The Low Energy Array of A Major Future VHE Gamma-ray Experiment

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Major Physics Goals

- Further observation of SNR: Origin of Cosmic Rays
- Detailed studies of physics of AGN jets
- Cosmology link: EBL γ-ray absorption
- Resolving morphology and spectra of γ-rays from PWN
- Detection of pulsed γ-ray emission from Pulsars
- Search for Dark Matter
- Observation of γ-ray Bursts
- etc

Extent of energy spectra below 100 GeV is highly desirable!

Major Imaging Cherenkov Telescopes

Experiment	Location	Latitude	Longitude	Height	Current status	Extension
CANGAROO	Australia, Woomera	-31.1	221.2 W	160 m	4 x 10 m	
HESS **HESS-II**	Namibia	-23.3	16.5 W	1800 m	4 x 12 m	**+ 28 m** in 2008
MAGIC **MAGIC-II**	Canary Island La Palma	28.7	17.9 W	2200 m	17 m	**+ 17 m** in 2007 **High Q.E.**
VERITAS	Arizona, USA	32	111.6 W	1275 m	4 x 12 m	
MACE	India, Hanle	32.7	281.0 W	4200 m		**21 m** in 2010

Problems at low energies

- Muons can be rejected by stereo trigger
- Electrons contribute to background
- Geomagnetic effect deteriorates images
- Hadron rejection is poor
- Angular resolution becomes critical

Low Photon Statistics at Low Energies

- Poor photon statistics, e.g. for a 17 m CT
  - 30 GeV ~700 photons/telescope → ~ 80 ph.e.
  - 10 GeV ~250 photons/telescope → ~ 30 ph.e.

    It does not trigger the telescope!
- Sampling factor* for a 17 m CT
  - mirror/light pool ~1/100
  - photon → ph.e. ~1/10
  - total efficiency ~1/1000

*ratio of detected photons to generated ones

Enhance Photon Statistics

- Large telescope:
  - HESS-II (28 m), ECO-1000 (34 m)
- High Q.E. photon detectors:
  - HPD, SiPM developments for MAGIC-II
- High Altitude:
  - MACE (4.2 km)

Sensitivity Gain at Low Energies

Major parameter : photon statistics

HESS/VERITAS: 4 x 100 m^2 x 0.1 = 40 m^2 (eff. area)
sampling factor ~ 10^{-3}

Next step: to achieve sampling factor ~ 10^{-2}

Possible scenario:

reasonable site ~ 3 km altitude x 1.3
effective mirror area ~ 120 m^2 x 3
advanced photo detectors x 2.5
(leave it for future upgrades!)

Overall factor: x 4 (x 10)

Various Alternatives

Telescope costs : ~ $(D/12)^{2.7}$ M$

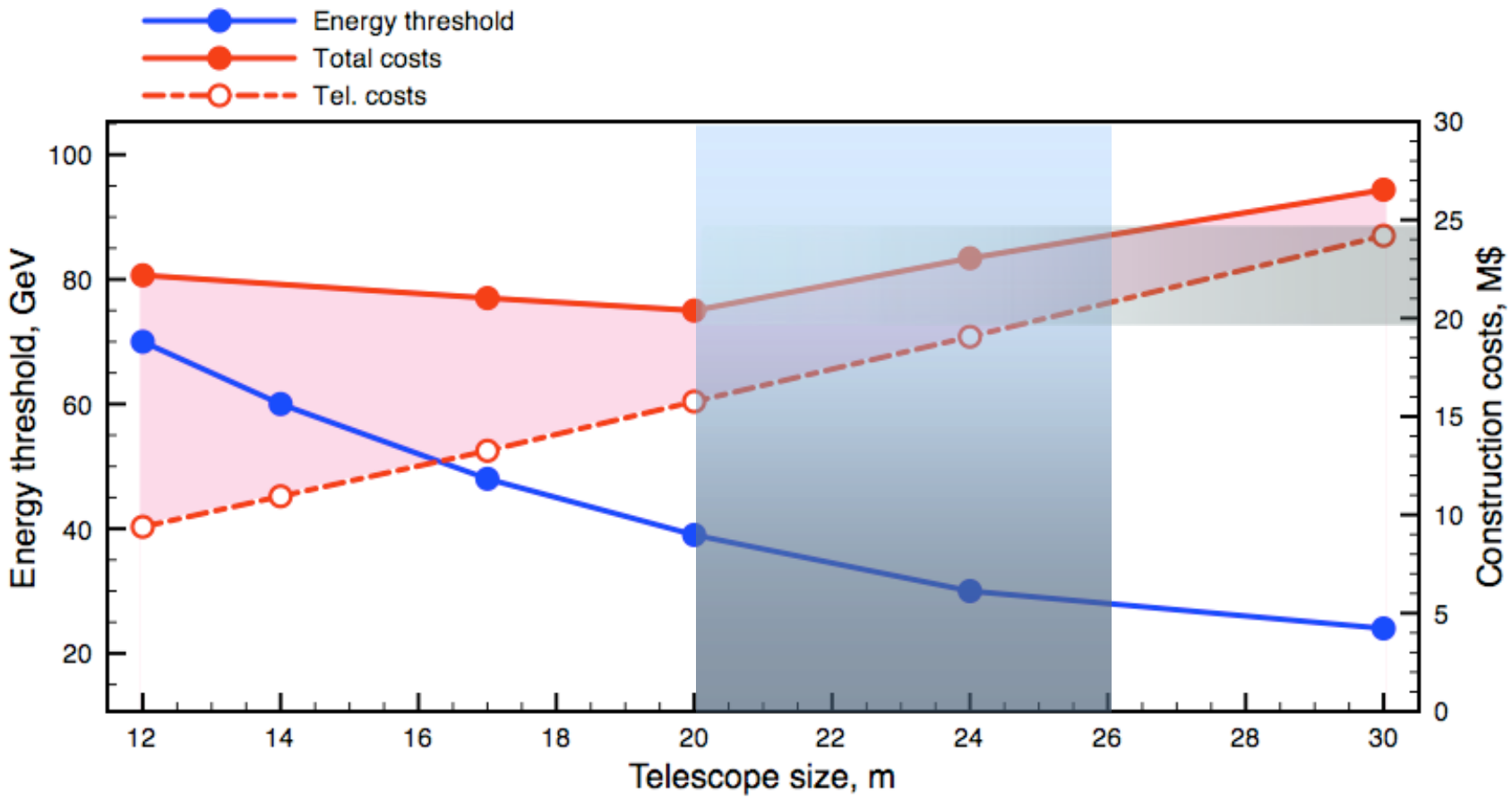
Camera costs : ~ 1 M$ (500$ per channel x 2000 channels)

