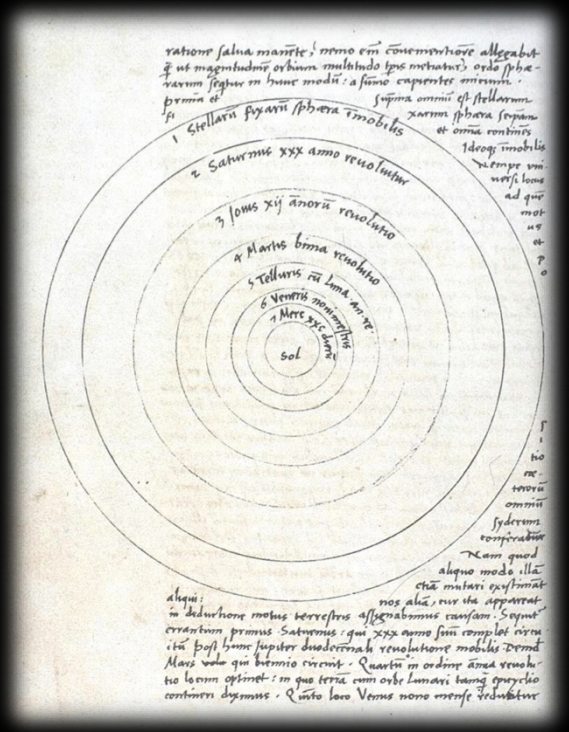
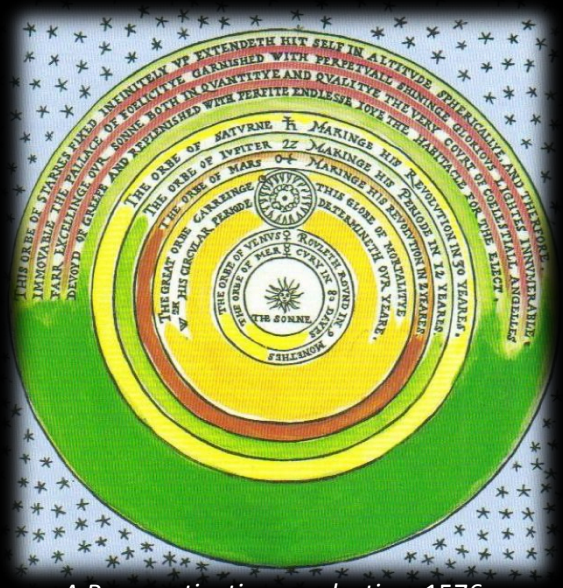


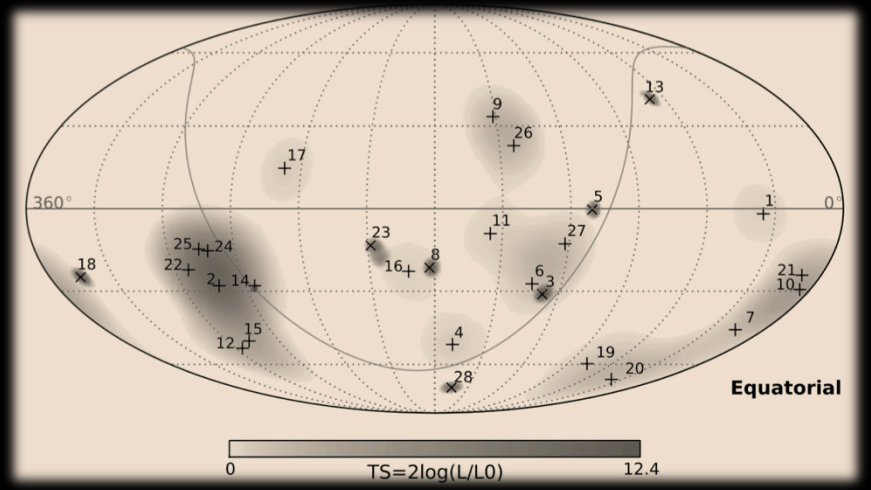
De Revolutionibus orbium coelstium, 1543,
Nicolaus Copernicus



A Prognostication everlasting, 1576,
Thomas Digges

Heinrich Olbers 1758-1840

Future Prospects For Neutrino Astronomy



Chad Finley
Oskar Klein Centre
Stockholm University

Caveats

I will not say too much about **galactic searches**

(now approaching needed sensitivity for TeV gamma sources)

I will not say too much about searches using **timing** (GRBs, flares)

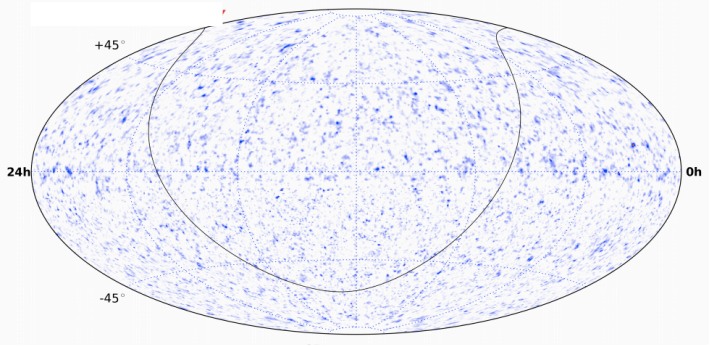
I will mainly focus on the **newly observed HE flux and challenges it poses**:

most likely needs extragalactic explanation

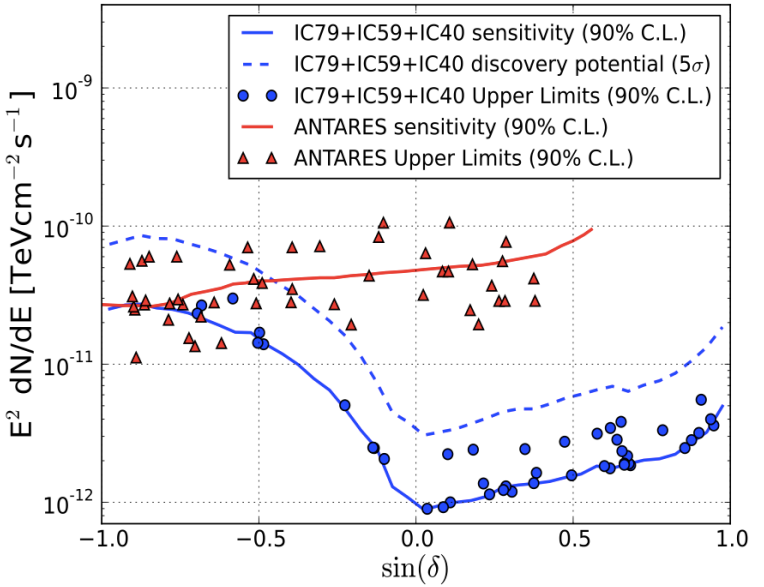
more likely related to UHECR

I will focus mainly on the experimental challenge

Neutrino Astronomy Today: No point sources so far

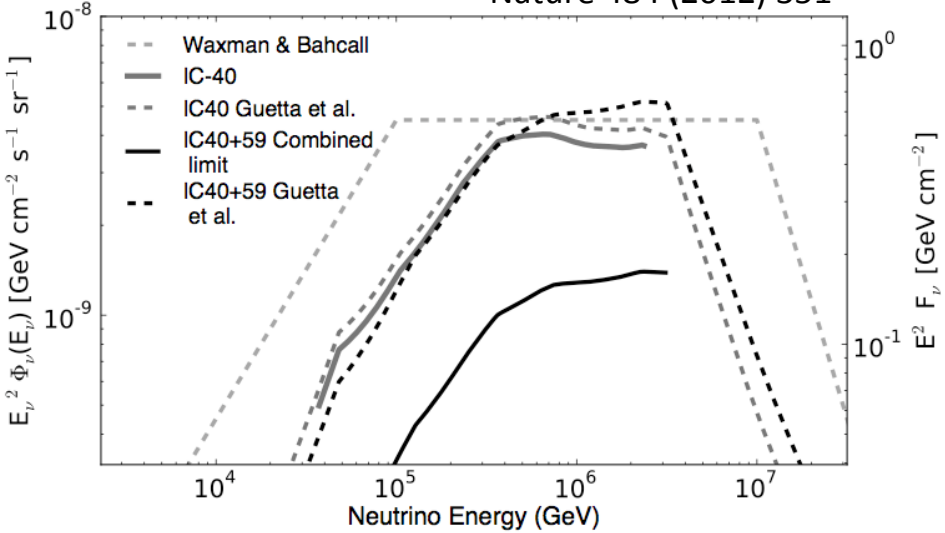


arXiv:1307.6669



No point sources detected so far.
(Approaching predictions for galactic sources; extragalactic predictions vary widely)

Nature 484 (2012) 351

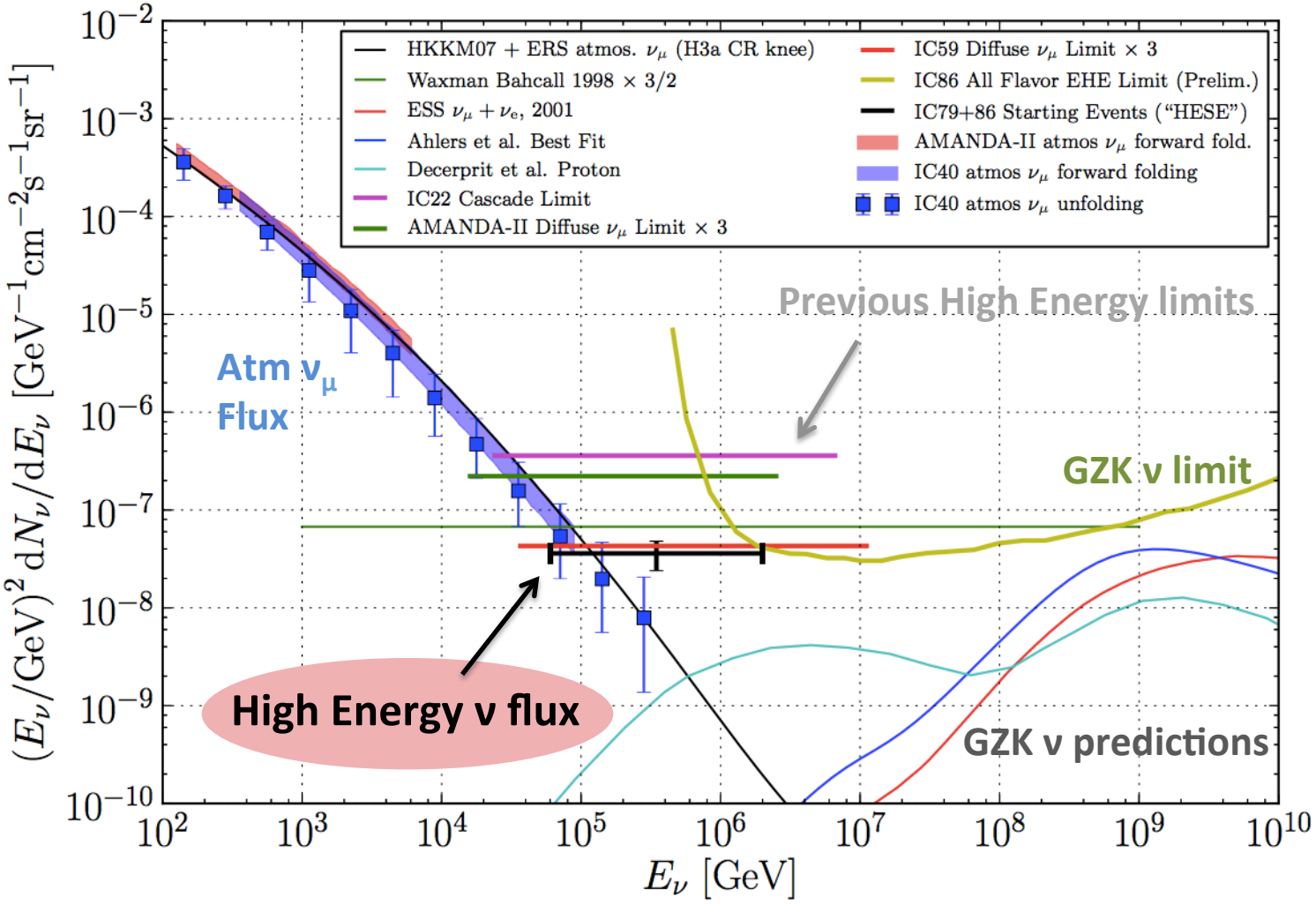


No GRBs seen (…yet?)

