INSTRUMENTATION FOR THE SCINTILLATOR UPGRADE OF ICETOP

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ICASiPM 2018

WIPAC
Wisconsin IceCube
Particle Astrophysics Center

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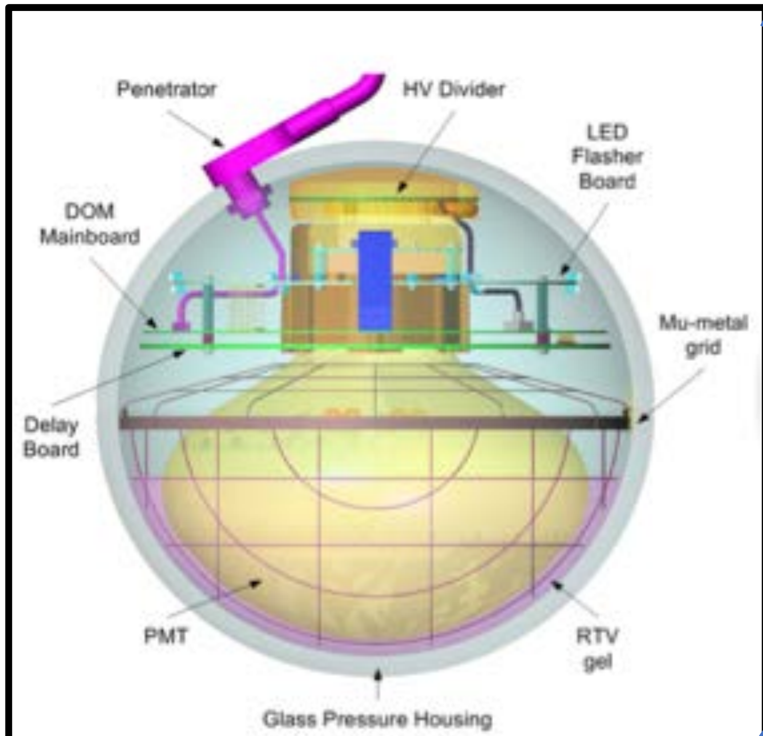
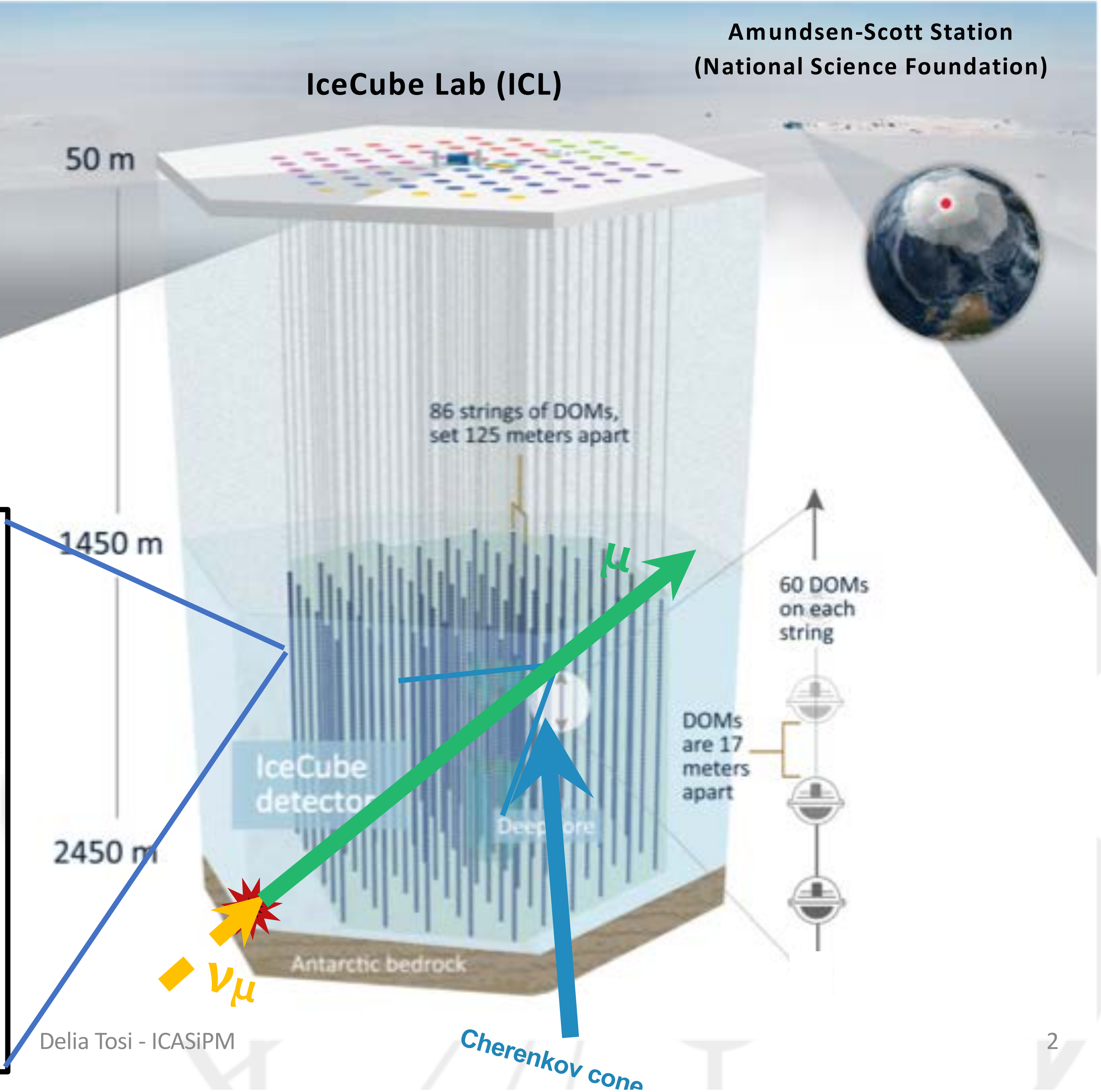
IceCube

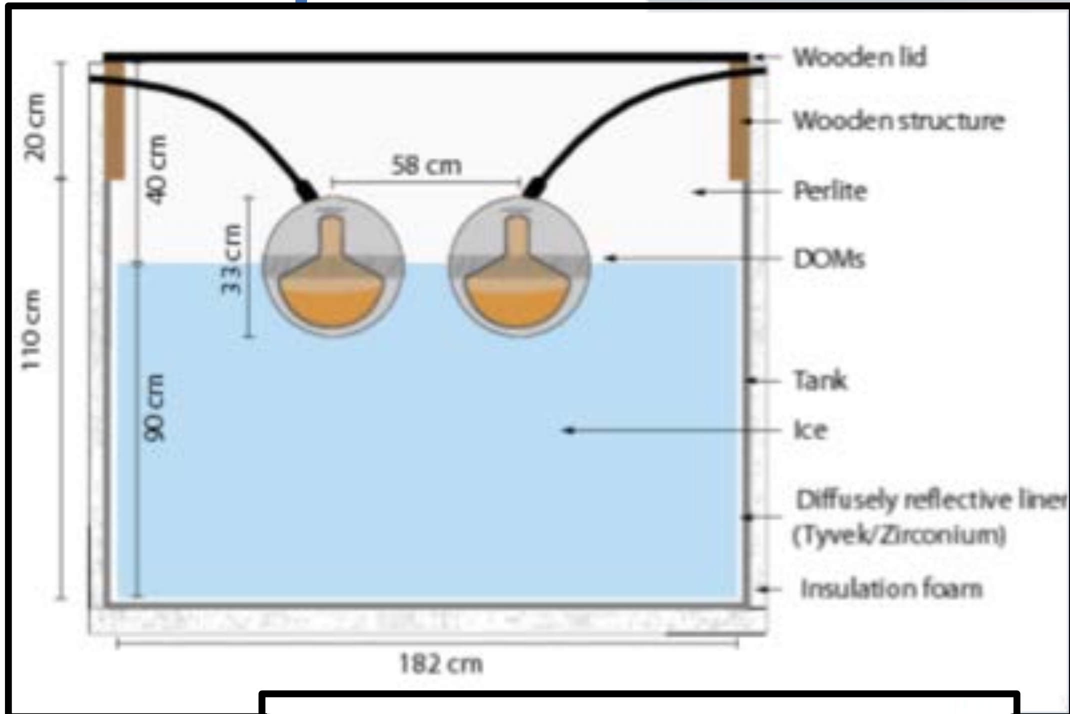
Digital Optical Module (DOM)

