Probing neutrino emission at GeV energies from compact binary mergers with IceCube

Gwenhaël de Wasseige,
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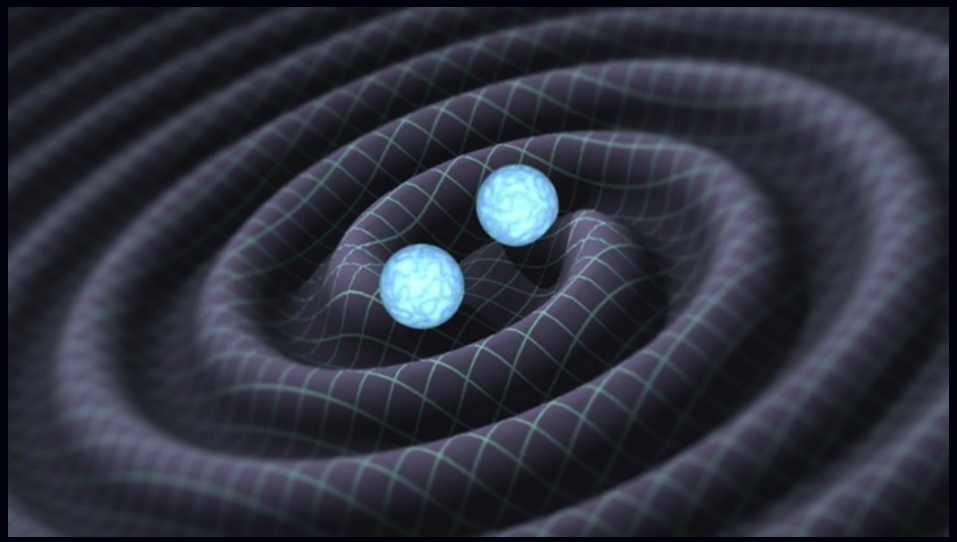
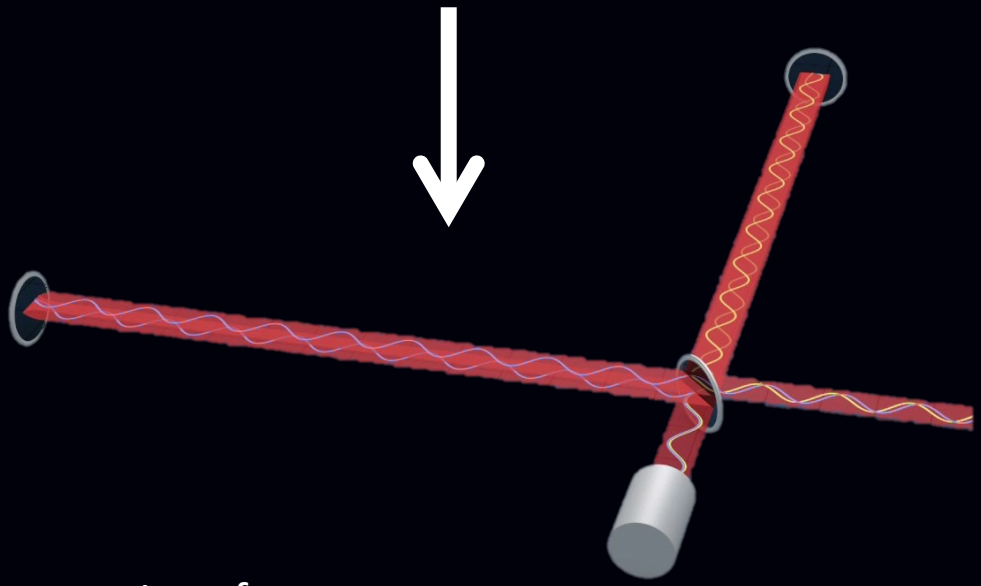
APC, CNRS, FRANCE

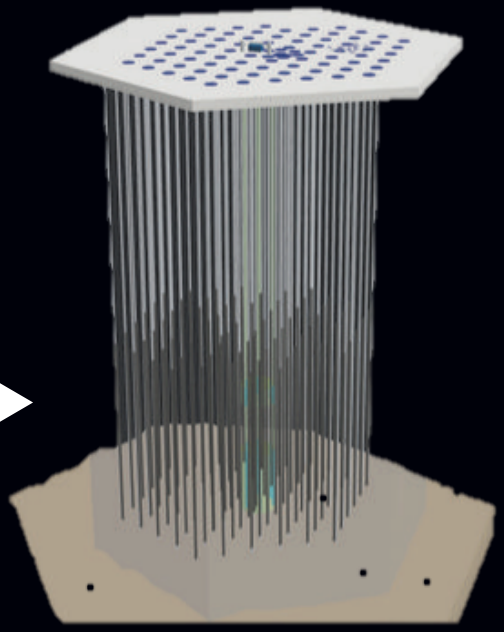
Ingredients

Compact binary mergers





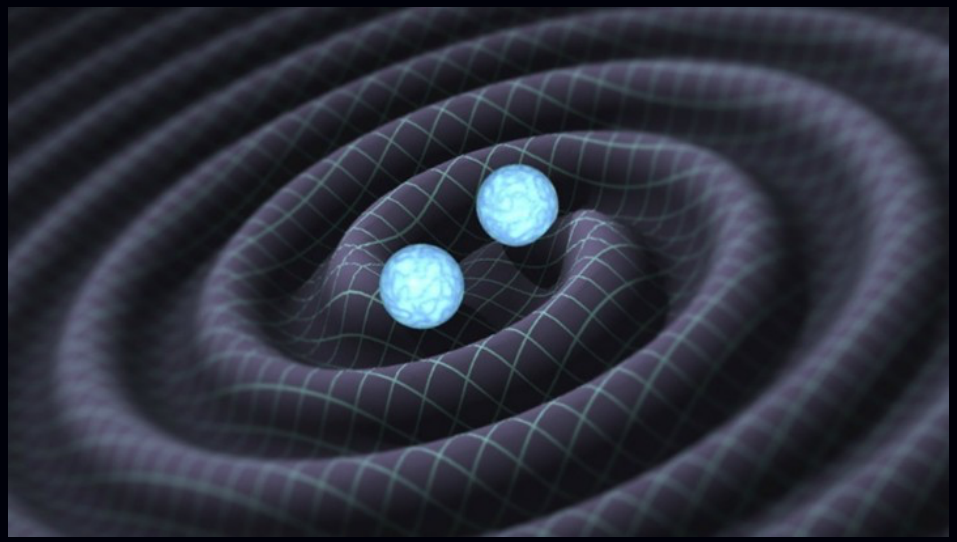
Interferometers



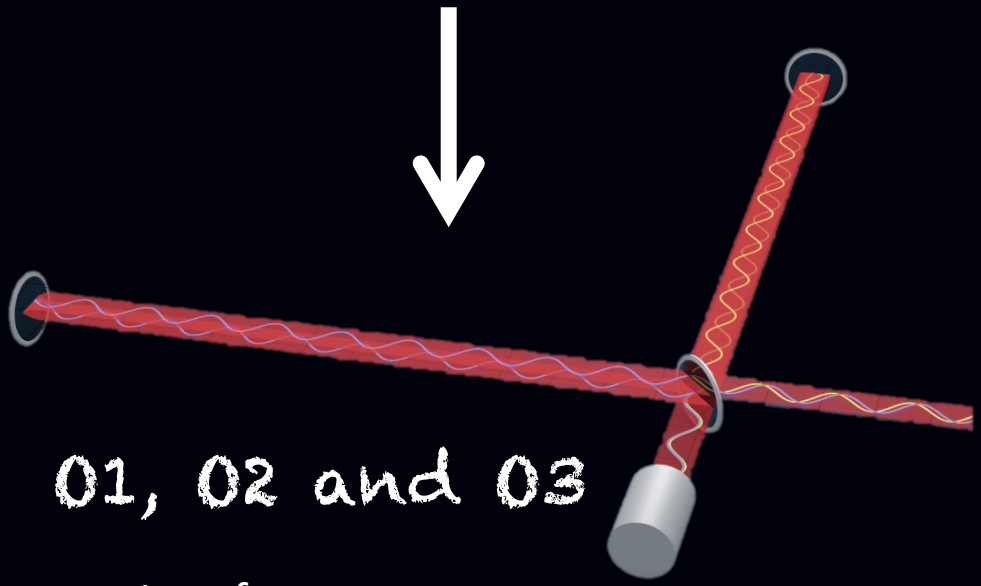
A neutrino detector

Ingredients

Compact binary mergers



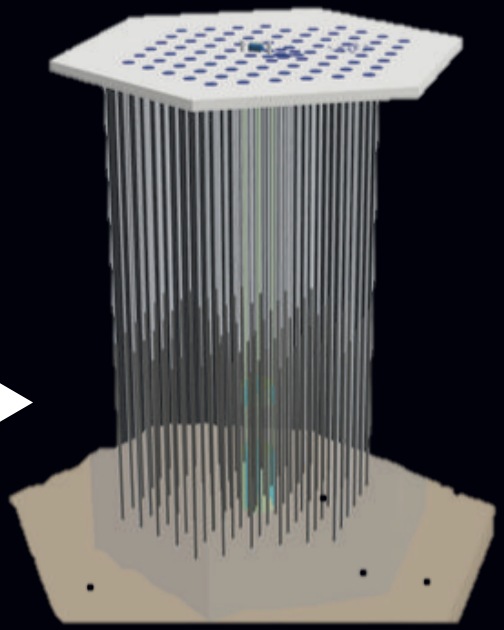
- BBH
- BNS and NSBH



O1, O2 and O3

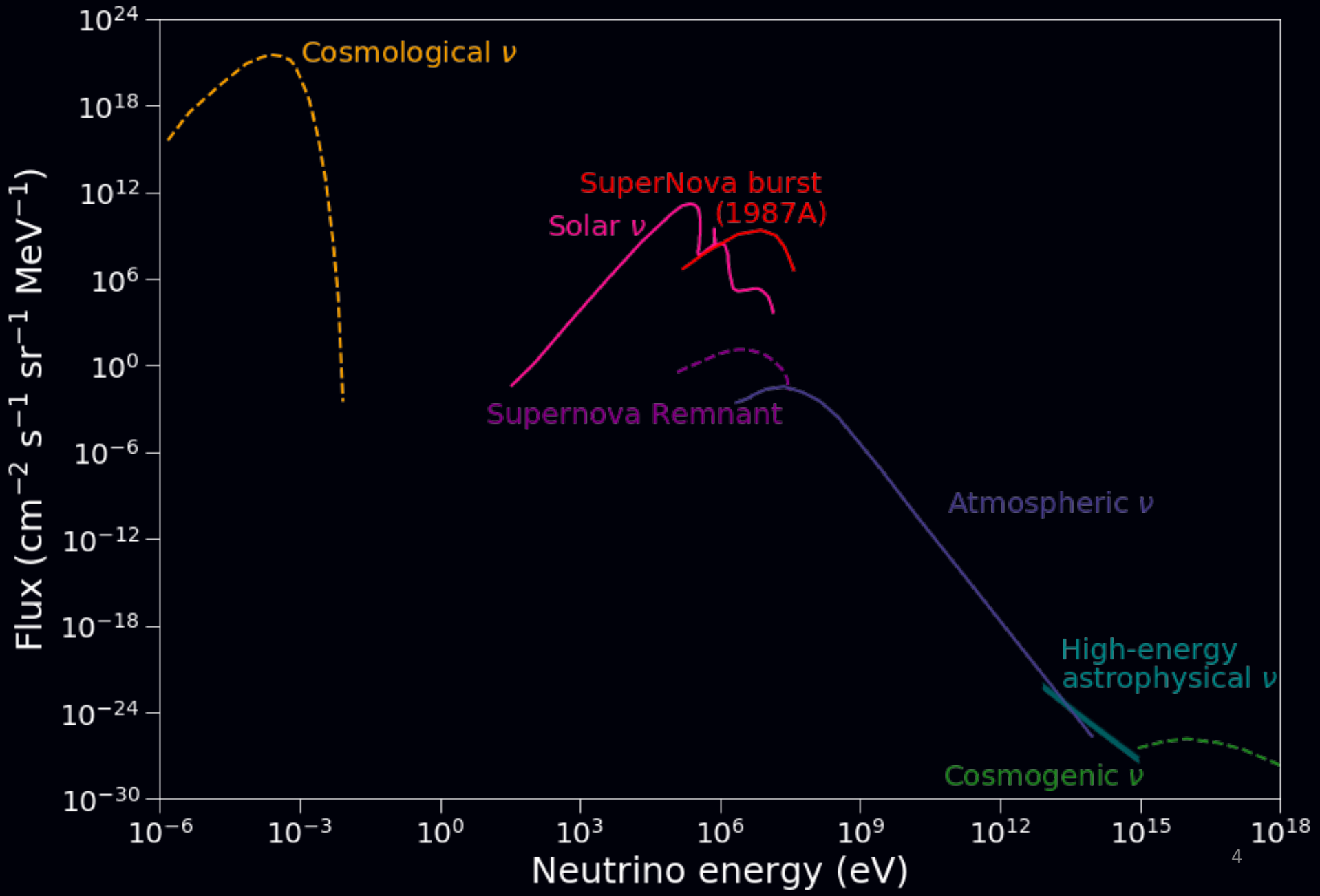
Interferometers

IceCube



A neutrino detector

Which neutrinos do we look for?



