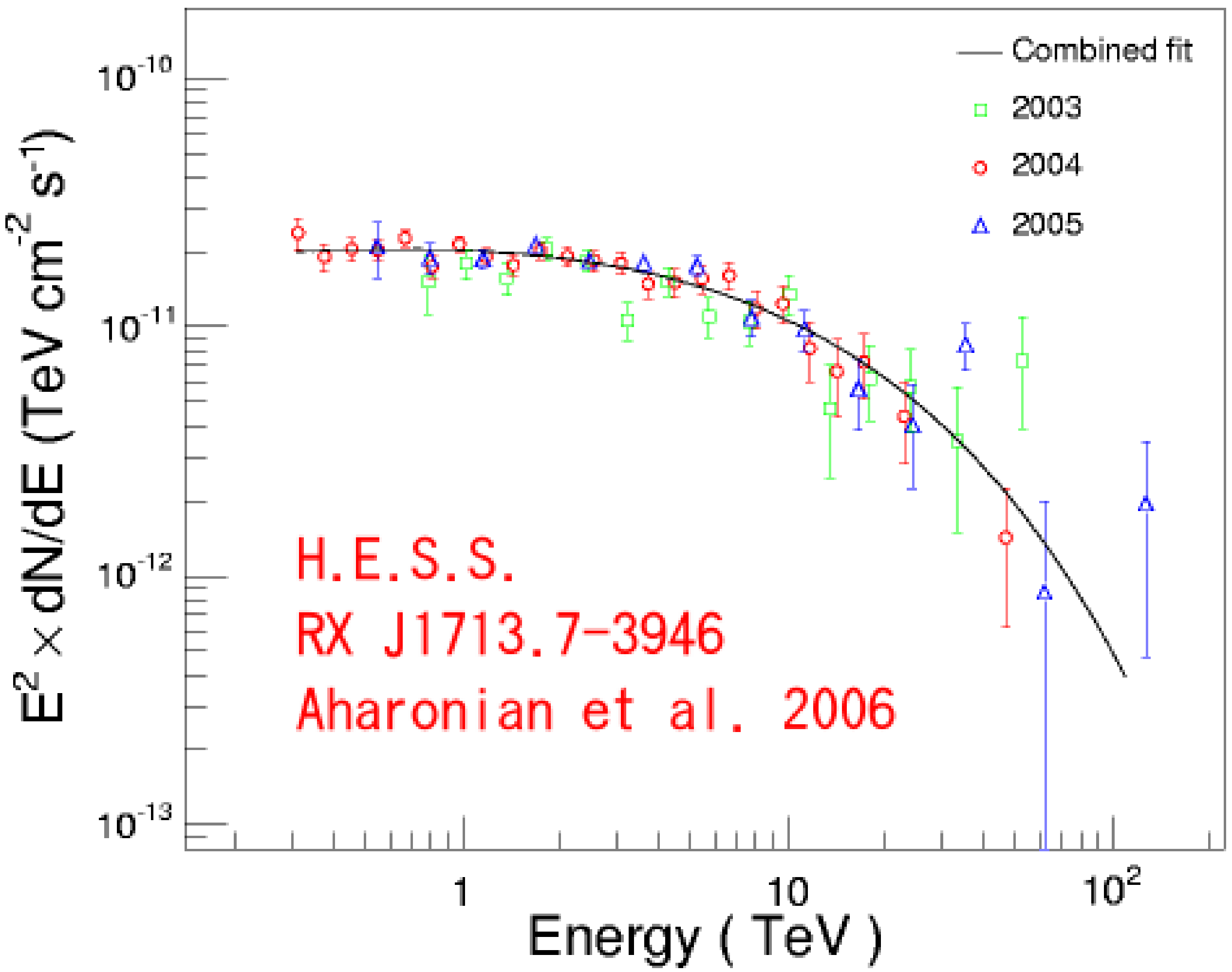
Simulations and R & D Studies for 100 TeV Gamma-Ray Astrophysics with a Large Effective Area IACT Array

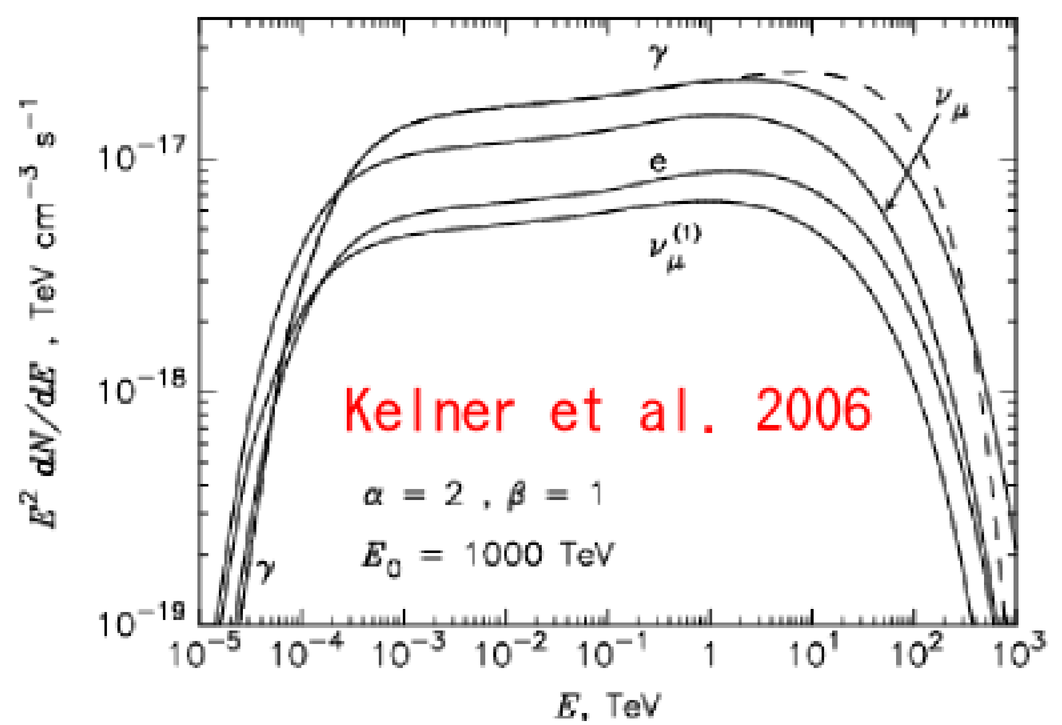
T. Yoshikoshi
ICRR, University of Tokyo
tyoshiko@icrr.u-tokyo.ac.jp

December 7, 2006 @ Adelaide Workshop

Scientific Motivation (1)

