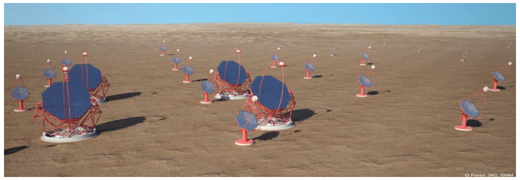


CTA Instrument Response Files

Journées CTA, Action Fédératrice CTA
October 2017, Meudon

B. Khélifi

Context and Scope

- IRFs
  - Mapping between the incoming photon flux and the detected events.
  - 'Detection' depends not only on the CTA hardware but also on the processing that calculates the event parameters from the observables and assigns 'probabilities' that an event is a photon.
- Scope
  - How are they produced?
  - How to use them?
  - Main characteristics

Their data format will not be detailed: see http://gamma-astro-data-formats.readthedocs.io/en/latest/index.html

It is a result of an international working group aiming to define standard key words for the HE experiments and for the VO access (IVOA). They might still evolved in the future (ASTERICS H2020 programme)

CTA IRFs

- Effective Area
  - Ground area × Probability that a γ-ray with a given set of input parameters is detected as an event with a set of observables
- Energy Dispersion
  - Ratio of the Reconstructed Energy to the True Energy for a γ-ray
- Point Spread Function (for γ-rays)
  - Angular distance between the Reconstructed Direction and the True Direction for a γ-ray

From Monte-Carlo Simulations

- Background model (for γ-like background evts)
  - Rate per solid angle of the Residual Background

