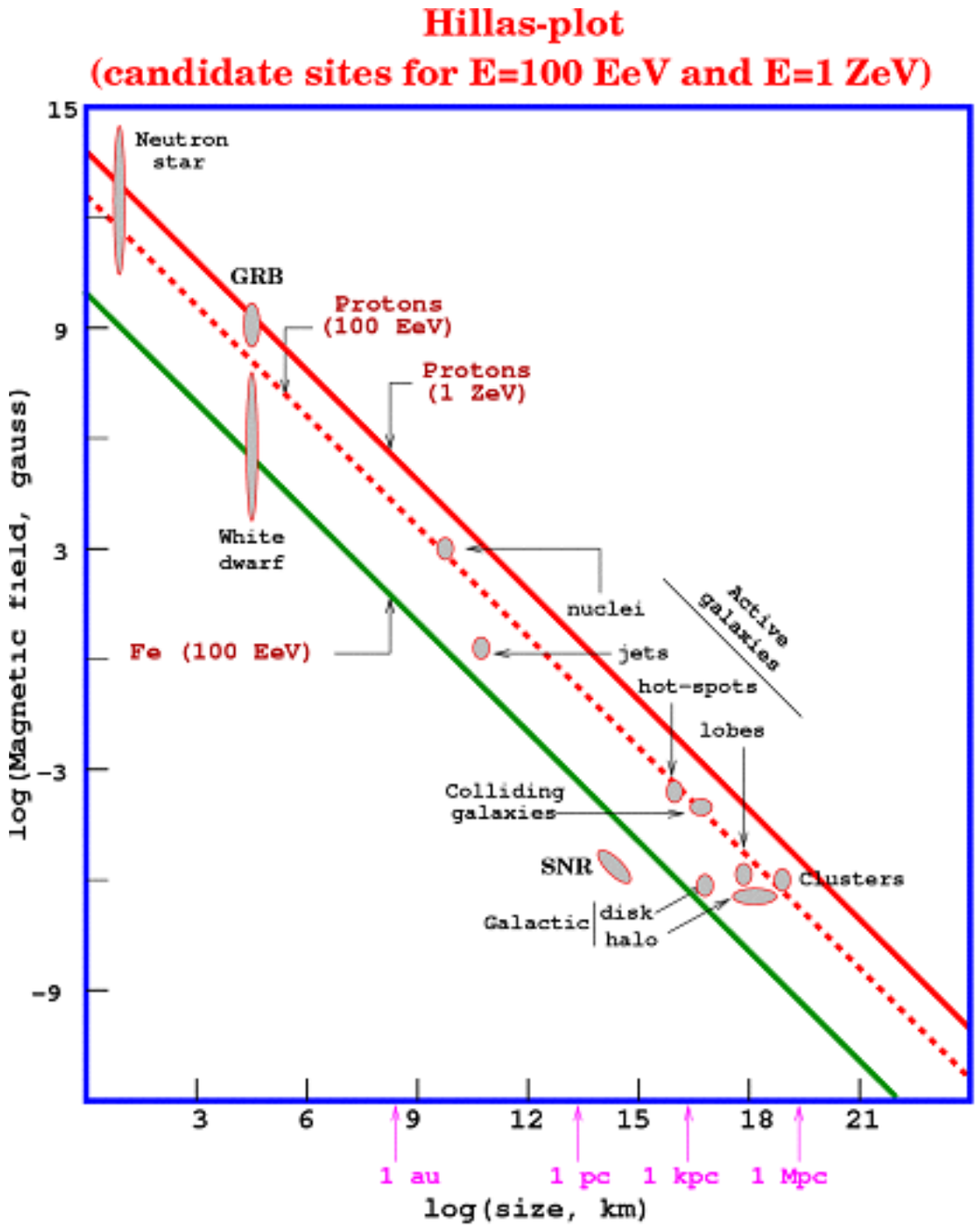
GRB as particle accelerator

D. Dornic, Z. Lee, X.Y. Wang

Context

- GRB seem to be one of the most favorable sources to accelerate CR to UHE
- Quite a lot of work on the acceleration in the relativistic jet (OK up to 10^{20} eV)

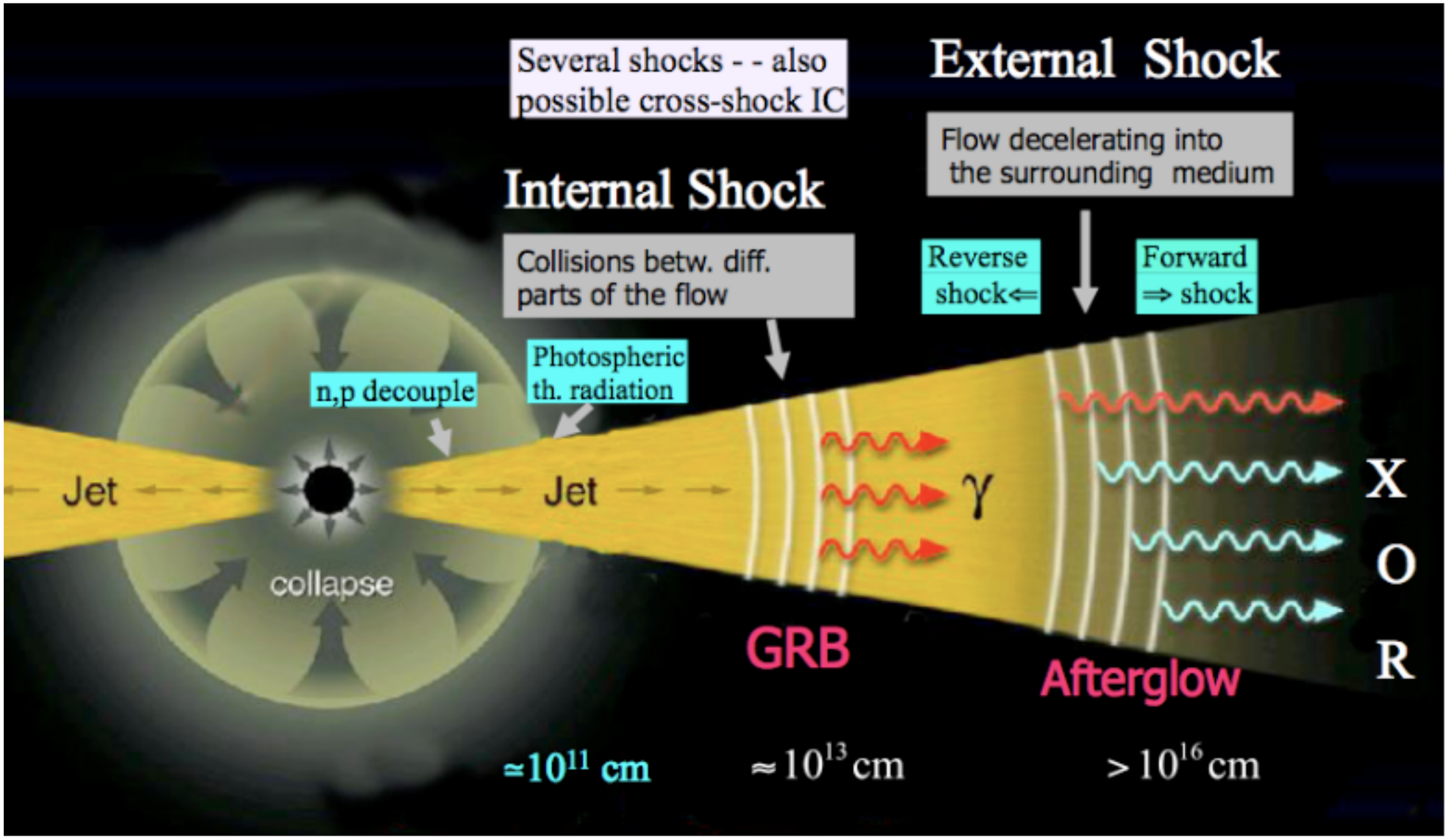
=> The detection of HE neutrinos would be a direct evidence of this hadronic component
=> Even the non-detection will bring serious constrains on the models



Main questions

- Physics of the jets (baryon load, boost factor, magnetization, acceleration processes, central engine…)
- Are GRBs an important sources of cosmic rays? UHECR ?
- GRBs: sources of high-energy neutrinos
- Constrain of the rate of choked GRB in the local universe
- Link with ccSNe/GRB
- More surprise on galactic/extragal Pevatrons

Introduction



$$p+\gamma \xrightarrow{\Delta^+} \begin{cases} p+\pi^0 \\ n+\pi^+ \end{cases} \rightarrow \underline{\langle x_{p\to\pi}\rangle} \sim 20\%$$

