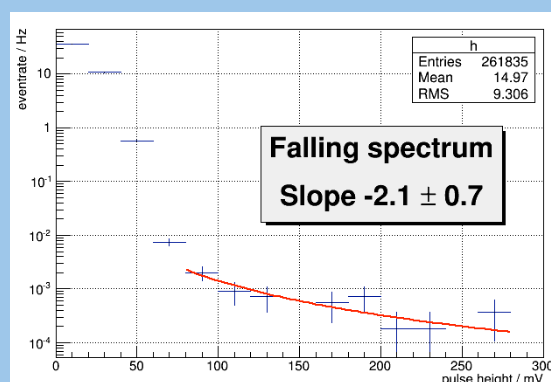
# The IceAct Prototype



# The IceAct Prototype




- All events with high pulses have a sharp rise time and are nicely coincident.
- The analyses and simulations are ongoing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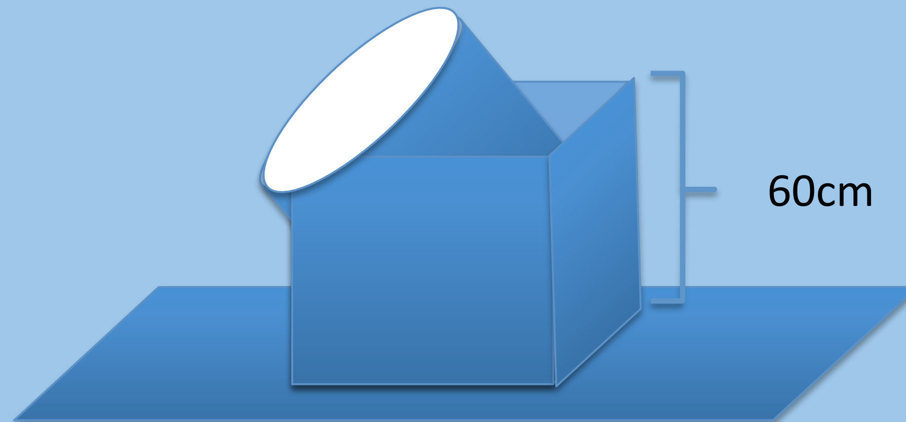
# Prototype for the South Pole

ICECUBE

- Carbon tubus light weight
- Glass in front of the Fresnel lens
- robust stand (box)
- DRS4 board based readout
- customized slow control
- 7 channel SIPM camera






DRS4 Evaluation Board (we will use 2)

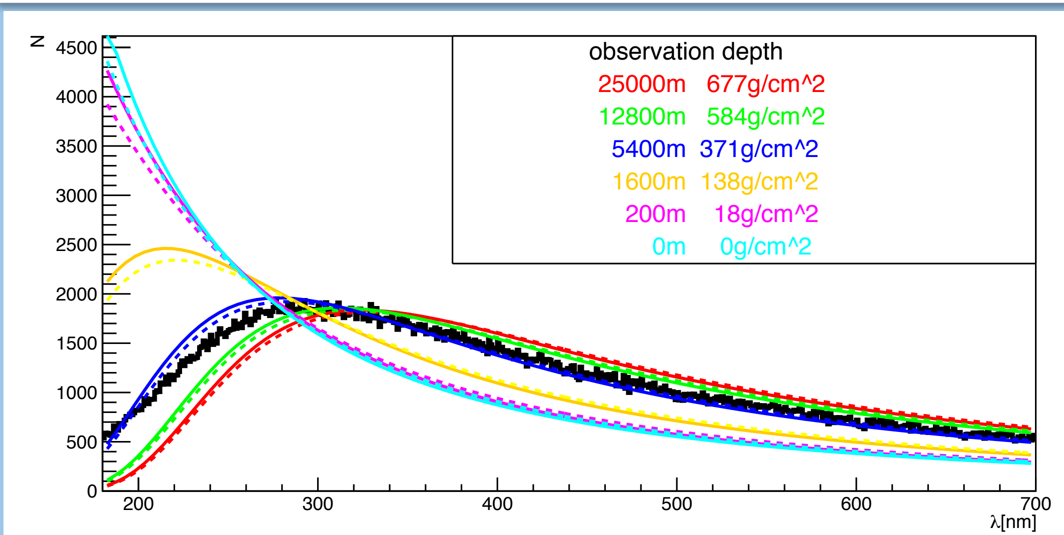
# AC photons from Corsika

Corsika simulates for the Cherenkov photons:

- production height (atmospheric)
- direction (on ground or relative to a detector plane)
- propagation through the atmosphere (absorption)
- range of the wavelength (180-700nm in our case)
- **NO particular wavelength/energy**

**But we can implement Rayleigh $1/\lambda^4$ and Mie scattering (independent of $\lambda$)**

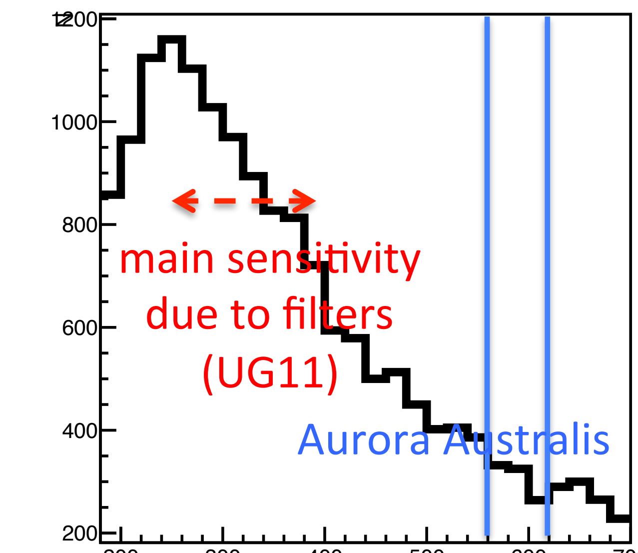
# Implementation of the wavelength



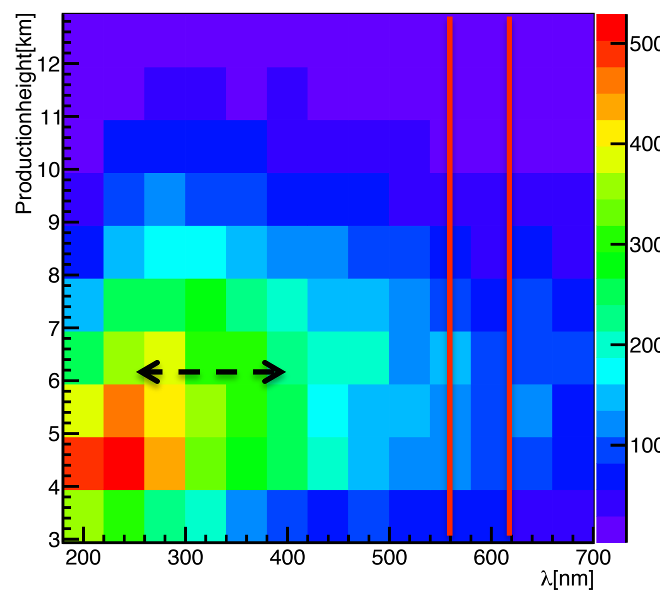

For 100 TeV vertical proton shower, telescope 141m from the shower axis

- production height of the photons at 7-4 km

Thus only 4-1 km above ground!




