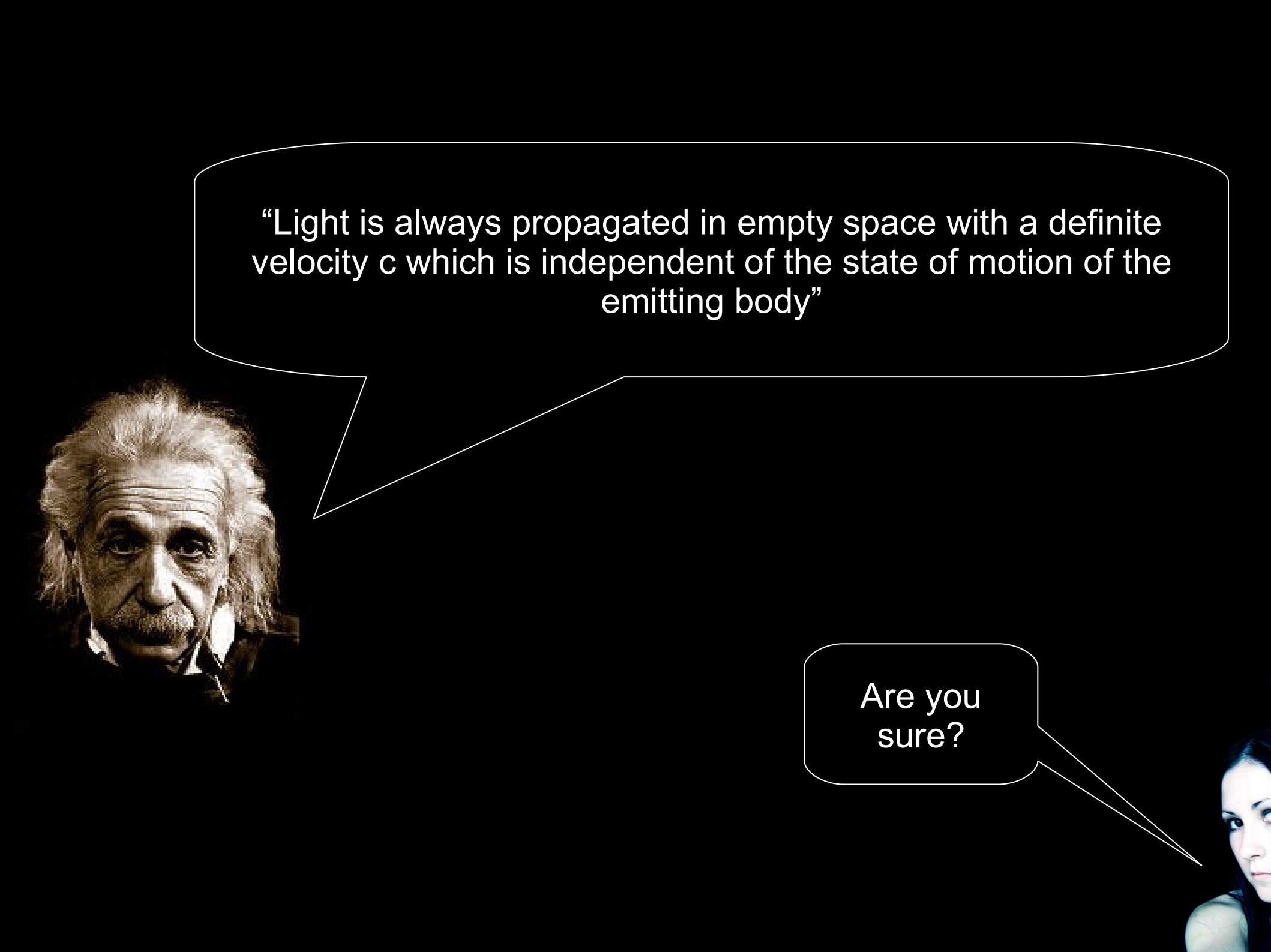


Probing Lorentz Invariance with a VHE-Flare of PKS 2155-304

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for the H.E.S.S. collaboration



“Light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body”

Are you
sure?



Is c energy dependent ?

