IRF concept and implementation status in the framework of the ASTRI MINI-ARRAY pipelines

I. Donnarumma, S. Lombardi
on behalf of the Rome ASTRI Team

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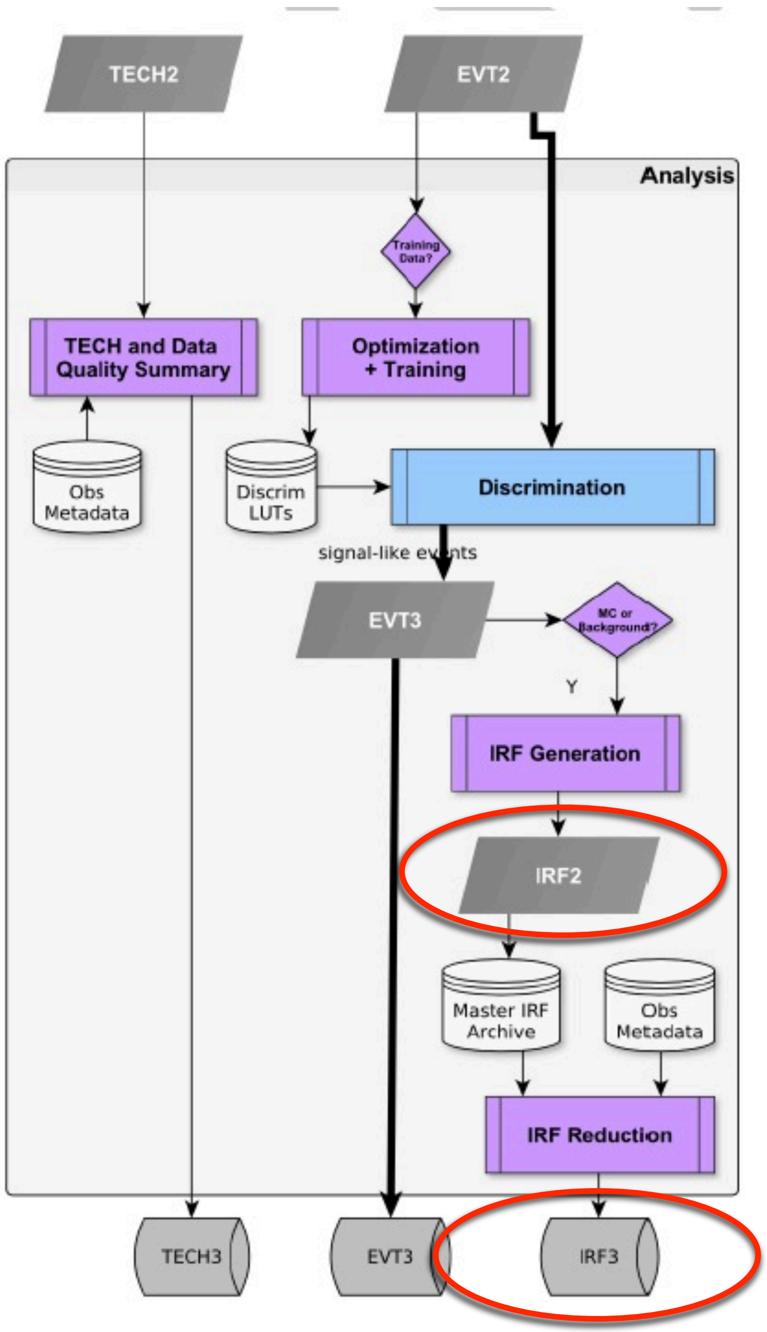
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

cta
cherenkov telescope array

IRF calculation layout



K. Kosack, DATA-PIPE-SRD, "Pipelines Software Requirements Document", v.0.0.1, September 15, 2014

- **Main Requirements**:
1. DL3 formats compliant with ctools
2. need to have a CALDB of pre-computed MC-based IRF2

- **IRF2** calculations in "fine-bins" of:
  - Energy (default: 150 bins, 5 GeV – 500 TeV)
  - cos(Zenith) (default: 100 bins, 0 – 1)
  - Azimuth (default: 36 bins, 0 deg – 360 deg)
  - Off-Axis (default: 50 bins, 0 deg – 5 deg)

- IRF2 + EVT2 ➔ **IRF3** (+ EVT3) with proper re-binning (user-defined "coarse-bins") and weights (real data Alt-Az distribution, supposed spectral slope,…)

- The IRF3 generation is univocally associated to a given set of real data (EVT2). IRF3 and EVT3 are then provided to ctools/science-tools user (on run-by-run or observation block bases) for scientific analysis

IRF2 dependencies

"Explicit" dependences

- True Energy / Estimated Energy
- Zenith
- Azimuth
- Source Position in the FoV (off-axis / DetX:DetY)

Note:
One IRF2 file for each combination of "implicit" dependences

"Implicit" dependences

- Array Configuration
  (full-array pointing, divergent pointing, sub-array pointing, ...)
- NSB level
  (dark, moon, ...)
- Atmosphere / Weather
  (Winter, Summer, … / A grade, B grade, ...)
- HW setting
  (default-settings, special-trigger, ...)
- Particle target
  (gamma, electrons, protons, …)
- Event Classes (based on gamma efficiency, …)
- Analysis methods (Hillas, template, …)

IRF2

- ☑ **Effective Area**
- ☑ **Point Spread Function**
- ☑ **Migration Matrix**
- ☑ **Background**

IRF2 generation inputs:
✧MC2 (gamma, hadrons, ...)
✧EVT2 background (optional)

