IceAct
Air Cherenkov telescopes for the South Pole

HAP Workshop Mainz

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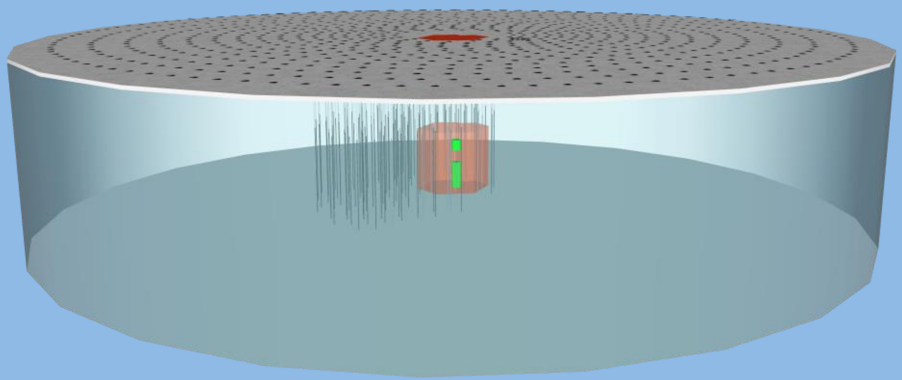

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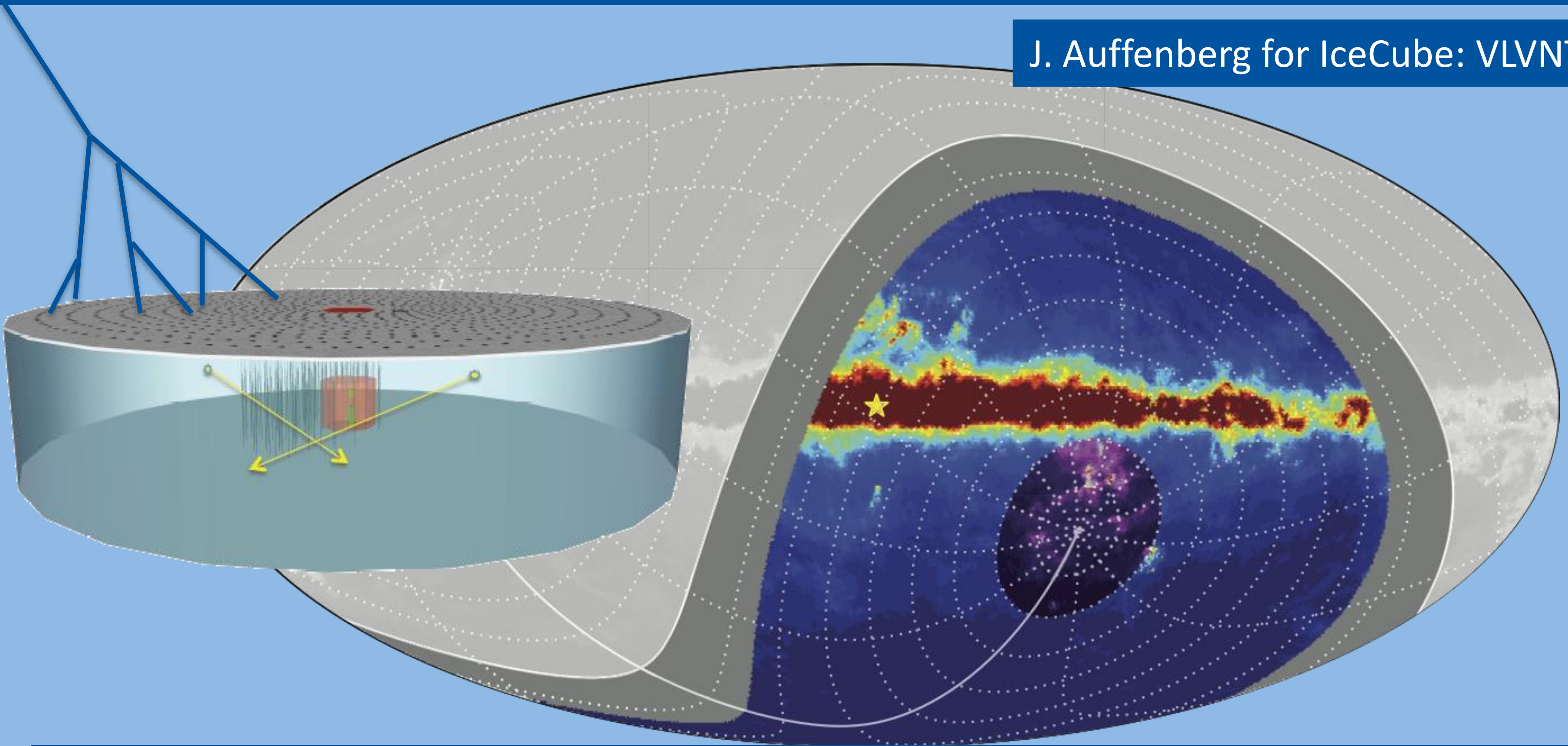
Part 0:
Why air Cherenkov telescopes for the veto

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

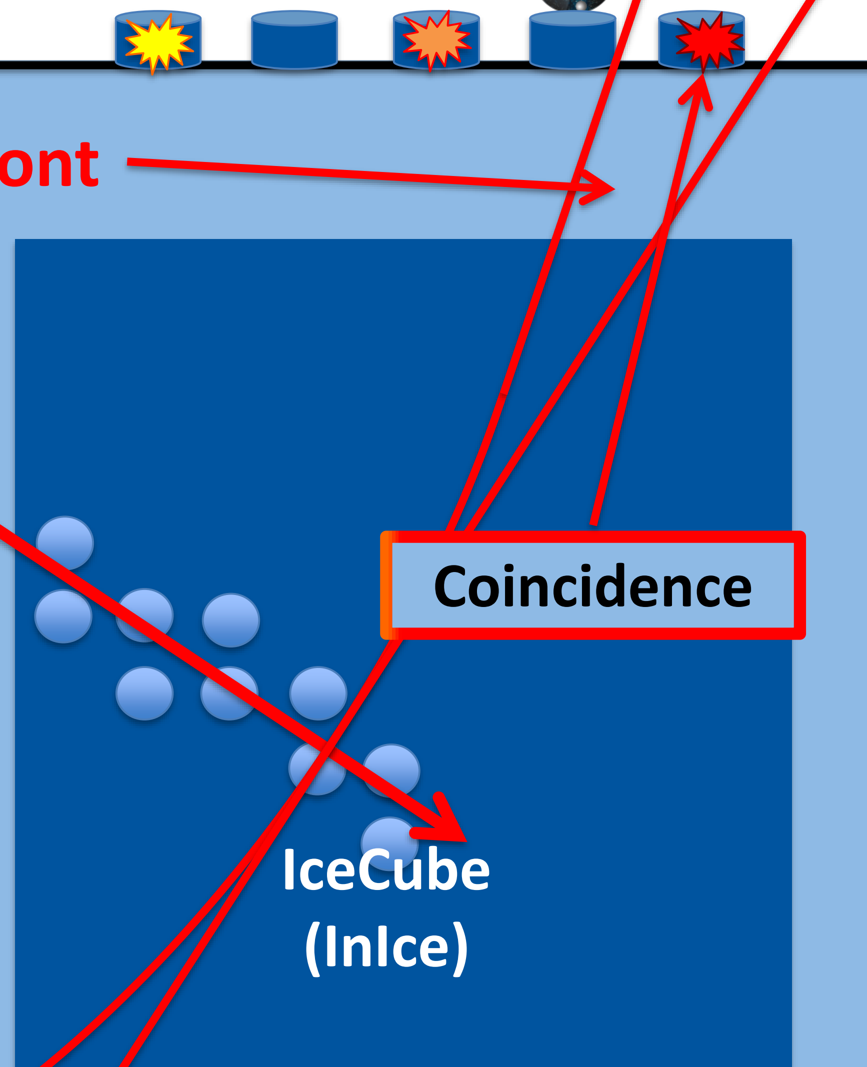
J. Auffenberg for IceCube: VLVNT13



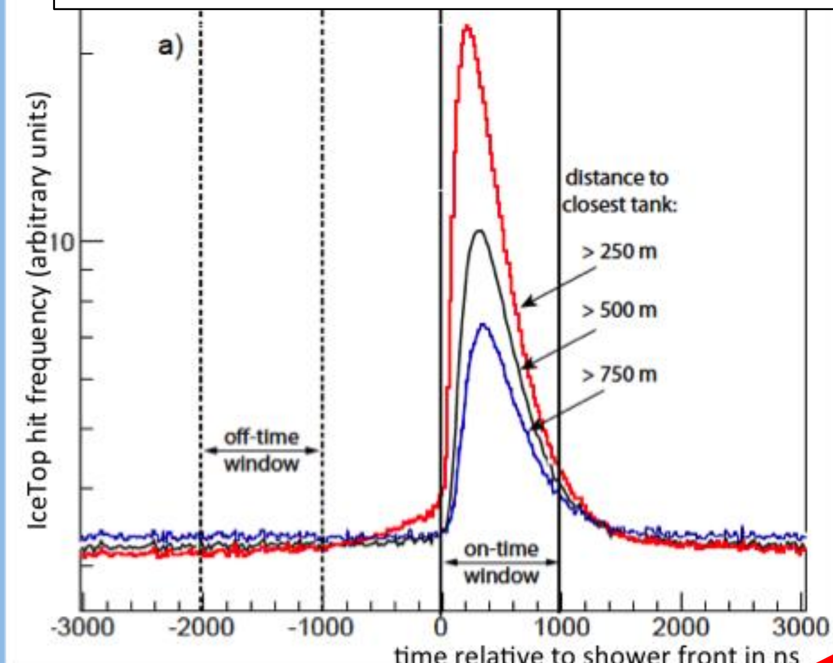
Open the southern sky for E < 100 TeV Neutrino induced muon tracks by vetoing signals with coincident air showers

IceTop Veto

Air-Shower Front



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

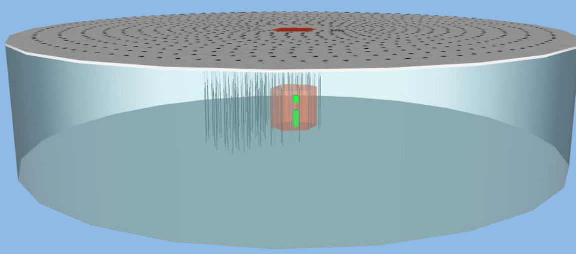


J. Auffenberg for IceCube: ICRC13 ID 0373

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.

- high duty cycle but high energy threshold due to the limited fill factor and low particle densities at low primary energy and more horizontal showers.

FAMOUS

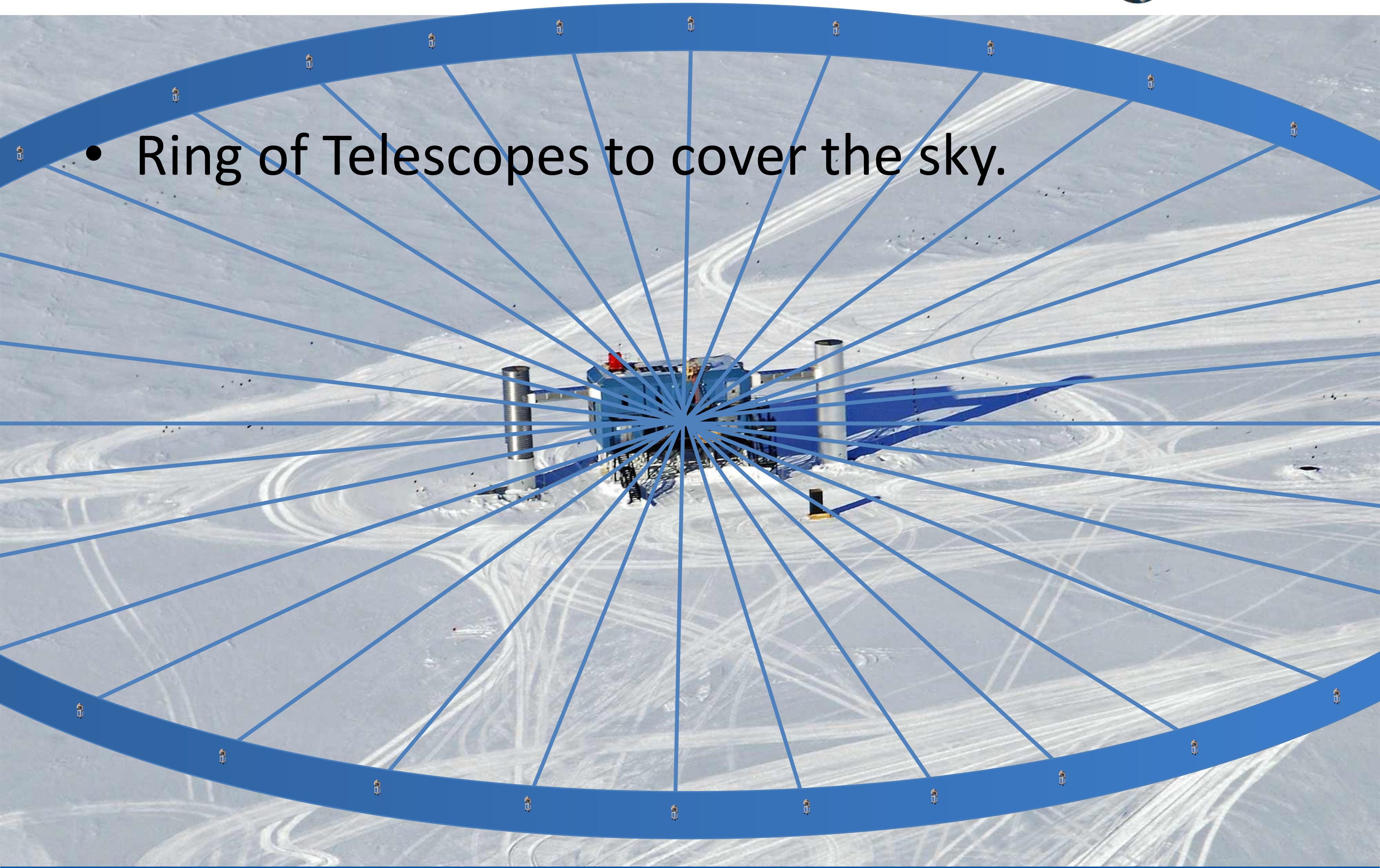
This idea: Take the atmosphere as active volume and measure the air-Cherenkov light of the air shower.

