Raggi gamma da terra: il futuro

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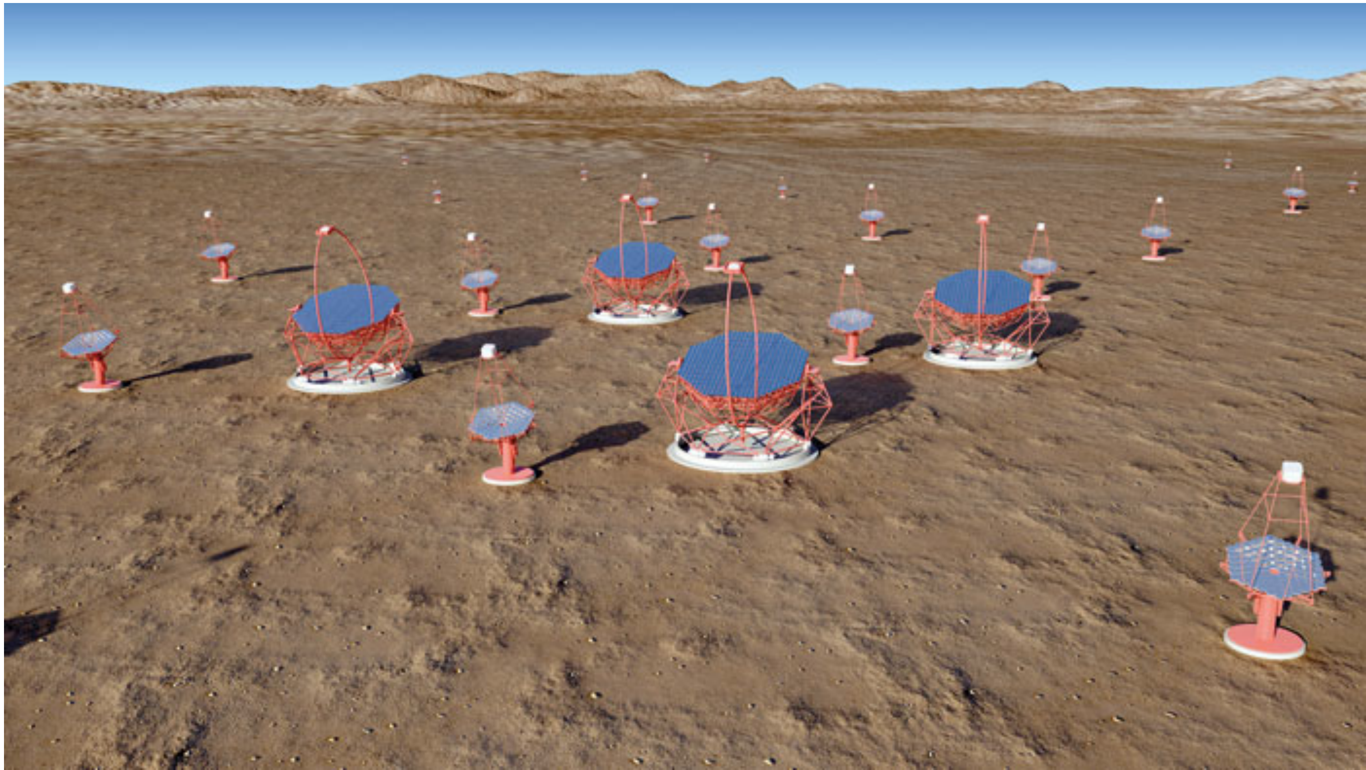
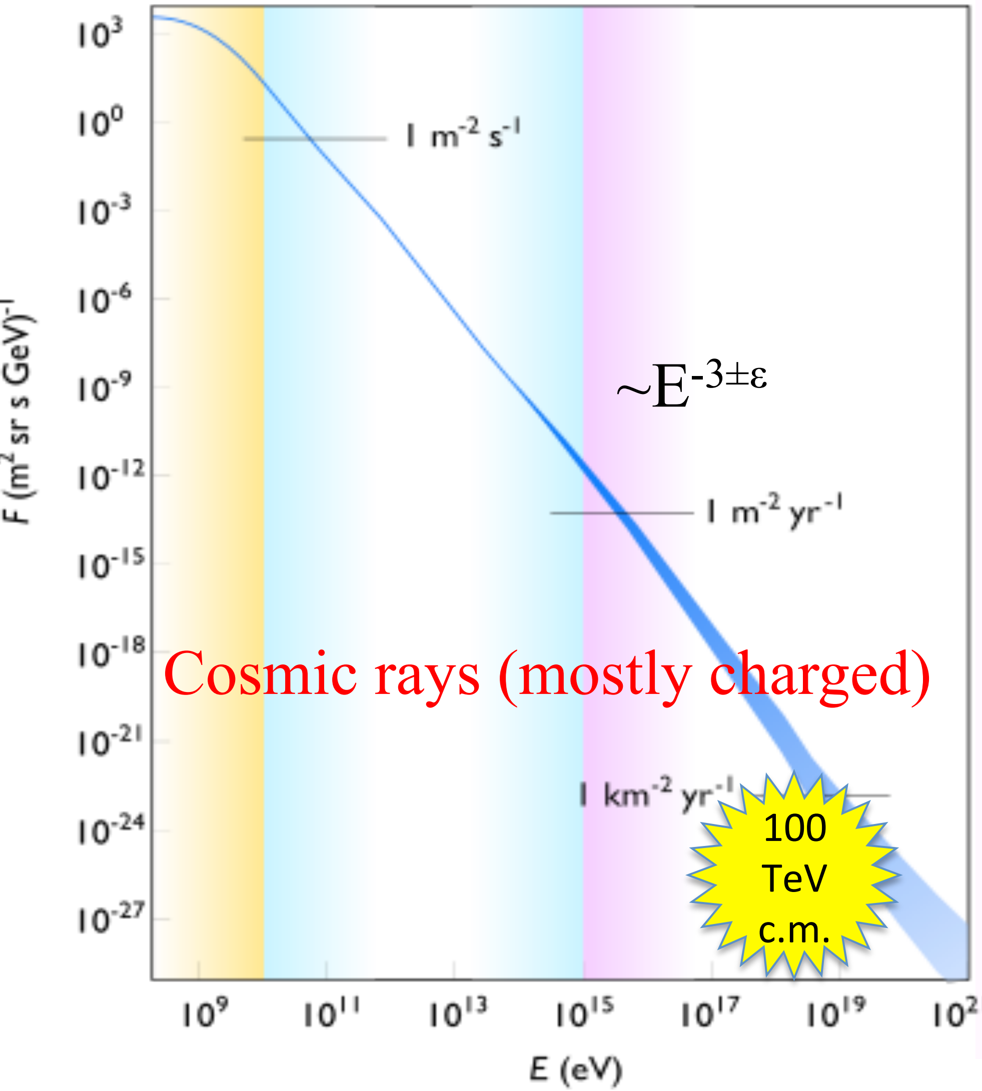
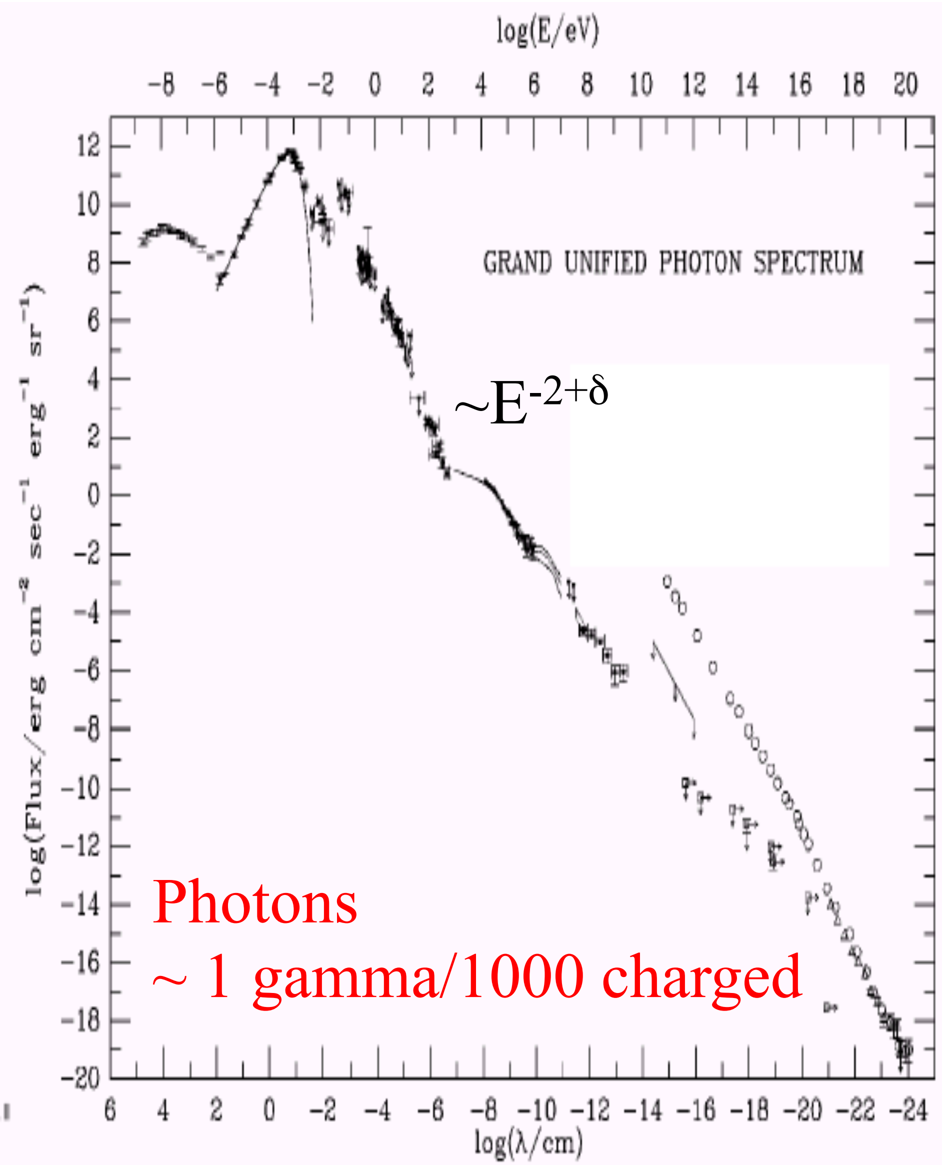
- VHE gamma rays: introduction; physics goals; detection techniques
- Physics: answers and questions from present detectors
- Future large projects: Cherenkov vs. EAS
- What more can be done in the next 20 years?



Padova, Dicembre 2014

Very-High Energy gamma rays

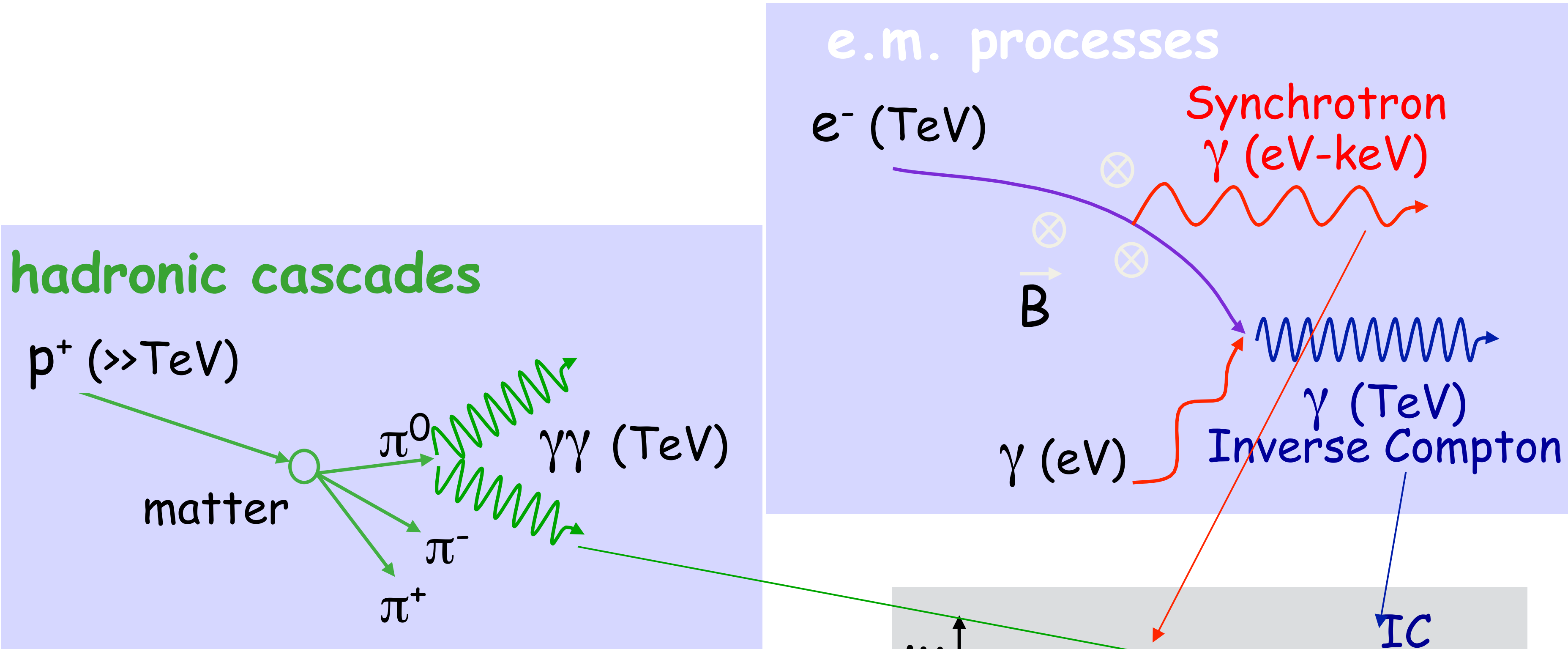


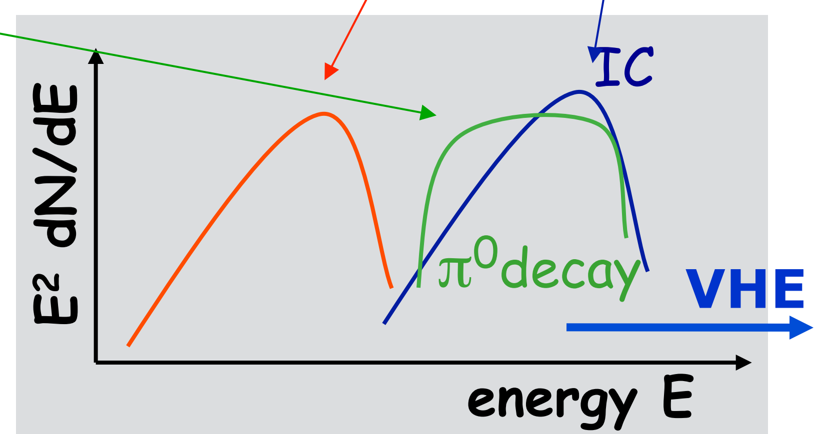


How are VHE (above 30 GeV) gamma rays produced?

- 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





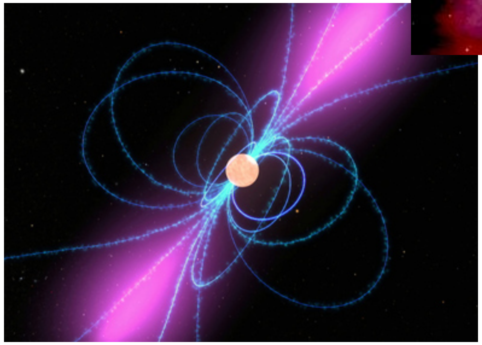
In the VHE region,
$dN/dE \sim E^{-\Gamma}$ (Γ: spectral index)

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

Where are these extreme environments?

In our galaxy

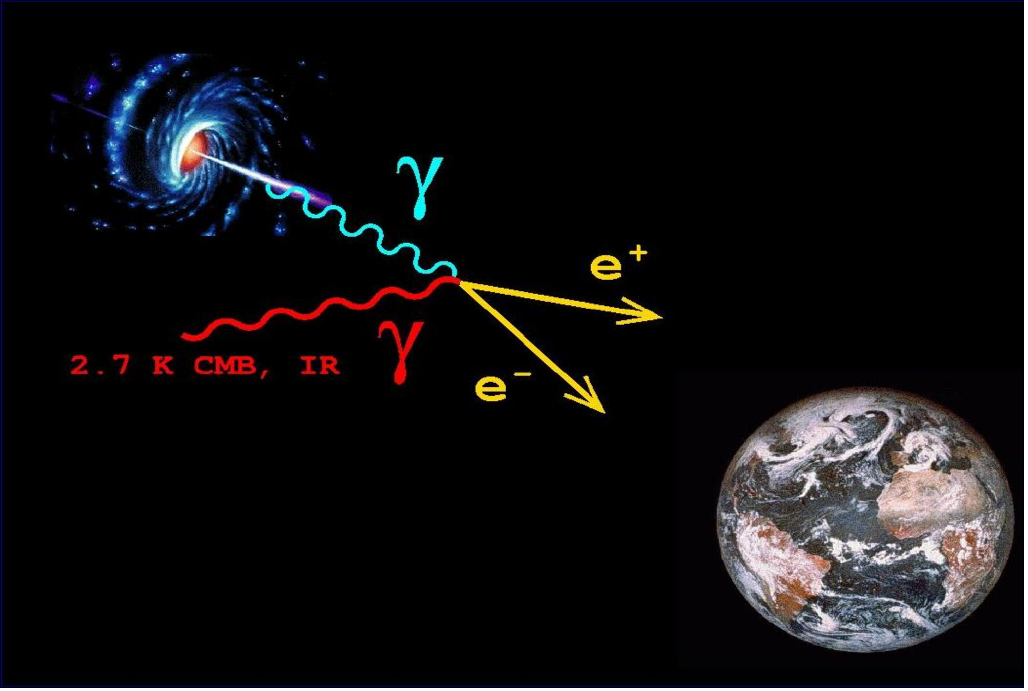
Mostly stellar endproducts:
SNRs, Pulsars



In other galaxies

Active Galactic Nuclei

Gamma-Ray Bursts

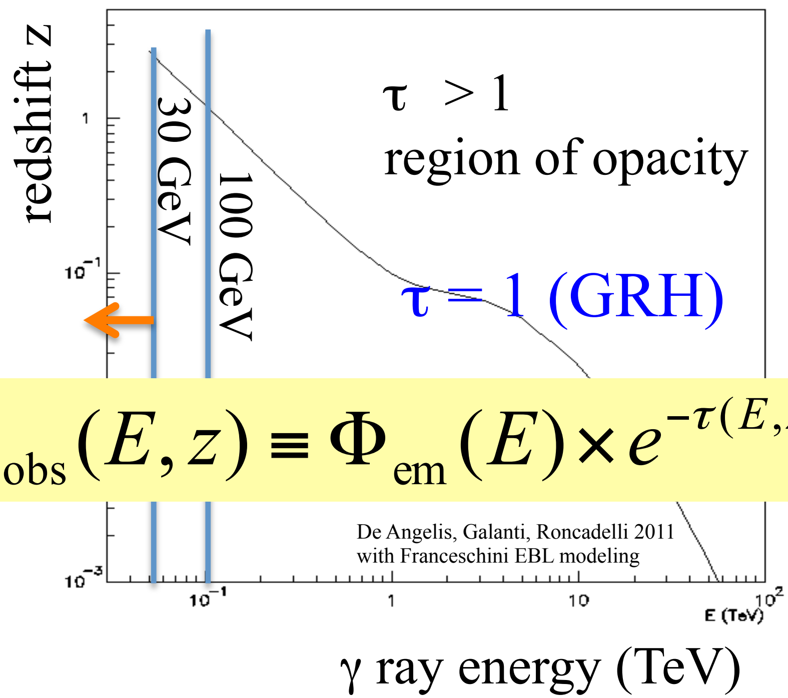


How do gamma rays reach us?

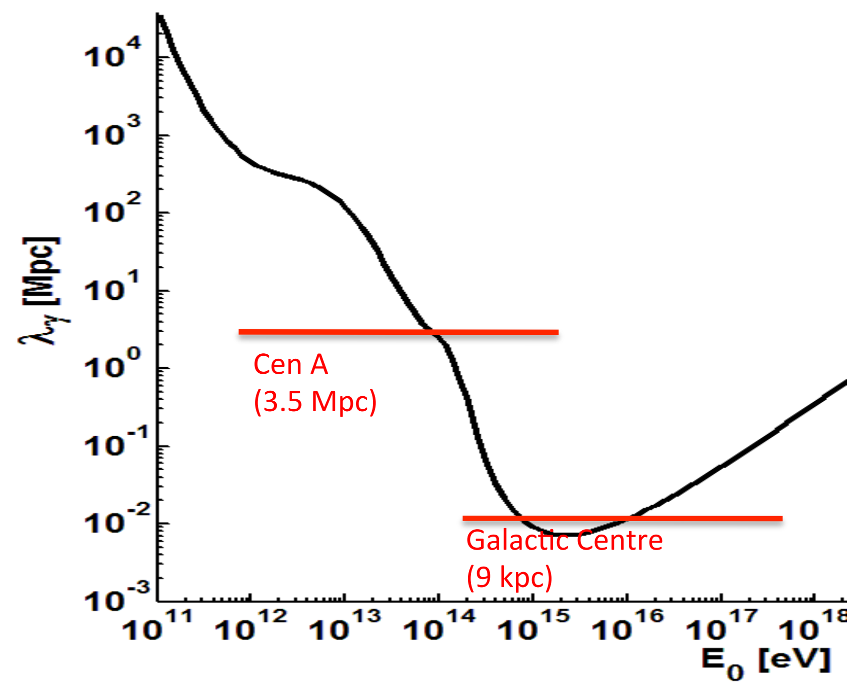
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

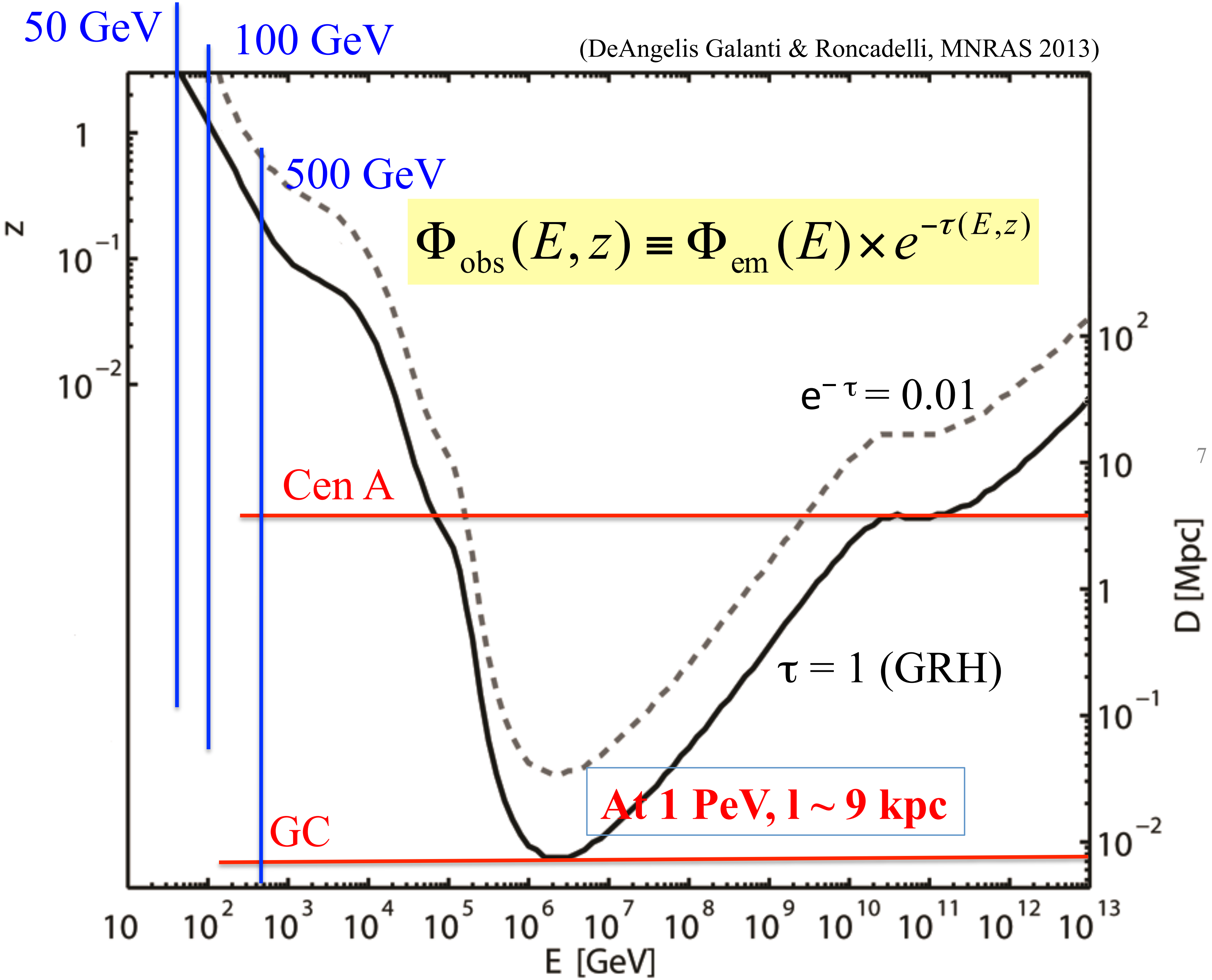
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2)\cdot\left[2\beta(\beta^2-2)+(3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right]\,\mathrm{cm}^2$$

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

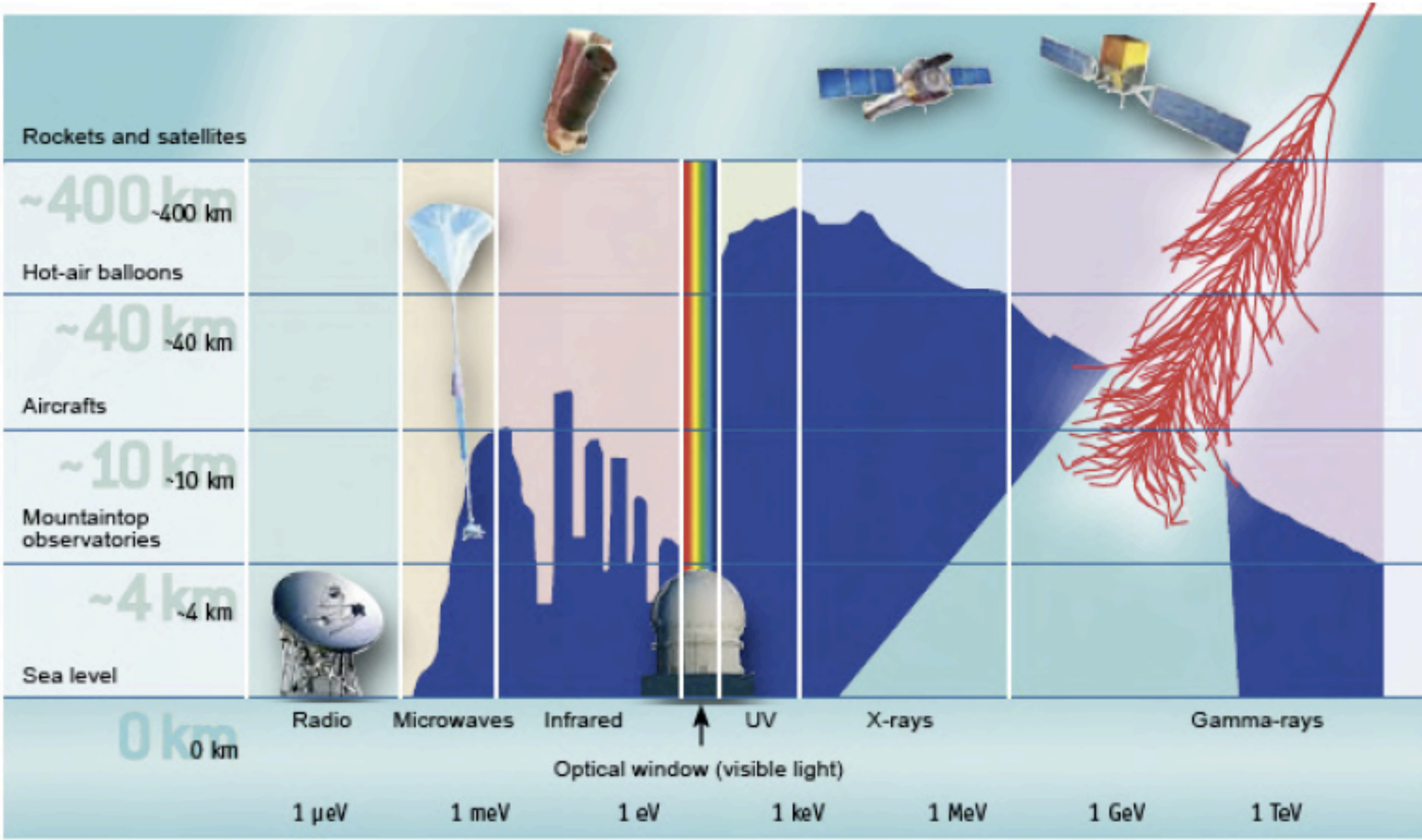


$$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$$




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
$\tau = 1$ (GRH)
At 1 PeV, l ~ 9 kpc
GC
z
1
10^{-1}
10^{-2}
10^{2}
10
1
10^{-1}
10^{-2}
D [Mpc]
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
E [GeV]

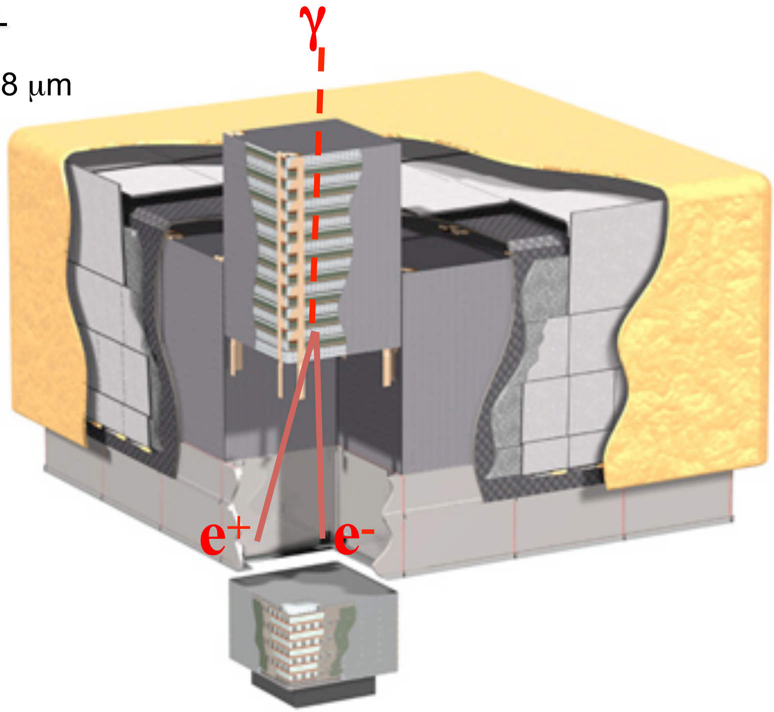
Gamma rays interact with the atmosphere



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

Detectors

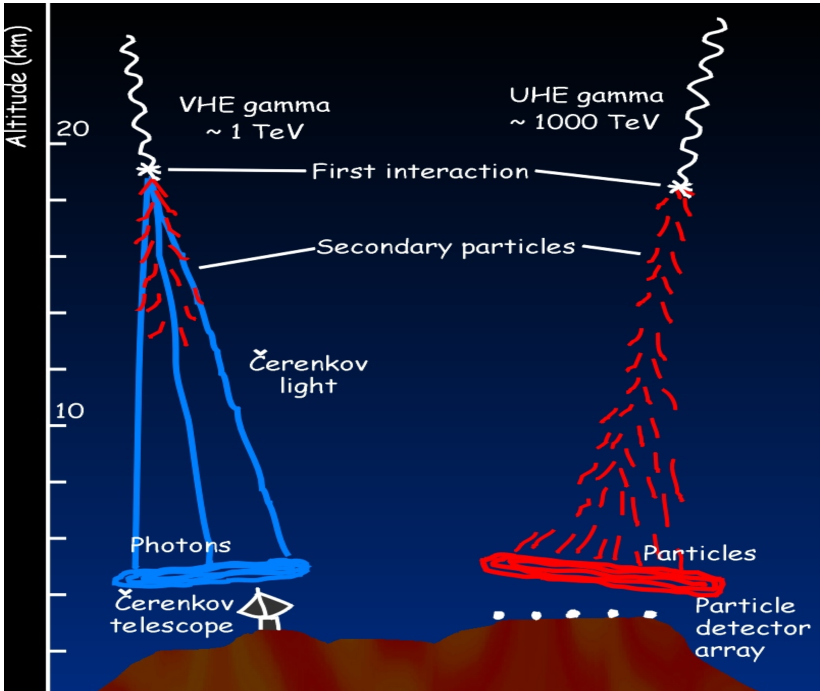
Precision Si-strip Tracker (TKR)
18 XY tracking planes
Single-sided silicon strip detectors 228 μm pitch, 8.8 10^5 channels
Measure the photon direction



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

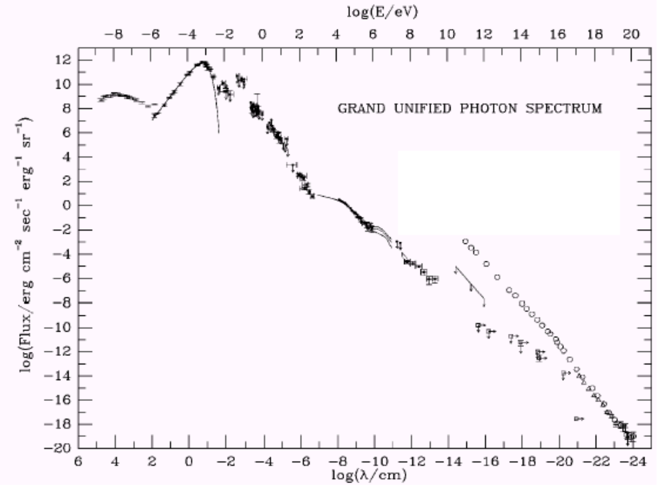
- Cherenkov telescopes (HESS, MAGIC, VERITAS)

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

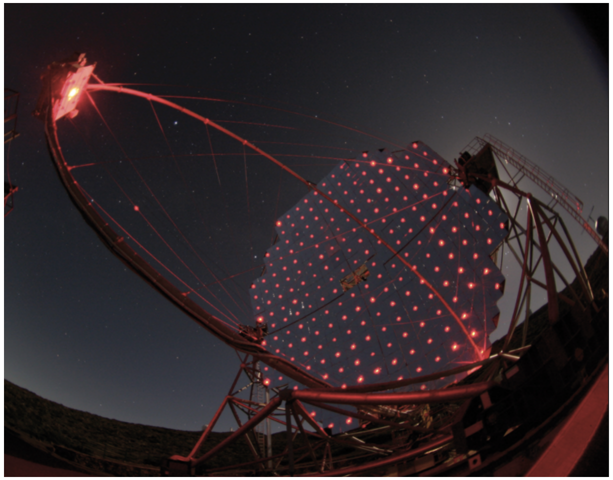


HEP detectors!

