The complete trigger chain simulation of the new LST camera

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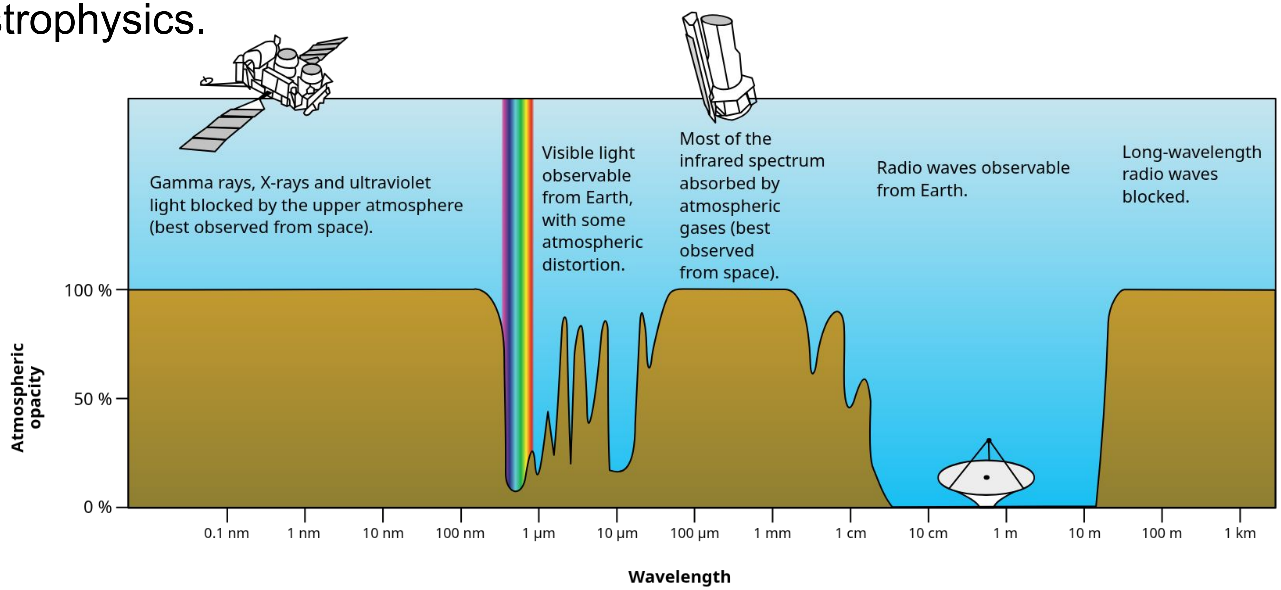
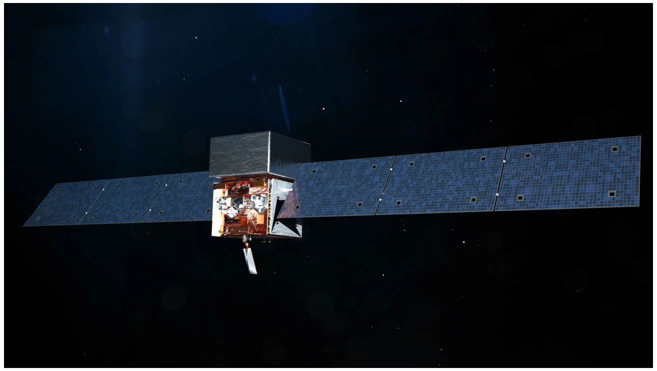
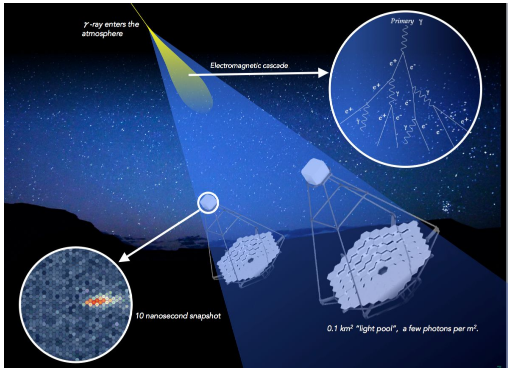
High energy astrophysics

- The atmosphere is opaque to high energy photons. Good for life in Earth, but bad for high energy astrophysics.



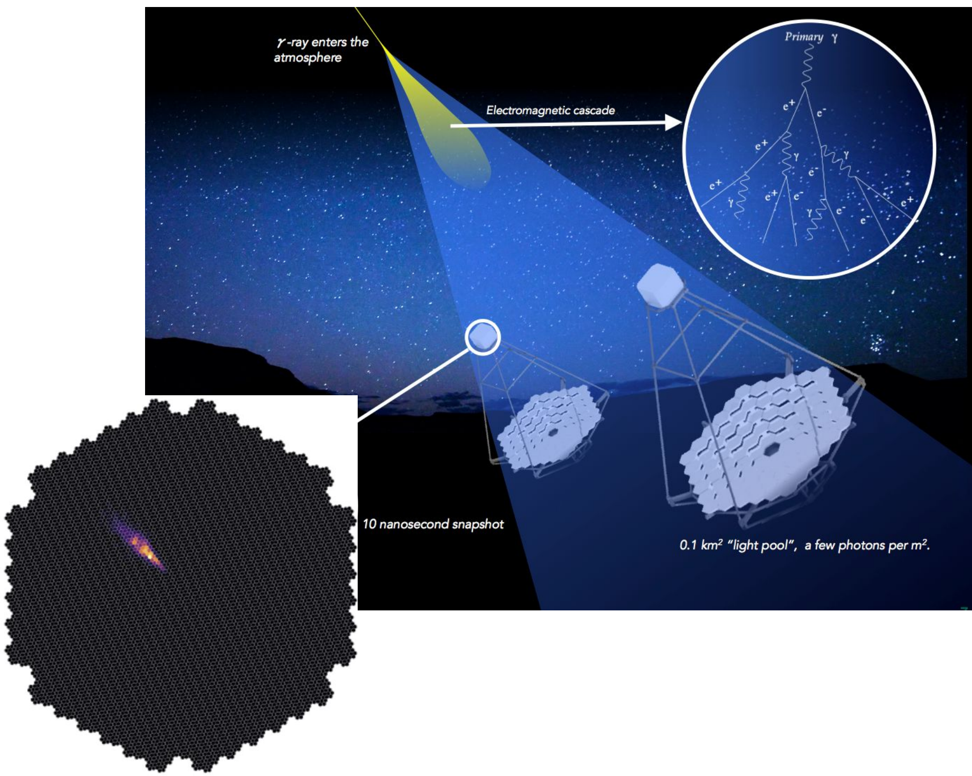
- Direct detection or indirect detection of high energy photons.





