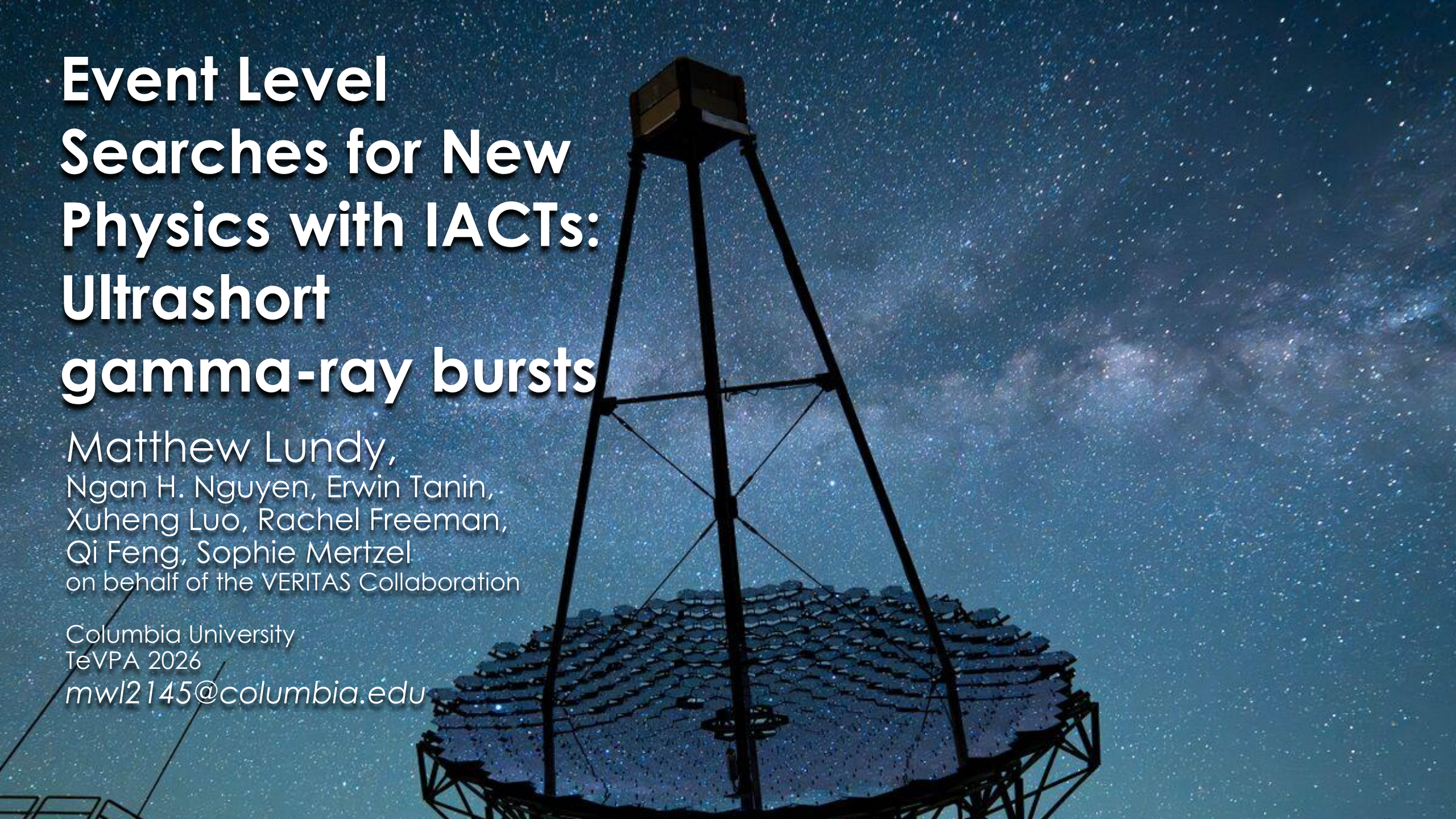
Event Level Searches for New Physics with IACTs: Ultrashort gamma-ray bursts

Matthew Lundy,
Ngan H. Nguyen, Erwin Tanin,
Xuheng Luo, Rachel Freeman,
Qi Feng, Sophie Mertzel
on behalf of the VERITAS Collaboration

Columbia University
TeVPA 2026
mwl2145@columbia.edu



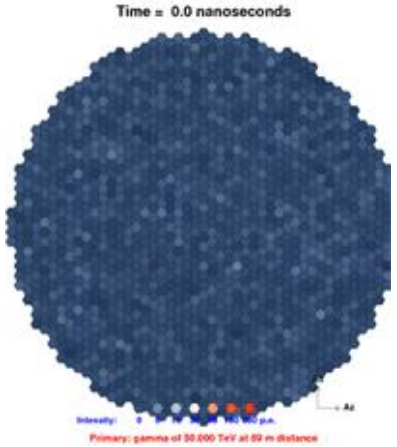
Very Energetic Radiation Imaging Telescope Array System

- Pointed Instrument (3.5 ˚ diameter)
- Good angular resolution (0.08 ˚ at 1 TeV)
- 85 GeV to >30 TeV Energy range

- ~905 h of "dark time" a year
- ~175 h in "moon time" (illum. >30%) a year
- Operating from 2007-2026 with continued operations planned through 2027, at least

