Multi-messenger prospects in a gamma-ray world

Valerie Connaughton

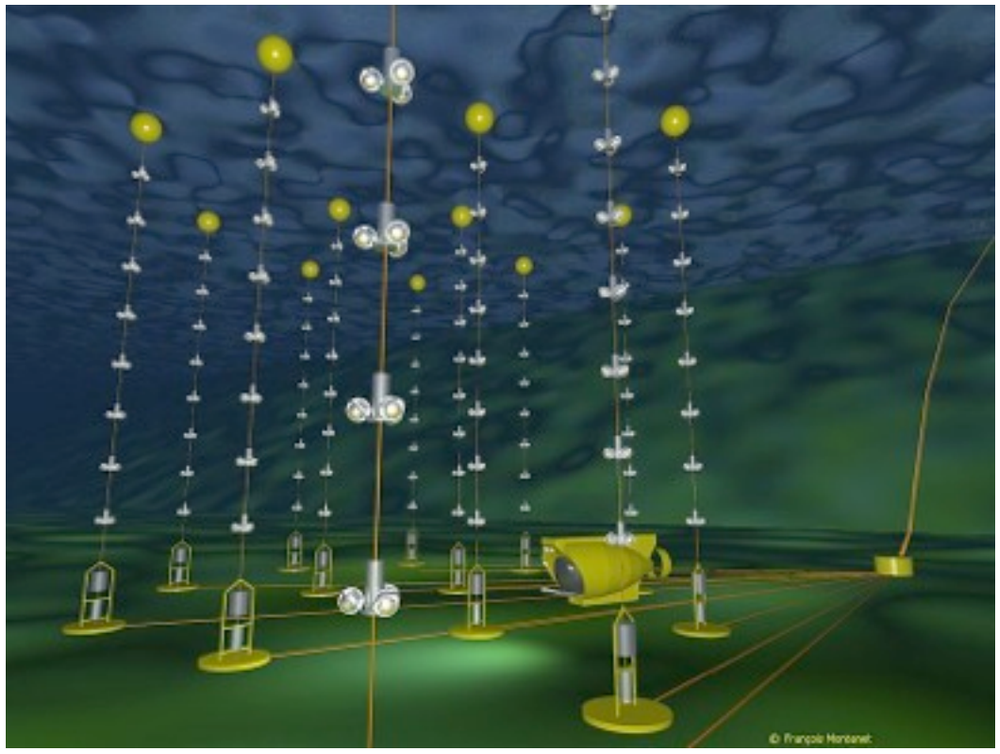
Neutrinos are fantastic indicators of proton acceleration

$$p + \text{nucleus} \rightarrow \pi^0, \pi^+, \pi^-$$
$$\pi^0 \rightarrow \gamma\gamma$$
$$\pi^+ \text{ or } \pi^- \rightarrow \mu^+ \text{or } \mu^- \ \nu_\mu$$
$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$
$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

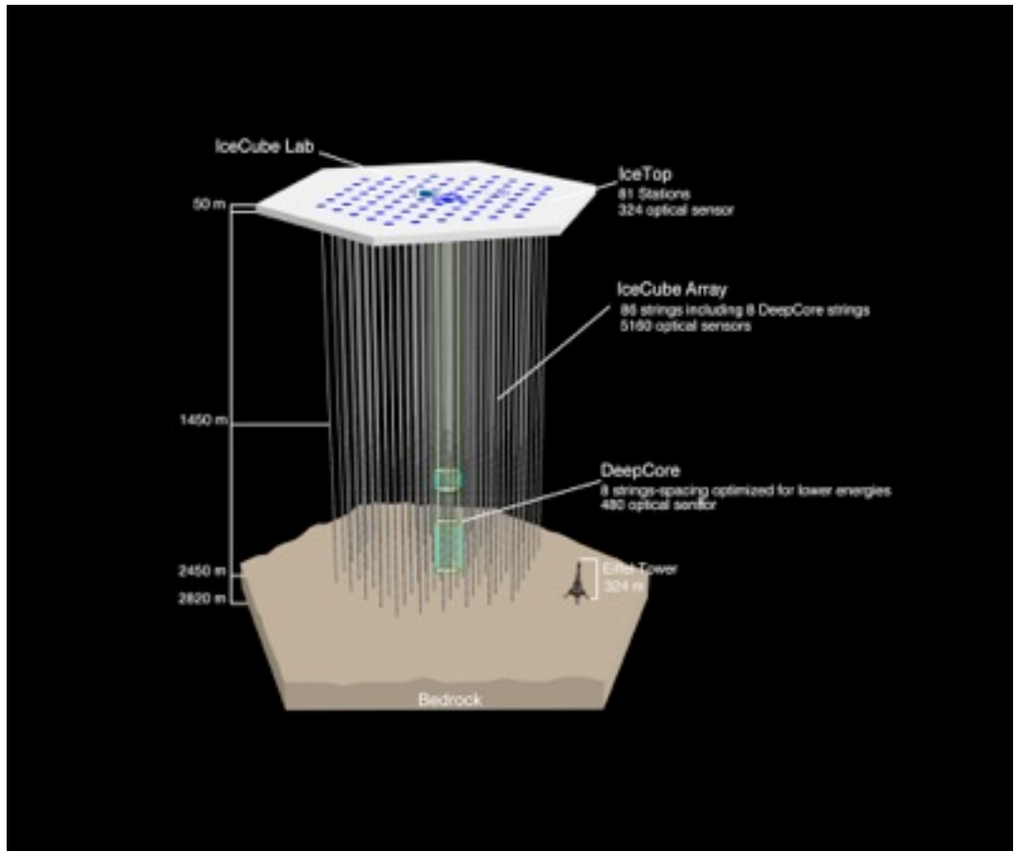
Similar neutrino production from p-γ interactions, via Δ^+ resonance

- TeV gamma-ray sources are all good candidates
- Neutrino detection would confirm hadronic over leptonic models e.g., in blazars. cf. Orphan flares in 1ES 1959+650
- characteristics of neutrino --> characteristics of protons
- Probe both galactic CRs and identify the source of UHECRs

