Fundamental physics with cosmic gamma rays And the Cherenkov Telescope Array

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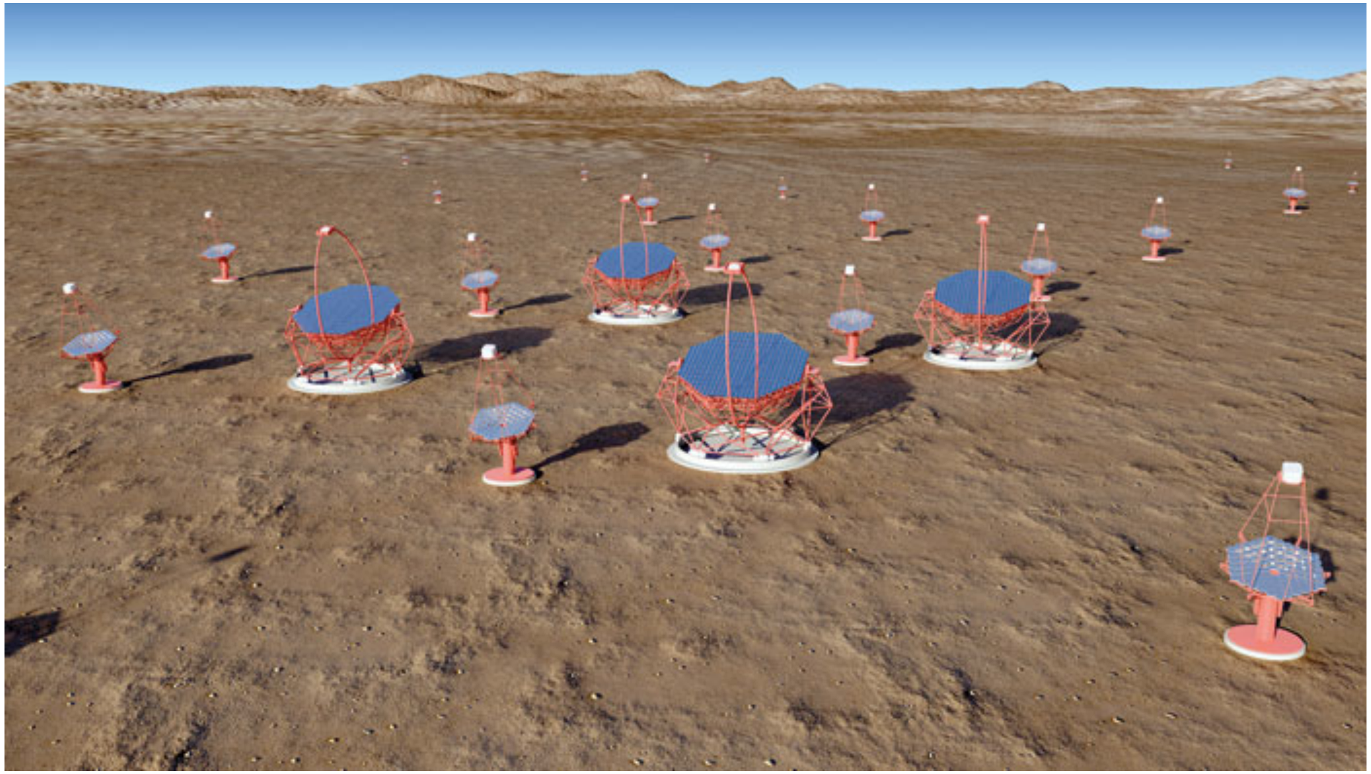
- VHE gamma rays: introduction; the Cherenkov technique
- Physics: answers and questions from present detectors
- The need for a new large project: the Cherenkov Telescope Array CTA
- The interplay with fundamental physics & technological research (with a bias towards INFN)



Frascati, June 2014

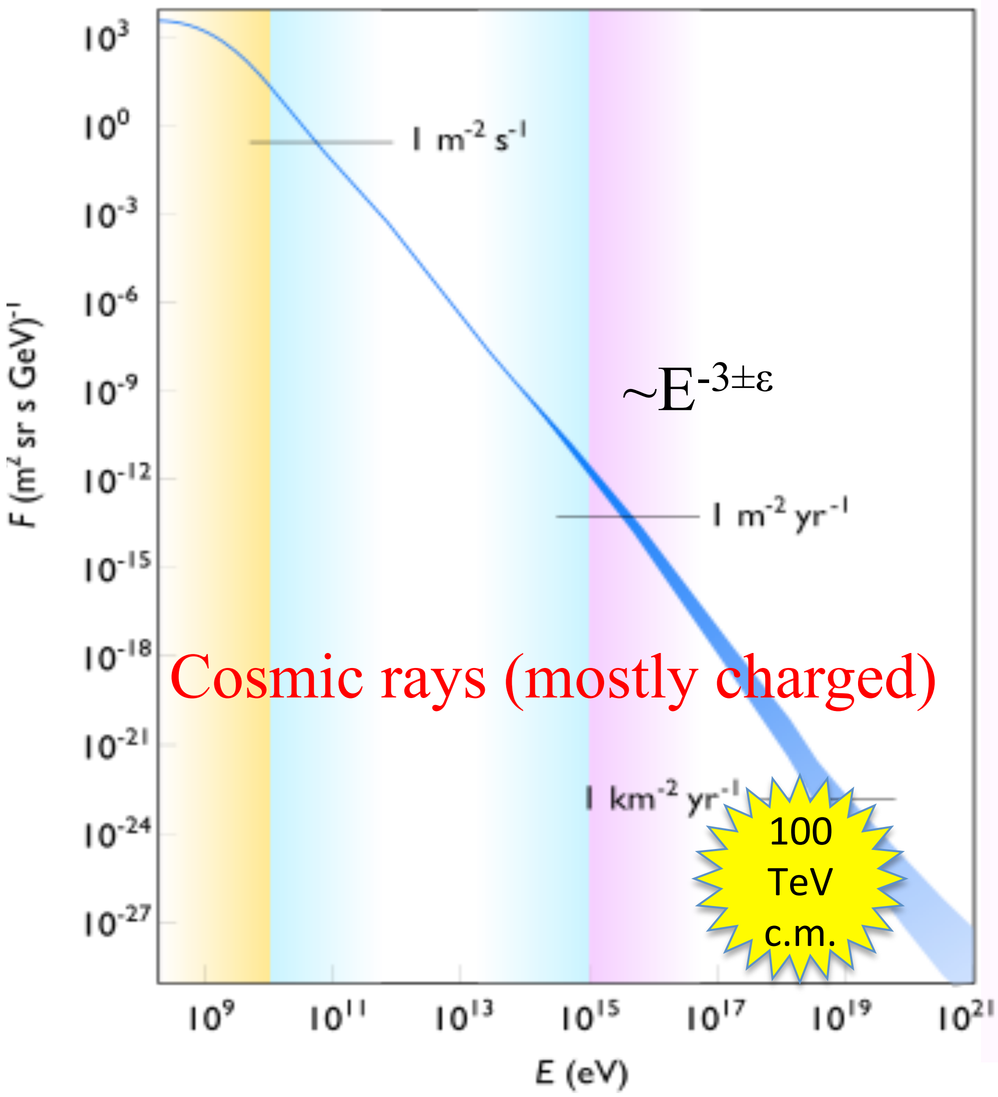
1953: the Cosmic Ray conference in Bagneres de Bigorre

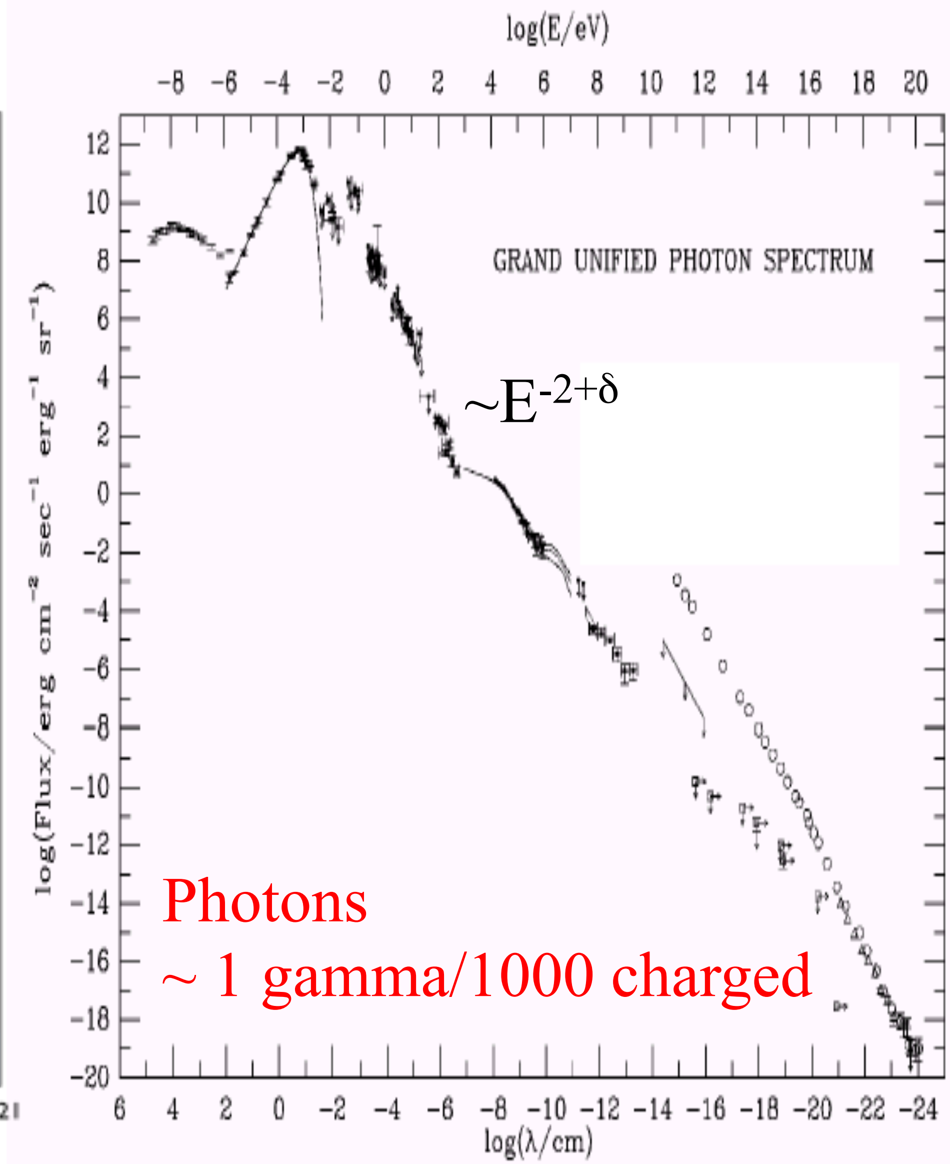
From the conclusions (Leprince-Ringuet):

“What is the future of cosmic rays? Should we continue to struggle for a few new results or would it be better to turn to the machines?

One can no doubt say that that the future of cosmic radiation in the domain of nuclear physics depends on the machines […]. But probably this point of view should be tempered by the fact that we have the uniqueness of some phenomena for which the energies are much larger.”

Very-High Energy gamma rays



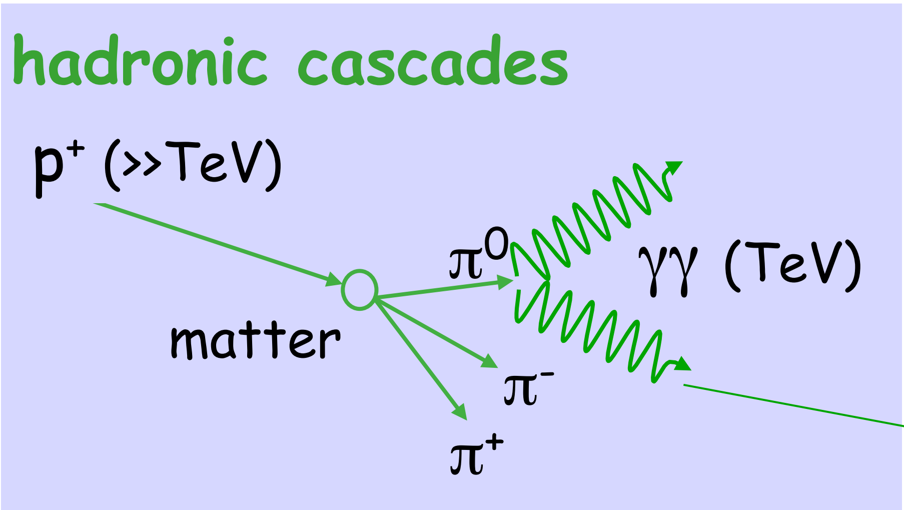


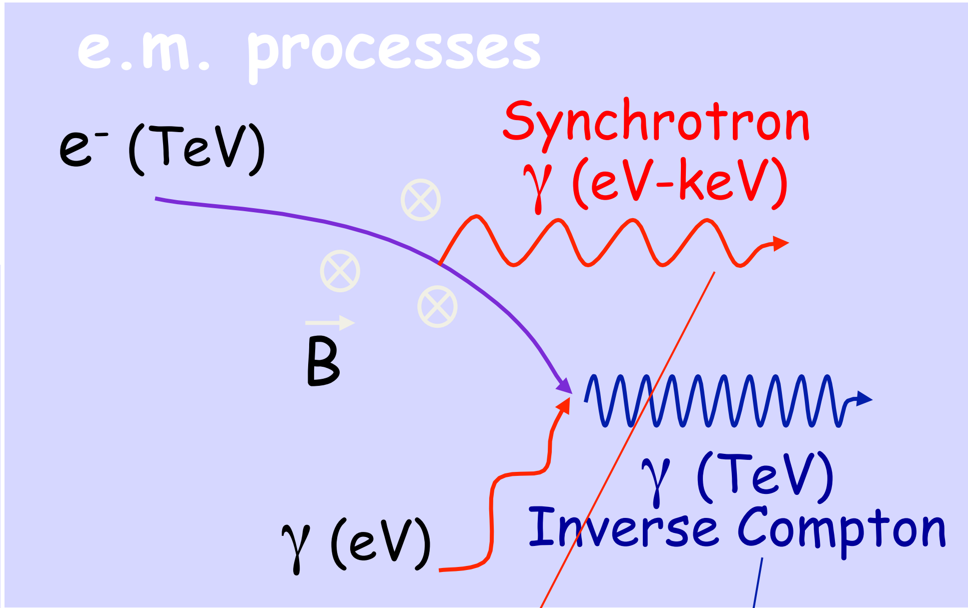
How are VHE (above 30 GeV) gamma rays produced?

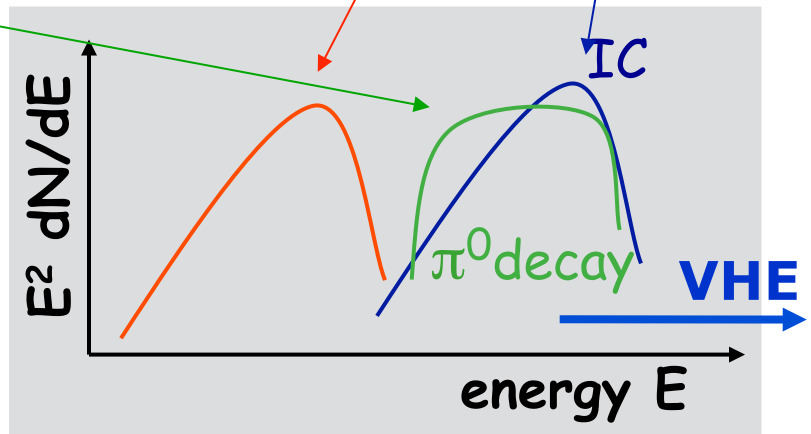
- Radiation from accelerated charged particles
  - Interaction with photon fields & clouds
  - Hadronic and leptonic mechanisms at work
    - Hadronic: photons are signatures of hadrons at energies ~10x

- But also (unobserved up to now)
  - Top-down mechanisms
  - New particles? Dark matter?

Cosmic γ rays: different production mechanisms expected to be at work







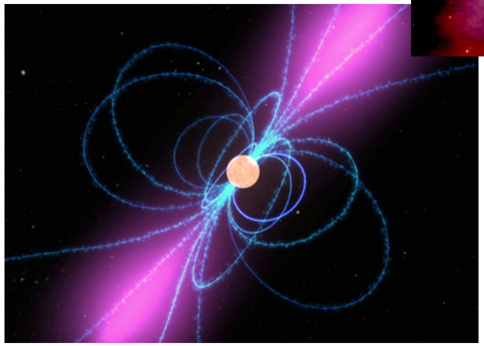
In the VHE region,
$dN/dE \sim E^{-\Gamma}$ (Γ: spectral index)

To distinguish between had/leptonic origin study Spectral Energy Distribution (SED):
(differential flux) $\cdot E^2$

Where are these extreme environments?

In our galaxy

Mostly stellar endproducts:
SNRs, Pulsars

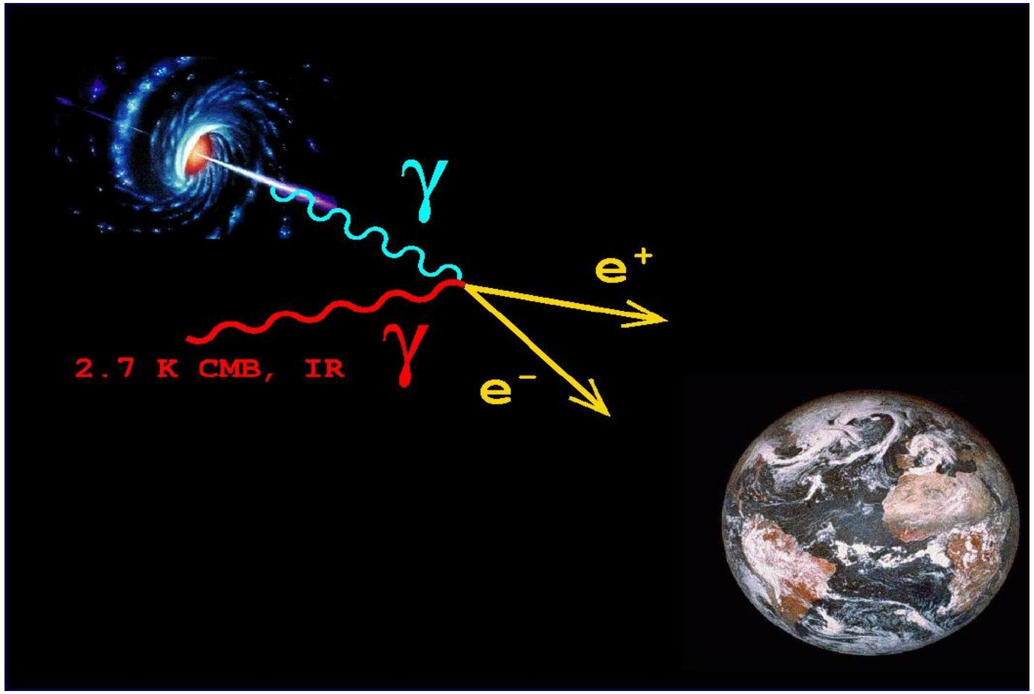


In other galaxies

Active Galactic Nuclei

Gamma-Ray Bursts

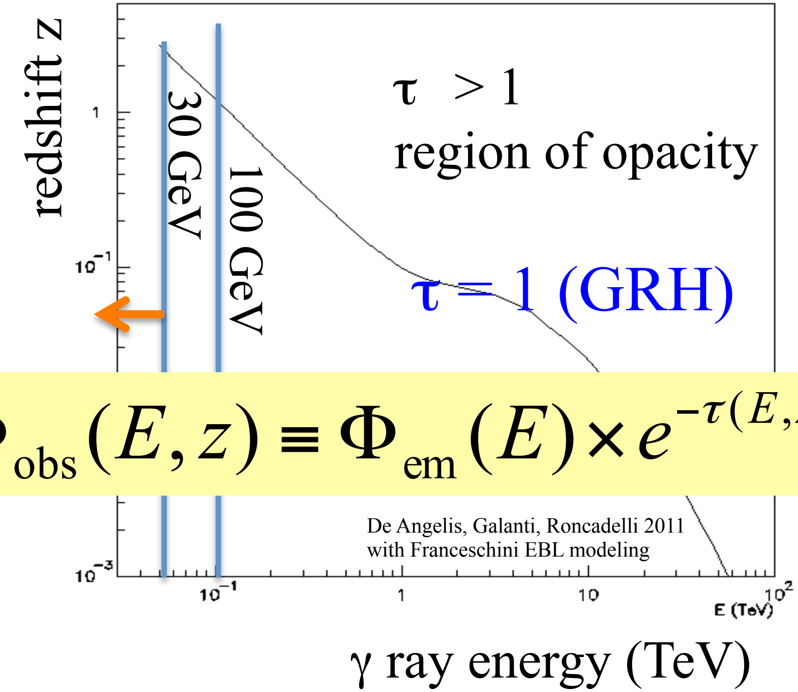
How do gamma rays reach us?



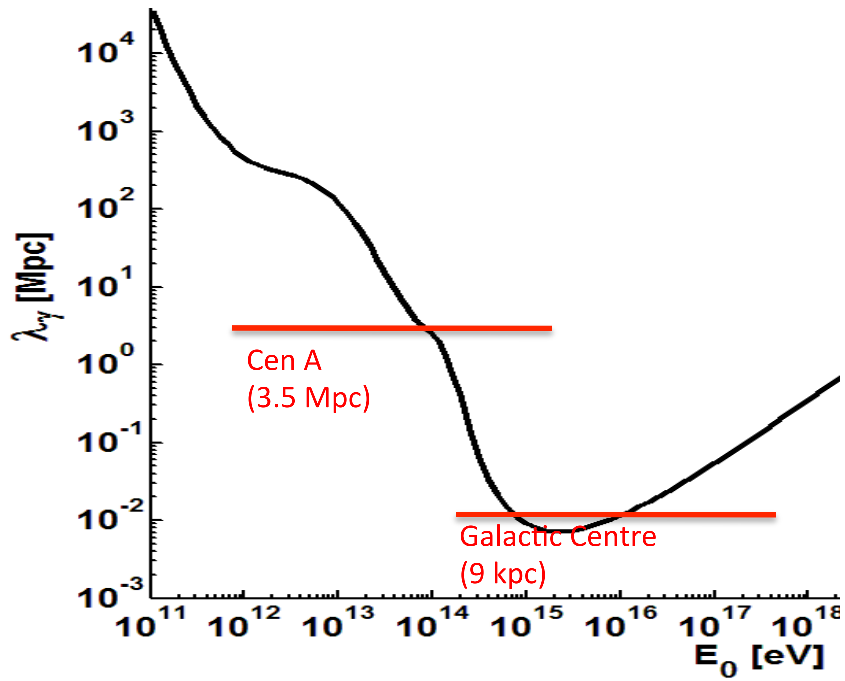
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

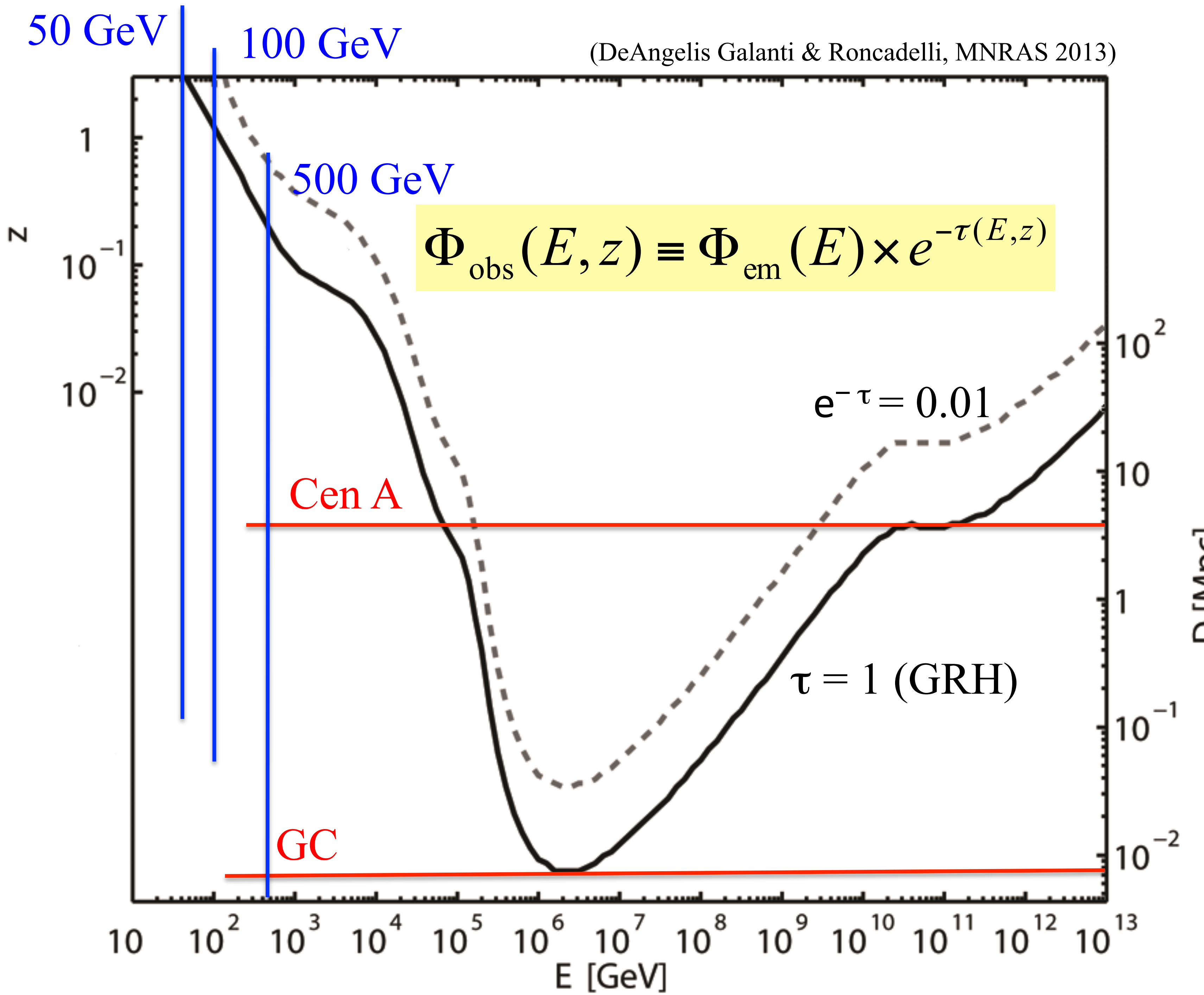
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

Max for: $$\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\ \mathrm{GeV}}{E}\right)\mathrm{eV}$$



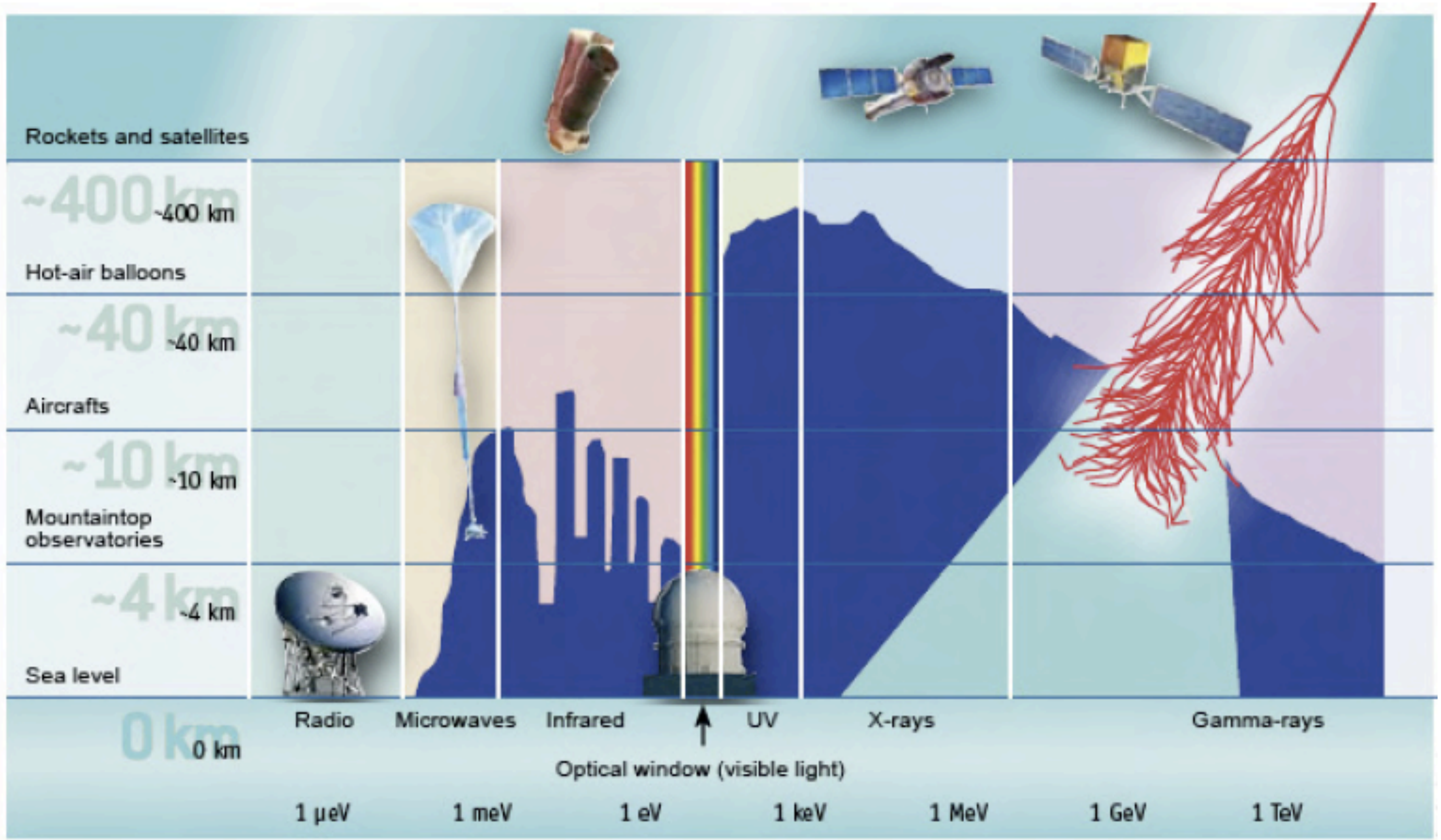
$$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$$





50 GeV
100 GeV
500 GeV
(DeAngelis Galanti & Roncadelli, MNRAS 2013)
$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$
$e^{-\tau} = 0.01$
Cen A
GC
τ = 1 (GRH)
z
D [Mpc]
E [GeV]

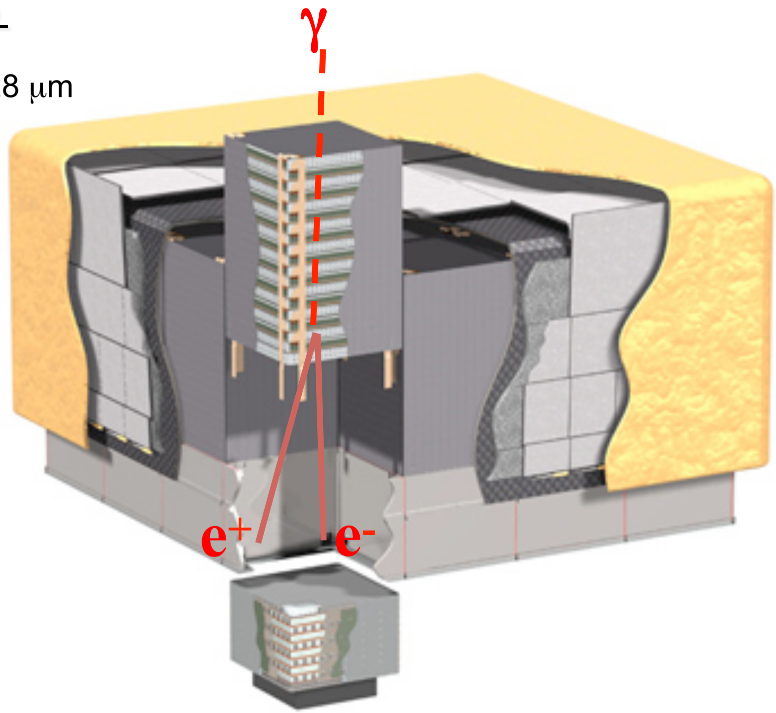
Gamma rays interact with the atmosphere



=> GeV (HE) detection requires satellites; TeV (VHE) can be done at ground

Detectors

Precision Si-strip Tracker (TKR)
18 XY tracking planes
Single-sided silicon strip detectors 228 μm pitch, $8.8 \cdot 10^5$ channels
Measure the photon direction

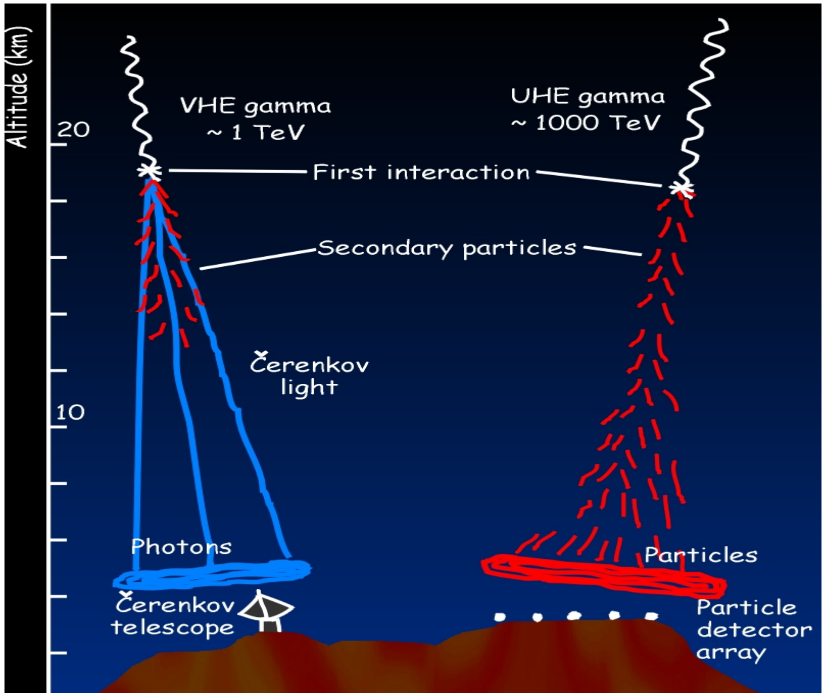


- Satellites (AGILE, Fermi)
  - Silicon tracker (+calorimeter)

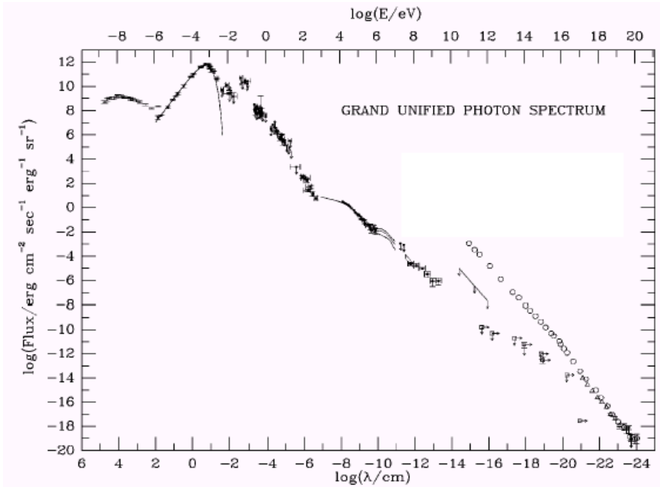
- Cherenkov telescopes (HESS, MAGIC, VERITAS)

- Extensive Air Shower det. (ARGO): RPC, scintillators

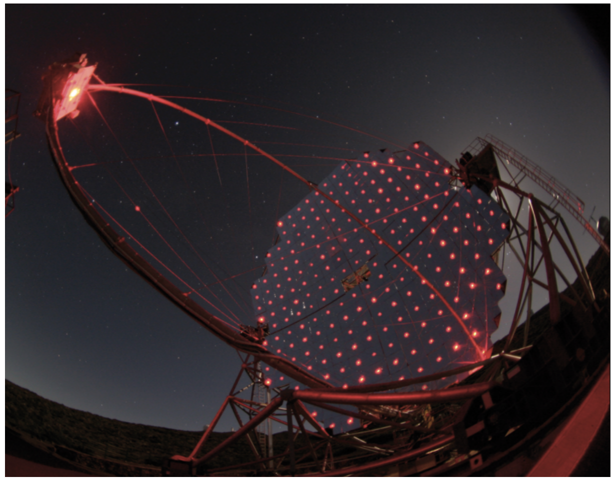
HEP detectors!