© Bengt Hansmann



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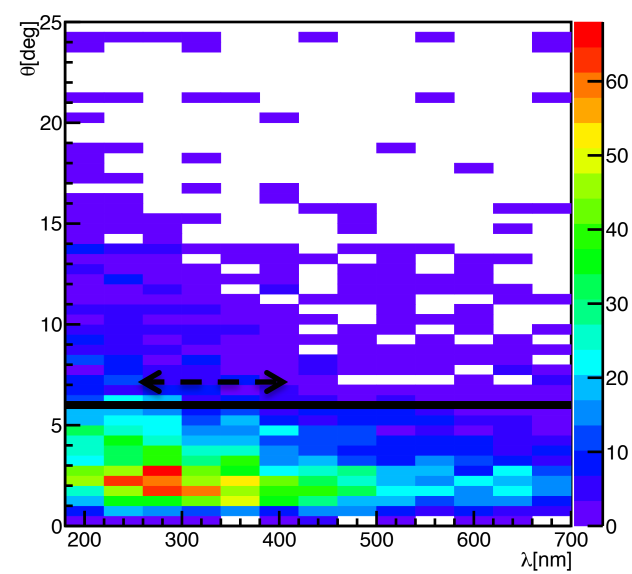
# Properties on the surface/lens

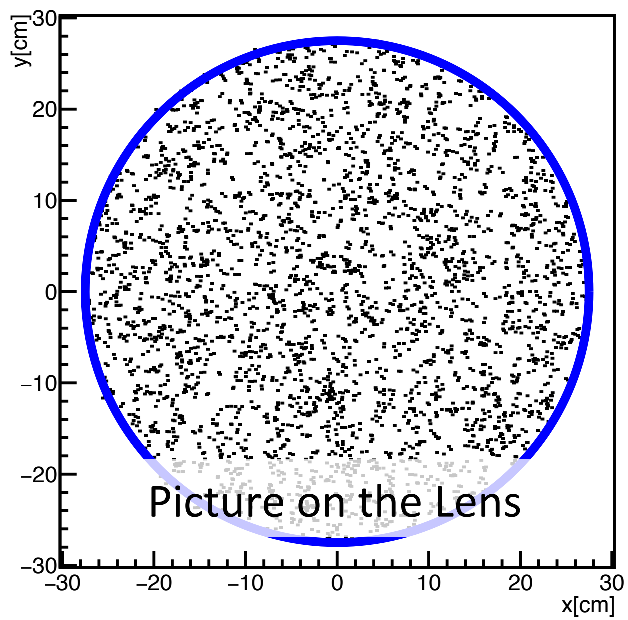
ICECUBE

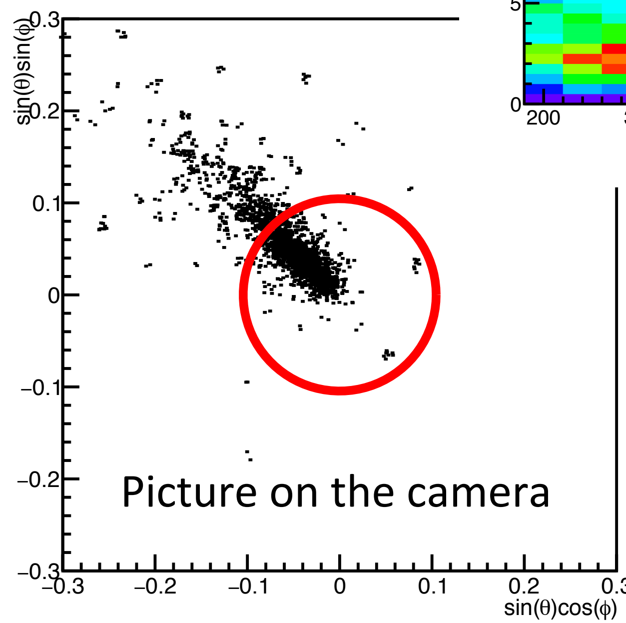
100 TeV Shower in 150m distance.

Some 500 photons reach the lens.

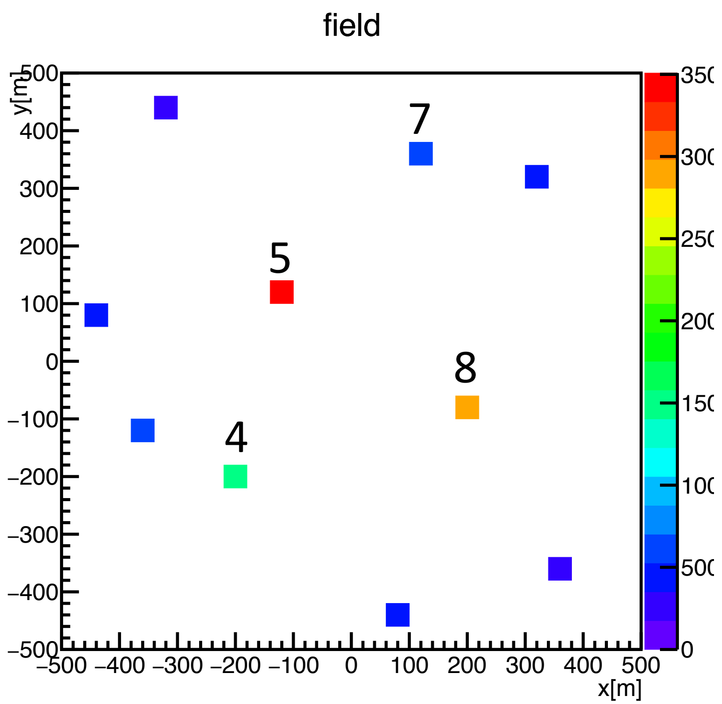
Threshold at South Pole: 15pe.