Several Quantum Gravity models have predicted energy dependence of the speed of light. General parametrization:

$$c' = c \left(1 \pm \xi \frac{E}{E_P} \pm \zeta^2 \frac{E^2}{E_P^2} \right), \text{ with } E_P = 1.22 \times 10^{19} \text{ GeV}$$

Leads to dispersion of poly-energetic signals:

Linear:

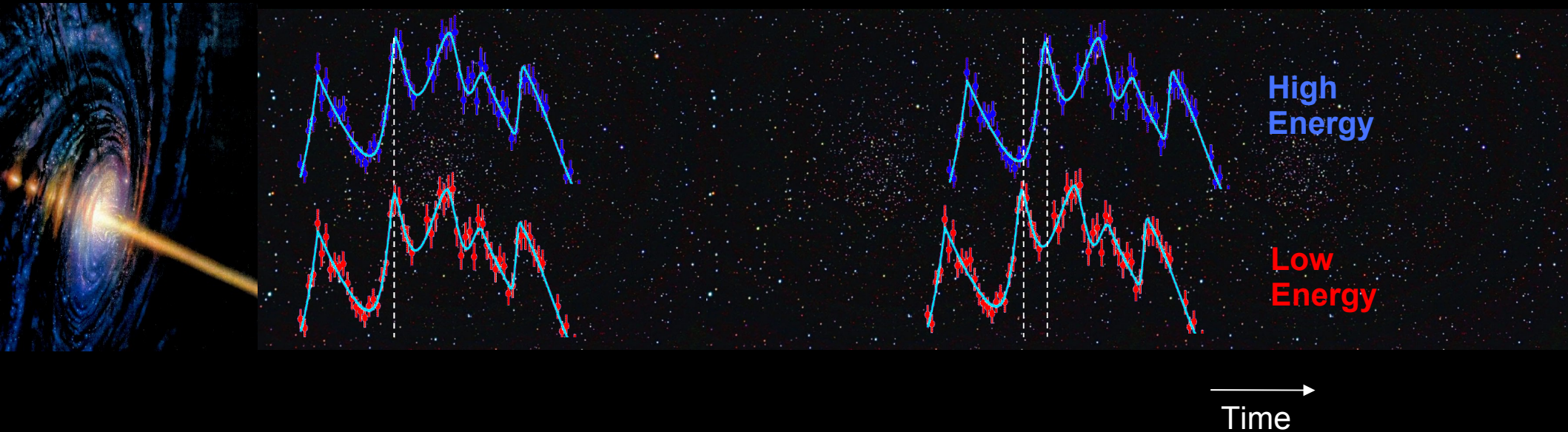
$$\frac{\Delta t}{\Delta E} \approx \mp \xi \frac{L}{E_P c}$$

Quadratic:

$$\frac{\Delta t}{\Delta E^2} \approx \mp \zeta^2 \frac{L}{E_P^2 c}$$



Measurable effect ?



Requirements:

Long distance, fast variability → GRB's (x-Ray) and AGN (VHE)

Caveat:

Cancellation due to source intrinsic effect
(unlikely if no dispersion)

→ Population studies



Current limits

Time of flight measurements

GRB's [1,2] :	$\xi < 150$	(population studies: $\xi < 1300$)
AGN's [3] :	$\xi < 200$	

Vacuum Birefringence

Radio Galaxies [4] :	$\xi < 10^{-5}$	(if sign helicity dependent)
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Modified thresholds

UHECR [5] :	$\xi < 10^{-14}$	(if sign negative)
Crab Nebula [6] :	$\xi < 10^{-5}$	(for electrons)

[1]Boggs et al., Ap. J. L. (2004)

[2]Ellis et al., Astr. Part. Phys (2006)

[3]Biller et al., PRL (1999)