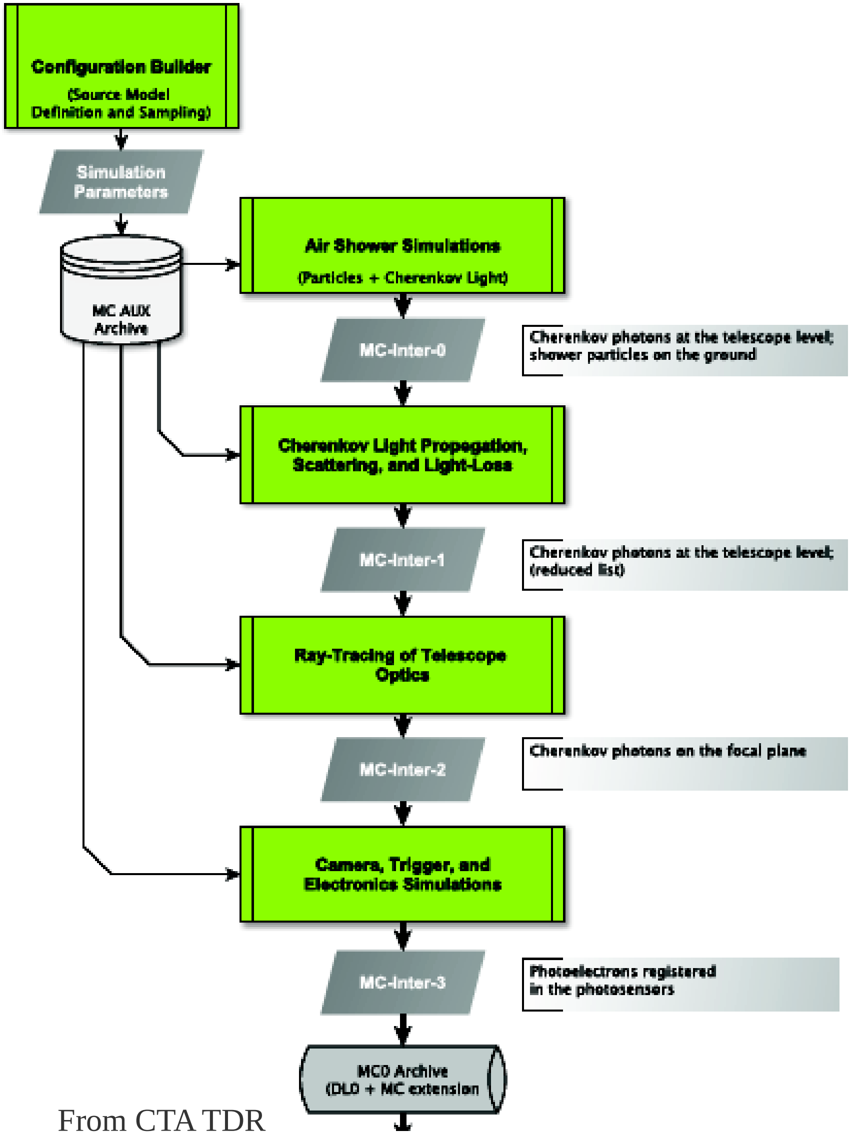
From Real Events

Production of the CTA IRFs

Monte Carlo Simulations

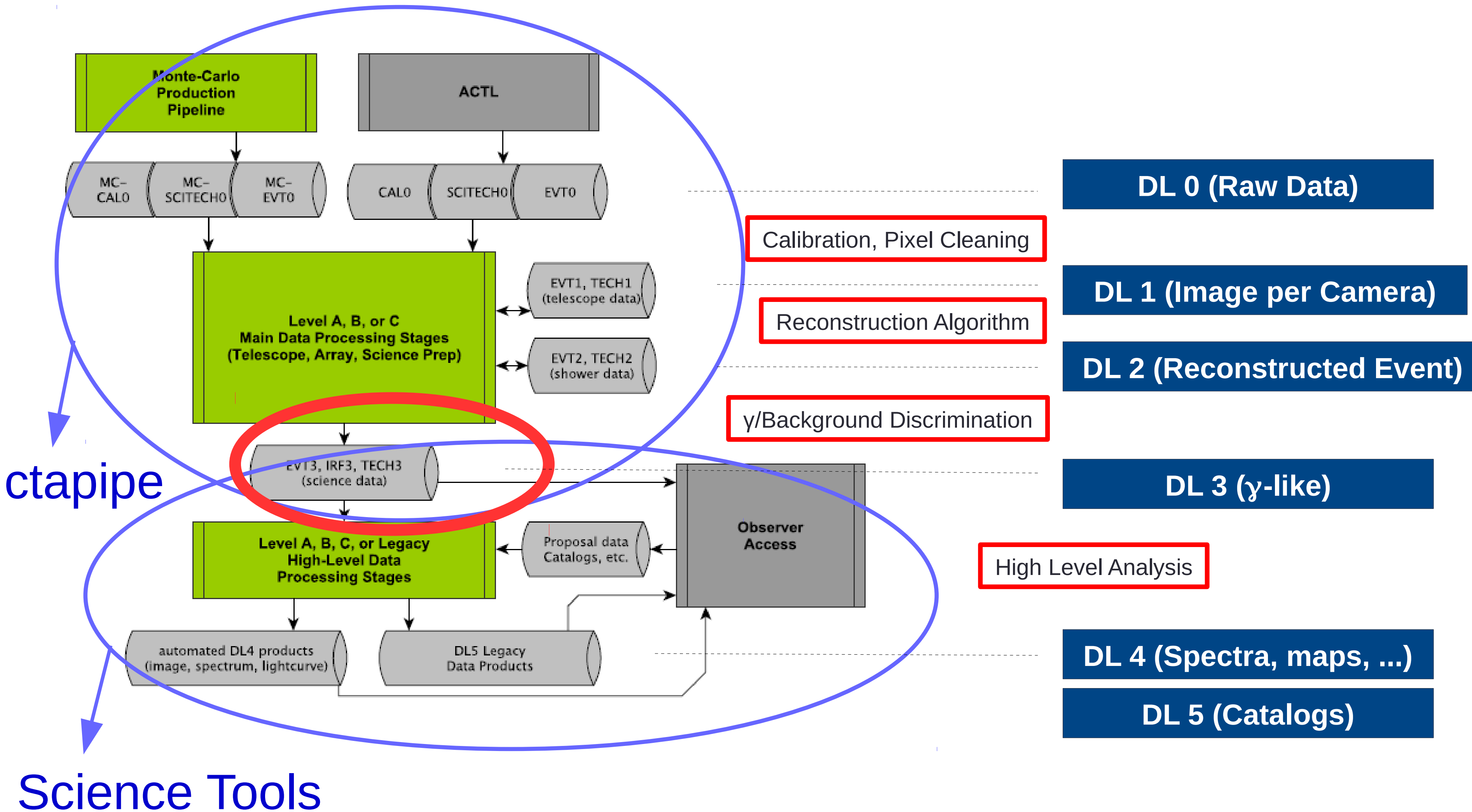
- Corsika: Atmospheric showers
  - Any particle type can be simulated
  - However, by experience since the 90's, it has been seen that these simulations of hadrons do not well reproduce data