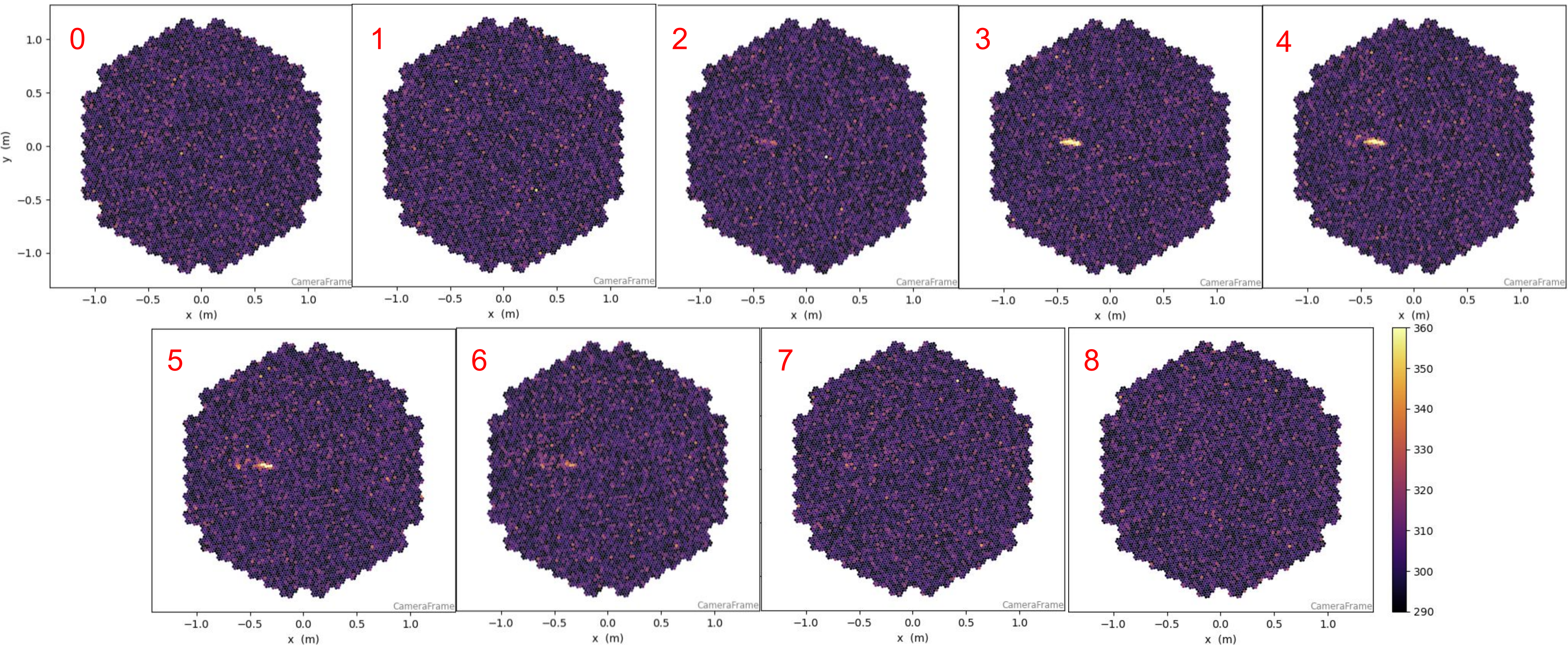
IACTs

- Imaging Atmospheric Cherenkov Telescopes.
- Cherenkov flashes last A FEW NANOSECONDS (10^{-9} s)!
- Telescopes need to be taking data at 1 GHz, 1 000 000 000 ‘pictures’ per second.
- Impossible to store all this data, so we need a powerful trigger chain.
- From these 1 000 000 000 ‘pictures’ per second we have:
    - ~ 50 000 have information about protons (not interesting for us),
    - ~ 10 have information about gammas!
    - The rest is just noise of the Night Sky Background.



Trigger

- Here we can see 9 interesting nanoseconds around a gamma event.

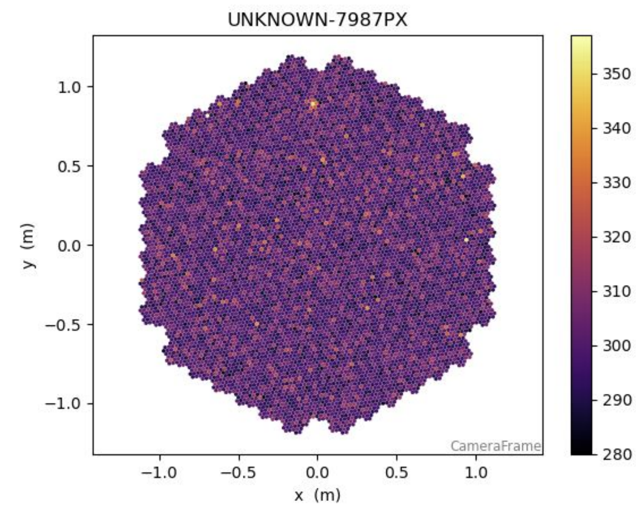


Trigger

- From theory to practical with the engineers of the lab:
  - cannot use the waveforms,
  - cannot use all pixels,
  - need an algorithm that can run very fast (1 GHz),
  - need an algorithm which is small to fit in the FPGAs.

