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# *Investigating the fluence of bright TGF events detected by the Atmosphere-Space Interactions Monitor*

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NTNU Det skapende universitet

# Terrestrial Gamma-Ray Flashes (TGFs)

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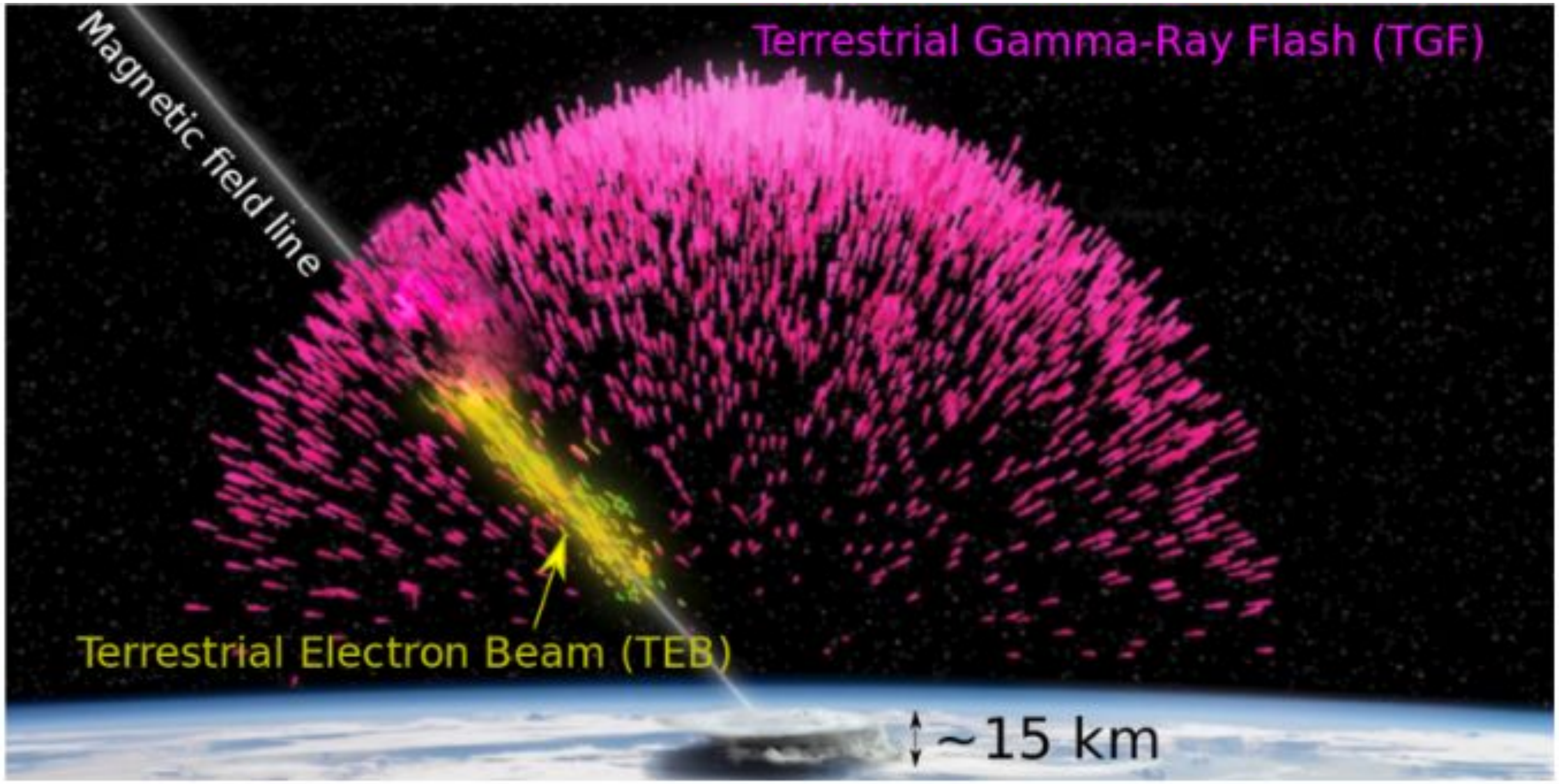


- TGFs are the most powerful natural source of X/gamma-rays produced or Earth
- Associated to thunderstorms and lightning leaders
- Energies up to 40 MeV
- Duration ~50μs to 2 ms, can have multiple peaks
- Detected by many spacecrafts (BTSE(CGRO), RHESSI, Fermi, AGILE and ASIM)
- Production mechanism still not fully understood