All of them are defined in a 4D space: energy, off-axis angle, zenith, azimuth

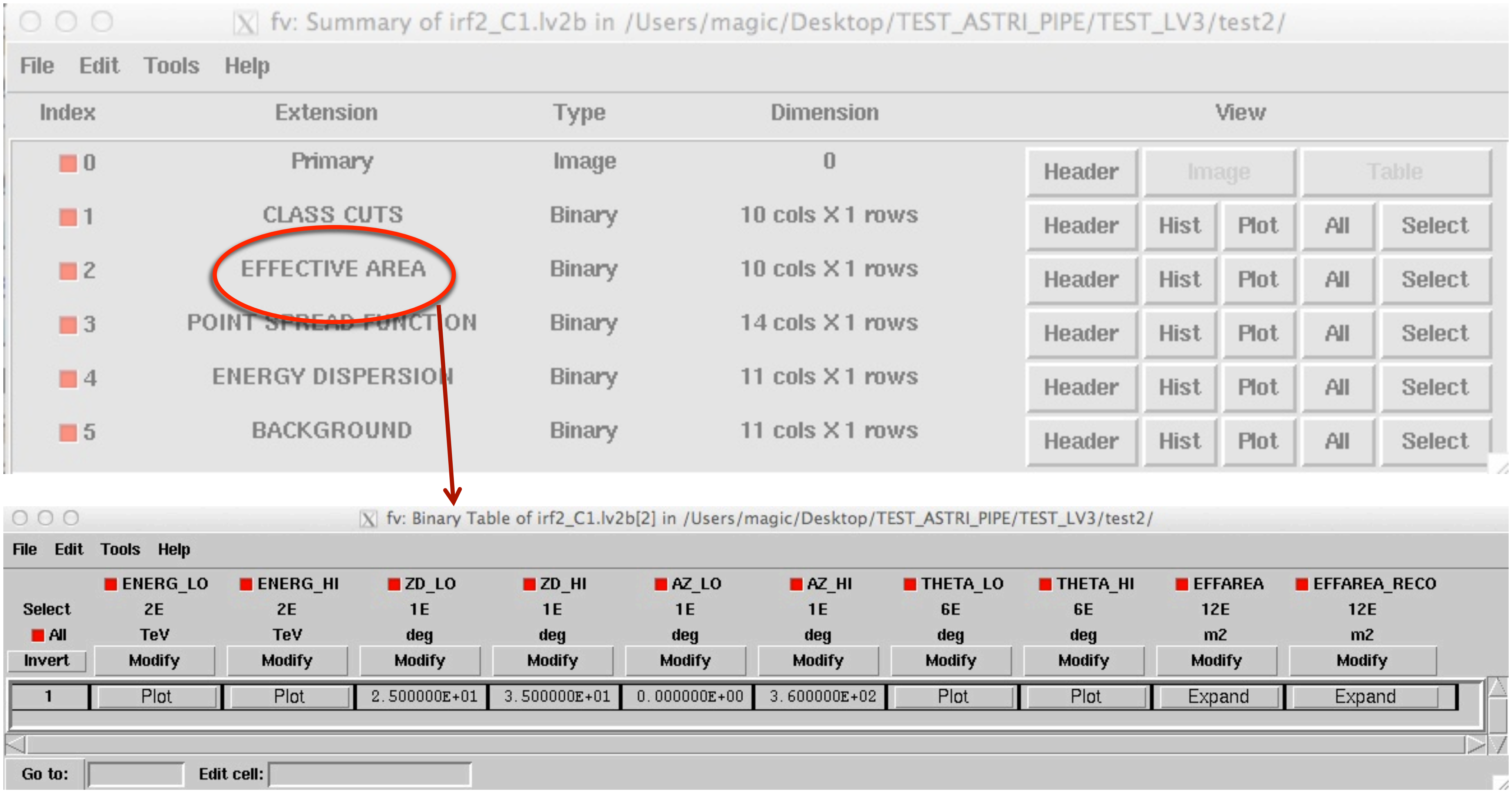
IRF2: ctools-like format

fv: Summary of irf2_C1.lv2b in /Users/magic/Desktop/TEST_ASTRI_PIPE/TEST_LV3/test2/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	CLASS CUTS	Binary	10 cols X 1 rows	Header Hist Plot All Select
2	EFFECTIVE AREA	Binary	10 cols X 1 rows	Header Hist Plot All Select
3	POINT SPREAD FUNCTION	Binary	14 cols X 1 rows	Header Hist Plot All Select
4	ENERGY DISPERSION	Binary	11 cols X 1 rows	Header Hist Plot All Select
5	BACKGROUND	Binary	11 cols X 1 rows	Header Hist Plot All Select

IRF2: ctools-like format



IRF2: ctools-like format

fv: Summary of irf2_C1.lv2b in /Users/magic/Desktop/TEST_ASTRI_PIPE/TEST_LV3/test2/

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Index	Extension	Type	Dimension	View				
0	Primary	Image	0	Header	Image		Table	
1	CLASS CUTS	Binary	10 cols X 1 rows	Header	Hist	Plot	All	Select
2	EFFECTIVE AREA	Binary	10 cols X 1 rows	Header	Hist	Plot	All	Select
3	POINT SPREAD FUNCTION	Binary	14 cols X 1 rows	Header	Hist	Plot	All	Select
4	ENERGY DISPERSION	Binary	11 cols X 1 rows	Header	Hist	Plot	All	Select
5	BACKGROUND	Binary	11 cols X 1 rows	Header	Hist	Plot	All	Select

fv: Binary Table of irf2_C1.lv2b[5] in /Users/magic/Desktop/TEST_ASTRI_PIPE/TEST_LV3/test2/

