cherenkov
telescope
array

Discussions on Systematics

First call indico page: here

Mission of the 'systematics group'

A dozen consortium publication coming up

→ perfect time to start systematizing the estimation of systematics from the instruments *whenever relevant*

Proposal that emerged *for papers for which this is relevant*

→ produce bracketing IRFs corresponding to +/- 1 σ cases for:
- Effective area
- Energy scale
- Background rate
- PSF
- others?

→ base the numbers on the observatory requirements (see last slides)
- proposal for the code: provide for each quantity the <u>requirement in %</u> + <u>given C.L.</u> + <u>relevant energy range</u> and then convert those in +/- 1 σ cases

→ aim for a few-week timescale work so that the publications are not put on hold
- refinements can/will come when we have a better understanding of our future instruments BUT at least at this stage standardized and 1st order way to treat systematics

Relevant requirements

Items covering our needs. Is the background systematics that relevant?

- **PROG-0100 Systematic Energy Uncertainty** :
  Systematic errors or biases in the energy of reconstructed gamma-ray photons must be < 10% at energies between 50 GeV and 300 TeV (at 90% confidence level).

- **A-PERF-0380 Effective Area Knowledge:**
  The contribution to the uncertainty on the energy-dependent effective collection area of the system as a whole at both sites above 40 GeV and under reference conditions from array level analysis and selection must be less than 5%.

- **PROG-0130 Background Estimation Uncertainty:**
  Estimates of the residual background level for point-like sources and the event selection cuts to meet the required 50 hour differential sensitivity must be accurate to a level of <4% (at 99% confidence level) for all energies between 50 GeV and 50 TeV.

- **PROG-0160 Gamma-ray PSF Uncertainty:**
  The Gamma-ray PSF Uncertainty for the full CTA system at the Northern and Southern sites must be < 10% or 20" at energies well above threshold in standard observing conditions and < 5% or 3" at energies well above threshold in favourable conditions.

Ievgen's implementation

See slides here

PSF

$$\sigma_{1..n} \to \alpha\, \sigma_{1..n}$$

A simple scaling of the (sum of) gaussian PSF components

Collection area

$$A_{eff} \to A_{eff}(\theta, E) \times [1+\varepsilon_1(E)B_1(E)] \times [1+\varepsilon_2(\theta)B_2(\theta)]$$

$B_1(E) = \tanh(1/k_1 \times \log(E/E_0))$ $B_2(\theta) = \tanh(1/k_2 \times \log(\theta/\theta_0))$

This modifies both the energy and spatial response.

Callable script:

```
python Scale_IRF.py --caldb="prod3b" --irf="North_z20_50h" --psf_scale=0.5 --aeff_energy_scale=0.05
```

First script available here

Attempt of layout of the plan

I - Starting point:

The most basic observables we reconstruct when detecting a source are (a) flux normalization at observed pivot energy, (b) spectral index (and higher-order parameters: curvature, cut-off), (c) extension

II - Goal:

Provide a tool enabling a CTA user to easily estimate the impact on (a), (b), (c) of the uncertainties on IRFs

III - Relevant high-level IRF components:

(i) Effective area: normalization for a), gradient vs energy for b), gradient vs offset for c)

(ii) Energy scale: normalization for b) -e.g. high-order spectral parameters (cut-off)-, gradient vs energy for b)
Note: gradient vs offset may not be relevant / well constrained by the requirements

(iii) PSF width: normalization for a) and c)
Note : gradient vs energy and vs offset may not be relevant / well constrained by the requirements

Note: uncertainties on background rate absorbed by the reconstruction ?

Attempt of layout of the plan

IV - Implementation method:

Modify Aeff, Escale, PSF_width by a factor **$[1 \pm \varepsilon \times B_E(E)]\times[1 \pm \varepsilon \times B_\theta(\theta)]$** with:

- $B_E(E) = B_\theta(\theta) = 1$ *or* 0 **for normalizations**

- $B_E(E) = \tanh[\ln(E/E1)/(1.31\times\sigma(E1)/E1)]\times(E<\sqrt{E1\times E2}) - \tanh[\ln(E/E2)/1.31\times\sigma(E2)/E2)]\times(E>=\sqrt{E1\times E2})$
  for gradients vs energy

- $B_\theta(\theta) = \tanh[(\theta-\theta1)/(1.31\times\sigma(\theta1))] \times [\theta<0.5\times(\theta1+\theta2)] - \tanh[(\theta-\theta2)/(1.31\times\sigma(\theta2))] \times [\theta>=0.5\times(\theta1+\theta2)]$
  for gradients vs offset

. with **E1**=0.15TeV, **E2**=5TeV, **θ1**=4.3°, **θ2**=7.6° (**transitions between LSTs/MSTs/SSTs** – see link)

. where the **ε values are provided by the observatory requirements:**

.. (i) ε_Aeff = 3.0% (A-PERF-0380: uncertainty < 5% above 40 GeV: let's consider this as a 90% C.L.)

.. (ii) ε_Escale = 6.1% (PROG-0100: uncertainty/bias < 10% in 50 GeV - 300 TeV at 90% C.L.)

.. (iii) ε_PSF = min(6.1%,12.2") (PROG-0160: uncertainty < min(10%,20") in std observing conditions, for a 90% C.L.)

Attempt of layout of the plan

V - Practical use - Guidelines for source extension <~ 2°

(a) **flux normalization**: rerun the analysis for

(i): ε_Aeff=3.0% with $B_E(E)$ = 1 and $B_\theta(\theta)$ = 0
(iii): ε_PSF = min(6.1%,12.2") with $B_E(E)$ = 1 and $B_\theta(\theta)$ = 0

→ **4 re-analysis**, combine the two lower and upper systematics quadratically

(b) **spectral parameters**: rerun the analysis for

(i): ε_Aeff=3.0% with $B_E(E)$ = "dromedary" and $B_\theta(\theta)$ = 0
(ii): ε_Escale = 6.1% with $B_E(E)$ = 1 and $B_\theta(\theta)$ = 0
(ii): ε_Escale = 6.1% with $B_E(E)$ = "dromedary" and $B_\theta(\theta)$ = 0

→ **6 re-analysis**, combine the two lower and upper systematics quadratically

(c) **extension**: rerun the analysis for

(iii): ε_PSF = min(6.1%,12.2") with $B_E(E)$ = 1 and B_theta(theta) = 0

→ **2 re-analysis**

Some possible todo's

Checks with simple simulations / reconstruction

Example:

- Simulate a ~10 Crab spectrum, with some curvature and a cutoff
- Use Ievgen's code and reconstruct the spectrum with different IRFs
- Questions to be answered:
  . Which effects have the most important impact on the observables?
  . Are the induced uncertainties symmetric / asymmetric?
  → **goal: reduce the potential number of re-analyses to be done**

Anyone interested?

- Quick and easy way to get used to GammaPy / ctools
- **Quite visible contribution without too much work!**