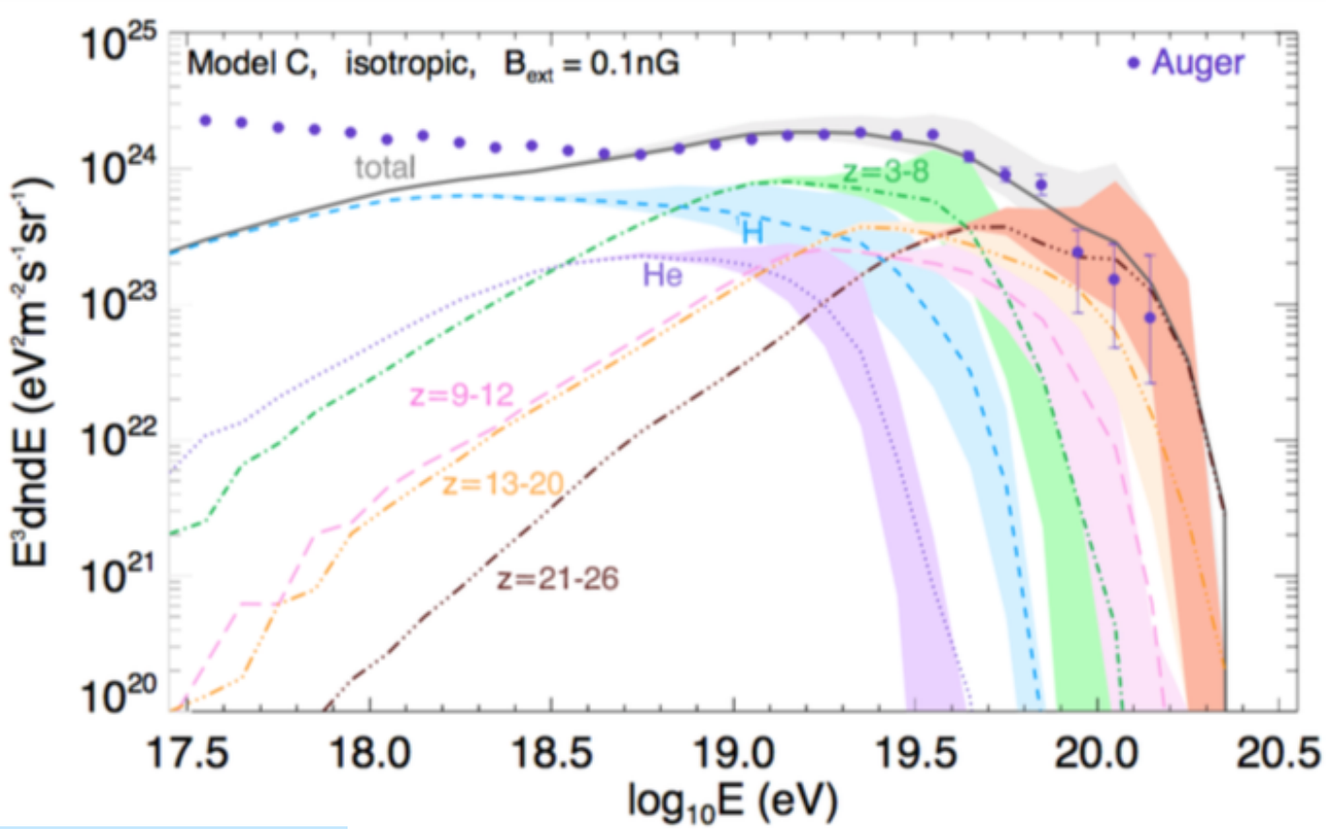
$$\pi^0 \longrightarrow \gamma+\gamma$$
$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \longrightarrow e^+ + \nu_e + \overline{\nu}_\mu$$
$$n \longrightarrow p^+ + e^- + \overline{\nu}_e \,.$$

$$p+\gamma \longrightarrow K^+ + \Lambda/\Sigma$$
$$K^+ \longrightarrow \mu^+ + \nu_\mu$$
$$\pi^- \longrightarrow \mu^- + \overline{\nu}_\mu$$
$$\pi^- \longrightarrow \mu^- + \overline{\nu}_\mu$$
$$\mu^- \longrightarrow e^- + \overline{\nu}_e + \nu_\mu$$

UHECR / GRB

Main ingredients of the model:

- Internal shock scenario (target photon SED)
- Fermi acceleration
- Mix-composition of the CR
- Propagated spectrum in the ISM
- Standard GRB population



Assumptions

$\varepsilon_e \ll 1$

$\varepsilon_B \sim 0.33$

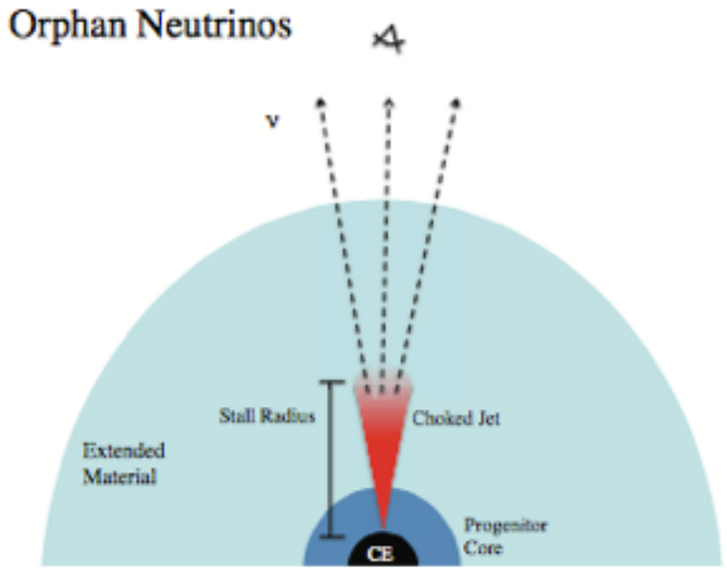
$\varepsilon_{CR} \sim 0.66$

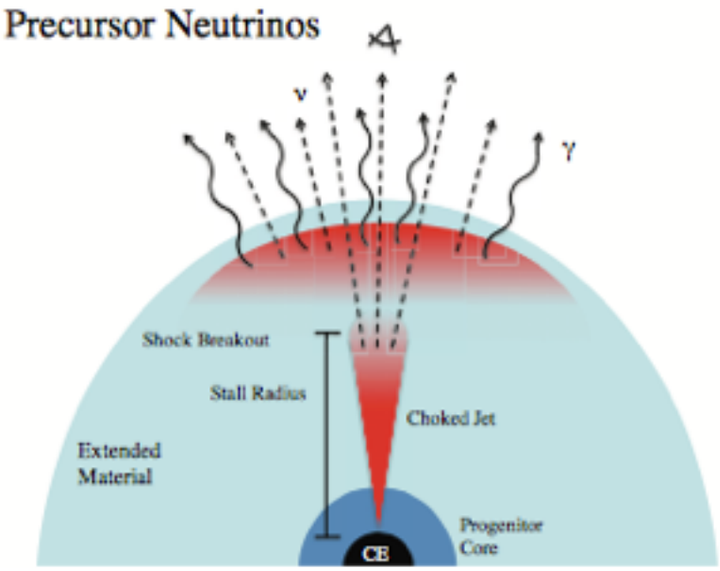
Important effort in Auger & TA
more events, better composition determination

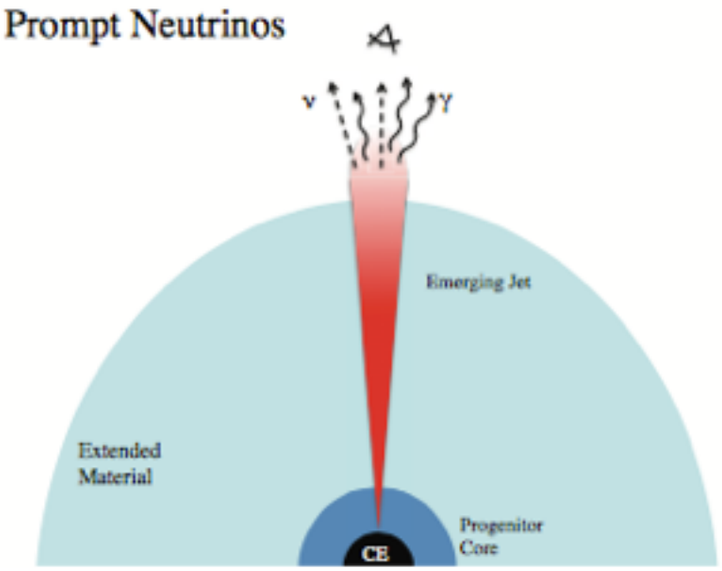
N. Globus, D. Allard, R. Mochkovitch, E. Parizot, MNRAS, 2015

Production of neutrinos

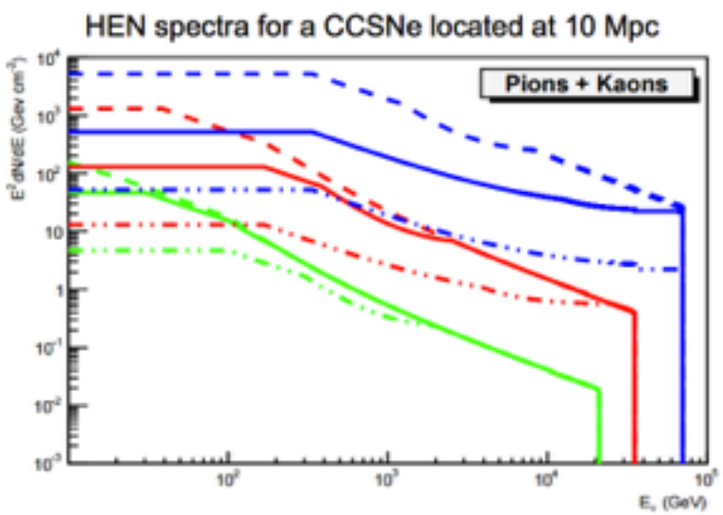
CR acceleration in the jets
+ interaction with photon/matter } Production of HE neutrinos and HE gamma-rays



