

The IceCube Realtime Program

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RUHR
UNIVERSITÄT
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RUB



ICECUBE
NEUTRINO OBSERVATORY

Summary

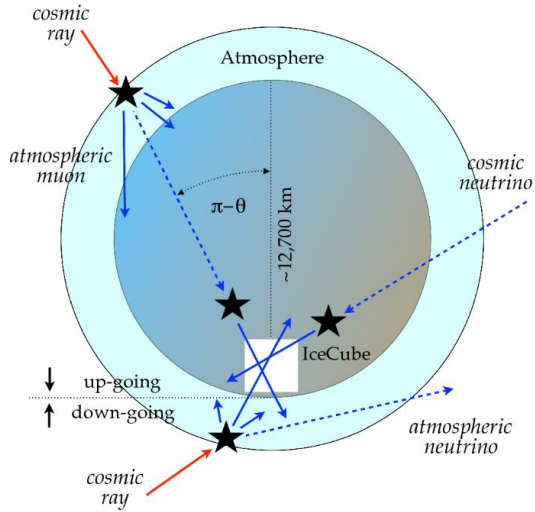
- Why a realtime program?
- Event selection
- Direction reconstruction
- New possibilities for the reconstruction



Why a realtime program?



Identify neutrino sources

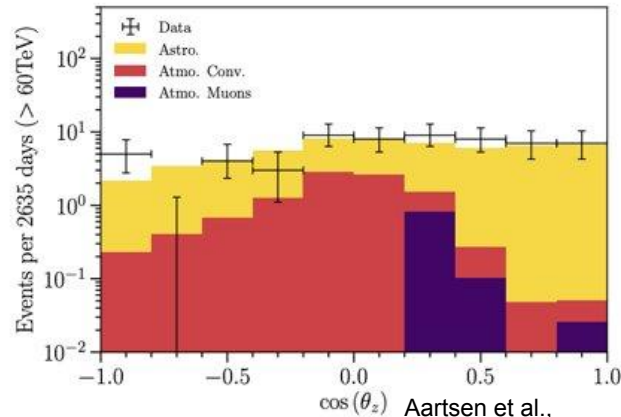
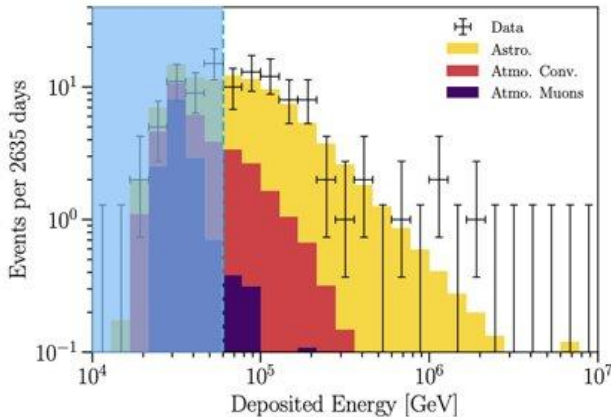


- Detection of a diffuse astrophysical neutrino flux in 2013.

Aartsen et al., *Science* 342 (2013), 1242856.



- Despite evidence of neutrino emission from some sources, origin of most of the astrophysical neutrino flux still unknown.

