Impact of H.E.S.S. Lidar profiles on Crab nebula data

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— AtmoHEAD —

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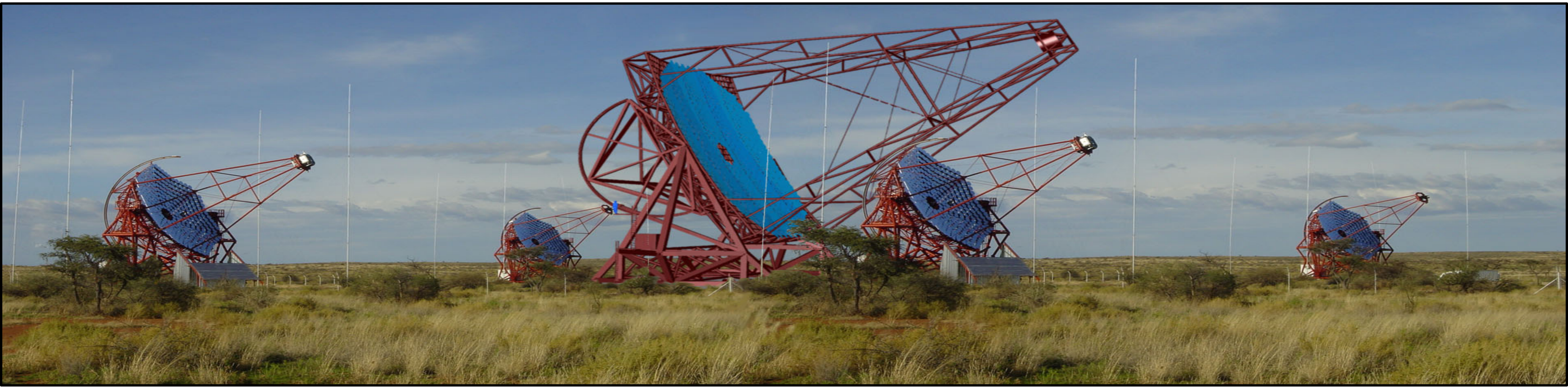
The H.E.S.S. experiment



- Four 13m diameter telescopes in Namibia
- 100 GeV to 100 TeV 15% energy resolution
- 5’ angular resolution 5 deg field of view
- One single 30m telescope
- Low energy threshold better sensitivity

I. The H.E.S.S. Lidar

Elastic Lidar

Biaxial/Coaxial Configuration

Laser Quantel Brillant 30
  355nm/532nm
  3.4W

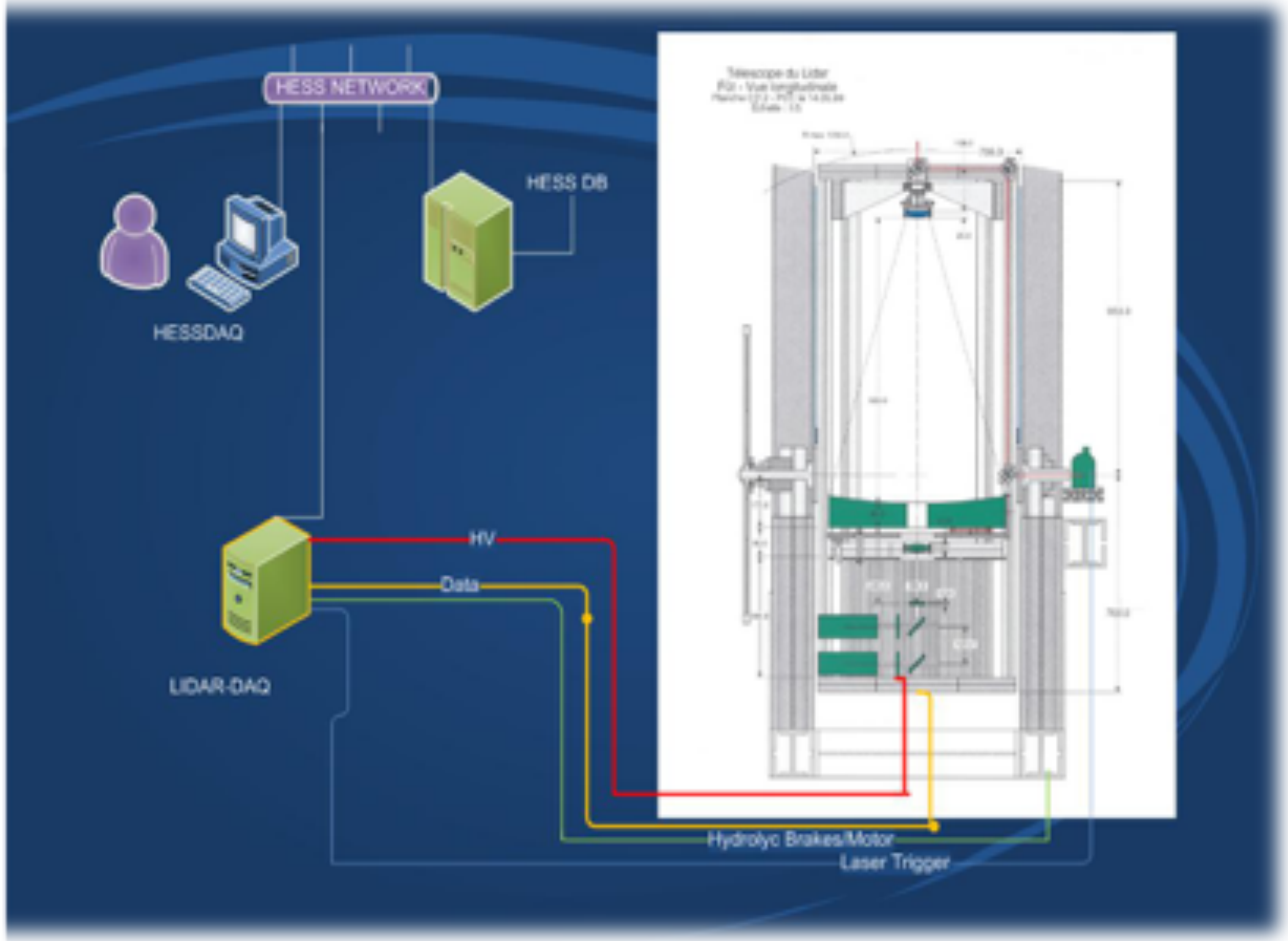
CasseGrain Telescope
  60cm/10cm, f1.4

PMTs readout

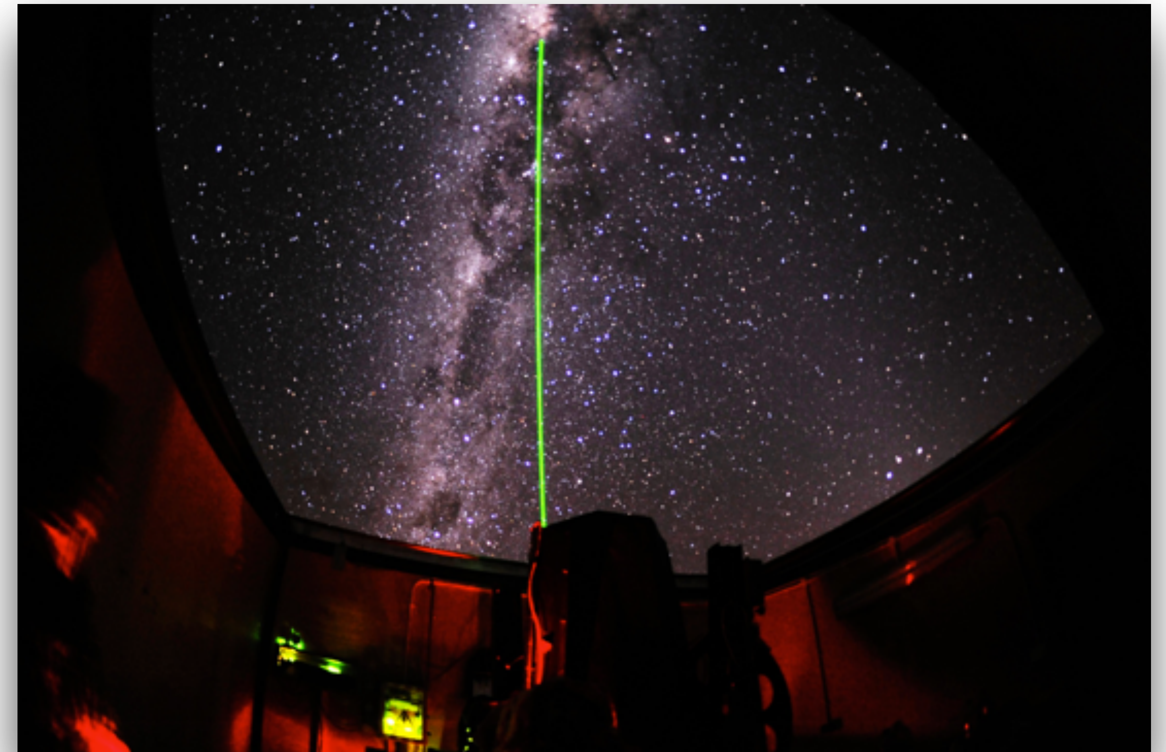
Octopus 12bit DAQ

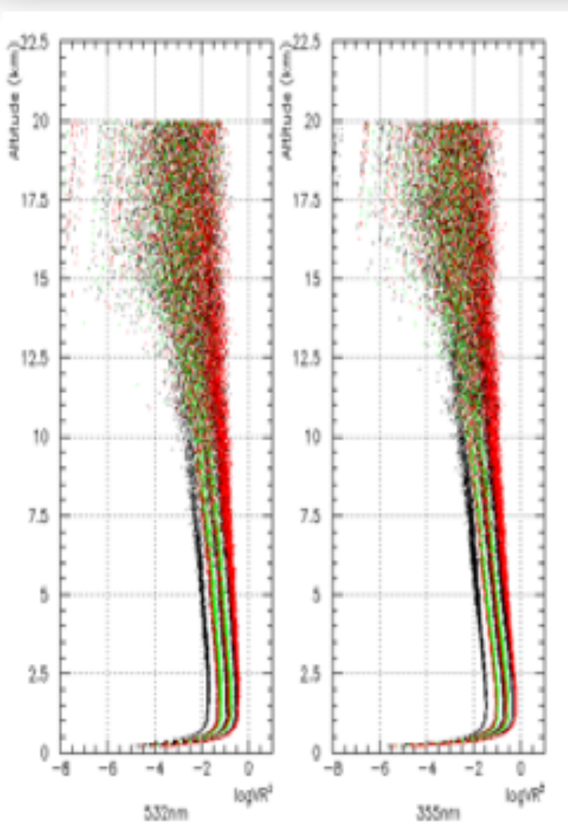
Fully automated

Fix pointing (zenith angle=15°)

