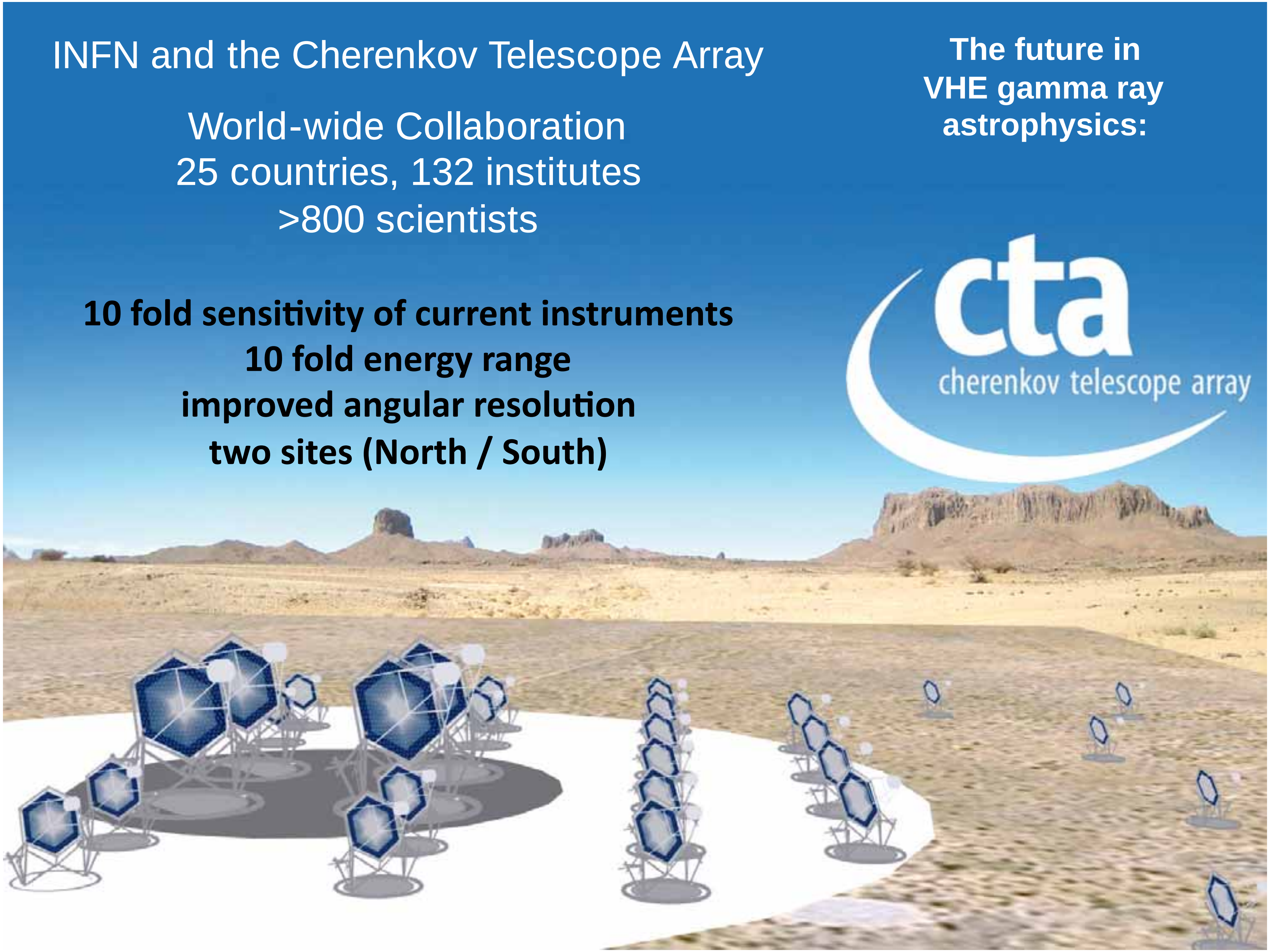
INFN and the Cherenkov Telescope Array

World-wide Collaboration
25 countries, 132 institutes
>800 scientists

10 fold sensitivity of current instruments
10 fold energy range
improved angular resolution
two sites (North / South)

The future in VHE gamma ray astrophysics:

cta
cherenkov telescope array



High Energy γ rays: non-thermal Universe

- Particles accelerated in extreme environments interact with medium
  - Gas and dust; Radiation fields – Radio, IR, Optical, …; Intergalactic Magnetic Fields, …
- Gamma rays traveling to us!
  - HE: 30 MeV to 30 GeV
  - VHE: 30 GeV to 30 TeV

Plus: "new" particles (e.g. Dark Matter)

- No deflection from magnetic fields, gammas point ~ to the sources
  - Magnetic field in the galaxy: ~ 1μG
    $R\ (\mathrm{pc}) = 0.01 p\ (\mathrm{TeV}) / B\ (\mu\mathrm{G})$
    => for p of 300 PeV @ GC the directional information is lost

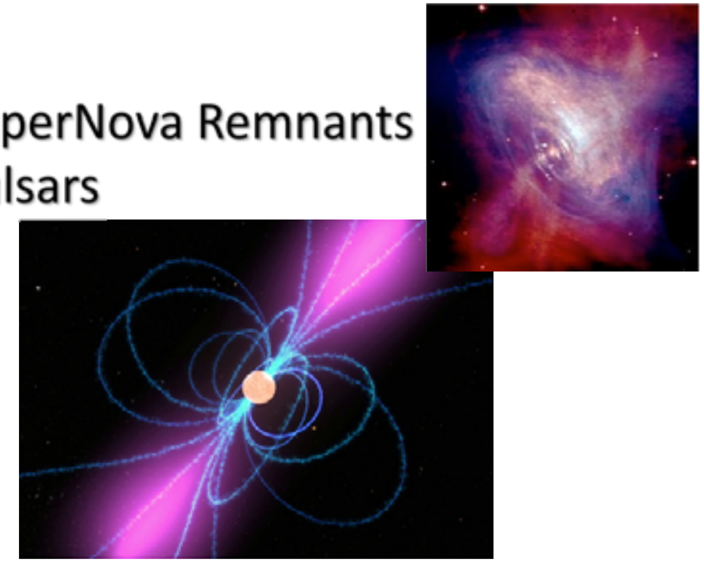
  ⇒ Gamma rays can trace cosmic rays at energies ~10x
- Large mean free path
  - Regions otherwise opaque can be transparent to X/γ

Studying Gamma Rays allows us to see these aspects of the Universe and the characteristics of photon propagation through "vacuum"

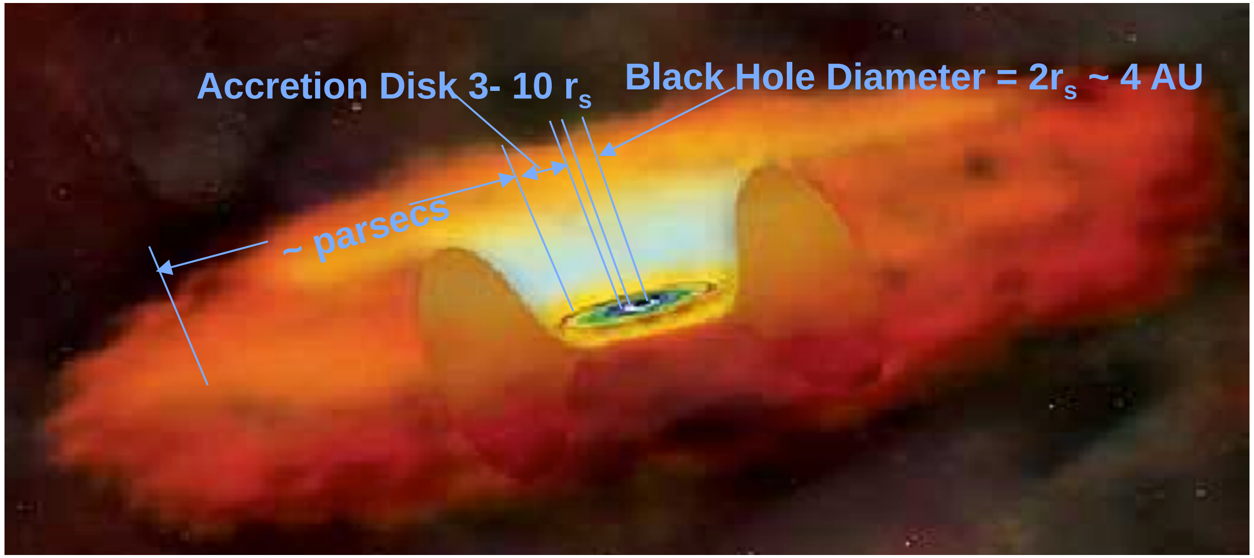
Examples of known extreme environments

GRB

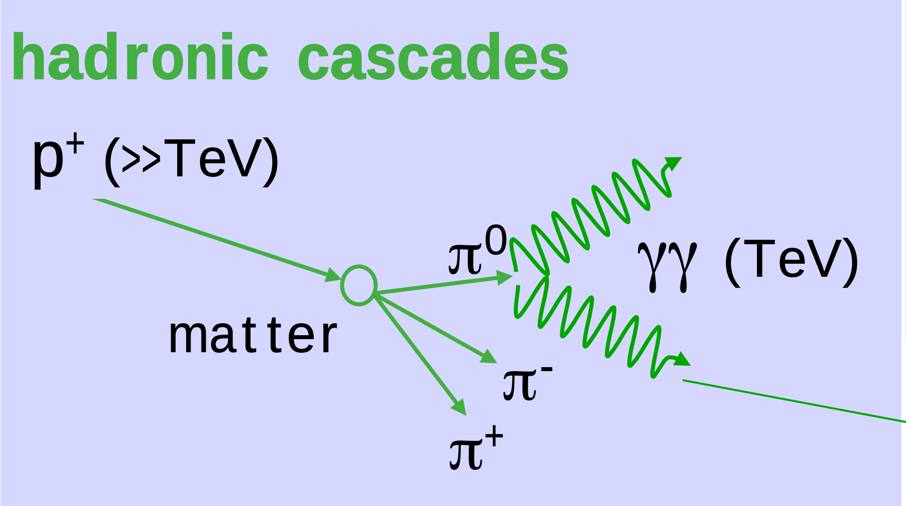
SuperNova Remnants
Pulsars



Active Galactic
Nuclei



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



hadronic cascades

p^+ (>>TeV)

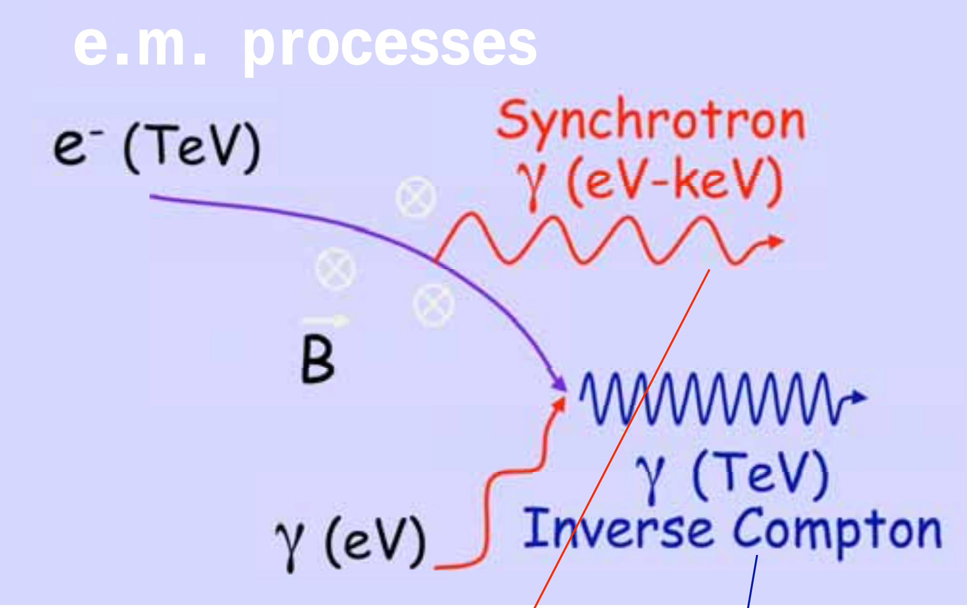
matter

π^0

$\gamma\gamma$ (TeV)