- Divide the hardware trigger in 2 main steps:
  - Single telescope trigger: each telescope trigger has to detect as many gamma events as possible, even with many false triggers.
  - Stereo trigger: each telescope tells the others if he has triggered or not.

- The telescopes are interested in the lowest possible energies, so the signals more difficult to distinguish from the Night Sky Background.



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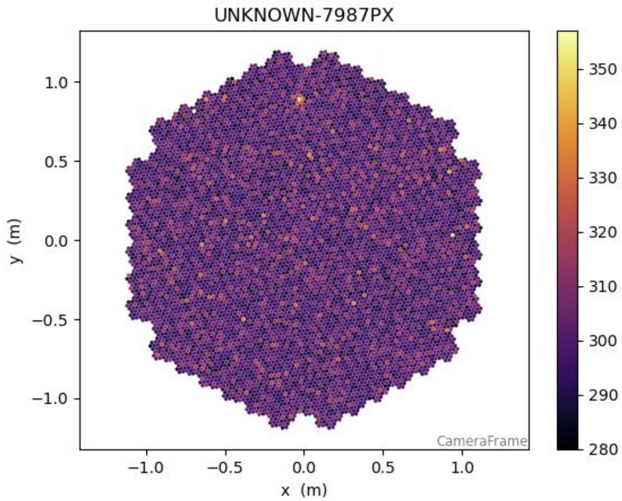
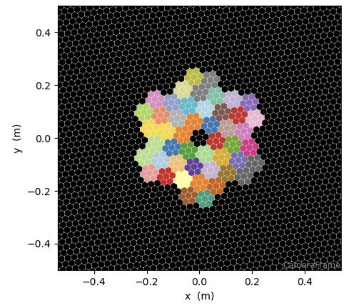
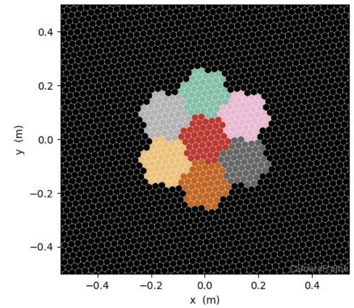


Single telescope trigger

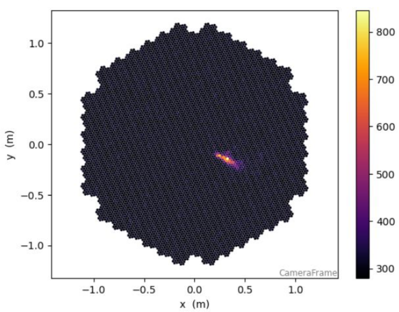
- We cannot send the 8000 pixels 12 bit information each nanosecond, so we reduce it:



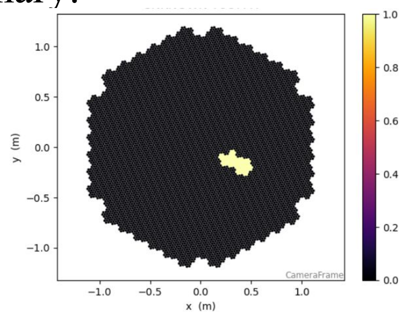


- Complex algorithms need more information so we test 2 different types of data:
  - binary
  - amplitude information data

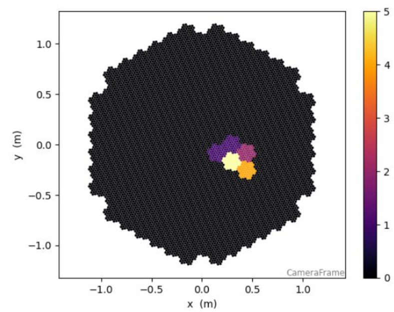
Waveform:

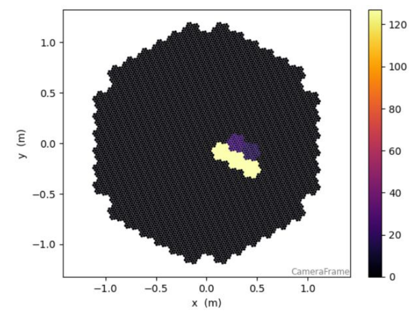


Binary:



Quantised:



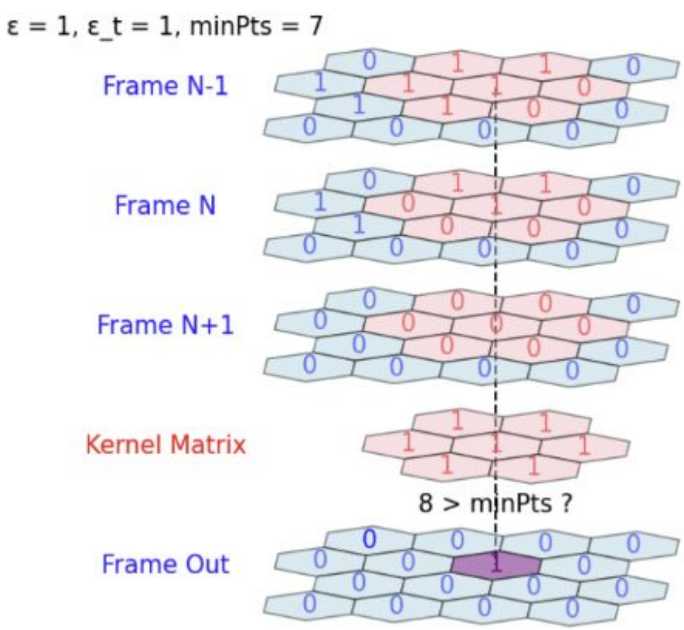


- We run from the simplest to more complex algorithms:
  - OR
  - TDSCAN
  - Very light Convolutional Neural Network

