Study of partial arrays impact on CTA optimization

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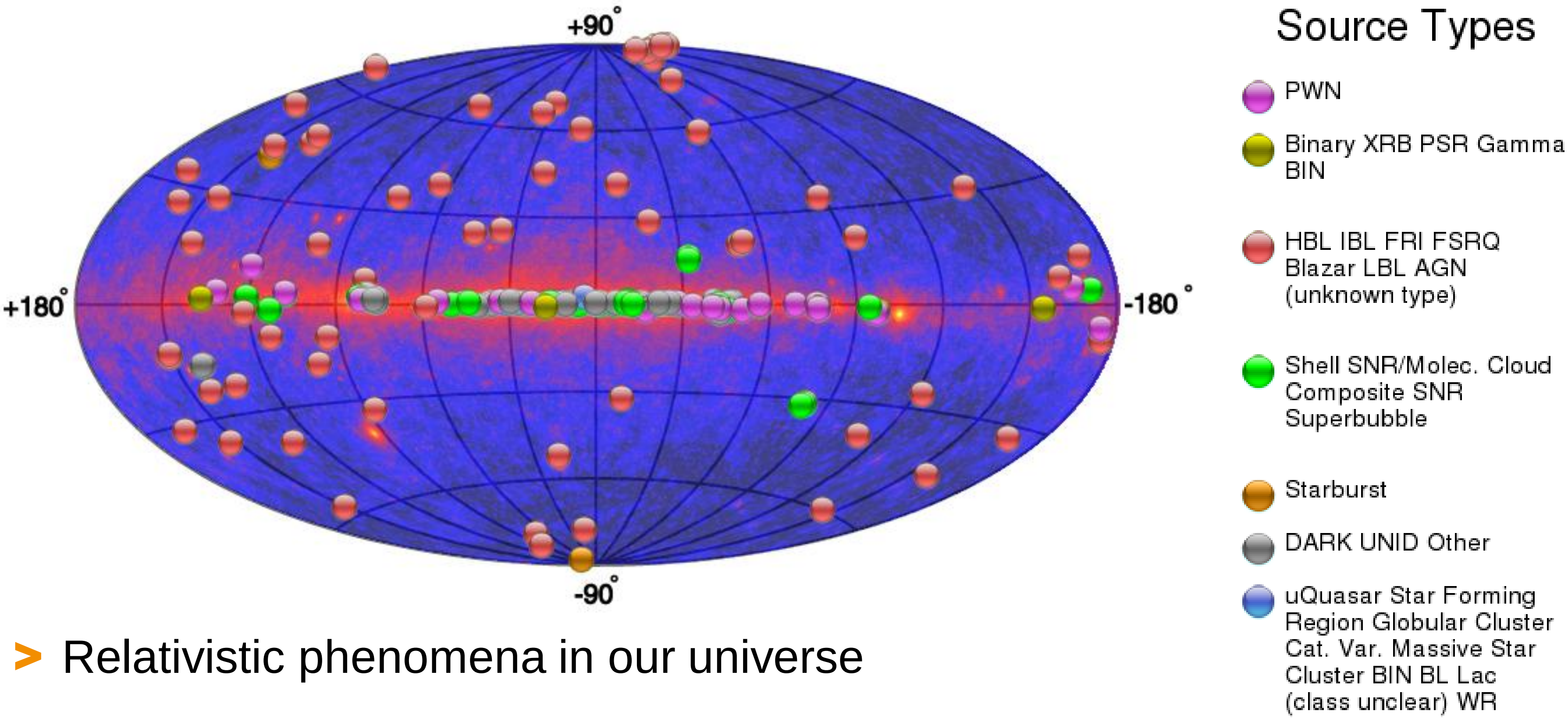
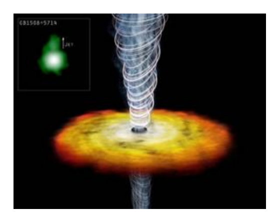
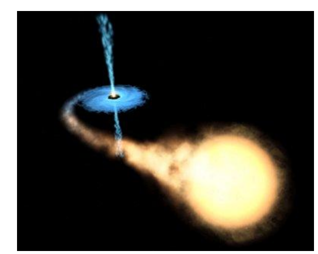
Gamma-ray astronomy



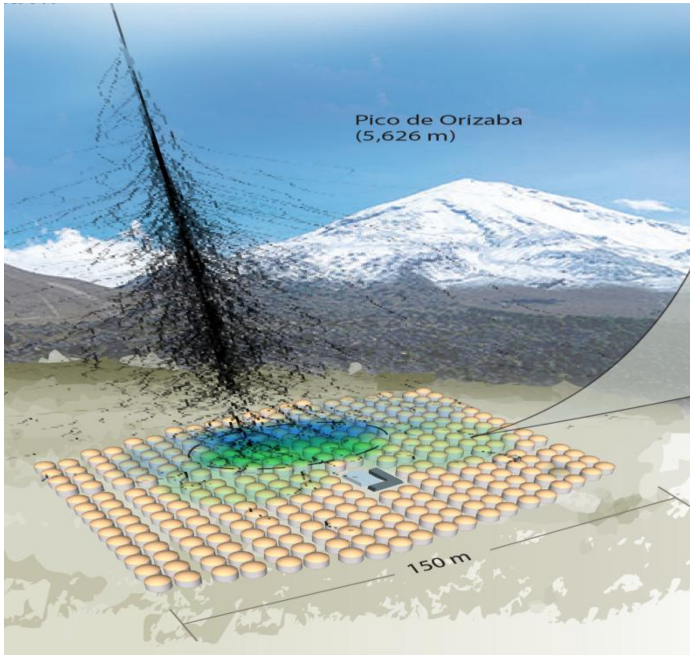
- Relativistic phenomena in our universe
- Broad energy range (~MeV to ~PeV)
- Sources: SNRs, binaries, AGNs, GRBs …
- Different detection techniques





Detection of gamma rays

- Direct measurements:
  - Can detect the primary flux
  - Limited effective area
  - Low sensitivity at high energies