π^-

π^+



e.m. processes

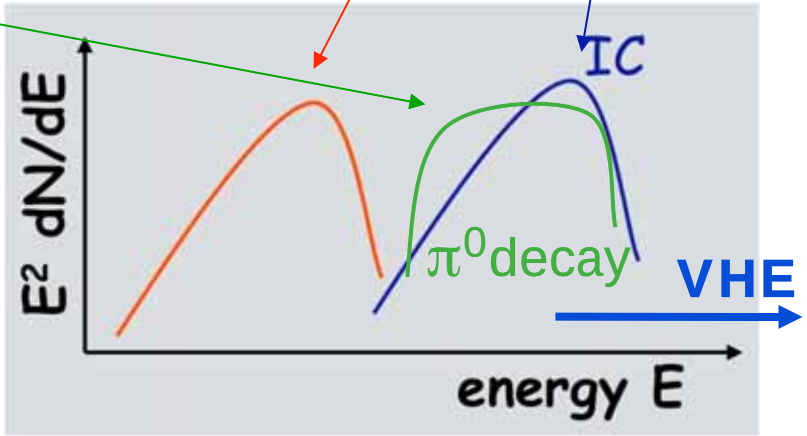
e^- (TeV)

Synchrotron
γ (eV-keV)

$\vec{B}$

γ (TeV)
Inverse Compton

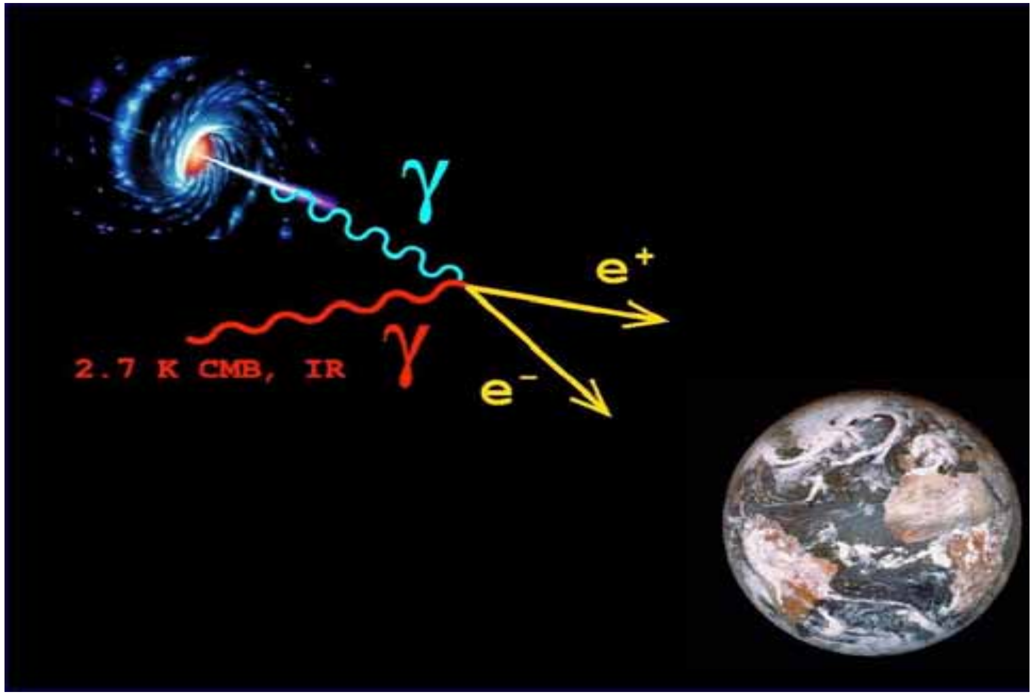
γ (eV)



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

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

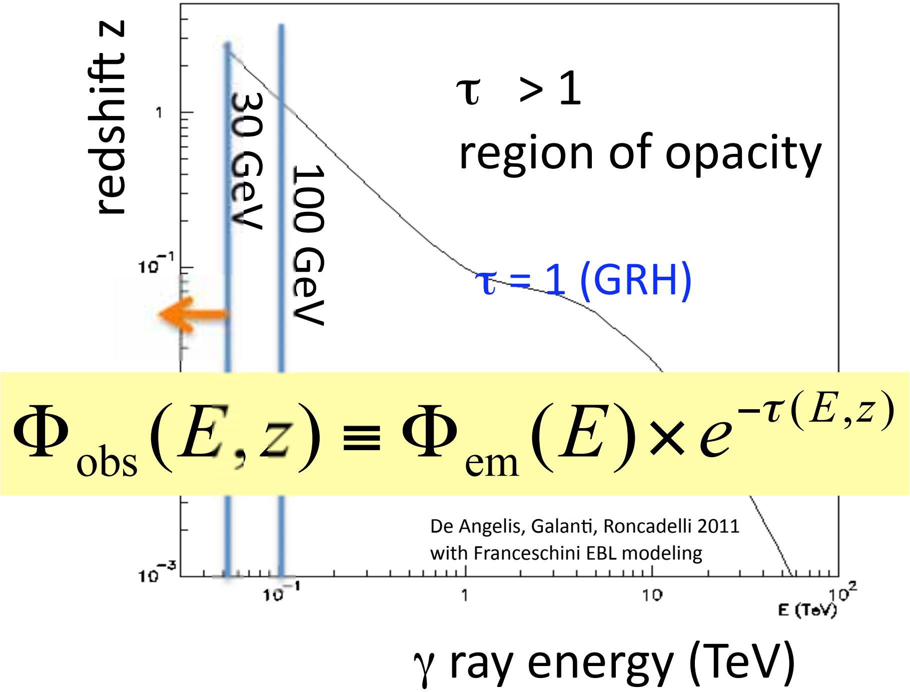
How do gamma rays reach us?



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

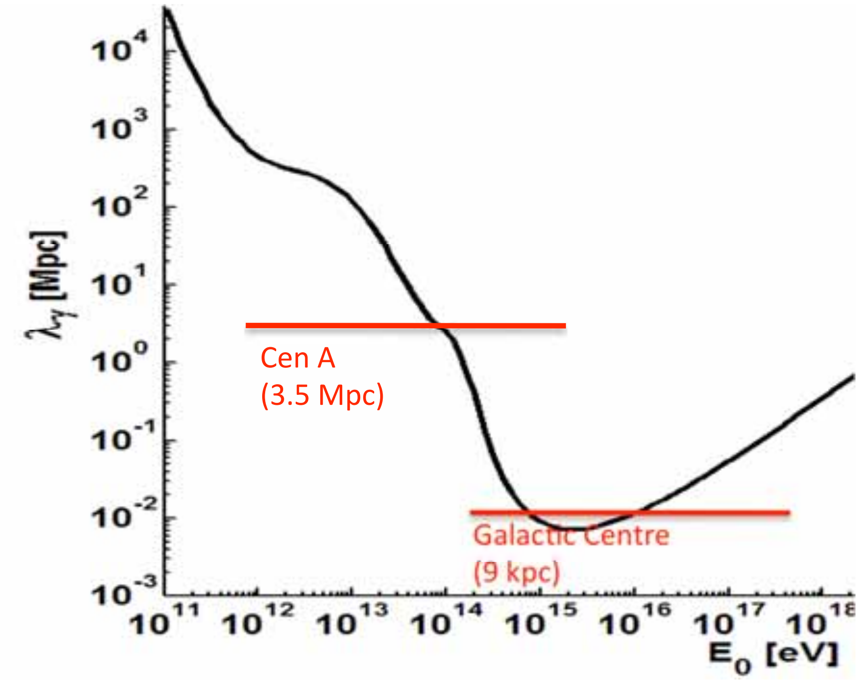
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2)+(3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