with 10" PMT
&
local DAQ electronics

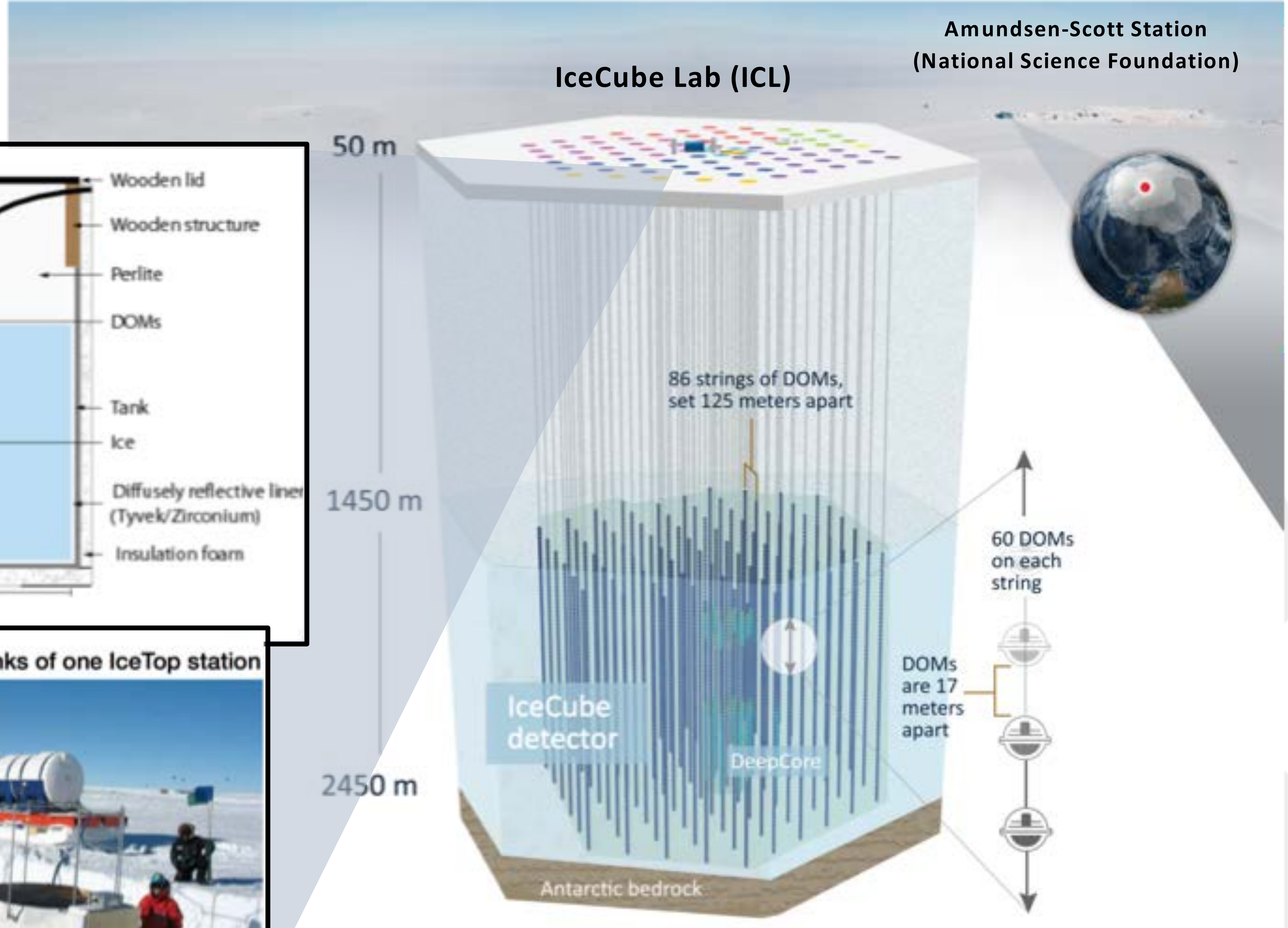




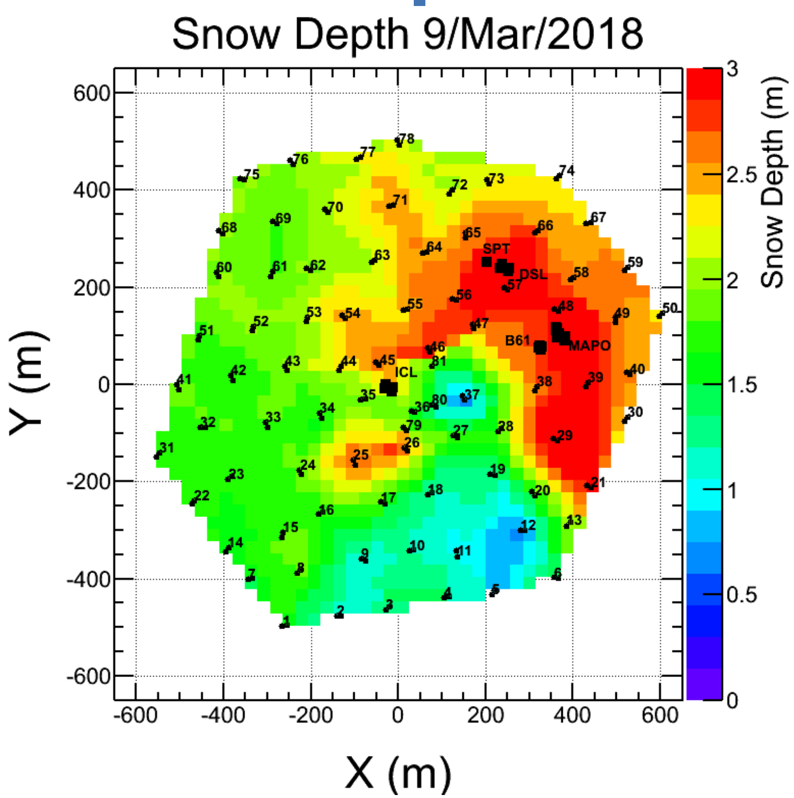
IceTop

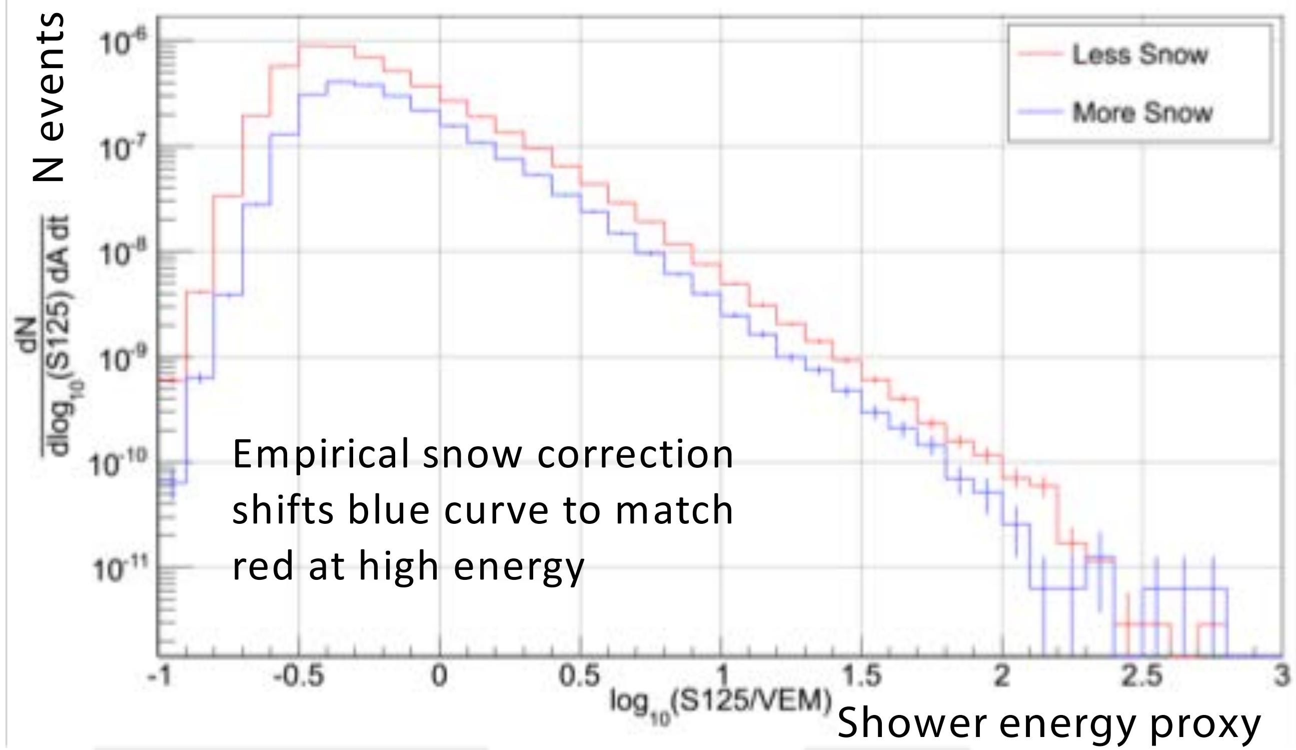


two tanks of one IceTop station



Snow depth & effects





Snow accumulates on top of IceTop tanks at an average rate of 20 cm/year.

- >70% tanks are under 2 meters of snow or more.

