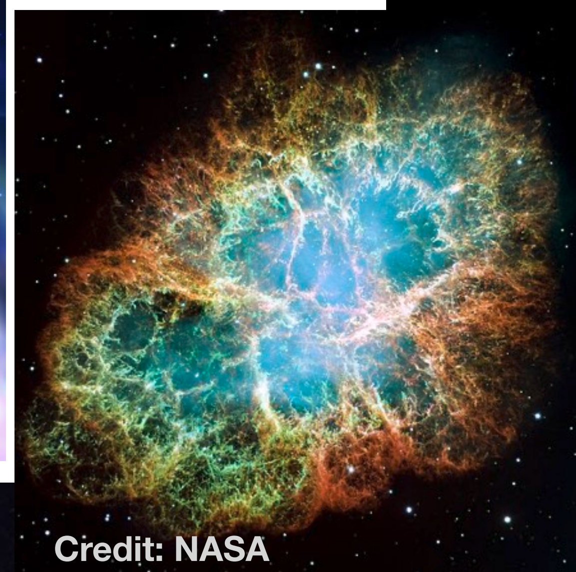
Performance of the joint observations with CTA LST-1 and MAGIC

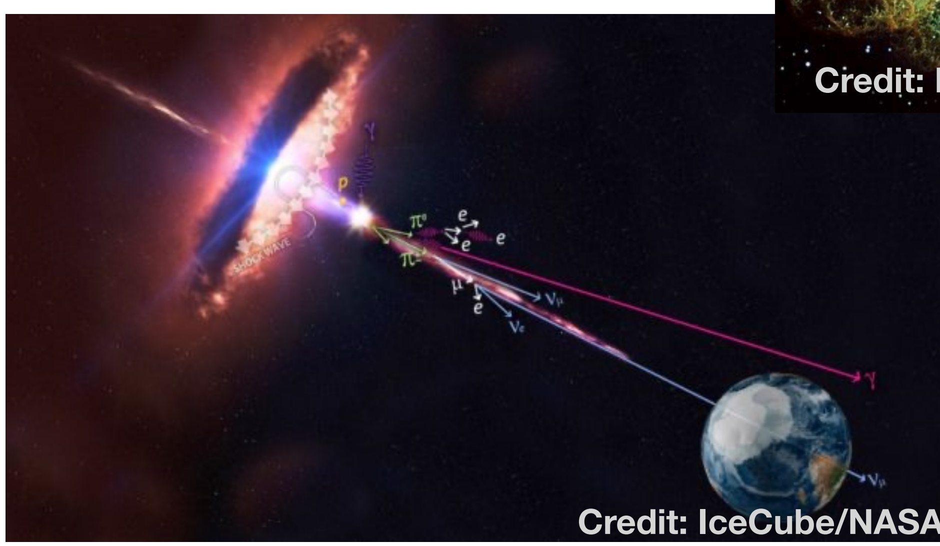
Y. Suda (Hiroshima U.),
A. Berti, F. Di Pierro, Y. Ohtani, J. Sitarek, E. Visentin
on behalf of the CTA-LST Project
and the MAGIC Collaboration