- Lower duty cycle but low energy threshold.

(see ICRC2015 PoS(ICRC2015)1156, PoS(ICRC2015)568, PoS(ICRC2015)649, PoS(ICRC2015)605, and PoS(ICRC2015)1047)

Of course the systems could be combined!

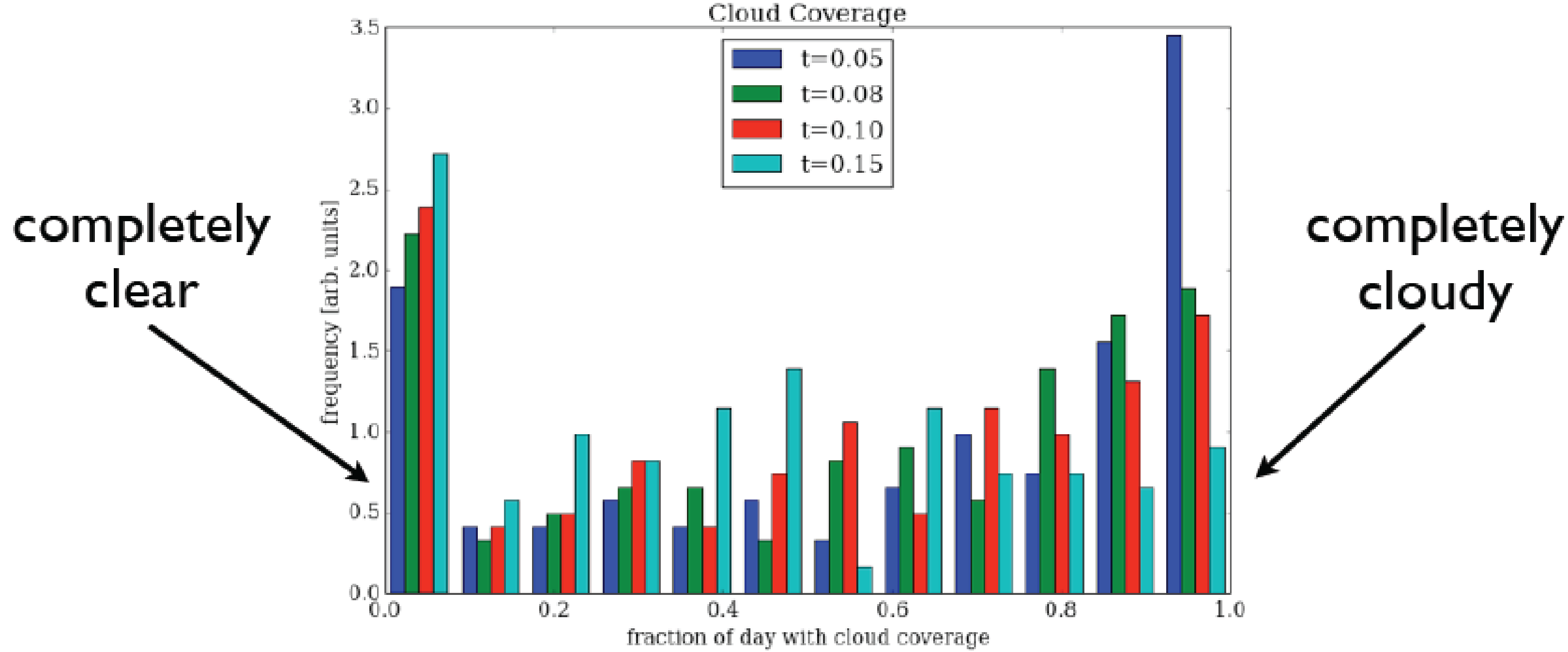
IceAct



- Ring of Telescopes to cover the sky.

iACT at South Pole Duty Cycle

- 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

Overall annual duty cycle at the South Pole can be in the order of impressive ~25% !

Cost estimate for one telescope

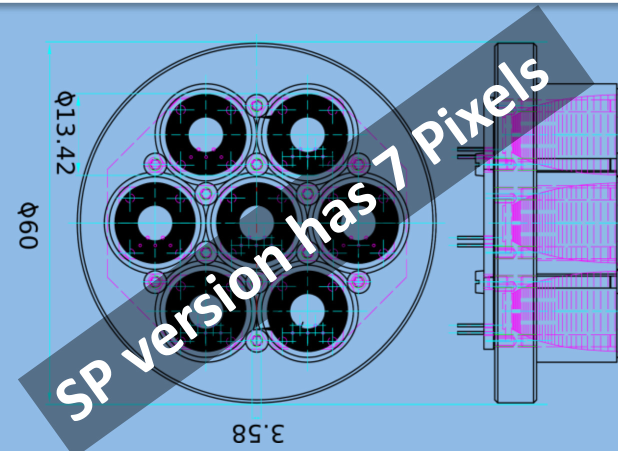
Item	Number	price for one	total price	comment
SIPMs			**1472€**	
$6 \times 6\,\mathrm{mm}^2$, $50\,\mu m$	64	23 €	1472 €	SensL C series
Mechanics			**2005 €**	
Fresnel lens	1	100 €	100 €	
Glass plane	1	30 €	30 €	
Lens tube	1	200 €	200 €	
Stand	1	100 €	100 €	
Focal plane	1	50 €	50 €	
Winston cones	61	25 €	1525 €	
Filter	61	1 €	61 €	
Electronic			**3250 €**	
Base board	1	50 €	50 €	
Power supply	64	10 €	640 €	
Data acquisition	64	40 €	2560 €	based on TARGET 7
Others			**18 €**	
Koax	0	32 €	0 €	price per m
Network cable	2	4 €	8 €	
ICE Power socket	1	5 €	5 €	
Network cable socket	1	5 €	5 €	

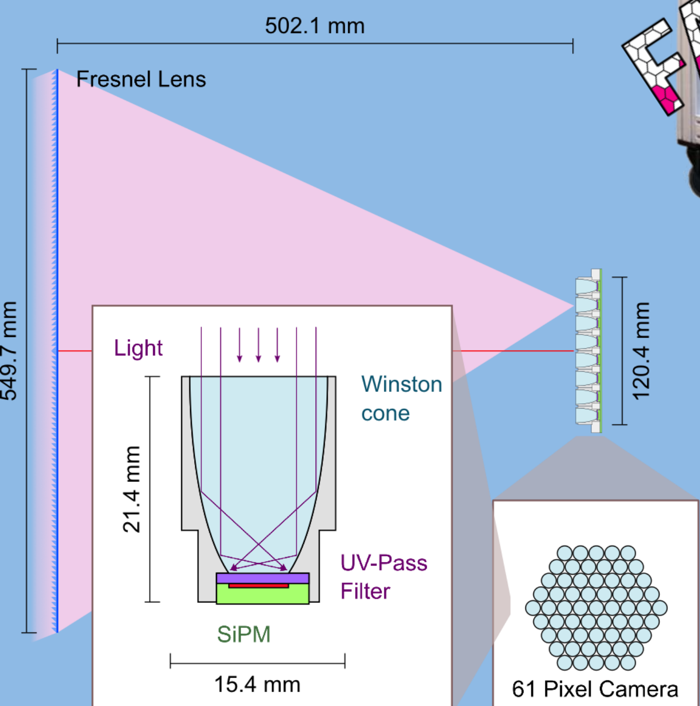
Part 1:
About the prototype in Aachen and at the South Pole (hardware)

IceAct Prototypes in Aachen

61 Pixel Prototype Telescope:

- Thin UV transparent UV lens
- Focus length 502.5 mm
- aperture ~f/1
- TARGET7 based DAQ
- 12° opening angle





Assuming:

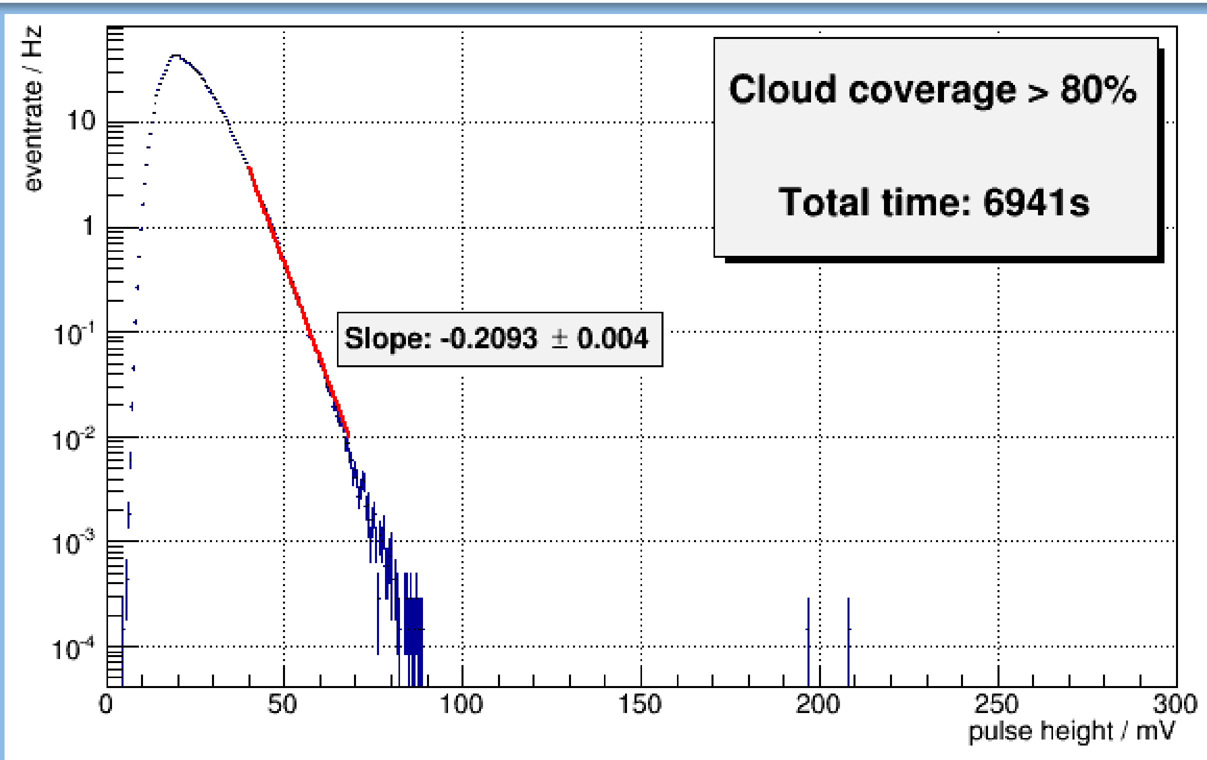
- an acceptable energy threshold (100TeV)
- acceptable duty cycle
- durability in harsh environments

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

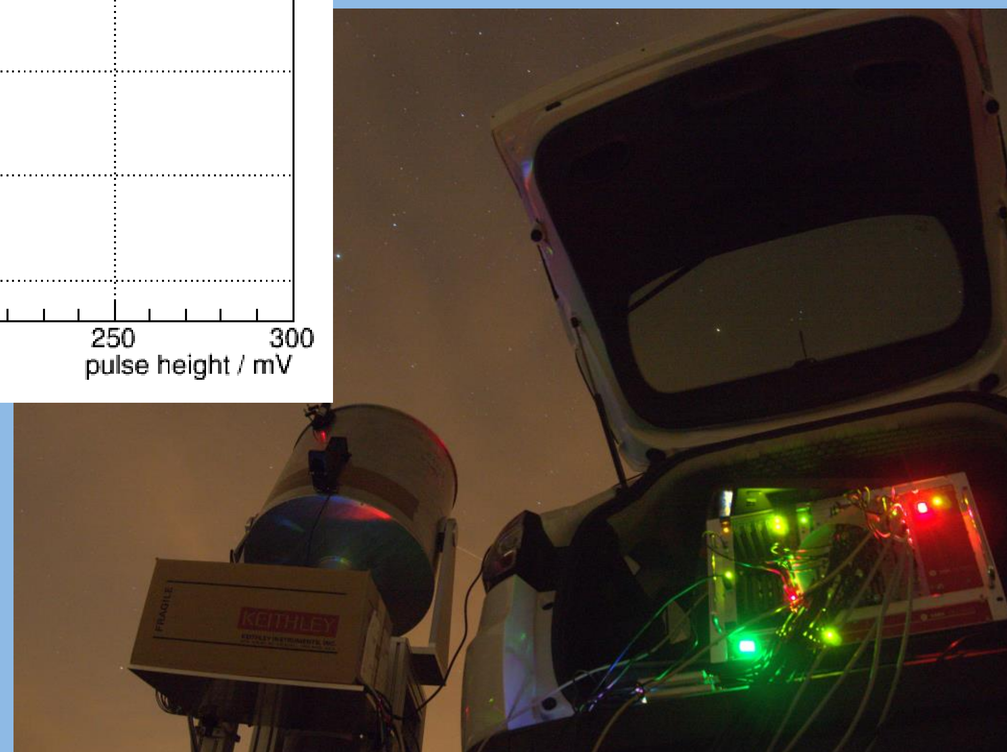
The instrumentation form 5-7km is ~13000 channels
;a cost equivalent to ~ 200 61 pixel telescopes
Goal: Test run of a prototype at South Pole