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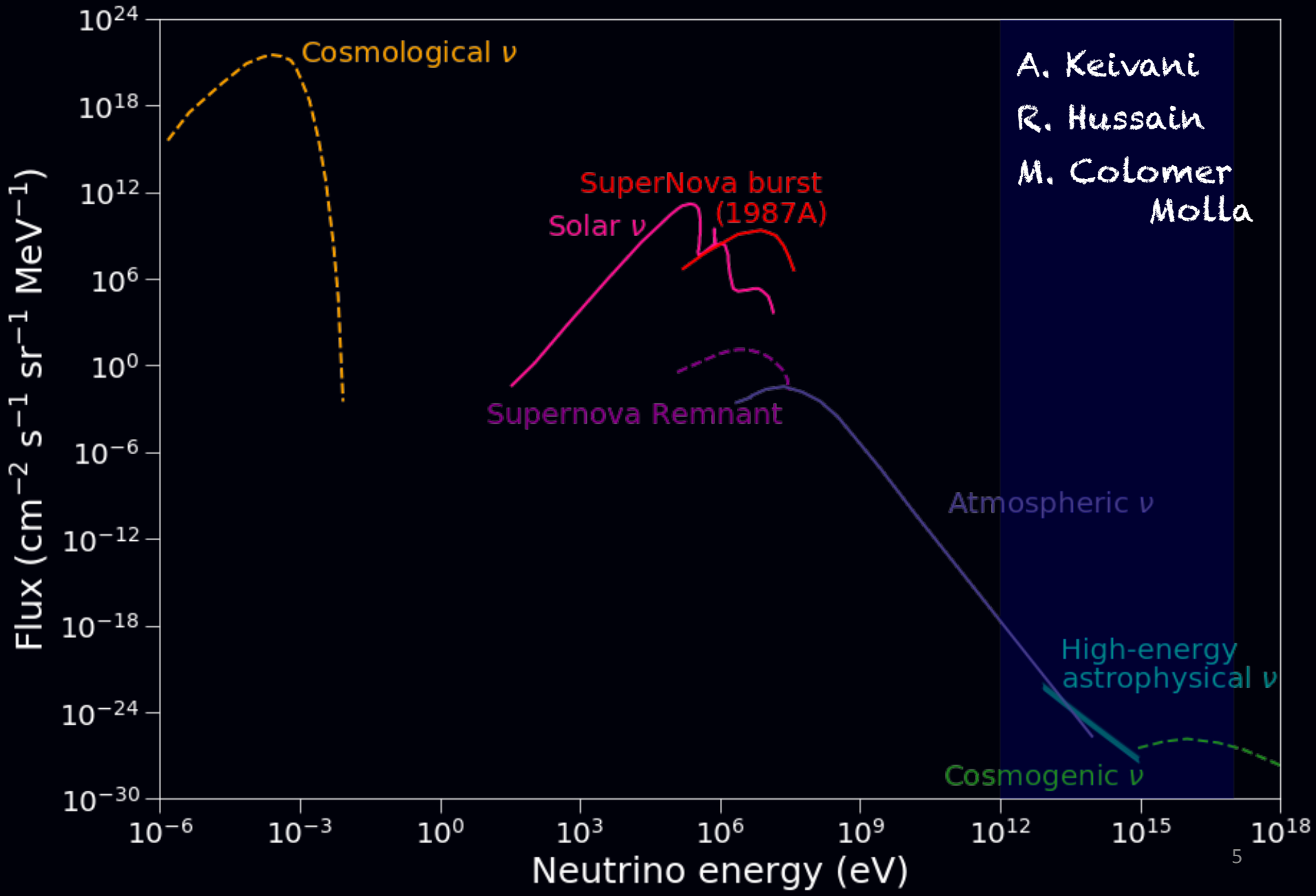
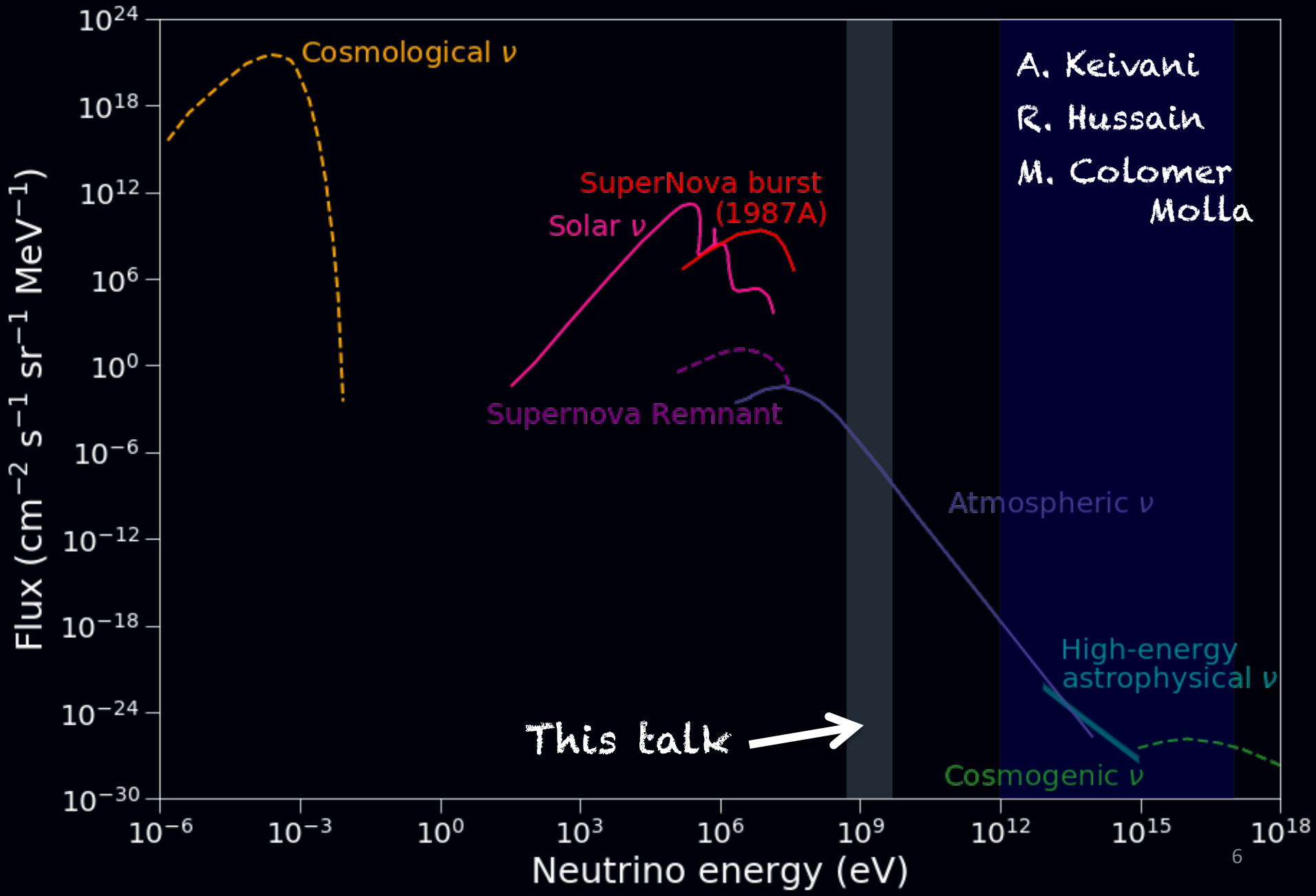
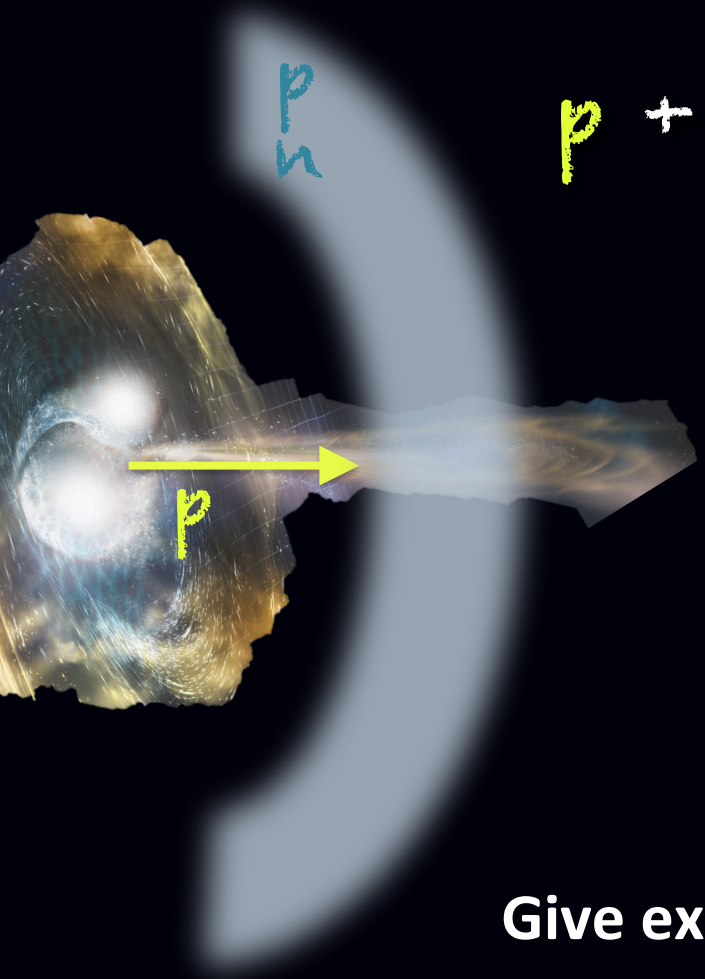


Which neutrinos do we look for?



How could GeV neutrinos be produced ?

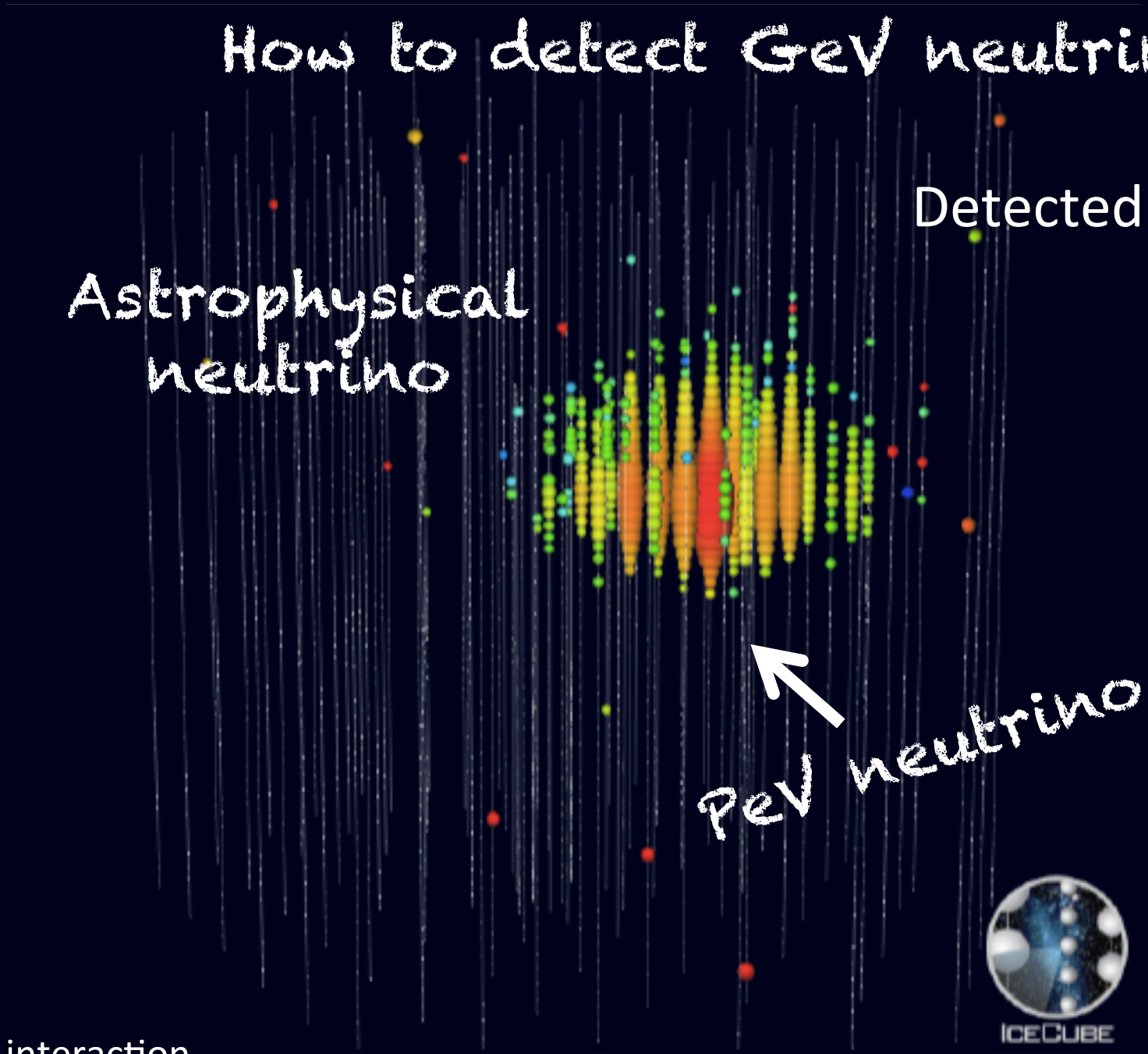


$$p + p, n \rightarrow \begin{cases} \pi^+ \rightarrow \mu^+ + \nu_\mu \\ \quad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \\ \pi^0 \rightarrow 2\gamma \\ \pi^- \rightarrow \mu^- + \bar{\nu}_\mu \\ \quad \mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \end{cases}$$