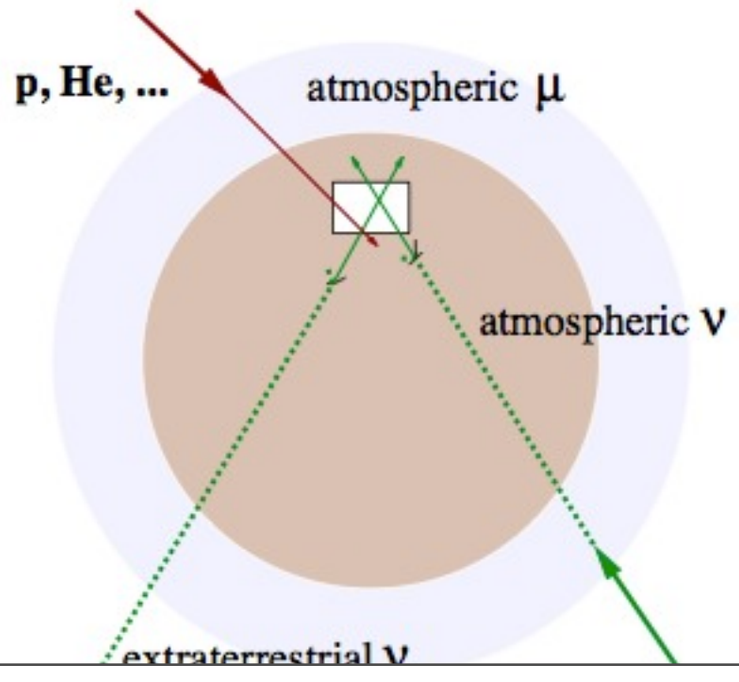
Neutrinos are difficult to detect



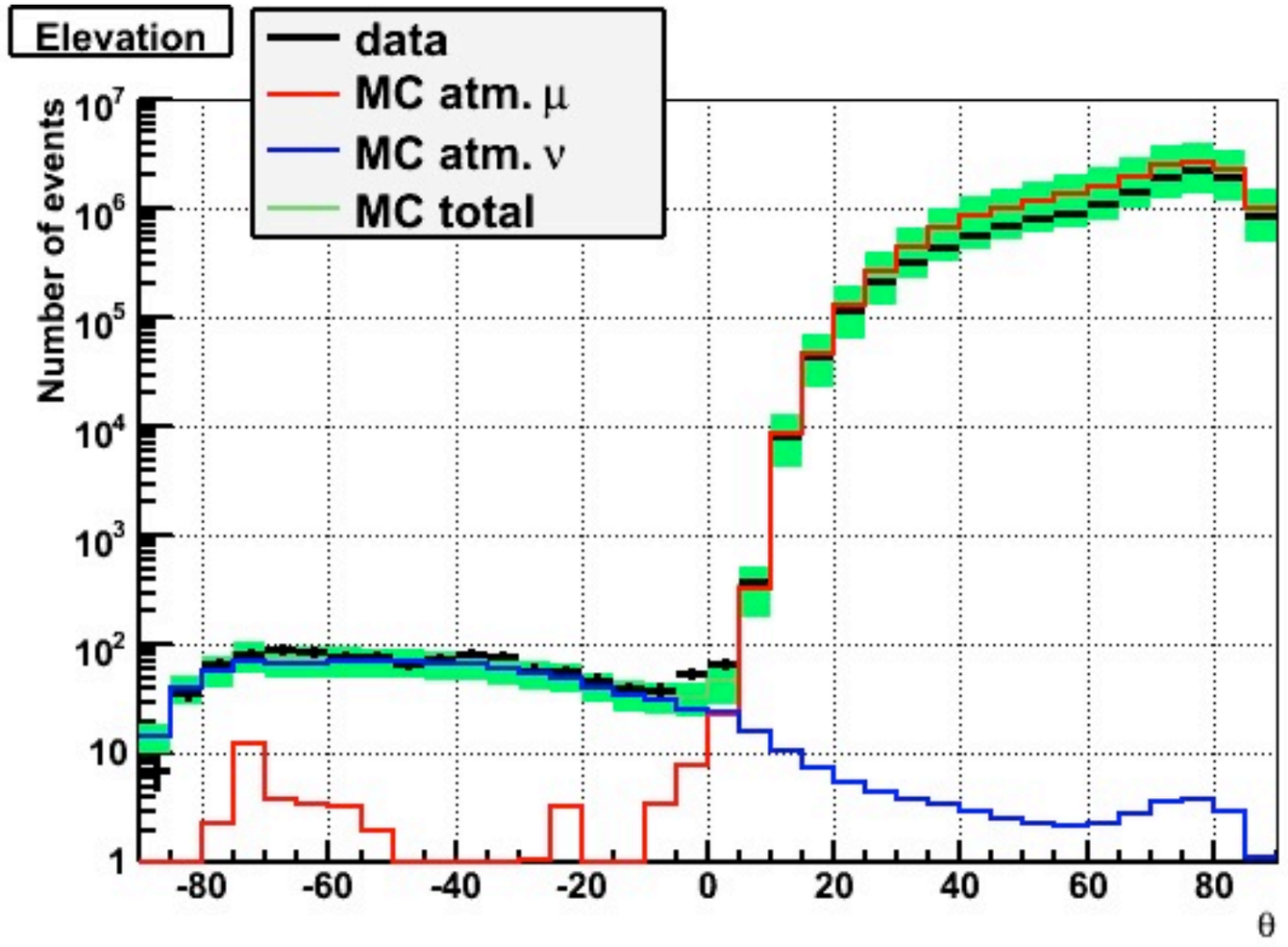
ANTARES



IceCube

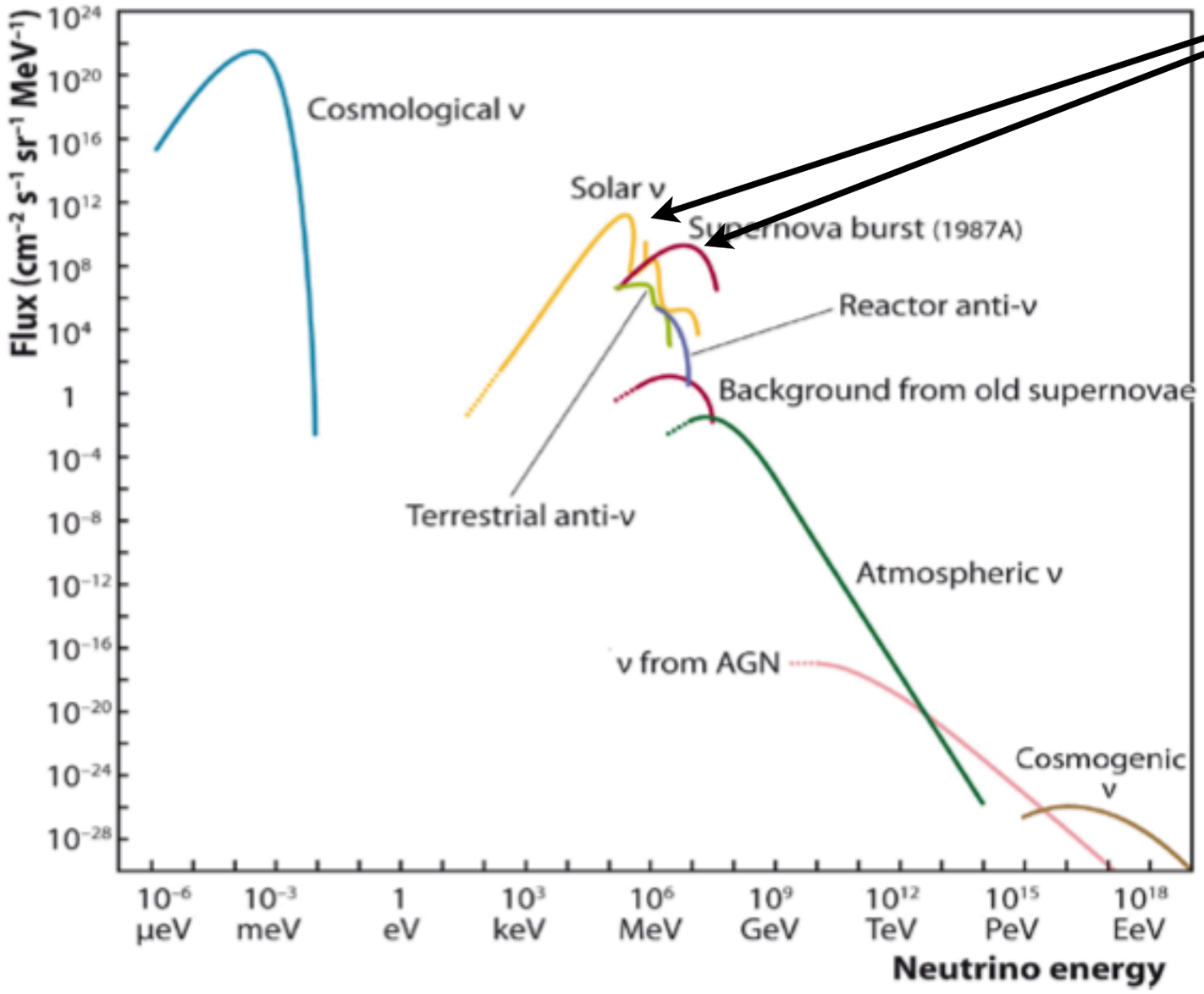


Neutrino detectors have a large background of atmospheric muons and atmospheric neutrinos



