UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

cherenkov telescope array

The LST Advanced SiPM Camera

M. Heller on behalf of the CTA-LST Project - ICRC 12-23/07/2021

ONLINE ICRC 2021
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Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

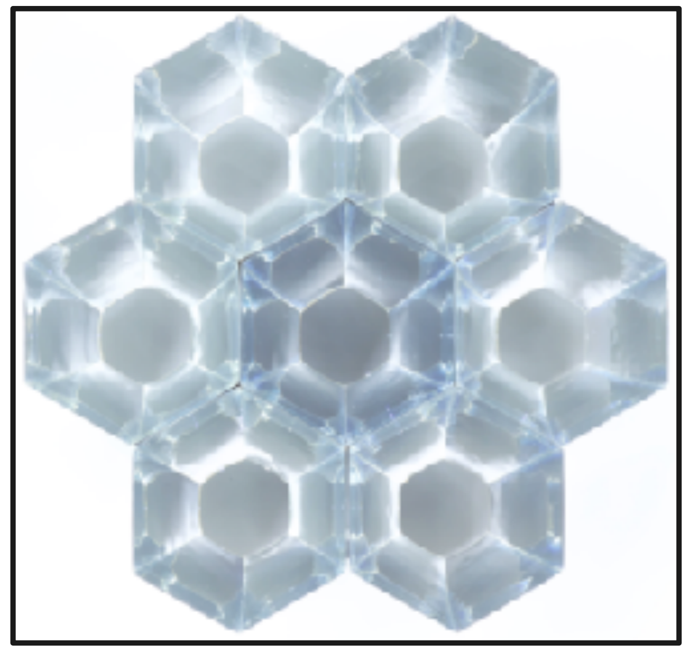
Courtesy of D. Kerszberg

Outline

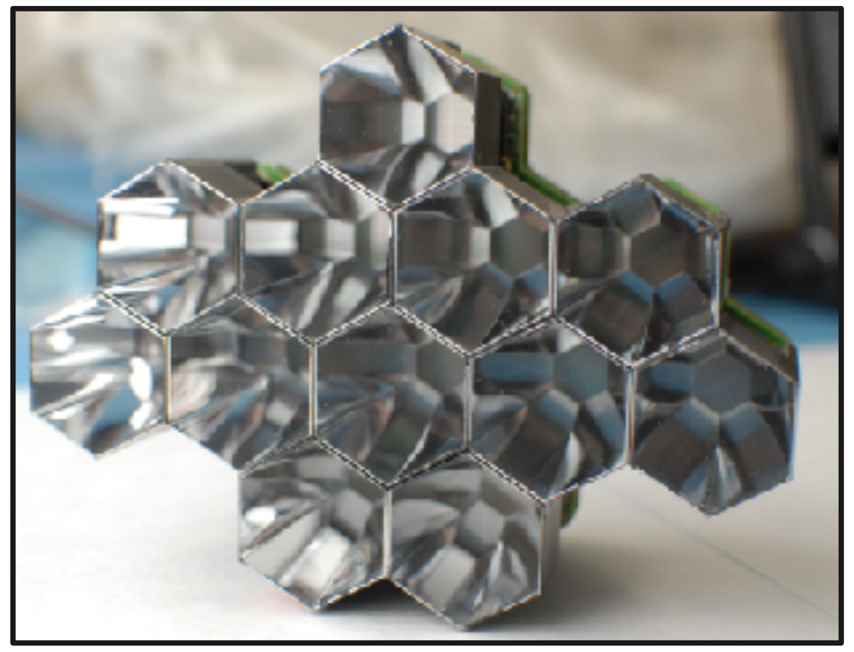
- Goal
- Project organisation
- Simulation and Analysis effort
  - Simulation phase-space
  - Analysis pipelines
- Photo-detection plane
  - Optical elements
  - Sensor technology
  - Front-end electronics
- Readout
  - Trigger approach

Goals

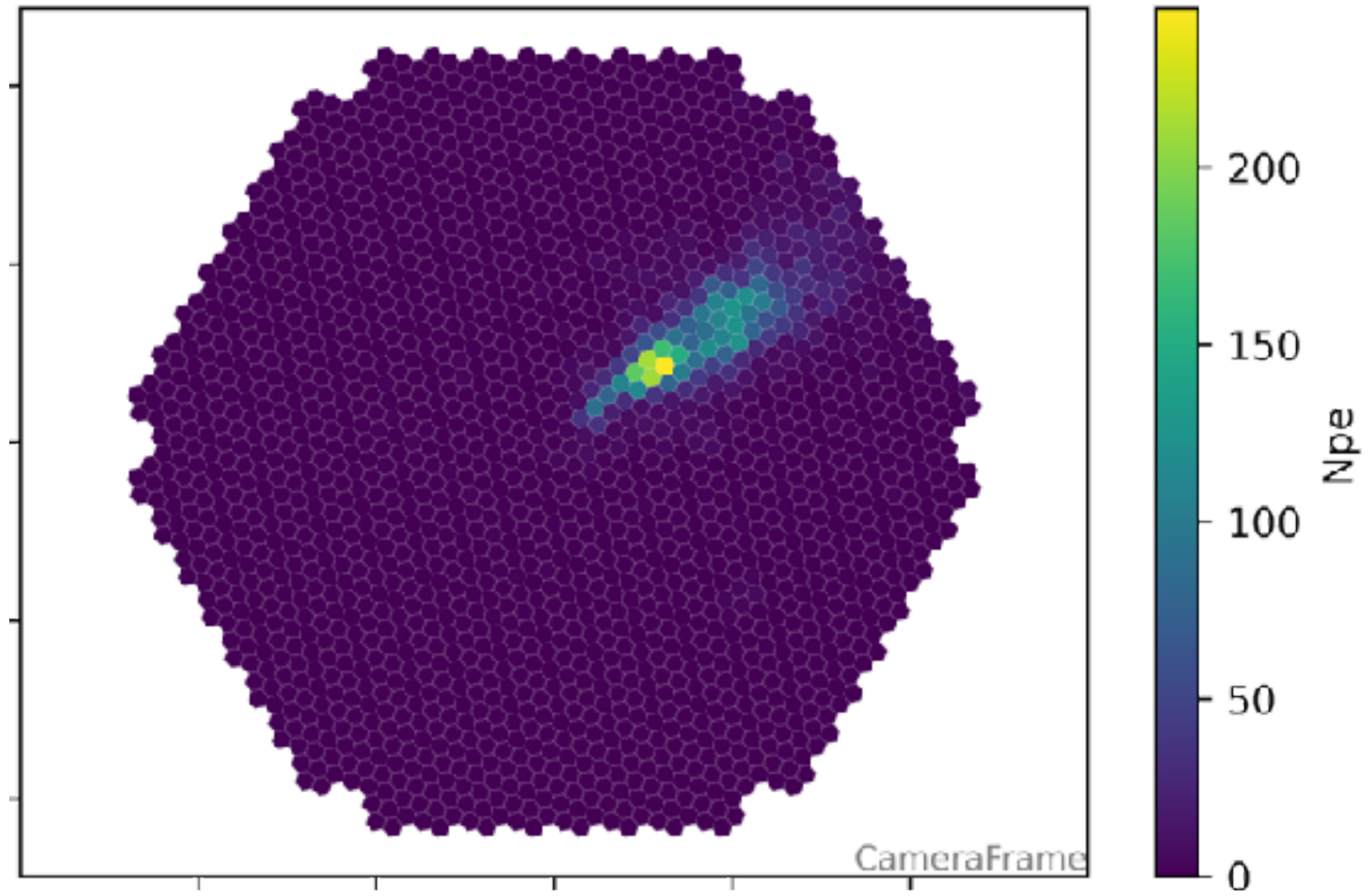
- The proposed design should take full advantage of the SiPM characteristics
  - ✦ Gain in duty-cycle, robustness, stability, self-calibration, etc…
- The Advanced SiPM Camera must:
  - ✦ outperform the existing camera over the entire energy range
  - ✦ be upgradable/reprogrammable
- Baseline design:
  - ✦ Decreasing pixel size **from 0.1° to 0.05°**
  - ✦ Going for **fully digital readout**
- Many challenges to tackle:
  - ✦ **Power consumption**
  - ✦ **Data throughput**
  - ✦ **Cost**
  - ✦ **5 years to complete 1st prototype**

