Atmospheric simulations

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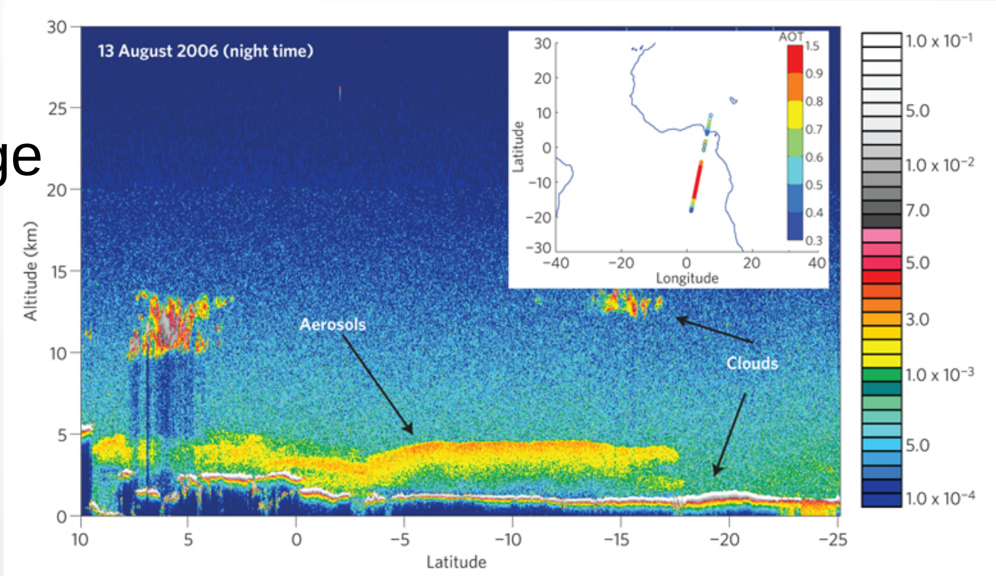
for the **ccf-atmosim** group (partial, sorry!): Bianca Maria Dinelli, Michele Doro, Markus Gaug, Tarek Hassan, Raquel de Los Reyes, Enzo Papandrea, Michael Prouza, Stefan Shüssler, Stanislav Stefanik, Piero Vallania, Carlo Vigorito, Michal Vrastil,...

Outline

- Goals of the simulations
- Studied atmospheric profiles
  - atmospheric transmission from MODTRAN
- MC *atmosim* production
- Event reconstruction
- Results
  - ideal case: perfect knowledge of the atmosphere
  - extreme case: only an average profile

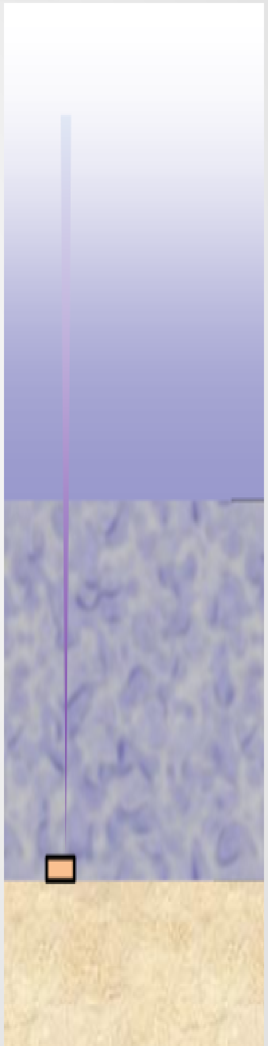


Goals

The Atmosphere, as part of our detector, has a strong influence on the data. Two main aspects are the molecular absorption profile and the presence of aerosols. In CTA the atmosphere will be monitored with several Atmospheric Calibration instruments and using external data (GDAS).

We want to estimate, by means of detailed MC:

- the effect of different **atmospheric profiles** on CTA performances
  - effective area (energy threshold, flux)
  - energy bias and resolution
  - angular resolution
- the effect of **aerosols** (dust, clouds) under different conditions.
- the effect of **atmospheric calibration uncertainties** on recontructed energy and flux uncertainties
  - their compliance with CTA performance requirements (for instance: A-PERF-0240, *Energy resolution)*
- the possible **strategy** for generating observation-wise **MC simulations**
  - inputs for CORSIKA: density, thickness, refraction index profiles
  - inputs for sim_telarray: atmospheric transmission (vs λ and photon production heigth)



Atmospheric profiles

- We focused on the La Palma site
  - very well known atmosphere, lots of measurements already available
  - profiles from GDAS* (< 25 km) and NRLMSISE-00 (25 - 100 km) and exponential extrapolation up to 120 km (technically needed by corsika)

Name	Description
Average Winter	Averaged over all winter profiles.
Average Summer	Averaged over all summer profiles.
Extreme14.0_low	Air density has the minimum value at 14 km.
Extreme16.0_high	Air density has the maximum value at 16 km.
Extreme7.0_low	Air density has the minimum value at 7 km.
Extreme5.0_high	Air density has the maximum value at 5 km.

Thanks to Markus Gaug!

  - the different "extreme" altitudes have been chosen to maximize the effects on the HE or on the LE events.
  - we used also the atmospheric profiles used in CTA-N MC Production 3

** GDAS (Global Data Assimilation System) data of NCEP (National Centers for Environmental Prediction, USA)*

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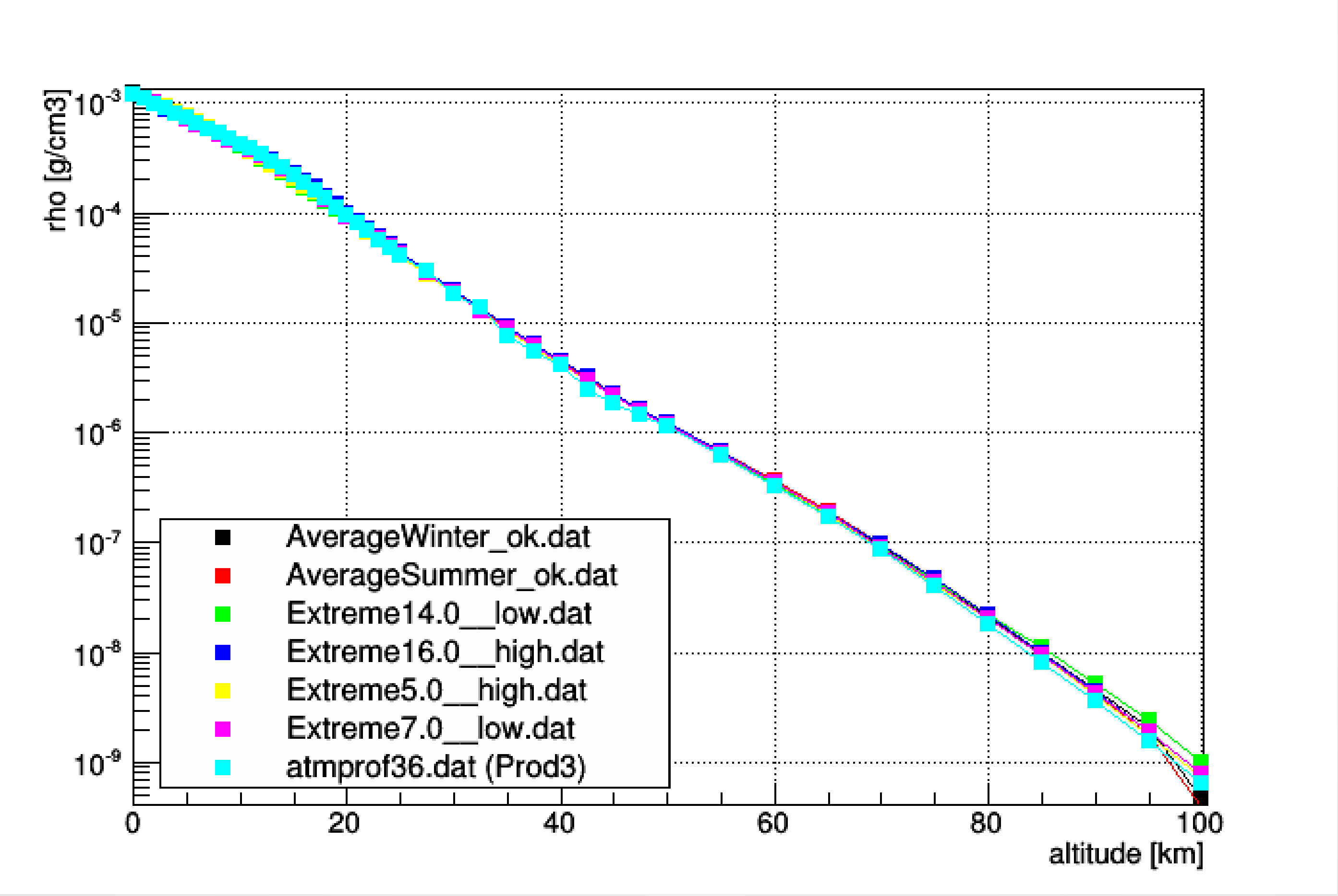

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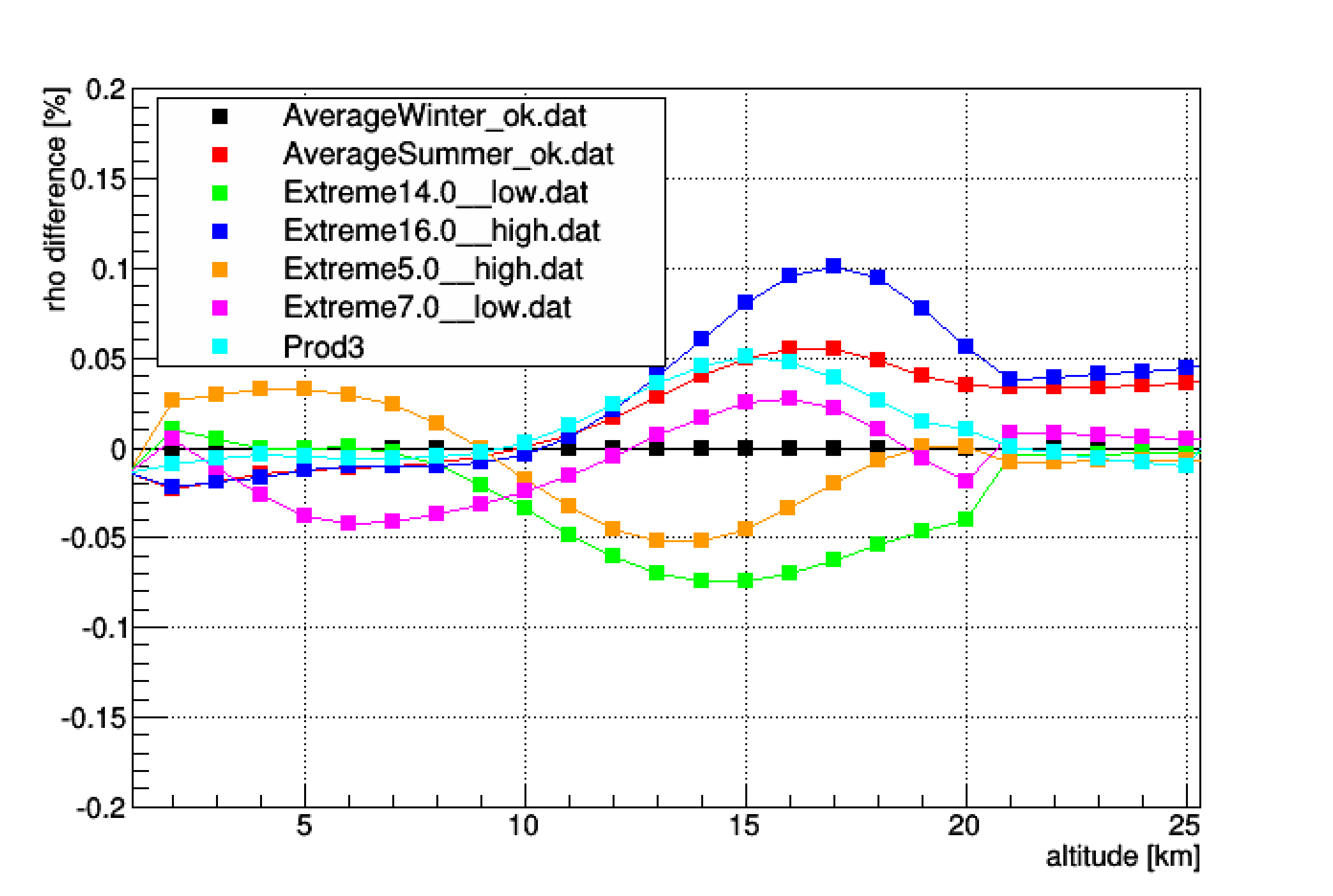

