H.E.S.S. Data analysis with open source tools

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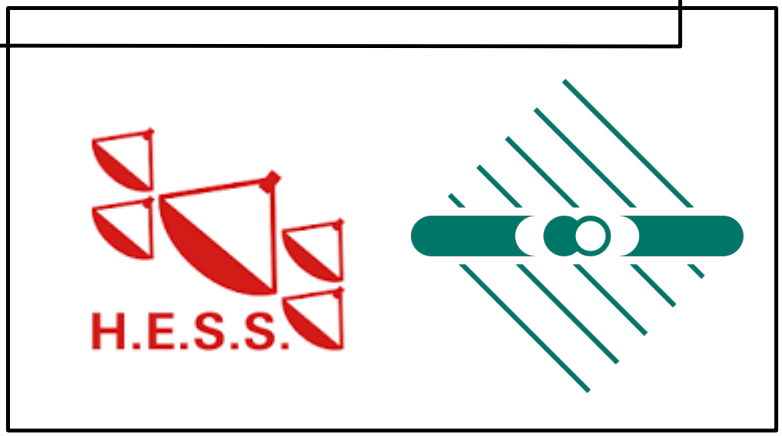
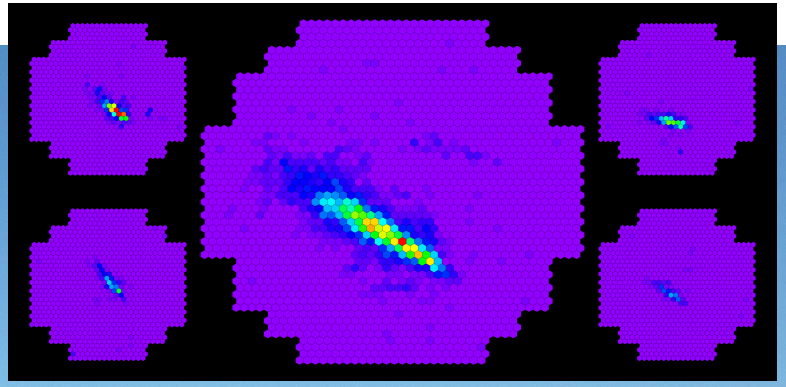
PyGamma15

16.11.2015



The H.E.S.S. telescopes



- Array of 5 IACTs
- Stereoscopic observation of air showers between < 100 GeV and 100 TeV
- Analysis modes: *mono*, *stereo*, *hybrid*
- Observations taken in 28 min. runs

CT5
614 m²
1024 pixels

CT1 – CT4
108 m²
960 pixels

H.E.S.S. internal analysis chains

- Raw Data stored in ROOT-based internal data format
- 2 completely independent analysis chains (starting from calibration)

