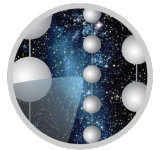
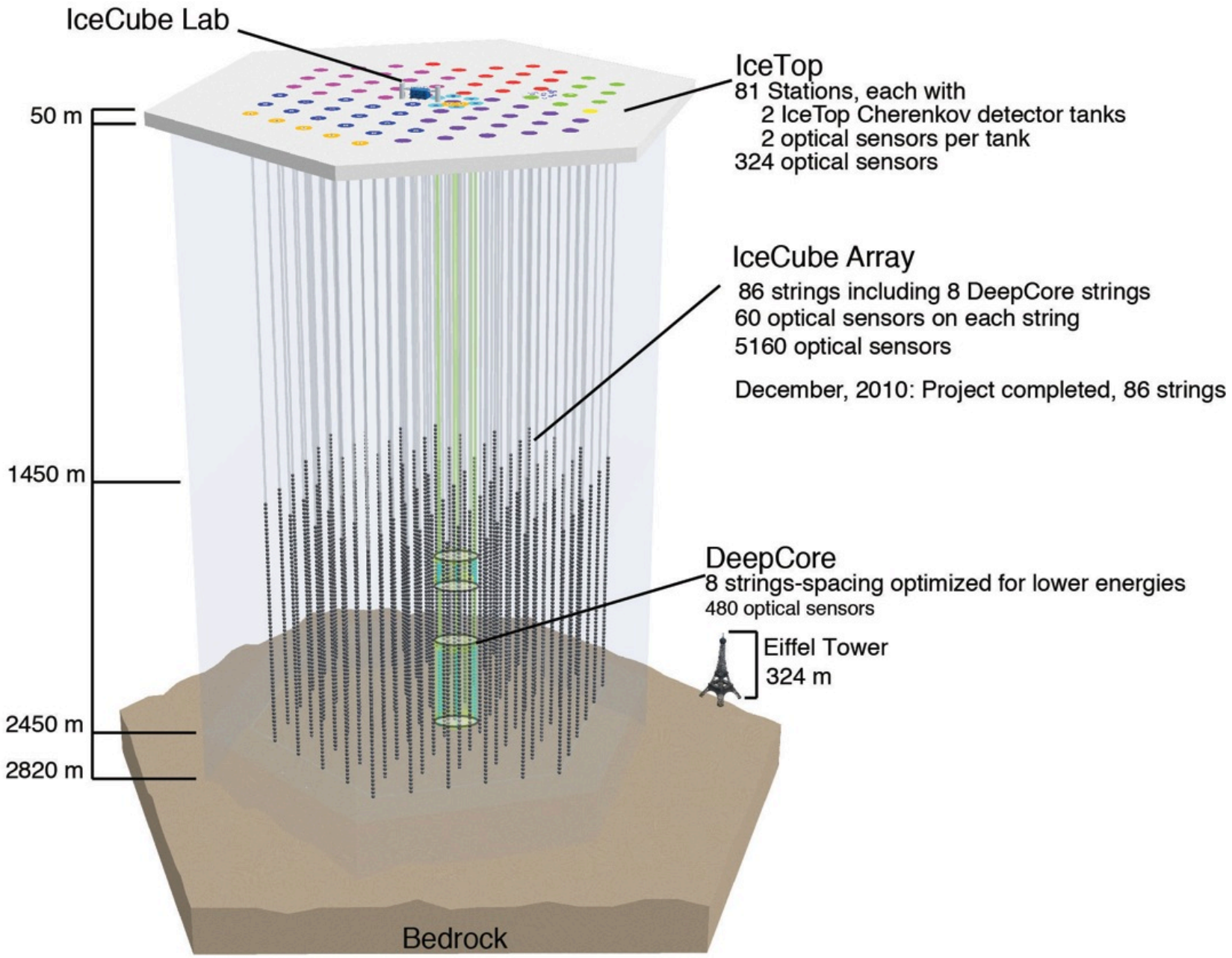
IceCube Science Highlights and Priorities

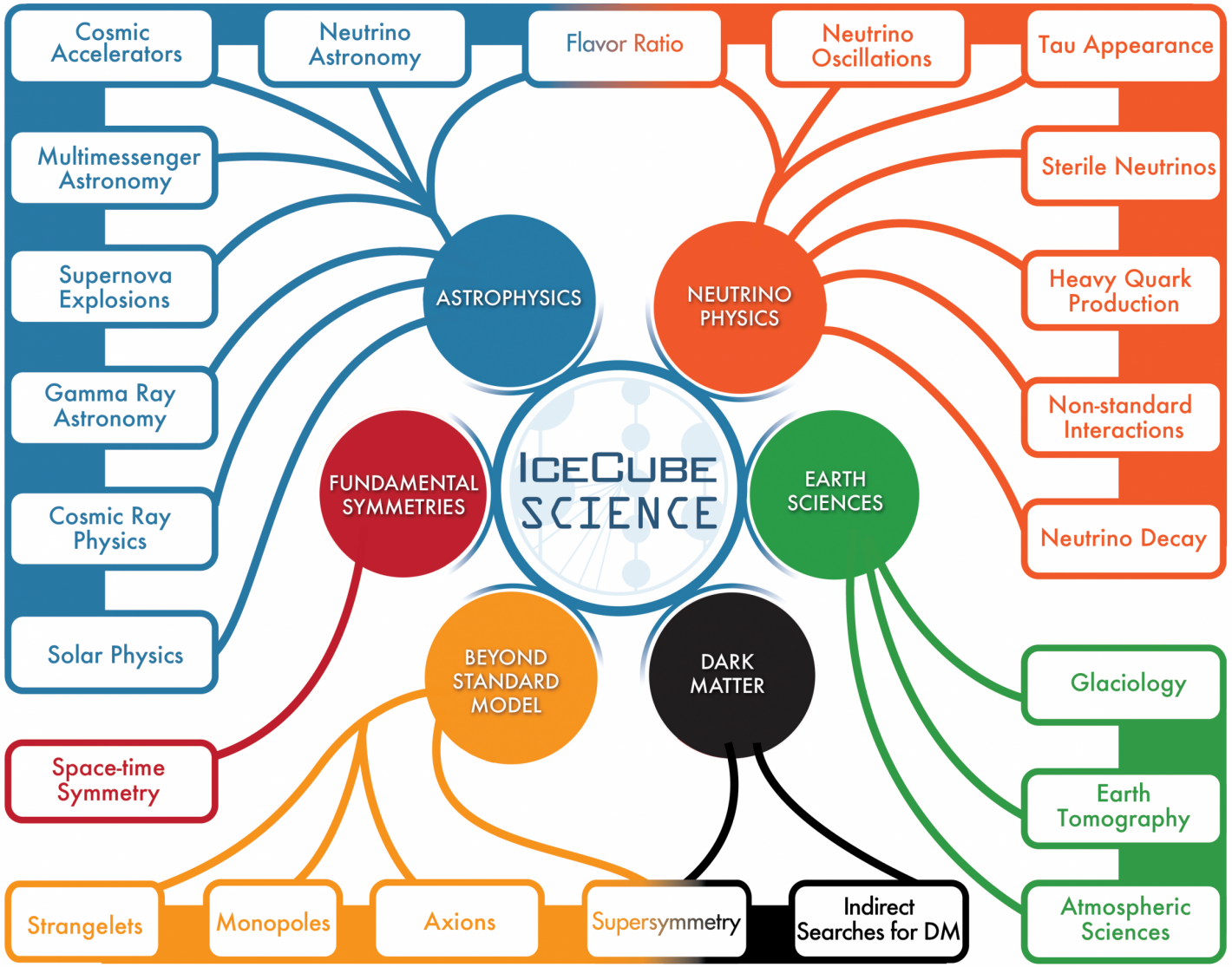
Ignacio Taboada
Georgia Institute of Technology



