The phase II of H.E.S.S.

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In 2010 the H.E.S.S. experiment will enter its phase II where the present 4-telescope configuration will be enriched with a new very-large telescope at the centre of the array. The $600\,\mathrm{m}^2$ mirror area and high-resolution camera will permit the lowering of the threshold to about 30 GeV in the single-telescope mode, opening a new observational window to a large number of new high-energy phenomena. Adding a new very-large telescope also helps to enhance the detection sensitivity in the multi-telescope mode. The status of the project and the preliminary estimates of the angular resolution and effective area in the low energy domain will be presented and discussed.

1 Scientific objectives

Very high-energy (VHE) γ-ray astronomy has been living through a very exciting era with the advent of the H.E.S.S. experiment: in 2003 there were only twelve VHE sources detected in total but at present the extra-galactic VHE sky is composed of 27 Active Galactic Nuclei (*AGN*), while the Galactic sky is composed of about 60 sources. Concerning H.E.S.S. about 52 galactic and extra-galactic sources have been published between 2004 and 2009 and the majority of these were discoveries. With the sensitivities given by the present atmospheric Cherenkov experiments, it is becoming more and more difficult to augment the VHE catalogue as the brightest sources have been detected. A 5σ detection of a flux level below 1% percent of the Crab Nebula (a *faint source*) currently requires a typical observation time of the order of 100 hours, due to the fact that the H.E.S.S. mirror reflectivity has been degrading over years, causing a significant loss in sensitivity. Faint fluxes are expected from new classes of high-energy phenomena as the *starburst* galaxies or *Ultra Luminous Infra Red Galaxies* (ULIRG), as well as from galaxy clusters and from radio-galaxies. For the moment only two sources having a flux level of the order of 1% of the Crab have been discovered by H.E.S.S. [1,2] after a significant amount of observation time integrated over several years. Efforts to improve the sensitivity by optimising shower reconstruction algorithms and γ/hadron discrimination procedures are ongoing [3]. But in parallel, in order to further enhance the experiment detection capability, the project is entering in its new phase planned since 2005, called HESS-II. The first objective of this phase is the lowering of the energy threshold to about 30 GeV in the single-telescope (or *mono*) mode and the second objective is a sensitivity improvement better than a factor of two in the multi-telescope mode. A considerable amount of new physics subjects will be accessible with a 30 GeV energy threshold. Since a negligible γ-ray absorption is expected in the [30–100] GeV energy range, more distant objects will become visible with their intrinsic features, enriching the extra-galactic source catalogue and permitting to put stronger constraints on the

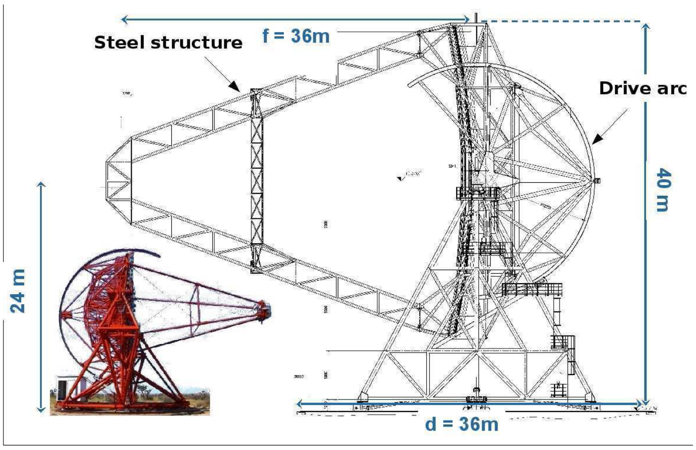

Figure 1: Sketch of the new very-large HESS-II telescope next to the former H.E.S.S. one shown on the left side of the figure.

EBL[a] absorption and on quantum gravity. Having access to the lower energy spectra will also permit the study of pulsar emission and to distinguish between different scenarios in several hadronic candidate sources thanks to the large effective area (see Par. 4) which allows results to be obtained in a reasonable observation time. It is worth noting that the H.E.S.S. studies of the [30–100] GeV energy spectra will be overlapping the Fermi analysis in the same energy range thus giving the chance to cross-check the different observations. Since the energy threshold is inversely proportional to square root of the reflecting mirror area, such a threshold level is being reached with the addition of a new very-large Cherenkov telescope (VLCT) at the centre of the present 4-telescope array.