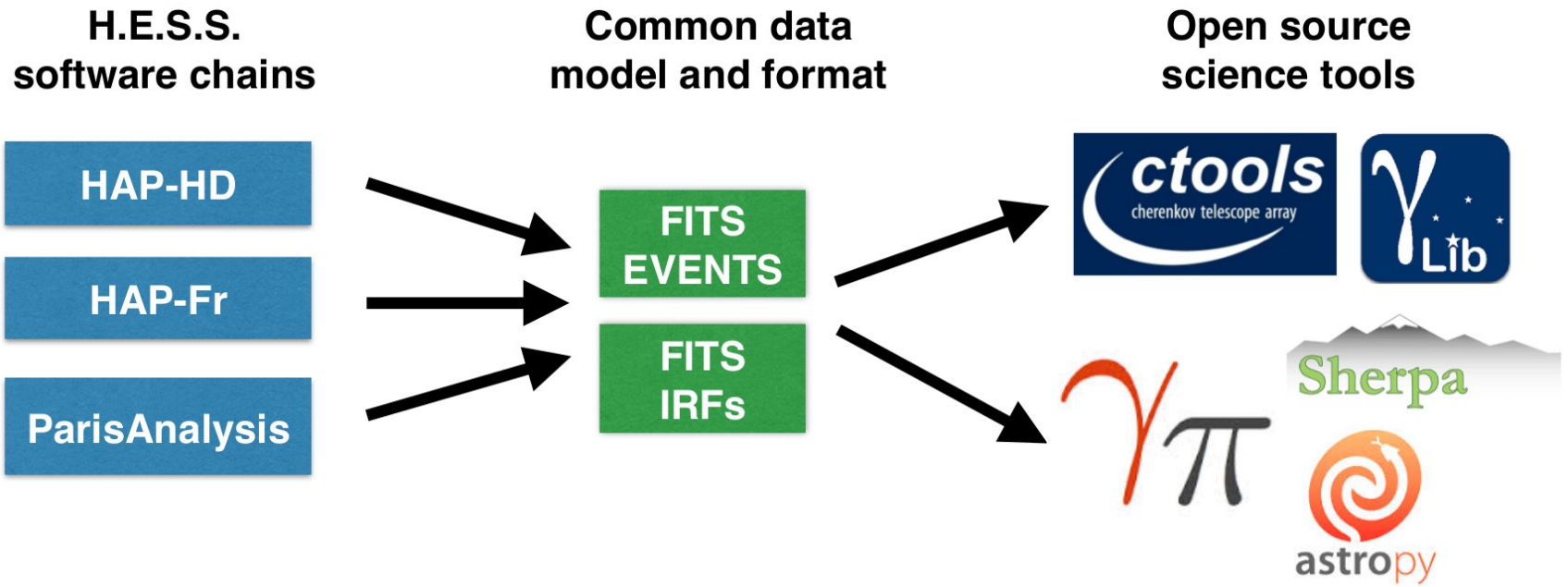
HAP HD/Fr

ParisAnalysis

- 1D spectral, 2D morphological analysis
  → *R. Terrier: Classical Cherenkov telescope data analysis*
- Different reconstruction algorithms and high-level analysis tools
- Incompatible formats for calibrated data, IRFs, spectra, lightcurves, ...

Difficult to diagnose problems when results are different

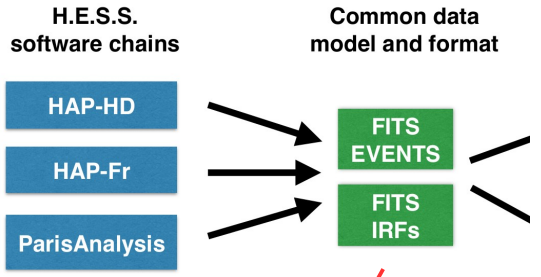
H.E.S.S. analysis with open source tools



- Idea: Export event list and IRFs for each run to common data format
- Perform high-level analysis using open source tools
- H.E.S.S Open Source tools (HOST) task group active since 2013

Detailed comparison between different chains possible ☺

FITS exporters



- Main issue: Which format to use?
- Ideally prototype CTA data format
  → *C. Boisson: CTA DATA overview*

Exporters available for HAP and ParisAnalysis

"Flexi Format"

- ICRC 2015 proceeding
  → *http://arxiv.org/abs/1508.07437*
- Proposed CTA data format
- Prototype C++ library exists
- Not implemented in Gammalib or Gammapy
- Will probably come in 2016

"Fermi-LAT format"

- BinTableHDU with 1 row and vectors in columns
- No specification or webpage
- Need H.E.S.S./Fermi example files
- Implemented in Gammalib and Gammapy

Hopefully CTA formats are specified soon!

Data distribution within H.E.S.S.

ParisAnalysis files rsync command

```
rsync -uvrl <username>@lfs1.mpi-hd.mpg.de:/lfs/l2/hess/users/mimayer/hessfits/latest/pa .
```

HD files rsync command

```
rsync -uvrl <username>@lfs1.mpi-hd.mpg.de:/lfs/l2/hess/users/mimayer/hessfits/latest/pa .
```

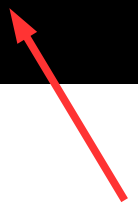
Only H.E.S.S. members (with MPIK cluster account)

- All H.E.S.S. I data and IRFs ready for download
- 4.5 GB (one cutset) → highly portable
- HAP: Easy to use exporter scripts (e.g. for H.E.S.S. II data)
- Regular updates planned - new calibration scheme, new software versions, new data format

Prototype CTA!