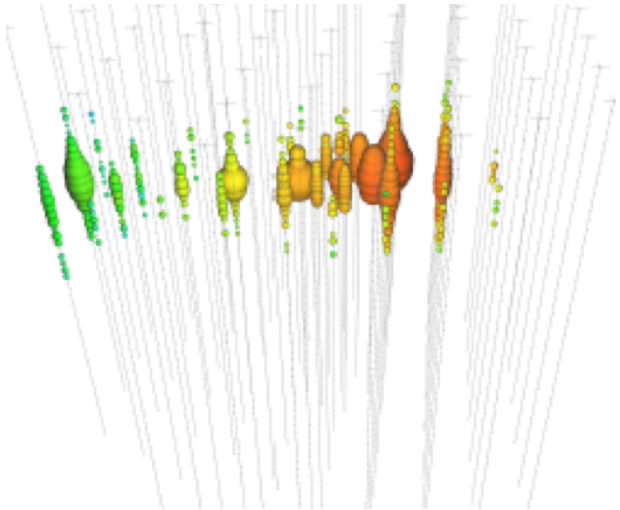

IceCube Lab
50 m
1450 m
2450 m
2820 m
Bedrock
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m

IceCube science is *very* diverse

I will focus on two studies today. The conclusions apply broadly to IceCube Science.



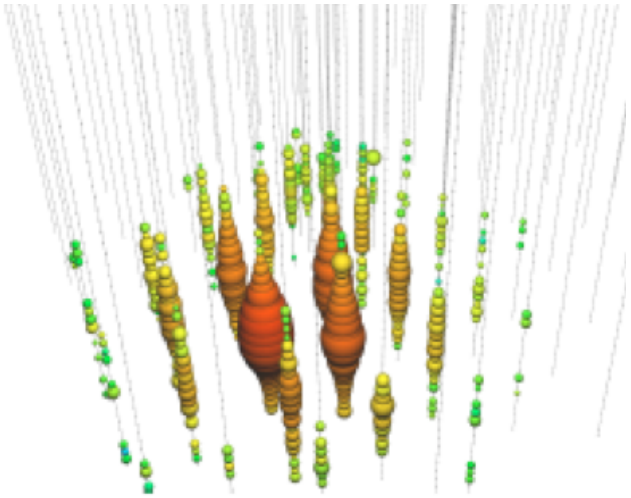
IceCube science is *very* diverse



Tracks:

CC ν_μ (dominant)

CC ν_τ; τ -> μ; (minor)

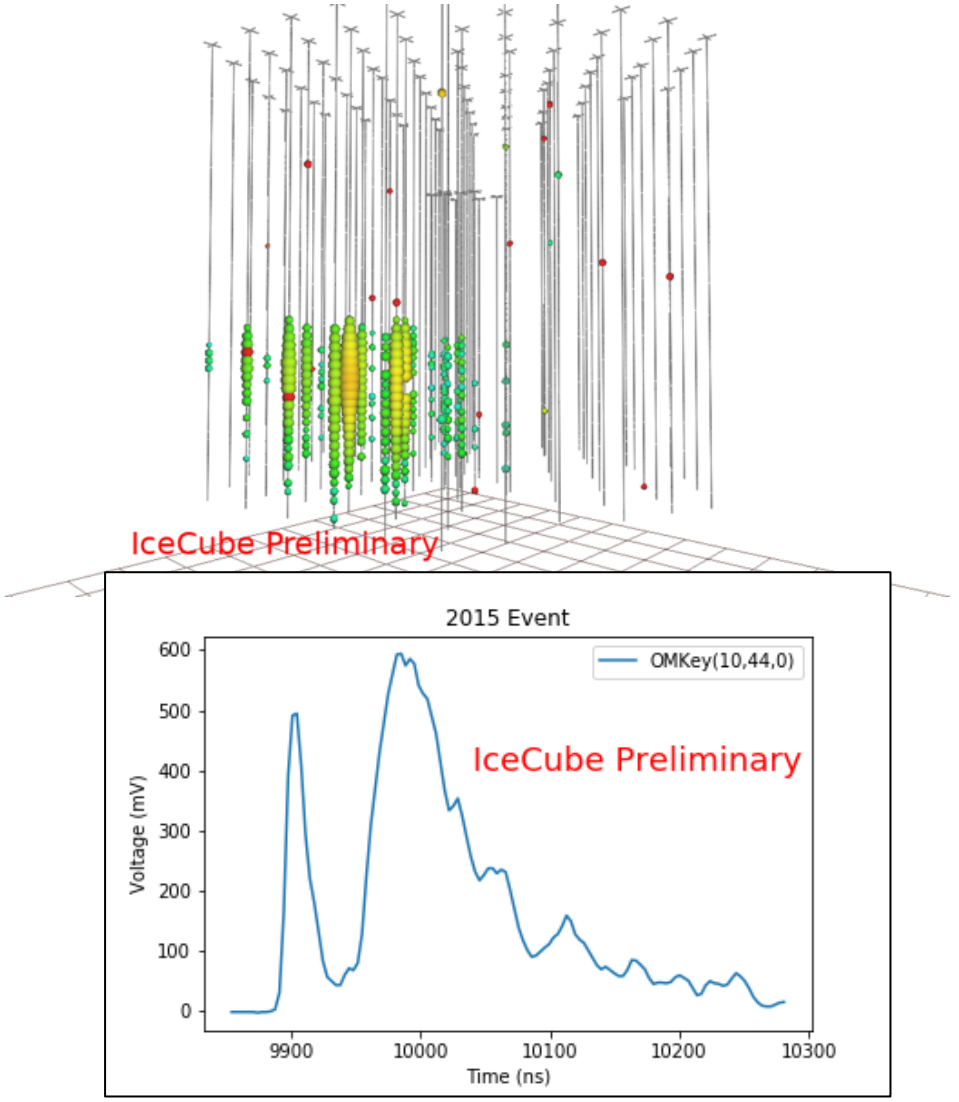


Cascades or Showers:

All other CC + all NC

Glashow resonance

A ν_τ candidate



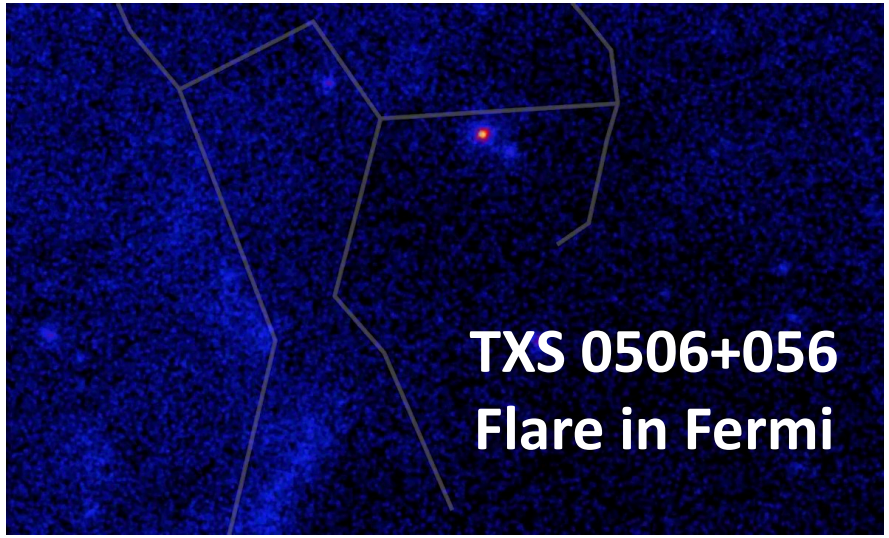
Working Group Structure

Analysis Coord.	Deputy Analysis Coord.
A. Franckowiak	I. Taboada

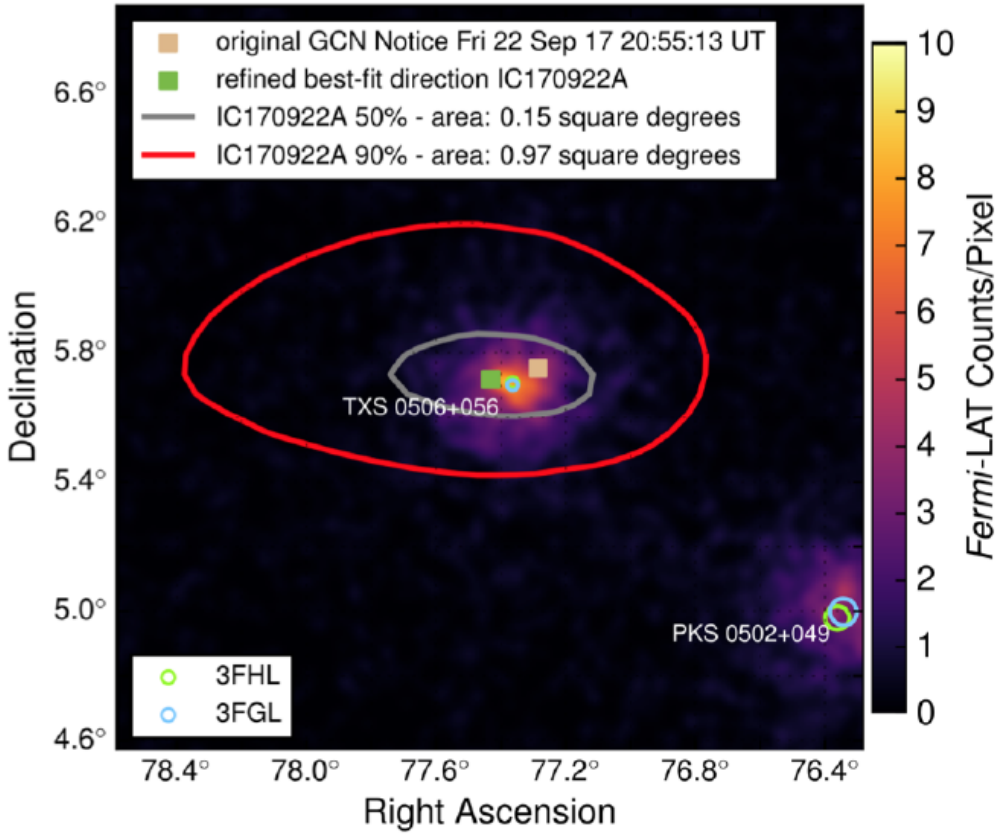
Science WG	Leads	Technical Leads
Neutrino Sources	M. Ahlers, J. Vandenbroucke	H. Niederhausen, M. Larson, S. Sclafani
Diffuse	N. Whitehorn, L. Lu, C. Kopper	M. Meier
Oscillations	T. Stuttard, B. Jones	P. Eller
Beyond the Standard Model	A. Pollman, J.A. Aguilar	C. Argüelles
Supernovae	S. BenZvi, E. O'Sullivan	
Cosmic Rays	D. Soldin, A. Haungs	K. Rawlings

Technical WG	Leads
Realtime	E. Blaufuss
Reconstruction	J. van Santen, C. Haack
Calibration	A. Halgren, M. Rongen