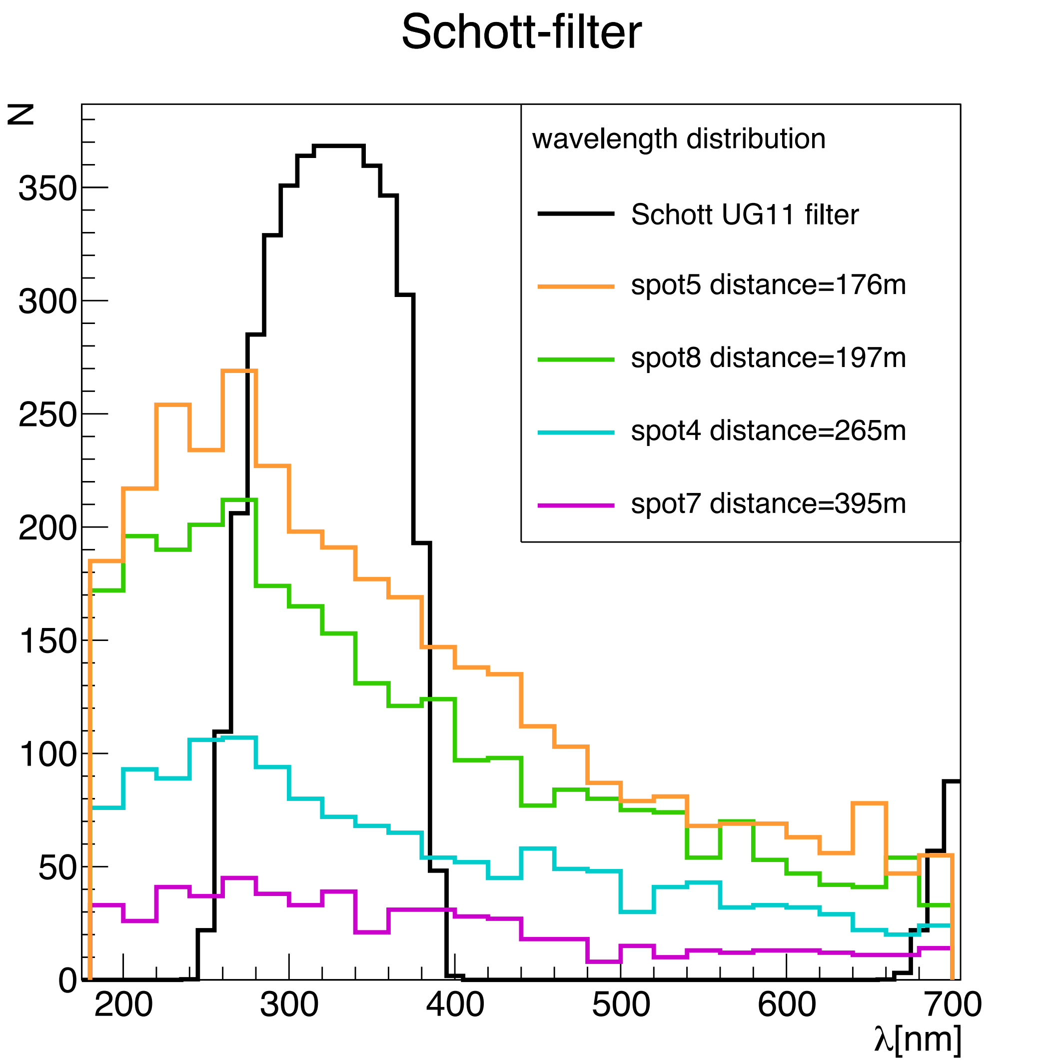


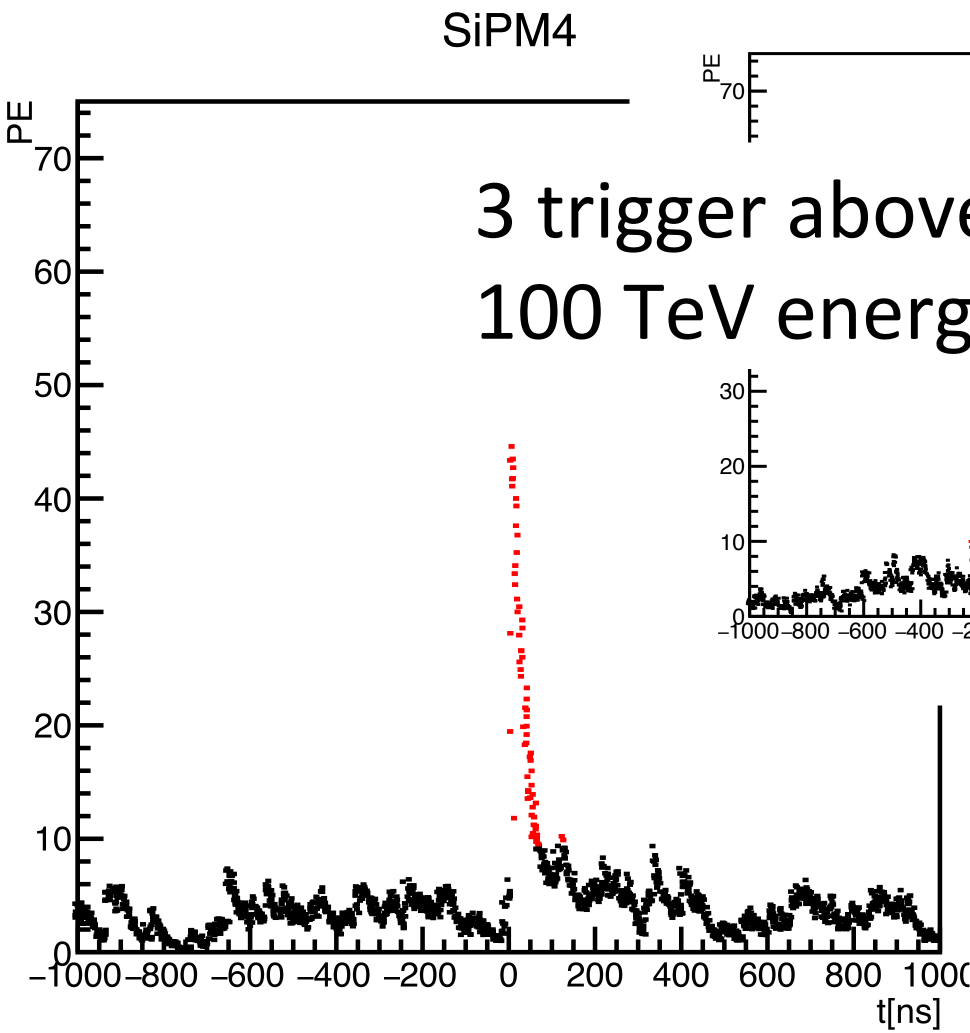
# 100 TeV shower in different distances

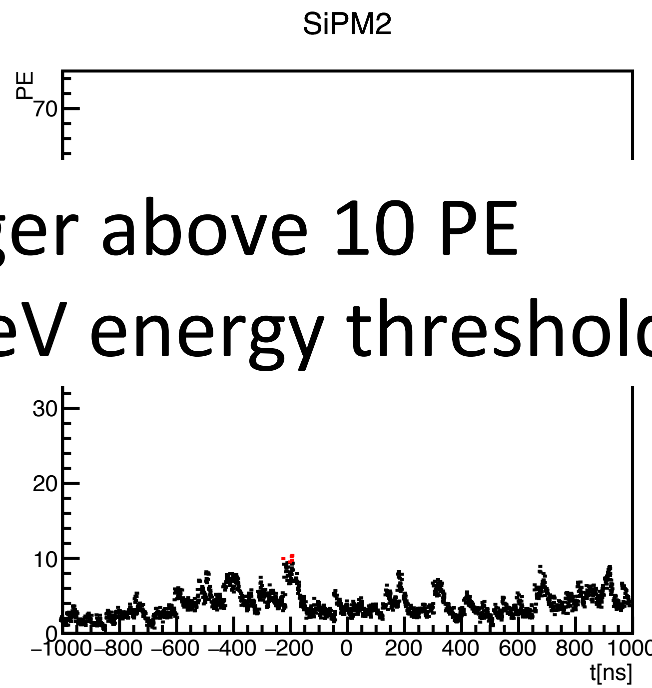



A clear photon signal at up to 250m distance

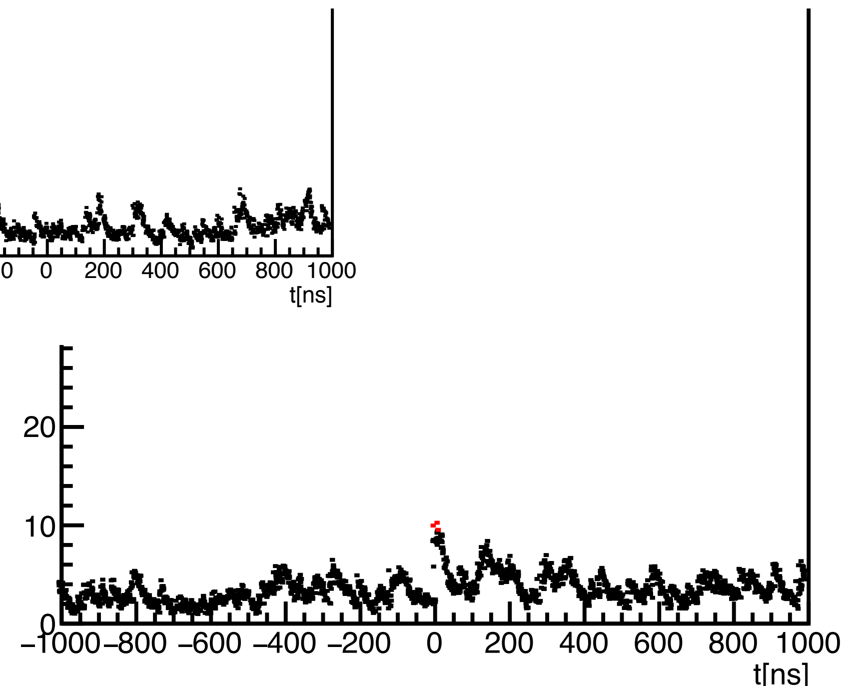
# Properties in the Telescope



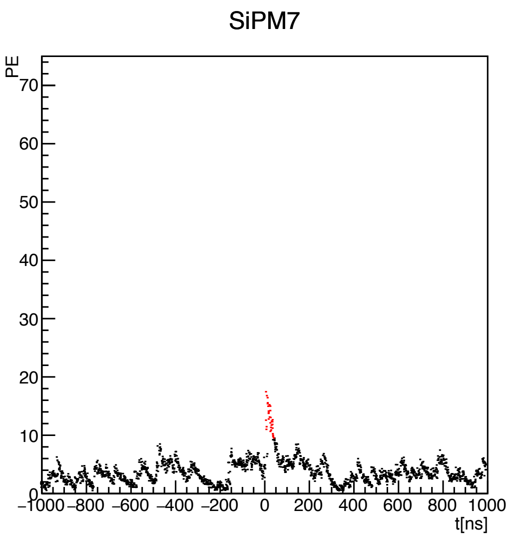

3 trigger above 10 PE

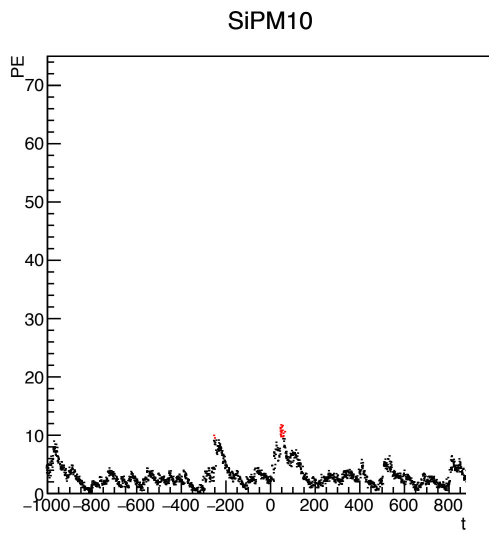
100 TeV energy threshold reasonable!



