Hunting neutrino sources in IceCube

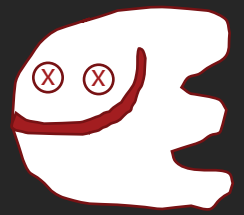
Étienne Bourbeau
Mohammed Rameez
David Jason Koskinen

Nordic Winter School
January 3rd 2019

UNIVERSITY OF COPENHAGEN

Multi-Messenger Astronomy

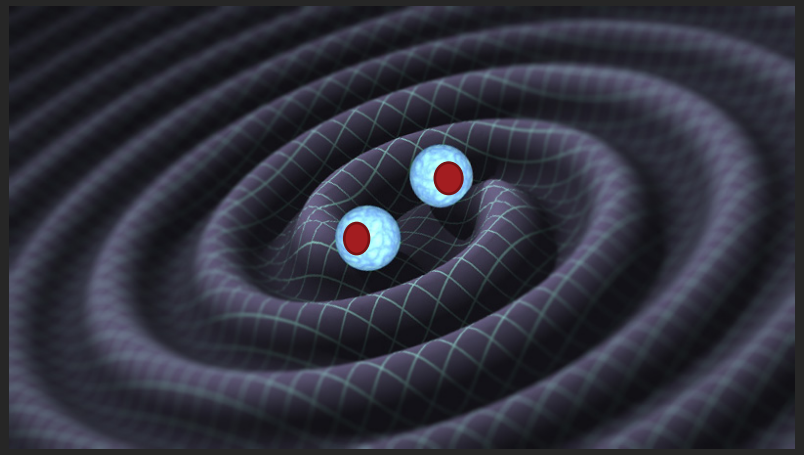
Photon (>1000 yrs old)



Cosmic Rays (~100 yrs)

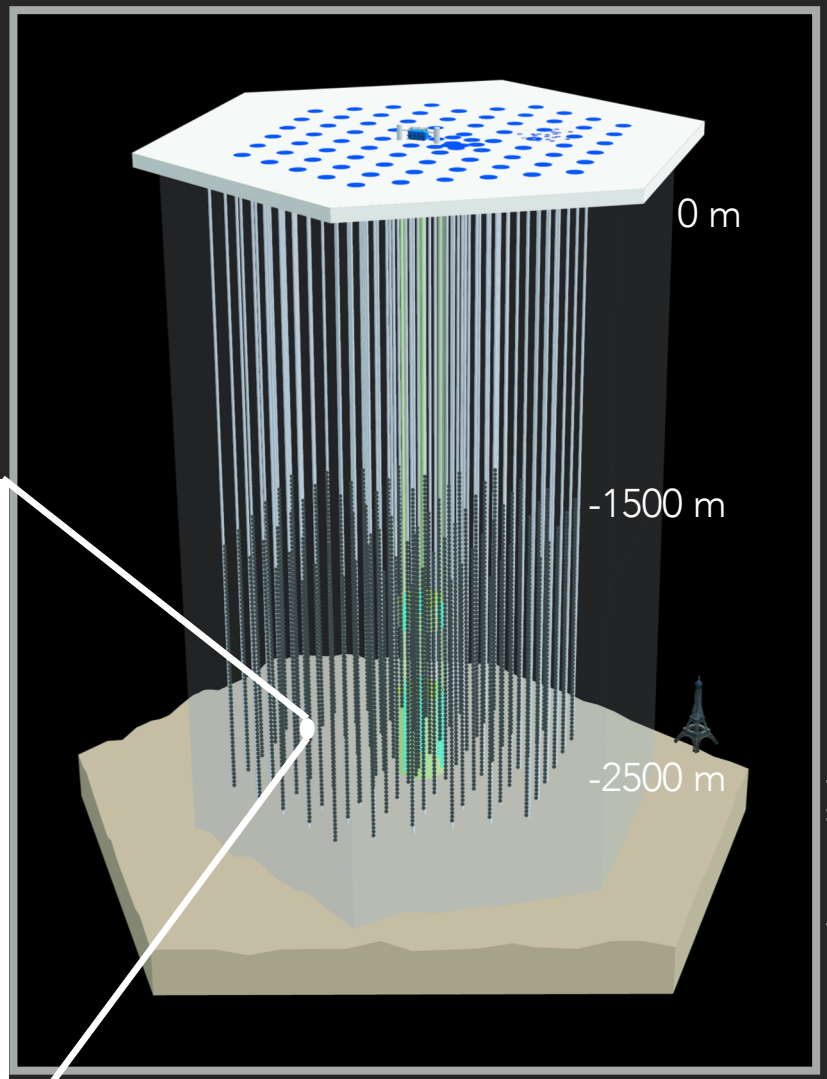
Neutrinos (~30 yrs old)

Gravitational waves (3 years old)