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

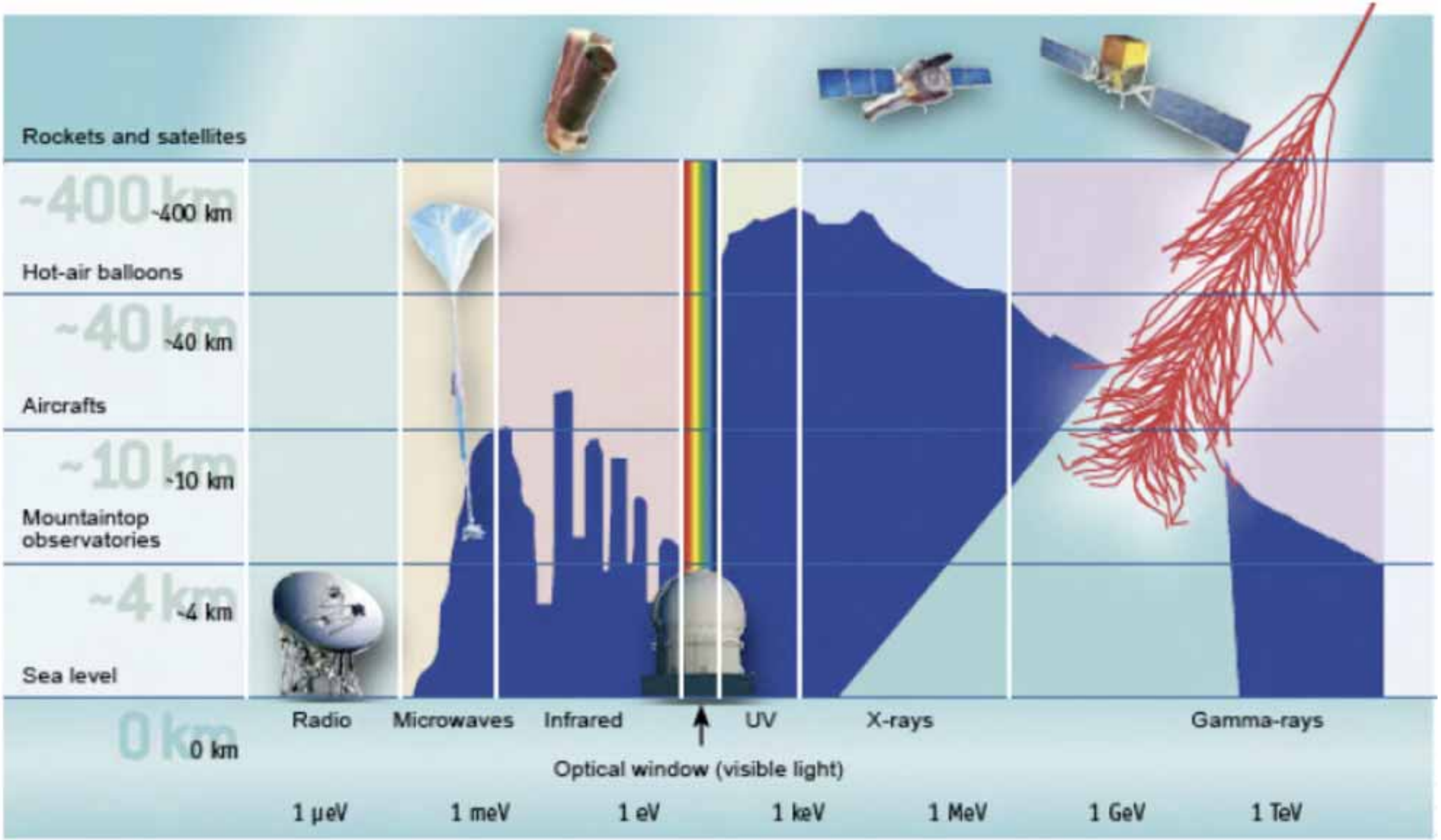


$$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$$

De Angelis, Galanti, Roncadelli 2011
with Franceschini EBL modeling

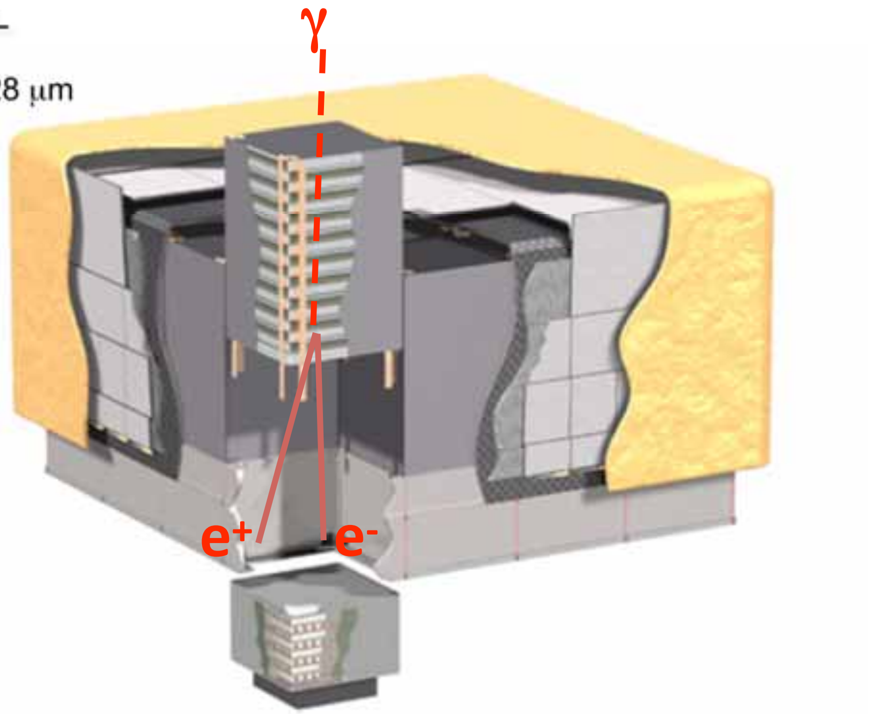


Gamma rays interact with the atmosphere



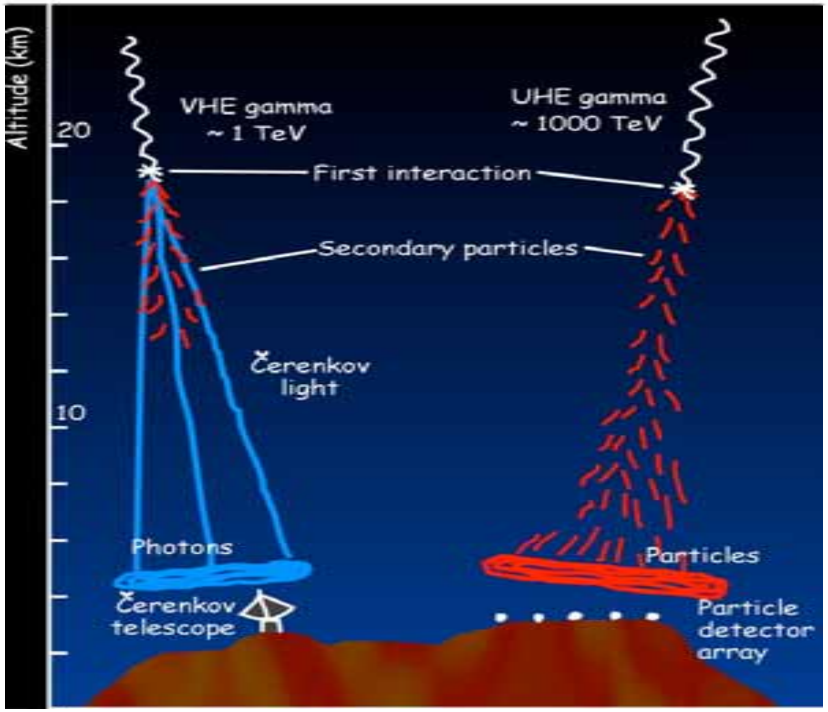
=> GeV (HE) detection requires satellites; TeV (VHE) can be done at ground

Detectors



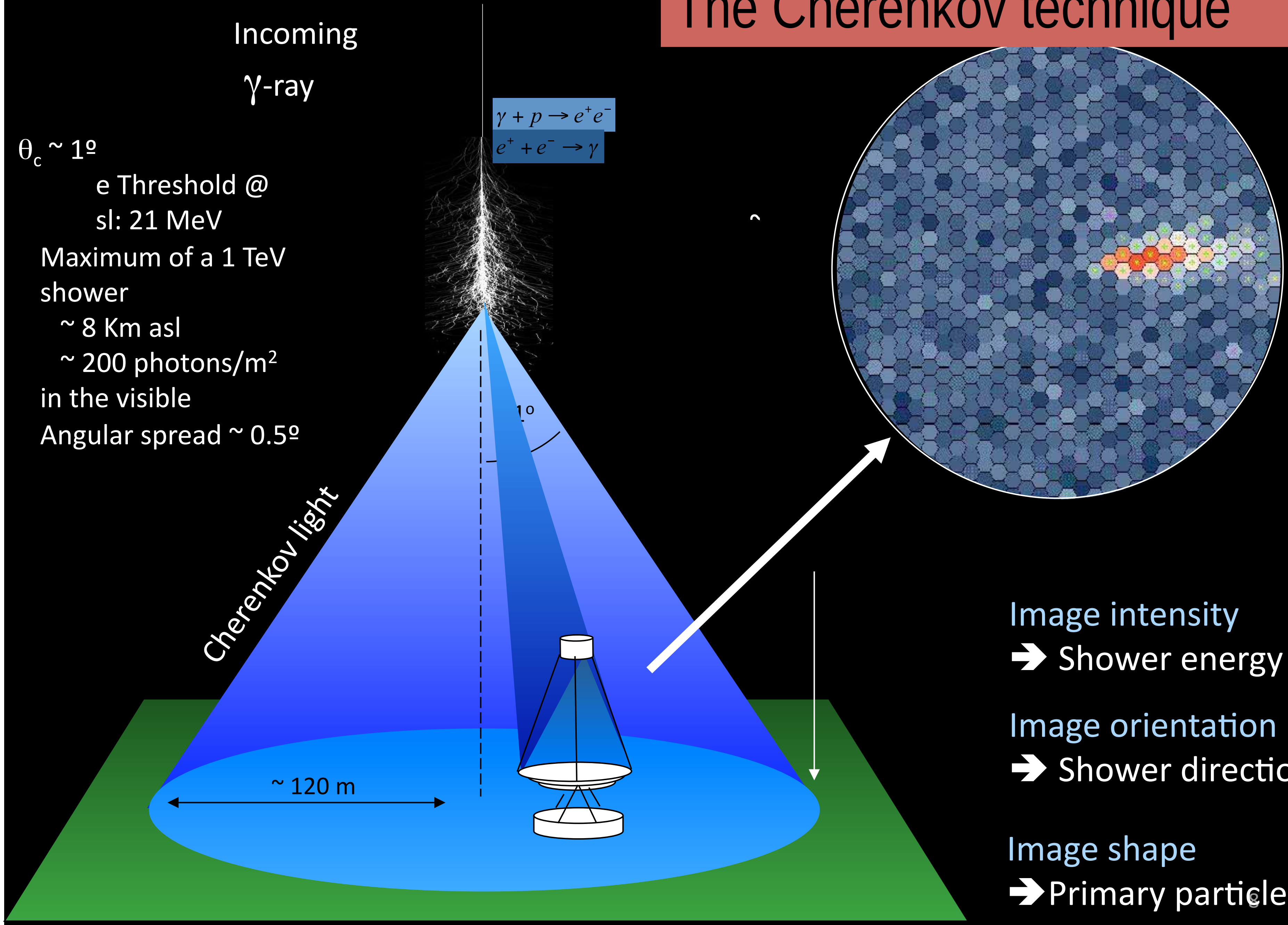
Precision Si-strip Tracker (TKR)
18 XY tracking planes
Single-sided silicon strip detectors 228 μm
pitch, 8.8 10^5 channels
Measure the photon direction

- Satellites (AGILE, Fermi)
  - Silicon tracker (+calorimeter)
  - $\Phi \propto E^{-2} \rightarrow$ up to ~ 100 GeV
- VHE: *Extensive Air Shower det. (ARGO): RPC, scintillators*
- Cherenkov telescopes (HESS, MAGIC, VERITAS)



HEP detectors!