    → **Only used for gammas**
- sim_telarray: proprietary code
  - It used a big configuration table containing the characteristics of almost all hardware pieces
  - Need to be adjusted during the commissioning phases



From CTA TDR

Data Processing



From CTA TDR

Scheme of IRFs Production

- First step: γ-rays Monte Carlo simulations
  - MC Raw Data
- Second step: Data Analysis Pipeline
  - Production of DL 3 events
  - Optimised Discrimination cuts are applied
  - From MC: Collection Area, Edisp, PSF
  - From real data with 'empty' field: Bkg Model
- Third step: Data Reduction and Storage
  - Reduction of the data in order to well characterise the arrays responses of γ-rays and γ-like background
  - In a format allowing the reduction of systematics of the High-Level Data Analysis (by the Science Tools)

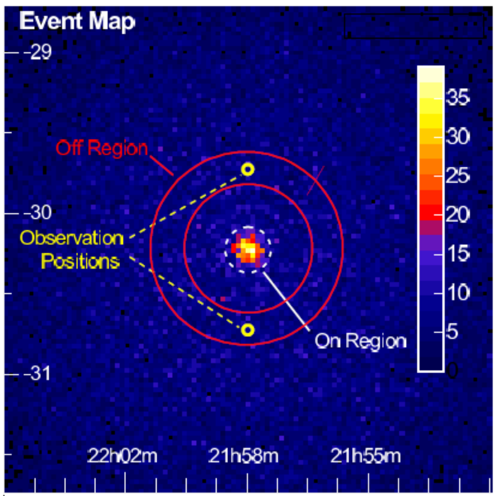
- Side Note: a set of IRFs is produced by a set of cuts!

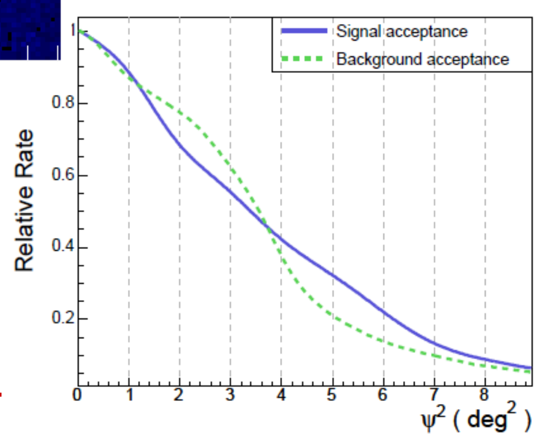
(Notion of EVENT_CLASS and EVENT_TYPE)

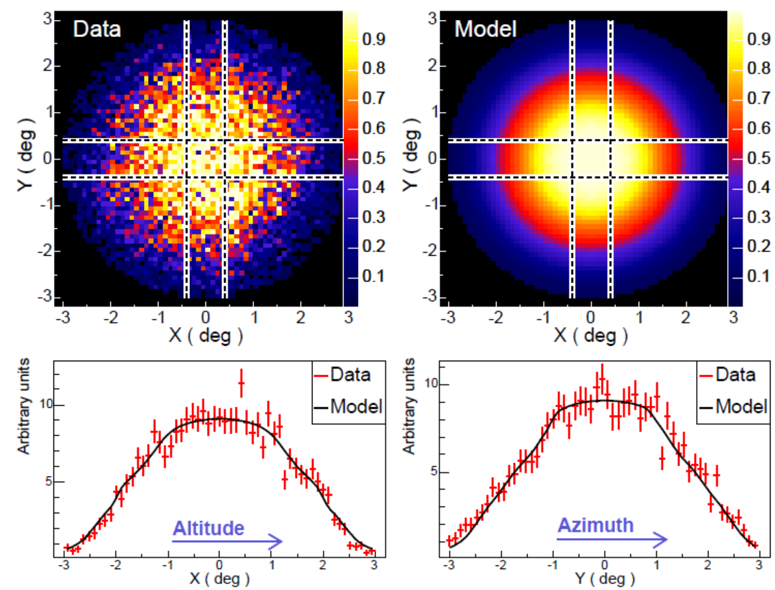
Use of the CTA IRFs

IRFs and High-Level Data Analysis

- Extraction of γ-ray maps: Bkg Model
  - One needs to 'remove' the residual background
  - Ring Background method
  - Background Model method