cherenkov telescope array

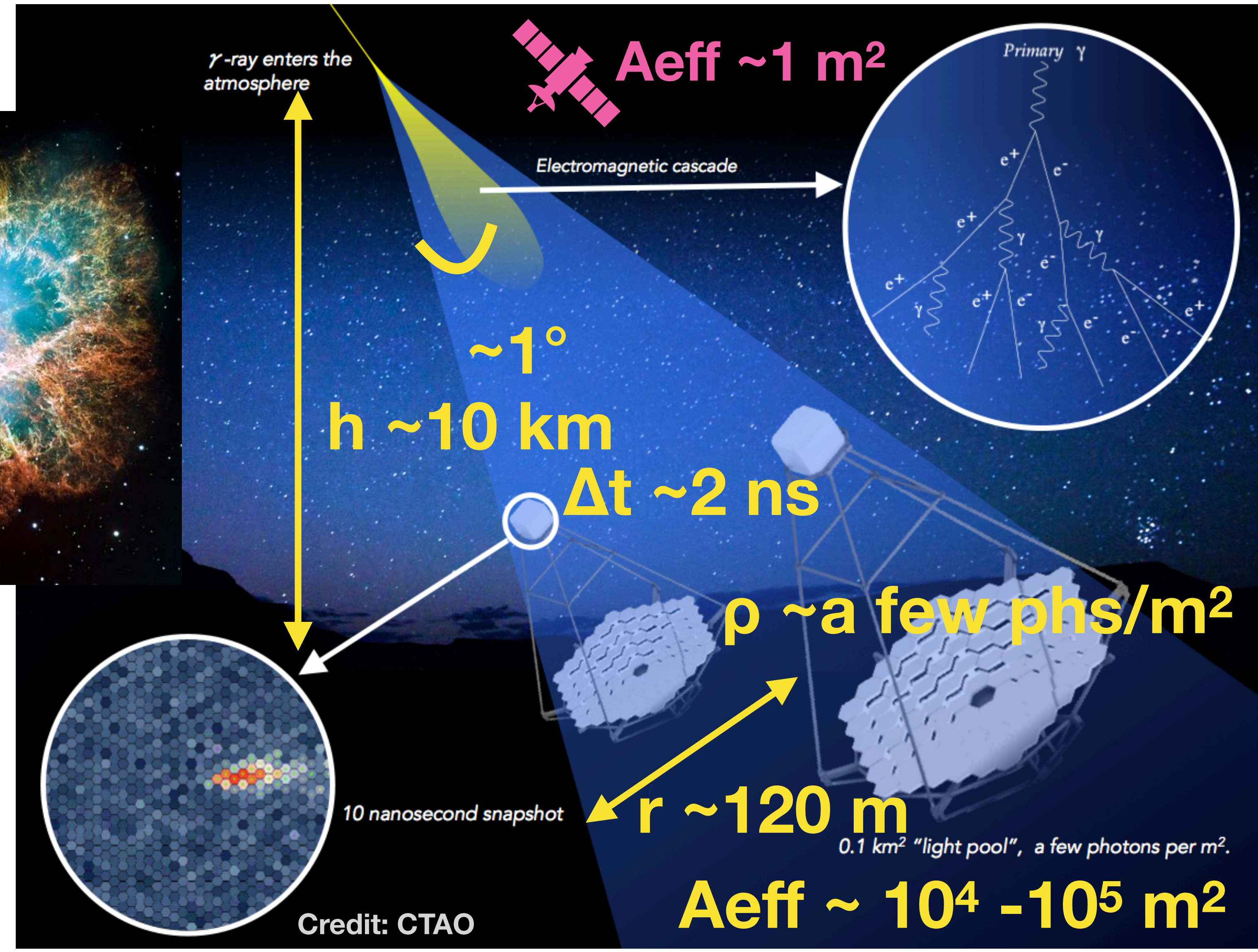
Very High Energy γ-ray Observations

Extreme Universe



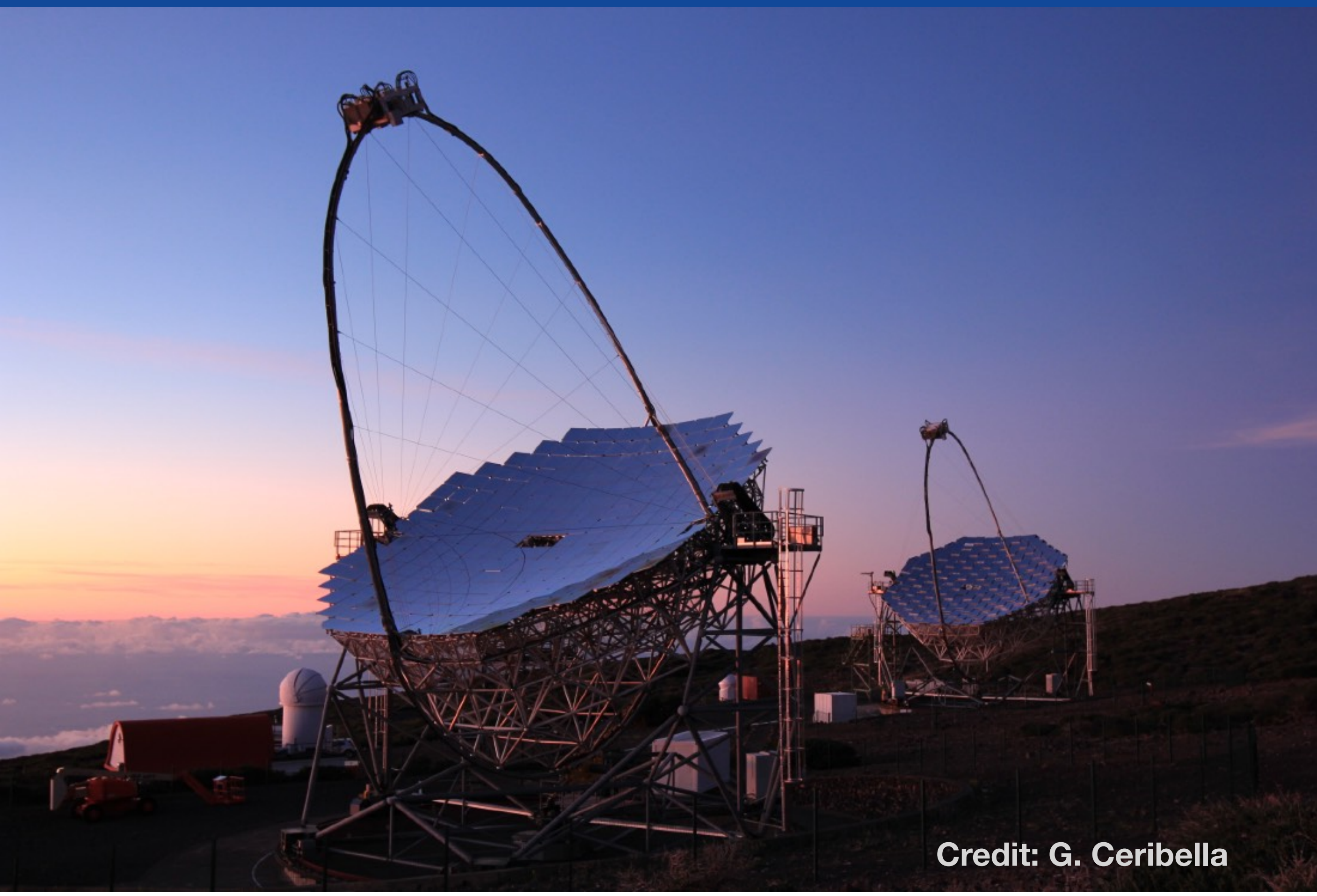


Imaging Atmospheric Cherenkov Telescopes (IACTs)



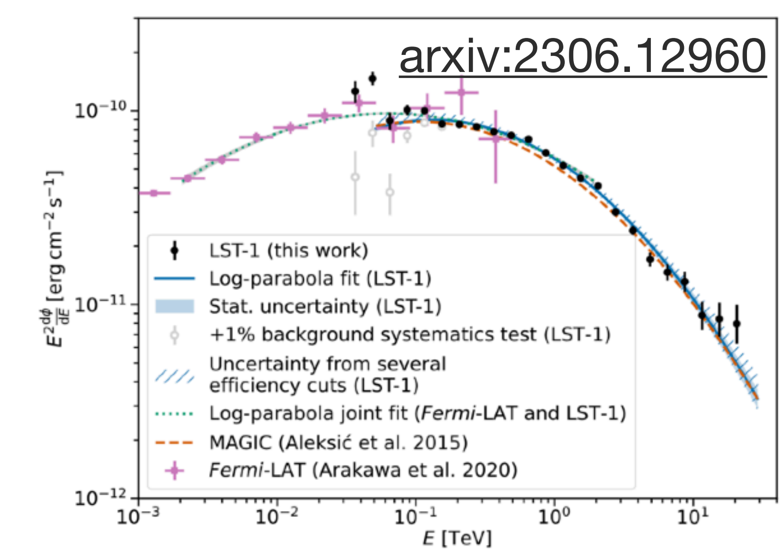
- > 200 very-high-energy (**VHE**, > a few tens of GeV) gamma-ray sources
  - Active Galactic Nuclei, Supernova Remnants, Pulsars, GRBs,..
- IACTs are suitable for studying physics in extreme environments (dense, strong gravity/magnetic field)

MAGIC and CTA LST-1



- *Current generation*: **MAGIC** telescopes
  - Two 17 m IACTs in stereo mode since 2009 (mono 2003) at La Palma, Canaries, Spain. 2200 m a.s.l. **20th anniversary** 🎉
- *Next generation*: **CTA**
  - North (La Palma): 4 LSTs, 9 MSTs
    South (Paranal, Chile): 2 LSTs, 14 MSTs, 37 SSTs
  - The first telescope **LST-1** is a 23 m IACT inaugurated in 2018
  - Constructions for the rest of LSTs (North) are ongoing