The Cherenkov technique



Incoming

γ-ray

θ_c ~ 1º

e Threshold @

sl: 21 MeV

Maximum of a 1 TeV shower

~ 8 Km asl

~ 200 photons/m^2 in the visible

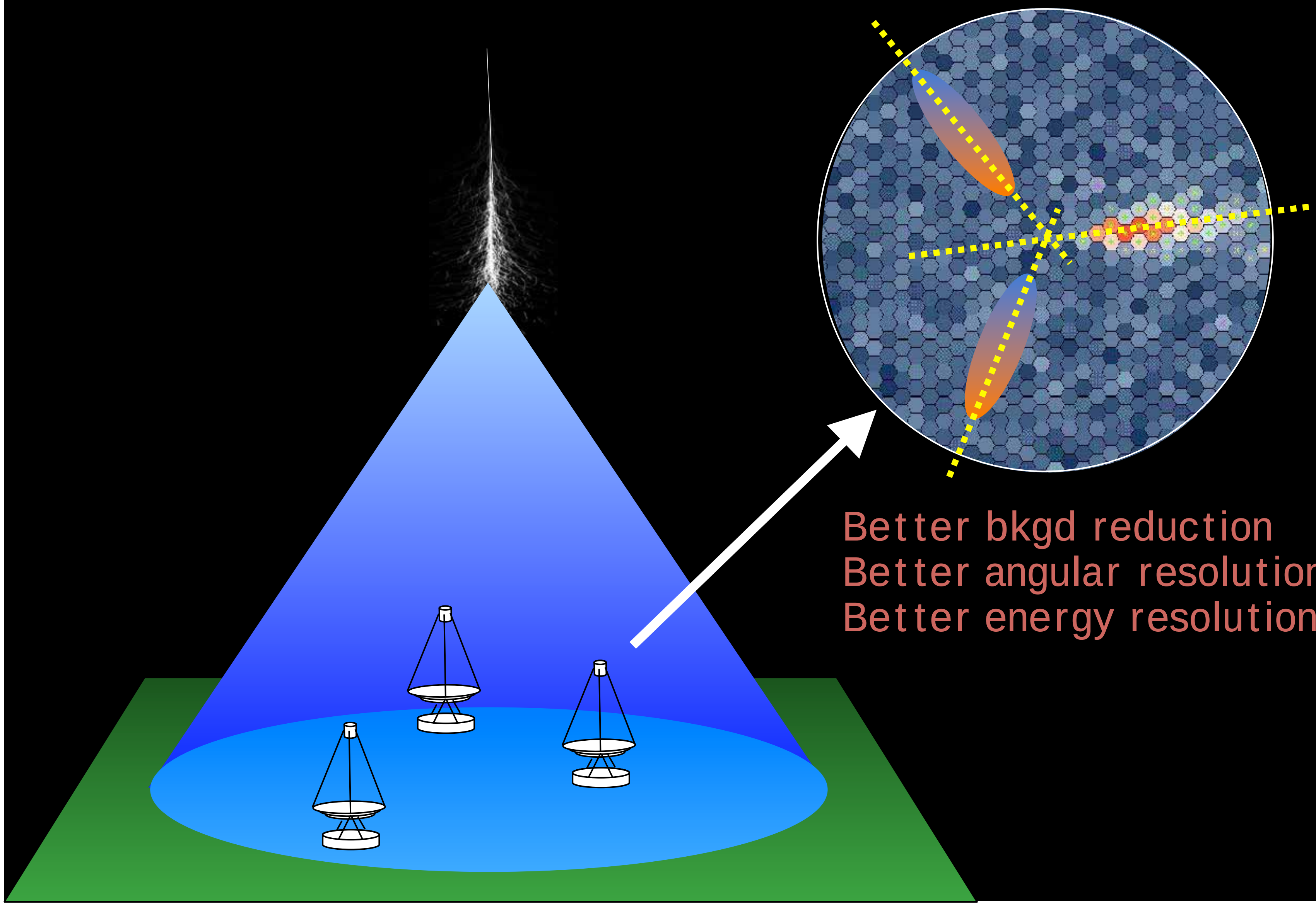
Angular spread ~ 0.5º

Image intensity
➔ Shower energy

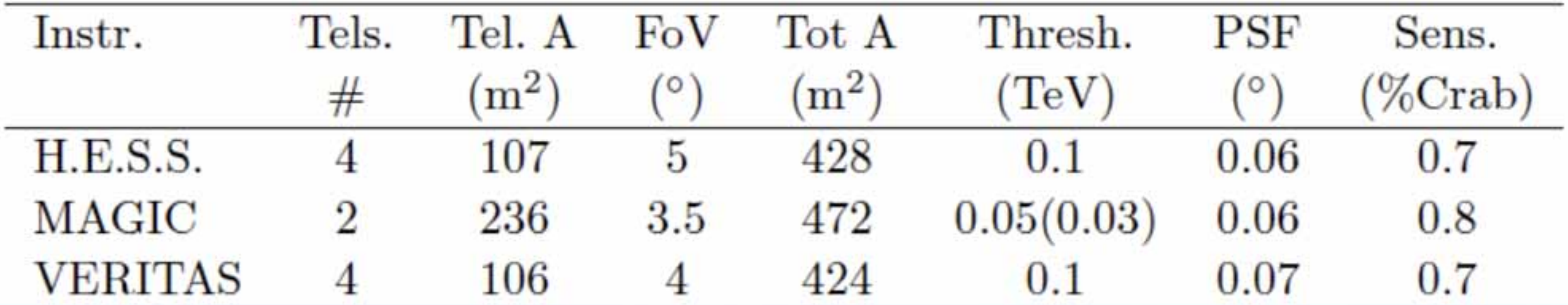
Image orientation
➔ Shower direction

Image shape
➔ Primary particle

Systems of Cherenkov telescopes



Better bkgd reduction
Better angular resolution
Better energy resolution



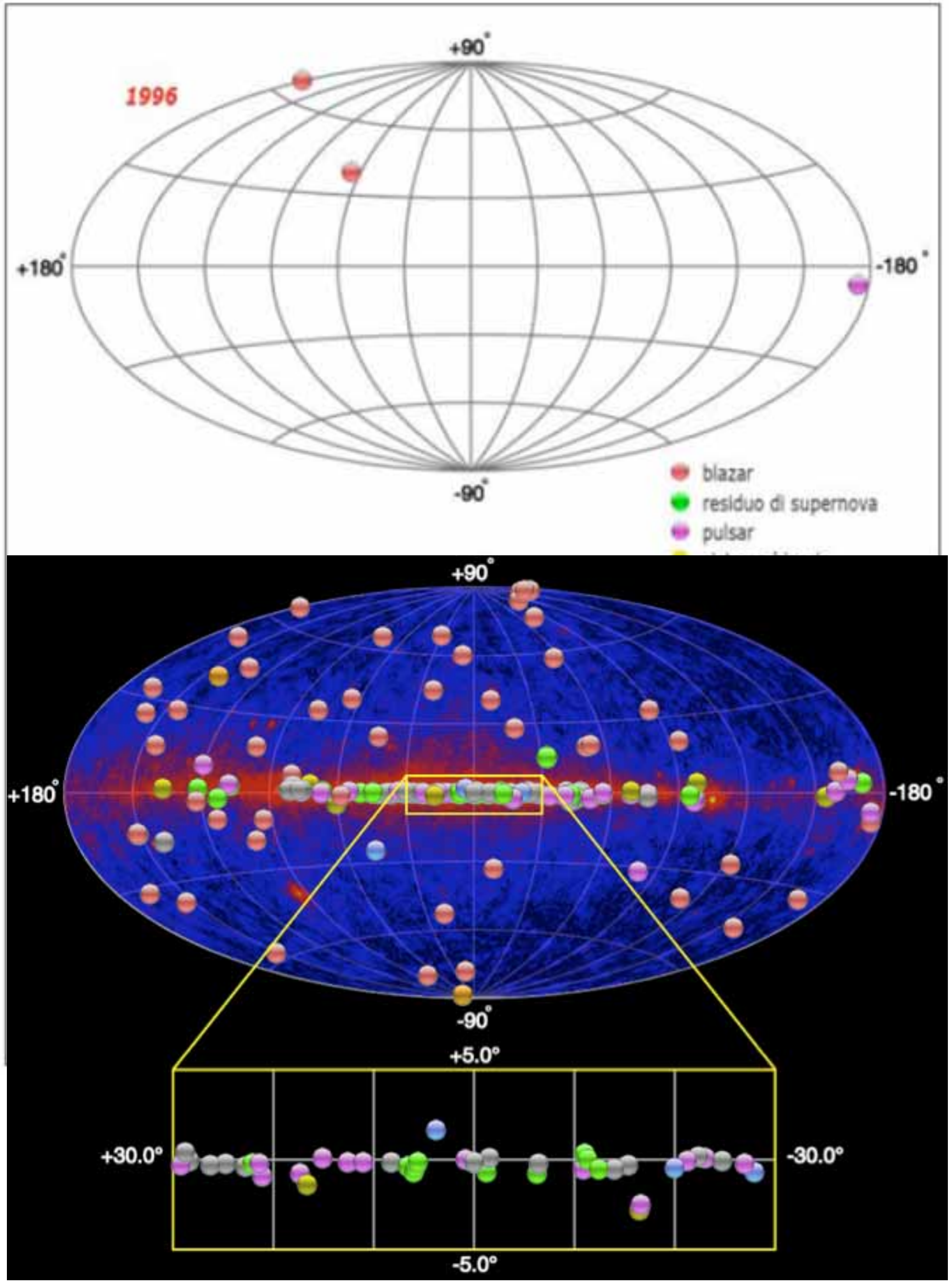
Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7

VERITAS: 4 telescopes (~12m) in Arizona operational since 2006

H.E.S.S.: 4 telescopes (~12m) in Namibia operational since 2003

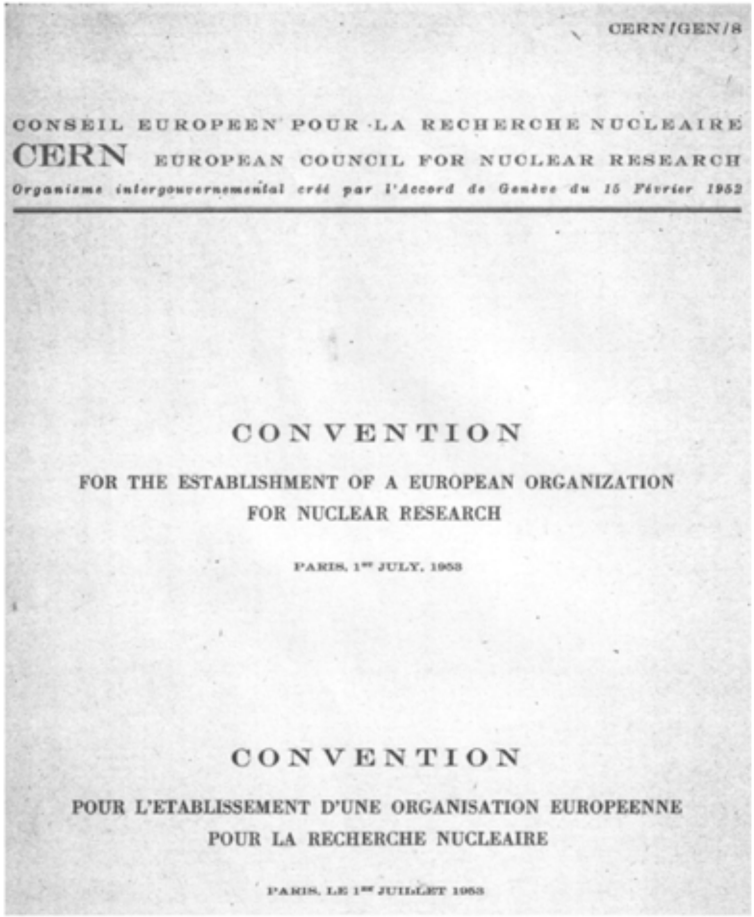
Highlight in γ-ray astrophysics (MAGIC, HESS, VERITAS)

- Thanks mostly to Cherenkov telescopes, imaging of VHE (> 130 GeV) galactic sources and discovery of many new galactic and extragalactic sources: ~ 150 (and >200 papers) in the last 7 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



Main physics results and perspectives
(with emphasis on fundamental physics)

- Cosmic Rays
- Transparency of the Universe;
  Tests of Lorentz Invariance;
  Axion-Like Particles
- Search for “WIMP” Dark Matter



CERN/GEN/8

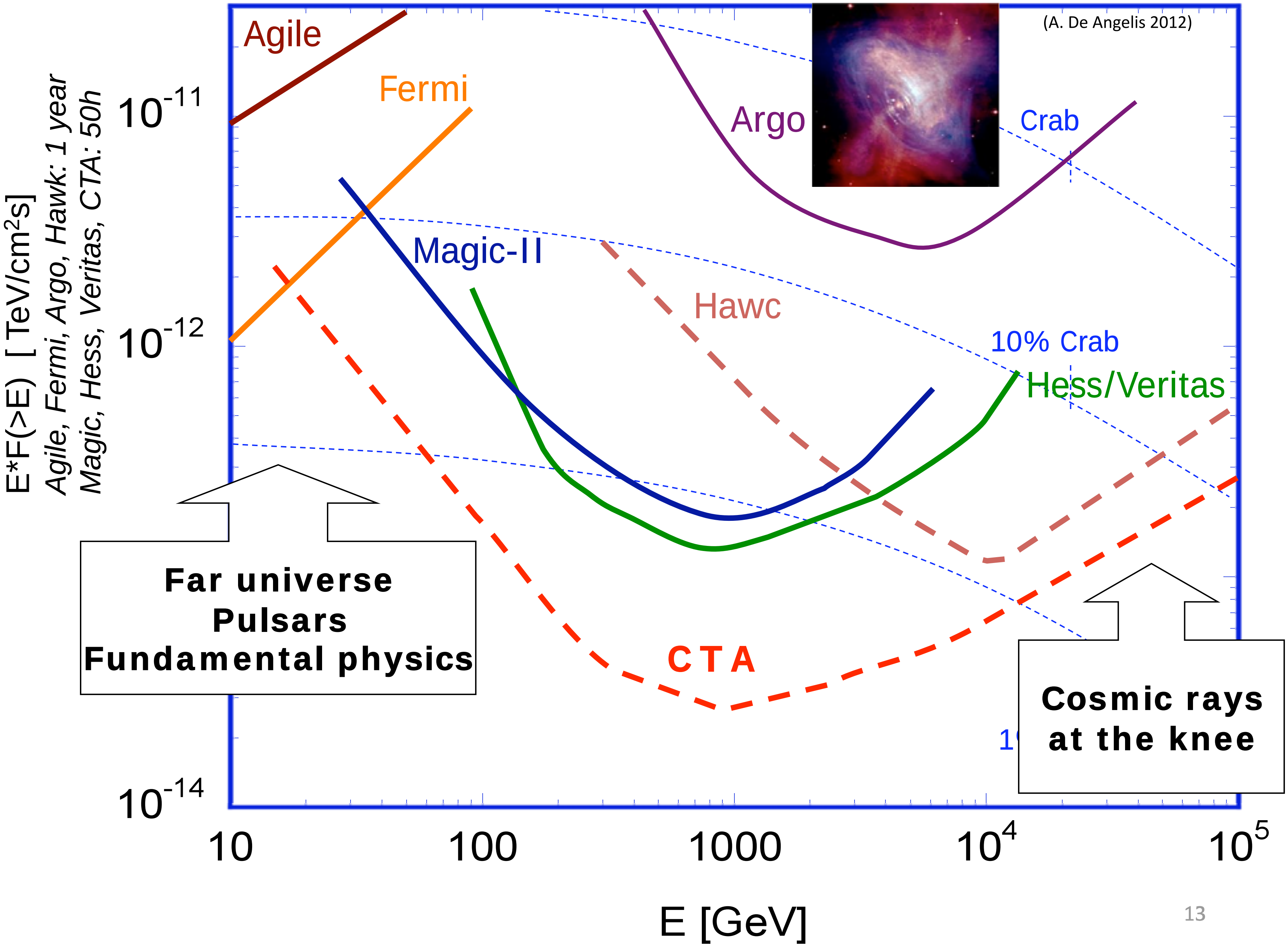
CONSEIL EUROPEEN POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN COUNCIL FOR NUCLEAR RESEARCH
Organisme intergouvernemental créé par l'Accord de Genève du 15 Février 1952