Event List

```
        Name                 Type        Dimensions
        ----                 ----        ----------
HDU 1   Primary Array        Null Array
HDU 2   EVENTS               BinTable     27 cols x 654 rows
HDU 3   GTI                  BinTable      2 cols x 1 rows
```



- Table with RA, DEC, Energy, Time, etc.
- Header with additional information (livetime, pointing position, target, telescope pattern, etc.)
- Few hundred up to ~ 4000 events

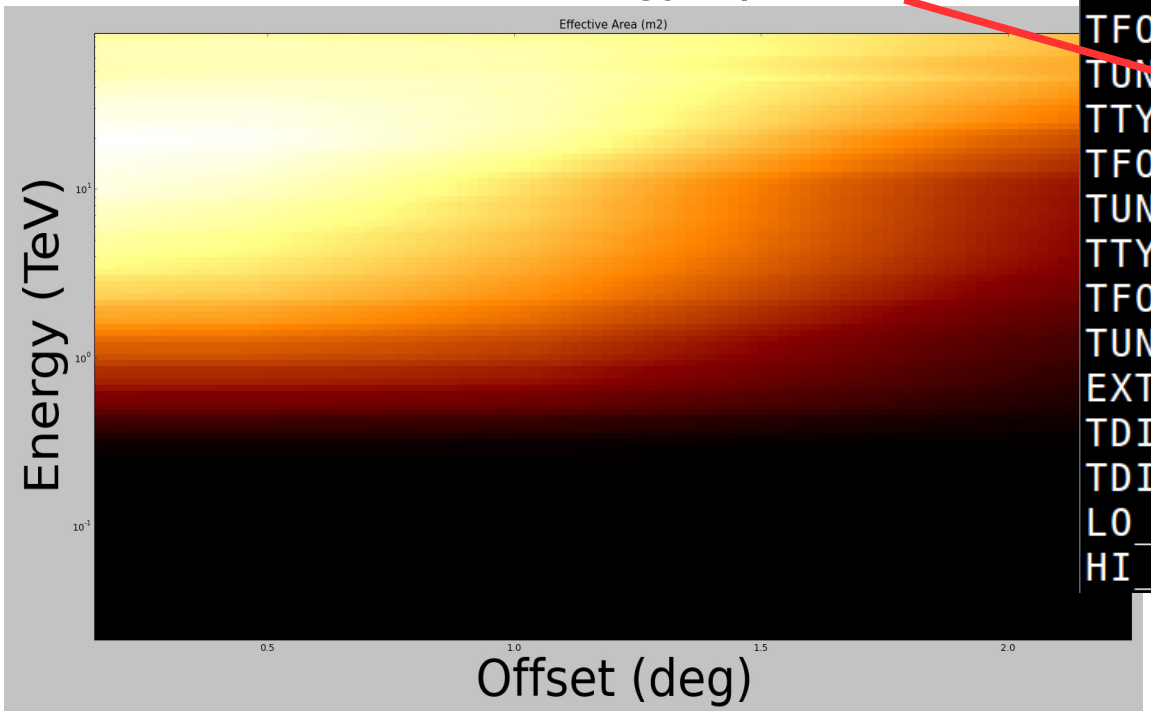
Effective Area

- Stored as function of

  Energy

  Offset from pointing position

- Available in true and reconstructed energy space




```
TTYPE1  = 'ENERG_LO'                / label f
TFORM1  = '15E     '                / data fo
TUNIT1  = 'TeV     '                / physica
TTYPE2  = 'ENERG_HI'                / label f
TFORM2  = '15E     '                / data fo
TUNIT2  = 'TeV     '                / physica
TTYPE3  = 'THETA_LO'                / label f
TFORM3  = '6E      '                / data fo
TUNIT3  = 'deg     '                / physica
TTYPE4  = 'THETA_HI'                / label f
TFORM4  = '6E      '                / data fo
TUNIT4  = 'deg     '                / physica
TTYPE5  = 'EFFAREA '                / label f
TFORM5  = '90E     '                / data fo
TUNIT5  = 'm2      '                / physica
TTYPE6  = 'EFFAREA_RECO'            / label f
TFORM6  = '90E     '                / data fo
TUNIT6  = 'm2      '                / physica
EXTNAME = 'EFFECTIVE AREA'          / name of
TDIM5   = '(15,6)  '
TDIM6   = '(15,6)  '
LO_THRES=    0.807899713516235 / [TeV]
HI_THRES=     42.0772705078125 / [TeV]
```

