Sexten 2025 - Advances in Modeling High-Energy Astrophysical Sources: Insights from recent multimessenger discoveries

CTAO
Cherenkov Telescope Array Observatory

Innovative Pointing Strategies for the CTAO: Divergent Mode Observations

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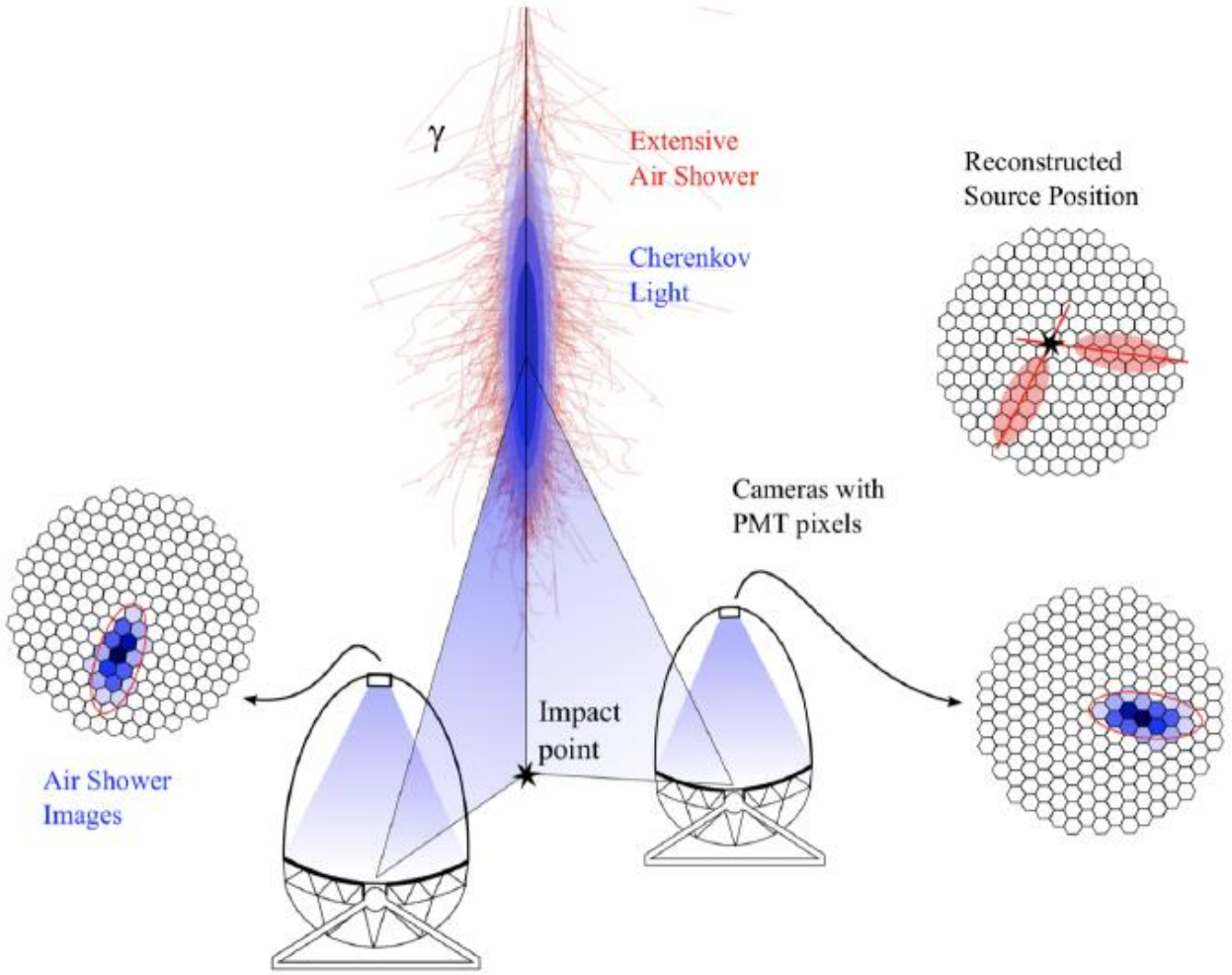
CTAO

1 Introduction to CTAO

2 Simulation and Analysis

3 Divergent Pointing

Imaging Air Cherenkov Telescopes

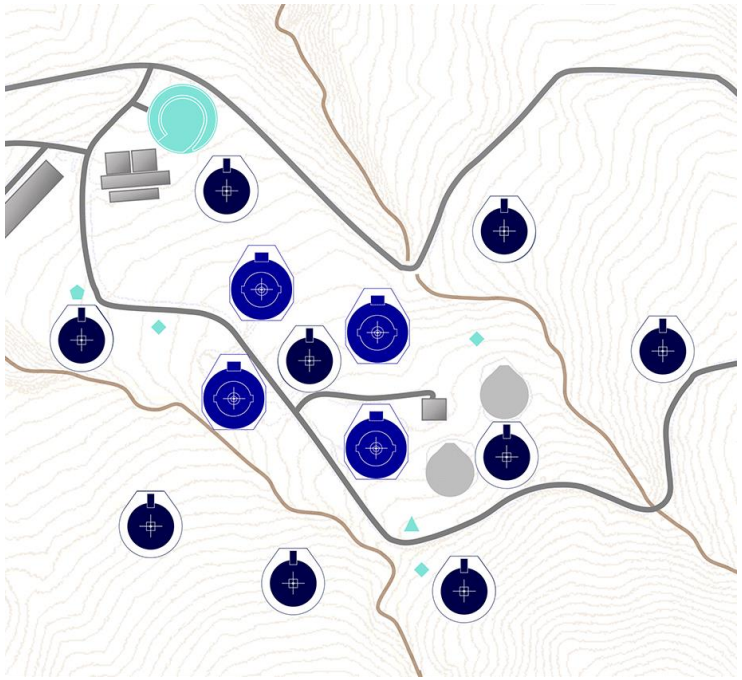


Stereoscopic Observation:

Multiple telescopes observe the same event or region from different angles, allowing for the **3D reconstruction**, improving spatial resolution and reducing background noise.

