# FUTURE INSTRUMENTS

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# FUTURE INSTRUMENTS

## HE + VHE RANGE

# WHY?

**Cosmic ray origin:**

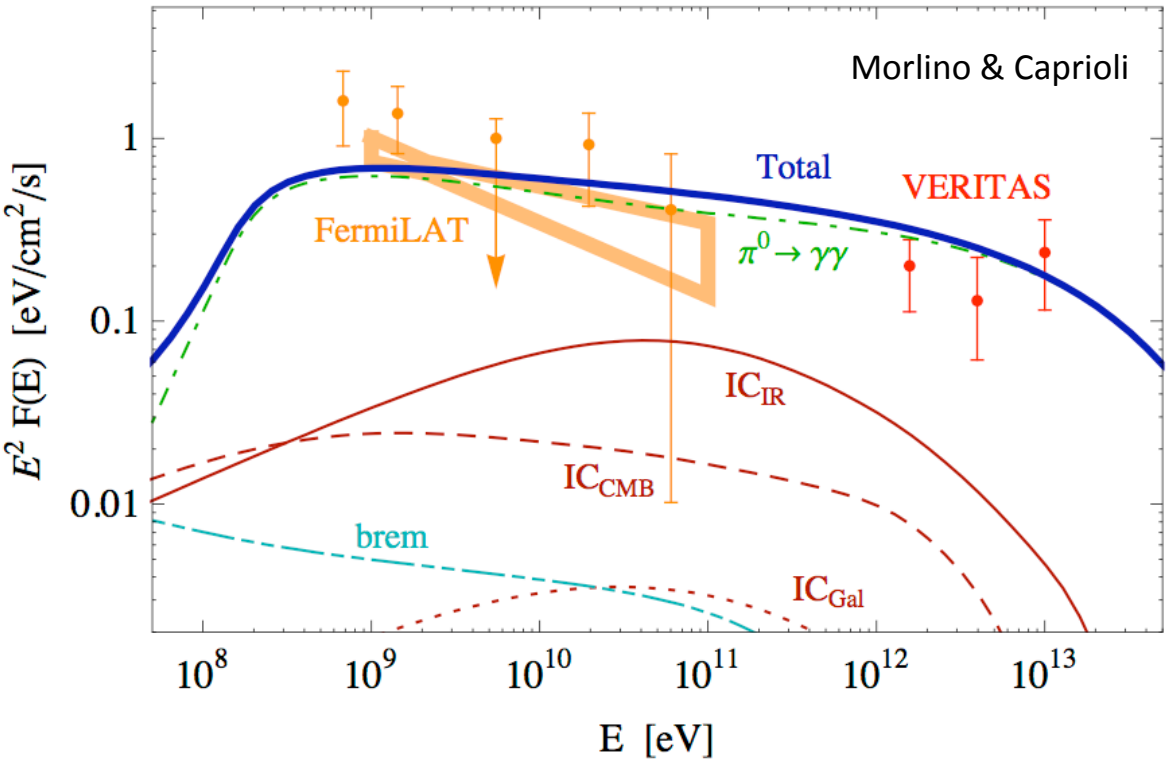
**"Tycho – best candidate for proton acceleration"**

Number of relevant young SNR in the Galaxy is small; currently of those only nearby ones detectable

Energy and shape of cutoffs ?

Escaping CR illuminating gas ?

Quantitative description of CR energy supply and spectrum




**Key phenomena within reach**

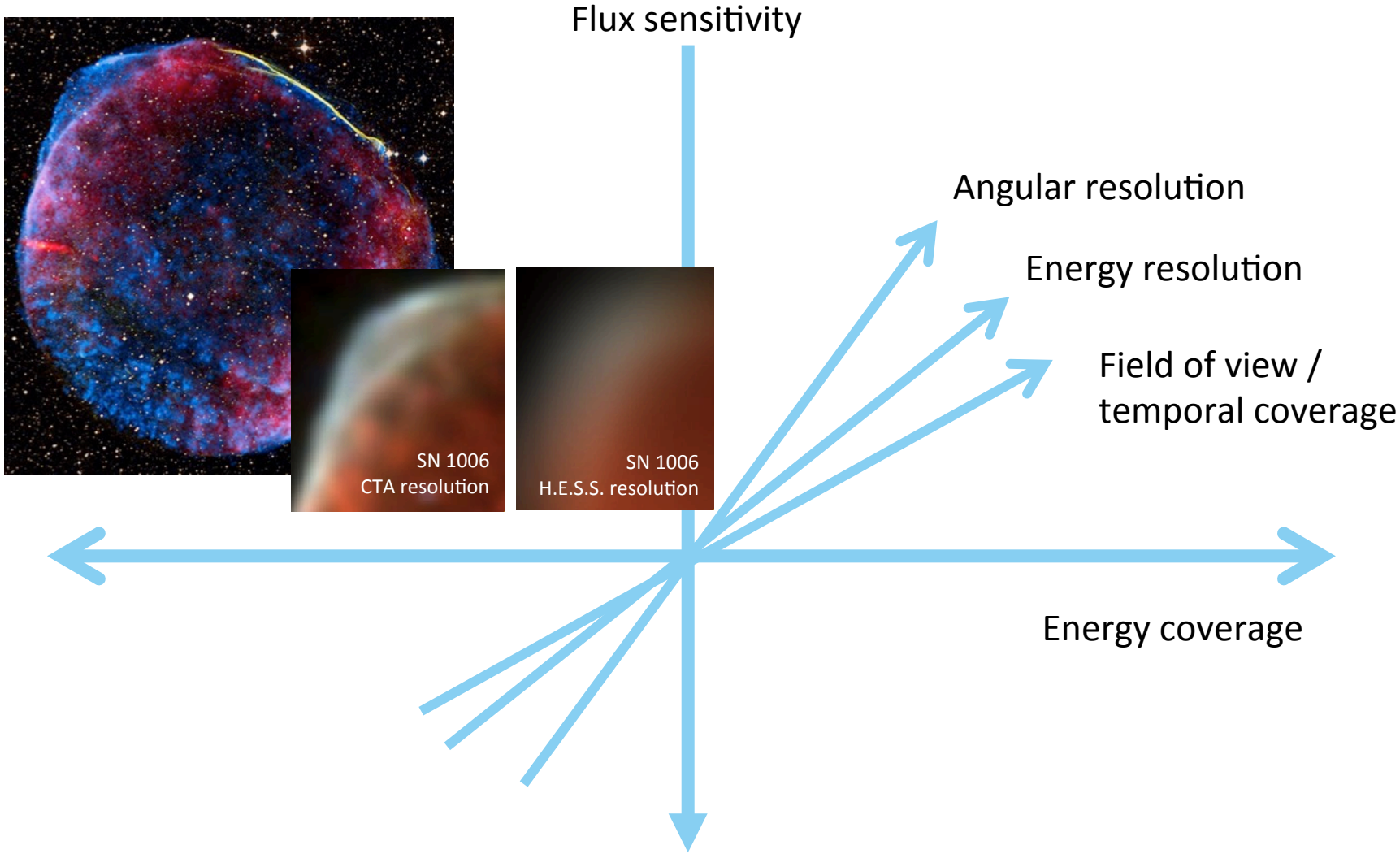
VHE gamma rays from galaxy clusters

VHE spectra of GRBs

Dark matter WIMP annihilation

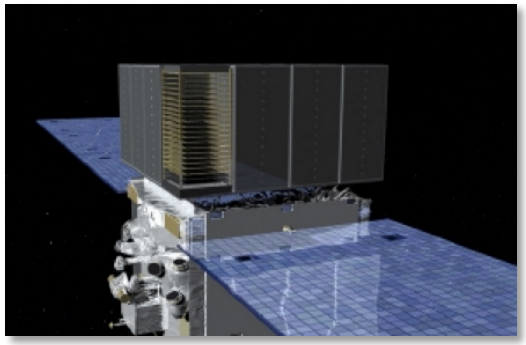
…

# FUTURE INSTRUMENTS



# GAMMA RAY TELESCOPES

Space-based
pair production
telescopes



0.1 – 100 GeV
Small area
Background-free
Large field of view
High duty cycle

Imaging Atmospheric
Cherenkov Telescopes

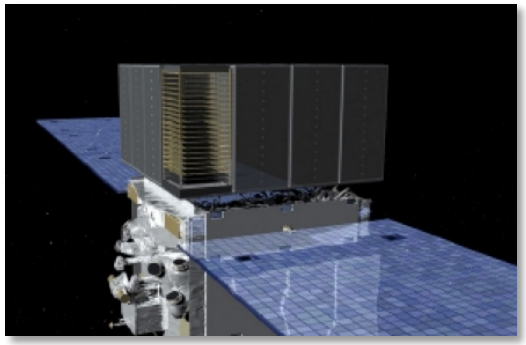
50 GeV – 100 TeV
Large area
Excellent bg rejection
Small field of view
Low duty cycle

Air shower
Arrays

100 GeV – 100 TeV
Large area
Good bg rejection
Large field of view
Large duty cycle

# GAMMA RAY TELESCOPES

Space-based
pair production
telescopes



0.1 – 100 GeV
Small area
Background-free
Large field of view
High duty cycle
{Increased area}
Improved tracking
Improved calorimetry

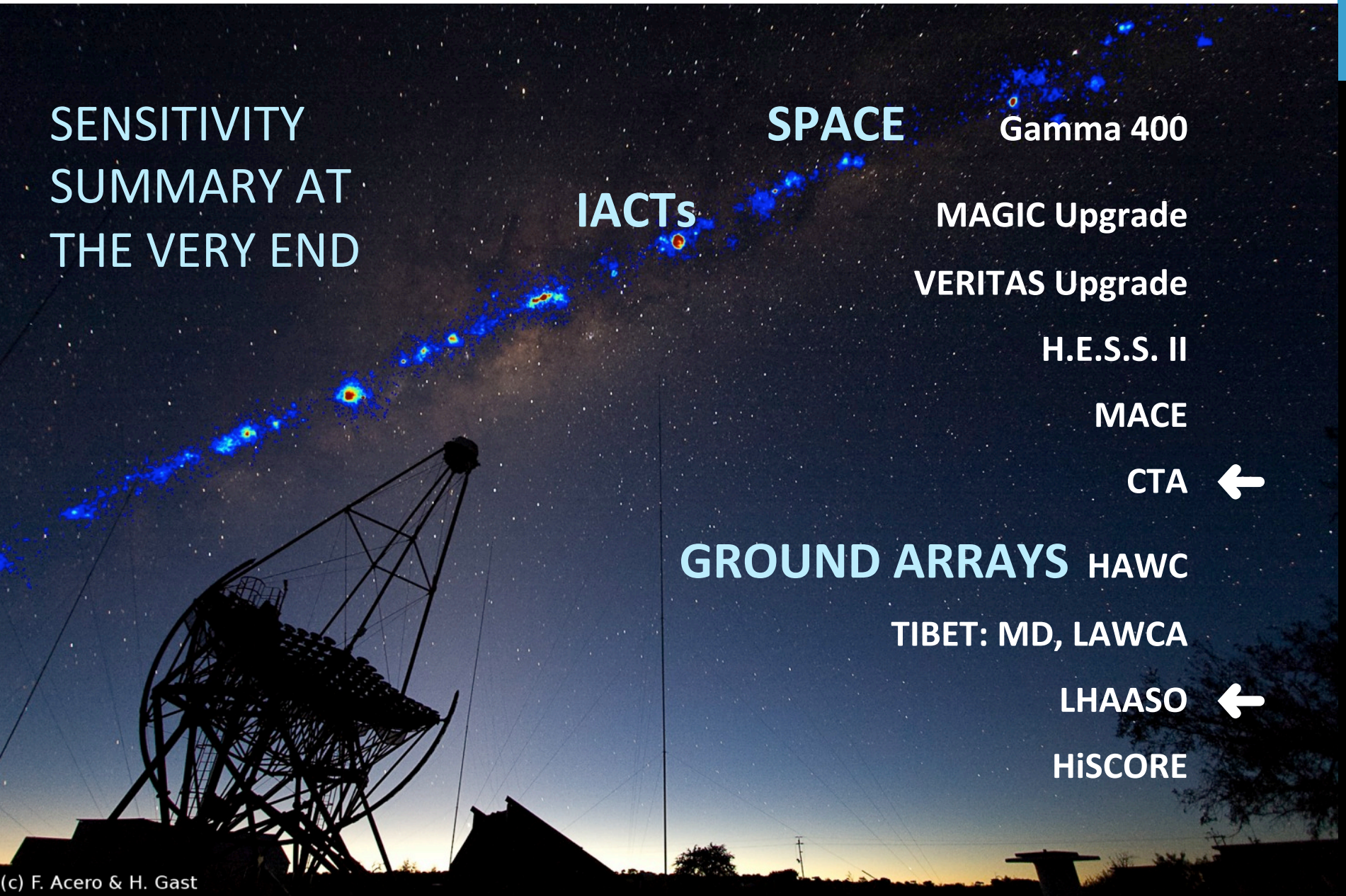
Imaging Atmospheric
Cherenkov Telescopes

50 GeV – 100 TeV
Large area
Excellent bg rejection
Small field of view
Low duty cycle
Increased ground area
Improved photon
collection and detection
Increased field of view

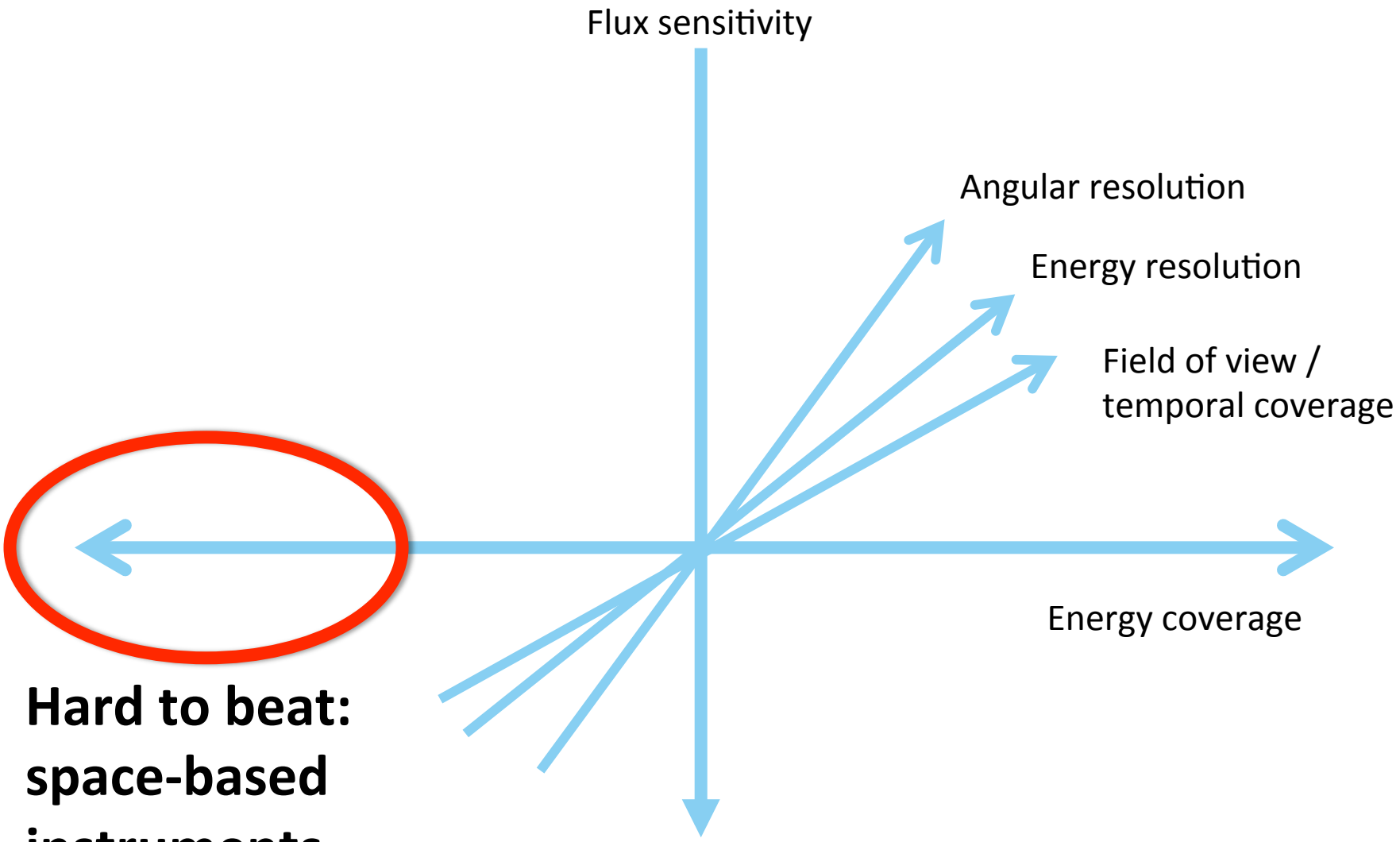
Air shower
Arrays

100 GeV – 100 TeV
Large area
Good bg rejection
Large field of view
Large duty cycle
Larger area
Improved coverage
and detection
Improved bg rejection

