Search for Lorentz Invariance Violation with gamma-rays

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Lorentz Invariance Violation and photon propagation

Certain models of quantum gravity predict violation of Lorentz Invariance (LIV) near the Planck scale due to quantum fluctuations

-> non-trivial refractive index in the vacuum

-> linear or quadratic variation of the vacuum speed of light with energy

$$c' \approx c\left[1 - s_n \frac{n+1}{2}\left(\frac{E_{ph}}{M_{QG,n}c^2}\right)^n\right]$$

, s_n = +1 for subliminal case (of greatest interest)

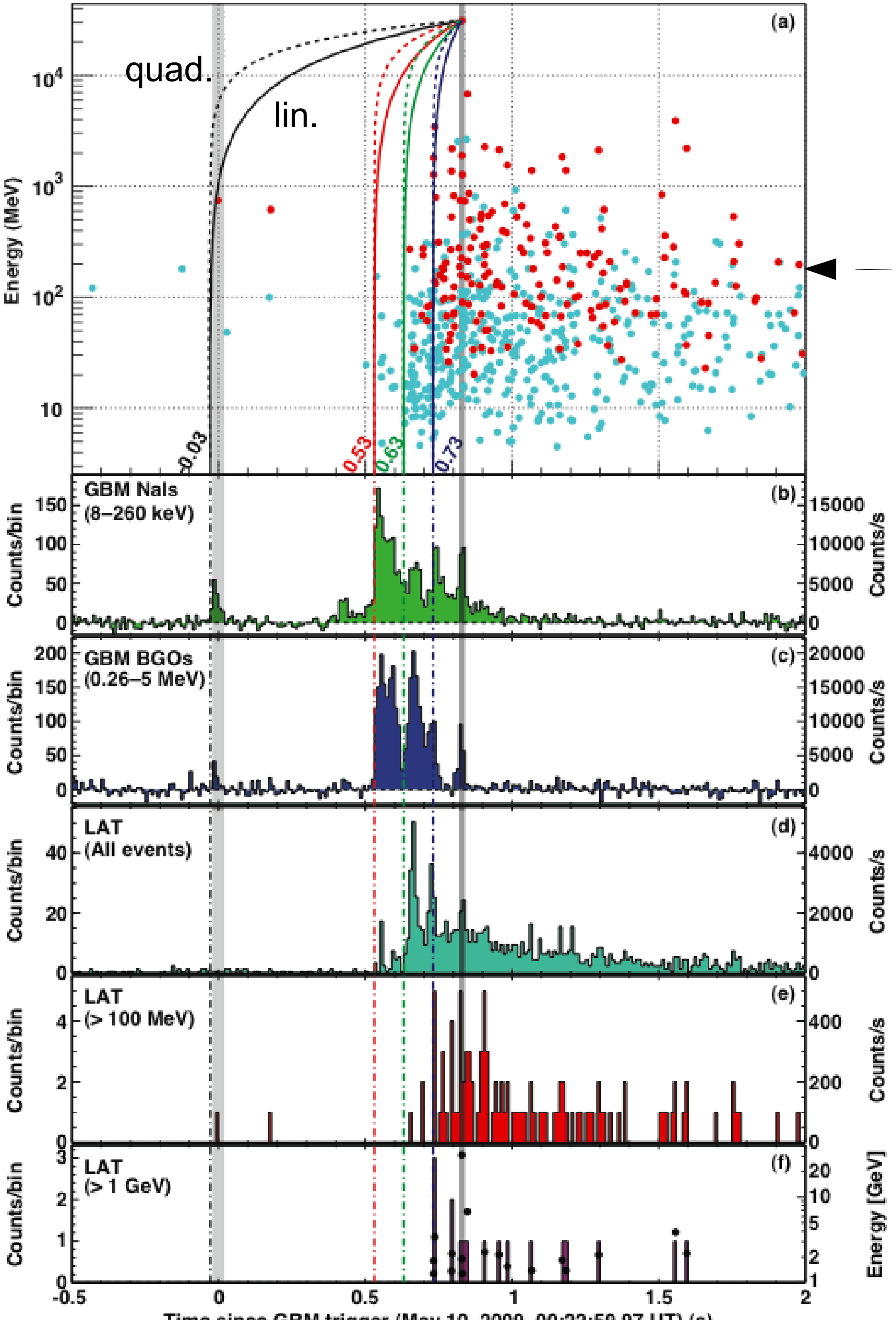
Amelino-Camelia, G. et al., Nature 393 (1998) 763

