The Cherenkov Telescope Array Observatory (CTAO)

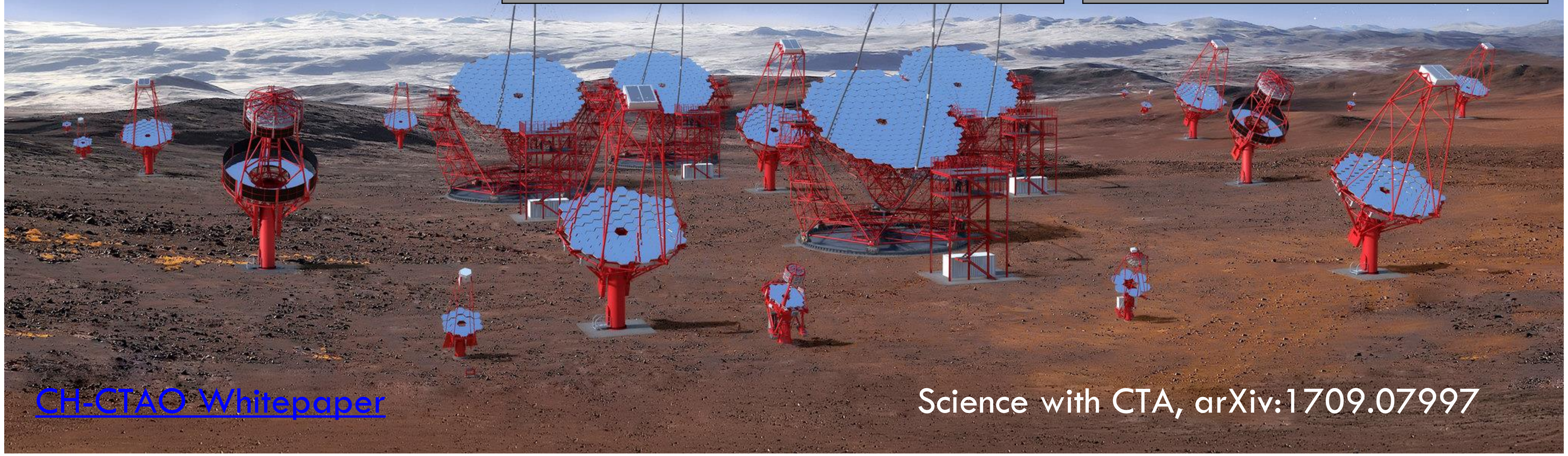
www.cta-observatory.org/

- 5-10 times better sensitivity w.r.t. current generation
- 4 decades of energy coverage: 20 GeV to 300 TeV
- Improved angular and energy resolution
- Two arrays (North/South)

Low-energy range:
23 m ø
Parabolic reflector
4.3° FoV
Sensitivity in 20 GeV-1 TeV

Mid energy-range:
11.5 m ø modified Davies-Cotton
9.7 m ø Schwarzschild-Couder reflector
7.5° - 7.7° FoV
Sensitivity in 150 GeV – 5 TeV

High-energy range:
4.3 m ø Schwarzschild-Couder reflector
10.5° FoV
Several km^2 area at multi-TeV energies



CH-CTAO Whitepaper

Science with CTA, arXiv:1709.07997

UNIVERSITÉ DE GENÈVE – FACULTÉ DES SCIENCES

University of Zurich UZH

ETH zürich

CSCS – Centro Svizzero di Calcolo Scientifico – Swiss National Supercomputing Centre

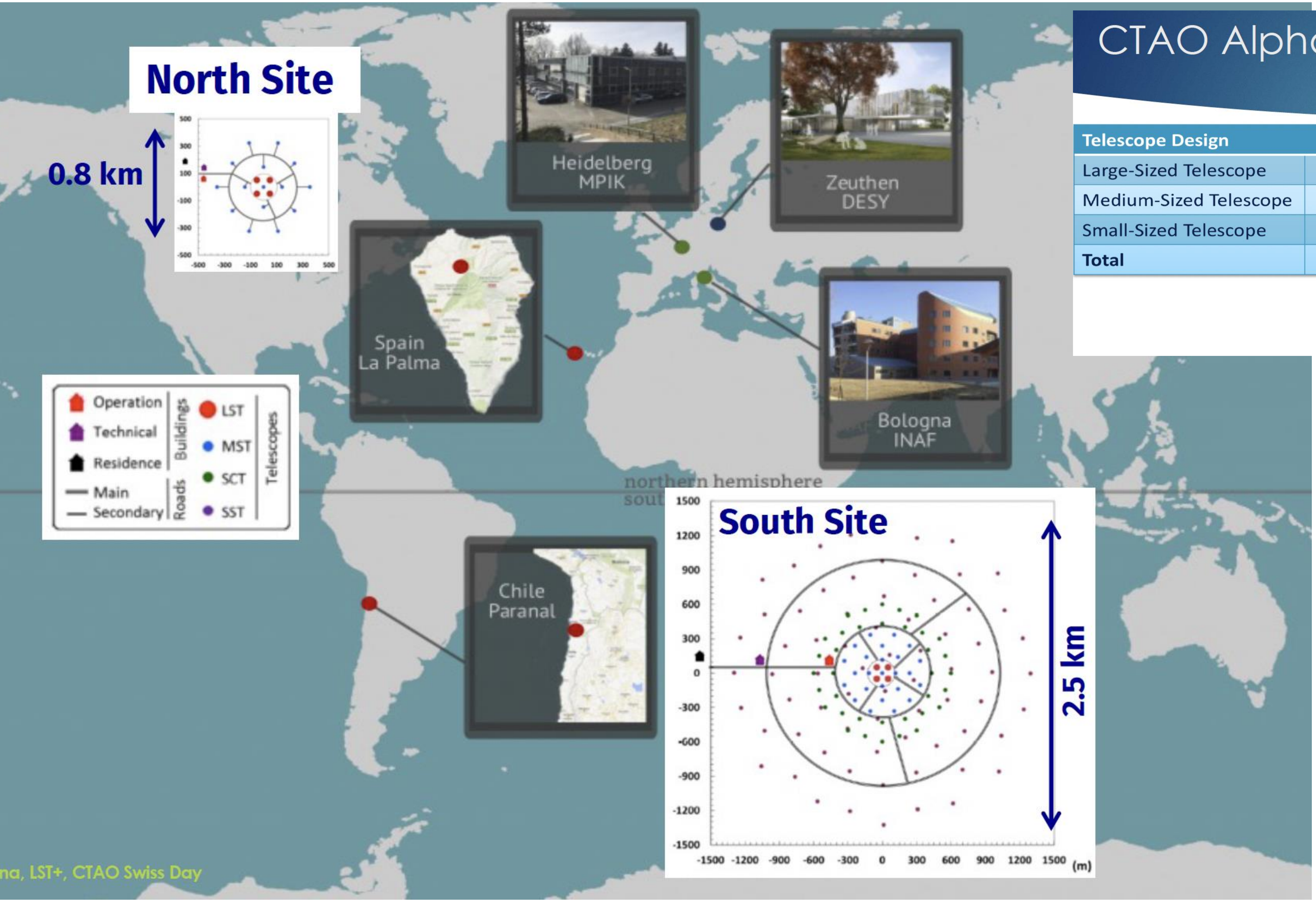
EPFL

u^b UNIVERSITÄT BERN

cta – cherenkov telescope array

CTAO-CH Collaboration is regulated by a collaboration agreement

A distributed RI



CTAO Alpha configuration >> LST+

Telescope Design	Northern Site	Southern Site
Large-Sized Telescope	4	2
Medium-Sized Telescope	9	14
Small-Sized Telescope		37
Total	**13**	**51**

- INAF+INFN received funding to upgrade CTAO south with LSTs.
- Switzerland, Japan etc have joined the effort: **LST+**

Switzerland : a funding member of CTA GmbH

- CTA first listed in the ESFRI roadmap of 2006, since 2018 landmark with ELT and SKAO for their prominent role in future shaping astrophysics

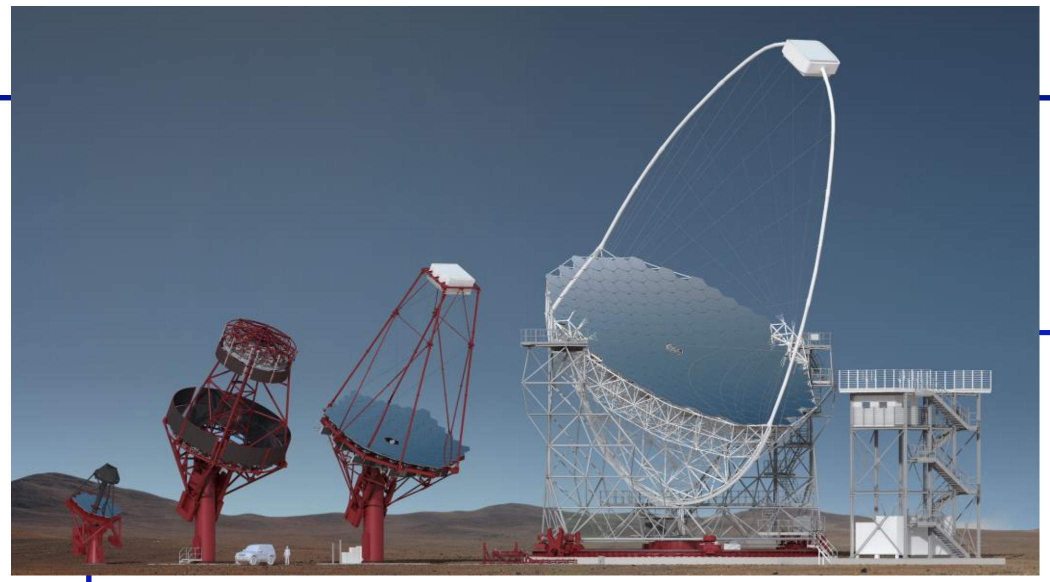
- UZH, UNIGE, ETHZ joined the CTA Consortium (CTAC) in 2007; since 2009 the Swiss groups have been supported by SNF (Div. 2, 3 Sinergia grants, **2 FLARE grants**) for the preparation phase.

- In 2012 a "**Declaration of Interest (DoI) for the pre-construction phase**" was signed by the funding agencies and ministries of 13 countries (of which 8 are European).

- In 2014 **UZH, DESY and INAF** funded the **CTAO gGmbH** and Prof. Straumann CTAO GmbH Director (2016-2018), signed CTA North agreement with IAC

- In 2016 entered the Swiss RI Roadmap and in f2019, UZH transferred the share of votes to UNIGE (Swiss coordinator: TM). Two performance agreements (2021-2024) of UNIGE and ETHZ/CSCS with SERI and a collaboration of Swiss institutes with a Cooperation Agreement.

- The CTAO ERIC is delayed by EC legal aspects with ESO IGO being now sorted out to start in 2025



Liste der Gesellschafter
und der übernommenen Geschäftsanteile
Cherenkov Telescope Array Observatory gemeinnützige GmbH
mit dem Sitz in Heidelberg
AG Mannheim, HRB neu

Lfd. Nummer	Gesellschafter	Wohnsitz/Sitz	Geb.-Datum	Geschäftsanteile in EUR

1 — 16.000,00 Euro
Deutsches Elektronen-Synchrotron DESY
Stiftung bürgerlichen Rechts
mit dem Sitz in Hamburg
Anschrift: Notkestr. 85, 22607 Hamburg

2 — 8.000,00 Euro
Istituto Nazionale Di Astrofisica (INAF)
mit dem Sitz in Rom
Anschrift: Viale del Parco Mellini, 84, 00136 Rom/Italien

3 — 1.000,00 Euro
Universität Zürich
öffentlich rechtliche Anstalt des Kantons Zürich
mit eigener Rechtspersönlichkeit
Anschrift: Künstlergasse 15, 8001 Zürich/Schweiz

gesamt

München, den 29.07.2

Dr. Werner Hofmann
Geschäftsführer

H:\sri\GmbHs 2014\Cherenkov Telescope Array Obs

Performance agreements of SERI with UNIGE and CSCS/ETHZ leading houses

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The State Secretary

Performance Contract 2021-2024

of the Swiss Confederation

represented by the Federal Council

here acting through the

State Secretariat for Education, Research and Innovation

(hereinafter "SERI")

represented by

State Secretary Martina Hirayama and
Vice-Director Gregor Haefliger

with the

University of Geneva (hereinafter "UNIGE") as coordinator of the Swiss CTAO Collaboration (hereinafter "CTAO-CH")

represented by the

Rector of the UNIGE Prof Yves Flückiger and
CTAO-CH Coordinator Prof Teresa Montaruli

Table 1:

Expenditure Budgets	*2021*	*2022*	*2023*	*2024*	*Total*
Measure 1: LST (including R&D on enhancement and support to project management)	441'211	474'000	474'000	474'000	1'863'211
Measure 2: DPPS	156'000	720'000	780'000	660'000	2'316'000
Measure 3: ACADA	400'000	346'000	346'000	346'000	1'438'000
Total	*997'211*	*1'540'000*	*1'600'000*	*1'480'000*	*5'617'211*

The contracts finance
the construction+operation of the 4 Large Size Telescopes (LSTs) in the North Site, the **not the Science/Synergy on Science with other RI and SKA/R&D** developments. Other Science grants are now in sufferance.