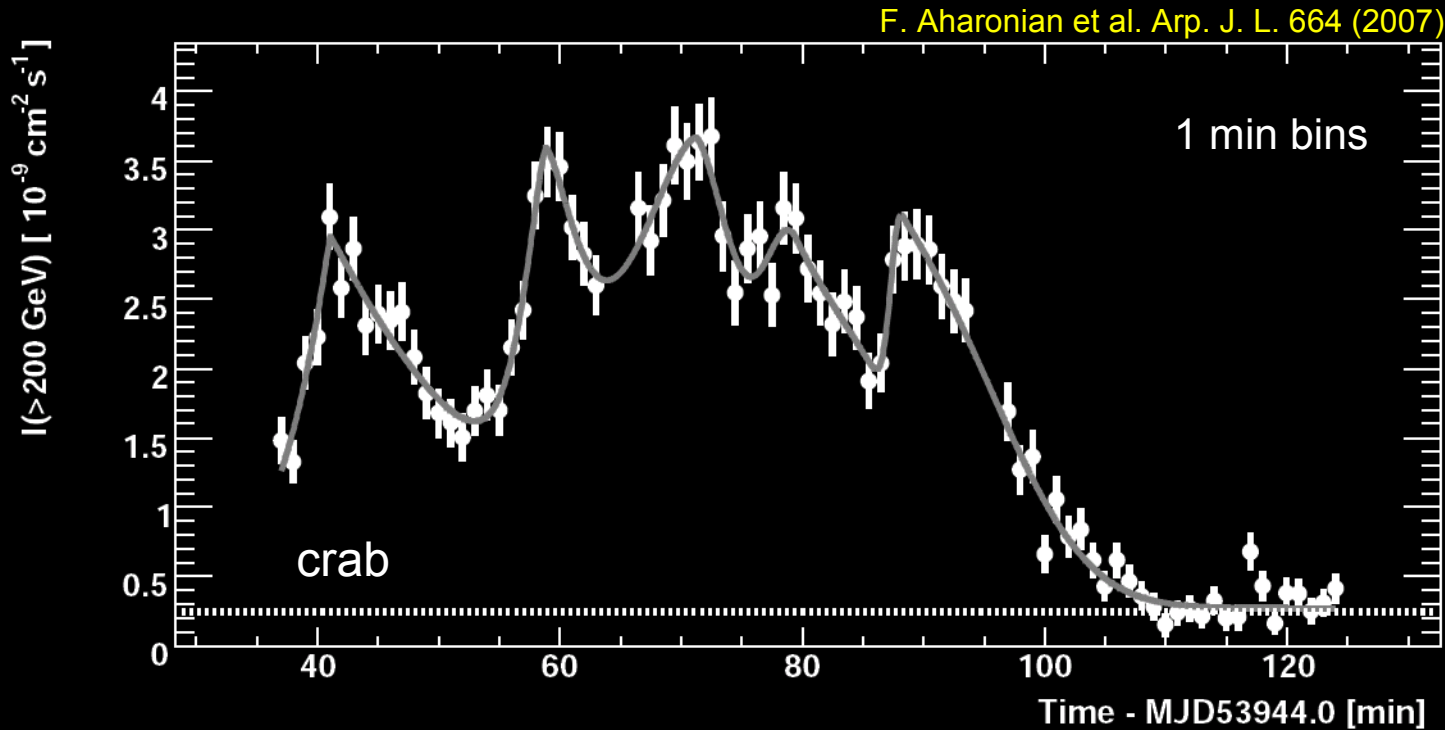
[4]Gleiser et al. , PRD (2001)

[5]Galaverni et al., PRL (2008)

[6]Maccione et al., JCAP (2007)

