ICECUBE
South Pole Neutrino Observatory

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Technical Advances towards the IceCube-Gen2 Neutrino Observatory

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(for the IceCube Collaboration)

SCAR Astronomy and Astrophysics from Antarctica

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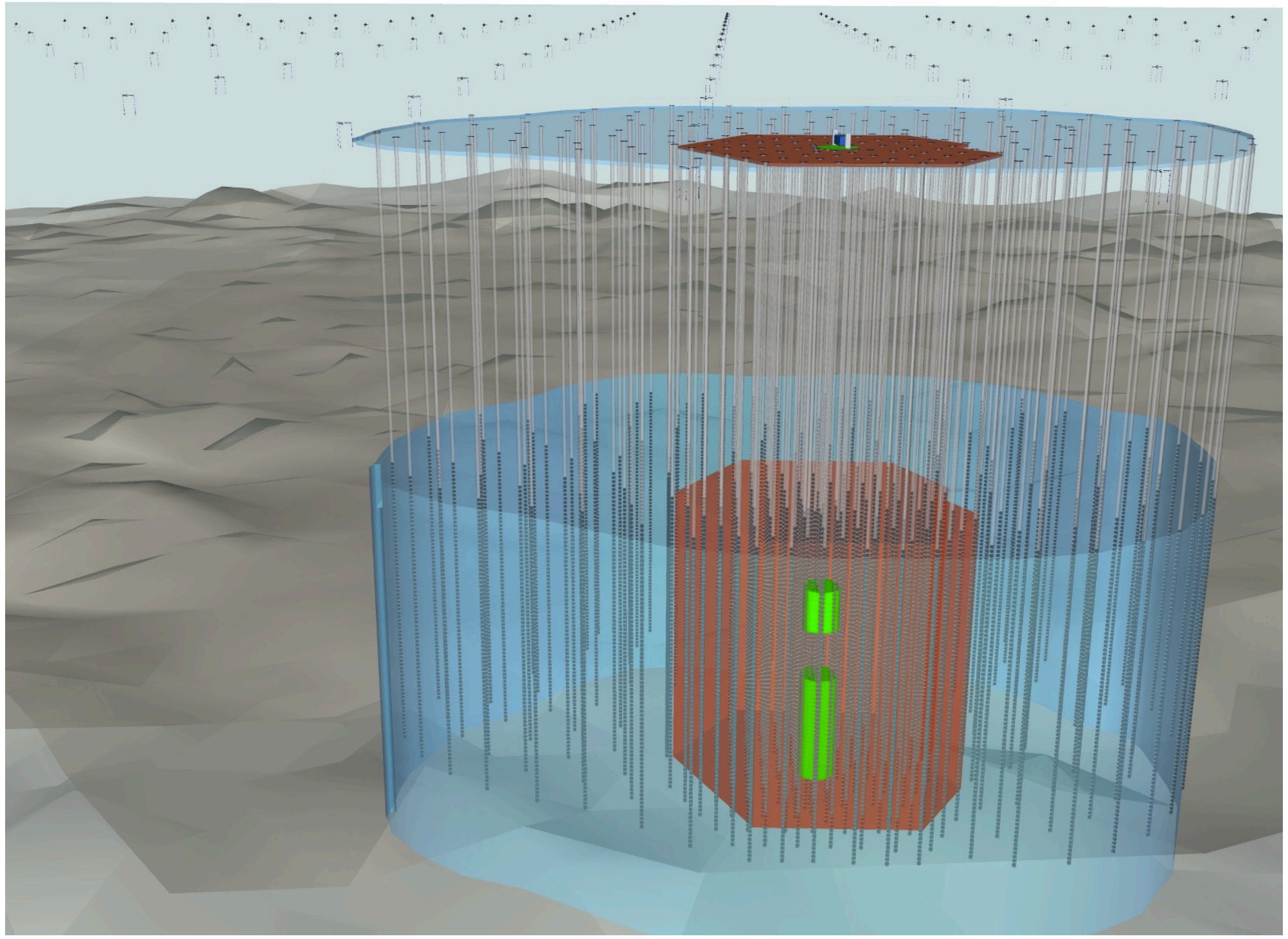
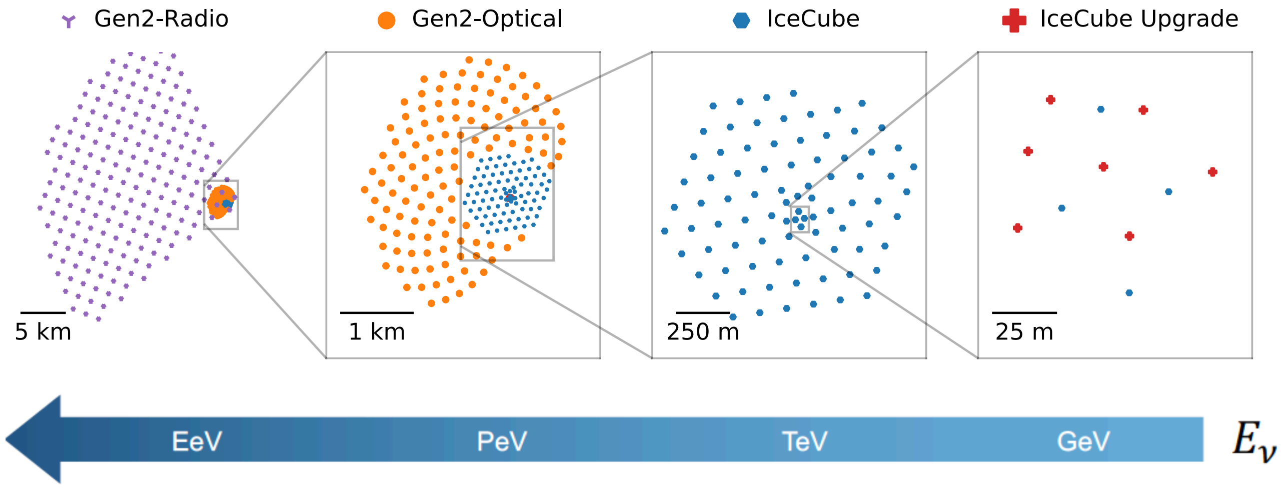
The IceCube-Gen2 Facility

A broadband neutrino observatory



Four new elements, leveraging complimentary technologies, to achieve sensitivity to MeV-EeV neutrinos

- Densely instrumented deep optical array (IceCube Upgrade)
- Extensive deep optical array
- Surface array
- Shallow radio array



Challenges for Gen2

- Large detector size ~ power distribution to far stations of the radio surface array
- South Pole Station Power Plant is operating near capacity
- Power distribution under runway to the dark sector is near capacity
- Logistics is limiting US Antarctic activities

What can we do to overcome these challenges ?

