THE CRAB NEBULA SPECTRUM AT ~ 100 TEV MEASURED WITH MAGIC UNDER VERY LARGE ZENITH ANGLES

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OUTLINE

Introduction

- Crab Nebula at the highest energies
- Why larger zenith angles?
- Very Large Zenith Angle observations

Methods

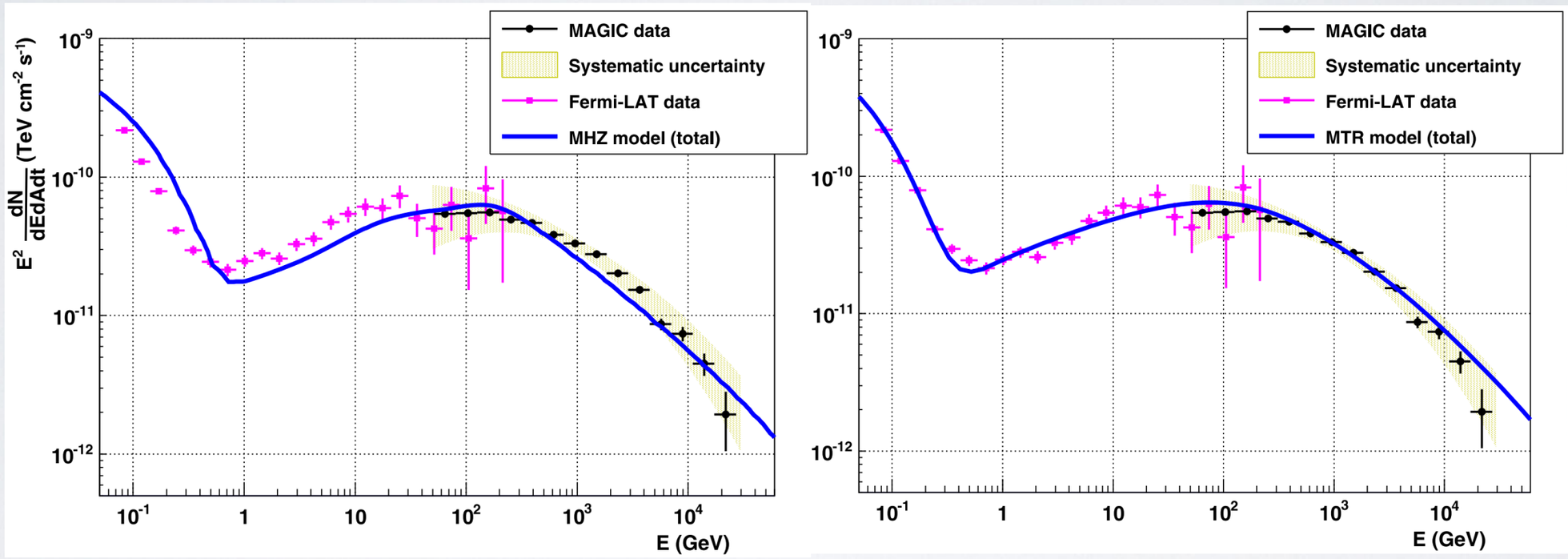
- Data analysis overview
- Systematics overview

Results

Summary

CRAB NEBULA AT HIGHEST ENERGIES

- Leptonic models used frequently to describe broad-band emission
- Notable models weak at keV → MeV and GeV → TeV data



MAGIC and Fermi-LAT data [1] against MHZ [2] (left) and MTR [3] (right) models

- The 10 → 100 TeV energy range can be useful to probe both regimes

WHY LARGER ZENITH ANGLES?