-> dispersion of photon arrival times

$$\Delta t \approx s_n \left(\frac{1+n}{2\mathrm{H}_0}\right) \frac{\Delta(E^n)}{(M_{QG,n}c^2)^n} \int_0^z \frac{(1+z')^n}{h(z')}\, dz'$$

Ideal targets for time-of-flight measurements are short photon pulses, emitted over a large energy range, from astrophysical/cosmological distances.

observational limits from MeV-GeV gamma-rays



GRB 090510 (z=0.9) detected with Fermi-LAT

lower limit on QG mass scale for linear models ~ **1.2 M_P**

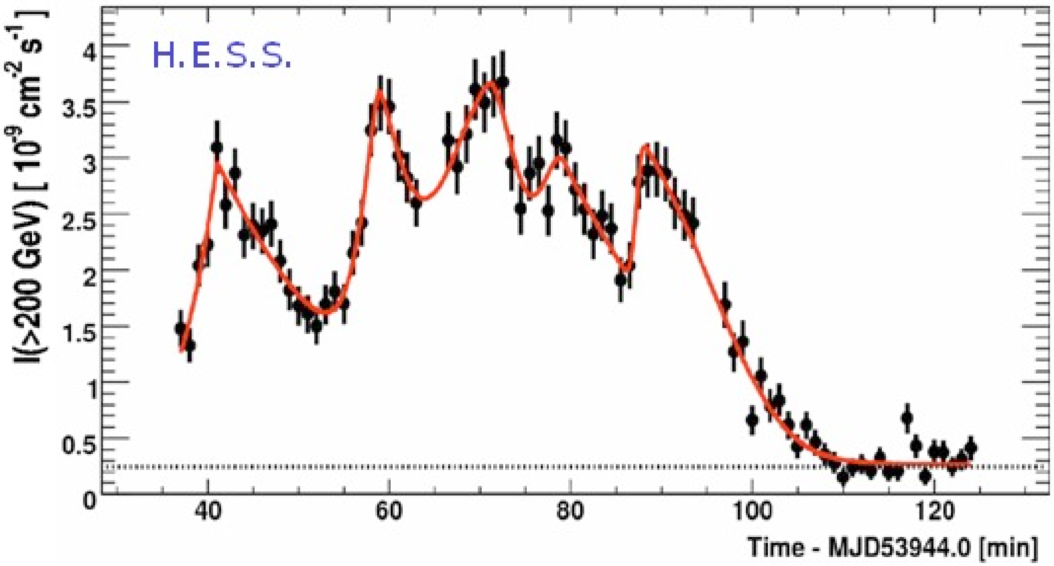
Abdo, A. A., et al., 2009, Nature, 462, 331

GRB 080916C (z=4.35) detected with Fermi-LAT

linear models: M_{QG} > 1.3×10^{18} GeV/c^2

Abdo, A.A. et al., Science, 323, 5922, 1688 (2009)

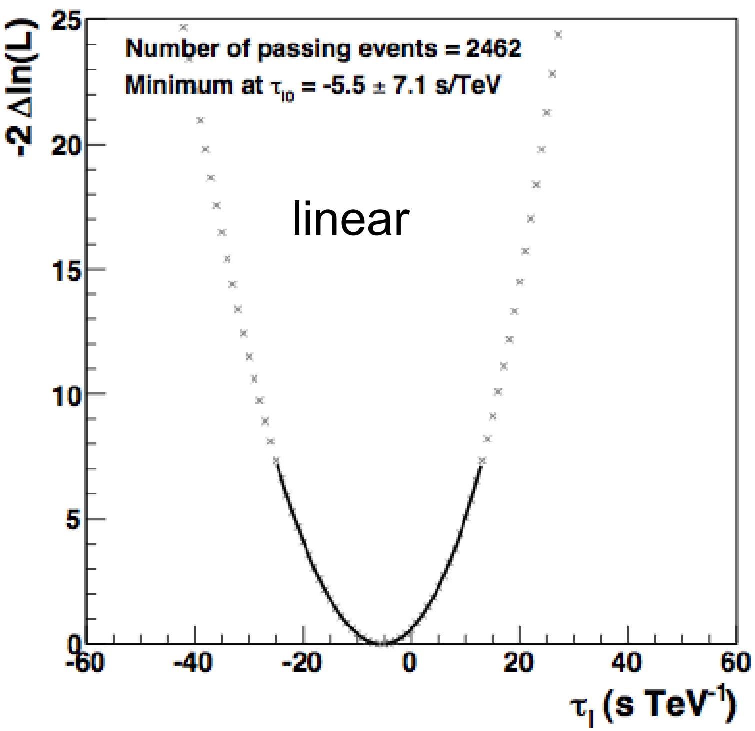
observational limits from TeV gamma-rays