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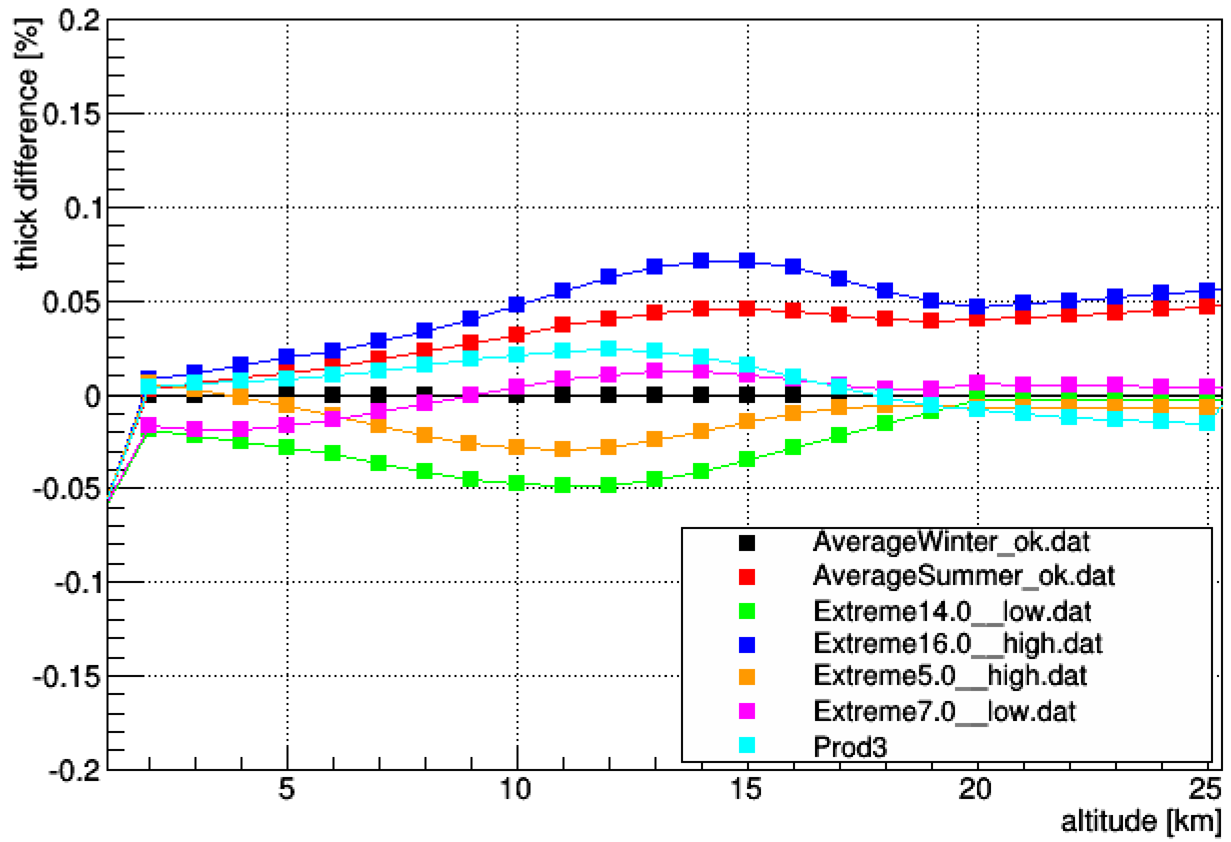
thickness [g/cm^2]



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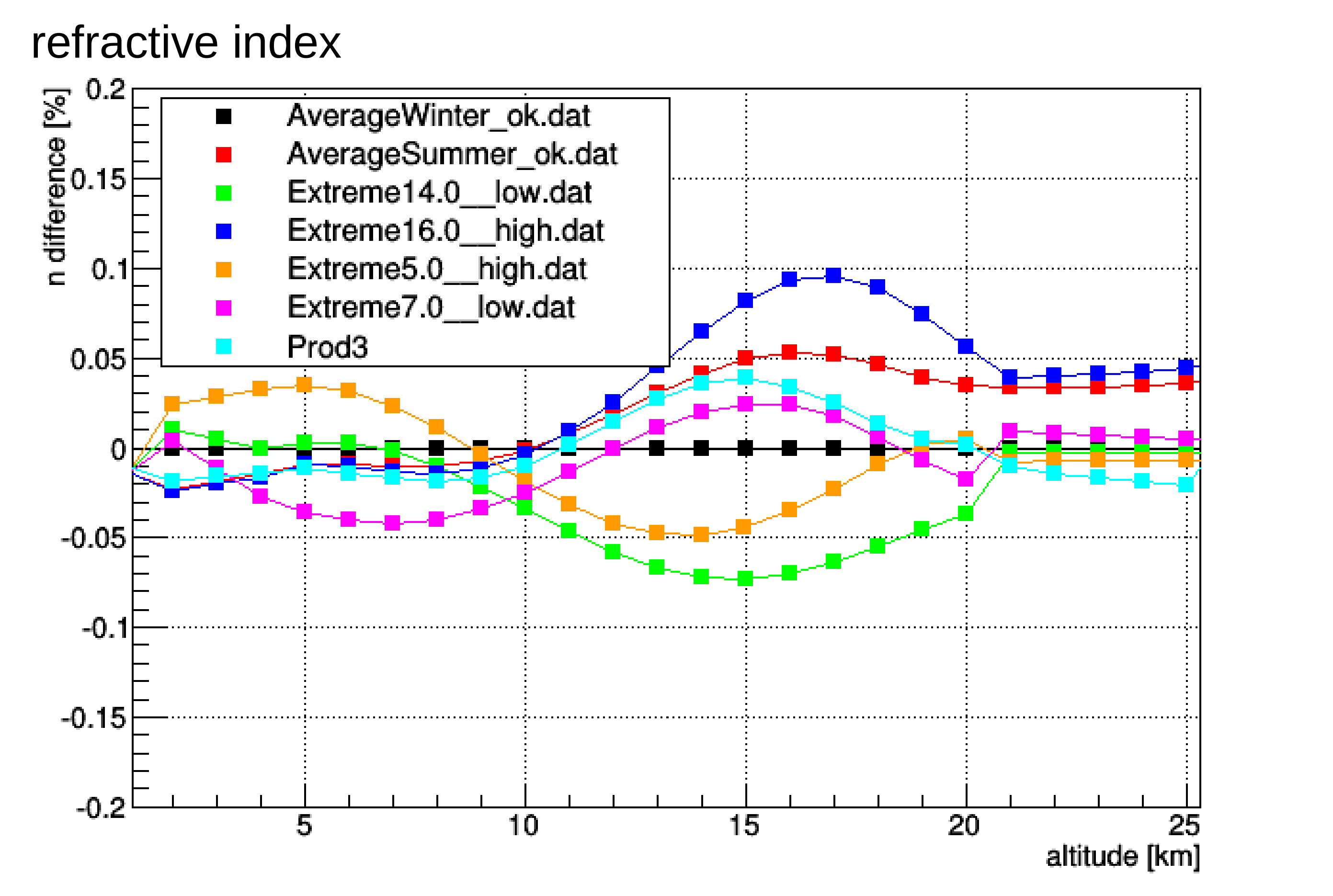
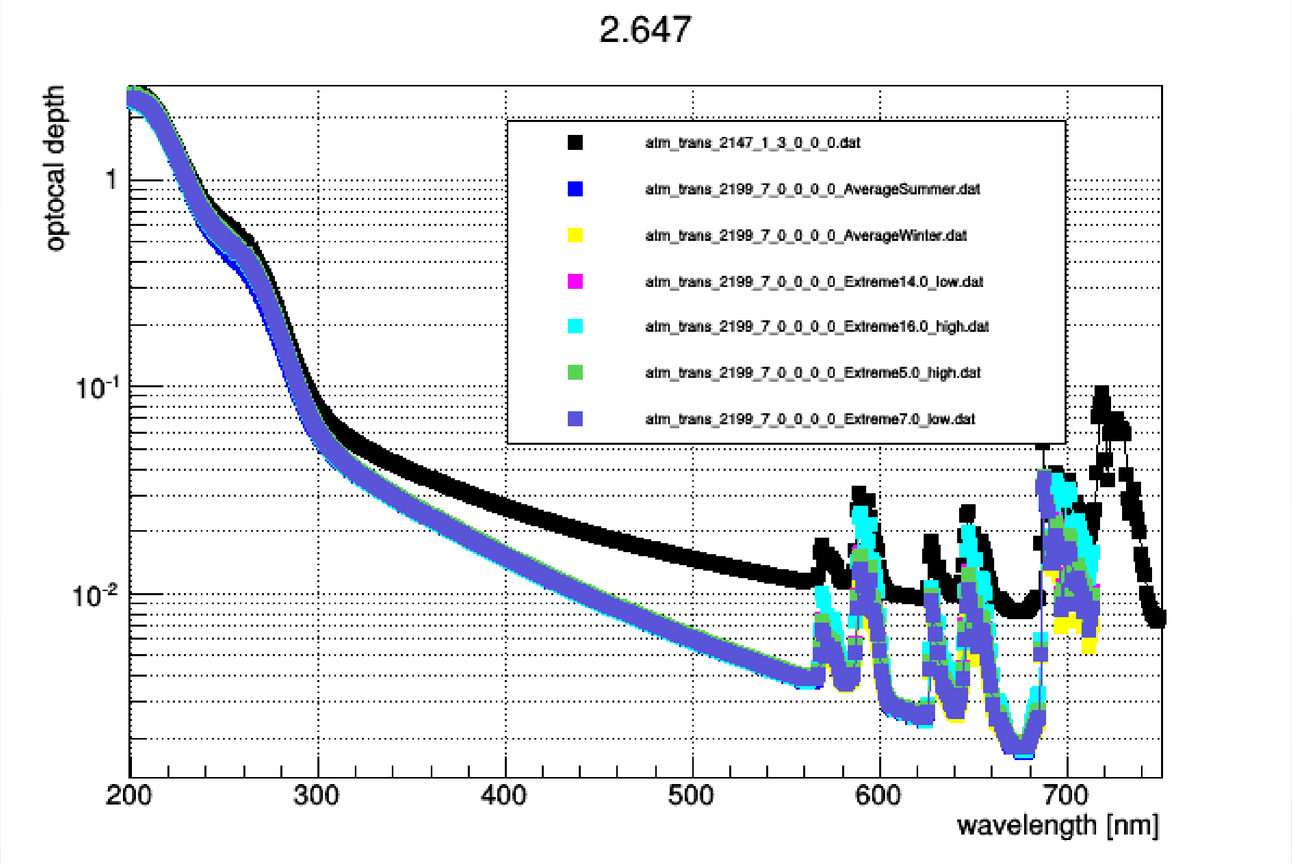


Atmospheric transmission

Thanks to Enzo Papandrea!

