The Atmosphere in the MC Simulations

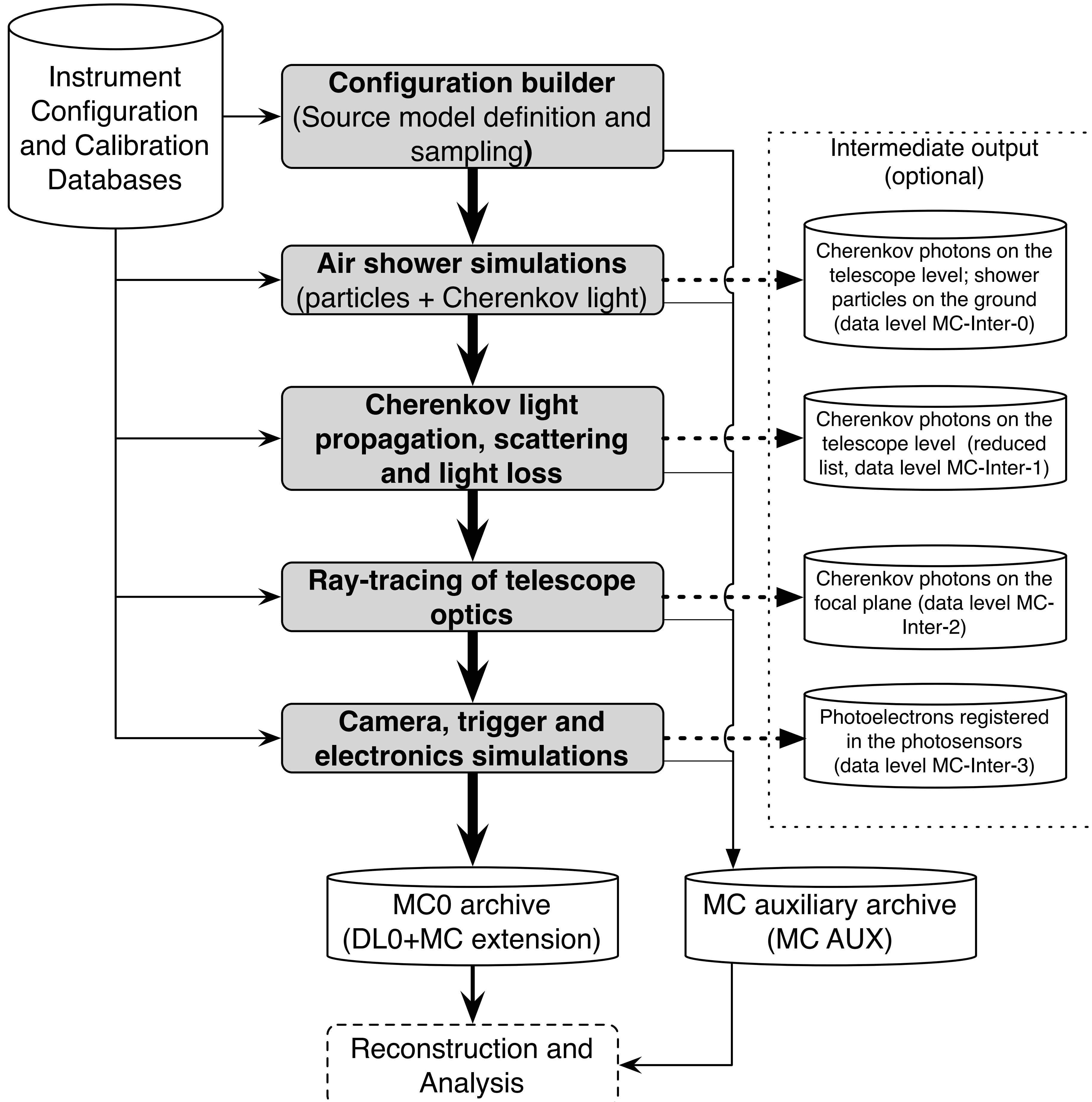
What MC expects from the calibration group

Steve Porter (2012)

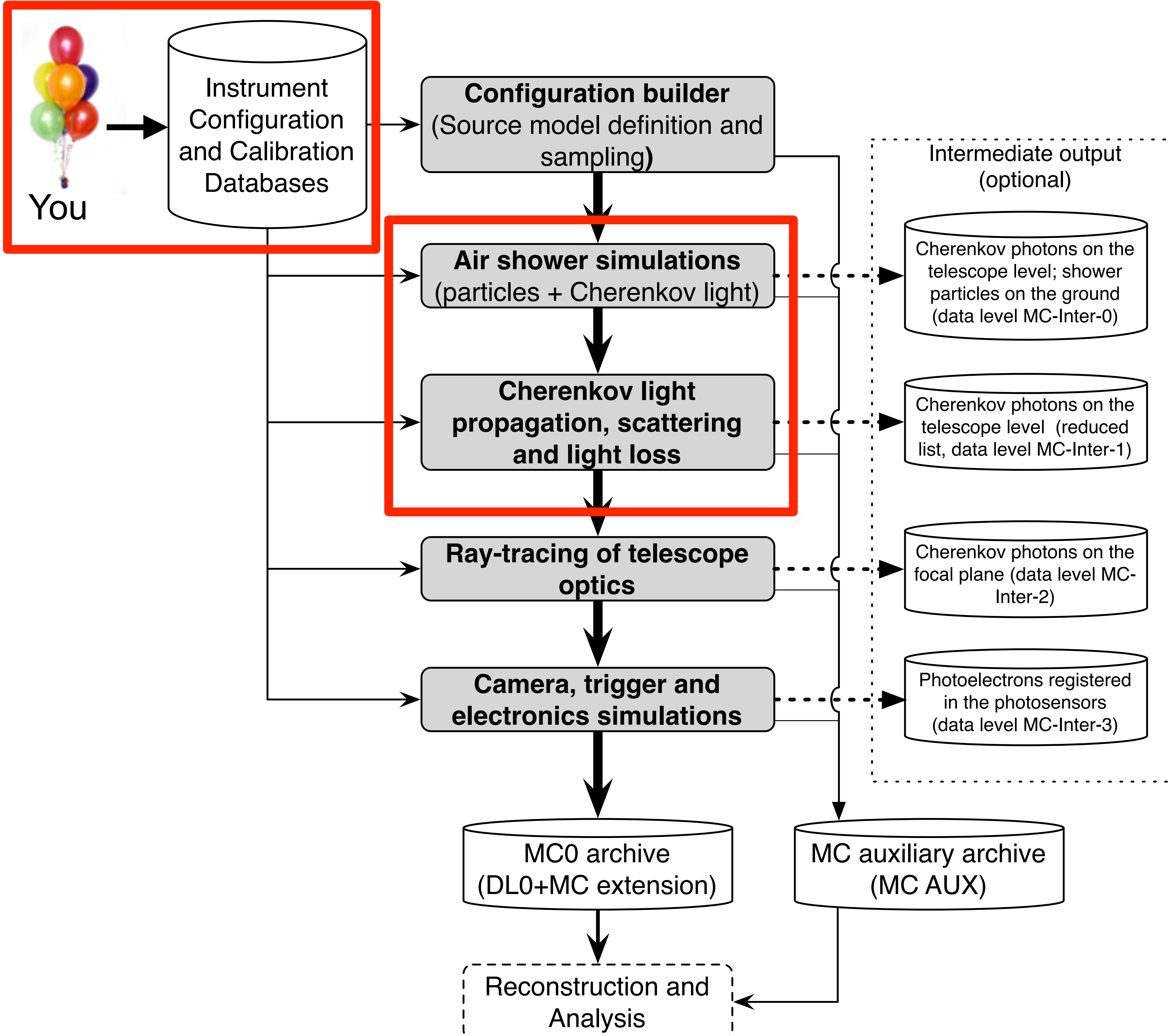
Gernot Maier

Alliance for Astroparticle Physics

Data flow of MC event generation



Data flow of MC event generation



Requirements

from science requirements document:

10% systematic uncertainty on energy scale (SCI-170)

100% of feasible operational time available for observations (SCI-120)

from performance requirements document:

A-PERF-0260 The systematic uncertainty of the energy of a photon candidate (at energies above 50 GeV) must be **<15 %**.
R, motivated by: SCI-080 *Applicable States: Observing*

A-PERF-0380 The uncertainty on the collection area of the system well above threshold (a factor of two above the lowest energy at which sensitivity is required, e.g. above 40 GeV for dark sky conditions) must be **<12 %**.
R, motivated by: SCI-170 *Applicable States: Observing*

A-PERF-0390 The goal uncertainty on the collection area of the system well above threshold (defined in A-PERF-0380) is **8 %**.
G, motivated by: SCI-170 *Applicable States: Observing*

MC Requirements document

	CTA	
cta cherenkov telescope array	MC Simulation Software Requirements	Ref : DATA-PIPE-MC/20130602 Version : 2.2 Date: Oct 17, 2014 Page : 1/34

MC Simulation Software Requirements

Authors	*Laboratory*
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Approved by	*Laboratory*

Get it from the CTA redmine:
https://forge.in2p3.fr/dmsf/files/515/download

The atmosphere in air shower simulations

1. **density profile**
   - determines shower development

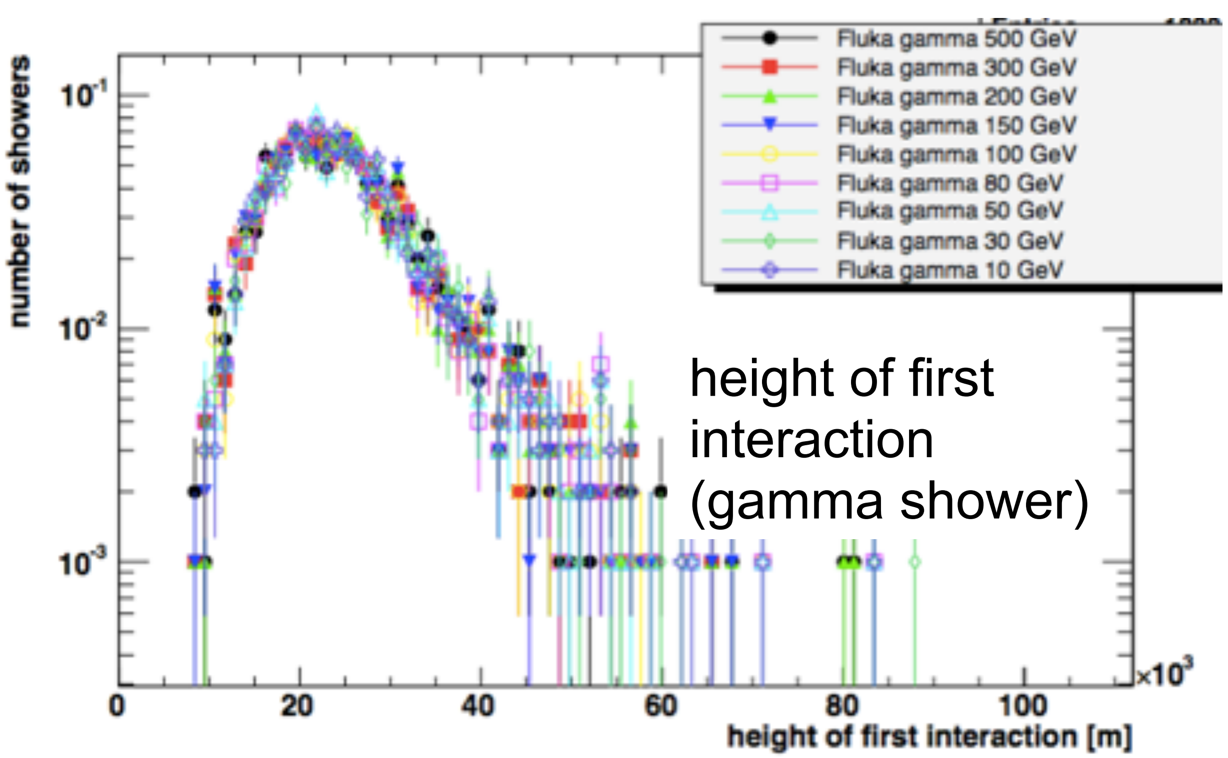
2. **refraction index profile**
   - determines Cherenkov light production and the image shapes