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

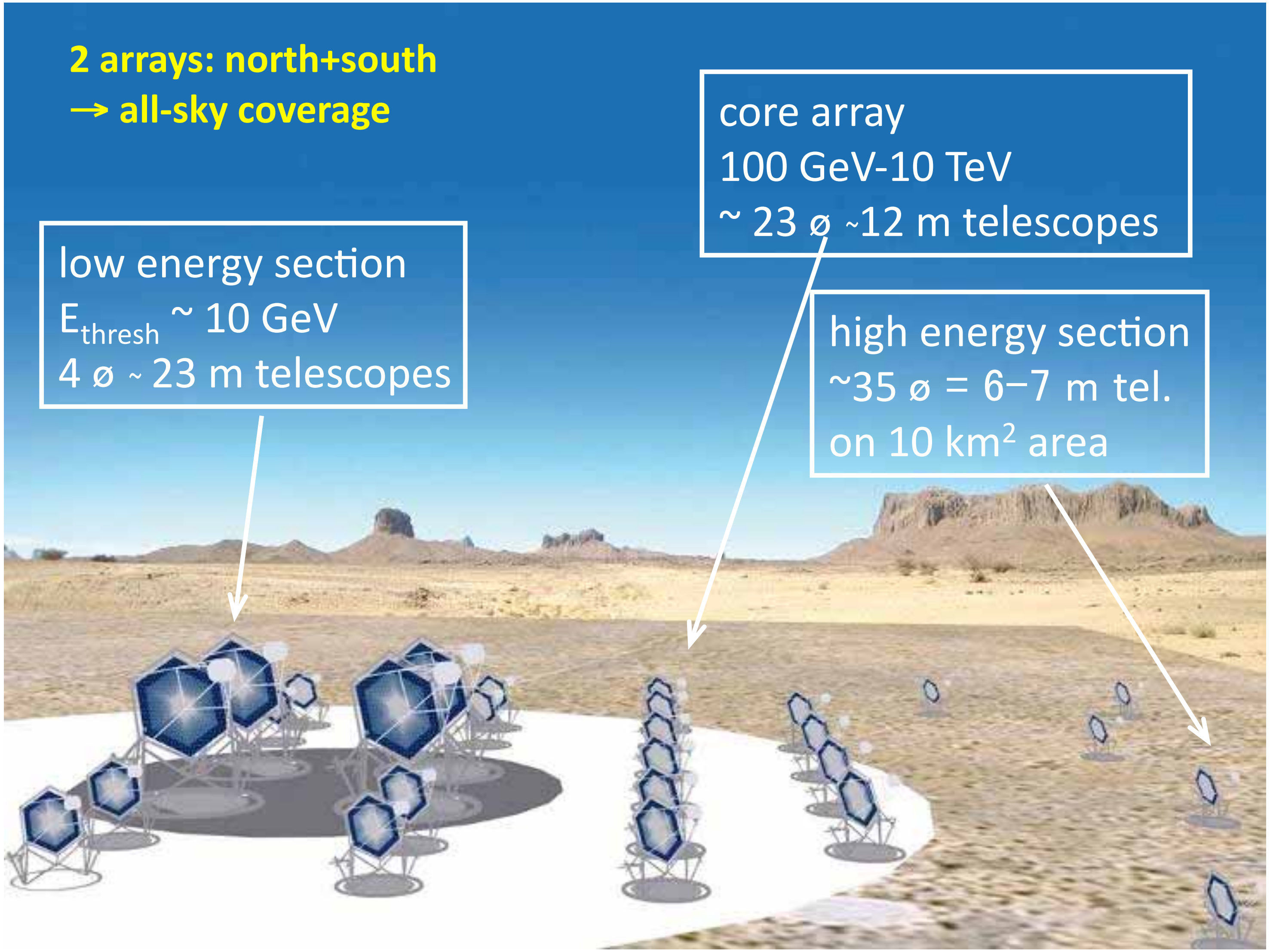
PARIS, LE 1er JUILLET 1953



Far universe
Pulsars
Fundamental physics

Cosmic rays
at the knee

The CTA concept (a possible design)



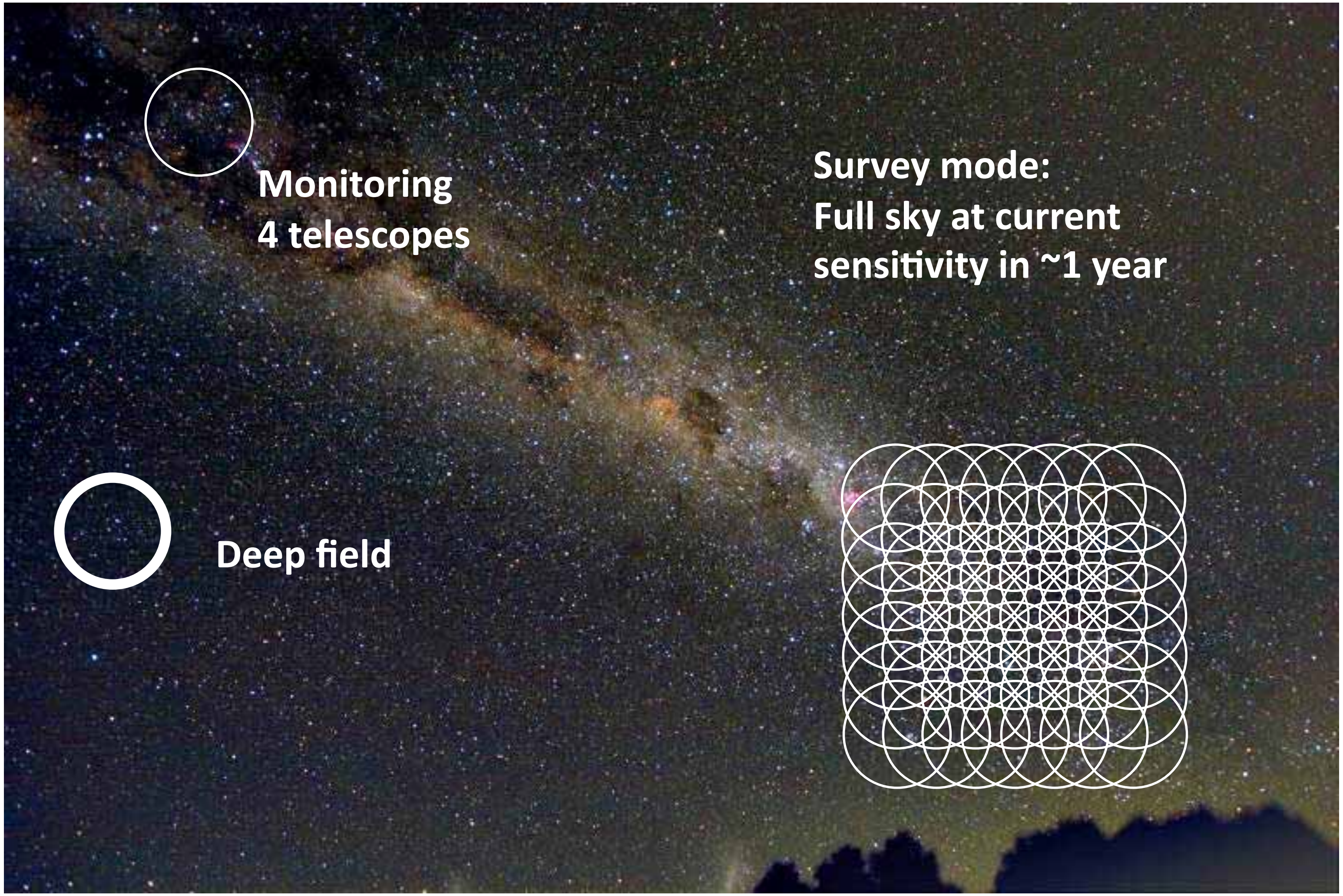
2 arrays: north+south
→ all-sky coverage

low energy section
E_{thresh} ~ 10 GeV
4 ø ~ 23 m telescopes

core array
100 GeV-10 TeV
~ 23 ø ~12 m telescopes

high energy section
~35 ø = 6–7 m tel.
on 10 km^2 area

CTA operation modes



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, HPDs, SiPMs
  - Analogue signal transmission via optical fibers
  - Readout system 2GHz ultra fast analogue ring sampler
  - Ultra fast trigger system
  - Large data flow, massive computing (GRID computing)

The INFN Group

- We asked Commissione 2 to open a line on this topic; this line will be supported by INFN members and associates from Bari, Como/Milano Bicocca, Napoli, Padova, Pavia, Perugia, Roma 2, Siena/Pisa, Torino, Udine/Trieste.
  - {Bari, Padova, Udine/Trieste, Roma2, Pisa/Siena, Perugia, Torino} can provide more than 1.5 FTE for CTA R&D; the remaining are likely to participate asking for funds in "Dotazioni"
- If the R&D will be approved, De Angelis (Ts/Ud) been designed as Coordinatore Nazionale for the first year (resigned from Coordinatore Nazionale of MAGIC).
- New groups are welcome

Interests of the INFN Group

- Interests of the people presently involved can be grouped as follows
  - Sensors (SiPM?): Perugia, Padova, Bari, Ud/Ts, Napoli, Roma2
  - Electronics: Bari, Pisa, Napoli
  - Atmospheric calibration/detector calibration & QC: Napoli, Pisa, Padova, Torino, Ud/Ts
  - Trigger: Padova, Pisa
  - Mirrors: Padova
  - MC ad analysis methods; physics: All.
- We are finalizing a letter of intent with a more detailed specification and we'll try to spend the next year, if approved, to converge as a group on the best topics for which we find a role of visibility in the collaboration, keeping in mind our INFN characterization
  - Newcomers are welcome also at 0% to sign the letter of intent

