Development and deployment of Artificial Intelligence algorithms for CTAO Telescopes

Comunidad de Madrid
Astrofísica y Física de Altas Energías
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU

AstroHEP-PPCC: Tecnologías Avanzadas para la Exploración del Universo y sus Componentes (TAU-CM)

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Grupo de Altas Energías - Instituto de Física de Partículas y del Cosmos - Universidad Complutense de Madrid

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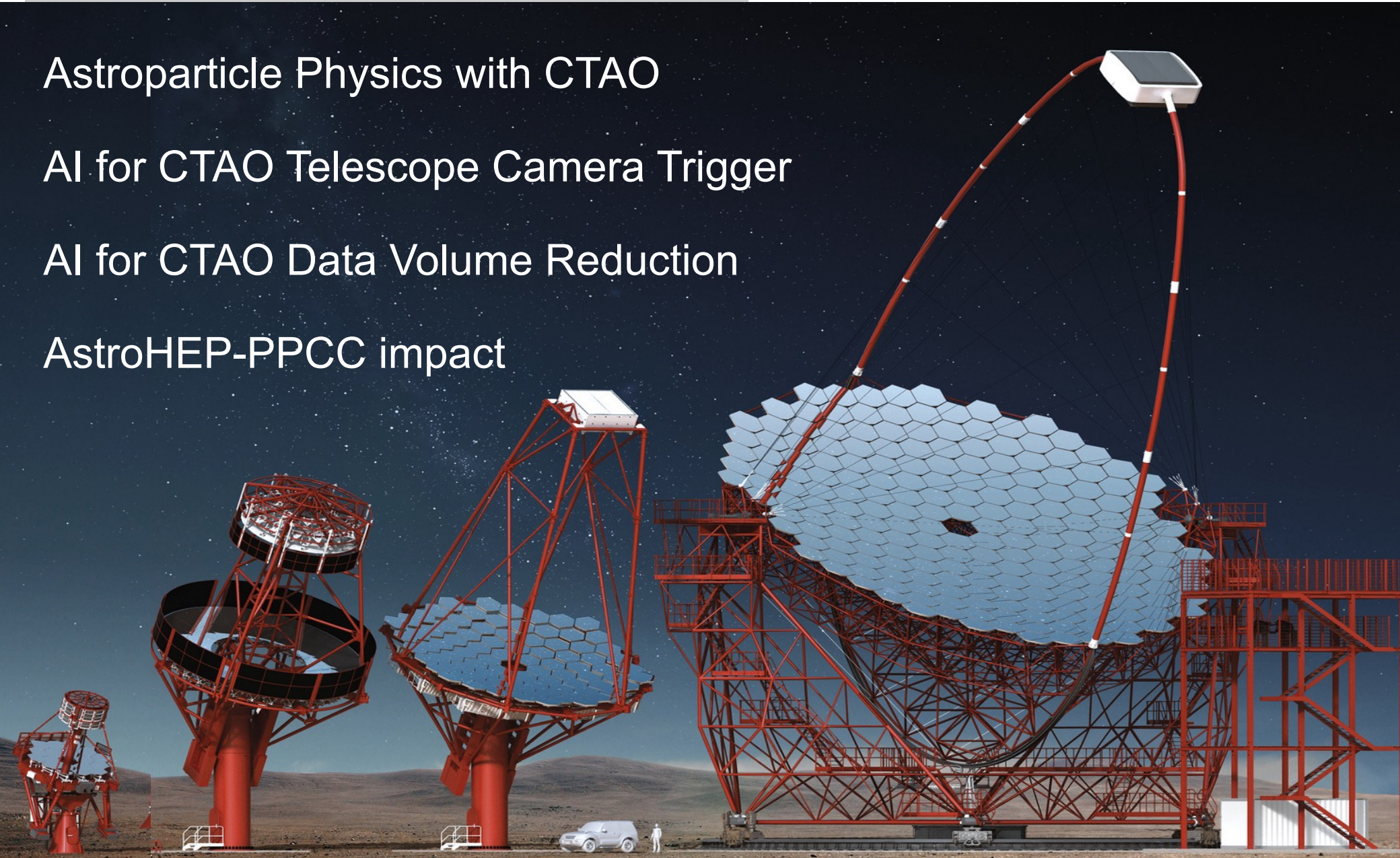
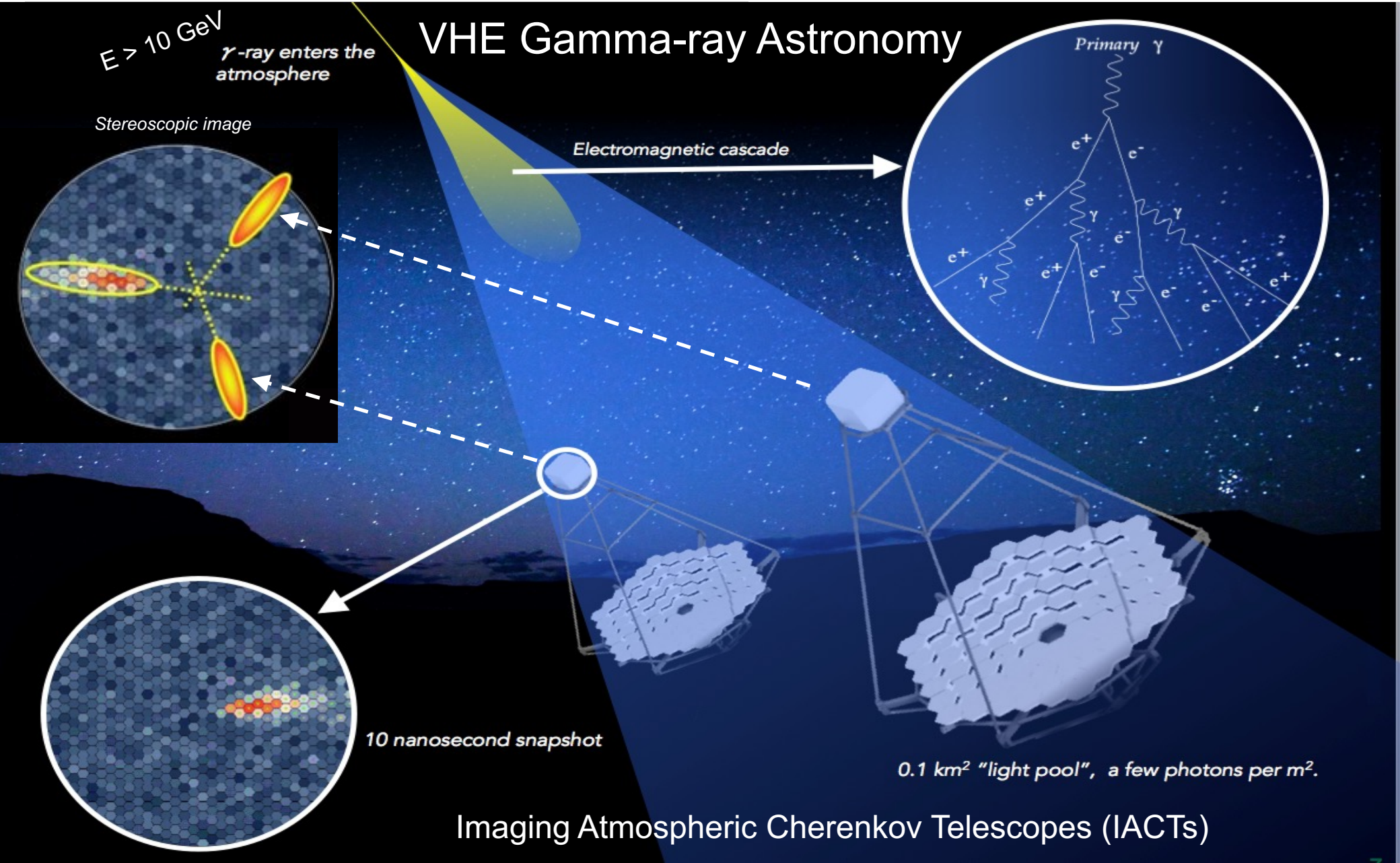
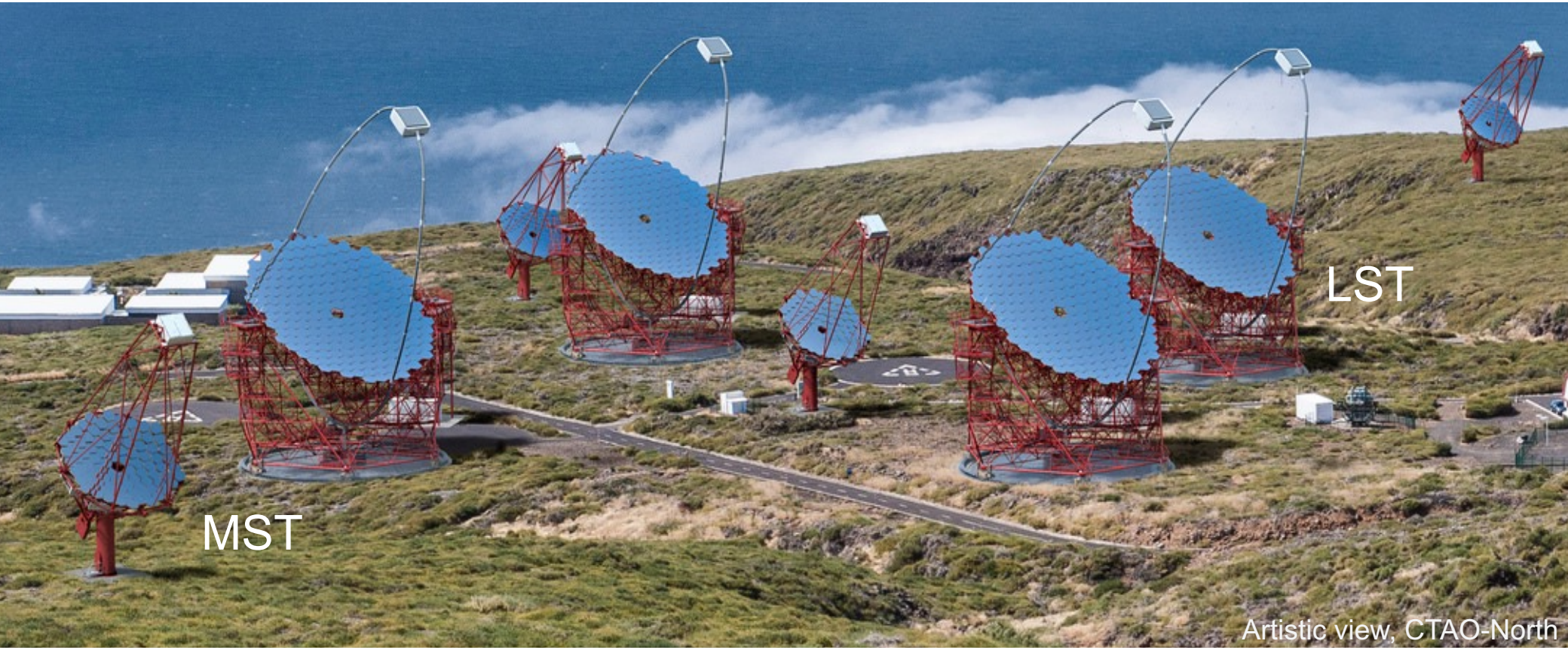