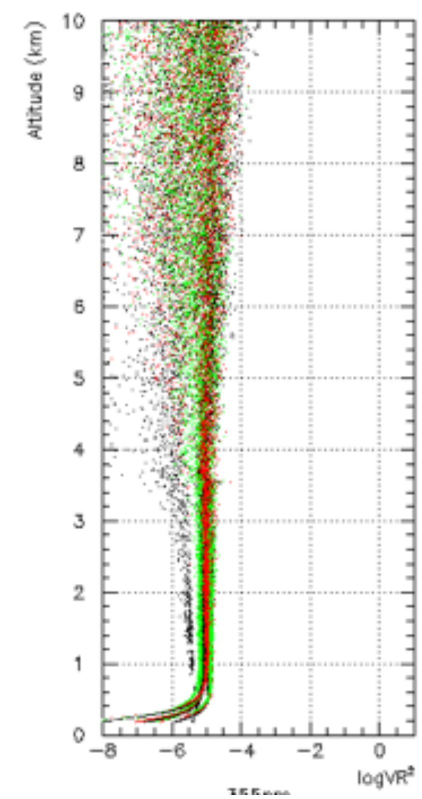


Operation modes



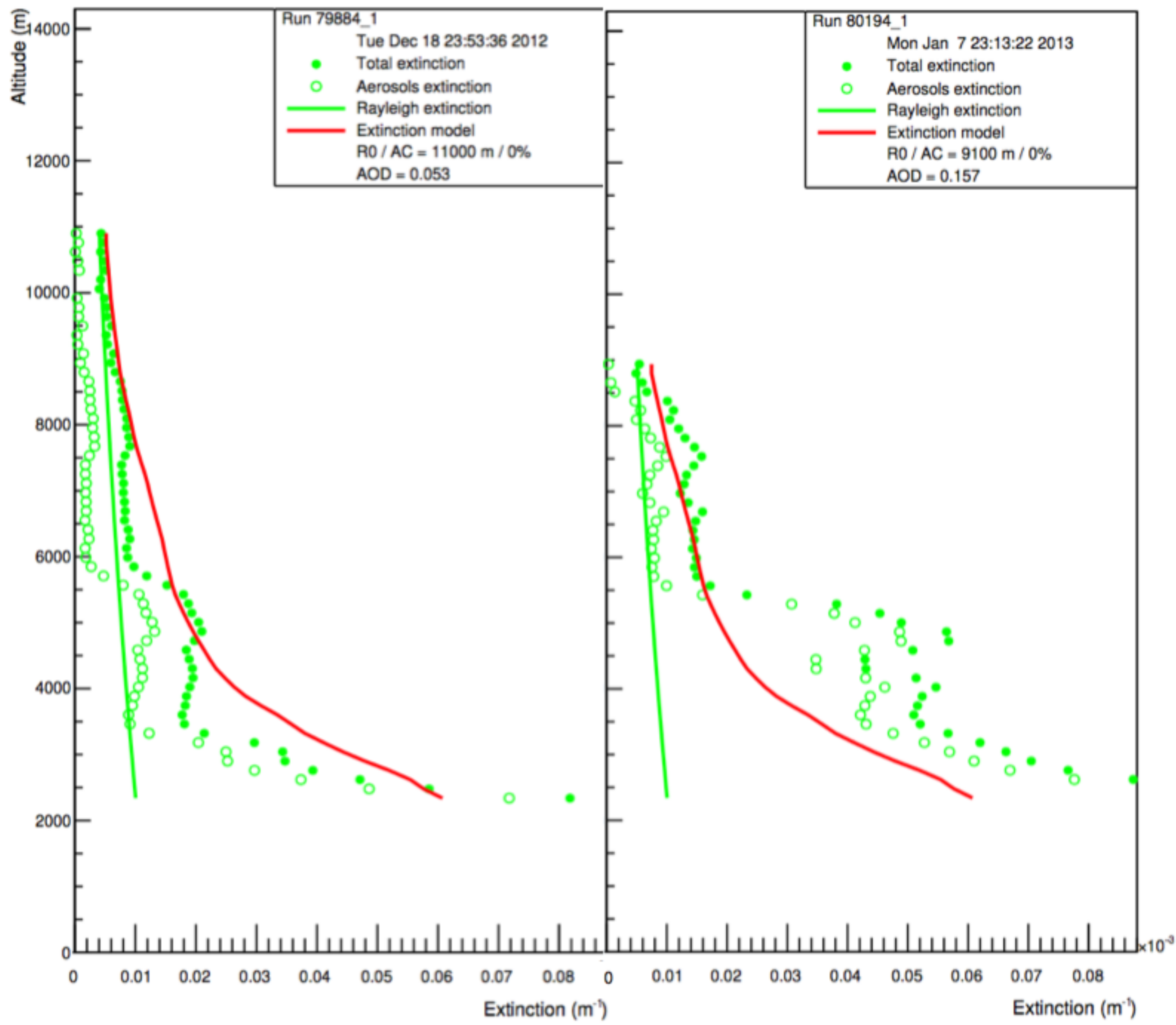


Biaxial / Coaxial Configurations
Analysis threshold 1.5 / .8 km



II. Absorption profiles

- **Klett / Fernald algorithm**
- **Requires Lidar Ratio assumptions**
  Usually 40-50 for the H.E.S.S. site
- **Calibration Height**
  Calculated where no Mie scattering expected
- **MODTRAN V5 Atmospheric model**



III. H.E.S.S. data analysis implementation

Atmopsheric variations impact the propagation of Cherenkov light to the telescope (total charge measured by the cameras, number of photons reaching the telescopes, etc.)

Main ideas:

- Deriving the instrument response functions (IRFs) for each run associated with the corresponding lidar profile

=> effective areas, energy bias

- And quantify the impact on the spectral reconstruction

Run-Wise Simulations

Classical H.E.S.S. analysis chain:

- Simulations for a certain set of parameters (zenith angle, optical efficiency, etc.) to derive the IRFs

- IRFs interpolation to cover the entire parameter space of all the H.E.S.S. observations

Run-Wise Simulations* (RWS) :

New simulation chain using the real observation conditions of each run (zenith angle, optical efficiency, etc.) in order to obtain the most realistic IRFs

RWS reduce the systematic errors => well suited for lidar studies

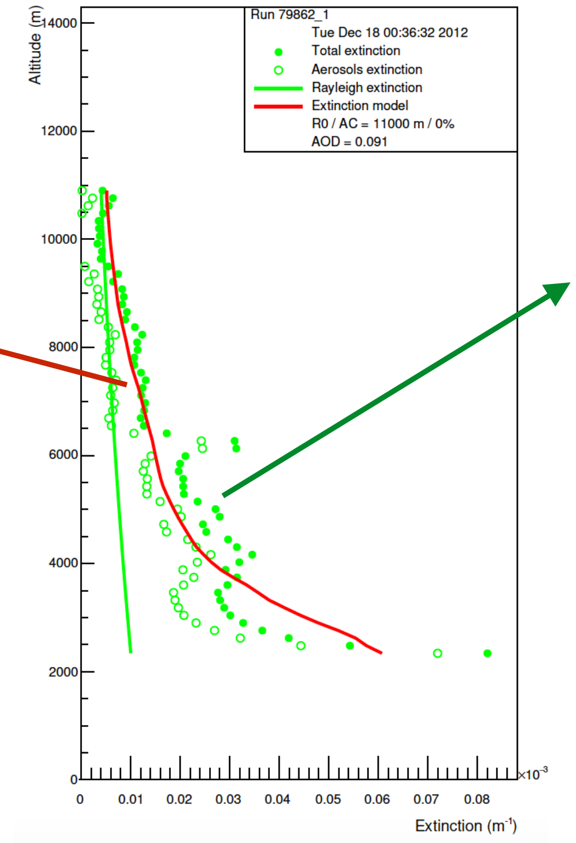
We use RWS to isolate the impact of lidar profiles on H.E.S.S. data