File Edit Tools Help

	DETX_LO	DETX_HI	DETY_LO	DETY_HI	ENERG_LO	ENERG_HI	ZD_LO	ZD_HI	AZ_LO	AZ_HI	BGD
Select	8E	8E	8E	8E	2E	2E	1E	1E	1E	1E	128E
All	deg	deg	deg	deg	TeV	TeV	deg	deg	deg	deg	1/s/MeV/sr
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	Plot	Plot	Plot	Plot	Plot	Plot	2.500000E+01	3.500000E+01	0.000000E+00	3.600000E+02	Expand

Go to: Edit cell:

IRF2: background calculation

The Background calculation

- Effective Area
- Point Spread Function
- Migration Matrix
- **Background**

At IRF2 level, the background can be calculated from *i)* MC2 (hadrons) *ii)* real EVT2 (background). The background may also not be computed and calculated at EVT3/IRF3 stage from EVT2 (under investigation, e.g. in case of wobble mode observations)

IRF3

IRF3 generation inputs:
✧IRF2
✧EVT2
✧TECH/GTI

☑ Effective Area

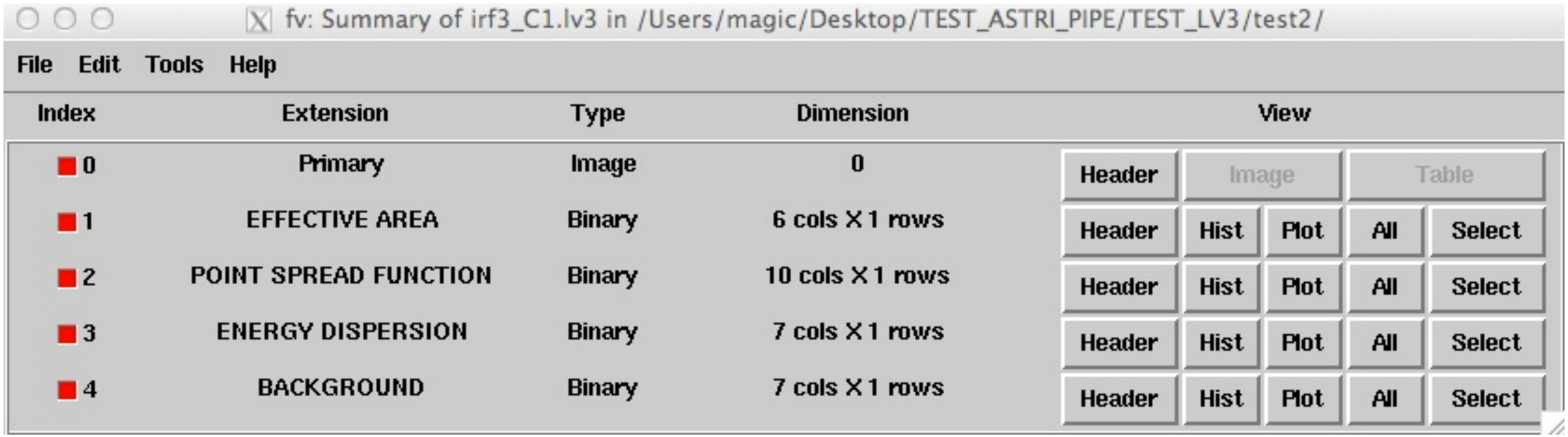
☑ Point Spread Function

☑ Migration Matrix

☑ Background

All of them are defined in a **2D space**: energy, off-axis angle

IRF3: ctools format


fv: Summary of irf3_C1.lv3 in /Users/magic/Desktop/TEST_ASTRI_PIPE/TEST_LV3/test2/

File Edit Tools Help

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2	POINT SPREAD FUNCTION	Binary	10 cols X 1 rows	Header Hist Plot All Select
3	ENERGY DISPERSION	Binary	7 cols X 1 rows	Header Hist Plot All Select
4	BACKGROUND	Binary	7 cols X 1 rows	Header Hist Plot All Select

(EVT3 also have ctools format)

IRF2 → IRF3

The input files to the IRF3 generation are:

•**Evt2 file (on source)**

•**IRF2** fits file for a given class cut and "implicit" dependences

•**Optional**: an **Evt2 file** for the background only (e.g. off mode) if background is not included in the IRF2 file; if the background is acquired in wobble mode, the background may be derived from the same evt2 file

•**metadata** with the weights for the rebinning of the key quantities, PSF, Aeff,.....accounting for the ZD, AZ variation along the observation. It is therefore connected to the evt2 file.

•a **GTI file** related (derived from TECH0+) to evt2 file

IRF2 → IRF3

The 2D quantities (PSF, Aeff, Dispersion matrix) will be obtained by applying proper weights to account for the Alt-Az variation in the eventlist:

- define the **metadata file with two variables**, that are the weights for the IRF2 quantities;

- **calculate the time spent at each bin of (ZD, AZ);**

- calculate the weighted average of the effective area by using this time only as a weight;

- calculate the weighted average of the PSF, by using the "exposure" as a weight, where exposure is defined by Aeff x time;

- calculate the weighted average of the Dispersion matrix by using the "time" as a weight.

- calculate the weighted average of **BACKGROUND** (if real data BKG not available**)**, by using the "exposure" as a weight.