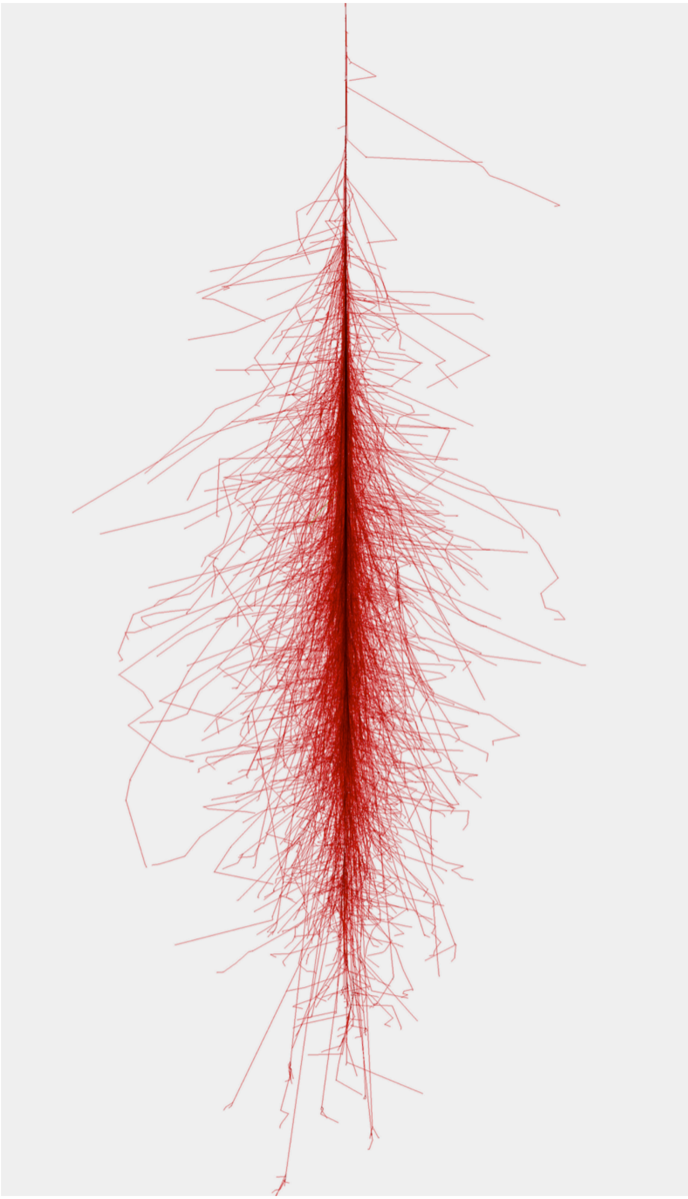
Why detection at ground?

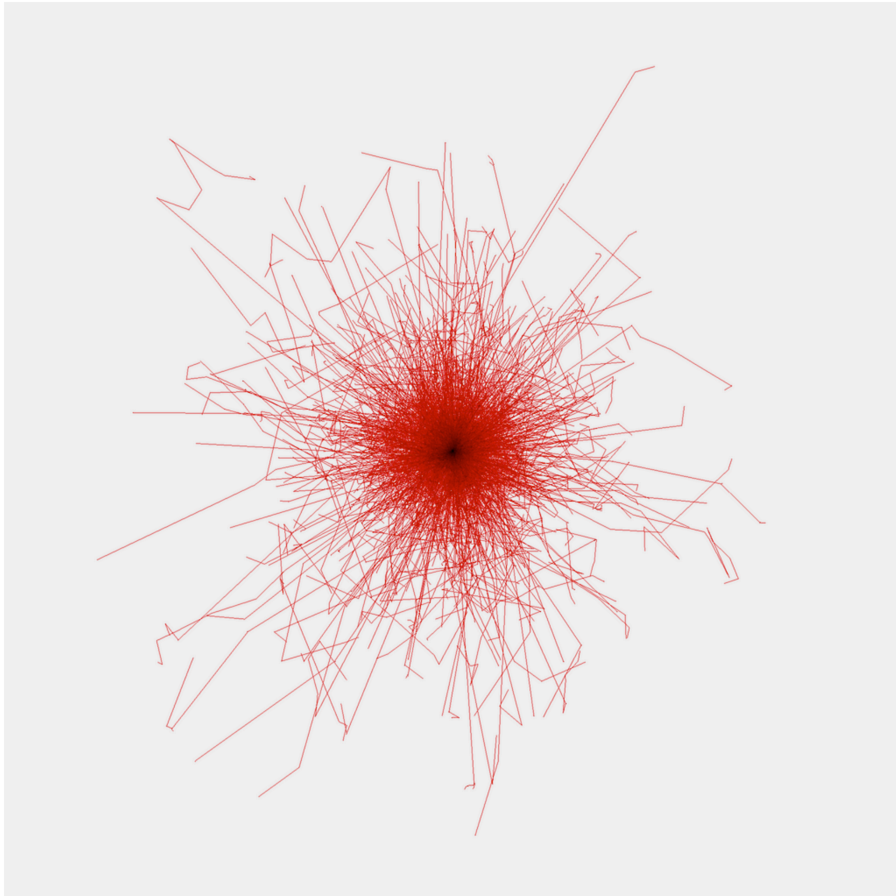


- High energies
  - Only way to build sensitive >TeV instruments
  - Maximum flux < 1 photon/h/m^2 above 200 GeV
- High statistics /short timescales
  - Large collection areas O(km^2)
- Precision (Cherenkov telescopes)
  - Superior angular resolution
- Limitations?
  - IACTs
    - Smaller duty cycle
    - Smaller field of view
  - EAS ground particle detectors
    - Modest resolution and background rejection power
  - Complementary approaches

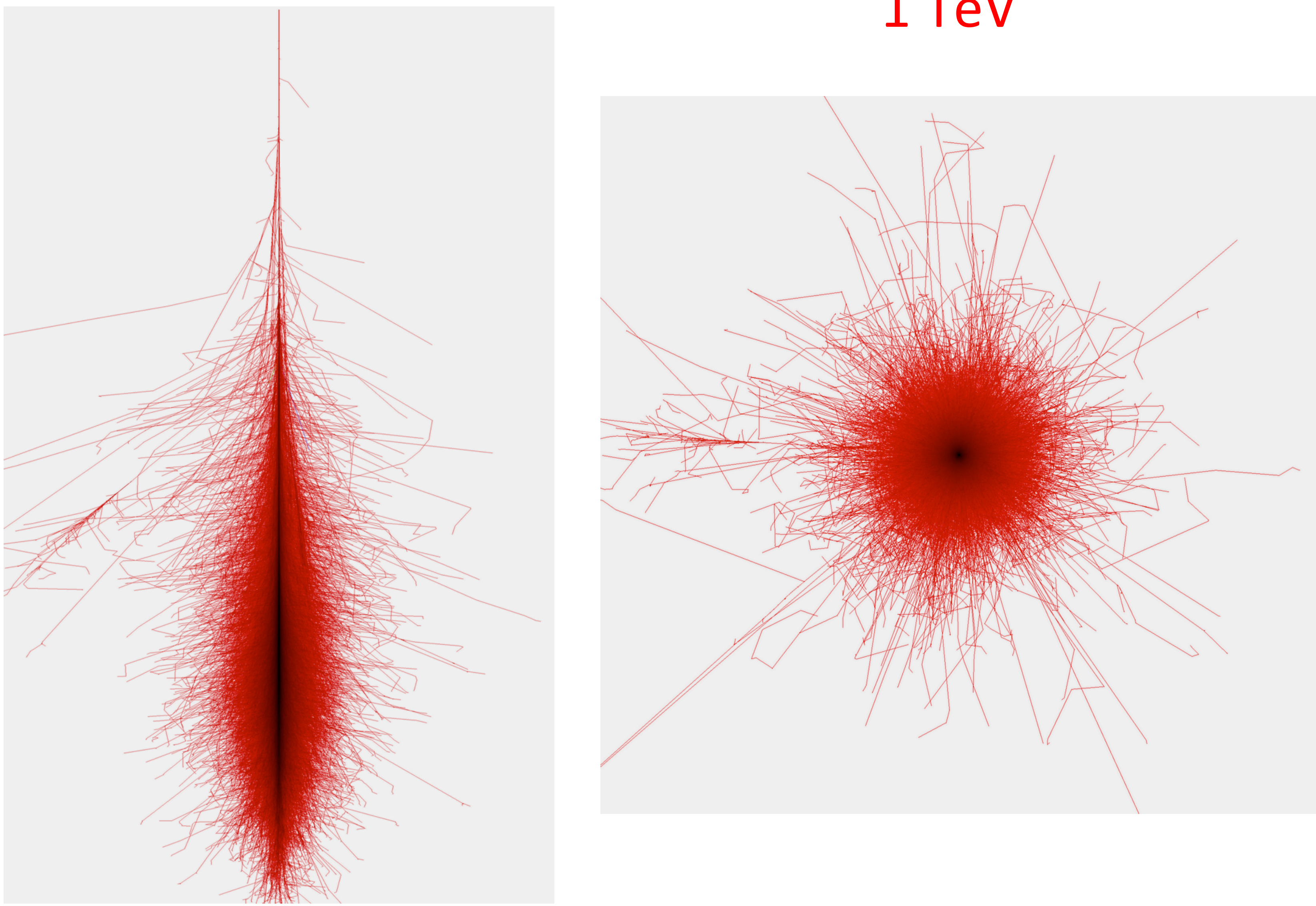


Simulated gamma
in the atmosphere:
50 GeV

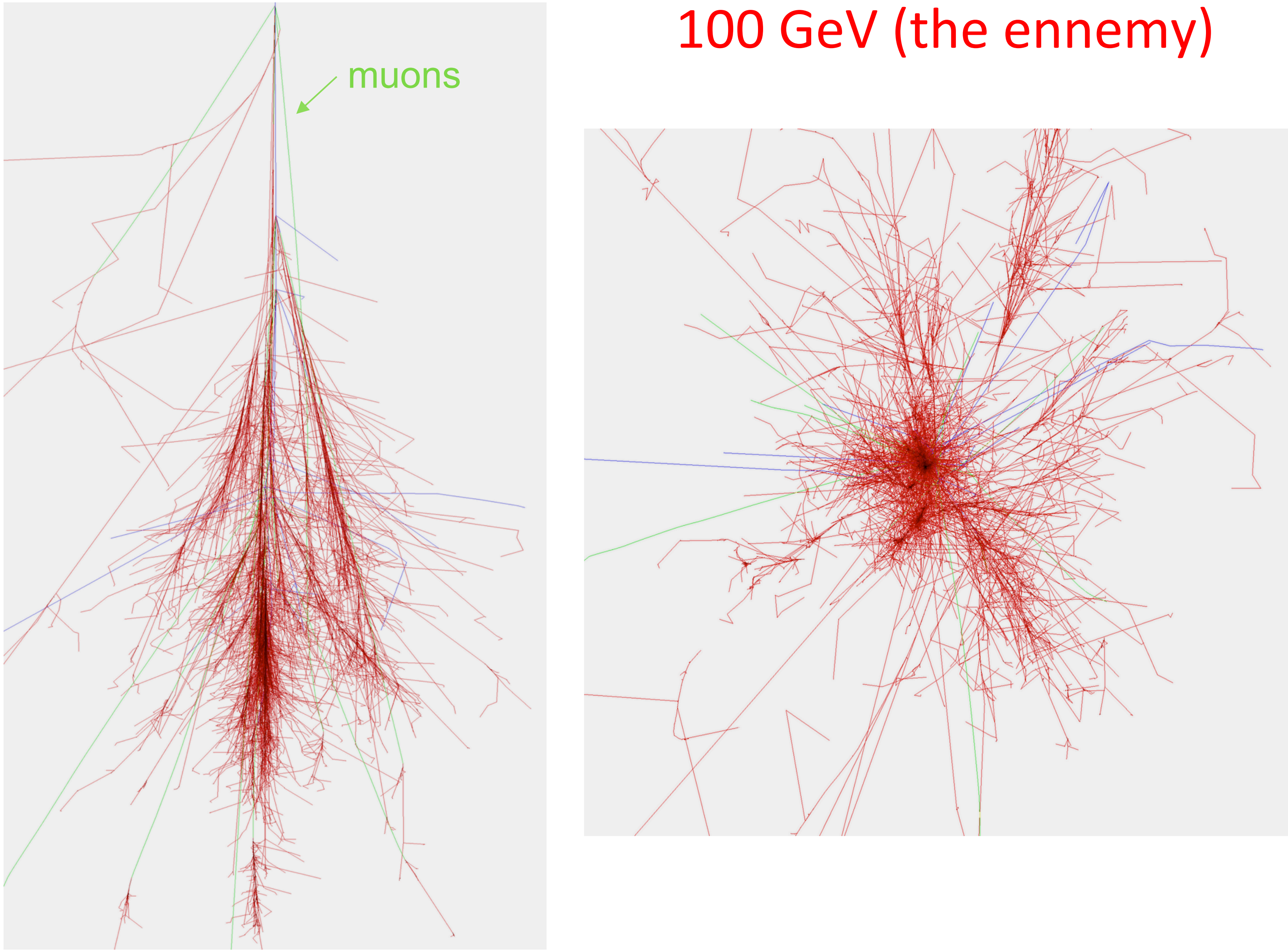


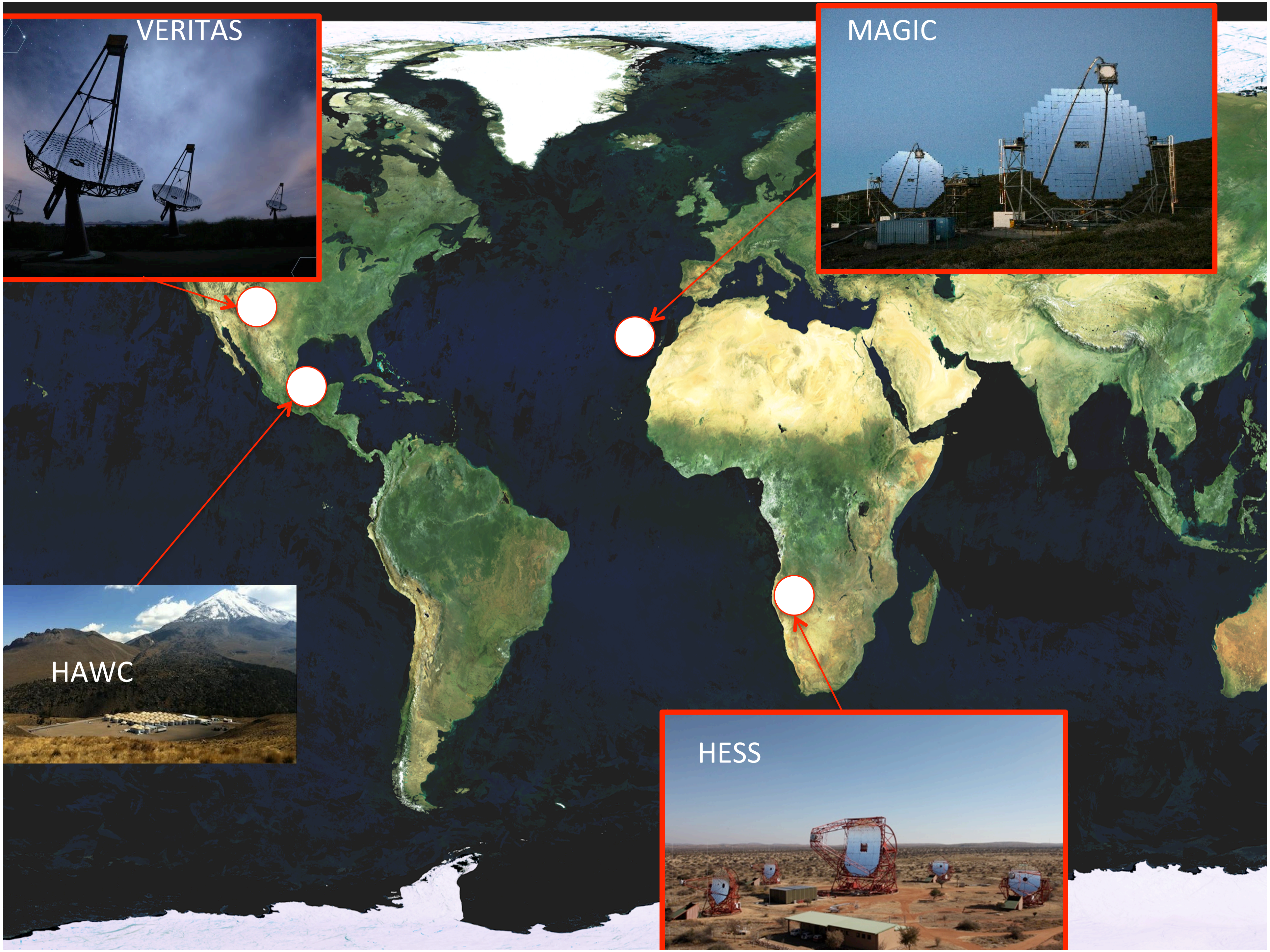


Simulated gamma
1 TeV



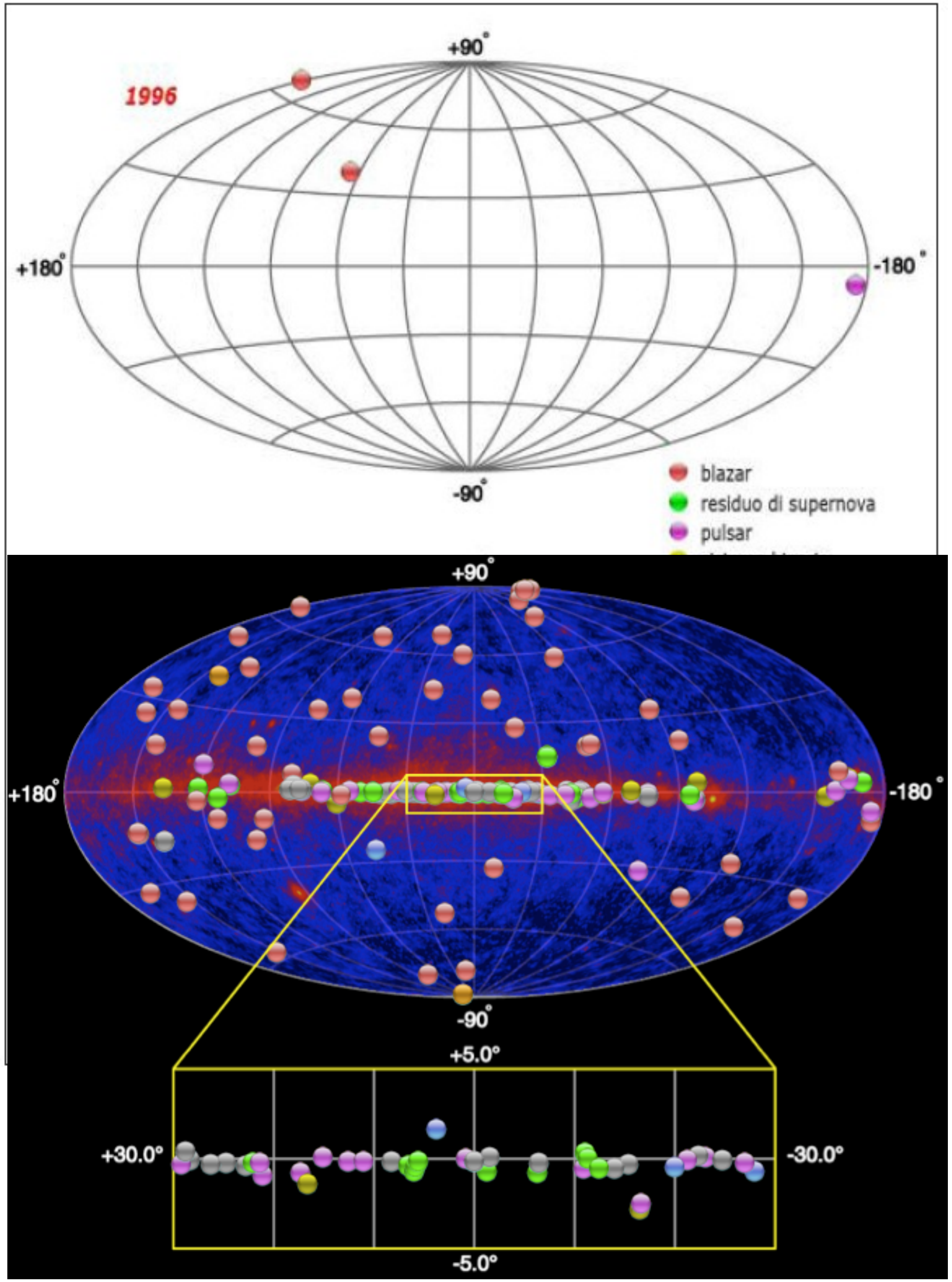
Simulated proton
100 GeV (the ennemy)




VERITAS
MAGIC
HAWC
HESS

Highlight in γ-ray astrophysics (mostly HESS, MAGIC, VERITAS)

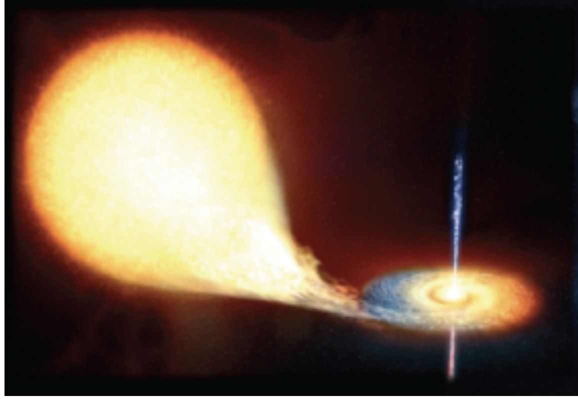
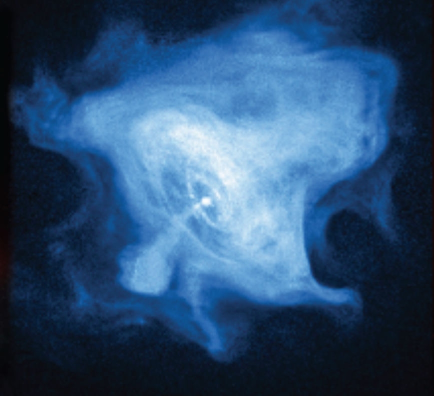
- Thanks mostly to Cherenkov telescopes, imaging of VHE (> 30 GeV) galactic sources and discovery of many new galactic and extragalactic sources: ~ 200 (and >200 papers) in the last 9 years
  - And also a better knowledge of the diffuse gammas and electrons
- A comparable success in HE (the Fermi realm); a 10x increase in the number of sources
- A new tool for cosmic-ray physics and fundamental physics

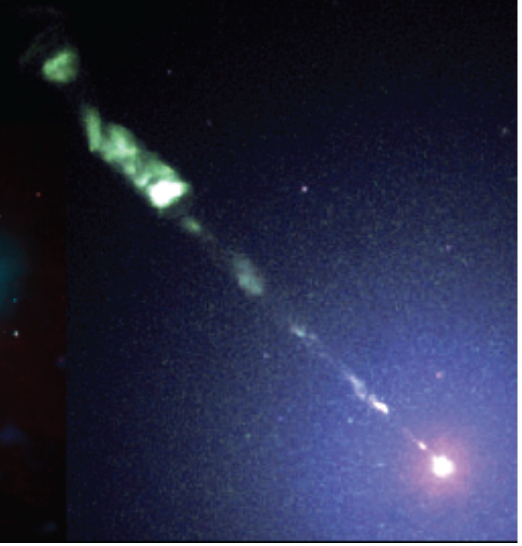


TeV Impact

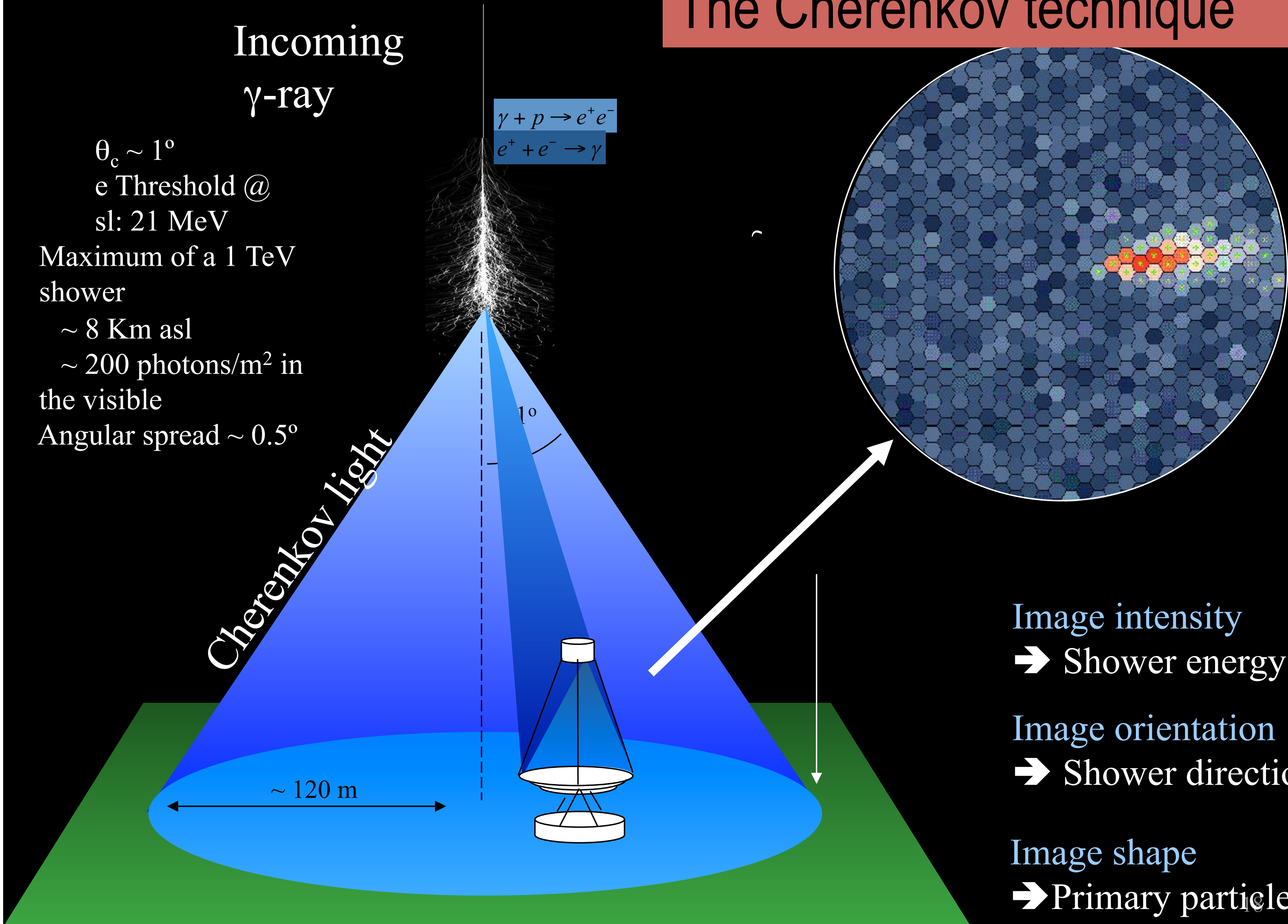
Highlights from **HESS, MAGIC, VERITAS & MILAGRO**

- *Microquasars:* Science 309, 746 (2005), Science 312, 1771 (2006)
- *Pulsars:* Science 322, 1221 (2008), Science 334, 69 (2011)
- *Supernova Remnants:* Nature 432, 75 (2004)
- *The Galactic Centre:* Nature 439, 695 (2006)
- *Surveys:* Science 307, 1839 (2005), PRL 95, 251103 (2005)
- *Starbursts:* Nature 462, 770 (2009), Science 326,1080 (2009)
- *AGN:* Science 314,1424 (2006), Science 325, 444 (2009)
- *EBL:* Nature 440, 1018 (2006), Science 320, 752 (2008)
- *Dark Matter:* PRL 96, 221102 (2006), PRL 106, 161301 (2011)
- *Lorentz Invariance:* PRL 101, 170402 (2008)
- *Cosmic Ray Electrons:* PRL 101, 261104 (2009)



The Cherenkov technique



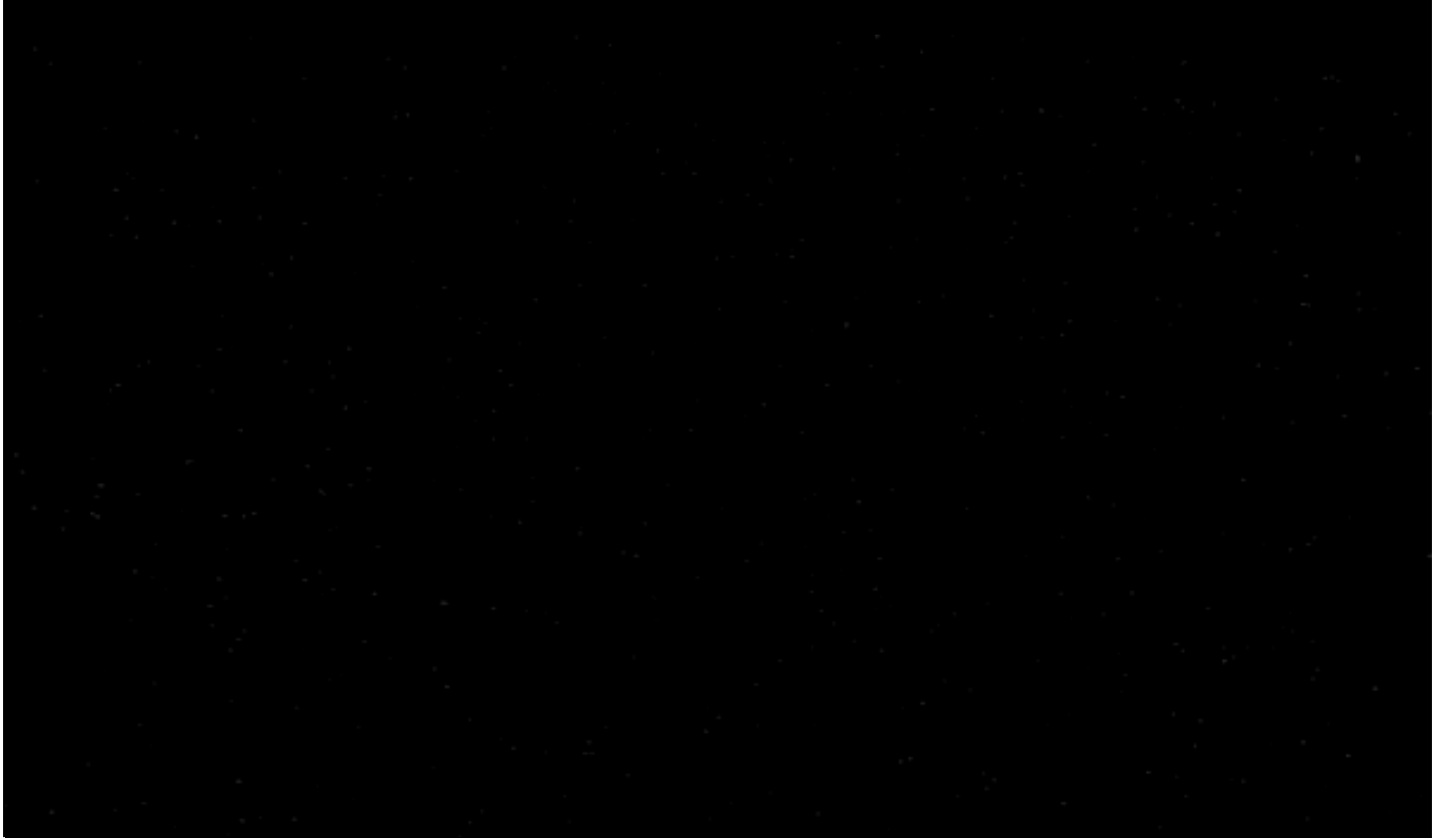
$\theta_c \sim 1^o$
e Threshold @ sl: 21 MeV
Maximum of a 1 TeV shower
~ 8 Km asl
~ 200 photons/m^2 in the visible
Angular spread ~ 0.5º