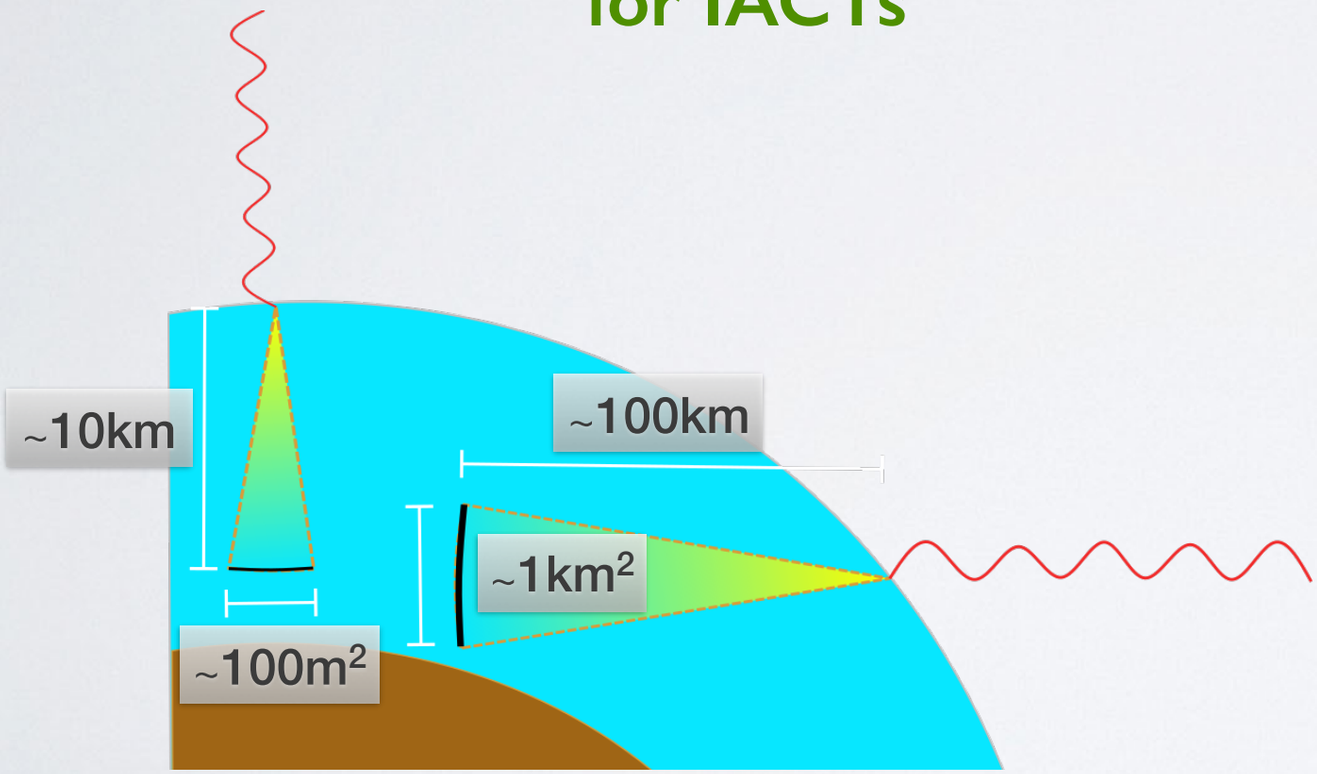
- **γ**-ray count rate drops fast at E >10 TeV
- IACTs effective collection areas limited by Cherenkov light-cone from **γ**-ray induced showers
- 2 immediate solutions
  - **Bigger arrays** of IACTs (e.g. CTA)
  - **Very Large Zenith Angle observations** (this work)

VERY LARGE ZENITH ANGLE OBSERVATIONS

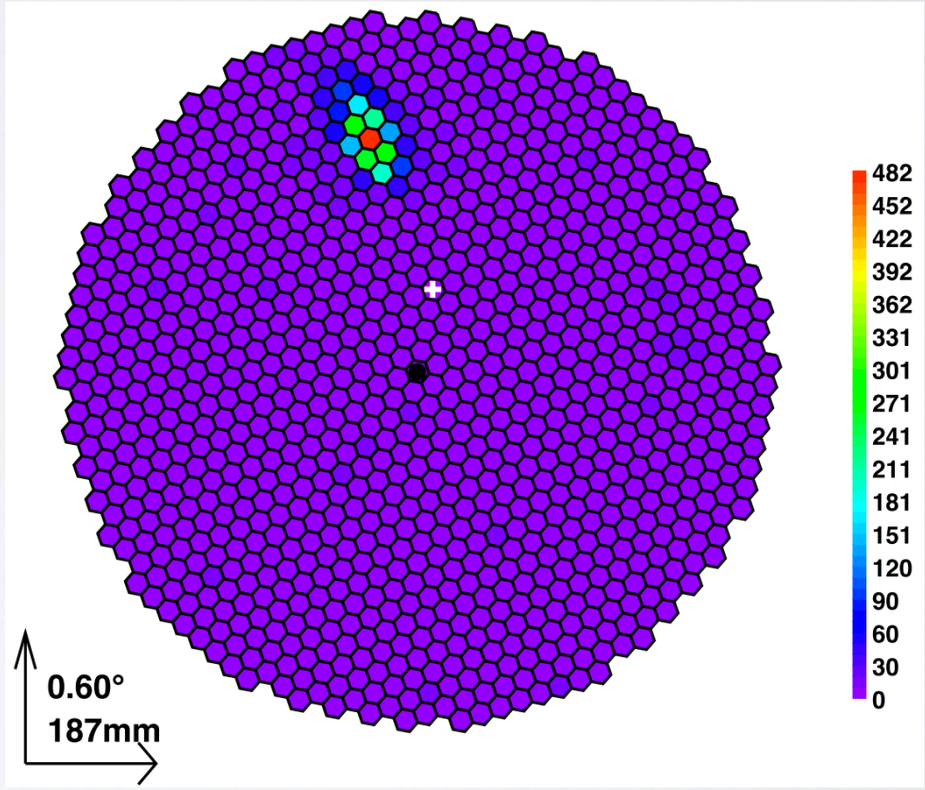
bigger collection areas

improved sensitivity at higher energies

increased operational range for IACTs



higher energy thresholds
increased light attenuation



VLZA event example: 77.8° @ 144.4 TeV [4]