TXS 0506+056: First evidence of a HE ν source

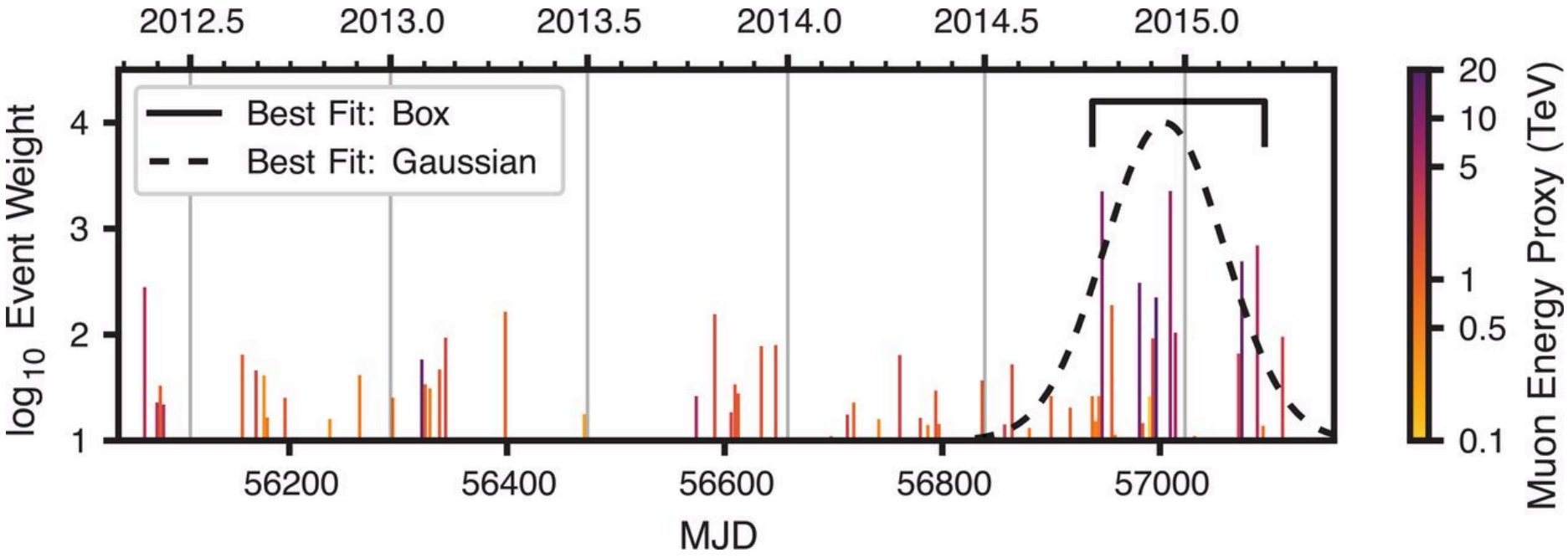


Science 361 (2018) eaat1378



IceCube-170922: a neutrino alert issued by IceCube
Fermi and MAGIC identify a spatially coincident flaring blazar: **TXS 0506+056**
γ-ray / neutrino correlation significance: 3 σ.

IceCube archival data towards TXS 0506+056



Excess of events: 13 ; spectral index: -2.2
Significance: 3.5 σ

Science 361 (2018) 147-151

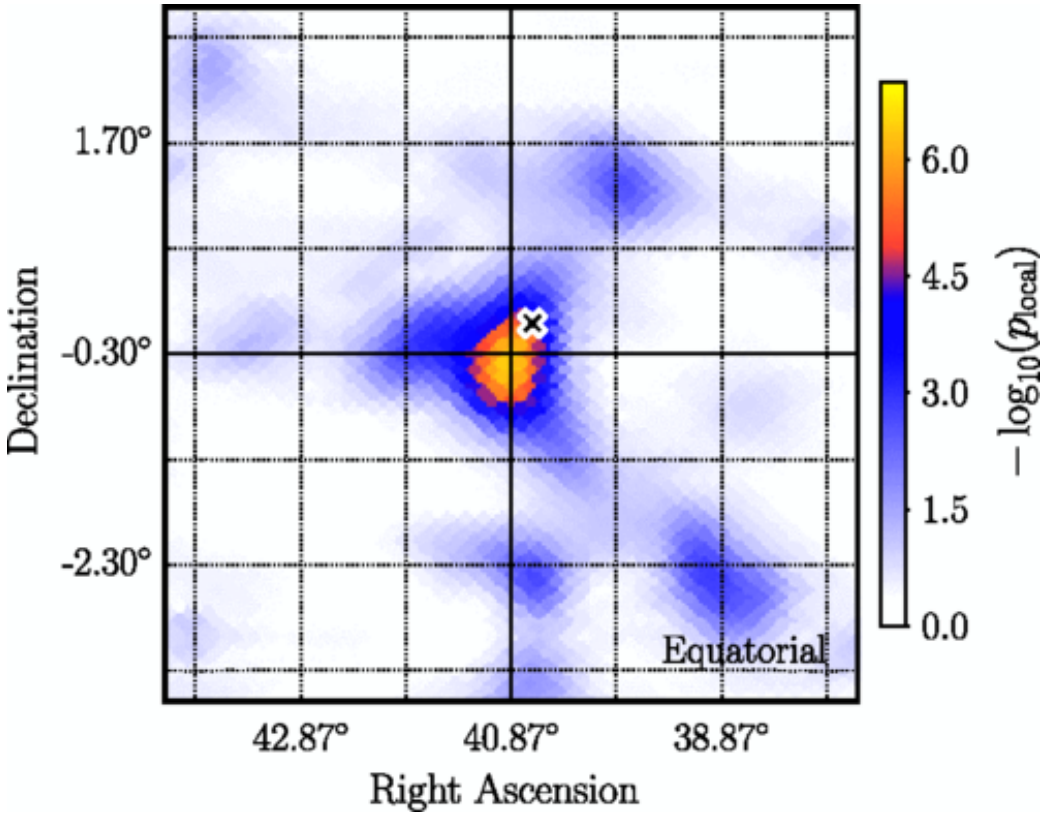
Improving IceCube's sensitivity to Neutrino Point Sources

Time-integrated study of 9.5 years
PRL 124, 051103 (2020)

* Hottest spot in the northern sky is 0.35° from Seyfert II / Starburst galaxy NGC 1068

* NGC 1068 is the most significant source out of a preselected list: 2.9 σ
(Back of the envelope if real: wait ~19 years for 5 sigma)

* The most significant group, 3.3 σ, (binomial stat.) out of the list has 4 sources: TXS 0506+056, NGC 1068, PKS 1424+240 and GB6 J542+6129
We already know about TXS 0506+056



Pre-trial p-value map
Cross: Location of NGC 1068

Improving IceCube's sensitivity to Neutrino Point Sources

It has been known, for a while, that we had a bias in the reconstruction of neutrino point source properties.

The best fit for TXS 0506+056 is:

$n_s = 12.3 \quad \gamma = 2.1$

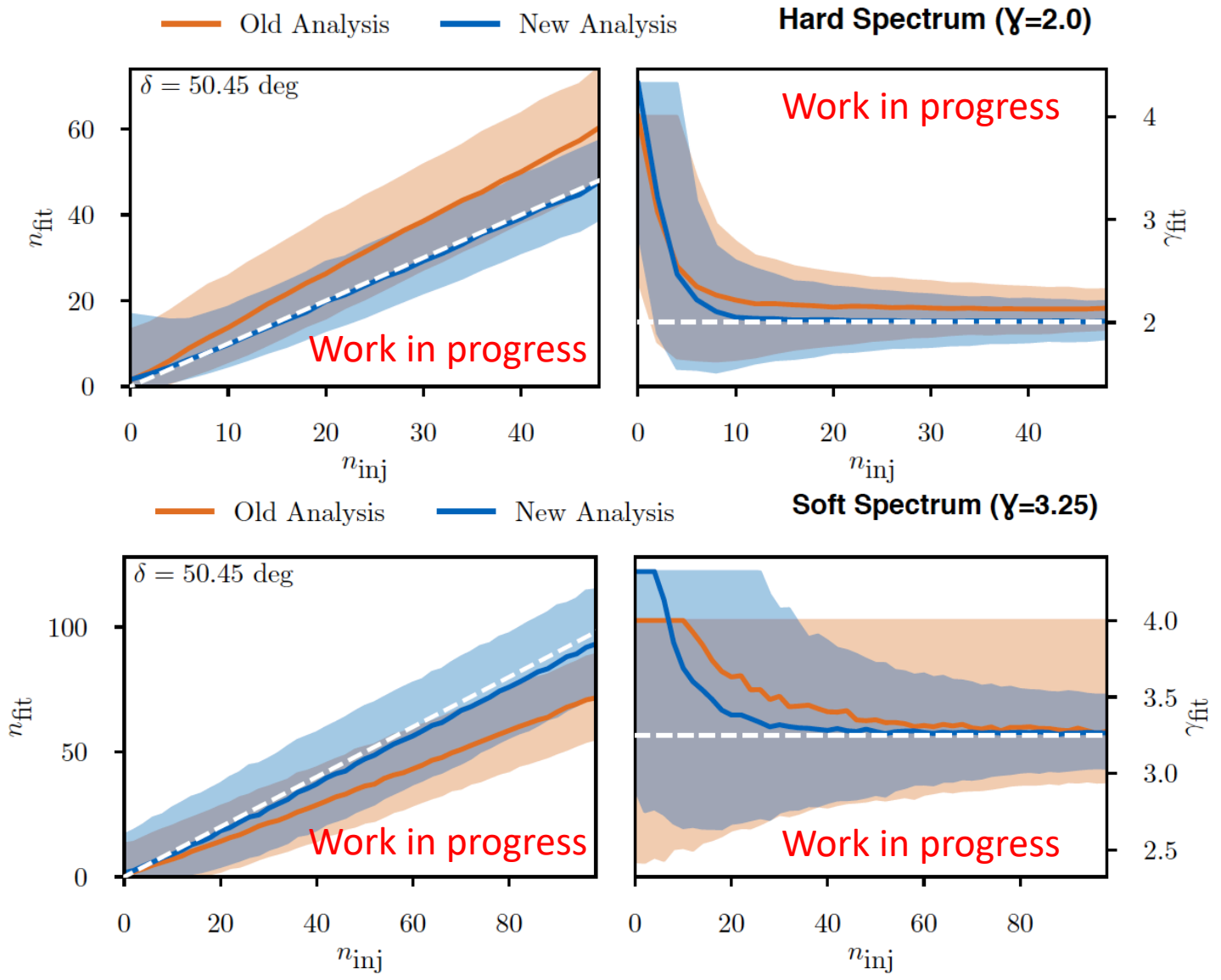
(Consistent with prev. pub.)

The best fit for NGC 1068 is:

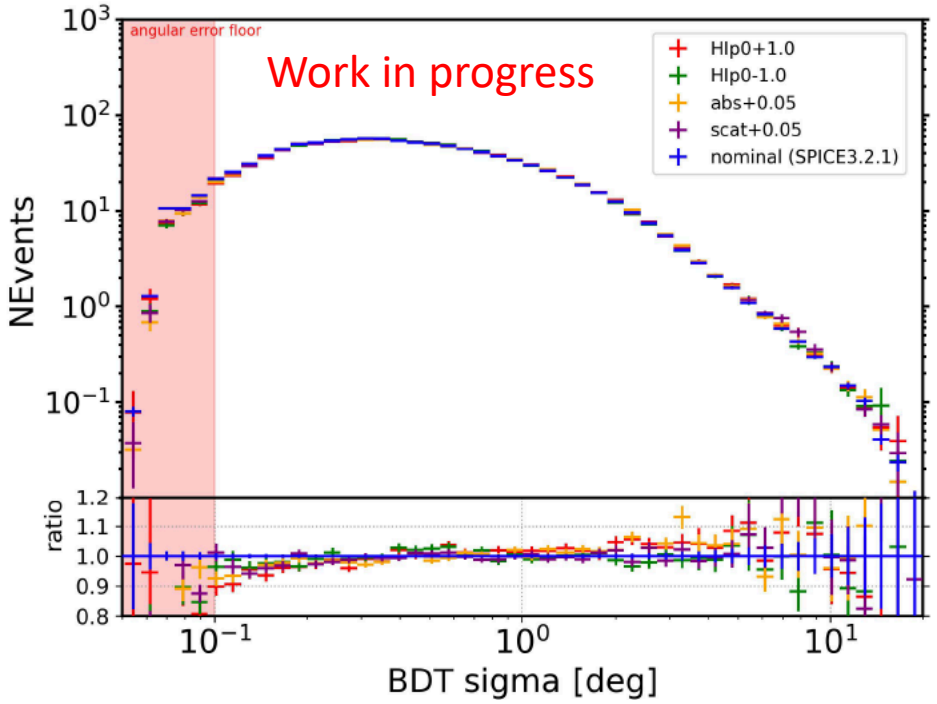
$n_s = 50.4 \quad \gamma = 3.2$

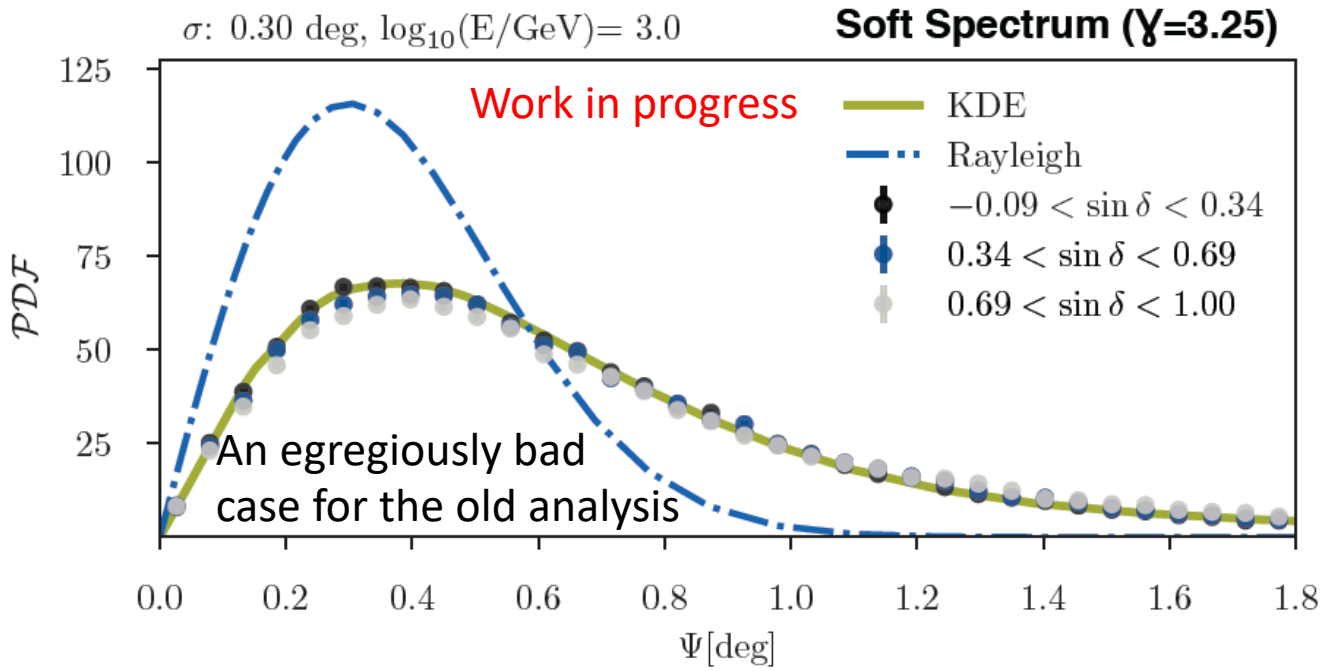
From: PRL 124, 051103 (2020)