# Example of "saturating" event

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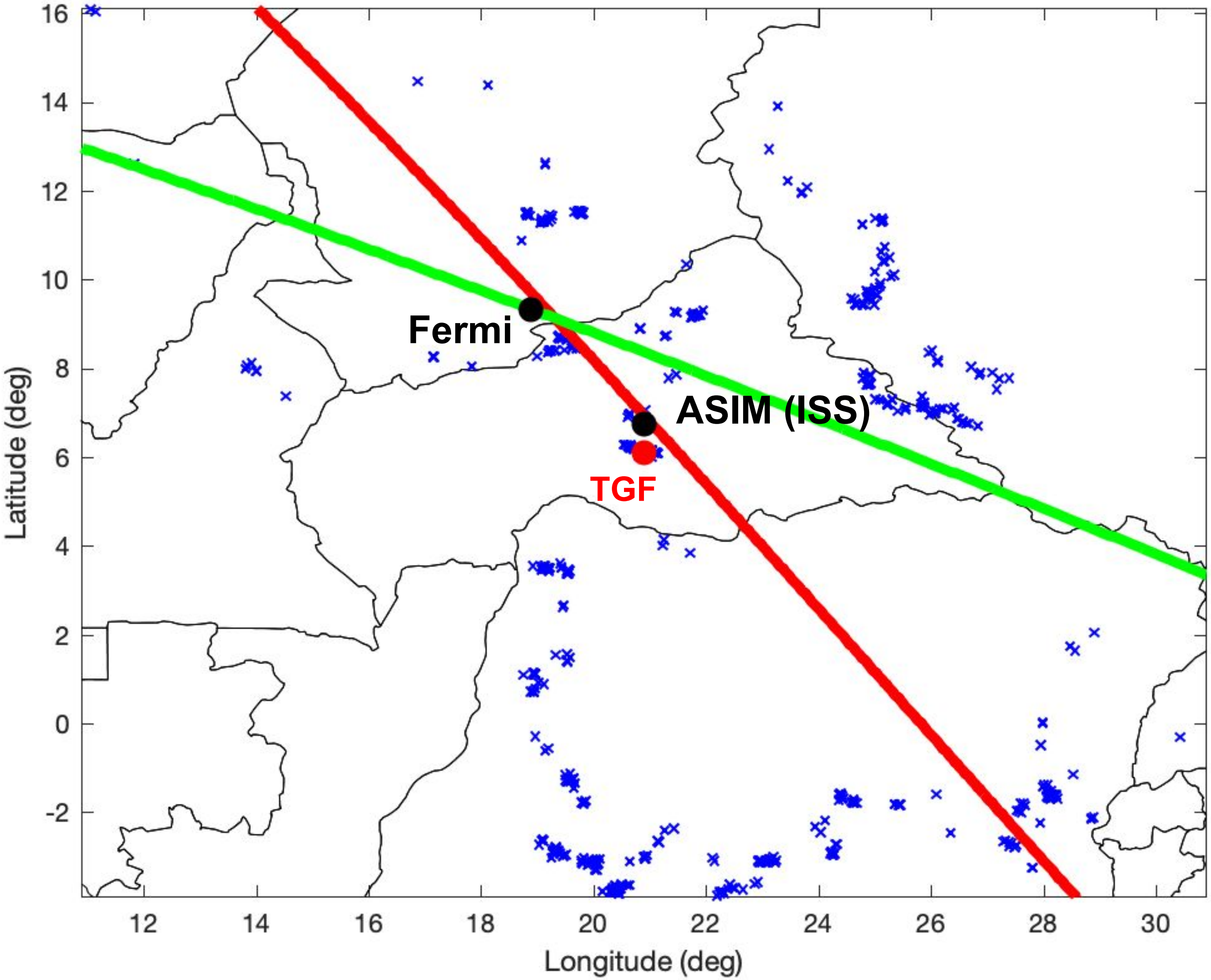