- Obtained using MODTRAN, with previous profiles as input
- Only molecular absorption (*Haze = 0, no aerosol attenuation*)
- In Prod3 aerosols* were included (*atm_trans_2147_1_**3**_0_0_0.dat*)



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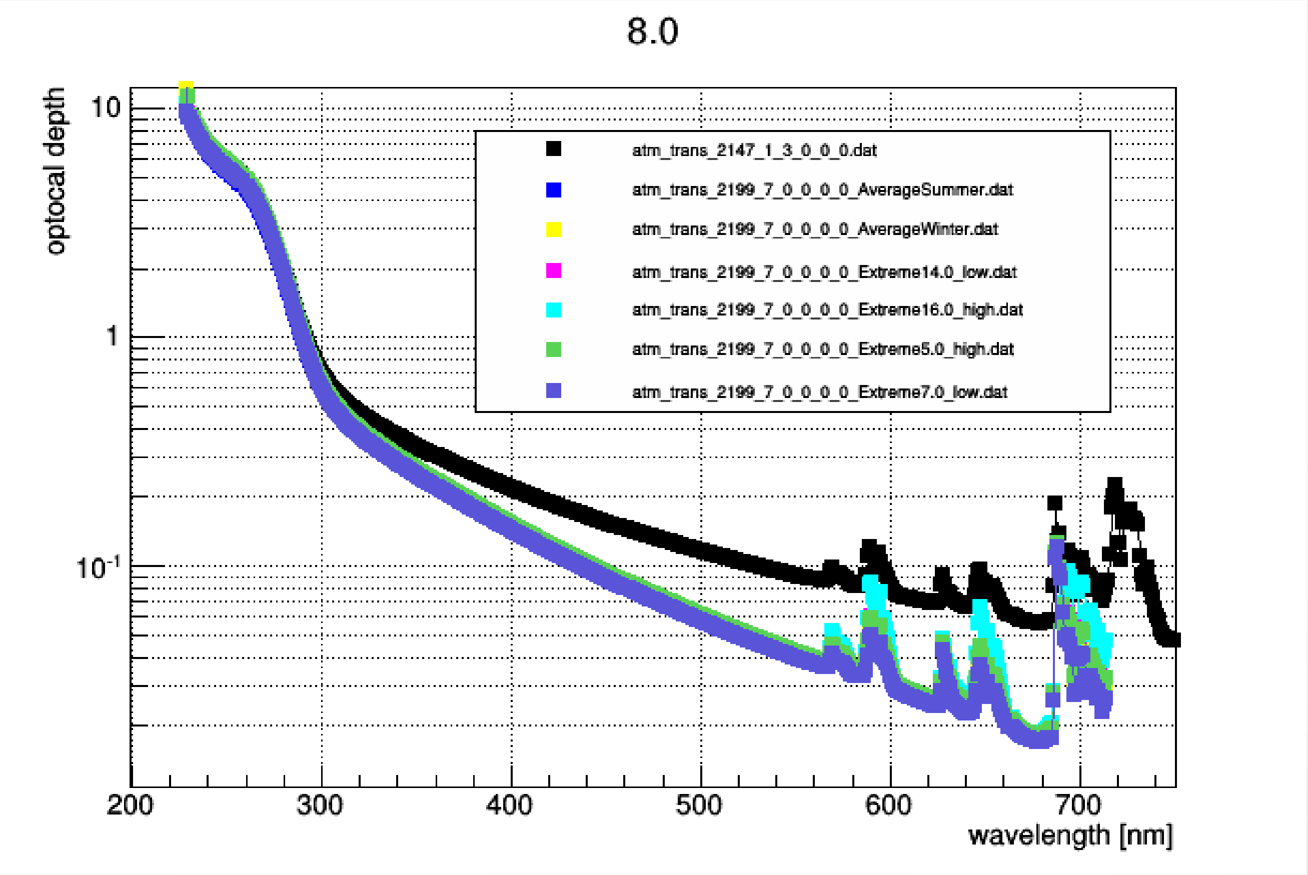

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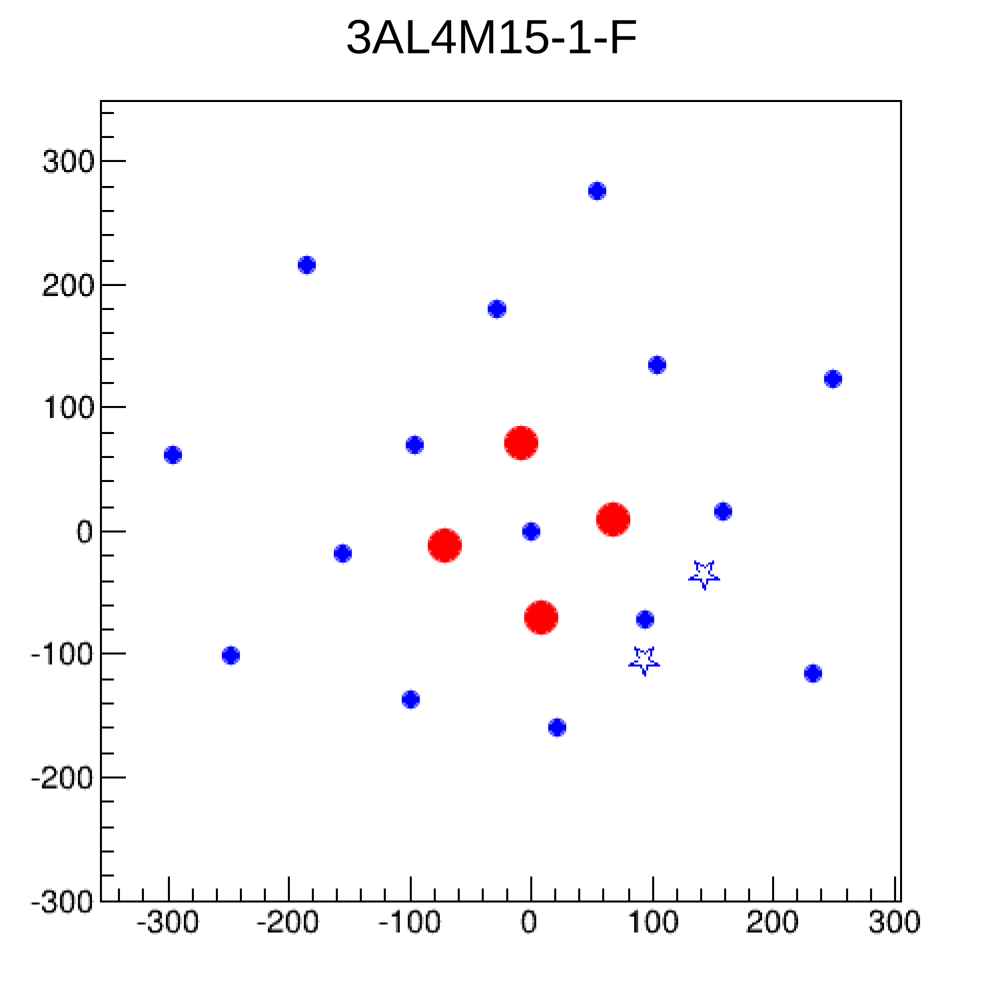
Production

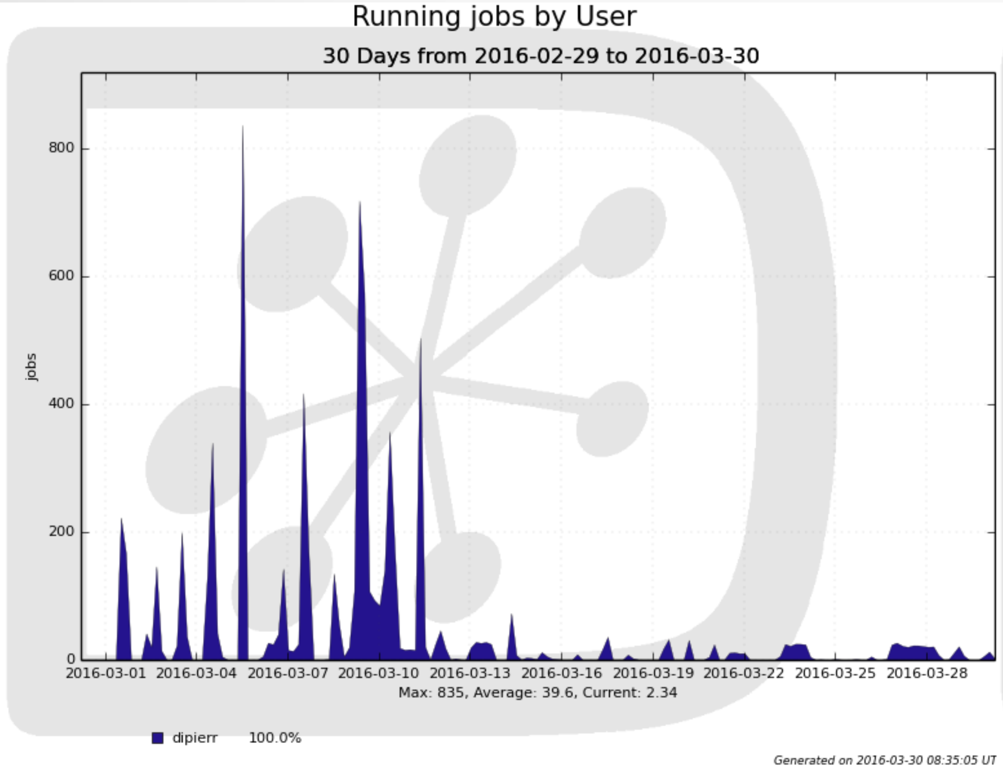
- CORSIKA
  - Primary: gamma, point-like
  - Zenith angle: 20 deg
  - Azimuth: South
  - Energy range: 3 GeV - 100 TeV
  - Spectral index: -2
  - Sampling area (radius): 1000 m, after optimization (< 0.1% lost events at any energy)
  - Number of showers: 5000/50000
  - core re-scattering: 10
  - 3000/300 jobs = ~ 150 M events

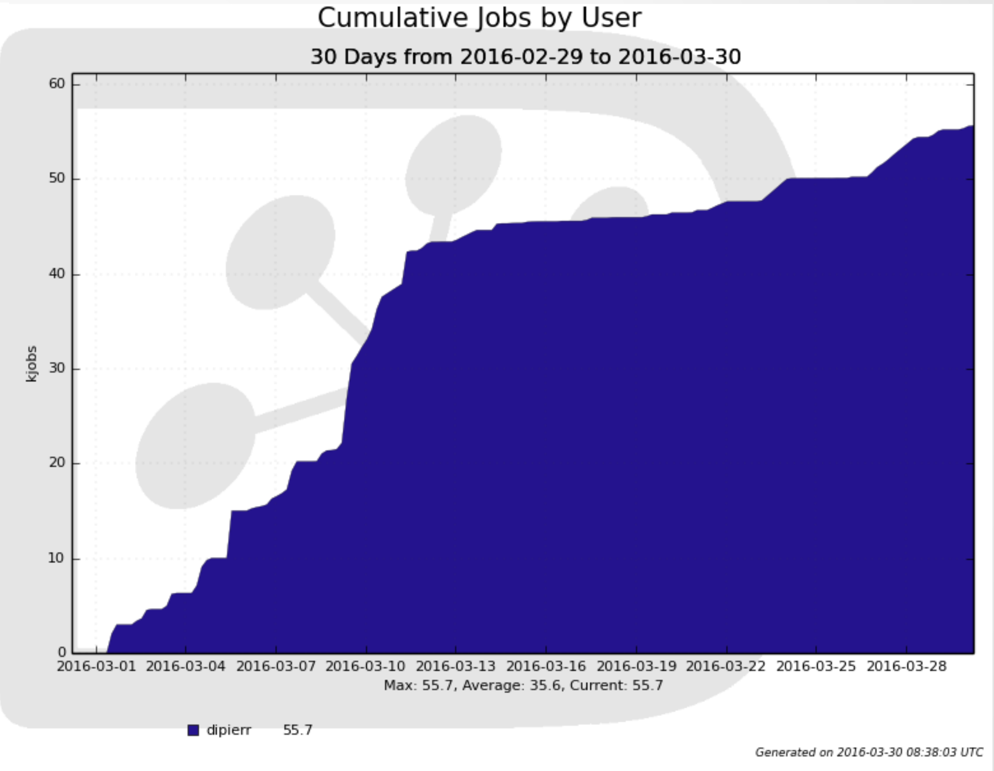
- SIM_TELARRAY
  - from Production 3: 4 LSTs and 15 MSTs (Flash-cam)



Production

- run on the GRID
- scripts adapted from Prod3, several issues solved (new DIRAC version, security update on the CE, multi CE improvement,...)





Thanks to Luisa Arrabito!

Production

- run on the GRID
- scripts adapted from Prod3, several issues solved (new DIRAC version, security update on the CE, multi CE improvement,...)
- small production (only gammas!), 1 model = ~300 cores, ~5 days, ~3 TB.

Atmospheric model	Corsika	Sim_telarray	Evndisp (stero rec)	Evndisp (LUT)
Prod3: with aerosols	Done 1.6 TB	Done 1.8 TB	Done 3.2 GB	Done 3.5 GB
Average winter	Done	Done	Done	Done
Average summer	Done	Done	Done	Done
Extreme_14.0_low	Done	Done	Done	Done
Extreme_16.0_high	Done	Done	Done	Done
Extreme_5.0_high	Done	Done	Done	Done
Extreme7.0_low	Done	Done	Done	Done

Thanks to Michal Vrastil!