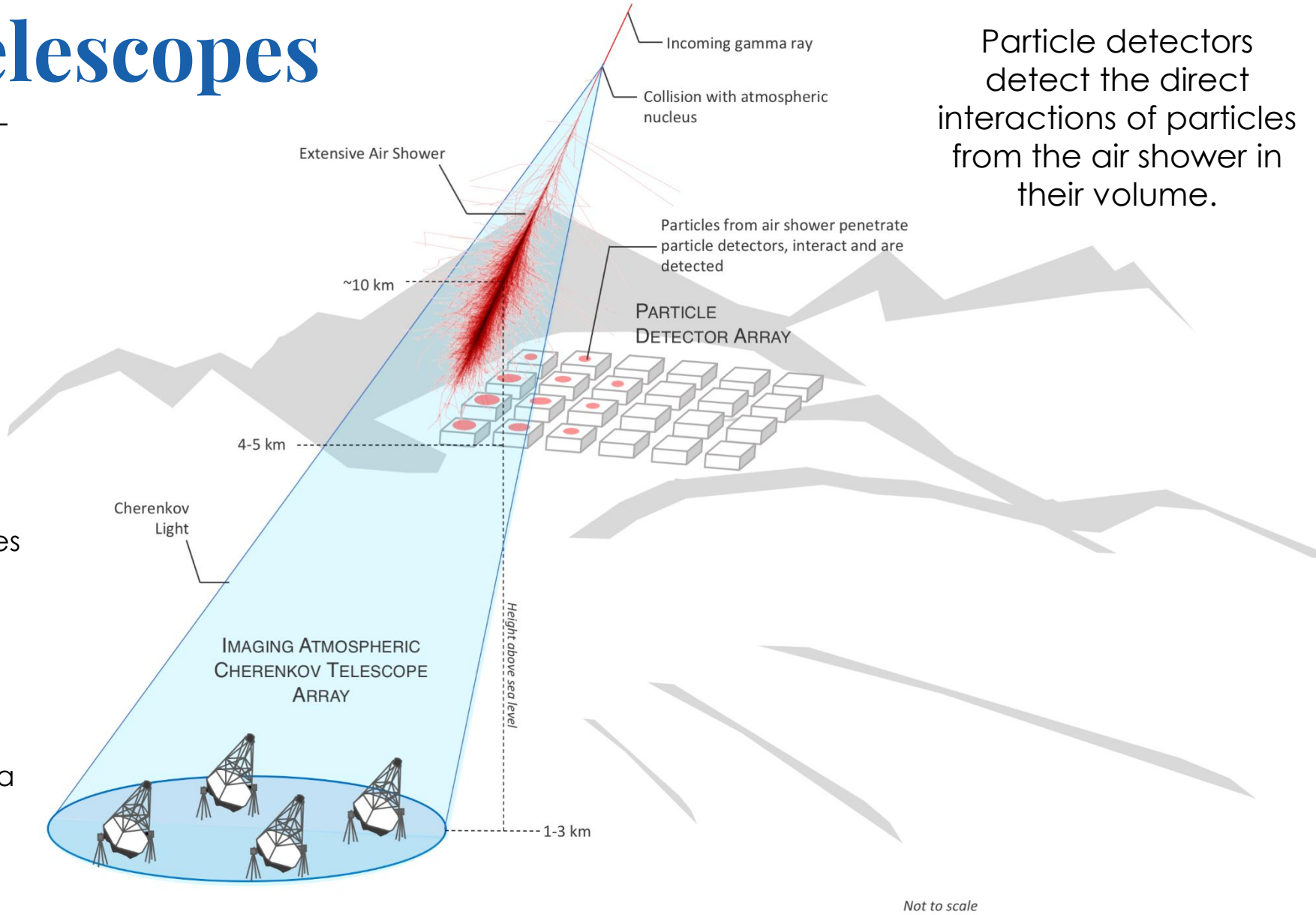
Cherenkov Telescopes

Credit: Barnacka



IACTs operate using an array of telescopes to **stereoscopically image** the approximately nanosecond flash of **Cherenkov** light from relativistic particles produced in an **extensive air shower** initialized by very high energy photons.

Typically showers occur ~10 km above sea level with a ~250 m light pool on the ground.

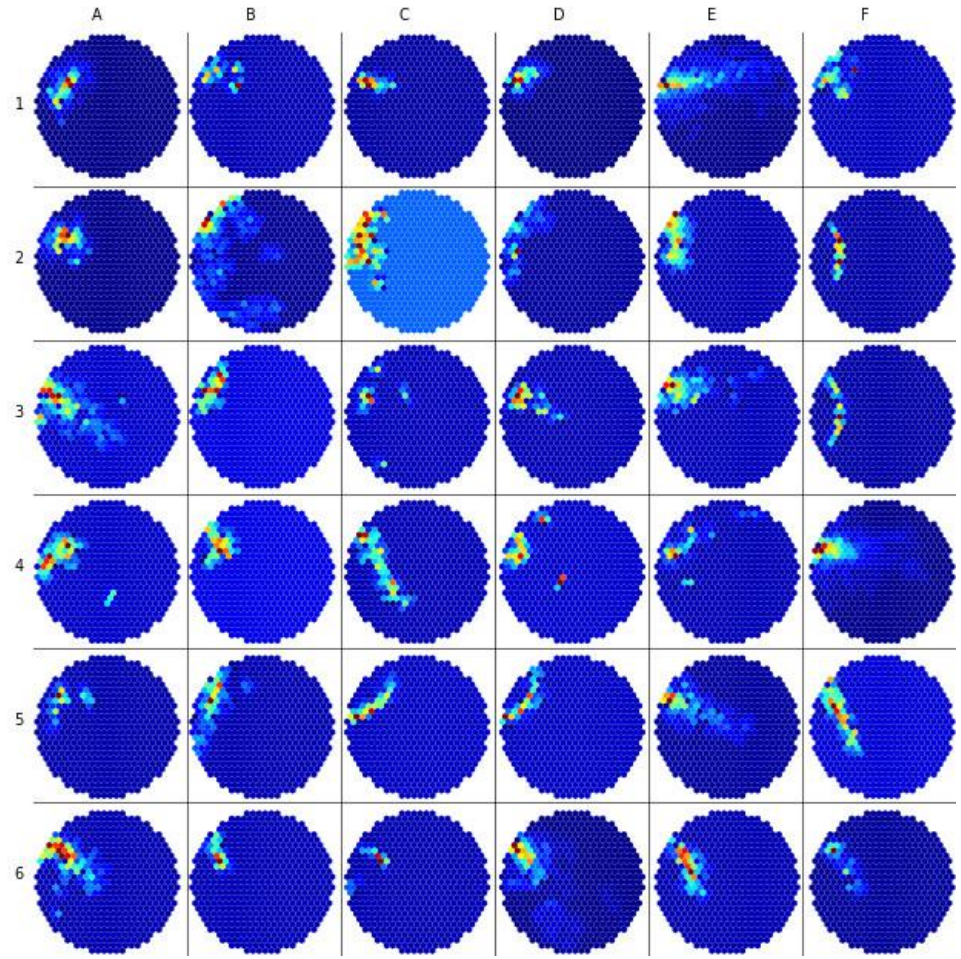


Particle detectors detect the direct interactions of particles from the air shower in their volume.

Credit: Richard White

The VERITAS Event Archive

Credit: Muon Hunter 2.0



Trigger Rate:
~300 Hz

Yearly Observations:
~1000 Hours

Years of Observations:
~20 years

Total Event Archive:
> 20 billion events!

The vast majority of these events (>90%) are rejected for not appearing as gamma-ray like events and never investigated further.

Is there a hidden subset of these events that are rejected automatically but encode **rare astrophysical phenomena or new fundamental physics**?

