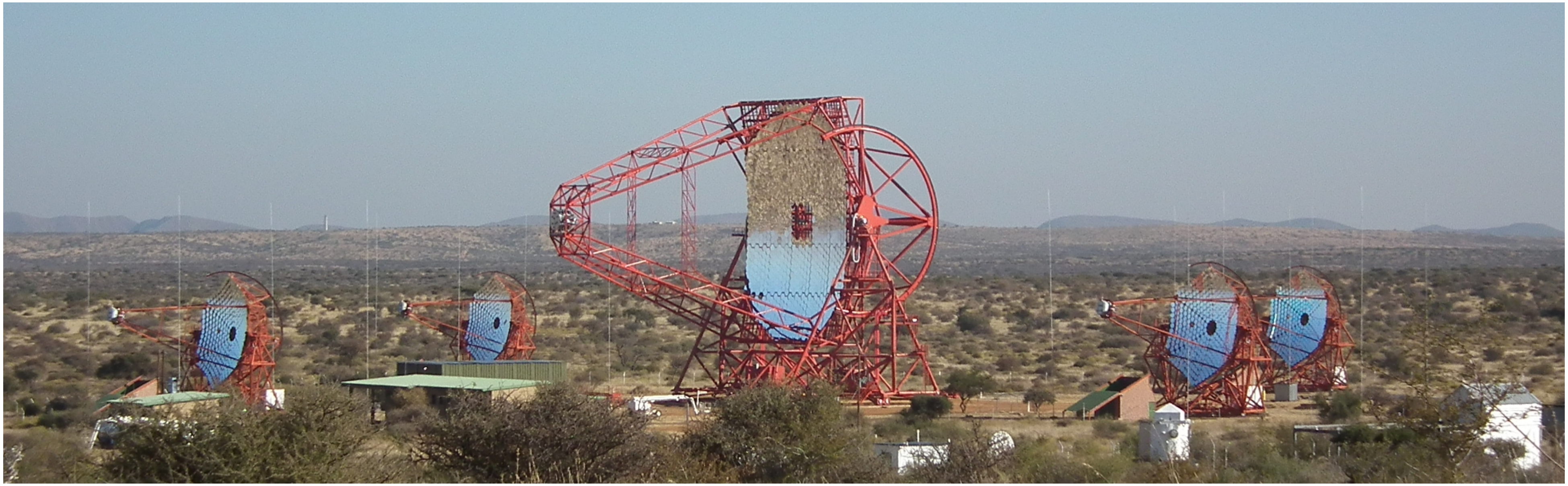
Detection of Atmospheric Showers with H.E.S.S.: Principle and Performance

Gamma-ray Astrophysics between 100GeV and 50TeV

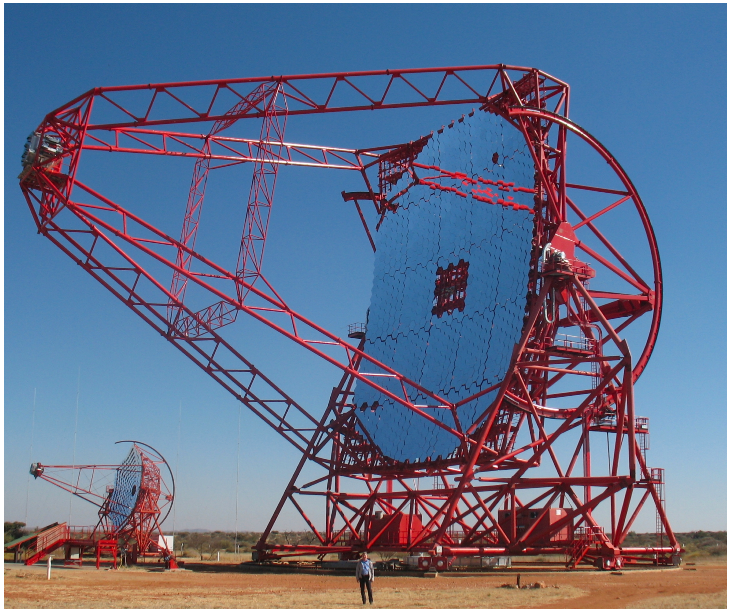
Bruno Khélifi
LLR, CNRS/École polytechnique

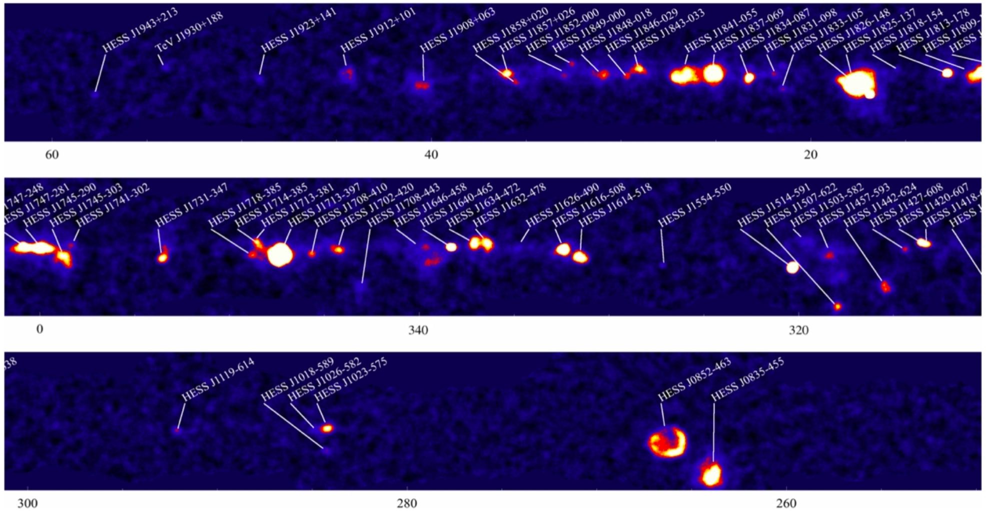


H.E.S.S.

Gamma-ray Astrophysics

- H.E.S.S. aims to observe the Southern γ-ray sky between 100GeV to 50TeV
  - Installed in Namibia since 2003 with 4 telescopes
  - Inauguration of a 5th large telescope in Sept. 2012
- Using the Imaging Atmospheric Cherenkov Technique
  - Array of telescopes observing the sky in stereoscopy





2nd Second
Galactic Scan
H.E.S.S. coll.

- Atmospheric Showers
- Cherenkov Radiation of showers
- H.E.S.S. Cherenkov Telescope Array
- Gamma-ray analysis methods
- H.E.S.S. performance and main physics topics

Atmospheric Showers for 100GeV-50TeV γ-rays

- Atmosphere is opaque to gamma rays
  - In total ~28 X_0 (X_0= 36,7 g/cm^2 for air; Si: 22, Fe: ~15)
  - Development of an EM atmospheric shower

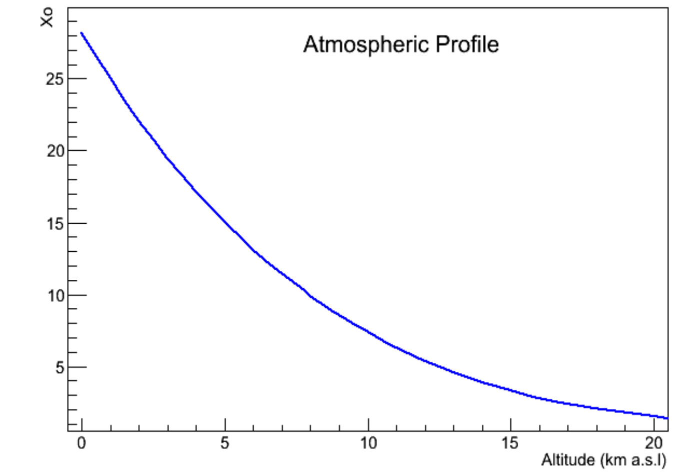
- Main phenomena that drive the shower properties
  - Pair creation and Bremsstrahlung
  - Multiple diffusion: $R_m = X_0 \times (21\text{MeV}/E)$ g/cm^2 (~71m at sea level)

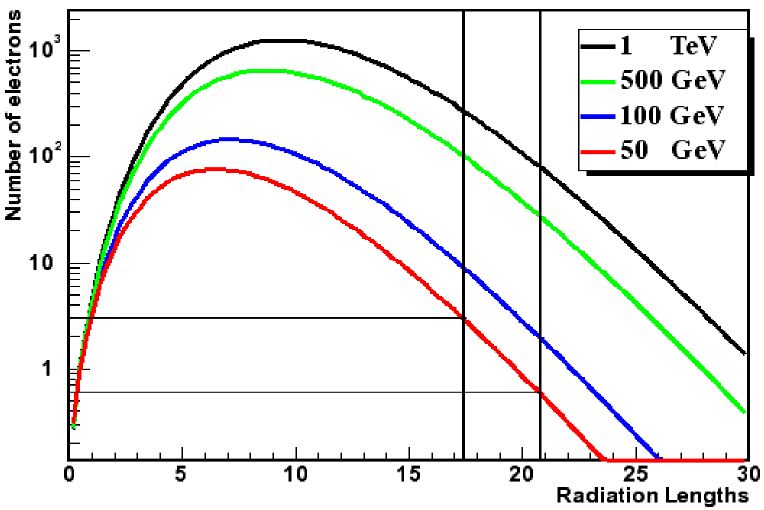
  (Pair creation, Bremsstrahlung and multiple diffusion:) In the coulomb field of nucleus

  - Ionisation: leading over Brem. of $E < E_c$=83MeV in air

- Secondary phenomena
  - At low energy, Compton effect and e^+ annihilation → Negative excess charge (Askaryan effect)
  - At high energy, photo-production of hadrons: $\sigma \approx 10^{-3}\,\sigma$(pair creation)

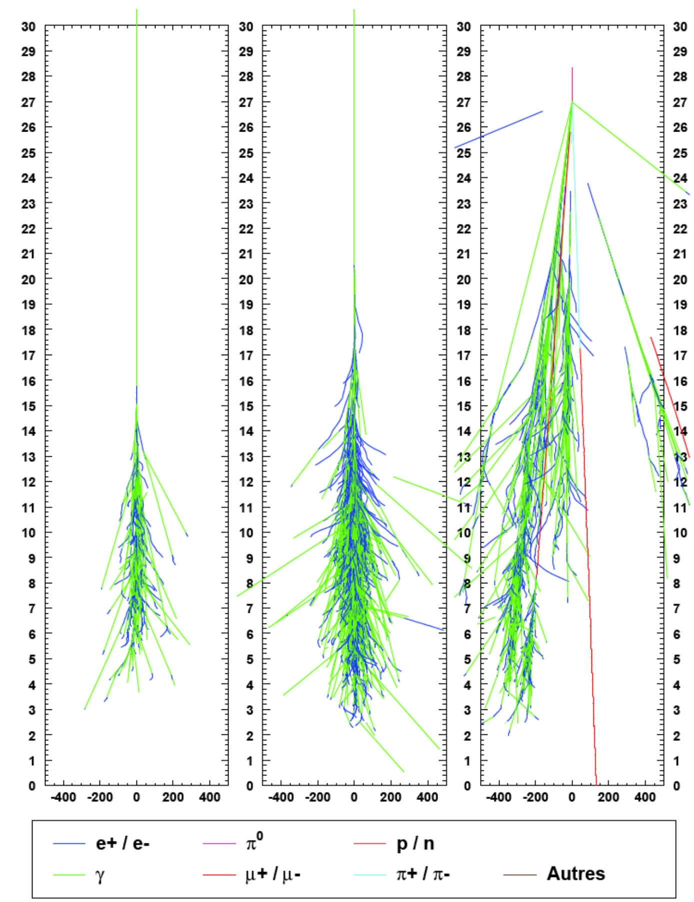
Atmospheric Showers for 100GeV-50TeV γ-rays