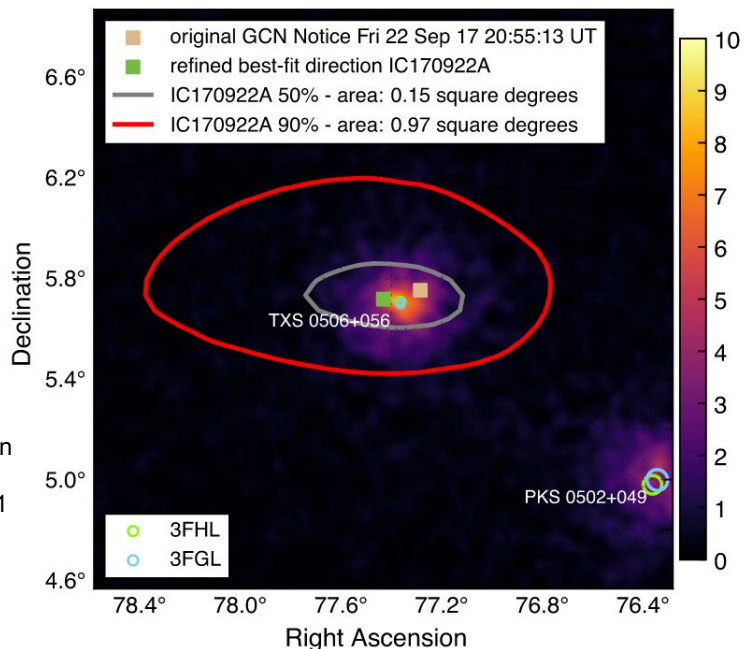


Aartsen et al.,
Science 342 (2013), 1242856.

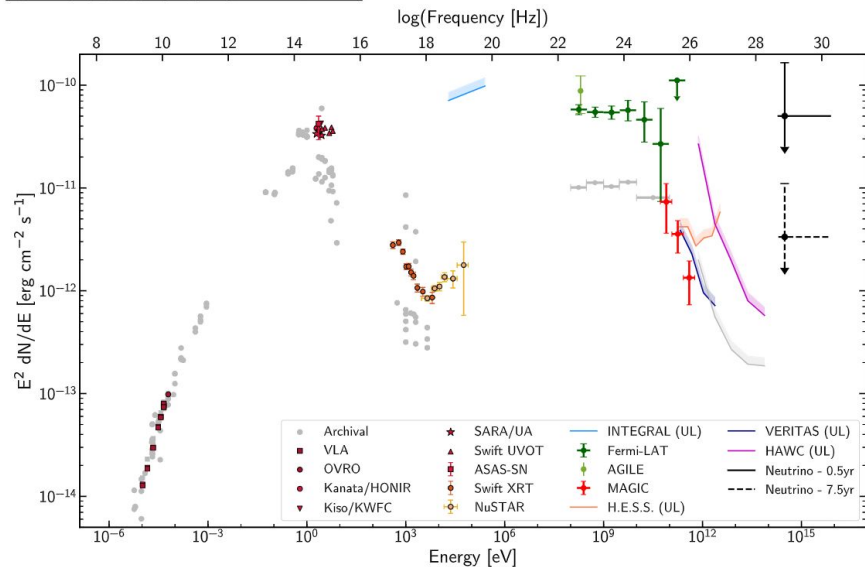
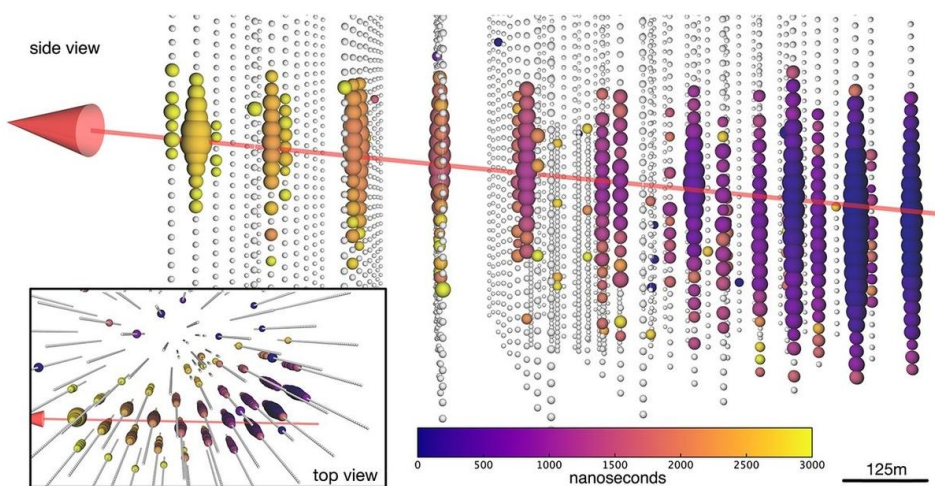
- **Realtime alerts** to identify possible sources. **Angular reconstruction extremely important.**

Multi-messenger astrophysics: IC170922A 290 TeV neutrino

Coincident with the flaring blazar TXS 0506+056.