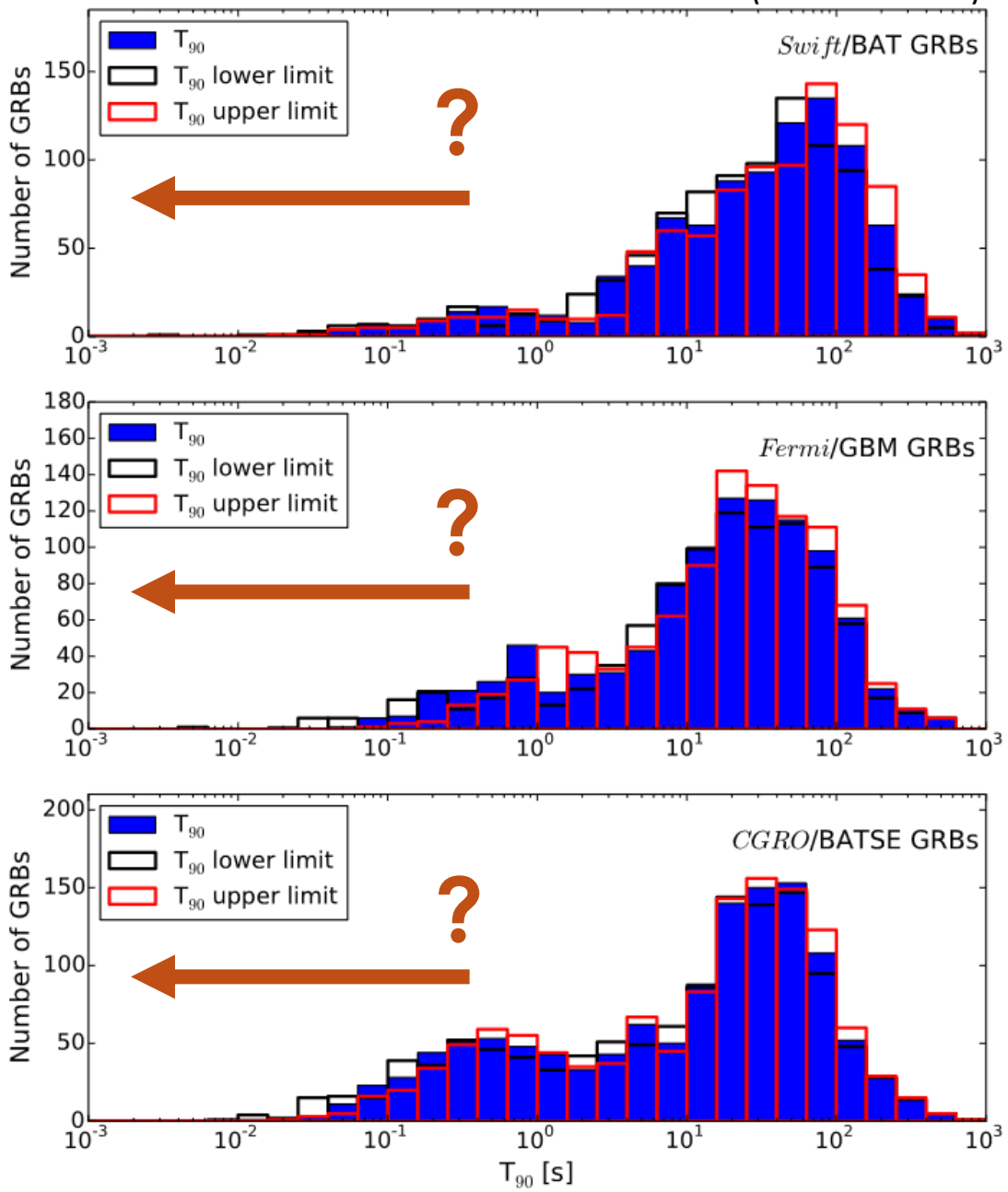
Gamma-ray Bursts

Gamma-ray bursts are typically detected by space based keV-GeV detectors, and clear distinct populations are separated by duration (~0.01-5 seconds and ~1-1000s).

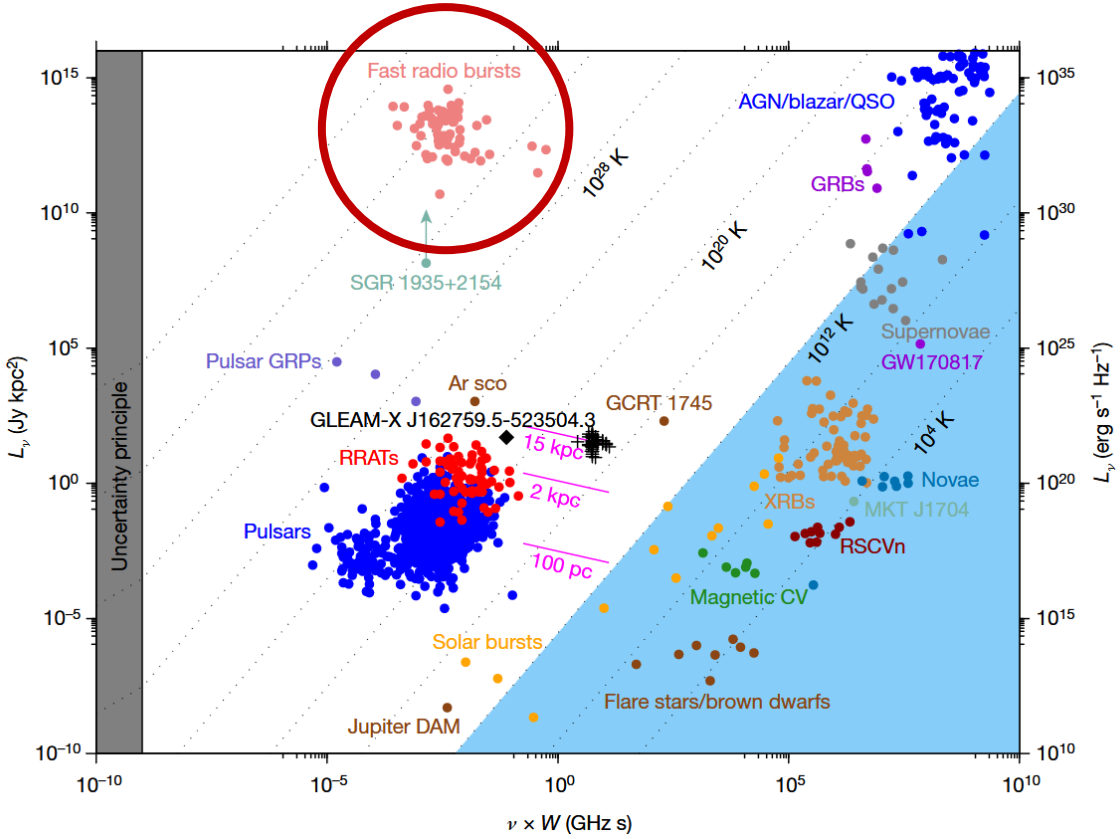
An obvious question to ask is if there exists additional populations **outside of the search window that traditional detectors** are sensitive to (LLGRBs for example).

If the event is narrow enough in time, **deadtime constraints may lead to a non-detection** of even extremely luminous events.

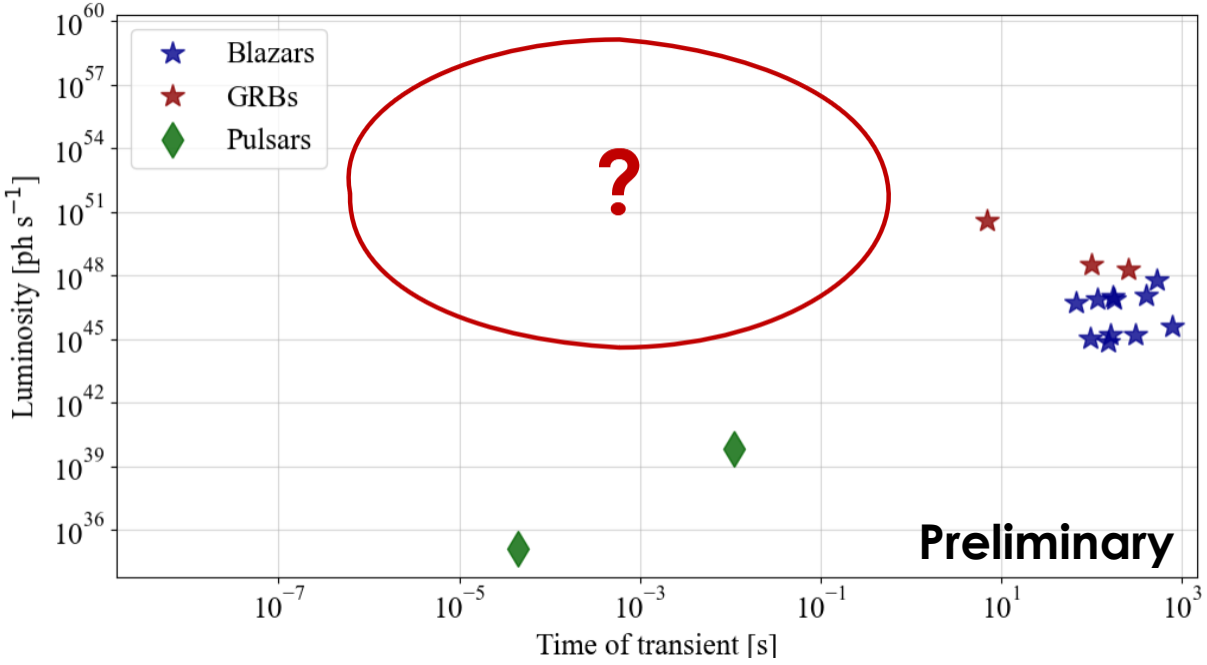
(Lien+, 2016)



Radio



Gamma-ray



Transients that had **orders of magnitude higher luminosity** went undiscovered for decades in the radio simply **because analysis had not been correctly targeted** for high dispersion measure narrow pulses.