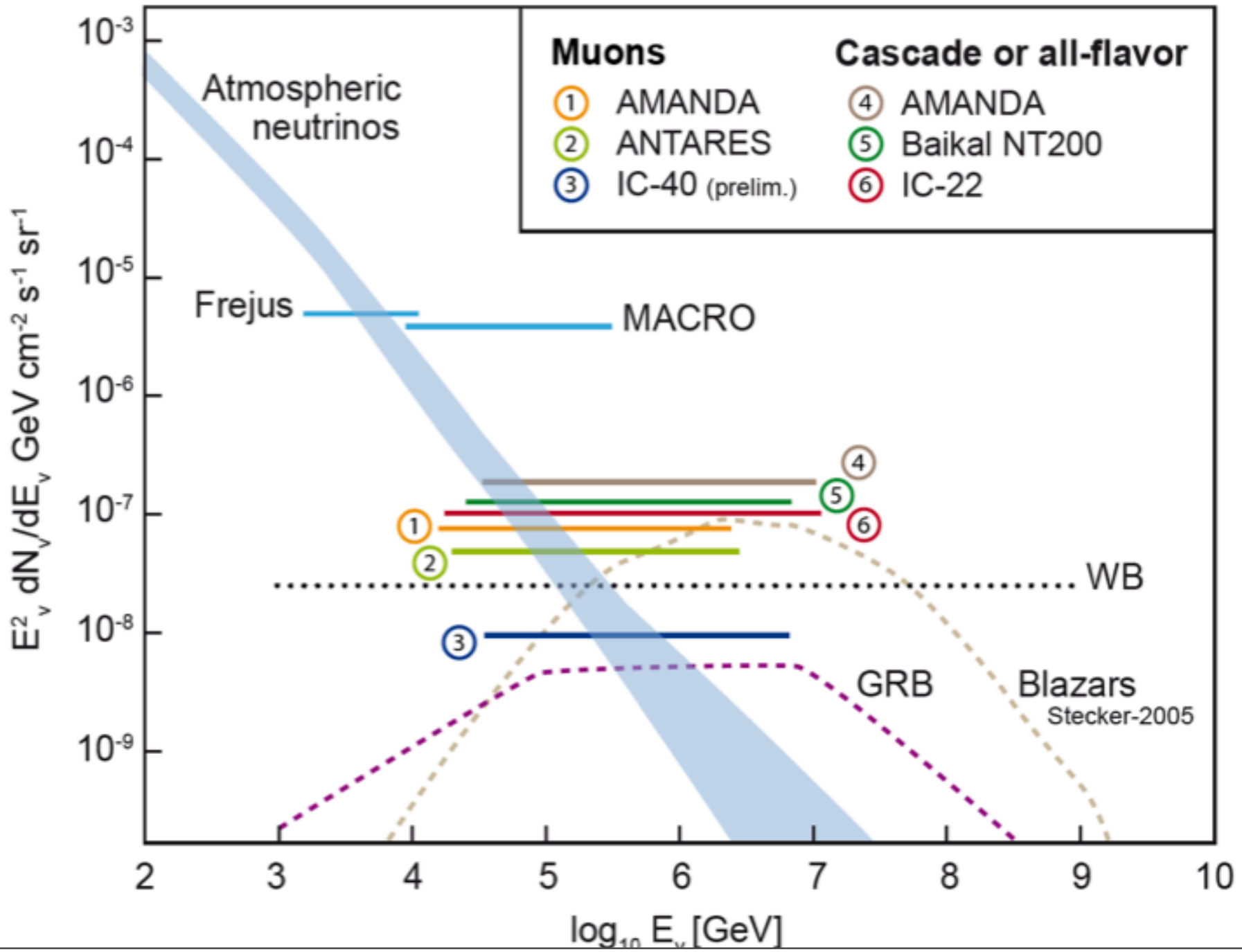
ANTARES

Expected neutrino fluxes as a function of energy give hope for > TeV detection from astrophysical sources

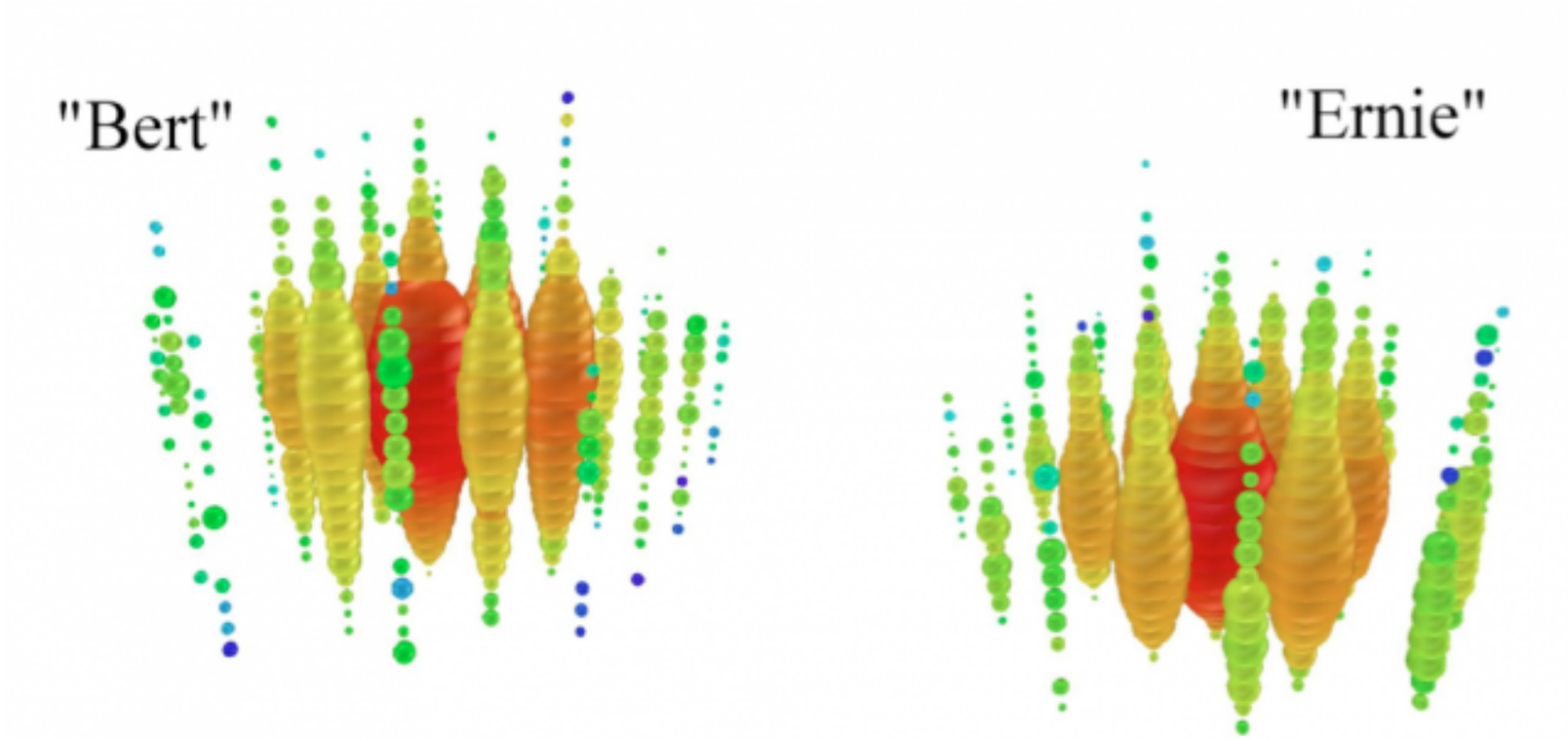


Spiering 2012

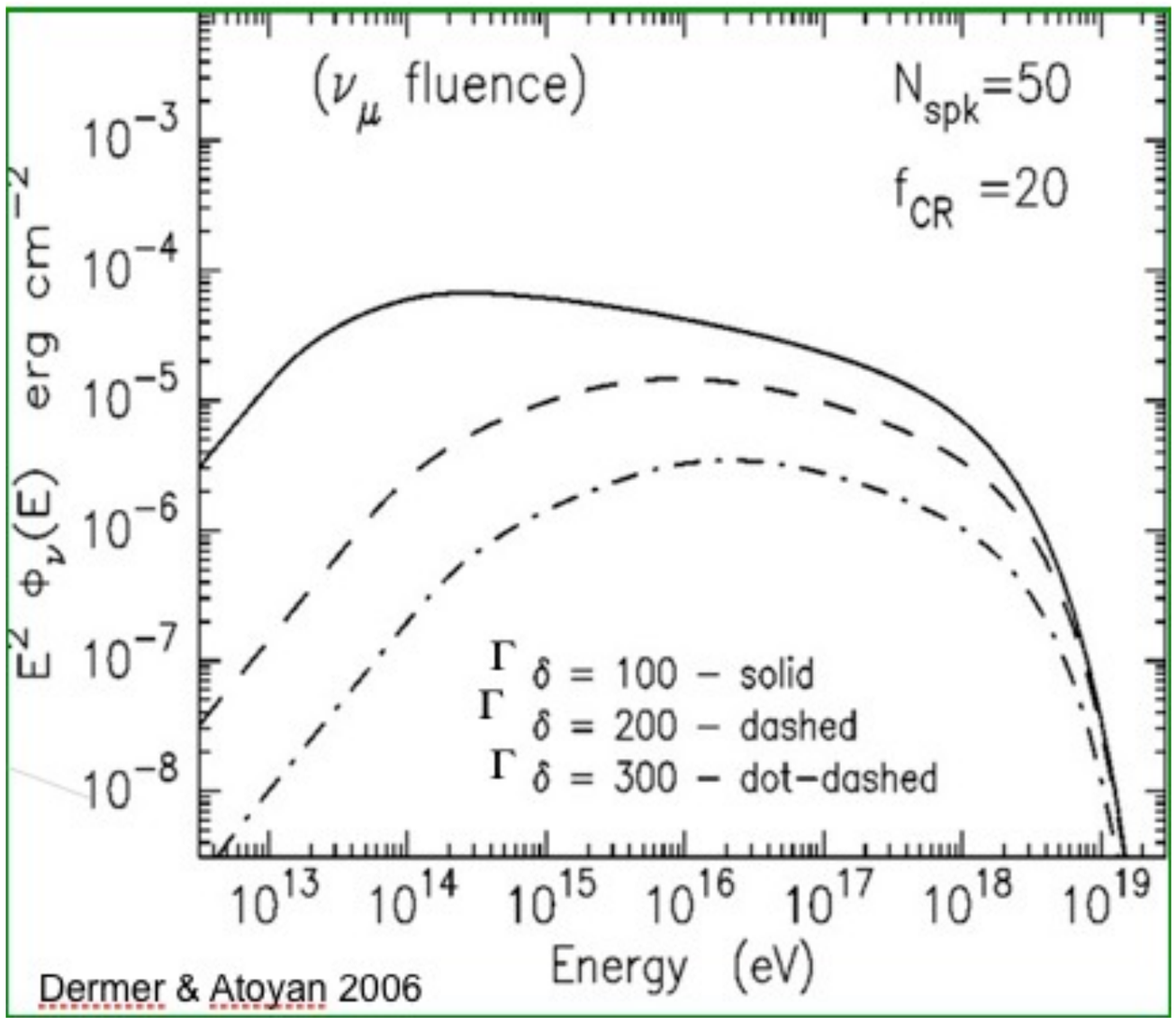
Limits from current neutrino experiments approach Waxman-Bahcall bound