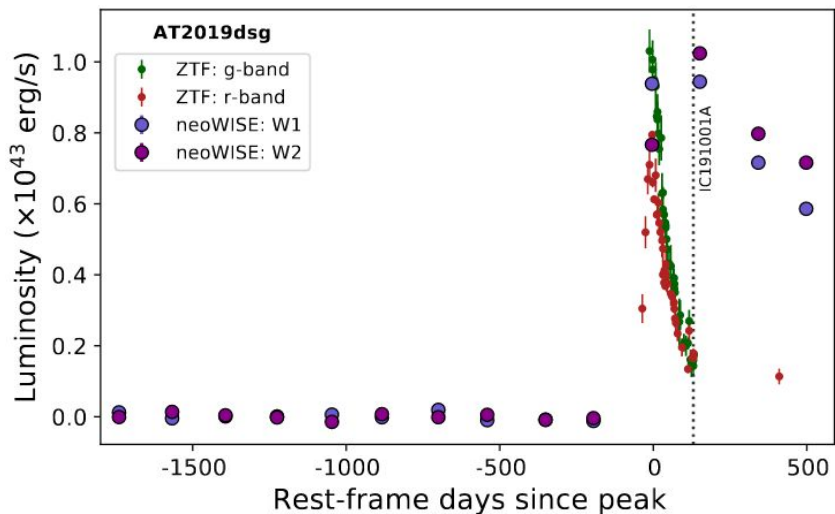


IceCube
Collaboration
et al.
Science 361
(2018),
eaat1378.