LST-1 Crab Nebula paper accepted by ApJ



Joint Observations

- MAGIC telescopes and LST-1 are located at a ~100 m distance
- Comparable to the size of the Cherenkov light pool → Showers can be observed in all three telescopes simultaneously
- Joint observations with LST-1 and MAGIC are expected to achieve better sensitivity w.r.t. LST-1 mono due to better rejection of background events (i.e. hadronic showers)
- "Pathfinder" for stereo analysis of CTA telescopes

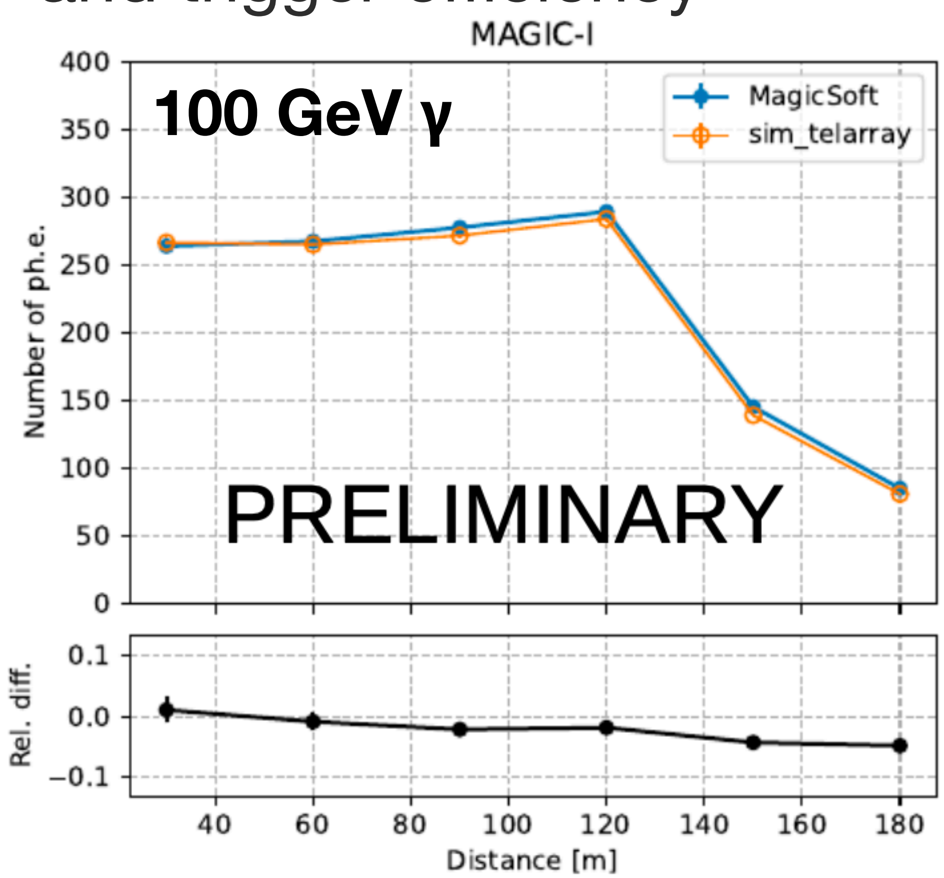
- In this talk, we show the developed analysis pipeline and the performance of the joint observations
  - Used data set: Crab Nebula (2020/2021 season, 4 hrs in total, 0.9 hrs in Zd < 30 deg.)

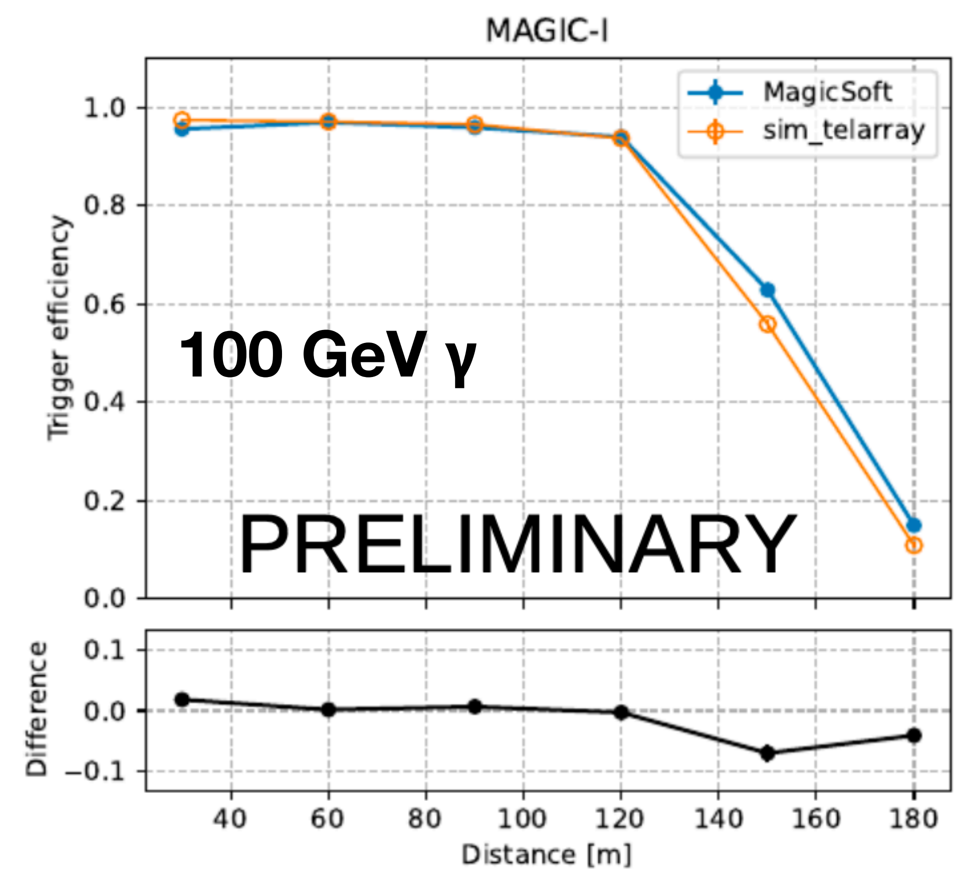
Monte Carlo Simulations

- To simulate the same shower events seen by both telescopes, we developed a common simulation and analysis framework

	Air shower	Telescope response	Analysis pipeline
LST	Corsika	sim_telarray	cta-lstchain (python)
MAGIC	Customized Corsika	MagicSoft	MARS (C++)
LST1-MAGIC	Corsika	sim_telarray	magic-cta-pipe (python)