Dark Matter Potential Model

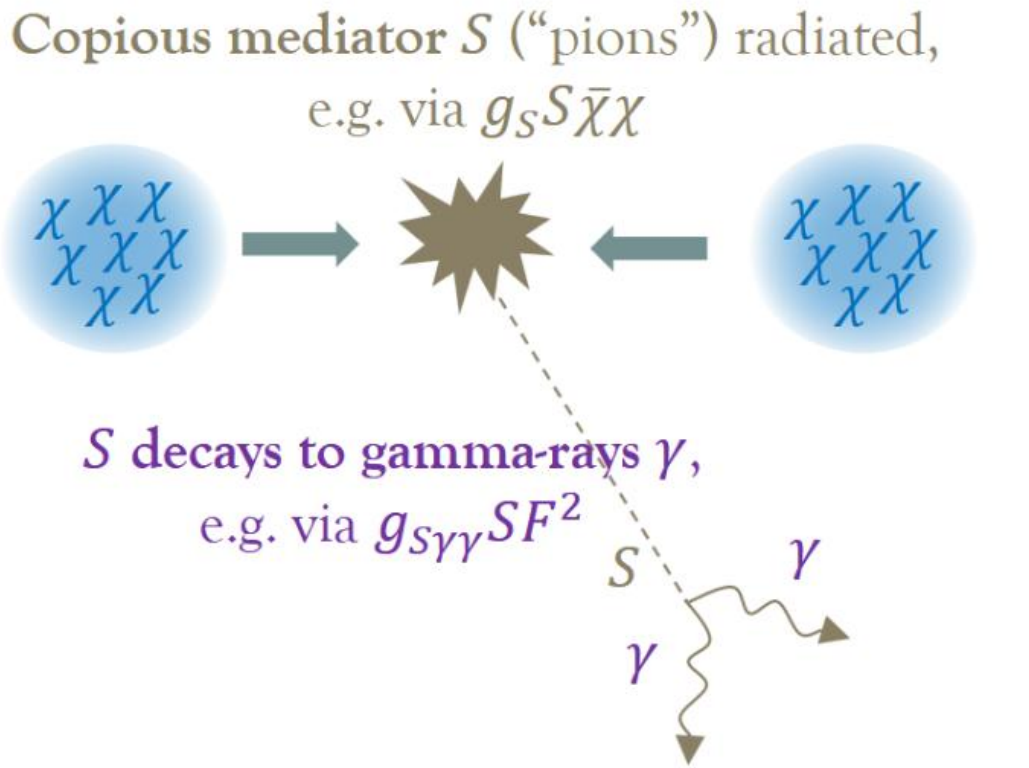
Most conventional IACT dark matter searches assume the signal from dark matter is **constant in time**, but perhaps bright local signatures may be ***transient***.

One scenario could involve systems of strong self-interactions and ultraheavy composites with **new particles** mediating DM self-interactions. Potential DM self-interaction scenarios include;

Collapse of cosmic perturbations
Savastano et al. (2019), Chang et al. (2019), Flores et al. (2021), Domenech et al. (2023), Bramante et al. (2024)

First-order phase transitions
Witten (1984), Bai et al. (2019), Hong et al. (2020), Gross et al.(2021), Asadi et al. (2021)

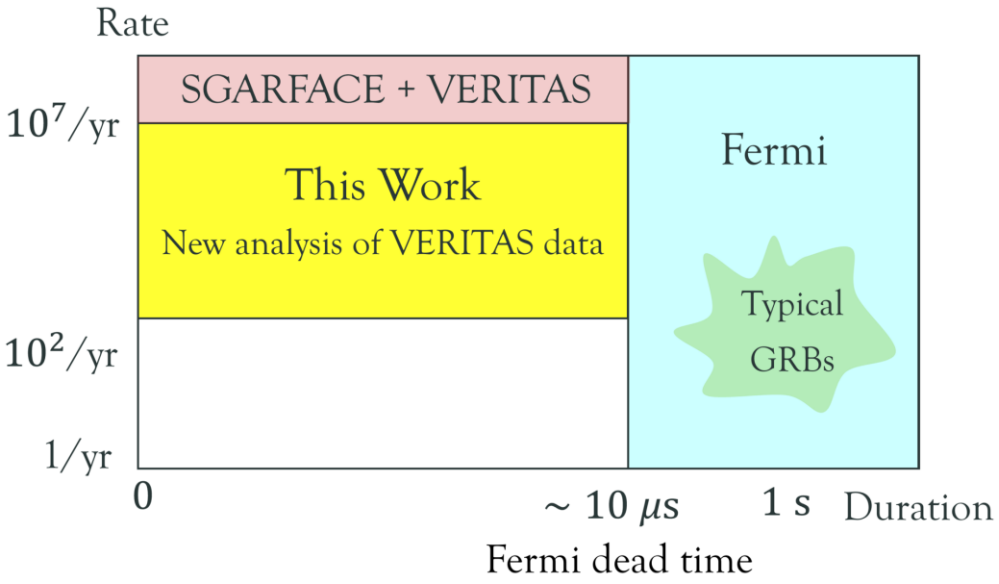
And many more….

