Galactic Center Project with CTA-LST-1

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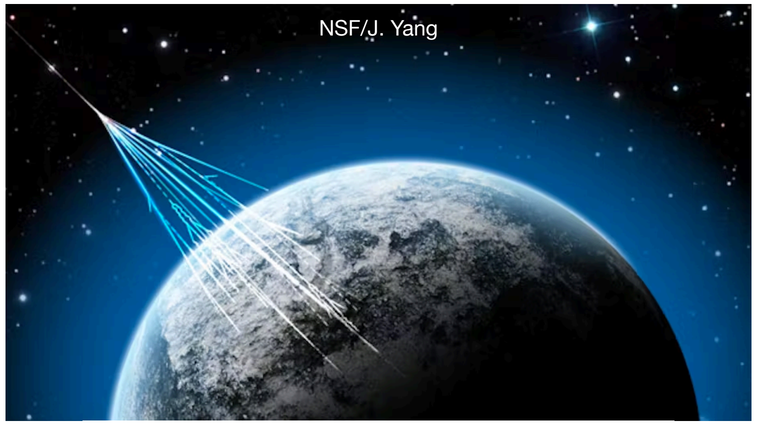
Introduction

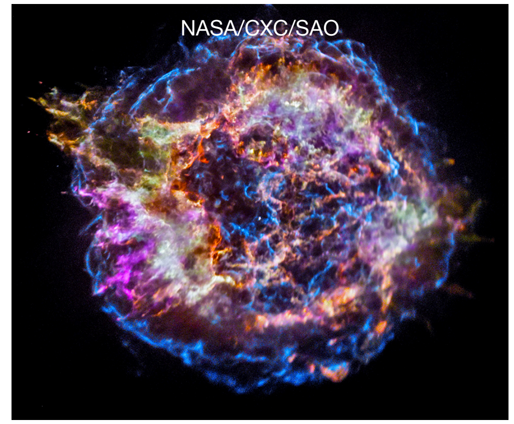
CTA-LST-1


CTA-LST-1
CTA-LST-1 @ La Palma, Spain

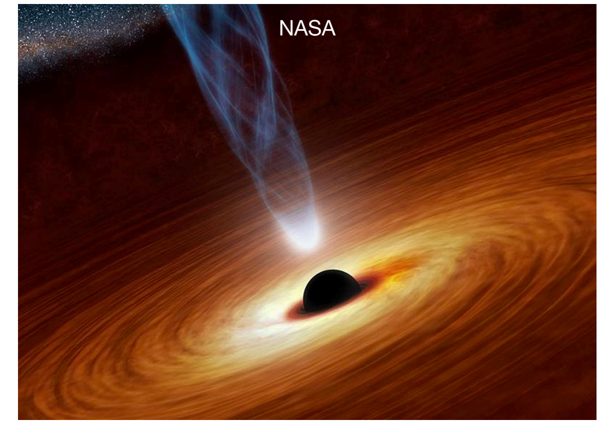
Gamma Ray Astronomy & Astrophysics



Origin of Cosmic Rays

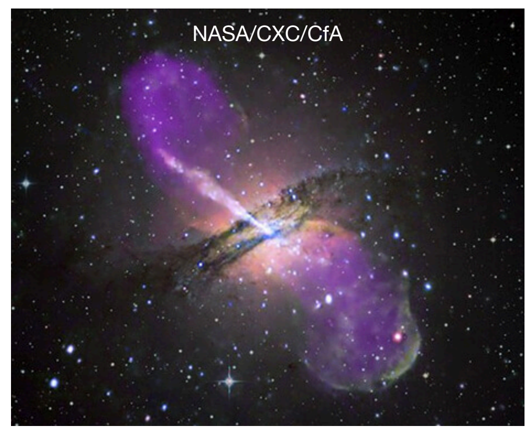


Supernova Remnant

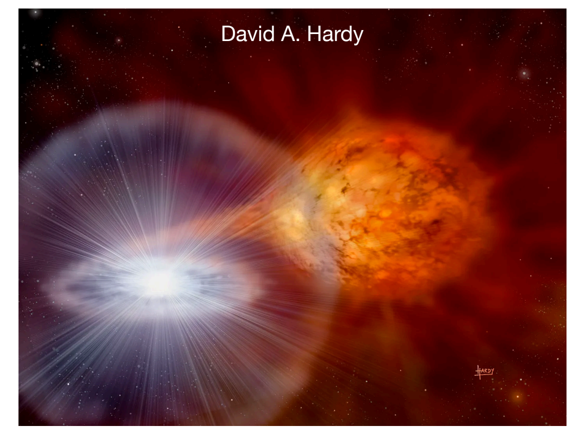


Supermassive Black Hole

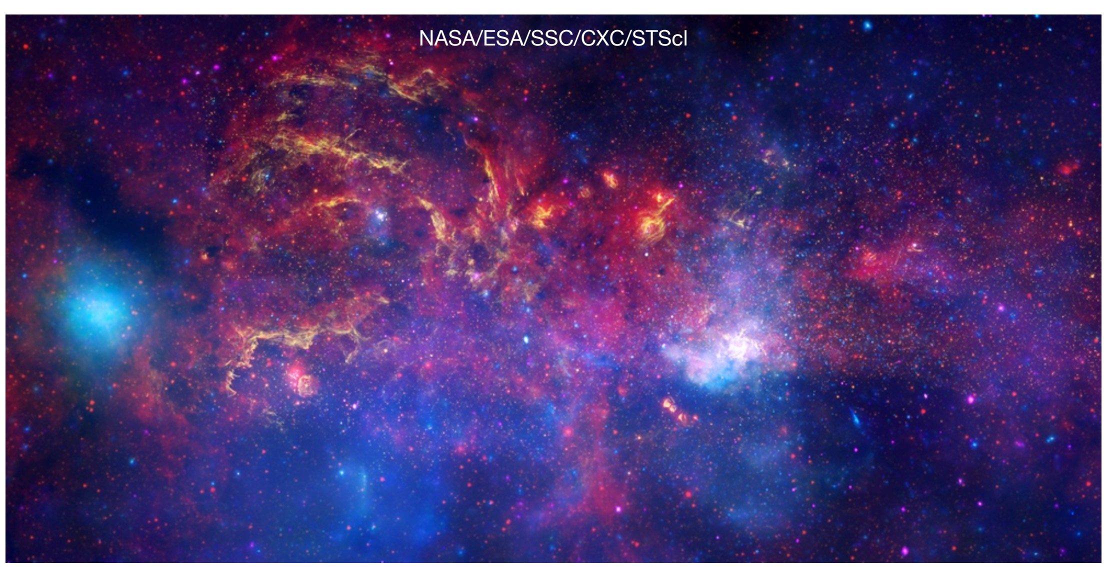
Gamma Ray Burst



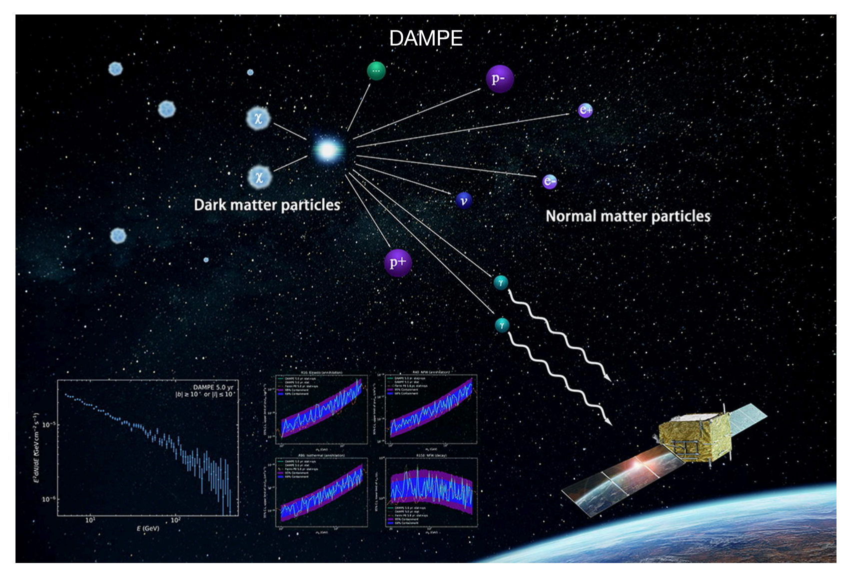
Active Galactic Nuclei



Binary / Nova

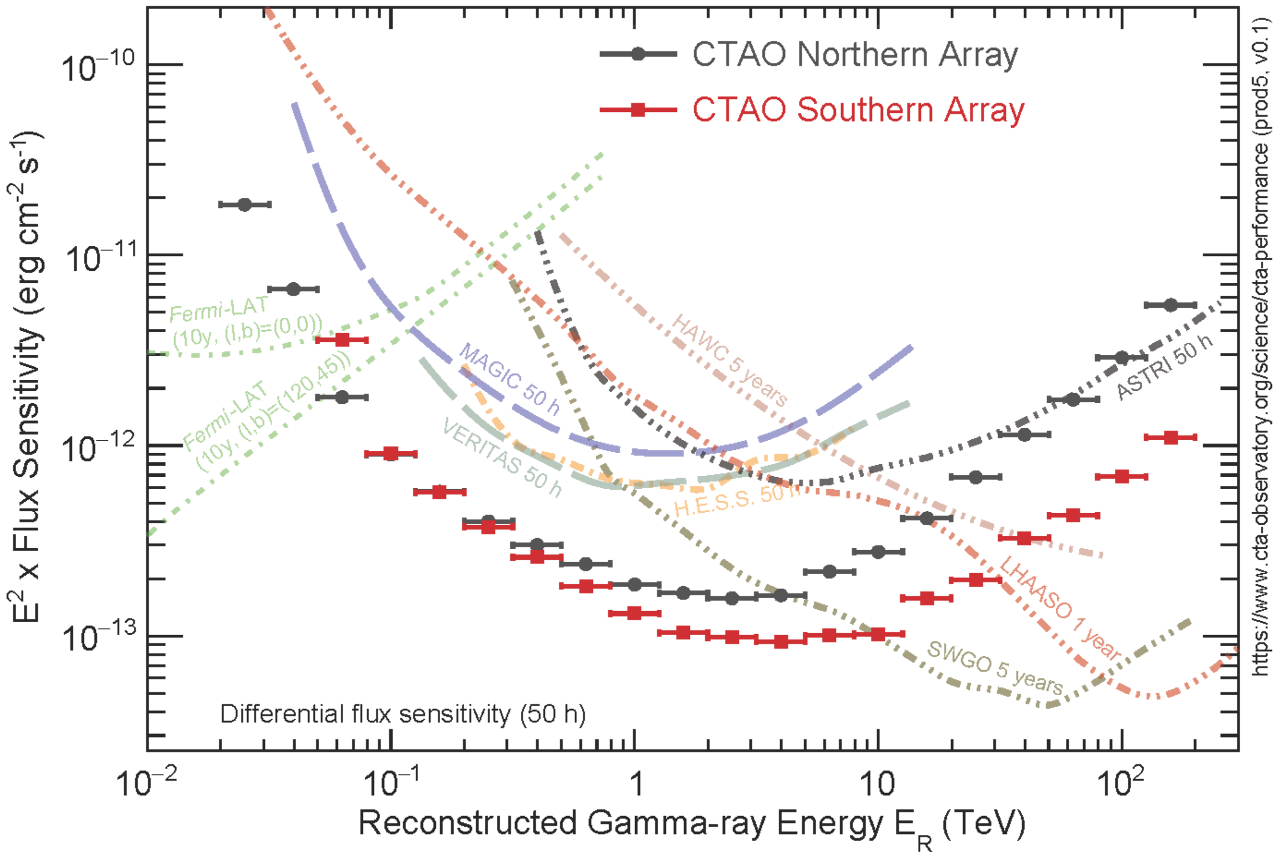


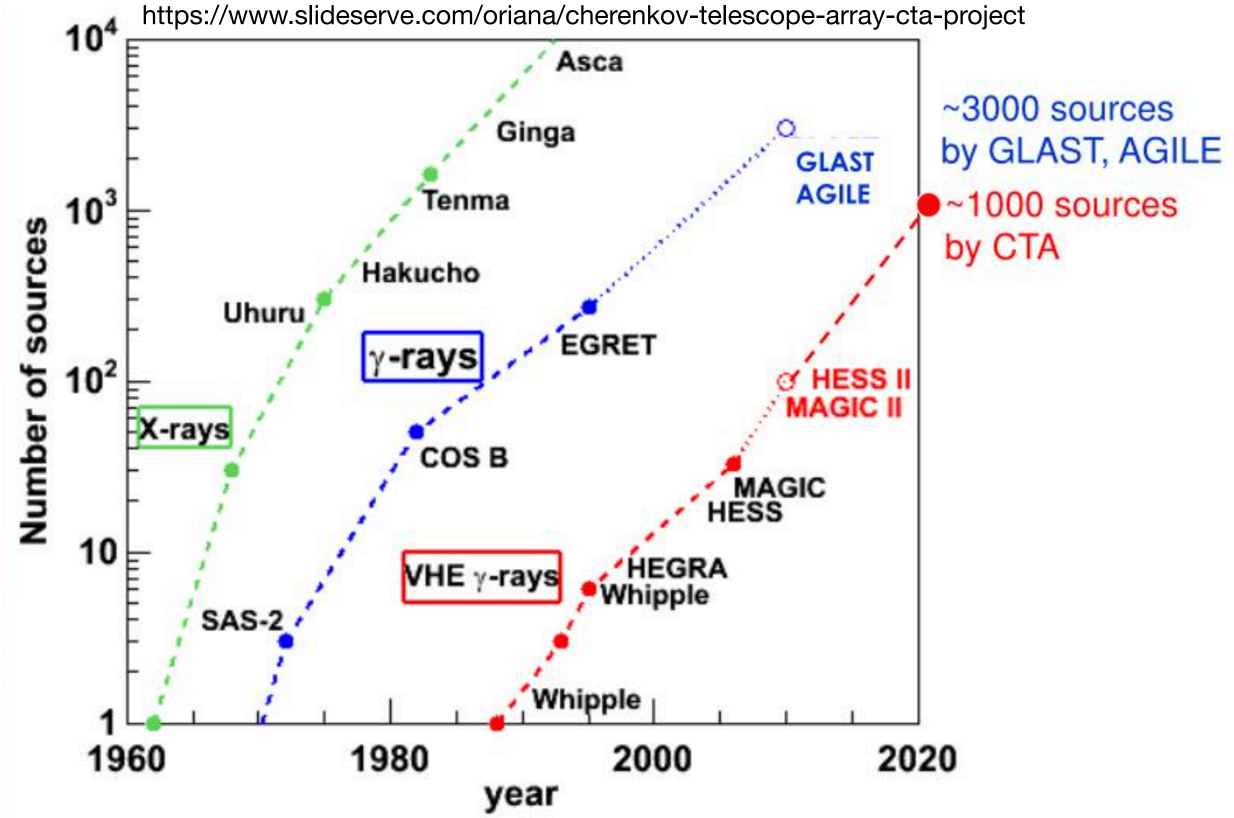
Galactic Center



Dark Matter

Cherenkov Telescope Array (CTA) is the next generation of ground-based very-high-energy gamma-ray observatory.