* see M. Holler et al., ICRC 2017

Method

Simulated events

with the standard profile



with the lidar profile

IRFs

IRFs

RWS

effective areas, energy biaises

data analysis

spectral reconstruction

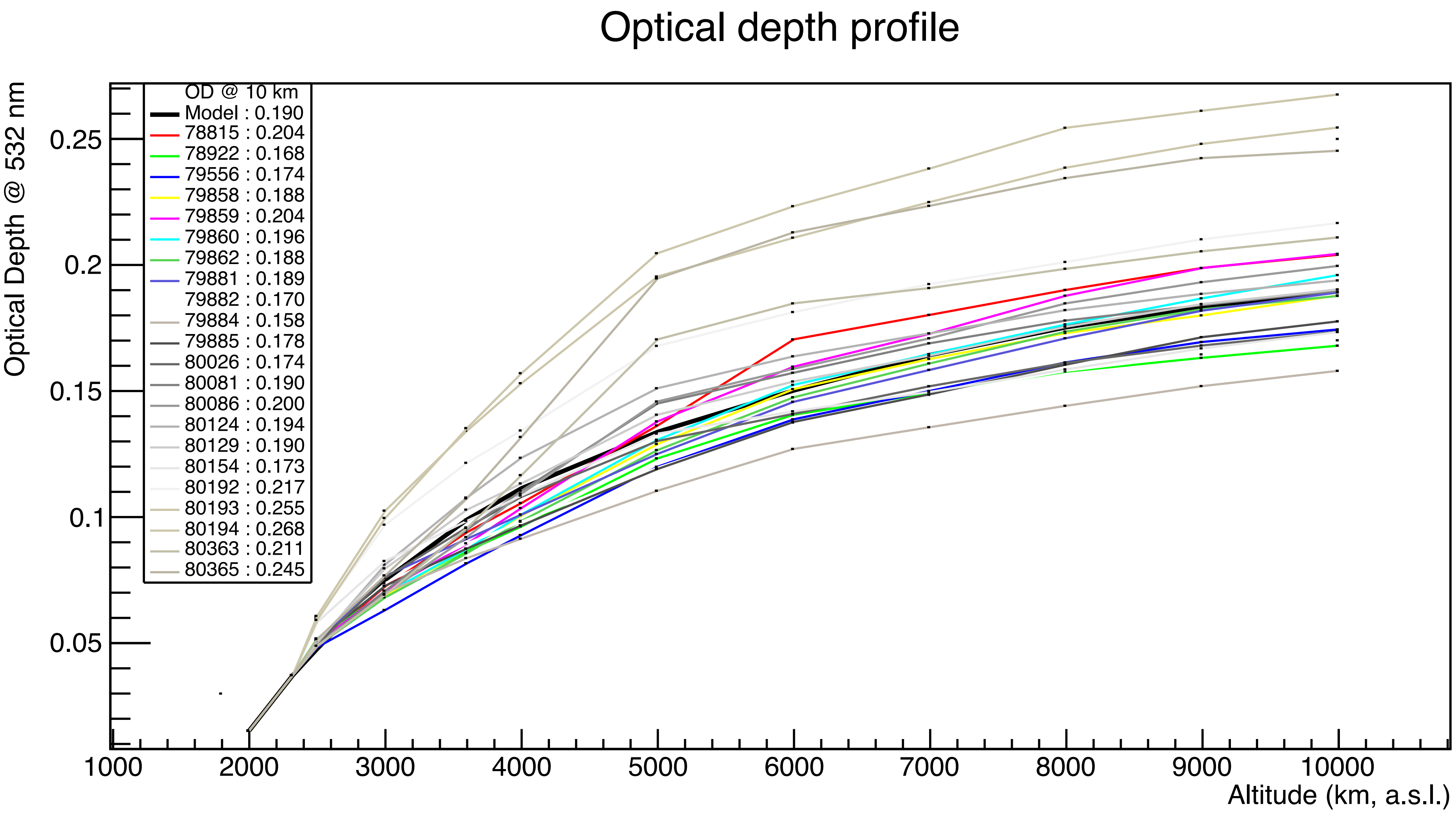
flux normalization dispersion

IV. Impact on Crab nebula data

Data set:

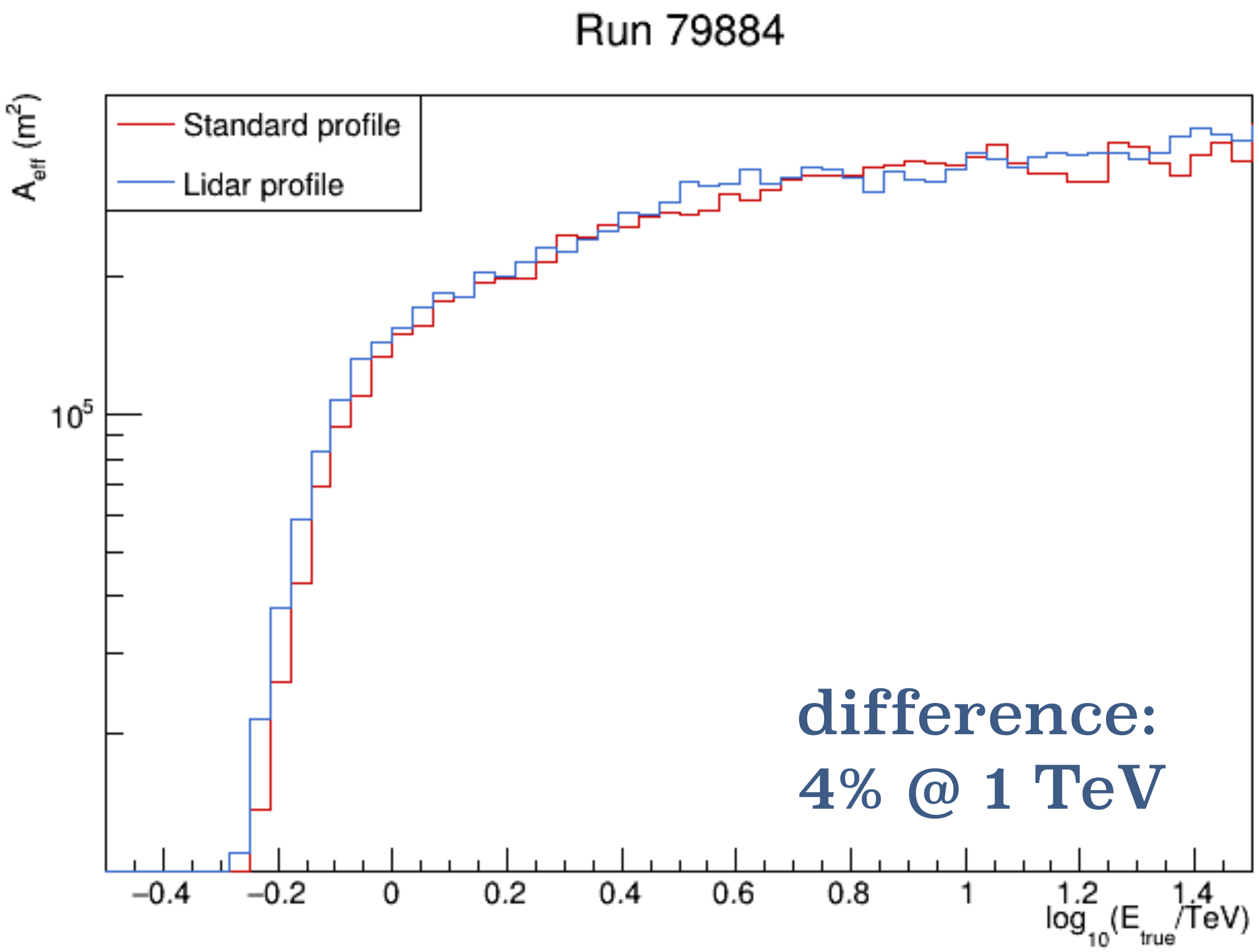
- 11 runs taken in 2012 and 11 runs taken in 2013 for which we have exploitable lidar profiles (taken just before the run)