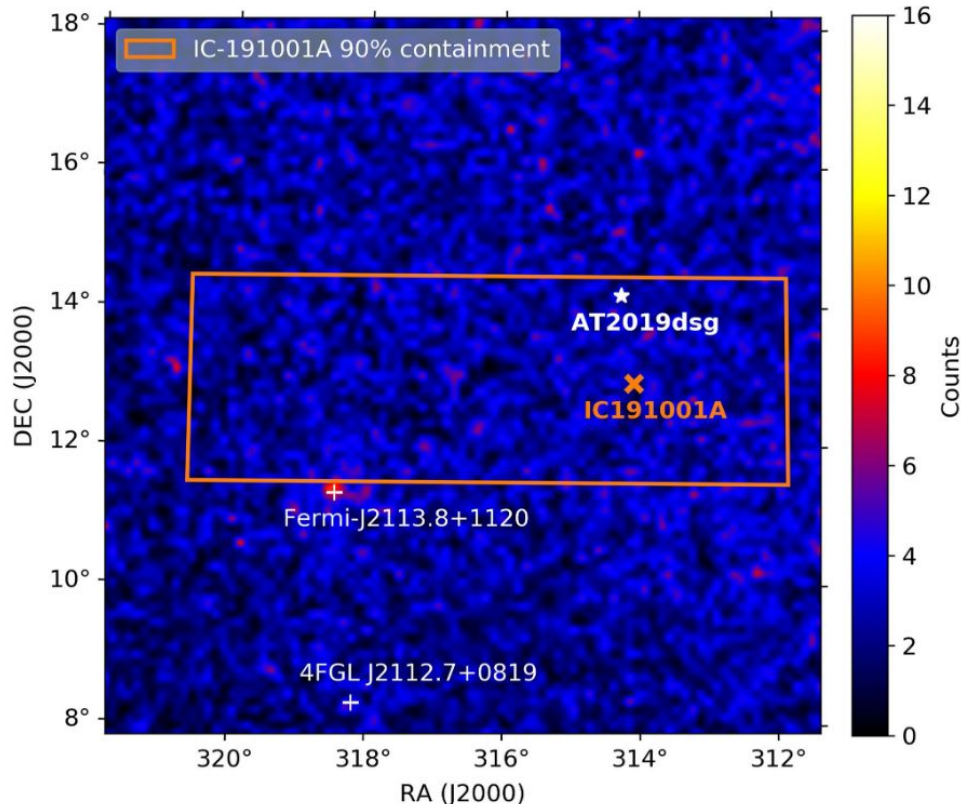


Multi-messenger astrophysics: Coincidence with a TDE

- Identification of a coincident TDE enabled by the realtime program.

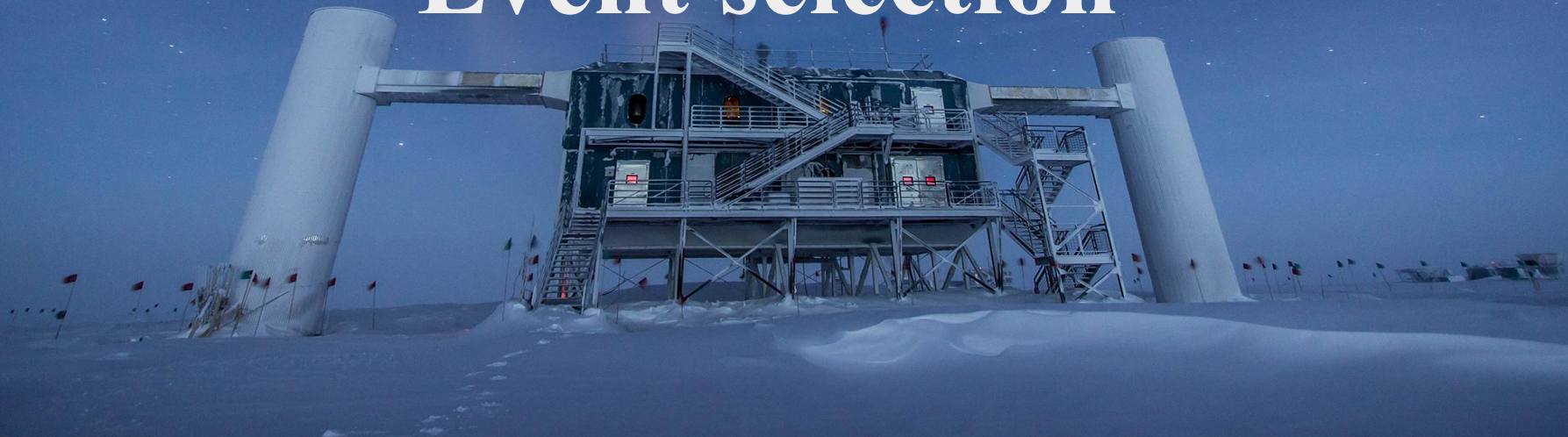


van Velzen et al., *arXiv e-prints* (2021), arXiv:2111.09391.



Stein et al., *Nature Astronomy* 5, (2021), 510-518.

Event selection



Event selection

Events selected through three different selections:

1. High-quality track events;

IceCube, MAGIC and VERITAS collaborations, *JINST* 11 (2016), P11009.

