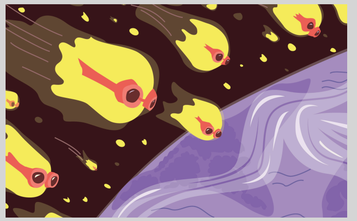
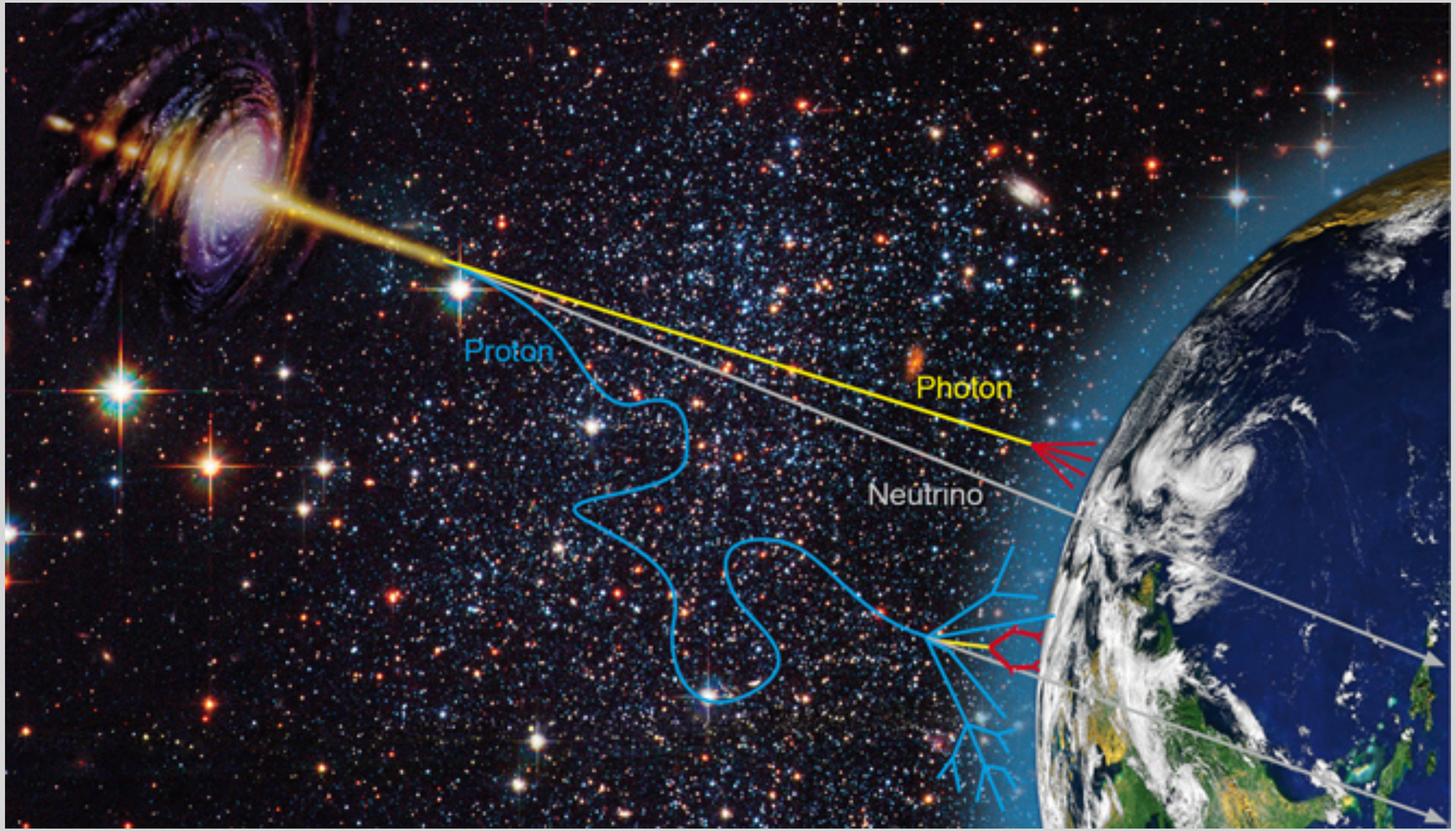
Multi-messenger NuEM Alerts with AMON

Hugo Ayala



PennState
Eberly College
of Science

Studying the universe with multi-messenger astrophysics



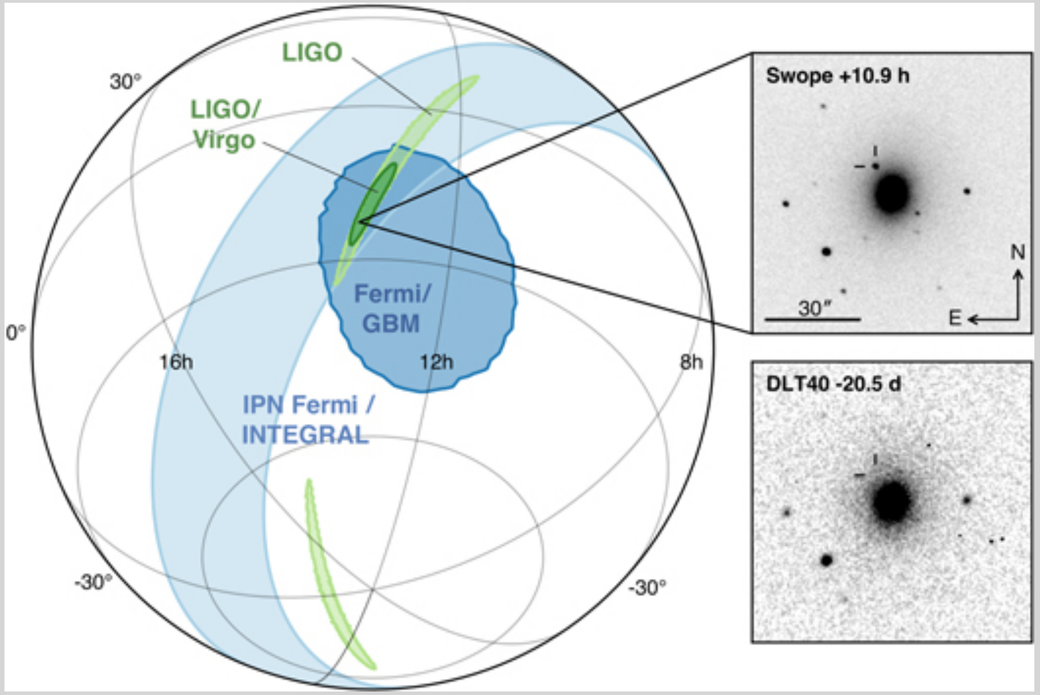
https://astro.desy.de/theory/multi_messenger_astrophysics/index_eng.html