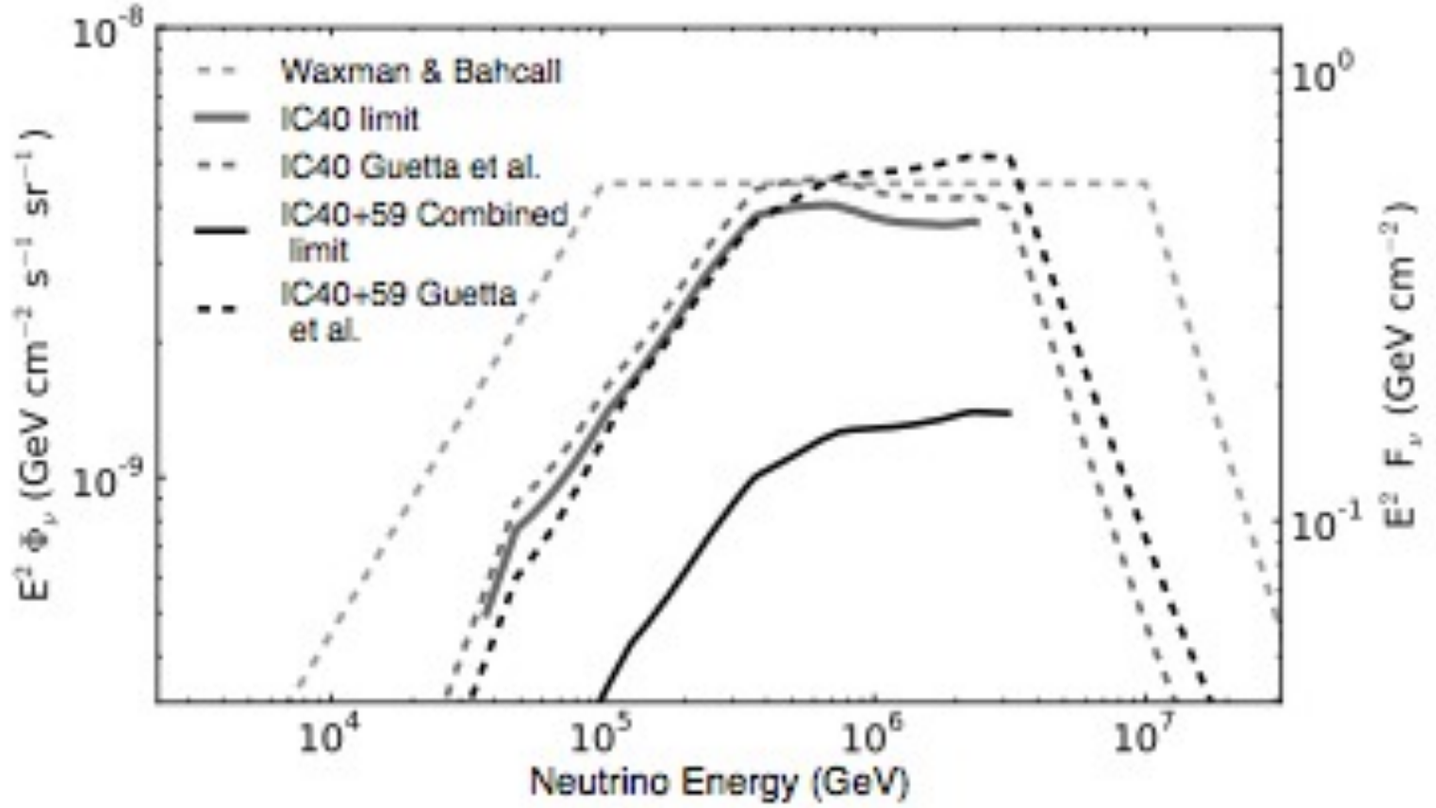
PeV neutrinos have been detected by IceCube
Bert and Ernie, origin unknown, but possibly astrophysical



We expect to be able to detect neutrinos from GRBs with IceCube unless the conditions in the GRB are unsuitable

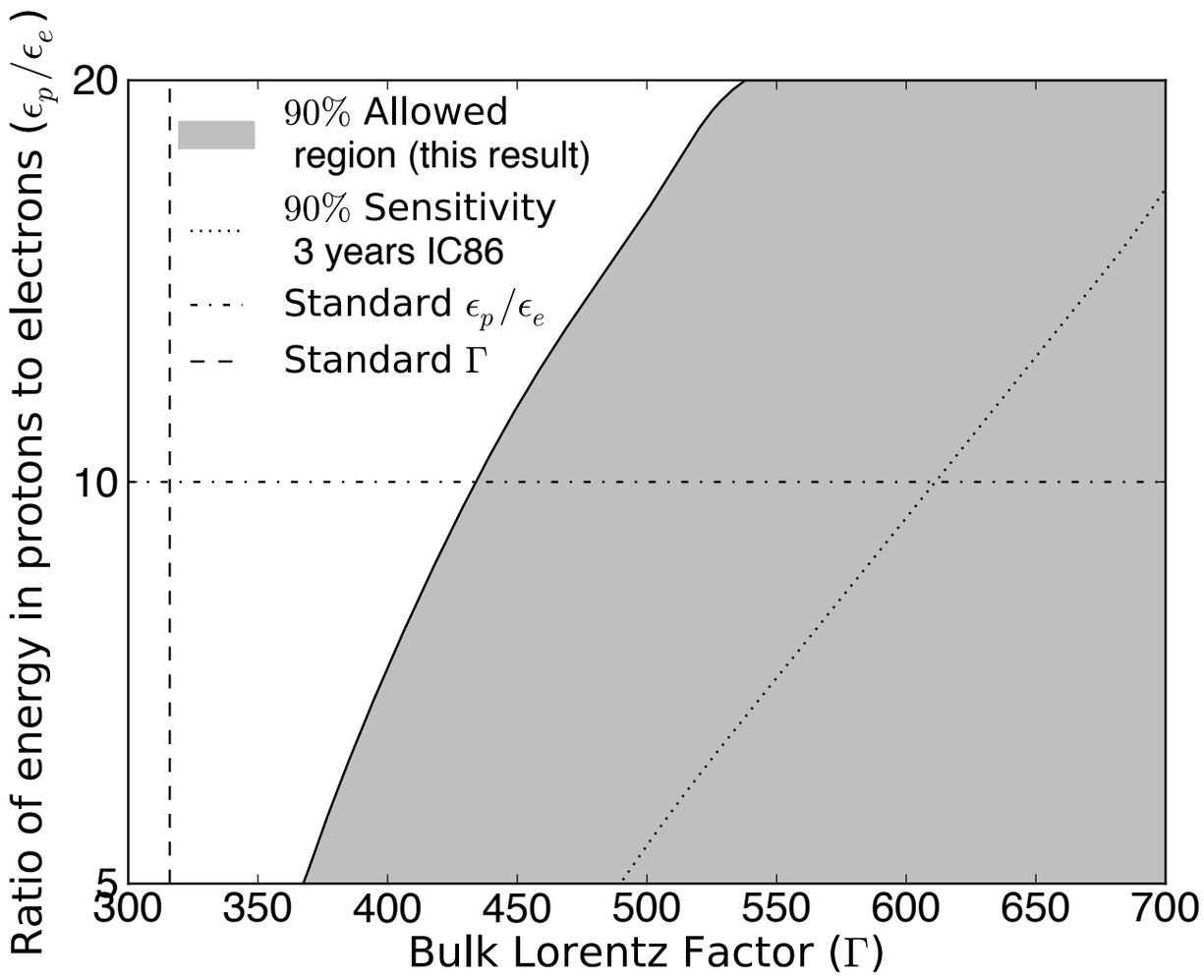


IceCube saw no neutrinos from a collection of 196 GRBs implying GRBs cannot be the sole source of UHECRs