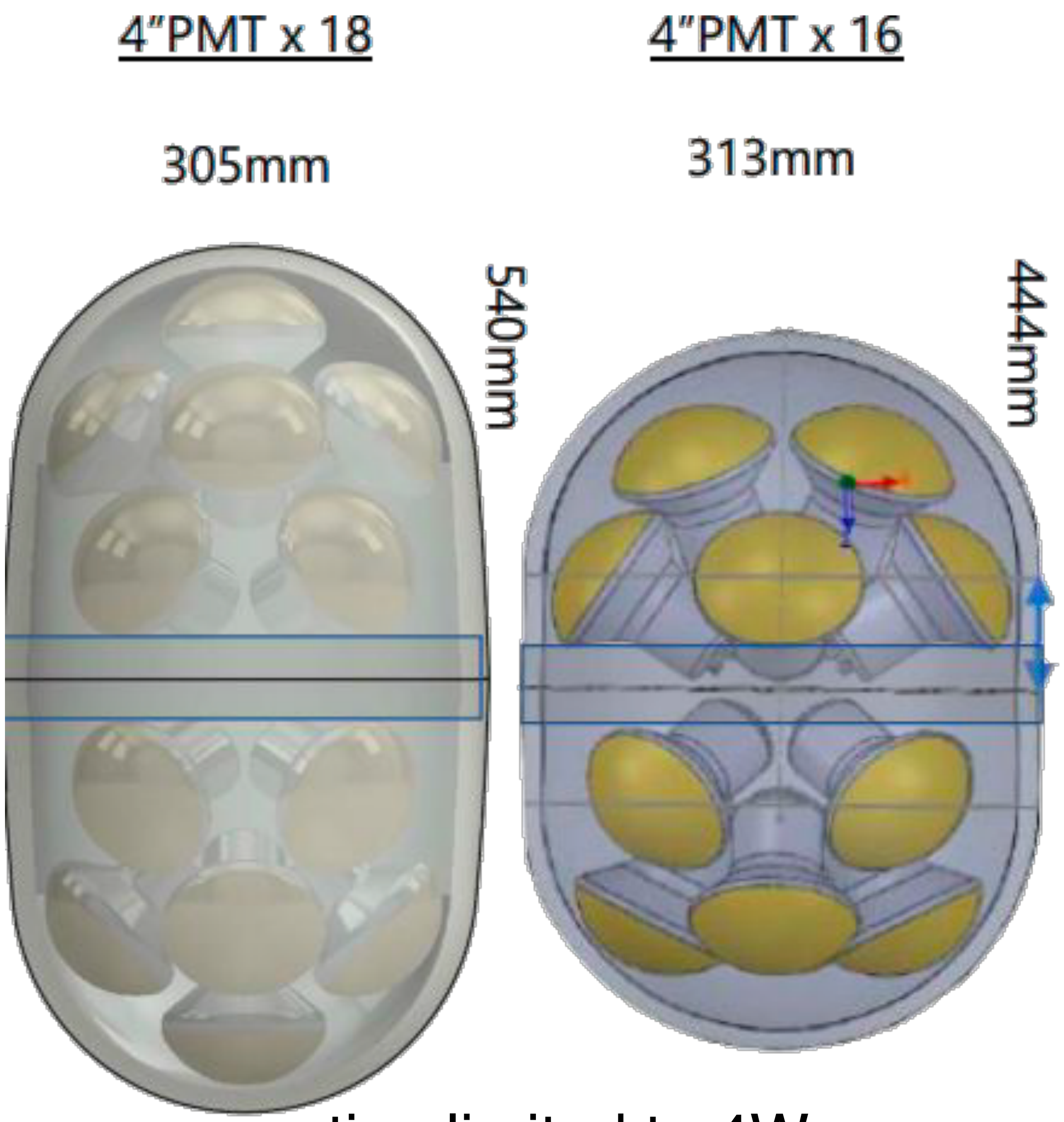
From Upgrade to Gen2 (optical modules)

Upgrade mDOM (24x3"PMTs)

Upgrade D-Egg (2x8"PMTs)

Long Optical Module (LOM)

ICRC(2021)1062

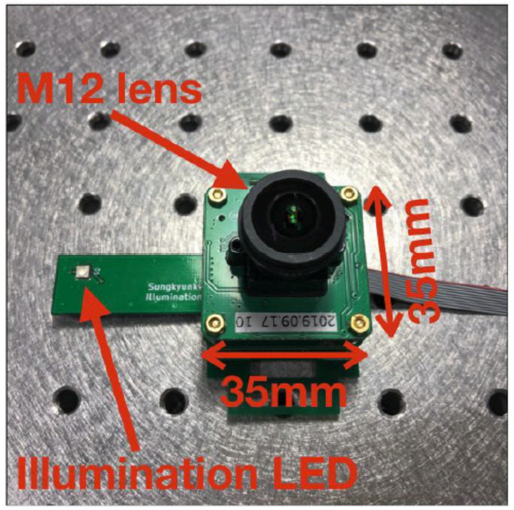


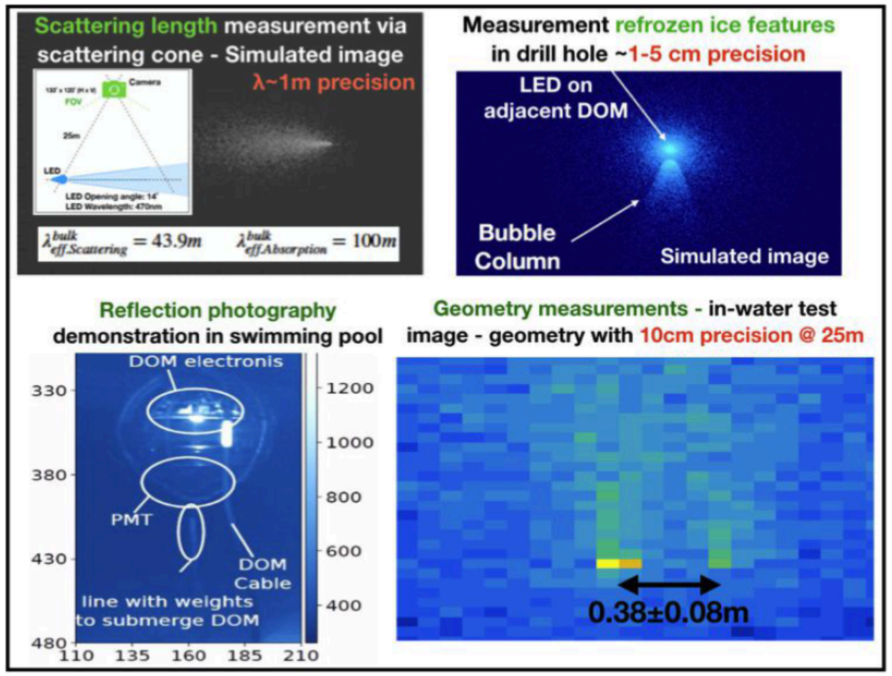
- Power consumption limited to 4W
- Lower digitisation rate of 60 MSPS
- Waveform processing shifted to PMT bases
- Due to Gen2's large string spacing (~240m), a lower ADC rate has only a modest effect on reconstructions.