Why detection at ground?

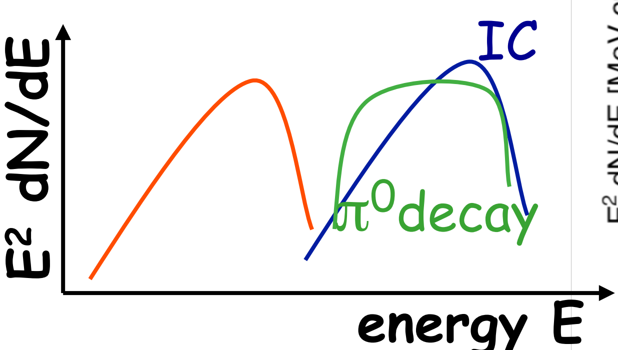


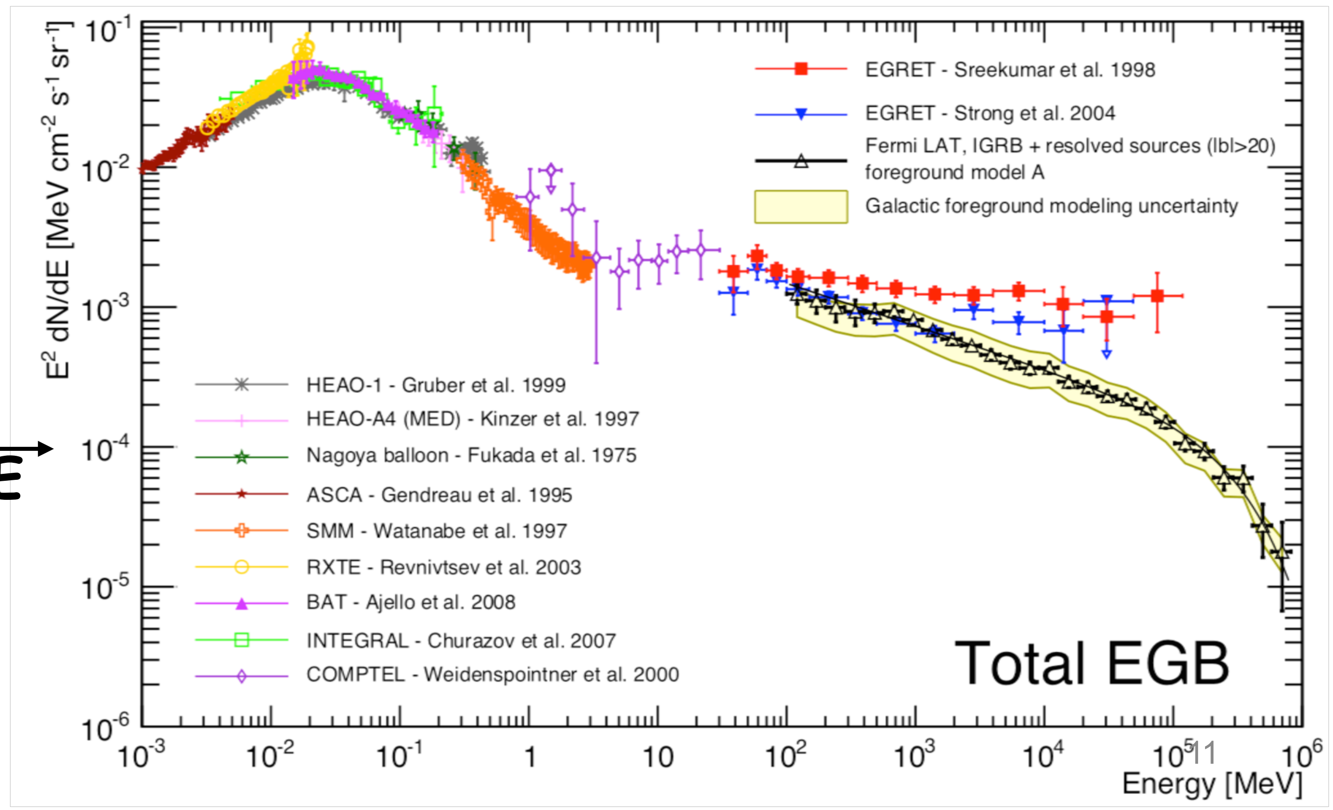
- High energies
  - Only way to build sensitive >TeV instruments
  - Maximum flux < 1 photon/h/m^2 above 200 GeV
- High statistics /short timescales
  - Large collection areas O(km^2)
- Precision (Cherenkov telescopes)
  - Superior angular resolution
- Limitations?
  - IACTs
    - Smaller duty cycle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



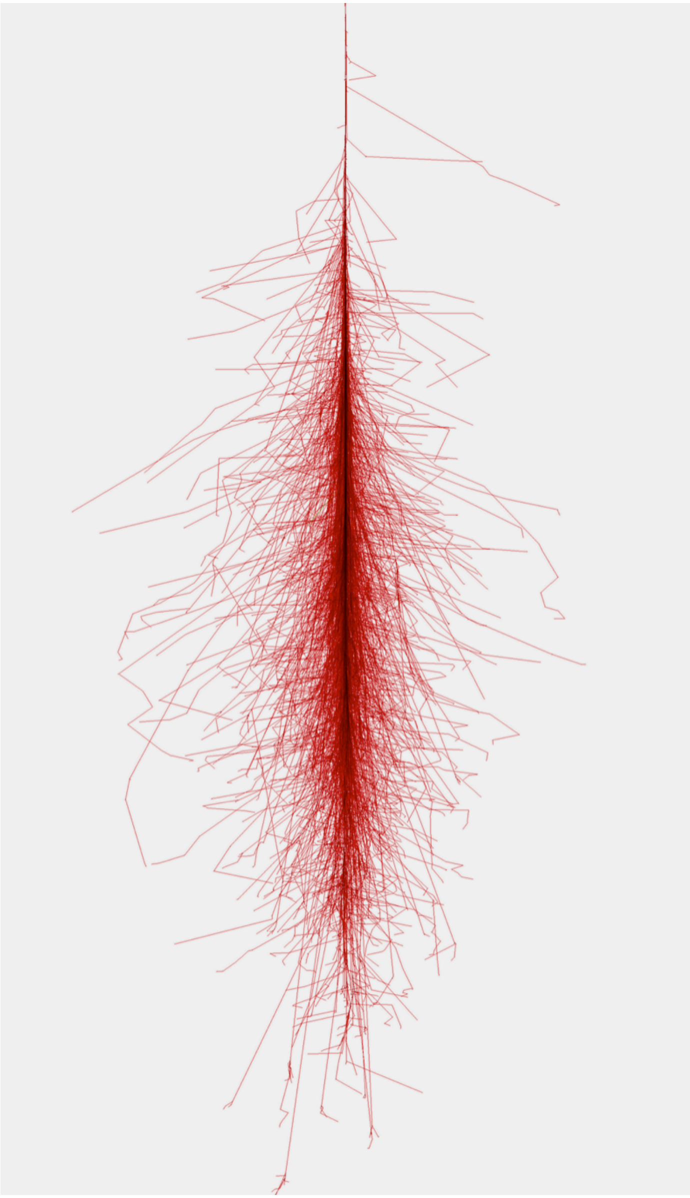
Back to the diffuse spectrum…

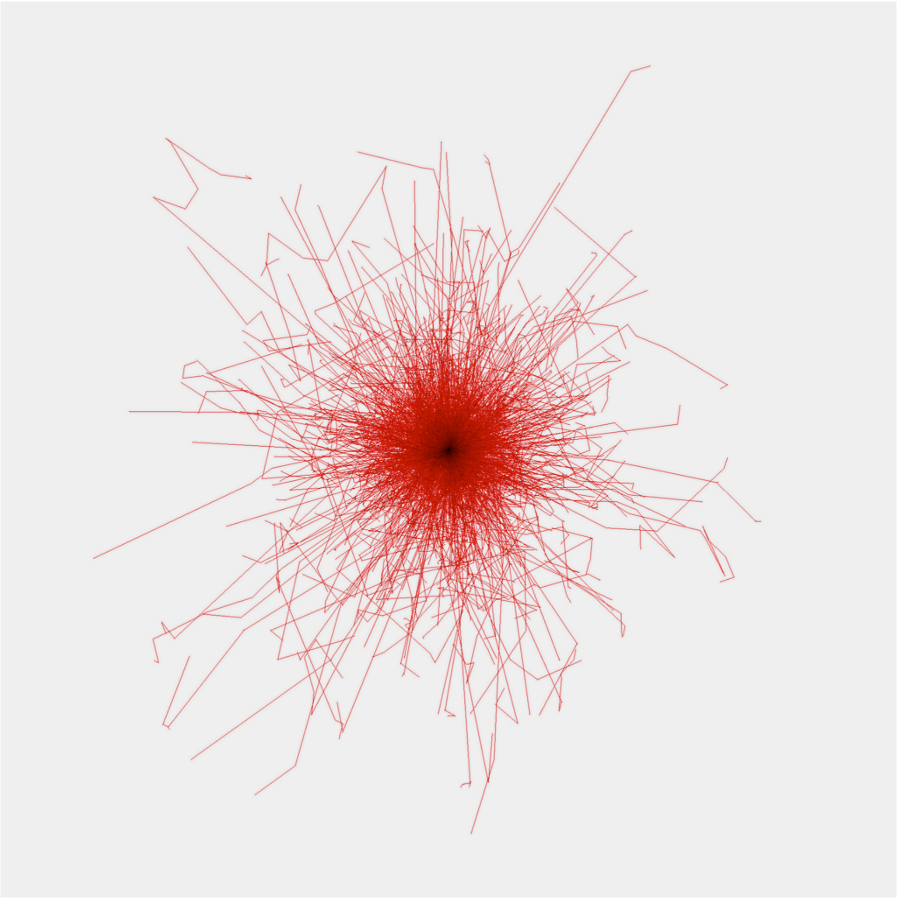
- If the dominant mechanism is SSC or hadronic, and if the bulk of the diffuse gamma spectrum is from unresolved sources, we expect a cutoff in the TeV-PeV region





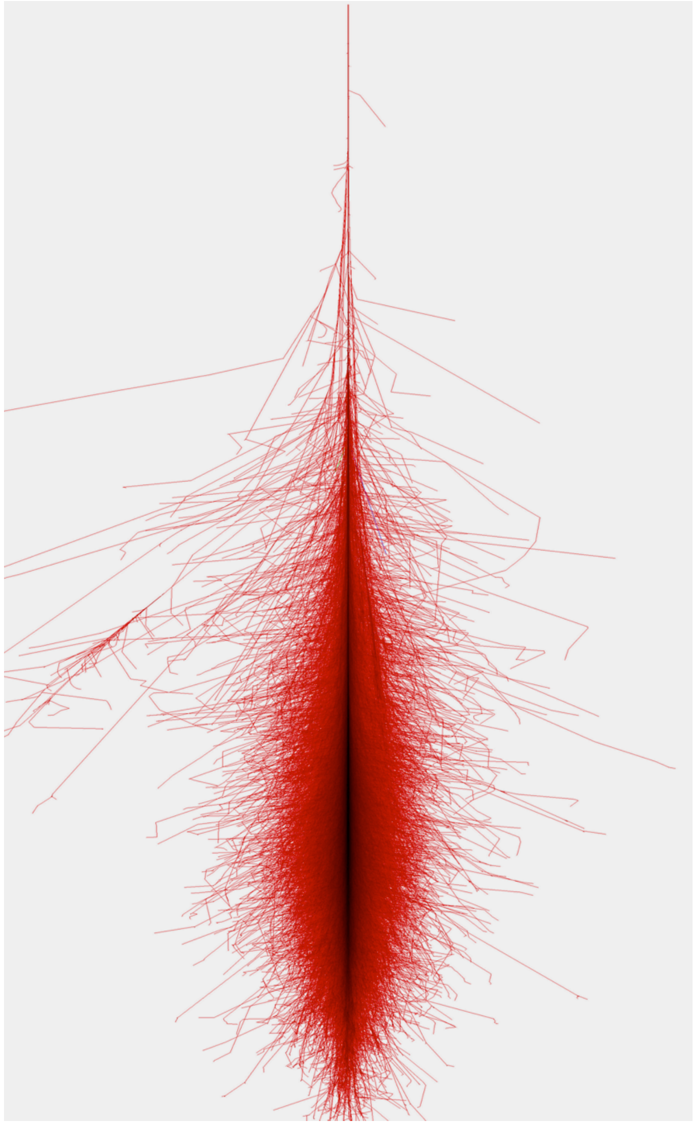
The main experimental problem: γ/hadron separation

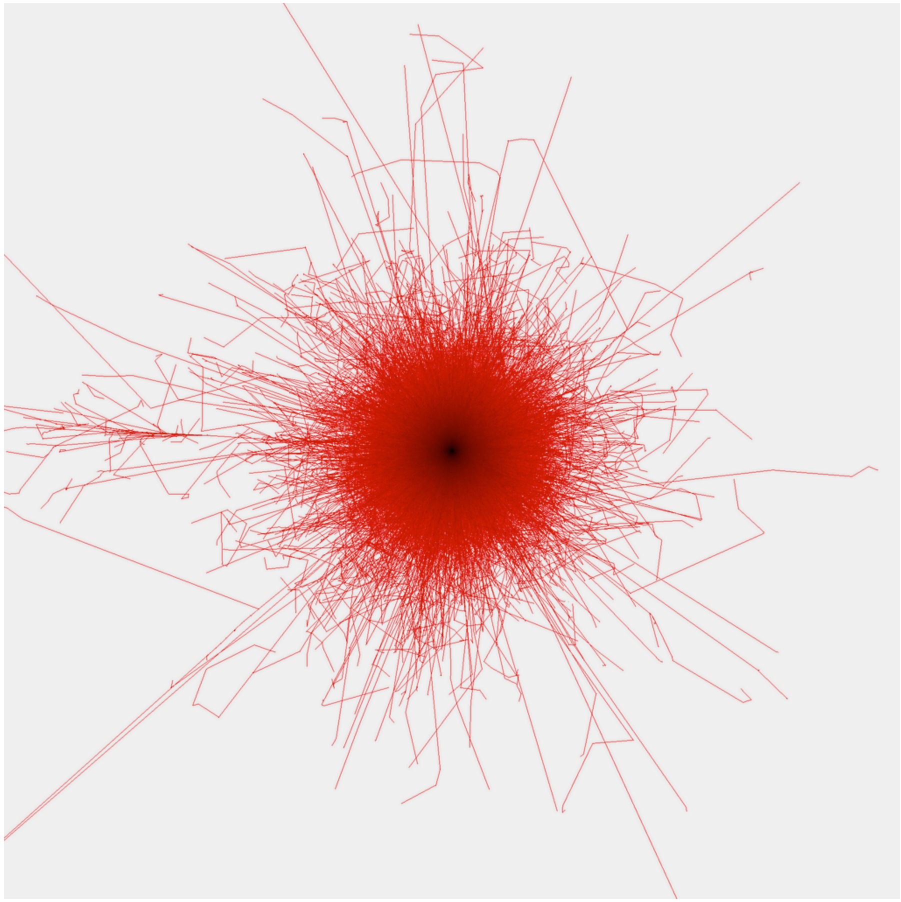




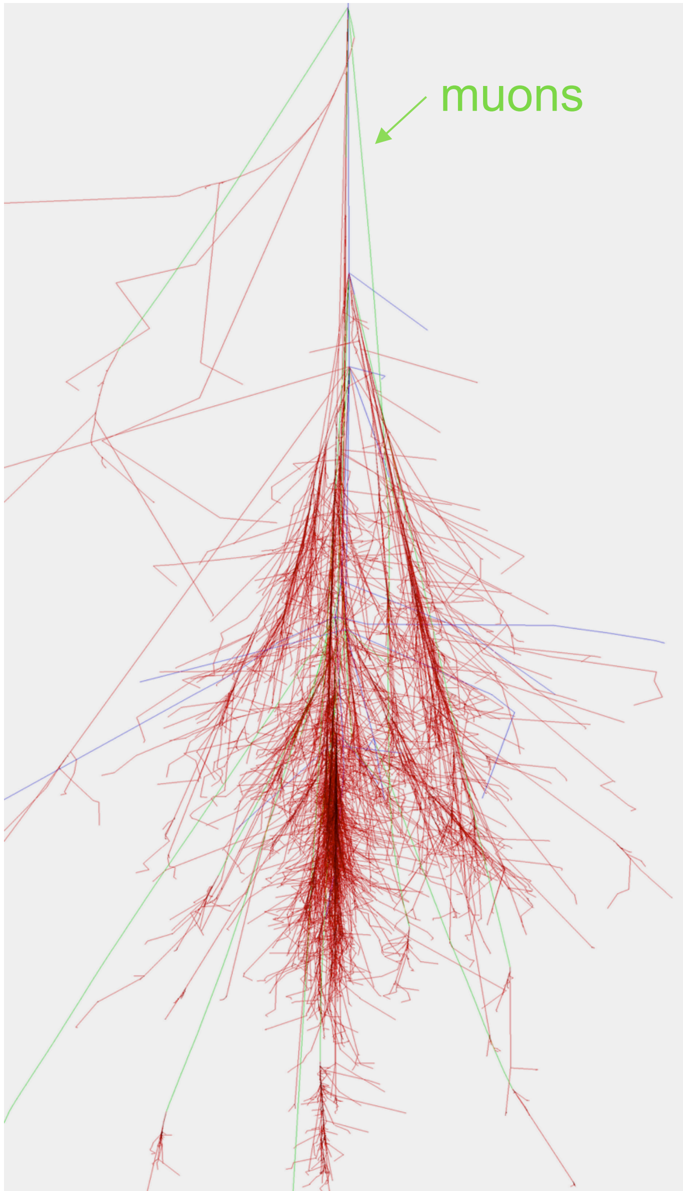
Simulated gamma
in the atmosphere:
50 GeV

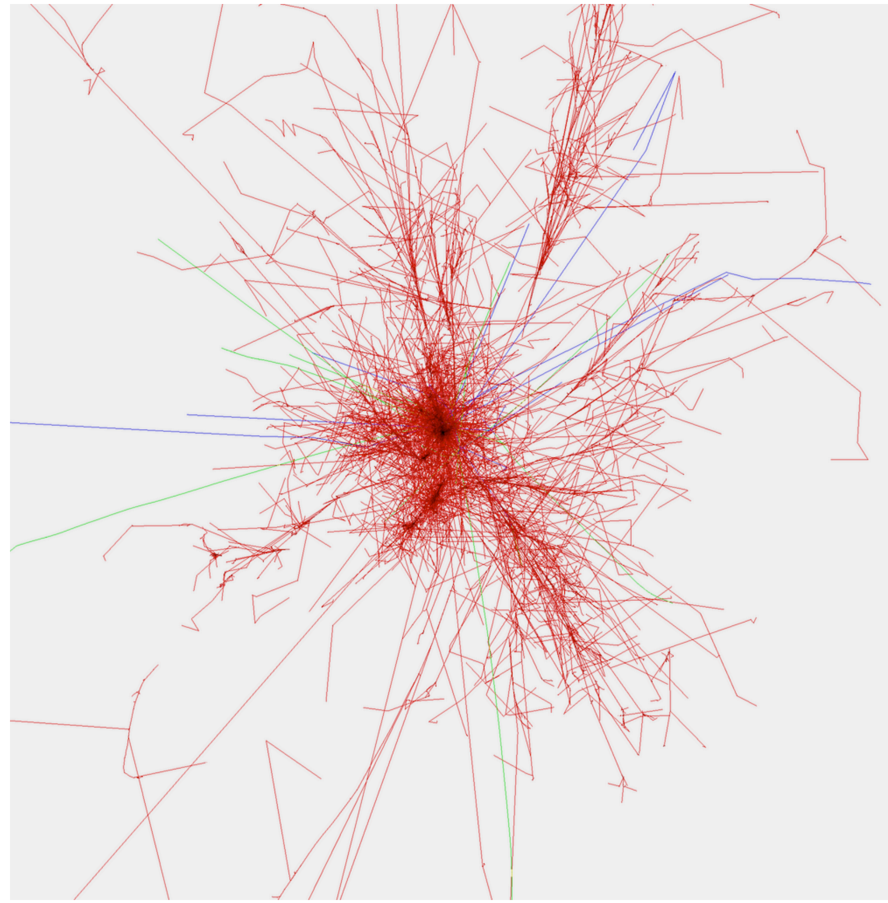
Simulated gamma
1 TeV





Simulated proton
100 GeV (the ennemy)

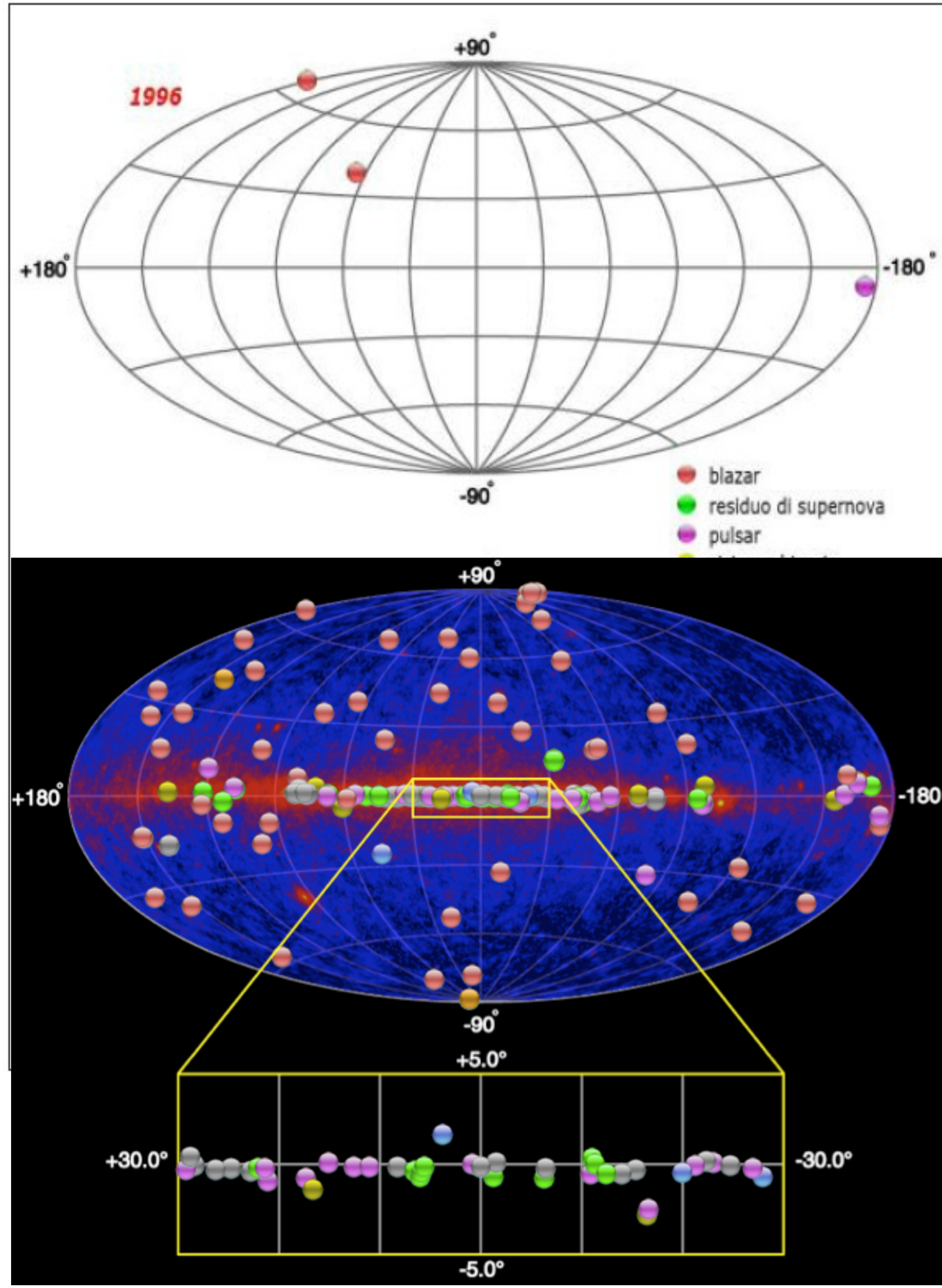





VERITAS
MAGIC
HAWC
HESS

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

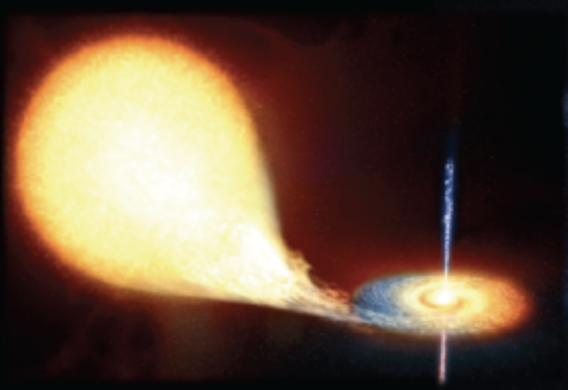
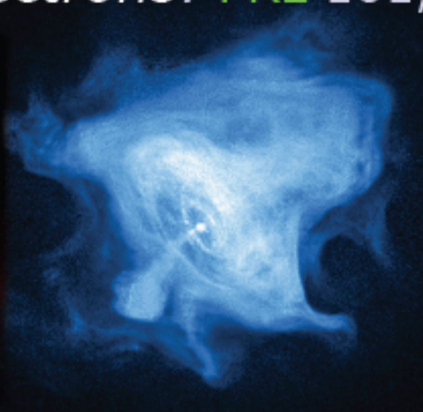
- Thanks mostly to Cherenkov telescopes, imaging of VHE (> 30 GeV) galactic sources and discovery of many new galactic and extragalactic sources: ~ 200 (and >200 papers) in the last 9 years
  - And also a better knowledge of the diffuse gammas and electrons
- A comparable success in HE (the Fermi realm);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

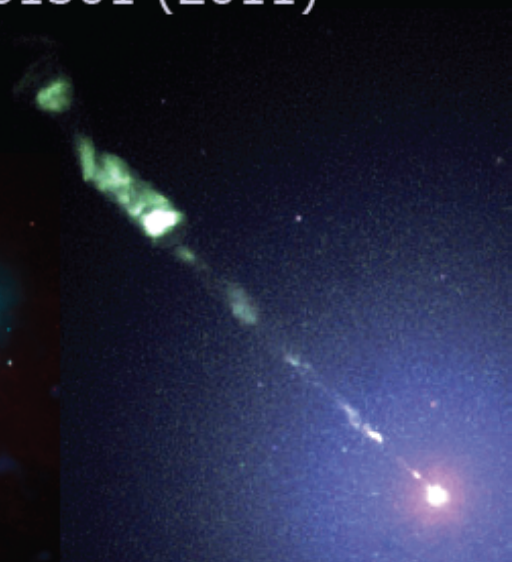


TeV Impact

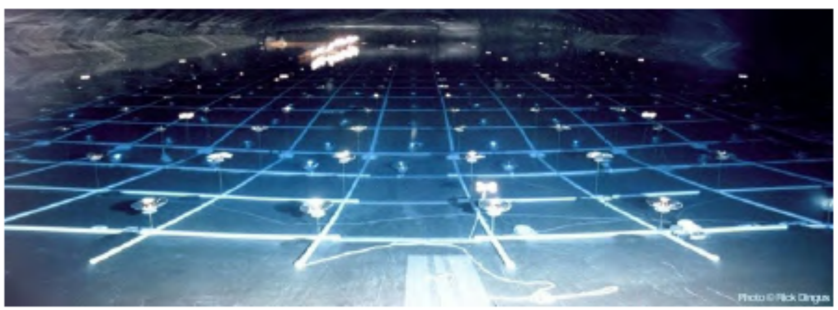
Highlights from **HESS, MAGIC, VERITAS & MILAGRO**

- *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)