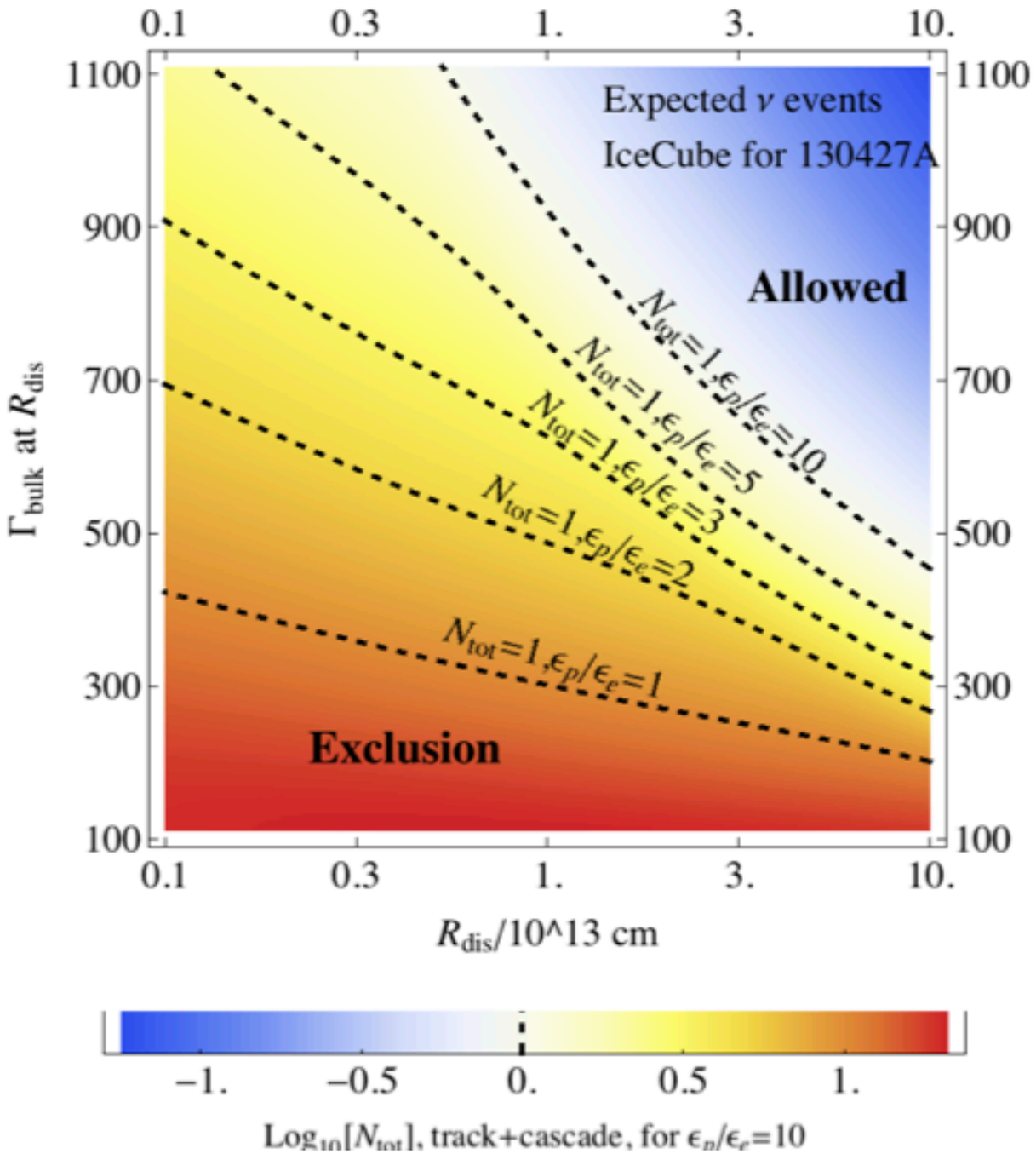
Abbasi+ 2012

IceCube saw no neutrinos from a collection of 196 GRBs implying low p content or high bulk Lorentz factor



Abbasi+ 2012

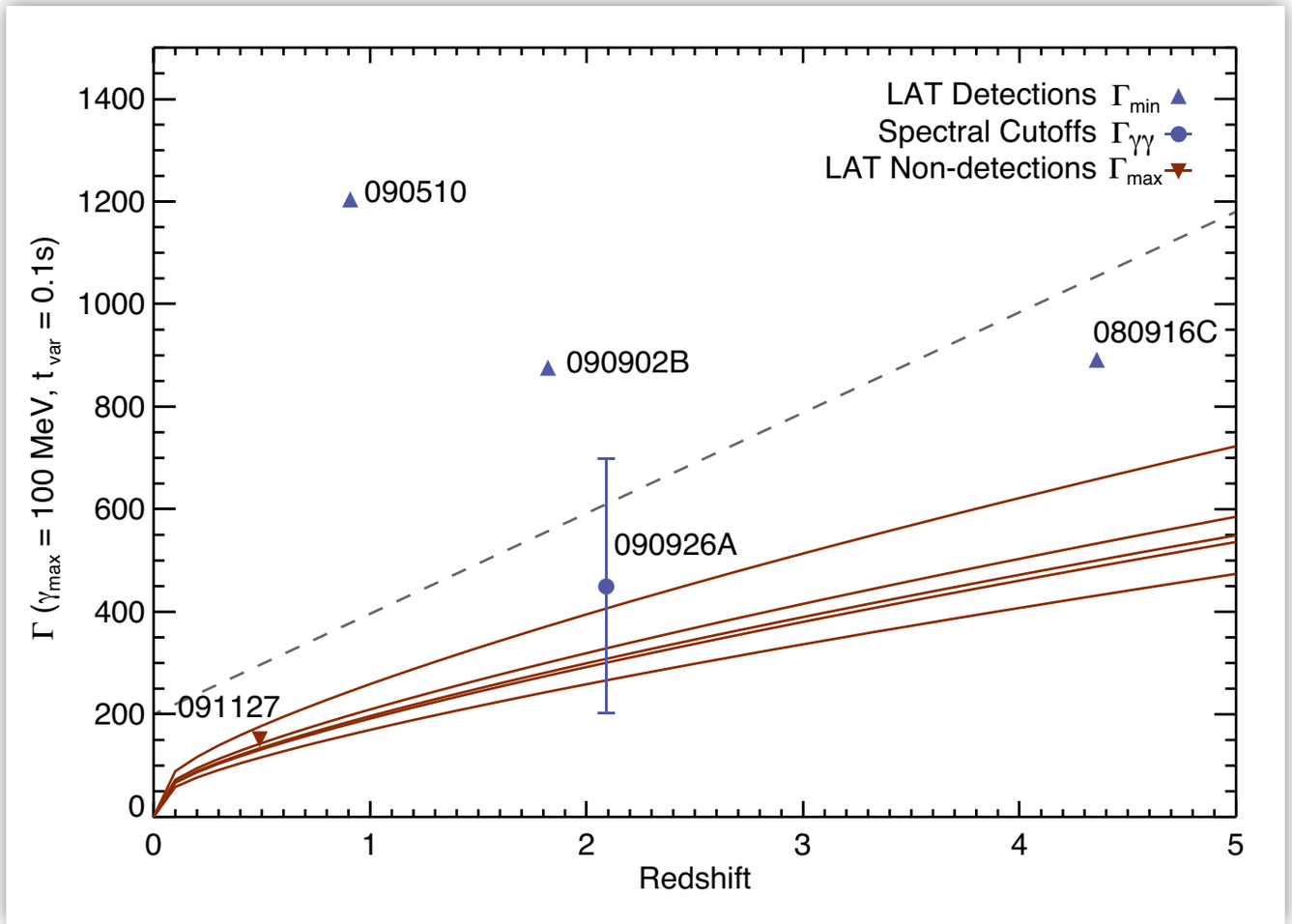
Limits from individual GRBs: non-detection of GRB 130427A



Gao, Kashiyama & Meszaros 2013

- Is this really a good GRB candidate? 100 GeV photons --> high Γ

Is there a distribution of Bulk Lorentz factors in GRBs?
This might be a way to explain LAT non-detections
and give hope to the neutrino community!