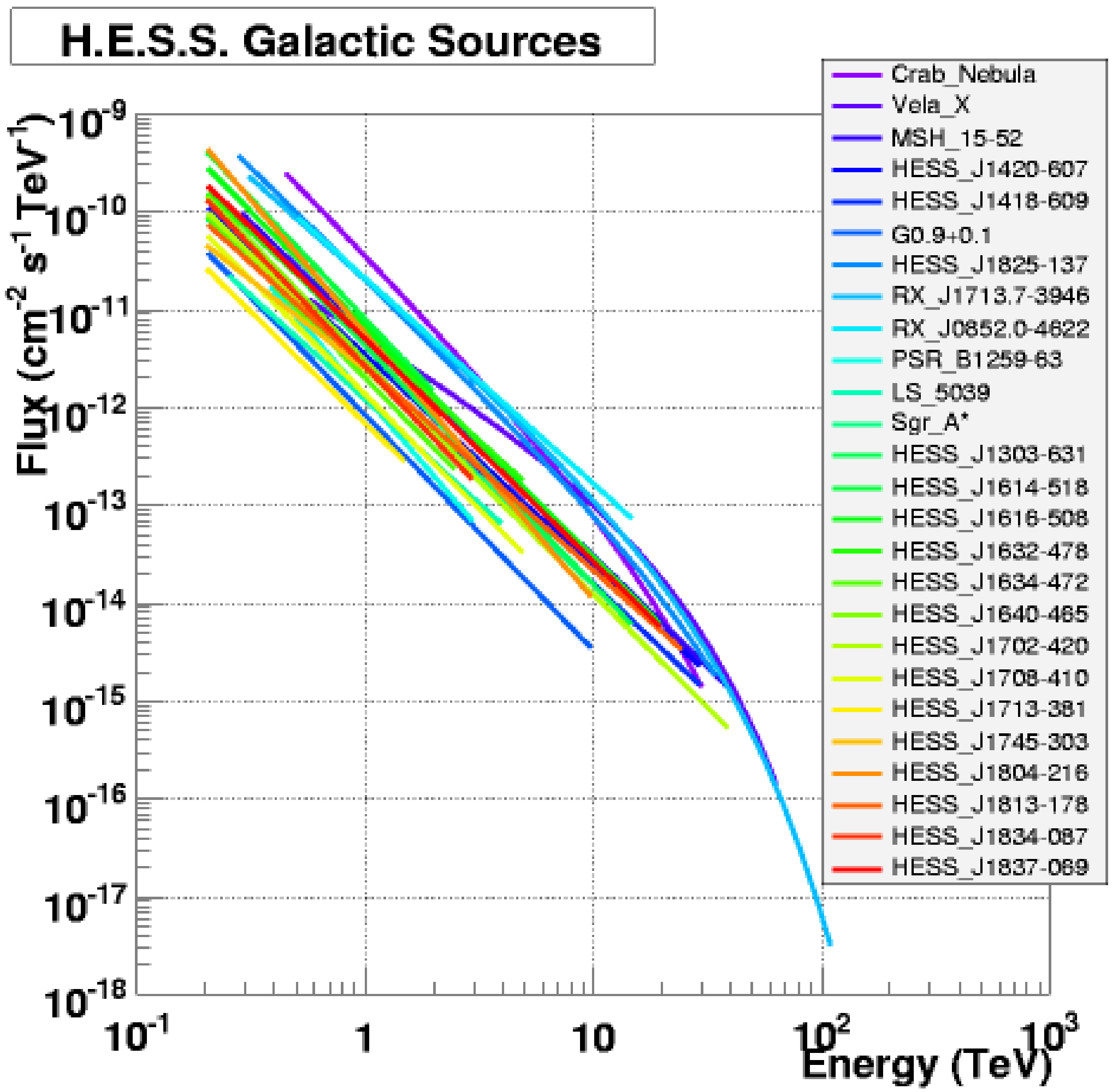
- **Origin of Galactic cosmic rays**
  - Shell-type SNR is the origin up to the knee?
- **RX J1713.7-3946 spectrum measured by H.E.S.S.**
  - Cut-off @ 18 TeV
  - Slow cut-off around 10 TeV expected
    - Kelner et al. 2006
    - Huang et al. 2006
  - No evidence up to the knee
- **Deeper observations necessary**
  - At higher energies
  - More SNR samples

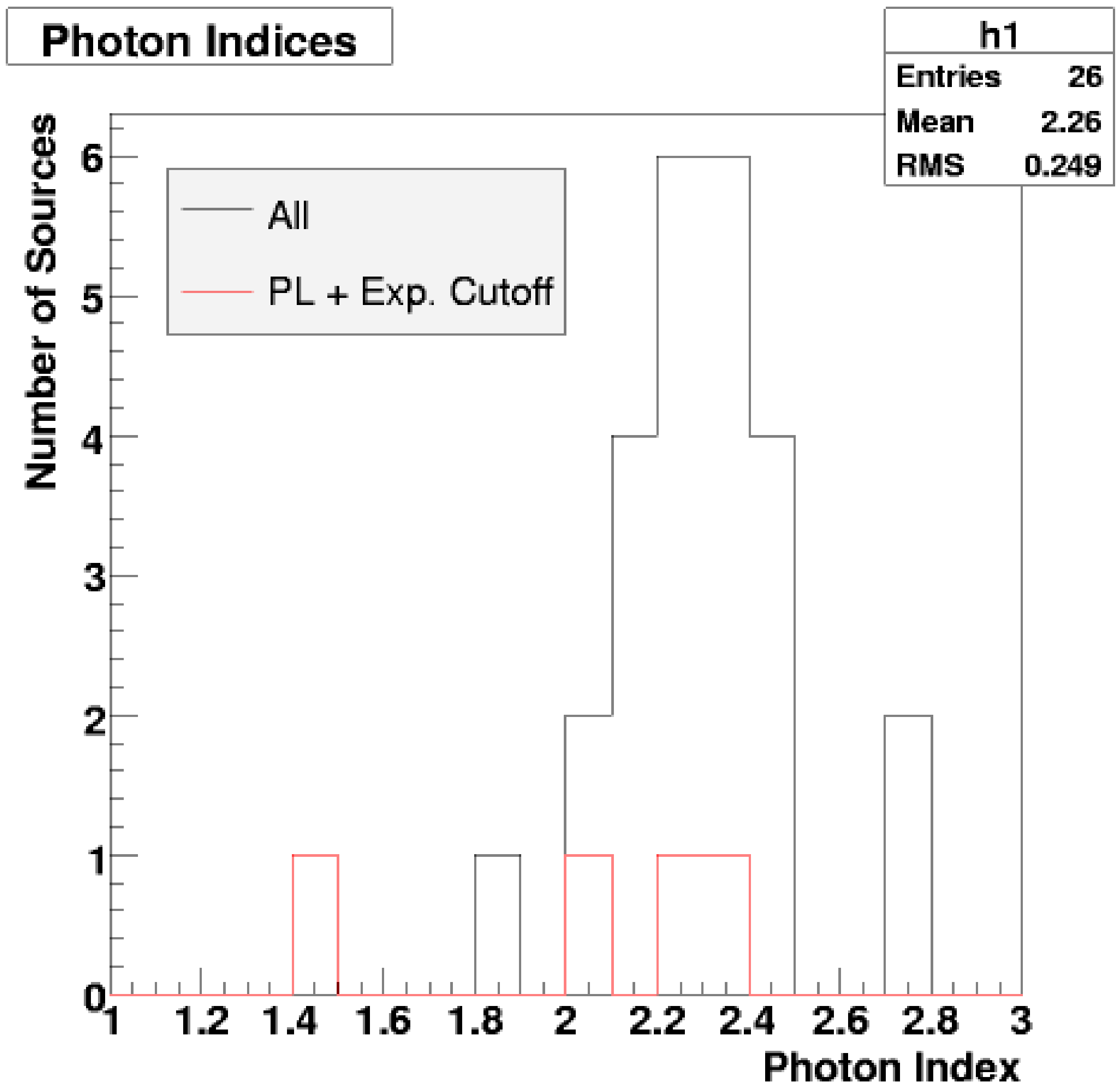




Scientific Motivation (2)

- Hard spectra of Galactic H.E.S.S. Sources
  - Better S/N at high energies





Large Effective Area Is Necessary

- **Sensitivity:**

$$N_\sigma = \frac{N_\gamma}{\sqrt{N_B}} = \frac{F_\gamma A_{\mathrm{eff},\gamma} t \epsilon_\gamma}{\sqrt{F_B \Omega A_{\mathrm{eff},B} t \epsilon_B}} \propto \frac{F_\gamma}{F_B^{1/2}\Omega^{1/2}} A_{\mathrm{eff}}^{1/2} t^{1/2} Q$$