Astroparticle Physics



CTA Observatory

Cherenkov Telescope Array Observatory



Sensitivity improvement x10
Energy range extension x10
Angular resolution improvement

Two observatories:
La Palma / Chile
~100 telescopes

CTA Observatory

Cherenkov Telescope Array Observatory

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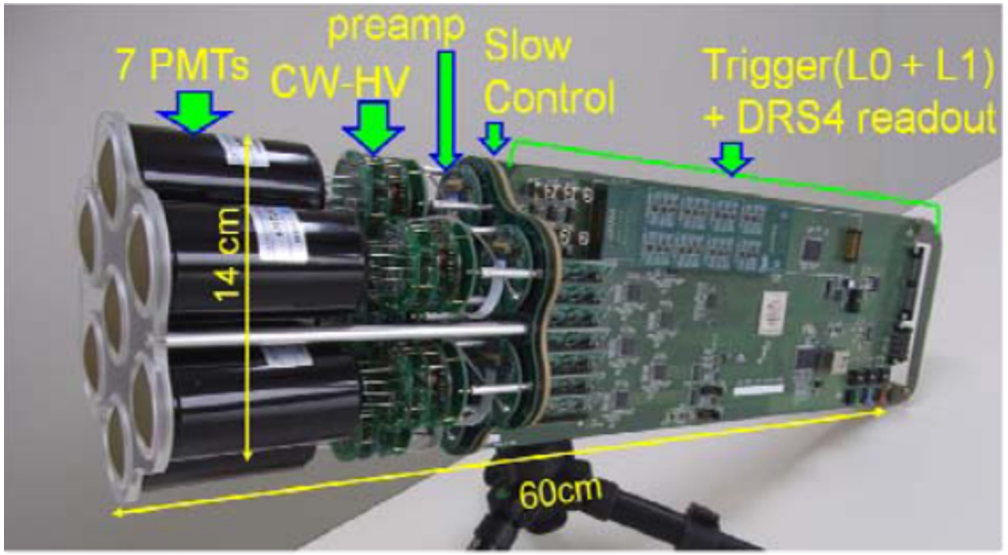
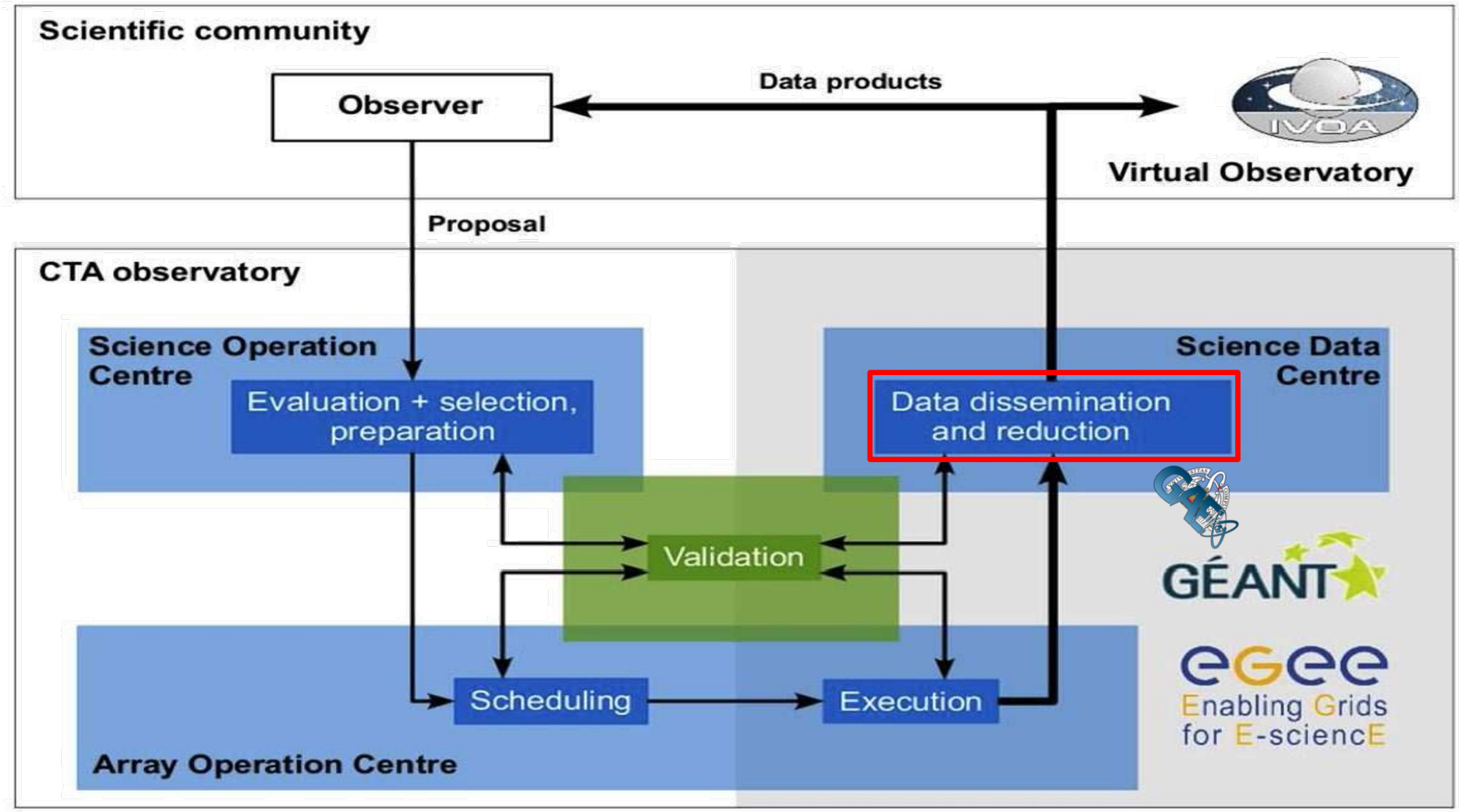