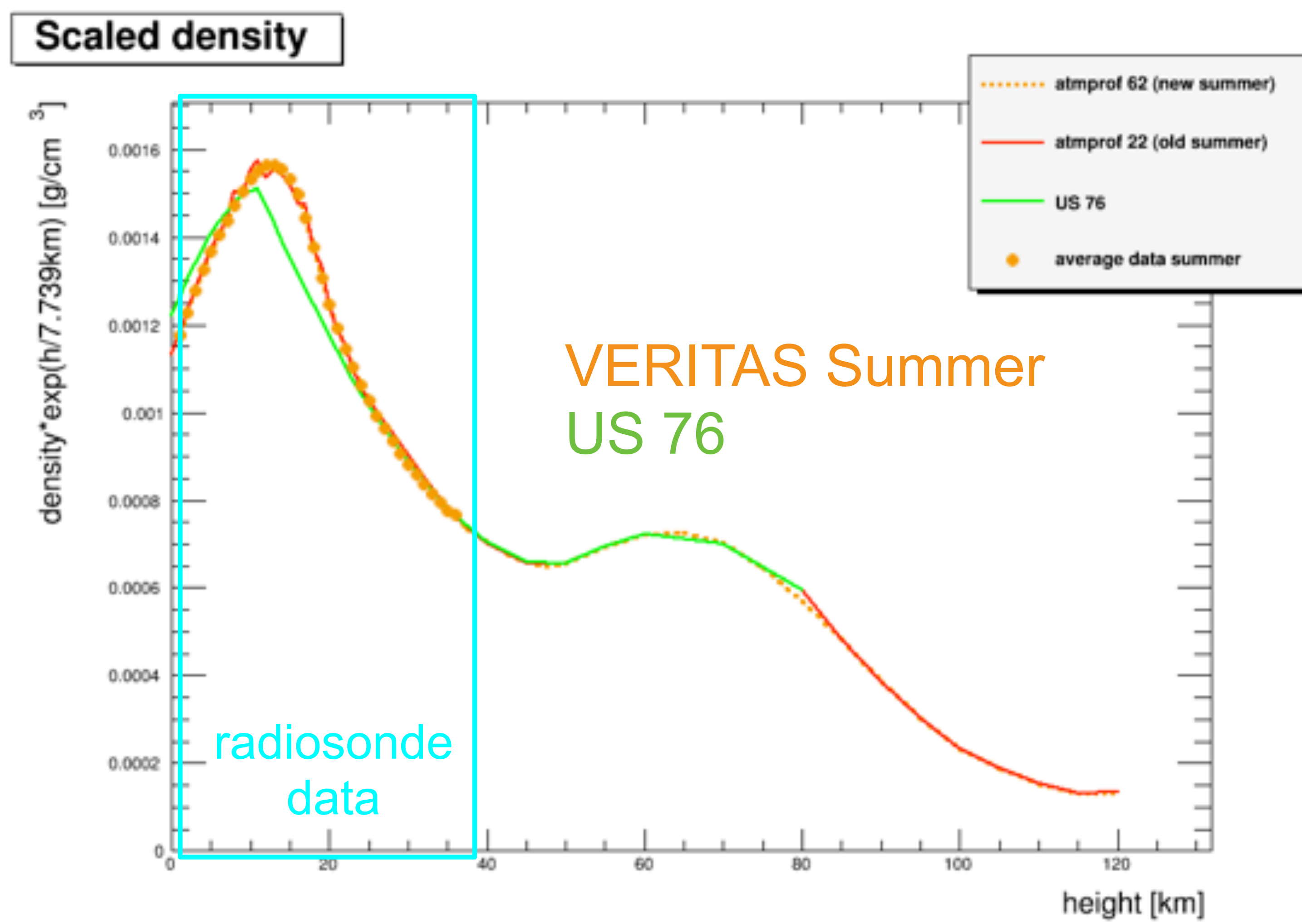
3. **extinction profile (absorption+scattering)**
   - determines light losses

none of the pre-defined models in the shower simulations (CORSIKA) will fit the CTA site; atmospheric parameters usually too variable for a single set of profiles

Atmospheric profiles (1)

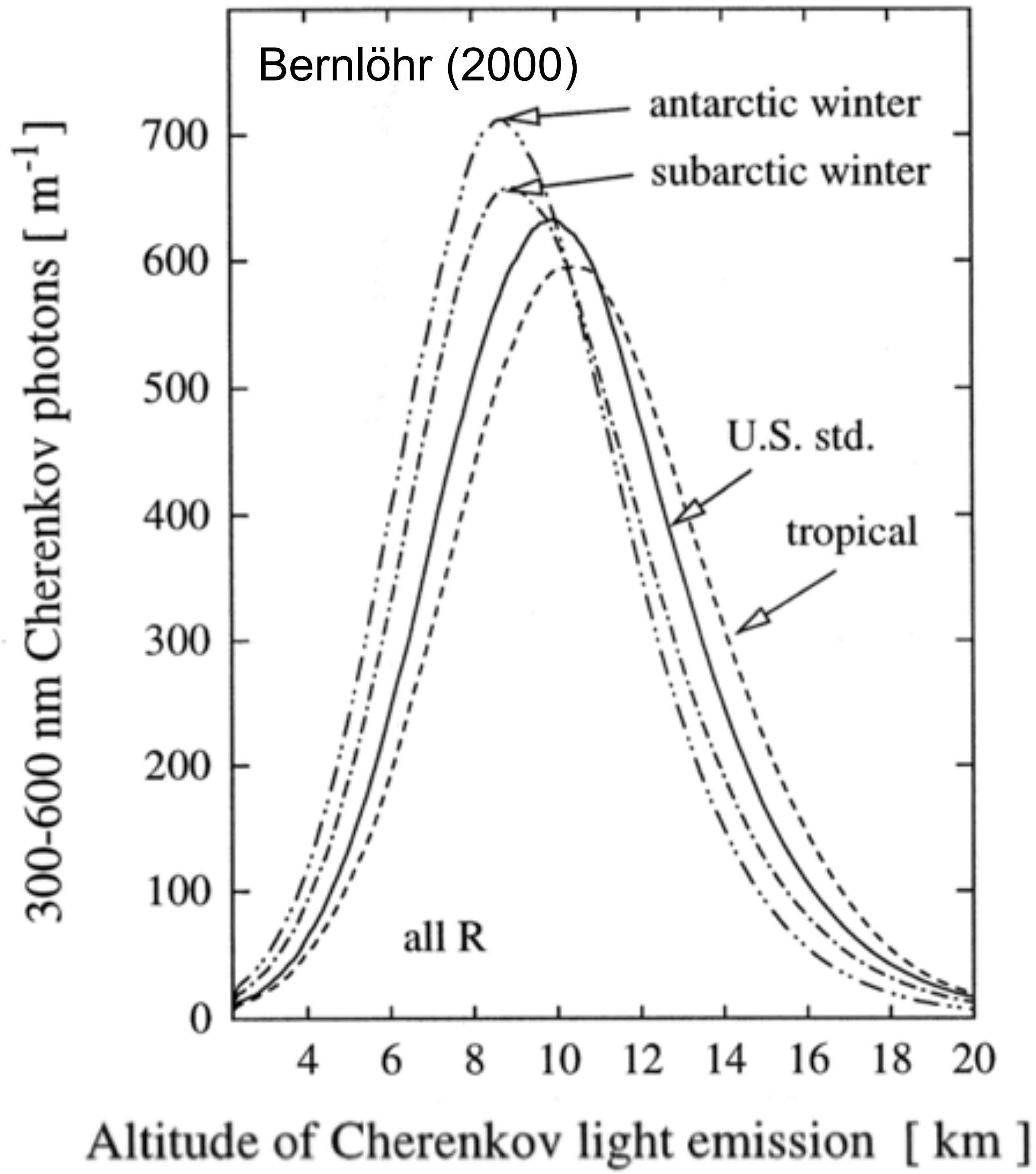
- atmospheric profiles in MC tabulated from 0 to 120 km
  - radiosonde flight give typically data up to 30 km
  - extension beyond 35 km with models, e.g. standard models or NRLMSISE-00 Atmosphere Model



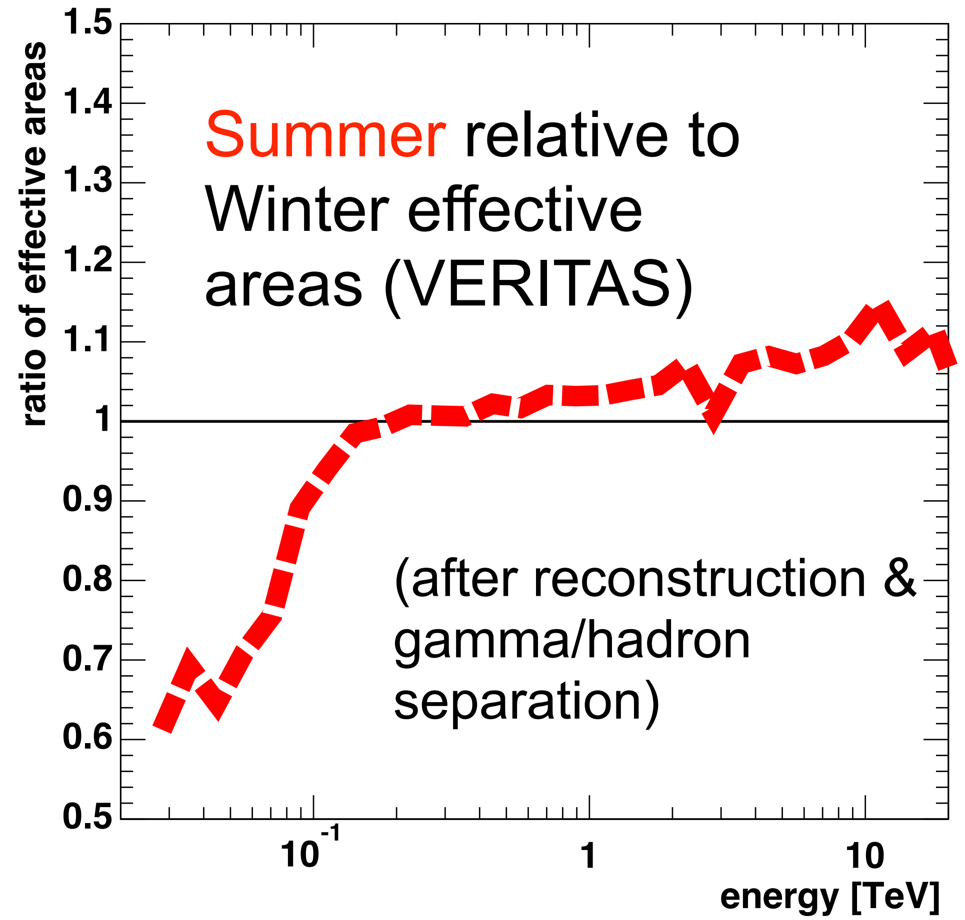


Atmospheric profiles (2)