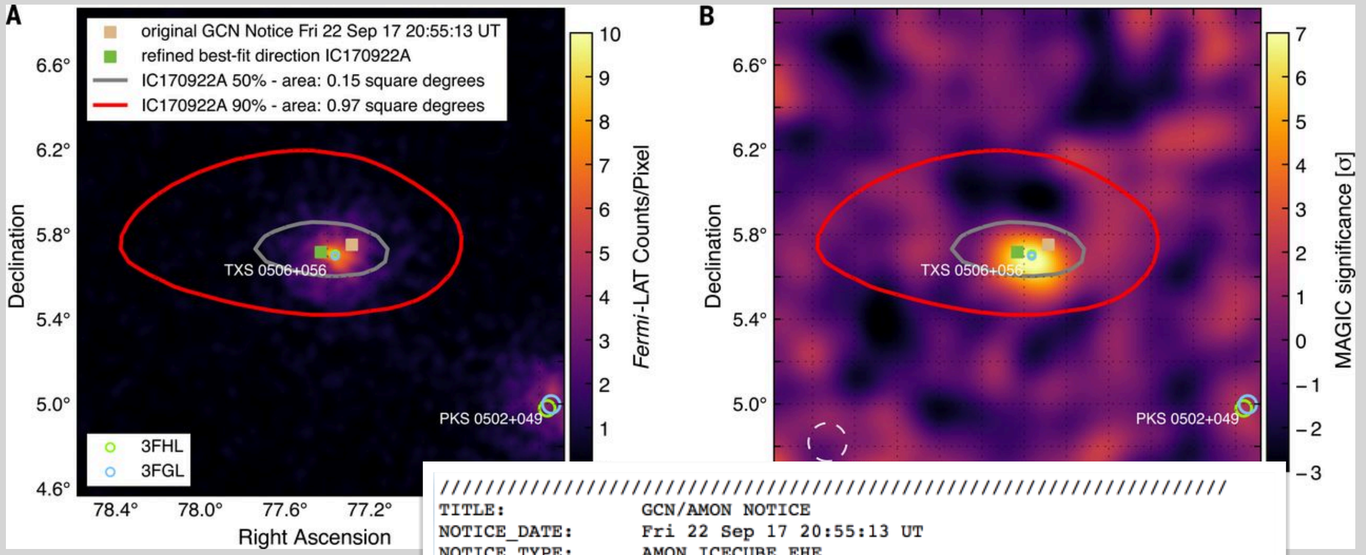
Studying the universe with multi-messenger astrophysics

Force	Messenger	Messenger Detected	Sources?
EM	Photons	👍	Several
Weak	Neutrinos	👍	Three (?) (Sun, SN1987A, TXS 0506 (3σ))
Strong	p, nuclei	👍	?
Gravity	Gravitational Waves	👍	Few and increasing

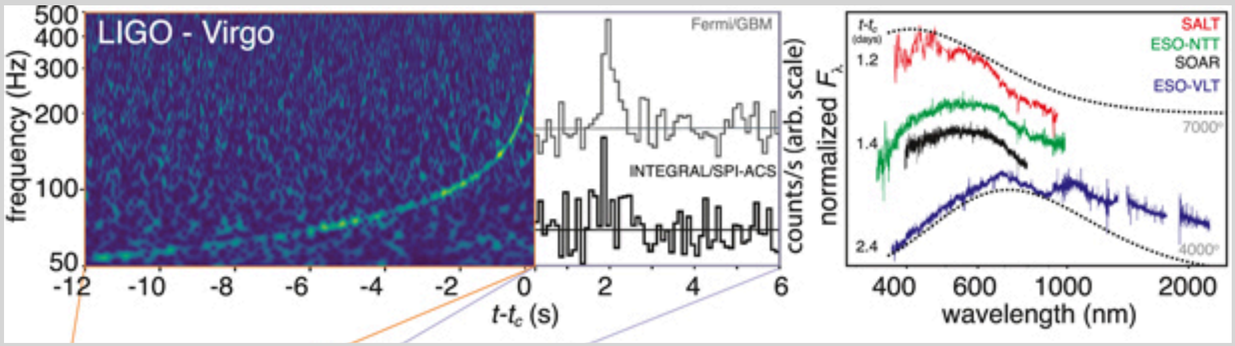
https://astro.desy.de/theory/multi_messenger_astrophysics/index_eng.html

