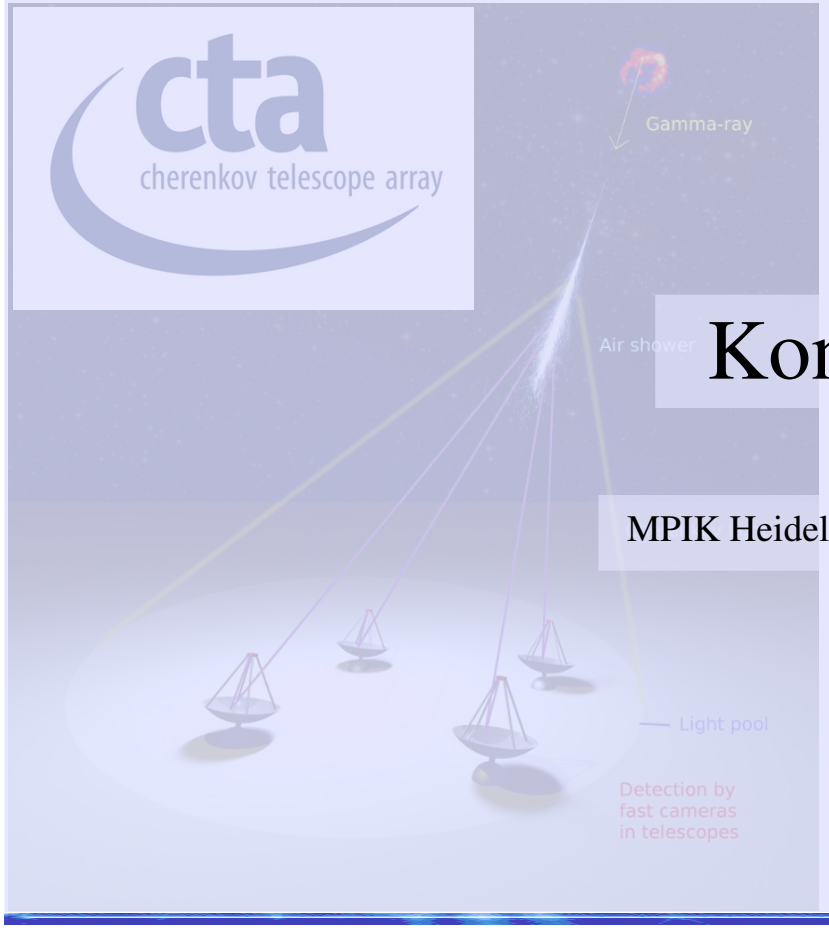
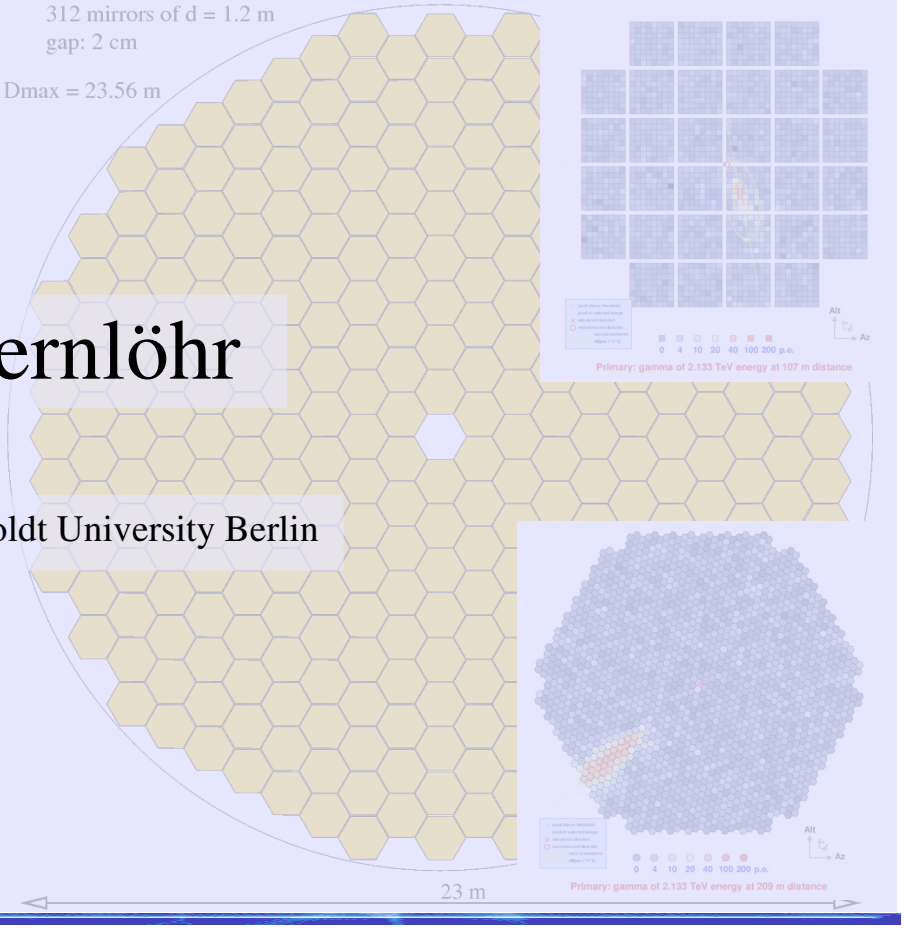
Tutorial 2: MC data reduction and analysis with 'read_cta' ('read_hess')