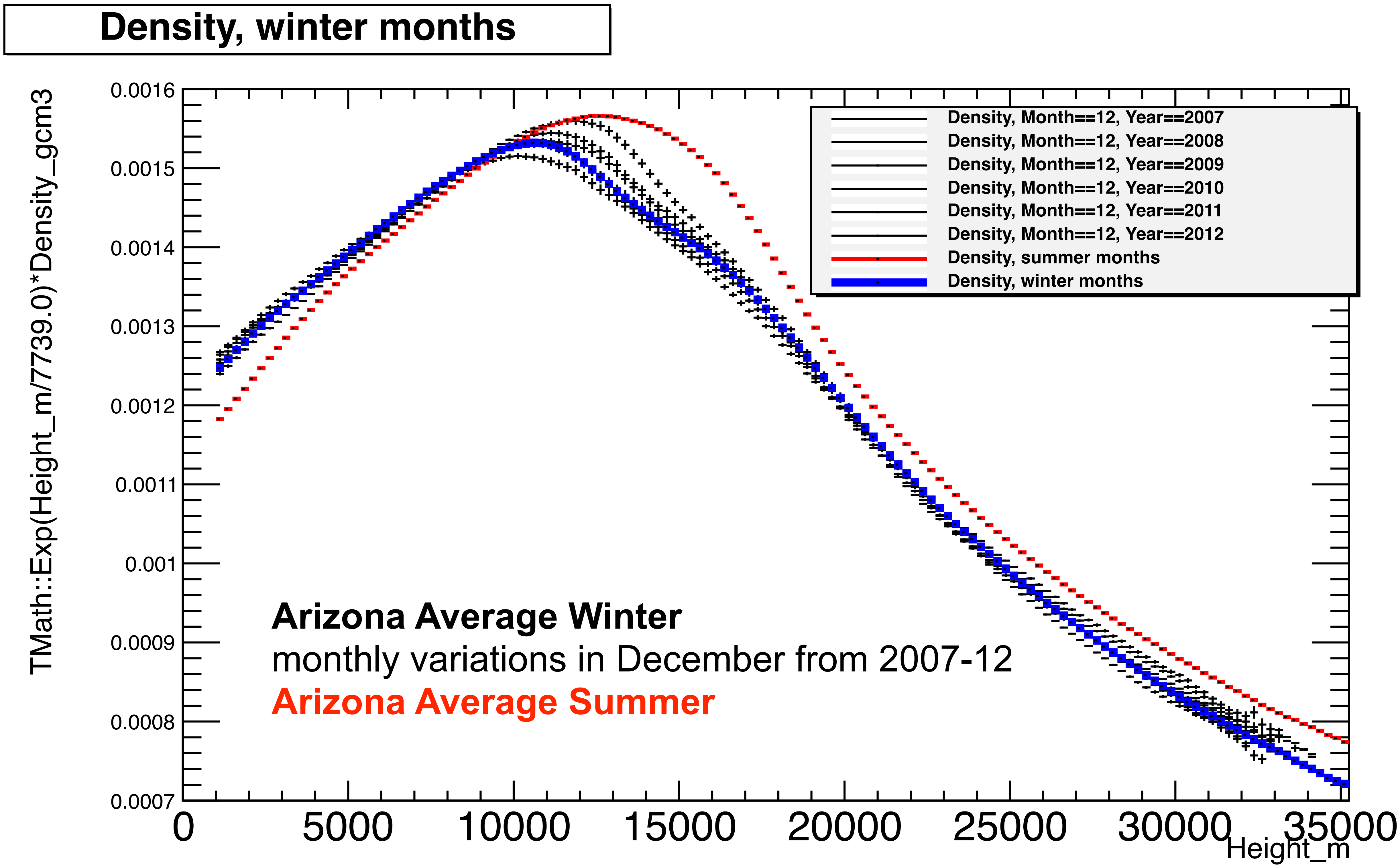
Average Cherenkov light emission along shower axis (100 GeV)



- extreme case on the left…
- VERITAS: typically 10-25% difference between Summer / Winter
  - 10% maximum systematic uncertainty in energy determination from multi-year average profiles

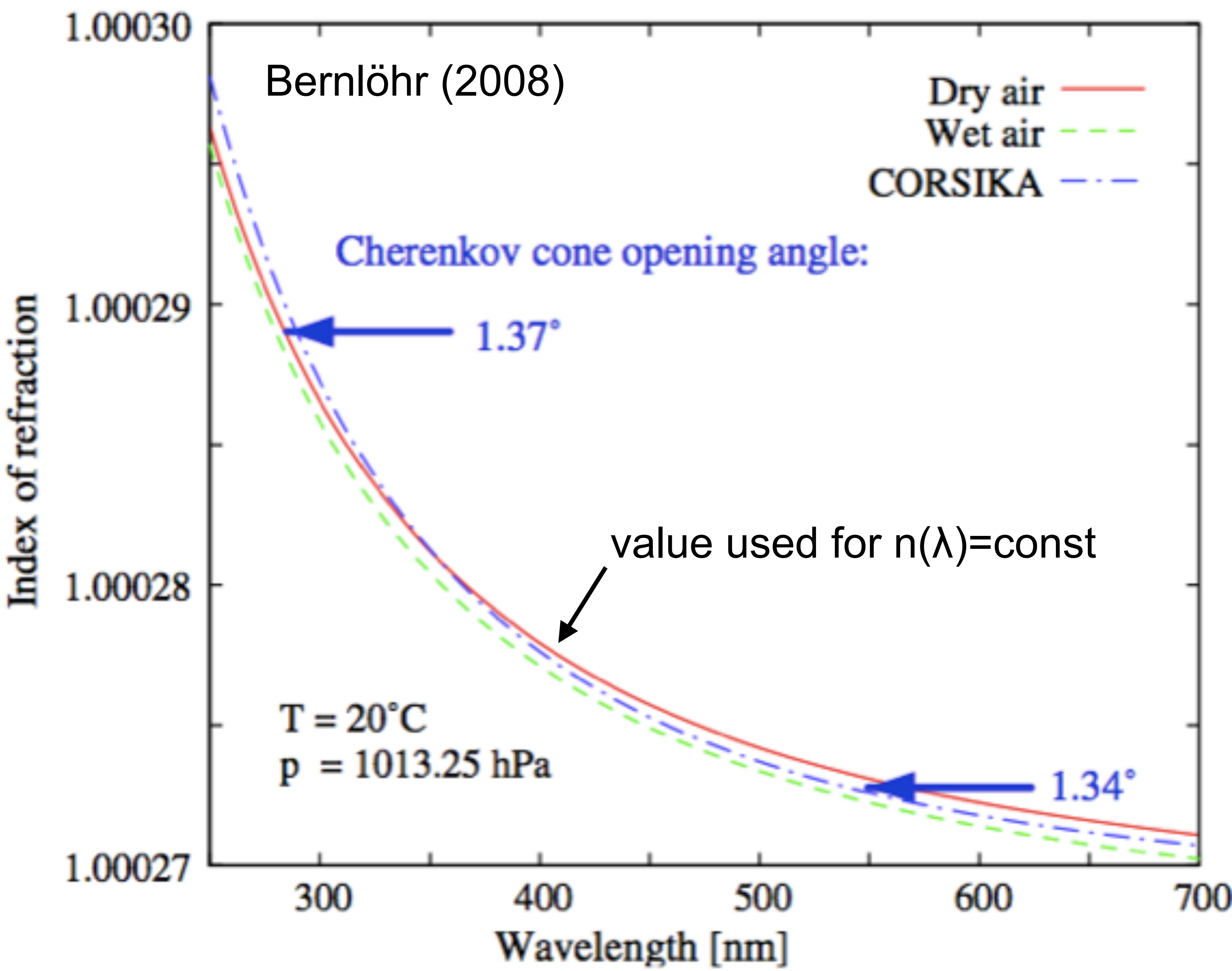


Variability



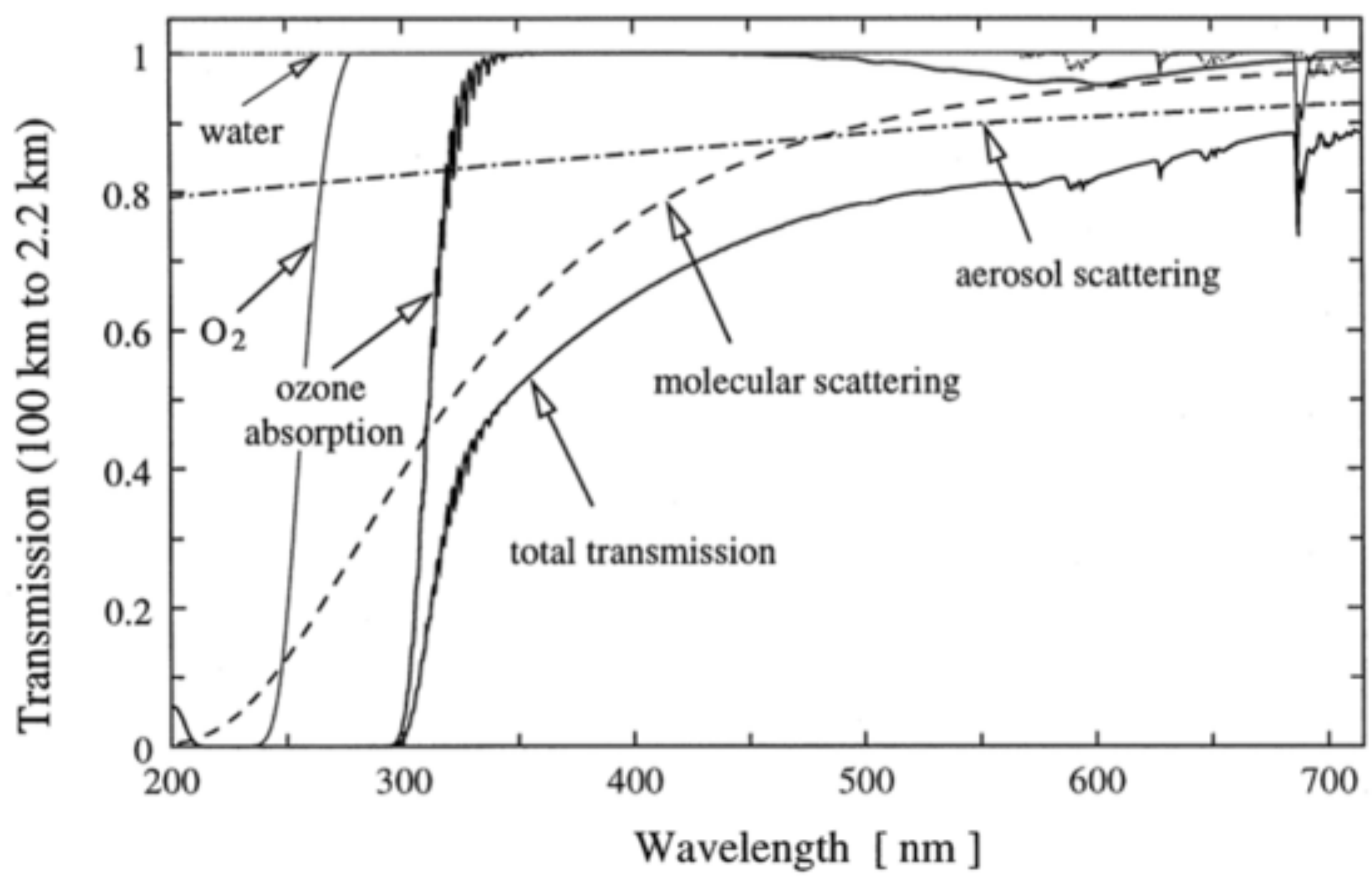
Index of refraction

- refraction index profile determined as a function of air density, humidity and temperature
  - (from tables, e.g. in MODTRAN)
- wavelength dependence of index of refraction usually ignored
  - (would produce a huge computational overhead in the simulations)

