Technical progress

- detector performance, calibration, R&D efforts

Albrecht Karle

March 2019

The IceCube Neutrino Observatory

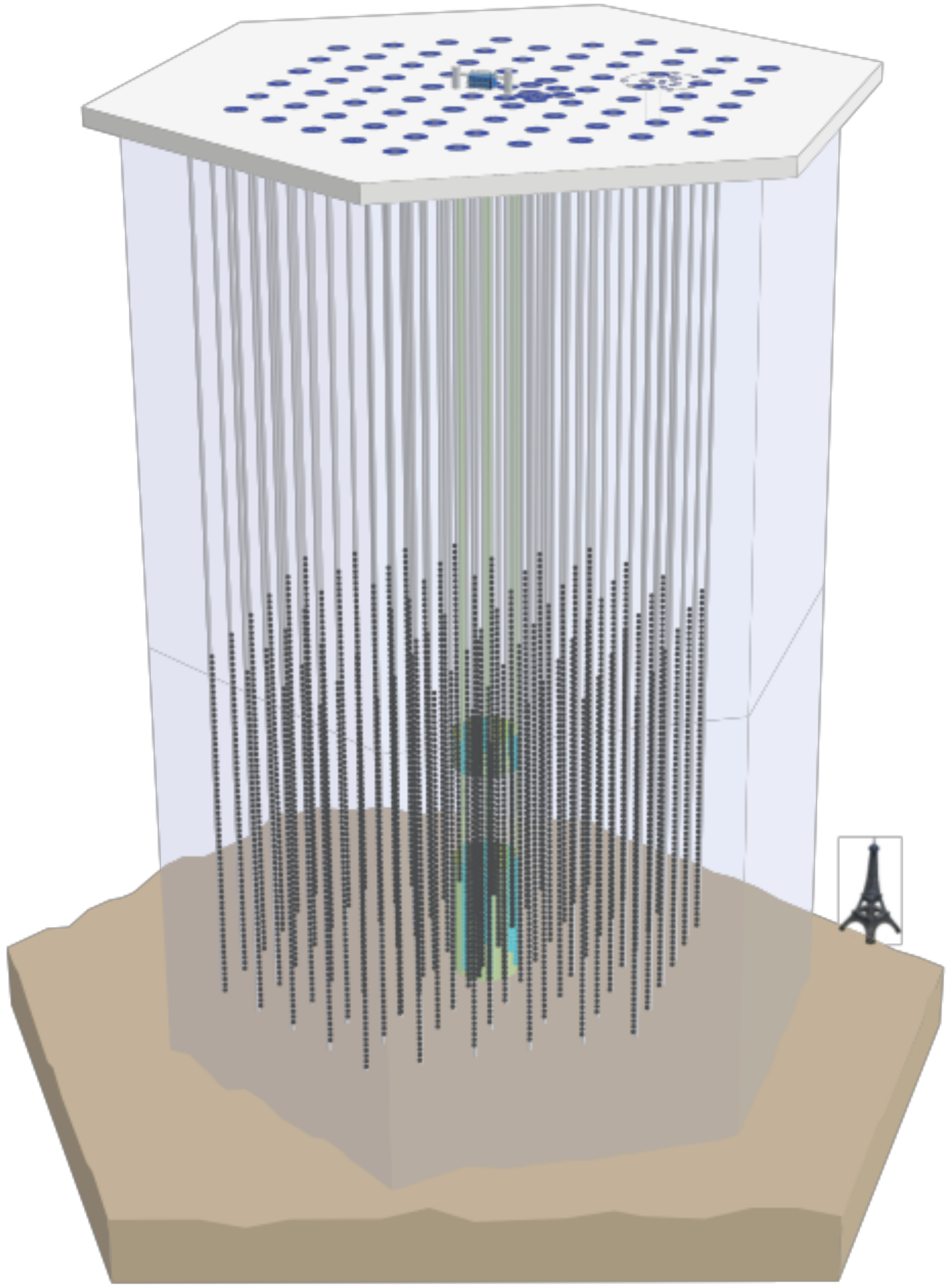
IceTop (surface array): 81 stations

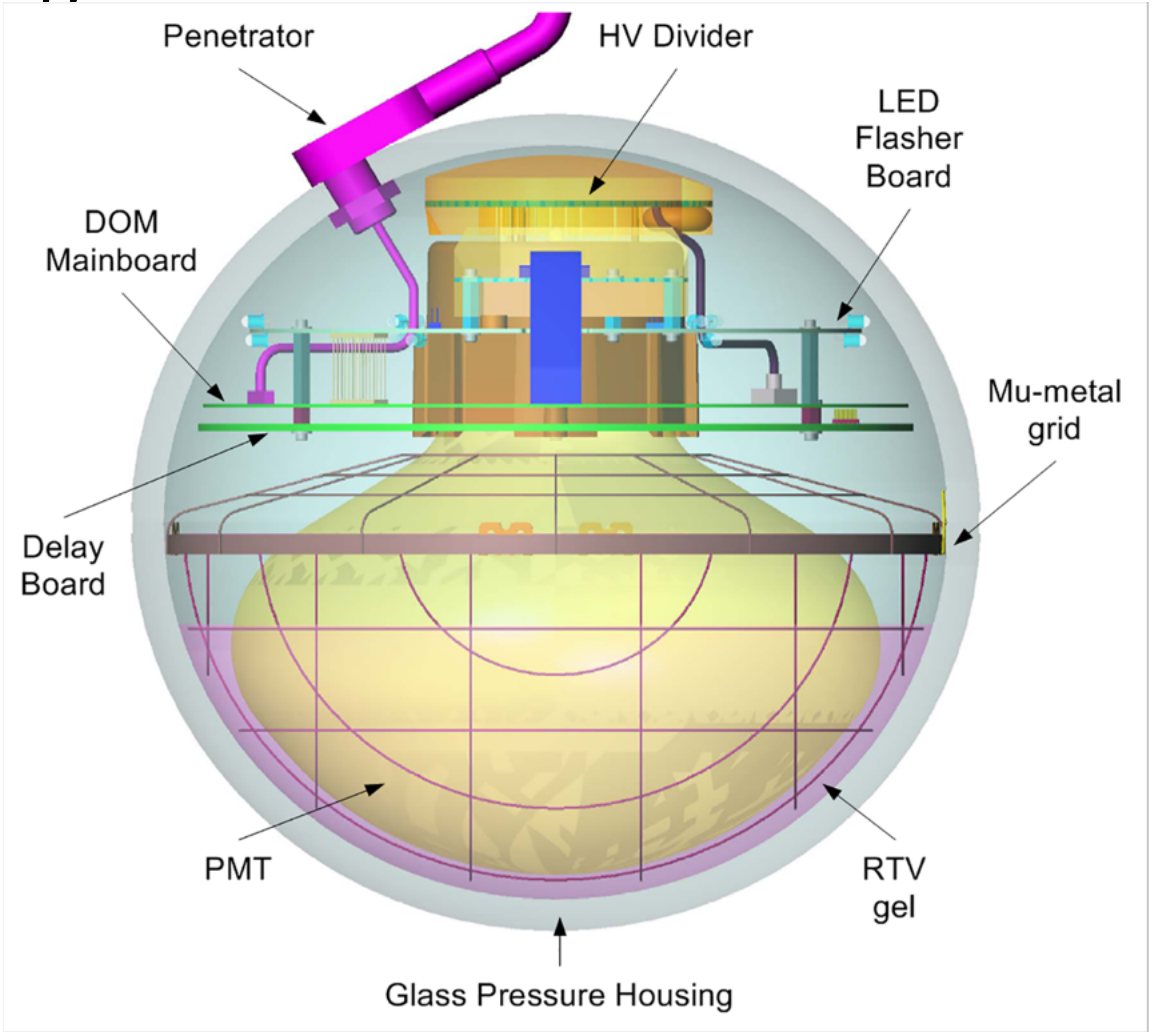
IceCube: 86 strings

5160 optical sensors over 1 km^3 volume

17 m vertical spacing

125 m horizontal spacing

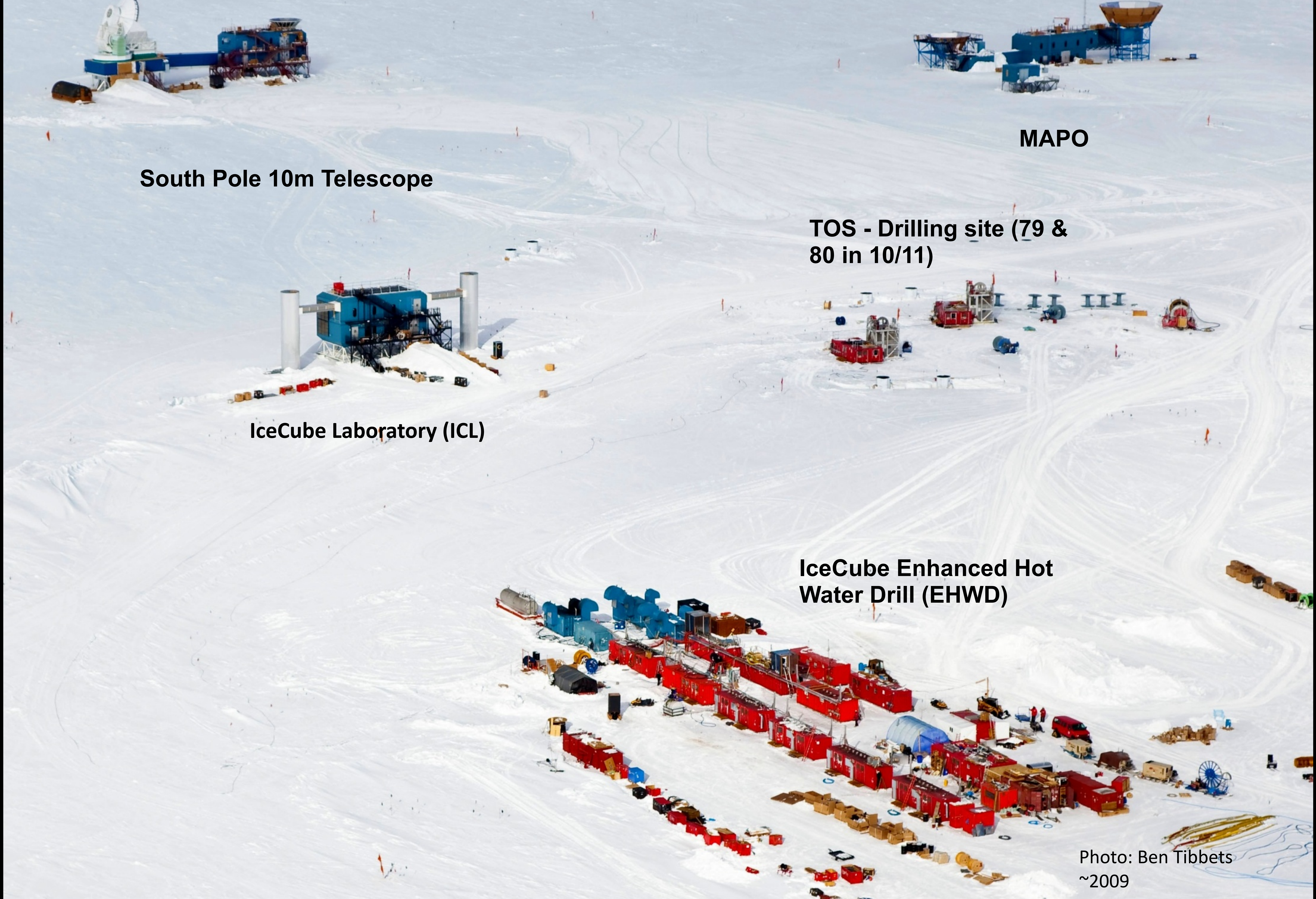




Highly stable operation.

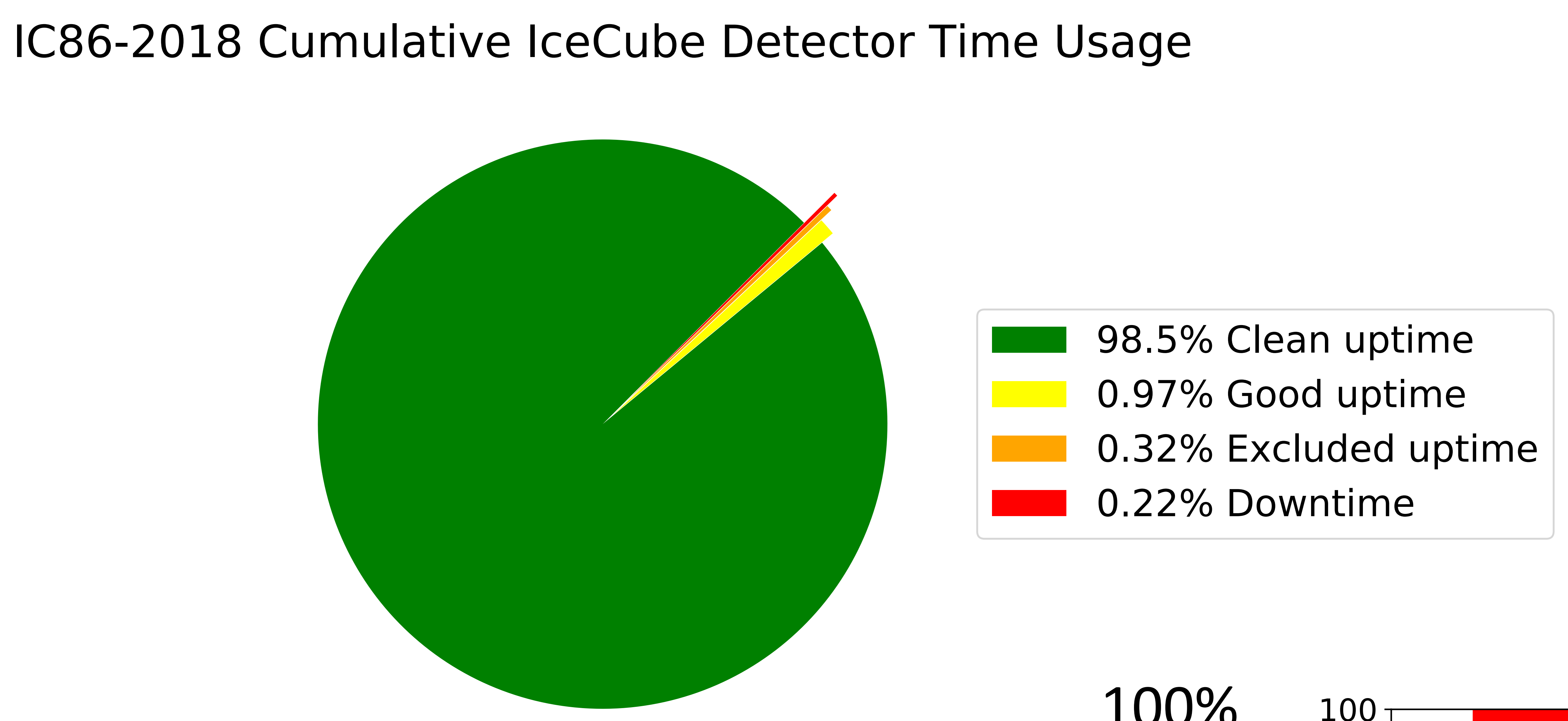
Since 2016: livetime > 99.5%

DeepCore (low energy threshold)

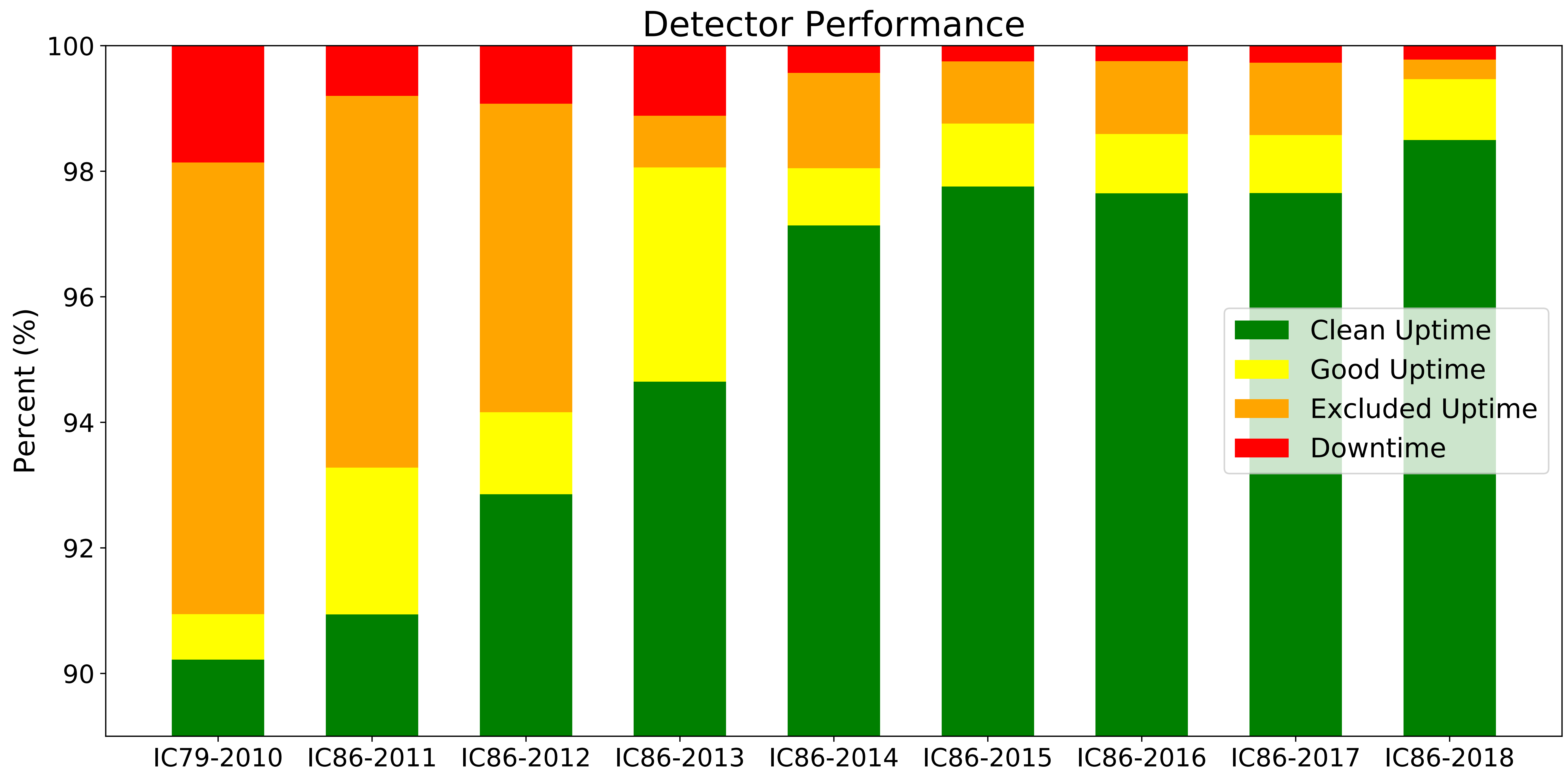

MAPO
South Pole 10m Telescope
TOS - Drilling site (79 & 80 in 10/11)
IceCube Laboratory (ICL)
IceCube Enhanced Hot Water Drill (EHWD)
Photo: Ben Tibbets ~2009

5160 sensors are deployed
to a depth between 1500
and 2500m.

Detector Uptime



100%



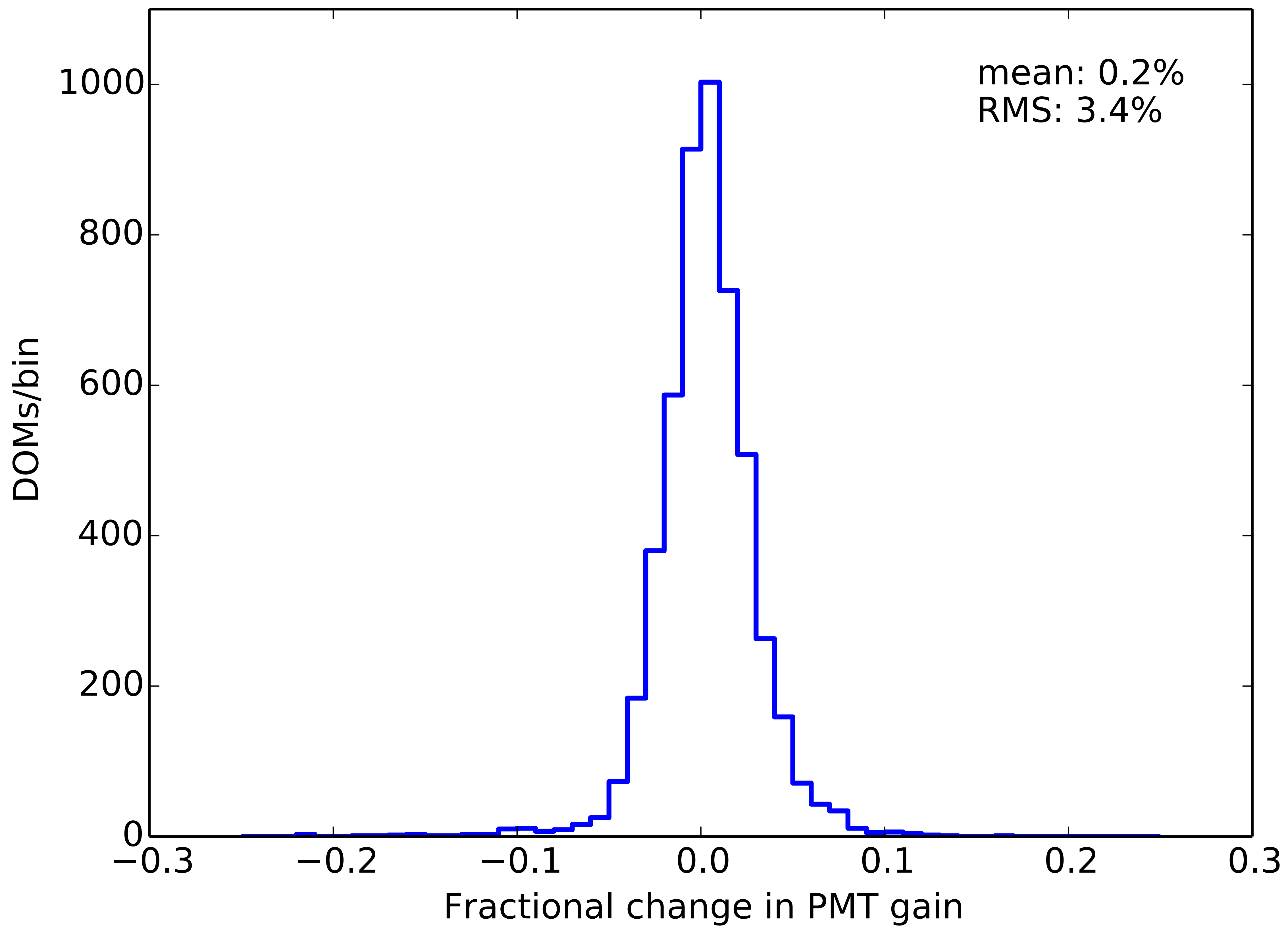
90%

2010

2018

PMT gain stability 2011 - 2016

No indication for any changes since 2016.