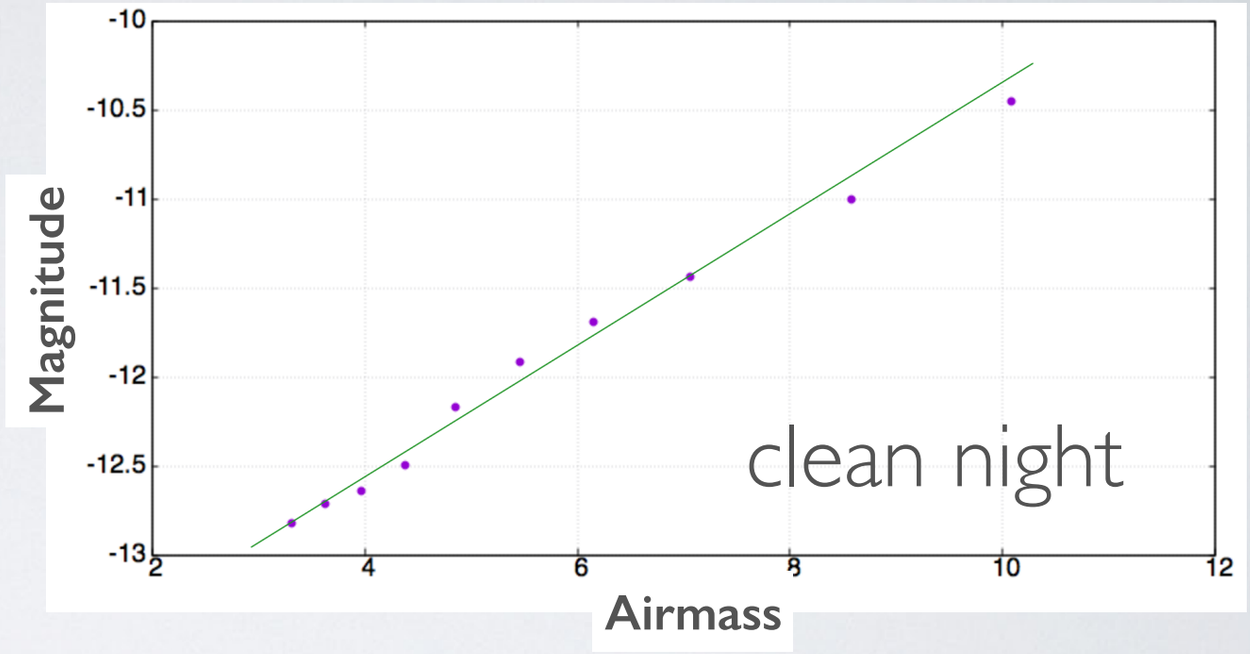
See also **VLZA technique poster - Session 3 #86, PoS(ICRC2019)828**

