Different Concepts of Next Generation IACT Arrays

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ECRS 2010

August 6th, 2010

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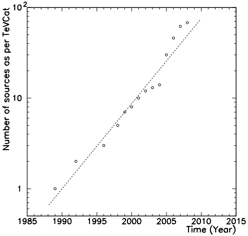
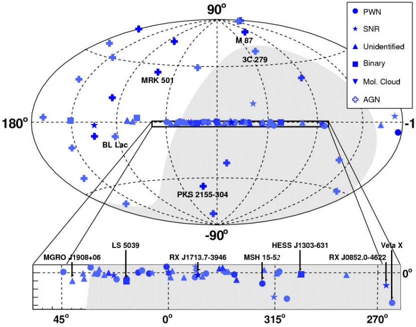
Status of IACT Technique

- $E > 100\mathrm{GeV}$
- Sensitivity: $\sim 1\%\mathrm{CU}$
- PSF: $\sim 5'$
- Energy Resolution: $\approx 15\%$
- Number of detected sources doubles every 3.2yr (P. Colin and S. LeBohec, 2009)





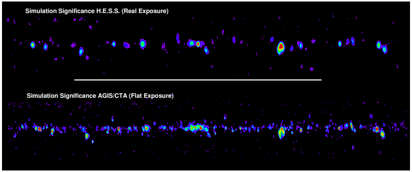
J.A. Hinton and W. Hofmann, 2010

IACT technique

- is the most powerful approach in the energy range above 100GeV
- has entered a phase of explosive development

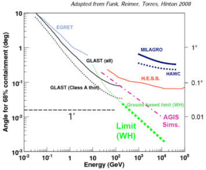
Future of IACT Technique

Modeled View of Galactic Plane



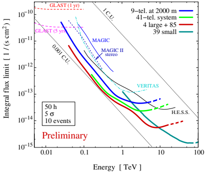
S. Funk, 2008

Angular resolution of Next Generation IACT



S. Funk, 2010

Sensitivity of Next Generation IACT



K. Bernlöhr, 2008

Scientific drivers (F. Aharonian, J. Buckley, T. Kifune and G. Sinnis):

- ($E \lesssim 30$ GeV) Extragalactic sources (AGN, GRBs) at cosmological distances ($z \gtrsim 1$), microquasars, pulsars
- (30GeV – 300GeV) Extragalactic sources at intermediate redshifts, search for dark matter, galaxy clusters, pair halos, Fermi sources, gamma ray bursts.
- (300 GeV – 30 TeV) Nearby galaxies, nearby AGN and their flaring states, detailed morphology of extended galactic sources, galactic diffuse emission.
- ($\gtrsim$ 30 TeV) Cosmic ray PeVatrons, origin of galactic cosmic rays, limits of galactic accelerators.

Next Generation IACT Array Target Specifications

- High sensitivity, down to mCrab.
- Widened spectral coverage (a few 10 GeV to above 100 TeV).
- Improved angular resolution down to arc-minute range.
- Temporal resolution down to sub-minute time scale.
- Widened Field Of View (up to 8°).

Next Generation Telescope Design

- **Field-of-View justification**
  This includes comparisons of two-mirror otical designs (ex: Schwarzschild-Couder) vs. conventional single-mirror designs (ex. DC)
- **Optical point spread function and pixel size**
  The impact of these parameters on the overall angular resolution of the array will be used to establish optical specifications for the prototype telescope
- **Slew time justification**
- **Trigger studies**

  The ideal Cherenkov telescope trigger system provides reliable triggering on the lowest energy gamma-ray events, with little or no contamination due to accidental triggers on night sky background fluctuations at the optimum gamma-ray/hadron separation at the trigger level
  - Trigger pixel size
  - Trigger multiplicities and other parameters
  - Coincidence time windows
- **Data acquisition and readout** Sampling rate, dynamic range and other questions
- **Focal plane mechanics**

  An important question in case of 2-tel mirror designs
  - Pixel locations, effects of optical cross-talk and dead spaces
  - Optimum design of light collecting cones

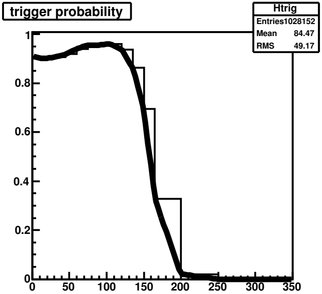
Different Levels Of Detalization For Optimization of IACT Arrays

- Using geometrical considerations and the properties of the atmospheric Cherenkov light from VHE γ-ray showers, it is possible to identify relationships between the energy range ($E_{Min} - E_{Max}$), A_γ, and the design parameters of a telescope array.
- Toy Models
  Monte Carlo studies of an IACT array can be done using PDFs of parameters such as trigger probability as function of impact parameter, parameters of orientation/location of Cherenkov image in the camera plane and others.
- Approximation of an infinite array.
- Detailed Monte Carlo study.