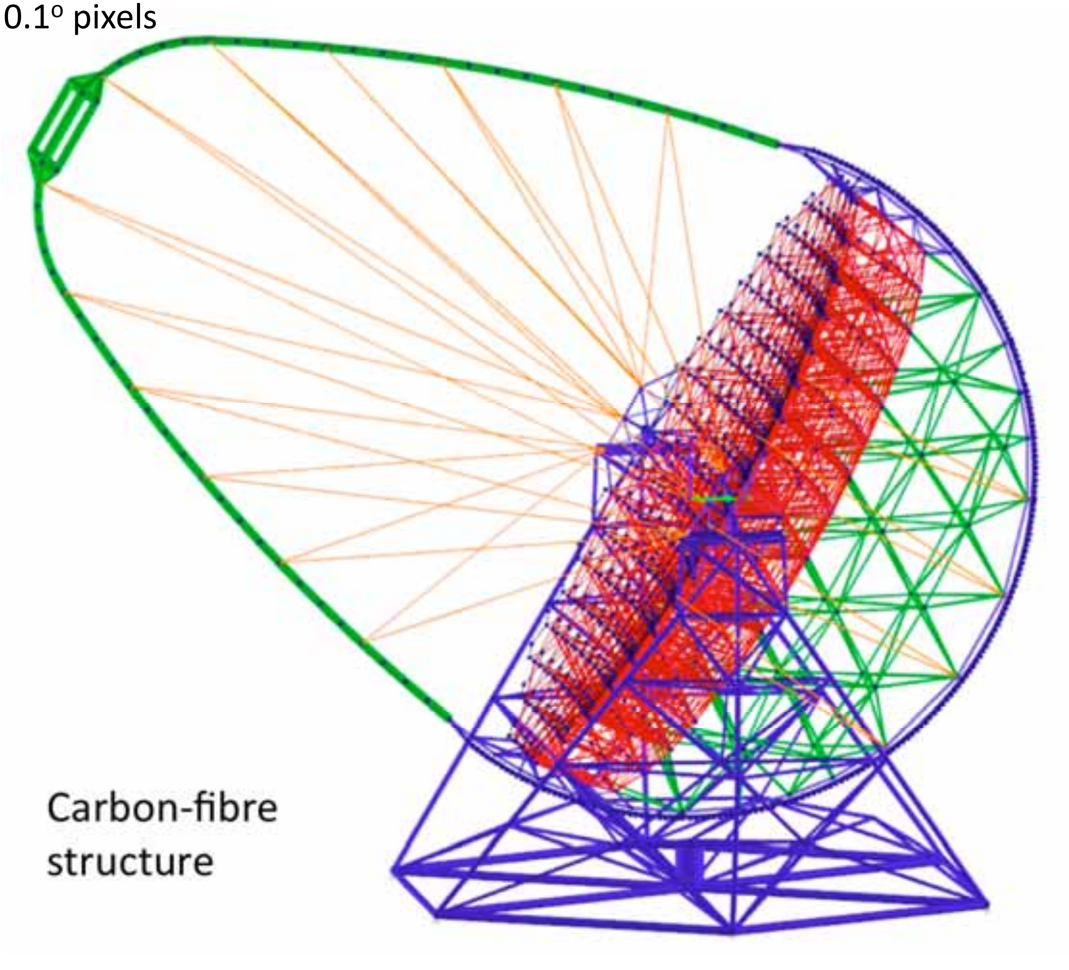
Industrial contribution

- ½ of the contribution expected from industry
- INAF will contribute with MediaLario mirrors (4MEUR?)
- INFN can contribute with Italian
  - Electronics
  - Sensors
  - Mirrors

The groups of Padova, Siena, Udine (as universities) have already a collaboration with Max-Planck Munich, IFAE and ICRR Tokyo for the Large-Size Telescope

optimized for the range below 200 GeV

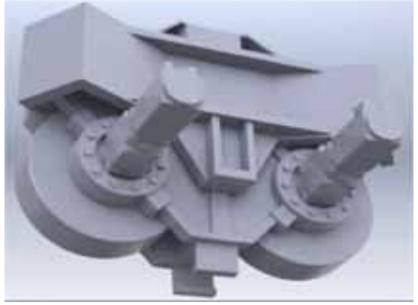
27.8 m focal length
4.5° field of view
0.1° pixels

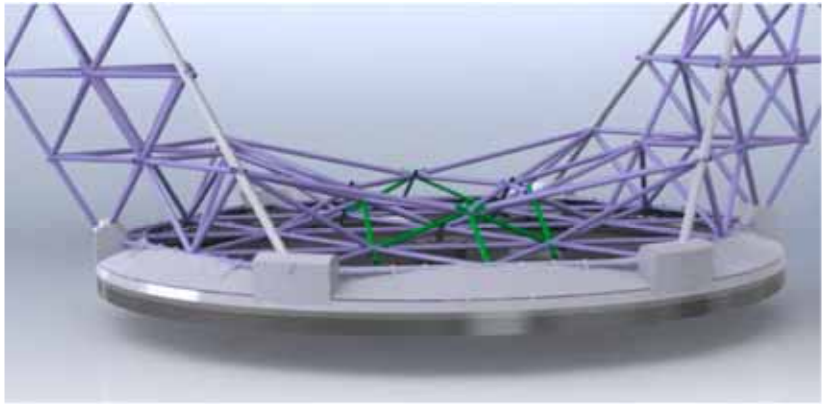


Carbon-fibre structure

400 m^2 dish area
1.5 m sandwich mirror facets

On (GRB) target in < 20 s



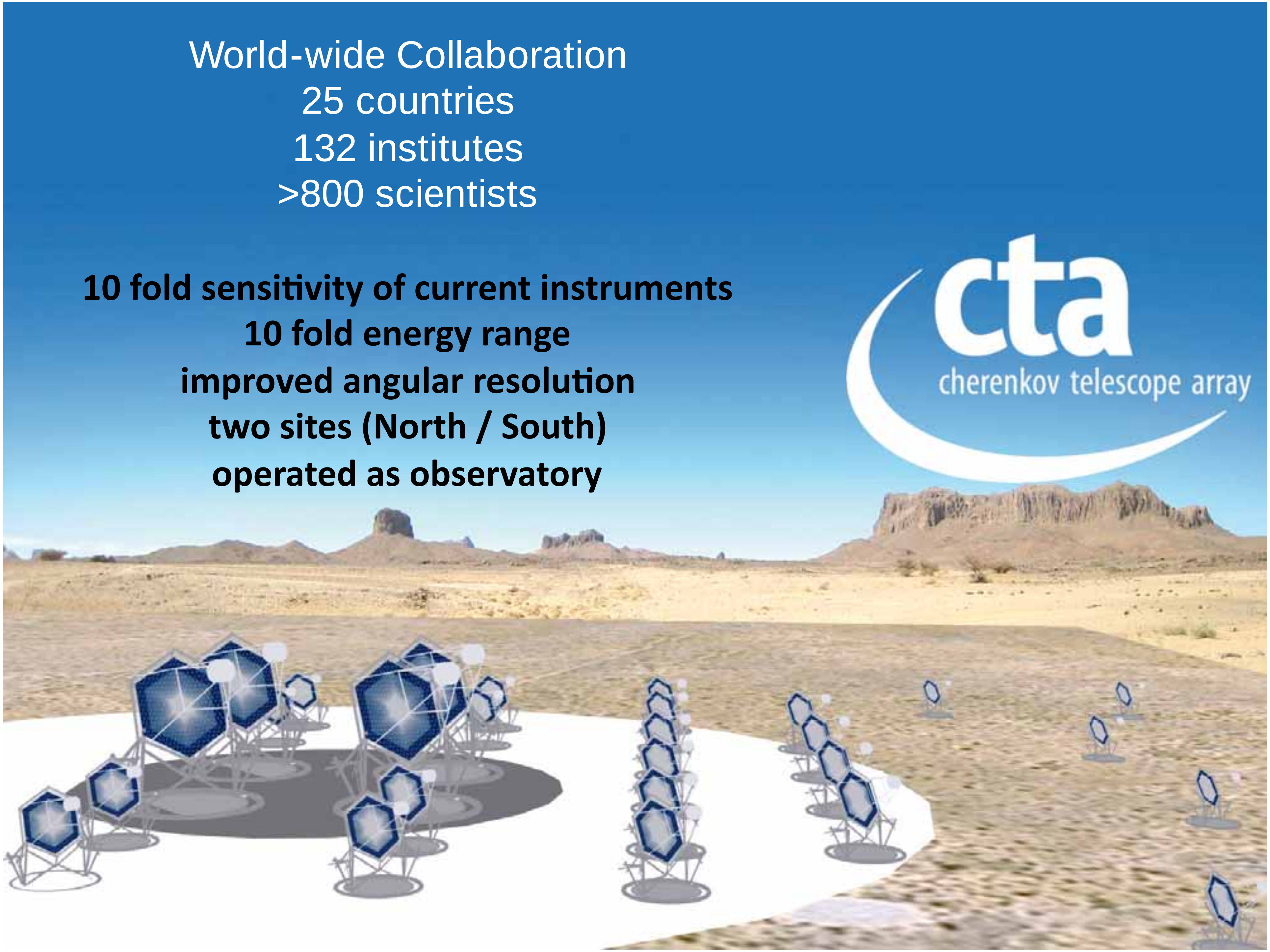


Possibility of cooperation also for SST sensors & electronics (geometry not yet defined)

Summary

- Clear interplay between VHE (γ) astrophysics and fundamental physics; this model of cooperation has worked well, and can work well in the future
  - We are confident that this exchange between complementary worlds will be useful, as history of particle physics demonstrated
- Cosmic Rays:
  - SNR as galactic sources established
    - Astronomy with charged CR is difficult
    - Astronomy with neutrinos will be difficult
    - VHE photons can be the pathfinder
- Still no detection of DM
- A few clouds might hide new physics
  - Photon propagation
- 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
  - INFN is naturally one of the main actors

BACKUP



World-wide Collaboration
25 countries
132 institutes
>800 scientists

10 fold sensitivity of current instruments
10 fold energy range
improved angular resolution
two sites (North / South)
operated as observatory

Recommended by relevant European roadmaps …

ASTROPARTICLE PHYSICS
the European strategy

European Strategy Forum
on Research Infrastructures
ESFRI

EUROPEAN ROADMAP
FOR RESEARCH
INFRASTRUCTURES

Roadmap 2008

STRONET

he ASTRONET
nfrastructure Roadmap:
Strategic Plan for European Astronomy

Status and plans

Design study phase concluded in Fall 2010

➜ Design Concepts for the Cherenkov Telescope Array (arXiv:1008.3703)

