MAGIC data in FITS format to be used in ctools

.. and some other DL3 approaches currently used by MAGIC people

DISCLAIMER : All that is shown here is still underdevelopment and not official nor sanctioned by MAGIC in any way

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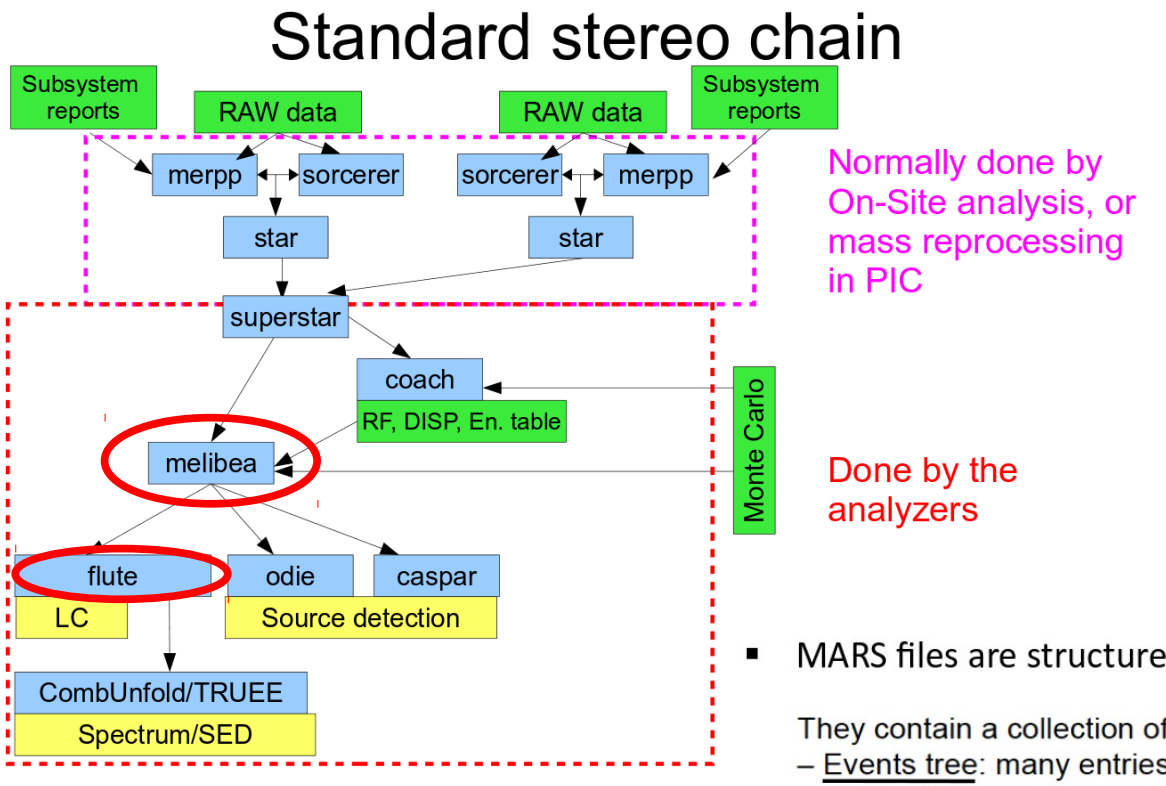
HELMHOLTZ ASSOCIATION

DESY

Snapshot of MARS (MAGIC Analysis Reconstruction Software)



Normally done by On-Site analysis, or mass reprocessing in PIC

Done by the analyzers

> MARS is a collection of classes, macros and programs for the analysis of MAGIC data. Using MARS one can perform the full analysis of the MAGIC data from the raw data files stored by DAQ up to high level products such as spectra and light curves

- MARS files are structured in Trees:

They contain a collection of root trees, among which at least these two:
– Events tree: many entries; each entry corresponds to one shower, or calibration event, or pedestal event.
– RunHeaders tree: tree with just one entry per file, containing global info valid for the whole file
– Other trees: subsystem information, or extra MC information (i.e., *OriginalMC*) and RunTails tree

AMC, CC, Camera, DAQ, DT, **Drive**, Laser, Lidar, Pyrometer, **Starguider**, Trigger, …