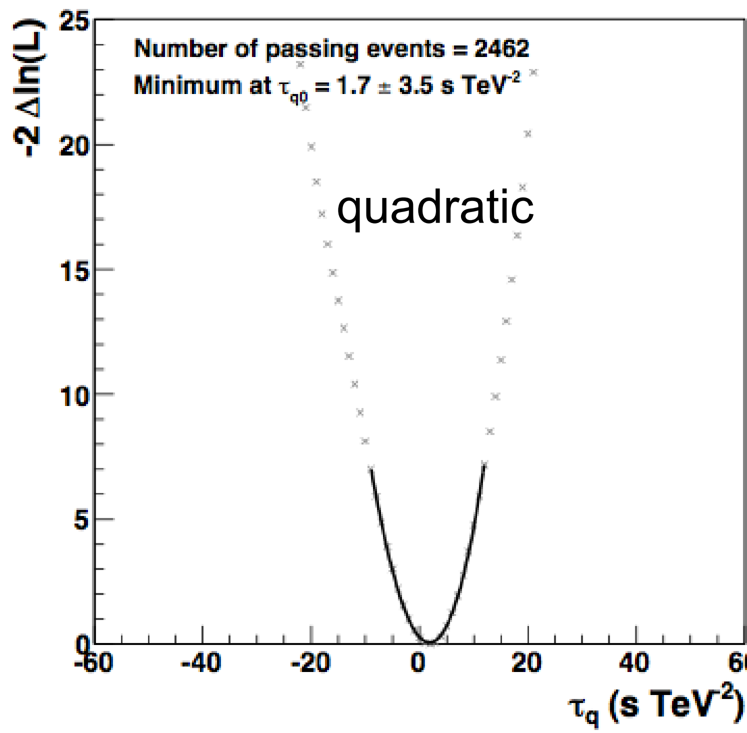


- exceptionally bright flare from the **blazar** PKS 2155-304 (z=0.117) with peaks of duration ~10 min.

- comparison of HESS light curves in different energy ranges

- different methods: cross-correlations, wavelets, likelihood analysis....





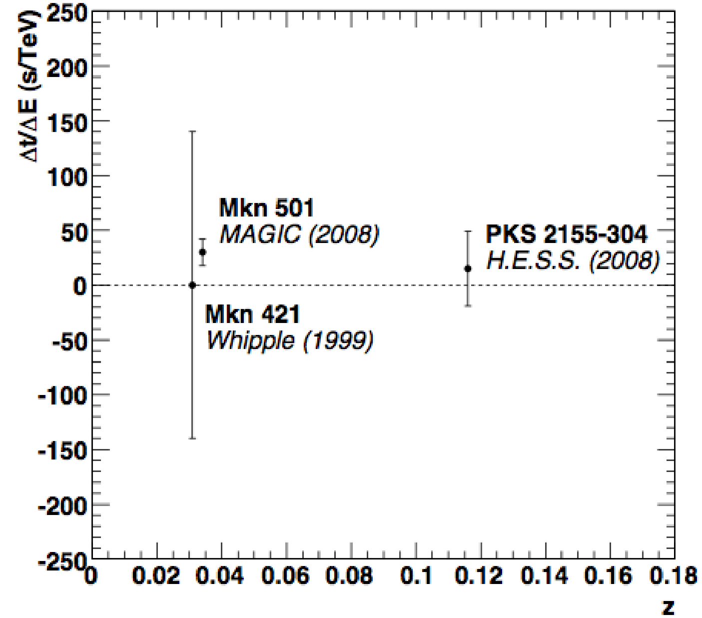
A. Abramowski et al. (HESS Collab.) Astropart. Phys. 34 (2011) 738

observational limits from TeV gamma-rays

H.E.S.S. limit from **blazar** PKS 2155-304 on the mass scale of QG for linear models (95% CL):