Total costs: No. of tel.-s. x $[(D/12)^{2.7} + 1]$ M$

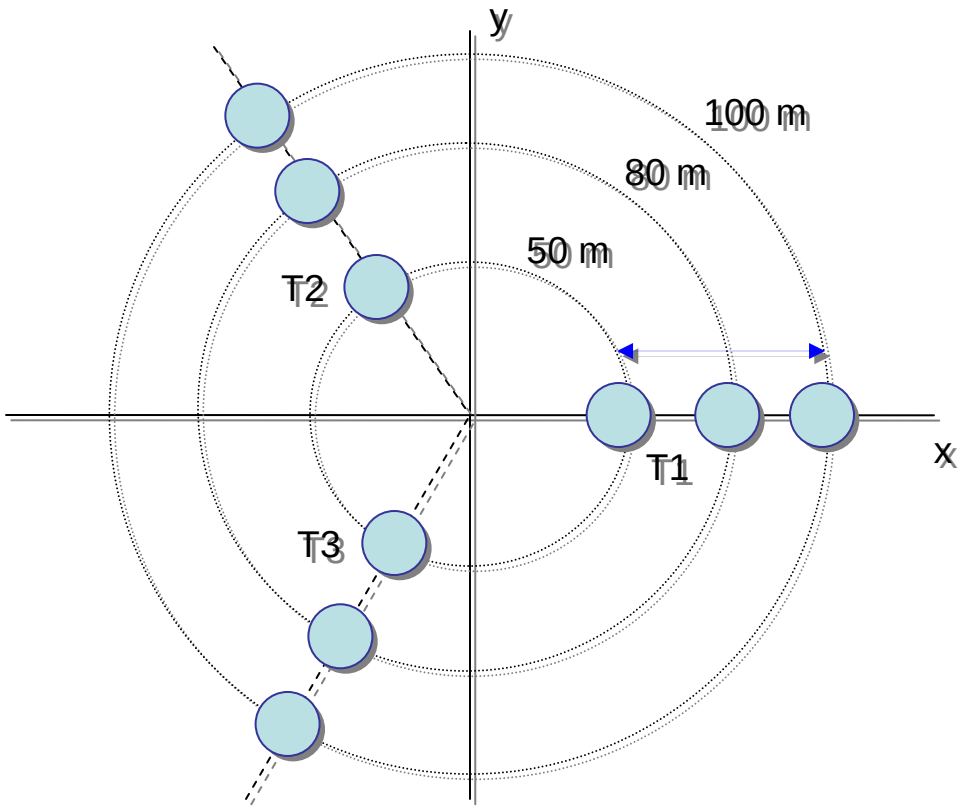
Energy threshold : ~ 100 GeV x $(12/D)^{1/2}$

D, m	A_{eff}, m^2	No. of tel-s.	Tel. costs	Total costs	E_{th}, GeV
12	11.2	11	1	11	100
14	15.4	8	1.5	12	73
17	22.6	6	2.5	15	50
20	31.4	4	4.0	16	36
24	45.2	3	6.5	19.5	25
30	70.6	2	12.	24	16

Energy Threshold vs Costs



Low Energy Stereo Array



We know:

Minimum number of telescopes is 3!

We don't know:

- Which aperture?
- Baseline distance

Large scale array can be composed of triplets

Design Studies

System layout

3 telescopes (parabolic dish)

Baseline distance:	50, 80, 100 m
Telescope size:	12, 17, 20, 24, 30 m
Camera:	various configurations