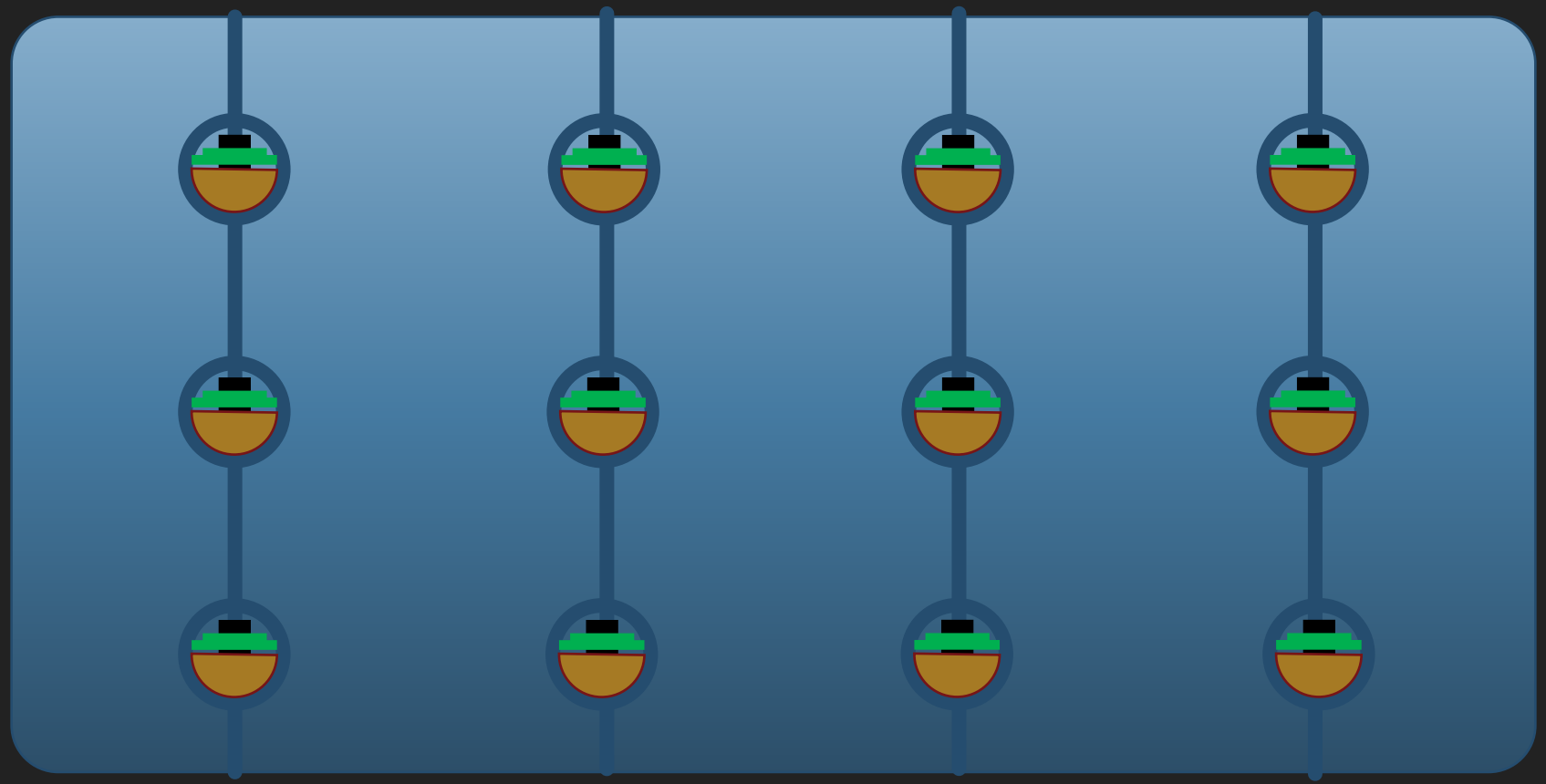


The IceCube Detector

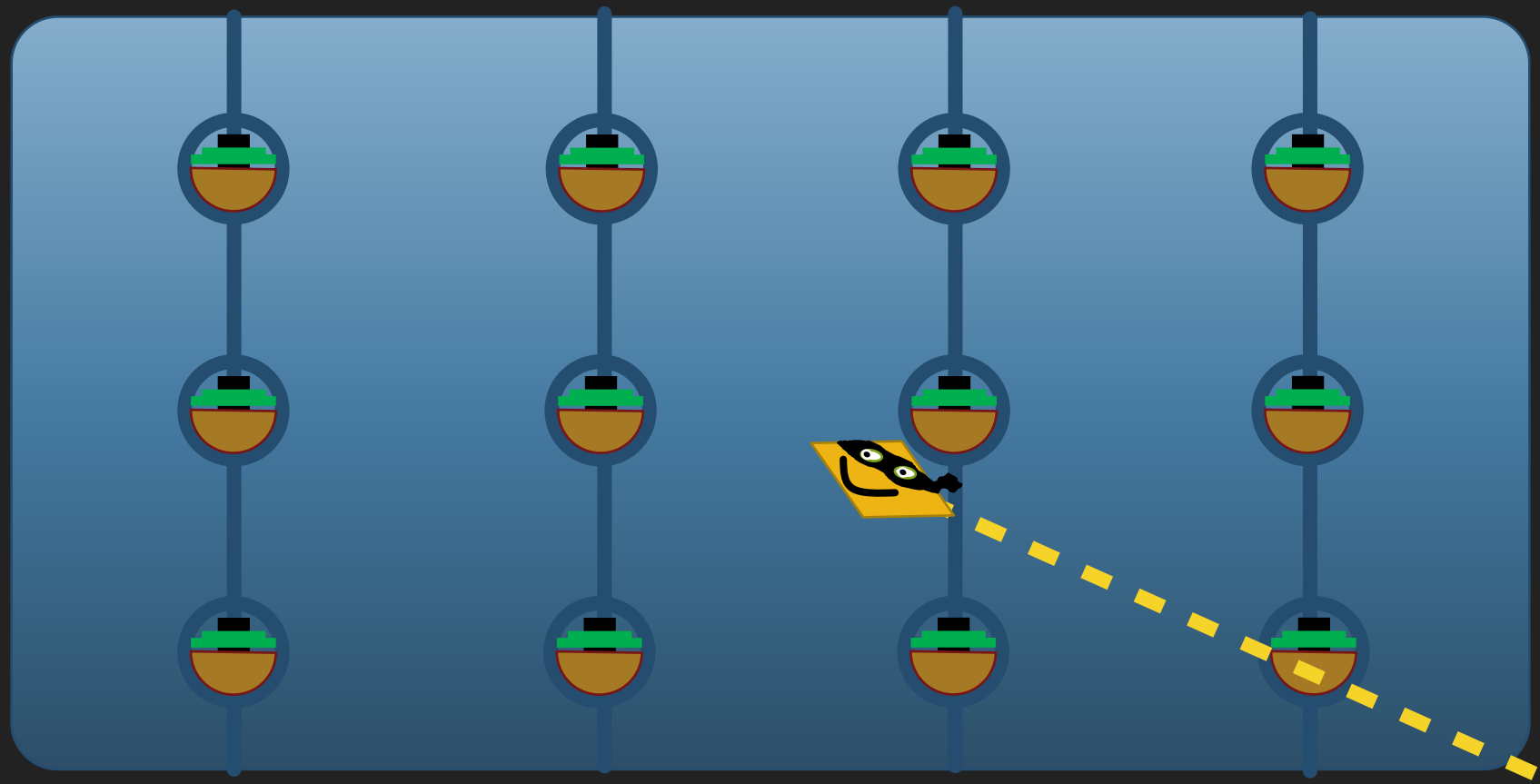
- 1 km^3 of ice
- 5160 light sensors
- Fully operational since 2011