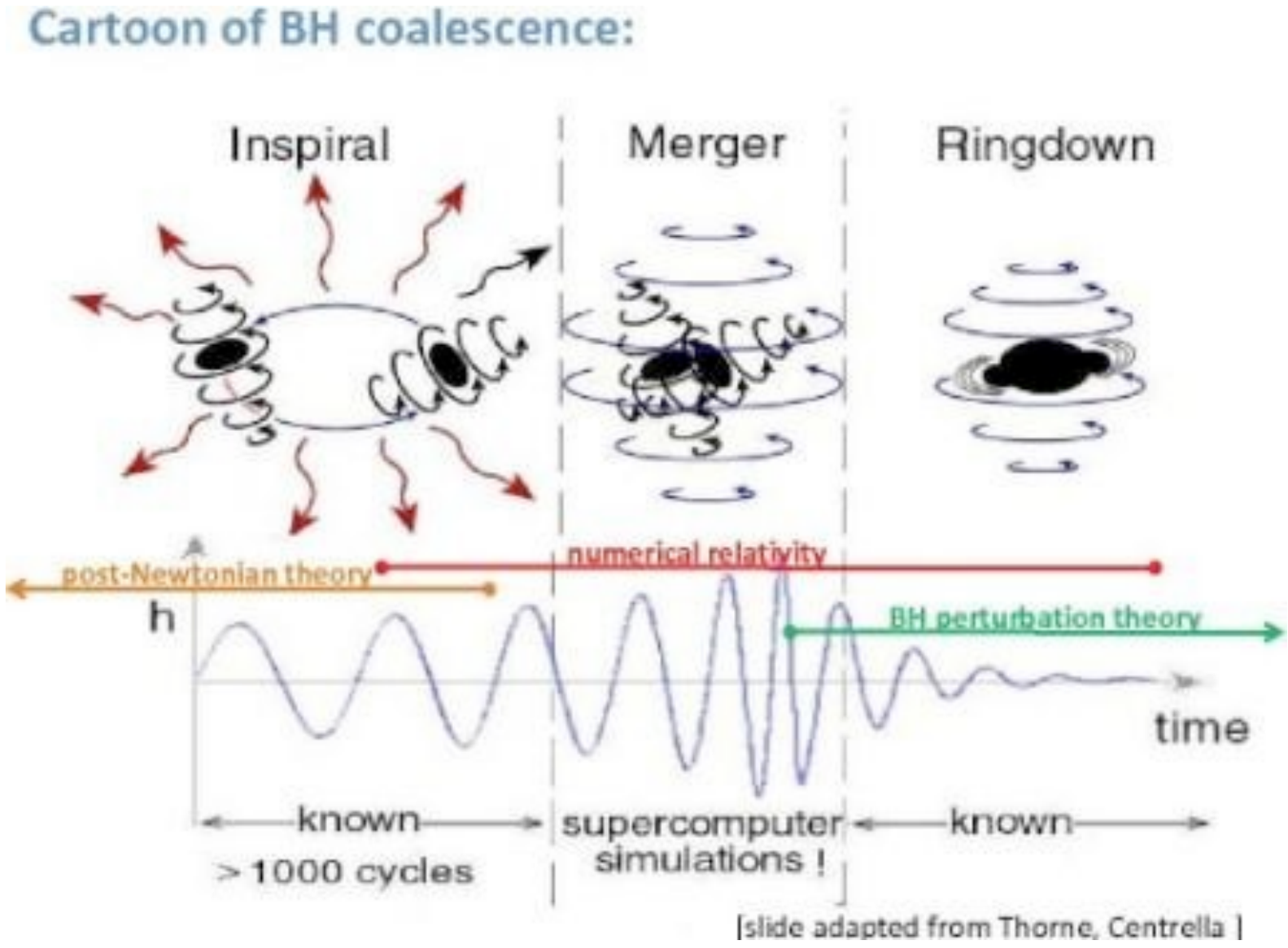


Ackermann+ 2011

Future of high-energy neutrino detection

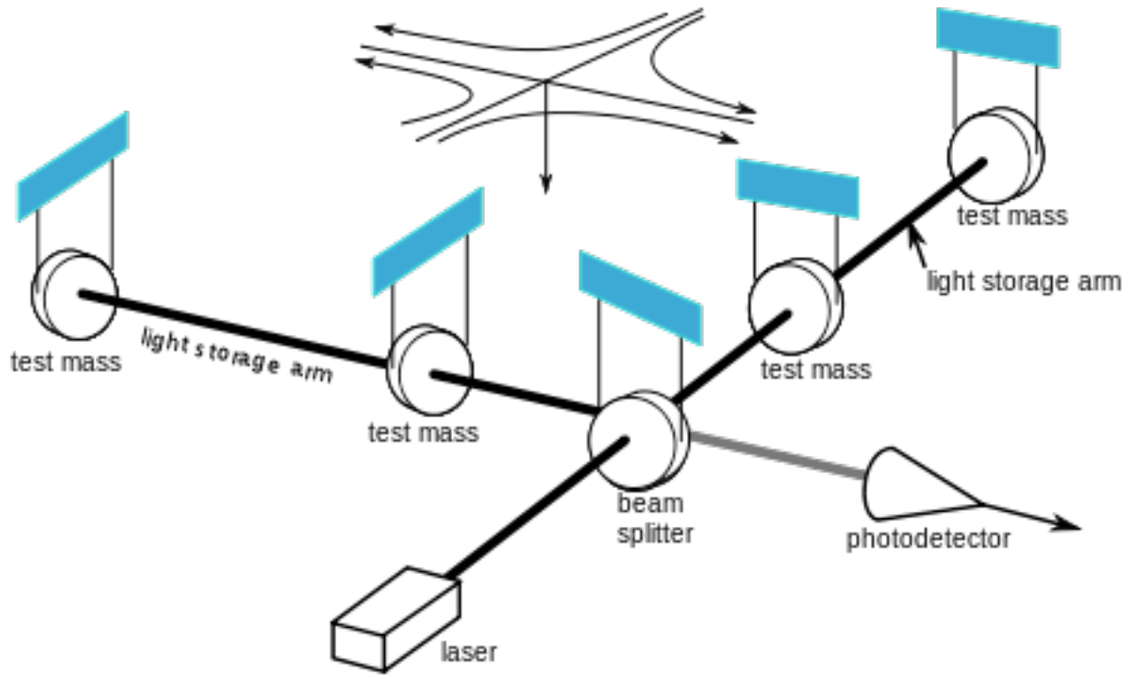
- IceCube is concentrating on its low-energy supplement DeepCore
- Km3NeT is a new water-based km^3 array

Gravitational wave detection is expected from General Relativity from sources such as merger GRBs



Inspiral signal enters sensitive band (> 50 Hz) about 50 s before coalescence.

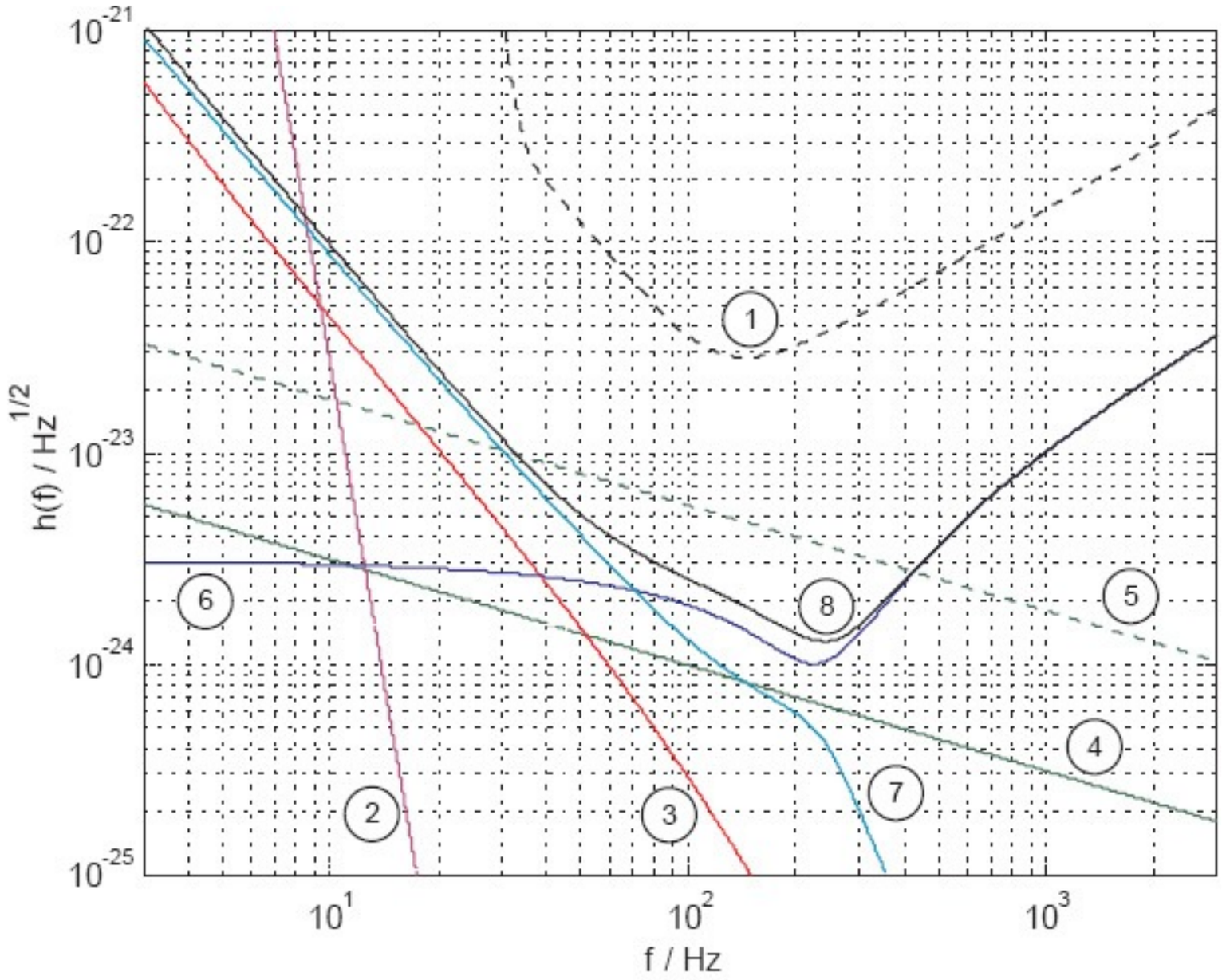
Gravitational Waves are difficult to detect