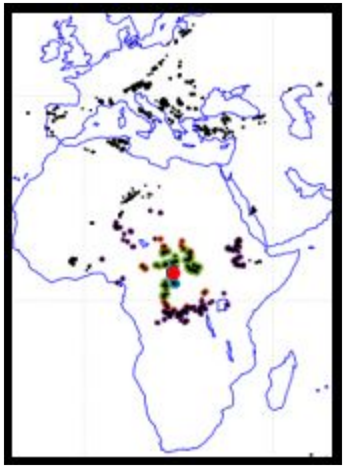
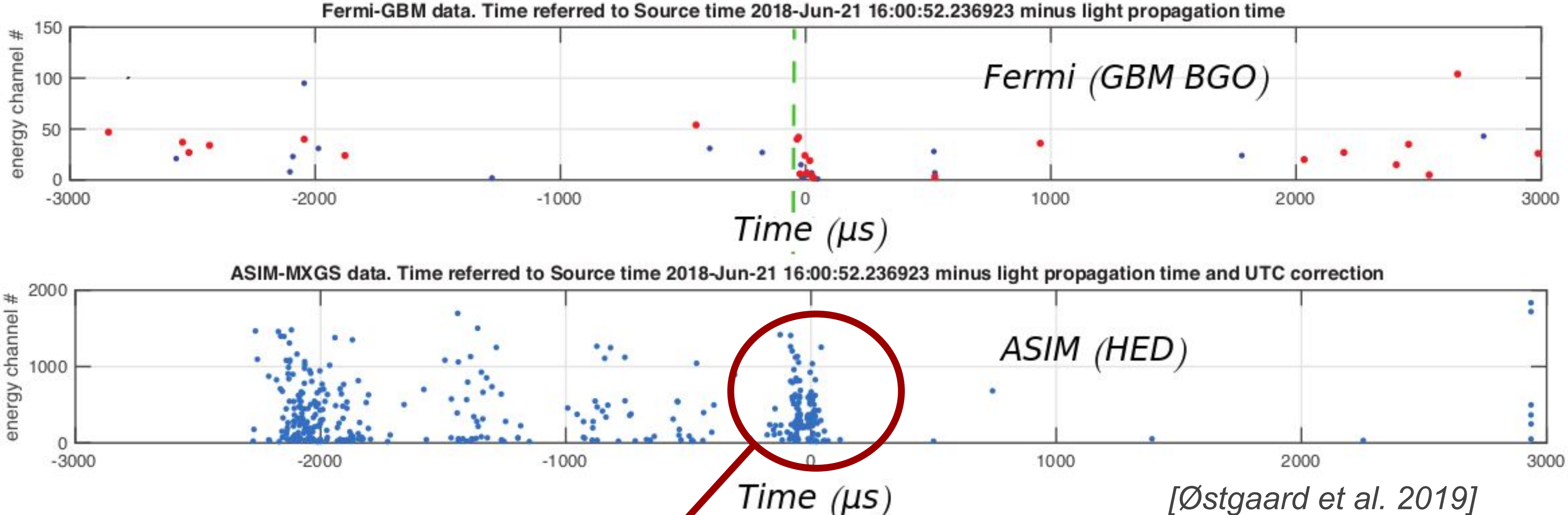
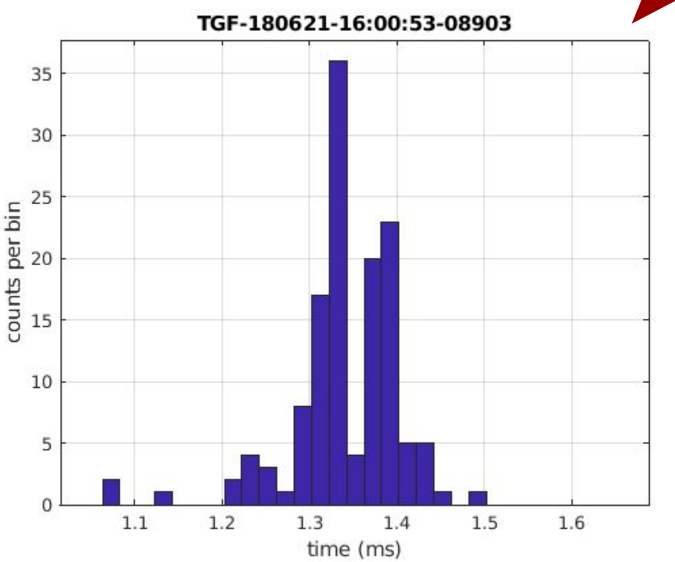
## TGF-180621-16:00:53-08903



