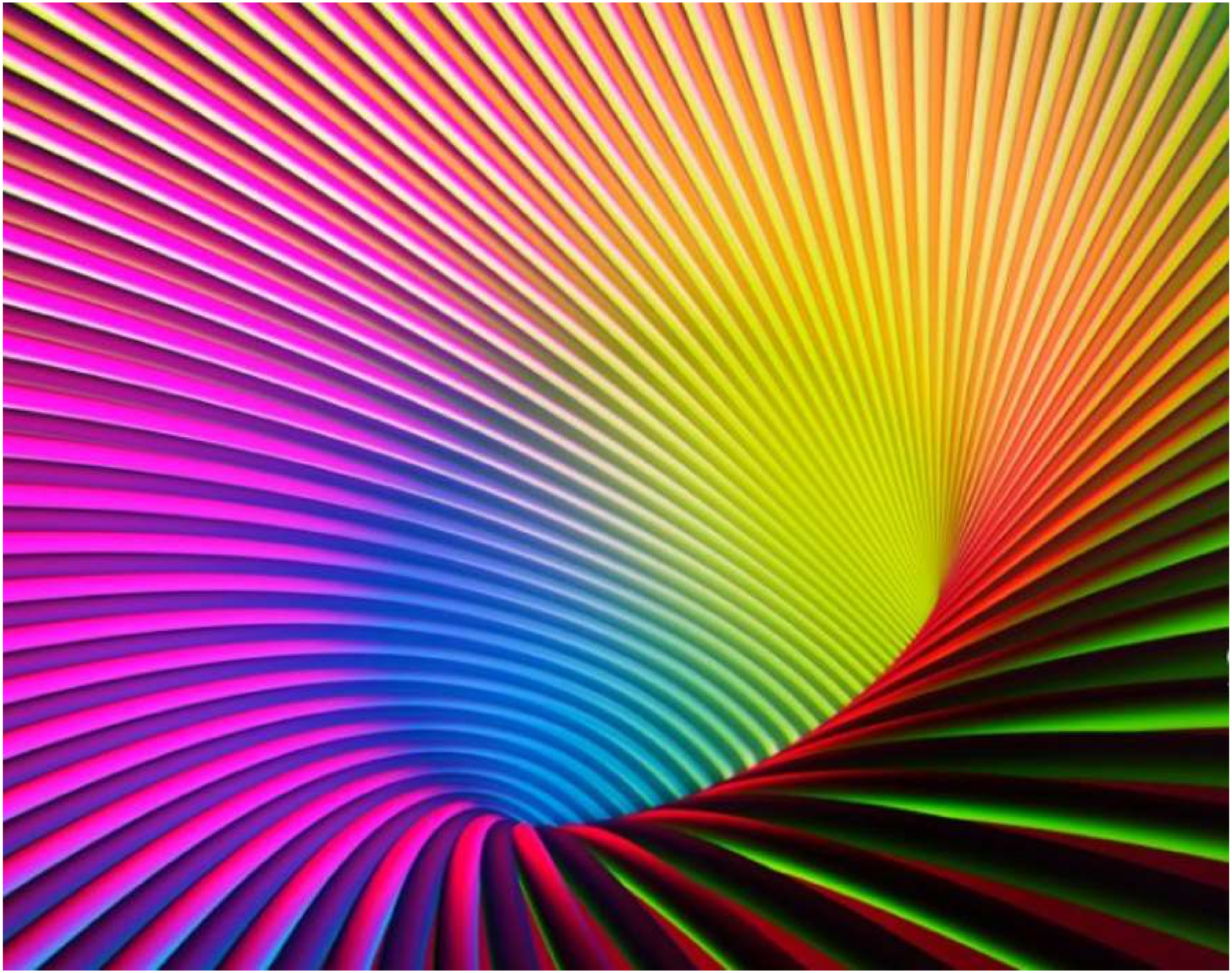
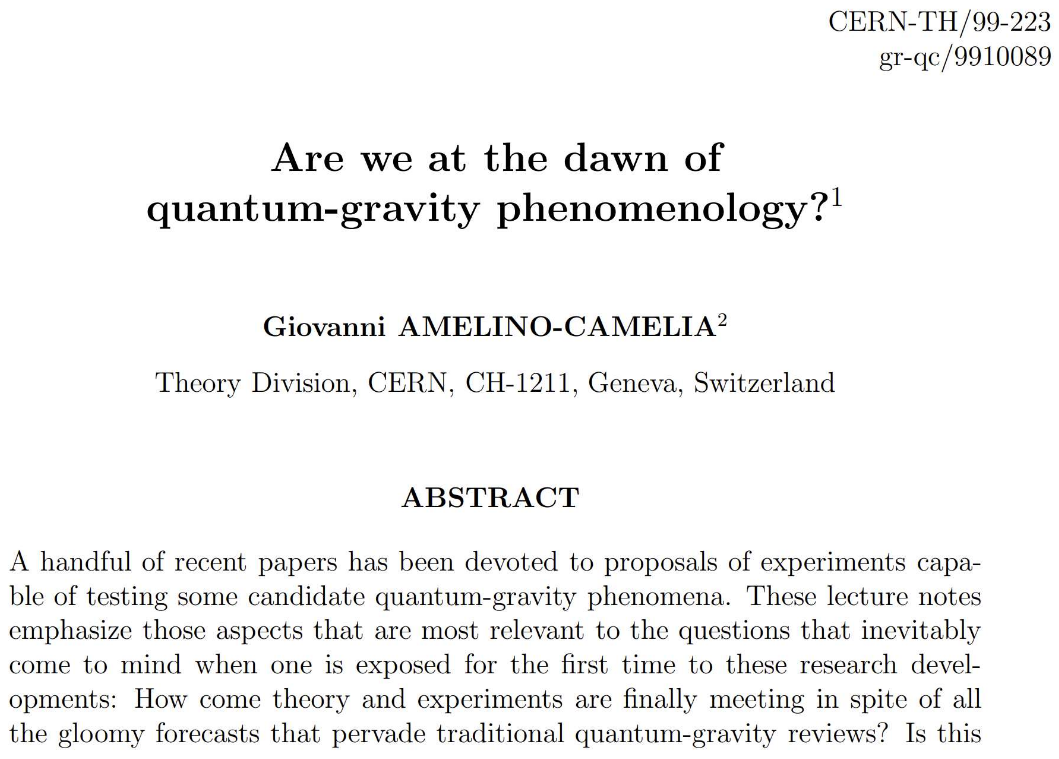
giovanni amelino-camelia