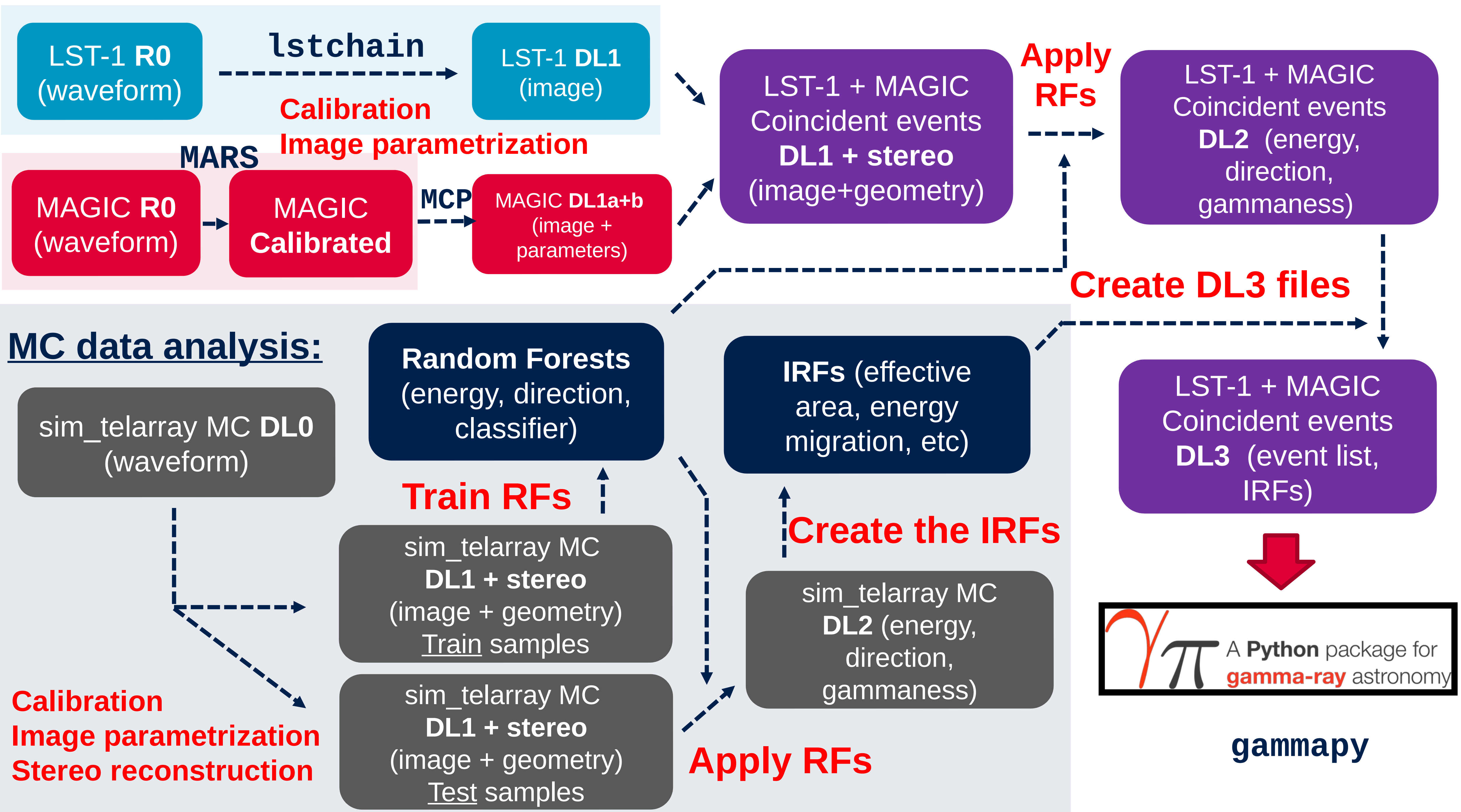
- We implemented MAGIC into sim_telarray and validated it
  - Good agreements in both the reconstructed true number of p.e. and trigger efficiency





Joint Analysis Framework

- MAGIC-CTA-Pipe (MCP) based on ctapipe/lstchain (python)
  - Long-term maintenance, capability for the state-of-the-art technology



Coincident Events

- LST-1 and MAGIC-stereo are operating independently, but all three telescopes point at the same direction in a semi-automatic way for joint observations
- Coincident events can be selected by using GPS time stamp
  - Hardware stereo trigger is under development
- LST-1 is also triggered by most of the gamma rays seen by MAGIC
- MAGIC-only events are excluded since the fraction for background is high
- Higher collection area can be achieved by including LST-1+M1/2 events which would be lost in MAGIC-only analysis (due to image cleaning and quality cuts)

Preliminary

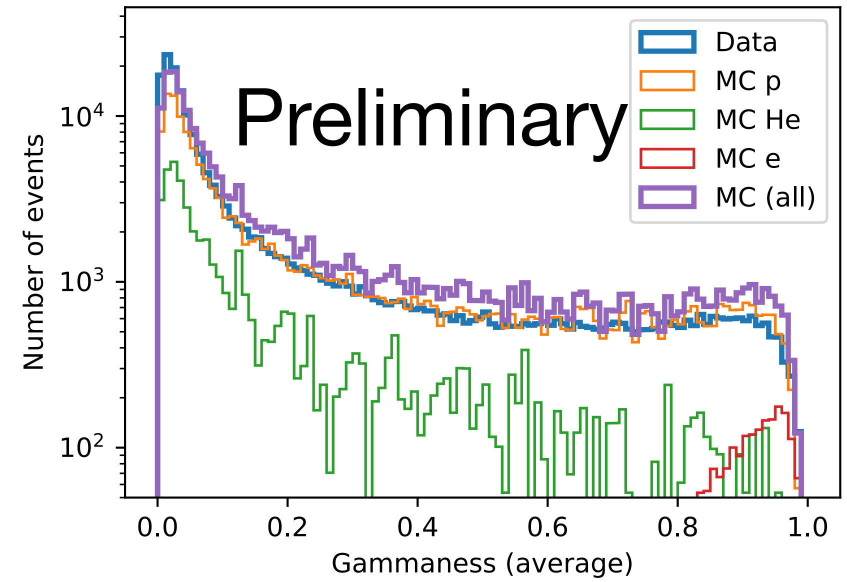
Type	MC γ (wobble)	MC γ (diffuse)	MC p	Data
M1+M2	6.2%	4.8%	20.4%	21.5%
LST-1+M1	7.1%	7.7%	6.2%	5.3%
LST-1+M2	12.5%	12.6%	11.9%	14.2%
LST-1+M1+M2	74.1%	74.8%	61.5%	59.0%