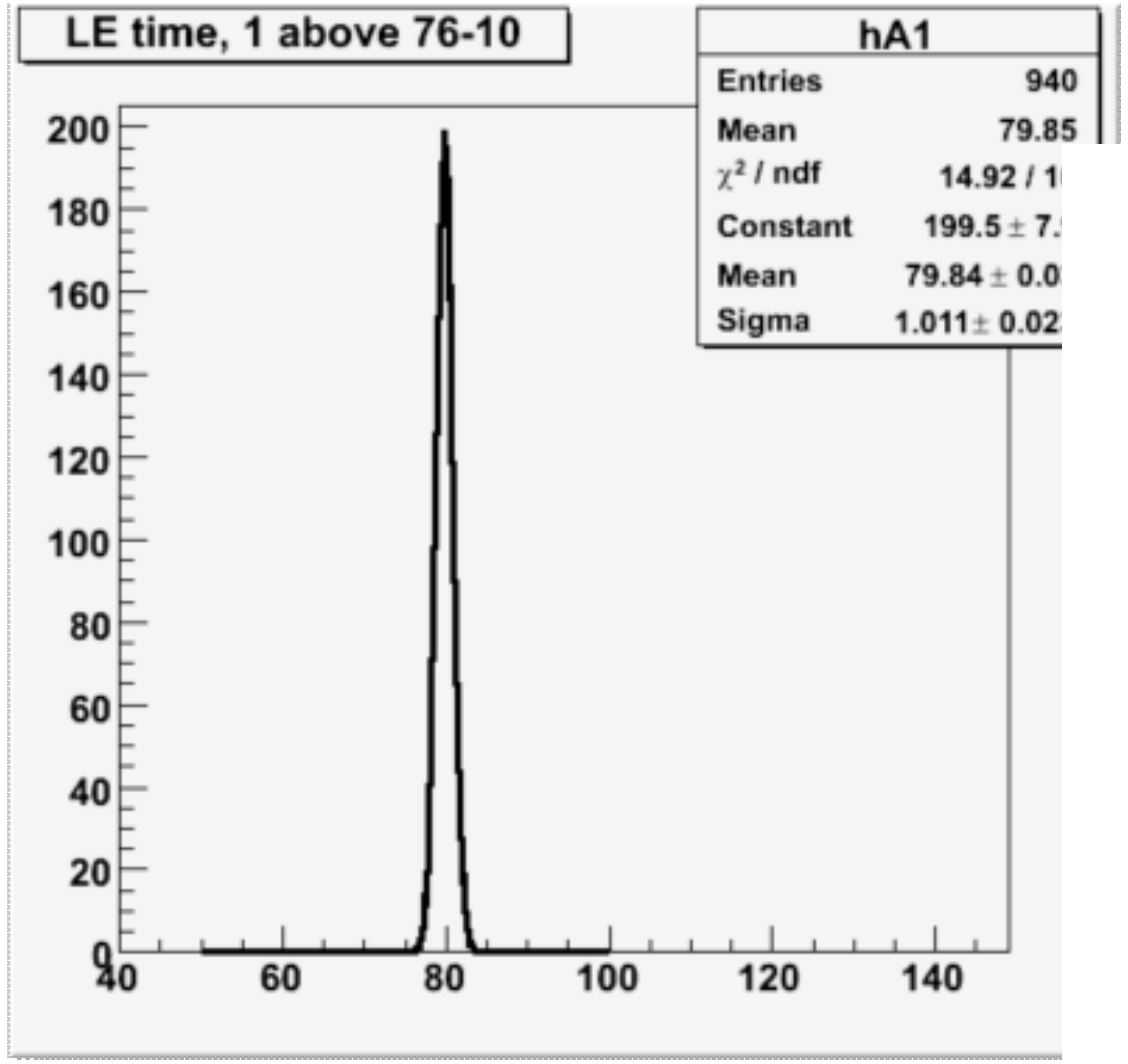
DOM gain appears stable!

(PMT gain of 1E7 is small.
Noise rates are small.
→Very small integrated current on anode.
→ No aging from that.

Time resolution:
~1ns for bright pulses

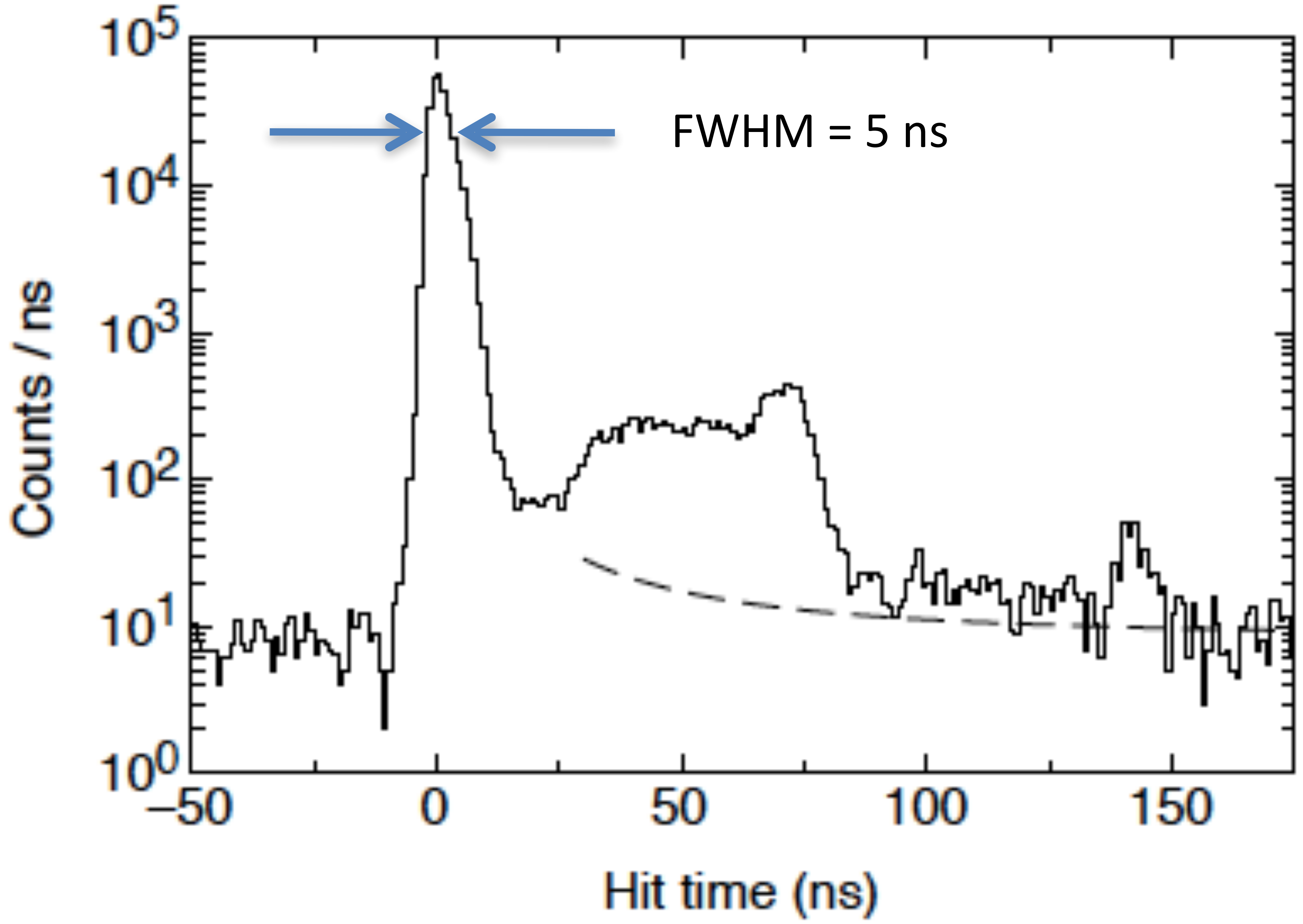
- Time difference between neighboring DOMs fired with (bright) flasher pulses: ~1 ns.

  (this includes clock timing)



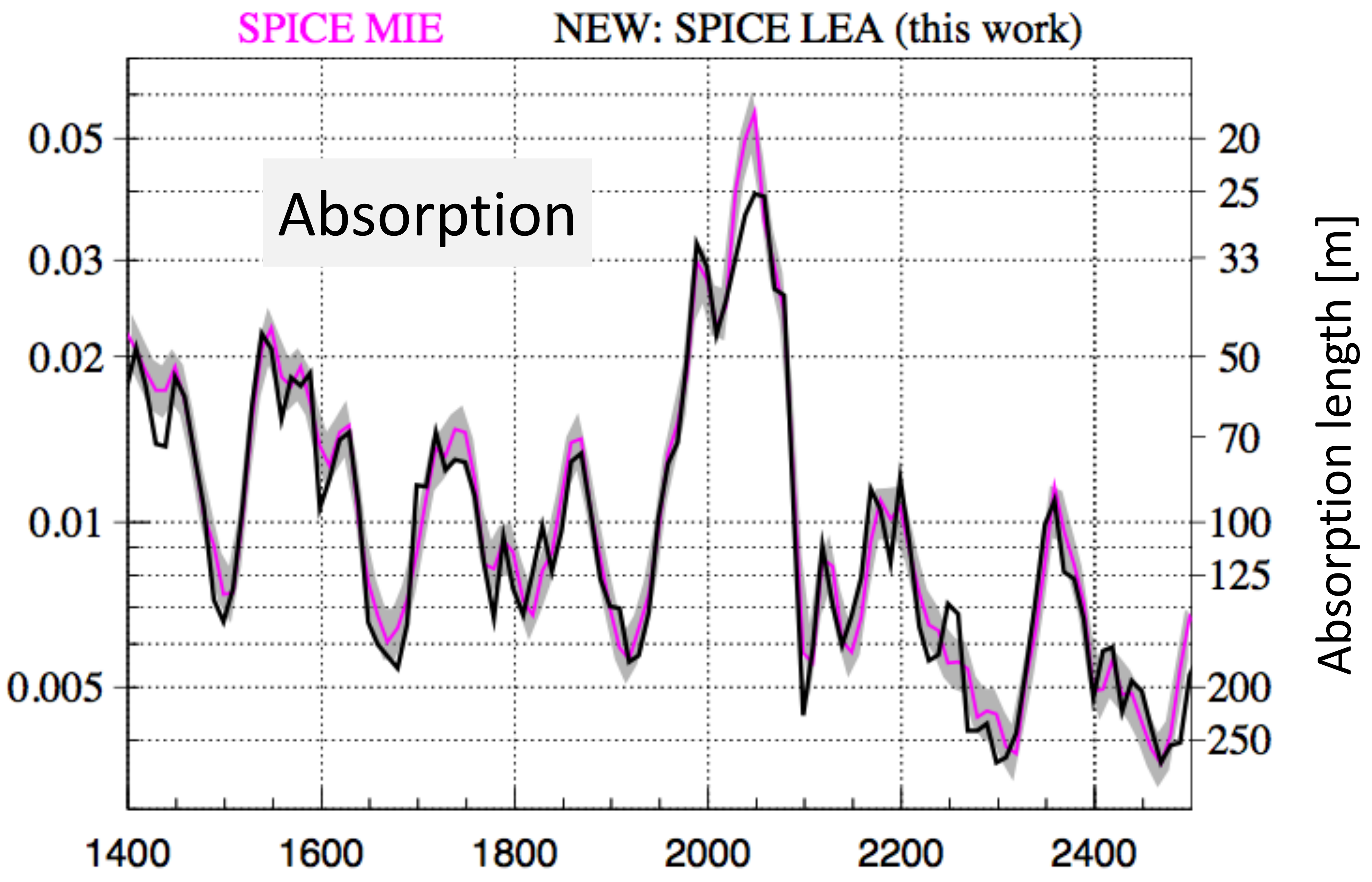
Single photoelectron pulse resolution limited by PMT.
RMS in the peak: ~2ns

Lab measurement with laser.



Understanding the ice

1. Vertical structure of ice parameters



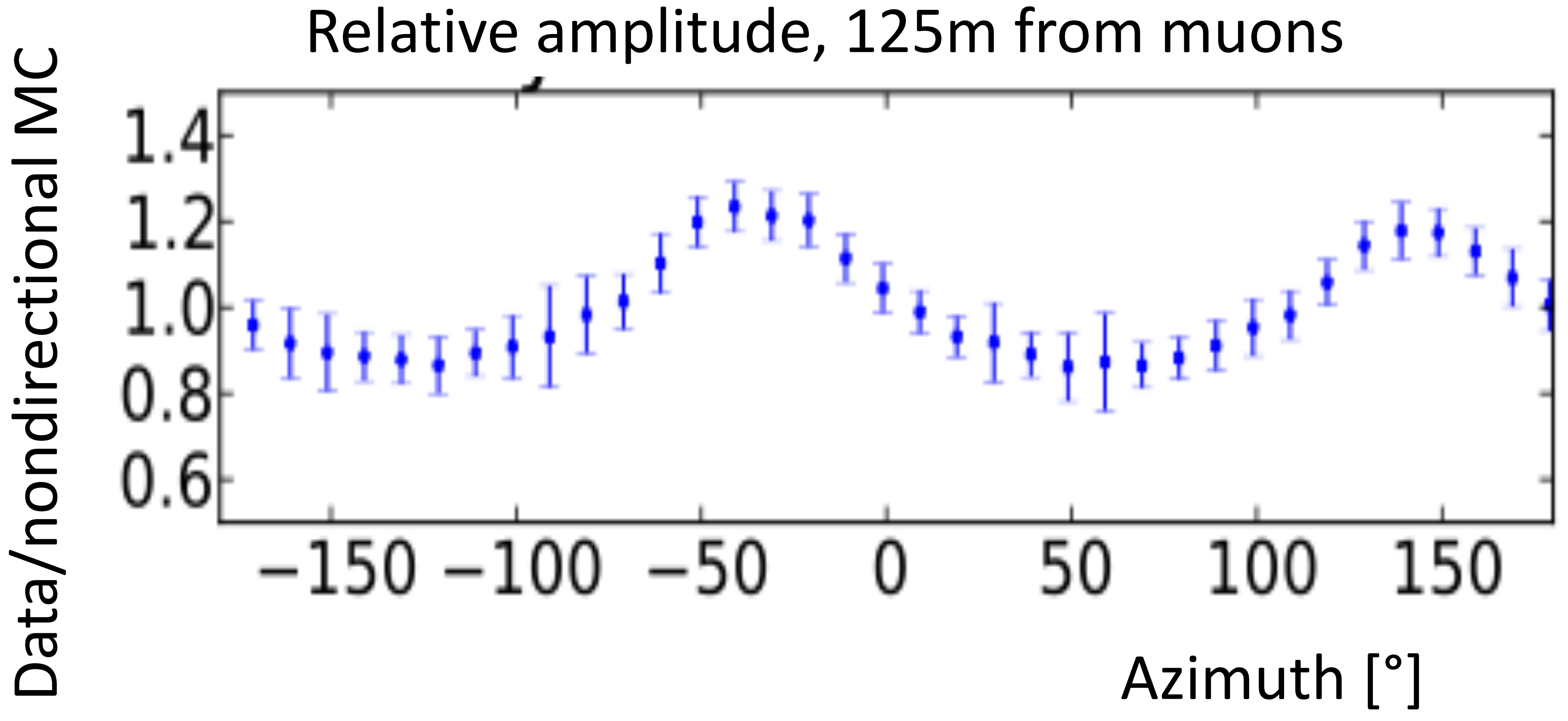
Scattering (eff.): 20 – 50 m
Absorption: 100 – 200 m

Measurement of South Pole ice transparency with the IceCube LED calibration system,

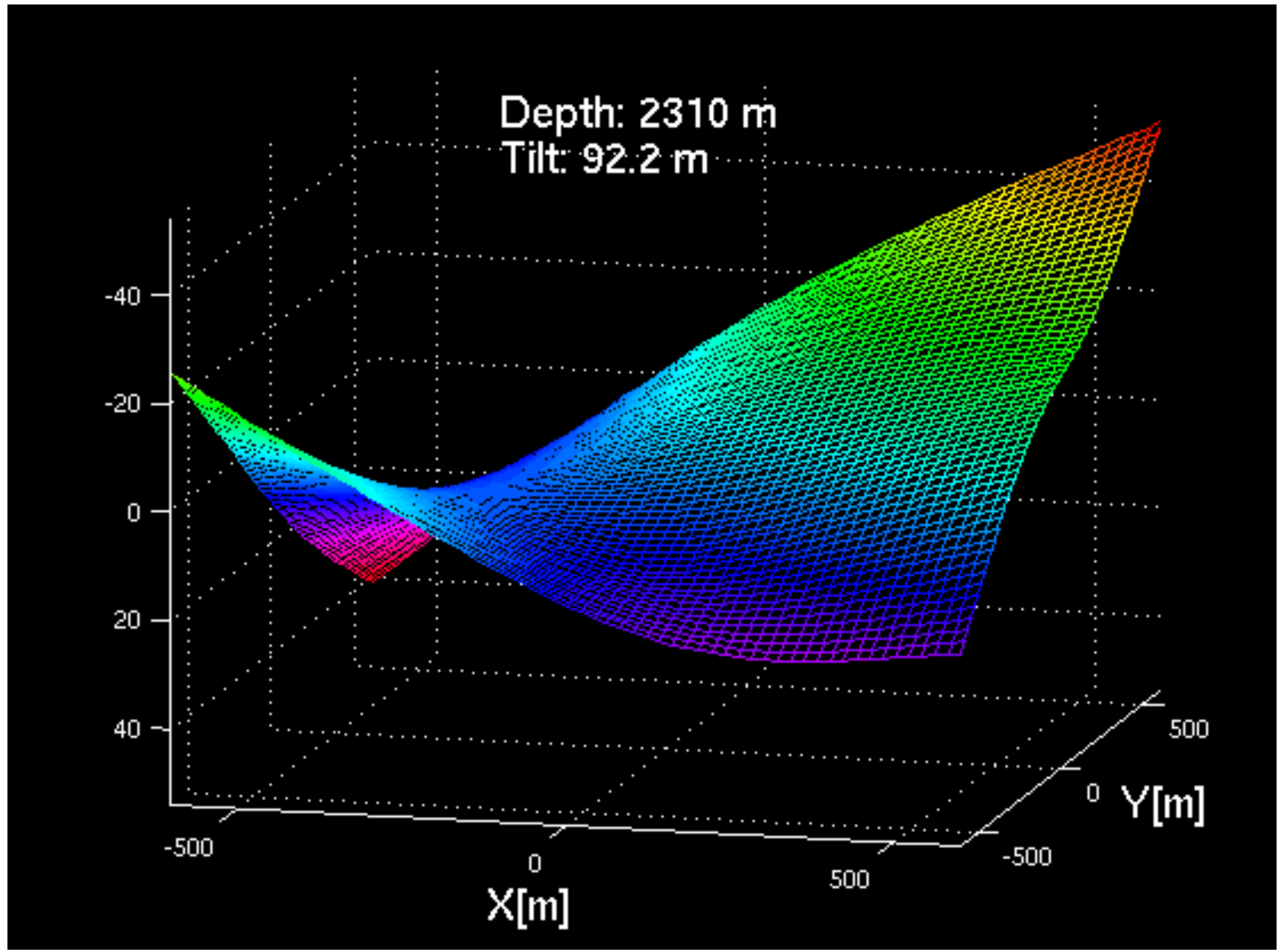
Aartsen et al., (IceCube Coll.), NIMA55353
http://arxiv.org/abs/1301.5361

2. Azimuthal variation in of scattering

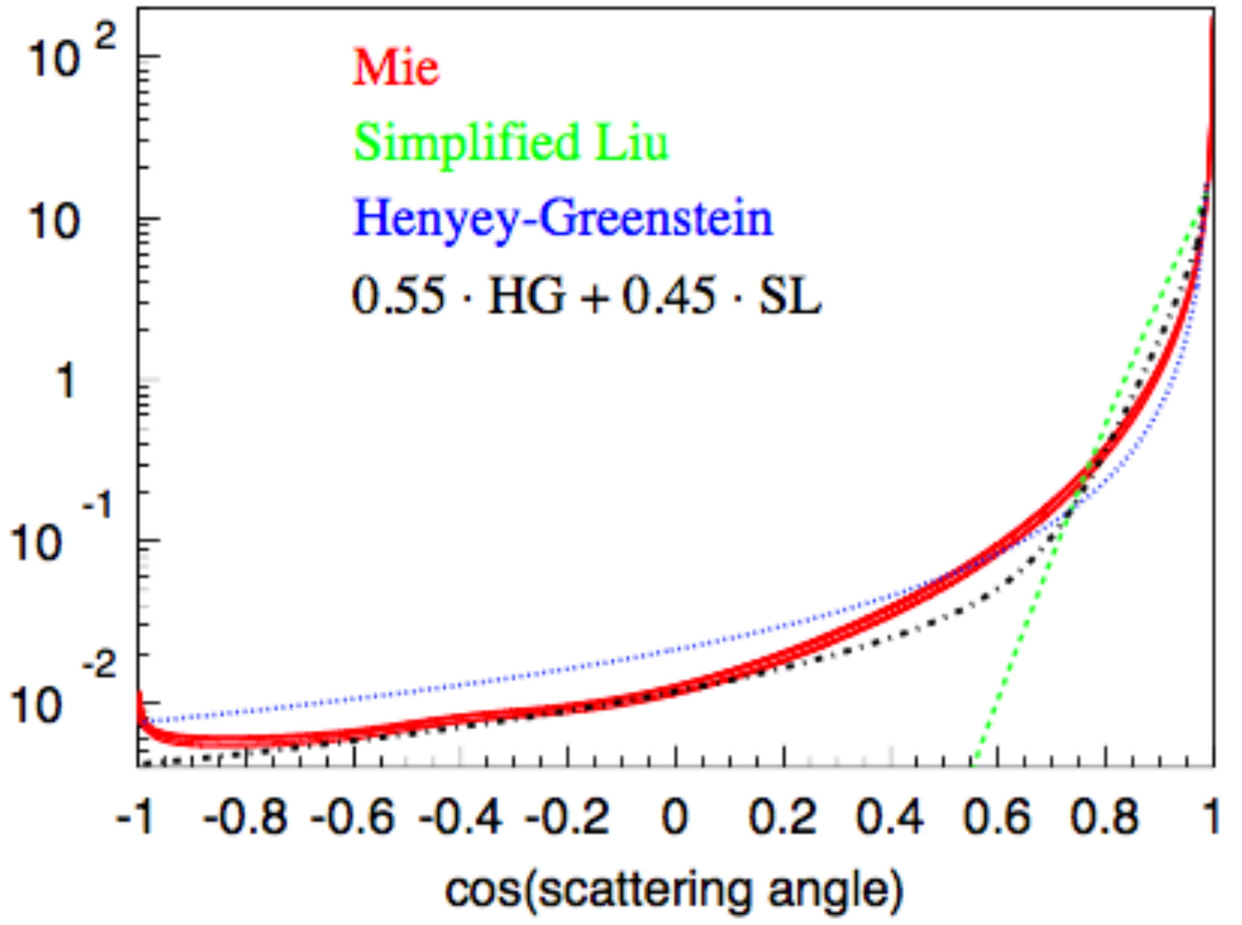
Less scattering in direction of ice flow:
→ up to ~10% /100m variation in amplitude