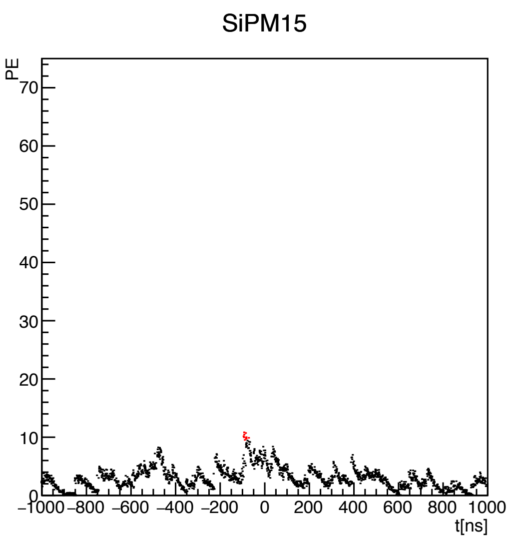

Vertical shower with 100TeV energy 170m distance

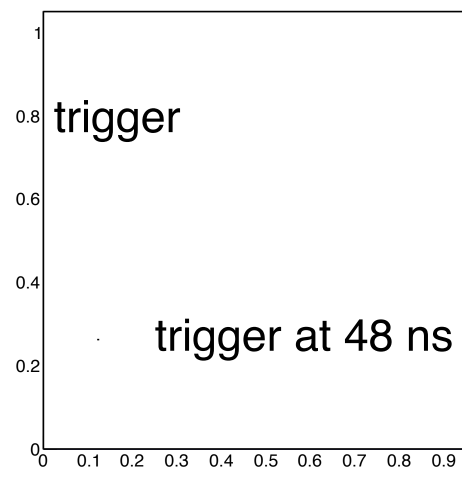
# Vertical 100TeV in 265m distance

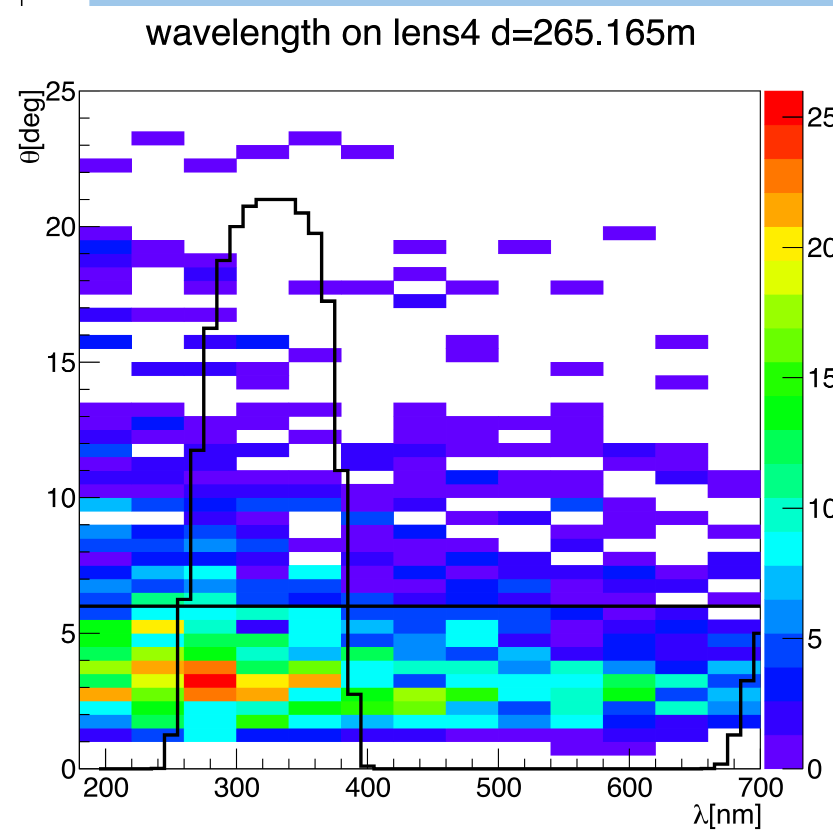



clear signals in the channels!