2 The new 600 m^2 telescope

The HESS-II telescope design is optimised for the detection of low energy γ-ray induced showers and has a field-of-view of 3.5°. The installation phase is planned for the end of 2009 and the system is expected to be ready for the first data taking runs in the upgraded configuration for mid-2010. The telescope is a sturdy steel structure of remarkable size (see Fig. 1): the system is 40-m high when pointing at the horizon and 50-m high when pointing at the Zenith. The reflector of HESS-II is composed of 850 hexagonal mirror facets of 90 cm width (flat-to-flat) installed on a 30 m diameter parabolic surface, in order to minimize the time dispersion of the photons forming the image on the focal plane. The Cherenkov photons reflected by the mirror surface are detected on the focal plane which is connected to the reflective surface by four steel arms. A minimal focal length over diameter ratio of 1.2 is required to achieve very good imaging over the field of view, therefore the focal length has been chosen to be 36 m. The focal plane is equipped with a high-resolution camera composed of 2048 photo-multipliers each having a 0.07° diameter. The depth of field of the VLCT is such that for optimum shower imaging the telescope should be focused on the average shower maximum. Since the distance to the average shower maximum varies with elevation, the telescope needs to be refocused by moving the camera closer towards the dish along the optical axis for observations at large zenith angles. The maximum shift of the camera is about 10 cm. The focal plane is instrumented with new electronics using the *SAM* (Swift Analogue Memory) which will allow an accurate digitisation of the arrival time (about 1 ns resolution) and charge of the detected pulses. A level-2 trigger is foreseen for the VLCT which should allow some extra discrimination based on the pixel topology above two

[a]Extra-Galactic Background Light

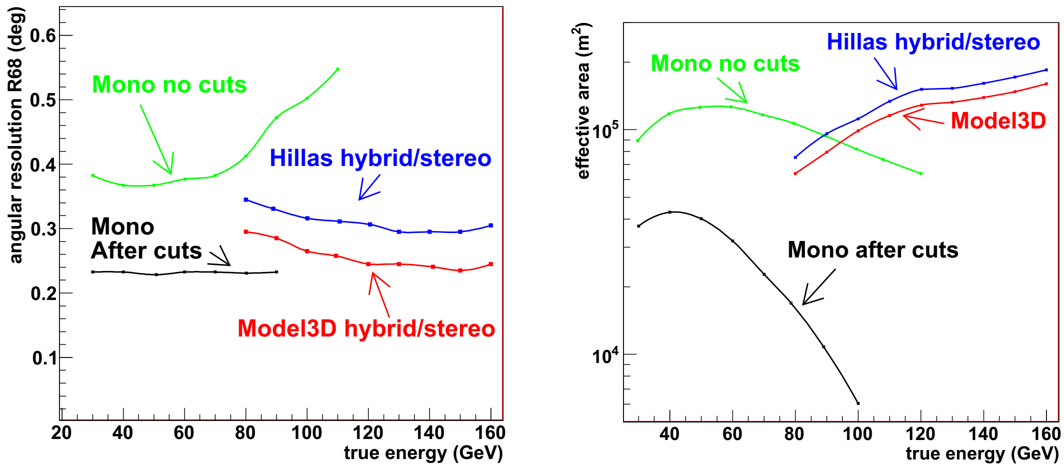

Figure 2: Left: Angular resolution for the different HESS-II detection regimes. The upper line *Mono no cuts* shows the curve for the pure *mono* events hitting the very-large telescope only, after image cleaning and reconstruction only, with no analysis cuts yet applied. For energies greater than 80 GeV the performance starts to worsen because the *mono* events in this range have a large impact parameter thus an image approaching the edge of the camera. The lower line *Mono after cuts* shows the angular resolution after background rejection cut and nominal distance cut (see text). The remaining curves show where the hybrid and stereo range take over and are obtained at trigger and image cleaning level i.e. no analysis cuts were applied (the upper line is for the Hillas case while the lower line is for the Model3D case). The final hybrid/stereo angular resolution is expected to be much better: 0.06° for H.E.S.S. after cuts. Right: Effective area given in m^2 for the different HESS-II detection regimes. The upper line *Mono no cuts* is again the curve obtained for the pure *mono* events after trigger and image cleaning, the curve after cuts is also indicated (*Mono after cuts*). The effective areas at higher energy after trigger and image cleaning (so no analysis cuts were applied) for the hybrid and stereo events for two different reconstruction algorithms are also shown by the upper line (*Hillas* case) and the lower line (*Model3D* case).

threshold levels.