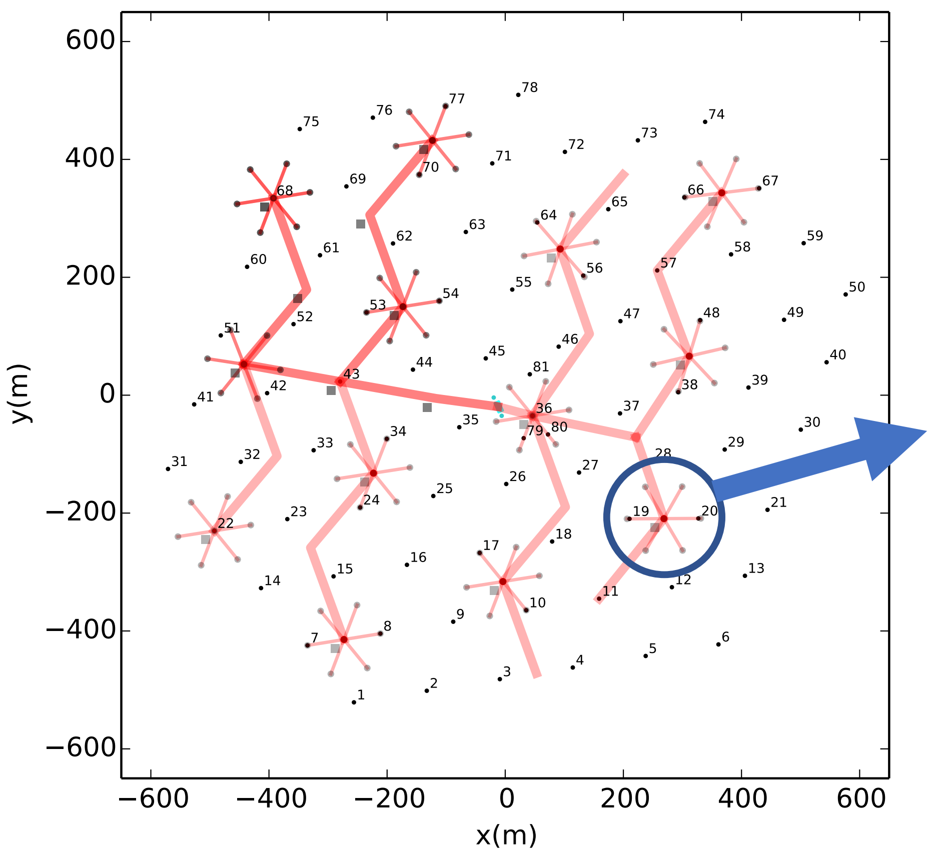
⇢ Sensitivity to low energy showers is reduced

⇢ Uncertainty affects a number of physics analyses

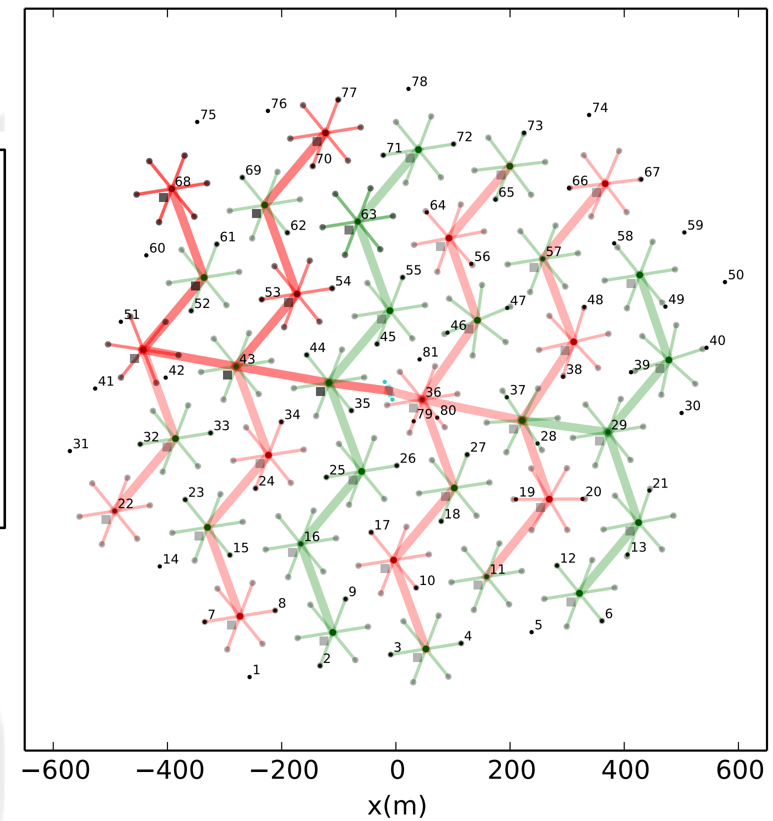
The Scintillator Upgrade of IceTop

Reduce snow -derived systematic uncertainty
Improve sensitivity to low energy showers

phase 1: sparser array → high energy showers



phase 2: denser array → low energy showers



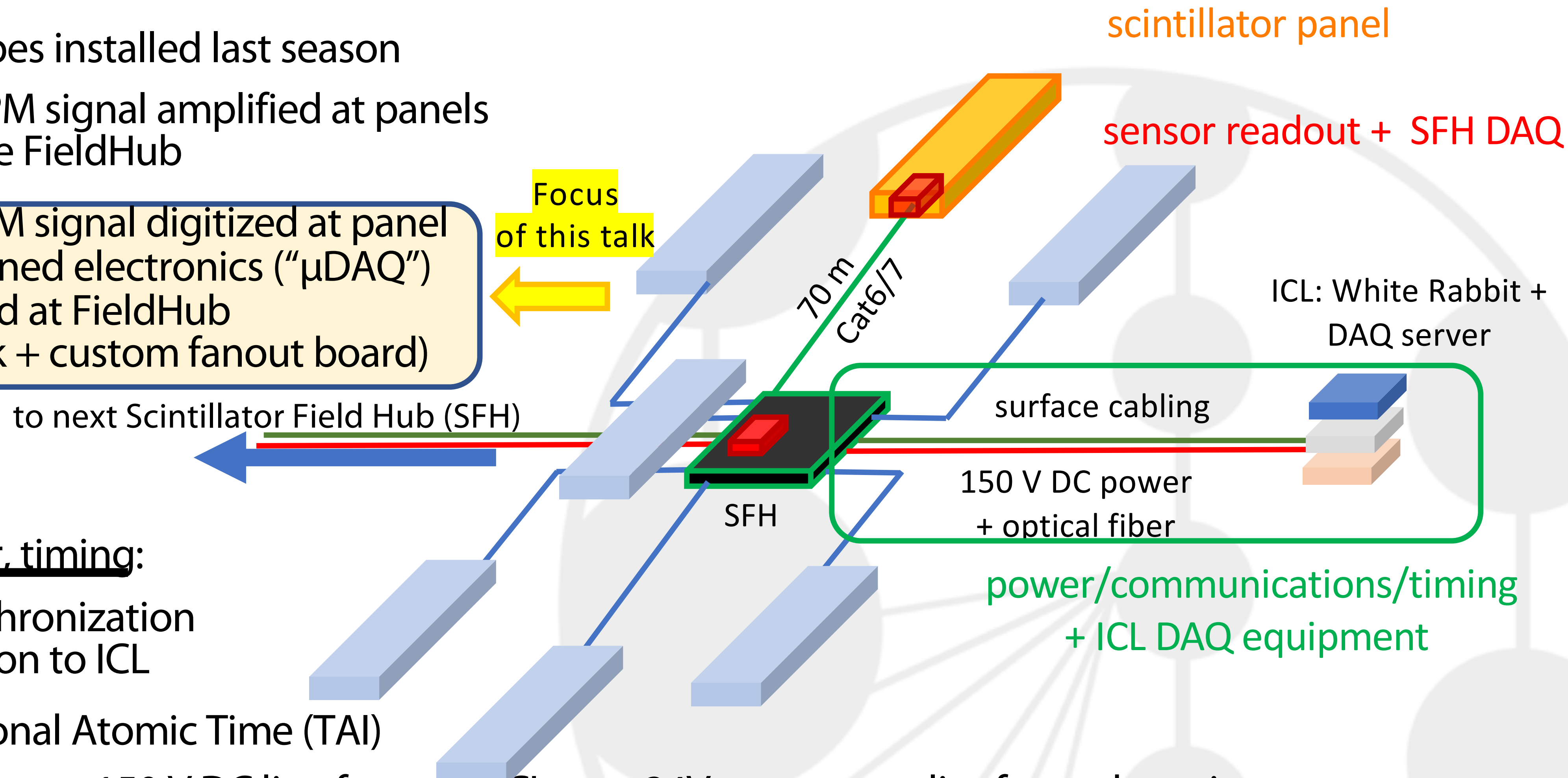
<u>Station:</u>
7 scintillator detectors (panels)
1 "FieldHub"

- 276 x 1.5 m² panels
- homogenous coverage at the end of each phase
- distance between panels 62.5m
- coverage similar to IceTop
- panels will be raised