D. C. Fidalgo. Springer Theses. Springer, 2019

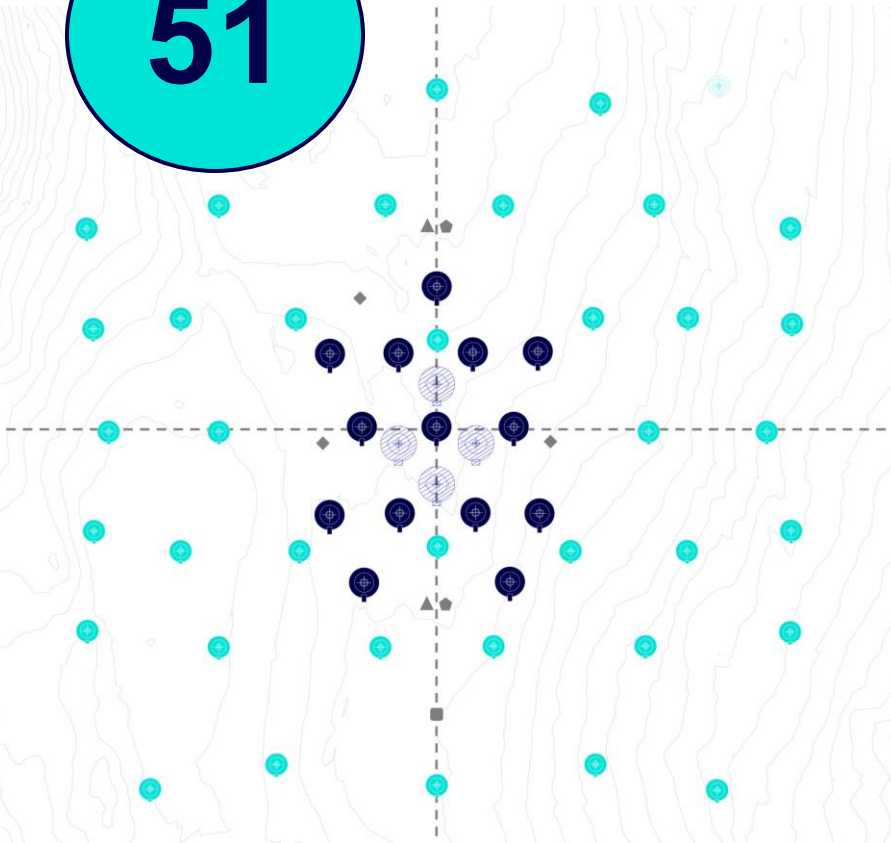
2 Sites



CTAO

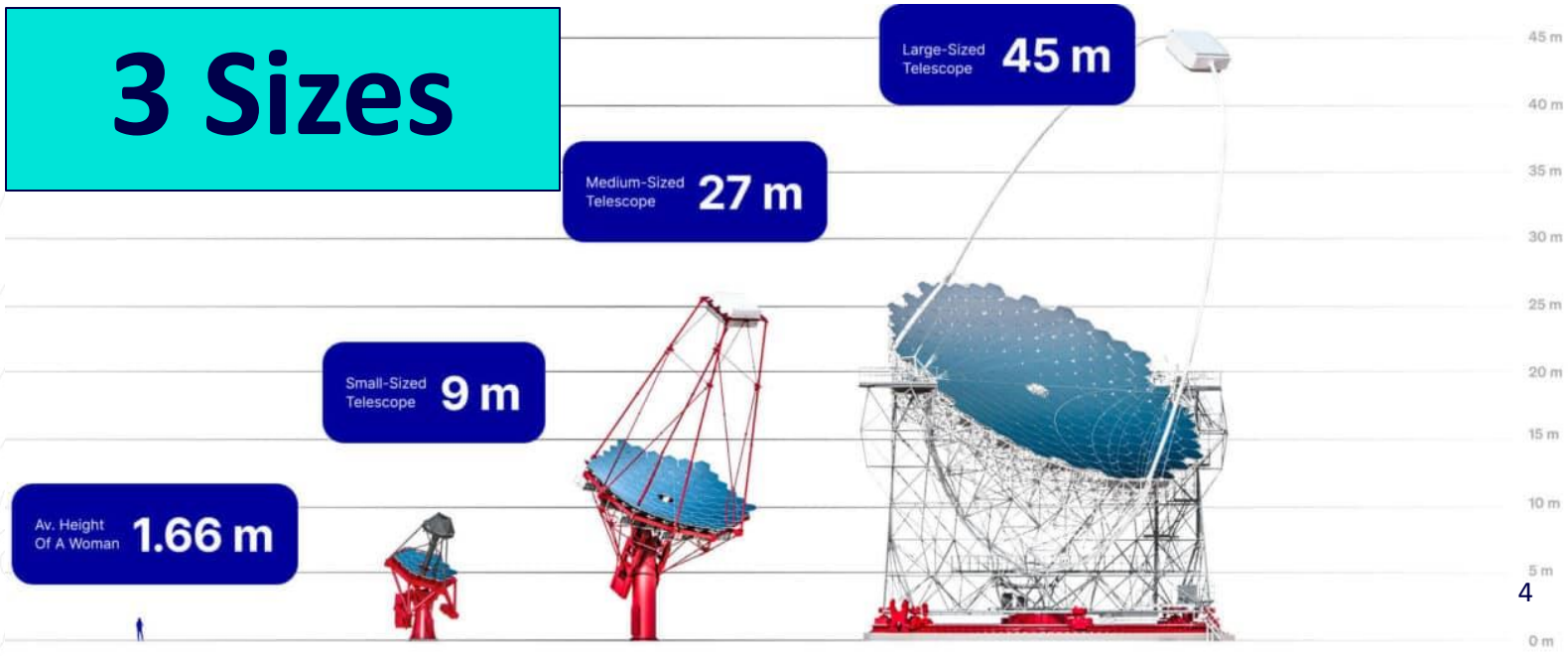
13

51

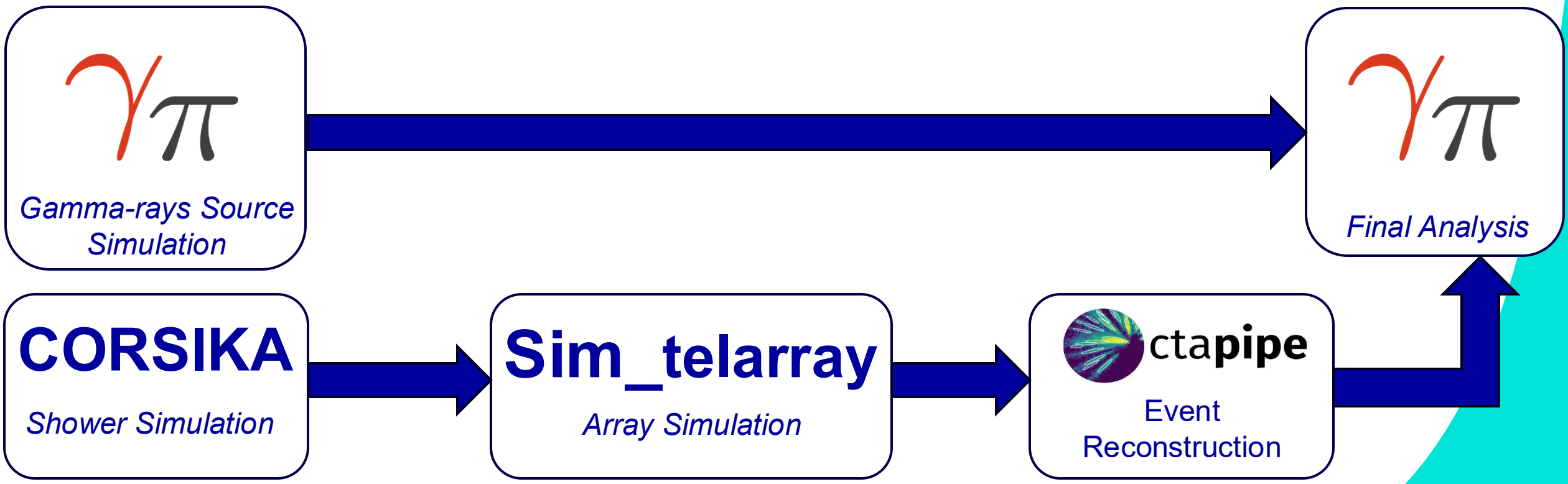


www.ctao.org

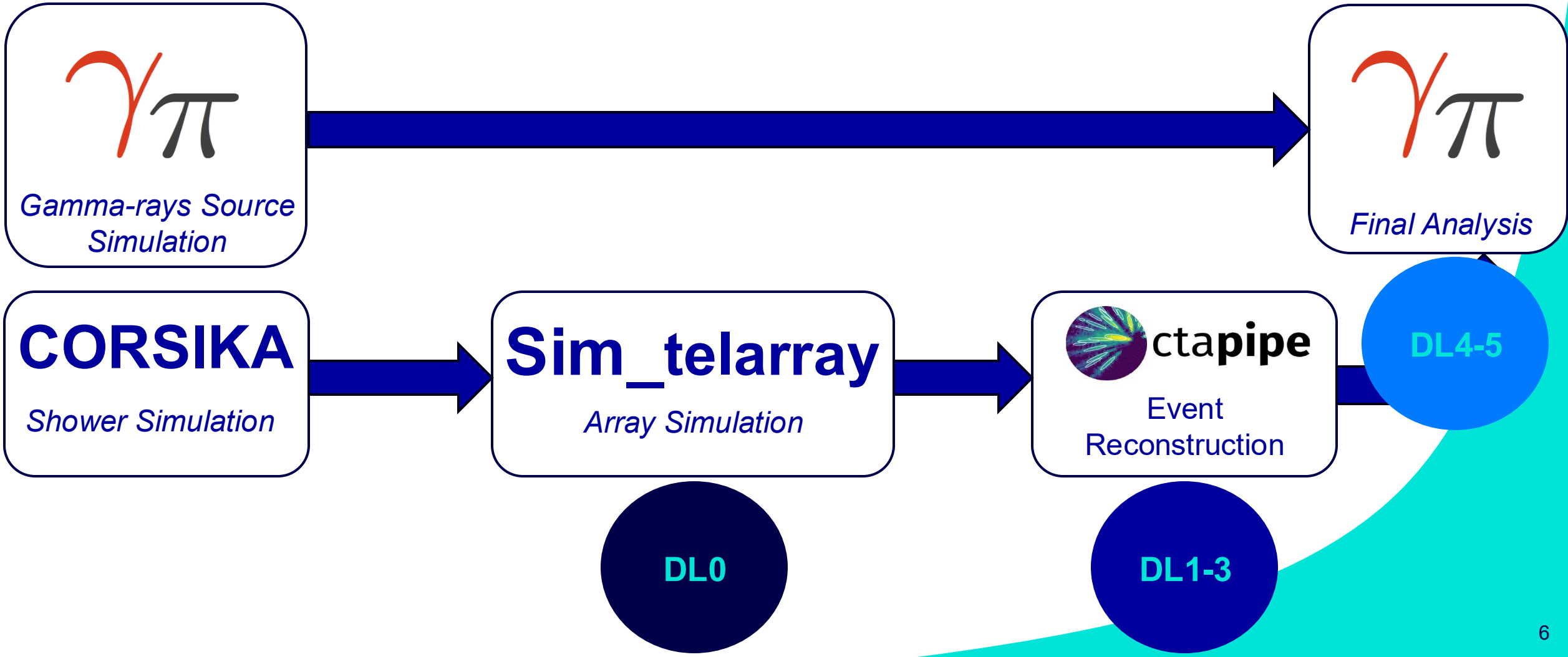
3 Sizes



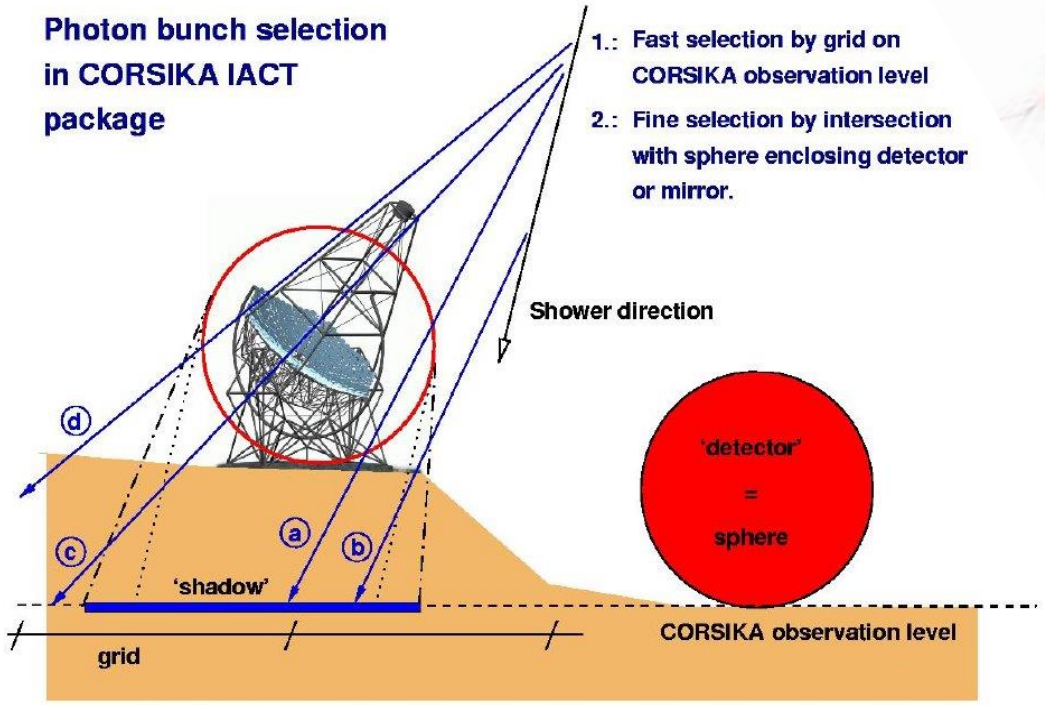