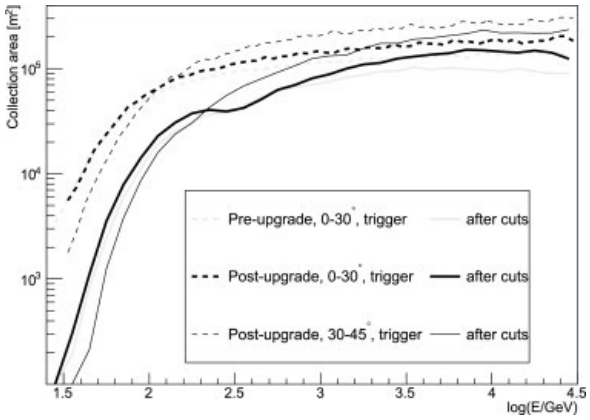
Melibea – in MARS code

- DL3 level for **event lists** is the output of the Melibea program (**_Q_**). Created for each run (~20min) of observations, or for MC events. Database of MC for each “hardware config”.
- Output includes “GTI” (Good Time Interval) cut. This cut is applied either removing subrun blocks or ignore events from actual time interval.
- Incident Direction: Sky position of the gamma-ray source
  - In the camera field of view
  - In the observatory coordinates: Azimuth / Zenith angle
  - In equatorial coordinates: Right Ascension / Declination
- Energy: Energy of the primary gamma-ray (Earth frame of reference)
- Hadronness (Value between 0 and 1)
  - 0: gamma-ray like
  - 1: Background like

DESY

Flute (Flux vs T vs E) – in MARS code

- Takes _**Q**_ in data and MC and calculates for each energy bin
  – # counts
  – effective area in MC energy, migration matrix, effective area in reconstructed energy and background rate
  – effective observation time
- → calculates most of the **Instrument Response functions** and outputs the differential flux in estimated energy and the lightcurve
- Can also correct the effective area for spill-over effects due to energy resolution and bias



Example of MAGIC eff area.
Aleksic+2016, performance paper

- Can optimize the cuts for each energy bin (in hadroness and thetasq) from the MC test sample, when a desired cut efficiency is given.
- Takes into account also info on zenith and azimuth of the observation: e.g the effective area is obtained as a weighted average, where the weights are proportional to the observation time spent in each bin of zenith and azimuth angle traversed by the source
- Many more details in Zanin+13 (ICRC)

DESY

Formats (at the moment in ctools perspective)

- This is a preliminary MAGIC step toward these high-level data analysis activities
- In principle you only need (example format used in ctools, basically what DL3 is used now)

  – event list: FITS table of events, with info on reconstructed and estimated quantities → translated from internal MARS file to FITS table, run by run;

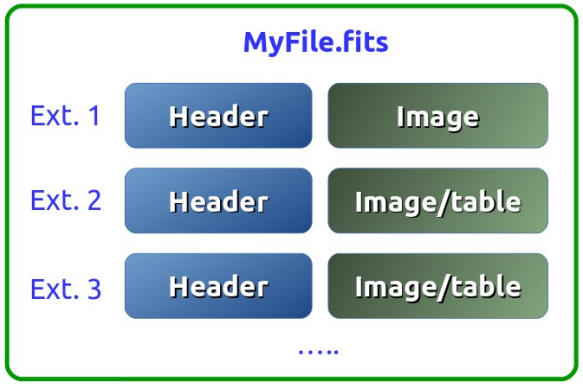
  – instrument response function: ctools already have internal functionality to translate “CTA root IRFs” into internal format (a simple text table if on-axis, a fits file if also off-axis).

Other MAGIC DL3 approaches

- gLike (Javi Rico, IFAE Barcelona)
  Full likelihood code developed for DM limits with MAGIC,CTA+FERMI in mind. It does not deal with FITS format (both data and IRFs), but can read the MAGIC and CTA DL3 IRFs and MAGIC root data.