Zd < 30 deg.
# of p.e. > 50

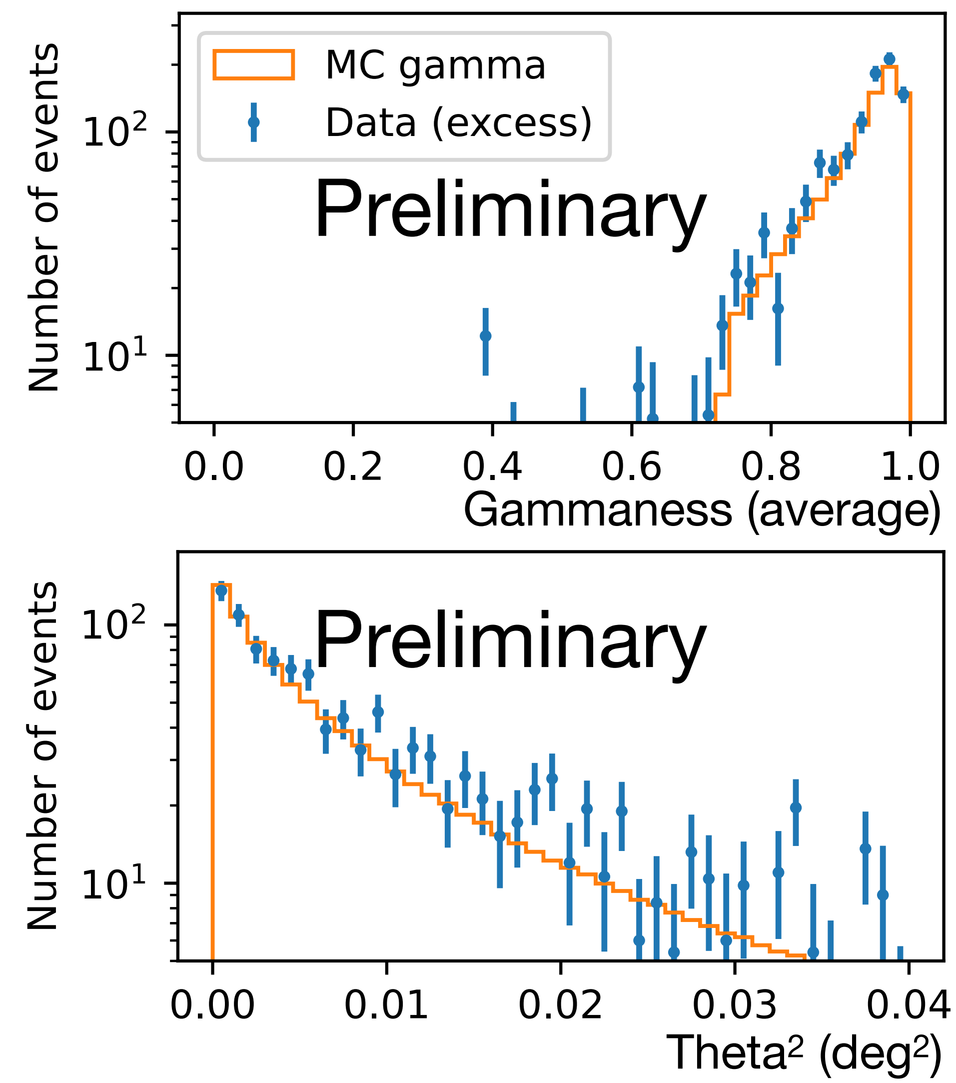
DATA-MC Agreements

- Two comparisons to check the data-MC agreements
  - Background comparison: data vs. proton+Helium (with a correction for higher elements) + electrons
  - Gamma comparison: data excess vs. simulated gammas
- Good agreements can be found in most of the parameters