The long-term operation CSCS CTAO DC (DL0 data flow for N/S site: ~2 PB/y and 10 PB/y MC) for at least 20 years from the end of construction in 2028-2029 is about 500k CHF

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The State Secretary

Performance Contract 2021-2024

of the Swiss Confederation

represented by the Federal Council

here acting through the

State Secretariat for Education, Research and Innovation (hereinafter "SERI")

represented by

State Secretary Martina Hirayama and
Vice-Director Gregor Haefliger

with the

Eidgenössische Technische Hochschule Zürich (ETH Zürich) / Swiss National Supercomputing Centre (CSCS)
Rämistrasse 101, 8092 Zürich
represented by

Prof. Dr. Detlef Günther and Prof. Dr. Thomas Schulthess

in support to the activities of

the **Swiss CTAO Collaboration** (hereinafter "CTAO-CH")

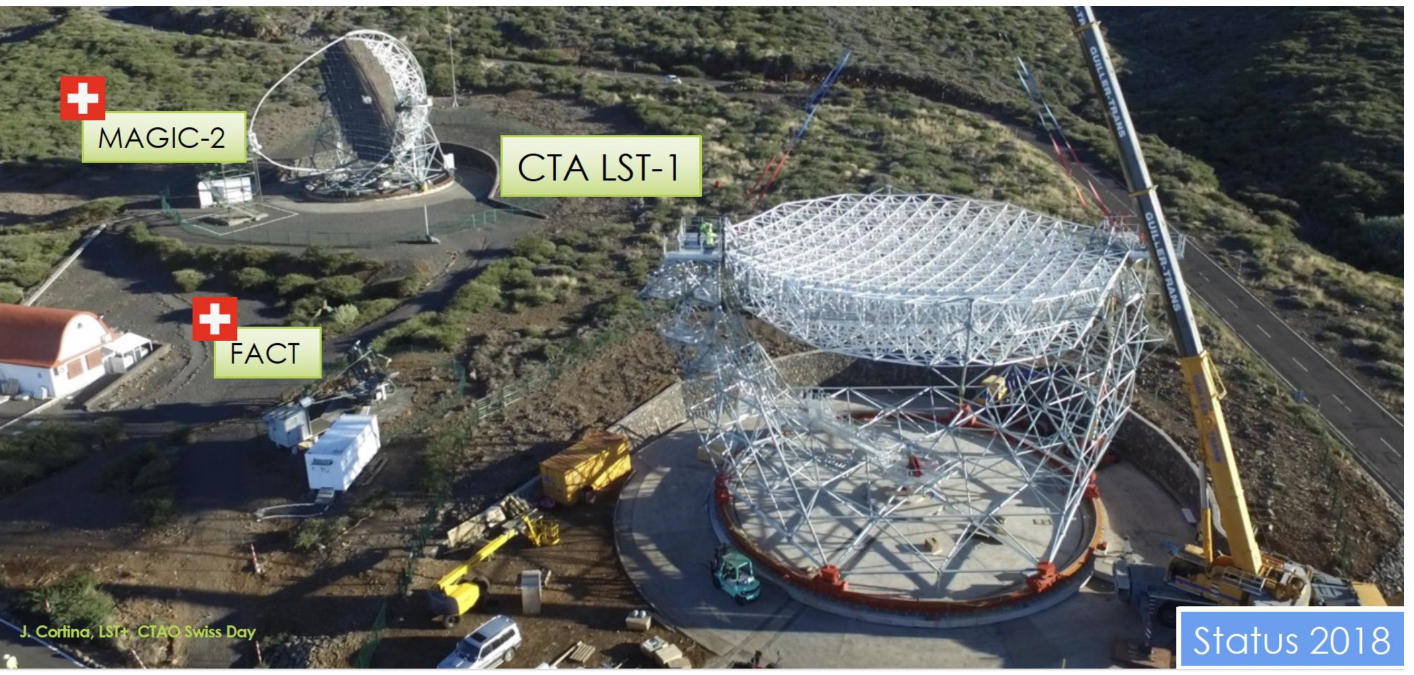
represented by
Prof Teresa Montaruli (hereinafter "CTAO-CH Coordinator")
Université de Genève (hereinafter "UniGE")
Rue du Général-Dufour 24, 1204 Genève

Table 1 :

Expenditure Budgets	*2021*	*2022*	*2023*	*2024*	*Total*
Measure 1: CTA Data Center	35'000	440'000	720'000	755'000	*1'950'000*
Measure 2: SKA Computing and Regional Center Prototyping	0	430'000	430'000	430'000	*1'290'000*
Total	**35'000**	**870'000**	**1'150'000**	**1'185'000**	*3'240'000*

2020 - 2024 Highlights

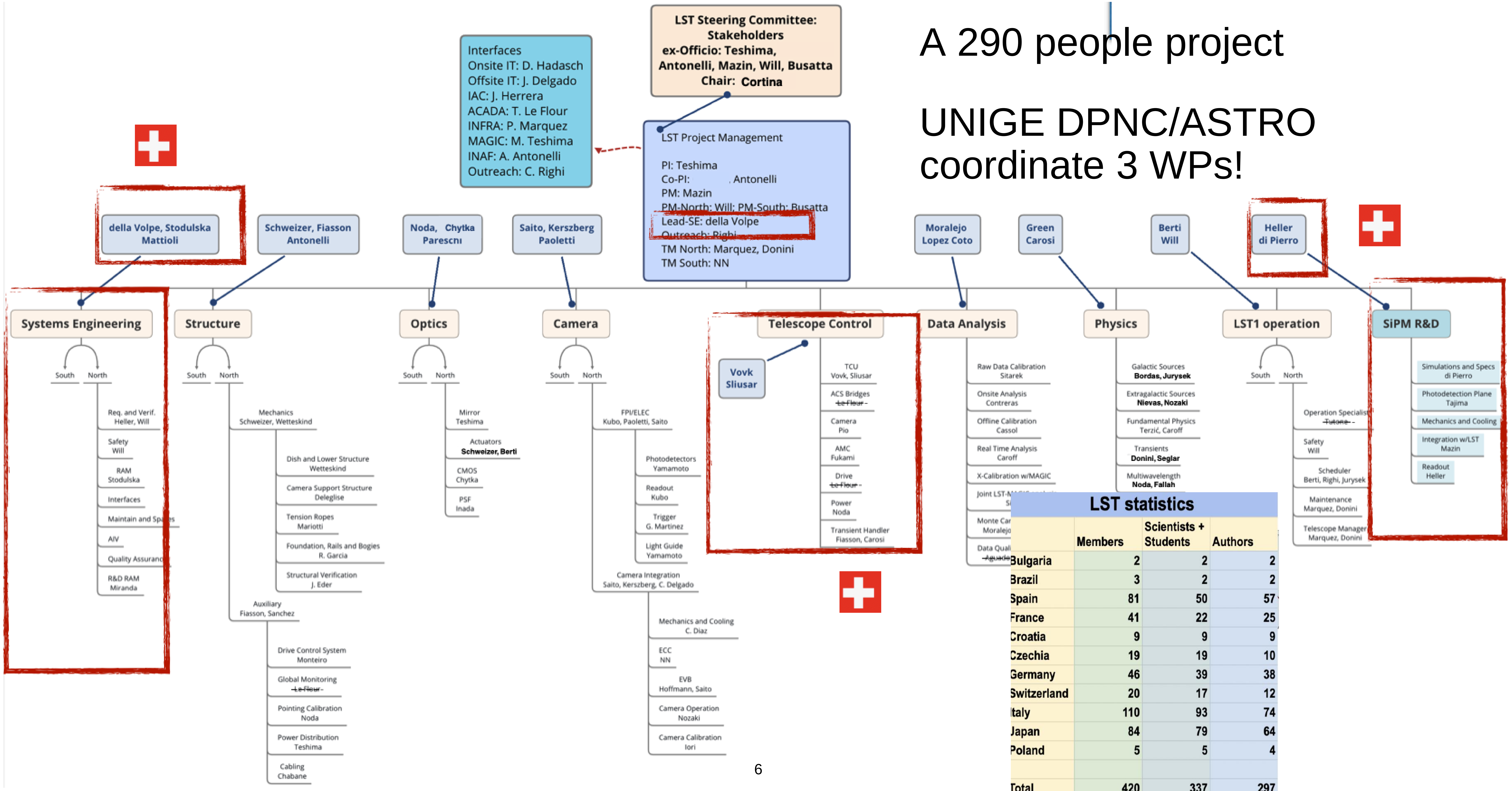
- Successful science operation of LST-1 >1.6kh
- CDR of LST-1 passed thanks to System engineering (Prof. D. della Volpe coordination); 3 LSTs in the North site could be delivered to CTAO already in 2026-2027; 2 LSTs in Chile financed and preparation of sites ongoing
- 1 of the 4 CTAO off-side DC at CSCS, first on which first CTAO data challenge will run and LST data duplication storage
- CDR of ACADA passed and integration in LST-1 (Prof. R. Walter, Prof. A. Biland)
- DPPS CalibPipe coordination and DPPS secondment for DPPS architecture, start of QualityPipe and possibly coordination,
- Participation in CTA+ (INAF, PNRR project for 2 LSTs in Chile) and cooperation with industry (Actuators/Fixation/ML in FPGA with UTH and Enclustra points of LST5-6 mirrors in Chile, LST Advanced camera for replacements of LST cameras with PMTs)



Swiss Institutes in LST+

A 290 people project

UNIGE DPNC/ASTRO coordinate 3 WPs!



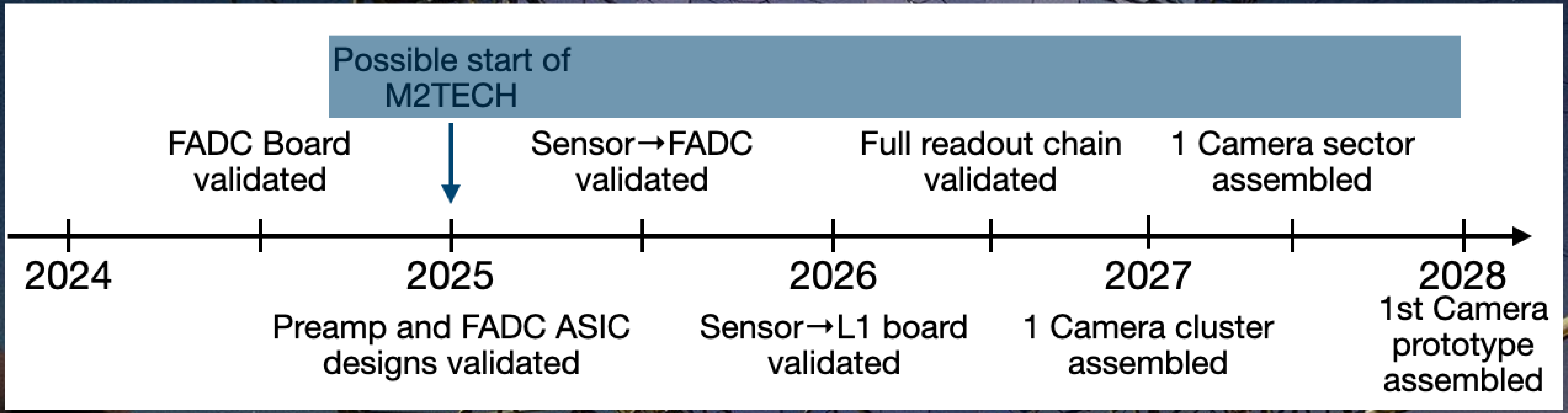
LST statistics

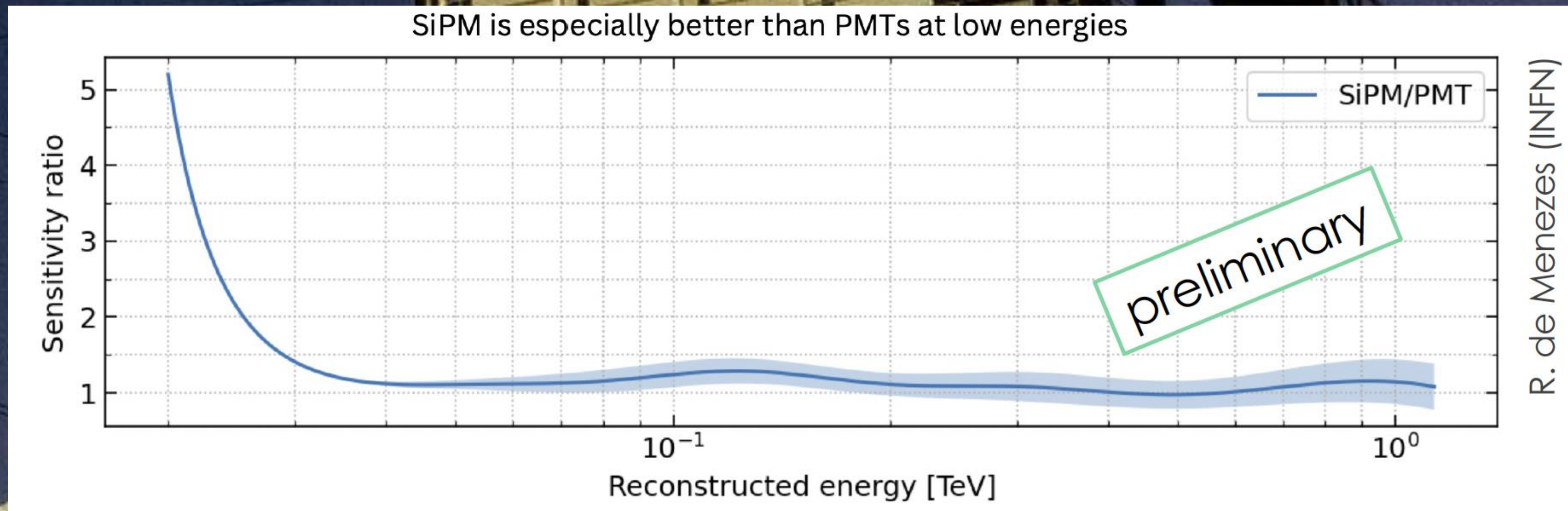
	Members	Scientists + Students	Authors
Bulgaria	2	2	2
Brazil	3	2	2
Spain	81	50	57
France	41	22	25
Croatia	9	9	9
Czechia	19	19	10
Germany	46	39	38
Switzerland	20	17	12
Italy	110	93	74
Japan	84	79	64
Poland	5	5	4
Total	420	337	297

