

# ICECUBE FOLLOWUP AND FUTURE ASTROPHYSICAL NEUTRINO ALERTS

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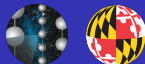
AMON Workshop, DESY

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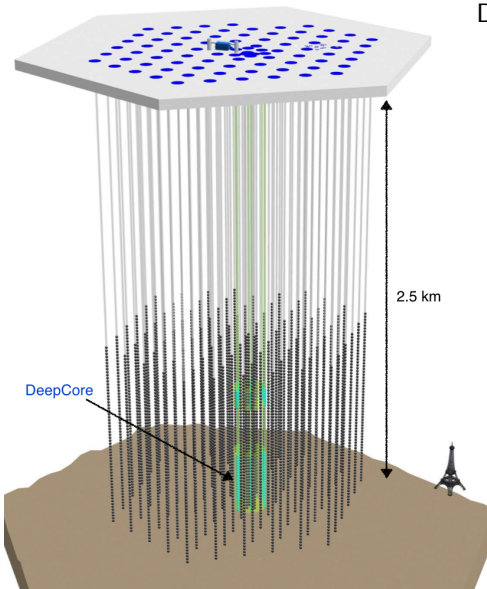
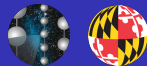


IceCube



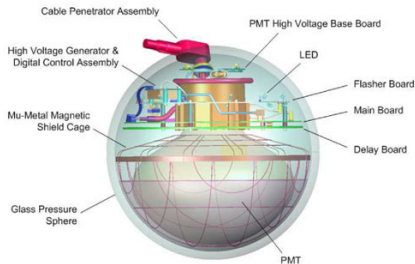


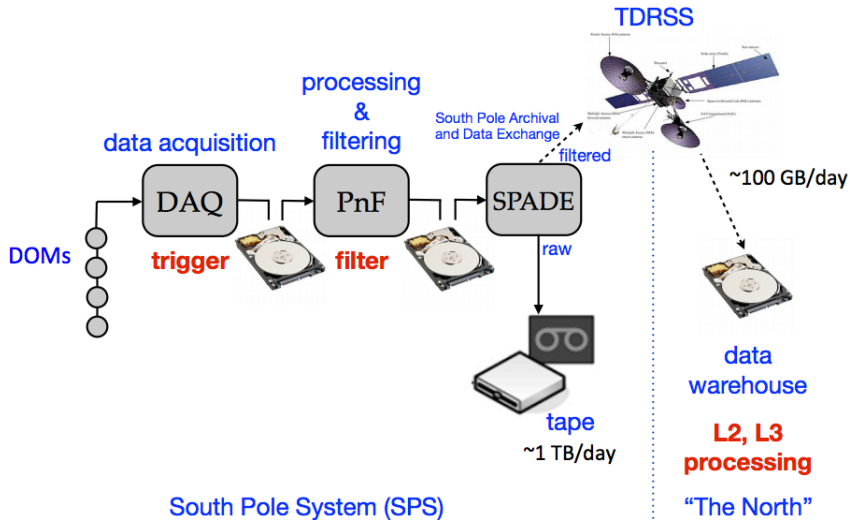
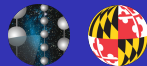
1. IceCube
2. Existing Followup Programs
3. Astrophysical Starting Events
4. Online Starting Event Alerts
5. Near Realtime Alerts and Analysis

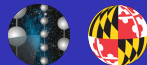


## Detector Info:

- ▶ 1 km<sup>3</sup> instrumented volume
- ▶ 86 Strings (completed May 2011)
- ▶ 60 Optical Modules per String
- ▶ 5160 total Optical Modules
- ▶ Wide Energy Range:  
~ 10 GeV < E → PeV
- ▶ ~ 99% uptime, 4 $\pi$  FOV