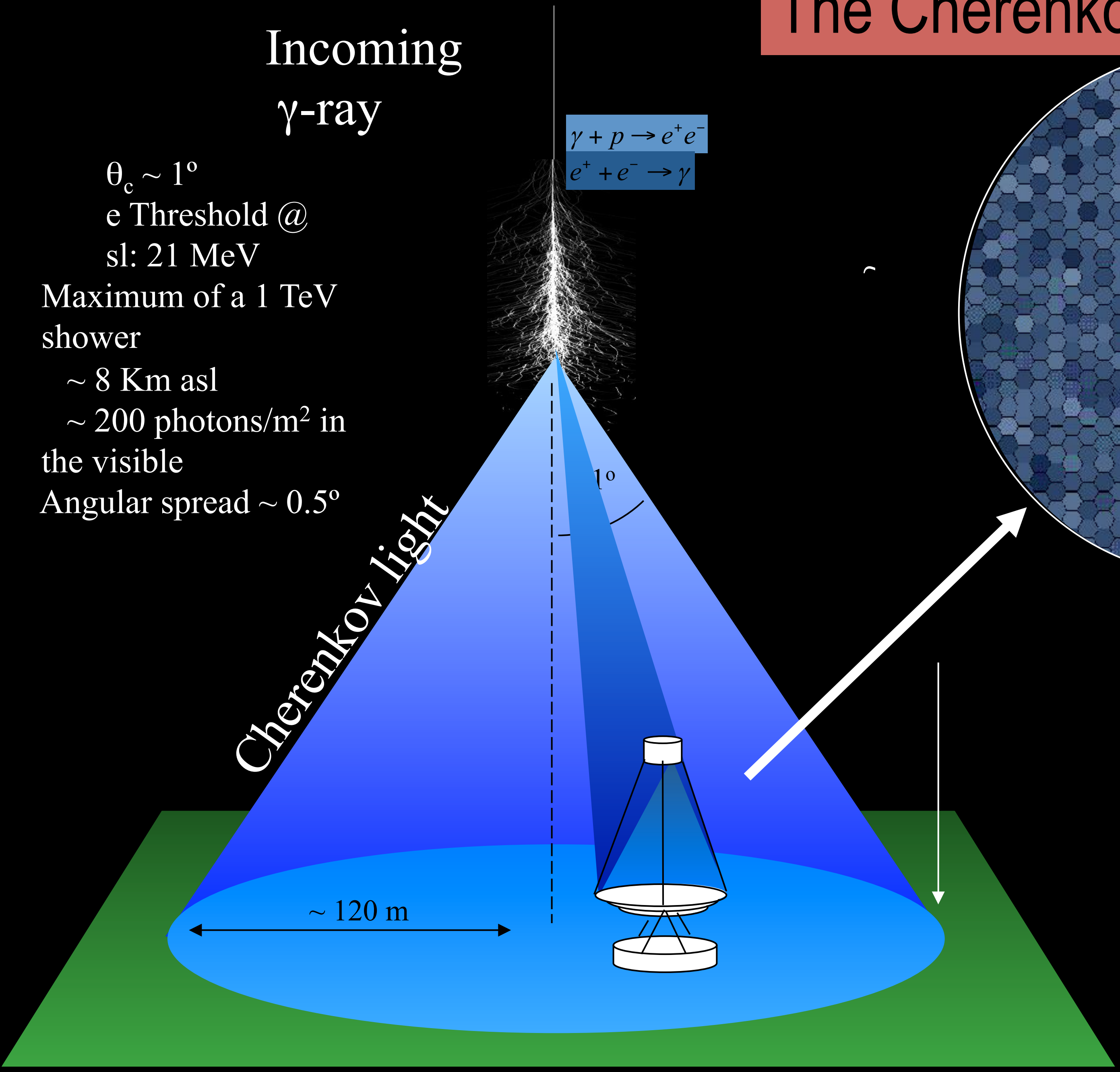
EAS



- Pro: wide field of view, continuous operation
- Minus: not yet the sensitibity (can be cured)

- Transients: plus is serendipity, can be the trigger; minus is sensitivity

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 ~ 0.5°

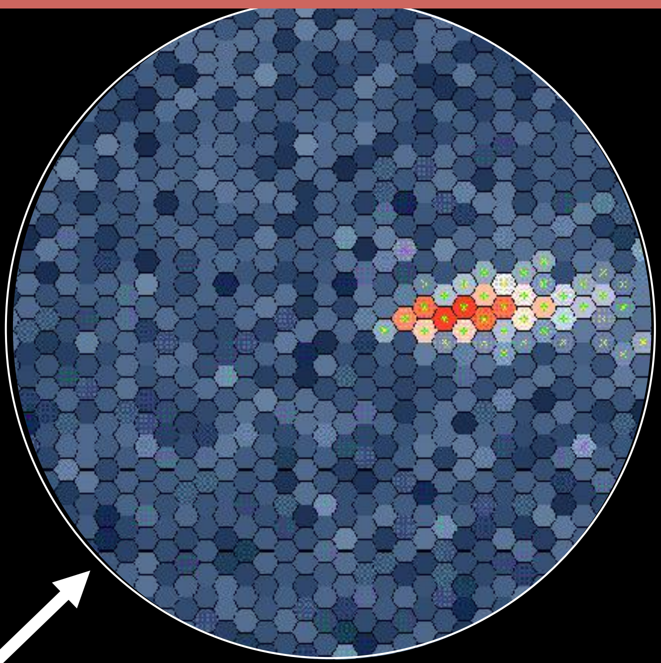


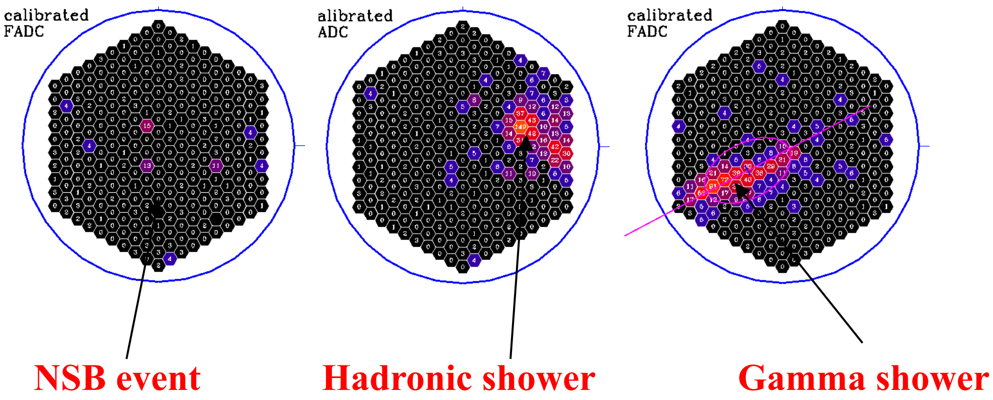
Image intensity
➔ Shower energy

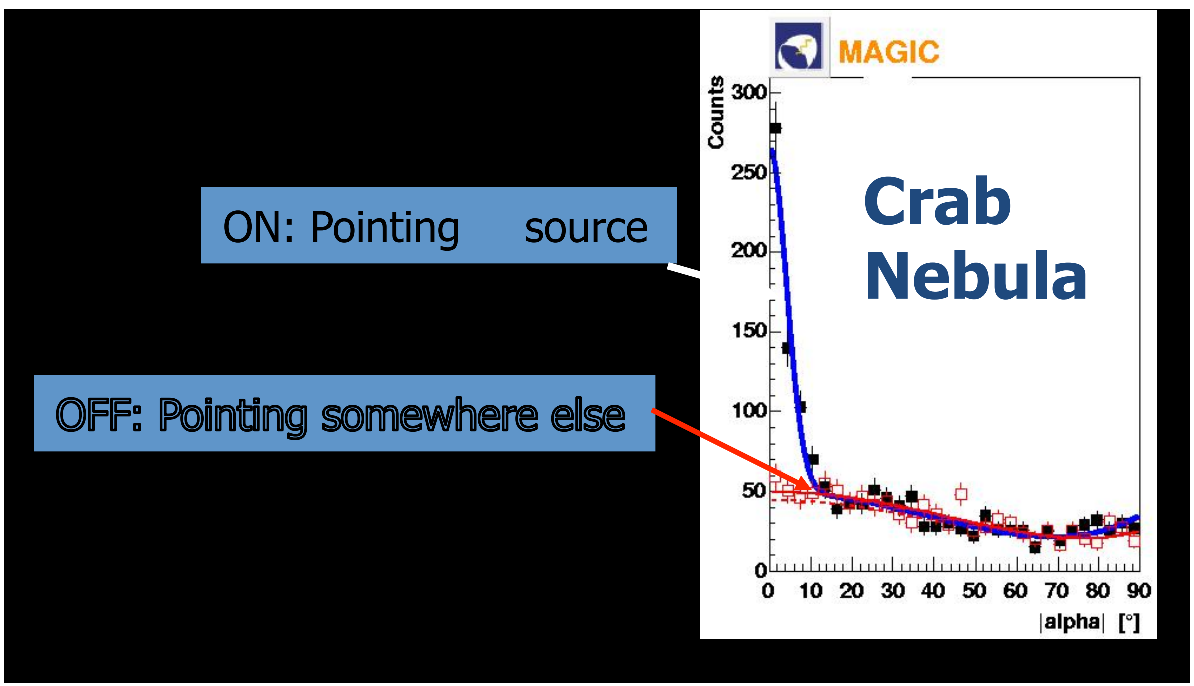
Image orientation
➔ Shower direction

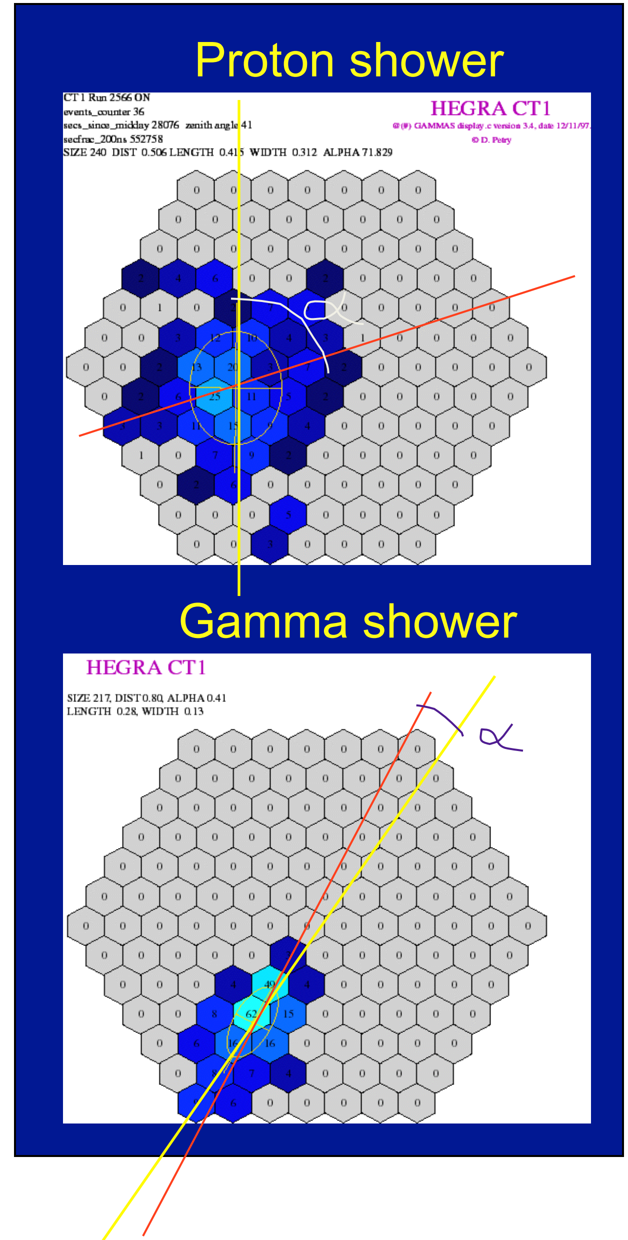
Image shape
➔ Primary particle

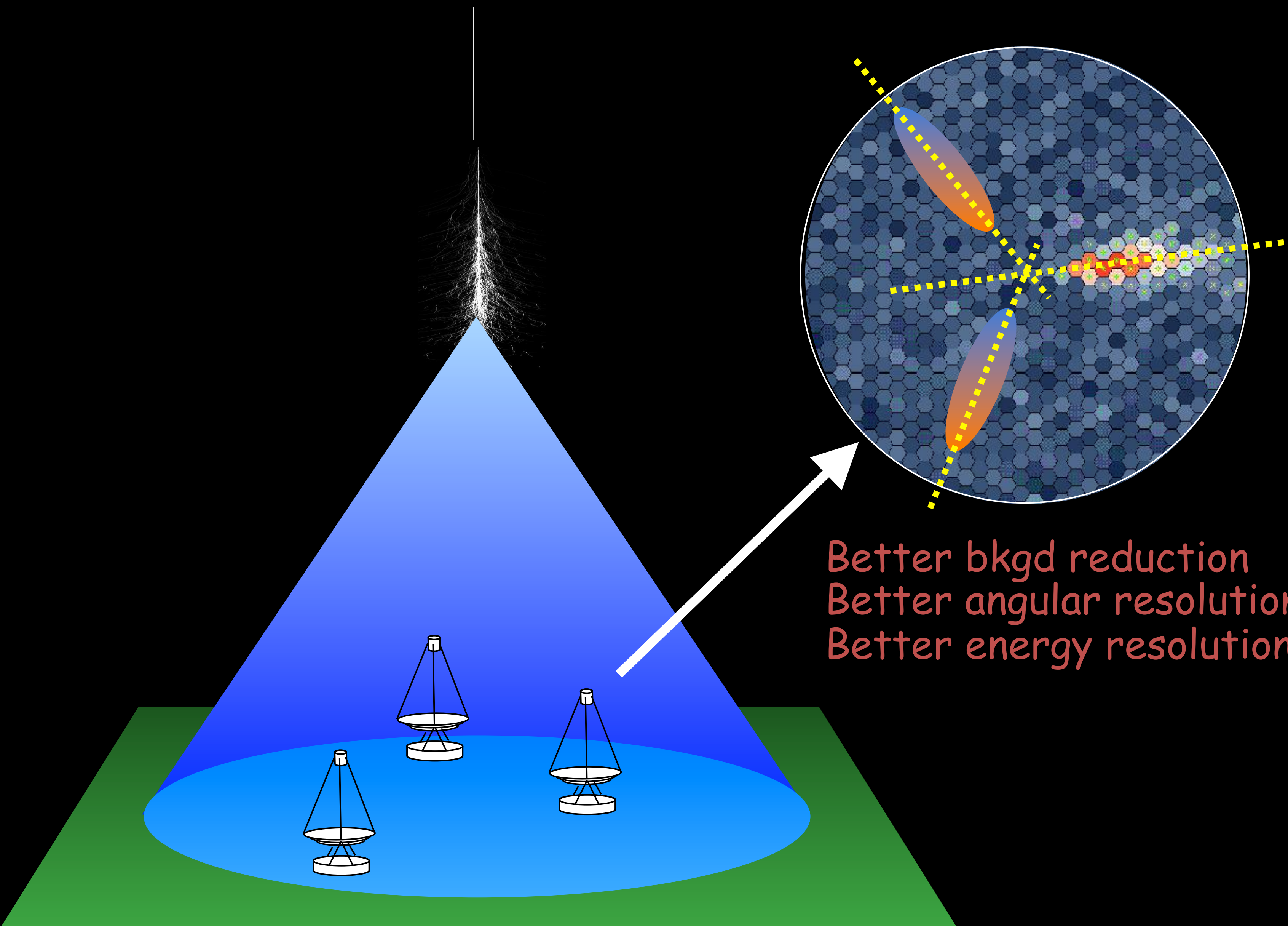
Signal duration: ~ 3ns

γ/h Separation







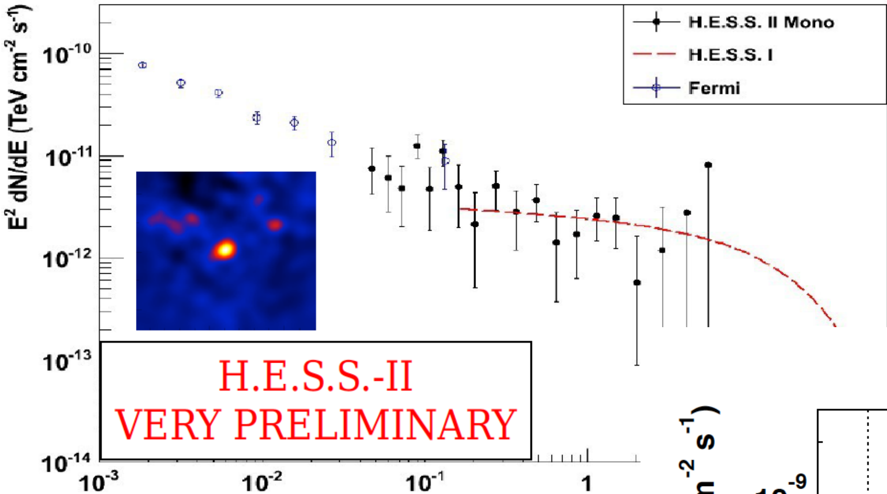

Better bkgd reduction
Better angular resolution
Better energy resolution

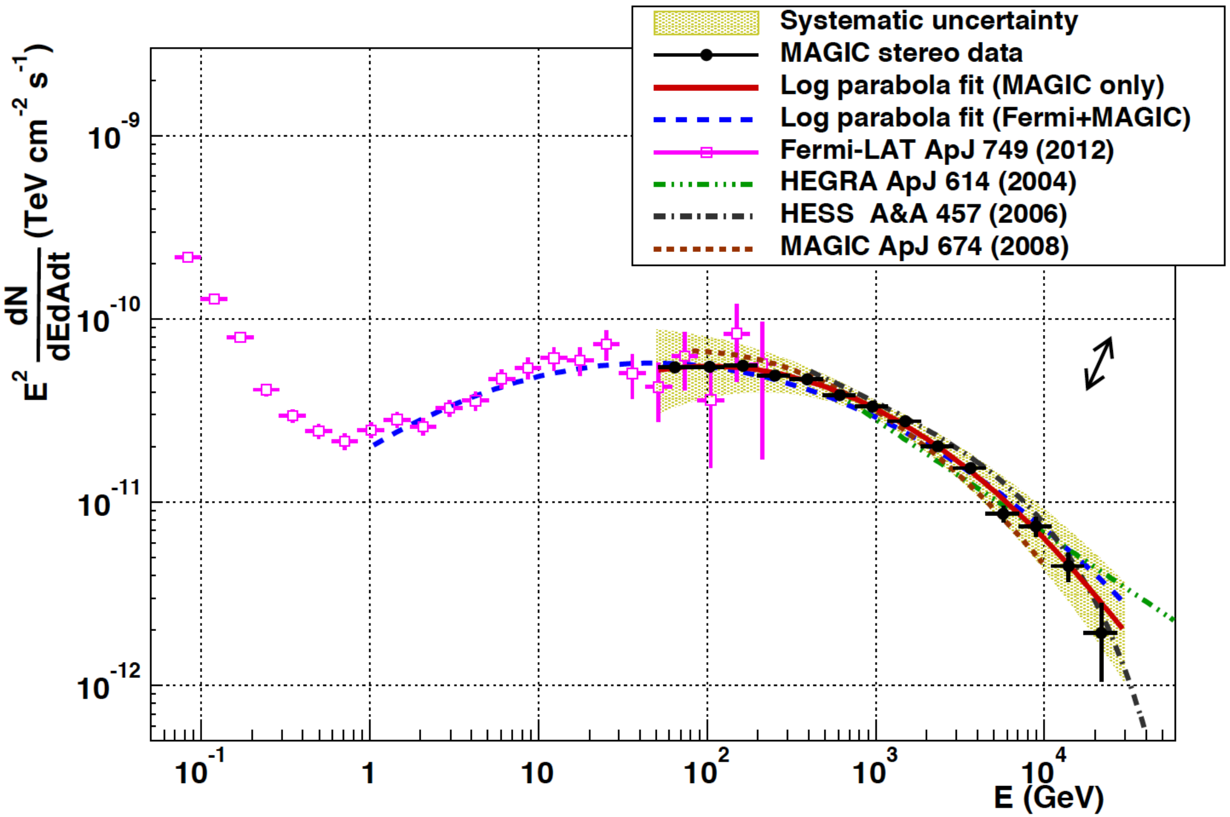
Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7


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

MAGIC

Crab Nebula from HESS2 and MAGIC





Why bigger and bigger?
Figures of merit of a Cherenkov telescope

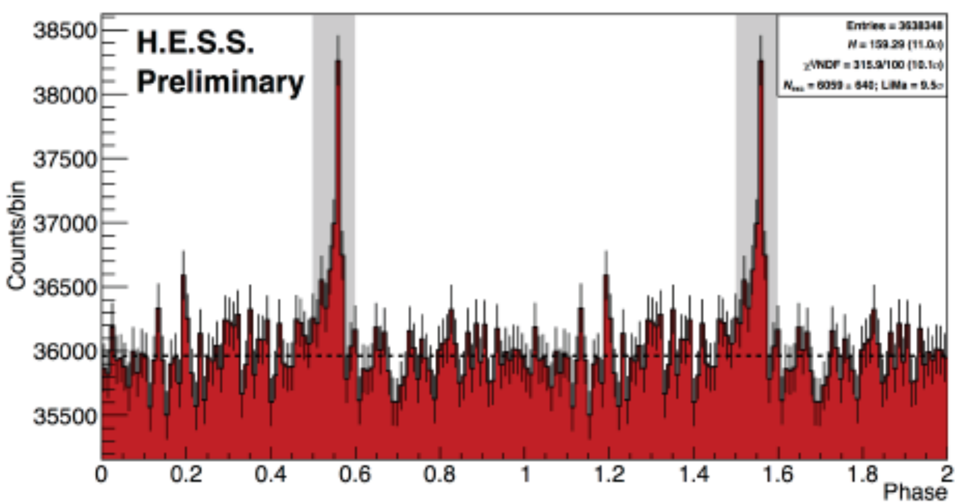
- Sensitivity: effective area (~ number of telescopes, effective area covered)
- Angular resolution: number of telescopes
- Serendipity: FoV, Duty Cycle

Figures of merit - II

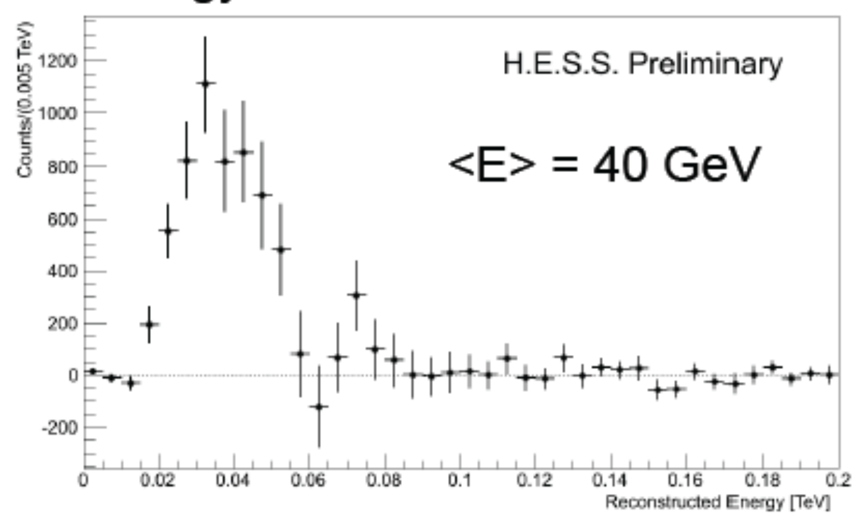
- The threshold is

$$E_{threshold} \propto \sqrt{\frac{\phi \Omega \tau}{\epsilon A}}$$

The Vela pulsar seen with CT5

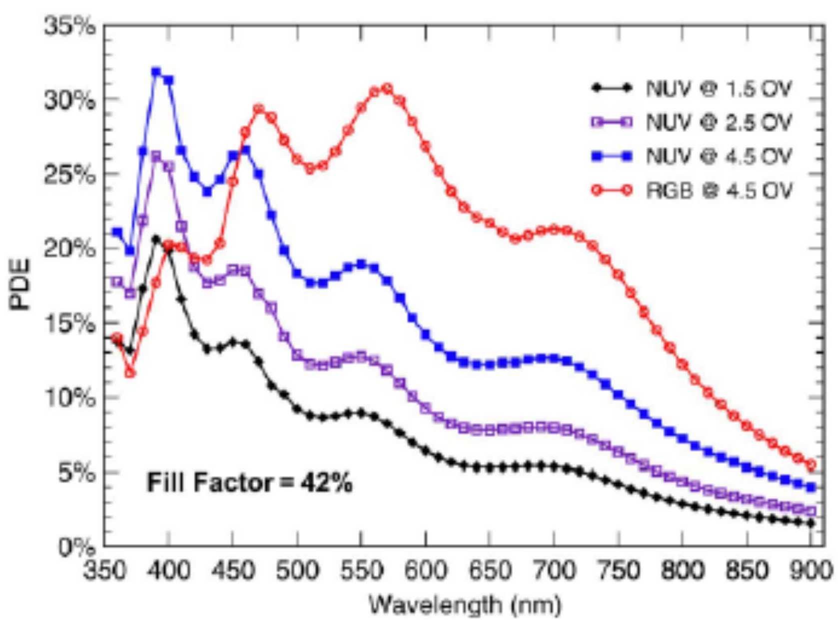


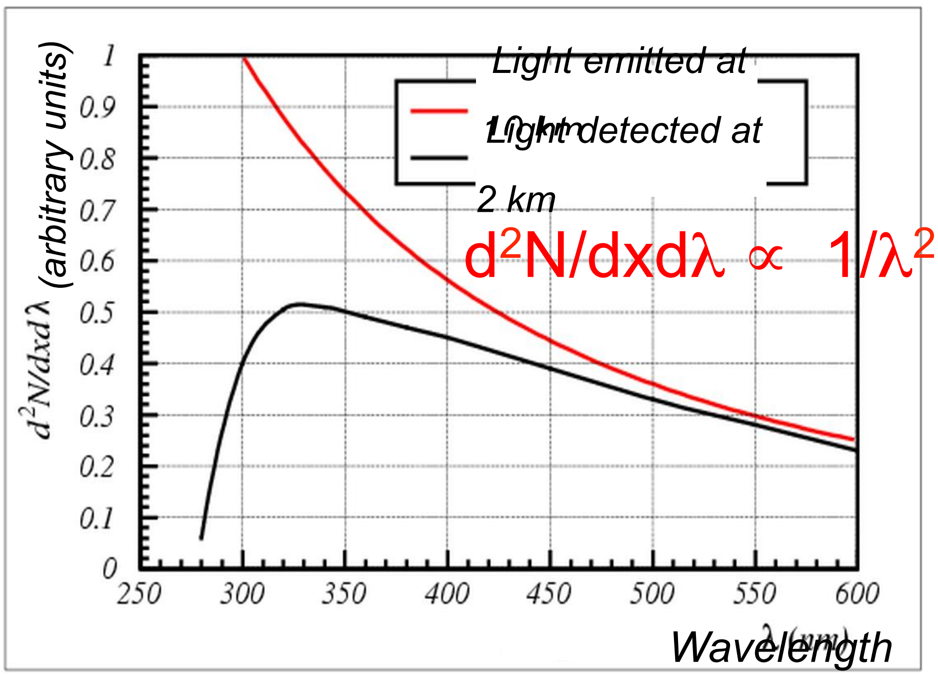
Energy distribution

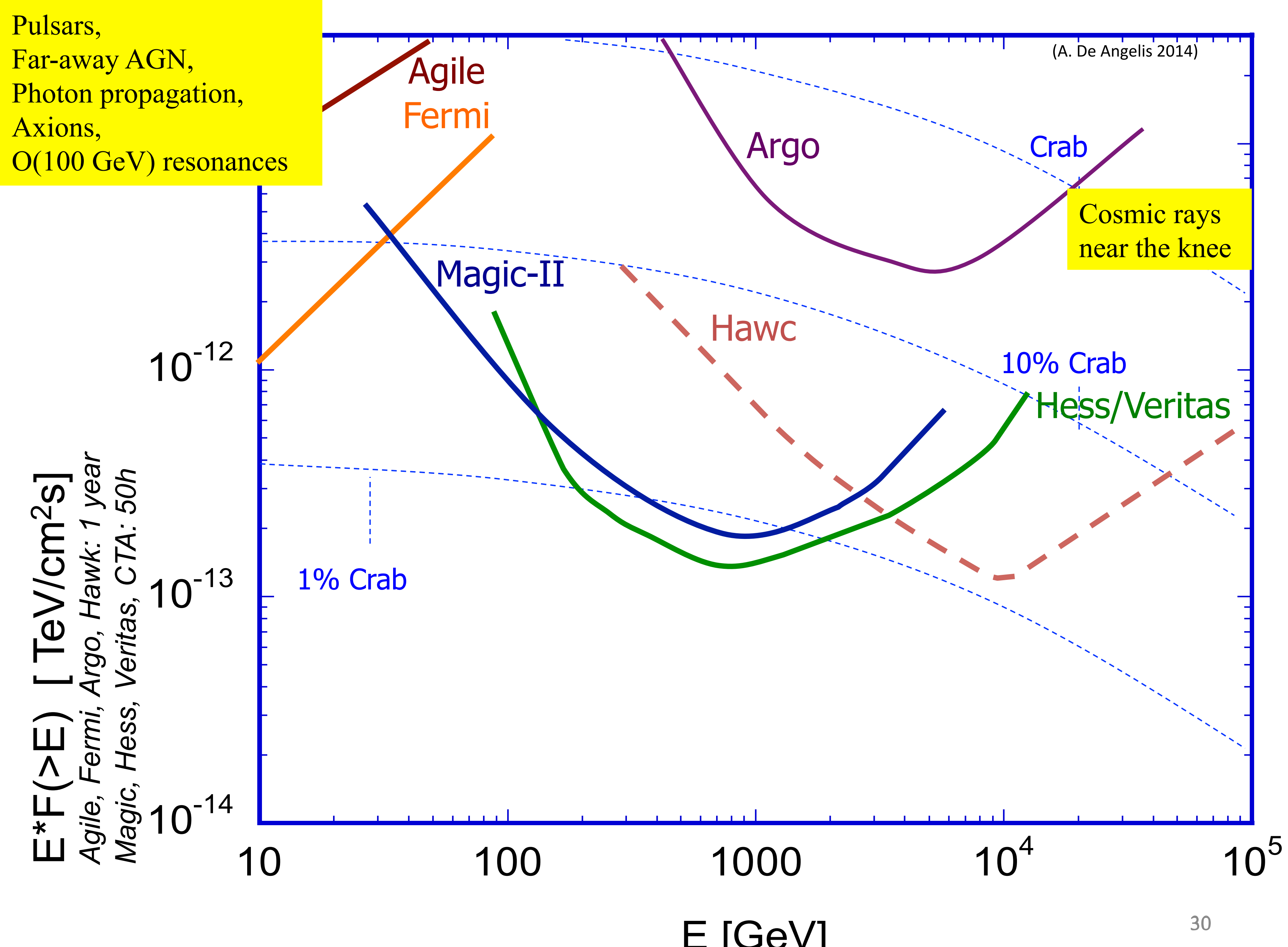


- Future is SiPM
- Technology already competitive
  - Wait some ~ 5 years to let prices to become comparable with PMT

(C. Piemonte et al., FBK)

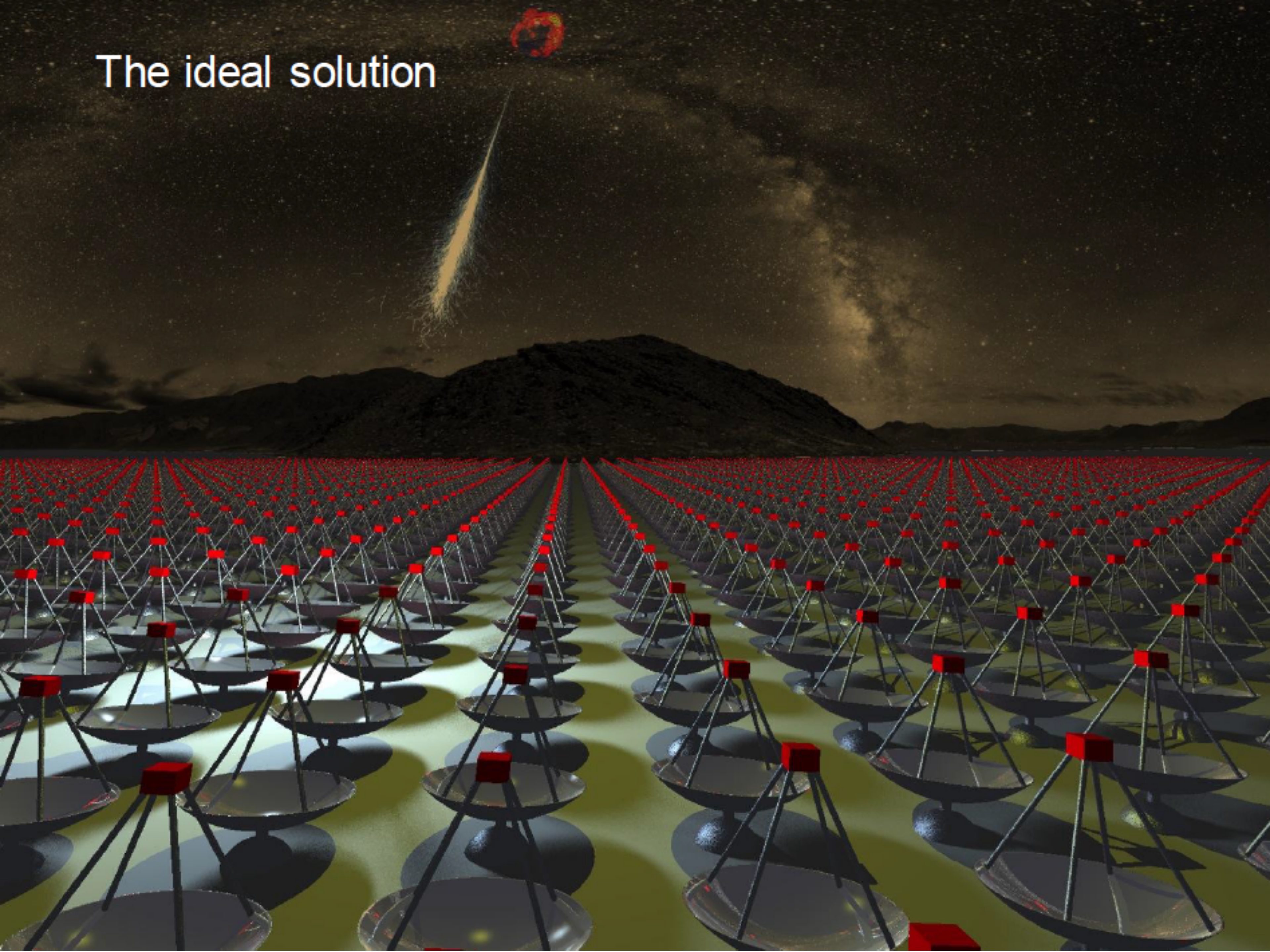






Pulsars,
Far-away AGN,
Photon propagation,
Axions,
O(100 GeV) resonances
(A. De Angelis 2014)
Agile
Fermi
Argo
Crab
Cosmic rays
near the knee
Magic-II
Hawc
10% Crab
Hess/Veritas
1% Crab
E*F(>E) [TeV/cm2s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
10-12
10-13
10-14
10
100
1000
104
105
E [GeV]

The ideal solution



Main physics results and perspectives

- Cosmic Rays

  SNR established as sources of CR up to (almost) the knee

  Go to the PeV?