Importance of Ice Properties and Calibration

Calibration Systems

Upgrade - camera-based calibration





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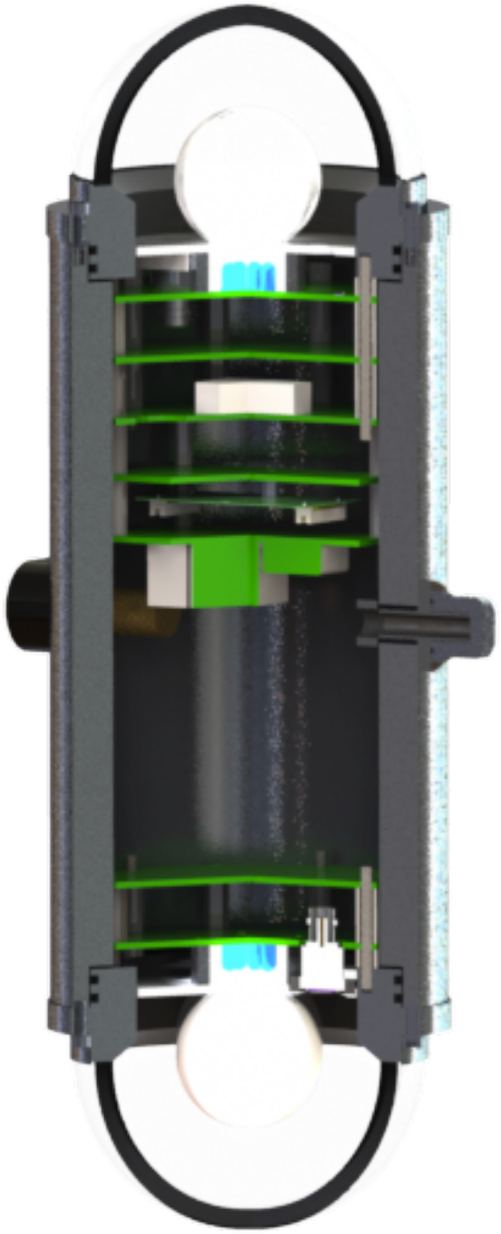
Absolute calibrated light beacons (POCAM)



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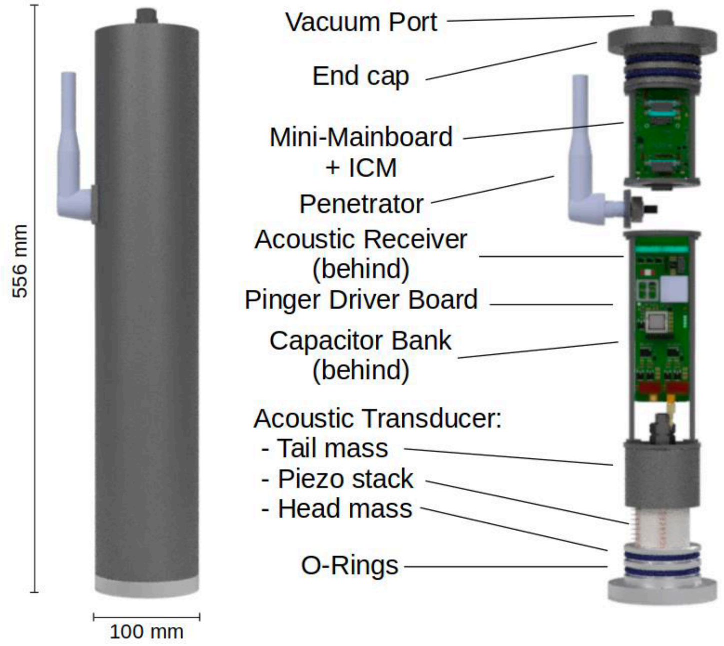
Acoustic modules