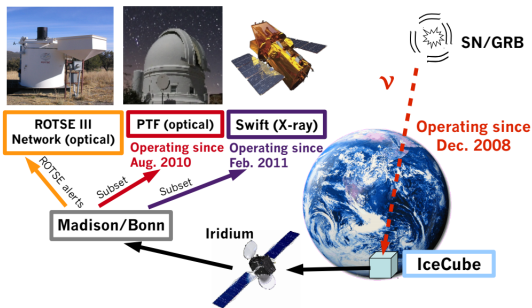






## Optical, X-ray, and Gamma follow-up (OFU, XFU, GFU)

[arXiv: 1309.6979](https://arxiv.org/abs/1309.6979) (p. 40)



### OFU/XFU:

- ▶ Neutrino Multiplets
- ▶ < 100s
- ▶ < 3.5°
- ▶ Alert ROTSE/PTF
- ▶ Alert Swift

### GFU:

- ▶ Neutrino Flares
- ▶ Seconds to Weeks
- ▶ Alert MAGIC/VERITAS

Typical latency for alerts is 1-2 minutes

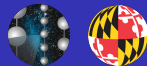


Iridium communication is limited, but not maxed out:

- ▶ Max 1800 Bytes per message
- ▶ Bandwidth: 90 kB/hour
- ▶ Latency: 1-2 min

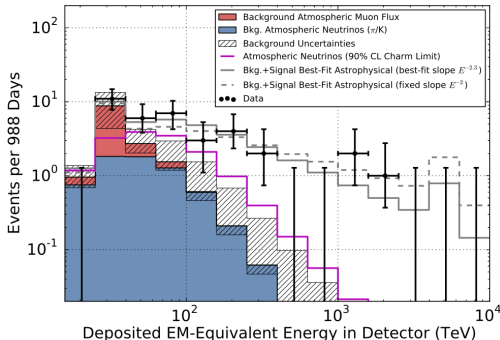
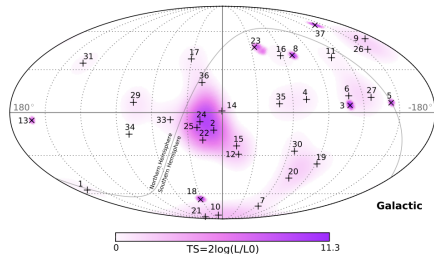
Current usage is  $\sim 30$  kB/hour  
so there is room for sending more!

# ASTROPHYSICAL STARTING EVENTS

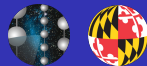


988 live-days between 2010 - 2013  
 37 events (2 coincident with IceTop)  
 Background:

$\sim 8.4 \pm 4.2$  cosmic ray  $\mu$   
 $\sim 6.6_{-1.6}^{+5.9}$  atmospheric  $\nu$

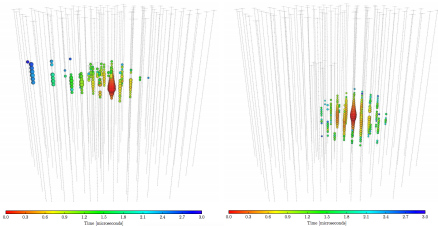


- ▶ [arXiv:1405.5303](https://arxiv.org/abs/1405.5303)
- ▶ No significant source detected
- ▶ Clear opportunity for multi-messenger searches
- ▶  $\sim 1$  event per month



## Additional Charge Cut:

- ▶ Total charge  $> 6000$  pe

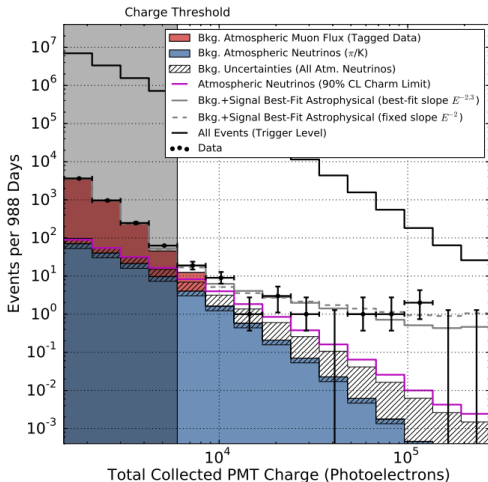


30.8 TeV Track

$\lesssim 1.2^\circ$  error

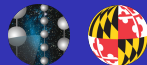
28.9 TeV Cascade

$\sim 11.7^\circ$  error



Simple, stable, fast event selection.