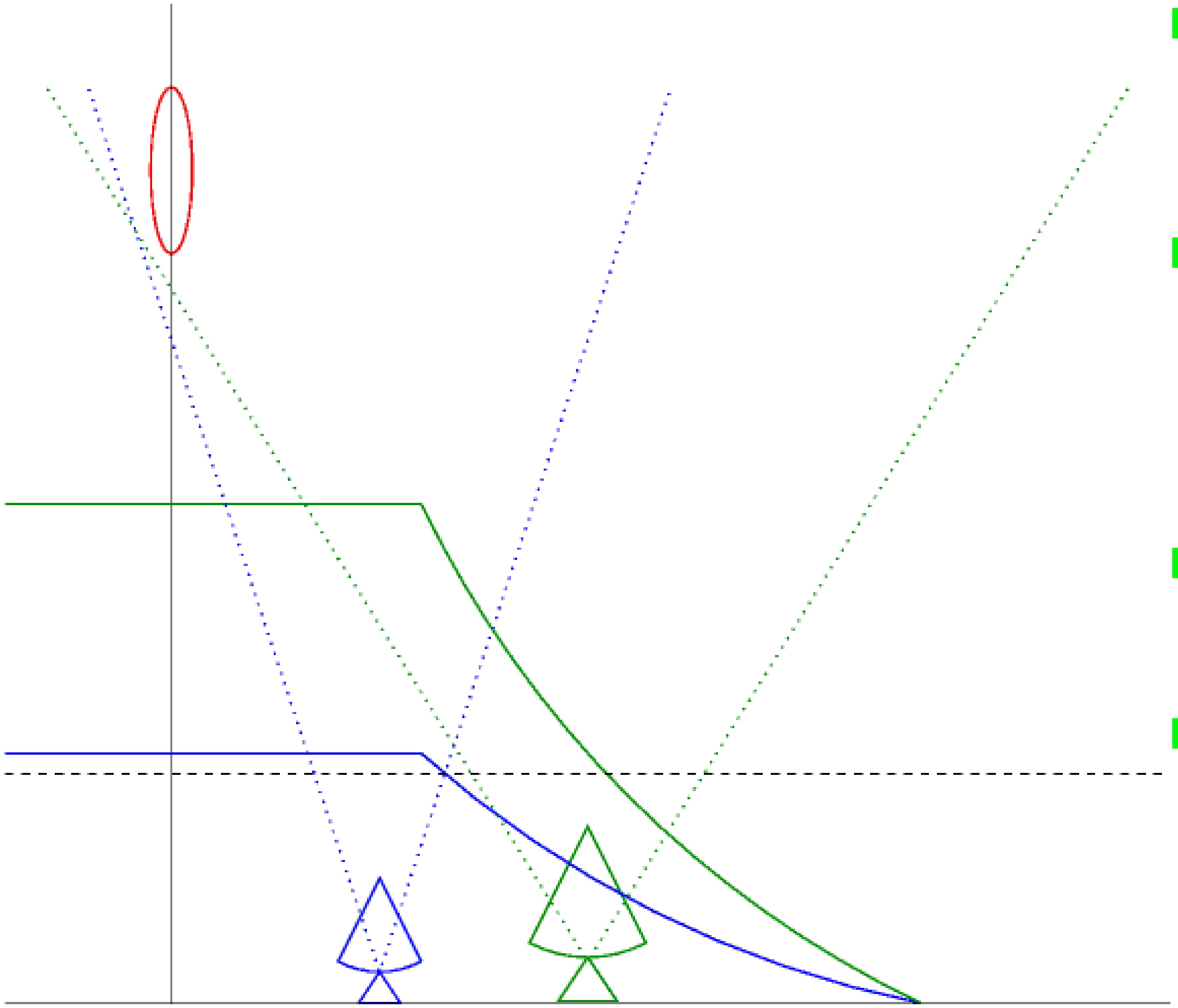
F: flux
Ω: field of view in solid angle
t: observation time
ϵ: efficiency of γ-ray image selections
$A_{\mathrm{eff}} = A_{\mathrm{eff},\gamma} \propto A_{\mathrm{eff},B}$ (assumption)
$Q = \epsilon_\gamma / \epsilon_B^{1/2}$

- Factor $A_{\mathrm{eff}}^{1/2} Q$ controlled relatively easily

- Large effective area is necessary
- Keep high Q → stereoscopic IACT system

→ IACT array

How Is the Effective Area Determined?



Plyasheshnikov et al. 2000

- **Cherenkov plateau**
  - Radius ～ 150 m
- **Cherenkov tail observable with larger aperture**
  - Expand effective area
- **Wider FOV necessary**
- **Effective area is a function of:**
  - Telescope aperture
  - Telescope span
  - Field of view