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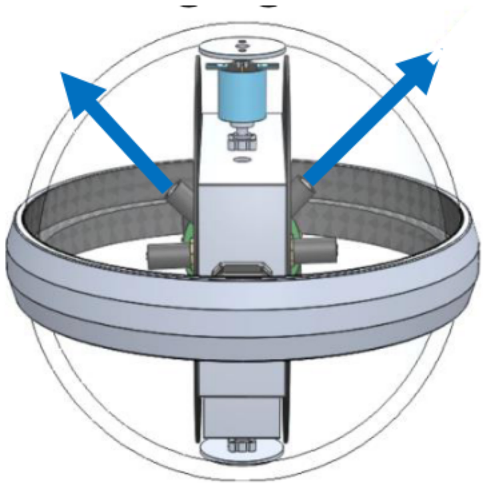
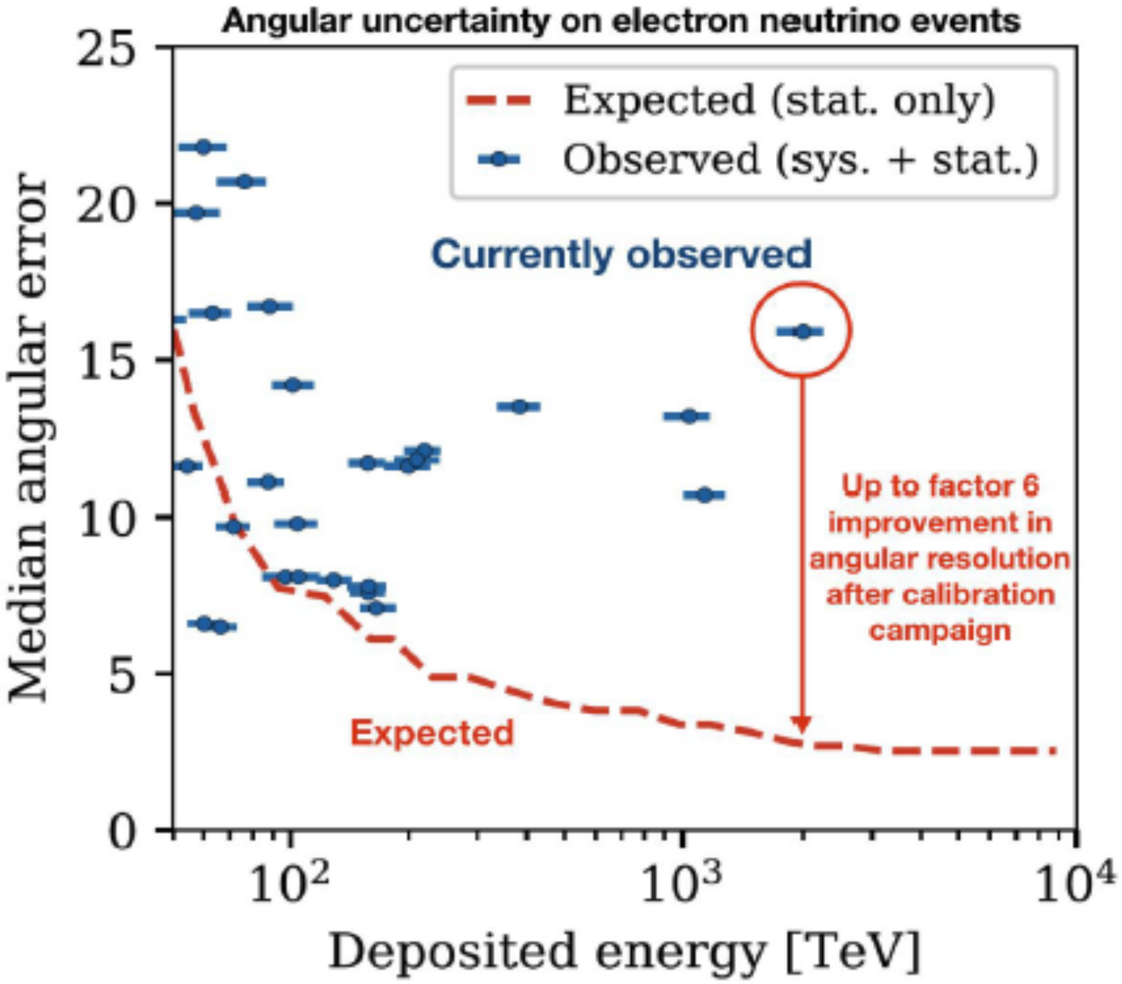
LEDs and pencil beam (beaming light source)

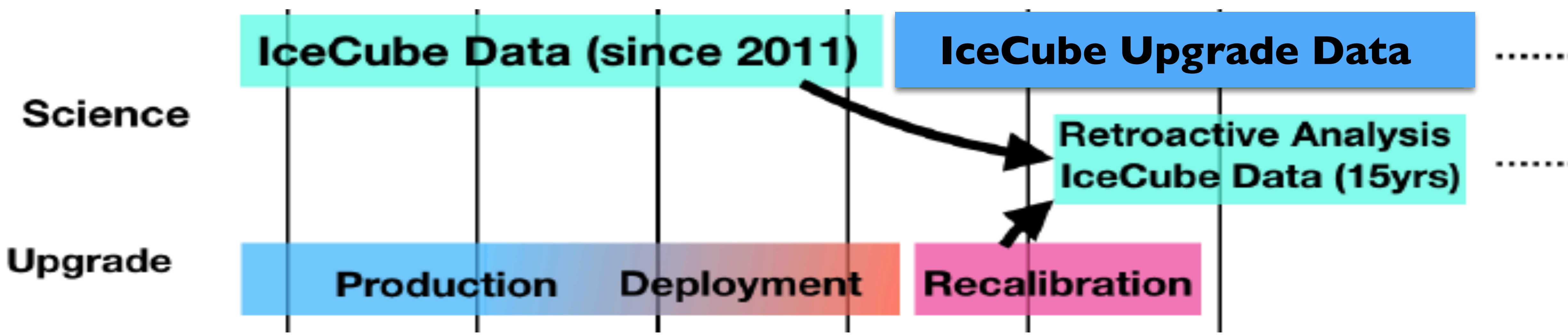


Calibration impact



Upgrade calibration systems key to comprehensive understanding of the detector medium

- ***Science multiplier*** Retroactively analyze more than 15 years of IceCube data with substantially improved angular and energy resolution
- ***Improved neutrino event pointing*** critical for multi messenger science



Drilling and potential to use solar as part of the drill system

Enhanced Hot Water Drill - Gen2

ENHANCED HOT WATER DRILL – HYBRID GENERATION 2 (EHWD-G2)
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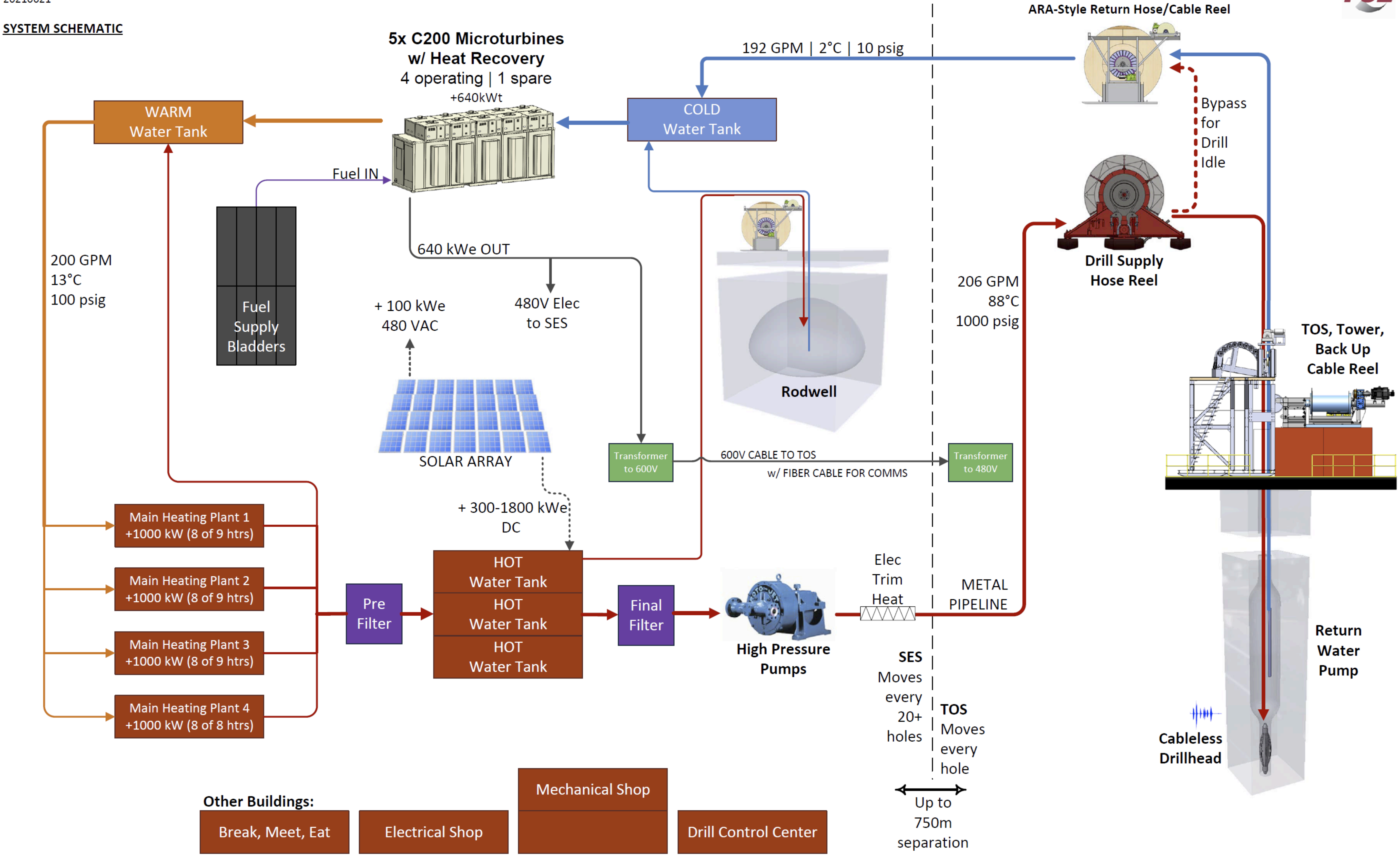


