Astroparticle Physics

Lecture 2

- The propagation from the sources to us
- Detectors for astroparticle physics
- Open problems, and future solutions?

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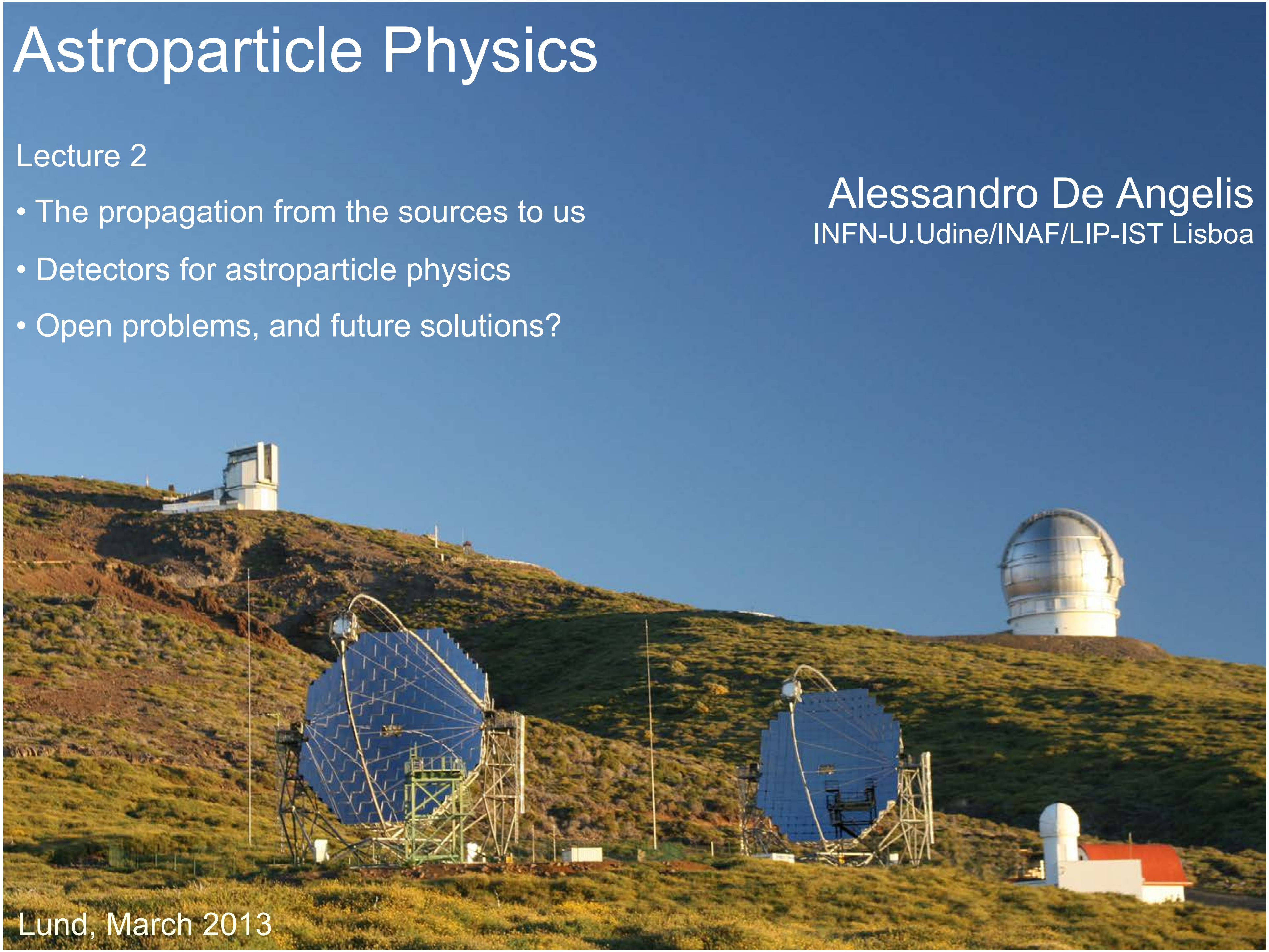