# Example of "saturating" event




- Event of June 21st, 2018
- Detected by both Fermi and ASIM(BGO only)
- Multi-pulse TGF: 5 to 6 peaks
- Heavy saturation on the last TGF pulse that is actually NOT a double pulse.

- **Maximum brightness is much larger than detected here**
- **Several similar events** in terms saturation

# HED vs LED counting capabilities

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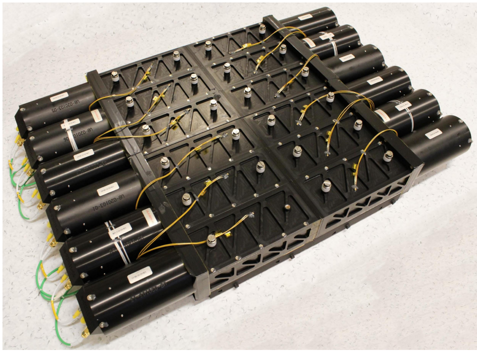
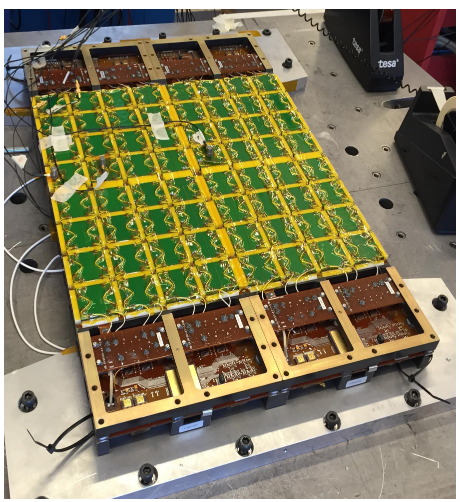


**HED:**

- 3.2 cm thick BGO crystals
- time resolution <1 us
- 12 modules
- counts showing overlap of photometer pulses tagged as "fast events"



**LED:**

- 5 mm thick CZT units
- TGF-detection effective area ~2 times less than HED
- time resolution 1.4 us
- 16 independent chains
- multi-hits capability (flagged from 1 to 4)

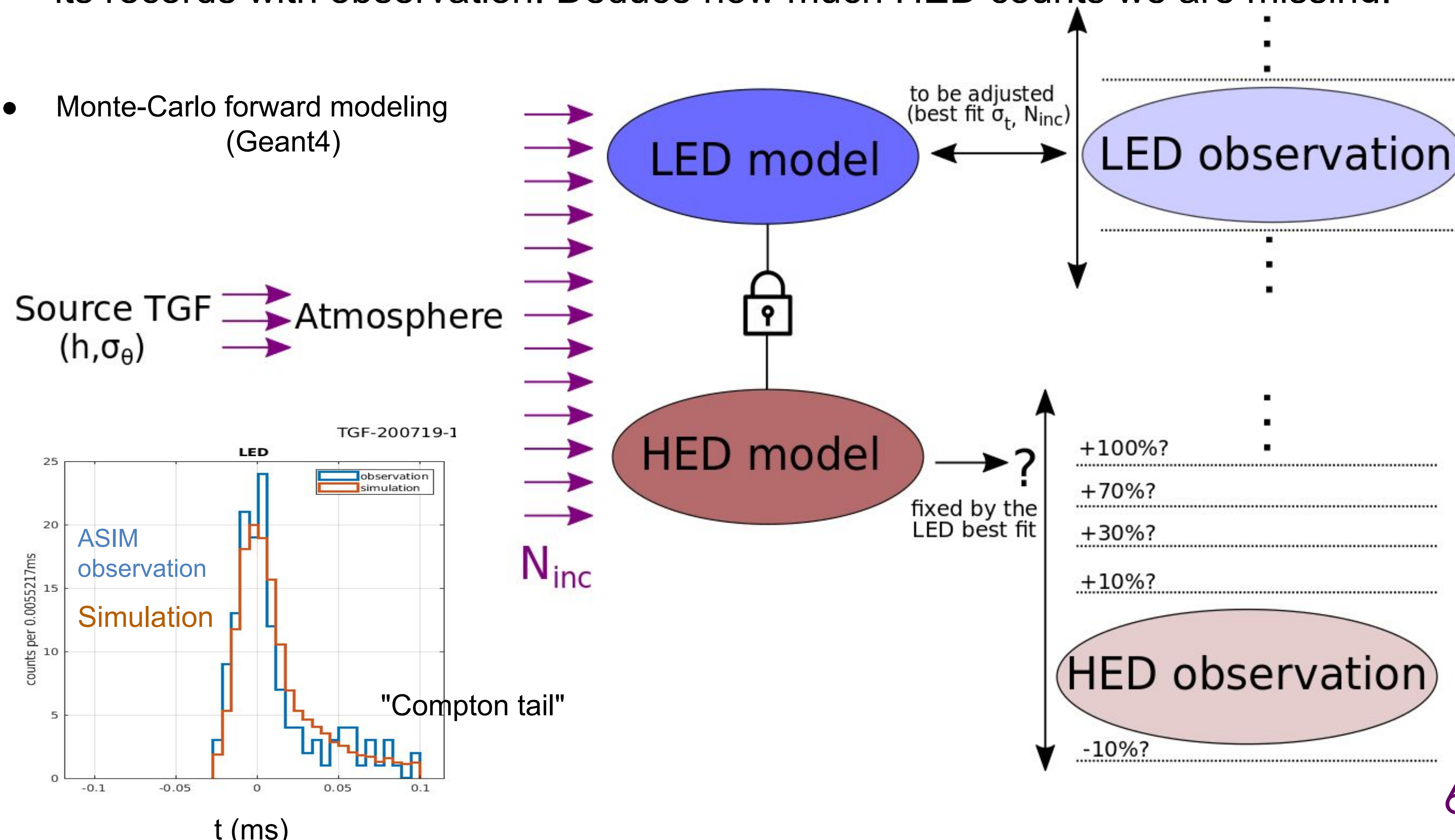
**Counting capability (before seeing signs of saturation) of LED is about 10 times better than HED**