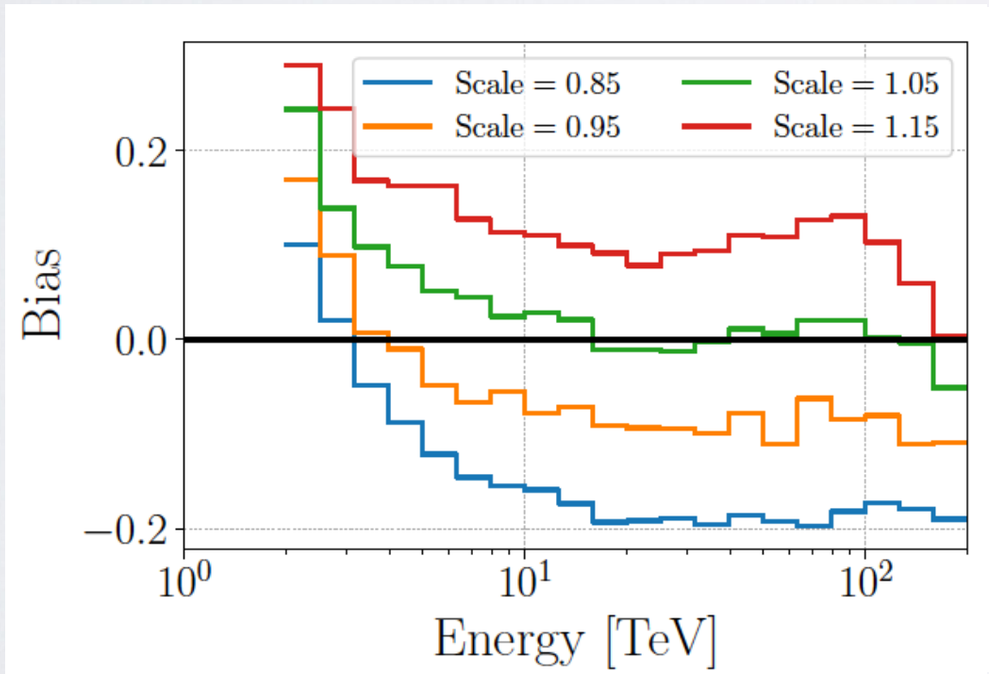
DATA ANALYSIS OVERVIEW

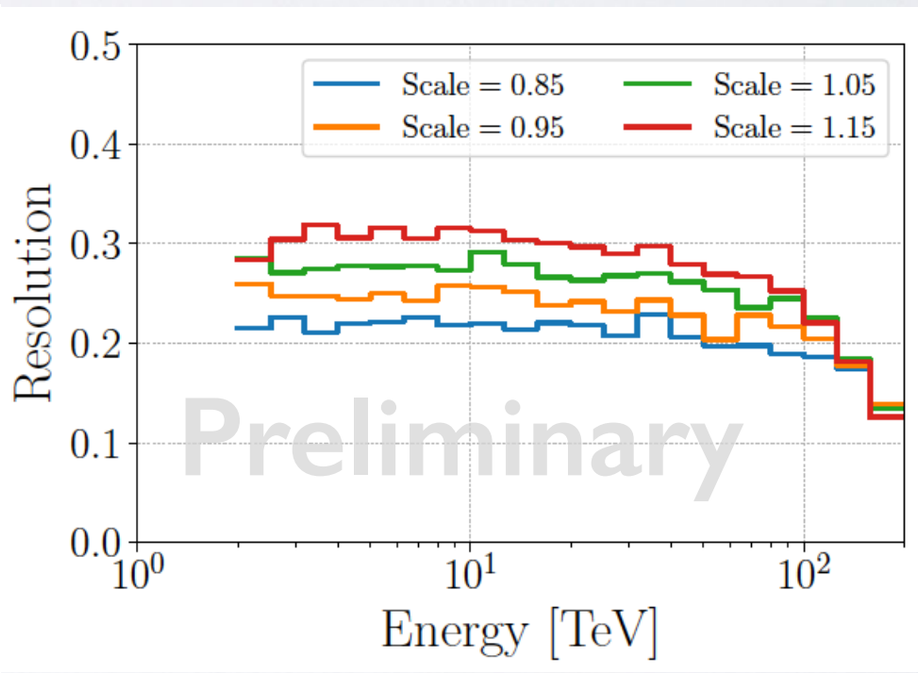
- Optimizes standard approach for VLZA data
  - Monte Carlo : tuned simulations 70° → 80° Zd
  - Atmospheric absorption : use bright stars to estimate optical absorption along Cherenkov spectrum
  - Data quality : cross-correlation between multiple MAGIC subsystems
    - #stars in FoV, Direct Current, Stereo Trigger Rates

ABSORPTION AND ENERGY ESTIMATION

- Background-subtracted CCD counts from bright stars
- 640 nm, 530 nm, 450 nm every 90 sec
- 1% uncertainty on counts + ~5% on unabsorbed counts

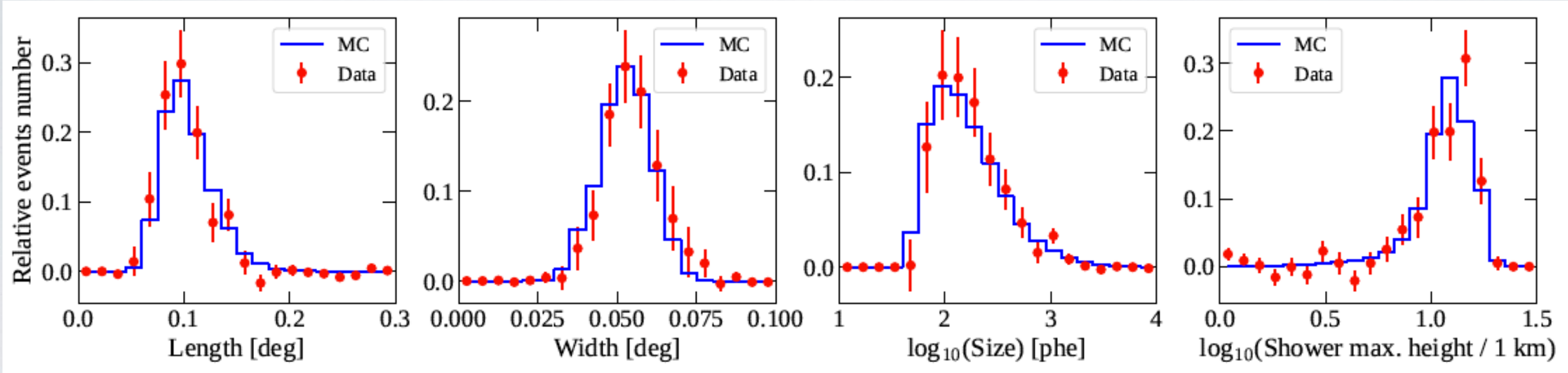






Additional estimate of energy uncertainties via up to 15% MC light-scaling: bias < 35%

MONTE CARLO TO DATA COMPARISON



Real data deviates from simulated by less than 2σ for each parameter

Loose cuts, e.g.