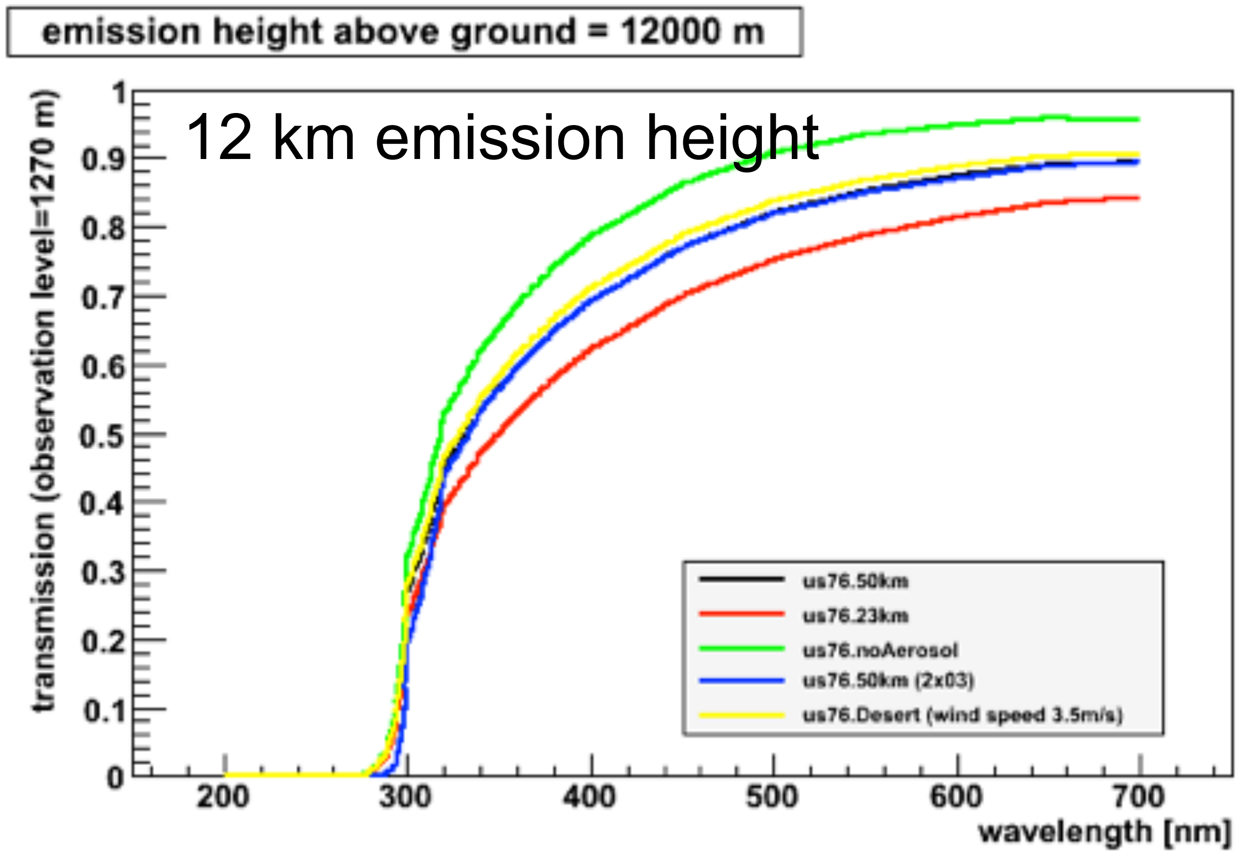


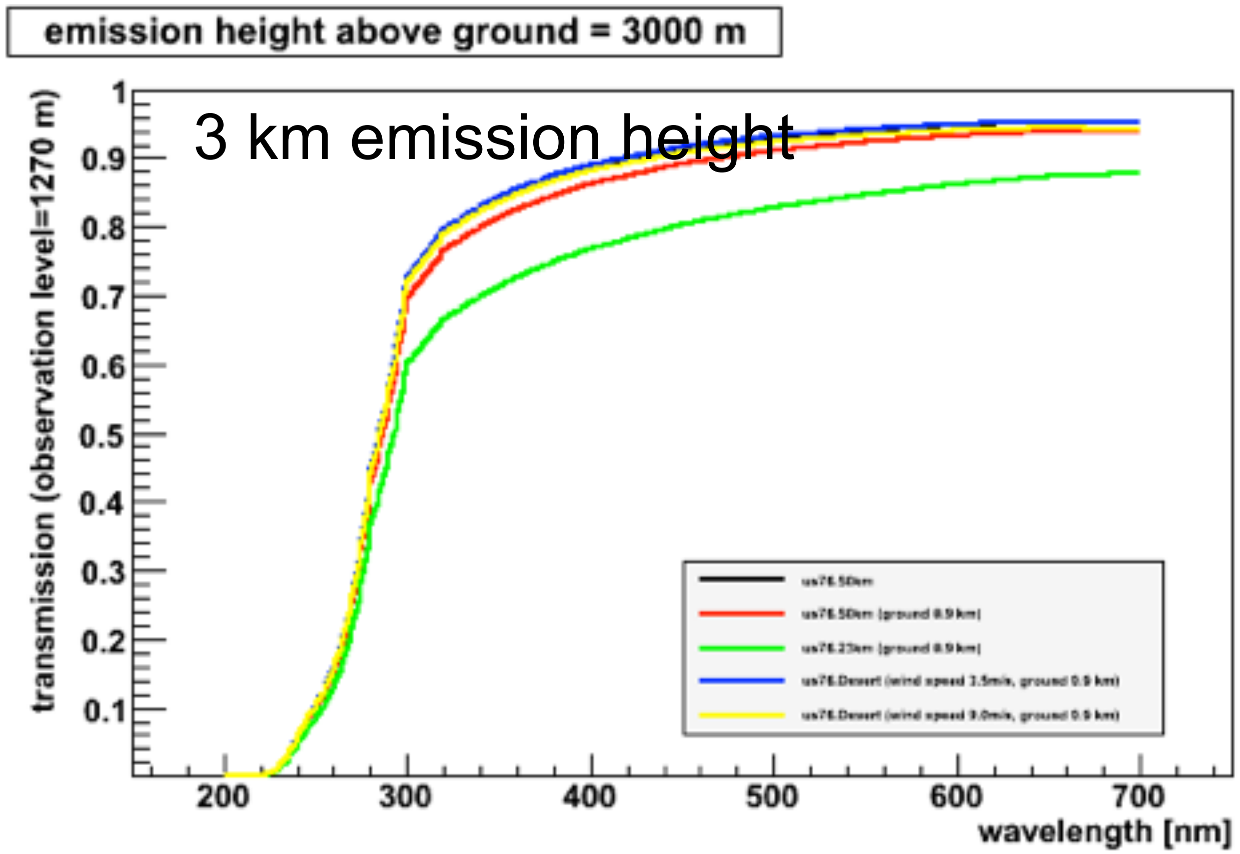
Extinction

- probability that a photon emitted at height Y reach a telescope at height X
  - absorption bands of several molecules, molecular Rayleigh scattering, Mie scattering and absorption
  - note: scattering is treated as extinction (might need to reevaluate this approach, Bernlöhr (2000) shows that scattered light is only important >400 m)
- radiative transfer code used to calculated extinction values
  - most (all?) current observatories use MODTRAN
  - tabulated values used in CORSIKA
- variability mainly in the boundary layer
  - other layers mainly impacted by external events (e.g. volcanic or desert dust)



Extinction





50 km visibility
23 km visibility
no aerosols
50 km visibility + 3.5 m/s wind

50 km visibility
23 km visibility
Desert + 3.5 m/s wind
Desert + 9.0 m/s wind

Atmospheric Model 21 (V.Winter.US76.50km)