12.10.2023 Procida





CERN-TH/99-223
gr-qc/9910089

Are we at the dawn of quantum-gravity phenomenology?[1]

Giovanni AMELINO-CAMELIA[2]

Theory Division, CERN, CH-1211, Geneva, Switzerland

ABSTRACT

A handful of recent papers has been devoted to proposals of experiments capable of testing some candidate quantum-gravity phenomena. These lecture notes emphasize those aspects that are most relevant to the questions that inevitably come to mind when one is exposed for the first time to these research developments: How come theory and experiments are finally meeting in spite of all the gloomy forecasts that pervade traditional quantum-gravity reviews? Is this

wider perspective on QGphen in my "living review" :

GAC, LivingRev.Relativity16,5(2013)

www.livingreviews.org/lrr-2013-5

specifically for «QGphen in the multimessenger era» see the very recent review

Prog.Part.Nucl.Phys. 125, 103948 (2022)

www.sciencedirect.com/science/article/pii/S0146641022000096

today focus on in-vacuo dispersion

in some quantum-spacetime/quantum-gravity models particles couple to quantum degrees of spacetime in ways that are roughly analogous to ordinary dispersion of light in certain materials

effects are predicted to be extremely small (because of the smallness of the Planck length) and cannot be tested in ground-based experiments

the needed sensitivity could be reached by studies of in-vacuo dispersion of particles observed from very distant astrophysical sources, like GRBs…

two decades of testing in gamma-ray astrophysics this particular formula for the correction to the arrival time due quantum gravity

$$\Delta t = \eta \frac{E}{E_P} \int_0^z d\zeta \frac{(1+\zeta)}{H(\zeta)}$$

$$\boxed{H(\zeta) \equiv H_0 \sqrt{\Omega_\Lambda + (1+\zeta)^3 \Omega_m}}$$

(besides being absent in some models, there is some model dependence of the formula… but this is the formula that applies most often and we are starting from this….)