Scintillator Station

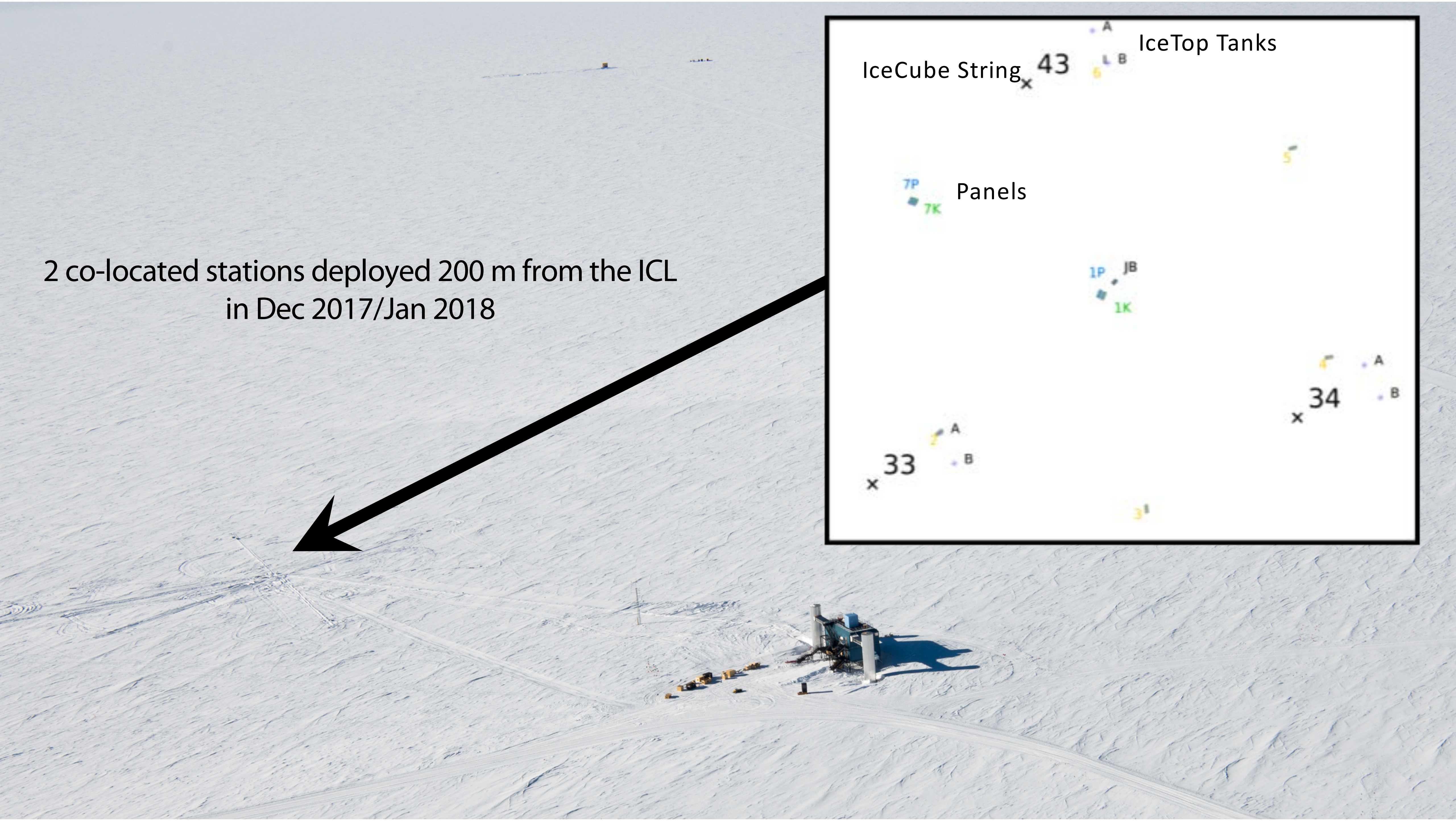
Two station prototypes installed last season

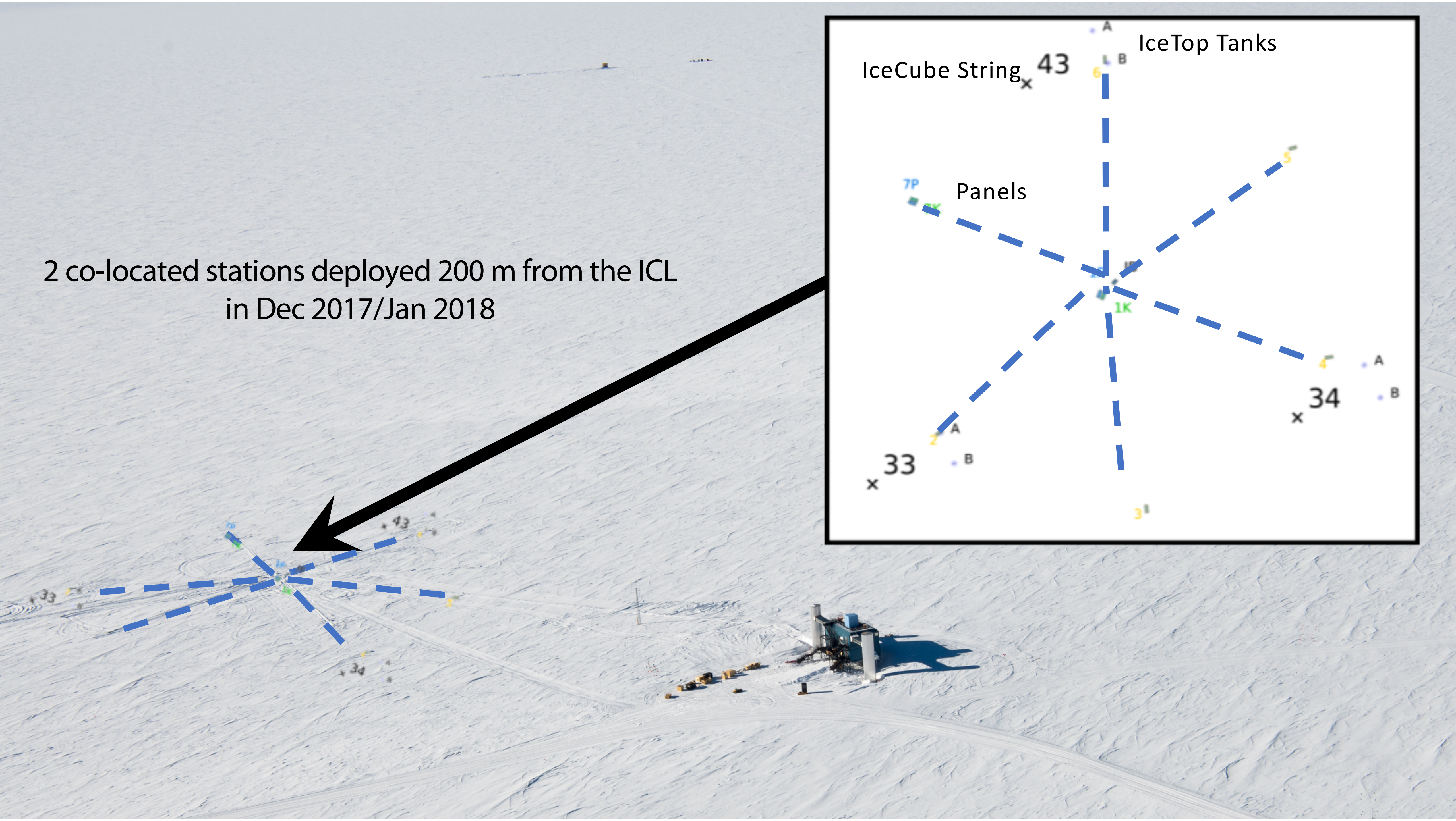
- Analog station: SiPM signal amplified at panels and digitized in the FieldHub
- Digital station: SiPM signal digitized at panel with custom designed electronics ("μDAQ") Signals multiplexed at FieldHub (Beagle Bone Black + custom fanout board)



Same comms, power, timing:

- White Rabbit Synchronization and fiber connection to ICL
- Clock on International Atomic Time (TAI)
- Power distribution: one 150 V DC line from the ICL, two 24V power supplies for each station.


2 co-located stations deployed 200 m from the ICL
in Dec 2017/Jan 2018
IceTop Tanks
IceCube String
43
Panels
7P
7K
1P
JB
1K
34
33
A
B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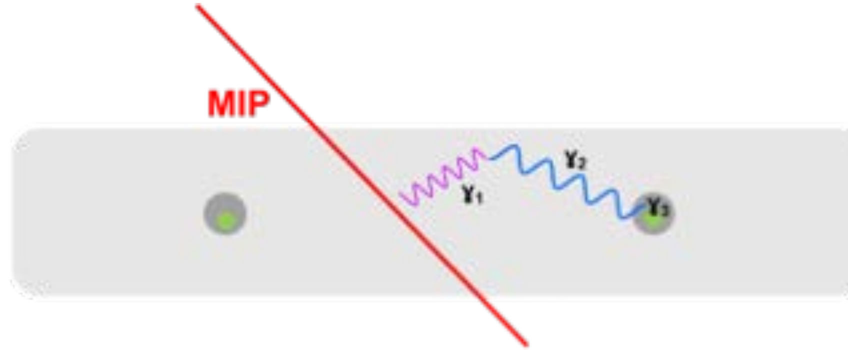
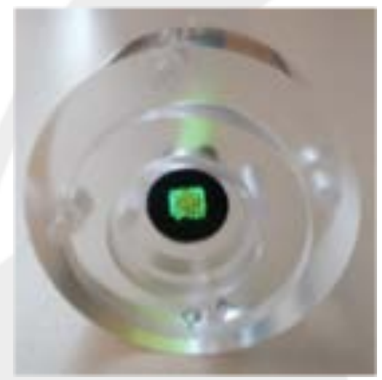
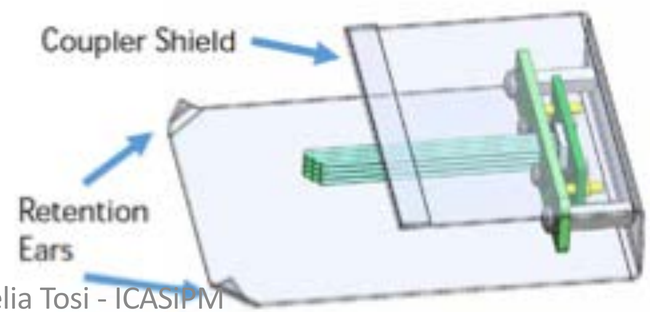
Scintillator panel

