Science with current/future Neutrino Detectors

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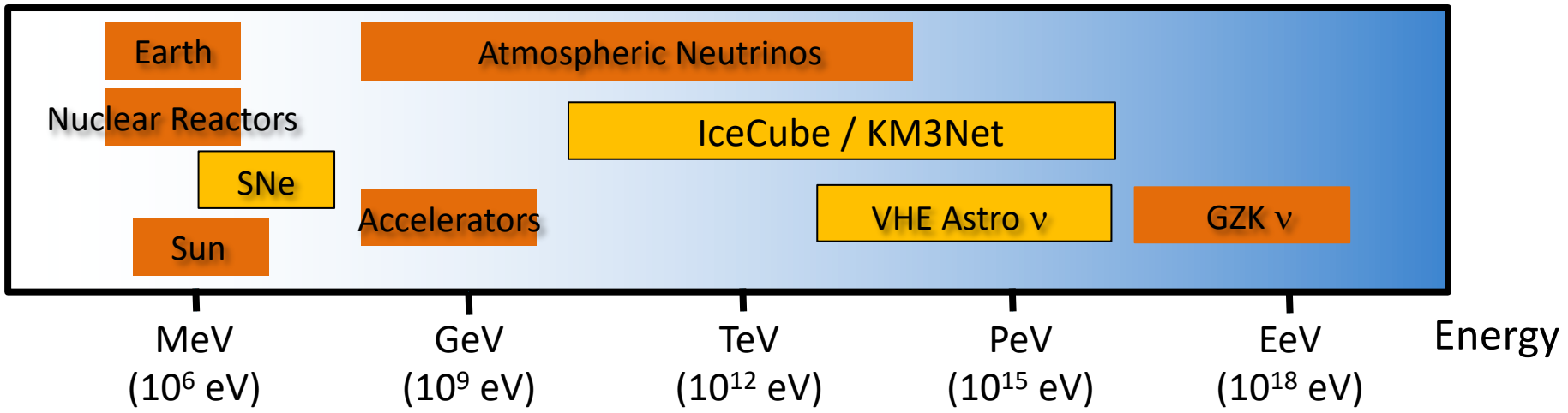
Astrophysics of Neutrino Detectors



Galactic Core-Collapse SNe: 1-100 MeV

SNEWS: Super-K, IceCube, Kamland, HALO, CEνNS, SNO+, nEXO, … any ν detector worth its salt

Diffuse ν flux from cosmological core-collapse SNe: 10 – 100 MeV

Super-K, Gd-loaded Super-K, Hyper-K

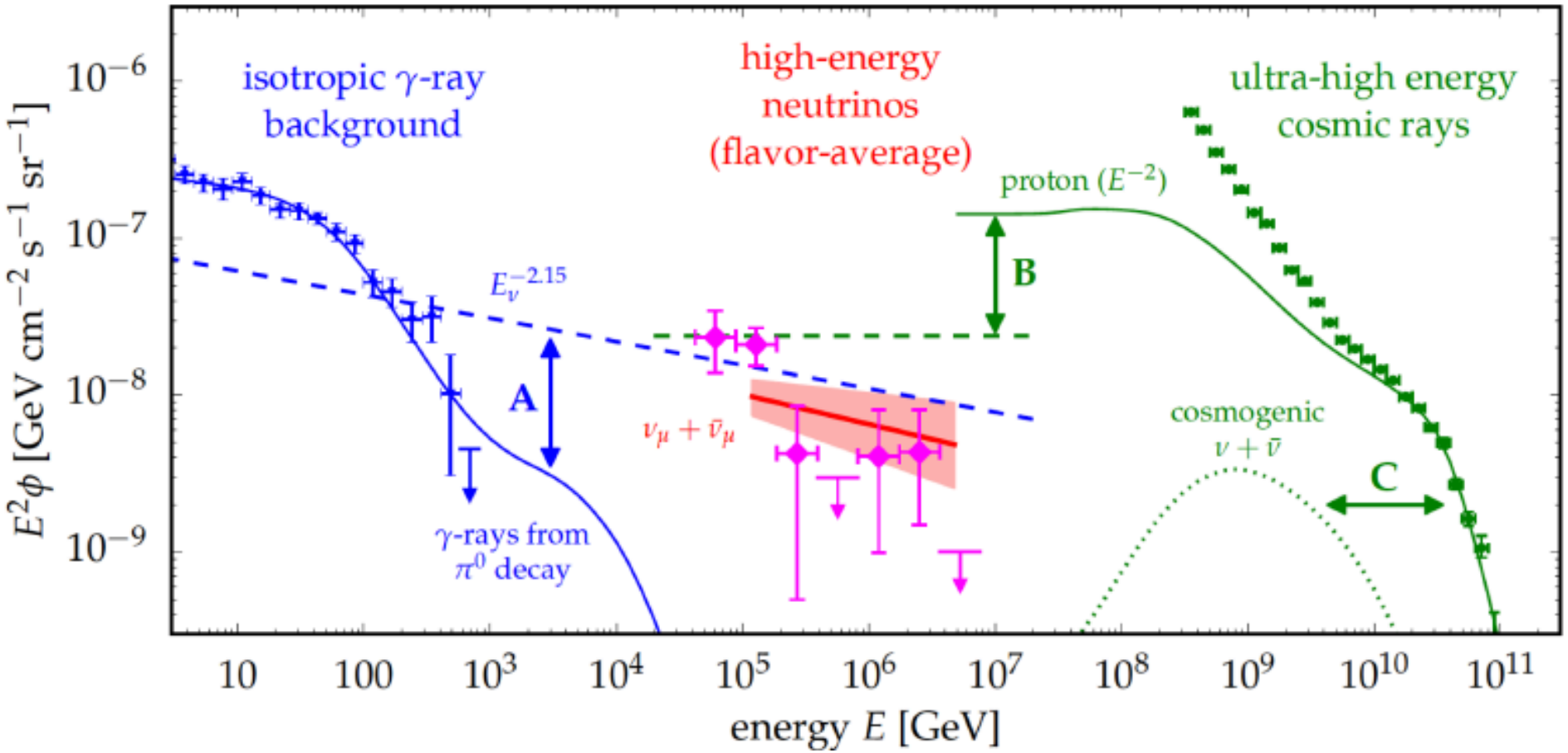
Very-High Energy Astrophysical ν: 10 TeV – 10 PeV