~2000 PMT-based camera

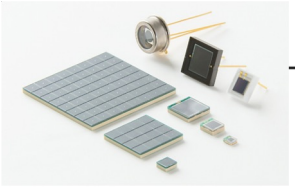
CTA Observatory

Cherenkov Telescope Array Observatory



AI for CTAO Trigger

Advanced LST SiPM Camera*



Candidate for mid-term upgrade of CTAO telescope cameras

Camara

Stereo trigger signals

SiPM cluster → Front - end board → L1 board

SiPM cluster → Front - end board → L1 board

Trigger management

Central Trigger Processor

L2 trigger

DAQ

Raw analog SiPM signal

Digital SiPM signal
1 GHz sampling rate
~72 Tb/s

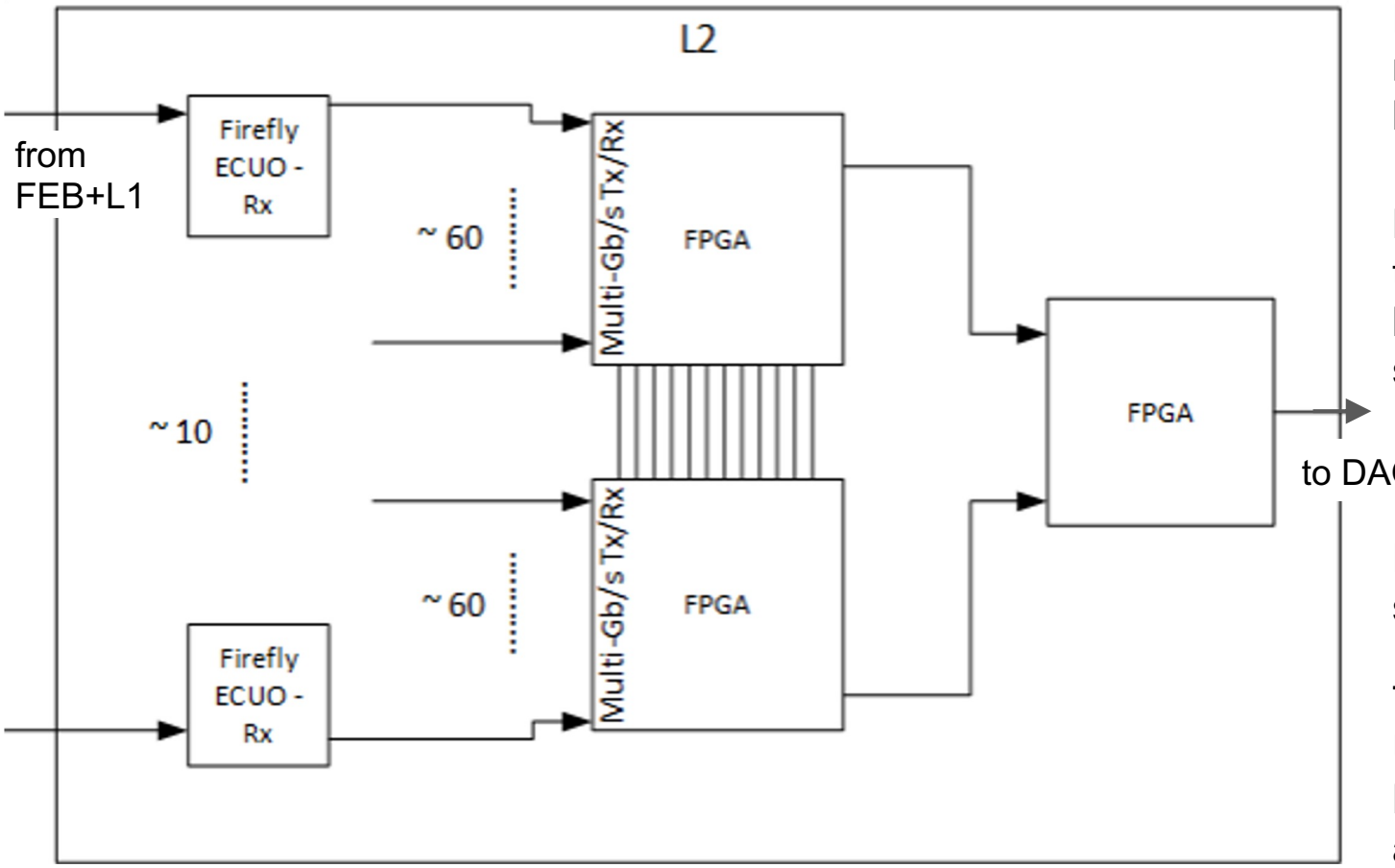
Full event after L1 trigger
300 kHz* event rate
10Gb/s optical links

Full event after L2 trig
30 kHz* event rate

*PoS(ICRC2023)740

AI for CTAO Trigger

Central Trigger Processor: AI-based L2 trigger on FPGAs



First layer of FPGAs for data reception, formatting and first layers of CNN algorithm.

Last FPGA will take care of the CNN last fully connected layers, Event Building and sending the data to DAQ.