$M_{QG} > 2.1 \times 10^{18}$ GeV (17% M_P)

quadratic models:
$M_{QG} > 6.4 \times 10^{10}$ GeV



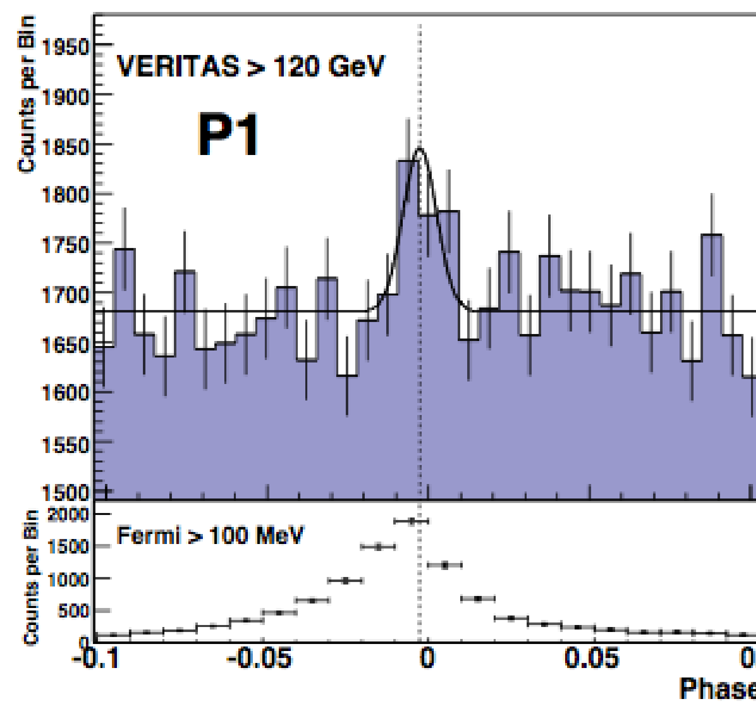
limits from the Crab **pulsar** for linear models:

VERITAS 2013:

$M_{QG} > 3 \times 10^{17}$ GeV

earlier limit from EGRET (MeV/GeV energies):