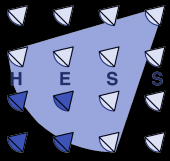


The "big flare" of PKS 2155 -304

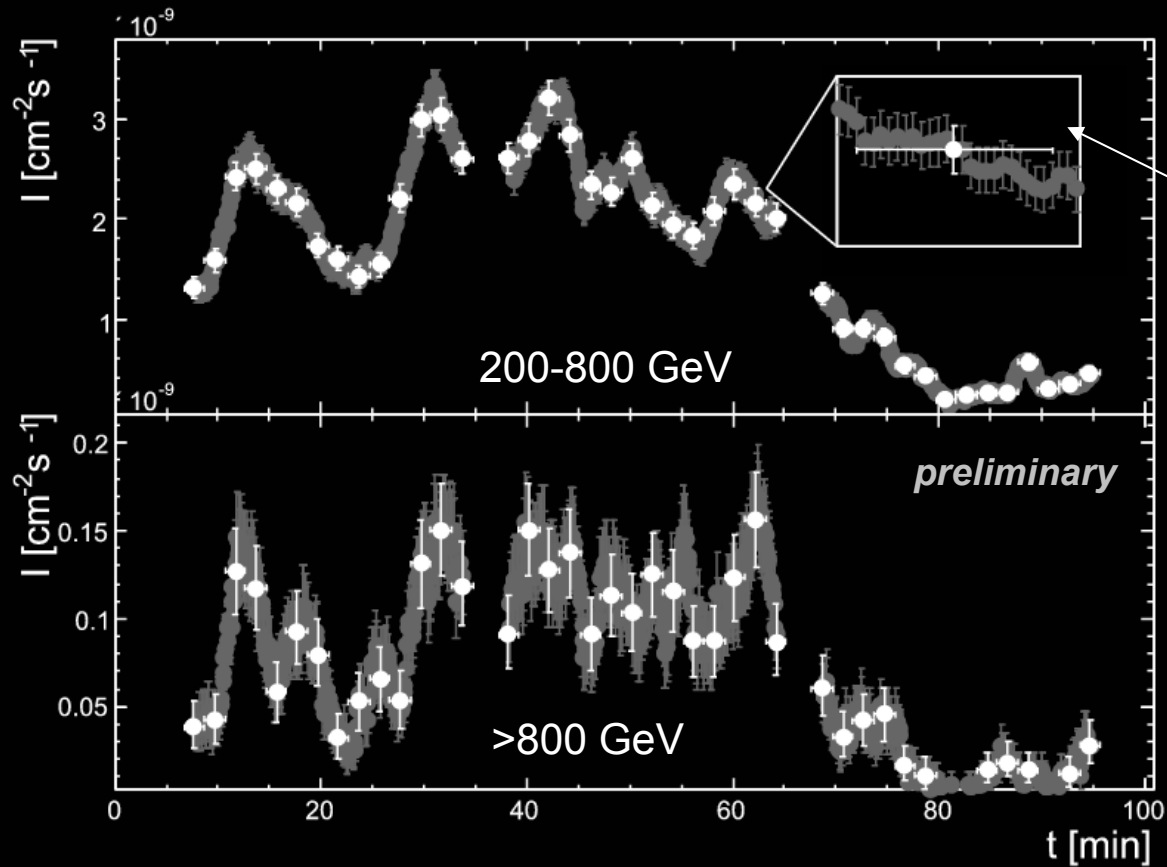


- Historic high fluxes (~ 14 crab or ~ 80 times normal)
- High statistics (~ 10000 photons)
- Five sub-burst with rise/fall times of ~ 200 s

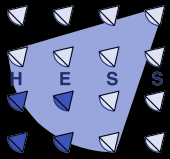
High state in all of July, see thursday ..