by

Konrad Bernlöhr

MPIK Heidelberg & Humboldt University Berlin



Goals of this tutorial

Show how to

- check what you have in your data,
- produce DSTs from raw data files
  - Note: a good integration of prod-2 traces is still missing!
- analysis procedures
- lookup tables
- output histograms for performance calculations
- calculating the sensitivity

read_hess

```
Syntax: /home/konrad32c/hess/hessio/bin/read_hess [ options ] [ - | input_fname ... ]
Options:
   -p ps_filename  (Write a PostScript file with camera images.)
   -r level        (Use 10/5 tail-cut image cleaning and redo reconstruction.)
                   level >= 1: show parameters from sim_hessarray.
                   level >= 2: redo shower reconstruction
                   level >= 3: redo image cleaning (and shower reconstruction
                               with new image parameters)
                   level >= 4: redo amplitude summation
                   level >= 5: PostScript file includes original and
                               new shower reconstruction.
   -v              (More verbose output)
   -q              (Much more quiet output)
   -s              (Show data explained)
   -S              (Show data explained, including raw data)
   ...
```

And many more options. Options in red not available with the reduced version read_hess_nr. Both full and reduced version are now distributed within CTA.

read_hess example

```
opts="-r 2 -u -q ${cuts} ...." # e.g.: --not-telescope 5,6,7,8
gamma_dst="../DST/gamma_${t1}_${t2}_-2.57.simhess-dst.gz"
proton_dst="../DST/proton_${t1}_${t2}_-2.70.simhess-dst.gz"
electron_dst="../DST/electron_${t1}_${t2}_-3.30.simhess-dst.gz"

read_hess ${opts} --powerlaw -2.57 --auto-lookup "${gamma_dst}"
read_hess ${opts} --powerlaw -2.57 --auto-lookup "${gamma_dst}"
read_hess ${opts} --powerlaw -2.57 --auto-lookup "${gamma_dst}"
read_hess ${opts} --powerlaw -2.57 "${gamma_dst}"

read_hess ${opts} --powerlaw -2.70 --theta-scale 6 "${proton_dst}"
read_hess ${opts} --powerlaw -3.30 --theta-scale 6 "$
  {electron_dst}"
```

New!

Note: electrons at this point still assumed to follow power law

The read_hess output

Output from read_hess may include:

- Histograms (again in eventio/hessio format, can be converted to ROOT, HBOOK, eventio/iactio), some used as lookups for further analysis.
- Reconstructed/selected data (DSTs etc.)
- Text-mode n-tuples of MC/image/shower data.
- Postscript camera images.
- All the data explained in full detail.