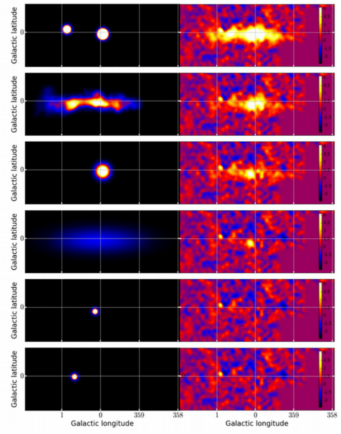


From Berge, Funk, Hinton 2006

IRFs and High-Level Data Analysis

Bkg Model
PSF

- Source Morphology
  - On γ-rays maps or counts maps: '2D analysis'
    → tutorial
  - For very large sources, one needs the Acceptance Maps on γ-rays (derived from the Collection Area)



From Jouvin 2017

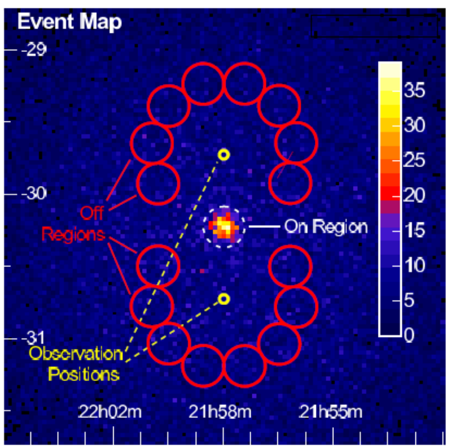
- Extraction of Flux maps
  - The γ-ray map is divided by the Exposure Map, ie Acceptance Map $\times$ Time
  - PS: one can use either the Collection Area in Reconstructed Energy or the Collection Area in True Energy convolved by the Energy Dispersion and an assumed Spectrum

Bkg Model
PSF
Collection Area

IRFs and High-Level Data Analysis

- Extraction of spectrum:
  - **Standard extraction**
    '1D spectrum' in a ON region

1) Bkg Estimation :
    Reflected Background Method



Collection Area
Edisp

2) Spectrum fit :
   Forward Folding Method using
   a (profile) likelihood fit

- **'3D Analysis' extraction**: very new
  Simultaneous fit of the
  morphology and the spectrum

Likelihood fit comparing the counts with the Bkg Model counts + the expected g-ray counts from a spatial and spectral model