Here, non-detection puts important constraints on models trying to connect UHECR to GRBs

… But a HE neutrino flux is now seen

C. Kopper



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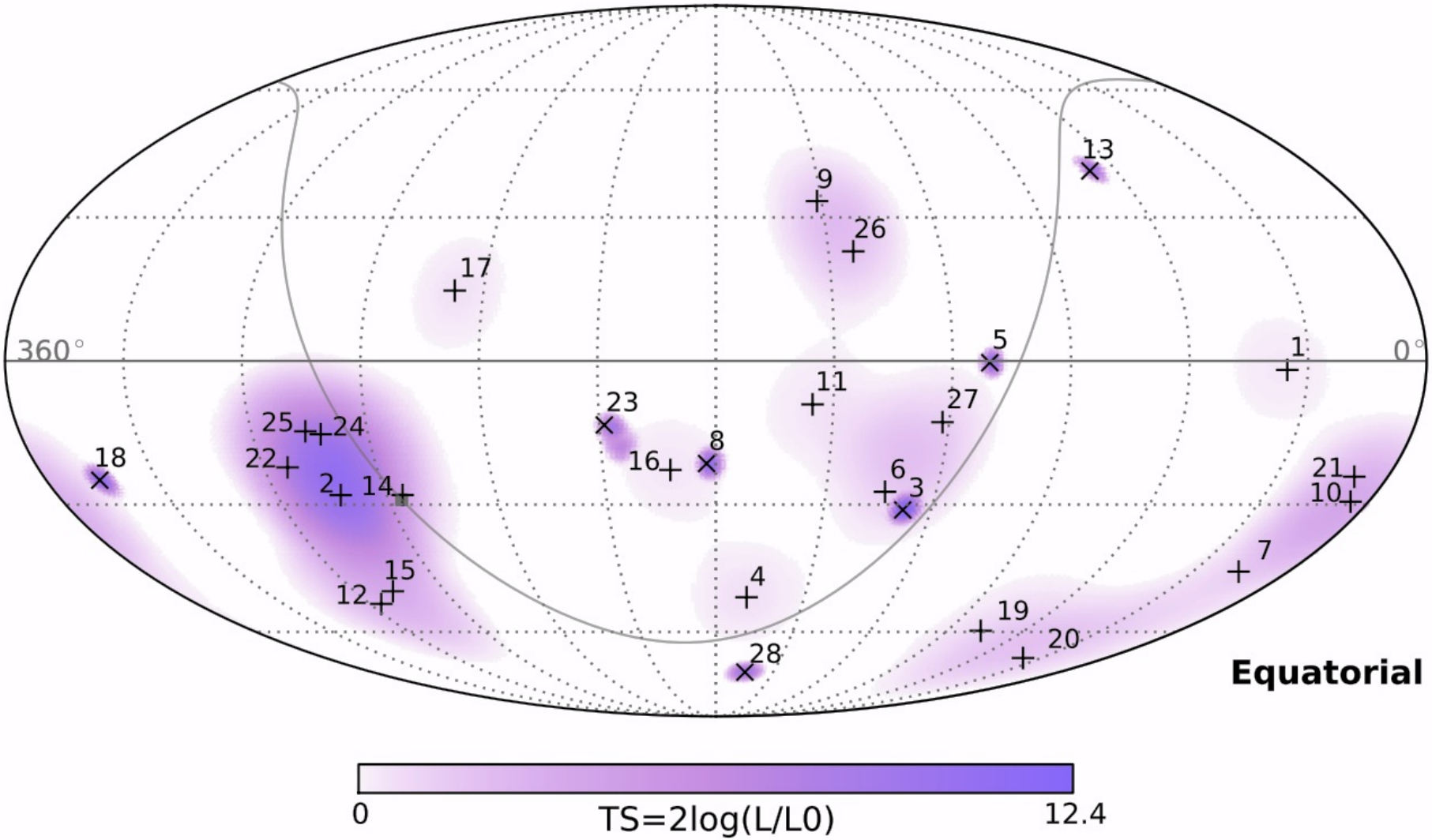


HE Neutrino Flux:

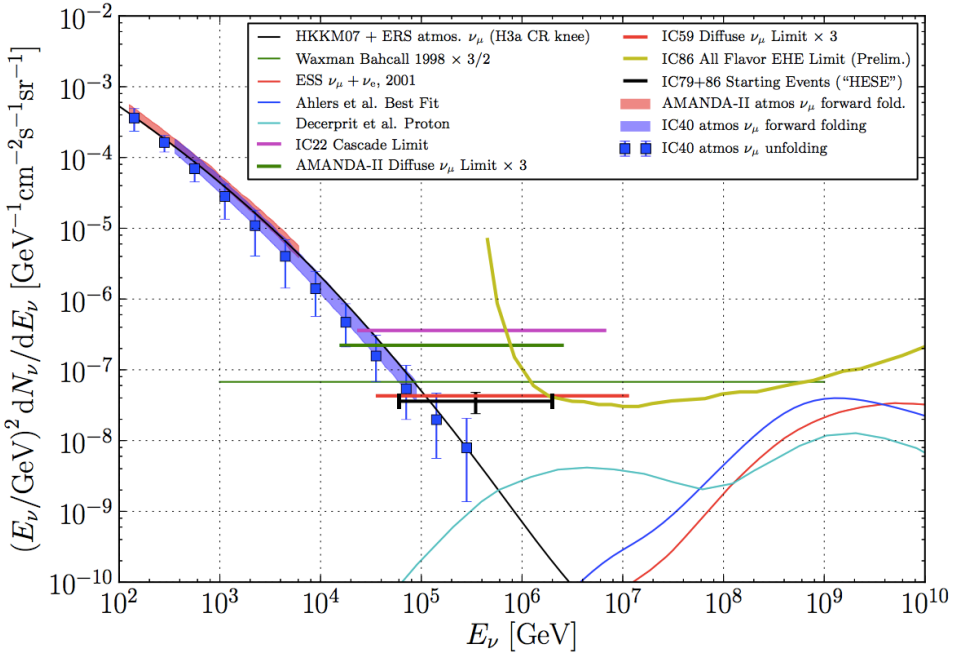
Up to 2 PeV (then Softening? Cutoff?)

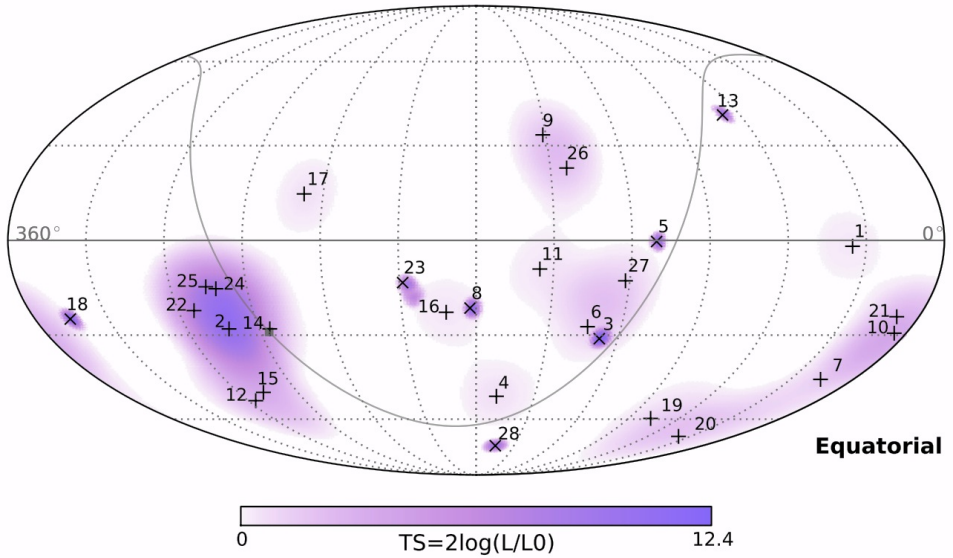
Events <u>consistent</u> with Isotropy

Evidence for anisotropy may grow (about 1σ excess right now)

But already can say:
there are multiple sources not associated with galactic plane.

⇒ Diffuse, extragalactic component





Astronomy at a PeV?

At PeV energies,

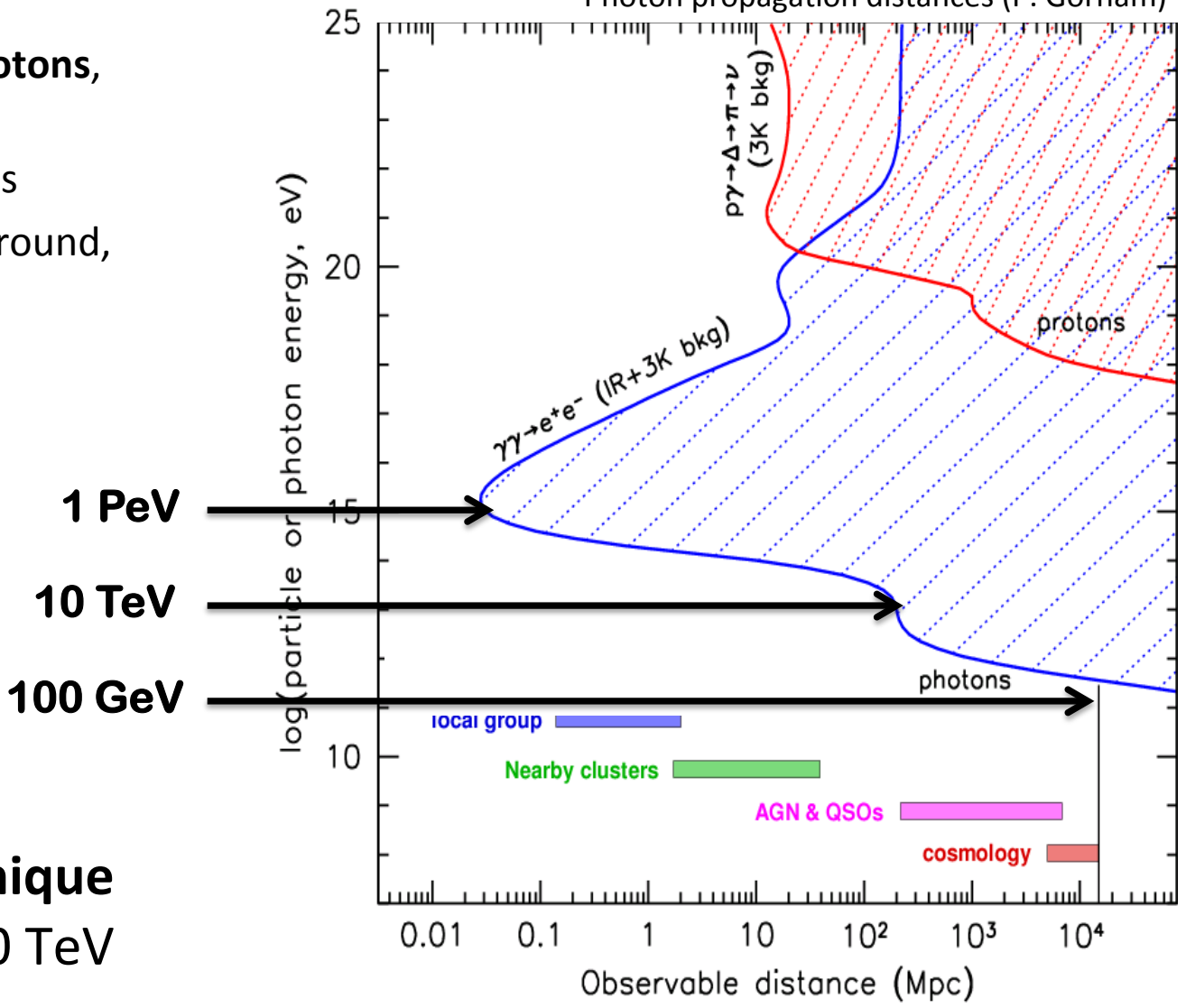
universe is **opaque for photons**,

due to pair-production off background radiation fields

(Cosmic Microwave Background, Infrared Background)

$\gamma + \gamma_{IR,\,CMB} \rightarrow e^+ + e^-$

Photon propagation distances (P. Gorham)



Neutrinos are **unique probe** above 100 TeV

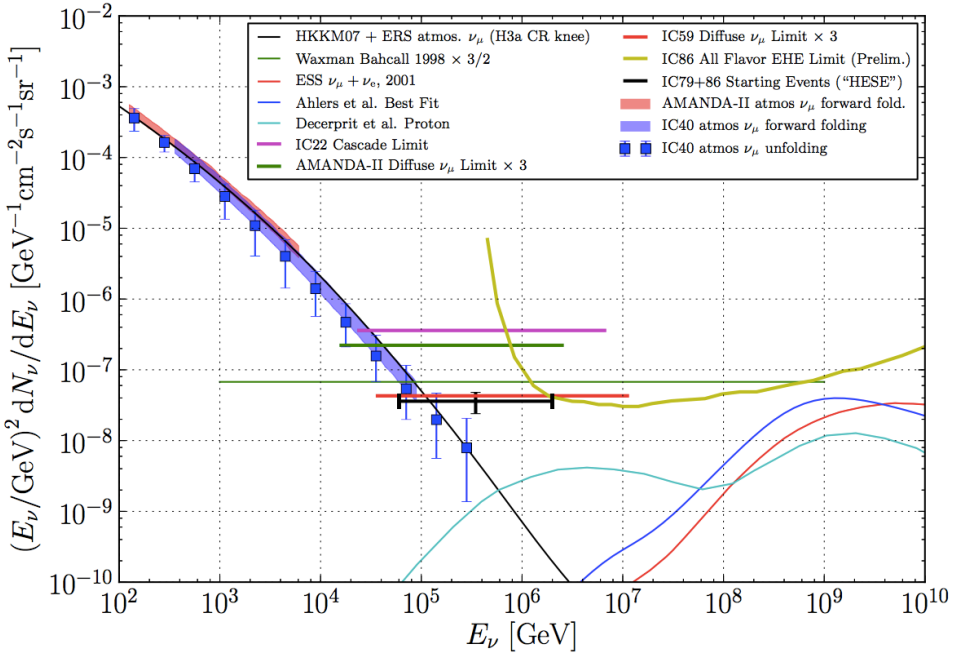
Neutrino Astronomy with the HE Flux

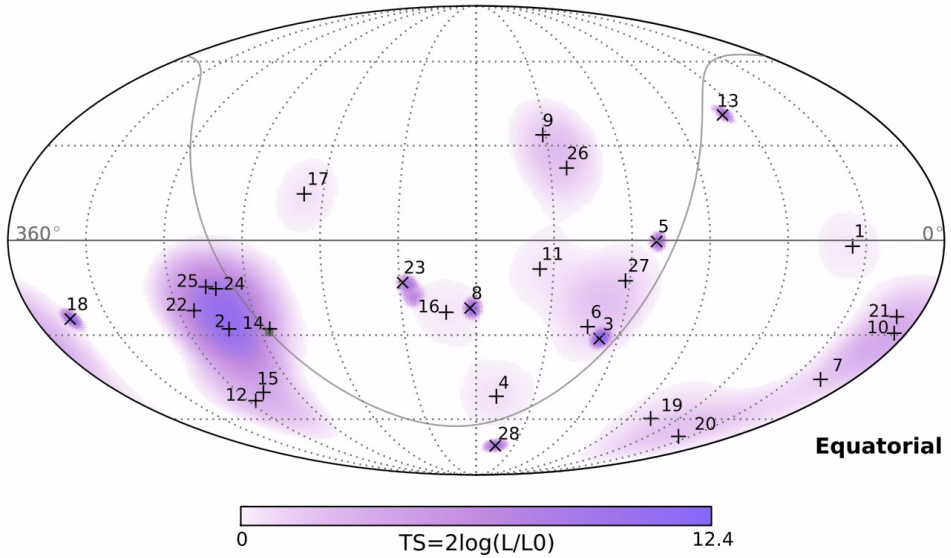
HE Neutrino energy spectrum will be measured (above 100 TeV) by Starting Event and Diffuse Analyses

Pointing not so important… at first!

