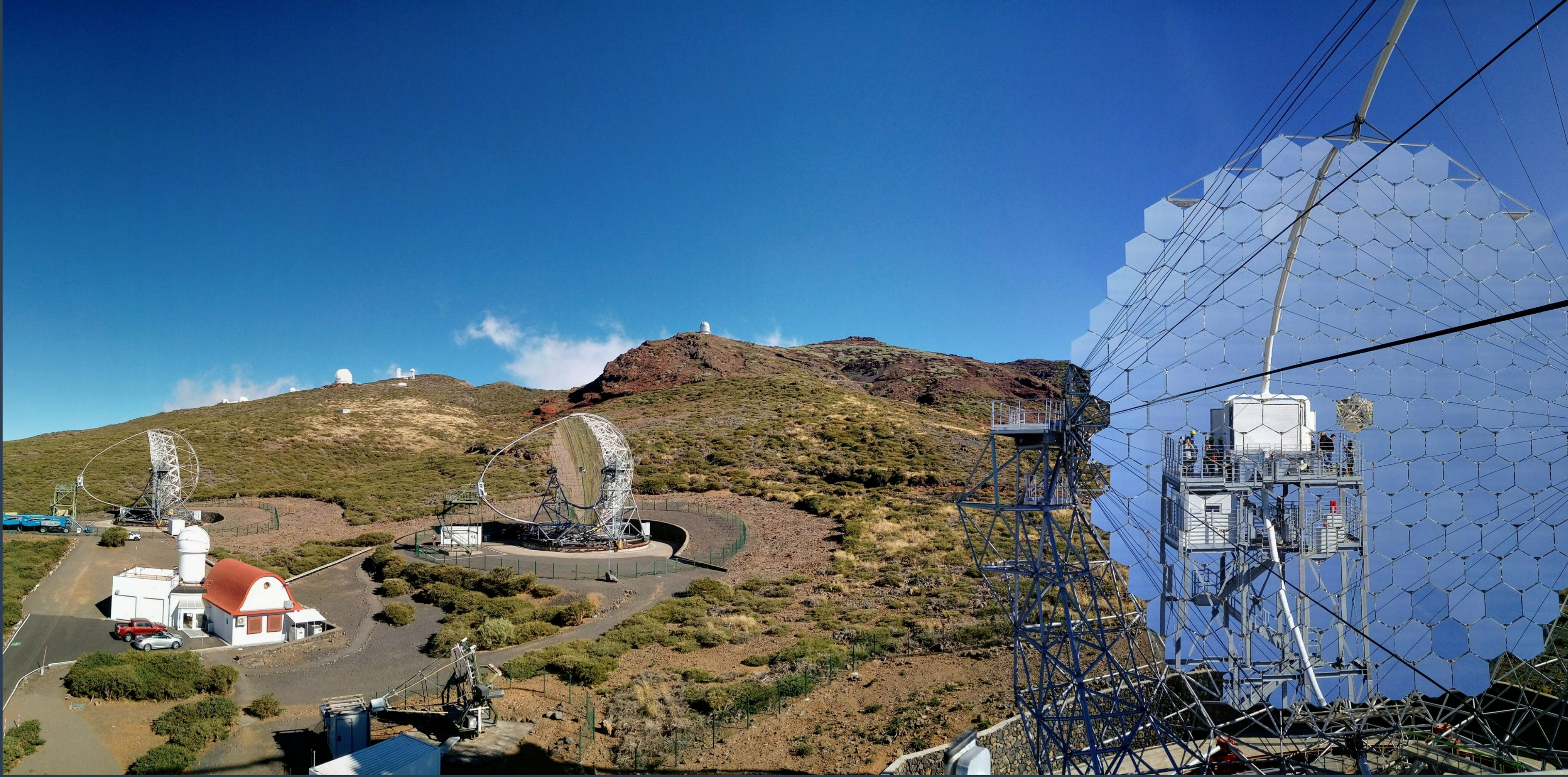


An introduction to Lorentz Invariance Violation analysis using MAGIC detection of GRB 190114C

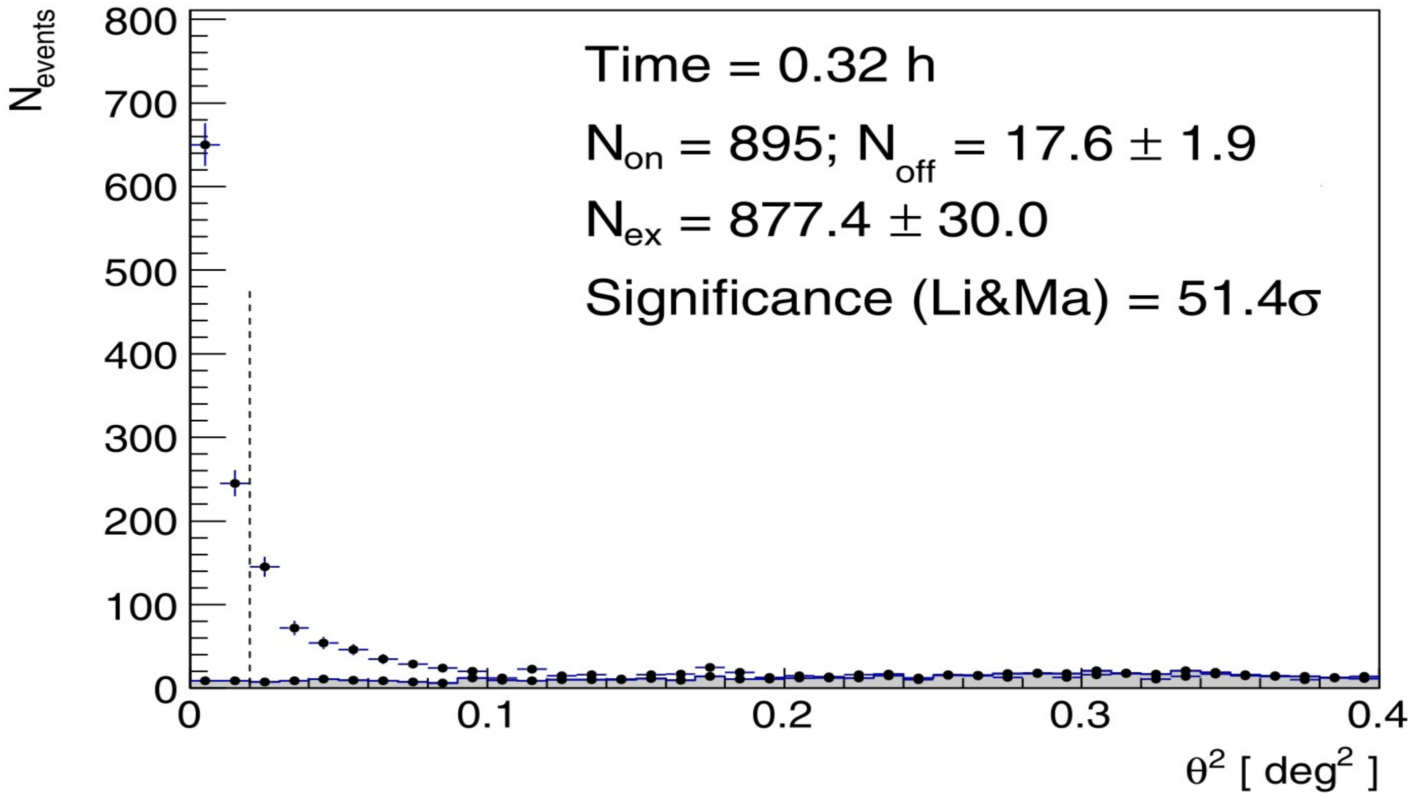
Daniel Kerszberg

Pizza seminar

IFAE Institut de Física d'Altes Energies
EXCELENCIA SEVERO OCHOA
BIST Barcelona Institute of Science and Technology

GRB 190114C detection by MAGIC

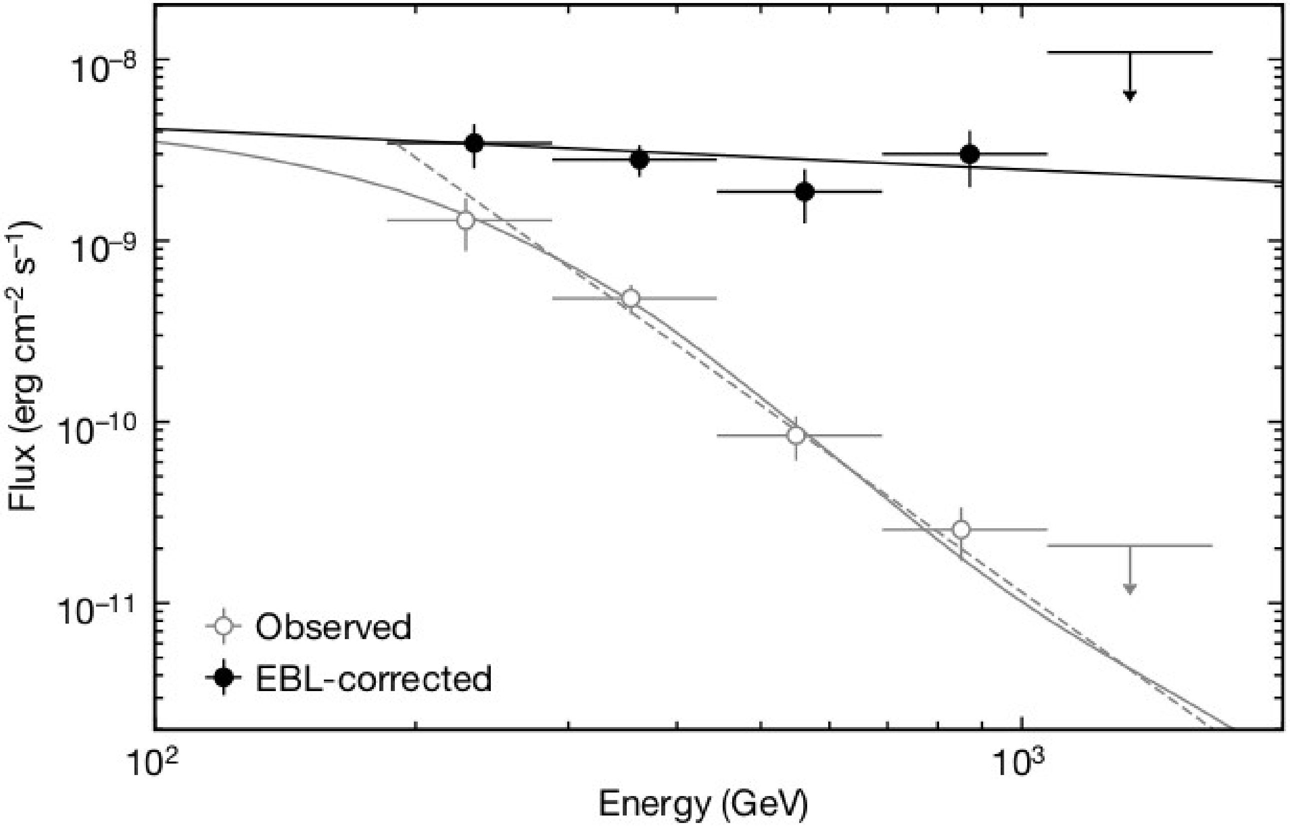
- T_0 = 20:57:03 UTC on the 14th January 2019
- Long GRB at redshift z=0.42



- N_{on}=895 (and very low background)

GRB 190114C: spectrum

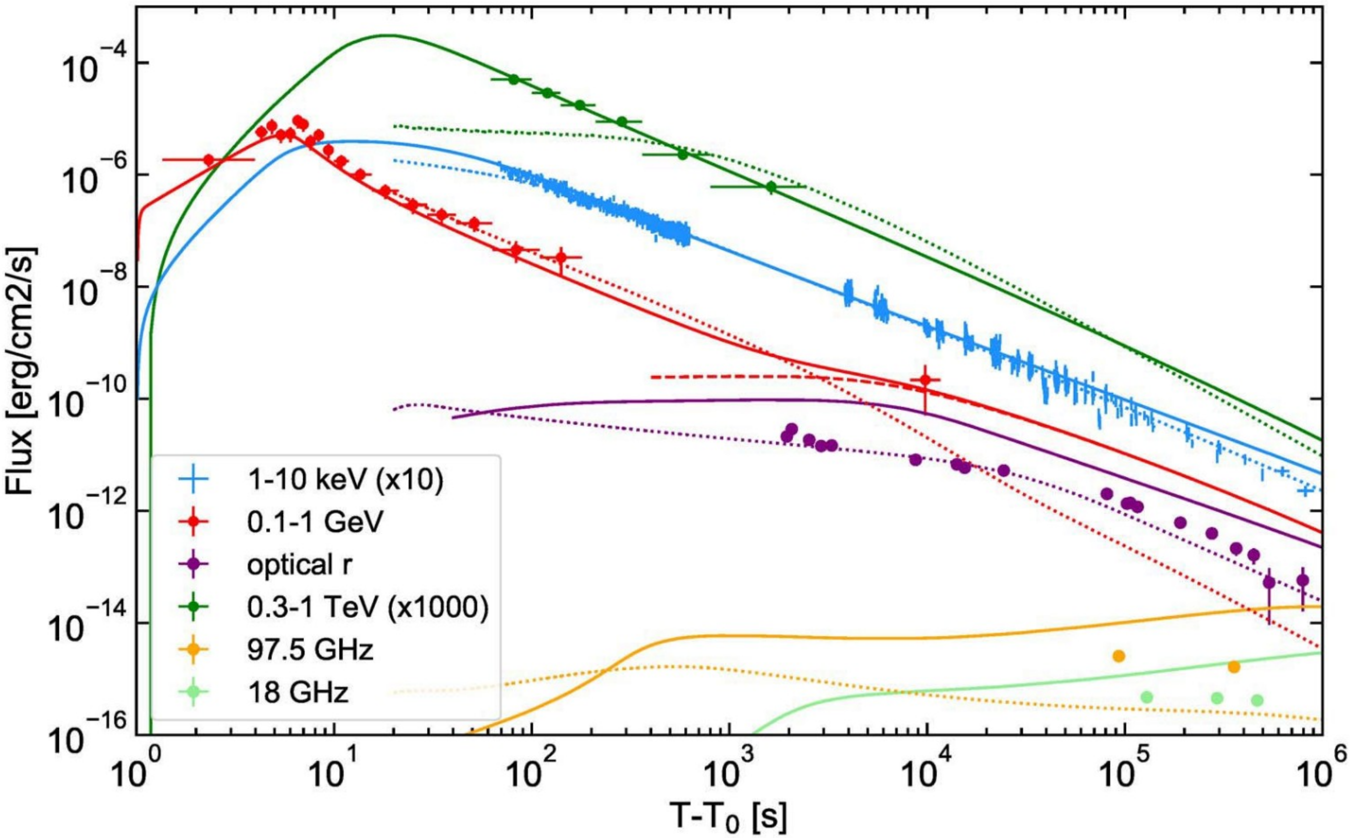
- T_0 = 20:57:03 UTC on the 14th January 2019
- Long GRB at redshift z=0.42