* Although all performances of an array can not realistically be addressed with precision without detailed simulations, semi-analytical approaches can be used to narrow down parameter space for detailed Monte Carlo simulations.

Toy Model Input Distributions

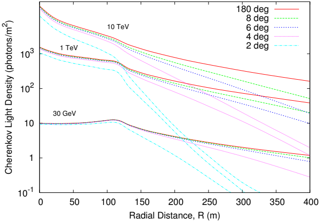
Telescope trigger probability

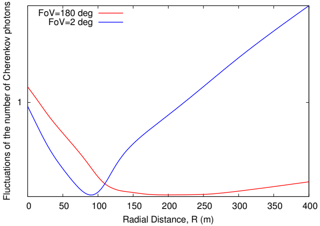


+

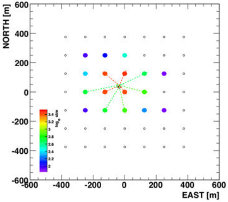
Distributions of orientation/location of Cherenkov image

Field Of View Justification





Telescopes with good shower images

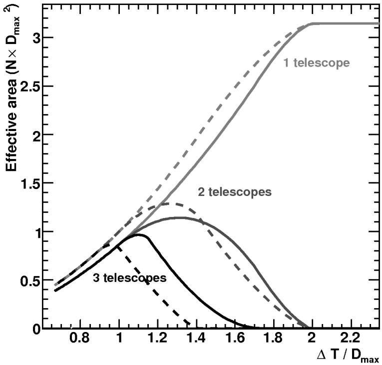


Wider FoV

- An 8 degree field of view would increase exposure by a factor of 4 compared with HESS/VERITAS, provide better background characterization for extended sources, provide a better match to some prompt GRB error boxes.
- A wider field of view combined with a high-resolution camera allows showers to be seen with larger impact distance and better direction determination reconstruction improving angular resolution and effective area.
- A wider field of view may improve spectral reconstruction due to reduced fluctuations in Cherenkov light intensity.

Geometrical Approach

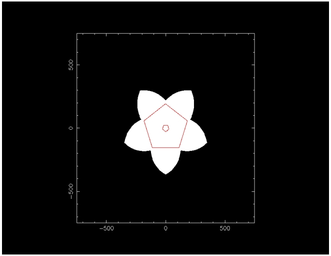
Assume: the effective collection area at a given energy depends on the maximal distance, D_{Max}, guarantying a single-telescope detection and on the minimal number of telescope required to participate in an event.



P. Colin and S. LeBohec, 2009 ΔT: inter-telescope distance.

- $\Delta T \ll D_{Max}$: $A_\gamma \sim \Delta T^2$
- 1 tel: $A_\gamma = N \cdot \pi \cdot D^2_{Max}$ at $\Delta T \geq 2D_{Max}$ (no more overlap)
- $A_\gamma \to 0$ when $\Delta T > 2D_{Max}$

+ assume: 2-tel trigger, the angle between the lines connecting triggered telescopes and the shower core is greater than $\sim 30^\circ$.



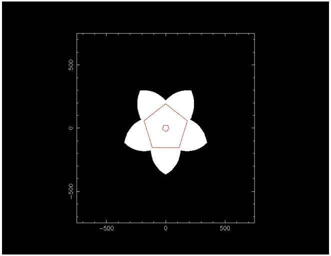
The *white* areas indicate the regions where showers would trigger an array consisting of two concentric cells, each having 5 telescopes.

Optimal layout/ΔT

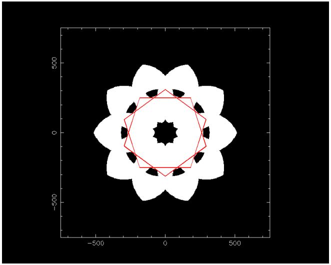
- $N_{\mathrm{trig}} \geq 2$: **square** array; ΔT =1.265 D_{Max}.
- $N_{\mathrm{trig}} \geq 3$: **hexagonal** array; ΔT = 1.1 D_{Max}.
- $D_{Max} \simeq$ **150**m as it will be shown later.