But many models will be able to match spectrum.

Source identification will require **precision localization**, in Space (or in Time)





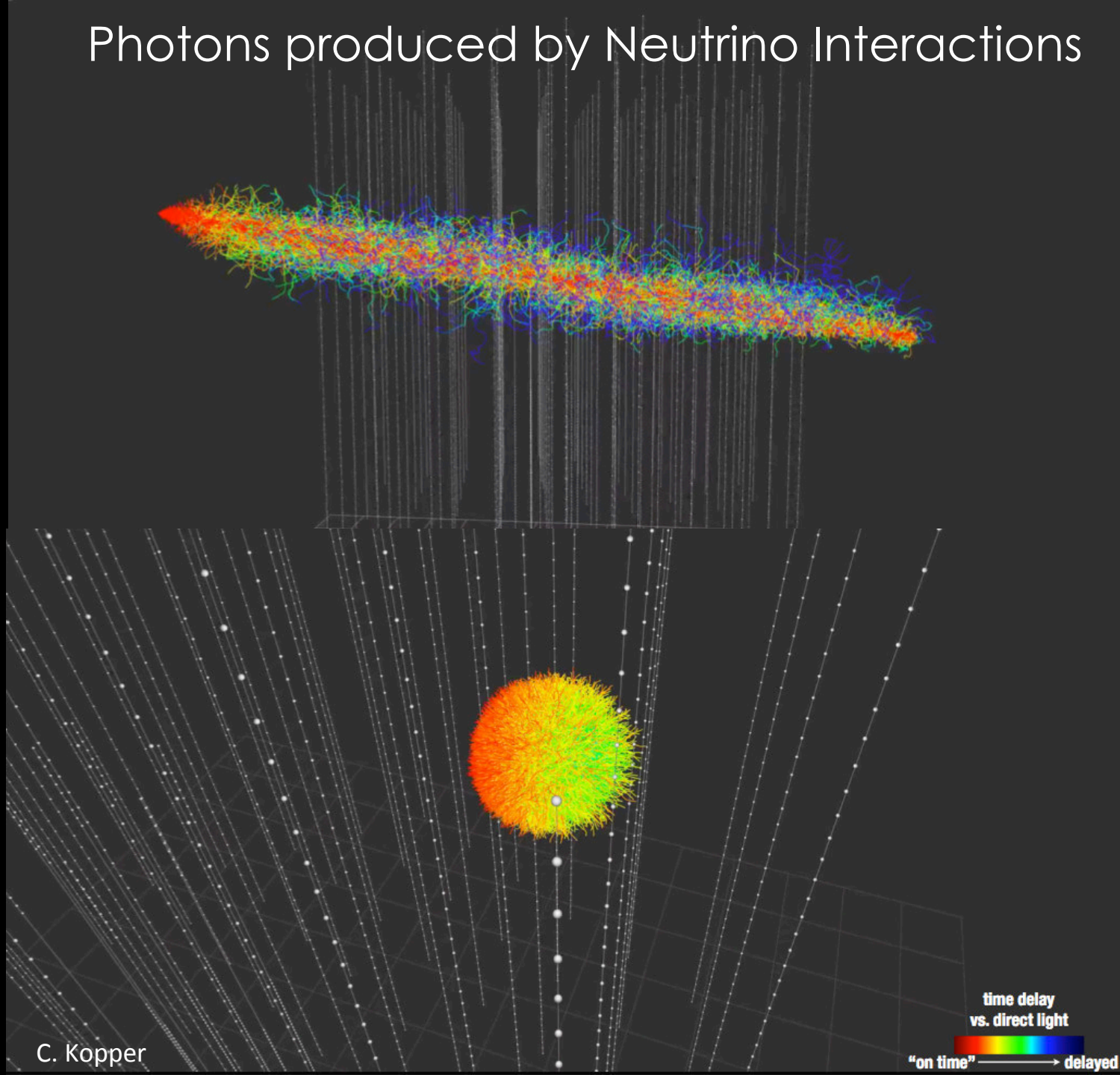
Photons produced by Neutrino Interactions

Track topology
(e.g. induced by muon neutrino)

Good pointing, 0.2° - 1°
Lower bound on energy

Cascade topology
(e.g. induced by electron neutrino)

Good energy resolution, 15%
Some pointing, 10° - 15°



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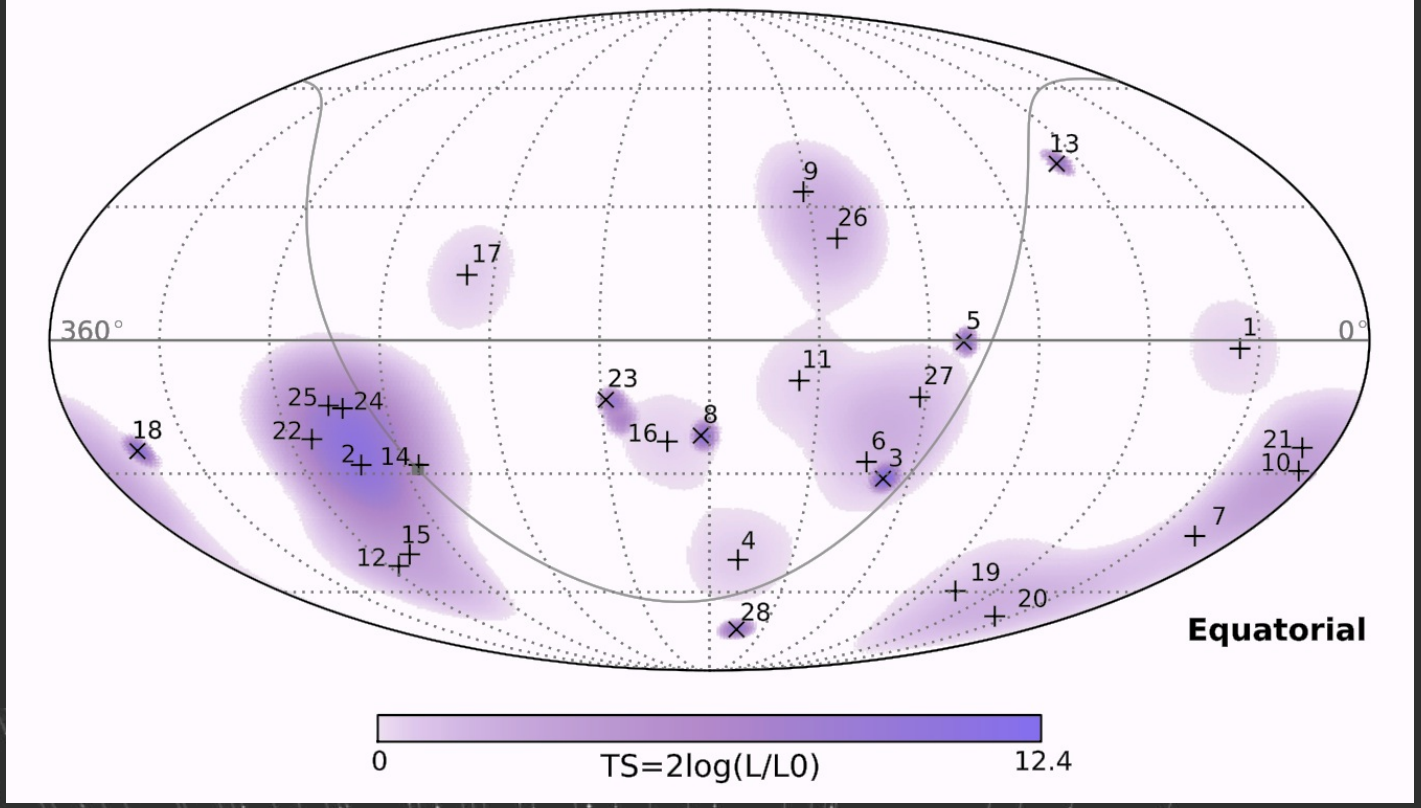

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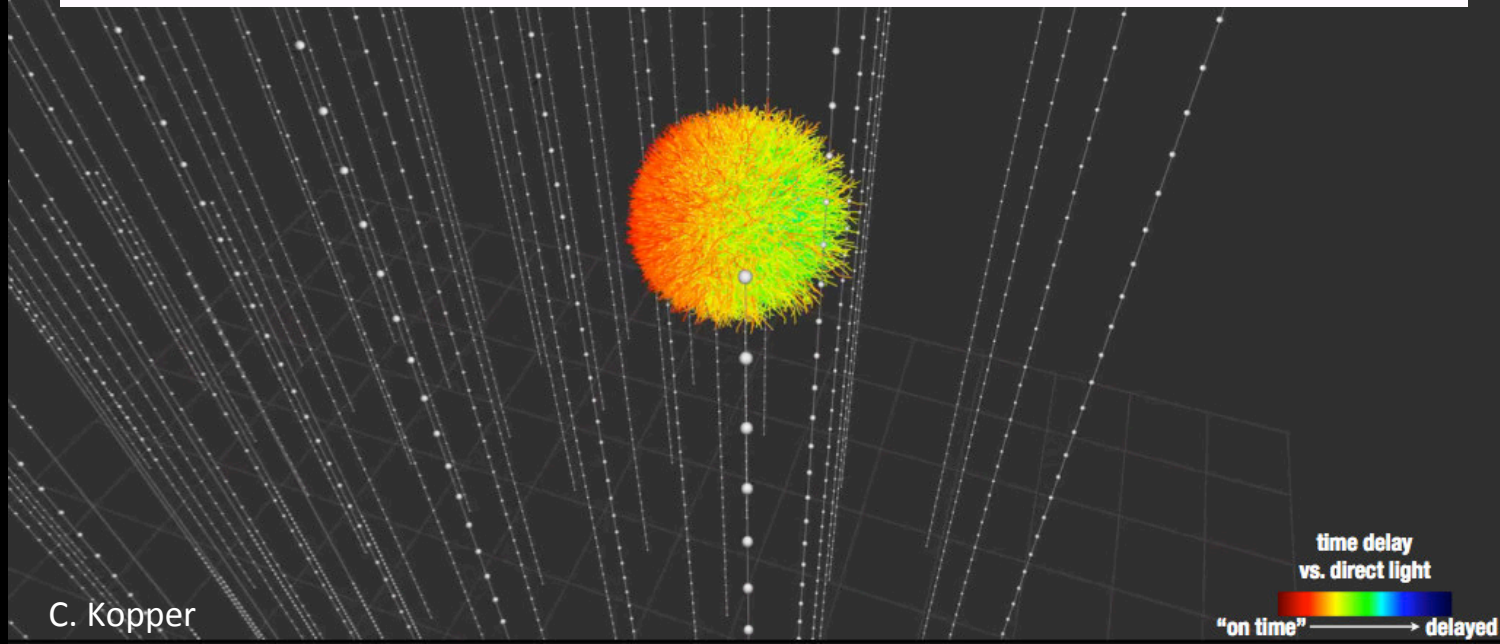