IceCube-Gen2 Micro Turbine

- EHWD used 3x Piston Engine driven generators with manual syncing to make 300 kW electric and 400 kW heat recovered into the generator return water
- Plan to use 5x C200 Micro Turbines (MT) for Gen2 Drill
- Less weight per kW than piston engines
- Straight forward heat recovery
- Micro Turbines have better reliability, require less maintenance, autosync, have better integrated heat recovery, and are more tolerant to load changes due to large batteries.
- New drill architecture requires more electricity
- The electronics and batteries in the MT and increased electrical ulilization in the drill will allow easier integration of Photo Voltaics in the drill

200 kW Micro Turbine Installed at UW-PSL

Case for solar for the drilling system

- IceCube GEN2 Drill plan has 5x 200 kW MicroTurbines (MT)
  - Plan for 4x MT running producing 640 kW electric & 640 kW thermal during deep drilling
  - **Solar** could be used to displace fuel usage for AC power production
- Hot water drill will have
  - 2x 10000 gallon hot water tanks maintained at about 83 C,
  - large warm water tank at about 15 C,
  - a large cold water tank at 0 to 5 C.
- Heating
  - During normal operation most of the water heating will be done in Jet fuel fired Model 75 heaters
  - Electric heating capability
    - **Solar** ideally suited, can use DC, no inverter needed, reduce complexity of the system and costs
  - For each 100 kW of PV we could turn off one model 75 and maintain the power output

Solar installation options for SES
Solar panels would need to be on a sled or the roof of the ARCS

https://www.southpolestation.com/0809

Case for Solar

Case for solar

- Case for solar at the South Pole during the months of daylight:
  - High level of insolation
  - Low cloud cover
  - Efficiency of photovoltaic cells increases with reduced temperature (Silicon -0.4% / °C)
  - Albedo Radiation - snow at pole very reflective (0.7-0.9?)

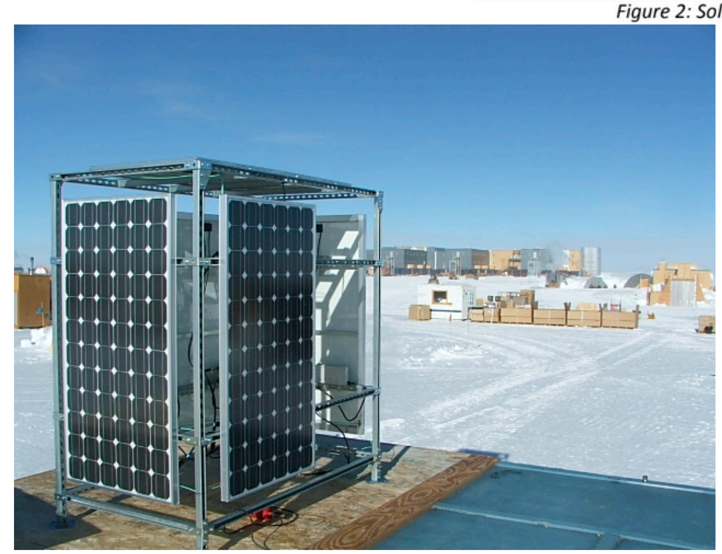
https://power.larc.nasa.gov/data-access-viewer/

The **insolation clearness index** (KT) is the amount of the total **solar radiation** incident on a horizontal surface divided by the incoming top-of-atmosphere (TOA) **insolation** (i.e. KT is the fraction of **insolation** at TOA which reaches the surface of the Earth)

Why solar now

- Past demonstrations and attempts to bring solar to pole
  - J. S. B. Mason (2007) "Photovoltaic Energy at South Pole Station" - Graduate Certificate in Antarctic Studies: ANTA504
    - Finds "Current electrical generation costs are estimated at **$1.39/kWh** based on just the fuel costs … Conservative estimates for a PV system assuming commercial single/multicrystalline silicon modules would place the cost of PV generation at around **$0.60/kWh** based on a twenty year depreciation of the system"
  - 2009 - Enphase Energy of Petaluma, California partnered with ASC - 6 Sharp 175 watt single crystal silicon photovoltaic modules were installed in the summer camp
    - Generated about 1.25MWh per season
  - "WIPAC Solar Power Installation Proposal for the South Pole Station"
    - Proposal to install 81 sharp panels at ICL ~ 21.9MWh per Pole year, annual savings $35,259 or 1684 gal/year of AN-8
  - Experience at Summit Station in Greenland
    - 40 Evergreen 205-Watt PV panels
      - 2-3 years return on investment