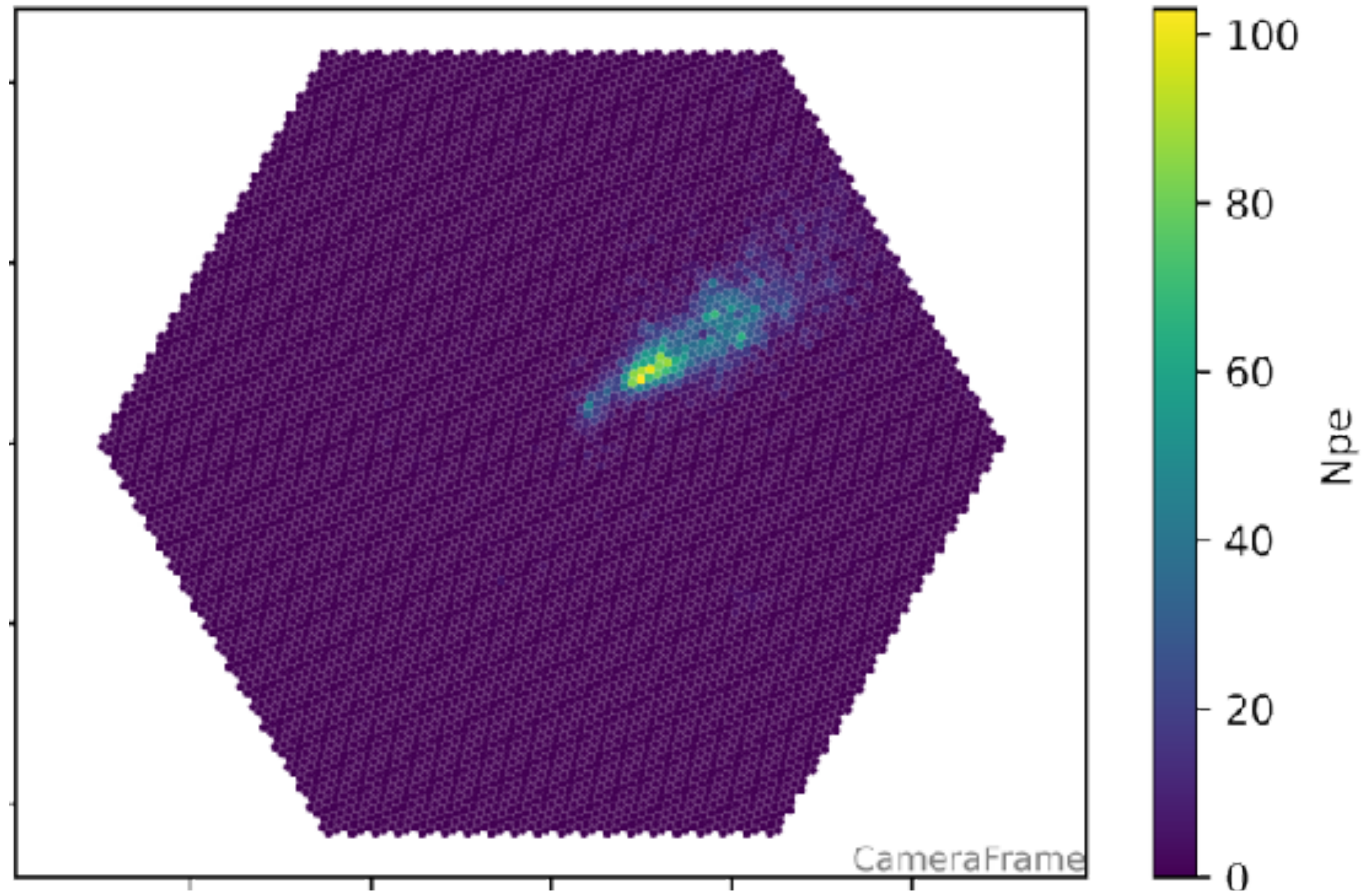


LST PMT camera **(0.1°)**



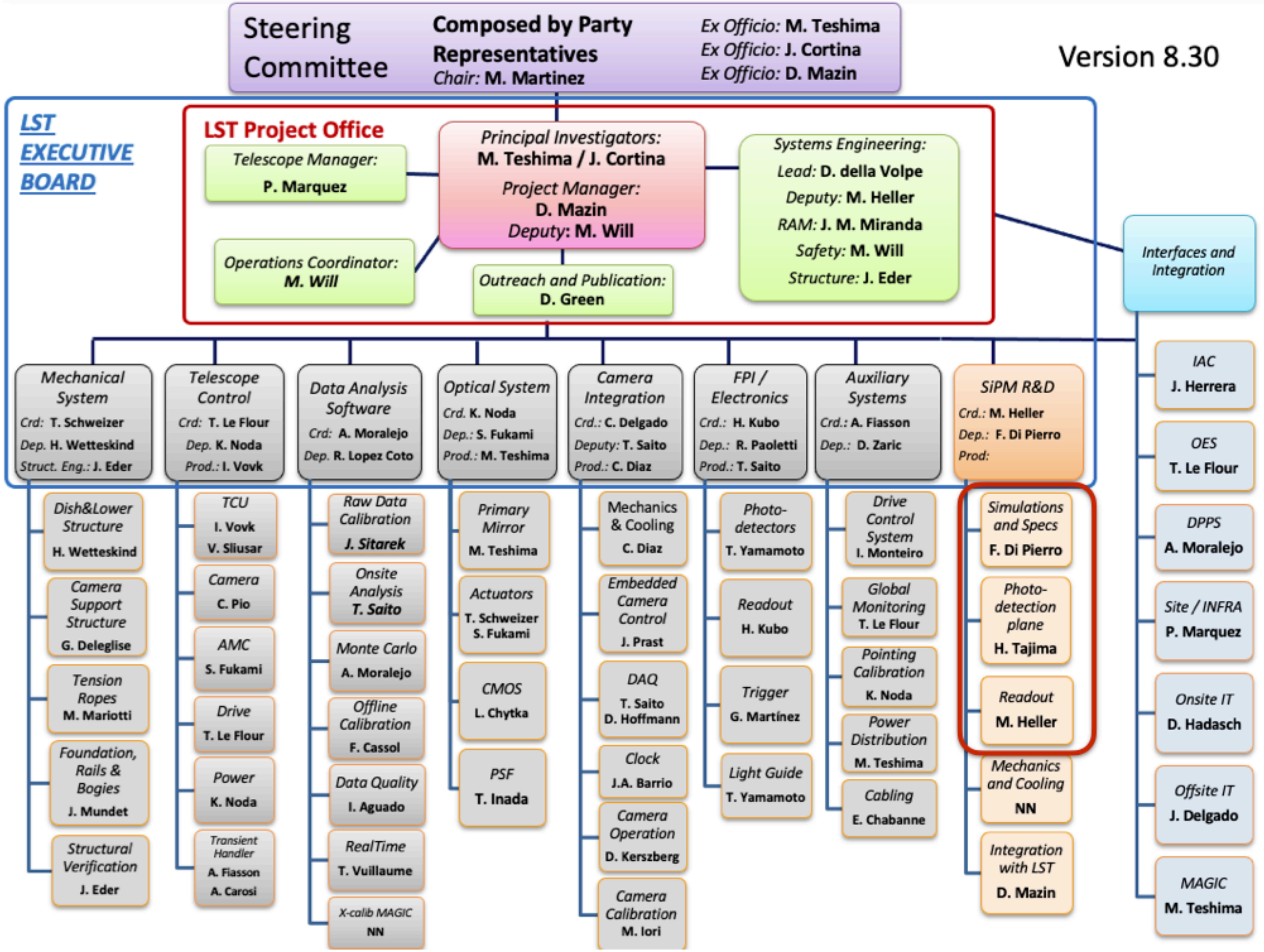
LST SiPM camera (**0.05°)**





Gamma event

The project organisation

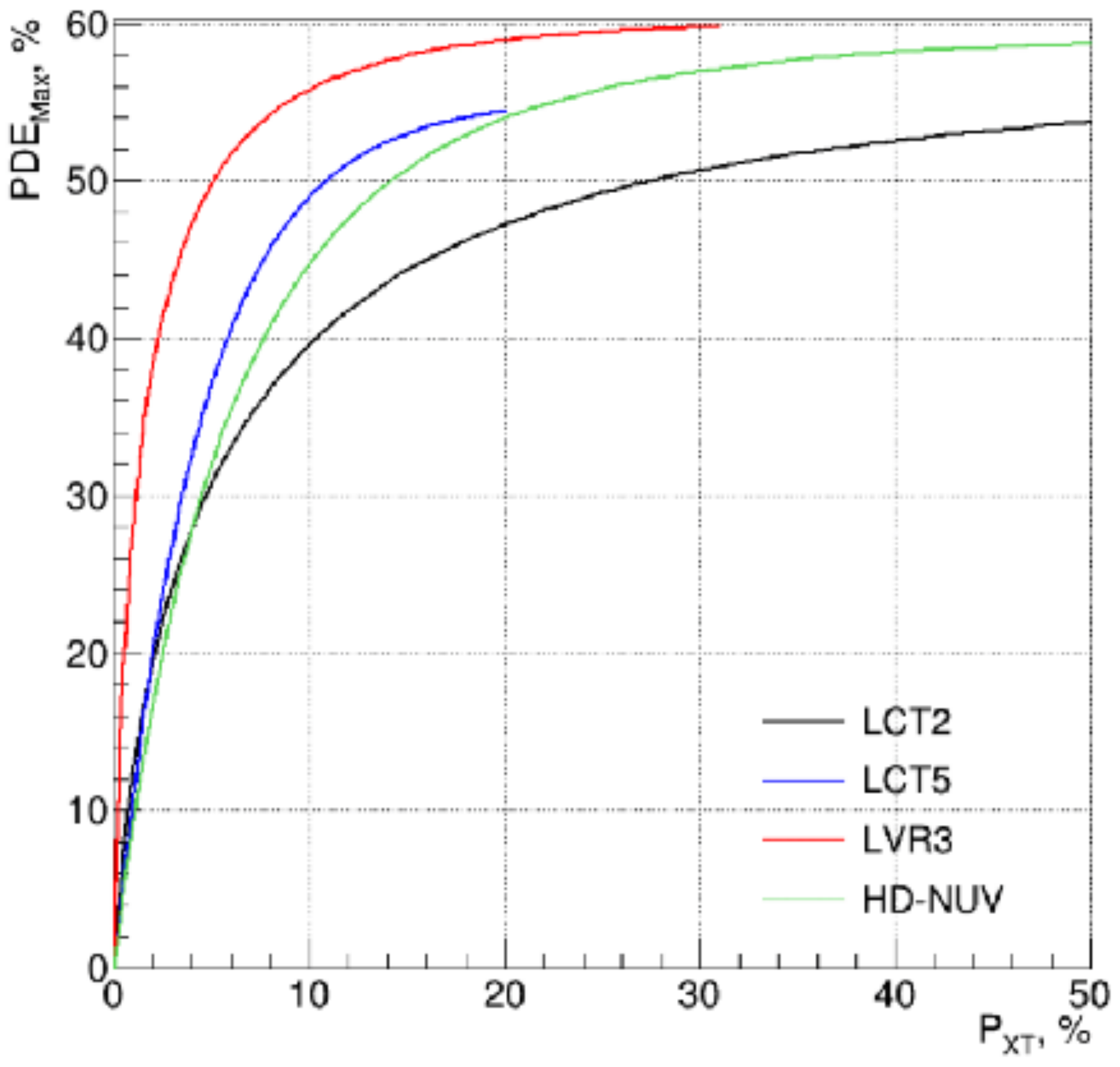


- The R&D program is part of the LST organigram
- But has its own organisation, split in five working groups:
  - ✦ Management
  - ✦ Simulation and Analysis
  - ✦ Photo-detection plane
  - ✦ Readout
  - ✦ Mechanics
- International project:
  - ✦ France, Italy, Japan, Poland, Spain, Switzerland