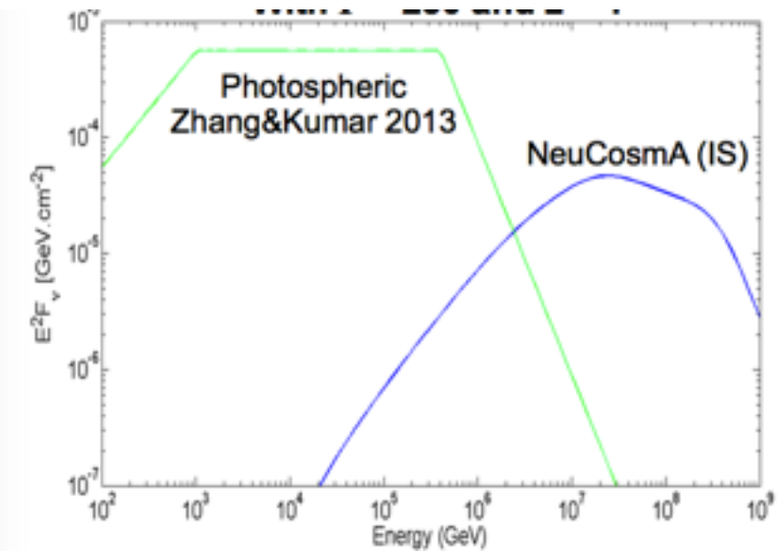




~100 GeV-10 TeV



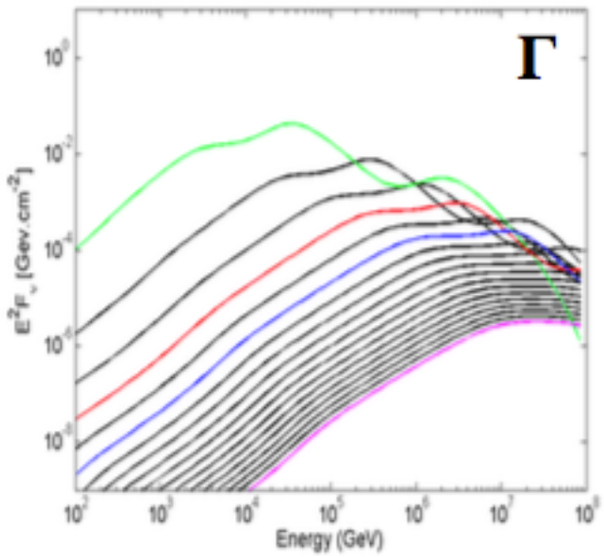
~50 TeV-100 PeV

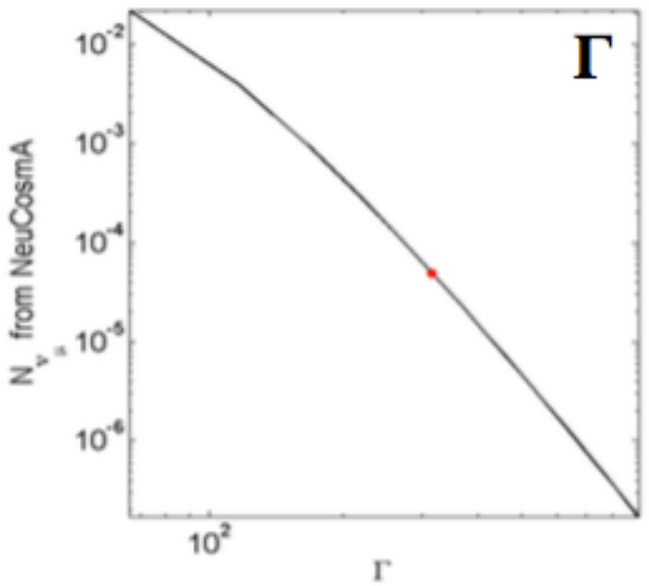


Production of neutrinos

Impact of f_p / Γ and $\varepsilon_e/\varepsilon_B$ on the prompt IS neutrino spectrum