Playing with IceAct Prototype

ICECUBE



Background measurement at a cloudy day



Almost no high pulse signals

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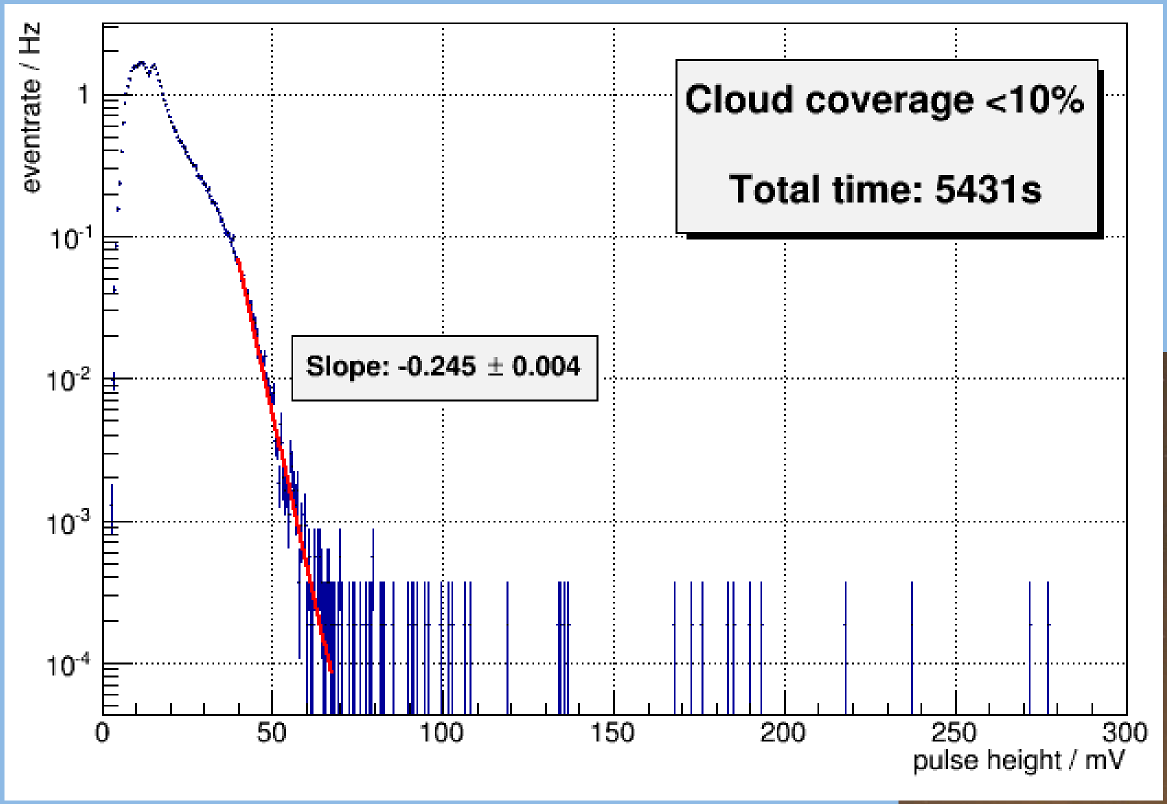
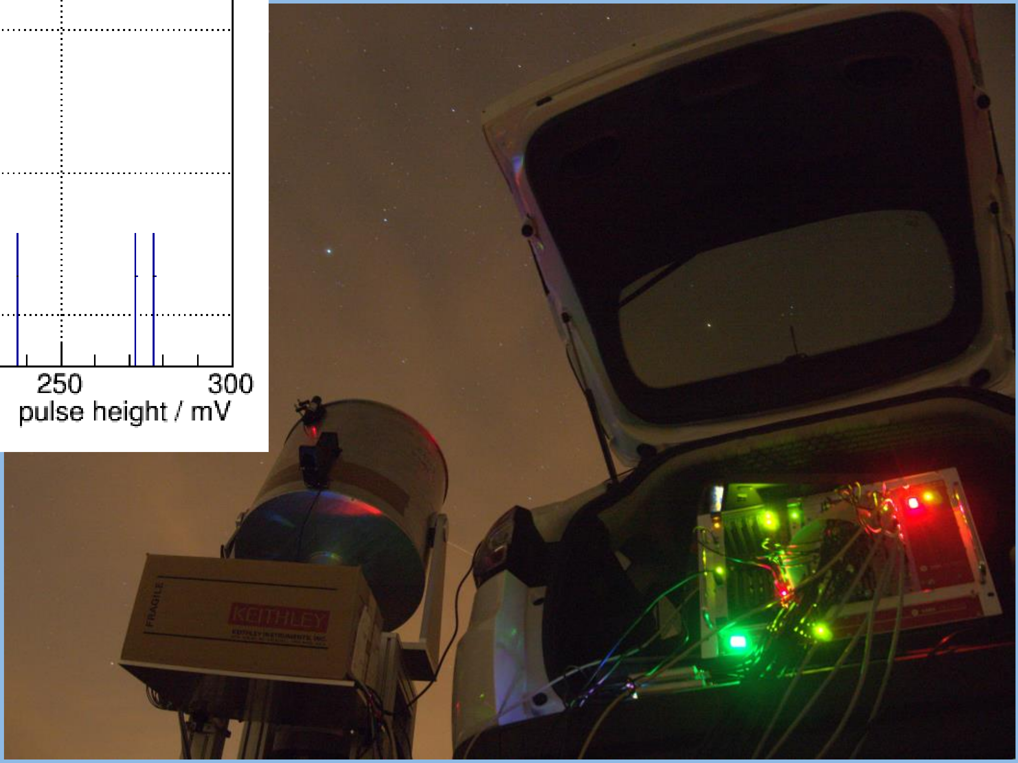
Playing with IceAct Prototype

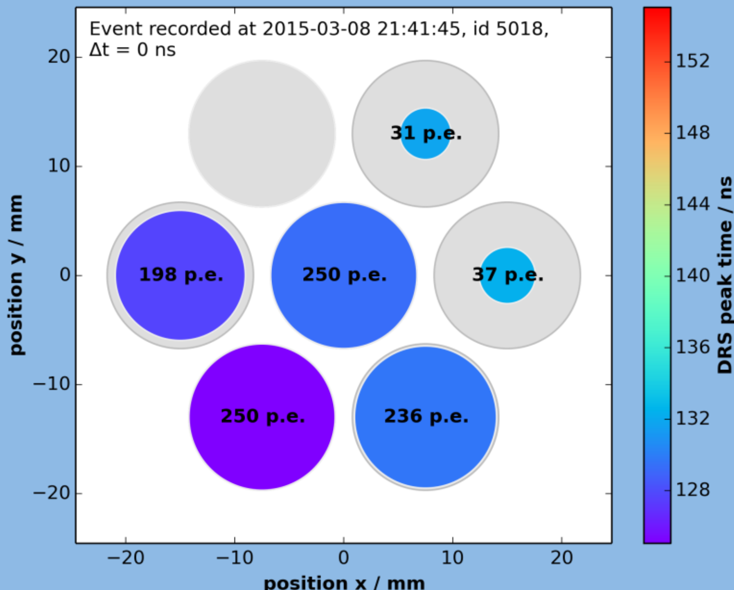


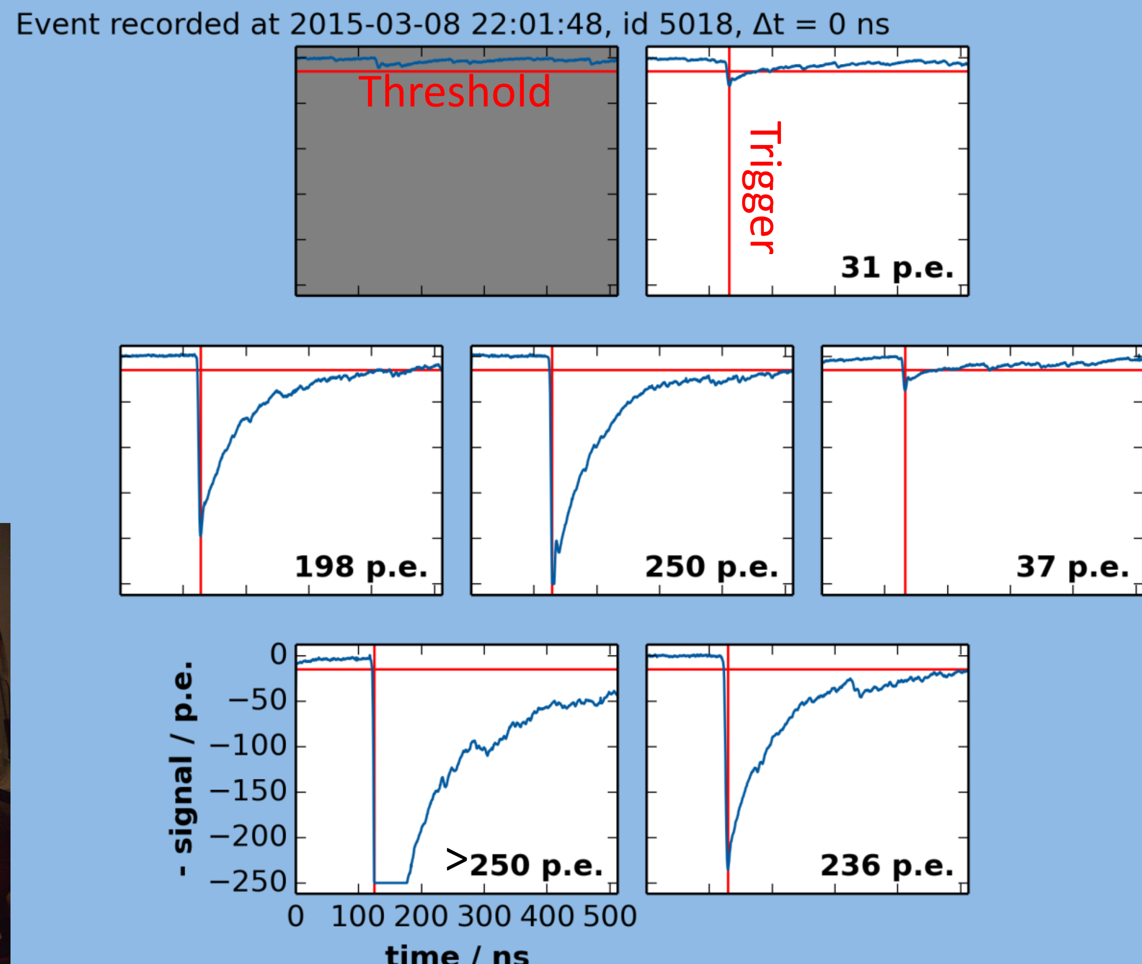
Air Cherenkov measurement at a clear day