Energy	Sh. Maximum Altitude (km)
100GeV	11.4
500GeV	9.7
1TeV	9.0
10TeV	7.2
50TeV	6.1

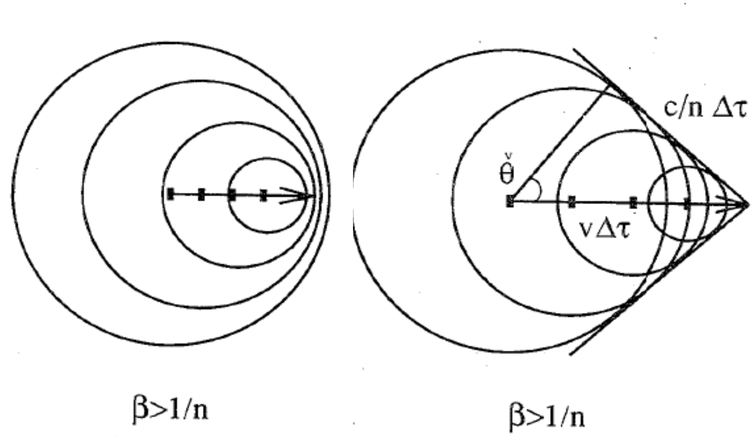
- Inhomogeneous calorimeter
  - Shower beginning at ~20km a.s.l.
  - Shower maximm : 6-11km a.s.l., ln(ln $E_{\gamma}/E_{ionisation}$)
  - Maximum diameter: O(100m)
  - Lenght: O(10km)

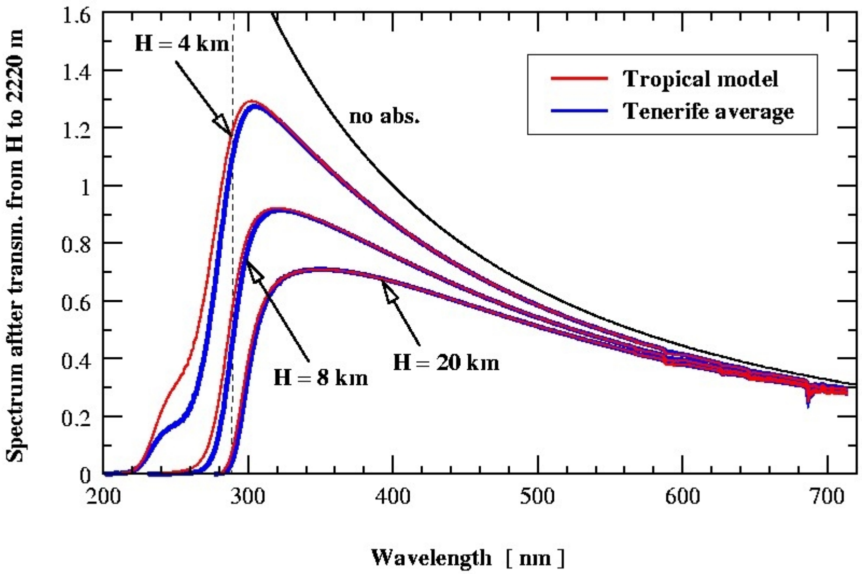


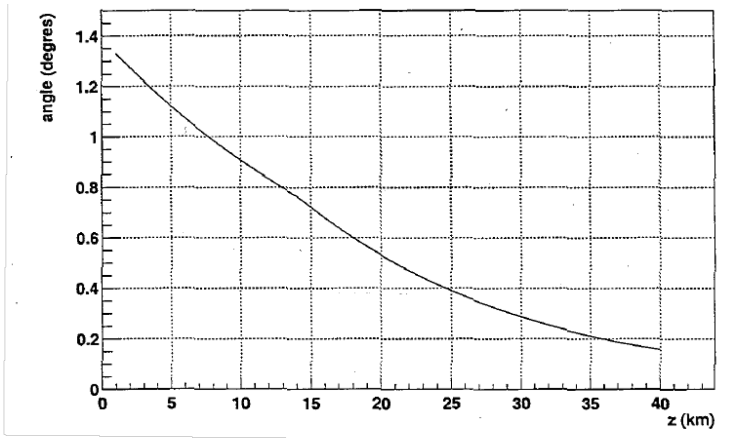
300GeV γ-rays
M. de Naurois
(PhD thesis, 2000)

Cherenkov Radiation of EM Showers

- When charged particles have $\beta > 1/n(\text{alt.})$
  - Emission collimated along the shower axis
  - Cherenkov angle is a function of altitude $1/\cos\theta_c = \beta\, n(\text{alt.})$
  - Light spectrum $\propto 1/\lambda^2$, before atmosphere absorption







- Other types of radiation (only for $E \gg 10^{17}$ eV)
  - Fluorescence of nitrogen:
    - Isotropic emission
    - 4 photons per electron per m on ground
  - Coherent radio emission:
    - Negative excess charge, geo-magnetic field
    - Weak emission in MHz or GHz range

H.E.S.S.

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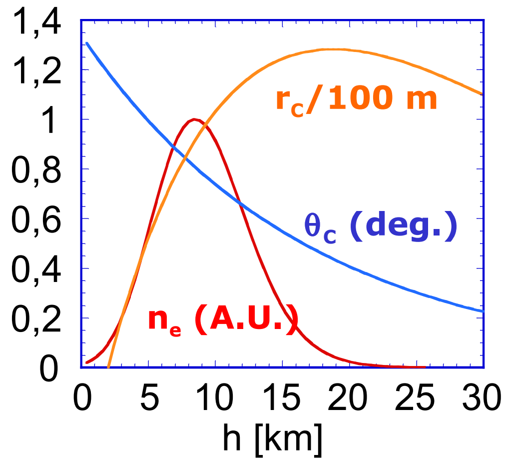
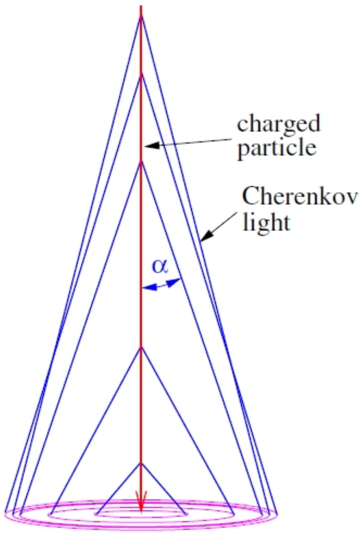
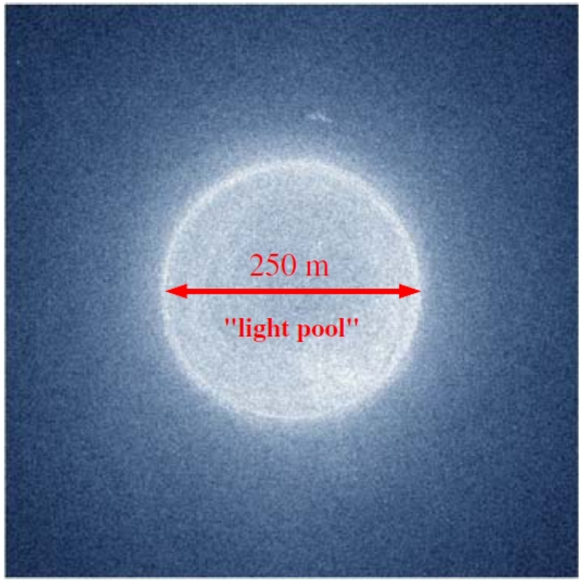
Cherenkov Radiation of EM Showers