Detection Area Optimization

Array layout *before* optimization



Array layout *after* optimization



The area *per telescope* A_{1tel}

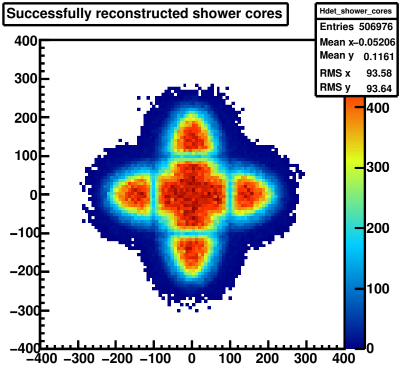
- Concentric cells (1–5) with different number of telescopes (3–8), $N_{\mathrm{trig}} > 1$.
  A_{1tel} is approximately the same.
- 1. Infinite arrays with uniform spacing vs.
  2. arrays consisting of widely spread cells with non-overlapping detection areas

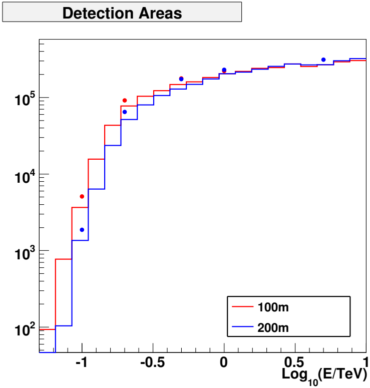
  triangular cells; $N_{\mathrm{trig}} = 3$

  According to the "toy" model $A_{\mathrm{1tel}} > 1.5 A_{\mathrm{1tel}}$.

  In case of a finite uniform array the inequality would be even stronger. Thus we observe the power of a large uniform array over a simple sum of independent cells.

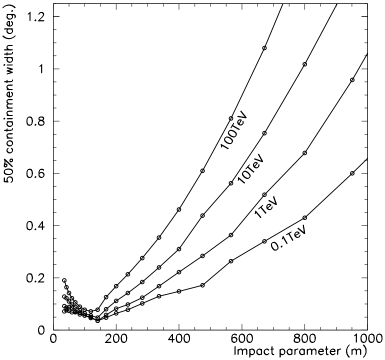
Calculation of Detection Area Using a Toy Model





General Considerations

Image *Width* parameter



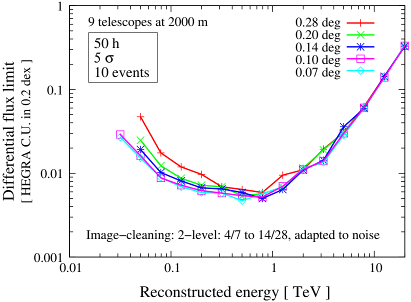
To allow good event reconstruction, *PS* should be smaller than image *Width* of the most compact shower images, which are in the closest telescope.
Distribution of the closest image parameter for a rectangular lattice peaks at $0.5\Delta T$.

Optimal Pixel Size

For an array with 100m rectangular cells the initial guess for the optimal *PS* is 0.1°.

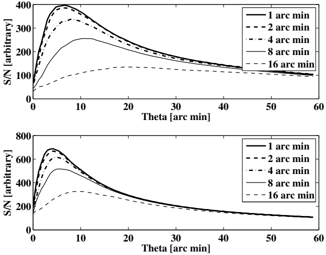
Detailed Simulations

9 420m^2 CTA telescopes



K. Bernlöhr, 2008

Infinite array of hexagonally packed 75m^2 telescopes; $\Delta T = 80$m

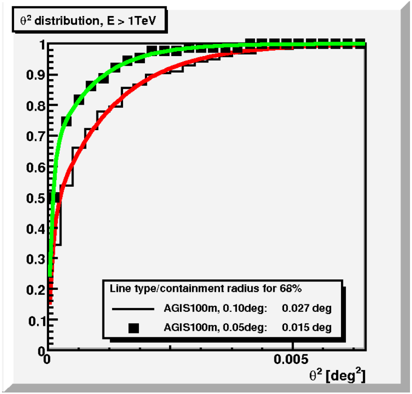


S. J. Fegan and V. V. Vassiliev, 2007

Smaller Pixel Size

- Smaller *PS* results in higher sensitivity. At least at lower energies.
- The sensitive area outside of an array is dominating at higher energies. It is the area with lower telescope trigger multiplicities. Lower multiplicities obscure the advantage of smaller *PS*.