Simulation and Analysis Pipeline

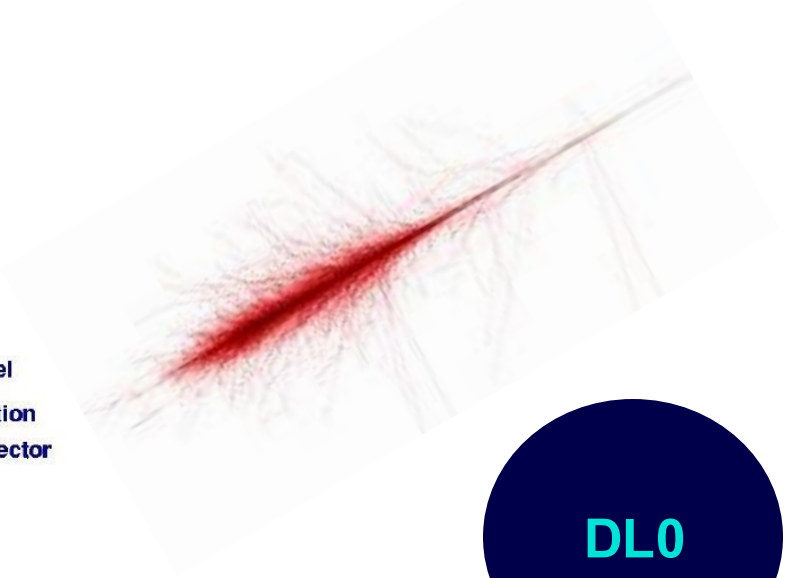


Simulation and Analysis Pipeline



CORSIKA + Sim_telarray

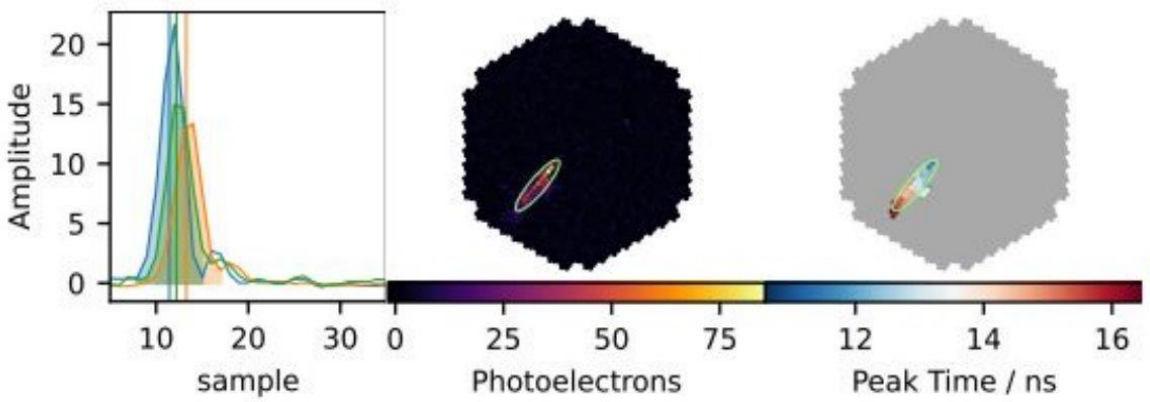


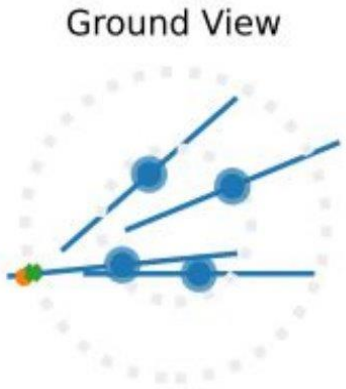


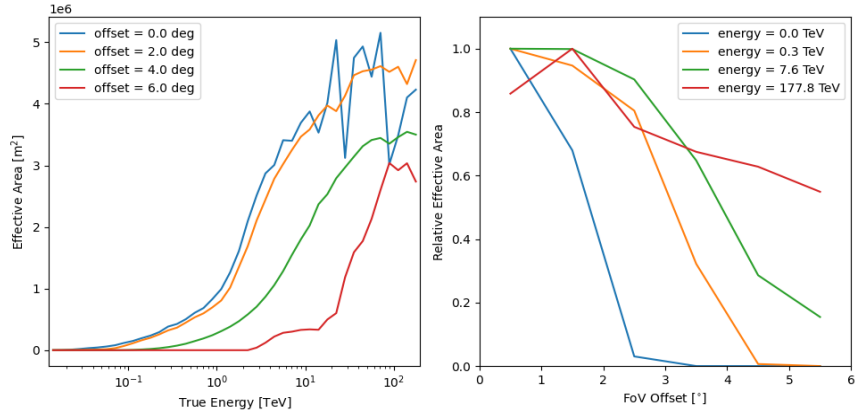
DL0

Shower and telescope response simulation

Ctapipe (+ pyirf)