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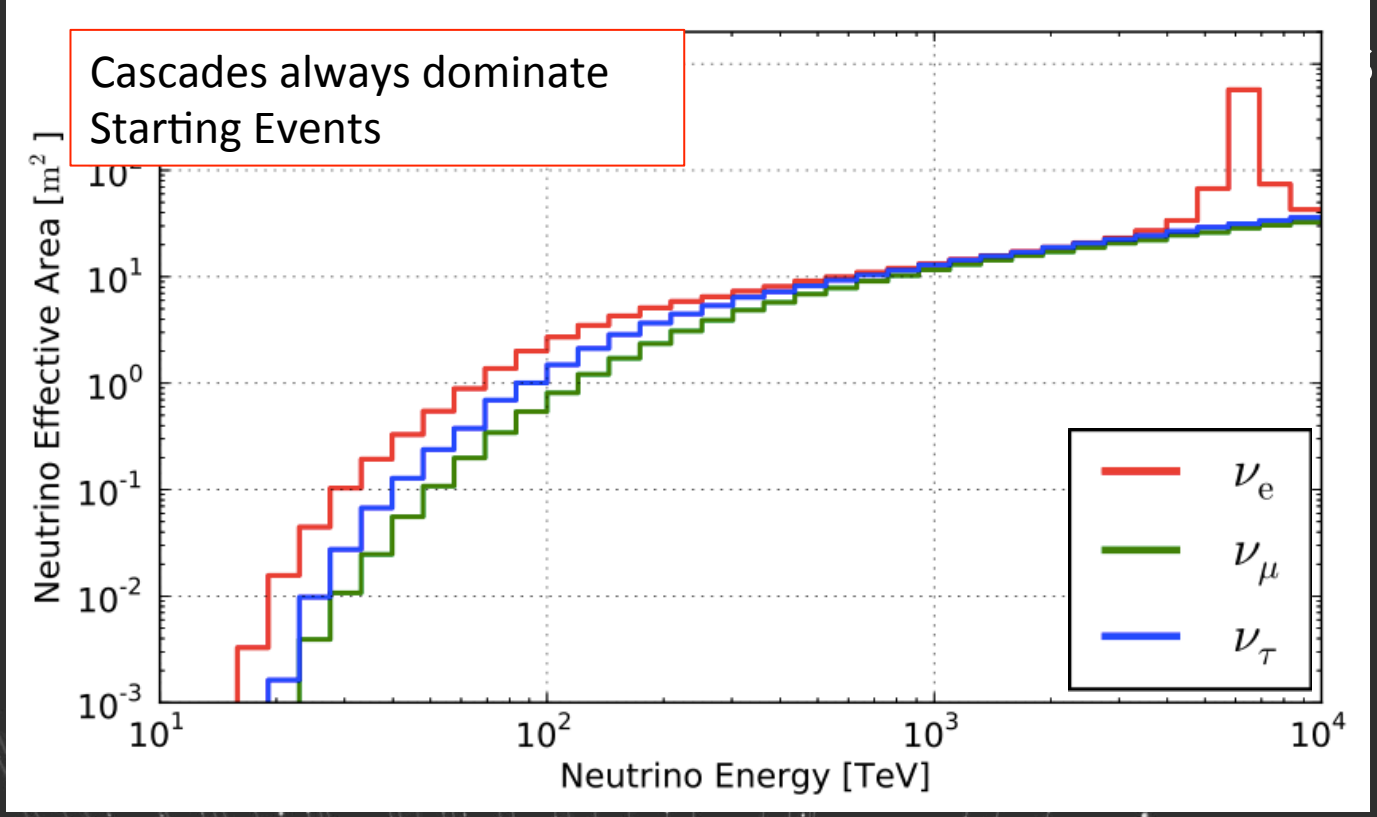
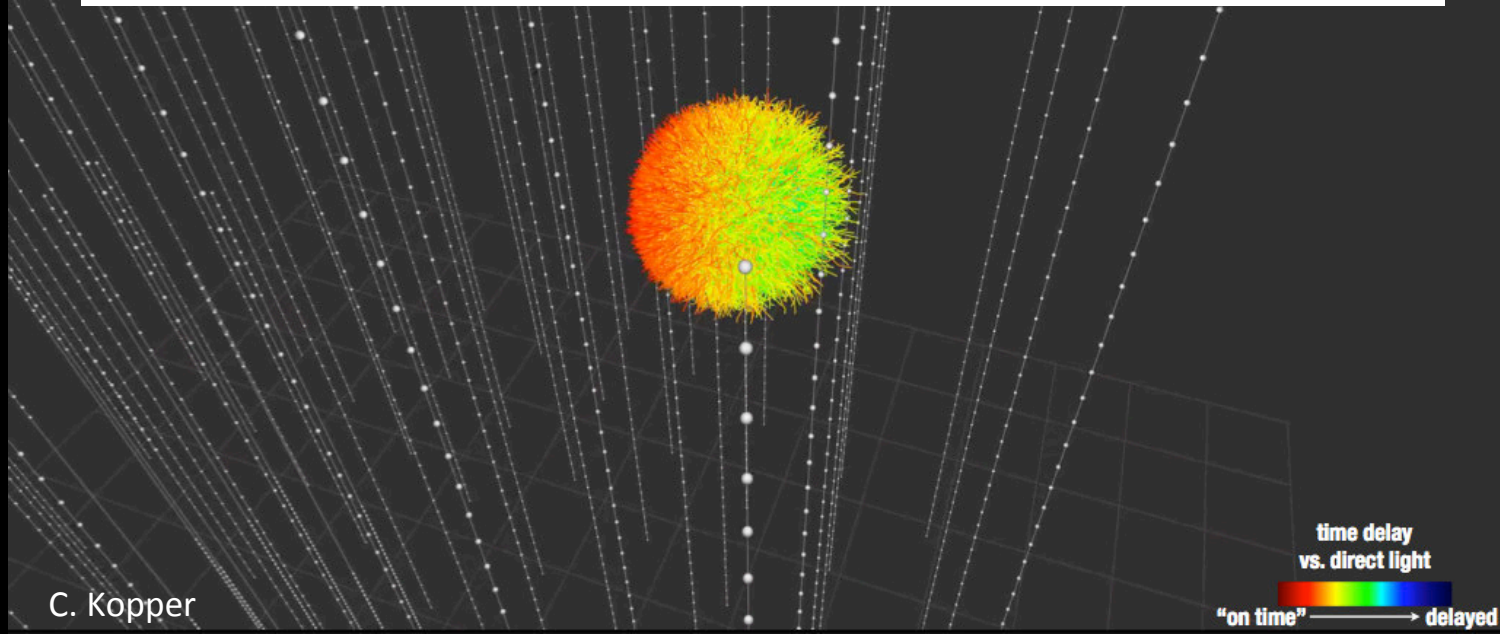




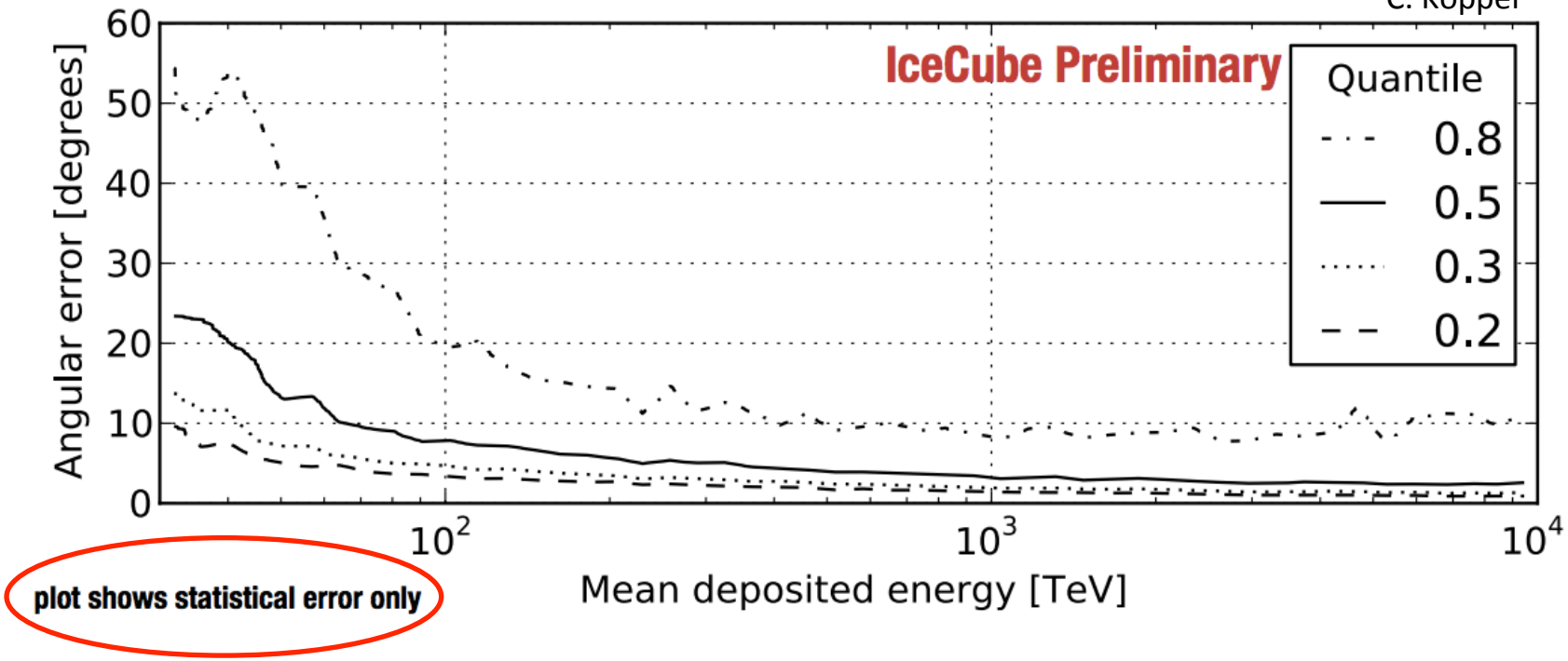
How much can Cascade reconstruction be improved?

IceCube – photon scattering length ~20 m, string separation ~125 m

But: current limitation is not scattering itself, it is **uncertainty** scattering

If systematic uncertainty could be reduced, angular resolution → **~ few deg**

C. Kopper



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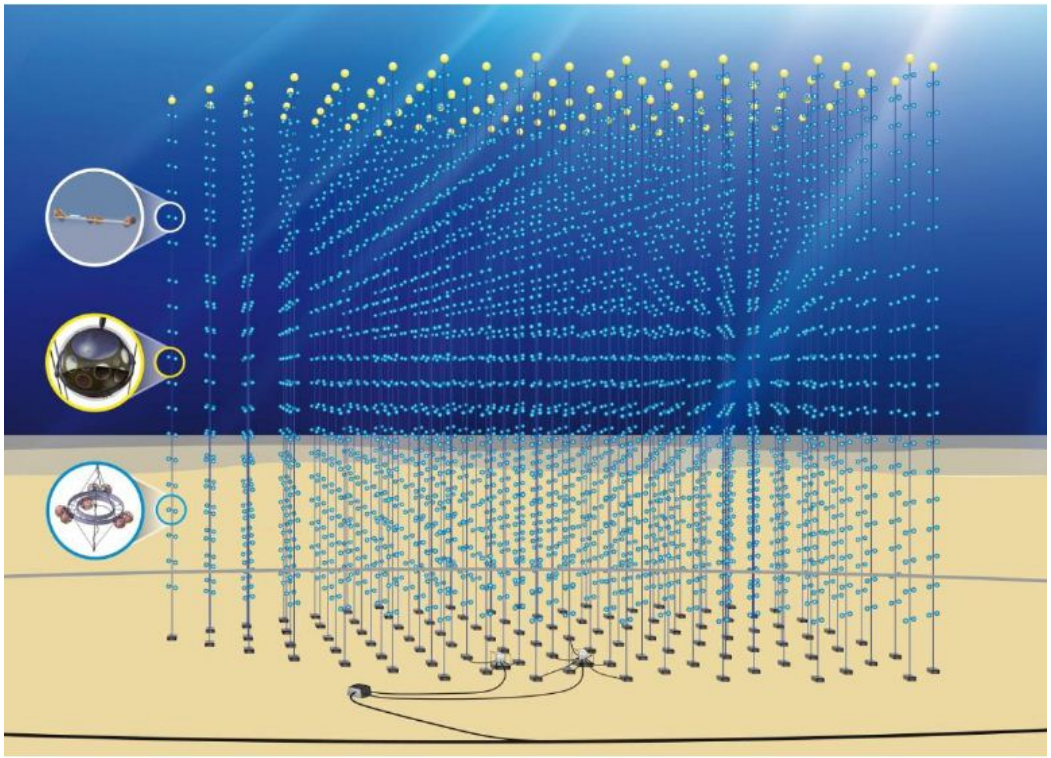
If systematic uncertainty could be reduced, angular resolution → **~ few deg**

Scattering length in deep sea water > 100 m

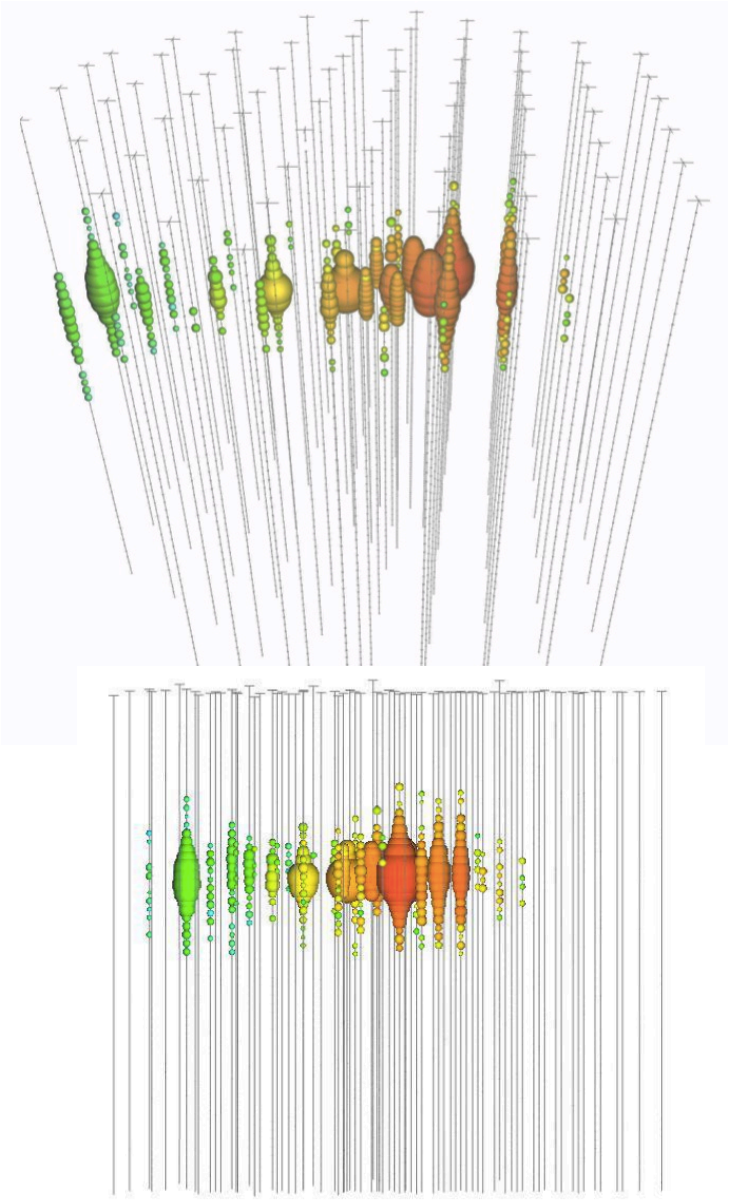
Intrinsically better resolution,
Also less sensitive to systematic uncertainties if
Scattering > String spacing

KM3NeT is actively studying ability to reconstruct cascades now…

KM3NeT

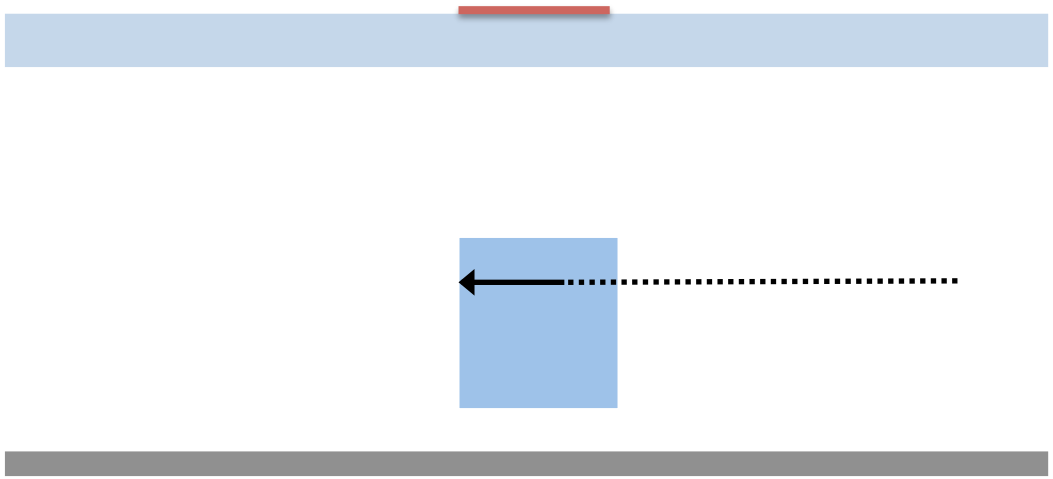


Alternatively, Get more HE Tracks:



Consider “Event #5”,
A beautiful High Energy starting track

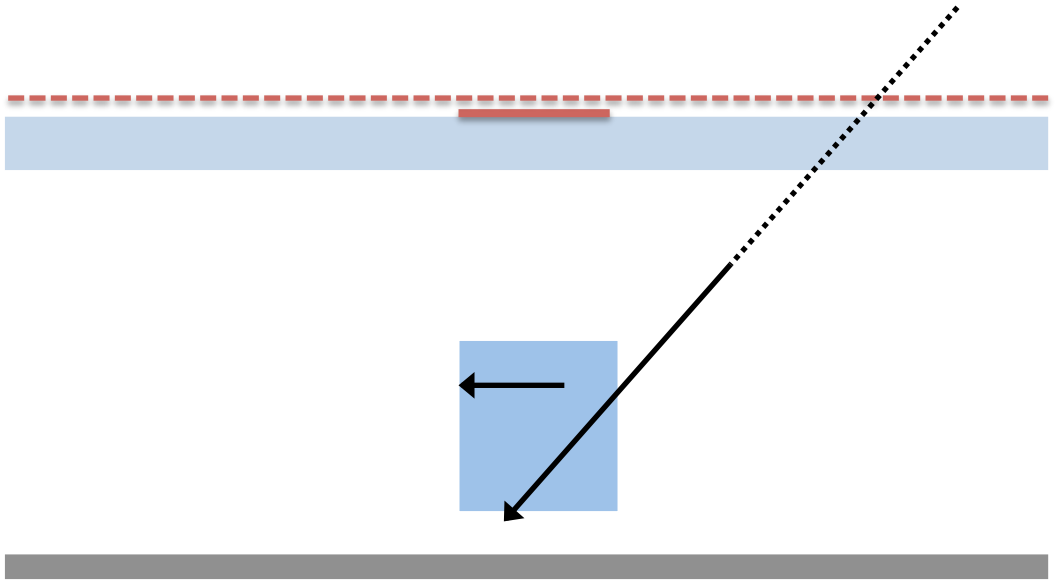
How to get more Starting Tracks?



Alternatively, Get more HE Tracks:

1) A large surface array,
Extending several kilometers
Can act as a CR muon veto

Enlarges volume of “Starting” track events



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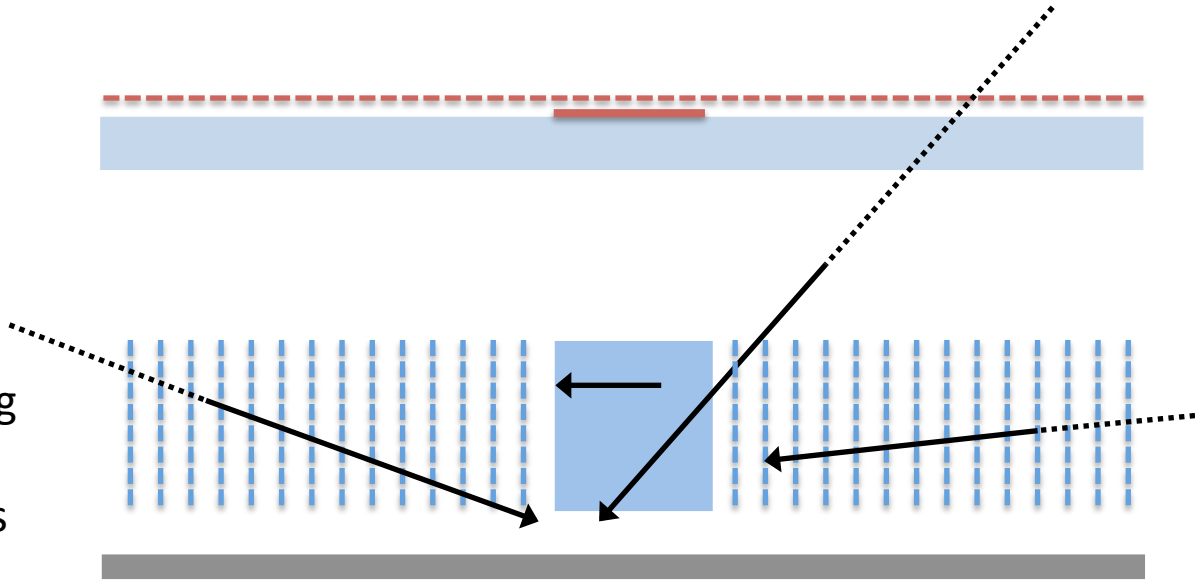


2) More strings, with wider spacing

Enlarges volume for starting tracks *and* ordinary tracks

Longer lever arm → better resolution

Tracks Point the Way

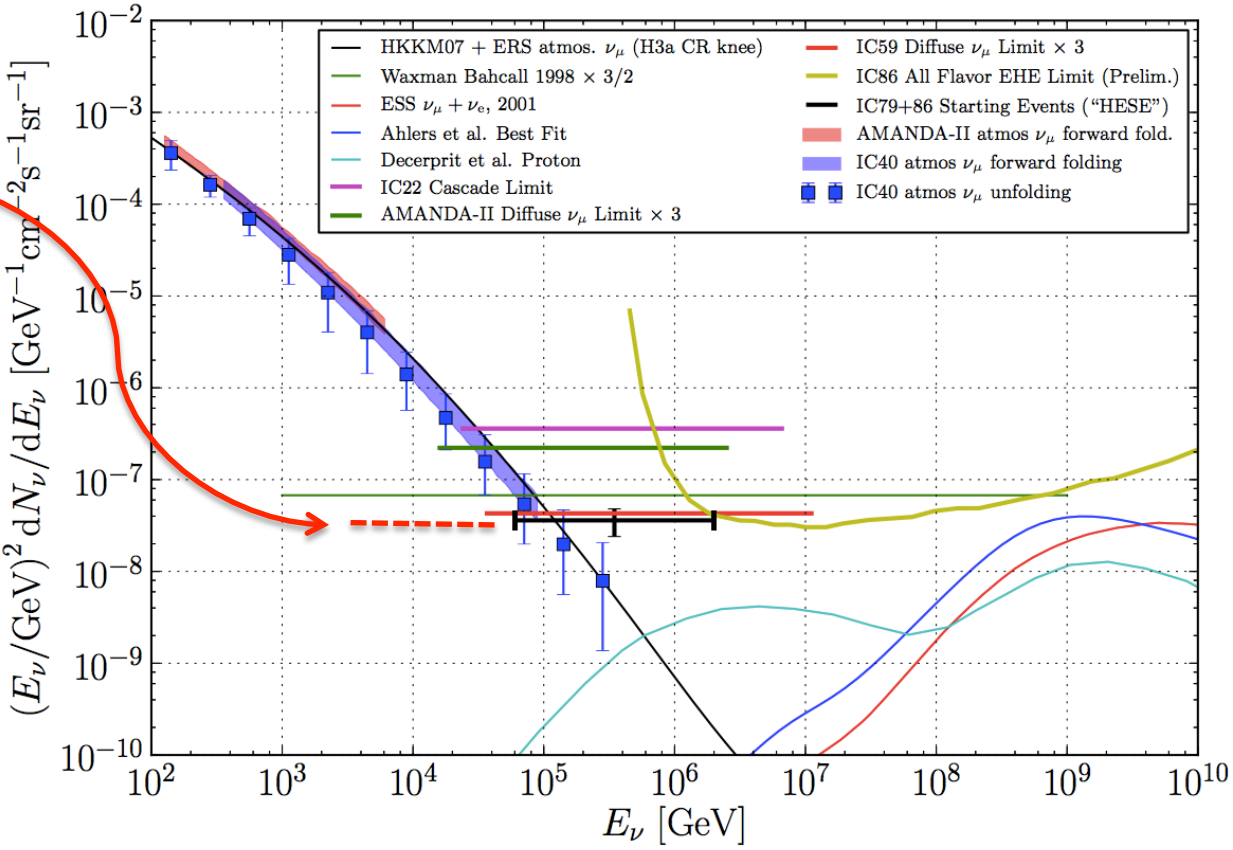
Starting Event samples provide astrophysical neutrinos with very low background (either from atmospheric muons or atmospheric neutrinos)

For pointing searches, though, it is easier to tolerate more background in data.

HE Flux likely extends to lower energies, hidden in the atmospheric bkg

Order of magnitude more events

Pointing with track events at lower energy will help unravel origins of HE flux

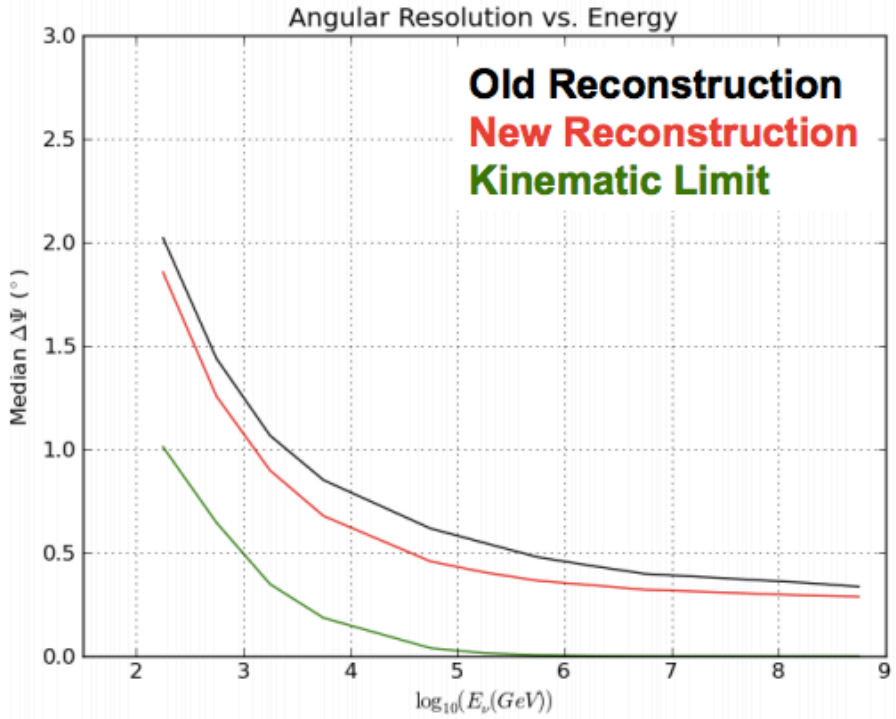


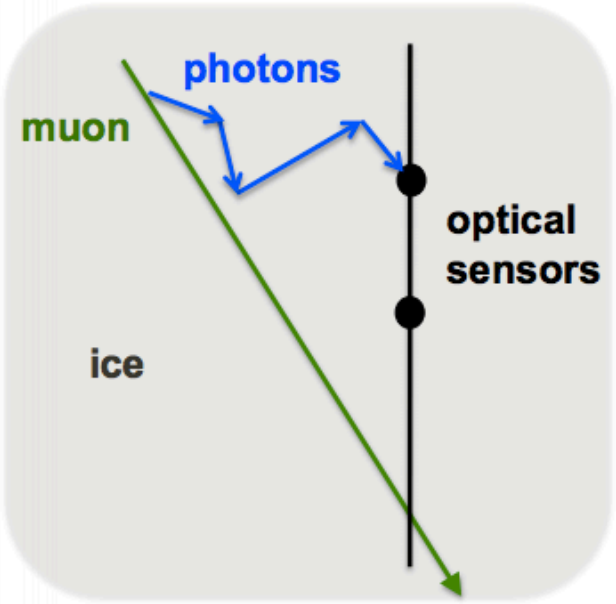
Improving Angular Resolution of Tracks

34

Progress on more advance reconstruction algorithms still continues:

- New event reconstruction techniques use detailed information on photon propagation in the glacial ice
- Results in improved angular resolution at all energies