Energy Dispersion

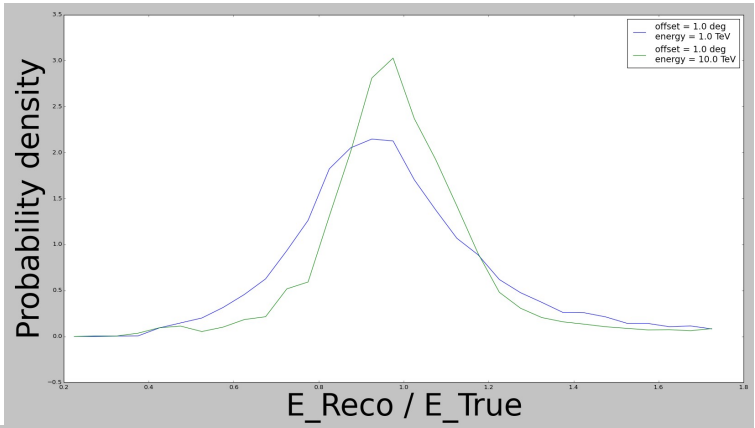
fixed offset & true energy

- PDF matrix stored as function of

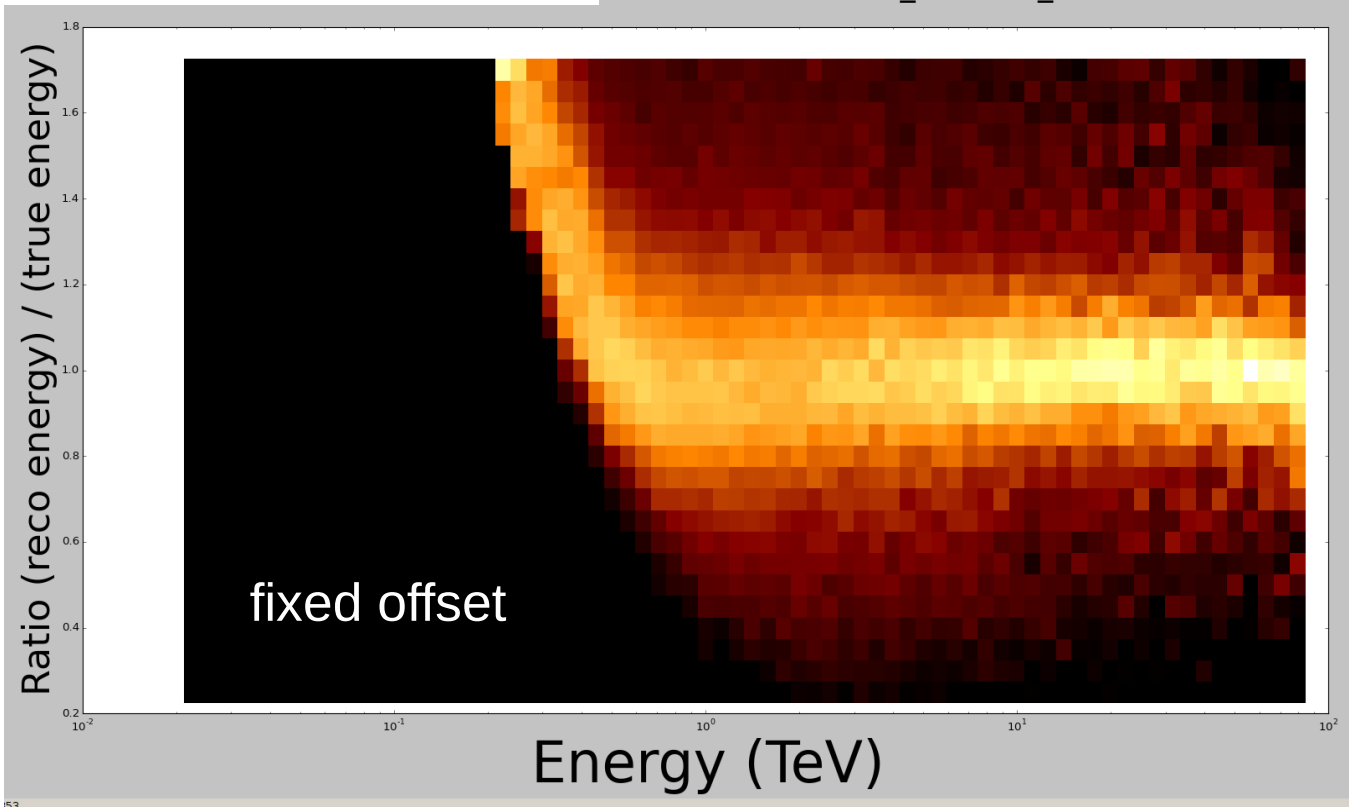
  Migration dE_{reco}/dE_{true}

  True energy

  Offset




```
TTYPE1  = 'ETRUE_LO'
TFORM1  = '15E     '
TUNIT1  = 'TeV     '
TTYPE2  = 'ETRUE_HI'
TFORM2  = '15E     '
TUNIT2  = 'TeV     '
TTYPE3  = 'MIGRA_LO'
TFORM3  = '100E    '
TTYPE4  = 'MIGRA_HI'
TFORM4  = '100E    '
TTYPE5  = 'THETA_LO'
TFORM5  = '6E      '
TUNIT5  = 'deg     '
TTYPE6  = 'THETA_HI'
TFORM6  = '6E      '
TUNIT6  = 'deg     '
TTYPE7  = 'MATRIX  '
TFORM7  = '9000E   '
EXTNAME = 'ENERGY DISPERSION'
TDIM7   = '(15,100,6)'
```