Recent discoveries

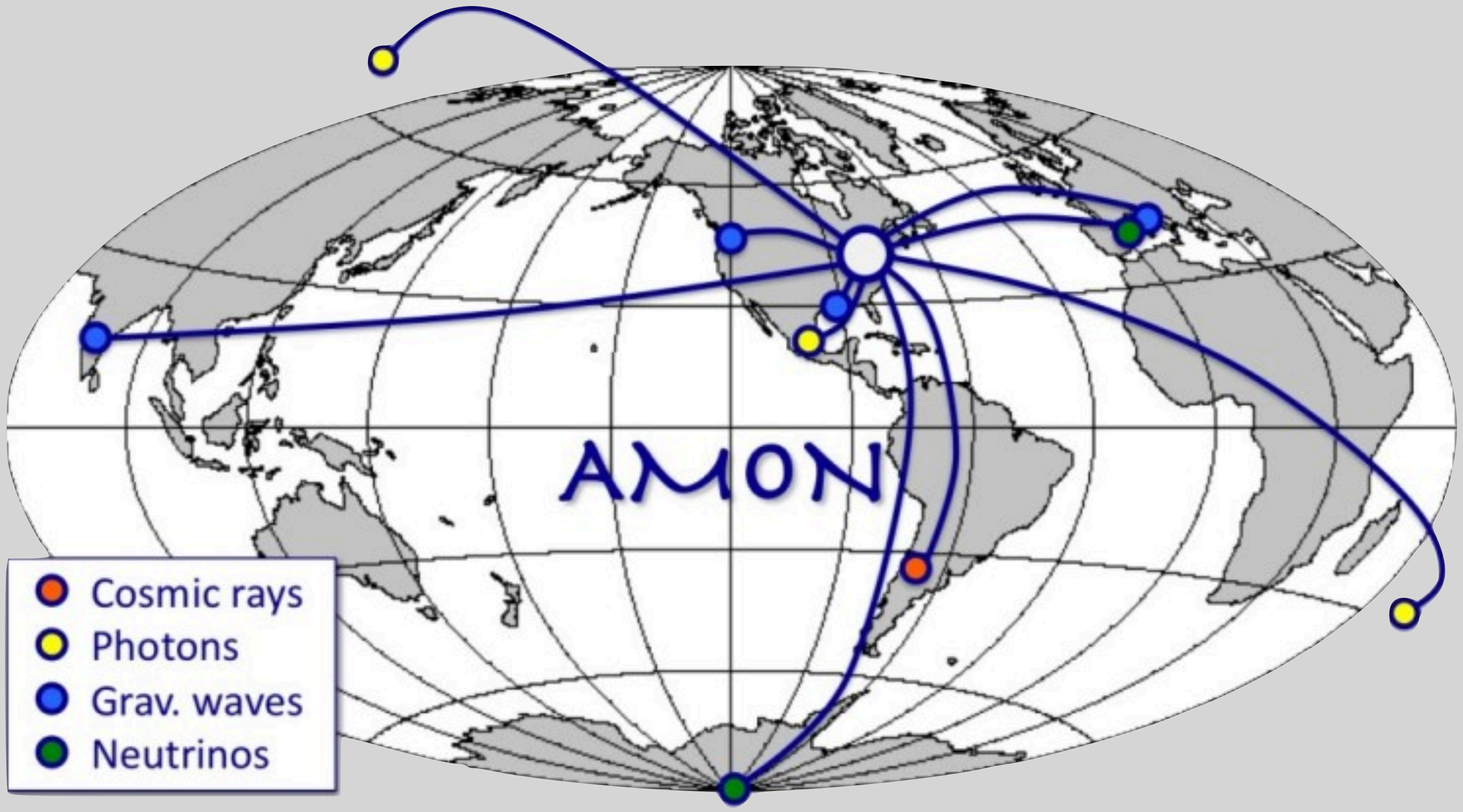





```
//////////////////////////////////////////////////////////////////////
TITLE:           GCN/AMON NOTICE
NOTICE_DATE:     Fri 22 Sep 17 20:55:13 UT
NOTICE_TYPE:     AMON ICECUBE EHE
RUN_NUM:         130033
EVENT_NUM:       50579430
SRC_RA:           77.2853d {+05h 09m 08s} (J2000),
                  77.5221d {+05h 10m 05s} (current),
                  76.6176d {+05h 06m 28s} (1950)
SRC_DEC:          +5.7517d {+05d 45' 06"} (J2000),
                  +5.7732d {+05d 46' 24"} (current),
                  +5.6888d {+05d 41' 20"} (1950)
SRC_ERROR:       14.99 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:  18018 TJD;   265 DOY;   17/09/22 (yy/mm/dd)
DISCOVERY_TIME:  75270 SOD {20:54:30.43} UT
REVISION:        0
N_EVENTS:        1 [number of neutrinos]
STREAM:          2
DELTA_T:         0.0000 [sec]
SIGMA_T:         0.0000e+00 [dn]
ENERGY :         1.1998e+02 [TeV]
SIGNALNESS:      5.6507e-01 [dn]
CHARGE:          5784.9552 [pe]
SUN_POSTN:       180.03d {+12h 00m 08s}   -0.01d {-00d 00' 53"}
SUN_DIST:        102.45 [deg]   Sun_angle= 6.8 [hr] (West of Sun)
MOON_POSTN:      211.24d {+14h 04m 58s}   -7.56d {-07d 33' 33"}
MOON_DIST:       134.02 [deg]
GAL_COORDS:      195.31,-19.67 [deg] galactic lon,lat of the event
ECL_COORDS:       76.75,-17.10 [deg] ecliptic lon,lat of the event
COMMENTS:        AMON_ICECUBE_EHE.
```



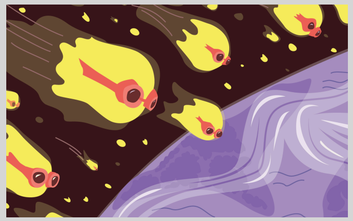
AMON: a framework to perform multi-messenger searchers