IRF2 → IRF3

Main steps:

Reweighting of IRF2 with proper Alt-Az weights taken from EVT2

Perform the rebinning in energy and off-axis angle in order to produce IRF3 with coarser energy – angle bins (fine-coarse binning definition depends on MC statistics)

The IRF2 → IRF3 is a flexible approach: this can be properly adapted to meet more general CTA requirements

STATUS

- IRF2 designed and implemented (IRF2→CALDB)
- IRF2, Evt2 → IRF3, Evt3 implemented
- On-going test on MC-bases
- Soon, a dedicated "data challenge" in order to simulate "real" Evt2 data and perform an end-to-end test DL0→DL4
- Extensively tests with ctools on-going

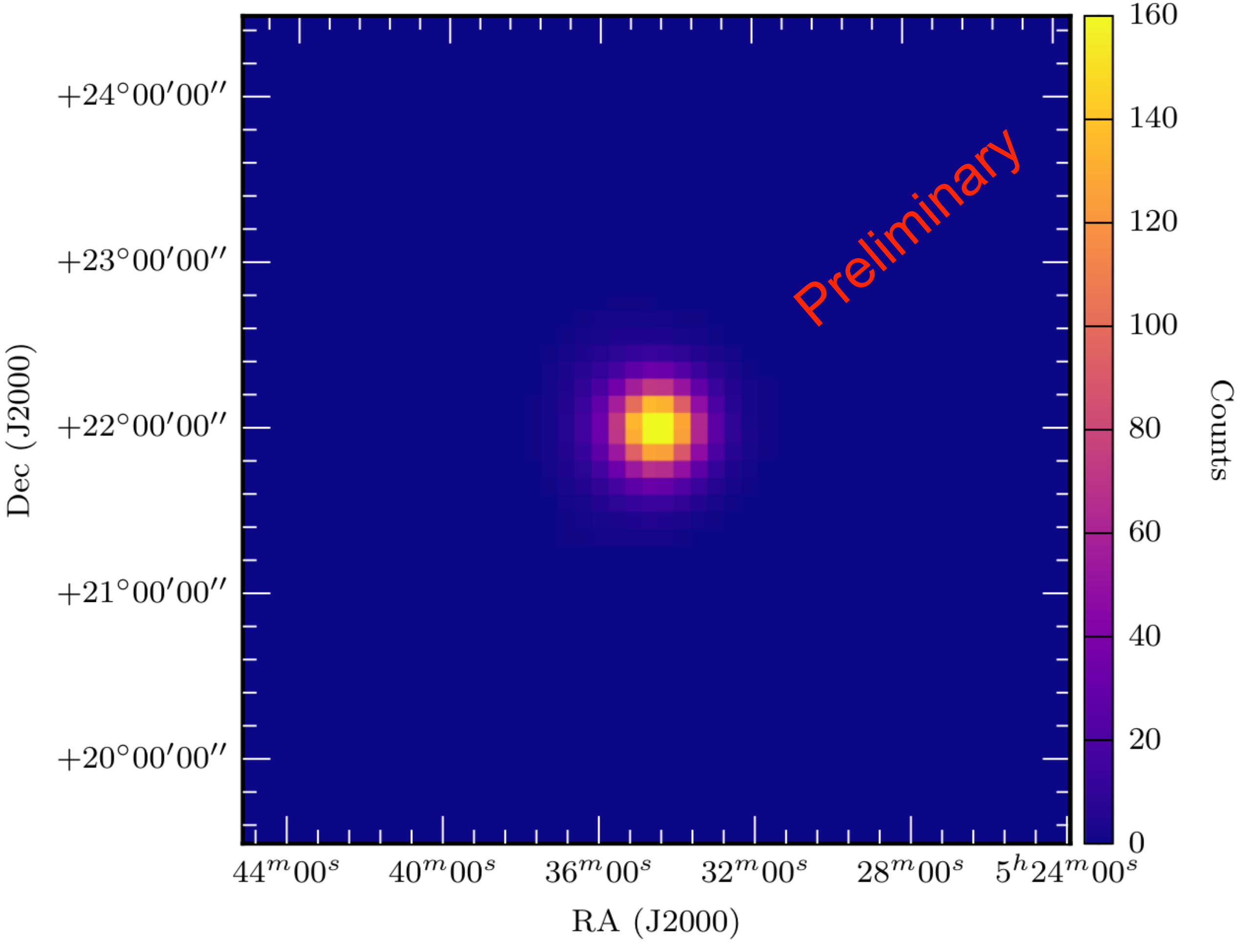
First ctools tests with IRF3

- **Simulate a Crab-like spectrum with the IRF3 (ASTRI mini-array ~250 m) produced by ASTRIANA**