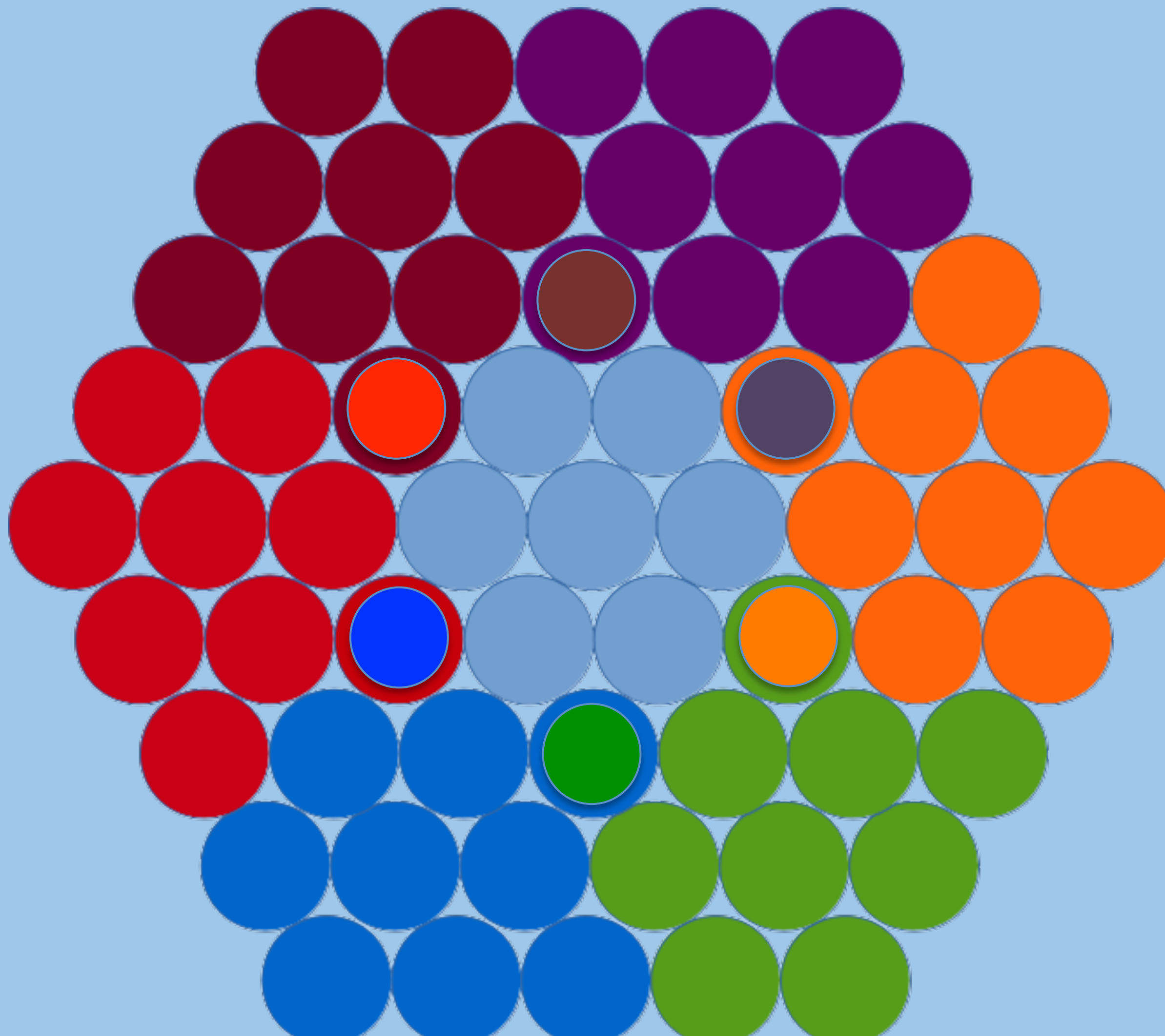



# Summary

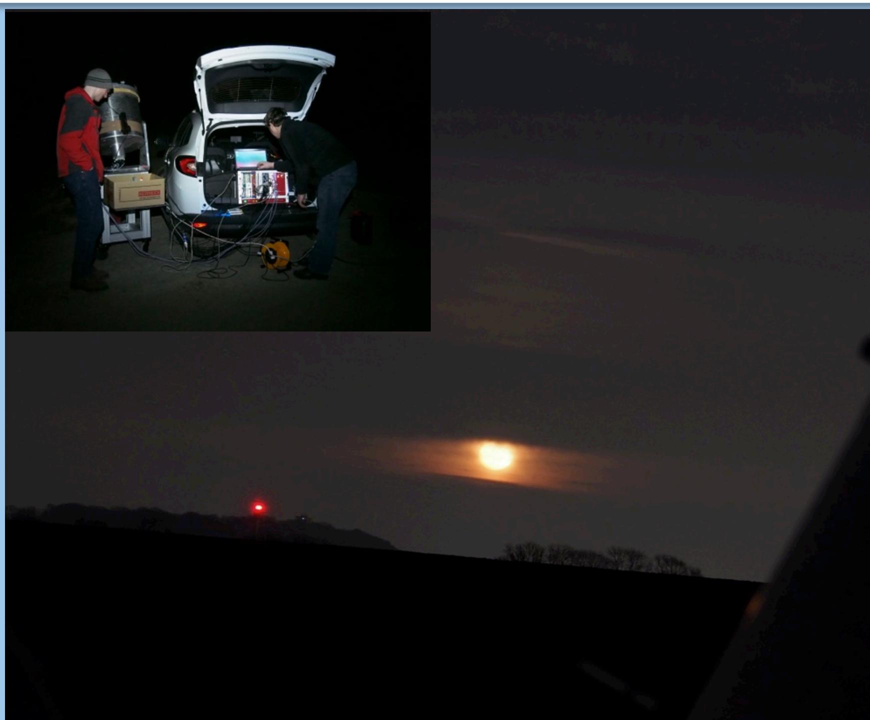
- A surface extension to veto air showers is a promising tool for neutrino astronomy
- high energetic neutrino induced tracks in the in-ice detector are the smoking gun for source detection.
- An extended surface Veto could detect order 10 astrophysical neutrino tracks per year on very small background.
- Possible technologies are charged particle detectors on the ground or Cherenkov light detectors.
- R&D of different technologies are under way

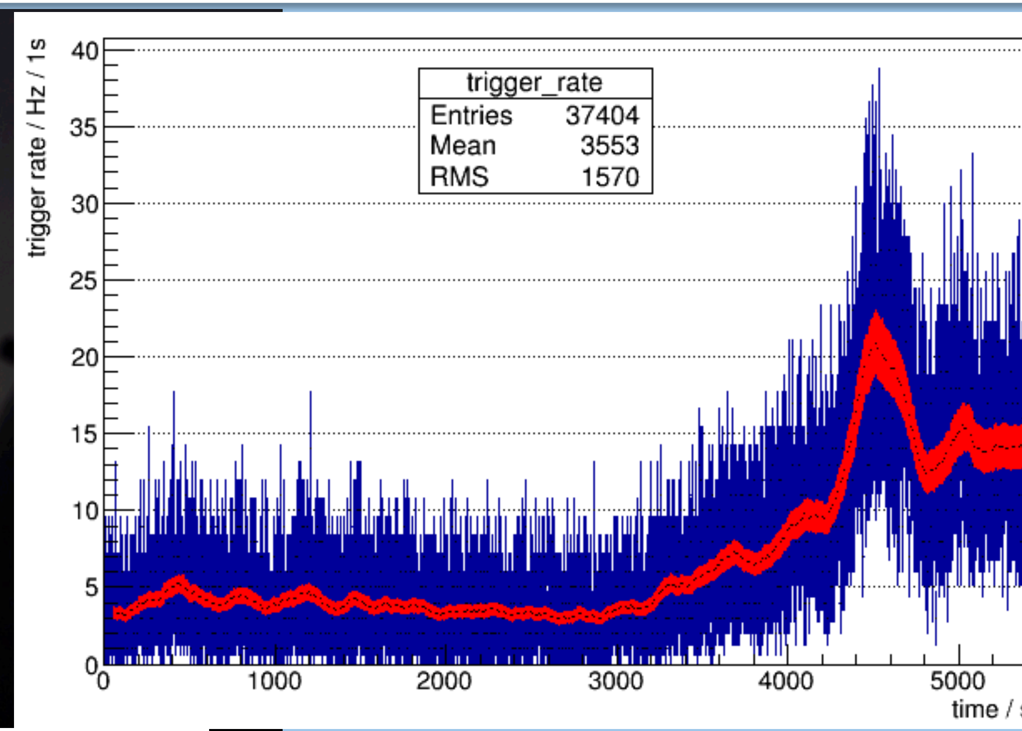
Thanks!

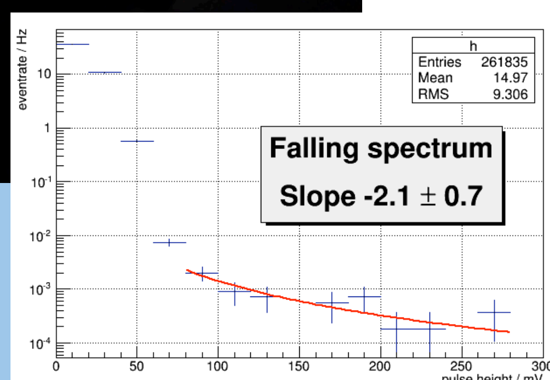
# Thanks!



# The IceAct Prototype






Moon increases the trigger rate but does not stop us from measuring

- The analyses and simulations are ongoing

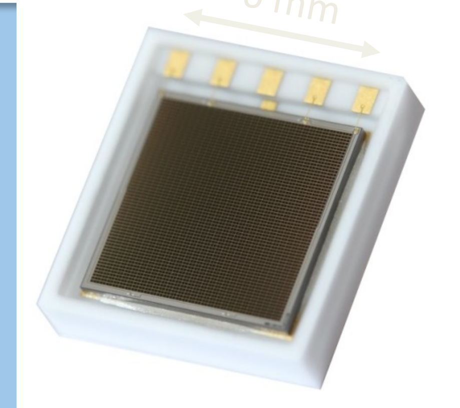
# Pole Plan Summary

- We want to bring one prototype ACT telescope to the South Pole and deploy it on top of the ICL (Goal: feasibility study for surface veto)
- We want to trigger at 10Hz and compare the data with IceTop
- When buying 50+ telescopes the cost would be about 5000$ for one 64 pixel telescope. (The same as an IceTop tank!)
- The duty cycle is an uncertainty. The energy threshold will be at ~100TeV.
- The robustness has to be proven (cold tests are almost finalized)
- The SIPM based camera+ DAQ has other possible applications (large gamma ray telescopes, scintillator based surface particle detectors, thin in-ice multi-channel OMs for smaller holes)