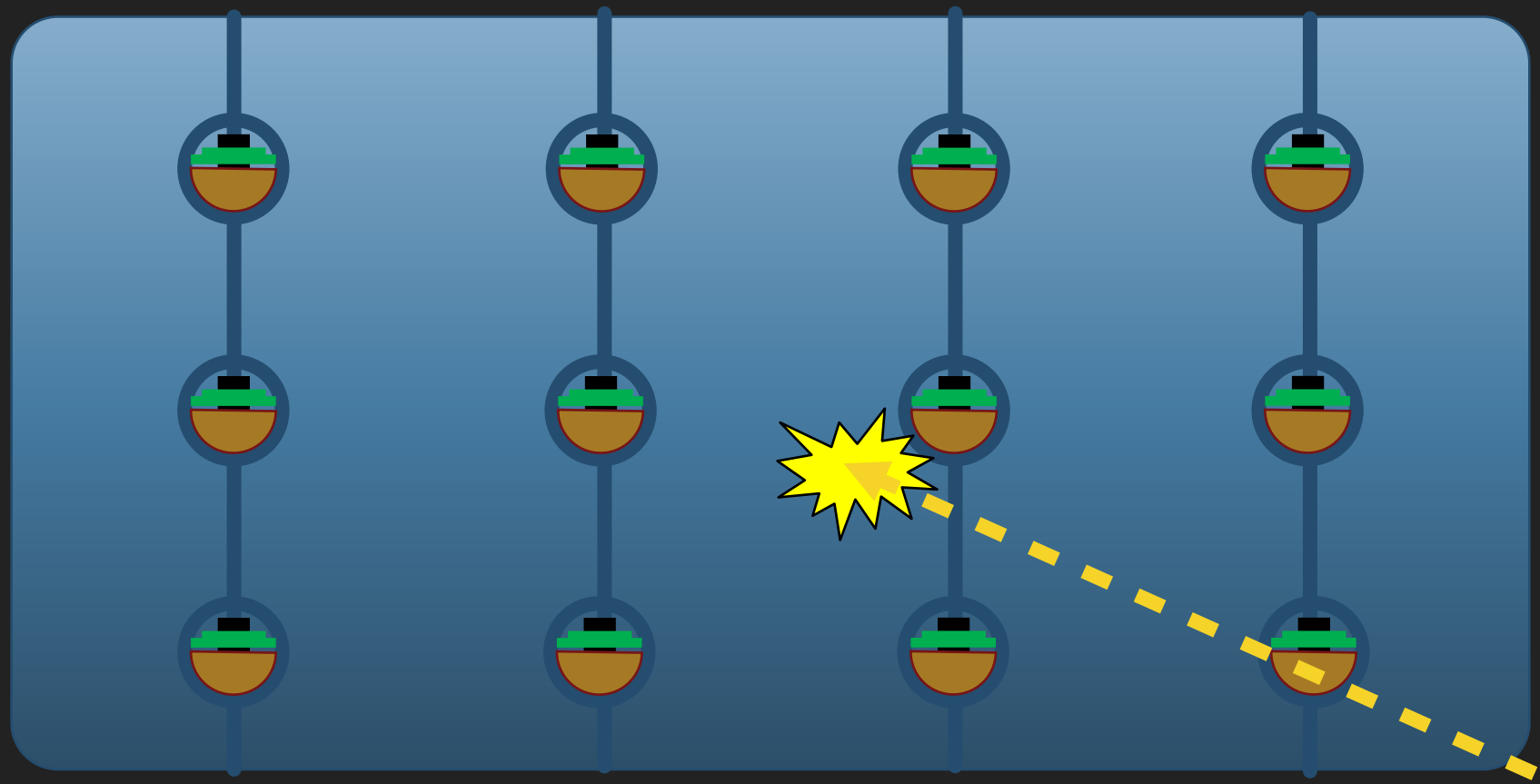
Detecting Neutrinos



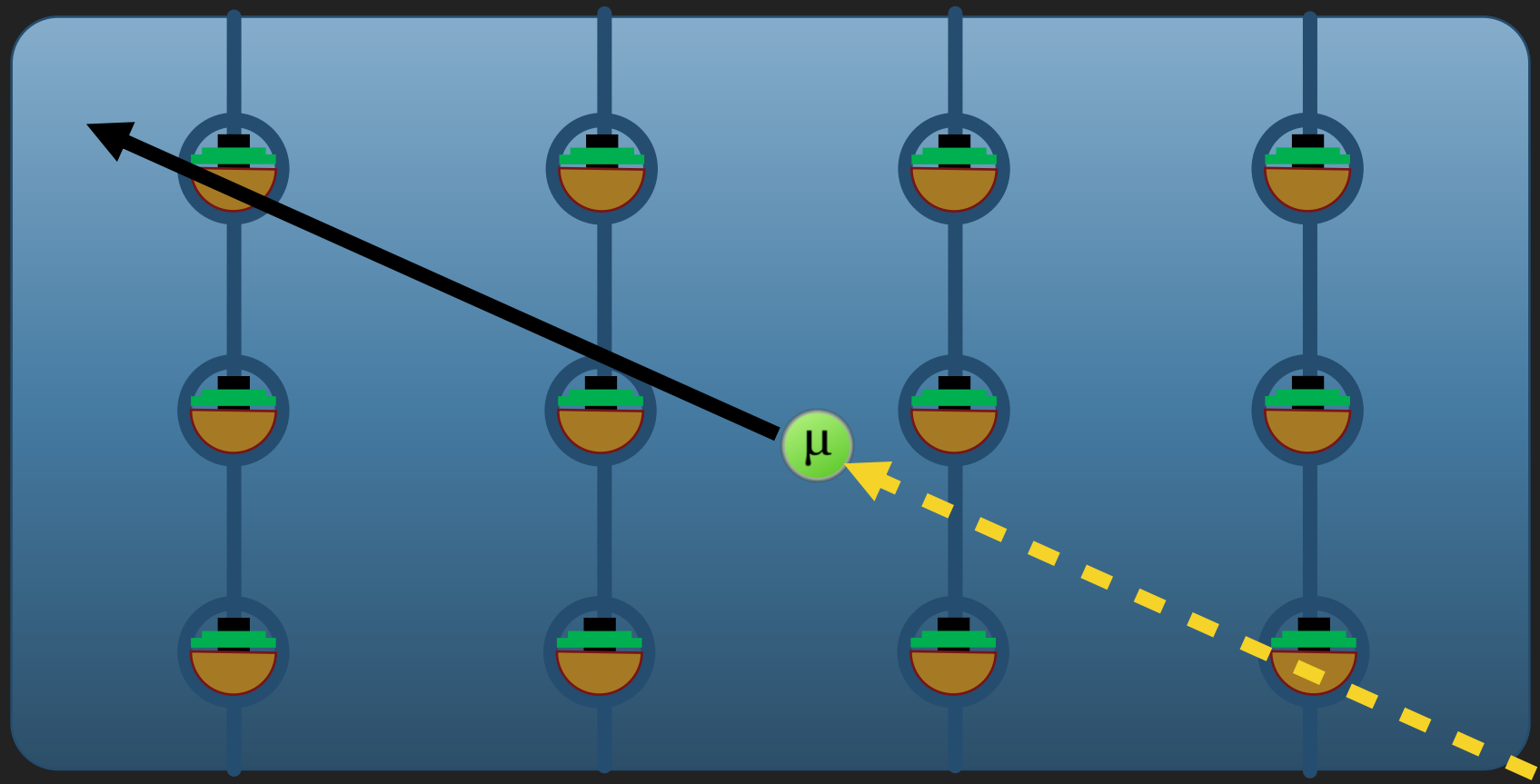
Detecting Neutrinos



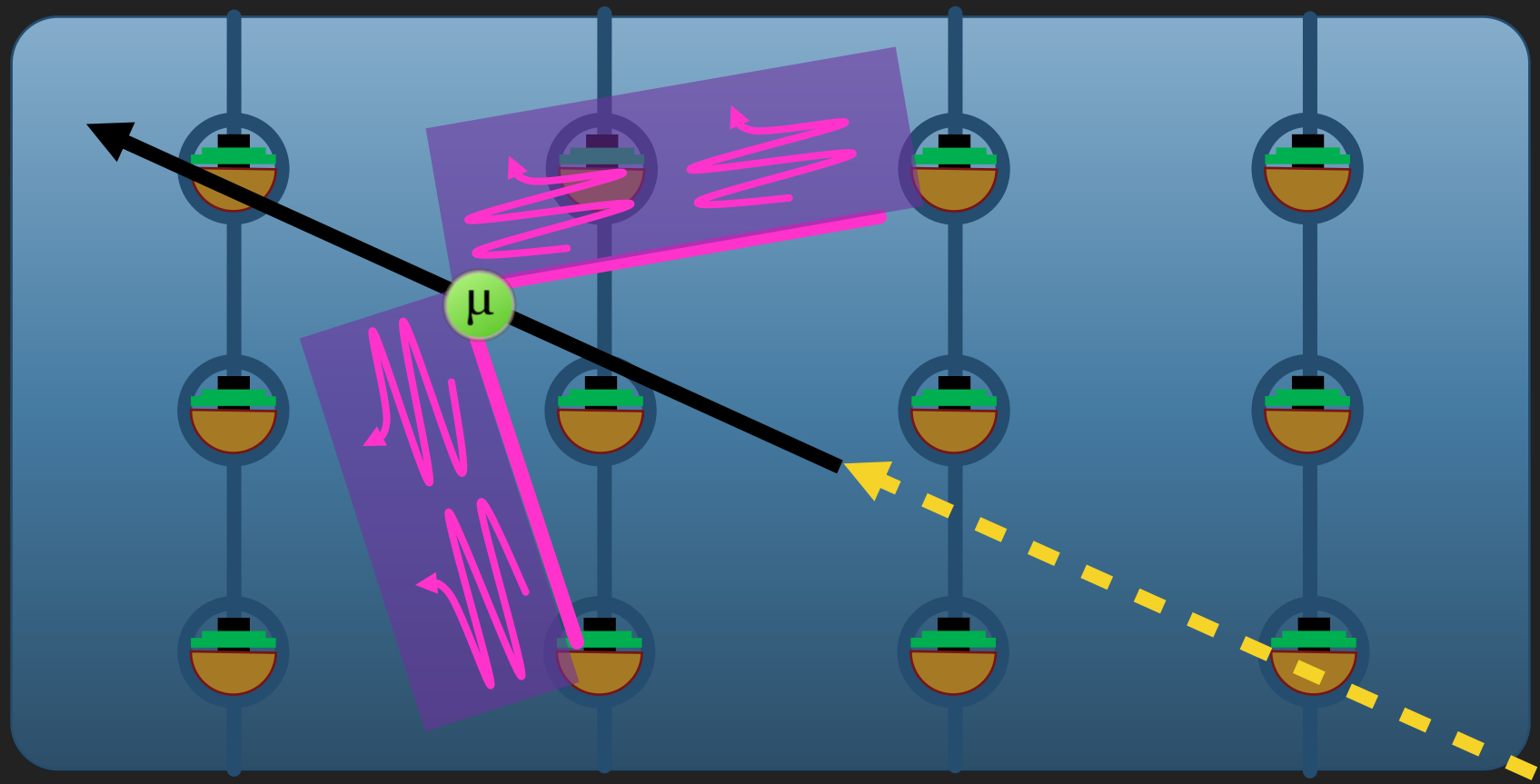