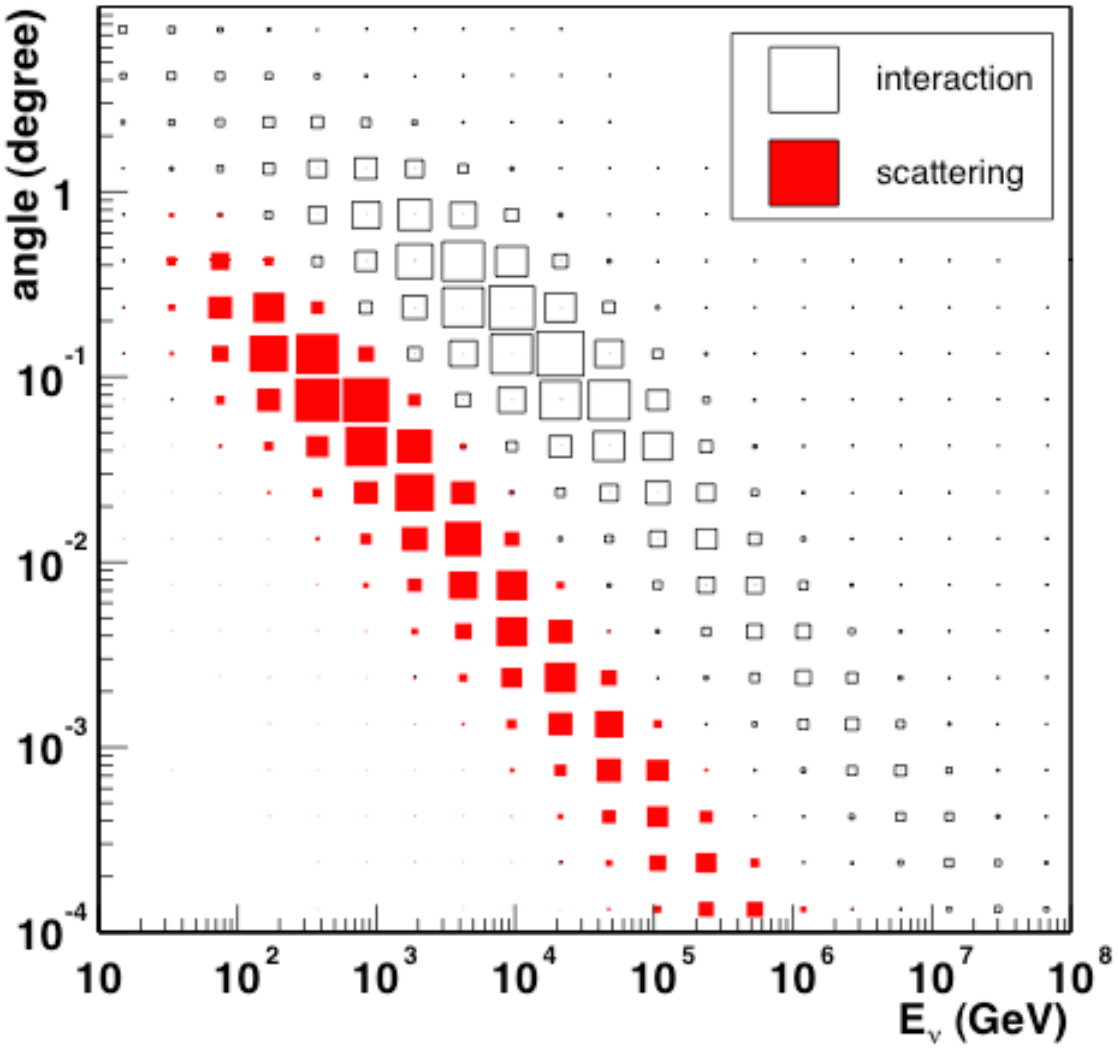


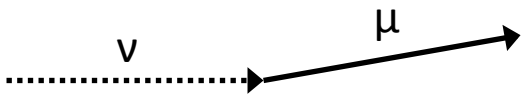


Jacob Feintzeig, UW-Madison – TeVPA, August 2013, Irvine, CA

Pointing: The Kinematic Limit

A. Heijboer



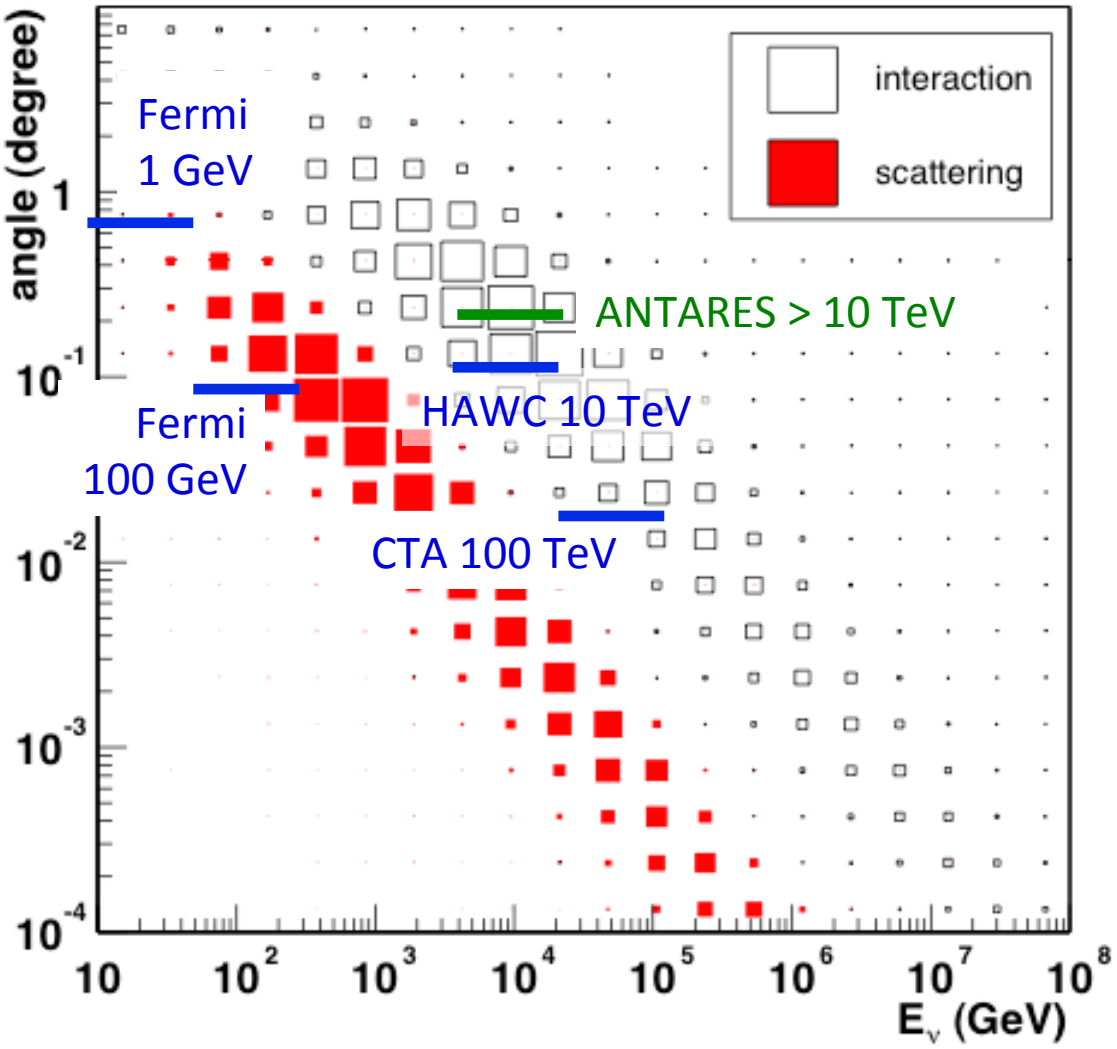


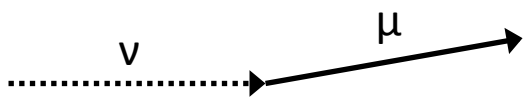
Interaction: angle between neutrino and muon

Scattering: angle muon is scattered between interaction point and reaching the detector

Pointing: The Kinematic Limit

A. Heijboer





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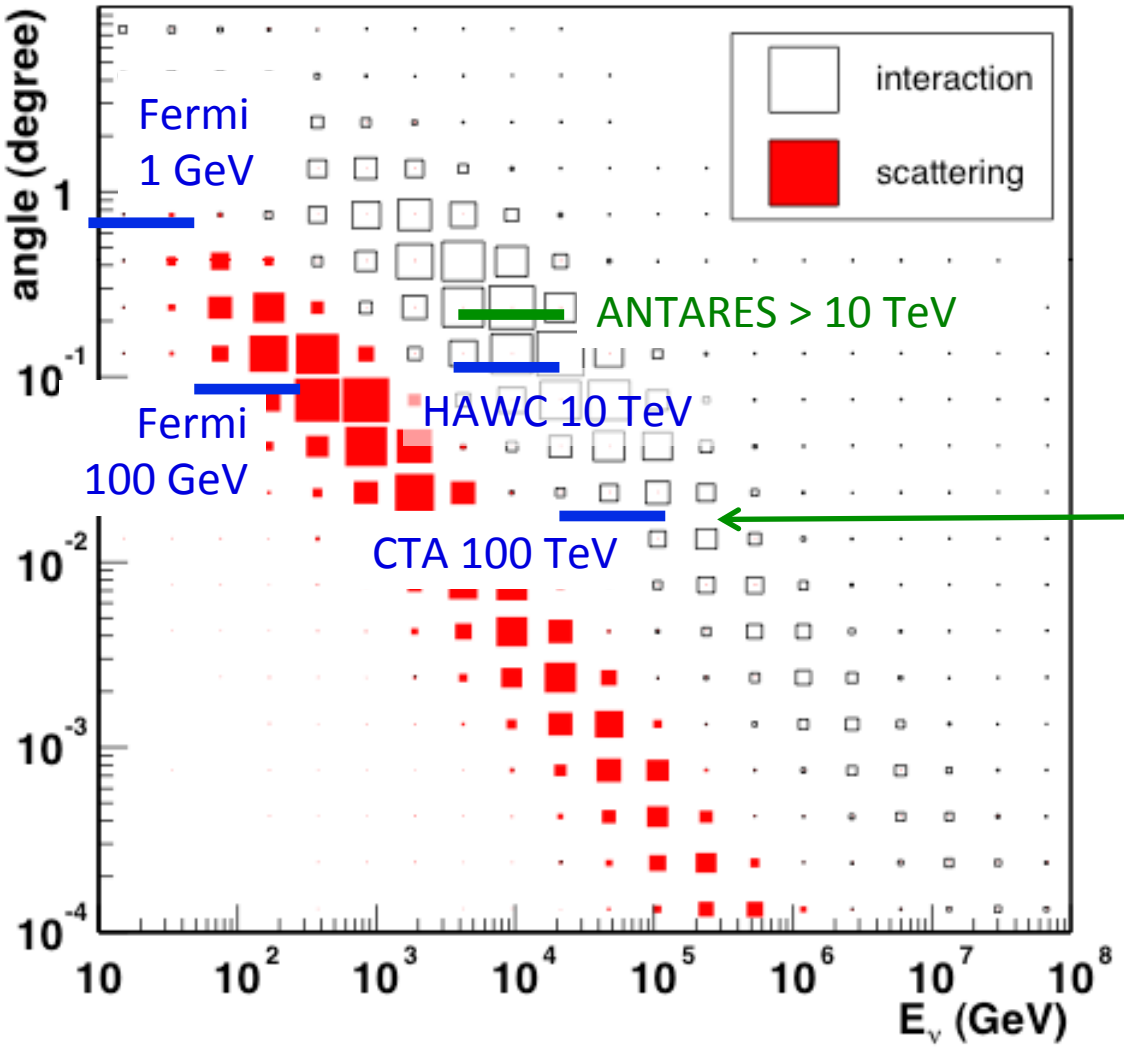
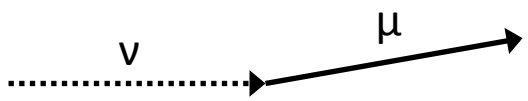




Interaction: angle between neutrino and muon

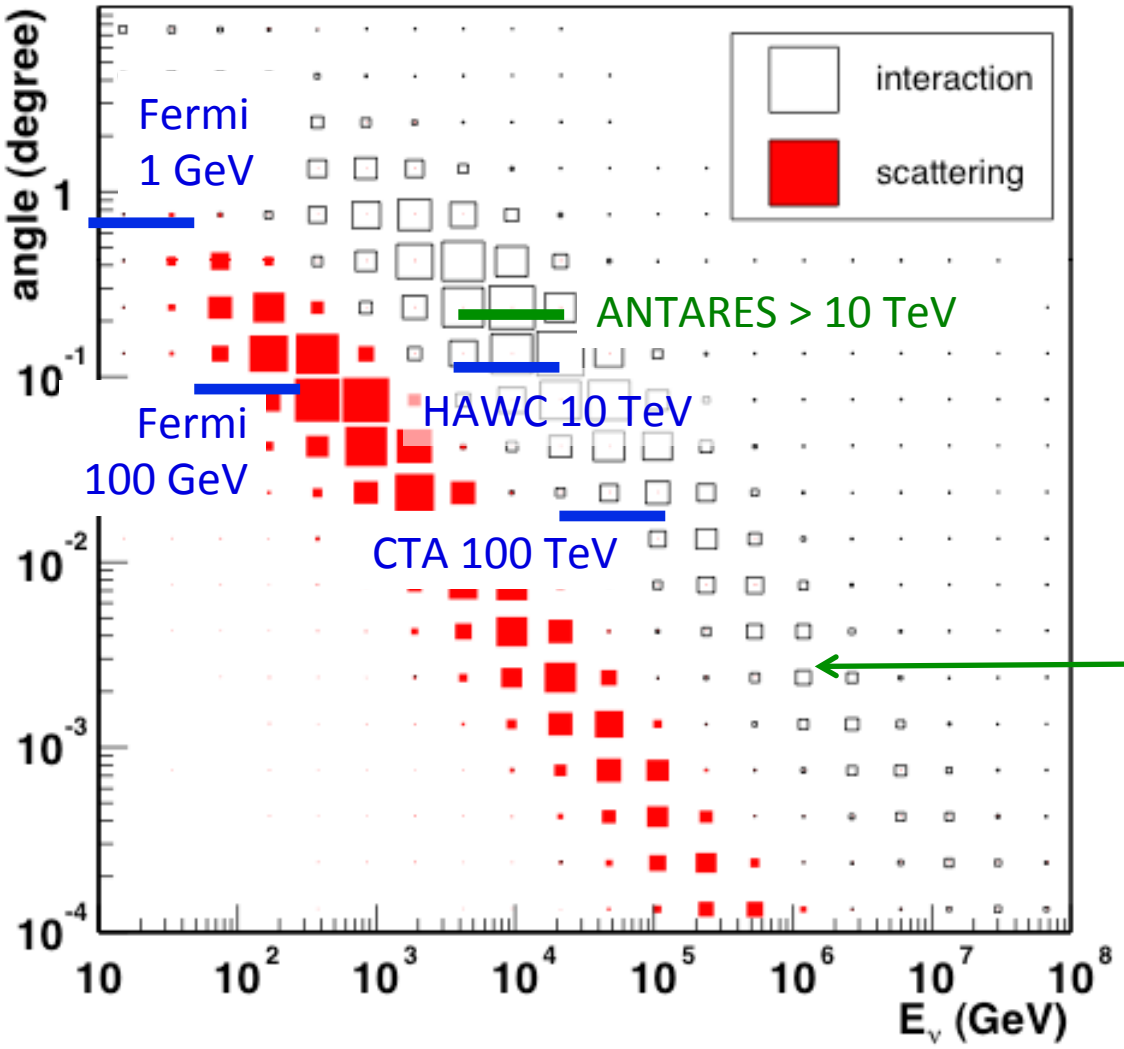
1 Arcmin possible above 100 TeV ?

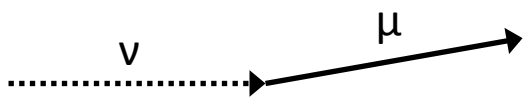
Need 0.3 m track positioning over 1 km !