#Col. #1	#2	#3	#4
# Alt [km]	rho [g/cm^3]	thick [g/cm^2]	n-1
0.000	1.22946e-03	1.03601e+03	2.89600e-04
1.000	1.09819e-03	9.23565e+02	2.58700e-04
2.000	9.90486e-04	8.15019e+02	2.33300e-04
3.000	9.01675e-04	7.24870e+02	2.12300e-04
4.000	8.13350e-04	6.39993e+02	1.91500e-04
5.000	7.33228e-04	5.63249e+02	1.72600e-04
6.000	6.59409e-04	4.93099e+02	1.55200e-04
7.000	5.84731e-04	4.22949e+02	1.37600e-04
8.000	5.38087e-04	3.80495e+02	1.26600e-04
9.000	4.66832e-04	3.17068e+02	1.09800e-04
10.000	4.14007e-04	2.73163e+02	9.74000e-05
11.000	3.75949e-04	2.43084e+02	8.84400e-05
12.000	3.20134e-04	2.03329e+02	7.53200e-05
13.000	2.74951e-04	1.73340e+02	6.47100e-05
14.000	2.39680e-04	1.50329e+02	5.63900e-05
15.000	2.02398e-04	1.25223e+02	4.76100e-05
16.000	1.71011e-04	1.04398e+02	4.02400e-05
17.000	1.51184e-04	9.15399e+01	3.55700e-05
18.000	1.24763e-04	7.55793e+01	2.93500e-05
19.000	1.09011e-04	6.61328e+01	2.56500e-05
20.000	8.99098e-05	5.49409e+01	2.11500e-05
21.000	7.63433e-05	4.69647e+01	1.79600e-05
22.000	6.49534e-05	4.02441e+01	1.52800e-05
23.000	5.46119e-05	3.41093e+01	1.28500e-05
24.000	4.67937e-05	2.94049e+01	1.10100e-05
25.000	3.91221e-05	2.47681e+01	9.20700e-06
30.000	1.63692e-05	1.07440e+01	3.85200e-06
35.000	7.60943e-06	5.13684e+00	1.79100e-06
40.000	3.61591e-06	2.58683e+00	8.52100e-07

```
ATMOSPHERIC EXTINCTION COEFF. FOR CERENKOV PHOTONS, 180-700nm, in STEPS of km
180
  0.000   7.807  14.751  20.937  26.459  31.392  35.804  39.754  43.289  46.454
 49.290  51.830  54.059  55.983  57.675  59.169  60.502  61.703  62.798  63.806
 64.748  65.639  66.476  67.262  67.976  68.626  69.226  69.751  70.205  70.595
 70.922  71.199  71.435  71.635  71.801  71.942  72.059  72.161  72.250  72.325
 72.388  72.443  72.493  72.540  72.583  72.621  72.658  72.691  72.721  72.749
 72.774
185
  0.000   7.807  14.751  20.937  26.459  31.392  35.804  39.754  43.289  46.454
 49.290  51.830  54.059  55.983  57.675  59.169  60.502  61.703  62.798  63.806
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 72.774
190
  0.000   7.807  14.751  20.937  26.459  31.392  35.804  39.754  43.289  46.454
 49.290  51.830  54.059  55.983  57.675  59.169  60.502  61.703  62.798  63.806
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 70.922  71.199  71.435  71.635  71.801  71.942  72.059  72.161  72.250  72.325
 72.388  72.443  72.493  72.540  72.583  72.621  72.658  72.691  72.721  72.749
 72.774
195
  0.000   7.807  14.751  20.937  26.459  31.392  35.804  39.754  43.289  46.454
 49.290  51.830  54.059  55.983  57.675  59.169  60.502  61.703  62.798  63.806
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 70.922  71.199  71.435  71.635  71.801  71.942  72.059  72.161  72.250  72.325
 72.388  72.443  72.493  72.540  72.583  72.621  72.658  72.691  72.721  72.749
 72.774
200
  0.000   7.807  14.751  20.937  26.459  31.392  35.804  39.754  43.289  46.454
 49.290  51.830  54.059  55.983  57.675  59.169  60.502  61.703  62.798  63.806
 64.748  65.639  66.476  67.262  67.976  68.626  69.226  69.751  70.205  70.595
 70.922  71.199  71.435  71.635  71.801  71.942  72.059  72.161  72.250  72.325
 72.388  72.443  72.493  72.540  72.583  72.621  72.658  72.691  72.721  72.749
 72.774
205
  0.000   6.770  12.786  18.142  22.920  27.188  31.005  34.421  37.479  40.217
 42.670  44.867  46.797  48.469  49.951  51.273  52.467  53.557  54.564  55.509
```
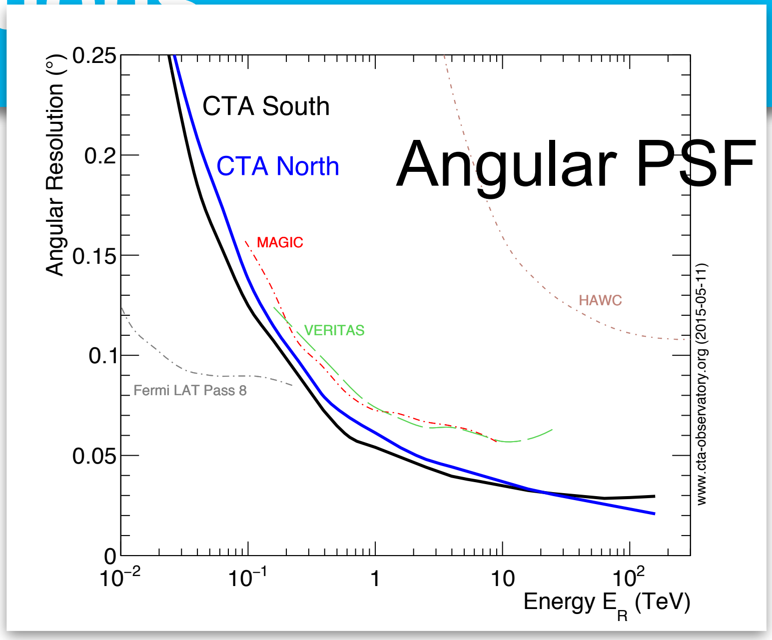
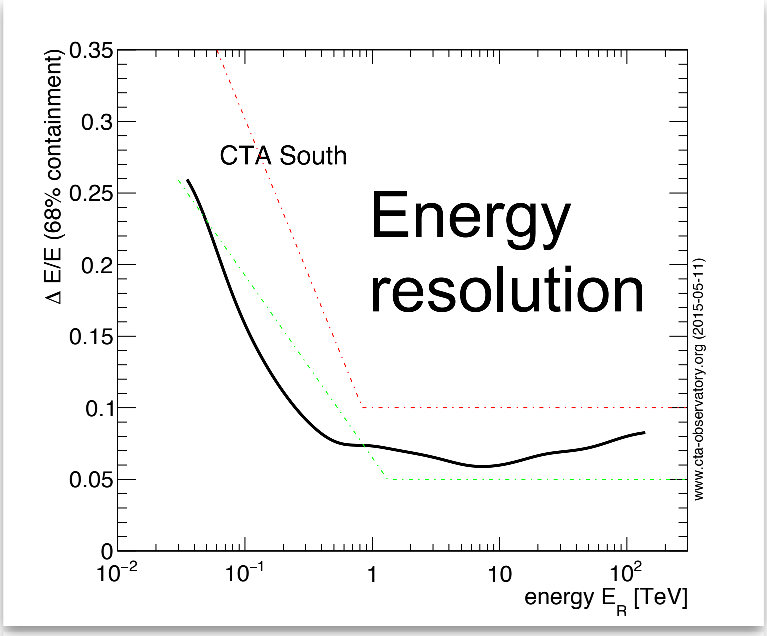
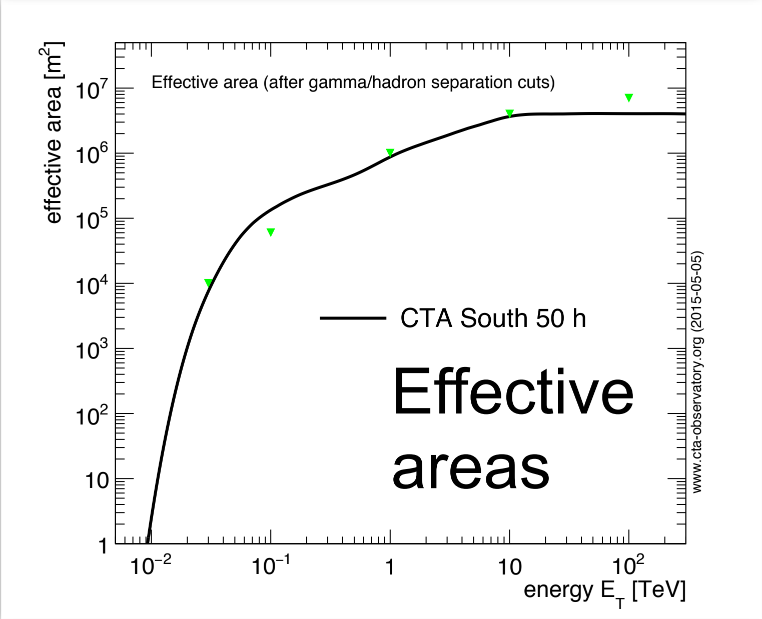

Note: need sufficient small step size, as CORSIKA does a linear interpolation only

Generation of Instrument Response Functions



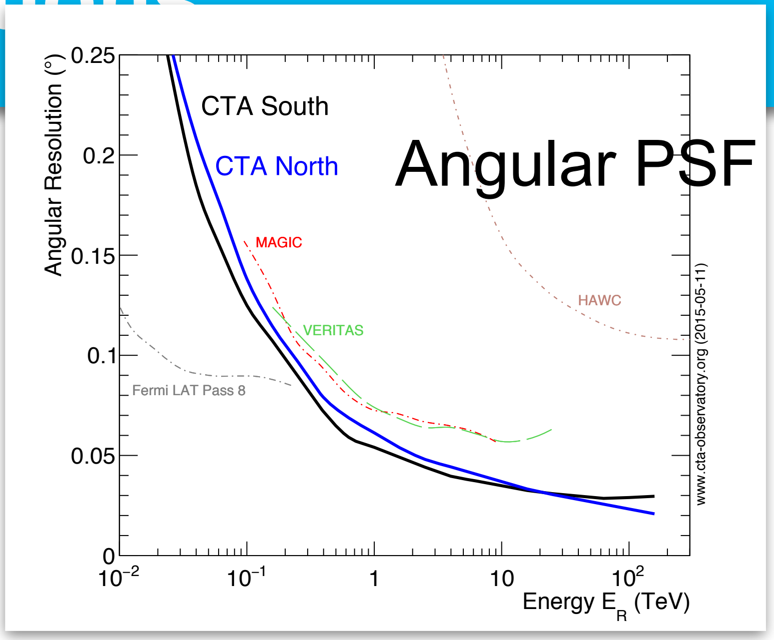


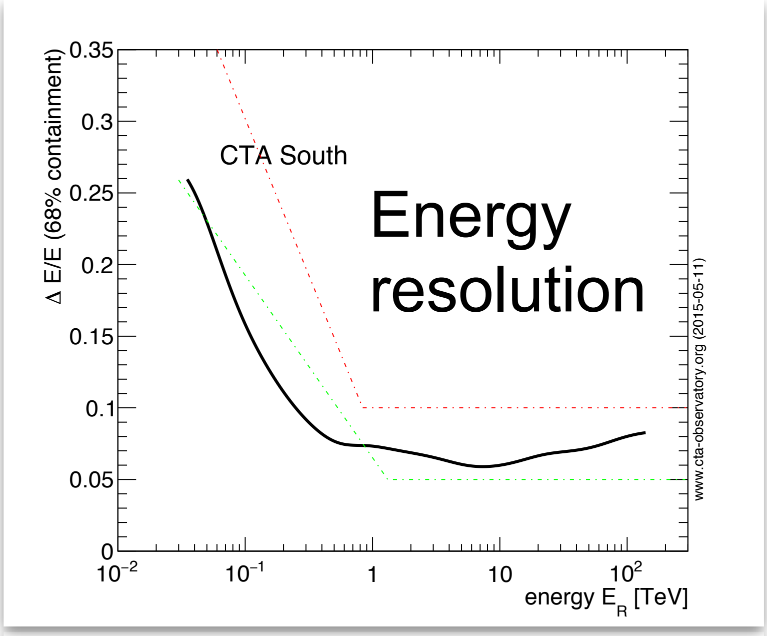


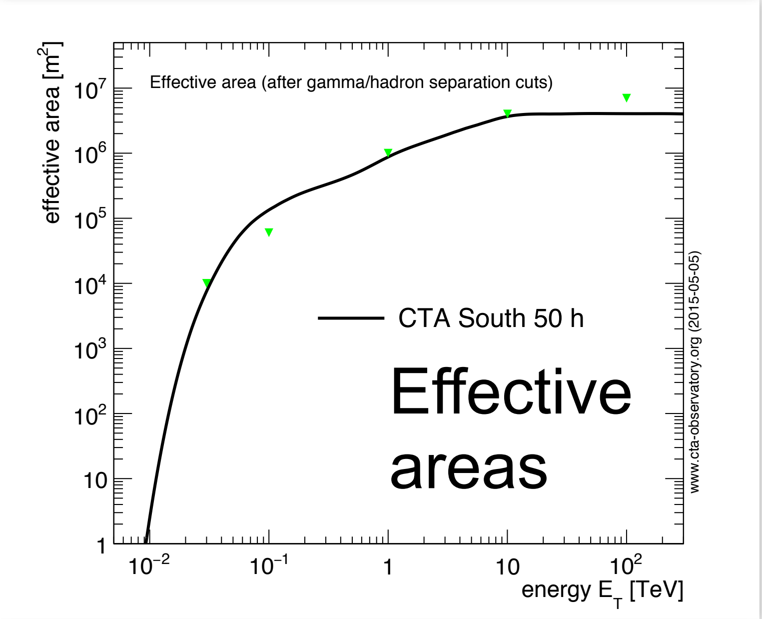
Generation of Instrument Response Functions

> full phase space (brute force) approach

- produce full MC sets for complete phase space (zenith, azimuth, night-sky background, array layout, atmos. profile,…)
- needs to be repeated each time atmospheric/detector parameters change significantly
- grows multiplicative with additional parameters