Detecting Neutrinos



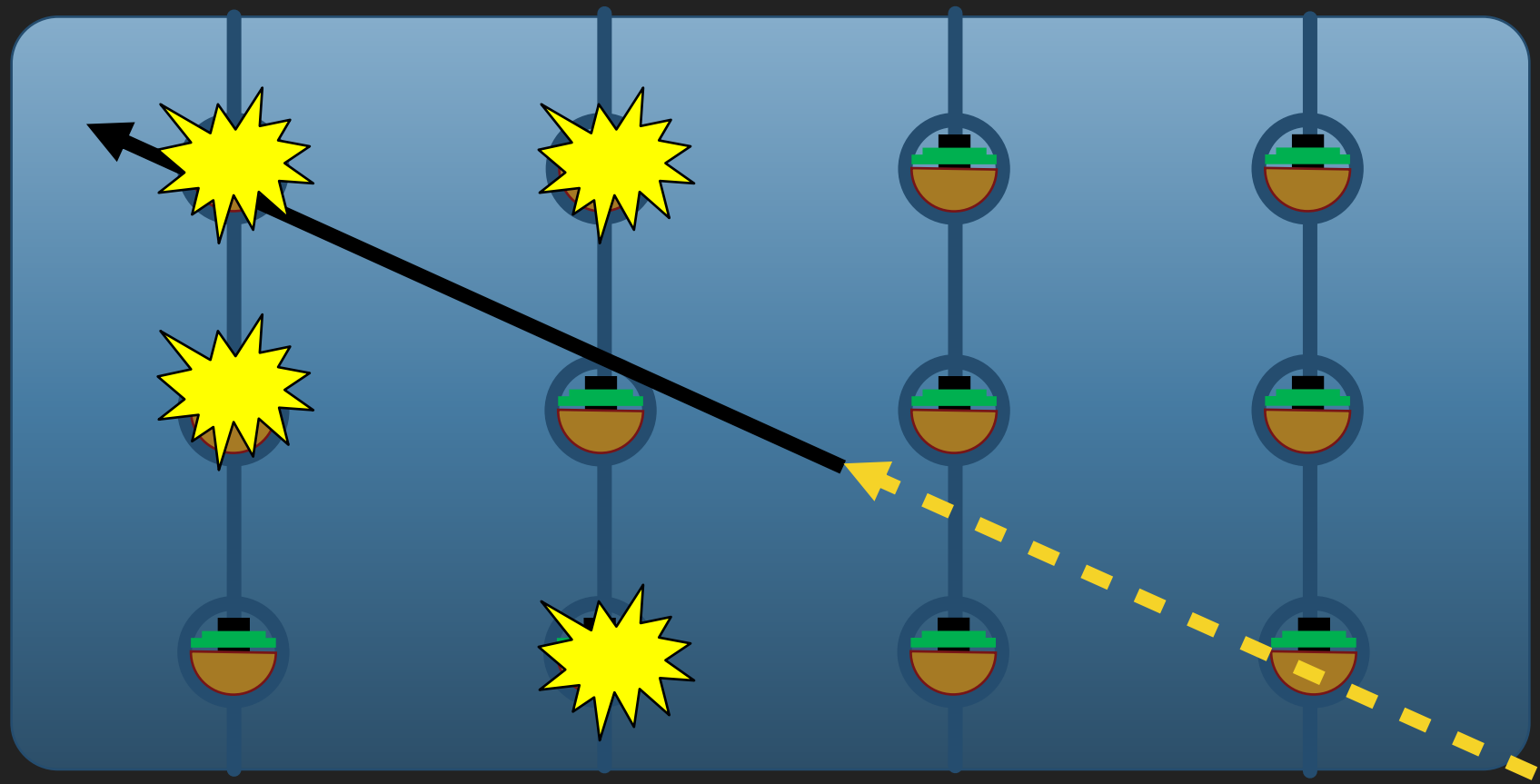
Detecting Neutrinos



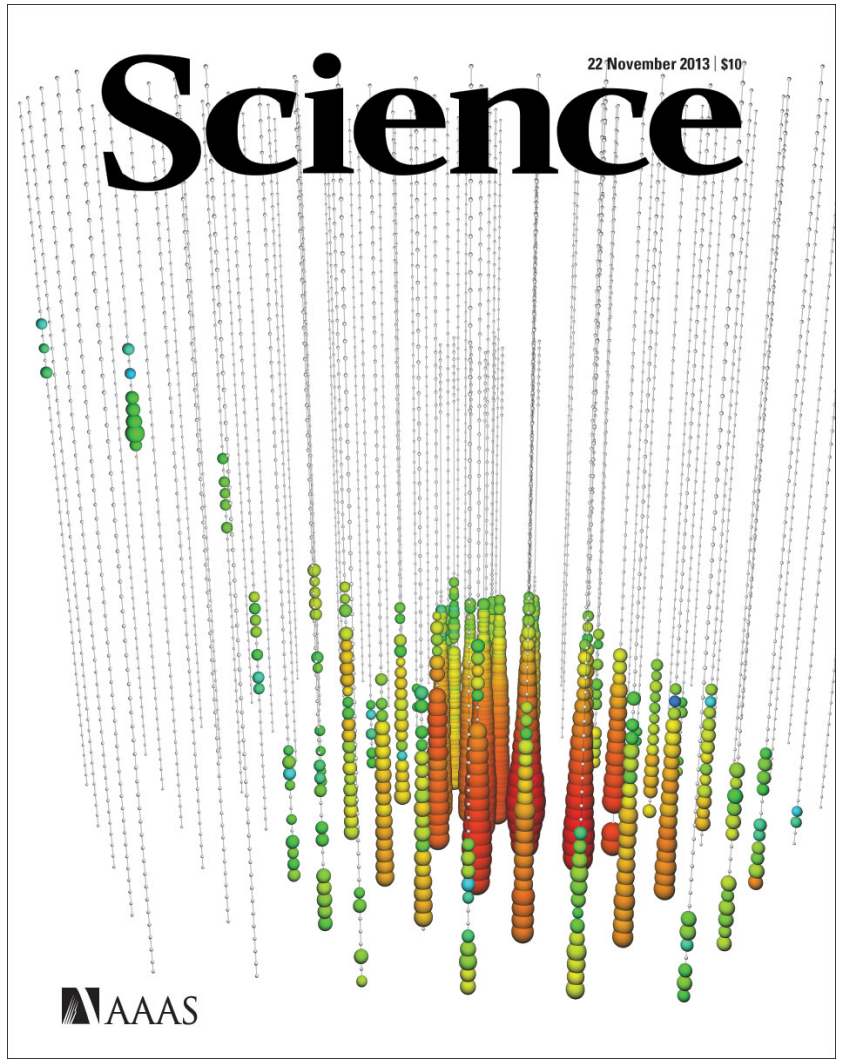
Detecting Neutrinos