IceCube, KM3Net

Cosmogenic (GZK) neutrinos 10 PeV – 1 EeV

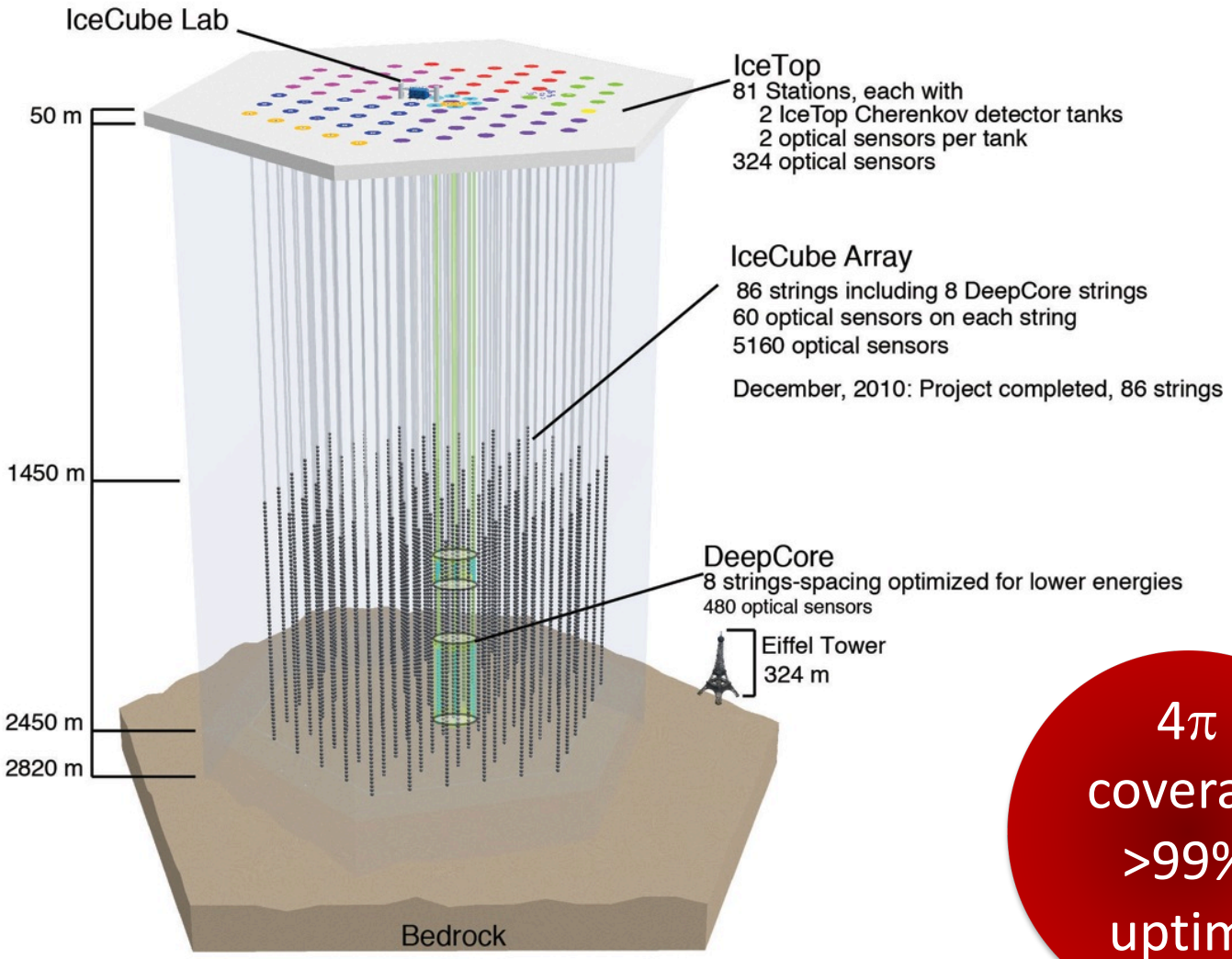
ARA, ARIANNA, RNO, TRINITY, GRAND, ...