3 Three-energy domain analysis

The inter-telescope trigger system of the HESS-II configuration will allow to trigger on three classes of events in parallel: at very low energies on purely mono-telescope events of the VLCT (*Mono* domain), at mid energies on combined events with an image from the VLCT and one from the smaller H.E.S.S. telescopes often with rudimentary information in the latter (*hybrid*[b] domain), and at even higher energies on current H.E.S.S. - Phase I type events with additional rich information in the central telescope (*full-stereo* domain). For the evaluation of the low energy performance of the upgraded system we simulated gamma and proton showers between 20 and 150 GeV at a zenith angle of 18° assuming an optimal optical efficiency in the five telescopes: all the results presented here have then to be considered valid only in the case of full-recoating of the four mirror dishes of H.E.S.S. phase I. The γ-ray source is simulated on the optical axis, so the source is projected at the centre of the cameras, and the simulations are carried out over a sufficiently large radius (500 m) from the centre of the array. The local trigger configuration used in this analysis can be summarised as follows: for the smaller telescopes we required a pixel threshold of 4 p.e. and a minimum number of pixels of 2.5, while for the VLCT we raised these values to 5 and 3.5 to allow a better online rejection of low energy hadrons. The event is then kept only if it has at least one telescope satisfying the local trigger condition. The

[b] The term hybrid is used in this paper to denote a particular event topology and should not be confused with the HESS-II "hybrid trigger mode" used in other contexts

algorithms for the level-2 trigger are still under development, so these are not included in the current study.

4 Performance in the [30–100] GeV range

A preliminary analysis aiming to evaluate the performance of the system in terms of angular resolution and effective area has been performed for the [30–100] GeV energy range. Images detected by the VLCT are used to reconstruct the parameters characterising the shower with the *Hillas* algorithm [4]. The resulting shower properties plus other robust parameters characterising the event has been used for the definition of a hadron rejection cut in a multi-variate approach. A cut on the nominal distance is required in order to reject the events giving images at the border of the camera, and to reject the events hitting the telescope too close to the source direction, which give non-elliptical images. Only the events giving images at a nominal distance greater than $> 0.45°$ and smaller than $< 1°$ are kept for further analysis.

The angular resolution, defined as 68% containment radius for all the pure *mono* events after image cleaning and reconstruction, is shown in Fig. 2 (left) with the upper line *Mono no cuts*, while the resulting curve after the background rejection and nominal distance cuts is shown with the lower line *Mono after cuts*. The angular resolution of the hybrid and stereo events, i.e. at higher energy, after reconstruction has been estimated with the Hillas and the Model3D [5] algorithms without any cuts, for comparison. The angular resolution for the pure *mono* events after cuts is of the order of 0.25°.

For the calculation of the effective area for a point-like source analysis, an additional cut on the squared angular deviation between the source position and the reconstructed direction θ^2 is applied: we select all the events having a $\theta^2 < 0.13$ deg^2. The effective area resulting after the three analysis cuts is shown in Fig. 2 on the right. The area in the *mono* range after cuts is also shown with the lower curve *Mono after cuts*: it has a maximum around 40 GeV then it drops quickly at about 80 GeV where the hybrid and stereo detection regimes take over.

It should be noted however that the three cuts applied to study the performance presented in this work are only roughly estimated and will be optimised with more enhanced analyses.

5 Conclusions

Monte-Carlo studies of the performance of the full H.E.S.S. system after the addition of the phase-II VLCT at the centre of the current array shows that the goals of lowered threshold will be achievable (down to 30 GeV in *mono* mode). Studies will continue to characterise the improvement in the sensitivity which will be attained in the hybrid/stereo ranges, together with the development of adapted analysis methods. HESS-II has great new physics potential, with results expected on AGNs, pulsars, and the differentiation of leptonic/hadronic models in SNRs in the lower energy range, and detection of weaker source classes thanks to the improved sensitivity. The first results are expected soon after first light, in 2010.

References

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