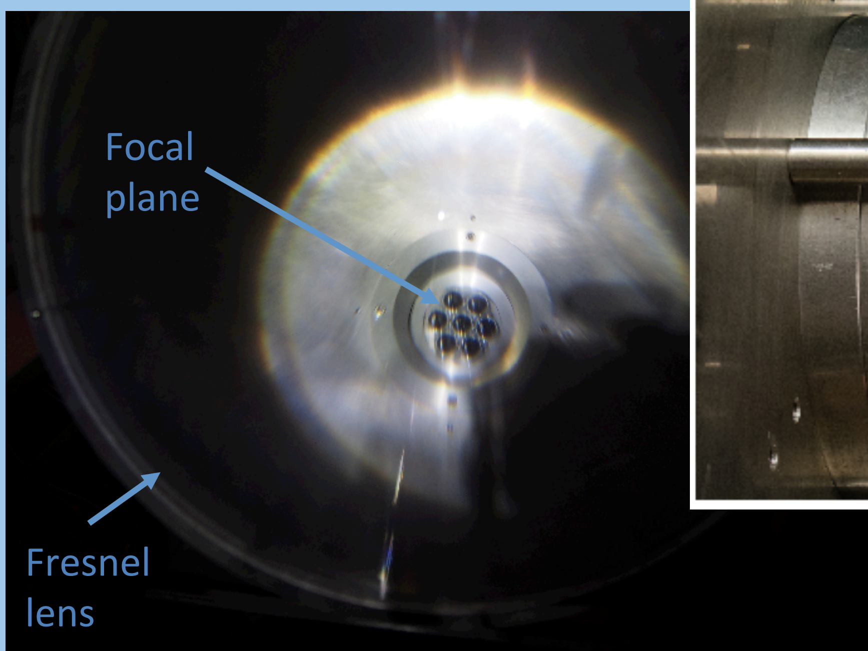
# IceAct Prototype with 7 Pixel

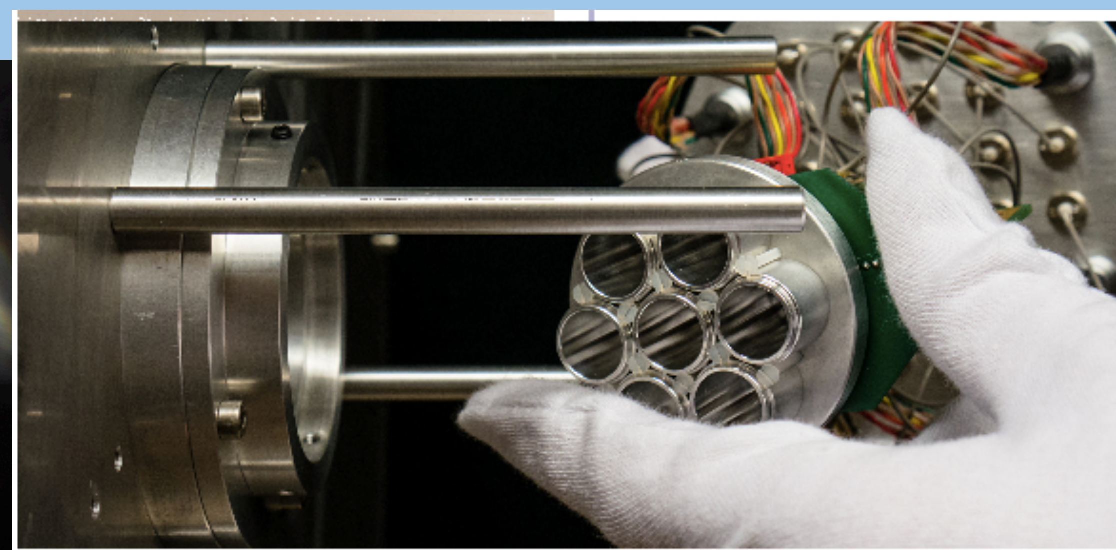
- 1-stage transimpedance pre-amp per SiPM (7 x 4)
- Analogue sum per pixel
- Digitisation using a QDC
- Temperature compensation of SiPM gain included