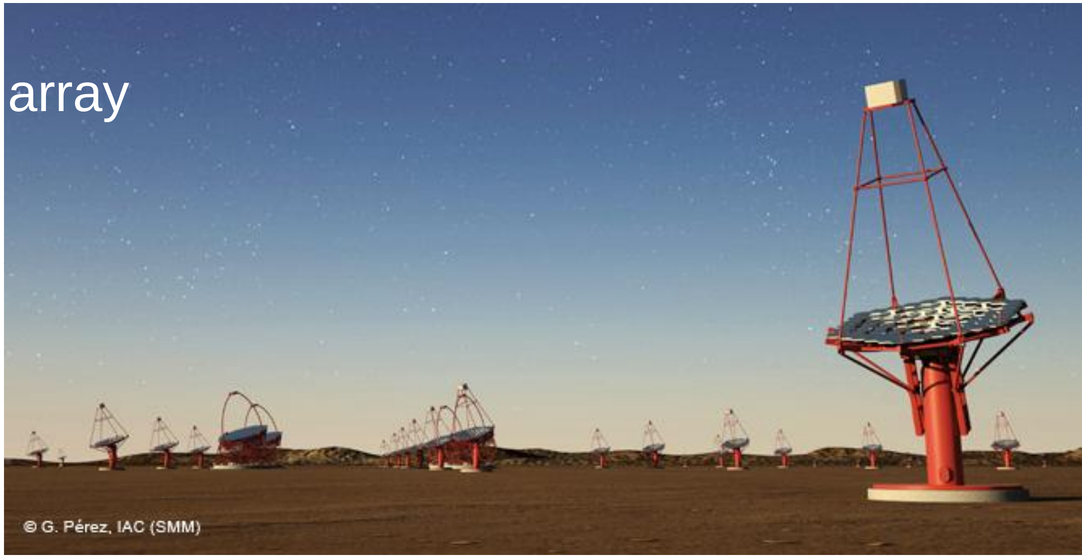


- Ground-based detectors:
  - Good knowledge of extensive air showers developement is necessary
  - Detection of the secondary component
  - High duty cicle
  - Large surface

Imaging Air Cherenkov Telescopes

- Cherenkov light as a track of air showers
- Large mirrors are used to collect the weak flashes
- The shower image is reconstructed in the camera

- CTA will be the largest IACTs array
  - ~120 telescopes
  - 3 different sizes
  - Wide energy range available
  - Works on CTA optimization rely on *simulations*



Spectrum reconstruction: the Response Functions

> Simulations are implemented through the *Response Functions (G.Maier)*:

- **Angular Resolution –** the radius which contains the 68% of the reconstructed gamma-ray signal;
- **Effective Area –** the area in which all gamma events are generated, scaled by the efficiency of the reconstruction of gamma event ;
- **Background Rate –** the rate of the residual background events, after the gamma-hadron separation;
- **Energy Bias –** the ratio between the reconstructed energy and the MC energy, as a function of the MC energy;
- **Migration Matrix –** 2-dimensional matrix, showing the correlation between the MC energy and the reconstructed energy.

Evaluated from MC simulations of gamma-like and background-like events

We can generate a source and infer how accurate will be the CTA measurement!

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Partial Arrays – Introduction

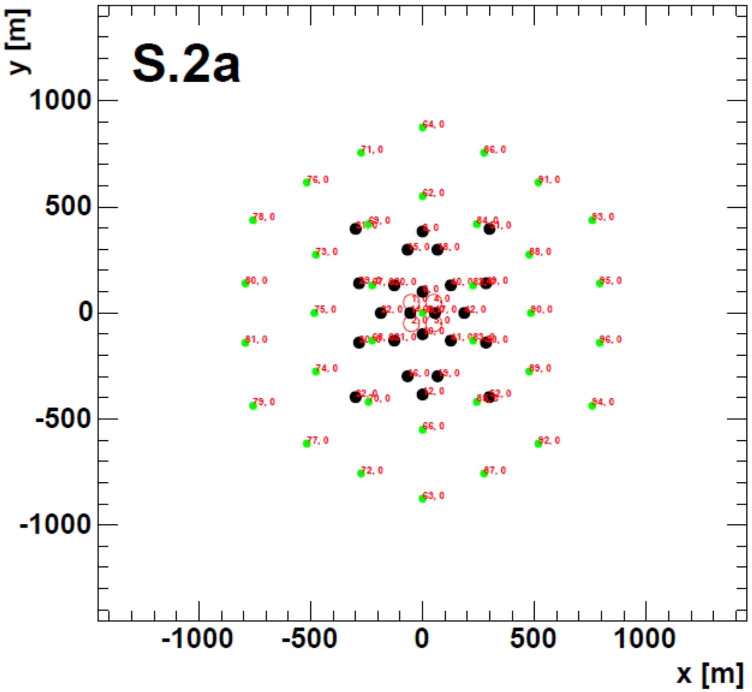
- CTA construction will require several years
- Importance of “making physics“ even with an uncomplete array
- Which kind of sources could we see during construction time?