Hanford, Washington

Livingston, Louisiana

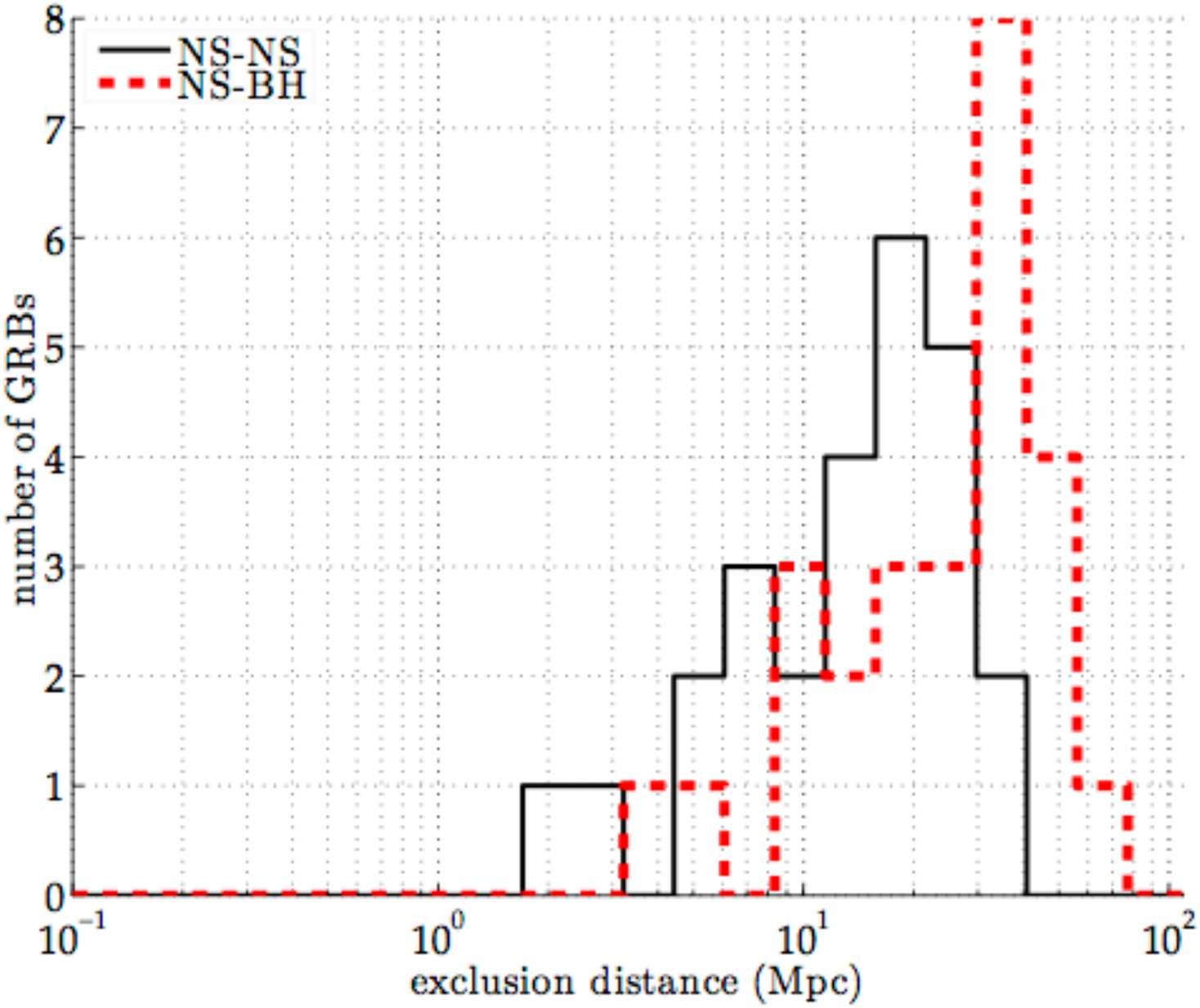
Gravitational Wave detectors have a strong background that limits their sensitive frequency range



1 LIGO I total
2 Filtered seismic noise
3 Suspension thermal noise
4 Internal thermal noise - sapphire
5 Internal thermal noise - fused silica (fallback)
6 Shot noise
7 Radiation pressure noise
8 LIGO II total

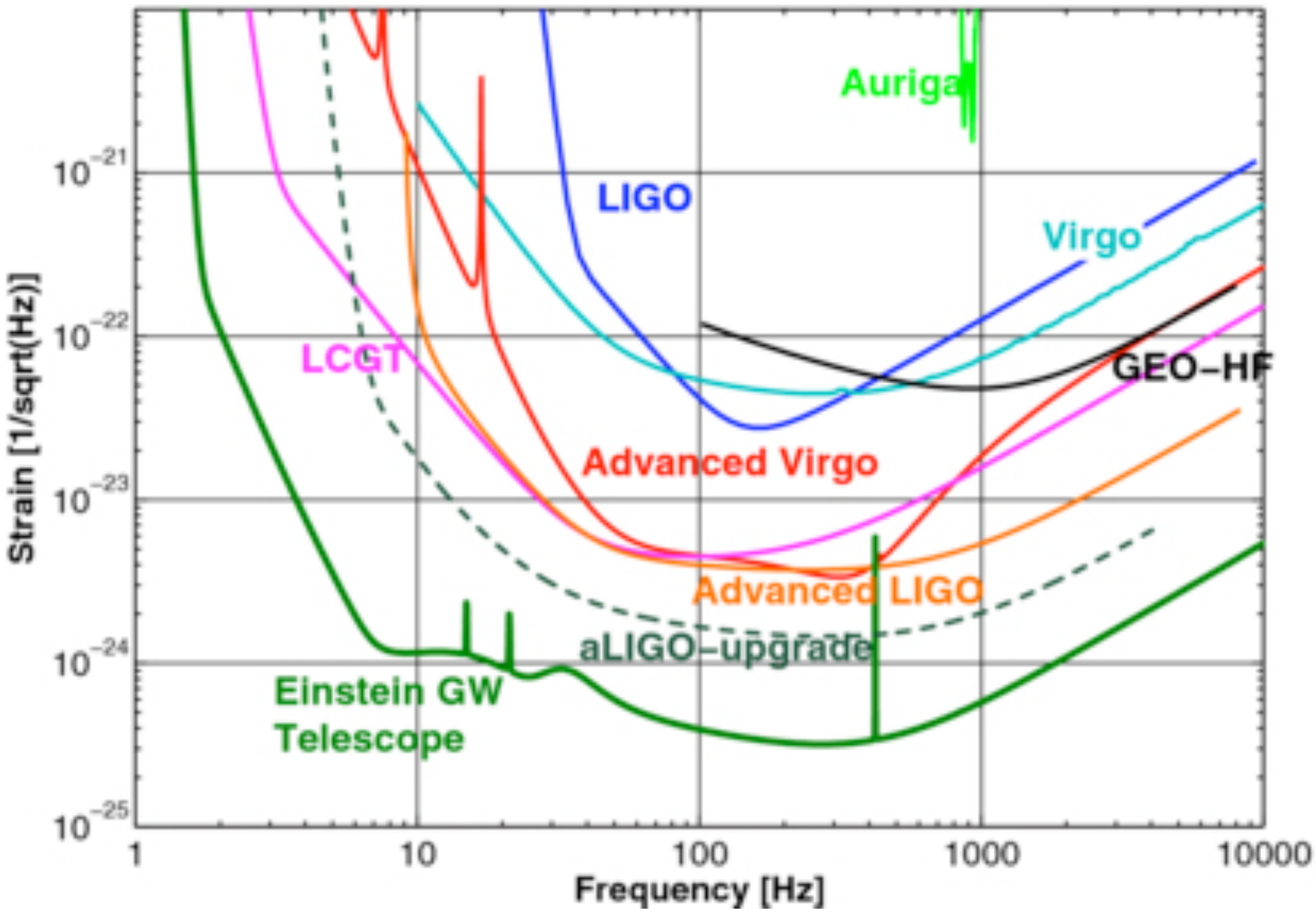
from hermes.aei.mpg.de

Gravitational waves have not been detected in a study of 154 GRBs with data from at least 2 GW stations (26 short GRBs)