- Likelihood image fitting package (Christian Fruck, Marcel Strzys, Ievgen Vovk, MPI Munich), developed for MAGIC data structure, but can be adapted to any kind of event list. Take _Q_ files and with python utilities constructs images (binned in energy) and IRFs in FITS format
  → **they are interested to adopt their development to agreed upon DL3!**
  – IRFs (PSF for the entire field of view and acceptance)
  are constructed following the pointing history of the observation

Slides at MAGIC coll meeting by M+C+I

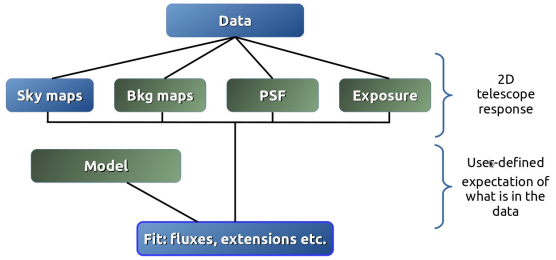


There are standard tools available to view/edit FITS files like fv or ds9.

Image/table fields contain the information we'd like to store – e.g. computed PSF or exposure shapes.

Headers contain the additional information – e.g. the coordinate system of the stored image.

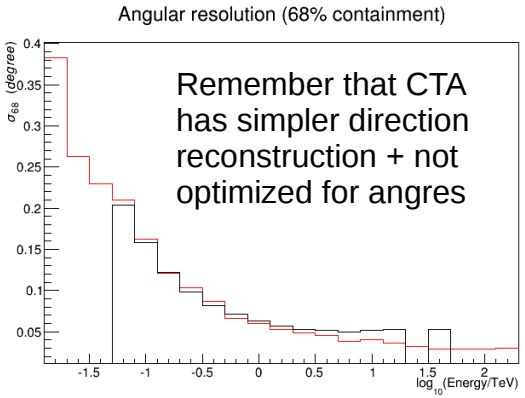
Each extension in our tools is assigned to a different energy bin, so all of them are stored in a single file via the easily accessible structure.

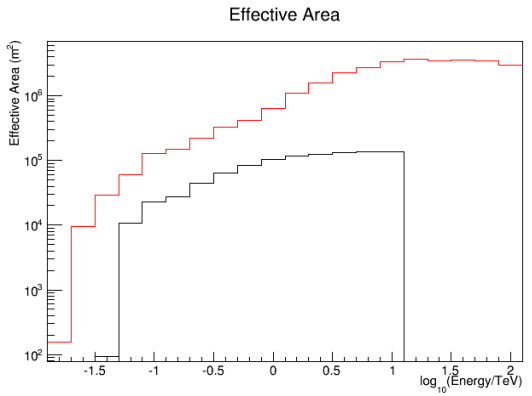


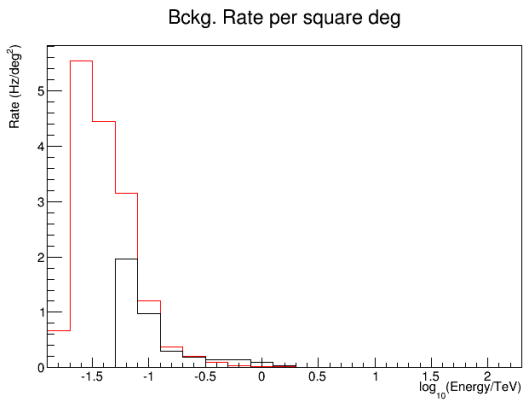
Response functions

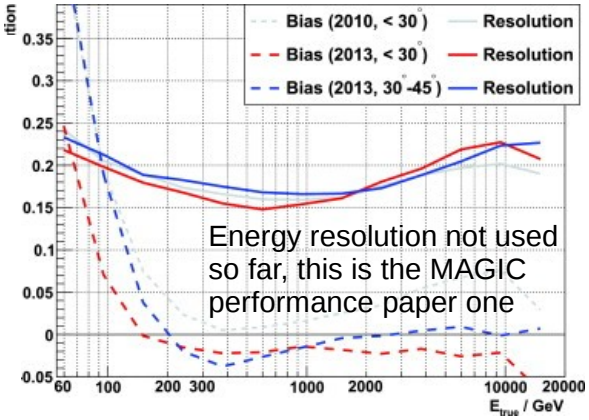
- Take the structure of CTA-IFAE root files
- Angular resolution from gammaMC fitting (exponential)
- Effective Area, Background Rate from output of MAGIC flux calculation program
- In flute, make the thetasq_cut=angres &&hadr<0.28 instead of optimizing cuts on MC