1. **Log Parabola**
2. **Power-law**

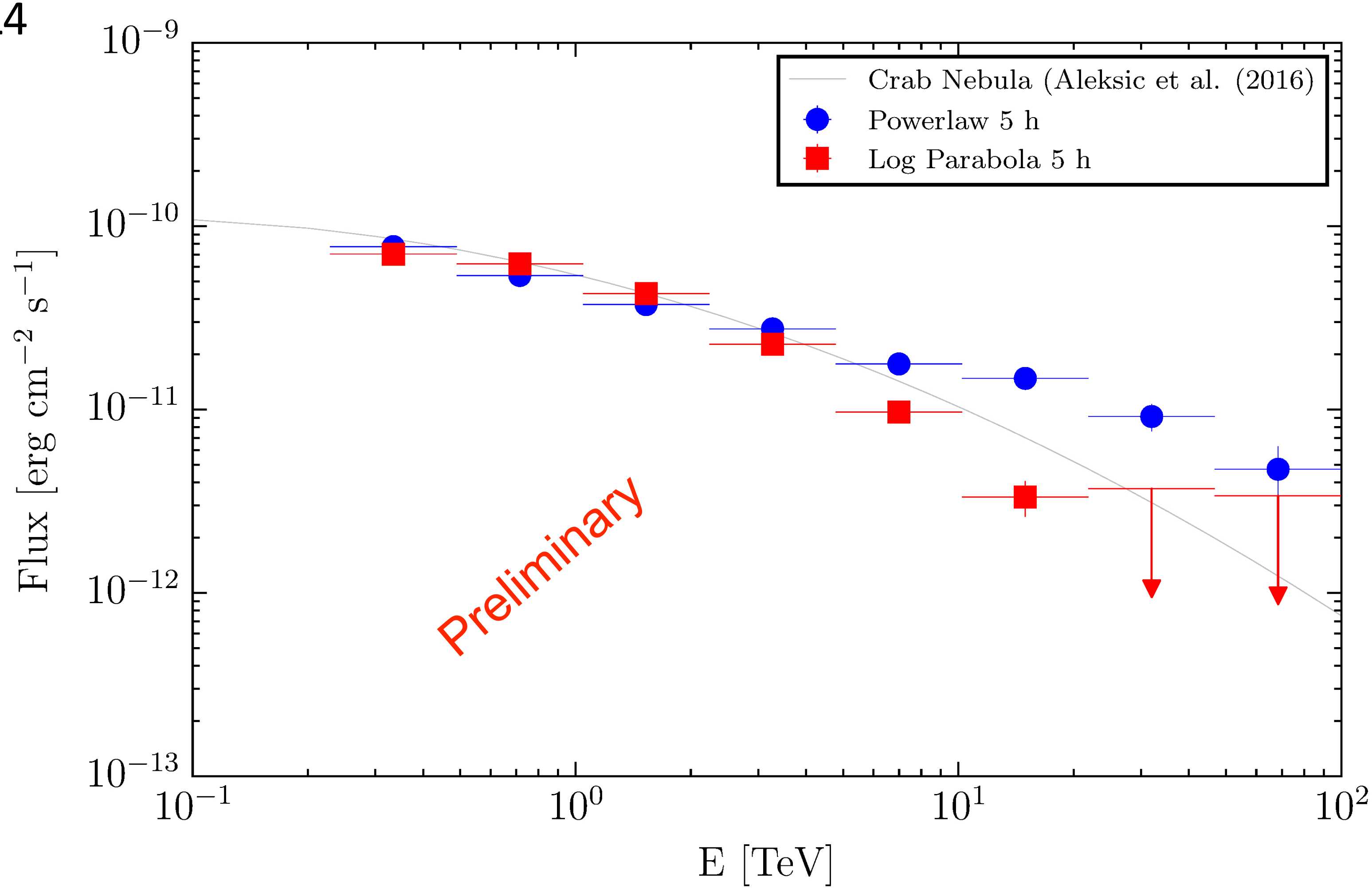
IRF 3 Testing: ctobssim + ASTRI IRF3

Map:



IRF 3 Testing: ctobssim + ASTRI IRF3

DL0➔DL4



Backup slides

ASTRI SST-2M mini-array: led by the Italian National Institute for Astrophysics in collaboration with:

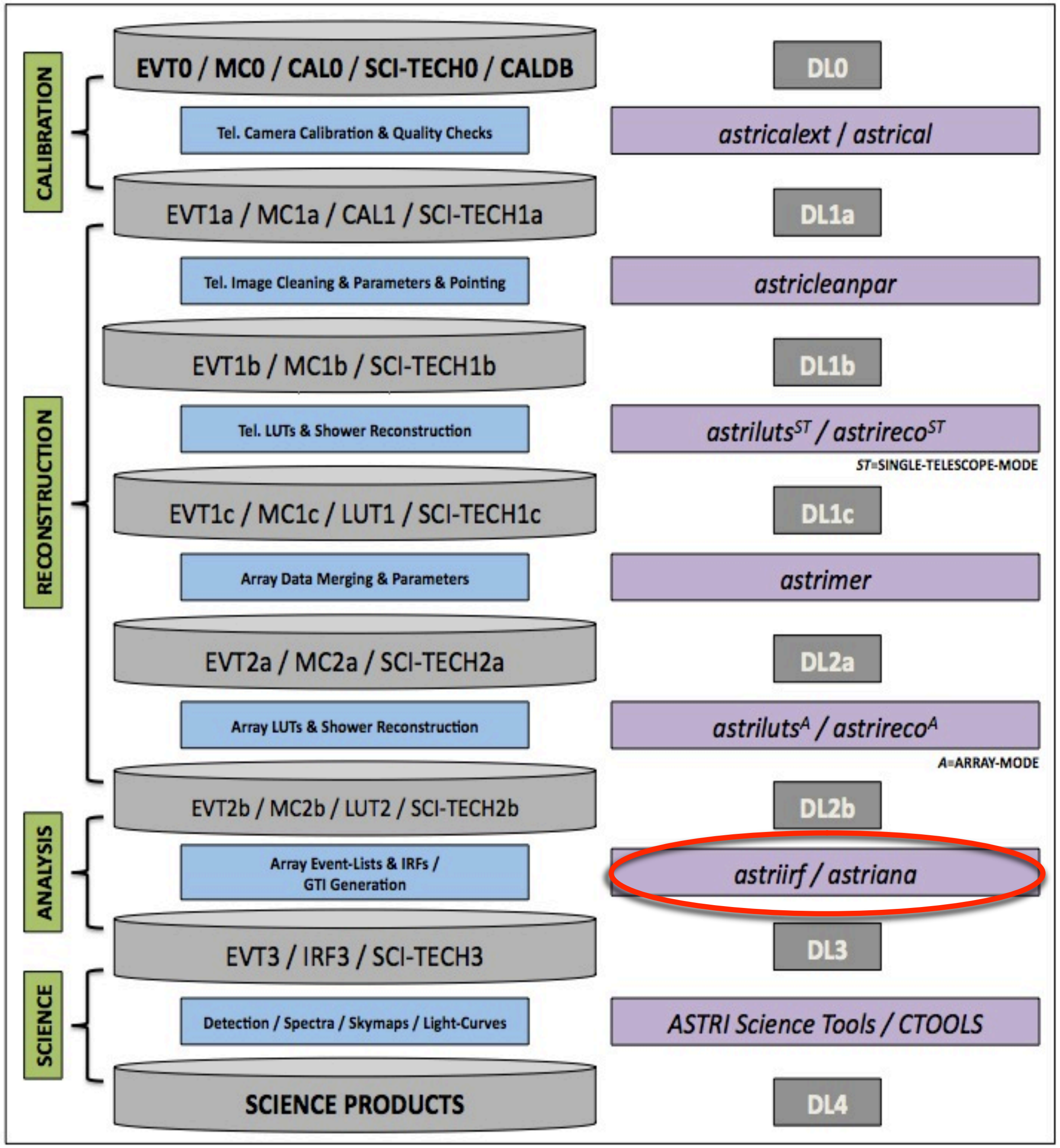
Universidade de São Paulo & FAPESP, Brazil