# Method

***Main idea:***

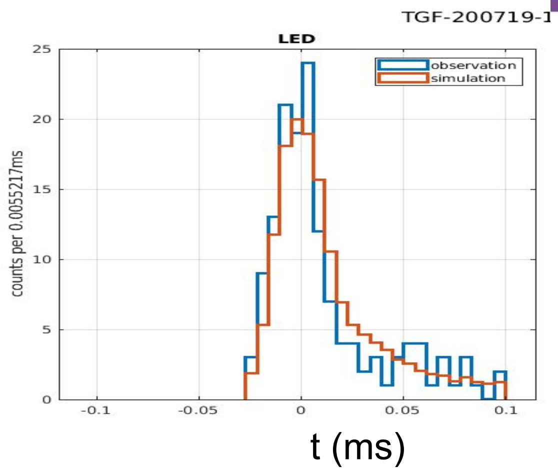
Assume we have a model of a "perfect" instrument (Geant4) and then compare its records with observation. Deduce how much HED counts we are missing.

- Monte-Carlo forward modeling (Geant4)



# Finding the best time profile






- Assumption : source (in-cloud) has a **Gaussian time profile with parameter $\sigma_T$** (to optimise)
- Based only on LED
  - atmospheric propagation
  - "material" response (Geant4)
  - multi-hits
    - keep all "counts" in observation
    - reproduce realistically in simulation
  - energy calibration of observation
  - energy threshold **> 50 keV** for both observation and simulation
  - maximum likelihood fit on the lightcurves (simulation to observation)
  - uncertainty on $\sigma_T$ due to :
    - ± Poisson fluctuations on LED observed number of counts ($N_{LED}^{O}$)
    - unknown source altitude and beaming

- Also perform consistency checks:
  - LED and HED lightcurves "by eye"
  - ratio of fast events (HED) ± Poisson fluctuation
  - ratio of multi-hit flags 0,1,2 (LED) ± Poisson fluctuation

- **Calculation of $\sigma_T$ gives a value for the number of incident photons $N_{inc}$ (± Poisson fluctuations)**

# Sources of uncertainties (confidence interval)

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**Final result: Simulated number of counts on HED ($N_{HED}^{S}$)**

This number has to include a confidence interval due to :