Figure 2: Solar Power generated at Pole in 12/13 Summer Season at Altie Meadows


Sharp NT-175UC1 82.6cm x 157.5cm (1.3m²)/ 16kg

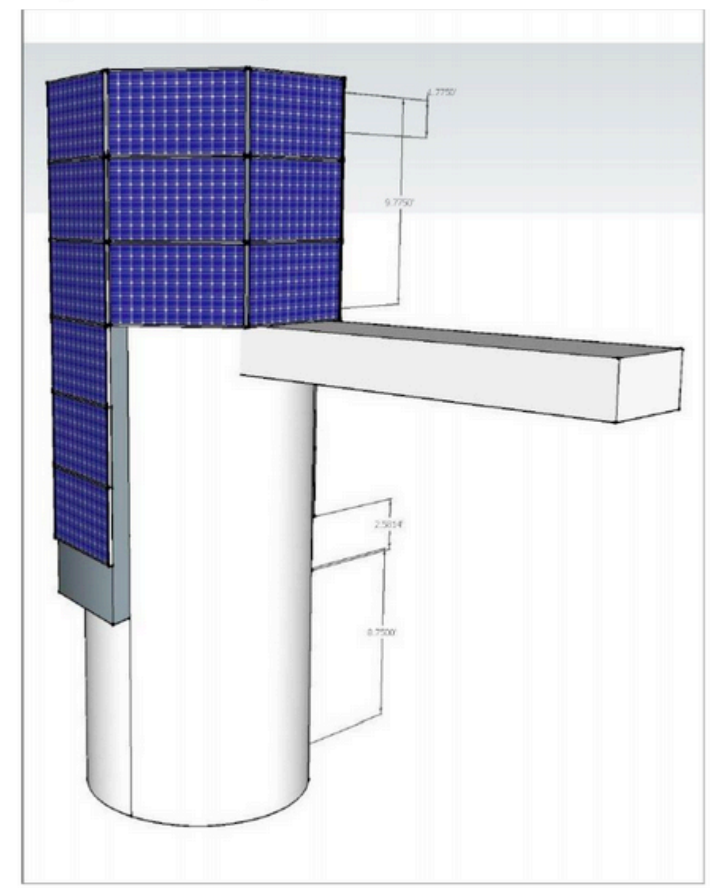


Figure 3: Possible configuration of solar panels on ICL west tower

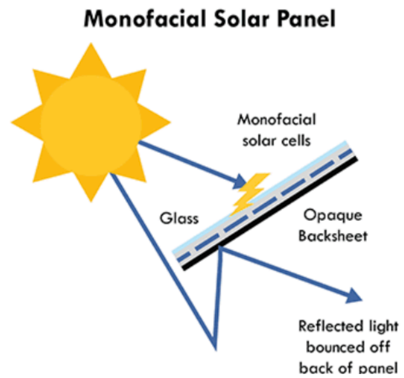
https://www.polarfield.com/blog/green-energy-greenland
https://geo-summit.org

Why solar

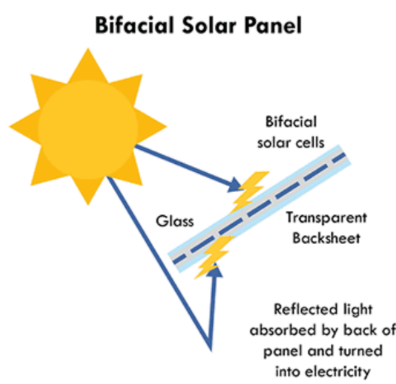
- Opportunity to reduce logistics footprint (flights)
- The use of Solar and Micro Turbines by IceCube-Gen2 in the dark sector could reduce requirements on the existing South Pole power system
- Solar has become more reliable and efficient
- Solar displaces fuel use and helps reduce fuel logistics and costs
- Could be used to increase power generation in the dark sector
- Social responsibility for sustainability in our research

Bifacial vs Monofacial panels

- Monofacial solar panel
  - Can generate power only fraction of the time
  - Could be mounted on the side of drill camp containers, easy maintenance - long term mounted on the side walls of ICL or station



- Bifacial solar panel
  - Can generate power continuously
  - Higher efficiency
  - Mounted vertically and facing into the wind ~ avoid snow accumulations
  - Optimal for power generation for drilling, long term could be mounted on roofs or walls of buildings

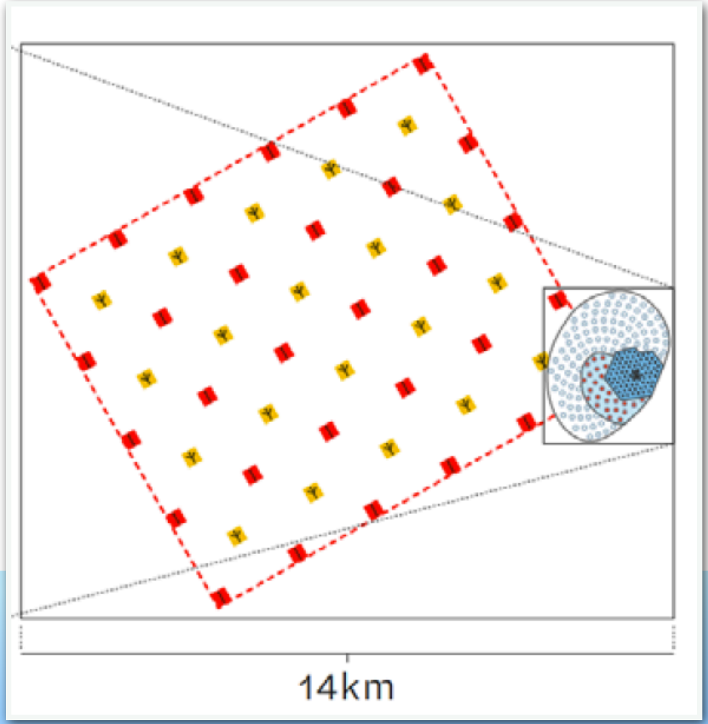


Mimic polar ambient light environment during Sun rise/set in salt flats

Bi-facial solar panel testing underway in Utah

Power generation

- Solar displaced fuel frees up cargo, reduces logistics requirements, and pays for itself due to fuel savings
  - Conservative estimate over an 8 year period, assuming 25% of rated output for 3 months per year
    - Factor 4 reduction in cargo
    - Cost ratio of fuel to solar panels 1.5
  - Output could potentially be higher
    - Based on Sharp system at pole 175W (single faced solar panel) generated 0.21MWh / season / panel
    - A 375W bi-facial solar panel vertically mounted could generate about 1.00MWh / season / panel assuming 10% bifacial gain
      - Assuming 5 month period ~ average power generation ~280W per panel