North-West University, South Africa

cta cherenkov telescope array

Proposed to be installed at the final southern CTA site as one of the CTA precursors (implementation in 2017)

Lombardi, Antonelli, Bastieri, Madonna, Mastropietro et al., in prep.



The ASTRI SST-2M prototype and mini-array Data Analysis:

- can handle *both prototype and mini-array data*
- *follows the general CTA design* and data model scheme defined in CTA Data Management
- is developed for *on-line/on-site/off-site* scientific analysis
- manages *FITS data* from DL0 to DL4 (CFITSIO/CCFITS libraries)
- is written in *C++/Python/CUDA*
- can run on *x86 / ARM CPUs* & *NVIDIA GPUs*
- is developed in *independent software modules* linked by pipelines written in *Python*
- makes use of *ad hoc and official CTA Science Tools*

The background from MC

The background has to be expressed in counts/s/MeV/sr (CTOOLS), while the counts produced with the Monte Carlo simulations are not, so we have to convert those counts to the proper units

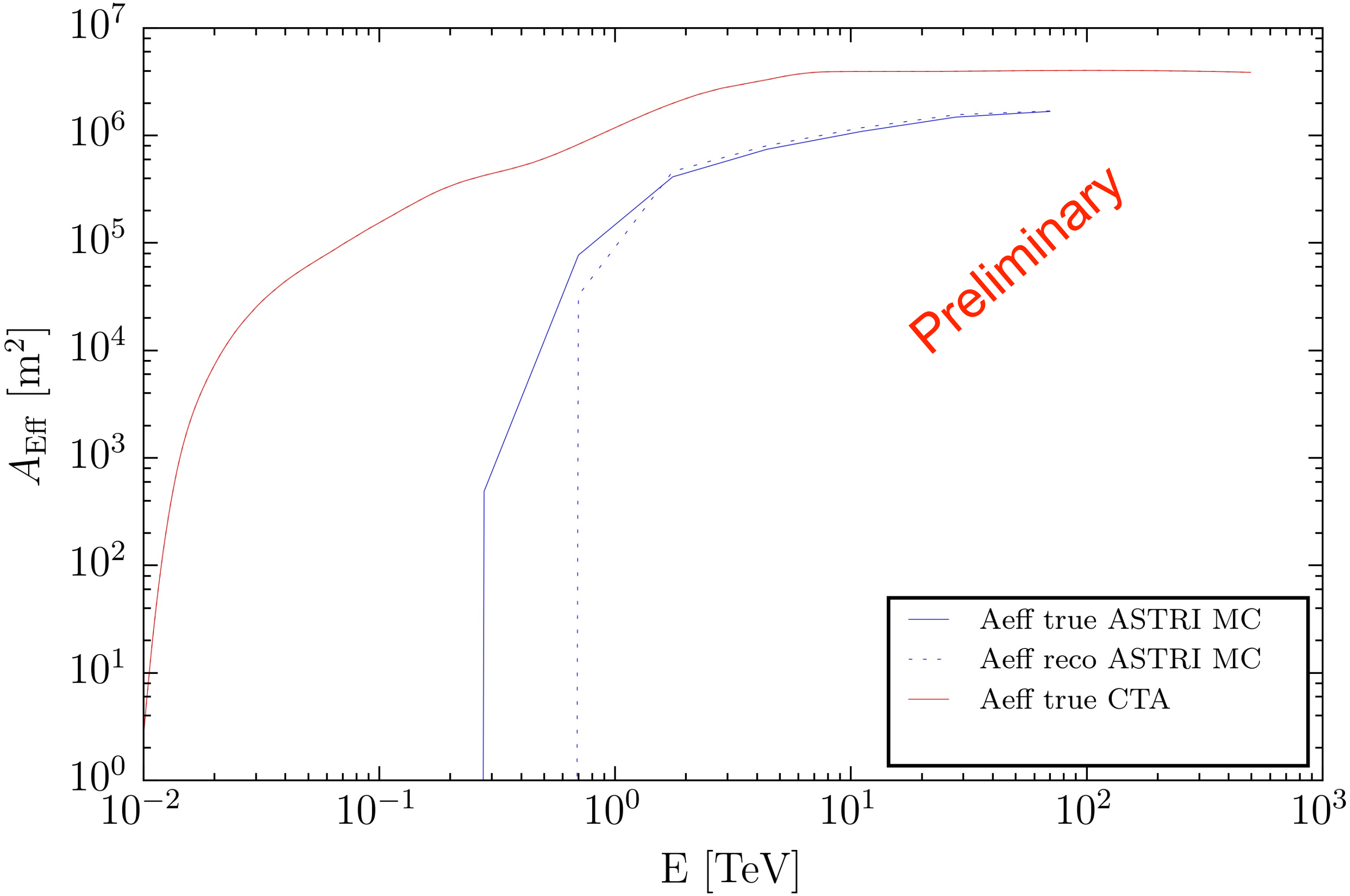
Starting from the key quantities used for the simulation of MC proton events