- Charge in cleaned image > 50 phe
- Estimated energy > 1 TeV
- impact within 1e5 cm

OVERVIEW OF SYSTEMATICS

- Mostly compatible with latest estimation of MAGIC hardware performance [5, 6]

- VLZA systematics affects mainly reconstruction techniques performances

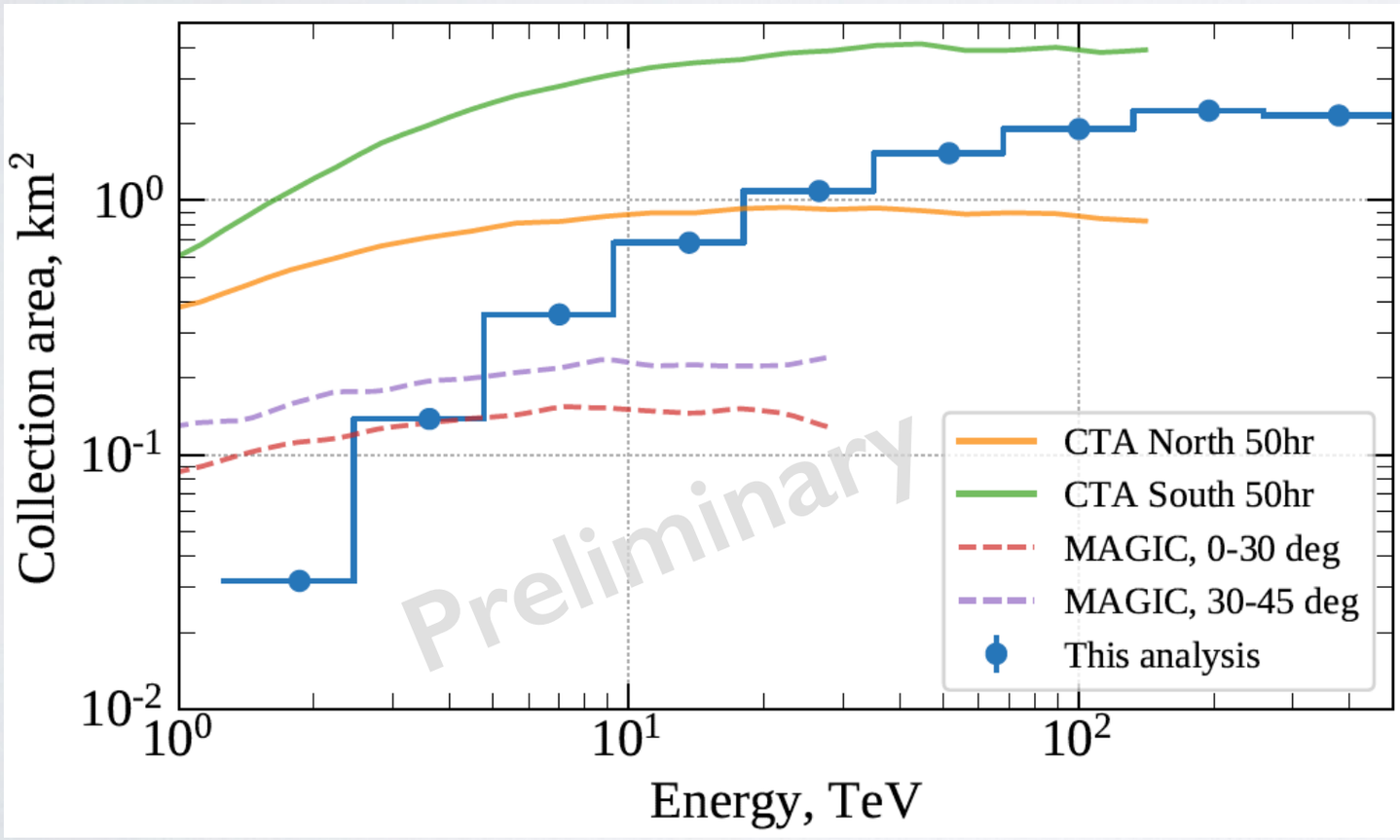
	Flux normalization	Spectral slope
Mispointing	≲ 2 %	~ 0.02
Atmosphere transmission	~ 15 %	≲ 0.02

Summary of the MAGIC Crab Nebula VLZA observations systematics

RESULTS (1)

After data selection cuts

- Energy threshold : 1 TeV @ 70° Zd → 10 TeV @ 80° Zd
- Effective time : ~50 h of good-quality data
- Collection area : already up to ~ 2 km^2 @ 70 TeV
- Signal : ~ 6.5 σ from 30 TeV