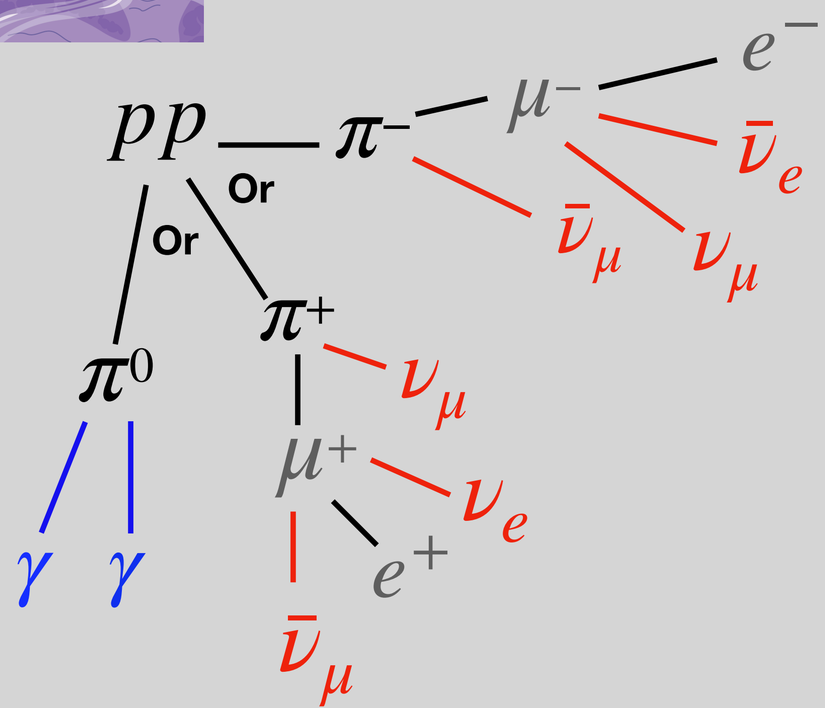
- **Real-time coincidences**
  - Use of **sub-threshold data**
- Archival Studies
  - Store events
  - Coincidence analyses
- Triggering Observatories
- Follow-up Observatories
- Pass-Through
  - Broadcast directly to GCN/TAN

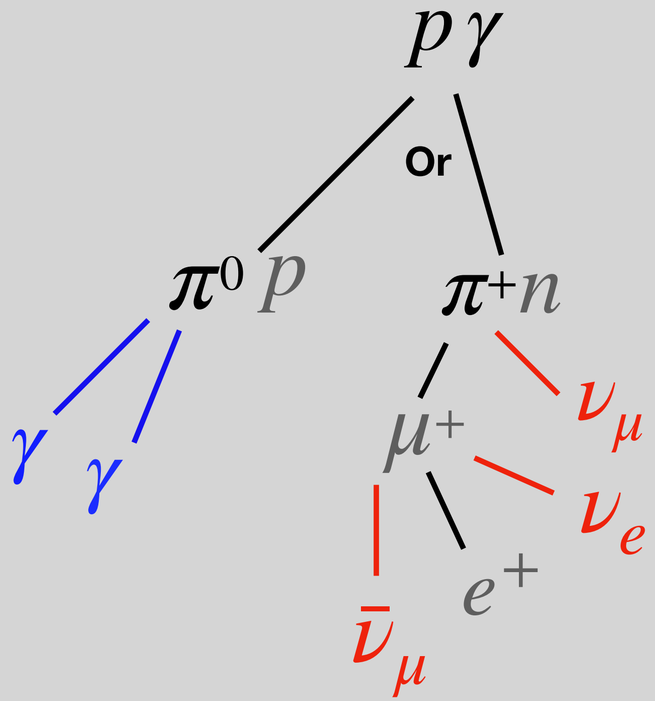
The Neutrino-Electromagnetic channel

- Coincidence analyses between high-energy gamma-ray data and high-energy neutrino data

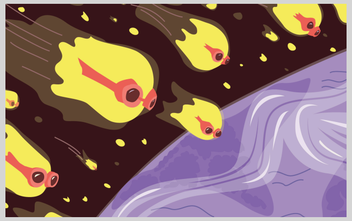


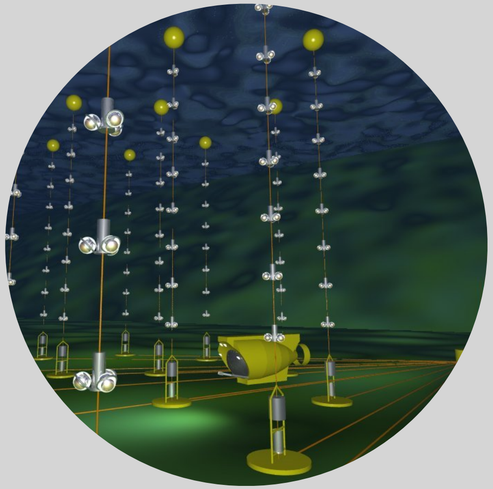
- Objective: Search for sources of high-energy neutrinos (i.e. hadronic accelerators)