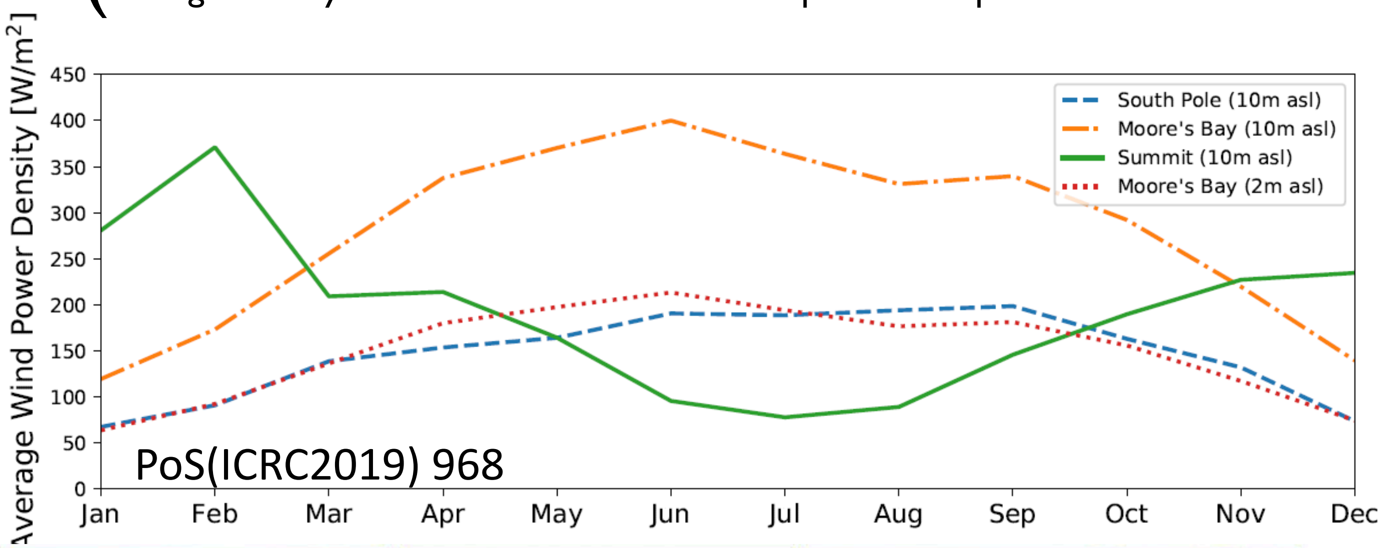
Sustainability of operations of Gen2-radio

Powering of Gen2-radio via the central South Pole Power plant is very inefficient (~half of power lost)
- autonomous power generation ?

Wind at South Pole

Very different from coastal areas of Antartica, the geographic South Pole is a more challenging environment for wind power

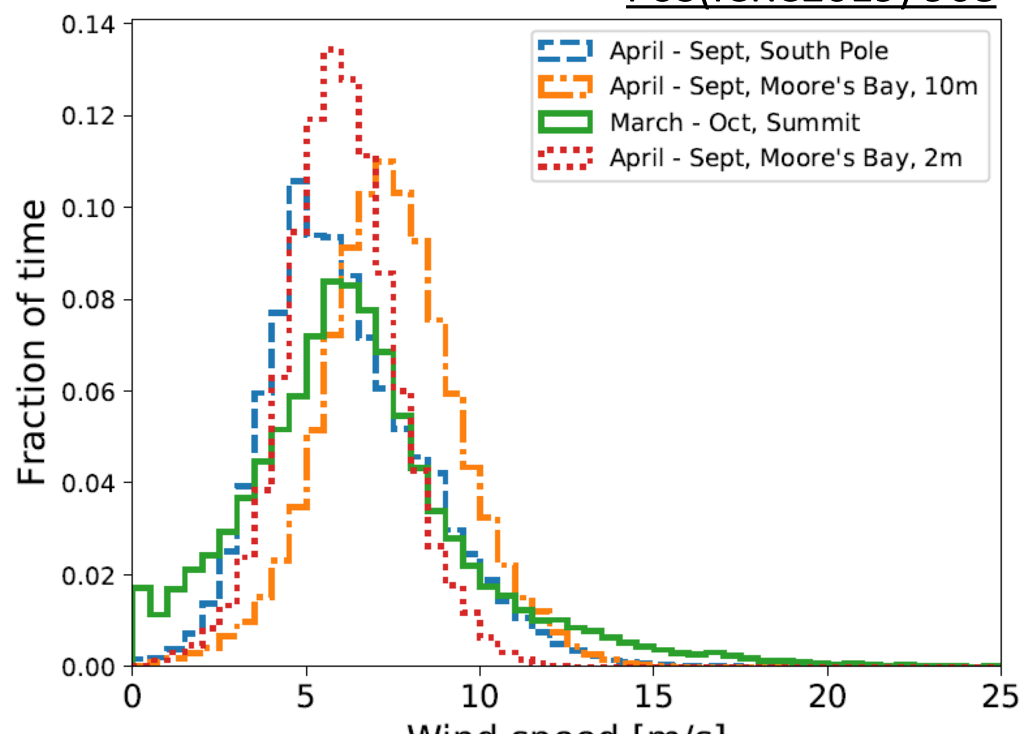
(Though already 2005 NREL/TP-500-37504 Report found potential to use wind at SPS)



Environmental Challenges:

- Very low temperatures
- Low pressure / high altitude
- Low wind speeds

PoS(ICRC2019) 968



Savant III turbine:
Diam 0.3 m, height 0.6 m
Weight 10.5 kg.

Wind turbines as installed at the ARIANNA site.
Figs and text from PoS (ICRC2019) 968

- SAVANT III is sufficient for the ARIANNA stations at Moores Bay
- Radio array at South Pole would require up-scaled system