Image intensity
➔ Shower energy

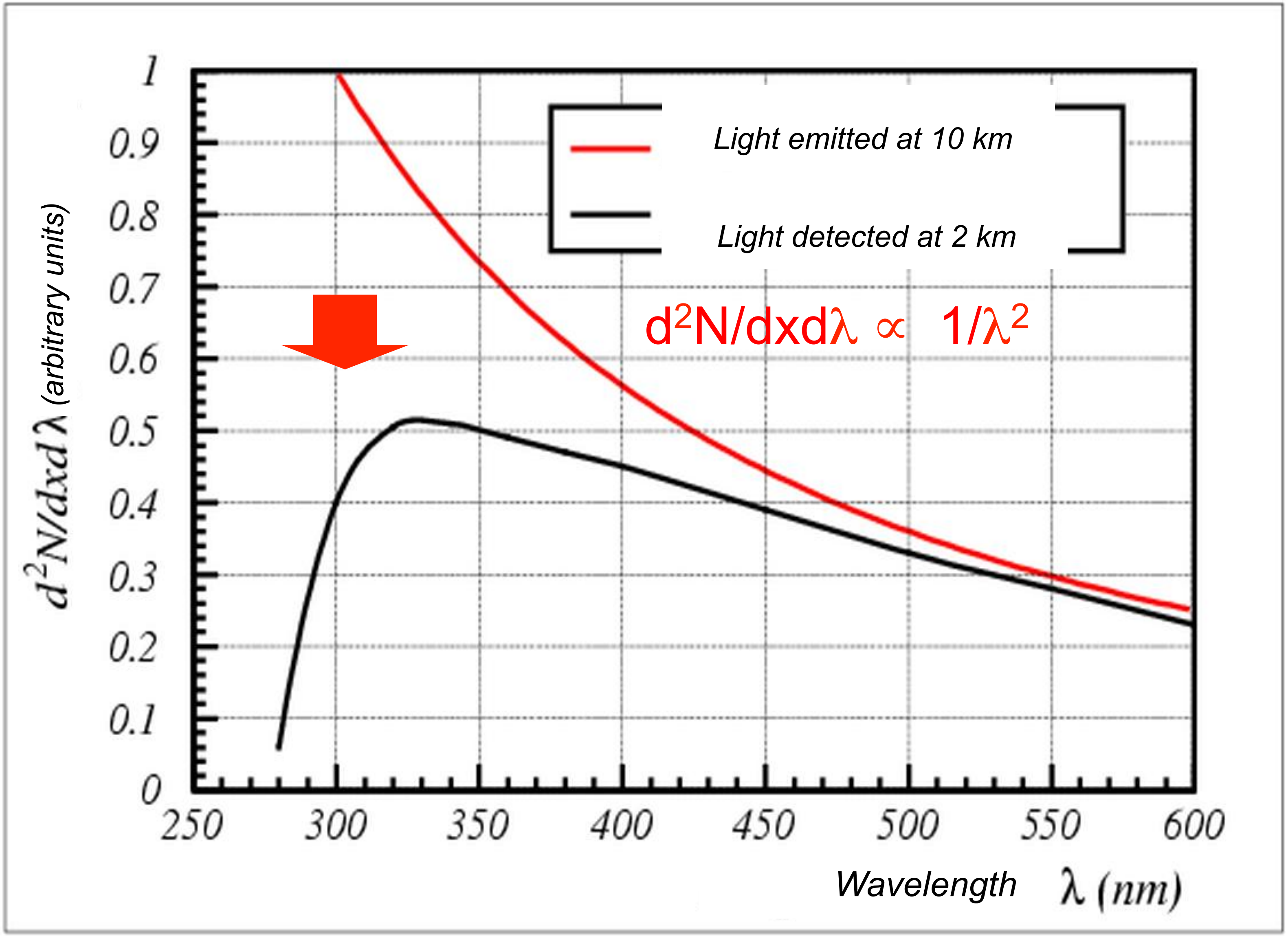
Image orientation
➔ Shower direction

Image shape
➔ Primary particle

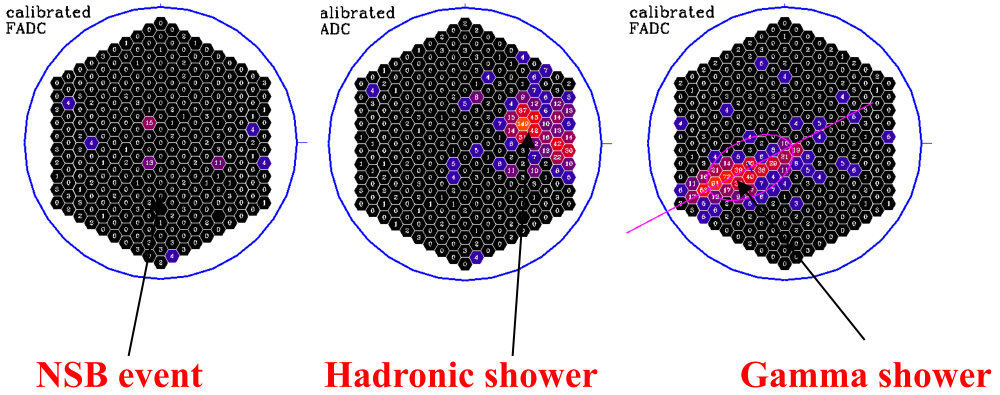
Signal duration: ~ 3ns

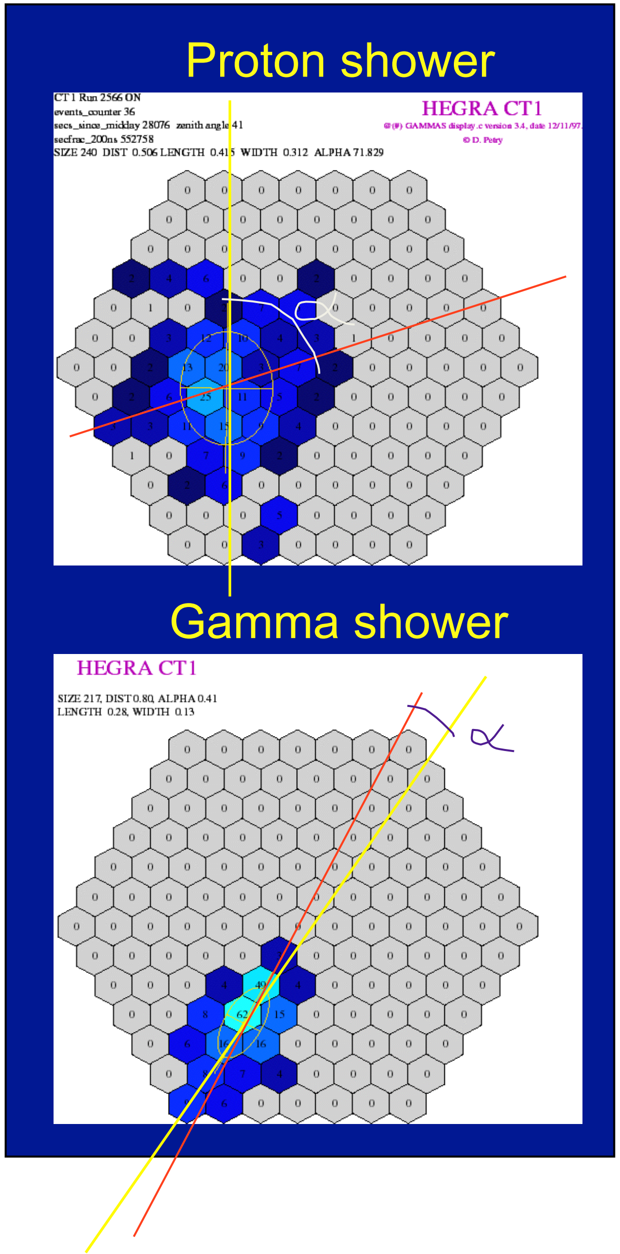


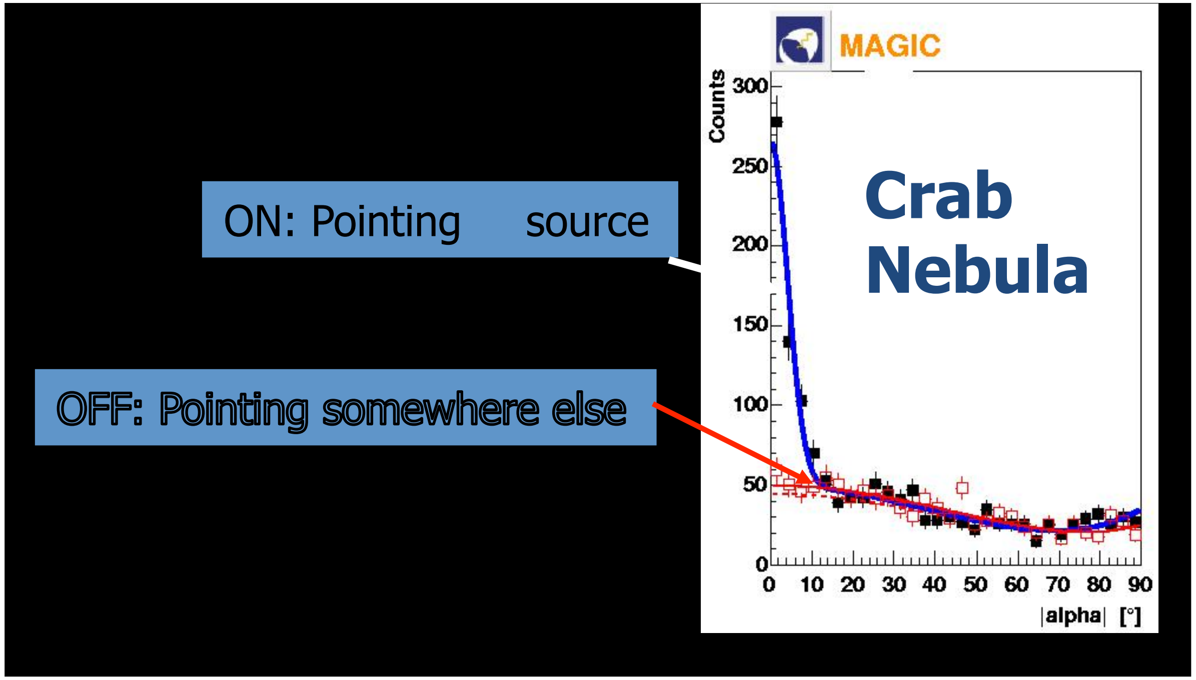
Wavelength spectrum of atmospheric Cherenkov light

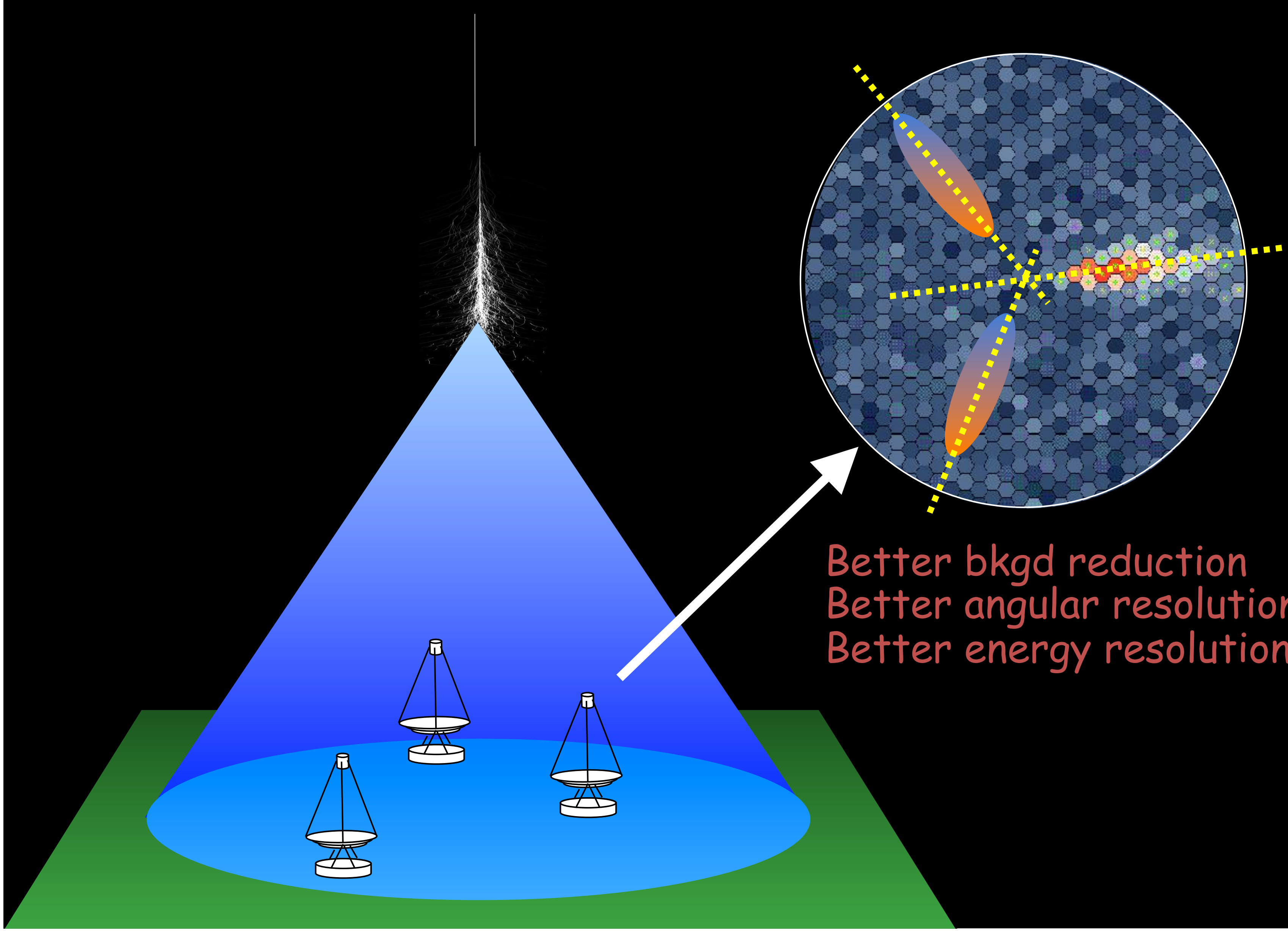


γ/h Separation









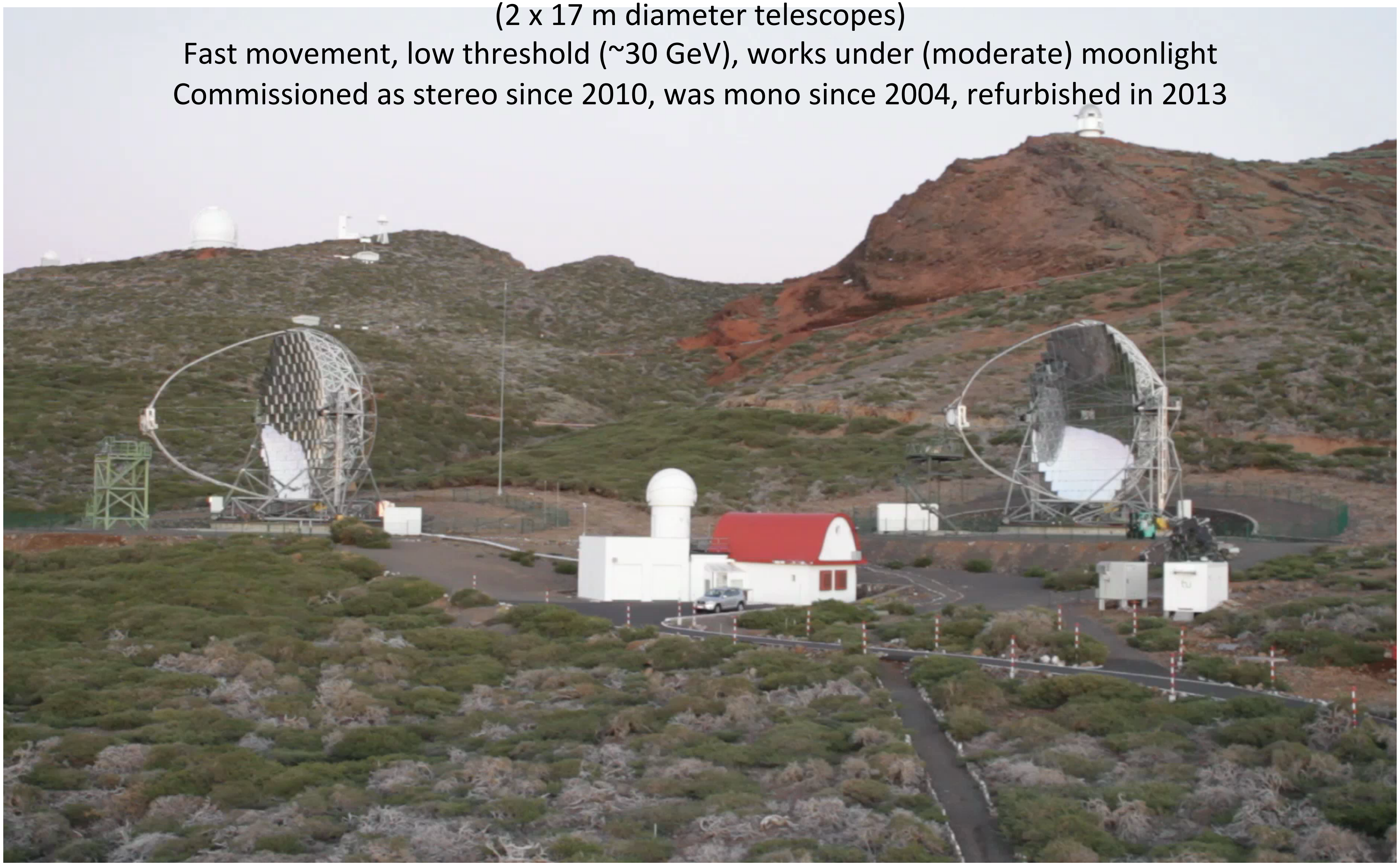
Better bkgd reduction
Better angular resolution
Better energy resolution

Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7

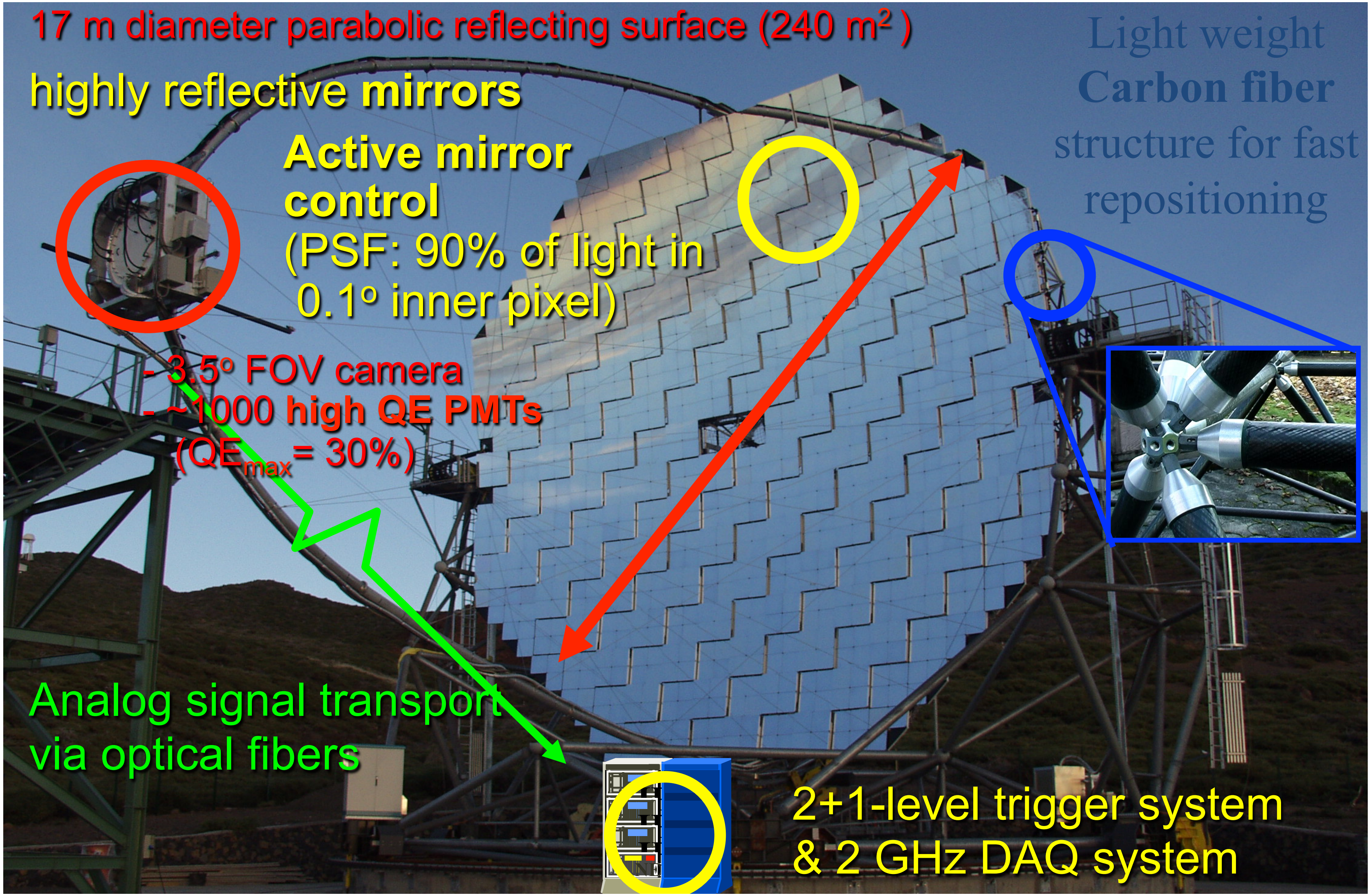

HESS
HESS-1: 4×12m tels
HESS-2: +28m tel.
Completed mid-2012

MAGIC at La Palma

(2 x 17 m diameter telescopes)
Fast movement, low threshold (~30 GeV), works under (moderate) moonlight
Commissioned as stereo since 2010, was mono since 2004, refurbished in 2013



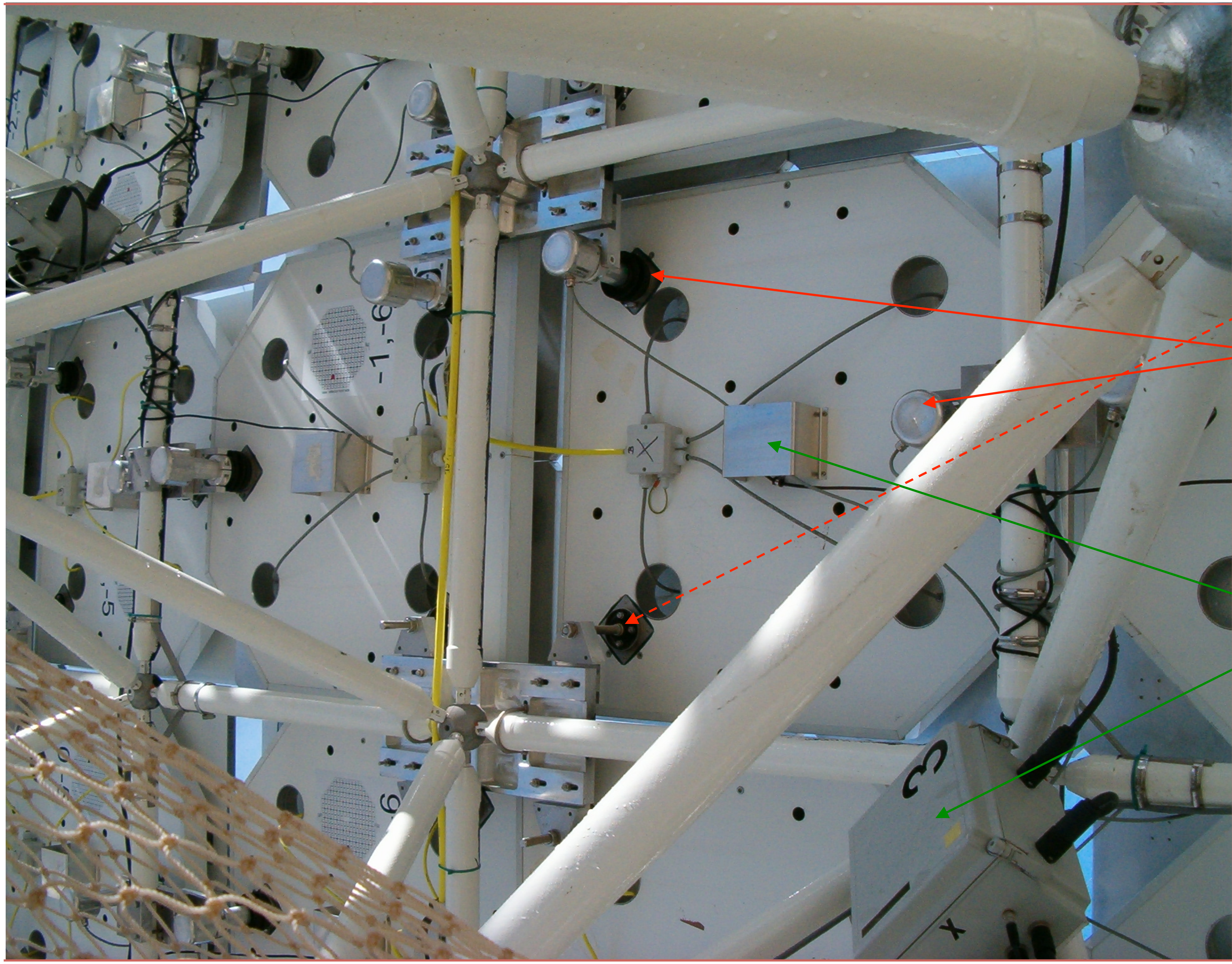
Key technological elements for MAGIC



Main technological novelties of MAGIC

- Active mirror control
- Light weight (60 tons), fast repositioning to catch transients (GRBs etc.)
- PMTs with low gain, to enhance duty cycle
- 2 GB sampling
- Smart triggers for low energy
- Daily monitoring of mirror performance thanks to a CCD camera
- …

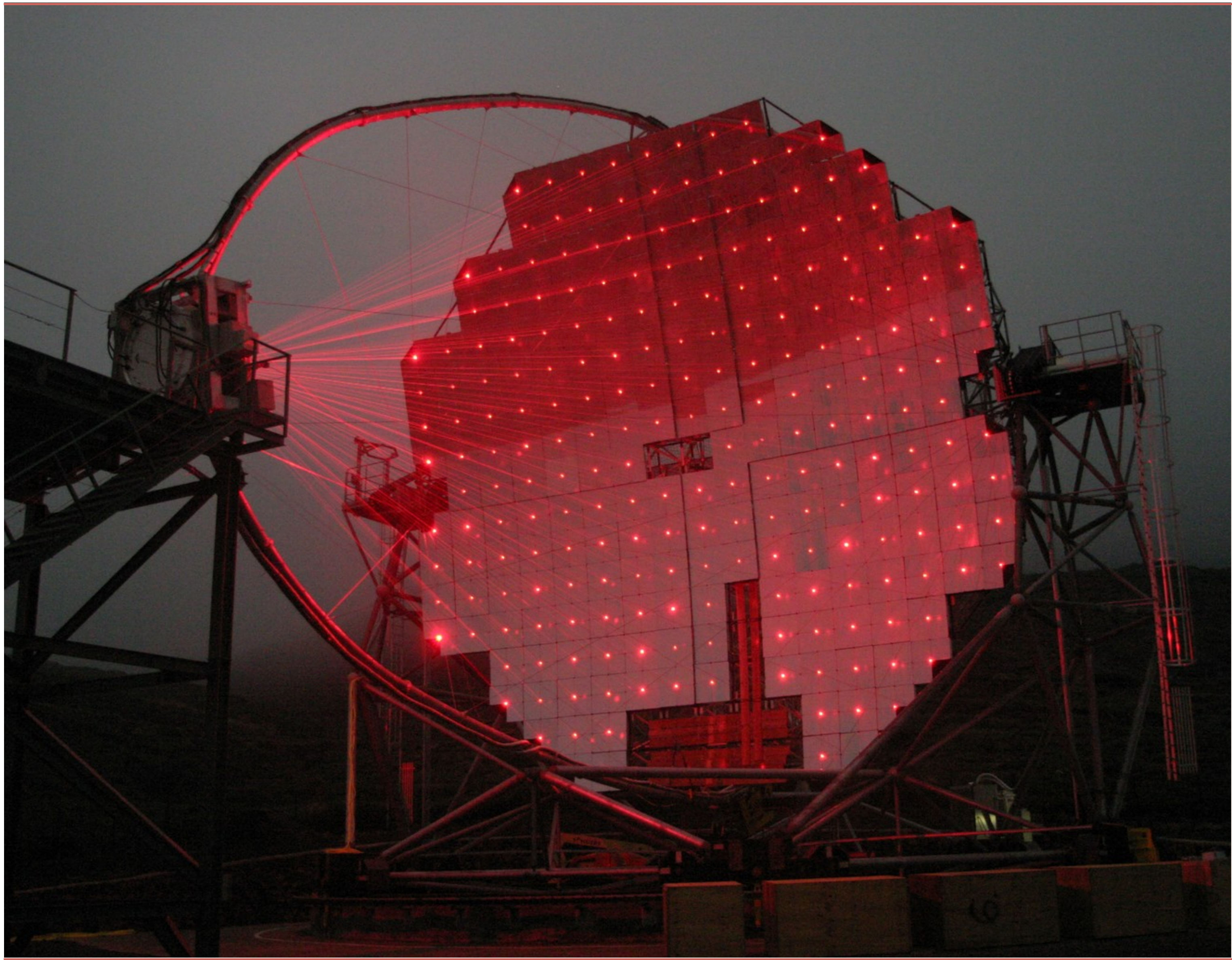
Active Mirror Control



Each segment attached to the support frame at 3 points :
1x fixed and
2x actuators

Other AMC components:
1 laser/segment
1 electr.box for 4 segments
1 CCD-camera (not shown)

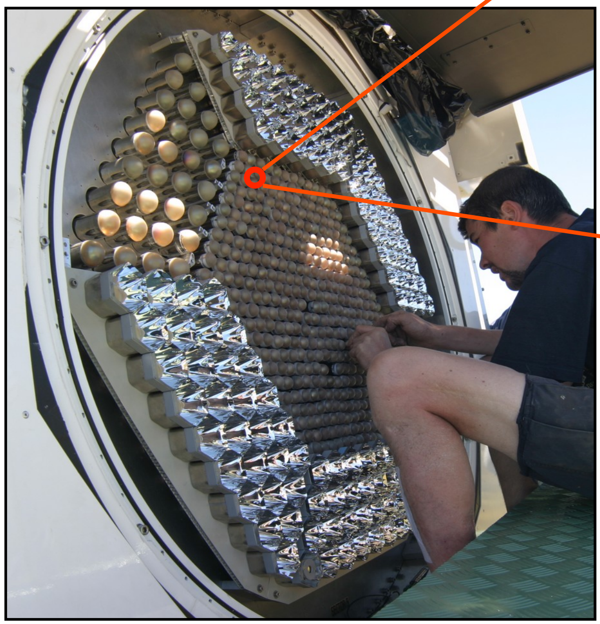
The MAGIC AMC System



All AMC Lasers switched on during foggy night

(nice propaganda picture; does never look like that during operation ...)

Enhanced QE PMTs Camera

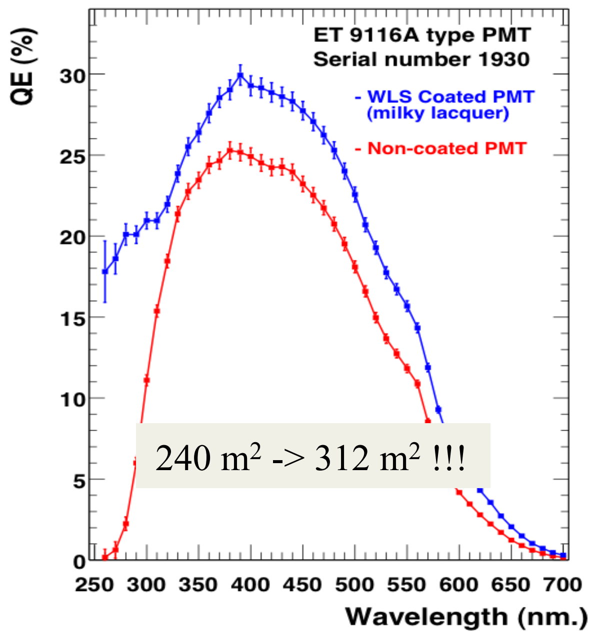


6 stage PMTs (low gain)

- ET 9116A (1”)   : 0.1°

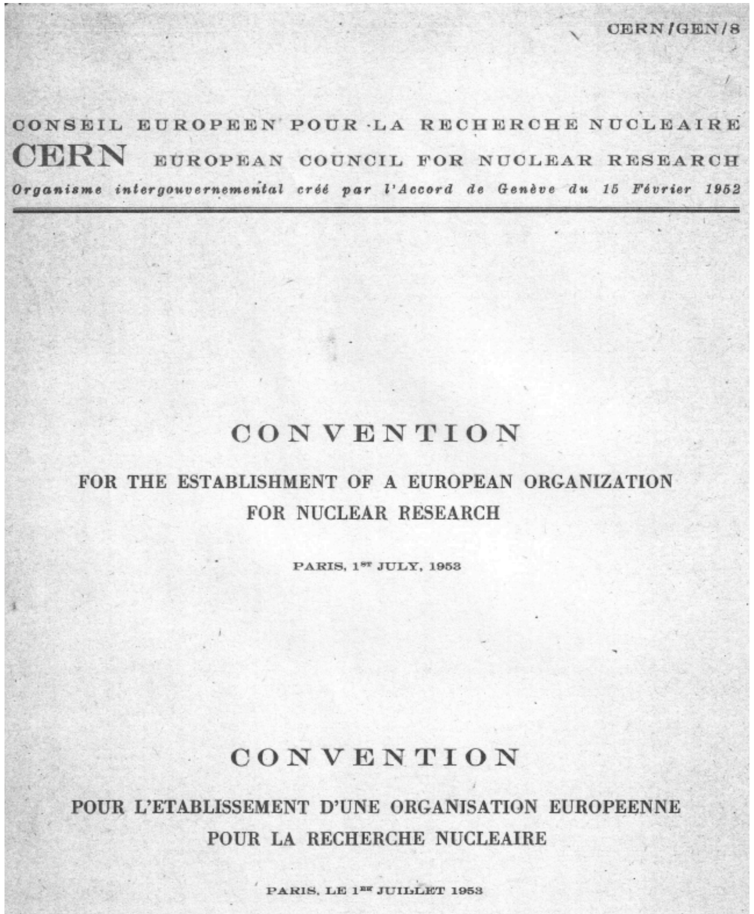
Quantum Efficiency increased up to 30 % with diffuse scattering coating

extended UV sensitivity using wavelength shifter coating



Main physics results and perspectives

- Cosmic Rays
  - SNR established as sources of CR up to (almost) the knee
- Photon propagation
  - Transparency of the Universe;
  - Energy of the vacuum;
  - Tests of Lorentz Invariance;
  - Cosmology
- Search for "WIMP" Dark Matter


CERN/GEN/8

CONSEIL EUROPEEN POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN COUNCIL FOR NUCLEAR RESEARCH
Organisme intergouvernemental créé par l'Accord de Genève du 15 Février 1952

CONVENTION

FOR THE ESTABLISHMENT OF A EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PARIS, 1ST JULY, 1953

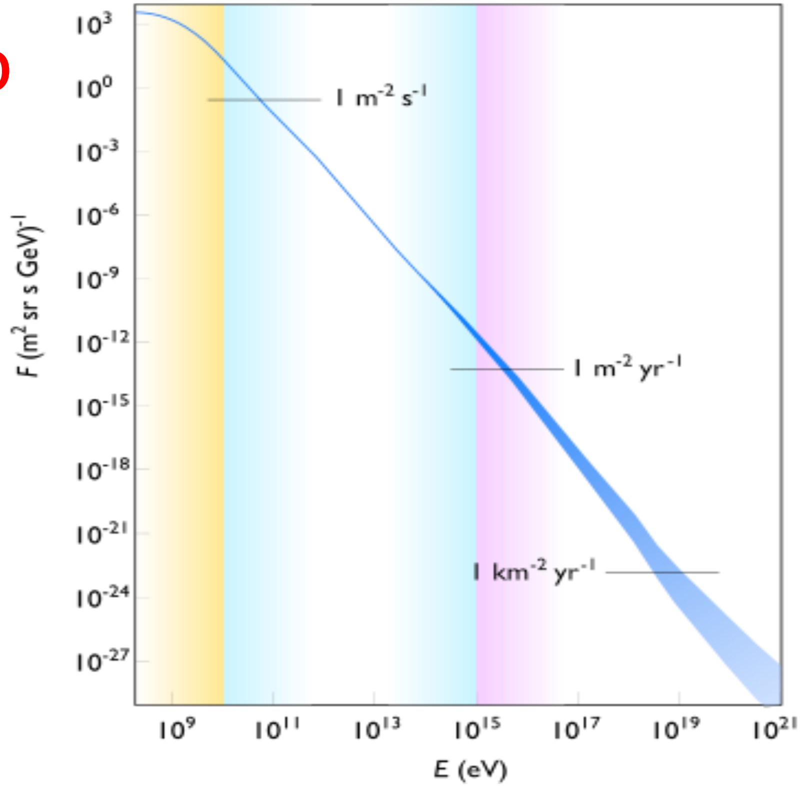
CONVENTION

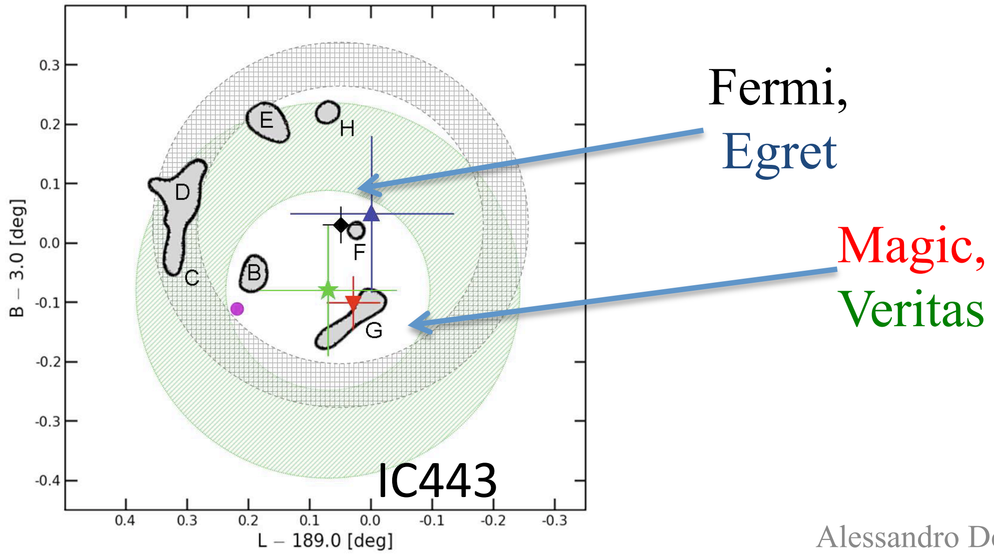
POUR L'ETABLISSEMENT D'UNE ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

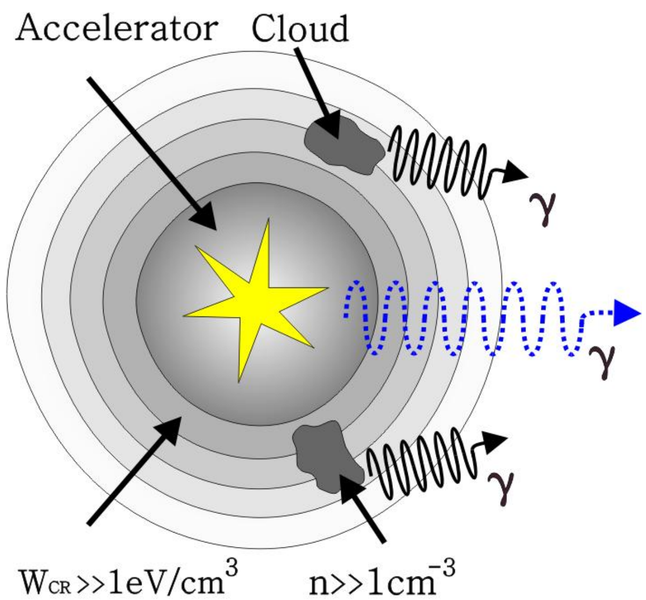
PARIS, LE 1ER JUILLET 1953

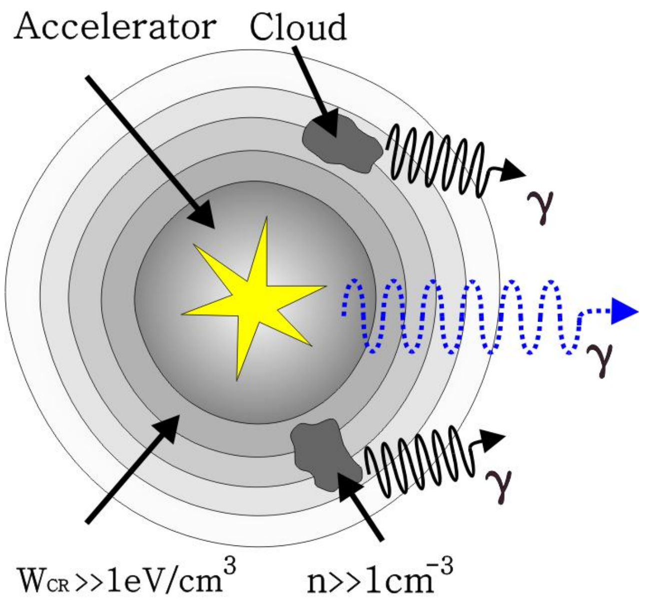
Proof of the origin of CR up to almost the knee