- Power law with spectral index $\alpha = -2.5 \pm 0.2$

GRB 190114C: light curve

- T_0 = 20:57:03 UTC on the 14th January 2019
- Long GRB at redshift z=0.42



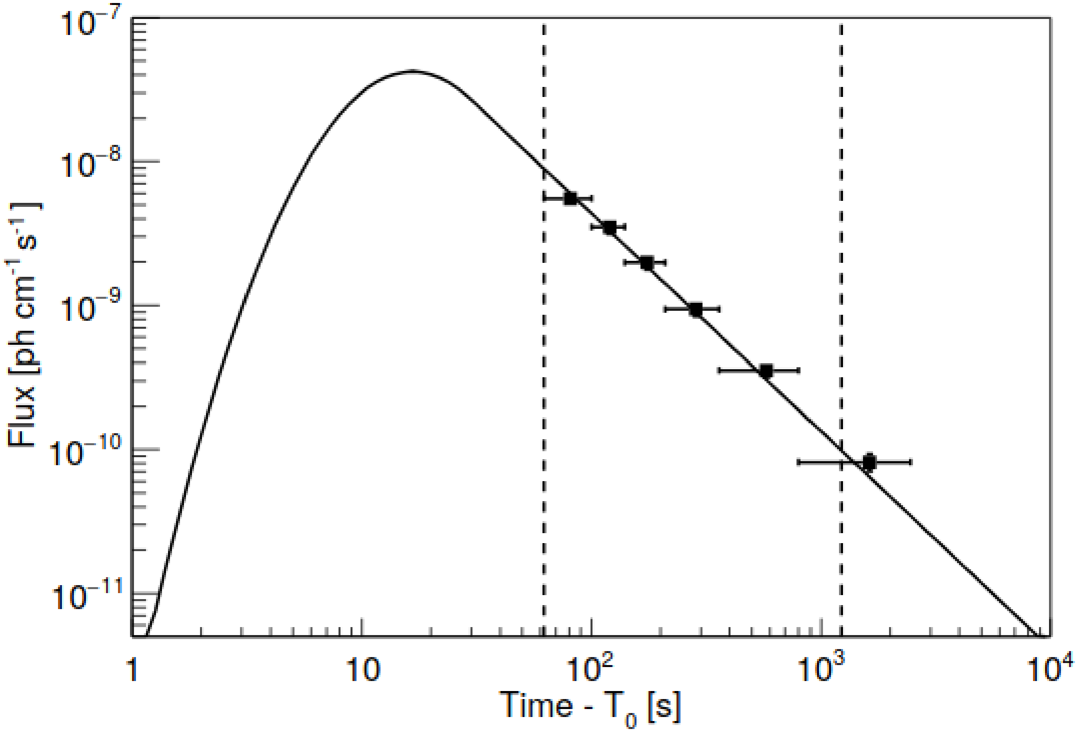
- Power law with spectral index $\beta = -1.51 \pm 0.04$

Lorentz Invariance Violation (LIV)

- **Without LIV effect:** **E=p ⇒ $v_\gamma=1$ ⇒ Δt=0**
- **With LIV effect:** **E≠p ⇒ $v_\gamma\neq1$ ⇒ Δt≠0**
- **You can compute the expected delay for any particular source with its redshift, the Hubble constant etc**
- **Here is the result for GRB 190114C:** $$\Delta t = \eta_1 \cdot \ 17\ \mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$
  (in the linear case)
- **What we measure/constrain:**
  - First order LIV-correction (linear case): $\eta_1 = \pm \frac{E_{Planck}}{E_{QG,1}}$
  - Second order LIV-correction (quadratic case): $\eta_2 = \pm 10^{-16} \frac{E^2_{Planck}}{E^2_{QG,2}}$

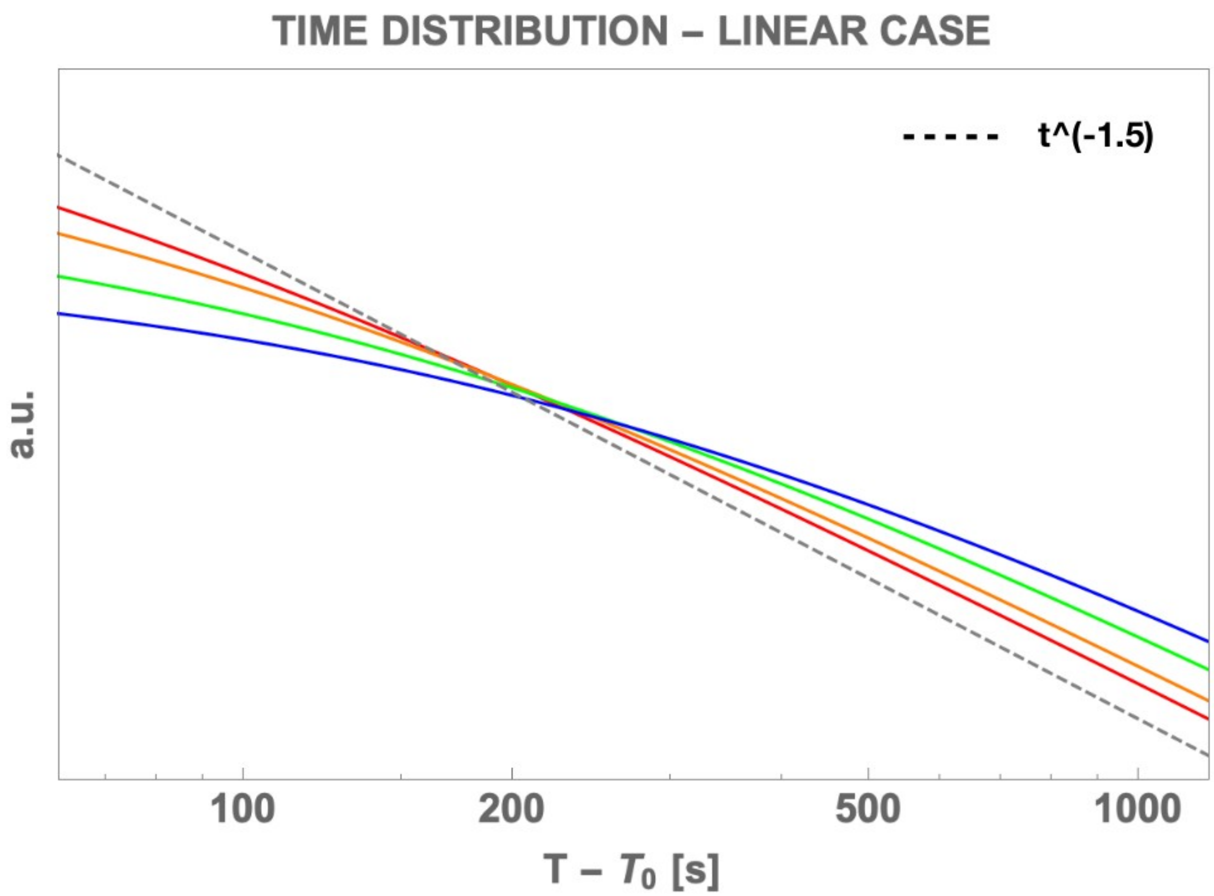
Assumed Light Curve

- **“Theoretical” model (from MWL observations):**



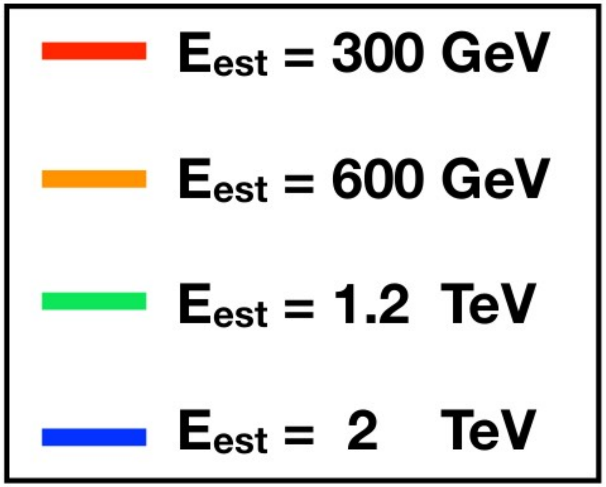
- **“Minimal” model (step function):**
  - **Flux = 0 for $t < T_0$**
  - **Flux = K (constant) for $t > T_0$**

What actually does the likelihood analysis?



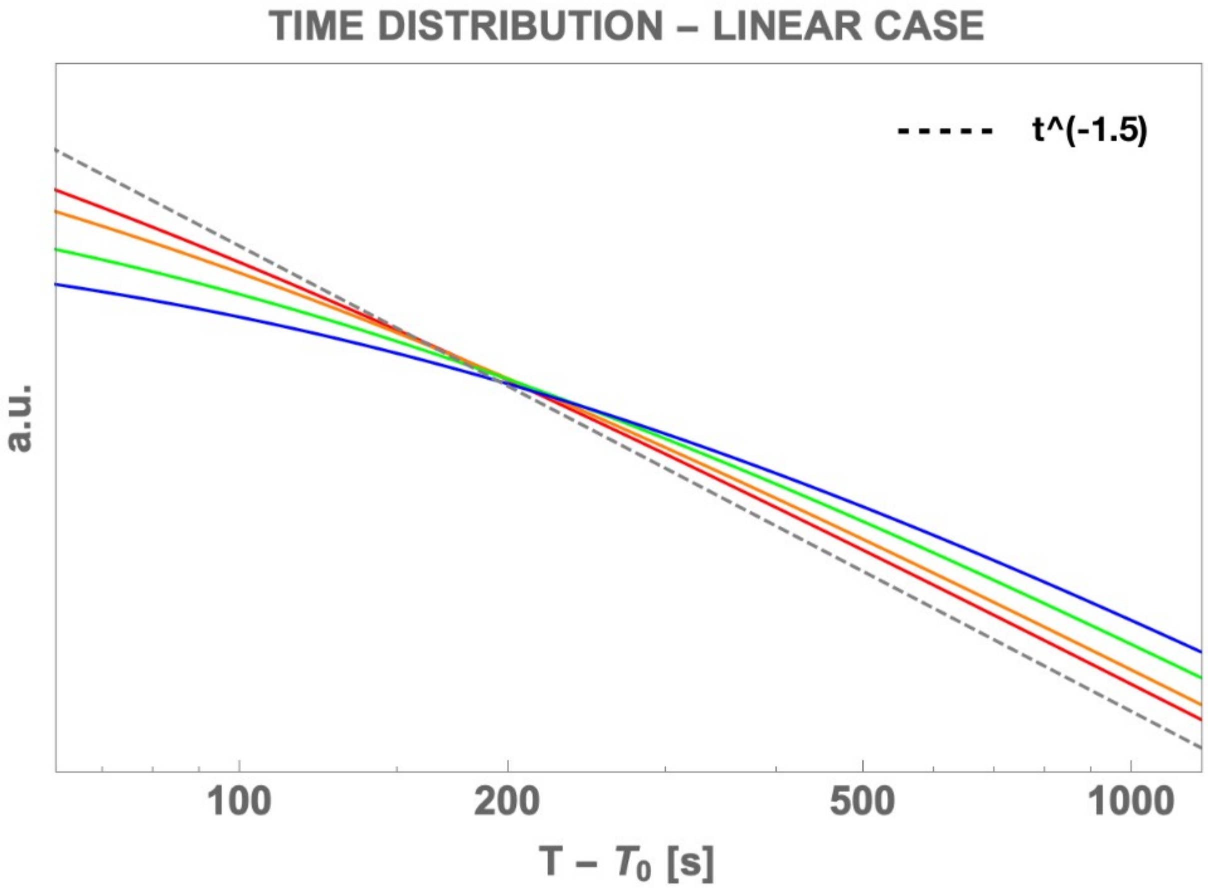
$$\eta_1 = -7$$

$$\Delta t = \eta_1 \cdot \; 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



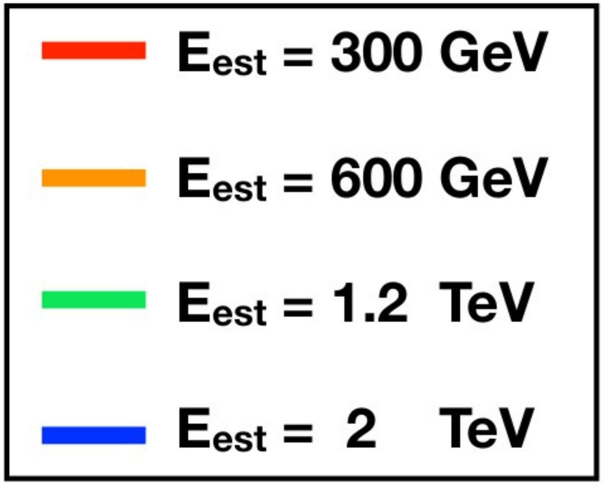
Courtesy of Giacomo D’Amico

What actually does the likelihood analysis?