3. Ice layers are tilted – not planar



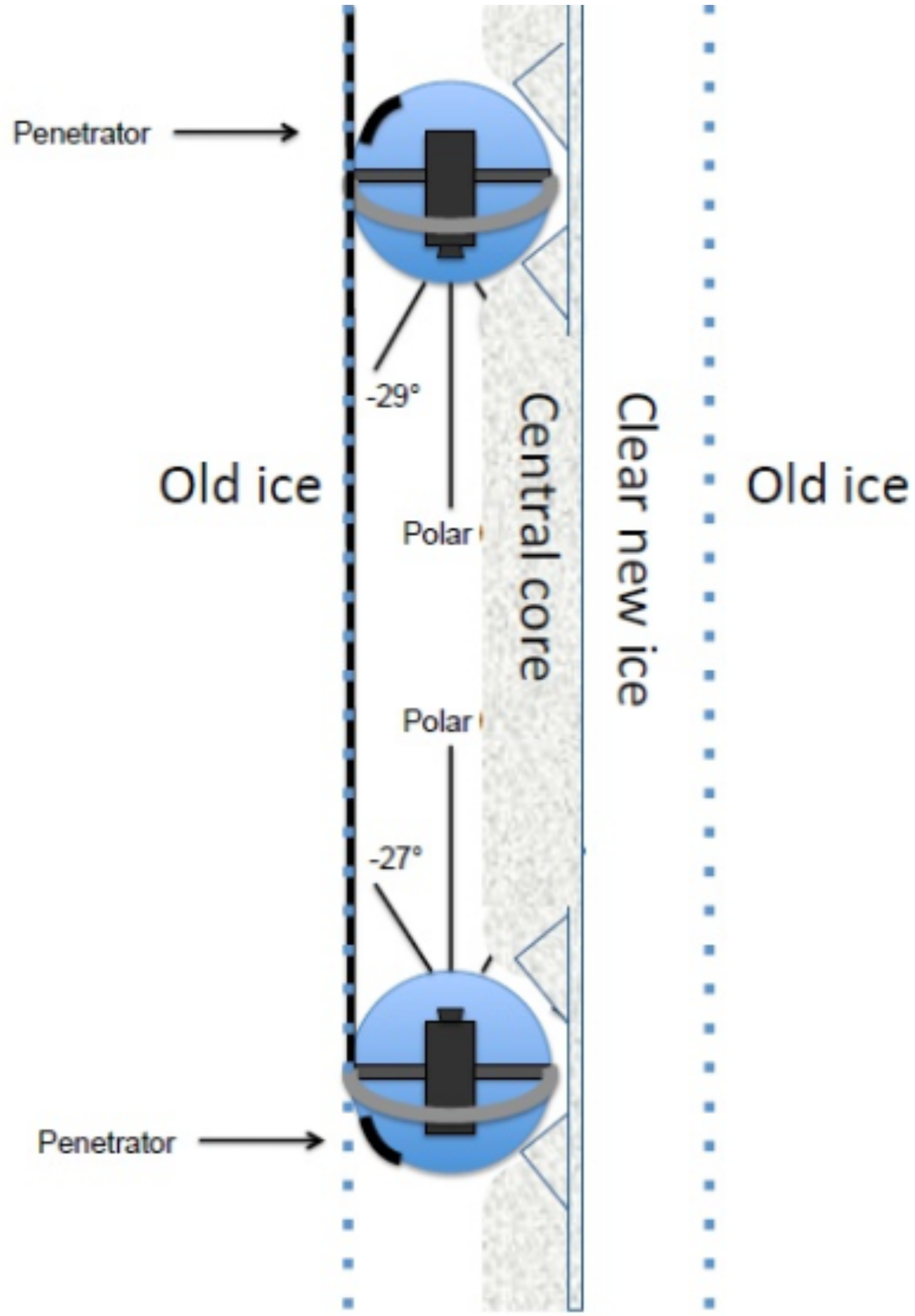
3. Scattering function

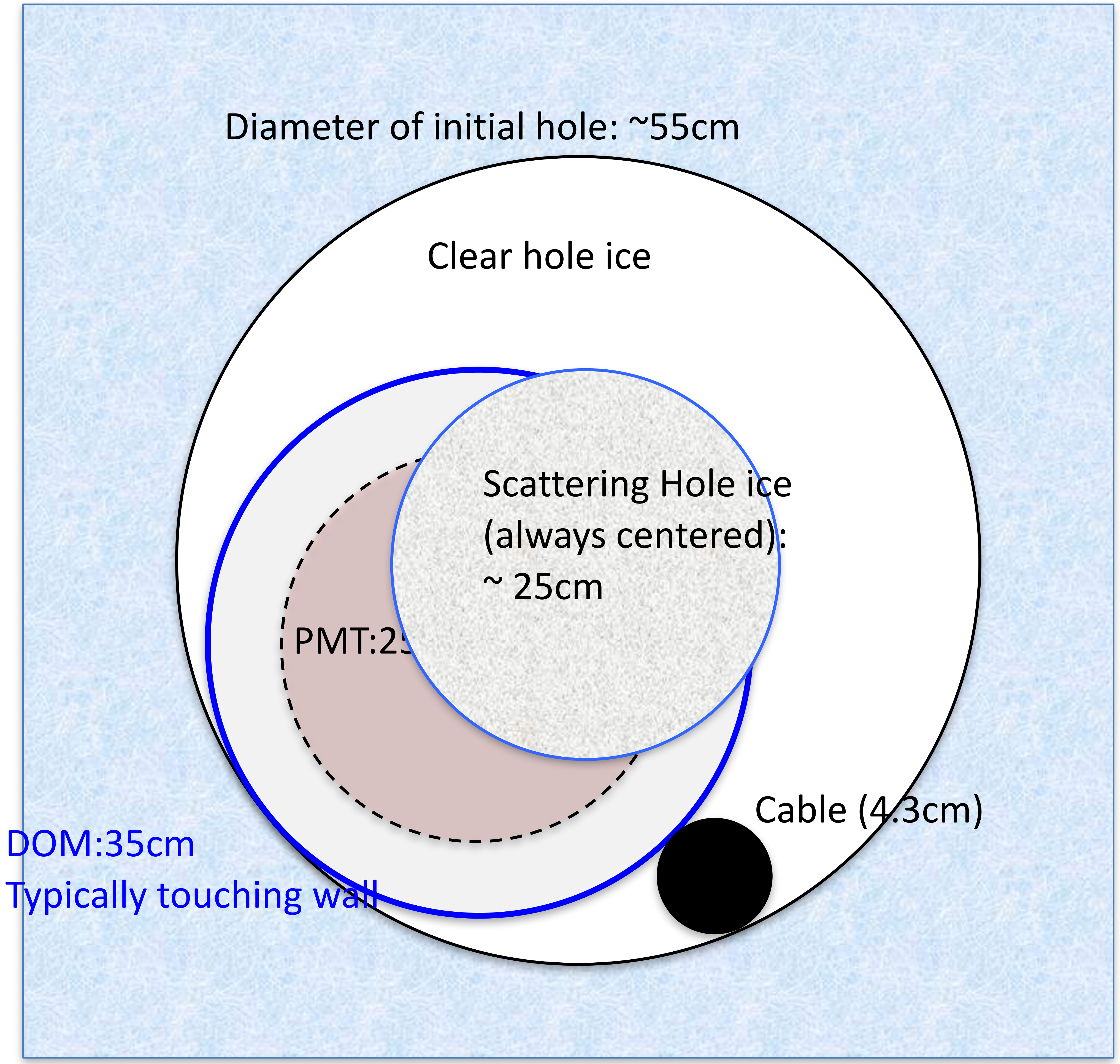


Systematic uncertainties: DOM and local ice

Current picture of hole ice

We plan to map the full surface sensitivity of every DOM precisely cable position to <3° (can be determined with local LEDs),
then fit effect of hole ice.





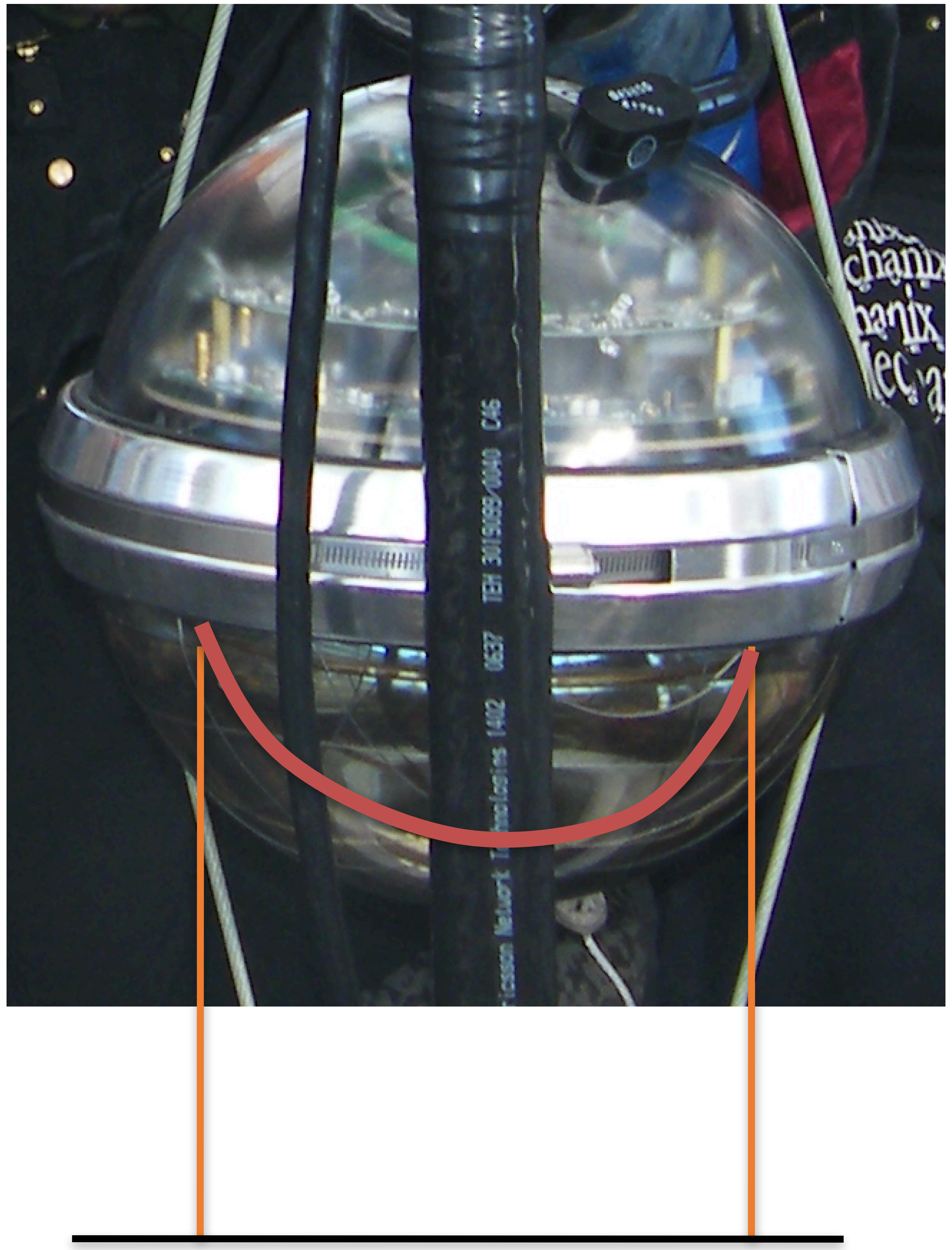
DOM and local ice

Images taken with camera ("Swedish Camera") during refreeze process:

Hole ice visible on the right.
Need to determine the effect
for every single DOM.

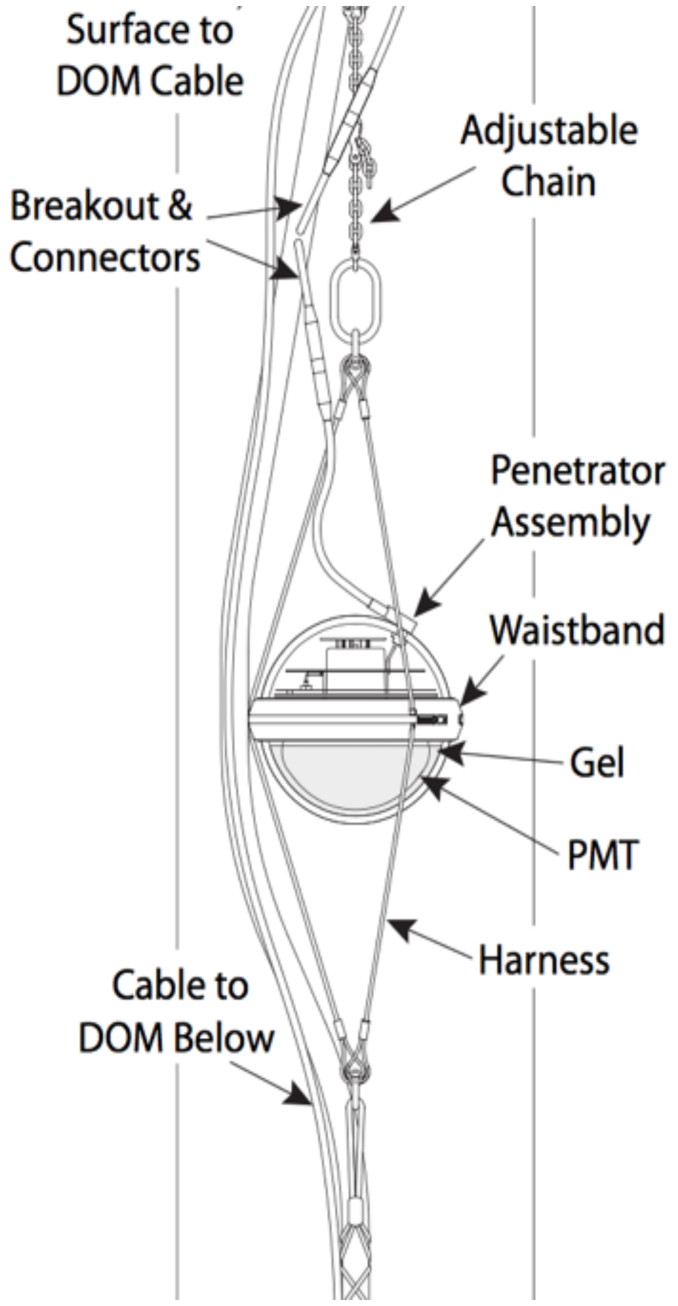
Cable shadow

Cable diameter: 4.5cm

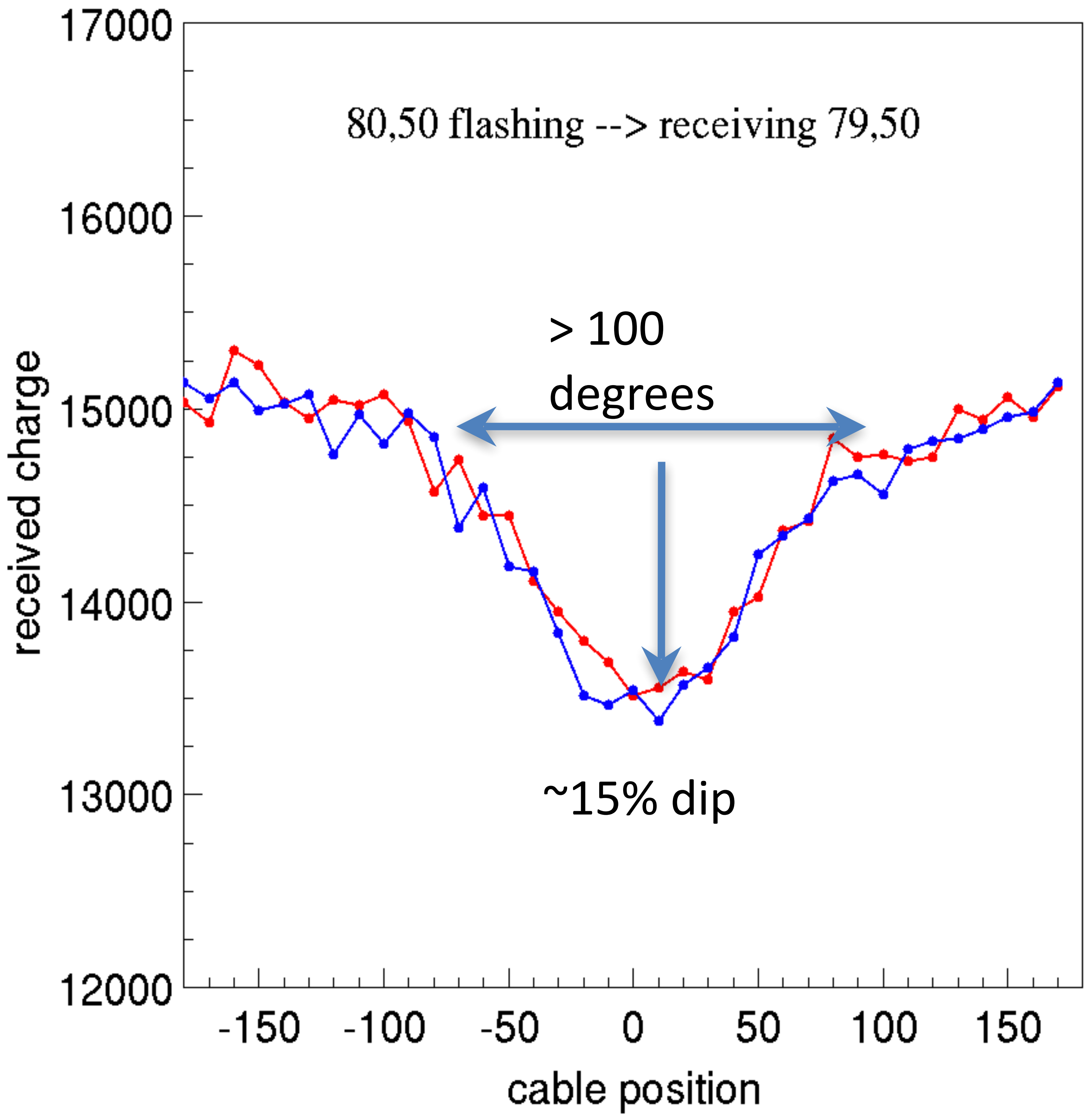


DOM sphere:32.5

PMT cathode diameter: 22 cm



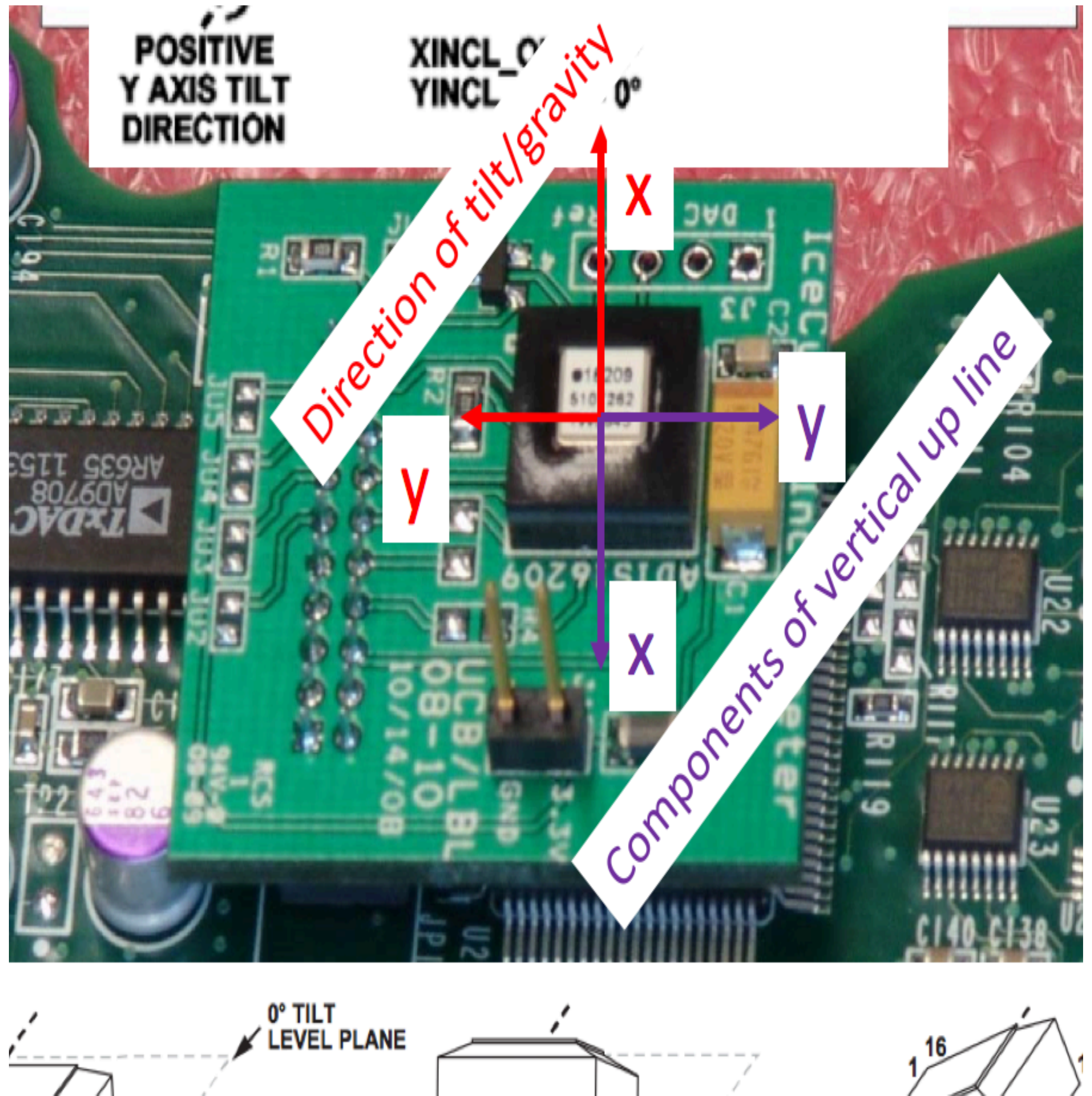
Azimuthal DOM response: Simulated effect on receiving DOM from flashers at close distance.

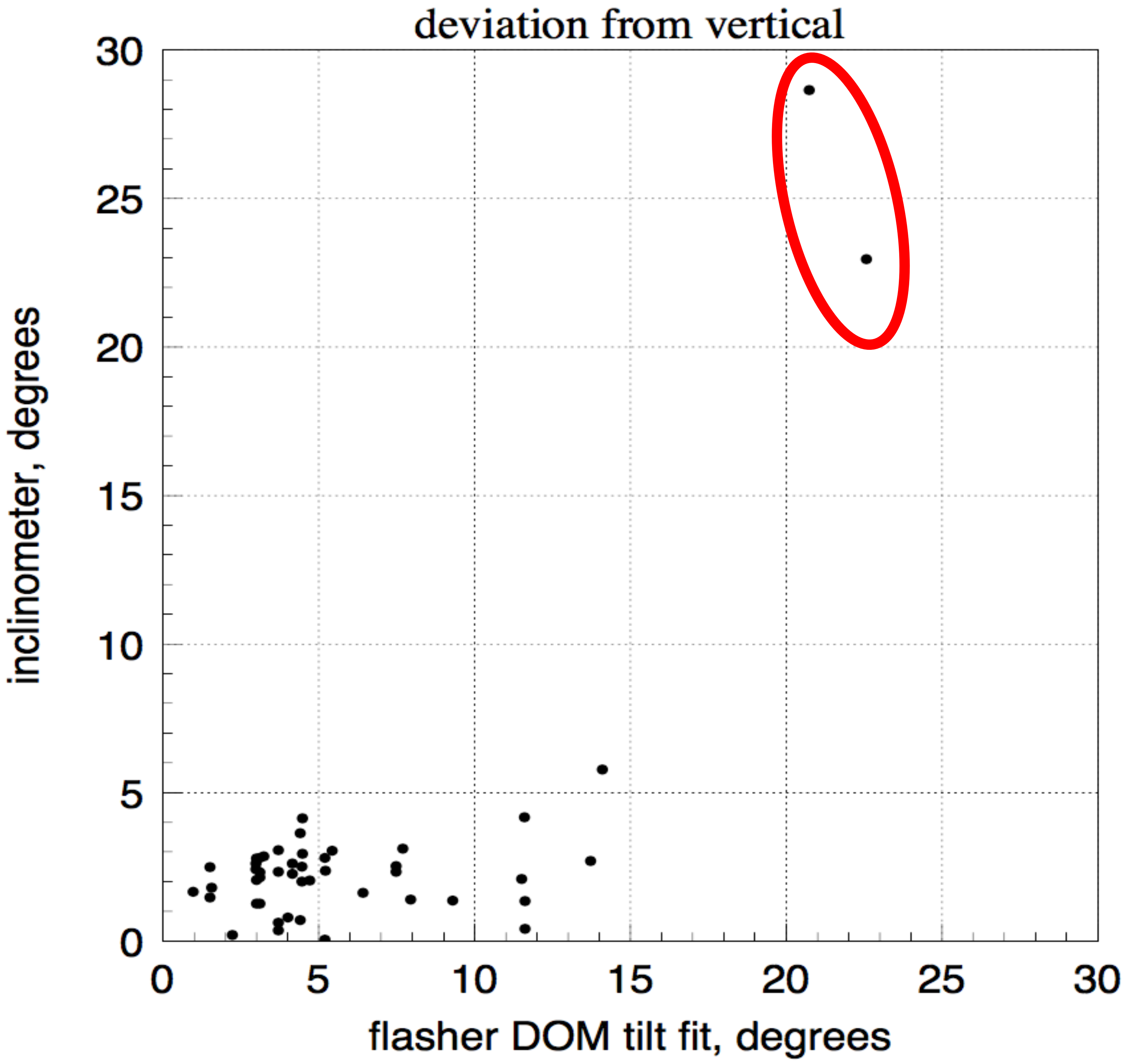


Built-in inclinometers vs DOM tilt fit

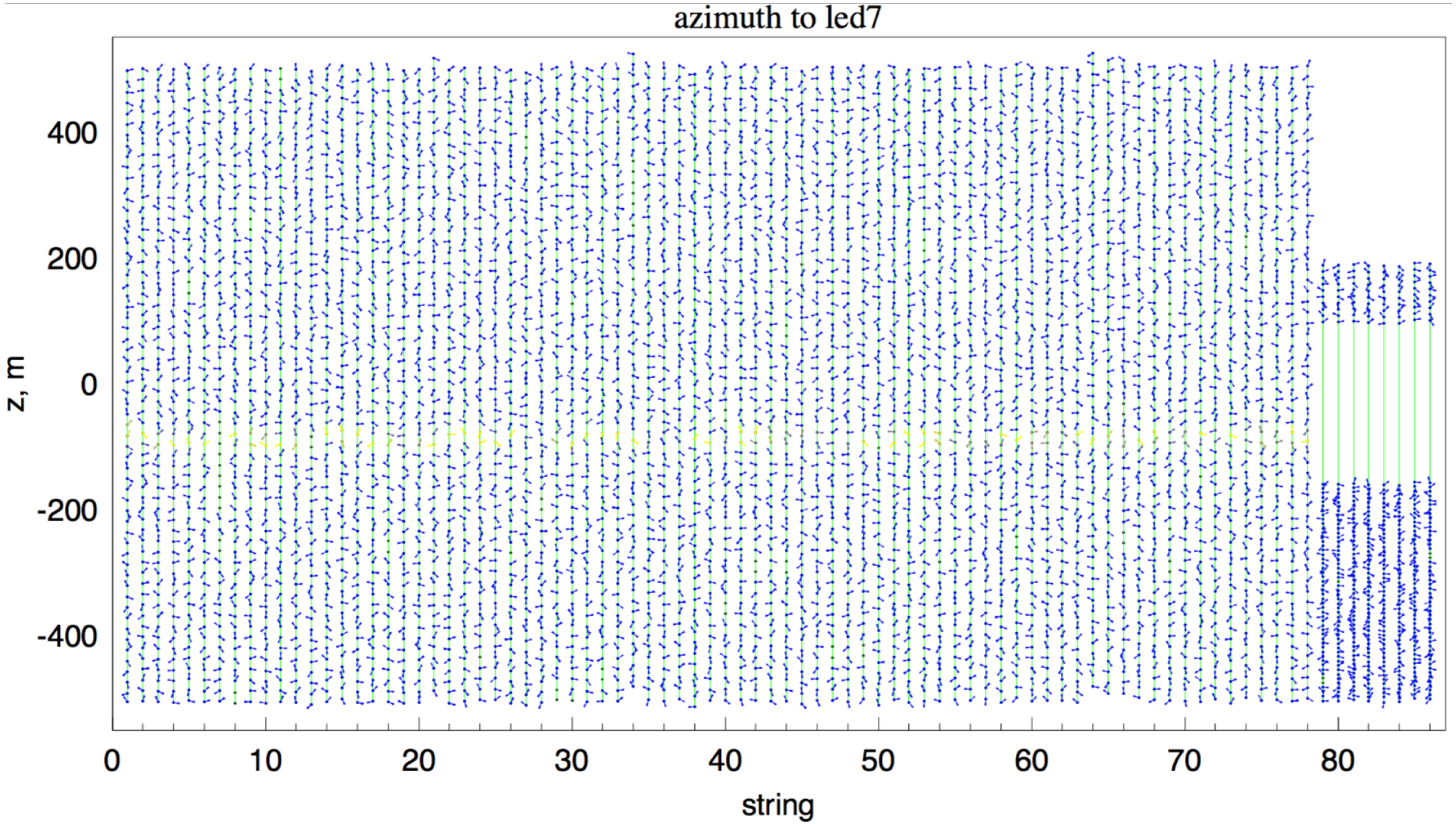
Indication of real tilt for 2 DOMs (out of 48)!