Reconstruction

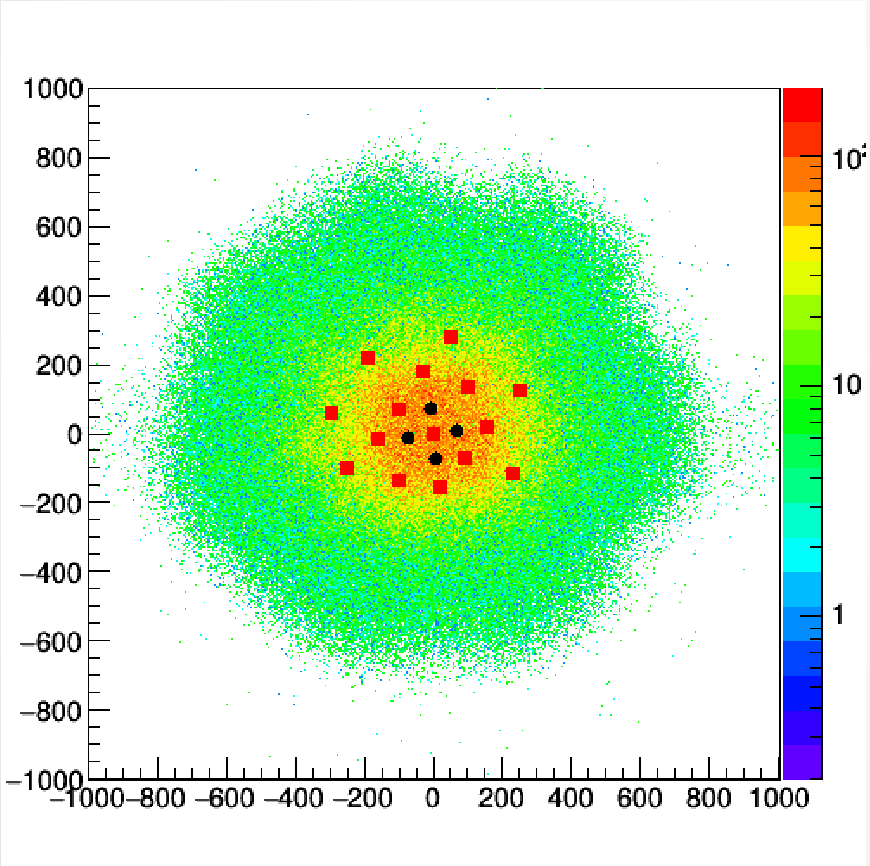
- **Eventdisplay package (version 2016.01.11)**
  - converter
  - stereo reconstruction
  - LUT (energy, mscw/l)

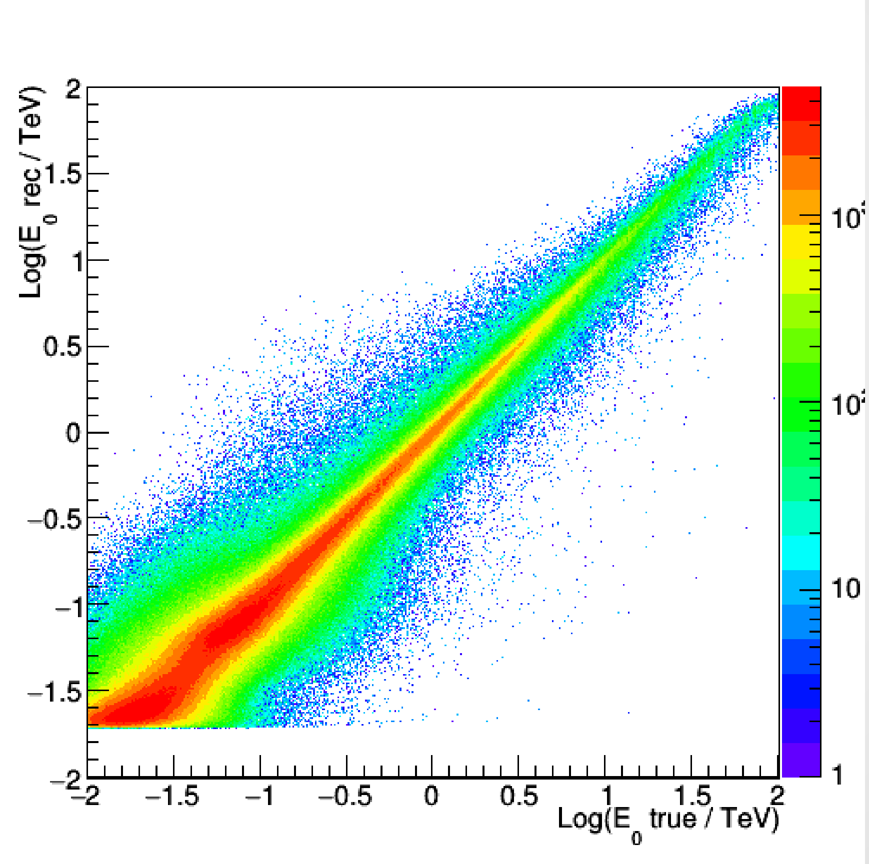
- Reconstruction options and cuts: **standard prod3 analysis**,
  - job.setCalibrationFile('ped.20151106.evndisp.root')
  - job.setNNcleaninginputcard('EVNDISP.NNcleaning.dat')
  - job.setReconstructionParameter('EVNDISP.prod3.reconstruction.runparameter.NN')
    - signals extraction:
      FADCANALYSIS 2 (sliding window)
      FADCSUMMATIONWINDOW 6 (LST) and 4 (MST-F)
    - image cleaning: "*TIMENEXTNEIGHBOUR*" (*arXiv:1307.4939v1*)
    - image edge fit: *if Loss >= 0.1 and ntubes >= 5 (MST-F)*
    - telescope-wise pre-cuts: *ntubes 4, max loss 0.1/0.2, no Size cut*
    - stereo-wise: *minangle 10 deg (LST), 15 deg (MST-F)*

- Simple reconstruction **quality cuts** (only to avoid too poorly reconstructed events), next performances are *pseudo-performances*.
  - number of telescopes (>= 2), linear reconstructed energy differences (dES < 1.5), Mean Scaled Width (-2 < MSCW < 0.5),...

Analysis: the selected events

Example: Prod 3 atmospheric model.

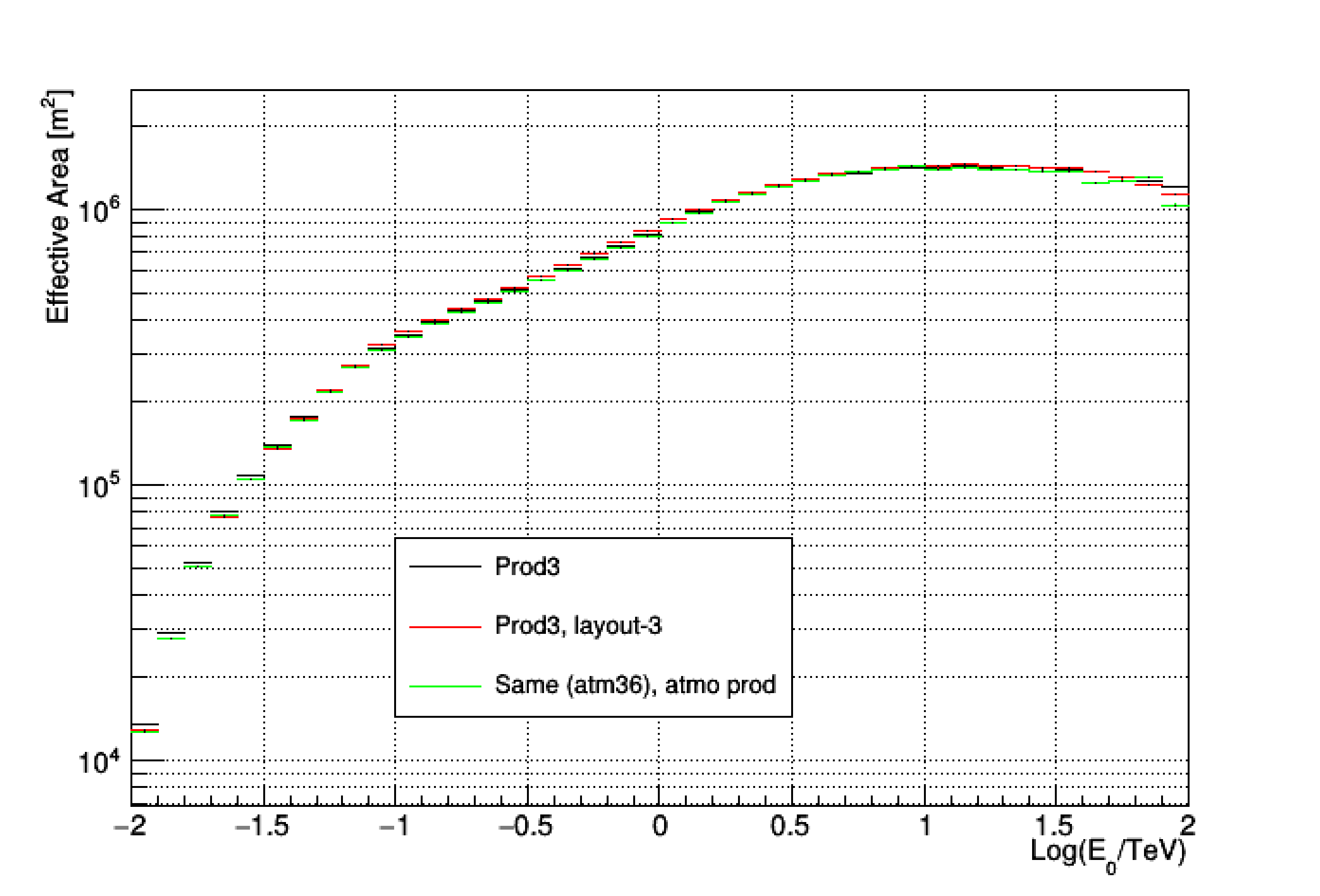




Minimum reconstructed energy (~ 20GeV)
Reconstructed energy shows features < 60 GeV

Cross-check with Prod3

- From Gernot's analysis:
  - 3A4L15M-3-F, February (red)
  - 3A4L15M-1-F, April (black)
- My production, same atmosphere (with aerosols), 3A4L15M-1-F, February (green)



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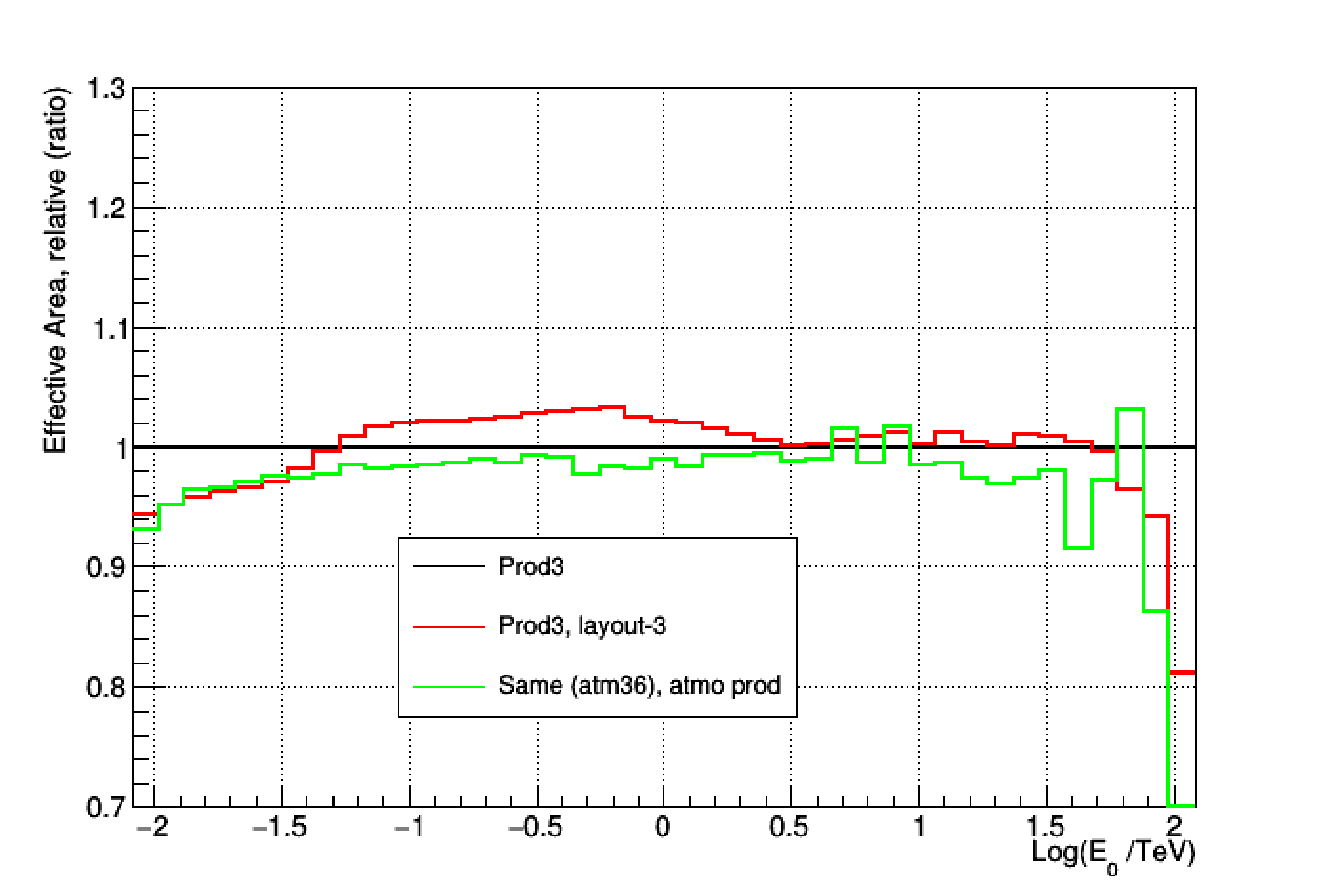