The bias has now been solved.



Improving IceCube's sensitivity to Neutrino Point Sources

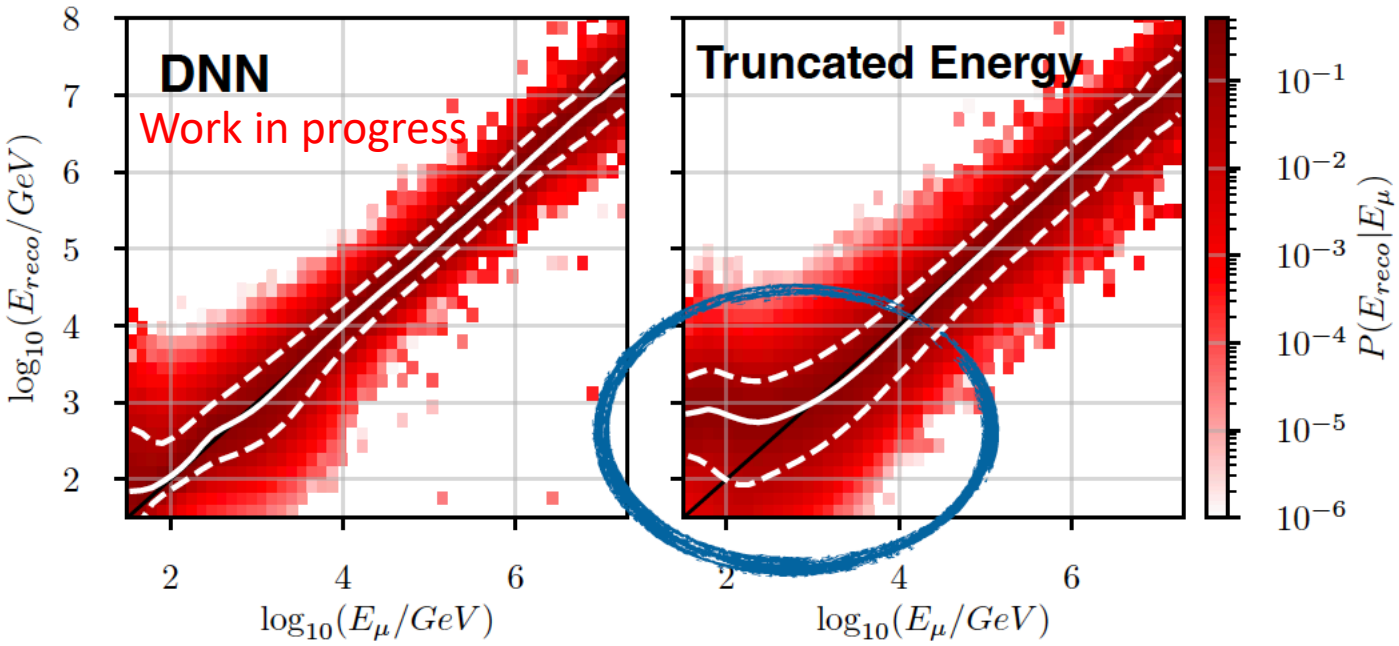




Per-event angular uncertainty, *for muons,* has a pdf (function of γ)
Neutrino-Muon kinematic angle is treated separately (function of γ)

The PDF of truth to reconstruction angle, Ψ, now uses a KDE from simulations.

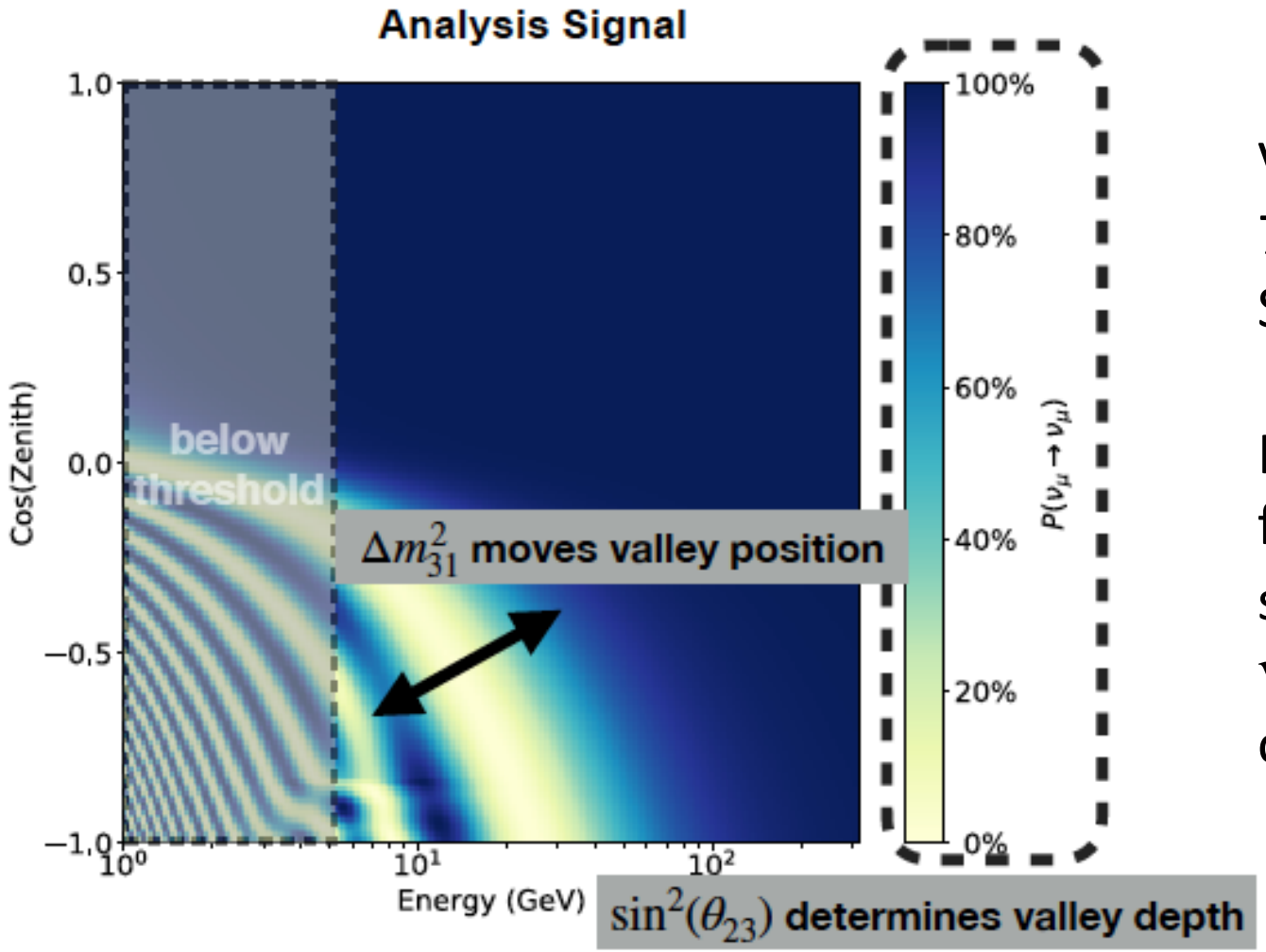
Improving IceCube's sensitivity to Neutrino Point Sources