Point Spread Function

- Parametrized PSF stored as function of

  Energy

  Offset

- HAP: Triple Gauss
- ParisAnalysis: King function

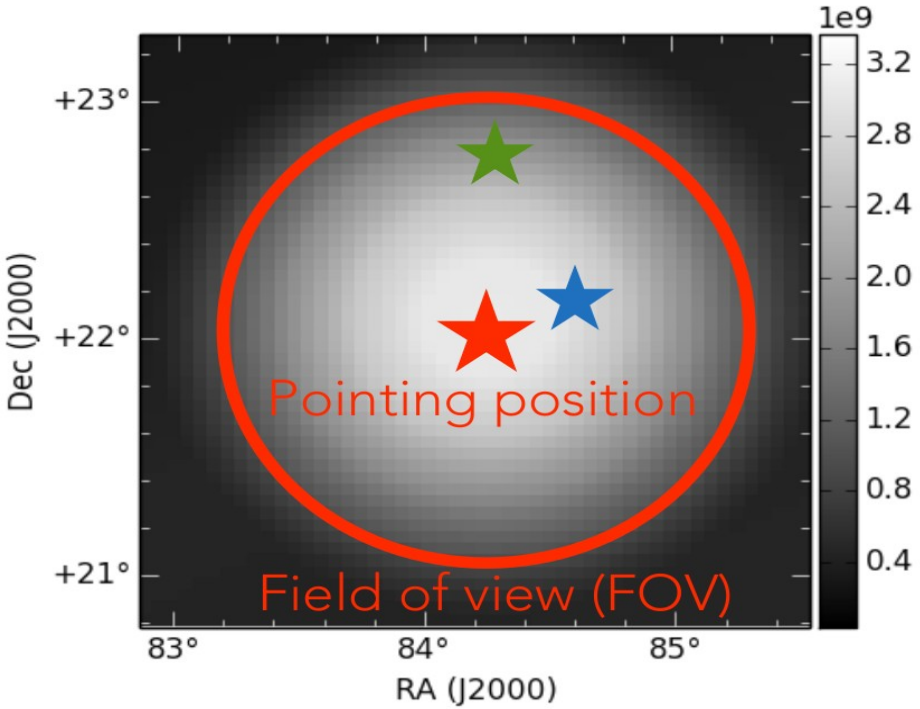
```
TTYPE1  = 'ENERG_LO'
TFORM1  = '15E     '
TUNIT1  = 'TeV     '
TTYPE2  = 'ENERG_HI'
TFORM2  = '15E     '
TUNIT2  = 'TeV     '
TTYPE3  = 'THETA_LO'
TFORM3  = '6E      '
TUNIT3  = 'deg     '
TTYPE4  = 'THETA_HI'
TFORM4  = '6E      '
TUNIT4  = 'deg     '
TTYPE5  = 'GAMMA   '
TFORM5  = '90E     '
TTYPE6  = 'SIGMA   '
TFORM6  = '90E     '
TUNIT6  = 'deg     '
EXTNAME = 'POINT SPREAD FUNC
TDIM5   = '(15,6)  '
TDIM6   = '(15,6)  '
```