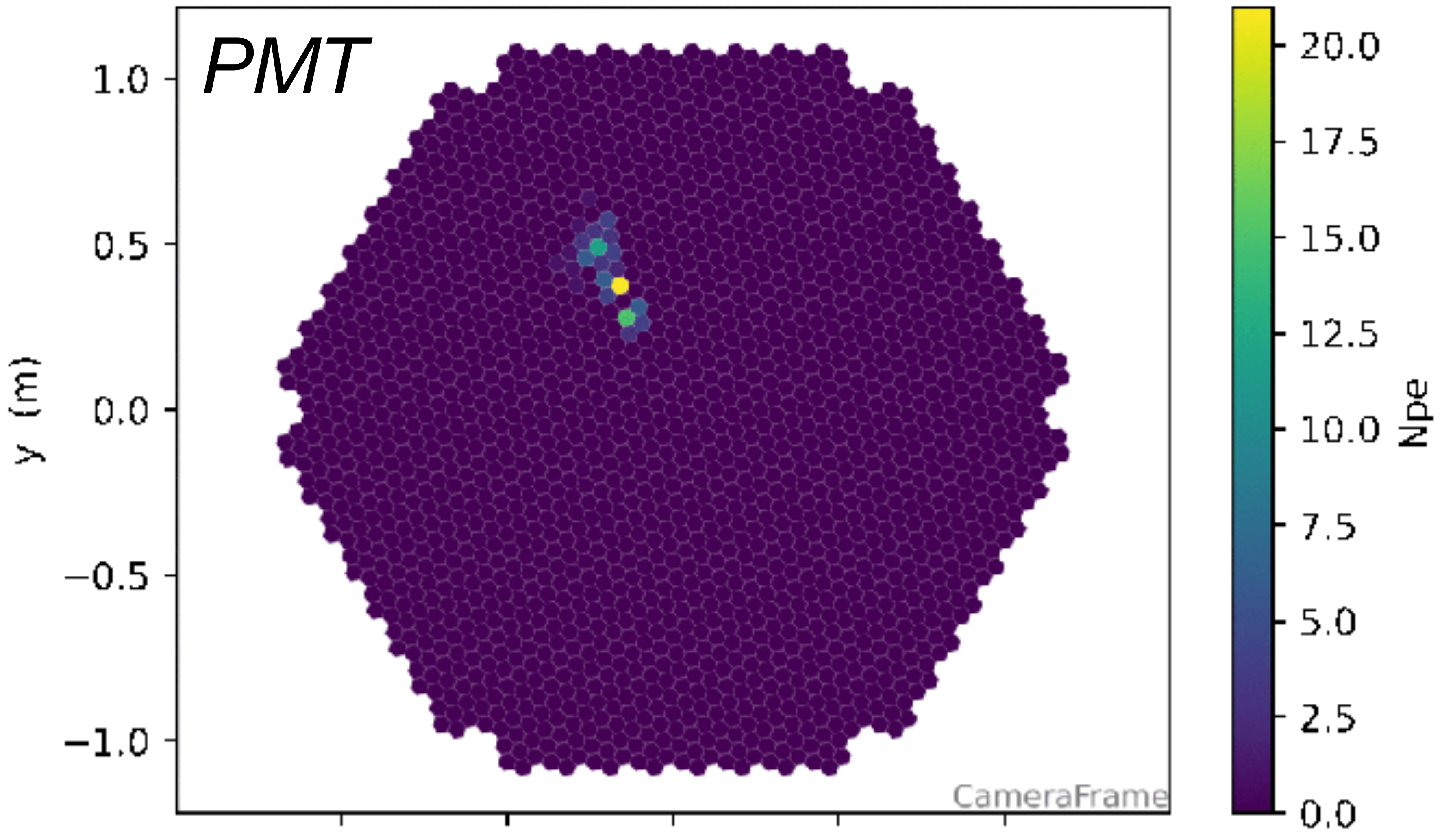
Simulation and Analysis

Large phase-space to explore

- Corsika + sim_telarray simulations used for parameters exploration



- Phase-space:
  - Entrance window
    - w/ or w/o optical filter ?
  - Pixel size:
    - 0.05° or bigger ?
  - Sensor choice:
    - photo-detection efficiency vs. λ, optical cross talk, Cμcell, etc…
  - Front-end:
    - Signal shaping, linearity, dynamic range
  - Trigger topology:
    - Standard analog sum trigger or advanced trigger



On-axis gammas increasing energy bins

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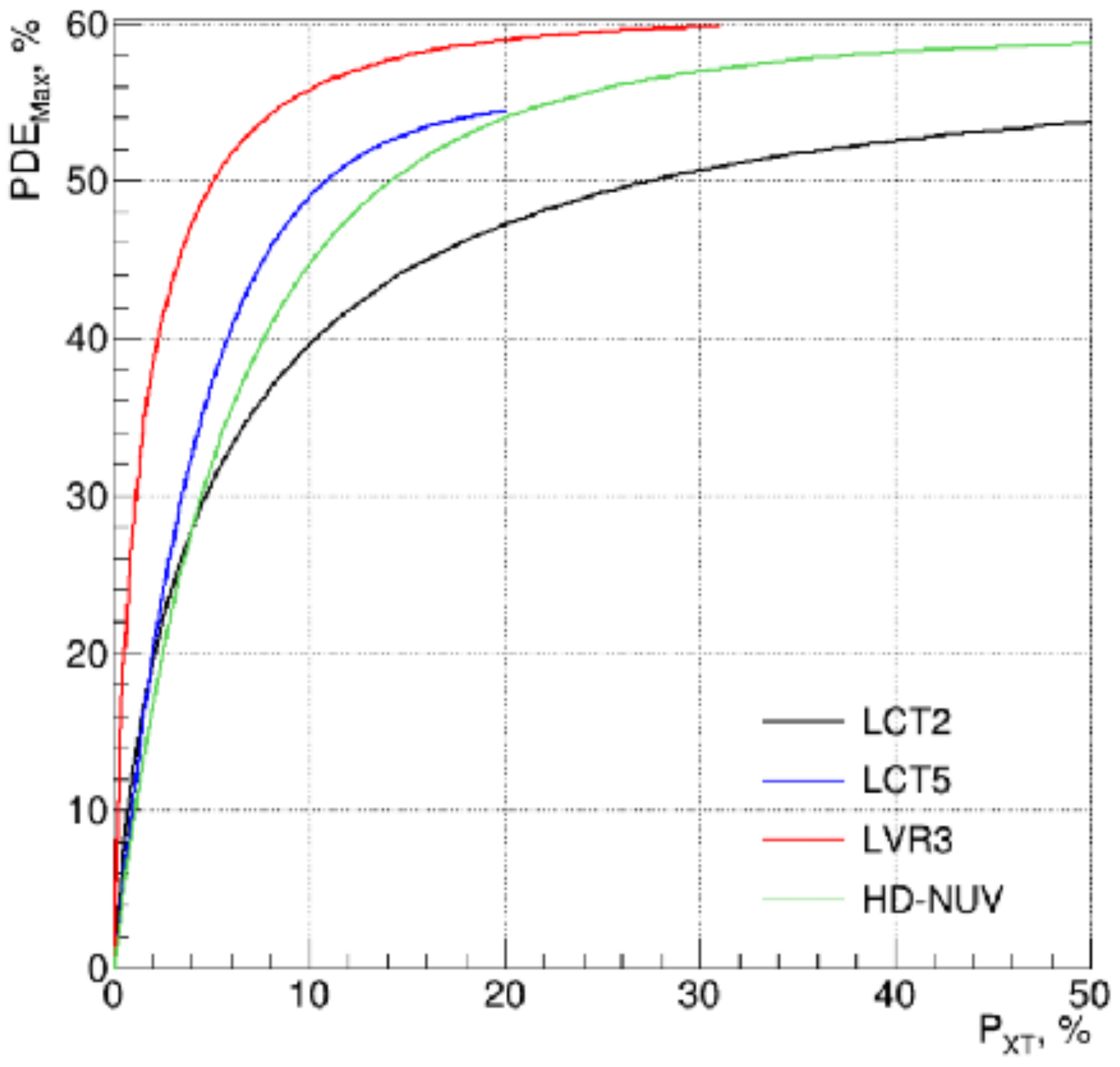

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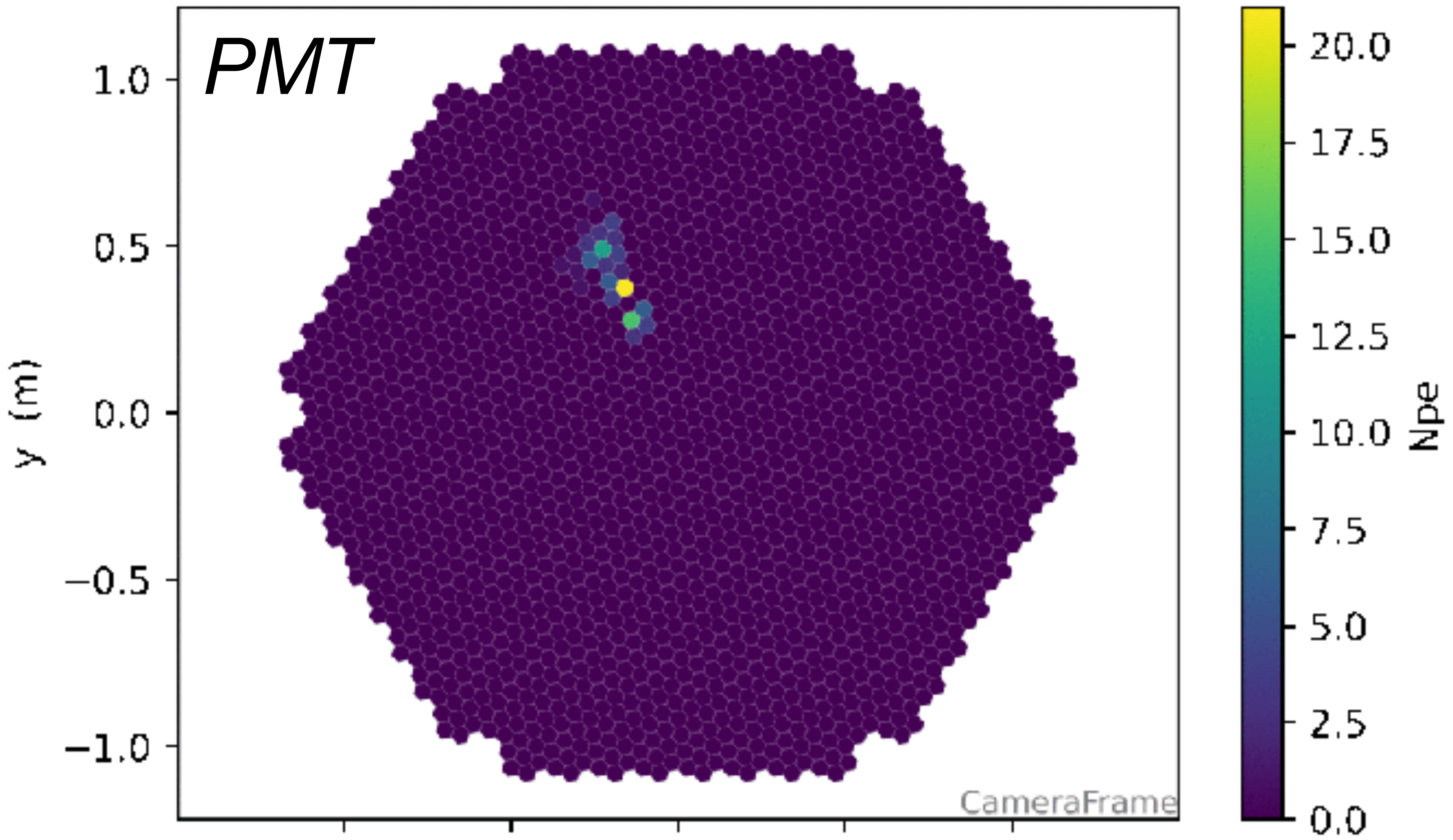