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

cta cherenkov telescope array

FLARE and The LST Advanced SiPM Camera





T. Montaruli and M. Heller (UNIGE) E. Charbon (EPFL) A. Biland (ETHZ) FLARE 201539: Development of the next generation of large SiPM camera for Large Size Telescopes
Next proposal for covering the Jun. 2025-Jun 2029 period (UNIGE, EPFL + N. Serra UZH)

Image Courtesy of D. Kerszberg

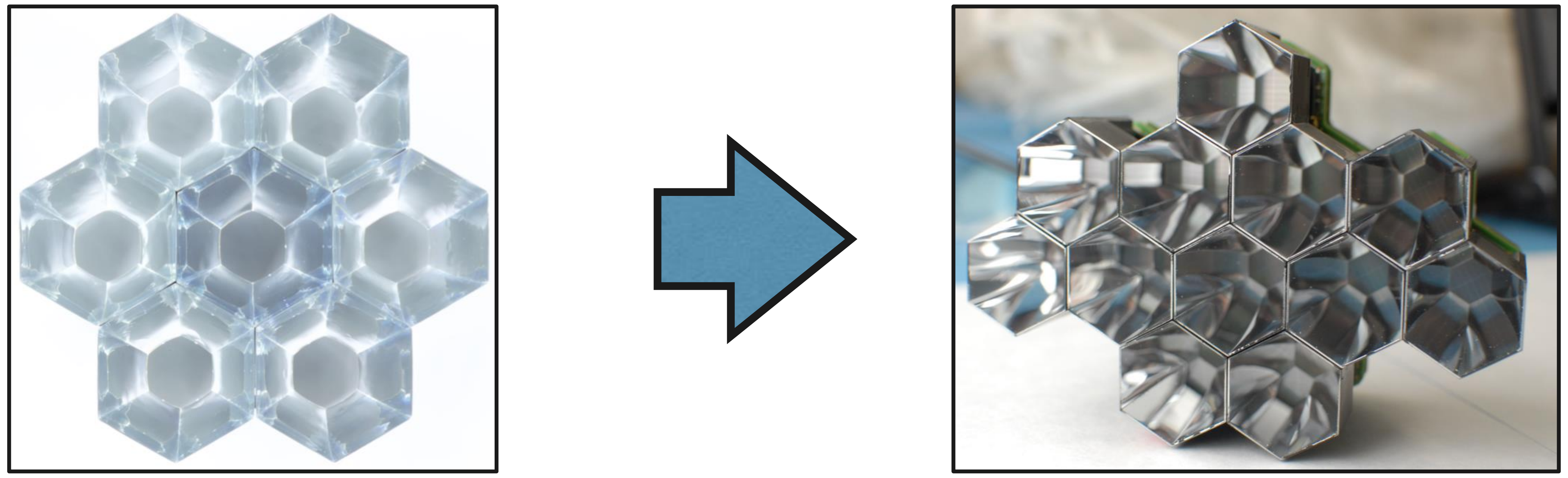
The Advanced SiPM Camera

- The proposed design should take full advantage of the SiPM characteristics
  - Gain in duty-cycle, robustness, stability, self-calibration, etc…
  - Utilise Swiss experience in using SiPM for IACT (FACT, SST-1M)

- The Advanced SiPM Camera must:
  - outperform the existing camera over the entire energy range
  - be upgradable/reprogrammable

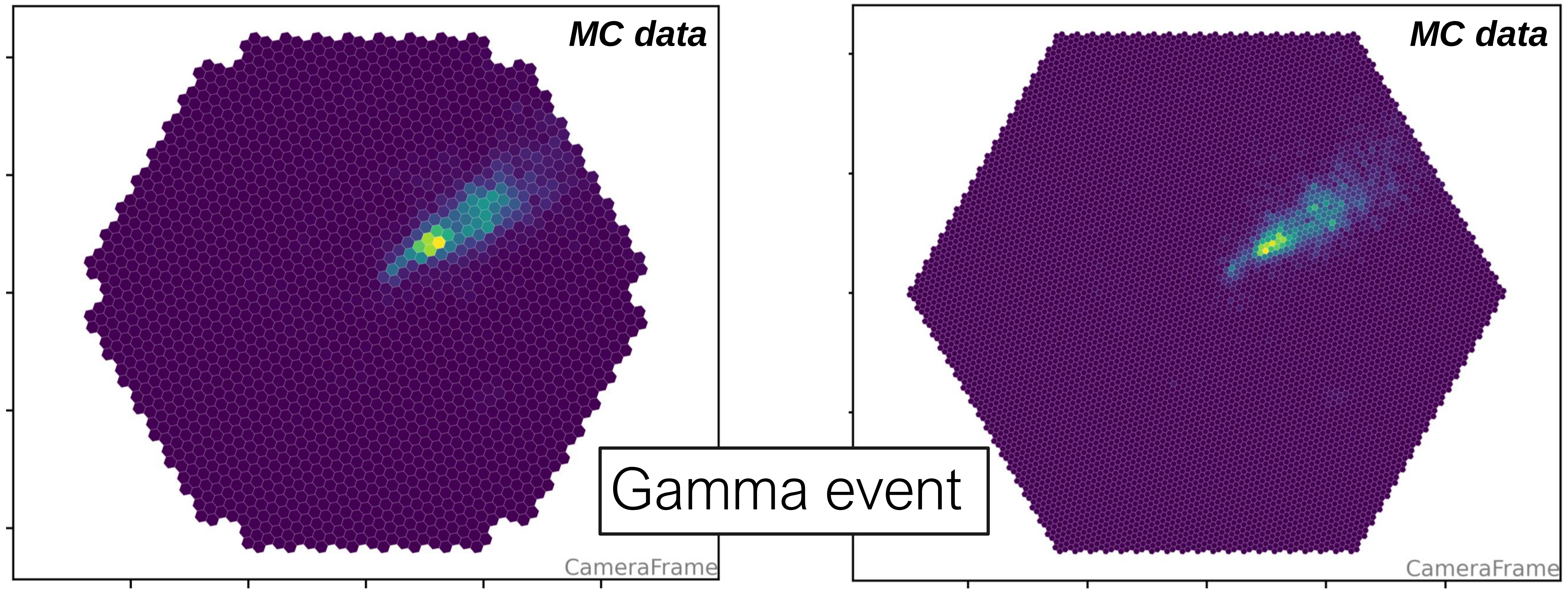
- Baseline design:
  - Decreasing pixel size **from 0.1° to 0.05°**
    - 4 times more pixels !
  - Going for **fully digital readout**

- Many challenges to tackle:
  - High power consumption
  - High data throughput
  - High cost

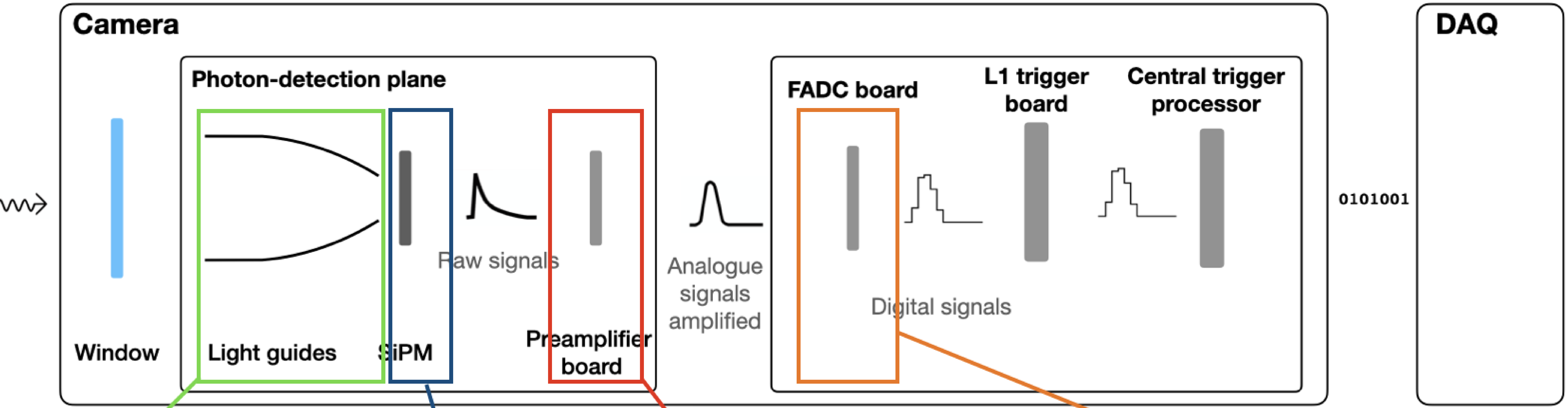


LST PMT camera **(0.1°)**

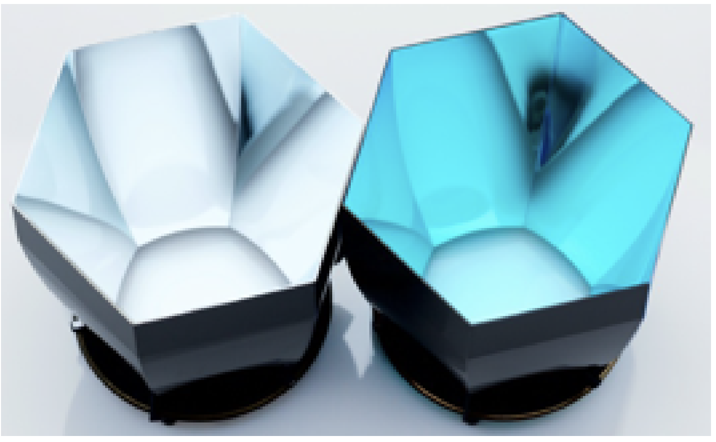
LST SiPM camera (**0.05°**)



The Advanced SiPM Camera project



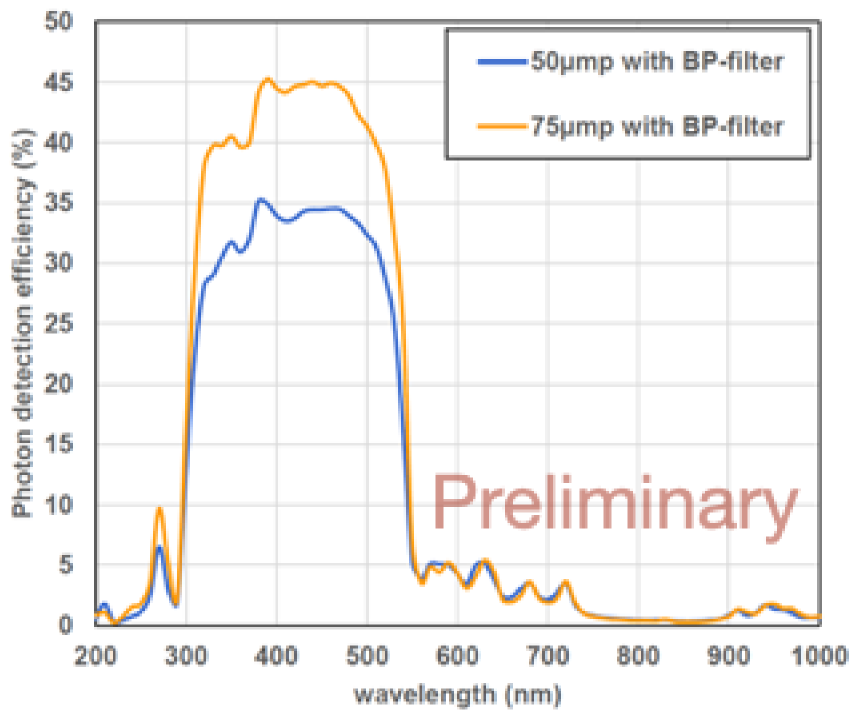
- UZH and UniGe collaborate on development of AI algorithms and their porting on FPGA for advanced trigger solution
- DAQ firmware to be developed in collaboration with HEPIA and CH industries