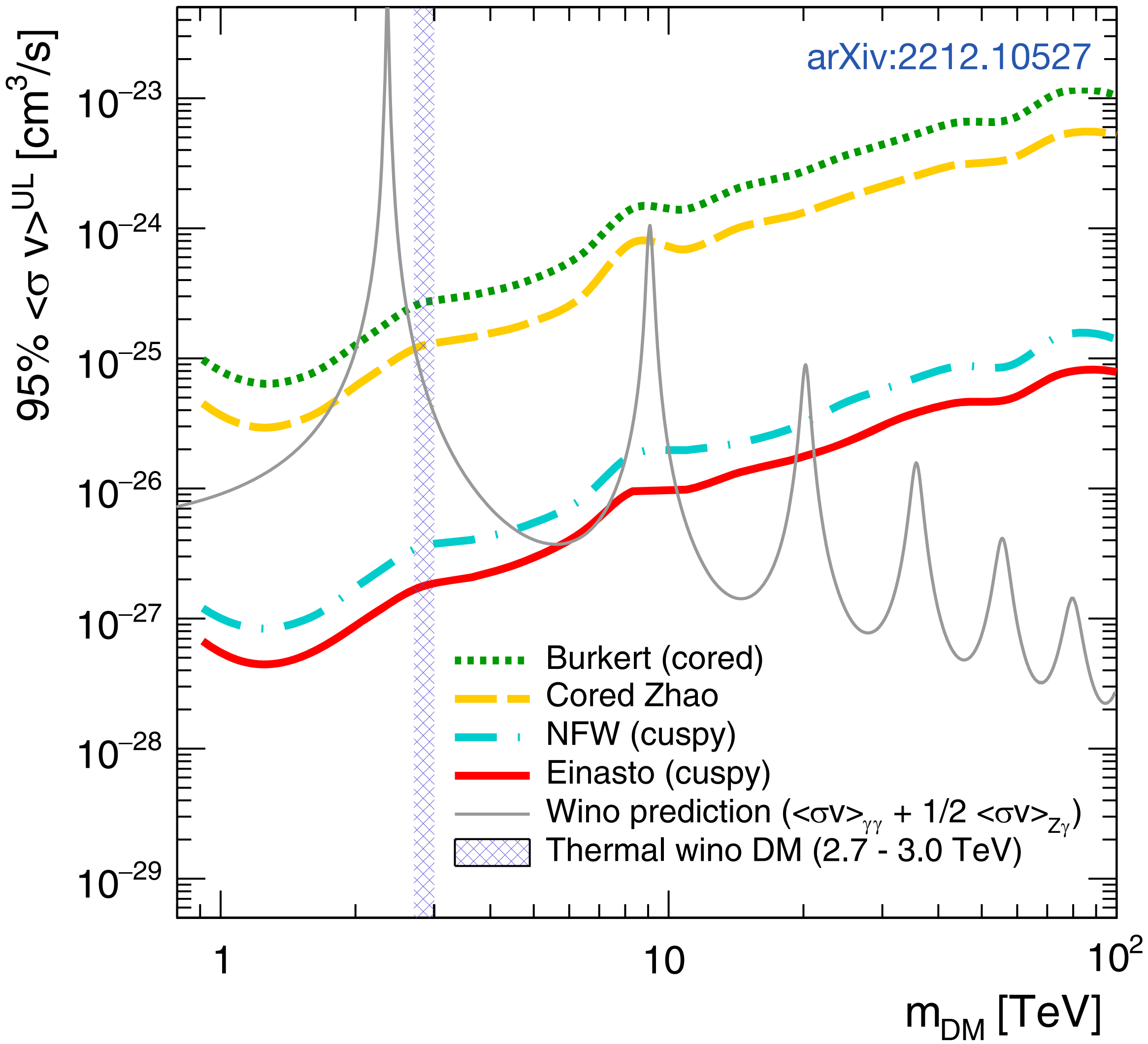


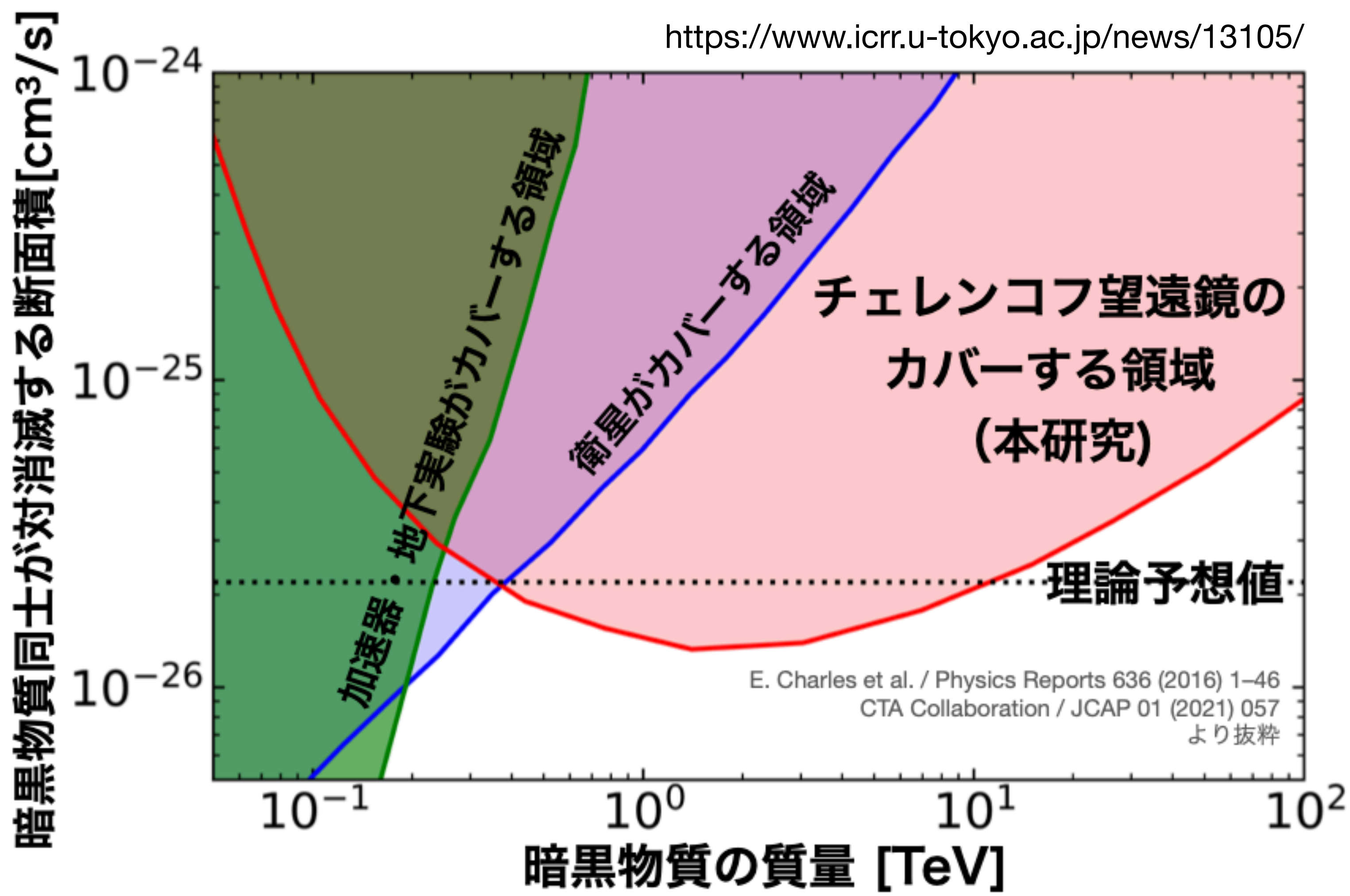


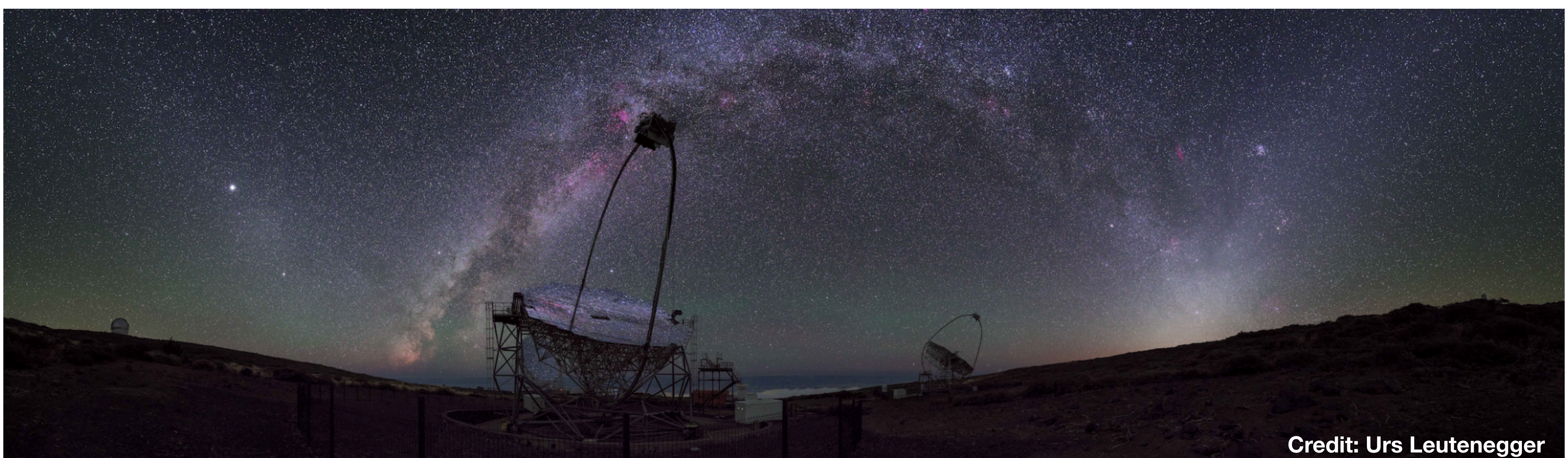
Rendering Image of CTA-North

Recent Hot Topic

Wino Constraint by MAGIC Galactic Center Observations



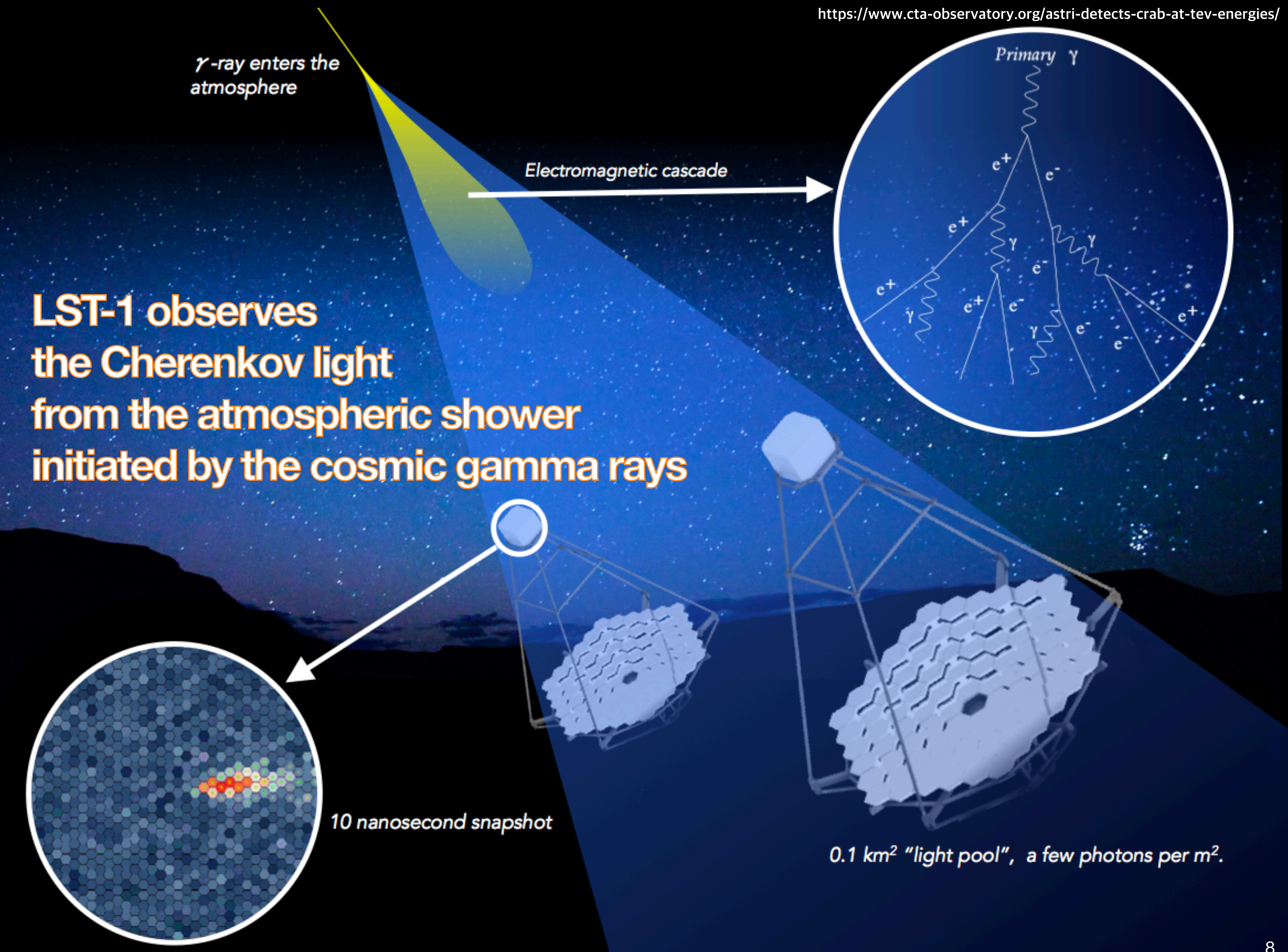




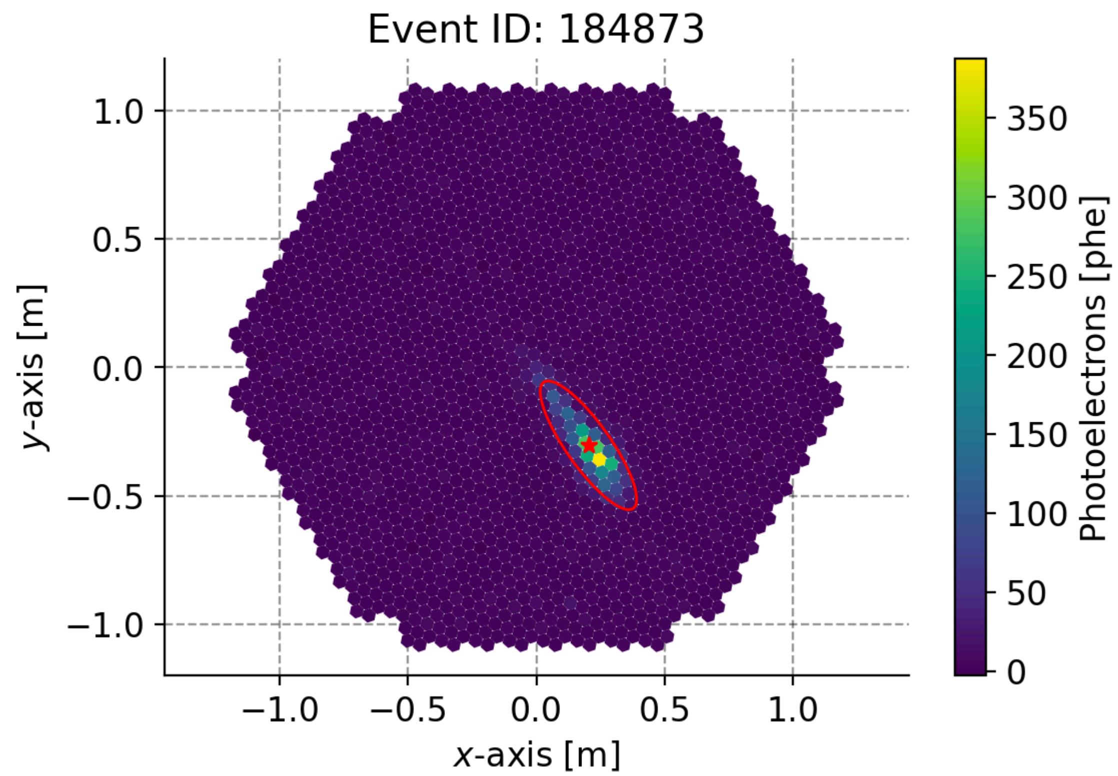
Research (1)

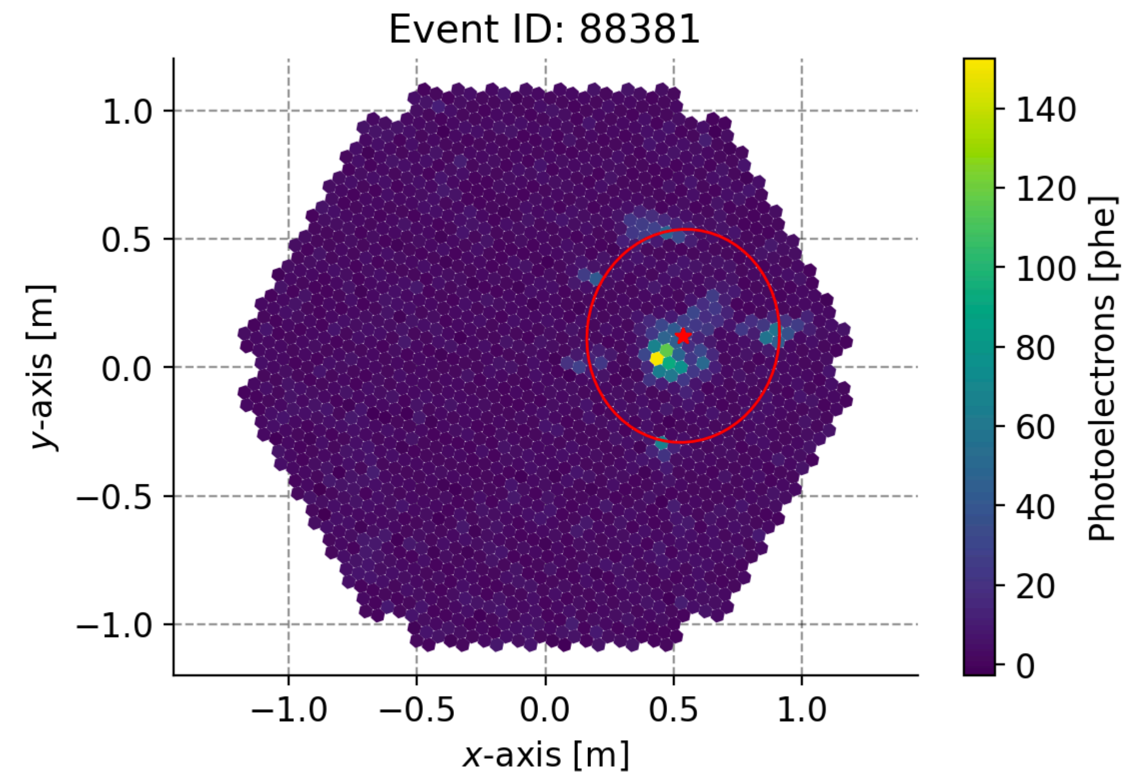
LST-1 Performance at the Large Zd

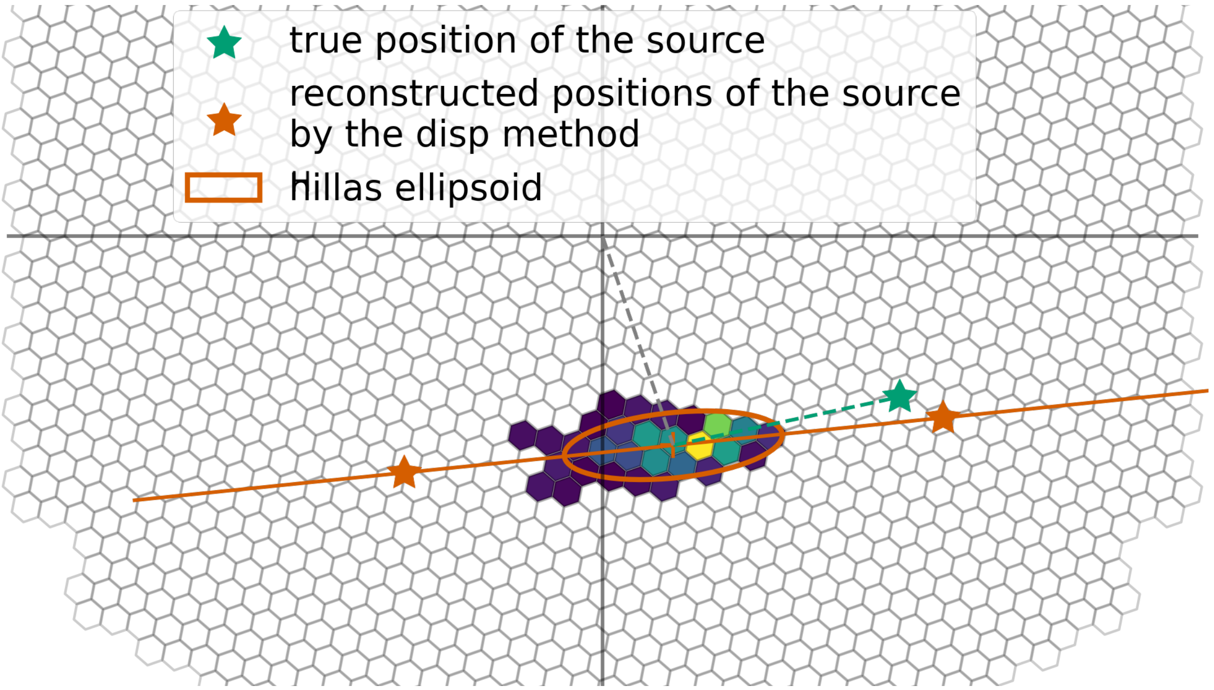
https://www.cta-observatory.org/astri-detects-crab-at-tev-energies/

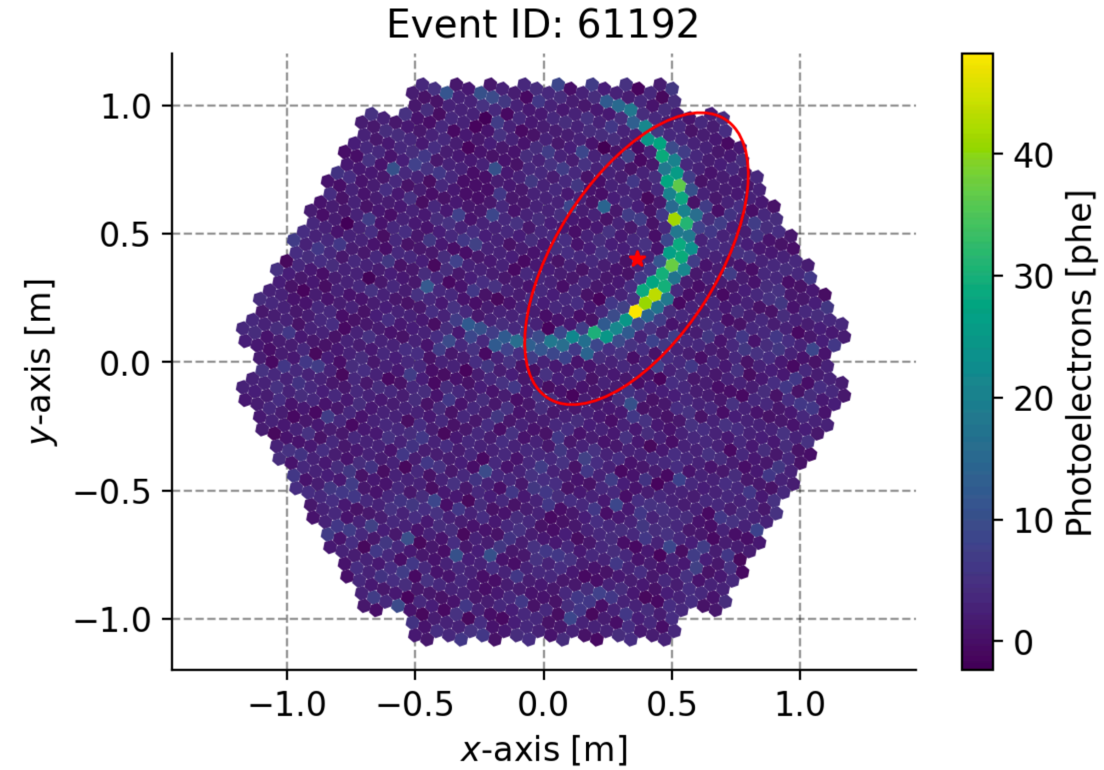


Imaging Atmospheric Cherenkov telescope (IACT) uses an "image" to reconstruct the primary particles.