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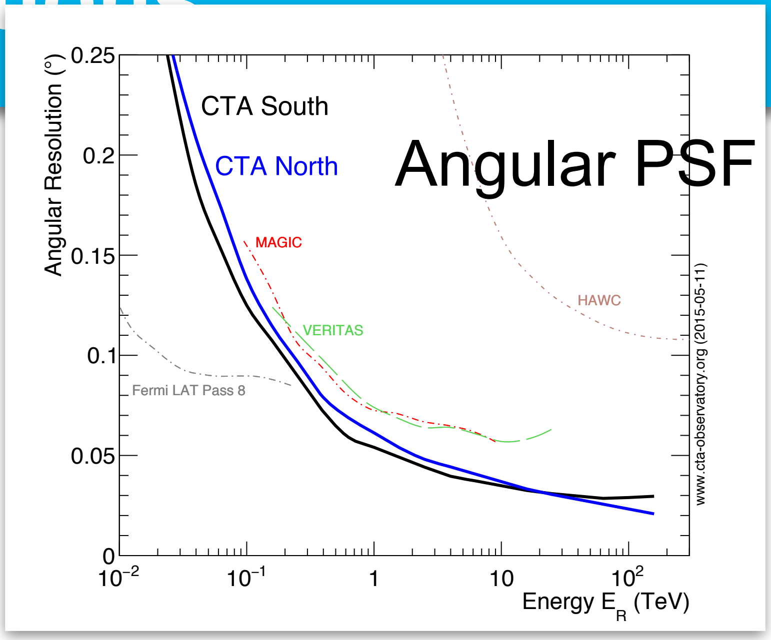
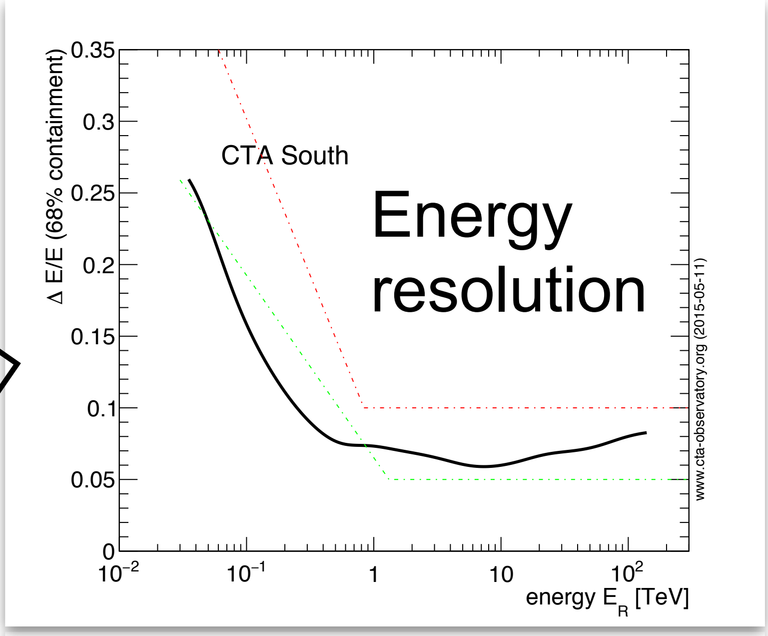
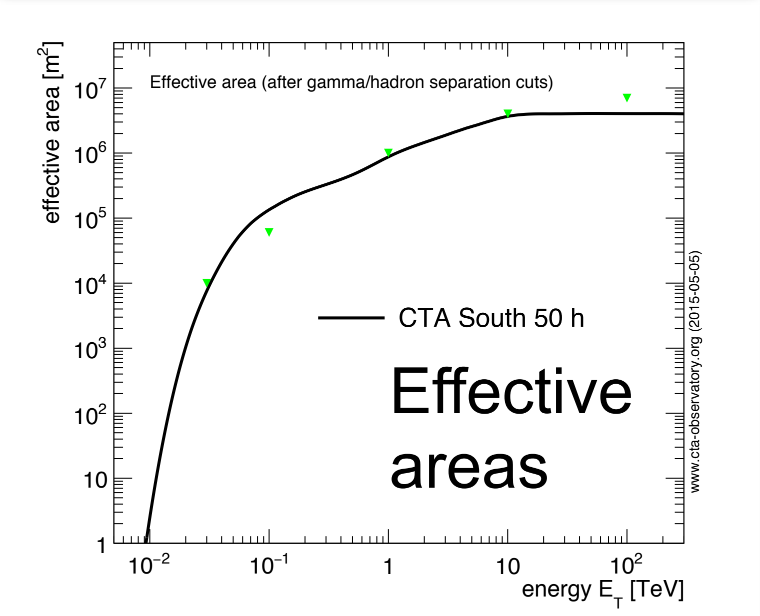
> run-wise simulations

- simulate (sub-)array of telescopes that are tracking a sky position for a given observation run
- consider broken pixels, atmosphere model for that observation, calibration, NSB, etc. (no need for Data Correction!)
- grows linear with number of runs
- by definition closer to reality (assuming good configuration parameters); difficult to fulfil 100% operational requirement otherwise

see Stefan Ohm's talk at the Liverpool meeting







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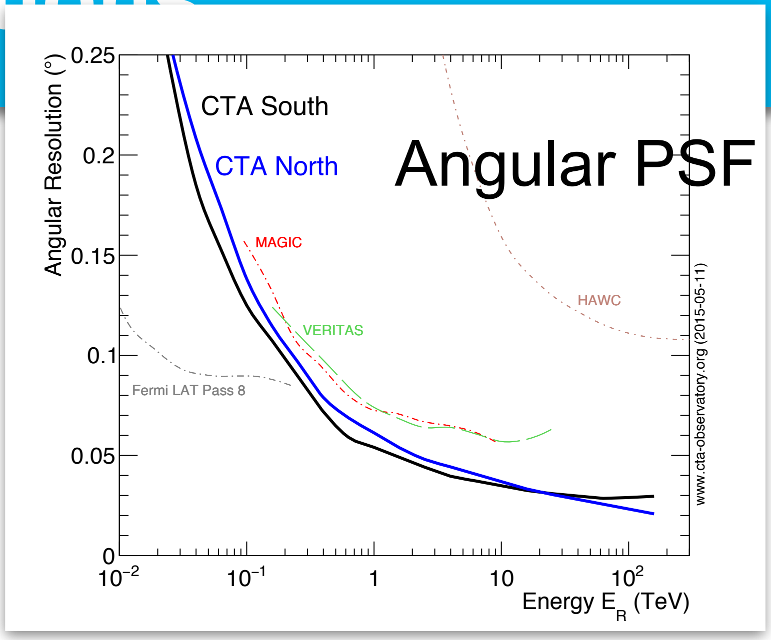
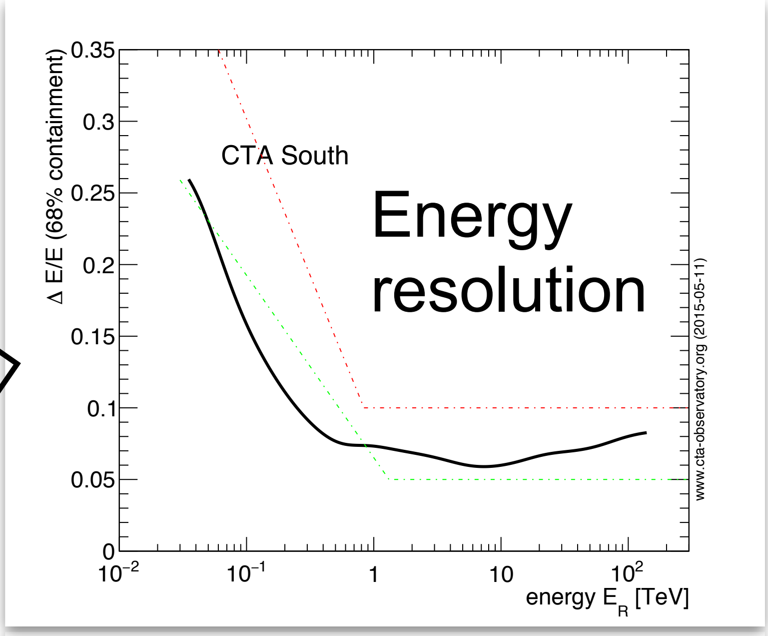
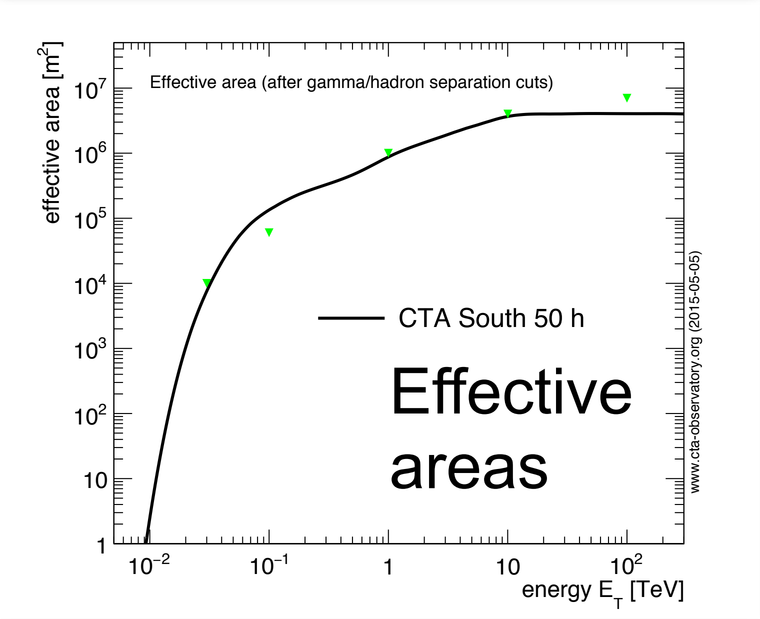
> intermediate approach

- populate phase space on request only
- tough part is to understand when to expand the parameters







Generation of Instrument Response Functions

> **full phase space (brute force) approach**

- produce full MC sets for complete phase space (zenith, azimuth,
  ni
- ne
  ch
- gr

MC needs average atmospheric parameters for a given period.

Challenge: understand when conditions changed significantly enough to start a new production (feedback loop Calib - MC)

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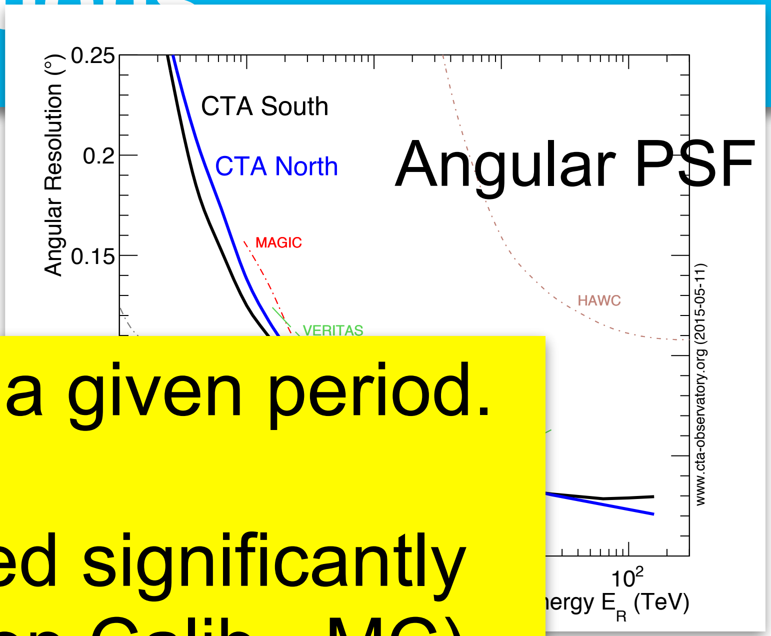

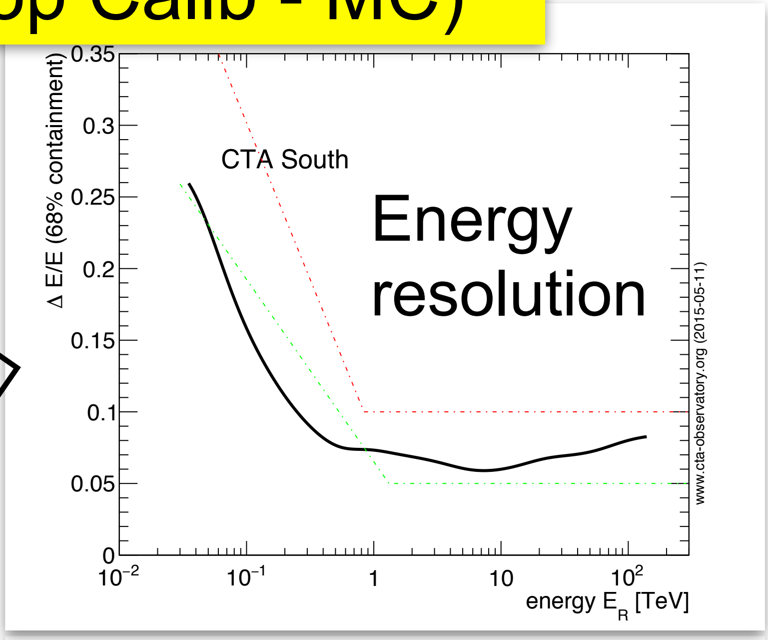

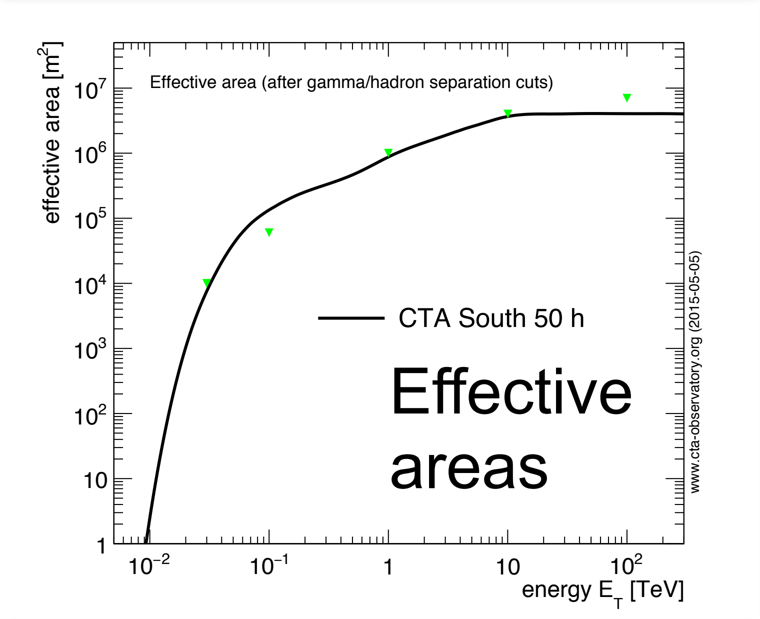

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MC needs atmospheric parameters for any given run.