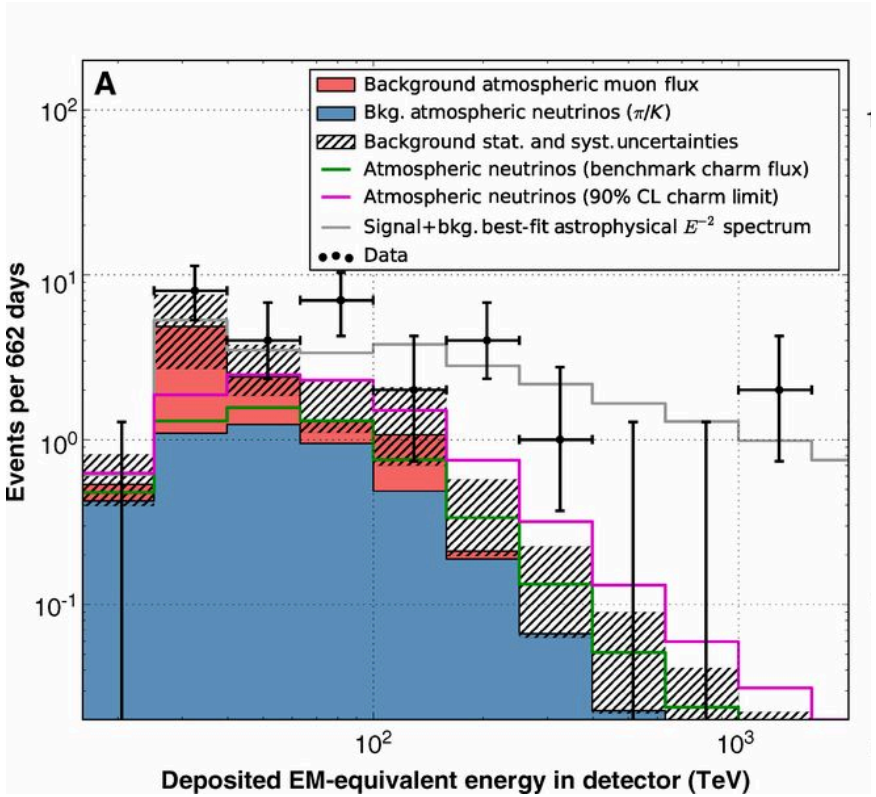
Detecting Neutrinos



2013: The search for neutrino sources begins

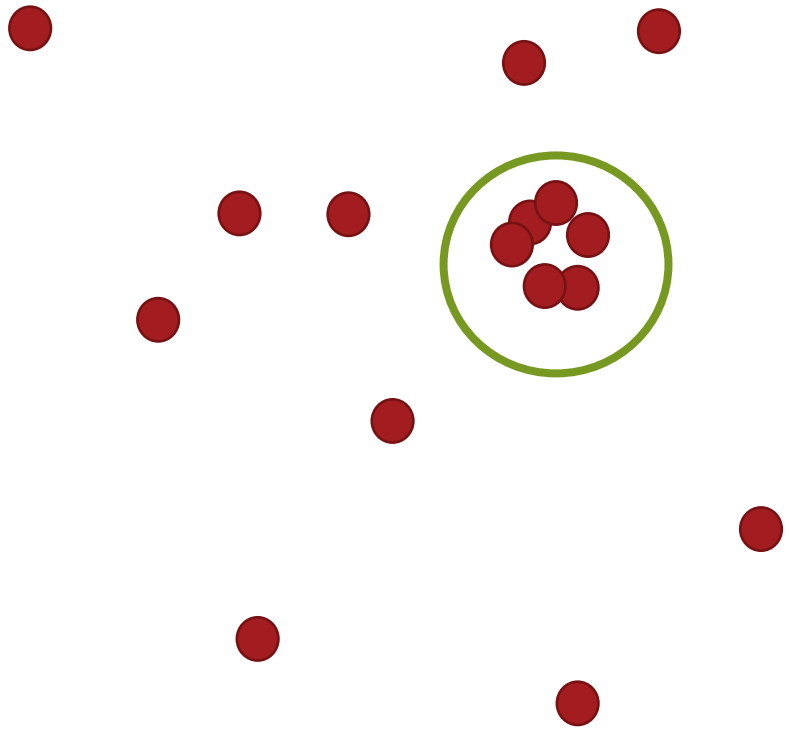