GAC+Ellis+Mavromatos+Nanopoulos+Sarkar, Nature393,763(1998)
Abdo et al, Science 323,1688(2009)
Ackermann et al, Nature 462,331(2009)
GAC, NaturePhysics10,254(2014)

gamma-ray telescopes used to be all we had but gamma rays have some limitations

- opacity of the universe for photons with E>10TeV
- time scale of predicted effect for a photon of, say, 100 GeV from a GRB at, say, z=1 is comparable to the time scale of intrinsic spectral legs which astrophycisists are unable to model reliably

neutrinos observed from distant astrophysical sources also observed in photons could be ideal for testing in-vacuo dispersion

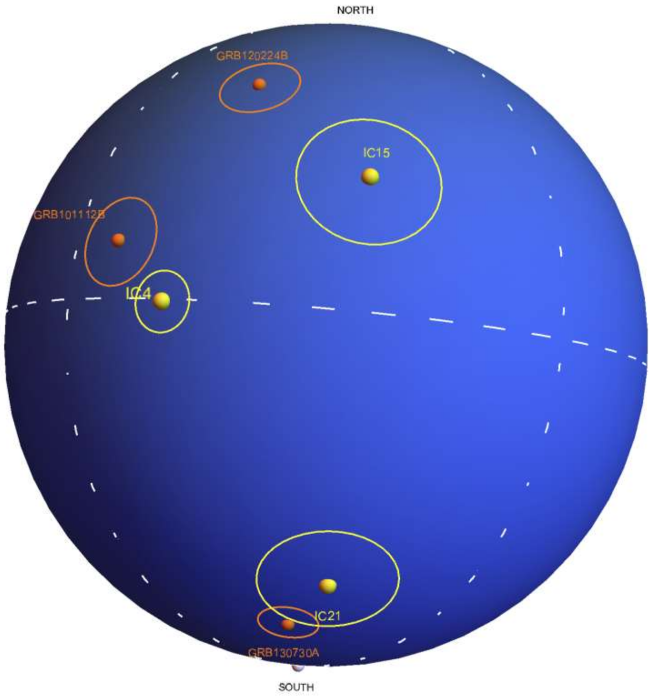
The prediction of a neutrino emission associated with Gamma Ray Bursts is generic within the most widely accepted astrophysical models

according to pre-IceCube predictions, IceCube should have seen a few GRB neutrinos in each year of operation but it has reported no GRB neutrinos!

most likely pre-IceCube models of neutrino production by GRBs were incorrect, but QG offers an alternative explanation: IceCube analyses look for GRB neutrino within a window of only 100 seconds of the GRB trigger
(time window might be too small if there is in-vacuo dispersion!!!)

GAC+D’Amico+Rosati +Loret, arXiv1612.02765, NatureAstronomy1,0139
GAC+Barcaroli+D’Amico+Loret+Rosati, arXiv1605.00496,PhysicsLettersB761(2016)318
GAC+DiLuca+Gubitosi+Rosati +D’Amico, arXiv2209.13726, NatureAstronomy7,996

focus on “shower neutrinos” with energy between 60 and 500 TeV
(“track neutrinos” have much worse energy estimation)