FP7-supported Preparatory Phase: Fall 2010 – Fall 2013

➜ Technical design, sites, construction and operation cost

➜ Legal, governance and finance schemes

➜ Small + medium-sized telescope prototypes

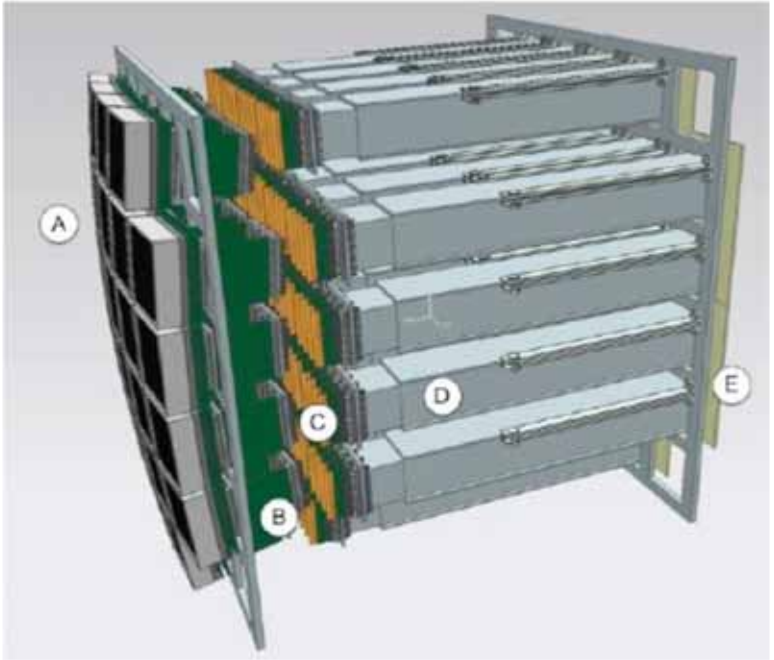
Aim for

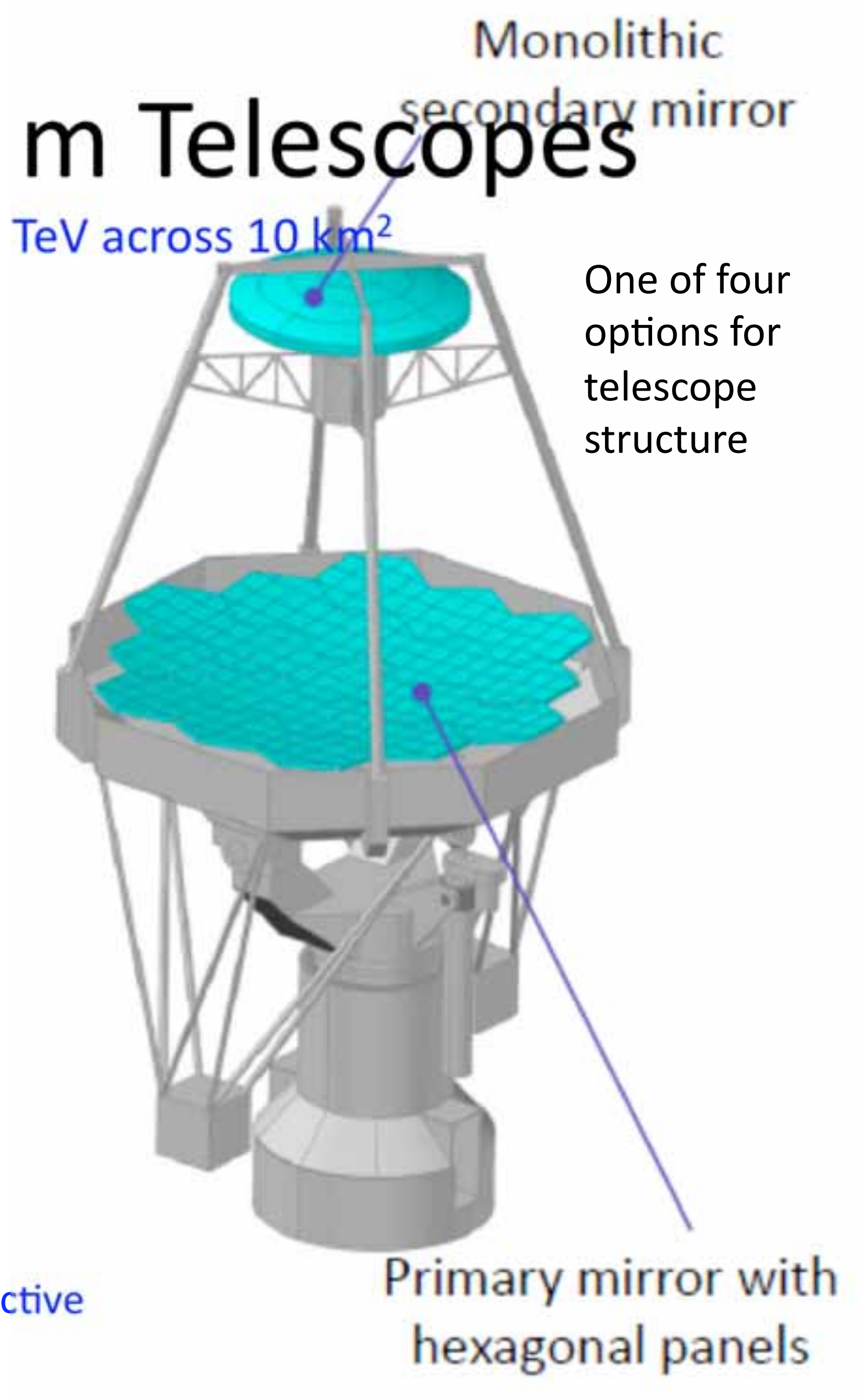
- start of deployment in early 2014
- first data in 2016/17
- base arrays complete in late 2018
- expanded mid-energy array driven by US
- total cost below 200 M€

Design: Small 4-6 m Telescopes

cover the range above few TeV across 10 km^2

Multi-Anode PMT camera option





One of four options for telescope structure

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

Telescope characteristics

Wavelenght range

300 – 600 nm

Mirror PSF

O(1’) on axis, worse off axis

Pixel size

0.1° – 0.2°

Source localization

5” – 10” for source centroid

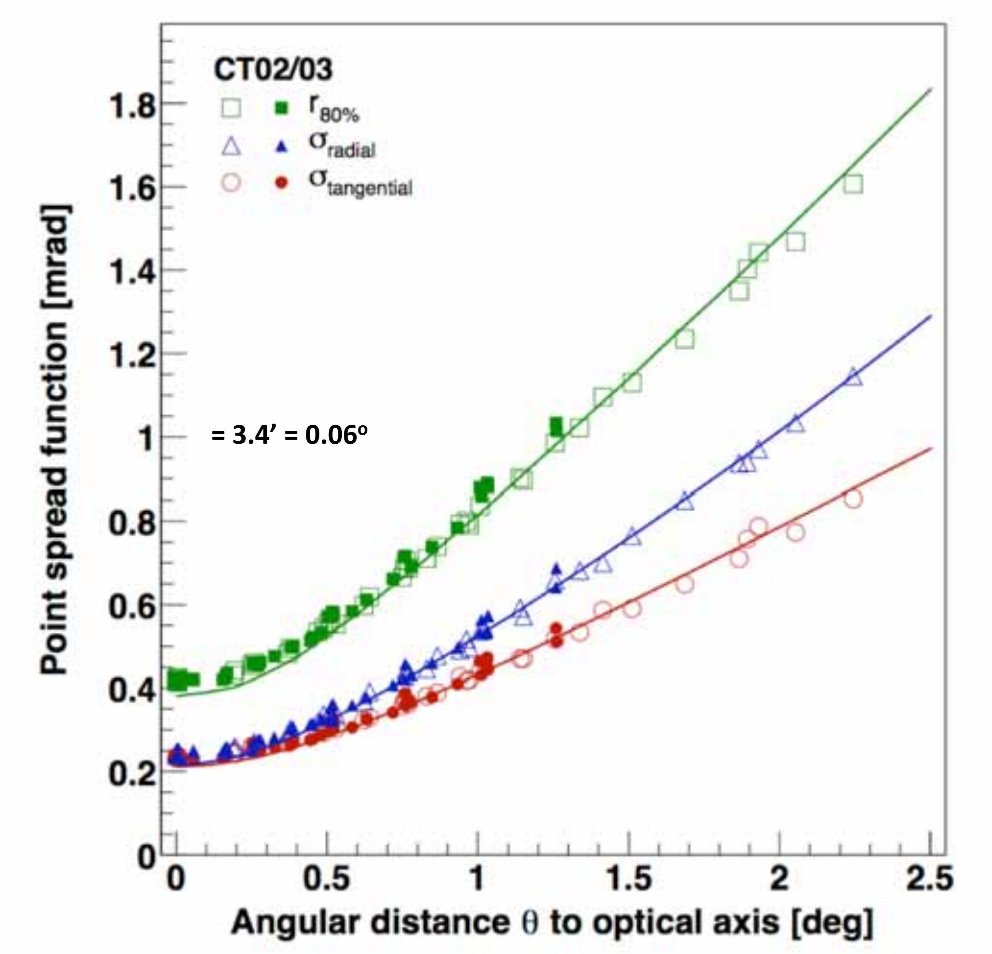
Image rate

kHz

Exposure time

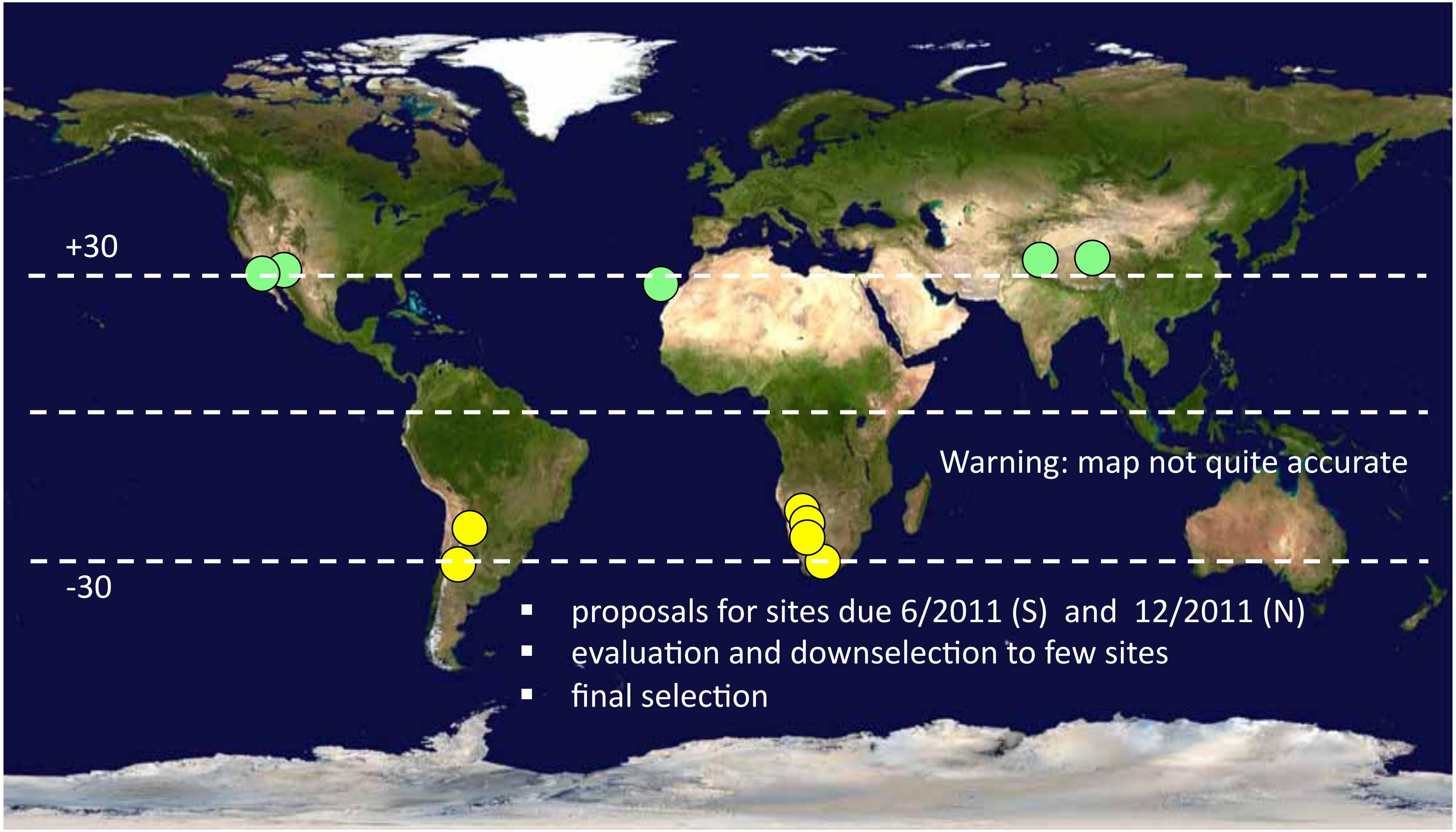
single image: O(10 ns)

typical source: 10 – 50 h



= 3.4’ = 0.06°

Sites under discussion



Warning: map not quite accurate

- proposals for sites due 6/2011 (S) and 12/2011 (N)
- evaluation and downselection to few sites
- final selection