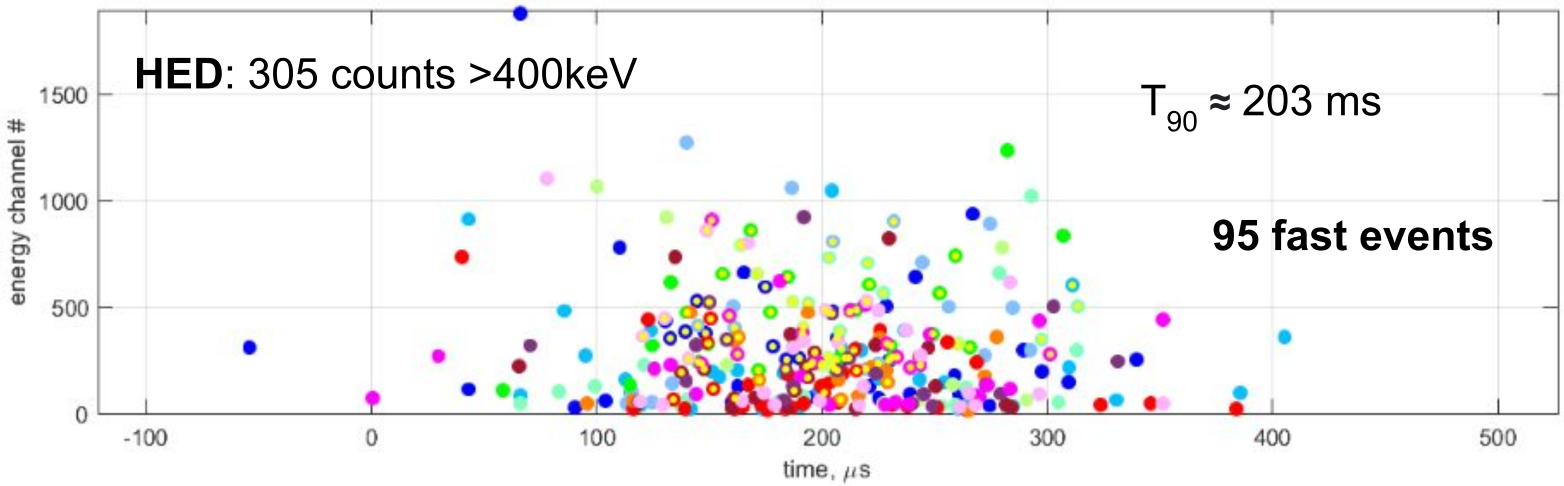
- Unknown *source altitude* and *angular distribution* (a.k.a. beaming)
    - (assumed: ALT = [9-15] km ; BEAM σ=[5-30] deg)
- Poisson statistical fluctuations of the number of LED observed counts ($N_{LED}^{O}$)
- Uncertainty on $\sigma_T$ (due to above)
- Statistical fluctuations on LED simulated counts $N_{LED}^{S}$
- 95% intervals

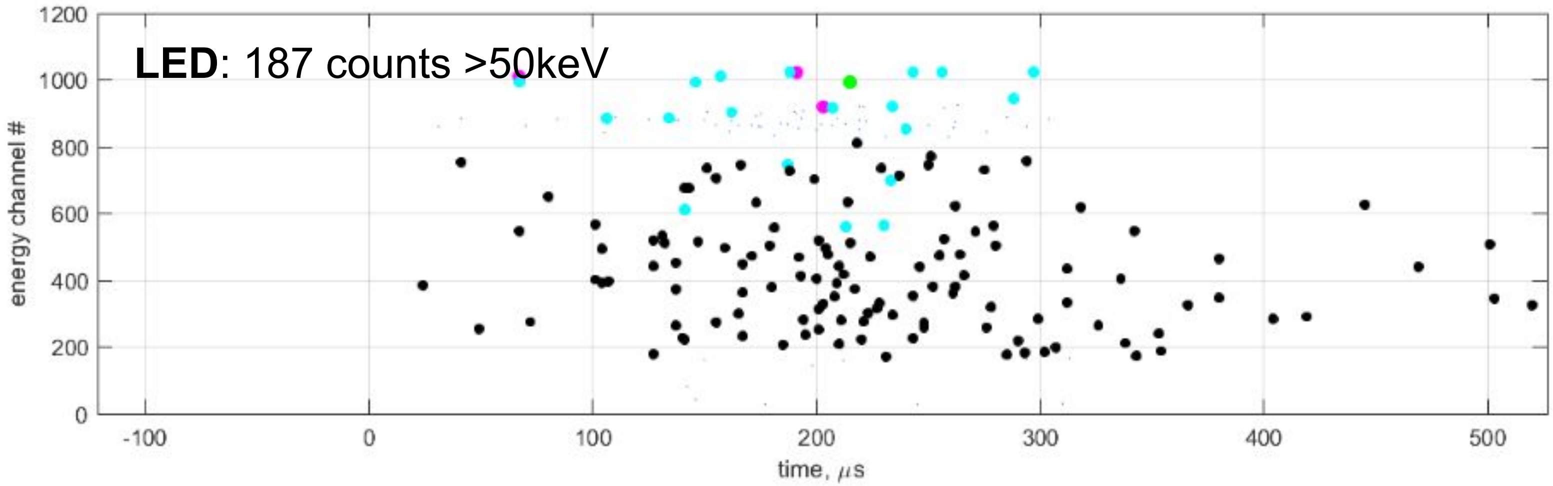
*The uncertainties are "summed" together with random samplings*