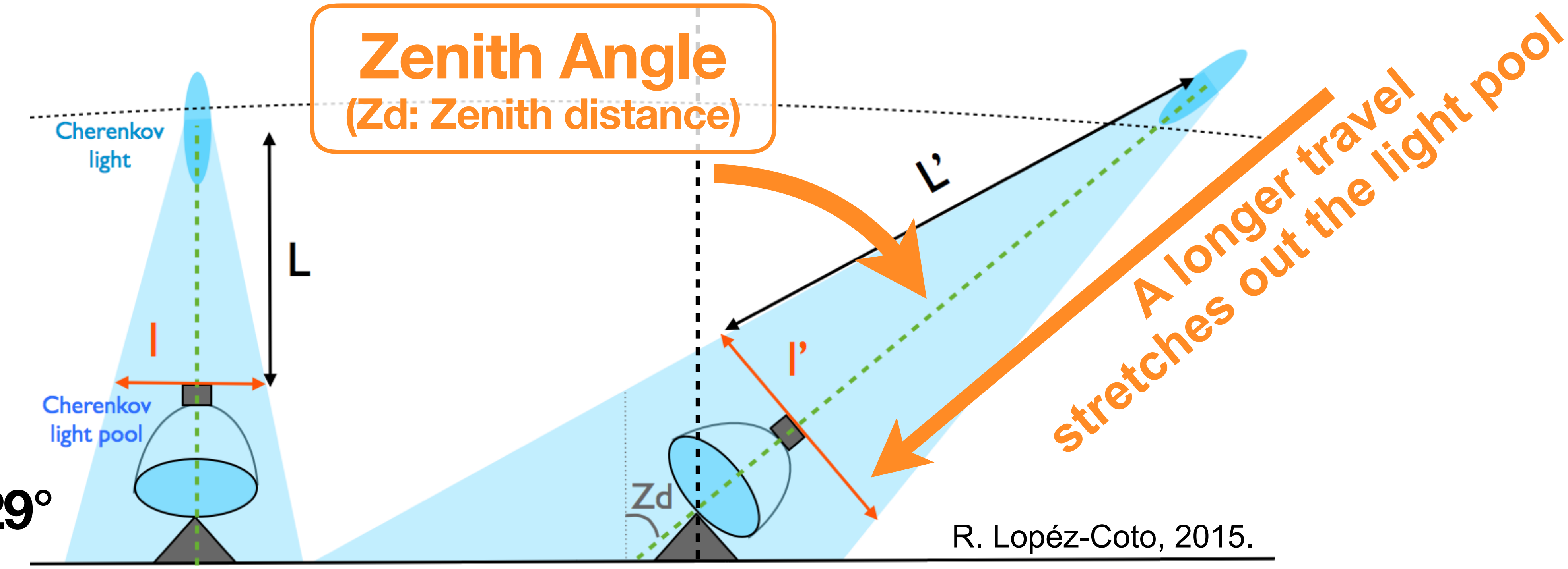


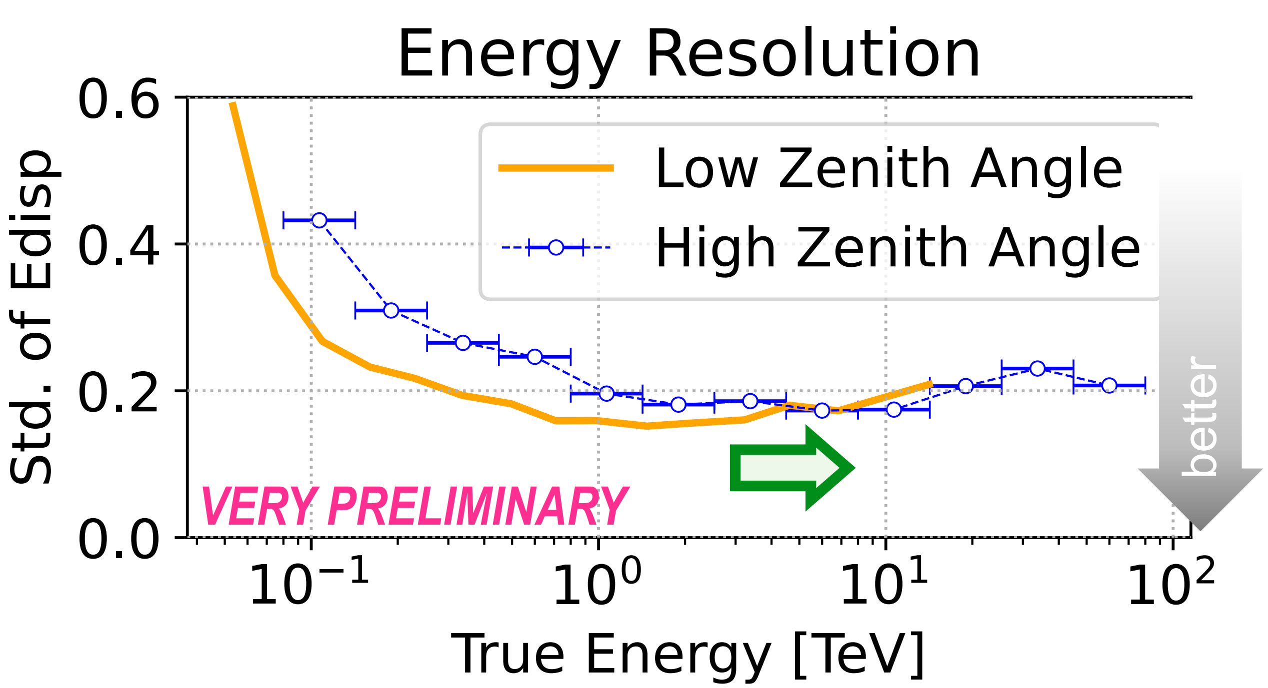


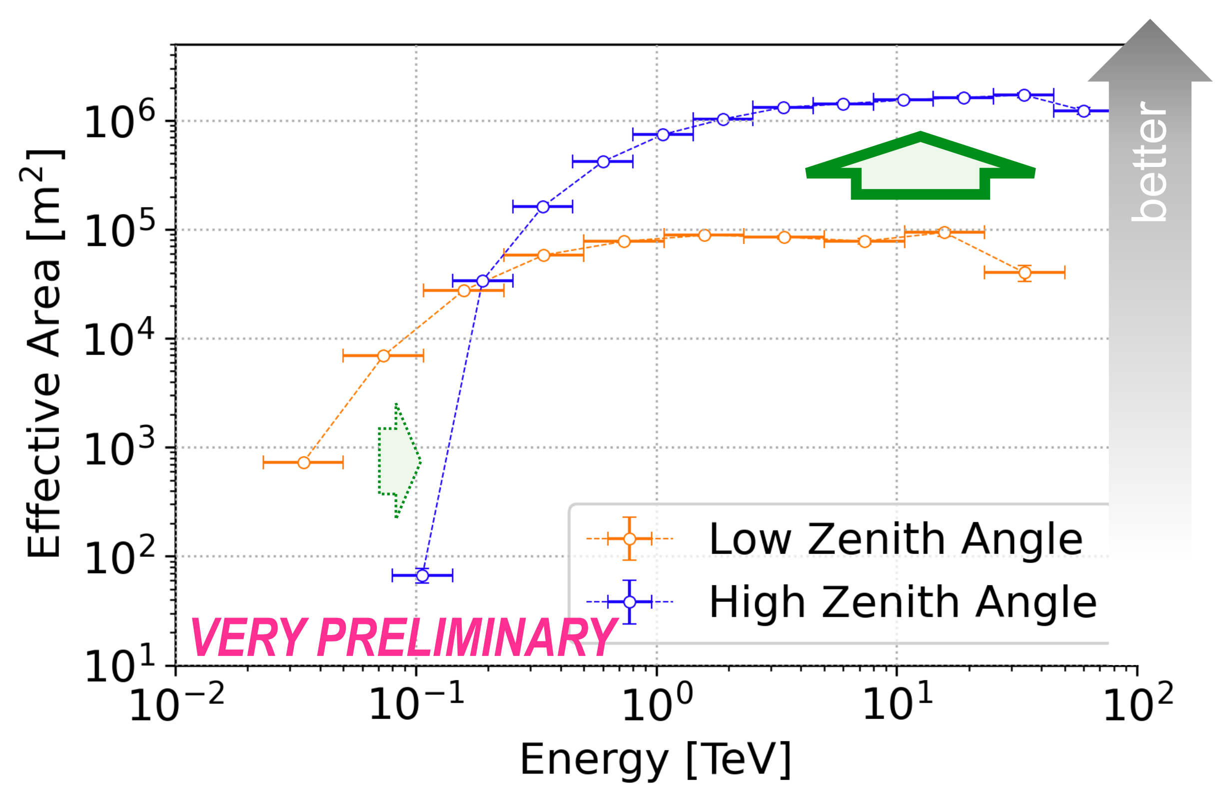


Large-zenith-angle observations (55-70 deg) enlarge the effective area at the high energies.

- **LST-1: 28°N**
- **Gal-Cent: Dec -29°**

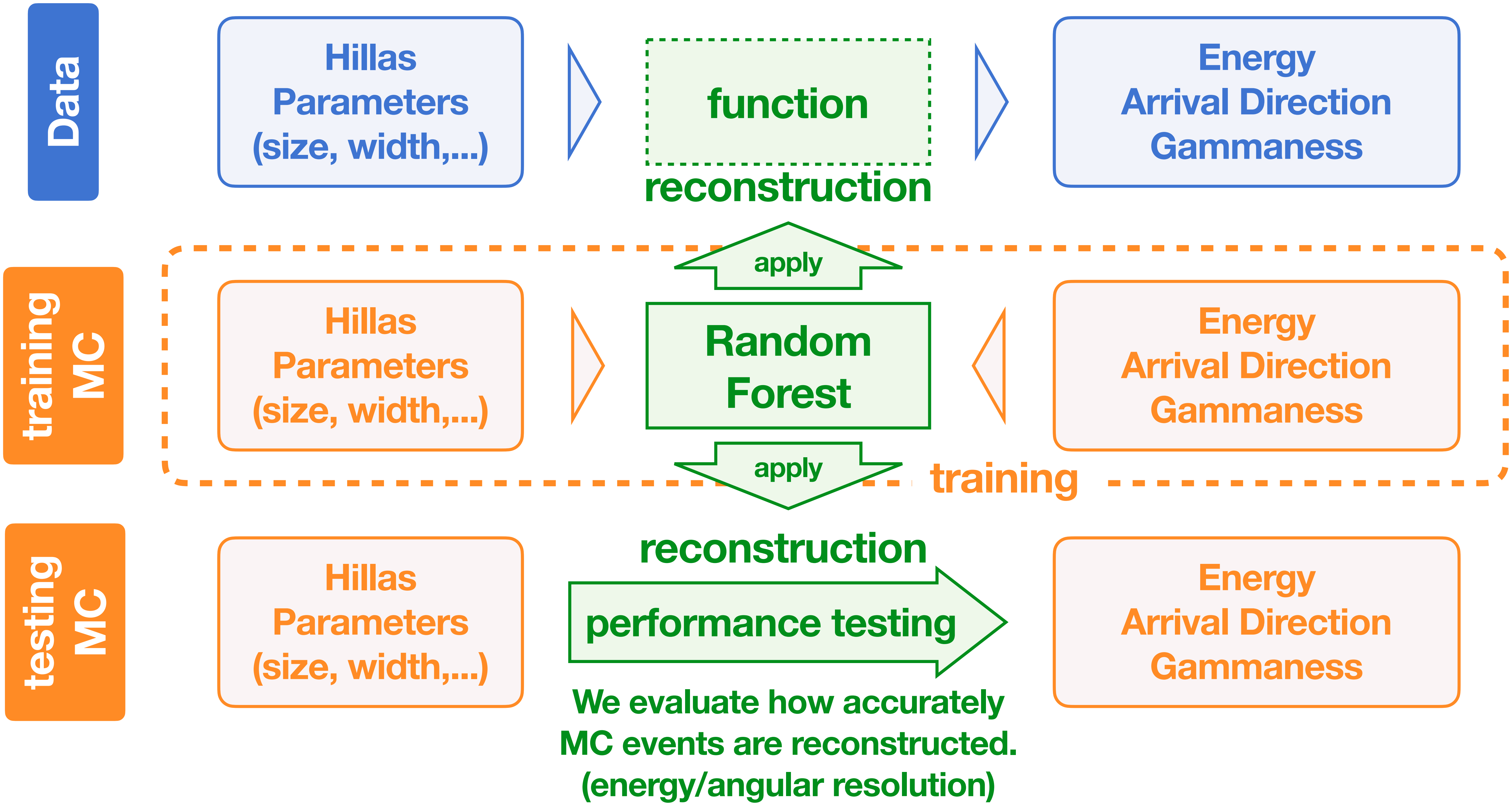






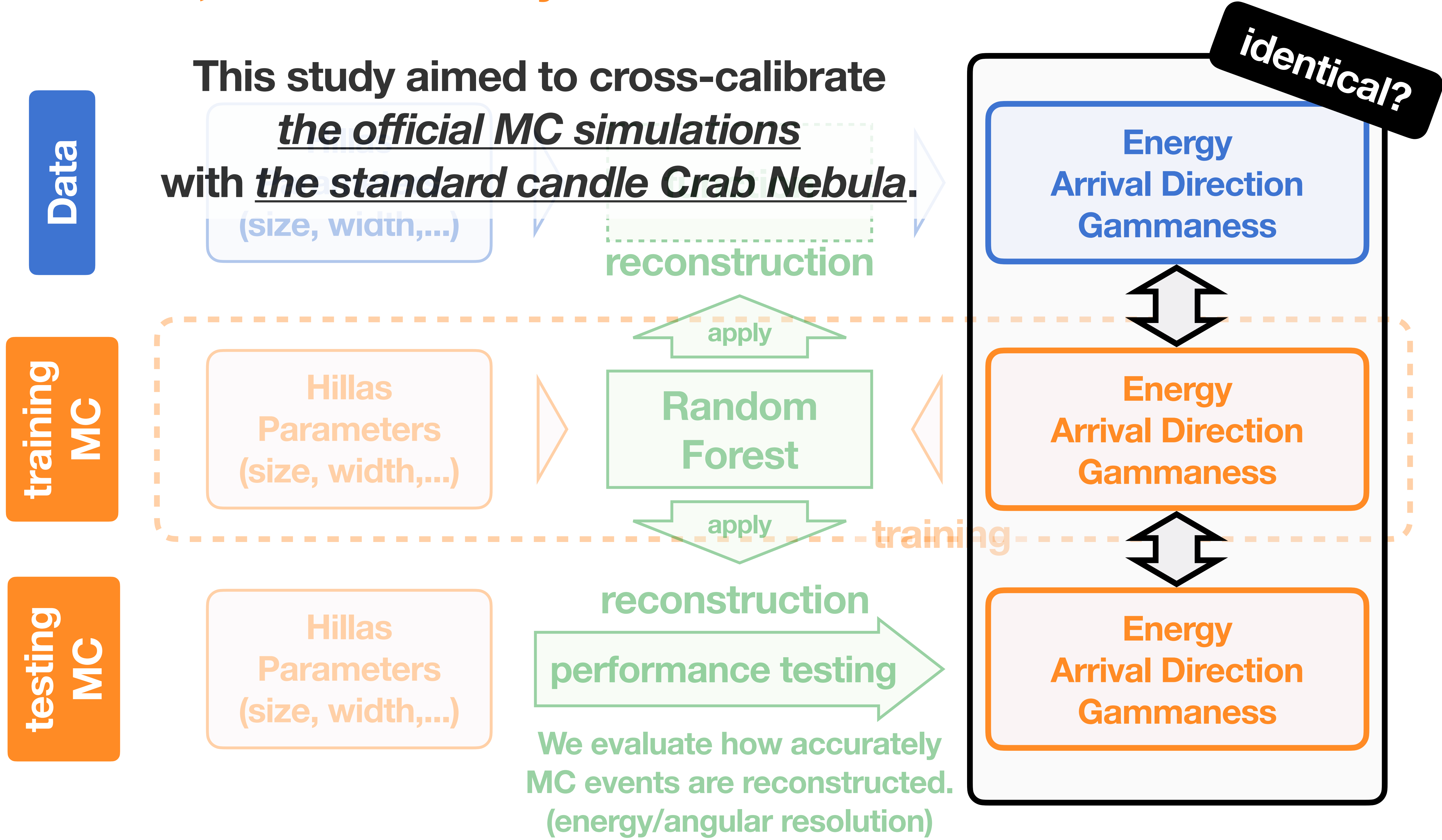
Different analysis results included. (cf. Lopéz-Coto, ICRC2021)

The IACT analysis entirely depends on the MC simulation. However, we cannot carry out a beam calibration!!



The IACT analysis entirely depends on the MC simulation. However, we cannot carry out a beam calibration!!

This study aimed to cross-calibrate *the official MC simulations* with *the standard candle Crab Nebula*.