Better track energy estimator, with lower variance and improved performance from 100 GeV to 1 TeV (See C. Kopper talk)

Using now *Pass 2* data. (See N. Kurahashi-Nielson talk)

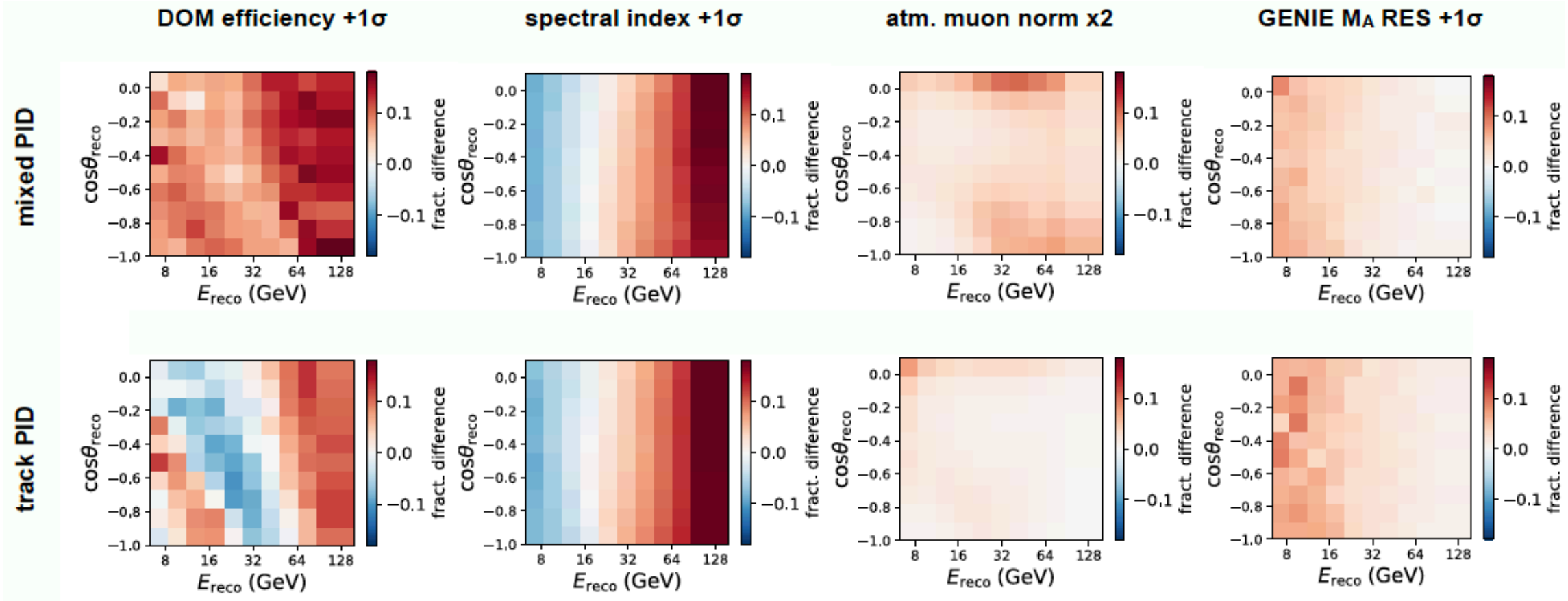
OscNext: Verification Sample. ν_μ disappearance.



Verification sample:
7.5 years of data – DeepCore
Sub-selection of 24k high quality events

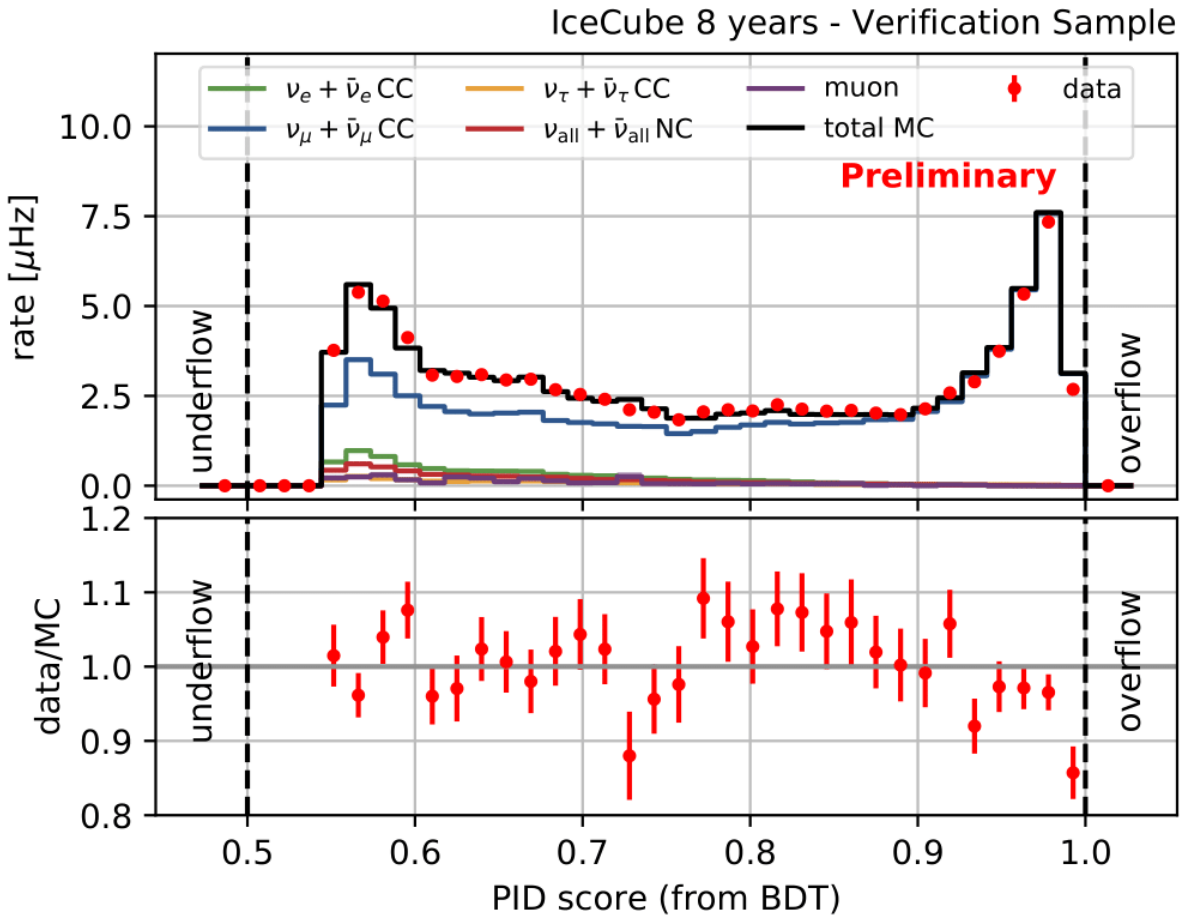
High-statistics OscNext with even better foreseen sensitivity on the works. To serve many studies, $\nu\mu$ disappearance, ν_τ appearance, non-standard oscillations, etc.