# Example : "moderate" event

TGF-181102-05:09:31-32676

**F = 0.7 counts/us**



# Example : "moderate" event

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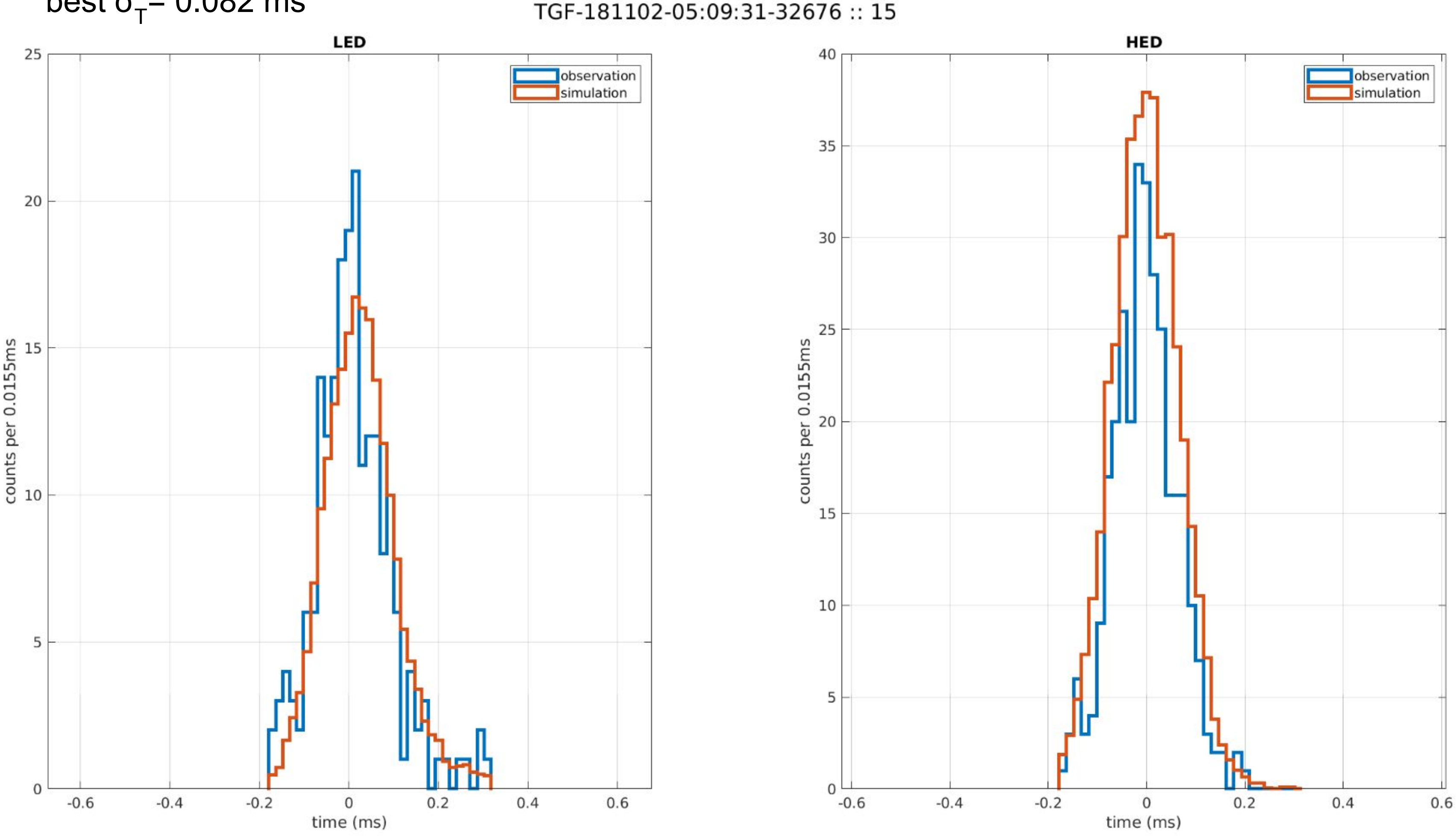
TGF-181102-05:09:31-32676

**F = 0.7 counts/us**

best $\sigma_T$= 0.082 ms




Radial distance TGF-source / ISS = 157 km.