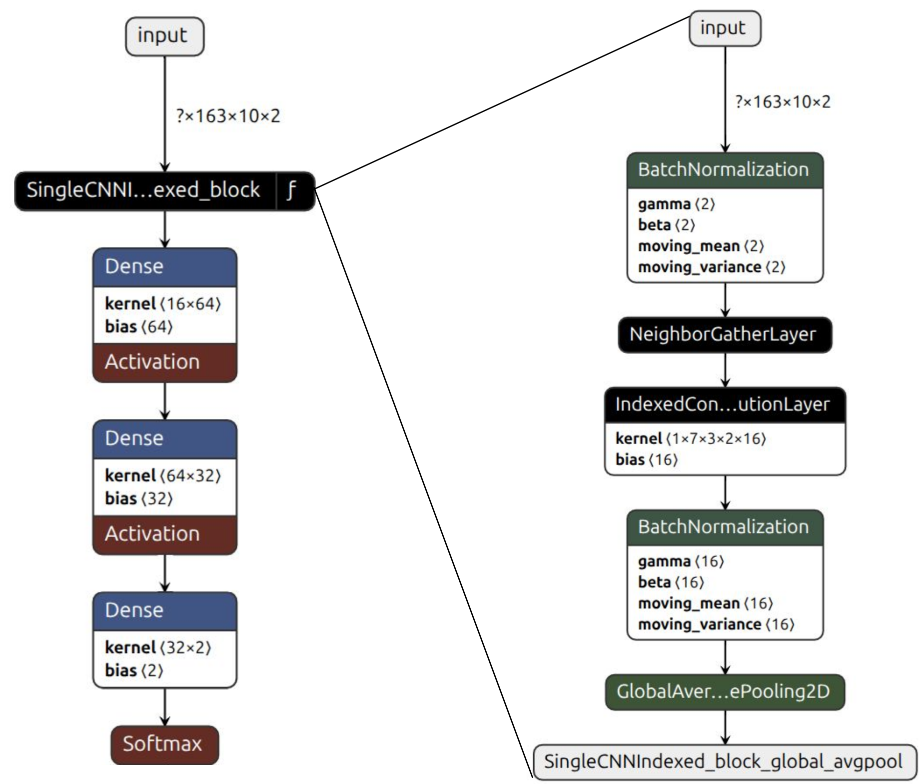
Single telescope algorithms

- OR, simple but very efficient
- TDSCAN, clustering algorithm that can run at 1 GHz
- Very light Convolutional Neural Network