Bkg comparison

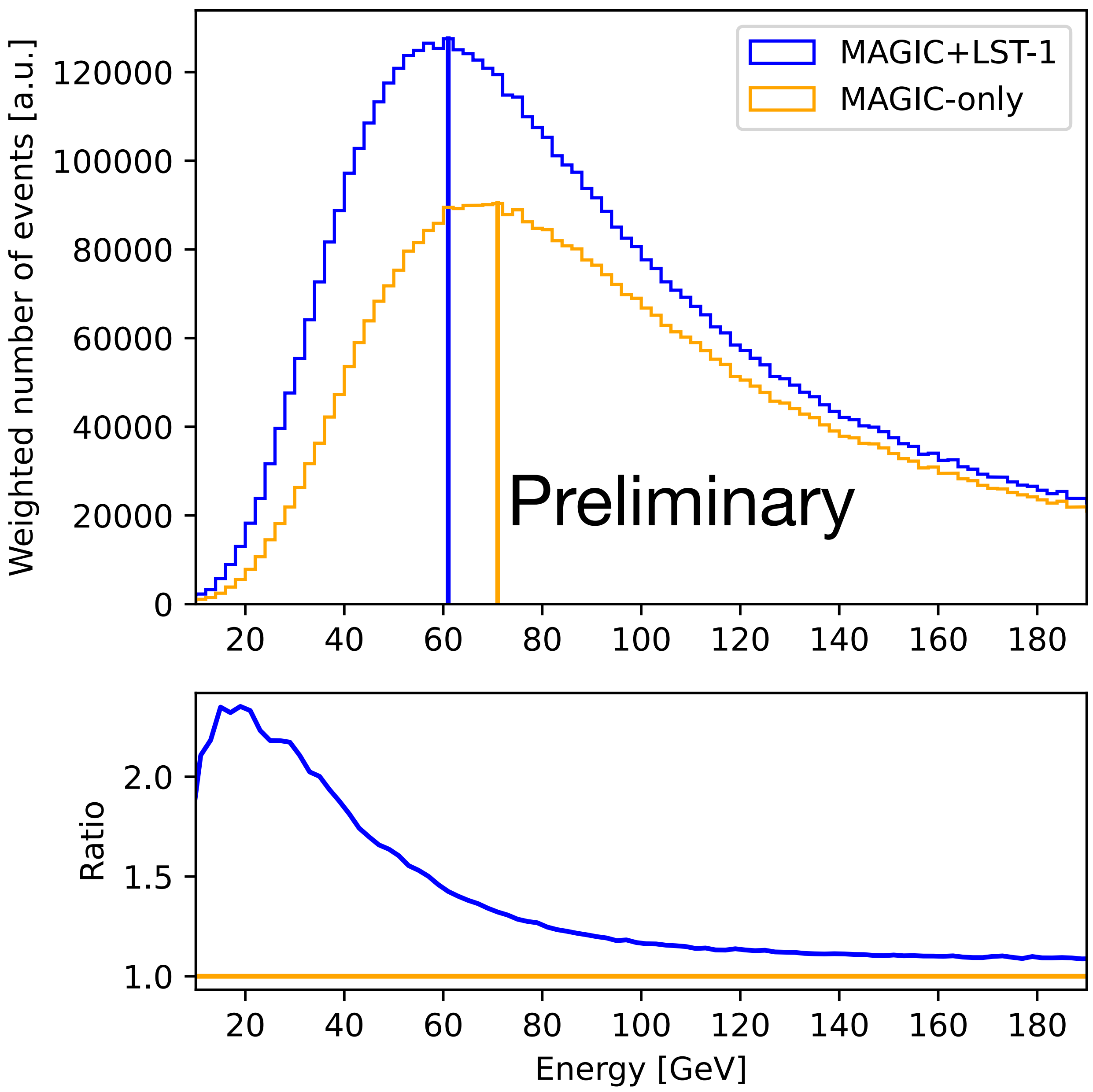


Gamma comparison



Energy Threshold

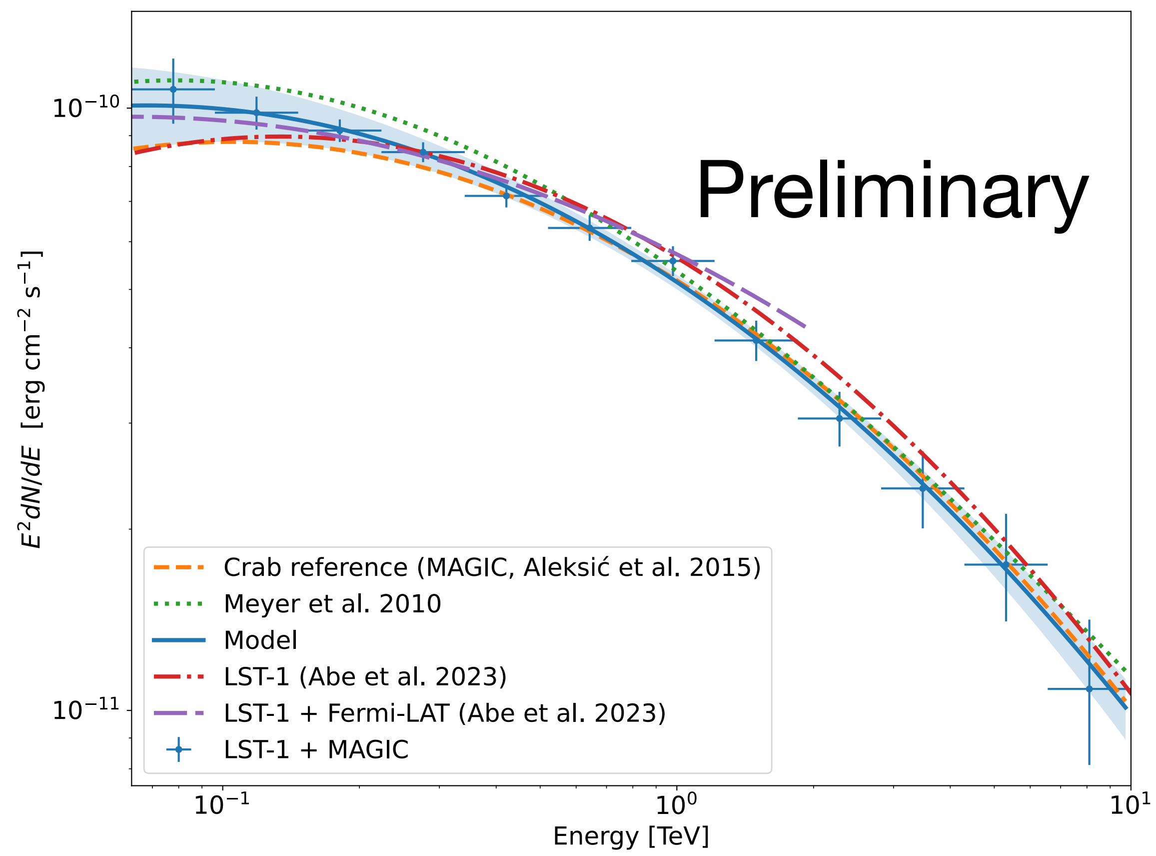
- Differential rate plot for a -2.6 slope source at the analysis level (# of p.e. > 50 cut) in Zd < 30 deg.
- **15%** improvement in the energy threshold w.r.t. MAGIC-only
- **Factor of 2** improvement in the collection area at 30 GeV w.r.t. MAGIC-only