- Spatial distribution on ground

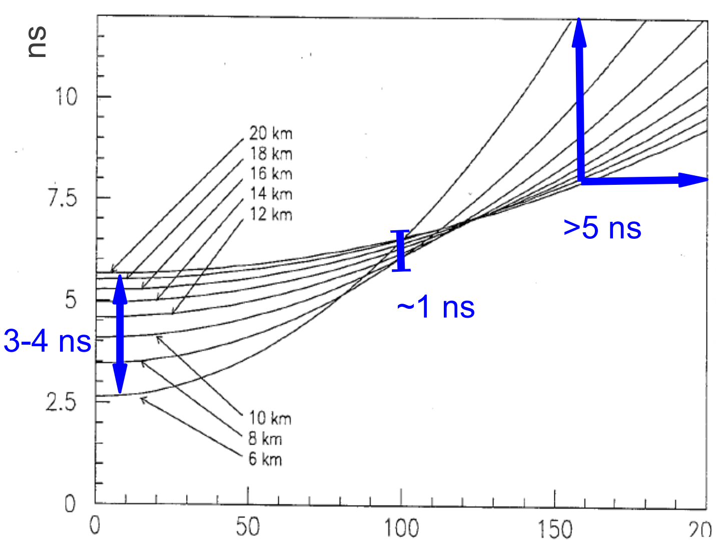




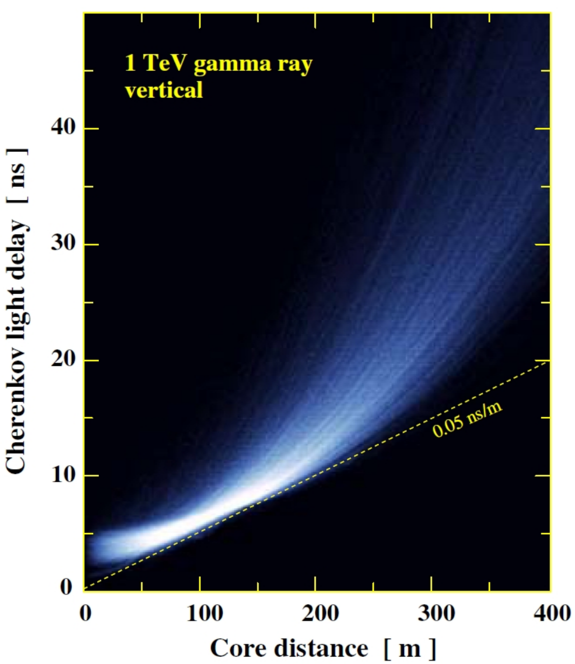


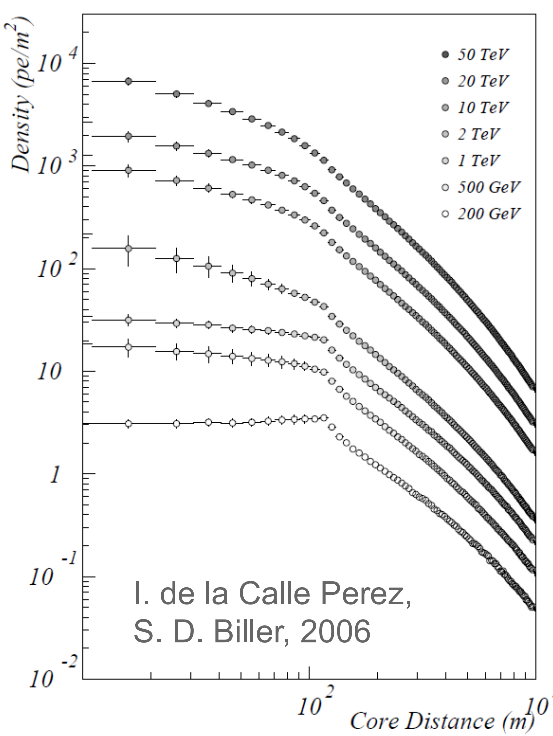
1TeV γ-ray, Völk & Bernlöhr, 2009

- Temporal properties on ground



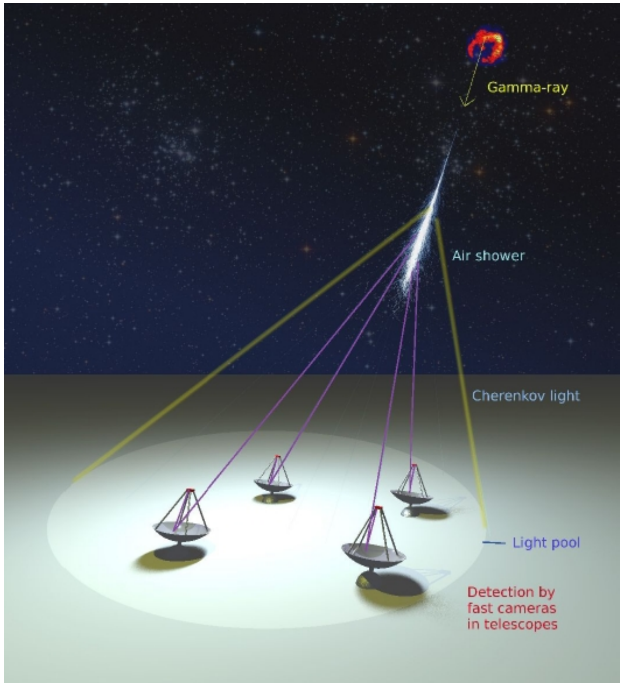
A. Djannati-Ataï, PhD Thesis (1995)

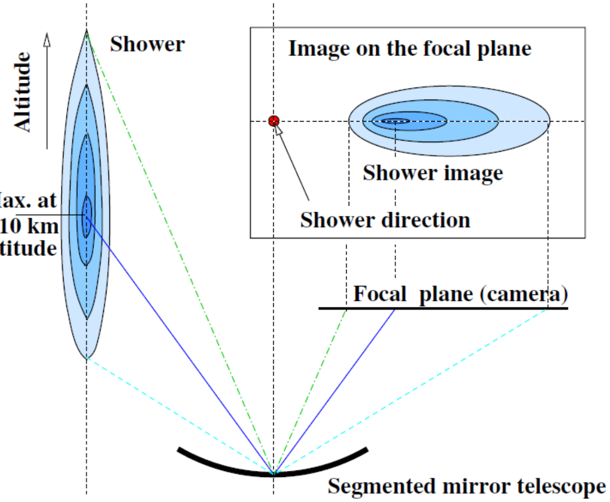




I. de la Calle Perez, S. D. Biller, 2006

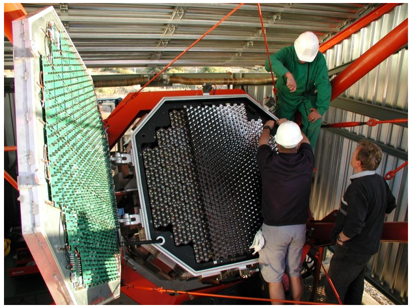
Imaging Atmospheric Cherenkov Telescope

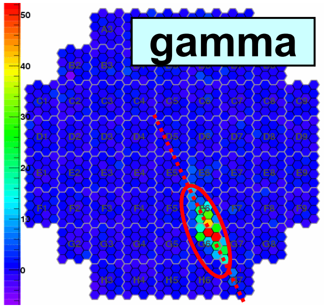




- Weak ground density of light → large collection area
- Cherenkov peaks at 300-350nm → optical wavelength

  ↳ Use large optical telescopes of O(100m^2)





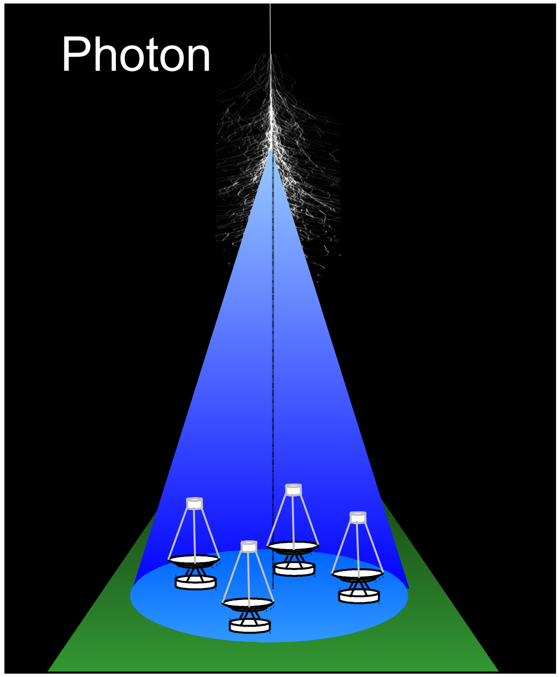
- Fast signal of O(10ns) and angular size of O(0.1°)

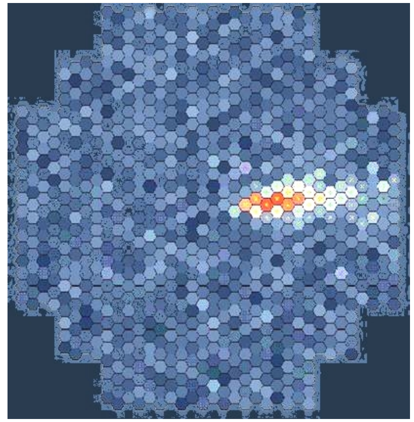
  ↳ Use fast (GHz) and finely pixelized camera

- Main sources of background
  - Ambient optical light (ground, sky): O(100MHz) with 0.18° pixels
  - Cosmic rays (hadrons and electrons): ~300Hz
    - Typical γ rate < 0.2Hz (flux from the Crab nebula)

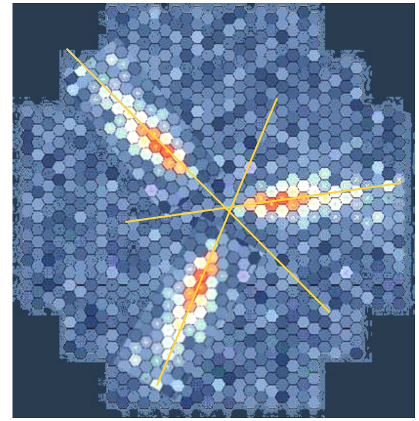
H.E.S.S.

Analysis Methods



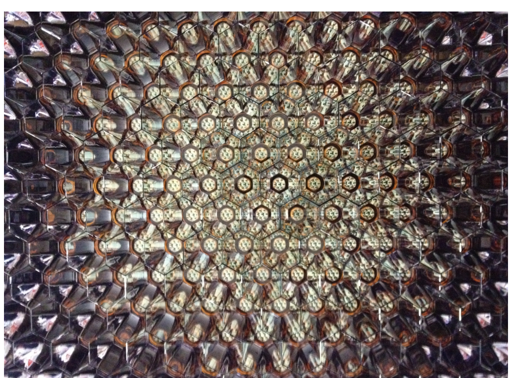


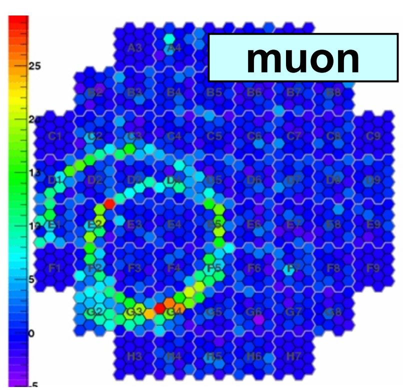
Single telescope event

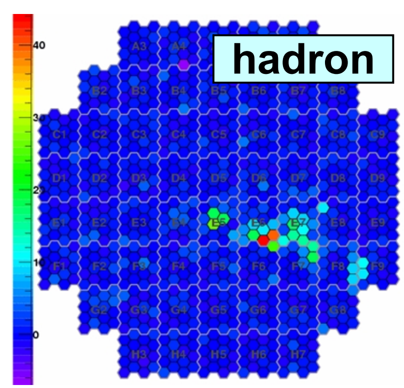


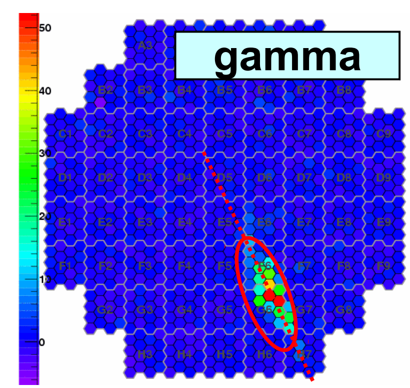
3-telescope event
in common camera plane