Assume once again validity of the formula

$$\Delta t = \eta \frac{E}{M_P} D(z)$$

with

$$D(z) = \int_0^z d\zeta \frac{(1+\zeta)}{H_0\sqrt{\Omega_\Lambda + (1+\zeta)^3\Omega_m}}$$

we should find that at least some of our GRB-neutrino candidates have difference of time of arrival with respect to the relevant GRB which grows linearly with energy, modulo the uncertainties in redshift

we set up the analysis in terms of the relationship between Δt and E^*

(but notice that sometimes we use notation E^* and sometimes we used notation Κ)

the large uncertainties in redshift will still be present, disguised as corresponding uncertainties for the determinations of E^* (i.e. Κ) but at least we will be working with a linear relationship:

$$\Delta t = \eta \cdot D(1) \frac{E^*}{M_P}$$

$$E^* \equiv E \frac{D(z)}{D(1)} \qquad D(z) = \int_0^z d\zeta \frac{(1+\zeta)}{H_0 \sqrt{\Omega_\Lambda + (1+\zeta)^3 \Omega_m}}$$

Within the ICeCube data so far publicly available only 7 turned out to be "GRB-neutrino candidates" with our angular and temporal selection criteria.

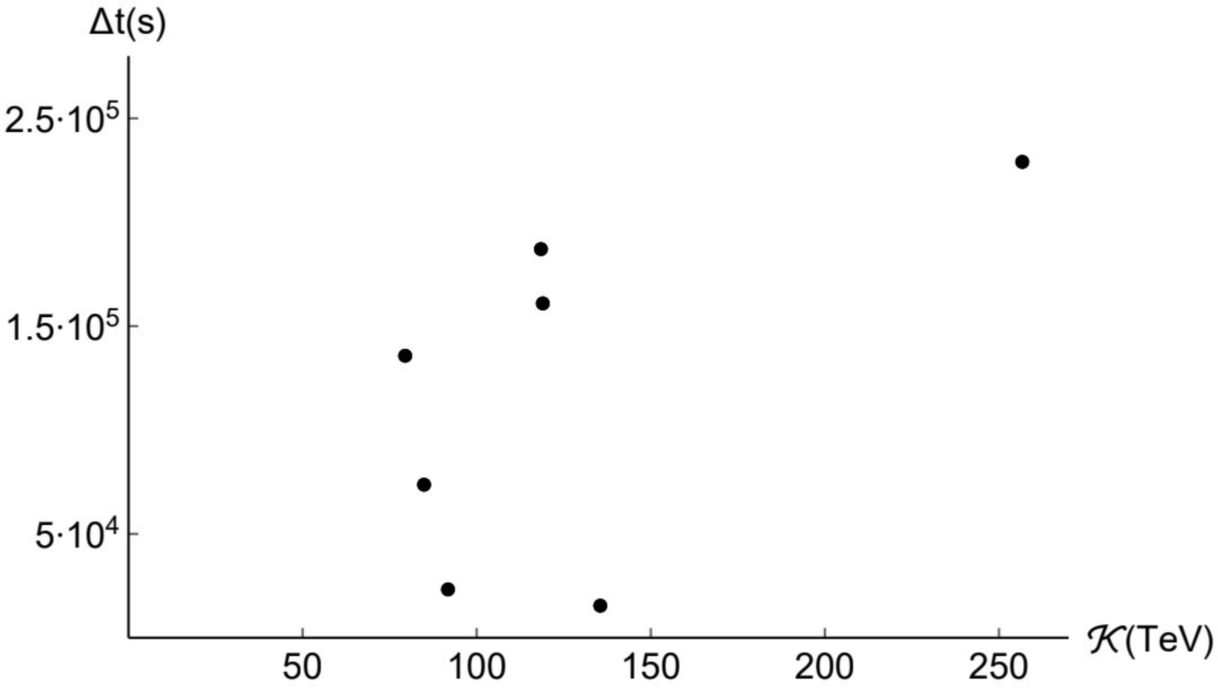
So let's see if they provided some support for the linear dependence between Δt and Κ