  Morphology near high density matter (including SMBH)

- Photon propagation

  Transparency of the Universe; density of photons; star count

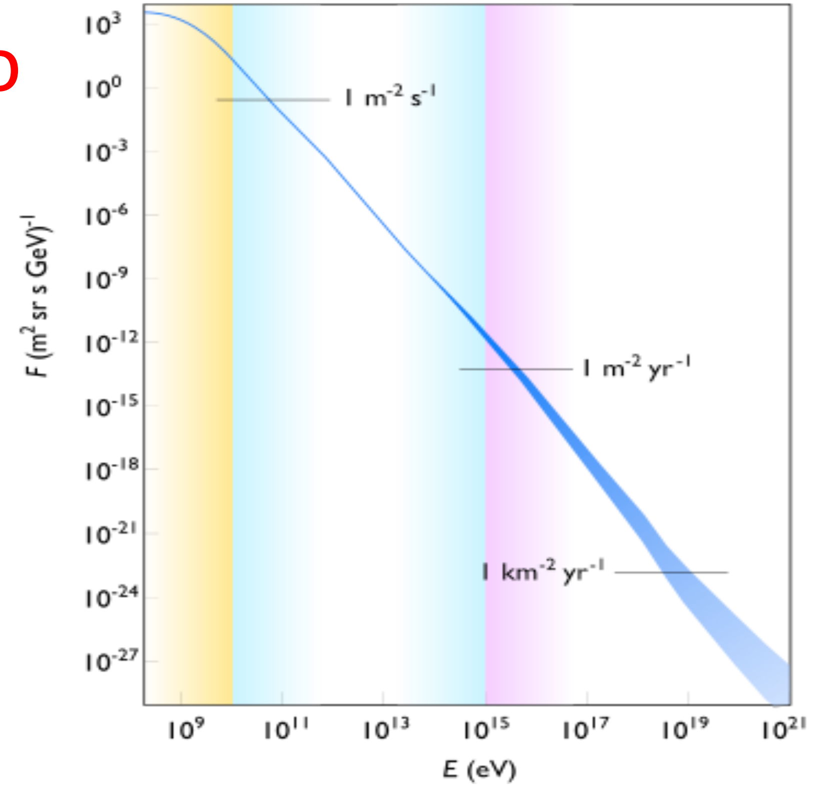
  Energy of the vacuum; ALPs

  Tests of Lorentz Invariance;

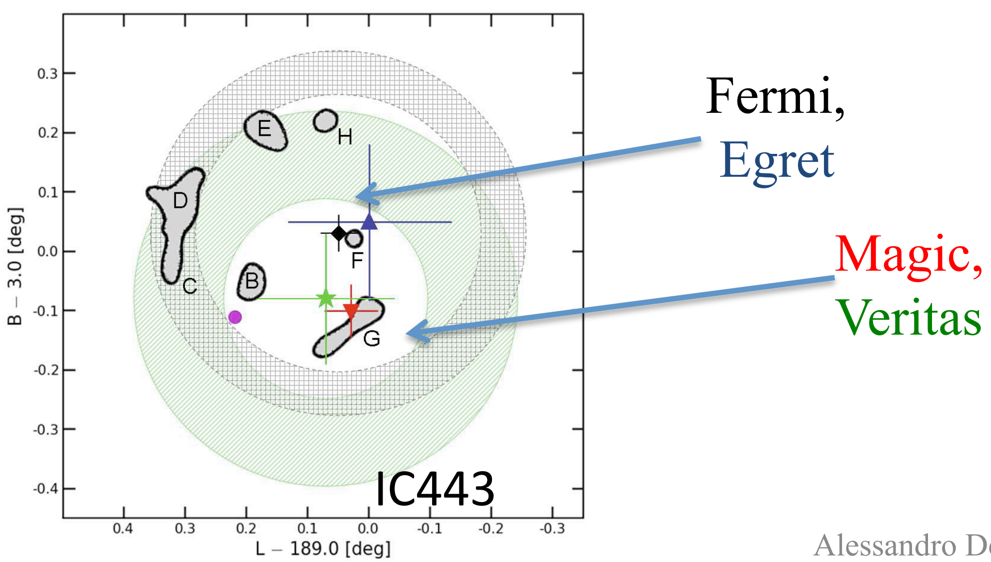
  Cosmology

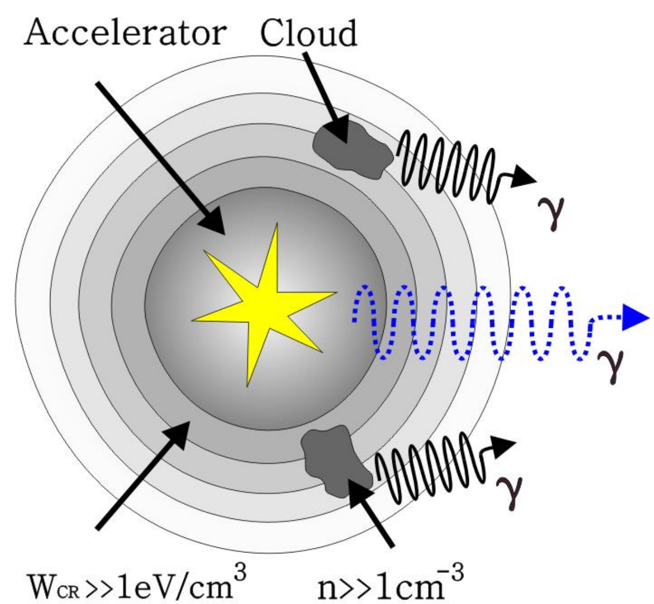
- Search for “WIMP” Dark Matter

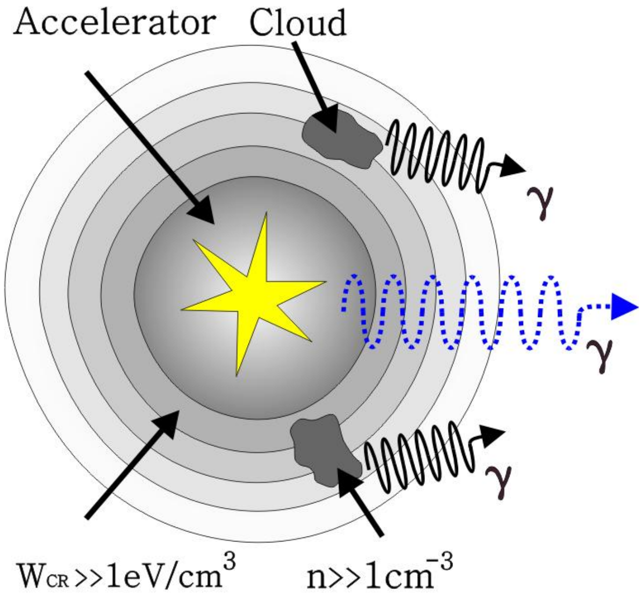
Proof of the origin of CR up to almost the knee

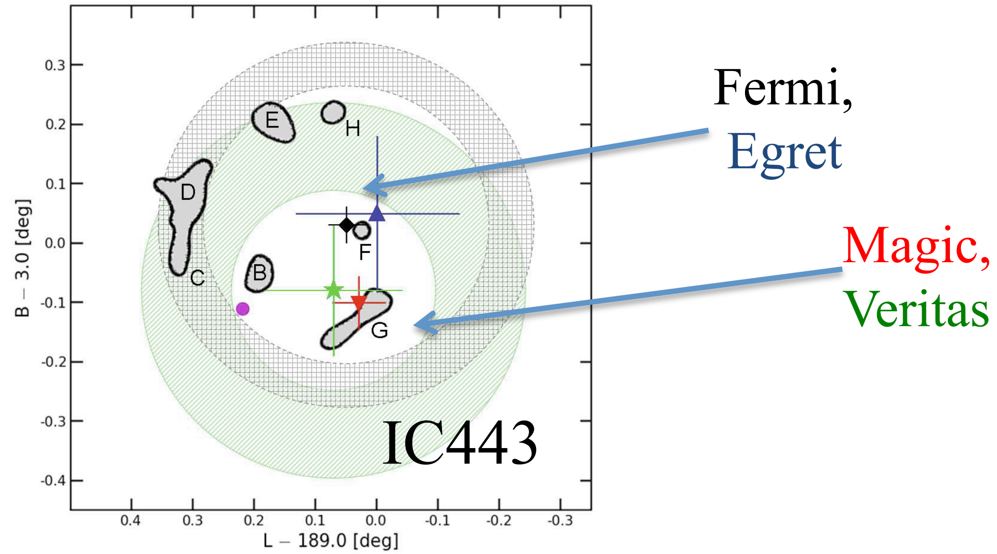


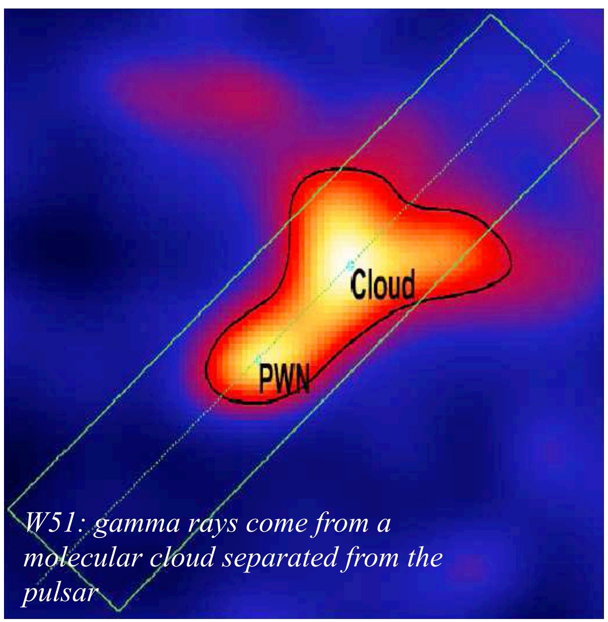
- Evidence that SNR are sources of CR up to ~1000 TeV (almost the knee) came from morphology studies of RX J1713-3946 (H.E.S.S. 2004) with photons
- Striking evidence from the morphology of SNR IC443 (MAGIC + Fermi/Agile 2010)



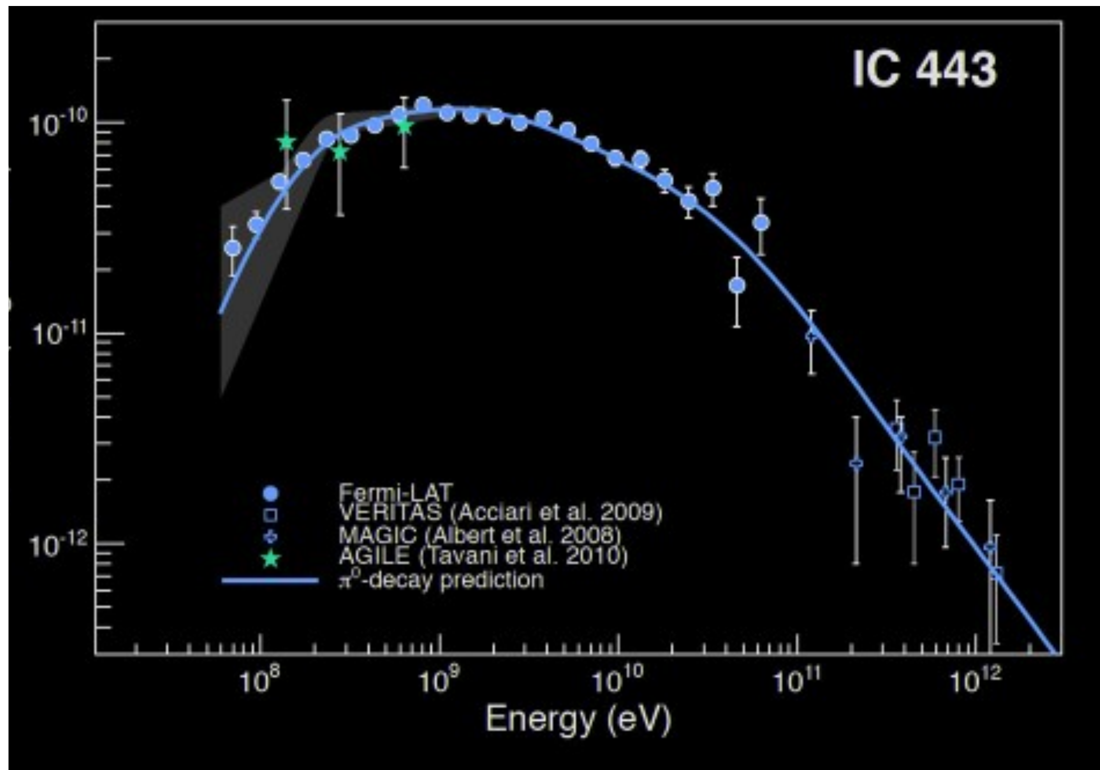








W51: gamma rays come from a molecular cloud separated from the pulsar

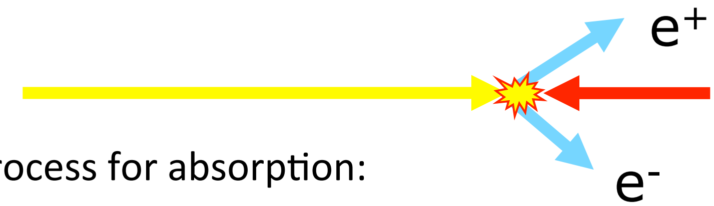


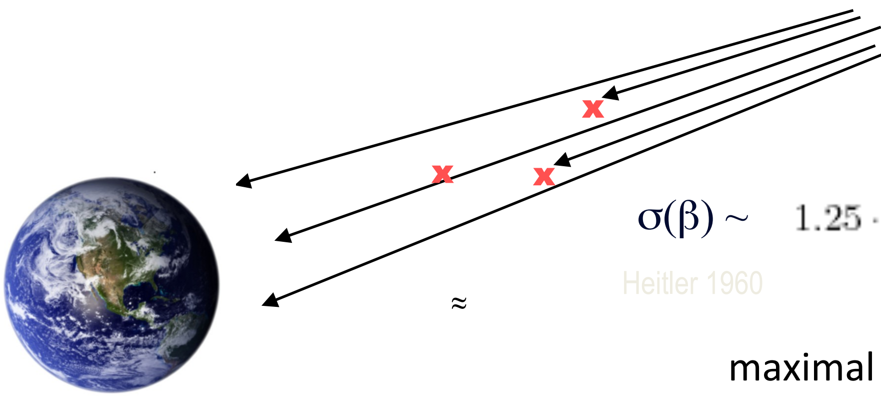
Not yet the PeVatron…

- Present detectors reach a maximum energy of 20 TeV x f ~ 200 TeV
- We cannot say we probe the knee

- We can study only galactic Pevatrons
- Few PeVatrons at North

Propagation of γ-rays





dominant process for absorption:

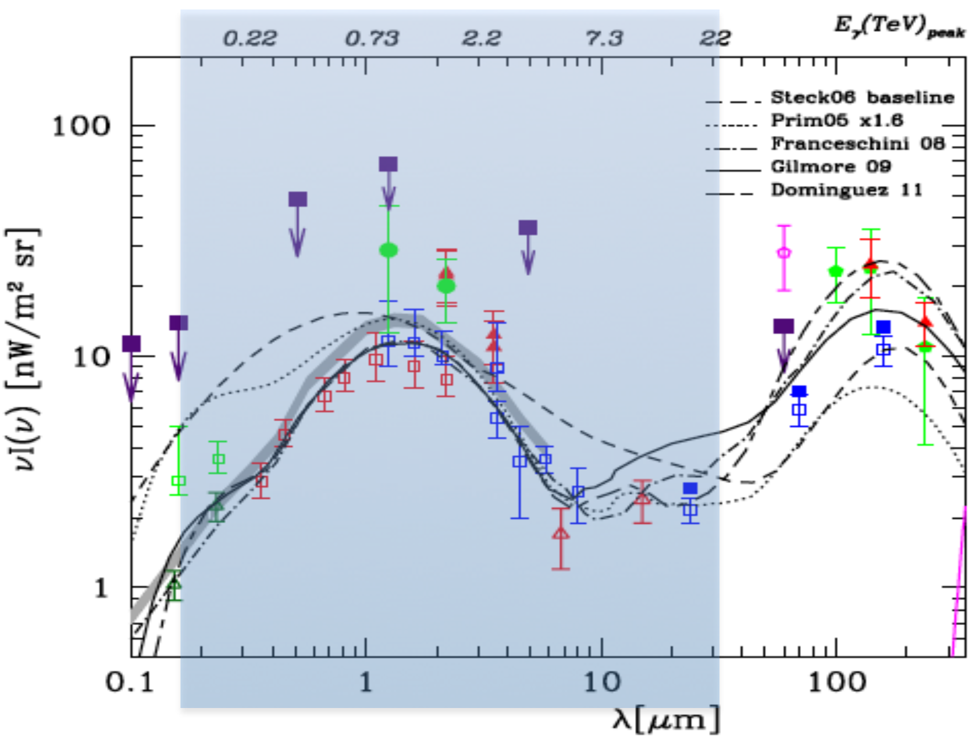
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

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

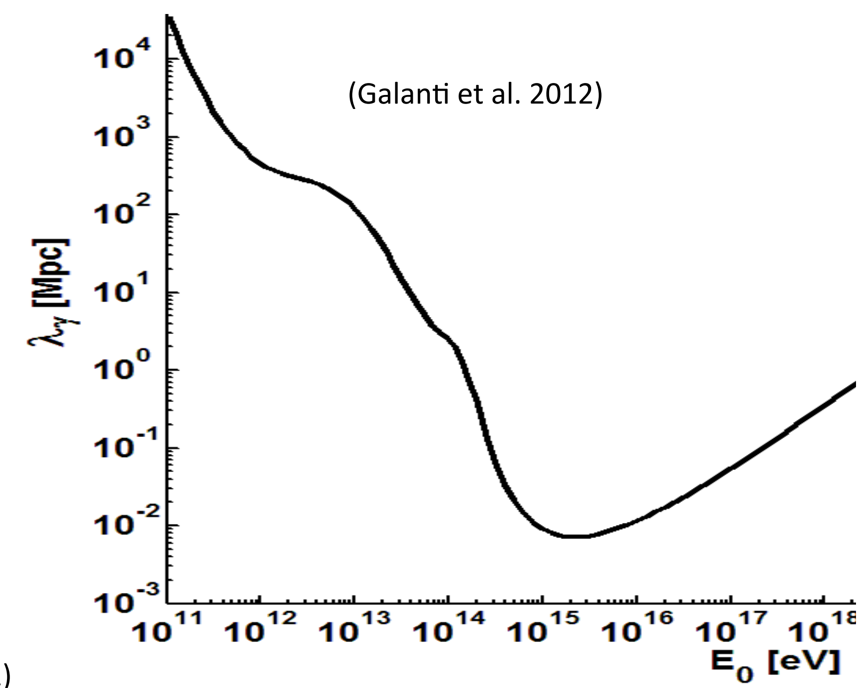
Heitler 1960

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)



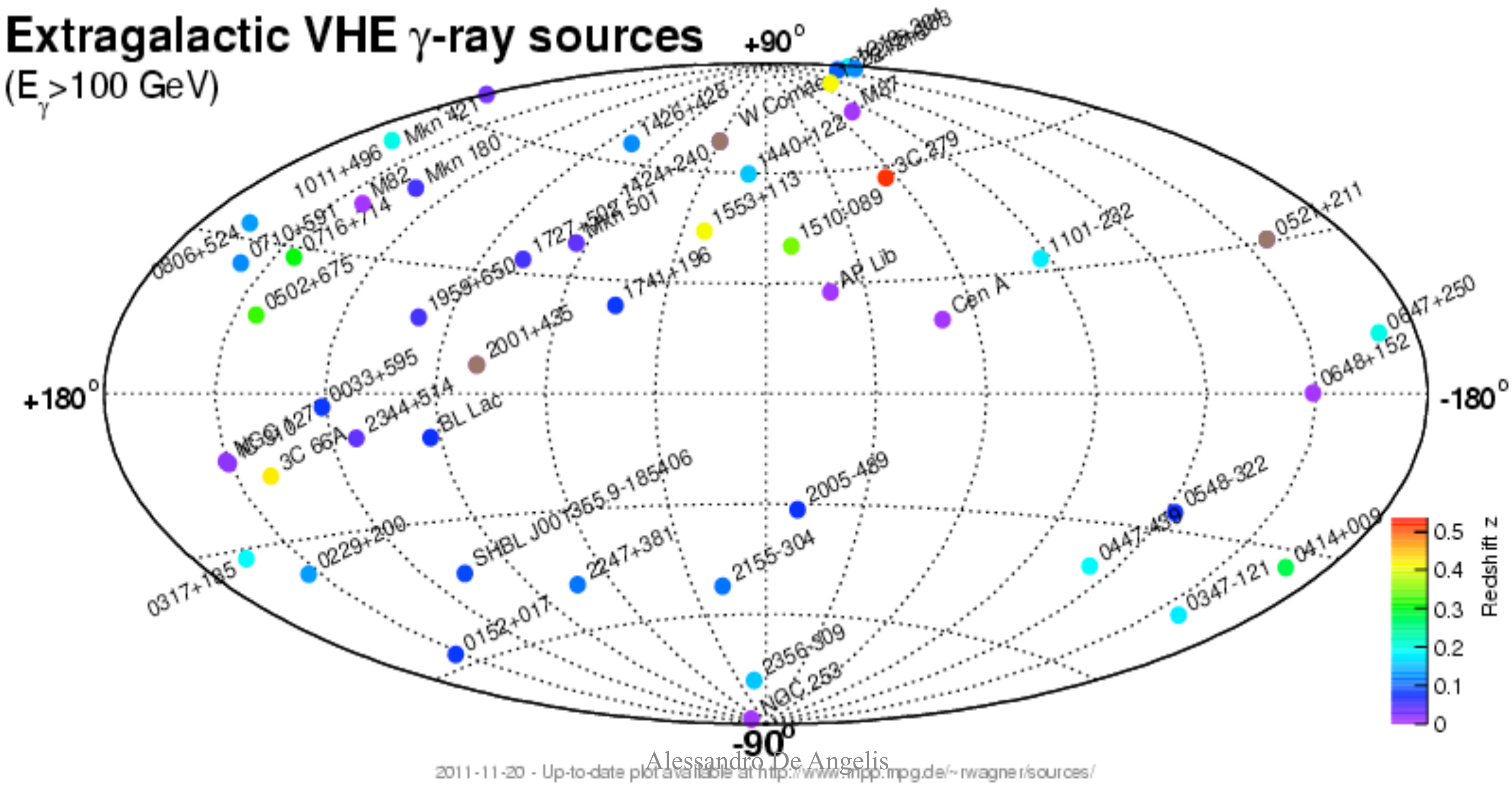
(Galanti et al. 2012)

Extragalactic Sources

~50 Sources

...

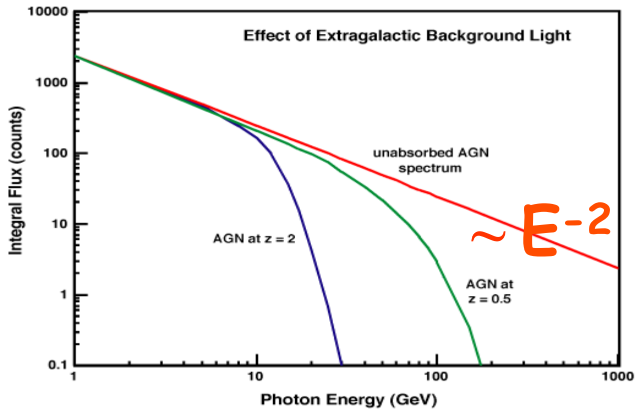
1ES 1011+496	**z=0.21**	**MAGIC 2007**
1ES 0414+009	z=0.29	HESS/Fermi 2009
S5 0716+71	**z=0.31±0.08**	**MAGIC 2009**
1ES 0502+675	z=0.34	VERITAS 2009
PKS 1510-089	z=0.36	HESS 2010
4C +21.43	**z=0.43**	**MAGIC 2010**
3C 66A	**z=0.44**	**VERITAS 2009**
3C 279	**z=0.54**	**MAGIC 2008**

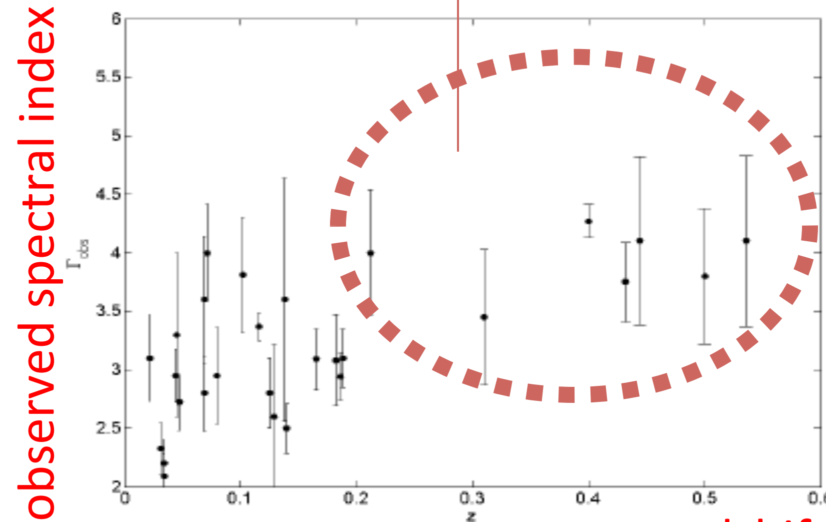


Are our AGN observations consistent with theory?

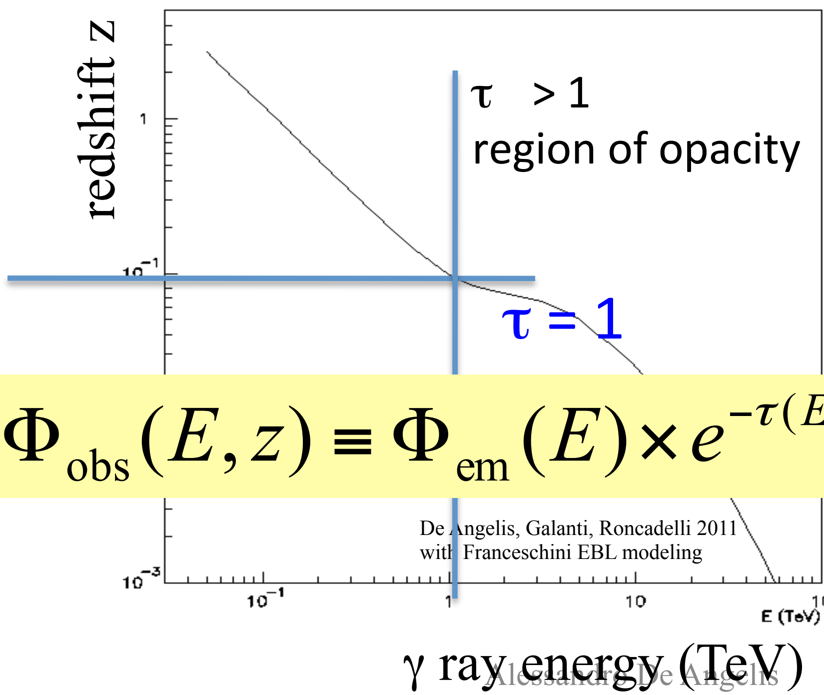
Selection bias?
New physics ?