Lund, March 2013

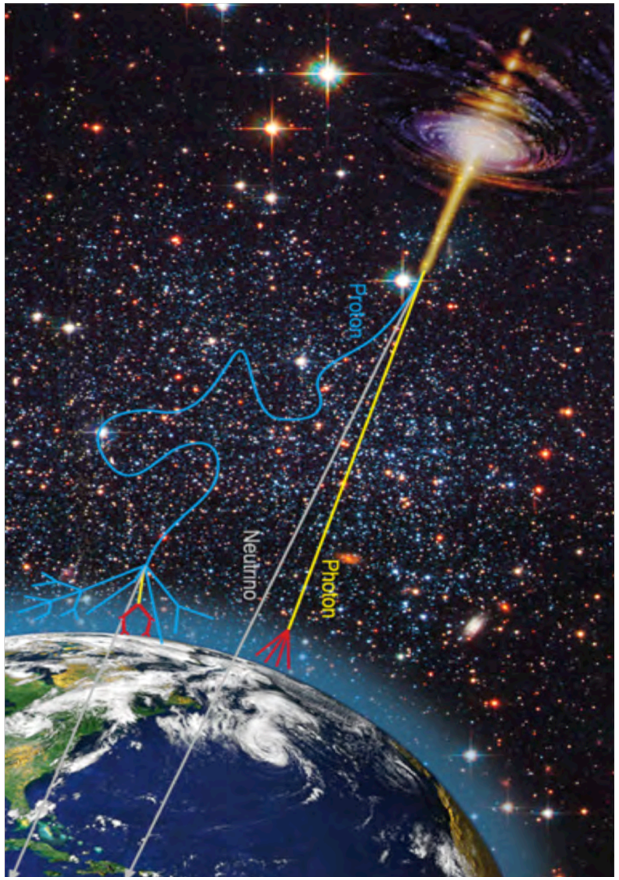
THE PROPAGATION

INTERACTION WITH THE SOLAR SYSTEM AND THE EARTH

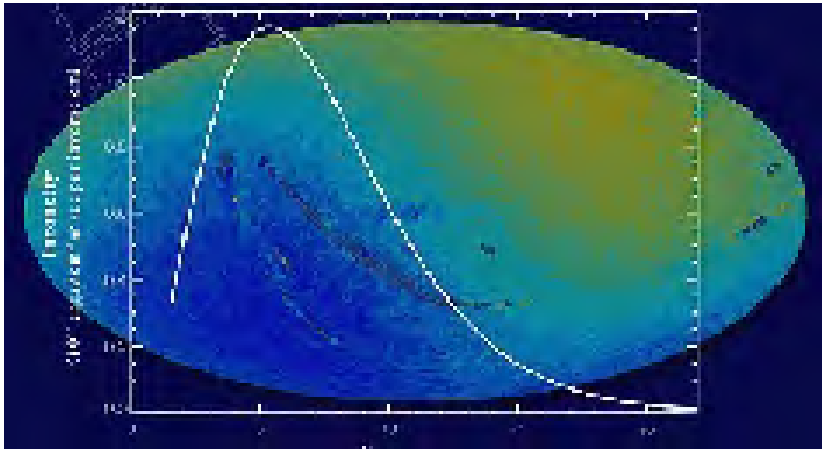
Propagation of charged CR in the Universe

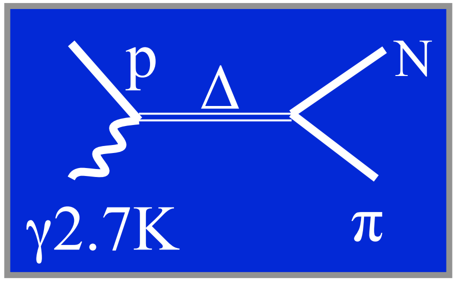
$$\frac{r}{1\ \mathrm{pc}} \cong \frac{\frac{E}{1\ \mathrm{PeV}}}{\frac{B}{1\ \mu G}}$$

- Gyroradius
- B in the Galaxy: a few μG; outside the Galaxy: 1nG > B > 1 pG
- If you want to look at the GC (d ~ 8 kpc) you need E > $2\ 10^{19}$ eV
  - But only 1 particle / km2 / year
  - And: no galactic emitters expected at this energy
- But in principle one could look outside the galaxy, were B is smaller and there are SMBHs…
  - No: the GZK cutoff provides a maximum E ~ 10^{19} eV