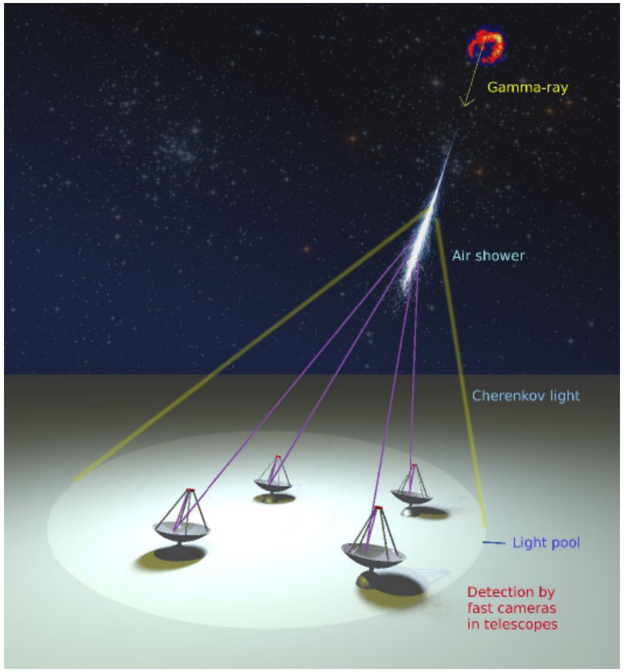
All IRFs

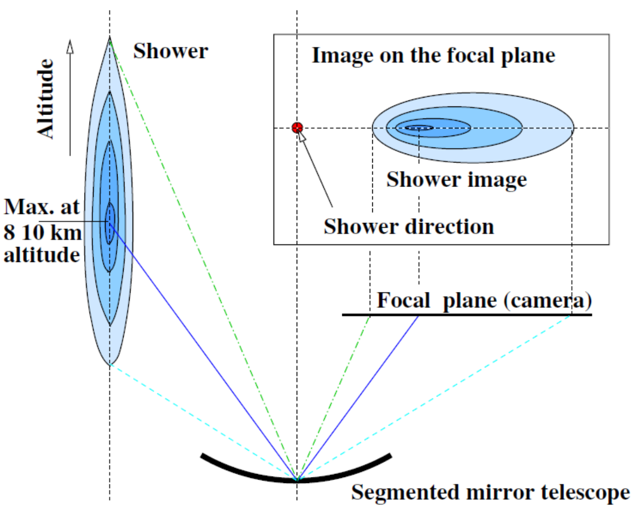
IRFs Use

- Accuracy
  - IRFs will be associated with observation for a Good Time of Interval, **GTI**
    - Using the same observational conditions than the ~28min runs
- Reduction of the systematic errors
  - The array configuration might be different to the nominal one: missing telescopes, missing pixels, ...
  - The atmosphere changes with time (Pressure profile, absorption profile)
- Foreseen strategy
  - **Run-wise simulations** with the measured atmosphere properties, the exact array configuration, and exact source trajectory on the sky
    - This would be used for γ-rays IRFs
  - Concerning the Background model, the plans are less clear and more studies are needed

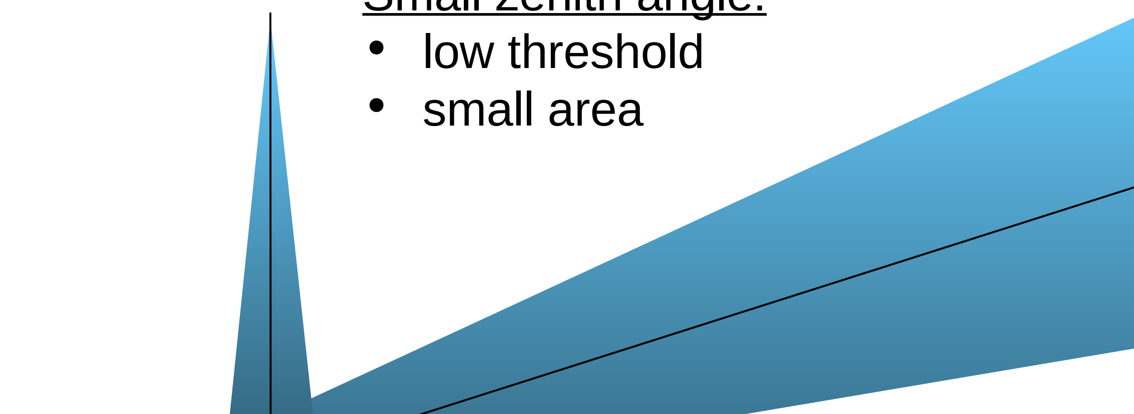
CTA IRFs Properties

Effective Area





- The collection area before the cuts is an effect of the:
  - Atmospheric showers
  - Cherenkov angle
  - Telescope separation
  - Camera Field of View



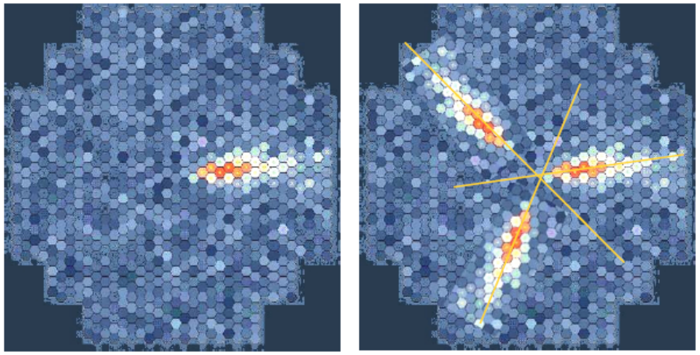
Small zenith angle:
- low threshold
- small area

Large zenith angl
- high threshold
- large area

Effective Area (2)