4 dozen DOMs have a built-in inclinometer, mounted on the mainboard, most of them have measured very small tilts, while 2 have tilts in excess of 20 degrees.





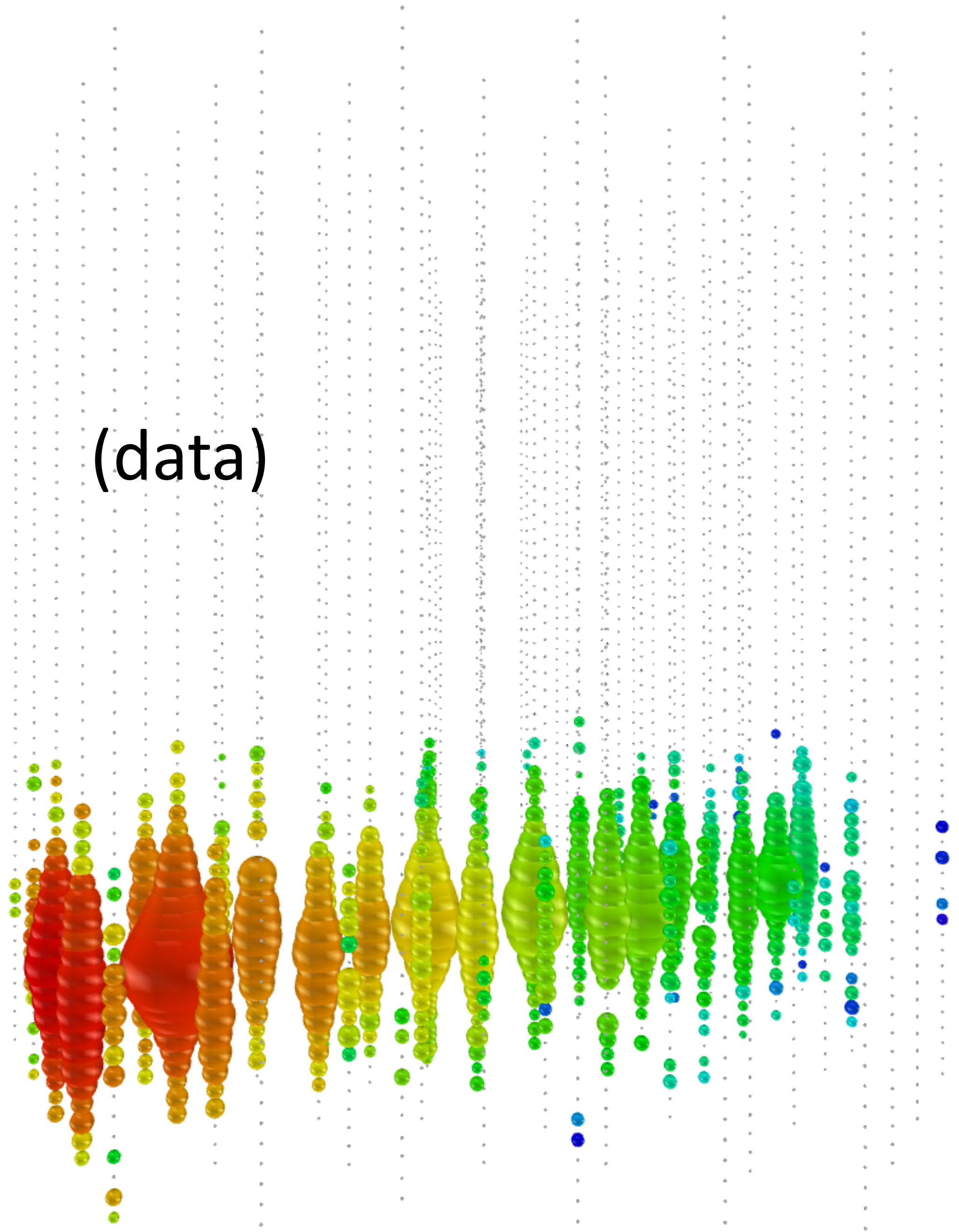
Example of DOM level calibration work: determined position of individual cables near DOM to few degree precision



Types of events and interactions

Charged-current ν_μ

(data)



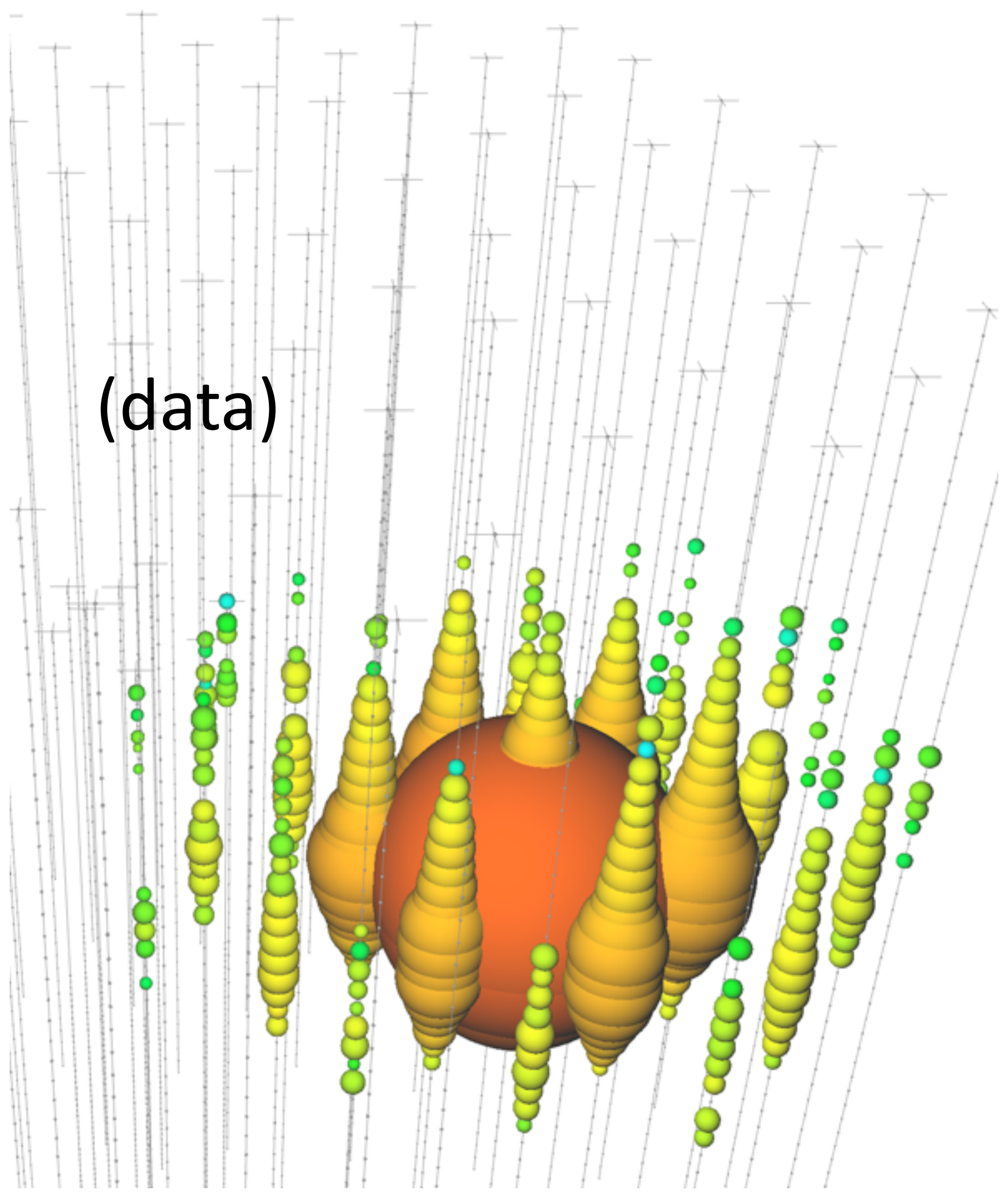
Up-going (throughgoing) track

Factor of ~2 energy resolution
~ 0.5° angular resolution

0.3° above 100 TeV

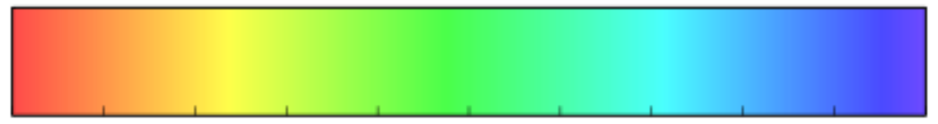
Neutral-current / ν_e

(data)



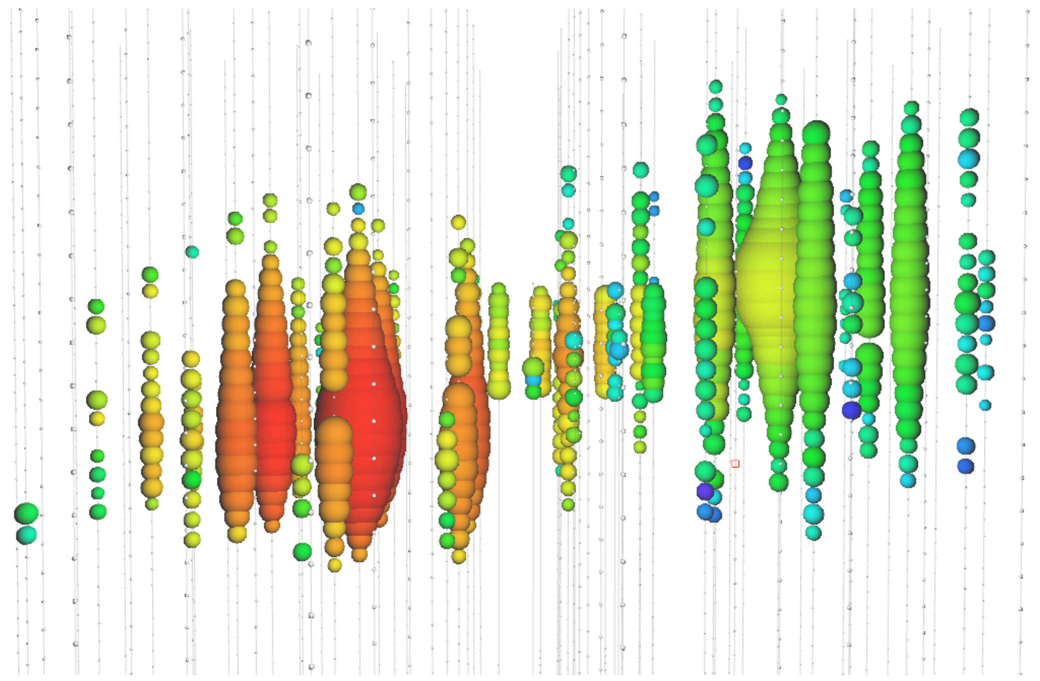
Isolated energy deposition (cascade) with no track

15% deposited energy resolution
10-15° angular resolution (above 100 TeV)
Working on improving that.

Early  Late

Charged-current ν_τ

(simulation)



"Double-bang"

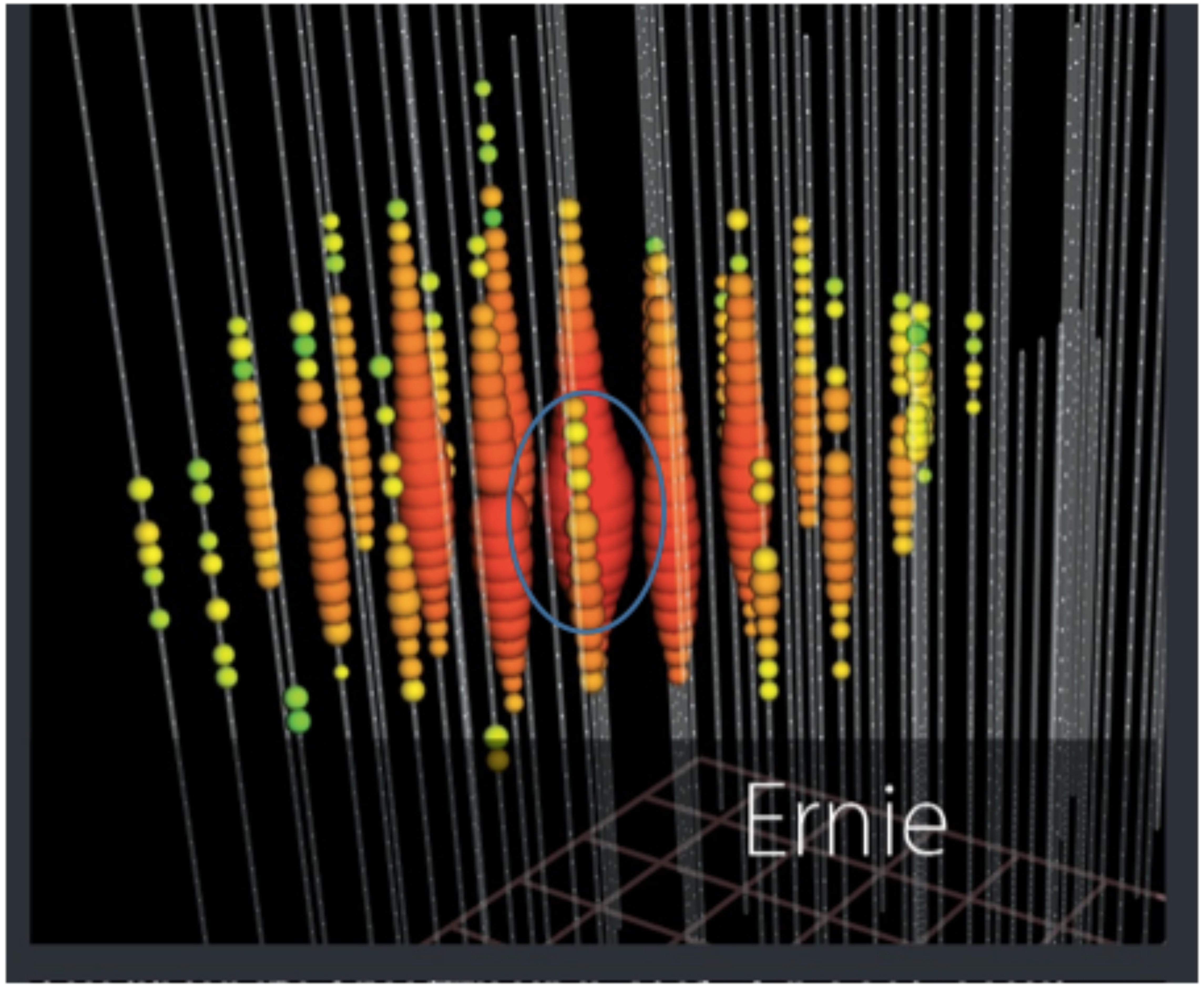
(none observed yet: τ decay length is 50 m/PeV)

ID: above~ 100 TeV (two methods)

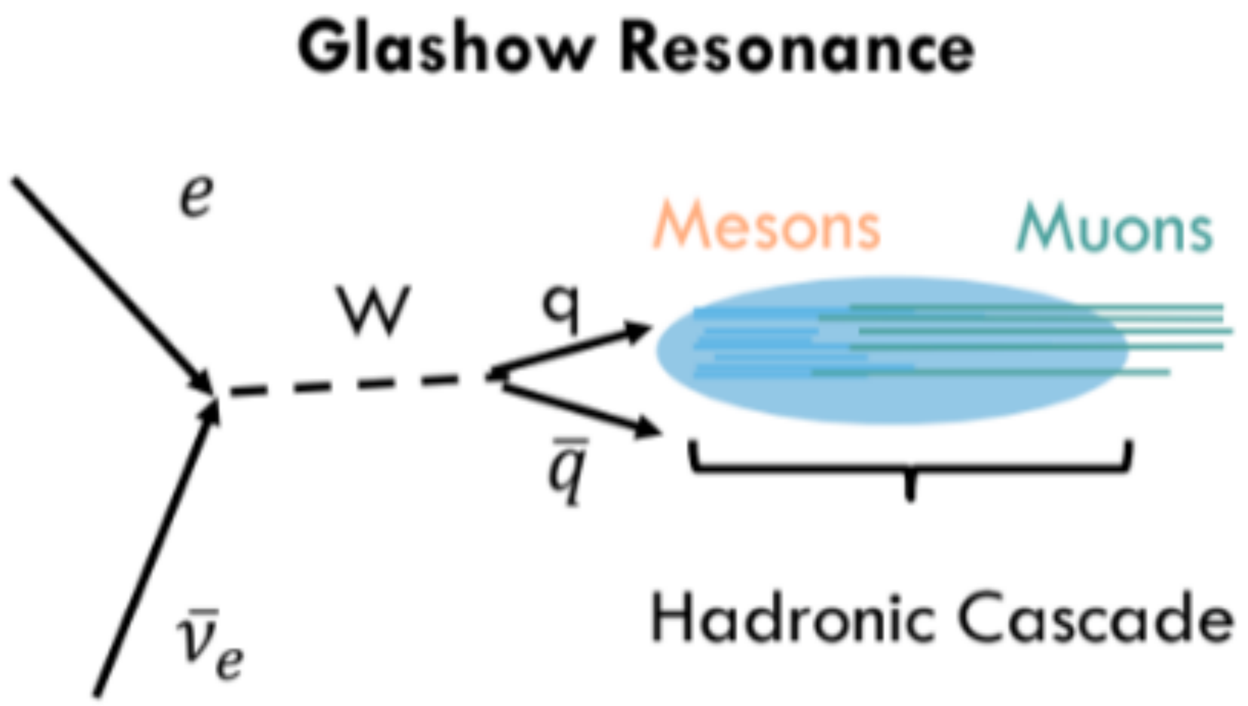
Bright DOMs

DOMs with $Q_{bright} > 10*Q_{avg}$ are classified as "Bright"

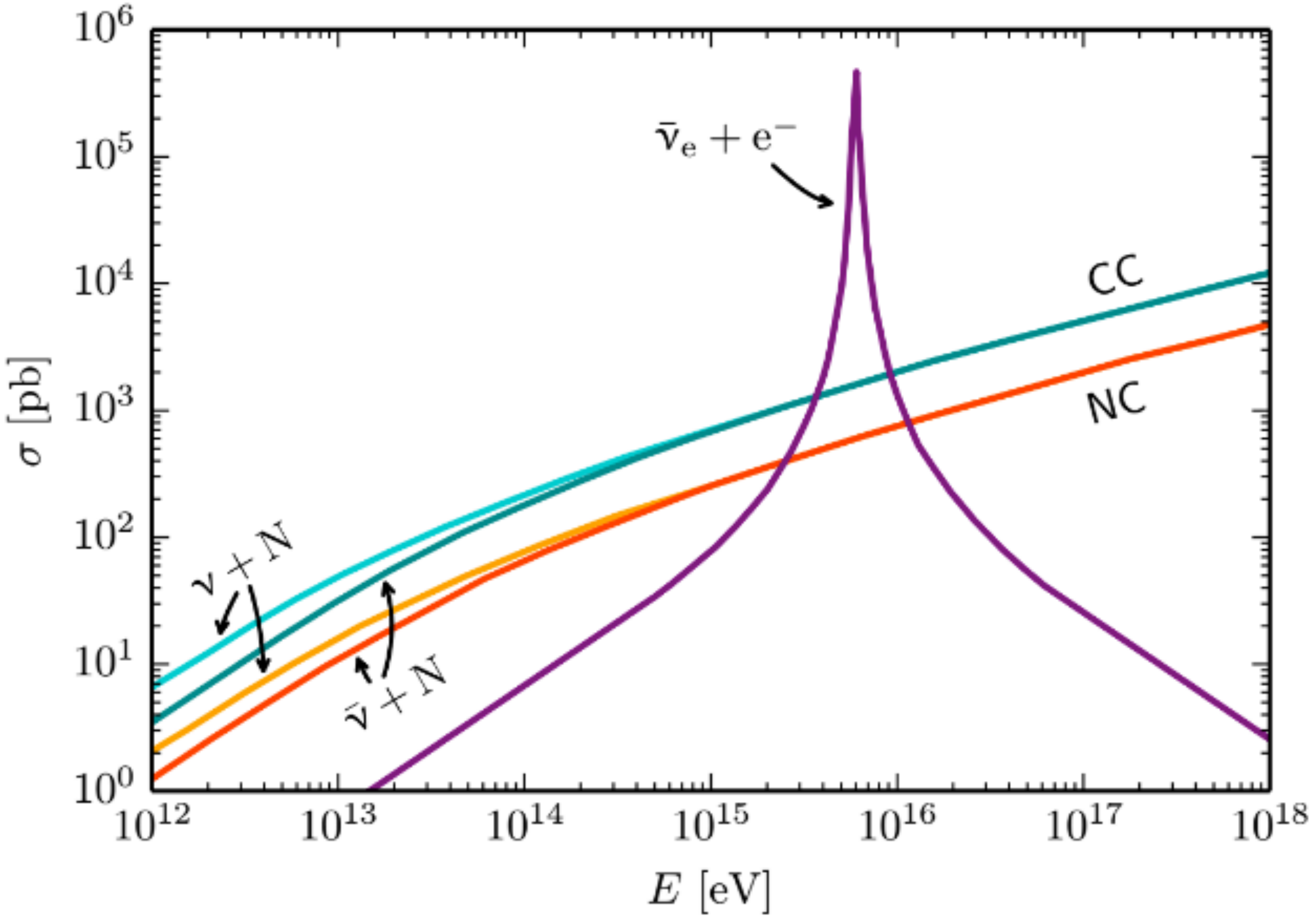
PMT not necessarily saturated, but excluded because unmodeled systematic uncertainties start to dominate at high photon statistics