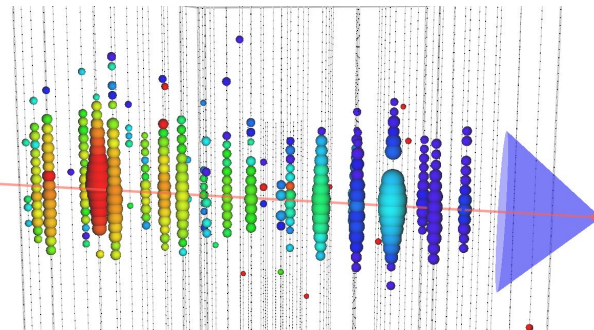
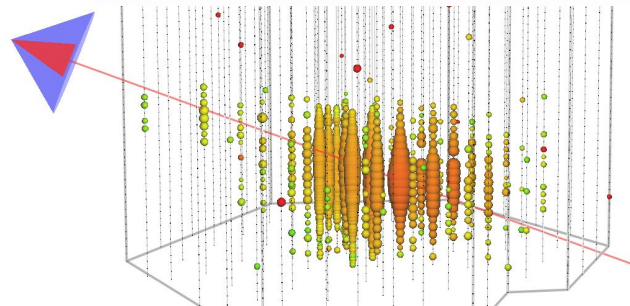
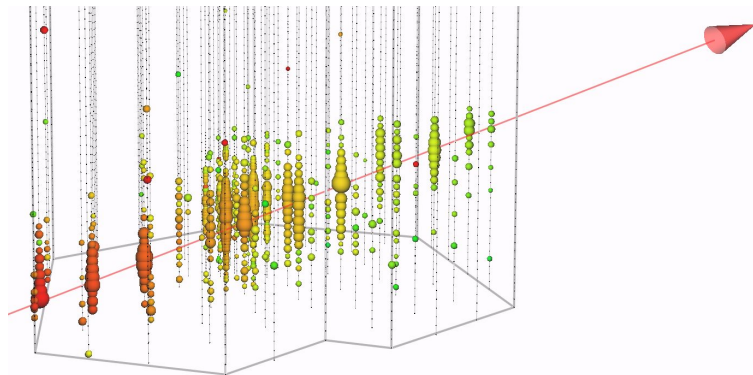
2. Starting events

(interaction vertex inside the detector);

IceCube collaboration, *Phys. Rev. Lett.* 113 (2014), 101101.

3. Very-high numbers of photoelectrons.

IceCube collaboration, *Phys. Rev. Lett.* 111 (2013), 021103.



Alert streams

Streams defined to have a certain *signalness*:

- E energy of the event;
- δ declination.

Estimated using simulations.

Blaufuss et al., *PoS ICRC2019* (2019), 1021.

$$\text{Signalness}(E, \delta) = \frac{N_{\text{signal}}(E, \delta)}{N_{\text{signal}}(E, \delta) + N_{\text{background}}(E, \delta)}$$

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**Bronze
stream**

$30\% \leq \text{Signalness}^* < 50\%$
~20 per year

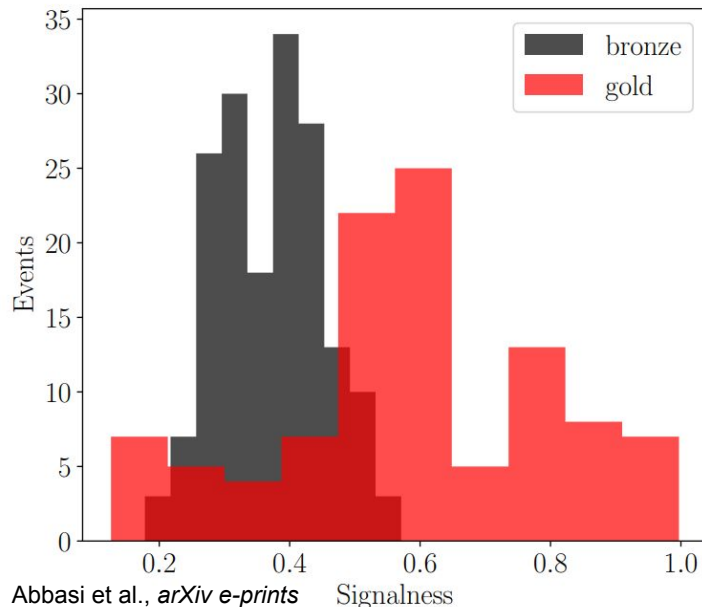


**Gold
stream**

$\text{Signalness}^* \geq 50\%$
~10 per year

*On average

Blaufuss et al., *PoS ICRC2019* (2019), 1021.