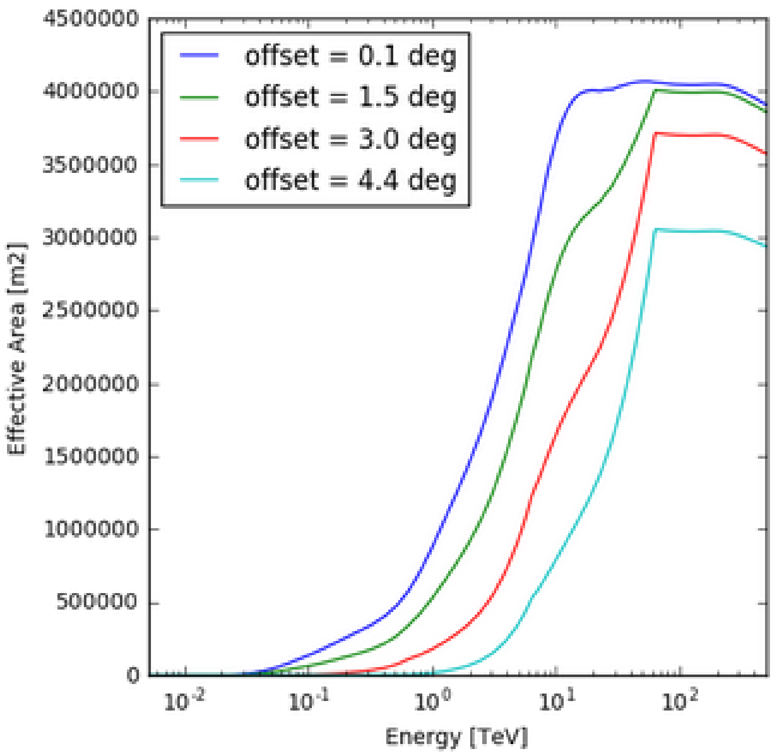
Dependency with the 'Offset':

- When an image is not more contained, loss of performances
- Large offset: high energy threshold and lower Collection Area



Single telescope event

3-telescope event
in common camera plane

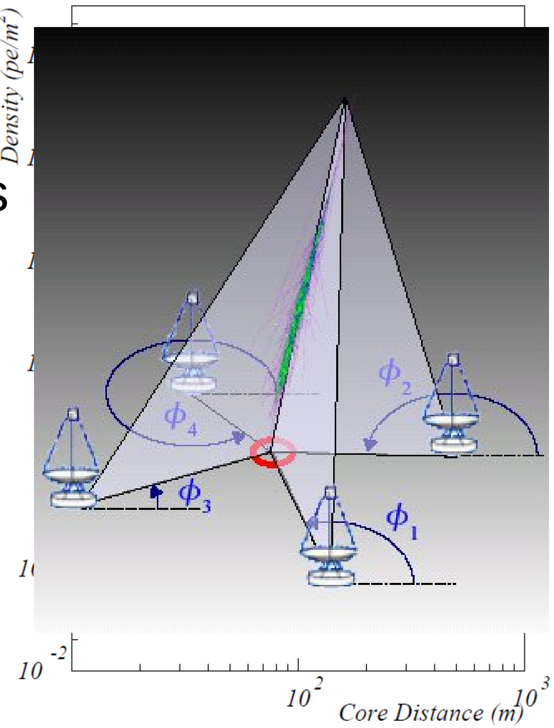


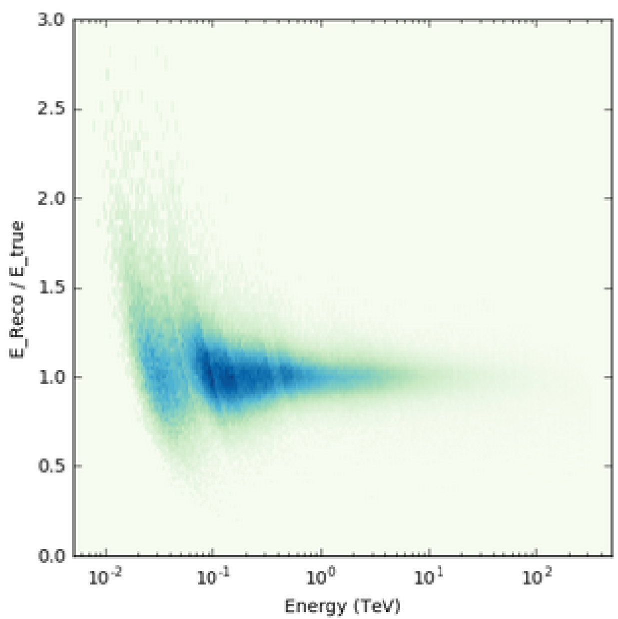
EffArea IRF dimension (per set of cuts):