RED histos are CTA-2A-Aar files from IFAE









BLACK histos are “my MAGIC IRFs”

IRF: tables

Performance tables

log(E)	Area	r68	r80	ERes.	BG Rate	Diff Sens
-1.7	261.6	0.3621	0.4908	0.5134	1.89924e-02	6.88237e-11
-1.5	5458.2	0.2712	0.3685	0.4129	1.00972e-01	1.72717e-11
-1.3	15590.0	0.1662	0.2103	0.2721	5.75623e-02	6.16963e-12
-1.1	26554.1	0.1253	0.1567	0.2611	2.13008e-02	2.89932e-12
-0.9	52100.5	0.1048	0.1305	0.1987	8.87292e-03	1.39764e-12
-0.7	66132.1	0.0827	0.1024	0.1698	1.09756e-03	6.03531e-13
-0.5	108656.8	0.0703	0.0867	0.1506	4.84287e-04	3.98147e-13
-0.3	129833.0	0.0585	0.0722	0.1338	1.57546e-04	3.23090e-13
-0.1	284604.3	0.0531	0.0656	0.1008	1.36703e-04	2.20178e-13
0.1	263175.3	0.0410	0.0506	0.0831	2.09694e-05	1.87452e-13
0.3	778048.6	0.0470	0.0591	0.0842	6.92374e-05	1.53976e-13
0.5	929818.8	0.0391	0.0492	0.0650	1.45844e-05	1.18947e-13
0.7	1078450.0	0.0335	0.0415	0.0541	1.15959e-05	1.51927e-13
0.9	1448579.1	0.0317	0.0397	0.0516	4.71231e-06	1.42439e-13
1.1	1899905.0	0.0290	0.0372	0.0501	8.14997e-06	1.96670e-13
1.3	2476403.8	0.0285	0.0367	0.0538	5.91940e-06	2.20695e-13
1.5	2832570.6	0.0284	0.0372	0.0636	7.33847e-06	3.22523e-13
1.7	3534065.3	0.0290	0.0386	0.0731	1.34549e-05	4.84153e-13
1.9	3250103.4	0.0238	0.0308	0.0729	4.42228e-06	6.26265e-13
2.1	3916071.6	0.0260	0.0354	0.0908	2.26648e-06	7.69921e-13

Notes
1) log(E) = log10(E/TeV) - bin centre
2) Eff Area - in square metres after background cut (no theta cut)
3) Ang. Res - 68% containment radius of gamma-ray PSF post cuts - in degrees
4) Ang. Res - 80% containment radius of gamma-ray PSF post cuts - in degrees
5) Fractional Energy Resolution (rms)
6) BG Rate - inside point-source selection region - post call cuts - in Hz
7) Diff Sens - differential sensitivity for this bin expressed as E^2 dN/dE - in erg cm^-2 s^-1 - for a 50 hours exposure - 5 sigma significance including systematics and statistics and at least 10 photons.

```
GCTAAeffPerfTable
GCTAPsfPerfTable
GCTAEdispPerfTable
GCTABackgroundPerfTable
```

Once you have the response functions in CTA format, you can translate them in ctools accepted format. This table if only on-axis, a fits table if you have another dimension (off-axis)

Only on-axis information

A_{eff} and B_{rate} off-axis dependence modelled using $B(\theta) \propto \exp\left(-\frac{1}{2}\frac{\theta^4}{\sigma^2}\right)$

Gaussians assumed for PSF and energy dispersion

IRF format for DL3

- Format is THE discussion point of the workshop: which information should be provided there?
- Binning in zenith and azimuth “inside” or “outside” the IRFs?
- Should IACTs give “end users” the tables or the MC files and the tools to tailor them?
- Are these tools to be part of DL3 or part of the analysis tool?
- Run by run off-axis IRFs are probably better (like ARF, RMF, PSF vector)
- Paolo Cumani and Tarek Hassan will be working on this for MAGIC too, building on experience from CTA