TDSCAN

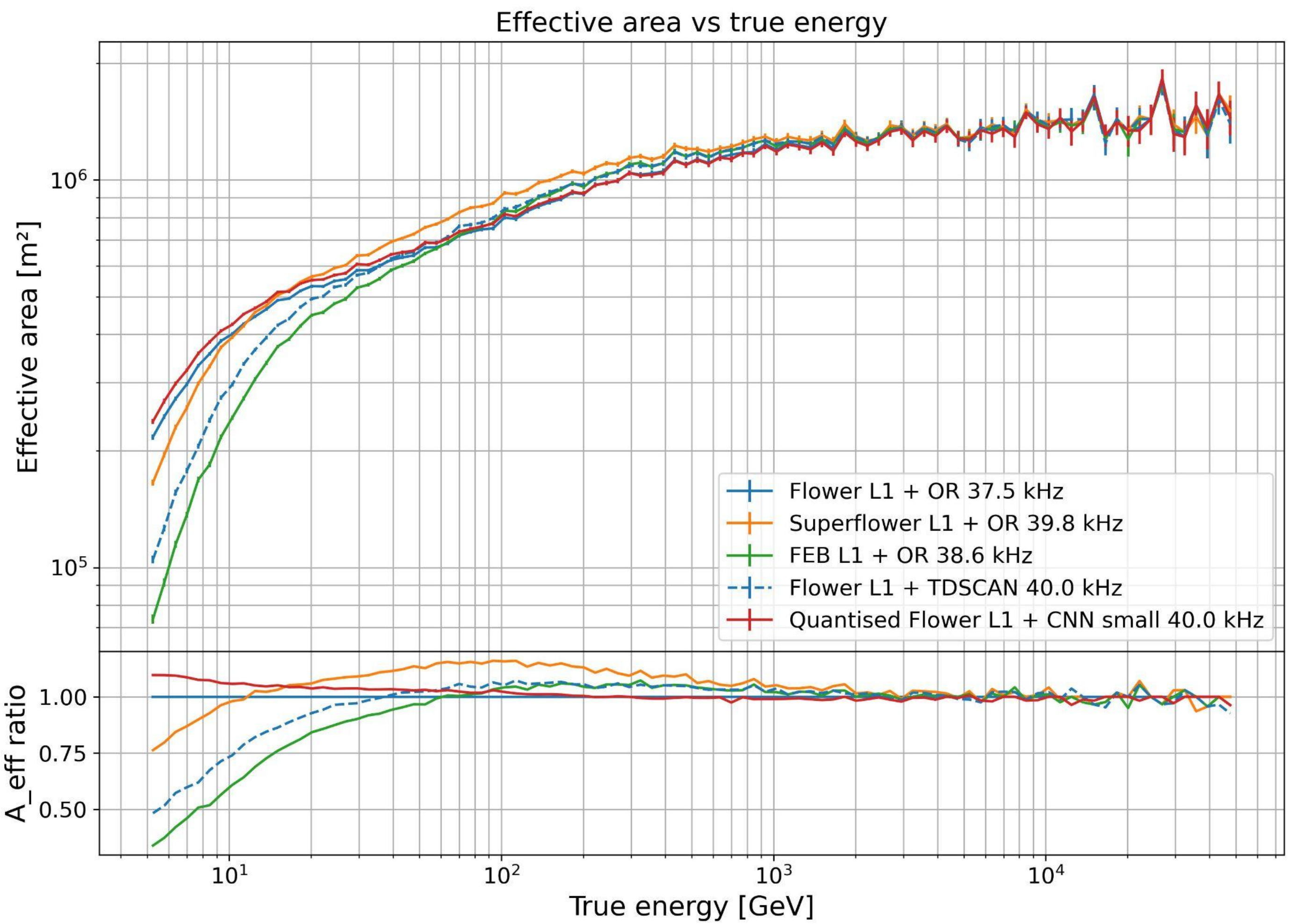


CNN



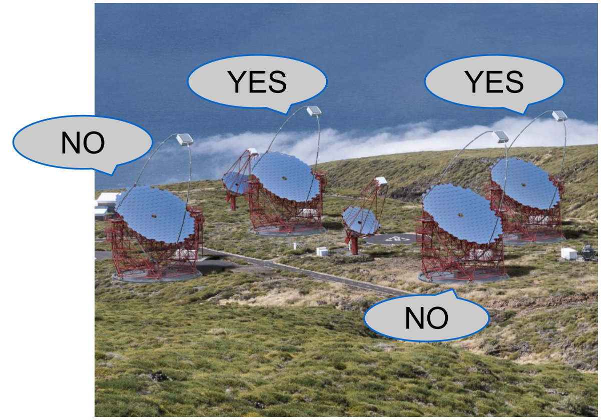
Single telescope algorithms

- OR, simple but very efficient
- TDSCAN, clustering algorithm that can run at 1 GHz
- Very light Convolutional Neural Network

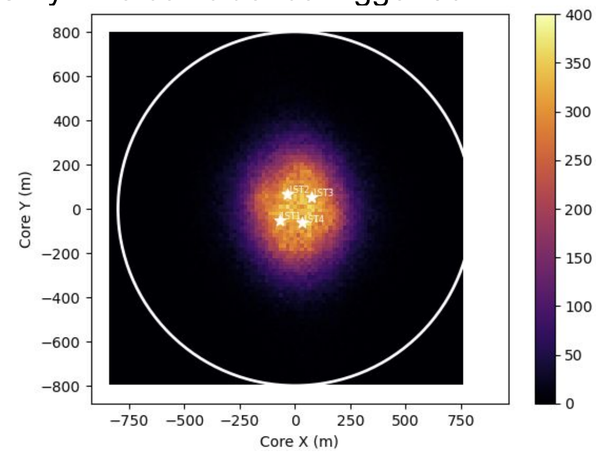


Stereo trigger

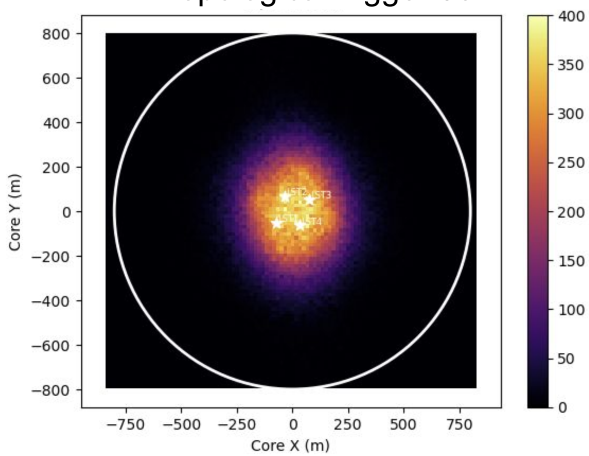
- Each telescope has a decision trigger after the first step, and then they exchange the trigger information, we use time and spatial information.
- Very efficient trigger method, reduces the random background coincidences, from 8 000 kHz of triggers on noise down to 30 kHz.
- Keeps practically all the events seen by 2 telescopes.

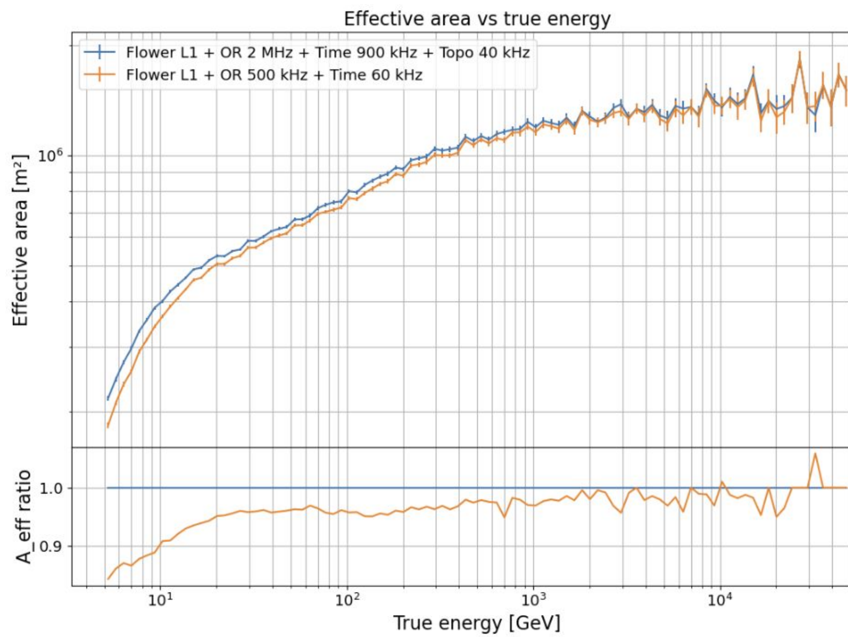


Only time coincidence trigger 30 kHz



With topological trigger 30 kHz





- Stereo topological trigger allows to go lower in energy, and get better angular resolution.

Conclusions

- Exchanging ideas with engineers is always good.
- Hardware constraints push forward new ideas.
- Improvements of the trigger at the lowest energies will provide better sensitivities at the lowest energies for high level data analysis.
- Low energy trigger require from more advanced trigger methods.

- Git of the tdscan soft and plottings: https://github.com/jbuces/low_trigger
- Branch for DL1DH: https://github.com/cta-observatory/dl1-data-handler/tree/Jorge_TriggerReader
- Branch for CTLearn: https://github.com/ctlearn-project/ctlearn/tree/RawTrigger

THANKS, QUESTIONS?

Acknowledgements

The research here presented has been partially supported by the MICIU/AEI/10.13039/501100011033 and by the European Union NextGenerationEU/PRTR, under grant PDC2023-145839-I00

The author(s) gratefully acknowledges the computer resources at Artemisa, funded by the European Union ERDF and Comunitat Valenciana as well as the technical support provided by the Instituto de Física Corpuscular, IFIC (CSIC-UV).