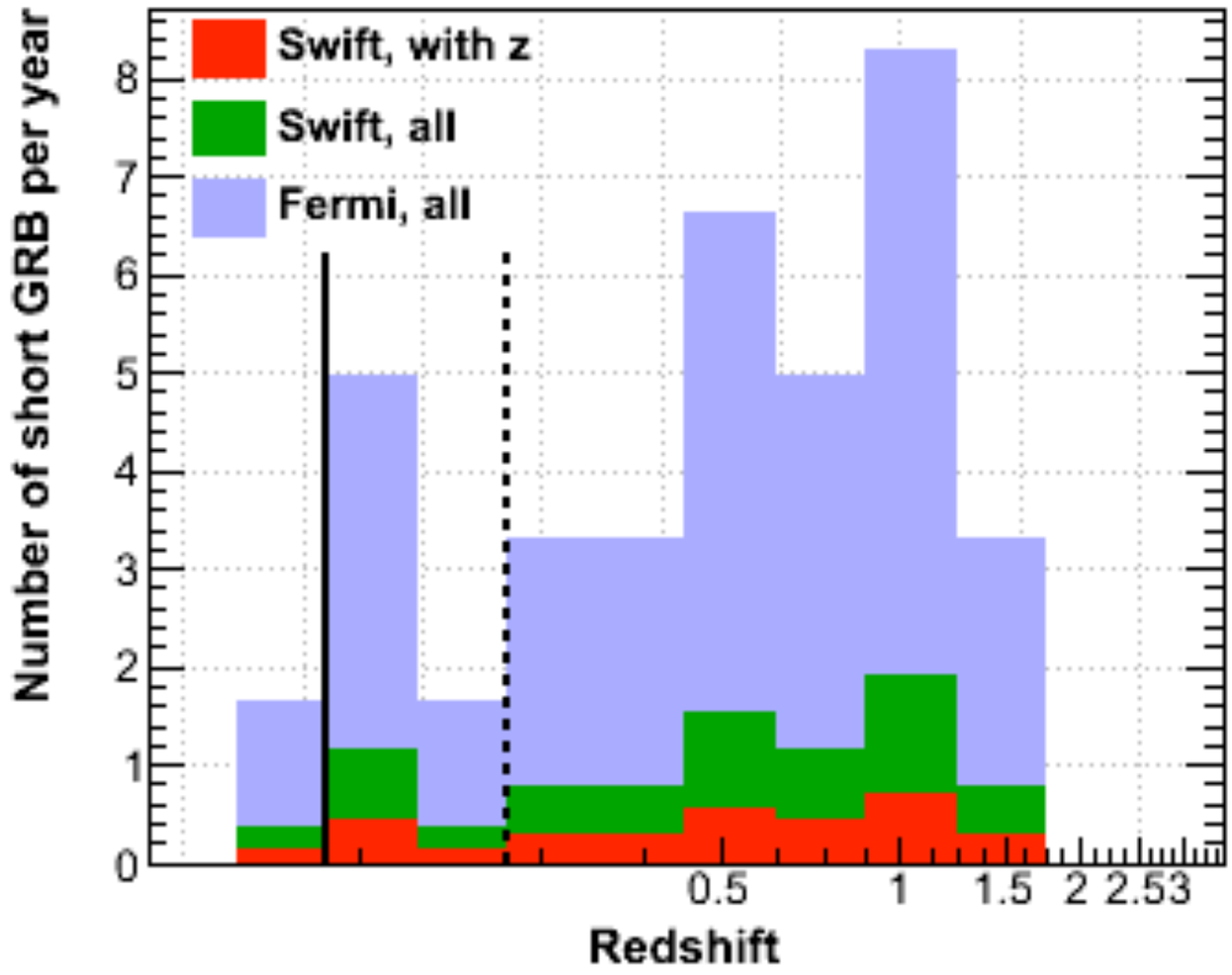


Abadie+ 2012

Advanced LIGO will be much more sensitive and will begin to come online (with A-Virgo and others) in 2016

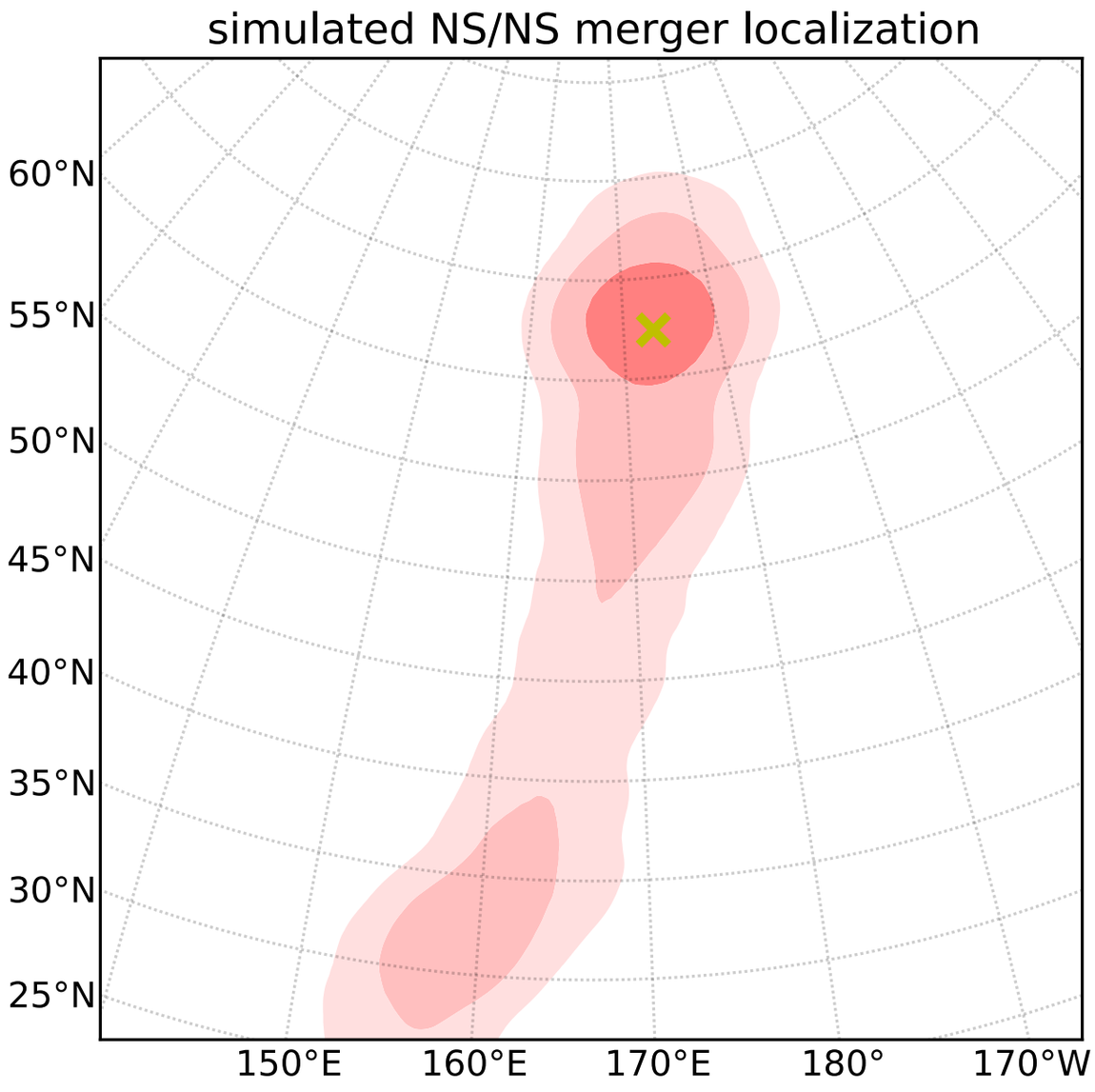


We expect good overlap between GBM-detected short GRBs and gravitational wave candidates from Advanced LIGO/Virgo



Pelassa+ 2012

GW detectors have crude localizations



Localization of GW-GRB

From Judy Racusin

There is a danger that a GW will be seen and nobody will believe it because nobody else can look!

Keep Swift & Fermi in operation in the A-LIGO era!
Encourage follow-up of GBM error boxes for short GRBs.

CTA in survey mode might get the best localization for follow-up of a short GRB seen in GW!

TeV astrophysics, too, used to be an exotic field viewed skeptically by real astronomers.