Monte Carlo simulations

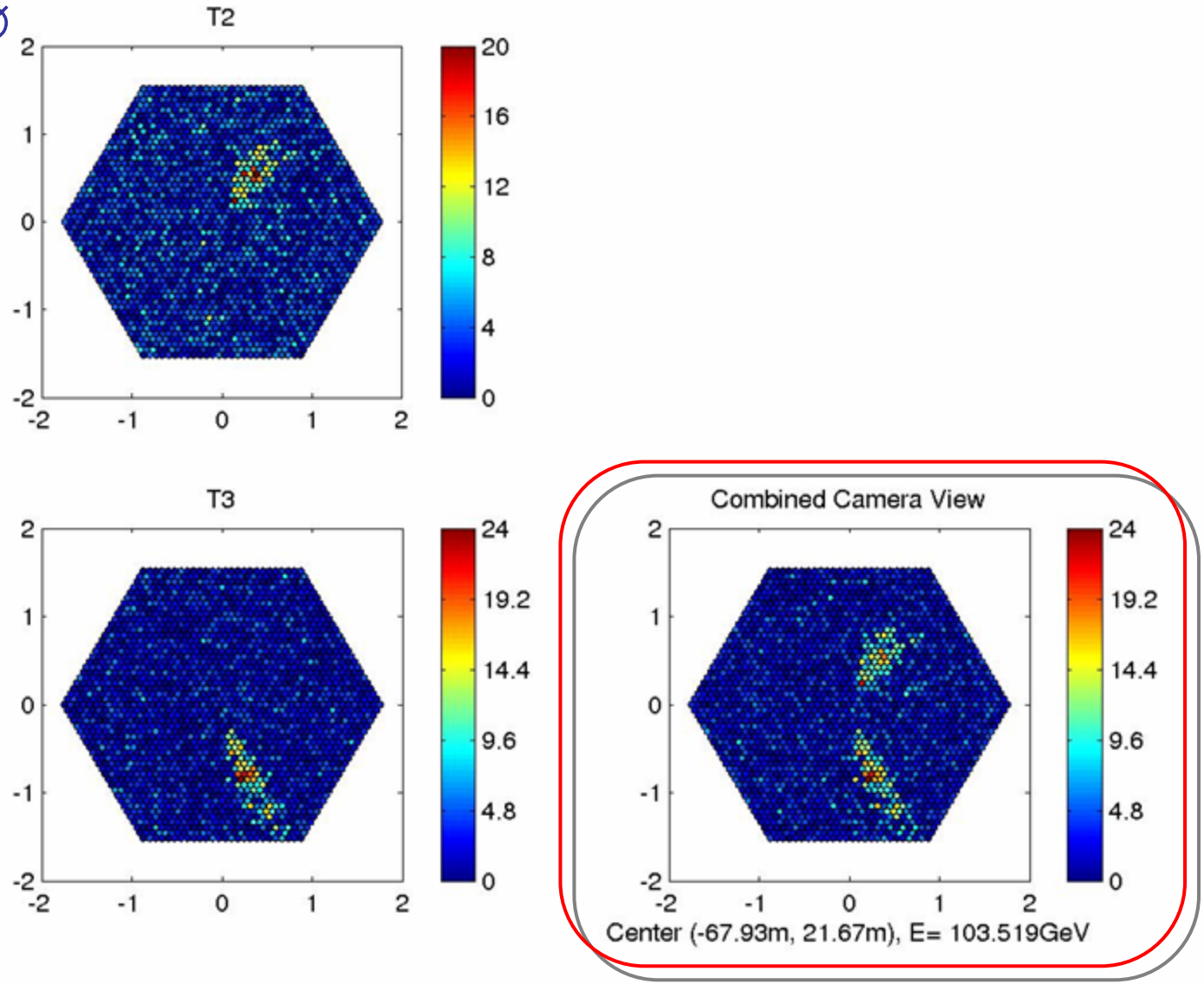
Energy range : 10 GeV - 1 TeV

Impact distance : 0 - 10^3 m

Primaries : γ rays, protons

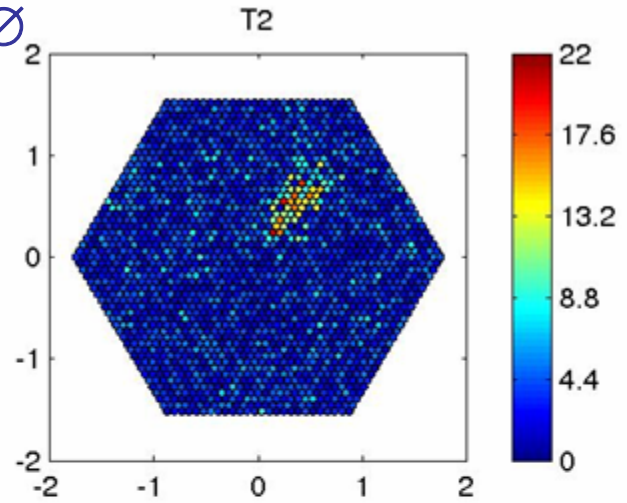
Stereo Event

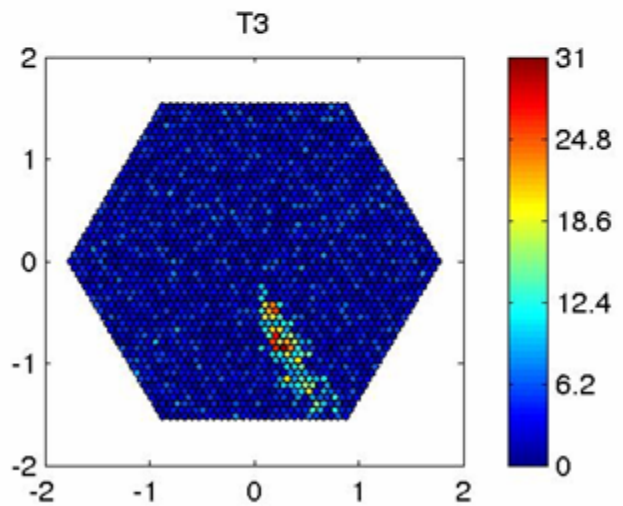
17 m ∅

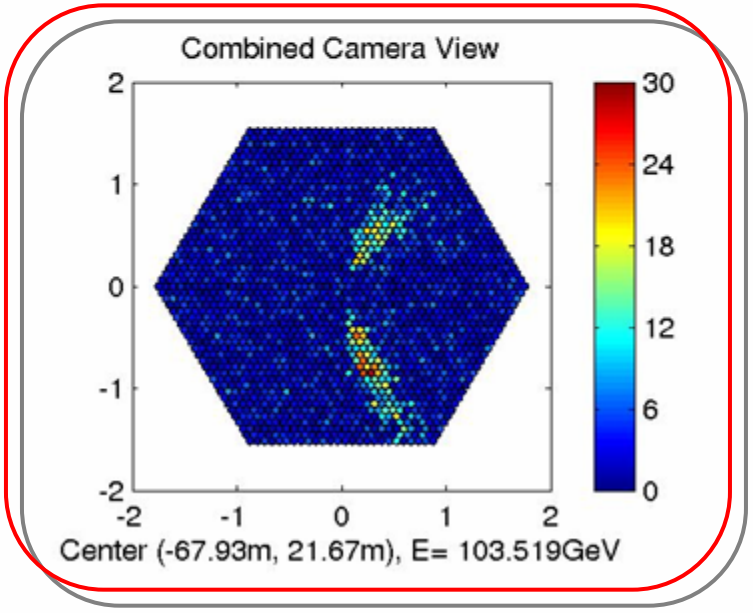


Stereo Event

20 m ∅