DL0

Raw
single telescope

DL1

Processed
single telescope

DL2

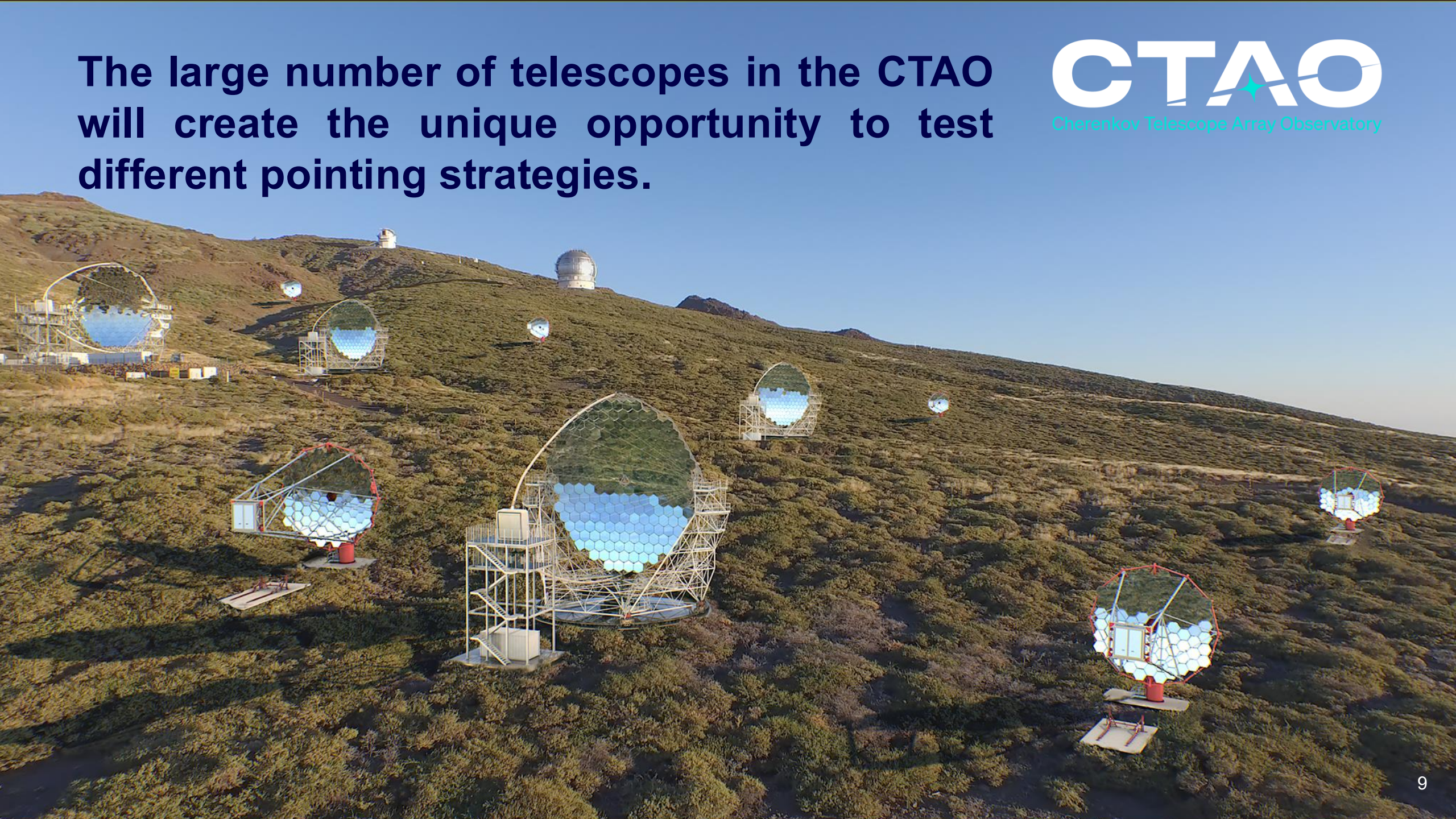
Reconstructed
event

DL3

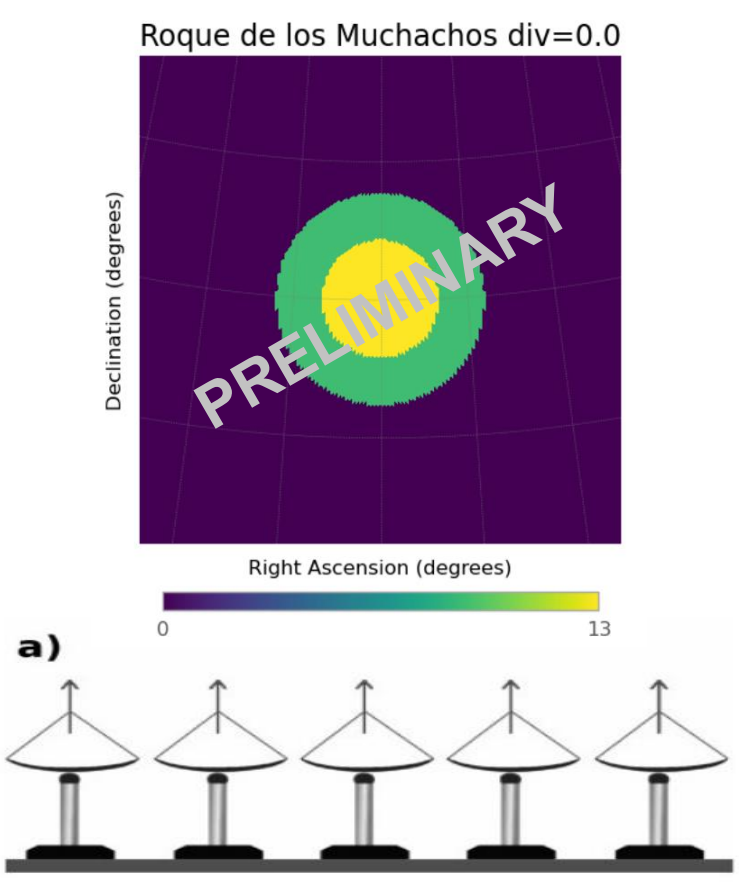
Gamma-like events,
Instrument Response
Functions

The large number of telescopes in the CTAO will create the unique opportunity to test different pointing strategies.

CTAO
Cherenkov Telescope Array Observatory

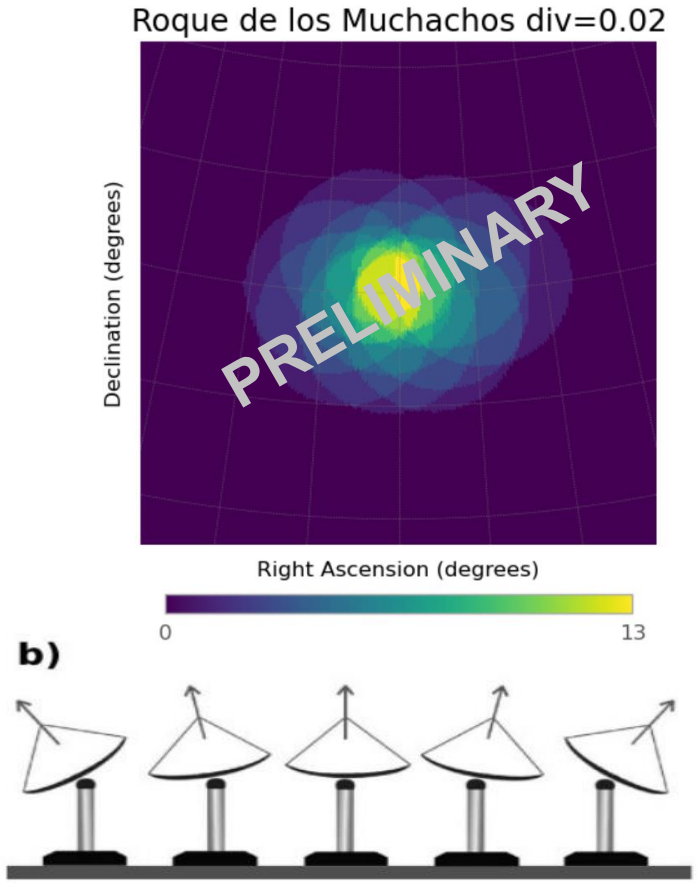


Pointing Strategies



Parallel Pointing

All telescopes point together at the same direction.



Divergent Pointing

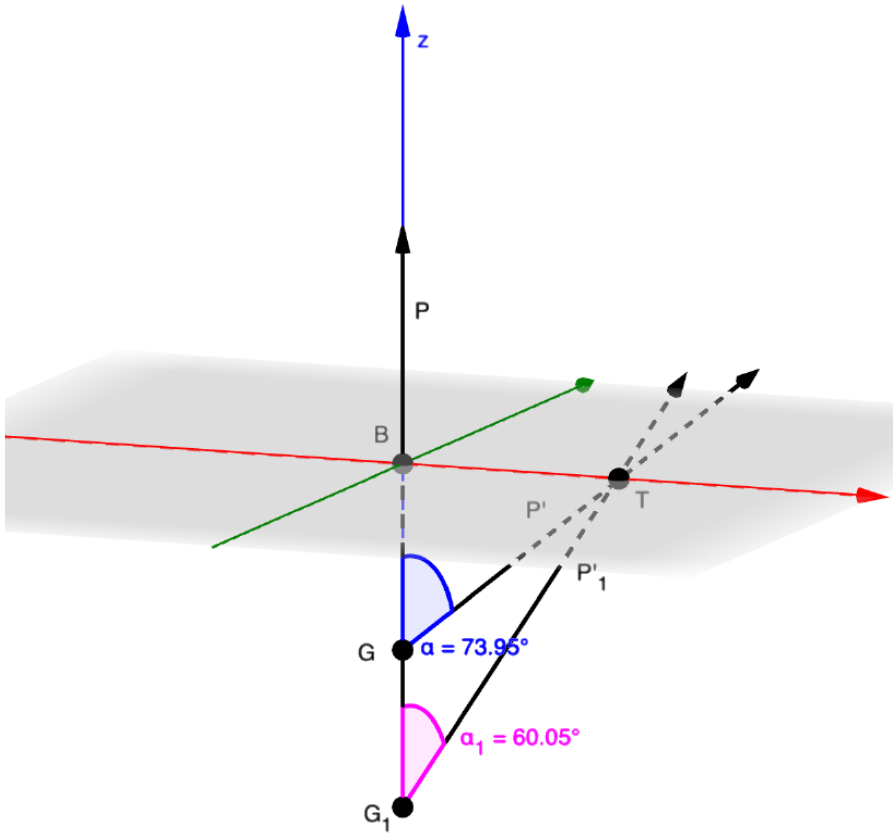
Telescopes are inclined into the outward direction by an angle increasing with the telescope distance from the array center.