A lot high pulse signals

Playing with IceAct Prototype





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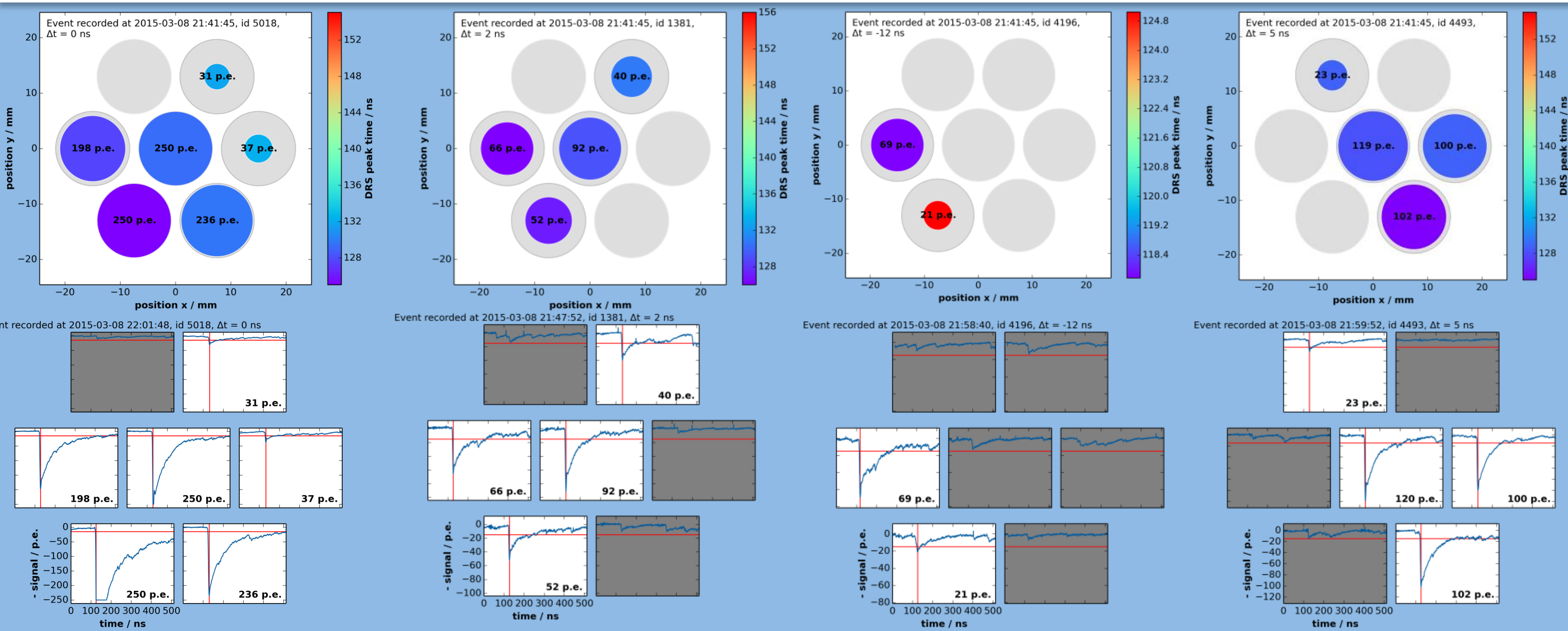
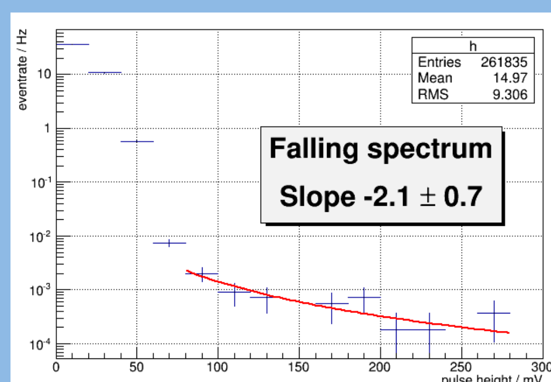
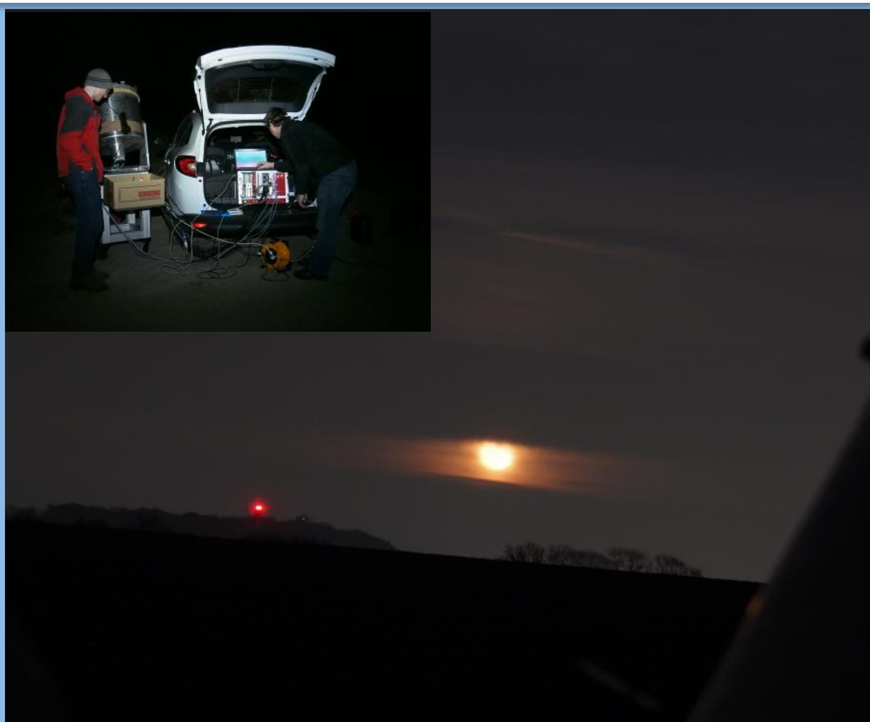
Playing with IceAct Prototype

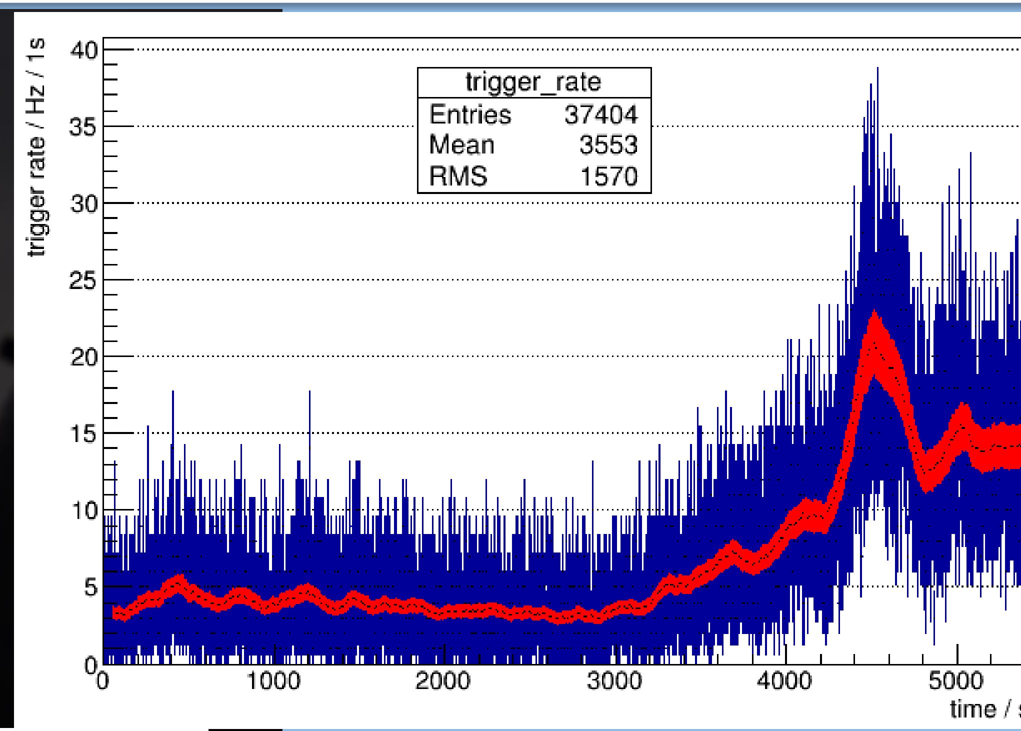


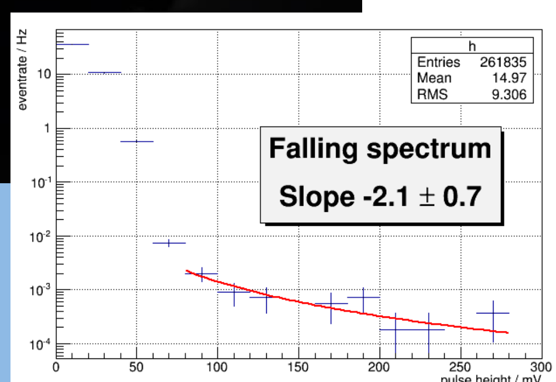


- All events with high pulses have a sharp rise time and are nicely coincident.
- The analyses and simulations are ongoing

Playing with IceAct Prototype







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

- The analyses and simulations are ongoing

Prototype for the South Pole

- 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)

Prototype for the South Pole

ICECUBE

Power supply (slow control)

110 V AC

Ethernet

SensL SiPMs

DRS4 Board

DRS4 Board

USB (Signal)

USB (Signal)

NUC

110 V AC

Ethernet (Data & Com)

SkyCam PC for data taking

- Cold testing for DAQ finalized and very promising
- Total power consumption ~30W right now (much room for improvement. The goal is 3W.)
- Data storage: ~100MB/h at 10Hz trigger rate
  First data analyses do not need much CPU.
  Can be done remotely.

Why Prototype at the South Pole

ICECUBE

What is the detection efficiency together with IceTop?

Is the technology South Pole ready?

- What is the impact of the South Pole environment to the duty cycle?
  (Aurora Australis, storms, firn (snow), moon, sun)
- We expect trouble but we don’t know what

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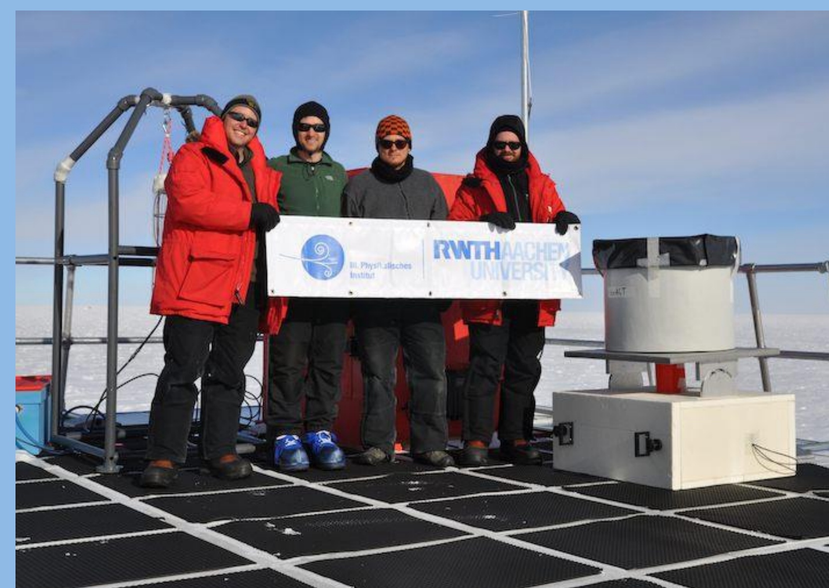
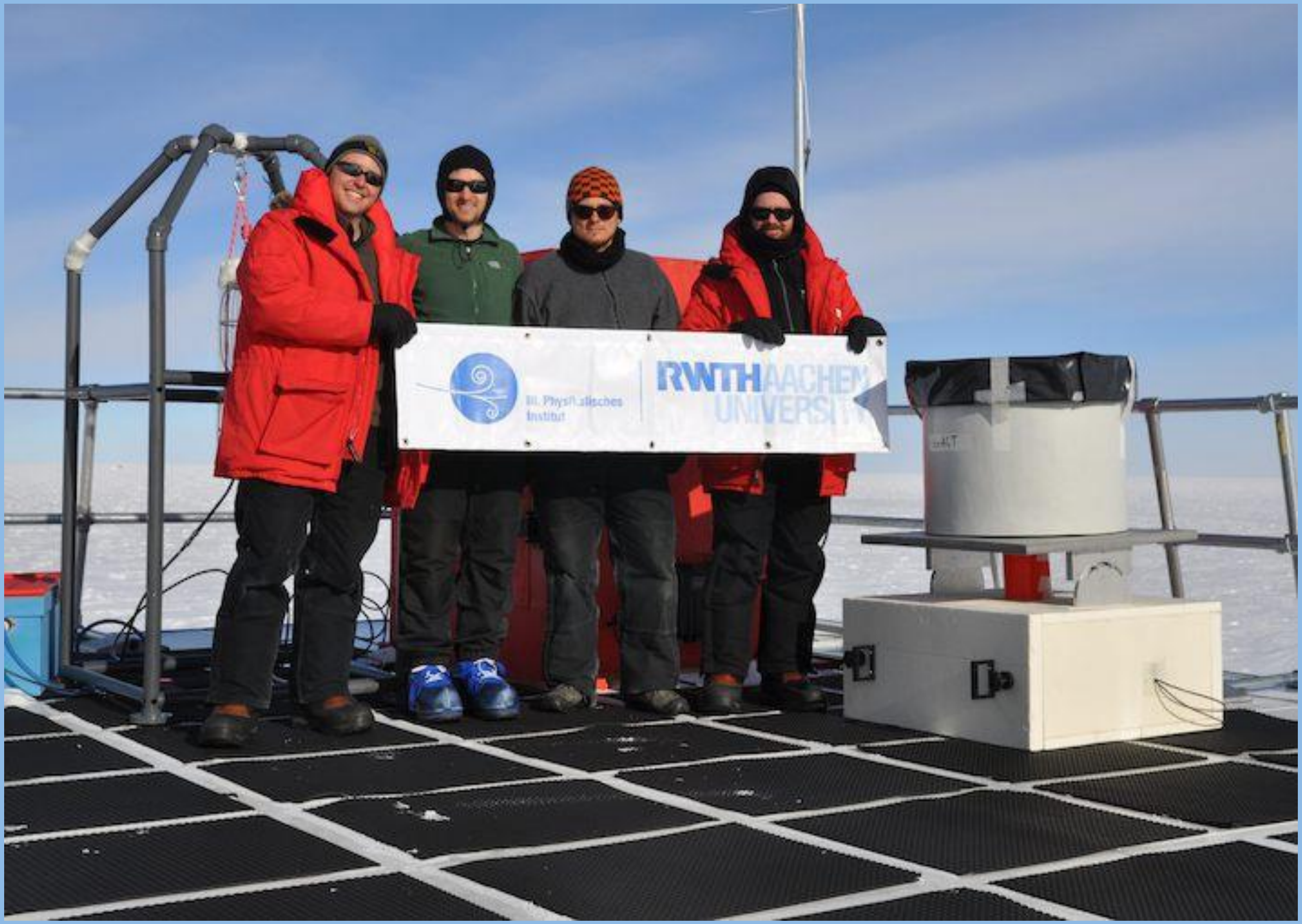
Deployment at the South Pole

- Telescope on the roof of the ICL.
- DAQ and power supply (slow control) in an insulation box with the camera.
- data acquisitions in an insulation Box Readout computer (Dell PowerEdge R710/00NH4P from the sky cam)
- Integration of trigger information in IceCube
- the overall integration was successfully finalized on January 25th!