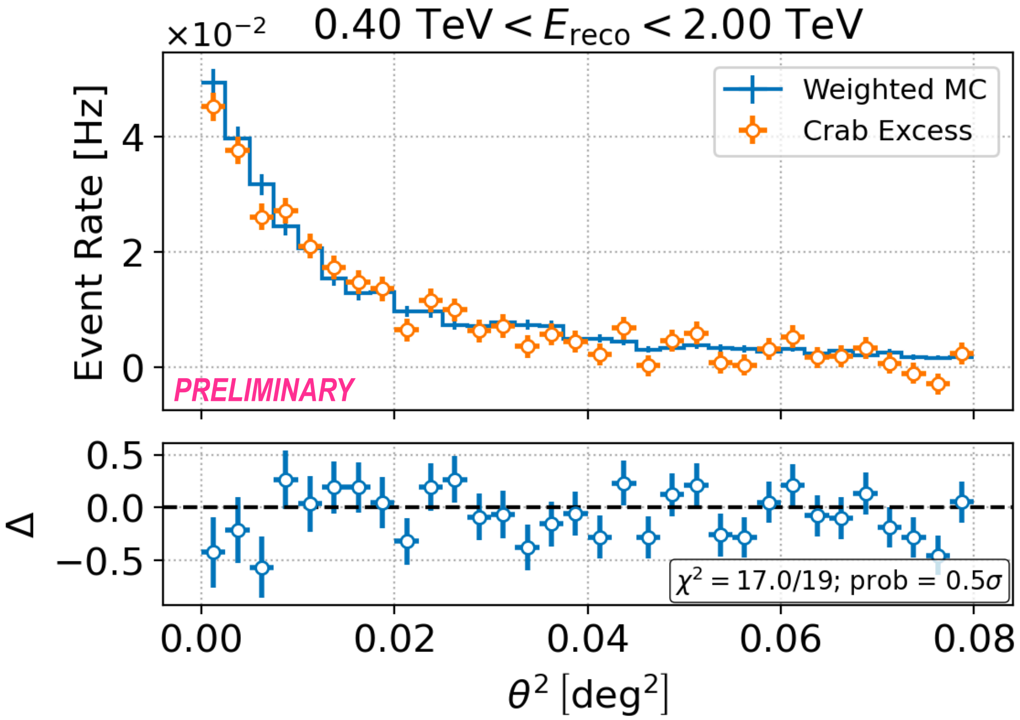


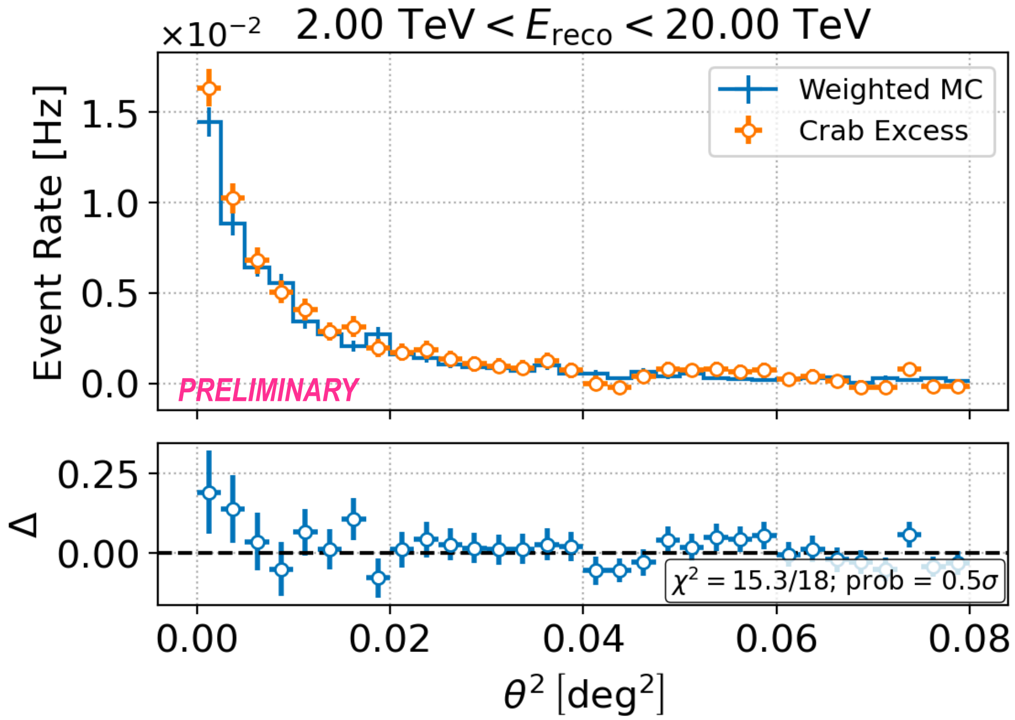
The squared-theta plots basically show a reasonable MC/Data agreement.

Low Energy

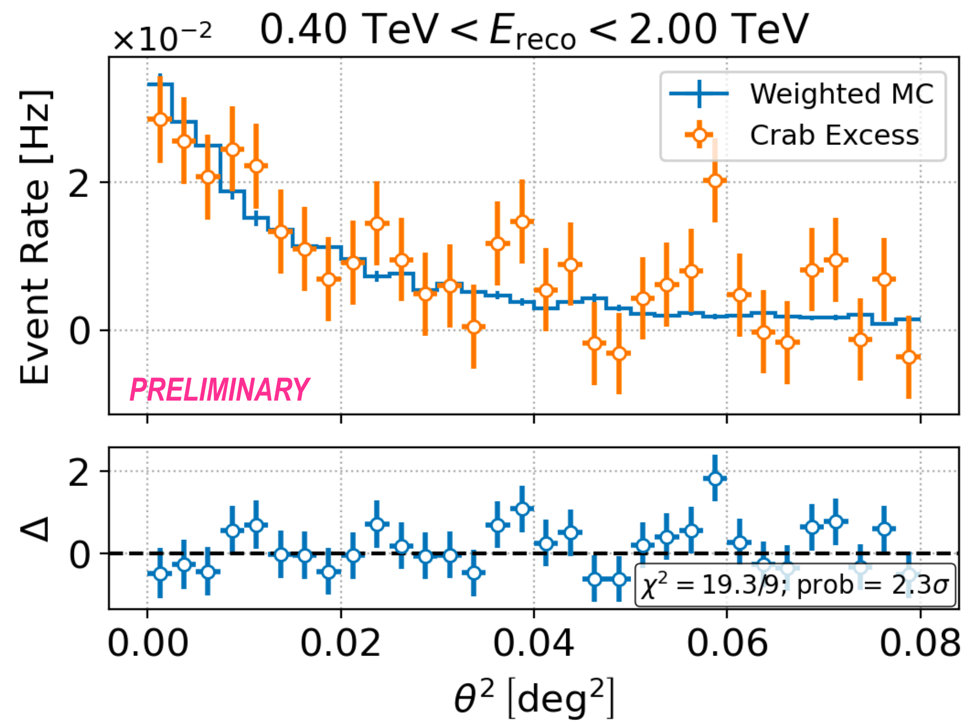
High Energy

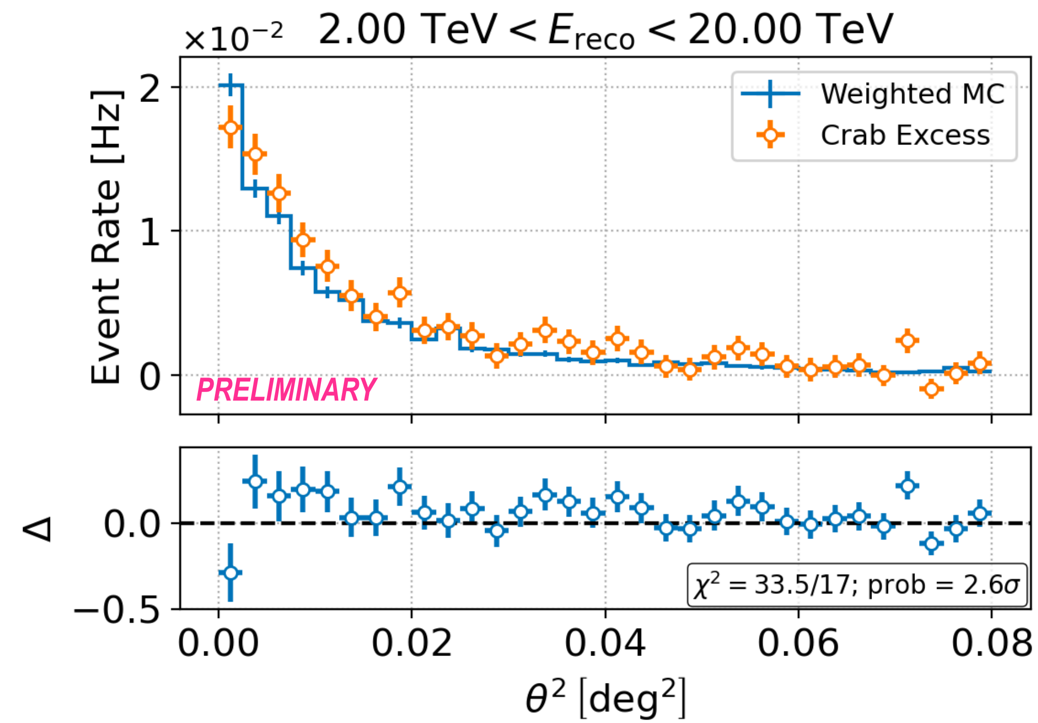
Zd ~ 59 deg





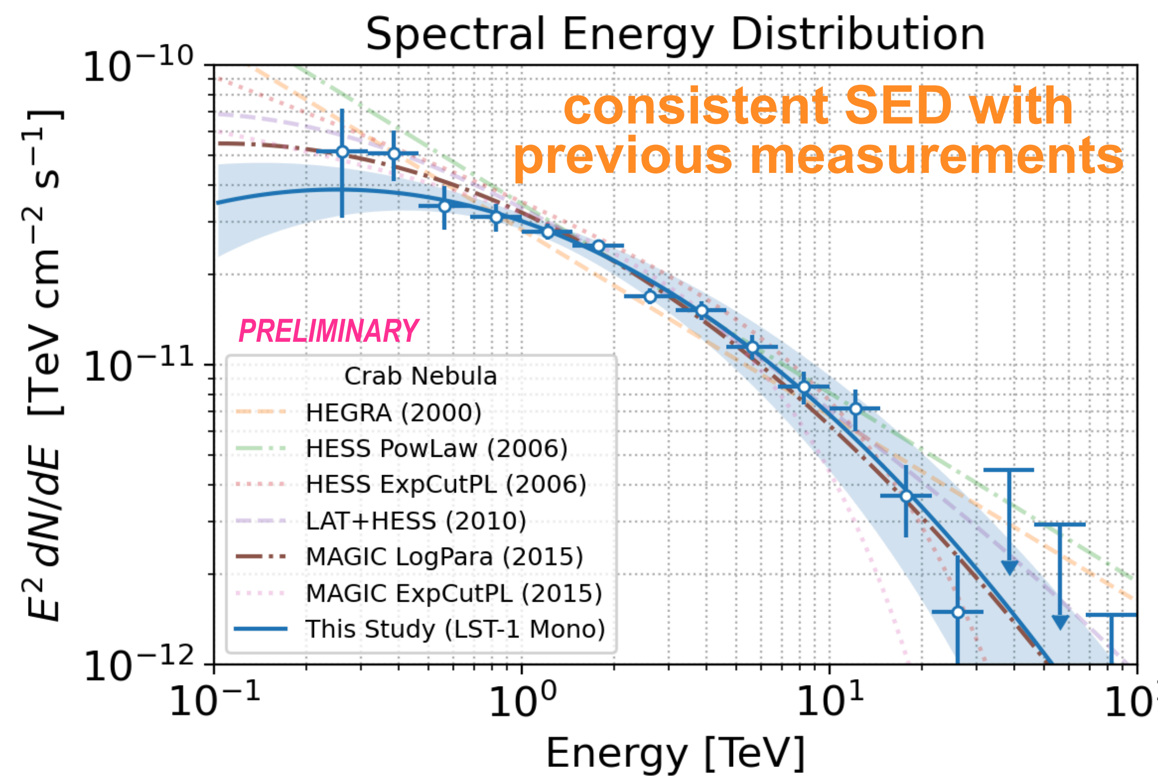
Zd ~ 66 deg

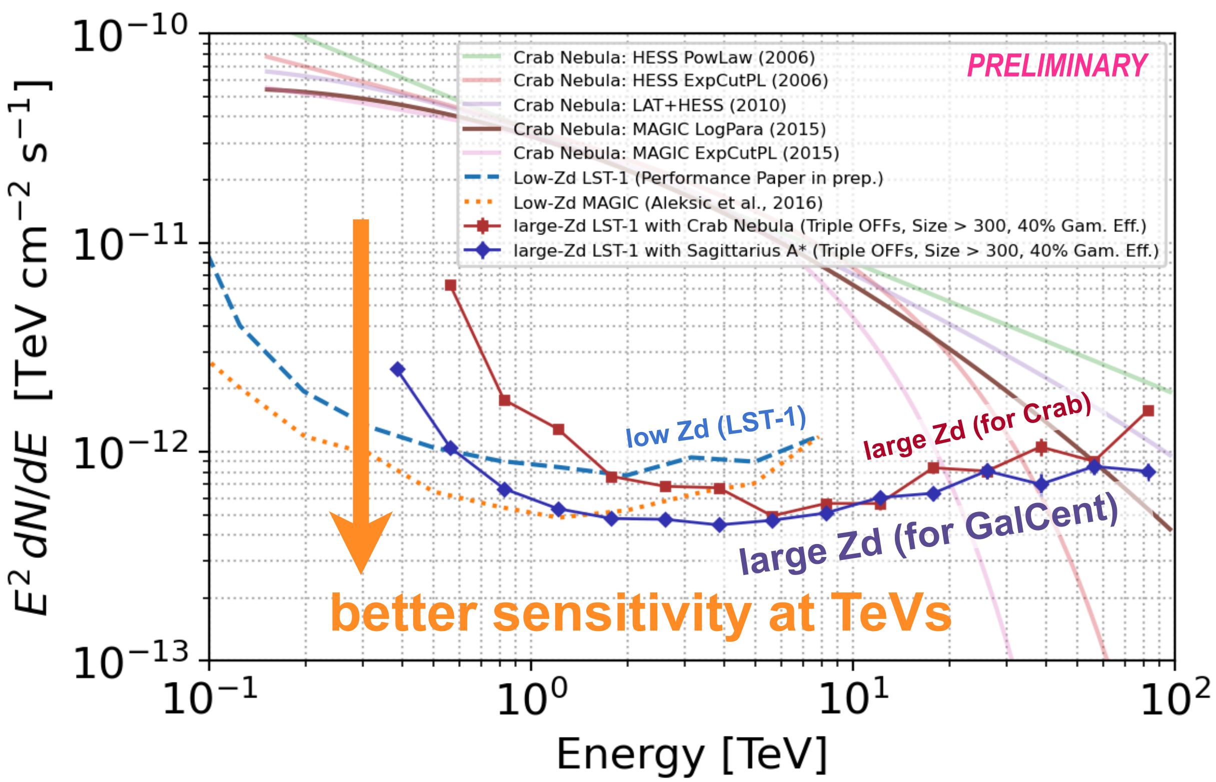


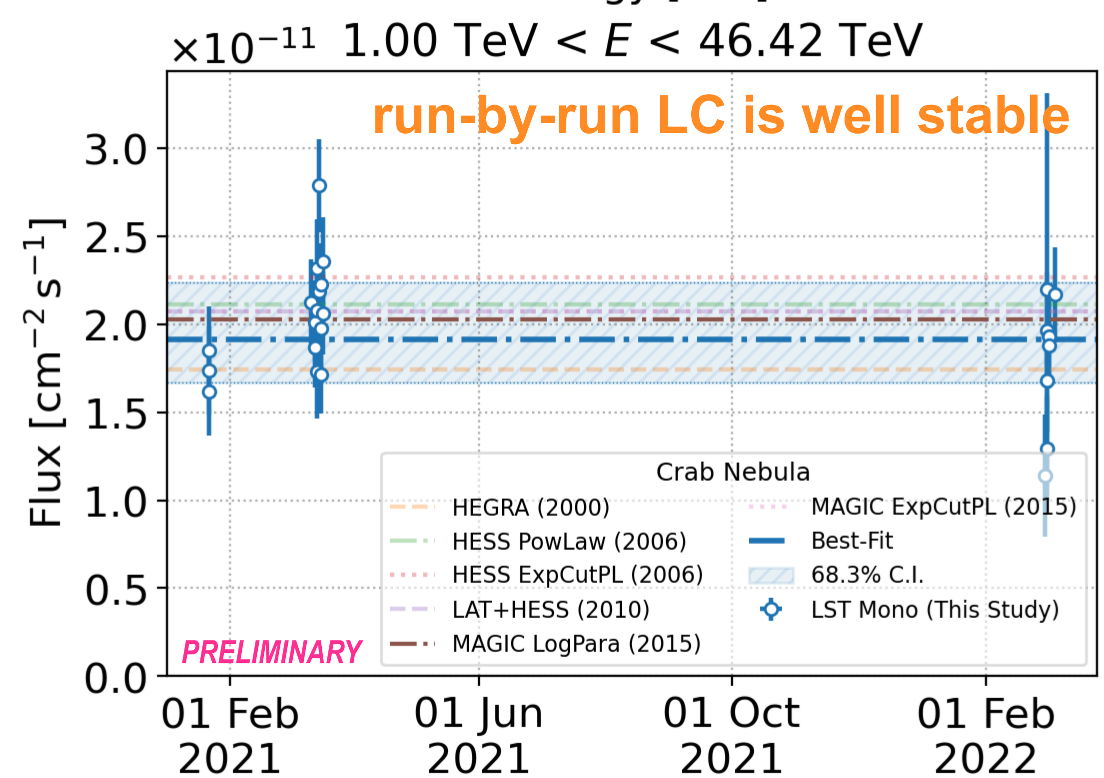


SED and LC of the *Crab Nebula* show stable data-taking and effective analysis in LST-1 even at high Zd.

- 5.9 hours good-quality Crab Nebula data at the large zenith angles (55-70 deg)
- trained pointing-by-pointing RFs, applied them for run by run.
- size > 100 phe, leakage < 0.2, 80%-efficiency gammaness, theta < 0.1 deg
- Log-parabola SED fitted above 1 TeV







Research (2)

Galactic Center

We required the following observation-quality criteria to select the Gal-cent data.