Produced using *divtel*

(A python code developed for divergent pointing simulations:* Thomas Vuillaume, et al. 2022 *)

Pictures Credit: Szanecki, M., et al. Astroparticle Physics 67, 33–46.

Umbrella Mode



A **simple** strategy to define the pointing directions of **all** telescopes using a **single** parameter:

$$\boxed{div = \sin(\alpha)}$$

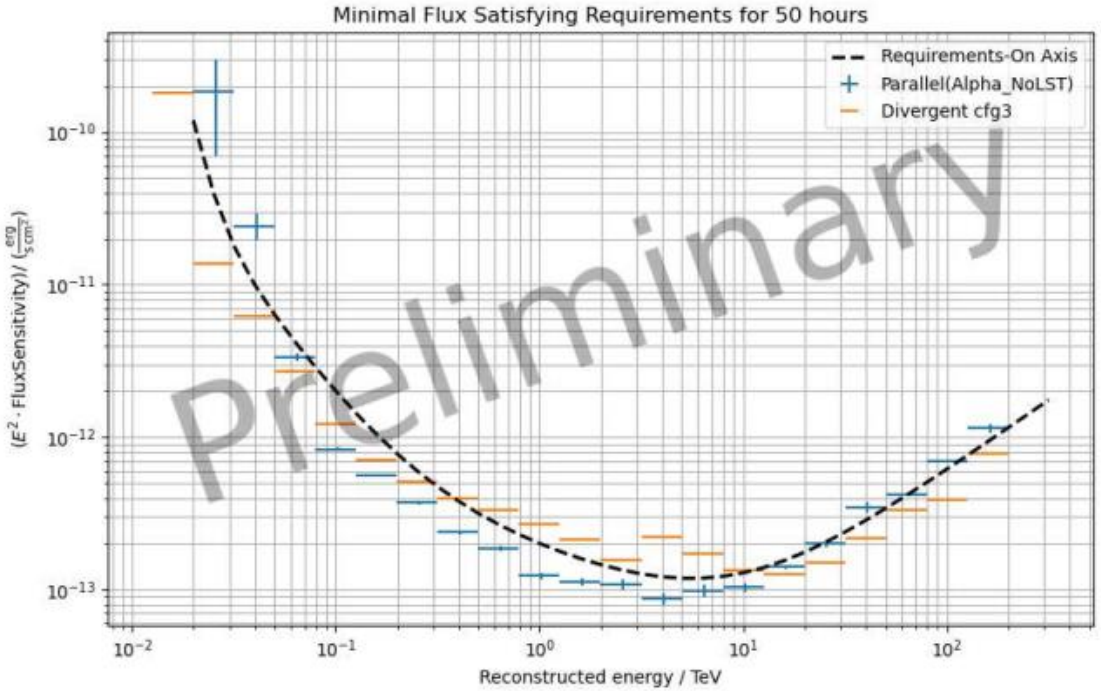
Input to *divtel*!

Credit: Donini, A. PhD thesis (Univerità degli Studi di Udine, 2020)

Preliminary Results

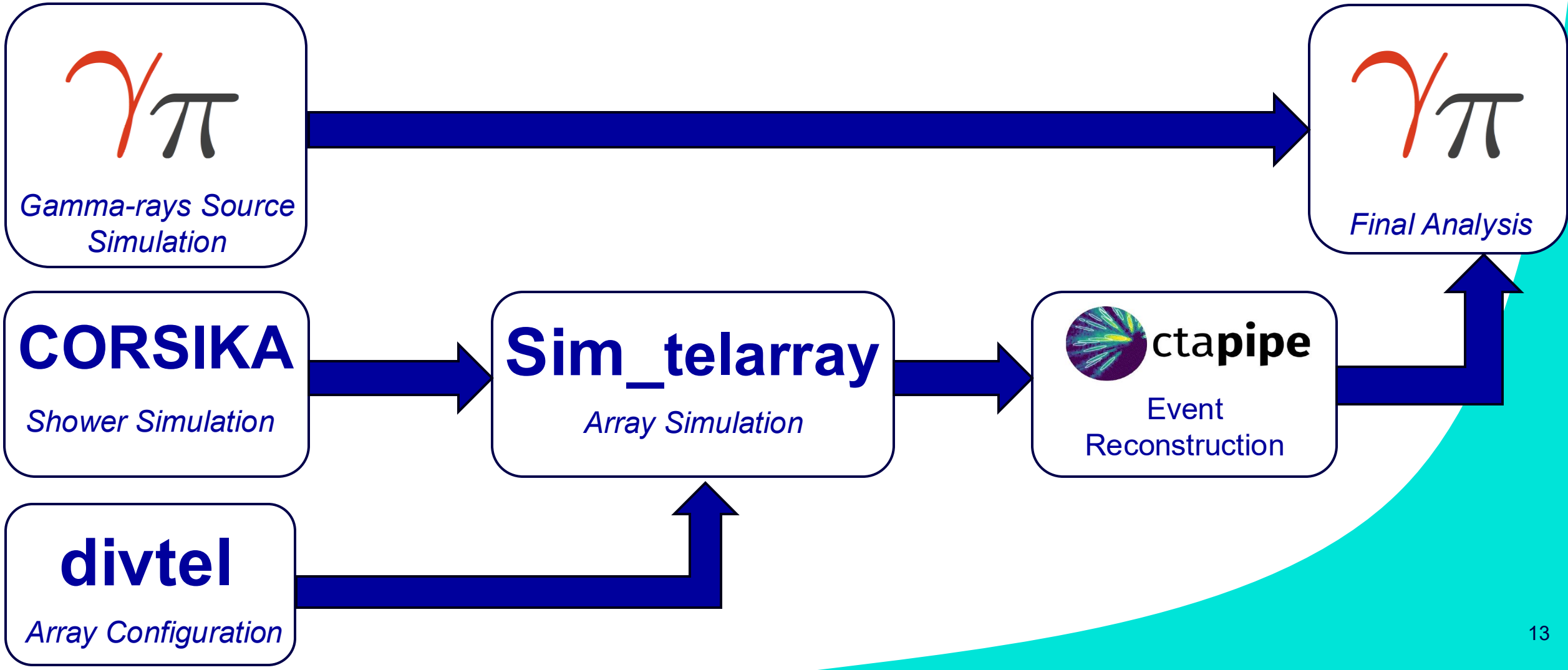
CTAO-South: 4 LSTs, 14 MSTs and 42 SSTs

Cfg name	div	hFoV (deg^2)	hFoV$_{eff}$ (deg^2)	m$_{ave}$
parallel	0.0	62.3	62.3	53.4
cfg1.5	0.0022	99.0	89.6	33.5
cfg2	0.0043	141.5	118.3	23.5
cfg3	0.008	232.1	174.7	14.3
cfg4	0.01135	331.2	230.1	10.0
cfg5	0.01453	439.3	285.5	7.6



Credit: Burelli, I. PhD thesis (Univerità degli Studi di Udine, 2024)

Simulation Pipeline for Divergent mode



Science with Divergent pointing

Introducing PhD Divergent Group

- **Gamma-ray bursts** (Jahanvi): Optimizing configuration for GRBs
- **Gravitational waves** (Daniele Ambrosino): GW event follow up
- **Extragalactic survey** (Helena Luciani): Large area with optimized sensitivity

Masters students in Divergent Group

- Diverging CTAO-South **sub-arrays** for transient study (Samanta Morales Sanchez de Lozada)
- Parallel and Divergent mode **comparison** for transient study (Martina Guadagni)

Take home messages

- Divergent pointing mode is promising for **wide-area surveys**, such as the extra-galactic survey, and for the **follow-up of loosely localized transient events** (e.g., gravitational wave or neutrino alerts).
- The **increased sky coverage**, however, results in a **reduction of angular and energy resolution**, requiring dedicated performance optimization strategy.
- The **Divergent Group is actively working** towards the optimization of the divergent mode configuration for CTAO telescopes for different science cases.

Stay tuned....!!