The event list, how I do it

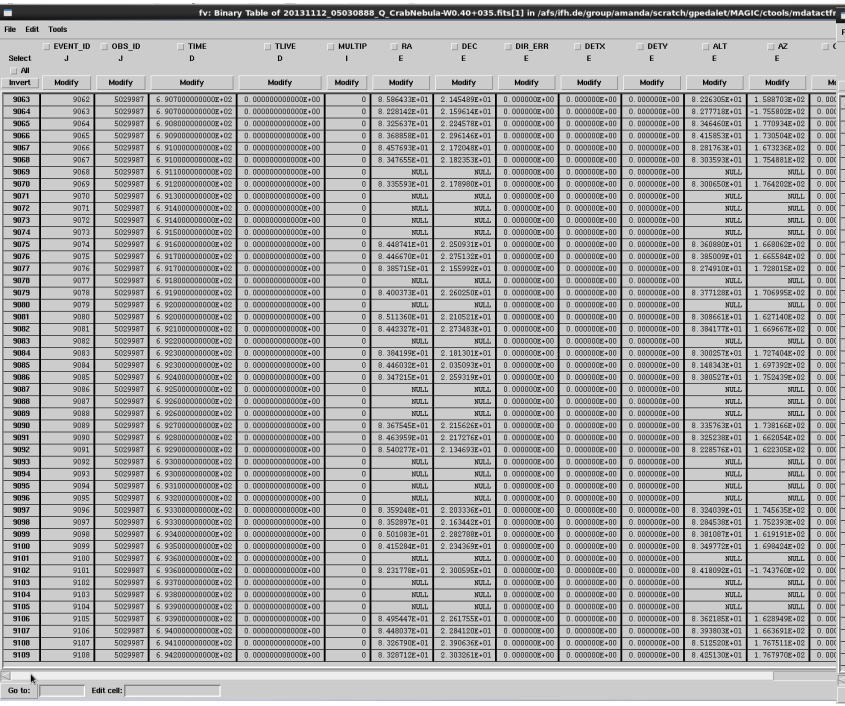
- Need to go from root tree to fits table (now roughly done in ROOT+pyfits).
- Elena Racero (Madrid) developed a code back in 2010 to do this directly integrating it in MARS, using cfitsio and DAL (X-ray) libraries → this should be used!!

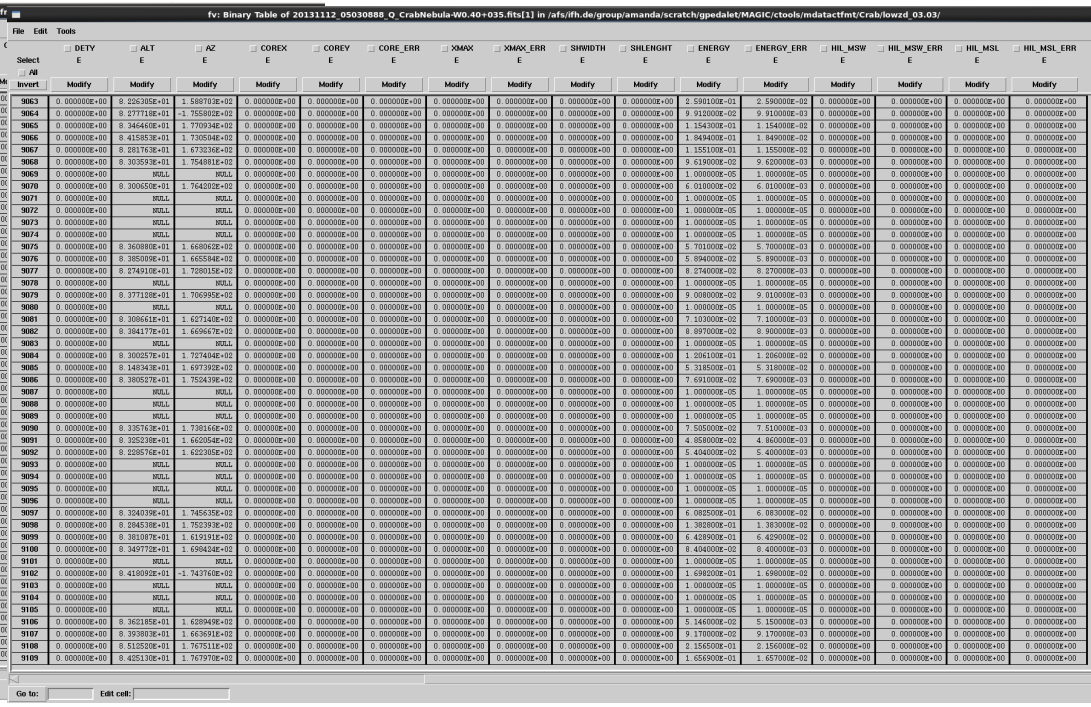
  We are working on upgrading it to whatever DL3 format is needed.