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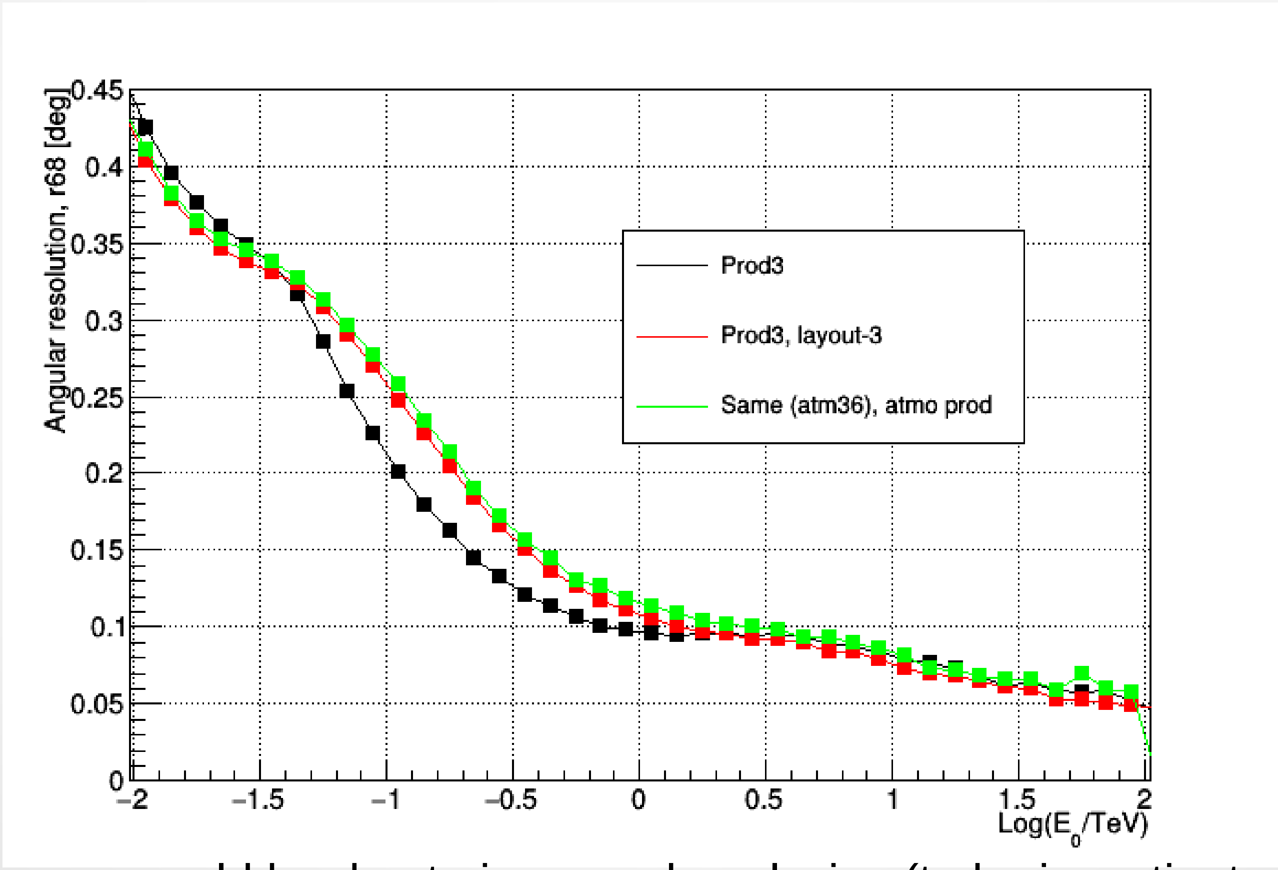
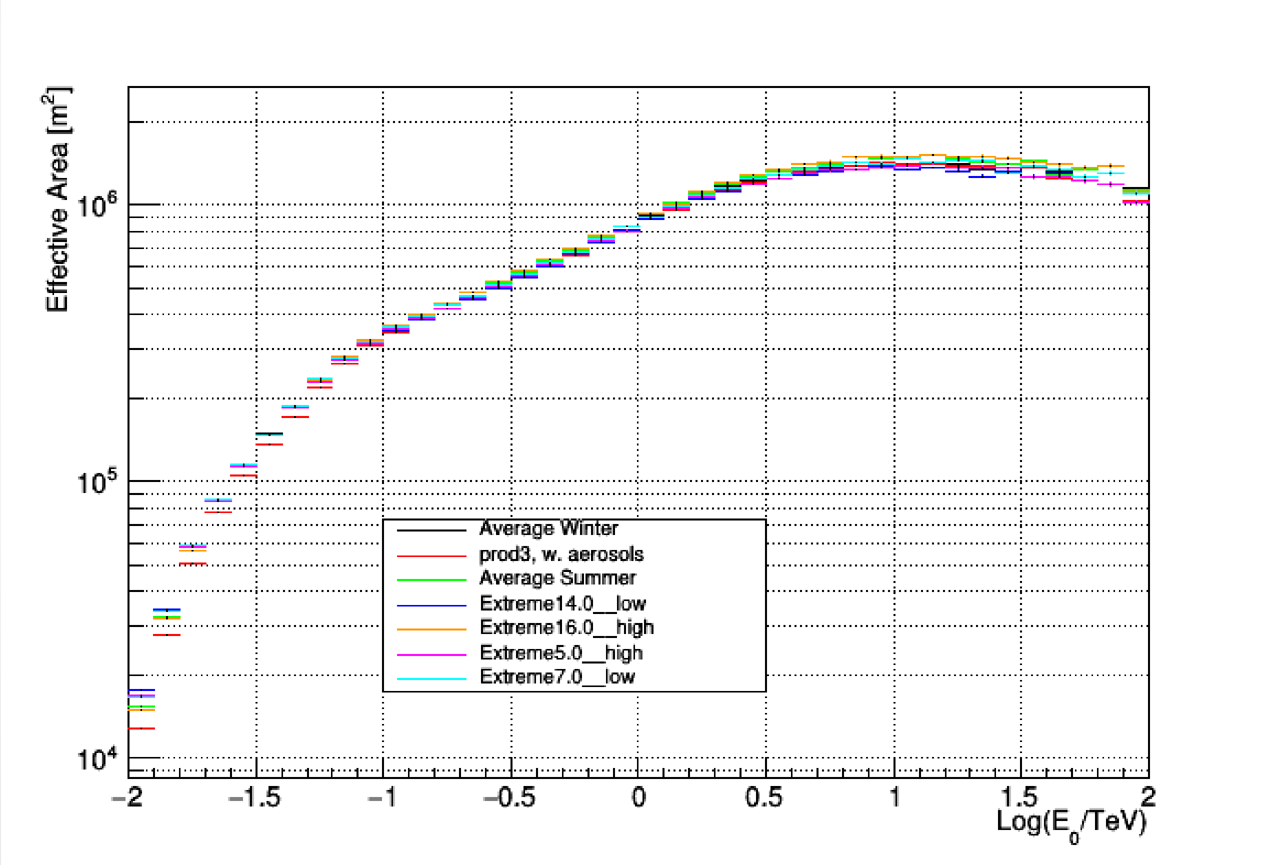


The difference could be due to improved analysis...(to be investigated)

The atmospheric models comparisons are done with the same analysis.

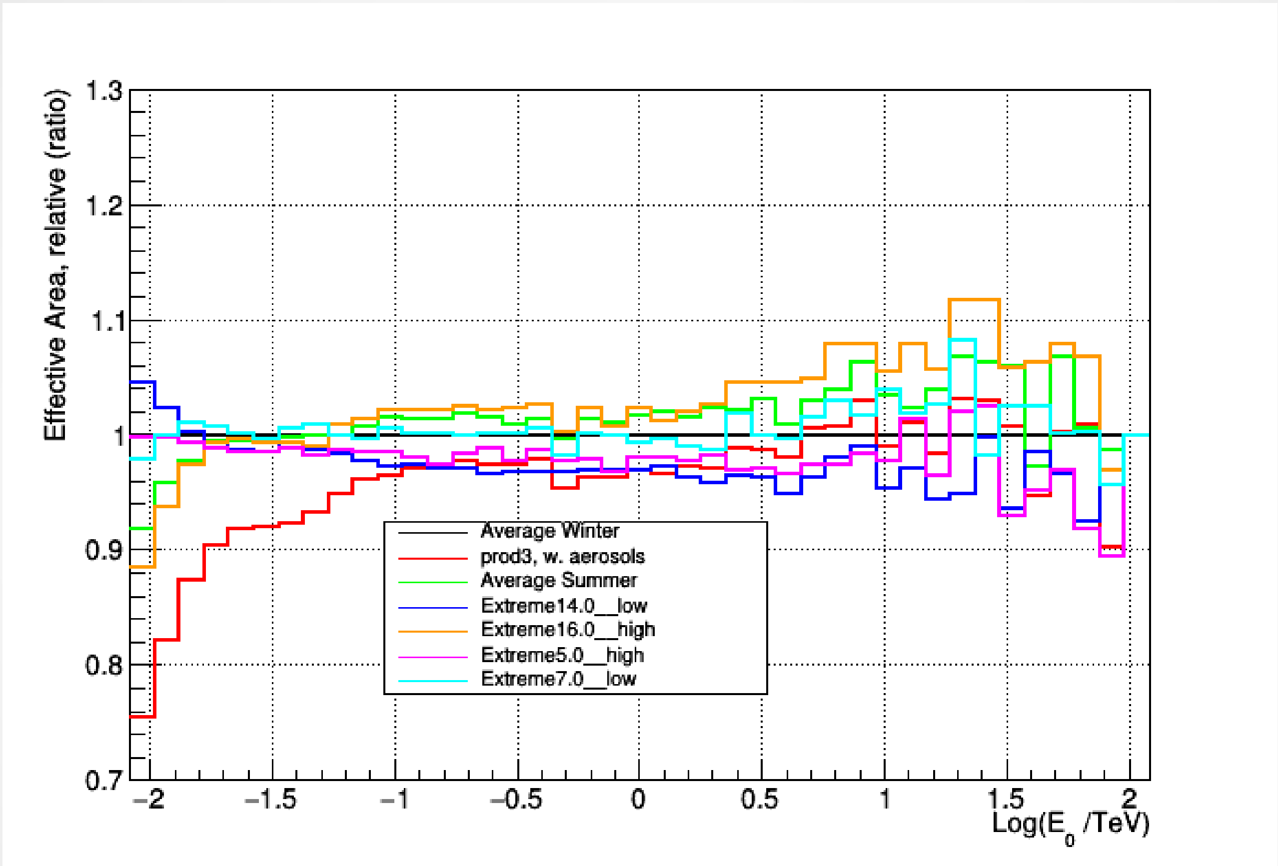
Effective area

- Effective area after trigger and reconstruciton
  - spectra rescaled to spectral index -2.5
  - uncertainty on the effective area reflects on the flux uncertainty



All following results should be intended as **pseudo**-effective area, **pseudo**-Energy resolution, etc...because it was not applied the full analysis.