South Pole/IceCubeGen-2

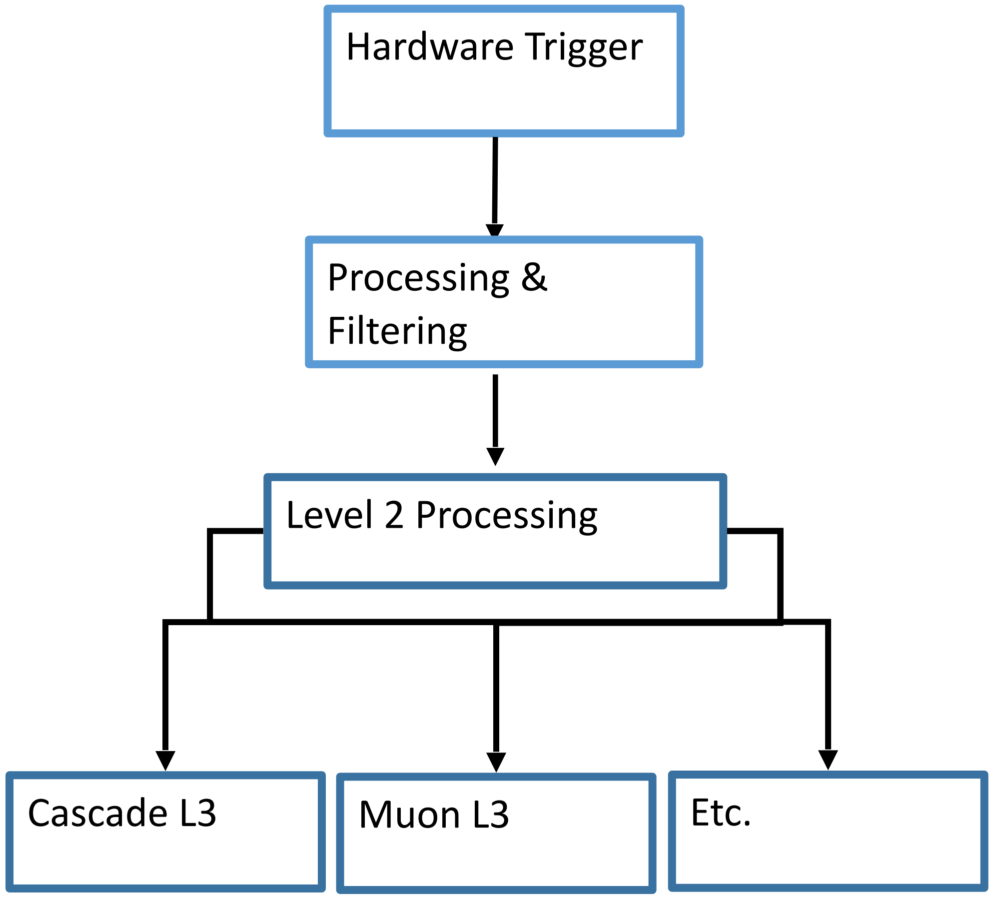
- Need to test prototypes under realistic conditions, Greenland and South Pole
- Long cycles for results from field tests, and to implement design improvements.
- Need to demonstrate long term reliability and no need for maintenance.


SAVANT III up in Swedish mountains

Smarter Computing and Data Processing at Pole

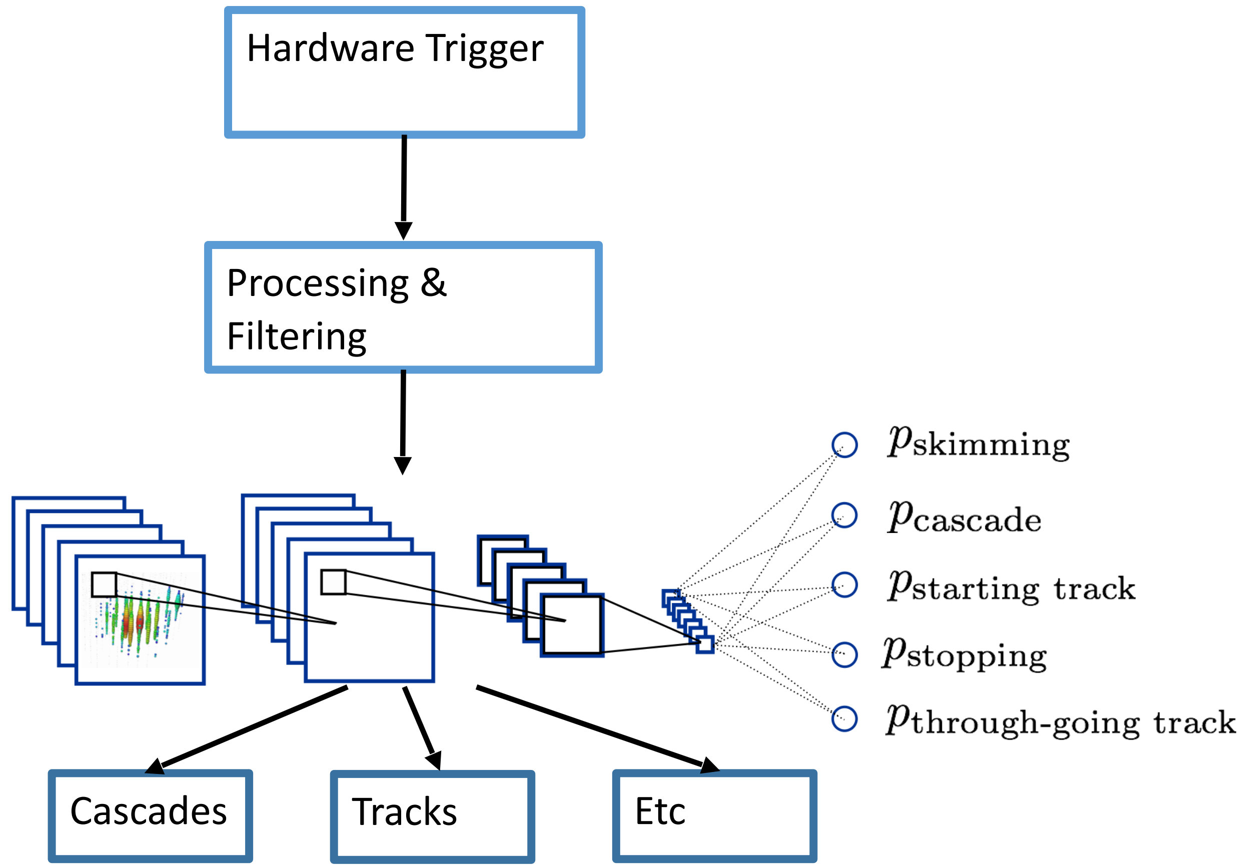
Improving the IceCube filtering pipeline with machine learning

Current System



Complicated dependency graph
Many data products are redone / not used later down the pipe

Proposed System



Split into cascade / tracks / etc channels directly after trigger. Apply only channel-specific reconstructions

- Testing is underway to replace current online and offline filter system with a more efficient machine learning based system
- New system requires at the present about 20-30 GPUs
- Potential for significant savings of CPU resources (and power) / Target to roll out new system mid next year

Conclusions

Conclusions

- Environmental impact and sustainability essential to IceCube-Gen2
  - Potential for significant cost savings and reduction of logistics foot print by augmenting power generation for drilling and operations with solar
- Renewable energy has been used successfully in Antartica and we have promising demonstrations at the South Pole
- Local power generation for Gen2 radio array is attractive - wind turbine testing underway
- Reduction of ice properties related systematic uncertainties with new calibration systems will result in improved event reconstruction capabilities
  - Multi-messenger science benefit via better pointing and event ID
  - Analysis benefit - retroactively analyze already collected data