ICRR, University of Tokyo (JP) (DOI signed by Kajita and Y. Flückiger) Kyoto, Conan, Nagoya Universities

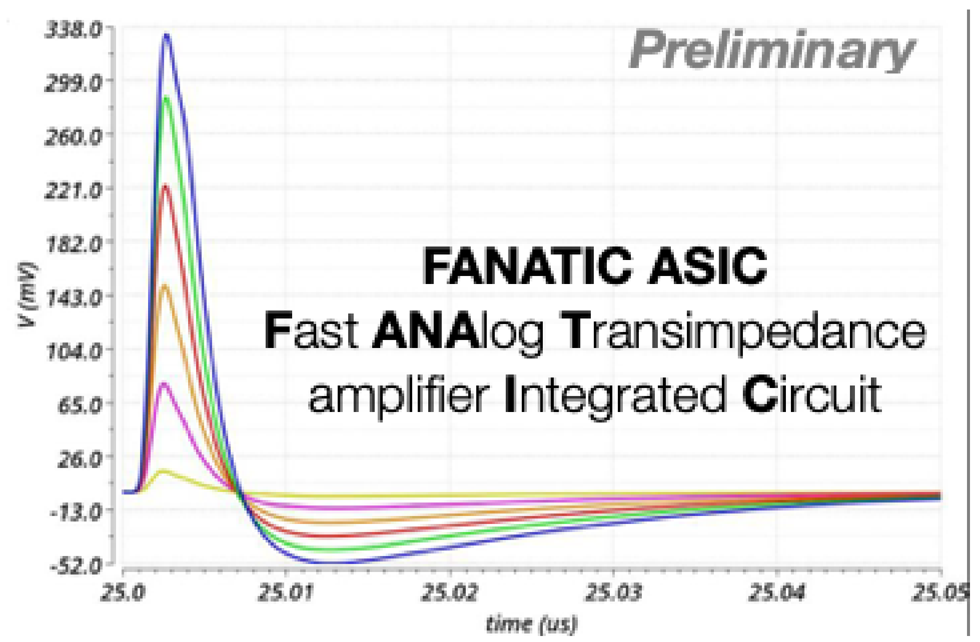
Camera mechanics to be developed by CIEMAT (ES) following design of LST camera

Dichroic filter on tailored Hamamatsu MPPC



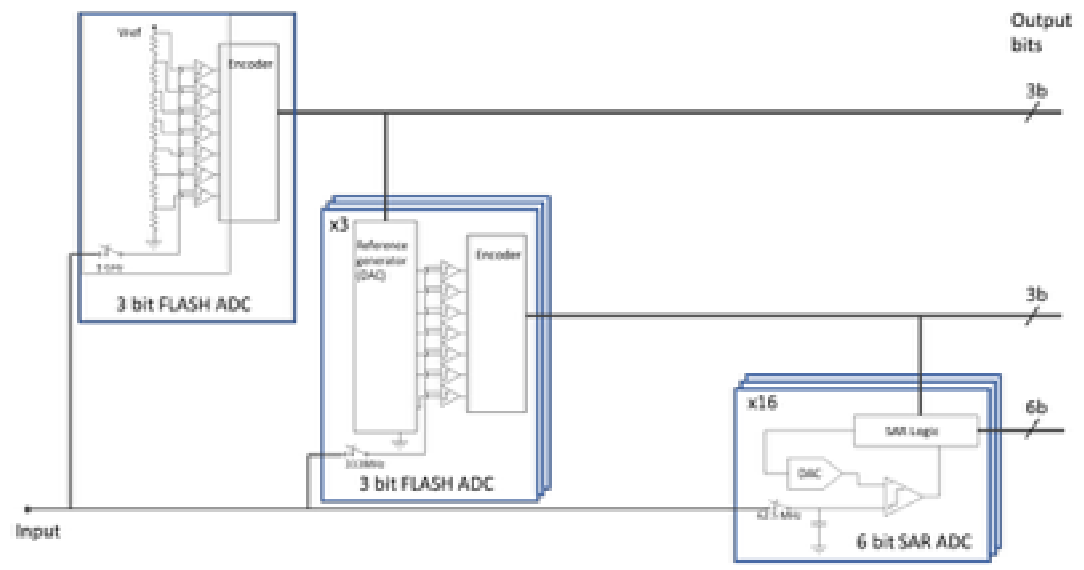
DoI UNIGE - ICRR

Unige designedfast pre-amplifying ASIC with active summation for large surface SiPM (40 mW/pixel, 3 ns FWHM)
CH companies involved for chip packaging (Altatec, Hybrid SA)

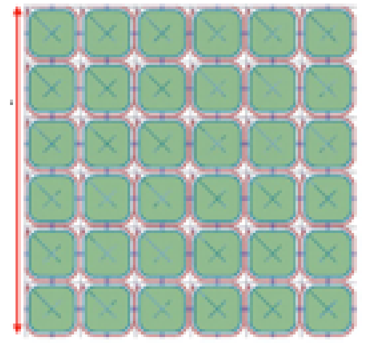


Sensor bias and operation stabilisation developed by IFAE (Spain)

EPFL/AQUA Lab designed digitising ASIC (12 bits @ 1 GSps, 200 mW/channel). Same CH companies involved for chip packaging



EPFL/AQUA Lab designed fully integrated digital photon counter in CMOS technology



And many more:

- FADC board developed by INFN/Pd (IT)
- L1 trigger board developed by CIEMAT (ES)
- Central trigger processor board developed by UCM (ES)
- Synchronisation and clock distribution

Objectives to 2032

The Swiss community's ambitions for the future are:

1) To secure access to **CTAO ERIC** by 2025;
2) To secure the e**nd of construction of the Alpha Configuration + 4 LSTs in Chile and delivery of telescopes to CTAO ERIC by 2028-2029**;
3) To secure the l**ong-term operation (up to at least 2045) of the CSCS offsite data center of CTAO** in synergy with SKAO. Such a data center will deal with 10 to 100 PByte per year and requires securing similar support to the Tier 2 of LHC. Long-term operation: 350 kCHF / yr HW (2025-2028) + FTE. Exponential decrease does not apply anymore to costs on DC and this is an issue to address globally for CHIPP.
4) To secure provision of **all software in-kind contributions of Swiss leadership by 2028:** the **Array Data Handler of the Array Control and Data Acquisition System (ACADA)** - first version is already operating on LST-1; **telescope array control system, CalibPipe of the array, the Bulk Archive** and the **QualityPipe** of the **Data Processing and Preservation System (DPPS).**
5) The construction of an **Advanced Camera for LSTs** in cooperation with Swiss Industry, Spain, INFN and Japan to replace the current LST-1 camera with PMTs in 2028-2029 for the robust and long-term running of LSTs and future LSTs in the South. The current **FLARE program (2021-2025 - UNIGE, EPFL, ETHZ)** offers microelectronics solutions for low-power preamplifiers and shaper and GHz data digitization and a new digital sensor. A future **FLARE program for 2025-2029 (UNIGE, EPFL, UZH)** will provide prototype modules for the camera with mechanical design. The project also requires the support of SERI and a collaboration with Spain, Italy and Japan.

Update in recommendations

Accession to Switzerland to the CTAO final legal entity should be secured.

The operation of CTAO is foreseen to last order of 20-30 yr from its completion. Participation in the construction of Large Size Telescopes and their cameras fosters innovation in the domain of sensors, micro-electronics and AI and participation of industry in the process.

As CSCS will be one of the 4 off-site data centres, this will require securing annual operation funds in synergy with SKA and other big data projects in astronomy.

Cherenkov detection from space

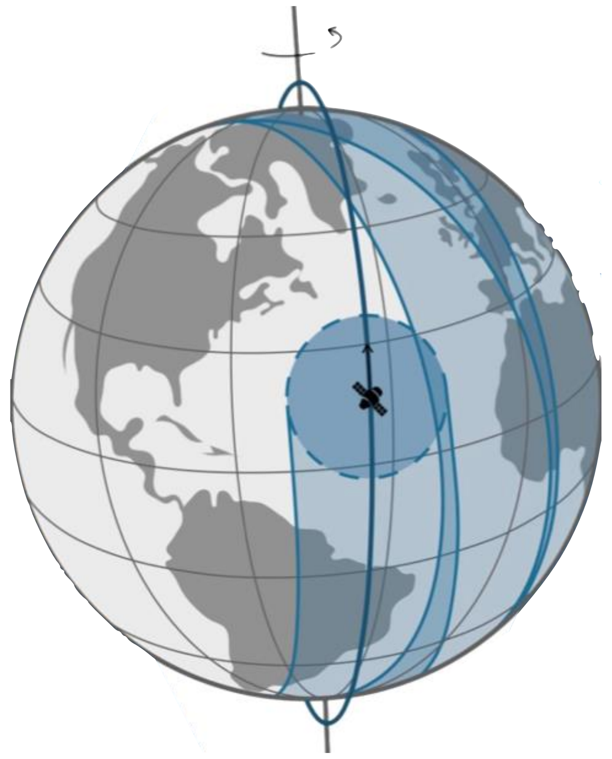
NUSES

Project led by GSSI

With INFN, THALES, FBK, Officina Stellar industrial partners

The NUSES spacecraft

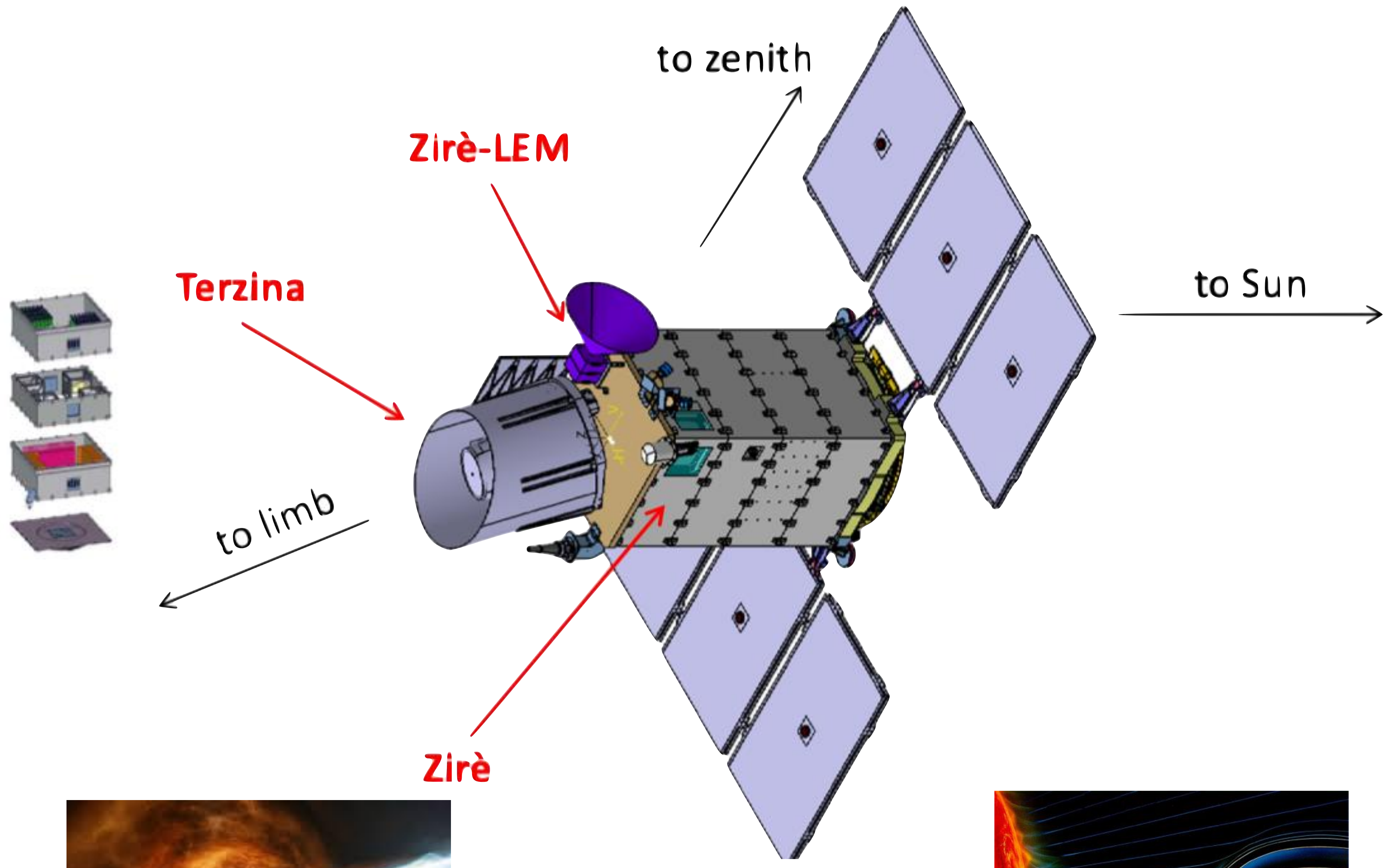
NeUtrino and Seismic Electromagnetic Signals