Diffuse ν, γ–rays, cosmic rays



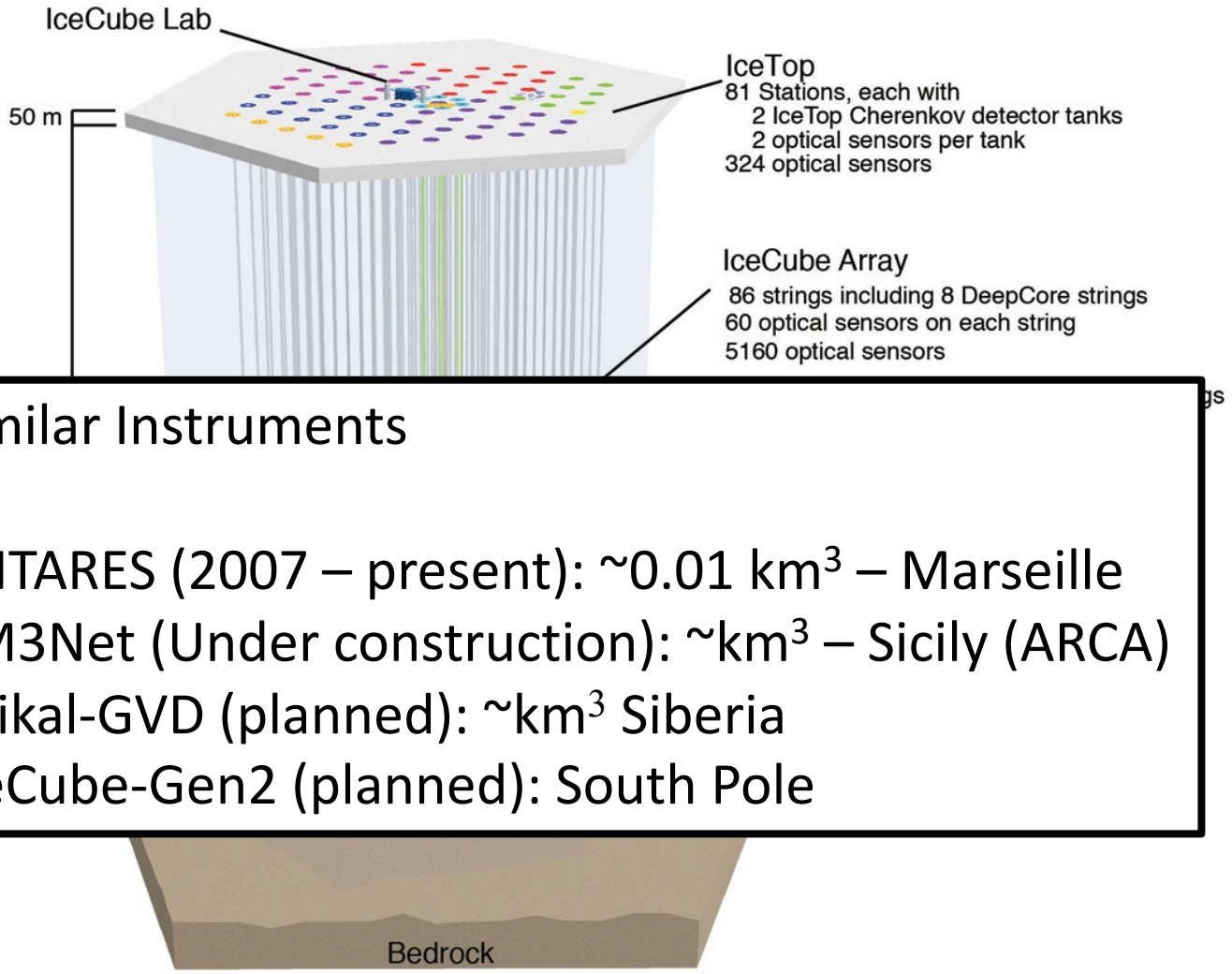
Ahlers, Halzen. PPNP 102 (2018) 73

IceCube: An Ice-Cherenkov ν Detector



4π coverage
>99% uptime

IceCube: An Ice-Cherenkov ν Detector



Similar Instruments

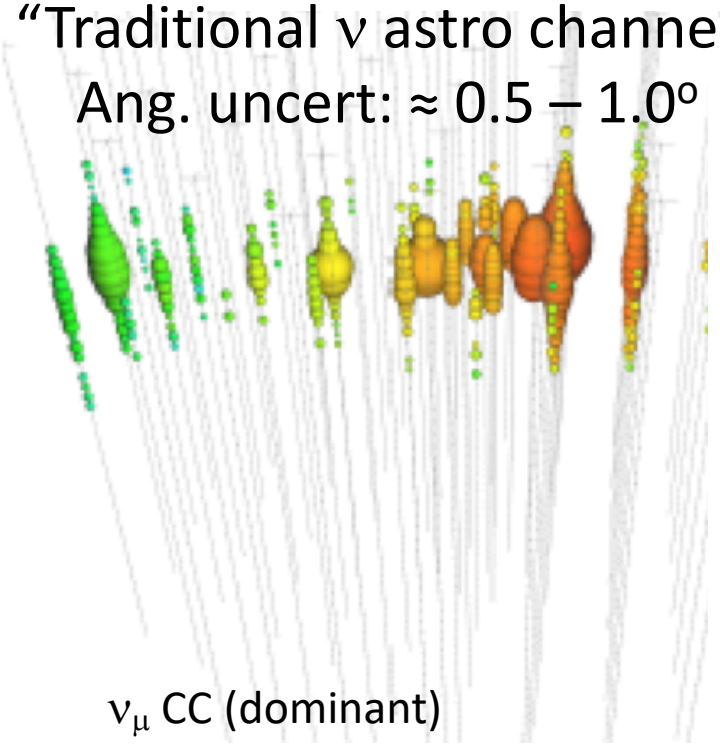
ANTARES (2007 – present): ~0.01 km^3 – Marseille
KM3Net (Under construction): ~km^3 – Sicily (ARCA)
Baikal-GVD (planned): ~km^3 Siberia
IceCube-Gen2 (planned): South Pole

Signals at IceCube

tracks

"Traditional ν astro channel"

Ang. uncert: ≈ 0.5 – 1.0°



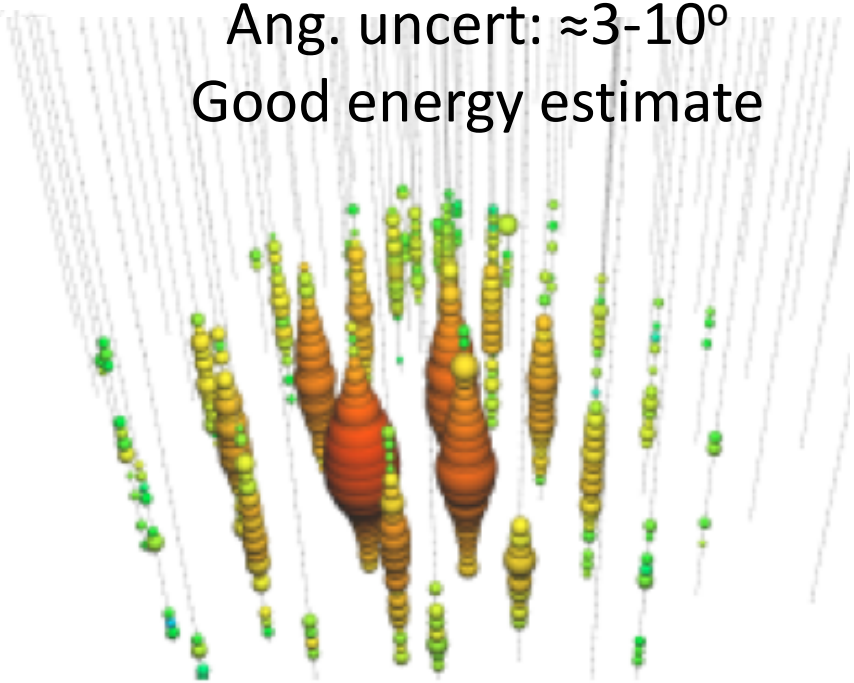
ν_μ CC (dominant)

ν_τ CC; τ decaying into μ (minor)

cascades / showers

Ang. uncert: ≈3-10°

Good energy estimate



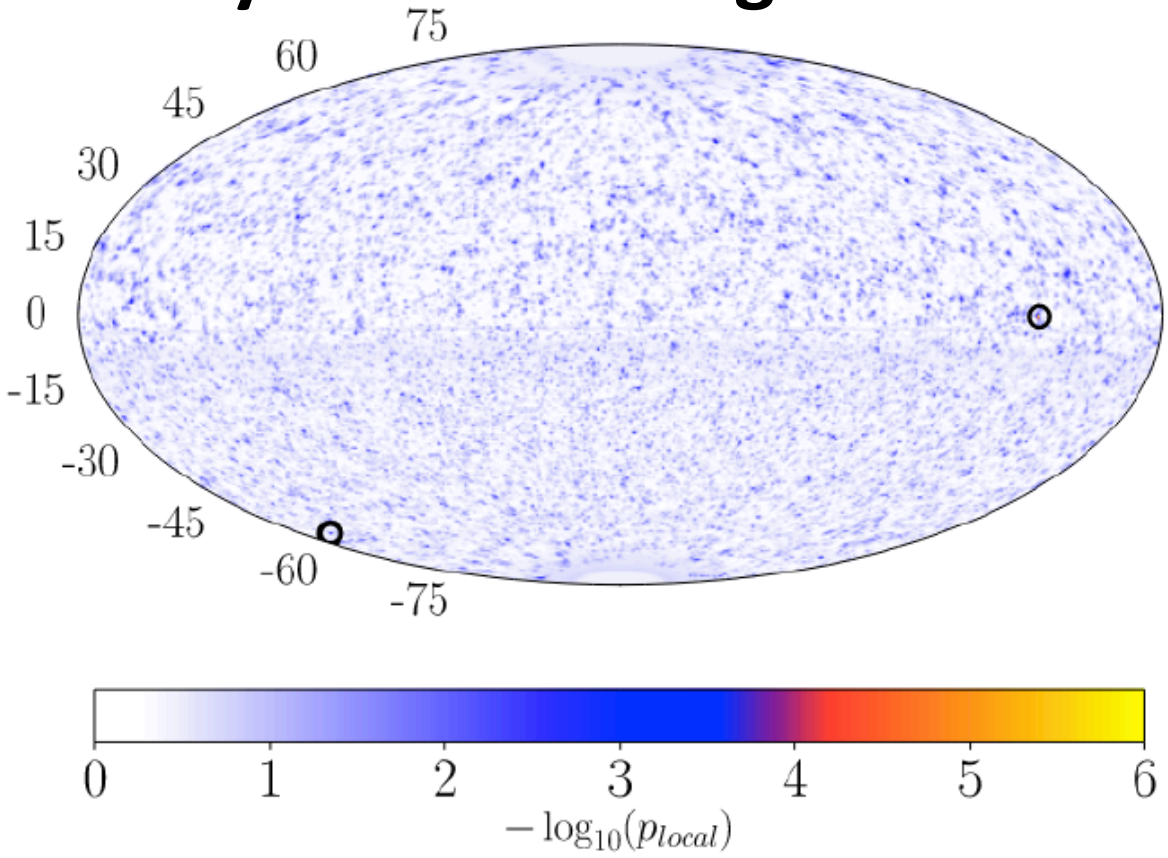
All other CC/NC/Glashow ν interaction (*)