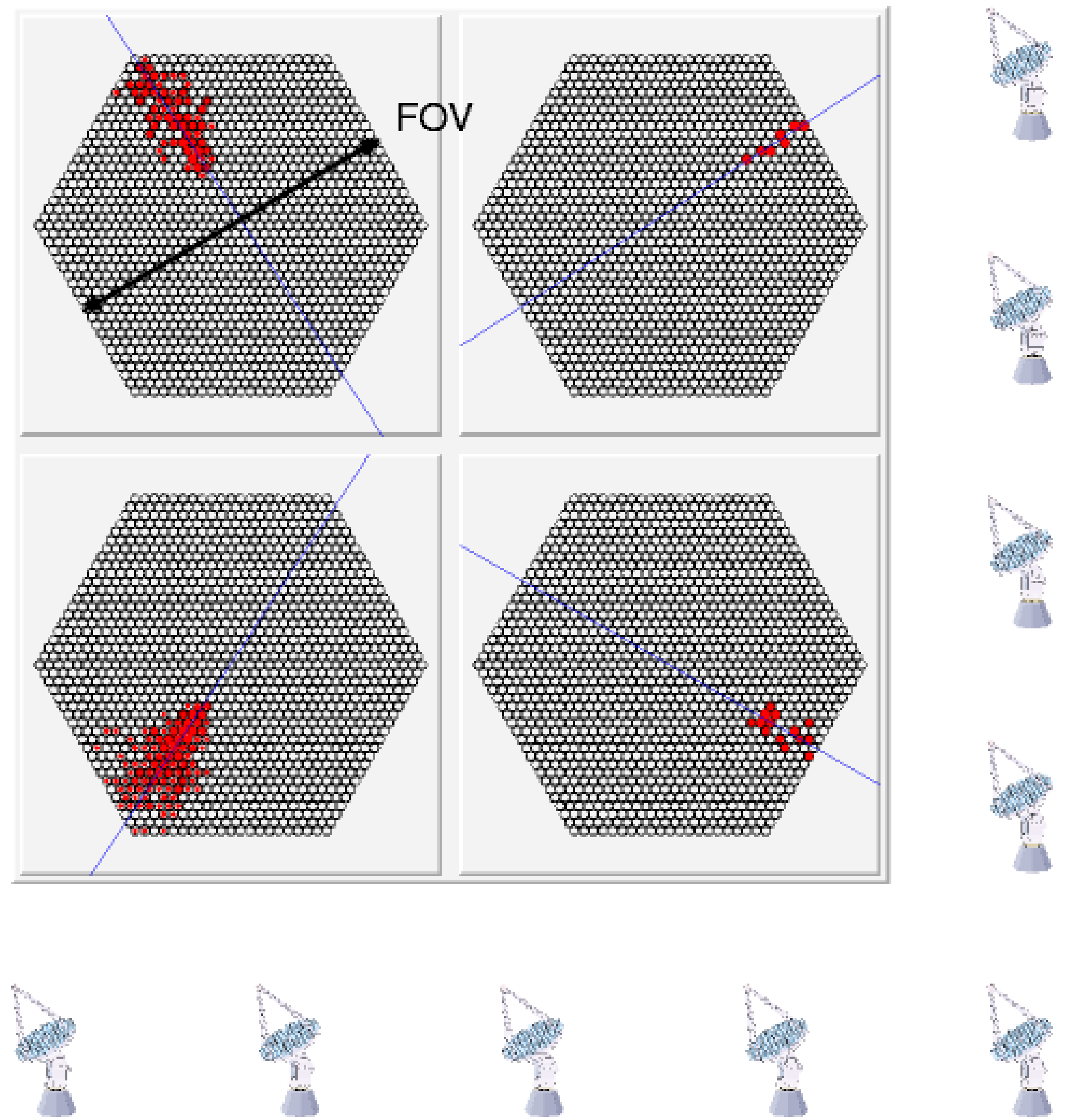
Simulations

Effective area of a cell

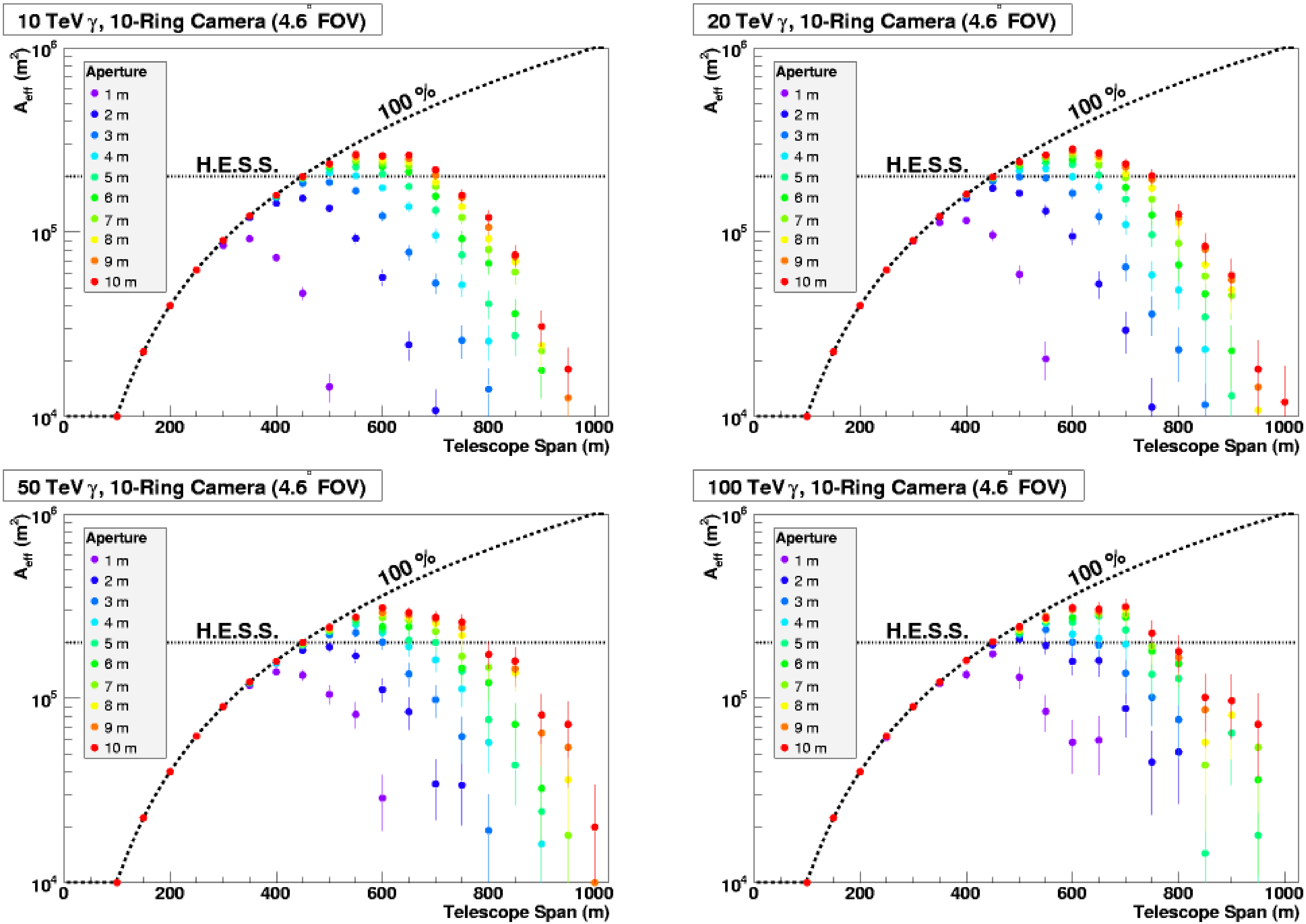
- Net response of one telescope
- $A_{eff}(total) = A_{eff}(cell) \times N$

Conditions:

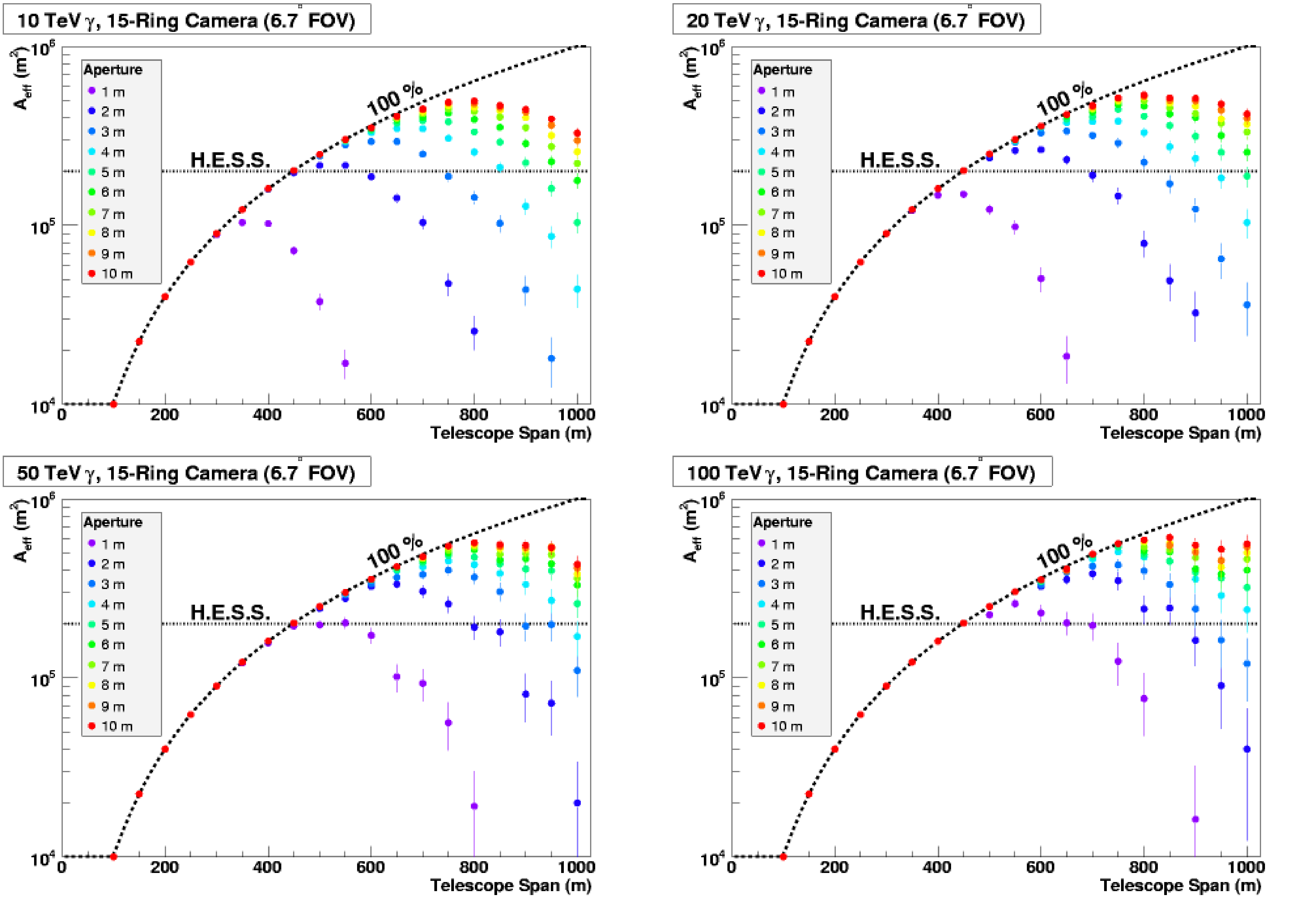
- CORSIKA 6.20
- Gamma rays from a vertical point source
- Geomagnetic field in Woomera
- Altitude: 160 m (Woomera)
- Parabolic reflector (f = 1)
- No blurring
- No NSB
- Hexagonal camera (0.25° pixel)
- Trigger: 5 p.e. × 3 adjacent pixels × any 2 telescopes
- Trigger efficiency only