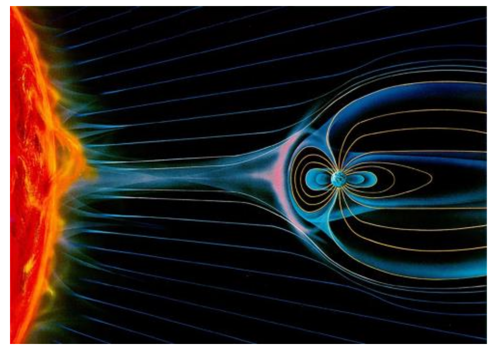


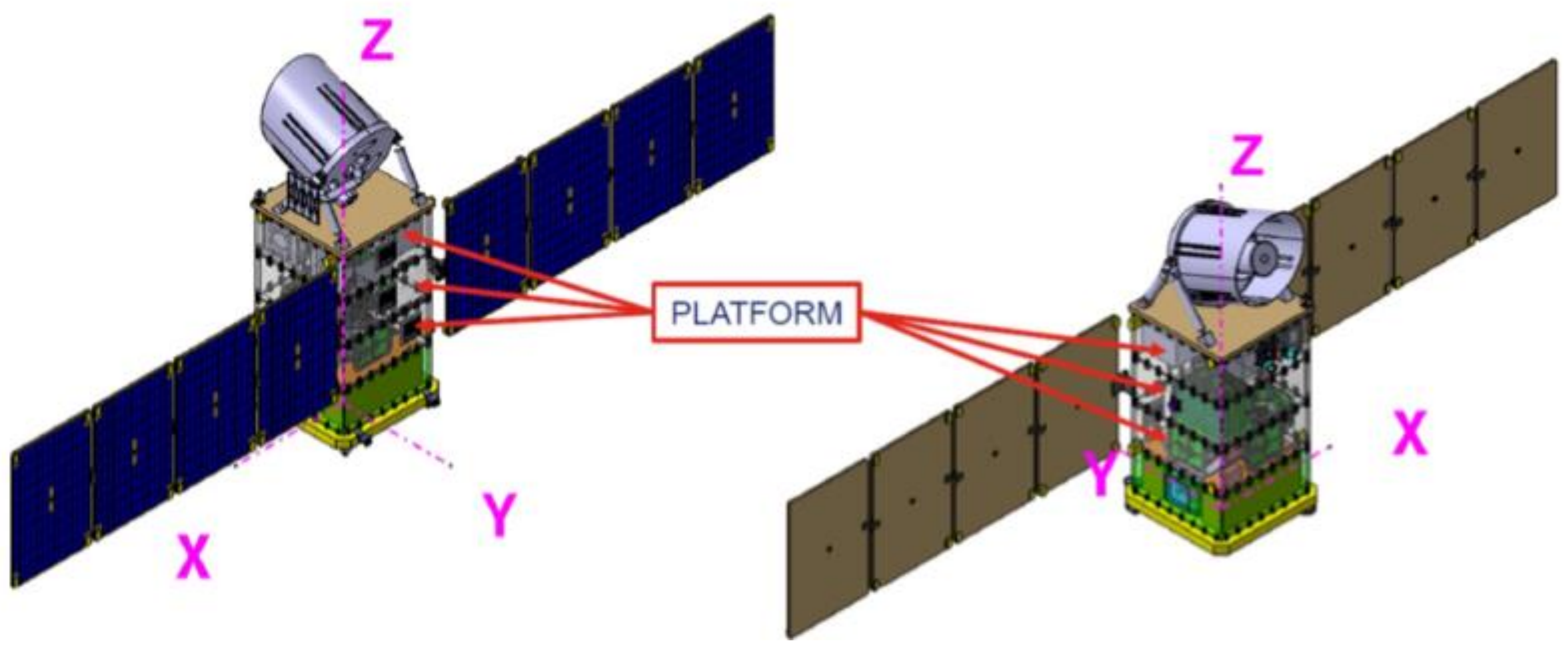
Financed by Italian ministry. NIMBUS (New Italian Micro BUS) new Platform for low orbit (LEO) micro satellites which foresees a modular approach relying on standard trays by THALES

Launch in 2026 by ASI to 535 km altitude

- Ballistic mission (no propulsion for orbital control)
- Weight: <150 kg







Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (BoL altitude 535 Km, inclination = 97.8°, LTAN = 18:00);

NUSES ahas also another payload: Ziré for

- Monitoring of low energy (<250 MeV) Cosmic Ray fluxes to study **Van Allen belts**, **space weather** and **lithosphere-ionosphere-magnetosphere** couplings;
- Detection of 0.1 MeV – 10 MeV photons for the study of **transient** (GRB, e.m. follow up of GW events, SN emission lines,…) and **steady gamma sources**.

