MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

MAX-PLANCK-INSTITUT FÜR PHYSIK

cta cherenkov telescope array

Performance of joint observations with LST-1 and MAGIC

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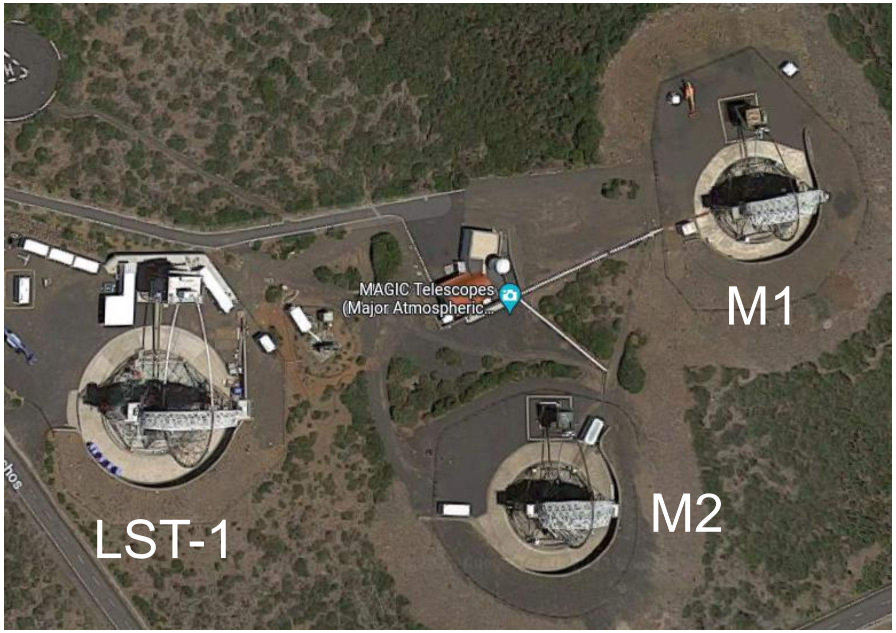
on behalf of the CTA-LST Project
and the MAGIC Collaboration

TeVPA 2023, September 2023

MAGIC and LST-1



- MAGIC has two 17m Cherenkov telescopes, operating since 20 years (~14 in stereoscopic mode)
- LST-1 is the first LST (Large-Sized Telescope) prototype of the upcoming CTAO
- Both MAGIC and LST-1 are located in the ORM (Observatorio del Roque de Los Muchachos)

- Separation between telescopes is ~100m
  - similar to radius of the Cherenkov pool, so events can trigger all three telescopes --> JOINT ANALYSIS
  - possible cross-calibration between the instruments

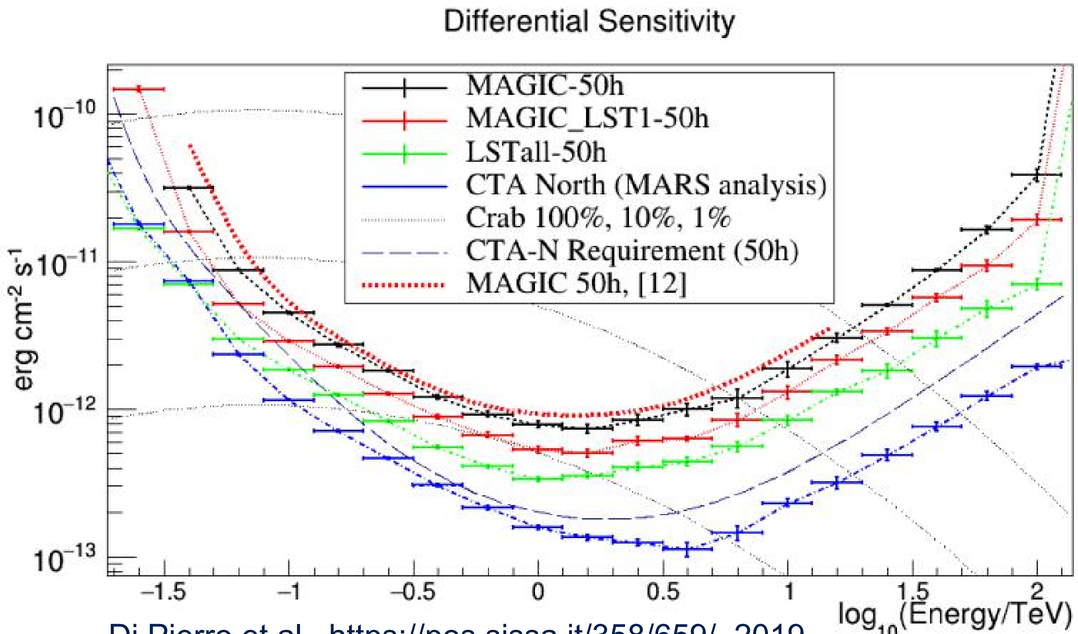
Why joint observations?

- The low-energy performance of a single Cherenkov telescope, like LST-1 at this moment, is limited by large background: stereoscopic reconstruction greatly reduces the background

- Previous studies on simulations showed a ~1.5 factor of improvement in sensitivity for MAGIC+LST-1, compared to MAGIC alone