- True Energy or Reconstructed Energy
- Zenith Angle
- Offset
- Azimuth

Energy Dispersion

- Energy measurement
  - Based on the density of the Cherenkov photons on ground
- Measurement Accuracy
  - Fluctuation of the Cherenkov photos
  - Camera properties
  - Measurement of the Core Distance (truncated images, pixel size, algorithms, cuts, ...)

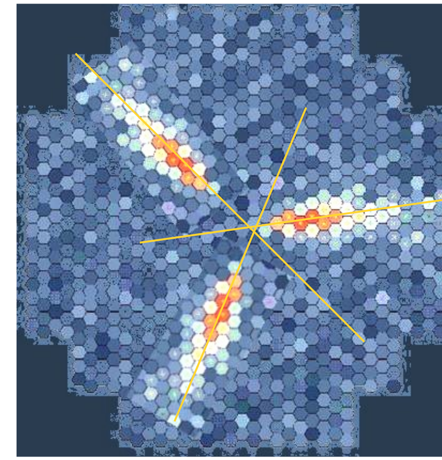


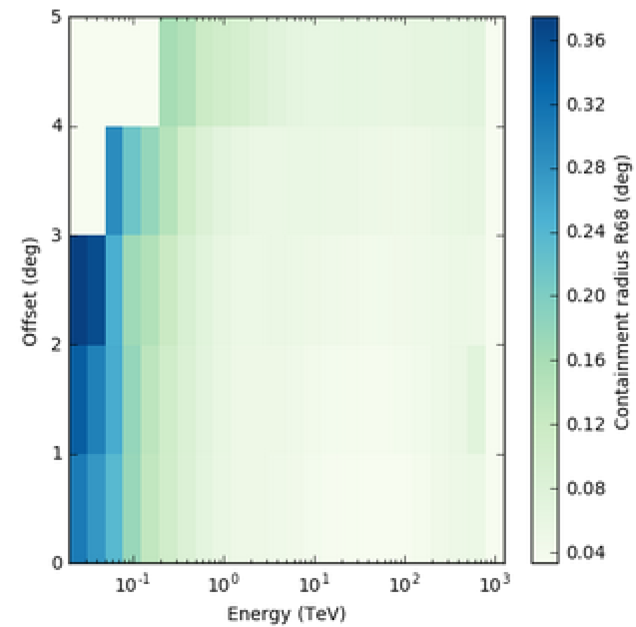


Edisp IRF dimensions (per set of cuts):
- True Energy
- Zenith Angle, Azimuth
- Offset

Point Spread Function

- PSF measurement
  - Based on the main axis of the shower images
- Measurement Accuracy
  - Fluctuation of the Cherenkov photos
  - Camera properties
  - Algorithm similar to the measurement o Core Distance (truncated images, pixel algorithms, cuts, ...)





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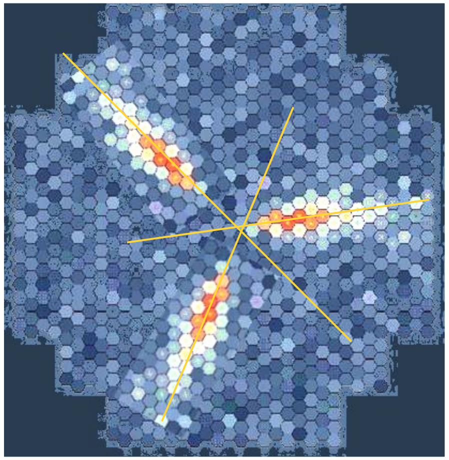
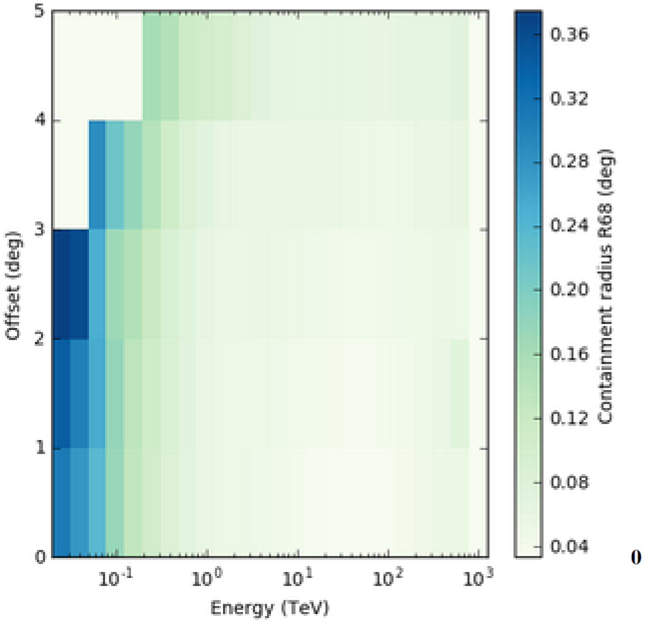
<u>PSF IRF dimensions (per set of cuts):</u>
- True Energy or Reconstructed Energy
- Zenith Angle, Azimuth
- Offset