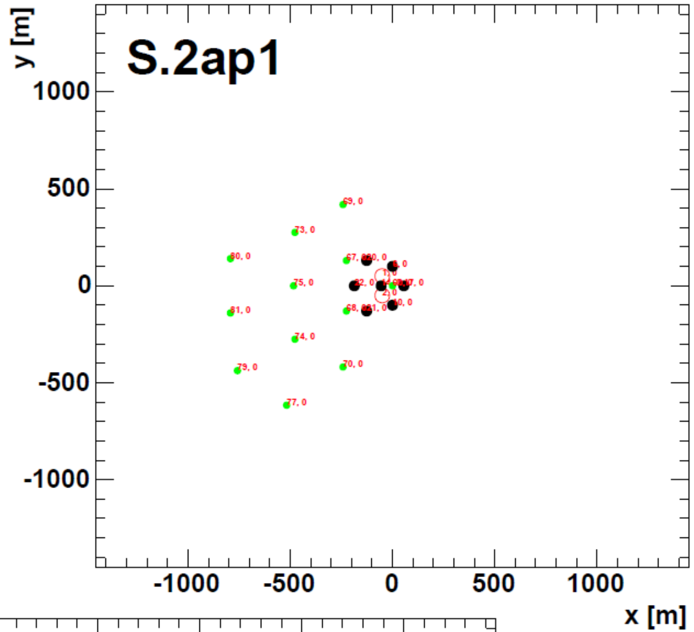
Partial Arrays – Introduction

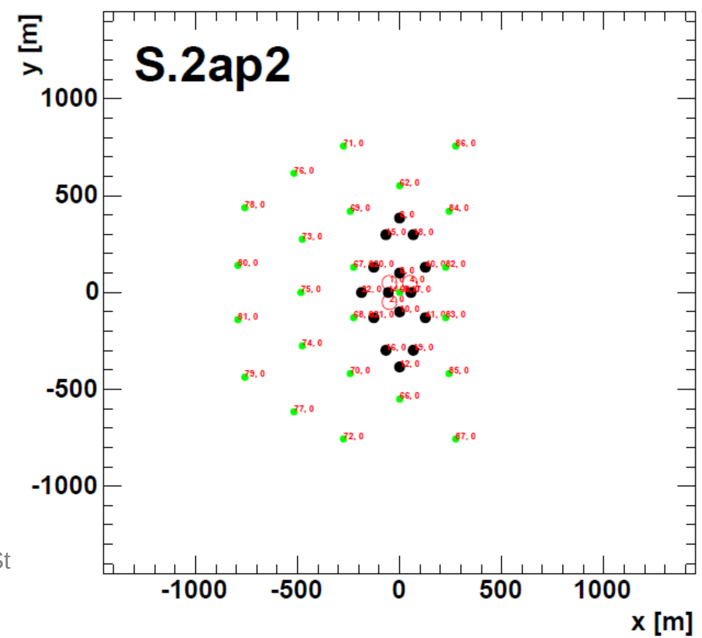
Array configuration	LSTs	MSTs	7m SSTs	4m SSTs
2a	4	24	35	0
2ap2	3	15	24	0
2ap1	2	7	12	0
2b	3	18	0	72
2bp2	2	12	0	48
2bp1	1	6	0	24
2c	3	32	0	38
2cp2	2	21	0	26
2cp1	1	11	0	12
2d	4	20	32	0
2dp2	3	12	20	0
2dp1	2	7	10	0
2e	4	24	0	72
2ep2	3	15	0	48
2ep1	2	7	0	24

Partial Arrays – Introduction

- As an example, we consider the **2a** layout



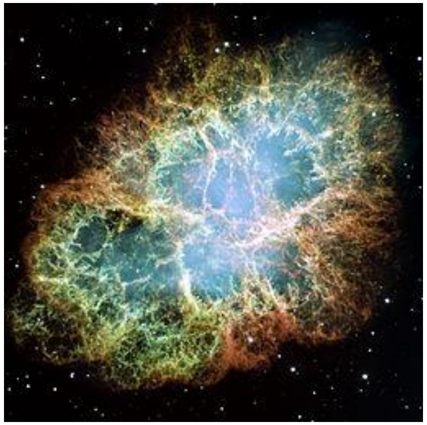




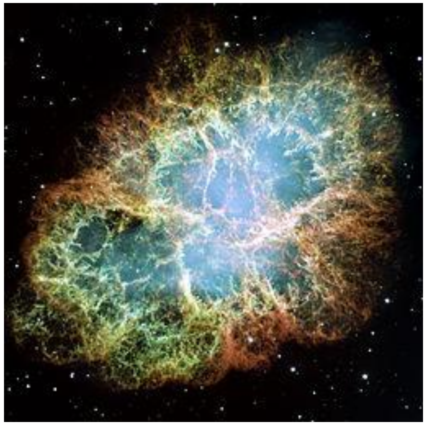
Partial Arrays – Spectrum reconstruction

- First we can generate a spectrum (Crab-like)

$$\frac{dN}{dE} \propto E^{-2.62}$$



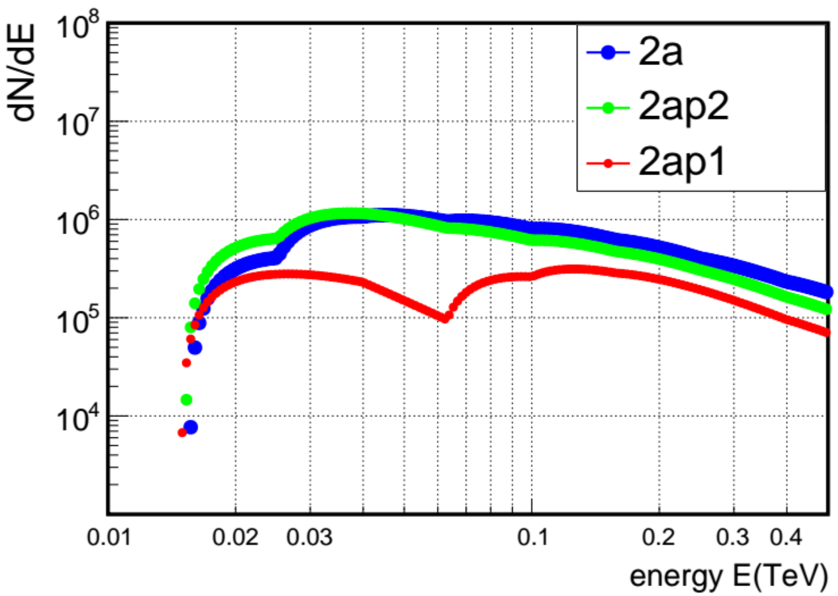
Partial Arrays – Spectrum reconstruction