Similar to the other IceCube followup programs. We are working to implement an online starting event selection along with alerts.

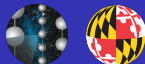
Event  $\rightarrow$  Online Alert  $\rightarrow$  UW Madison  $\rightarrow$  AMON

Highlights:

- ▶ Pre cut on charge reduces data to  $\sim 1\text{Hz}$
- ▶ Starting event selection is fast
- ▶ Alerts can be sent over Iridium (1-2 min)
- ▶ Low charge cut:  $\sim 5/\text{day}$
- ▶ High charge cut:  $\sim 1/\text{month}$

But...

- ▶ 80% of sample is cascades
- ▶ Full event reconstruction is slow



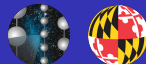
For all events, good timing and energy can be obtained online. For angular pointing, however, we will want to distinguish tracks and cascades.

## Tracks:

- ▶ Online reconstructions do OK
- ▶ 1-2° online
- ▶ < 1° offline

## Cascades:

- ▶ Poor online reconstruction 10's°
- ▶ Offline reconstruction does better

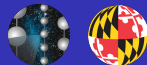


## A staged approach.

For the high energy events, the hits alone are 30-40 kB, too large for an Iridium message (1.8 kB).

- ▶ Could split the data into smaller packets and recombine in the north
- ▶ Might be able to expand fast data transmission capabilities from pole

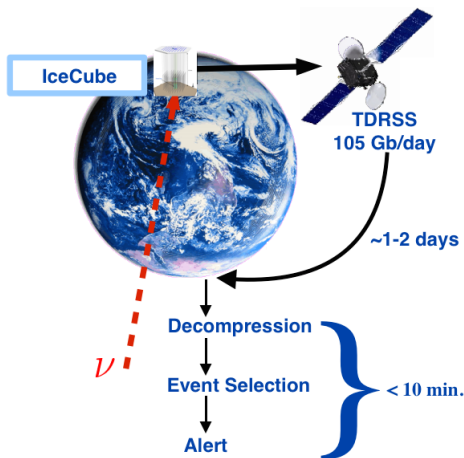
In any case, we would then automatically run the offline reconstructions and provide a second update alert with best angular estimate and errors. These will be delayed one to a few hours, depending on final configuration.

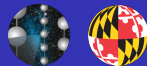


A testbed realtime system has been running in the north for many months now.

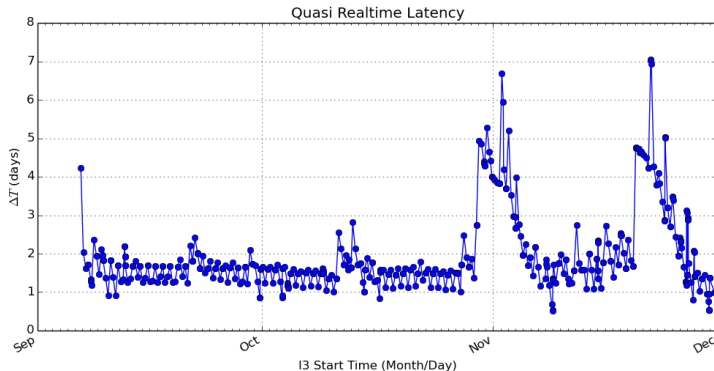
- ▶ Uses normal data transmission
- ▶ Decompress data
- ▶ Recalculate online variables.
- ▶ Apply event selections
- ▶ Send internal alerts (email)
- ▶ Save alerts (VOEvent format)

This system is being used develop procedures, but also functions as a near realtime alert system. It is not broadcasting alerts, however.

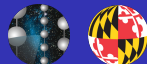




Compared to the wait time for data transmission, the data processing is fast. Latencies are typically 1-2 days.



\* The increased latency periods correspond to file system reconfigurations at UW-Madison and are not indicative of normal running.



This is a very active time for IceCube as we transition from discovery to realtime observations.

Stay tuned, and thanks to AMON for their role in all of this.