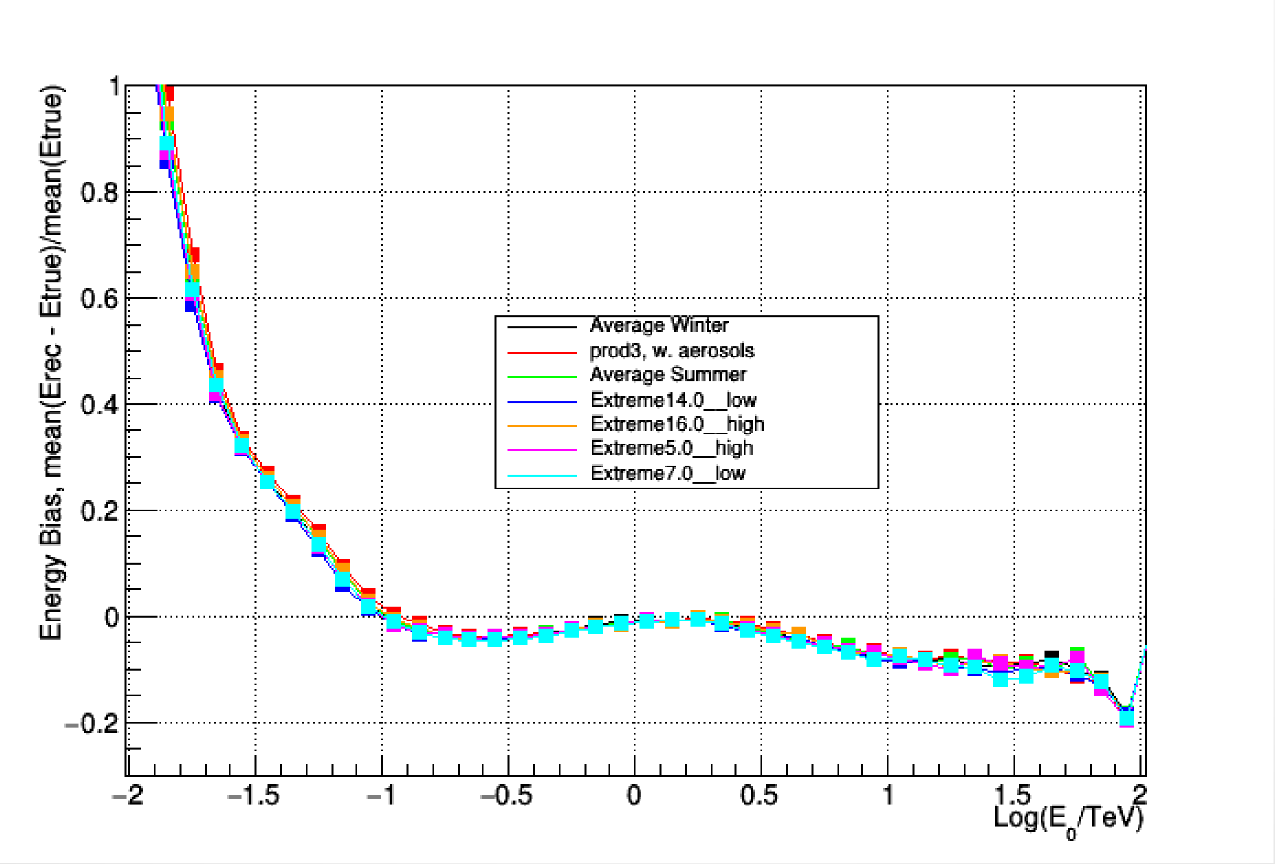
Effective area



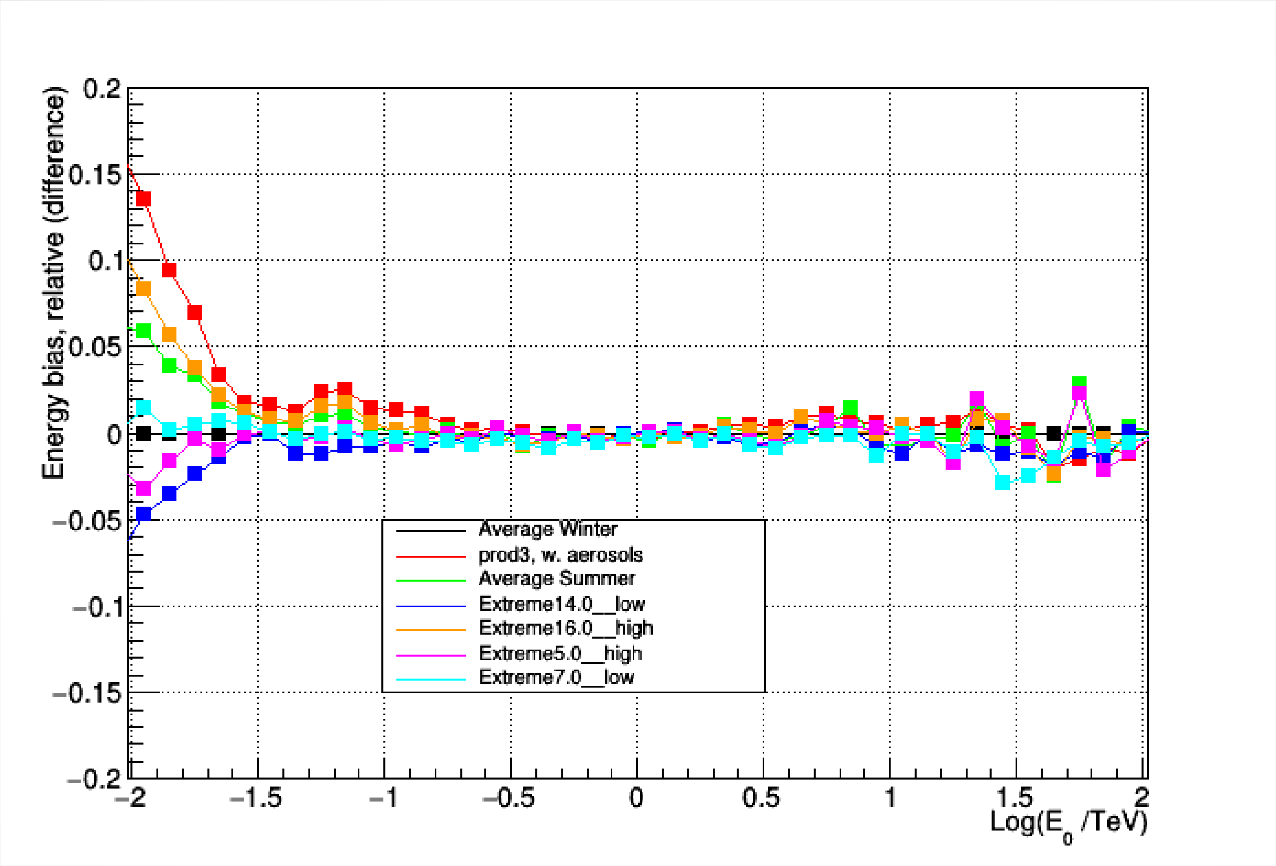
- Maximum difference for the atmosphere including aerosols
- At high energy the atmospheres denser in their higher part (~14 km) produce larger effective areas, at LE the atmospheres denser in their lower part (<7km) produce larger effective areas. All models are consistent.
- The largest effects is at the threshold, however always of the order 5-10%.

Energy bias

- mean of $\frac{E_{rec} - E_{true}}{E_{true}}$
- not expected a large effect, we are using the same atmosphere for filling the LUTs and for the data production



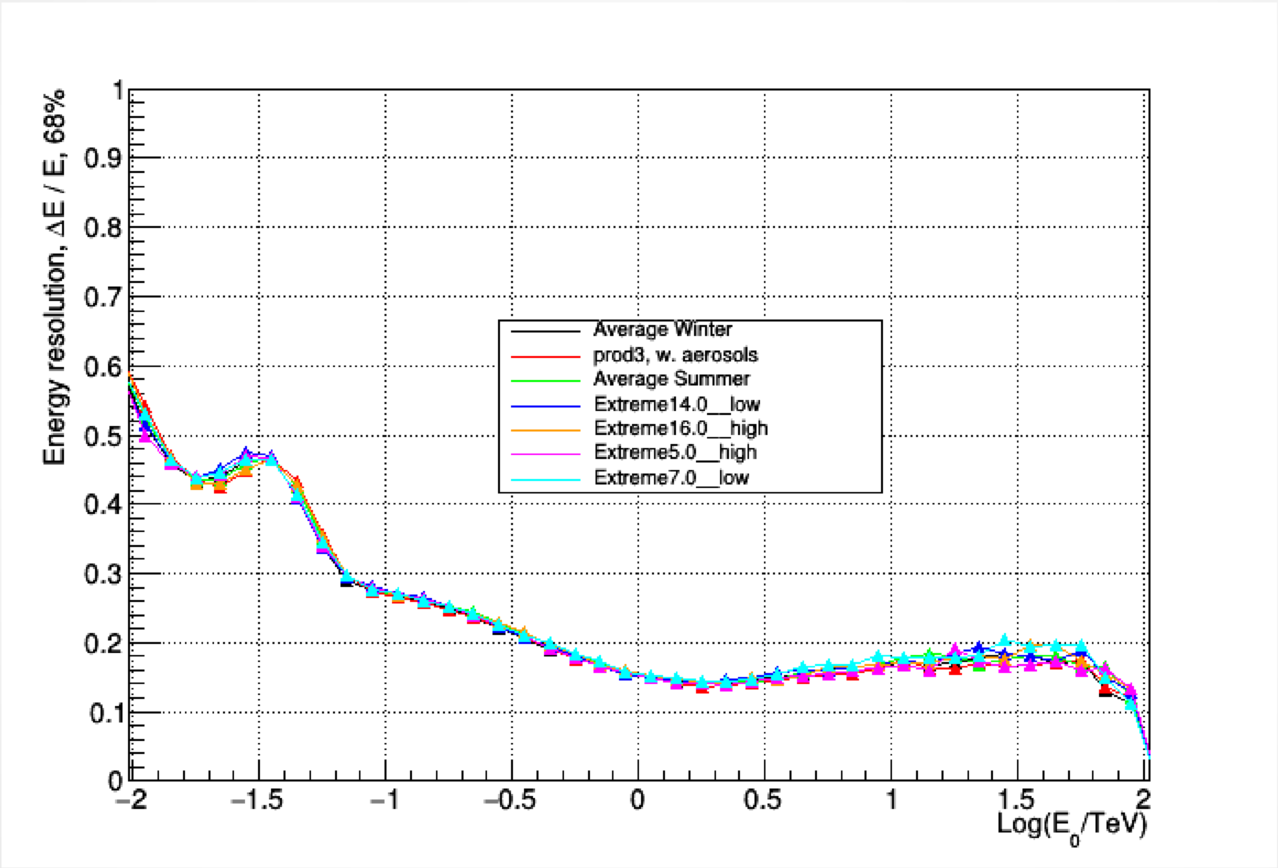
Energy bias



- The difference of the energy biases w.r.t. Average Winter's one
- The large effects < 20 GeV are due to a *selection* of the events which suffered large fluctuations
- Above 20 GeV, ± 2 % effect.

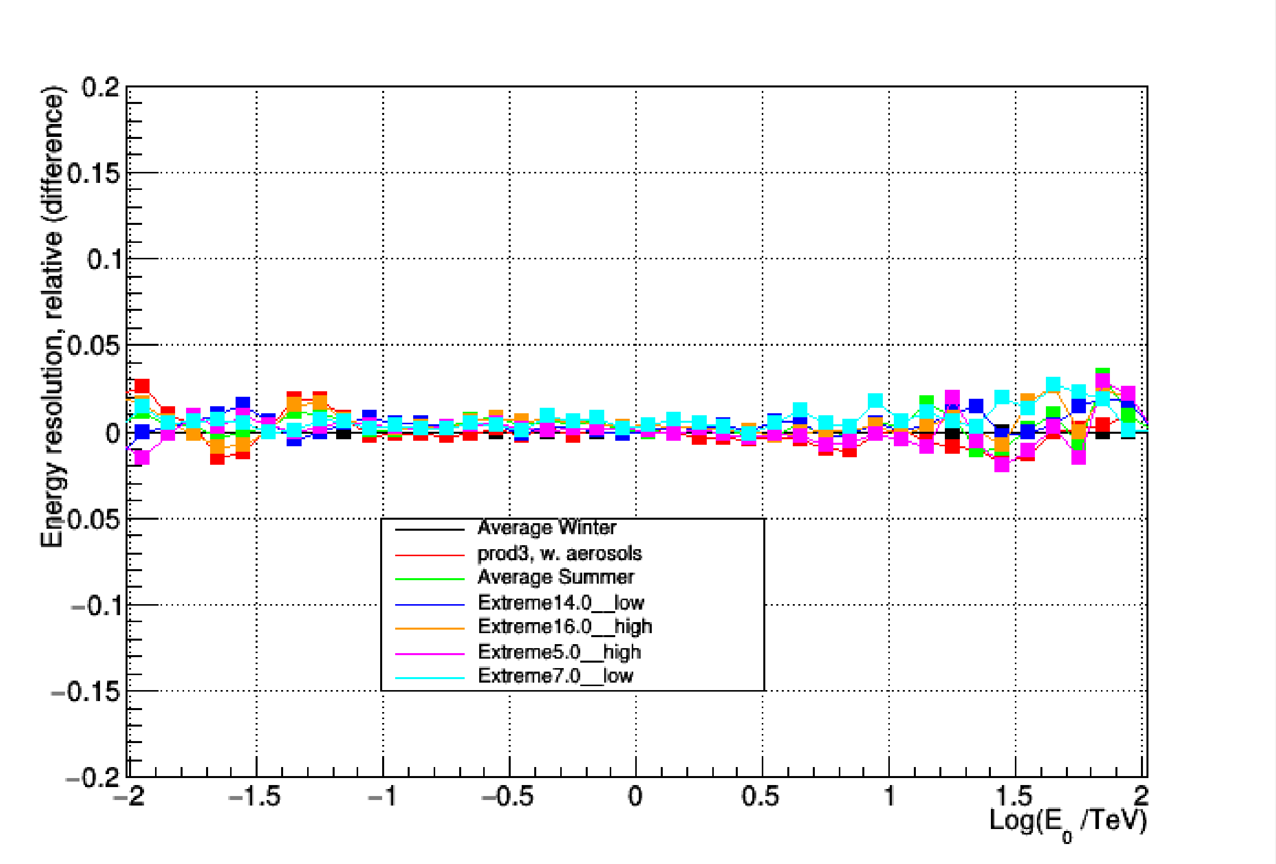
Energy resolution

- ΔE interval including 68 % of the events (w.r.t. to mean(Erec - Etrue))