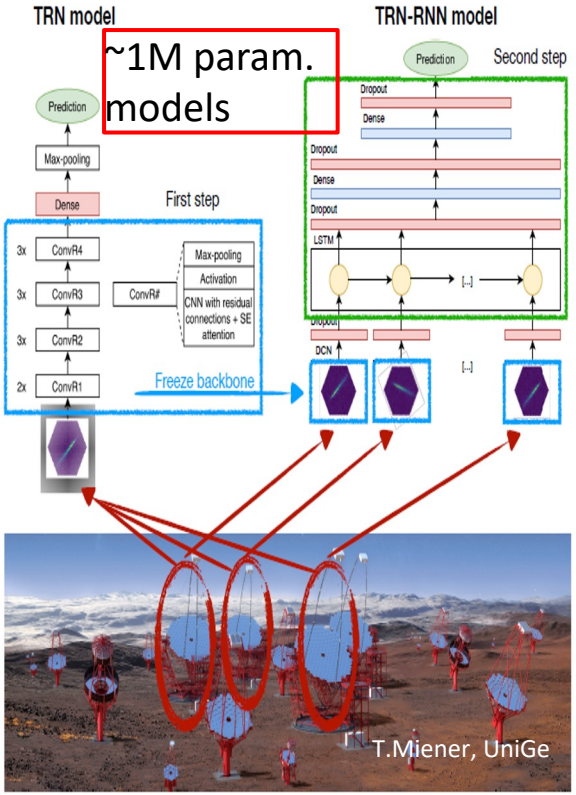
FPGAs in layers to allow scalability

Tentative FPGA models: Kintex UltraScale KU085, KU095 or KU115, with moderate cost and a large number of high-speed resources.

AI for CTAO Trigger

AI algorithms for CTAO camera trigger

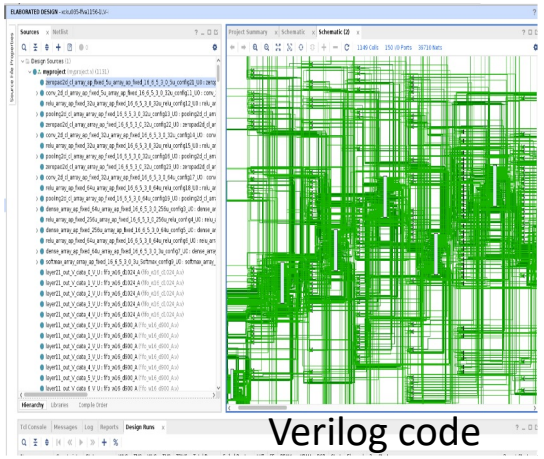
- CTLearn*, led by IPARCOS-UCM members, builds CNN models for IACT array-based gamma/hadron/Night-Sky-Background separation
- Train small CNNs to fit in FPGAs → promising telescope-based shower/NSB separation
- Translating CNN models to firmware code

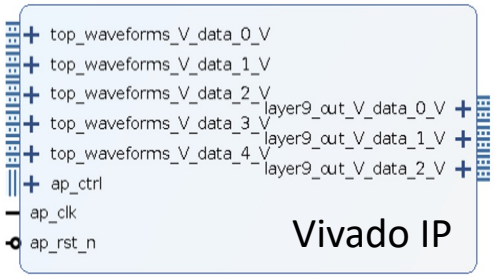


~2k param. models

```
Model: "CTLearn_model"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
waveforms (InputLayer)       [(None, 30, 30, 5)]       0

SingleCNN_block (Functiona   (None, 16)                1536
l)

fc_particletype_1 (Dense)    (None, 32)                544

particletype (Dense)         (None, 3)                 99

type (Softmax)               (None, 3)                 0

=================================================================
Total params: 2179 (8.51 KB)
Trainable params: 2179 (8.51 KB)
Non-trainable params: 0 (0.00 Byte)
```

hls 4 ml



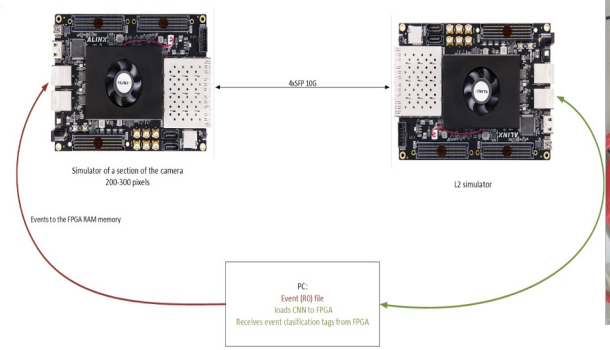


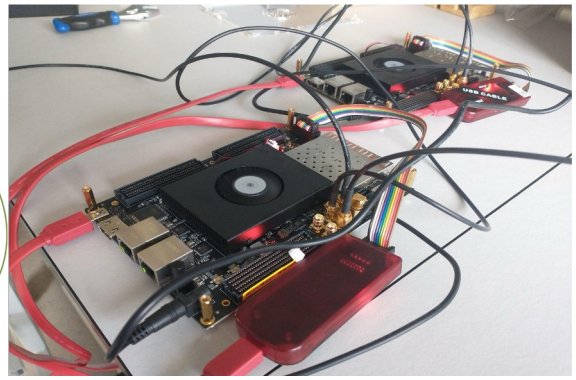
*https://github.com/ctlearn-project/ctlearn