Abbasi et al., *arXiv e-prints* (2023), arXiv:2304.01174.

Signalness

Gamma-ray Coordinate Network (GCN) Notices and Circulars



time

Gamma-ray Coordinate Network (GCN) Notices and Circulars



GCN Notice (Rev0)

- Processed at South Pole.
- With:
 - Discovery time and date;
 - IceCube run and event number;
 - Best-fit coordinates;
 - Angular radii 50% and 90%;
 - Signalness;
 - False Alarm Rate;
 - Likely Neutrino energy
(assuming a spectral index = 2).

Gamma-ray Coordinate Network (GCN) Notices and Circulars



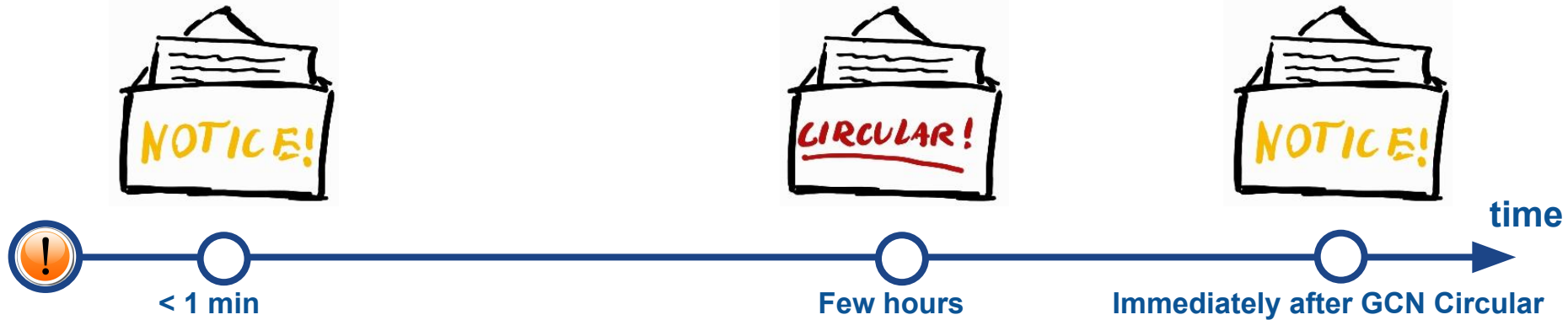
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GCN Circular

- Processed at north.
- More sophisticated algorithm.
- Refined direction and angular coordinates (rectangular error region).

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GCN Circular

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GCN Notice (Rev1)

- Best-fit position and angular radii updated with circularized errors from GCN Circular.

Direction reconstruction



Differences between reconstruction algorithms

Differences between reconstruction algorithms

Abbasi et al., *JINST*
16 (2021), P08034.

GCN Notices (Rev0) → **SplineMPE:**

- Continuous light emission assumption (simplification);
- Fast;
- Same reconstruction algorithm of many offline analyses (example: 4.2 sigma result for NGC 1068).

Aartsen et al., *Science* 378 (2022), 538.



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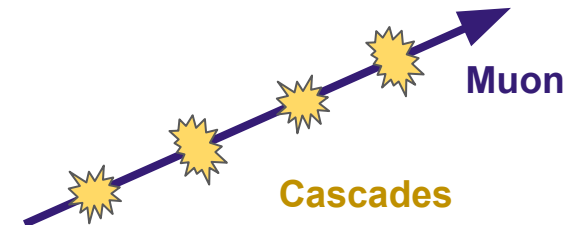
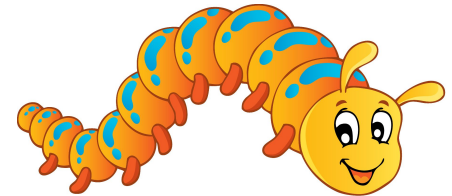
Aartsen et al., *Science* 378 (2022), 538.