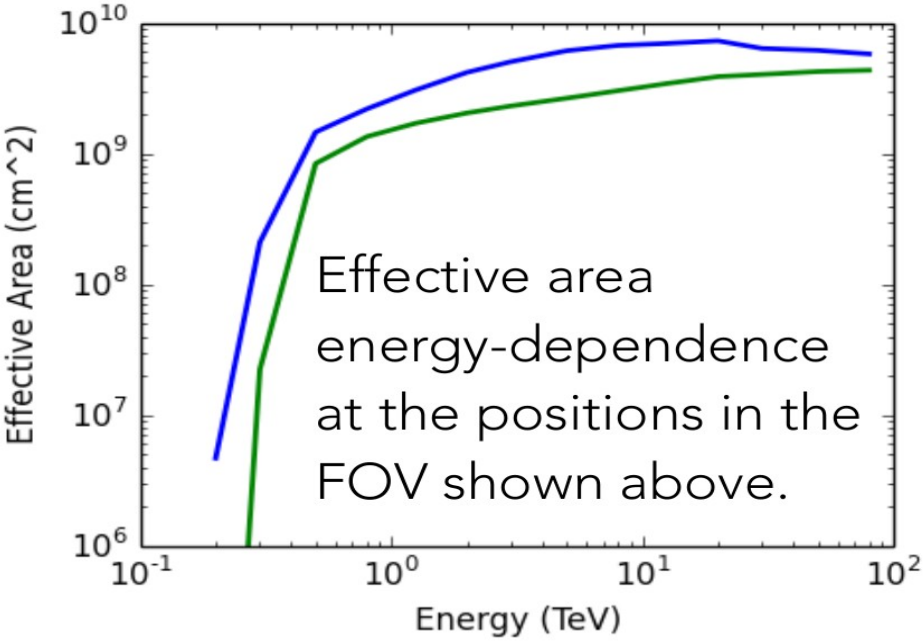
- Background models

  → *P. Eger: 3D cube Cherenkov telescope data analysis*

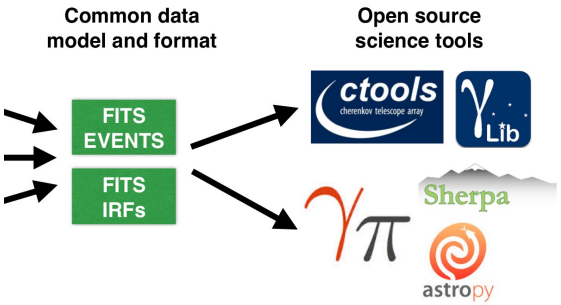
Conversion to OGIP format

- For region based analysis need data in OGIP format
- ARF (effective area), RMF (energy dispersion)
  → *R. Terrier: Classical Cherenkov telescope data analysis*
- Slice out from effective area and energy dispersion table