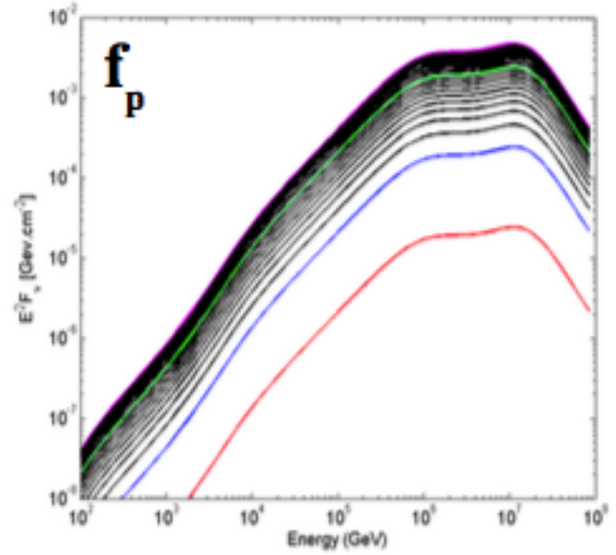
60 → 900

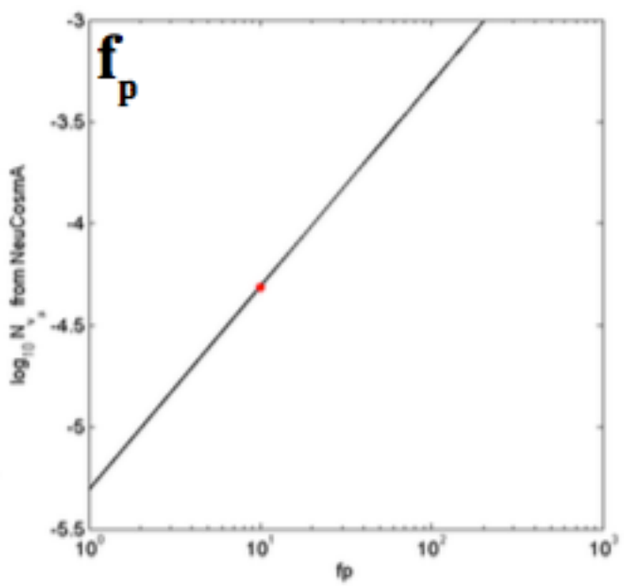




~5 orders of magnitude on the neutrino expectations

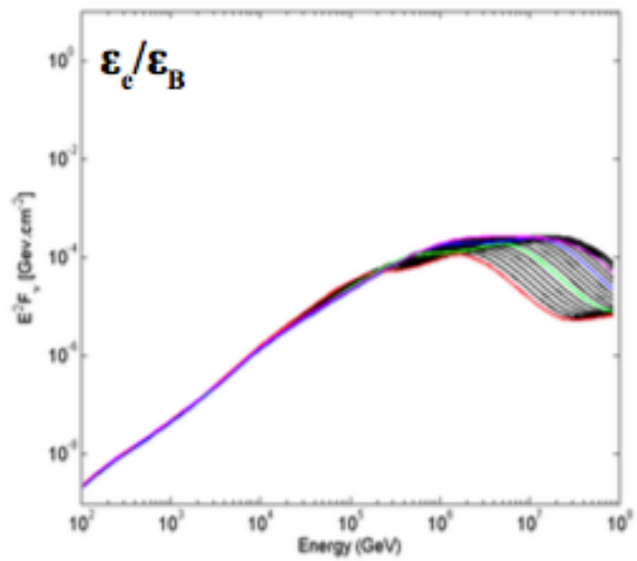
1 → 200

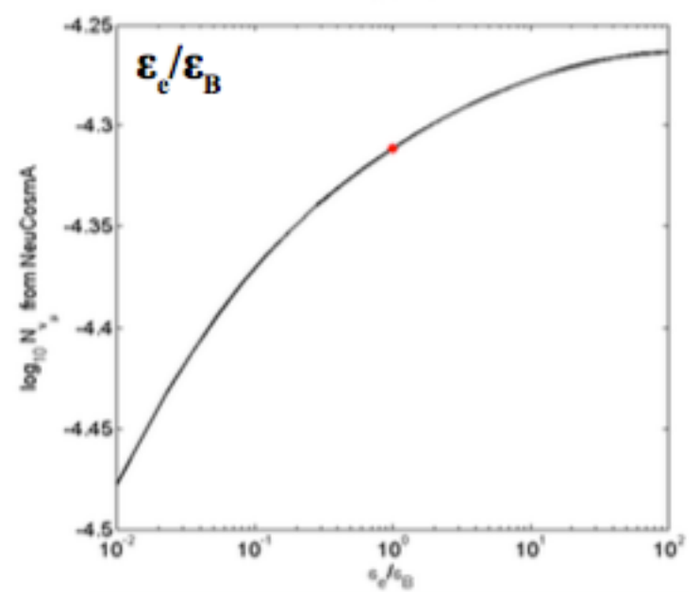




~2 orders of magnitude on the neutrino expectations

0.01 → 100

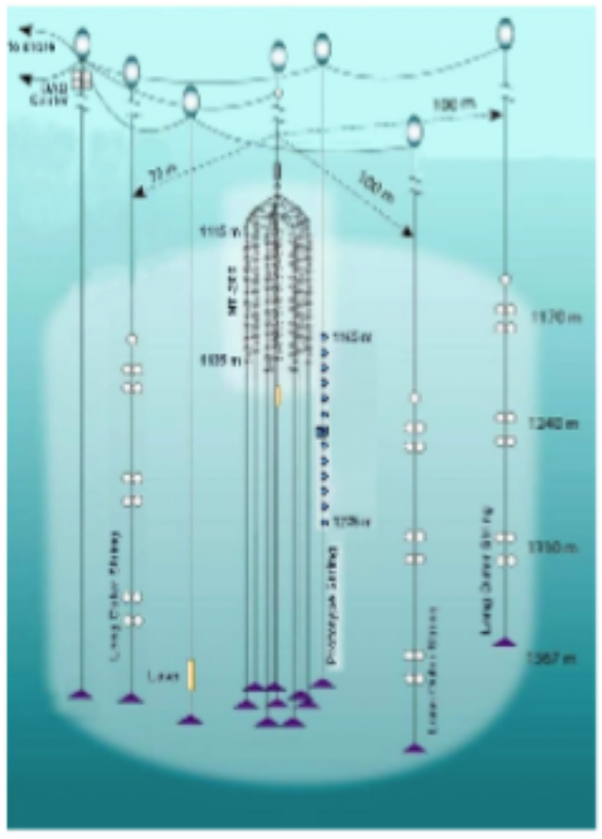




Negligible impact on the neutrino expectations

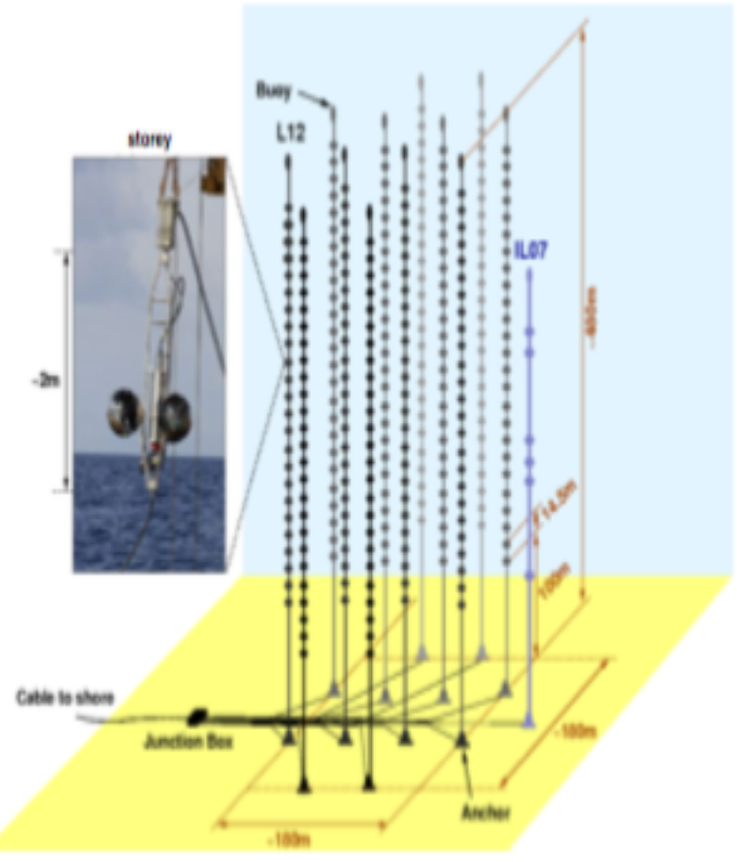
Neutrino telescopes in the world

NT-200+



Lake Baikal
1/2000 km3
228 PMTs

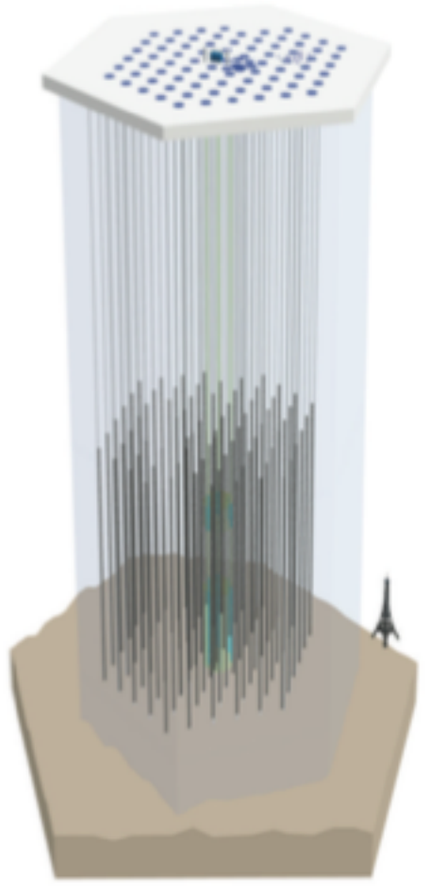
Antares



Mediterranean Sea
1/100 km3
885 PMTs

Upgrade: KM3NeT (2015-202X)

IceCube



South Pole glacier
1 km3
5160 PMTs

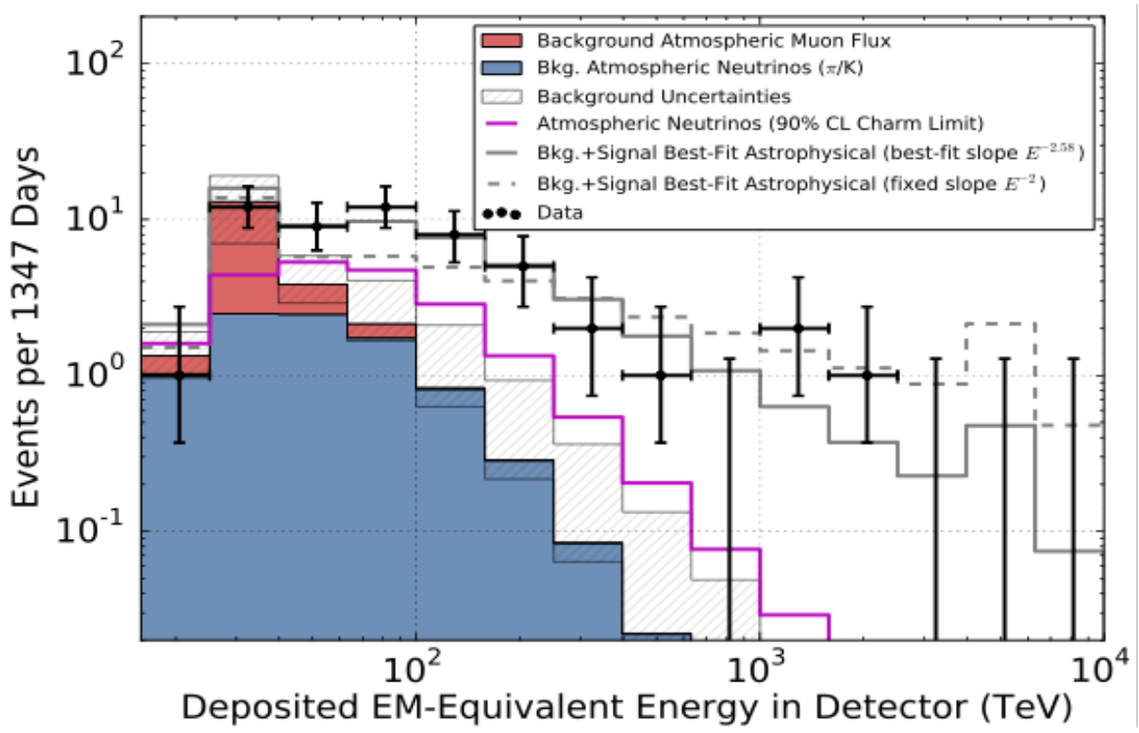
IceCube Gen 2 (202X-2035)