Thank you

CTAO

www.ctao.org

Instrument Response Functions

A mathematical description *R* of the response of a telescope.

$$n(\boldsymbol{p}, E) = t_{obs} \int_{E_T} dE_T \int_{\boldsymbol{p}_T} d\boldsymbol{p}_T R(\boldsymbol{p}, E|\boldsymbol{p}_T, E_T) \times \Phi(\boldsymbol{p}_T, E_T)$$

The standard procedure for IACTs, including CTAO, is to factorize the function *R* into three independent functions:

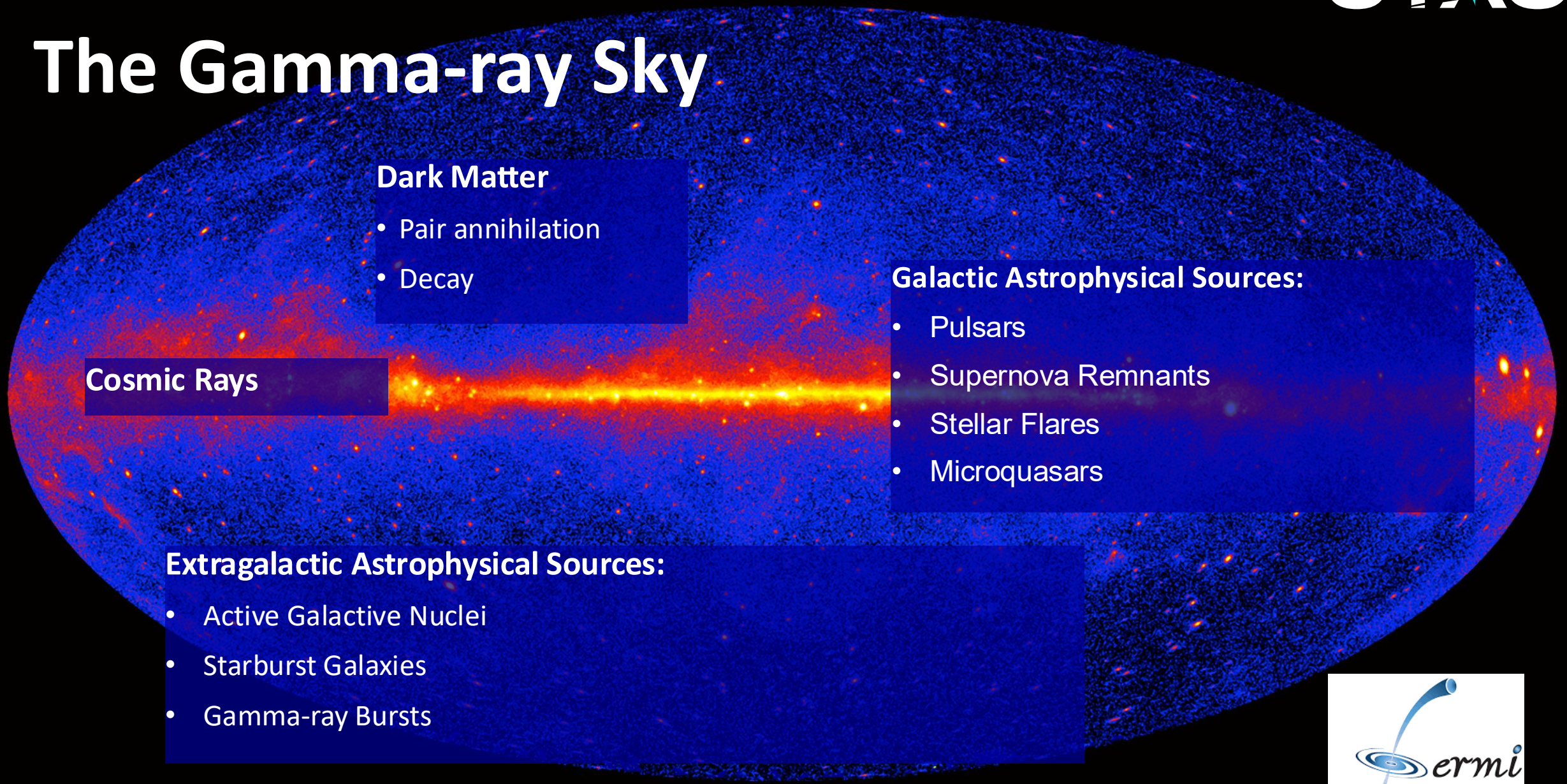
$$R(\boldsymbol{p}, E|\boldsymbol{p}_T, E_T) = A_{eff}(\boldsymbol{p}_T, E_T) \times PSF(\boldsymbol{p}|p_T, E_T) \times E_{disp}(E|\boldsymbol{p}_T, E_T)$$

Effective Area

Energy Dispersion

Point Spread Function

The Gamma-ray Sky



Dark Matter

- Pair annihilation
- Decay

Cosmic Rays

Galactic Astrophysical Sources:

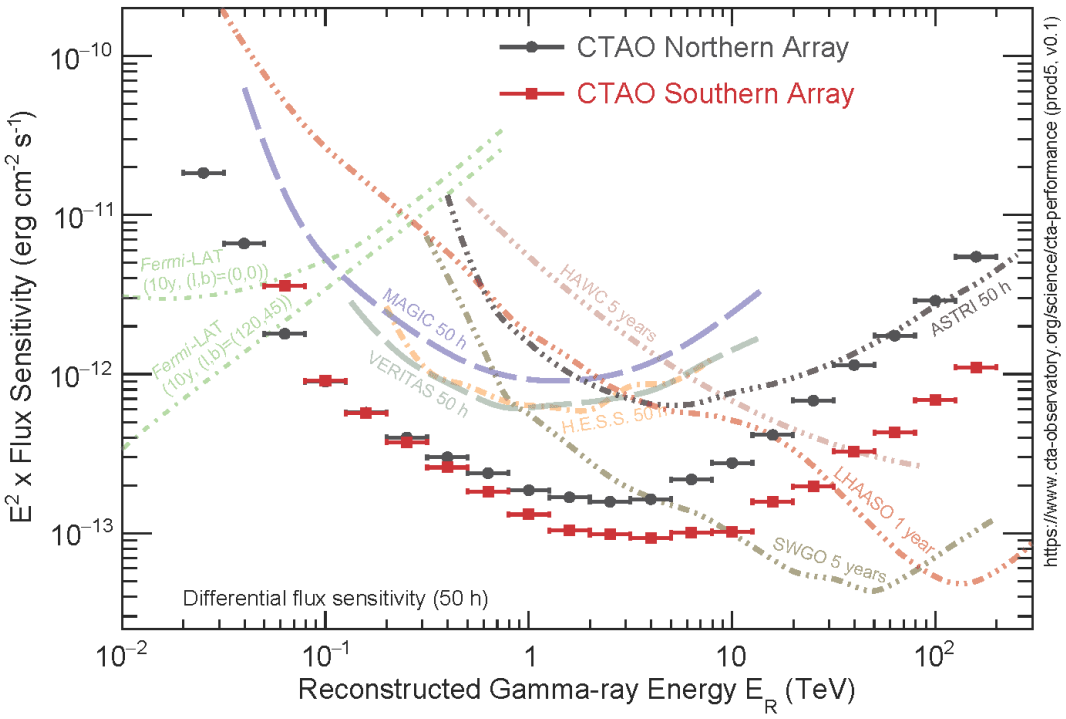
- Pulsars
- Supernova Remnants
- Stellar Flares
- Microquasars

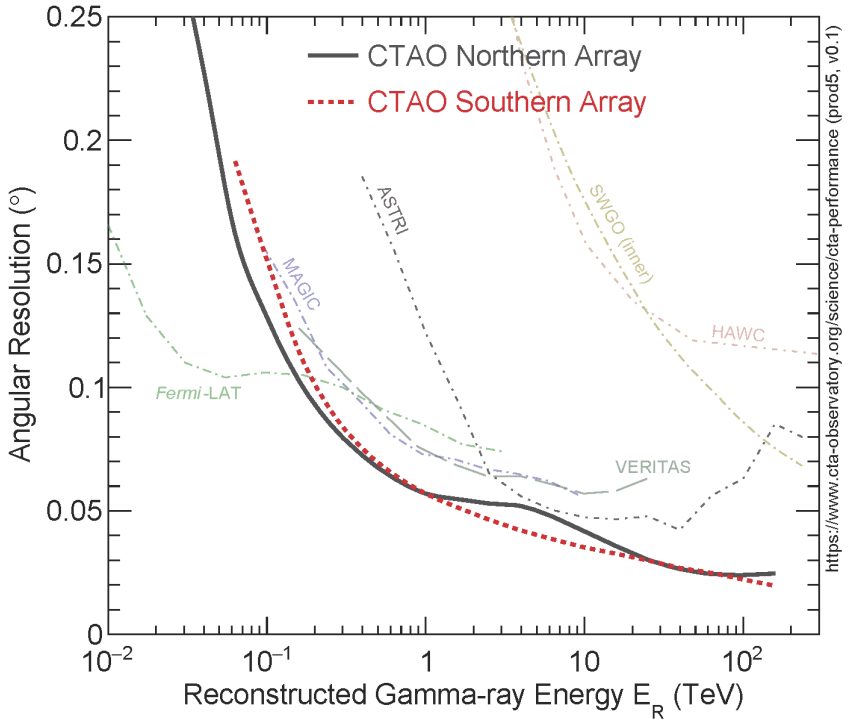
Extragalactic Astrophysical Sources:

- Active Galactive Nuclei
- Starburst Galaxies
- Gamma-ray Bursts

Fermi Gamma-ray Space Telescope

CTAO Performances





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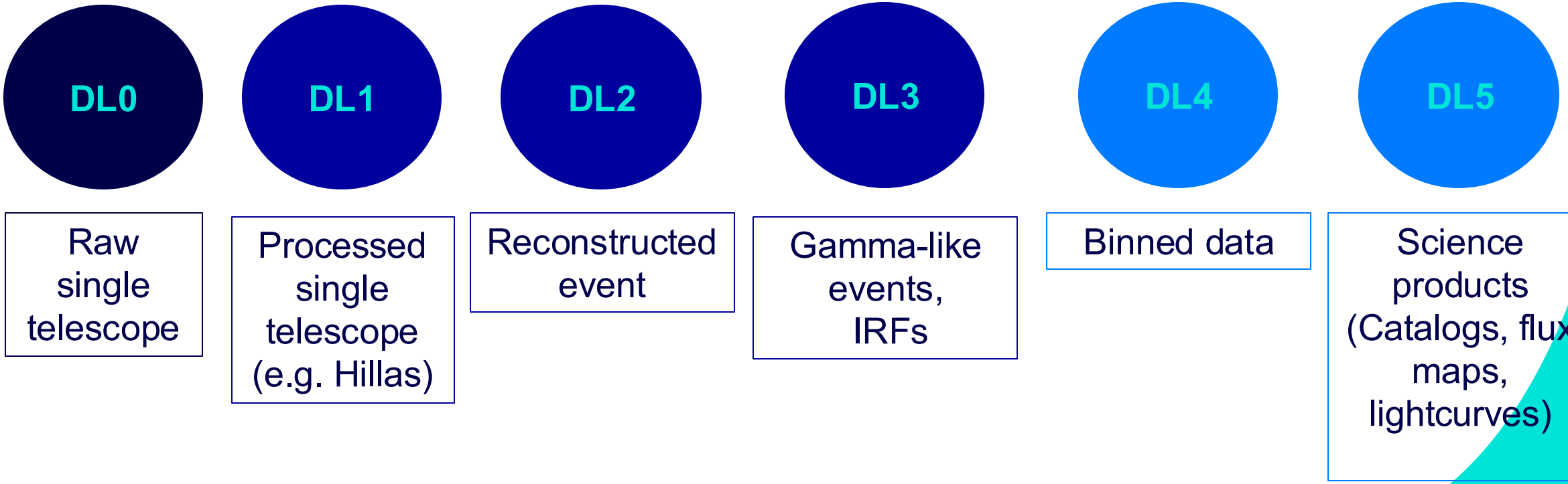
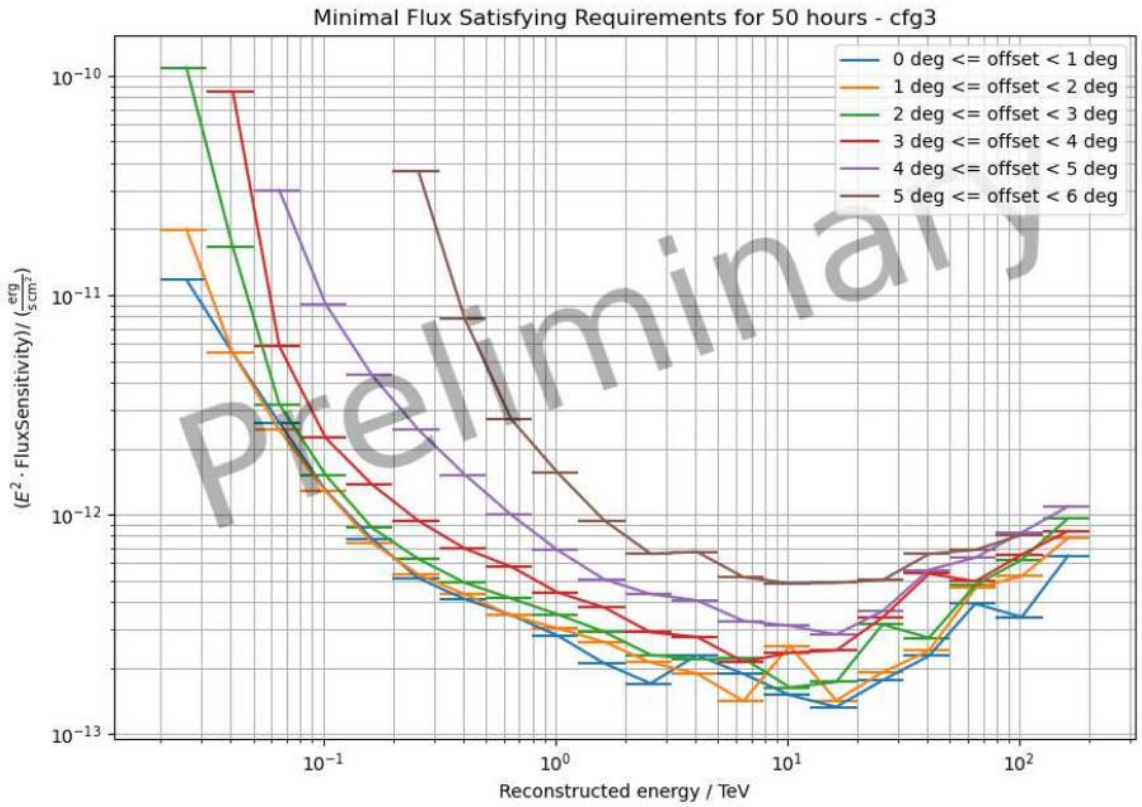
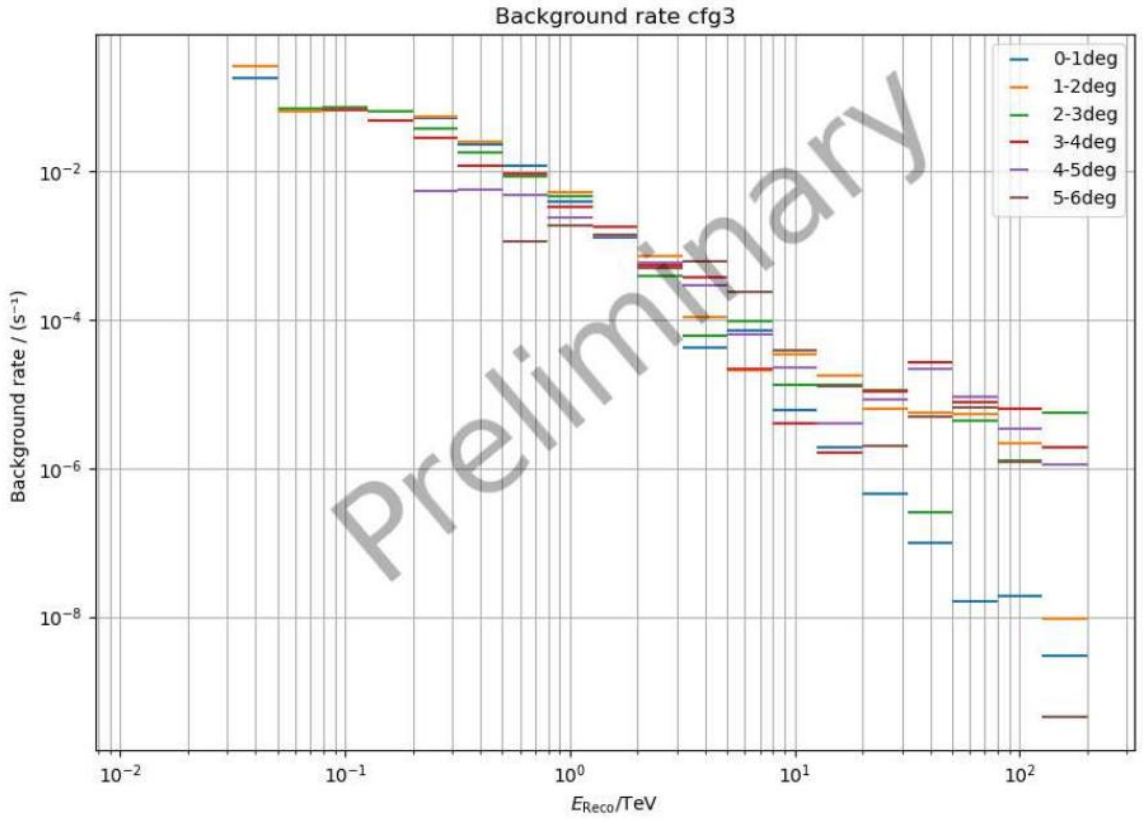
Data Levels in CTAO