- Therefore, clear advantage in having MAGIC+LST-1 observations

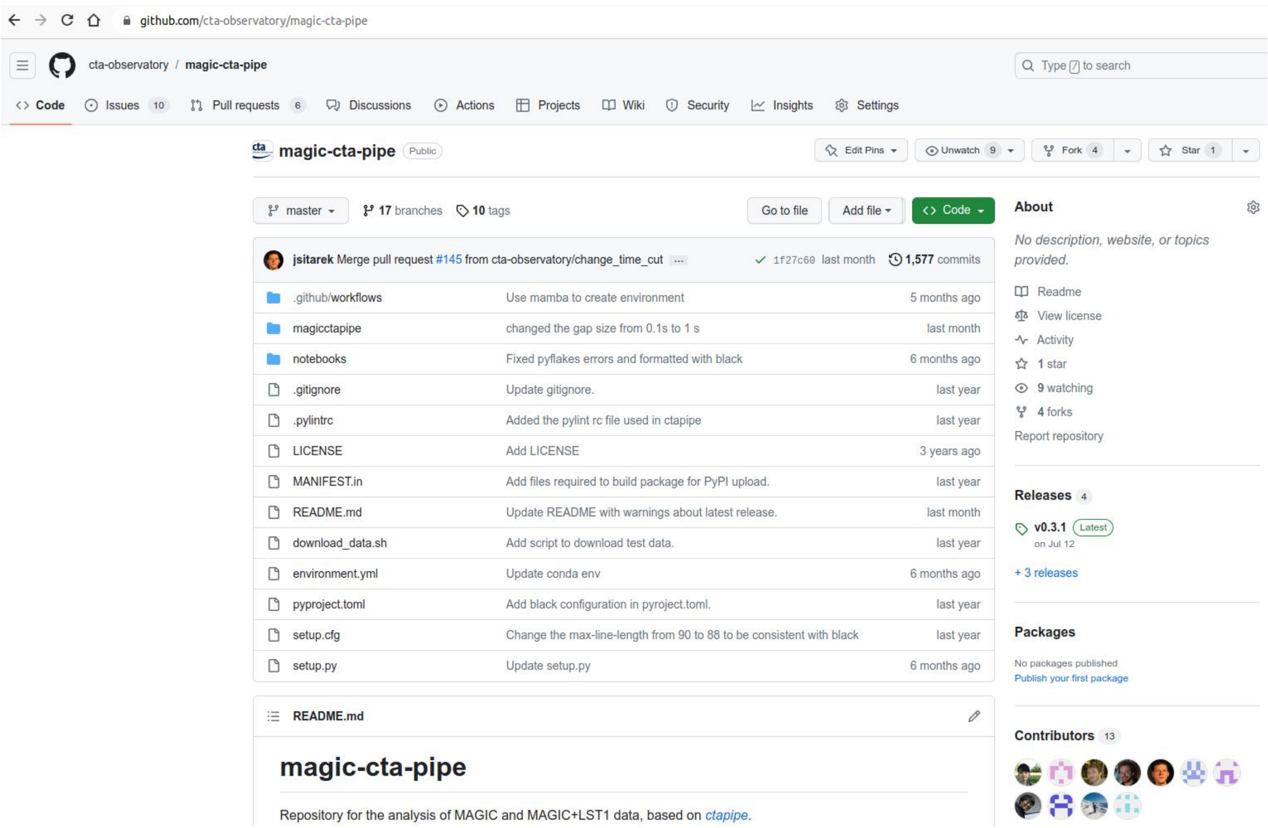
- Also, precursor of stereo analysis of CTAO telescopes



Di Pierro et al., https://pos.sissa.it/358/659/, 2019

Common simulation and analysis famework

- **CORSIKA+sim_telarray** for MonteCarlo simulations (same as used in CTA/LST-1)
- a pipeline called **magic-cta-pipe** (aka [MCP](), public repository), based on *ctapipe*, for the data analysis



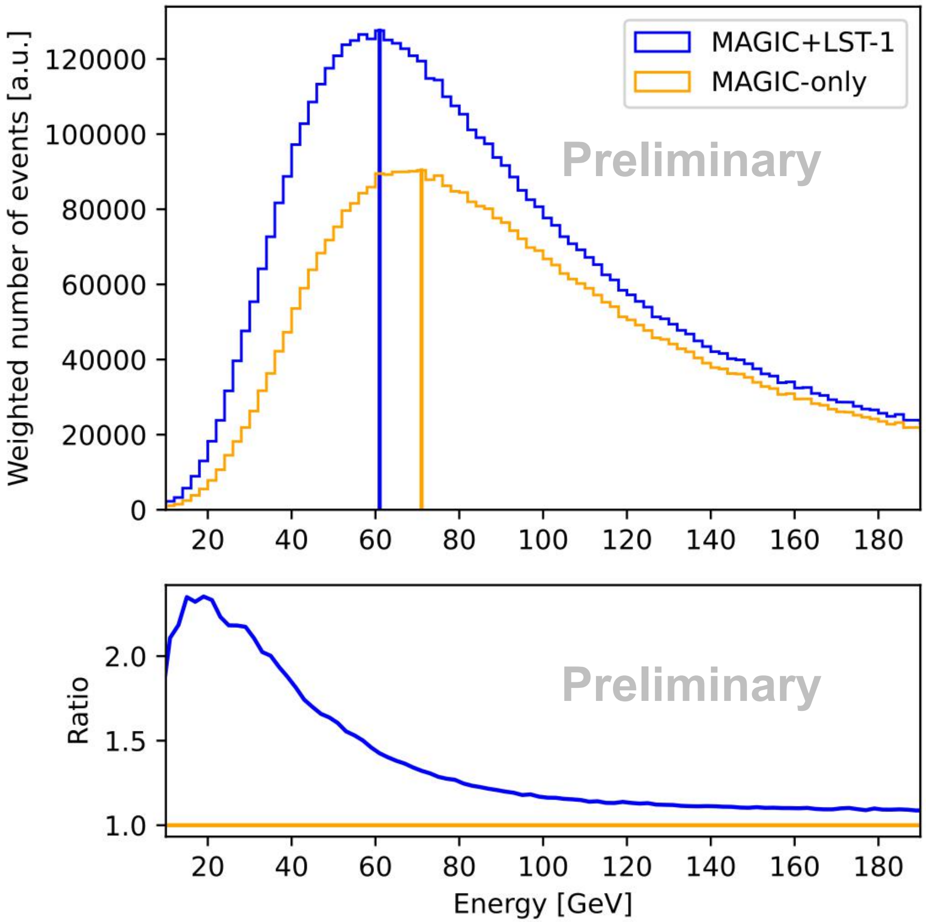
MAGIC+LST-1 coincident events

- No hardware trigger available yet: coincidence of events is performed offline via software using the events GPS timestamp