Astro : Atm ν : Atm μ

$1 : 10^3 : 10^9$

(*) Actually ν_τ interactions may have complicated topologies

10-year Time Integrated Point Source Searches



IceCube arXiv:1910.08488

δ>-5° : Atmos. ν

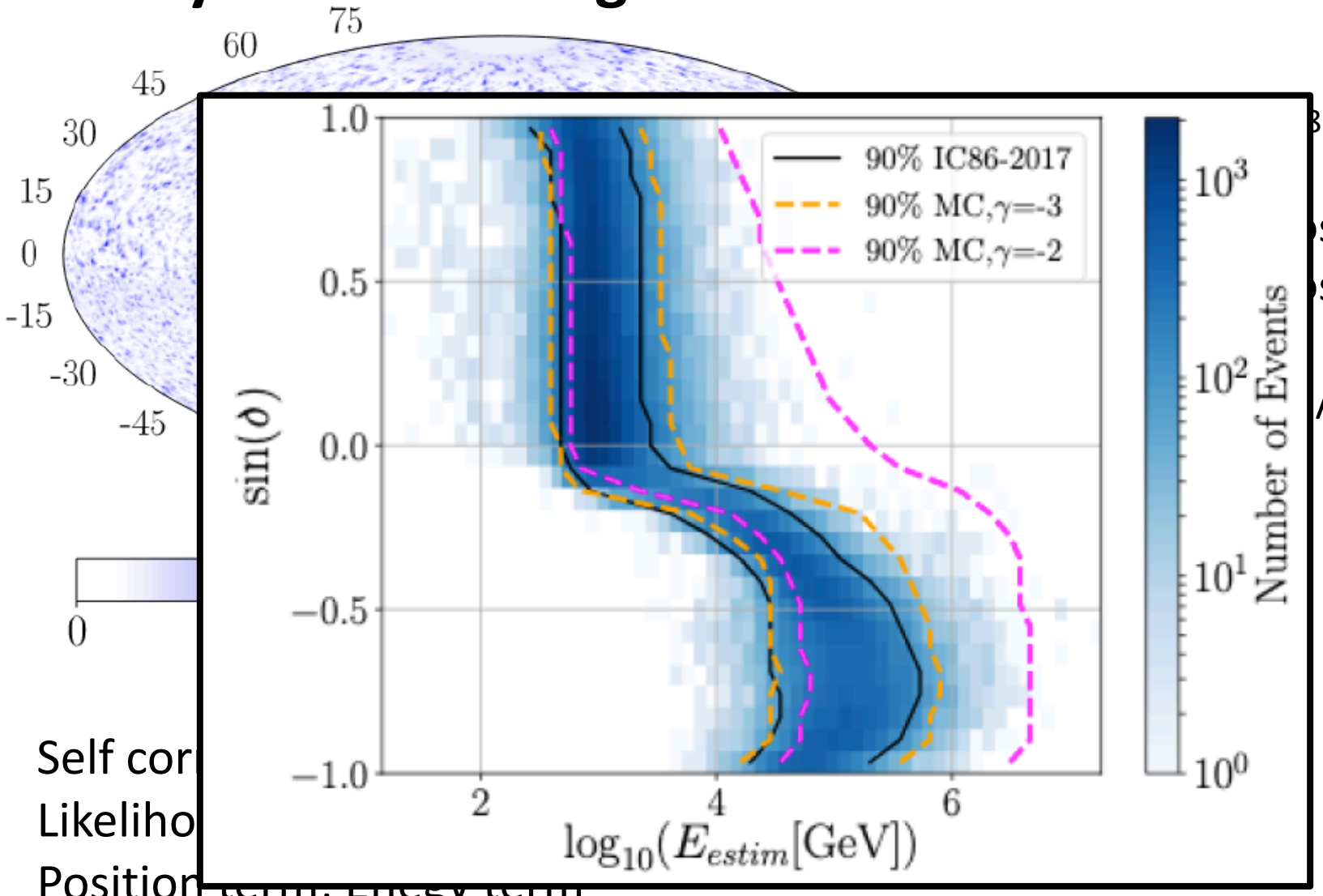
δ<-5° : Atmos. μ

100,000 evt./year

Self correlations in IceCube data North & South / Correlation with list of EM sources / Population search