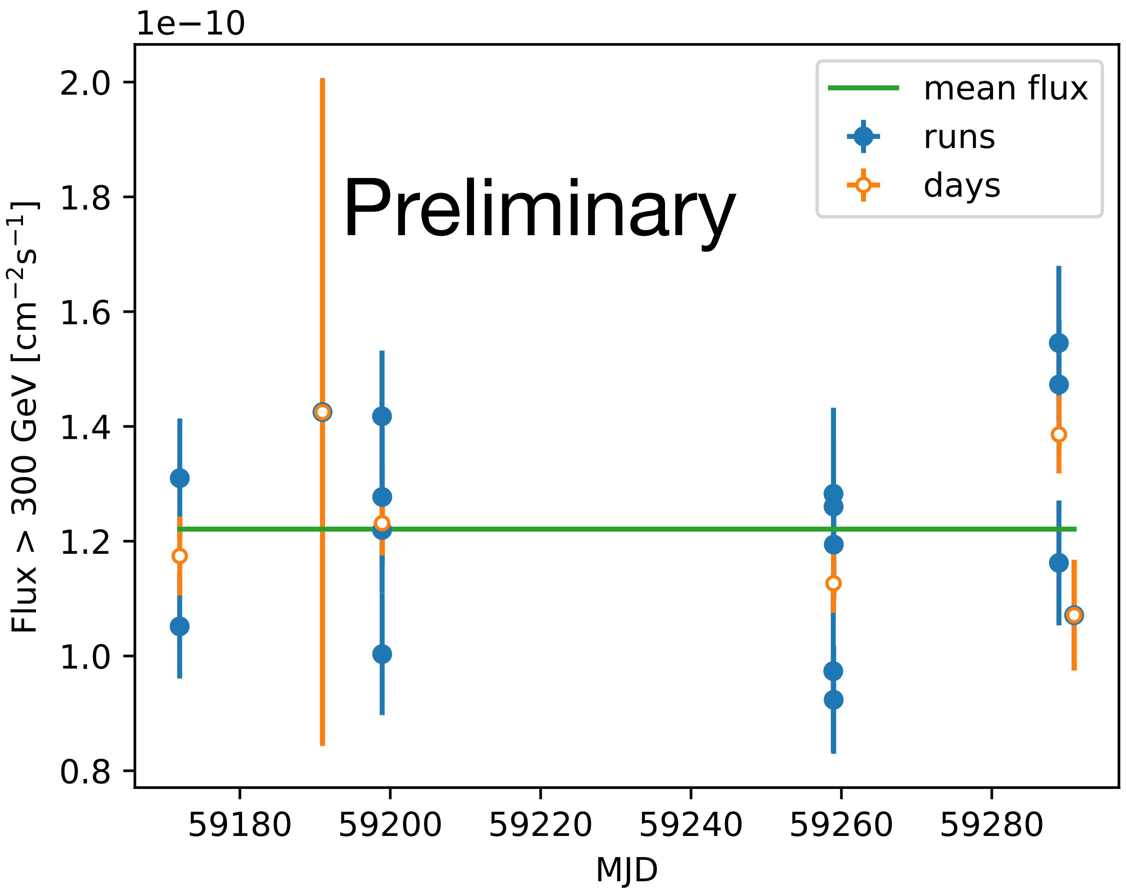
SED & Flux Stability

- The data set is mostly at mid-zenith, so that the spectrum starts from ~80 GeV. In agreement with MAGIC and LST-1 curves within 10%
- Flux stability plot tells us a small relative systematic uncertainty needs to be considered to achieve consistency with a constant flux (comparable to MAGIC and LST-1)

SED (Crab Nebula)



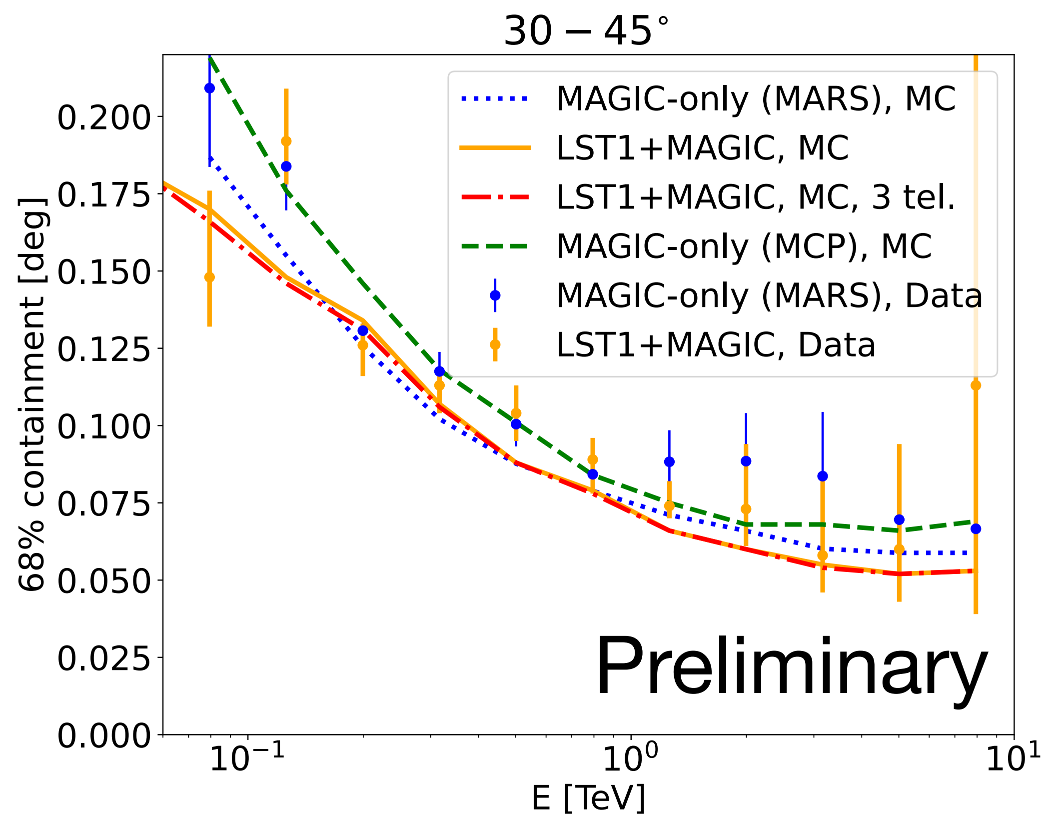
Flux stability (Crab Nebula)



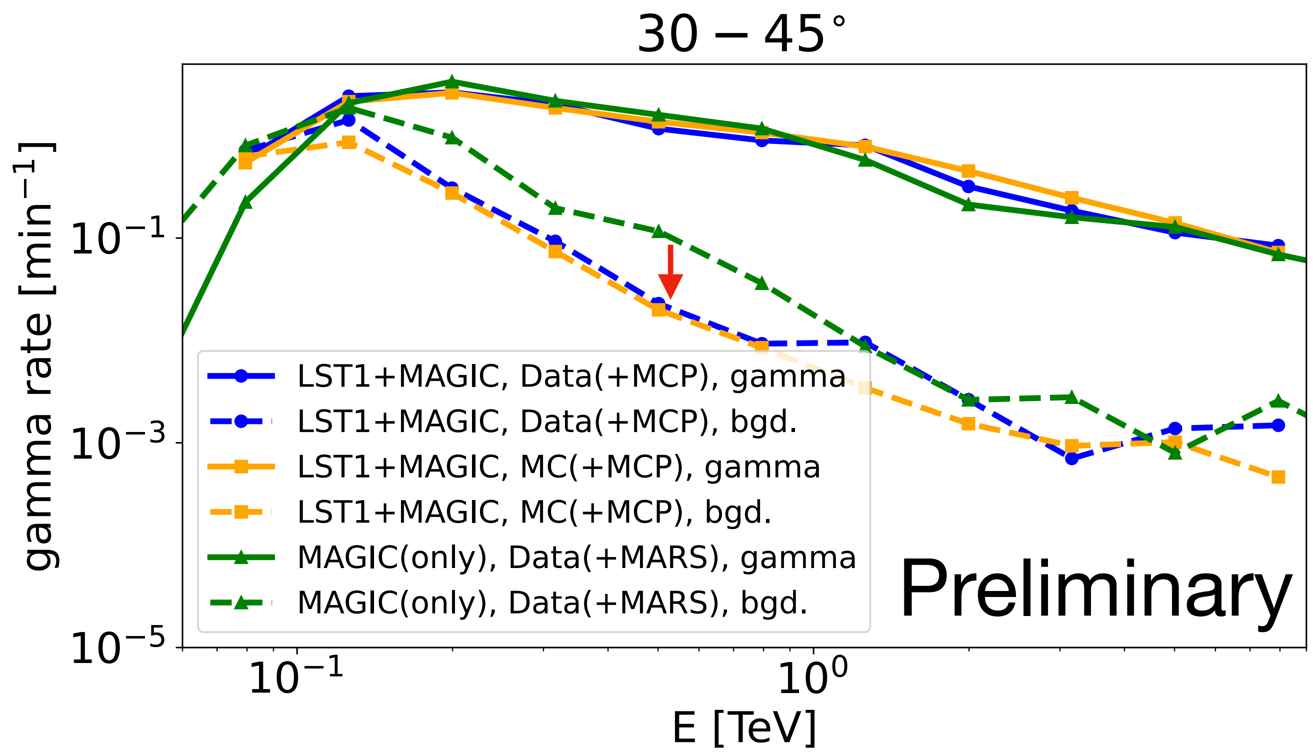
- Angular resolution in joint analysis is comparable to that in MAGIC-only MARS analysis. MARS can reconstruct gamma-ray direction better than MCP for MAGIC-only data. Further optimization in MCP can be performed