CNN algorithms

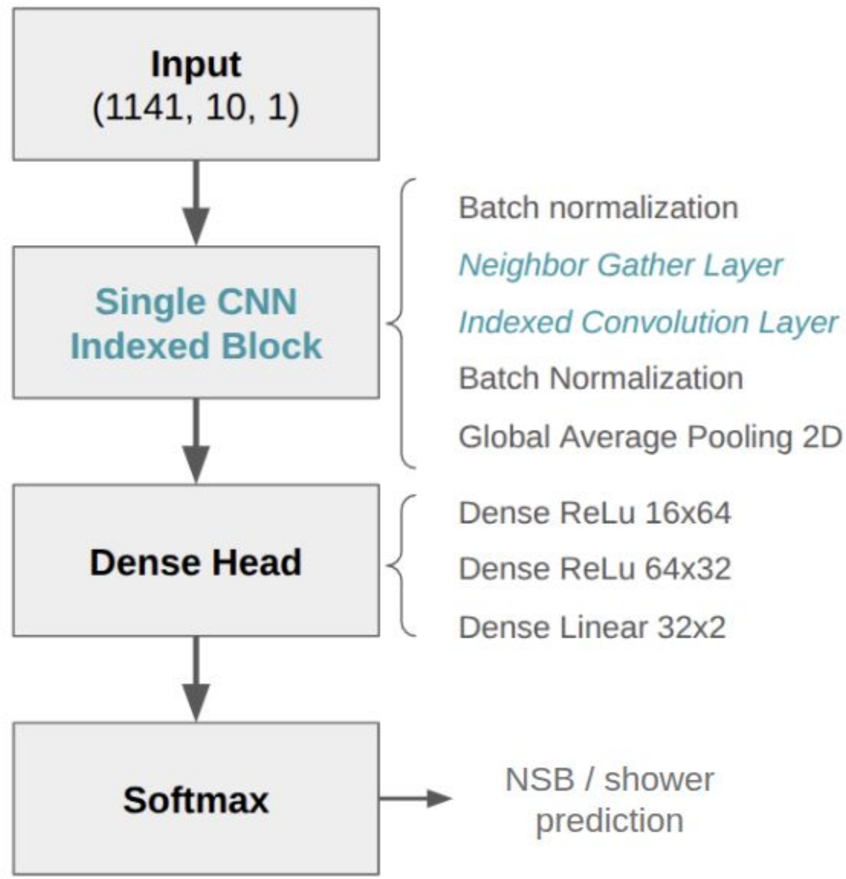
- 2 types of input data:
  - binary L1,
  - quantised L1 data.

- 3 different size of models for comparison:
  - Huge model (439 thousand params.) (with attention layers),
  - Big model (230 thousand params.),
  - Small model (3 thousand params.).

- The goal of the CNNs would be to equal the results of the superflower triggers using flowers L1.

- Cannot run at 1 GHz ⟶ We perform an OR in the CTP to get down to 10 MHz and then run the CNN.

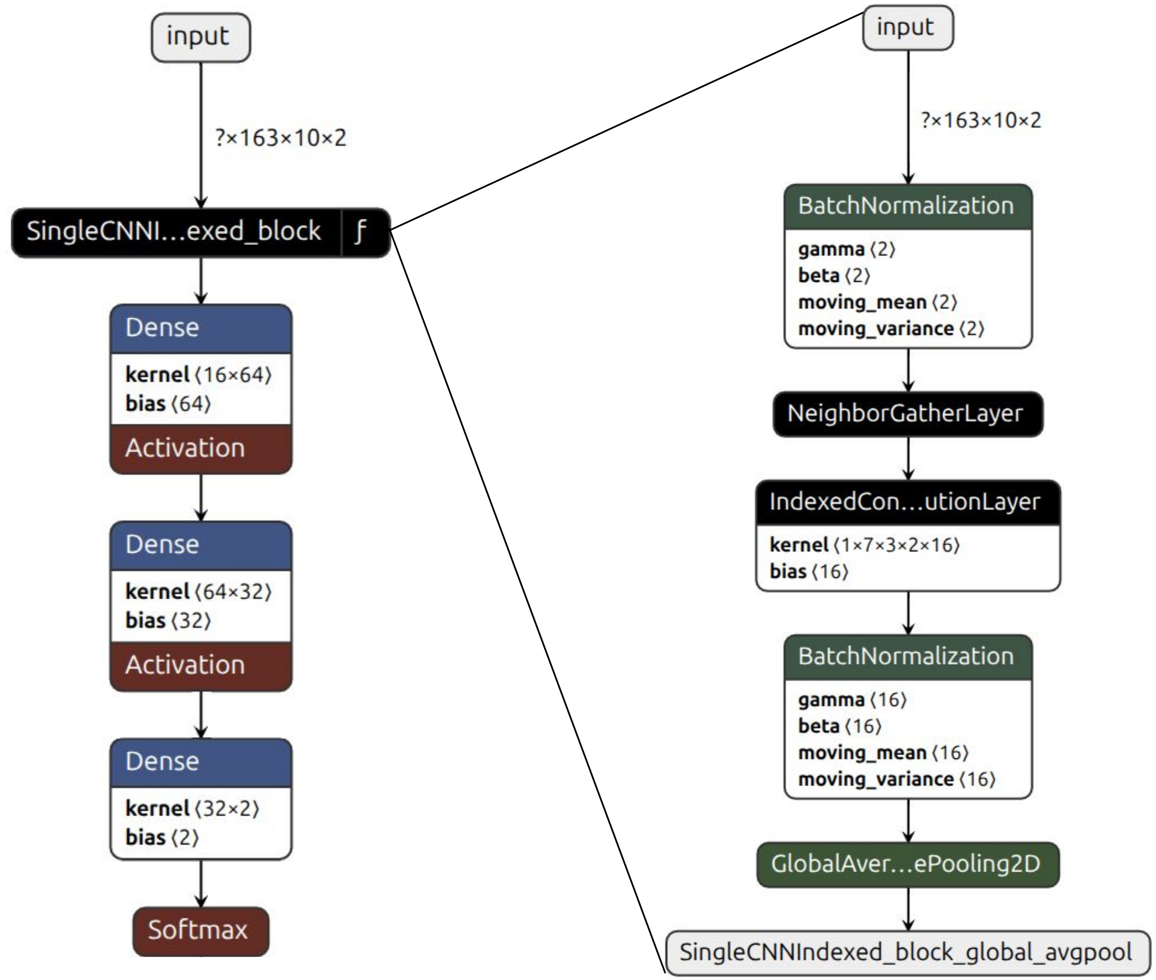
- Challenge of running on binary or quantised data, very little information.