Type	MC γ (0.4°)	MC γ (0 – 2.5°)	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%

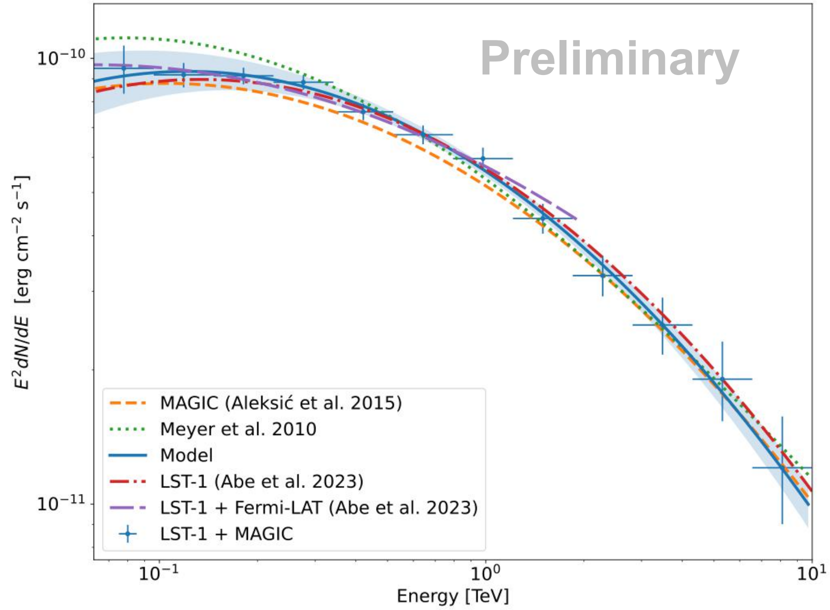
- Three-telescopes events are the dominating fraction and LST-1 sees most of the events that MAGIC sees
- MAGIC-only events in 3-telescope analysis are mostly background --> removing them improves background rejection!
- Recovering events that in MAGIC-only analysis would be rejected because they do not pass the selection (i.e. too dim images) in one of the two MAGIC telescopes --> increase in collection area!

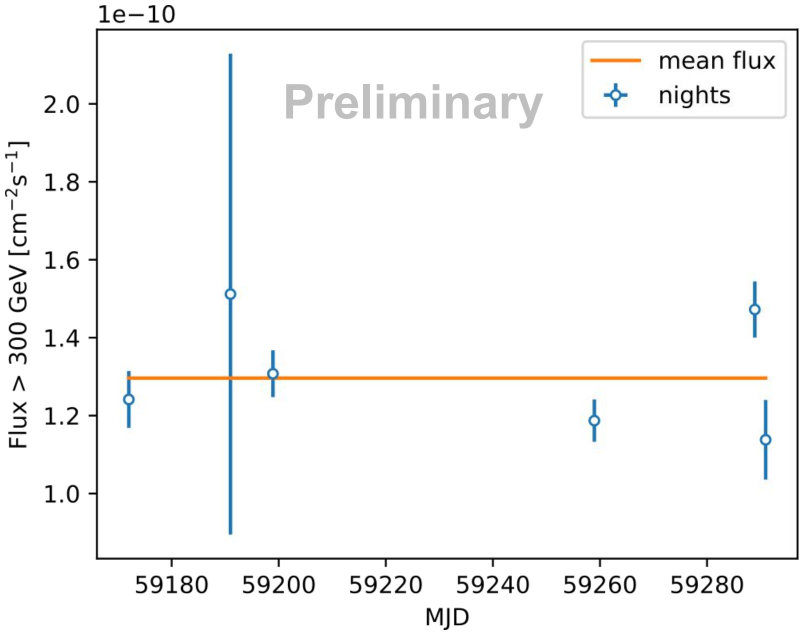
Energy threshold (reconstruction level)



- The energy threshold, considering events with at least two images, goes down from 70 GeV (MAGIC-only) to 60 GeV (MAGIC+LST-1)
- The collection area is also higher, especially at low energies
  - factor ~2 at 30 GeV
  - factor ~1.5 around 50 GeV
  - factor ~1.2 around 100 GeV