# FUTURE INSTRUMENTS

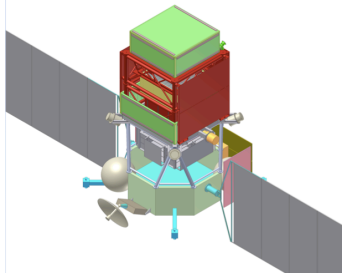


# FUTURE INSTRUMENTS




**Hard to beat: space-based instruments**

# SPACE-BASED: GAMMA 400

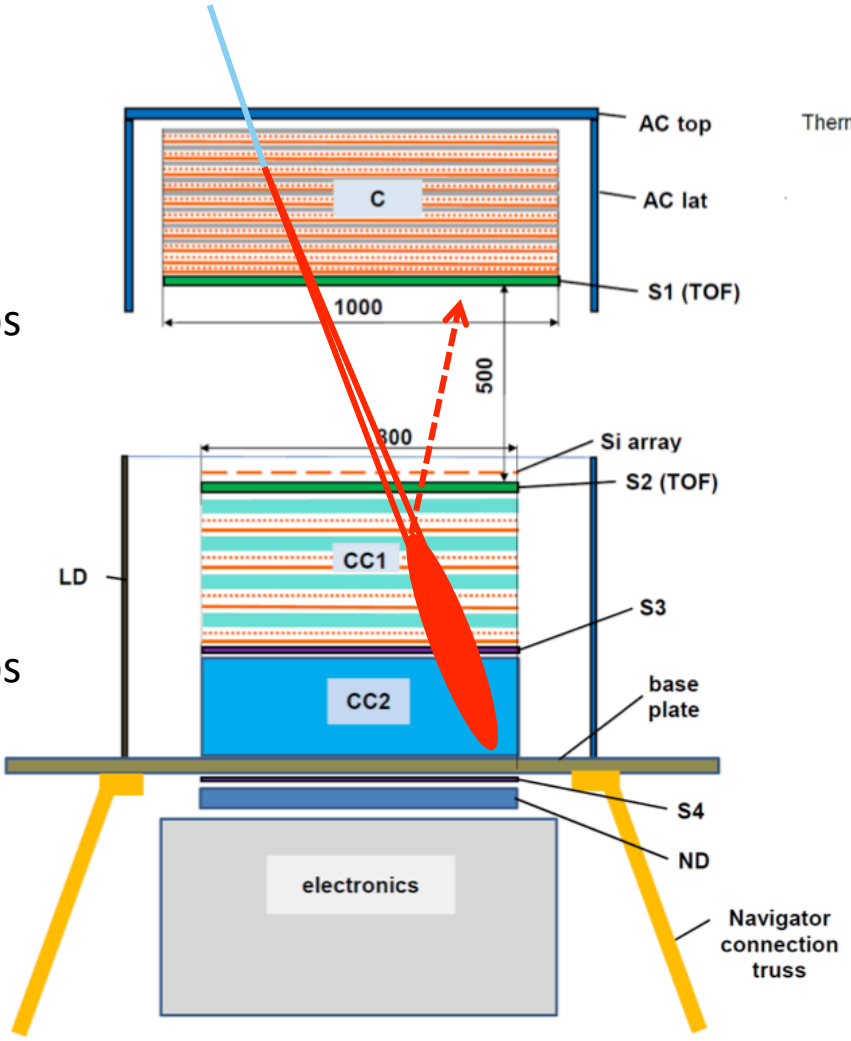


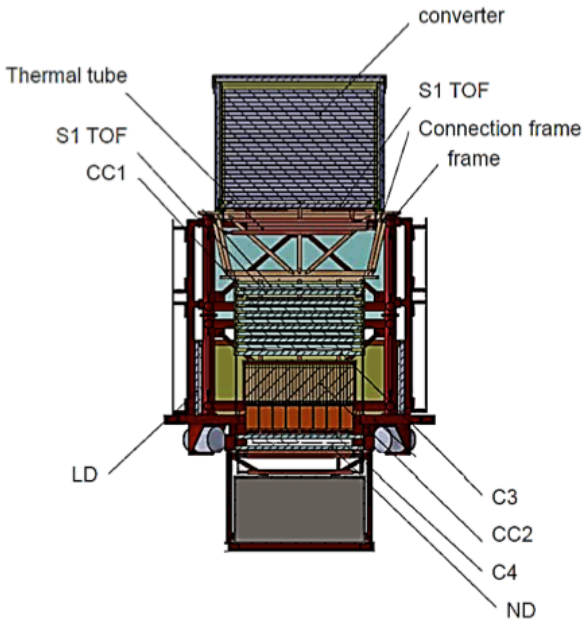
**Russian/Italian/US collaboration**

**Launch 2018**

10-layer converter/ tracker 0.1 mm strips

Imaging calorimeter 0.5 mm strips




**AC - anticoincidence detectors (AC top + AC lat)**

**C - Converter-Tracker - 1 Xo**
**10 Si(x,y) (pitch 0.1 mm) + 8 W (0.1 Xo)**

**S1, S2 - TOF detectors**

**Si array - Si pad (1x1 $cm^2$ ) detector**

**S3, S4 - calorimeter scintillator detectors**

**CC1 - imaging calorimeter 3Xo**
**4 layers: CsI 0.75 Xo + Si(x,y) (pitch 0.5 mm)**

**CC2 - electromagnetic calorimeter 22Xo**
**BGO (1024 crystals 2.5x2.5x25 $cm^3$ )**

**LD - 4 lateral calorimeter detectors 50x120 $cm^2$**

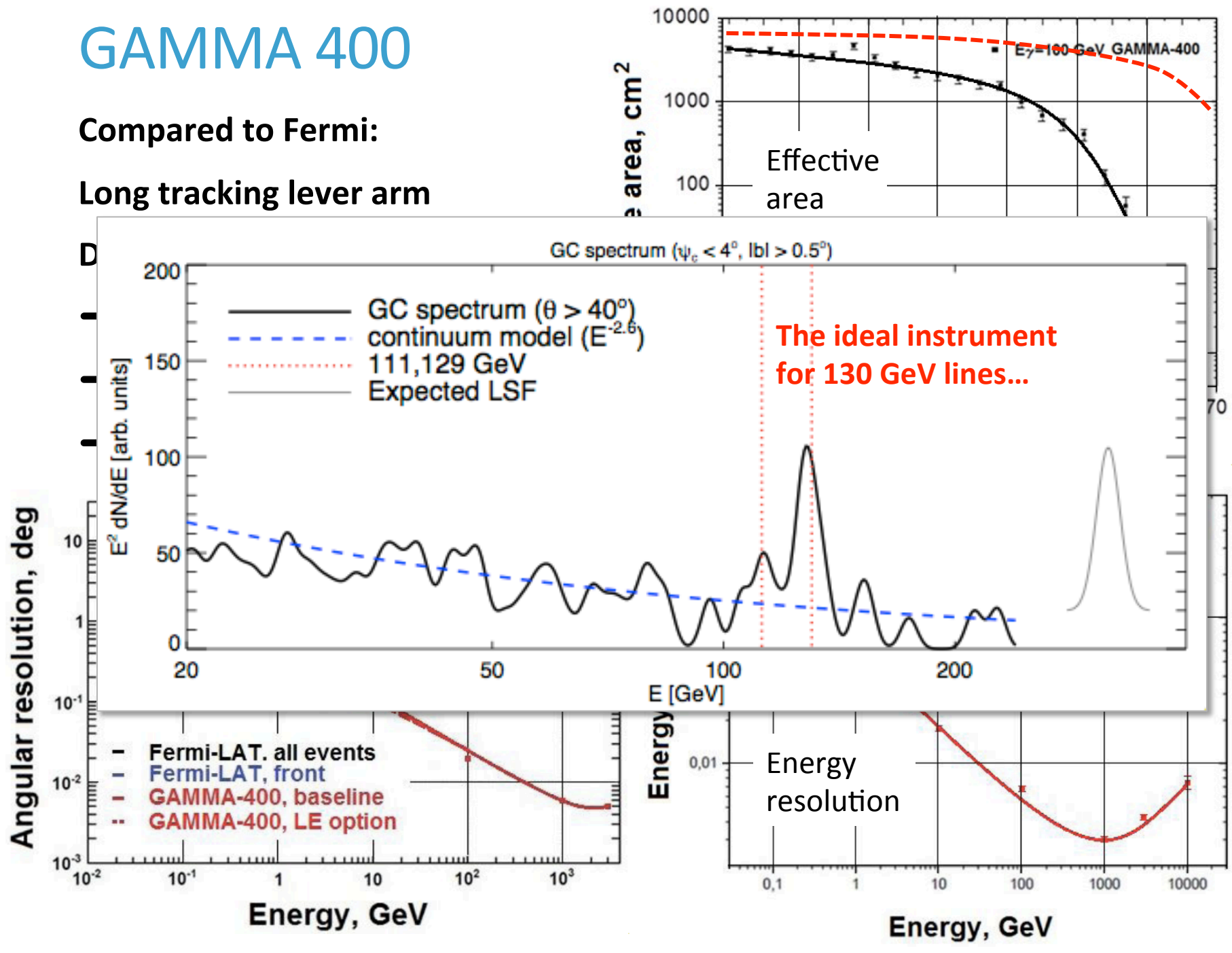
**ND - neutron detector**

# GAMMA 400

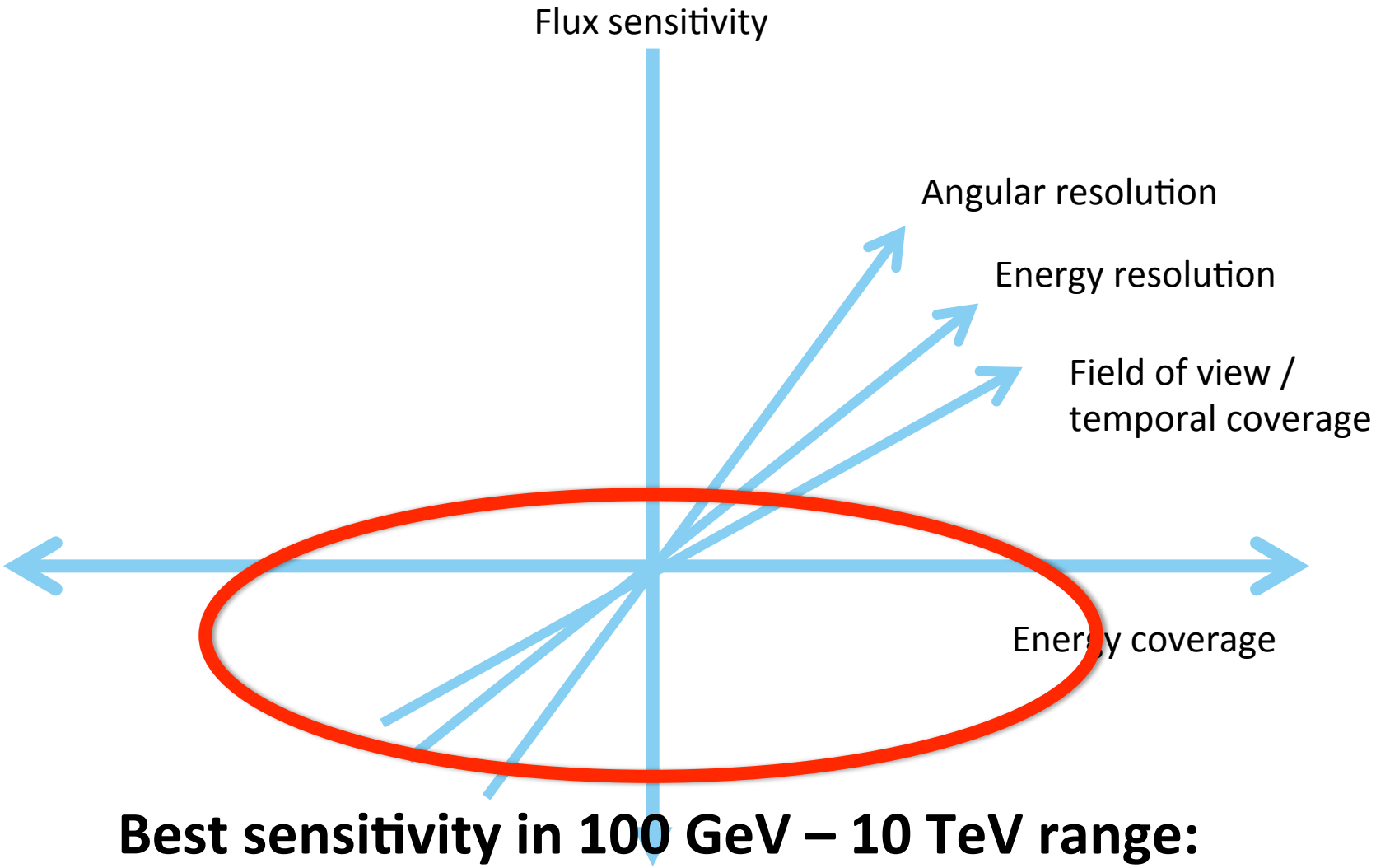
**Compared to Fermi:**

**Long tracking lever arm**

**D**



# FUTURE INSTRUMENTS




**Best sensitivity in 100 GeV – 10 TeV range:**
**Cherenkov telescopes**

# MAGIC UPGRADE

MAGIC:
Two 17 m telescopes

Upgrade of older MAGIC I camera in pro

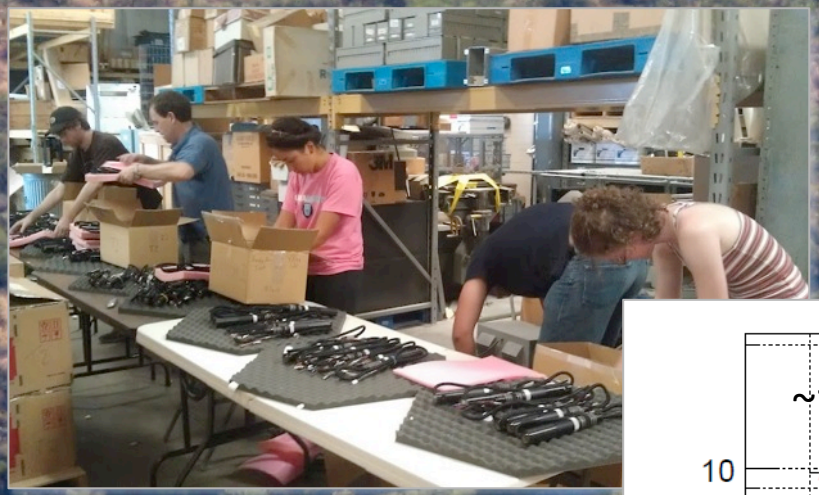
- Unification of subsystems and readou
- Improved reliability and sensitivity
- 576 ➜ 1039 pixels
- enlarged trigger area
- analog sum trigger for both

➜ *talk by D. Mazin*

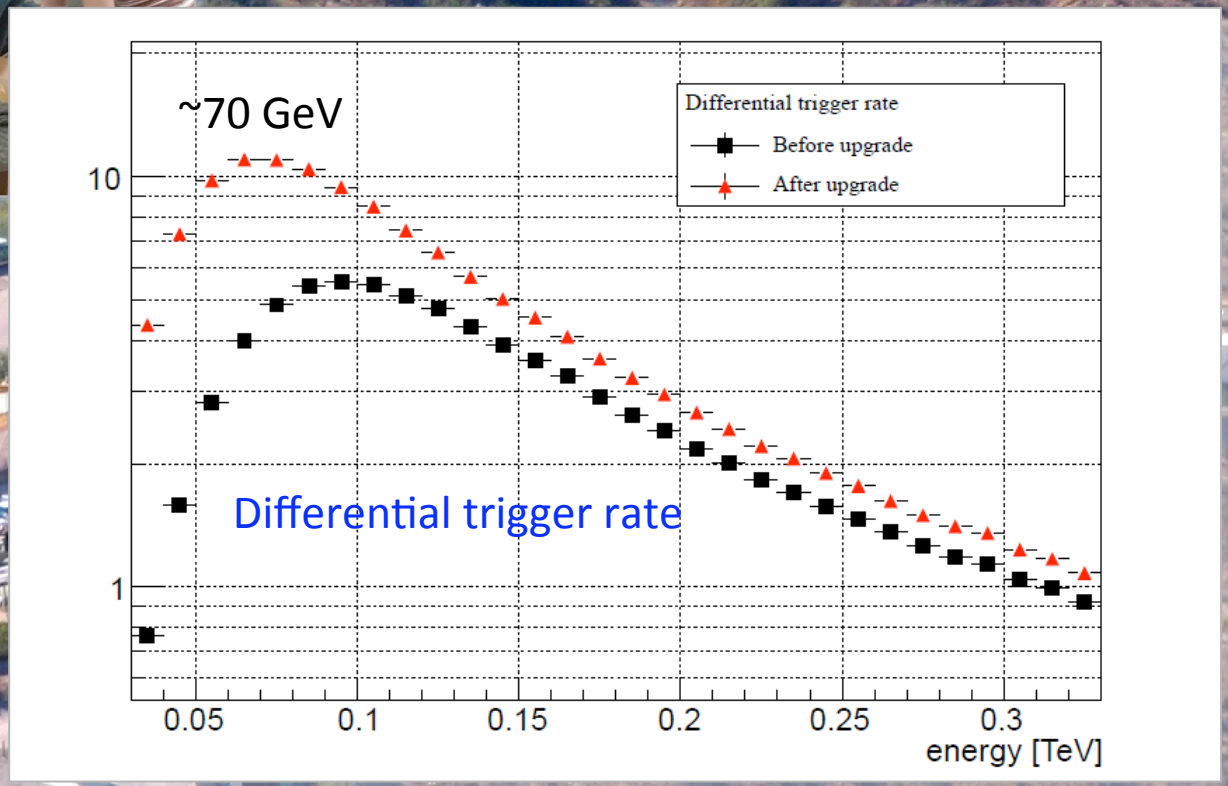
# VERITAS UPGRADE

VERITAS:
Four 12 m telescopes

| Year | Item | Status |
|---|---|---|
| 2009 | Relocation of Telescope 1 | Complete |
| 2010 | Network Upgrade | Complete |
| 2011 | Trigger Upgrade: faster, more flexible telescope trigger. | Complete |
| 2012 | Camera Upgrade: replacement of all 2,000 PMTs with high-QE devices. | In Progress (Completion: 8/2012) |

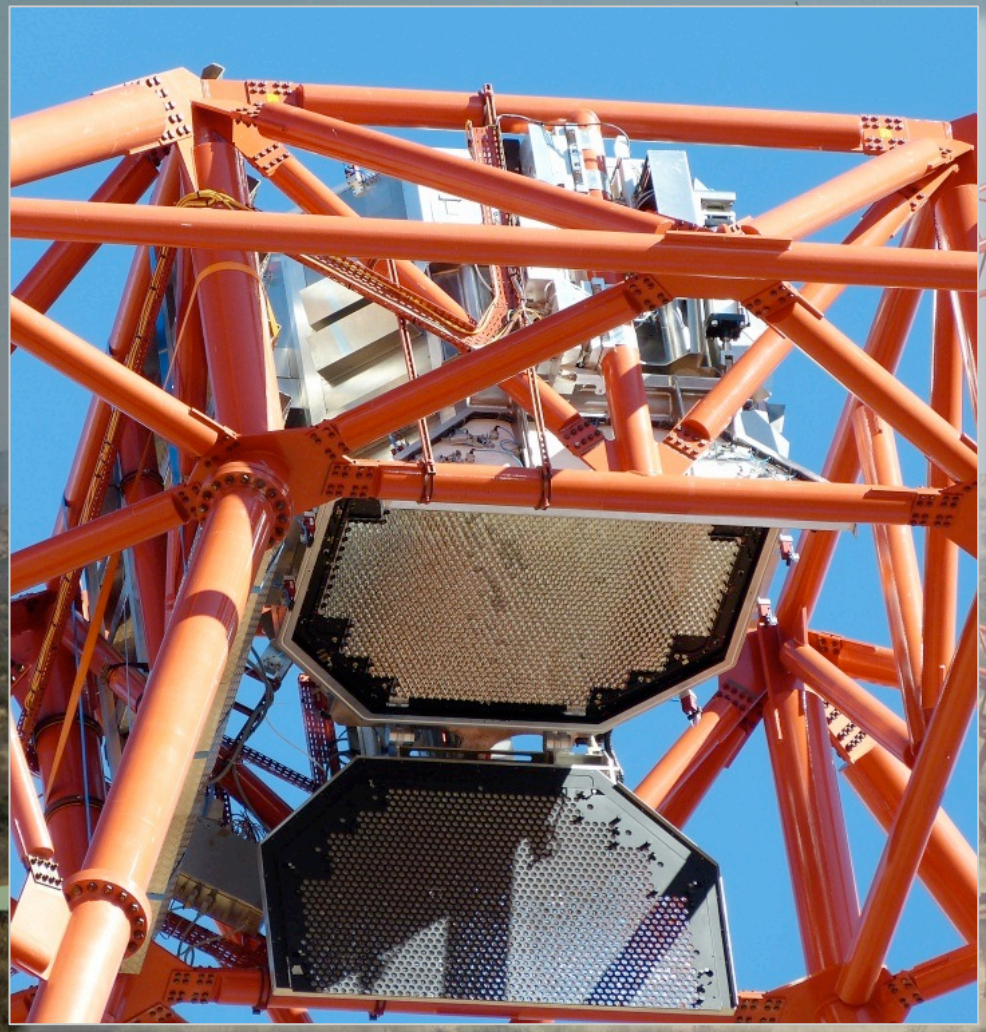


➜ *talk by N. Galante*



# H.E.S.S. II

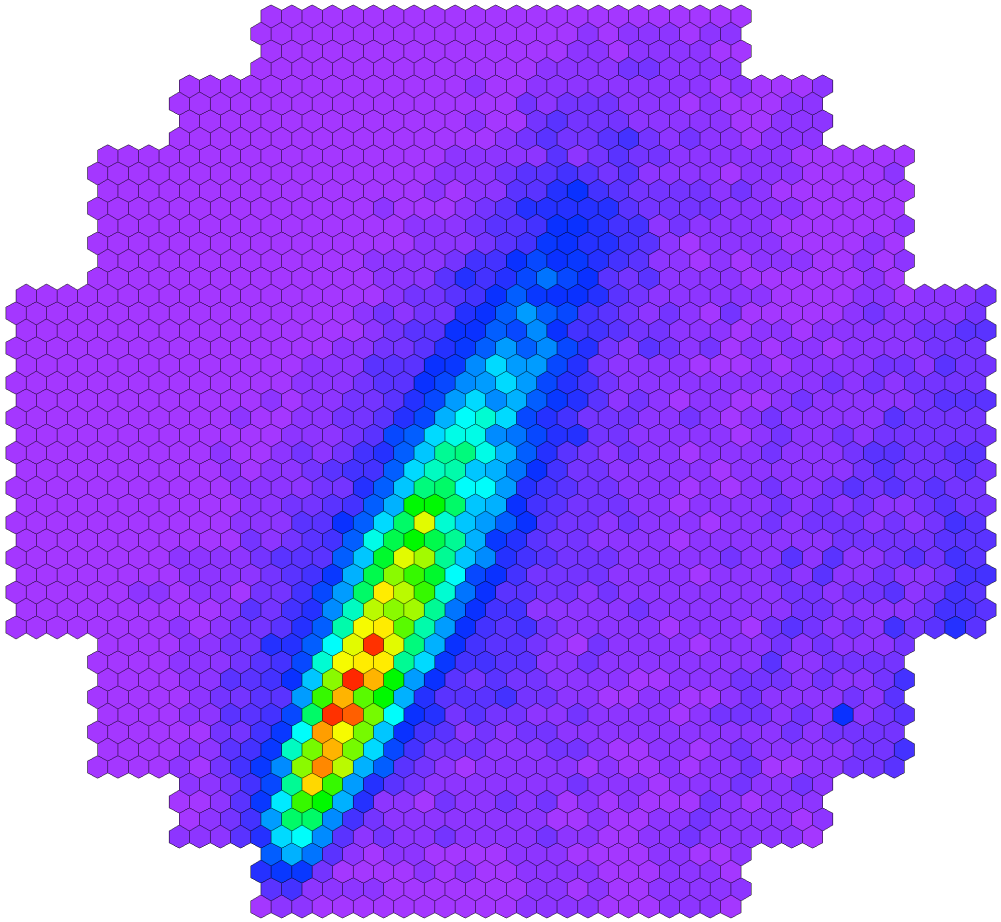
**~600 m² mirror area**
**0.07° pixels**
**~20 GeV peak trigger rate in stand-alone mode**
**trigger modes: stand-alone & coincidence 2/5**



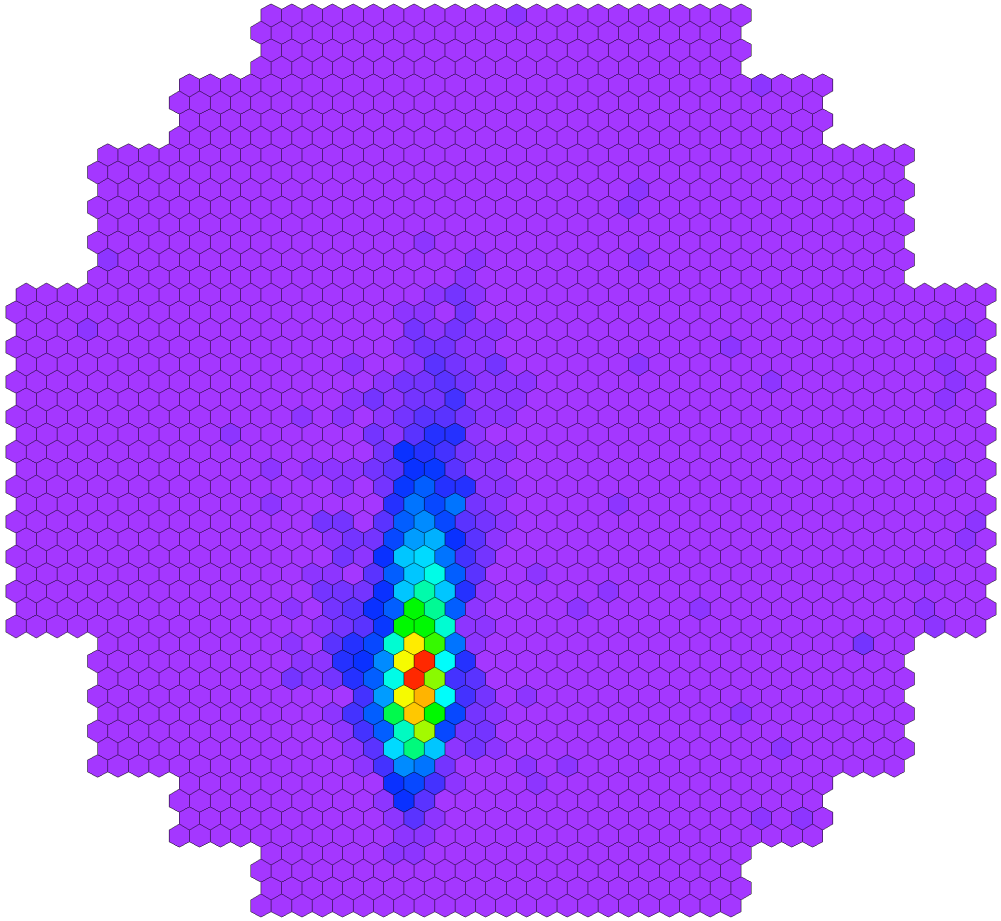
➜ *talk by C. Stegmann*

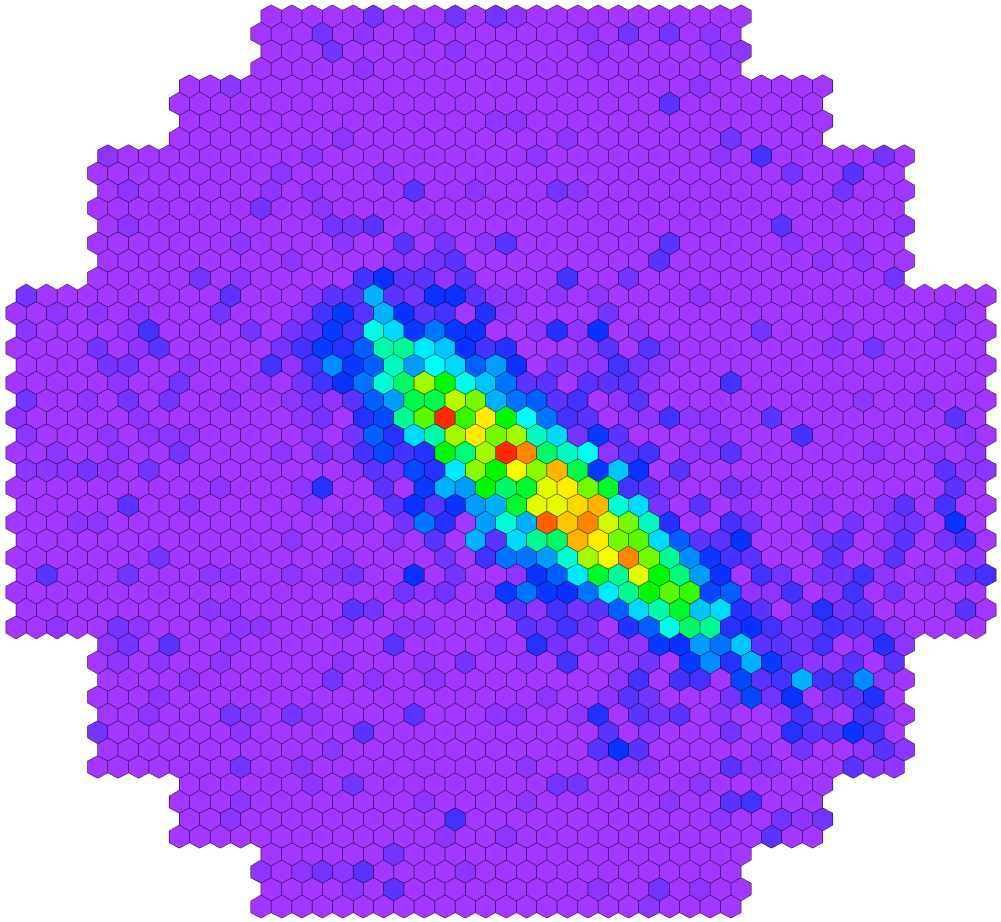
Currently only ~180 m² of mirror surface aligned