Give extra information on source environment

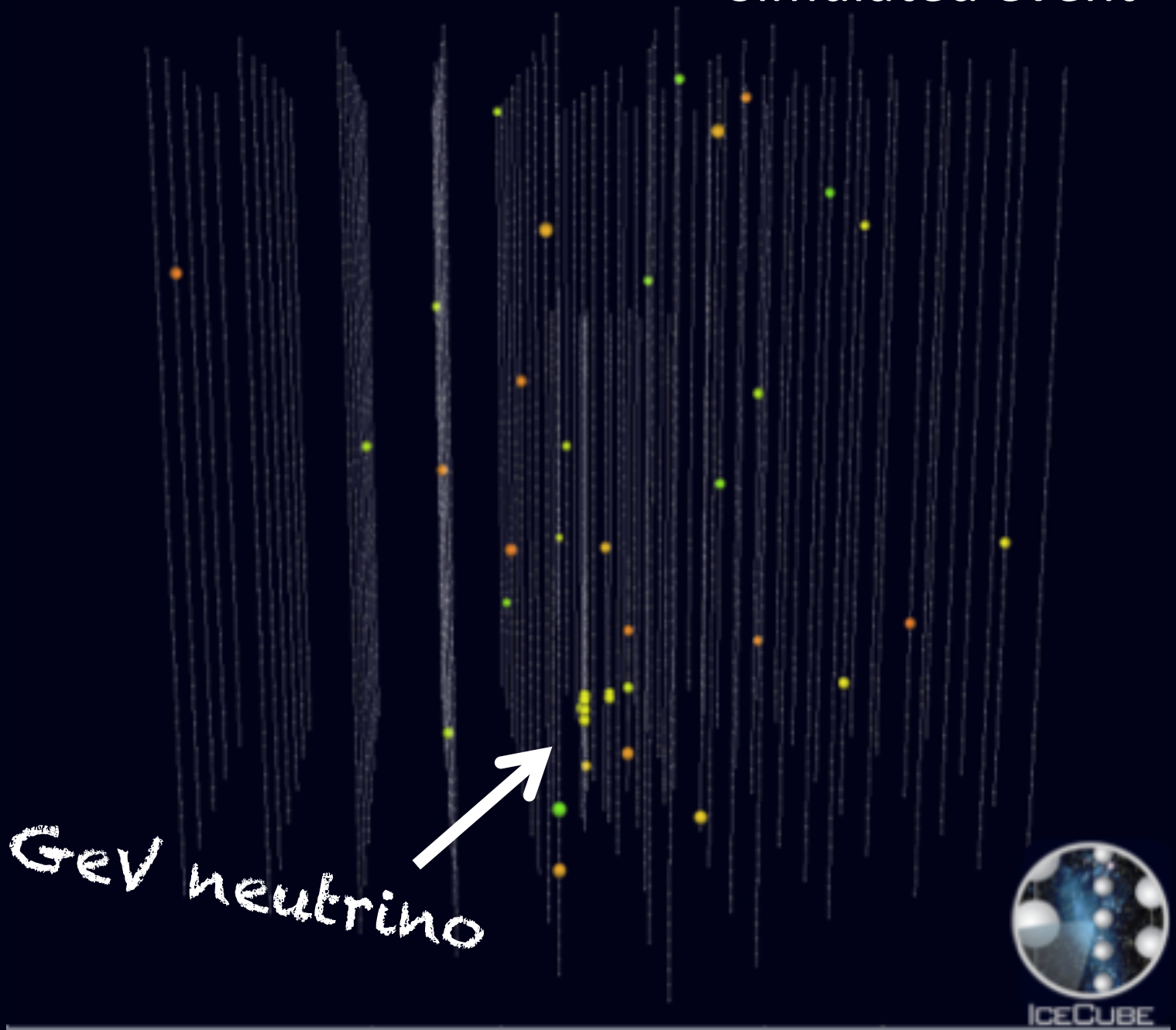
Murase *et al.,* Phys.Rev.Lett. 111 (2013) 131102
Bartos *et al.*, Phys.Rev.Lett. 110 (2013) 241101
Maouloud, GDW, Ahlers, Bustamante, van Elewyck, PS2-129

How to detect GeV neutrinos?