- power-law spectral slope, a_{MC}
- Emin – Emax
- Viewcone
- ImpactMax

and assuming that the MC differential flux is given by $dN/dE = N_{MC} \times (E/E_{MC})^{aMC}$, we apply a **proper spectral correction** to account for the real proton spectrum encoded in the parameter file (e.g. BESS Proton spectrum ApJ 545, 1135 (2000)) with a differential flux $dN/dE = N_{RD} \times (E/E_{RD})^{aRD}$ and then obtain the background rate in the expected units.

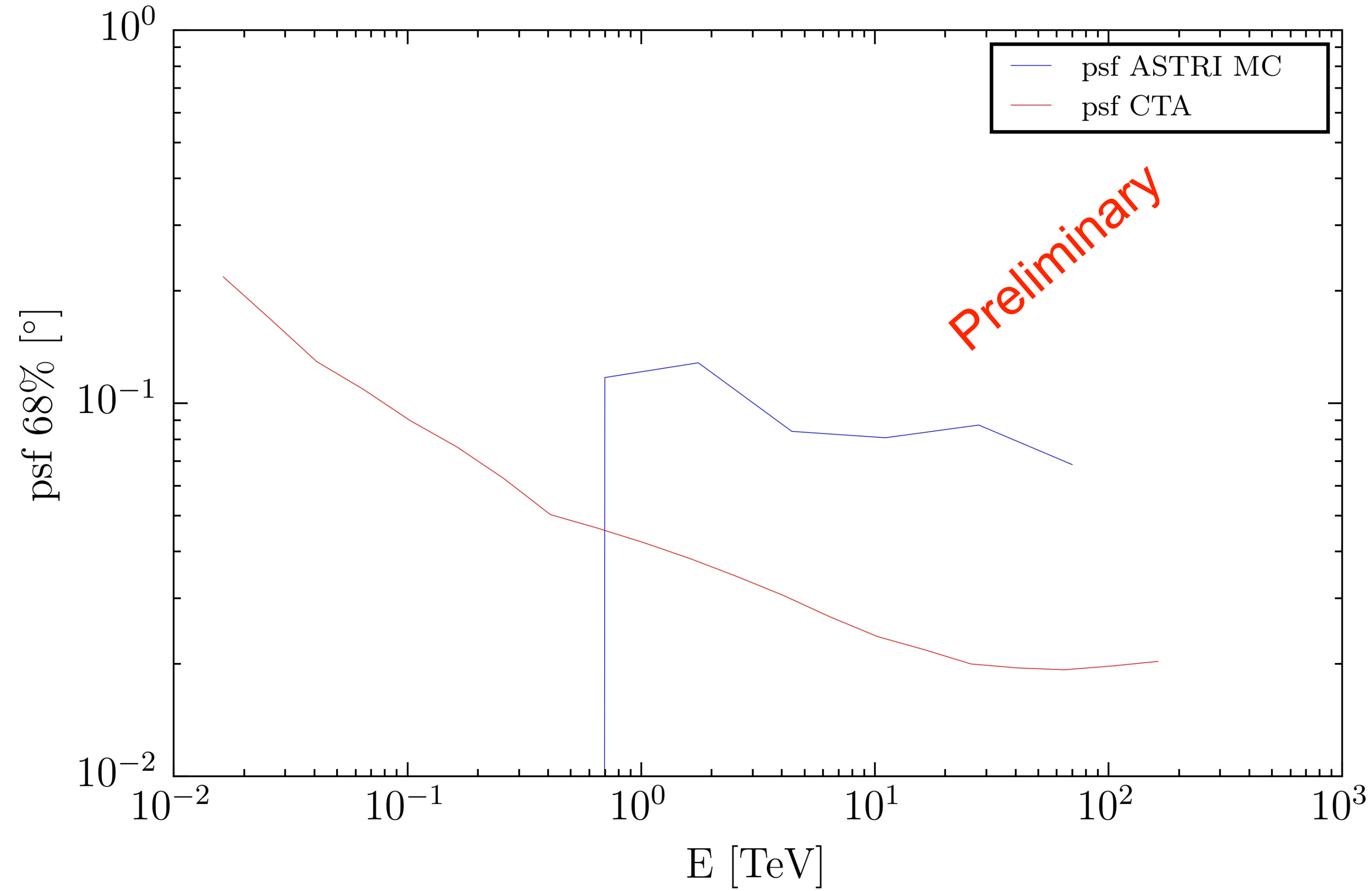
IRF3 Testing

Effective area:



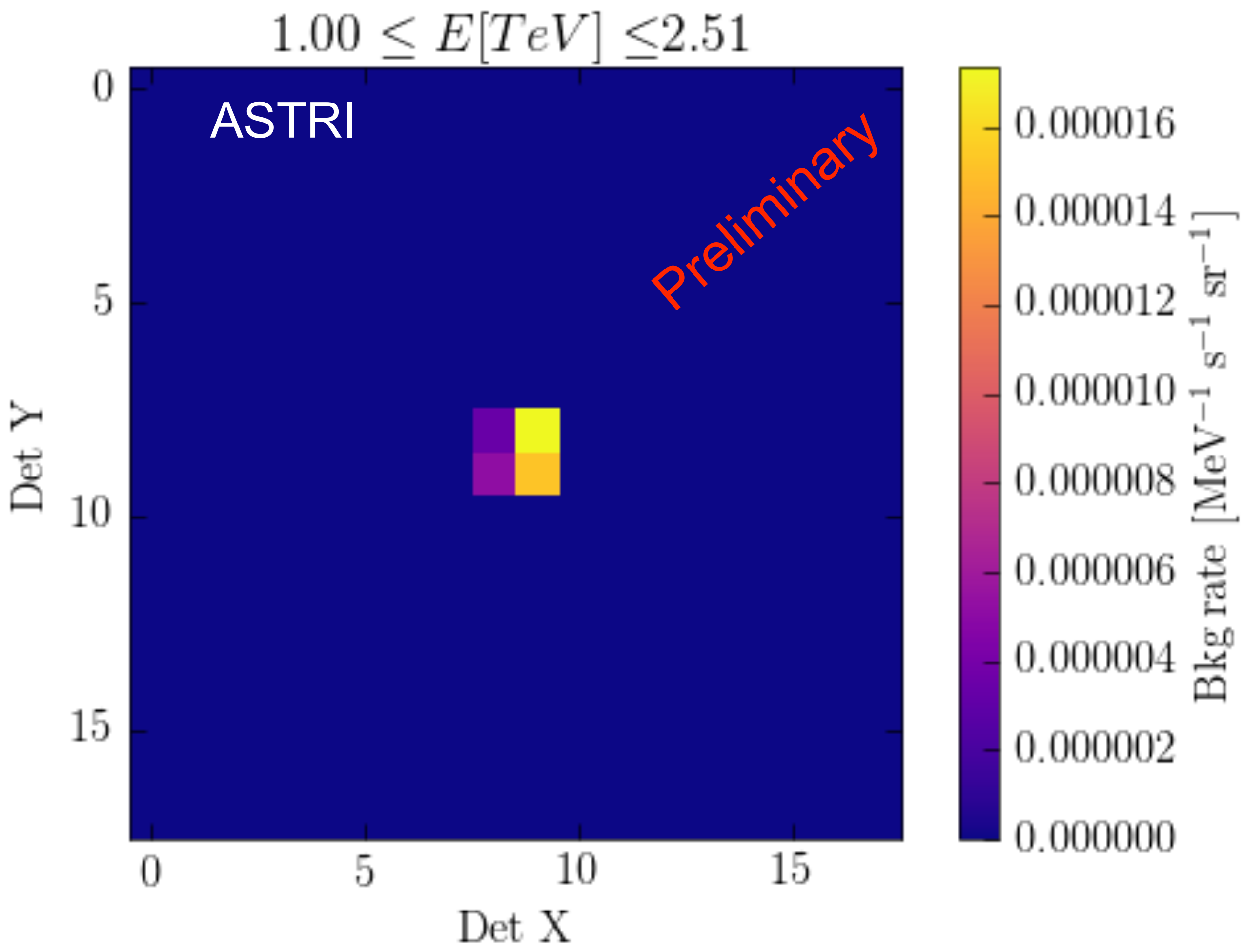
IRF3 Testing

Angular resolution:



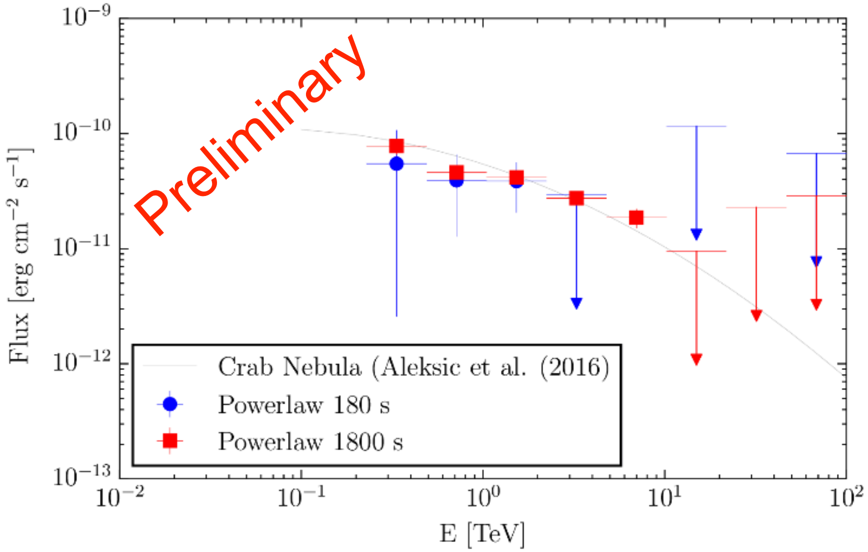
IRF3 Testing

Background:



IRF 3 Testing: ctobssim + ASTRI IRF3

- Crab spectrum
  - Powerlaw



  - Log Parabola