IceAct commissioning at the South Pole



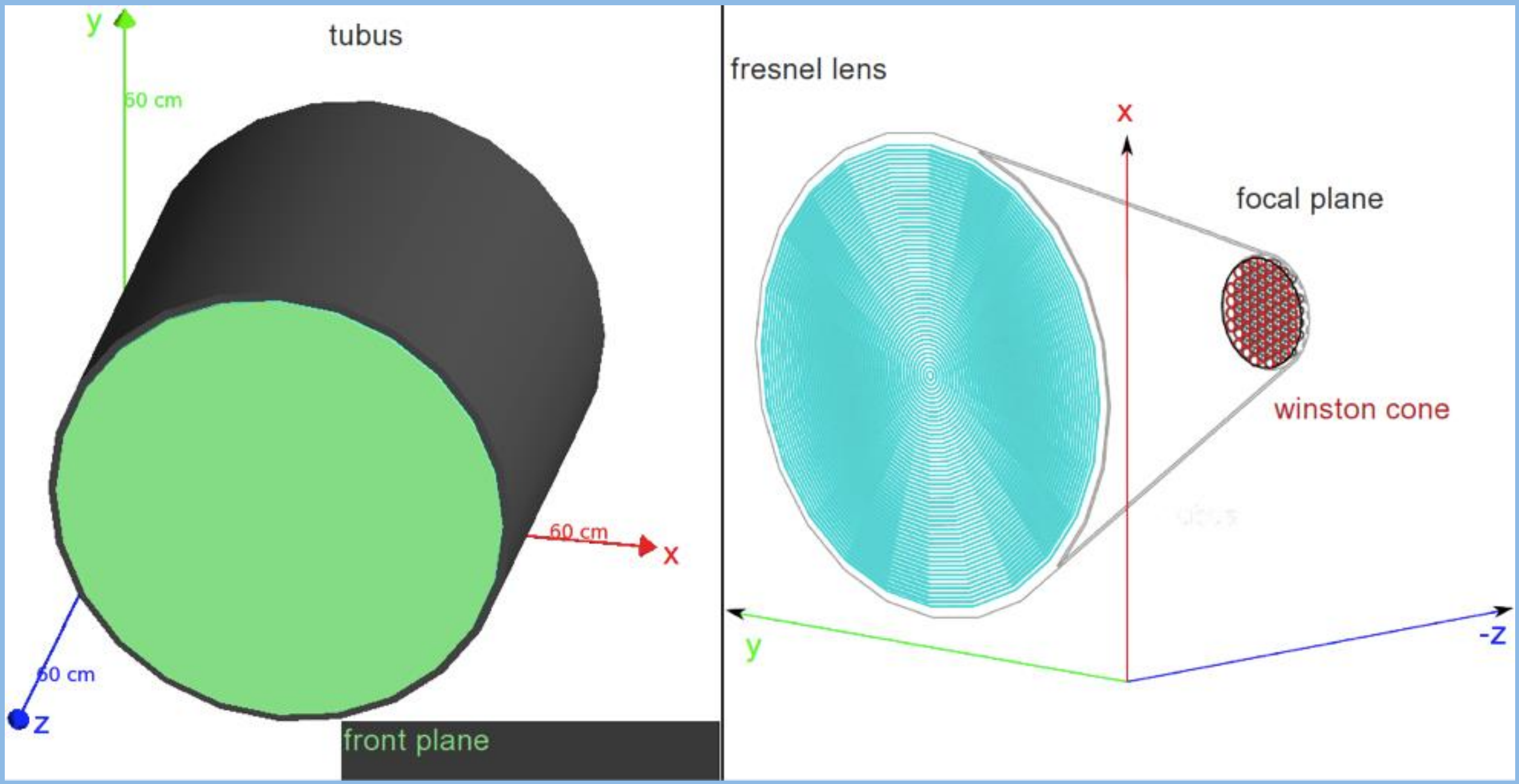
Part 2:
About the prototype in Aachen (simulation)

Corsika Simulation at the South Pole

- Parameterize the GEANT4 model of the IceAct prototype.
- Starting with 100 TeV proton showers with different inclination.

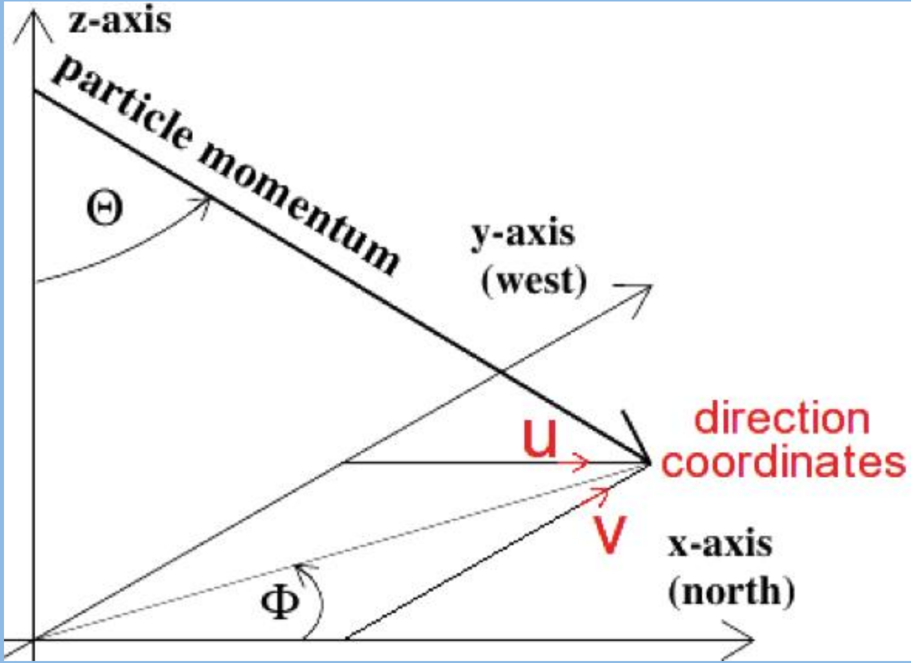
Thanks to Bengt Hansmann!

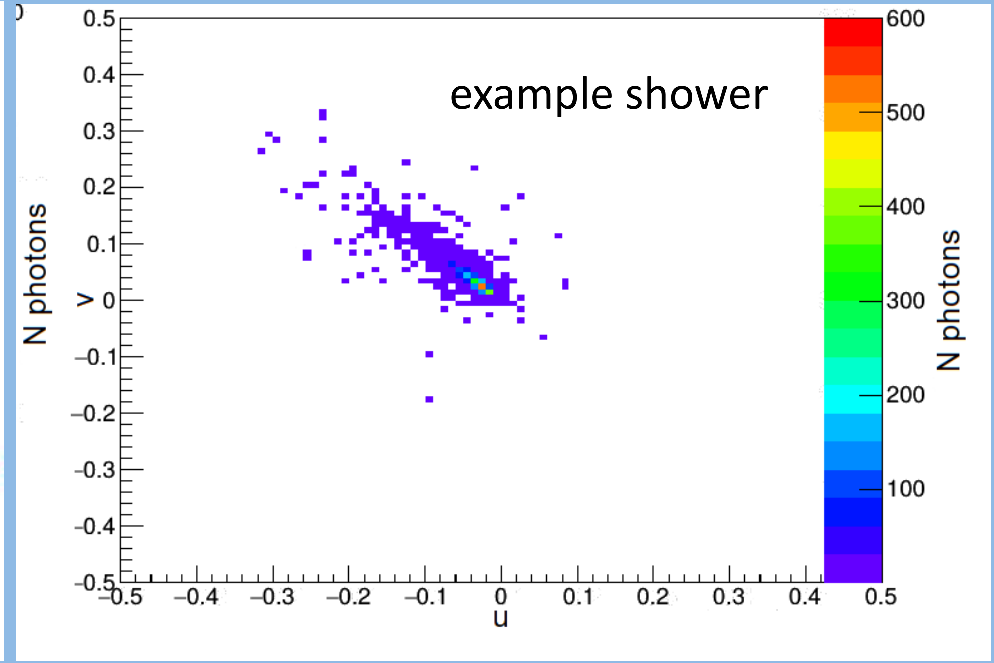
IceAct parameterization



parameterize the path of the photons through the telescope

Direction of the photons in u and v





The Photon direction can be projected on the Lens
But each photon with a given λ and direction has a particular probability to reach the camera.

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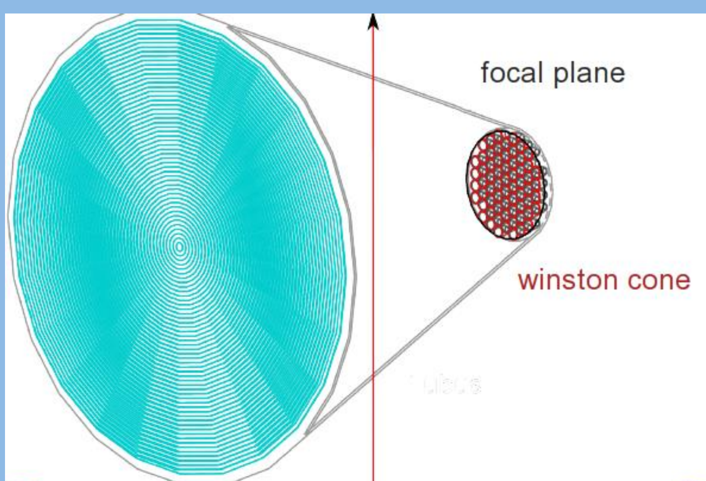
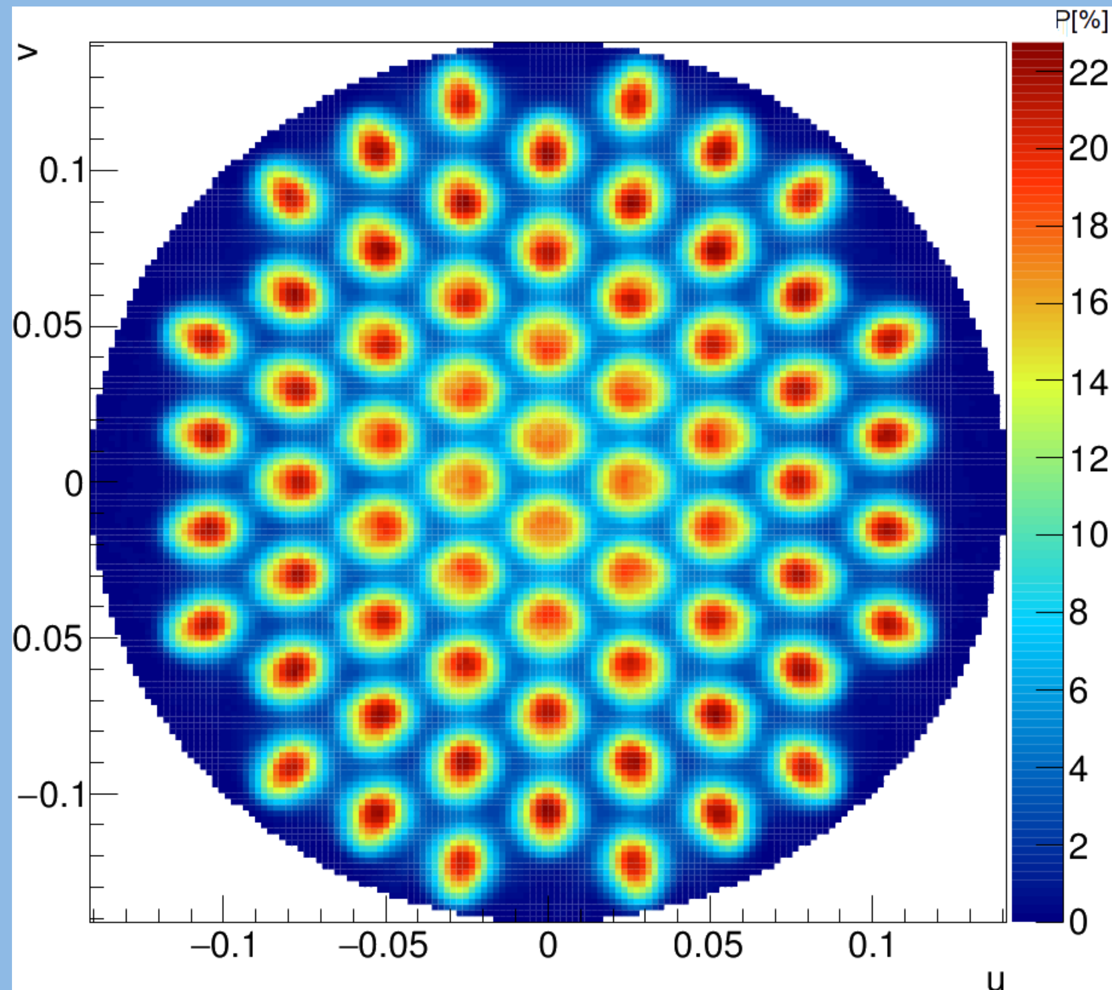
IceAct parameterization