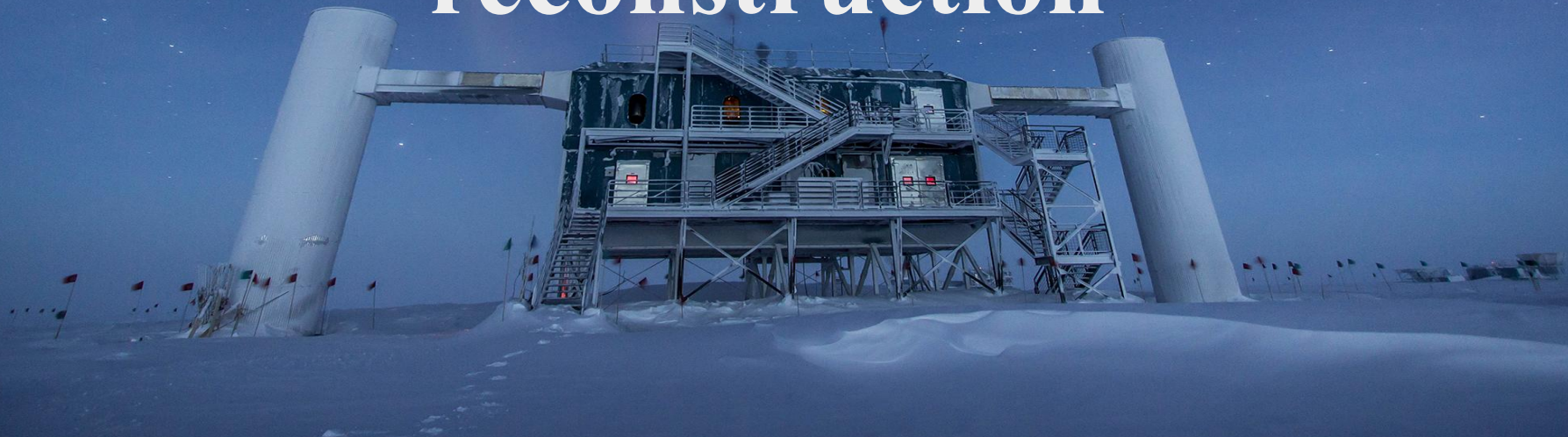
GCN Circulars → algorithm inspired on and referred to as **Millipede**:

Aartsen et al., *JINST*
9 (2014), P03009.

- Stochastic-light-emission assumption (more realistic);
- Very computationally expensive;
- Combined with spatial likelihood scan (more resistant against local minima)