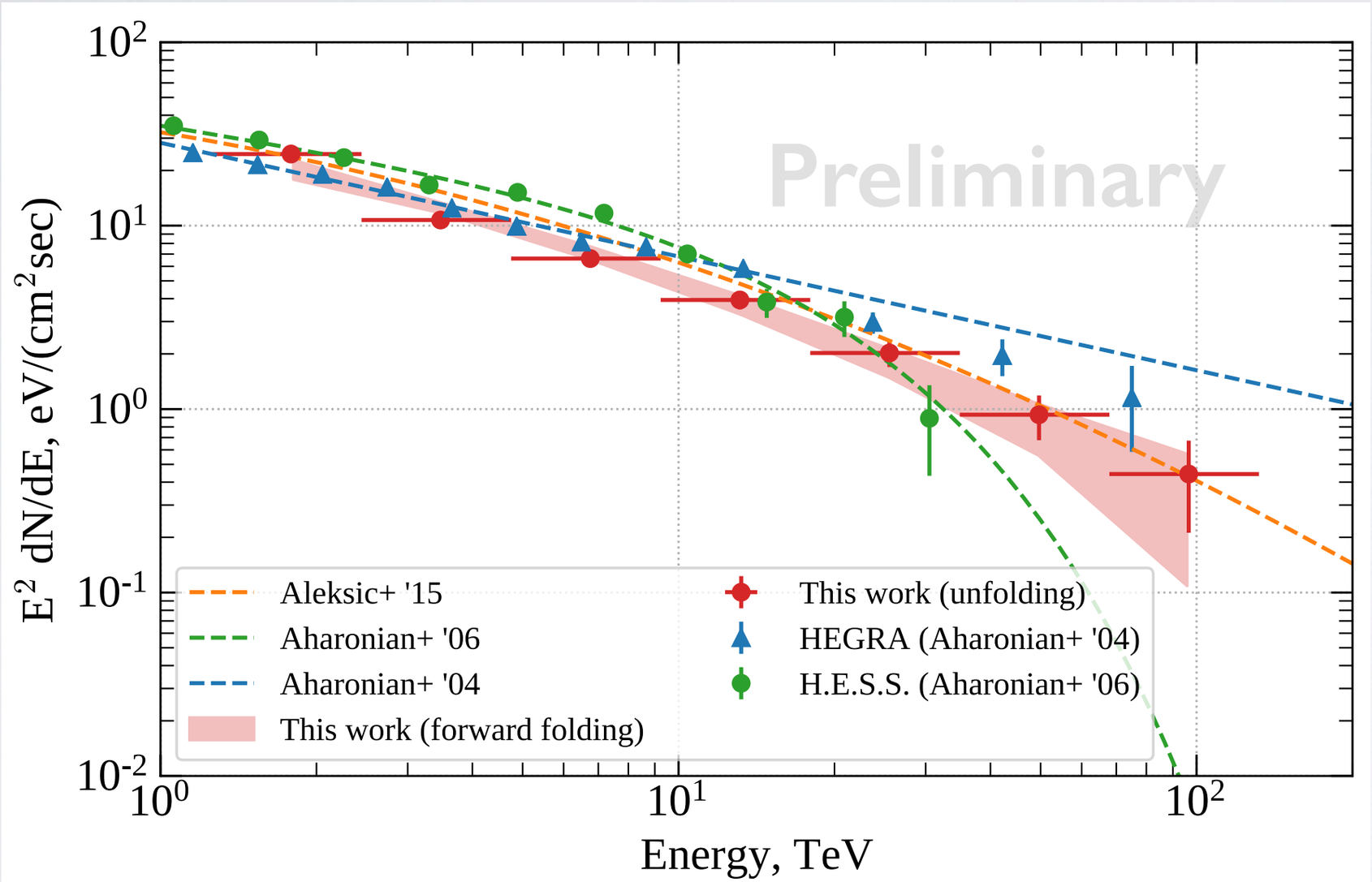


MAGIC Collection area improved ~ 20 times from low-zenith

Also 2 times better than CTA-North at low zenith

RESULTS (2)

Crab Nebula SED up to 100 TeV : **highest IACT measurement to date**



Energy estimation
(all compatible results)