The NuEM channel: observatories

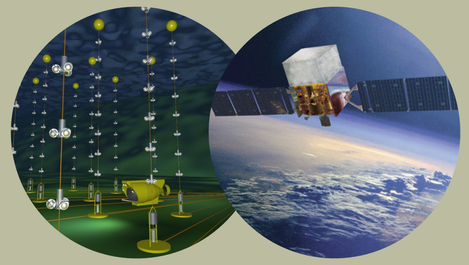




The NuEM channel: analyses

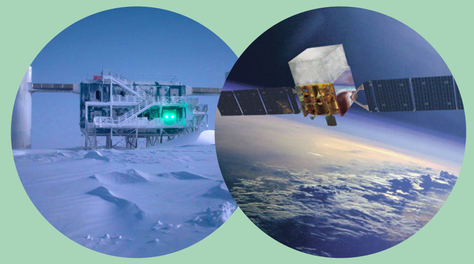
Archival Analysis

Real-time analysis

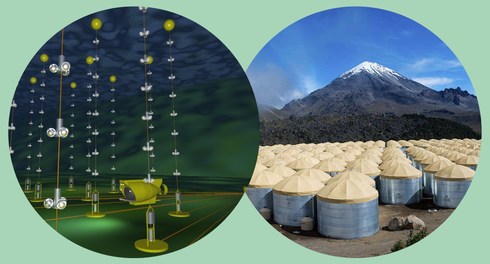


ANTARES +Fermi LAT

IceCube + HAWC



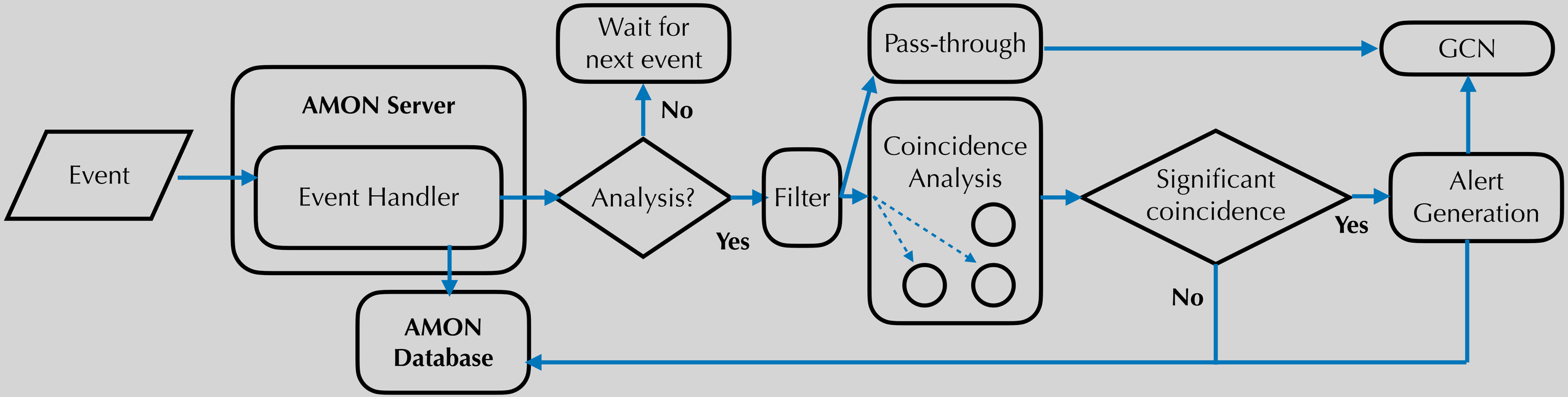
IceCube +Fermi LAT



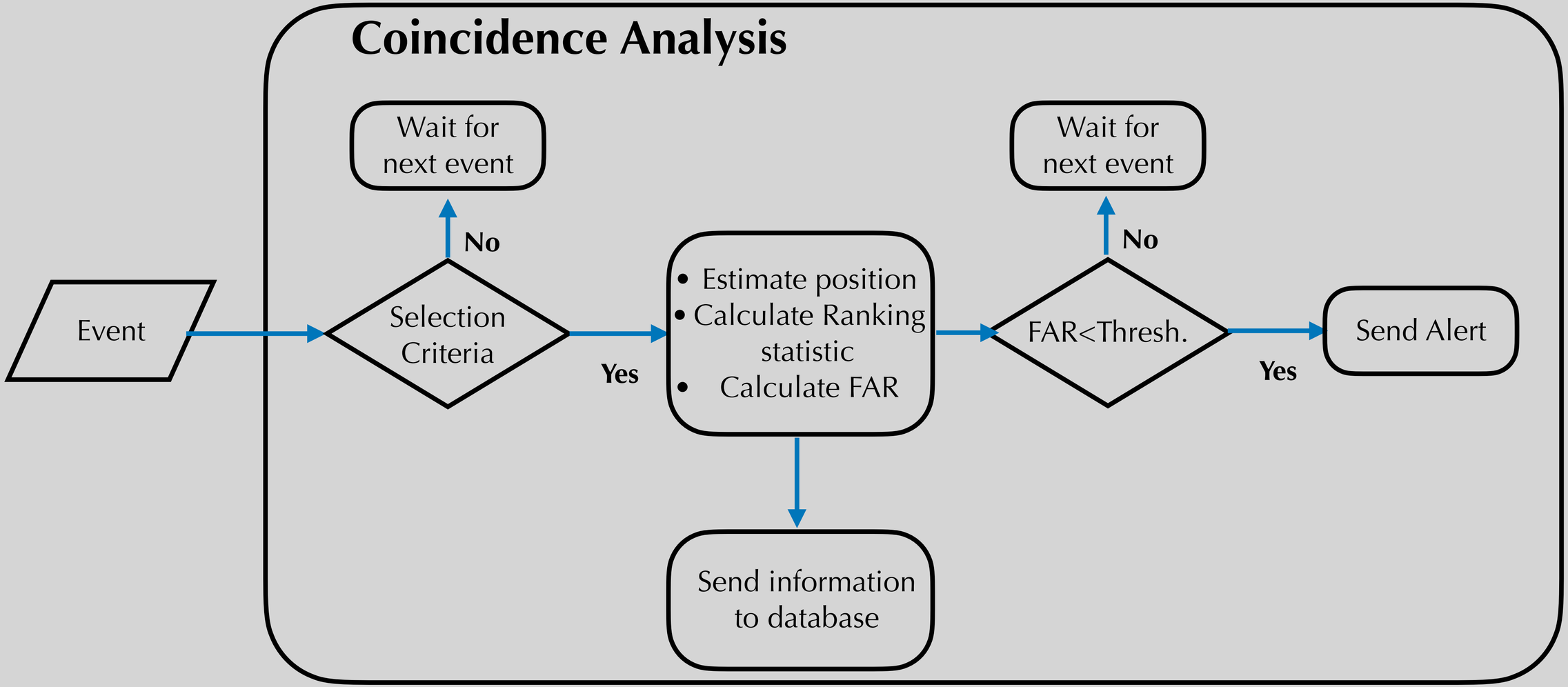
ANTARES + HAWC*

***Preliminary results in this presentation**

The NuEM channel: pipeline

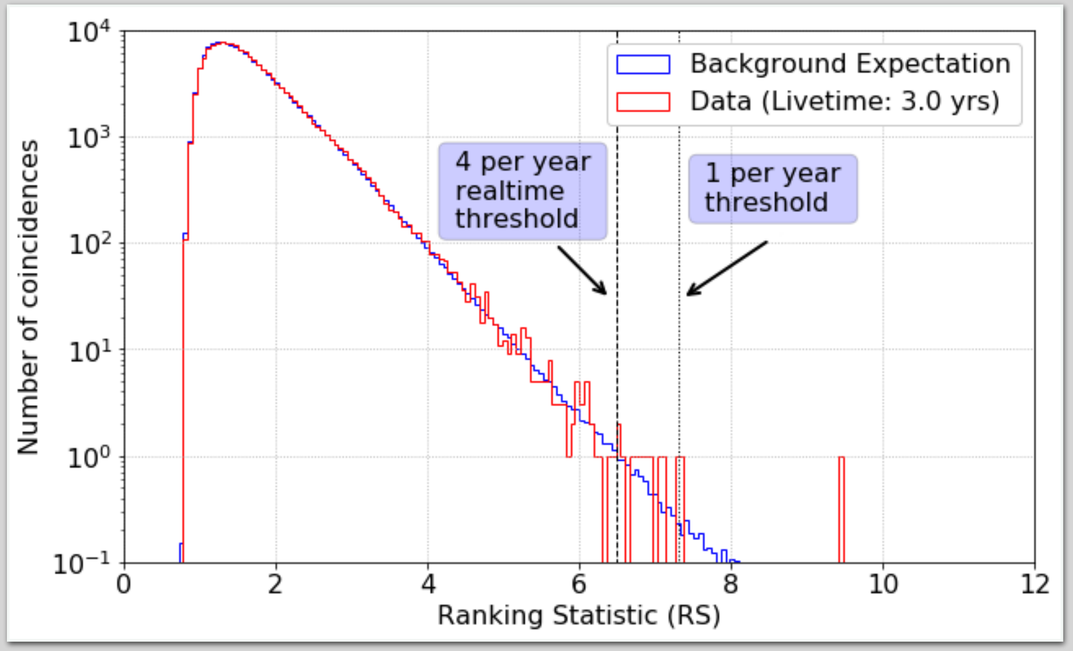