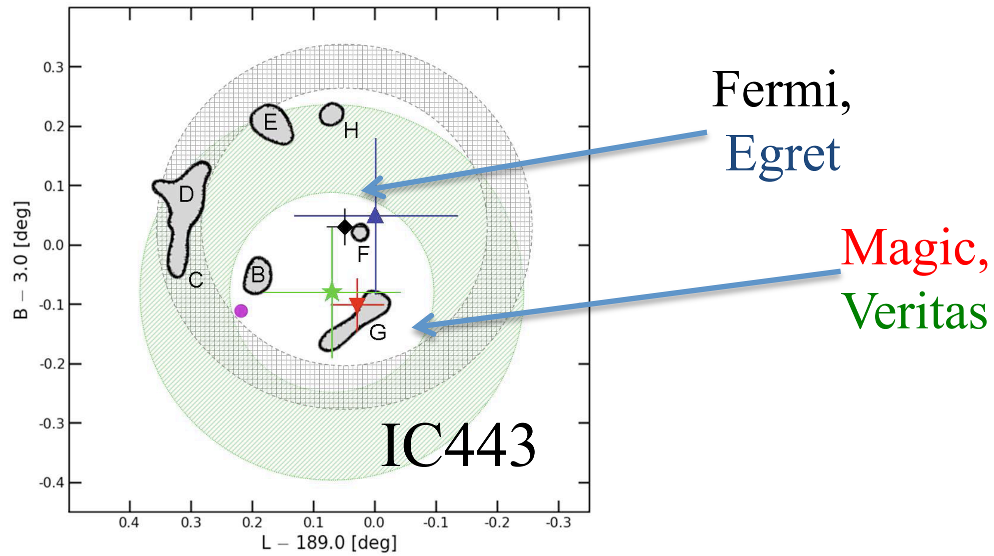
- Evidence that SNR are sources of CR up to ~1000 TeV (almost the knee) came from morphology studies of RX J1713-3946 (H.E.S.S. 2004) with photons
- Striking evidence from the morphology of SNR IC443 (MAGIC + Fermi/Agile 2010)

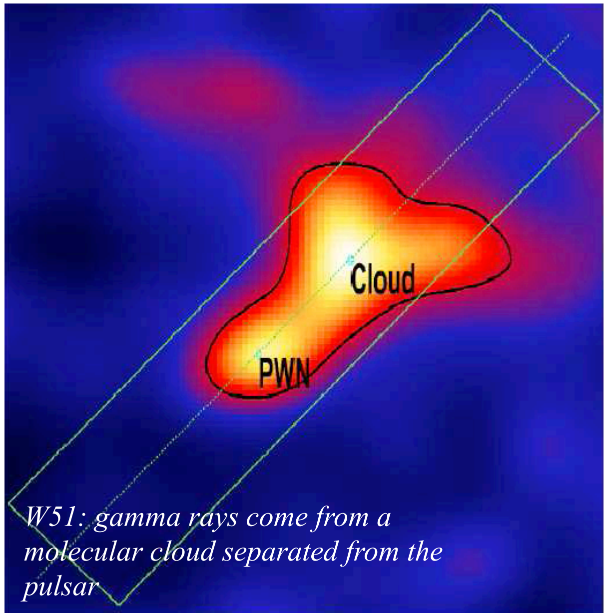




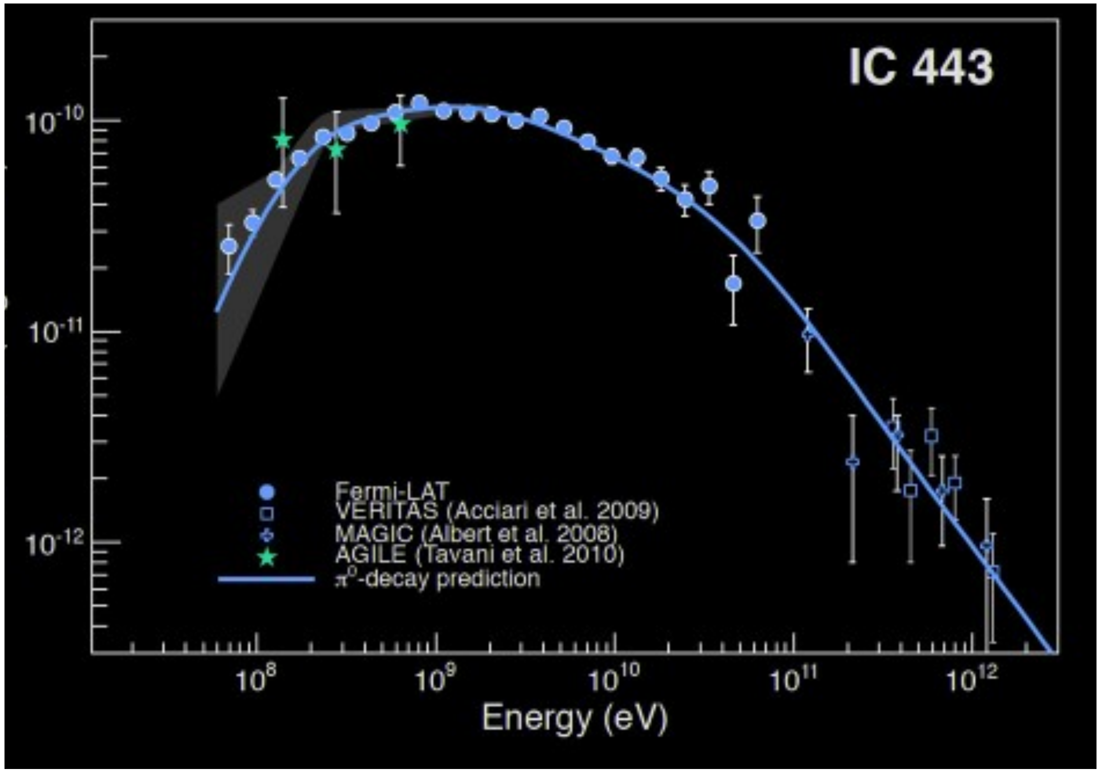




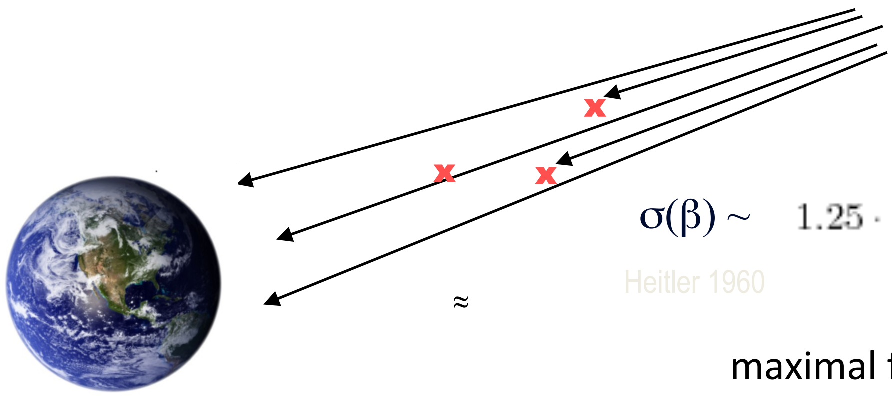


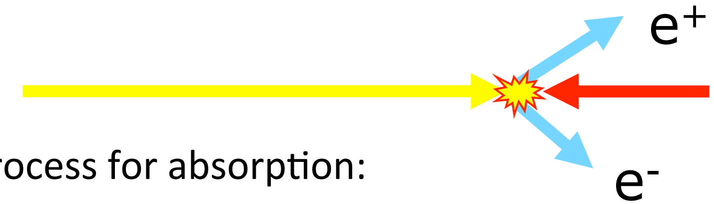


W51: gamma rays come from a molecular cloud separated from the pulsar



Propagation of γ-rays





dominant process for absorption:

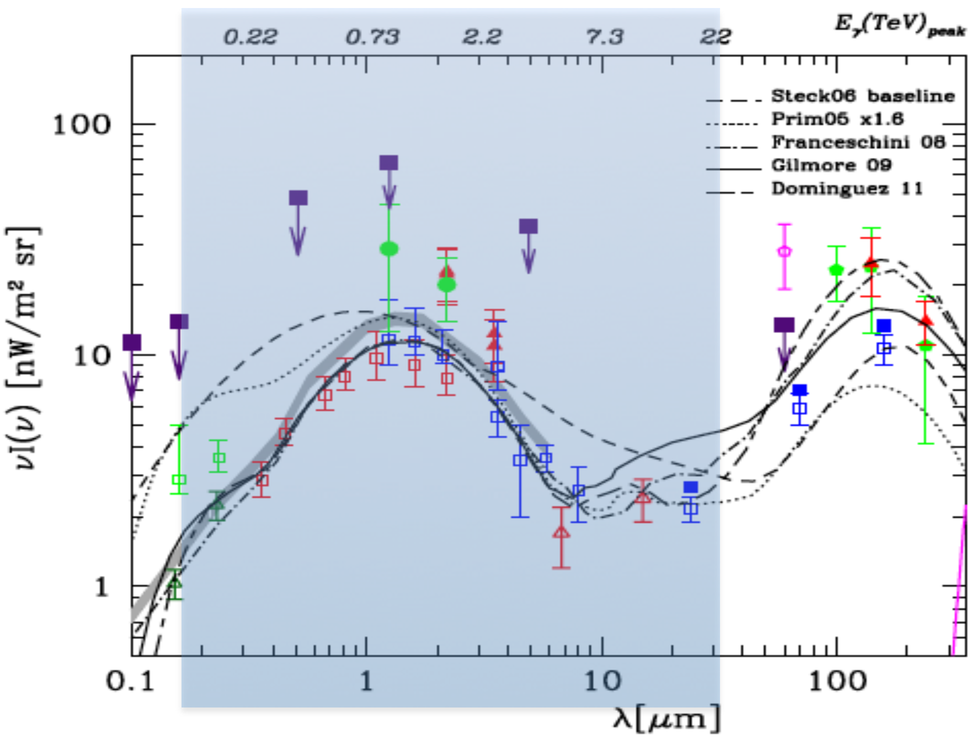
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^{+}e^{-}$$

$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

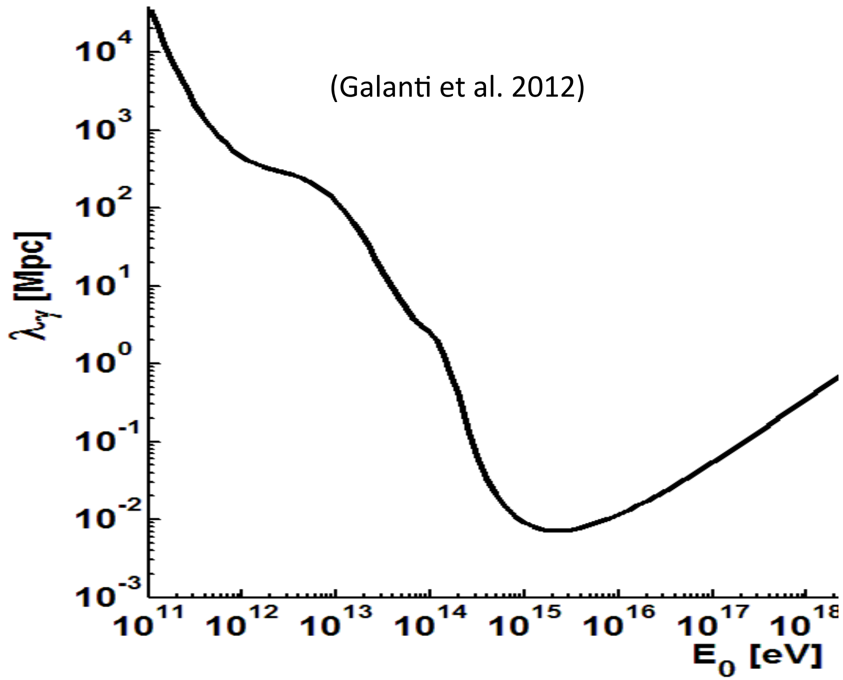
Heitler 1960

maximal for: $\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\ \mathrm{GeV}}{E}\right) \mathrm{eV}$

- For gamma rays, relevant background component is optical/infrared (EBL)
- different models for EBL: minimum density given by cosmology/star formation



2011)



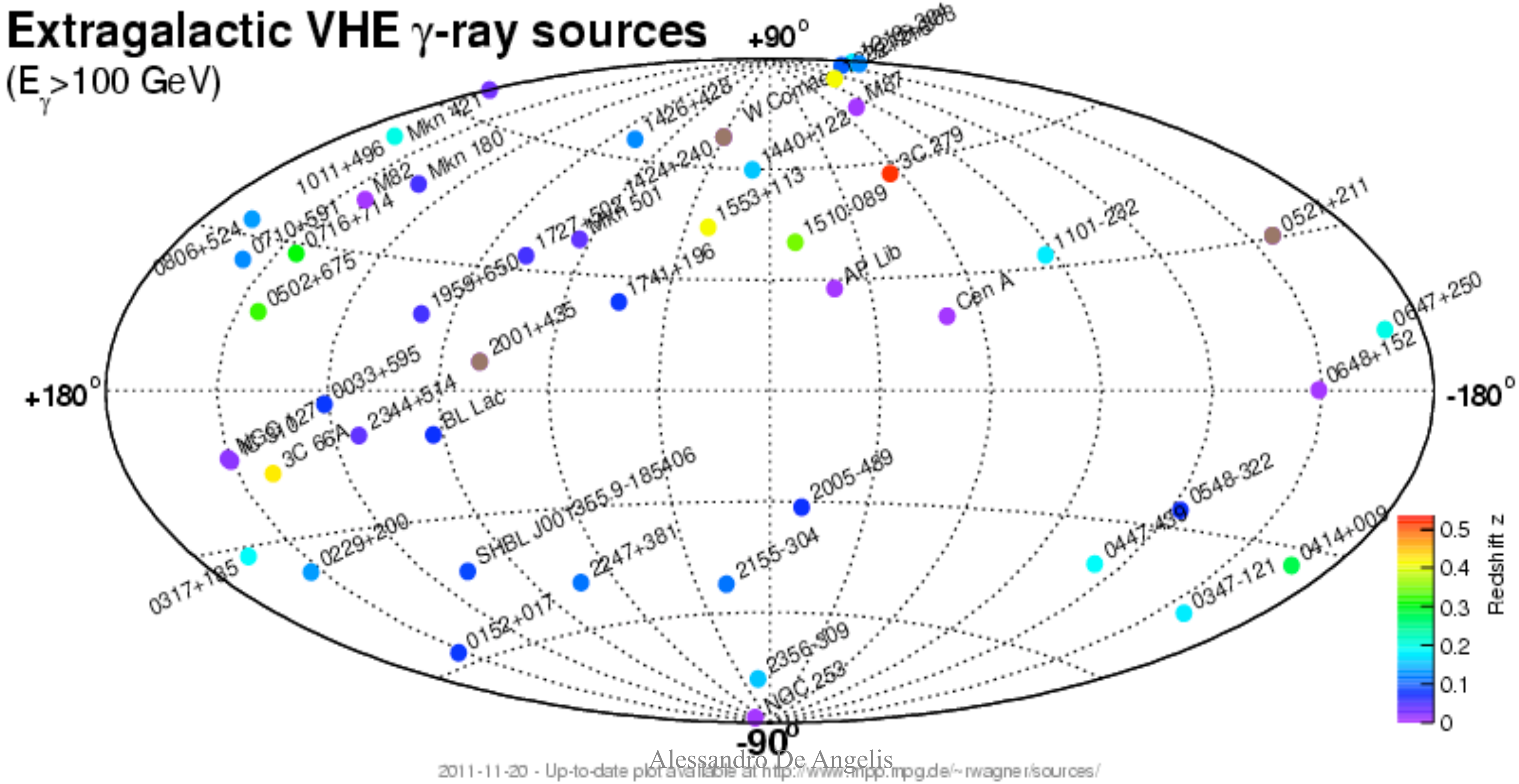
(Galanti et al. 2012)

Extragalactic Sources

~50 Sources

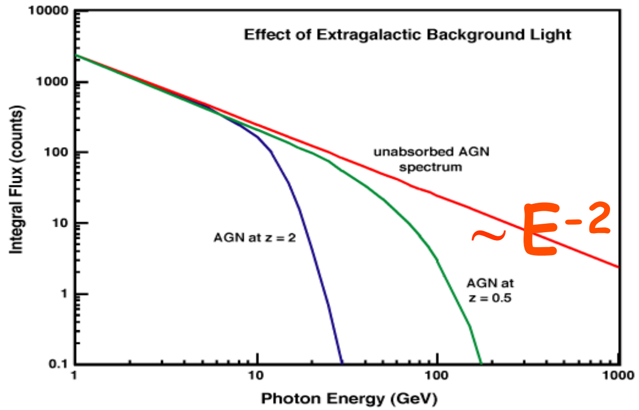
…

1ES 1011+496	**z=0.21**	**MAGIC 2007**
1ES 0414+009	z=0.29	HESS/Fermi 2009
S5 0716+71	**z=0.31±0.08**	**MAGIC 2009**
1ES 0502+675	z=0.34	VERITAS 2009
PKS 1510-089	z=0.36	HESS 2010
4C +21.43	**z=0.43**	**MAGIC 2010**
3C 66A	**z=0.44**	**VERITAS 2009**
3C 279	**z=0.54**	**MAGIC 2008**

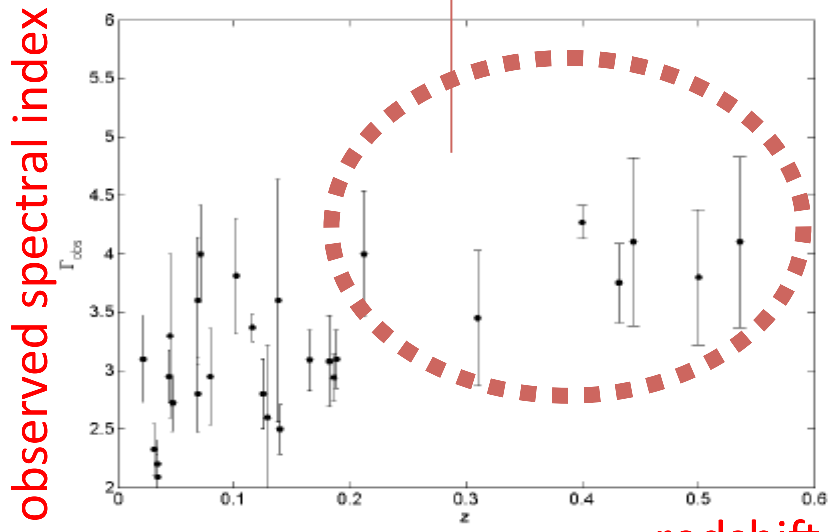


Are our AGN observations consistent with theory?

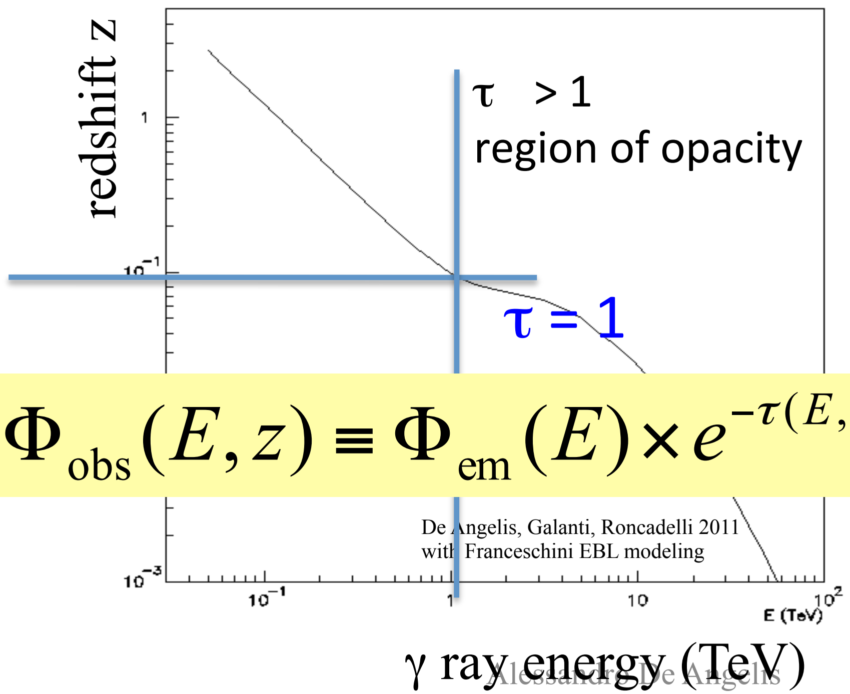
Measured spectra affected by attenuation in the EBL:



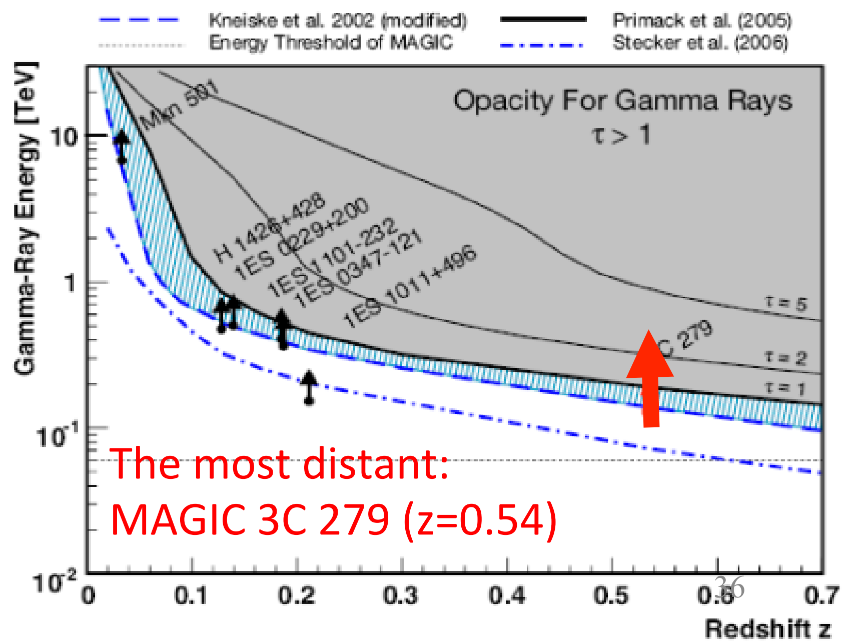
Selection bias?
New physics ?



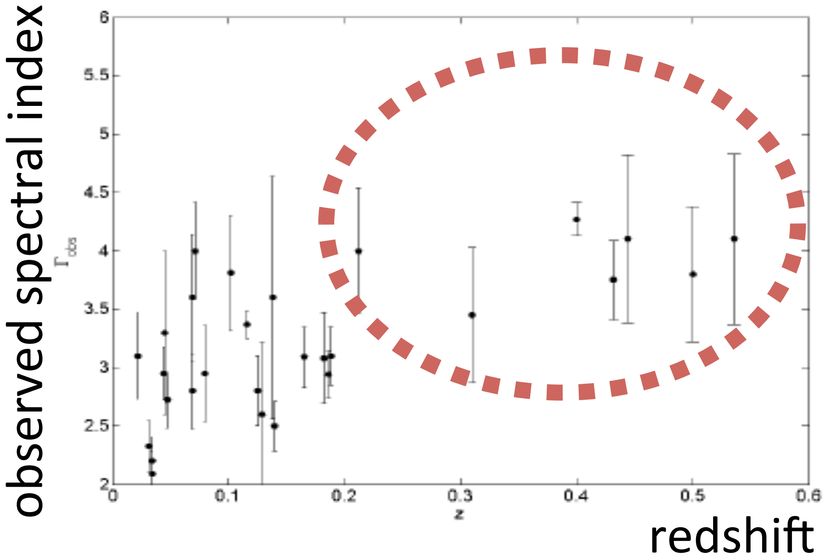
(DA, Galanti, Roncadelli; PRD 2011)

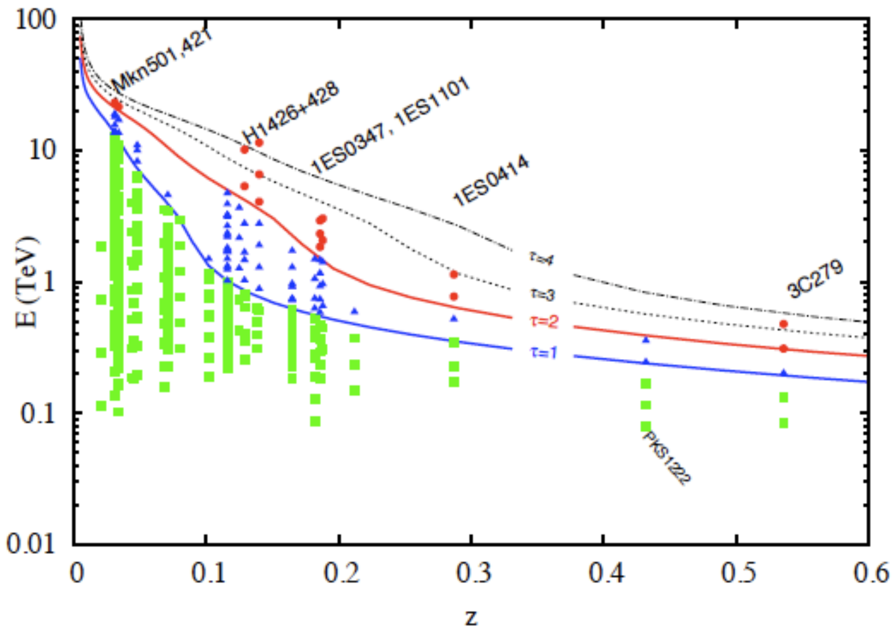


$$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$$



If there is a problem





Explanations from the standard ones

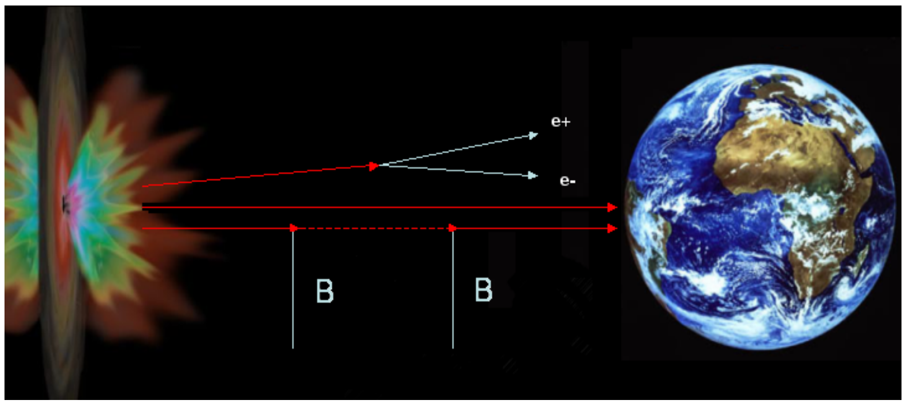
- very hard emission mechanisms with intrinsic slope < 1.5 (Stecker 2008)
- Very low EBL, plus observational bias, plus a couple of "wrong" outliers

to almost standard

- γ-ray fluxes enhanced by relatively nearby production by interactions of primary cosmic rays or ν from the same source

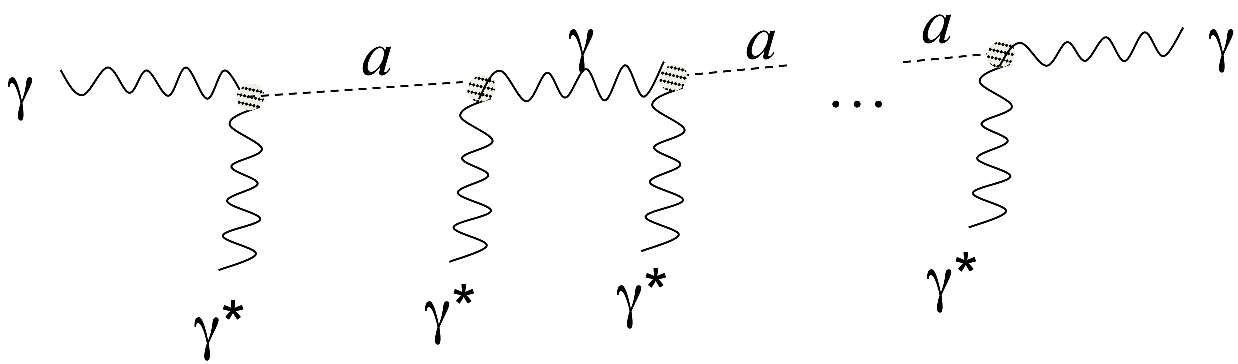
to possible evidence for new physics

- Oscillation to a light "axion"? (DA, Roncadelli & MAnsutti [DARMA], PRD2007, PLB2008)
- Axion emission (Simet+, PRD2008)
- A combination of the above (Sanchez Conde et al. PRD 2009)



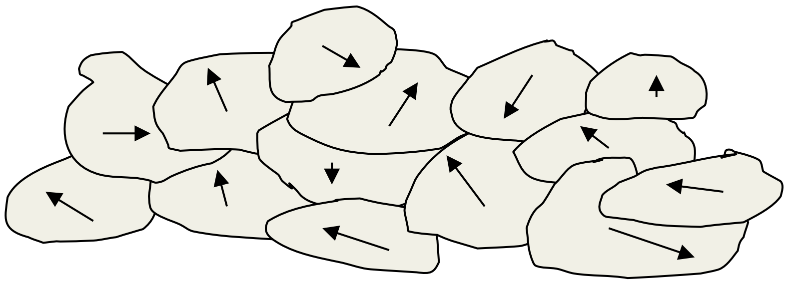
The photon-axion mixing mechanism

$$L_{a\gamma\gamma} = g_{a\gamma}\left(\vec{E}\cdot\vec{B}\right)a$$



Propagation: Raffelt-Stodolsky 1987; Csaki-Kaloper-Terning 2002; DA Roncadelli MAnsutti 2007; Simet Hooper Serpico 2008

- Magnetic field 1 nG < B < 1aG (AGN halos). Cells of ~ 1 Mpc



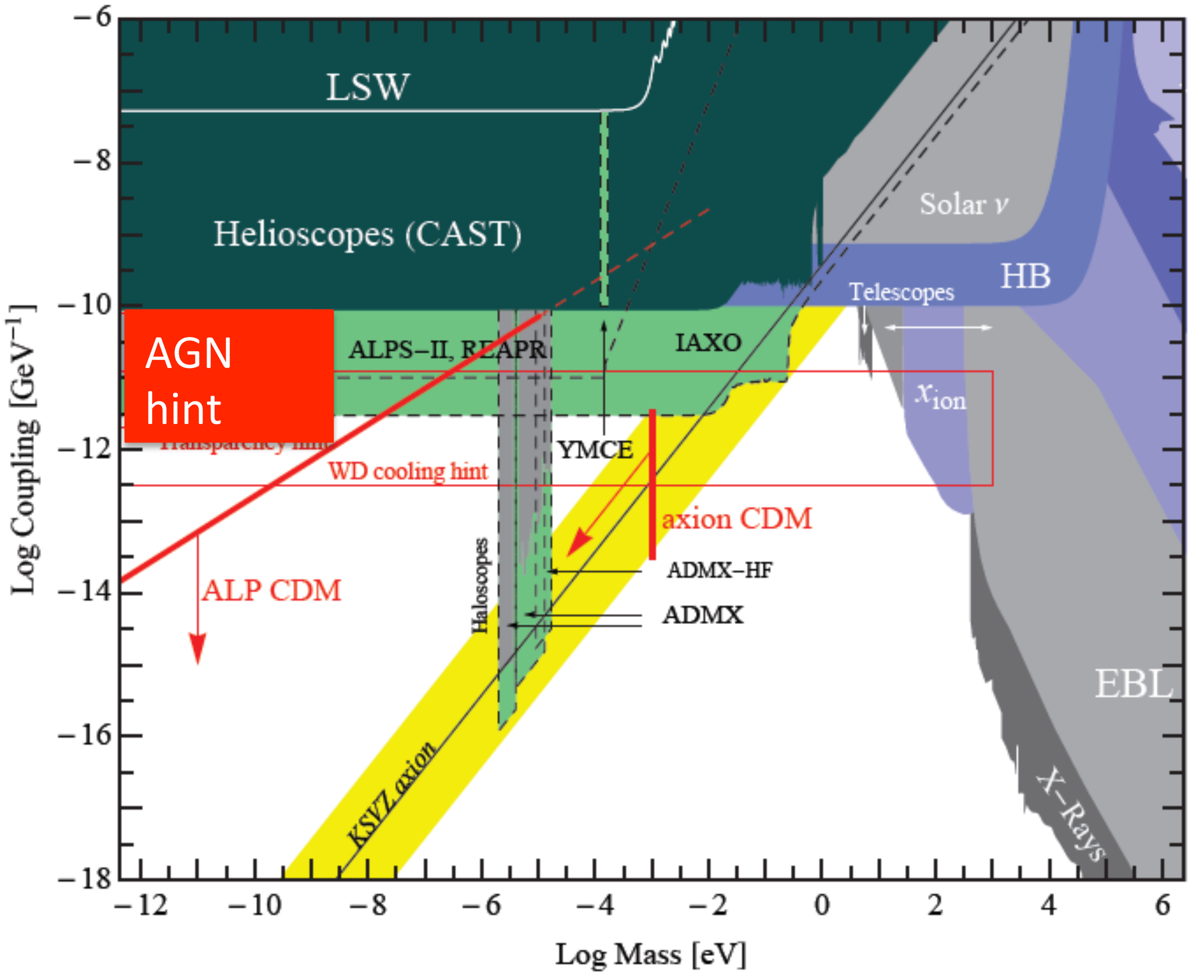
$$P_{\gamma\to a} \approx NP_1$$

$$P_1 \approx \frac{g_{a\gamma}^2 B_T^2 s^2}{4} \approx 2\times 10^{-3}\left(\frac{B_T}{1\mathrm{nG}}\frac{s}{1\mathrm{Mpc}}\frac{g_{a\gamma}}{10^{-10}\,\mathrm{GeV}^{-1}}\right)^2$$

- m_a < 0.02 eV (direct searches)
- $g < 10^{-10}\mathrm{GeV}^{-1}$ from the non observation of γ-rays from the SN1987A, and direct searches

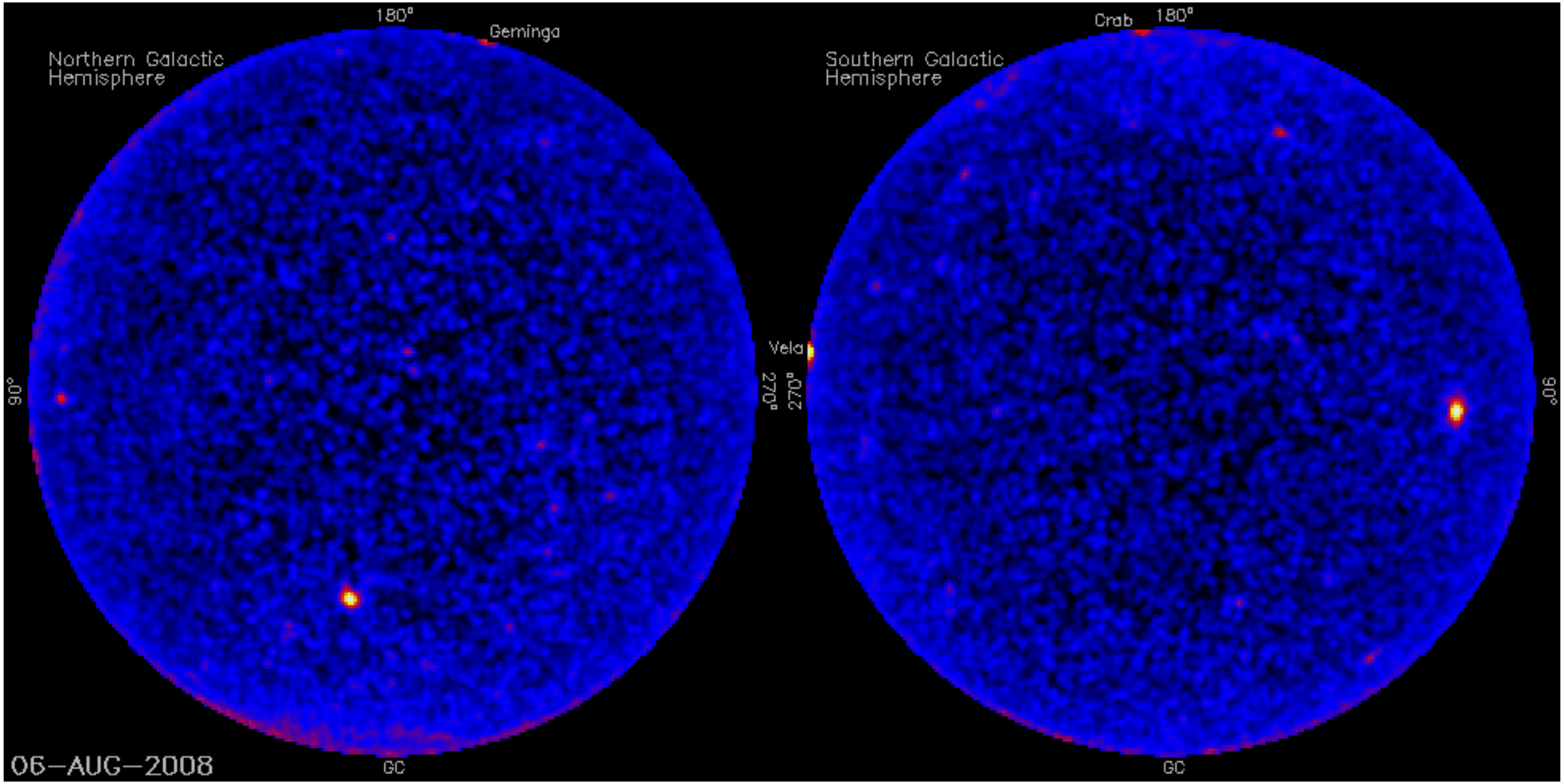
Axions

Parameter space for axions or axion-like particles



- Experimentally excluded
- Astronomy constraints
- Cosmology constraints
- Sensitivity of planned experiments