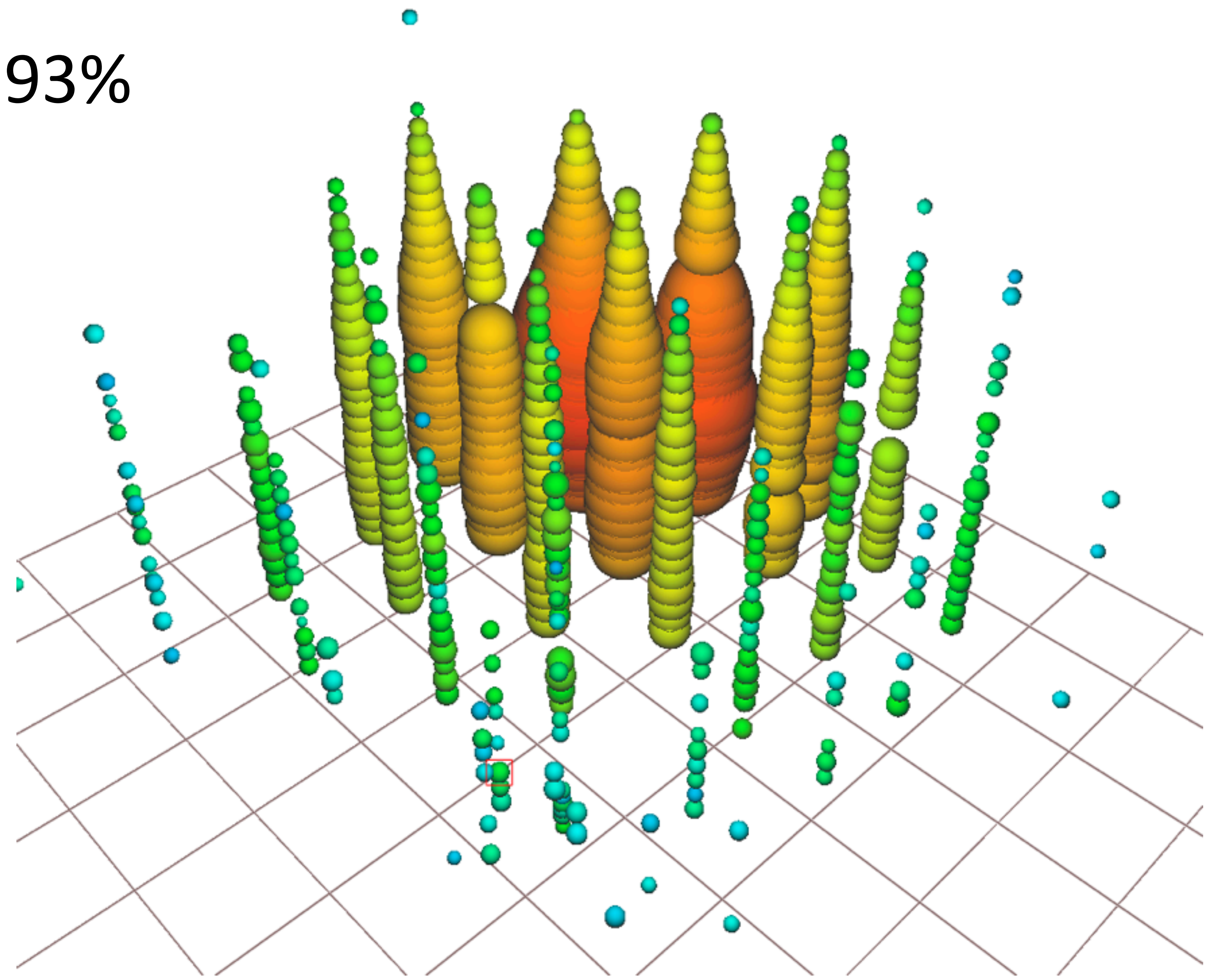
Observation of a 6 PeV neutrino



Resonance: E_ν = 6.3 PeV
Typical visible energy is 93%



Work in progress



Event identified in a partially-contained PeV search (PEPE)
Deposited energy: 5.9±0.18 PeV (stat only)
ICRC 2017 arXiv:1710.01191

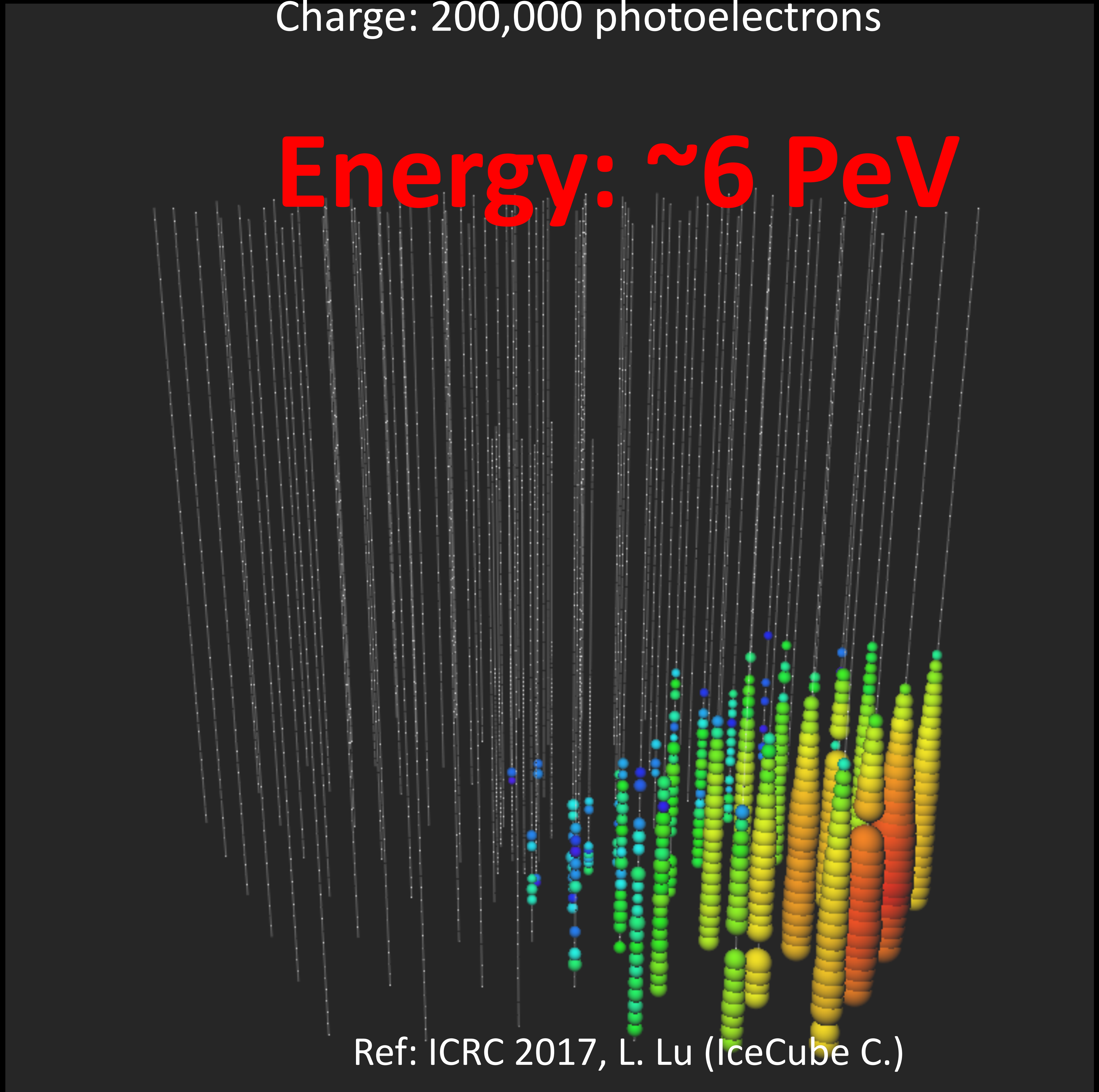
Slide courtesy: I. Taboada, Neutrino 2018

A neutrino event near Glashow resonance

Interesting event found in expanded search.

Charge: 200,000 photoelectrons

Energy: ~6 PeV



Ref: ICRC 2017, L. Lu (IceCube C.)

Energy resolution is critical

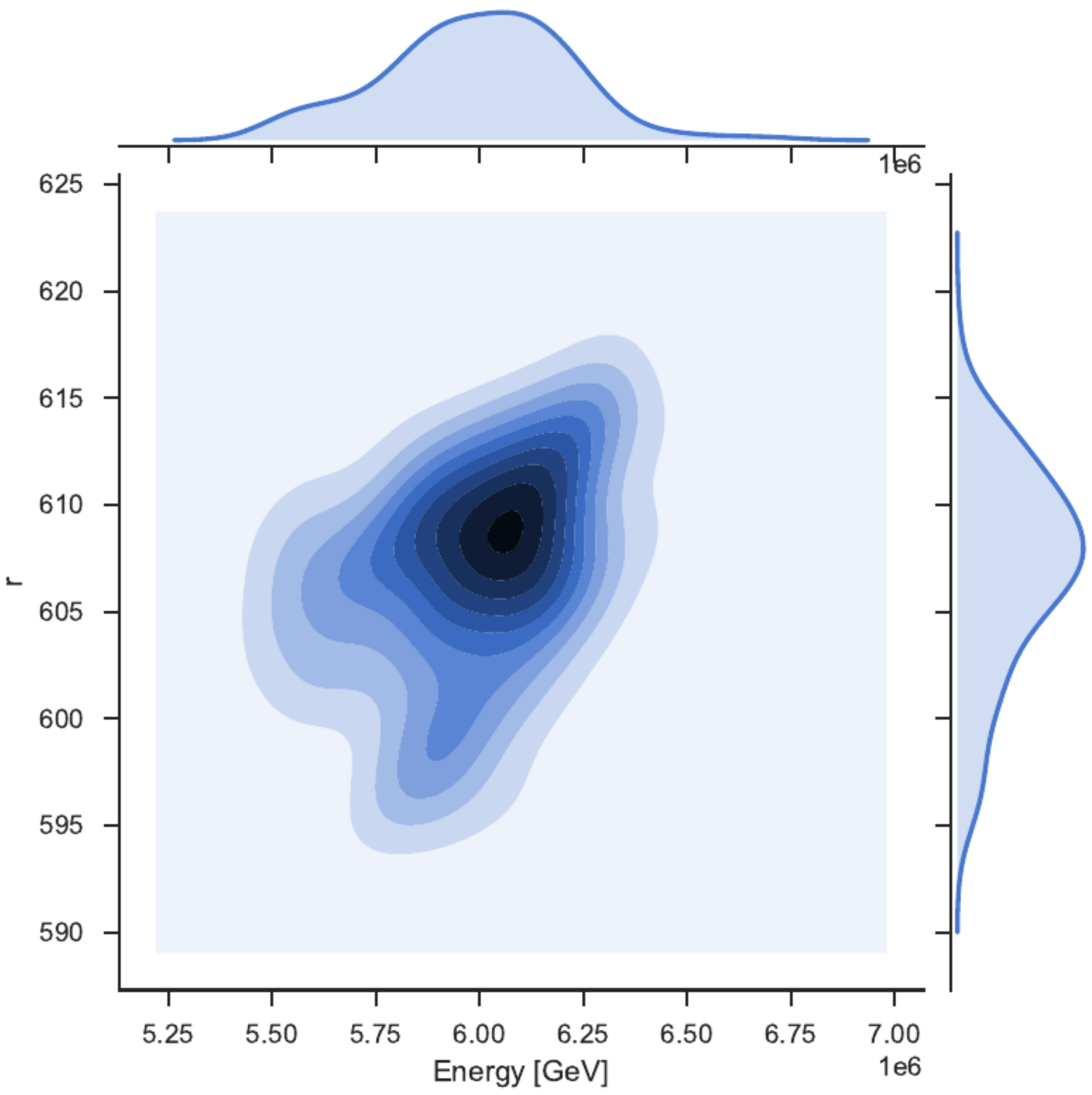
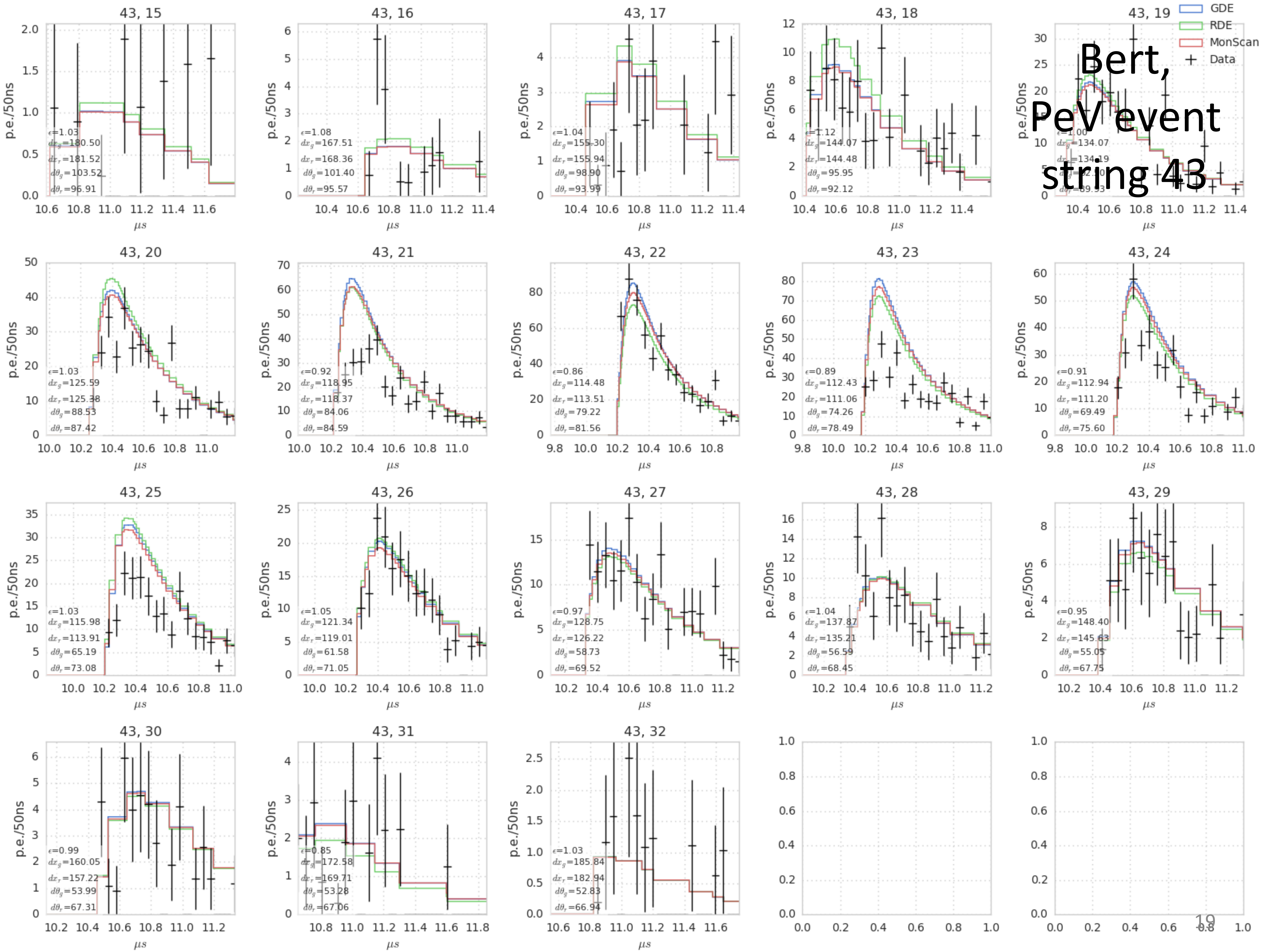
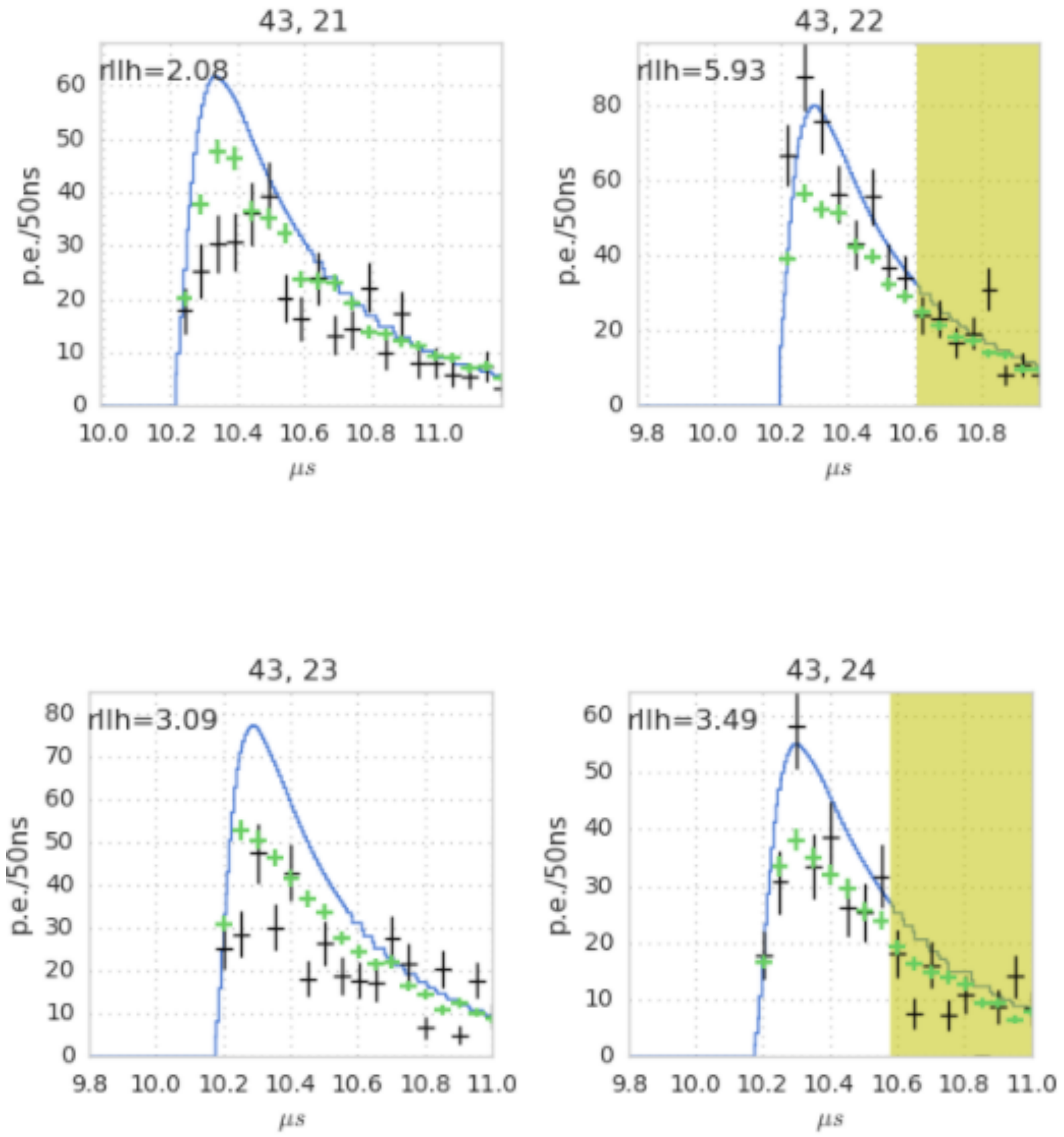


Figure from Tianlyu that shows
difference of
resolution with and without systematic errors.


Bert,
PeV event
string 43
GDE
RDE
MonScan
Data
43, 15
43, 16
43, 17
43, 18
43, 19
43, 20
43, 21
43, 22
43, 23
43, 24
43, 25
43, 26
43, 27
43, 28
43, 29
43, 30
43, 31
43, 32
p.e./50ns
μs

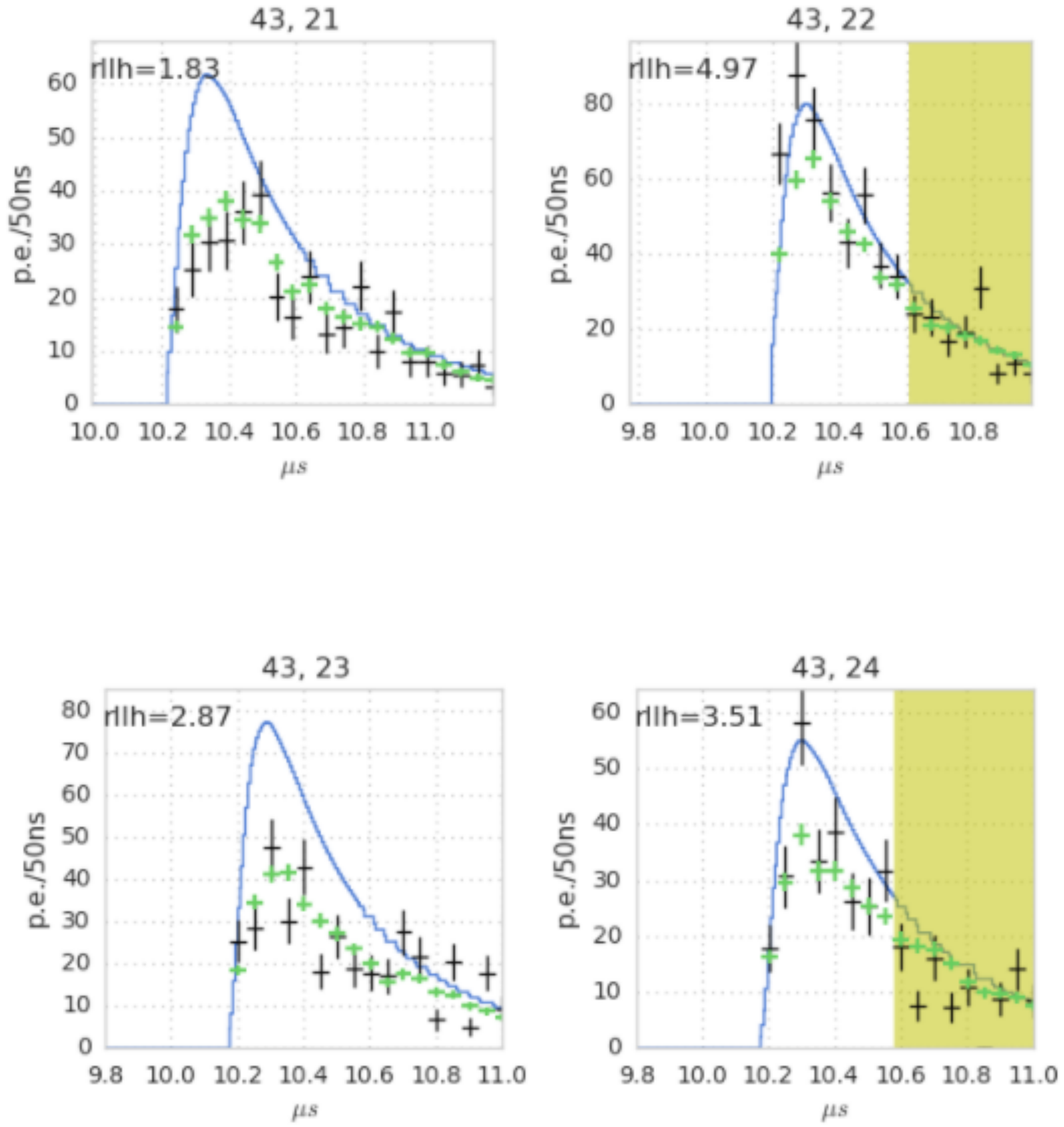
Local effects: DOM orientation and cable position