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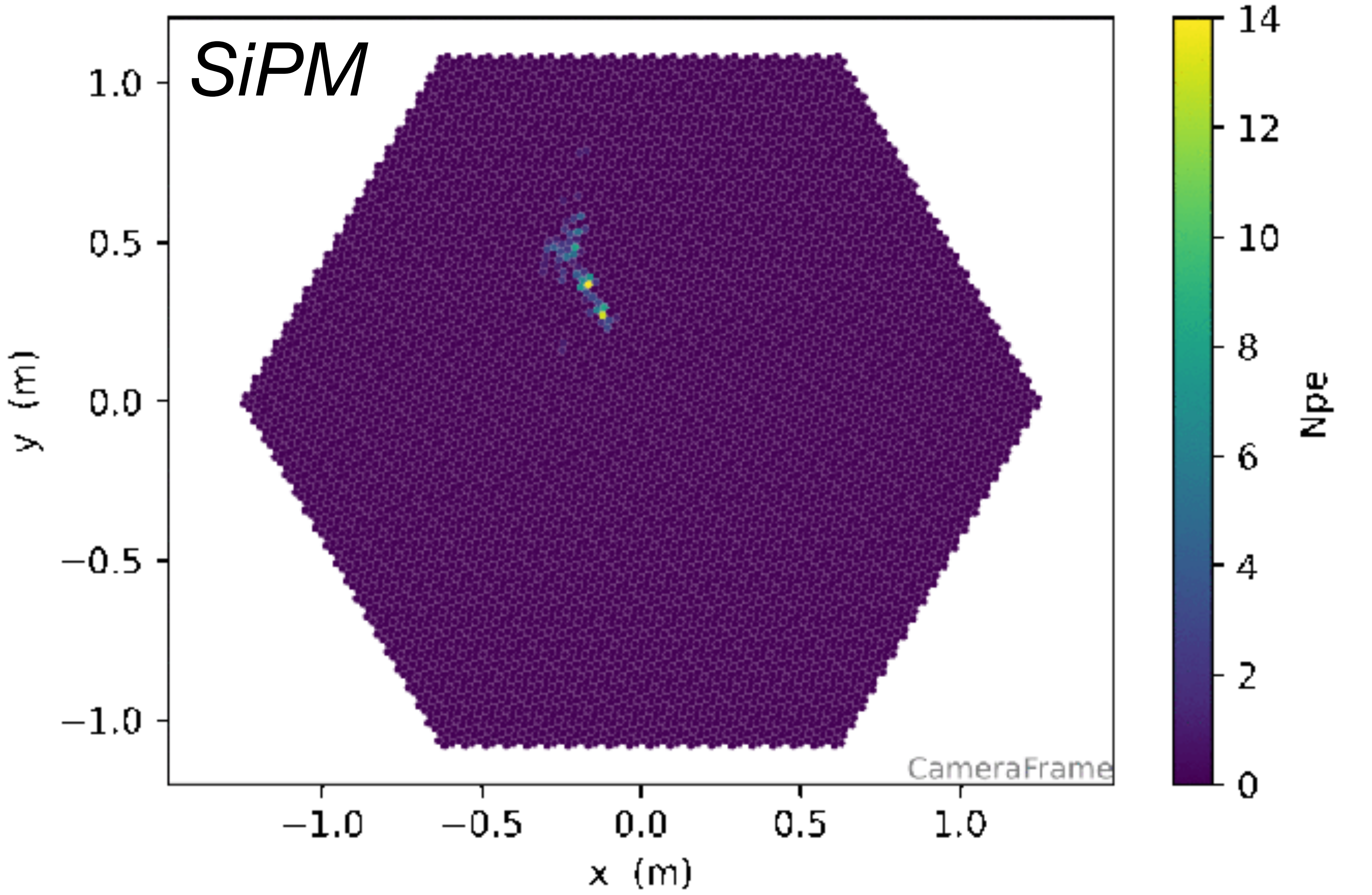
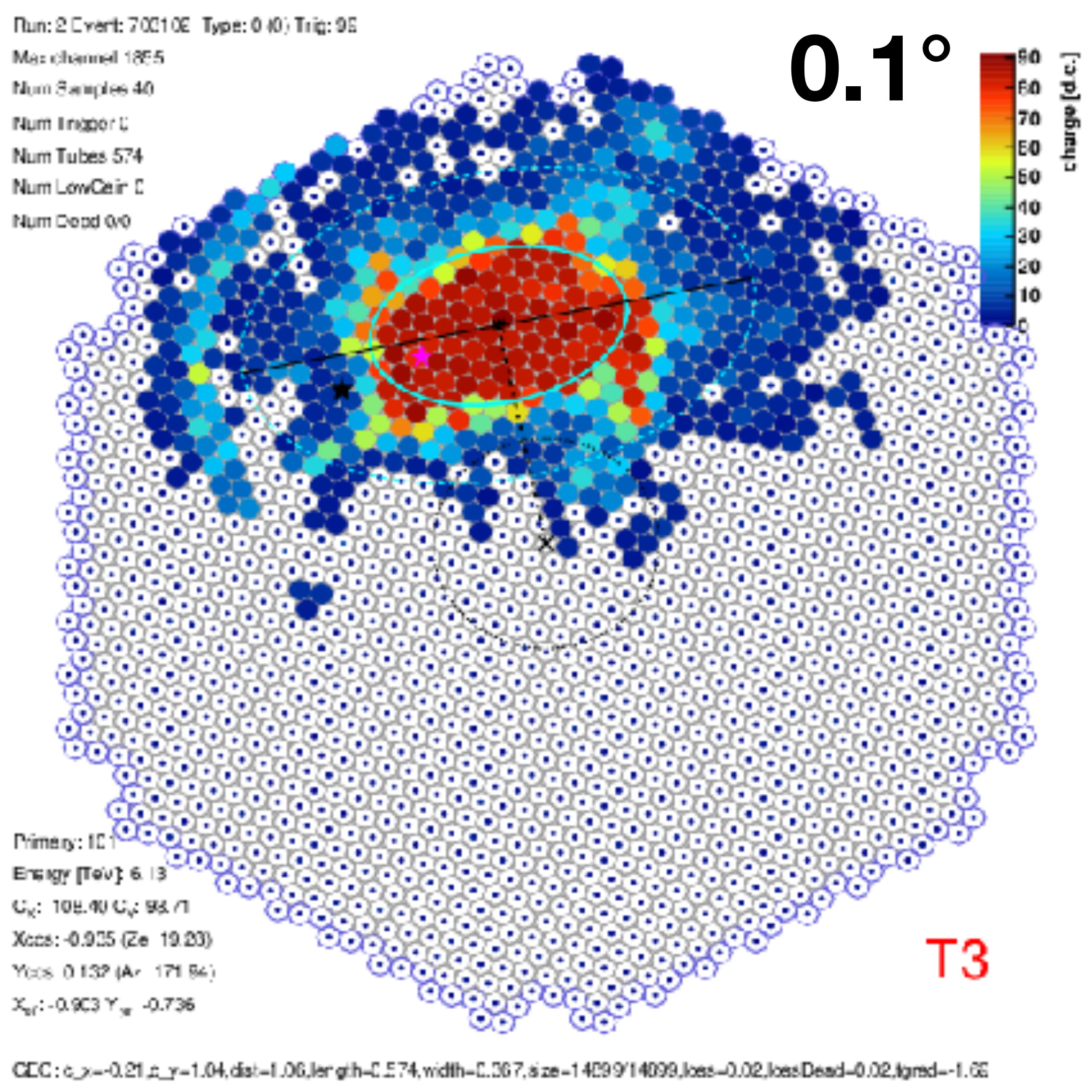


Simulation and Analysis

Analysis Pipelines

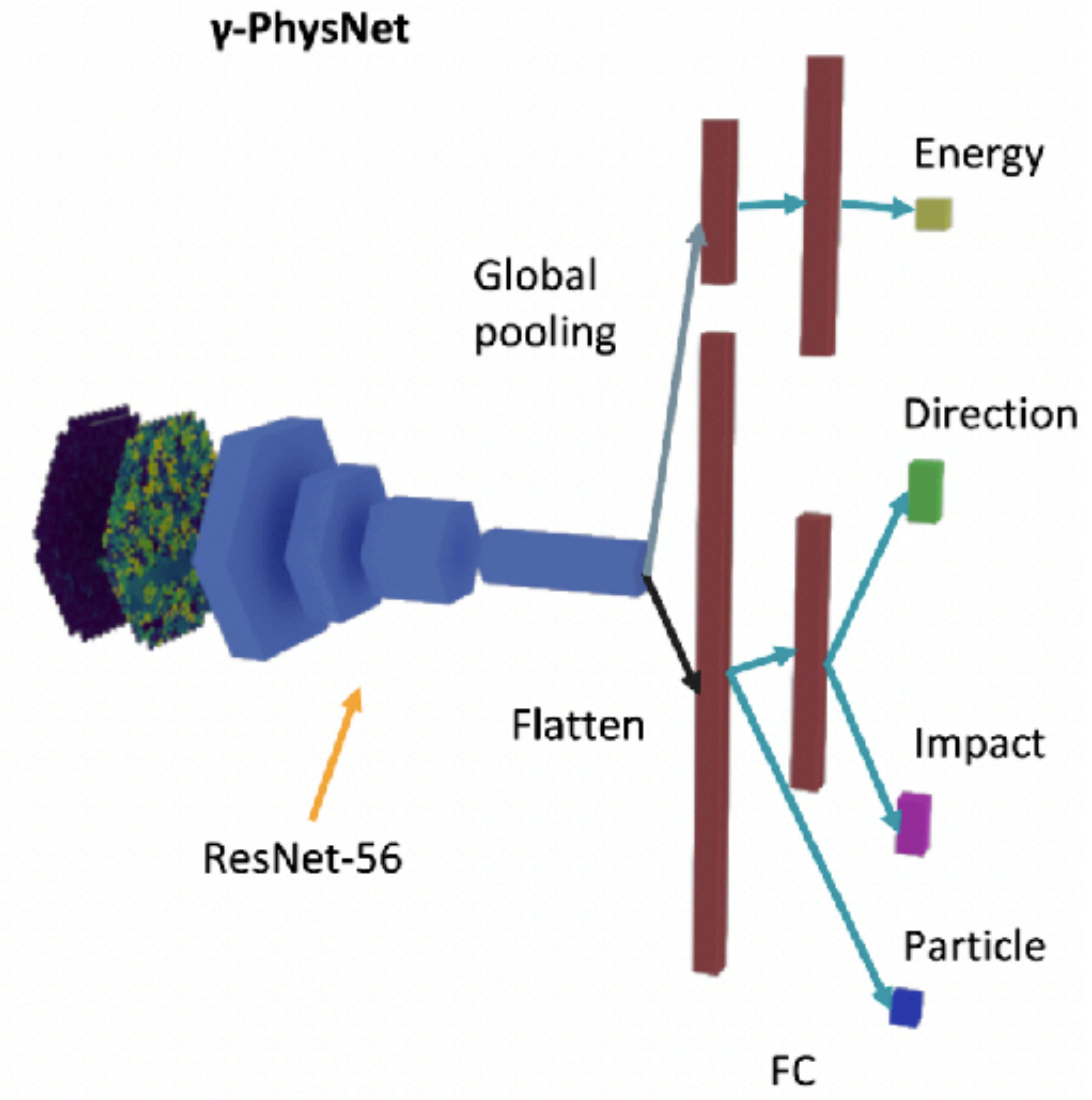
- The increased image granularity reveals more image features