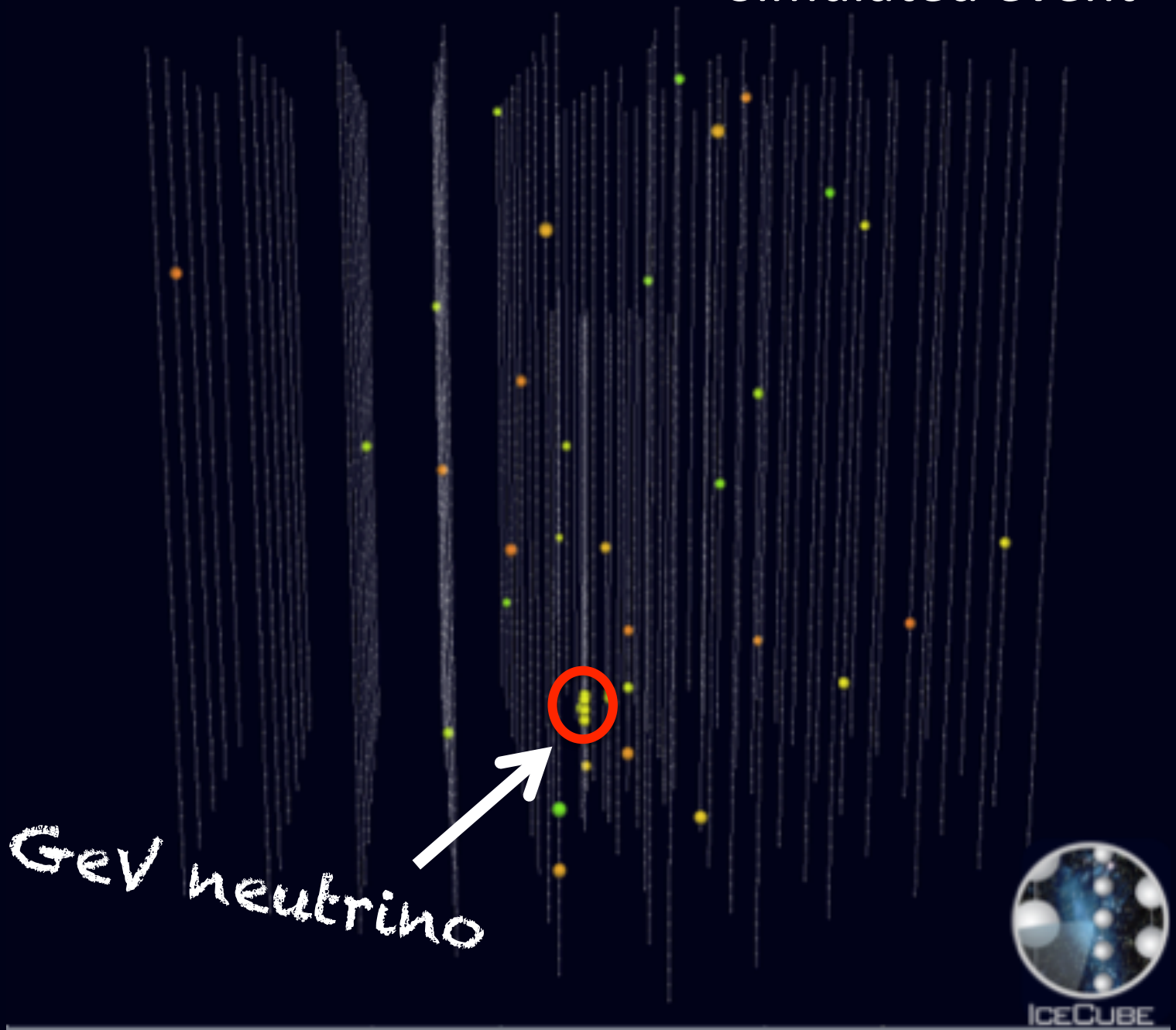


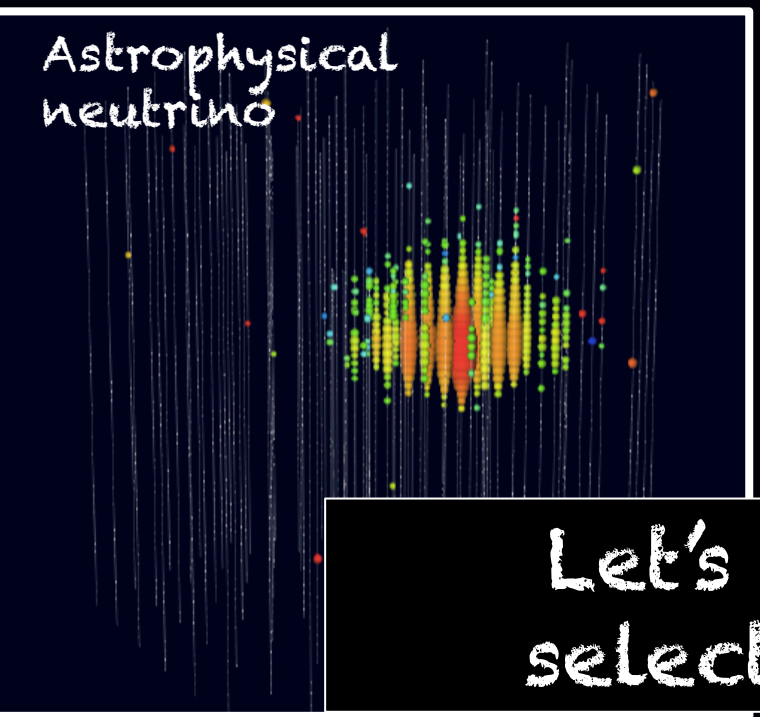
Not ν_μ CC interaction

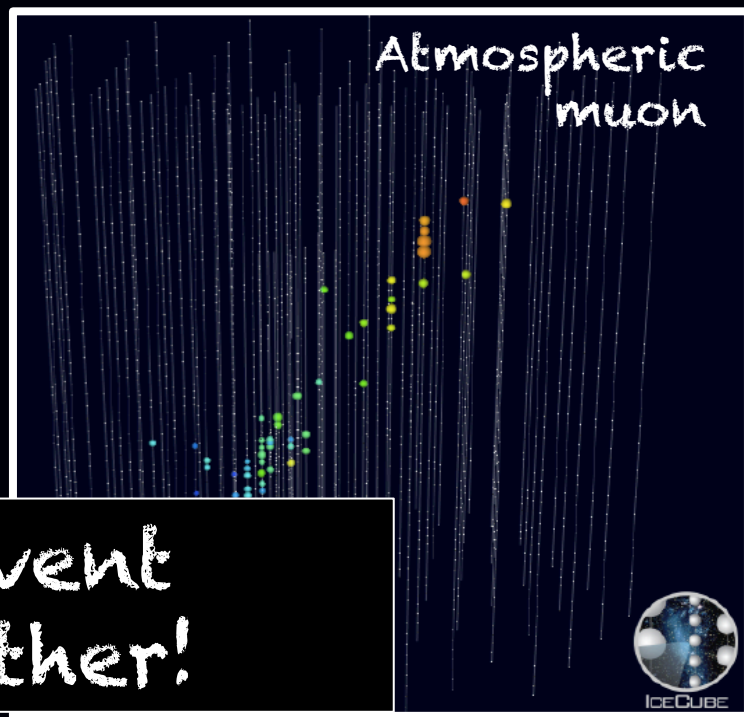
Simulated event



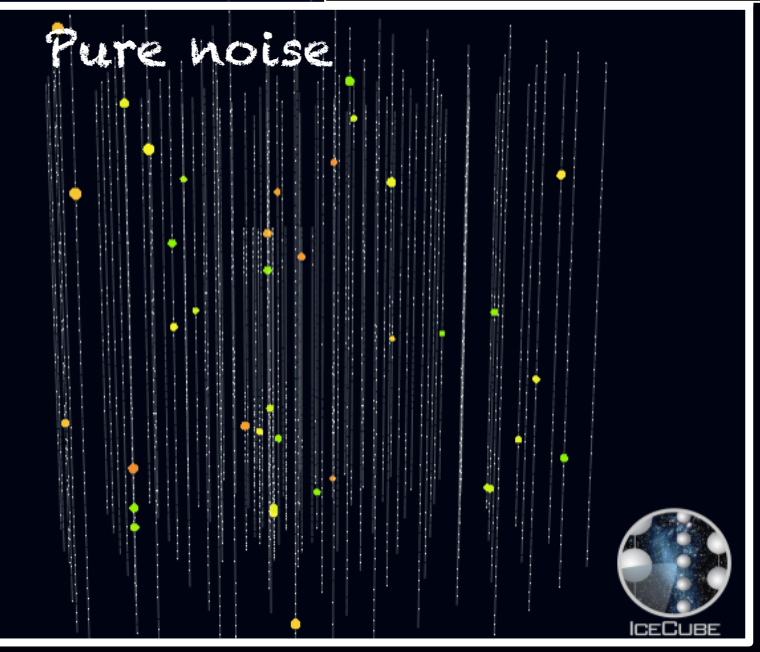
Simulated event

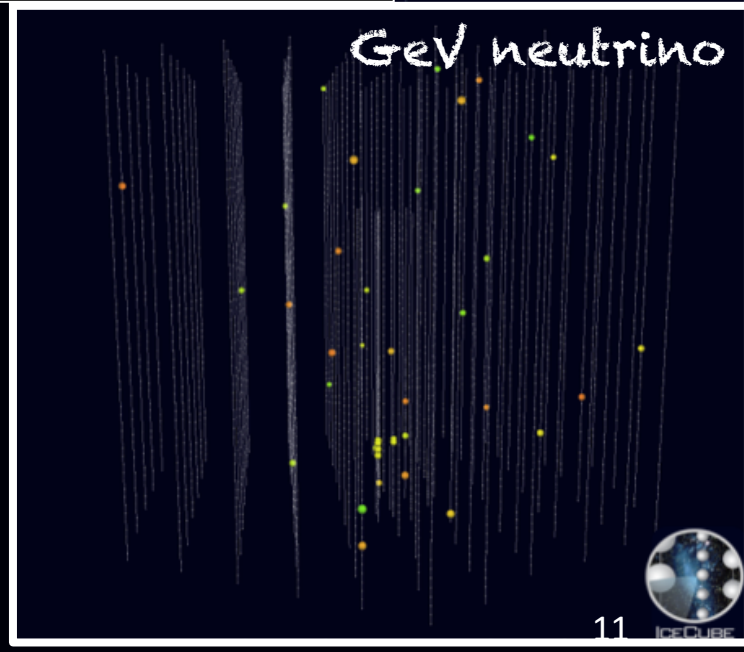


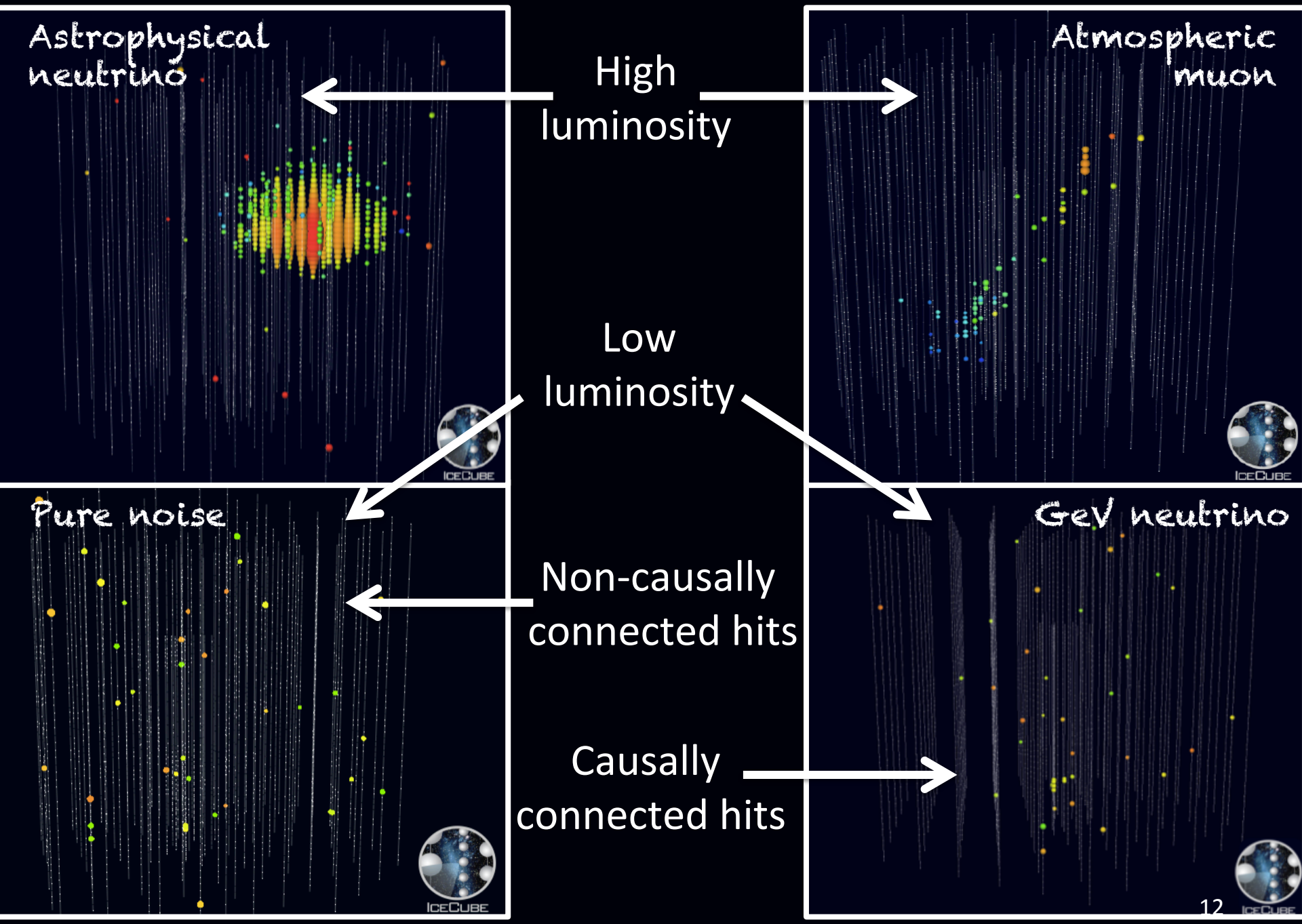


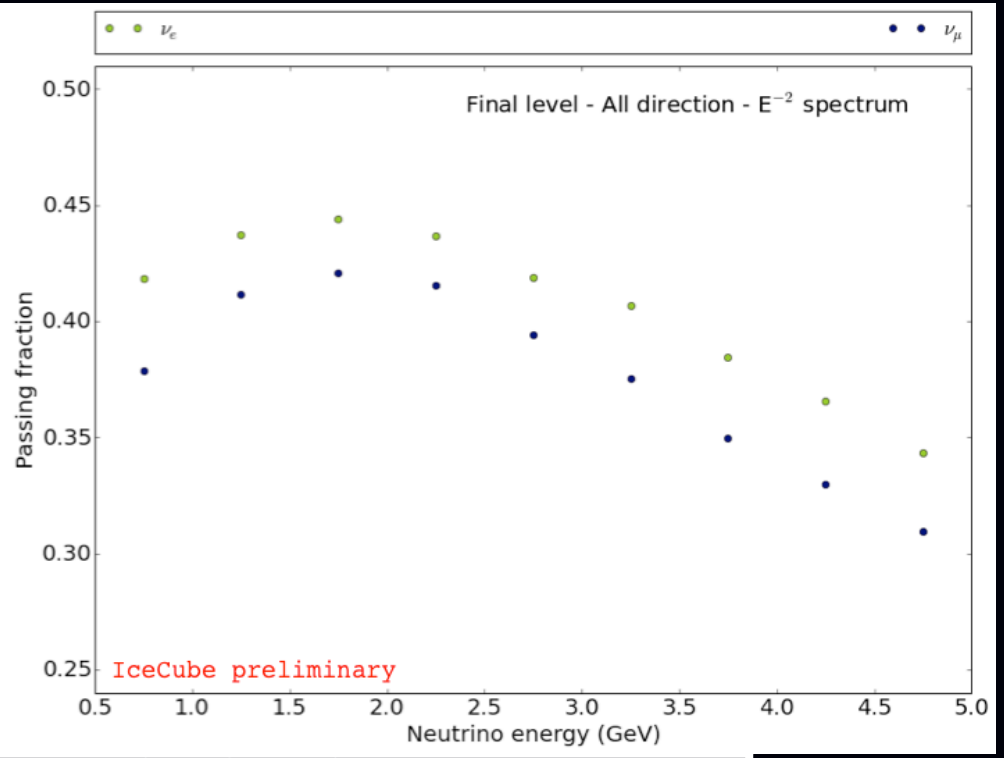


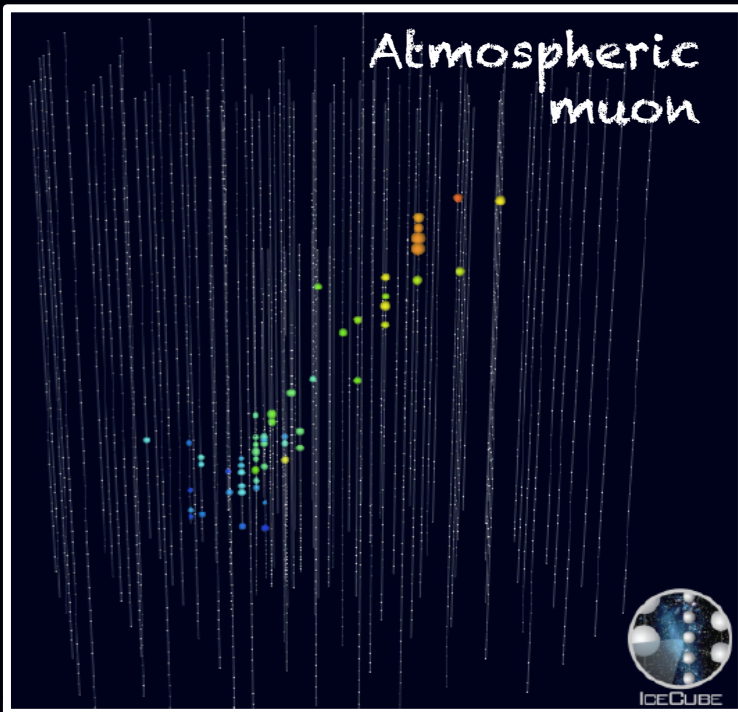
Let's do the event selection together!

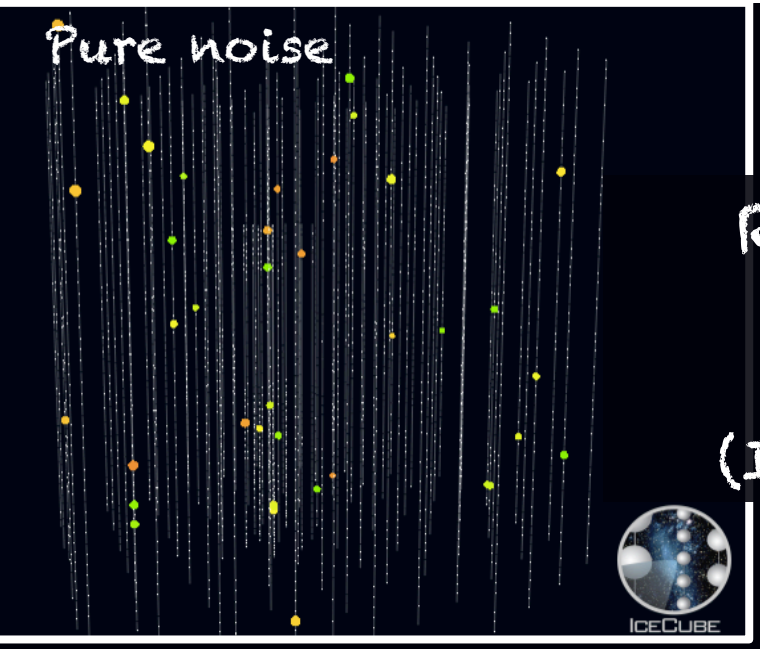





Astrophysical neutrino
Atmospheric muon
Pure noise
GeV neutrino
High luminosity
Low luminosity
Non-causally connected hits
Causally connected hits
ICECUBE
ICECUBE
ICECUBE
ICECUBE

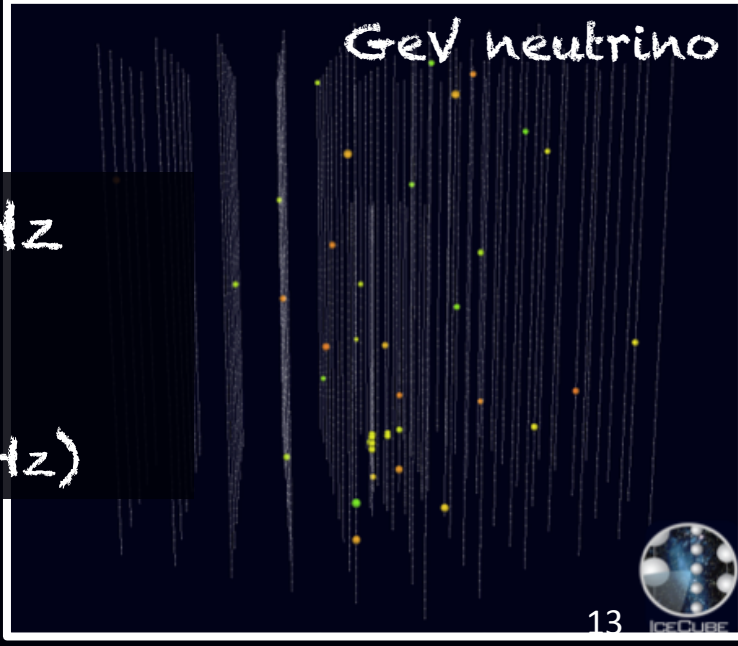




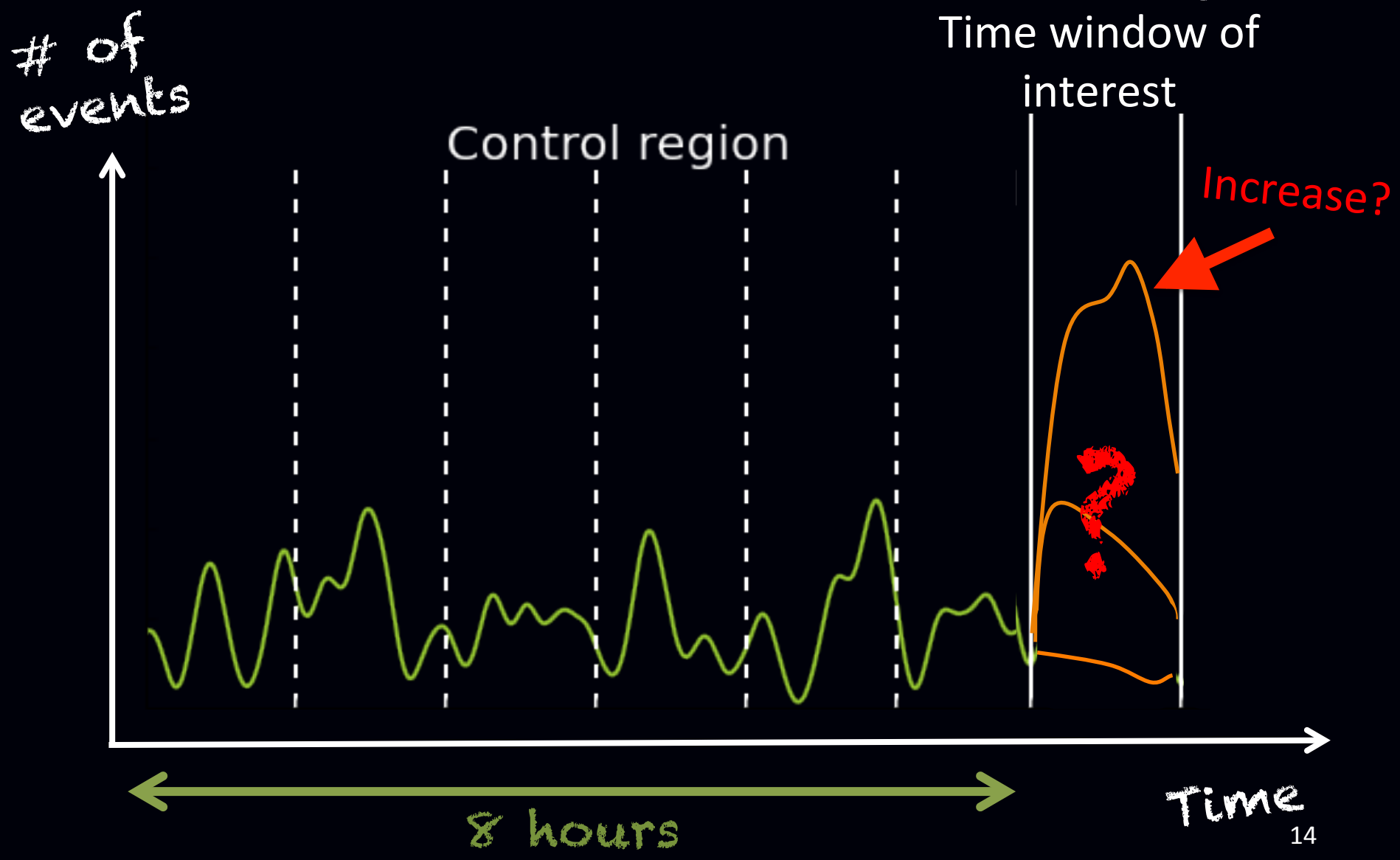


Rate = 0.02Hz

(Initial rate: kHz)