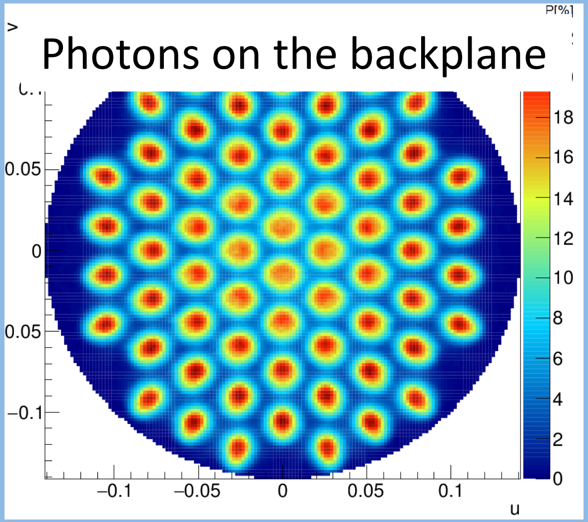
Photons that reached the backplane

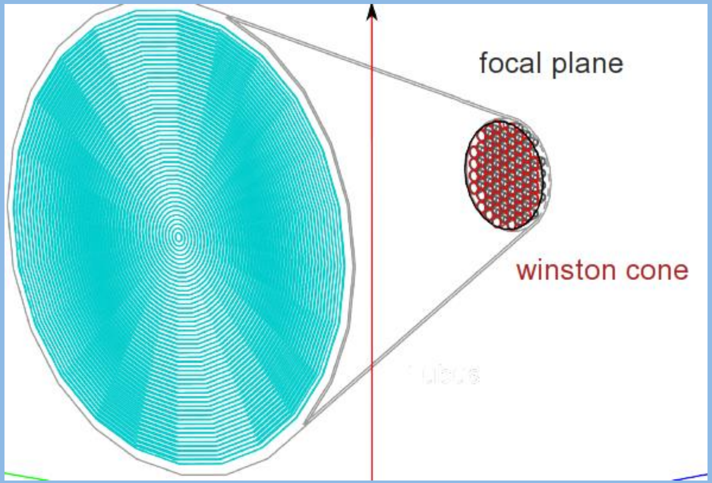


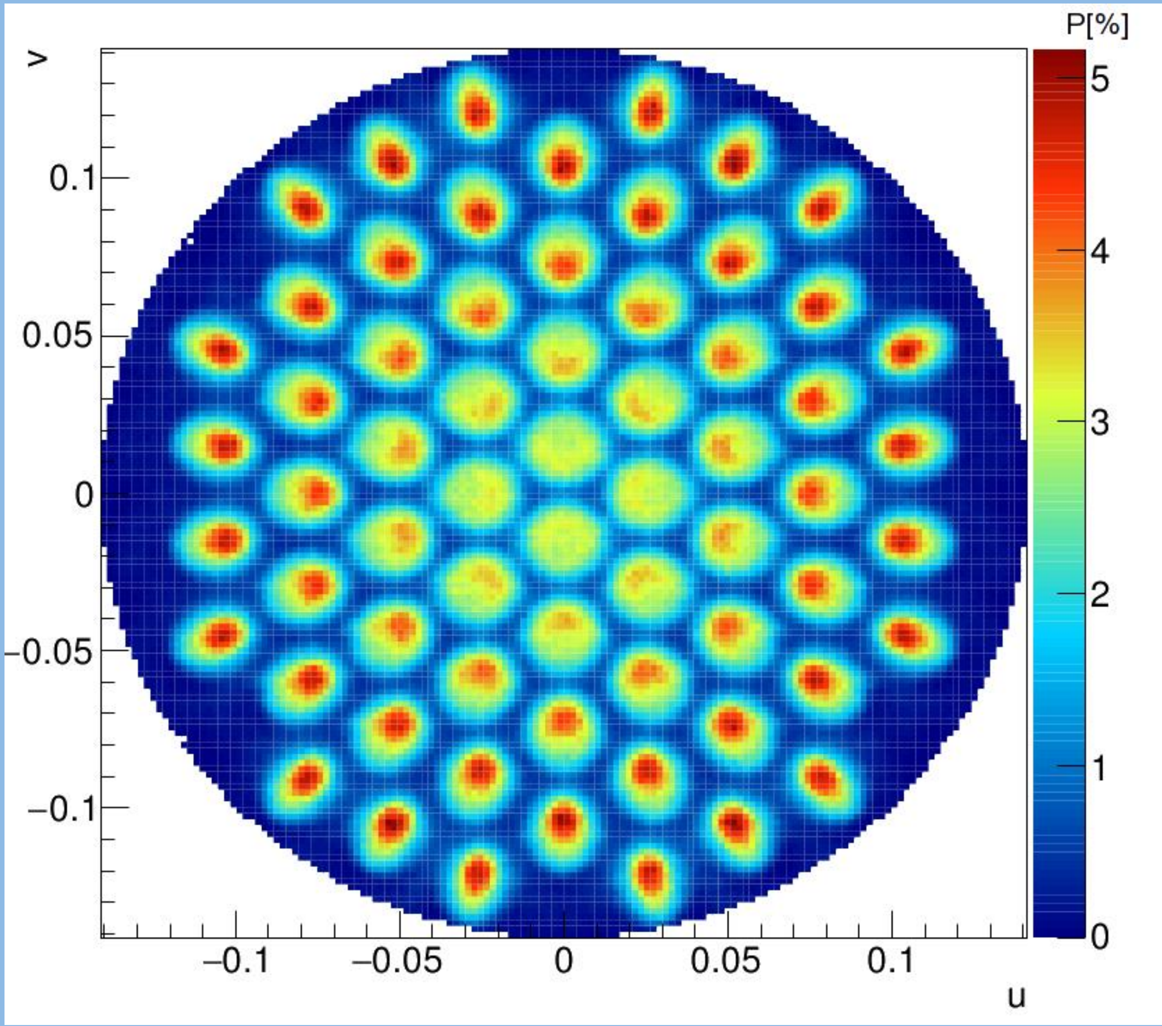


IceAct parameterization

Photons that passed the filter and got detected by the SIPMs

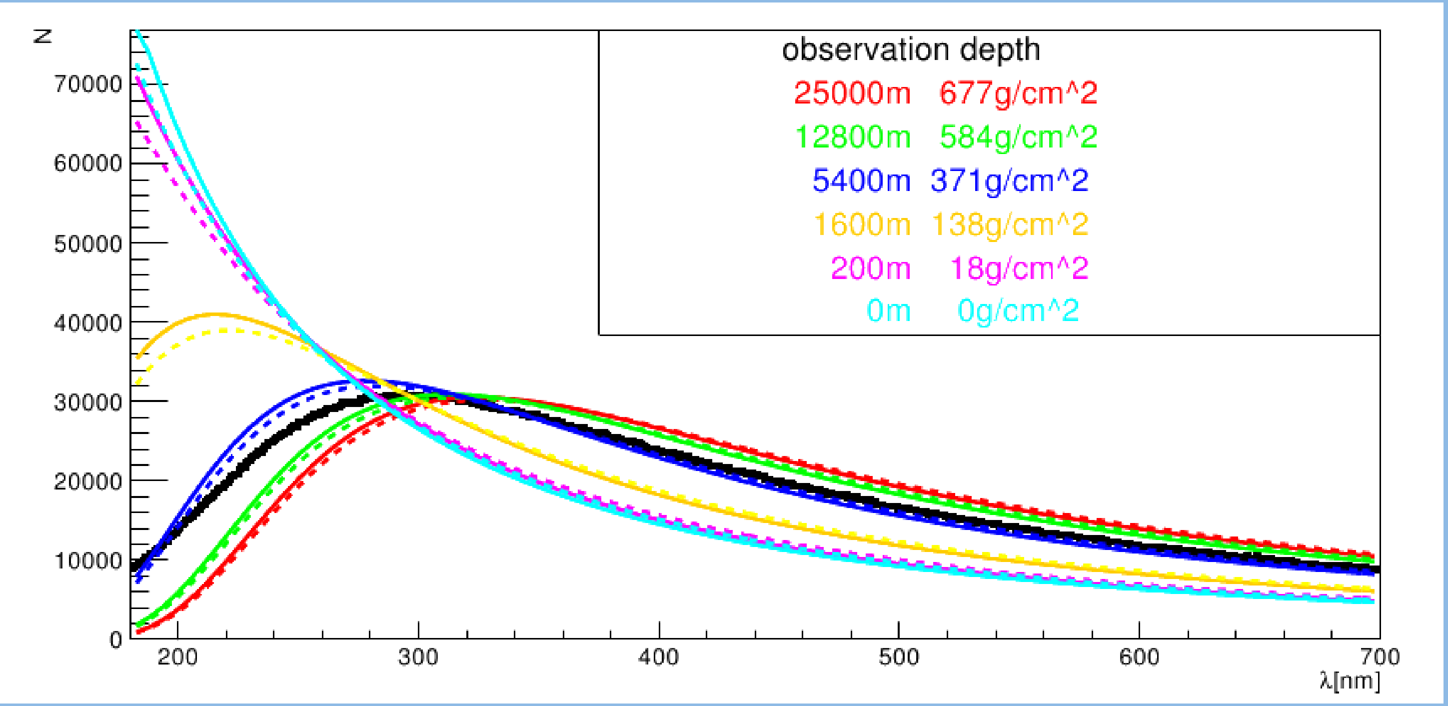






IceAct parameterization

- We substitute the wavelength response of the Photons with its production height.