- Intensity ⇒ Energy
- Orientation ⇒ Direction
- Form ⇒ Primary particle



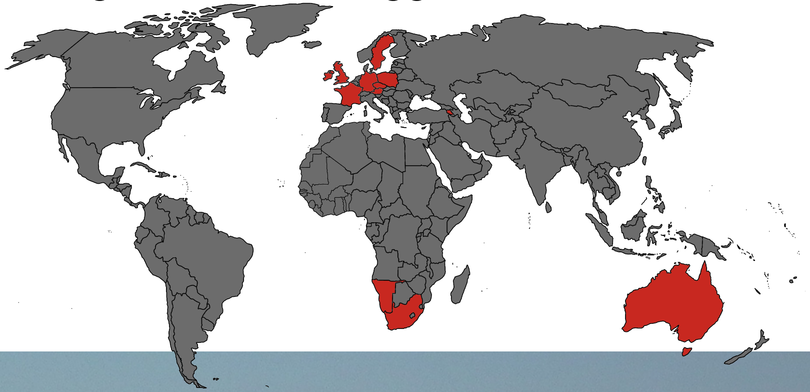


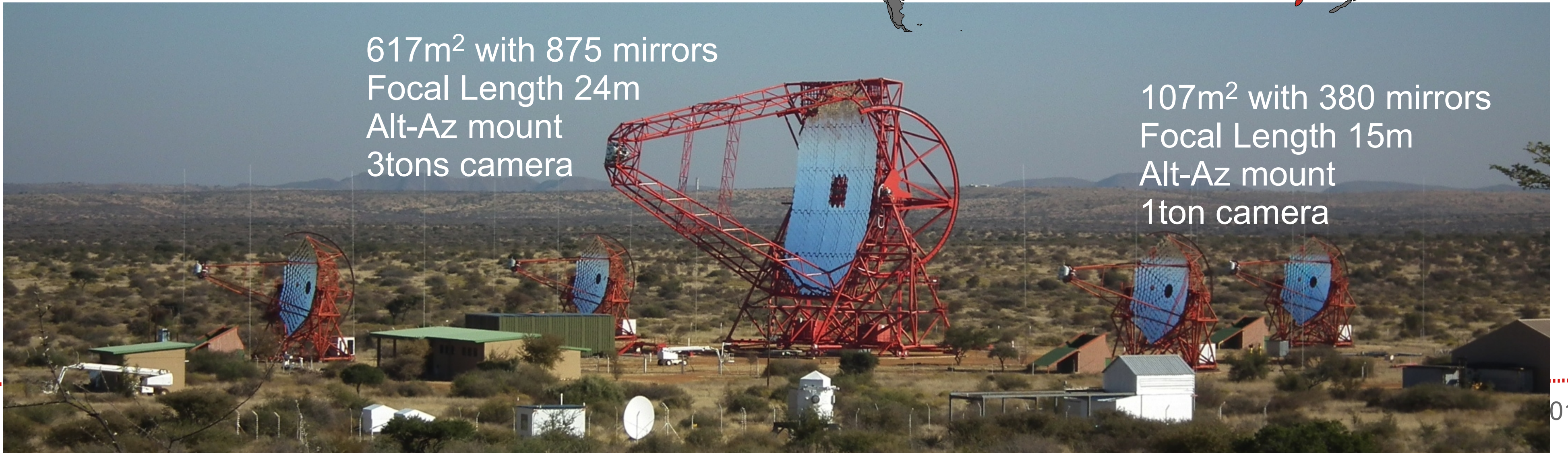




H.E.S.S. array

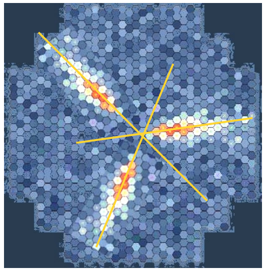
- Located in Namibia, 1800m a.s.l., at the edge of the Namib desert, 1000 h/year
- Since 2003, 4 telescopes of ∅=12m separated of 100m
  - 960 pixels, 1GHz sampling and 16ns integration time, Trigger Rate of 300Hz, Field of View of 5° on the sky
- Since 2013, a 5th telescope of ∅=28m → Phase 2 of the H.E.S.S. Experiment
  - 2048 pixels, 1GHz sampling and 16ns integration time, Trigger Rate of 3.6kHz, Field of View of 3.2° on the sky
- Mainly an European experiment + ...

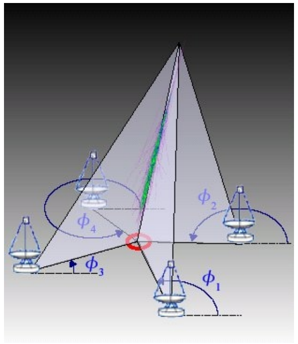


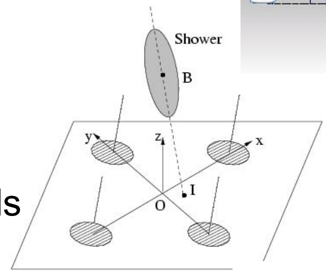


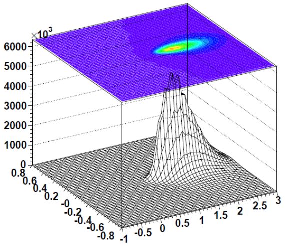
Analysis Methods

- Reconstruction Methods
  - "Hillas" analysis
    - Determination of the image moments after 'cleaning'
    - Intersections of the main axis in the good reference frame
  - Model3D analysis
    - Shower photosphere approximated by a 3D Gaussian
    - Adjustment by comparing expected charge to the measured one into pixels
  - Model analysis
    - Image templates generated by a shower toy Monte Carlo
    - Adjustment by comparing expected charge to the measured one into all pixels

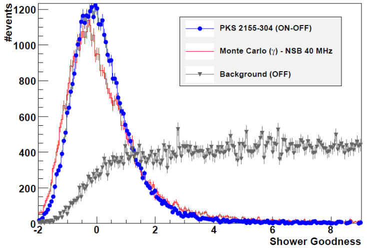






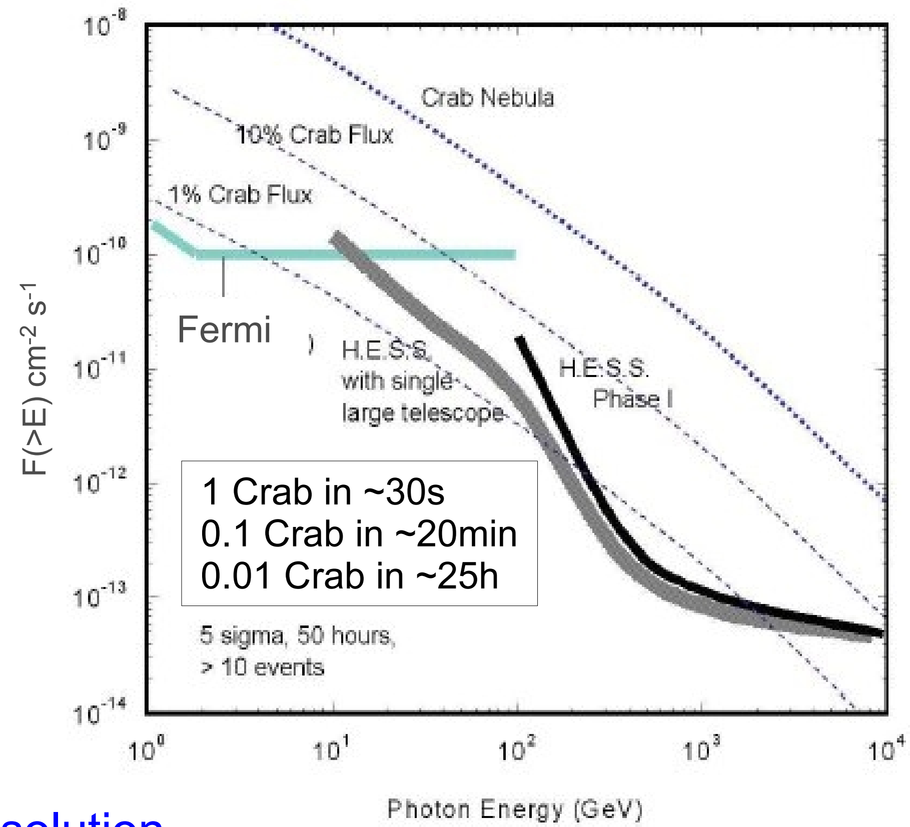


- Gamma/Hadron Discrimination
  - Hillas method: based on the image widths
  - Model3D method: based on the 3D Gaussian width
  - Model method: based on the fit likelihood
  - Boosted Decision Tree (TMVA) using discrimination variables from all the reconstruction methods
  - Likelihood method based on the p.d.f. of several discrimination variables



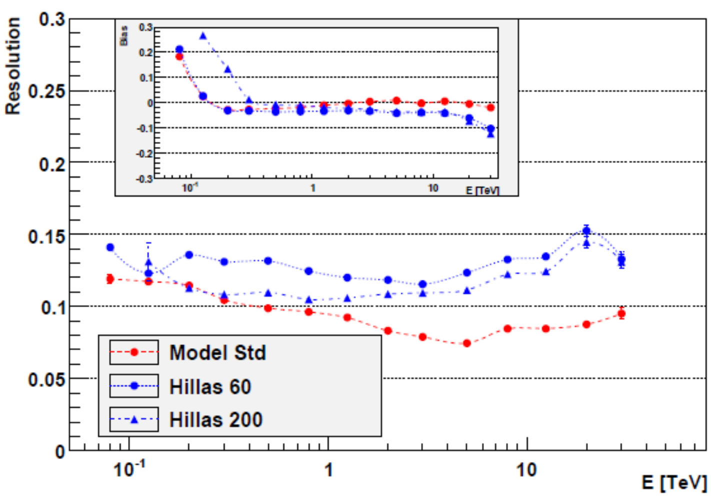
H.E.S.S. performance

- Sensitivity : minimum detectable flux at 5σ in 50h
  - Crab Unit: $F(E>1\mathrm{TeV}) = 2\times10^{-11}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
  - Observation time per year: 1000 hours

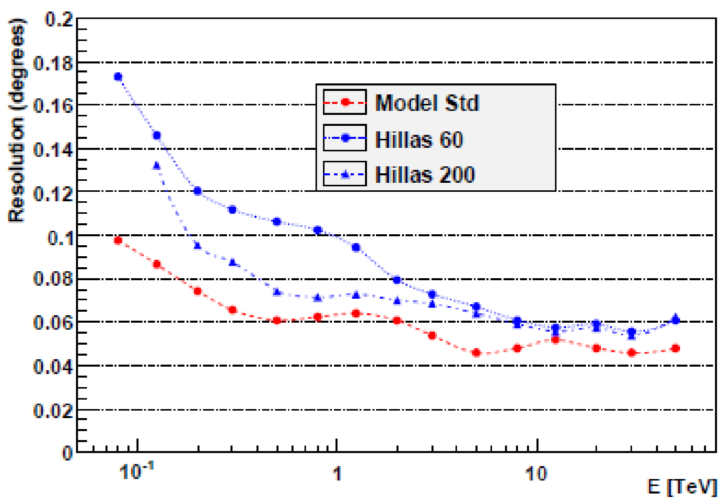


- Energy Threshold
  - H.E.S.S.: ~120GeV
  - H.E.S.S. II: 20-50GeV (expected)

- Energy Resolution

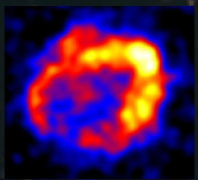
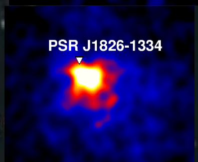


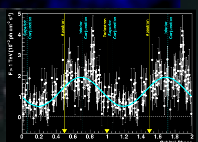
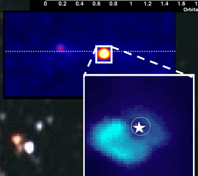
- Angular Resolution



Rolland, de Naurois (2011)