Variability (down to the ~10s scale)



A heuristic approach: modified dispersion relations (perturbation of the Hamiltonian)

- We expect the Planck mass to be the scale of the effect

$$E_P = \sqrt{hc/G} \cong 1.2 \times 10^{19}\,\text{GeV}$$

$$H^2 = m^2 + p^2 \rightarrow H^2 = m^2 + p^2\left(1 + \xi \frac{E}{E_P} + \ldots\right)$$

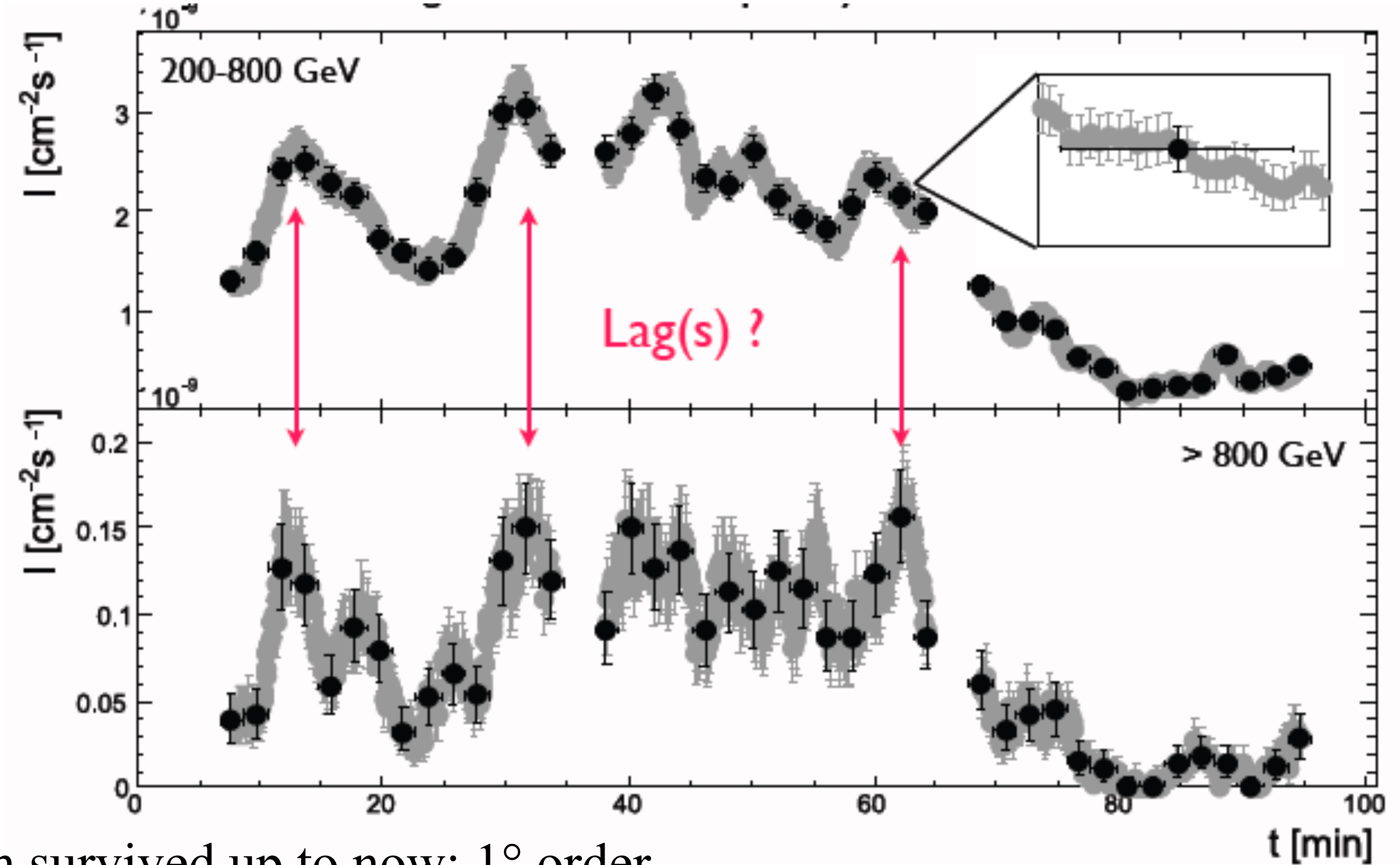
$$H \xrightarrow[p>>]{} p\left(1 + \frac{m^2}{2p^2} + \xi \frac{p}{2E_P} + \ldots\right)$$

$$v = \frac{\partial H}{\partial p} \cong 1 - \frac{m^2}{2p^2} + \xi \frac{p}{E_P} \Rightarrow \boxed{v_\gamma \cong 1 + \xi \frac{E}{E_P}}$$

=> effect of dispersion relations at cosmological distances can be important at energies well below Planck scale:

$$\boxed{\Delta t_\gamma \cong T \Delta E \frac{\xi}{E_P}}$$

Tests of Lorentz violation: the name of the game



No claim survived up to now; 1° order effects unlikely

HESS, PKS 2155

2^{nd} order? Cherenkov rules!

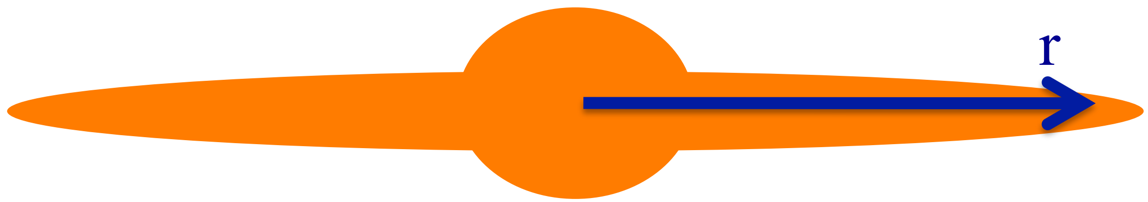
$$(\Delta t)_{obs} \cong \frac{3}{2}\left(\frac{\Delta E}{E_{s2}}\right)^2 H_0^{-1}\int_0^z dz' \frac{(1+z')^2}{\sqrt{\Omega_M (1+z')^3 + \Omega_\Lambda}}$$

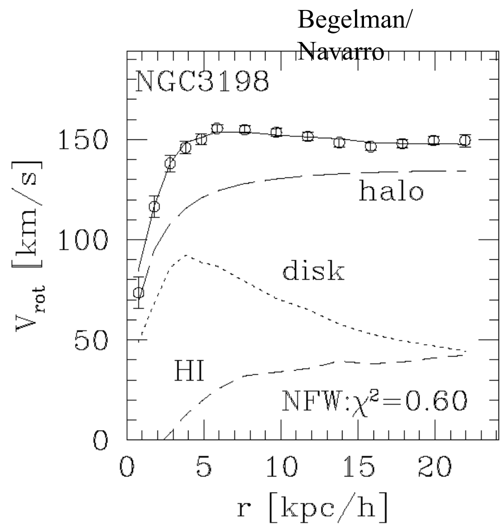
$E_{s2} > 6\ 10^{10}$ GeV ($\sim 10^{-9}$ M_P) (HESS, MAGIC)

A no-loss situation:
if propagation is standard, cosmology with AGN

The Dark Matter Problem

Measure rotation curves for galaxies:



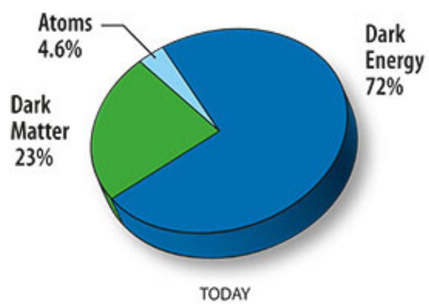


For large r, we expect:

$$G\frac{M}{r^2} = \frac{v^2(r)}{r} \quad \Rightarrow \quad v(r) \sim \frac{1}{\sqrt{r}}$$

we see: flat or rising rotation curves

Hypothesized solution: the visible galaxy is embedded in a much larger halo of Dark Matter (neutral; weakly interacting; mix of particles and antiparticles - in SUSY Majorana)



Famous Bullet Cluster

(B. Atwood)

Which signatures for gamma detectors?

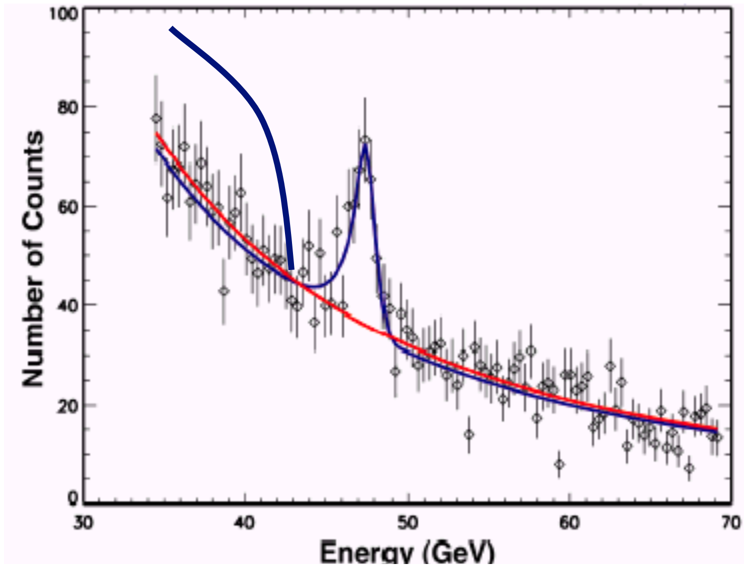
- Self-annihilating WIMPs, if Majorana (as the neutralino in SUSY), can produce:
  - Photon lines ($\gamma\gamma$, γZ)
  - Photon excess at E < m from hadronization
- Excess of antimatter (annihilation/decay)
- Excess of electrons, if unstable

$$\Phi \propto \sigma \frac{\langle v \rangle}{m^2} \int_{los} \rho^2 \, dl$$

from particle physics

from astrophysics

Look to the closest point with M <<L



Many Places to Seek DM!

Galactic Center

Good statistics but source confusion/diffuse background

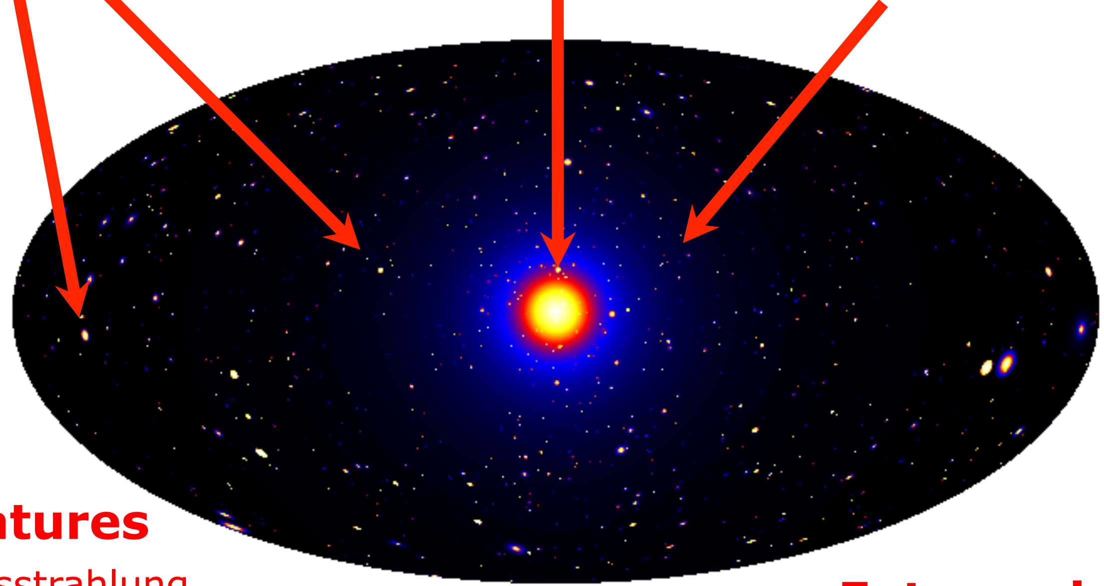
Satellites

Low background and good source id, but low statistics, astrophysical background

Milky Way Halo

Large statistics but diffuse background

All-sky map of simulated gamma ray signal from DM annihilation (Pieri et al 2006)



Spectral Features

Lines, endpoint Bremsstrahlung,…

No astrophysical uncertainties, good source Id, but low sensitivity because of expected small BR

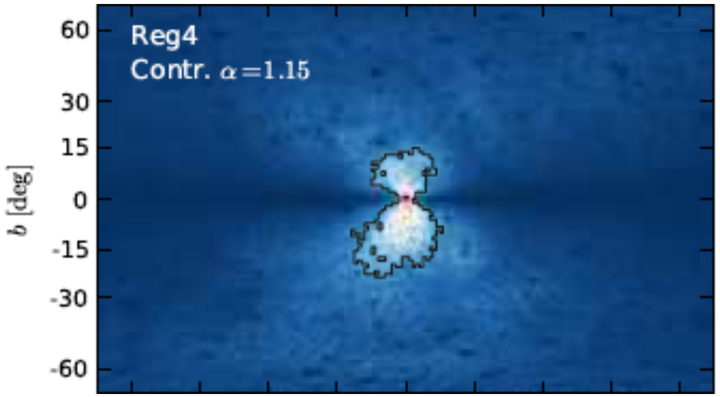
Extra-galactic

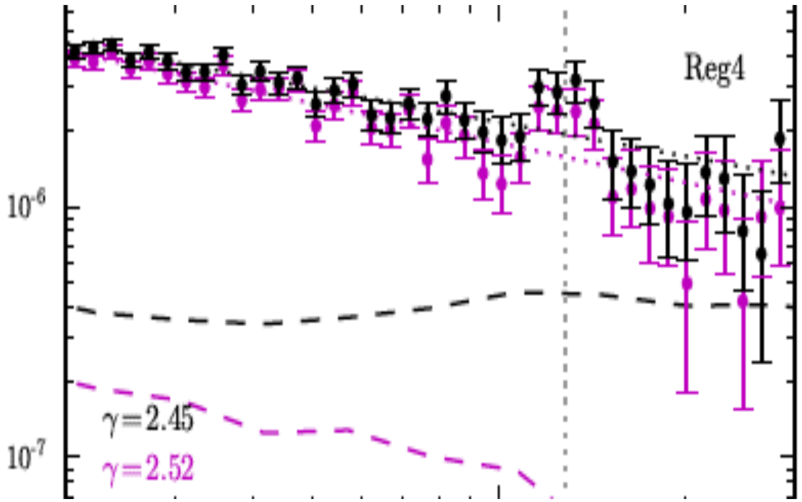
Large statistics, but astrophysics, galactic diffuse backgrounds

No signal from possibly expected sources

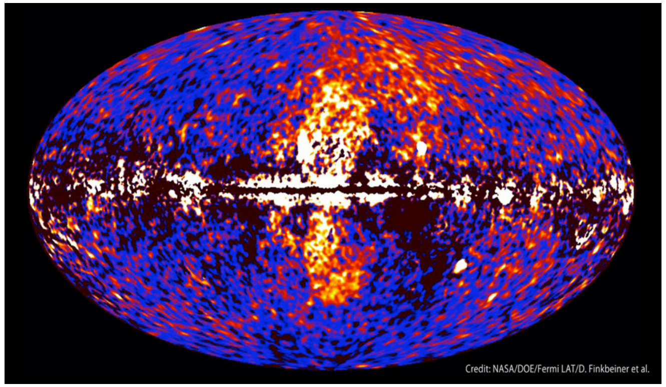
Data-driven line searches

- Very recently, one paper claims a positive signal (a ~4σ photon excess at ~130 GeV from Fermi data)
  - C. Weniger, arXiv:1204.2797





Selection of the region
b(i)ased on data
Large overlapping with
The Fermi "bubbles"
Prospects for present IACT: bad.
LHC? Future Cherenkov?

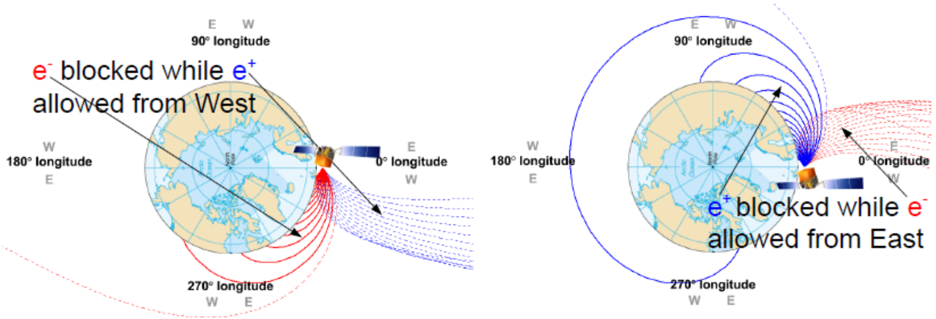


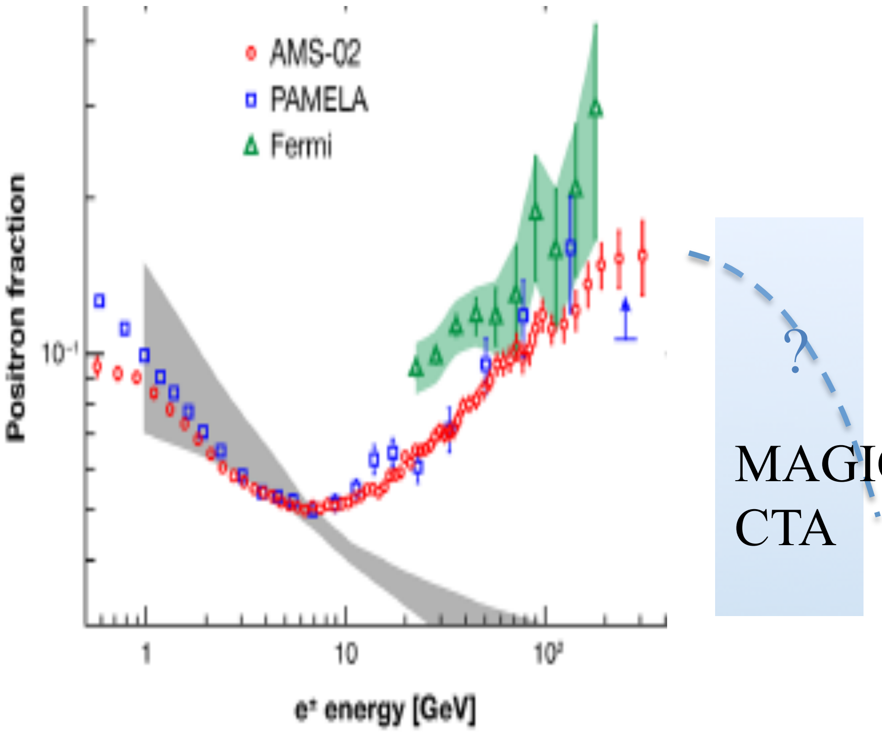
DM: interplay with accelerators

- LHC may find candidates but cannot prove that they are the observed Dark Matter, nor localize it
- *Direct searches (nuclear recoil) may recognize local halo WIMPs but cannot prove the nature and composition of Dark Matter in the sky*

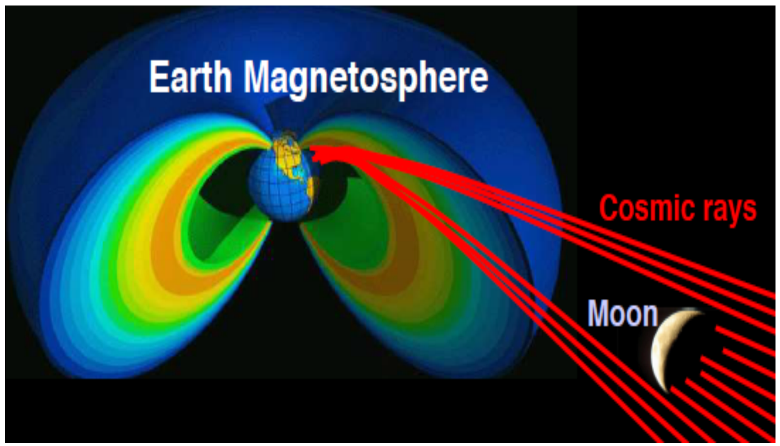
- LHC reach limited to some 200-600 GeV; IACT sensitivity starts at some ~200 GeV (should improve)

Antimatter: the PAMELA anomaly





probe e+/e- ratio at 300-700 GeV

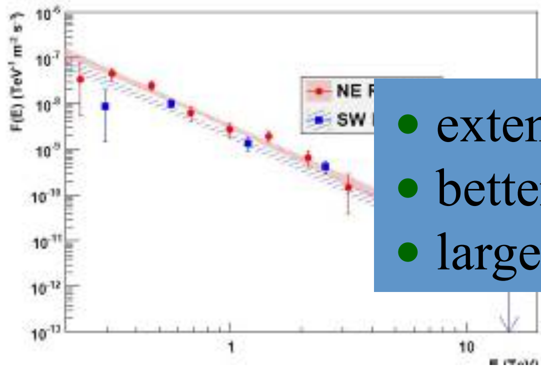


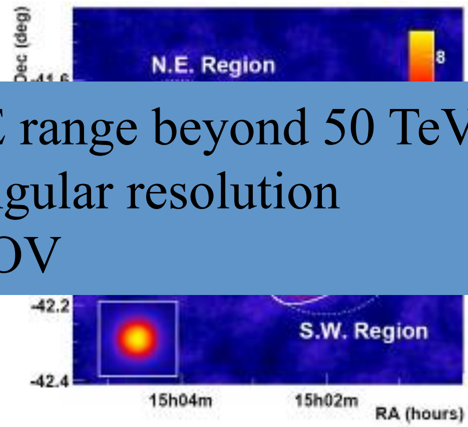
Moon shadow observation mode developed for the MAGIC telescopes [MAGIC ICRC 2011]

sensitivity (50h): 300-700GeV: ~4.4% Crab
measurement possible in few years

A wish list for the future

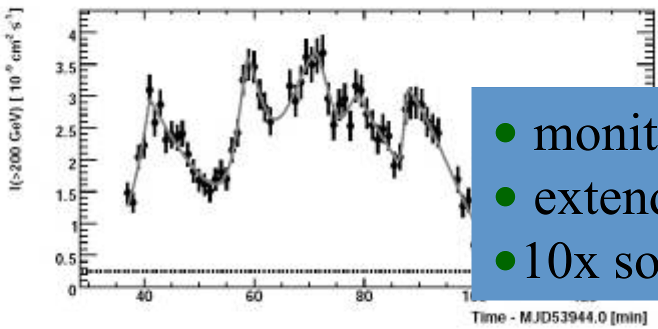
- Galactic sources & CR





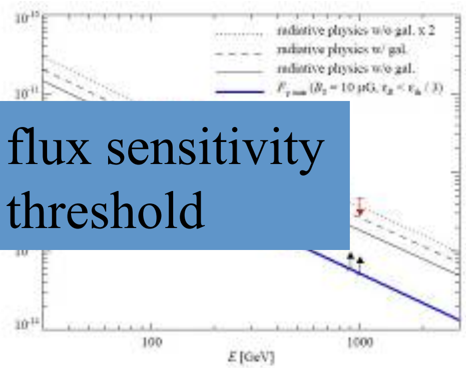
- extend E range beyond 50 TeV
- better angular resolution
- larger FOV

- AGN & gamma prop.



- monitor many objects simult.
- extend E range under 50 GeV
- 10x sources

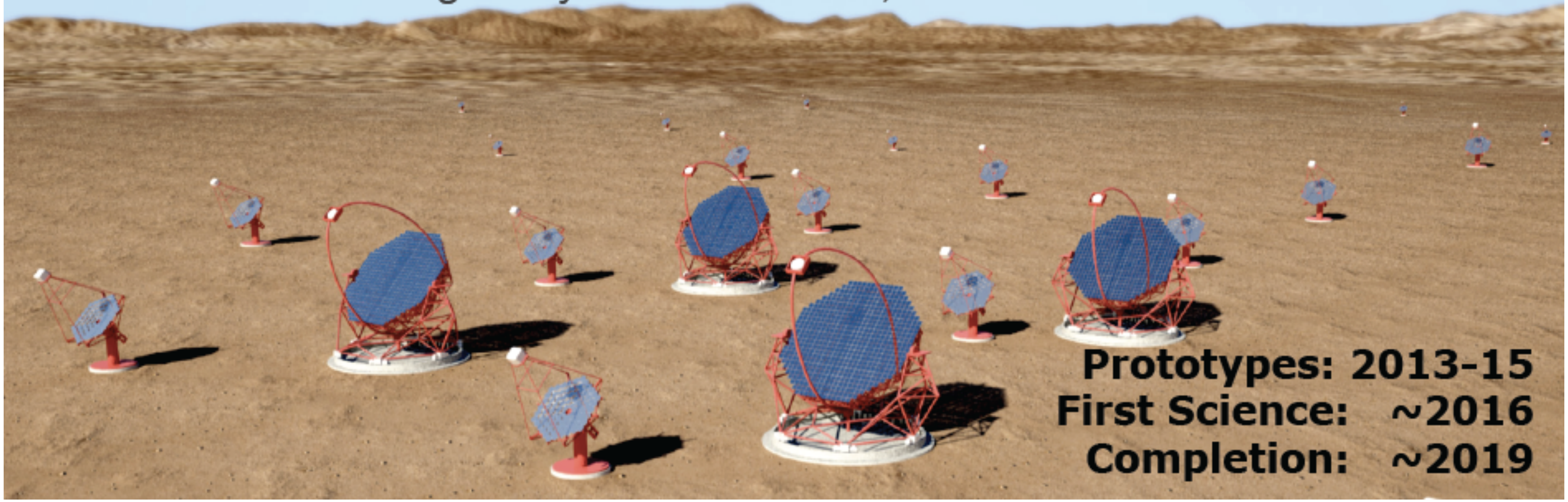
- New particles, new phenomena
  - dark matter and astroparticle physics



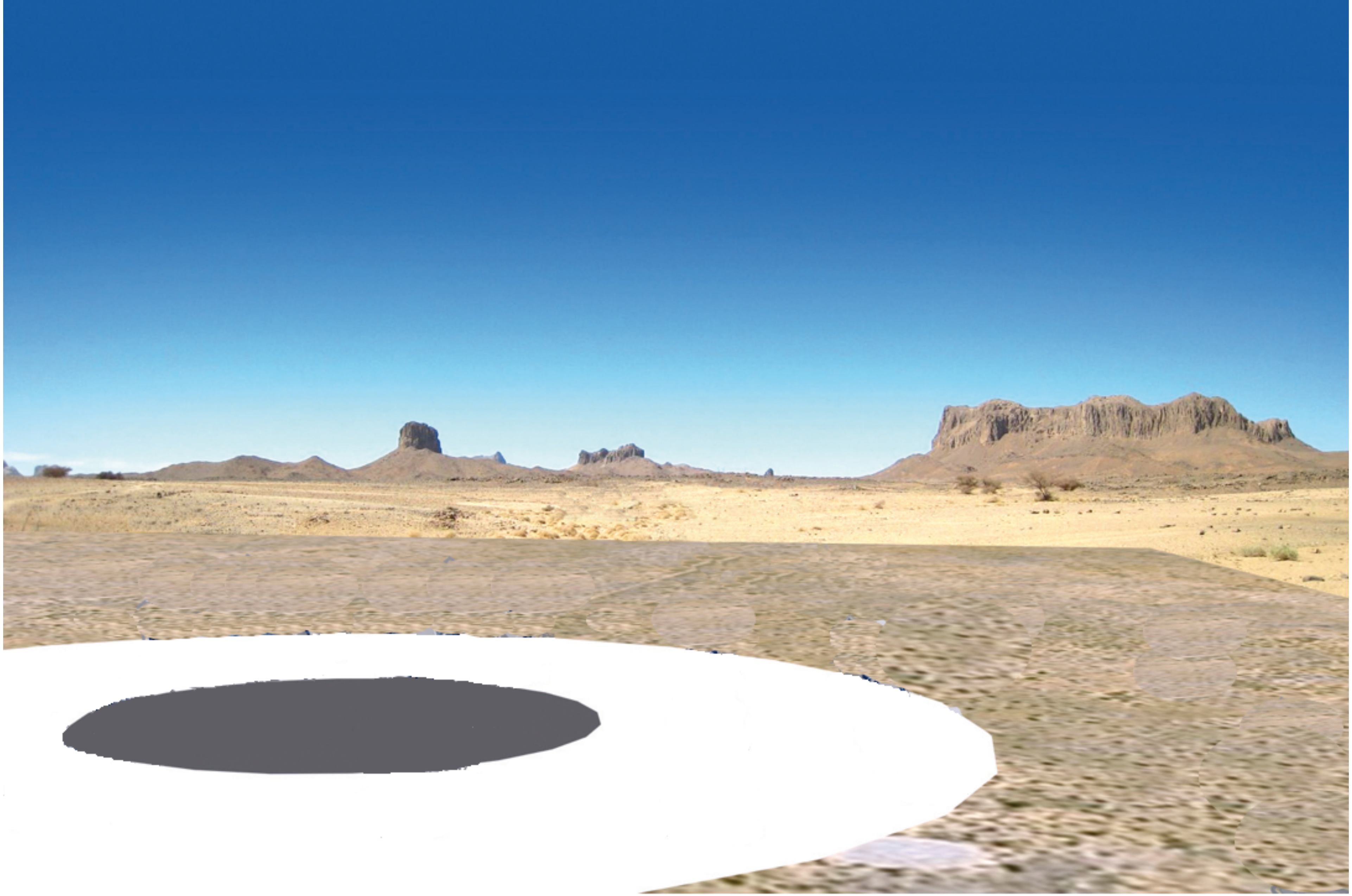
- better flux sensitivity
- lower threshold

The Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 27 nation ~€200M project
  - Including everyone from HESS, MAGIC and VERITAS

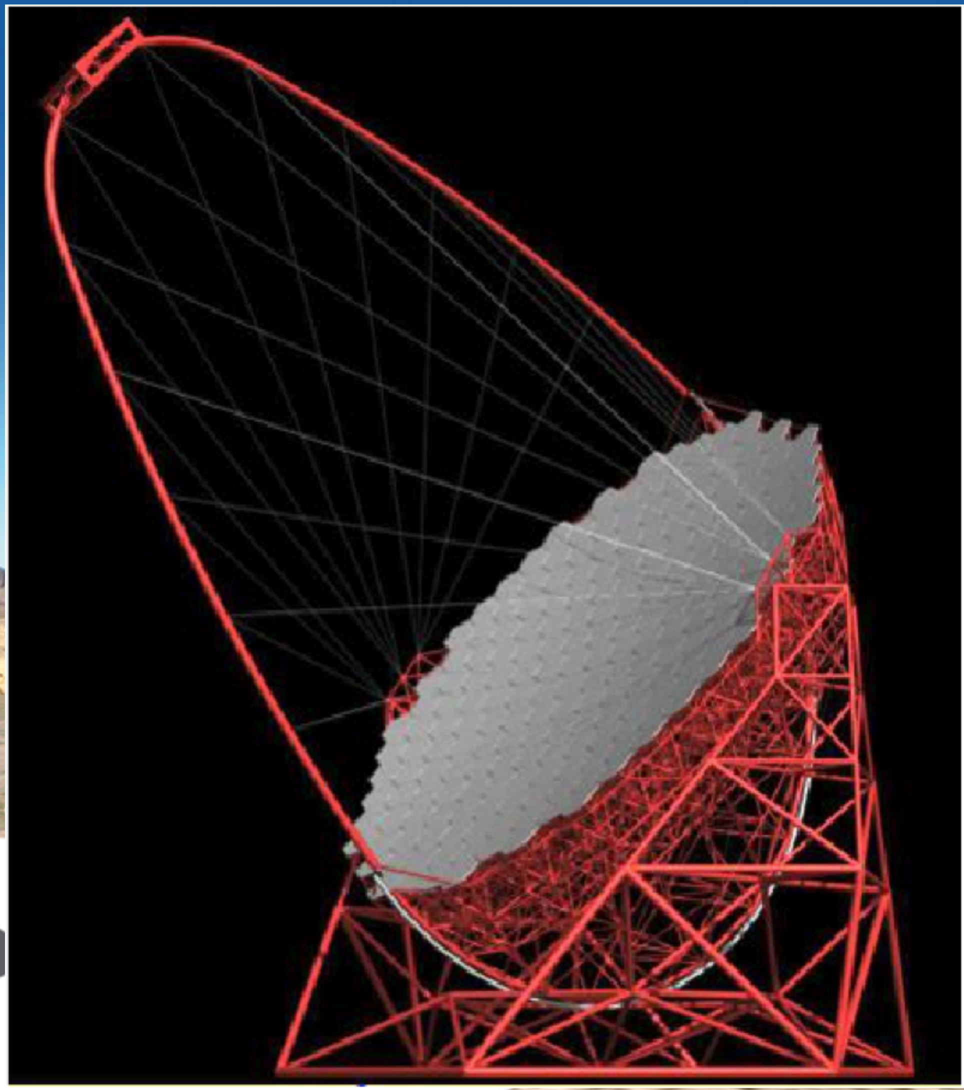


The Cherenkov Telescope Array concept



The Cherenkov Telescope Array concept

Low energy
Few 23 m telescopes
4.5° FoV
~2000 pixels
~ 0.1°



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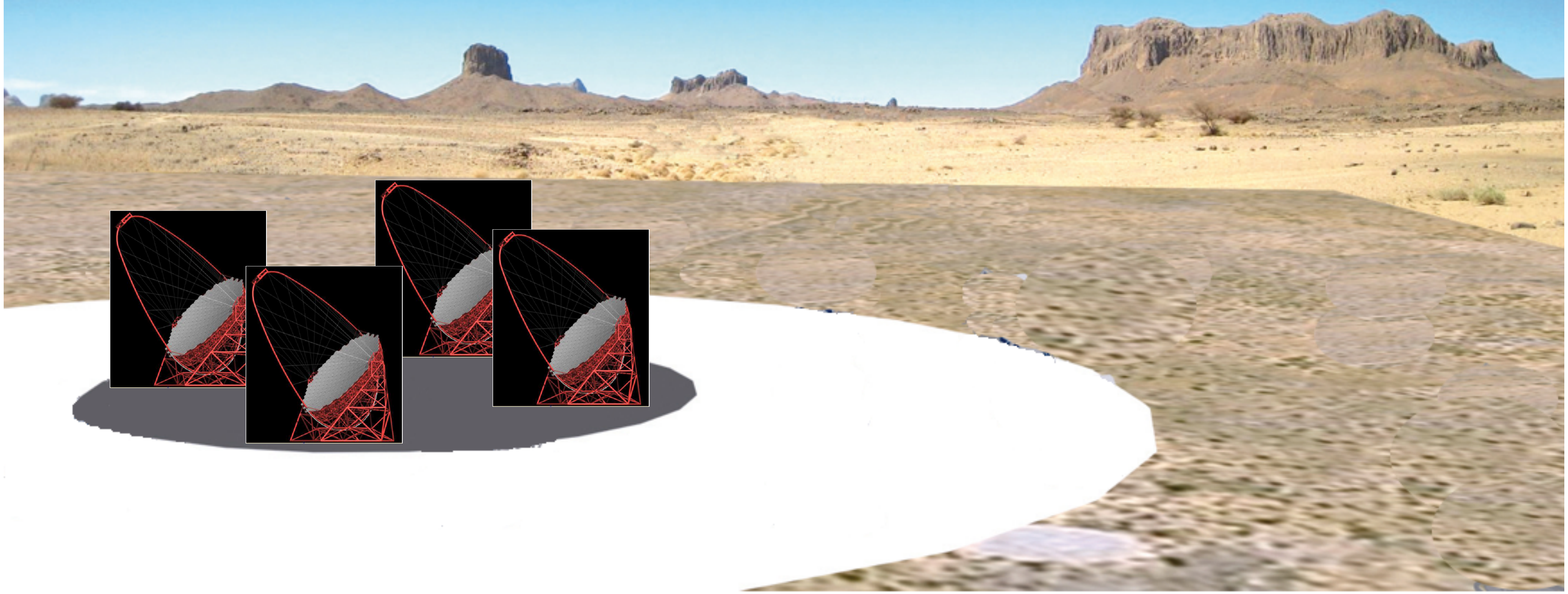