- First we can generate a spectrum (Crab-like)

$$\frac{dN}{dE} \propto E^{-2.62}$$

- Then we convolve the spectrum with efficiency cuts



Partial Arrays – Spectrum reconstruction

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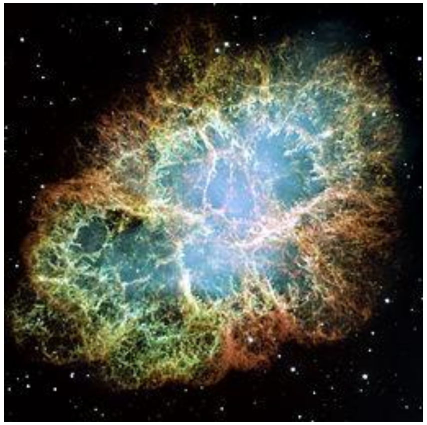
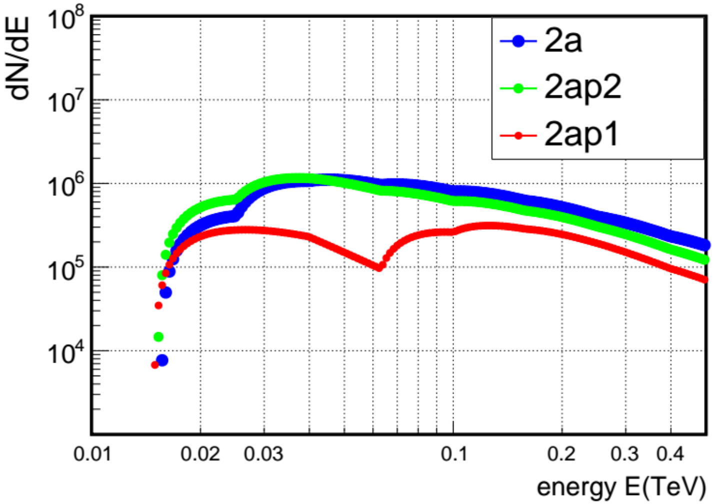
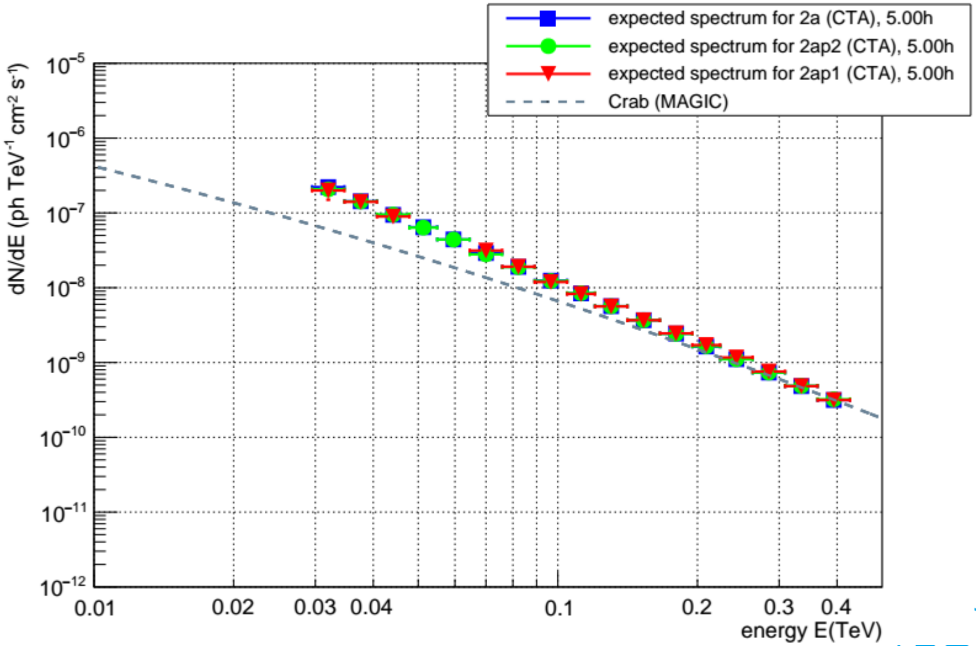


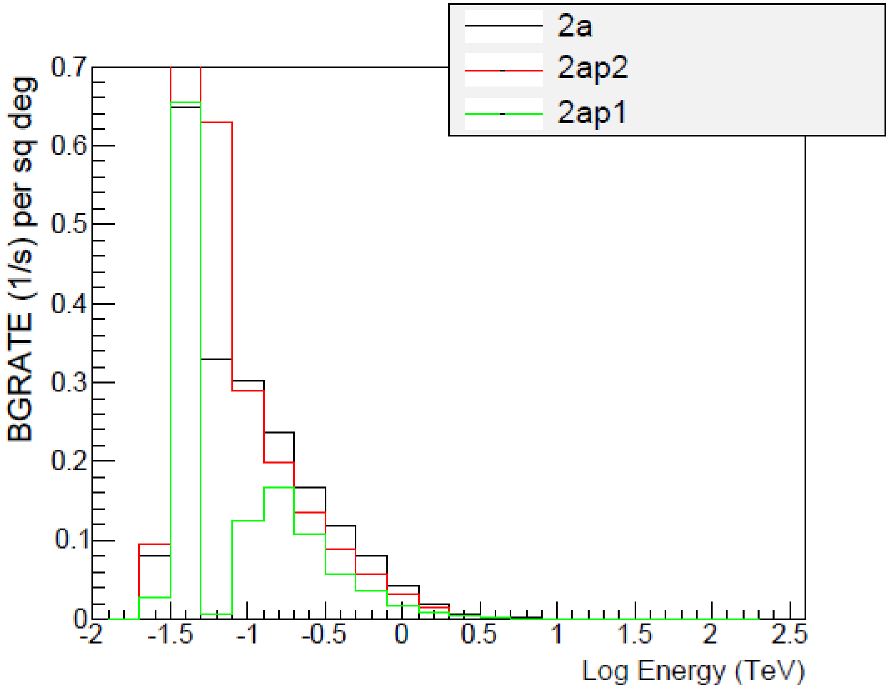
- Last, the reconstruction algorithm sets the energy bins requiring:
  - 3σ signal over background;
  - ≥7 events per bin;
  - $N_\gamma \geq 0.03 \times N_{bkg}$.