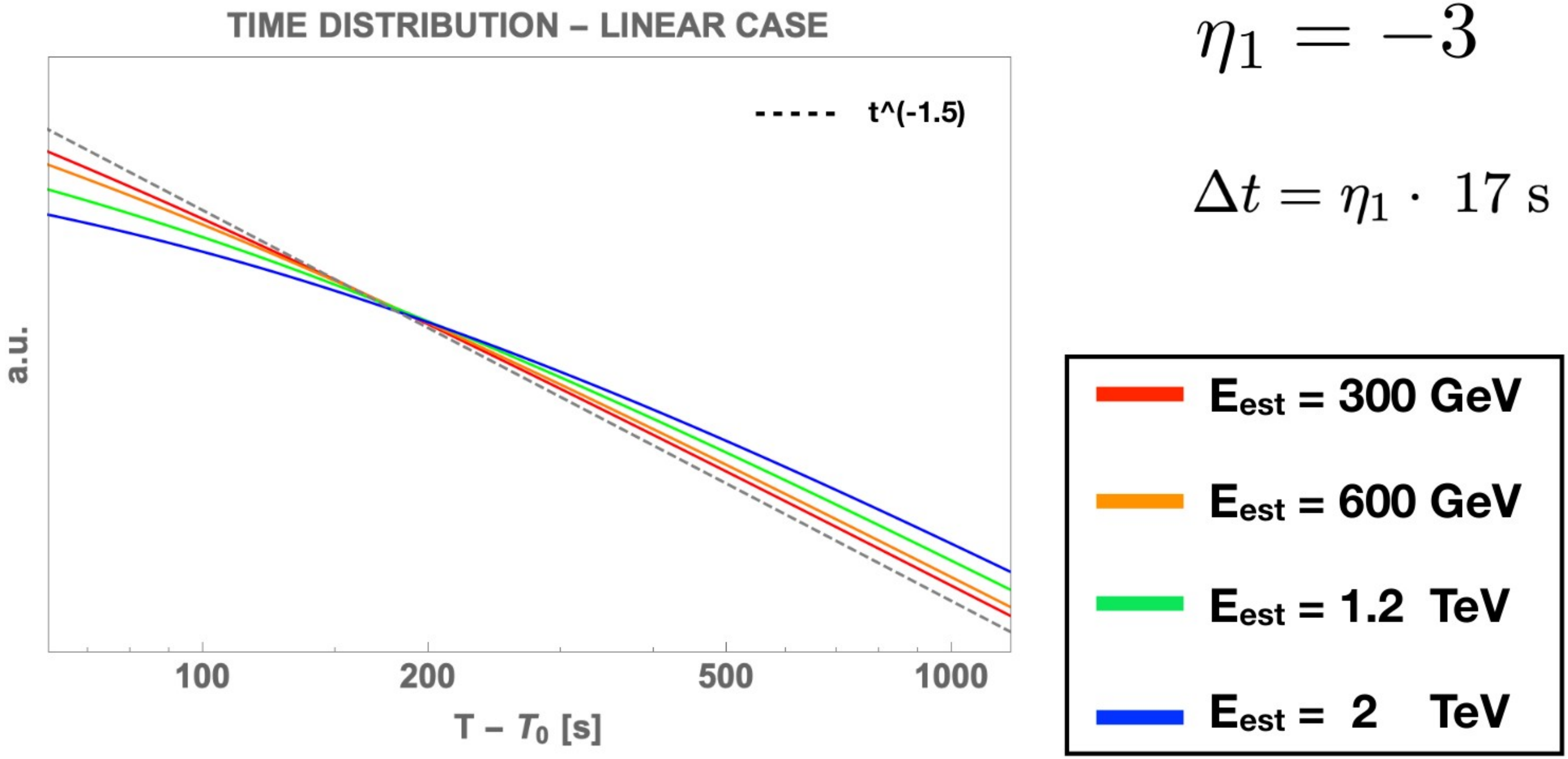
$$\eta_1 = -5$$

$$\Delta t = \eta_1 \cdot\ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?

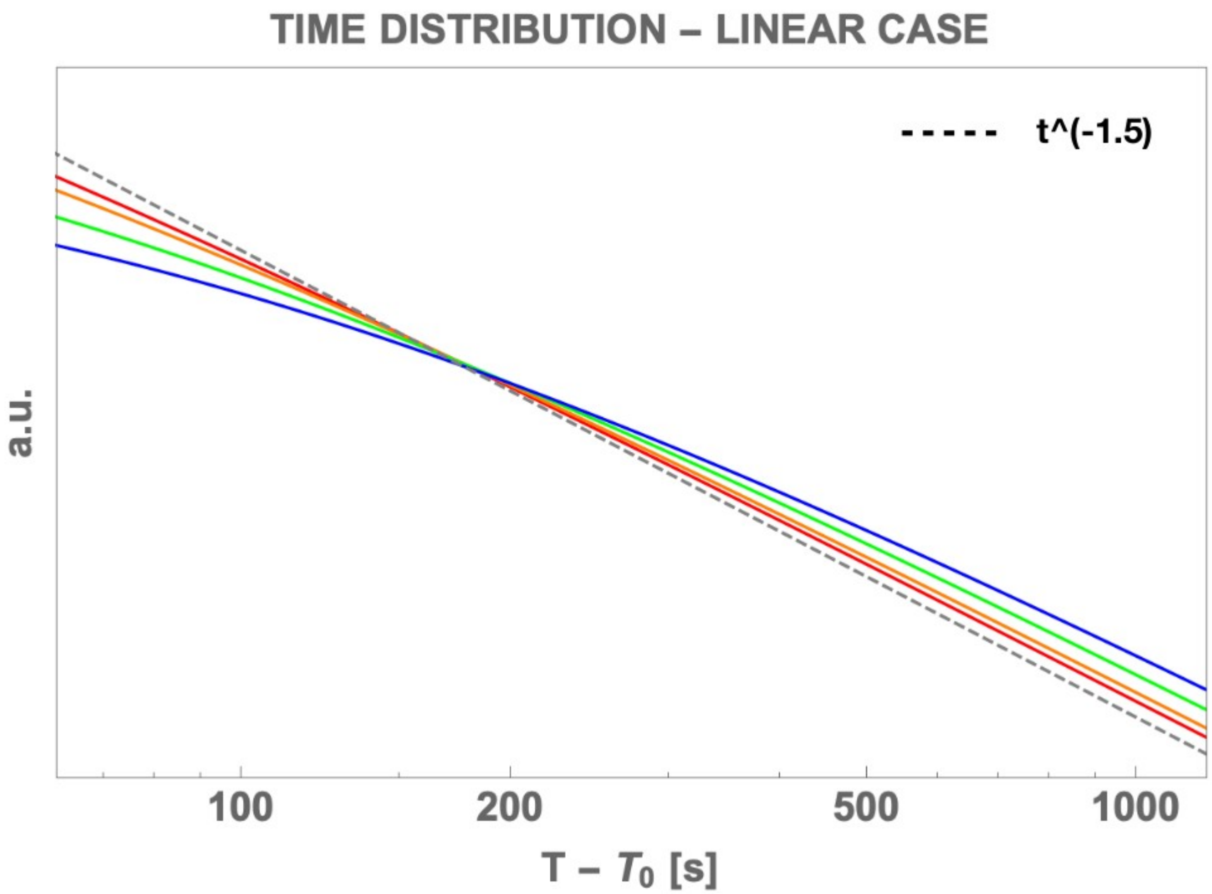


$$\eta_1 = -3$$

$$\Delta t = \eta_1 \cdot\ 17\ \mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

Courtesy of Giacomo D’Amico

What actually does the likelihood analysis?



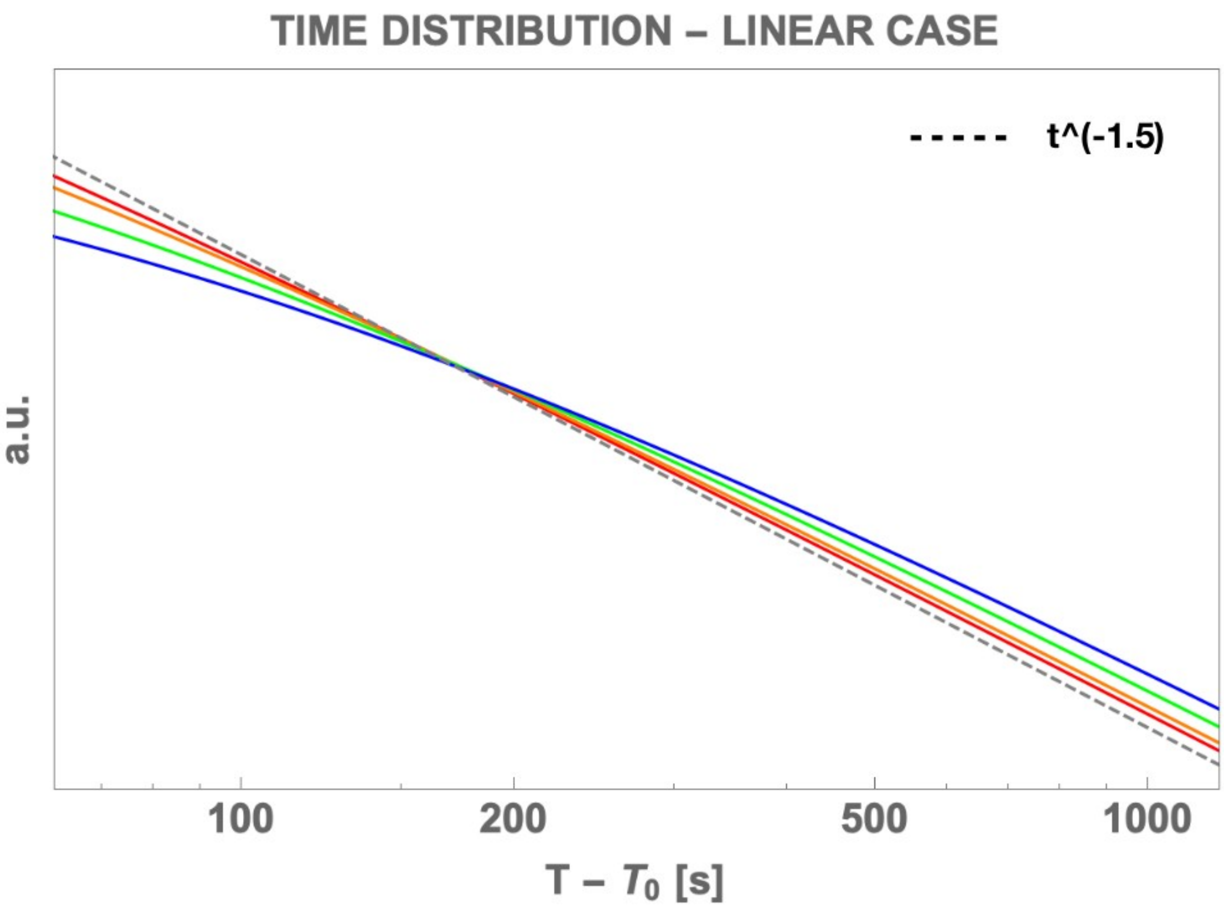
$$\eta_1 = -2.5$$

$$\Delta t = \eta_1 \cdot\ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

E_{est} = 300 GeV
E_{est} = 600 GeV
E_{est} = 1.2 TeV
E_{est} = 2 TeV

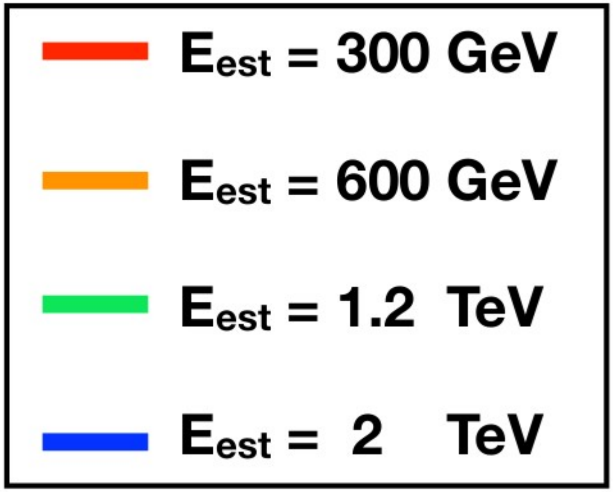
Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



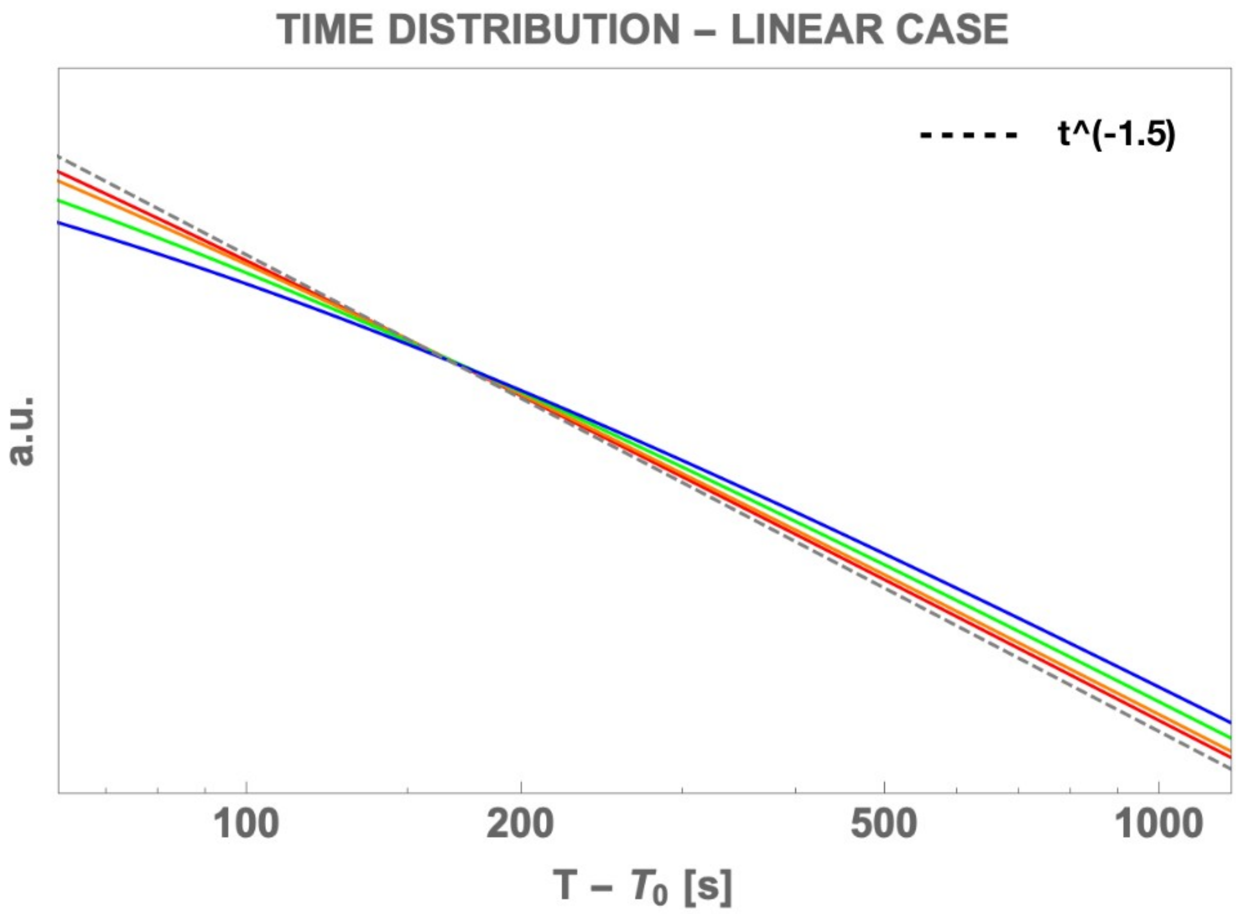
$$\eta_1 = -2$$

$$\Delta t = \eta_1 \cdot\ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



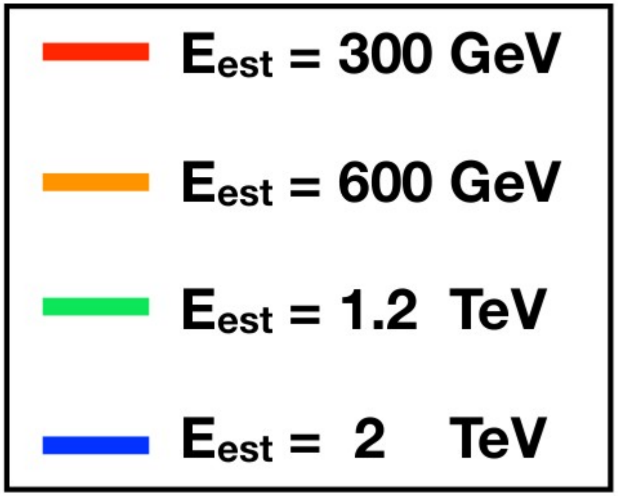
Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