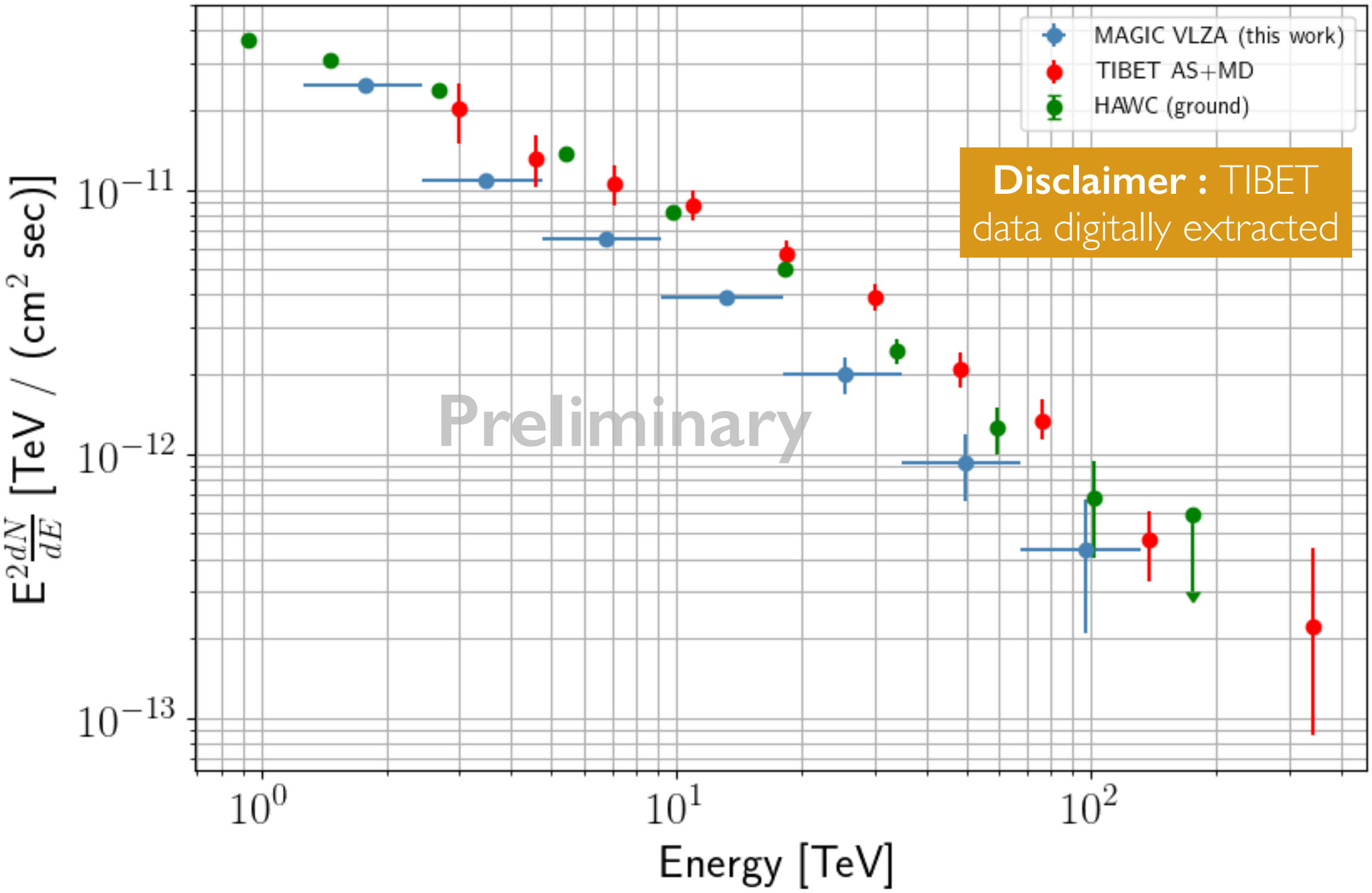
- **LUTs** (standard approach - this work)
- random forest (**RF**) multivariate analysis
- neural network (**NN**) regression

Background suppression

- RF classification
- 90% γ-ray efficiency cuts

No indication of cut-off at ~ 14 TeV [7]
HEGRA result within ~20% in ~8 x less observational time

RESULTS (3)



Best-fit MAGIC parameters compatible with archival data

SUMMARY

What we did

- 70° to 80° IACT observations
- pointing to Crab Nebula
- auxiliary atmospheric monitoring
- dedicated systematic studies
- tailored MC simulations

What we found

- MAGIC Crab observations extend up to ~ 100 TeV
- Competitive PSF
- Improved effective collection area compared to low-zenith observations
- Independent confirmation for $\geq$ 100 TeV emission

REFERENCES

- [1] Aleksić et al. 2015, Journal of High Energy Astrophysics, 5, 30
- [2] (MHZ) Meyer et al. 2010, A&A, 523, A2
- [3] (MTR) Martín et al. 2012, MNRAS, 427, 415
- [4] Mirzoyan, R., et al. (2018). NIMA, in press, 10.1016/j.nima.2018.11.046
- [5] Aleksić et al. 2016, Astroparticle Physics, 72, 76
- [6] Aleksić et al. 2016, Astroparticle Physics, 72, 61
- [7] Aharonian, F., Akhperjanian, A. G., Bazer-Bachi, A. R., et al. 2006, A&A, 457, 899