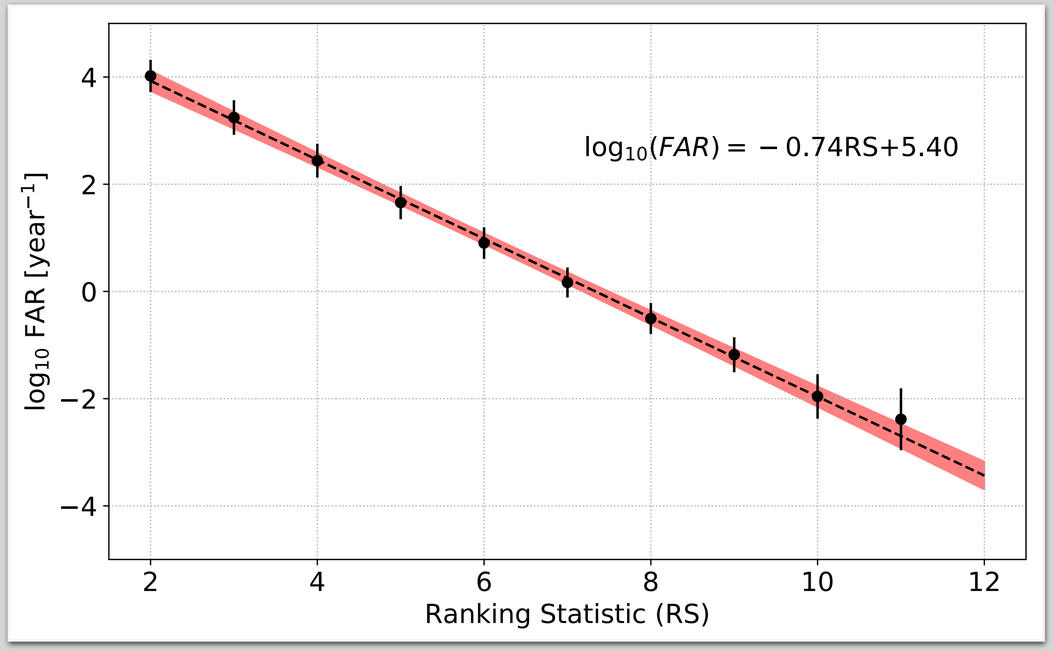
The NuEM Channel: algorithm



The NuEM channel: how to obtain the FAR

- We perform simulations by scrambling the datasets several times.
- Build the ranking statistic distribution
- Calculate the false alarm rate





H. A. Ayala Solares *et al* 2021 *ApJ* **906** 63

Coincidences in the NuEM Channel

- FAR threshold is < 4 per year for real-time alerts.
- For archival coincidences we looked at the ones with <1 per year