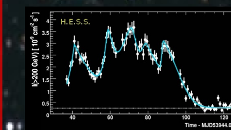
Main Physics Topics

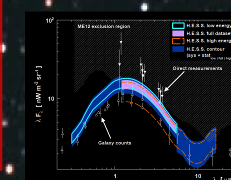



Galactic Sources

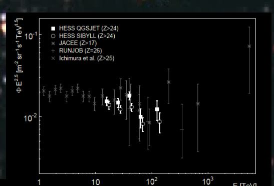
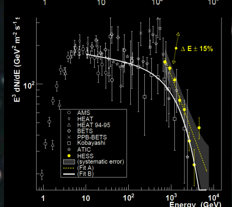
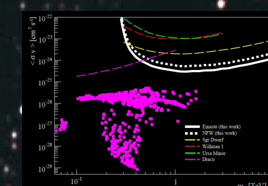
- Origin of Cosmic Rays (SNRs?)
- Pulsar and Pulsar Wind Nebula physics
- Binary System and Stellar Winds
- Galactic Centre
- CR sea and Molecular Clouds
- "Dark" sources



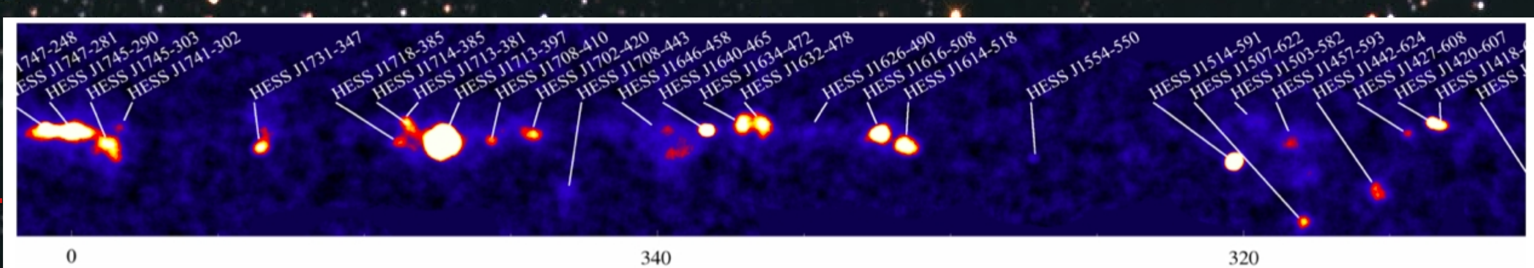
Extragalactic Sources

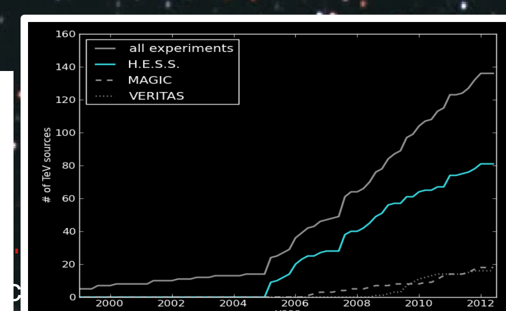
- Active Galactic Nuclei
- Starburst Galaxies and Gal. Clusters
- Physics of accretion/jets and Black Holes
- Cosmology: Density of Extragalactic Background Light, AGN Evolution, Intergalactic Magnetic Field

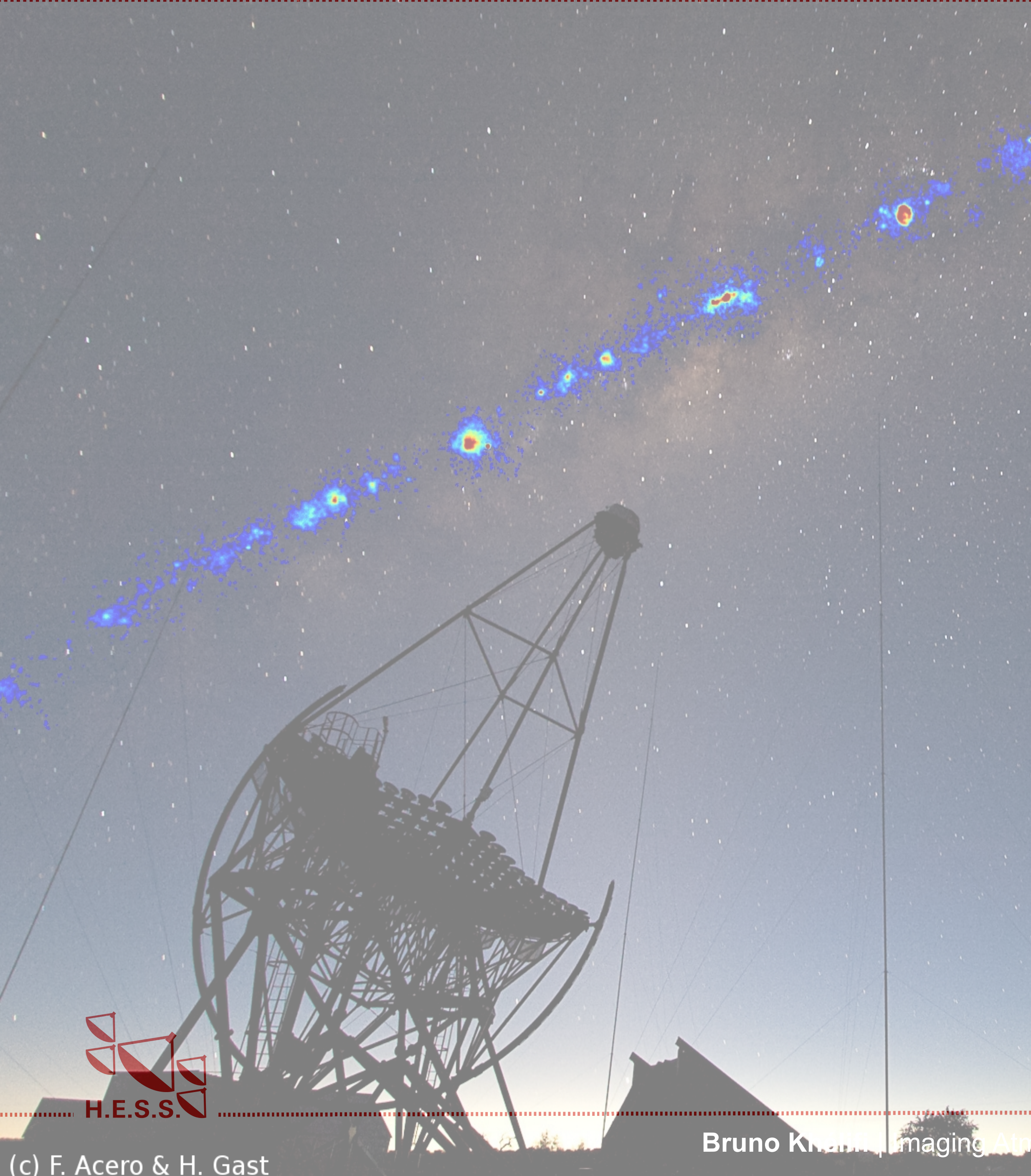
Astroparticle Physics

- Charged Cosmic Rays spectrum (hadrons, electrons)
- Dark Matter search
- Search for Lorentz Invariance Violation





Summary



(c) F. Acero & H. Gast

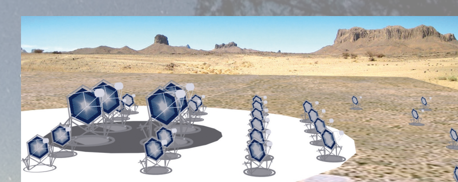
Properties of the Cherenkov light pool (R~100m) are used to provide a large collection area, O(10^5 m^2)

Stereoscopy and instrumentation give good astronomical performance and excellent background rejection

« H.E.S.S. Was a revolution »
- Discovery of the TeV sky richness
- The Phase 2 will bring a bright future

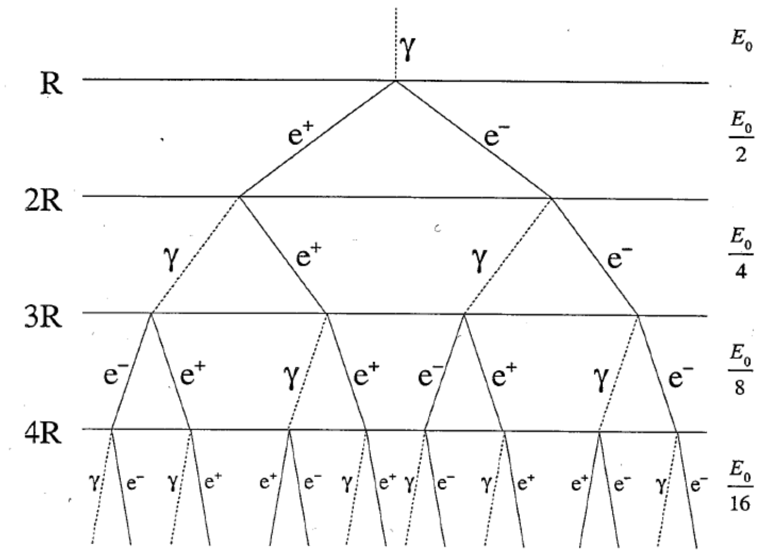
The next generation of instrument is already in preparation:

Cherenkov **T**elescope **A**rray



ANNEXES

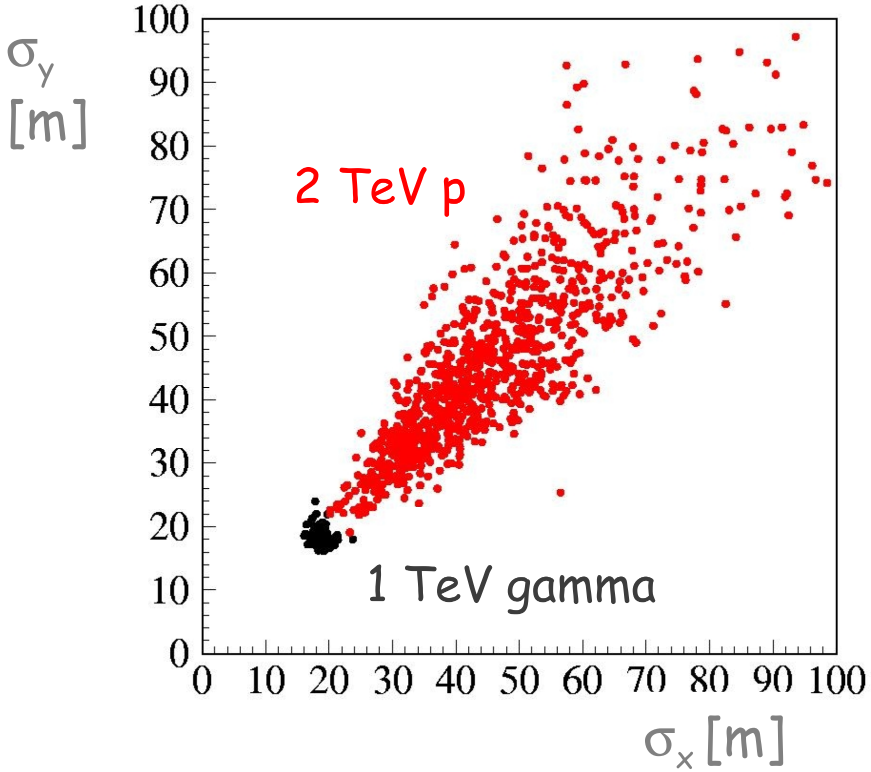
Atmospheric EM Shower: Simplified model of Heitler