New possibilities for the reconstruction

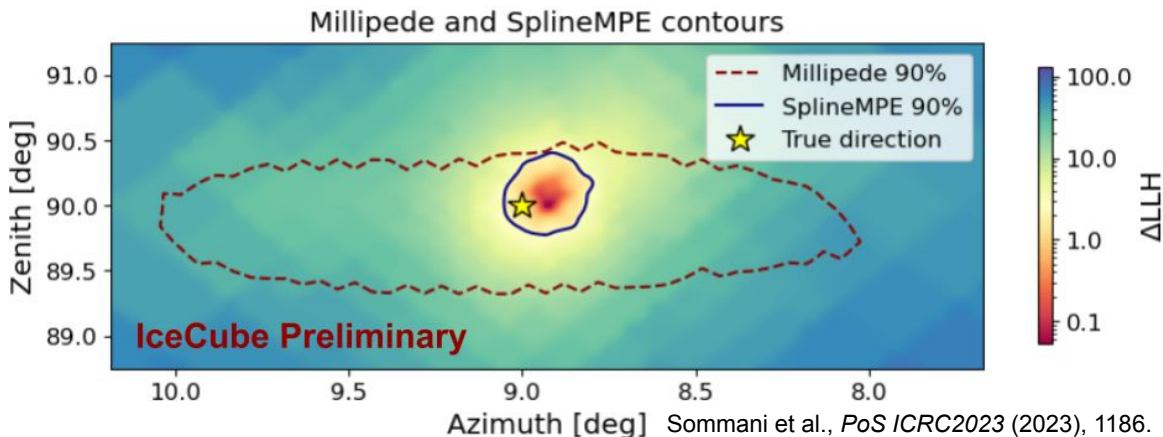


- **Millipede affected by known systematic uncertainties (as in the south-pole ice models)**
Lagunas Gualda et al., *PoS ICRC2021* (2021), 1045.
- **Efforts to improve Millipede's performances.**
Yuan et al., *PoS ICRC2023* (2023), 1005.
- **SplineMPE robust against known systematics.**
Sommani et al., *PoS ICRC2023* (2023), 1186.

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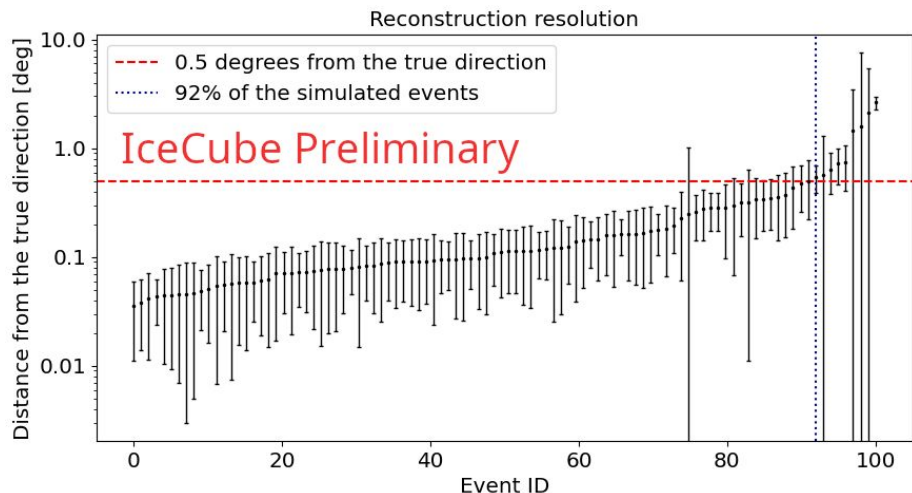


- SplineMPE ends up easily in local minima;
- But, SplineMPE + sky scan approach → contours much smaller than with Millipede (and still compatible).

Sommani et al., *PoS ICRC2023* (2023), 1186.

- **Improved Millipede and SplineMPE implemented and currently tested on the infrastructure for the IceCube realtime system.**

Lincetto et al., *PoS ICRC2023* (2023), 1106.



Conclusions

- ❖ IceCube realtime program promising for :
 - Multimessenger astrophysics;
 - Discovering new neutrino sources.
 - ❖ Realtime alerts sent out:
 - From three different selections;
 - In two different streams (Gold and Bronze), depending on the *Signalness*.
 - ❖ GCN Notice:
 - Immediately sent out;
 - SplineMPE.
 - ❖ GCN Circular:
 - Few hours later;
 - Millipede.
 - ❖ New possibilities for the reconstruction in realtime.
- 
- The background of the slide is a photograph of the IceCube observatory. It shows a complex metal structure with multiple levels, stairs, and railings, situated in a snowy, high-altitude environment. Two large, white cylindrical structures are visible on either side of the main building. The sky is dark blue with many stars and the faint Milky Way galaxy visible. Small flags are planted in the snow around the base of the structure.

A silhouette of a large radio telescope dish is positioned on the right side of the frame, pointing towards the left. The background is a dramatic sunset or sunrise, with a bright orange sun low on the horizon, creating a lens flare effect. The sky transitions from a deep orange near the horizon to a dark, almost black, color at the top. The overall mood is serene and contemplative.

Thank you for listening

Credit: Sven Lidstrom, IceCube/NSF