Measured spectra affected by attenuation in the EBL:

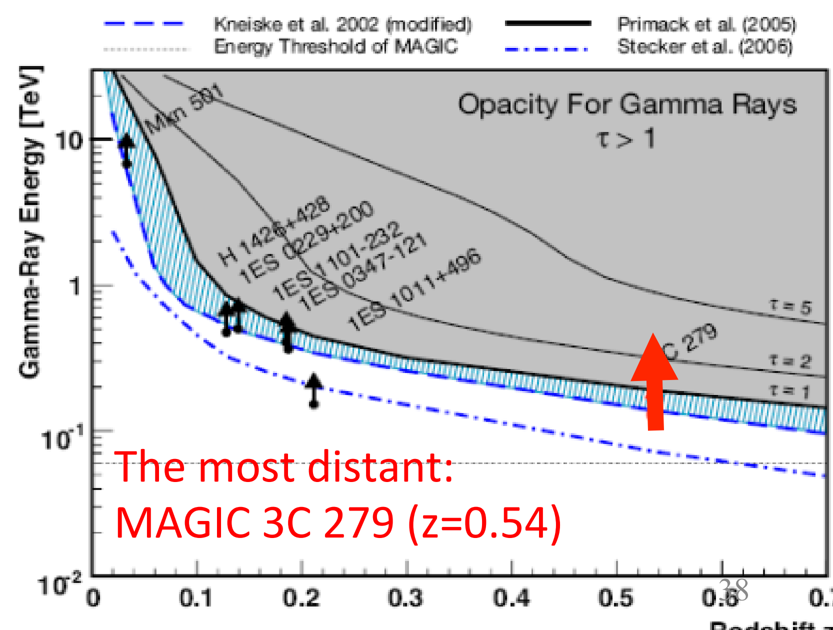




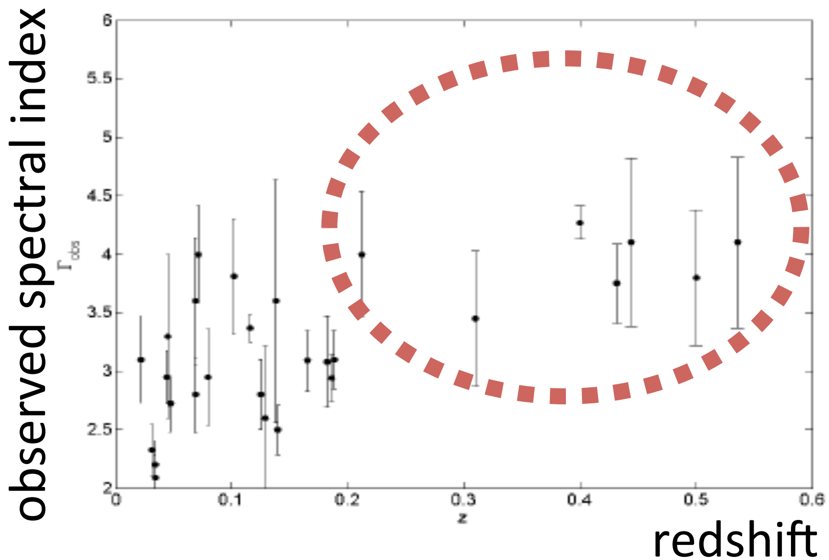
(DA, Galanti, Roncadelli; PRD 2011)



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



If there is a problem



Explanations from the standard ones

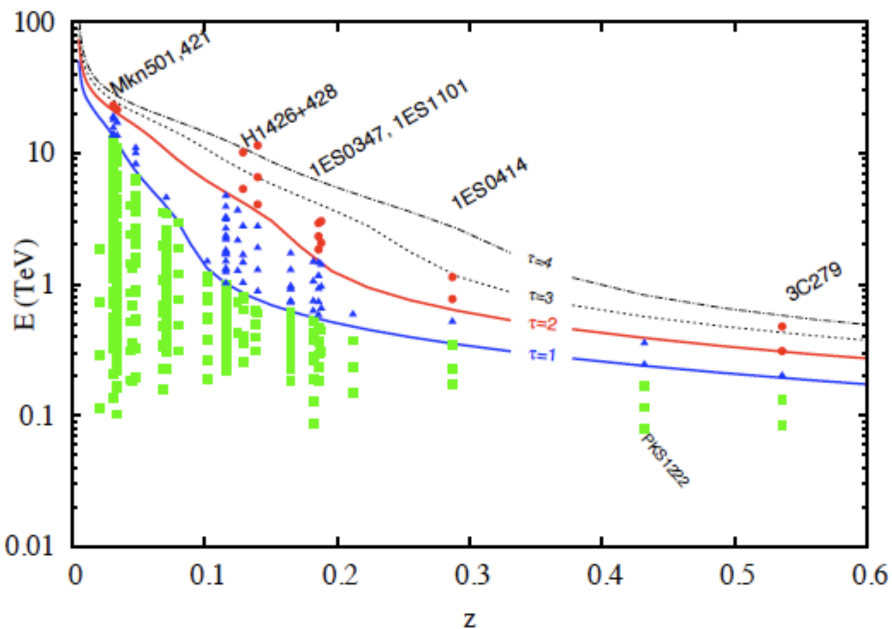
- very hard emission mechanisms with intrinsic slope < 1.5 (Stecker 2008)
- Very low EBL, plus observational bias, plus a couple of “wrong” outliers

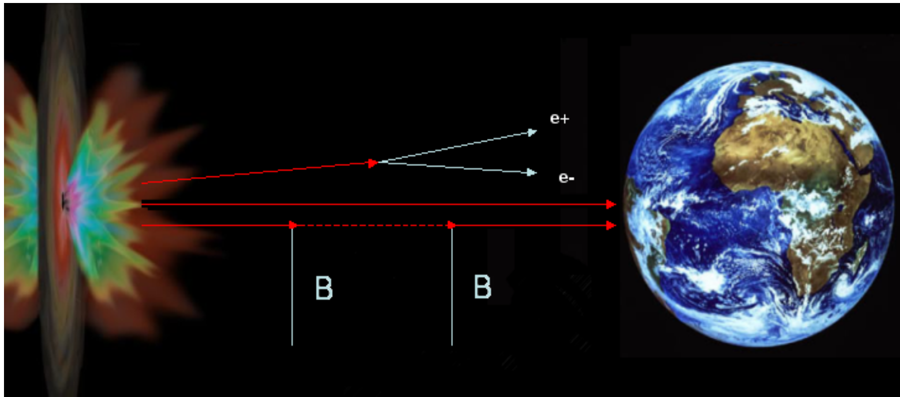
to almost standard

- 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

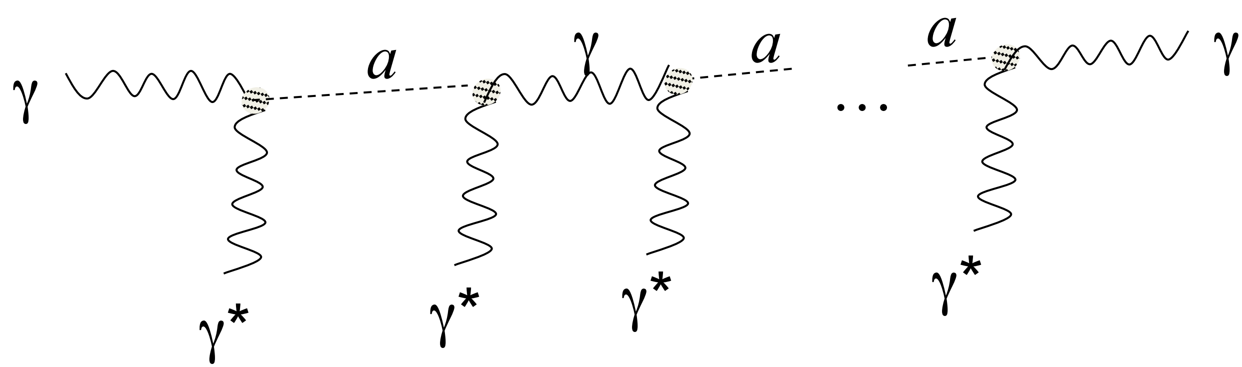
- Oscillation to a light “axion”? (DA, Roncadelli & MAnsutti [DARMA], PRD2007, PLB2008)
- Axion emission (Simet+, PRD2008)
- A combination of the above (Sanchez Conde et al. PRD 2009)





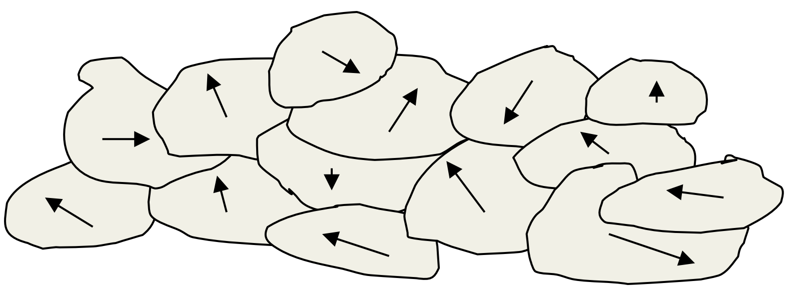
The photon-axion mixing mechanism

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



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



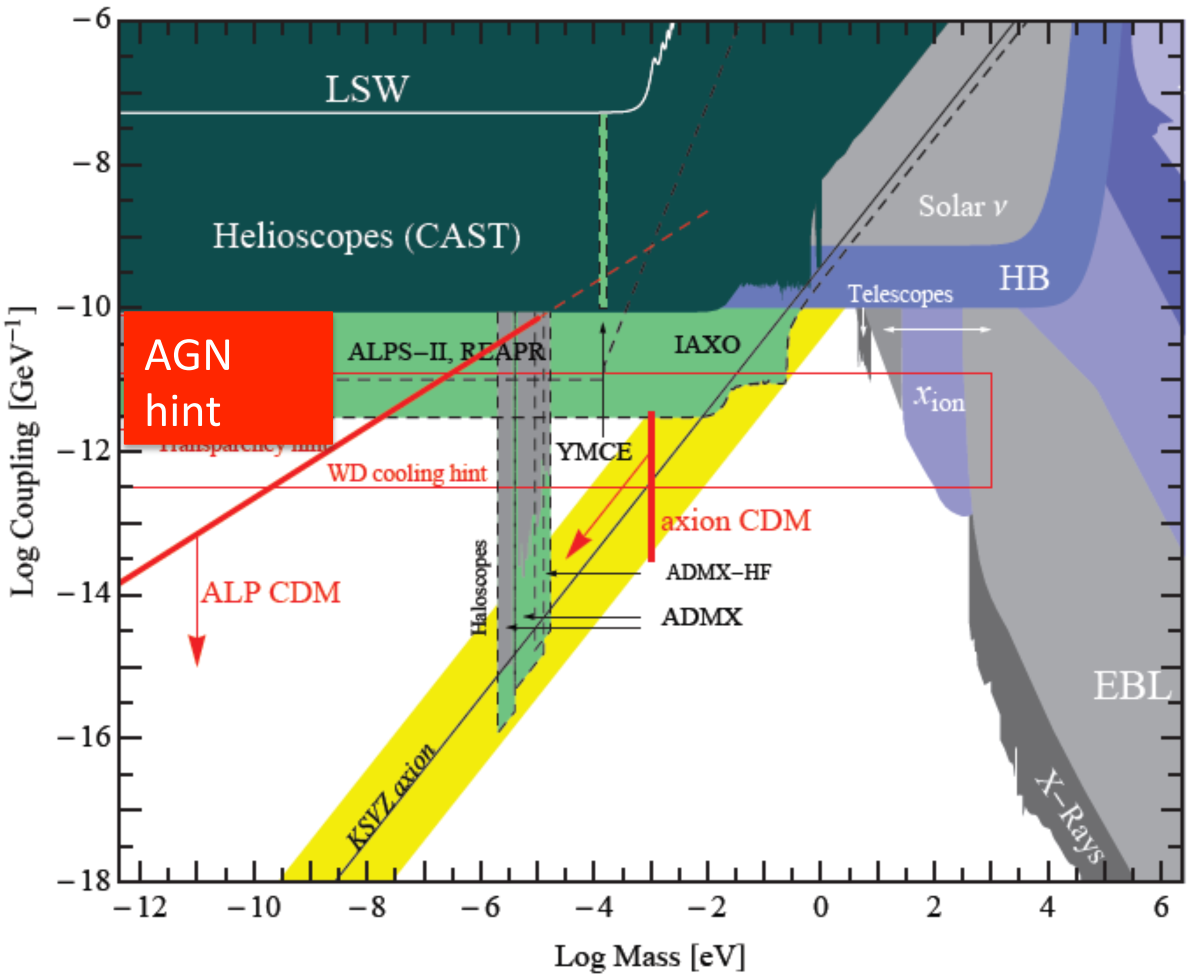
$$P_{\gamma\to a} \approx NP_1$$

$$P_1 \approx \frac{g_{a\gamma}^2 B_T^2 s^2}{4} \approx 2\times10^{-3}\left(\frac{B_T}{1\text{nG}}\frac{s}{1\text{Mpc}}\frac{g_{a\gamma}}{10^{-10}\,\text{GeV}^{-1}}\right)^2$$

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

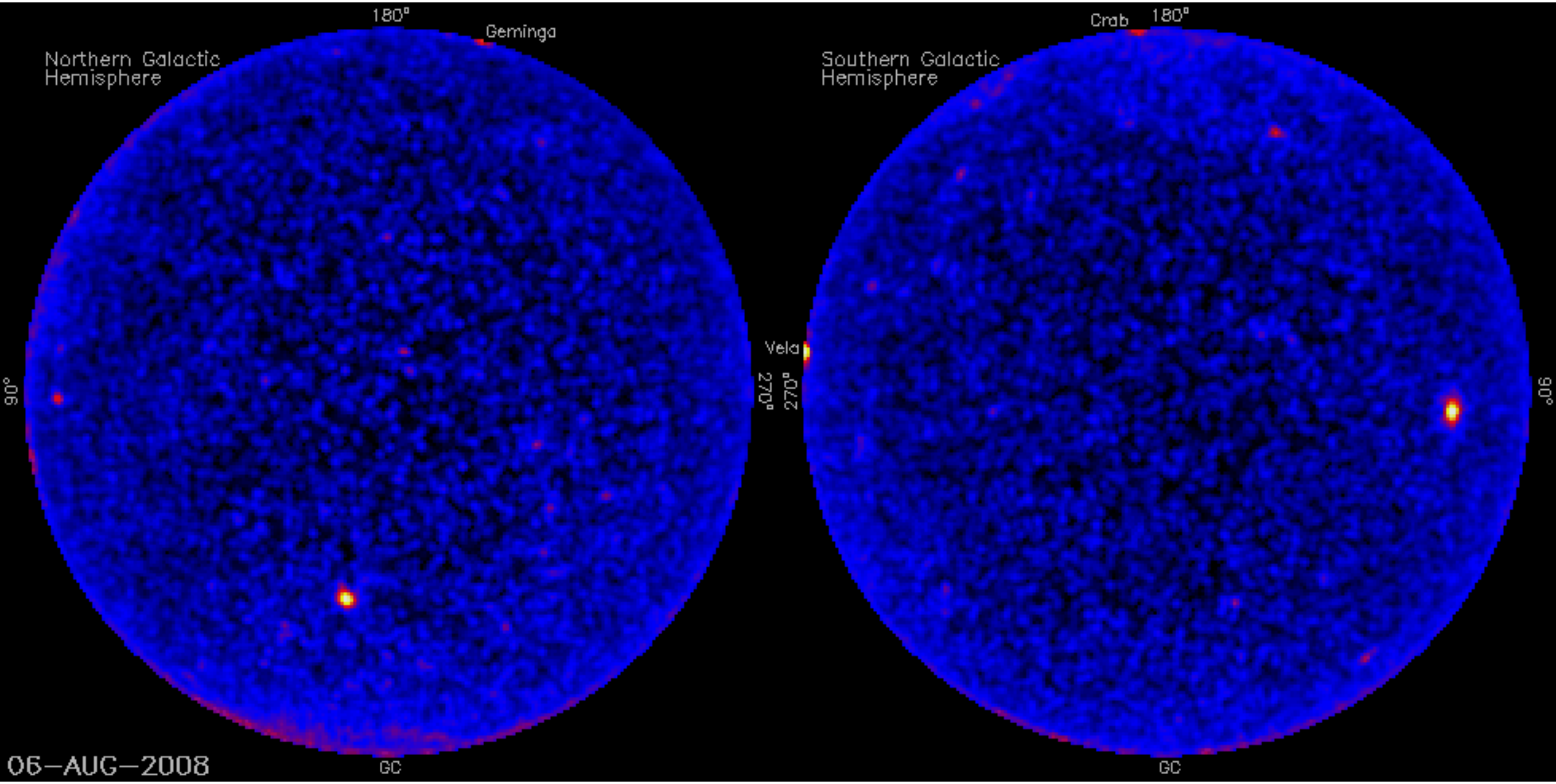
Axions

Parameter space for axions or axion-like particles

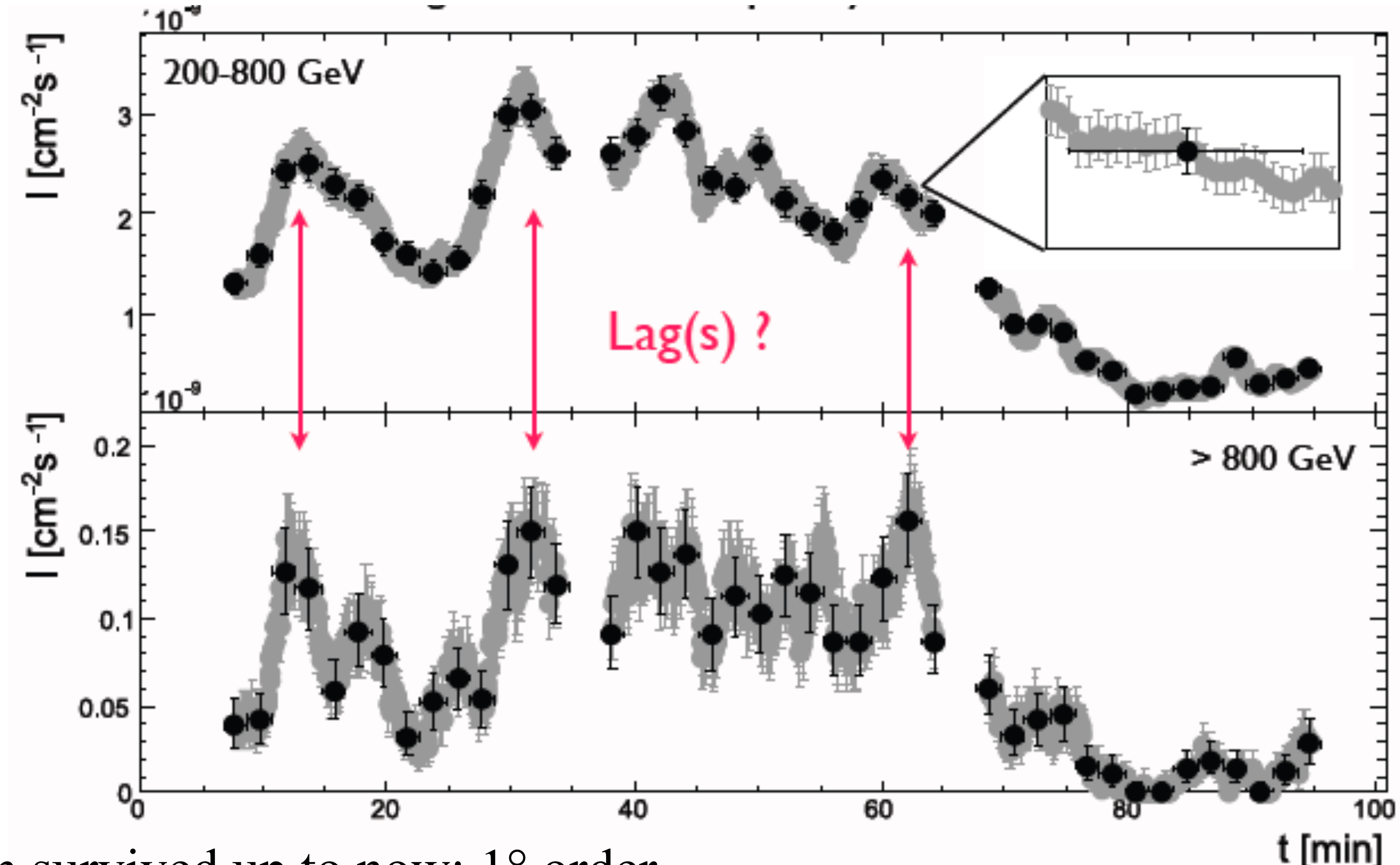


- Experimentally excluded
- Astronomy constraints
- Cosmology constraints
- Sensitivity of planned experiments

Variability (down to the ~10s scale)



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!

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

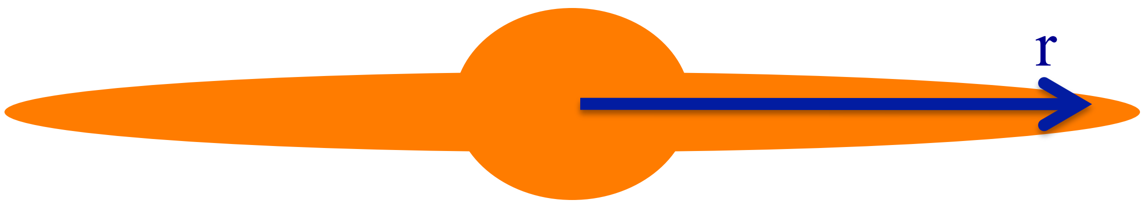
$E_{s2} > 6\ 10^{10}$ GeV ($\sim 10^{-9}$ M_P) (HESS, MAGIC)

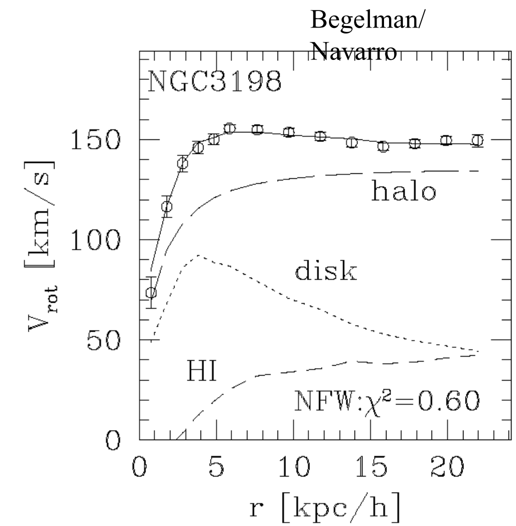
A no-loss situation:

if propagation is standard, cosmology with AGN

The Dark Matter Problem (see Morselli)

Measure rotation curves for galaxies:



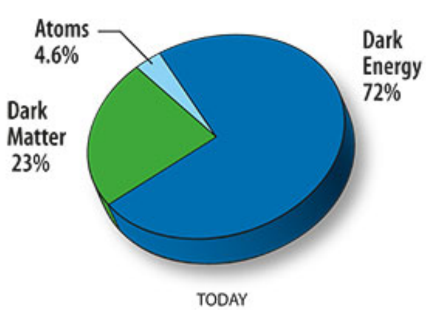


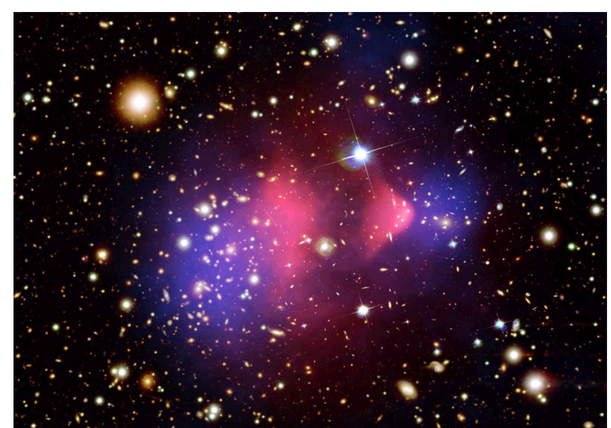
For large r, we expect:

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

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)





(B. Atwood)

Which signatures for gamma detectors?

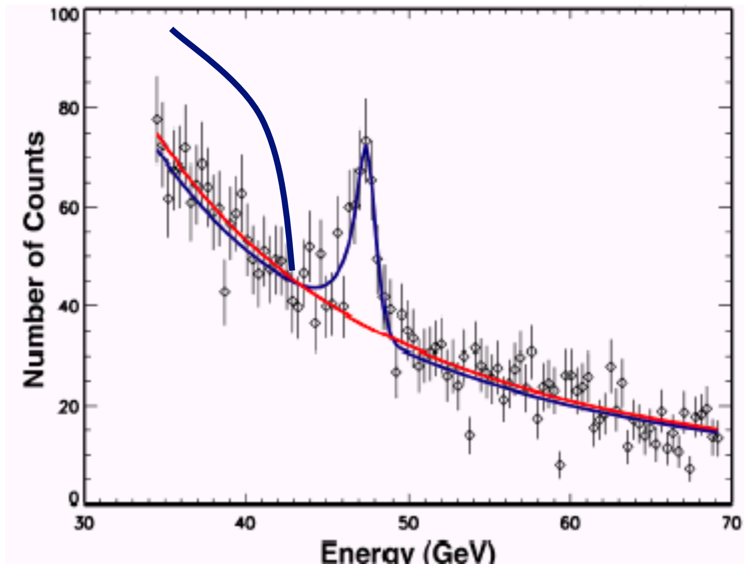
- Self-annihilating WIMPs, if Majorana (as the neutralino in SUSY), can produce:
  - Photon lines ($\gamma\gamma$, γZ)
  - Photon excess at $E < m$ from hadronization
- Excess of antimatter (annihilation/decay)
- Excess of electrons, if unstable

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

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

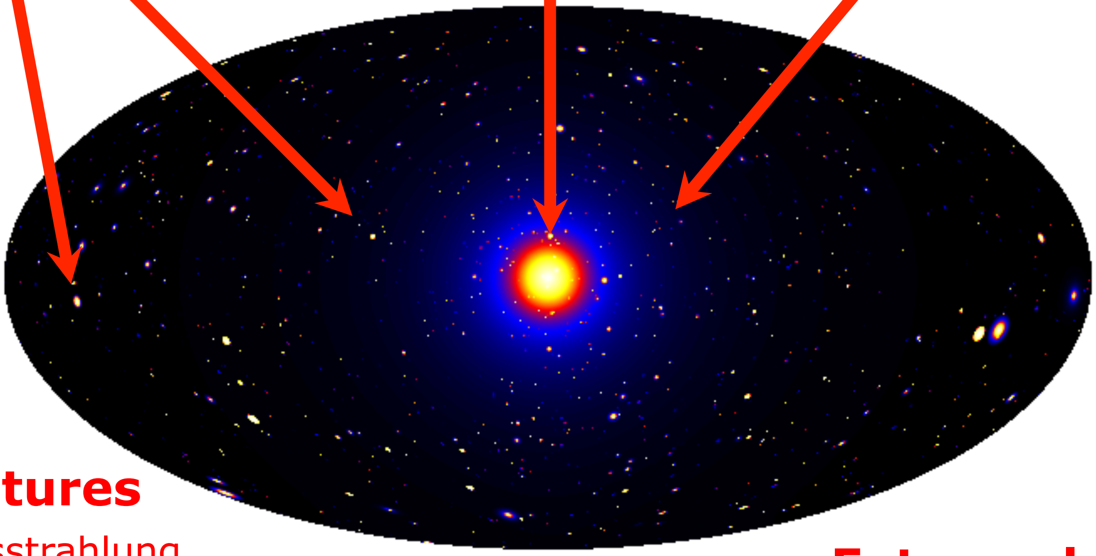
Satellites

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

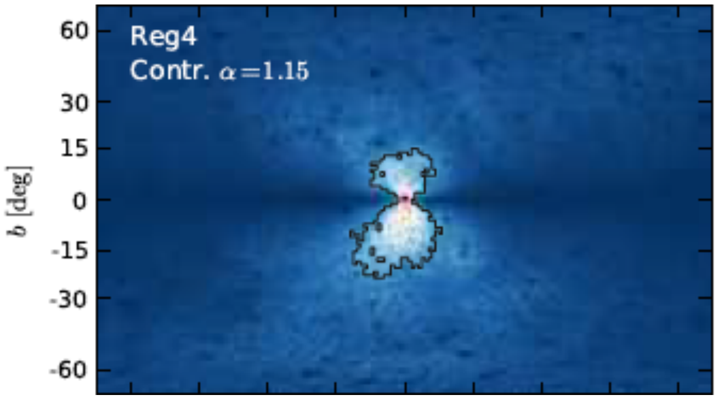
Extra-galactic

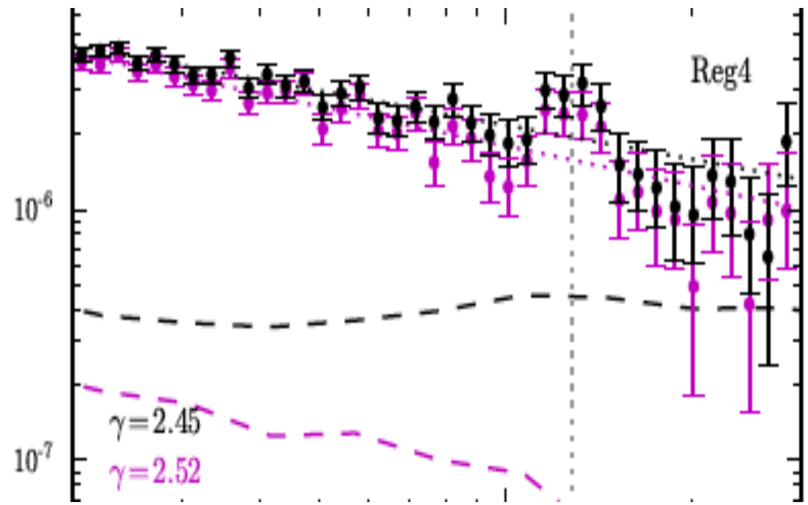
Large statistics, but astrophysics, galactic diffuse backgrounds

No signal from possibly expected sources

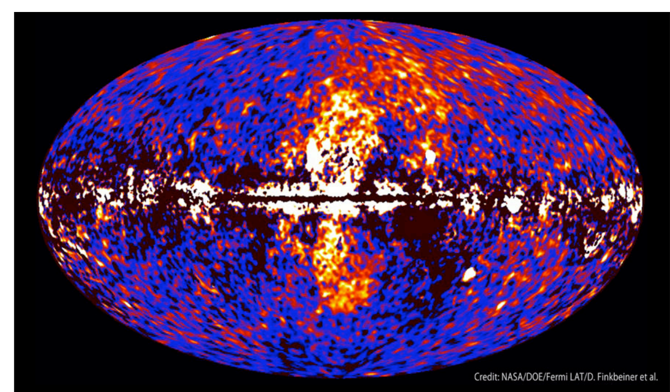
Data-driven line searches

- 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 <u>present</u> IACT: bad.
LHC? <u>Future Cherenkov?</u>



DM: interplay with accelerators

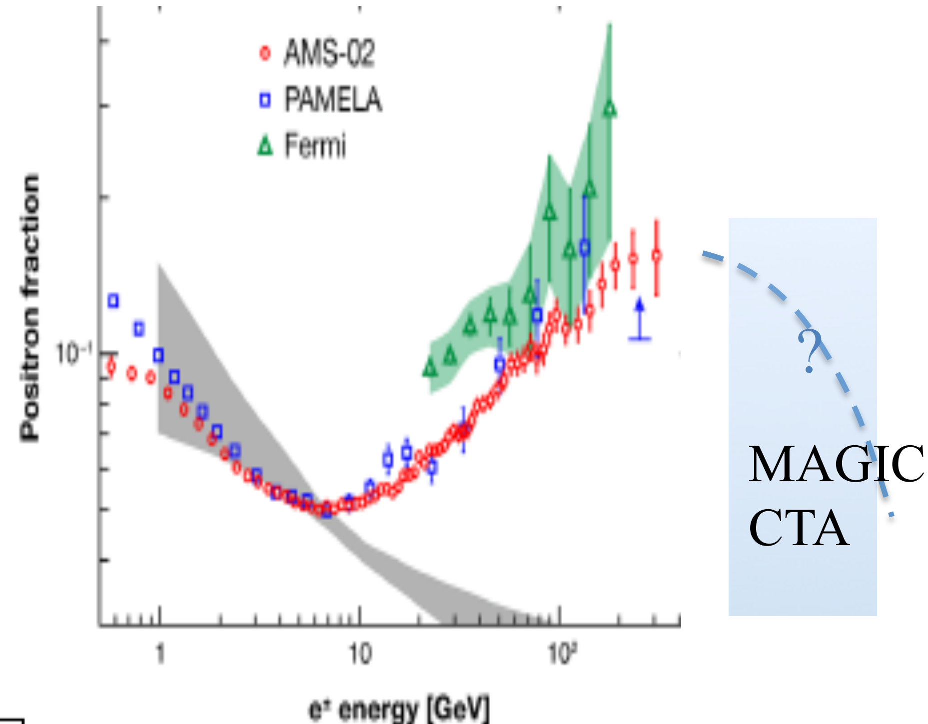
- LHC may find candidates but cannot prove that they are the observed Dark Matter, nor localize it
- *Direct searches (nuclear recoil) may recognize local halo WIMPs but cannot prove the nature and composition of Dark Matter in the sky*

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

Antimatter: the PAMELA anomaly

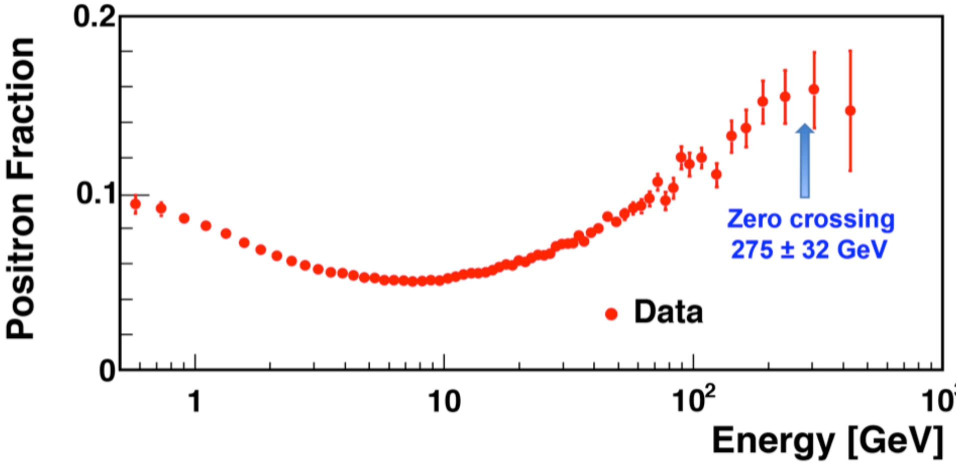
Moon shadow observation mode developed for the MAGIC telescopes [MAGIC ICRC 2011]