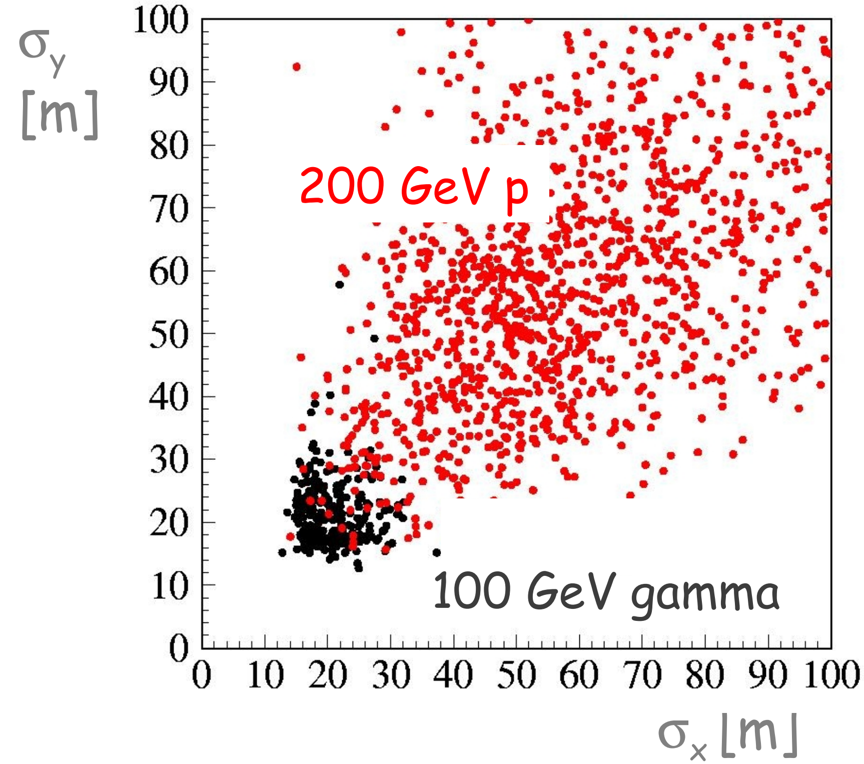


- After t X_0, there is 2^t particles of energy $E(t) = E_0/2^t$
- Maximum development at $t_{max}(E_0) \approx \ln (E_0/E_c)$
- At Shower Maximum, $N(X_{max}) \approx E_0/E_c$

Background Rejection: Protons

Scatter of (true) emission points

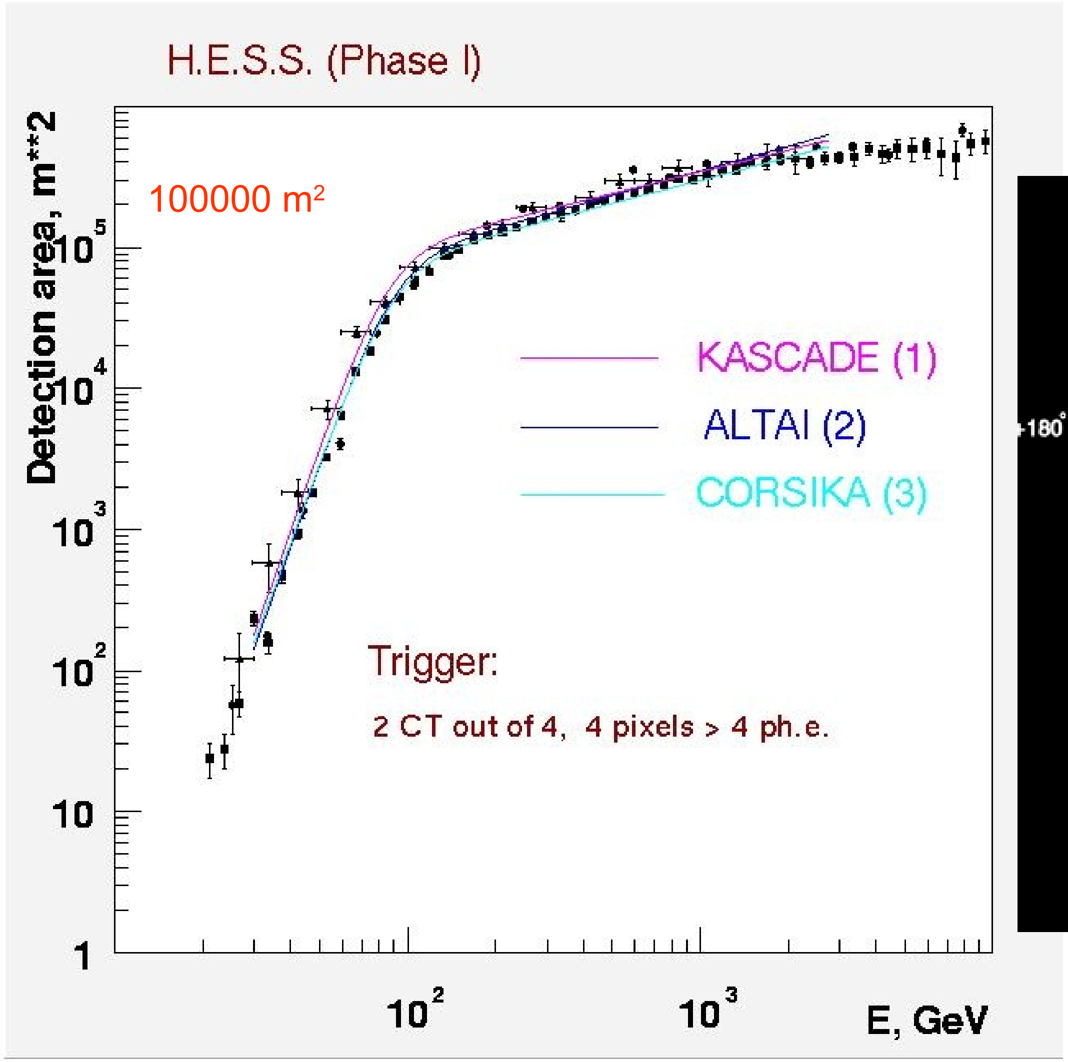


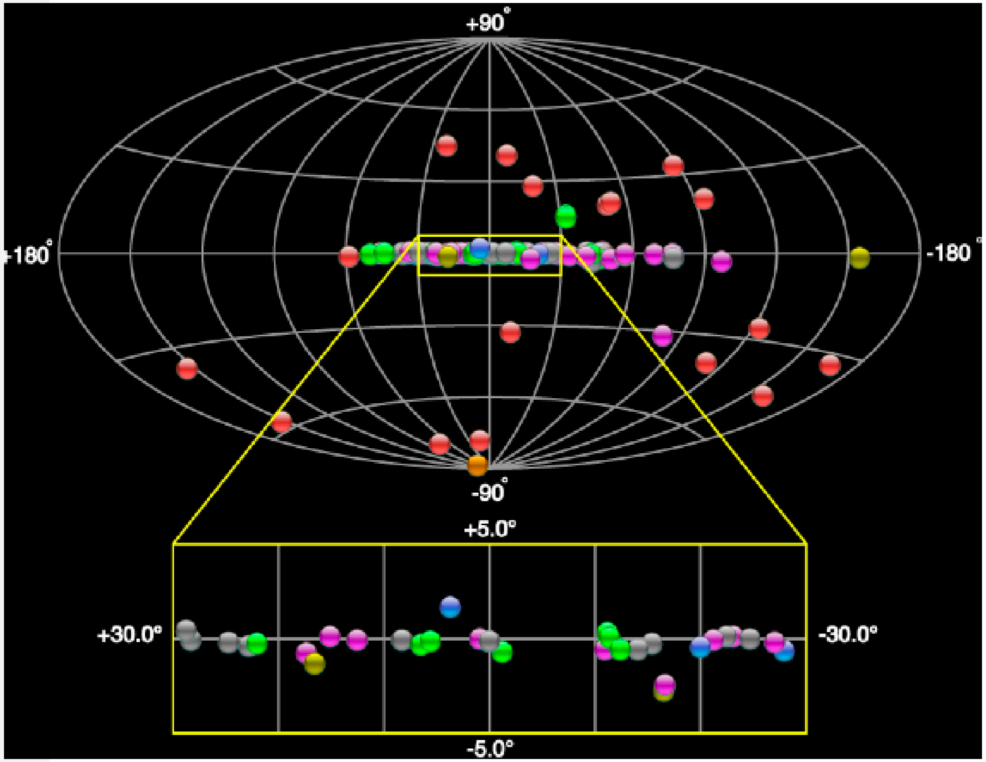


Ideal rejection: few 10^{-4}
Current tels.: ~ $10^{-2...3}$

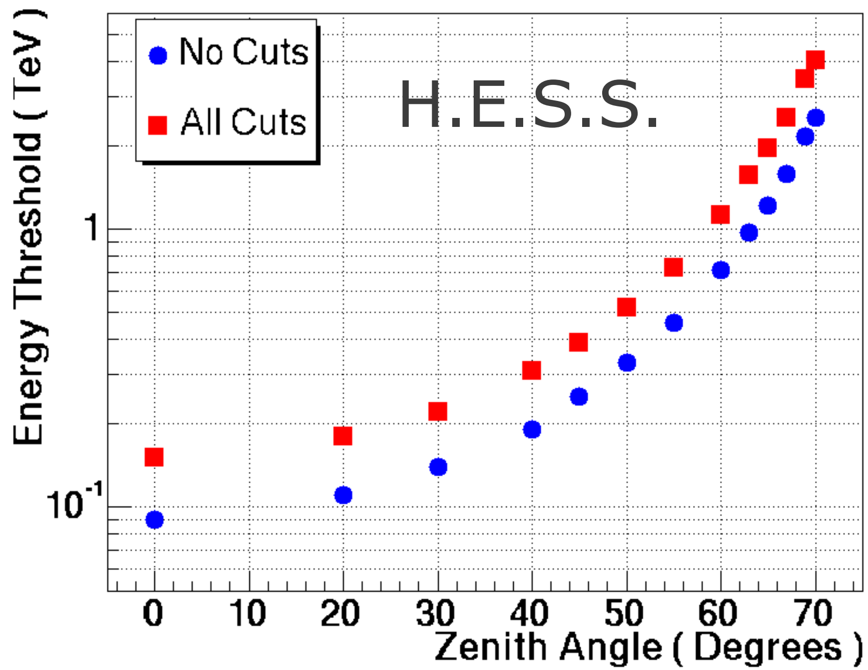
Ideal rejection: ~ 10^{-2}
Current tels.: ~ 10^{-1}