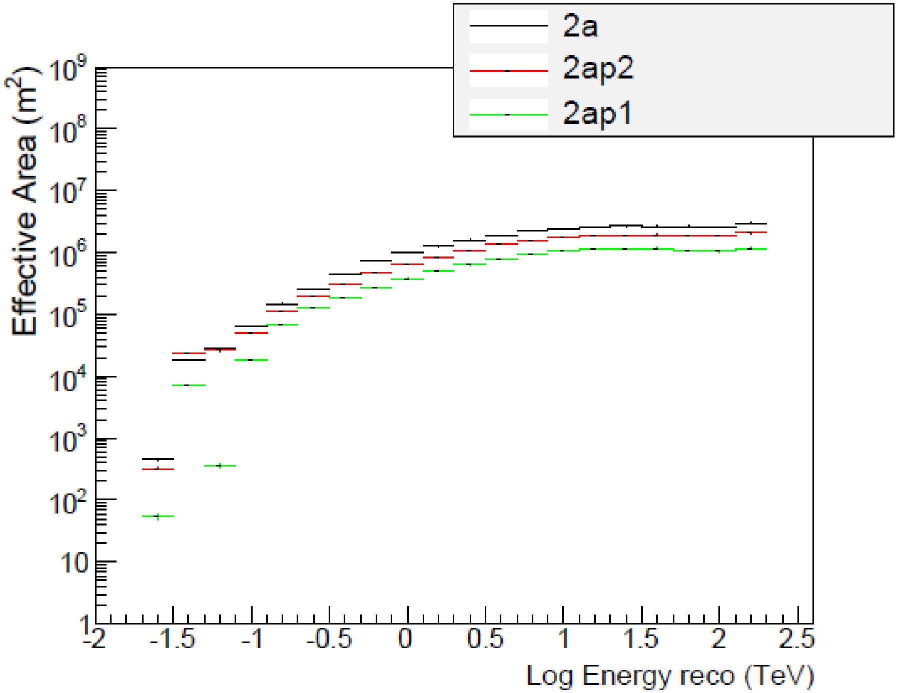




Partial Arrays – Spectrum reconstruction

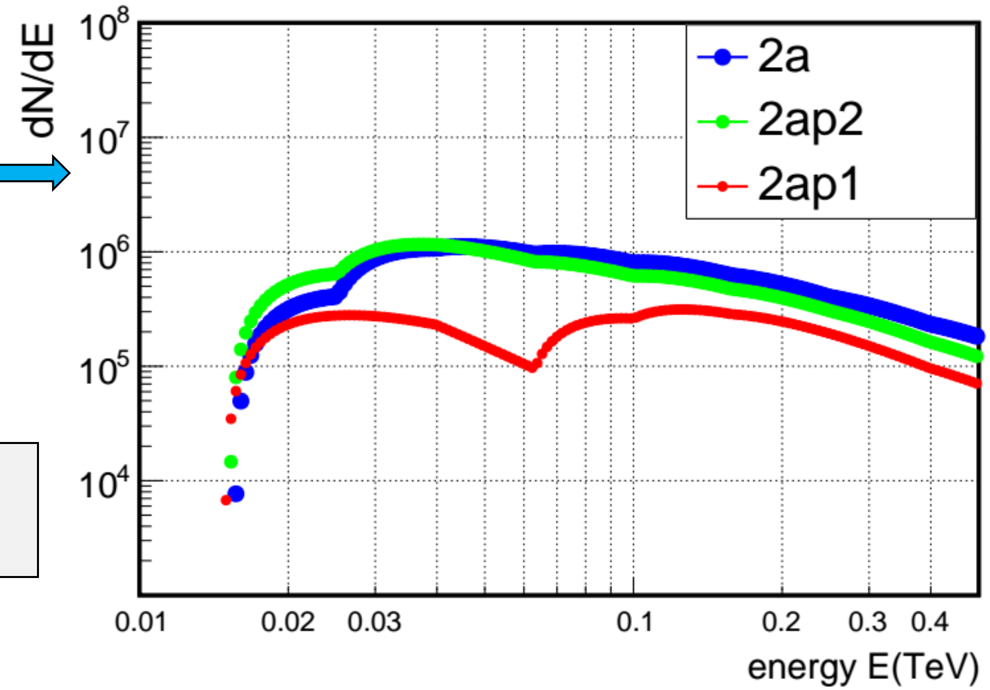
- The "hole" in the 2ap1 can be explained looking at the response functions:
- The array is not able to detect events around 70 GeV
- Probably an uncorrect optimization in this energy range

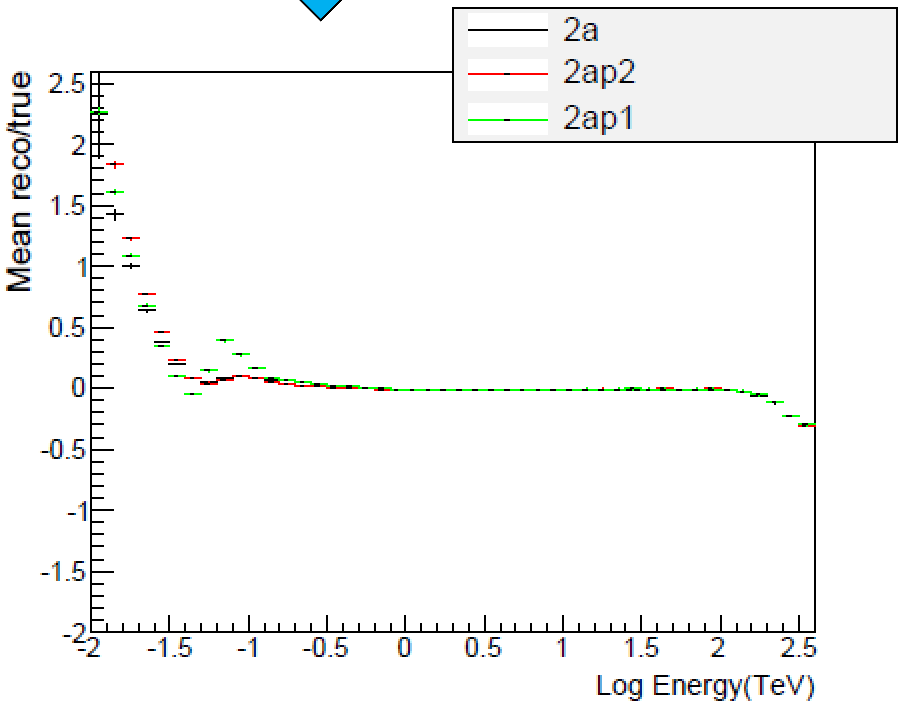




Partial Arrays – Threshold

- Estimation of the minimum detectable energy
- Different definitions:
  - Maximum peak;
  - Lowest-energy peak;
  - Energy bias over 10%