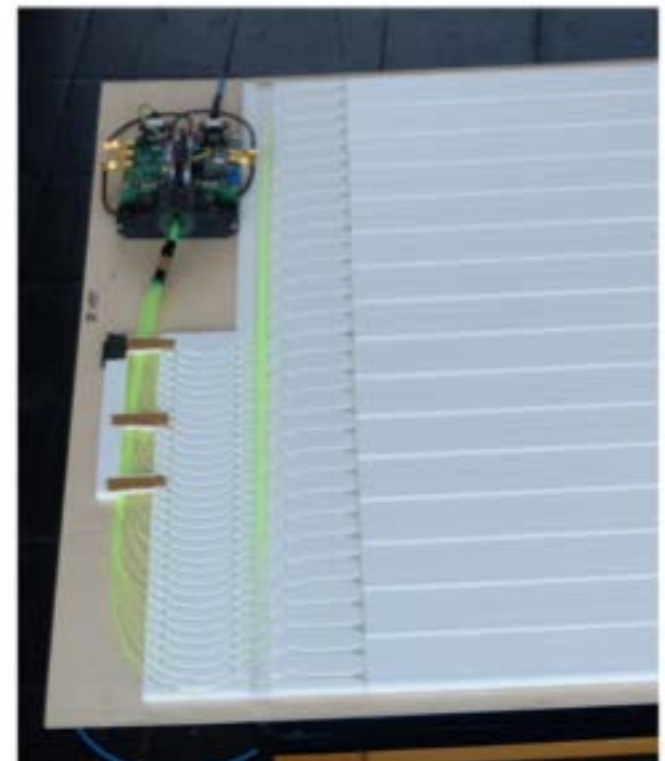
- Combines extruded plastic scintillator and wavelength shifter fibers
- Well developed technology used in many experiments
  - good energy resolution
  - fast timing
  - long term stability
  - easy to build
  - much cheaper than high quality cast material
- 16 bars, 5cm x 1cm x 1.875m
- Two holes in each bar
- 16x2 Kuraray-Y11 fiber ends (⌀:0.7mm or 1mm) bundled together, polished and coupled to a SiPM
- GEANT4: Light yield for one muon: 60 to 100 SPE before losses at SiPM interface



- Polystyrene + dopants emitting at λ_1 (385 and 410 nm)
- WLS fiber absorbs at λ_1 and emits at λ_2 (476 nm)
- $\lambda_{2,fiber}$ att. length is >> $\lambda_{1,polystyrene}$







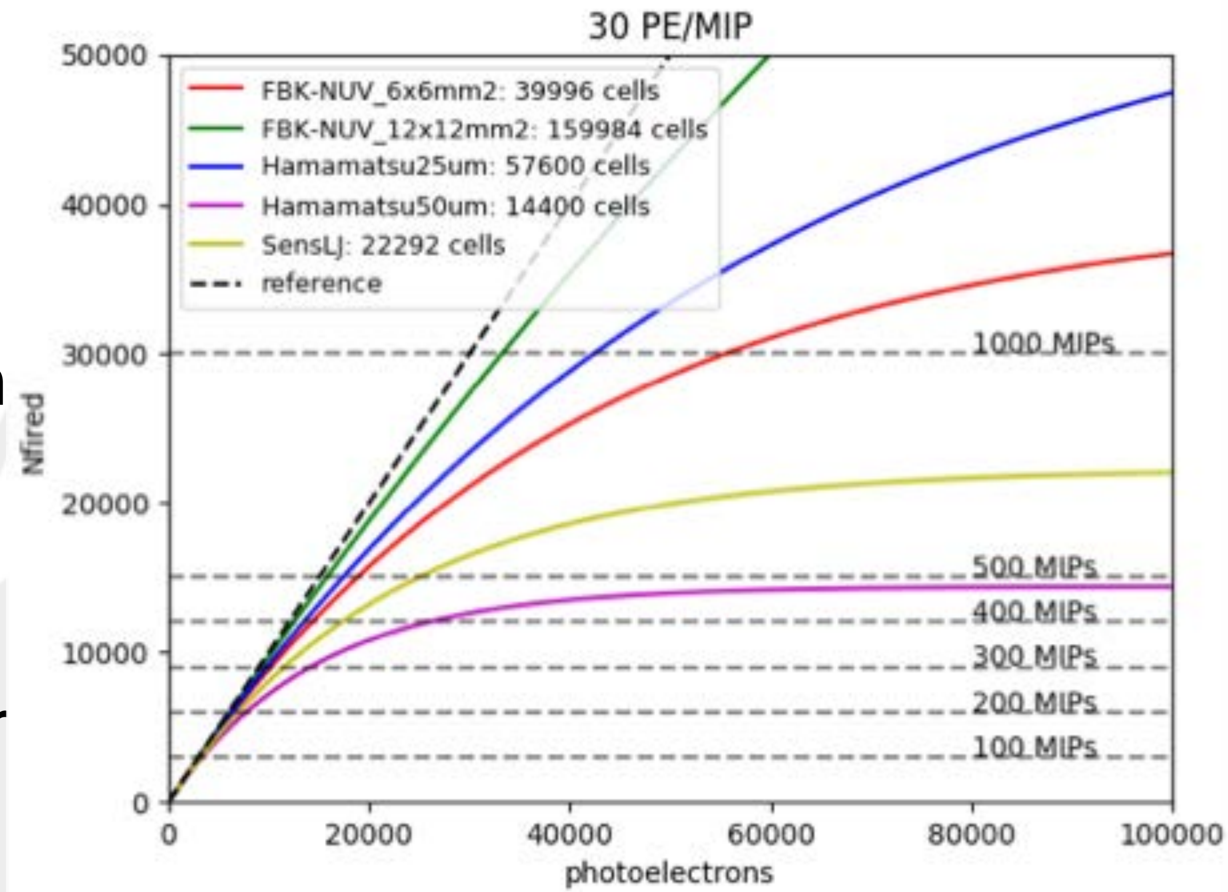
Choice of SiPM

Multiple sensors were tested at Georgia Tech (FBK, SensL, Hamamatsu):

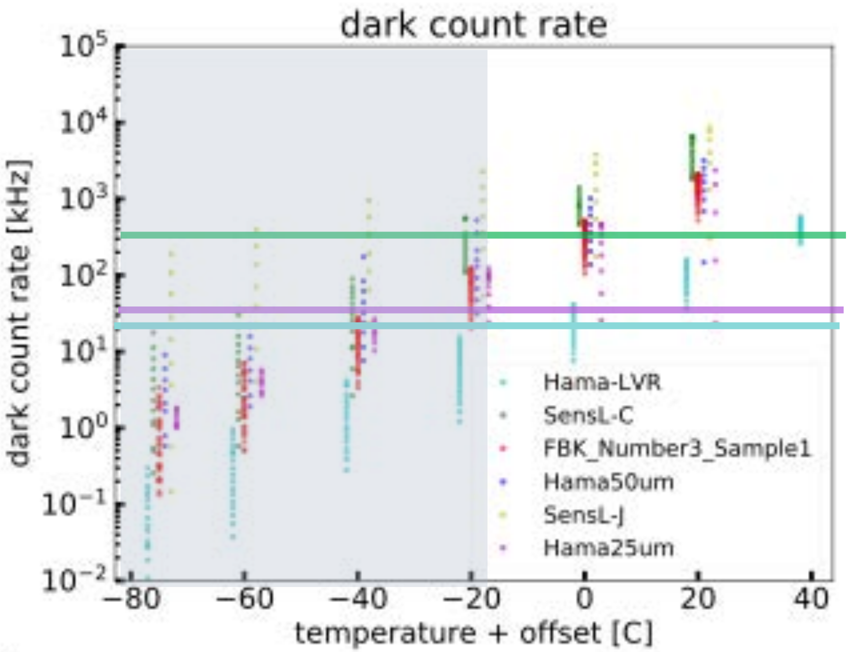
- Cross talk/dark noise/afterpulsing

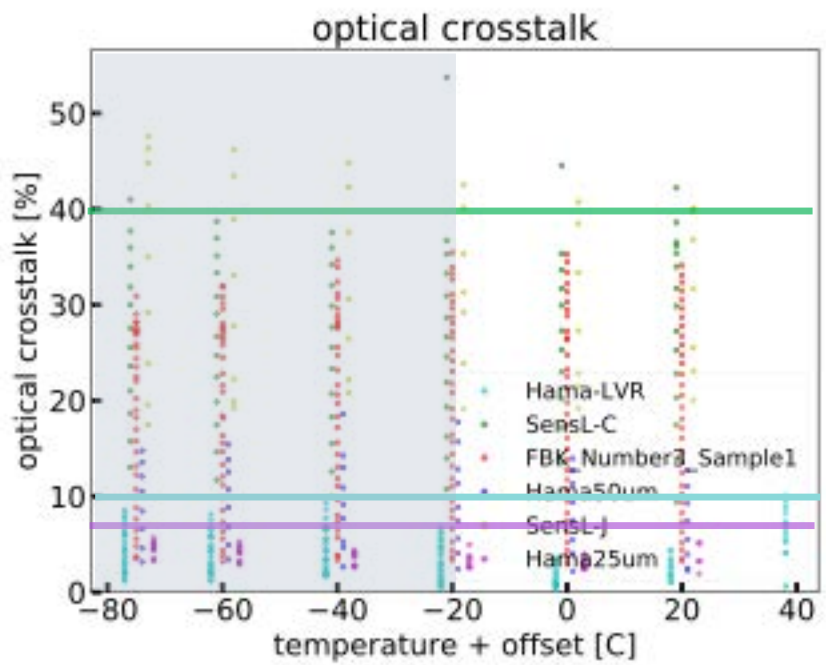
Hamamatsu S13360-6025PE chosen for:

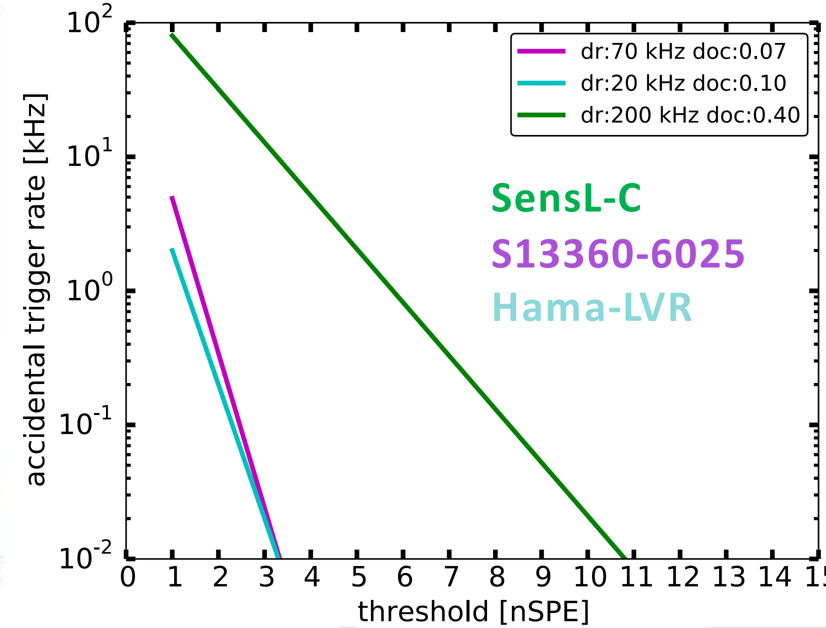
- High dynamic range (required to reach 1000 MIPs as IceTop tanks)
- Low noise rate
  - → But also low gain
- 6mmx6mm sensor area matching fiber bundle
- Availability (~1 month)



Dark count rate and optical crosstalk







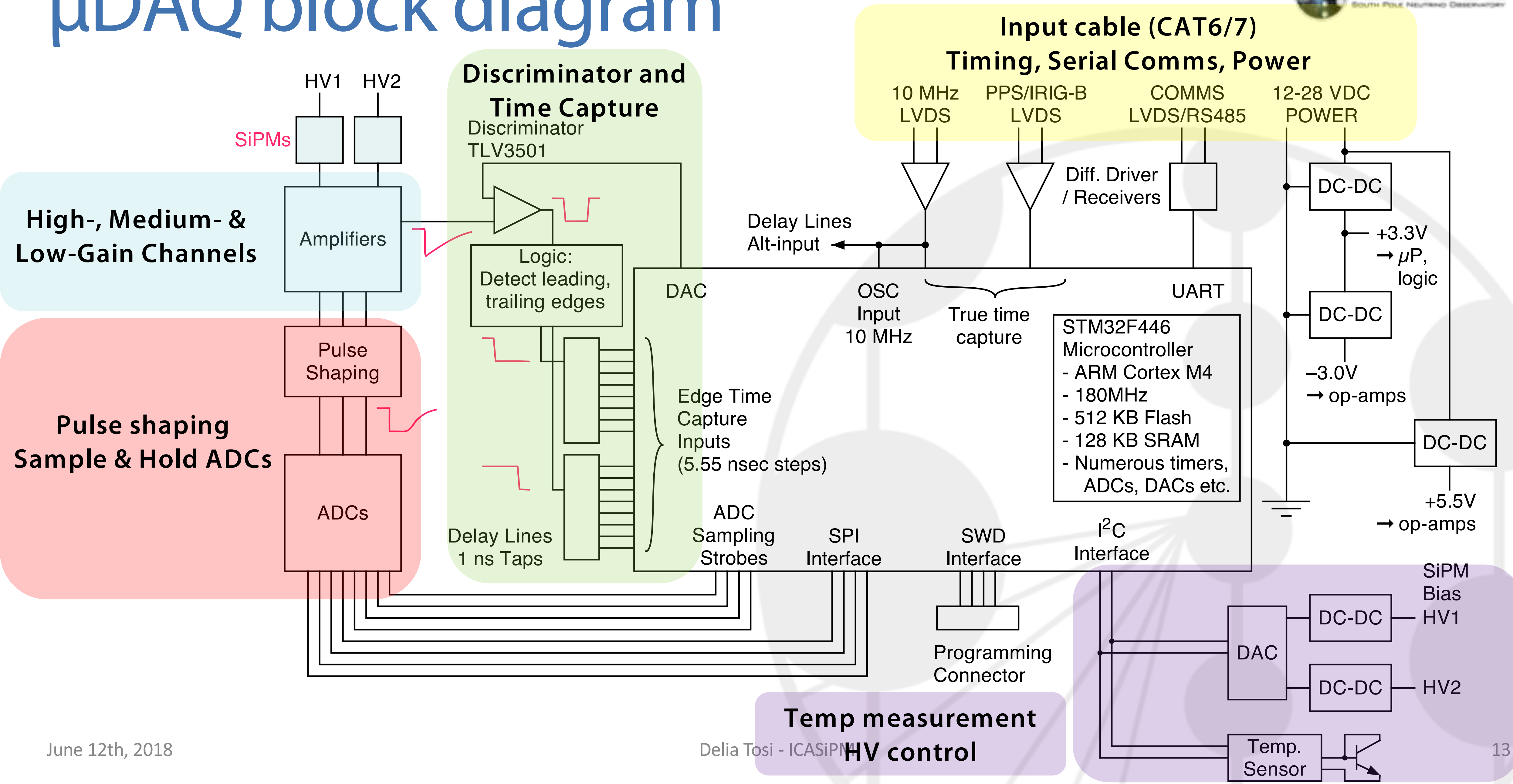
Accidental trigger rate calculated as

- Dark rate x (Direct optical crosstalk)^{nSPE}
- Dark rate and direct optical crosstalk both depend on temperature and overvoltage – here data-points are shown for any reasonable operating voltage at a certain temperature

µDAQ system

- Microprocessor-based DAQ board, dedicated to single sensor (SiPM or PMT)
- Designed at UW Madison by Chris Wendt. It will be used in the CHIPS experiment.
- Small: 1.75" x 5" (4.45 cm x 12.7 cm)
- Low cost: 30$/unit for 400 units
- Low power: currently 0.7 W but can be reduced to 0.3 W or less

µDAQ block diagram



Amplification

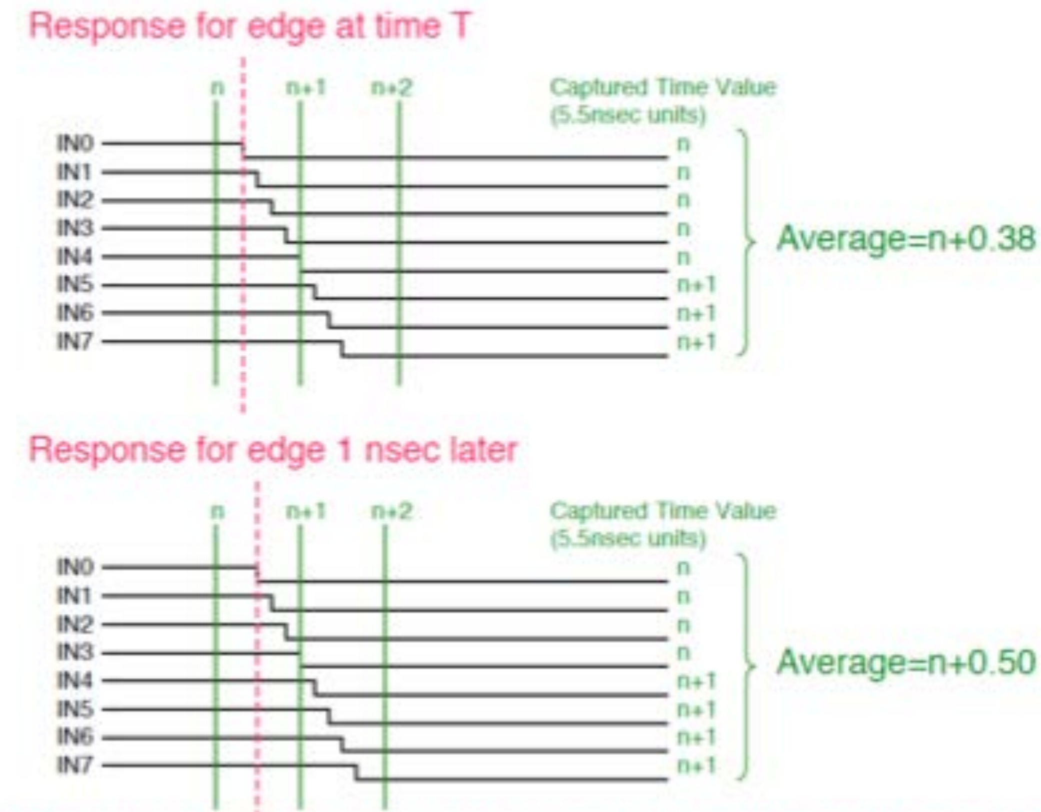
- Tolerates short cable (15 cm coax) to the sensor
- Choice of components depends on MIP/PE, SiPM Capacitance, SiPM Load Resistor and can be studied via SPICE and optimized with prototype boards
- 3 stages amplification with gain up to 1000
  - Each ADC gives 4096 counts over 3.3V range
  - Example for target MIP=20 PEs with a SiPM with C ~1.3nF and a gain G of 0.8e6
  - Dynamic range spans 1-20000 SPEs
  - Final MIP ~ 40 SPE → Medium- and High-Gain electronics gain reduced to reach same #PEs