Collection Area



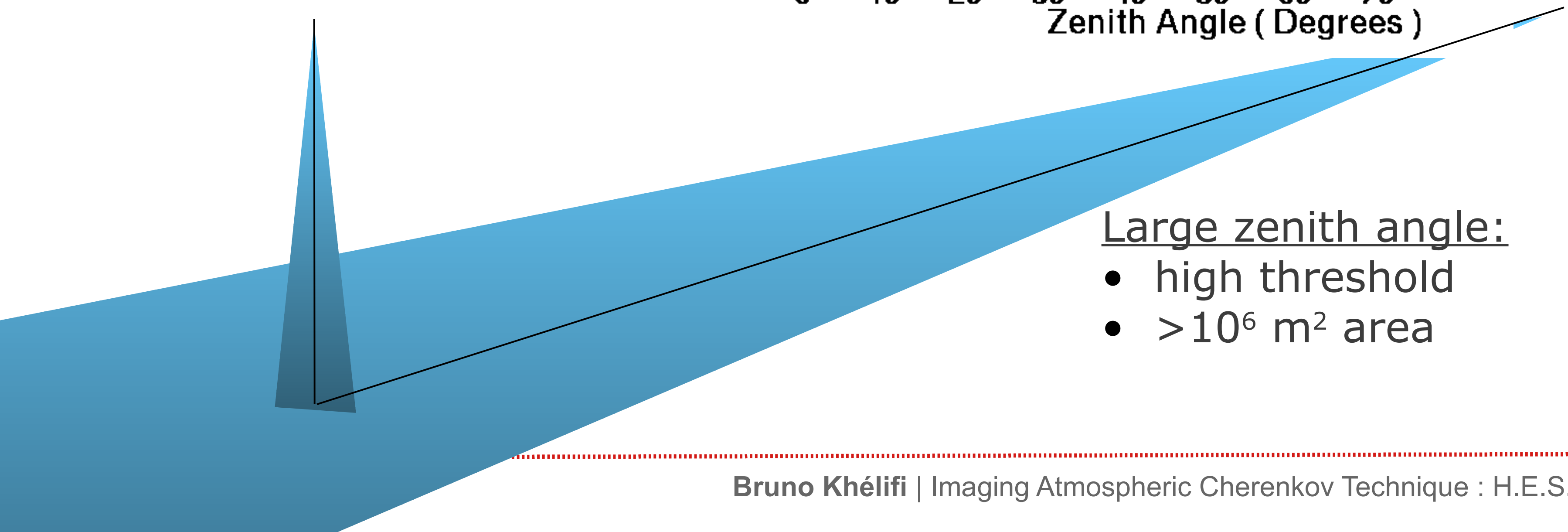


Energy Threshold



Small zenith angle:

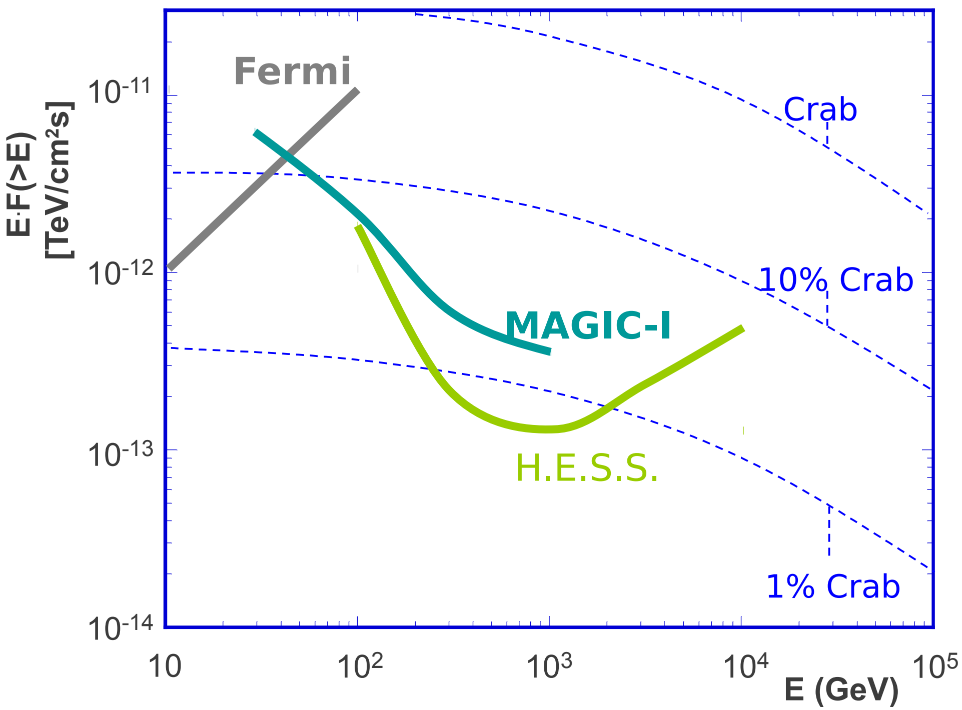
- low threshold
- ~10^5 m^2 area

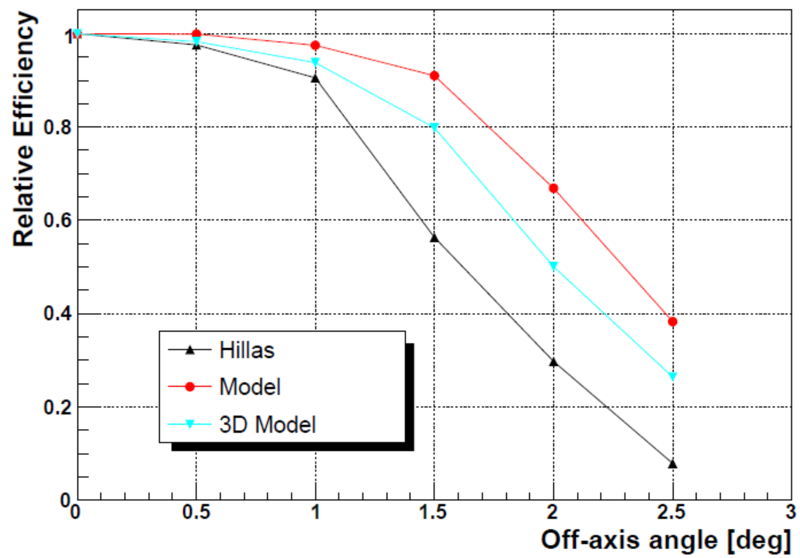


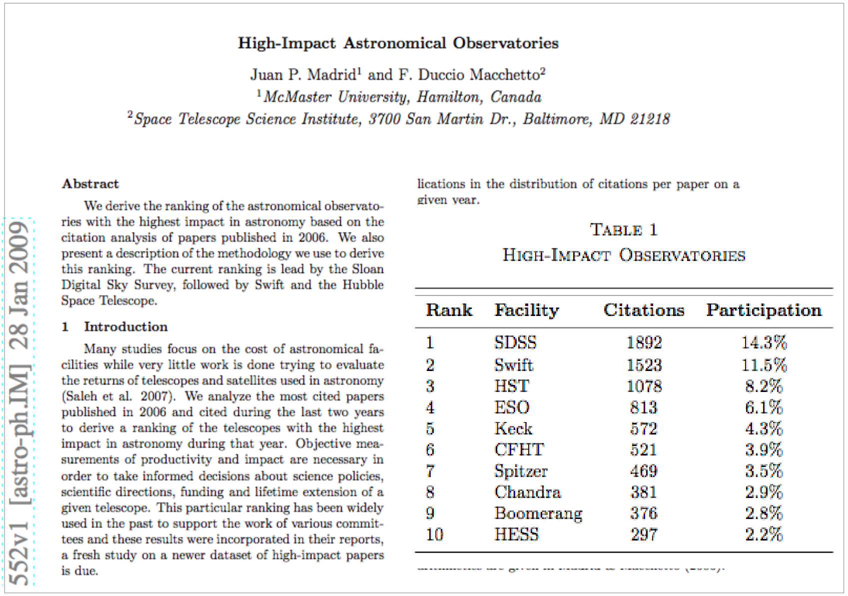
Large zenith angle:

- high threshold
- >10^6 m^2 area

νFν Sensitivity and Off-Axis Performance







High-Impact Astronomical Observatories

Juan P. Madrid[1] and F. Duccio Macchetto[2]

[1] *McMaster University, Hamilton, Canada*

[2] *Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD 21218*

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Abstract

We derive the ranking of the astronomical observatories with the highest impact in astronomy based on the citation analysis of papers published in 2006. We also present a description of the methodology we use to derive this ranking. The current ranking is lead by the Sloan Digital Sky Survey, followed by Swift and the Hubble Space Telescope.

1 Introduction

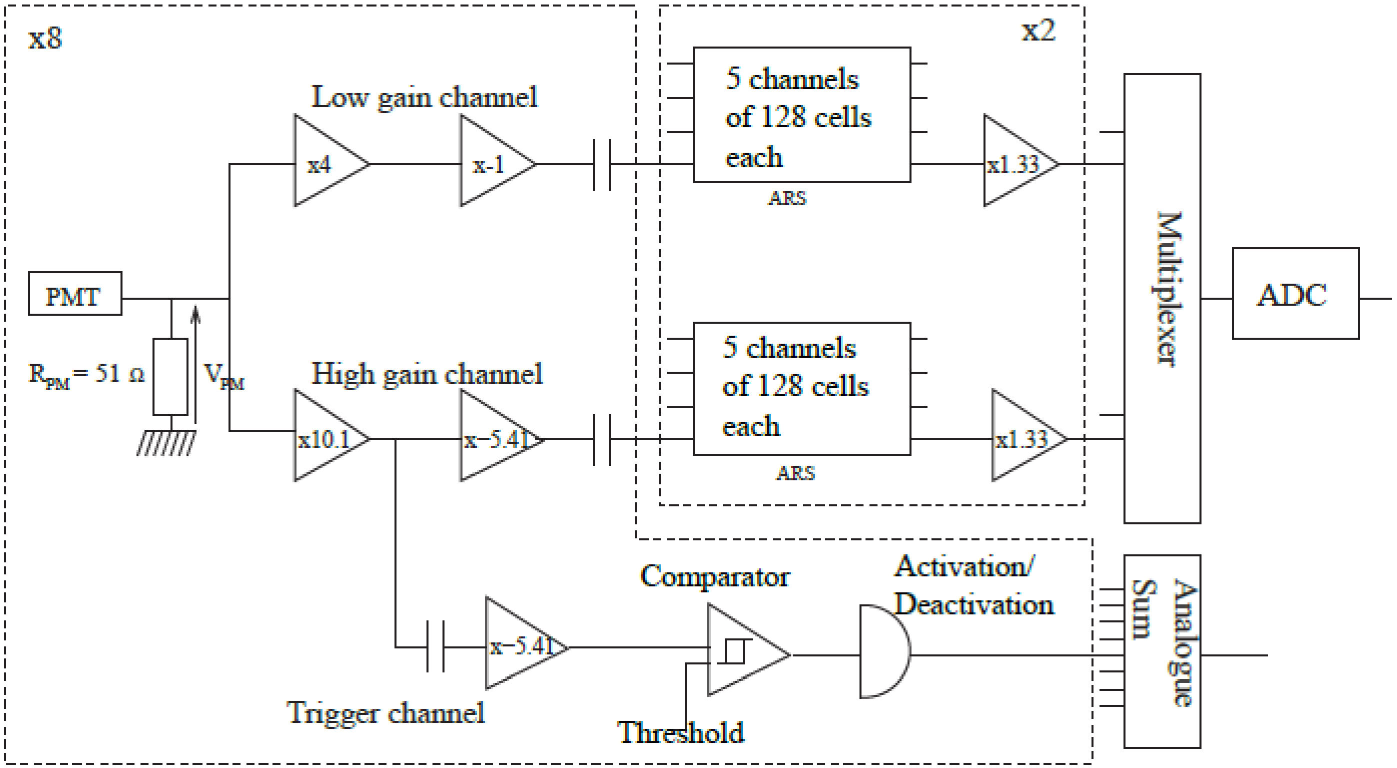
Many studies focus on the cost of astronomical facilities while very little work is done trying to evaluate the returns of telescopes and satellites used in astronomy (Saleh et al. 2007). We analyze the most cited papers published in 2006 and cited during the last two years to derive a ranking of the telescopes with the highest impact in astronomy during that year. Objective measurements of productivity and impact are necessary in order to take informed decisions about science policies, scientific directions, funding and lifetime extension of a given telescope. This particular ranking has been widely used in the past to support the work of various committees and these results were incorporated in their reports, a fresh study on a newer dataset of high-impact papers is due.