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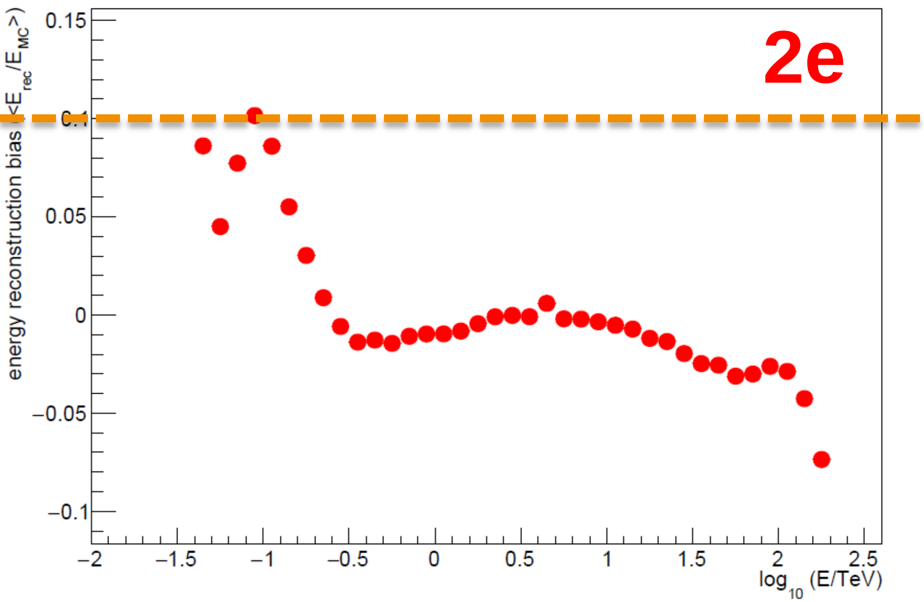
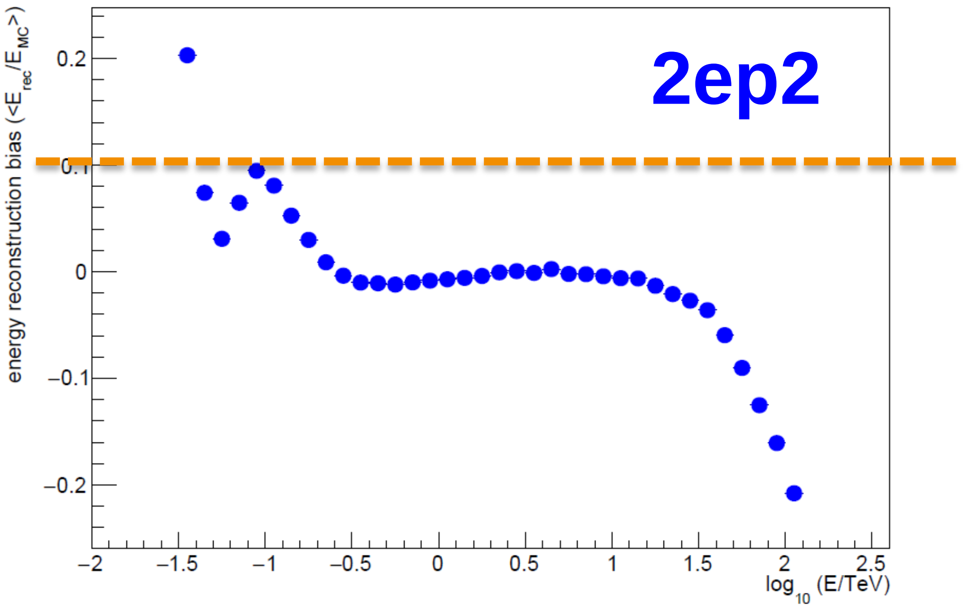
Partial Arrays – Threshold

Array configuration	Main peak	Lowest-energy peak	Energy bias
2a	78 GeV	49 GeV	35 GeV
2ap2	39 GeV	39 GeV	35 GeV
2ap1	175 GeV	142 GeV	112 GeV
2b	43 GeV	43 GeV	35 GeV
2bp2	184 GeV	184 GeV	112 GeV
2bp1	197 GeV	197 GeV	141 GeV
2c	197 GeV	40 GeV	112 GeV
2cp2	206 GeV	206 GeV	141 GeV
2cp1	211 GeV	211 GeV	141 GeV
2d	43 GeV	43 GeV	35 GeV
2dp2	39 GeV	39 GeV	89 GeV
2dp1	142 GeV	142 GeV	112 GeV
2e	48 GeV	48 GeV	89 GeV
2ep2	39 GeV	39 GeV	35 GeV
2ep1	179 GeV	146 GeV	112 GeV

Partial Arrays – Threshold

- Energy bias definition seems to work better, except for 2e configuration, where p2 exhibits better performances than full array