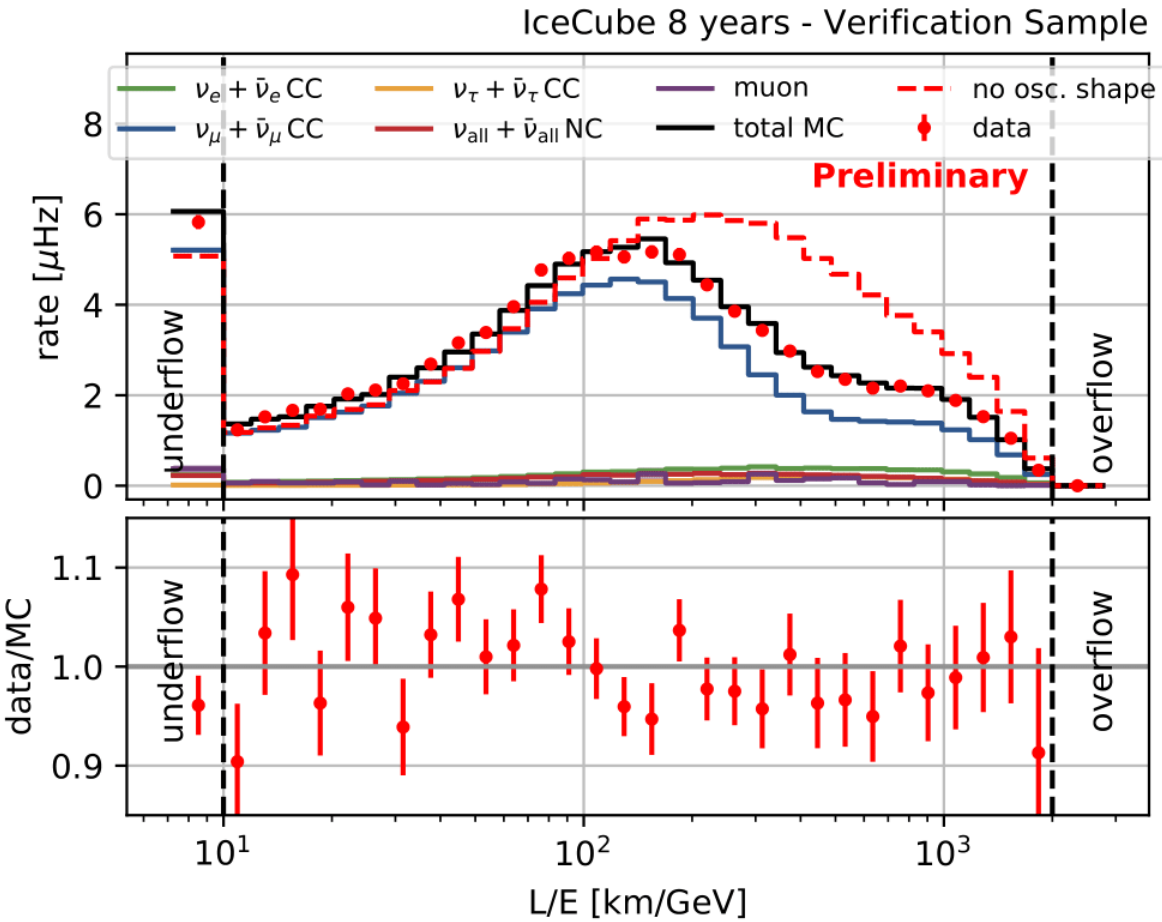
OscNext: Verification Sample. ν_μ disappearance.



Pass 2. Best knowledge of hole/bulk ice optical properties; relative DOM sensitivity; atmospheric neutrino spectrum; CR-muon contamination; neutrino cross-section, etc.

OscNext: Verification Sample. ν_μ disappearance.





Analysis-level & reconstruction software: a bottom-up approach

Analysis level software, e.g., SkyLLH (improved PS analysis) begins life as a single student or few people project. Lives in a github sandbox. Ditto for reconstruction algorithms.

When useful, even if for a single analysis, tagged versions are used. Here WG tech leads play a critical role. Also, reconstruction WG co-leads

When it's even more useful, the project evolves into a collaboration project. Such software is maintained as part of M&O for IceCube. Example, snowstorm.

Analysis software can retire, example psLab.

This life cycle for analysis software is a natural consequence of the wide diversity of science topics in IceCube.

Summary

Life is harder when your detector is no longer statistics limited. We are already improving analysis by studying systematics and improving detector description.

Our data is archival and can be re-analyzed to apply improvements.
(This is not always the case for astrophysical instruments)

A ‘systematics-free’ simulation of our detector shows that we still have ample room to improve the angular resolution, specially >100 TeV
… and Point Source sensitivity is ~linear in angular resolution.

Improvement in bulk/hole ice systematic uncertainties will continue to yield improvements in sensitivity to neutrino oscillations. (See Upgrade talk by E. Blaufuss)

<u>We can still extract a lot of good science from IceCube.</u>