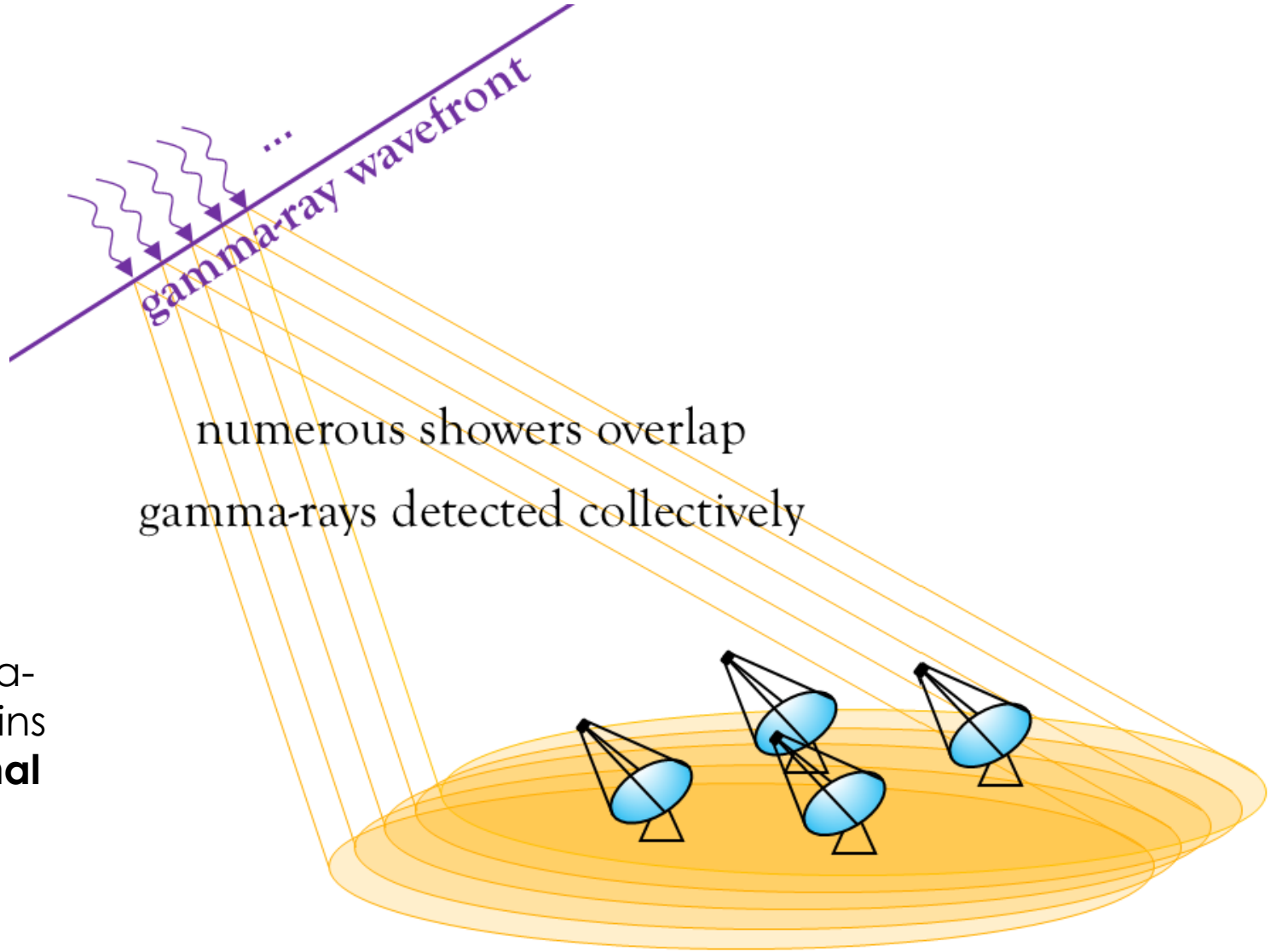


Signal: **burst of gamma rays**
Duration unknown
$\Delta t_{\mathbf{burst}} \lesssim \mathbf{10}\boldsymbol{\mu s}$ basically **unconstrained**

(Tanin, 2024)

USGRBs in IACTs

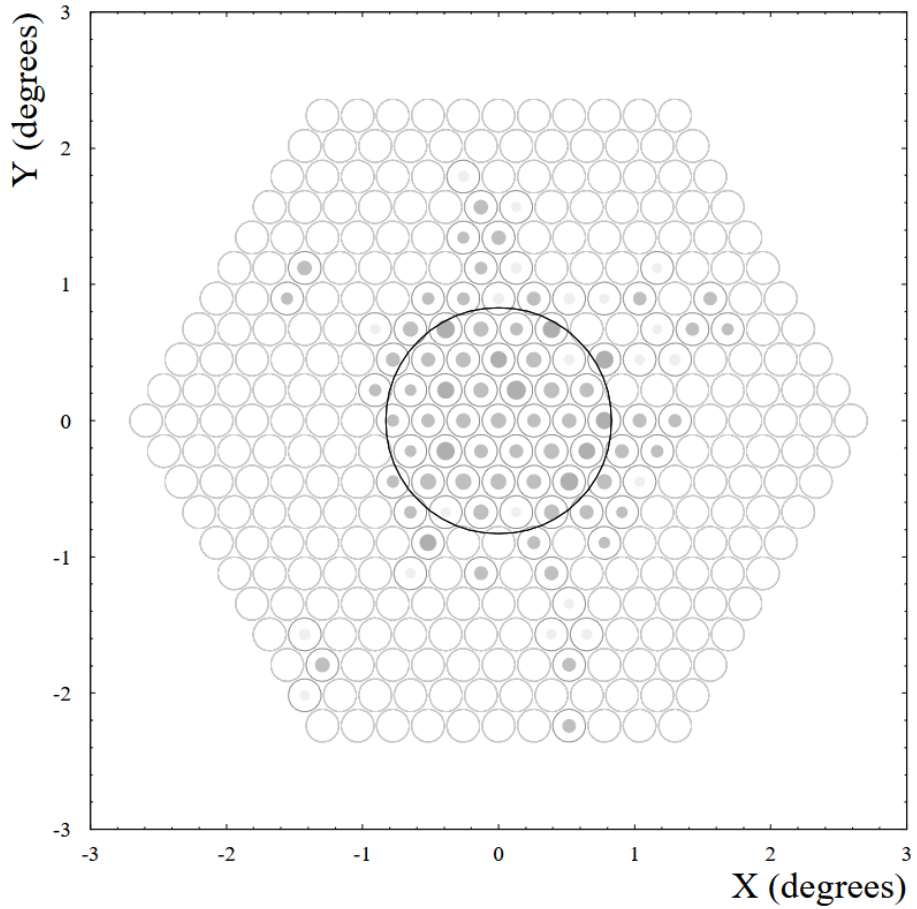




The region of parameter space for ultra-short gamma-ray bursts (USGRBs) remains effectively unprobed **since conventional analyses reject such signals.**

Ways of Identifying a Wavefront Event

(Krennrich+, 1999)



Previous searches with Whipple + VERITAS relied on several key difference between traditional air-showers and wavefronts.

Size of light pool

- Separating telescopes beyond the typical light pool radius of single showers and searching for coincidences (Porter+, 1979)

Shape of Image

- Due to the unique symmetric profile of the images compared to traditional ellipses the radius and eccentricity can be used to discriminate between traditional events and wavefronts (Krennrich+, 1999)

Duration of Events

- The typical event duration is >100 ns compared to the ~10 ns duration of a single shower (LeBohec+ 2005).

Previous searches were limited in duration and/or had higher backgrounds due to the telescope(s) configuration.

Basic Analysis Chain

Simulations

- Traditional gamma-ray showers are simulated with *CORSIKA* (1, 10, 100 GeV gamma rays)
- Fluence levels can be simulated from **stacking random subsets** of Cherenkov photon distributions

Threshold Determination

- Photons are then passed through optics and camera simulations (*GrOptics + CARE*)
- Effective fluence sensitivity is then determined for **various camera offsets (~5 degree)** and photon energies.

Characterization

- Triggered events are then parameterized with a standard moment analysis ("Hillas Parameters")
- **Self-similarity of parameters ("parallax") are then used as an initial discriminant for wavefront identification.**

Search and Candidate Validation

- Initial parallax based cuts are applied to the VERITAS processed archive to select candidate subsets.
- **Candidates can be further reduced with trace level verification of the time decomposed event images.**

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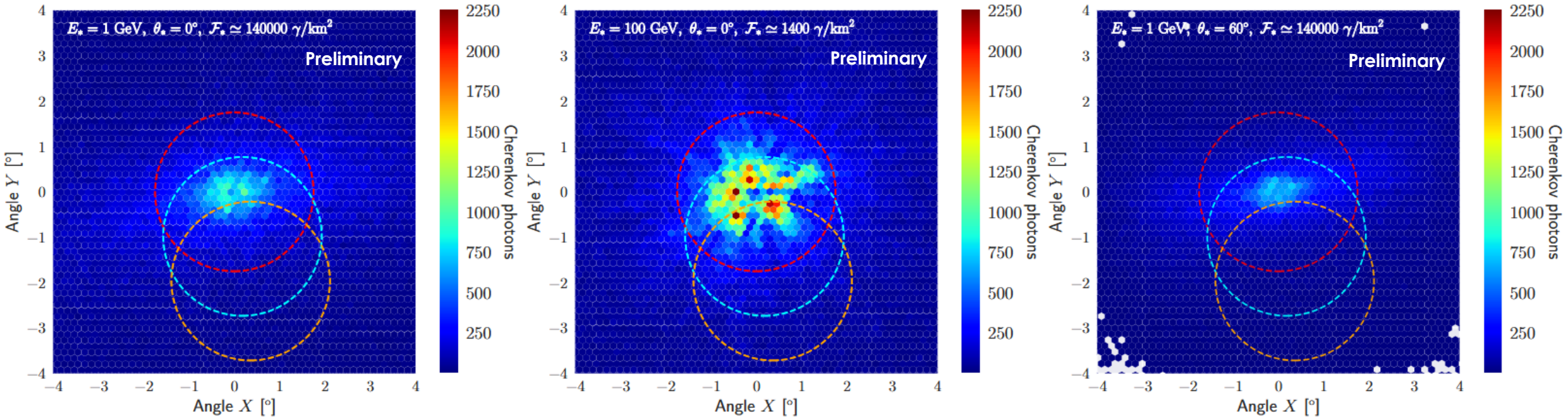