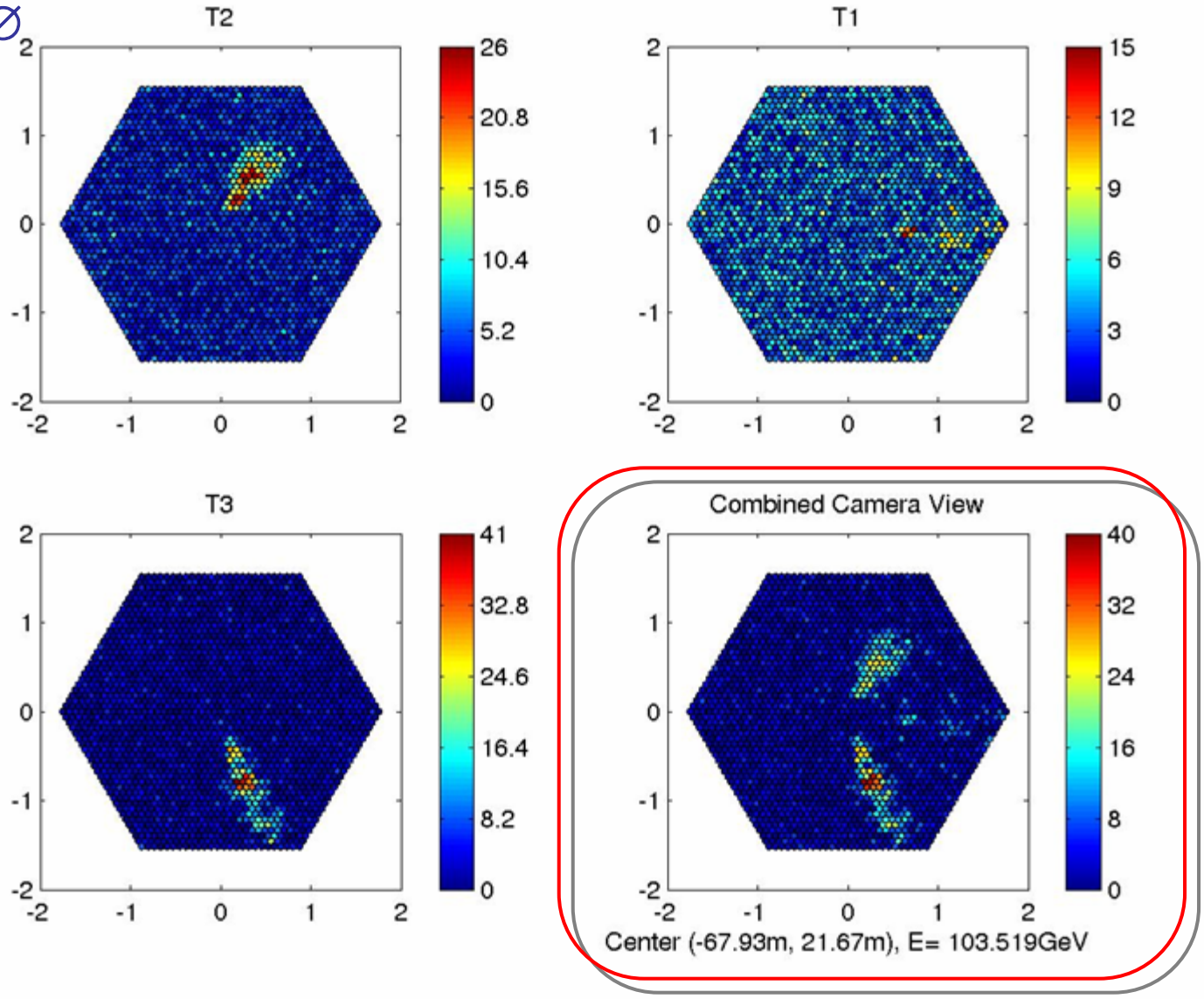






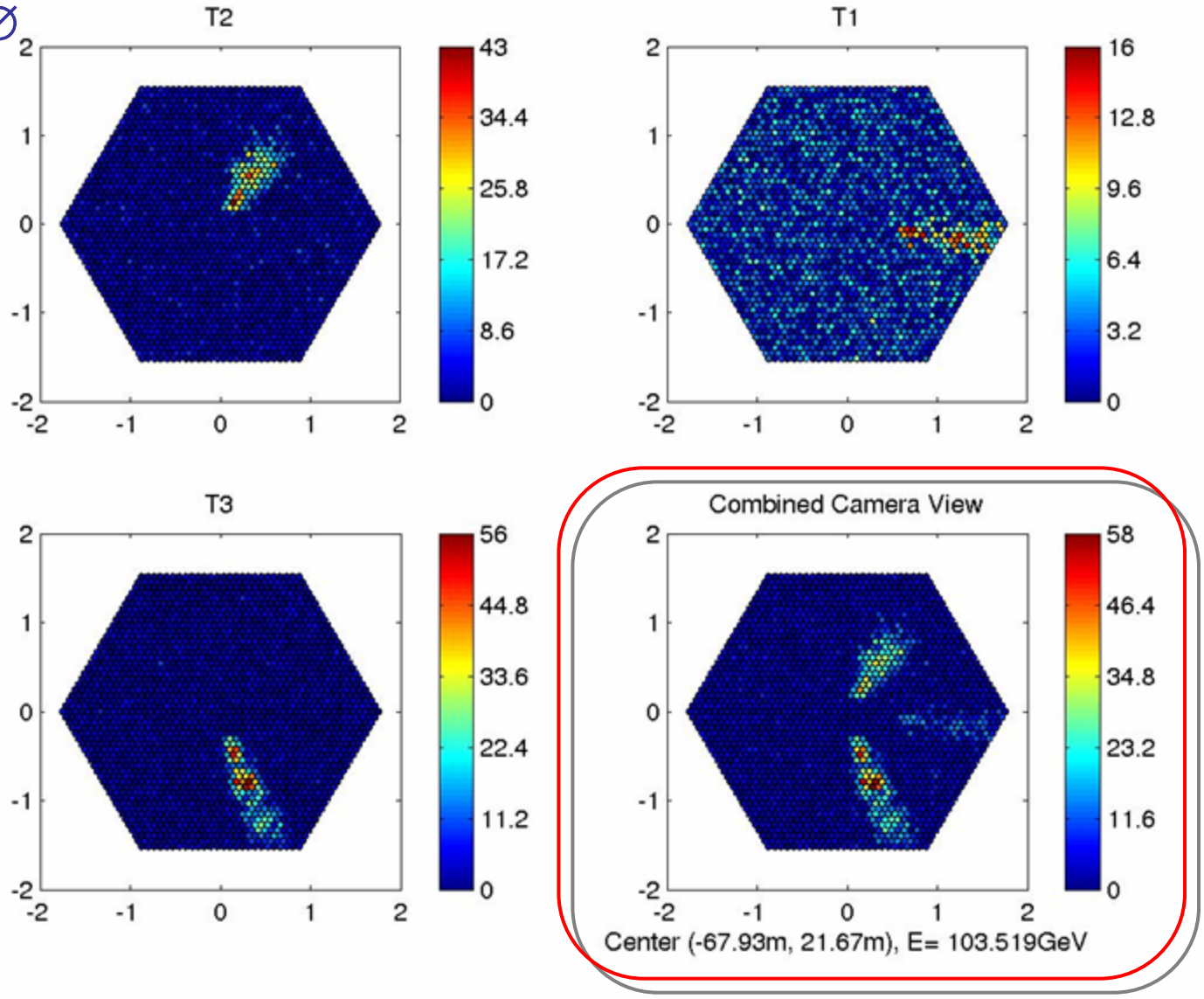
Stereo Event

24 m ∅

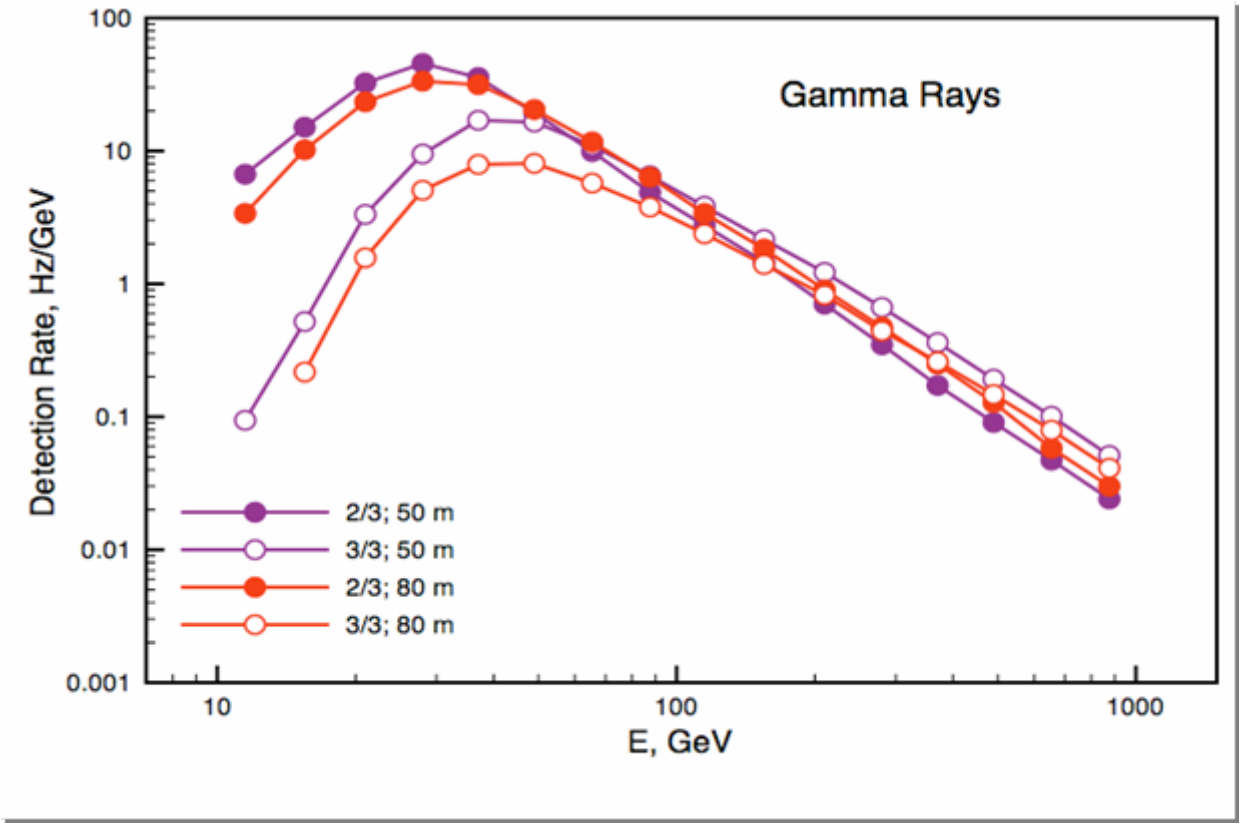


Stereo Event

30 m ∅



Baseline Distance



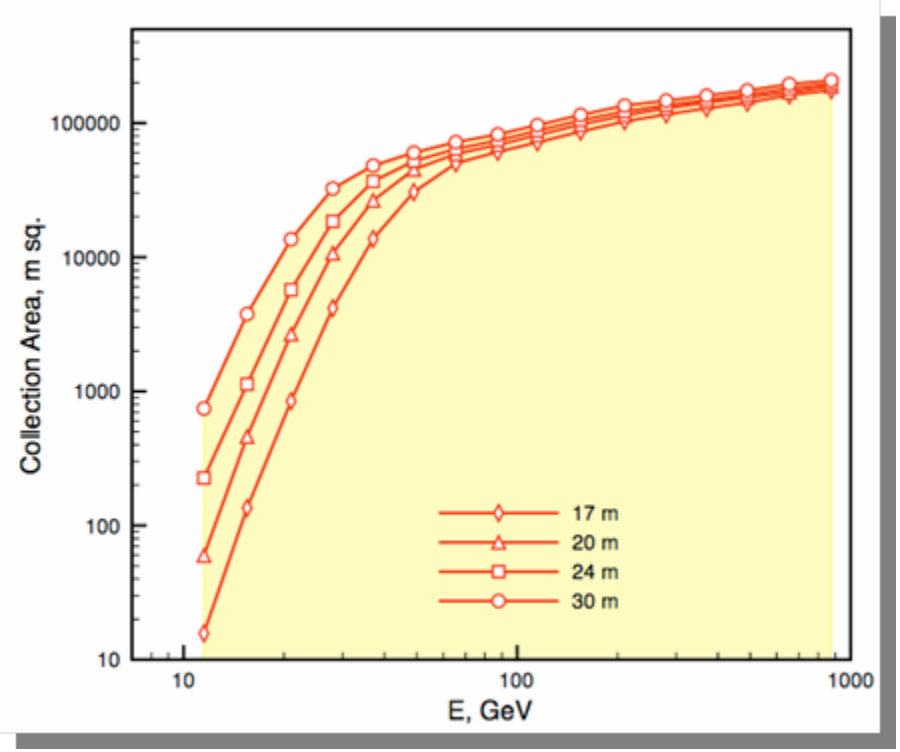
Large separations substantially suppress 3 telescope events!

Go for close-packed stereo array!