On Crab

> Cut on Size (>30), zd (<30) and hadr(<0.28) done when creating the fits table

Fits binary table, readable by ctools, basically event list



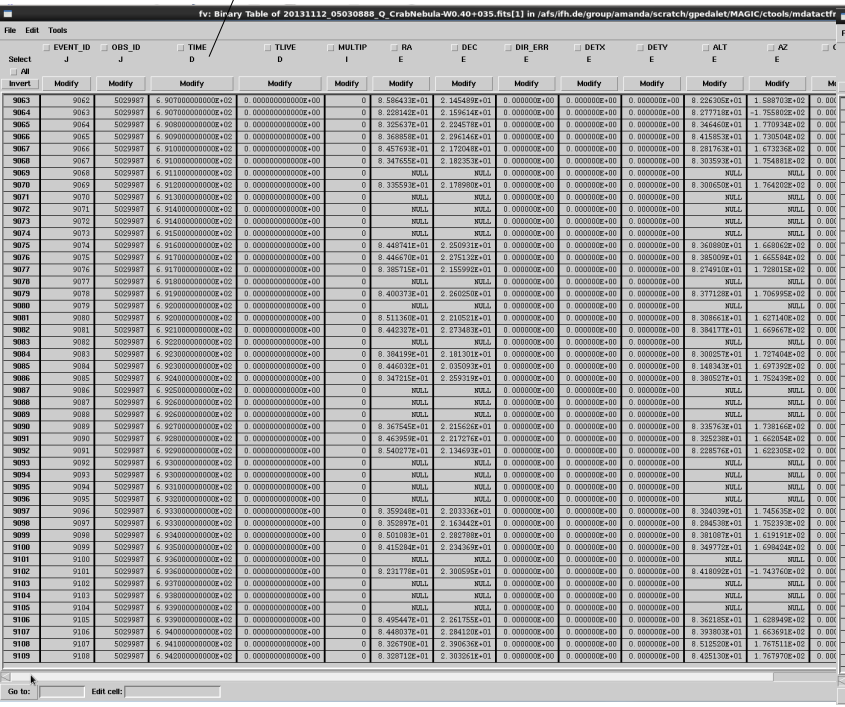


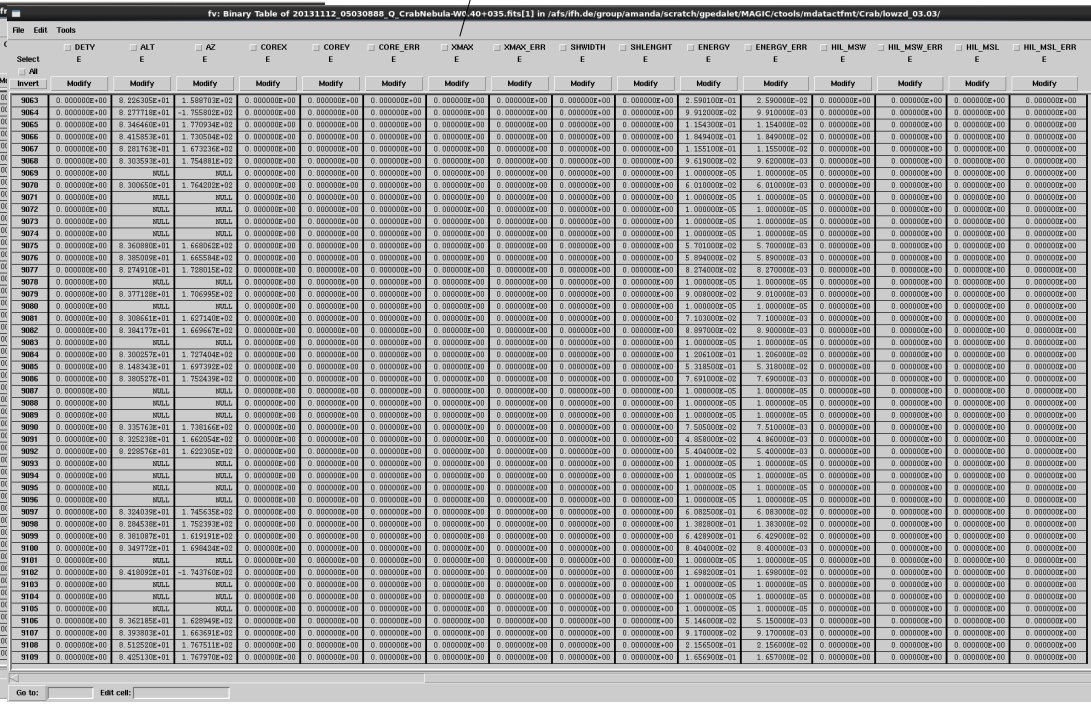
On Crab … cheats

> Cut on Size (>30), zd (<30) and hadr(<0.28) done when creating the fits table

This is equally spaced from flute calculated effective time .. to be changed, but I integrate everything anyway and do not use GTI

Many quantities are left to zero for simplicity since I dont apply any cuts or reconstructions with ctools, are these even needed in future?