Charge to digital converter

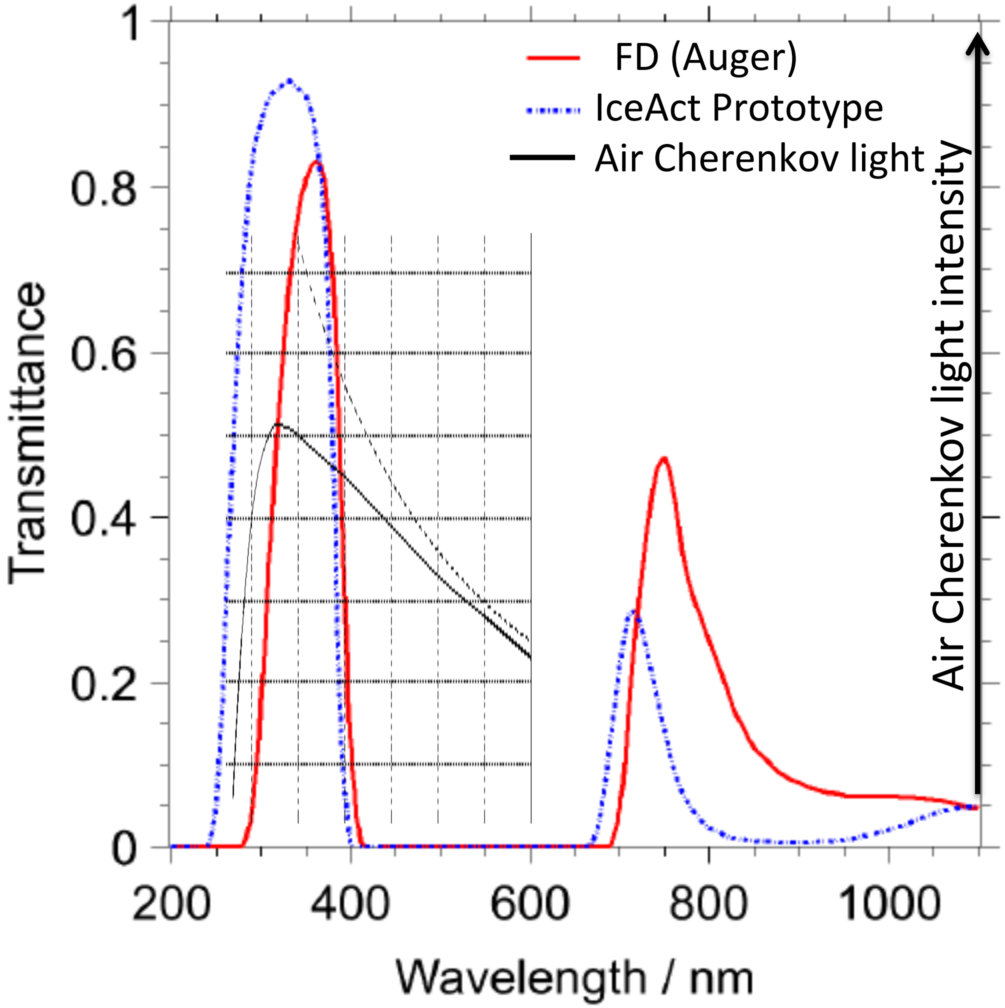



Each pixel consists of one 4-channel SiPM module



# Filter against polar light

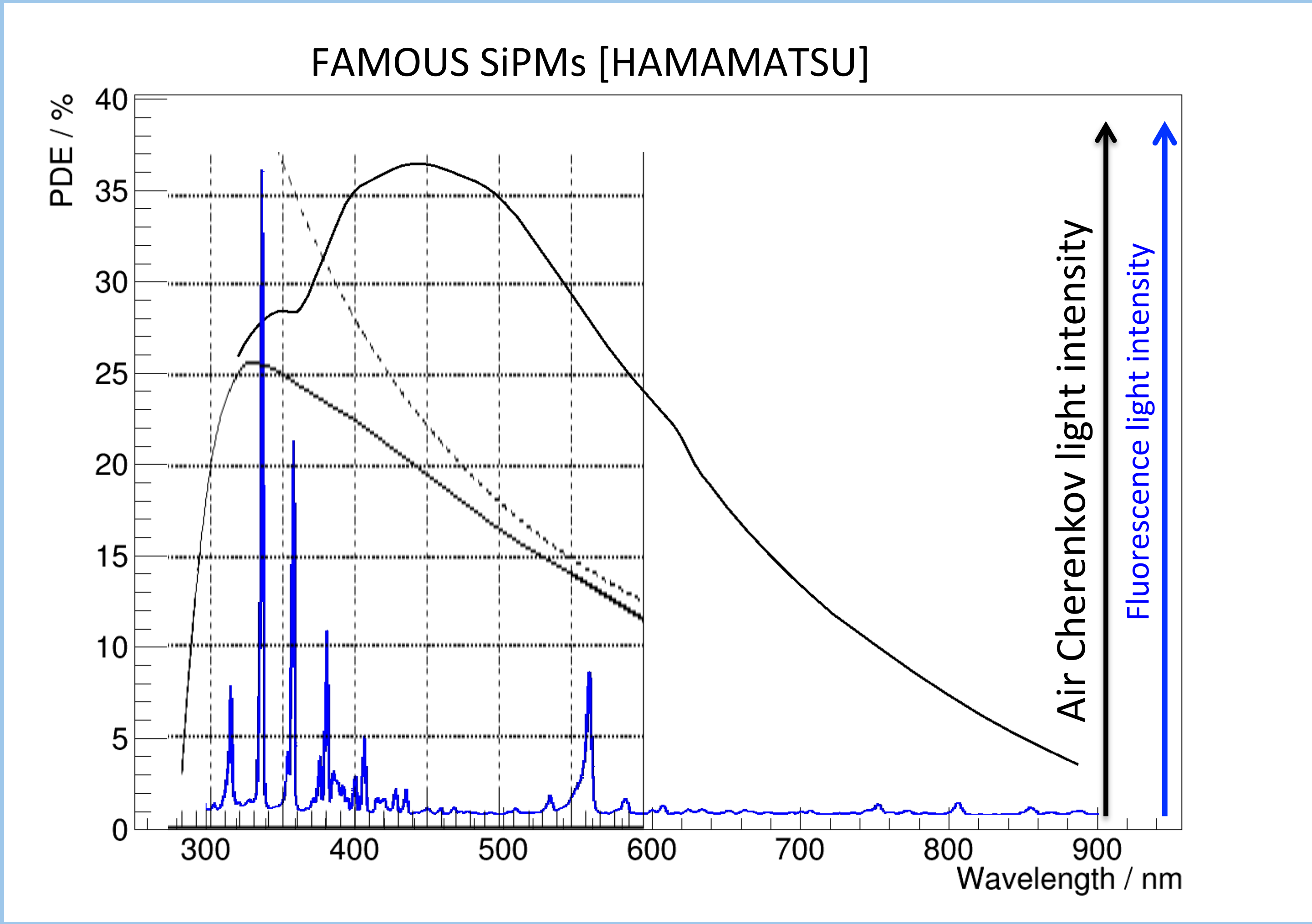



UG 11 compared to M-UG 6:

- Higher transmittance in UV/blue region
- Less transmittance in (infra-)red region

⇒ Better Signal/Noise

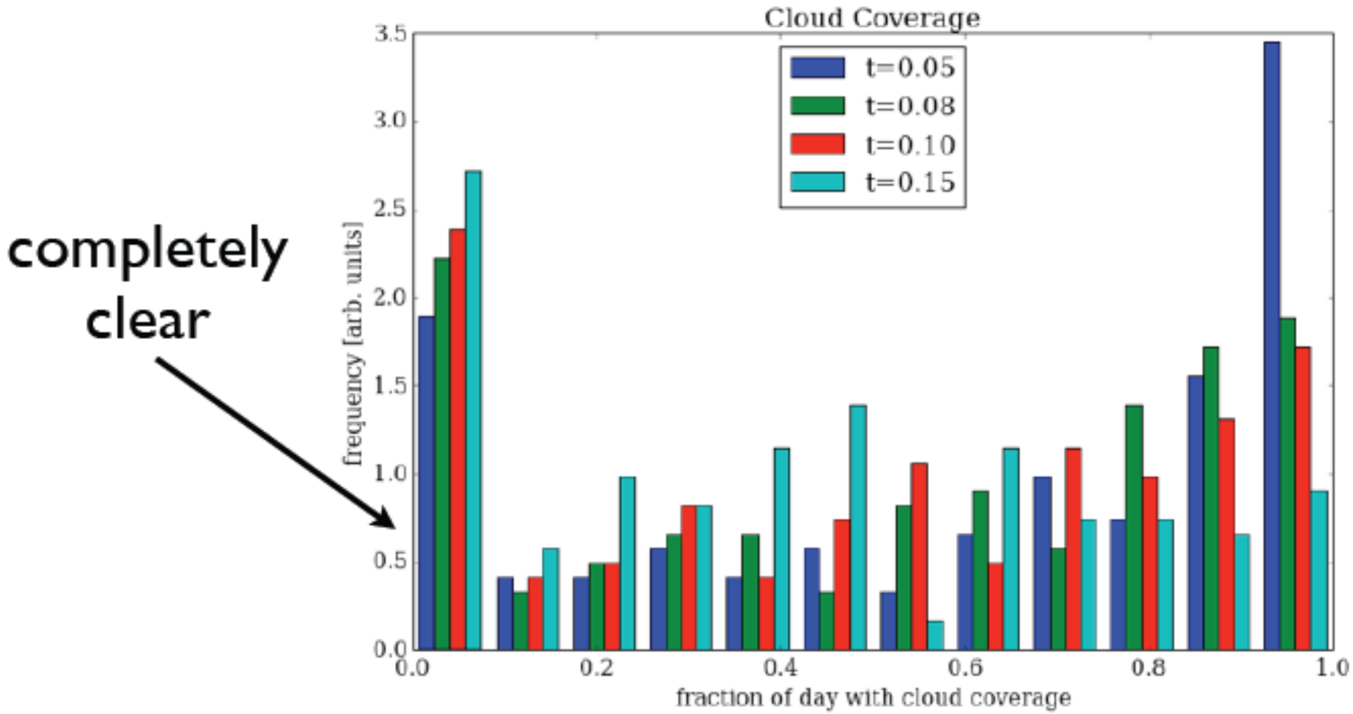
# PDE of SIPMs



FAMOUS SiPMs [HAMAMATSU]
PDE / %
40
35
30
25
20
15
10
5
0
300
400
500
600
700
800
900
Wavelength / nm
Air Cherenkov light intensity
Fluorescence light intensity

# Air Cerenkov Telescopes at South Pole

- Fraction of each day with cloud coverage using different edge-finding thresholds *t* (smaller *t* is more sensitive to cloud)