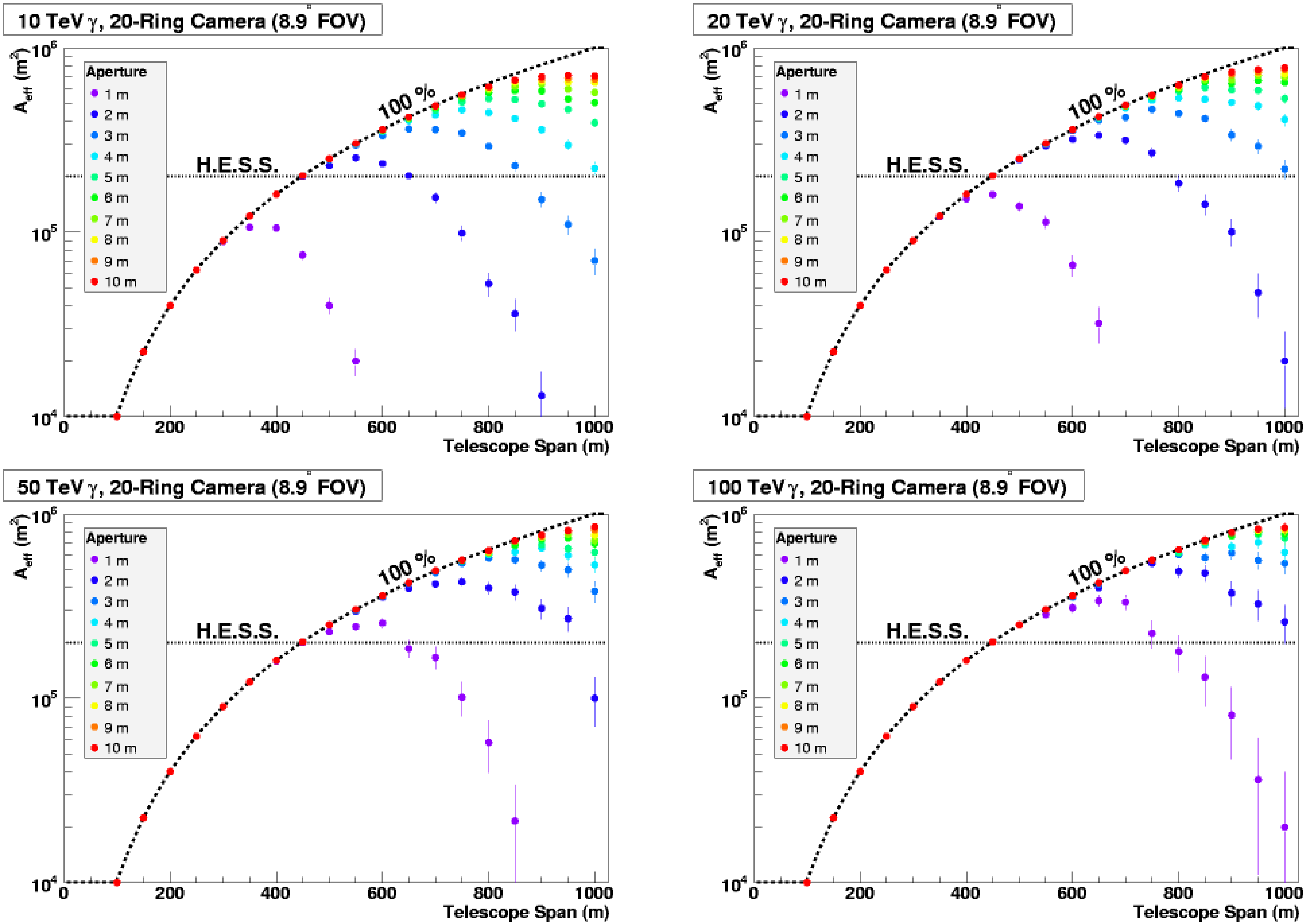
Effective Area of a Cell (4.6° FOV)



Effective Area of a Cell (6.7° FOV)



Effective Area of a Cell (8.9° FOV)



Optimization of the Array Design

Cost curve for one telescope:

- Mount and mirrors: Cost $\propto D^{2.7}$ (D: aperture)
- Camera and electronics: Cost $\propto N_p$ (N_p: number of pixels)
- Total: Cost $\propto D^{2.7} + \alpha N_p$
- Normalization α assumed as:
  - $(5\ \mathrm{m})^{2.7} = \alpha \times 500$ pixels