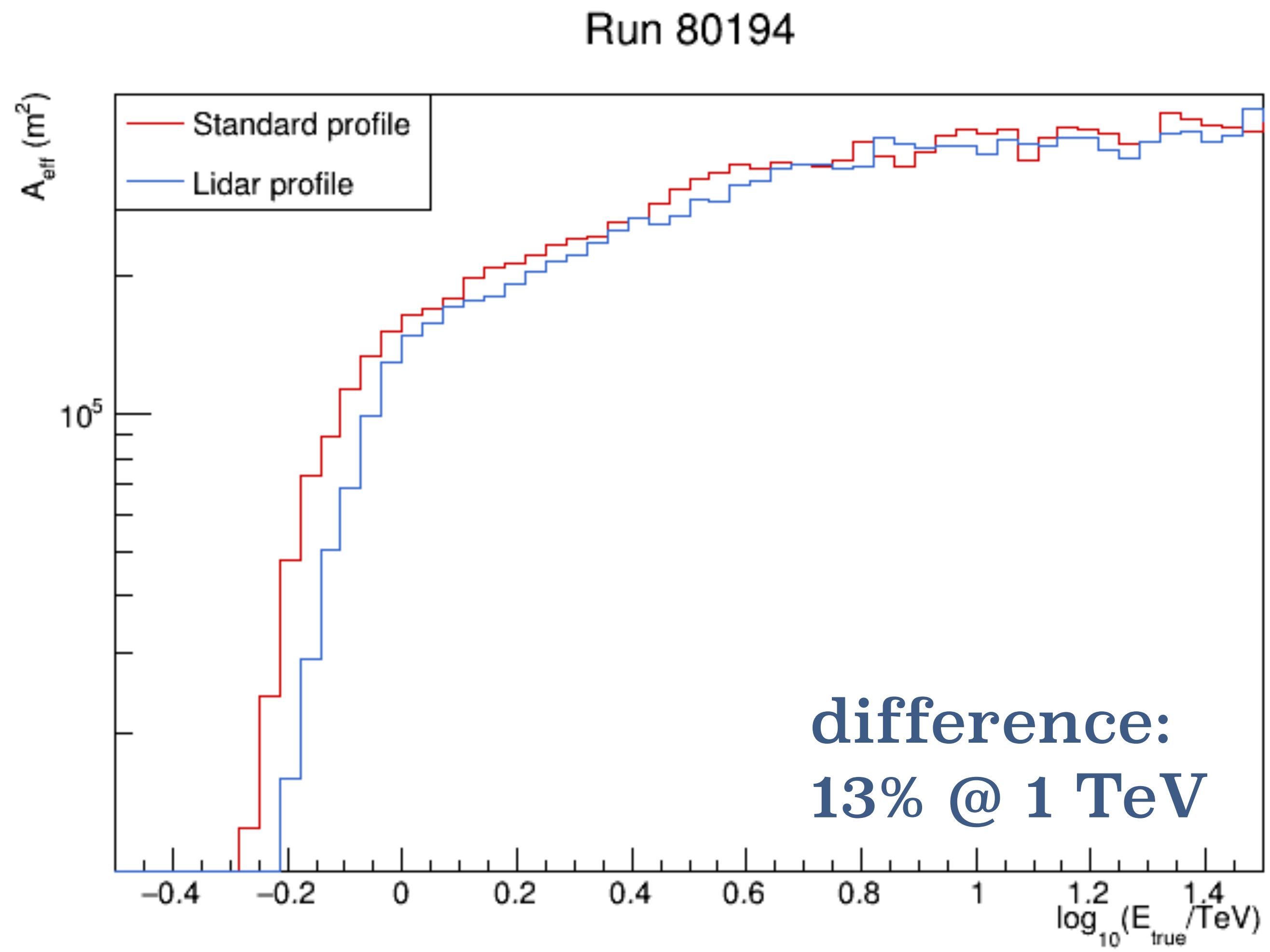
The 11 runs in 2013 have mostly the worst atmospheric conditions



Part of the runs did not pass the standard quality selection criteria defined in the H.E.S.S. collaboration

IRFs - Effective areas





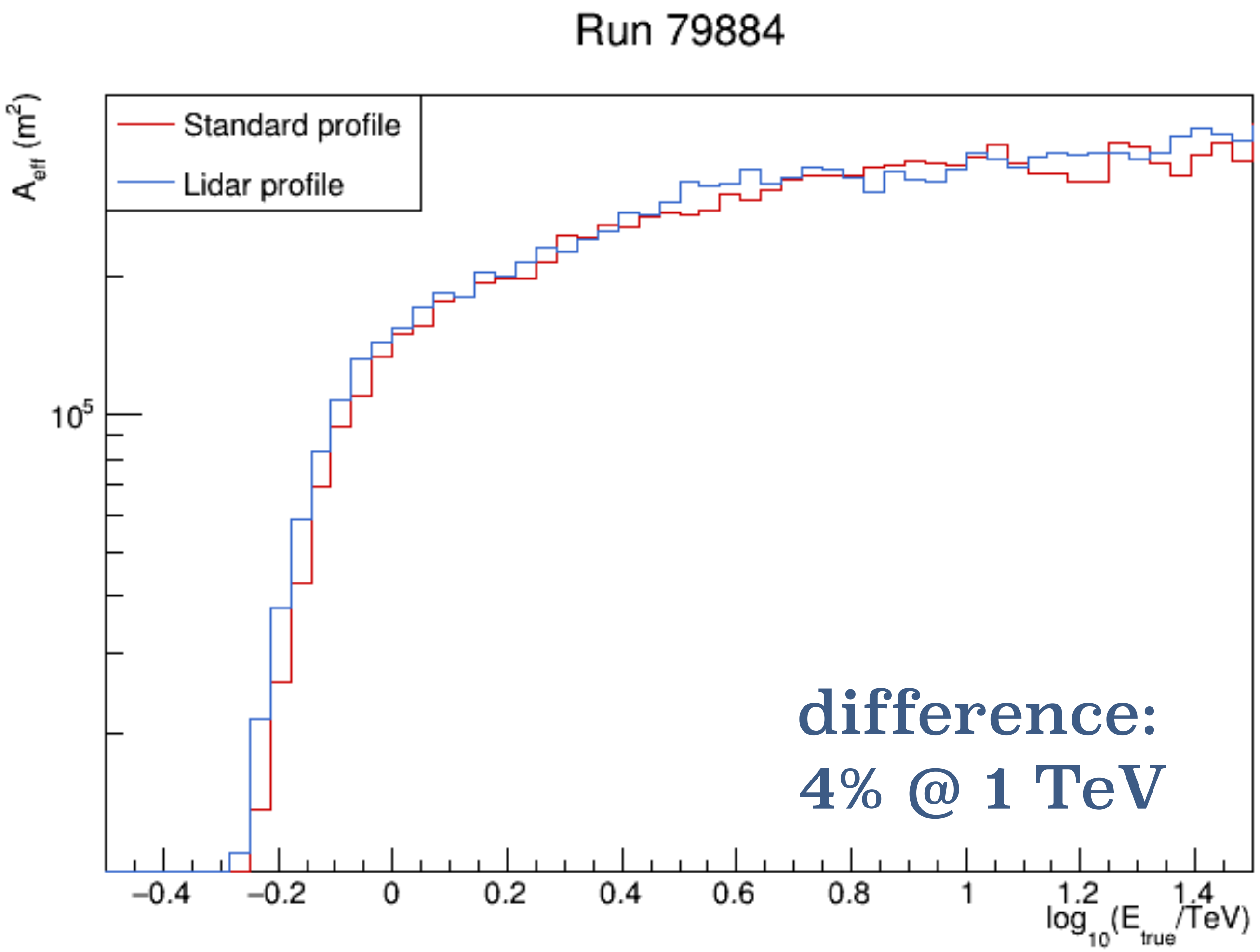
lidar profile more **transparent** than the model

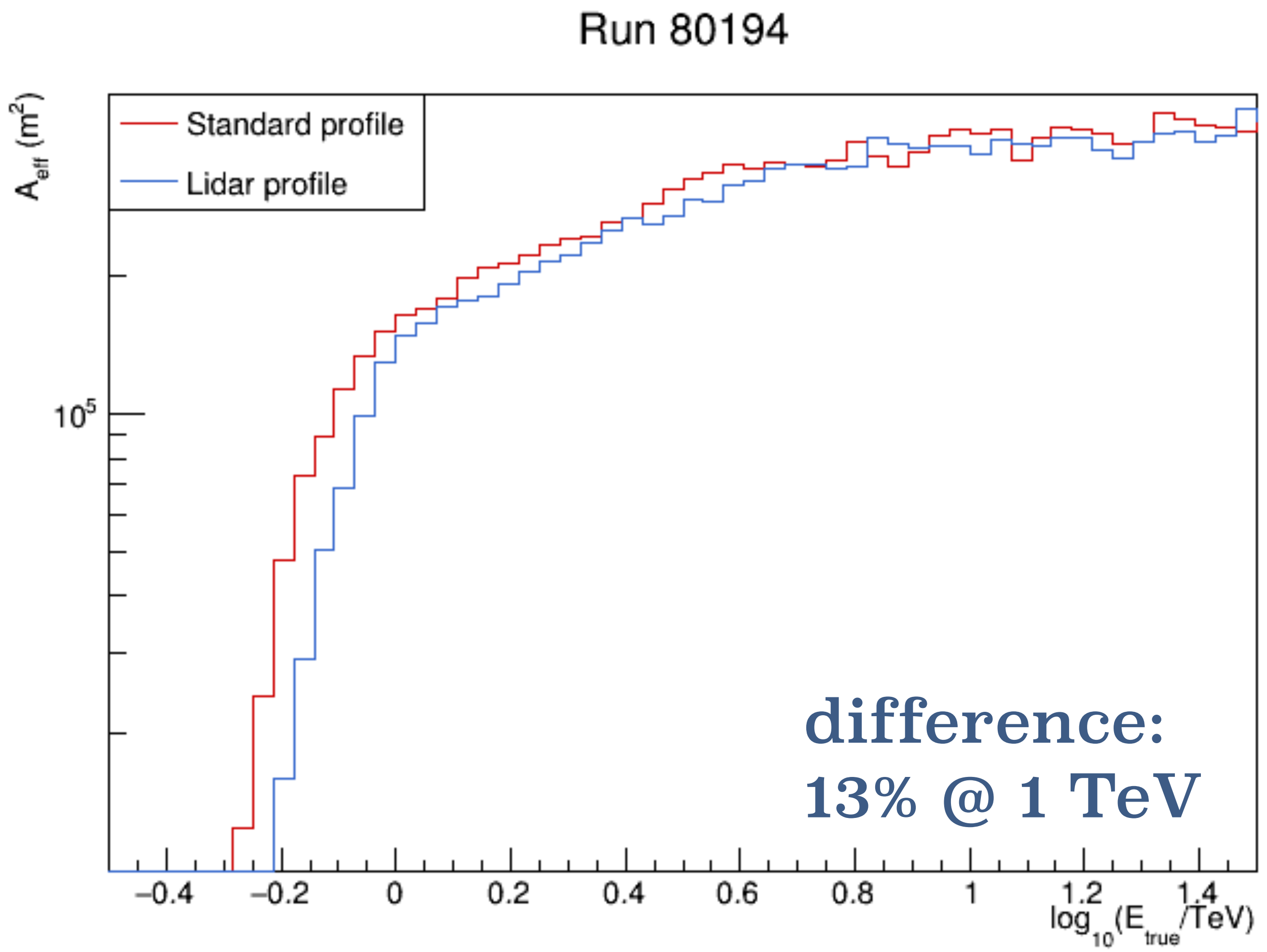
lidar profile more **opaque** than the model