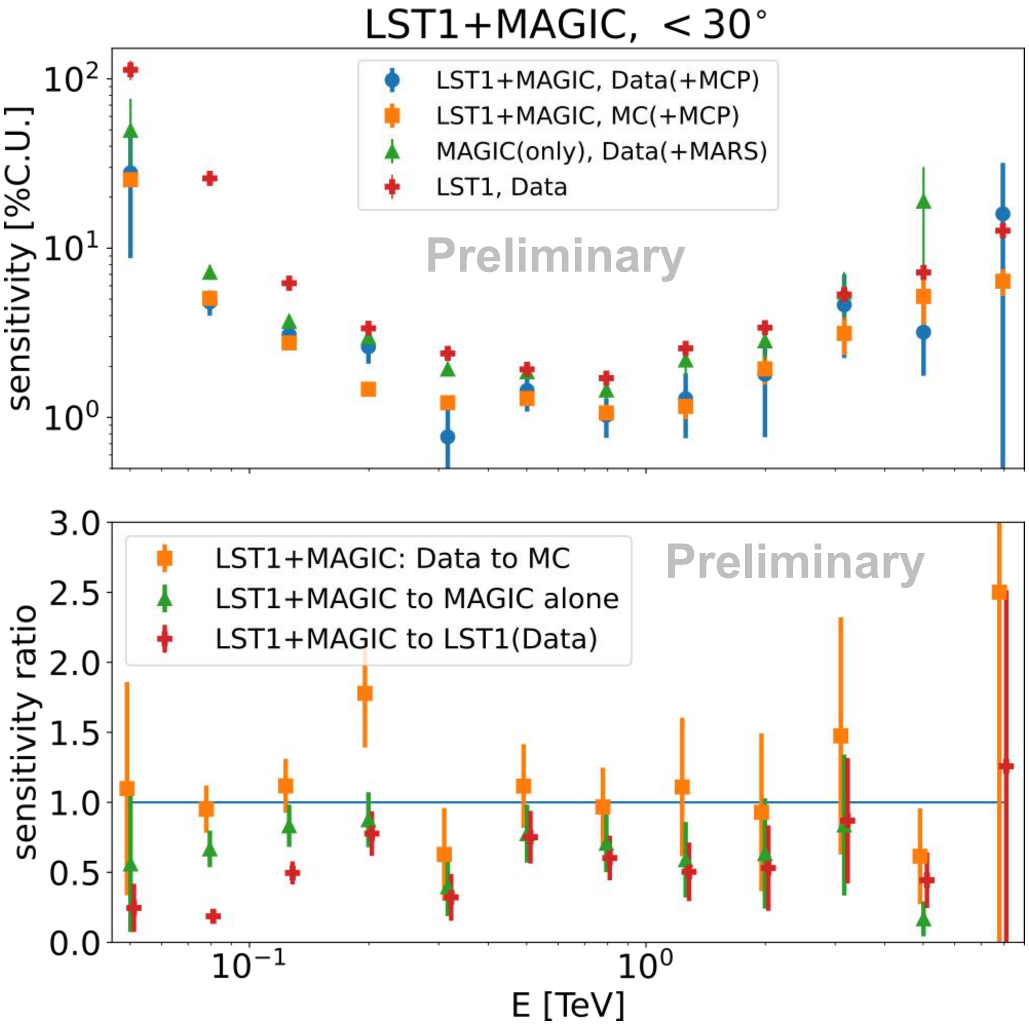
Crab Nebula spectrum and light curve





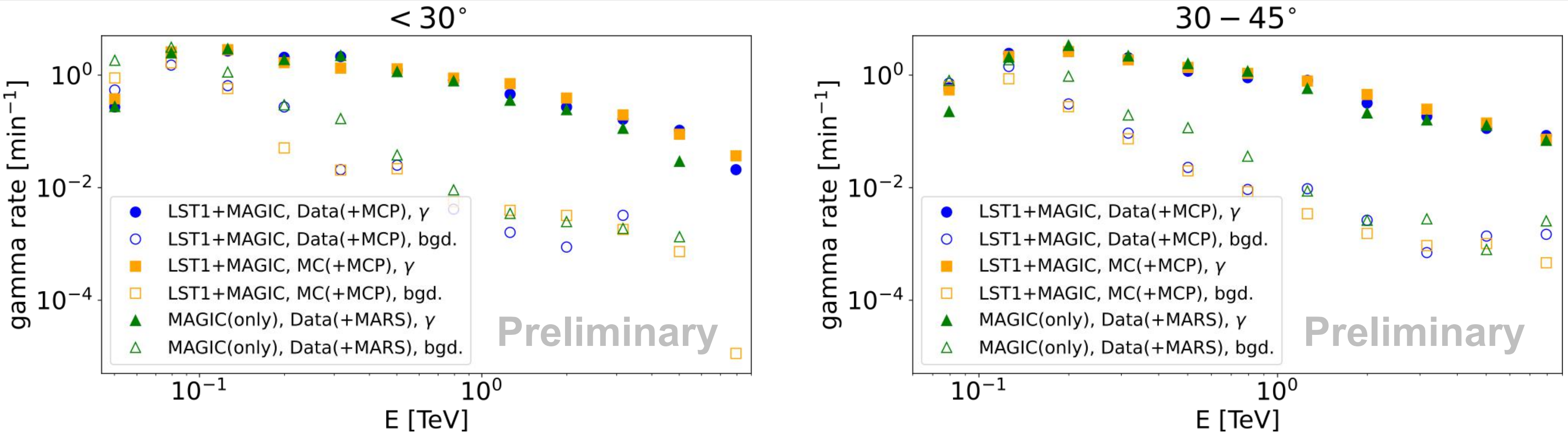
- Using ~4h of data from the Crab Nebula (period: October 2020-March 2021)
- Spectrum is consistent within ~10% with previous measurements
- Light curve shows some flux instability, probably related to systematics --> ~12% (8%) systematic uncertainty needed for run-by-run (night) analysis to be consistent with a constant flux (similar to MAGIC studies)

Differential flux sensitivity



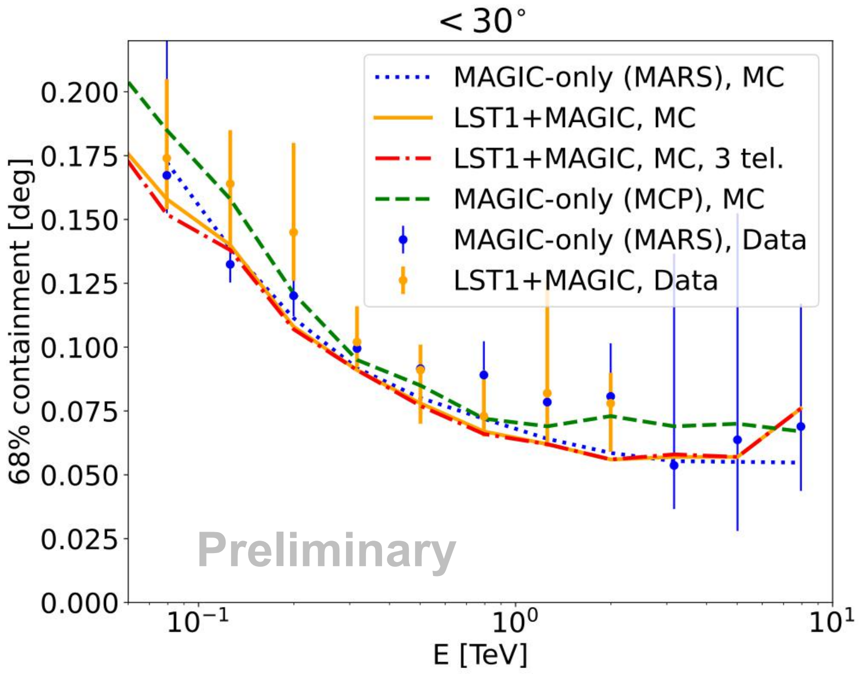
- Joint observations allow detection of 30% (40%) lower fluxes than MAGIC alone (LST-1 alone)
- Main reason is the better background rejection (see next slide)
- Increased sensitivity translates in less observation time to detect the same flux level