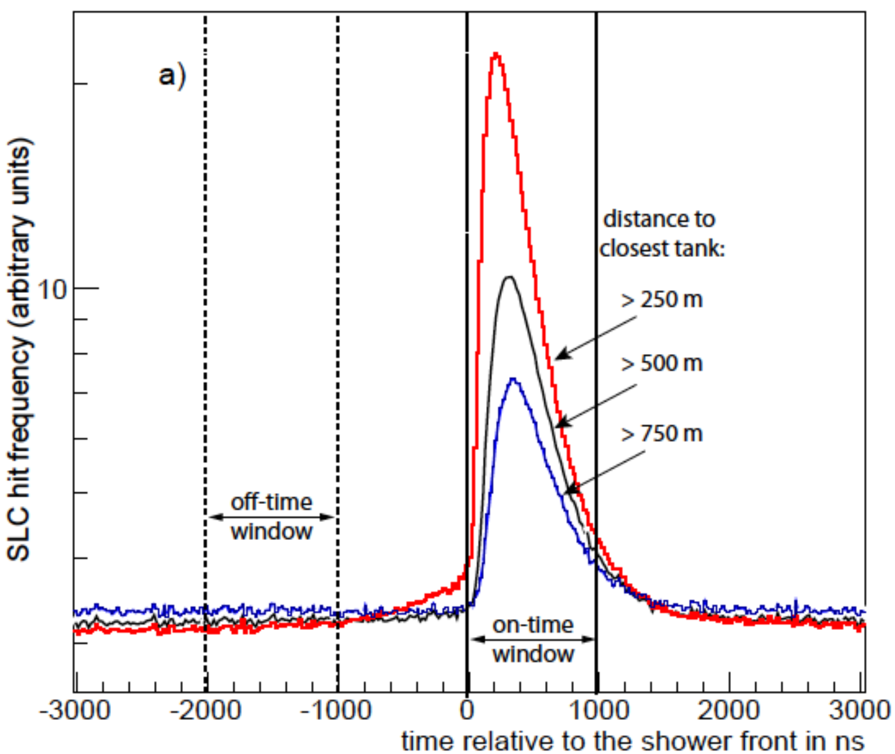


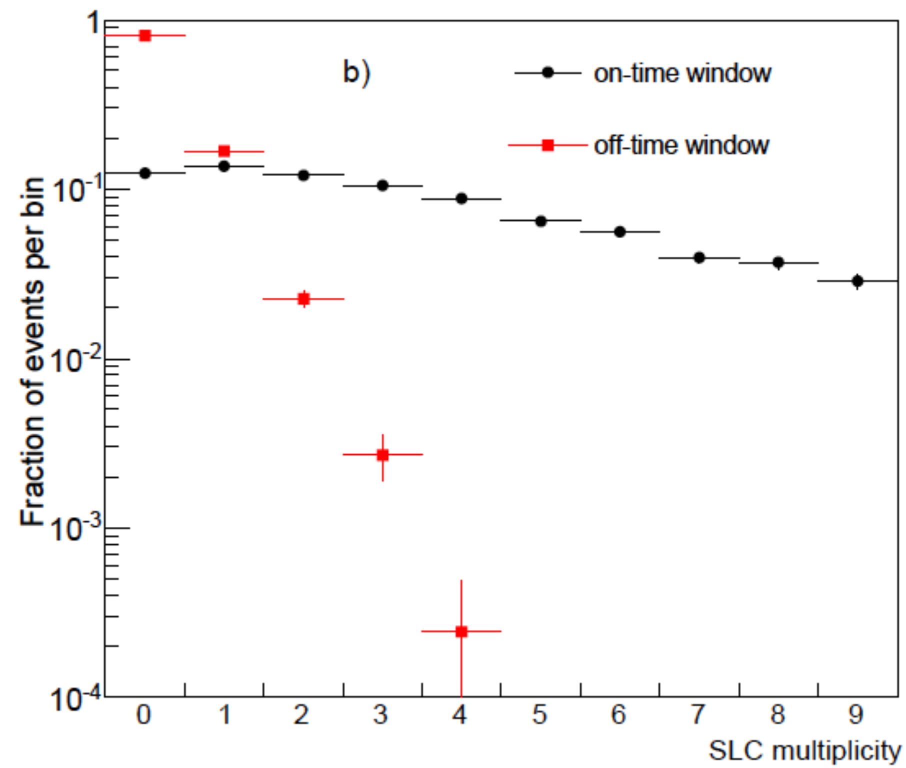

- Roughly bimodal distribution. Note: definition of "cloud" depends on optical depth we're willing to tolerate in ACT data

# Cost of 50+ Telescopes

- SiPMs: \$1500 (64 6*6 $mm^2$ SensL)
- Mechanic: \$800 (Tubus+ Lens+Glass)
- Electronic: \$2000 (DAQ+ Power supply for 64 channels)
- Slow control: \$1250 bzw. \$700 (PC, HDD, Switch,...)

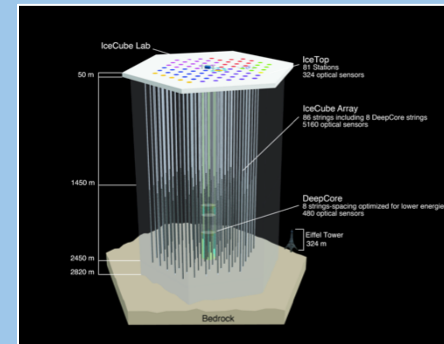
# Veto



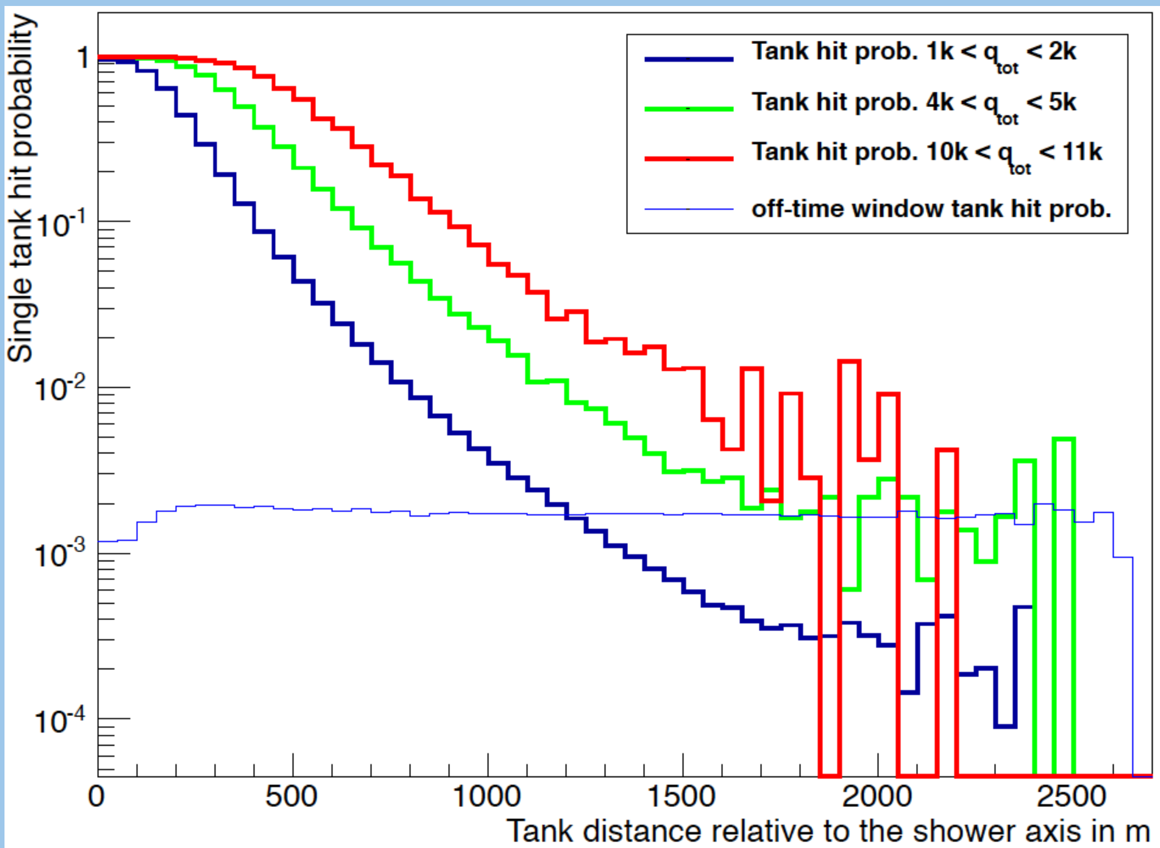



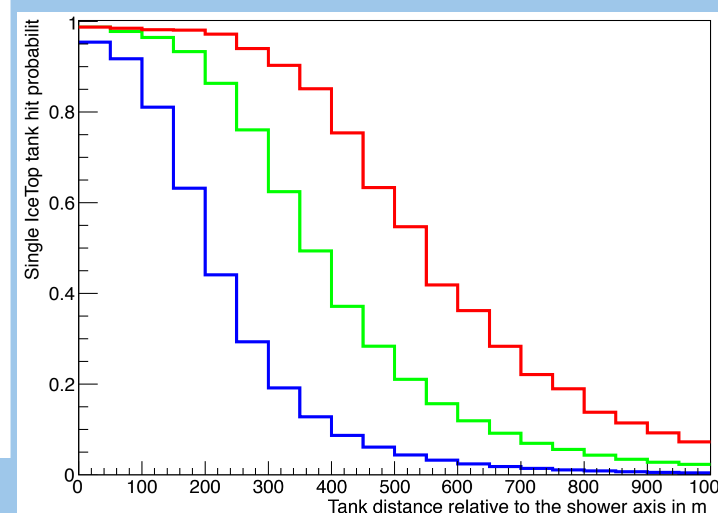

Signal loss below 2% for a >1 Hit cut !

# Single IceTop tank hit probability




Tank hit probability increases with increasing NPE in the deep detector




The background hit probability is at $2 \times 10^{-3}/\mu s$

Slide and work credit to Kai Schatto

# Averaging SplineMPE Fun and Millipede