=> Variation of the energy threshold:

- **- 5%** for the run 79884 with lidar data
- **+ 17%** for the run 80194 with lidar data

IRFs - Effective areas





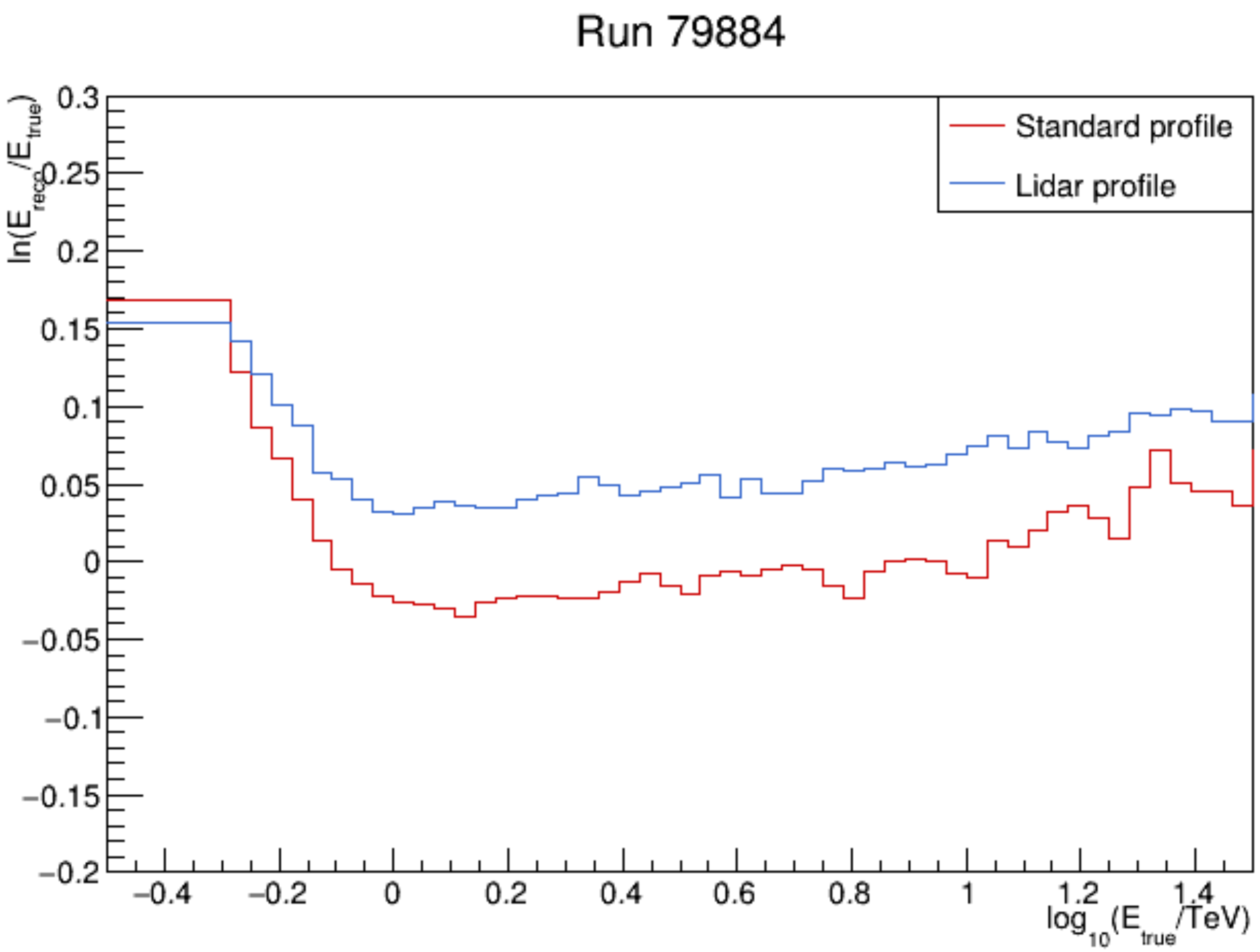
lidar profile more **transparent** than the model

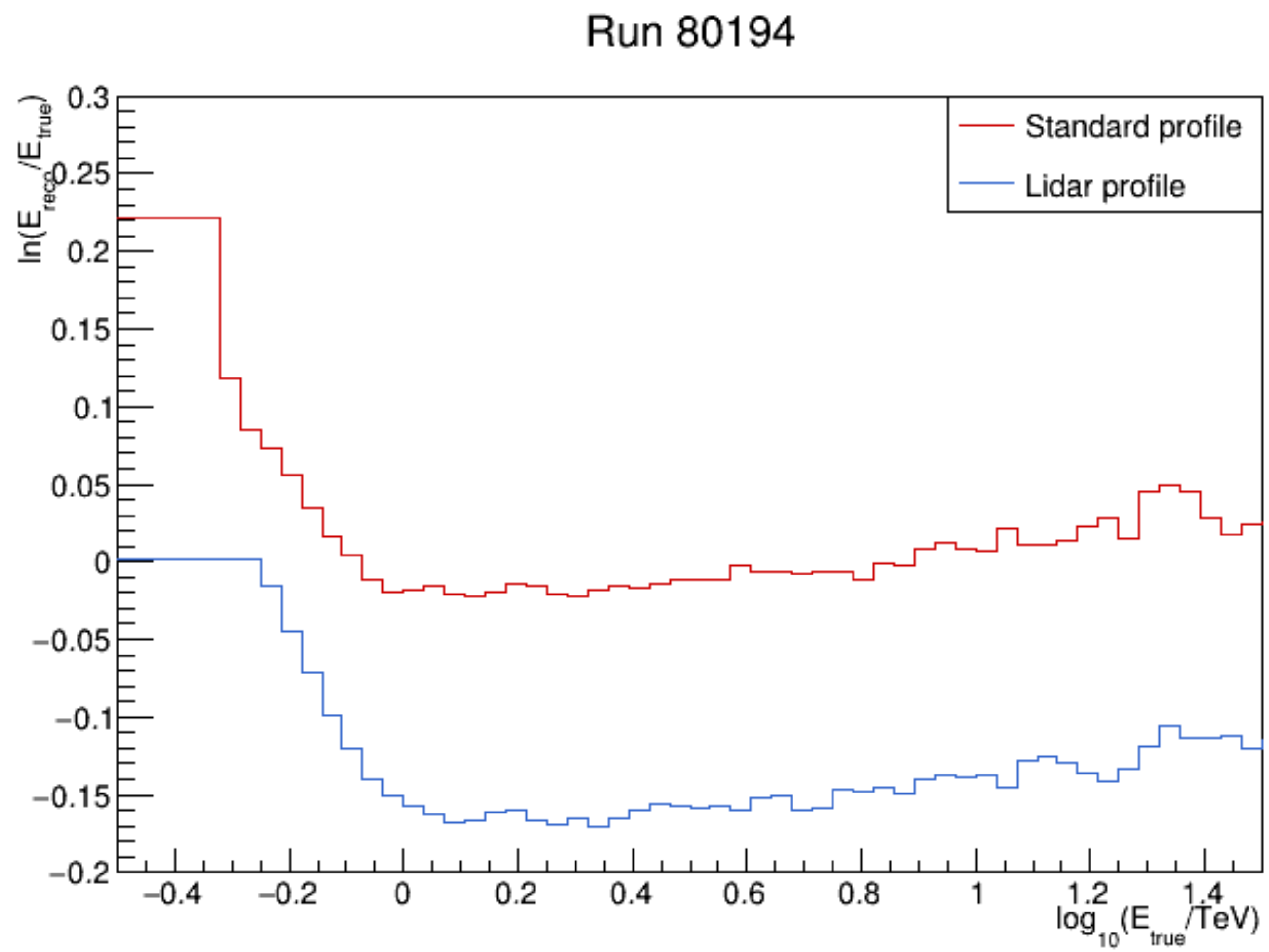
lidar profile more **opaque** than the model

=> Noticeable impact on the effective areas

=> Less photons and higher energy threshold when the lidar profile is more opaque than the model