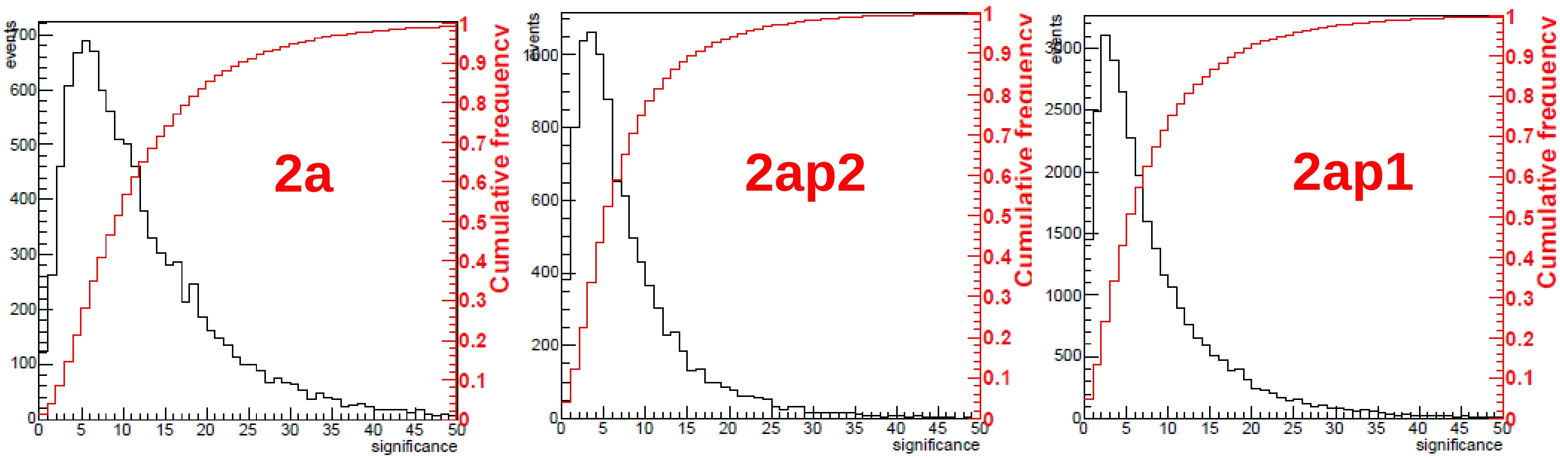
- The 10% cut “supports” 2ep2 configuration
- Need for more complex definitions

Partial Arrays – Physics cases

- Assuming a Fermi-LAT detection in the HE range:

$$\Phi = N_0 \left(\frac{E}{E_0} \right)^{-(2.50 \pm 0.15)} \qquad \int_{100MeV}^{10GeV} \Phi dE = (1.0 \pm 0.1) \times 10^{-6} cm^{-2} s^{-1}$$

- We can evaluate the probability of a CTA detection in the VHE range
- Given the measurement and the errors, we extrapolate the spectrum
- Define “detection” all measurement over 5σ confidence level



- 1h acquisition time

Partial Arrays – Physics cases

Configuration	Full array	Partial array 2	Partial array 1
2a	72%	48%	27%
2b	54%	34%	42%
2c	59%	43%	54%
2d	68%	49%	27%
2e	70%	49%	29%

- In some cases p1 configurations get larger detection probability than p2 configuration → inconsistency
- Evidence of complexity in merging different telescopes
- More detailed studies in the future

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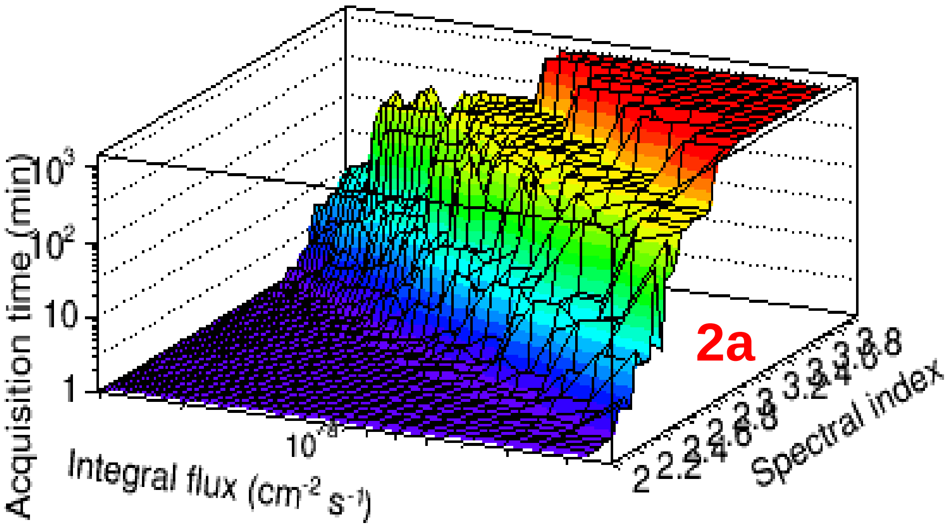
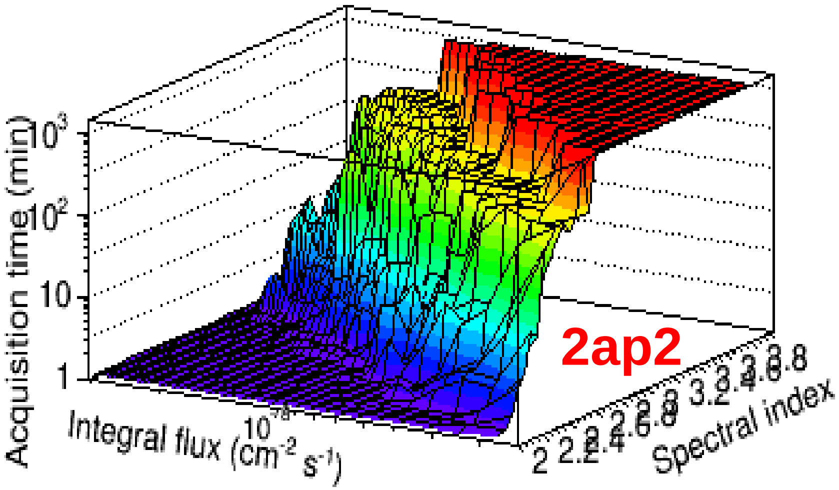
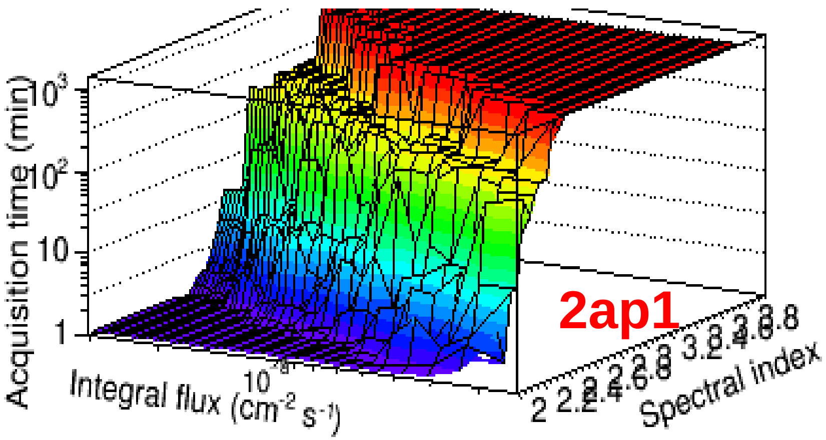
Partial Arrays – Time sensitivity