Or, 1.5 m over 5 km …

Pointing: The Kinematic Limit

A. Heijboer





Interaction: angle between neutrino and muon

PeV neutrinos exist!

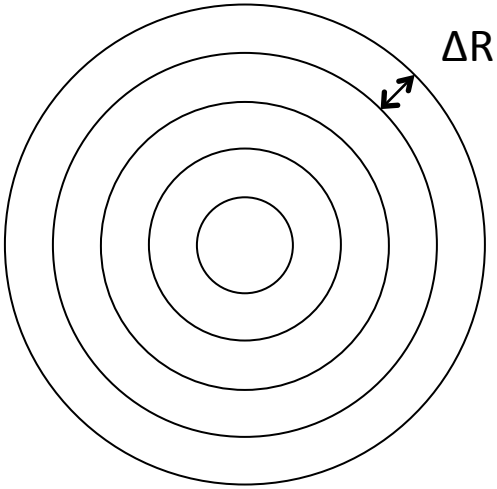
0.1 Arcmin resolution ?

What to do with such pointing?

With diffuse HE flux, we face a sort of Olbers' paradox, in reverse:

Heinrich Olbers 1758-1840

Every line of sight does actually end at a source (within angular unc.)



Each spherical shell of thickness Delta R contributes (on average) the same number of events as every other shell.

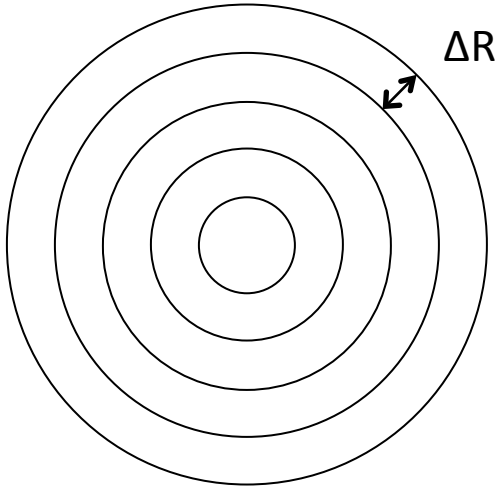
What to do with such pointing?

Heinrich Olbers 1758-1840

Divide up cosmos into N shells so that innermost shell R contains (on average) one source. ($R \sim \rho^{-1/3}$)

Need ~ N neutrino events to get ~ one neutrino from nearest/brightest source.

If source class is common, N could be large



What to do with such pointing?

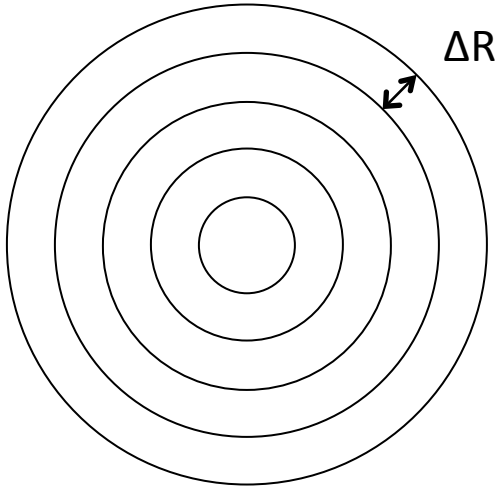
If source class is common, N could be large

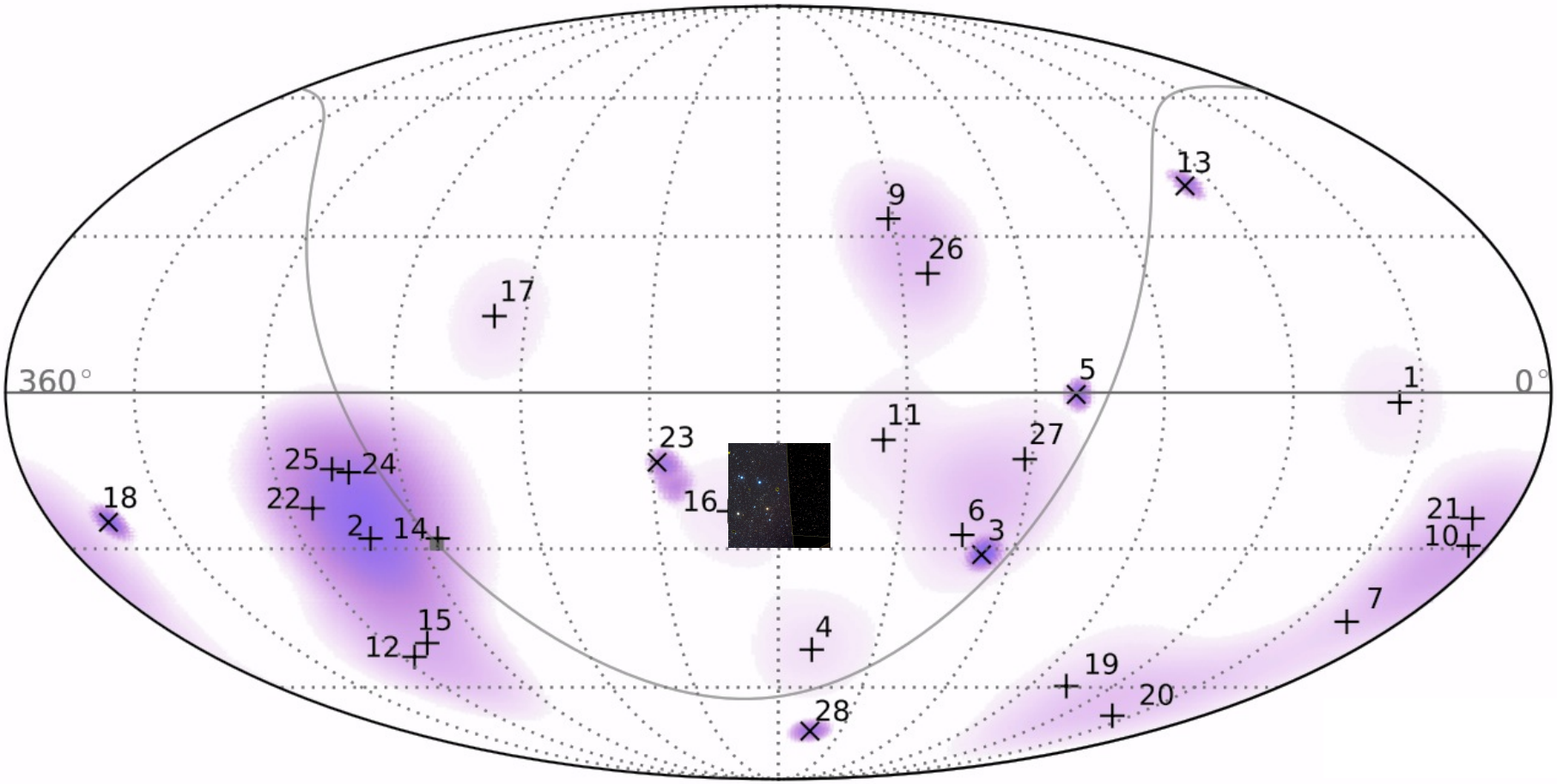
(Somewhat ironic: once you have a diffuse flux, you hope sources are rare, and that nearest contributor is far away)

Heinrich Olbers 1758-1840

For this reason, all diffuse neutrinos, not just the highest energy ones, will be needed.

The low background provided by vetoes helps; but is not crucial. Angular resolution provides the low background for pointing searches

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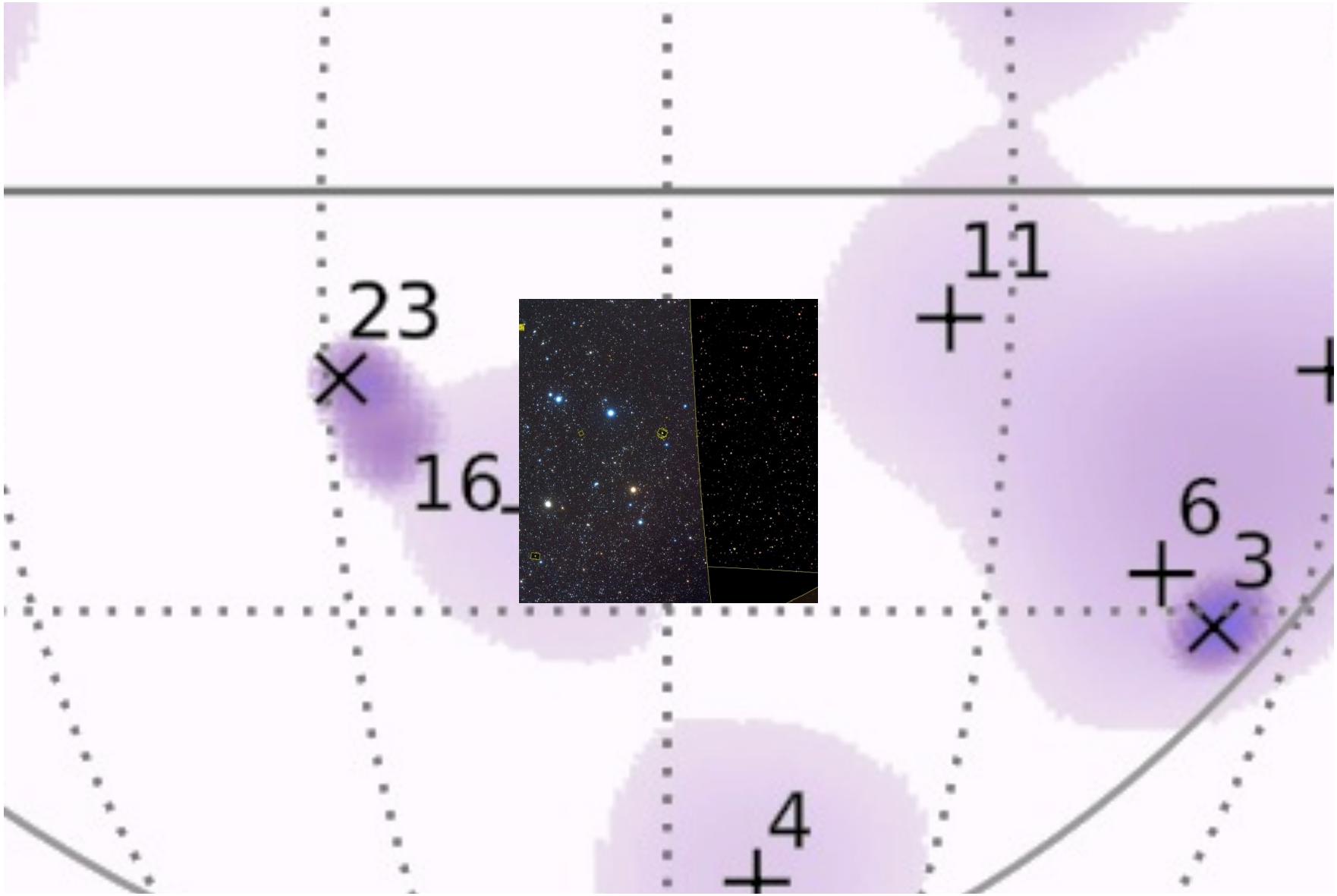
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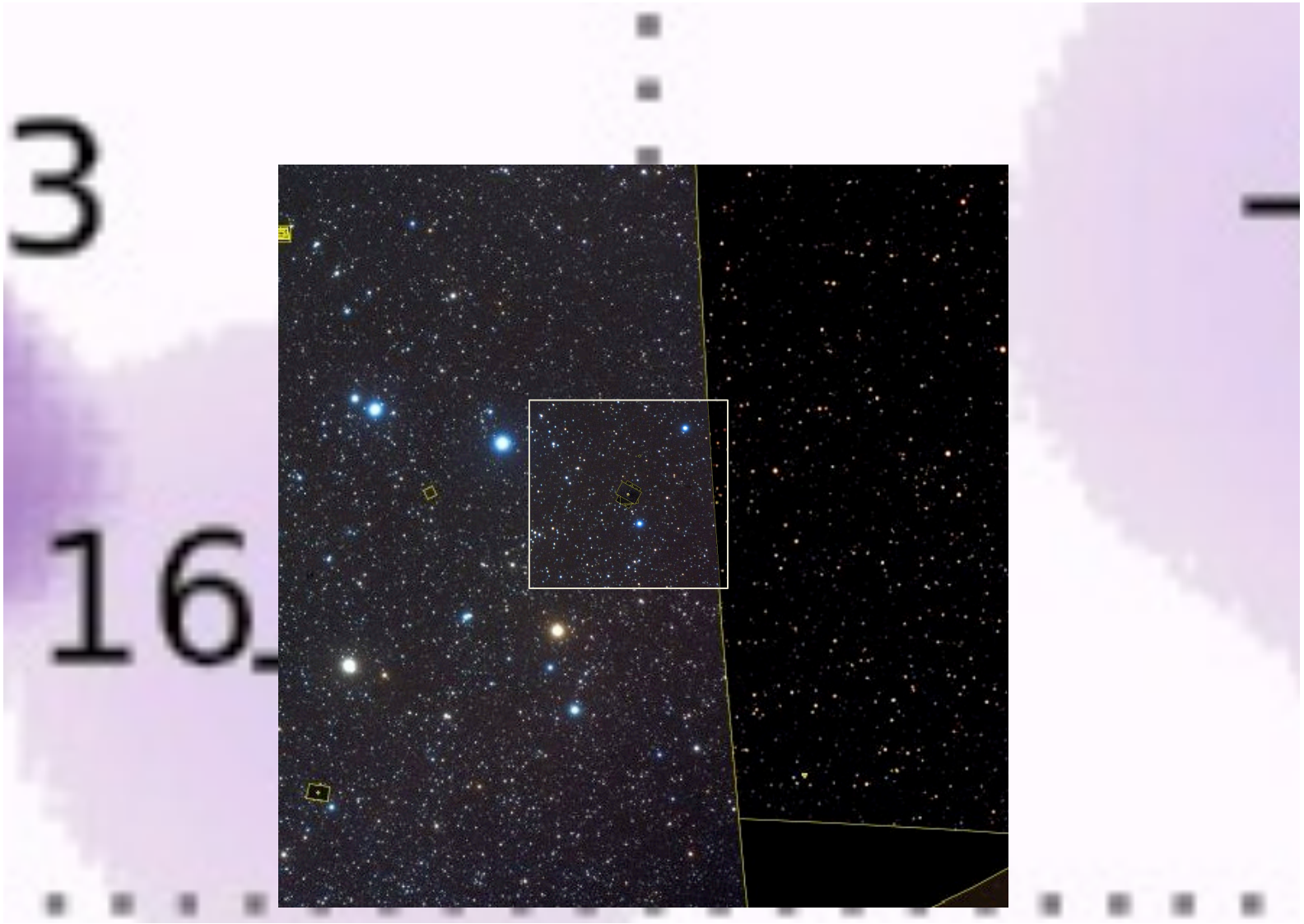
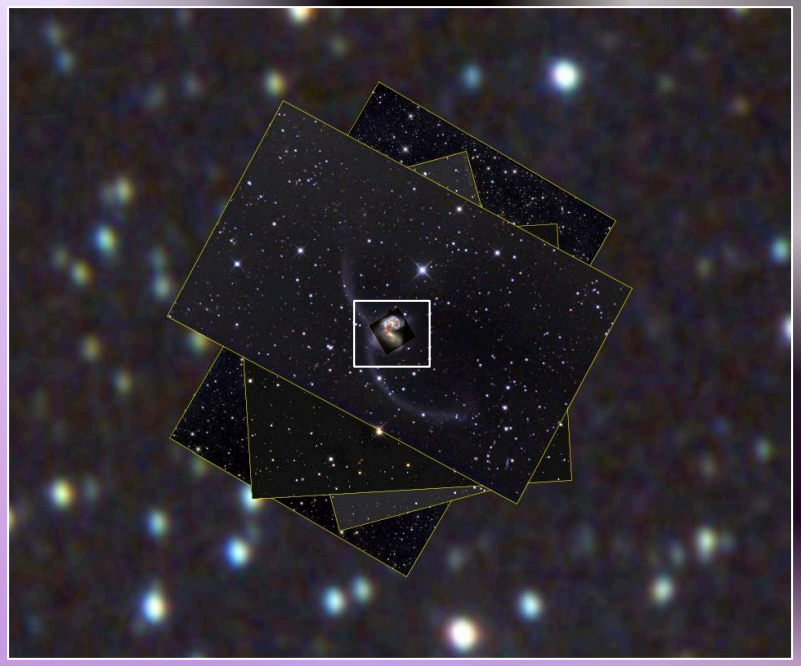