Heidelberg CTA-MC Analysis 1

- Simple analysis (with updates since last meeting):
  - Cleaning: 4/7, 5/10, 8/12 p.e. tail-cuts and other scheme;
  - Image amplitude > 30 p.e., up to 200 p.e.
  - Image c.o.g. Radius + 0.5 image length < 0.85 R_{cam} and variations of it ("edge cut"). Potential problem at high *E*.
  - Geometrical shower reconstruction (direction and core position) from Hillas parameters, using weighted mean of pair-wise intersections of image major axes.
    This is certainly sub-optimal and can be improved!

Heidelberg CTA-MC Analysis 2

- Generating lookup tables width+length of gamma rays.
- Using the lookups, get mean reduced scaled width+length

$$mrscw = \frac{1}{N} \sum_{i=1,N} \frac{(w_i - \bar{w}(r_c, A, z))}{\sigma_w}$$

and cut on *mrscw* and *mrscl* for gammas and protons ("shape cuts"). Energy dependent cuts.

- Get angular resolution and apply point source selection ("angle cut"). Multiplicity-dependent cut.

Heidelberg CTA-MC Analysis 3

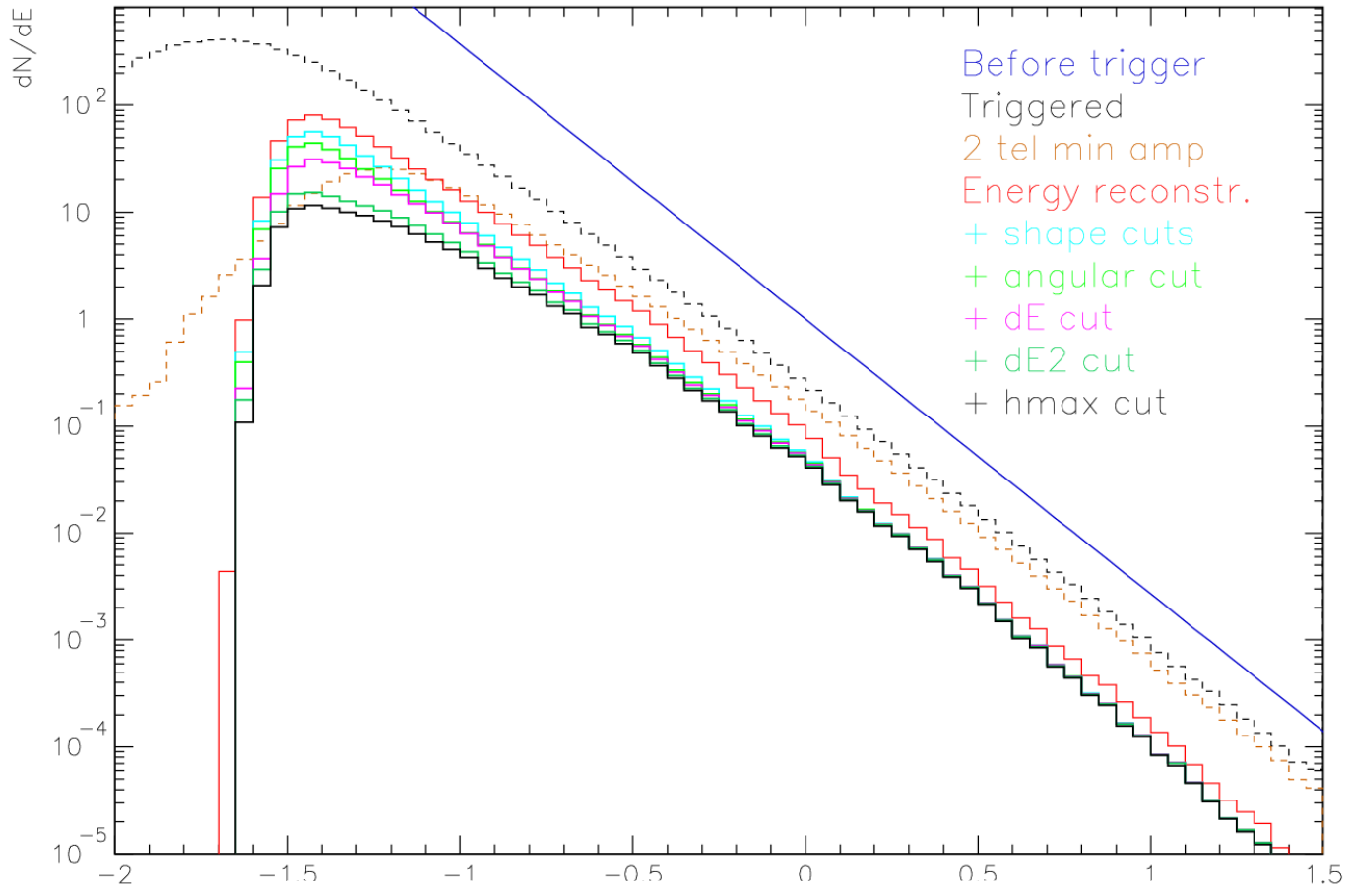
- Generating lookup tables for image amplitude / energy (*I*/*E*) as with width and length.
- Using that lookup an energy estimate and estimate of its fluctuation for each telescope is obtained.
- Get energy *E*, energy accuracy σ_E/E, and χ^2/n.d.f.
- Discard showers with bad σ_E/E ("dE cut").
  Rejects also gammas at large (but energy dependent) R_c.
- Discard showers with bad χ^2/n.d.f. ("dE2 cut").
- Calculate distance of shower maximum and discard showers inconsistent with gammas ("hmax cut").