# Example : "moderate" event

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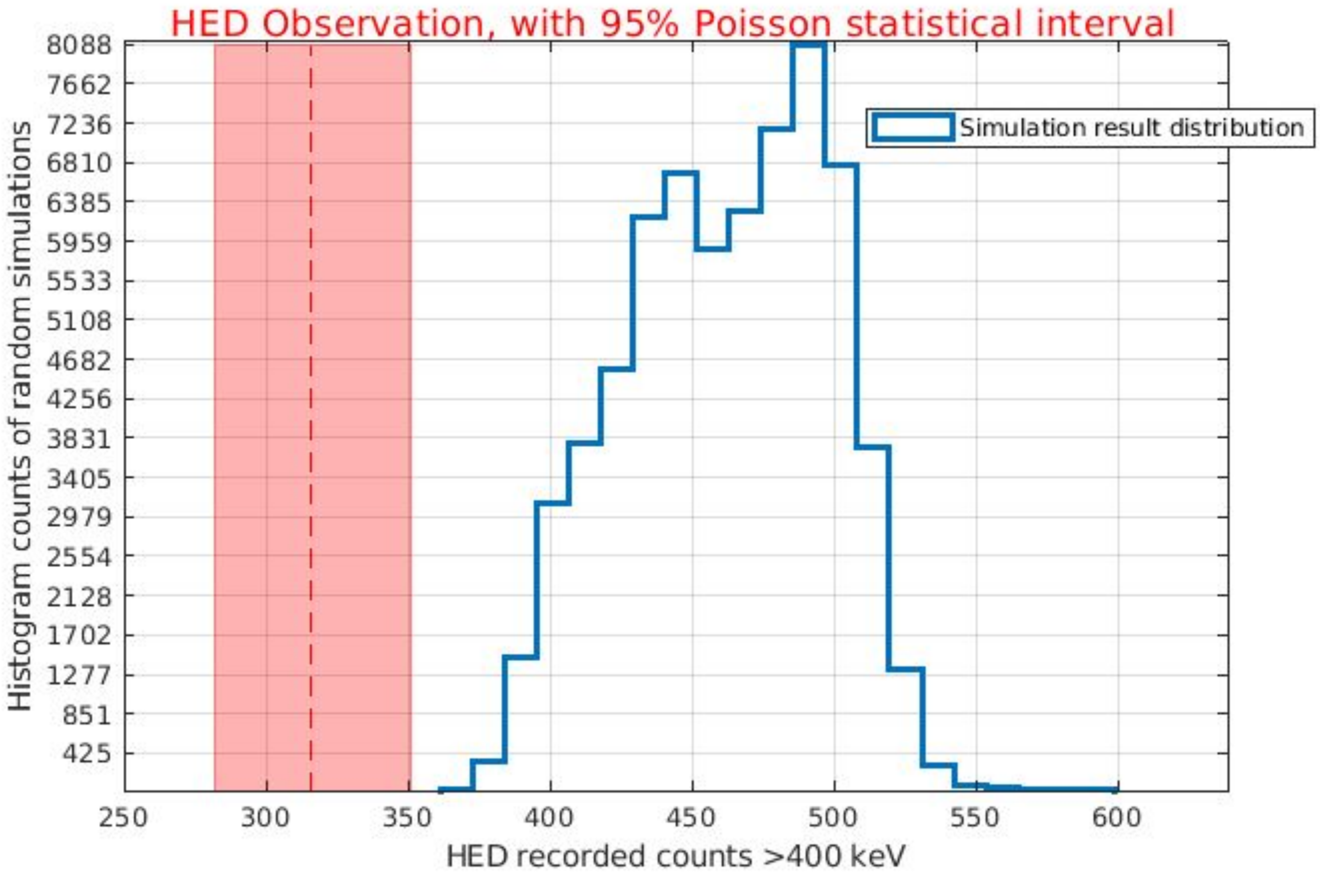


Missed fraction between 15% and 40%

# Conclusions

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- We propose a new method to evaluate the number of photon counts we could be missing during high flux TGF events.
    - It relies on having two independent detectors on the same platform, as well as monte-carlo modeling
    - New and comprehensive (almost no simplification or approximation)

- Estimated intervals of "missed factors" are fairly large... (e.g. "15% to 40%")
- ***preliminary results***

- Results seem consistent with expectations

  ( low flux −> no lost counts

  high flux -> many lost counts )

- *Only considering "moderate" events, we could miss ~40% of counts*
    - *lower limit of what we might miss during the brightest events*
    - ***work in progress***

- **Future work:** apply to largest flux events (if possible), and set a lower limit to the a maximum possible TGF brightness.

# Thank you for your attention !

References:

- Østgaard et al., *First 10 Months of TGF Observations by ASIM* ***(2019)***, https://doi.org/10.1029/2019JD031214
- Neubert et al., *The ASIM Mission on the International Space Station* ***(2019),*** https://doi.org/10.1007/s11214-019-0592-z
- Østgaard et al., *The modular X- and gamma-ray sensor (MXGS) of the ASIM Payload on the International Space Station* ***(2018)***, https://doi.org/10.1007/s11214-018-0573-7