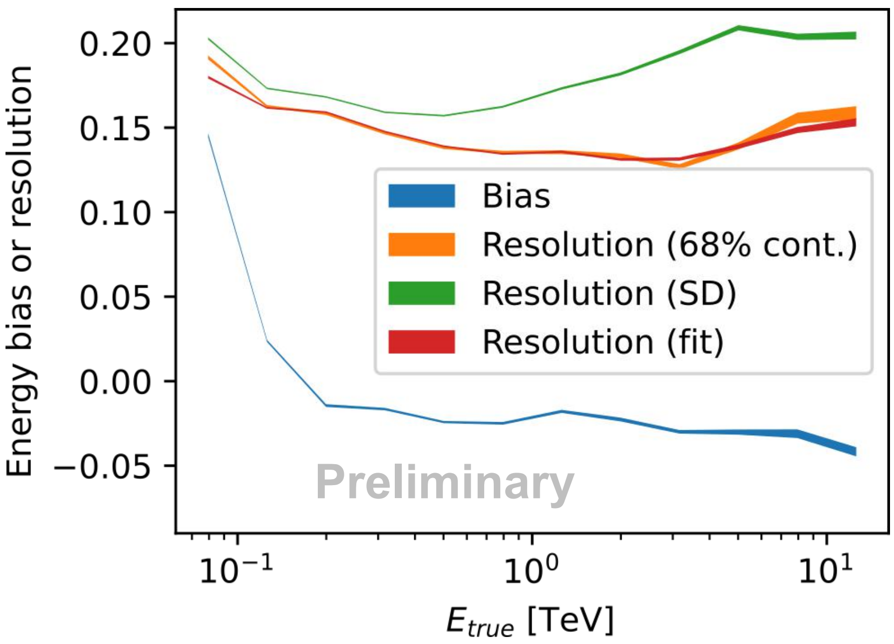
Gamma/background rates comparison



- Better background rejection across almost all the energy range, which improves the sensitivity
- Some improvement of gamma-ray rate at multi-TeV energies: either the cuts can be relaxed, or additional high impact events are reconstructed

Angular and energy resolution





- Angular and energy resolution show only slight improvements wrt MAGIC-only: probably due to optimized methods used in MAGIC-only analysis and not implemented in MAGIC+LST-1

- Some data/MC mismatches at high energies for angular resolution

Summary

- Proximity of MAGIC and LST-1 makes joint analysis possible
  - a pipeline was developed for this specific purpose
  - first study of stereoscopic analysis scheme applied to the data taken with a prototype of a CTA telescope

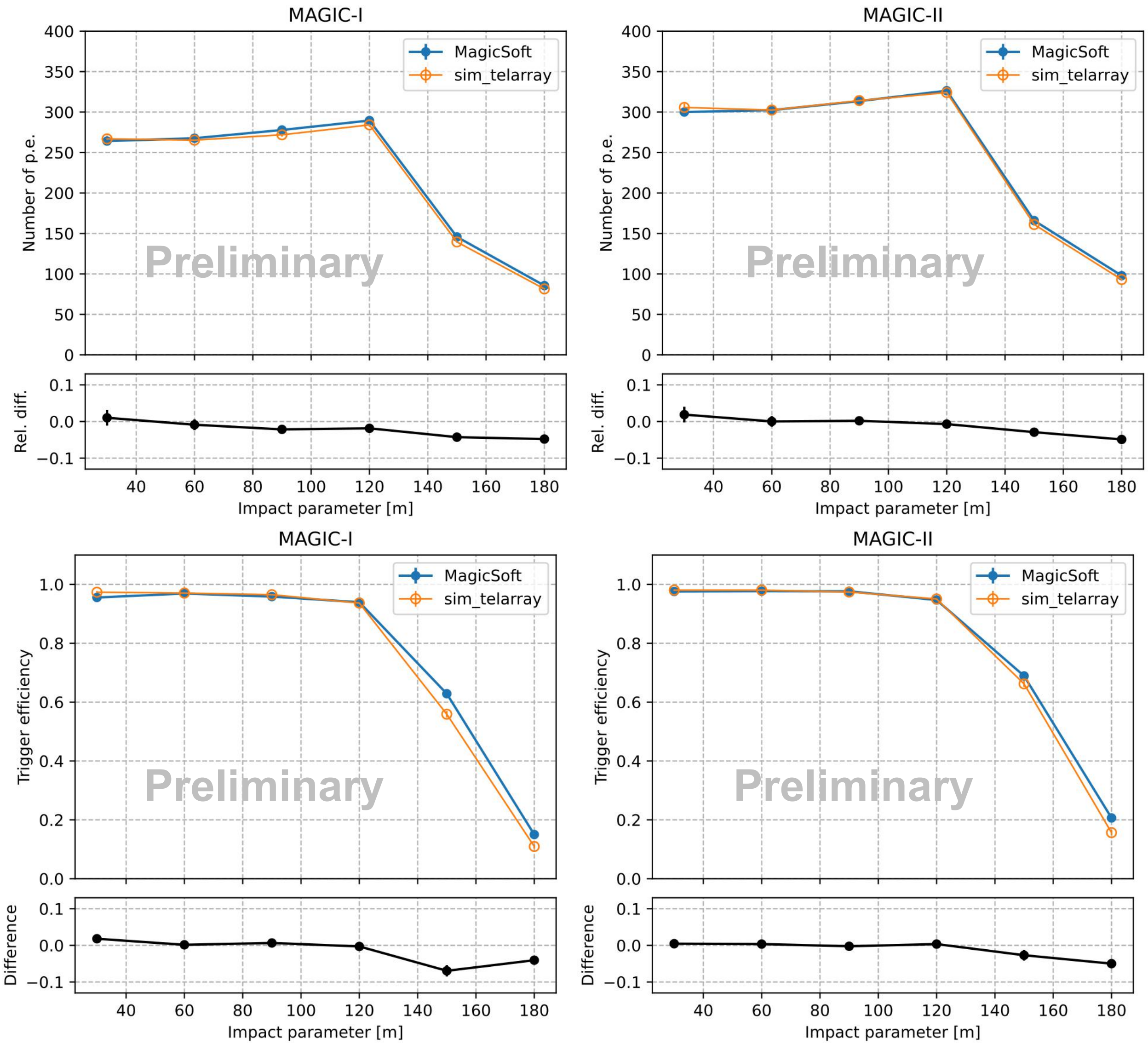
- Good match between the MAGIC+LST-1 reconstructed Crab Nebula spectrum and previous measurements