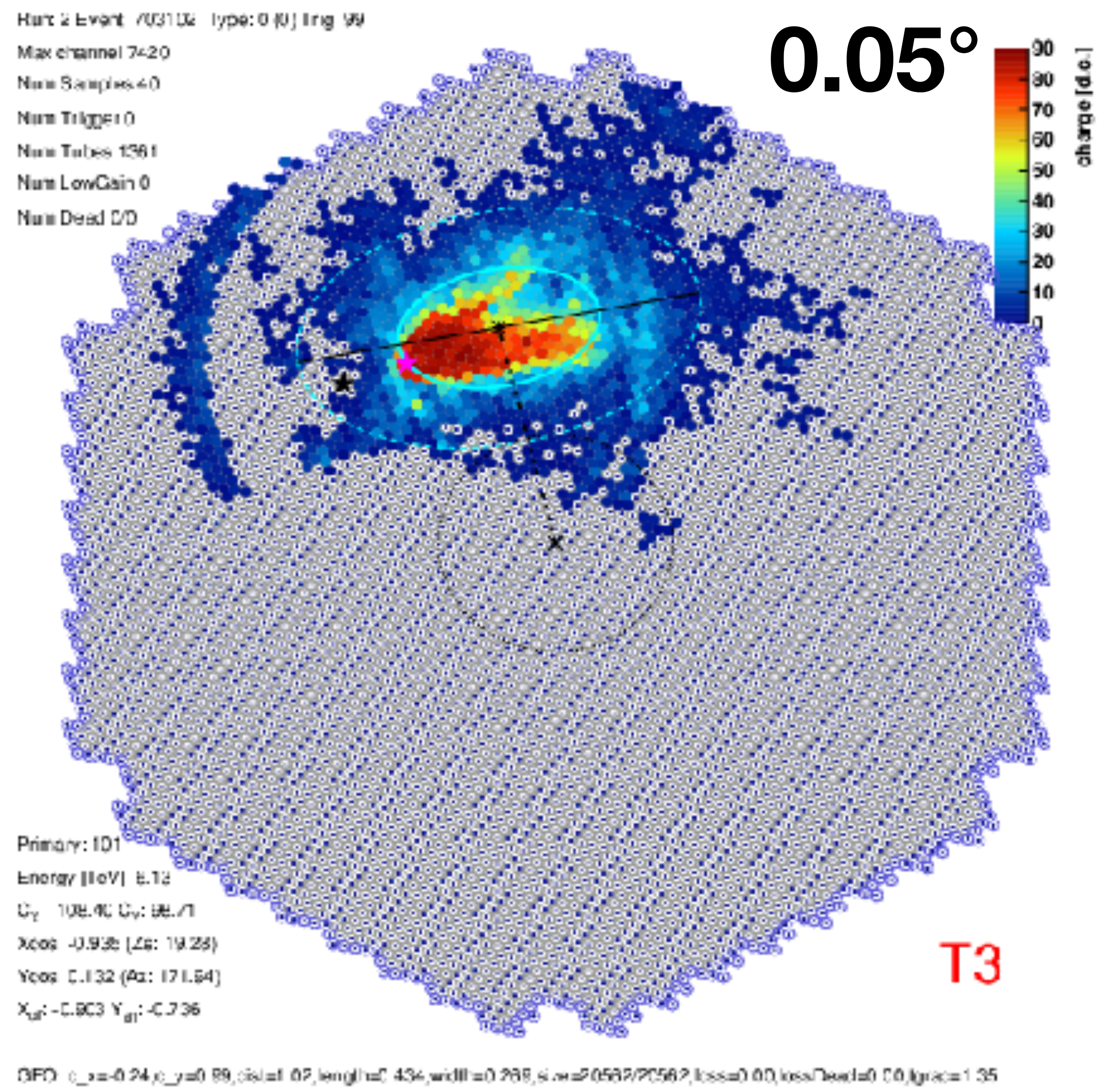


- Standard LST analysis pipeline (see contribution):
  - ✦ Hillas parameter extraction fed to random forests as:
    - regressors for energy and direction reconstruction
    - classifier for gamma/hadron separation

- Template-based or Likelihood method
  - ✦ ImPact, method++
  - ✦ LHFit (this ICRC21)

- Deep Learning analysis pipeline
  - ✦ Convolutional Neural Network for regression and classification
    - CTLearn
    - γphysnet





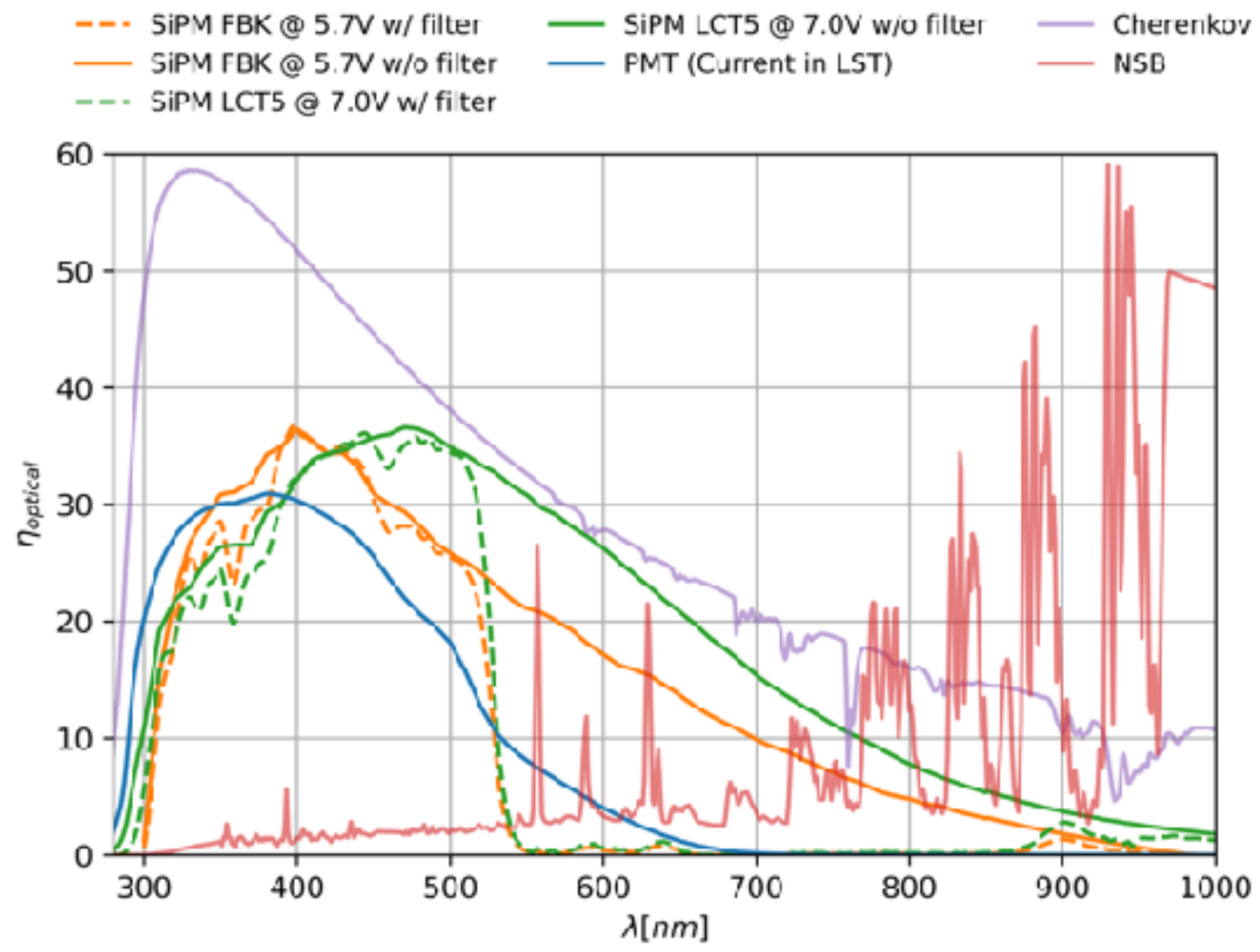
Photon-detection Plane

Optical elements and sensors

- Night Sky Background becomes a real issue when such large light collection surface are used
  - PMT (0.1°)
    - w/o filter: 246 MHz p.e./pixel
  - SiPM (0.05°)
    - w/o filter: 386 MHz p.e./pixel
    - w filter: 134 MHz p.e./pixel

- Pile up of NSB photons result in increase of the hardware threshold

- Filter decrease NSB contribution but also limits the gain of SiPM increased PDE compared to PMTs



Configuration	Safe Threshold [photons]	NSB rate [MHz/pixel]	Cherenkov cum. efficiency [%]	NSB cum. efficiency [%]	Optical Cross-Talk [%]	Safe Threshold [p.e.]
PMT w/o filter	286	246	15.9	1.7	0	45
LCT5 w/o filter (ΔV=4.4)	272	386	20.8	6.2	8	61
LCT5 w/ filter (ΔV=4.4)	229	108	14.0	1.9	8	34
LCT5 w/o filter (ΔV=7.0)	218	426	24.3	8.1	15	67
LCT5 w/ filter (ΔV=7.0)	179	109	16.0	2.5	15	36