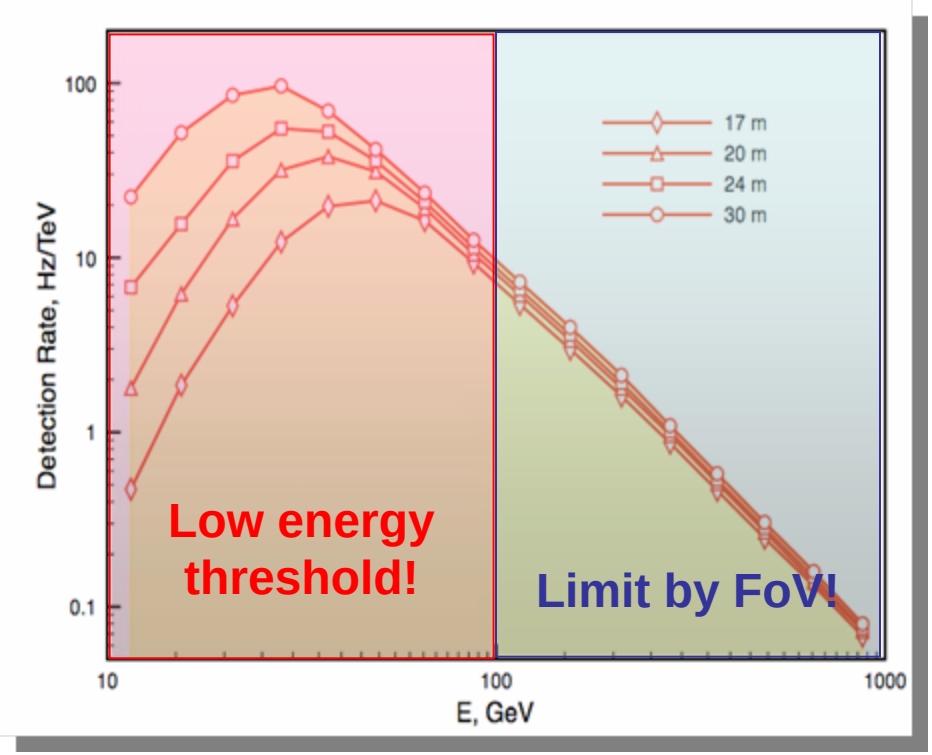
Detection Areas & Rates

γ rays, 2 out 3 tel. trigger, 50 m separation

Collection areas



Detection rates

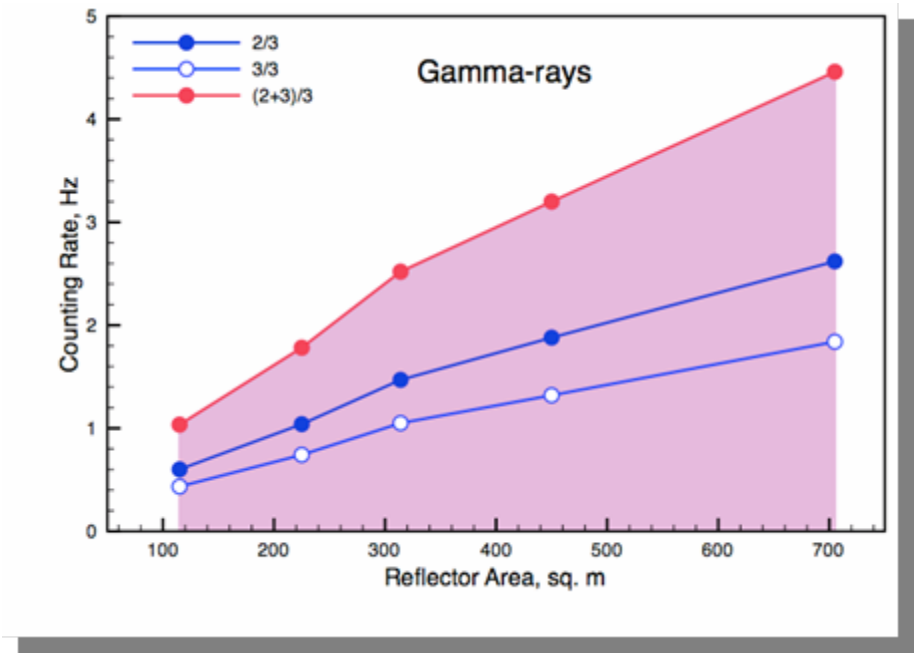


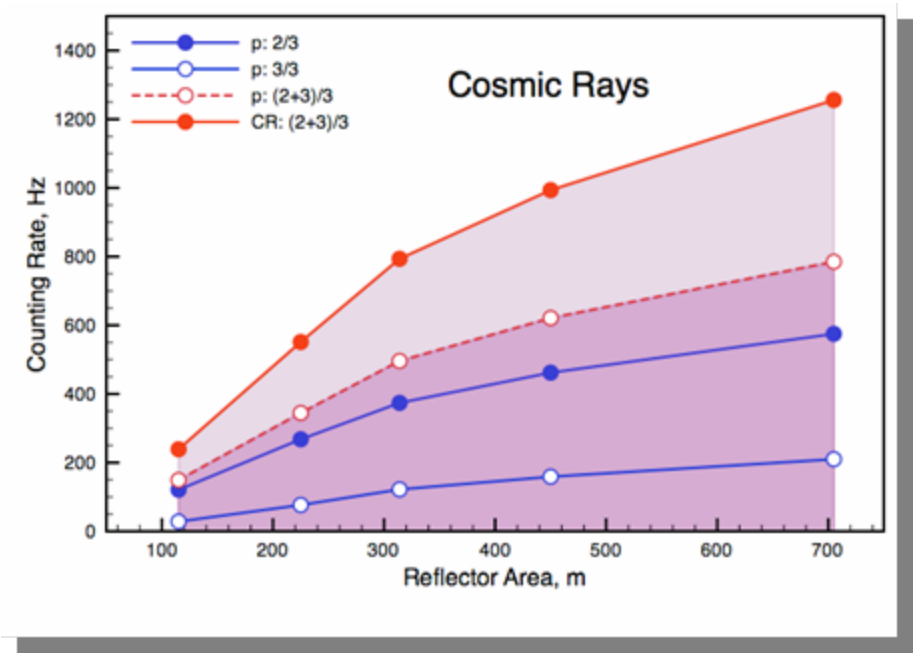
Energy threshold is well below 100 GeV!

Integral Detection Rates

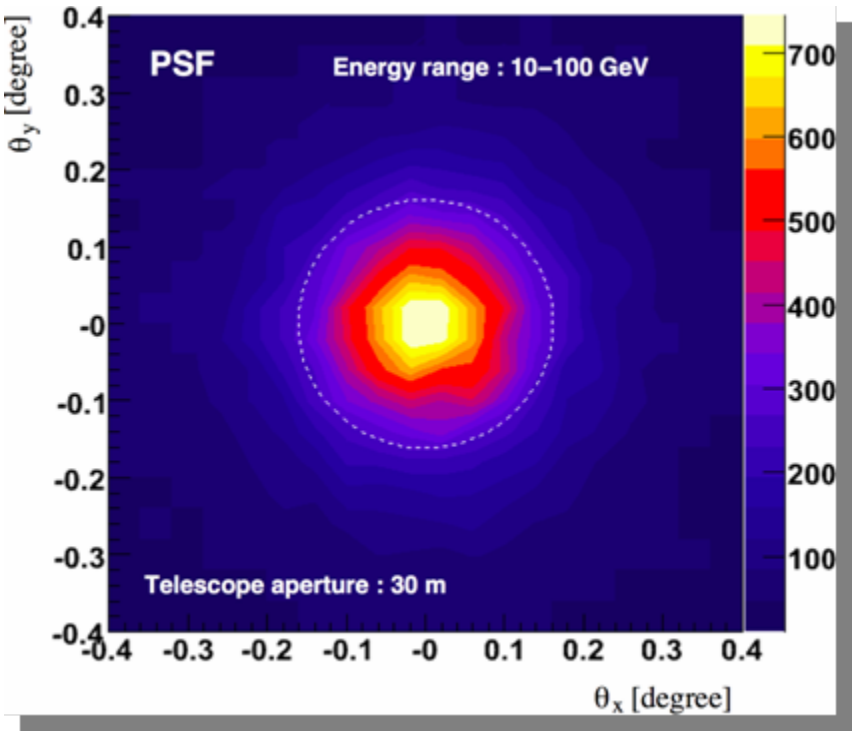
Array of 30 m telescopes
Raw event rate : 1.3 kHz
γ-ray rate : 4.5 Hz