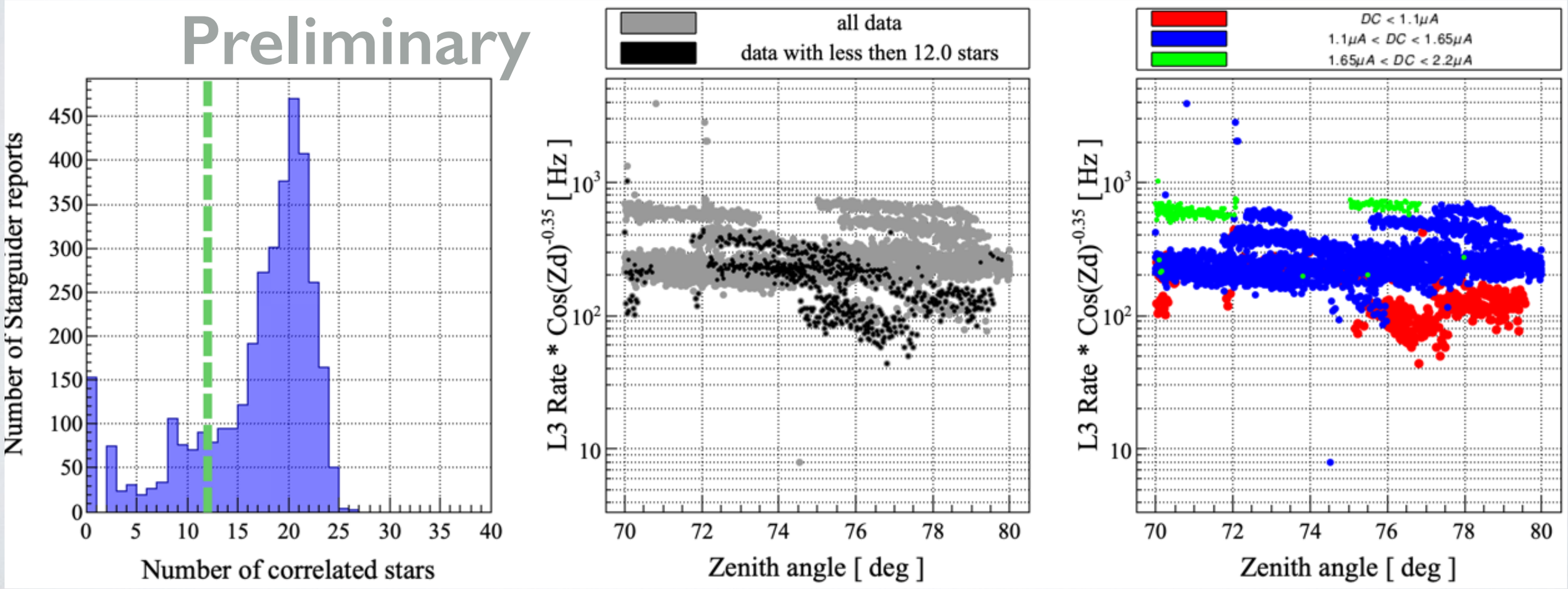
BACKUP

DATA QUALITY PROCEDURE

For a each DC level
and each wobble

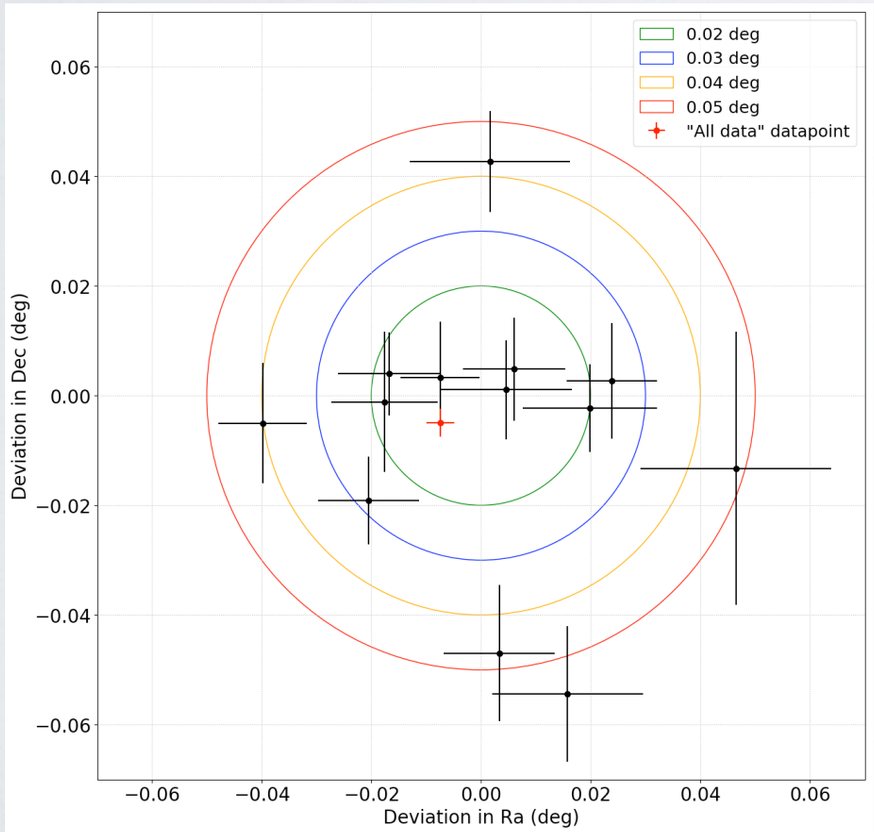
- **high rate + enough stars:**
  not necessarily "bad", simply higher DC
- **low rate + few stars** : absorption
- **high rate + few stars**: diffusion

Preliminary



MISPOINTING SYSTEMATICS AND PSF ESTIMATION

- Additional estimate on telescopes mispointing
- Fit Nebula's total angular profile vs MAGIC PSF [5]
- For E>10 TeV, mispointing < 0.03° @ 68% CL



Pointing accuracy ≲0.027° at 68% CL