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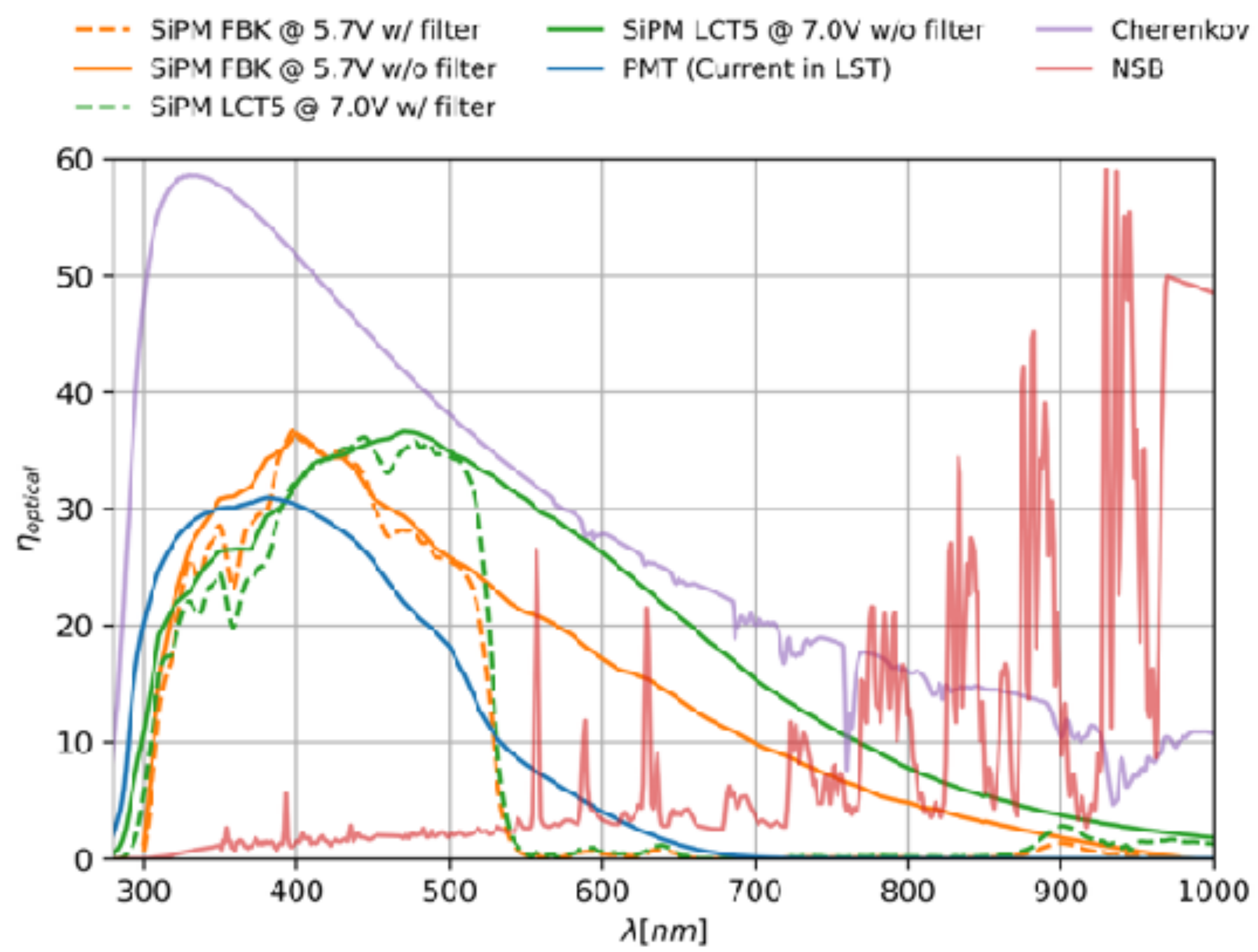

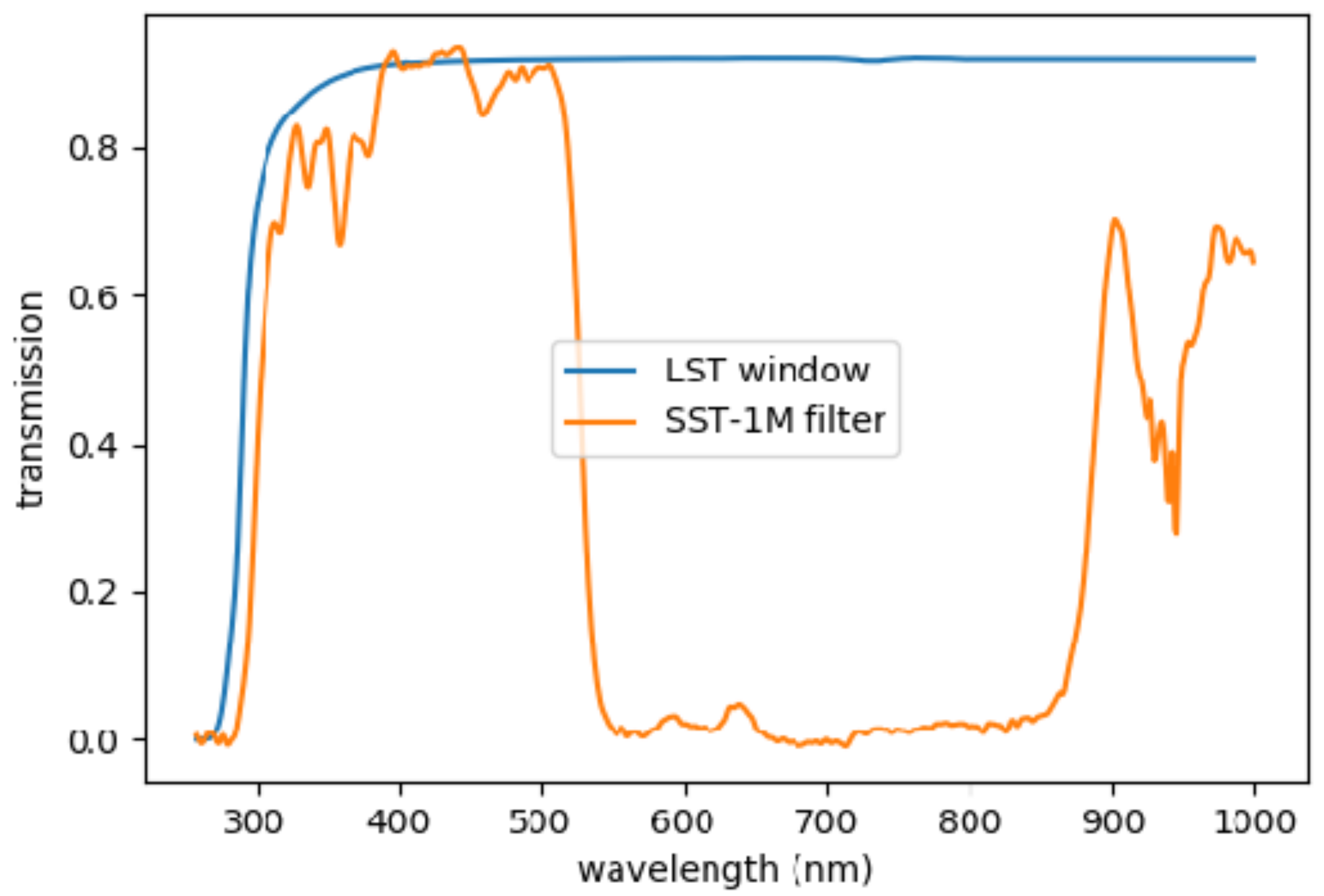

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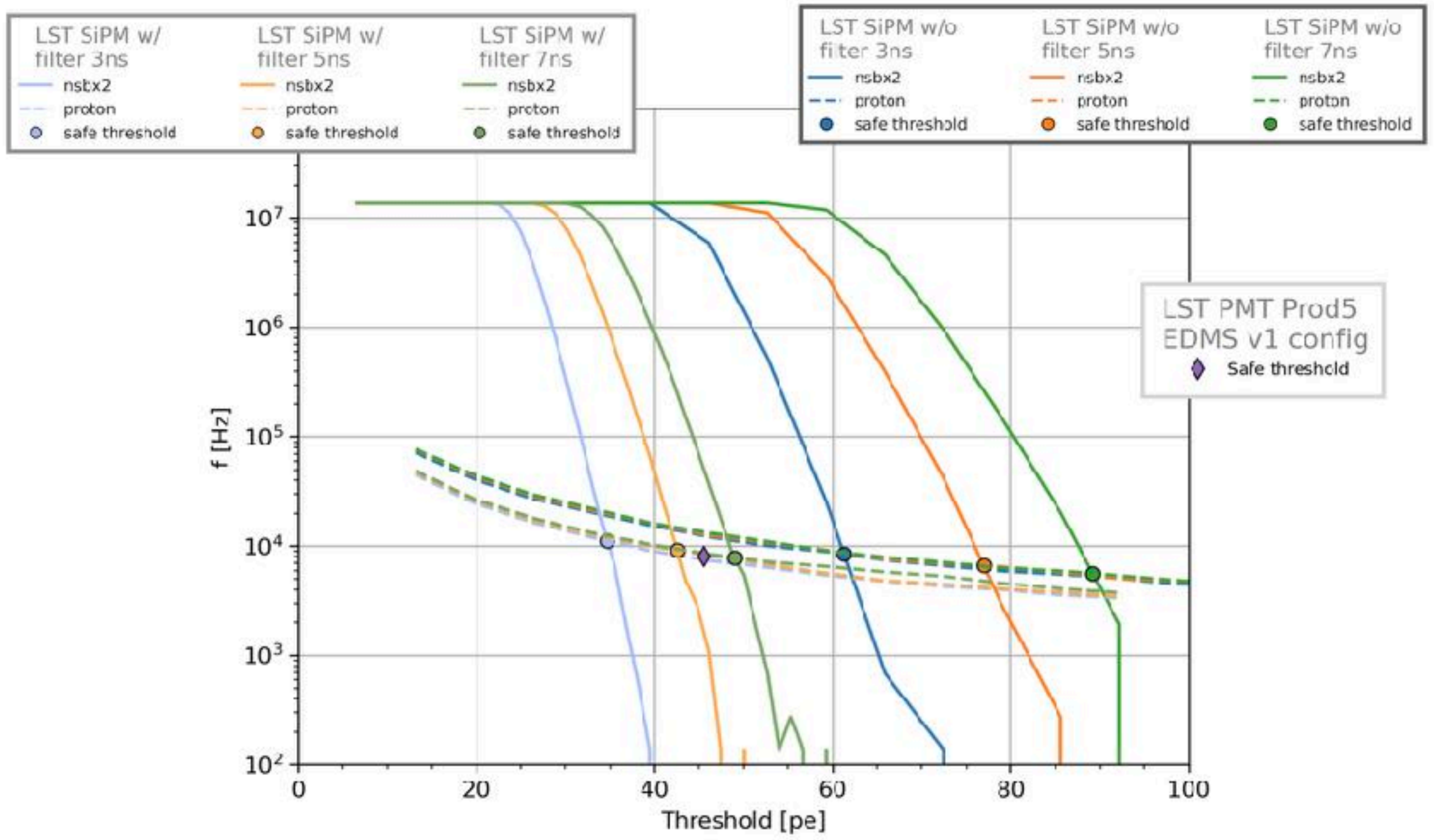
Photon-detection Plane

Front-end electronics

- The main design drivers here are the power consumption and the speed
  - ✦ < 100 mW/ch
  - ✦ Pulse FWHM < 3 ns