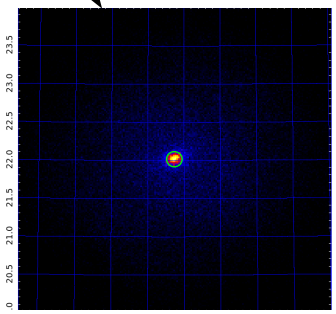




Lets run it

> We have (basically) the IRF and (basically) the event list, we can run things

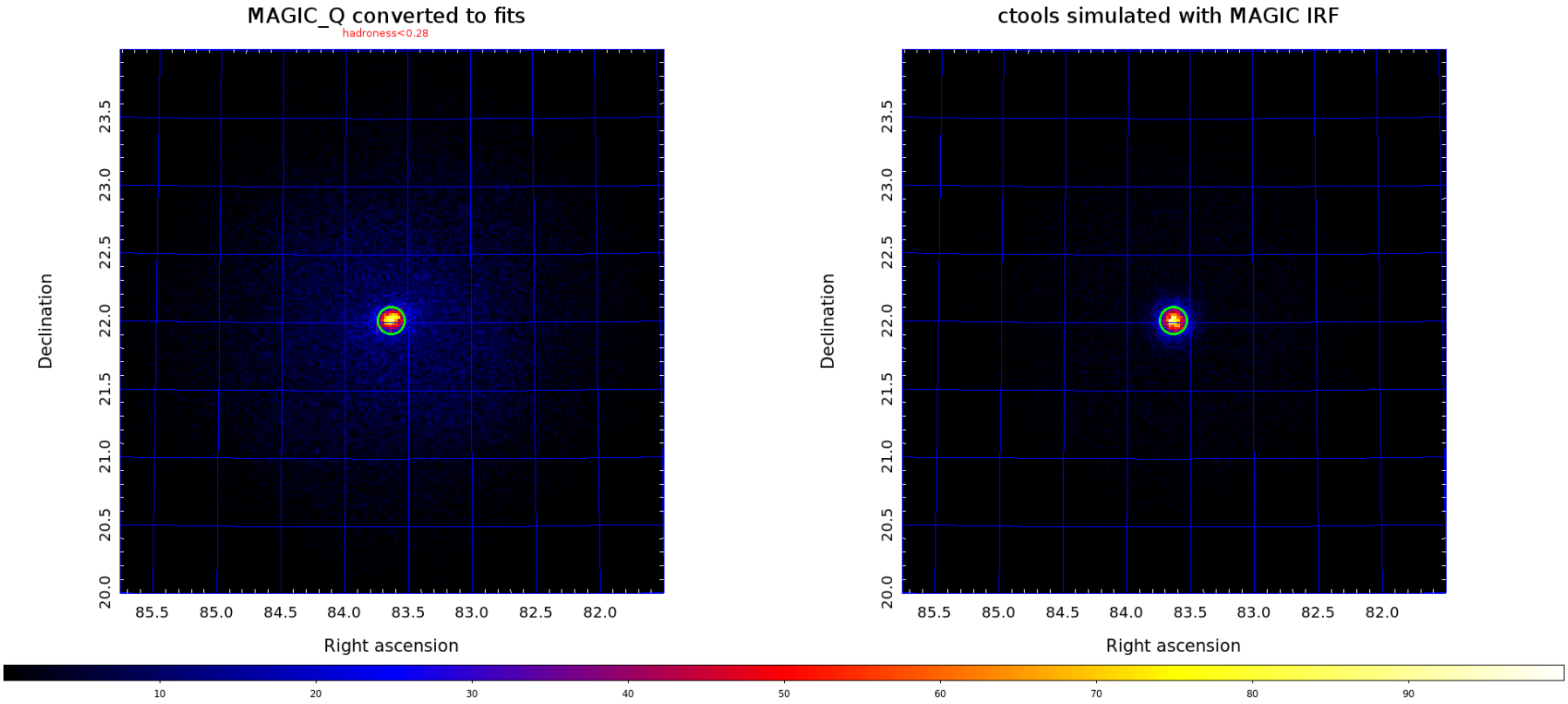
```
# Test ctbin
# ==========
$ECHO -n "Test ctbin: "
#
# Run 1
#$ctbin evfile="20131004_05029747_Q_CrabNebula-W0.40+035.fits" \
$ctbin evfile="listfits.xml" \
       outfile="cntmap.fits" \
       emin=0.05 \
       emax=100.0 \
       enumbins=20 \
       ebinalg="LOG" \
       nxpix=200 \
       nypix=200 \
       binsz=0.02 \
       coordsys="CEL" \
       xref=83.63 \
       yref=22.01 \
       proj="CAR"
$ECHO -n "."
if [ -s "cntmap.fits" ]
then
  $ECHO -n "."
else
  $ECHO " cntmap.fits file is not found"
  exit 1
fi



# Test ctselect
# =============
$ECHO -n "Test ctselect: "
$ctselect infile="listfits.xml" \
          outfile="selected_events.fits" \
          ra=83.63 \
          dec=22.01 \
          rad=10.0 \
          tmin=0.0 \
          tmax=21074.6 \
          emin=0.05 \
          emax=100.0
$ECHO -n "."
if [ -s "selected_events.fits" ]
then
  $ECHO -n "."
else
  $ECHO " selected_events.fits file is not found"
  exit 1
fi
$ECHO " ok"
```




```
−<observation_list title="observation list">
 −<observation name="Crab_1" id="1" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131004_05029747_Q_CrabNebula-W0.40+035.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
 −<observation name="Crab_2" id="2" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131004_05029748_Q_CrabNebula-W0.40+215.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
 −<observation name="Crab_3" id="3" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131004_05029749_Q_CrabNebula-W0.40+035.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