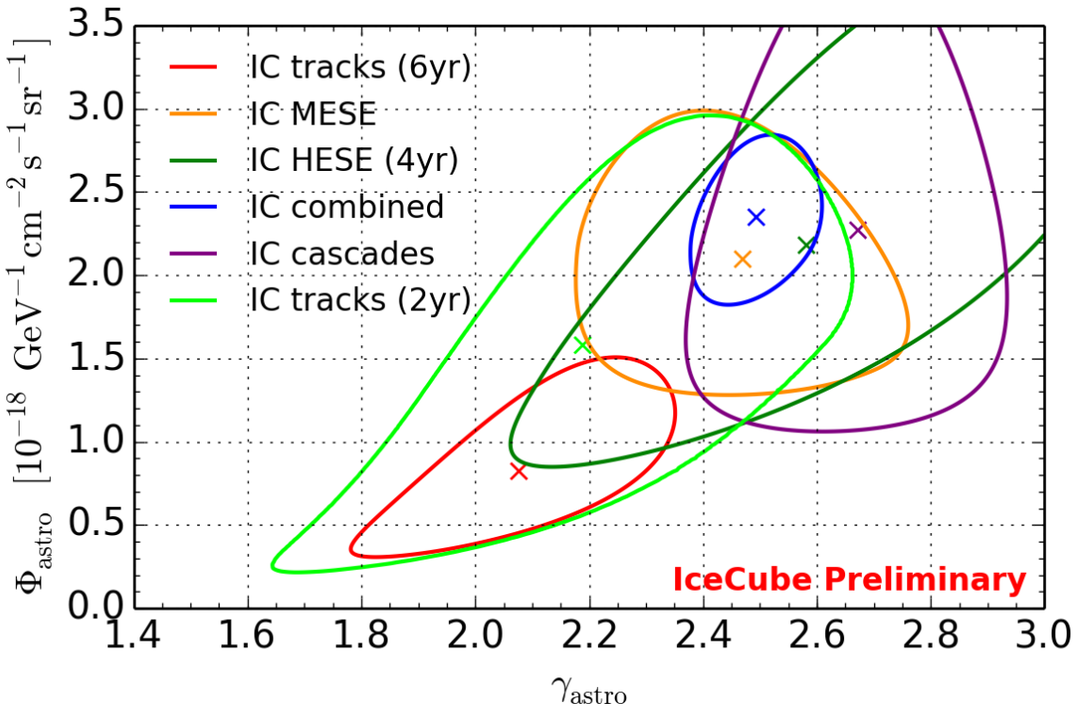
First HE astro signal

4 year HESE analysis (ICRC 2015)

53 events -> 5.7 sigma
Eth = 60 TeV

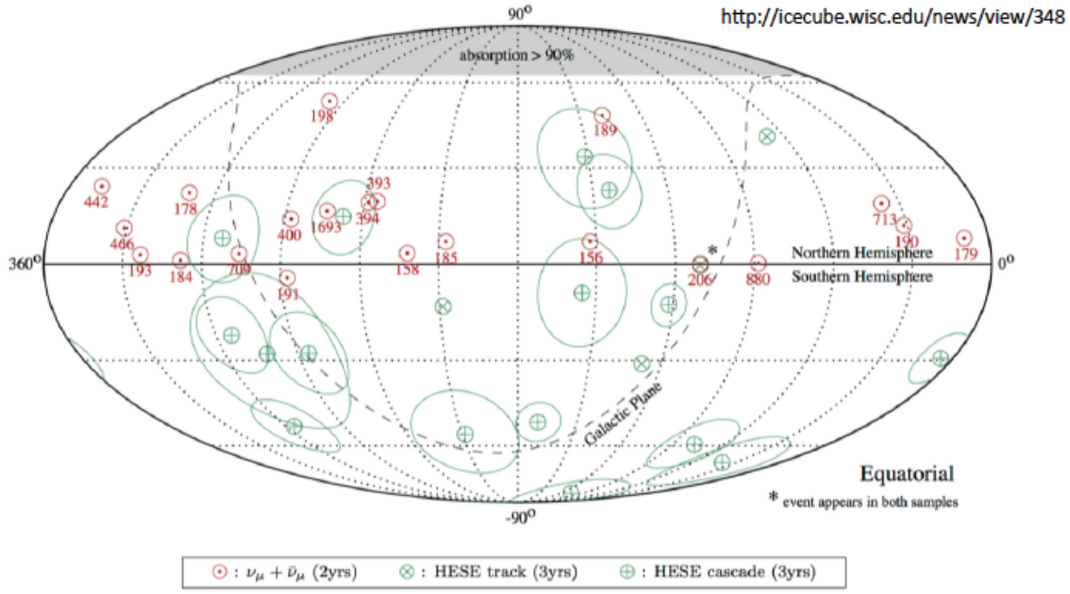
Best fit spectral index: -2.58





Only highest energy events are shown.

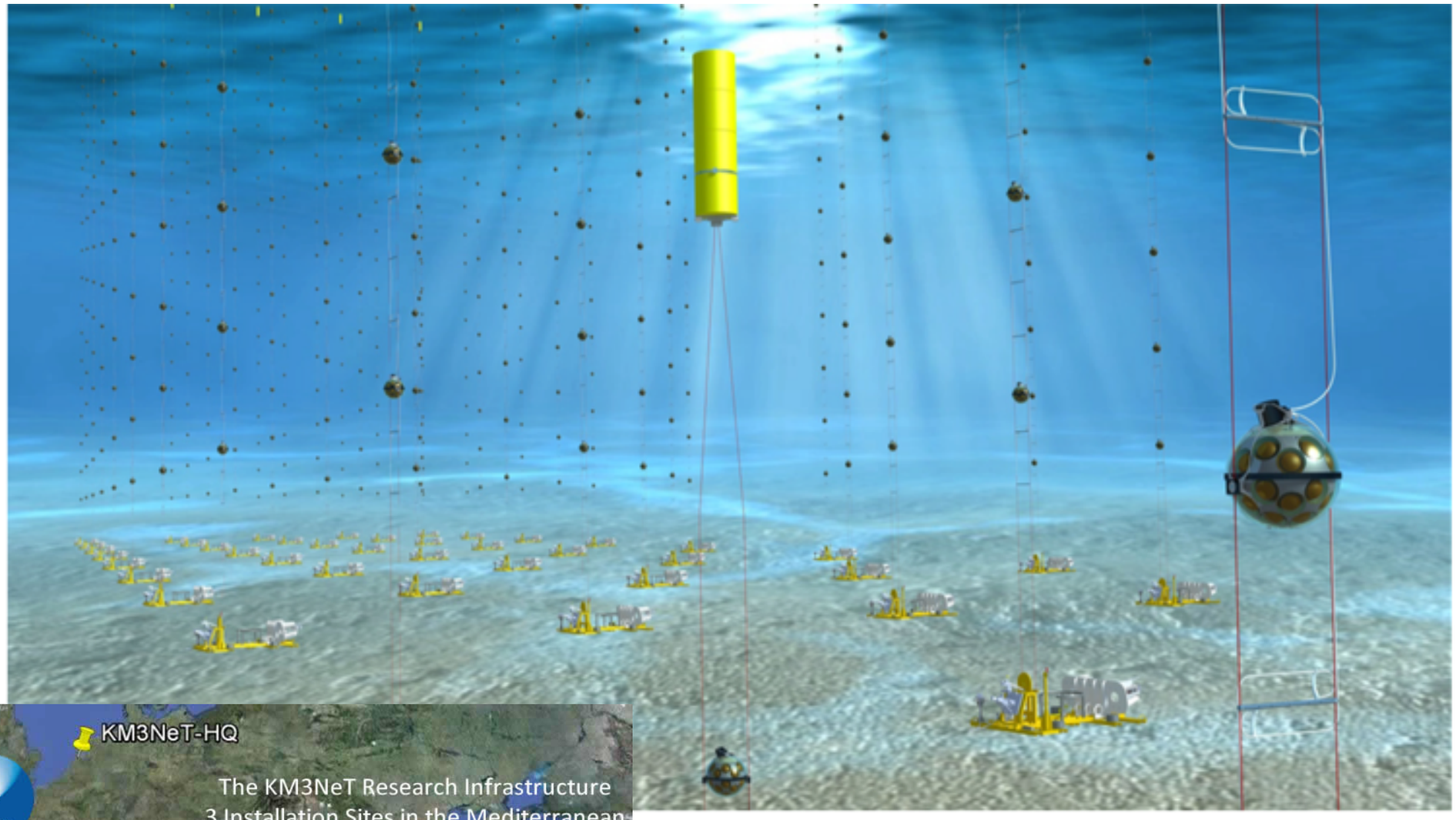
Most of these events are of astrophysical origin.