IRFs - Energy biases





lidar profile more transparent than the model

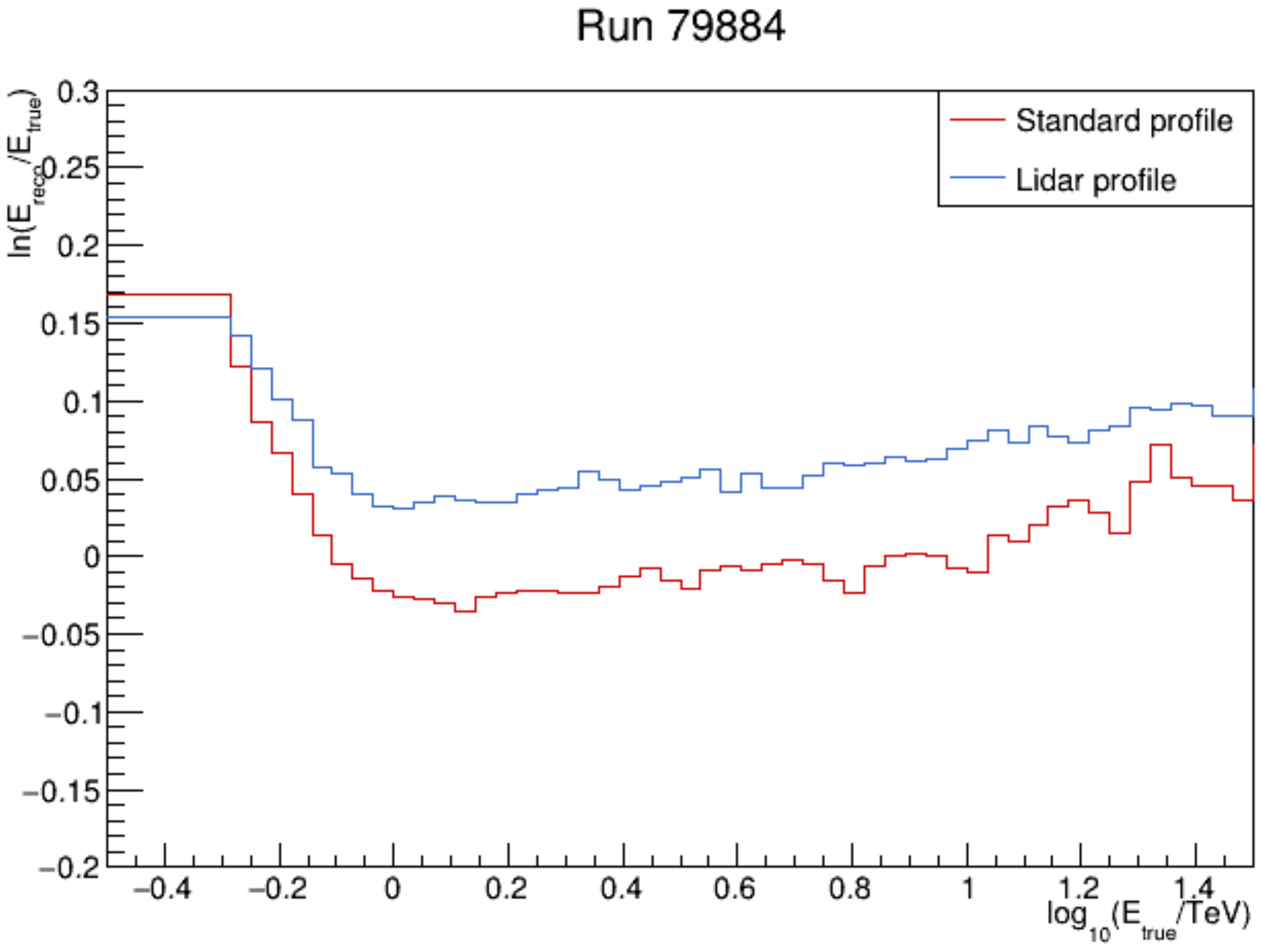
lidar profile more opaque than the model

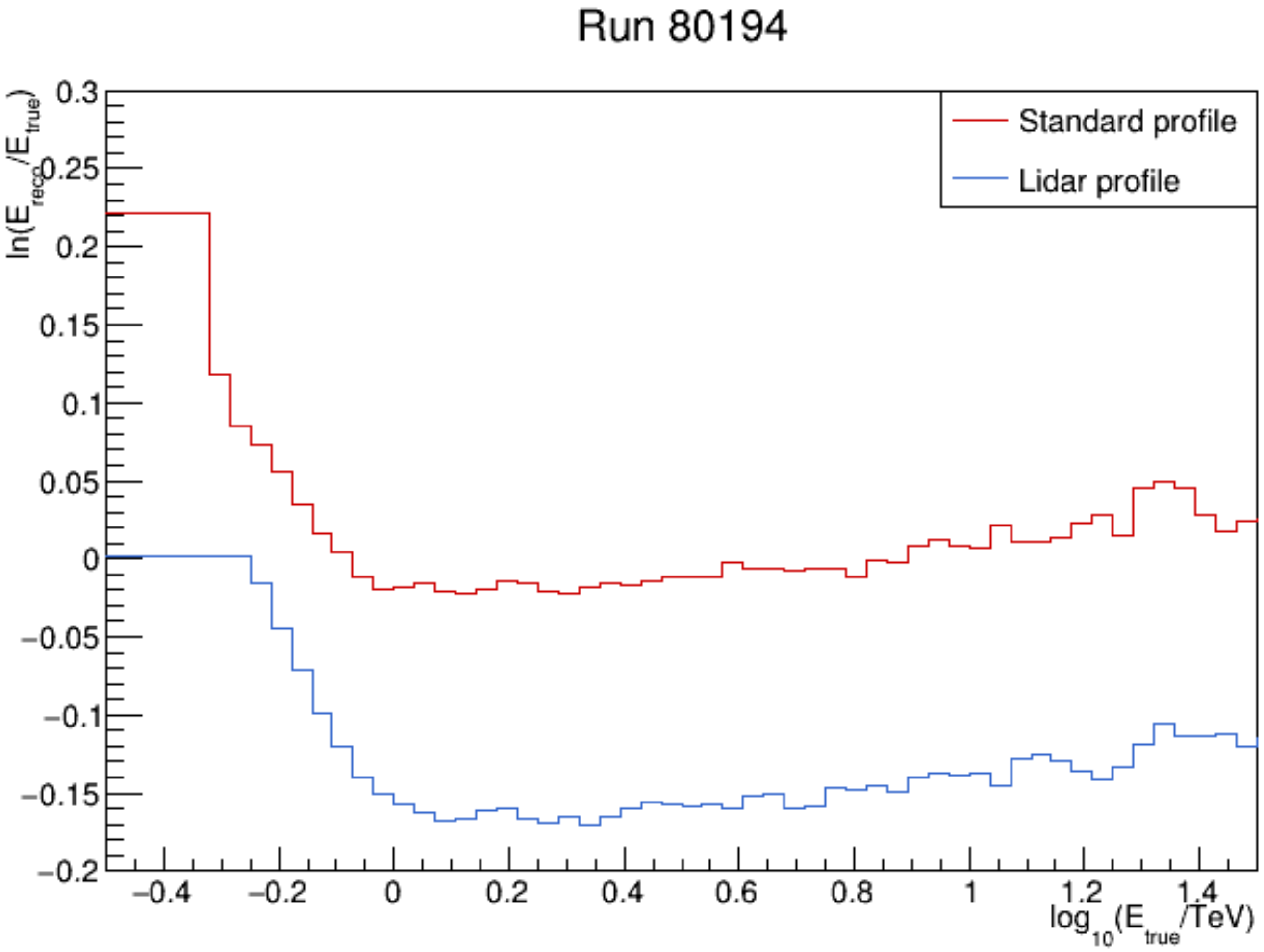
=> Different reconstructed energy:

$E_{\rm reco} \sim 1.06 E_{\rm true}$ **for the run 79884 with lidar data (E > 1 TeV)**

$E_{\rm reco} \sim 0.91 E_{\rm true}$ **for the run 80194 with lidar data (E > 1 TeV)**

IRFs - Energy biases





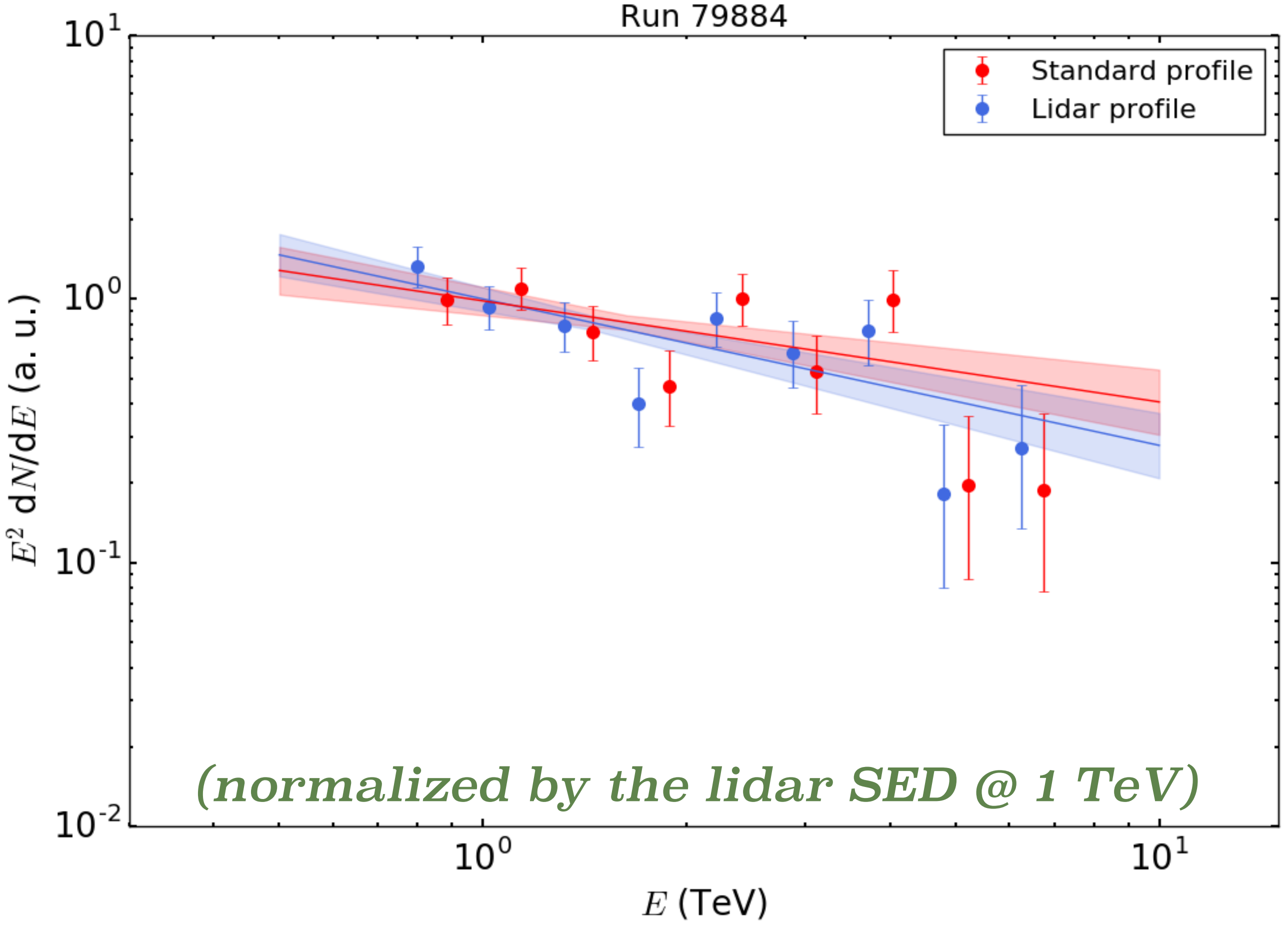
lidar profile more transparent than the model