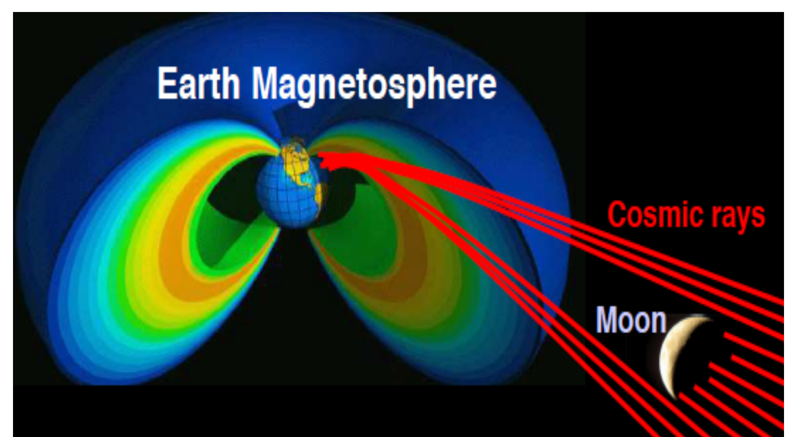
sensitivity (50h): 300-700GeV: ~4.4% Crab measurement possible in few years



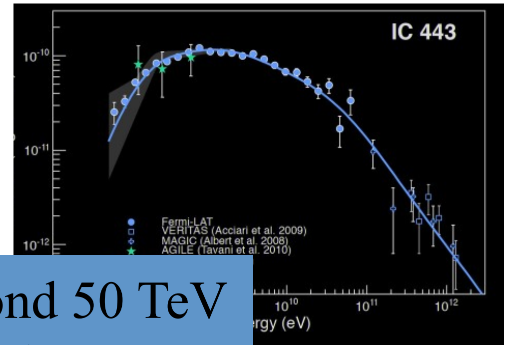
probe e+/e- ratio at 300-700 GeV

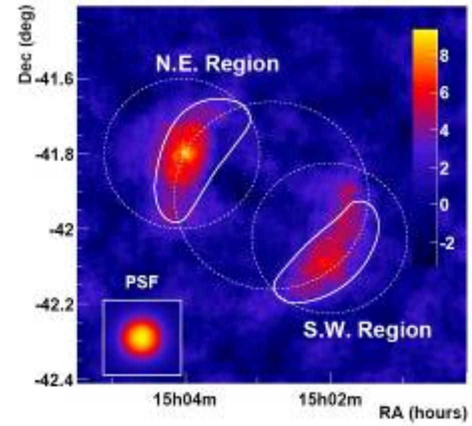
BUT: partly scooped by AMS



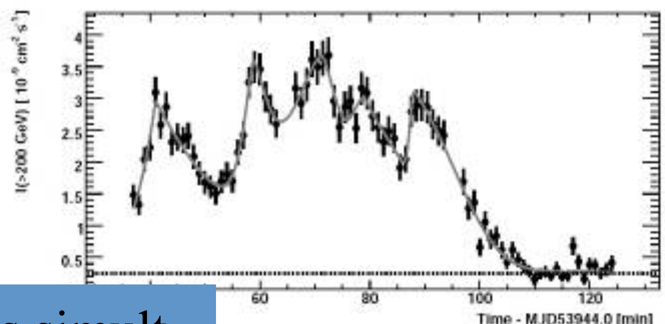


A wish list for the future

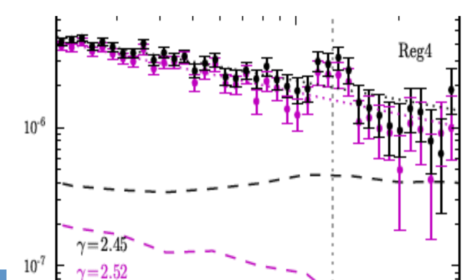




- Galactic sources & CR
  - extend E range beyond 50 TeV
  - better angular resolution
  - larger FOV



- AGN & gamma prop.
  - monitor many objects simult.
  - extend E range under 50 GeV
  - 10x sources

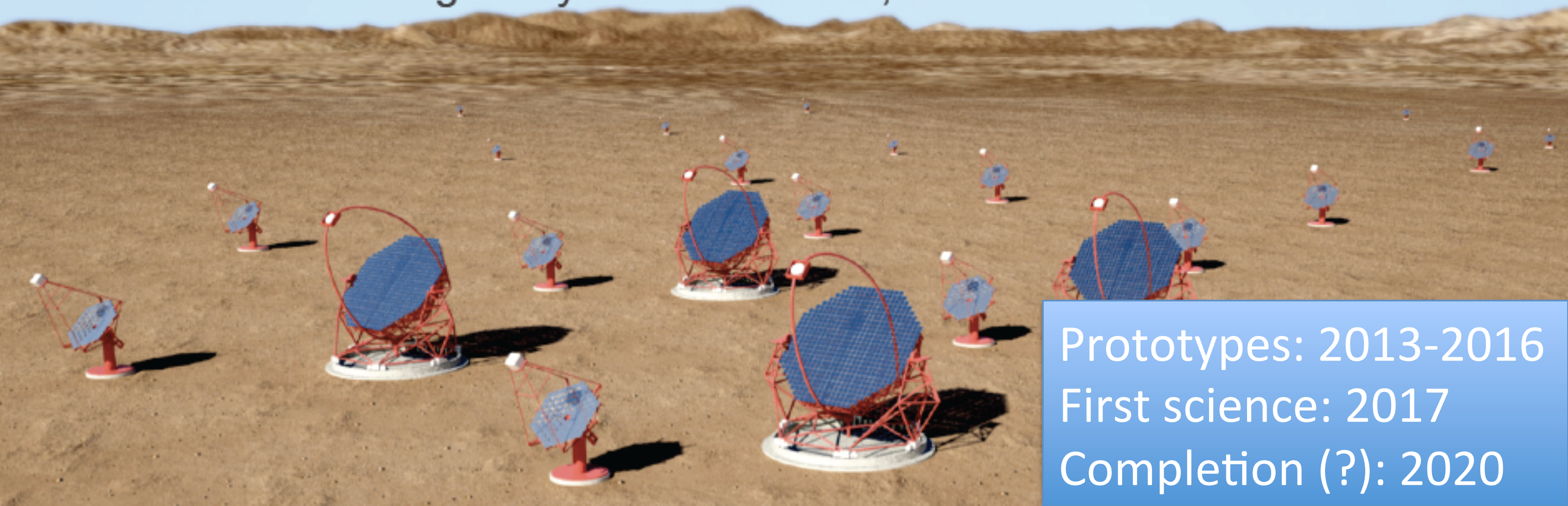


- New particles, new phenomena
  - dark matter and astroparticle physics
    - better flux sensitivity
    - lower threshold