Open source tools

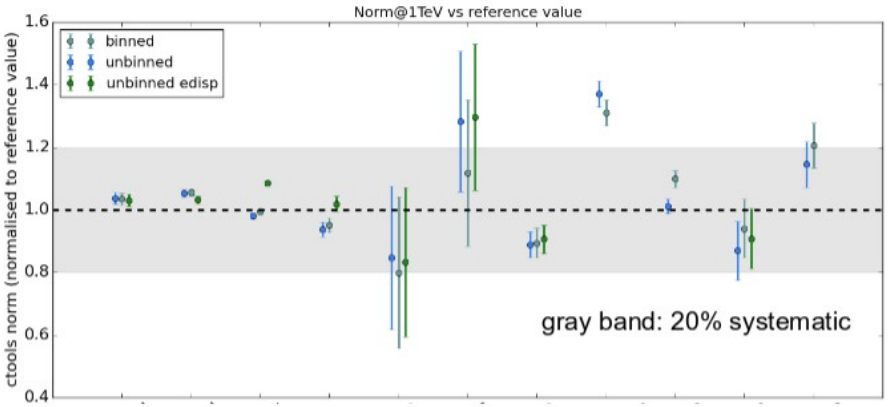


→ *N. Kelley-Hoskins: VERITAS data analyses - Progress with Gammalib / ctools*

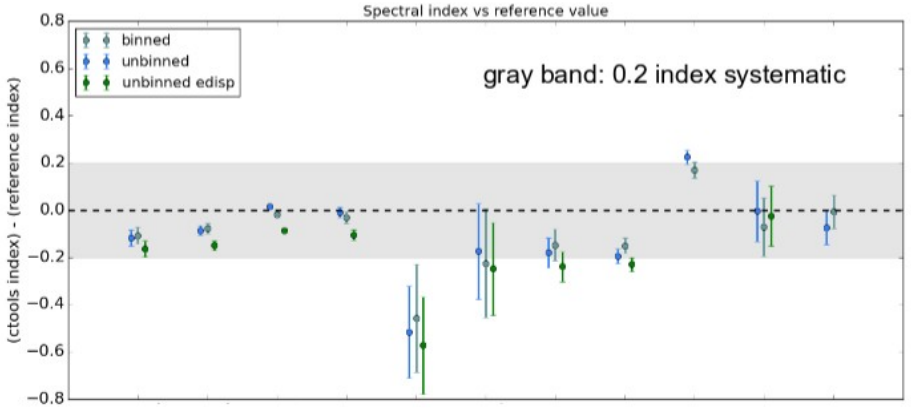
→ *A. Donath: Astropy, Sherpa, Gammapy*

1D Spectra		✓
2D Morphology		✓
3D Cube	✓	
Unbinned	✓	✗
Binned	✓	✓

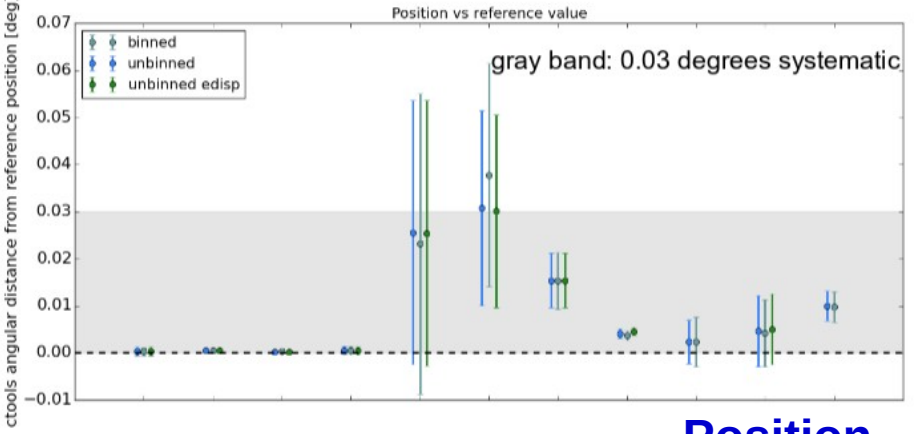
Flux Normalization



Spectral index



- Reference analysis for 10 sources provided by dedicated task group
- Deviations not fully understood