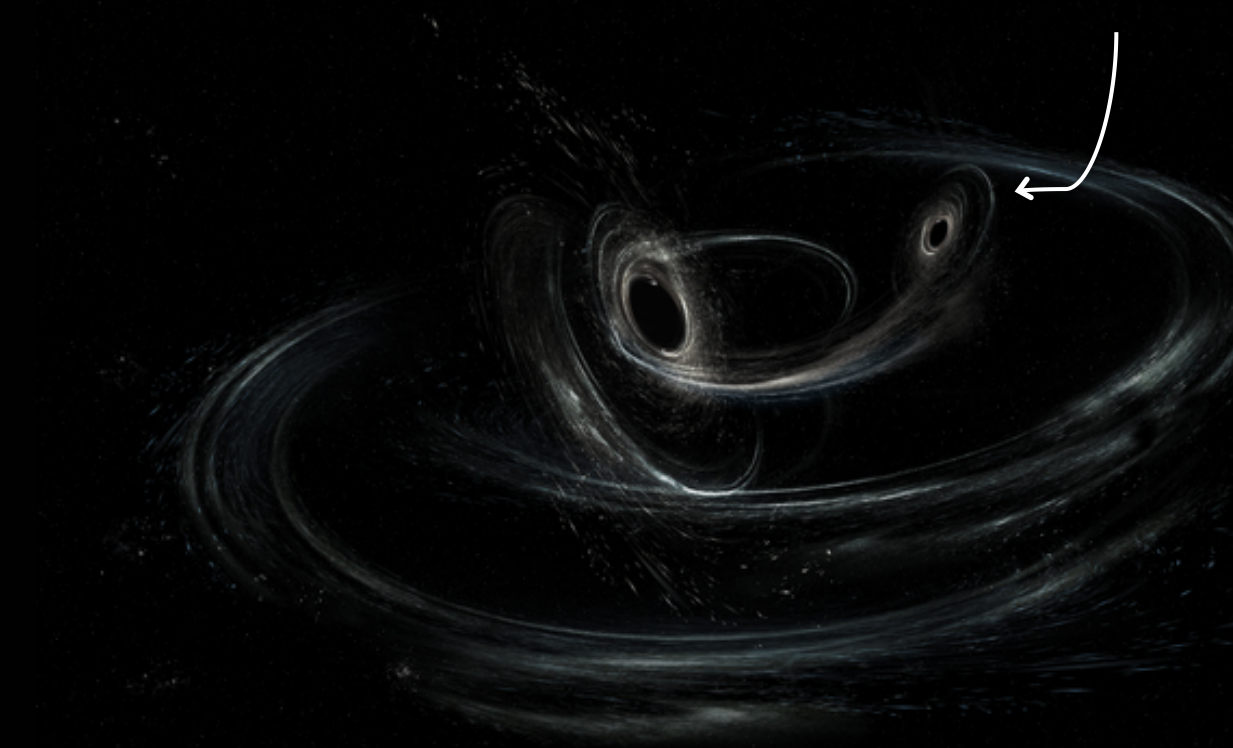
How to detect a GeV neutrino signal?



Did we find GeV neutrinos?

"Spiraling Black Holes"

(Artist's conception)

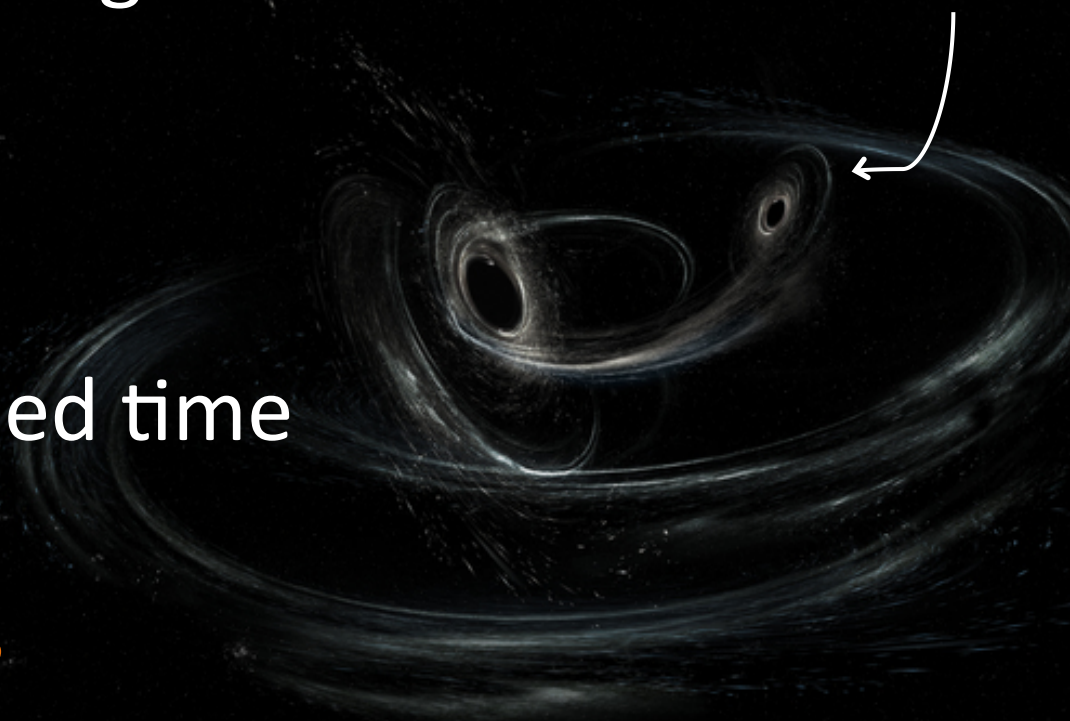


Did we find GeV neutrinos?

- <u>3 BNS + 1NSBH mergers</u>
  Search for a prompt signal
  $[t_0, t_0+3]$ s

- <u>6 BBH mergers</u>
  Search in an extended time windows
  $[t_0-500, t_0+500]$ s

"Spiraling Black Holes"
(Artist's conception)



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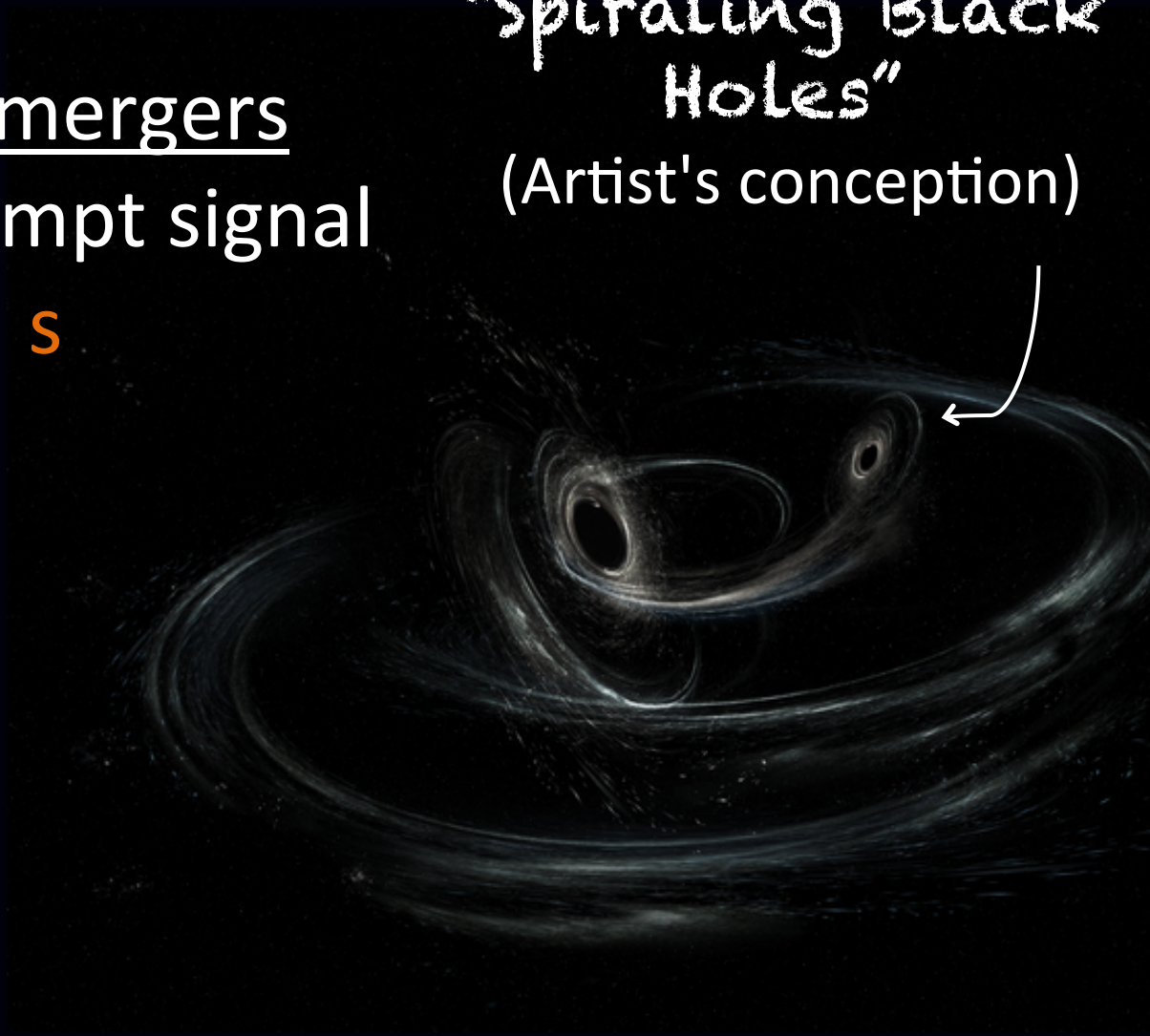

BNS + NSBH

Did we find GeV neutrinos?

	Type	EM counterpart?	# of ν events in [t, t+3s]
BNS170817	BNS	Yes	
S190425z	BNS	No	
S190426c	NSBH	No	
S190510g	BNS	No	

BNS + NSBH

Did we find GeV neutrinos?

	Type	EM counterpart?	# of ν events in [t, t+3s]
BNS170817	BNS	Yes	0
S190425z	BNS	No	0
S190426c	NSBH	No	0
S190510g	BNS	No	0

BNS + NSBH

Did we find GeV neutrinos?