Solution I: Imaging Cherenkov

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



Prototypes: 2013-2016
First science: 2017
Completion (?): 2020

The Cherenkov Telescope Array concept

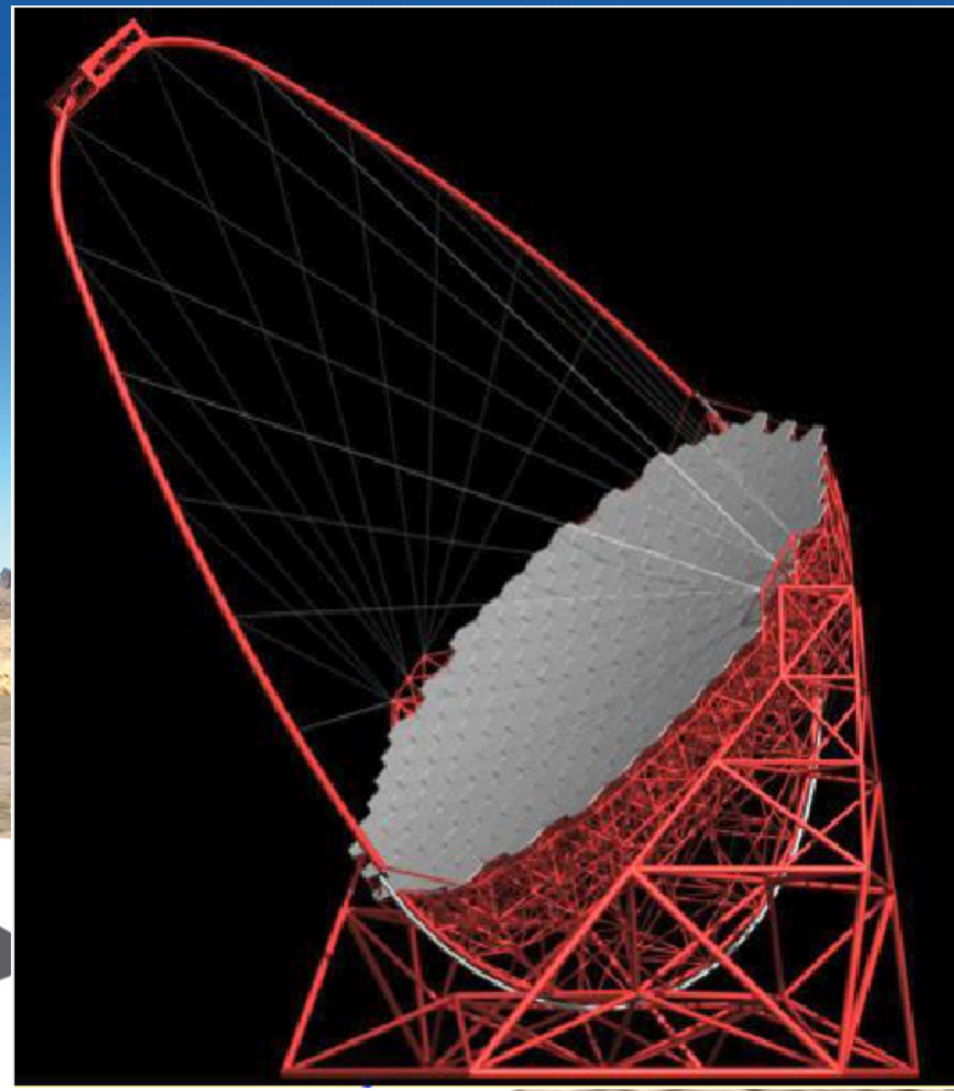
Low energy

Few 23 m telescopes

4.5^{o} FoV

~2000 pixels

~ 0.1^{o}



The Cherenkov Telescope Array concept

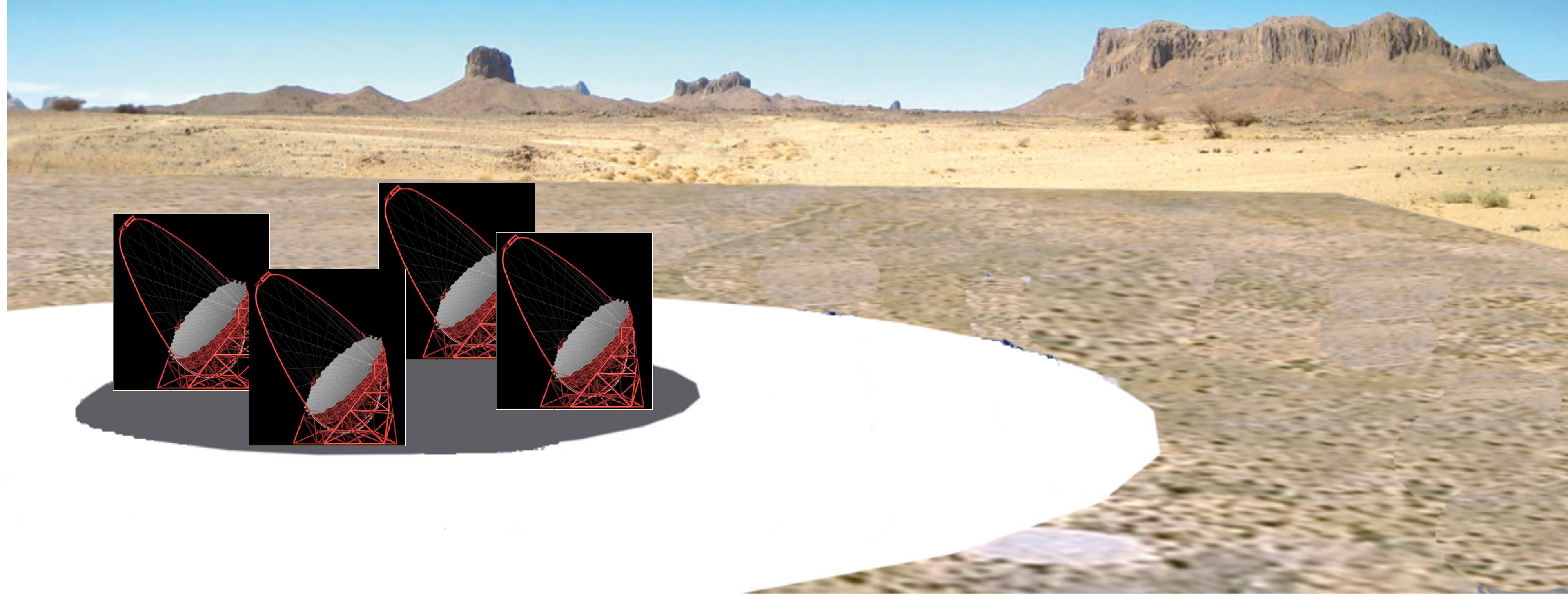
Low energy

Few 23 m telescopes

4.5° FoV

~2000 pixels

~ 0.1°



The Cherenkov Telescope Array concept

Medium energy

About twenty 12 m telescopes

~8° FoV

~2000 pixels

~ 0.2°

The Cherenkov Telescope Array concept

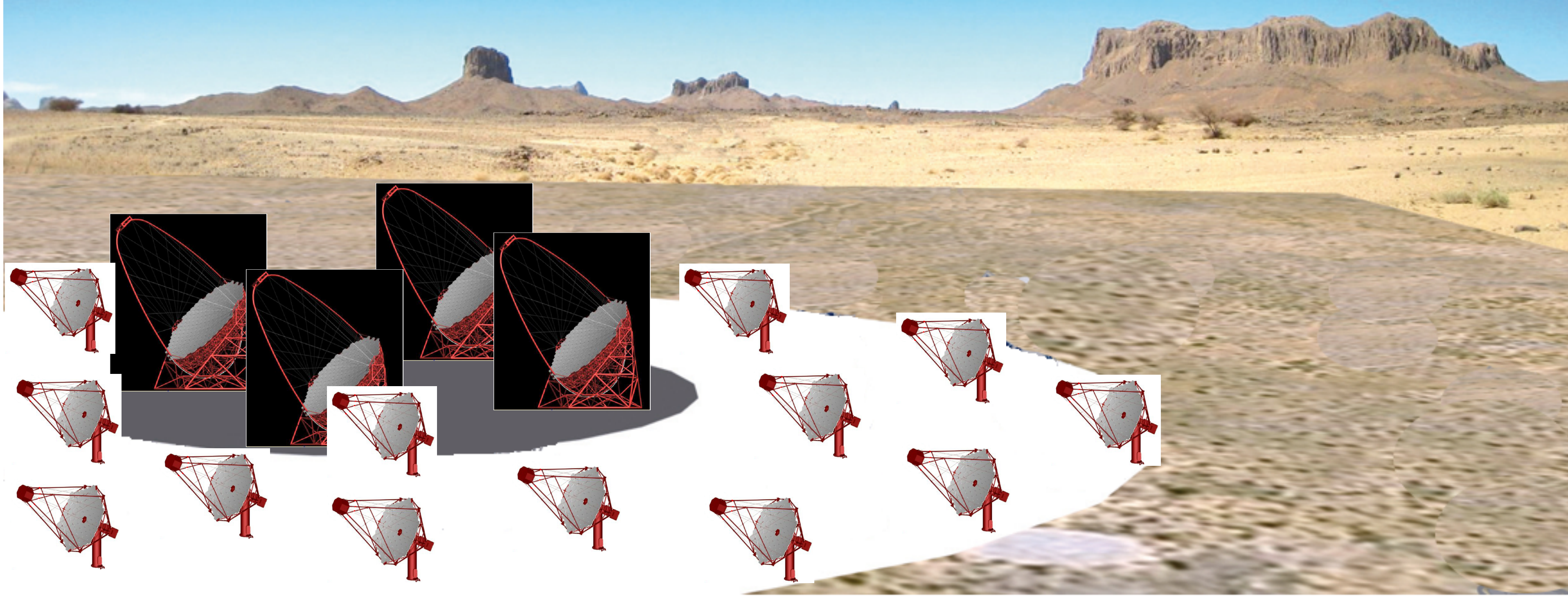
Medium energy

About twenty 12 m telescopes

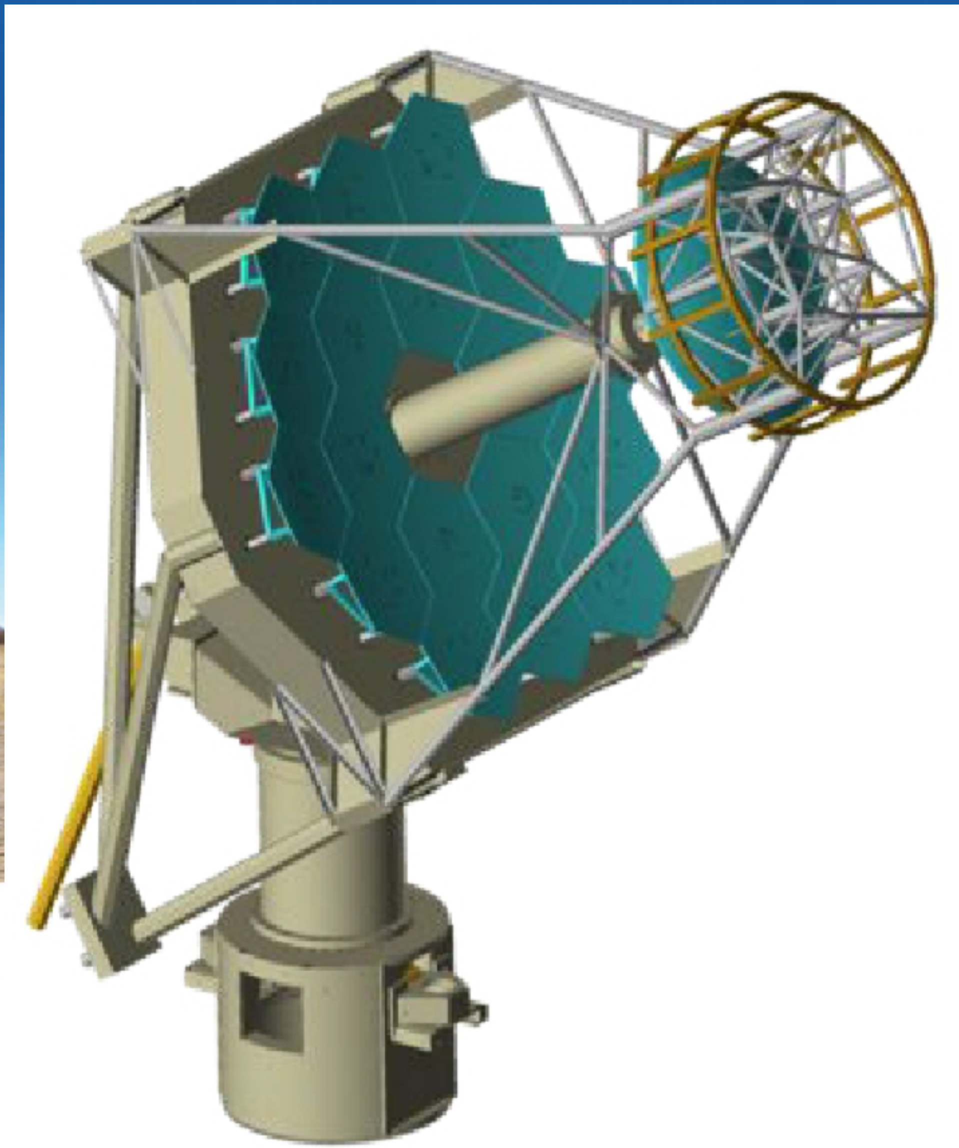
~8° FoV

~2000 pixels

~ 0.2°



The Cherenkov Telescope Array concept



High energy
Fifty + 4.3 m telescopes
9.6° FoV
Compact Silicon Camera
~ 0.25

The Cherenkov Telescope Array concept

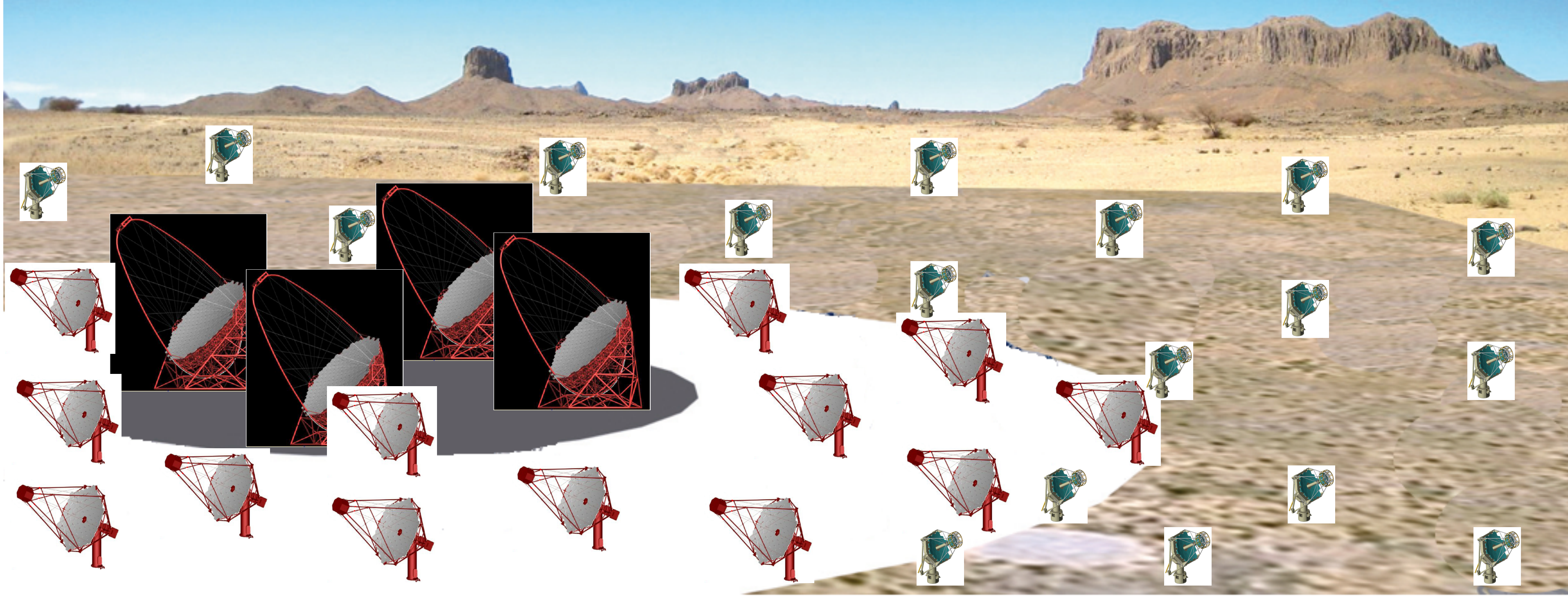
High energy

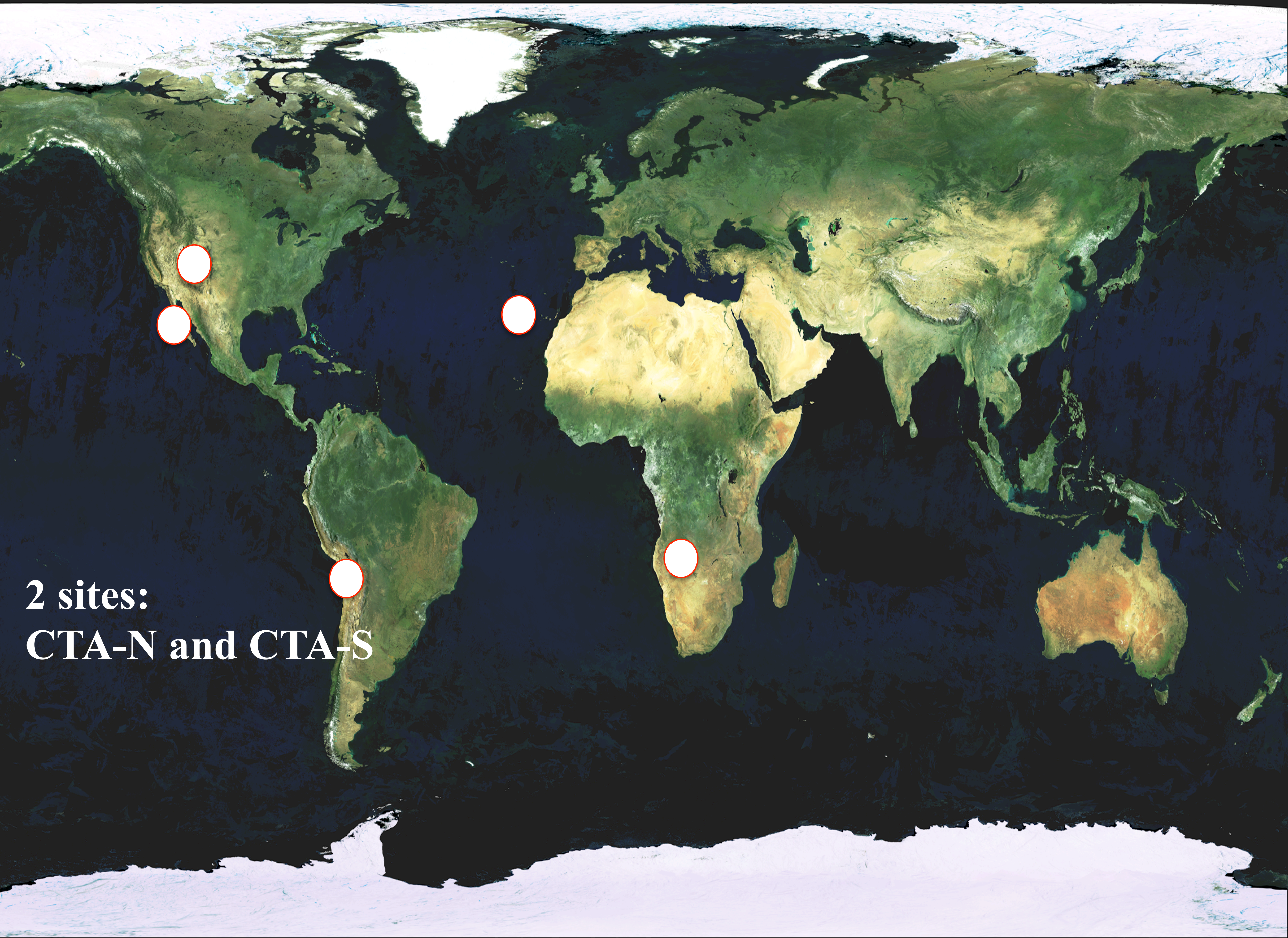
Fifty + 4.3 m telescopes

9.6° FoV

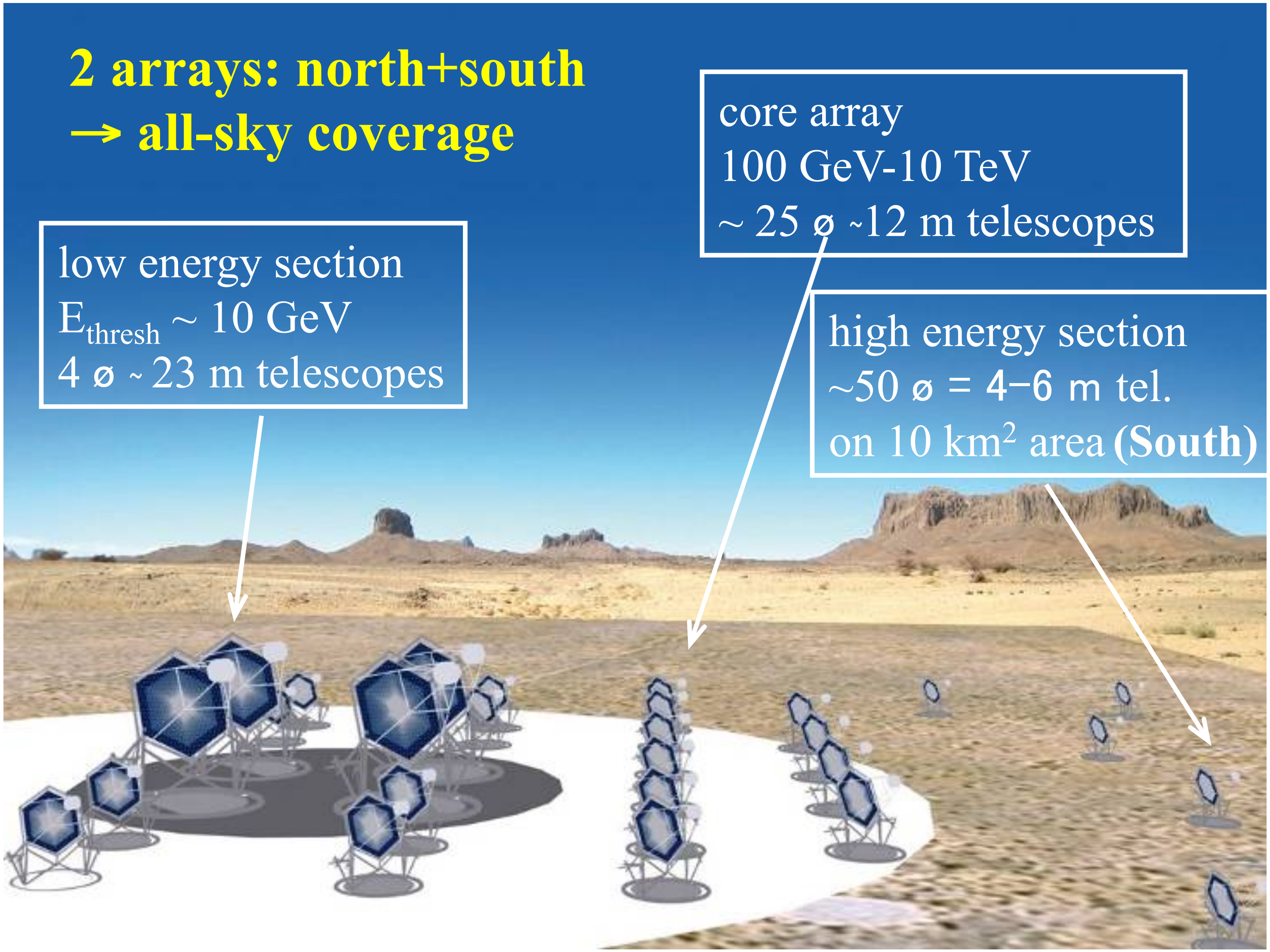
Compact Silicon Camera

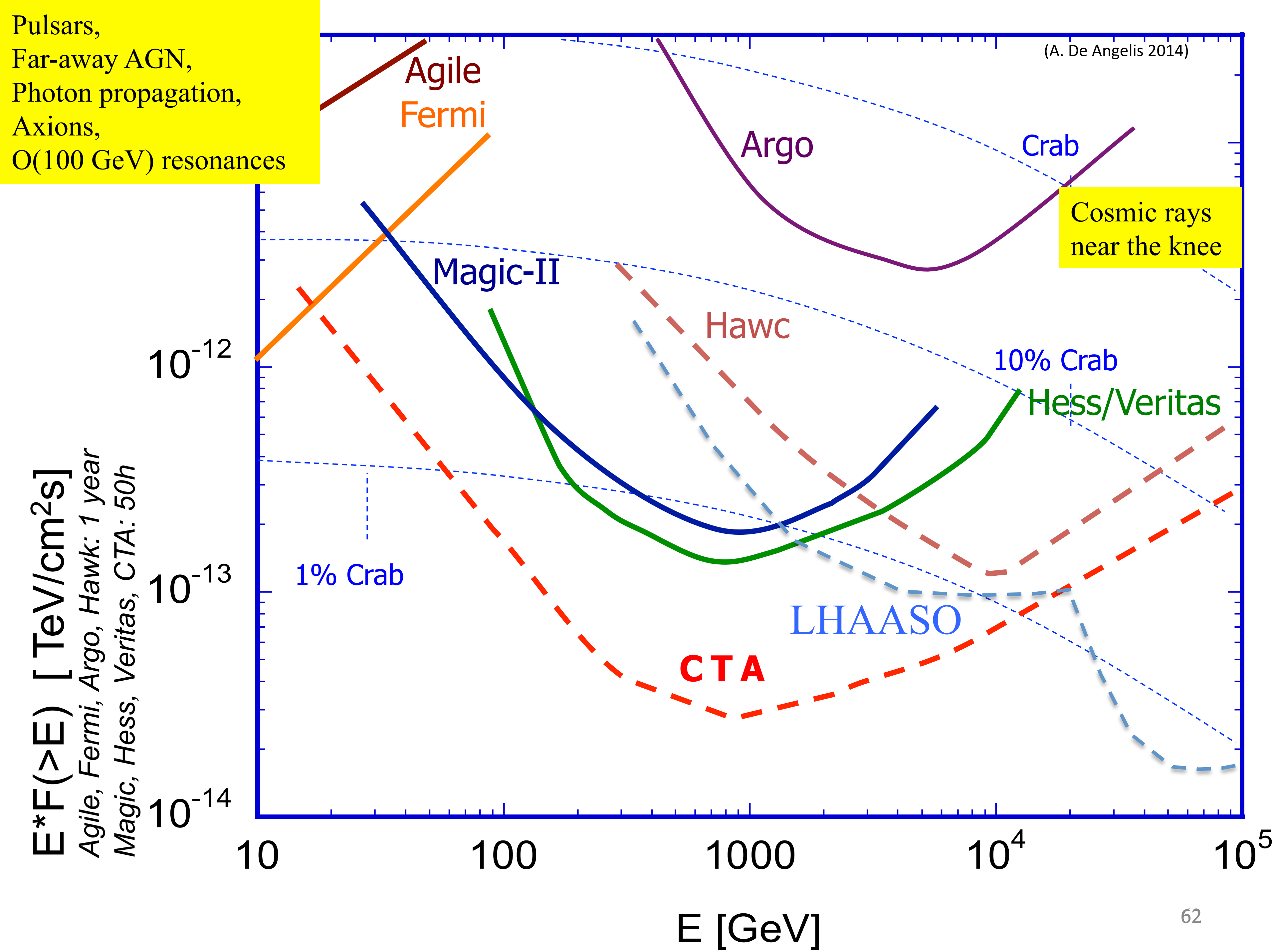
~ 0.25




2 sites:
CTA-N and CTA-S

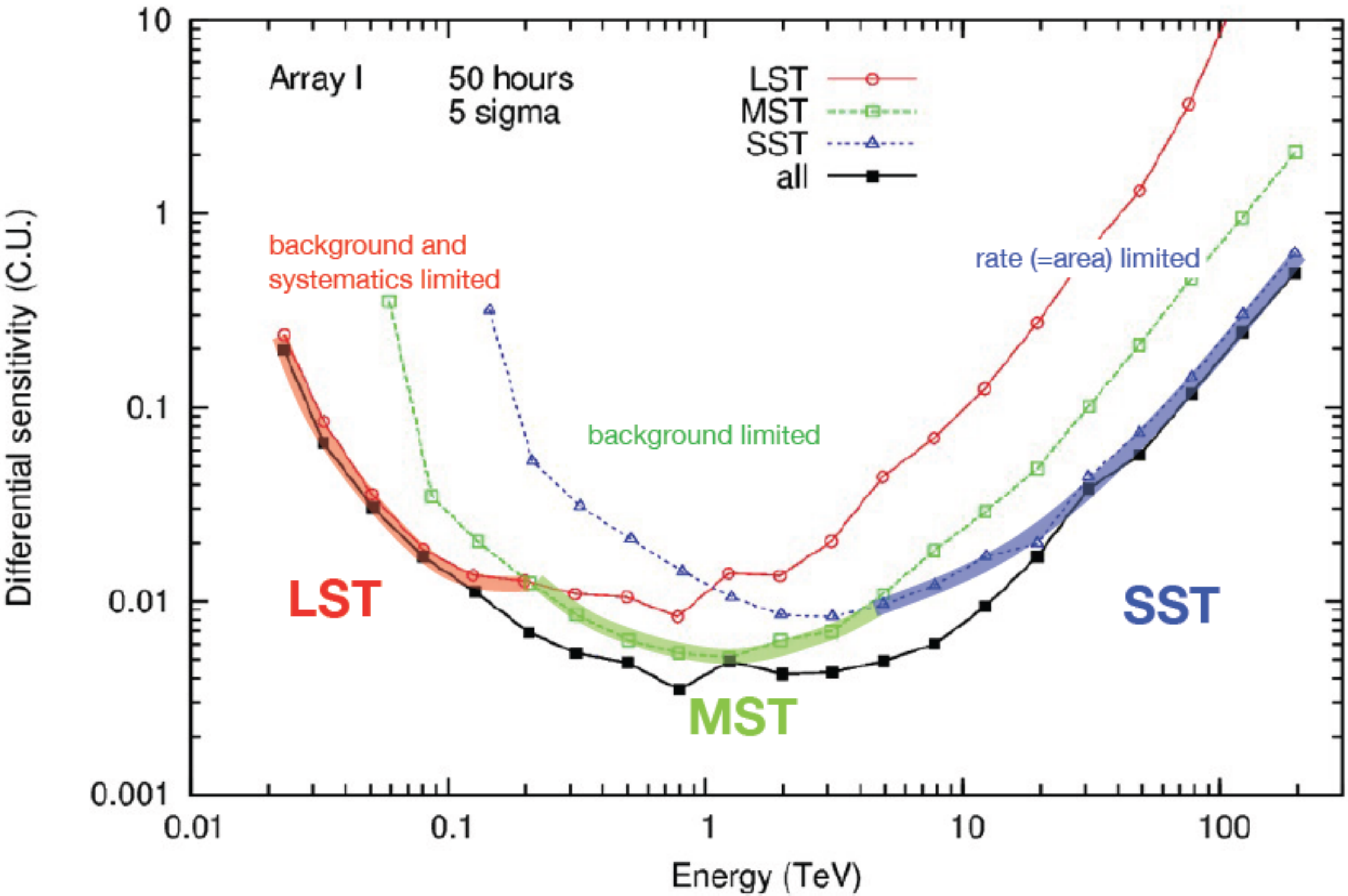
The CTA concept (a possible design)





Pulsars,
Far-away AGN,
Photon propagation,
Axions,
O(100 GeV) resonances
(A. De Angelis 2014)
Agile
Fermi
Argo
Crab
Cosmic rays near the knee
Magic-II
Hawc
10% Crab
Hess/Veritas
1% Crab
LHAASO
CTA
10^{-12}
10^{-13}
10^{-14}
10
100
1000
10^4
10^5
E*F(>E) [TeV/cm^{2}s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
E [GeV]

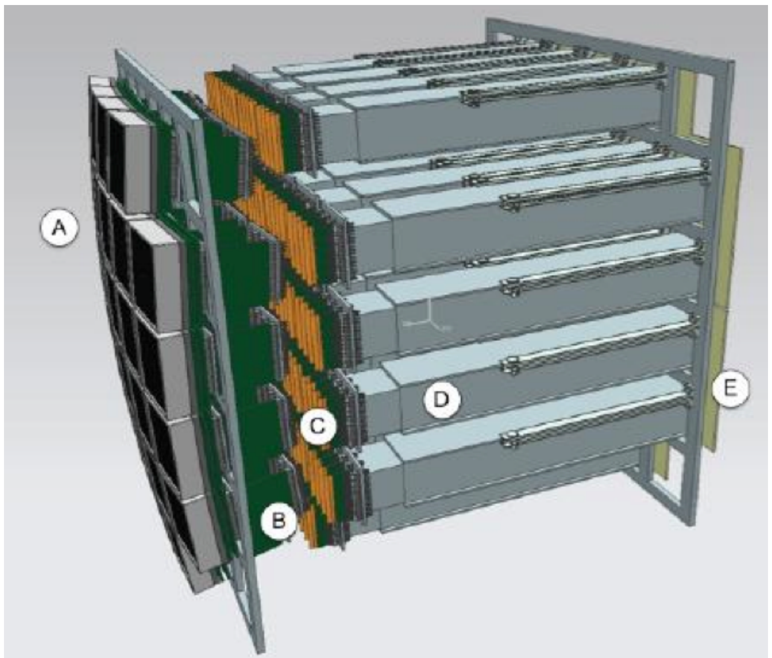
Large/Medium/Small Size Telescopes in CTA



SST Telescopes

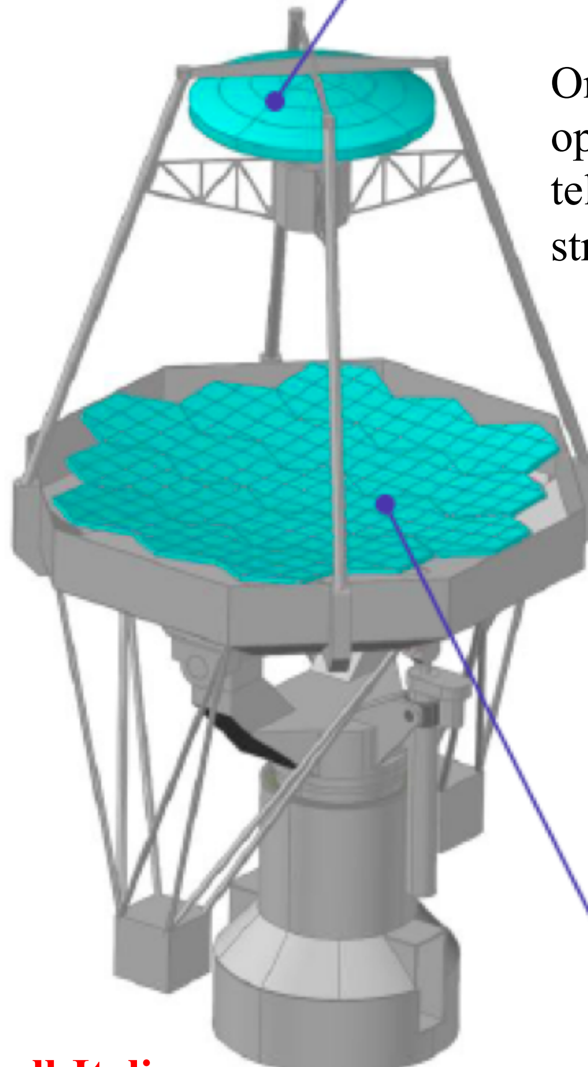
cover the range above few TeV across 10 km^2

PMT camera option



Monolithic secondary mirror

One of 3 options for telescope structure



Primary mirror with hexagonal panels

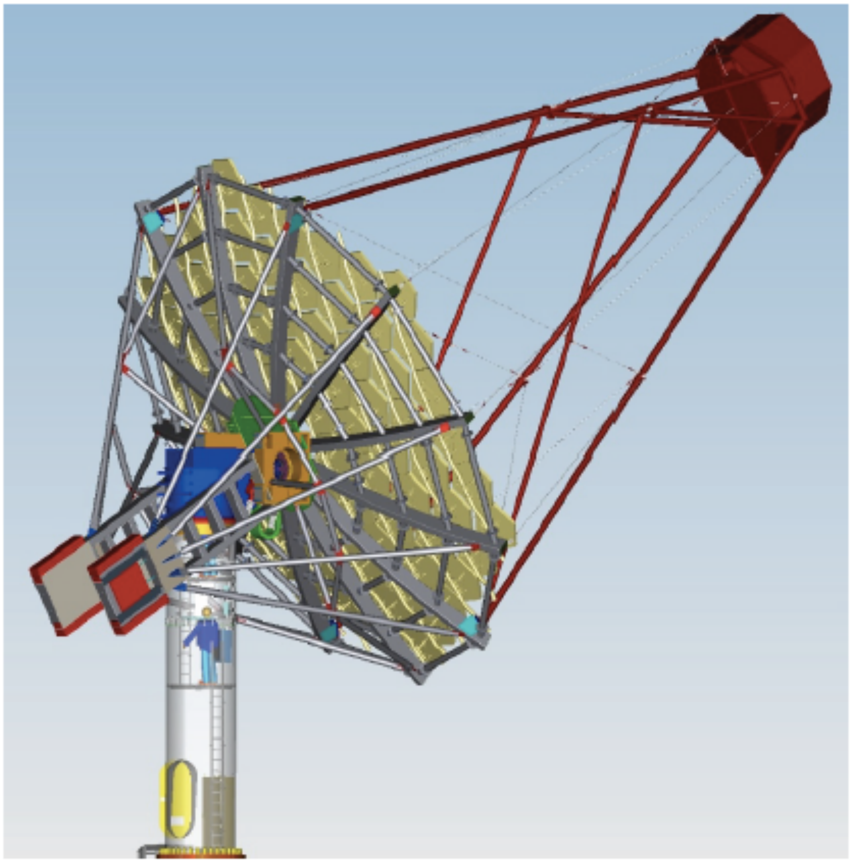
Under study:
dual-mirror optics with compact photo sensor arrays
Si-based sensors
➜ Not yet conclusive which solution is most cost-effective

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

Mechanical (for now) demonstrators: ASTRI telescope (INAF)

- Camera diam. D_C = 36 cm, FoV = 9.6°
- Mechanics ready in September; prototype on Mount Etna
- Full prototype in 2015 (May?)

The Medium size telescope

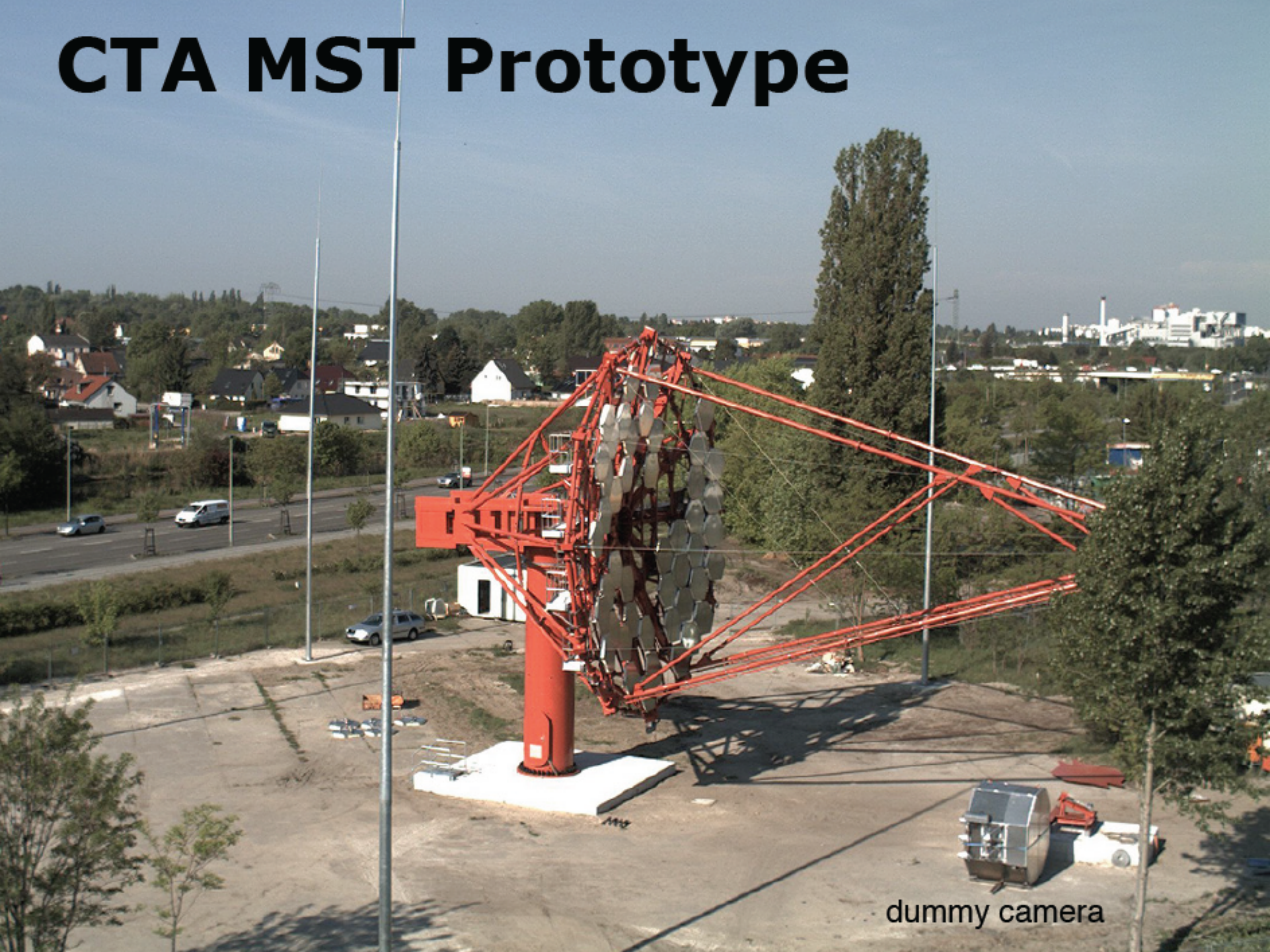


Hot numbers & parameters

- 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

(camera is missing)

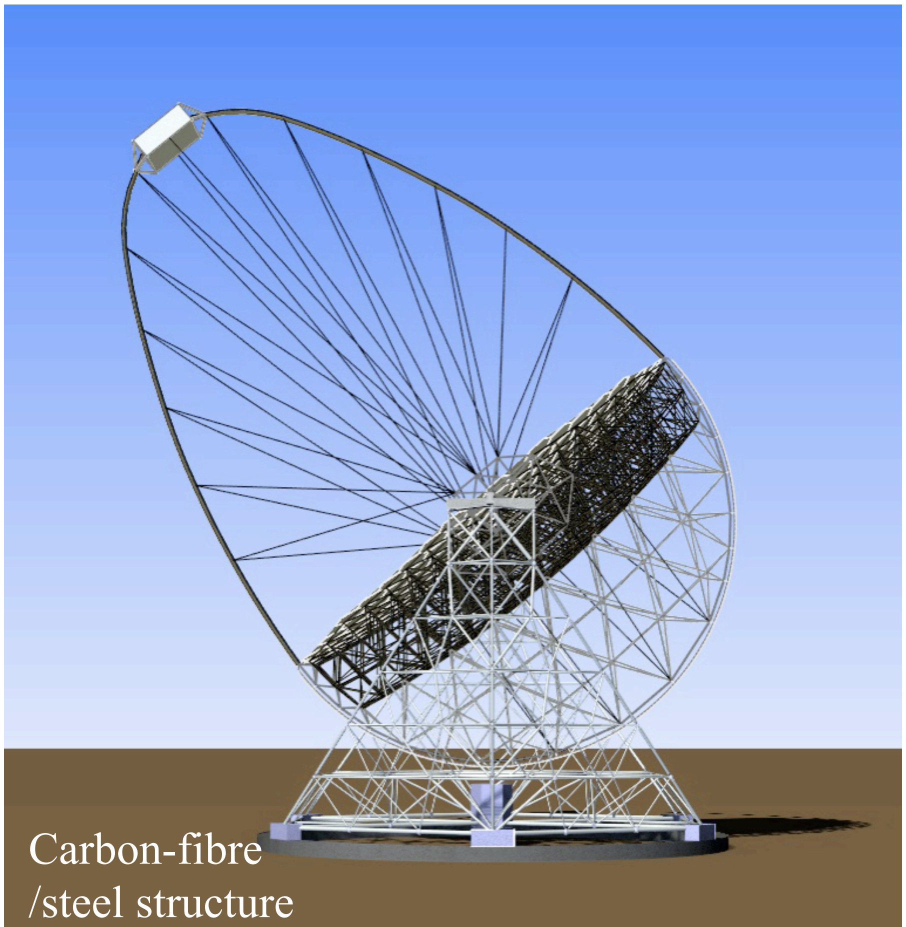
CTA MST Prototype



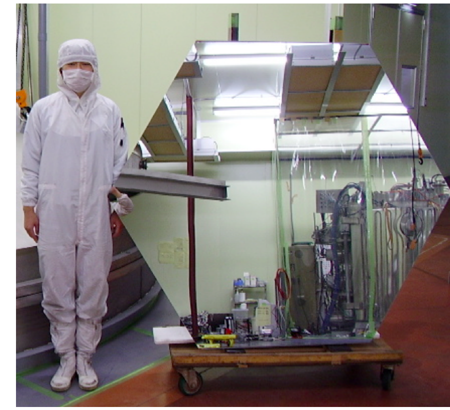
CTA: 23 m LST (precursor in 2016)

Japan/Germany/Spain/CNRS/INFN

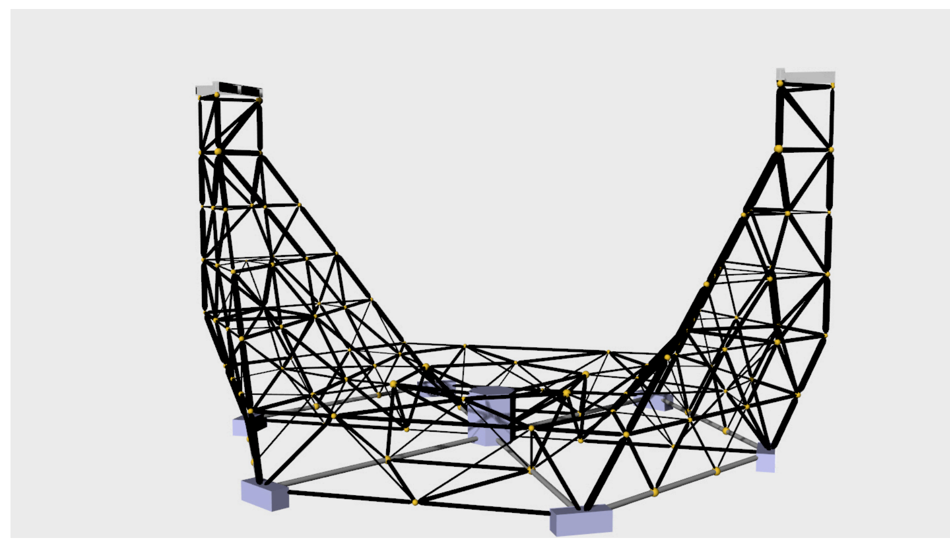
27.8 m focal length
4.5° field of view
0.1° pixels



400 m^2 dish area
1.5 m sandwich
mirror facets



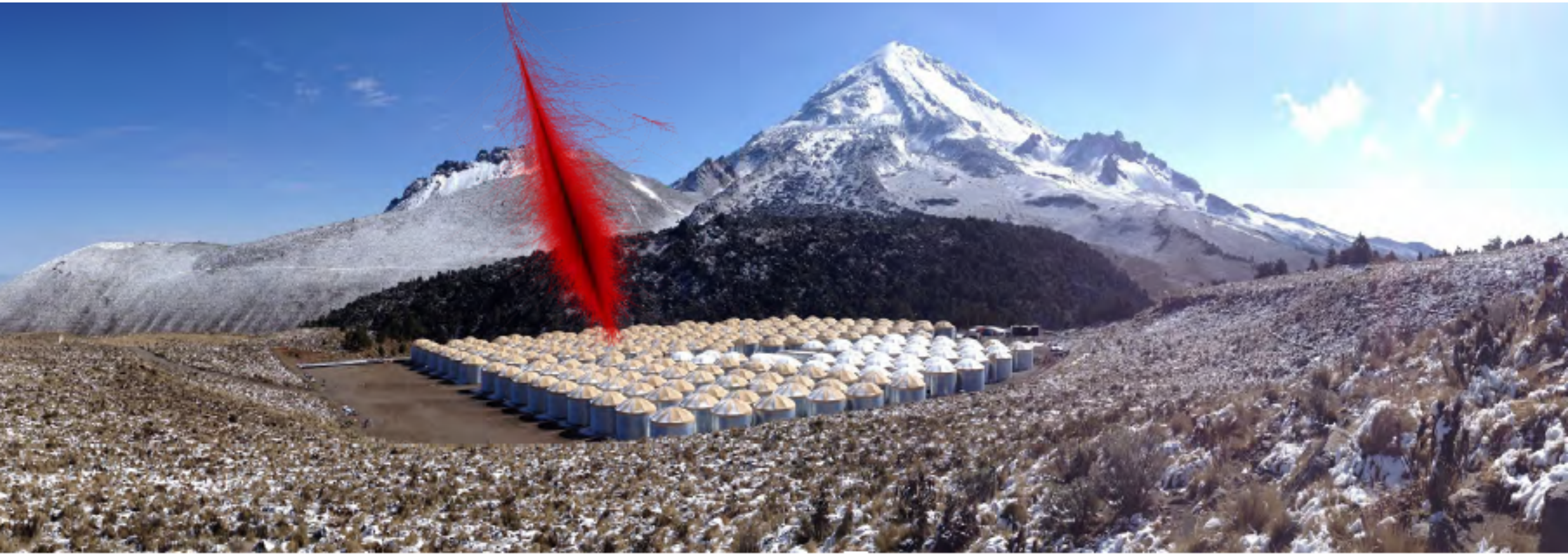
On (GRB) target
in < 20 s



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

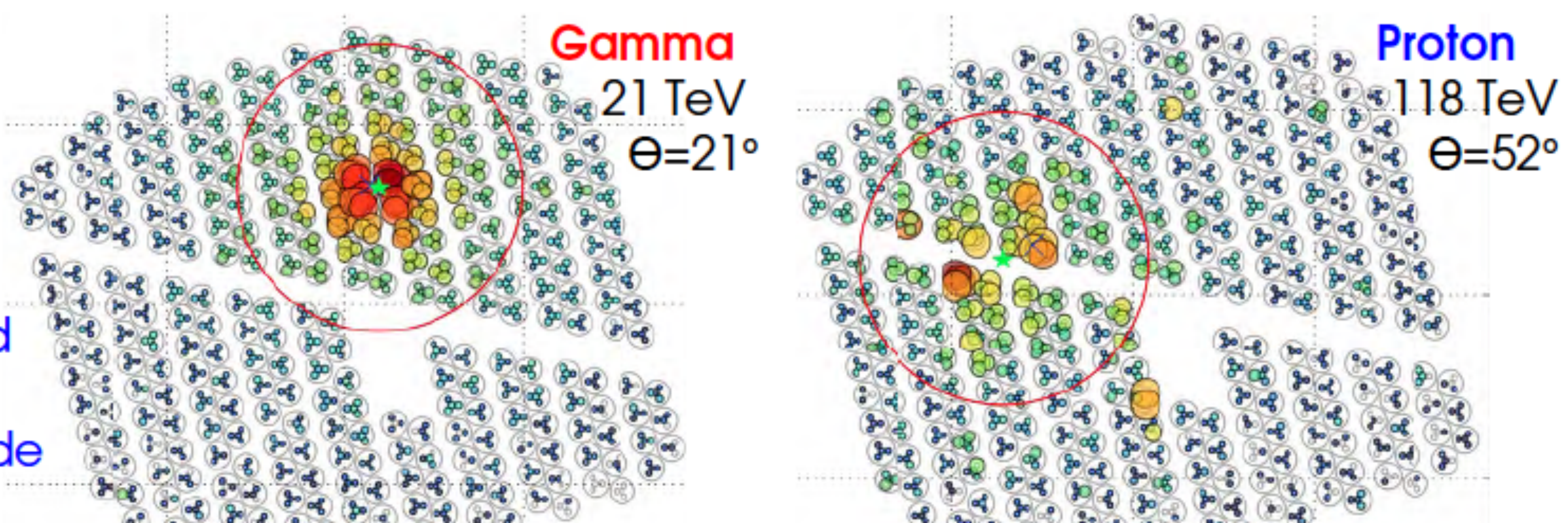
3
2
4
1
88 m
90 m
105m
103 m
113m
38m
40m
32m
93 m
85 m
50m
FACT
Fence
Oval, short arm= 60 m
Oval, long arm~ 70 m
diameter=26 m
Barranco de las Grajas
Ctra. al Roque de los Muchachos

Solution II: EAS



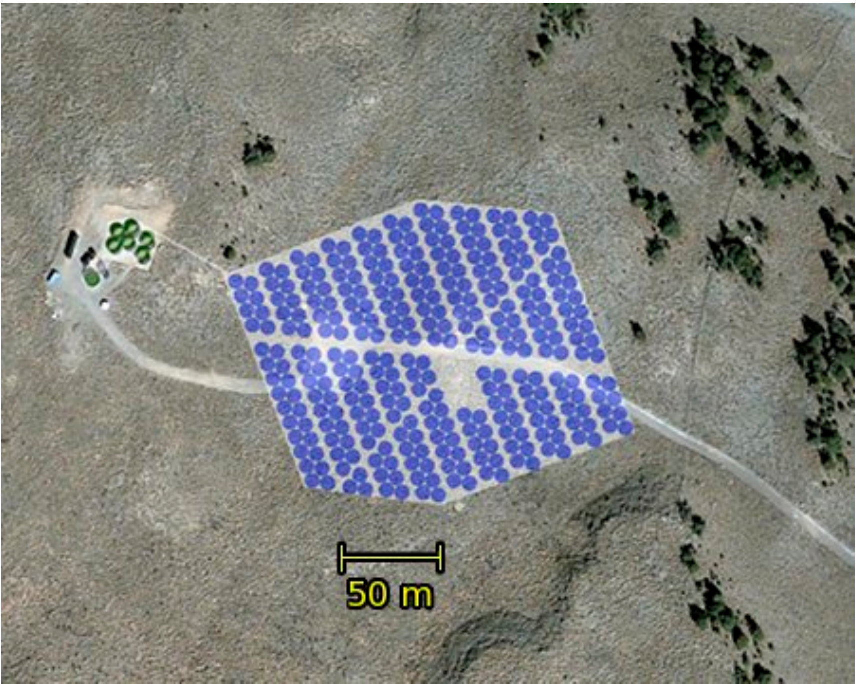
Reconstruct air showers based on PMT hit times and charges

Reject charged primaries via bright hits outside the core



HAWC

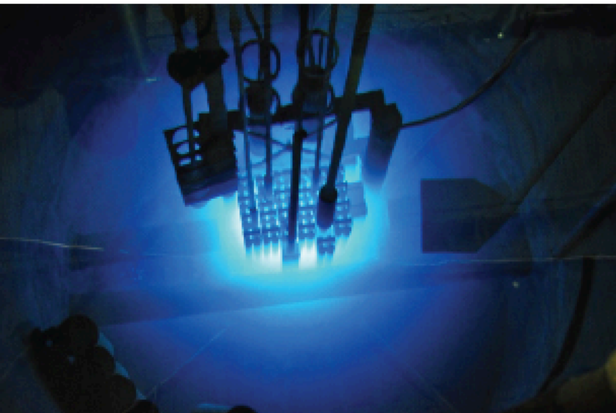
- EAS detectors have advantages on Cherenkov: duty cycle, serendipitous searches
- But the EAS up to now (Argo, Milagro, Tibet-AS) were not sensitive enough
- The High-Altitude Water Cherenkov Observatory, or HAWC, is a facility designed to observe TeV gamma rays and cosmic rays with large FOV, with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