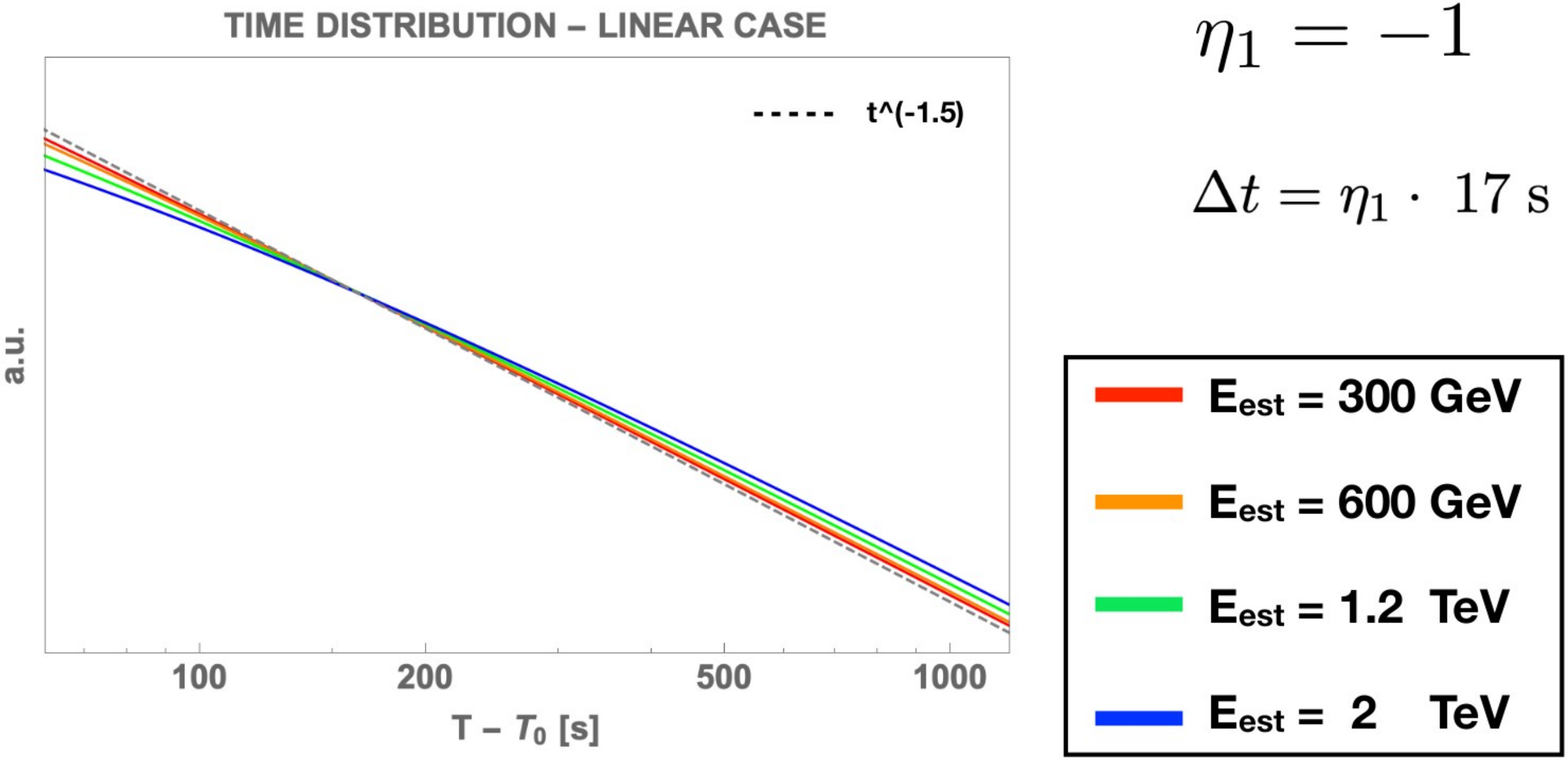
$$\eta_1 = -1.5$$

$$\Delta t = \eta_1 \cdot \ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?

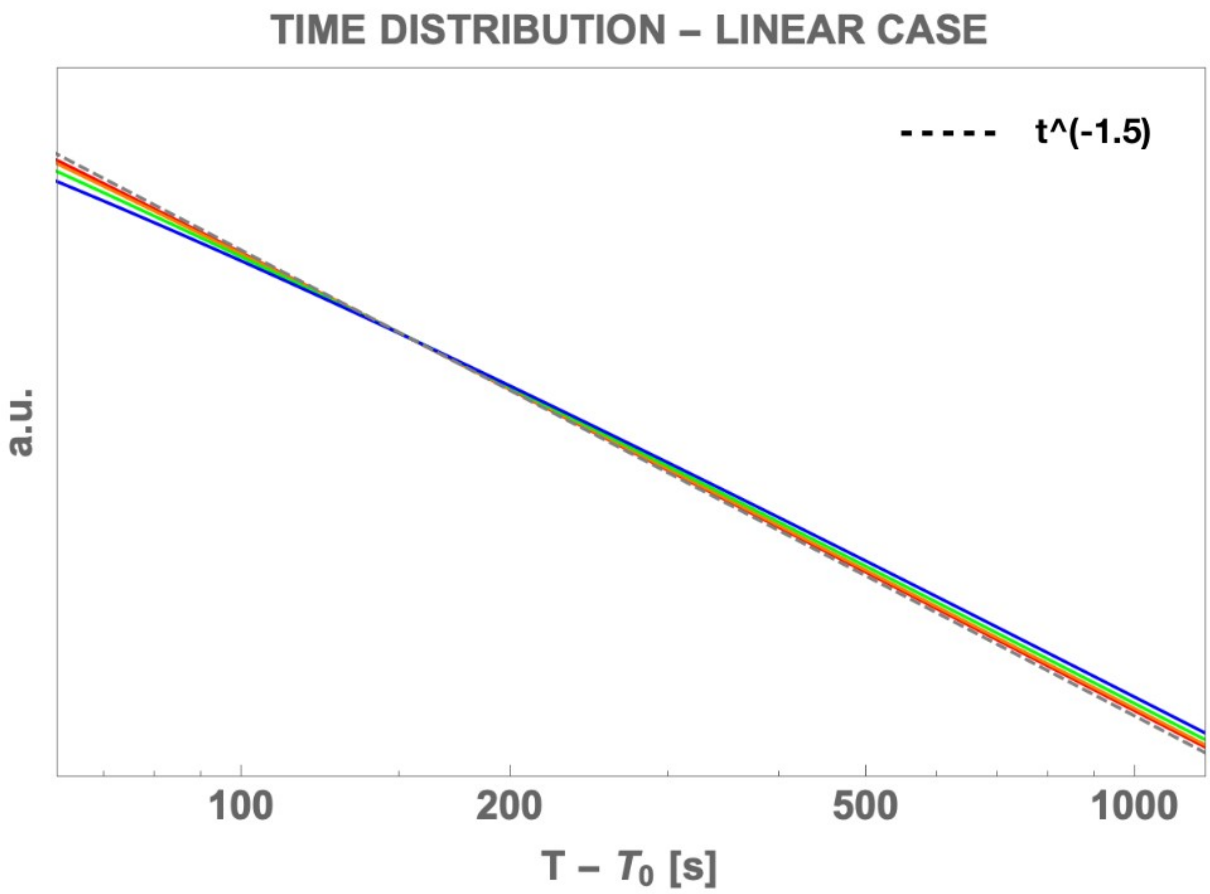


$$\eta_1 = -1$$

$$\Delta t = \eta_1 \cdot \; 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

Courtesy of Giacomo D’Amico

What actually does the likelihood analysis?



$$\eta_1 = -0.5$$

$$\Delta t = \eta_1 \cdot\ 17\ \mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

E_{est} = 300 GeV

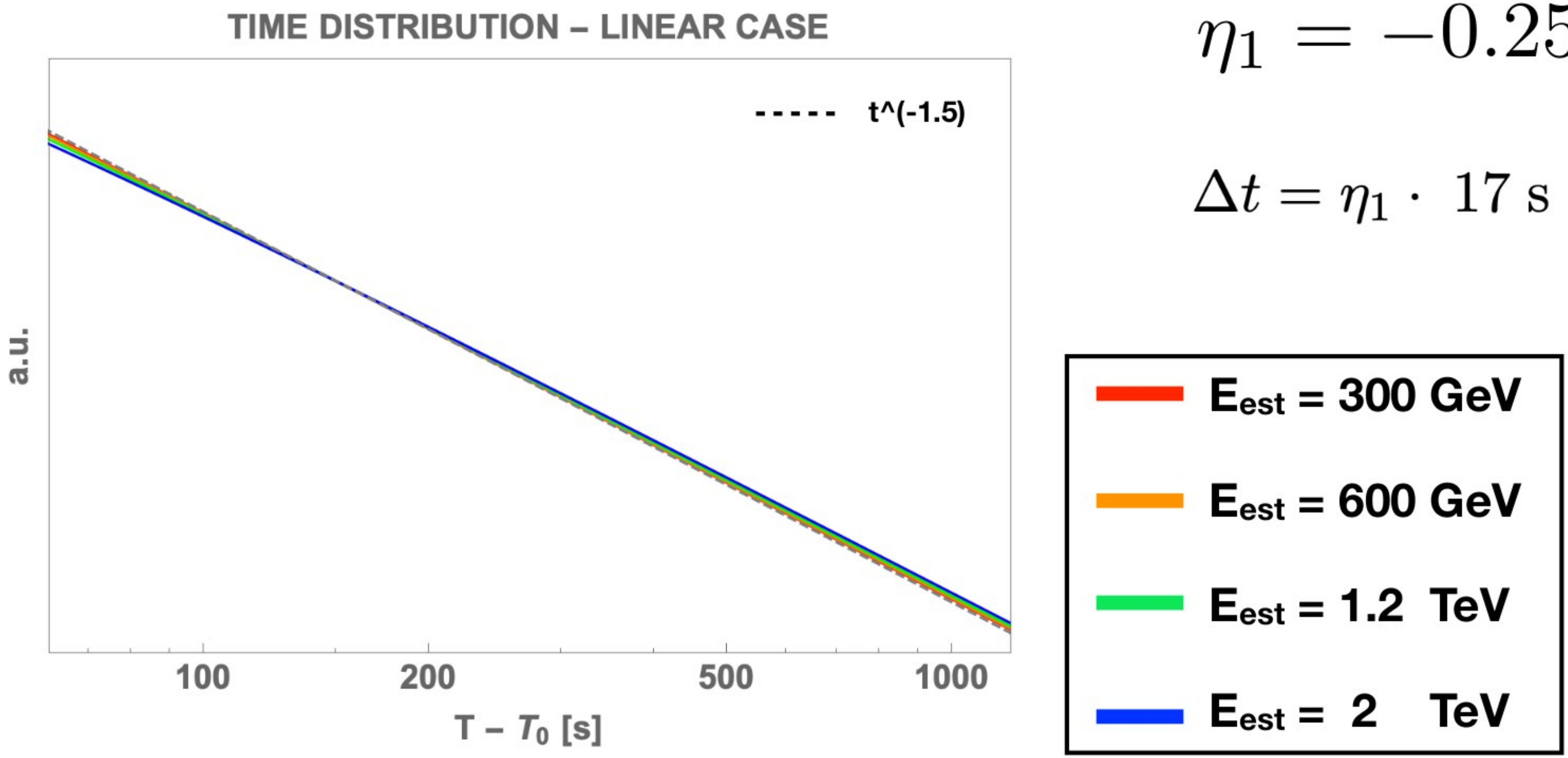
E_{est} = 600 GeV

E_{est} = 1.2 TeV

E_{est} = 2 TeV

Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?