Photon-detection Plane

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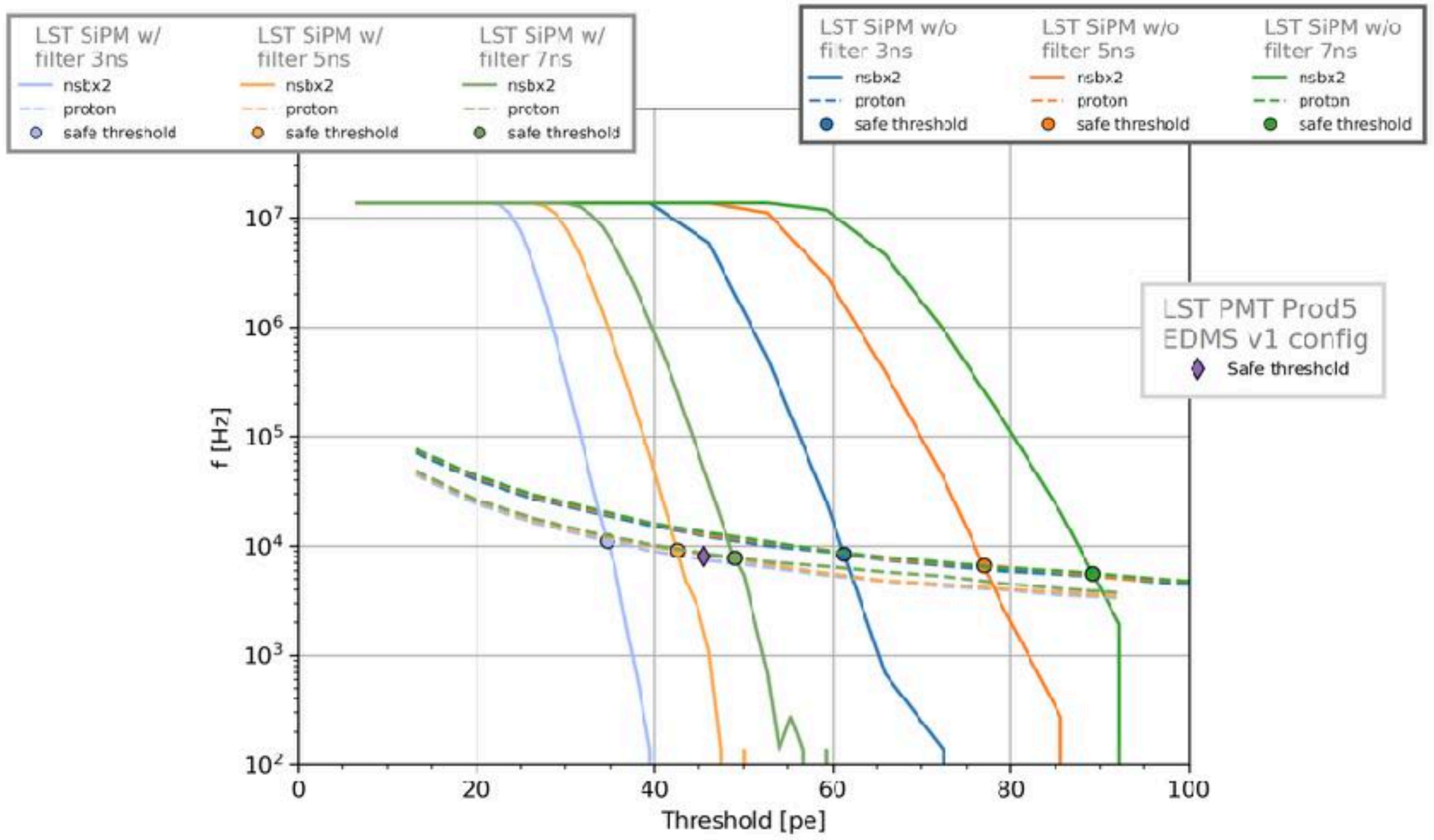
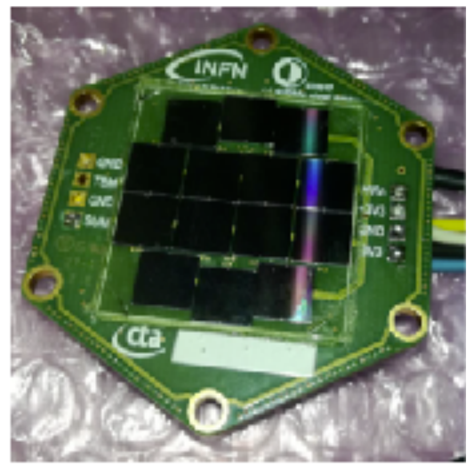
  - Pulse FWHM < 3 ns

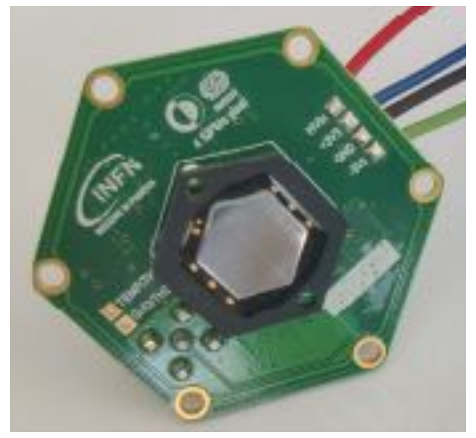
- Discrete components pre-amplifying stages can reach very short pulses but power consumption prohibits their use for such a large amount of pixels

- Using an ASIC or developing one is required
  - FAST, MUSIC, FastIC
  - Tailored design

- Single gain and ~300 p.e. dynamic range





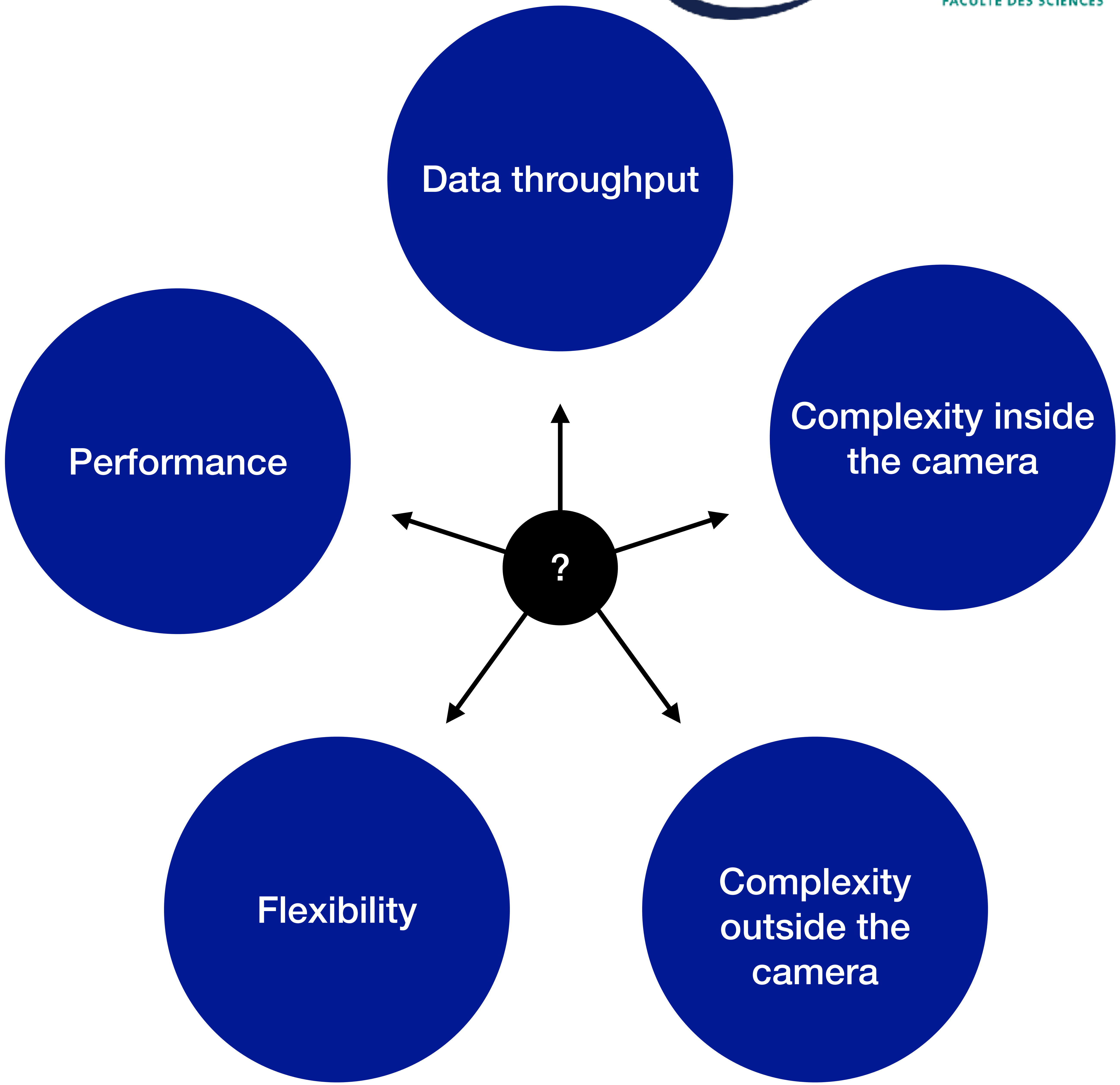


	Pixel size [°]	Pre-amplifying stage	FWHM [ns]	Power consumption [mW/ch]
FBK NUV-HD 14 x (6x6 mm^2)	0.1	INFN	**3.4**	**1500**
FBK NUV-HD 12 x (6x6 mm^2	0.1	MUSIC	**5.3**	**830**
HPK LCT2 (hex. sensor)	0.05	INFN	**2.9**	**450**
HPK LCT2 (hex. sensor)	0.05	MUSIC	**5.1**	**100**

The LST Advanced SiPM Camera

Readout

- Baseline design will feature 12 bits FADCs @ 1 GSps allowing a fully digital readout architecture
- Different approaches under study with different balance between complexity vs. performance
  - Trigger-less approach
  - Advanced trigger in the camera
  - Loose trigger in the camera / more complexe in the camera server
  - Digital photon counter (DiPC)
- In all cases, real-time processing is a must
- Experience on architectures design from IACT field and others will be used
- Several architectures are being studied to accommodate the proposed solutions