see Stefan Ohm's talk the Liverpool mee…

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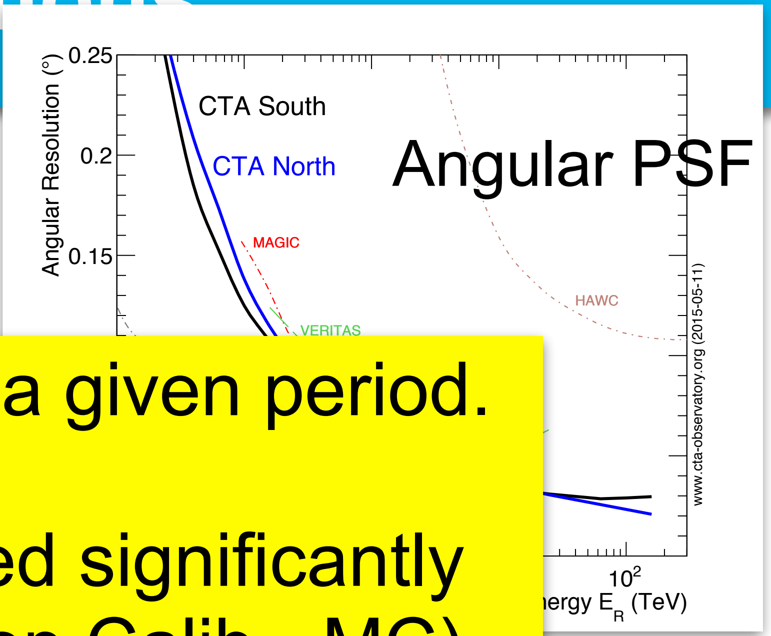