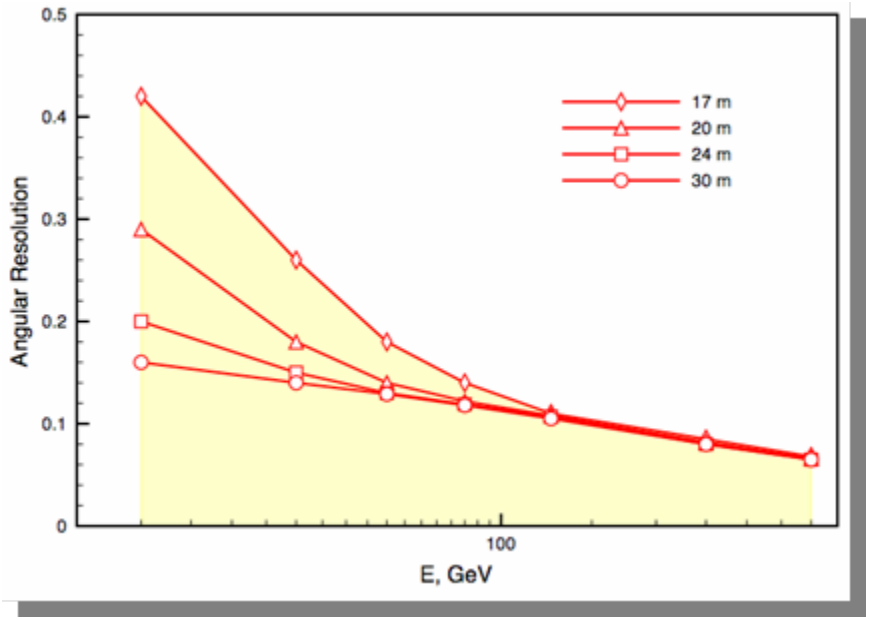
Still maintainable rate without online topological trigger!





Angular Resolution





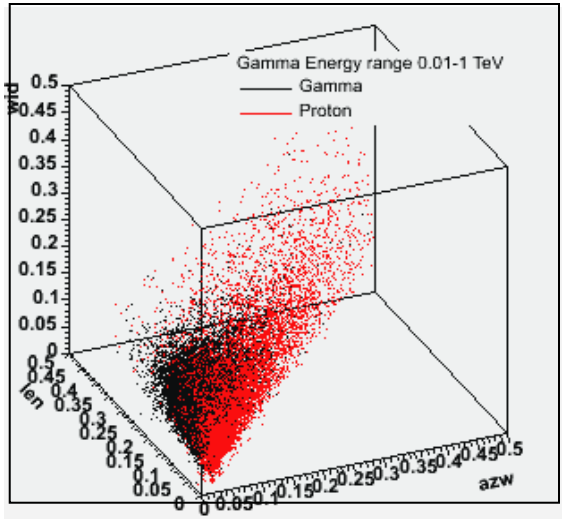
Angular resolution improves with aperture!

Single Telescope Analysis

'Straightforward' approach:

- Simultaneously 'orientation' & 'shape'
- Standard image parameters
- Non-parametric estimation of multi-variate probability density
- Bayesian decision rules
- Test on MC simulated events

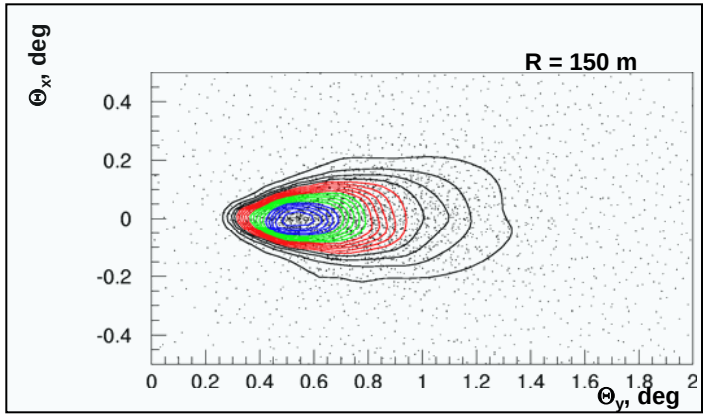
In the energy range of 10-30 GeV the maximum achievable Q-factor is about 3.0 for the 50% γ-ray acceptance



3D visualization of the signal & background samples.

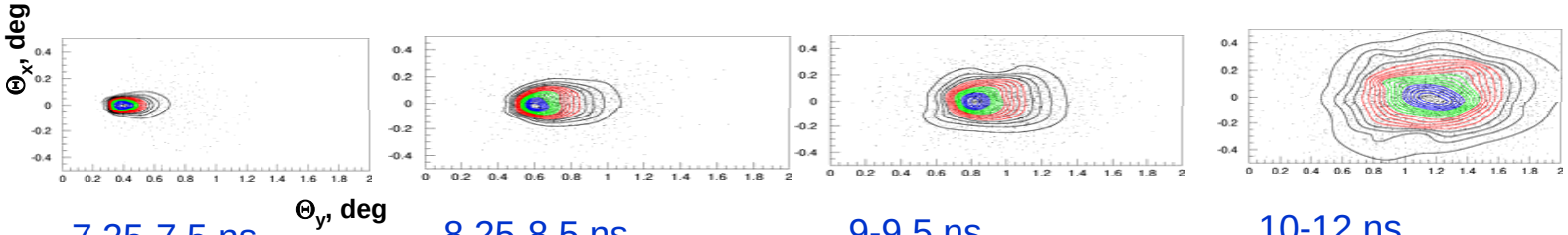
Konopeko, Chilingarian, Reimers (2006)

Time-Dependent Analysis



C-light image of a 10 GeV γ-ray shower averaged over a sample of events.

- 'Centroid' is close to the center of FoV
- Small angular size
- Very high fluctuations of image shape