The Cherenkov Telescope Array concept

Medium energy
About twenty 12 m telescopes
~8° FoV
~2000 pixels
~ 0.2°

The Cherenkov Telescope Array concept

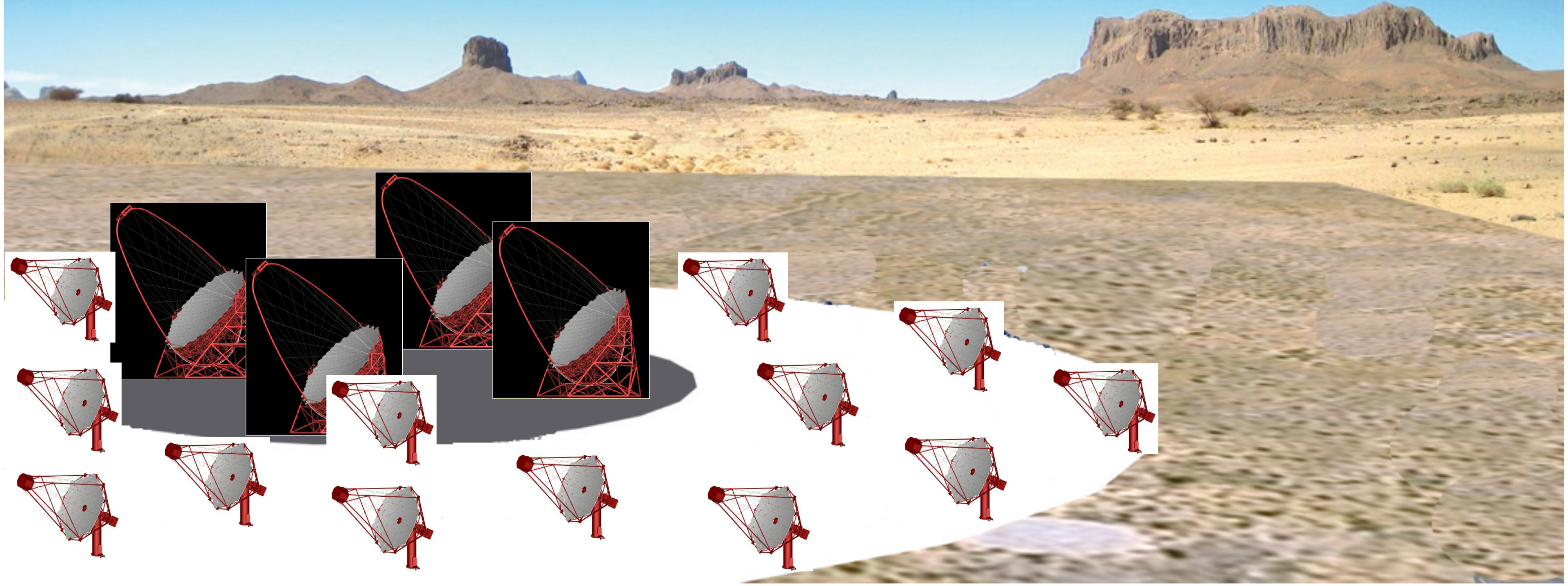
Medium energy

About twenty 12 m telescopes

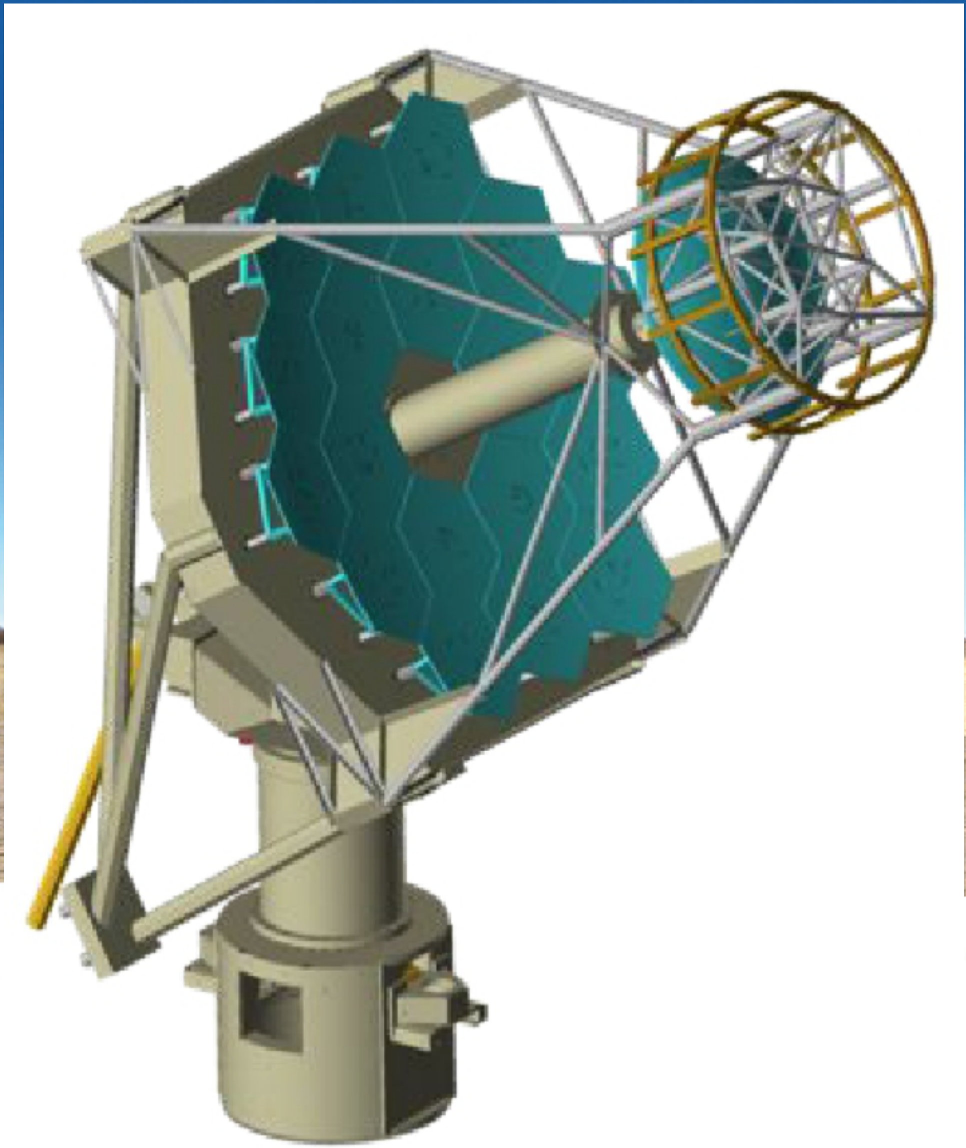
~8° FoV

~2000 pixels

~ 0.2°



The Cherenkov Telescope Array concept



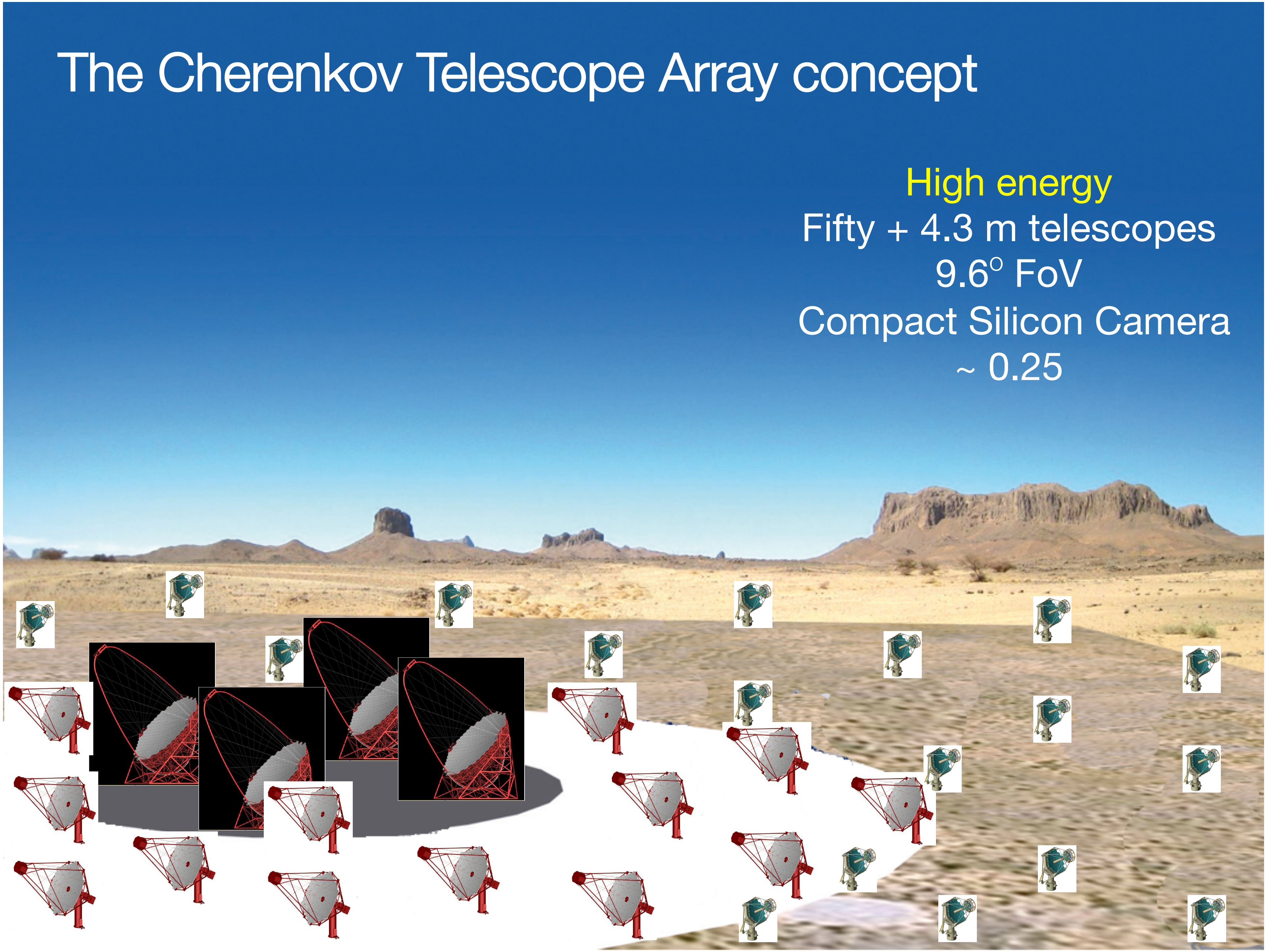
High energy

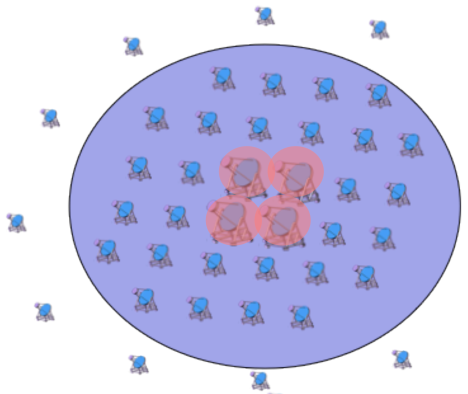
Fifty + 4.3 m telescopes

9.6^{o} FoV

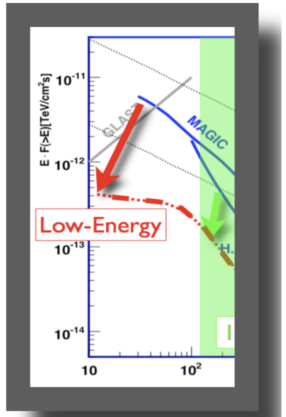
Compact Silicon Camera

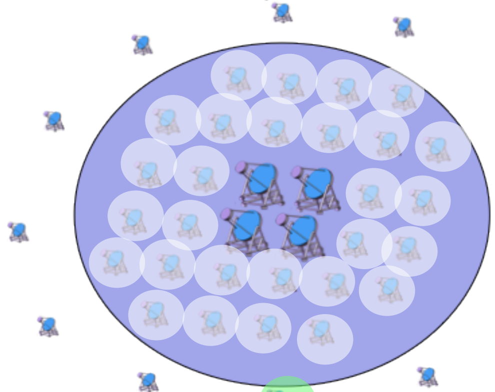
~ 0.25


The Cherenkov Telescope Array concept
High energy
Fifty + 4.3 m telescopes
9.6° FoV
Compact Silicon Camera
~ 0.25

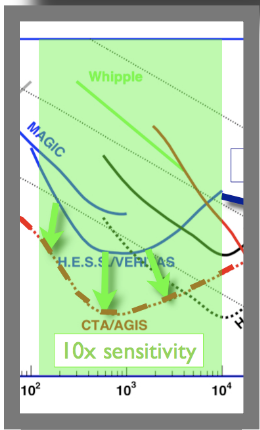


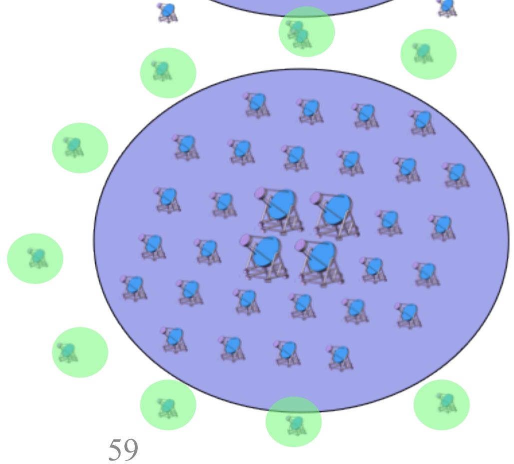
- Few Large Size Telescopes should catch the sub-100 GeV photons
  – Technique imroved from MAGIC
  – Large reflective area
  – Parabolic profiles to maintain time-stamp
  – FOV ~ 4 deg



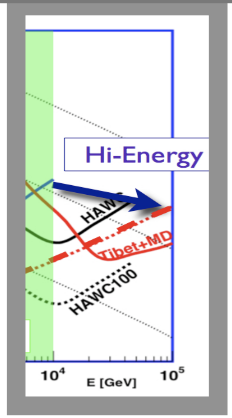


Several Medium Size Telescopes perform 100 GeV-50 TeV search
- well-proven techniques (HESS)
- goal is to reduce costs and maintenance
- core of the array

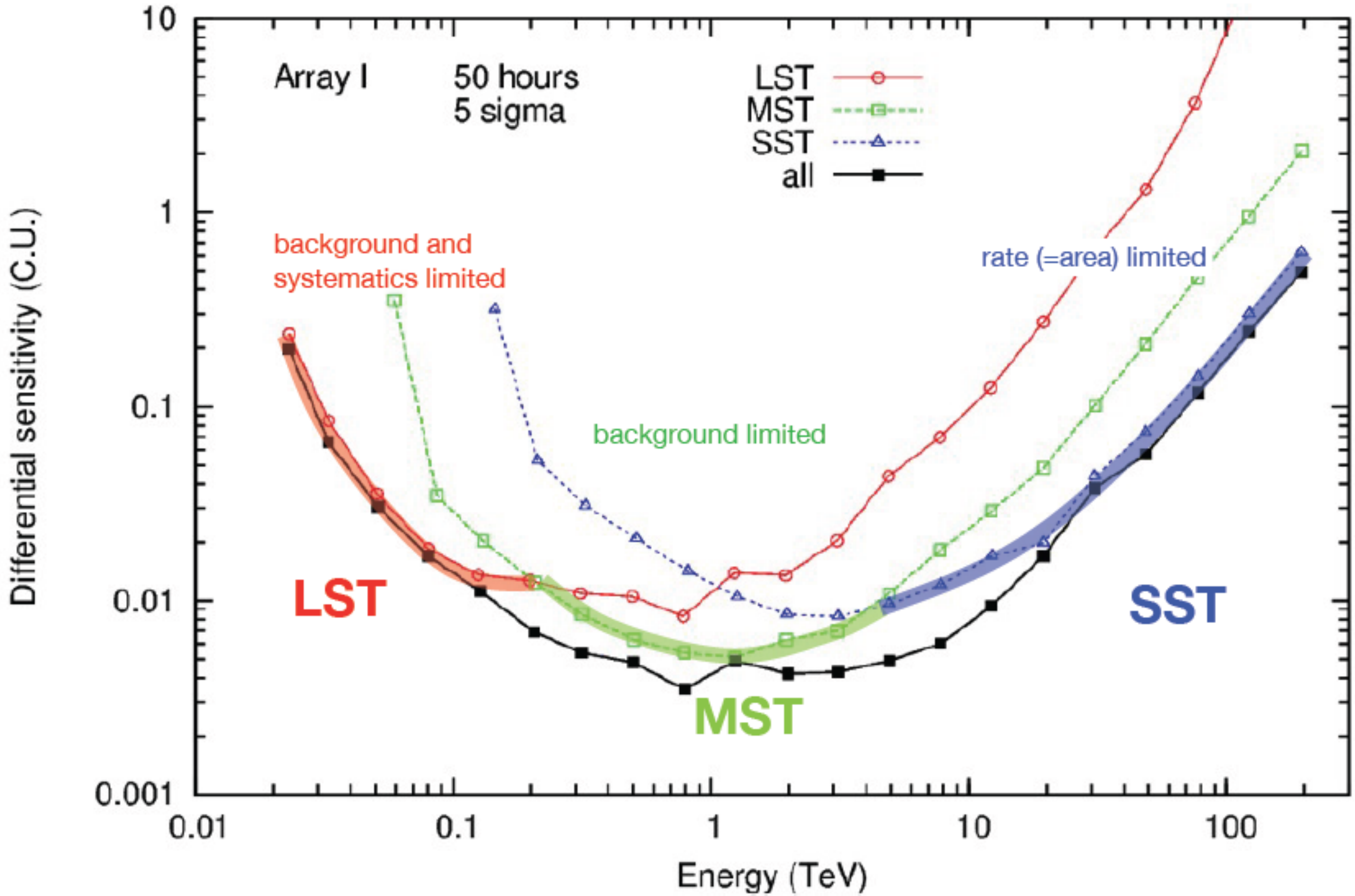




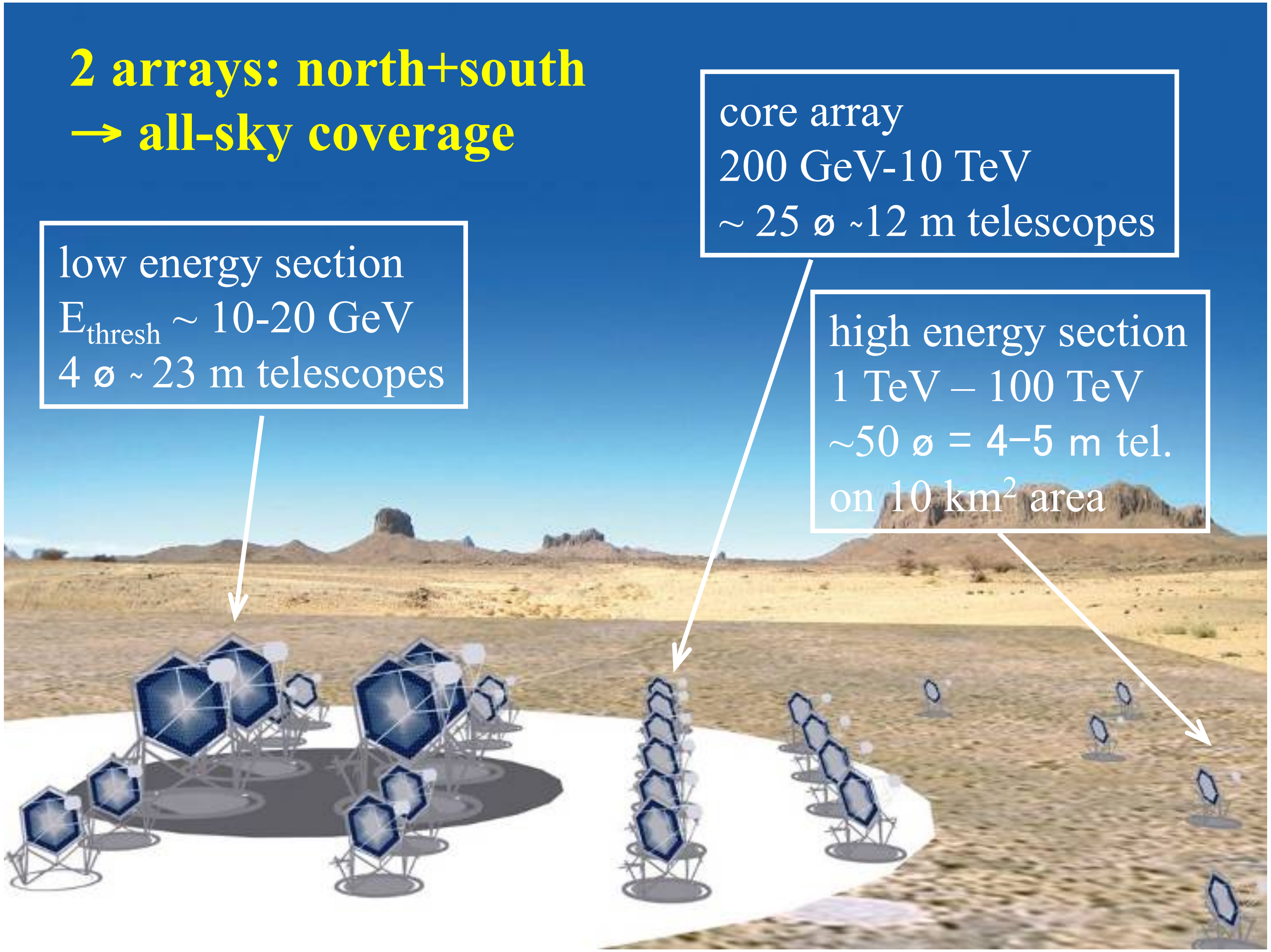
Several Small Size Telescopes perform ultra-50 TeV search
- NEW
- very simple construction
- price should be small compared to full observatory

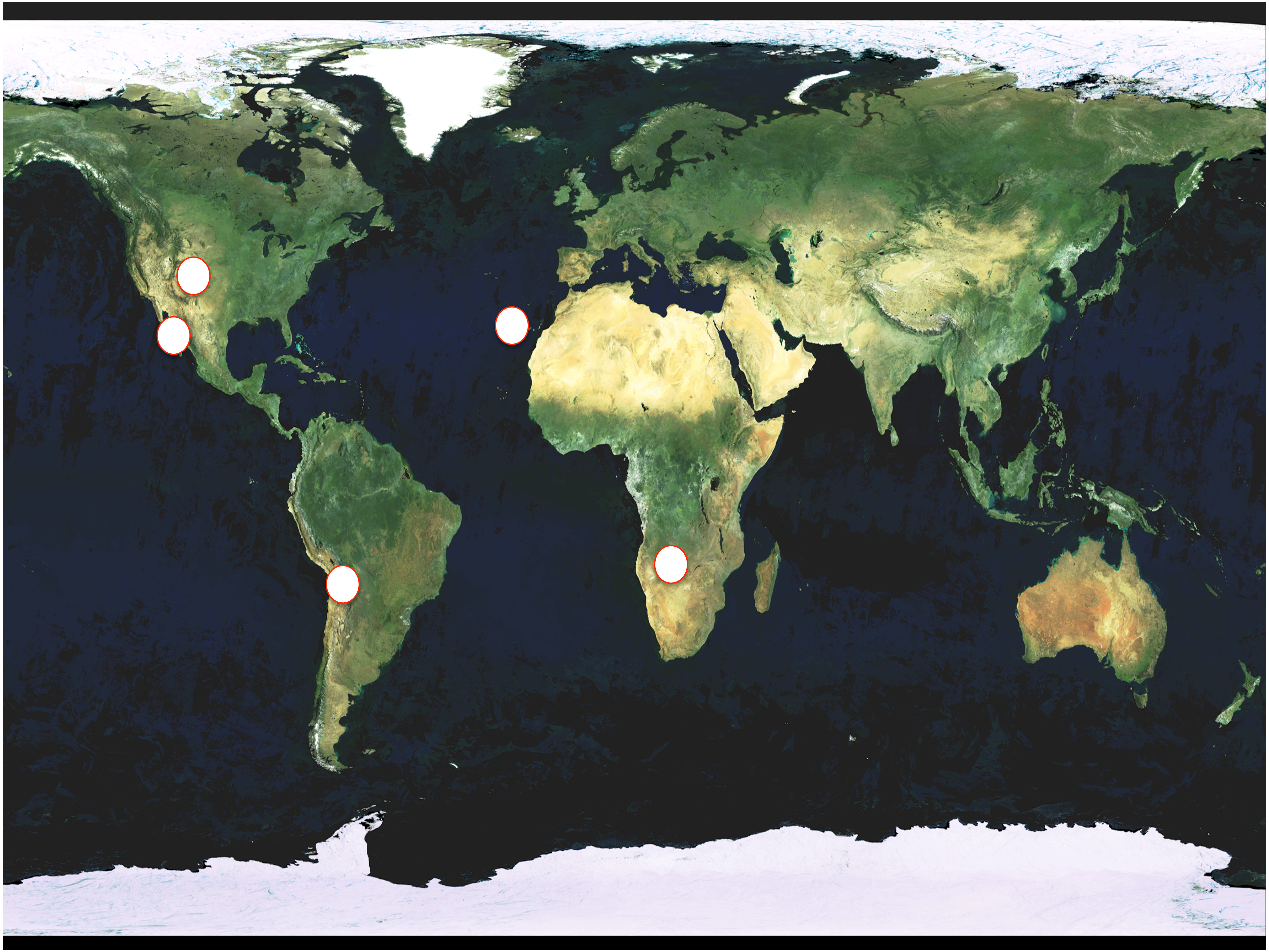


Large/Medium/Small Size Telescopes in CTA

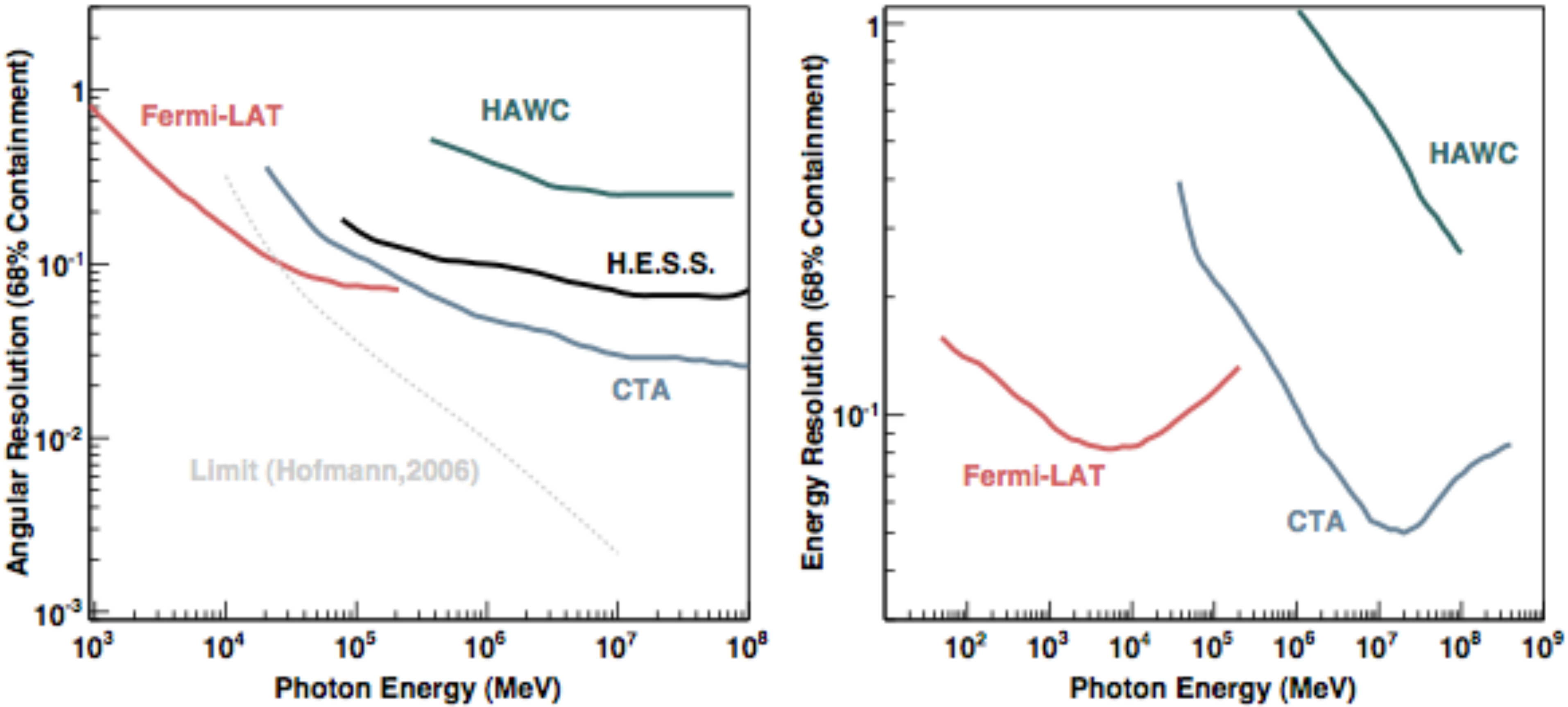


The CTA concept (a possible design)



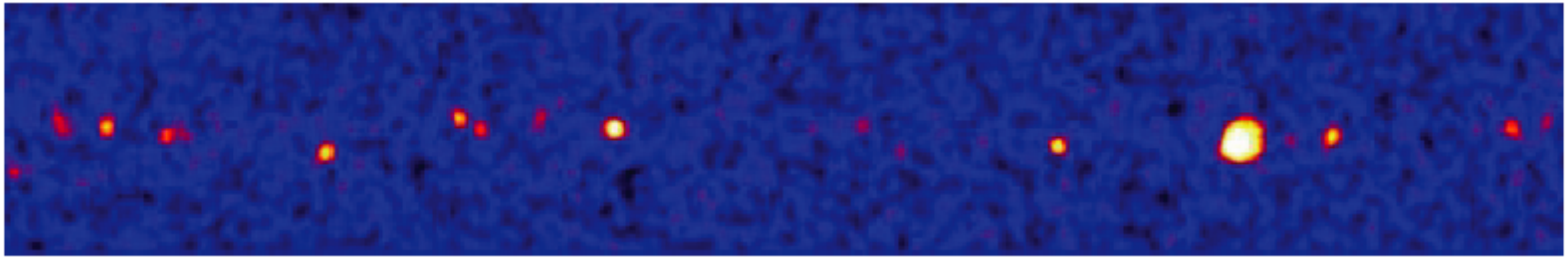


Energy resolution, PSF

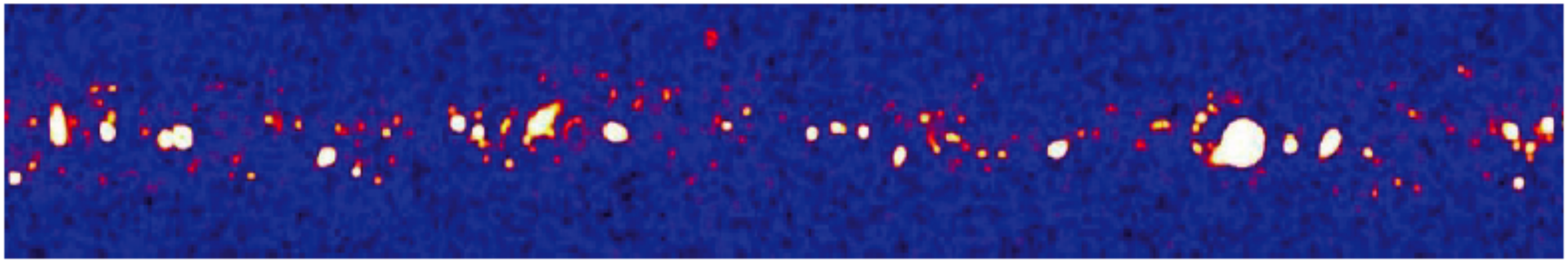


Better PSF & Energy resolution (matching Fermi)
CTA: Expectations for Galactic plane survey

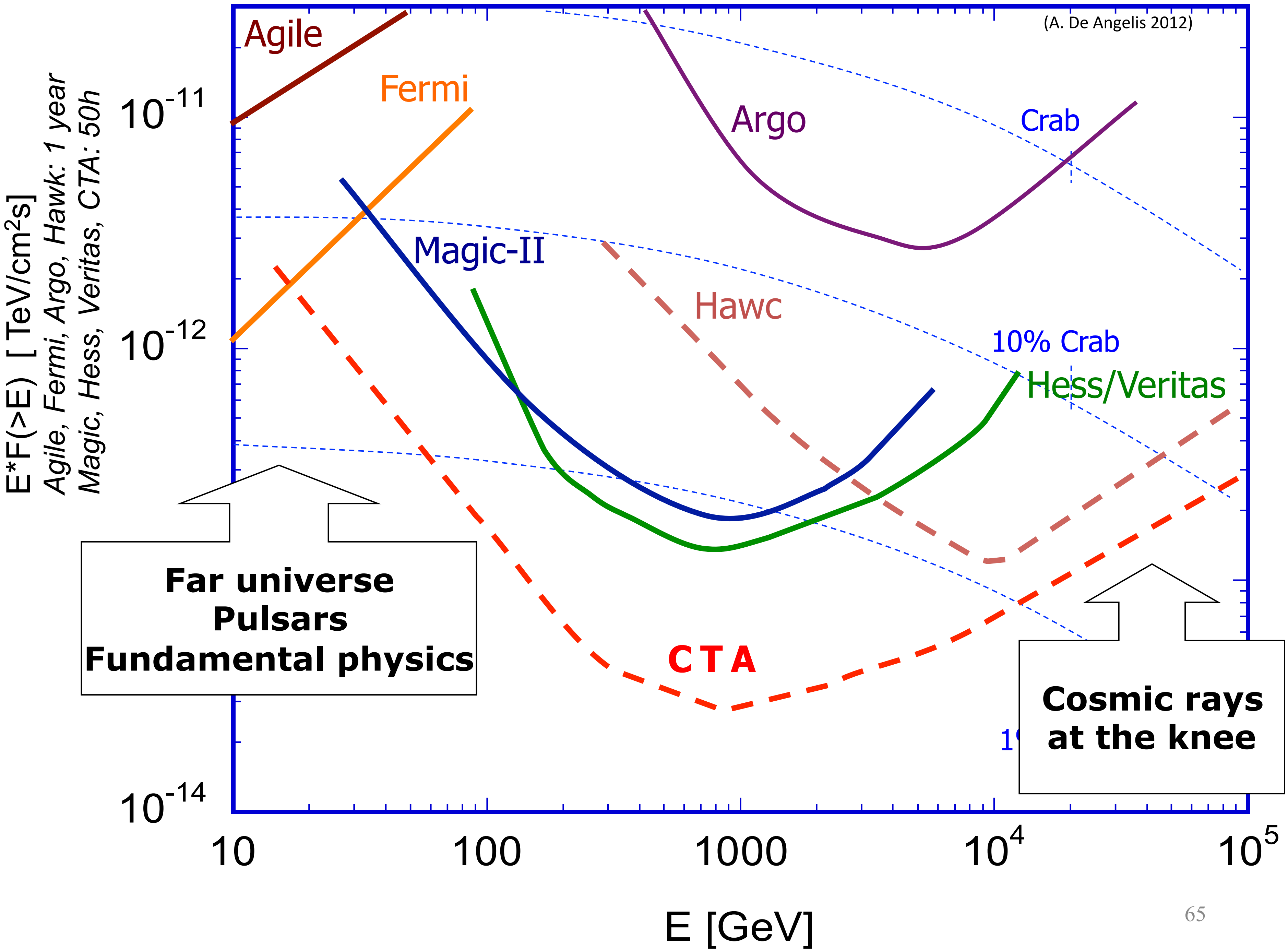
H.E.S.S.