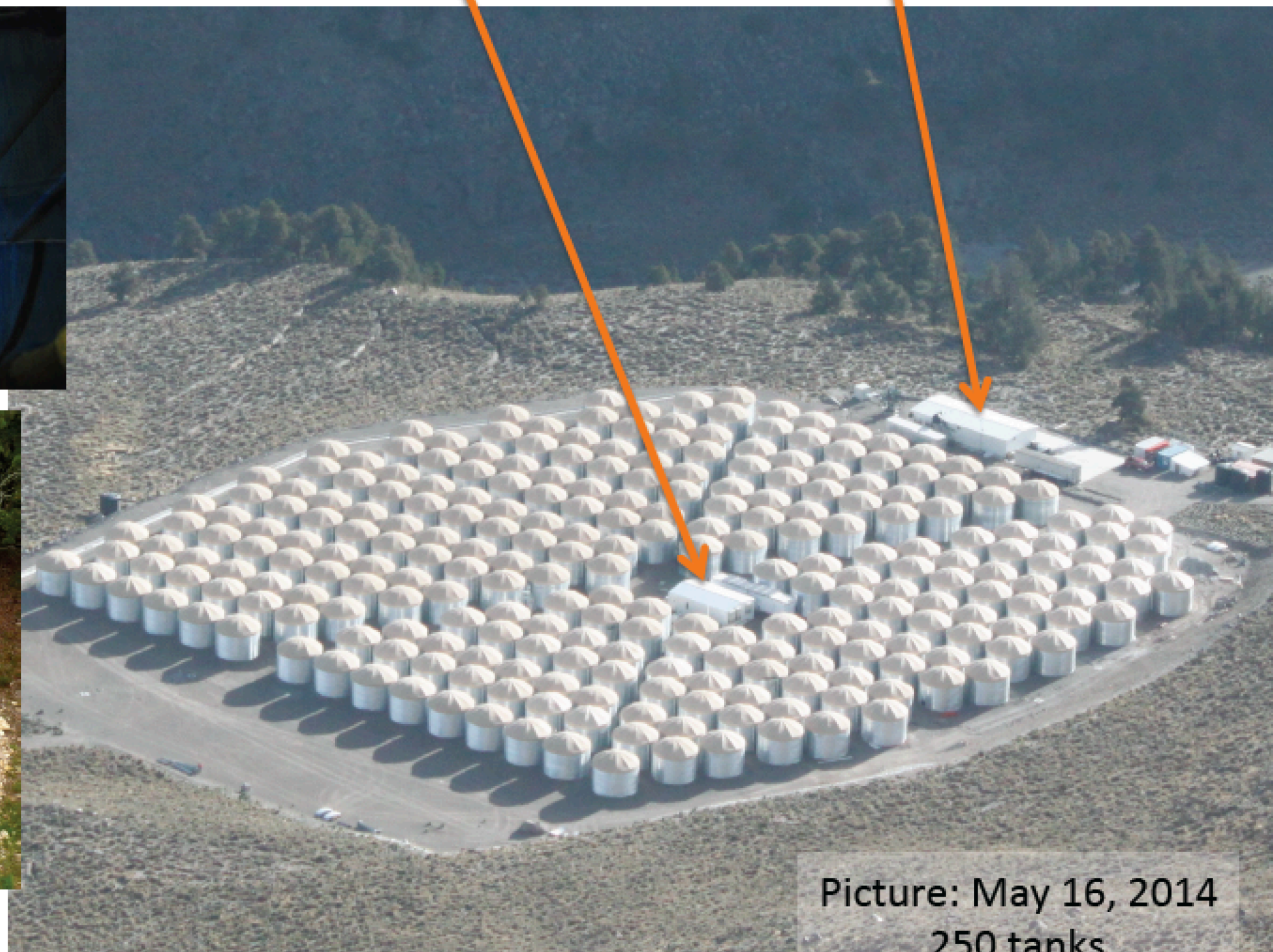


Height is one of the keys…

HAWC is almost complete…

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

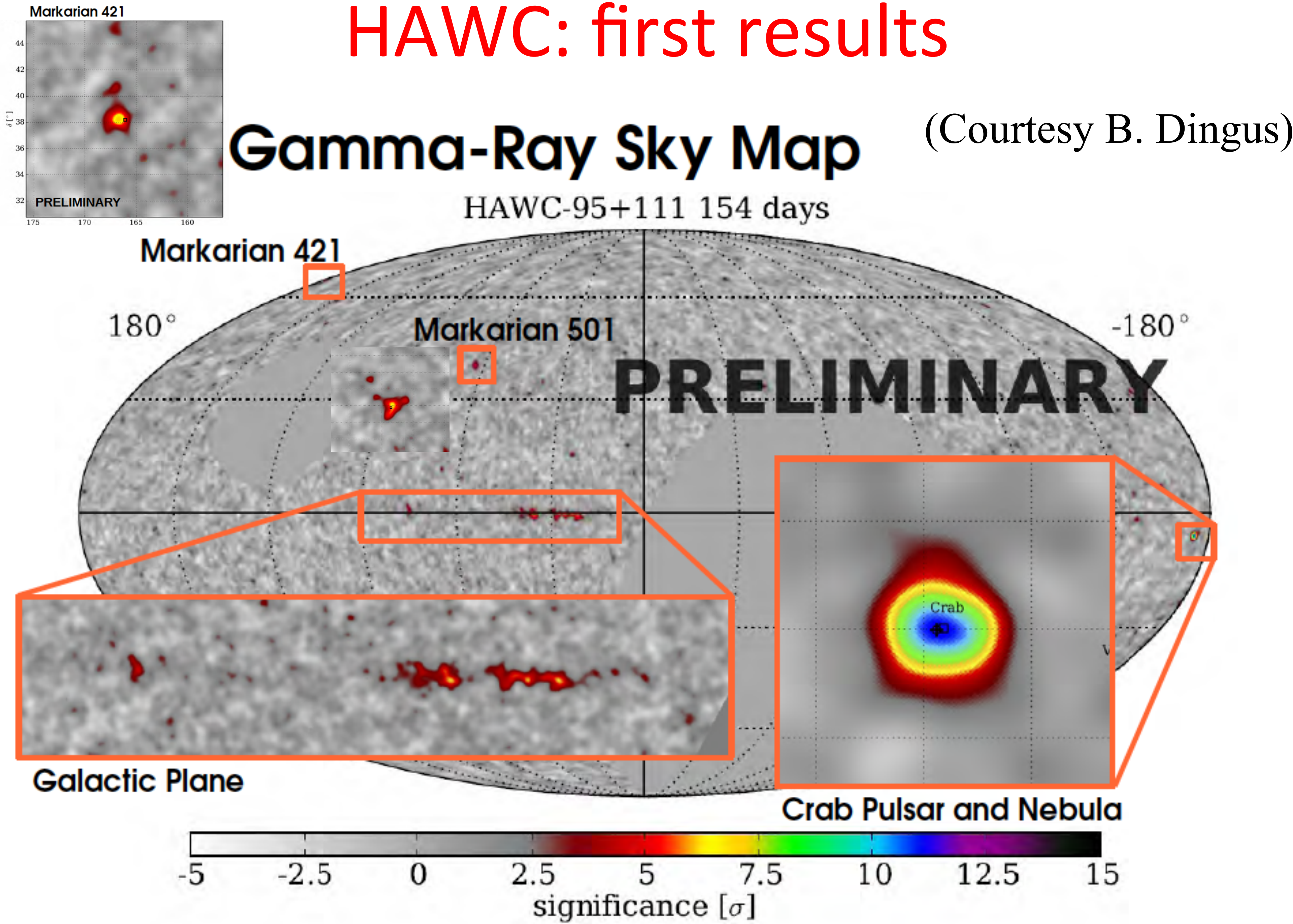




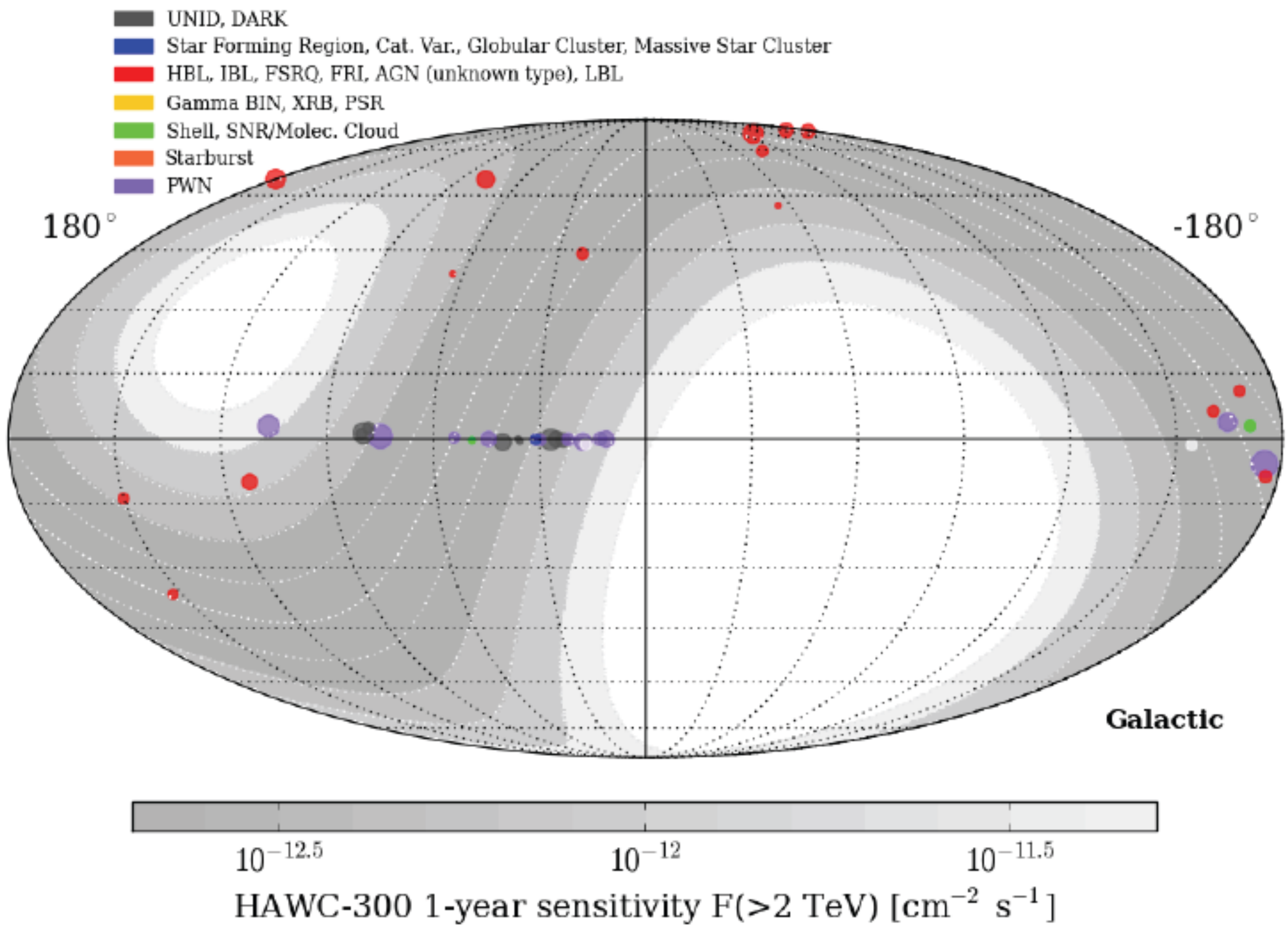
HAWC is almost complete…

HAWC: first results

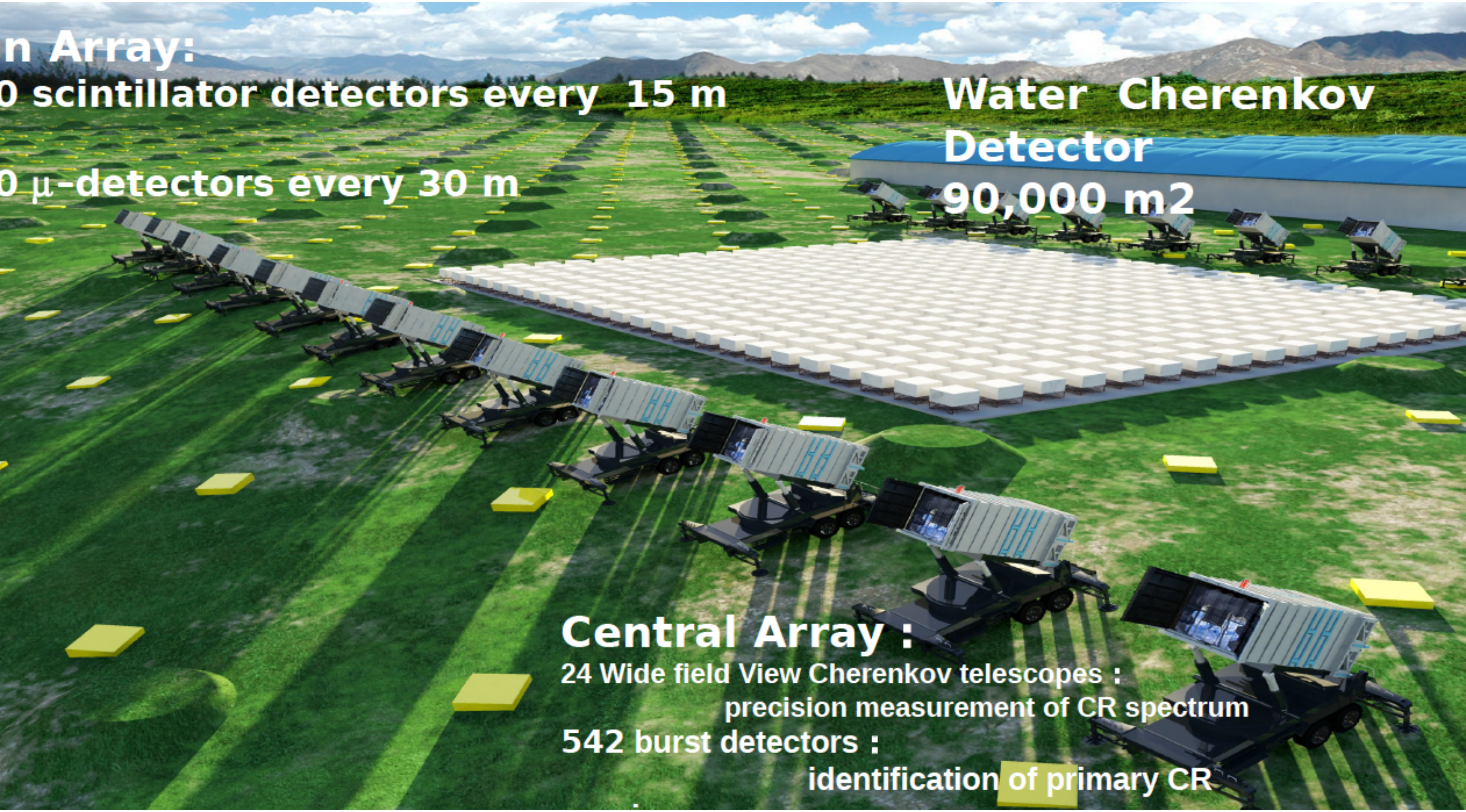
(Courtesy B. Dingus)



> 40 steady sources in 5 years



LHAASO (see dedicated talks, Chiavassa/Vernetto)



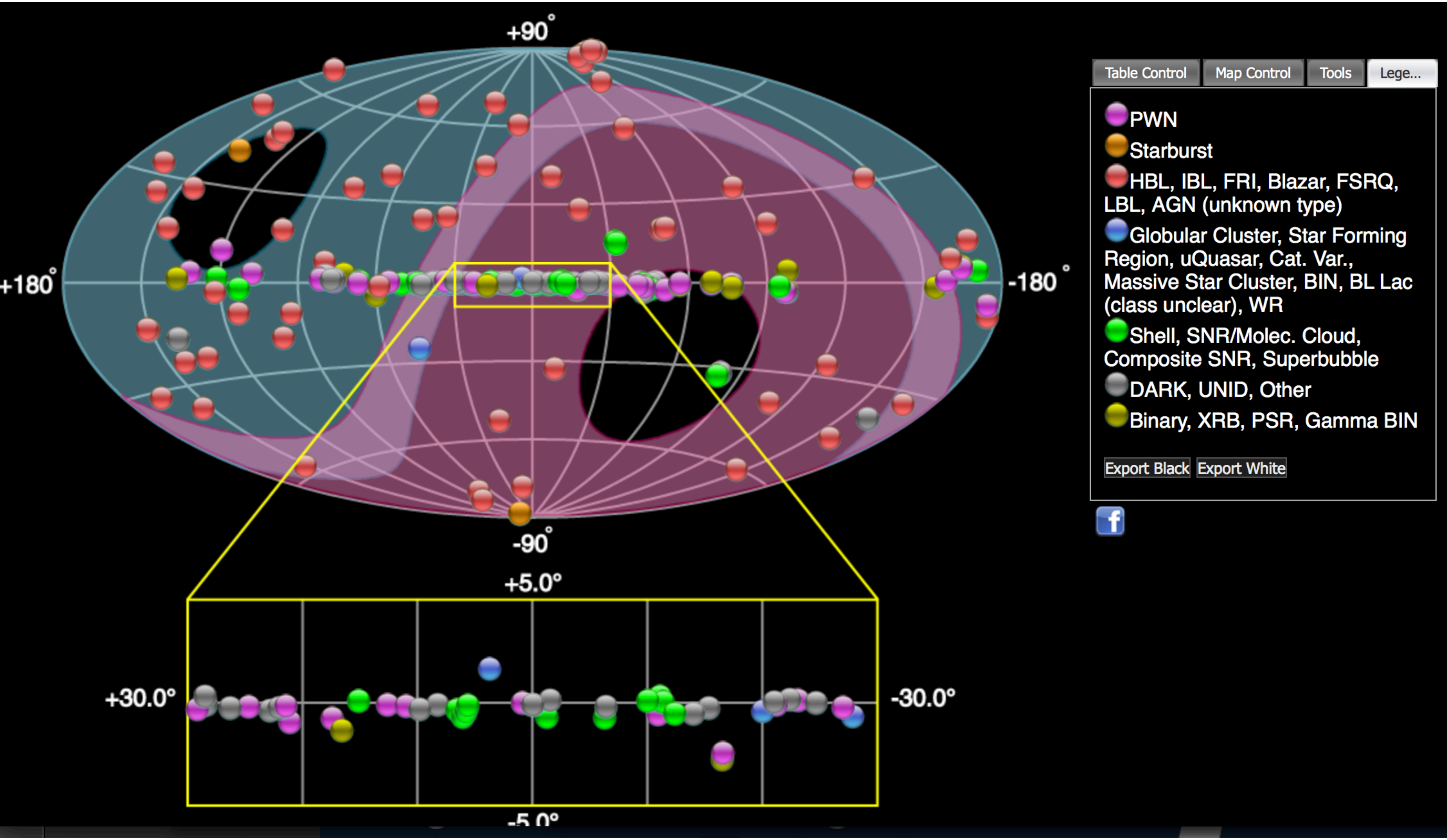
New detectors for the next 20 years?

- CTA is the best compromise detector
- It "should" have a Northern and a Southern site

- Is it the best detector for particle physics?
  - Energy threshold could be reduced by going to 4000-5000 m asl
  - High energy performance is better for steady sources in a 4000-5000 m EAS

- **North versus South?**

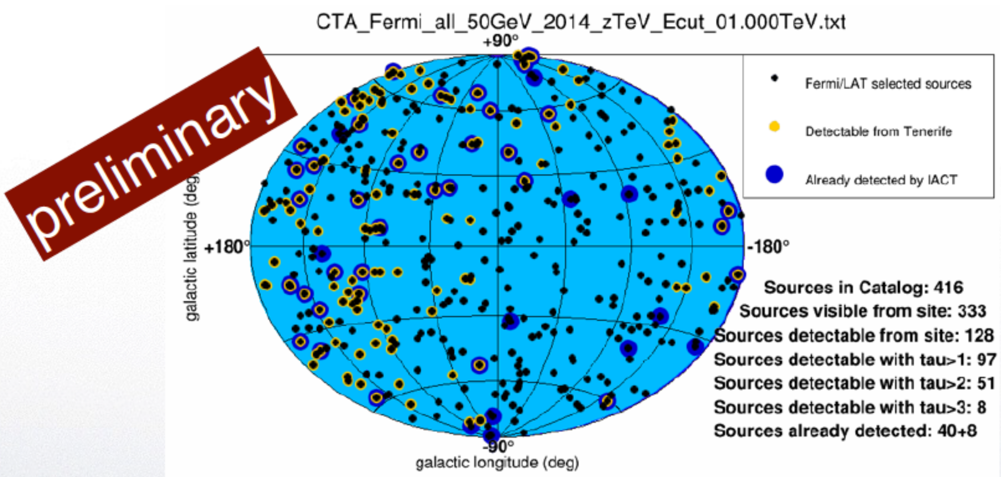
North vs. South



A false dogma: S>N for GAL; S=N for extraGAL

DM & D. Semikoz, A. Zech 2014, in preparation

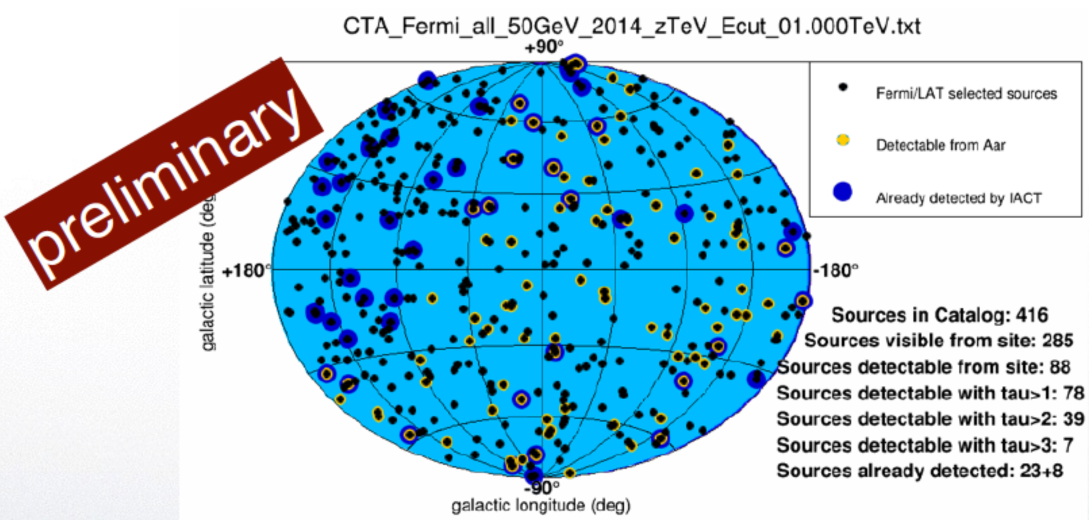
NORTH



1) from 416 hard spectra sources, CTA-NORTH can detect 128 (31%)

ExtraGAL:

North ~ 1.5 x South

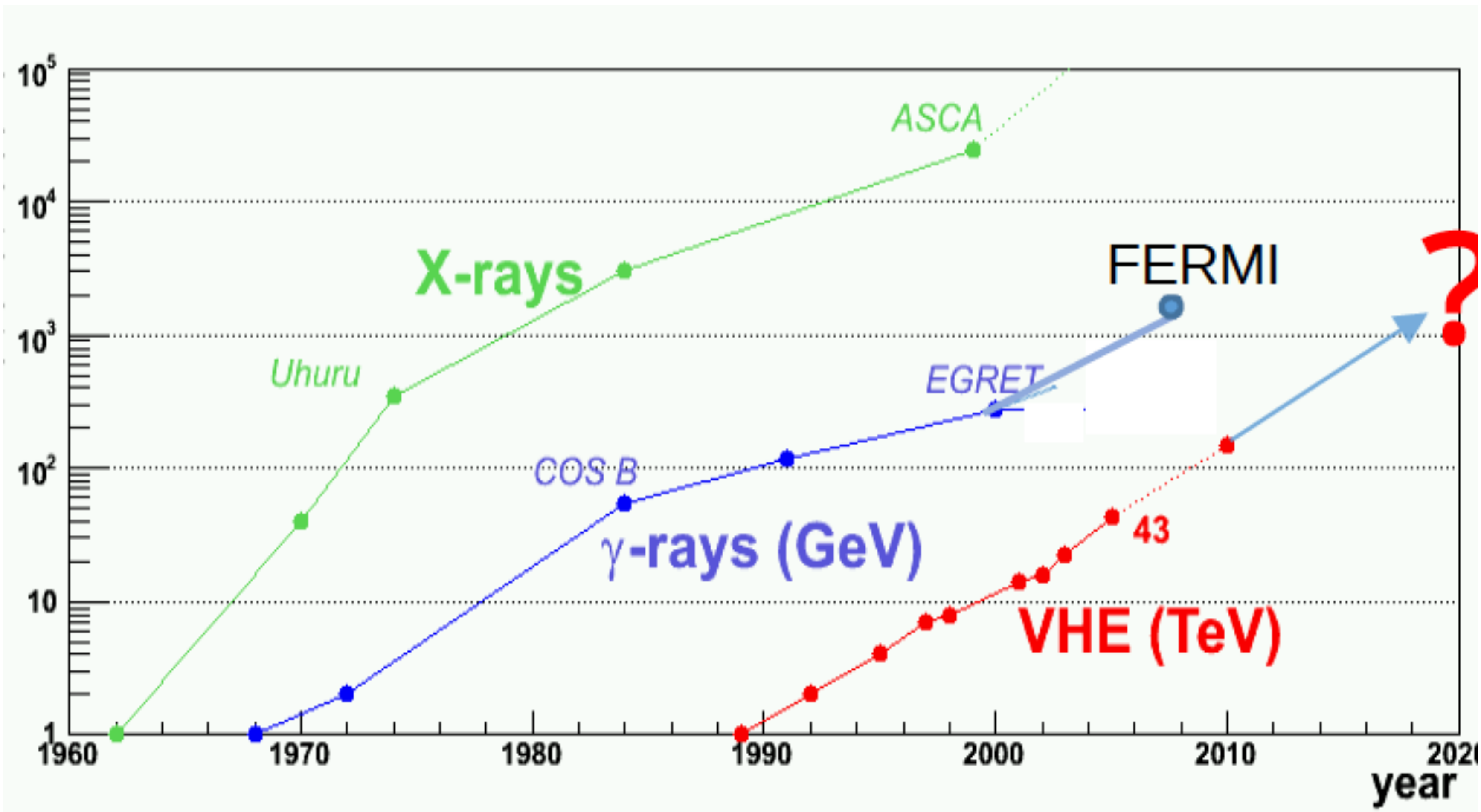


1) from 416 hard spectra sources, CTA-SOUTH can detect 88 (21%)

Likely hits in the next 10-20 years (beside astrophysics, which in any case…)

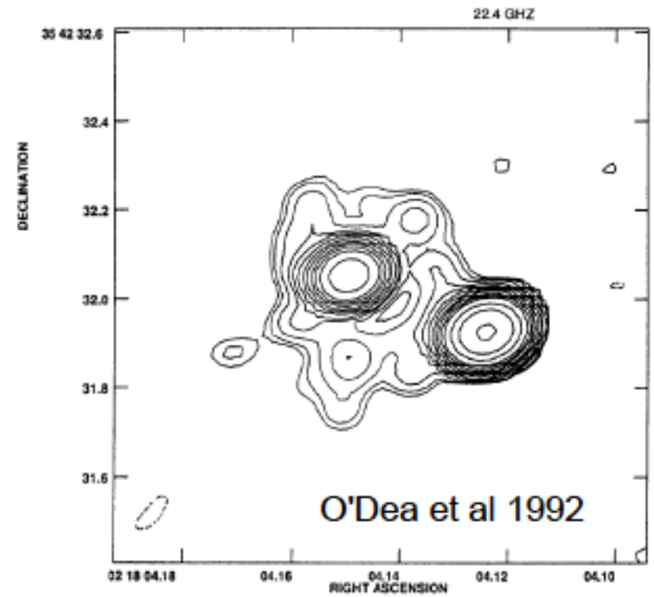
- EBL, interaction of photons with the vacuum
  - Anything anomalous?
  - If not, independent measurement of cosmological parameters (test of cosmology?)
  - The Universe at z=0.6-1 (near the stellar formation)
- Something better on DM
  - But we don't know too much what: in the worst case,
    - constraints on DM density/annihilation X section or decay rate
    - Backgrounds
- Test of fundamental symmetries in an unknown regime
  - Nobody knows what can come out

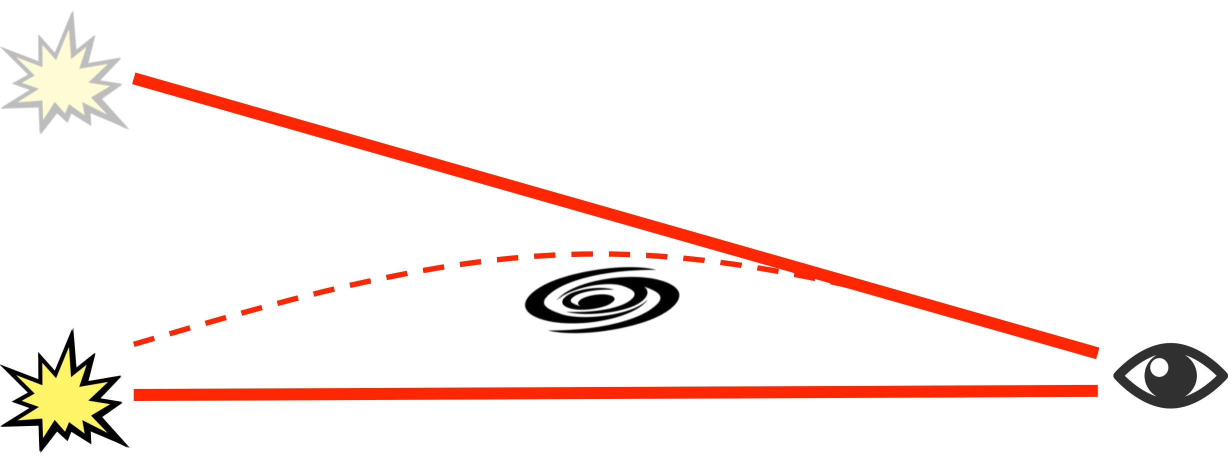
New sources, new source types…

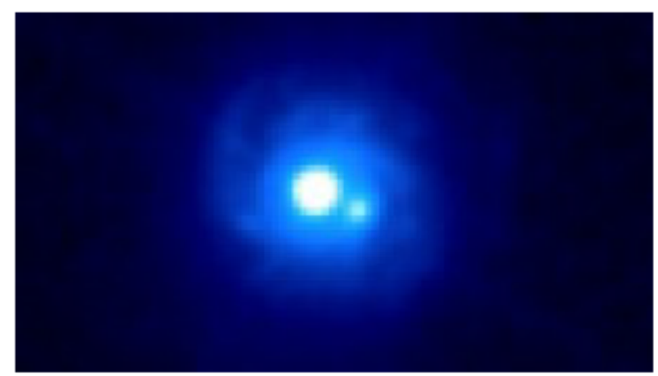


Morphology of the sources: physics near a neutron star, a BH, a SMBH, not only astronomy

- More physics from lensing
  - Microlensing/chromaticity of light propagation: insight on the behavior of matter near a SMBH
  - A multiwavelength study







Should we rethink to an extreme project for low energies?

- 5@5 (Aharonian et al. 2000): 5 large (~20 m) detectors at 5000 m

- Why 5000 m?
  (i) Observed Cherenkov light from O(10 GeV) shower increases by factor 3!
  => a 20 m diameter mirror is enough to collect ~50 photo-electrons from a shower with core < 100 m away (future SiPM would of course further lower this requirement)
  (ii) Less important, but still significant: At GeV gamma-ray energies, the proton shower that produces as much light as the gamma-ray develops at lower altitudes …
  => some background suppression for free.

Threshold as low as 5-10 GeV could be expected, with pointing times < 1 min

Summary

- Impressive success of Cherenkov Imaging technique in the recent years; will continue with CTA (balistic)
- But we know what was wrong with EAS; HAWC demonstrated we can cure it (balistic)

- Purely scientific priorities, my point of view (then we can discuss about the political constraint):
  1. An EAS (HAWC-like?) at 4000-5000 m in the South (Bolivia? Chile?)
     - LATTES?
  2. A 5@5 Cherenkov Imaging at 4000-5000 m in the South (Bolivia? Chile?)
     - LATTES?
  3. A serendipitous PeVatron detector at North (LHAASO?)

  (1) and (2) have nonnegligible costs (30-40 MEUR each) – might interfere w/ CTA

- **New detection techniques?**

Alessandro De Angelis

And an important thing missing

- A world infrastructure for discussing multimessenger astroparticle physics
  - What is CERN for accelerator physics
  - Could it be a CERN division?
  - Could it be in Italy? (What next has been a seed)