- Joint observations allow detection of 30% (40%) lower fluxes than MAGIC alone (LST-1 alone)
  - mainly better background rejection
  - less observation time!

- “Performance paper” under review: stay tuned for the final publication!

BACKUP

Simulation validation

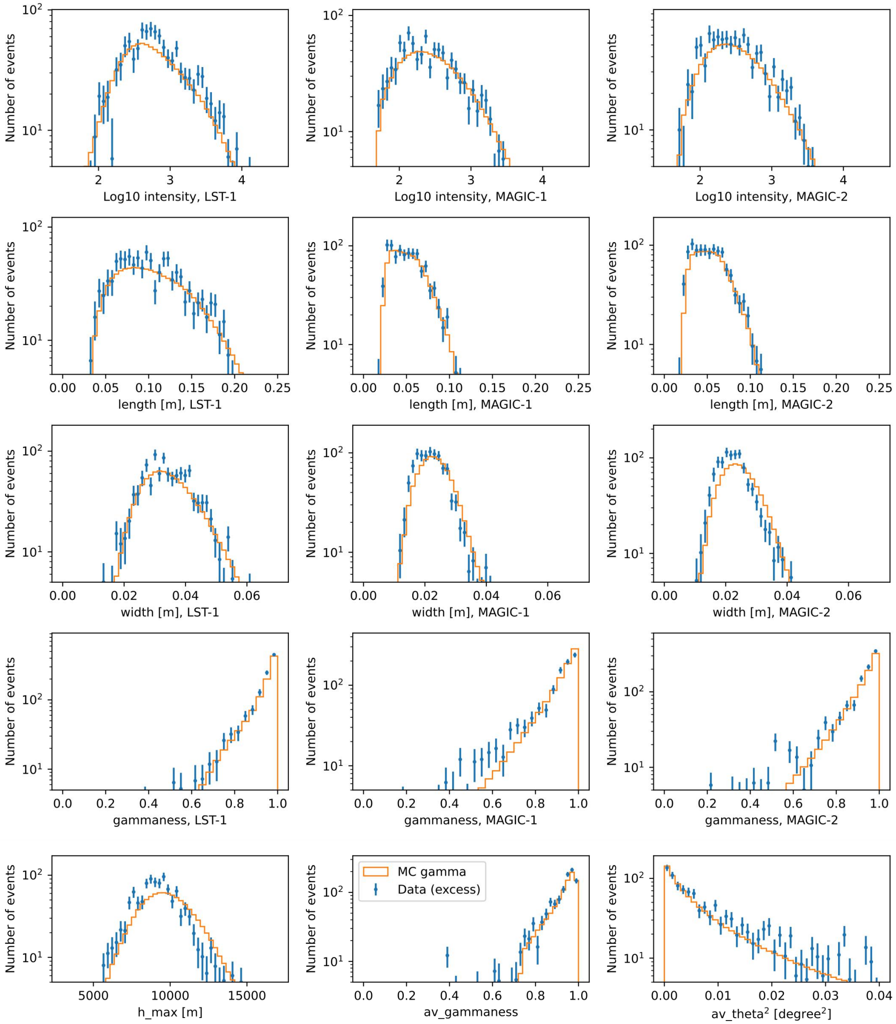


- Validated sim_telarray simulation of MAGIC telescopes with 100 GeV vertical gamma-ray showers, at different fixed impact parameter

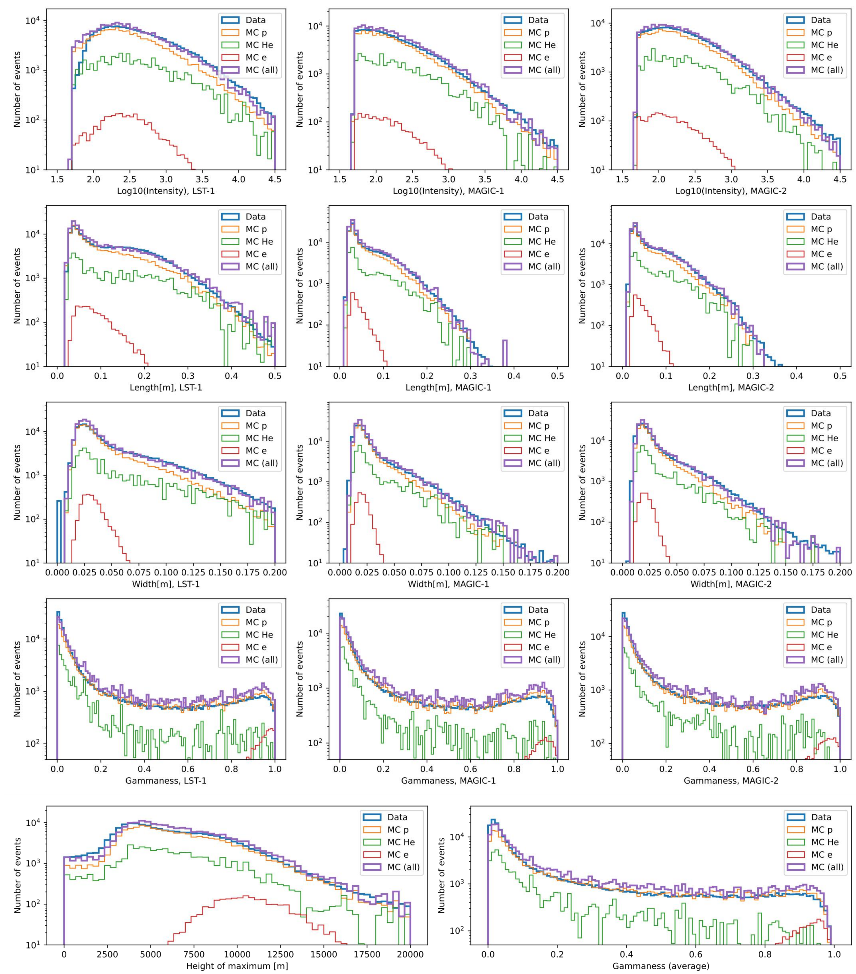
- Compared the reconstructed true number of p.e. and trigger efficiency, agreement at few % level