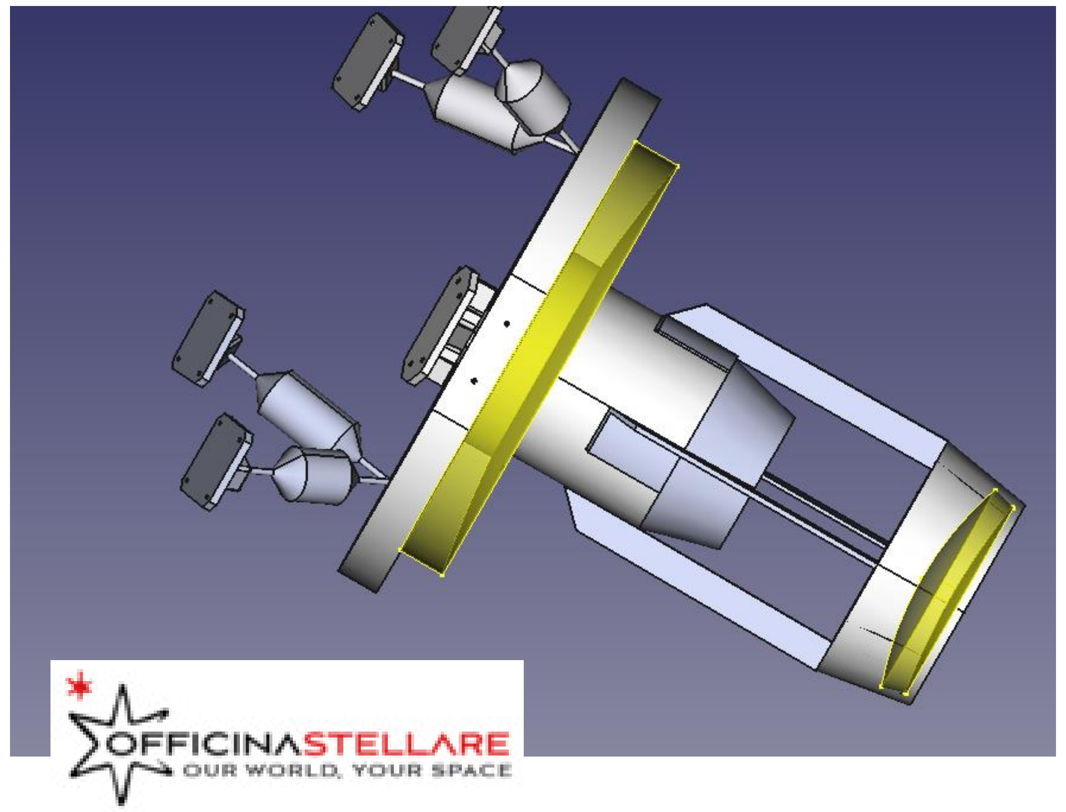
https://pos.sissa.it/444/139/

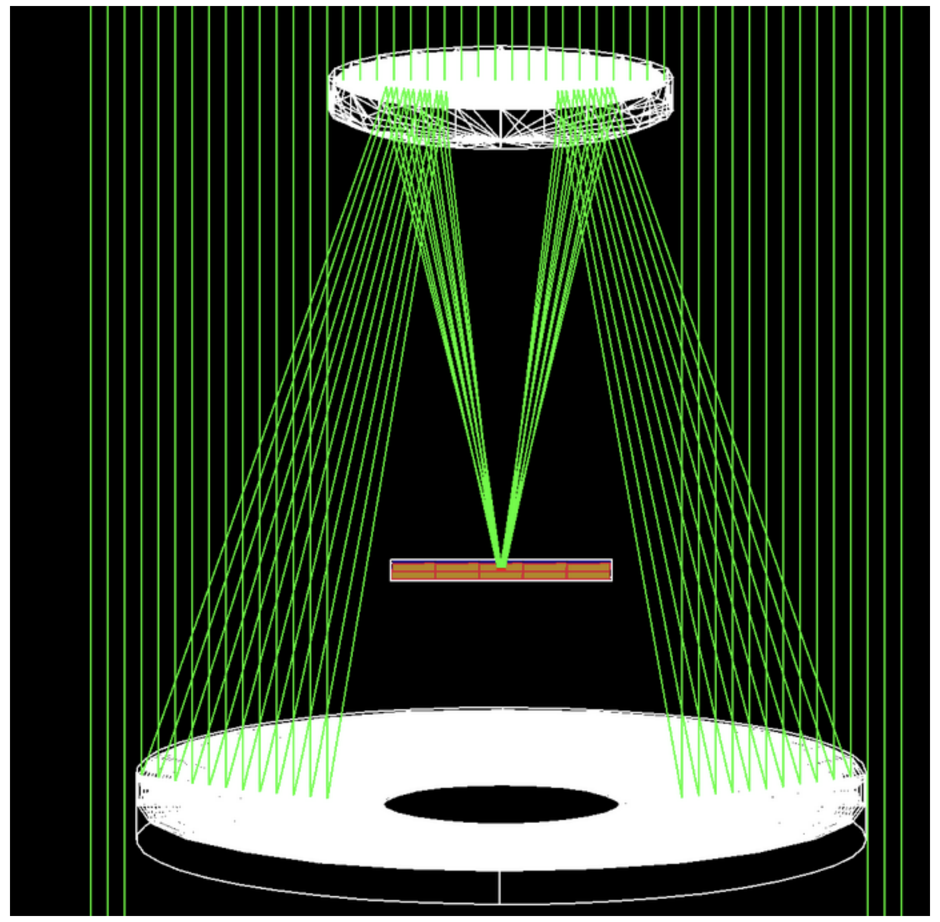
The TERZINA Telescope

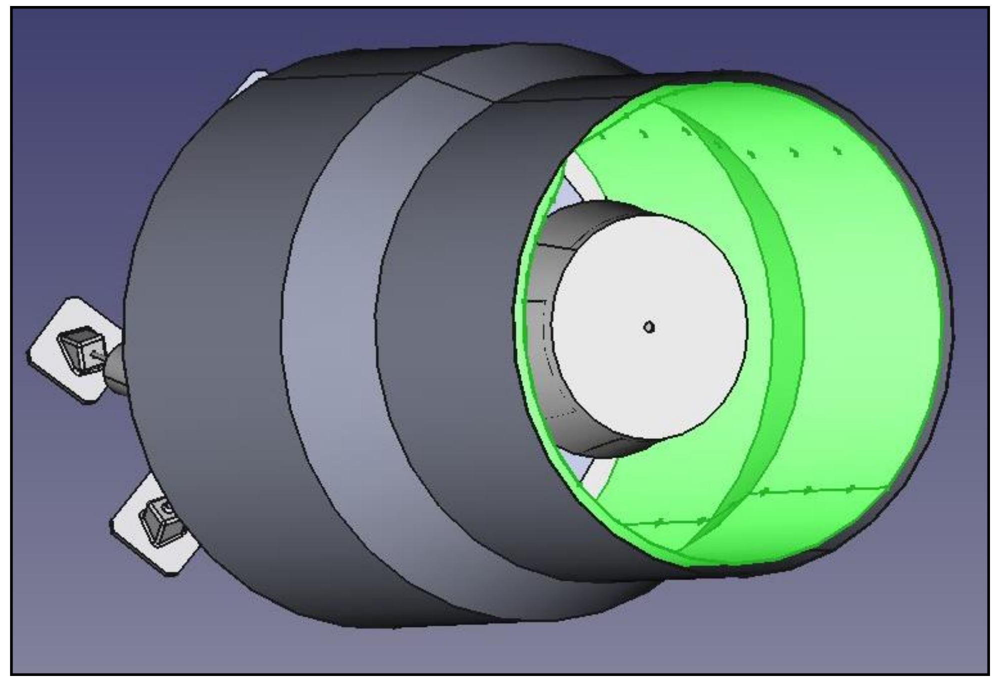
Inside: Mirrors

60x60x50 cm^3
Terzina total weight ~35 kg

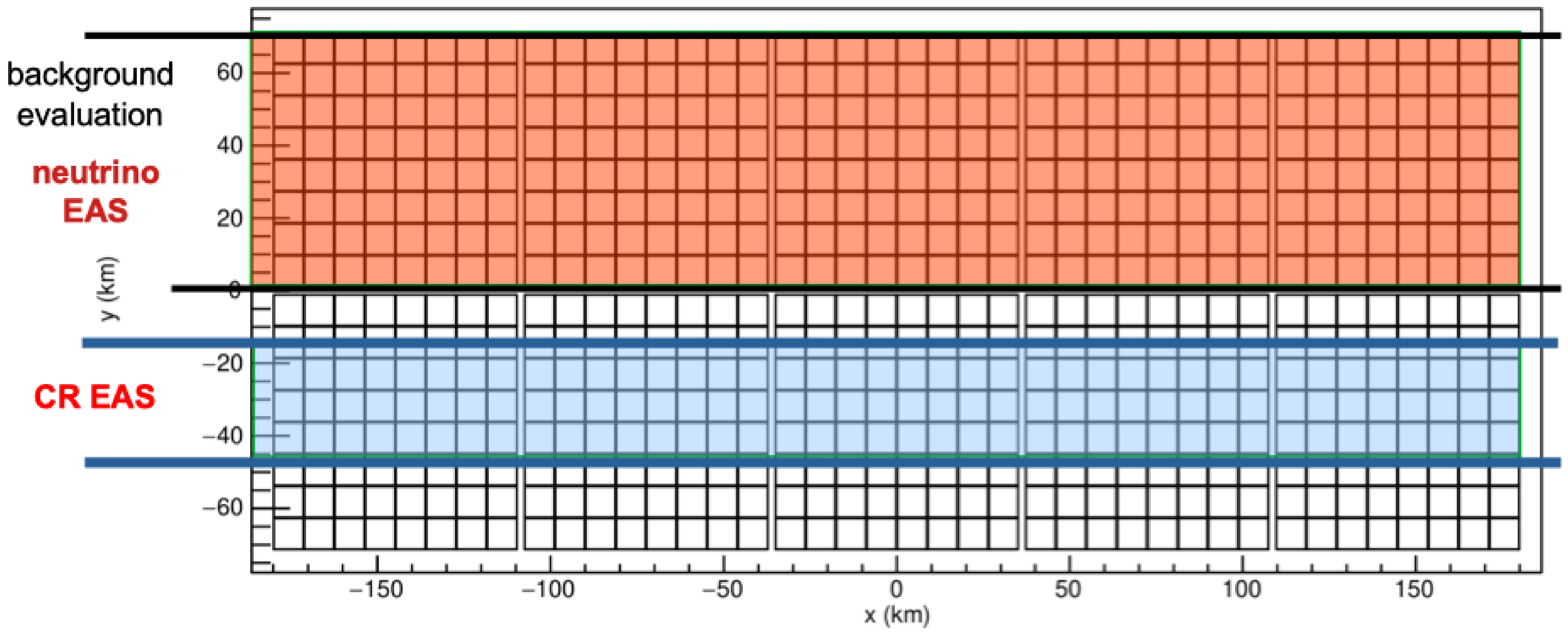
SiPM arrays 8x8 pixels
5x2 = 10 SiPM arrays
(8x8) x 10 = 640 pixels







- Pixel: 2.3 mm x 2.7 mm
  Field of View per pixel~0.18°° (with $r_{\mathrm{SiPM}} \simeq 3$ mm)
- ASIC for WF 100 MHz 5 mW/ch



- Schmidt-Cassegrain optics
- Equivalent focal length $F_L = 925\mathrm{mm}$
- Telescope Field of View: 7.2° along the Earth's limb and 2.9° across it
- Point spread function (PSF): < 1 mm
- Effective area of the telescope: 0.1 m^2
- M1 and M2 parabolic mirrors

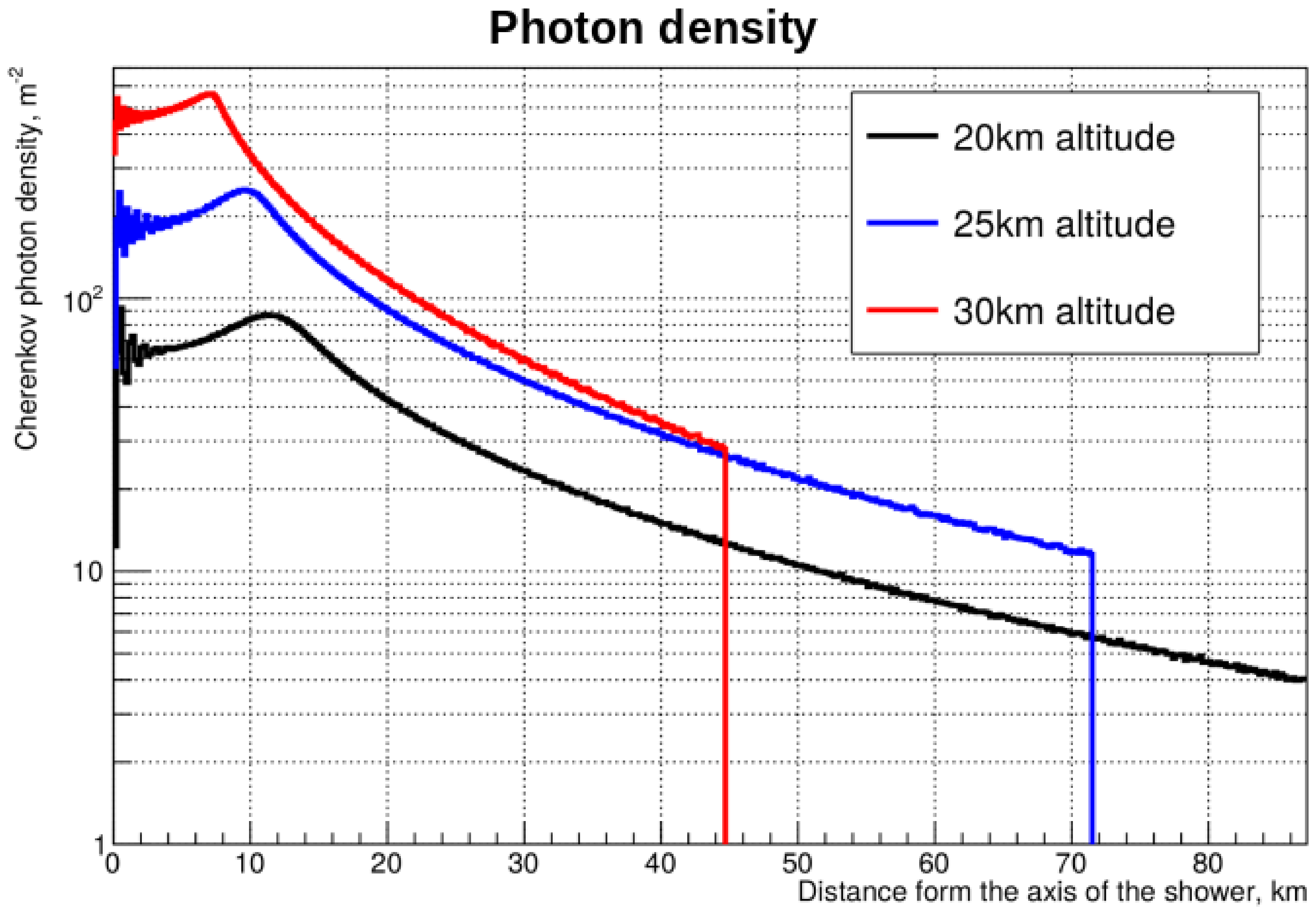
OFFICINA STELLARE OUR WORLD, YOUR SPACE

FONDAZIONE BRUNO KESSLER

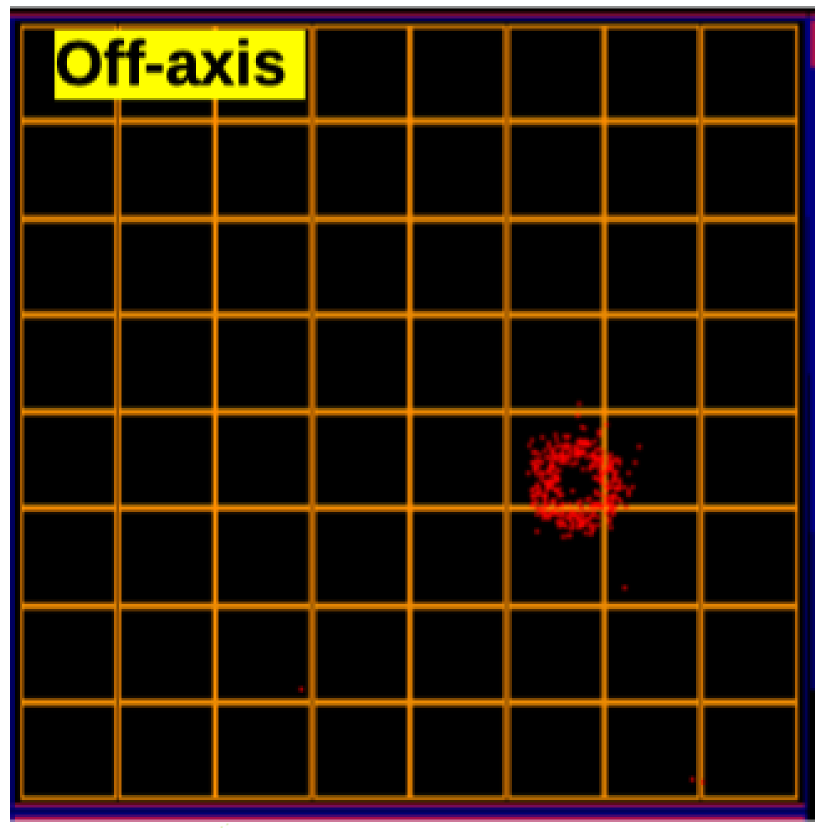
https://arxiv.org/abs/2304.11992

TERZINA Simulation and RadHard (UNIGE)