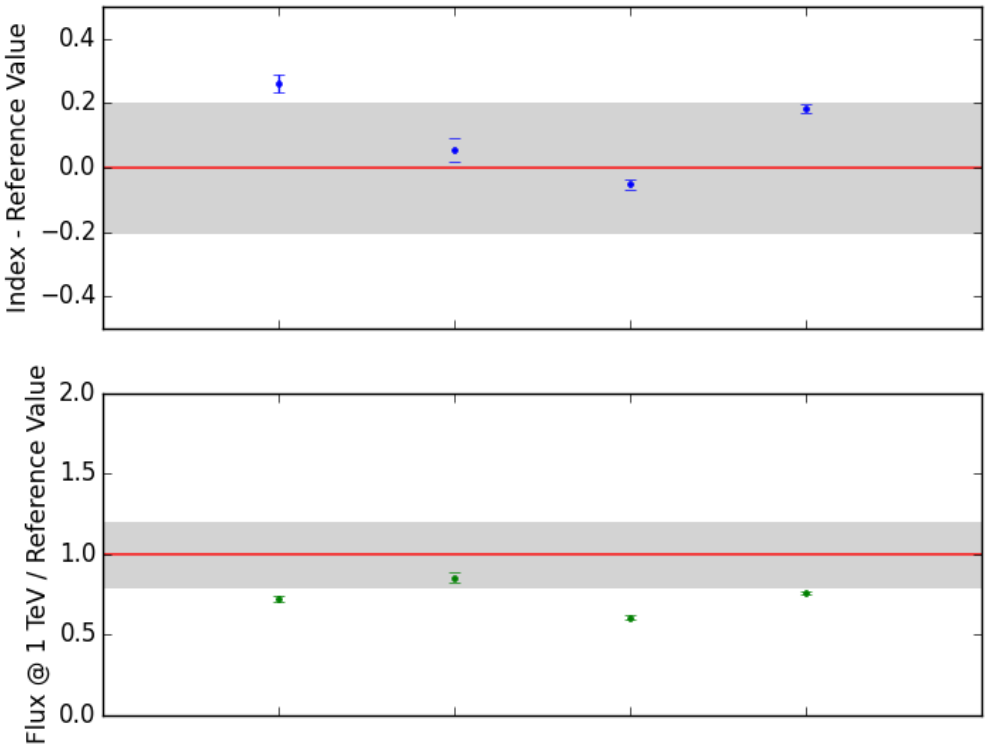


Position

Task on-going

- Same X-check source list as for ctools
- Only spectral analysis so far

Spectral index

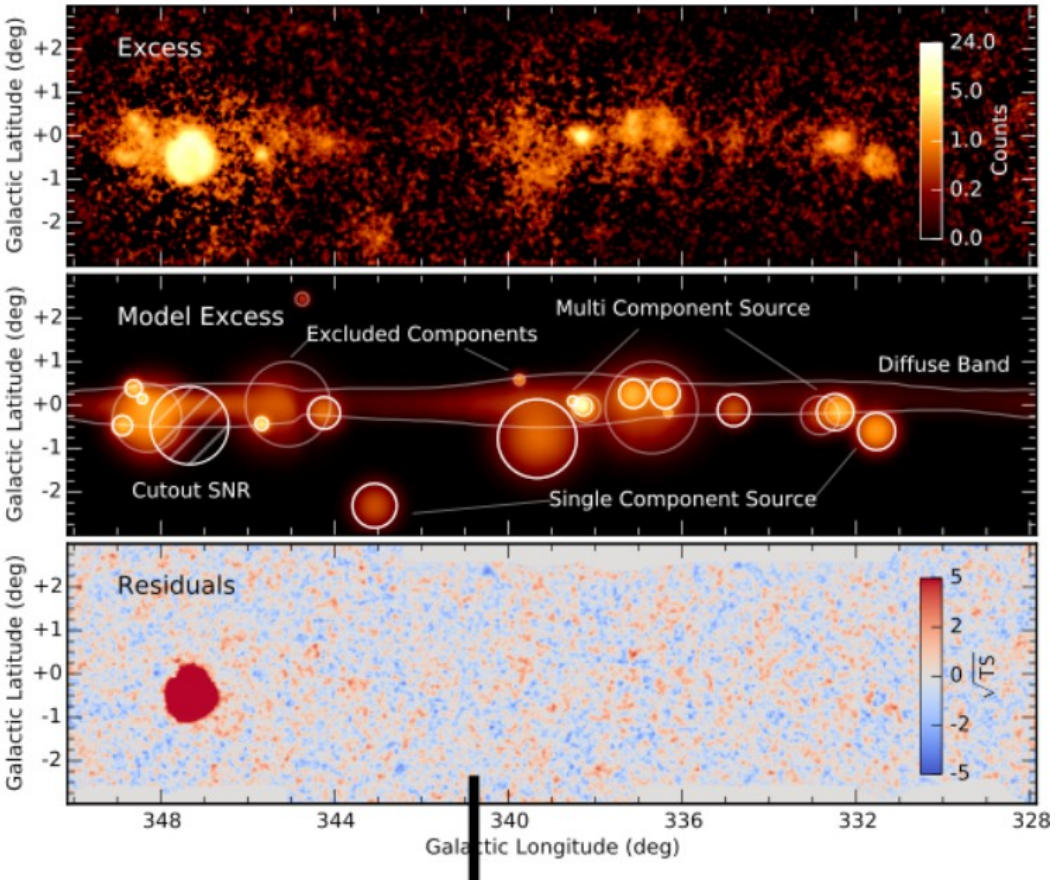


Flux Normalization

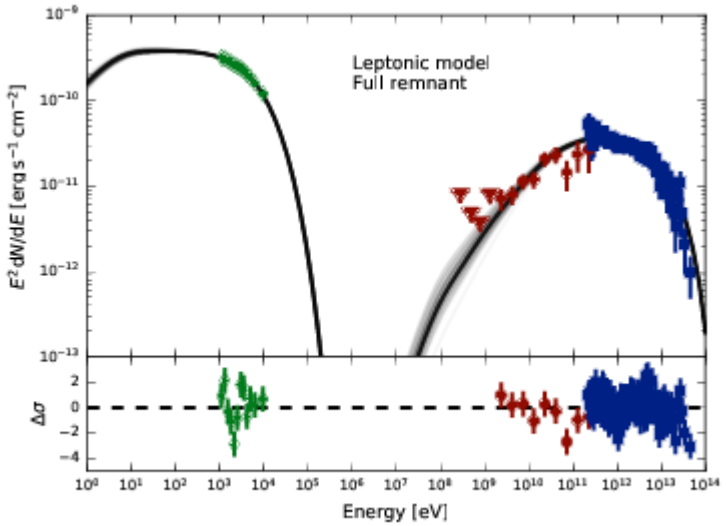
Task just started

Use of open source tools in H.E.S.S. publications

- Open source tools not really used in publications
- Few examples where a specific task was performed



HGPS morphology fitting



RXJ 1713 SED fitting

Conclusion

- H.E.S.S. has exported high-level data and IRFs to FITS. First analyses with open-source tools ongoing.
- Need CTA data format specifications
- Need better science tools
- Let's do it!