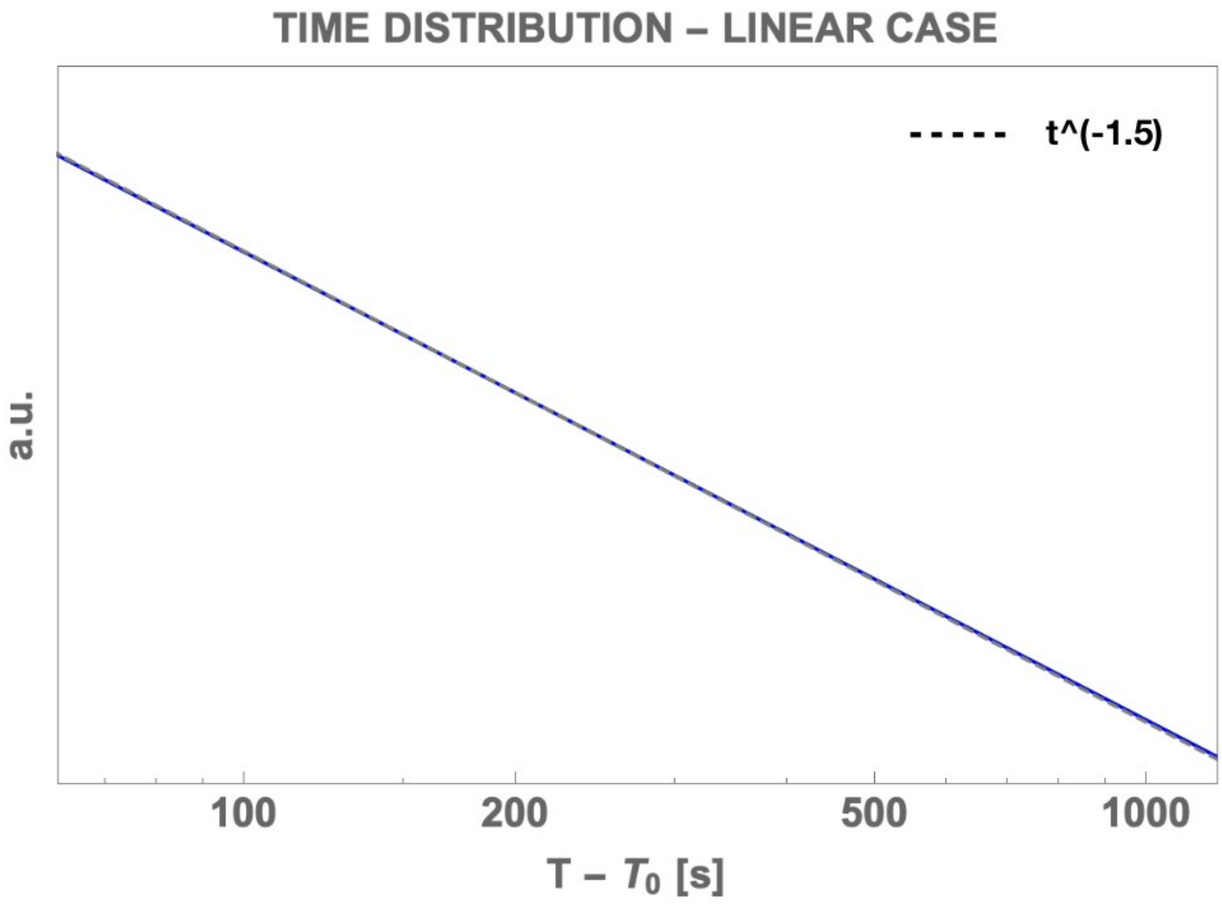


$$\eta_1 = -0.25$$

$$\Delta t = \eta_1 \cdot \ 17\ \mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

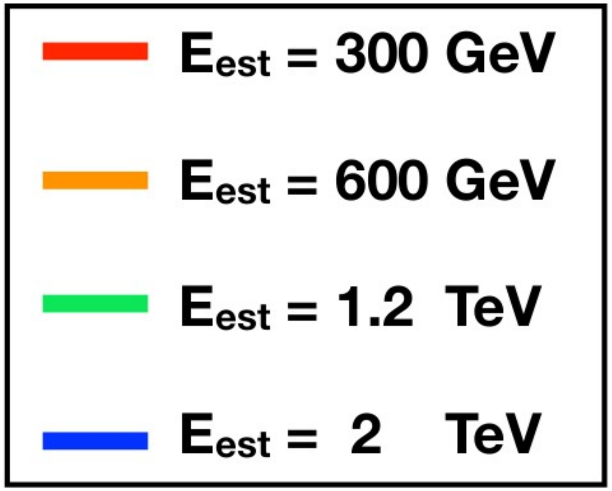
Courtesy of Giacomo D’Amico

What actually does the likelihood analysis?



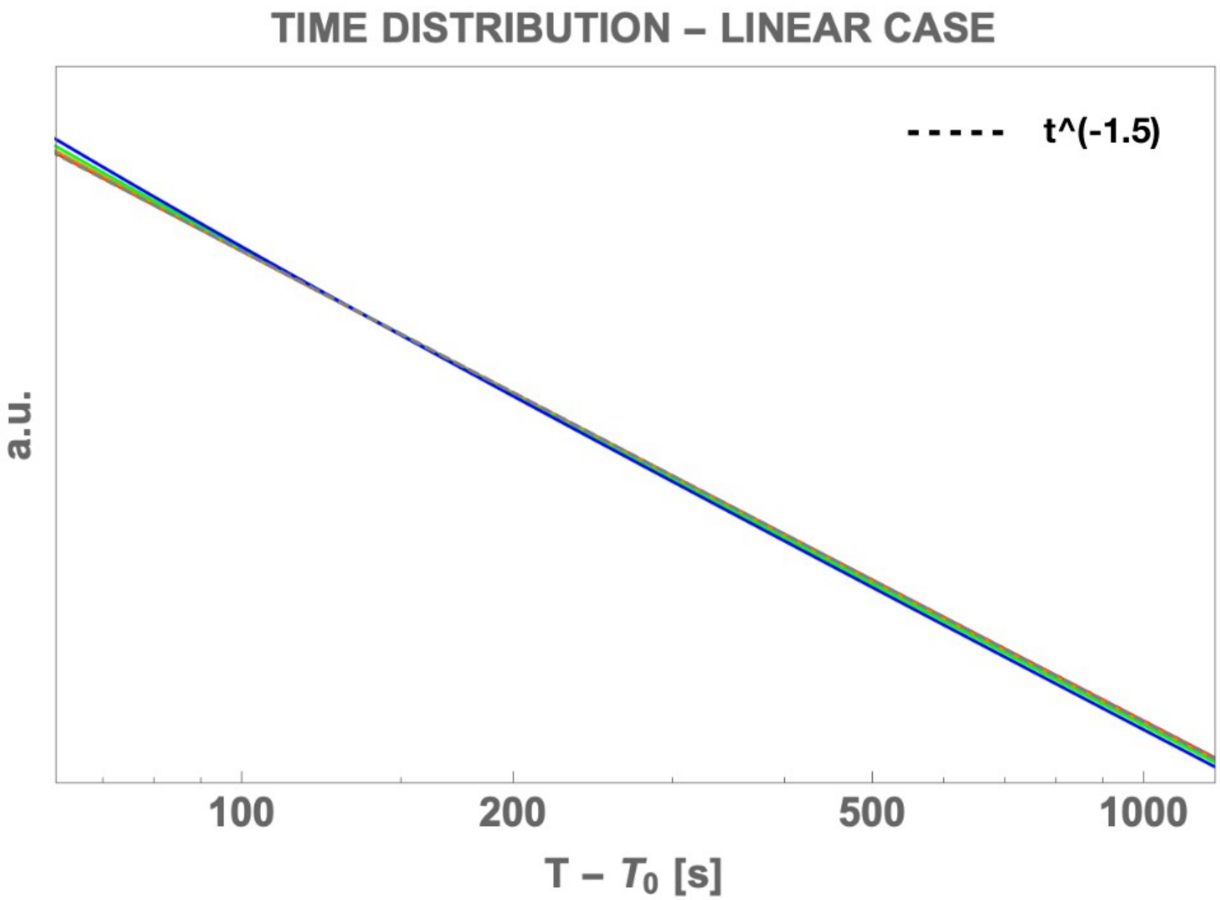
$$\eta_1 = 0$$

$$\Delta t = \eta_1 \cdot \ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



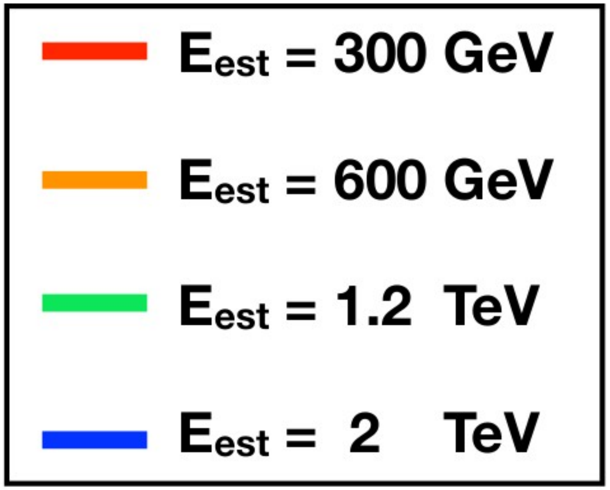
Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



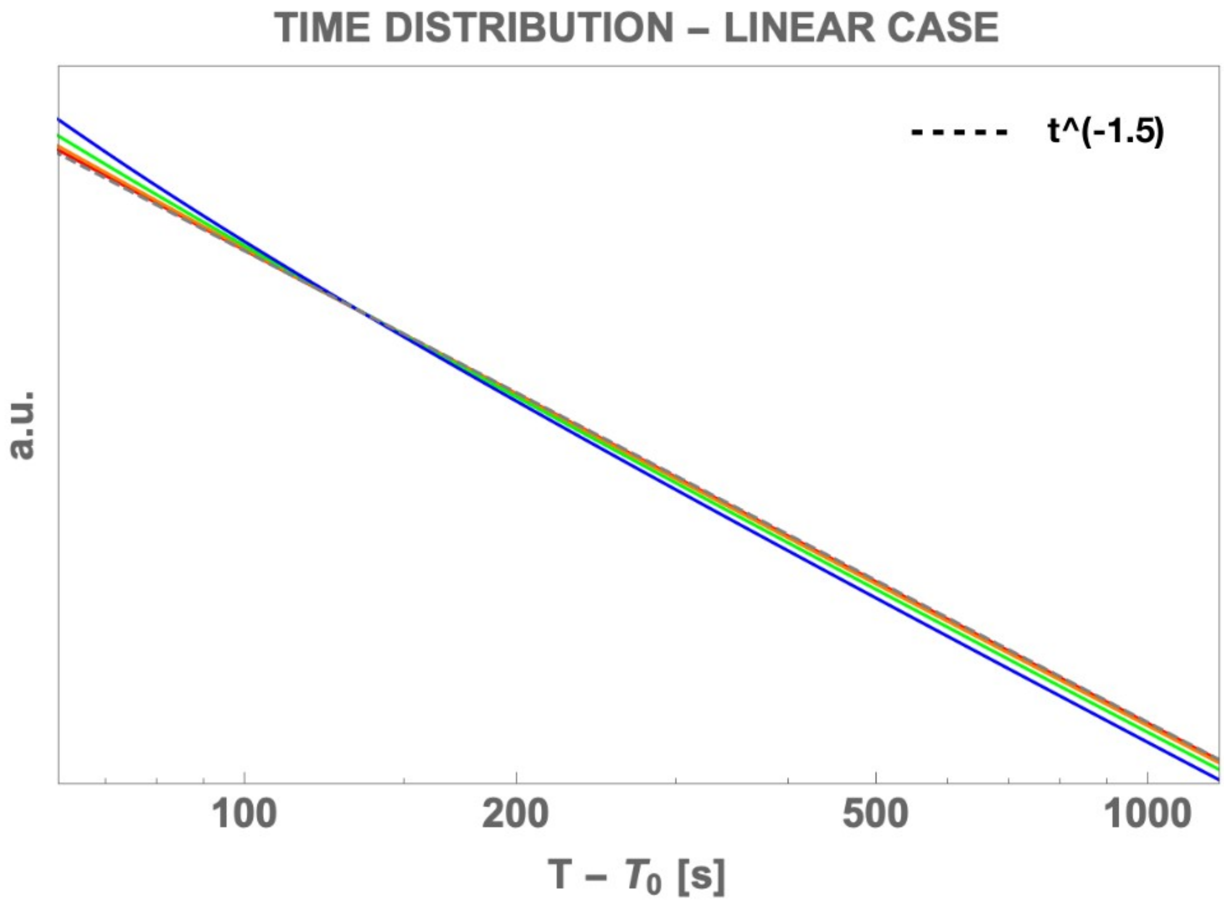
$$\eta_1 = 0.25$$

$$\Delta t = \eta_1 \cdot 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



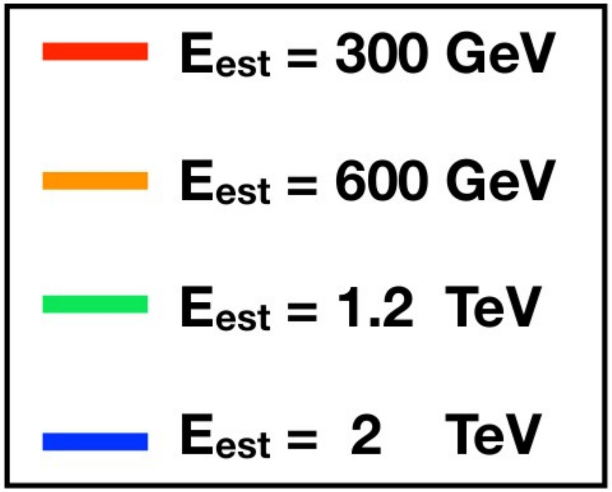
Courtesy of Giacomo D’Amico

What actually does the likelihood analysis?



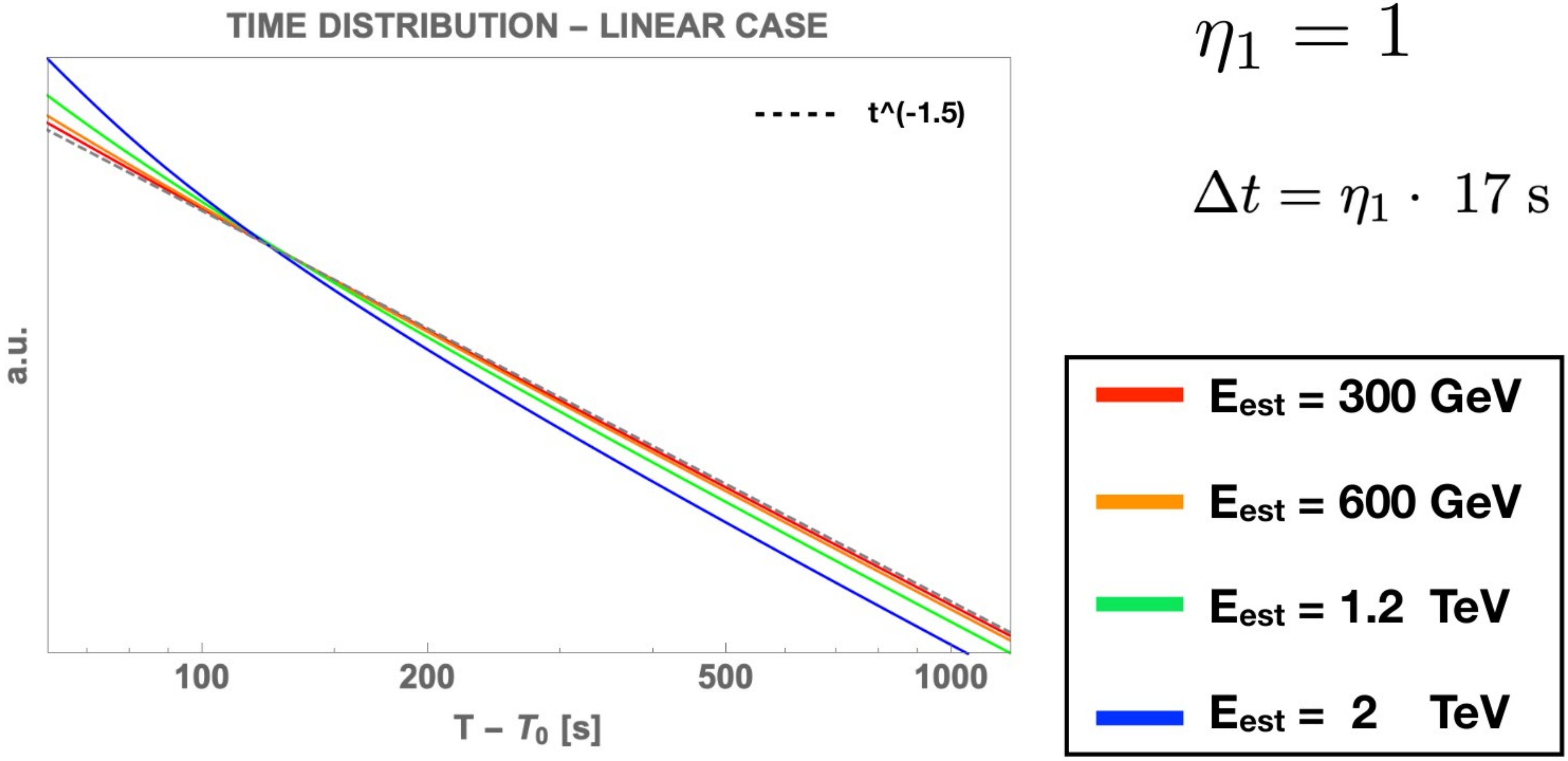
$$\eta_1 = 0.5$$

$$\Delta t = \eta_1 \cdot \, 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?