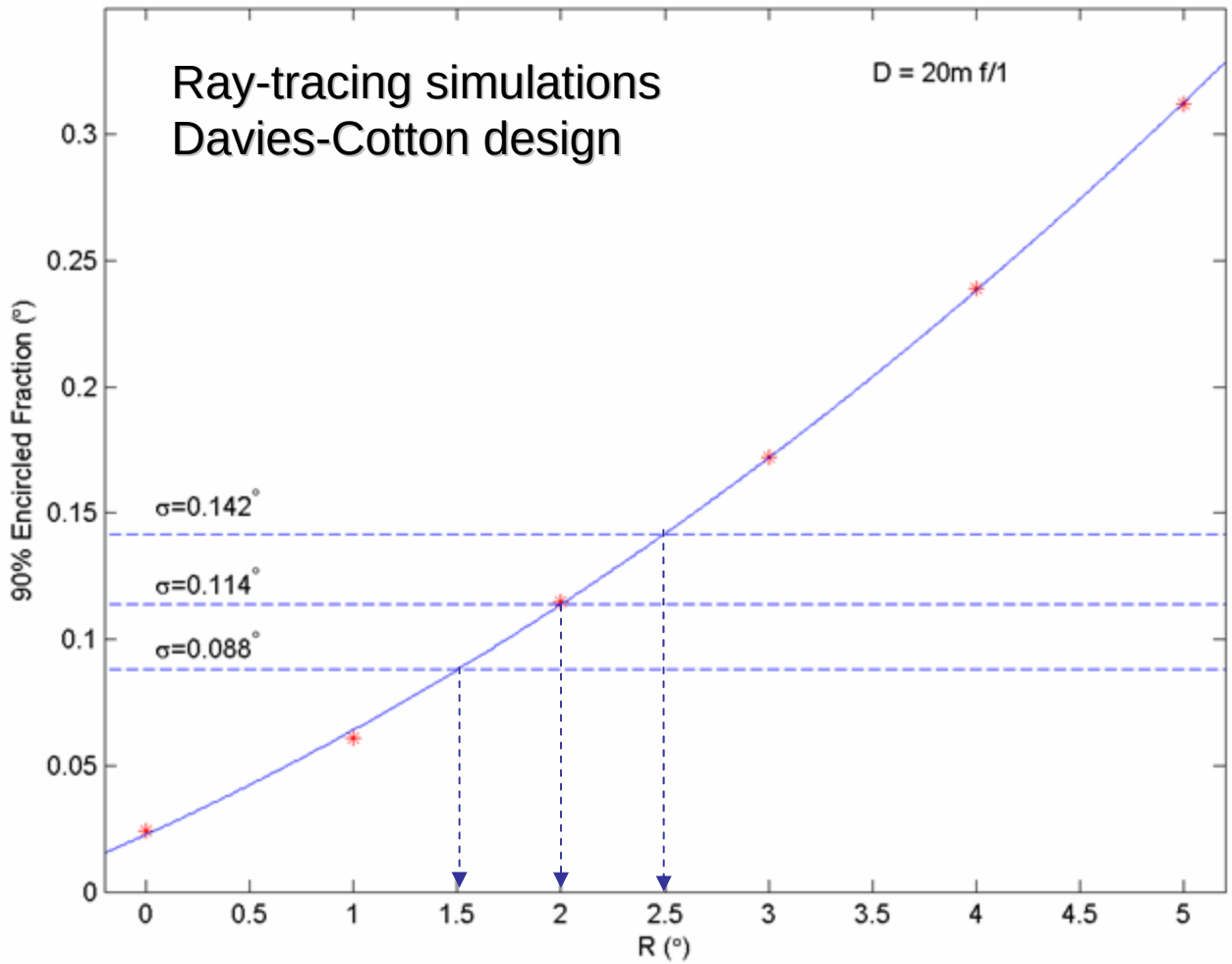


7.25-7.5 ns 8.25-8.5 ns 9-9.5 ns 10-12 ns

Reflector

- A 20-26 m dish-mount is technically easy!
- Focal length of 25-35 m
- Parabolic dish is preferable
  - Small time spread of reflected light
  - Good PSF for off-axis light (<2.0^{o})
- Glass mirrors are ok
- Automatic mirror adjustment
- Camera auto focus [dislocation by ~20 cm]
- High slewing speed: 200 deg/min
- Approximate cost: $4-8M

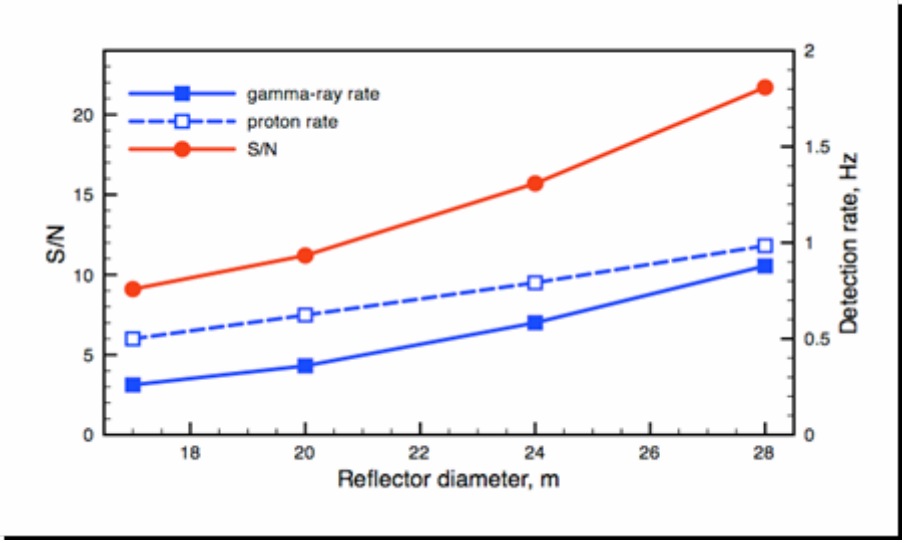
Optical Quality



Camera

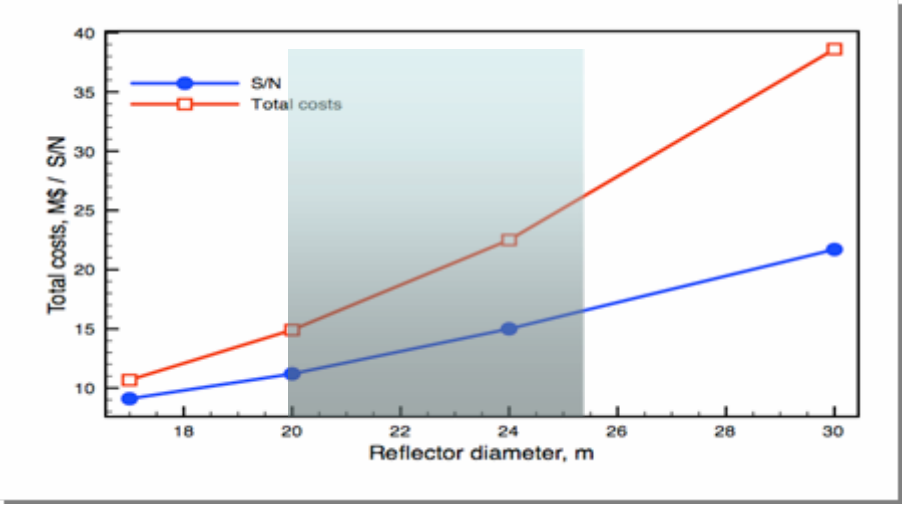
- FoV of ~4°-5° diameter
  - Limited by a broad PSF at large off-set
  - Low energy events shrink to the camera center
  - Scan window of about 2° diameter
- Small pixels of ~0.09°
  - Reduce n.s.b. contamination
  - Better imaging of low energy events
  - Limited by PSF for a 20 m dish
- Homogeneous design
- Custom PMs
- Fast electronics
- Approximate cost: ~$1-1.5M

Sensitivity vs Costs



S/N* : signal-to-noise ratio
Crab-like source

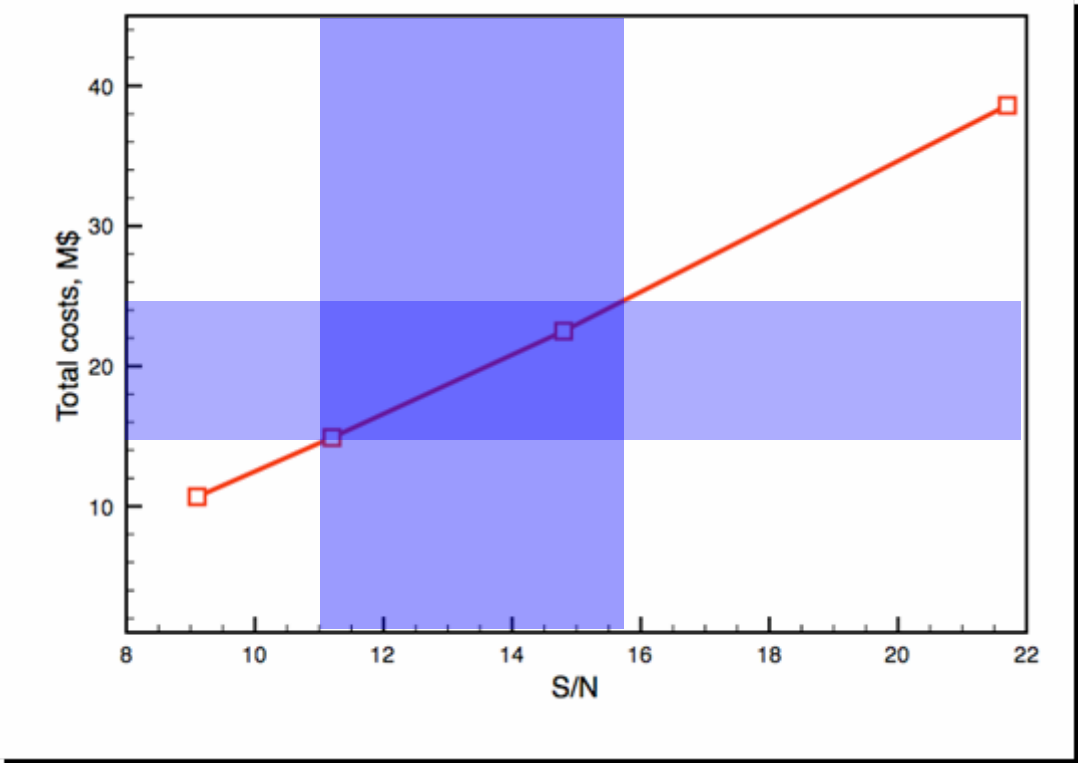
(not optimized)