Costs

- Given for ESFRI: 150 M€ investment cost (in 2006)
- 100 M€ south site
- 50 M€ north site
- Escalates to about 190 M€ for 2013-2018 construction period

Hardware key elements:

- O(100) Telescope structures/drives: very resistant, reliable, accurate, light-weight (LST)
- O(10.000) m^2 Mirrors: good quality, stable in extreme conditions, cheap, light-weight
- O(2-3 x10.000) camera channels:
  * **Photosensors:** PMT (and eventually SiPMs)

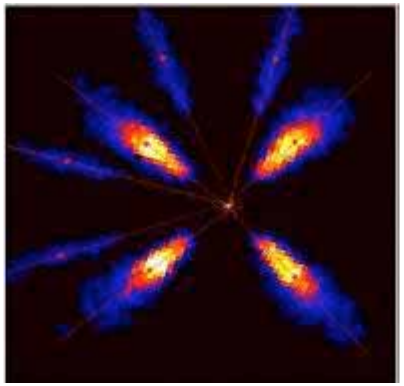
* **Readout Electronics:** fast, low dissipation, compact, reliable, cheap

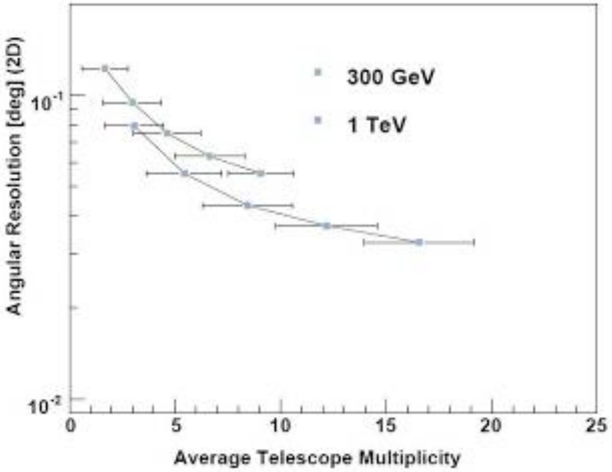
- Timing/Synchronization: comparable to LHC machine requirements

- Trigger/Data: comparable to LHC experiments

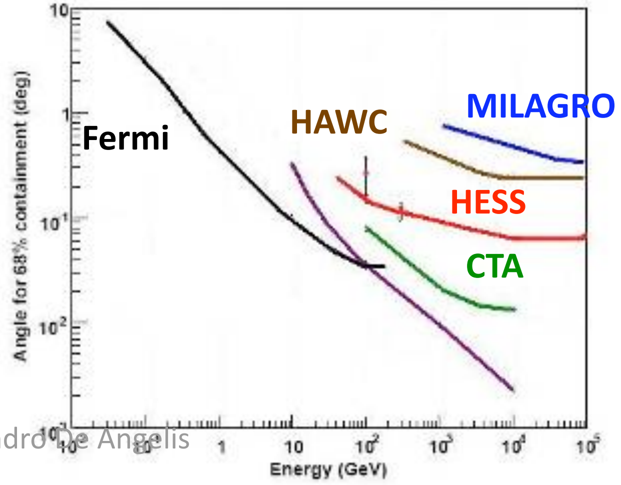
CTA performance: angular resolution

- Angular resolution improves as more telescopes used in reconstrution



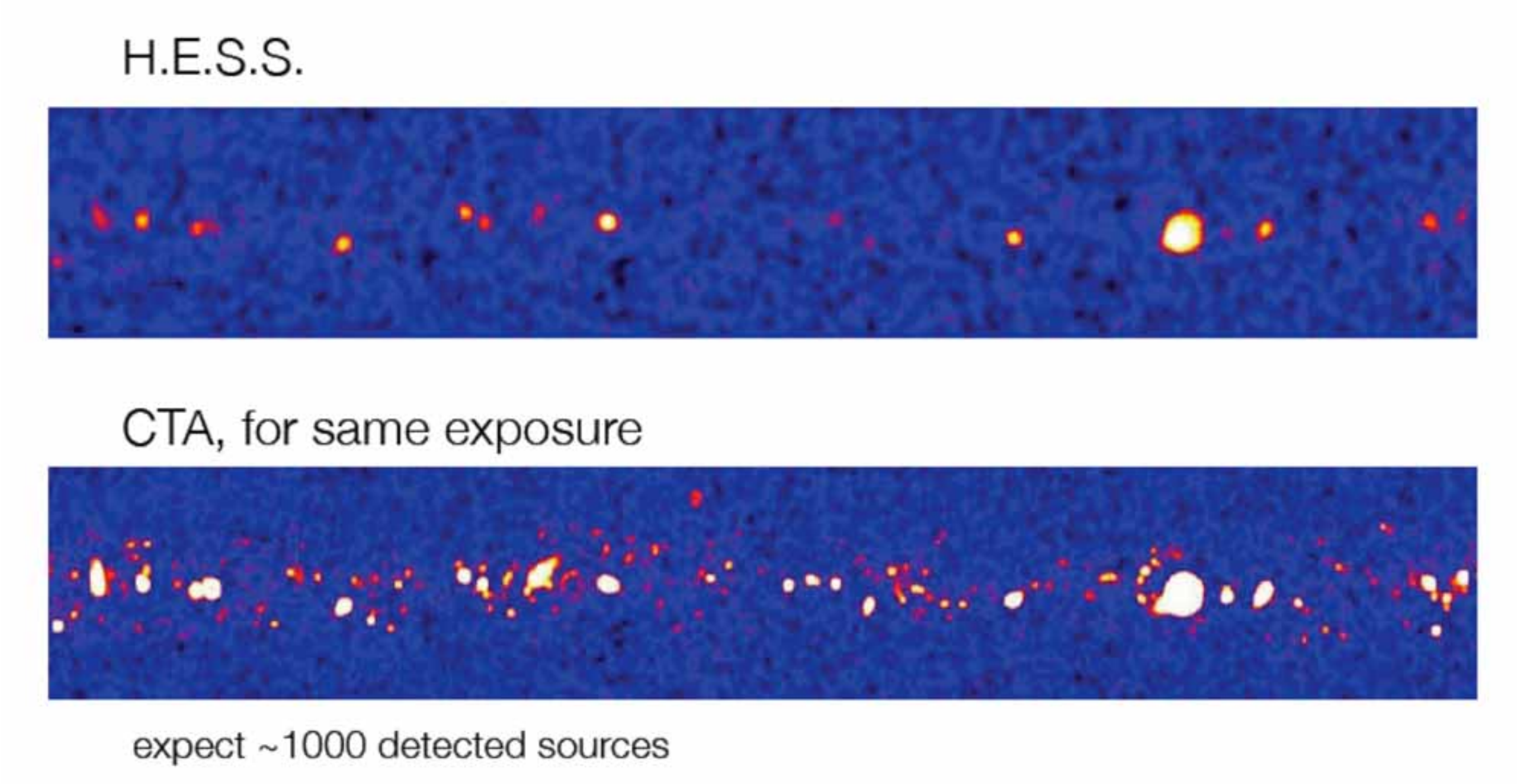


- Angular resolution closer to theoretical limit



↕ factor **3** improvement

CTA: Expectations for Galactic plane survey

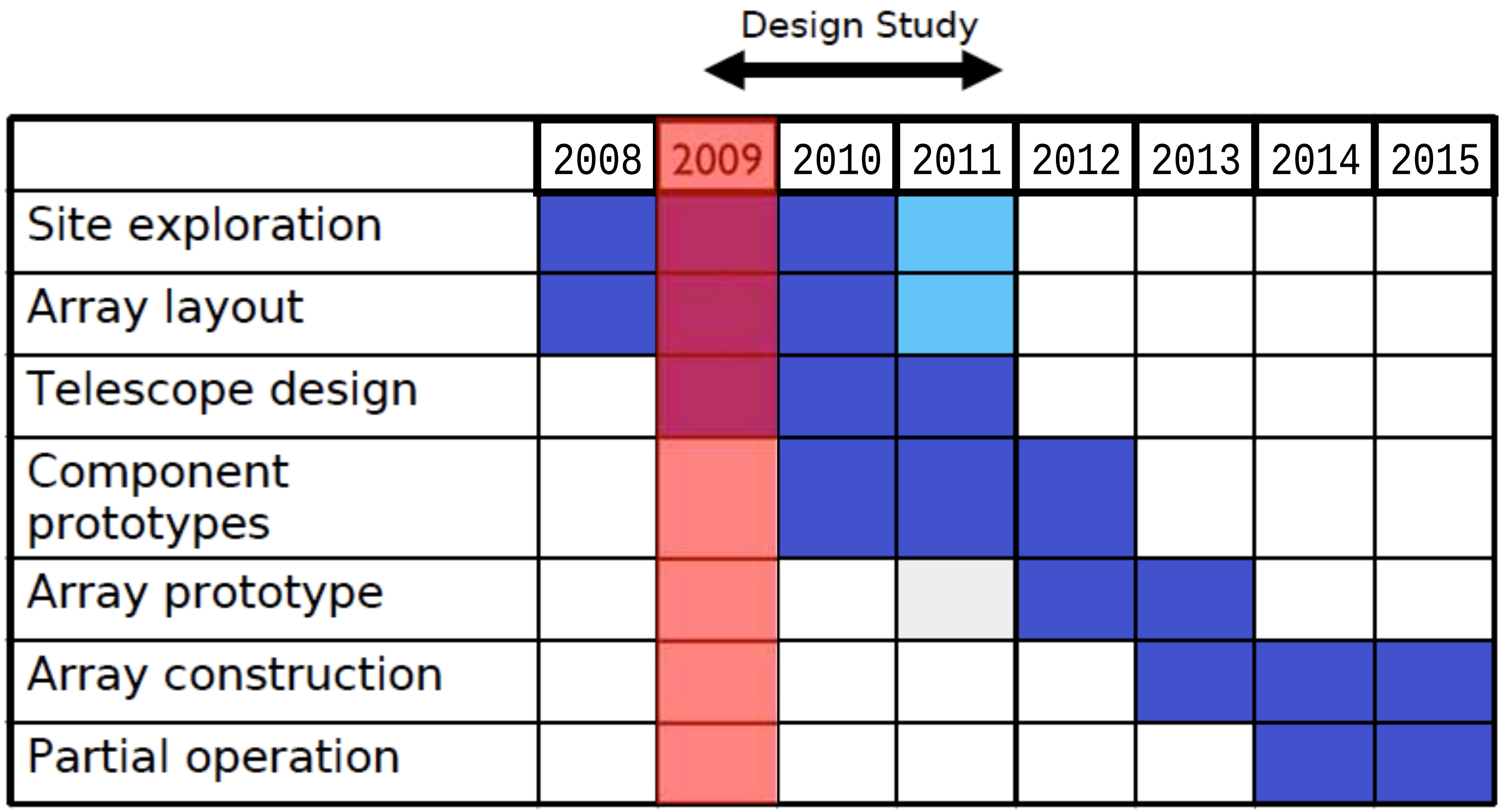


H.E.S.S.

CTA, for same exposure

expect ~1000 detected sources

CTA schedule (optimistic)



	2008	2009	2010	2011	2012	2013	2014	2015
Site exploration	■	■	■	▨				
Array layout	■	■	■	▨				
Telescope design		■	■	■				
Component prototypes			■	■	■			
Array prototype				░	■	■		
Array construction						■	■	■
Partial operation							■	■

Very funding dependent!

System fully operational in 2018