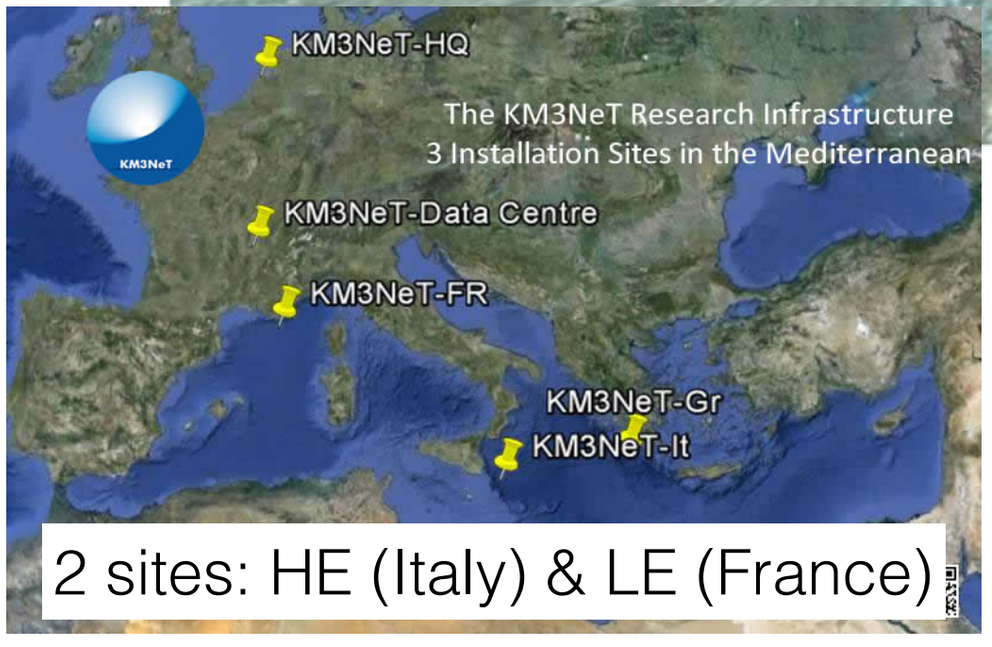


KM3NeT

KM3NeT is a distributed research infrastructure with 3 main science topics:

- The origin of cosmic neutrinos (high energy)
- Measurement of fundamental neutrino properties (low energy)
- Deep Sea Observatory: Oceanography, bioacoustics, seismology

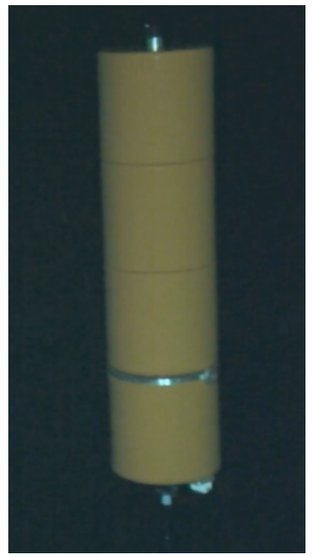




Phase	Total costs (cumulative) M€	Primary deliverables
1	31	Proof of feasibility and first science results;
2.0	125	Study of the neutrino signal reported by IceCube; Determination of the neutrino mass hierarchy;
3	220–250	Neutrino astronomy including Galactic sources;

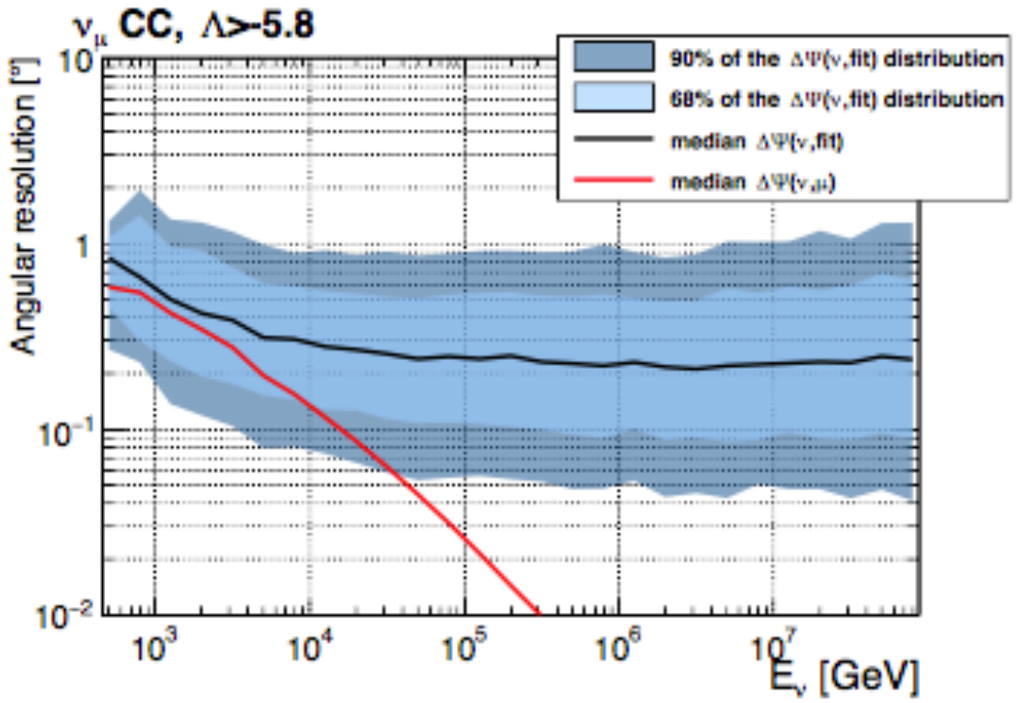
KM3NeT

2014-5: construction of the 2 infrastructures
1st string deployed Dec 2015 in Italy
May 2016: +2 strings in Italy
June 2016: +2 strings in France