Credits M. Molina

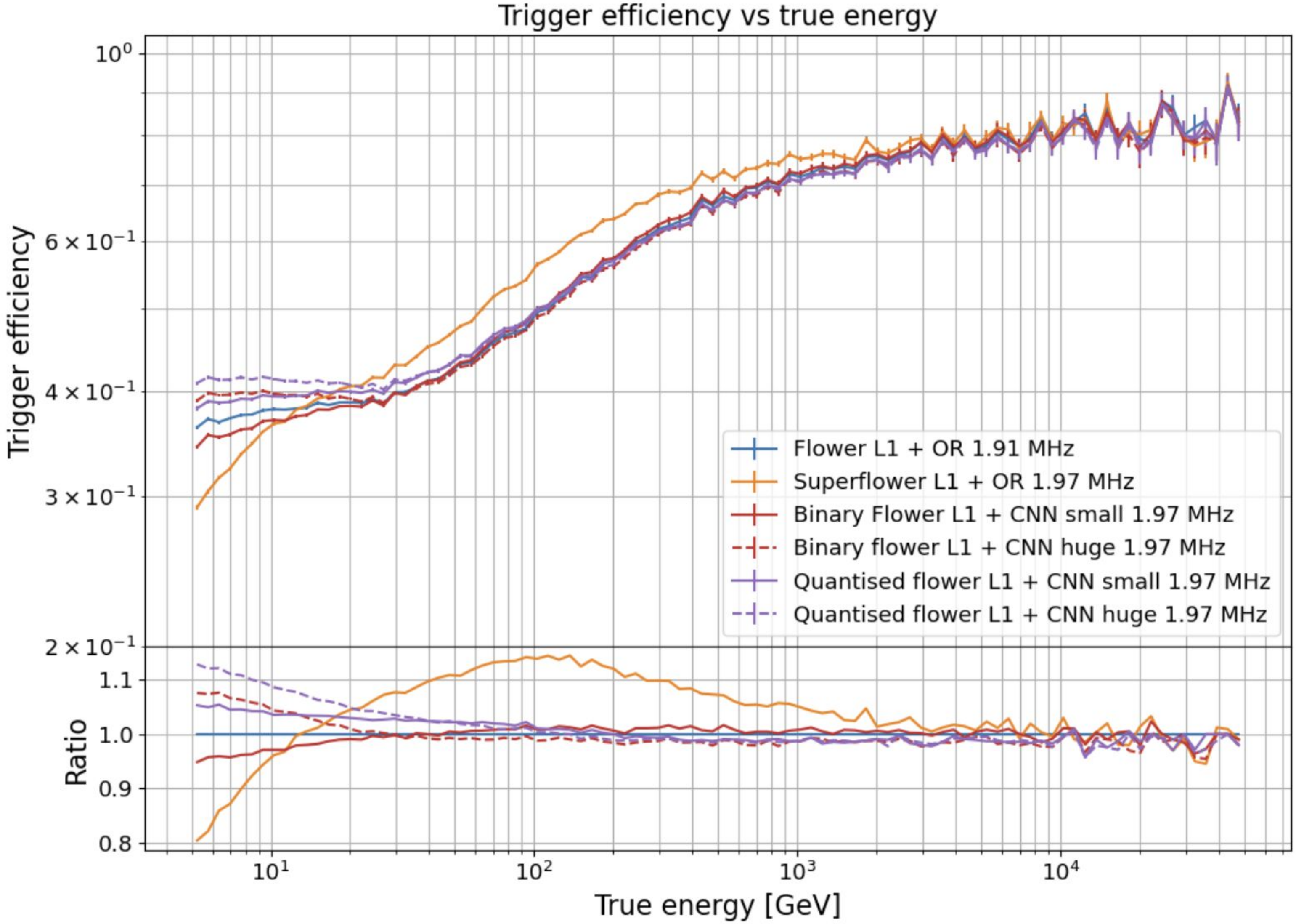
CNN size

- 3 different size of models for comparison:
  - Huge model (439 thousand params.):
    - 4 conv. layers (32,32,64, 128 filters)
    - 3 squeeze excite layers (attention)
    - dense head (512,256,2 neurons).
  - Big model (230 thousand params.):
    - 3 conv. layers (32,32,64 filters),
    - dense head (512,256,2 neurons).
  - Small model (3 thousand params.):
    - 1 conv. layer (16 filters),
    - dense head (64,32,2 neurons).