Total costs: 3 large IACTs

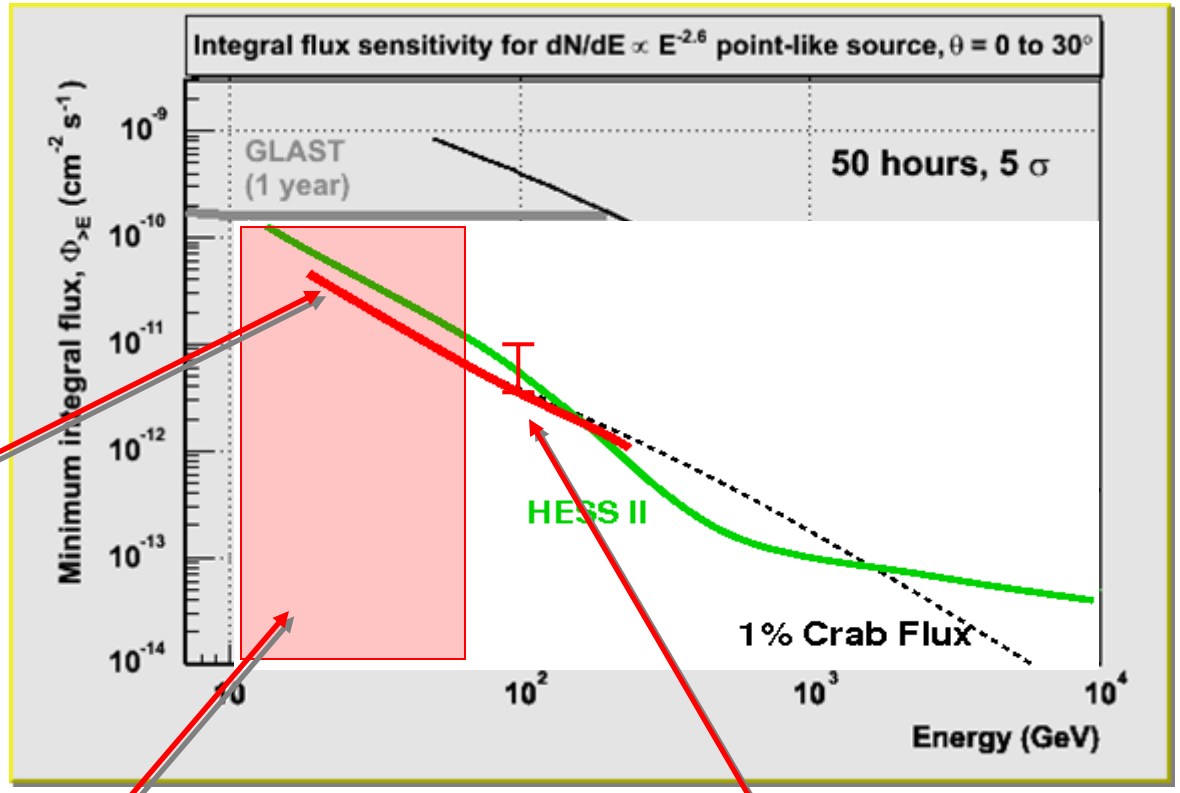
*given in arbitrary units

Sensitivity vs Costs



Array of 3 IACTs: 20-25m Ø
Total costs : ~15-28.5 M$

Sensitivity



3 x 20 m CT

Lower Energy Threshold

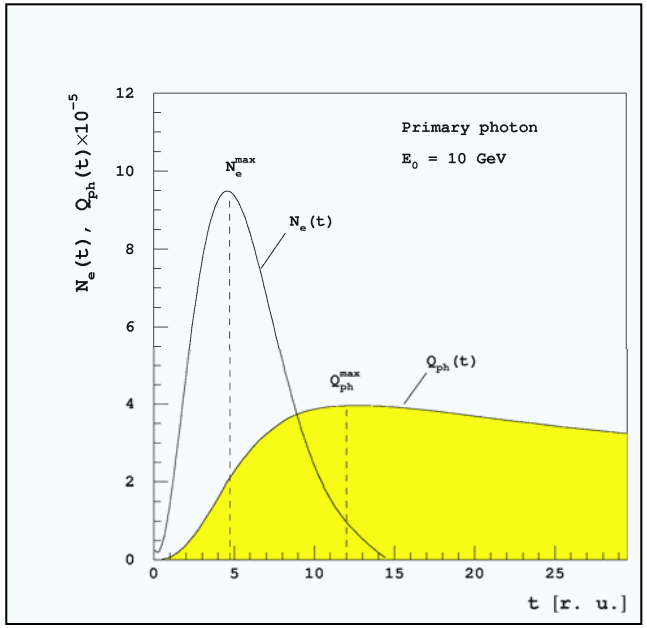
Gain at 100 GeV

$$F_{\gamma}^{\min}(>20GeV) \propto 6 \cdot 10^{-11} (D/17m)^{-2.5} cm^{-2} s^{-1}$$

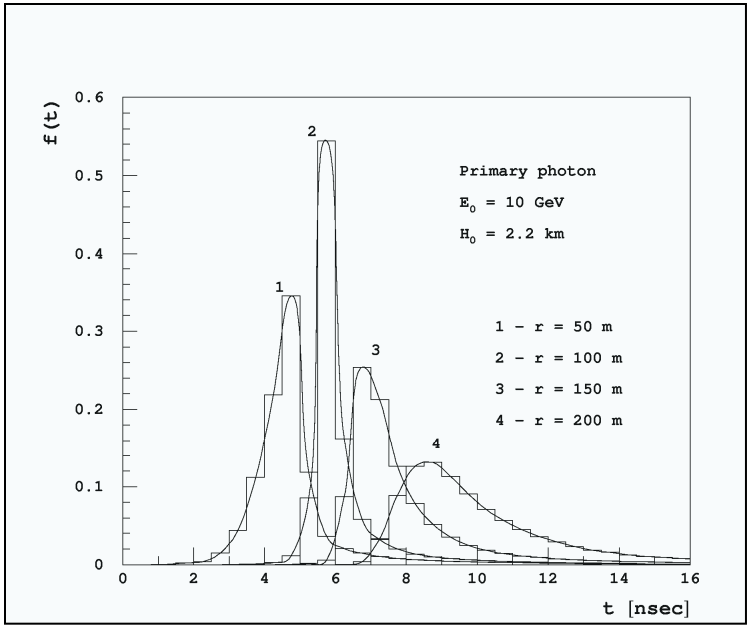
Conclusions

- Reduction of energy threshold is likely to remain a significant drive for VHE γ-ray astronomy
- Next generation of ground-based imaging atmospheric Cherenkov detectors need a low energy array
- 3 telescopes of 20-26 m diameter is a good start!
- Such a detector will help to achieve many scientific goals as currently perceived by γ-ray astrophysics community!

Low Energy Events



Longitudinal development, C-light emission of a 10 GeV γ-ray shower.



Average time pulses of the C-light emission from a 10 GeV γ-ray shower.