Likelihood ratio method Signal+Bckg. vs. Bckg. Position term and Energy term

10-year Time Integrated Point Source Searches



s. ν

s. μ

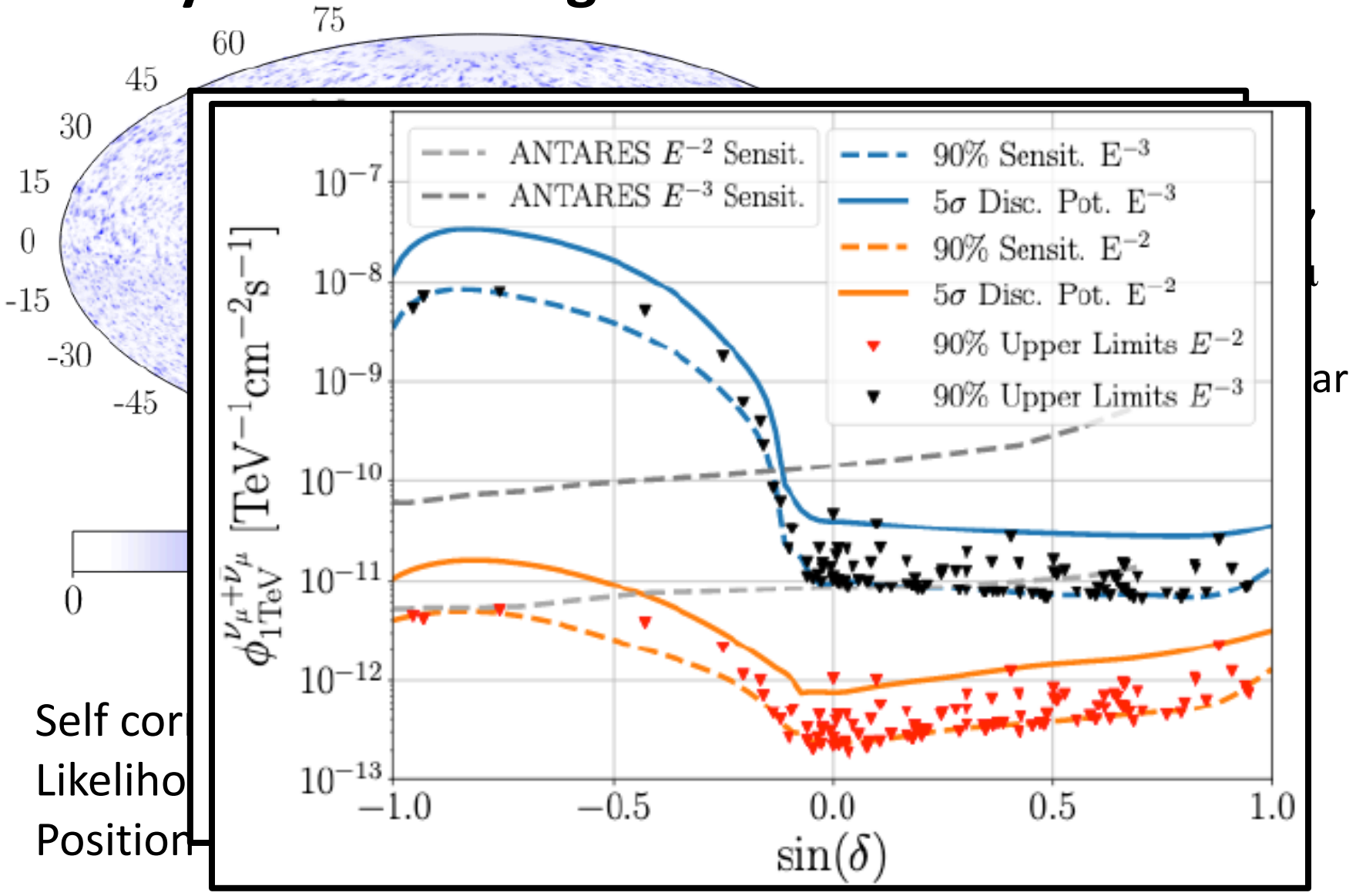
/year

Self cor

Likeliho

Position term, Energy term

10-year Time Integrated Point Source Searches



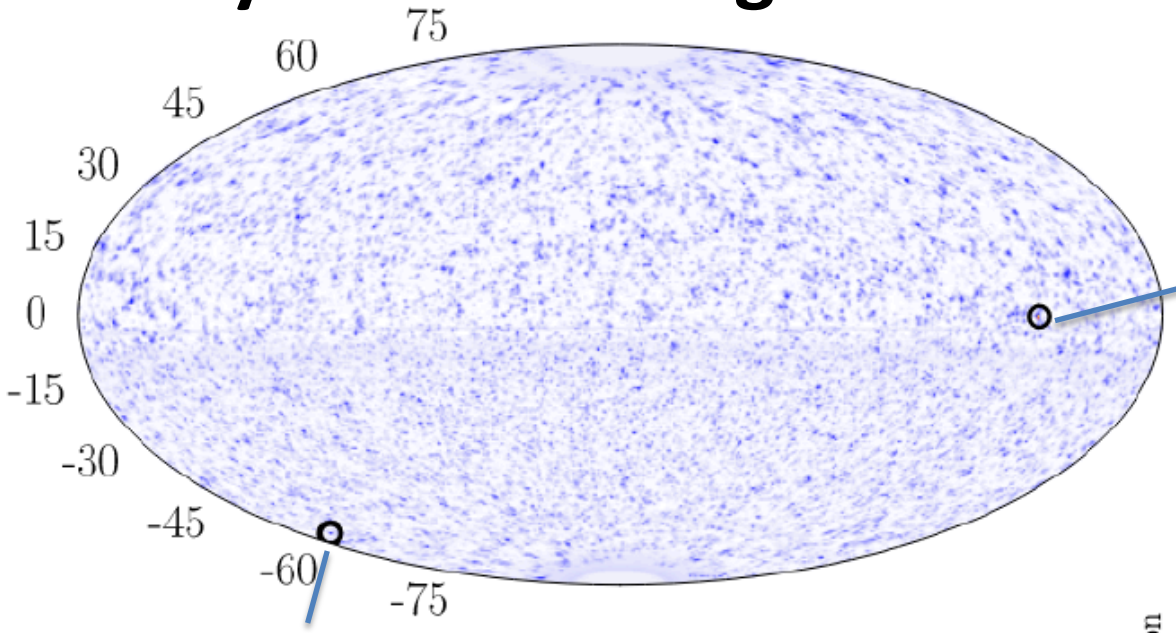
Self cor

Likeliho

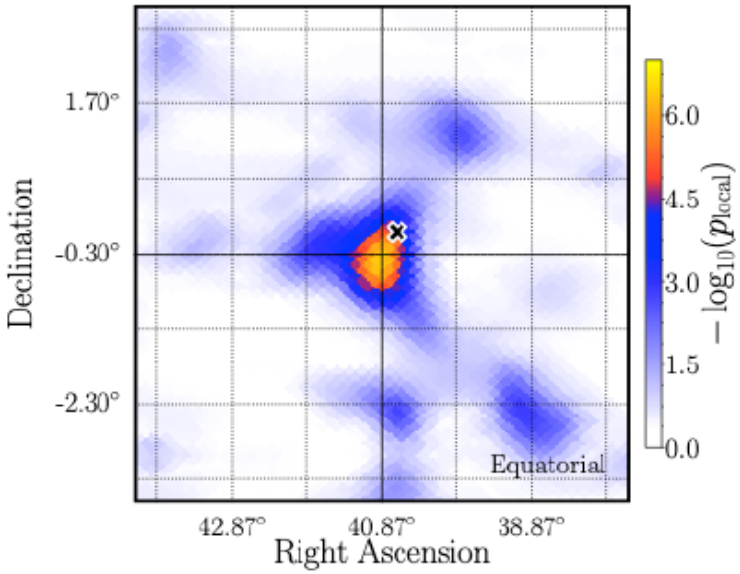
Position

ar

10-year Time Integrated Point Source Searches



NGC 1068
δ>-5°
p-value: 0.099
γ = -3.4 n_s = 61.5



RA: 350.2°, δ=-56.5°
δ>-5°
p-value: 0.75
γ = -3.3 n_s = 17.8

Source list: NGC 1068: 2.9 σ

Population search. 4 sources (NGC 1068, TXS 0506+056, PKS 1424+240, GB6 J1542+6129): 3.3 σ

IceCube's Neutrino Alerts

Realtime alerts V1: April 2016 – June 2019

- Starting tracks
- EHE (Extremely high-energy) tracks

9 / year

~25 % signalness (not optimized)