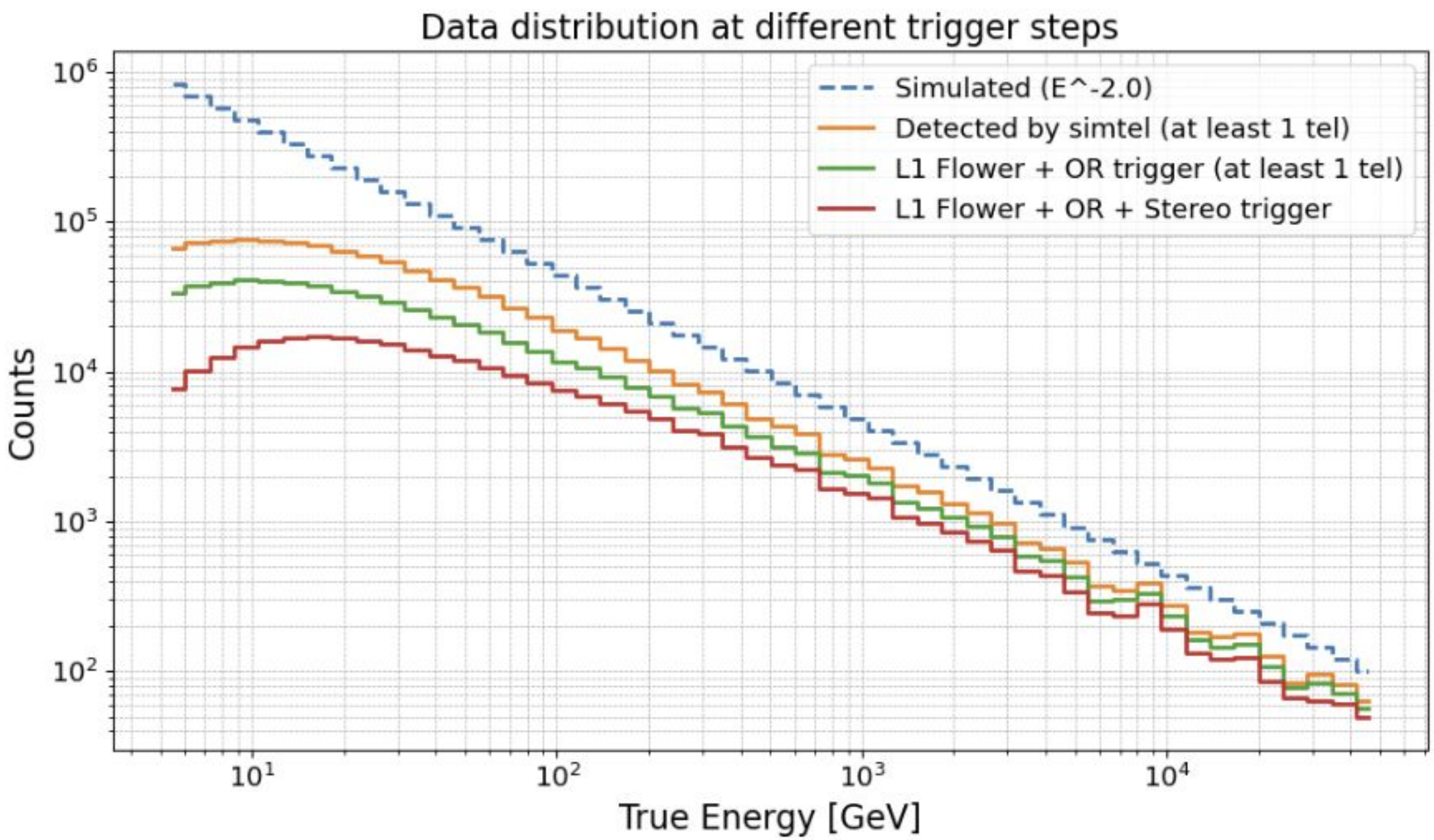
CNNs comparison

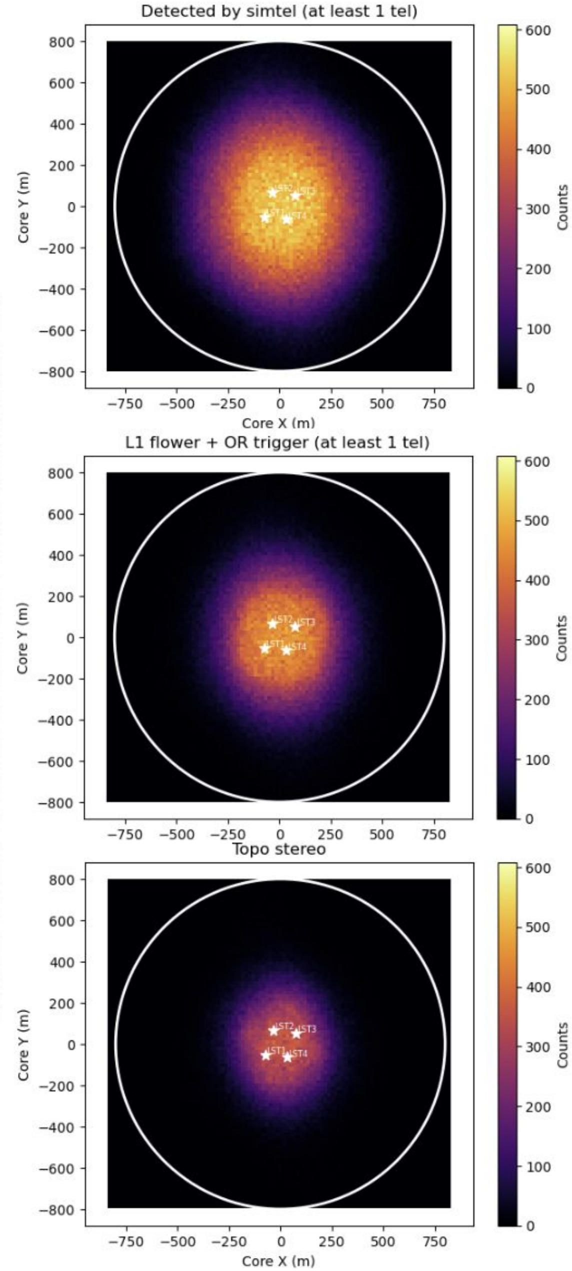
- L1 + OR vs. L1 + CNN (for huge and small models), for fixed output NSB rate @ 2MHz:



Data check with distributions

- The shower distribution as a function of energy, and its core position evolves for simulated, detected by at least 1 telescope from simtel, and time + topo stereo like:






```
Emin (GeV): 5.0
Emax (GeV): 50000.0
Total simulated showers (used for normalization): 5000000
Showers detected by simtel: 1018416
Showers detected by L2 single (at least 1 tel): 569172
Showers detected by L3 Stereo: 272208
```

CNN size

- We can see that because of the poor input data and the small reduction rate (10 MHz to 2 MHz) the CNN models with very different size do not vary much in gamma trigger efficiency.