AI for CTAO Trigger

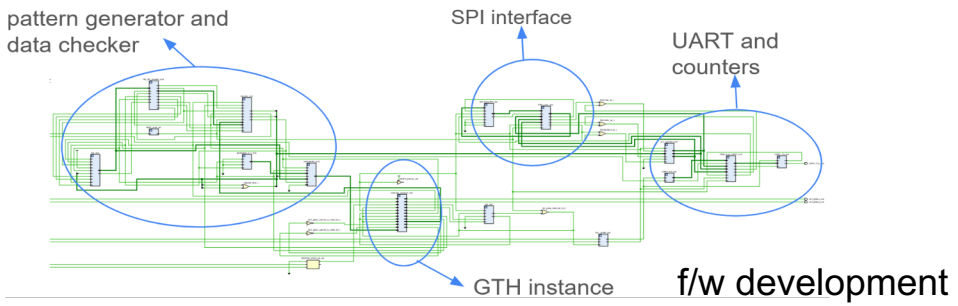
Prototype 1: CNN4FPGA trigger testbench

- Building the testbench
  - 2 development boards with Kintex UltraScale tier FPGAs (Alinx XCKU040 with 4 SFPs)
  - One board to simulate pixel data information (i.e. FEB+L1) and the other to implement & test firmware core and L2 algorithms

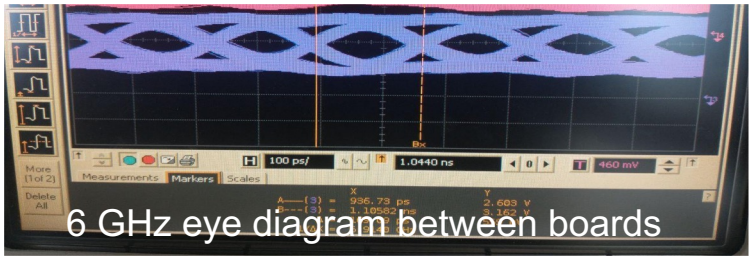




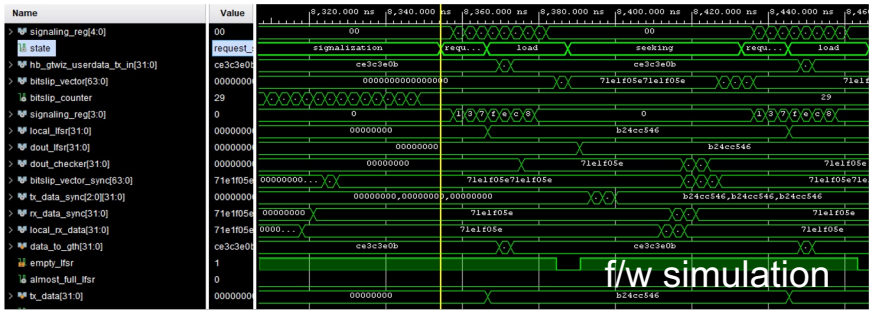
- Using the testbench
  - Develop f/w for multi-gigabit transceivers and other interfaces.
  - Test f/w in the development boards.