IceCube. Astropart. Phys. 92 (2017) 30

Realtime alerts V2: June 2019 – present

- Starting tracks
- EHE tracks
- Through-going tracks
- Human-selected subthreshold (infrequent)

Two Streams: Gold and Bronze

Better angular uncertainty

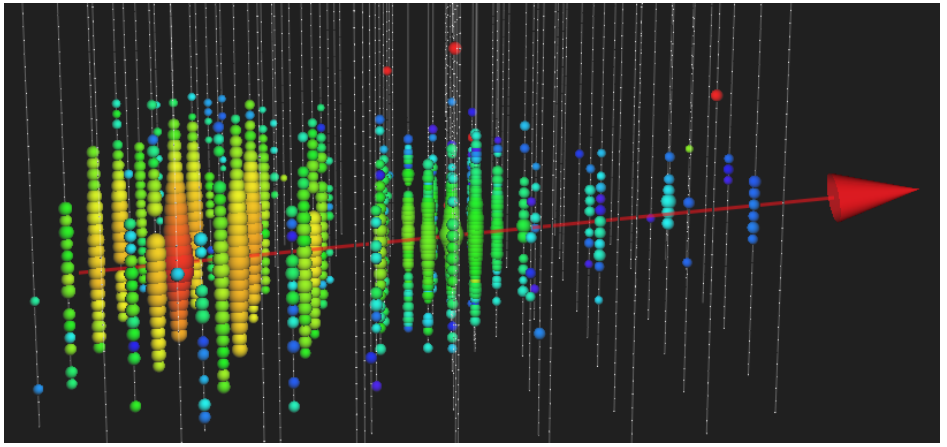
Lower rate of retractions (mis-reconstruction)

Almost all EHE are also through-going

10 (30) / year

Well defined signalness: 50 % (30%)

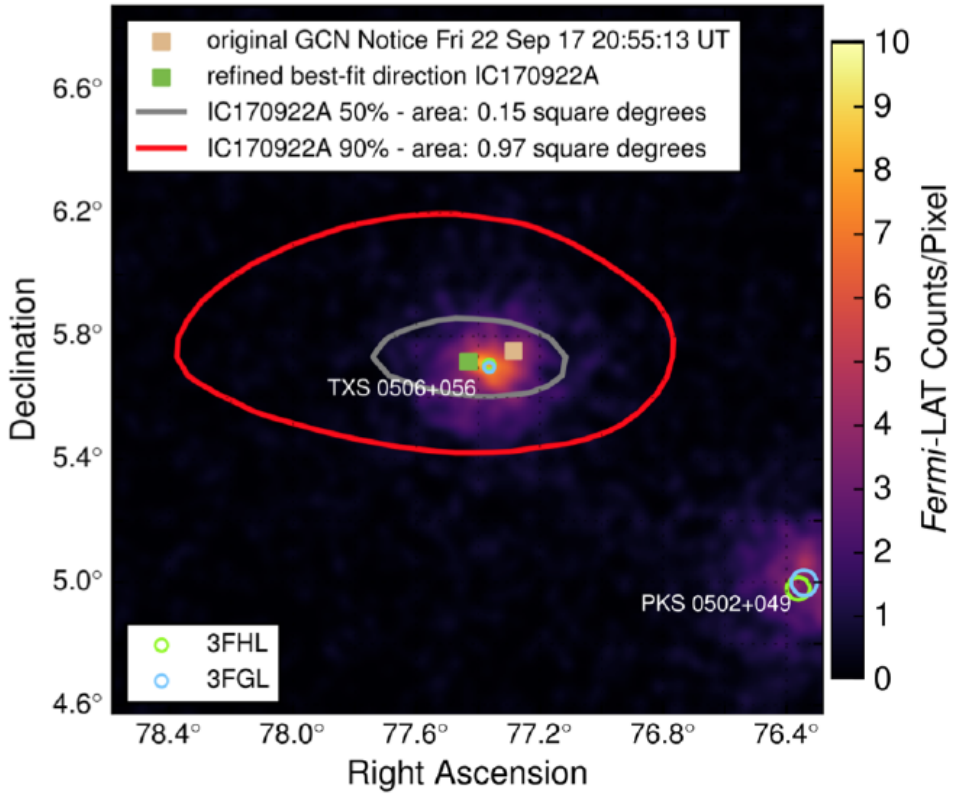
IceCube. PoS (ICRC2019) 1021



First public ν Alert: IceCube-160427

Initial discussion on V3 on-going

TXS 0506+056 / IceCube-170922A



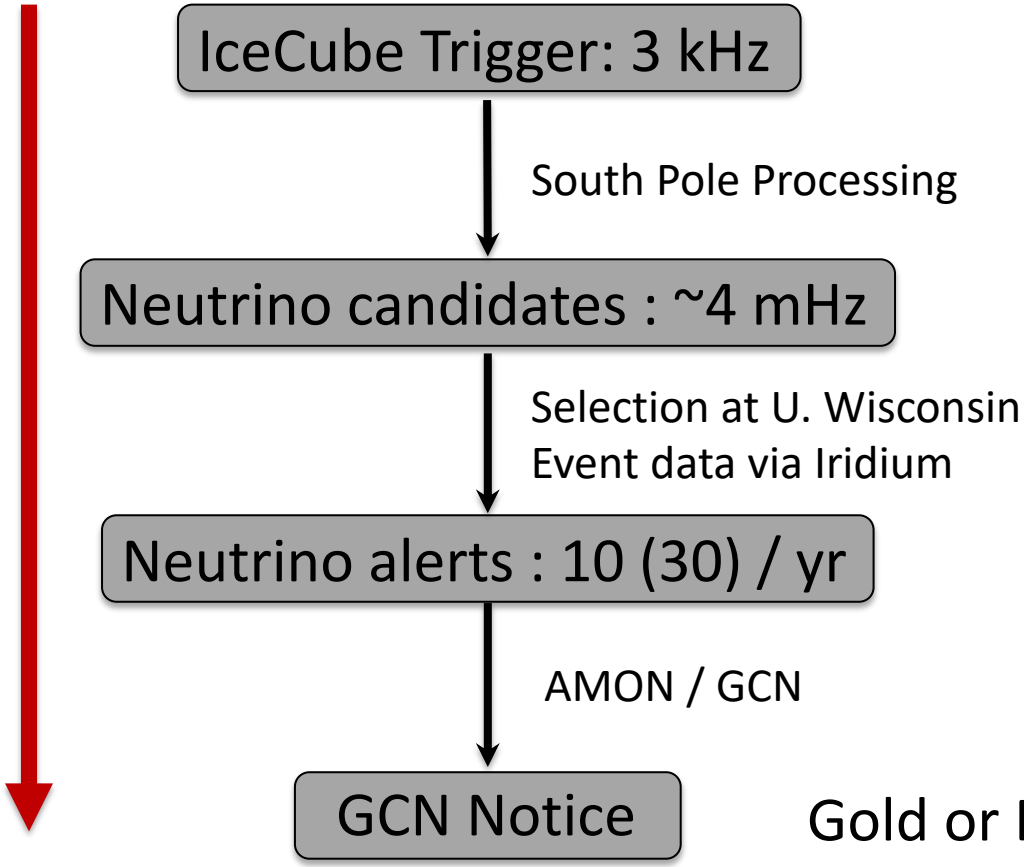
IceCube. Science 361 (2018) eaat1378
IceCube. Science 361 (2018) 147-151

Fermi and MAGIC identify a coincident flaring blazar (TXS 0506+056)
A ν-flare was found in archival IceCube data (10/2014 – 03/2015)

Evidence that (γ-ray) blazars are no more than ~20% of diffuse flux.