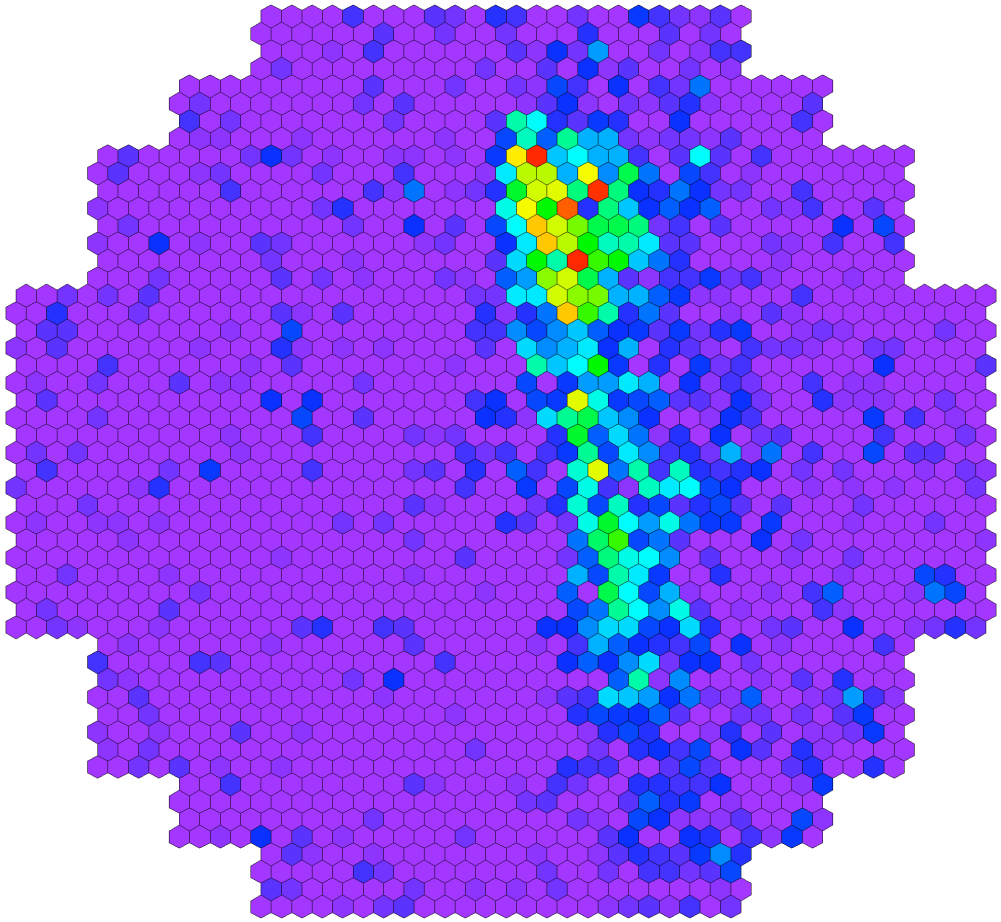
# JULY 11, 1:42 AM: CAMERA TEST



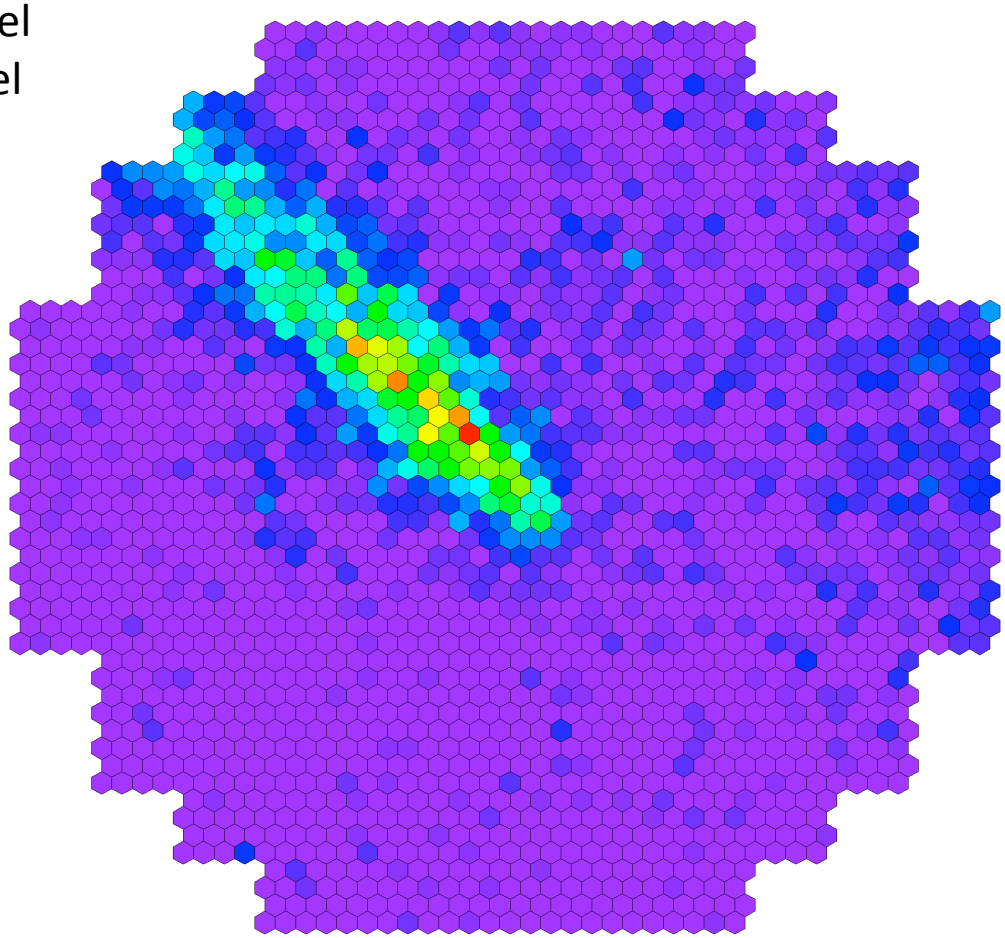
Currently only ~180 $m^2$ of mirror surface aligned







Data for each pixel:
High-gain channel
Low-gain channel
Timing
Pulse width



Aim to have
mirror fully aligned
in 1-2 weeks

# MACE @ HANLE

**Hanle: 4200 m asl, 32.7N**

**337 m² mirror,**

**356 diamond-turned Al panels**

**Actuator-aligned**

**1088 pixel camera**

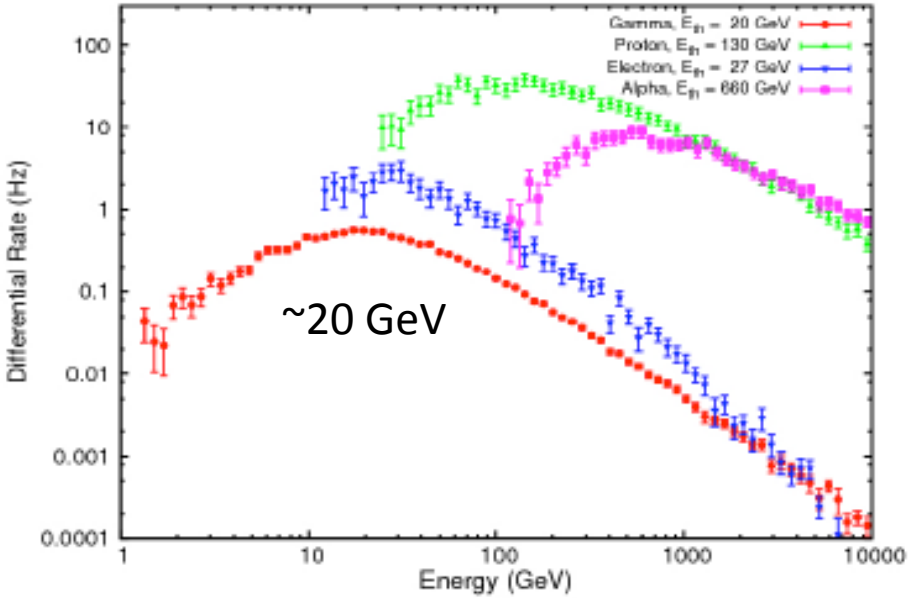
**0.125° pixel size**

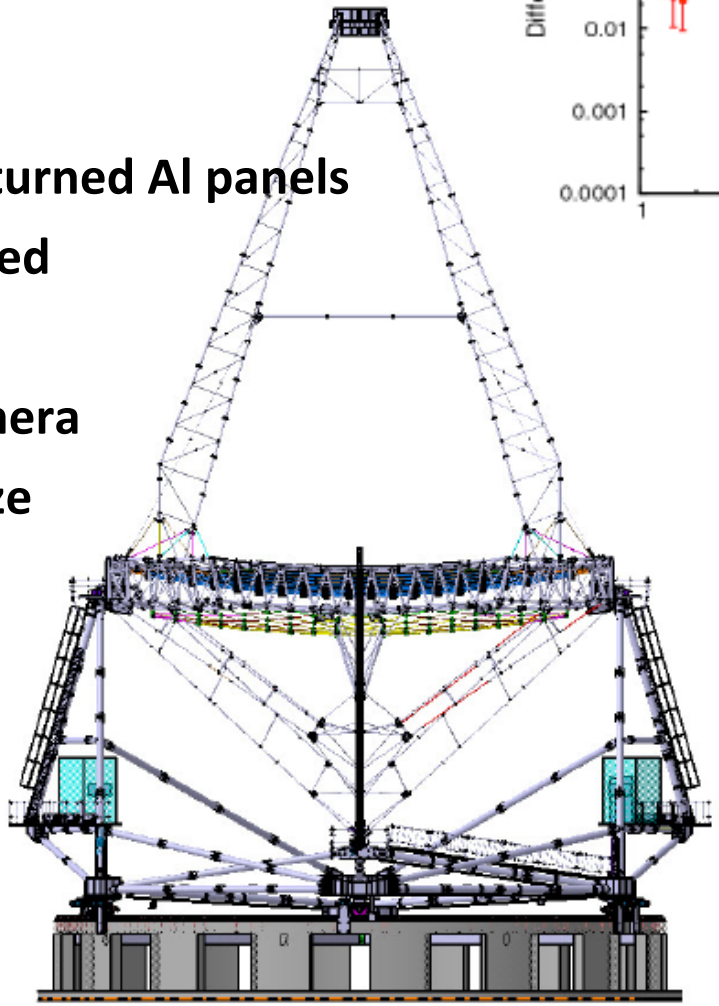
**4.0° FoV**

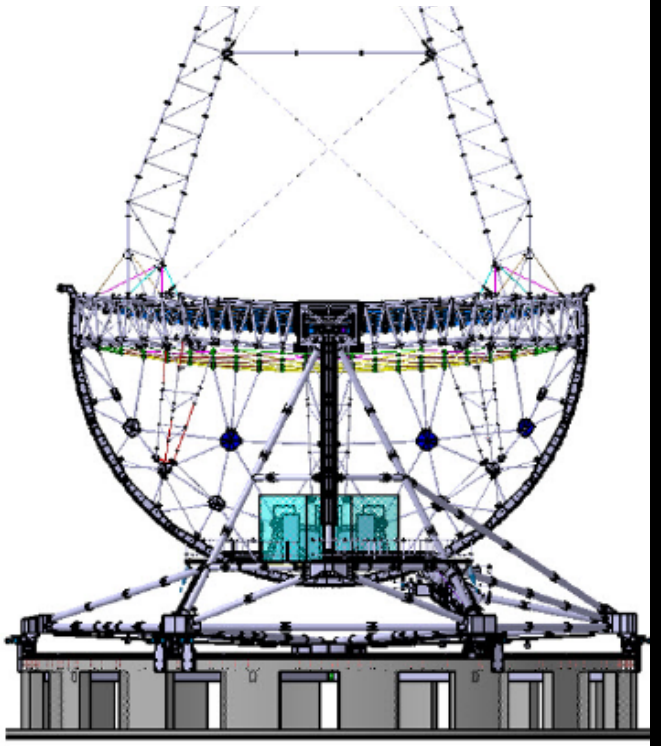
**ARS-4 readout**

**Threshold:**

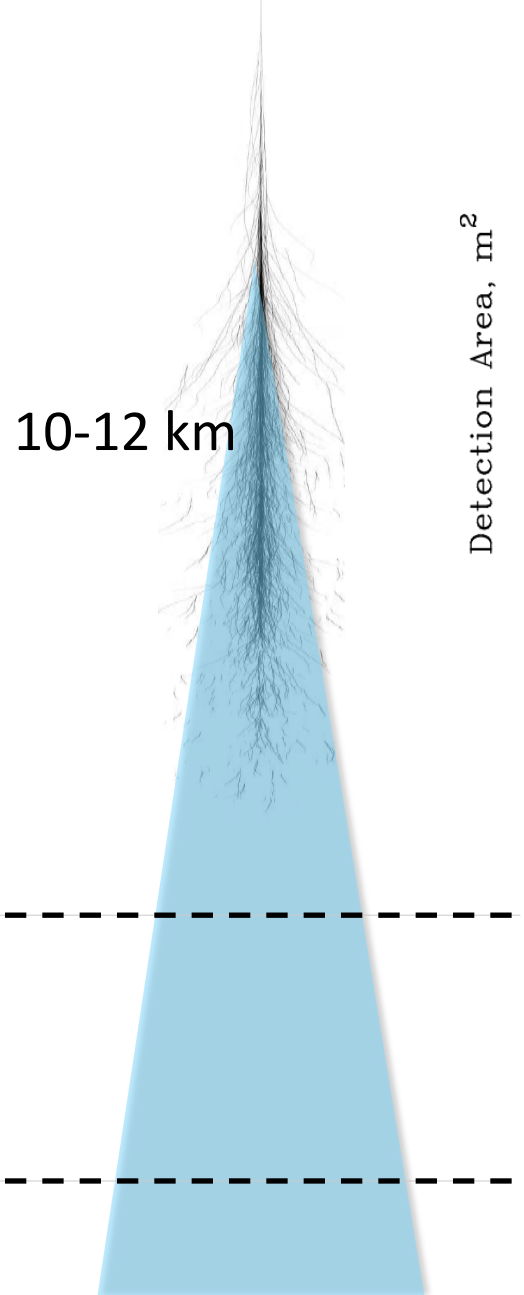
**~20 GeV**



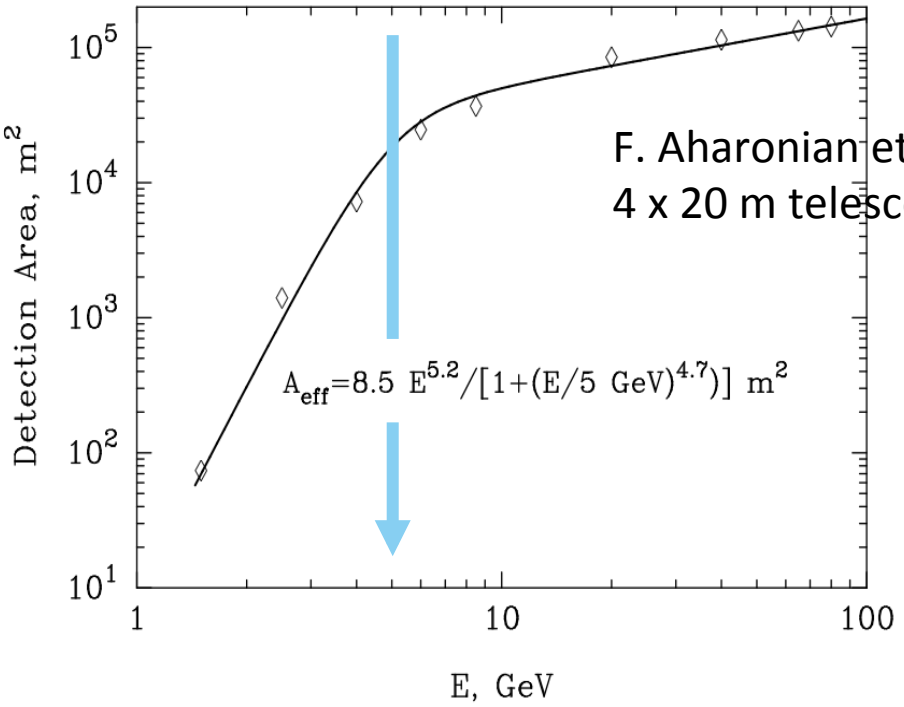





# HIGH-ALTITUDE CHERENKOV TELESCOPES



10-12 km




F. Aharonian et al., astro-ph/0006163
4 x 20 m telescopes @ 5000 m asl

higher light intensity (5000 m: x2)
➜lower threshold
smaller light pool area (5000 m: /2)

Reference height ~2000 m

# MACE TELESCOPE:
# TRIAL ASSEMBLY AT HYDERABAT

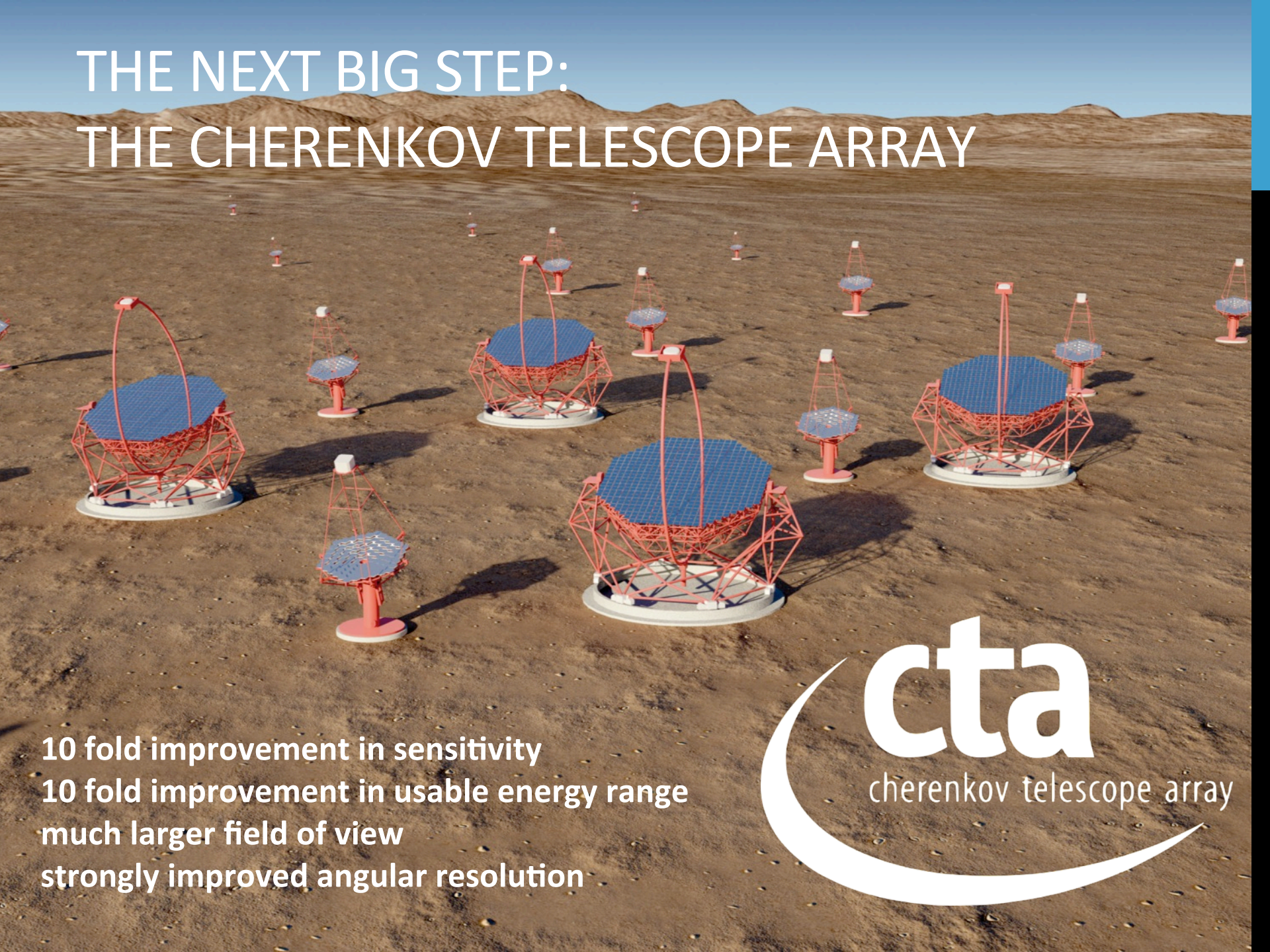
# MACE CHERENKOV TELESCOPE

**Plan to start assembly at Hanle by July 2013**

**First engineering runs by Nov. 2013**


**Hanle site**

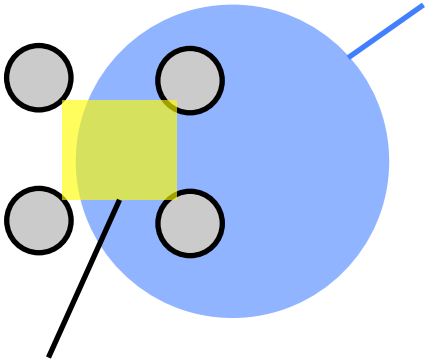
# THE NEXT BIG STEP:
# THE CHERENKOV TELESCOPE ARRAY



**10 fold improvement in sensitivity**
**10 fold improvement in usable energy range**
**much larger field of view**
**strongly improved angular resolution**