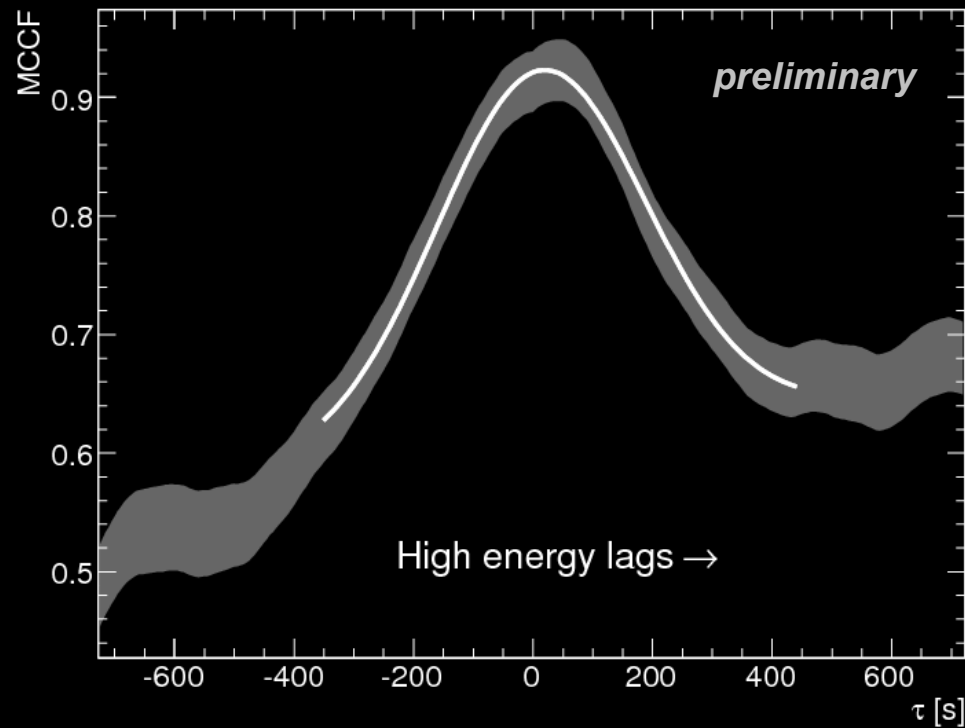
The "big flare" of PKS 2155 -304



$$\Delta E_{\text{mean}} = 1 \text{ TeV}$$



The Modified Cross Correlation Function

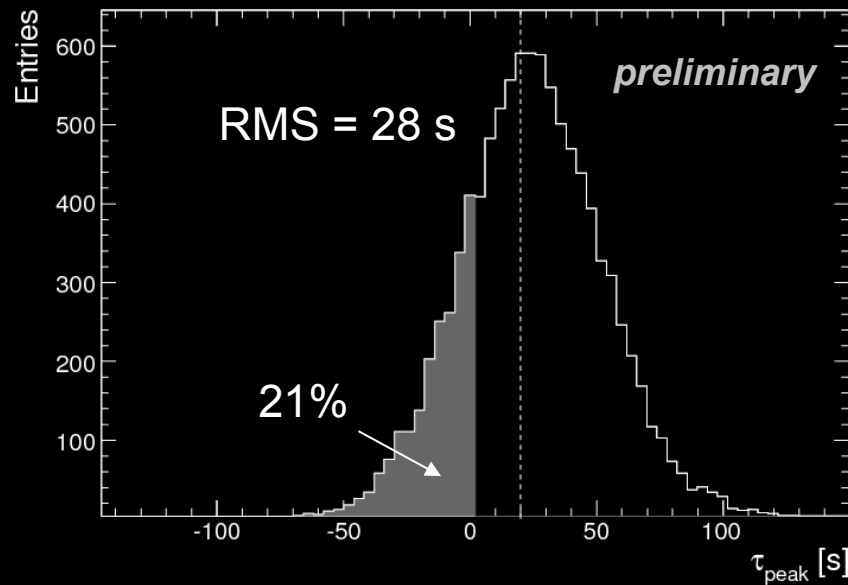


Apply MCCF \rightarrow Peak at 20 s , error?



Limit determination

Error propagation by simulating light curves within errors (including bin correlations)



$$\rightarrow \frac{\Delta t}{\Delta E} < 73 \text{ s TeV}^{-1}$$

(95% confidence)