Point Spread Function

- PSF measurement
  - Based on the main axis of the shower images
- Measurement Accuracy
  - Fluctuation of the Cherenkov photos
  - Camera properties
  - Algorithm similar to the measurement o Core Distance (truncated images, pixel algorithms, cuts, ...)

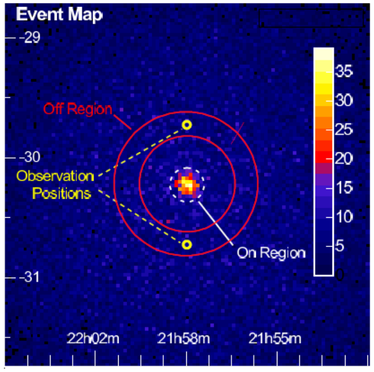


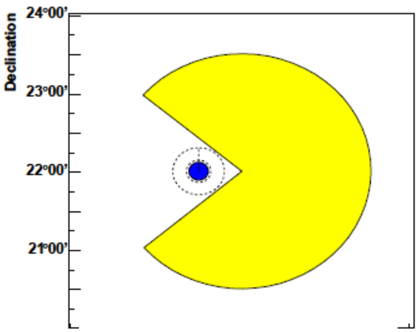


PSF IRF dimensions (per set of cuts):
- True Energy or Reconstructed Energy
- Zenith Angle, Azimuth
- Offset

Background Model

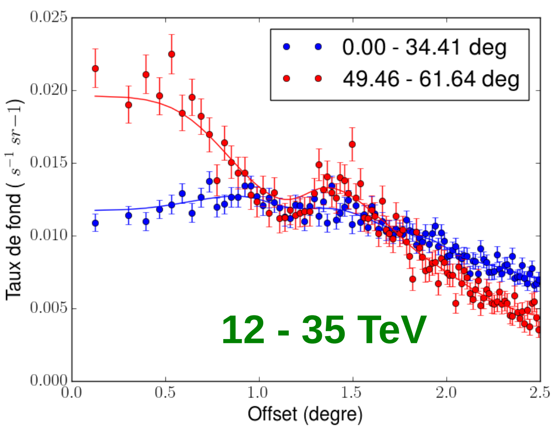
- Frequently use in 1D as 'radial lookup'
  - Use to estimate the background to make maps with the 'RingBackgroundModel'
  - Integrated over energies
- With CTA, try to extend its use
  - From 1D to 2D, and for different Energy bins
- Production
  - Only real data can be used
  - Use of 'empty' fields and creation of 1D (2D?) lookup





From Marandon 2010

Current Bkg IRF dimensions (per set of cuts):
- Reconstructed Energy
- Zenith Angle, Azimuth



PS : a lot to do to minimize systematics

Summary

- CTA will use IRFs as DL3 to be used by Science Tools
  - As for other HE experiments
  - A new format is under construction for IVAO compliance
- Some specificities
  - From the Cherenkov technics (e.g. Offset And Zenith angle, FoV changes with energy, simulation or real data, ...)
  - To be adjusted for/with the Science Tools requirements to reduce analysis systematics
- Current IRFs
  - Approaching to the final format
  - But now:
    - Only from simulations
    - No statistical error
    - Far to have systematic error....