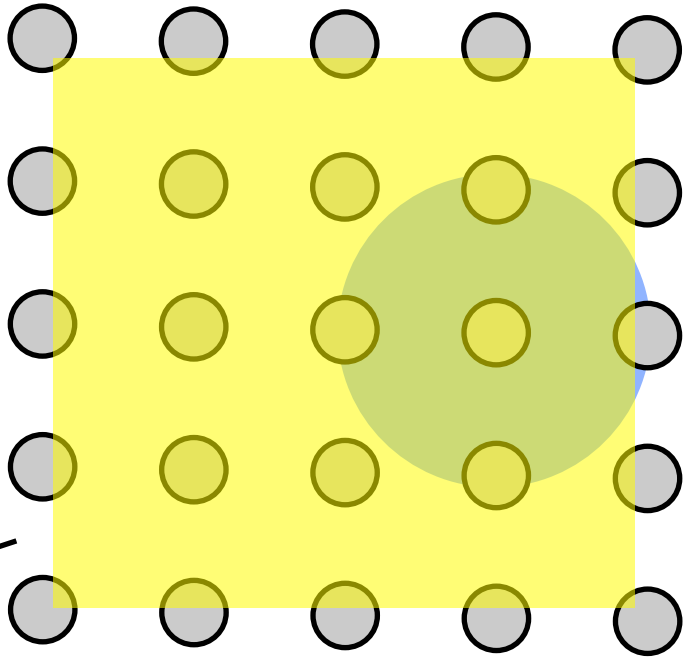
cta
cherenkov telescope array

# PERFORMANCE LIMITATIONS FOR IACTS

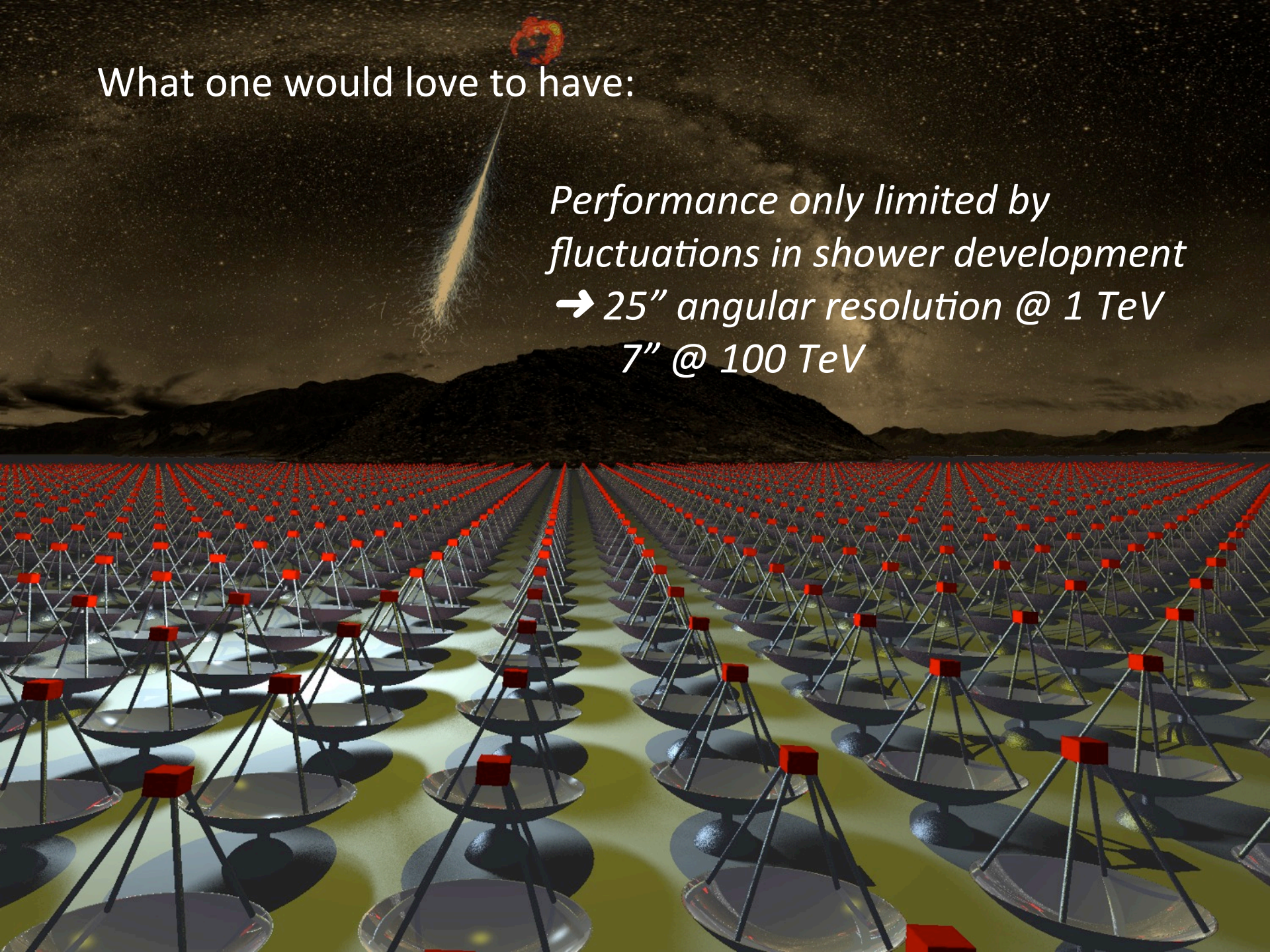


light pool radius
R ≈100-150 m
≈ typical telescope spacing

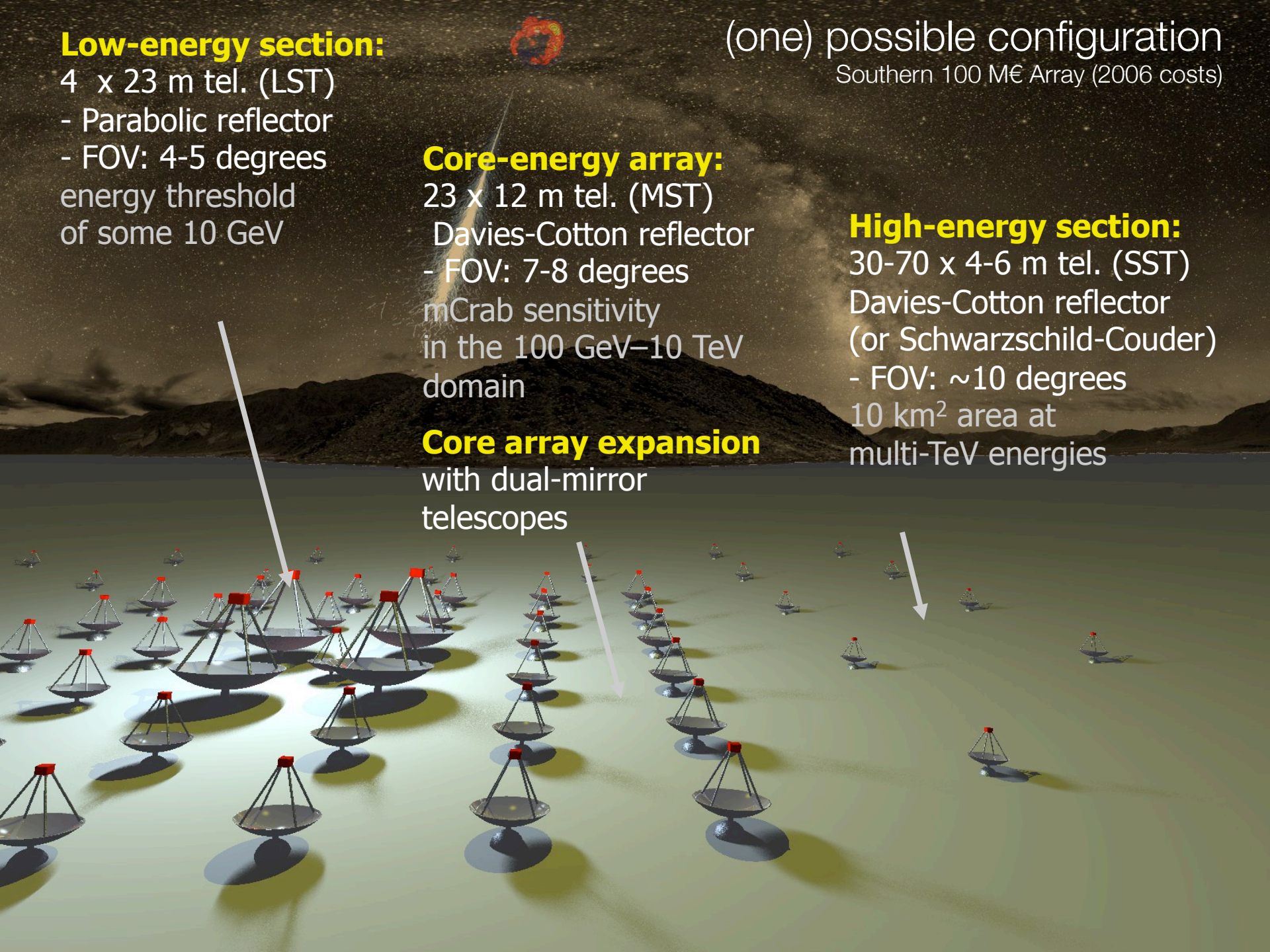
Sweet spot for
best triggering
and reconstruction:
most showers miss it!



large detection area
more images per shower
lower trigger threshold

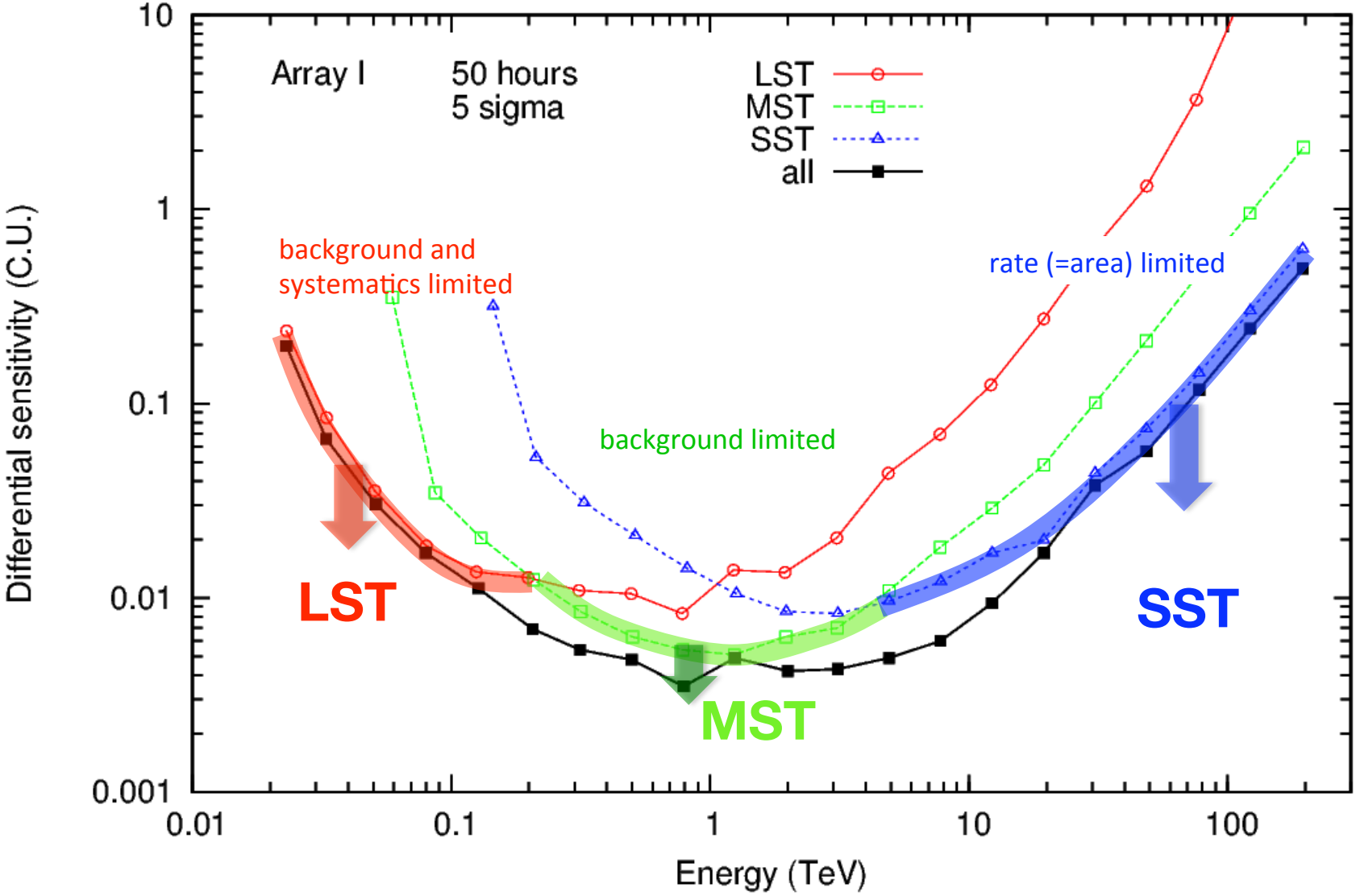

What one would love to have:
*Performance only limited by fluctuations in shower development*
➜ *25” angular resolution @ 1 TeV*
*7” @ 100 TeV*

What one can (hopefully) afford:

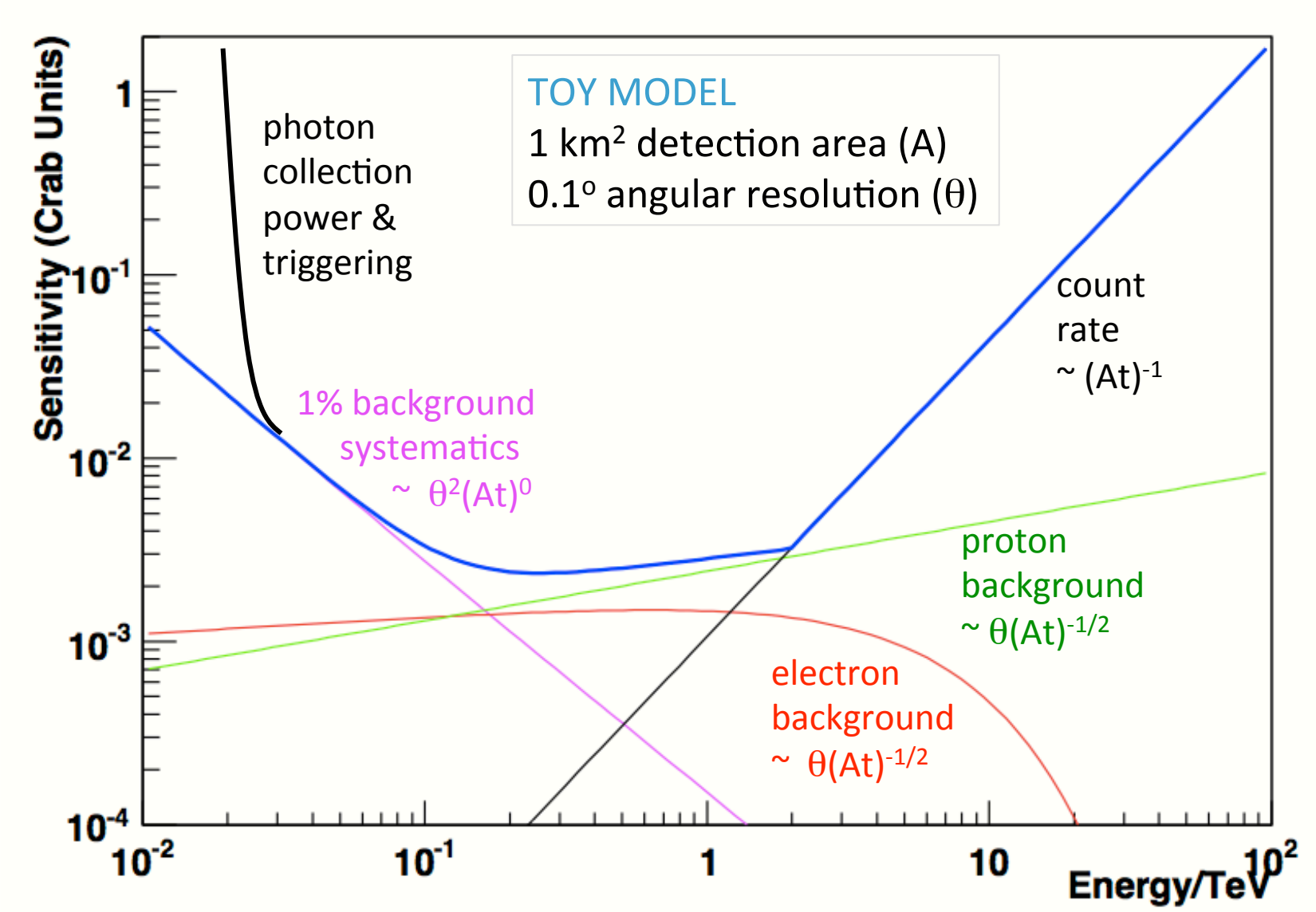

(one) possible configuration
Southern 100 M€ Array (2006 costs)
Low-energy section:
4 x 23 m tel. (LST)
- Parabolic reflector
- FOV: 4-5 degrees
energy threshold
of some 10 GeV
Core-energy array:
23 x 12 m tel. (MST)
Davies-Cotton reflector
- FOV: 7-8 degrees
mCrab sensitivity
in the 100 GeV–10 TeV
domain
Core array expansion
with dual-mirror
telescopes
High-energy section:
30-70 x 4-6 m tel. (SST)
Davies-Cotton reflector
(or Schwarzschild-Couder)
- FOV: ~10 degrees
10 km2 area at
multi-TeV energies

# SENSITIVITY (IN UNITS OF CRAB FLUX)

FOR DETECTION IN EACH 0.2-DECADE ENERGY BAND



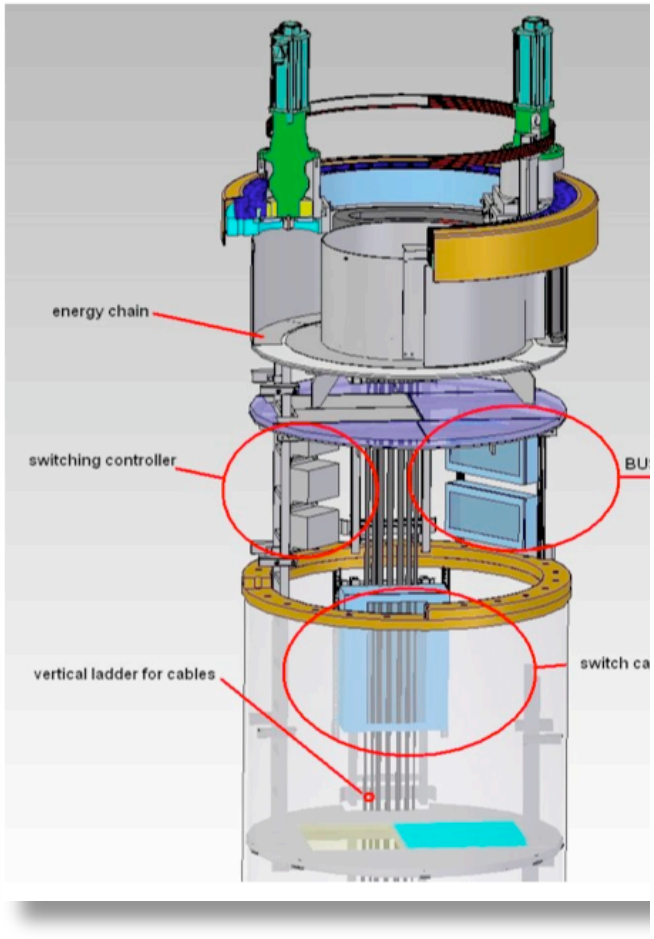
# PERFORMANCE LIMITATIONS FOR IACTS



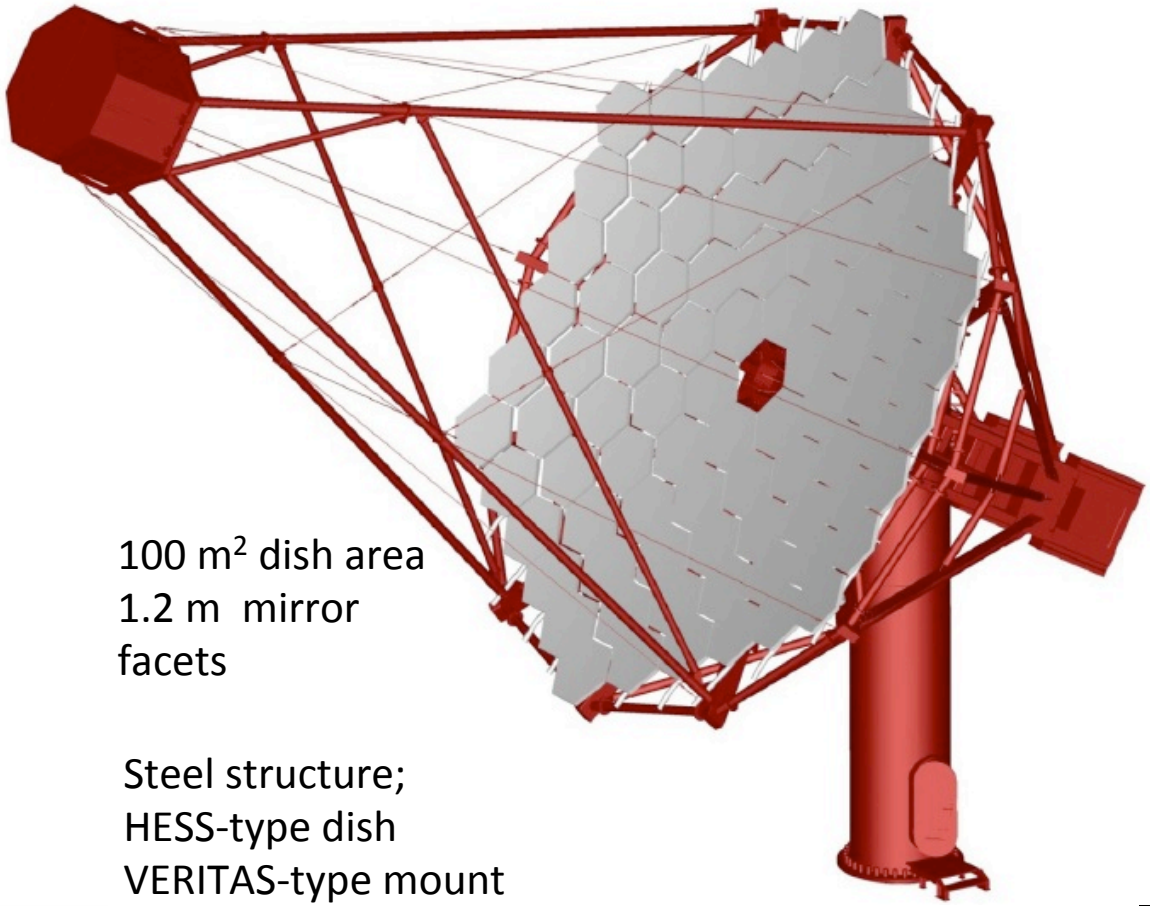
# MEDIUM-SIZED 12 M TELESCOPE

## OPTIMIZED FOR THE 100 GEV TO 10 TEV RANGE

Prototype under construction




16 m focal length
7-8$^{o}$ field of view
0.18$^{o}$ pixels



100 m$^2$ dish area
1.2 m mirror facets

Steel structure;
HESS-type dish
VERITAS-type mount

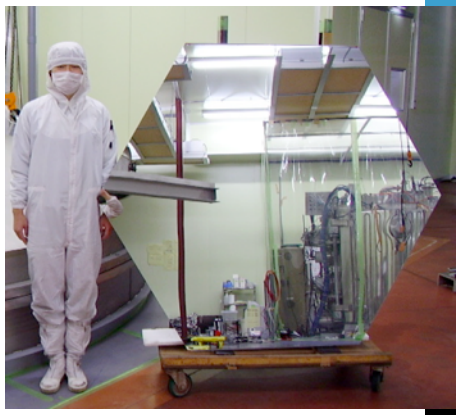
# DESIGN: 23 M LARGE TELESCOPES

## OPTIMIZED FOR THE RANGE BELOW 200 GEV

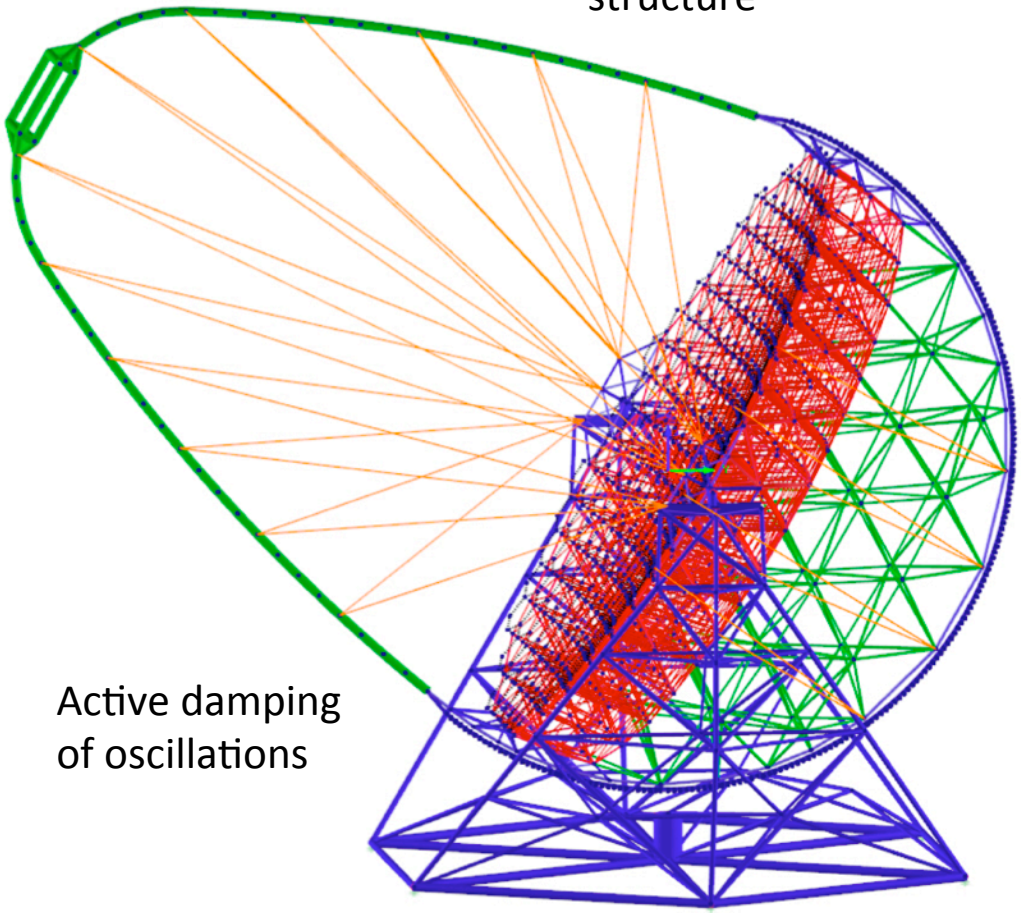
27.8 m focal length
4.5° field of view
0.1° pixels

Carbon-fibre structure

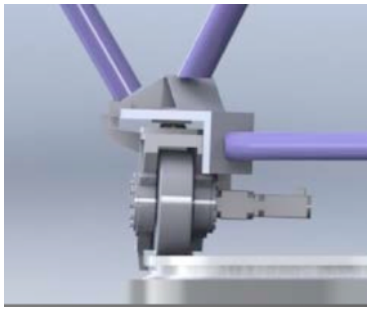
400 $m^2$ dish area
1.5 m sandwich mirror facets

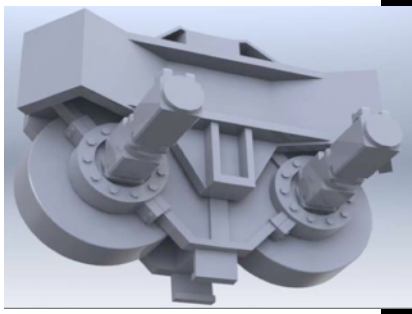


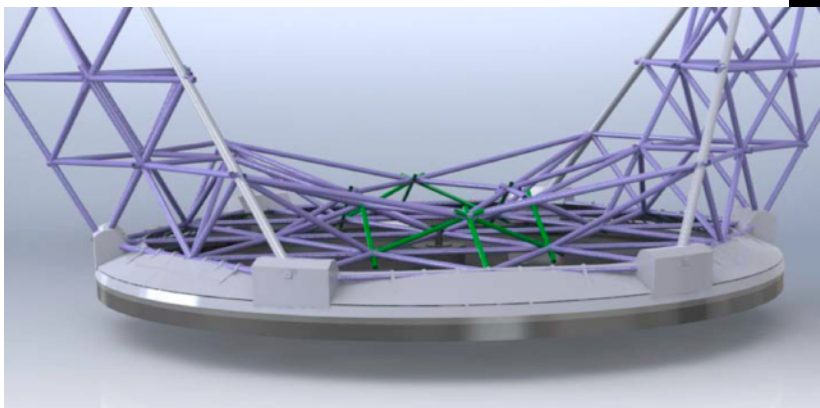
On (GRB) target in < 20 sec.