IceCube measures a diffuse flux of astrophysical neutrinos



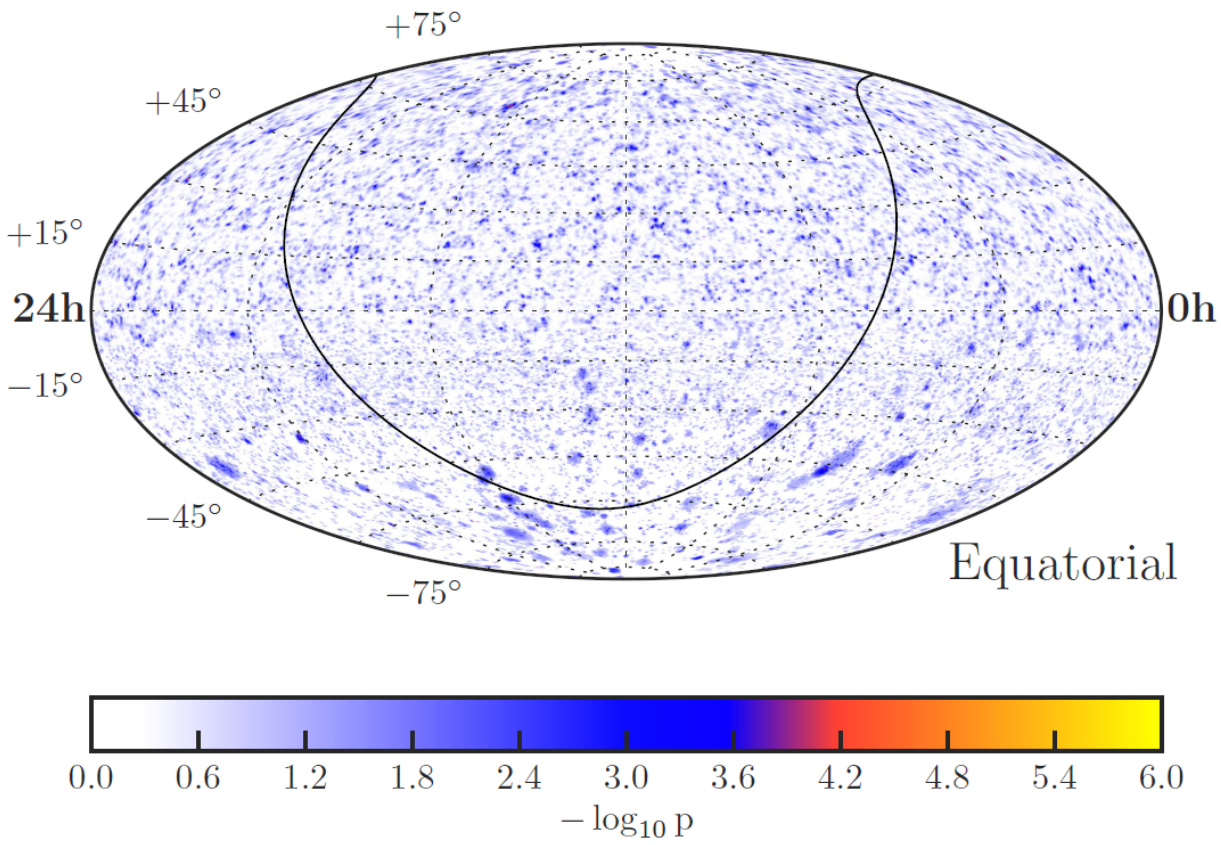
Context – The Search for Neutrino sources