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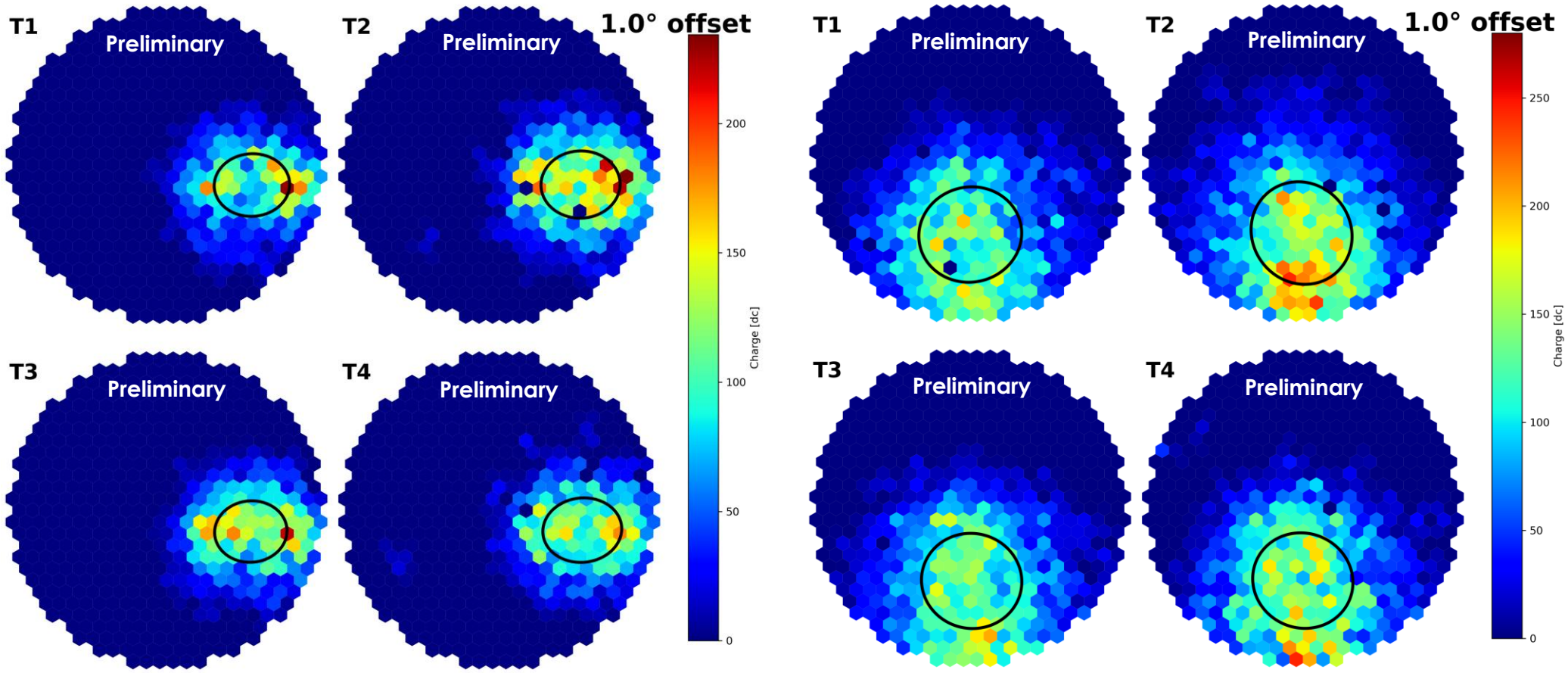
Rare Event Searches – Realistic Simulations

VERITAS Collaboration, in prep.



First modern shower simulations for wavefront events have been performed to realistically simulate USGRBs in VERITAS. Rates and acceptances have been calculated for all typical array configurations.
Search ongoing through ~20 years of events with search optimization based on simulations.

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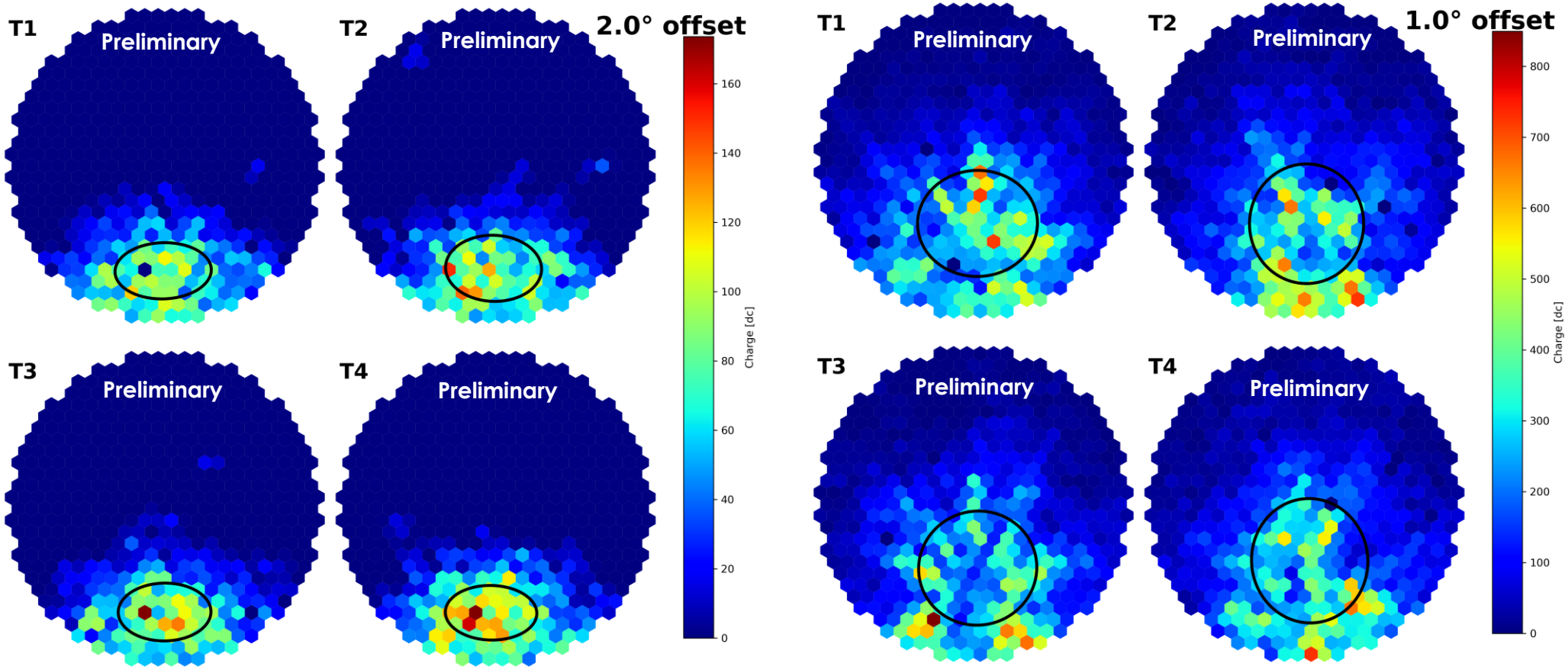