Active damping of oscillations







# CTA DESIGN

Proven technology as design baseline
Improvements in many details

Operation as observatory &
large number of telescopes
requires improved reliability and
ease of maintenance

Advanced options followed in parallel

# DUAL MIRROR OPTION

## FOR MEDIUM-SIZED TELESCOPE

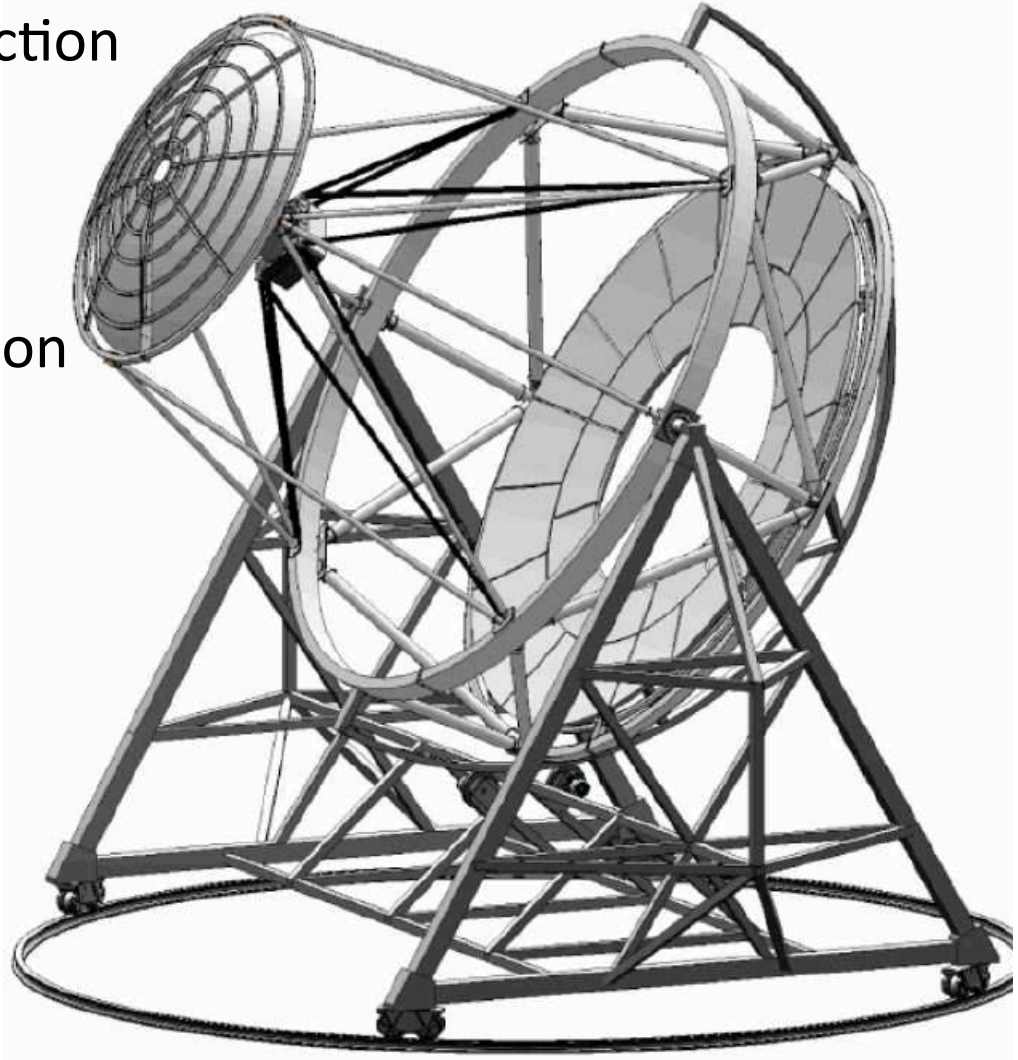
V. V. Vassiliev, S. J. Fegan,
P. F. Brousseau
Astropart.Phys.28:10-27,2007

- Improved point spread function and improved angular resolution
- Small plate scale
- Suitable for MAMPT or silicon sensors

but also

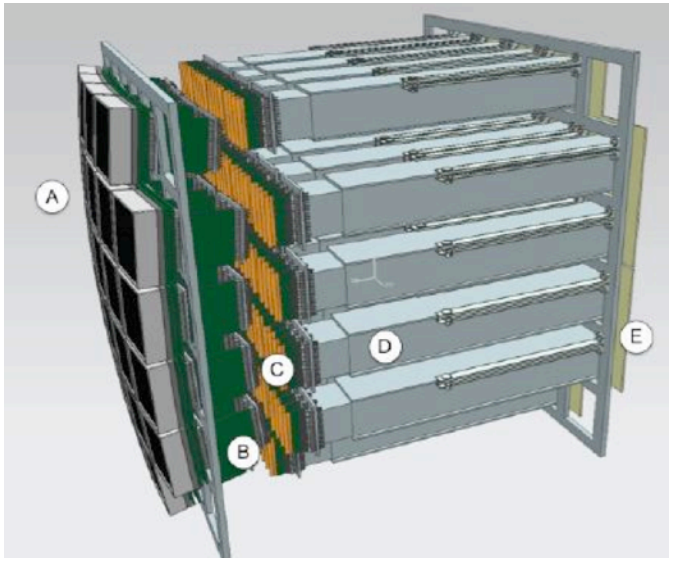
- Non-spherical mirrors
- Challenging alignment
- Not prototyped yet

Aim at expanding
MST array with
dual-mirror telescopes

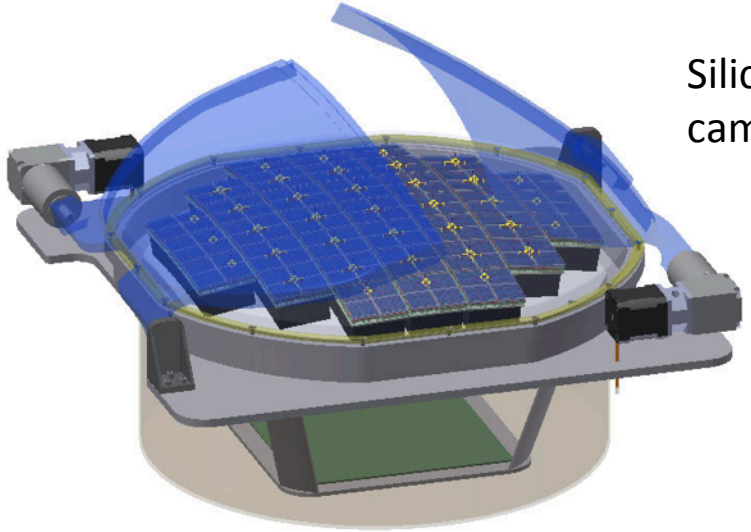


# DUAL-MIRROR SMALL TELESCOPES

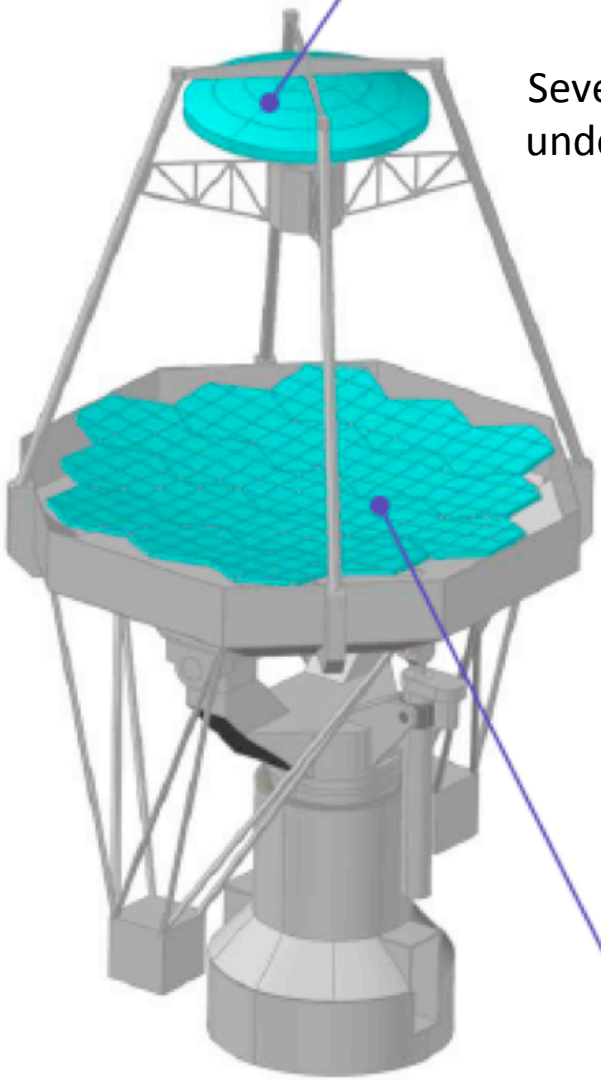
## ALLOW USING LOWER-COST SENSORS




Multi-Anode PMT camera option



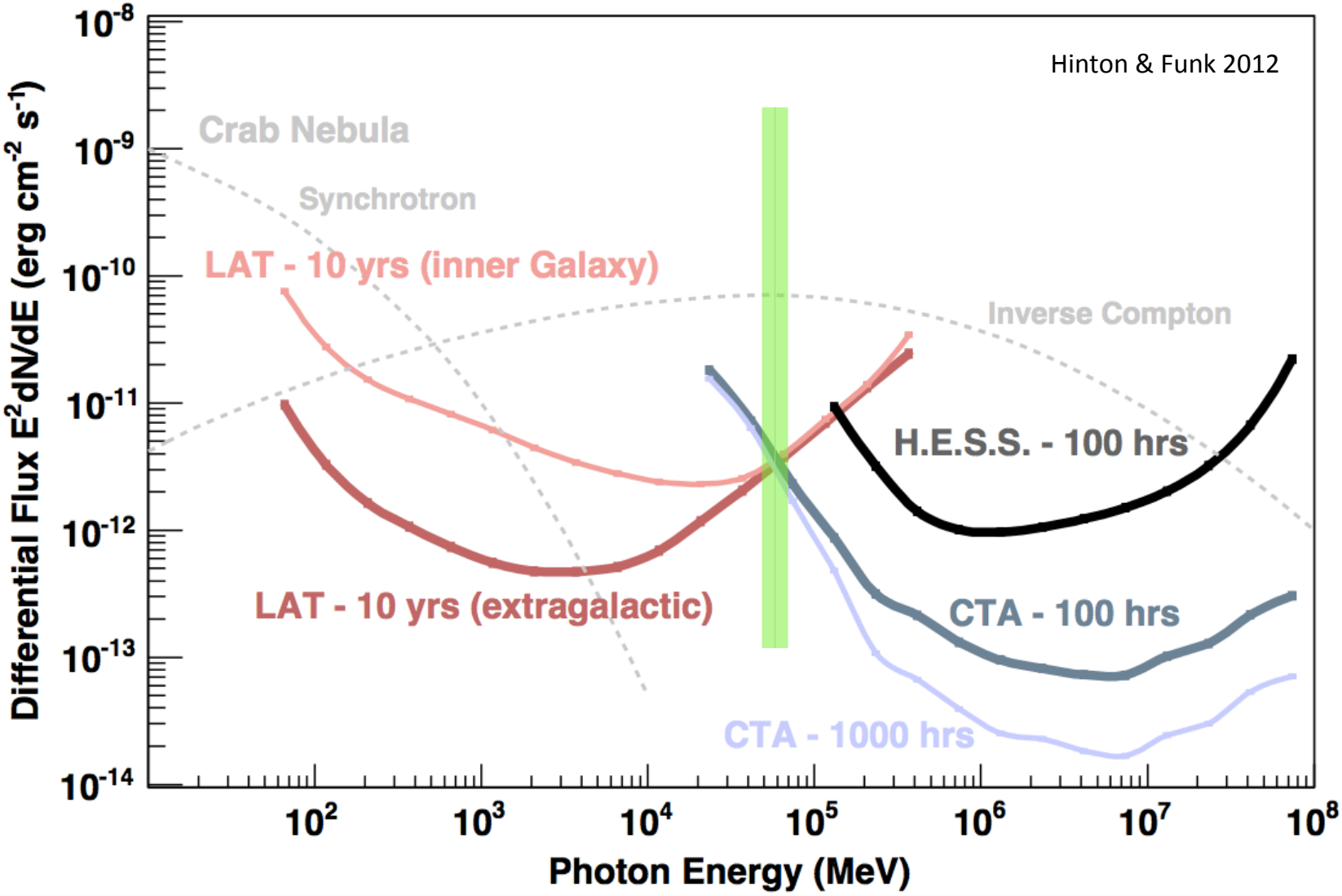
Silicon sensor camera option



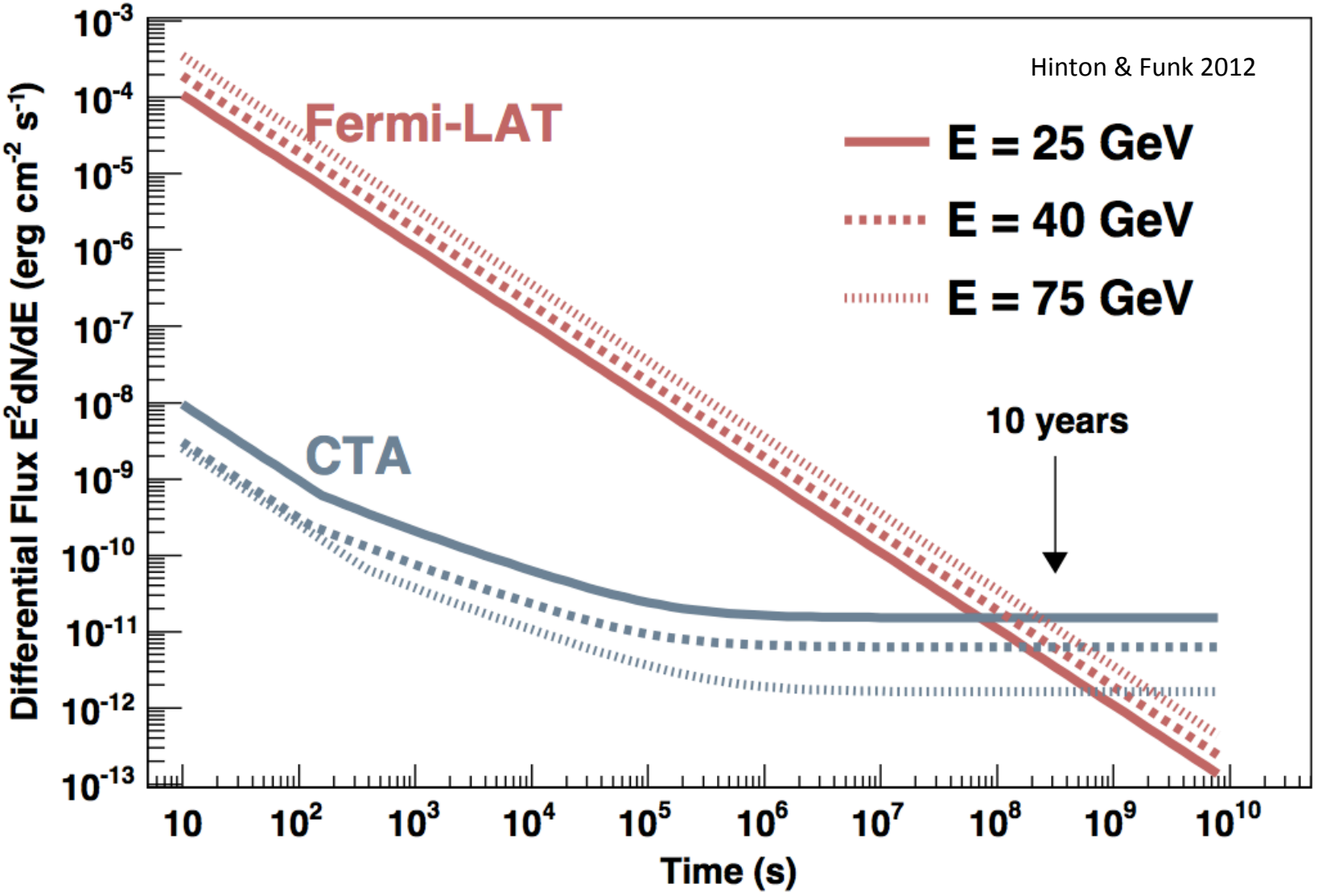

➜ *talk by S. Vercellone*

# CTA VERSUS FERMI – STEADY SOURCES

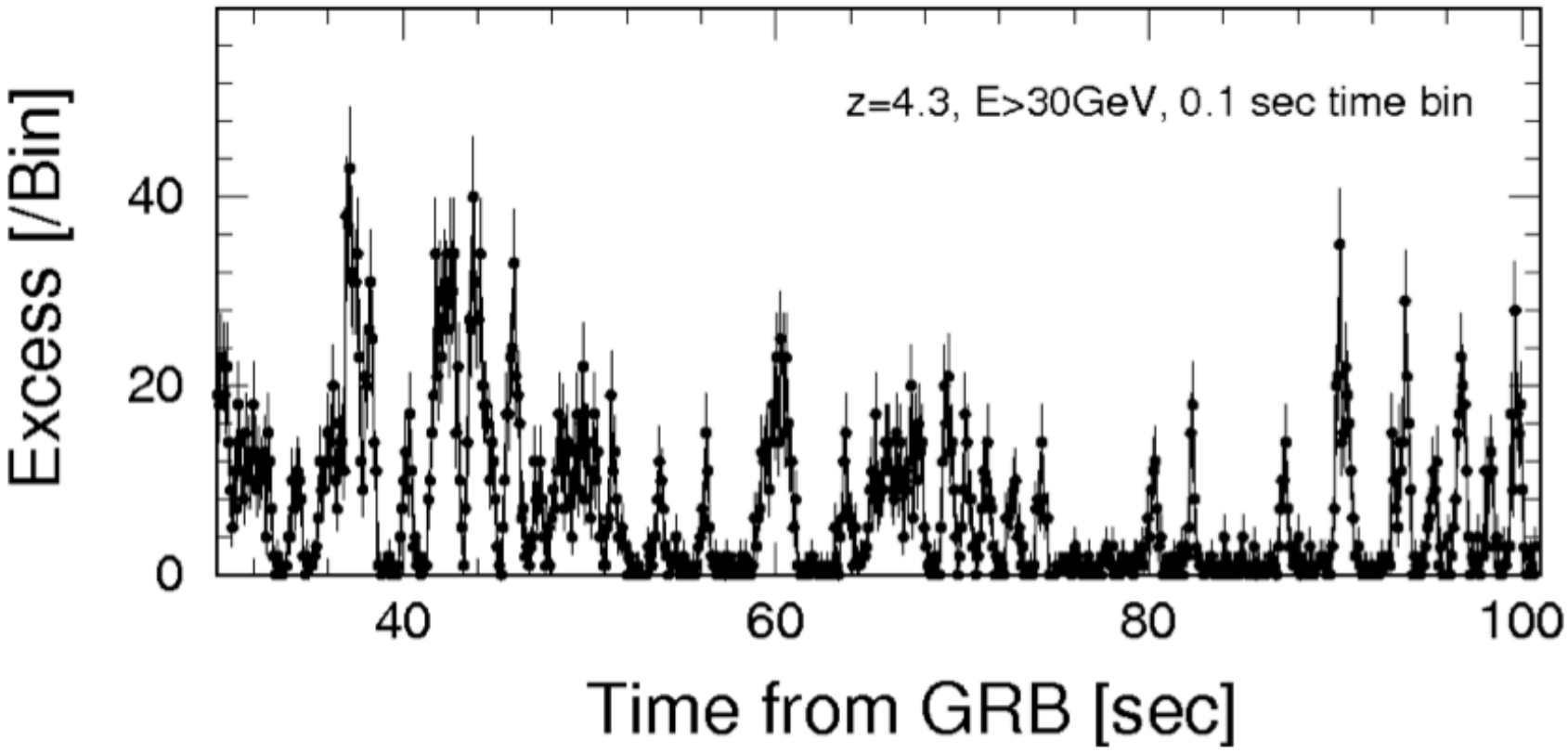
➜ *talk by S. Funk*



# CTA VERSUS FERMI – TRANSIENT SOURCES

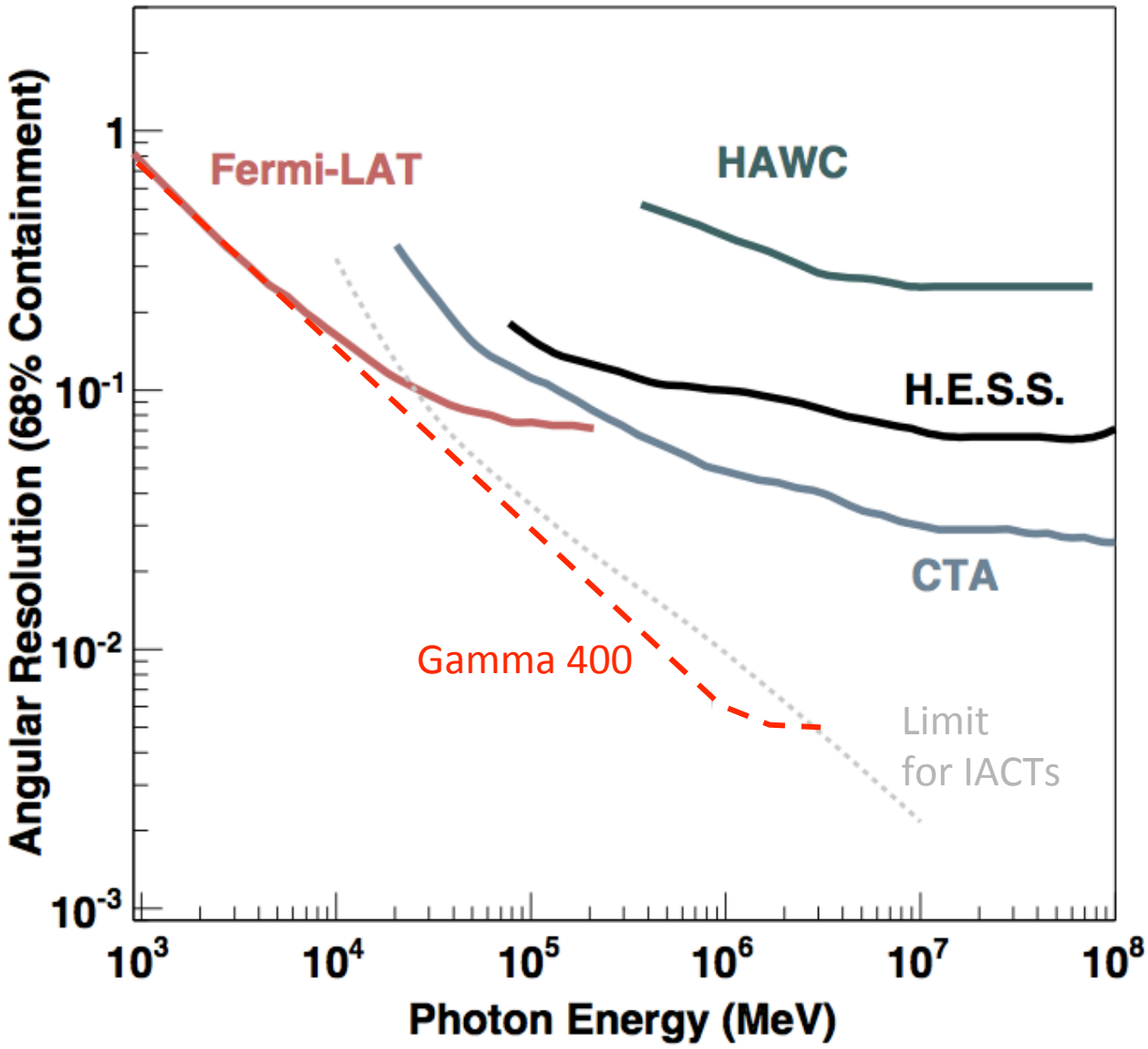


# A SIMULATED GRB (E > 30 GEV)



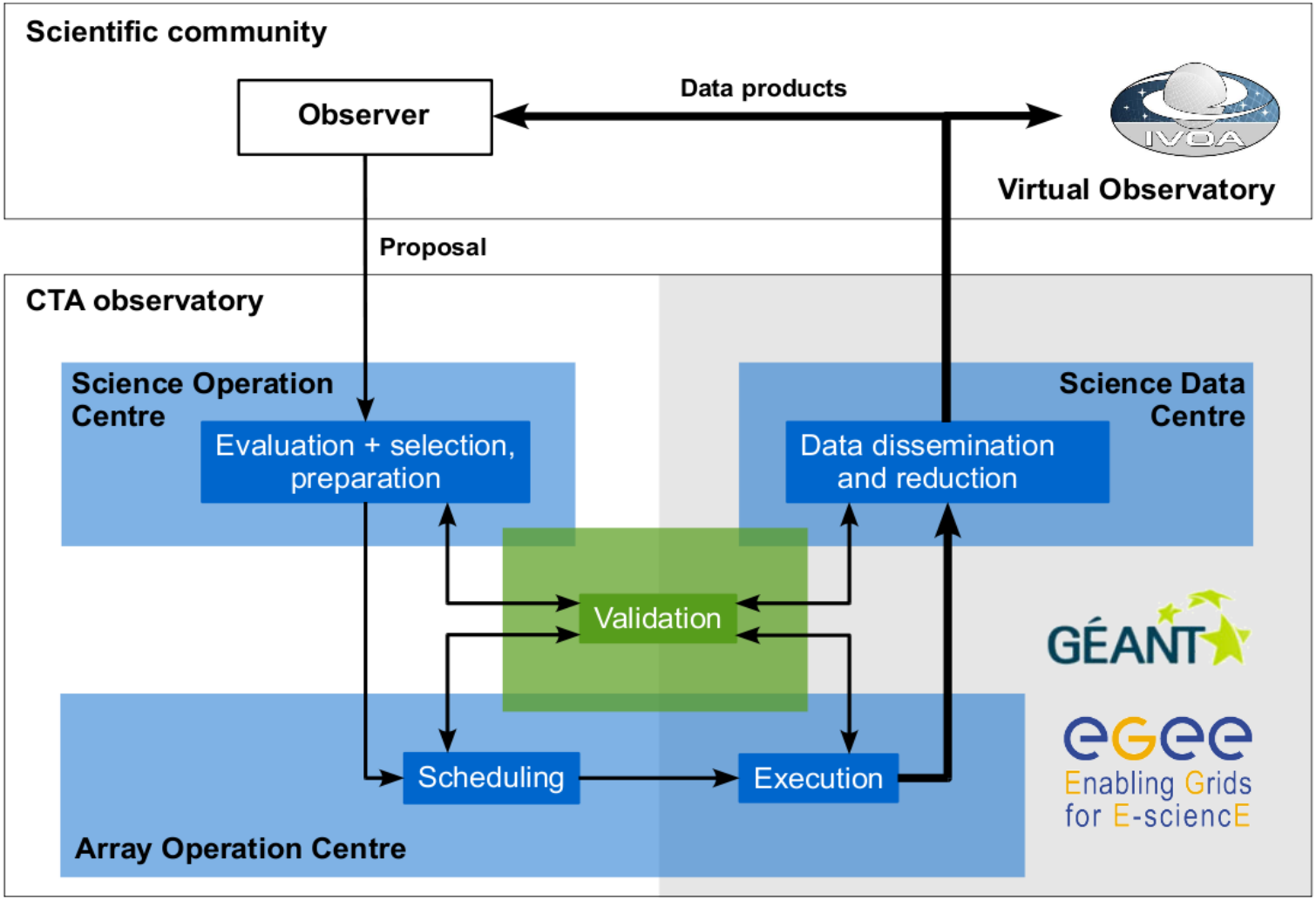

from
Gamma-Ray Burst Science in the Era of Cherenkov Telescope Array
(Astroparticle Physics special issue article)
Susumu Inoue et al.