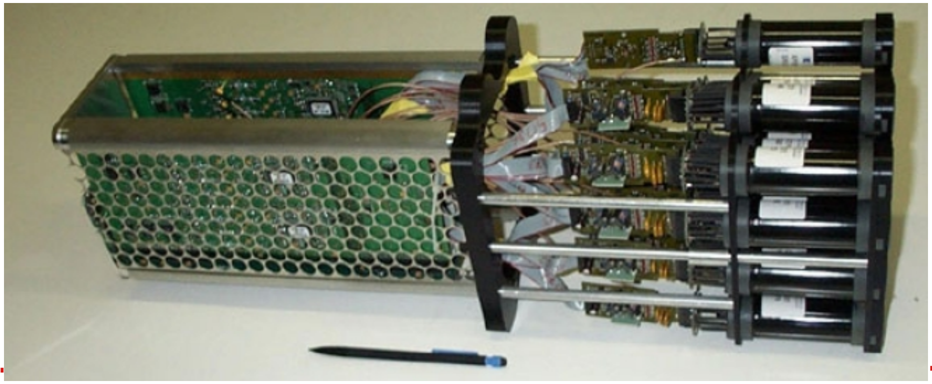
lications in the distribution of citations per paper on a given year.

TABLE 1
HIGH-IMPACT OBSERVATORIES

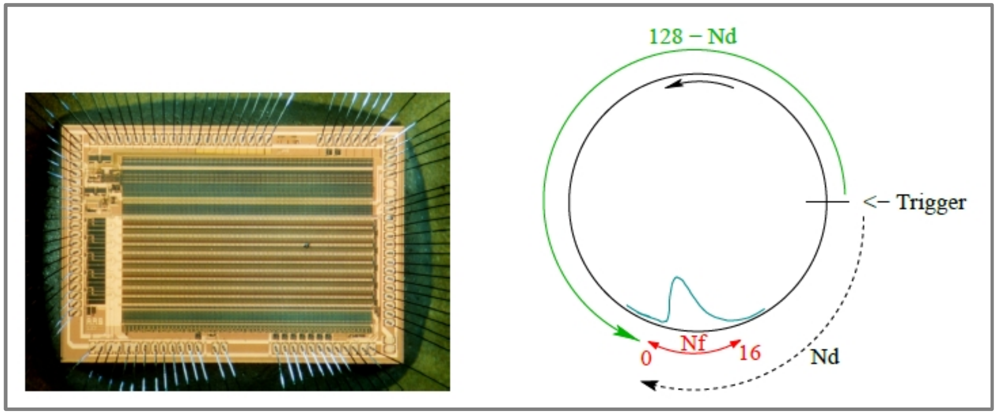
Rank	Facility	Citations	Participation
1	SDSS	1892	14.3%
2	Swift	1523	11.5%
3	HST	1078	8.2%
4	ESO	813	6.1%
5	Keck	572	4.3%
6	CFHT	521	3.9%
7	Spitzer	469	3.5%
8	Chandra	381	2.9%
9	Boomerang	376	2.8%
10	HESS	297	2.2%

H.E.S.S.-I Camera Electronics

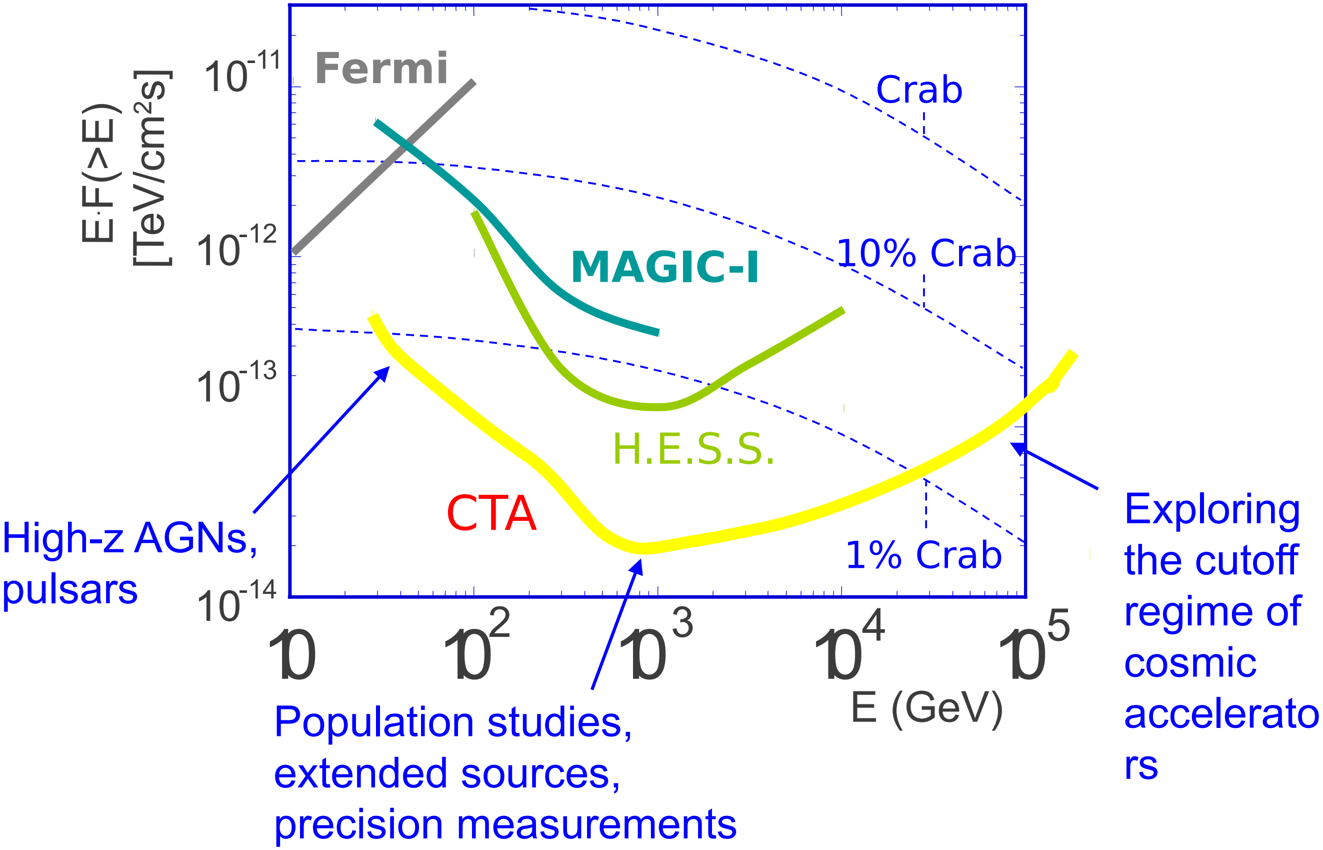




ARS chip
(Analogue Ring Samples)

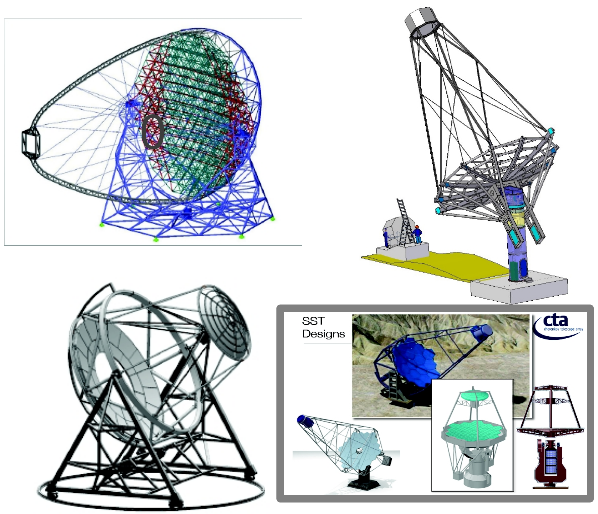


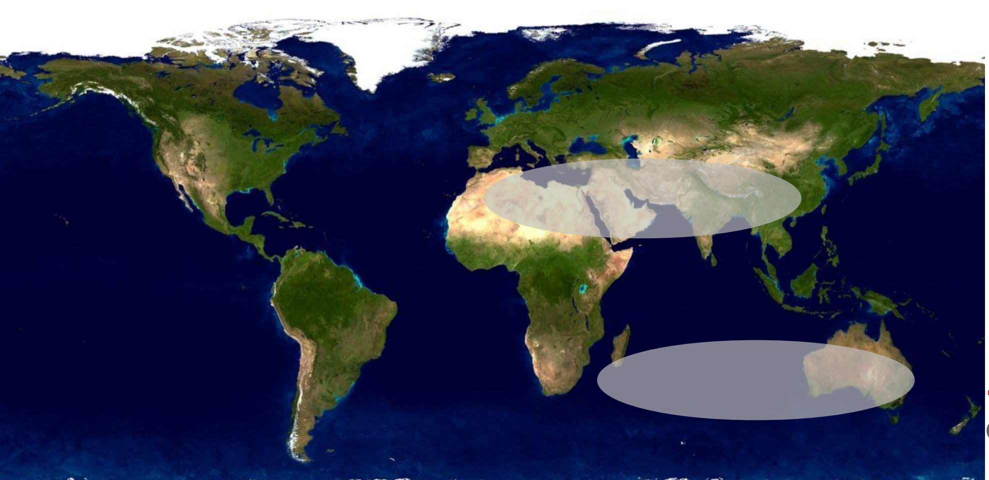
Cherenkov Telescope Array



Instrumentation

- Large Size Telescope
- Medium Size Telescope
- SC Telescope
- Small Size Telescope





One observatory with two sites

Southern Array

Full size and full Science Case

Northern Array

Reduced size and mainly extragal. Science Case