Cherenkov cone in space

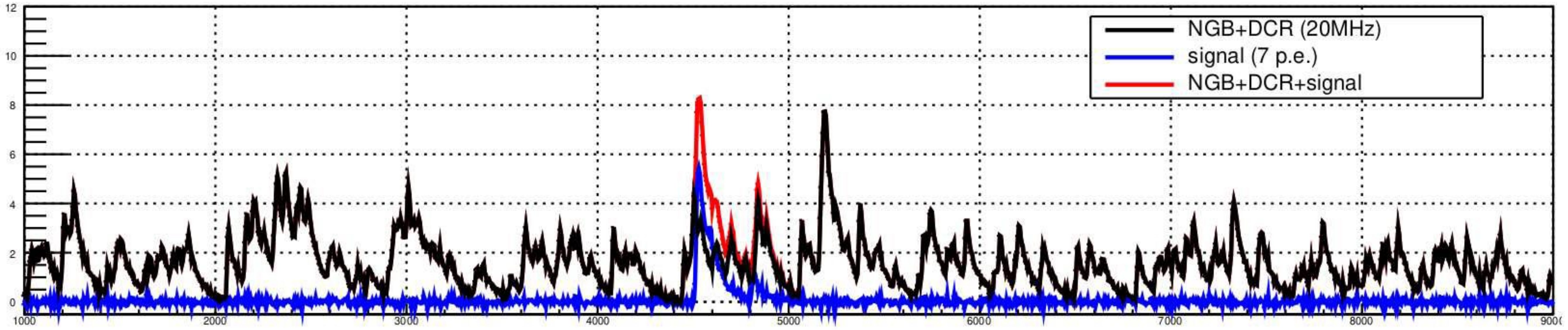


An EAS in the camera



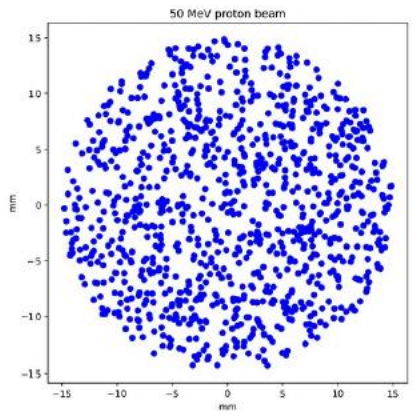
G4

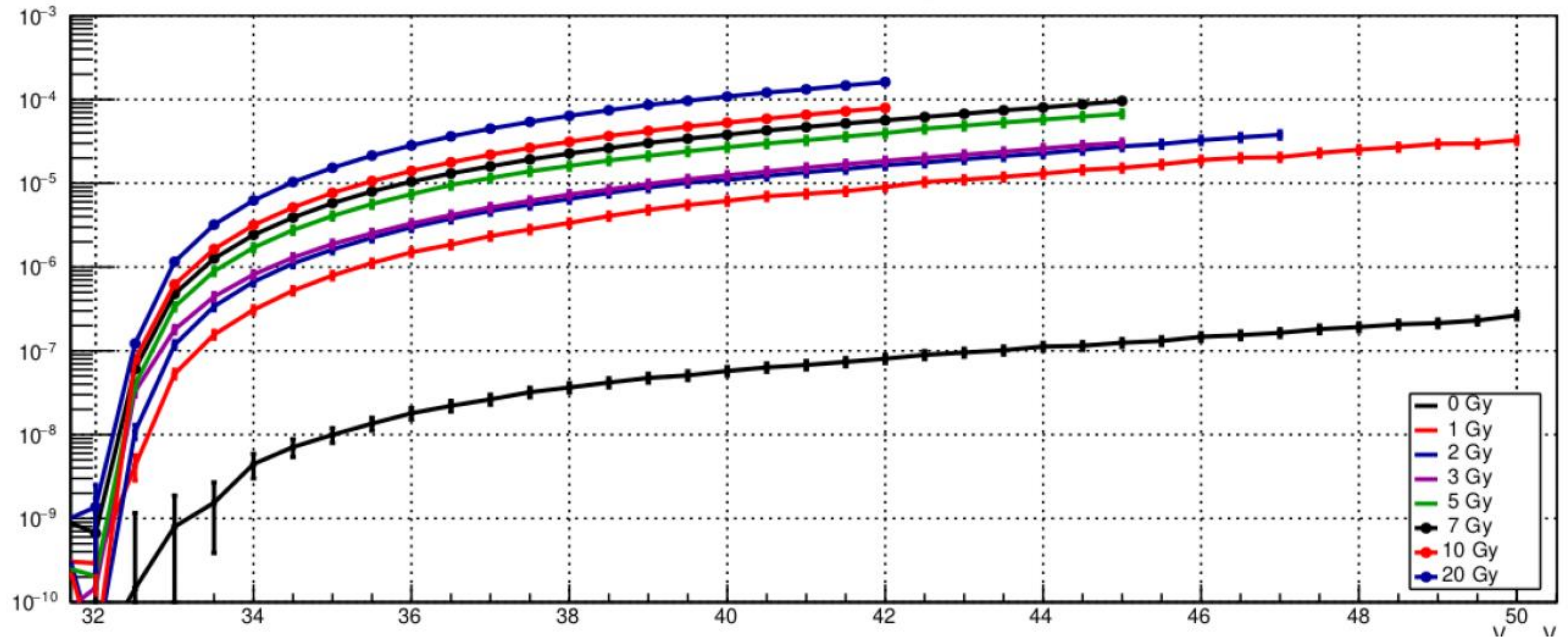
Simulating the SiPM response



DCR increase in SiPM due to proton dose in space ~800 than electrons

- 25um SiPM with resin coating
- 50MeV proton – 3cm diameter ~3% uniformity
- Temperature: 22.0 – 25.0





https://arxiv.org/abs/2304.11992

cherenkov telescope array

CTLearn: Deep Learning Framework for Ground-based Gamma-ray Astronomy

Leonid Burmistrov (leonid.Burmistrov@unige.ch)
Matthieu Heller (matthieu.heller@unige.ch)
Tjark Miener (tjark.miener@unige.ch)
Teresa Montaruli

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

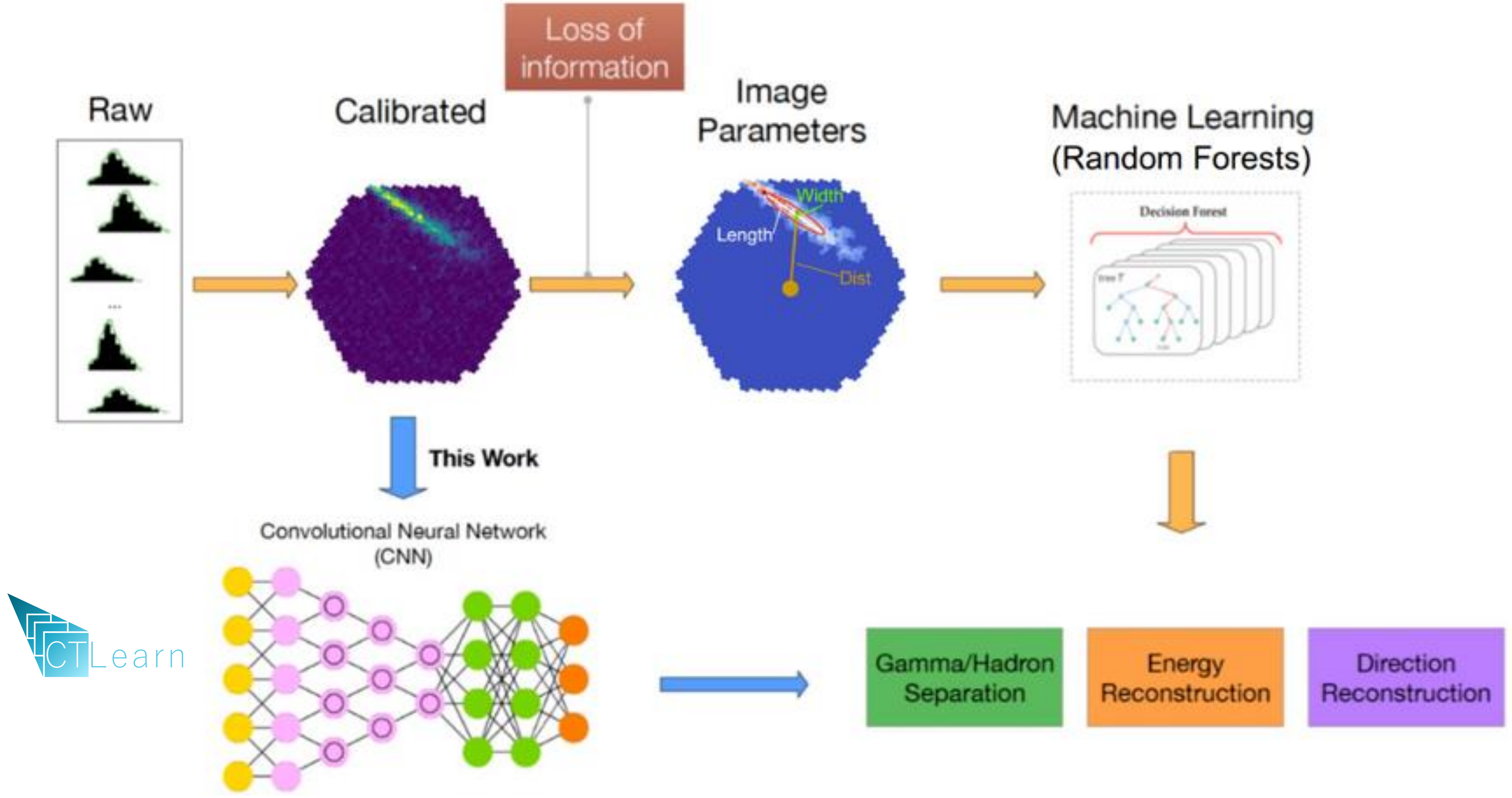
CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

Carlos Abellan Beteta
Iaroslava Betshyko
Nicola Serra

University of Zurich[UZH]

ML with CTAO and Gamma-ray astronomy

- Data analysis:
  - ✦ Use CNN architecture to perform full event reconstruction (direction, energy, type of primary particle)
  - ✦ Complexity due to:
    - ◉ Variety of shower imprints in camera (energy, impact distance, angle wrt. optical axis)
    - ◉ Variety of observation conditions (telescope pointing direction, atmosphere conditions, background light)



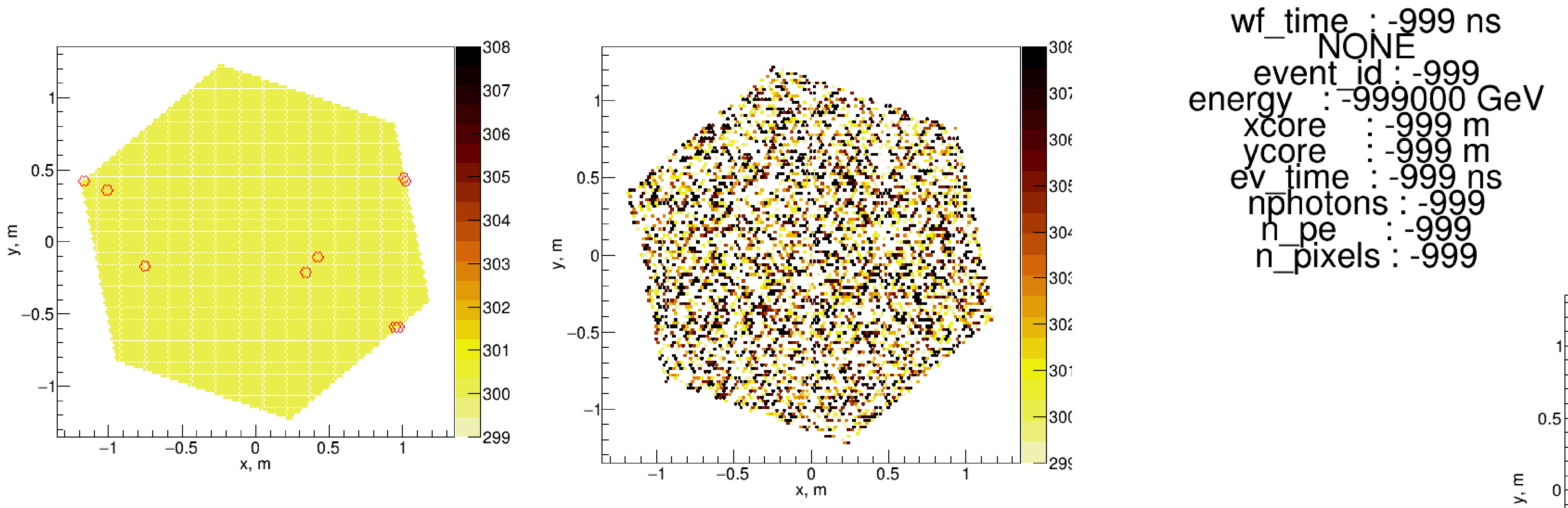
- Data volume reduction:
  - ✦ Train models to capture the image or event features relevant to high-level information extraction (e.g. photon count, energy, direction)
  - ✦ Use this to compress the event representation
  - ✦ Auto-encoder model studied, the key is to evaluate the impact on the performance of lossy compression

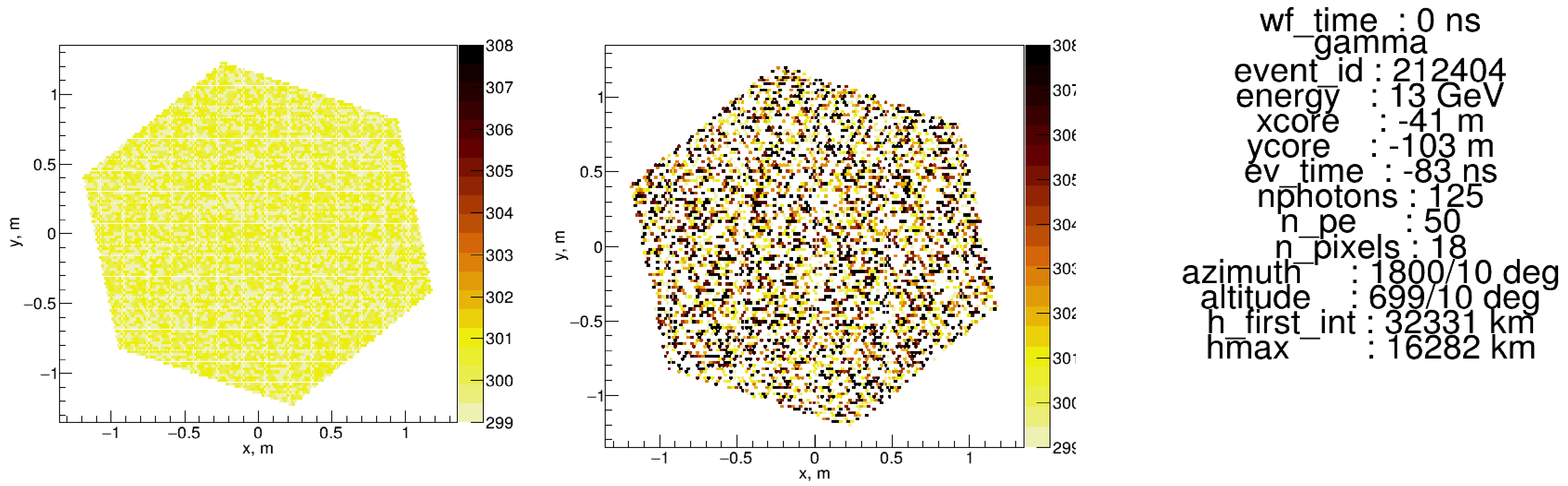
DOI 10.5281/zenodo.3345947
https://github.com/ctlearn-project/ctlearn https://ctlearn.readthedocs.io