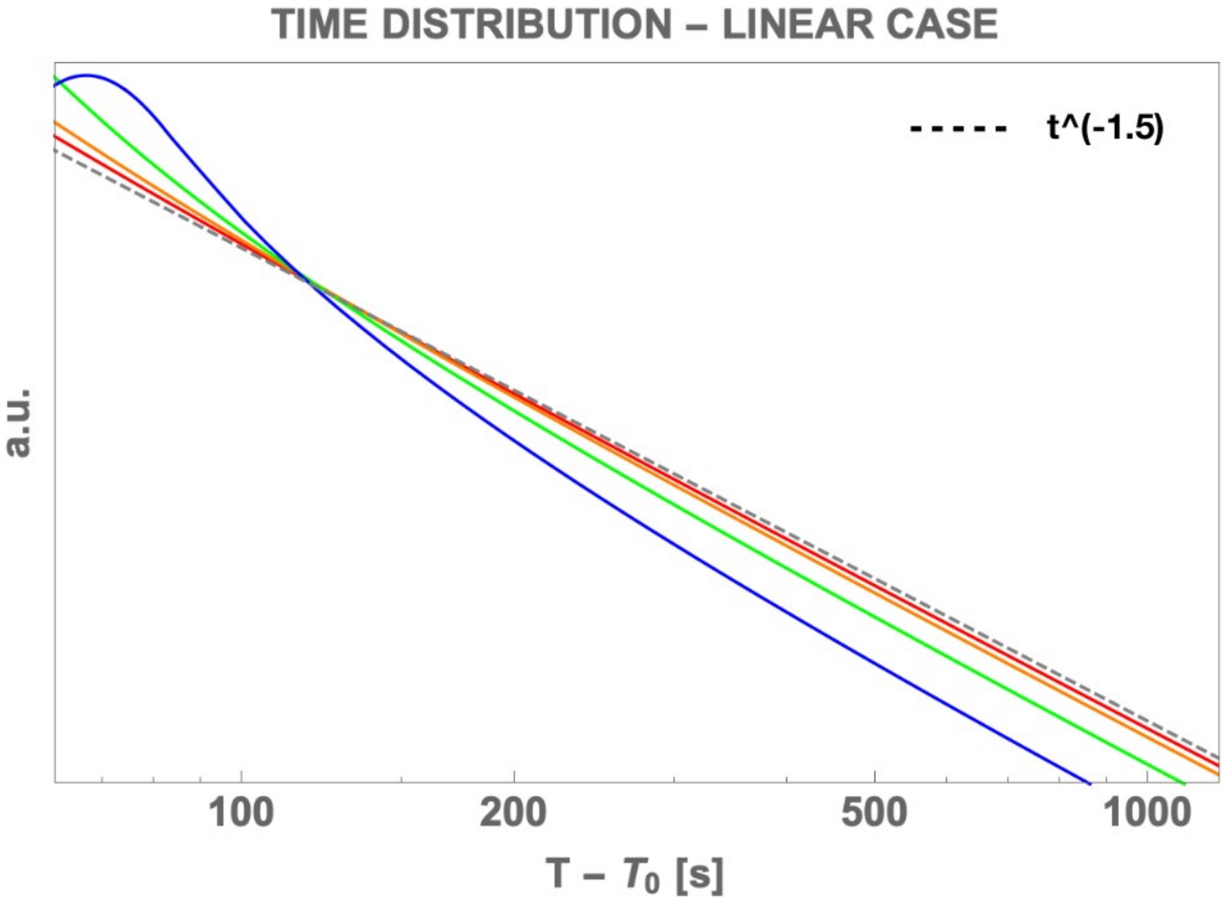


$$\eta_1 = 1$$

$$\Delta t = \eta_1 \cdot \ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

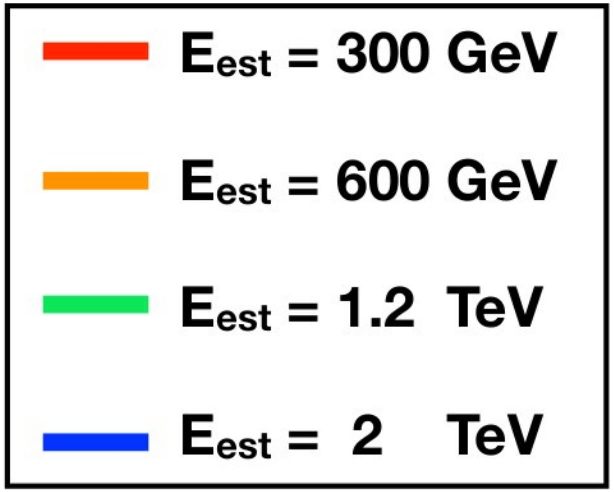
Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



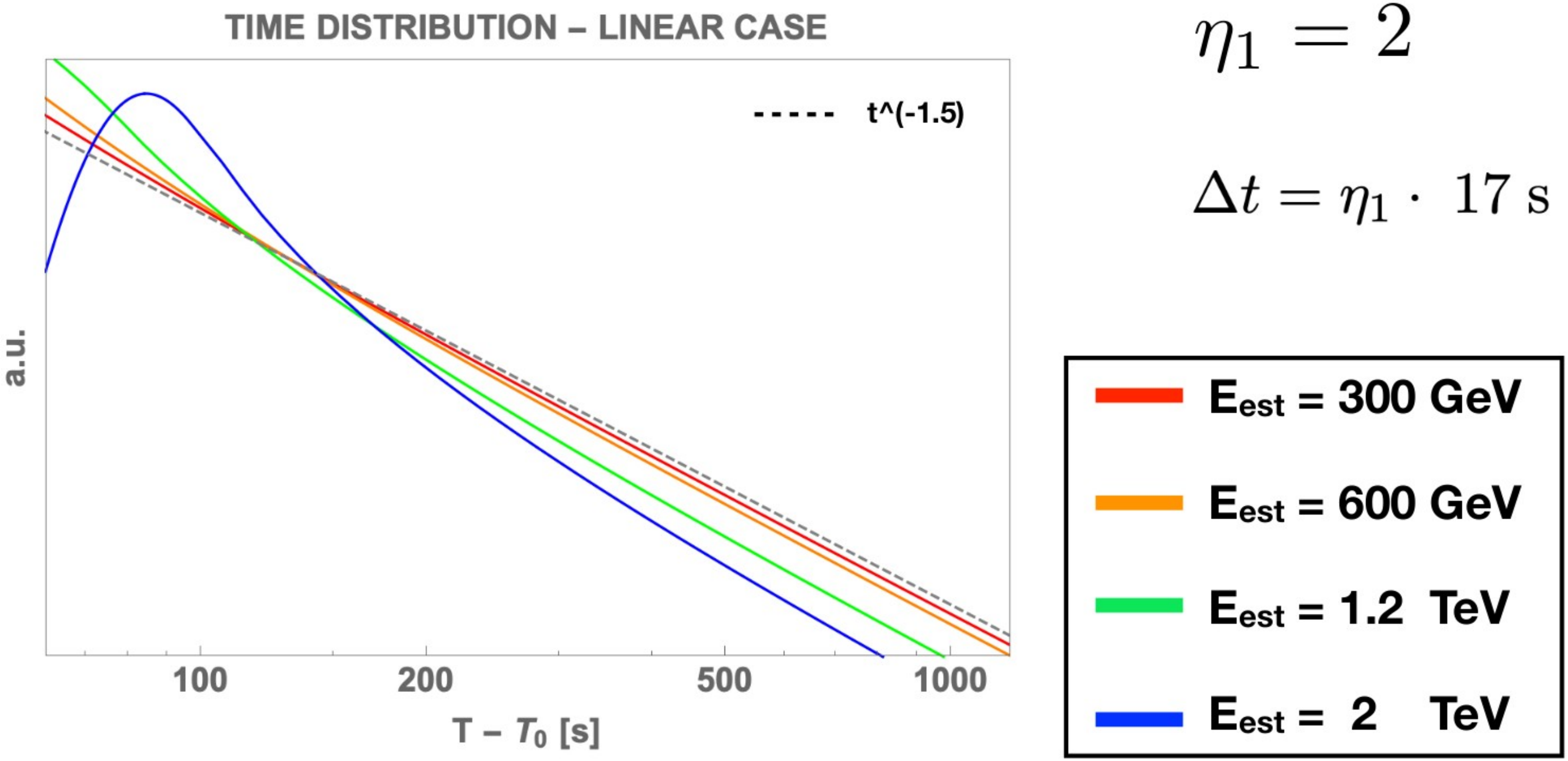
$$\eta_1 = 1.5$$

$$\Delta t = \eta_1 \cdot\ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?