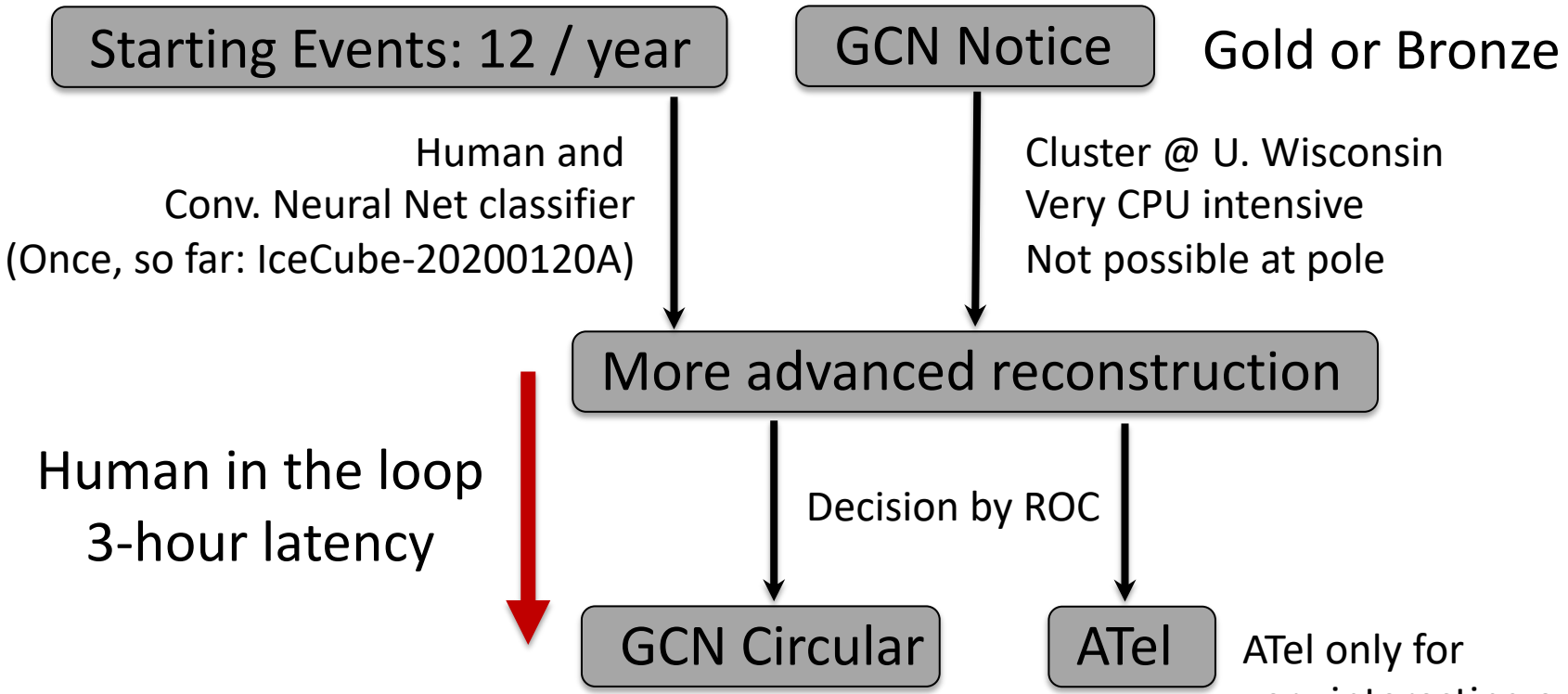
IceCube's Neutrino Alerts

Automated.
2-minute latency



Gold or Bronze

IceCube's Neutrino Alerts



ROC: Realtime Oversight Committee. ~15 people

Multiple time-zone coverage, but no explicit schedule shifts.

Works well.

GW/ν coincidences

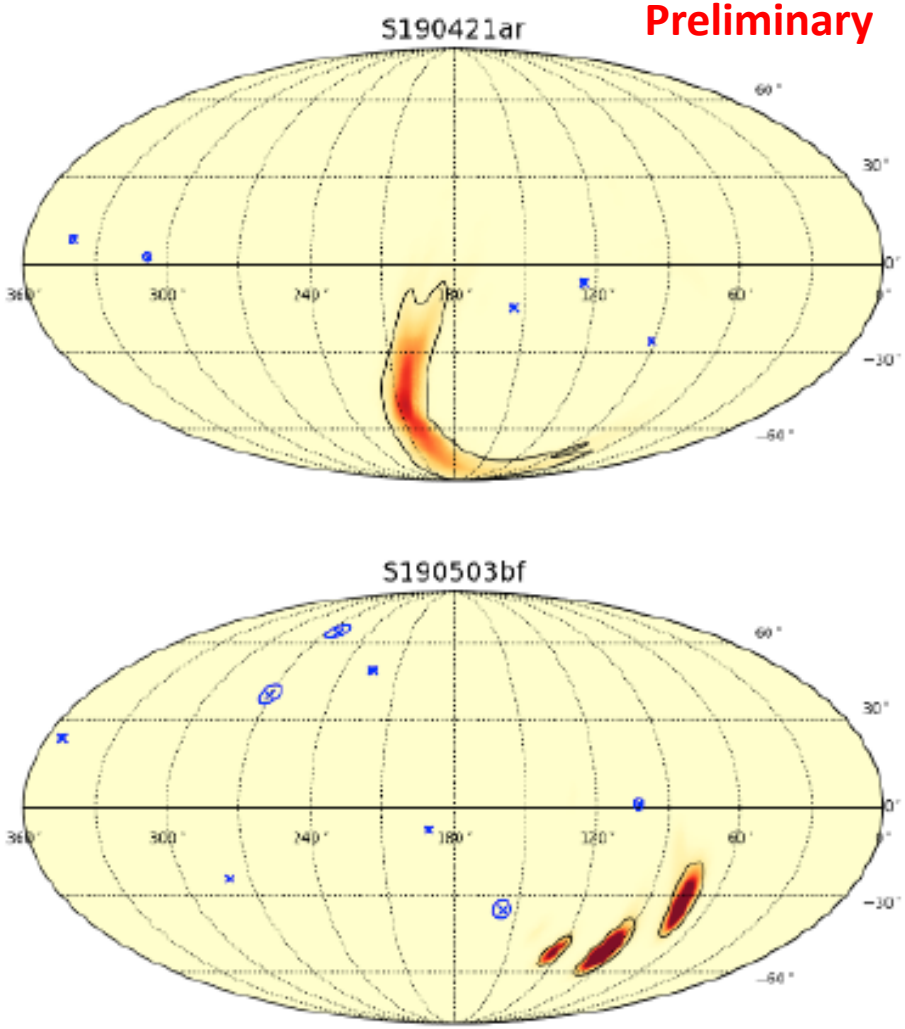
IceCube and Antares have realtime (latency ~1-2 hr) follow-up to public GCN GW alerts.