 −<observation name="Crab_4" id="4" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131004_05029750_Q_CrabNebula-W0.40+215.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
 −<observation name="Crab_5" id="5" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131004_05029751_Q_CrabNebula-W0.40+035.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
 −<observation name="Crab_6" id="6" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131005_05029783_Q_CrabNebula-W0.40+215.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
 −<observation name="Crab_7" id="7" instrument="MAGIC">
    <parameter name="EventList" file="../lowzd_03.03/20131005_05029784_Q_CrabNebula-W0.40+035.fits"/>
    <parameter name="EffectiveArea" file=""/>
    <parameter name="PointSpreadFunction" file=""/>
    <parameter name="EnergyDispersion" file=""/>
  </observation>
```

For now empty bec using caldb simple text file

3.71 hours in ctools



Same scale for the colorbar, in principle it works but there are problems already with the background reconstruction (i.e the bkgrate IRF that should be refined and made offaxis)

DATA format for DL3

- Again, which information should be there?
- MAGIC standard DL3 data inherits also information of telescope subsystems, should future DL3 fits also have this?
  - Leave this in metadata (like a tag of instrument configuration?)
  - Or should there be different classes of data cleaning? (like in LAT, “source, “clean” ...)
- If we leave info on reconstructed quantities, the high level analysis tool should be able to handle cuts on them? At the moment I cut beforehand ...

Final remarks

- MAGIC is setting up a more structured discussion on this topics, what presented here is not official
- Looking forward to discuss all of this in the following days!