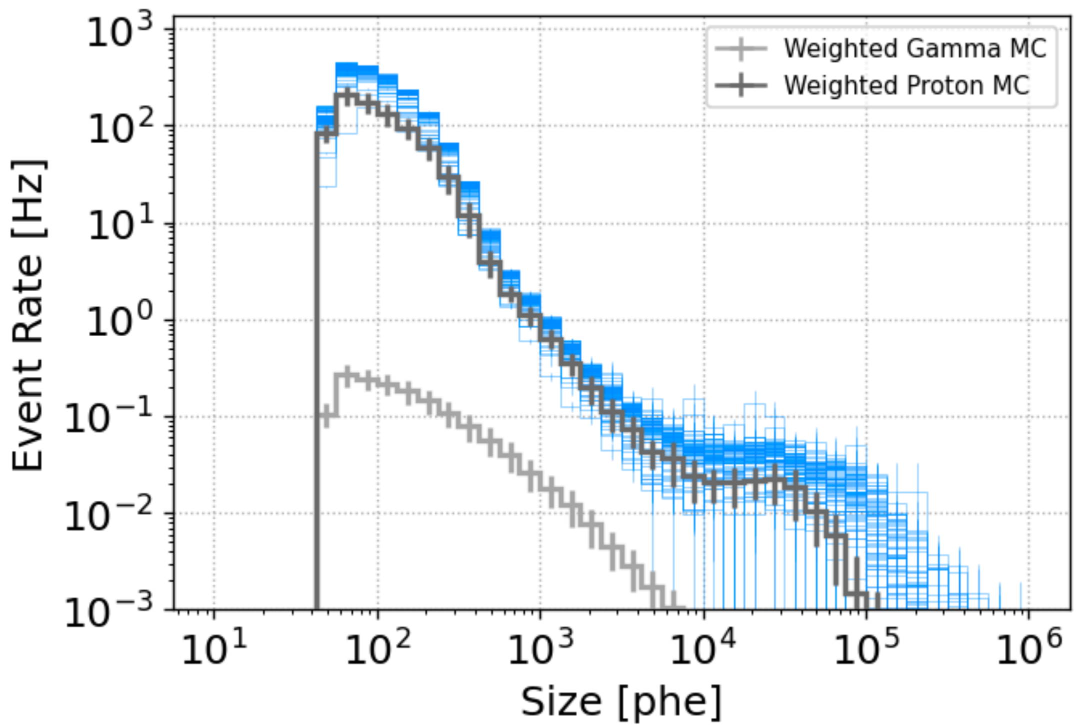
- **<u>before: 212 runs, 49.87 hours</u>** -> **<u>after: 171 runs, 41.57 hours</u>**
- changed thresholds for large-Zd data, but not fully optimized

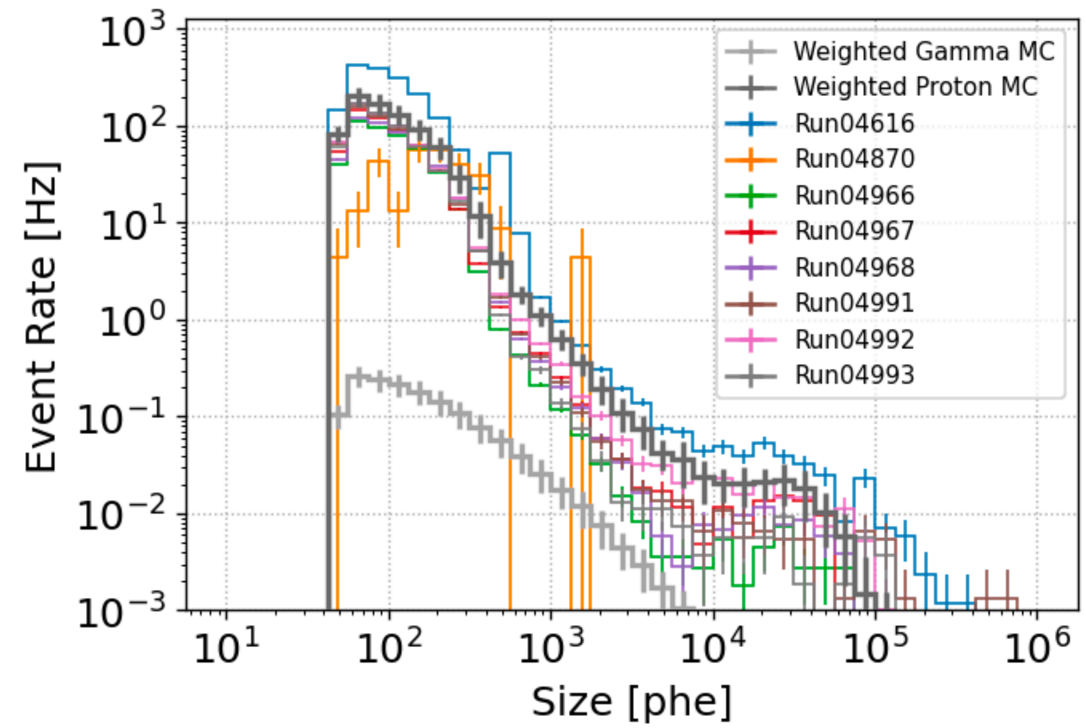
mask	quantity
Moon	Moon Altitude < 0 deg (except for run #4877)
Cosmic Rate	**<u>Cosmic Rate > 3000 Hz</u>**
Pixel Rate	Rate above 10 phe > 10 Hz
	Rate above 30 phe > 0.8 Hz
Muon Charge	**<u>Muon Size Ave. > 1800 phe</u>**
Pedestal	**<u>Pedestal St. Dev. < 3 phe</u>**
	Pedestal Rate > 40 Hz
Flat Field	Flat-Field Rate > 40 Hz
	Pixel Time St. Dev. < 1 sec
	FF Pixel Charge Ave. > 60 phe

We checked the *size* spectrum: 165 runs of 37.9-hr livetime survived. We may need stricter check if lowering the size cut.

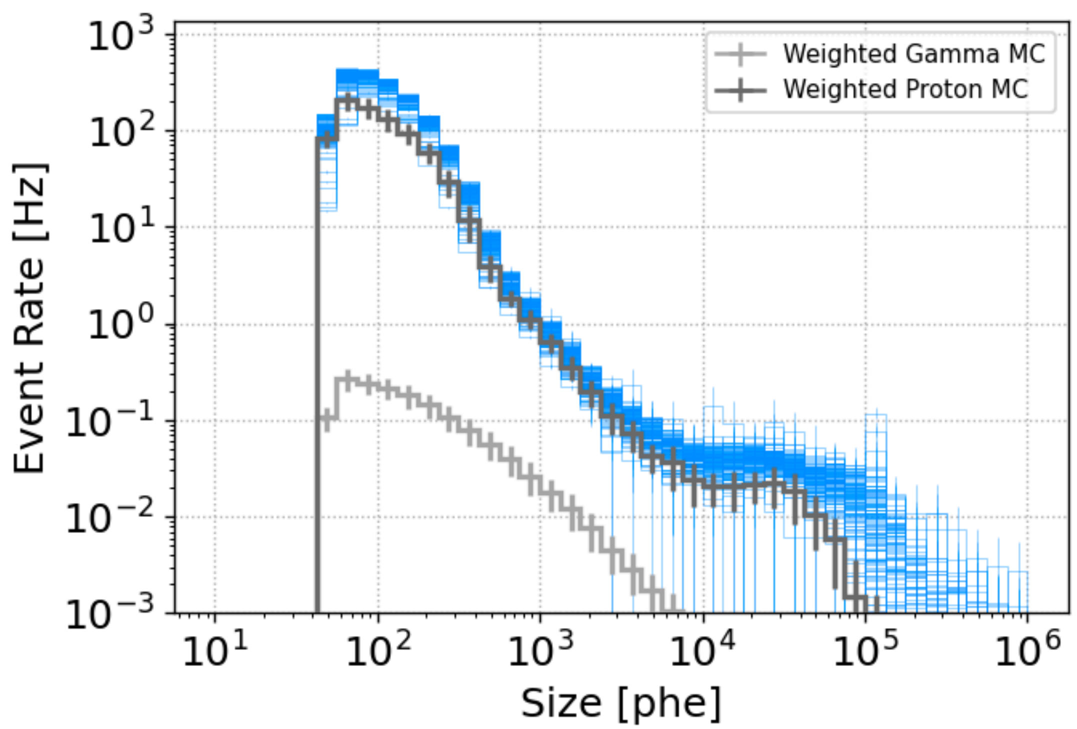
Seems Good | Seems Strange

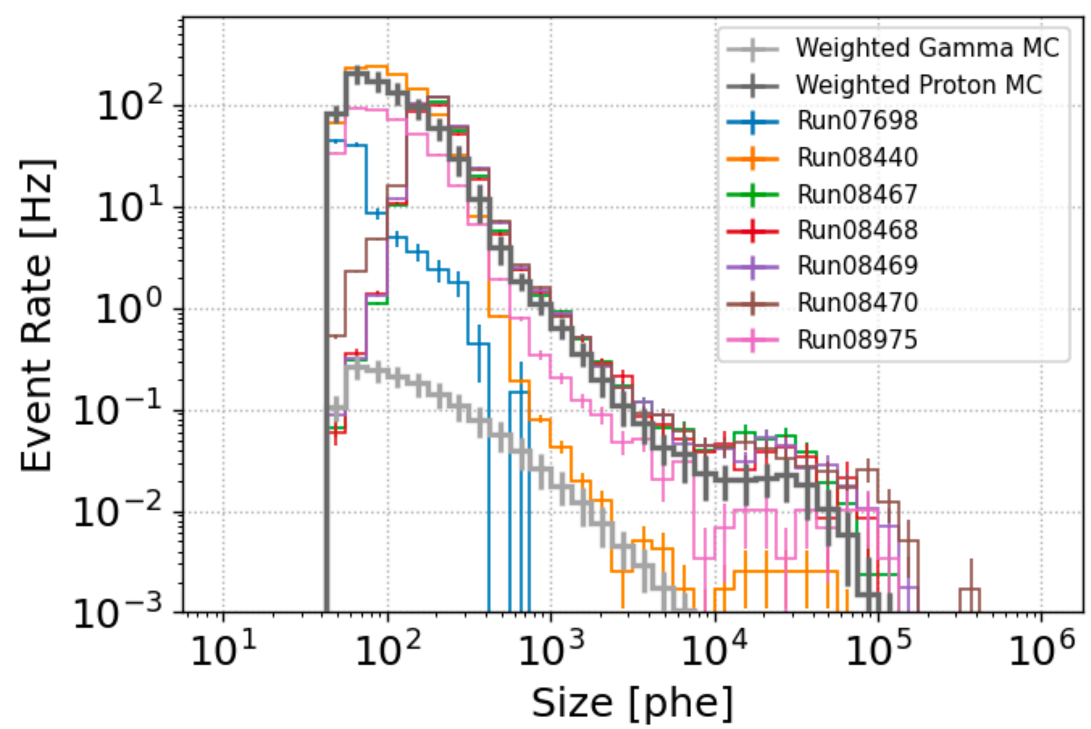
2021



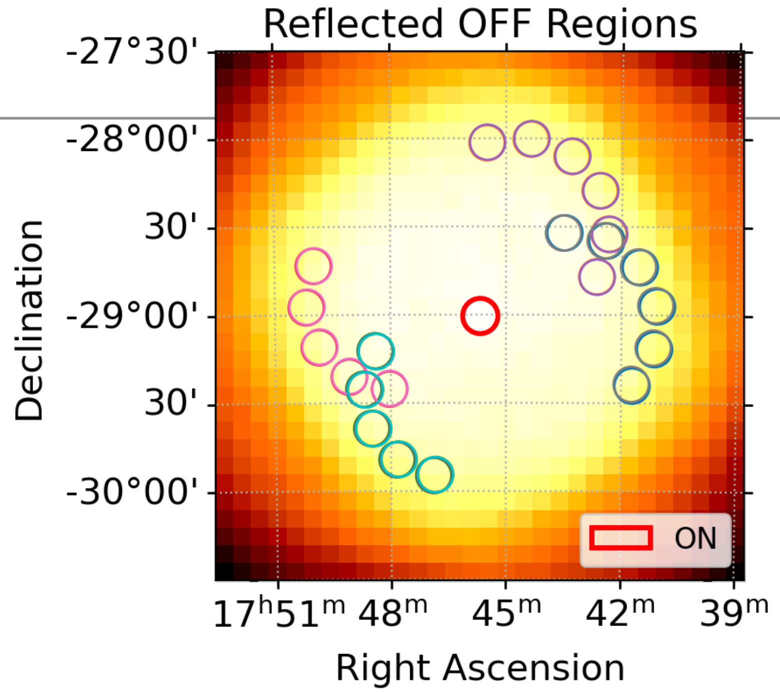


2022

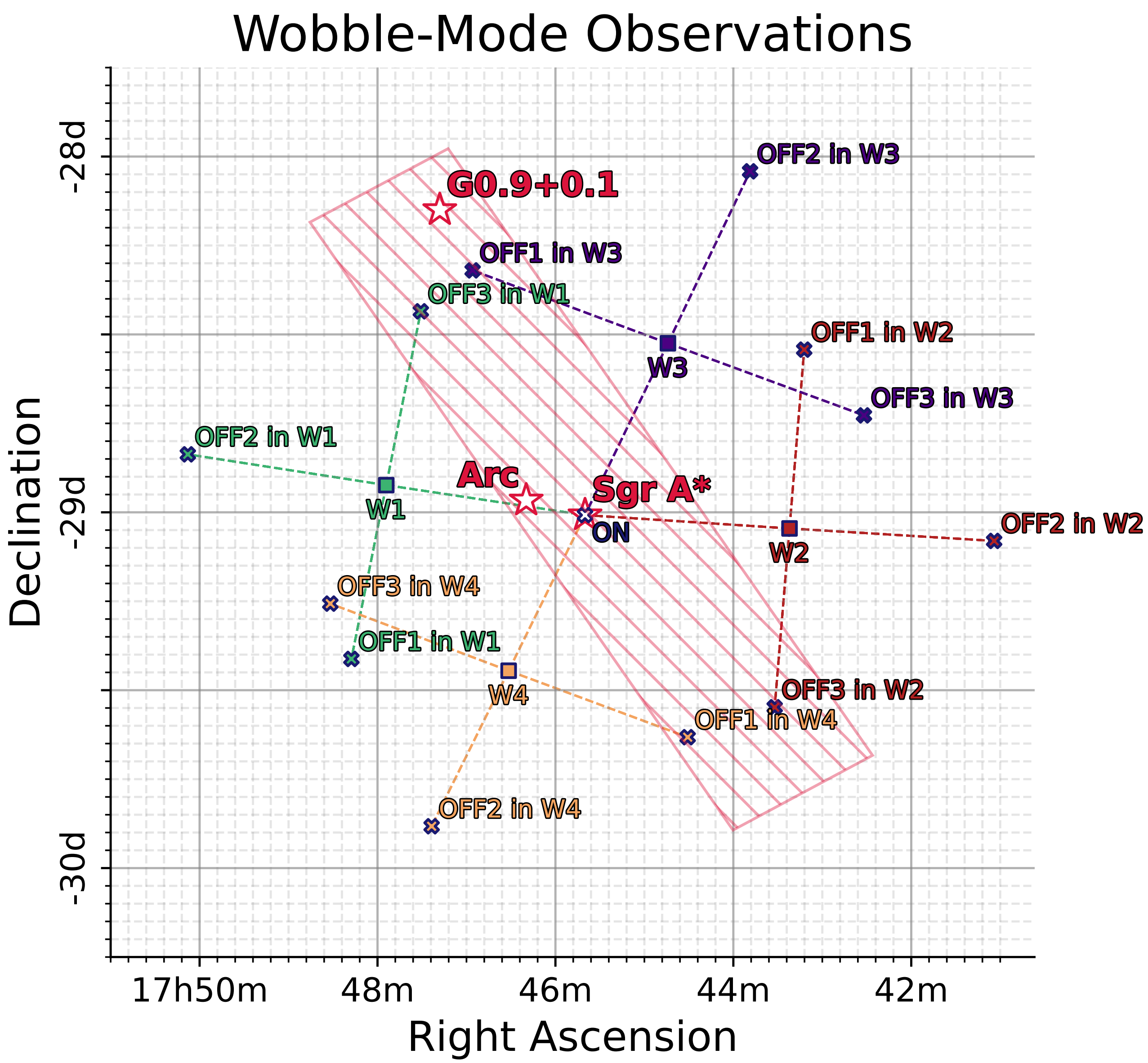


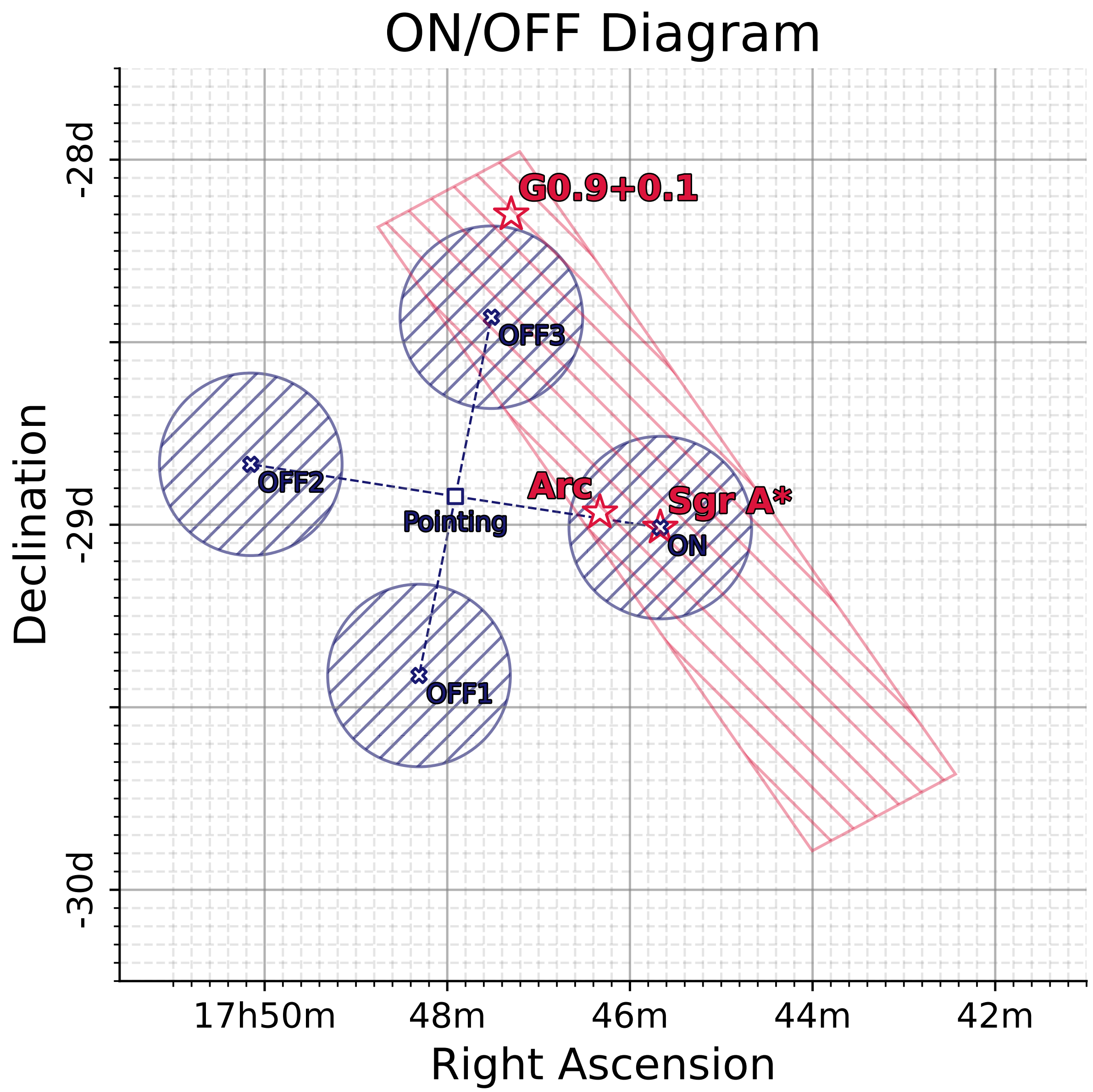


Wobble-Mode Observation & ON-OFF Analysis



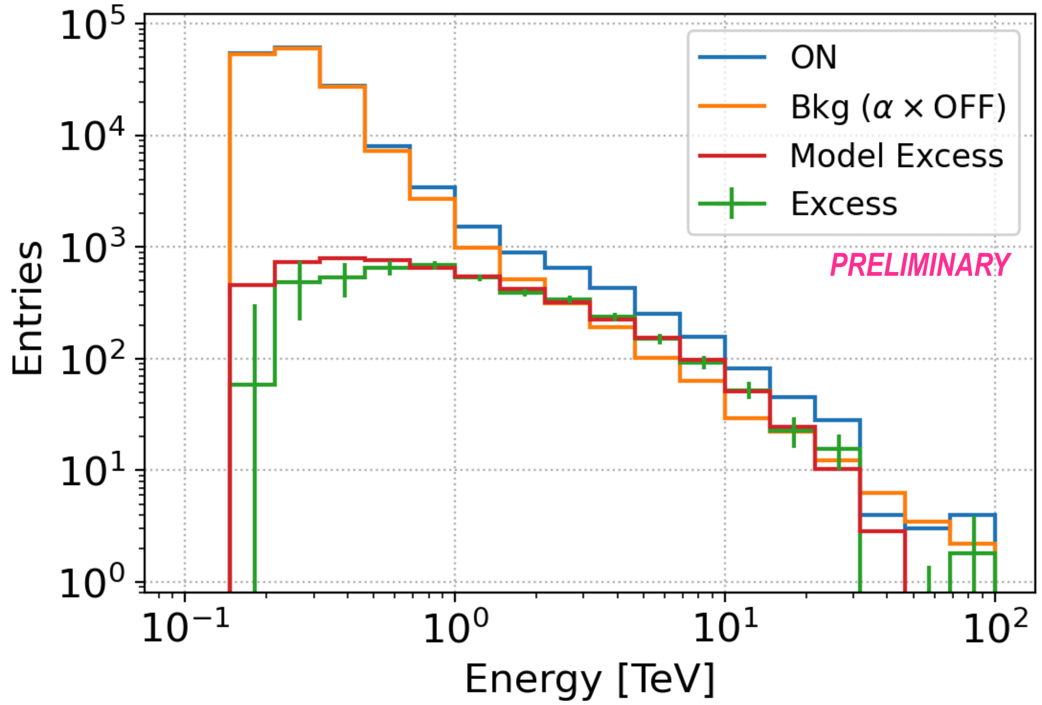
- **Wobble-Mode Observation**
  - LST-1 was pointed 0.5/0.7 deg away from Sgr A*
- **ON-OFF Analysis** (for point sources)
  - the background was estimated in the OFF regions