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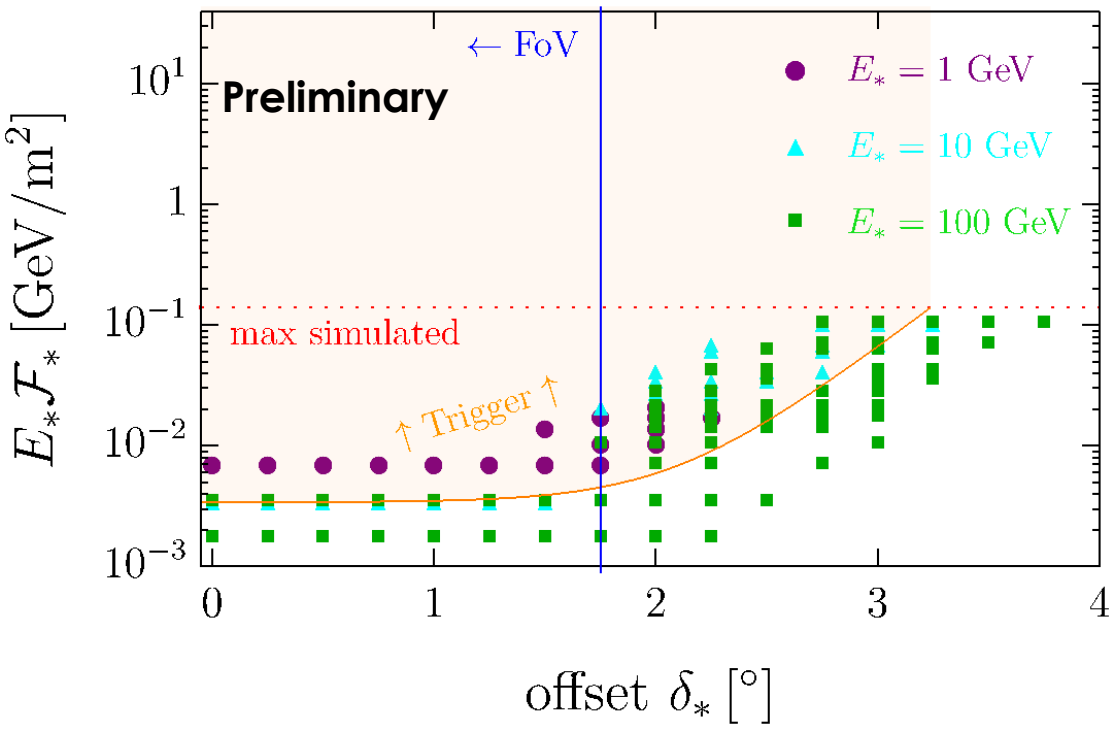
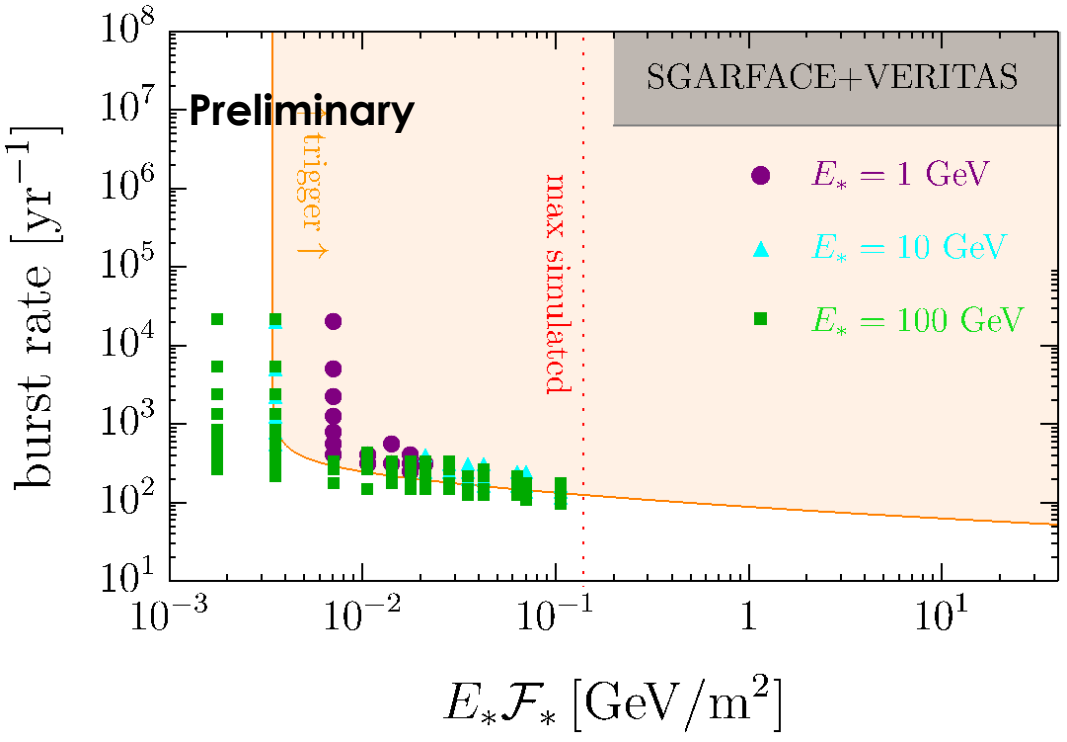
Projected Sensitivity

VERITAS Collaboration, in prep.

VERITAS's offset range



VERITAS's reach



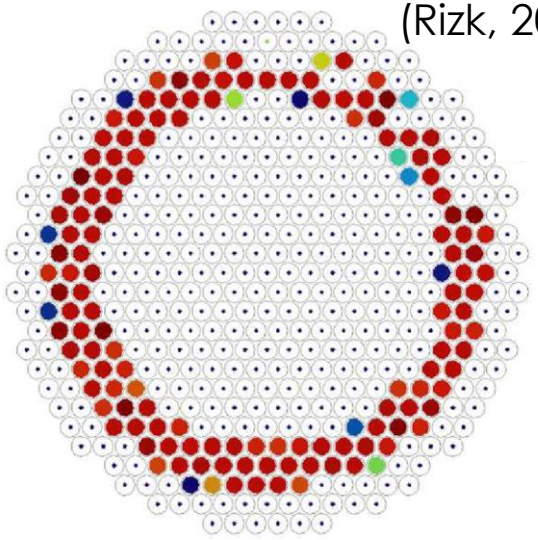
Simulation are processed through **a standard VERITAS gamma-ray trigger procedure** to estimate the reach and sensitivity of VERITAS to various configurations of shower parameters and estimate the burst rate sensitivity.

Future of Rare Event Searches With VERITAS

Magnetic Monopoles

(Rizk, 2025)

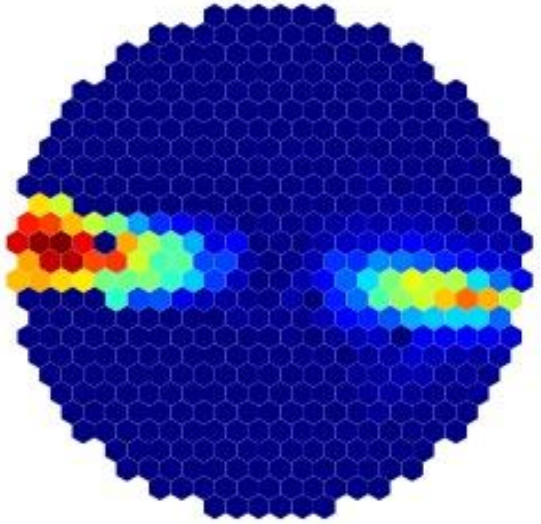
Simulation



Bright "muon ring" like signals.