Without local effects



With local effects

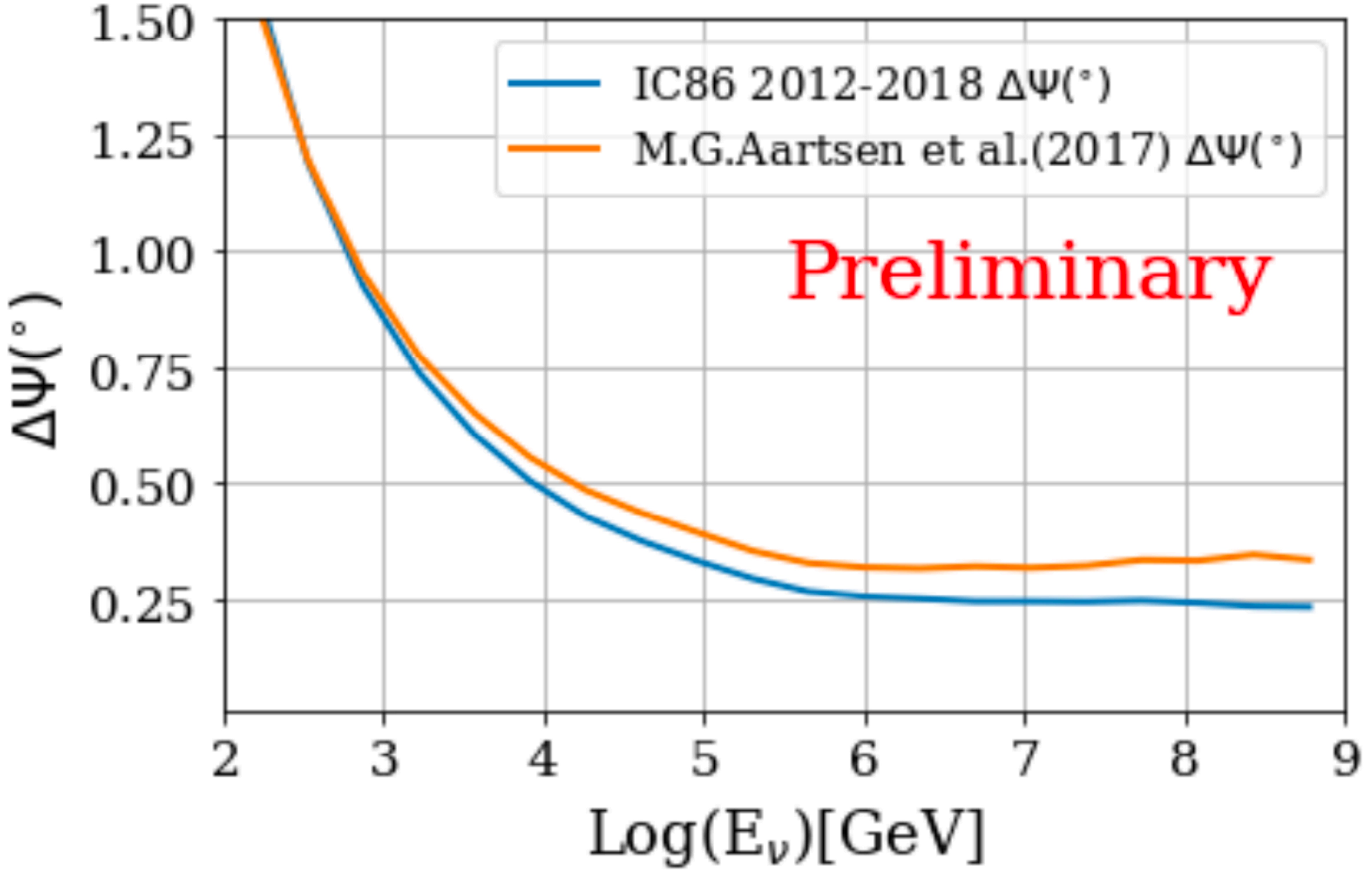
Bert data
Direct photon MC
Effective photon MC



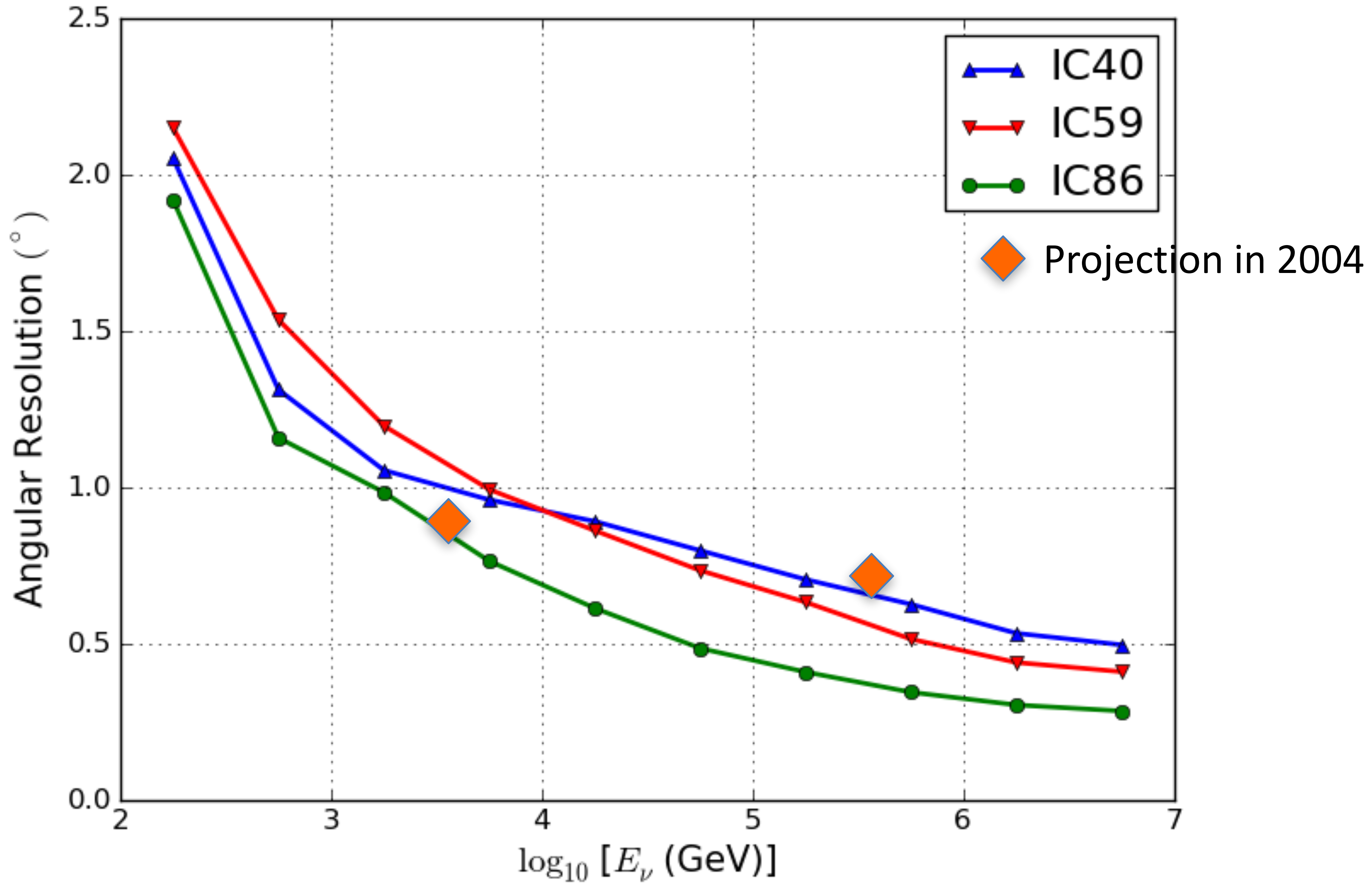
Higher level performance parameters

Angular resolution for muon neutrinos

2019



2011



Moon shadow

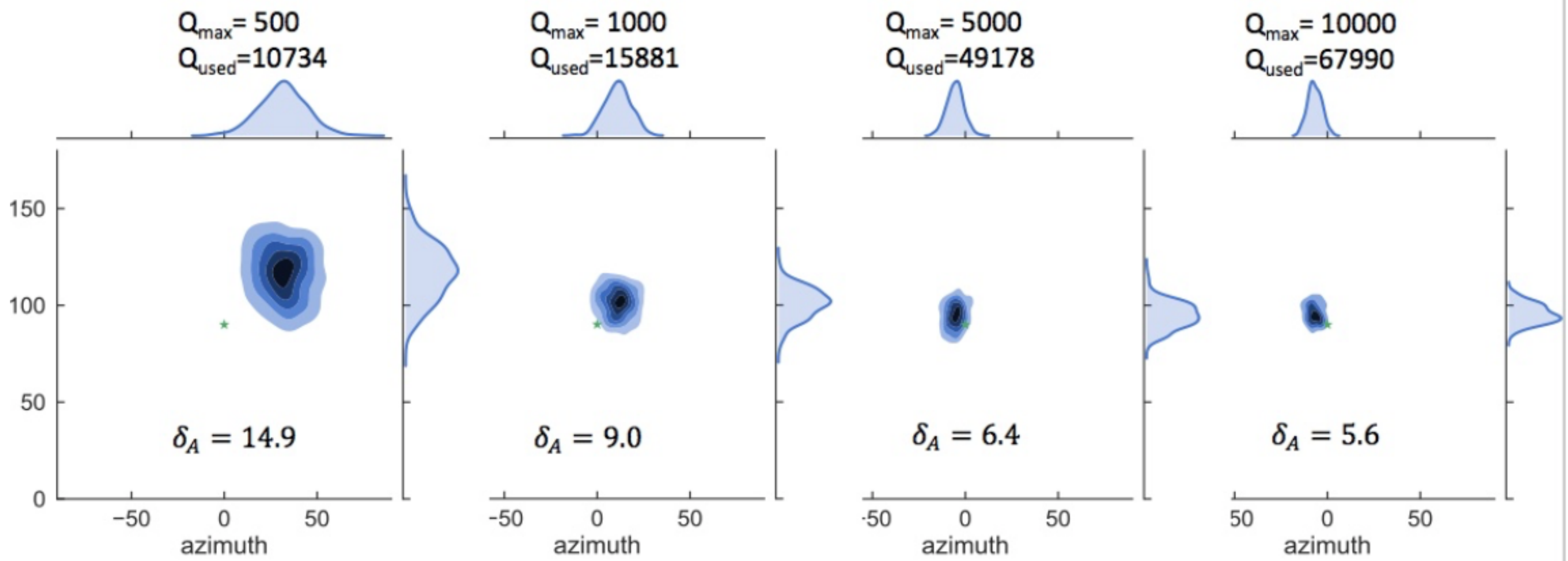
Angular resolution for muon neutrinos

Simulated cascade

Bright DOMs: Q > 10*Q_{avg}

DirectFit (Dima) reconstructing data events with direct photon simulation with ppc.

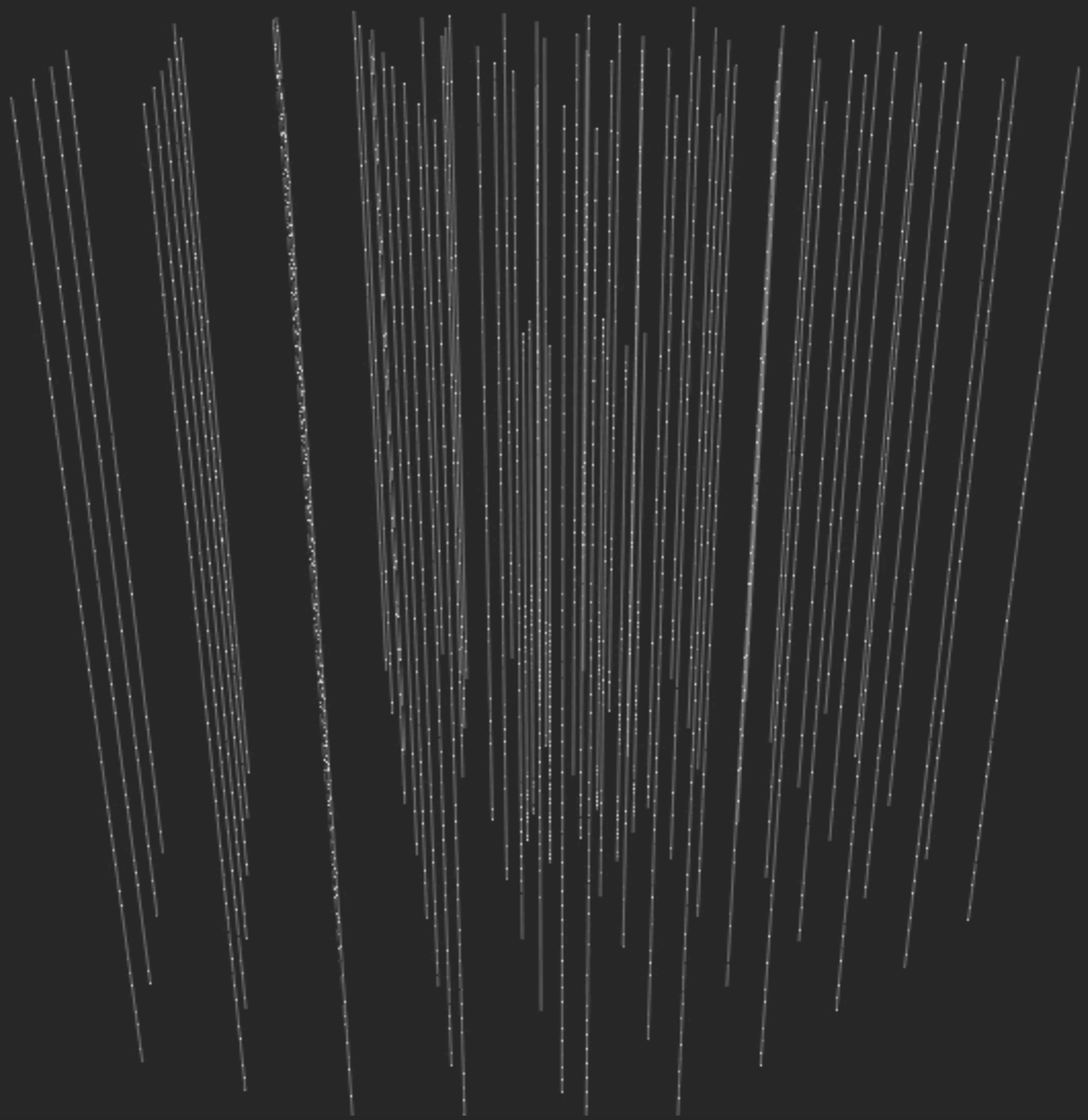
PeV-cascade: (Sim: 3.2, Reco: Mie)



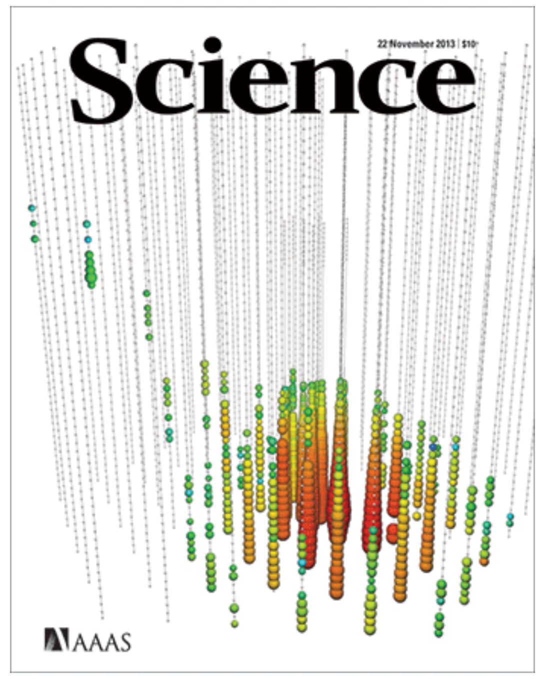
Angular resolution improves with increased values of total charge used and maximum charge per DOM

-> see Tianlu Yuan talk

Starting muon
“Dr. Strangepork”
contained vertex,
Deposited energy: 7

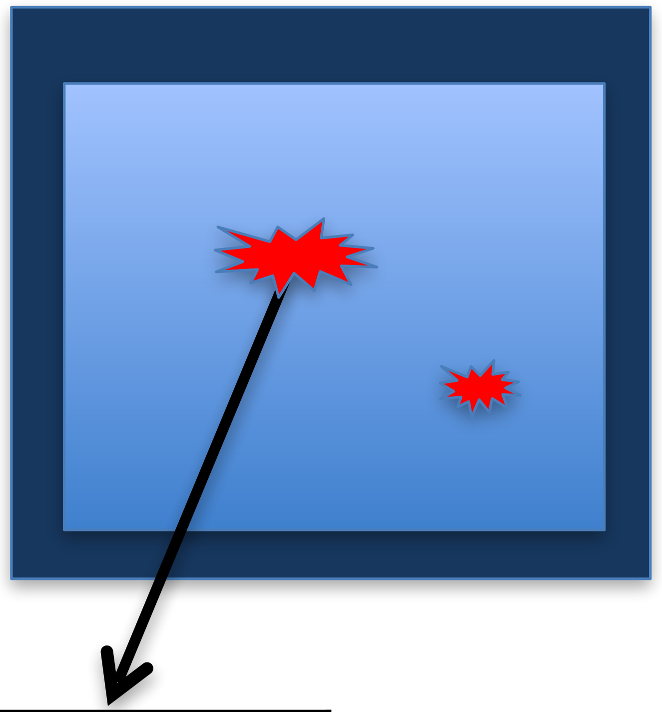


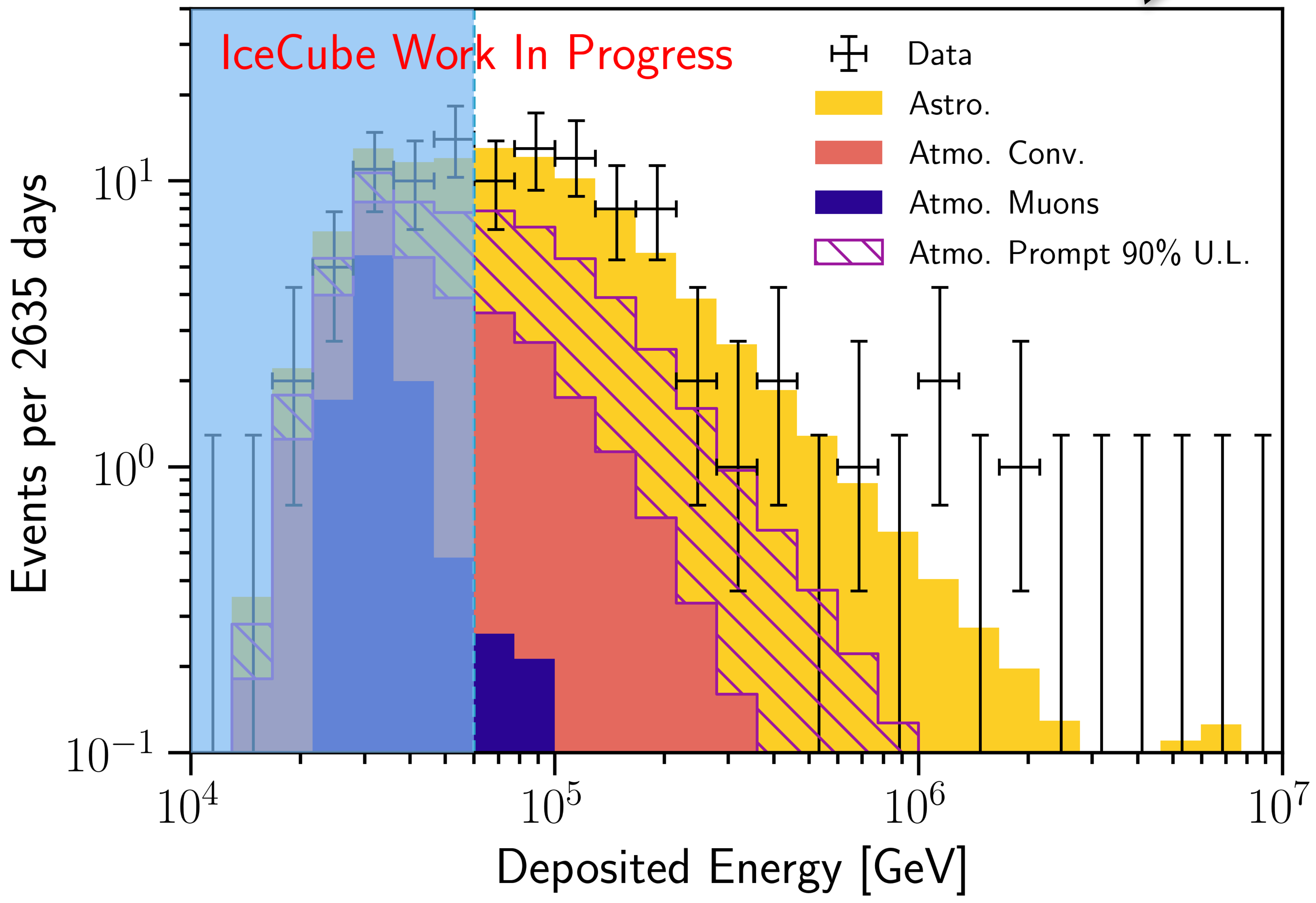
Milestone 2013: Discovery of diffuse cosmic neutrino flux



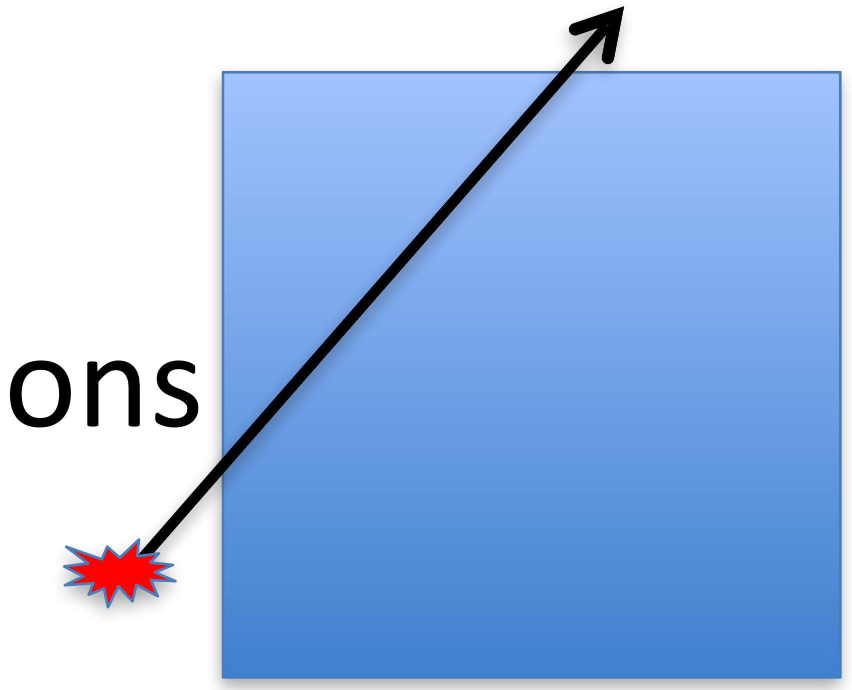
Initially with 2 - 3 years of data

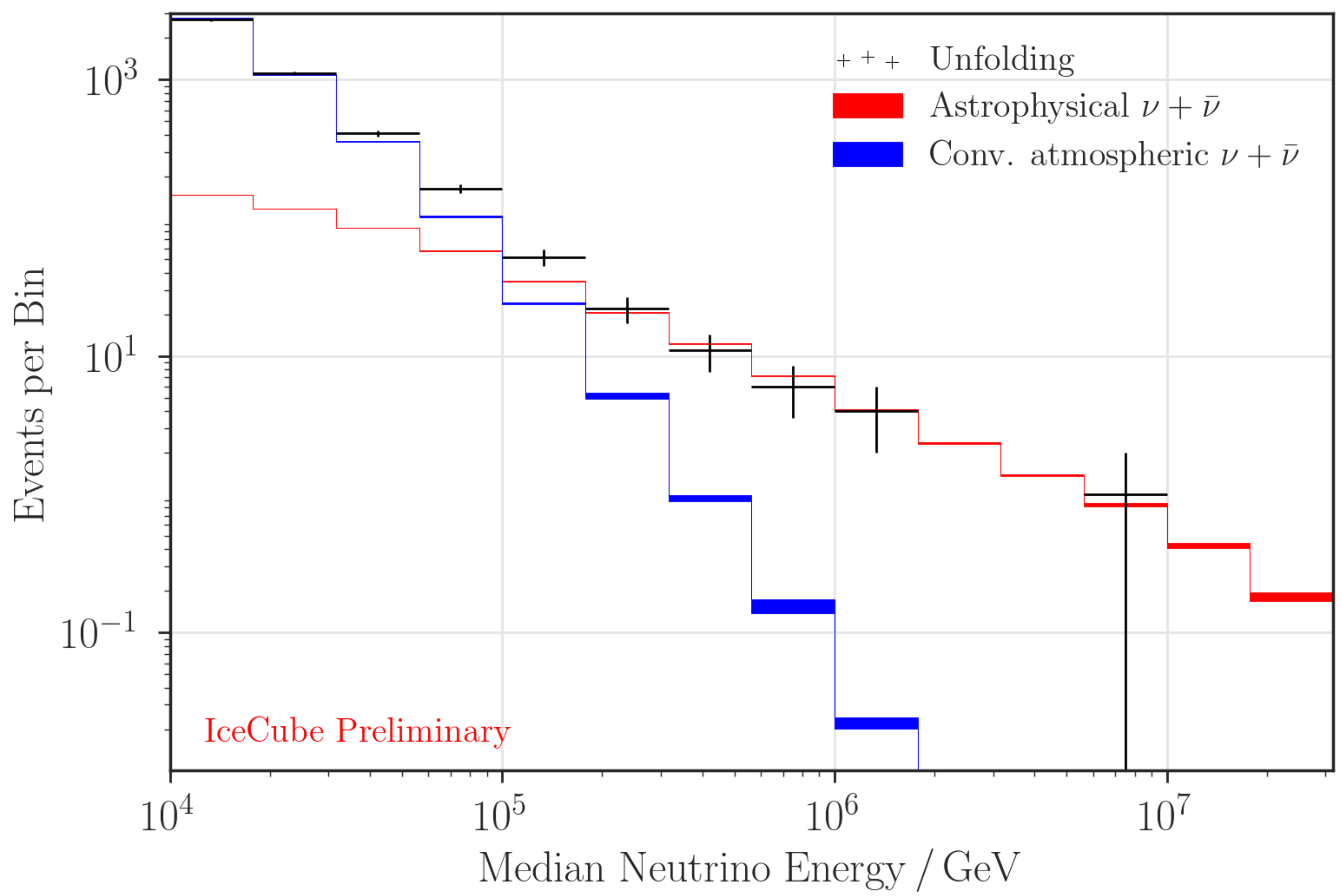
Contained vertex events
7 years of data





Through and upgoing muons
8 years of data





R&D

- R&D related to M&O and continued optimization of IceCube proper
  - Surface instrumentation
  - SpiceCore
- R&D geared towards the future: Upgrade and Gen2
  - Detector R&D, new optical modules