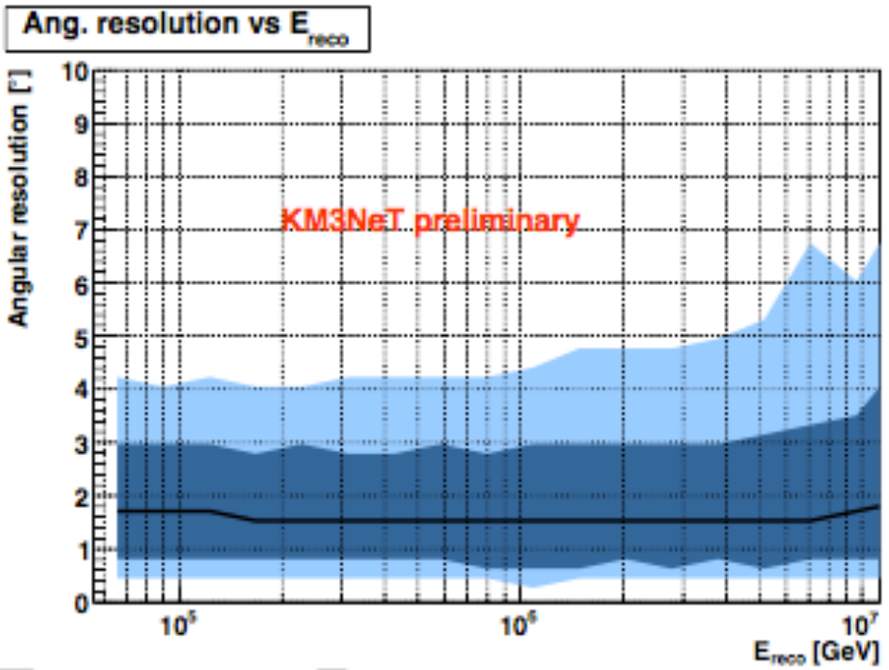
KM3NeT

Track channel

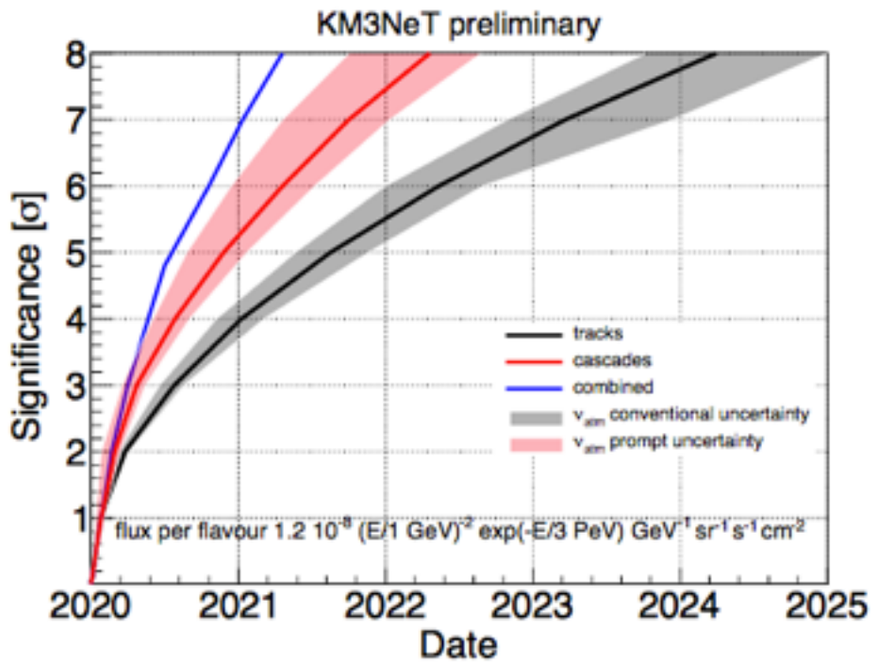


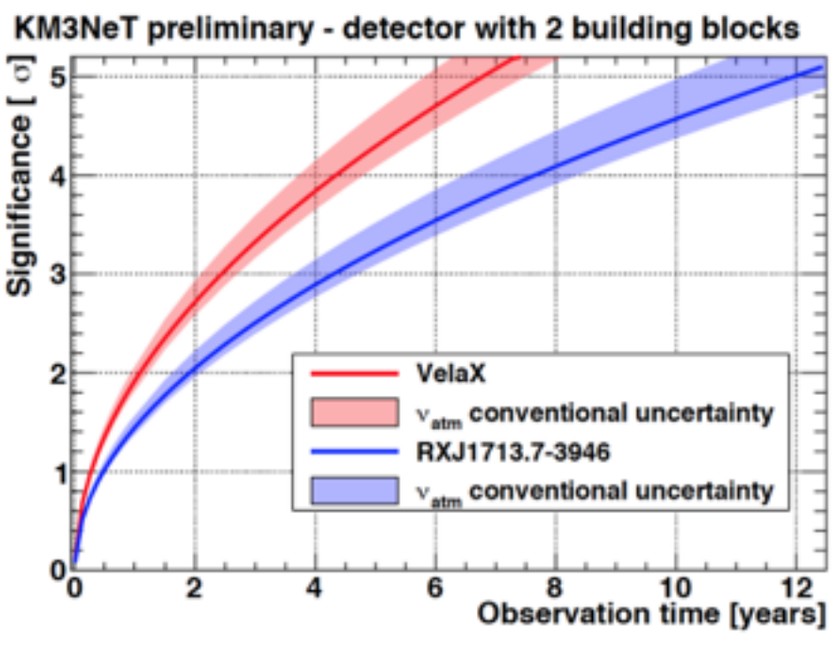
IceCube: 0.5°

Cascade channel

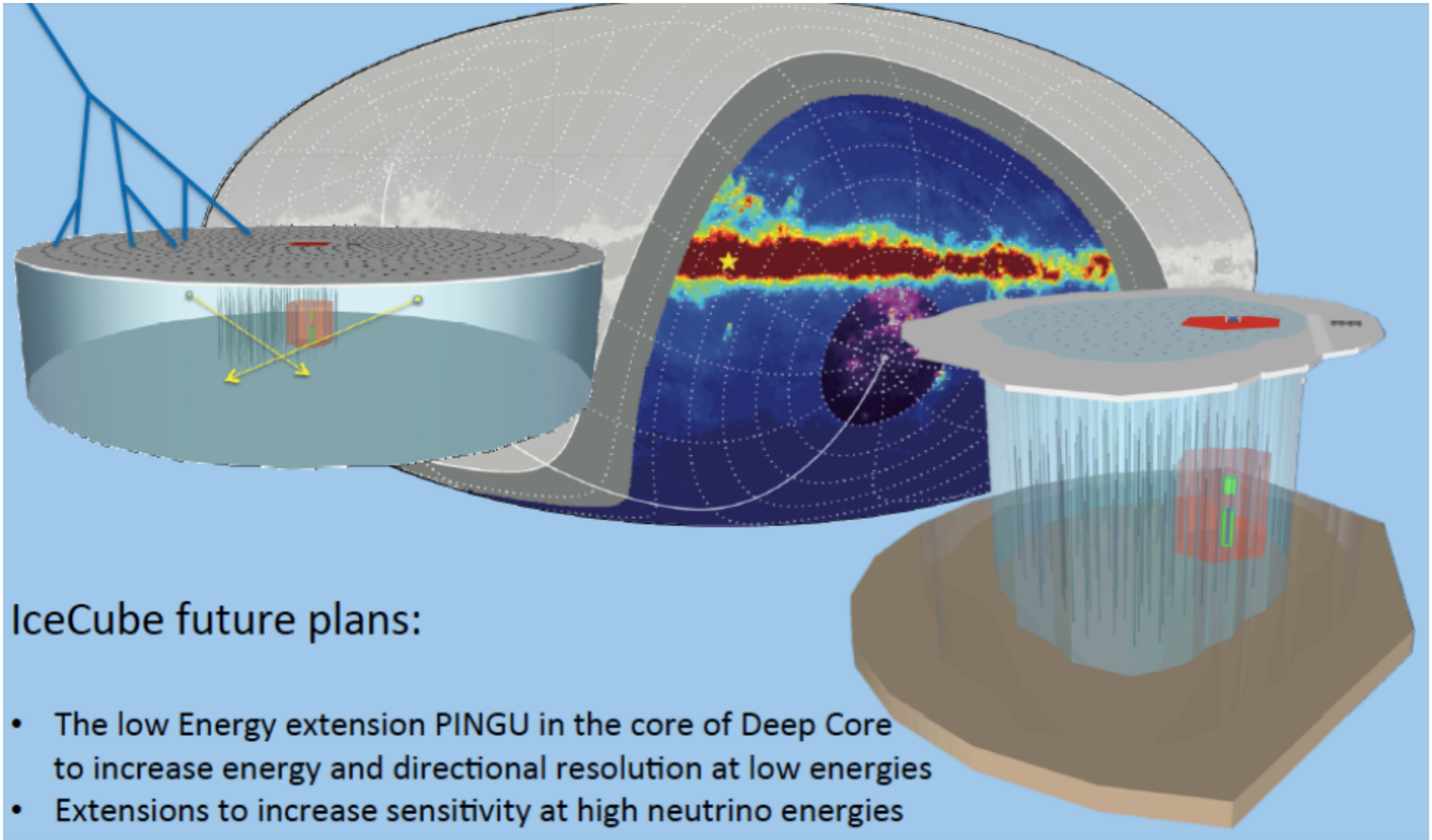


IceCube: 15°





IceCube Gen 2



IceCube future plans:

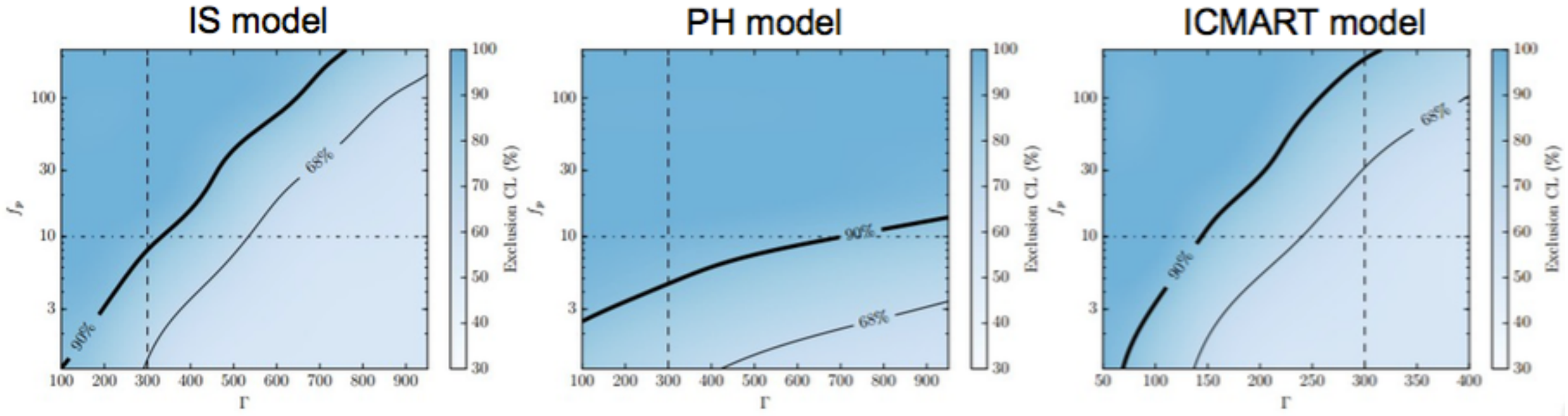
- The low Energy extension PINGU in the core of Deep Core to increase energy and directional resolution at low energies
- Extensions to increase sensitivity at high neutrino energies

No construction before 2020 (funding process)

Neutrinos @ GRB

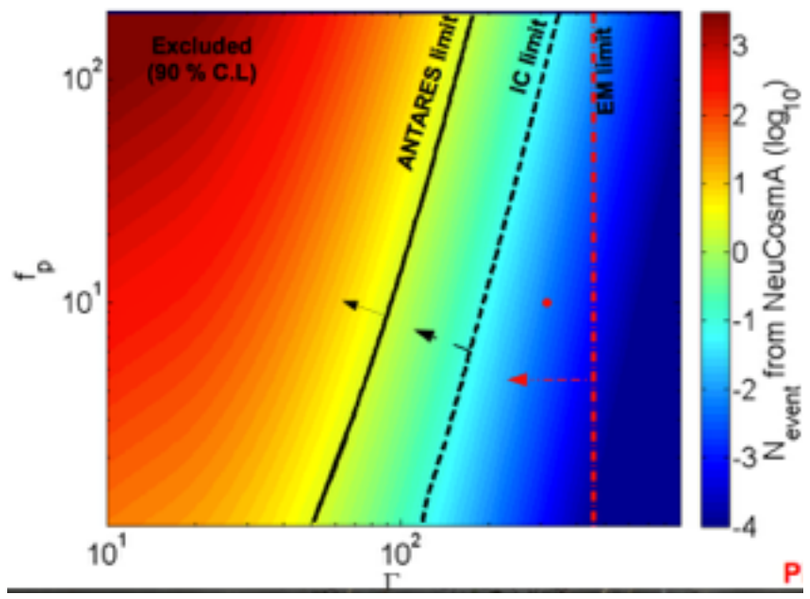
Extensive searches in ANTARES and IceCube since 10yrs
=> No detection yet, constrains on model

IceCube constraints (807 stacked GRBs)