Double Events

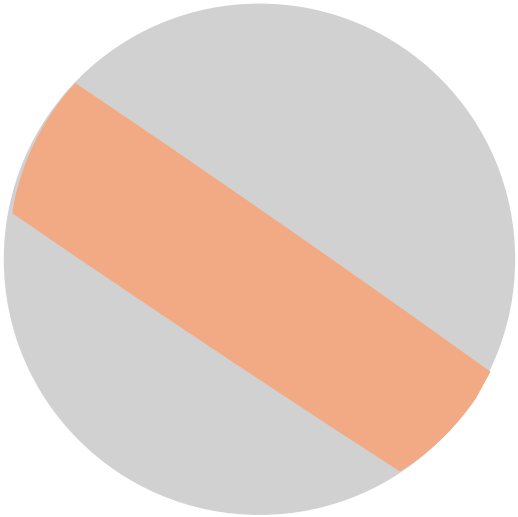
Data



Air showers with double event

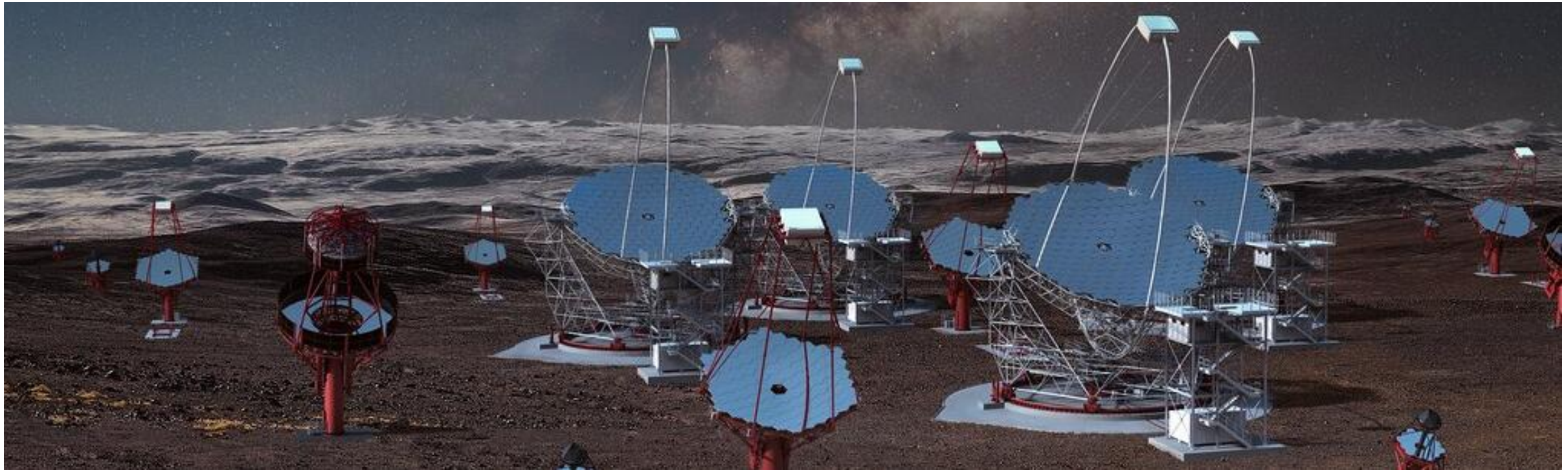
Quark Nuggets

Sketch



Strip like showers

Prospects for Future IACTs



Next generation IACTs are currently under construction with larger effective areas and number of instruments.

CTAO, LACT, ASTRI, and PANOSETI are all expected to be partially or fully operational by ~2026-2028.

But they do not have the archive of the current generation -> critical for rare events!

Image Credit: CTAO

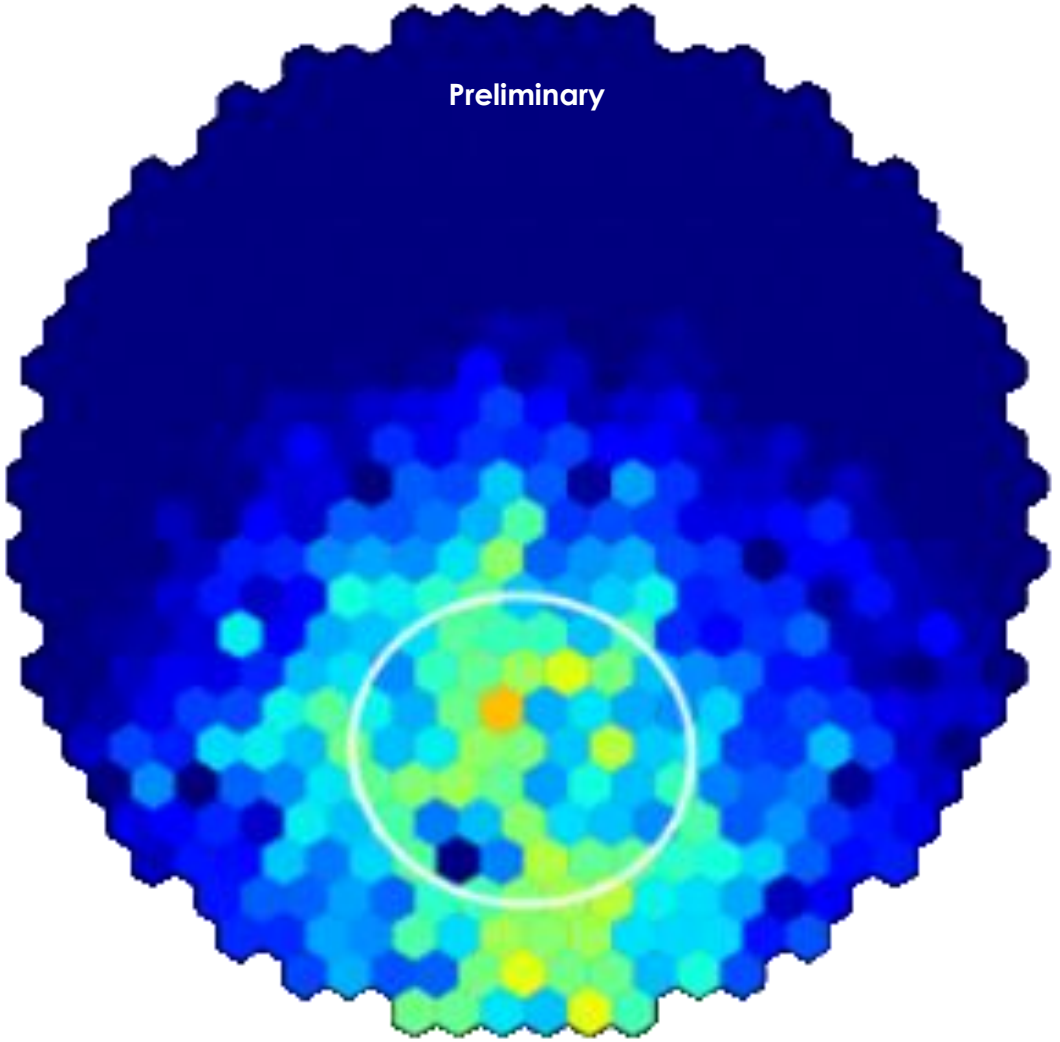
VERITAS USGRBs – Summary

IACTs are sensitive to a new potential class of transients called Ultra-Short Gamma-ray Bursts

Realistic shower simulations from *CORISKA* processed through a VERITAS pipeline have allowed for accurate estimations of the VERITAS sensitivity to events from 1 GeV – 100 GeV

VERITAS's default gamma-ray trigger will record USGRB showers down to fluences of 10^{-3} GeV/m^2

Current search through the VERITAS archival data for these candidates is ongoing.



Questions?

Contact:
mwl2145@columbia.edu