# ANGULAR RESOLUTION




adapted from Hinton & Funk 2012

# FOR THE FIRST TIME IN VHE ASTRONOMY: CTA AS OPEN OBSERVATORY



# FOR THE FIRST TIME IN VHE ASTRONOMY: OPEN AND SUPPORTED USER TOOLS

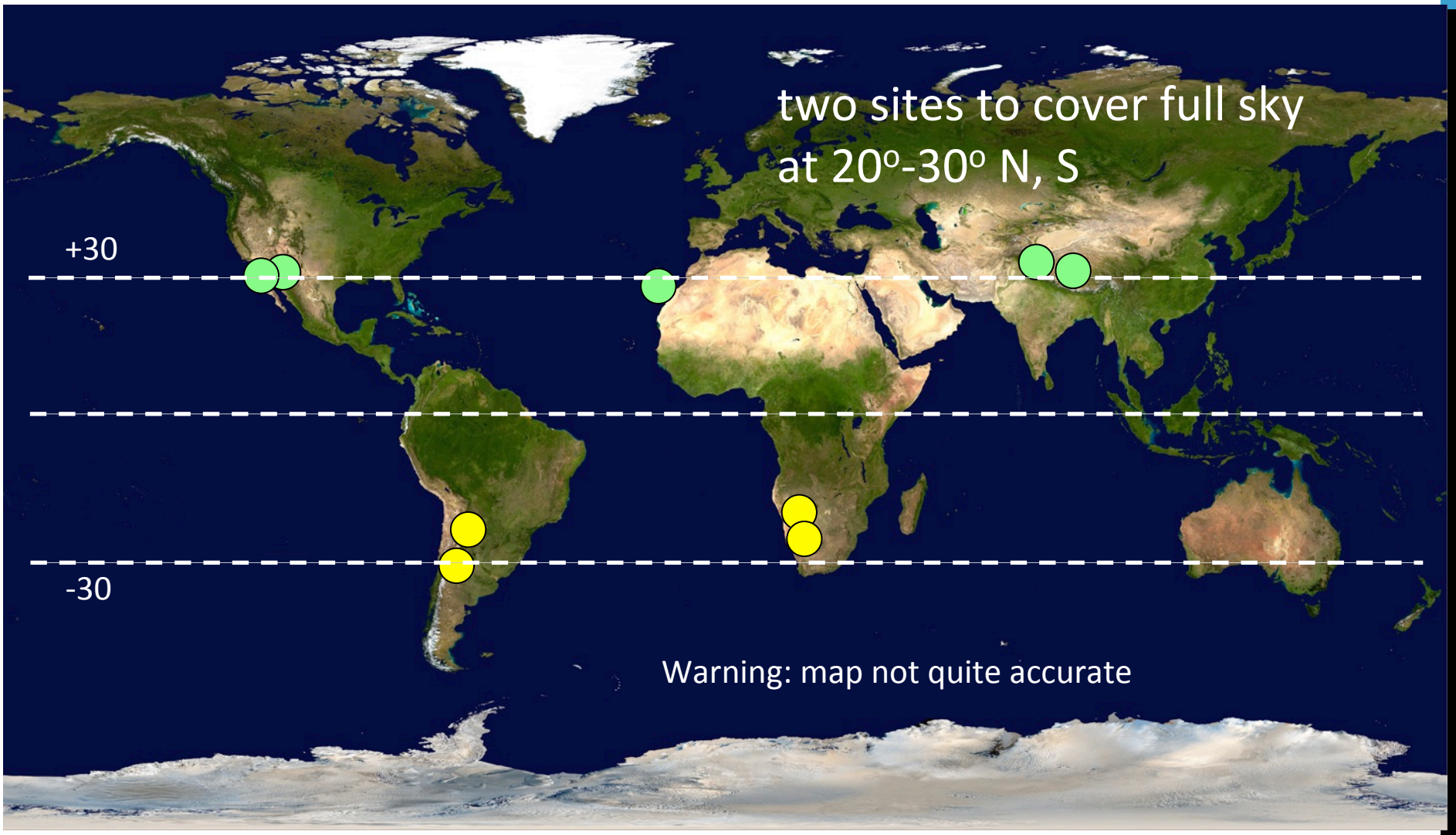
- open formats and tools following astronomy standards (FITS) to represent and analyse data and instrument response functions (IRFs)
- user-oriented data center & Virtual Observatory interfaces

Evolution of FITS-based data & metadata formats:

Optical and X-ray images → HE gamma tracks (Fermi/LAT) → VHE gamma showers (CTA)

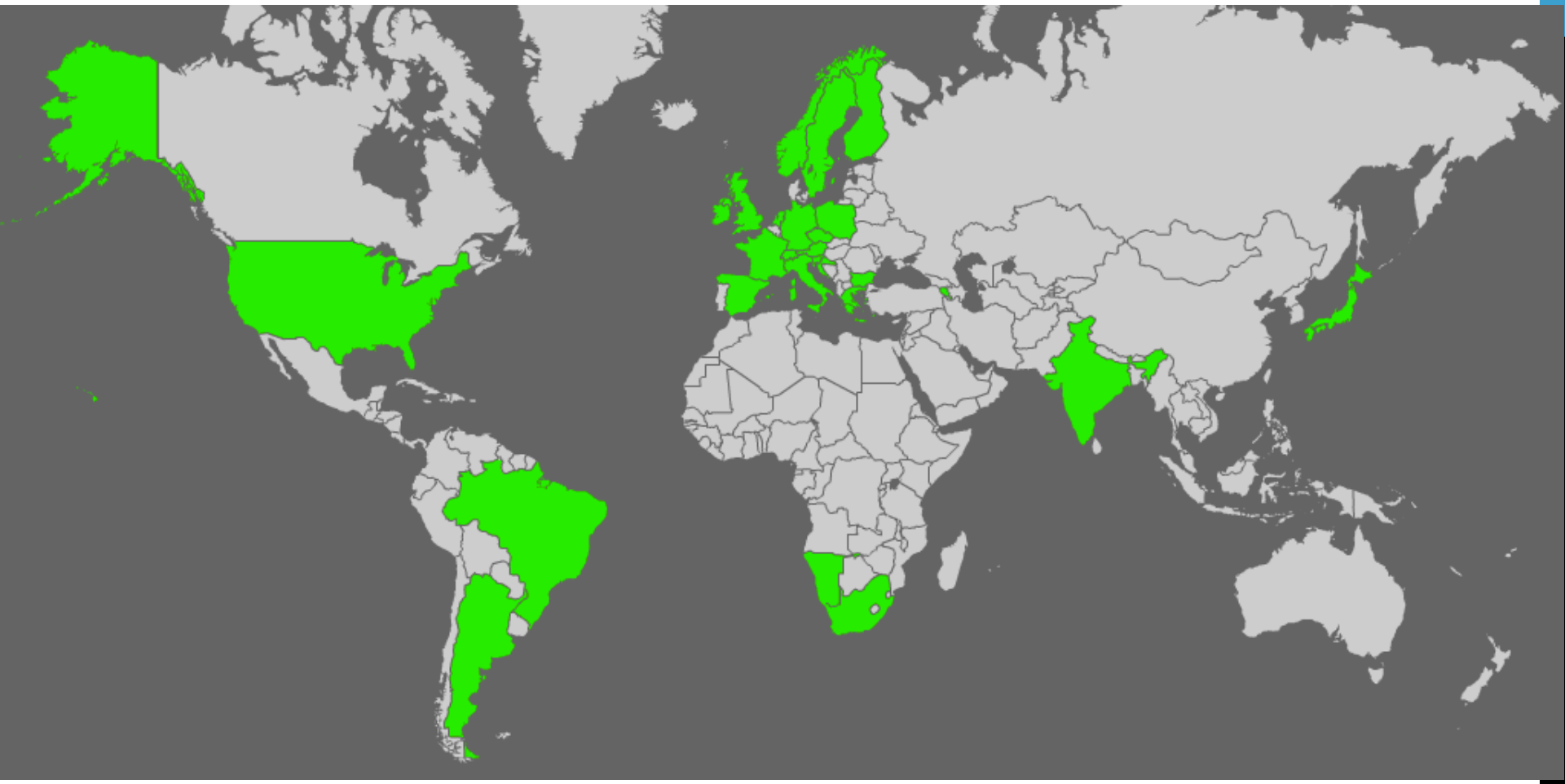
# SITE CANDIDATES

Working towards quantifying site-dependent differences in performance and cost



# CTA MEMBERS: 26 COUNTRIES

~1000 PERSONS FROM 163 INSTITUTIONS

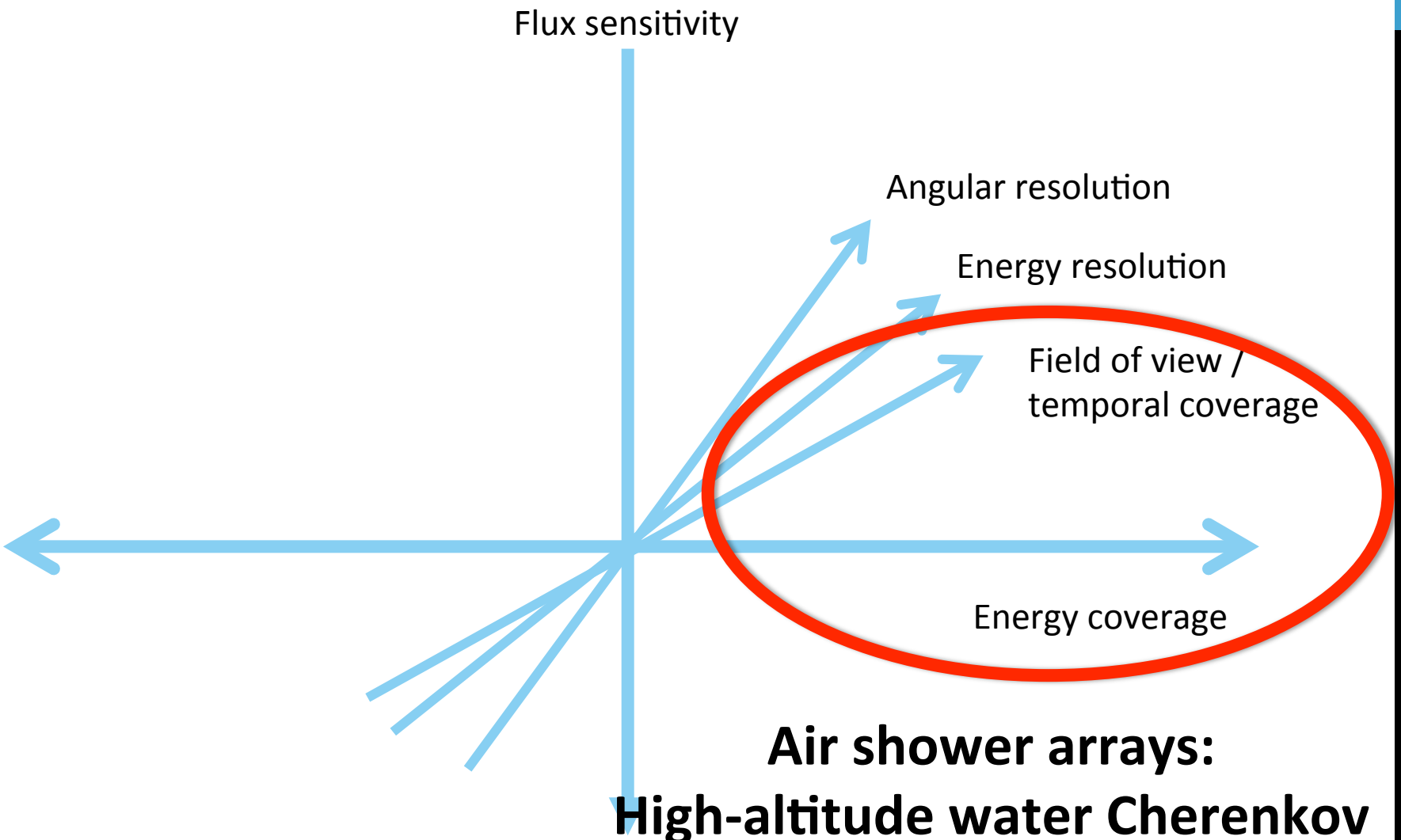


Argentina, Armenia, Austria, Brazil, Bulgaria, Czech Republic, Croatia, Finland, France, Germany, Greece, India, Italy, Ireland, Japan, Namibia, Netherlands, Norway, Poland, Slovenia, Spain, South Africa, Sweden, Switzerland, UK, USA

# RECOMMENDED BY RELEVANT ROADMAPS …



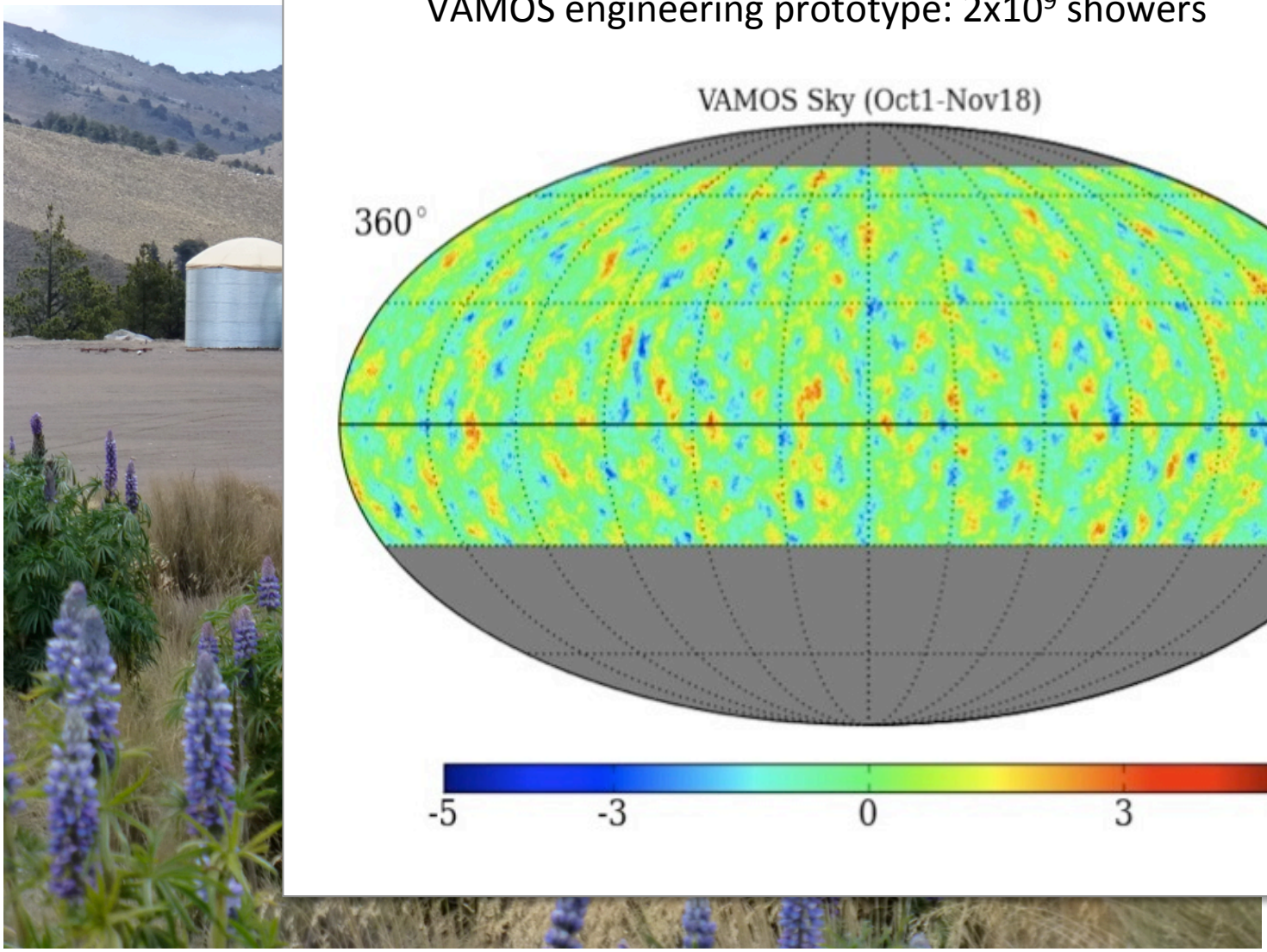
# FUTURE INSTRUMENTS




**Air shower arrays:**
**High-altitude water Cherenkov**
**Large-area muon veto**

# HAWC

➜ *TALK BY A. SANDOVAL*



VAMOS engineering prototype: $2 \times 10^9$ showers

# LAWCA LARGE AREA WATER CHERENKOV ARRAY @ TIBET

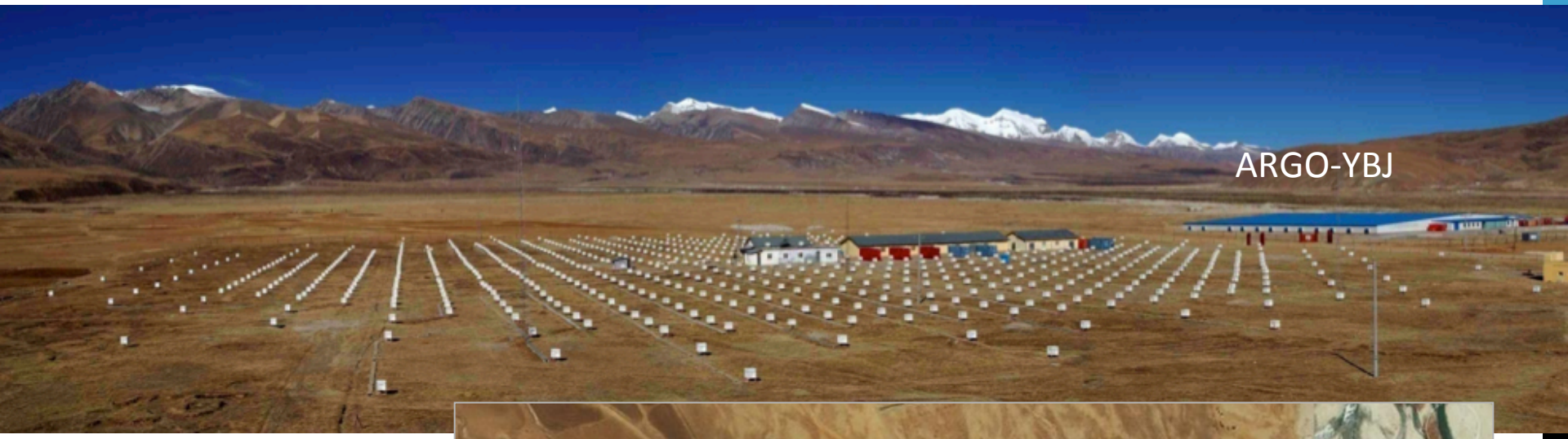
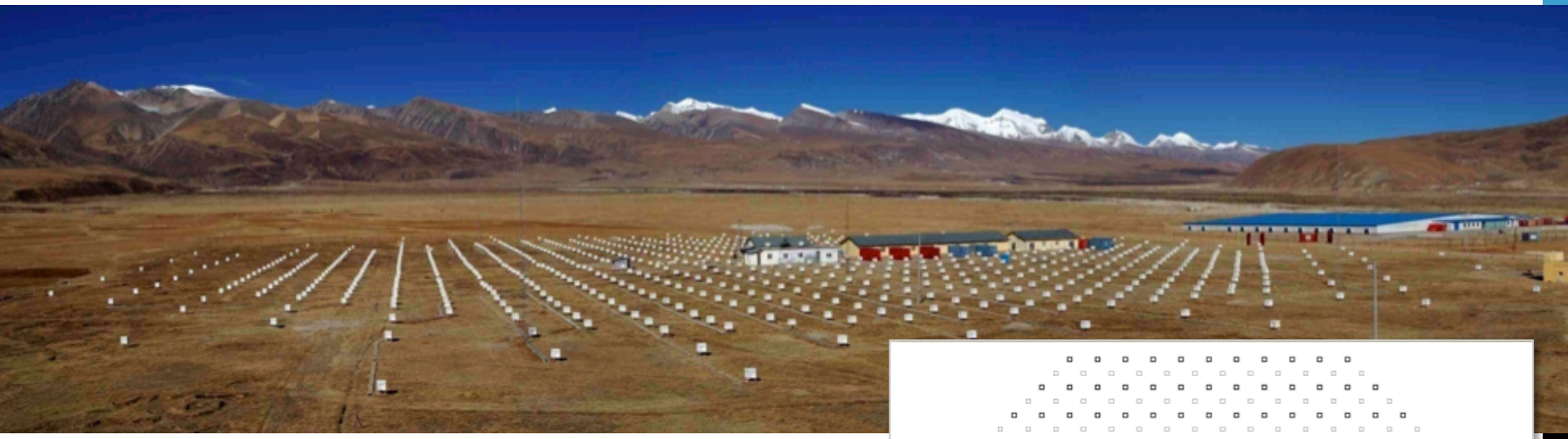



**Fig. 1.** Picture of the prototype water Cherenkov detector. It is a cylin
tank, 7.07 m in diameter and 5.00 m in height.