Science case

Snow attenuation mitigation:

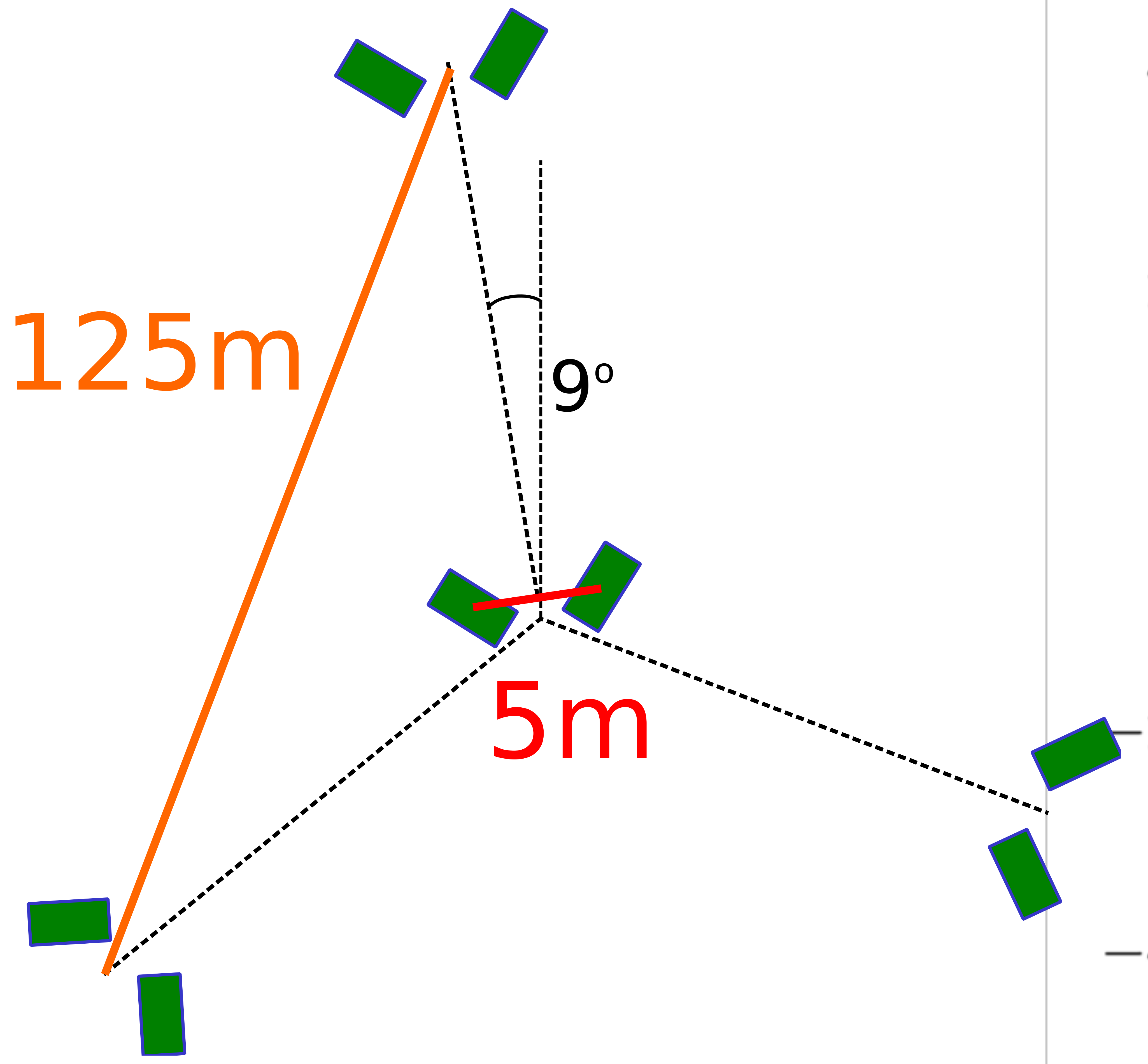
- Measure the effect of snow on IceTop tank sensitivity, binned by energy, zenith, and radial distance from shower core.
- Recover the sensitivity to low-energy showers that are currently not detected by tanks buried under several feet of snow.

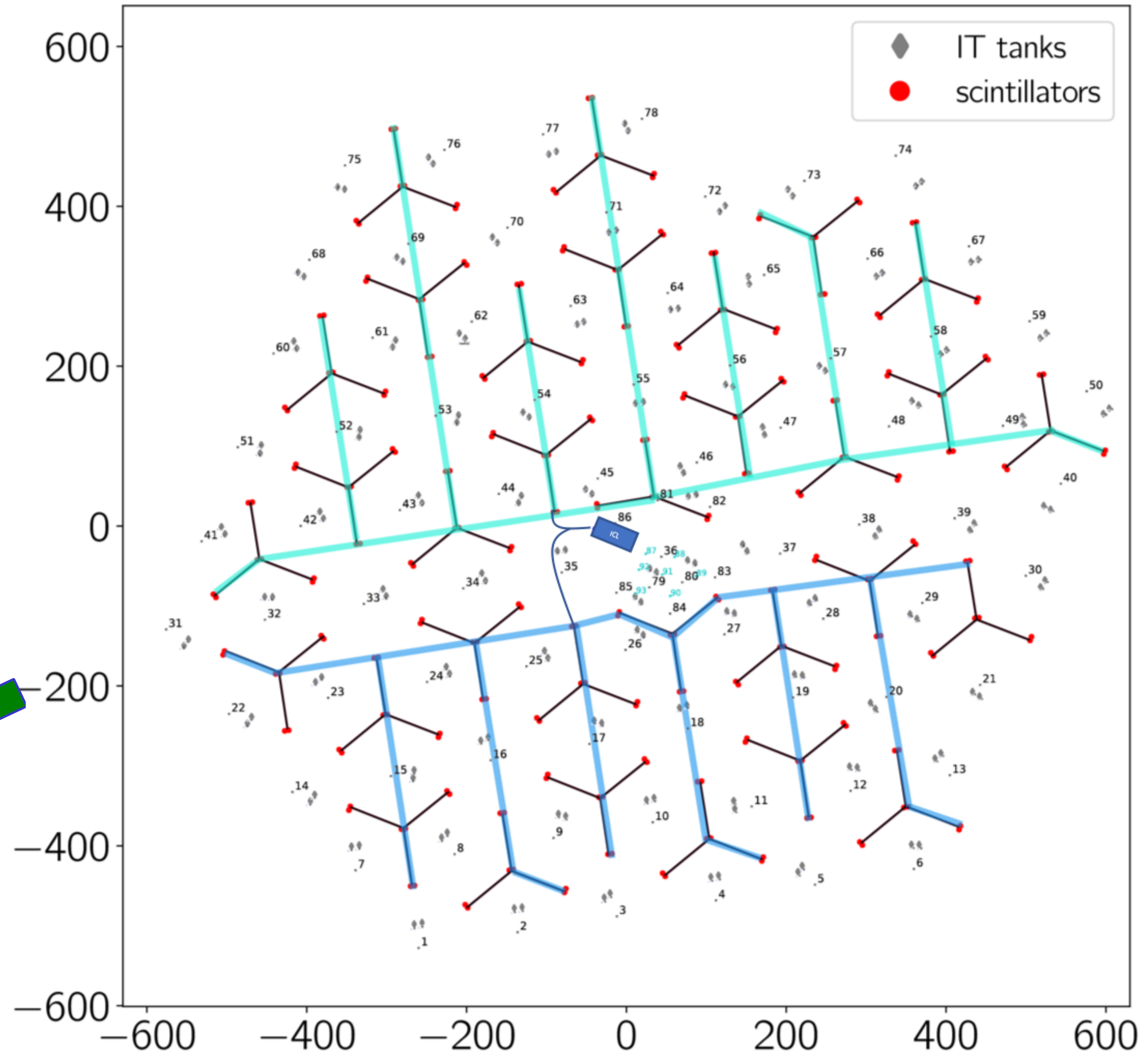
Veto efficiency improvement:

- By adding scintillators with a similar coverage as IceTop, the energy threshold at which the veto becomes efficient at a 10^4 to 10^5 rejection factor is estimated to be lower by a factor of two.

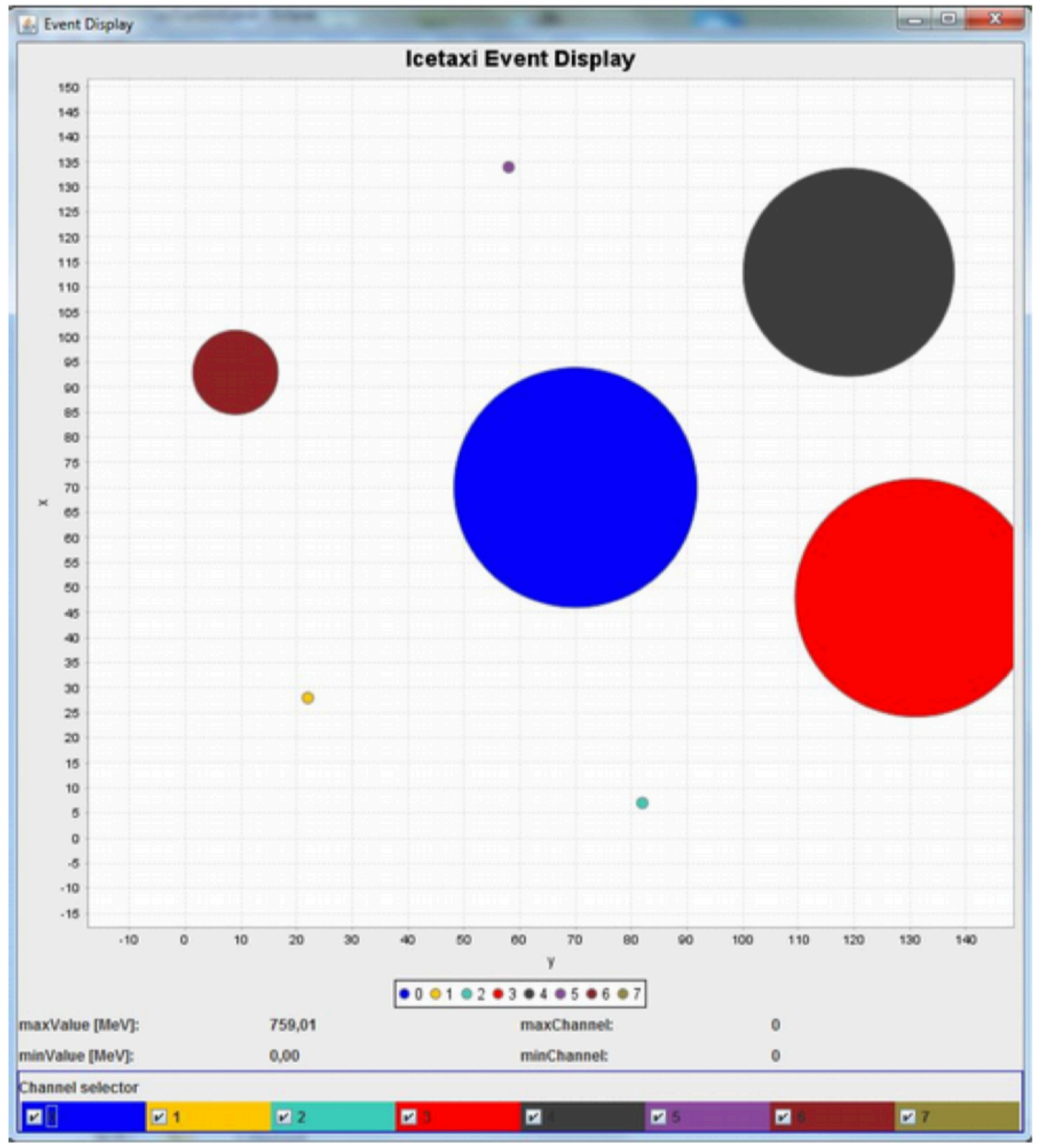
R&D for future detector upgrades:

- A new, scalable precision timing and high-speed communications scheme for IceCube M&O and possible future projects.
- Efficient trenching procedures for instrumentation installation.
- Mechanical solutions to raise scintillator panels above the snow during the period of array deployment.

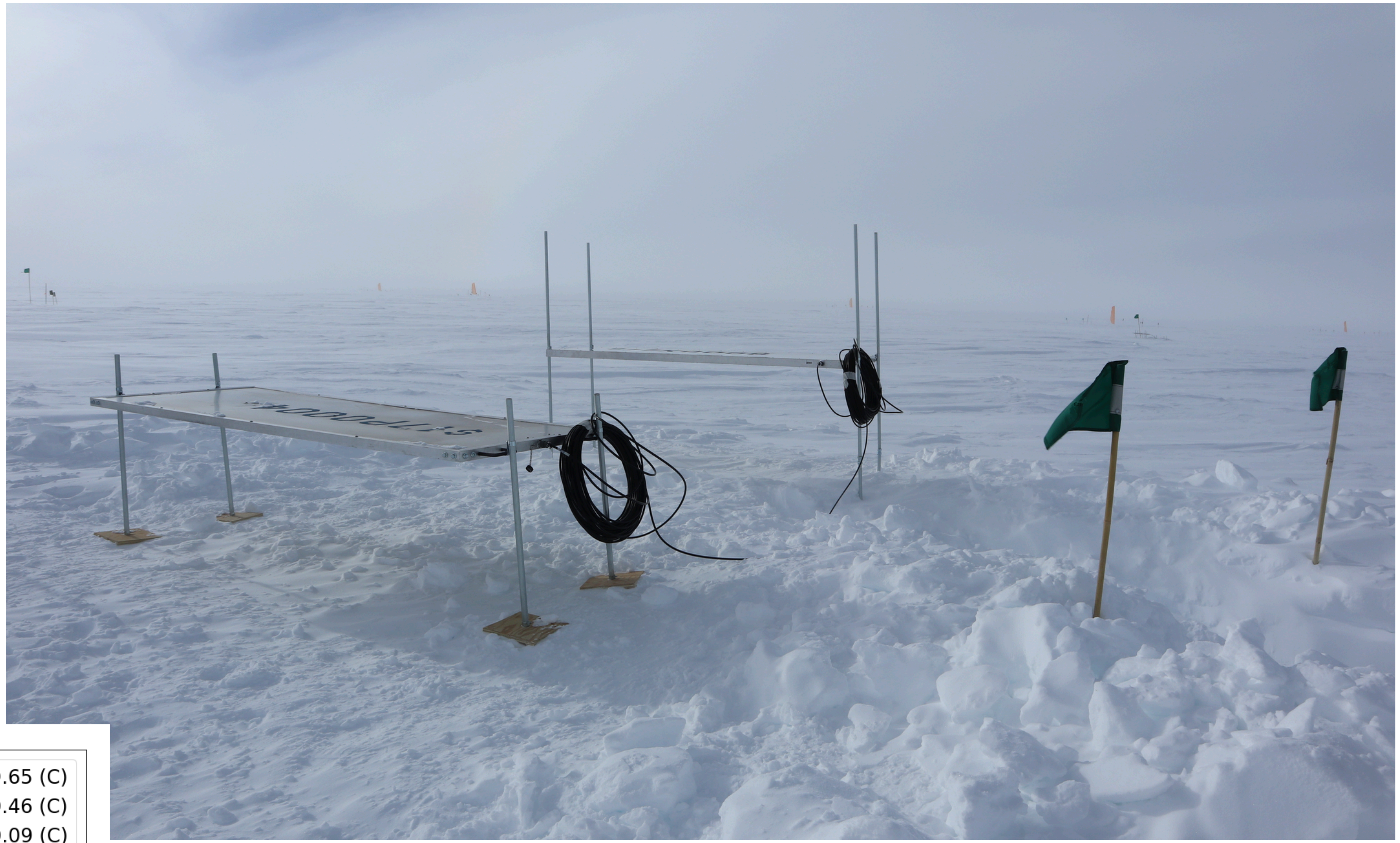

125m
9°
5m

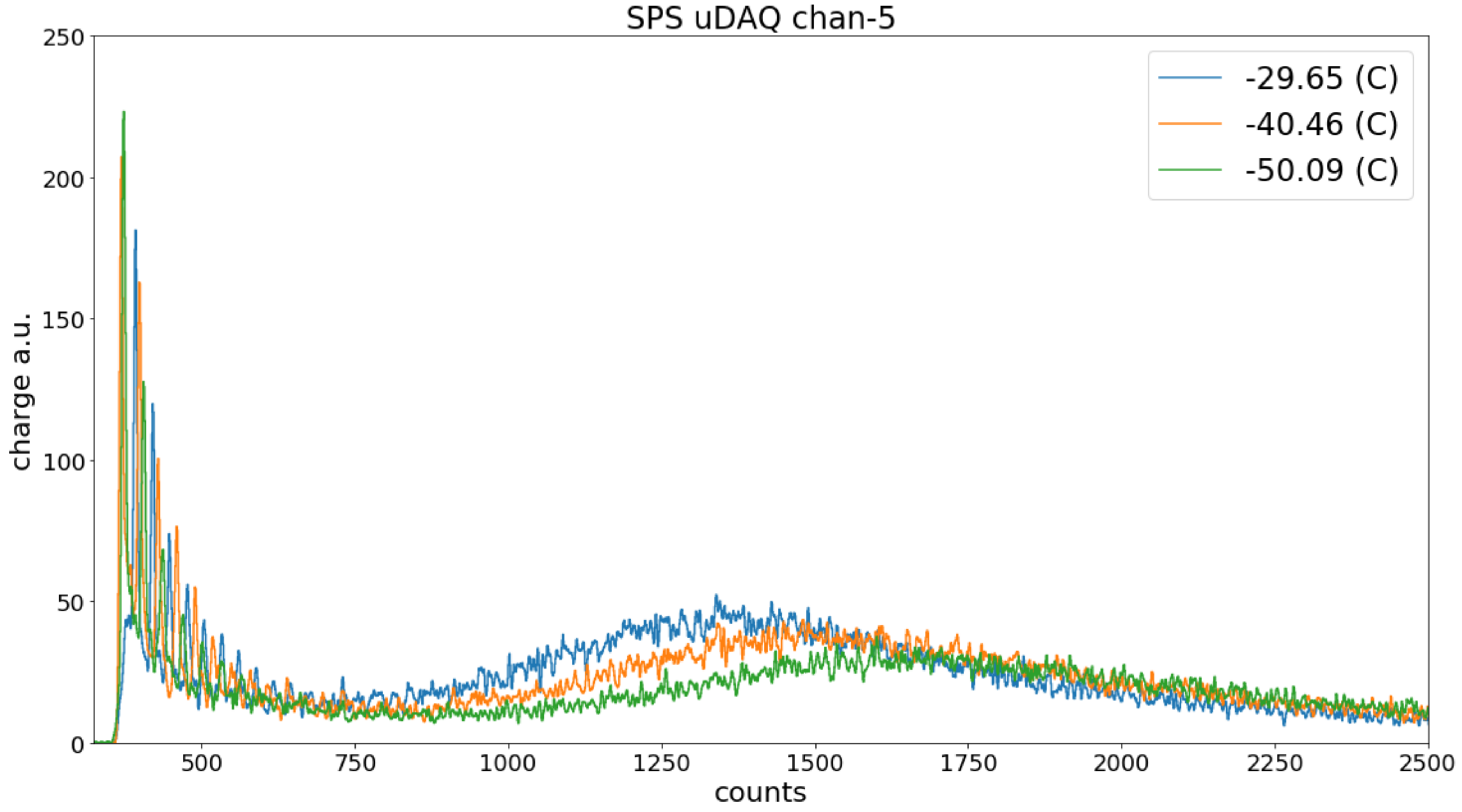

IT tanks
scintillators
600
400
200
0
−200
−400
−600
−600
−400
−200
0
200
400
600

→ Position Y (m)



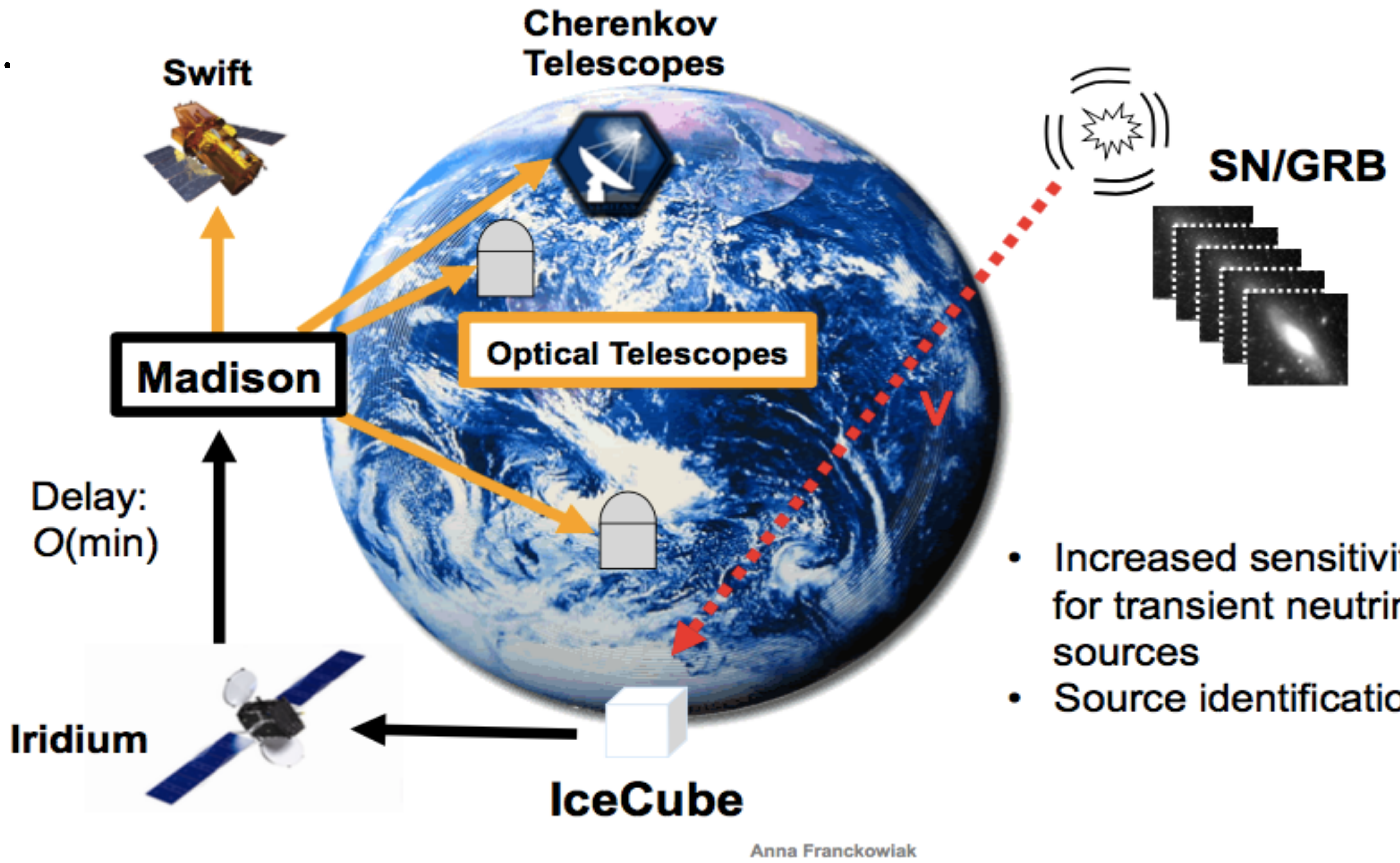
→ Position X (m)





Multimessenger astronomy in real time - flares
Implementation of efficient realtime system online

Technical progress:
TXS alert published 43 seconds after interaction.