Data-MC comparisons

MC gamma-rays and gamma-ray excess from data



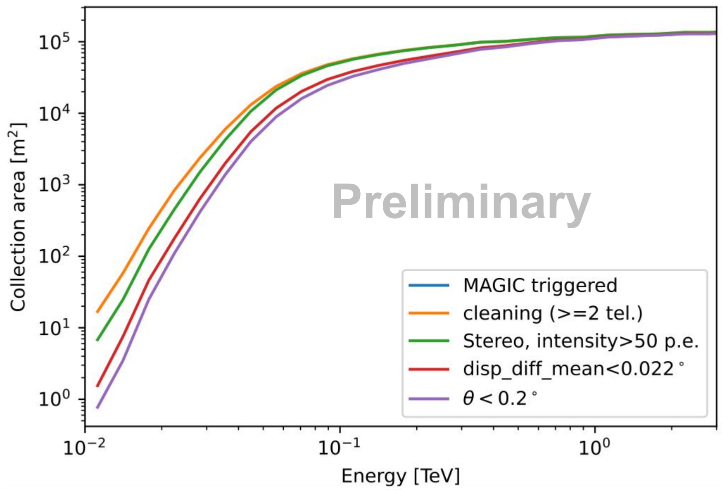
MC (p, He, e) and data

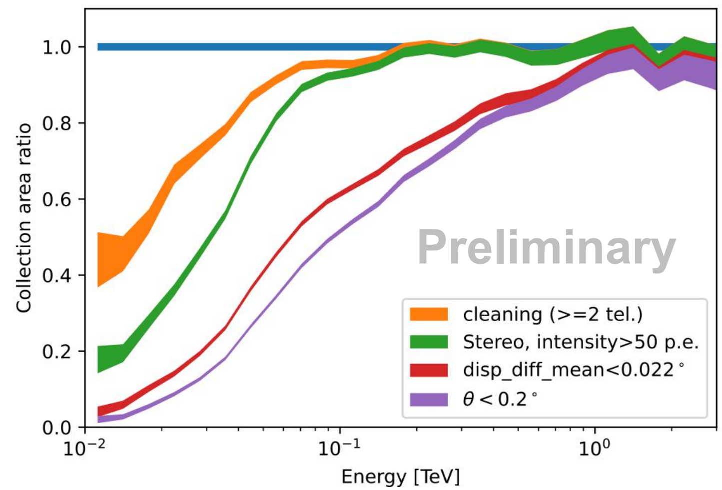


Preliminary

Preliminary

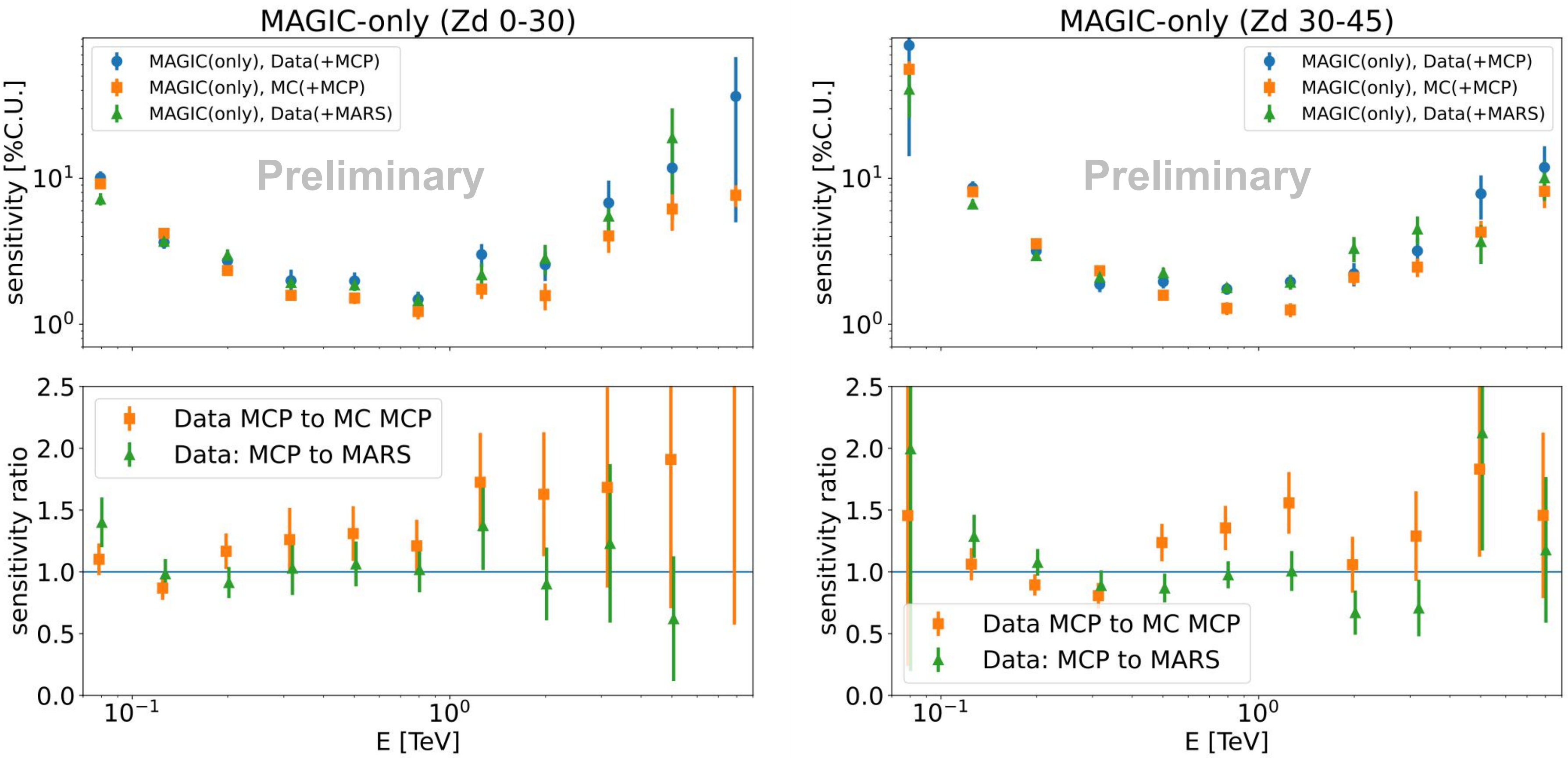
Effective area





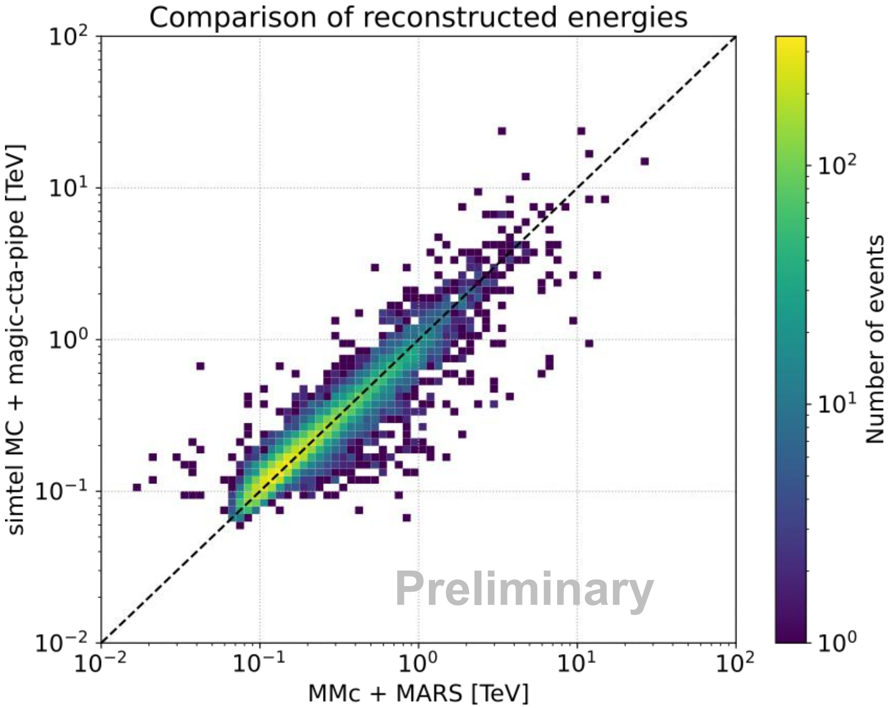
- Collection area for simulated gamma rays, for zenith=10 degrees and different level analysis stages
- For energies above 80 GeV, most MAGIC events survive stereoscopic reconstruction