GAC+DiLuca+Gubitosi+Rosati +D'Amico, arXiv2209.13726, NatureAstronomy7,996

error bars on later slide with some relevant comments

first focus on IcecCube neutrinos with energy between 60 and 500 TeV

Δt is the difference in time of observation between the neutrino and the GRB

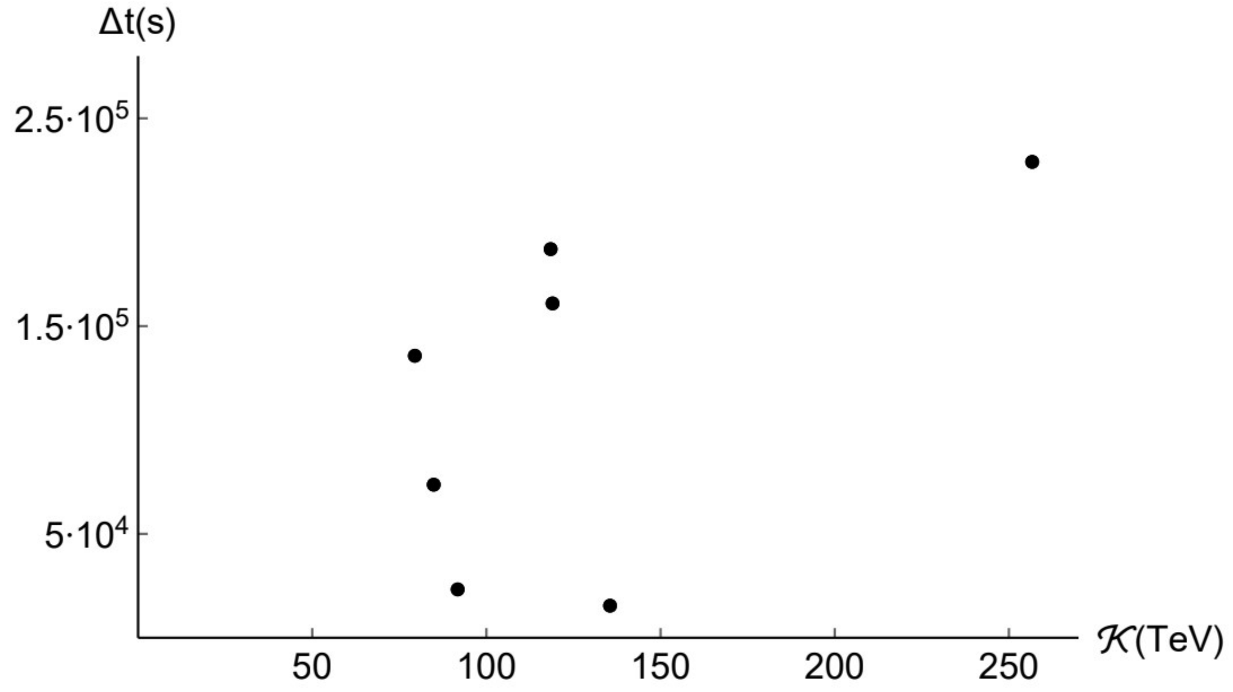


- also within standard physics one expects that an analysis such as ours should find some "GRB-neutrino candidates" but there should be only very few and they should manifest NO CORRELATION since they would only be "accidental GRB-neutrino candidates"

· within the quantum-spacetime picture one expects more candidates (some true GRB neutrinos plus some accidental candidates) and these candidates should manifest a CORRELATION

we find 7 candidates between 60 and 500 TeV
probability of having at least 7 events within standard physics is 4.6%