Name	R.A. [°]	Decl. [°]	$\delta\theta$ [°]	FAR [yr^{-1}]	Time UTC
Real-time alerts					
NuEM-210515A	93.64	14.66	0.15	3.93	2021-05-15 00:20:43
NuEM-210515B	93.93	12.51	0.20	1.90	2021-05-15 00:19:27
NuEM-210111A	162.34	19.46	0.37	3.85	2021-01-11 13:06:41
NuEM-201124A	134.99	7.74	0.23	2.96	2020-11-24 14:13:37
NuEM-201107A	140.20	29.76	0.15	3.49	2020-11-07 15:55:31
ANTARES-Fermi 200704A	255.42	-34.48	0.43	0.98	2020-07-04 15:53:48
NuEM-200202A	200.30	12.71	0.17	1.39	2020-02-02 14:07:52
ANTARES-Fermi 191011A	49.96	18.80	0.40	1.21	2019-10-11 15:54:32
Archival Coincidences					
ANTARES-Fermi	248.00	-7.7	0.07	0.09	2012-11-21 20:19:52
ANTARES-Fermi	279.68	-5.05	0.10	0.09	2014-08-05 11:13:33
HAWC-IceCube	4.93	2.96	0.16	0.99	2016-12-12 04:38:41
HAWC-IceCube	173.99	2.27	0.53	0.026	2018-04-12 07:54:51
HAWC-ANTARES	25.6	25.0	0.2	0.7	2016-01-08 04:39:38
HAWC-ANTARES	222.8	-0.8	0.2	0.87	2017-09-07 01:21:22
HAWC-ANTARES	85.4	3.4	0.2	0.41	2019-03-29 03:01:18

Archival coincidences: HAWC-IceCube

- No counterpart found in the SIMBAD catalog and the Fermi All-sky Variability Analysis (FAVA) monitoring, but several sources in the region.

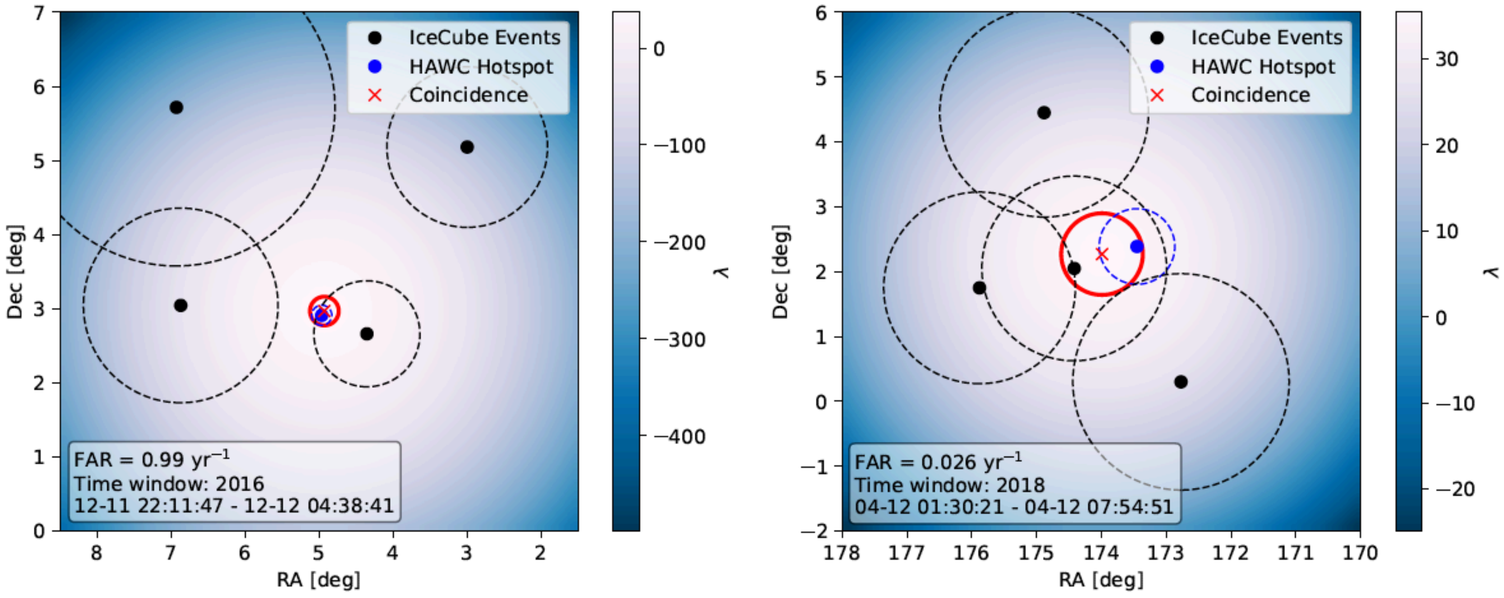
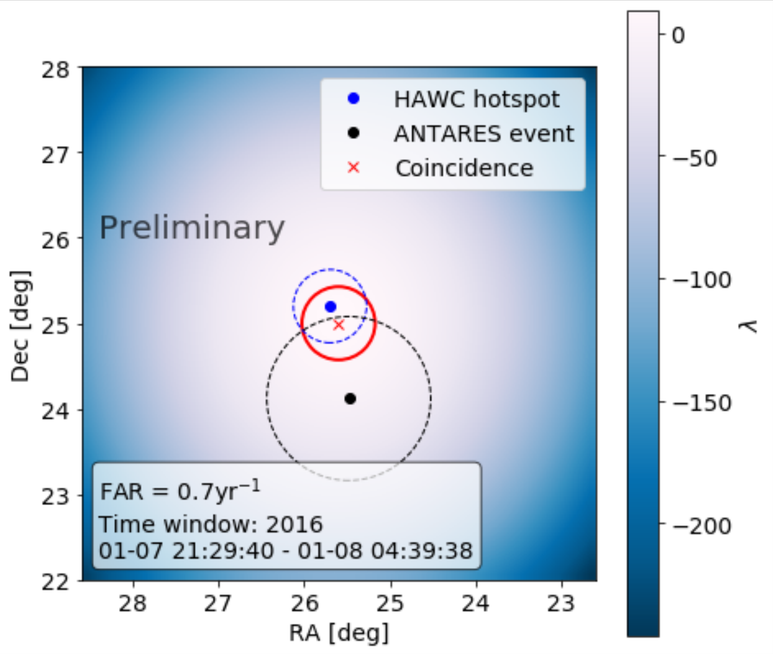