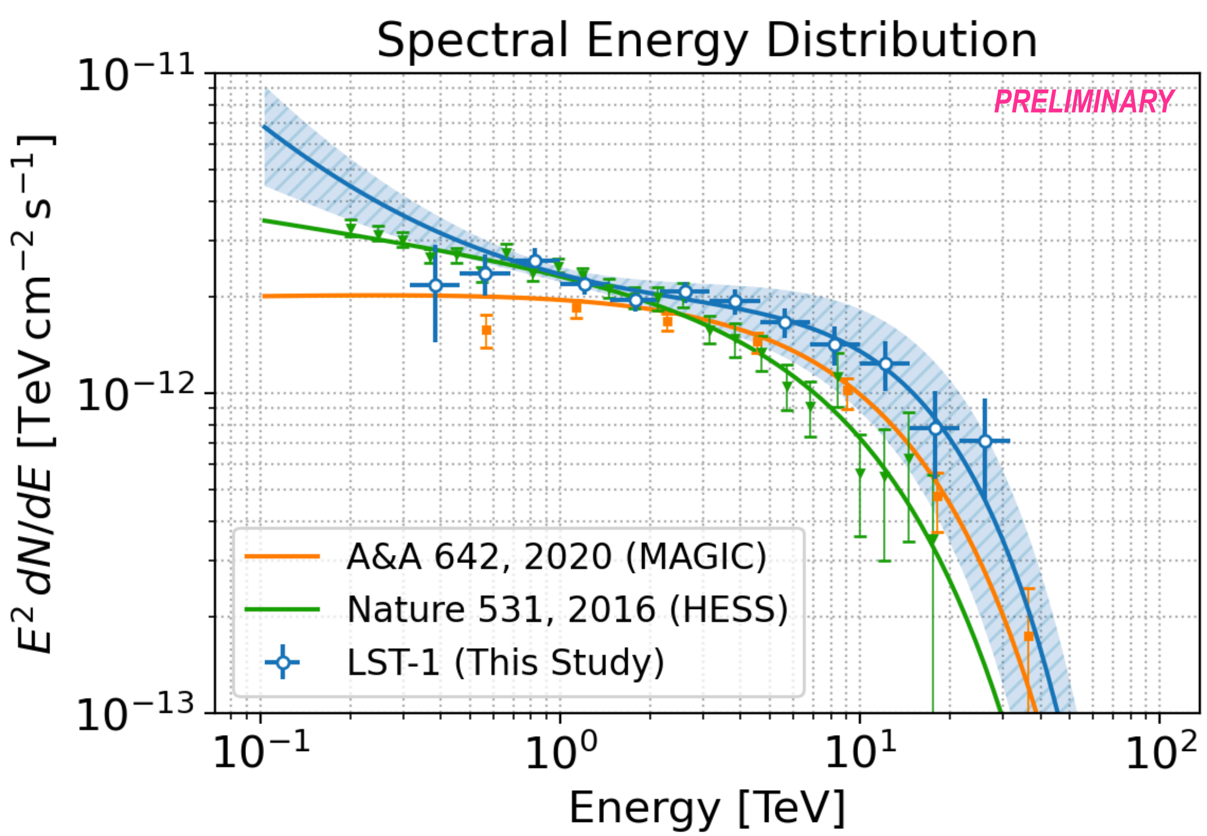


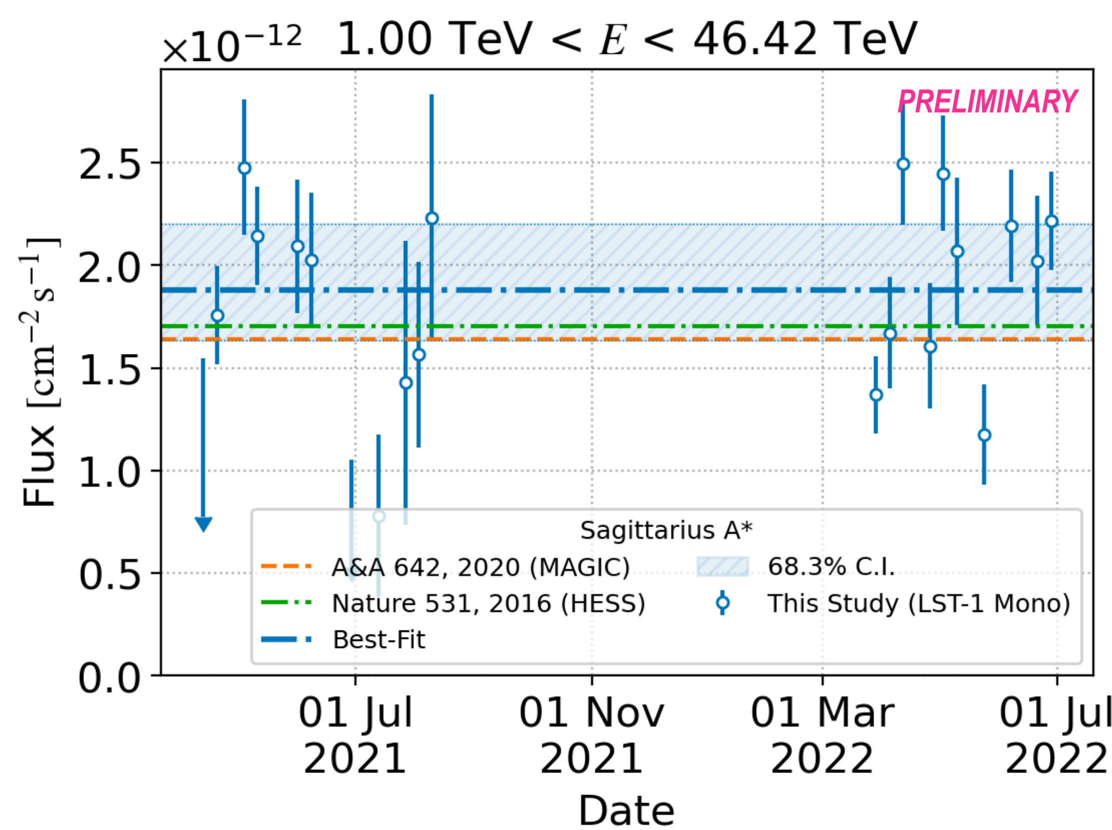


SED and LC show comparable results with HESS and MAGIC, though our flux is slightly higher.

- SED model: Log Parabola with Cutoff fitted above 0.7 TeV
- detected the central gamma-ray emission at 3,400 GeV
- tested the variability in the light curve: no variability but still slightly high (3.3σ)







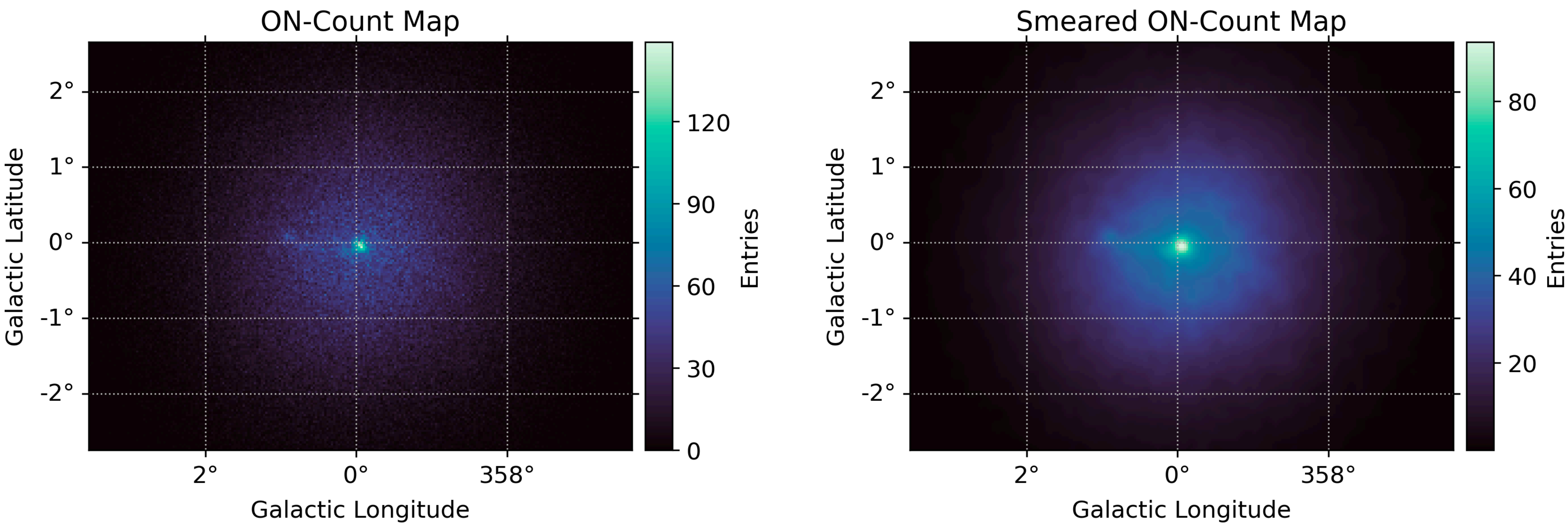
Research (3)

SkyMap Technique

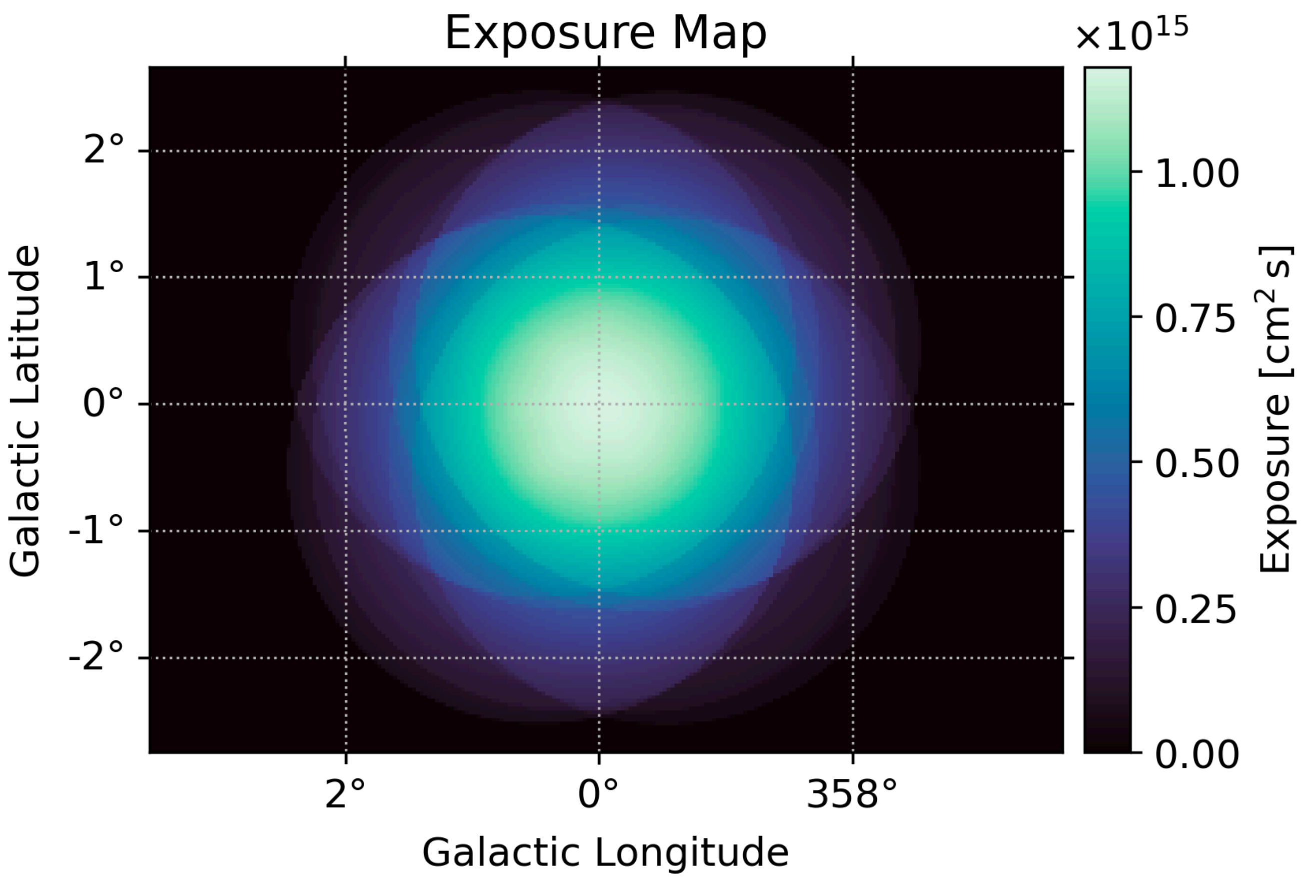
- The wobble-mode observation allows to define the ON/OFF regions easily.
- drawbacks:
  - have to know the shape/location of sources/background a priori.
  - nearby regions (especially extended ones) easily overlaps others.
- The point-source analysis worked for Sgr A*, *relatively*.
- To cope with the GalCent complexity,
  analysis should be carried out in the "x-y-energy" phase space.
- The extended-source analysis has not been standardized in LST.
  We are implementing the skymap technique.
- **basic scheme in this study**:
  - Flux Map = (**ON** Map - **Bkg** Map) / **Exposure** Map
  - **ON Map**: Just a count map in the Sky coordinate
  - **Exposure Map**: Aeff X obstime in the Sky coordinate
  - **Bkg Map**: **a Template Background in the Camera coordinate**,
    and **the Exclusion Map in the Sky coordinate**.
- due to the difficulty (impossibility) of 3D unfolding, the skymap analysis
  should not be separated from physical models to be fitted.
  but this study just avoided it and independently reconstructed the skymap.

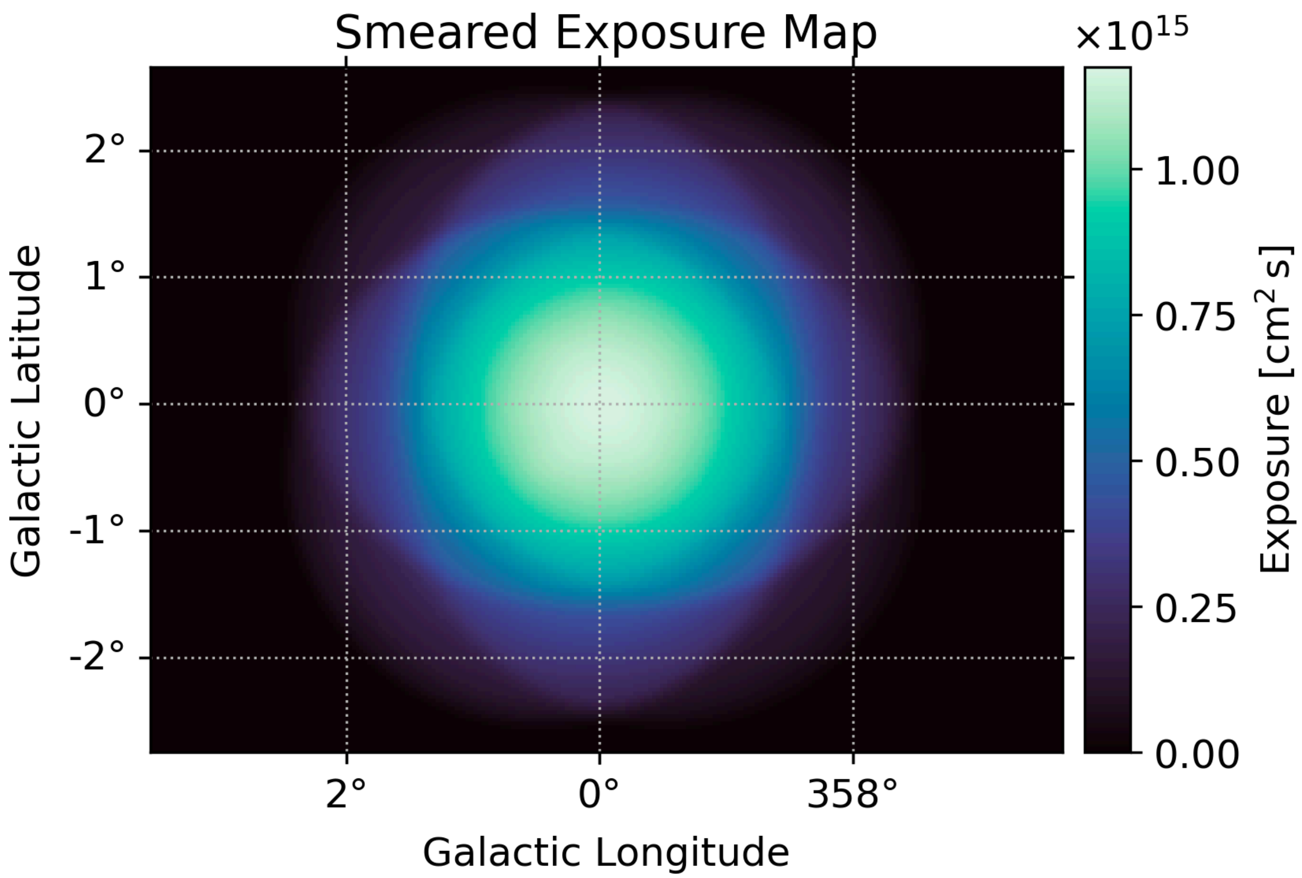
ON Count Map

- used the same LST-mono GalCent DL3 dataset (**38-hour** livetime)
- stricter hadron suppression than usual:
  size > 200 phe, 60%-eff. gammaness
- spatial geometry: **0.03 x 0.03 deg** in 7.2 x 5.4 deg (240 x 180 pixels)
- energy: **0.8 TeV to 80 TeV (1 bin)**
- smearing: 0.06 deg (psf ~ 0.1 deg)