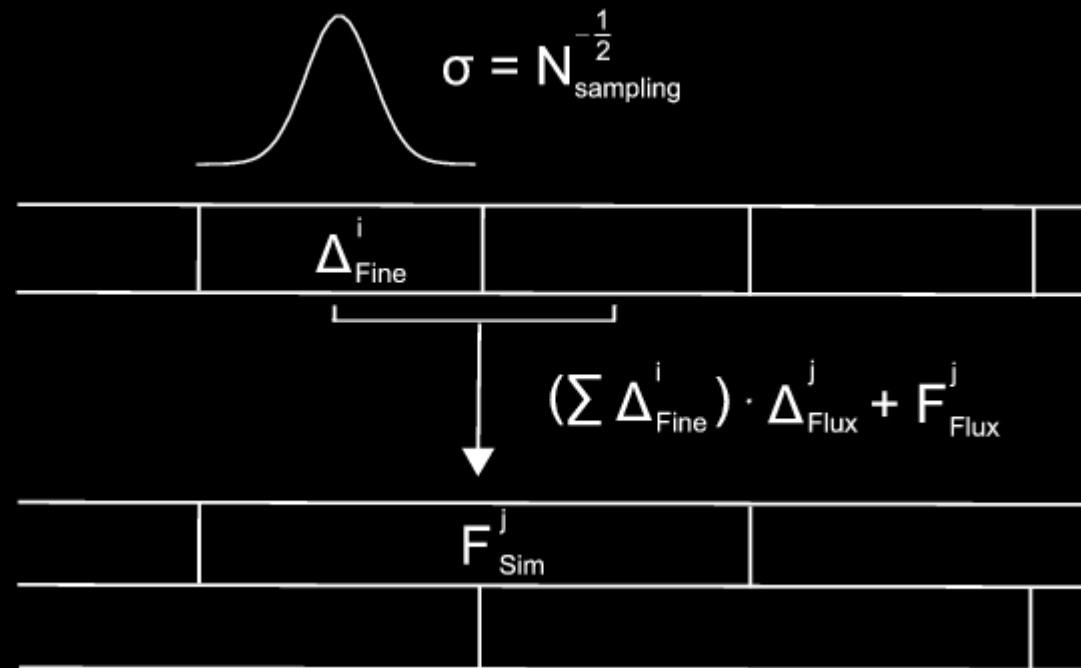
Linear: $\xi < 17.6$ ($\xi^{-1} E_p > 6.9 \times 10^{17} \text{ GeV}$)

Quadratic: $\zeta < 1.10 \times 10^{10}$ ($\zeta^{-1} E_p > 1.11 \times 10^9 \text{ GeV}$)



Simulations of bin correlations

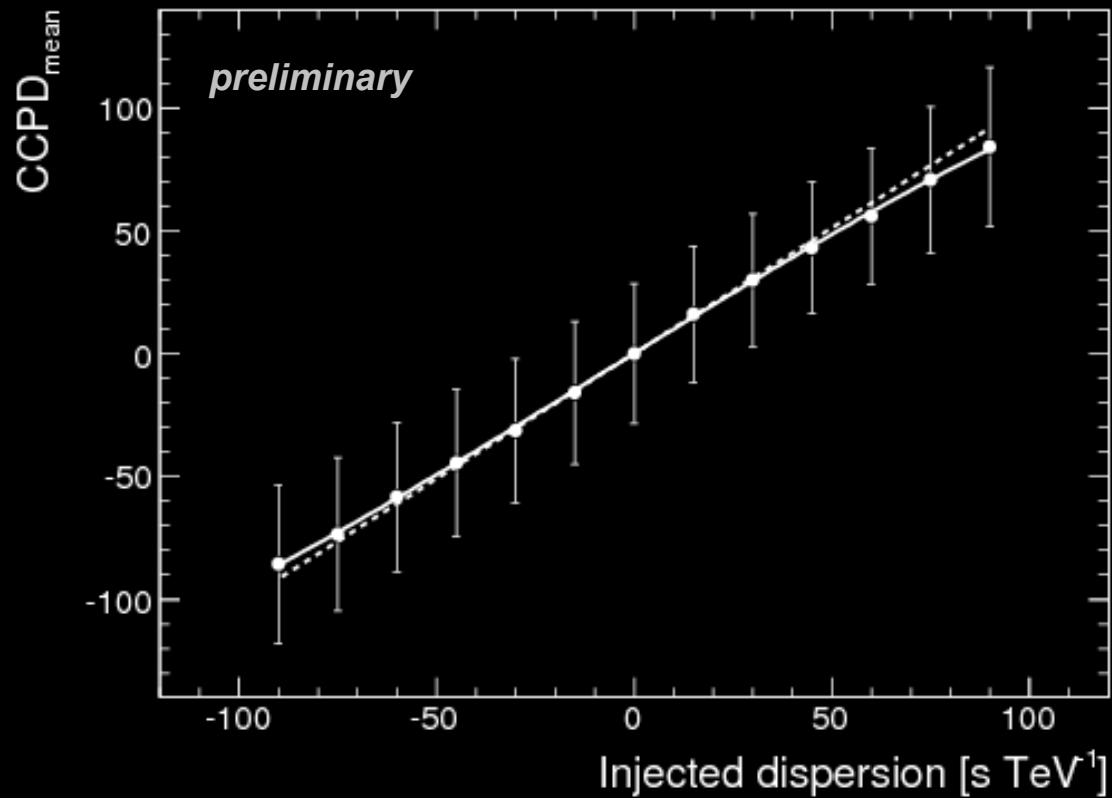
Example for oversampling of two:



- Throw random numbers on a fine grid
- Add and multiply with measurement error on coarse grids



Test – Inject dispersion

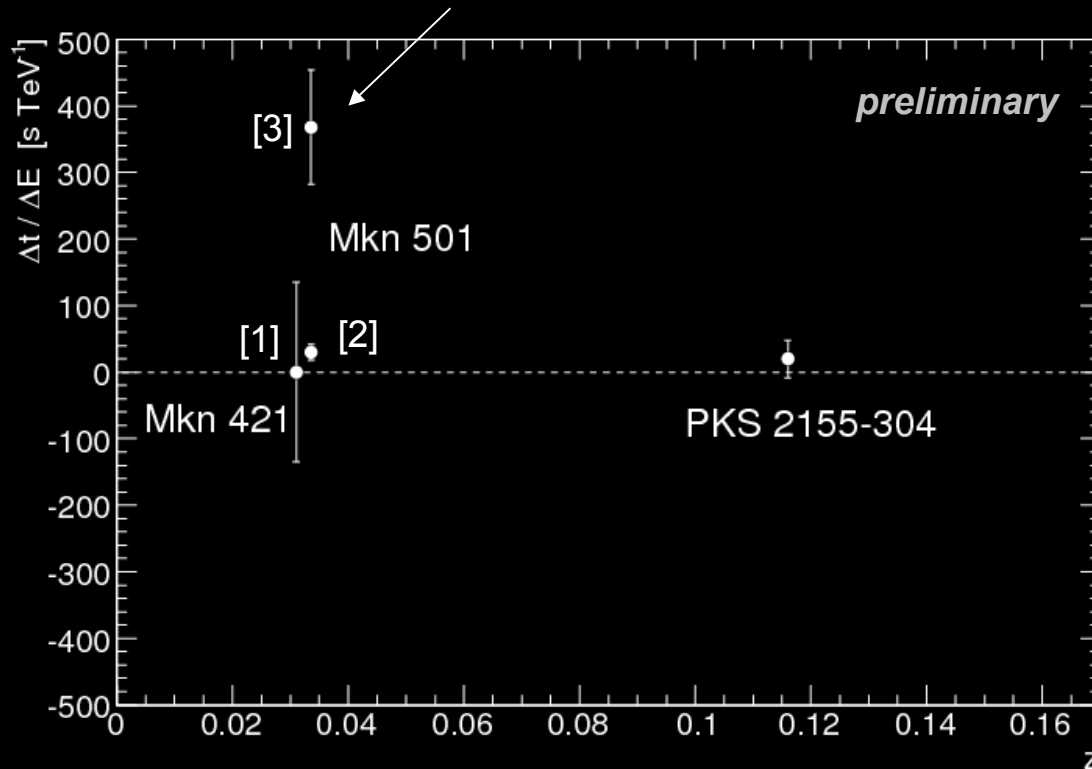


- Recovery of injected dispersion in data



Towards an AGN population

Derived from
232 \pm 54 s lag
between 0.15-0.25
and 0.6-1.2 TeV



- To date three measurements at VHE
→ No trend with redshift

- Future measurements will allow conclusions on “delay cancellation”



Conclusions

- VHE signal from PKS 2155-304 shows no energy dispersion. This yields the *most constraining limits* on speed of light modifications to date:

$$\xi < 17.6$$

(Linear)

$$\zeta < 1.10 \times 10^{10}$$

(Quadratic)

$$c' = c \left(1 \pm \xi \frac{E}{E_P} \pm \zeta^2 \frac{E^2}{E_P^2} \right)$$

- Measurement opens a new redshift window for populations studies, however for a final verdict on time-delay cancellation further observations are needed