Advantage of a Smaller Pixel Size



Comparison of angular resolutions for $PS = 0.05^\circ$ and $PS = 0.10^\circ$.
$E > 1\mathrm{TeV}$
Infinite array
$\Delta T = 100\mathrm{m}$

Typical angular scales

- Nearby SNR $\sim 10 - 30'$
- Extended PWNe $\lesssim 2 - 10'$
- Crab Termination shock $0.8'$

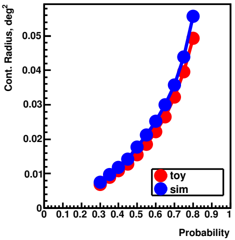
Advantage of Smaller Pixel Size

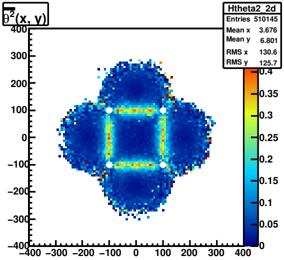
- Smaller *PS* results in higher angular resolution for higher energies in case of infinite array.
- Results on angular resolution calculated for infinite array approximation can be achieved (improved) for a finite array by taking into account only showers with cores within the footprint of the array.
- The improvement would be achieved by sacrificing 50–70%.

Pixel Size Optimization Using a Toy Model

- Angular resolutions for a few telescope layouts per second can be calculated using toy models.
- Distributions of trigger probability and image orientation/centroid parameters are used in the model.

A satisfactory agreement on angular resolution between the toy model and detailed simulations.

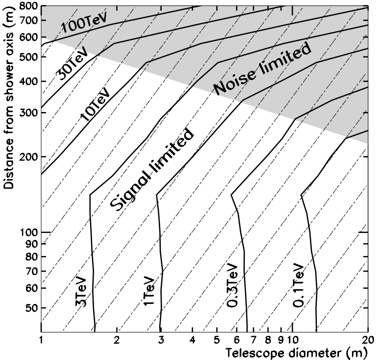




Optimal Pixel Size

If distributions of image orientation/centroid parameters for some small pixel size are "better" than distributions for larger *PS*, such *PS* is the optimal pixel size.

Optimal Telescope Spacing

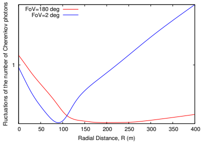


P. Colin and S. LeBohec, 2009

The dashed lines are iso-cost curves for arrays assuming the price is proportional to $\frac{d^{2.7}}{\Delta T^2}$.

- For energies higher than 0.3TeV, the distance of the first break in the isolines determines the upper limit for the telescope spacing. Larger telescope dishes result in higher cost of 1m^2 of Effective Area.

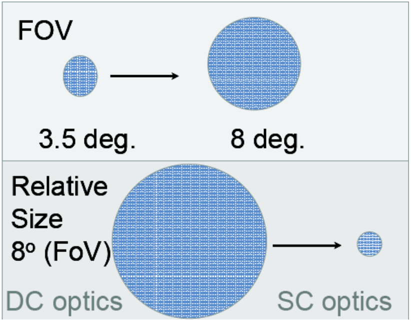
Fluctuations in the image size

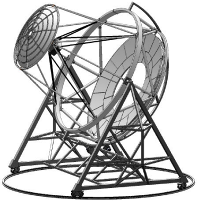


Optimal Spacing

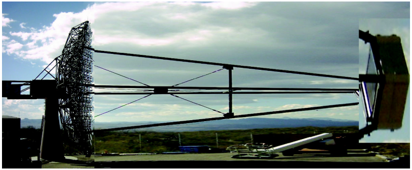
- For $Ze = 30^\circ$, the optimal spacing is $\simeq$ 175m. This is the distance to Cherenkov hump (150m) adjusted with respect to the Ze angle.
- The most probable shower impact parameter would also be in the range (70 – 150 m) providing smaller image fluctuations

Schwarzschild Couder Optical System

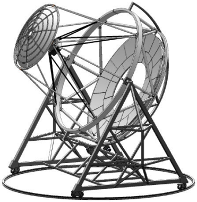


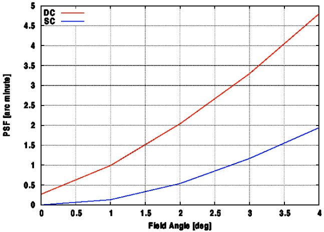


versus



Schwarzschild Couder Optical System





SC Optical System provides

- plate scale reduction
- aberration correction
- isochronous optics for fast timing
- lower moment of inertia for fast slewing

Summary

- Design of Next Generation IACT arrays involves optimization of many key telescope characteristics and parameters of an array layout.
- Properties of γ showers as well simple geometrical considerations may be used for selection of an initial guess for detailed Monte Carlo simulations.
- Parameters of IACT arrays considered: Field of View, Pixel Size, array layout, array spacing.