To look for sources you can search for *clusters of events in space*



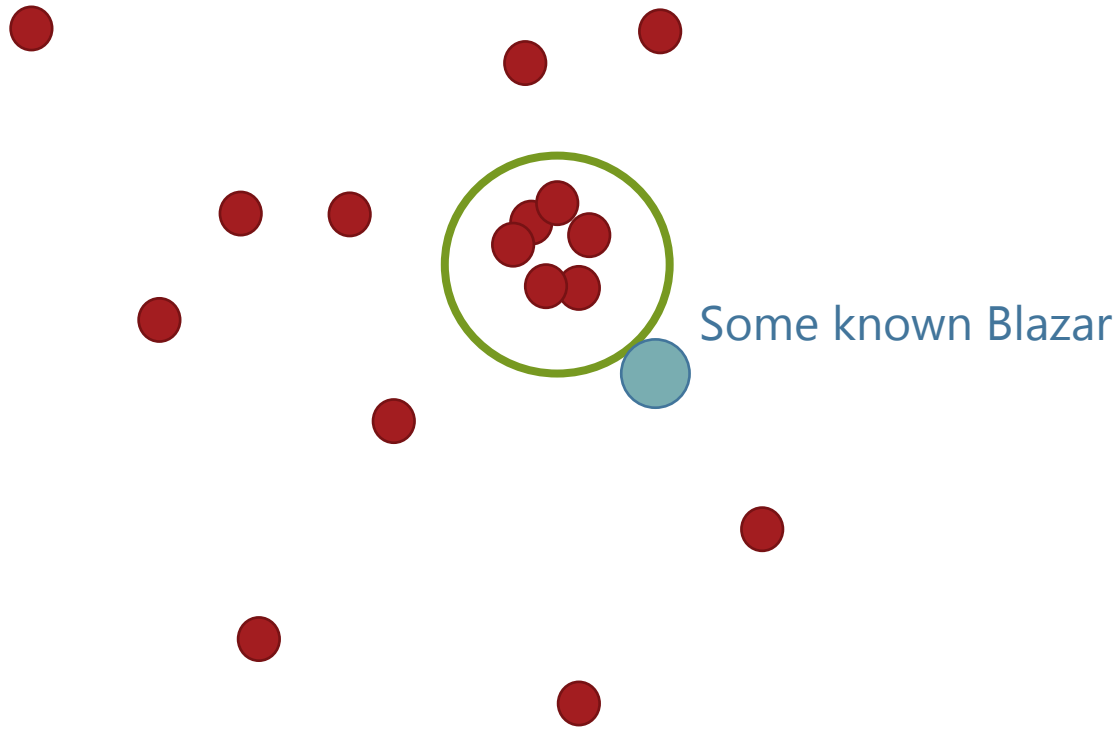
Context – The Search for Neutrino sources

- Currently, the state-of-the art search has been the all-sky Point Source analysis
- Sample of neutrino tracks with angular resolution < 0.5°
- All-sky unbinned likelihood methods fitting for 2 parameters (given a source hypothesis)
- **Many "warm spots" found, but none are significant post-trials**