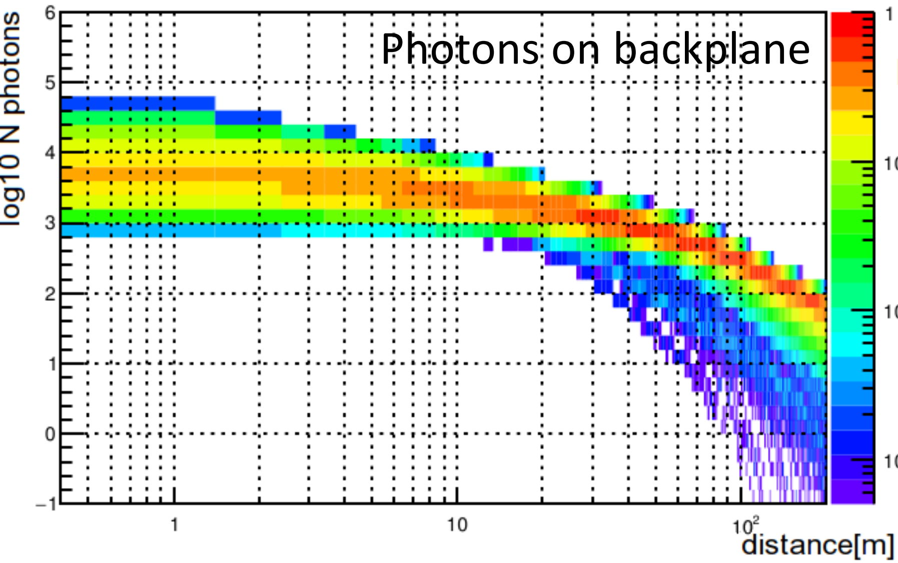


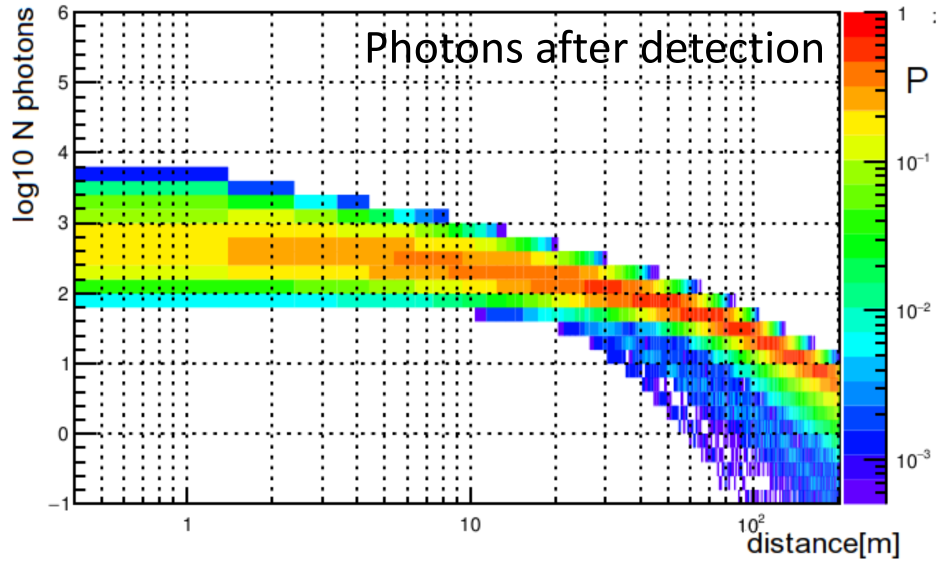
Results

Take 900 proton Corsika showers at 100TeV

Fold it with the telescope response

Probability for photons in a given distance to the shower axis

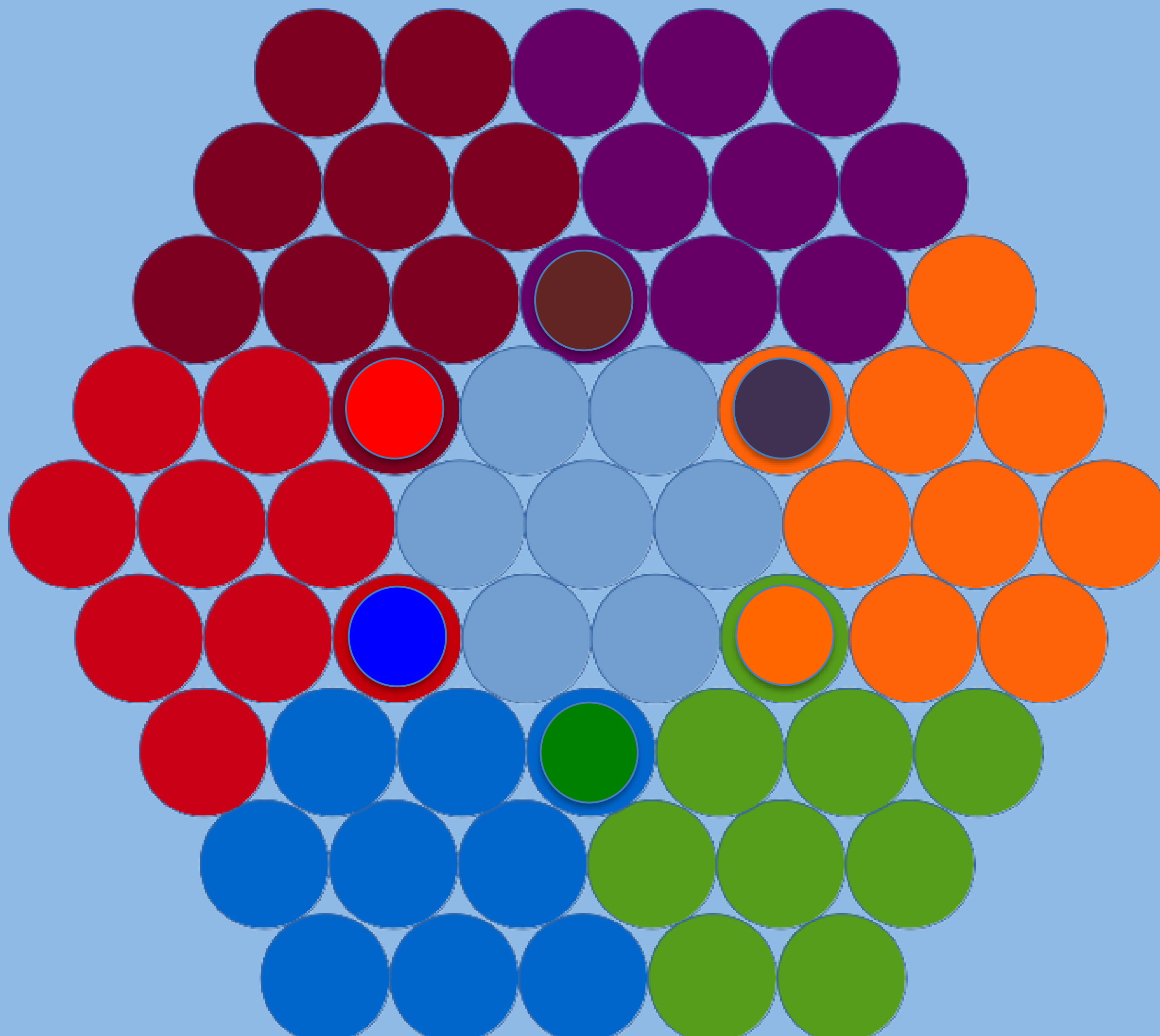




Summary

- We brought one prototype ACT telescope to the South Pole and deployed it on top of the ICL (Goal: feasibility study for surface veto)
- We willtrigger at 10Hz and compare the data with IceTop
- When buying 50+ telescopes the cost would be about 6000$ 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
- 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)

Thanks !



The geometry of a veto with ACTs

$$a_{vertical} = 180 - 2a_{ws}$$

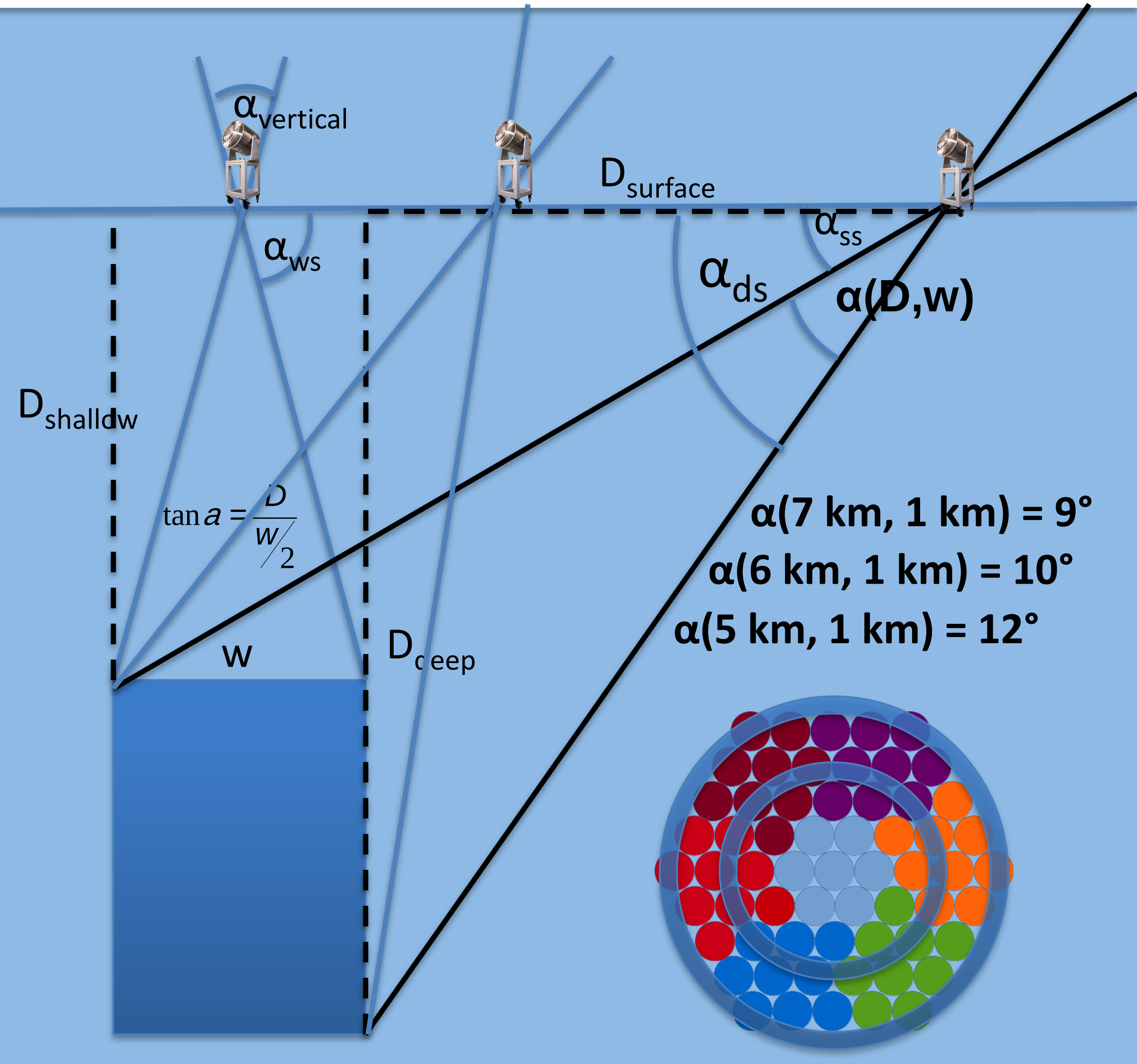
$$\tan a_{ws} = \frac{D_{shallow}}{w/2}$$

$$\boxed{a_{vertical} = 37°}$$

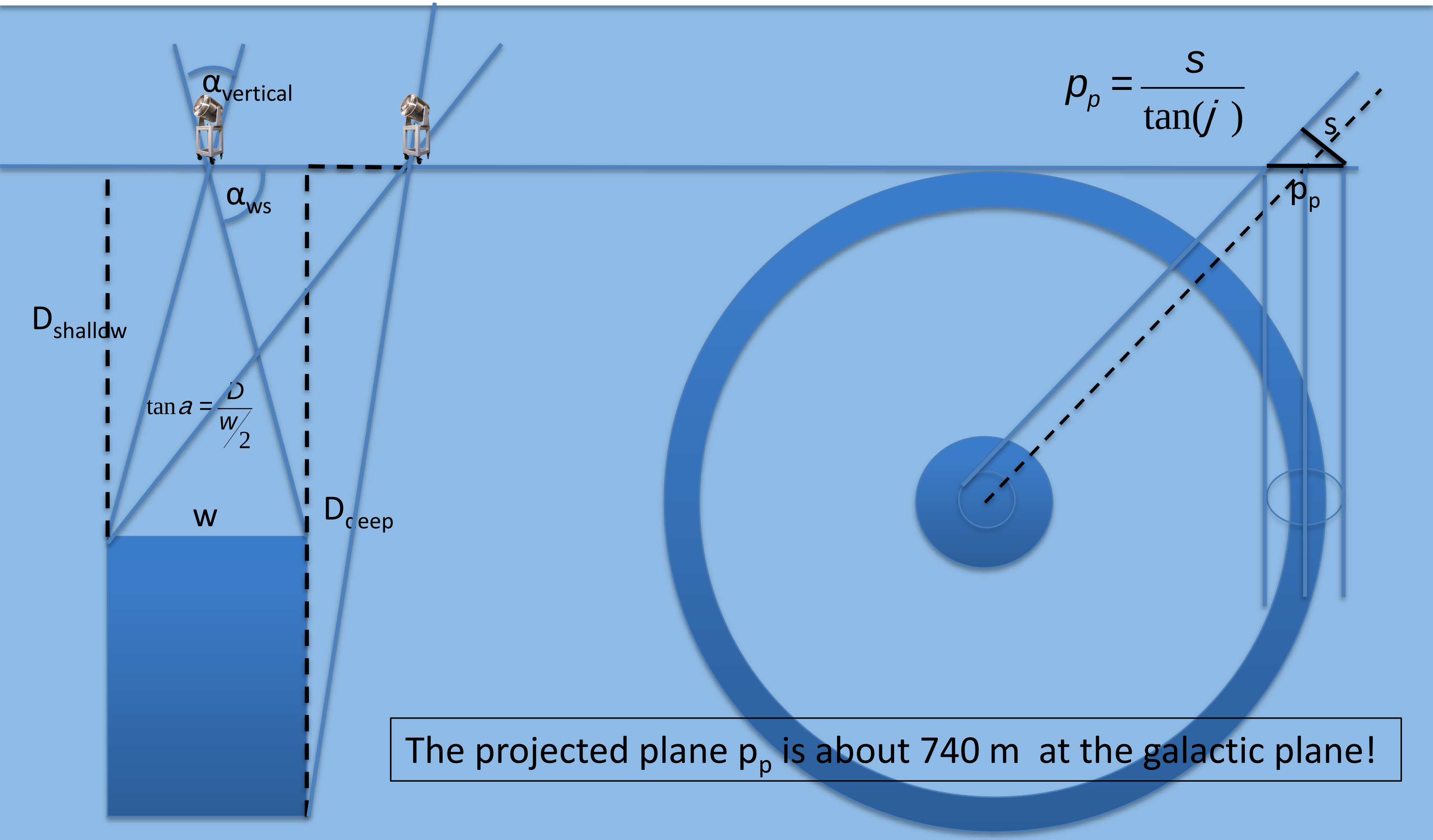
$$a(D,w) = a_{ds} - a_{ss}$$

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

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



Projected Cherenkov Cone Size



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

Expected detector response o the IceAct prototype

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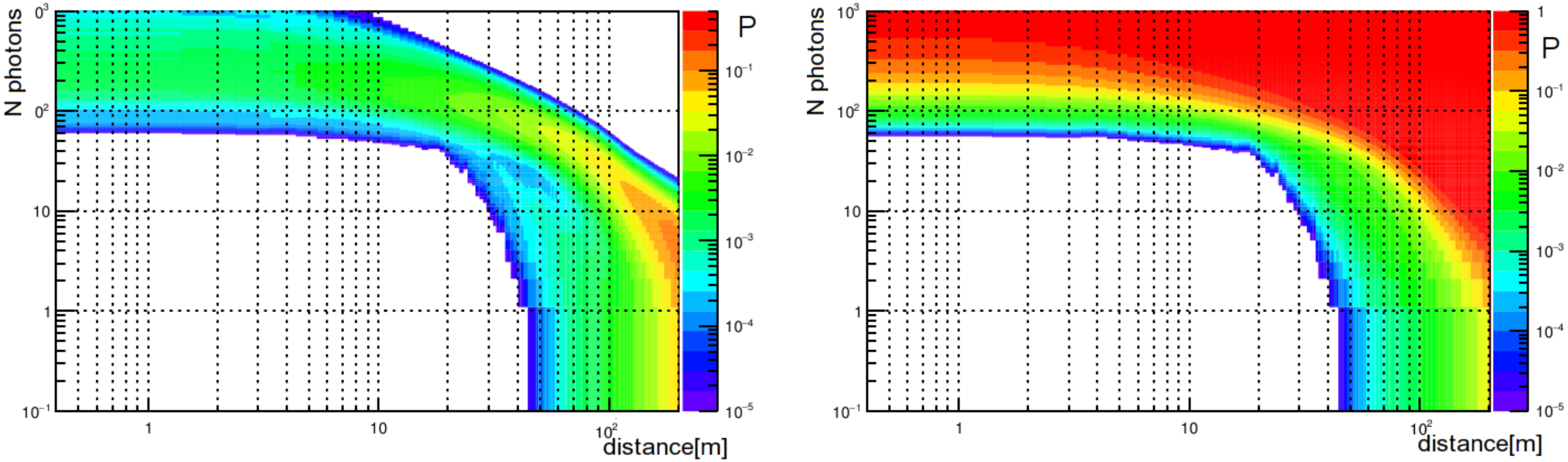
The Poisson smeared values predict the detector response



Cumulative probability for a shower to produce less than n photons
Most 100 TeV showers should be detected at 100m distance.