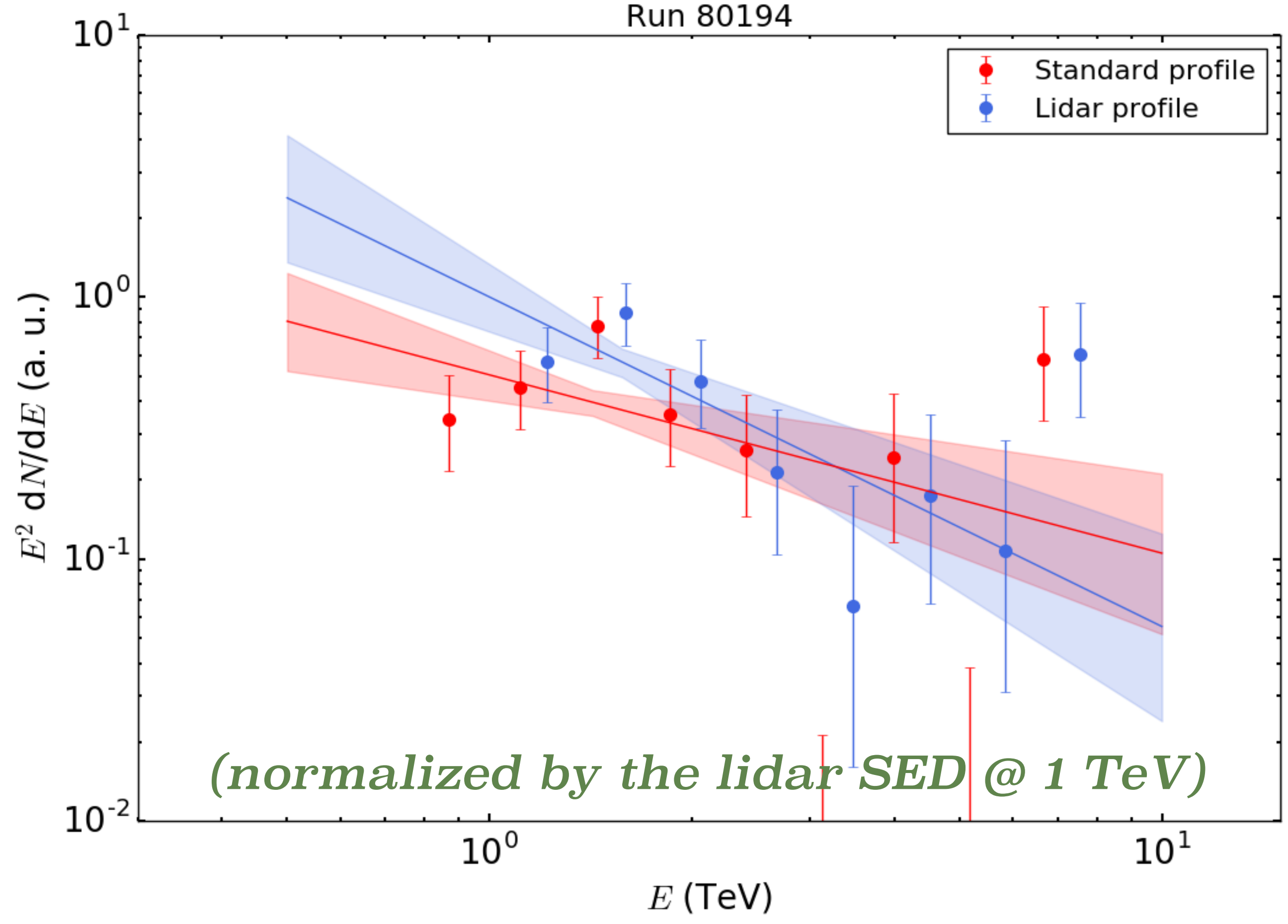
lidar profile more opaque than the model

=> Noticeable impact on the reconstructed energy

=> Lower reconstructed energy when the lidar profile is more opaque than the model

Spectra per run





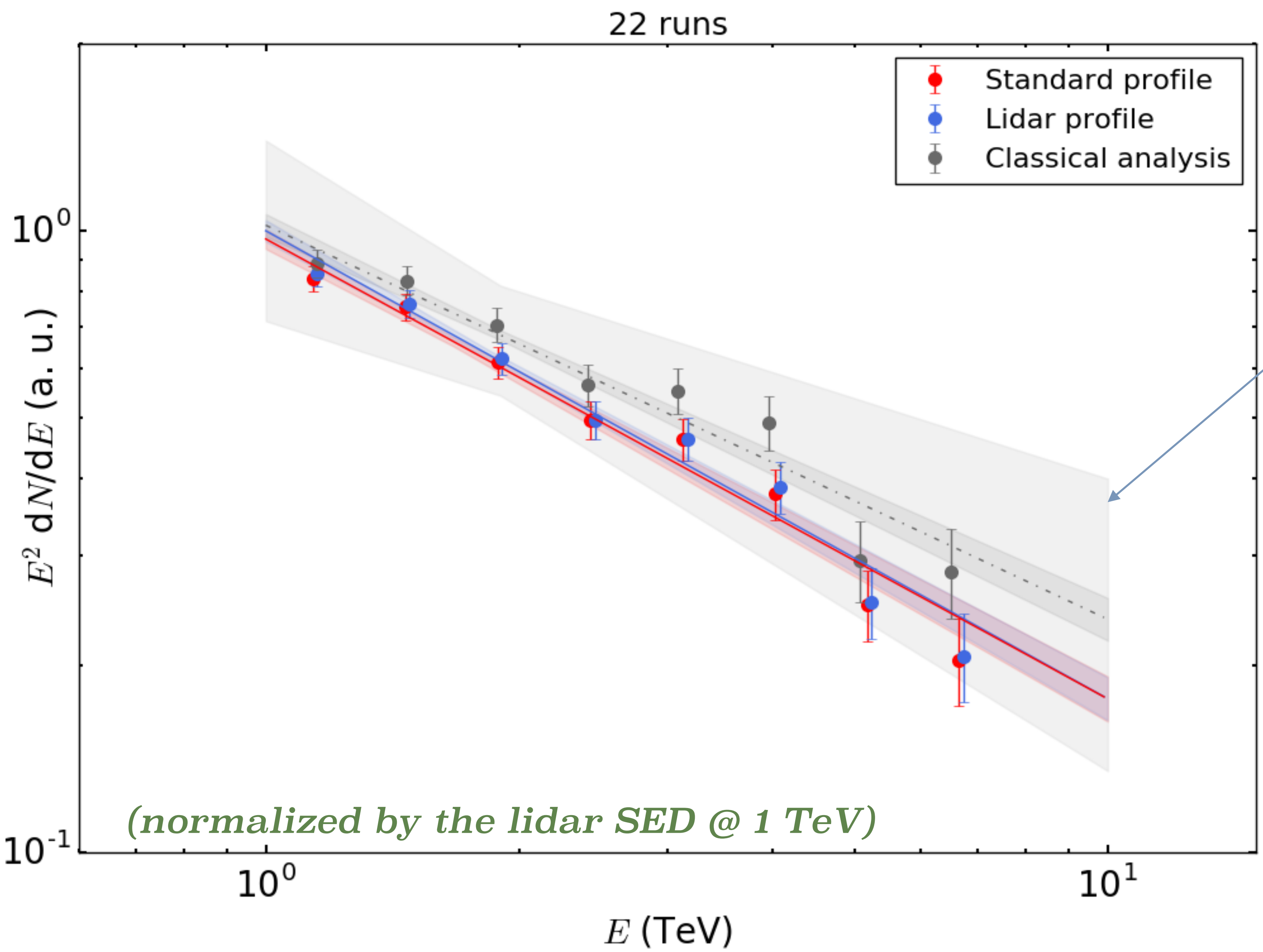
lidar profile more transparent than the model

lidar profile more opaque than the model

=> Lower effective area and reconstructed energy lead to a higher flux for a more opaque atmosphere than the model

=> Differences in spectra but too few statistics in one run to quantify the improvement when using lidar data

Spectra with 22 runs



Quadratic sum of statistic and systematic errors (20% on the flux norm. and +/- 0.2 on the spectral index)