3
16

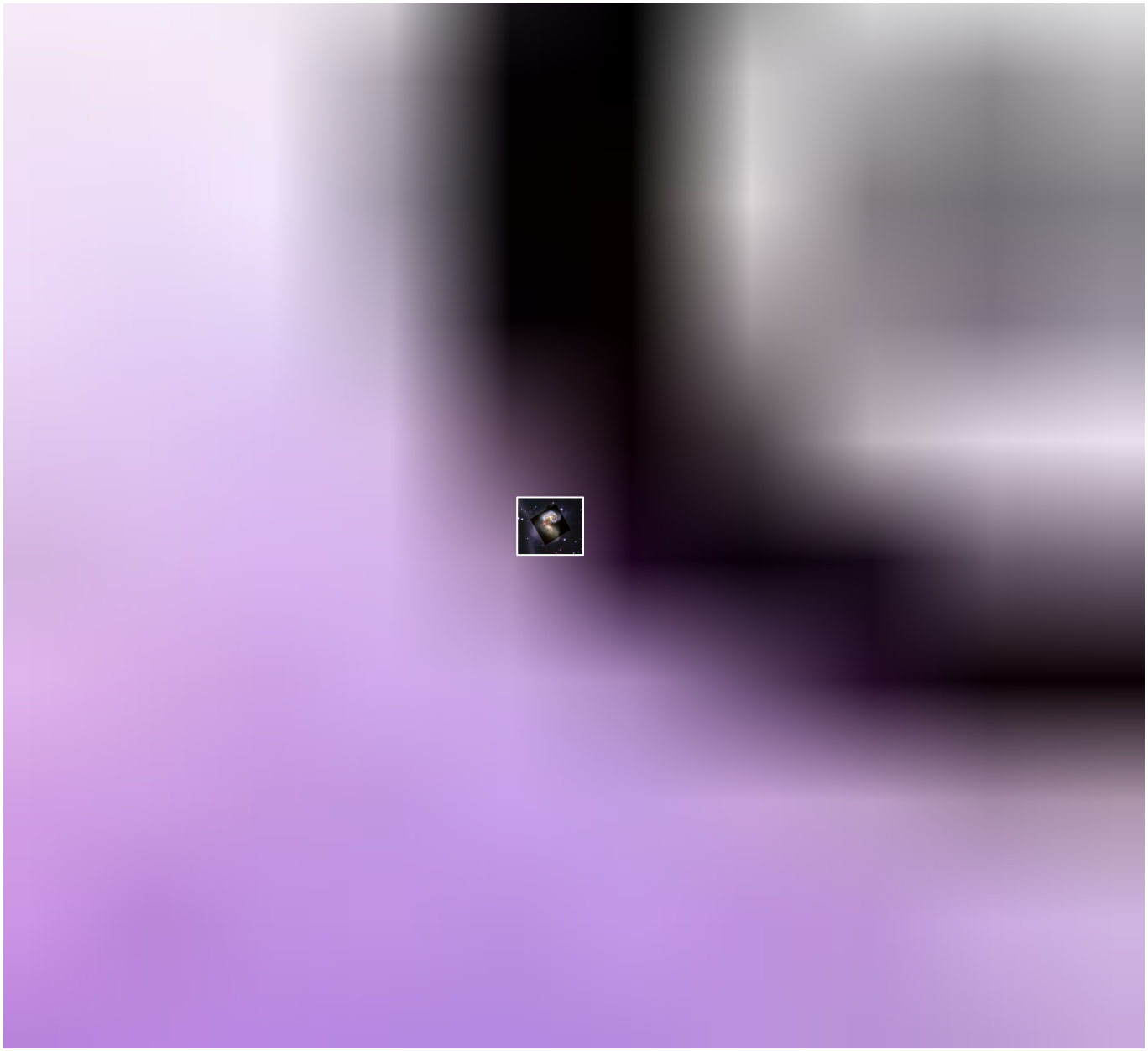
1° PSF

1° PSF

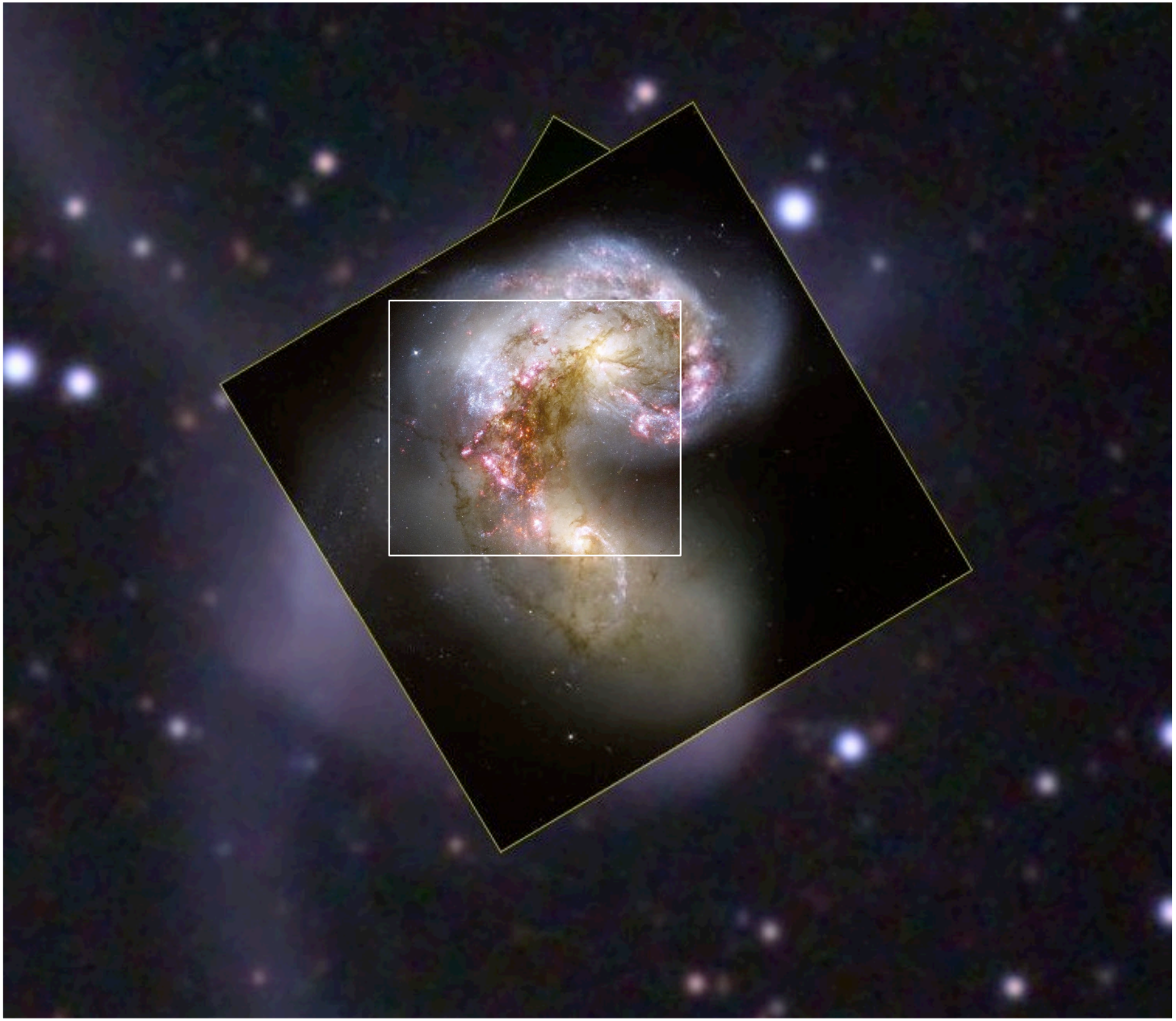
0.3° PSF



0.3° PSF



100 TeV



1’ PSF

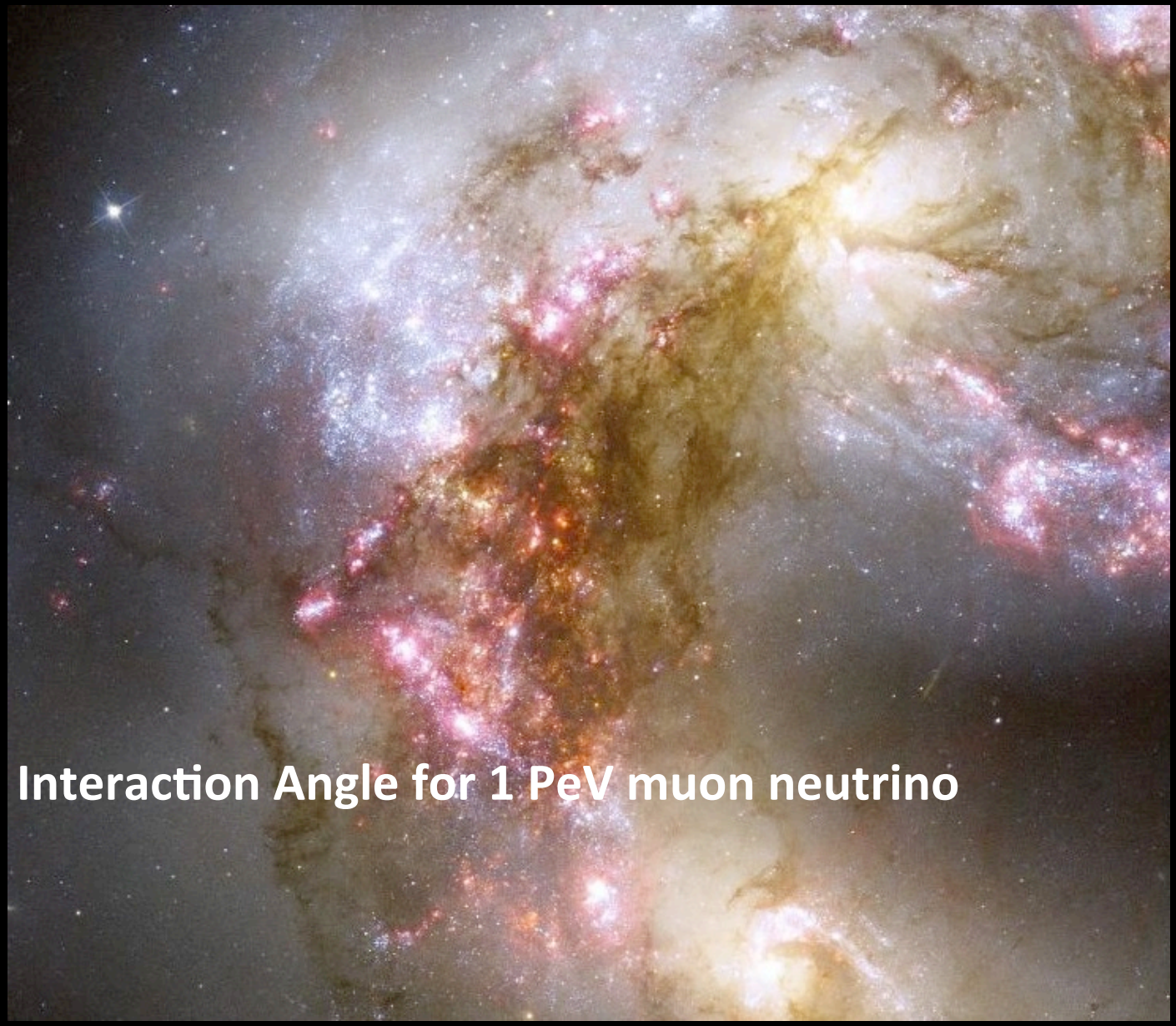
100 TeV

1’ PSF

1 PeV

0.1’ PSF

Ultimate Pointing: How far can we follow kinematic limit?



0.1’ PSF