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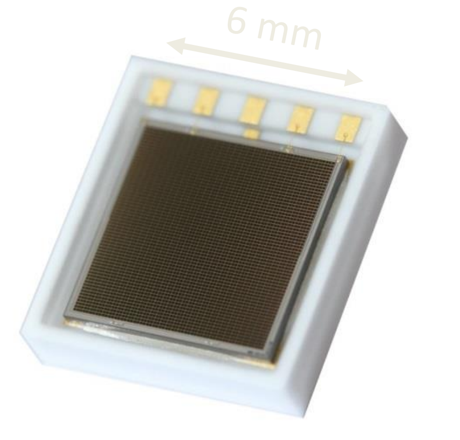
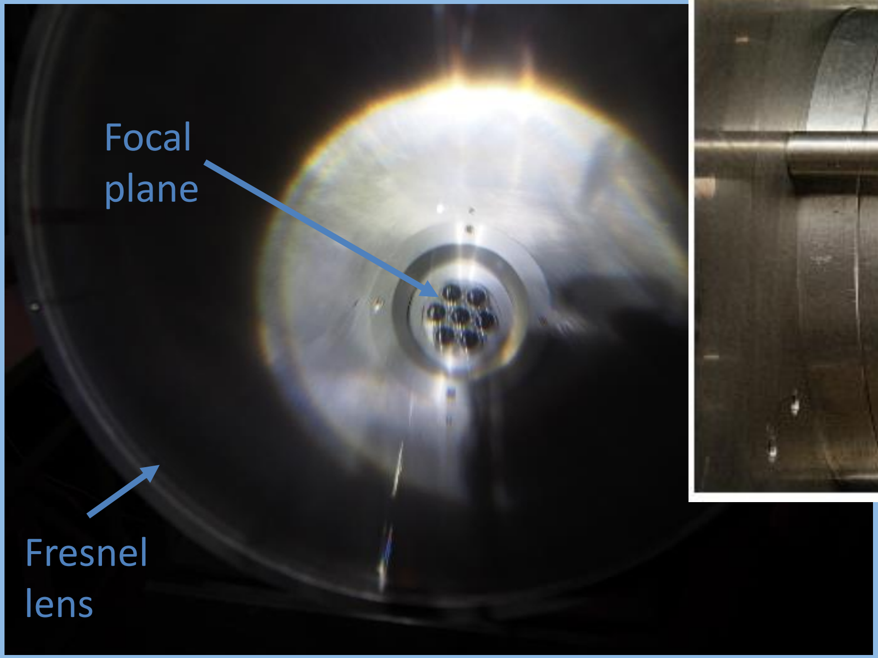
IceAct Prototype with 7 Pixel

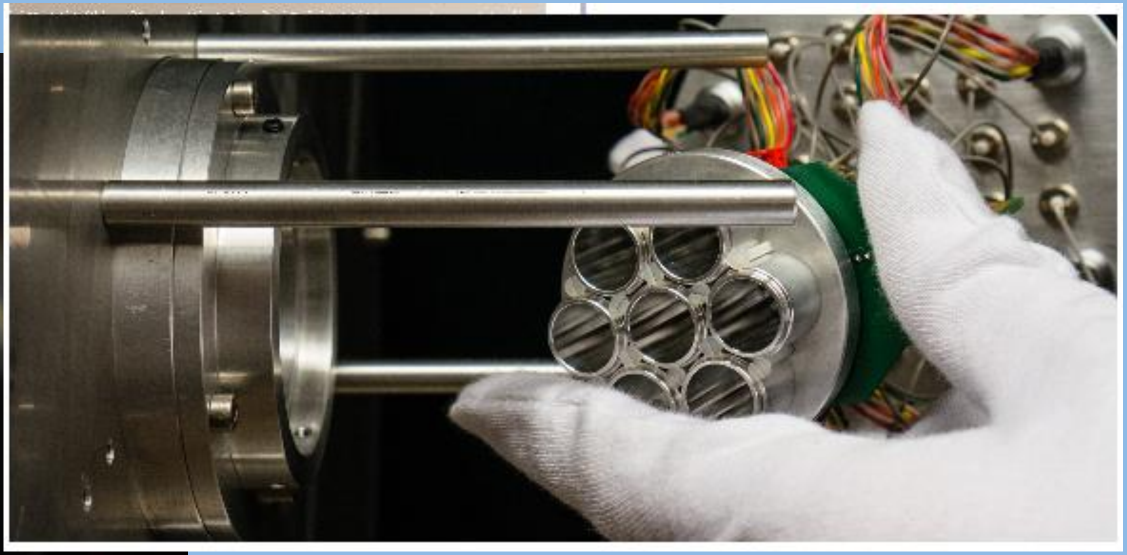
- 1-stage transimpedance pre-amp per SiPM (7 x 4)
- Analogue sum per pixel
- Digitisation using a QDC
- Temperature compensation of SiPM gain included

Charge to digital converter

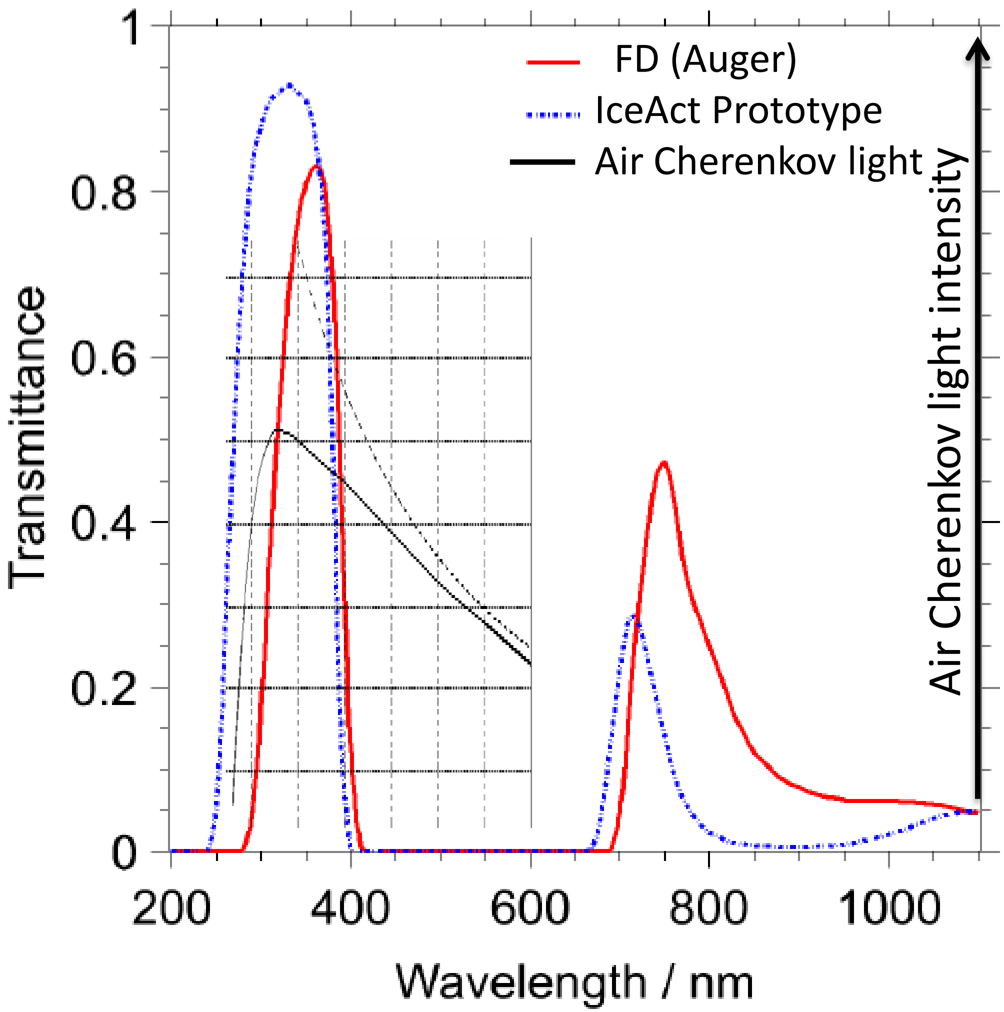


Each pixel consists of one 4-channel SiPM module





Filter against polar light

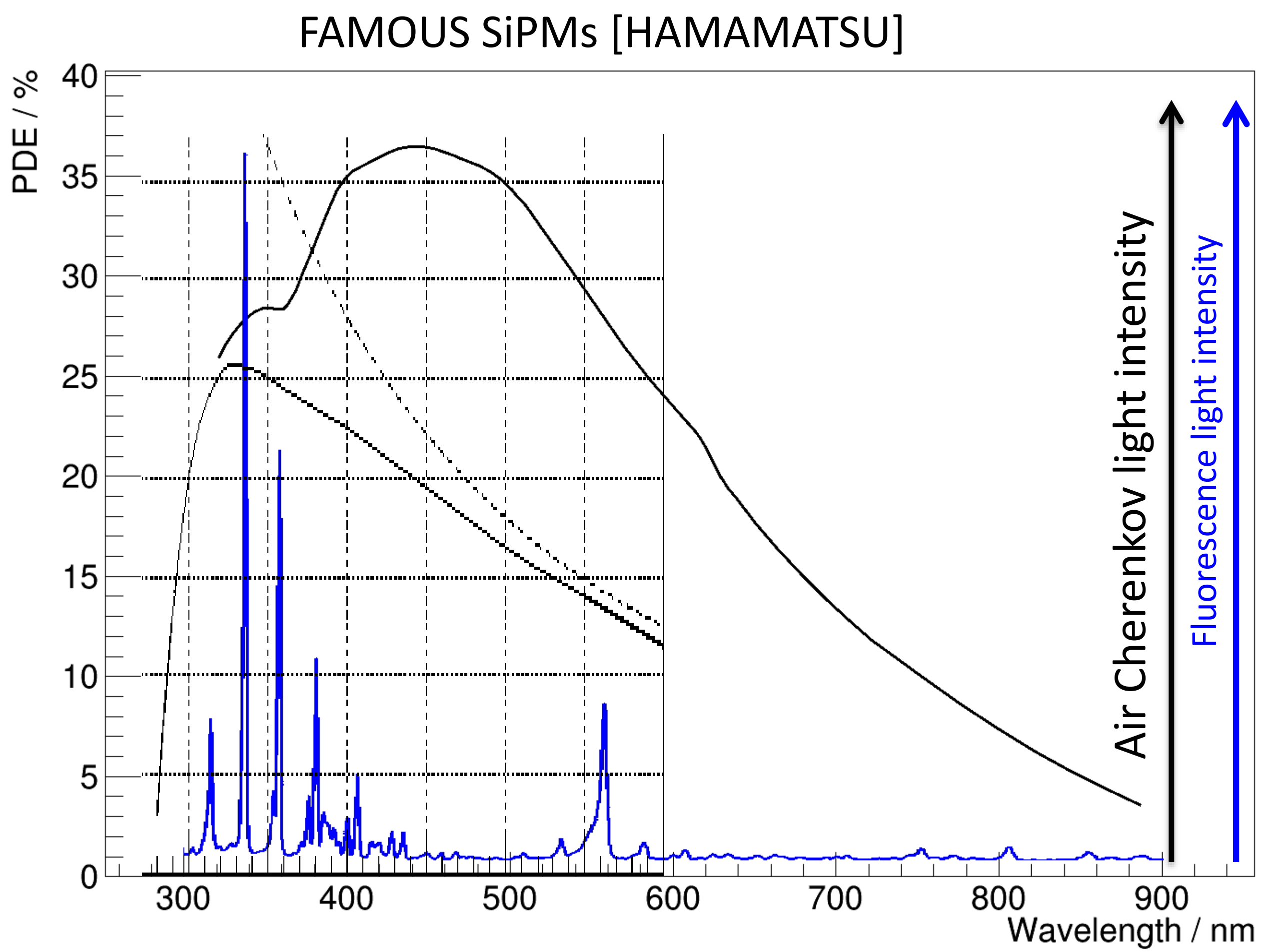


UG 11 compared to M-UG 6:

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

⇒ Better Signal/Noise

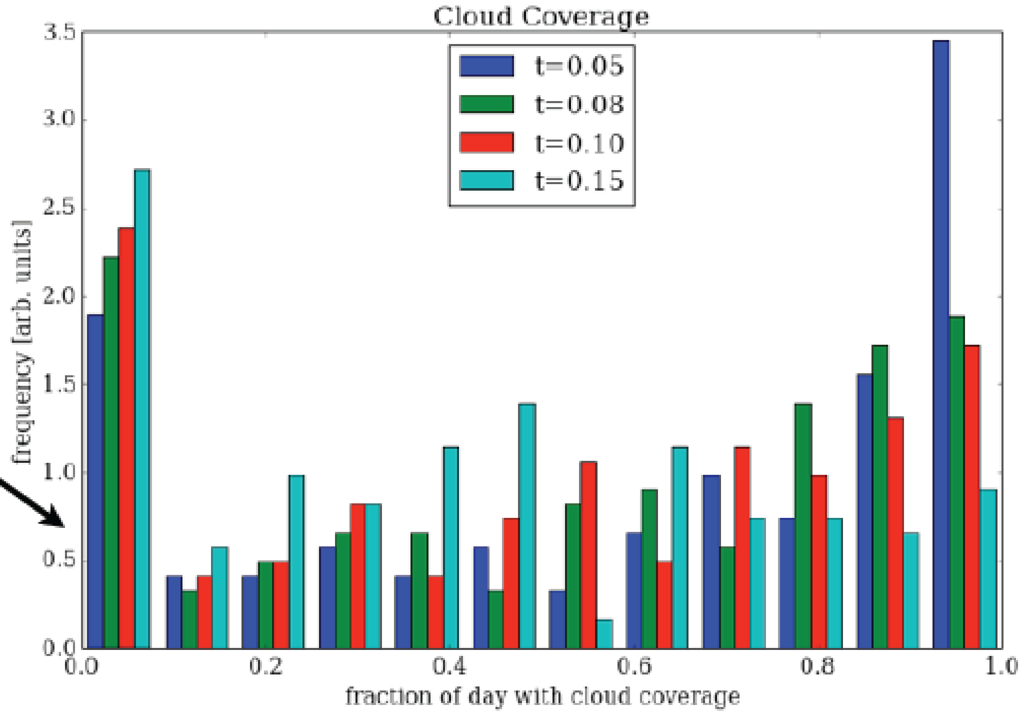
PDE of SIPMs


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)

completely clear



completely cloudy

- 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,...)

Requirements Summary

- Power:

on the ICL <30W

- Data Storage at pole:

100MB/h running at 10Hz

100MB/h * 5 Month = 400GB for one season.

- Data i/o from pole:

limited remote access + small data amounts

(Maybe 0.1Hz triggered data?)

- Time stamps if possible:

For coincidences with IceTop we get a

forced trigger every second with IceCube time.