- Drop when requiring agreement between the reconstructed position in different telescopes

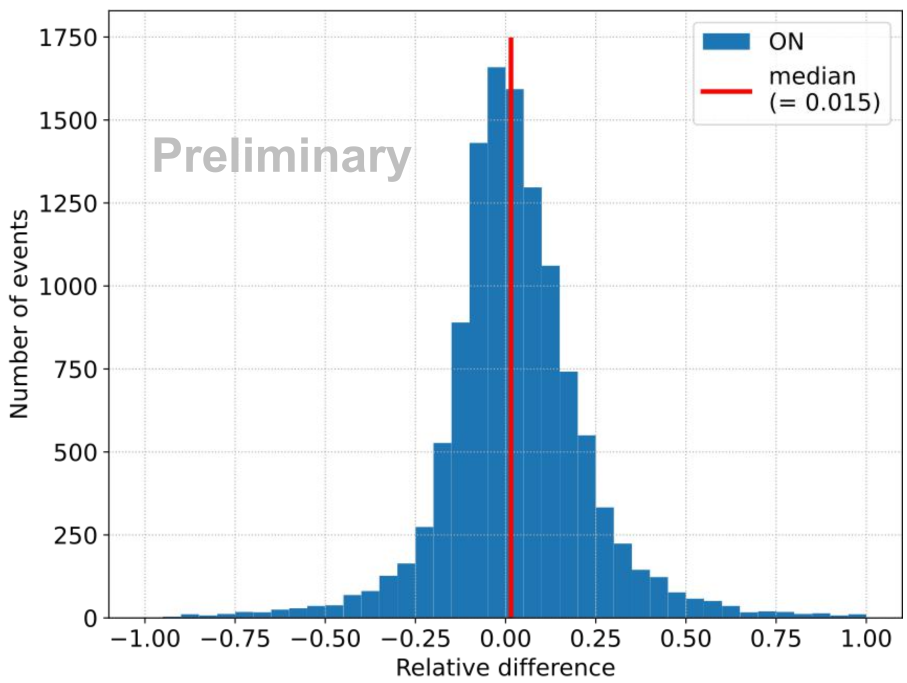
MAGIC-only sensitivity



Good agreement, especially in medium energy range, between sensitivities obtained on MAGIC-only data analyzed with MARS and MCP

Energy reconstruction





Comparing the energy estimation of the same gamma-like events for MAGIC-only events reconstructed with MARS and MCP, consistency around 2%