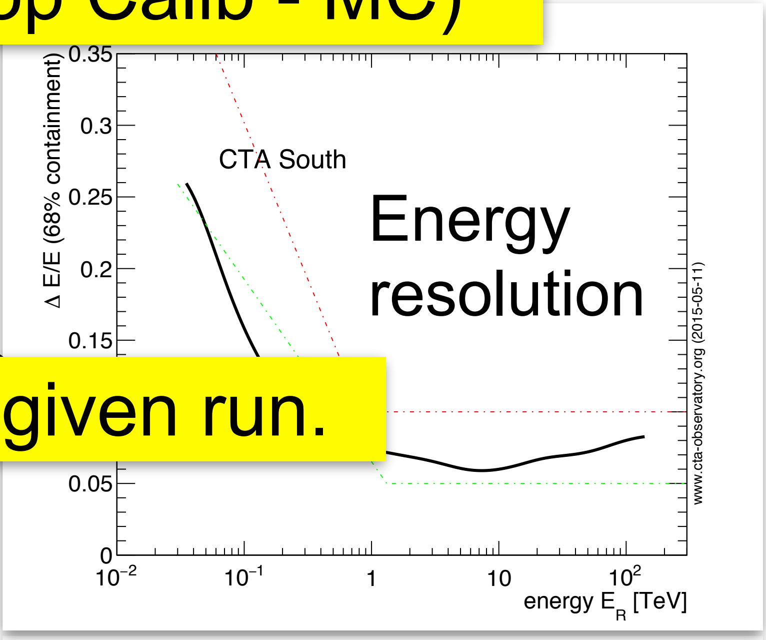

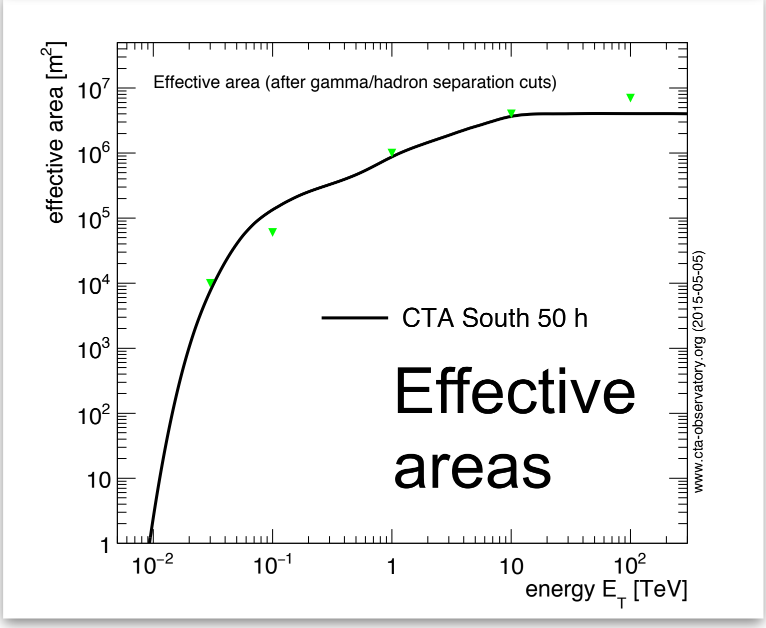

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the Liverpool mee

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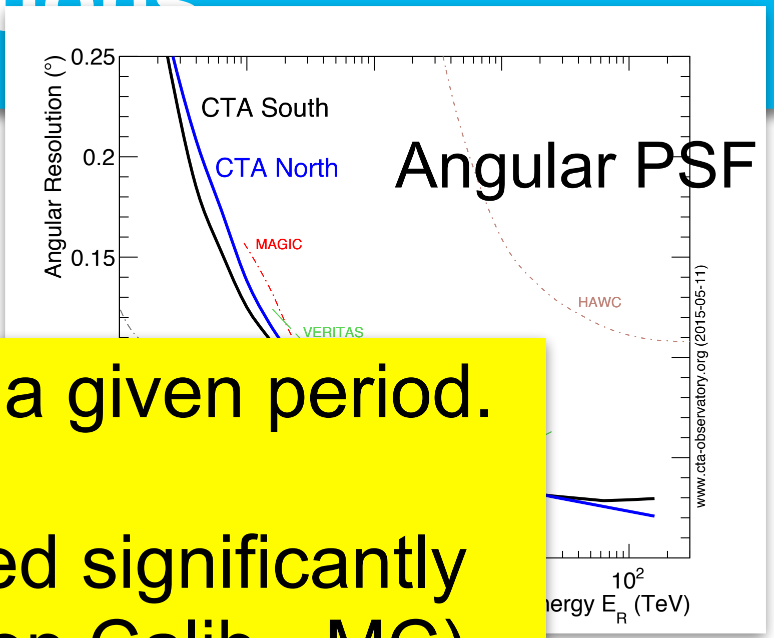
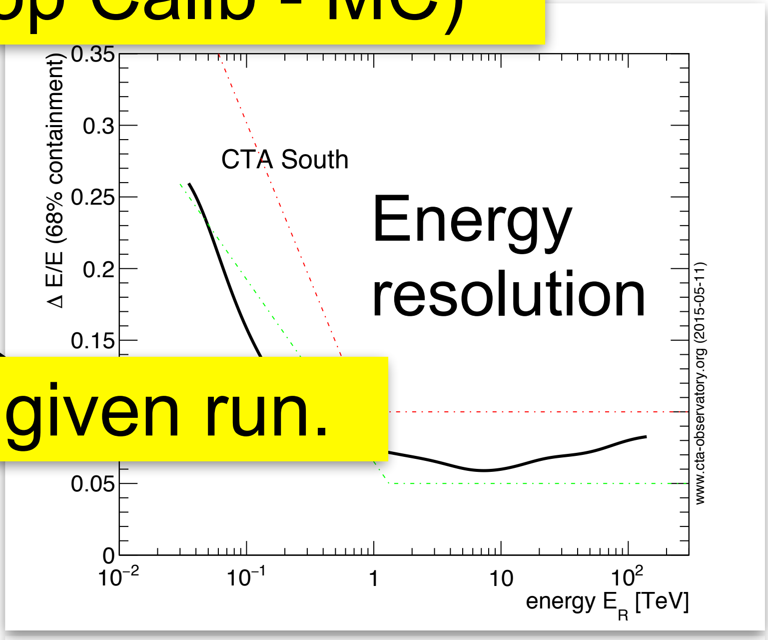
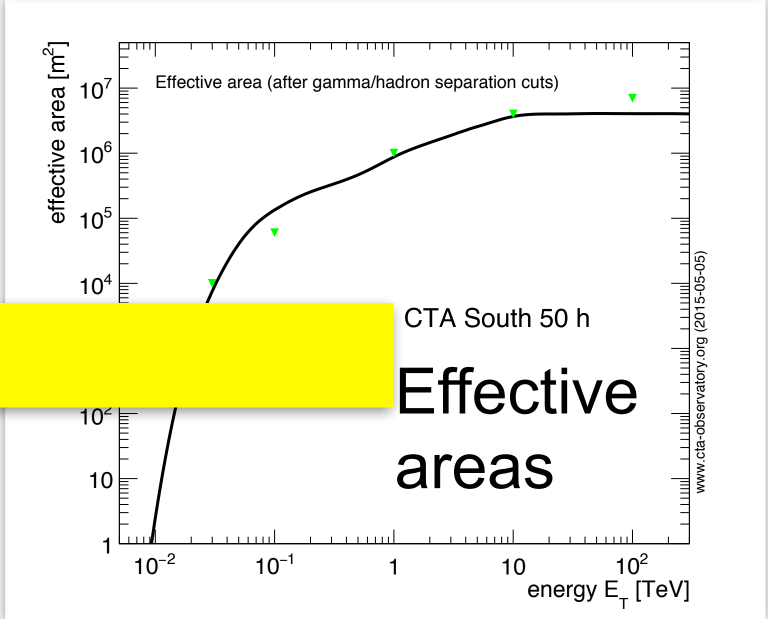
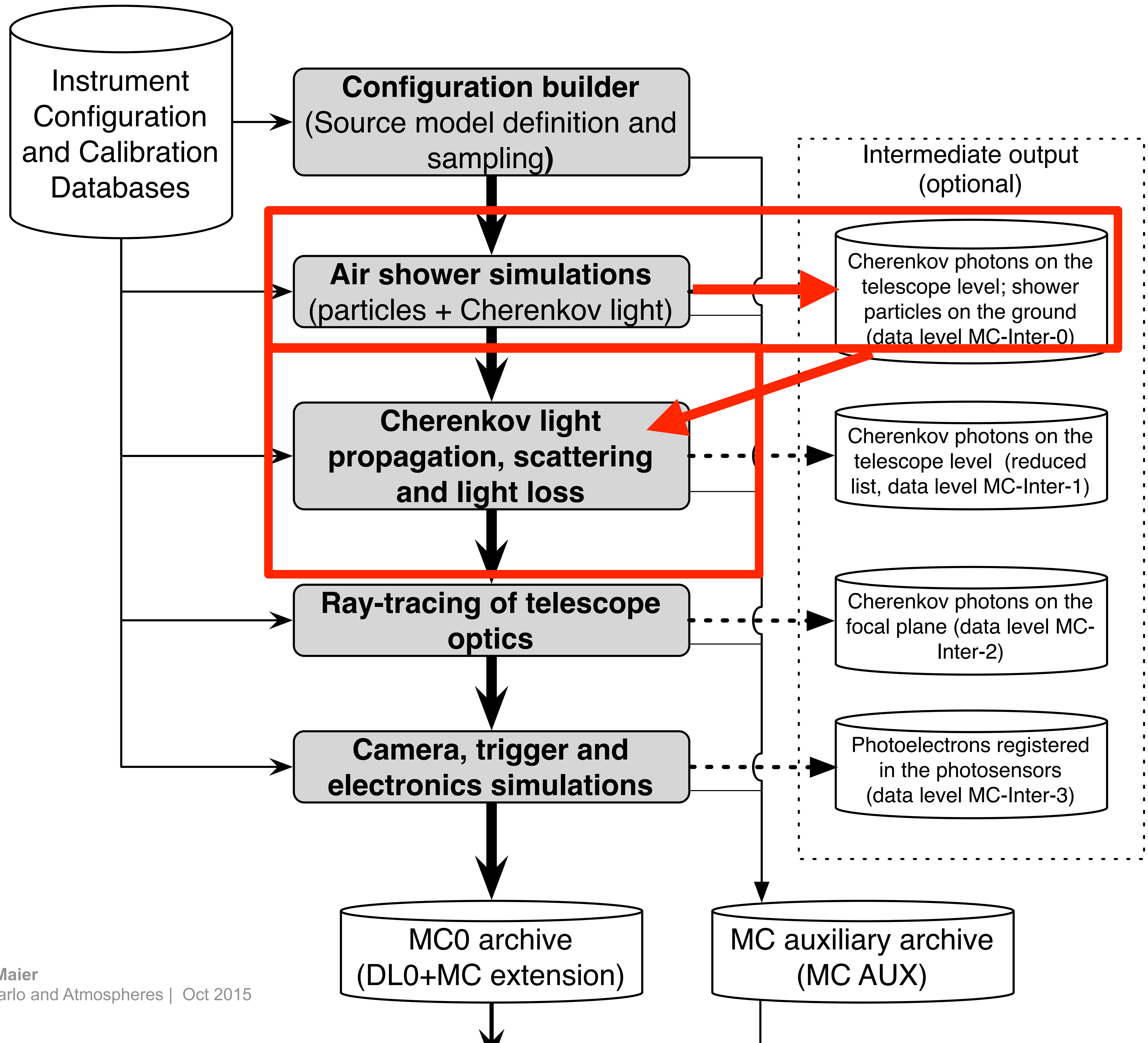
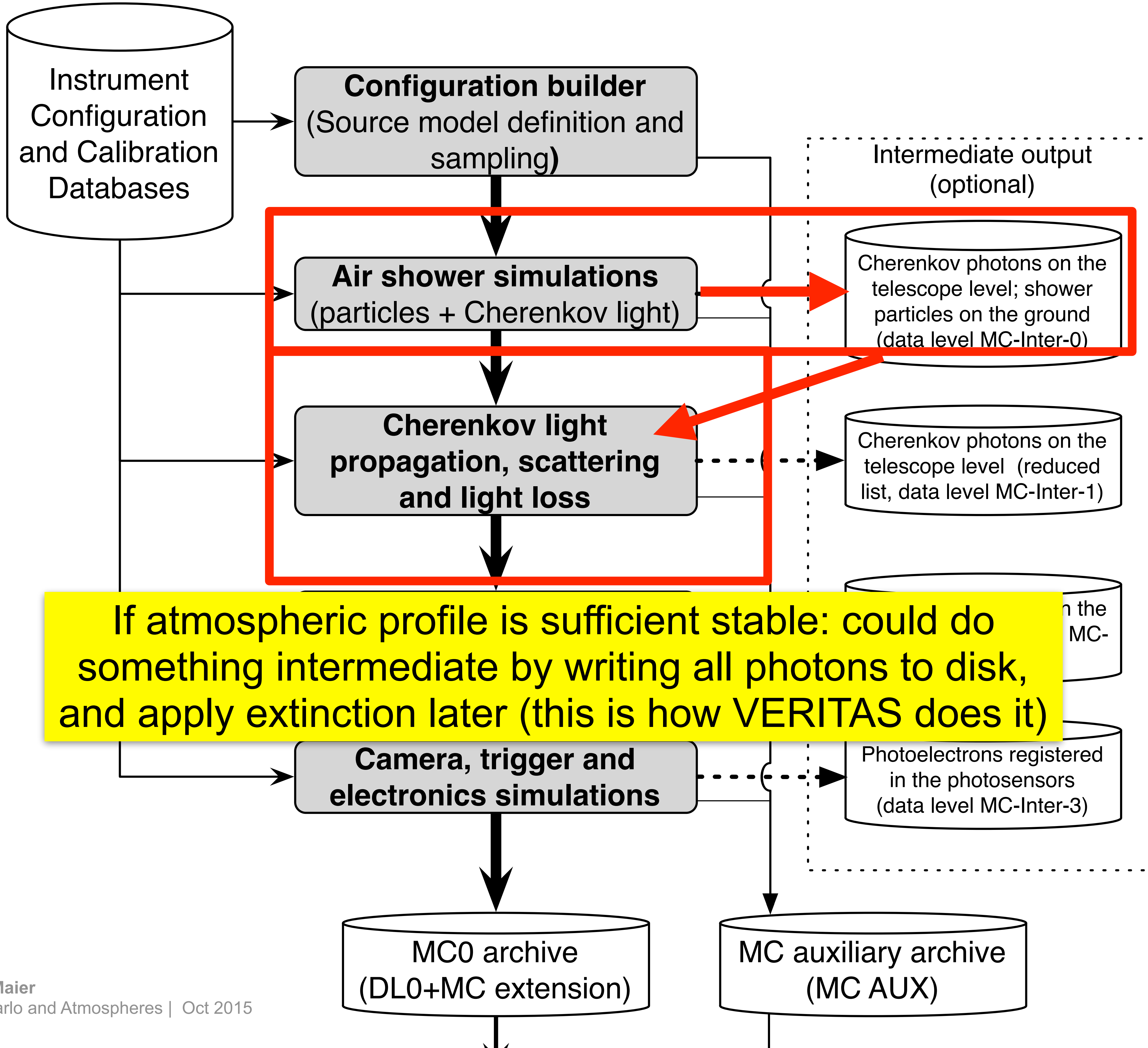
(same is brute force approach)







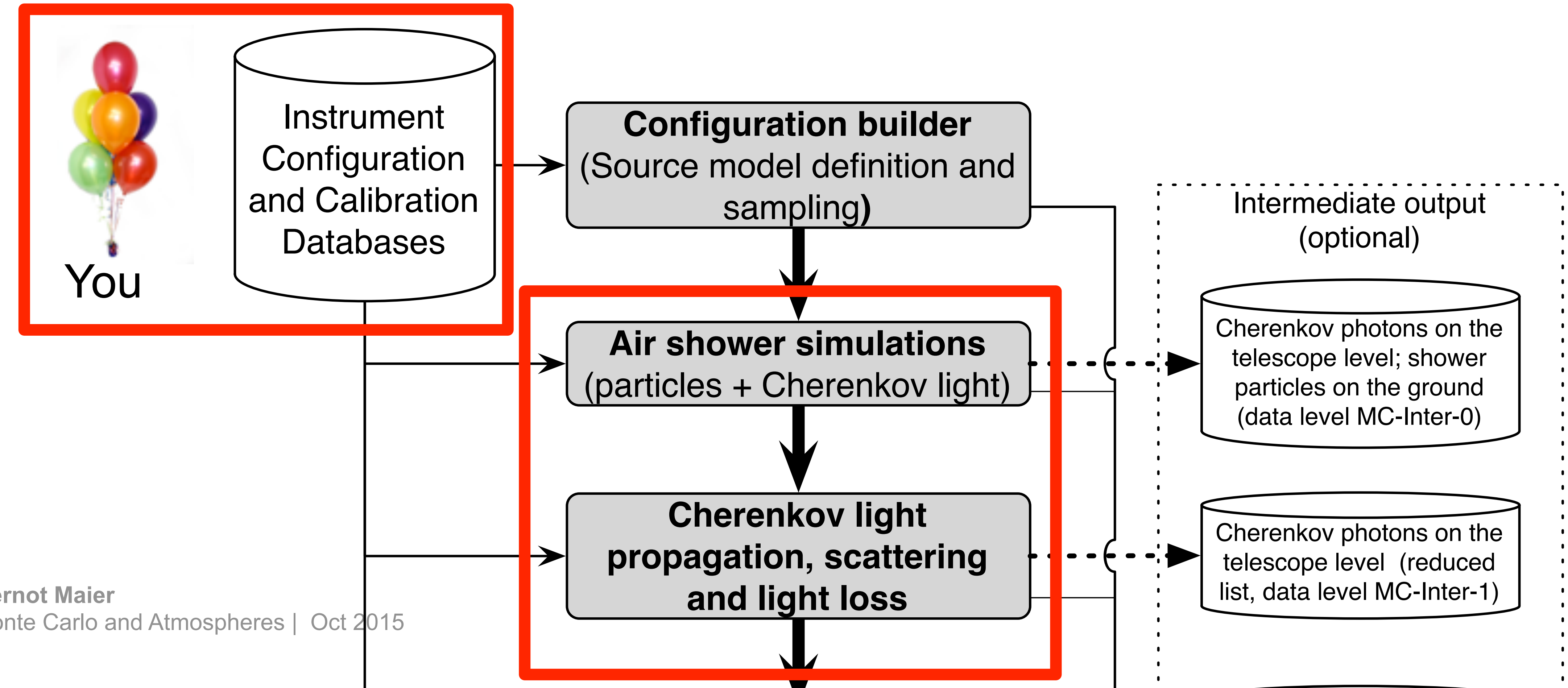

Instrument Configuration and Calibration Databases
Configuration builder
(Source model definition and sampling)
Intermediate output (optional)
Air shower simulations
(particles + Cherenkov light)
Cherenkov photons on the telescope level; shower particles on the ground (data level MC-Inter-0)
Cherenkov light propagation, scattering and light loss
Cherenkov photons on the telescope level (reduced list, data level MC-Inter-1)
Ray-tracing of telescope optics
Cherenkov photons on the focal plane (data level MC-Inter-2)
Camera, trigger and electronics simulations
Photoelectrons registered in the photosensors (data level MC-Inter-3)
MC0 archive
(DL0+MC extension)
MC auxiliary archive
(MC AUX)



If atmospheric profile is sufficient stable: could do something intermediate by writing all photons to disk, and apply extinction later (this is how VERITAS does it)

Interface Calibration - Monte Carlo

- MC would like to get from calibration group for a given period the best estimates for the atmospheric parameters
  - a period could be a single run, a month, a season
  - expect all parameters describing the atmosphere in a format digestible for MC
  - means that calibration group is running all steps, including the radiative transfer (extinction values from e.g. MODTRAN)
- this is the fundamental point we need to agree - everything else are technicalities



What could be next steps?

- characterisation of sites important to estimate impact on Monte Carlo
  - how variable is the atmosphere? Are there stable seasons?
  - any input at this point would be valuable
- define (automatic?) procedures of how to propagate calibration measurements into MC
- radiative transfer codes - anybody working with them?
  - MODTRAN5 (http://modtran5.com/; >1200$)
  - any other in use?
- development of MC pipeline will provide a hopefully easy to use feedback loop to test the impact of atmospheric parameters on the shower development