CTA, for same exposure

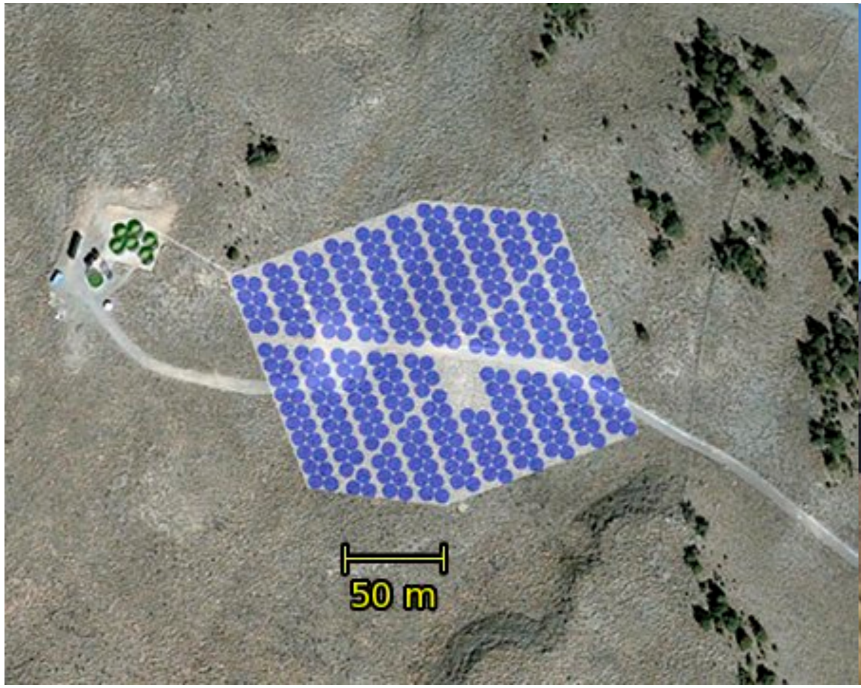


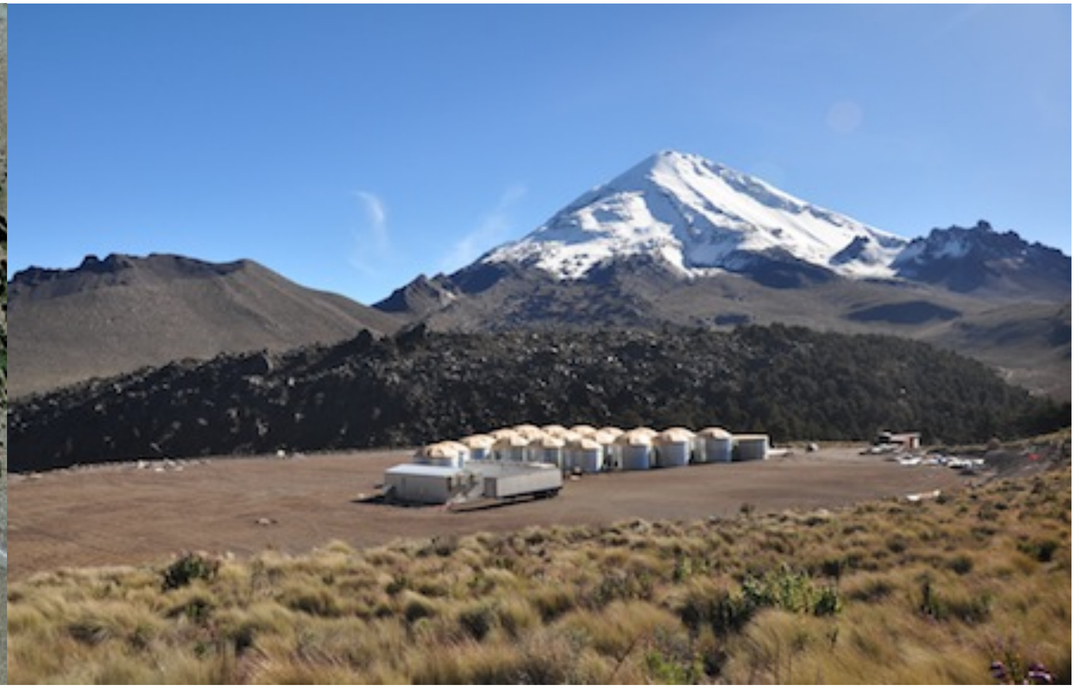
expect ~1000 detected sources


(A. De Angelis 2012)
Agile
Fermi
Argo
Crab
Magic-II
Hawc
10% Crab
Hess/Veritas
CTA
Far universe
Pulsars
Fundamental physics
Cosmic rays
at the knee
E*F(>E) [TeV/cm2s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
10-11
10-12
10-14
10
100
1000
104
105
E [GeV]

HAWC

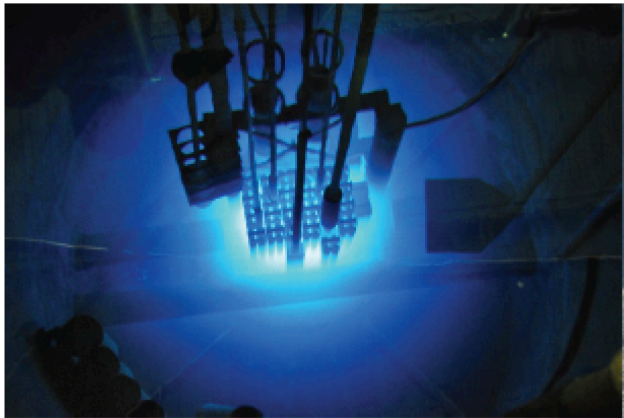
- EAS detectors have advantages on Cherenkov: duty cycle, serendipitous searches
- But the EAS up to now (Argo, Milagro, Tibet) were not sensitive enough
- The High-Altitude Water Cherenkov Observatory, or HAWC, is a facility designed to observe TeV gamma rays and cosmic rays with large FOV, with sensitivity better than 10% Crab in 1 year between 200 GeV and 100 TeV
- HAWC is under construction at 4100 m asl in Mexico



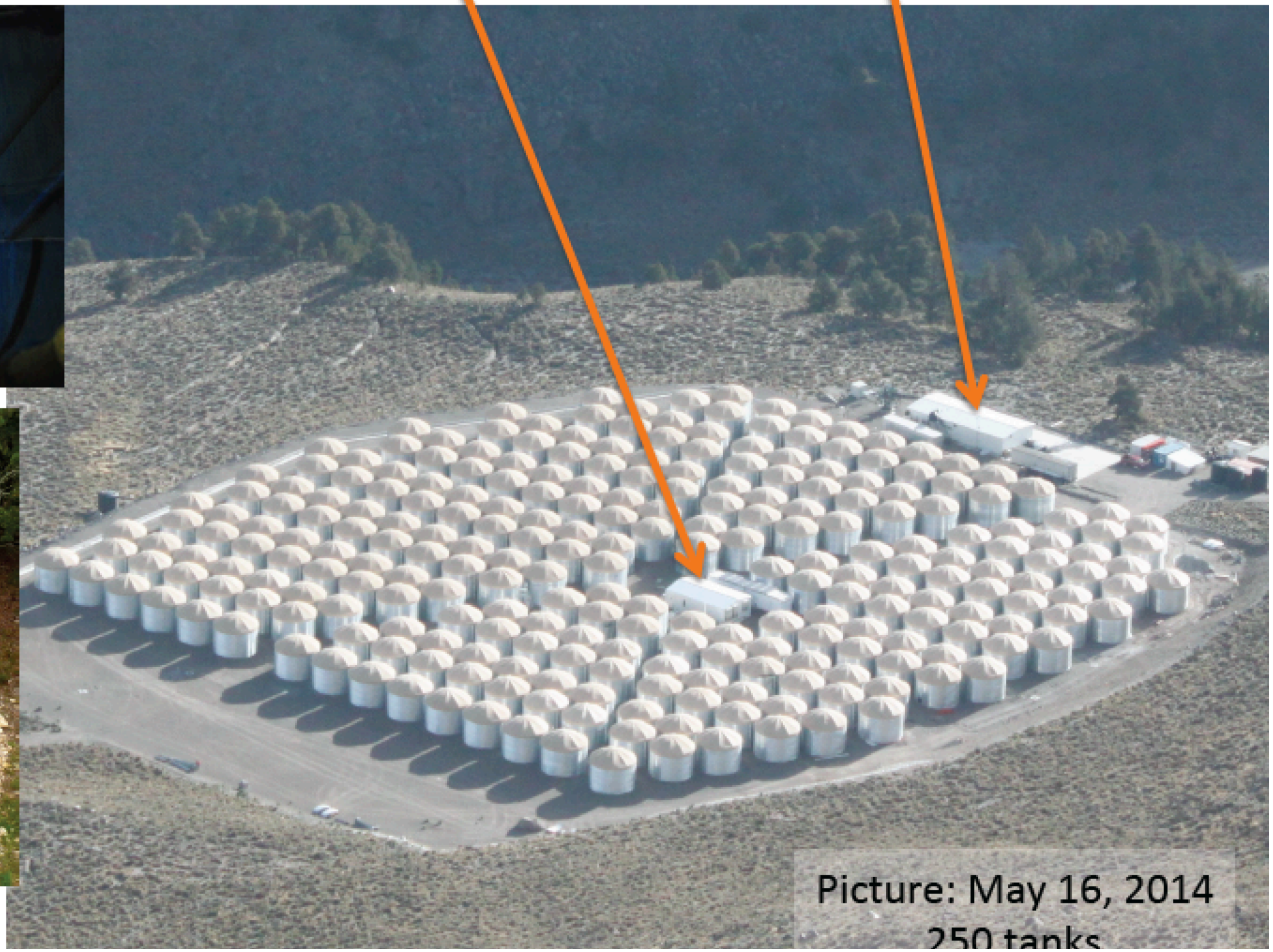


HAWC is almost complete…

HAWC 300 Water Tanks. 7.3 m (diam), 4.5 m deep. 20,000 m^2



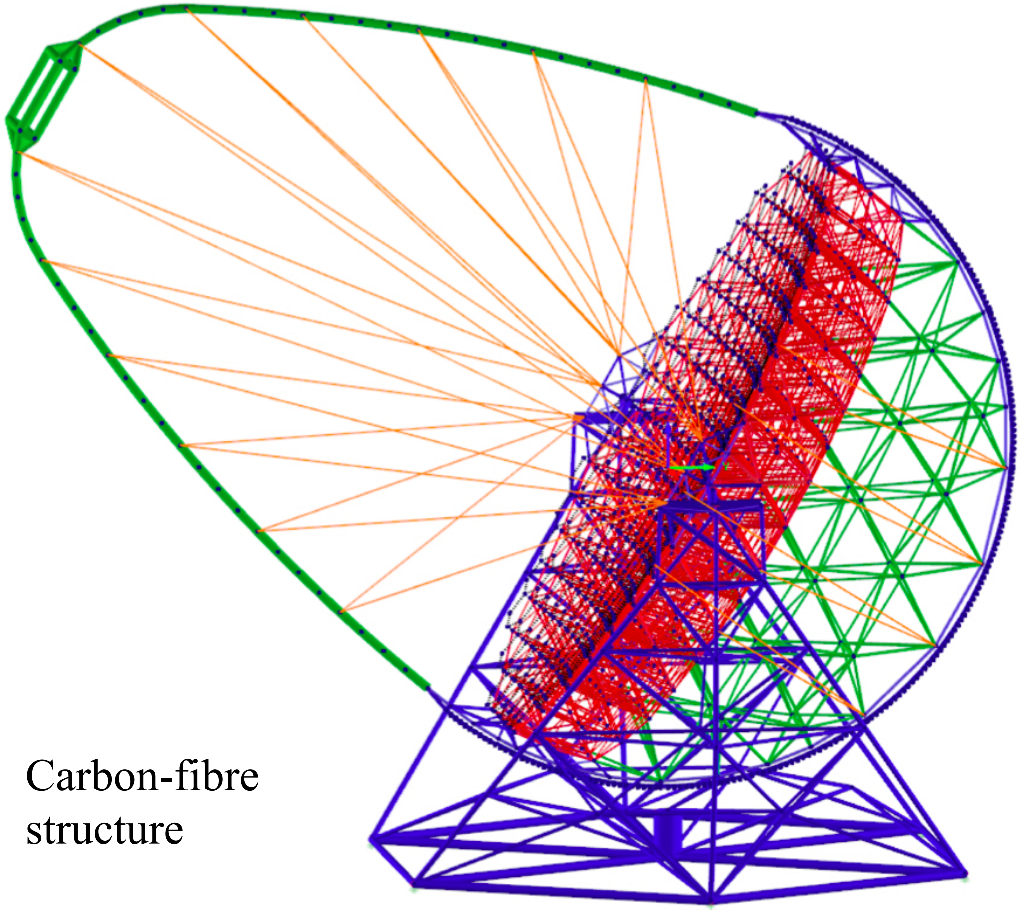
Electronics Bldg. Utility Bldg.



STATUS OF CTA: 23 m LST (precursor in 2016)

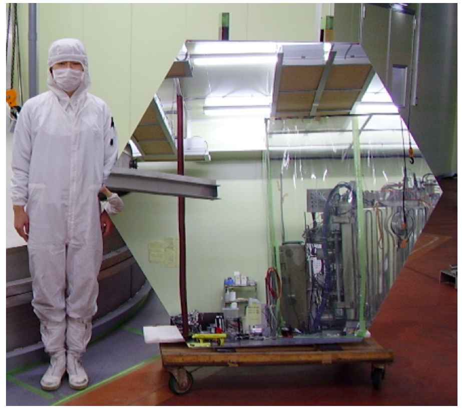
Japan/Germany/Spain/CNRS/INFN

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

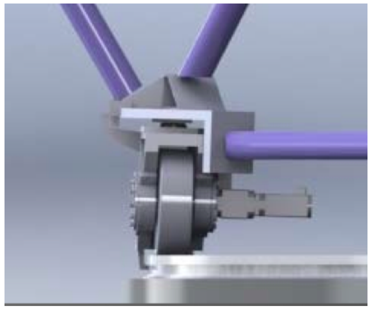


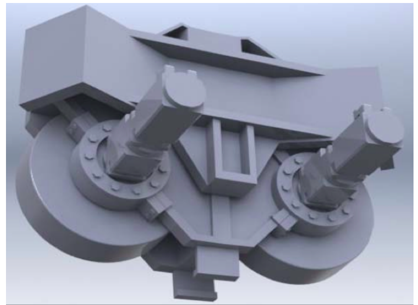
Carbon-fibre
structure

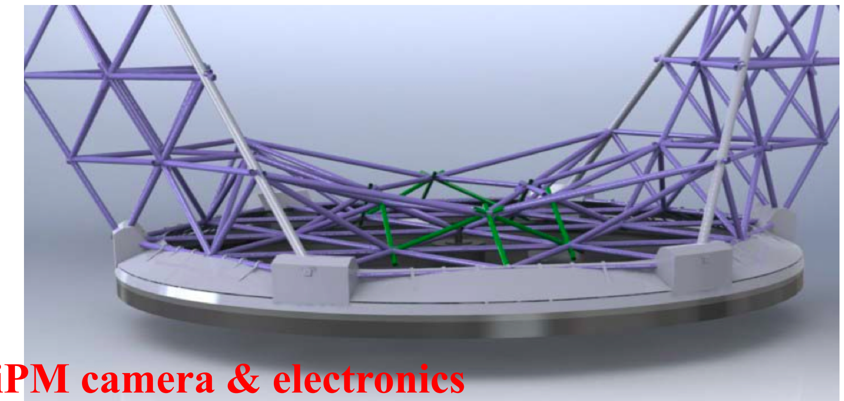
400 m² dish area
1.5 m sandwich
mirror facets



On (GRB) target
in < 20 s

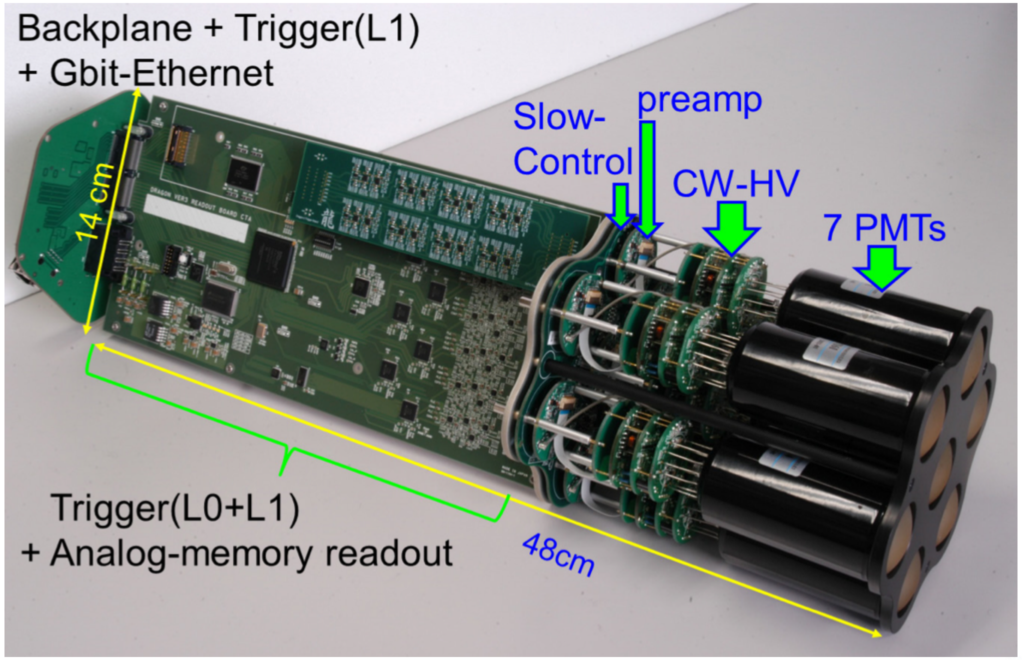






INFN working on electronics and a cluster for a possible SiPM camera & electronics

Imaging Camera with PMTs

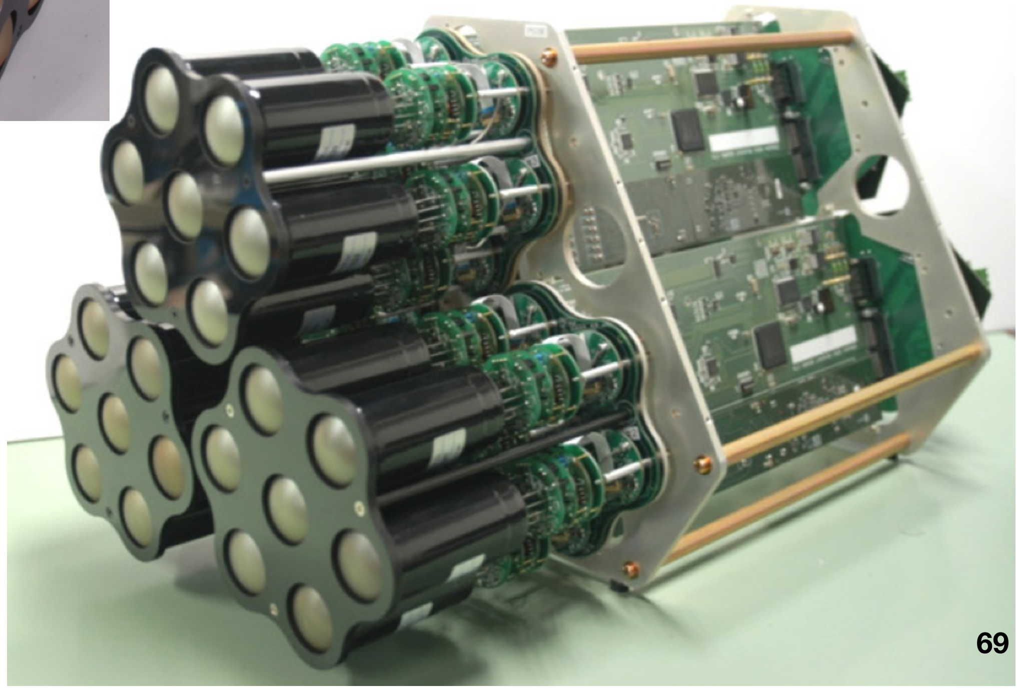


Dragon cluster:

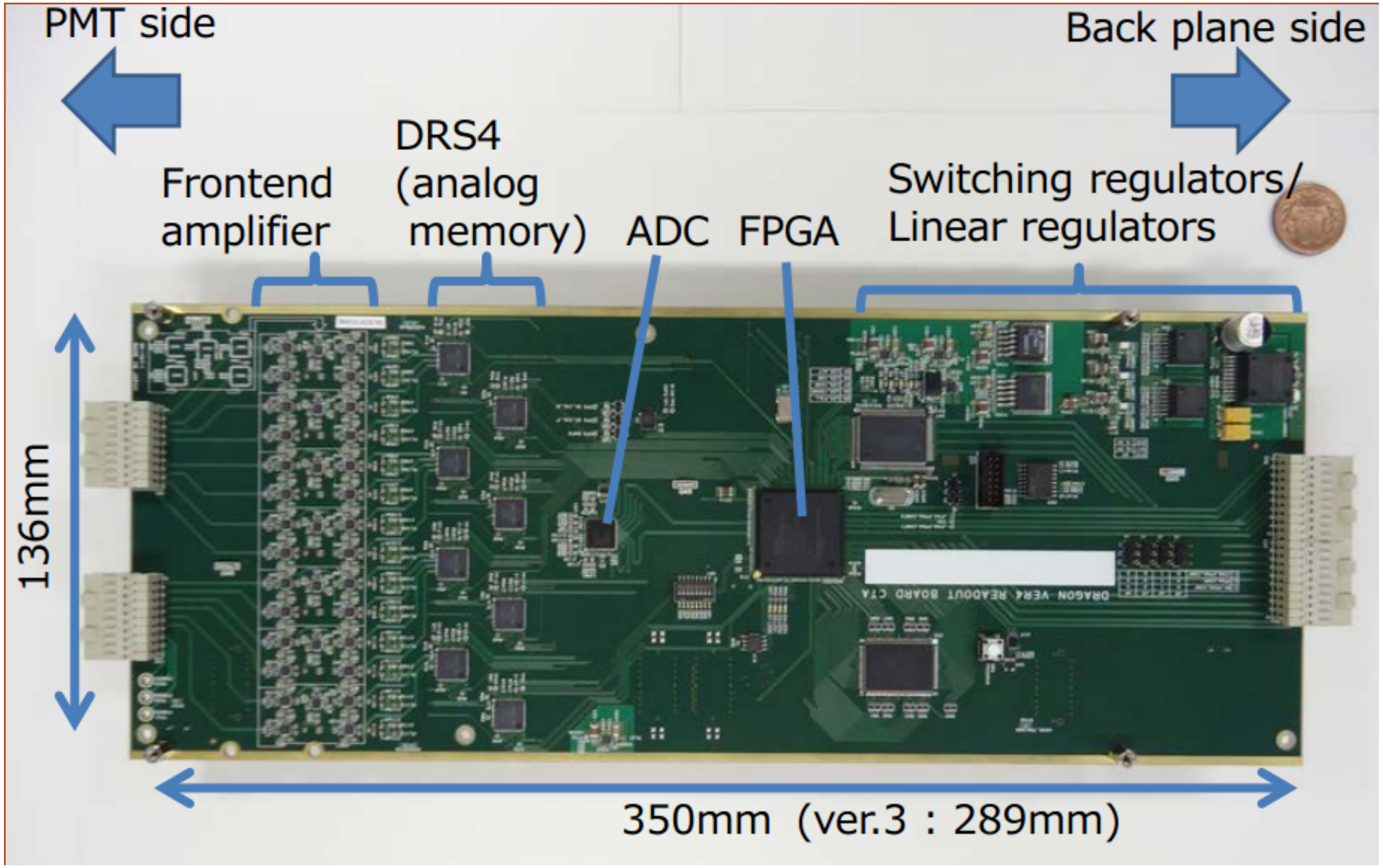
- DRS4 at 1 GHz and 4 µs memory depth
- Hamamatsu PMT R11920-100, superbialkali
- Low noise, low power, low cost preamplifier
- Trigger system in mezzanines
- Backplane

Micro-Camera (3 clusters)

- Extensively tested with good performance
- Dragon v4 (most likely the one for production),

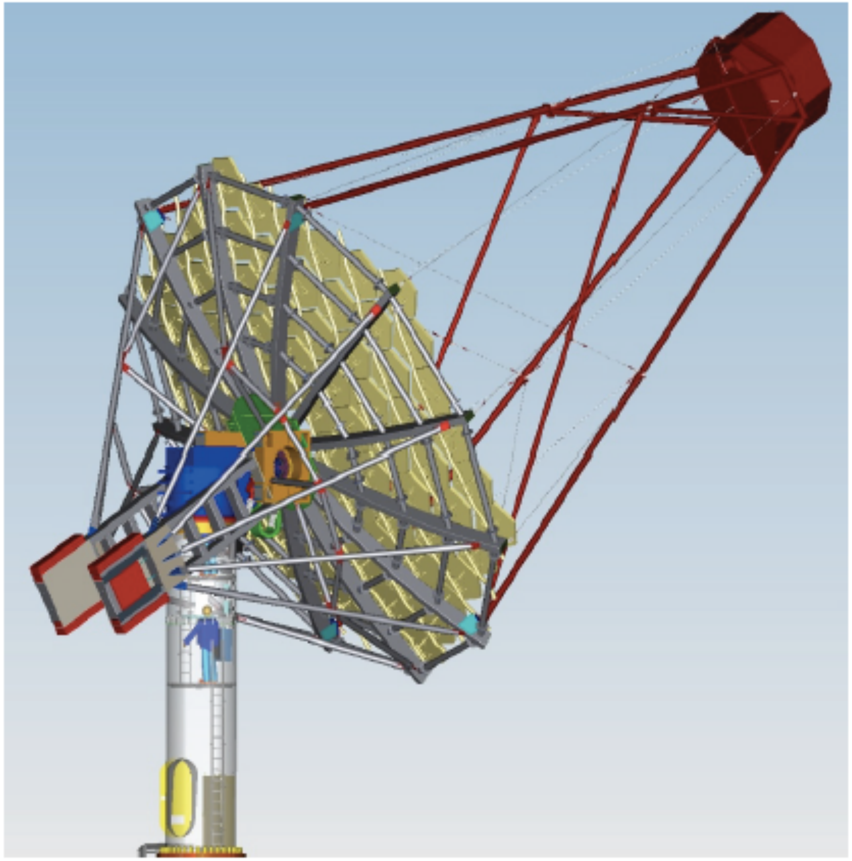


Electronics of the prototype. The contribution from INFN: 50% of the electronics from the PMT to the event formation (Dragon4). Sampling up to 4 GHz



And in addition, INFN is responsible for an “all-Si” camera

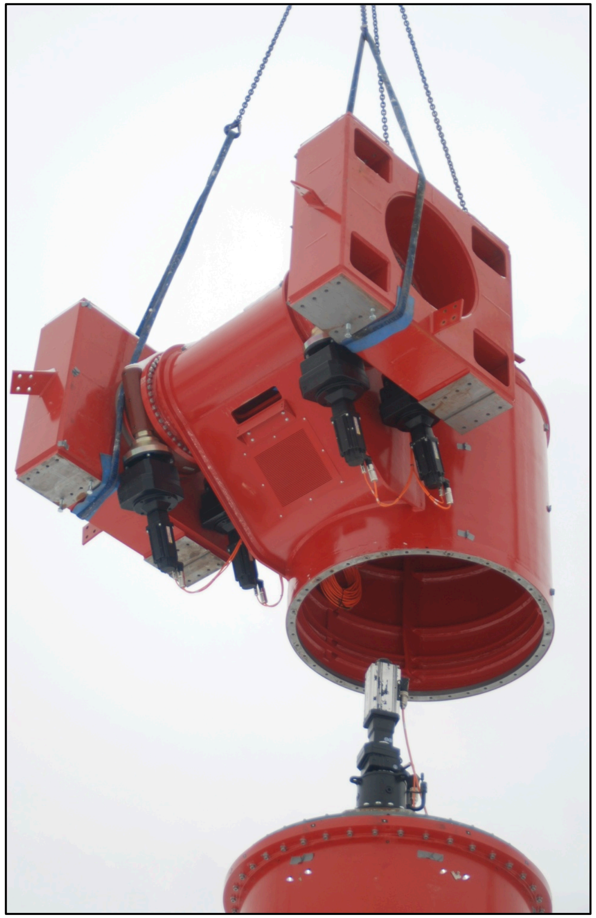
The Medium size telescope



Hot numbers & parameters

- Diameter 12 m
- Focal length ~ 16.2 m.
- (Modified) Davies-Cotton optics.
- Camera support and dish in steel.
- Camera ~ 2 t.
- Central tower cheaper wrt rails
- Designed by ANL-DESY-CEA
- Prototype installed in Berlin by DESY

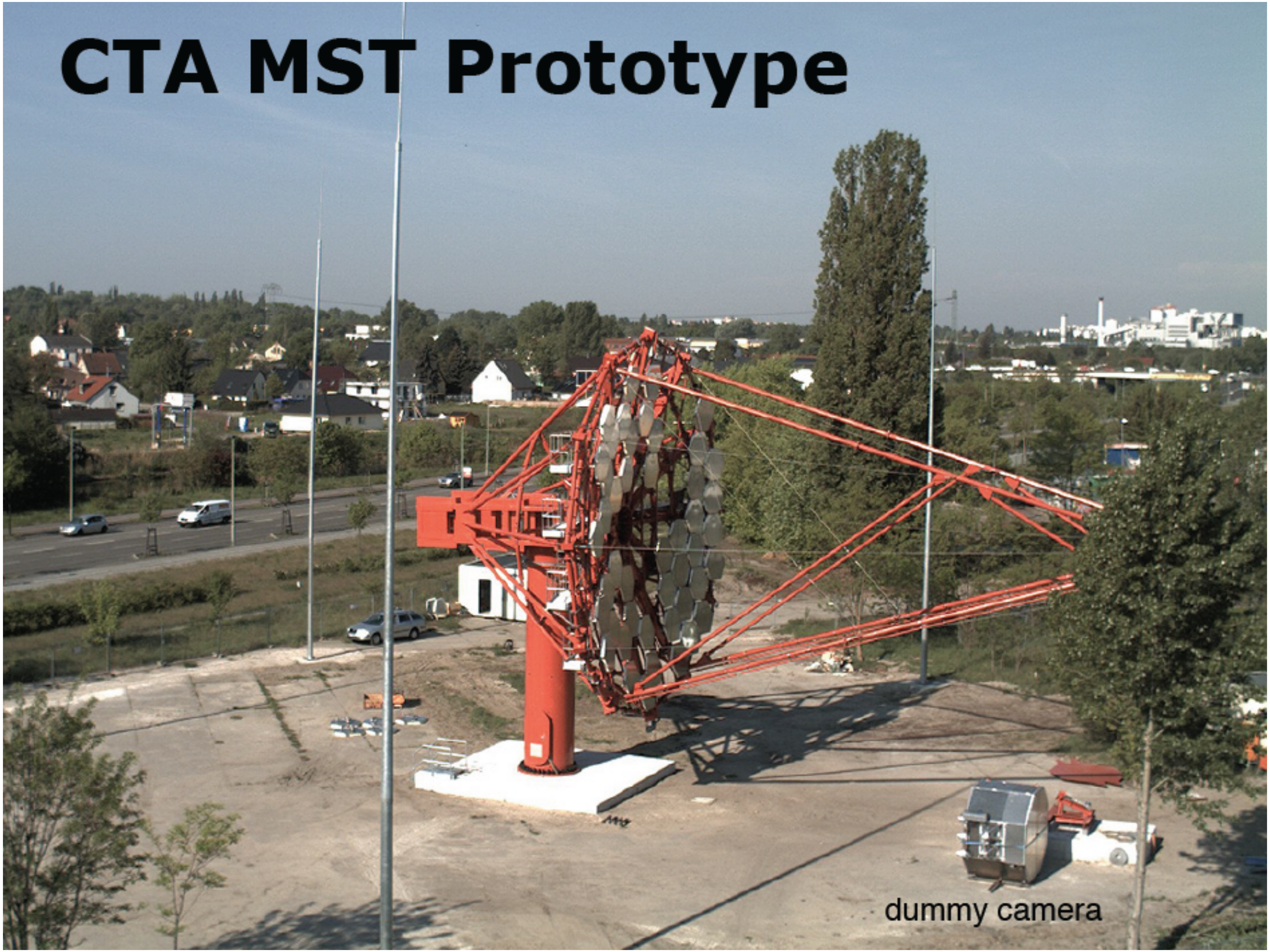
The Medium Size Telescope



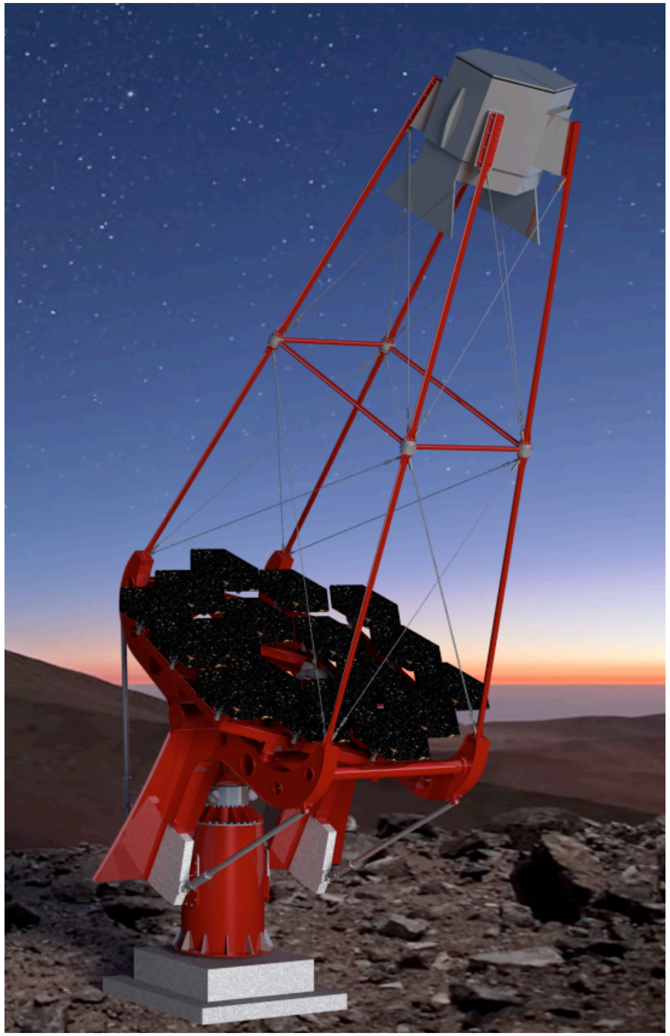
Steel structure made by assembled tubes (bolted joints)
The column hosts the azimuth drives and electric cabinets

The telescope is studied by a consortium of German-French-US Institutes and Universities
<u>Prototyping activities planned/ongoing</u>
PI: Stefan Schlenstedt – DESY

CTA MST Prototype



SST: the 1-Mirror design



This design is similar to a scaled-down MST and uses the same driving system

HOT NUMBERS

Diameter: 4m; f/D = 1.4; f=5.6m
Collecting area: 10 m^2

Active mirror Control
Camera weight: 0.3 ton

Total weight: 10 tons

Grand total of 50-70 telescopes needed

Dual mirror optics for SST

- **Take one, compact camera:**

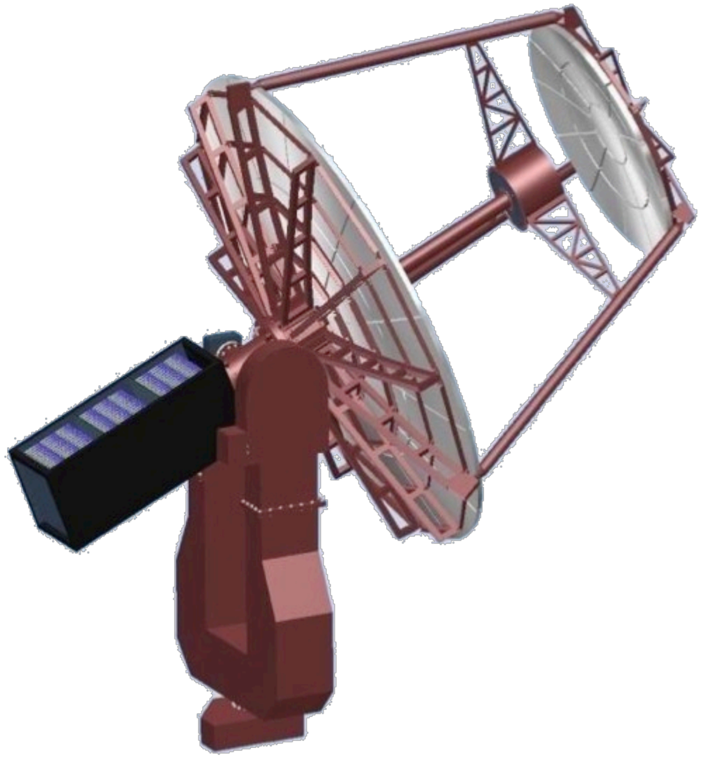
- Affordable commercially available SiPM units have pixel dimensions ~ 6 mm.

- Want angular pixel size of ~ 0.2°.

- Together, these imply Focal Length ~ 2 m.

- Coupled with requirement that Diameter ~ 4 m, gives focal ratio of f ~ 0.5..