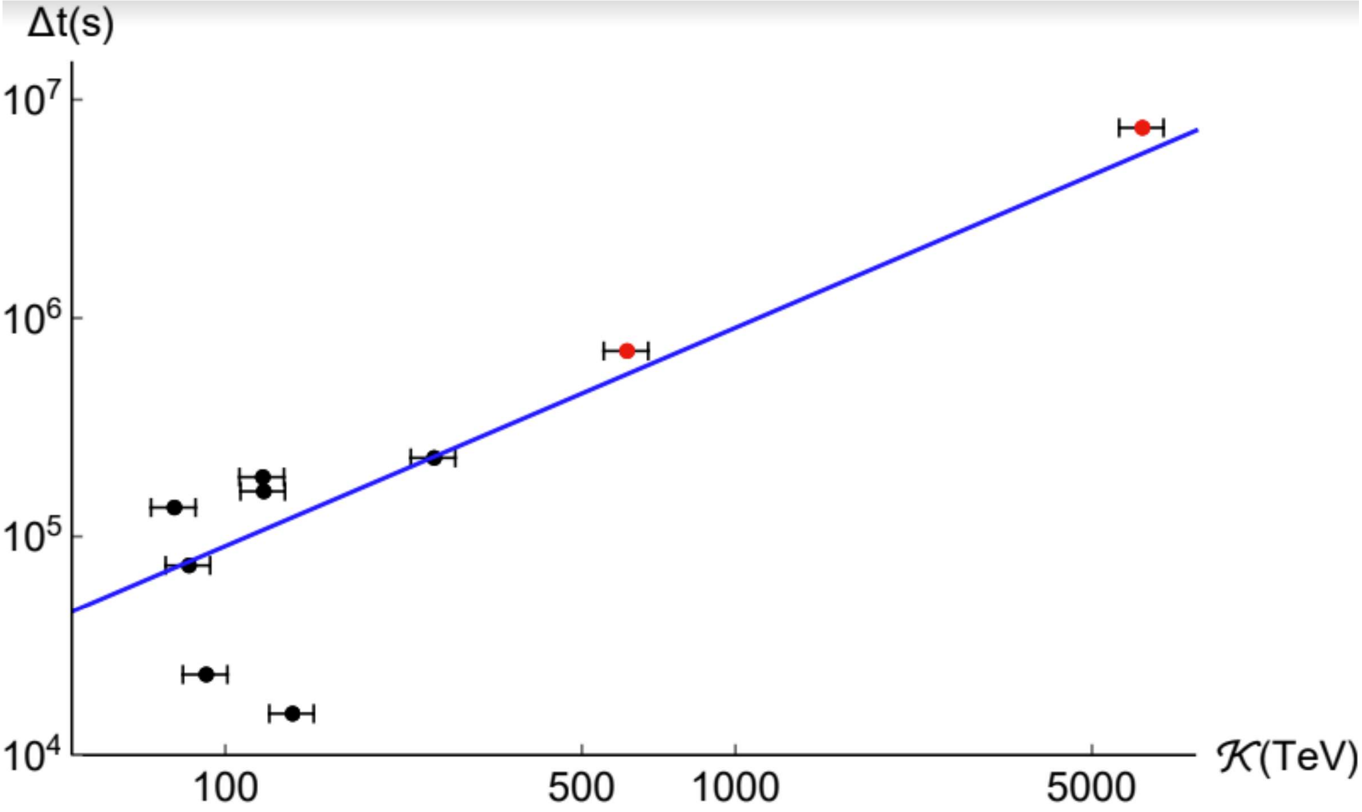
GAC+DiLuca+Gubitosi+Rosati +D'Amico, arXiv2209.13726, NatureAstronomy7,996



for the 7 candidates corelation K vs Δt is 0.56
(and keep in mind that, even with the quantum-spacetime picture we estimated that it is likely
that 2 or 3 of our 7 candidates are not really GRB-neutrino candidates)

we produced "simulated data" by reshuffling directions and times of observation within the data set
at our disposal and this allowed to estimate that within standard physics the probability of having
at least 7 candidates is 4.6% (as I already mentioned) and the probability of having
at least 7 candidates with correlation of at least 0.56 is 0.7%

GAC+DiLuca+Gubitosi+Rosati +D’Amico, arXiv2209.13726, NatureAstronomy7,996



error bars are surely underestimated (missing info on distribution in redshift of GRBs which are observable in neutrinos)

the slope of the blue line is obtained by best-fitting our neutrinos with E<500TeV

in our data sample only 3 neutrinos with E>500TeV and 2 of them are GRB-neutrino candidates and they both have ratio Δt/K compatible within one sigma (taking into account that also the blue line has a calculable uncefrtainty) with the blue line