=> This non-detection suggests that this standard GRB population is not the major contribution to the diffuse HEN flux

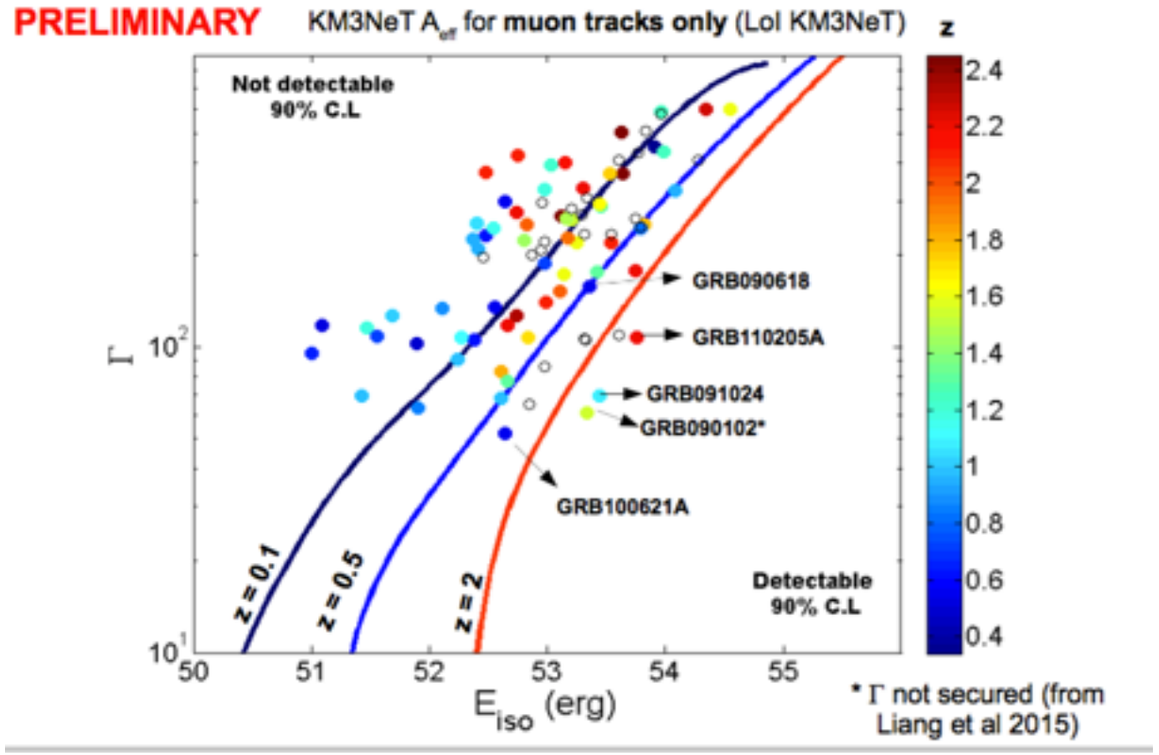
ANTARES/IceCube constraints (GRB130427)



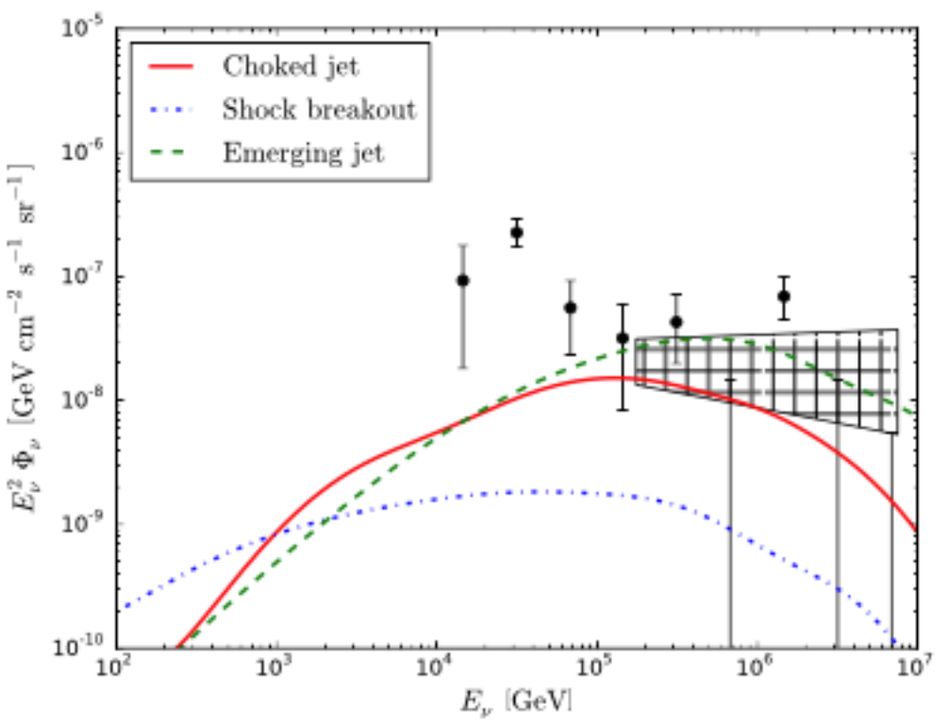
Other GRB populations

Which GRB is needed?

- Low boost factor
- Quite close
- Very dense region (more target)



Low-luminosity GRB => more numerous + lower power jet (stacked neutrino searches)
Dirty GRB, chocked jets => denser environment (p-y & p-p)

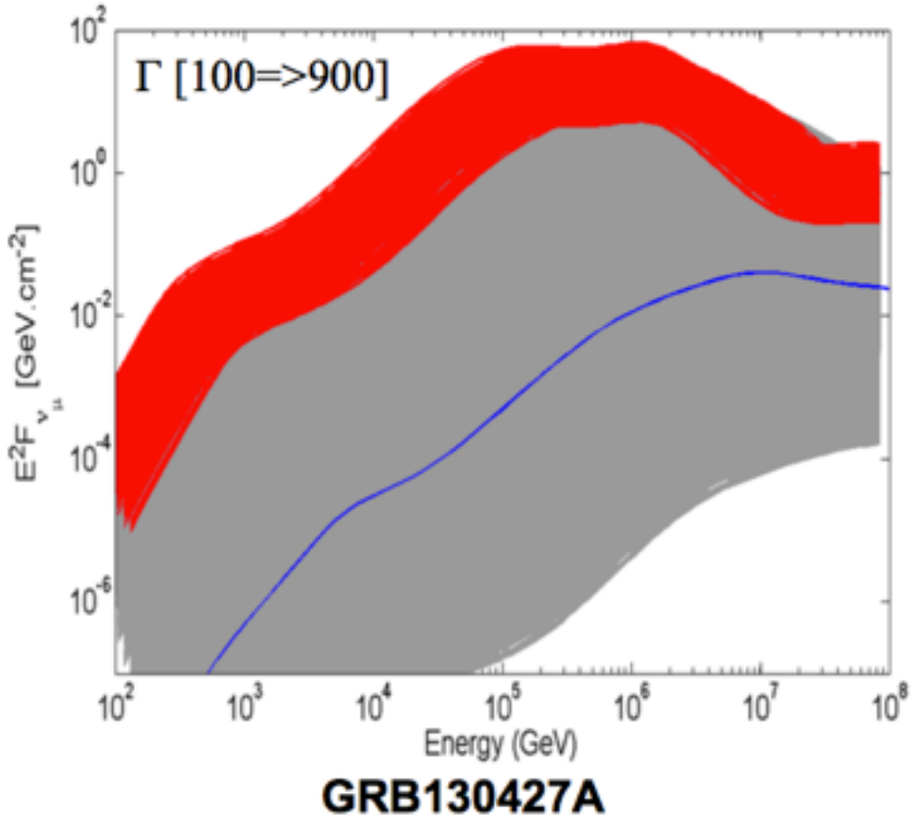


=> 4 keV ECLAIRs threshold
+ECLAIRs trigger

Better GRB measurements

For the neutrino spectrum parametrization, we need a better coverage of the GRB parameters:

- redshift
- full prompt spectrum
- detailed prompt LC (time variability)
- early afterglow LC (estimation of the boost)…



Up to now, several orders of magnitude uncertainties !!!

SVOM: multi-wavelength coverage
+ good synergy ground/space

Neutrino telescopes <=> SVOM

<u>In practice:</u>

-> SVOM sends GRB alerts to the neutrino telescopes
(On/off-line searches in time/space coincidence)

<- Neutrino telescopes will send ToO alerts to SVOM
(single VHE events, multiplet…)

This strategy is active within ANTARES/IceCube / Swift

(C. Lachaud)

Summary: multi-messenger astronomy

- First detection of cosmic HE neutrinos in 2012 by IceCube. Even if no source identification, serious constraints on hadronic models.

- Neutrino telescopes: IceCube will be operational in the next decade (Gen 2, will probably arrive in fall). ANTARES will be stopped next year and KM3NeT is joining the game very soon.

- A lot of effort in the phenomenology (acceleration, jet composition, radiative processes, microphysics…)

- SVOM: provide GRBs alerts (better measurement, new populations?) and be an efficient partner for the follow-up of VHE neutrinos

Text for the white paper