Heidelberg CTA-MC analysis 4

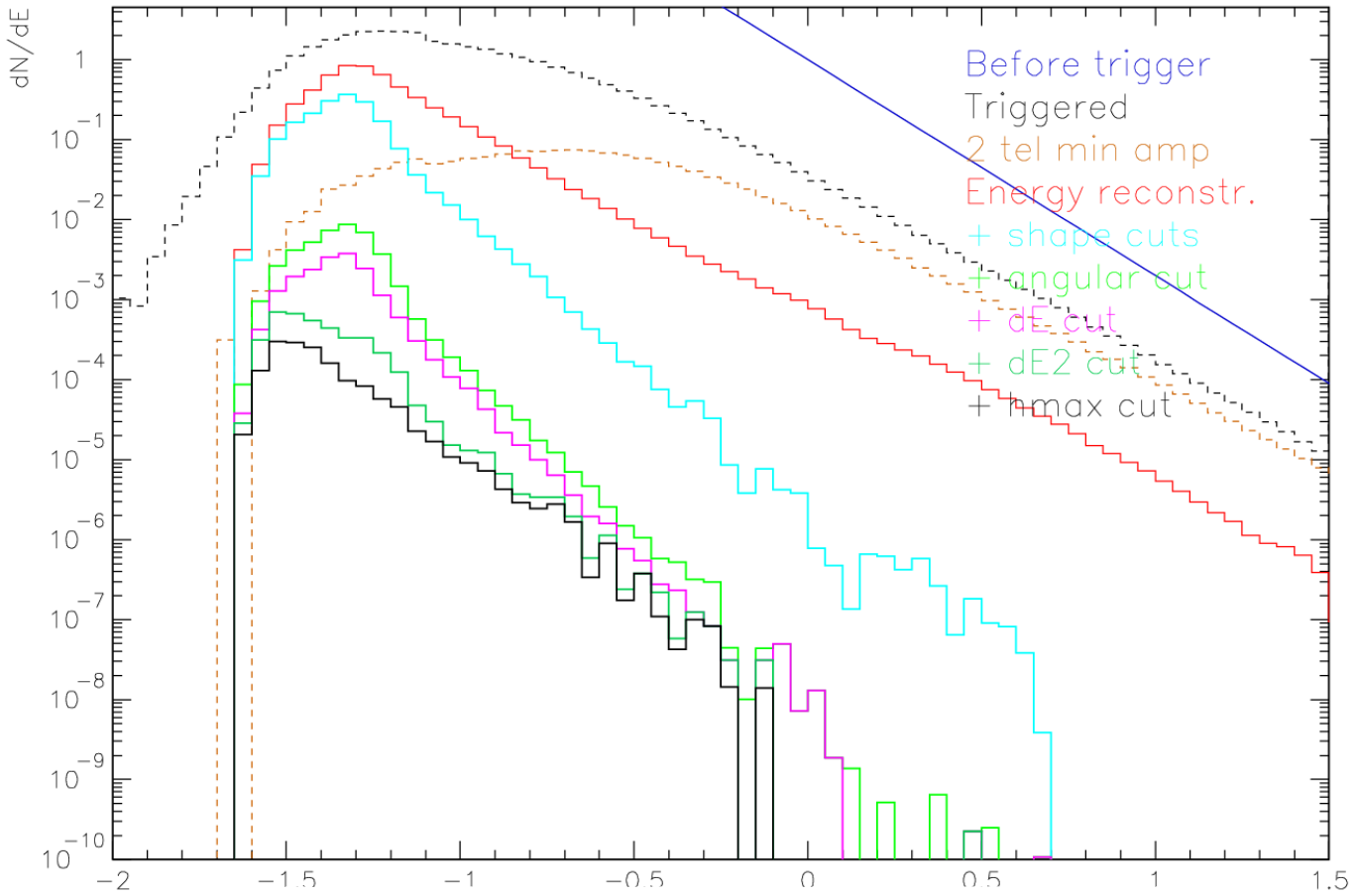
Also in the eventio/hessio format for some time now:

- Inter-telescope trigger time difference w.r.t. nominal shower plane.
- “Online” pixel pulse shape analysis (peak, rise, width). For pixel amplitudes above threshold.
- Pulse shape analysis summary at DST level: peak time gradient (along major axis), r.m.s. residuals, mean pixel pulse widths (20%, 50%), mean rise time.

Cut efficiencies (gammas)



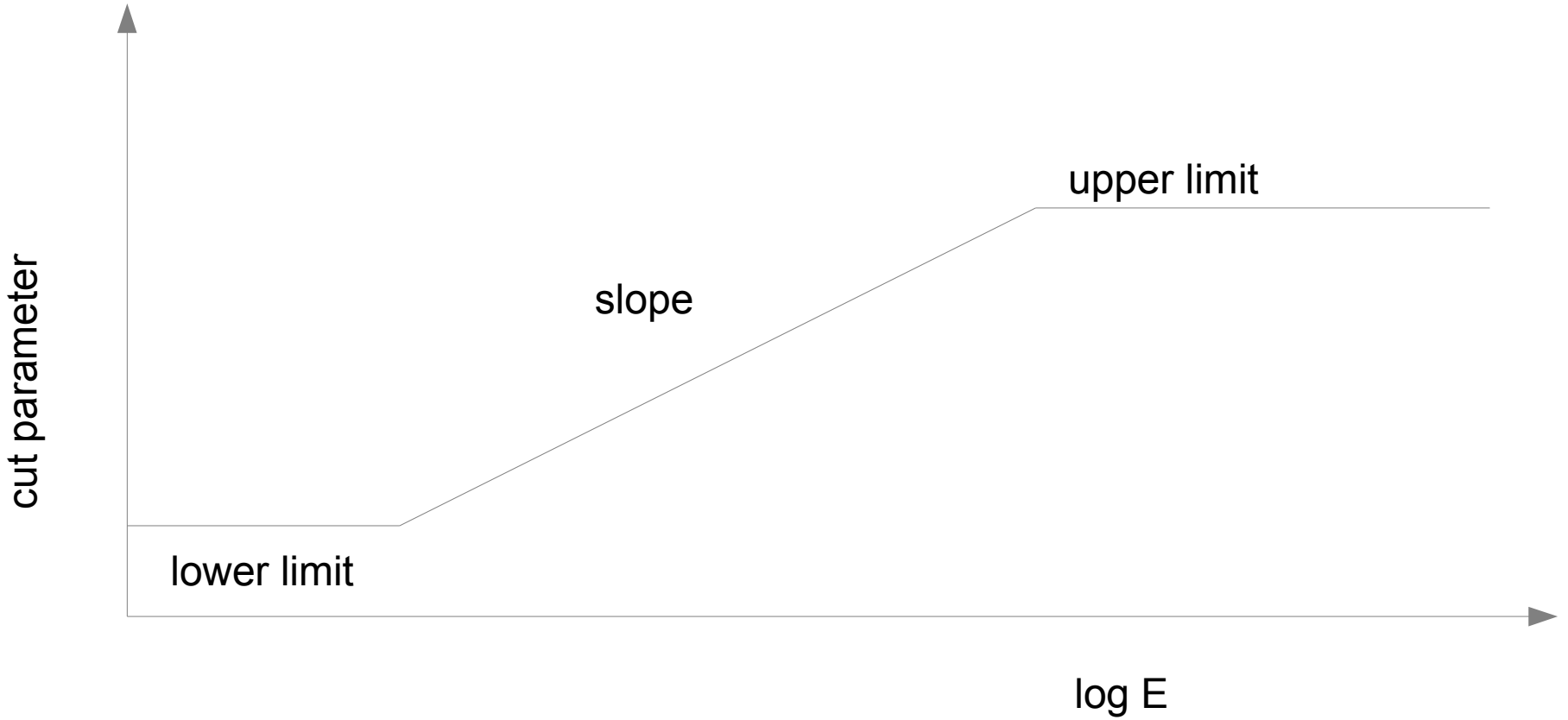
Cut efficiencies (protons)