	Type	EM counterpart?	# of ν events in [t, t+3s]
BNS170817	BNS	Yes	0

<u>Upper limit on the fluence at Earth:</u>

1.84×10^{7} neutrinos $\mathrm{MeV}^{-1}\,\mathrm{cm}^{-2}$

in the 3 seconds
integrated over 3 flavours

Comparison with other neutrino searches

		E_{iso} (erg)
This work	[t, t +3s]	3×10^{54}

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Super-Kamiokande	[t-500s, t+500s]	$1\text{-}6 \times 10^{53}$
HE neutrino in IceCube	[t-500s, t+500s]	2.66×10^{50}

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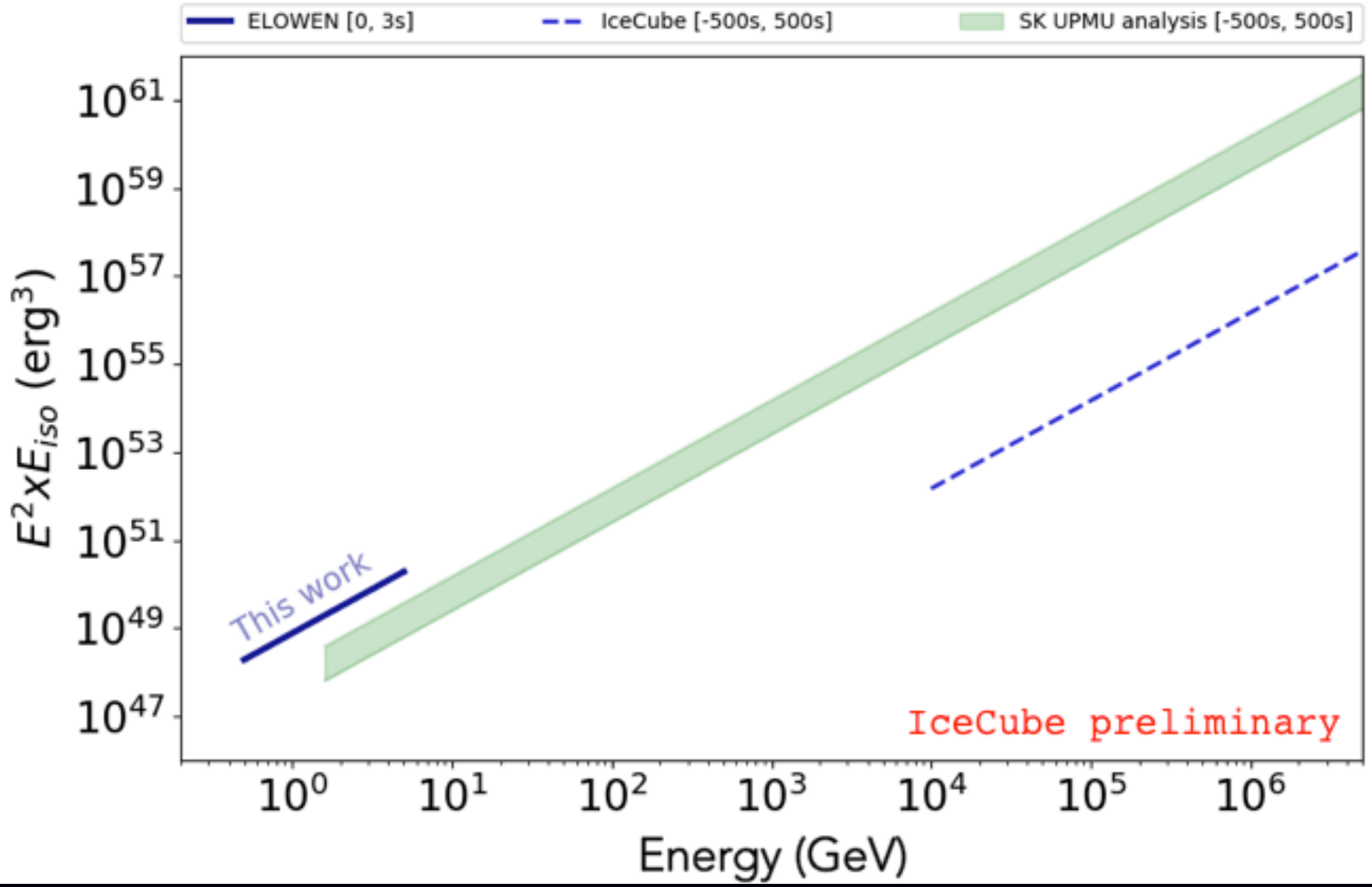
Fermi-GBM detection		4×10^{46}

Comparison with other neutrino searches



Did we find GeV neutrinos?

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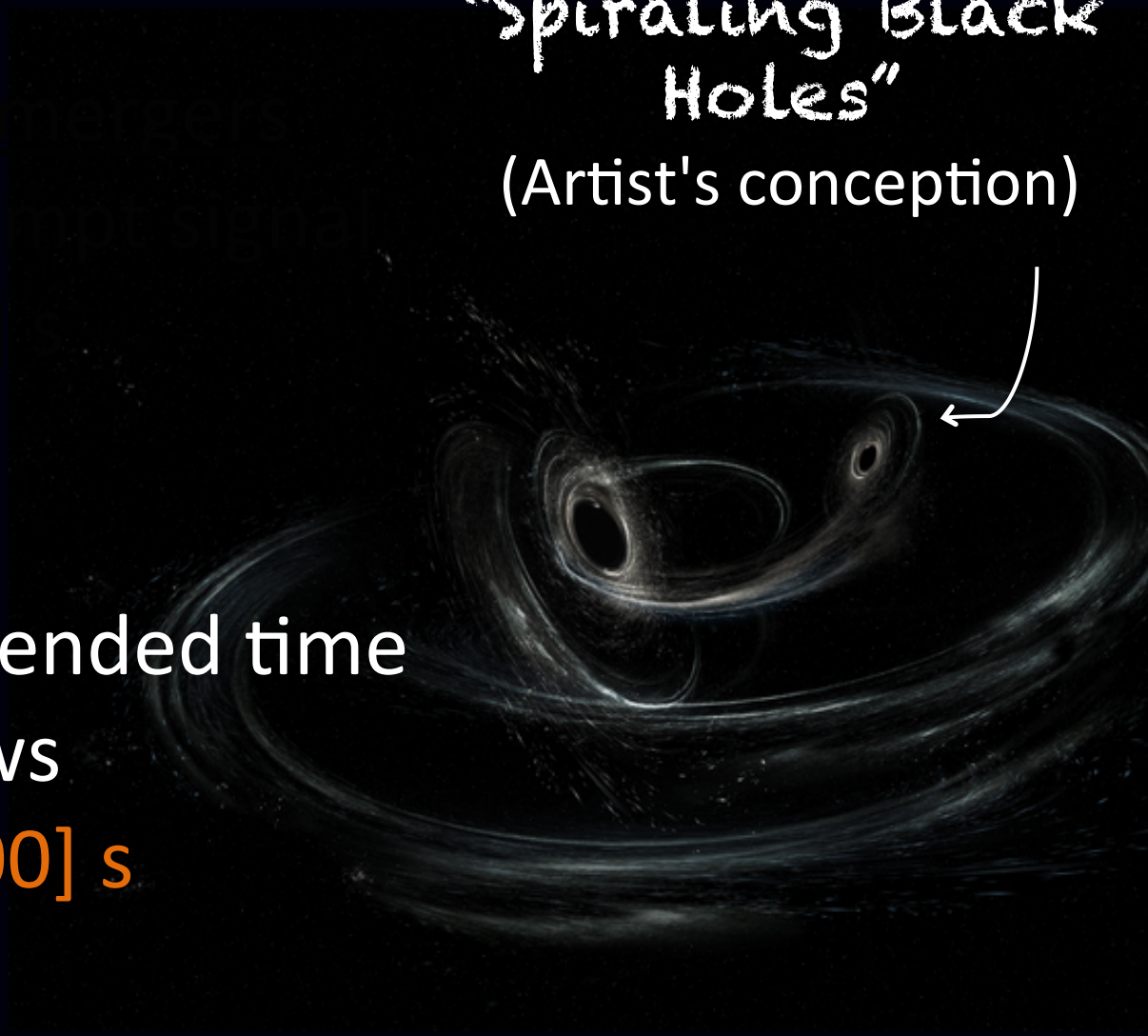
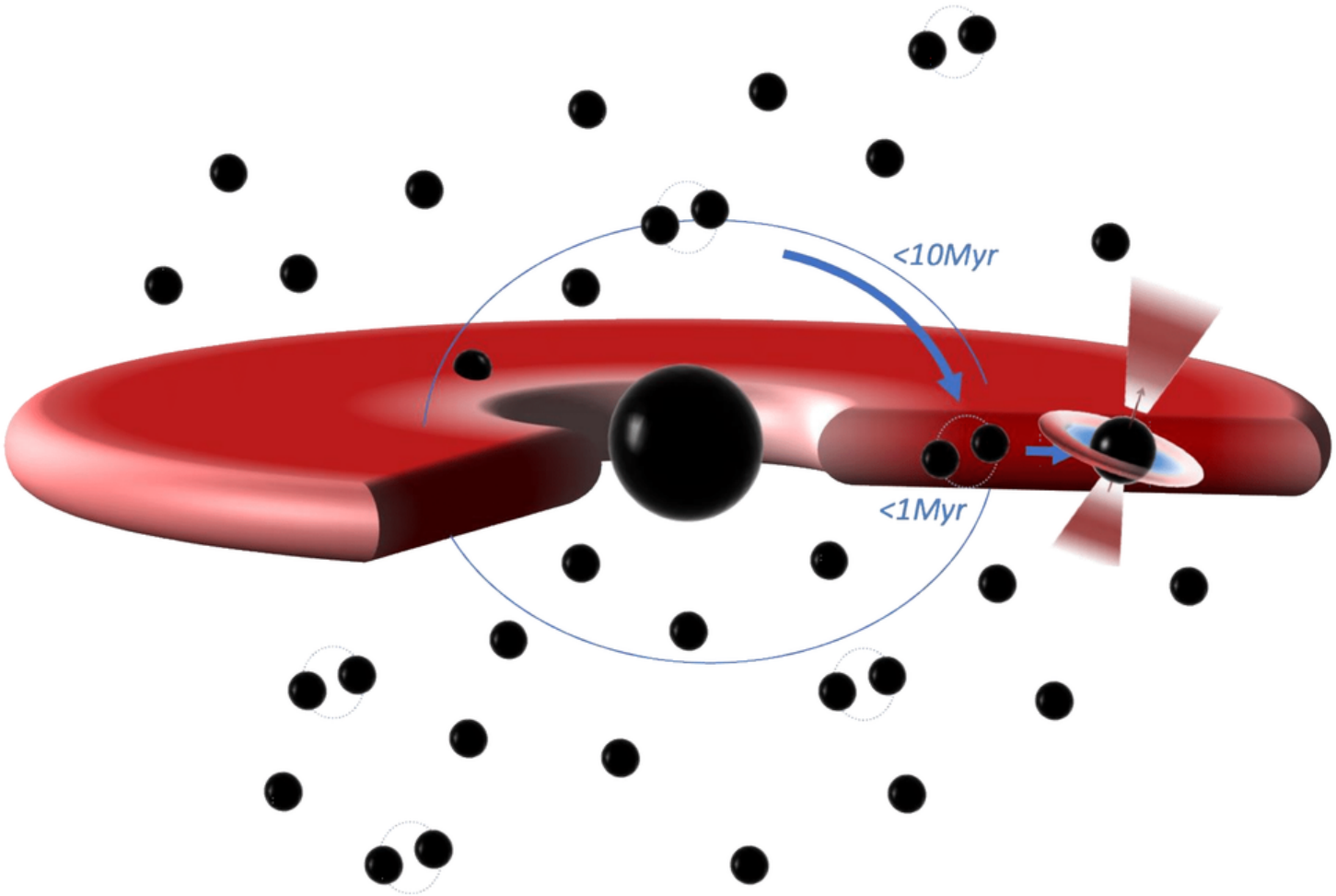
(Artist's conception)

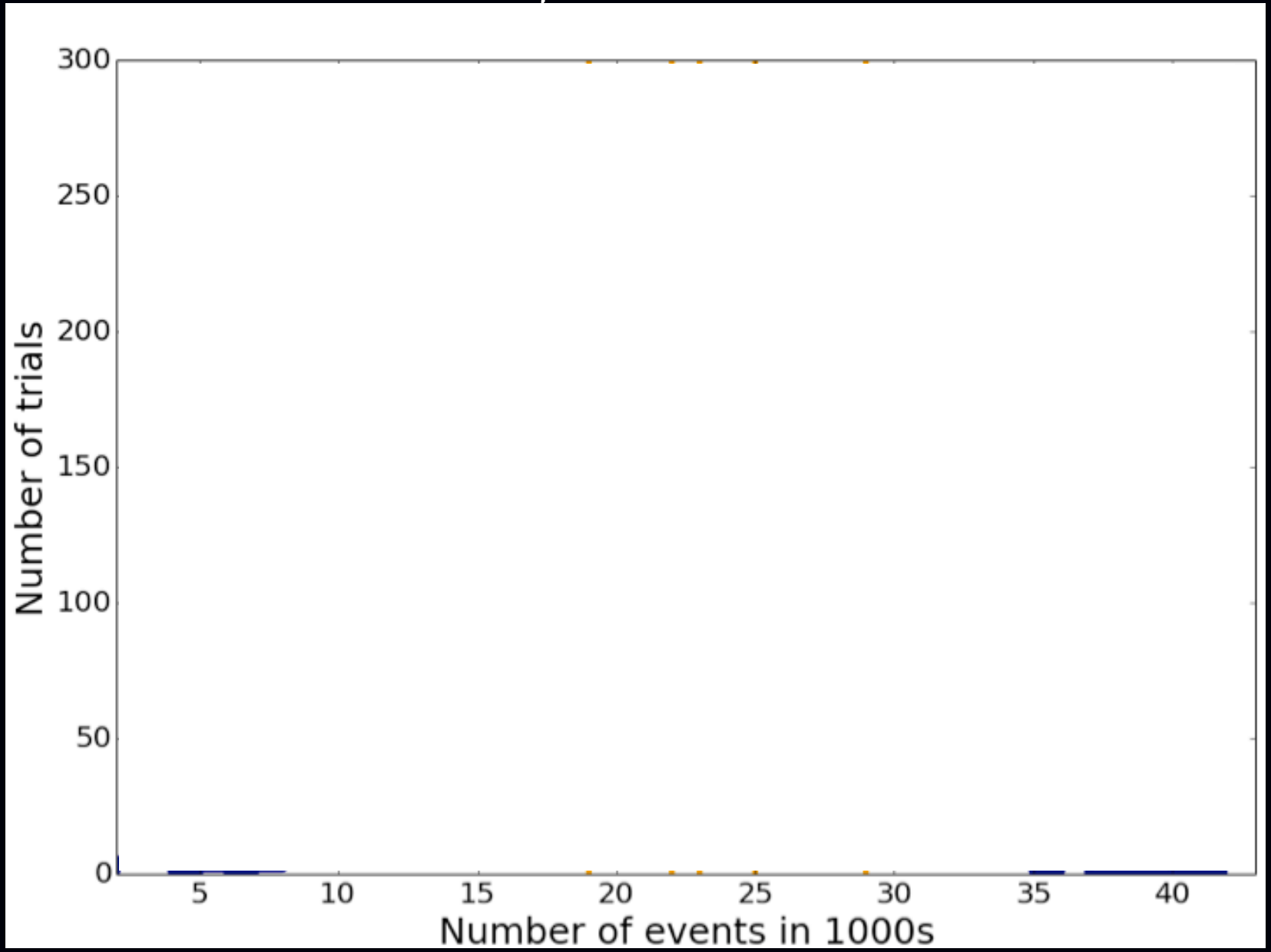


- <u>6 BBH mergers</u>
  Search in an extended time windows
  $[t_0\text{-}500, t_0\text{+}500]$ s



Bartos *et al.*, Astrophys.J. 835 (2017) 165

Did we find GeV neutrinos?