- structure below 100 GeV, transition from LST to MST?
- compliant with requirements

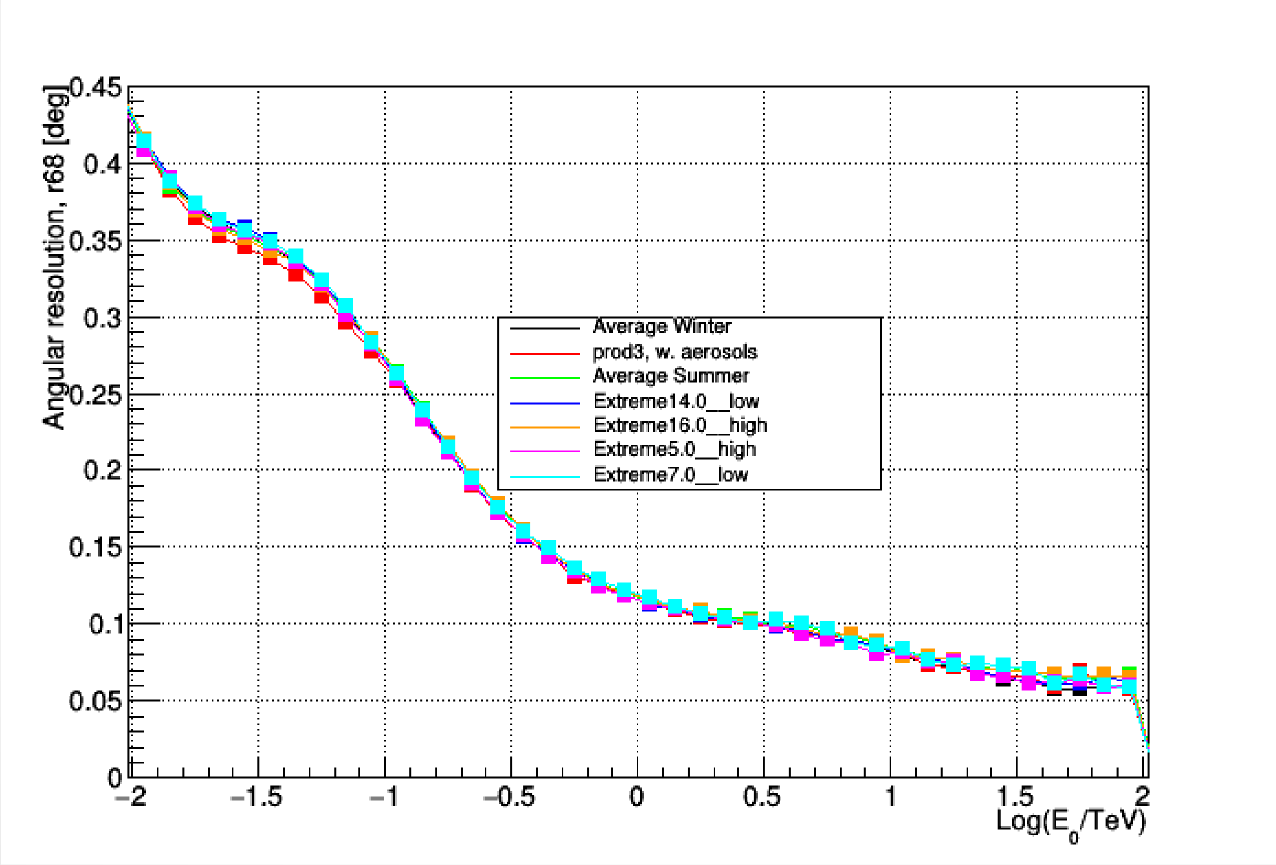
Energy resolution



- as expected, very small effect ± 2 % effect.

Angular resolution

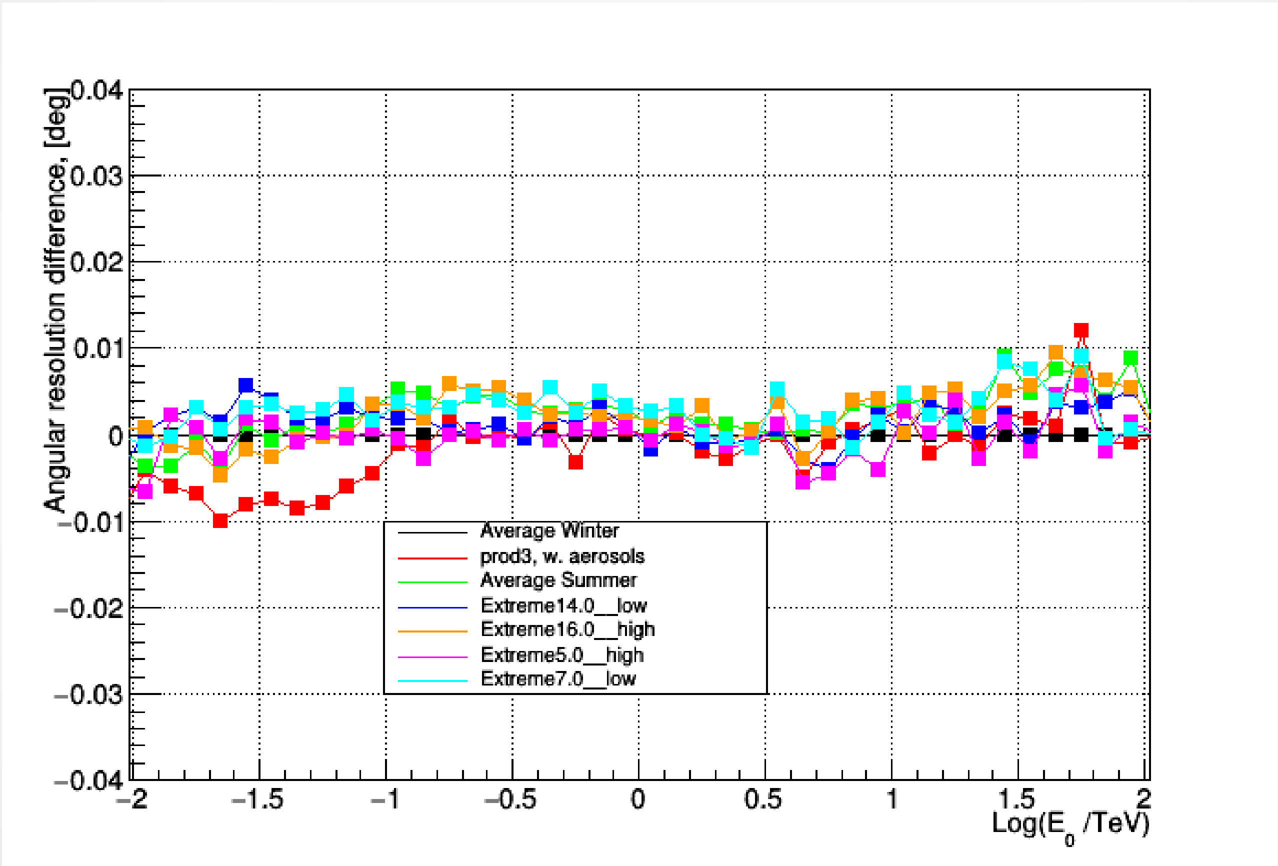
- 68 % containment radius



- We expect a *second order* effect on the angular resolution due to the different atmospheric profiles

Angular resolution

- 68 % containment radius



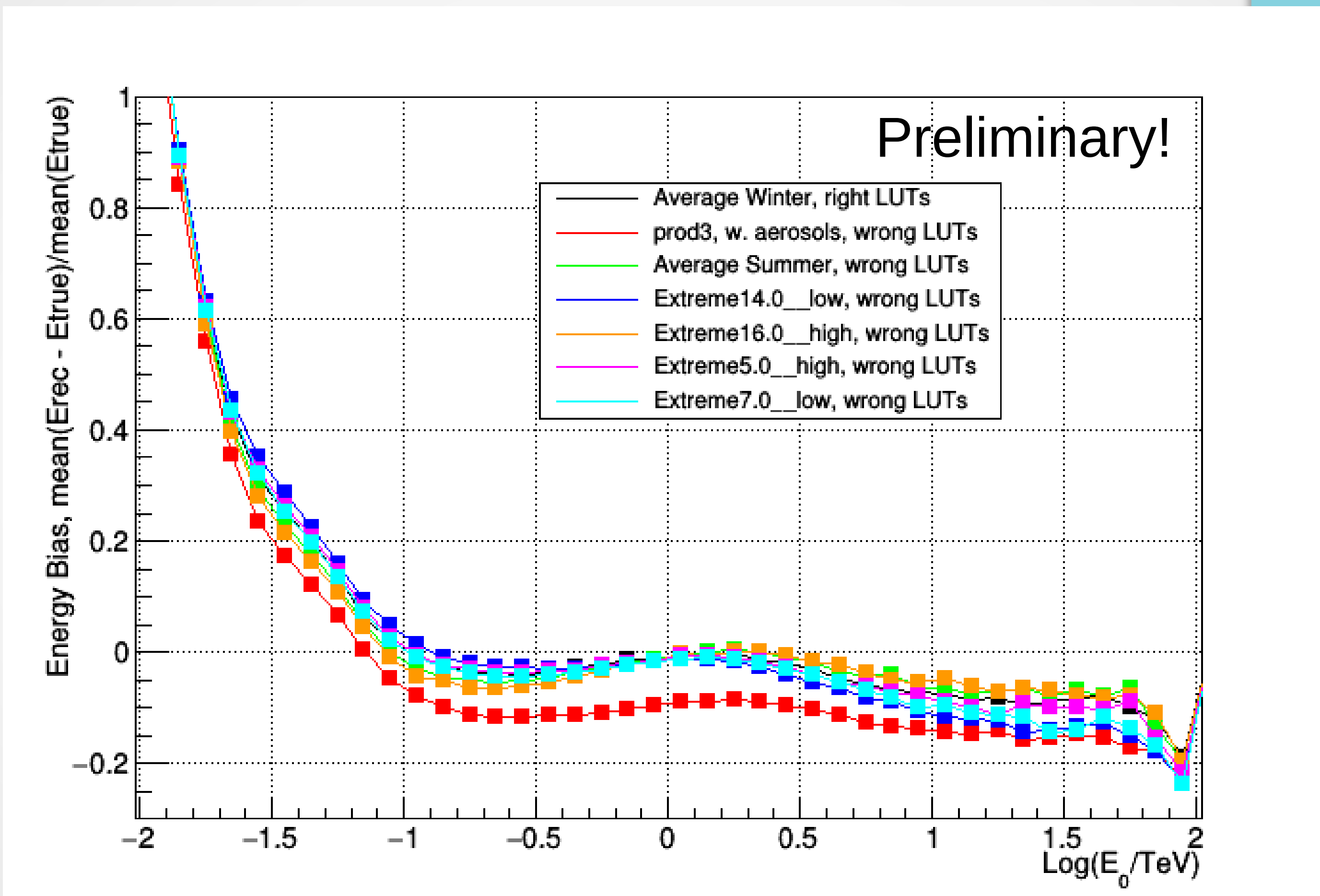
- We expect a *second orde*r effect on the angular resolution due to the different atmospheric profiles

Extreme case: no atmo calibrations

- Using the Average Winter LUTs to reconstruct data produced with all other atmospheric profiles
  - we expect a large effect on the Energy bias
    - same Size corresponds to different energy
  - only minor effects on the Energy resolution
    - the spread of the reconstructed energies should not increase

- Very recent results: Preliminary!