Optimizing shape cuts etc.

- Background falls off rapidly at higher energies.
- Optimum shape cuts are, compared to fixed cuts:
  - more strict at low energies (better hadron rejection)
  - less strict at high energies (more gamma signal)
- Similar for additional cuts like
  - *dE* cut (accepting events with well-determined energy),
  - *dE2* cut (events with consistent energy estimates from individual telescopes), and
  - *hmax* cuts (height of maximum as expected for gammas) .

Allowed dependence of cut parameters



Example read_hess parameters

Example (from initial prod-2 analysis, ~ from prod-1):

- read_hess -r 2 -u -q --min-trg-tel 2 --min-tel 2 --min-pix 4 \
  --min-amp 55 --tail-cuts 5,10 --shape-cuts -4.0,0.5,-2.0,1.2 \
  --width-cut 0.5,0.3,0.2,2.0 --length-cut 1.2,0.6,1.2,2.0 \
  --dE-cut 1.0,0.0,1.0,1.0 **--dE2-cut 0.6,0.35,0.12,2.0** --hmax-cut 0.8 \
  --only-telescopes 2,3,5,6,8,10,12,23-26,31-33,43-46,51-53,97-168 \
  --type 1,1,5 --tail-cuts 7.655,15.310 --min-amp 81.550 --min-pix 4 \
  --type 2,5,59 --tail-cuts 7.468,14.937 --min-amp 79.68 --min-pix 3 \
  --type 3,97,168 --tail-cuts 1.991,3.983 --min-amp 24.91 --min-pix 3 \
  --powerlaw -2.57 --auto-lookup -f ../gamma_dst.lis

Energy-dependent cut values

- Energy-dependent cut parameter example:
  dE2 is cutting on how consistent the energy estimates from the individual images are,
  - **--dE2-cut 0.6,0.35,0.12,2.0**
    - Lower limit of parameter: 0.6,
    - rising by 0.35 per decade in energy,
    - lower limit used for log10(E/TeV) < 0.12,
    - upper limit of 0.6+(2.0-0.12)*0.35 used for log10(E/TeV) > 2.0

Telescope-type dependent parameters

Example: image cleaning tail-cuts:

- --tail-cuts 5,10 \

  --type 2,5,59 --tail-cuts 7.468,14.937
- Default value: 5, 10 (p.e.), meant as nominal for 100 MHz NSB
  - applied if no type-specific value seen
  - used for file names
- Telescope type 2 is for telescopes with ID from 5 to 59
  - IDs not strictly necessary (auto grouping by optical parameters)
- For telescopes of type 2 the tail-cut levels are 7.468 and 14.937 p.e.
  - Higher tail-cut levels for telescopes with more NSB: $\propto$ sqrt(NSB)

Histogram files

- Generated in eventio-based format
- Conversion tools available into
  - old PAW (HBOOK), needs CERNLIB: hdata2hbook
  - ROOT histograms: hdata2root
- Some specialized tools directly working on them, like
  - gen_lookup (generating look-ups from accumulated hist.s)
- → Let's look into a histogram file