Prototype @ IHEP
(NIM A644:11, 2011)

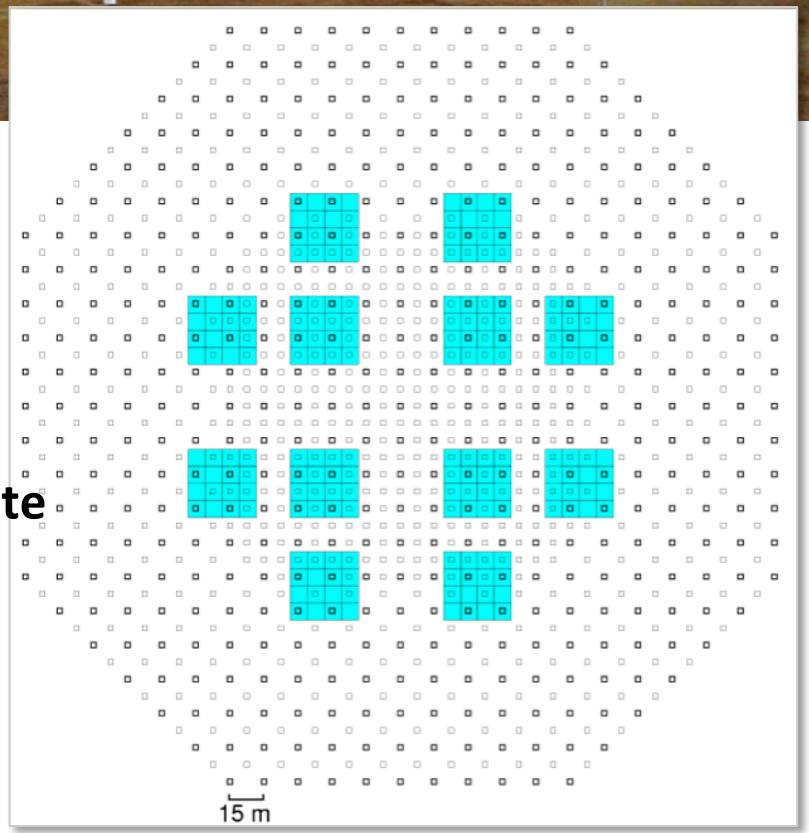
# TIBET MD



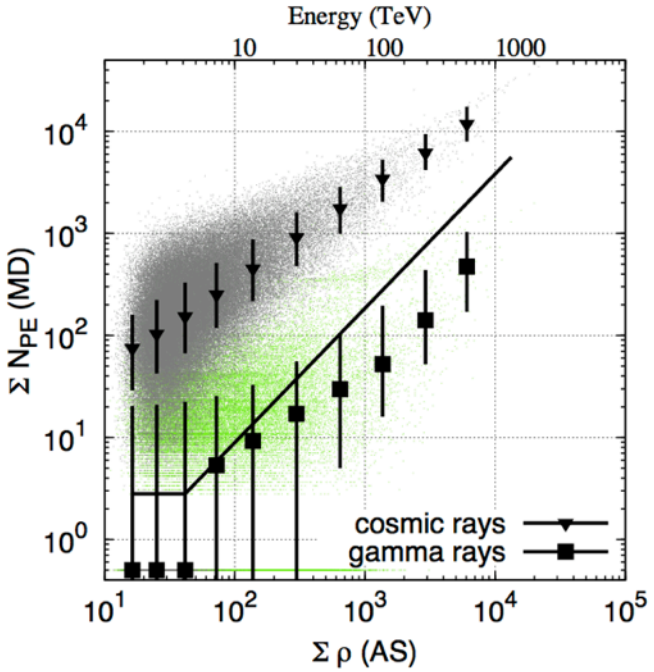
Add 10000 $m^2$ of muon detectors

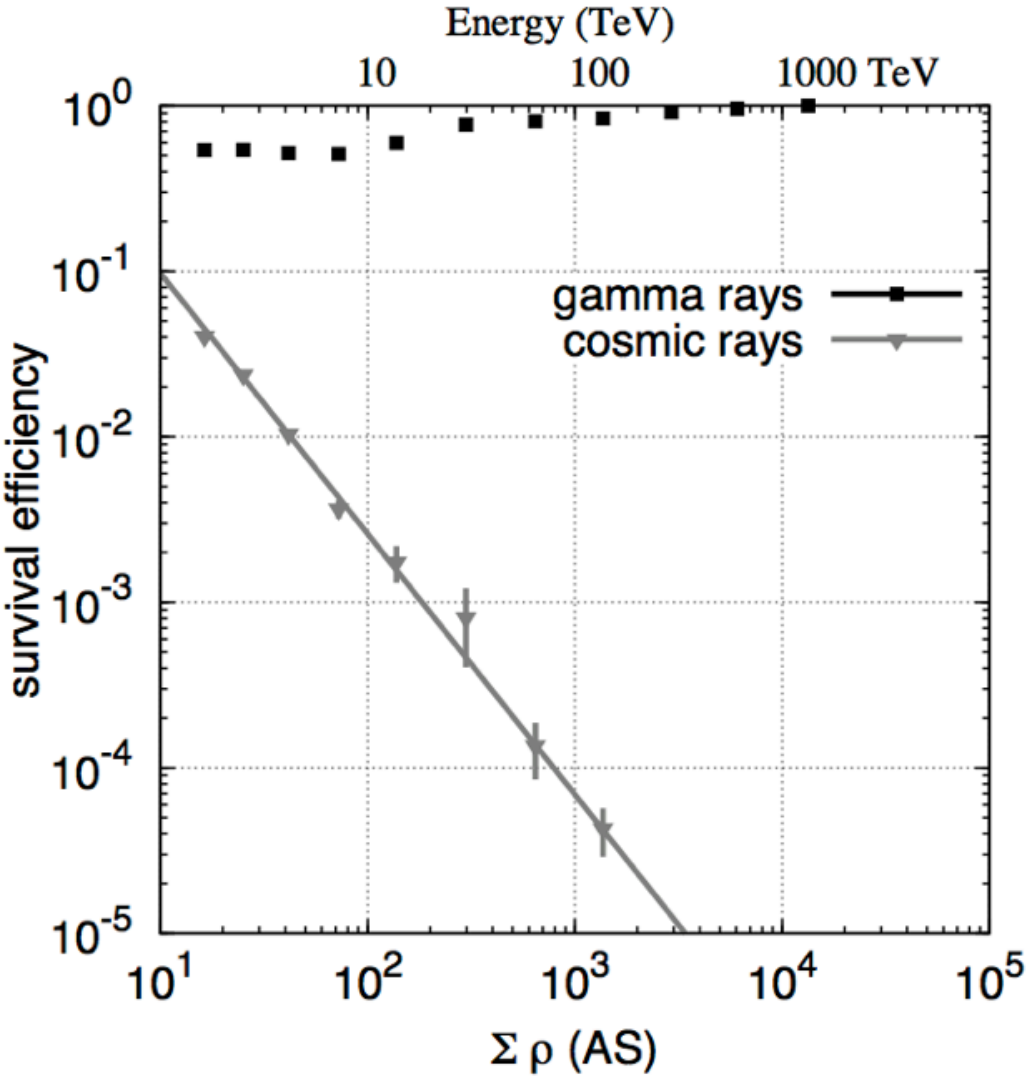
Expand array to 83000 $m^2$

**Status: 5 of 12 muon detector pools complete**



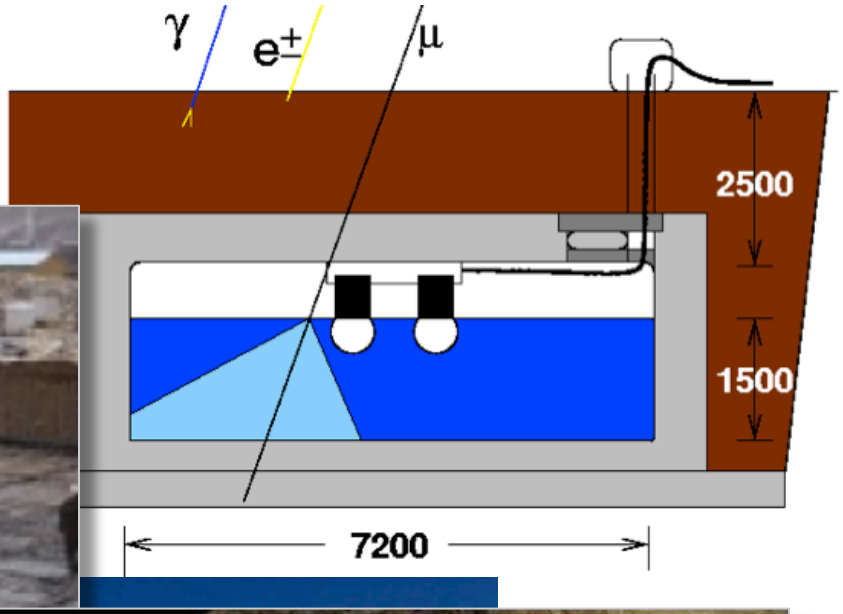
# TIBET MD: BACKGROUND REJECTION



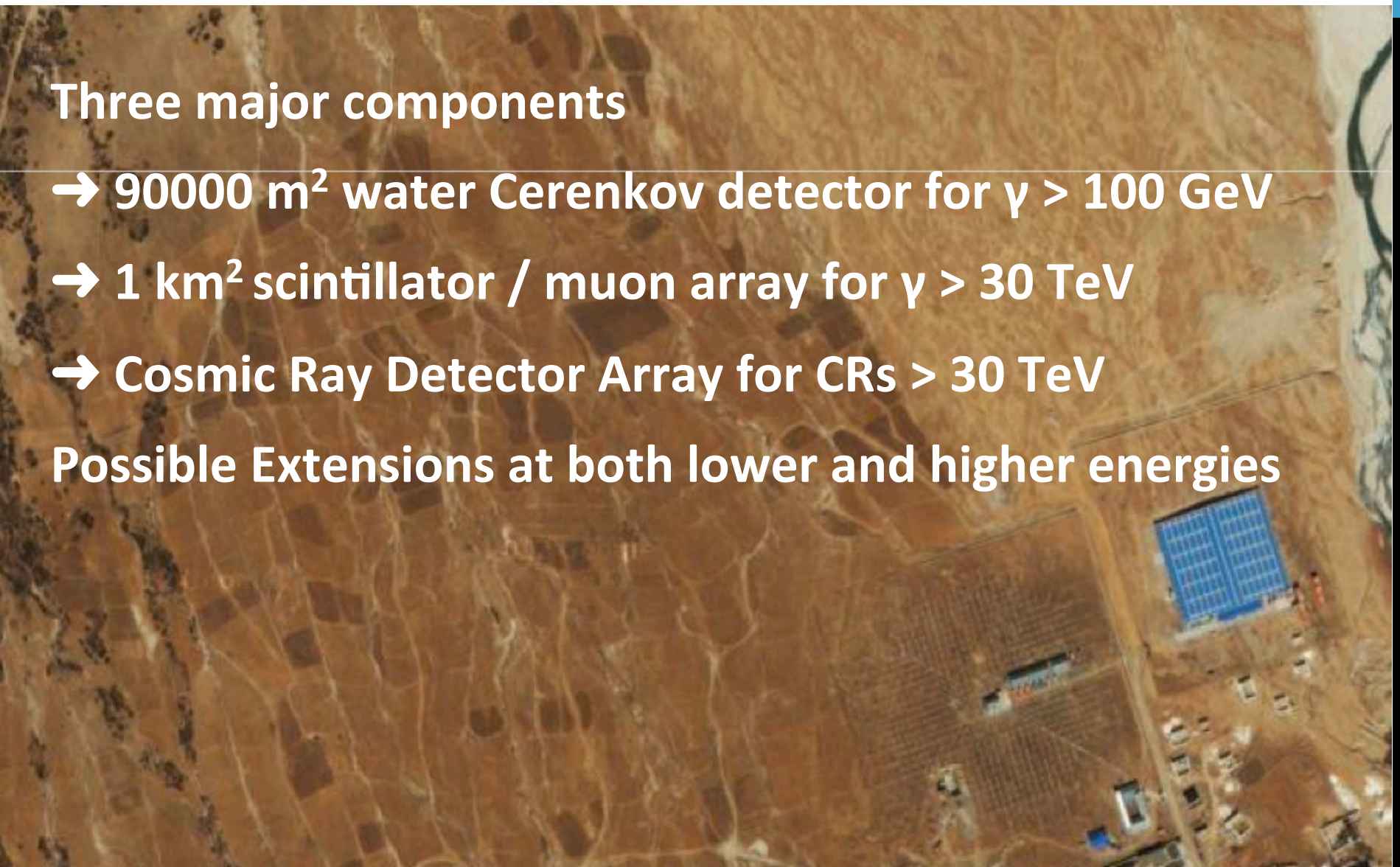

T.K. Sato et al.
arXiv:0907.45

# TIBET MD




# LHAASO

## LARGE HIGH ALTITUDE AIR SHOWER OBSERVATORY



**Three major components**

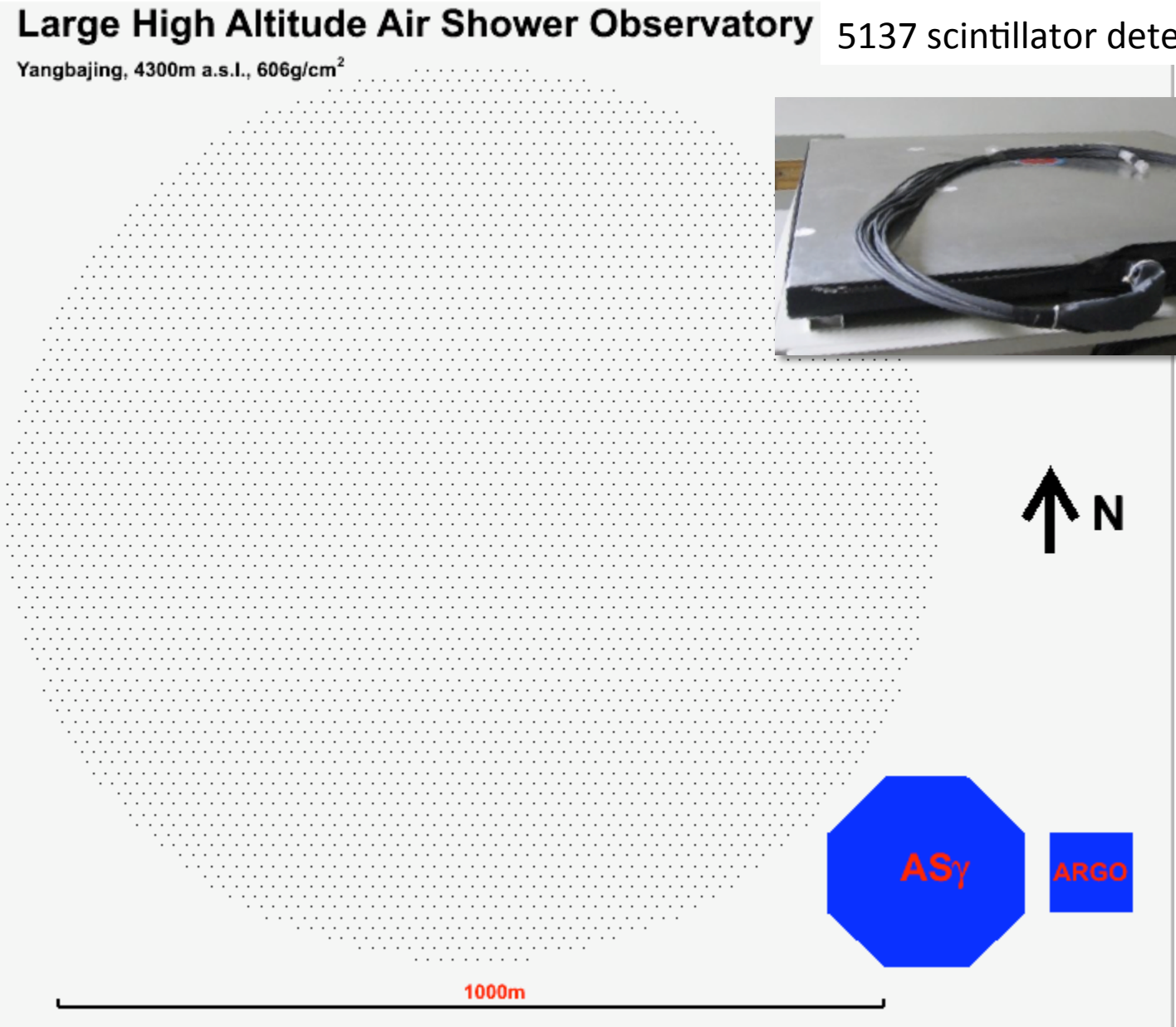
➜ **90000 $m^2$ water Cerenkov detector for γ > 100 GeV**

➜ **1 $km^2$ scintillator / muon array for γ > 30 TeV**

➜ **Cosmic Ray Detector Array for CRs > 30 TeV**

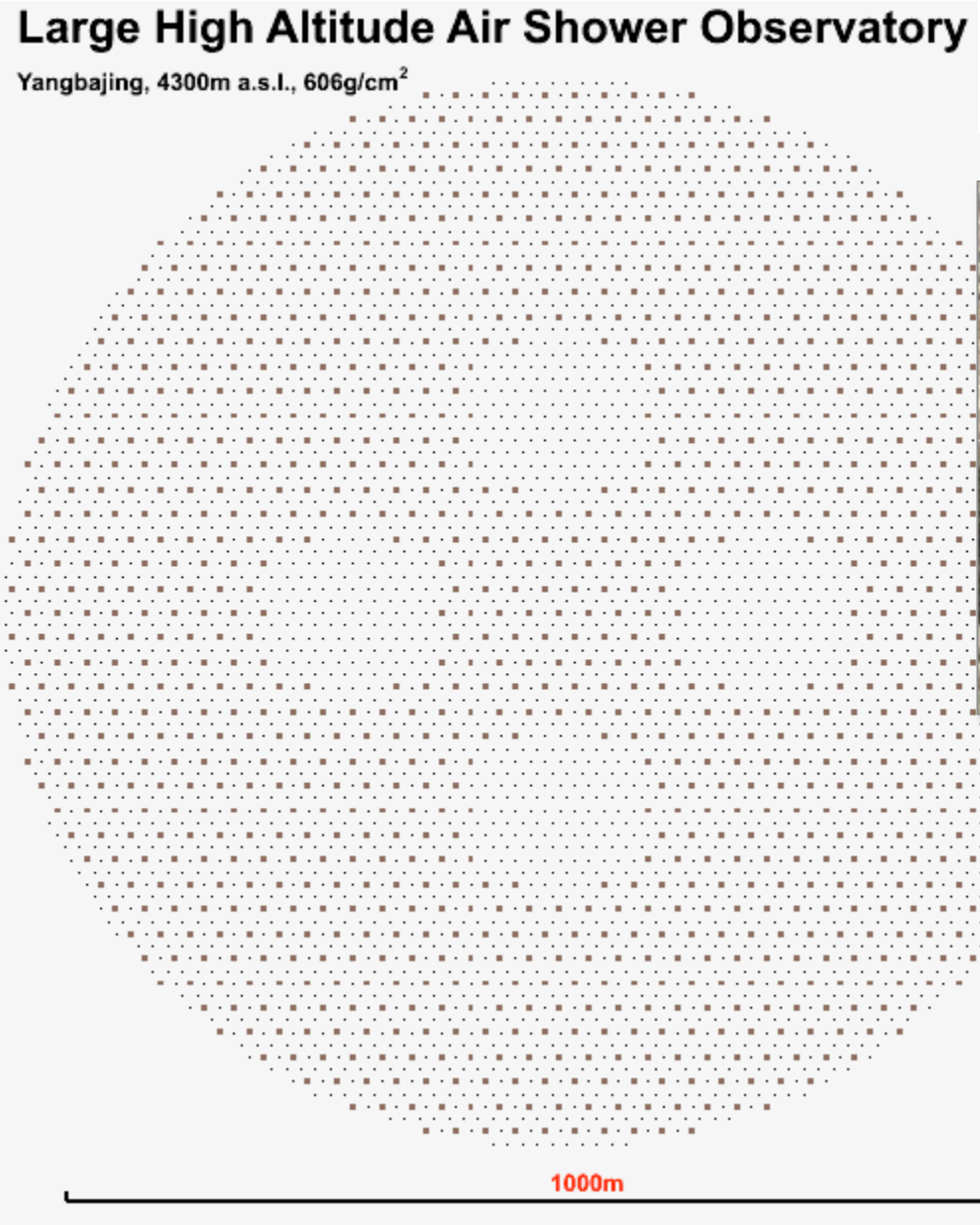
**Possible Extensions at both lower and higher energies**