Waveform peak values listed at specified points in circuit

PE's	SiPM	Discriminator	Shaper Out High Gain		Shaper Out Medium Gain		Shaper Out Low Gain	
	mV	mV	mV	ADC counts	mV	ADC counts	mV	ADC counts
1	0.1 (single)	50	50	62	5	6		
20	2.0 (single)	1000	1000	1241	100	25	3	4
20x20	20 (each)	sat.	sat.	sat.	2000	2482	60	74
20x1000	1000 (each)	sat.	sat.	sat.	sat.	sat.	3000	3724

Discriminator & Time Capture

- Discrim. threshold set via 12-bit DAC in μP
- Logic gates generate separate signals responding to leading and trailing edges
  - Later crossings ignored until trigger is re-armed
  - Edges used to trigger time capture in μP
- Leading edge recorded by 8 built-in registers in integer multiple of 5.55nsec (internal clock 180MHz)
  - each register sees same edge as input but delayed by successive increments of ~1ns
  - averaging the registers' outputs results in ~1ns time resolution on pulse rising edge
- Internal μP clock is synchronized to WR via timing inputs

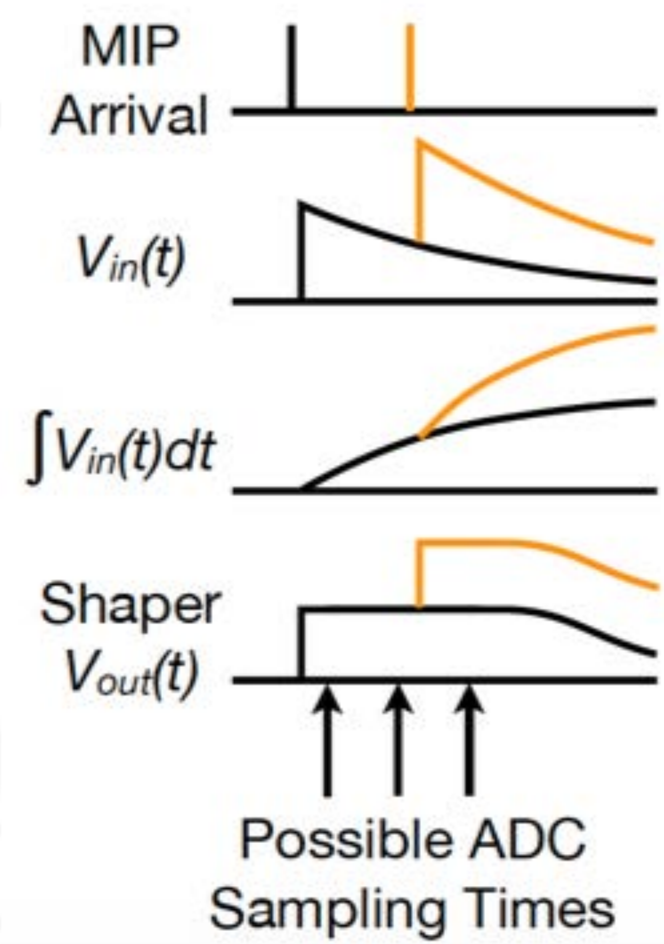


Possible values for average are n, n+0.13, n+0.25, n+0.38, n+0.50, ...
➡ Allows time resolution ~ 1 nsec even though n increments each 5.5nsec

- Exact mapping from N_{avg} to time will be calibrated from from occupancy histogram of 8 possible N_{avg} values

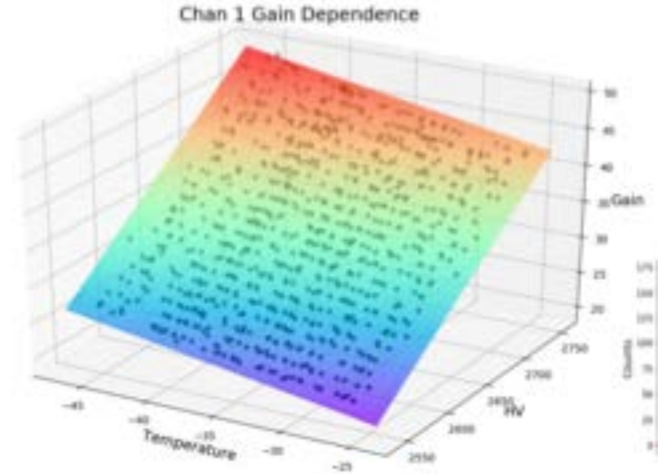
Shapers and Sample/Hold ADCs

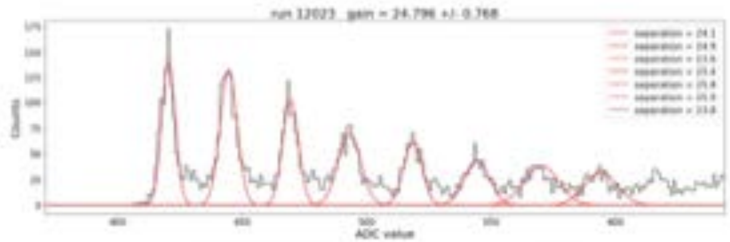
- Pulses are shaped before Sample / Hold ADCs to obtain the integral of the number of photons
  - 16x40 MHz bandwidthx12 bits MAX11665 wired to any gain channel (2x3 installed)
- Timing signals from µP close the S/H window at certain delays after Tstart
- Individual delay times can be setup in software (2 installed, board design allows up to 8)
- The time profile of the number of photons is captured
- Deadtime due to reading and clearing ADCs (~5us per trigger)

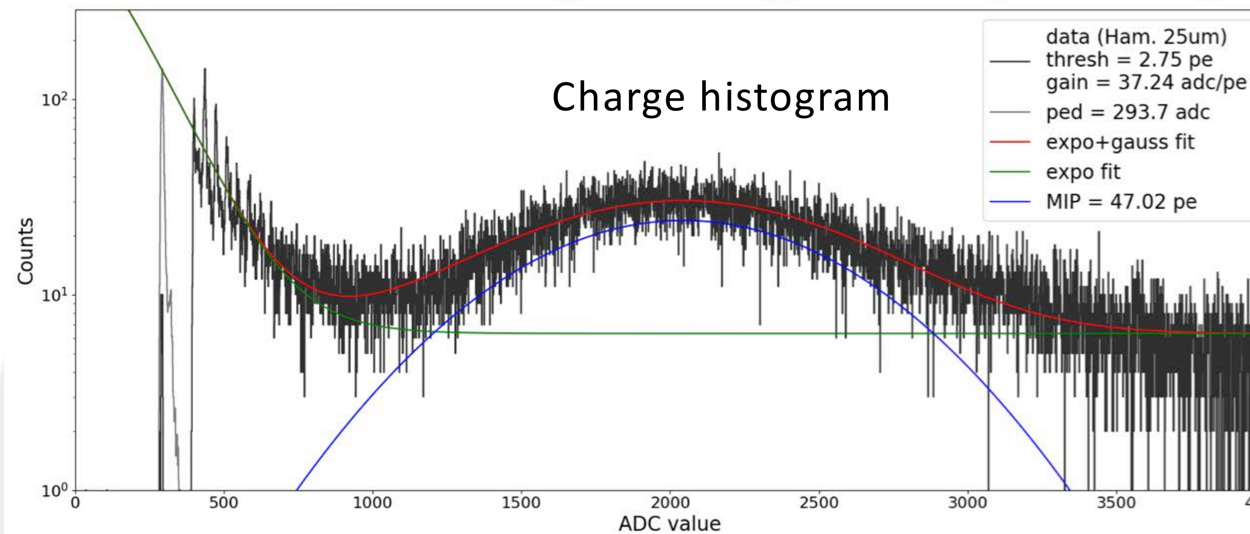


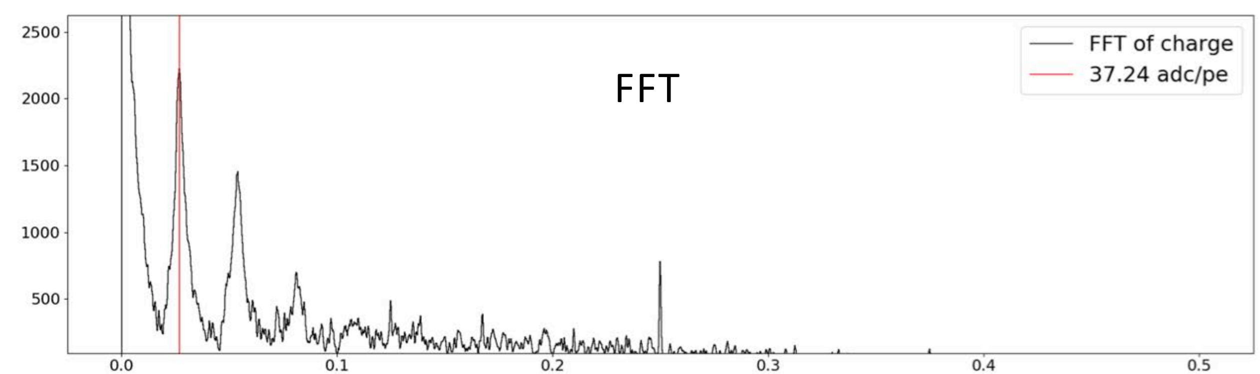
µDAQ performance

- Recording SPE peaks allows gain to be determined on the fly (via FFT method)
- MIP energy can be calibrated according to gain
- Gain vs HV & Temperature fitted offline
- Microcontroller can implement HV / Temperature feedback loop locally (i.e. storing the fit)
- Low/Medium/High can can be cross-calibrated in-situ
- Data format: binary, 15 bytes/hit