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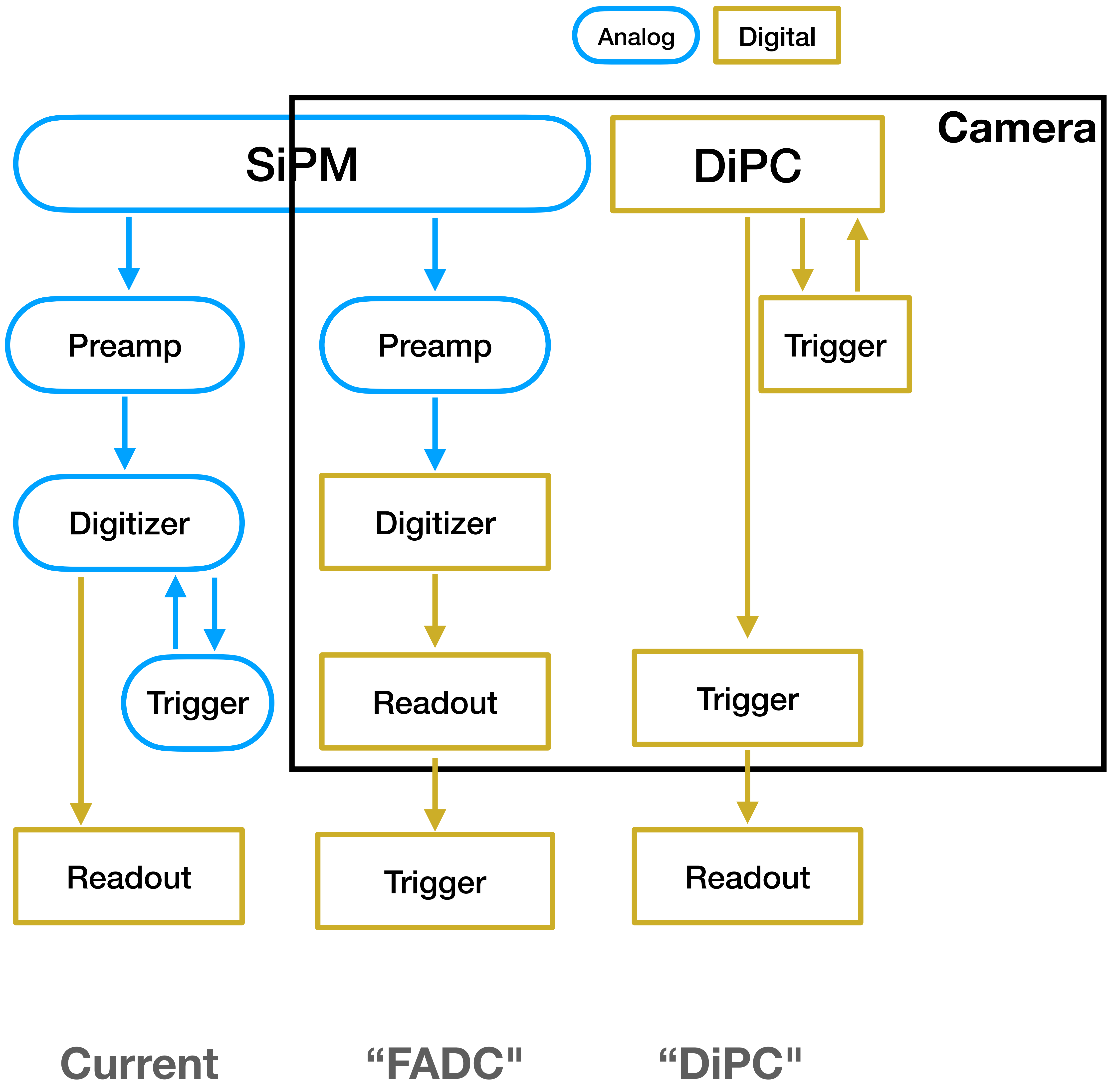

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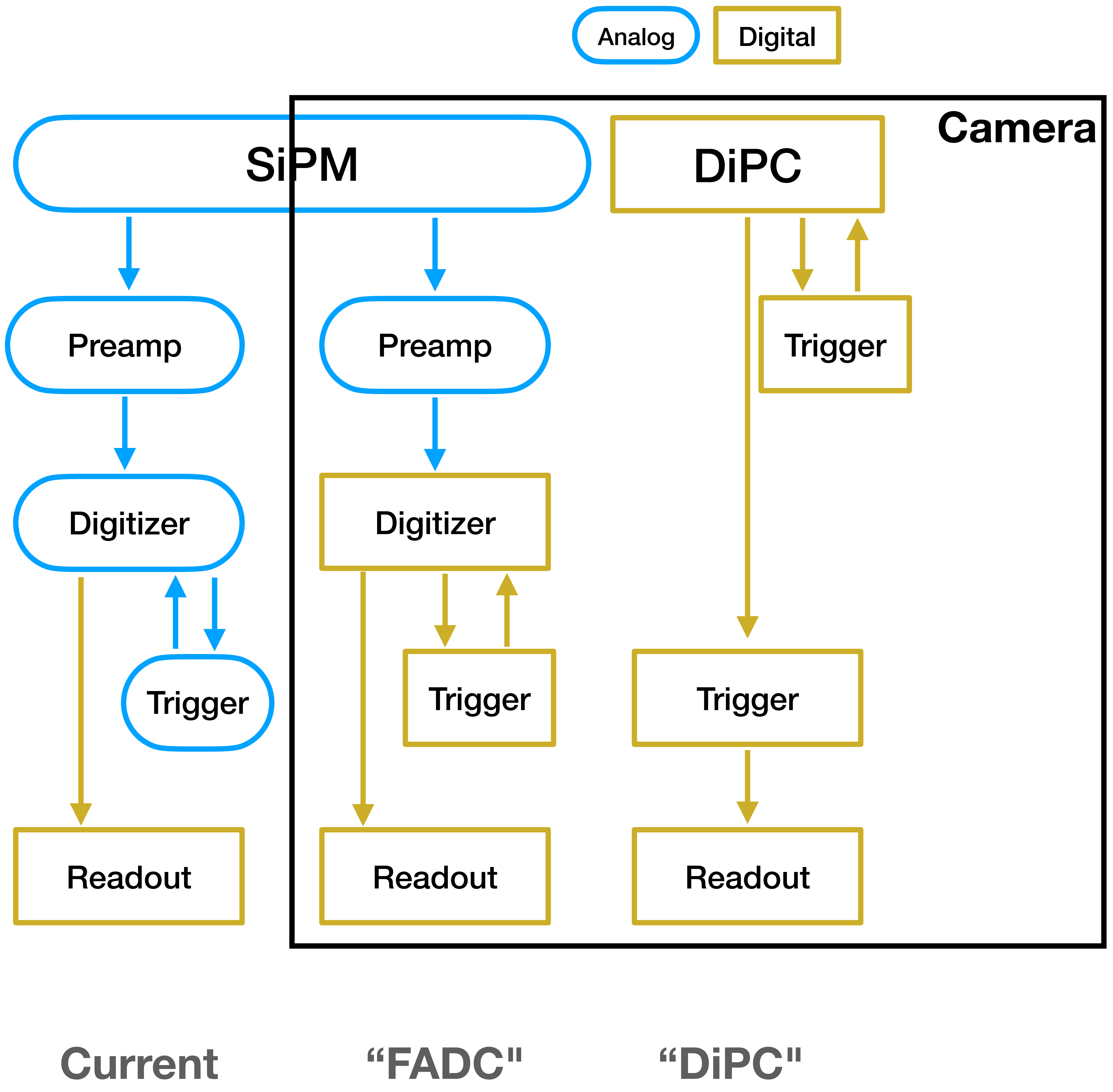


The LST Advanced SiPM Camera

Conclusion and prospects

- If using SiPMs seems like a natural evolution, their use is not trivial for large telescopes (speed, IR sensitivity, …)

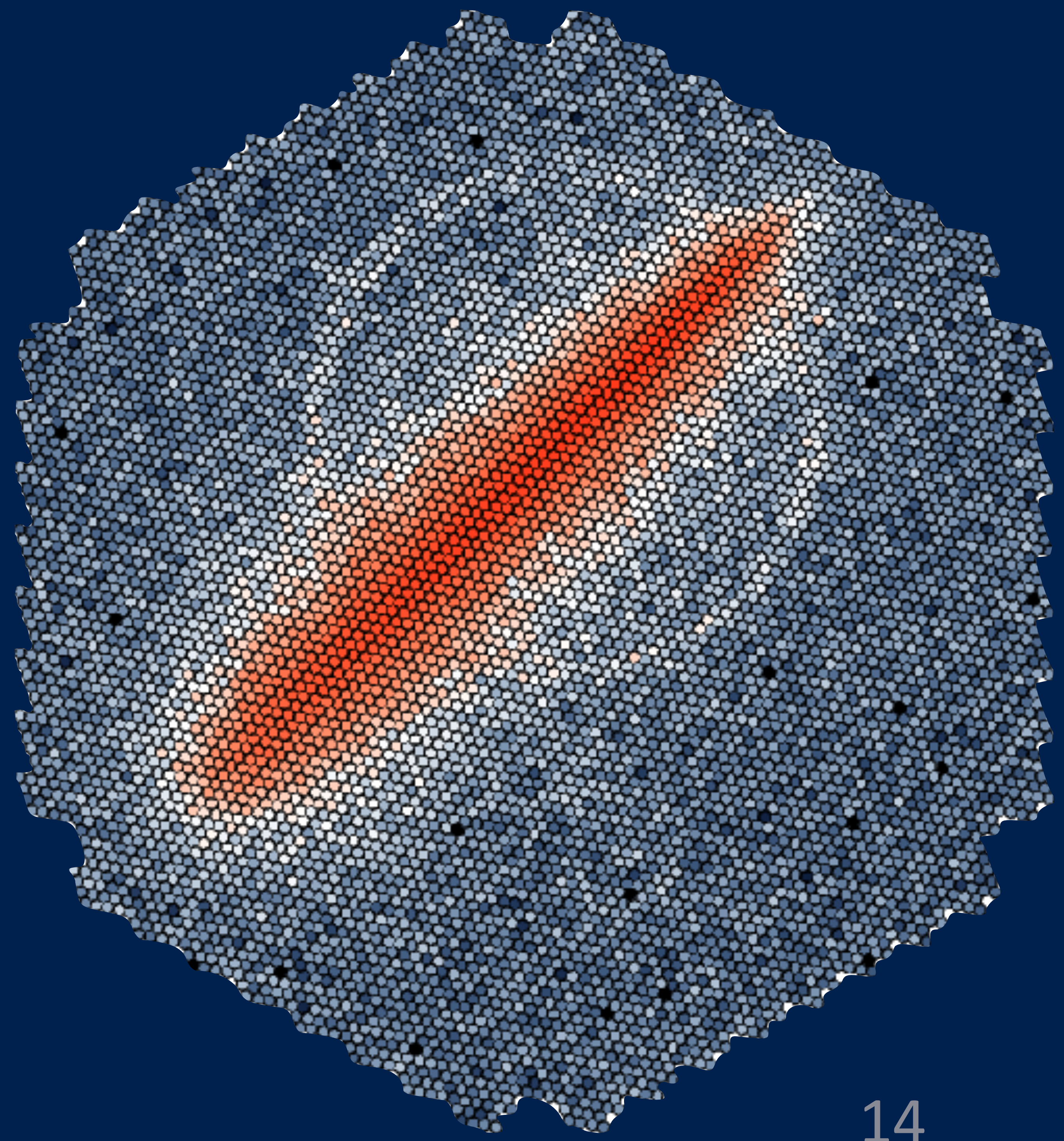
- Important effort on dedicated simulations and analysis pipelines on-going
- Parameter phase-space is large and machine learning based stereo analysis are still not ready

- Technological challenges are being tackled by group of experts
  - ✦ Low power components (pre-amplifier, FADC, etc ..)
  - ✦ Architectures to cope with large data throughput

- Dedicated funding for the project R&D are starting to come

- Stay tuned, first results will come soon cta cherenkov telescope array

Thank you for your attention !



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www.cta-observatory.org/consortium_acknowledgments