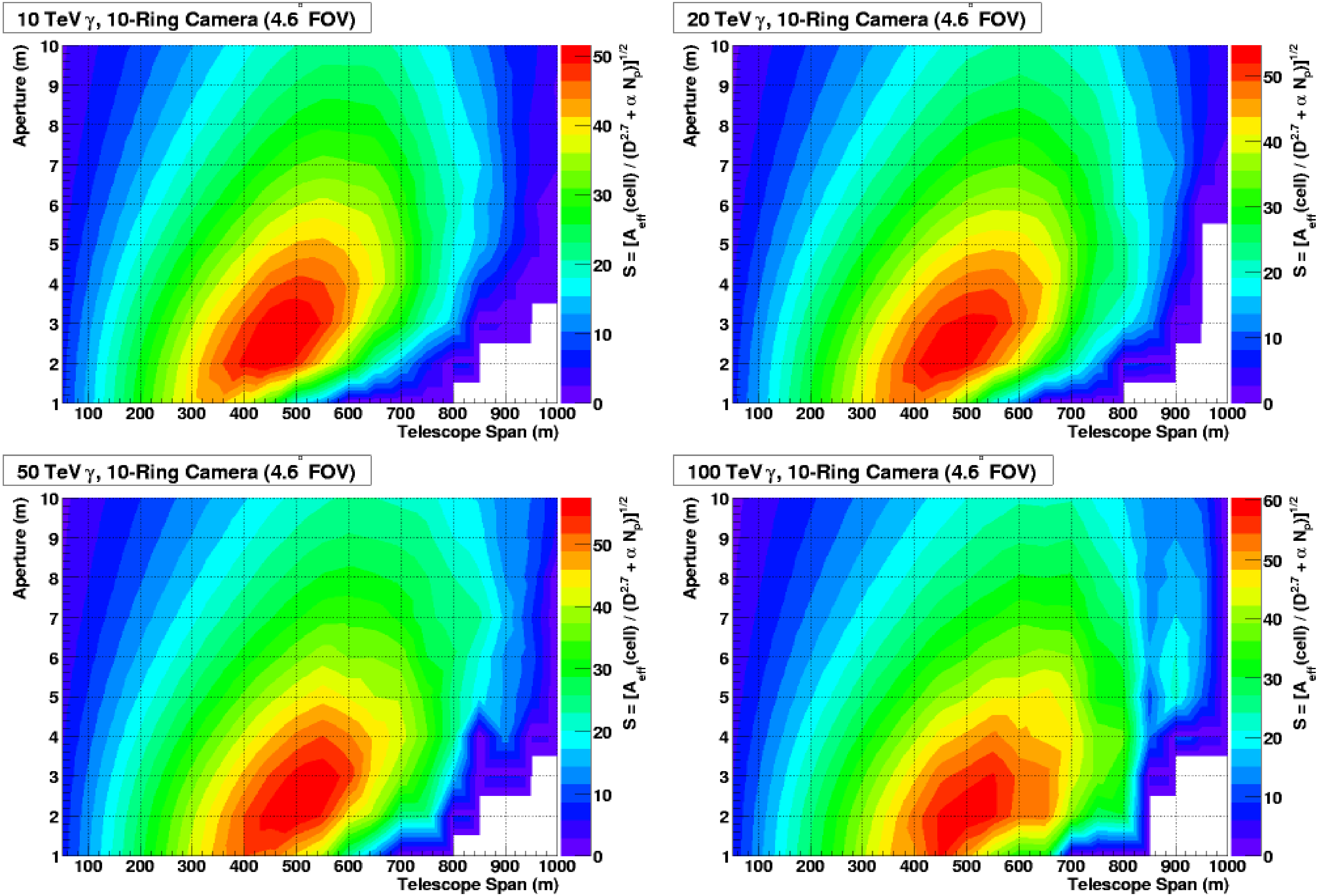
Maximize the effective area with a fixed cost:

- $A_{eff}(\mathrm{total}) = A_{eff}(\mathrm{cell}) \times N$ (N: number of telescopes)
- Cost $\propto (D^{2.7} + \alpha N_p) \times N$
- $A_{eff}(\mathrm{total}) \propto A_{eff}(\mathrm{cell}) \times \mathrm{Cost} / (D^{2.7} + \alpha N_p)$

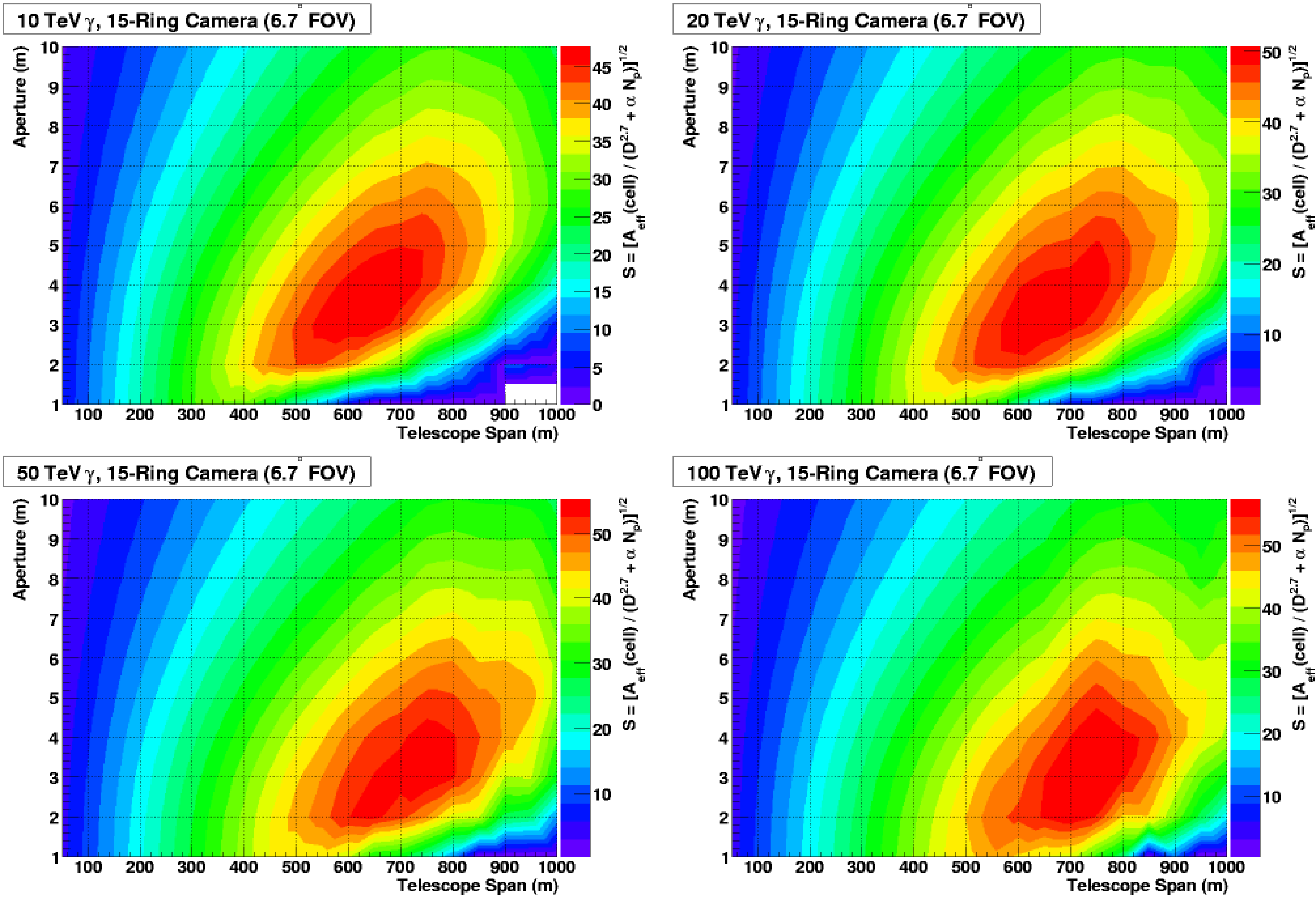
Sensitivity proportional to:

- $S \equiv [A_{eff}(\mathrm{cell}) / (D^{2.7} + \alpha N_p)]^{1/2}$

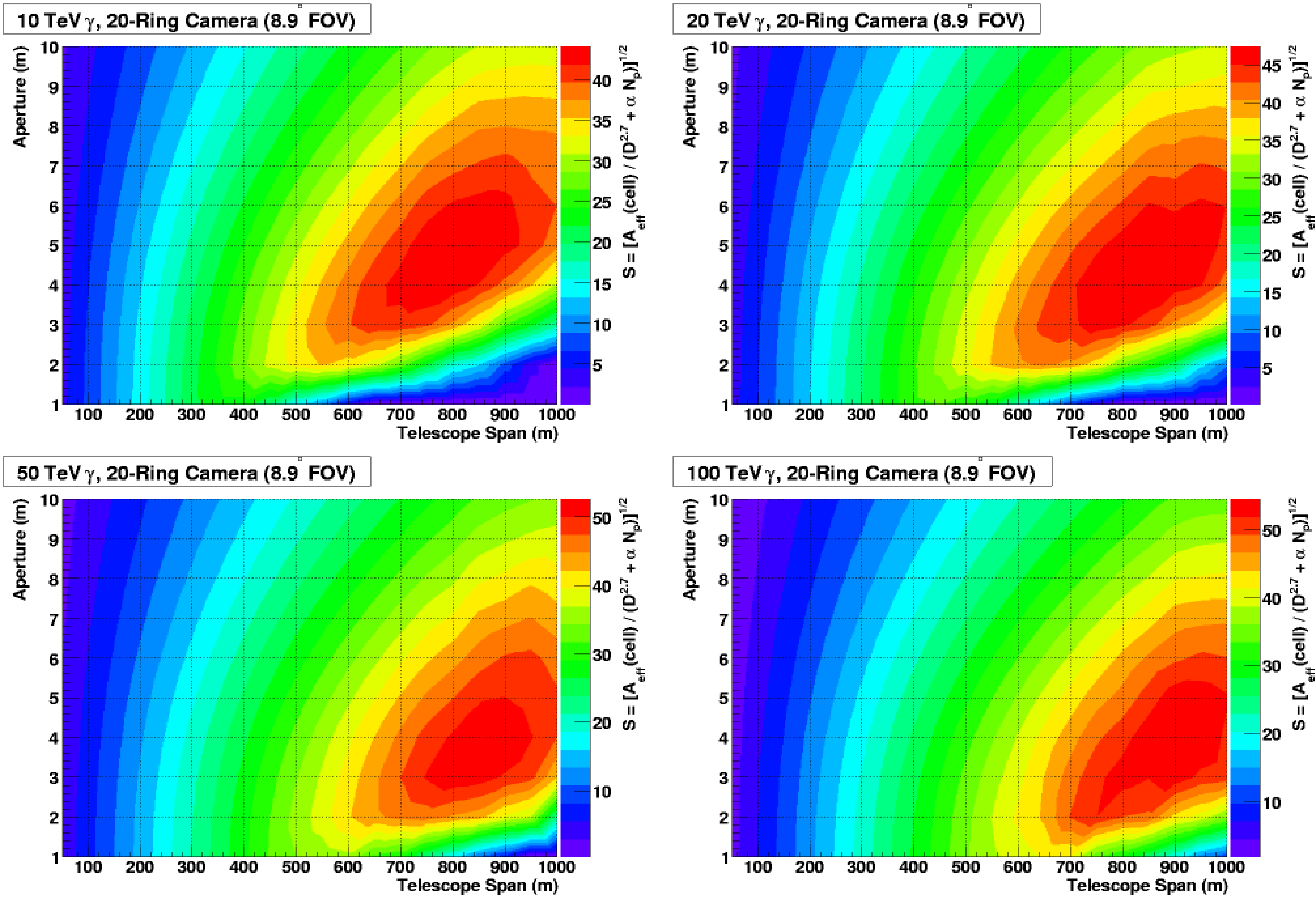
Relative Sensitivity (4.6° FOV)



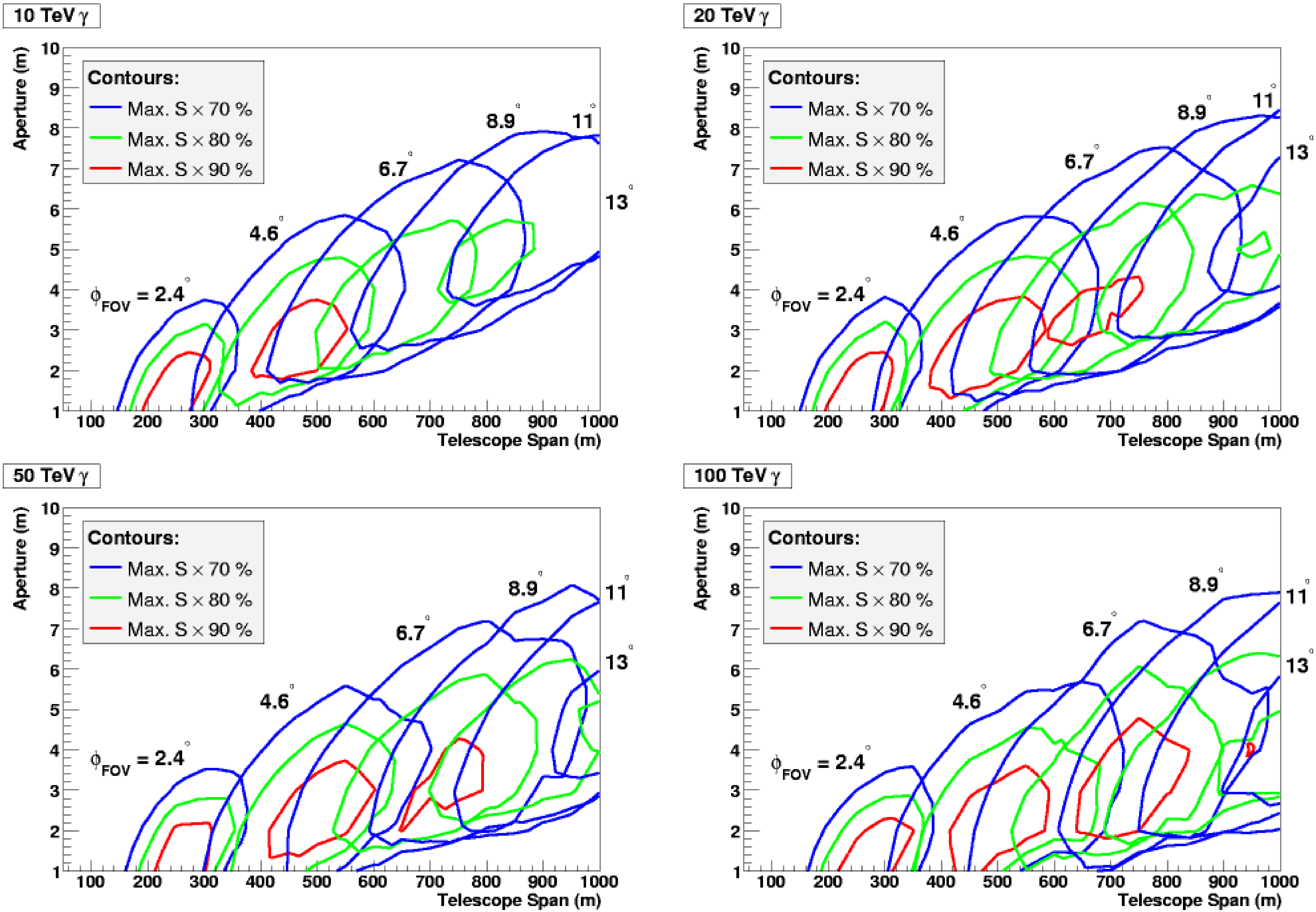
Relative Sensitivity (6.7° FOV)



Relative Sensitivity (8.9° FOV)



Relative Sensitivity (Combined)



Rough Estimation of the Sensitivity

Assumption:

- $A_{eff}(\gamma\text{-ray image selections}) \sim A_{eff}(\text{trigger}) \times 0.5$
- Q is the same as H.E.S.S.