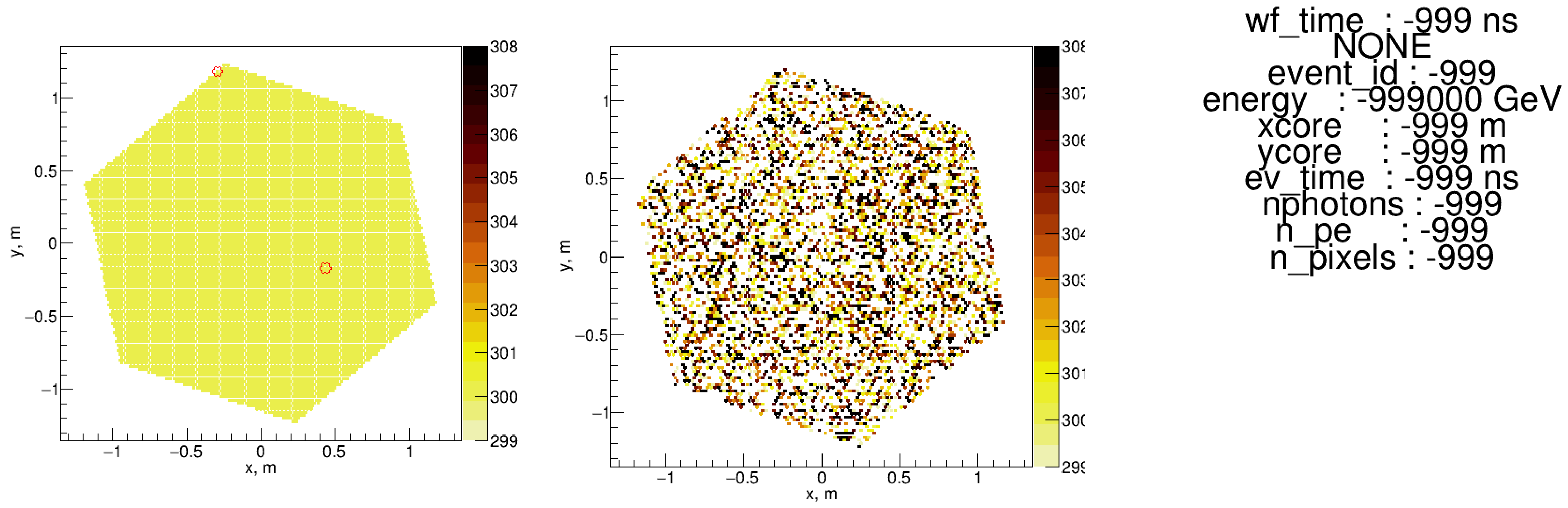
Adding another coordinate to space

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

Time through WF gives an early image and allows to reach 10 GeV



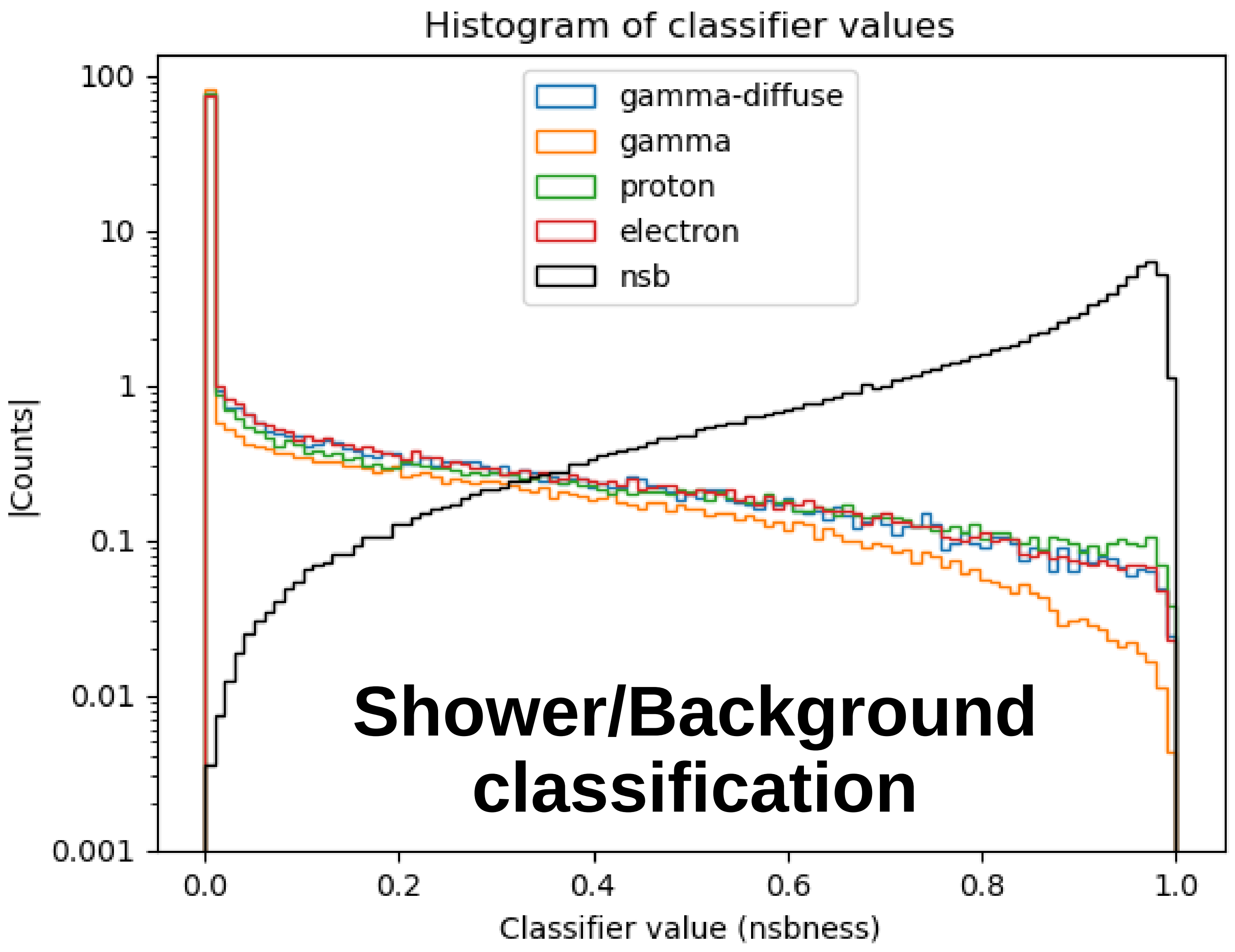


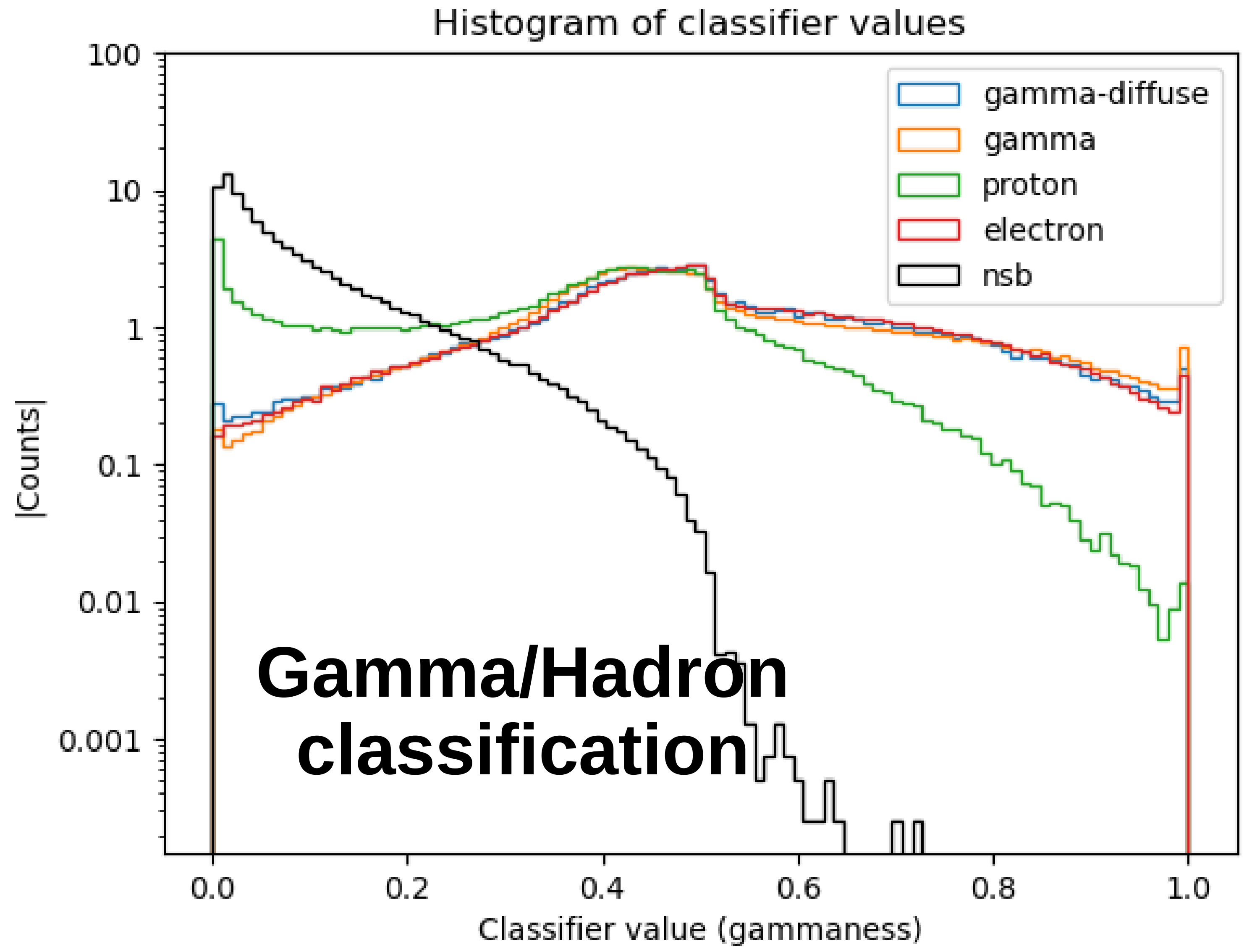


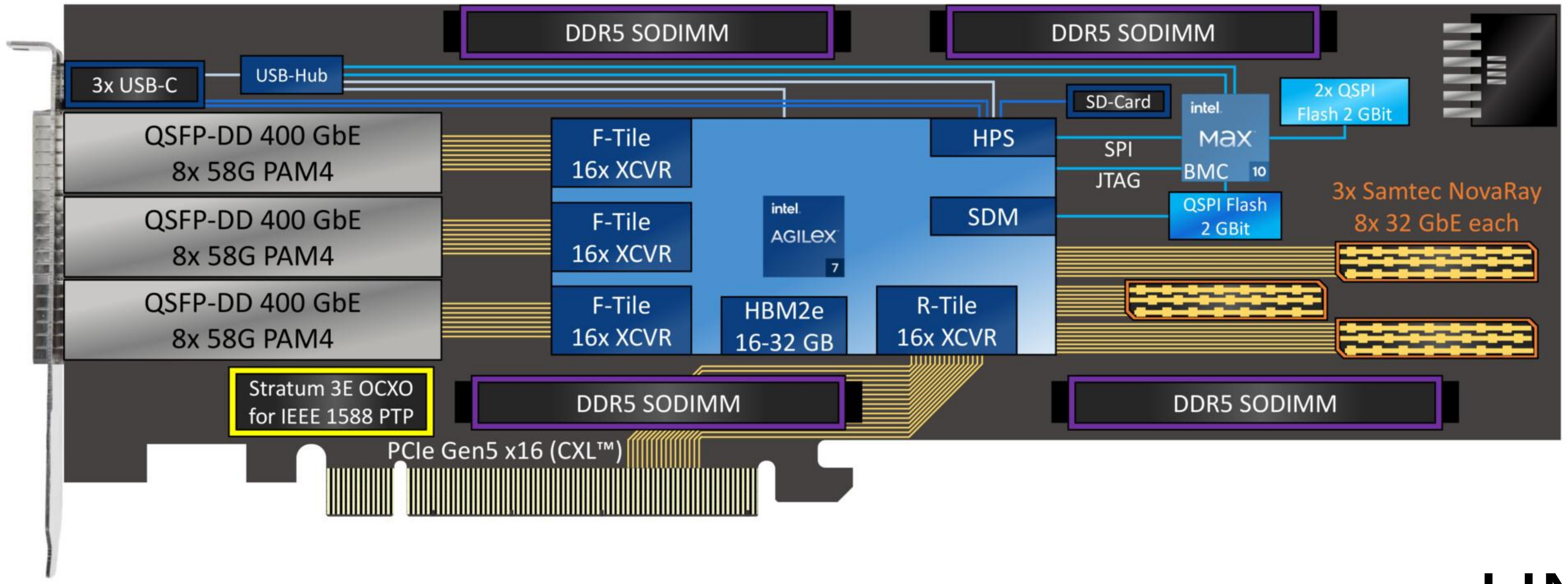
ML as close as possible to sensors

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

- Advanced Trigger :
  - ✦ Trigger selects relevant images on top of night sky background ~100 MHz/pixel and cosmic ray showers (~10^5 more than gamma-ray showers)
  - ✦ Need to achieve large data volume reduction (72 Tb/s to 24 Gb/s) with fixed latency and negligible dead-time.
    - ◉ Multiple trigger levels are required to achieve such a large reduction, which increases complexity at each step
  - ✦ Effort on optimising algorithms for different trigger levels
  - ✦ Using computing resources at CSCS (Pitz Daint) for this work and algorithms will be ported on advanced FPGAs







prodesign FALCON Agilex® 7 M Acceleration Card

hls4ml

OpenVINO™

UNIGE/ETHZ/Enclustra/CSEM