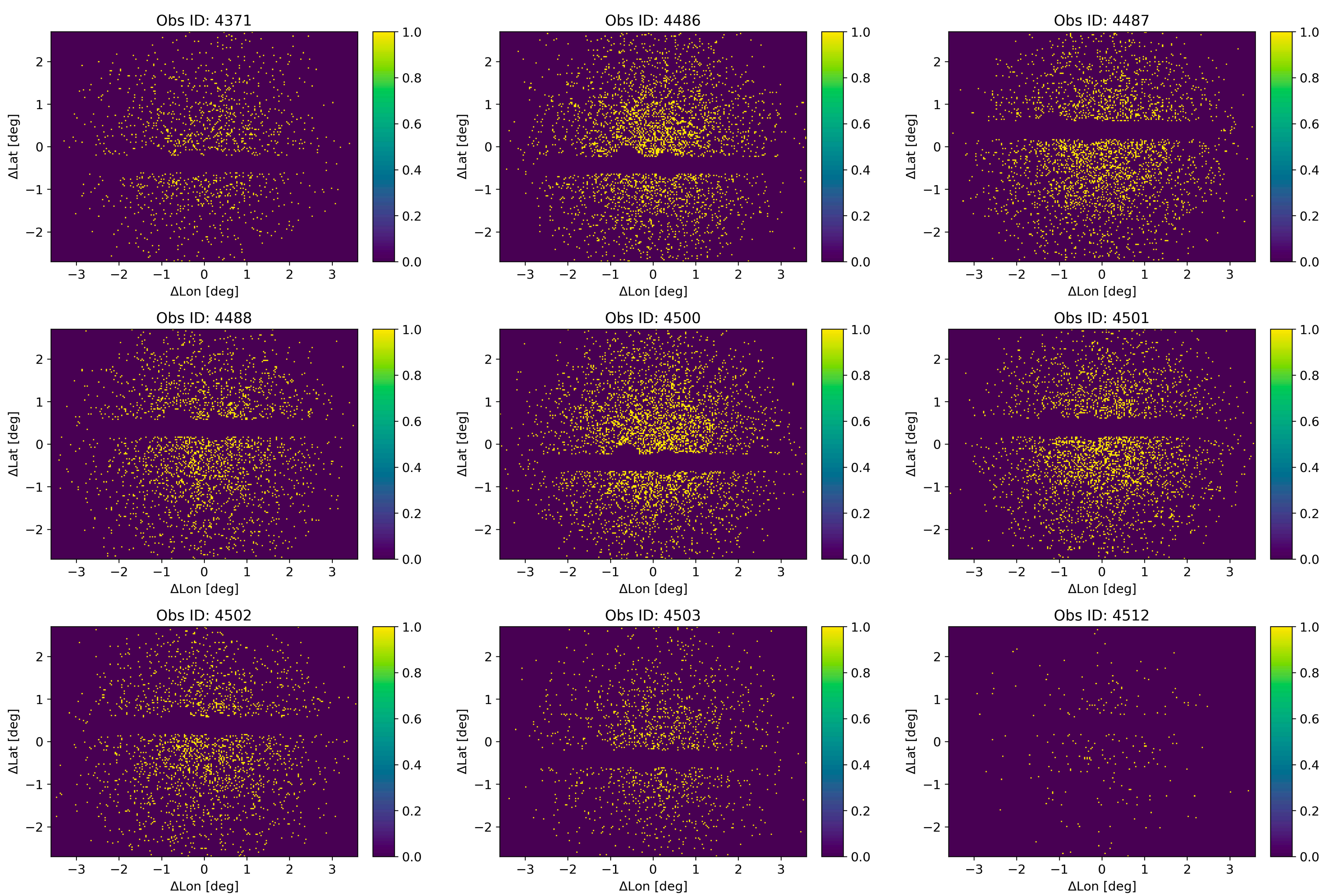


- estimated the exposure (= Aeff x T) map with gammapy
- weighted/superimposed the exposure maps along the true energy, assuming a power-law energy spectrum
- smoothed the exposure map similarly to the count map
- took only the off-axis angle into calculation:
  the zenith-angle effect is not reflected to the exposure map.

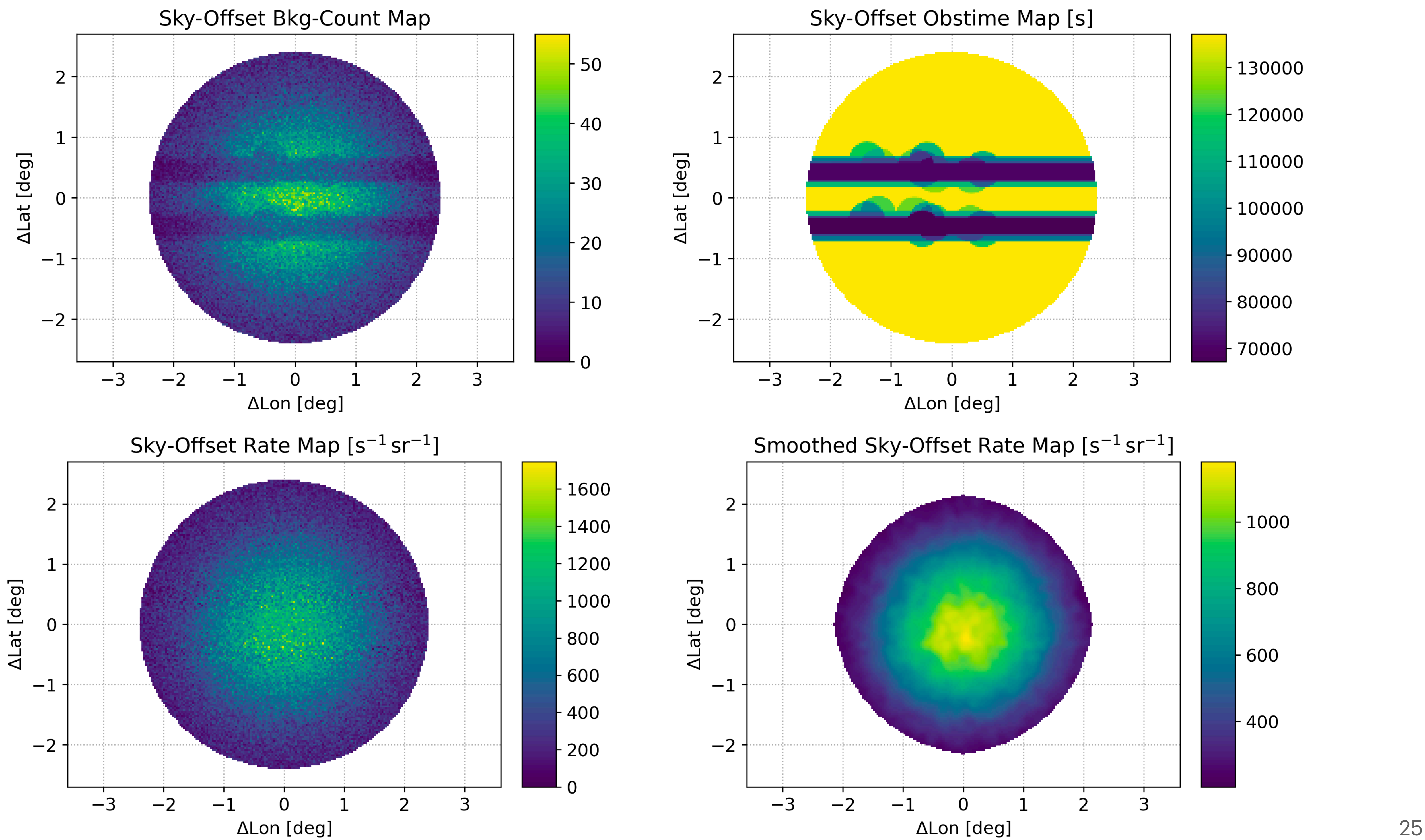




- scheme: stacked exclusion map
- for each run, **events are binned in the sky-offset coordinate** (effectively in the camera coordinate)
- excluded "**0.3 deg from Sgr A***", "**0.3 deg from G09+01**", and "**6 deg x 0.4 deg for the Gal. plane**"

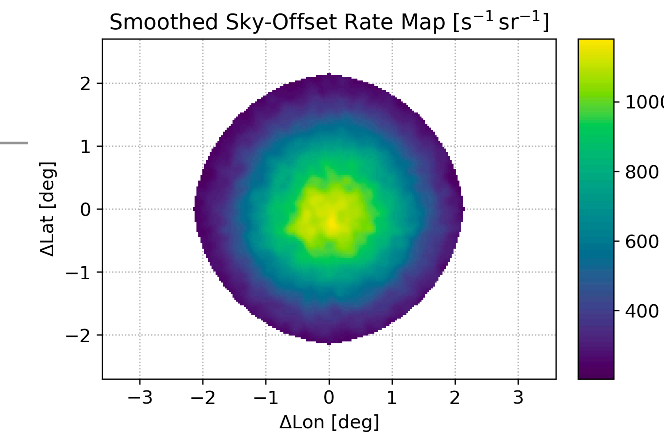


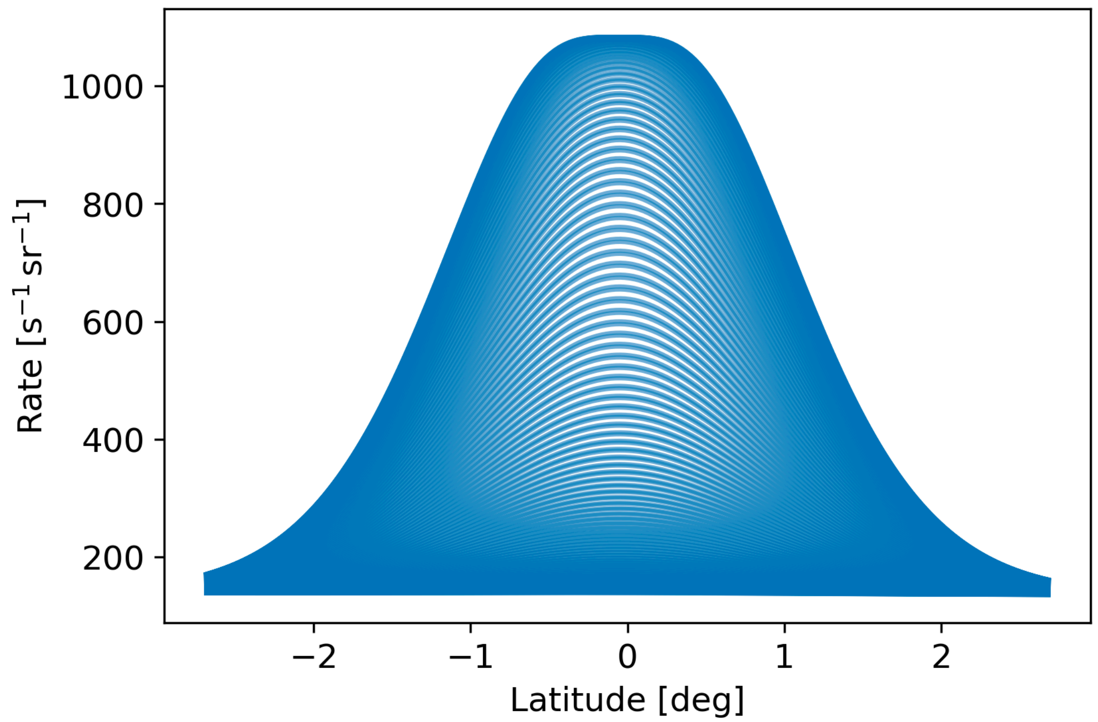
- similarly binned the observation times in the same coordinate
- got the **bkg rate map** by "bkg count / obstime" (within 2.4 deg)
- taking no account of the zenith angle, wobble position, etc

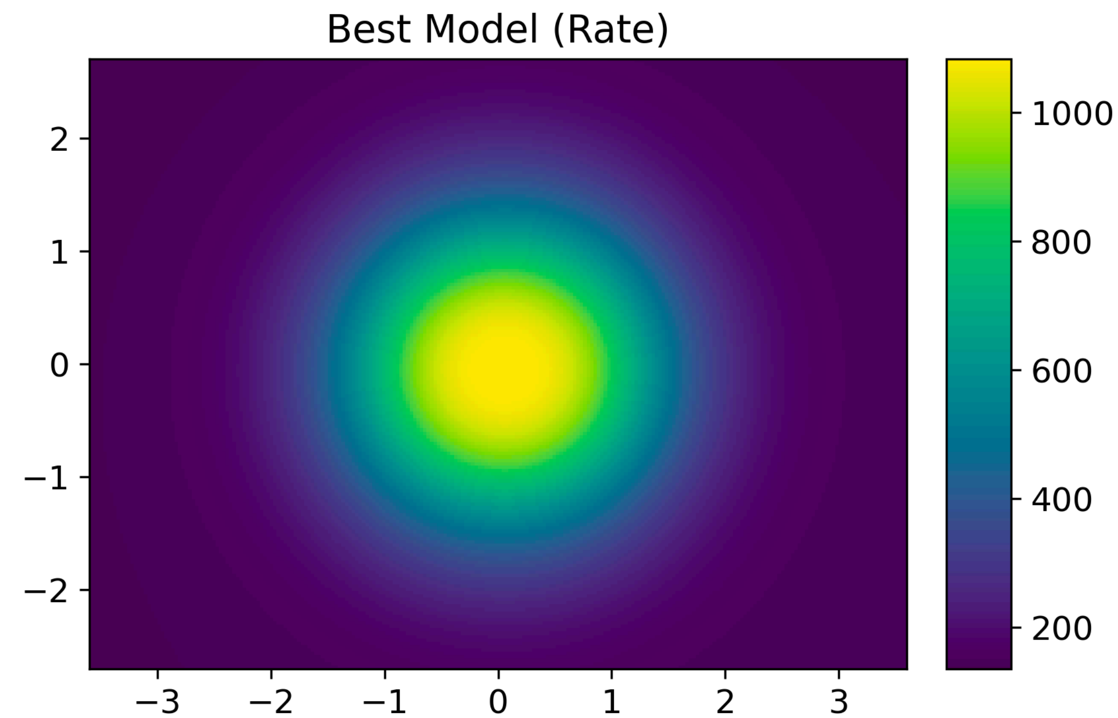


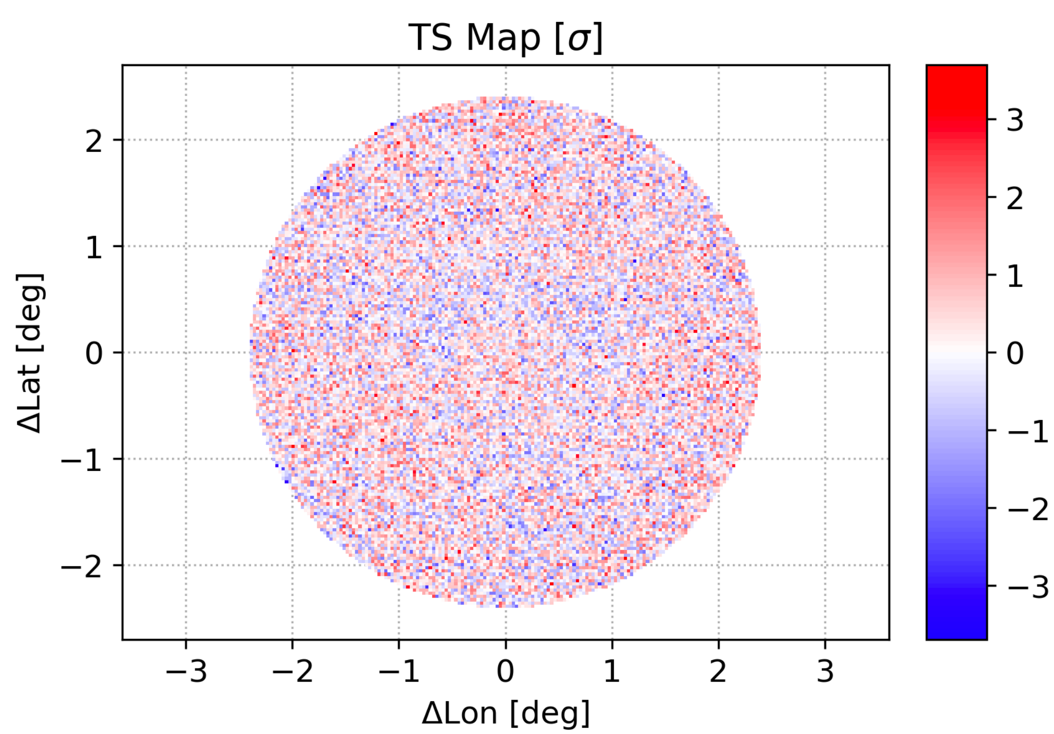
Bkg Estimation (3): Fitted the Bkg Model

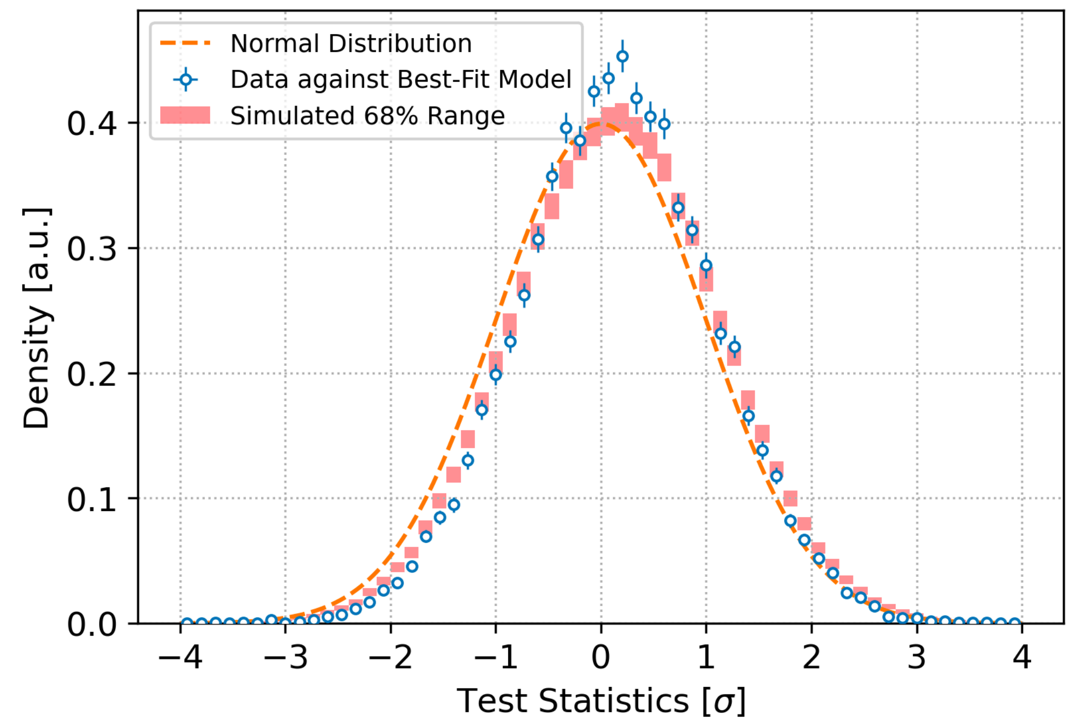
- fitted the model function to the bkg count map (deformed Gaussian + gradient)
- This model describes the background well