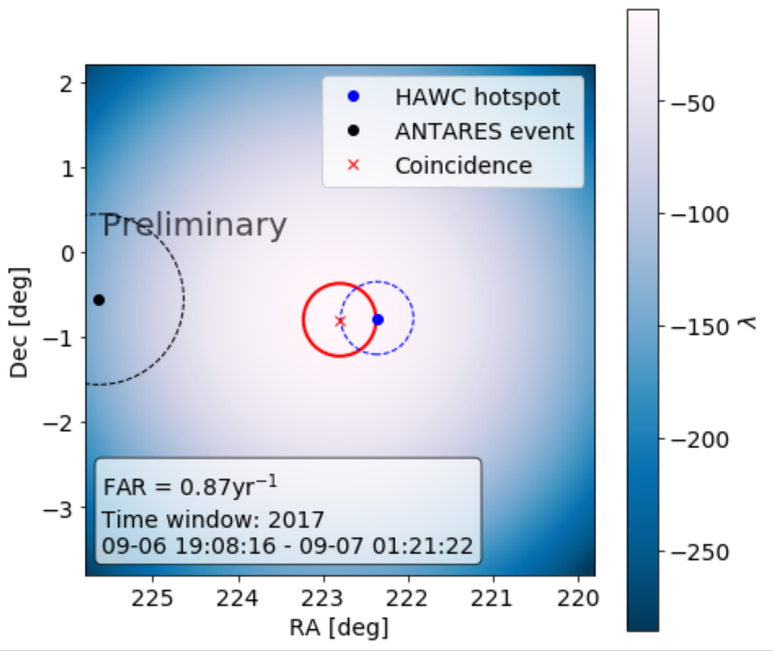
Figure 5. Skymaps of the coincidences with the lowest FAR found in the 3 years of archival data. Position of the individual events are marked with the dots. The best-fit combined positions $\boldsymbol{x}_{\mathrm{coinc}}$, found after optimizing Eq. 3, are marked with a cross. Circles are the 50% containment region.

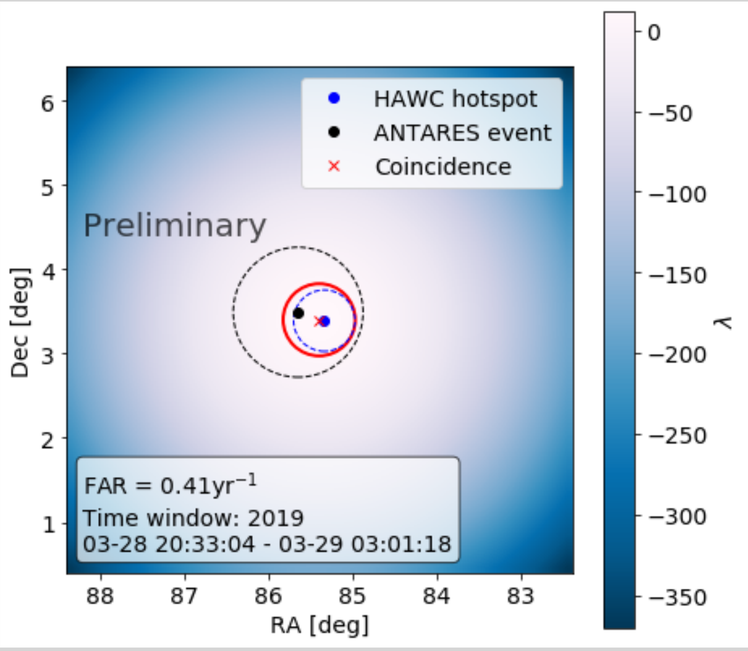
H. A. Ayala Solares *et al* 2021 *ApJ* **906** 63

Archival coincidences: HAWC-ANTARES

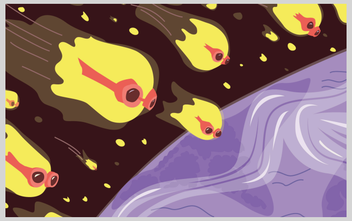
- No counterpart found in the SIMBAD catalog and the Fermi All-sky Variability Analysis (FAVA) monitoring







Outlook



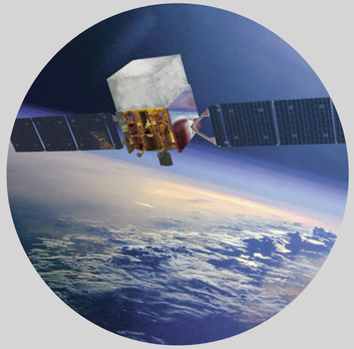
- AMON NuEM channel is active
  - Searching for high-energy gamma-ray and neutrino coincidences
  - Using sub-threshold data
- We encourage follow-up observations of these coincidences

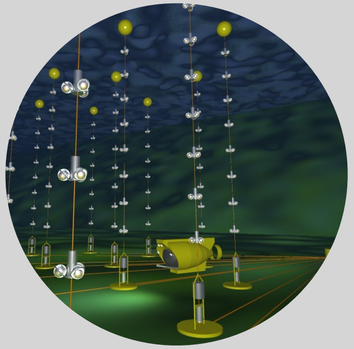
Name	Followed by
NuEM-210515A/B	ANTARES
NuEM-210111A	ANTARES, INTEGRAL,MAXI
NuEM-201124A	ANTARES
NuEM-201107A	*Fermi*-LAT
NuEM-200202A	MASTER, ANTARES
FERMI-ANTARES-191011A	MASTER

- Visit the https://amontom.science.psu.edu/ to query alerts
- Email: hgayala@psu.edu

Thank you

AMON
Astrophysical Multimessenger Observatory Network





PennState
Eberly College
of Science