- While there are no big improvements in both energy and angular resolutions in joint analysis, the background rejection power is found to be higher → Better sensitivity

Angular resolutions

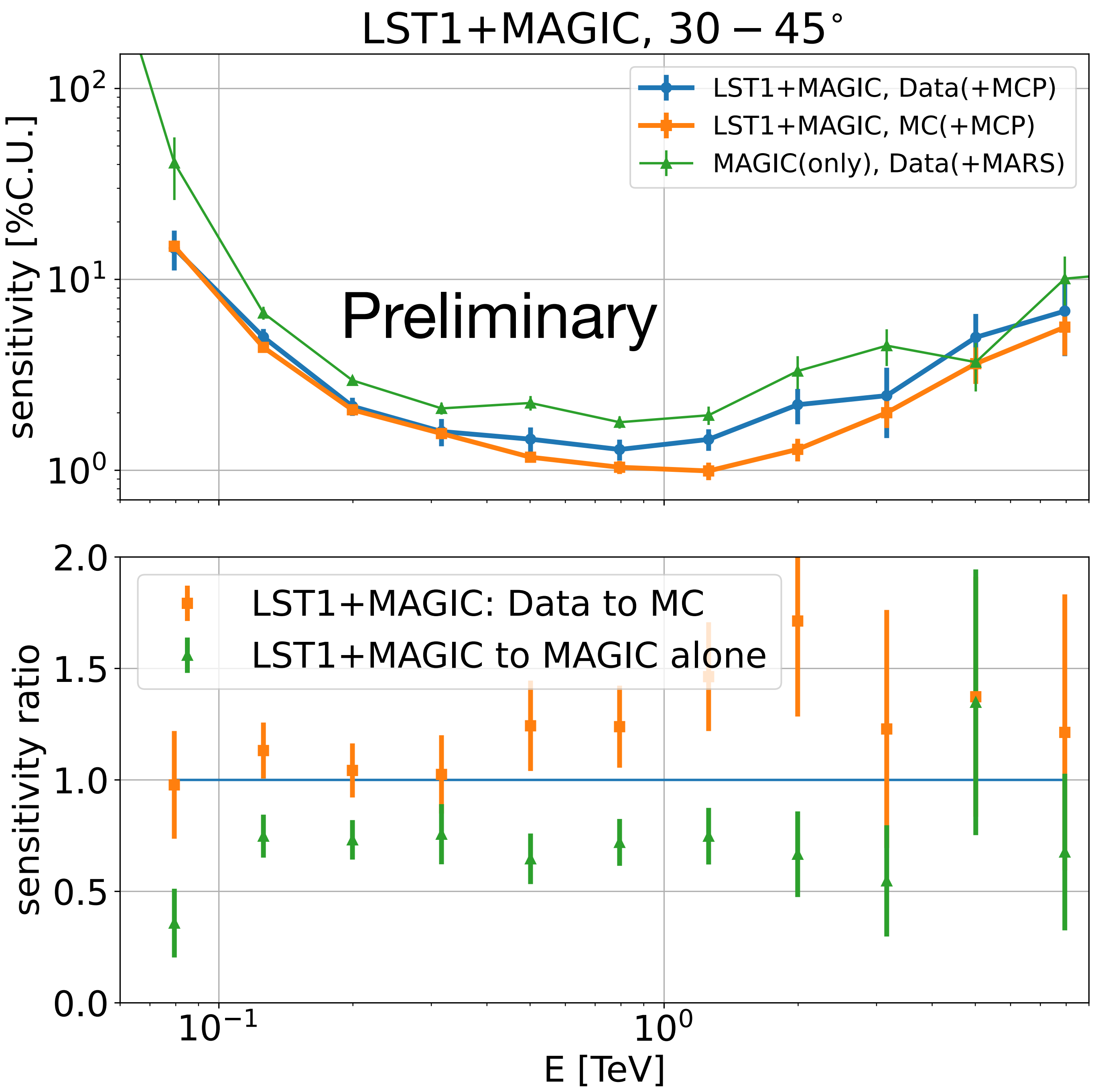


Gamma-ray/Background rates



Differential Sensitivity

- Some data-MC sensitivity mismatch above a few 100 GeV, which is also visible in a MAGIC-alone paper
- Joint observations can detect **30% (40%) weaker flux** than MAGIC (LST-1)
  → **Twice (three times) shorter observing time required!**
- Similar improvement can be seen in low-Zd (< 30°)



Summary

- Taking advantage of the proximity of the telescopes, we can observe the same shower events under a good coordination between the two collaborations
- Joint simulation and analysis chain have been developed in accordance with the CTA standard
    - Good data-MC agreements in most of the parameters
    - Energy threshold: 15% improvement
    - Collection area: a factor of 2 improvement at 30 GeV
    - Reasonable flux reconstruction achieved
    - Detection of 30% (40%) weaker flux than MAGIC (LST-1) is possible thanks to the better background rejection capability
- We can explore extreme universe by utilizing joint observations two times faster than our previous observations
- Joint performance paper is under a journal review
- LST-1 is the first major operating element of CTAO, and the verification of performance with MAGIC is a key step towards building the full observatory!