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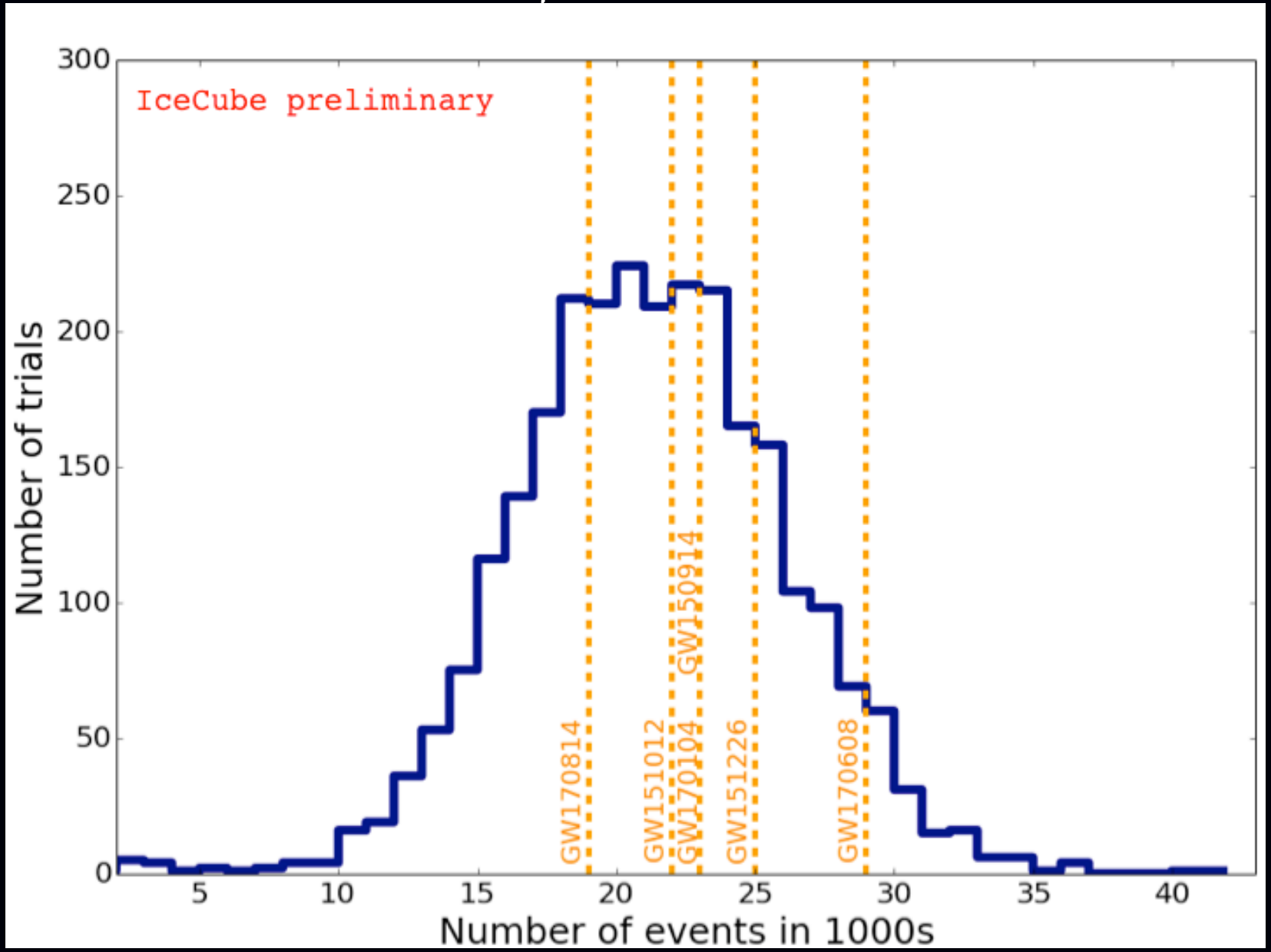

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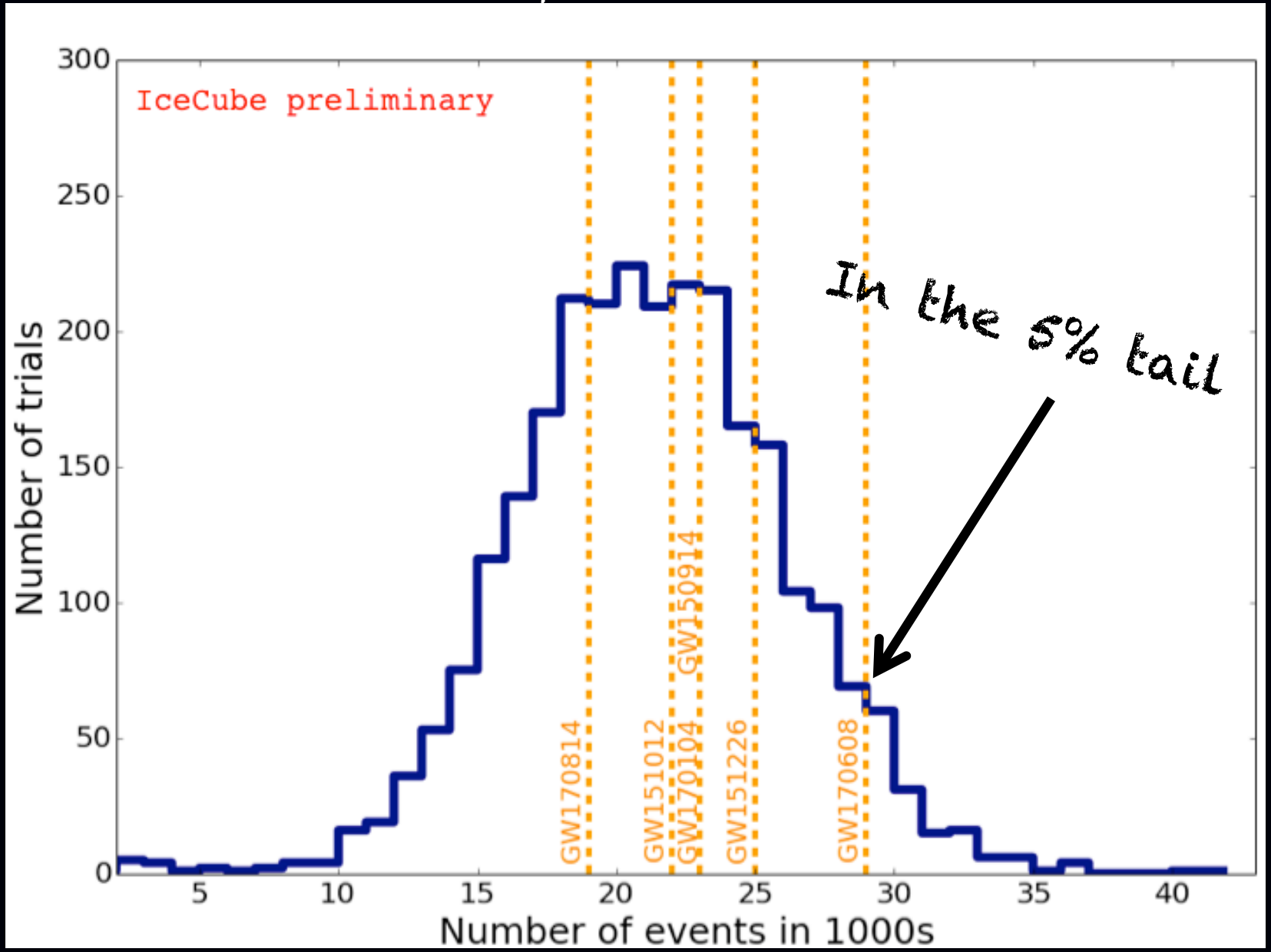


Fermi-LAT counterpart?

//

TITLE: GCN CIRCULAR
NUMBER: 21227
SUBJECT: LIGO/Virgo G288732: Fermi-LAT detection of a weak candidate
DATE: 17/06/08 19:10:16 GMT
FROM: Nicola Omodei at Stanford U <nicola.omodei@stanford.edu>

We have searched data collected by the Fermi Large Area Telescope (LAT) for possible high-energy (E > 100 MeV) gamma-ray emission in spatial/temporal coincidence with the LIGO/Virgo trigger G288732.
At the time of the trigger (T0 = 2017-06-08 02:01:16.492 UTC, 518580081.492 MET), none of the LIGO Bayestar probability map was in the LAT field of view. Part of the region entered the LAT field of view 70 seconds after T0, and we reached 100% cumulative coverage within ~6.5 ks after the trigger. We define "instantaneous coverage" as the integral over the region of the LIGO probability map that is within the LAT field of view at a given time, and "cumulative coverage" as the integral of the instantaneous coverage over time.
We performed a search for a transient counterpart within the 90% contour of the LIGO map in the time window from T0 to T0 + 10 ks, and no significant new sources are found above a Test Statistic (TS) of 25. On this time scale, the highest significance excess found was at R.A.,Dec.=128.11, 43.39, (J2000) with a localization error of 0.24 degrees (90% c.l.), with a TS of 23, corresponding to a pre-trial significance of 4.8 sigma. Given the number of trials involved, the post trial significance of this excess is estimated to be ~3.5 sigma. The location of the candidate was occulted by the Earth at the time of the LIGO trigger, and came into the FoV at ~1200 s after T0.
A Swift ToO observation has been requested to initiate follow-up observations at the location of this candidate source and we encourage additional follow-up observations.

Take-home message

- Search for GeV neutrino counterpart…

  …with IceCube!

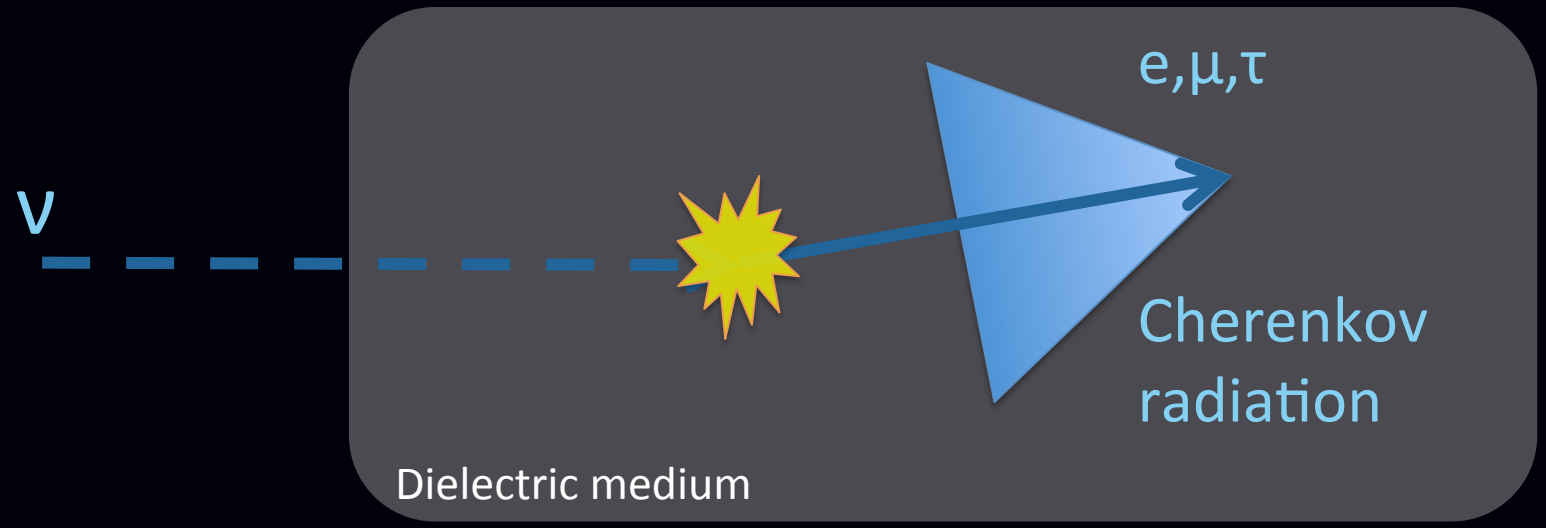
- Two different searches
  - [t, t+3s] for BNS and NSBH
  - [t-500s, t+500s] for BBH

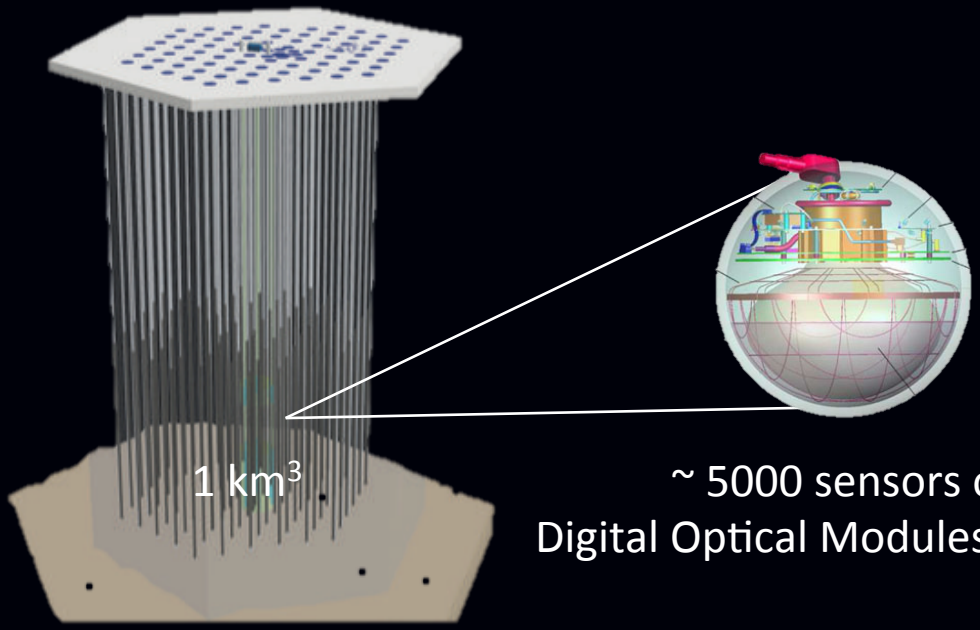
- No significant detection

- Many events in O3
  - Systematic follow-up of BNS and NSBH
  - Stacking analysis for BBH at the end of the run

Thanks!