- Increased sensitivity for transient neutrino sources
- Source identification

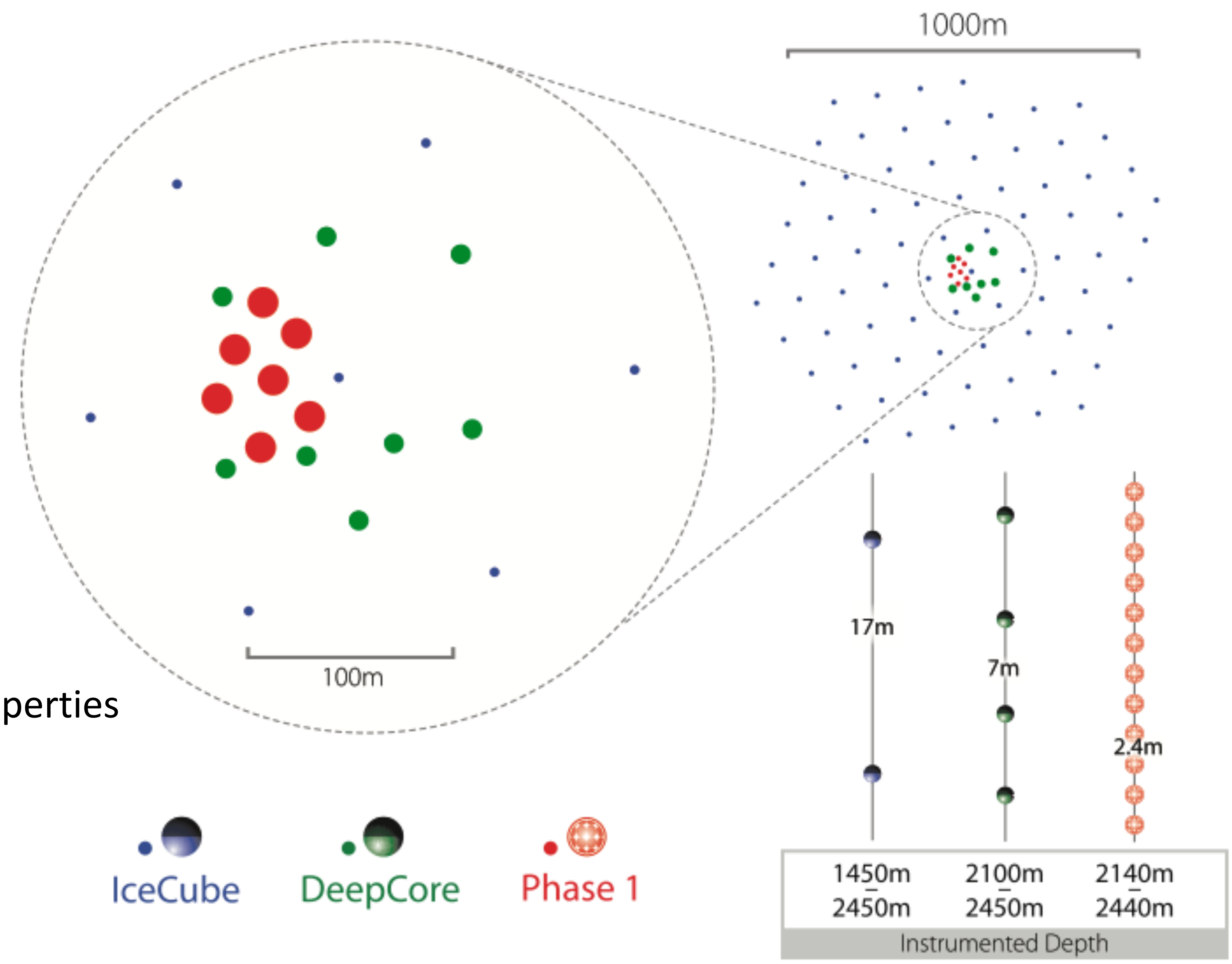
IceCube Upgrade (a step towards Gen2)

Funded.

7 strings in center of IceCube, densely instrumented

Science goals:

- ν_μ disappearance
- ν_τ appearance
- Precise calibration of IceCube optical properties and DOM response



A big step towards IceCube-Gen2

Slide on sensor development

IceCube-Gen2

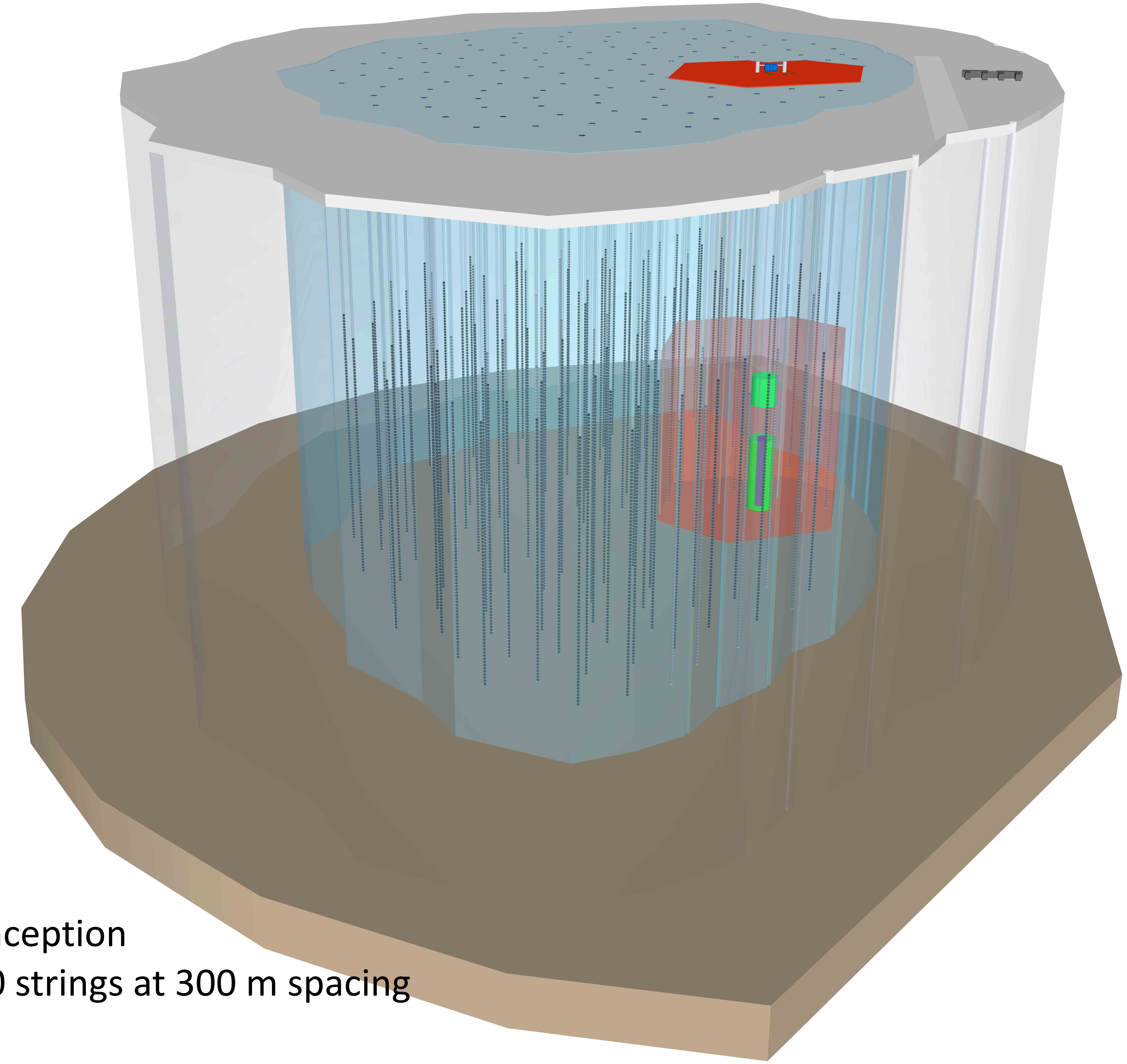
The next Generation IceCube: from discovery to astronomy

Multi-component observatory:
- IceCube-Gen2 High-Energy Array
- Surface air shower detector
- Sub-surface radio detector

Surface Area: ~6.5km² (0.9)
Instrumented depth: 1.26 km (1.0)

Instrumented Volume: 8 km³

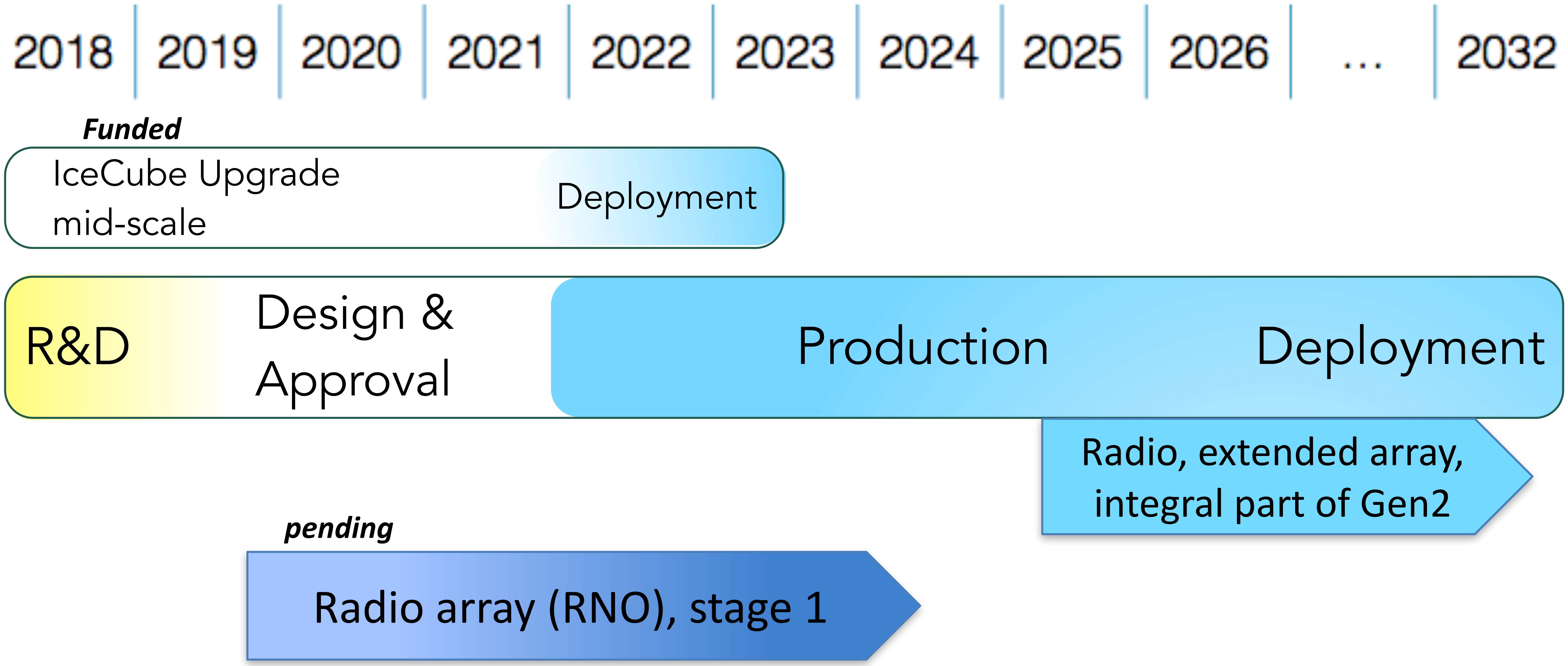
Order of magnitude increase of contained event rate at high energies.



Artist conception
Here: 120 strings at 300 m spacing

summary slide on Gen 2 sensitivity

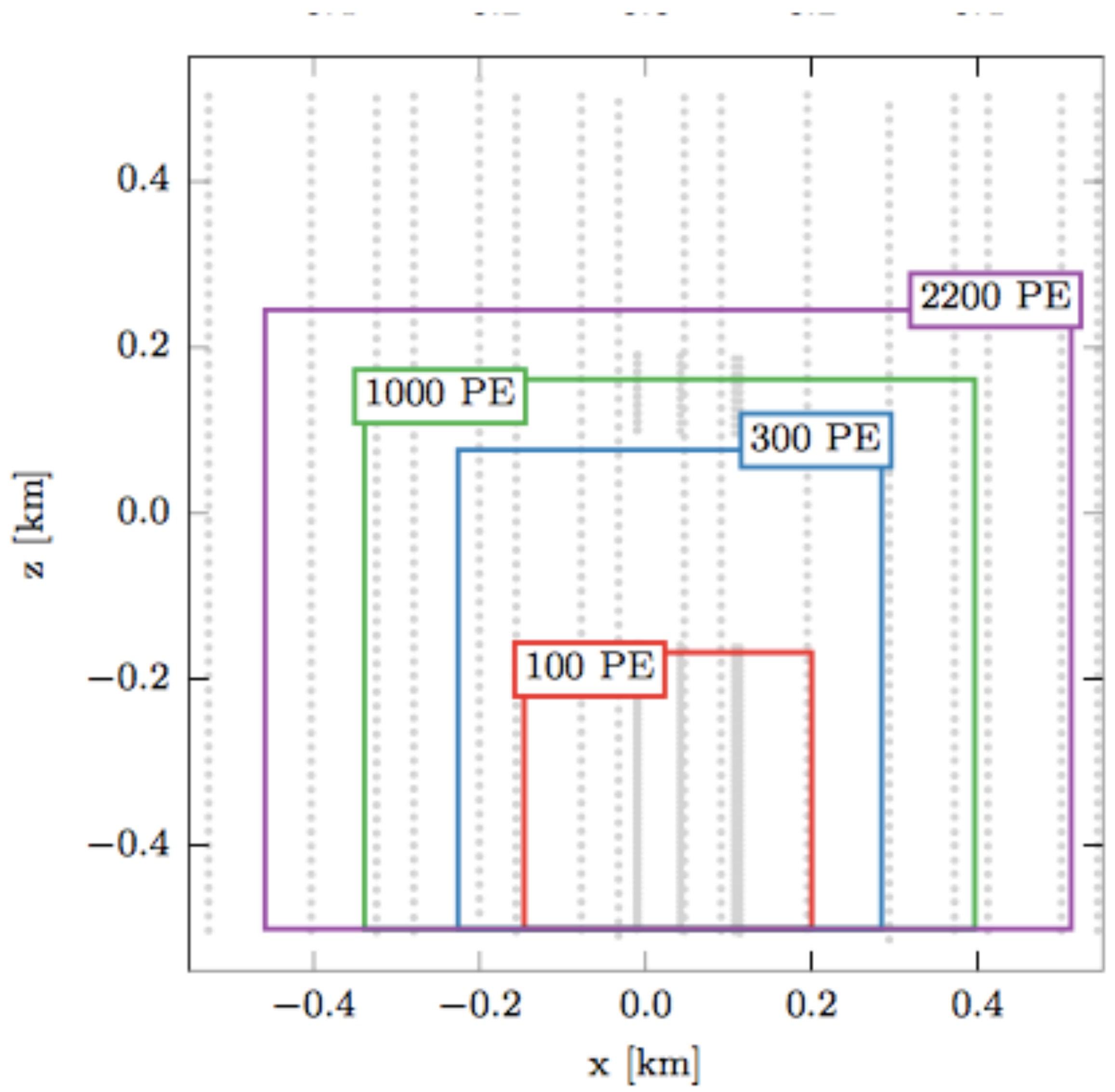
IceCube Gen2 schedule




Thank you!
ICECUBE
DETECTOR COMPLETION
Grad School is Awesome!!

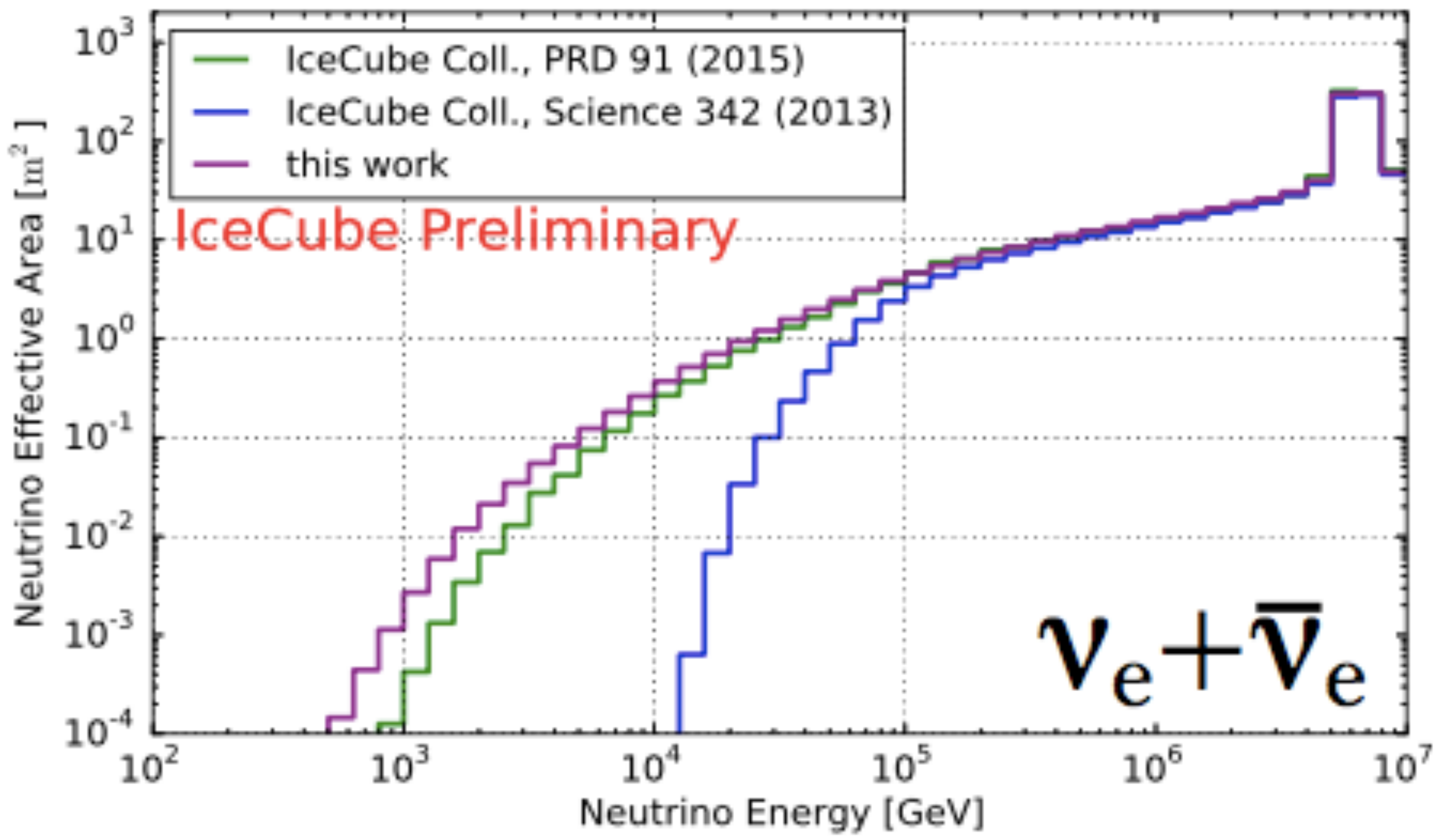
New event selections “below” HESE and throughgoing muons…

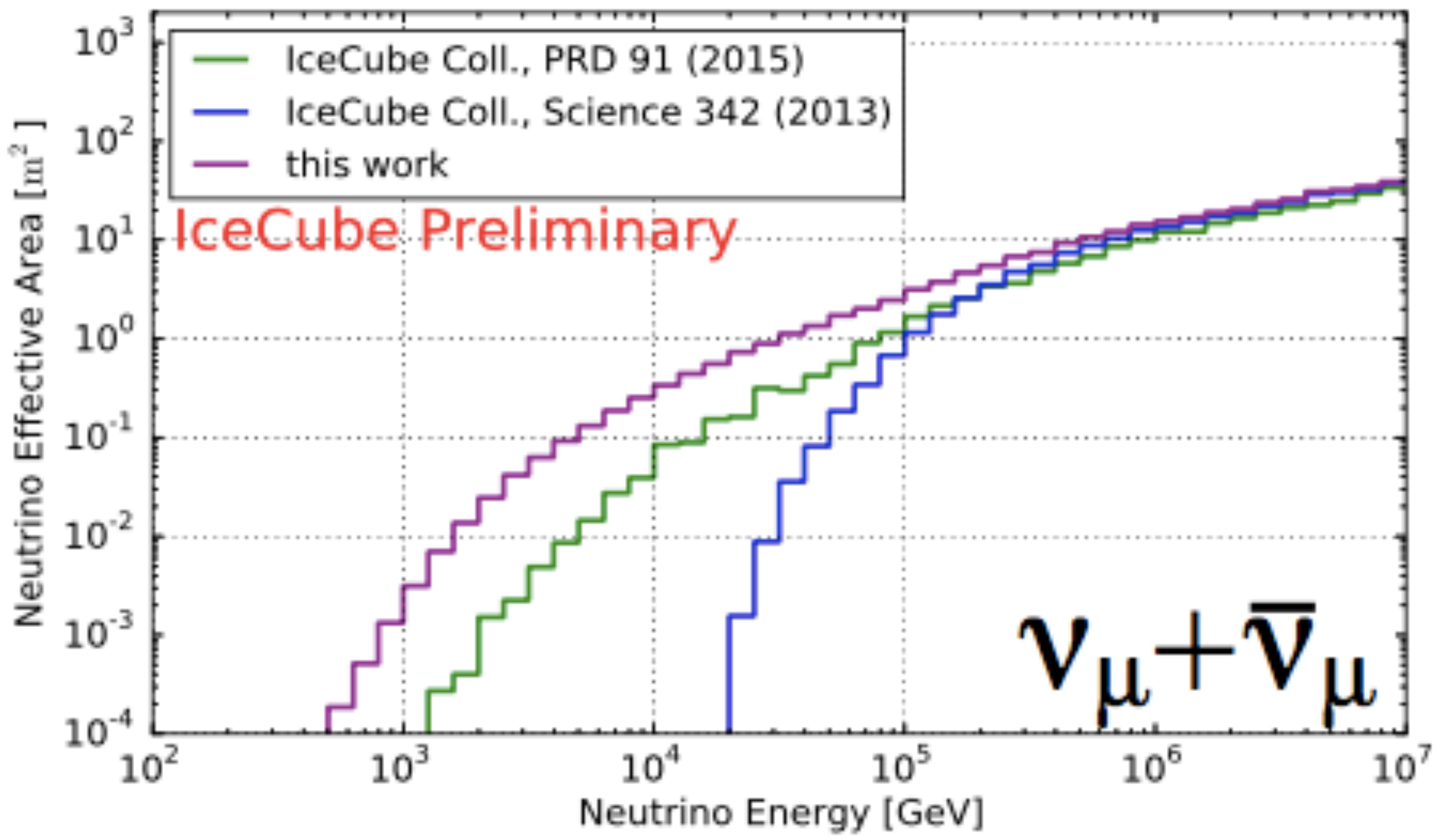
From High to Medium energy: Part 1 - MESE



Follow-up analysis to arxiv.org/1410.1749

- 2 years → 7 years
- and optimized





From High to Medium energy:

Low-threshold

14

7-yr unfolding

et!

- Unfolding to ne
  - assume isotropic
  - compatible with tl