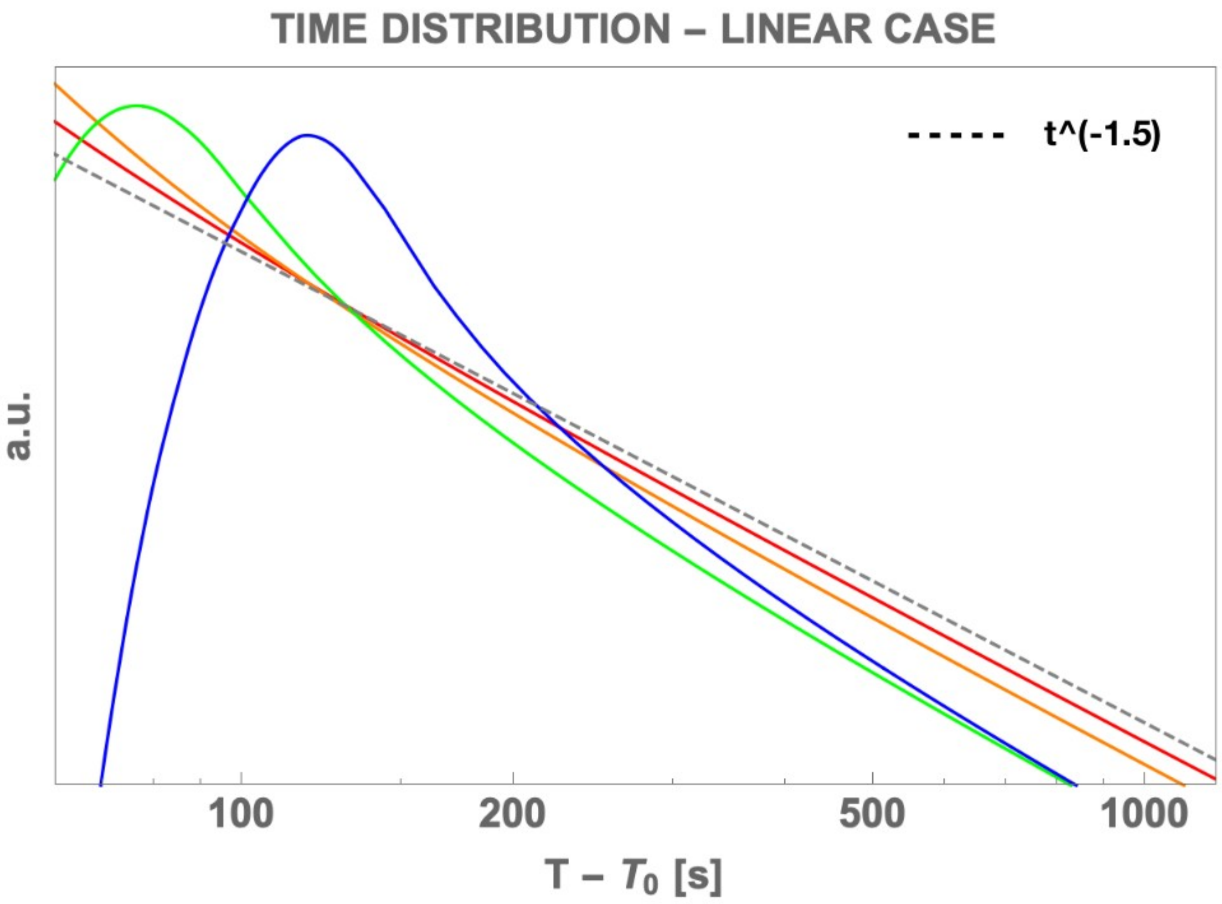


$$\eta_1 = 2$$

$$\Delta t = \eta_1 \cdot 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



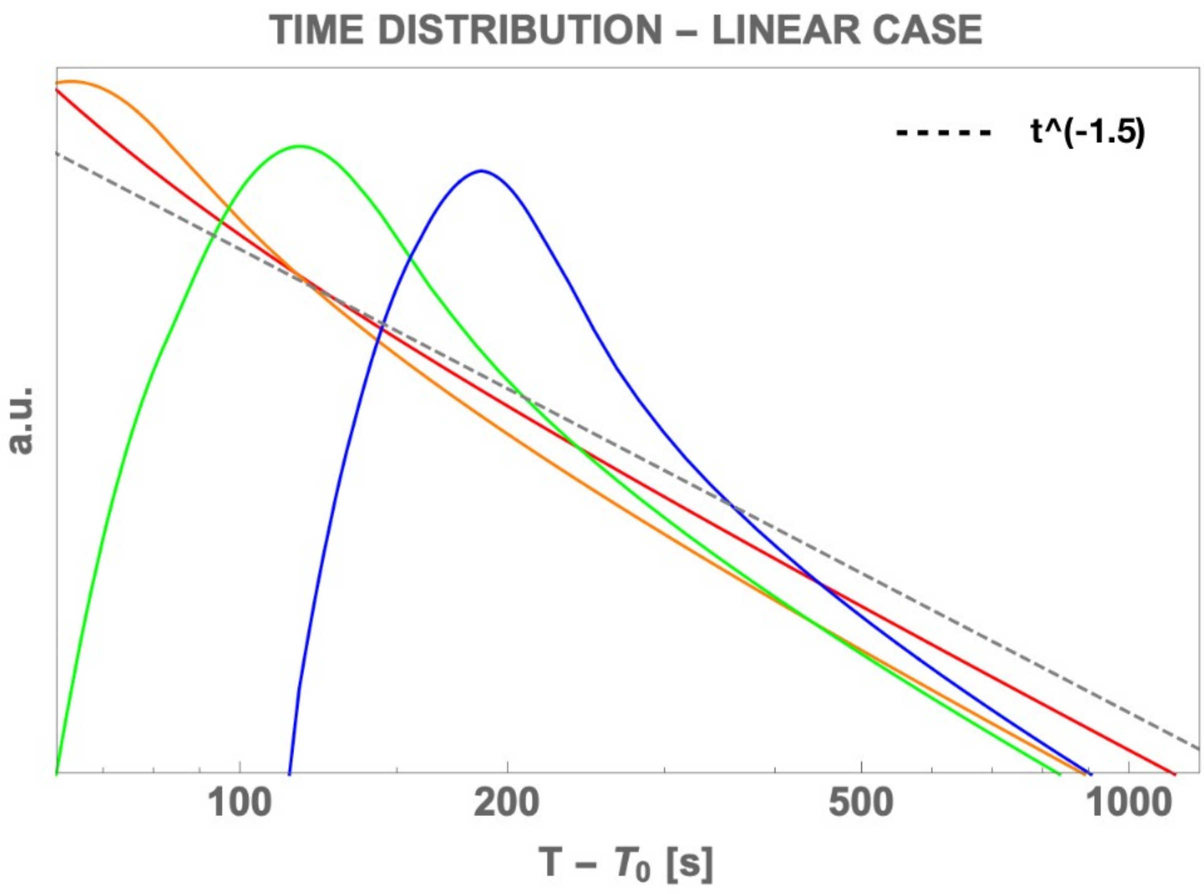
$$\eta_1 = 3$$

$$\Delta t = \eta_1 \cdot \ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$

E_{est} = 300 GeV
E_{est} = 600 GeV
E_{est} = 1.2 TeV
E_{est} = 2 TeV

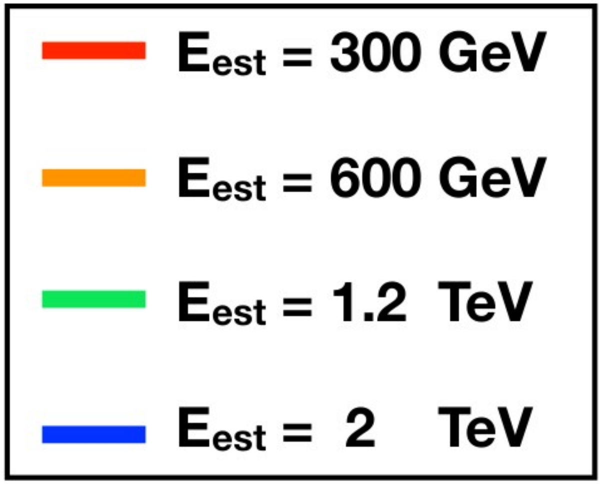
Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



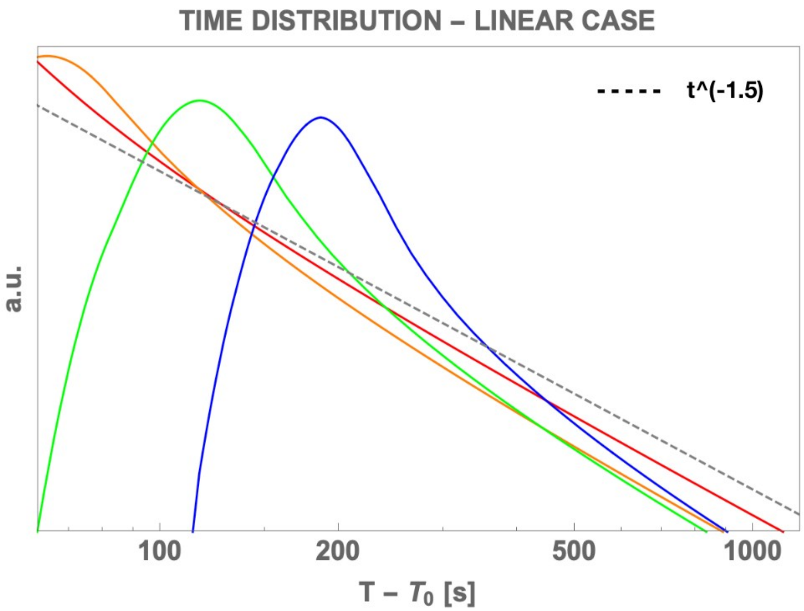
$$\eta_1 = 5$$

$$\Delta t = \eta_1 \cdot \ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



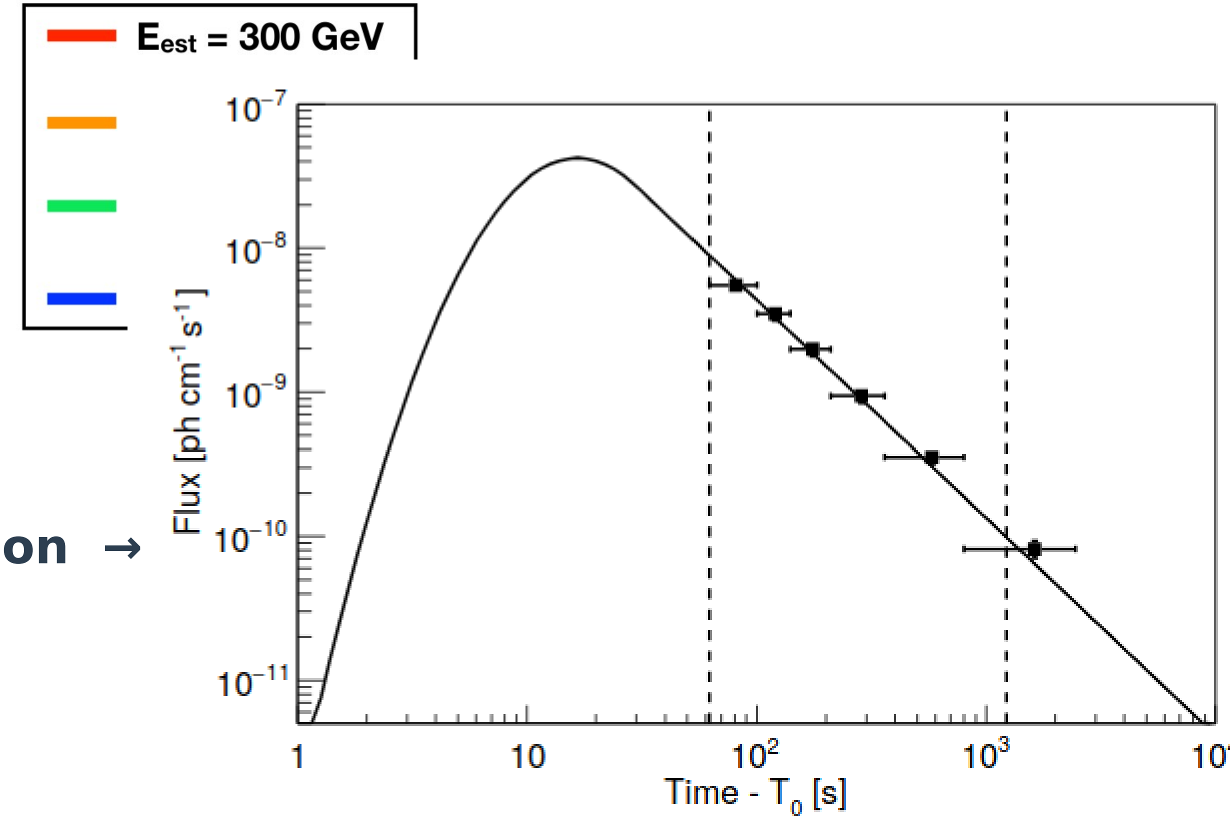
Courtesy of Giacomo D'Amico

What actually does the likelihood analysis?



$$\eta_1 = 5$$

$$\Delta t = \eta_1 \cdot \ 17\,\mathrm{s} \cdot \frac{E}{\mathrm{TeV}}$$



Caveat:

This is a binned representation →

In practice, the likelihood analysis is unbinned

Comparison with previous results

Source	Source type	Redshift	$E_{QG,1}$ [10^{19} GeV]	$E_{QG,2}$ [10^{10} GeV]	Instrument
GRB 090510	GRB	0.9	9.3	13	*Fermi*-LAT[1]
GRB 140119C	GRB	0.42	**0.58**	**6.3**	MAGIC
PKS 2155-304	AGN	0.116	0.21	6.4	H.E.S.S.[2]
Mrk 501	AGN	0.034	0.036	8.5	H.E.S.S.[3]
Mrk 501	AGN	0.034	0.021	2.6	MAGIC[4]
Mrk 421	AGN	0.031	pending	pending	MAGIC
Crab Pulsar	Pulsar	2.0 kpc	0.055	5.9	MAGIC[5]

10.1103/PhysRevLett.125.021301

https://arxiv.org/abs/2001.09728

More details on the likelihood, how the bias of the method is computed, how we calibrate intervals to set the limits...

LIV with GRB190114C: conclusion

- **For LIV we need distant, reaching high energy, variable sources:**

  → GRB perfect for that
- **GRB 190114C: first GRB detected at TeV energies!**

  → among the best limits even if the prompt phase was not detected

- **These LIV studies are sensitive to intrinsic time delays at the source, but intrinsic time delays are distinguishable from LIV/propagation delays which are redshift dependent**

  → Need to combine LIV observations from different observations of various sources (at different redshifts) in a redshift-dependent likelihood analysis

  → Ongoing work between MAGIC, H.E.S.S., and VERITAS

LST-1: the first on site telescope

- **Optics:**
  - Parabolic primary mirror of 23 m diameter and 28 m focal length
  - Primary dish made of 198 hexagonal segments
  - Effective mirror area is 368 m²
- **Focal plane:**
  - Made of 1855 PMTs
  - Pixel field of view of 0.1°
  - Total field of view of 4.5°
- **Structure:**
  - Alt-az mount
  - Maximum time for repositioning is 20 seconds
  - Total weight of the telescope is ~120 tons

GRBs with the LSTs

In total there will be 4 LSTs in La Palma:

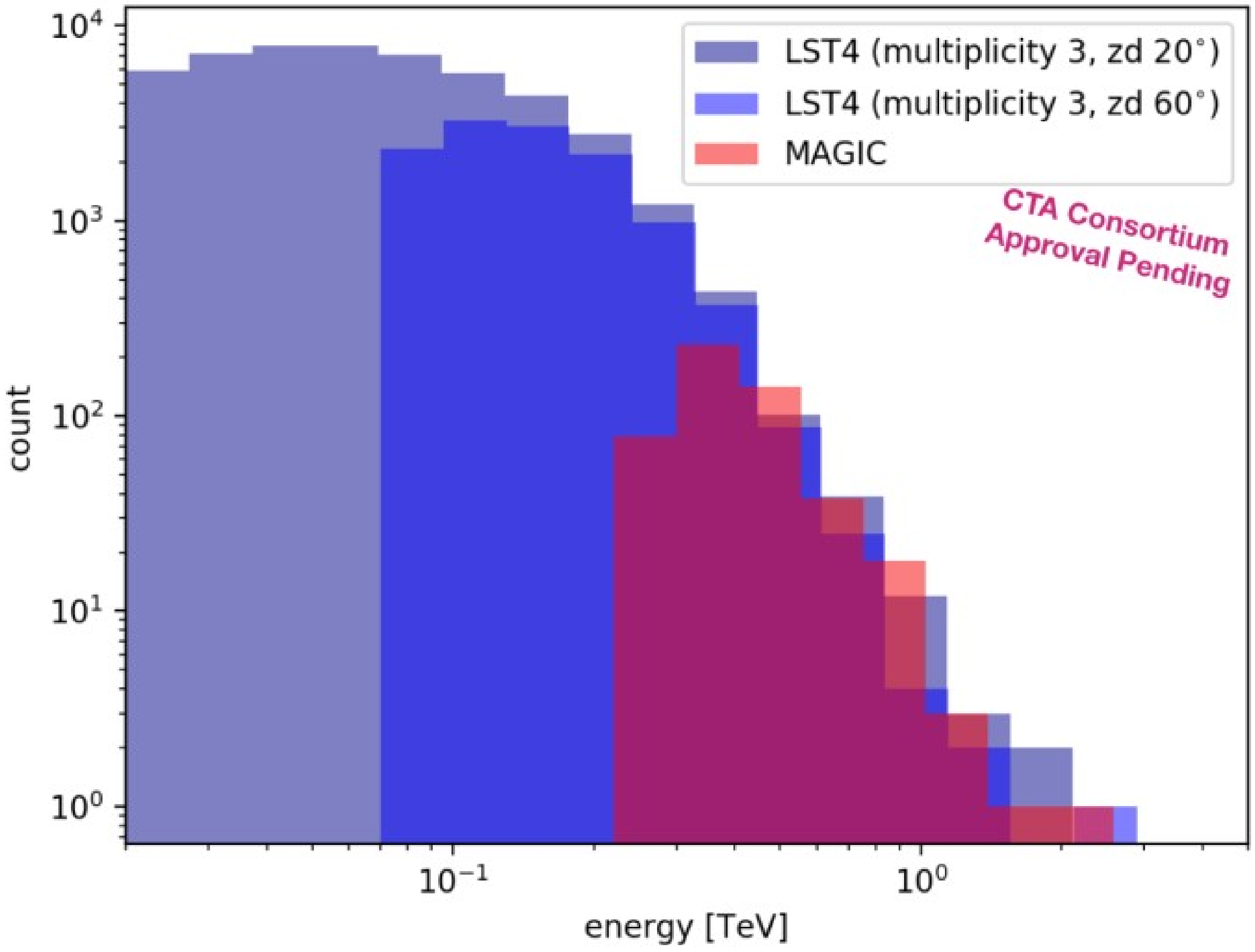
- Lower energy threshold → more events detected
- Faster repositioning → more events detected

What would GRB 190114C look for the 4 LSTs?