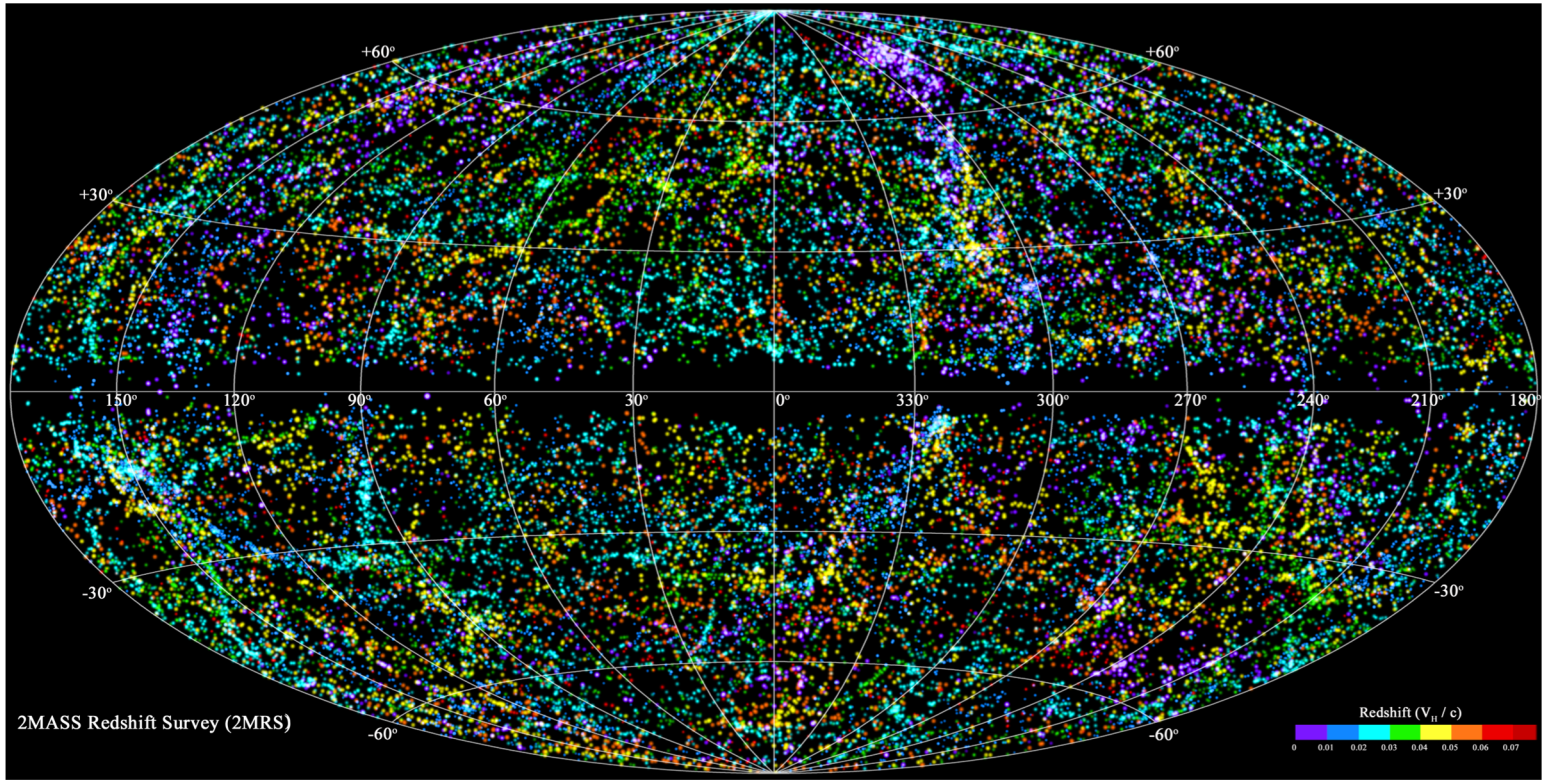


Refining the search

... by matching neutrinos to *templates*



Refining the search



- In this analysis, the template is a catalog of **galaxies up to redshift 0.03**
- This serves as a template mapping the **matter distribution in the local universe (up to 100 Mpc)**
- At this distance scale, matter distribution is **anisotropic**

Correlating warmspots to the local matter distribution

- The previous template can be compared to the **distribution of neutrino multiplets** detected by IceCube
- Here, we select a **subset of multiplets** matching some quality criteria.
- If a significant portion of these multiplets actually come **from low-luminosity sources**, their distribution should be anisotropic as well

Quantifying our correlation

- Maximize the **likelihood that a fraction f of neutrino multiplet** coming from the signal template

$$\ln \mathcal{L}(f) = \sum_{i=1}^{N_{ws}} \ln(f \cdot S_i + (1 - f) \cdot \mathcal{B}_i)$$

- From this we compute the following test statistic:

$$TS = -2 \cdot \frac{\ln \mathcal{L}(f)}{\ln \mathcal{L}(f = 0)}$$

- Then compare our result with the TS distribution of data **randomly scrambled in RA**

Results and Conclusion

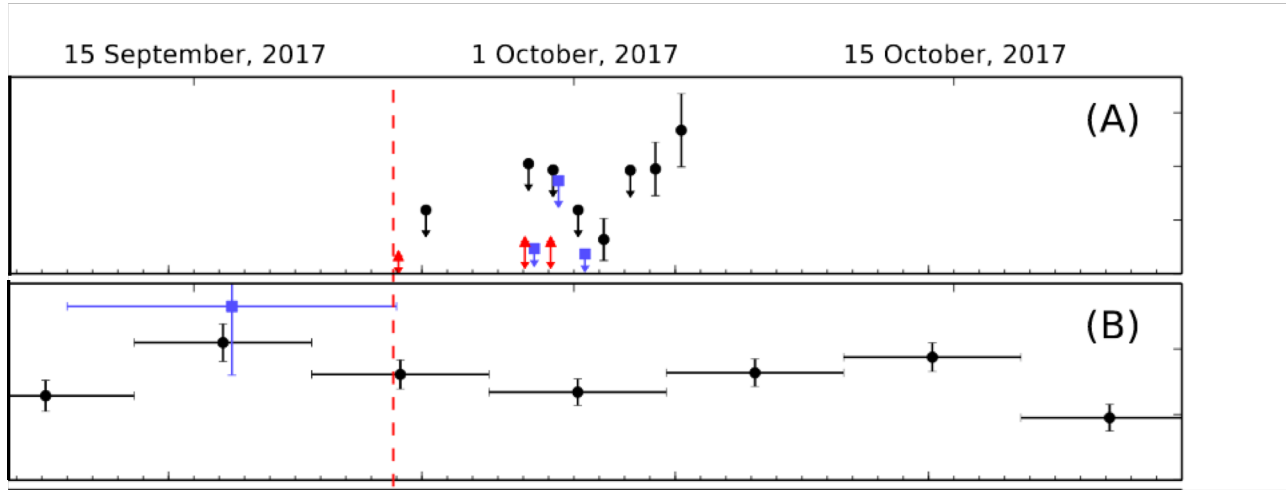
- **No correlations found**... ☹
- High-energy neutrinos are rare. Detecting HE neutrinos sources will require luck or **more refined hypotheses**
- Many other templates are being investigated, in both time-integrated and time-dependant domains
- At the same time, one must keep in mind **systematics** and the **look-elsewhere effect!**

Speaking of luck…

2018: First hints of a High-Energy Neutrino Source

MAGIC
(>90 GeV)

Fermi-LAT
(>100 MeV)



Backup - Expected outcome

(see 1612.07311)

$$n_o < \frac{TS(p)}{2(4\pi\sigma)^2} \cdot \frac{1}{\Delta\Omega} \cdot \left(\frac{c}{H_o} z_c\right)^{-3} \cdot f(n_s)$$

Where, for low-luminosity populations:

$$f(n_s) \sim \lambda_c^{-3/2} \frac{3\Gamma(n_s)}{\Gamma(n_s - 3/2)} \cdot \left(1 + \sqrt{1 + \frac{4N_{bkg}(4\pi\sigma)^2}{TS(p)}}\right)$$