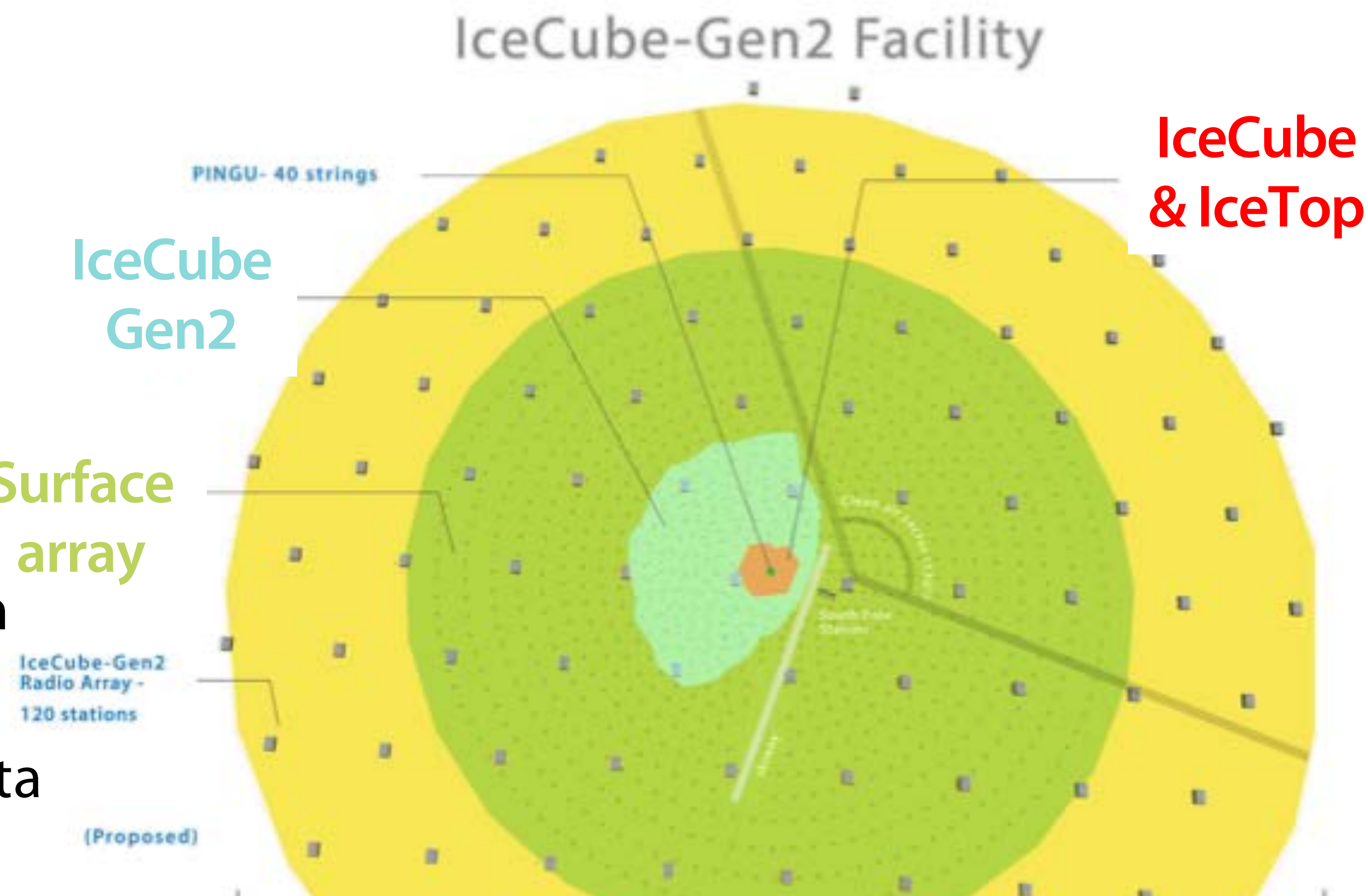






Outlook

- IceTop upgrade offers the opportunity to develop hardware suitable for future large-scale surface array
- Density of detectors affects energy threshold and cost
- Configuration and extension under study
- Either case needs to be low power, low cost, efficient data rate



Number of 1.5m² detectors	1 km² (IceTop Upgrade)	10 km²	75 km²
Spacing: 62.5m	259	~2.5k	20k 6k (if spacing increased to 125m outside 10km²)

back up slides

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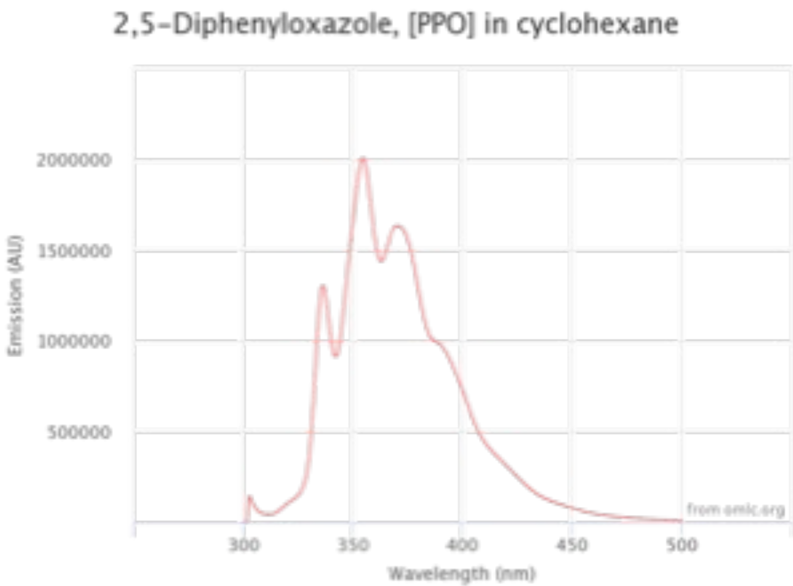
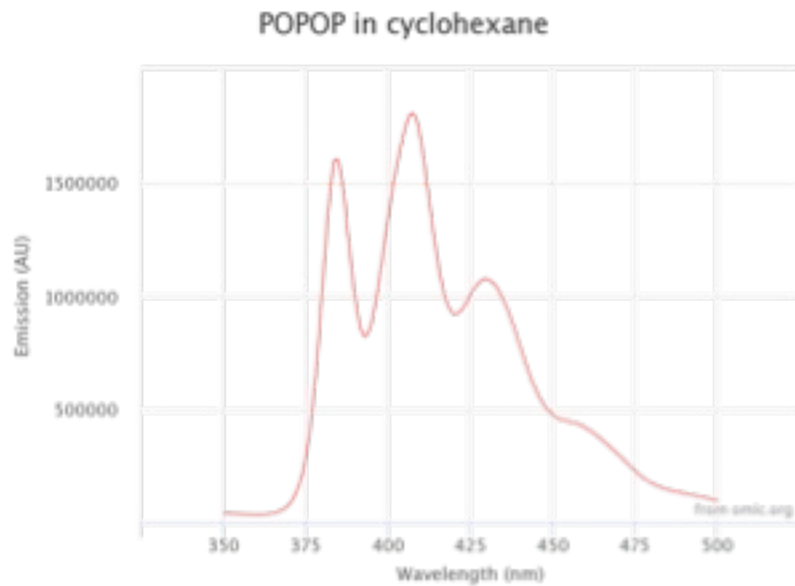
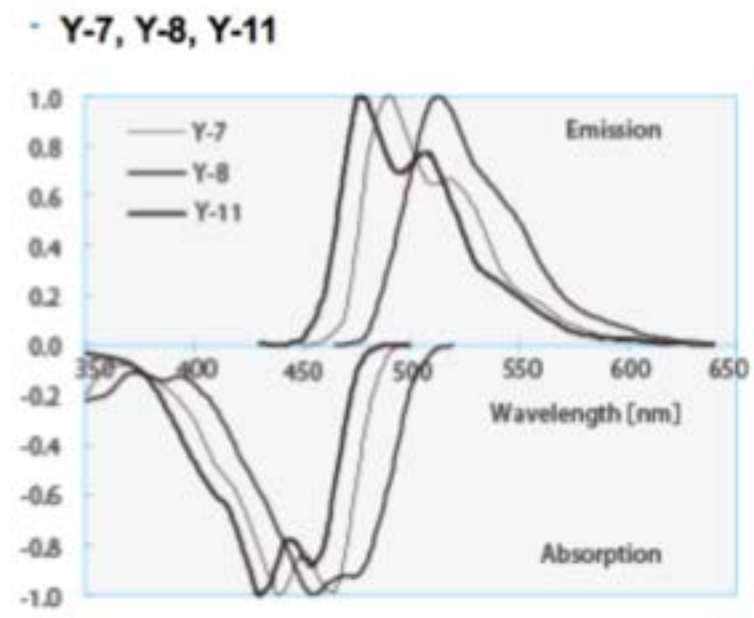
Wavelength shifting







Dopants in plastic scintillator

Absorption/Emission in wavelength shifter fiber (Y11)

Afterpulsing / Delayed Optical CrossTalk / Recovery Time