Extreme case: energy bias



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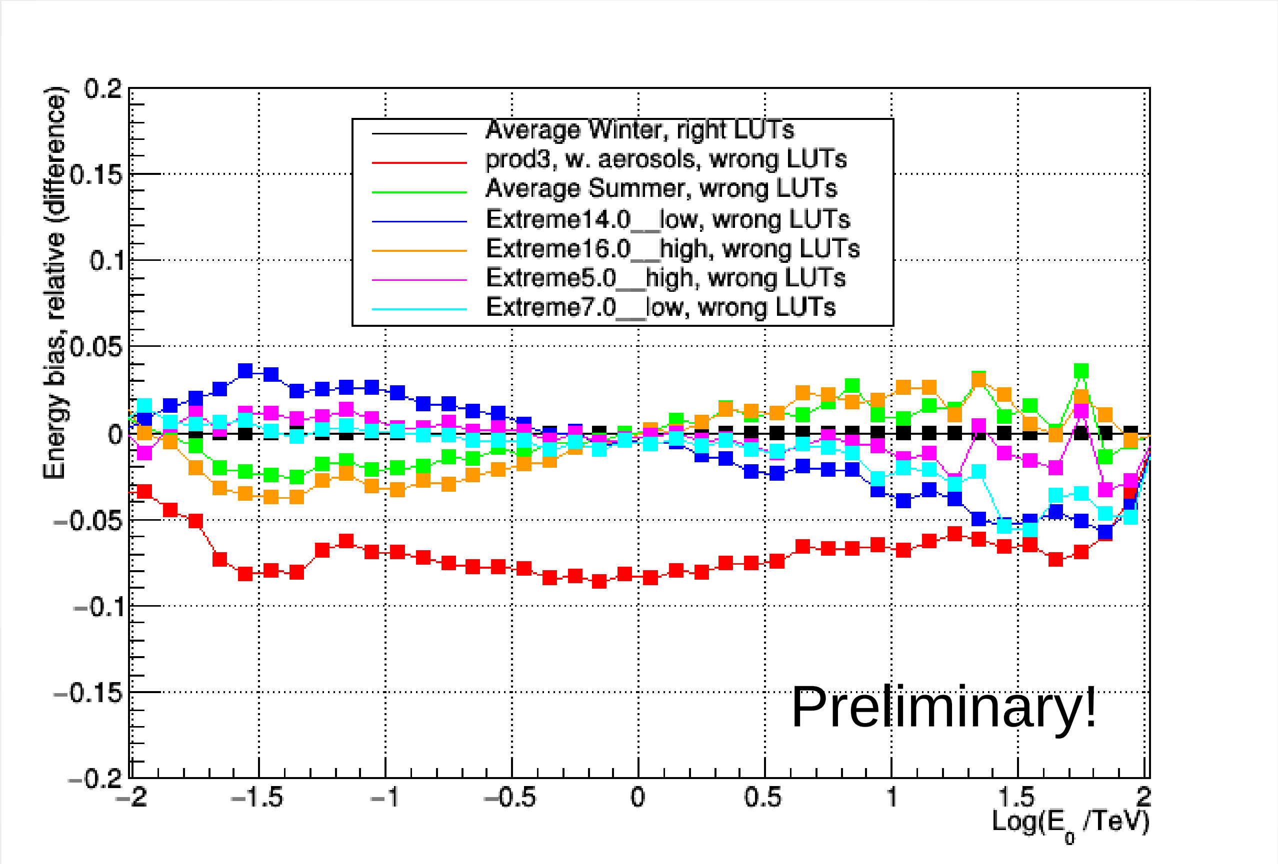
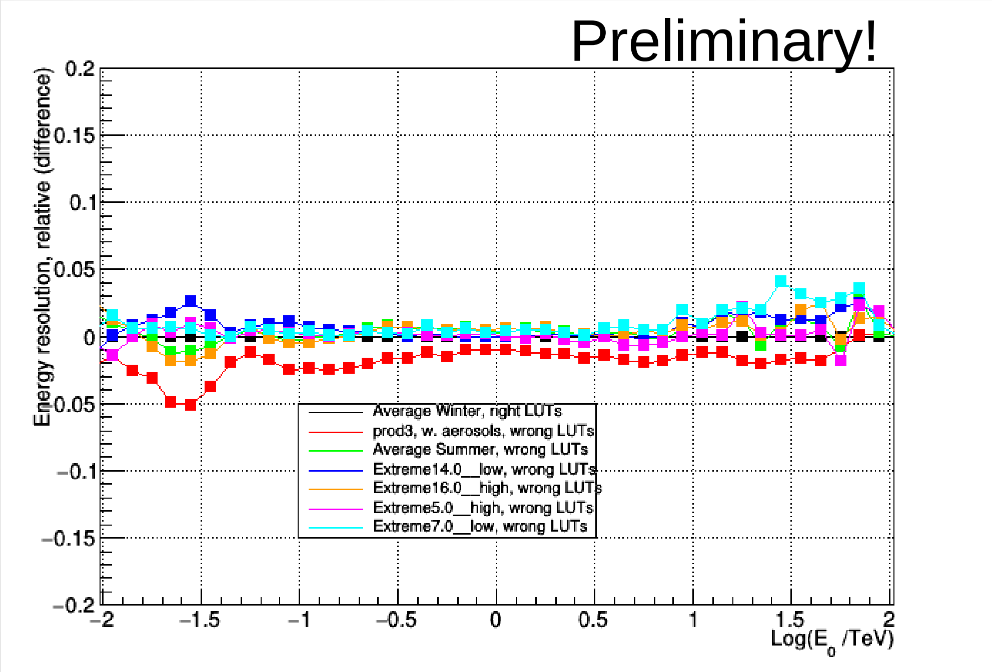


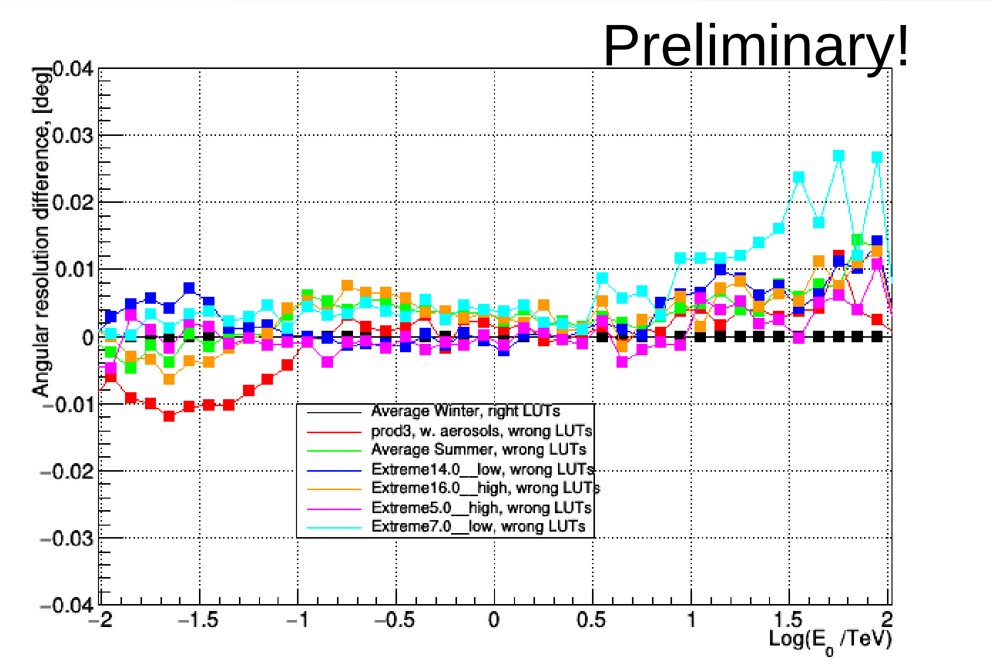
- The difference with the atmosphere with aerosols is the largest (rather constant 8% energy underestimation)
- The purely molecular profiles show an Energy dependency (± 4 %)
  - dangerous for energy spectra!
  - largest effects for the extreme atmospheric profiles occuring at high altitude

E.c.: Energy and Angular resolutions

- Energy resolution



- Angular resolution

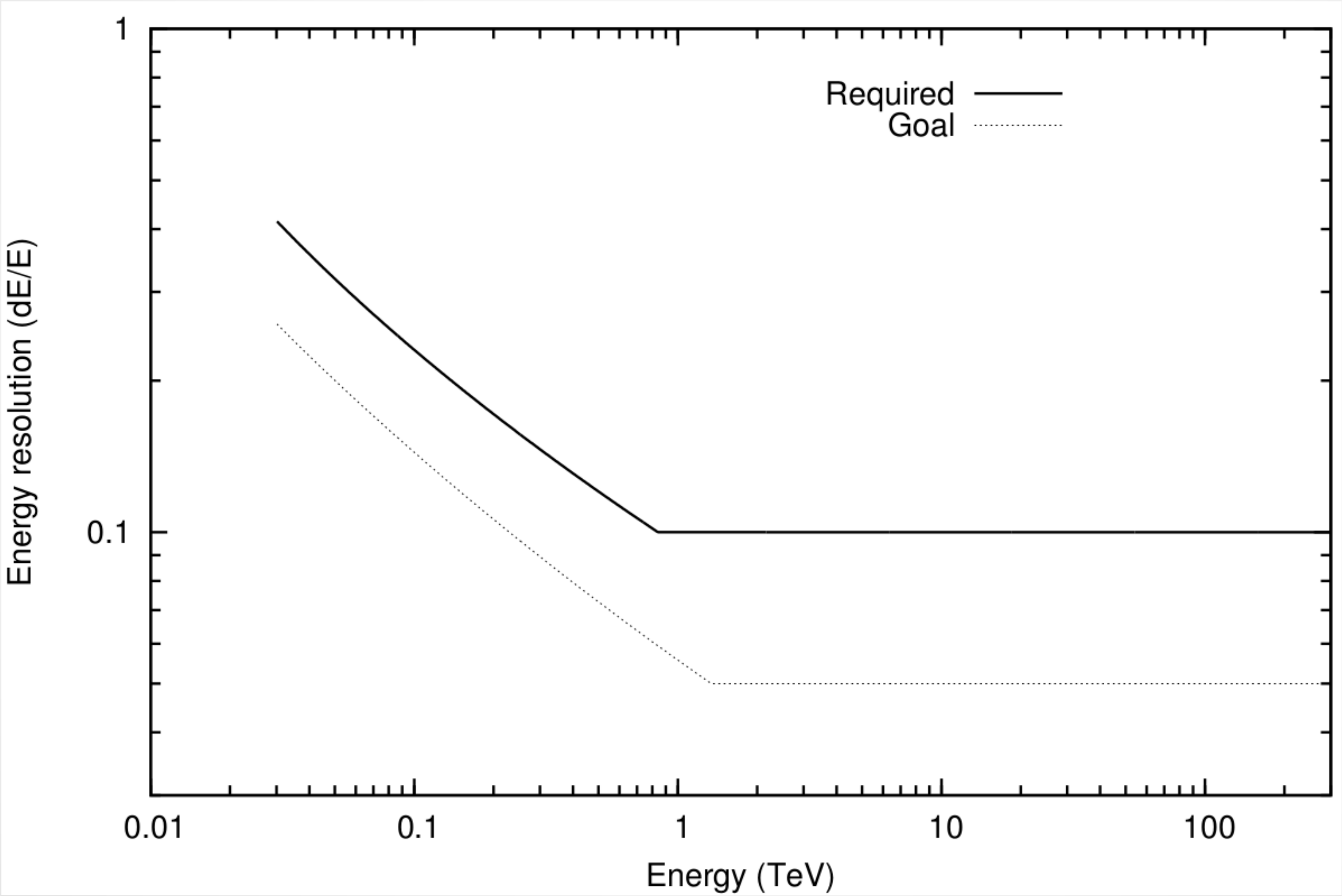


- The effects are rahter small as expected

Next steps

- To study with MODTRAN the dependencies of the Optical Depth on the variations of the atmospheric profiles (density, thickness, refractive index, RH, Water Vapor fraction...)
- To introduce the aerosols in the atmospheric transmission
  - different kind of aerosols
  - different altitude and thickness
  - *George has already provided measured atmospheric transmission profiles at the HESS site.*
- Same studies at different zenith angle
- To study the effects of the uncertainties of the currently foreseen CTA atmospheric measurements
  - *how much and how fast do the molecular and aerosols profiles change?*
  - *how precisely will they be measured?*

Backup



Required
Goal
Energy resolution (dE/E)
1
0.1
0.01
0.1
1
10
100
Energy (TeV)