Best combination of the parameters:

- Aperture ～ 3 m
- Telescope span ～ 500 m
- FOV ～ 5°
- $A_{eff}(\text{cell}, \gamma) \sim$ H.E.S.S. × 0.5
- Sensitivity of 25 IACTs ～ H.E.S.S. × 3

If we want a wider FOV for extended sources:

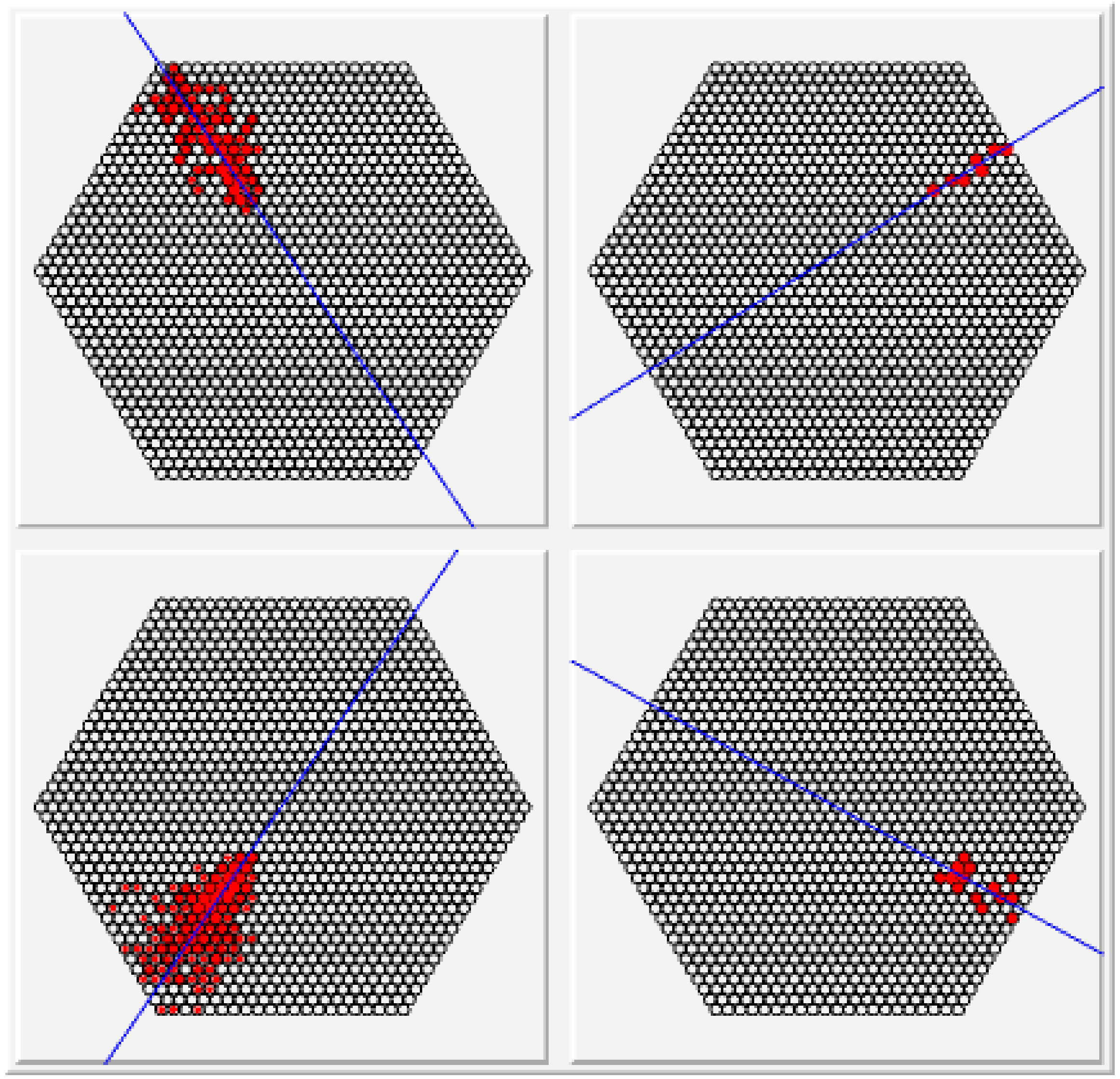
- Aperture ～ 3 m
- Telescope span ～ 700 m
- FOV ～ 7°
- $A_{eff}(\text{cell}, \gamma) \sim$ H.E.S.S. × 1
- Sensitivity of 25 IACTs ～ H.E.S.S. × 5

Cherenkov Image Quality at Large Core Distances

- Angular resolution expected to be worse
  - Less photons → more fluctuation
  - Photons from scattered electrons
  - Longer distance between image and source in FOV
  - Effect of coma aberration

- These effects should be considered in simulations

10 TeV γ
3 m aperture
500 m span
20-ring camera (8.9° FOV)



R & D Plan

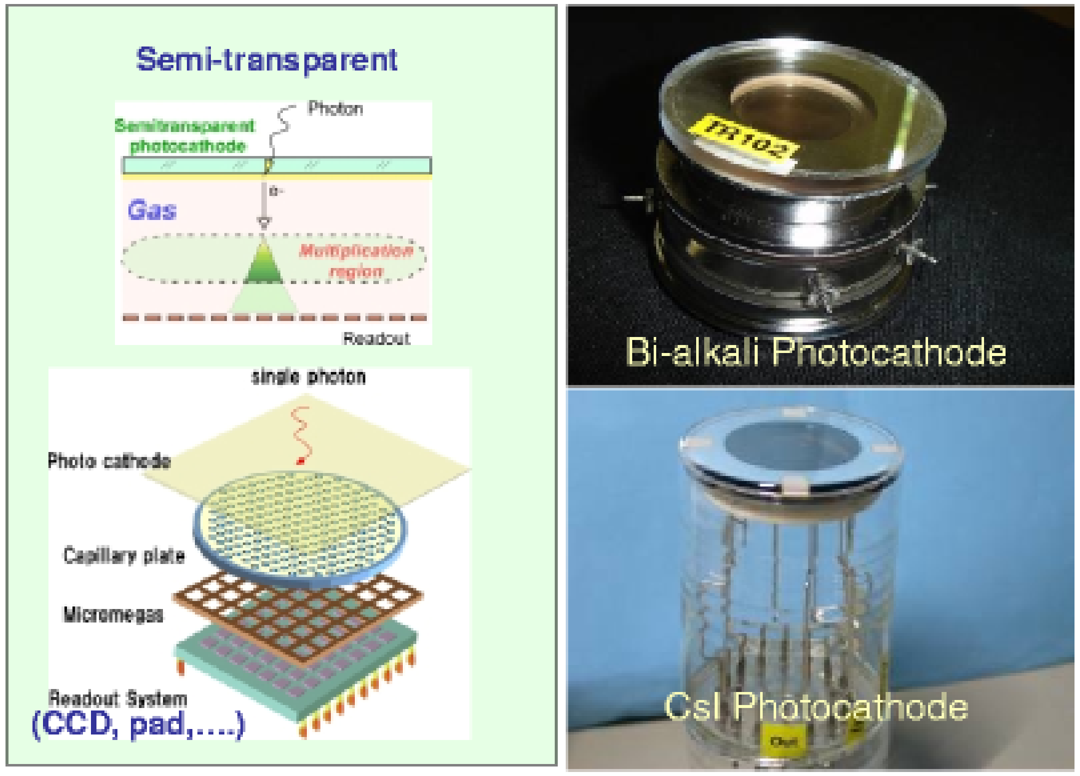
Make a prototype telescope first

- Place it in Woomera
- Stereoscopic performance checked with the Adelaide group

Options:

- Adaptive optics:
  - Fresnel lens to correct aberrations
    - Ohmori (RIKEN)
- Photodetectors:
  - Normal PMT camera as first stage
  - Gas PMT camera developed
    - Tokanai, Sakurai, Gunji (Yamagata)
    - Sumiyoshi (TMU)
    - Hamamatsu

Future plan of gaseous PMT using MPGD



Tokanai et al., IEEE NSS 2006, San Diego

Summary

Simulations of IACT arrays

- Energies between 10 and 100 TeV
- Effective area of a cell as a function of
  - Telescope aperture
  - Telescope span
  - Field of view
- Cost effective design investigated
  - H.E.S.S. sensitivity × 3 ～ 5 is possible with 25 IACTs
- Further study including imaging analyses necessary

R & D plan

- Prototype telescope placed in Woomera
- Cooperation with the Adelaide group