$M_{QG} > 1.8 \times 10^{15}$ GeV

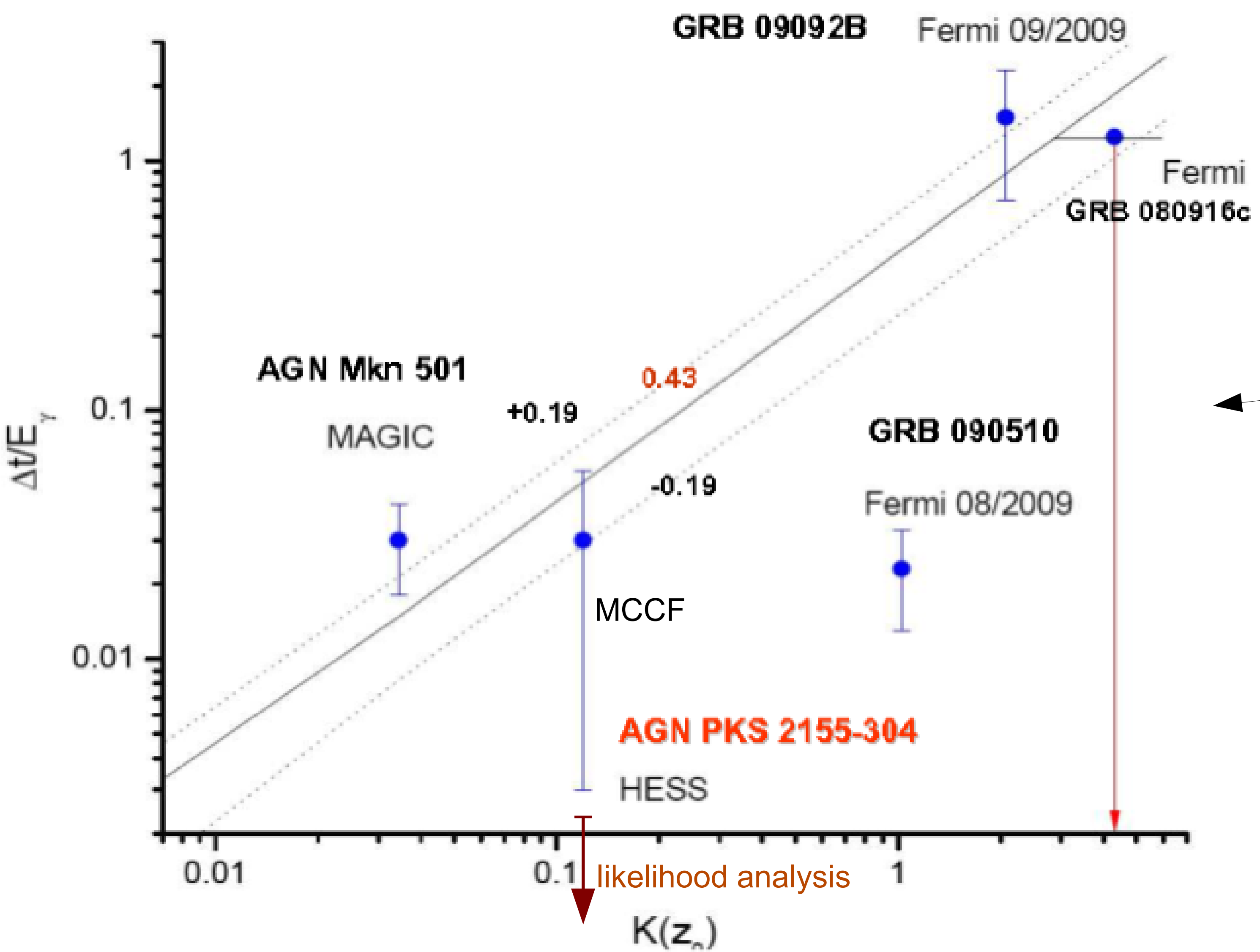


Limits from different experiments

Table 1: A selection of limits obtained with various instruments and methods for both GRB and AGN

Source(s)	Experiment	Method	Results (95% CL limits)
GRB 021206	*RHESSI*	Fit + mean arrival time in a spike	$M^{l}_{QG} > 1.8\times10^{17}$ GeV
GRB 080916C	*Fermi* GBM + LAT	associating a 13 GeV photon with the trigger time	$M^{l}_{QG} > 1.3\times10^{18}$ GeV $M^{q}_{QG} > 0.8\times10^{10}$ GeV
GRB 090510	*Fermi* GBM + LAT	associating a 31 GeV photon with the start of any observed emission, DisCan	$M^{l}_{QG} > 1.5\times10^{19}$ GeV $M^{q}_{QG} > 3.0\times10^{10}$ GeV
9 GRBs	BATSE + OSSE	wavelets	$M^{l}_{QG} > 0.7\times10^{16}$ GeV $M^{q}_{QG} > 2.9\times10^{6}$ GeV
15 GRBs	*HETE-2*	wavelets	$M^{l}_{QG} > 0.4\times10^{16}$ GeV
17 GRBs	*INTEGRAL*	likelihood	$M^{l}_{QG} > 3.2\times10^{11}$ GeV
35 GRBs	BATSE + *HETE-2* + *Swift*	wavelets	$M^{l}_{QG} > 1.4\times10^{16}$ GeV
Mrk 421	Whipple	likelihood	$M^{l}_{QG} > 0.4\times10^{17}$ GeV
Mrk 501	MAGIC	ECF	$M^{l}_{QG} > 0.2\times10^{18}$ GeV $M^{q}_{QG} > 0.3\times10^{11}$ GeV
		likelihood	$M^{l}_{QG} > 0.3\times10^{18}$ GeV $M^{q}_{QG} > 5.7\times10^{10}$ GeV
PKS 2155-304	H.E.S.S.	MCCF	$M^{l}_{QG} > 7.2\times10^{17}$ GeV $M^{q}_{QG} > 1.4\times10^{9}$ GeV
		wavelets	$M^{l}_{QG} > 5.2\times10^{17}$ GeV
		likelihood	$M^{l}_{QG} > 2.1\times10^{18}$ GeV $M^{q}_{QG} > 6.4\times10^{10}$ GeV