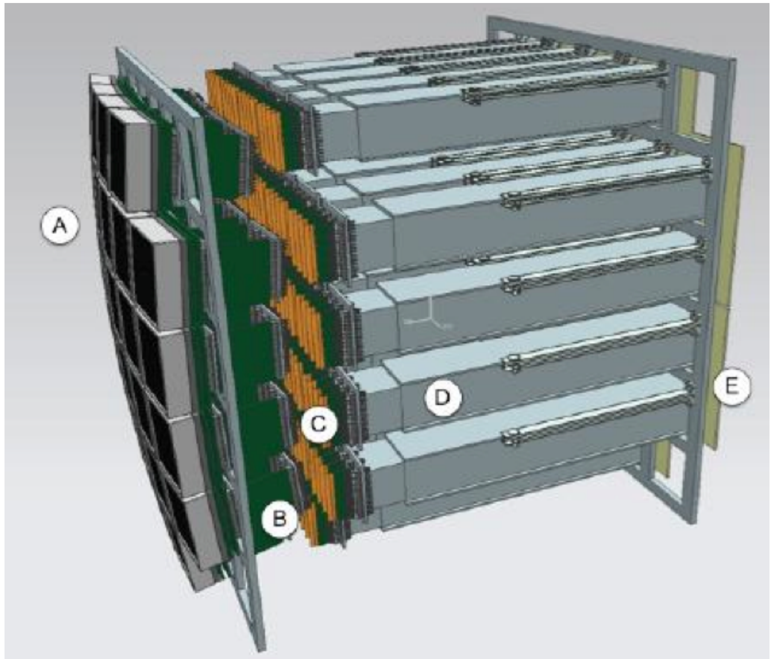
- Must use more sophisticated (Schwarzschild-Couder) optics, as first suggested by Vassiliev, et al., Astroparticle Physics, 2007, 28, 10-27

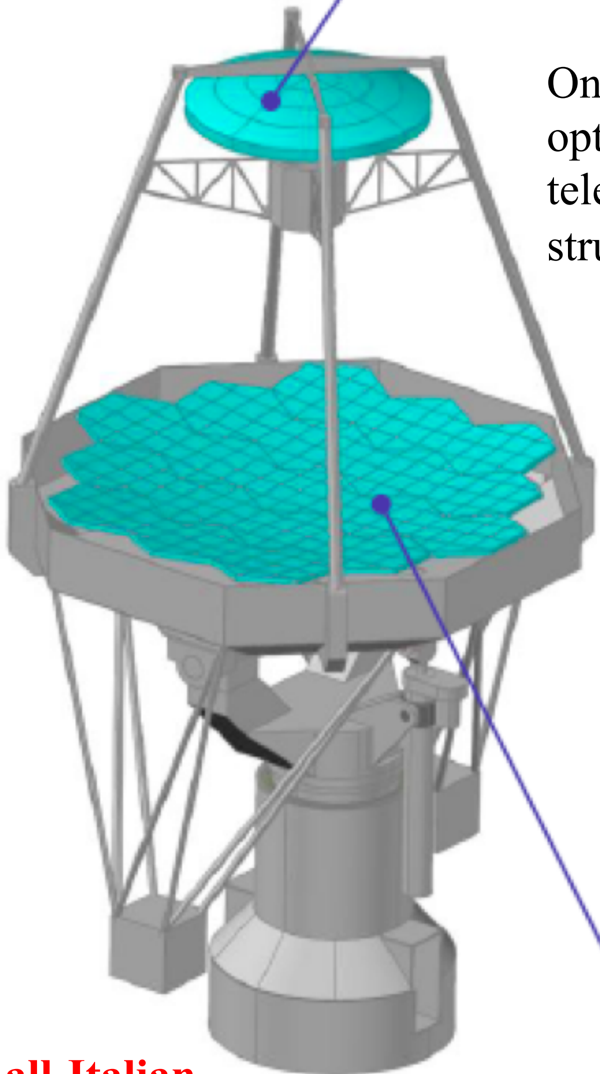


Dual-mirror 4-6 m Telescopes

cover the range above few TeV across 10 km^2

PMT camera option



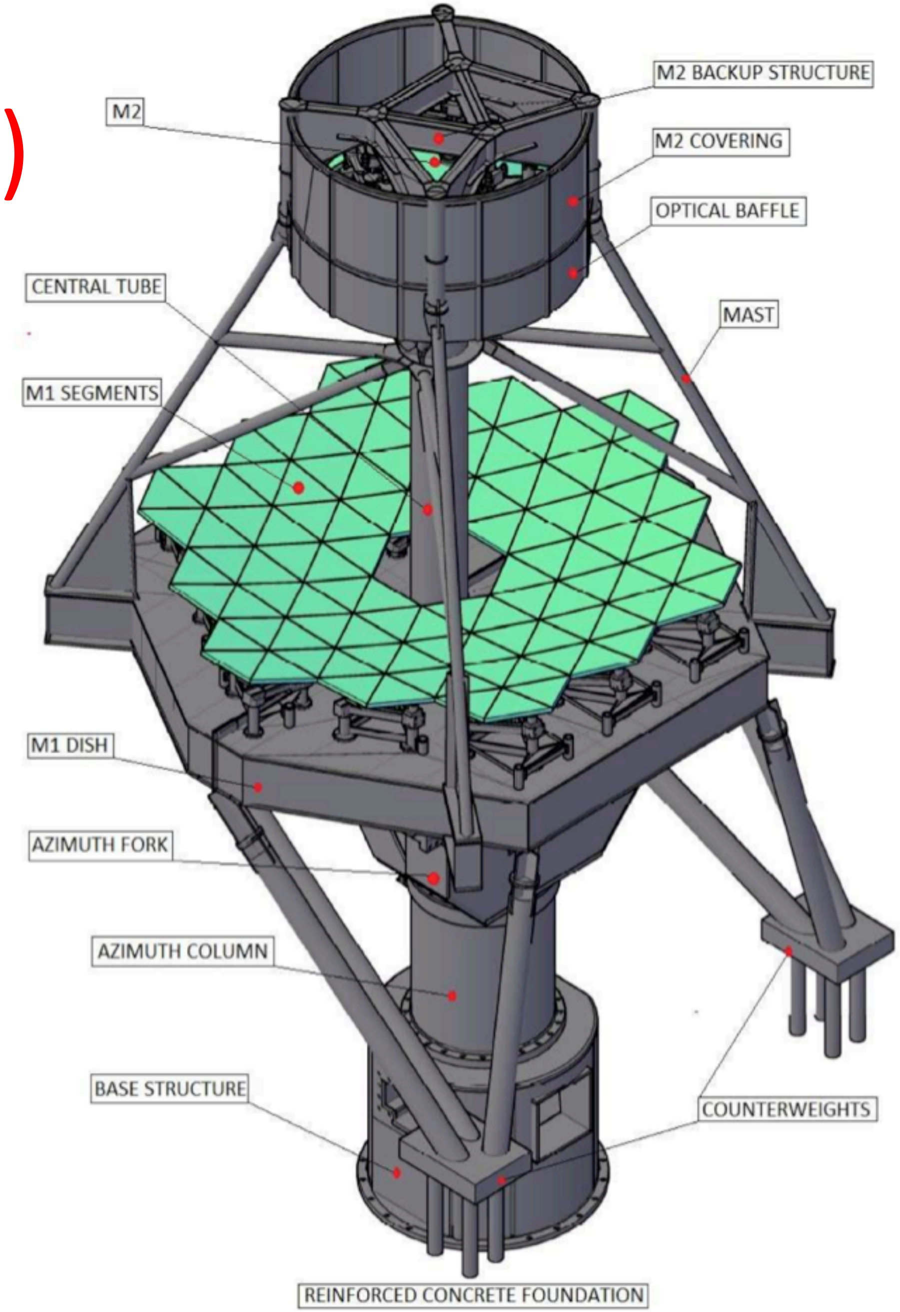


Under study:
dual-mirror optics with compact photo sensor arrays
Si-based sensors
➜ Not yet conclusive which solution is most cost-effective

INAF prototype (ASTRI) ready soon, INFN working on all-Italian camera & electronics

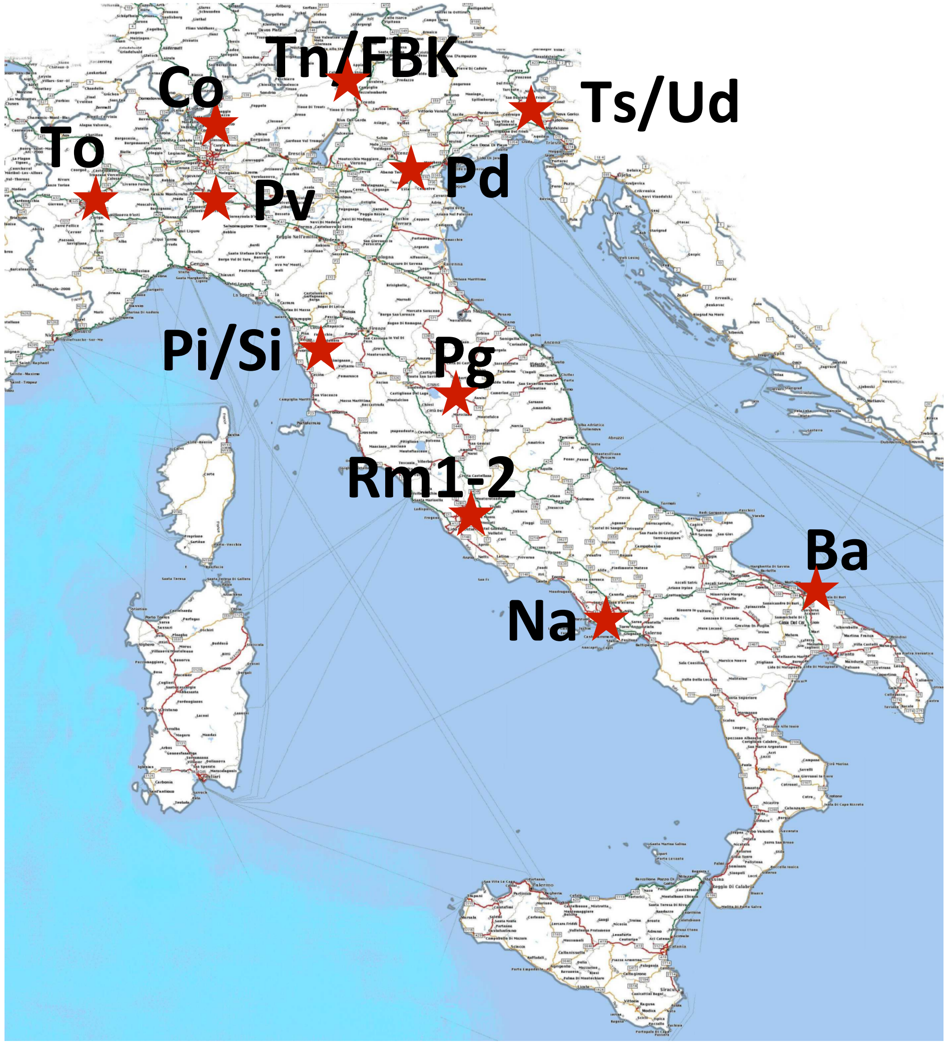
A demonstrator: the ASTRI telescope (INAF) Prototype in 2015

- Camera diam. D_C = 36 cm, FoV = 9.6°
- Mechanics ready in September; prototype under Mount Etna
- Full prototype in 2015



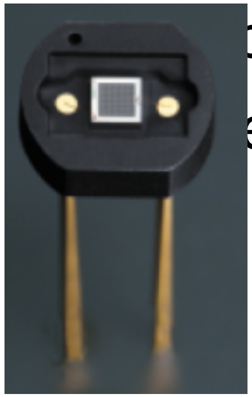
The INFN participation to CTA

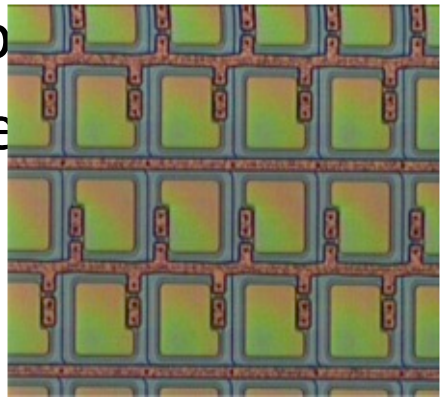
- 3 INFN groups (Pd, Si, Ud) already in CTA since 2008, via national University funding
- ~40 INFN scientists working to INFN CTA-RD since September 2012
  - Seevogh meeti gs every 2nd week, a few physical meetings (Roma, Mestre, …)
- January 2013: proposal of a "premiale" INAF + INFN; SiPM (industrial partnership with FBK) + electronics (CAEN, SITAEL); approved in September 2013, money coming now
  - ~1.3 MEUR for INFN: 2/3 for SiPM, 1/3 electronics
  - Sensor ~ few mm for the SST camera (~2000 for a 40 cm detector), where granularity could be the issue
  - 1" for LST, where sensitivity might be the issue
  - Camera for SST; cluster of 7 photosensors for LST
- Prototypes for a new mirror technology
- Atmospheric monitoring
- Simulation & science; computing



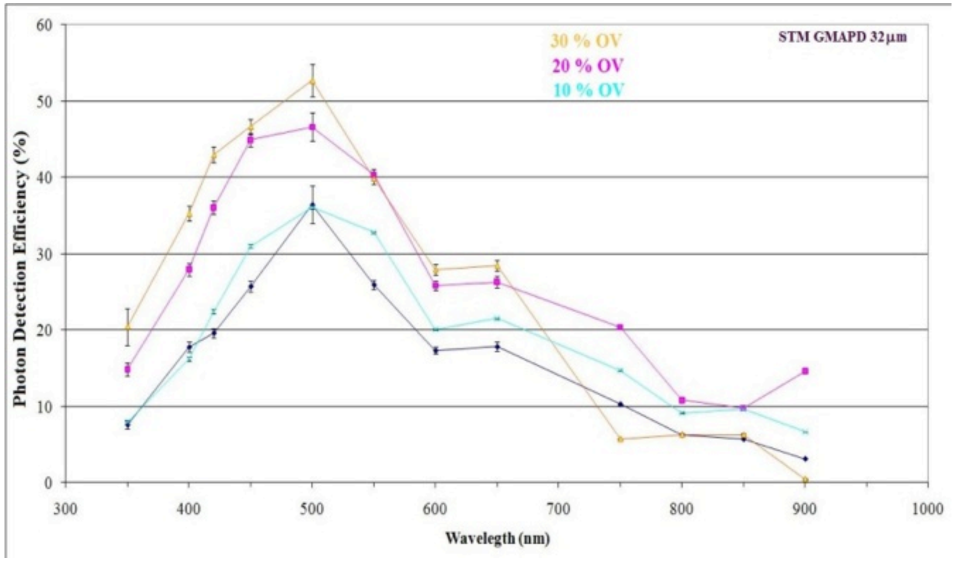
Advanced sensors – Si PMs

- Silicon photomultipliers, reverse biased p-n junction.
- Photon liberates initial e-h pair.
- High bias voltage leads to "shower" of electrons and holes and significant





- Can have good QE...



- Recently, NUV technology
- Hamamatsu produced SiPM with QE > 25% in the Cherenkov range

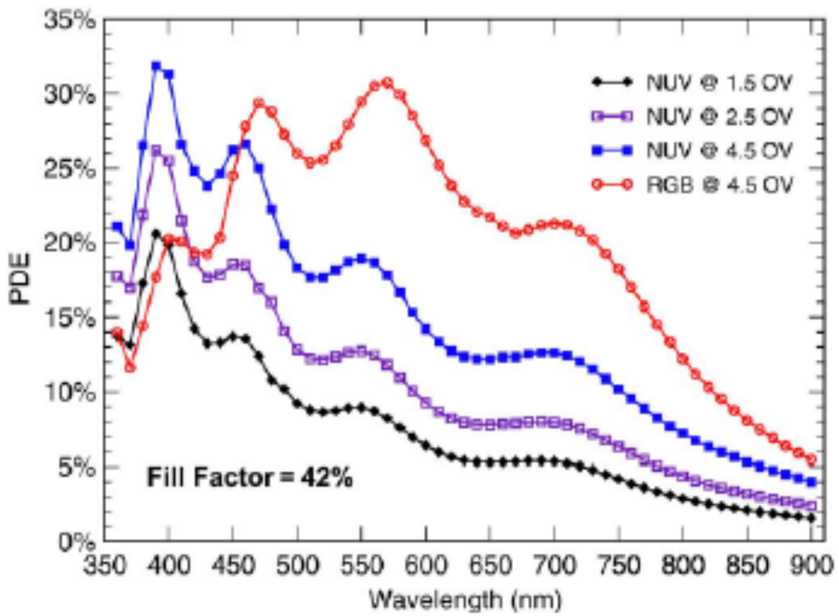
Work on SiPM

- General plan: can we offer a national product competitive with Hamamatsu?
  - Possibility to build a camera for SST (all-Italian SST?)
  - Possibility to build a cluster (7 photodetectors+ electronics) for LST
- SiPM from FBK (our research partner):
  - First batches of standard NUV (fill factor 42%) tested in Bari, Padova, …
  - First batches of high fill factor (>~60%) 40 um NUV to be delivered before January 2014 and immediately tested
  - NUV HD 25 um (fill factor >~70%) to be delivered end March 2014 (1x1, 4x4 mm2)

  Interaction with FBK very satisfactory
- Involves exchanges between labs

- Progetto premiale 2012: 1.3 MEUR assigned (money arriving now)

- 2produzioni di SiPM sviluppate con FBK in MEMS; 2 sono in corso con i nuovi wafer da 6”
- PDE: i 3x3 di FBK e Hamamatsu sono confrontabili allo stato attuale
- Anche il Dark Rate, ormai sui livelli di qualche centinaio di kHz/mm^2 , non vede grandi differenze tra prodotti ottenuti in diverse fonderie (NSB: 10 fotoni/mm2/ns full moon)
- Entro fine 2014 FBK potrebbe produrre una nuova generazione di SiPM definiti High Density (HD): il sensore HD prevede un nuovo disegno delle microcelle delle dimensioni di 30 µm x 30 µm => PDE dell’ordine del 50% nel range UV, prestazioni superiori ai SiPM tradizionali. Se i test sono positivi, per luglio potremmo ordinare una produzione di 3x3 pronti per l’uso su SST



(C. Piemonte et al., FBK)

R&D Activities on Electronics

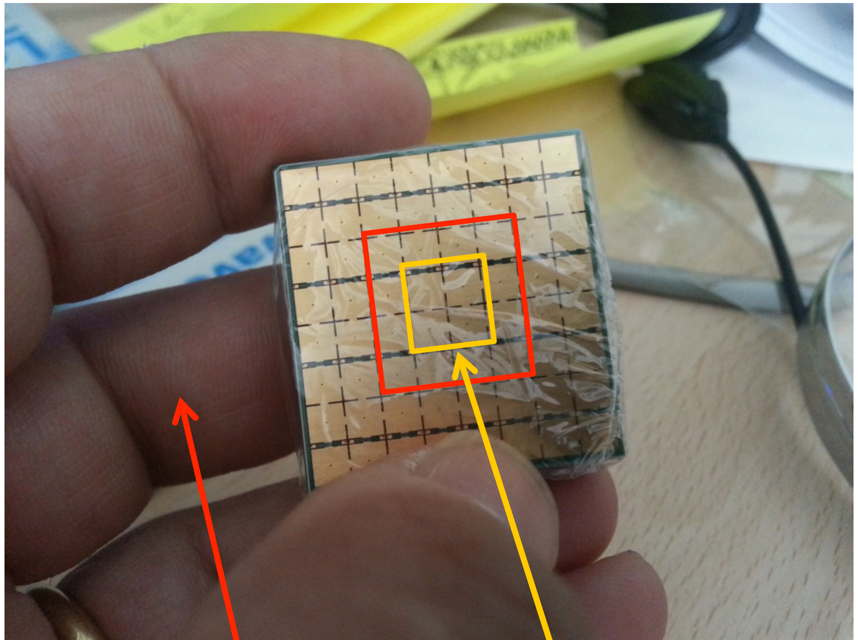
- SiPM interface for LST and SST
  - Holder board for sensor matrix (bonding PG)
    - 64 NUV sensors 3x3mm^2 for LST cluster (PD/PI)
    - 16 NUV sensors 3x3mm^2 for SST camera demonstrator (BA/NA/PI)
    - Single sensor for characterization with readout chain (BA/UD/ROMA1)
  - Amplifier tests
    - SUM circuit with discrete components (PD/PI)
    - Preamplifier circuit for SST demonstrator, BW measurements (BA/NA)
- High voltage power supply for SiPM
  - LST cluster (PD)
  - SST camera (NA)
- Tests on different digitization chips
  - EASIROC sample-and-hold system, external ADC (BA/NA/PI)
    - Test board built, used for SiPM characterization
  - TARGET7 waveform digitizer, embedded ADC (BA/NA/PI)
    - Working on evaluation board by SLAC
    - Planned development of modular readout electronics for camera demonstrator

- STATUS NOW:
  - DRS4 electronics for LST developed, production starting
  - Prototype DSR4 electronics for SST developed, in production
  - TARGET7 electronics for SST in development

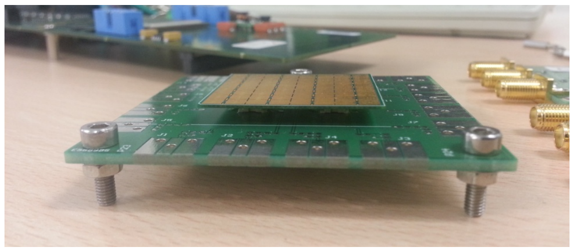
SiPM Holder PCB

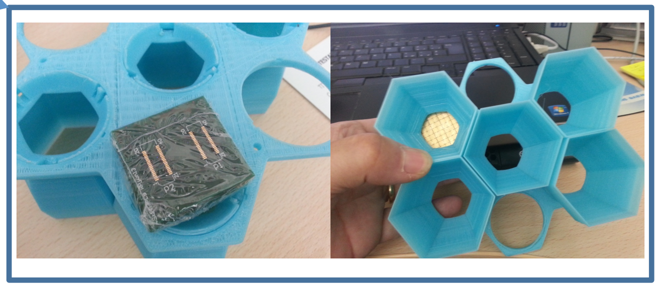
- Produced 10 PCBs to hold a matrix of 64 (8x8) SiPM 3mm x 3mm
- 5 PCB sent to PG for NUV sensor bonding
- To be used for
  - LST cluster study (sum circuit of 16 or 64)
  - SST camera demonstrator
  - Characterization studies
- Can be interfaced to
  - SUM circuit for LST
  - Preamplifier test
  - Readout board
- Light concentrators

  For SST (full?) (RM1, TO)



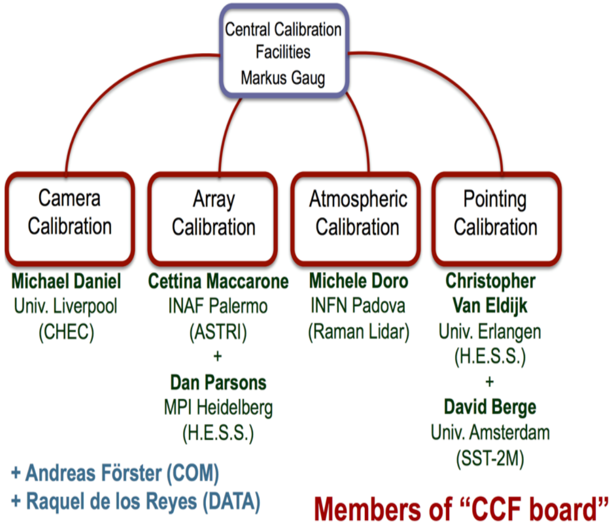
e.g. 50 NUVs = 2 x 16 + 2 x 4 + 10 single





Calibrazione atmosferica

Implementation Strategy Document:



COM-CCF-ATMO.

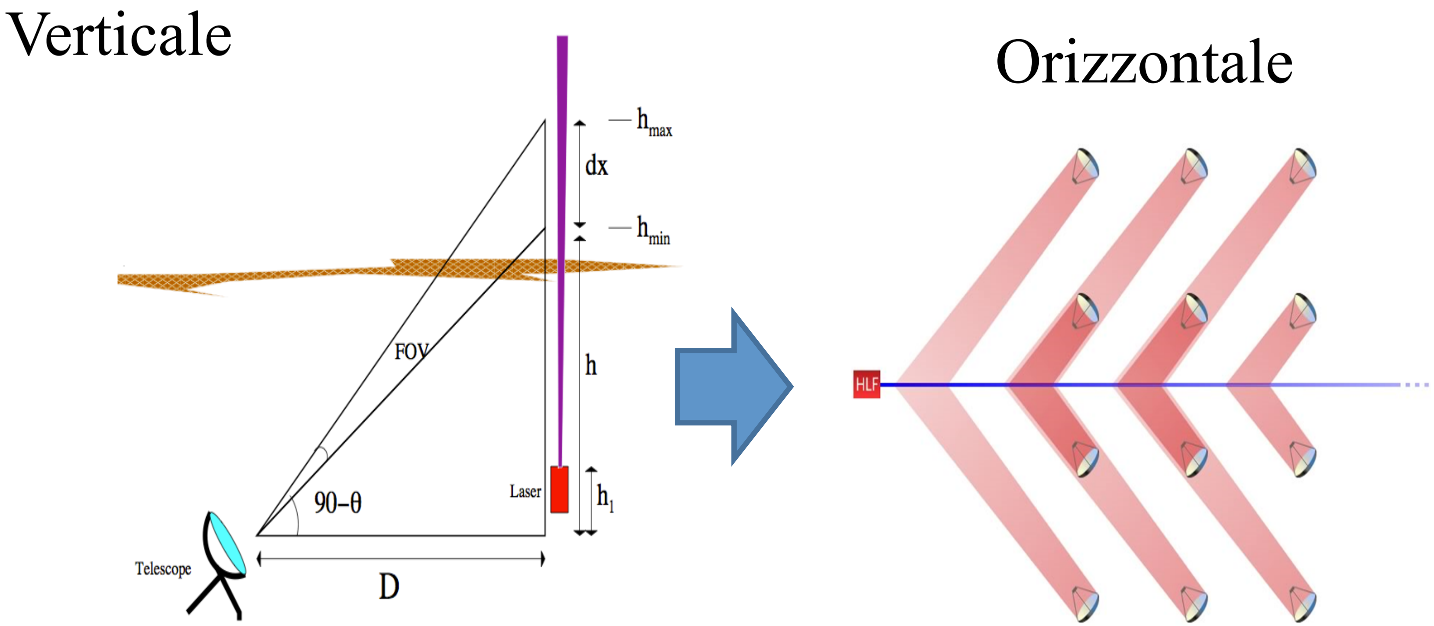
Atmospheric Calibration Strategy

Edited by: Michele Doro michele.doro@pd.infn.it

April 2, 2014

Would like to **start characterizing** atmosphere of the site **as soon as site is available** (with radio-sondes, LIDARs, Ceilometers)

Have the **option** to bring a **cross-calibrated reference LIDAR** from INFN to the site as early as Summer 2015!



ARCADE: Lidar Raman costruito in collaborazione tra i gruppi di Napoli e Torino nel FIRB 2010

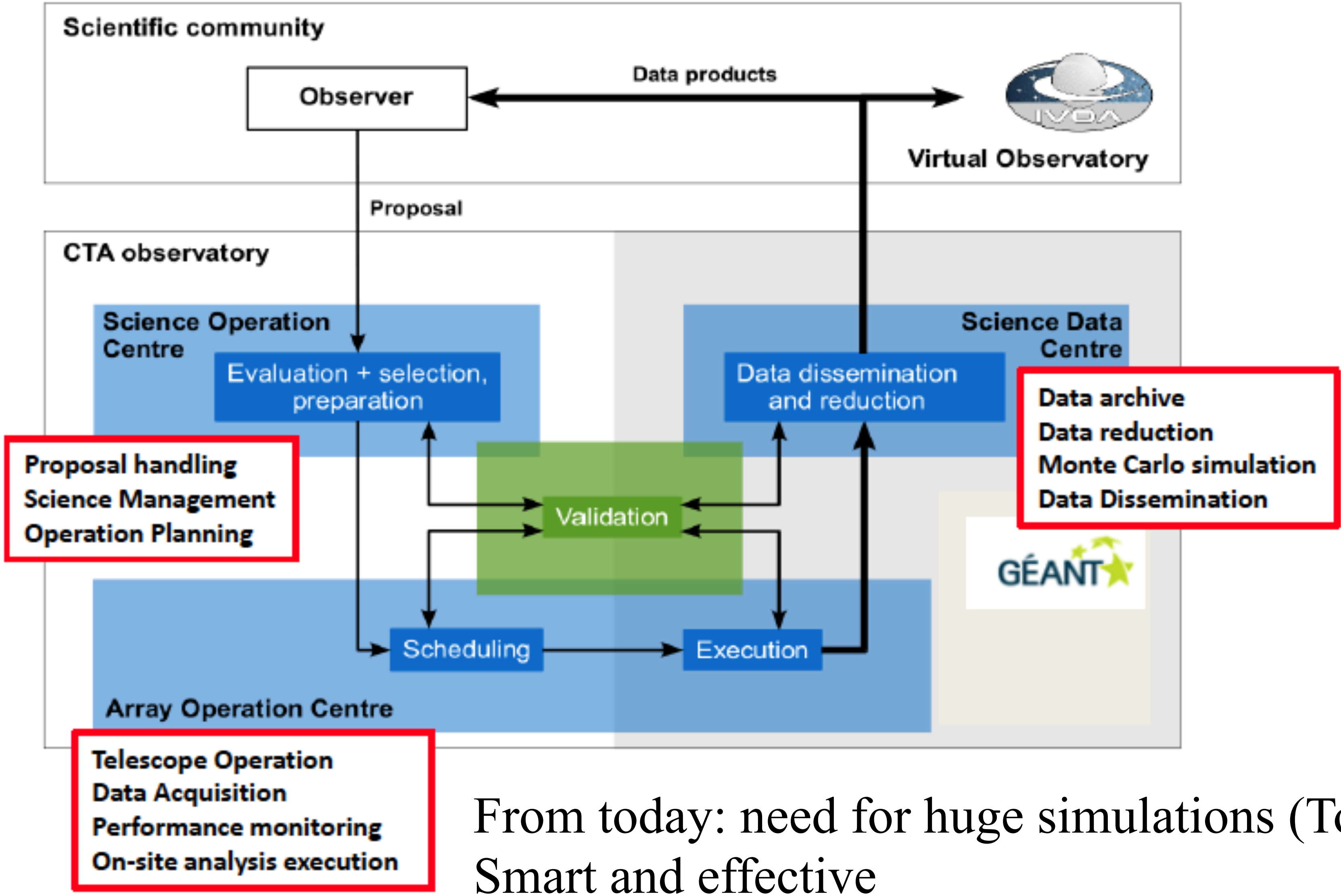
Obiettivo di ARCADE : studio delle diverse tecniche attualmente in uso nella comunità degli raggi cosmici per la misura dell'attenuazione da aerosol atmosferici della luce UV

La costruzione è stata appena completata

Al termine del progetto (marzo 2015), la proposta è di riutilizzare il sistema come prototipo per CTA

Computing & science

CTA is a PB big data scale project and operating as an Observatory



From today: need for huge simulations (To, …)
Smart and effective

Astroparticle Physics 43 (2013) 189–214

Contents lists available at SciVerse ScienceDirect

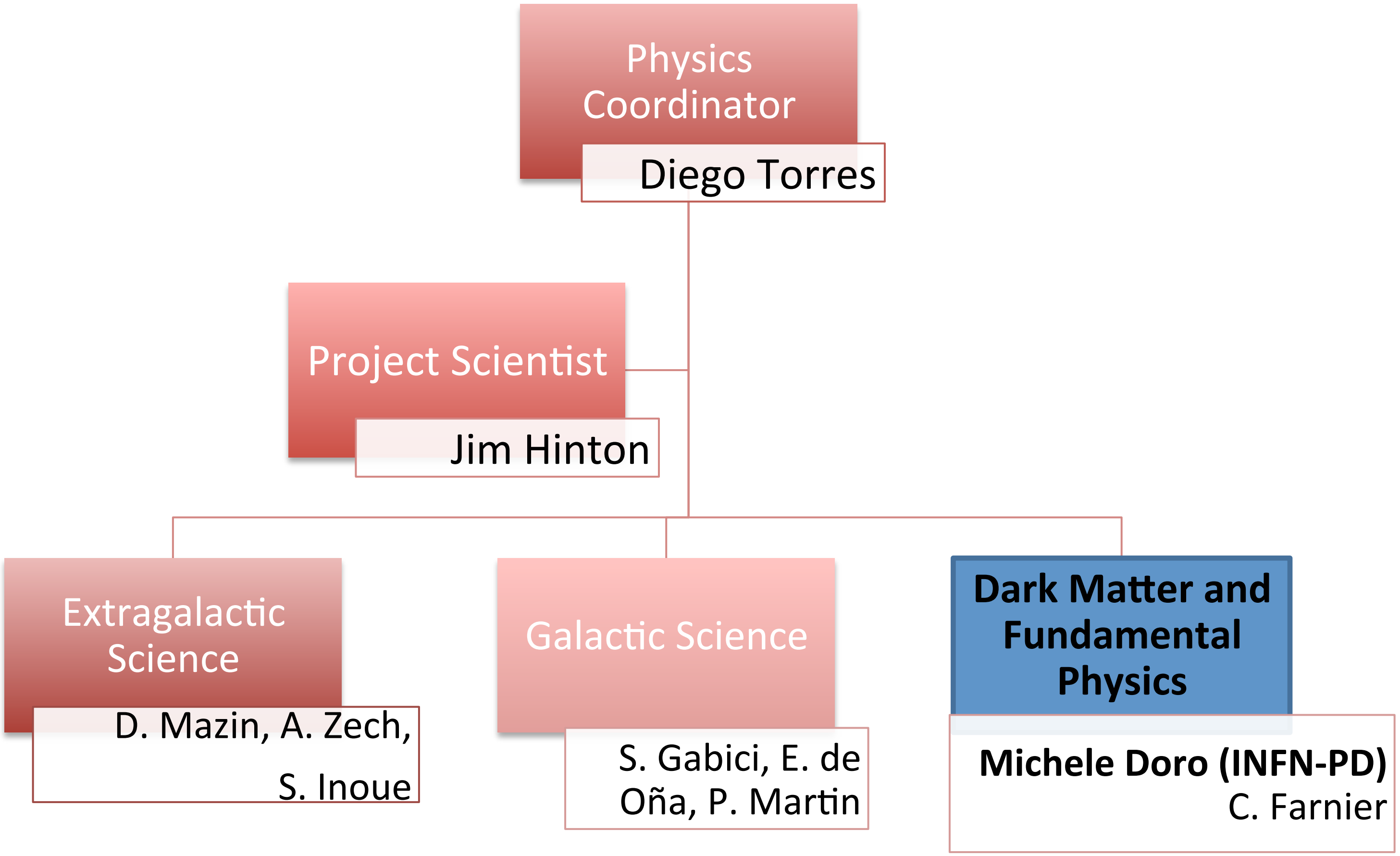
Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart

Physics

Dark matter and fundamental physics with the Cherenkov Telescope Array

M. Doro [k,*], J. Conrad [h,i,*], D. Emmanoulopoulos [l], M.A. Sànchez-Conde [r,s,t], J.A. Barrio [a], E. Birsin [b], J. Bolmont [c], P. Brun [d], S. Colafrancesco [e,f], S.H. Connell [g], J.L. Contreras [a], M.K. Daniel [j], M. Fornasa [m,n], M. Gaug [k], J.F. Glicenstein [d], A. González-Muñoz [m,n], T. Hassan [a], D. Horns [o], A. Jacholkowska [c], C. Jahn [p],



And new developments for computing

- Strategy for data analysis (Hw/Sw)
- In-camera data processing? Digital electronics & computing progress fast…
  - The goal imposed by the physics bounds is: computing at GHz or better
  - New architectures, new machines (GPUs, …)
  - Interplay with the accelerators environment

CTA: Relevance to high energy physics

- Physics
  - Energy: TeV energy scale (particle acceleration, elementary processes in the Universe)
  - Evolution of the Universe
  - Fundamental physics
    - Search for cosmological Dark Matter
    - Axion-like particles and new particles
    - Probe Quantum gravity (space time structure of vacuum) – close to the Planck Scale
  - Hadronic interactions (Gamma / Hadron separation)
  - Synergy with neutrino detectors

- Cutting edge technologies developed in HE physics
  - High QE advanced photodetectors,
  - Analogue signal transmission via optical fibers
  - Readout system 2GHz ultra fast analogue ring sampler
  - Ultra fast trigger system (new computing architectures?)
  - Large data flow, massive computing

Summary

- Clear interplay between VHE (γ) astrophysics and fundamental physics; this model of cooperation has worked well, and can work well in the future
- Cosmic Rays:
  - SNR as galactic sources established
- Still no detection of DM
- Many new things to discover, some in a clear scenario; few clouds (photon propagation?) might hide new physics
- Rich fundamental science (and astronomy/astrophysics) from gamma rays
  - HEA is exploring regions beyond the reach of accelerators
  - A "simple" extension of present detectors is in progress: CTA
- Technology and phenomenology are the key ingredients for this rich new science
  - And the INFN know-how will be essential