- Assuming observations by 4 LSTs during 100 sec at the La Palma site
- Using T_0 +62 sec and T_0 + 162 sec (where MAGIC and Fermi-LAT overlap)

  → ~450 events detected by MAGIC in this interval
- Requiring trigger from 3 out of 4 LSTs
- Assuming angular resolution of 0.15 degree at 100 GeV
- Assuming the intrinsic spectrum of GRB 190114C from MAGIC

Energy distribution of the events

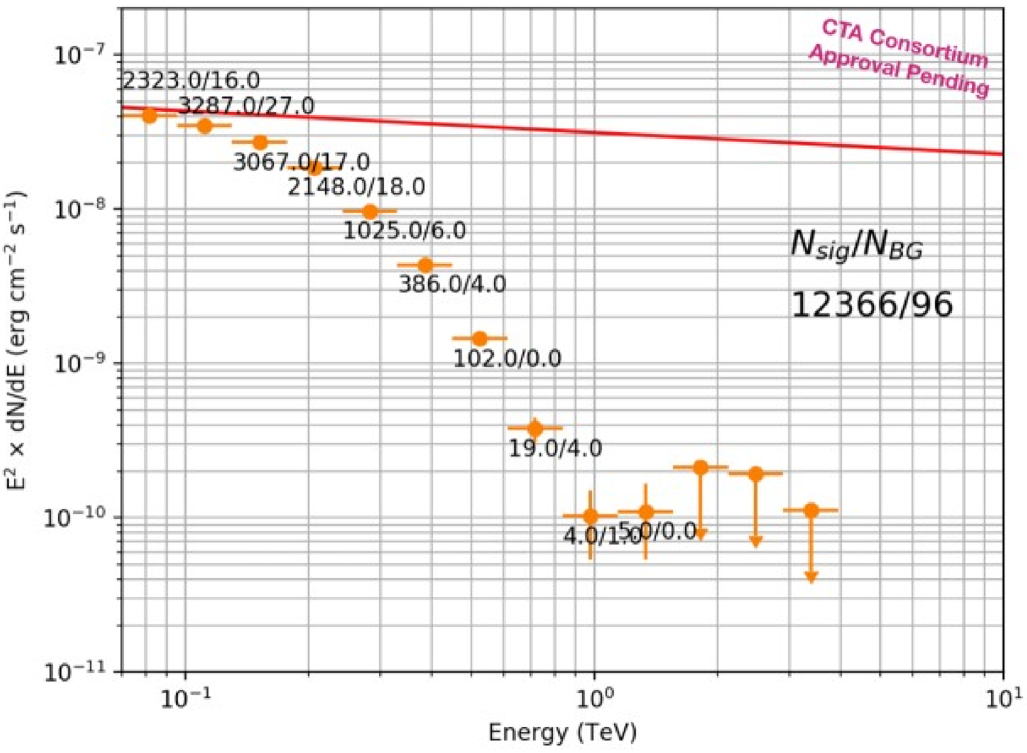


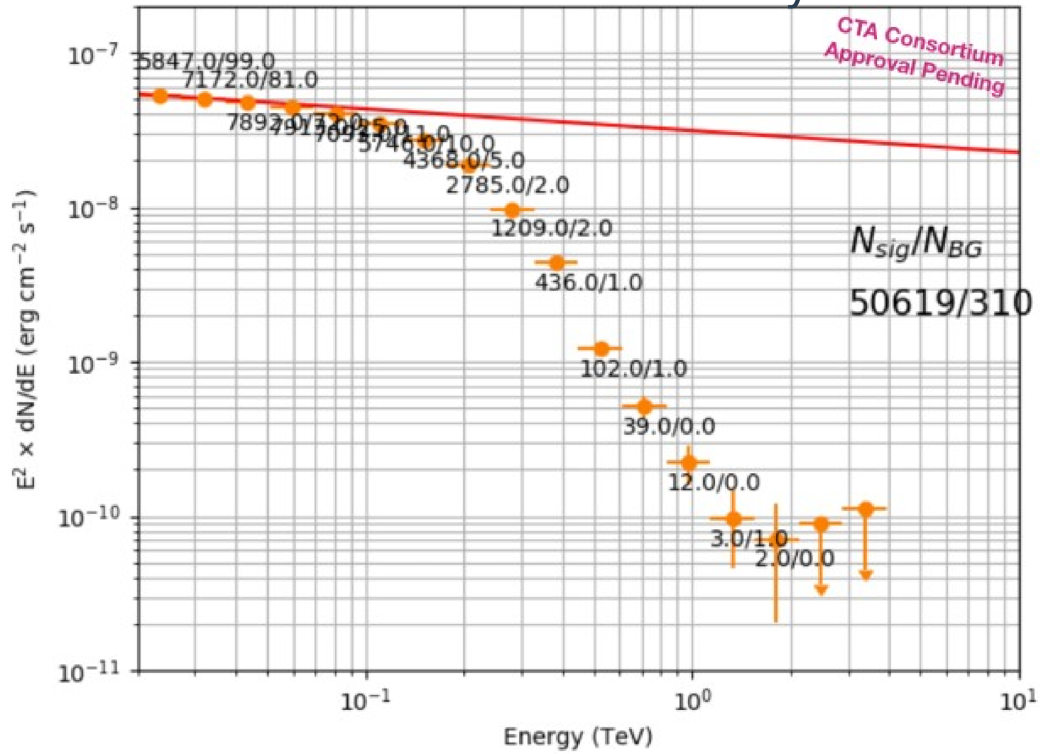
Plot by S. Fukami

- **Relaxing trigger multiplicity to 2 telescopes would increase even more the numbers of events detected**

Effect of the zenith angle

Plots by S. Fukami



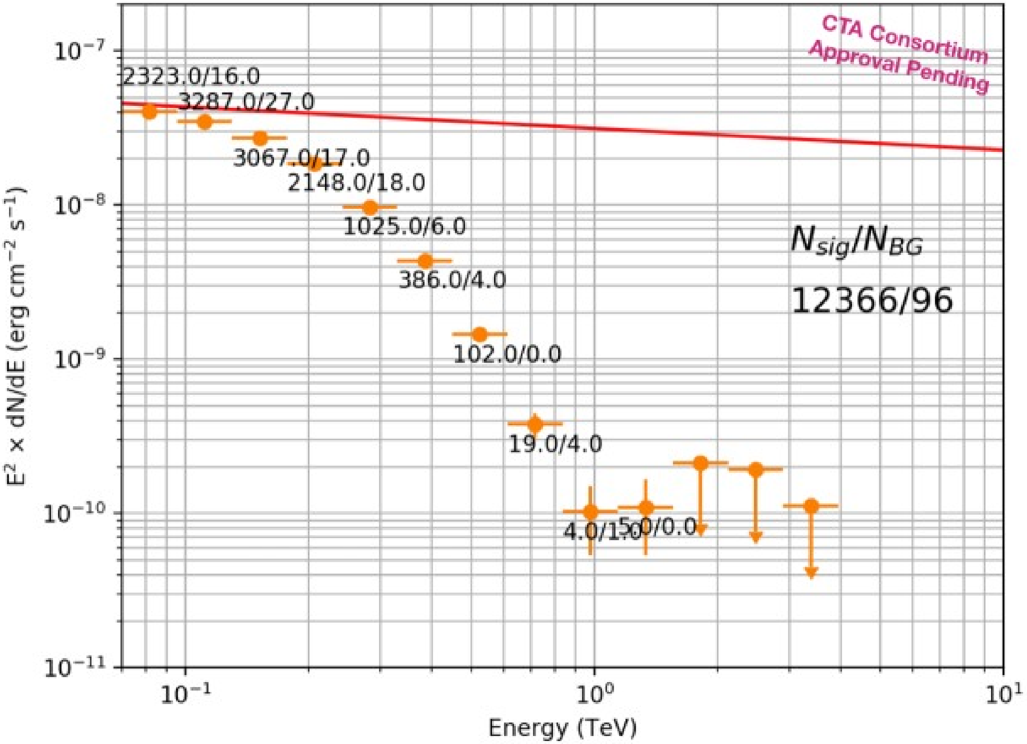


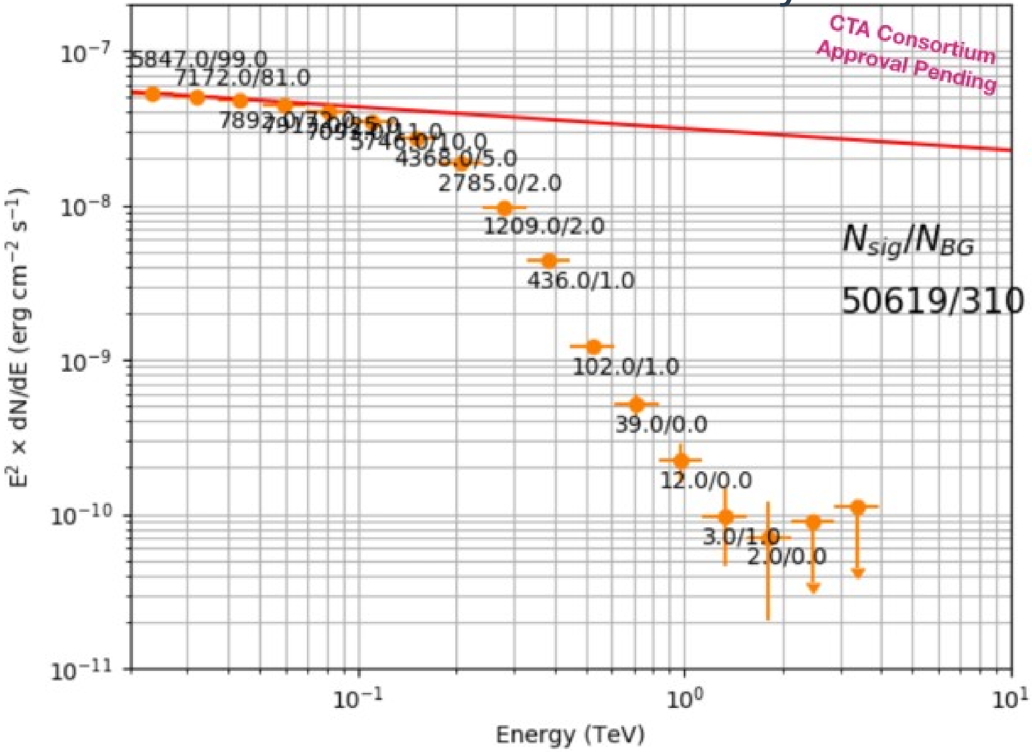
zenith angle = 60 degrees **zenith angle = 20 degrees**

- **At 60°, 4 LSTs would have seen ~ 30 times more events than MAGIC**
- **At 20°, 4 LSTs would have seen ~ 100 times more events than MAGIC**

Effect of the zenith angle

Plots by S. Fukami



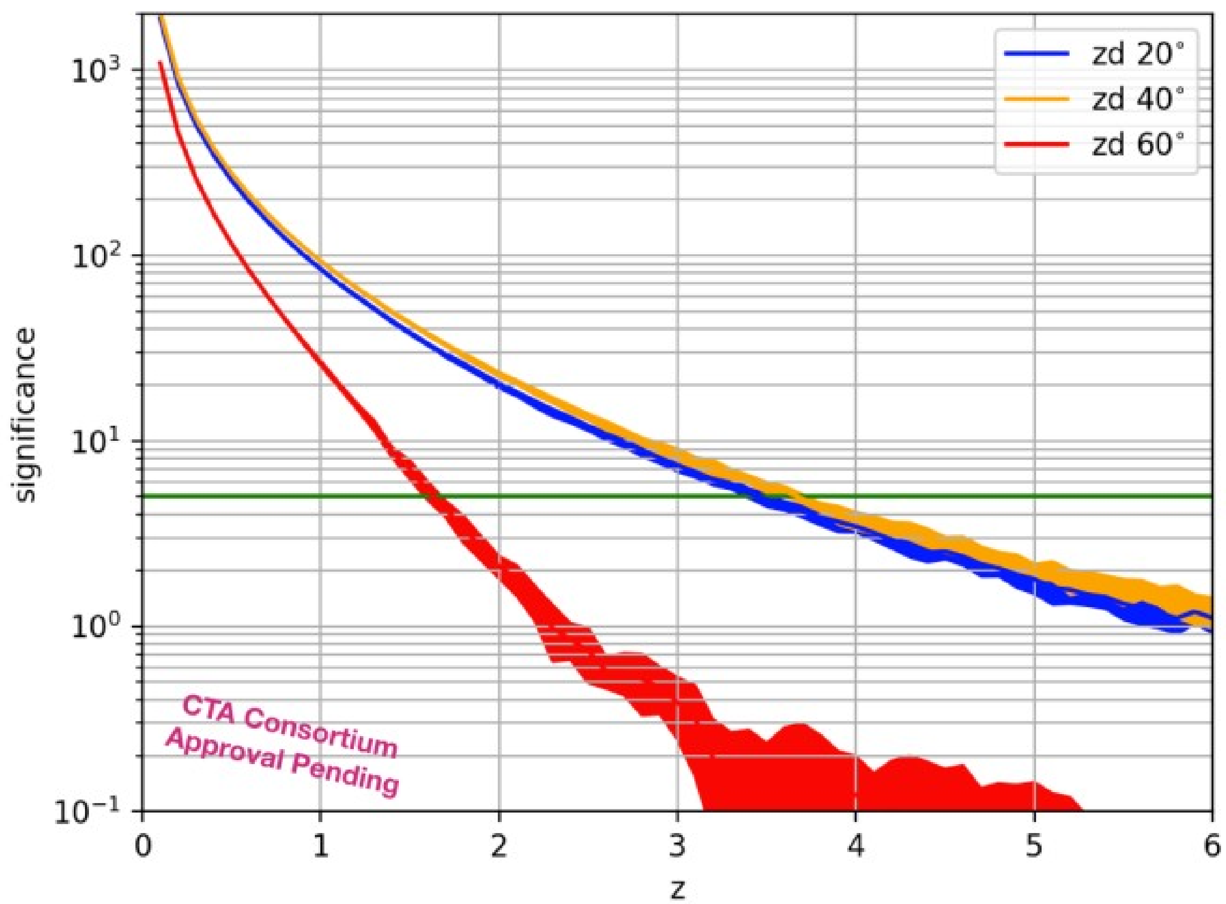


zenith angle = 60 degrees

zenith angle = 20 degrees

In the lower energy bins the statistics is so high (> 1000 events) that the 100 seconds interval can be divided in much shorter time bins

Redshift effect on the detectability



Plot by S. Fukami

- **4 LSTs could detect an event similar to GRB190114C up to:**
  - **z ~ 1.5 in similar zenith angle conditions (60 degrees)**
  - **z ~ 3 with better observation conditions (zenith angle < 40 degrees)**

Conclusion

We will have to see for real but

LIV studies (among others) with the LSTs promise to be incredible!

Thank you for your attention!