IceCube has two analyses. Temporal and directional correlati within +- 500 s.

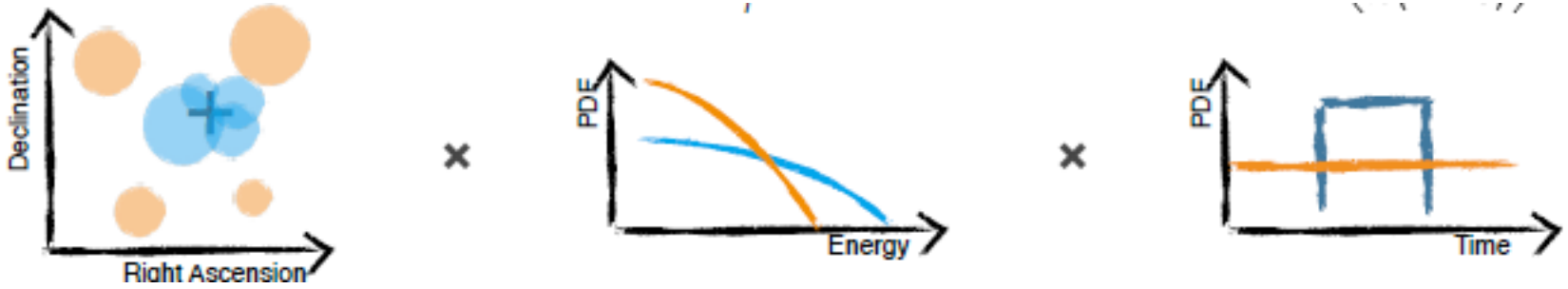
In IceCube, ROC, organizes producing public report: A GCN Circular

IceCube. PoS (ICRC2019) 856
IceCube. PoS (ICRC2019) 918
Antares. PoS (ICRC2019) 930
Antares. PoS (ICRC2019) 984

IceCube Preliminary



Fast Response Analysis

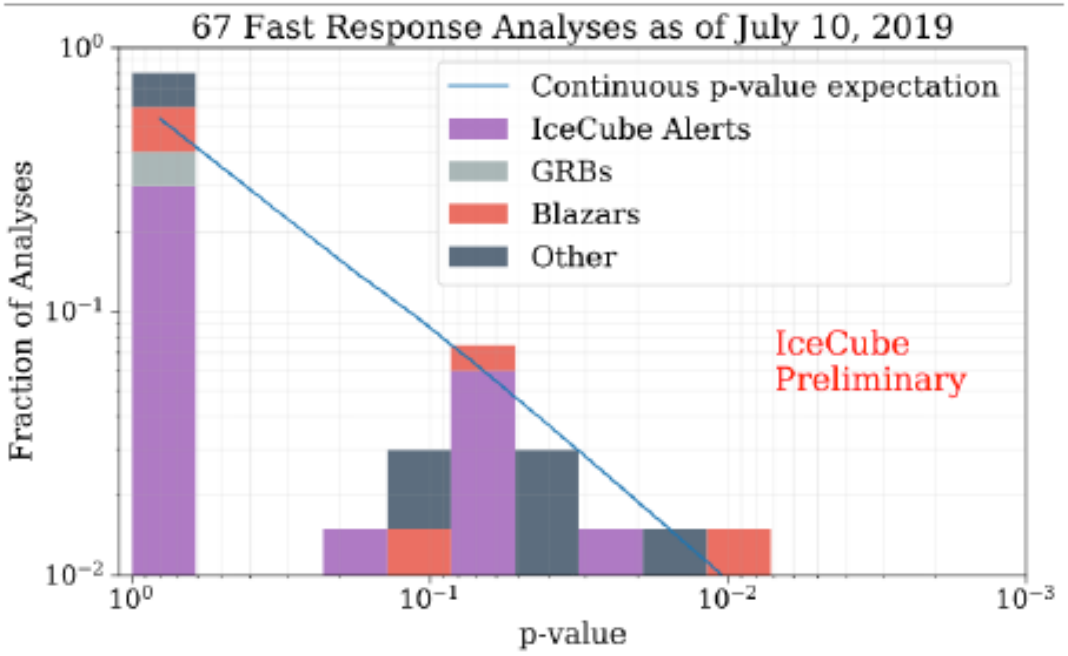


Human triggered (ROC) response to relevant ATel, GCNs, other.
IceCube responds publicly on initiating channel.

4π sensit. > 99% uptime.

Method is appropriate for < 30-day time scale.

IceCube. PoS (ICRC2019) 1026



Memoranda of Understanding

IceCube has private collaboration agreements with many collaborations: PTF, ZTF, HAWC, VERITAS, MAGIC, HESS, Fermi LAT, Fermi GBM, Swift, LIGO/VIRGO, etc. ANTARES, etc. do the same.

Data can be shared both ways, in confidence.

IceCube strives to share simultaneously with all instruments with MoU for a given band, e.g. share with VERITAS, H.E.S.S, Magic, Fermi.

Have led to many joint publications.

Neutrinos from a Galactic Core Collapse SNe

SNEWS 2.0: Seven neutrino detectors. Recently funded by NSF.

Regular trigger: 1s scale. Core collapse. Milky Way and Magellanic Clouds.
Nearly all (100% NIR, 98% VIS) would be detectable.
(Shock breakout median m_V ~12.5; m_K ~ 4; max m_v ~25 ; m_K 14.3)
Adams et al. ApJ, 778(2):164, 2013.

Potentially detectable in GW. GCN Circ: 26235

SNEWS points via triangulation. More alerts coming via higher false alert rate.
CCSN in MW ~3.2 / century.

Late burning stages trigger. Days pre-core collapse. Observable in ν within a few hundred pc. Only a fraction of detectors sensitive to this.

Neutrino flavor sensitivity is detector dependent. Some detectors can provide pointing by themselves, e.g. Super-K.

Summary

Realtime systems have led to one major observation: TXS 0506+056.

Public systems (high-signalness alerts, fast response, GW-tailored) are a critical component of ν-astro science.

A galactic CCSNe neutrino-detector model: usually not principal science objective, but always planned for.

Difficulties:

- Language: physics vs. astronomy.
- Culture: ν-detectors are like high-energy-physics.
- Multi-detector MoUs can be done – but it's much harder.

Diffuse (unresolved) VHE ν-flux

Several methods: Tracks (δ>-5°), Starting Events (HESE), Cascades

Different energy coverage (>60 TeV for HESE vs. >200 TeV for tracks). Two populations? -> But we don't know what the sources are.