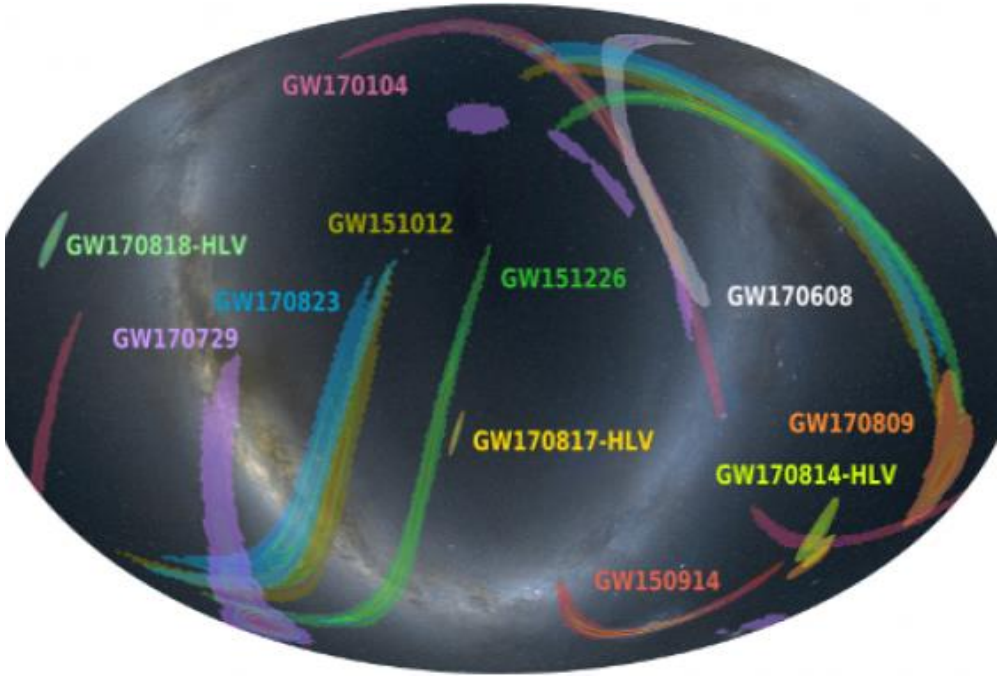


Preliminary results





GW Alert Follow Up



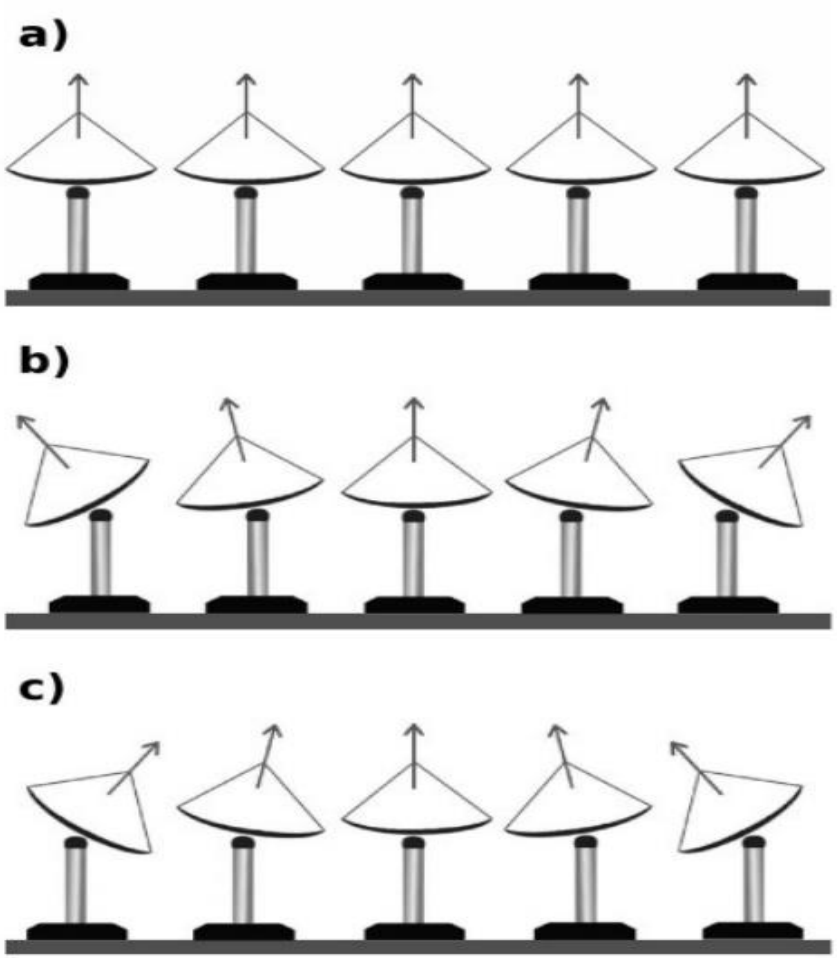
A&A 678, A126 (2023)
https://doi.org/10.1051/0004-6361/202345850

Astronomy & Astrophysics

Pre-merger alert to detect prompt emission in very-high-energy gamma-rays from binary neutron star mergers: *Einstein* Telescope and Cherenkov Telescope Array synergy

Biswajit Banerjee[1,2,3], Gor Oganesyan[1,2], Marica Branchesi[1,2,3], Ulyana Dupletsa[1,2], Felix Aharonian[4,5], Francesco Brighenti[1], Boris Goncharov[1,2], Jan Harms[1,2], Michela Mapelli[6,7], Samuele Ronchini[1,2], and Filippo Santoliquido[6,7]

CTAO Pointing Strategies



Parallel

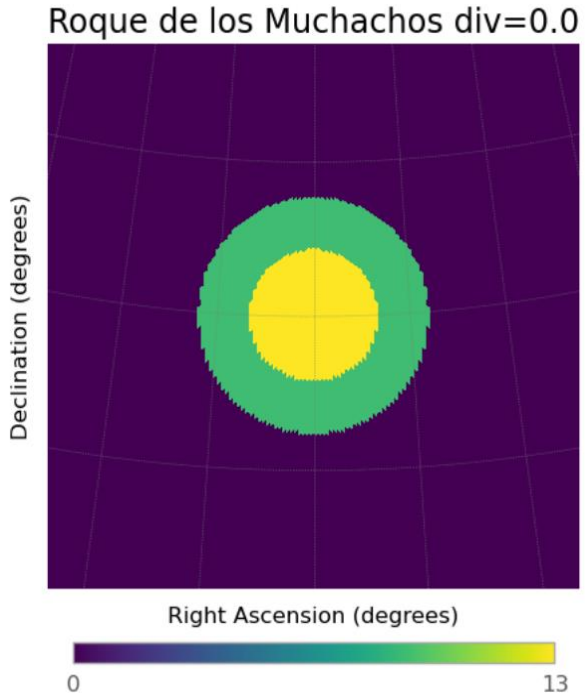
Divergent

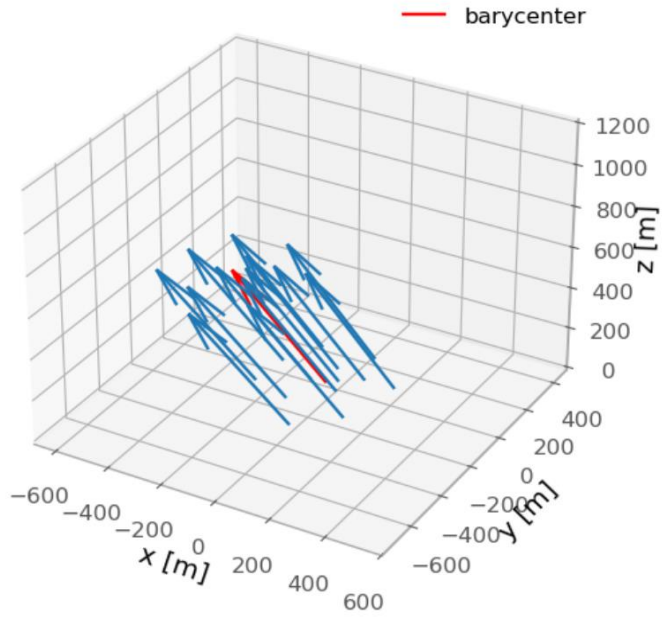
Convergent

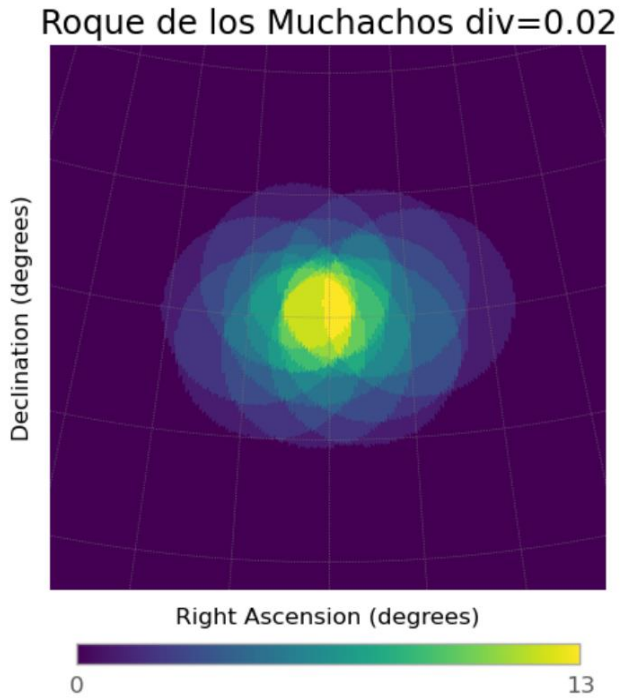
The **divergent** approach expands the field of view (FoV) at the cost of reduction in sensitivity and resolution. Conversely, narrowing the FoV with a **convergent** mode can improve these aspects, providing flexibility for diverse scientific goals.

Szanecki, M., et al. Astroparticle Physics 67, 33–46.

Array Configuration with *divtel*







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