# LHAASO



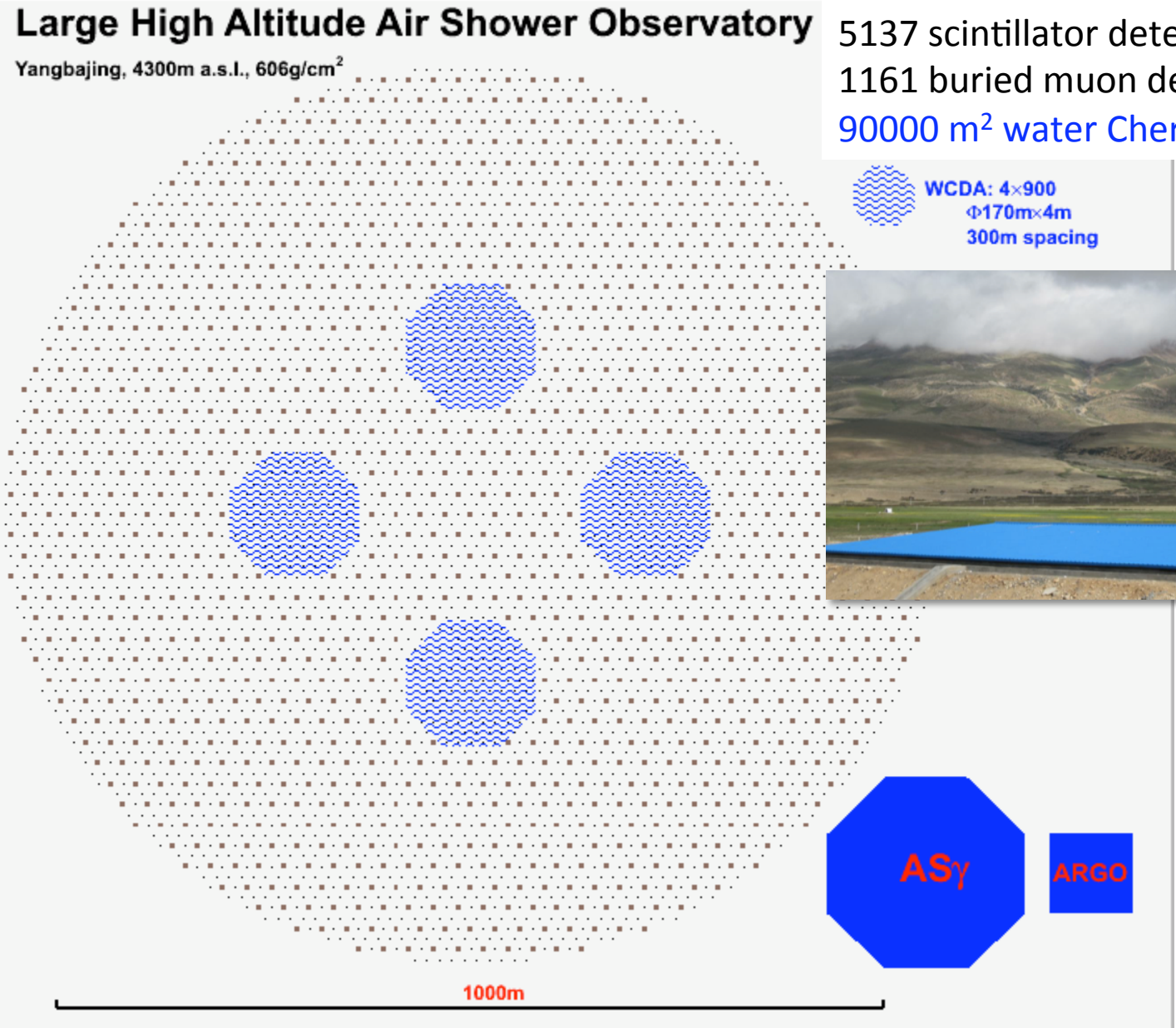

5137 scintillator detectors, 1 m x 1 m

# LHAASO



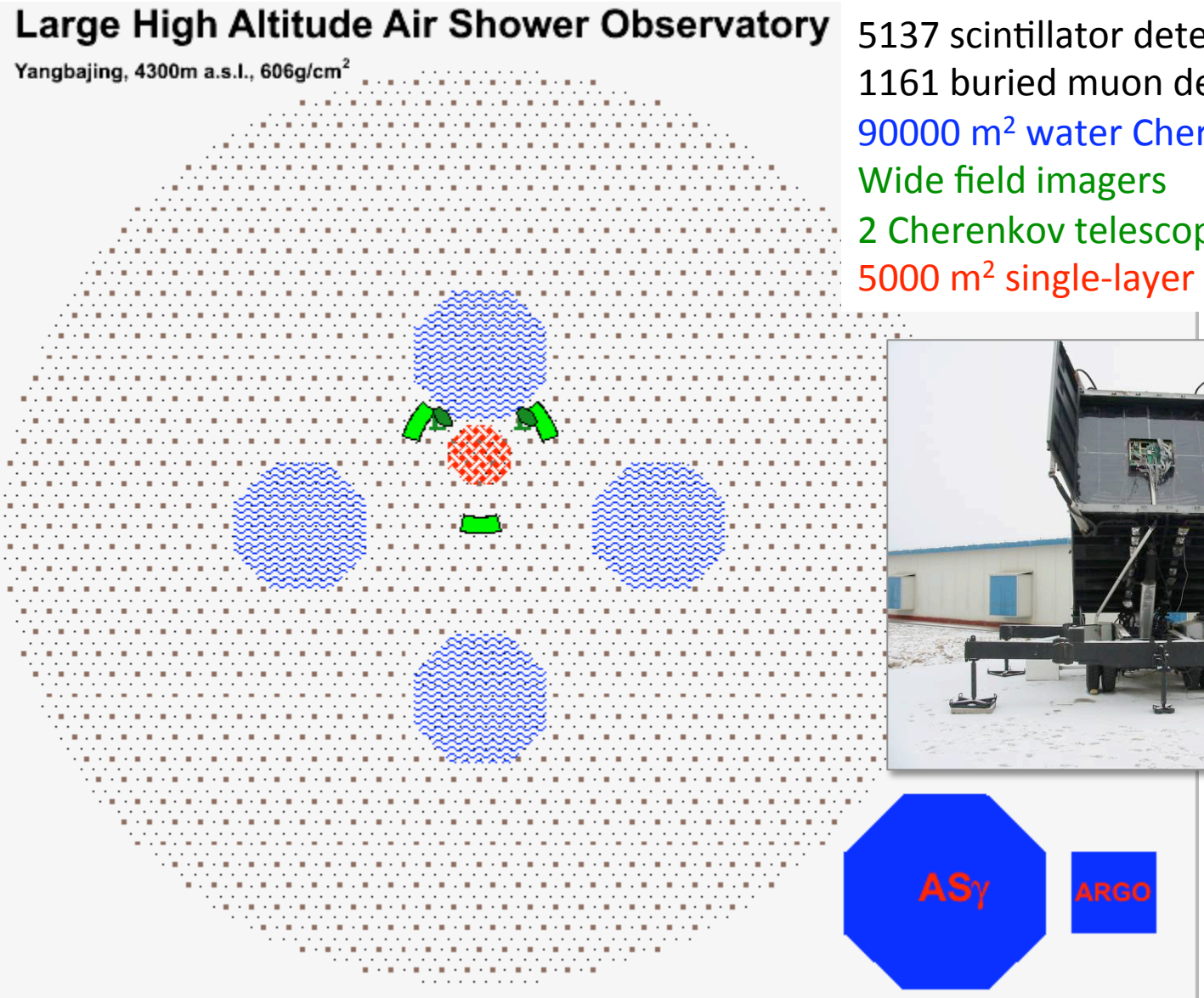

5137 scintillator detectors, 1 m x 1 m
1161 buried muon detectors, 6 m x 6 m

# LHAASO



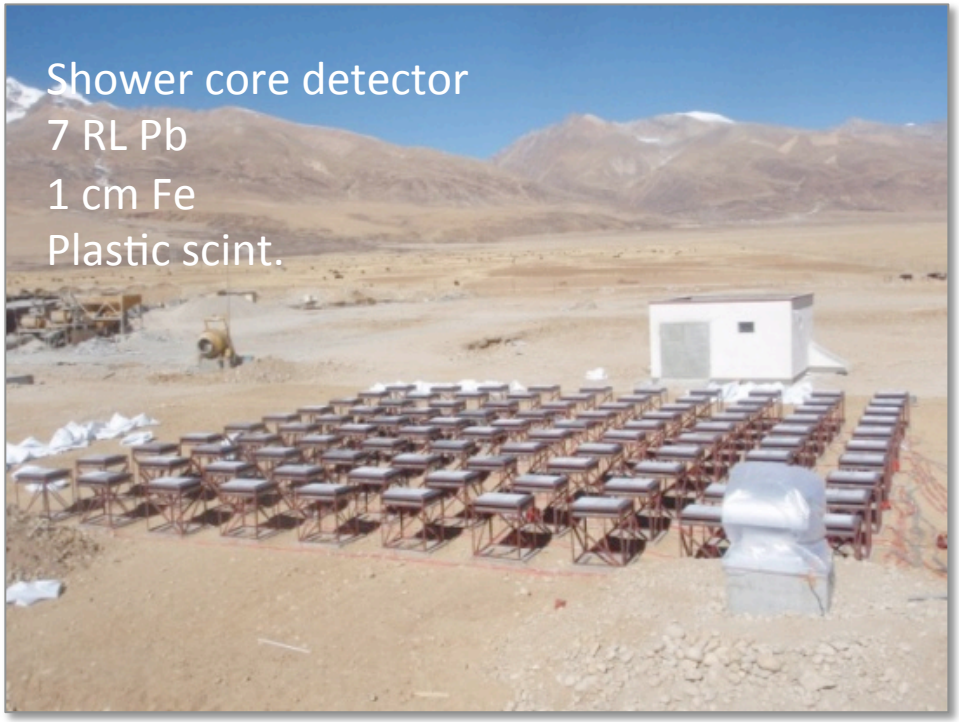

5137 scintillator detectors, 1 m x 1 m
1161 buried muon detectors, 6 m x 6 m
90000 m$^2$ water Cherenkov detectors

# LHAASO



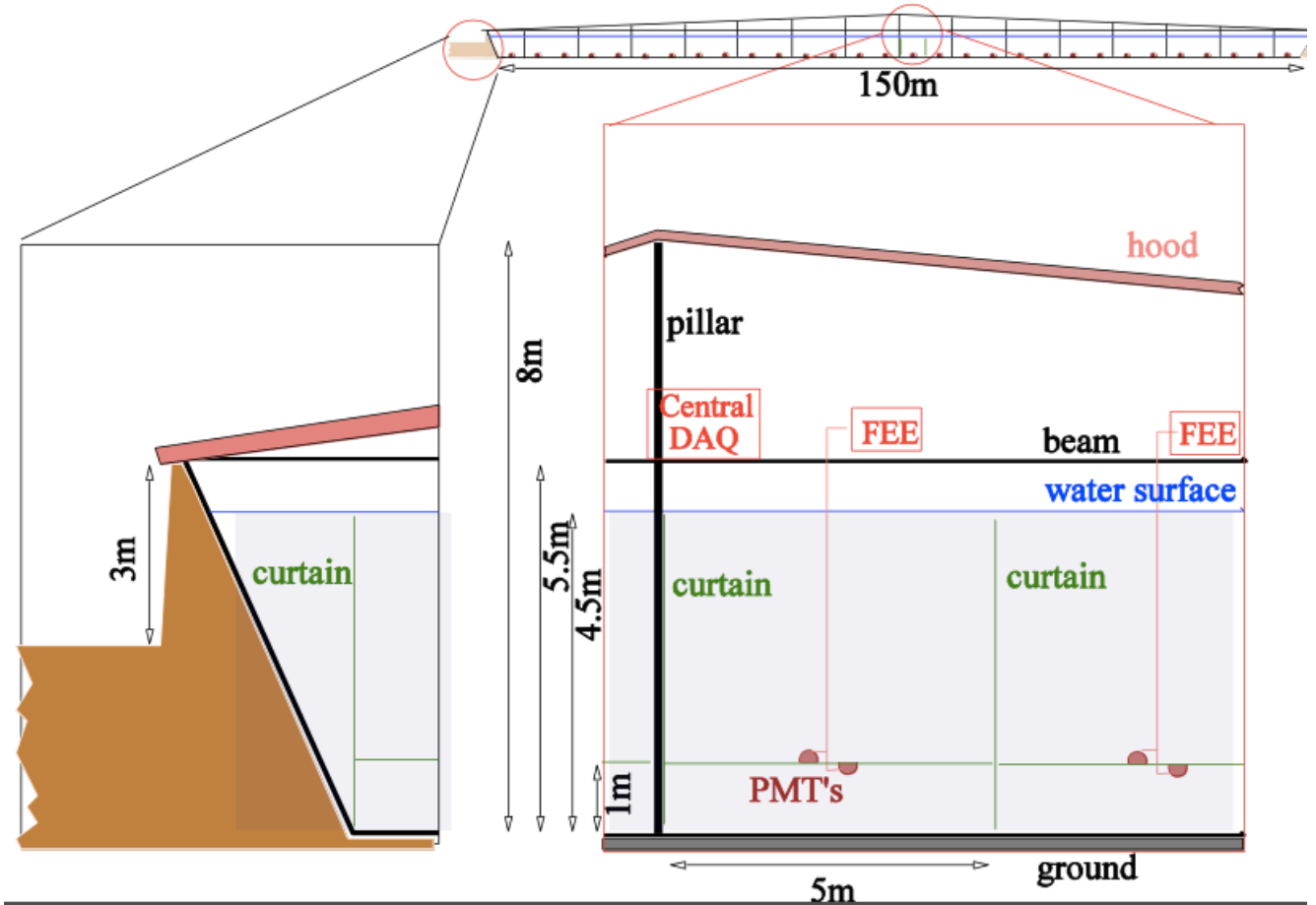

5137 scintillator detectors, 1 m x 1 m
1161 buried muon detectors, 6 m x 6 m
90000 m$^2$ water Cherenkov detectors
Wide field imagers
2 Cherenkov telescopes
5000 m$^2$ single-layer hadron detector

# 1% ENGINEERING ARRAY OPERATIONAL




Water Cherenkov
Muon detectors

# WATER CHERENKOV DETECTOR



# STATUS

LHAASO has been listed as one of 16 selected projects in a roadmap of construction of infrastructure for basic scientific researches in China in the next 5 years.

Formal proposal due in next 2-3 months.

First formal review on budget and environment impact will be started in next Oct.

“Construction will start next year and will last 5-6 years.”

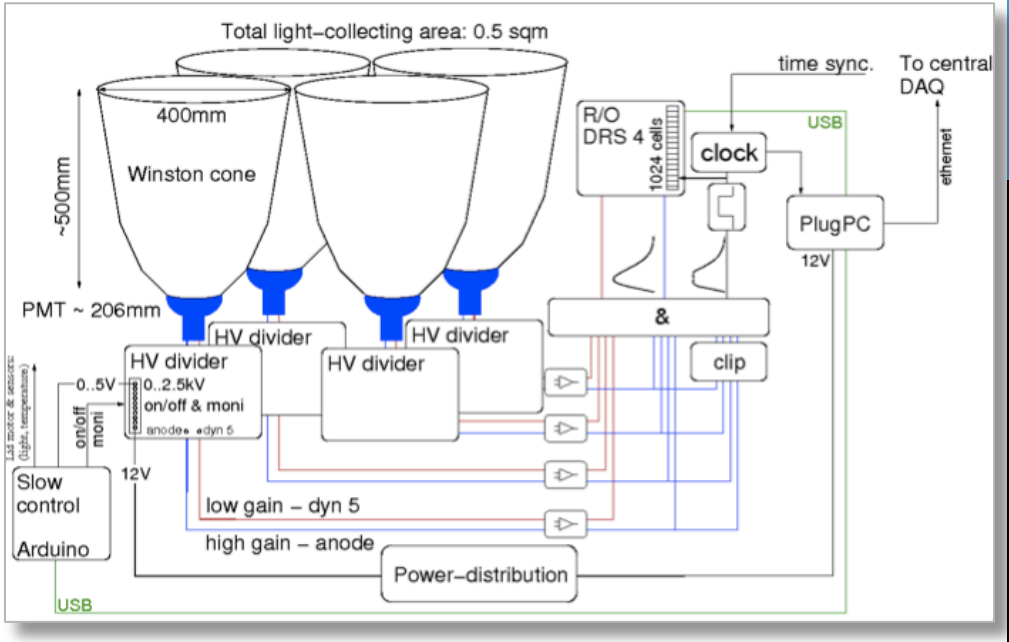
# EVEN MORE AREA… HISCORE

Non-imaging Cherenkov detector

Large fov of ~0.6 sr

Large area of few 100 km$^2$

Sensitive about some 10 TeV






100 – 200 m spacing

# HISCORE

Angular resolution
0.2 – 0.35 deg. @ 100 TeV
0.05 – 0.2 deg. @ 1 PeV
depending on timing jitter

Prototype deployed in
Tunka air shower array
(4/2012),
cross-calibrated with Tunka

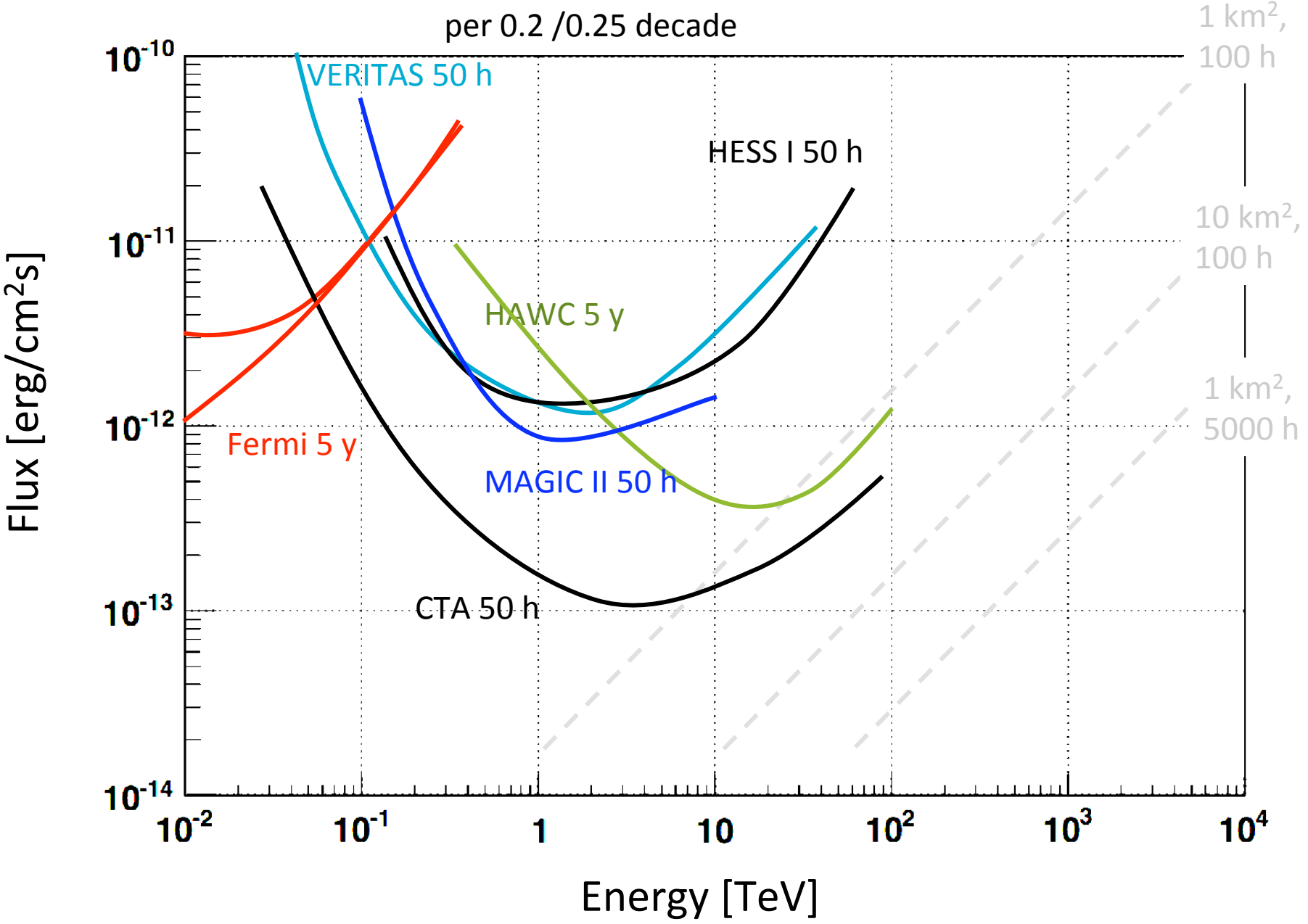
Next steps:
Engineering array @ Tunka
Small array @ Auger

# SENSITIVITIES

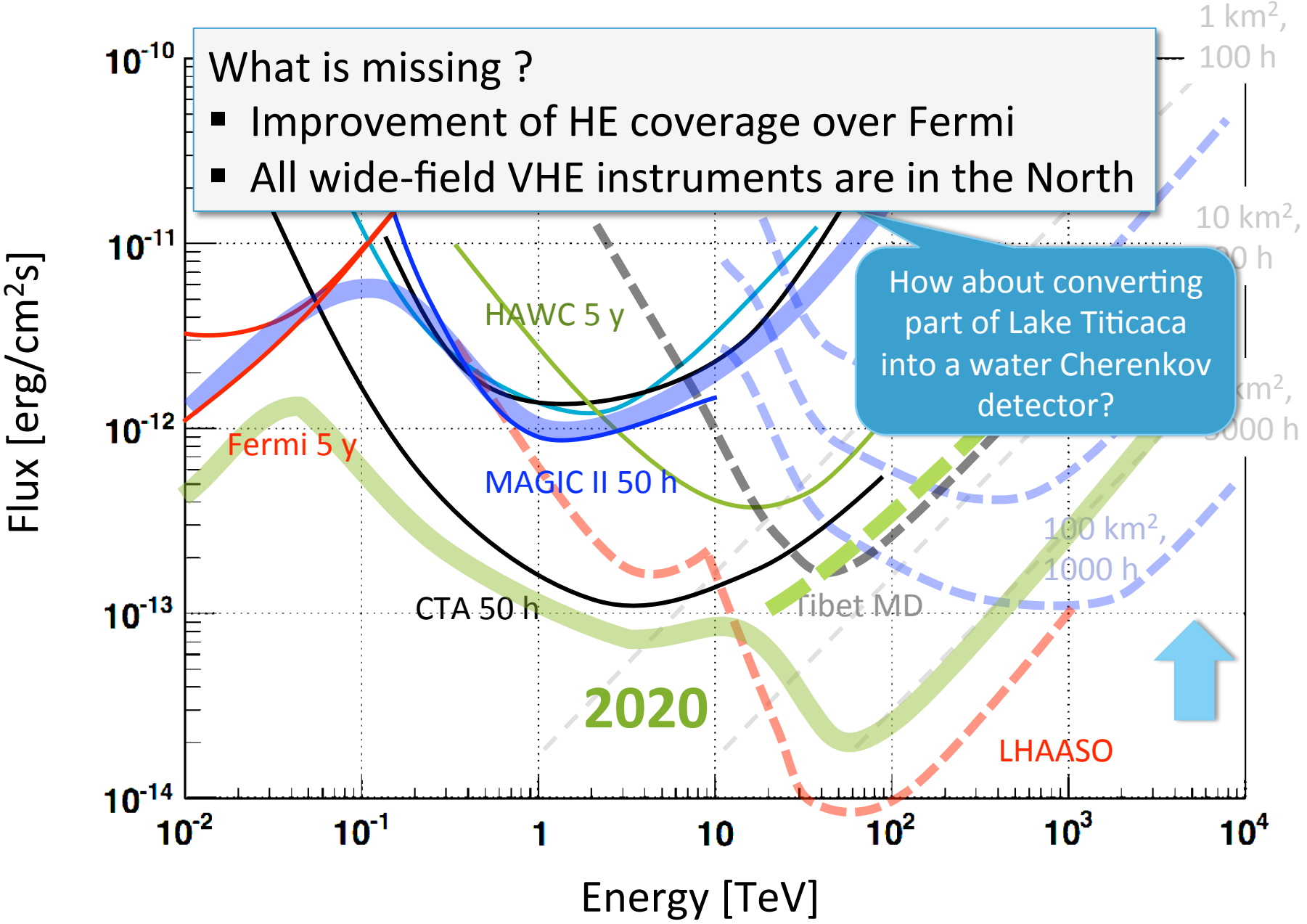
Caveats

- Moving targets
- Quoted either as differential sensitivity (5 sigma in 0.2-0.25 decade band)
- or (spectrum-dependent) integral sensitivity (5 sigma above some energy);
- Integral sensitivity is typically a factor of a few (2-3) higher
- Devil in the details (sensitivity shown as function of true energy or reconstructed energy, …)
- *Curves copied by hand*

# DIFFERENTIAL SENSITIVITY



# DIFFERENTIAL INTEGRAL SENS.



# THANKS TO

**Zhen Cao**
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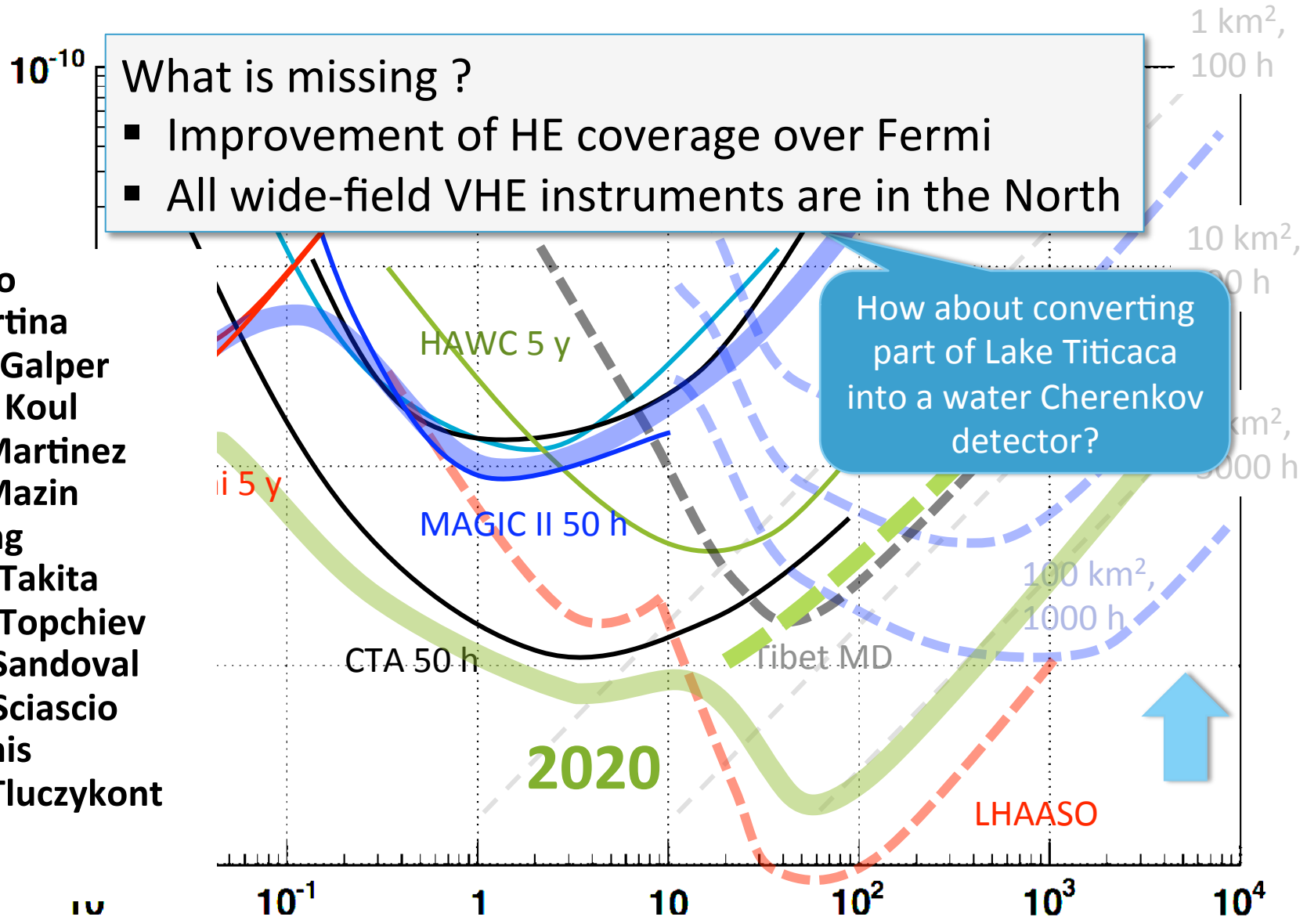
**Arkadiy Galper**
**Ramesh Koul**
**Manel Martinez**
**Daniel Mazin**
**Rene Ong**
**Masato Takita**
**Nikolay Topchiev**
**Andrés Sandoval**
**Pino Di Sciascio**
**Gus Sinnis**
**Martin Tluczykont**
**…**




# APOLOGIES FOR MISTAKES & OMISSIONS

Credit:
Multimedia Service,
Institute of Astrophysics of Canary Islands

cta
cherenkov telescope array