Sensitivities to Δt/E

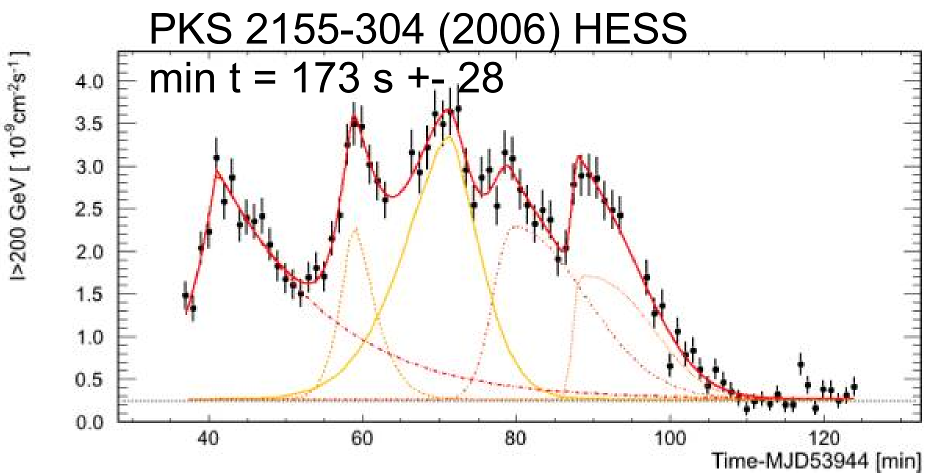


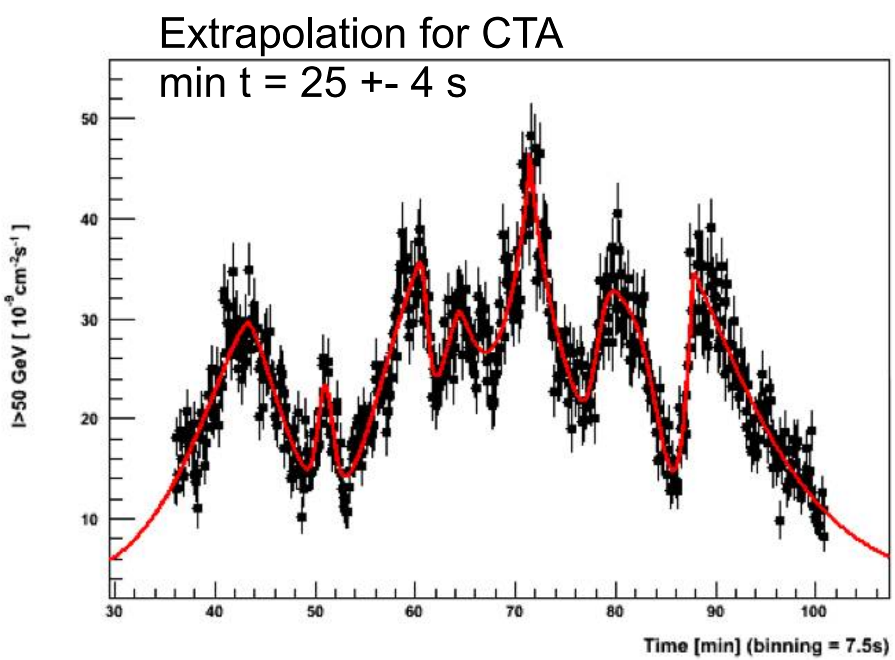
- **linear models**: currently **GRBs** most constraining due to finer time structure and higher z

- **quadratic models:** currently **AGN** most constraining due to higher energies

Ellis & Mavromatos, Astropart. Phys. 43 (2013) 50

Outlook: what to expect from CTA





Biteau, Giebels, AGN Physics in the CTA era

disentangle source-dependent effects (acceleration, cooling, particle escape...) from LIV: need population study at different z, larger statistics of flares, different objects

targets:
- **AGN flares**
  -> dedicated ToO & "snapshot" programme
- **GRBs**
  -> not yet detected at VHE, but very promising
- **pulsars**
  -> promising targets for CTA following the detection of Crab pulsar with MAGIC & VERITAS

advantage of CTA:
- larger energy coverage
- higher statistics
- smaller temporal structures