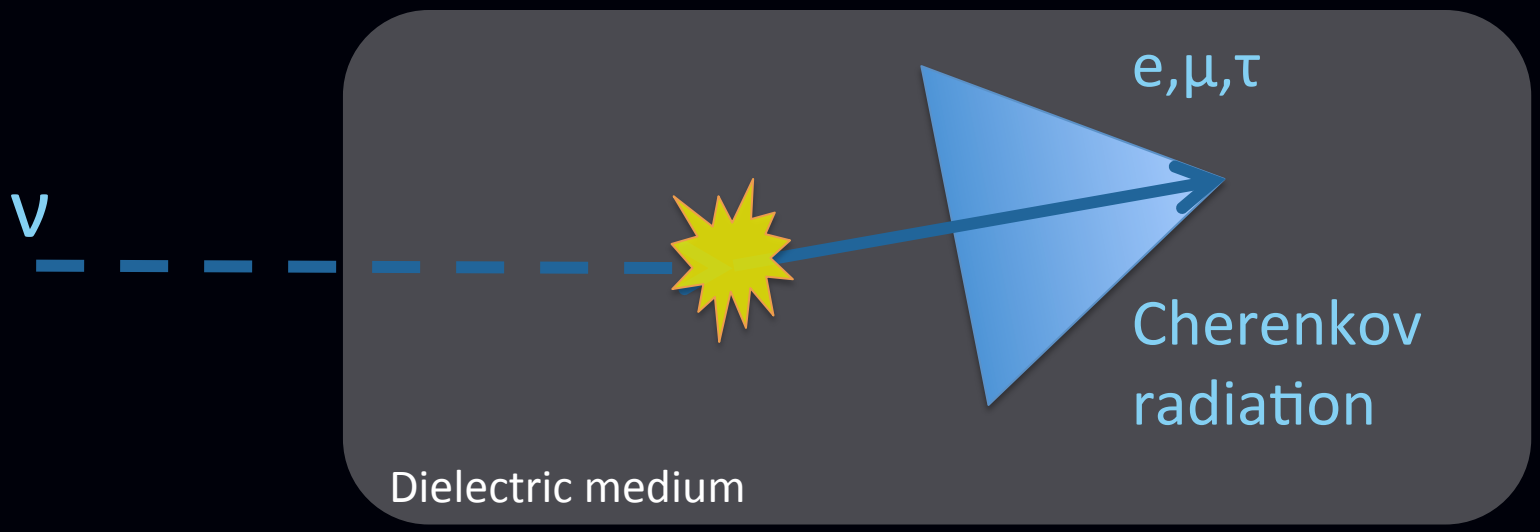
How to detect neutrinos?

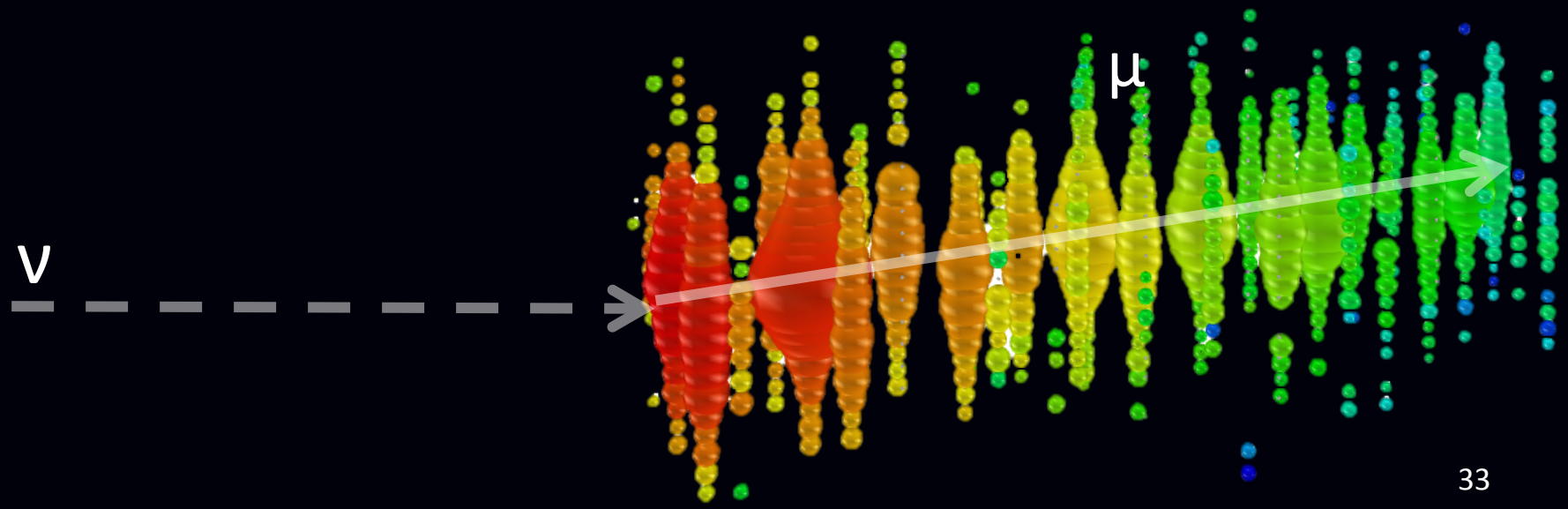


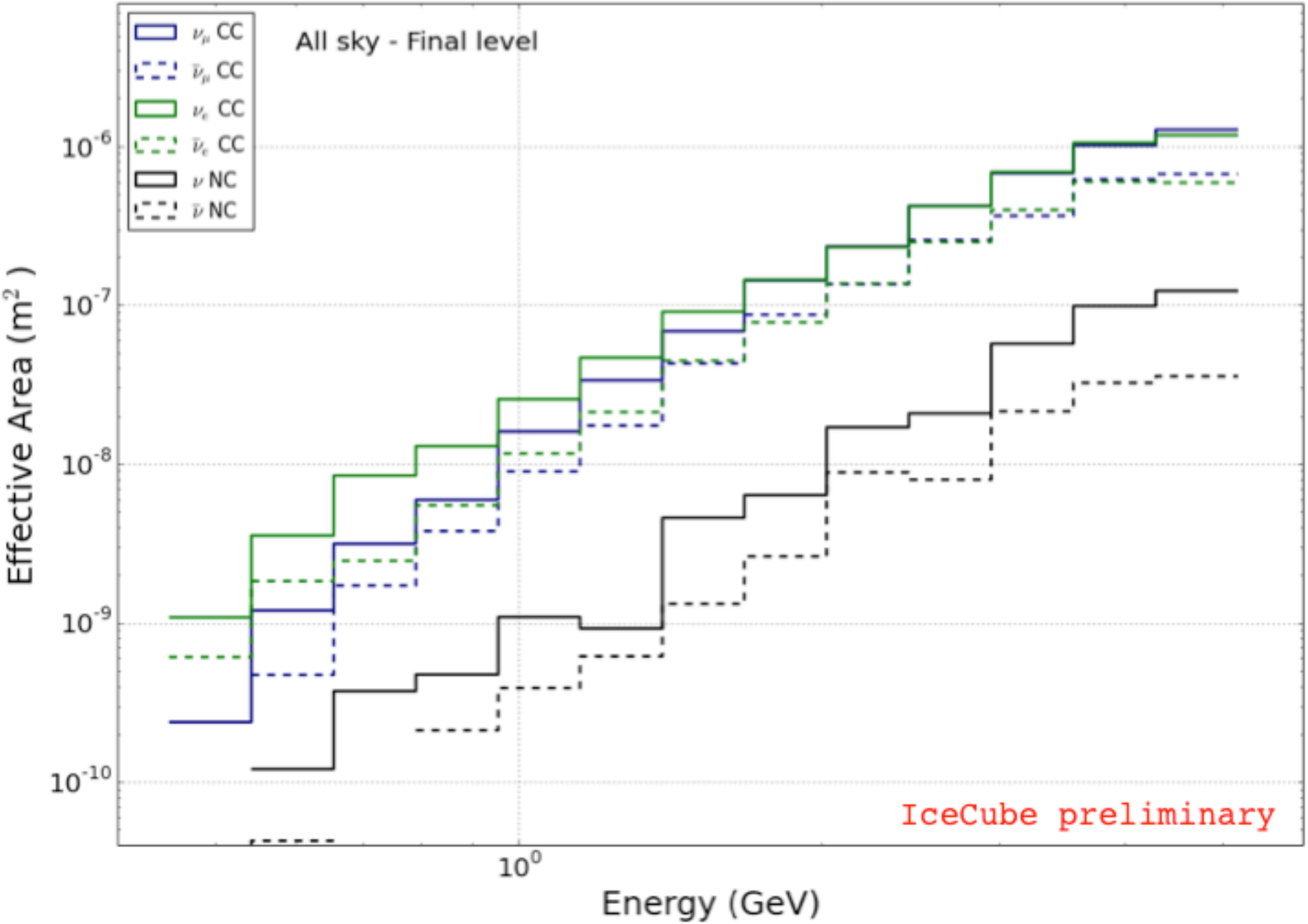


~ 5000 sensors or
Digital Optical Modules (DOMs)

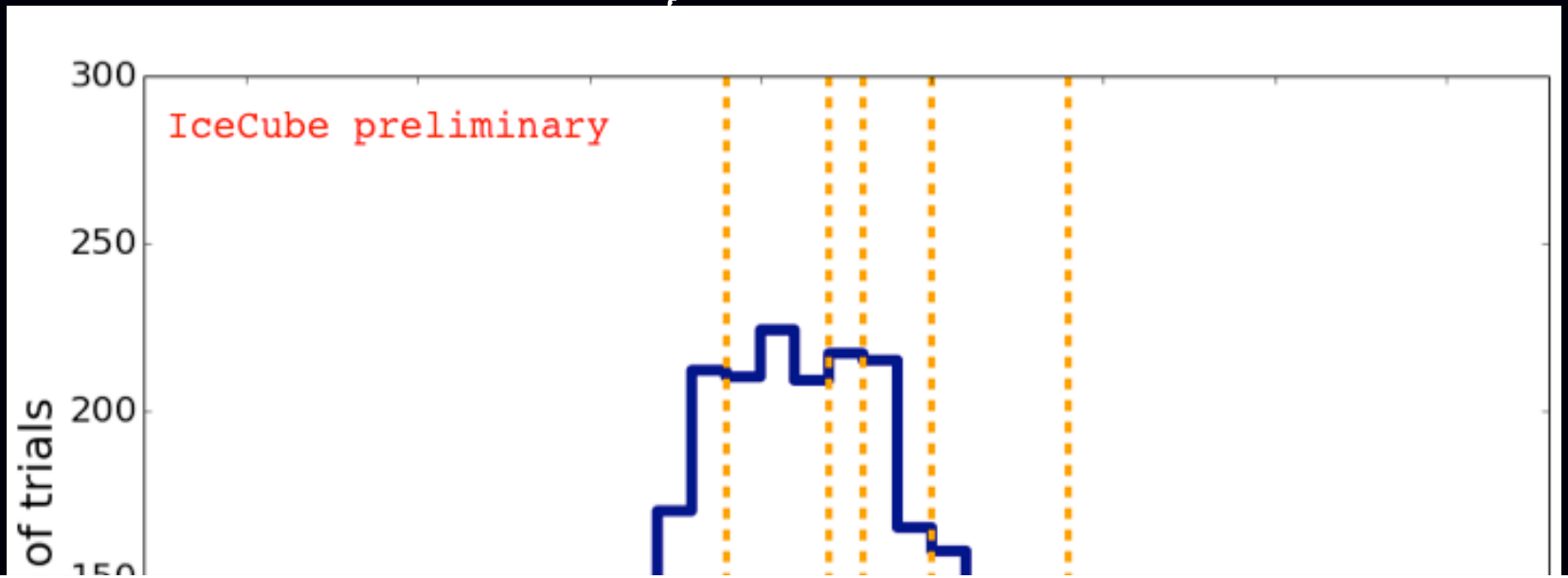
How to detect neutrinos?






All sky - Final level
ν_μ CC
$\bar{\nu}_\mu$ CC
ν_e CC
$\bar{\nu}_e$ CC
ν NC
$\bar{\nu}$ NC
Effective Area (m^2)
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{0}
Energy (GeV)
IceCube preliminary

Did we find GeV neutrinos?



Upper limit on the fluence at Earth:

5×10^4 neutrinos $\mathrm{MeV}^{-1}\,\mathrm{cm}^{-2}$

in the 1000 seconds
integrated over 3 flavours