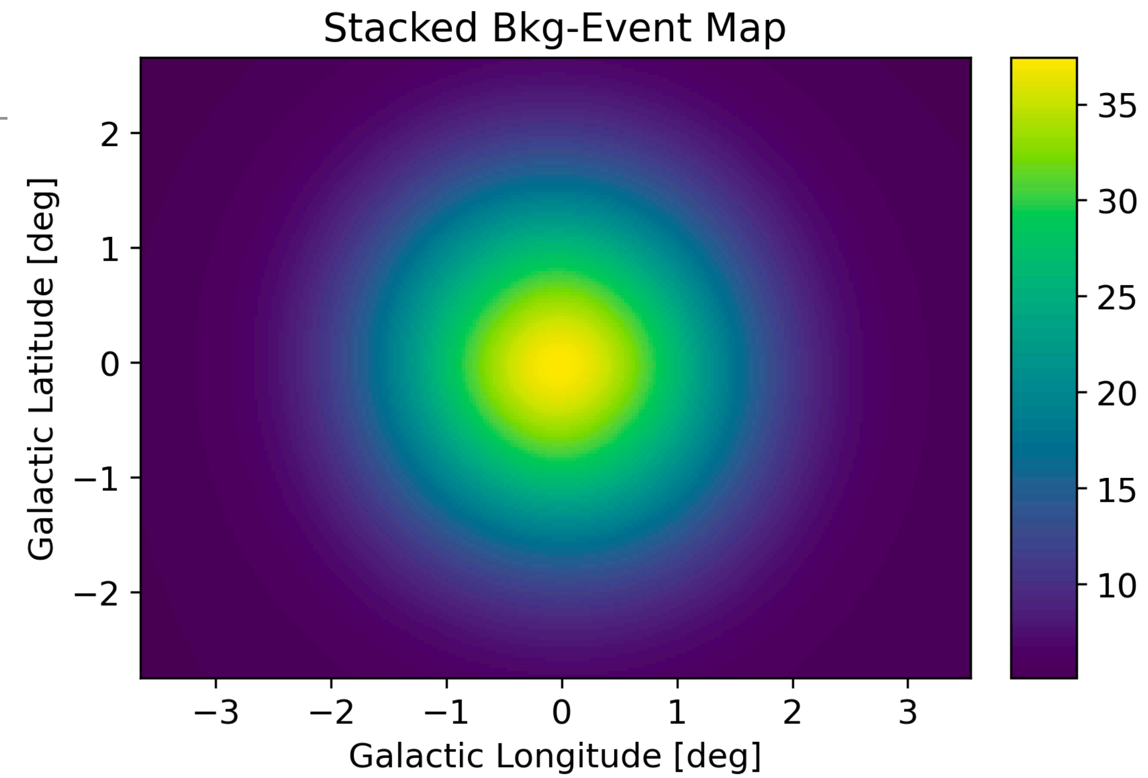


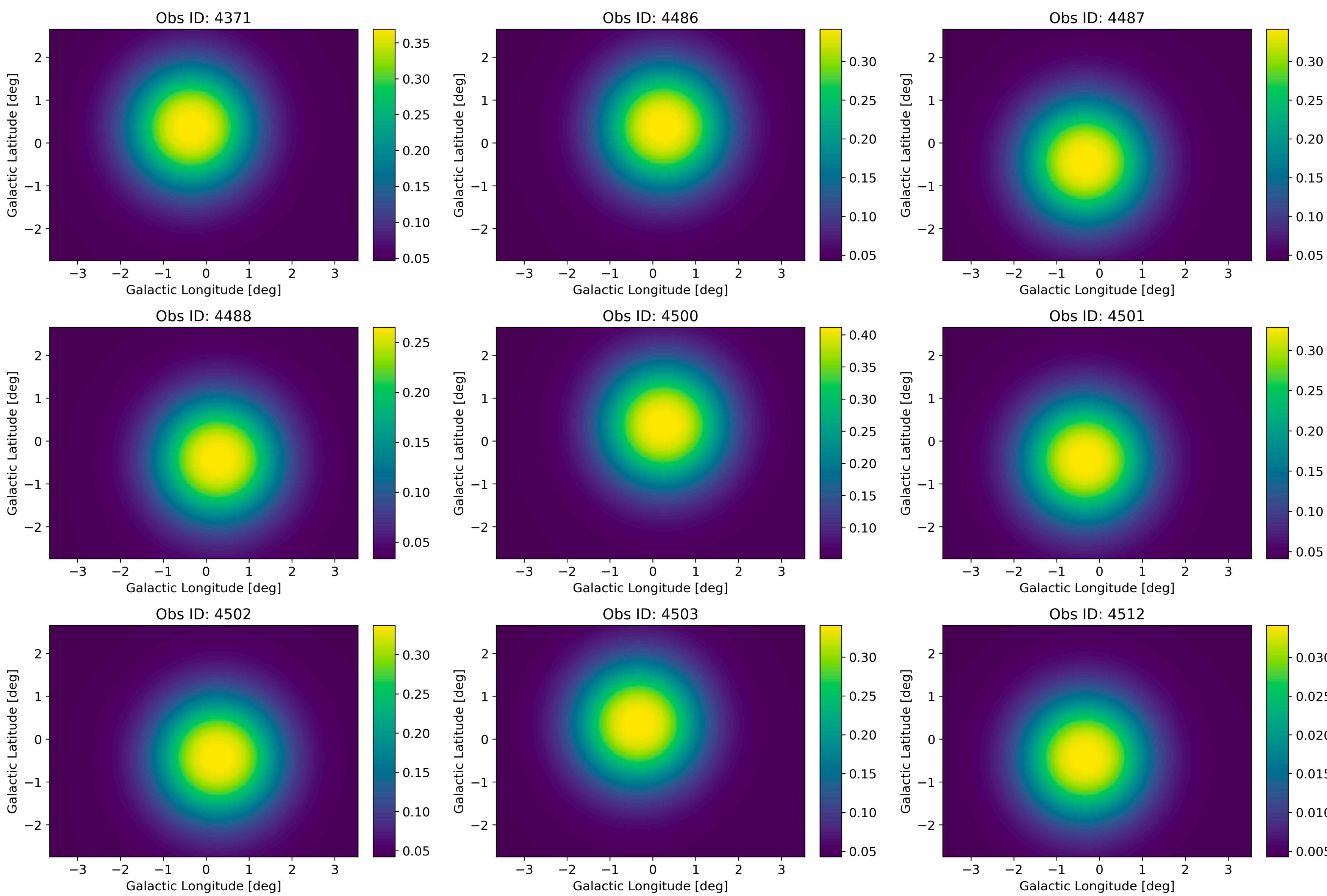




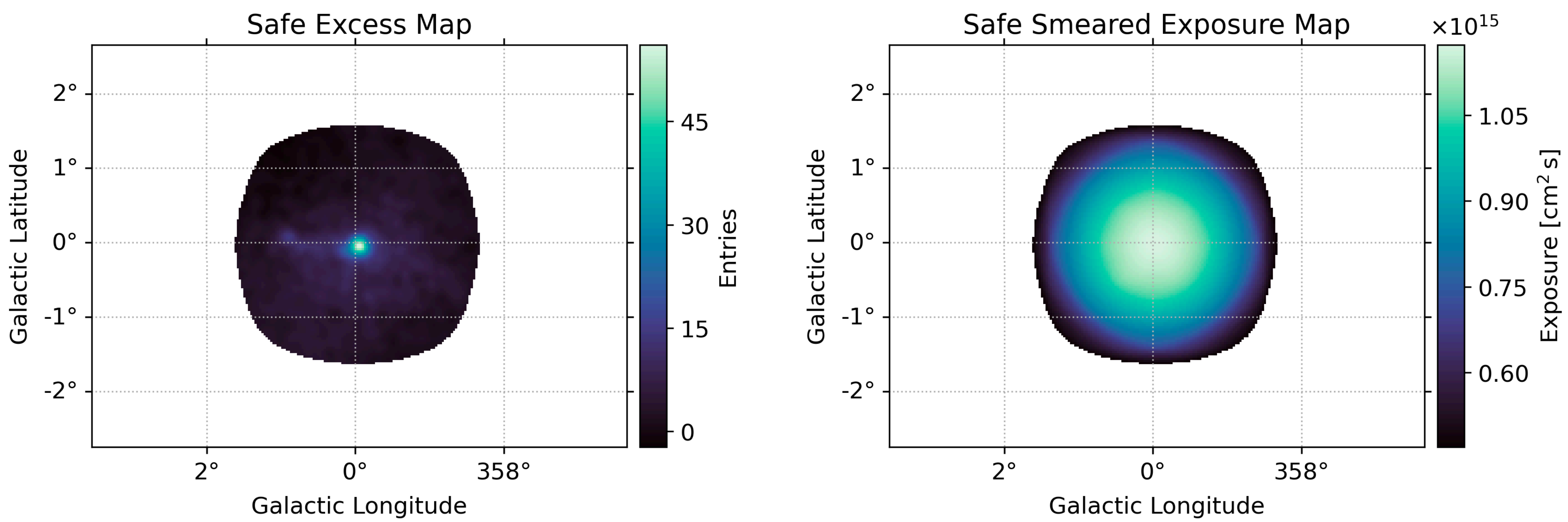
Bkg Estimation (4): Conversion to Sky

- estimated the bkg counts in the sky coordinate (panels below)
- summed them up into a single map (the right plot)

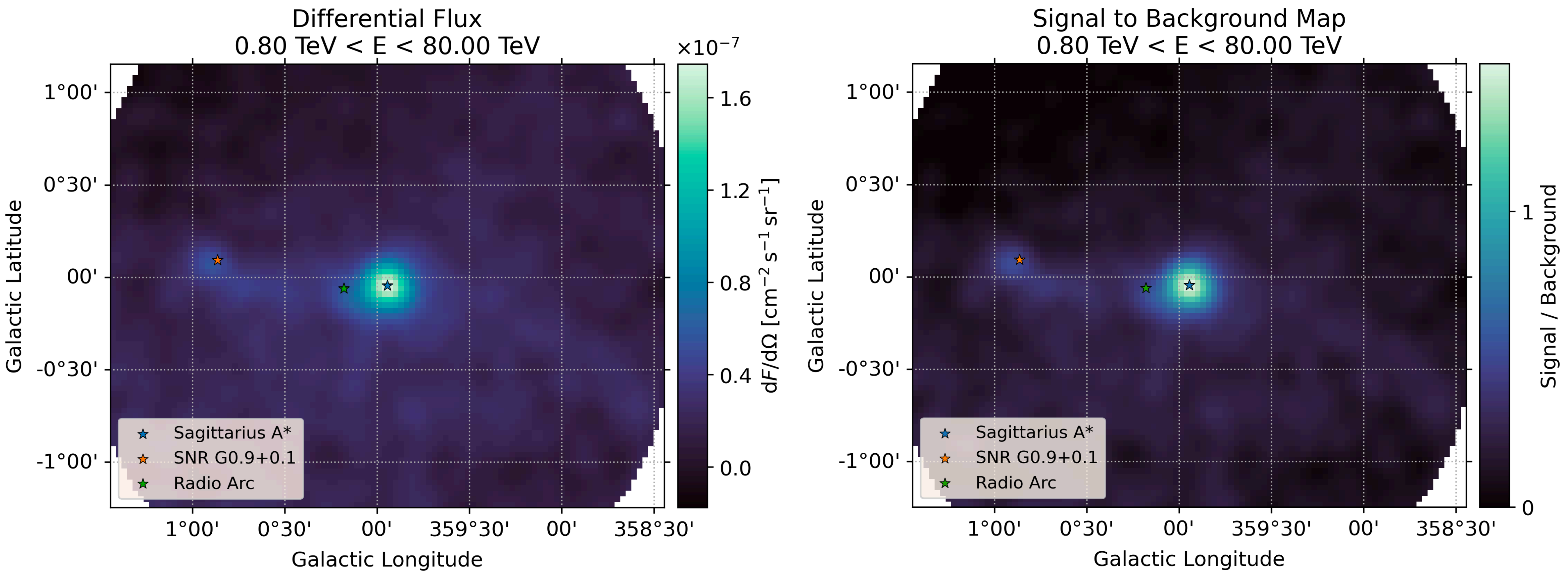


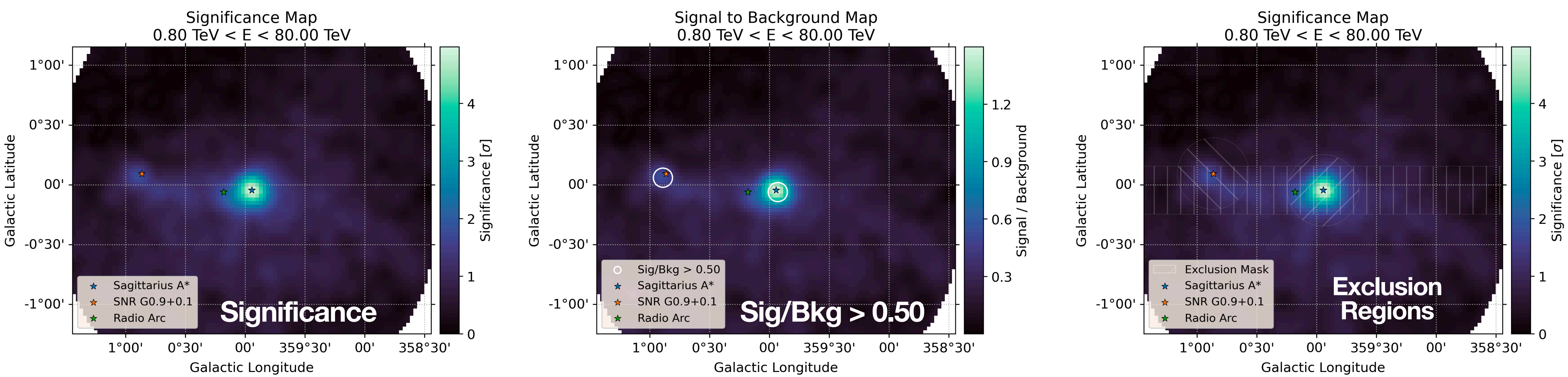


- when standard point source analysis, we usually adopt "10%" threshold for the effective area, mainly in order to avoid the MC/Data discrepancy
- this study: **exposure above 40% of the maximum**, roughly corresponding with a radius of 1.5 deg.



Sky Map


Differential Flux
0.80 TeV < E < 80.00 TeV
Signal to Background Map
0.80 TeV < E < 80.00 TeV
Galactic Latitude
Galactic Longitude
dF/dΩ [cm⁻² s⁻¹ sr⁻¹]
×10⁻⁷
Signal / Background
Sagittarius A*
SNR G0.9+0.1
Radio Arc


Significance Map
0.80 TeV < E < 80.00 TeV
Signal to Background Map
0.80 TeV < E < 80.00 TeV
Significance Map
0.80 TeV < E < 80.00 TeV
Significance
Sig/Bkg > 0.50
Exclusion Regions
Sig/Bkg > 0.50
Exclusion Mask
Sagittarius A*
SNR G0.9+0.1
Radio Arc
Significance [σ]
Signal / Background
Galactic Latitude
Galactic Longitude

Summary

- The CTA project is the next generation of ground-based observatory for very-high-energy gamma rays with unprecedented performance
- LST-1 was inaugurated in 2018, and is now accumulating data.
- **Applied the standard wobble (point-source) analysis for the large-Zd Crab Nebula and Galactic Center**
- The Crab-Nebula SED/LC seem consistent with the previous studies
    - showing **the successful data-taking and analysis at the large Zd**
- The Galactic-center SED in this study looks comparable with the results of MAGIC and HESS
- **Newly developing a skymap technique** for an extended-source study
    - the skymap prototype suggests an excess at SNR G09+01 and Gal Plane.
- Further research: Model-driven skymap analysis

Backup

arXiv:1806.03167

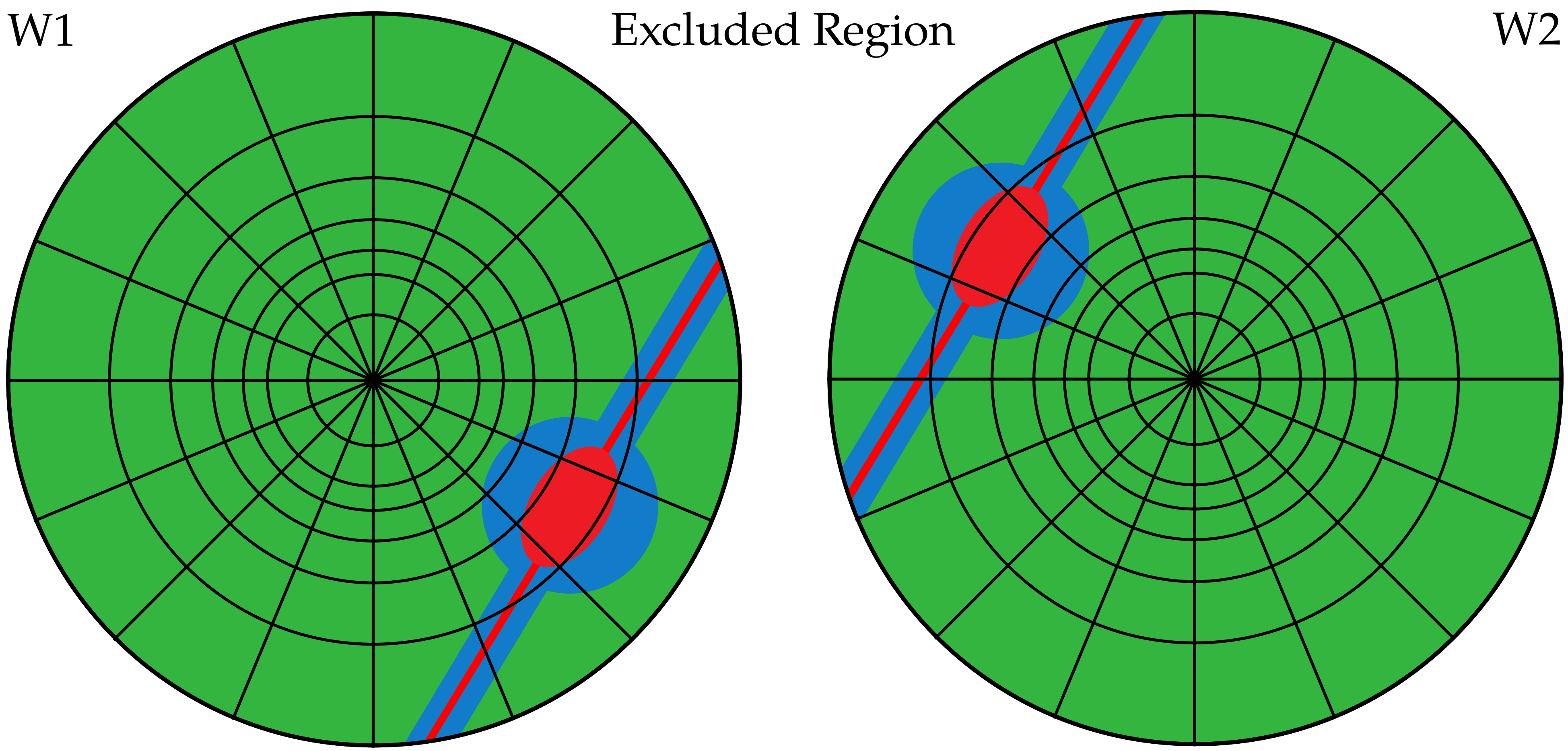


Fig. 1. Illustration of the different methods for the construction of a background camera exposure model from wobble observations (here one wobble pair). The source position and extension is shown as red point, ellipse, or stripe. The blue shading marks bins excluded from the background map reconstruction.