- Study of the acquisition time of a power law spectrum, necessary to have a 5σ measurement
- Variables: integral flux, spectral index







- Consistency of the results
- For an IF=2x10^-8 cm^-2 s^-1 and Γ=2.6
  - 2ap2: < 3 min
  - 2ap1: ~10 min

Conclusions

- The study of partial arrays is an interesting topic, for the final optimization of CTA
- Measurements in short-time scales seem to be available also with partial arrays
- The definition of the minimum detectable energy has to be faced with more complex procedures
- Exploration of a physics case shows an inconsistency about the detection probability of a source

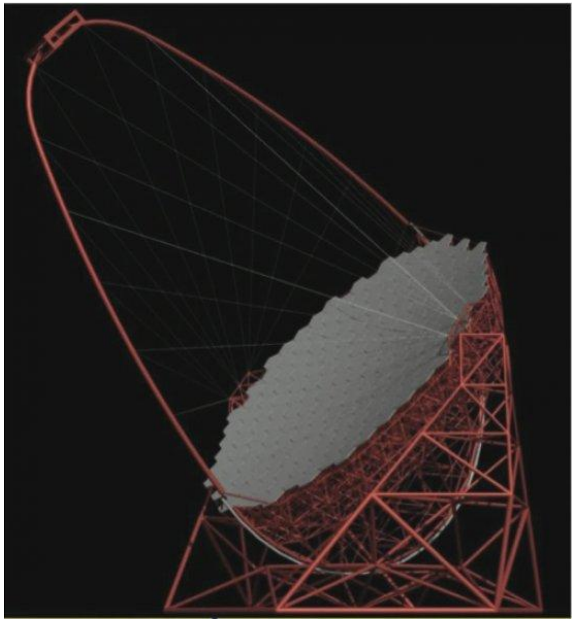
↓

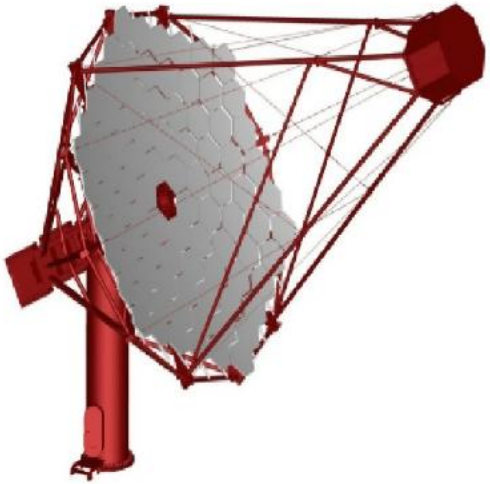
- The optimization procedure for CTA exhibits some problems (probably due to the use of different telescopes), and need further analyses

backup slides

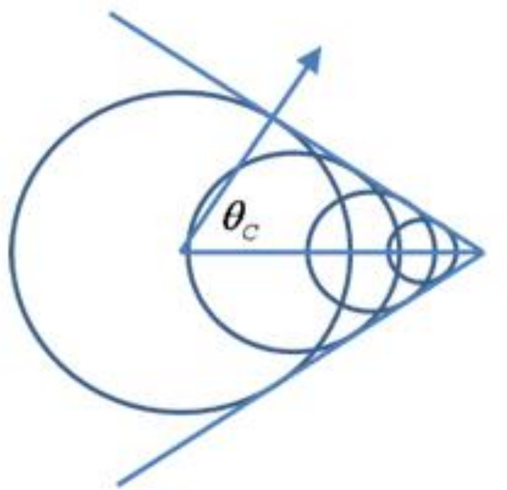
CTA telescopes

Telescope	Diameter (m)	Energy Range
Large Size Telescope (LST)	23	E $\leq$ 100GeV
Medium Size Telescope (MST)	12	100GeV $\leq$ E $\leq$10TeV
Small Size Telescope (SST)	4/7	E $\geq$ 10TeV



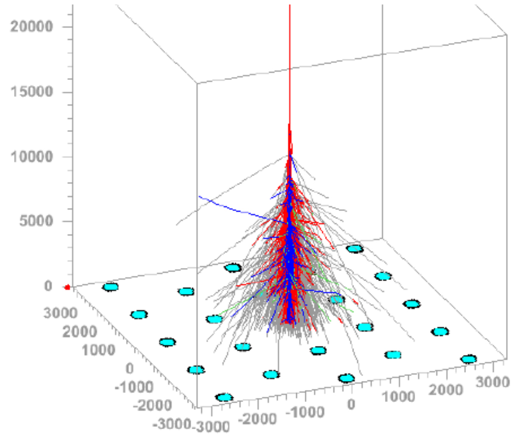


The Cherenkov light



$$\theta_C = \cos^{-1}\left(\frac{1}{\beta n}\right)$$

β > 1/n



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