=> Only **3%** difference for the differential flux at 1 TeV using the 22 runs (not significant)
=> Model used by the collaboration seems to well reproduce the average atmospheric composition

Normalization dispersion

To avoid edge effects (different statistics at low energy) due to different atmospheric profiles, we perfom the following analysis **from 1 TeV to 10 TeV**

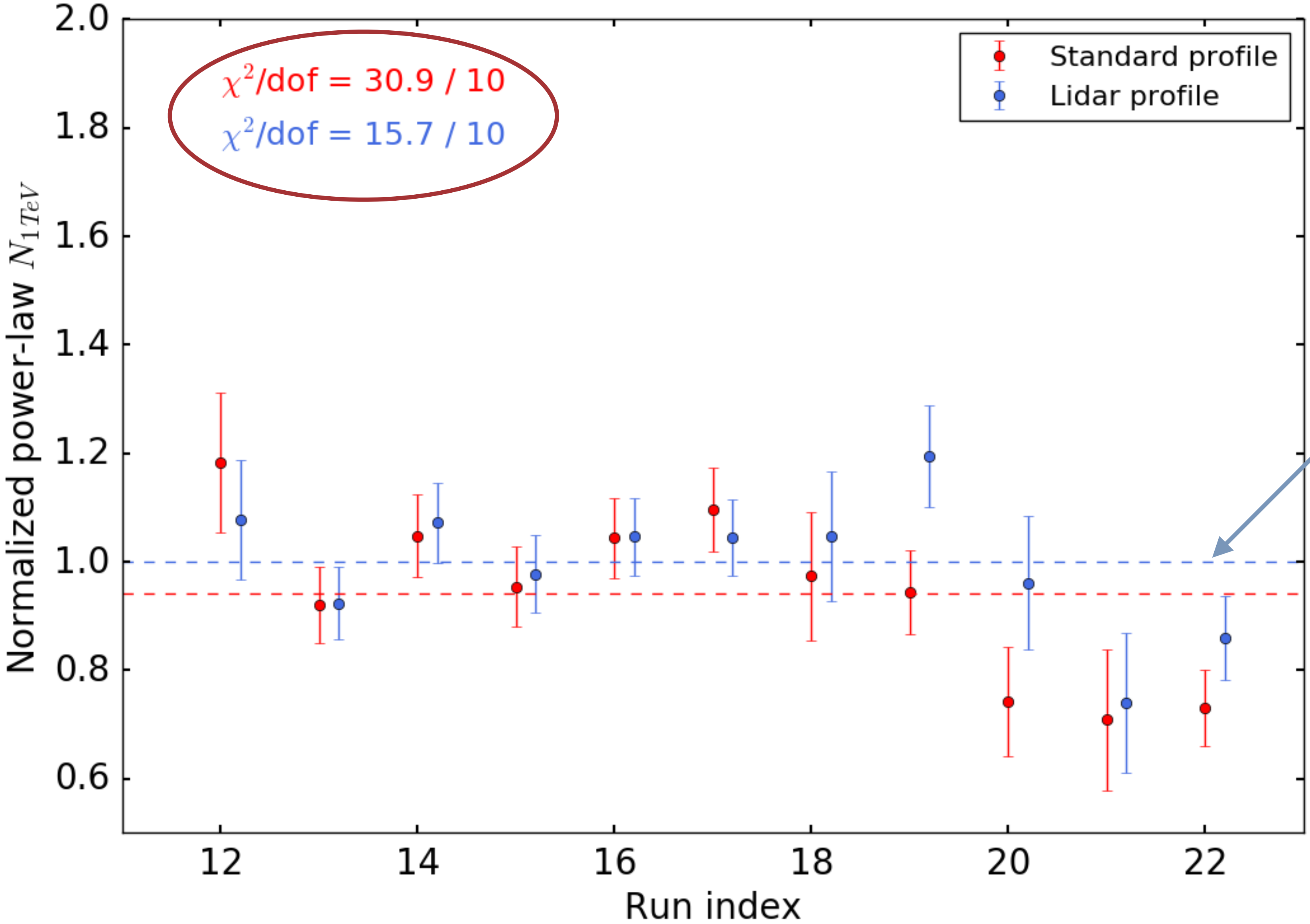
Spectral fit (run by run) with a power law with fixed spectral index (= best-fit spectral index obtained with the 22 runs, which is the same when using the lidar and standard profiles)

Study of the two data set (from 2012 and 2013) separately:

- run taken in 2012: **5** triggered telescopes, mostly **good** quality sky
- run taken in 2013: **4** triggered telescopes, mostly **worst** atmospheric conditions

Normalization dispersion (1)

11 runs, mostly with the worst atmospheric conditions



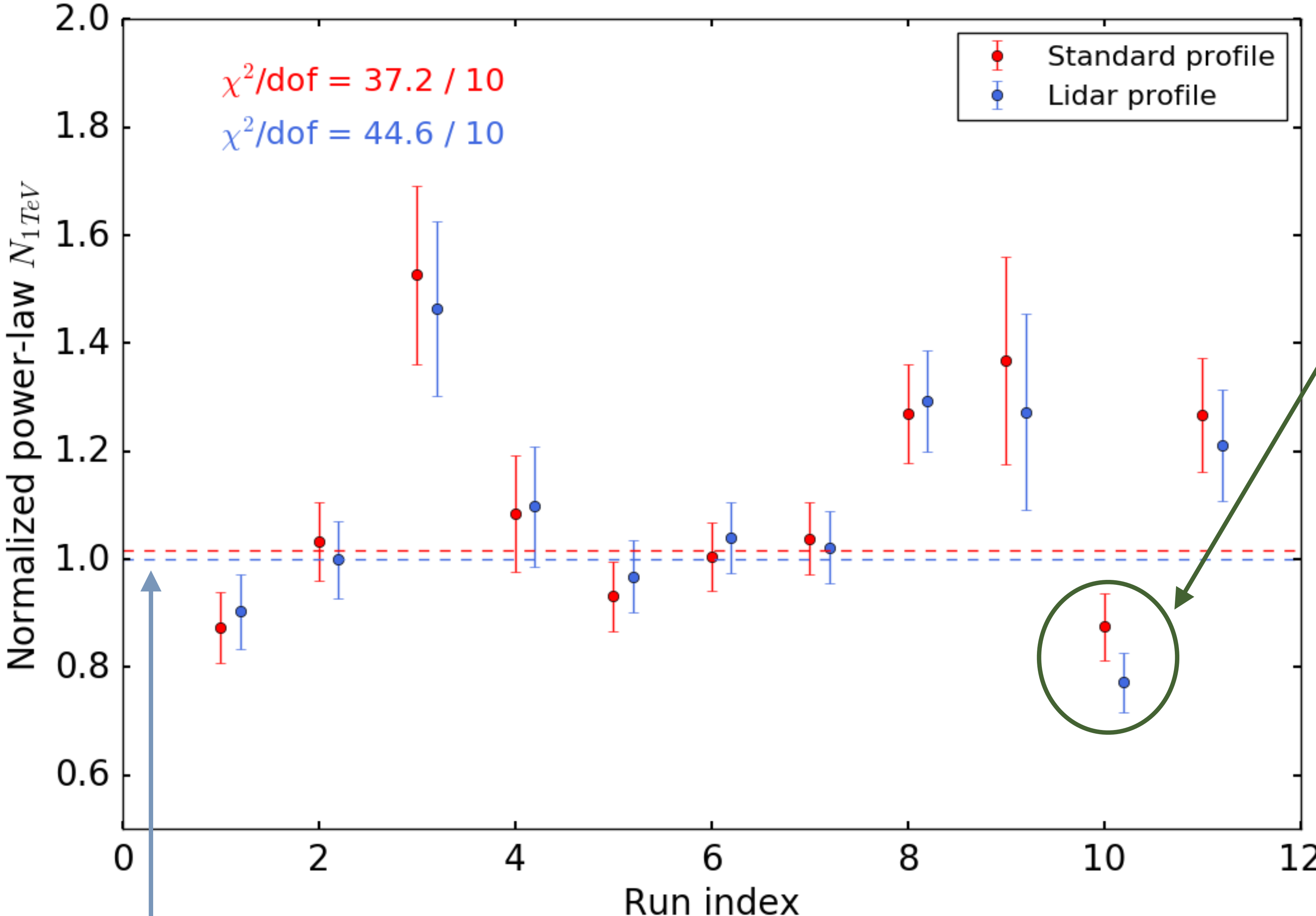
Values normalized to the one minimizing the Chi2 with lidar data

Incompatible with a constant flux at 3.3 sigma and 1.3 sigma for the standard and lidar profile respectively

Reduced dispersion when using the lidar profiles for these runs

Normalization dispersion (2)

11 runs, mostly with a good quality sky



Dispersion is not reduced with lidar data due to this run

Without this run: χ^2/dof = 31.4 / 9 χ^2/dof = 25.1 / 9

Problem still under investigation (trigger rate, lidar profile, etc.)

Other sources of systematic errors not yet understood? (and not related to the atmosphere?)

Values normalized to the one minimizing the Chi2 with lidar data

Conclusions

- Noticeable impact on the IRFs

  Better determination of the low-energy threshold
  Better knowledge of the photon energy

- IRFs should impact the spectral reconstruction at some point

  For the 22 runs studied here, the difference in the spectra is not significant, but it is with a run-by-run analysis

- Normalization dispersion should be in principle reduced with lidar data

  This is significantly the case for the 11 runs with the worst atmospheric conditions

- We need more lidar profiles but the first results are encouraging to reduce the systematic errors and to retrieve runs that did not pass the standard quality criteria