f/w development



6 GHz eye diagram between boards

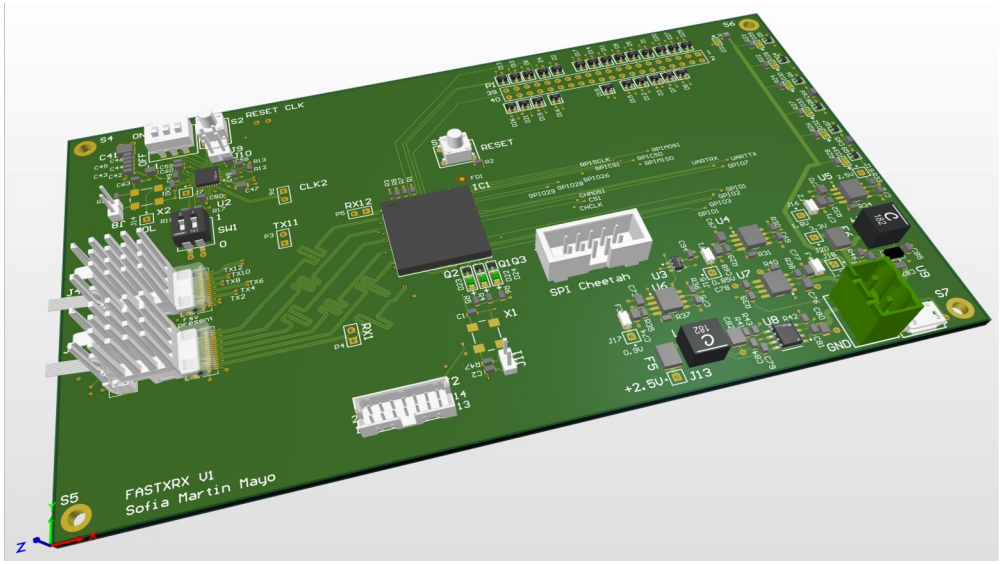


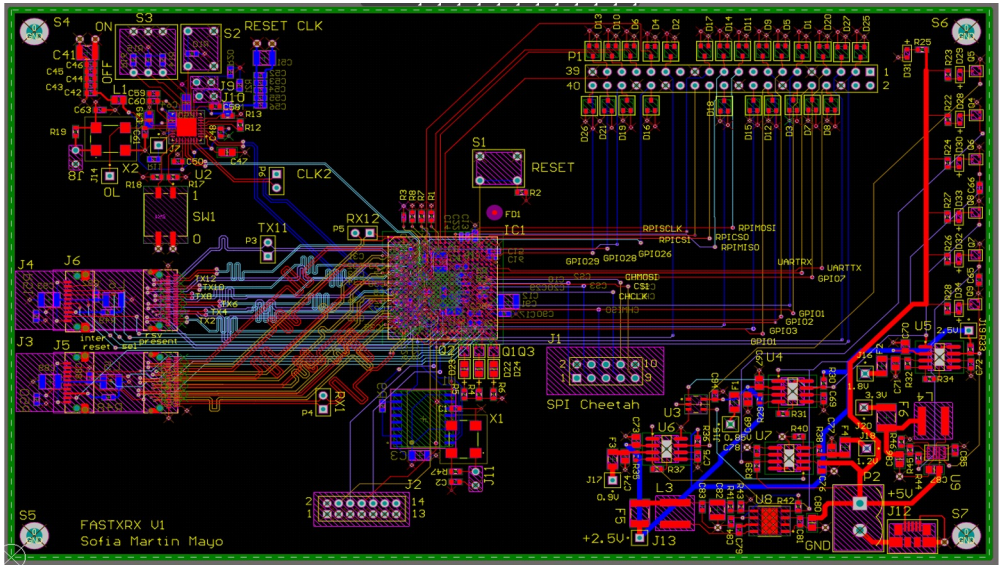
f/w simulation

AI for CTAO Trigger

Prototype 2: CTP high-speed testbench

- Building the testbench
  - Firefly optical transceiver + Microwave PCB + FPGA interface.
  - Test the capabilities and quality of the companies to produce the final board.
  - Design finished and files sent to the manufacturing company.





CTA Offline Data Volume Reduction: AI algorithms on GPUs

- Status
  - Prior experience in IACT event reconstruction (LST-OnSiteAnalysis) using AI (CTLearn)
  - Applying analogous CNN algorithms to address the challenge of offline Reducing the CTA Data Volume ← *Data Rate* x *Data size*
  - Integrate AI capabilities into the CTA offline analysis pipeline, seeking a more efficient processing chain in both computational and storage aspects
  - Initial activities fostered after *AI for CTAO Trigger* activities
  - Contribution needed in 2025-2028

AstroHEP PPCC impact

- Scope
  - ~90 k€
  - Engineer costs: A. Pérez-Aguilera, May 2023 – March 2025
- Impact
  - Support of initial involvement in Advanced LST SiPM-CAM
  - Current design and prototyping of a SiPM-CAM key element
  - Allow to apply for other grants (PDC2023 ✓ , EU INFRA-Tech 🤞)
  - Transfer of knowledge started for fast AI-based image processing on FPGA
- Plea
  - 4-month extension

Summary

- CTAO ESFRI construction started
- TAU-CM supports IPARCOS-UCM involvement in key R&D for CTA
- Transfer of Knowledge pursued/expected from TAU-CM activities
- TAU-CM extension needed