The Greisen-Zatsepin-Kuzmin (GZK) cutoff

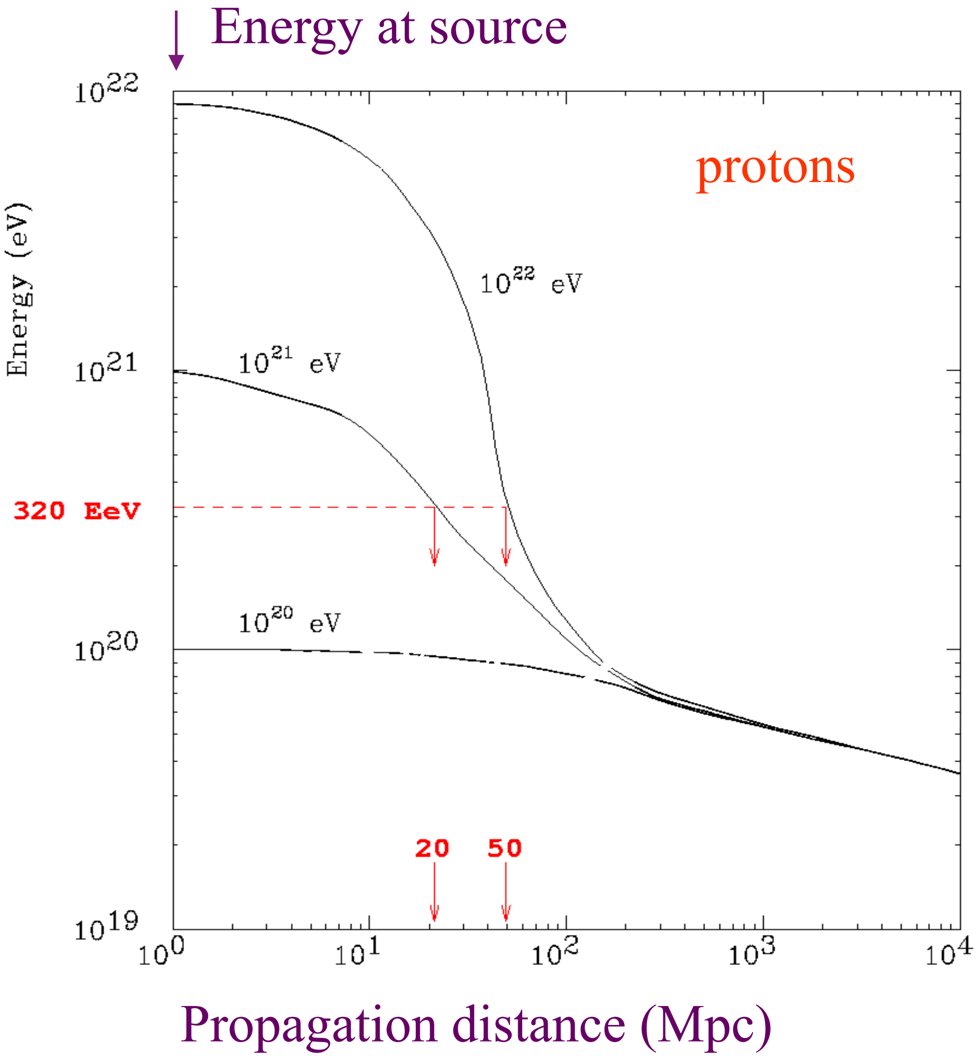




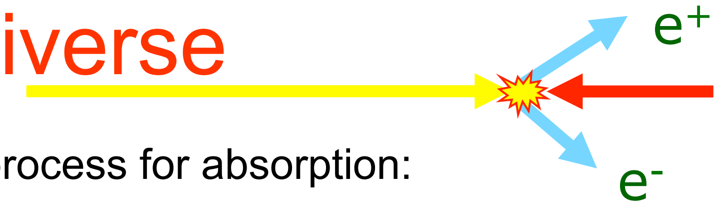
$$E_p \approx 10^{20}\,\mathrm{eV}$$

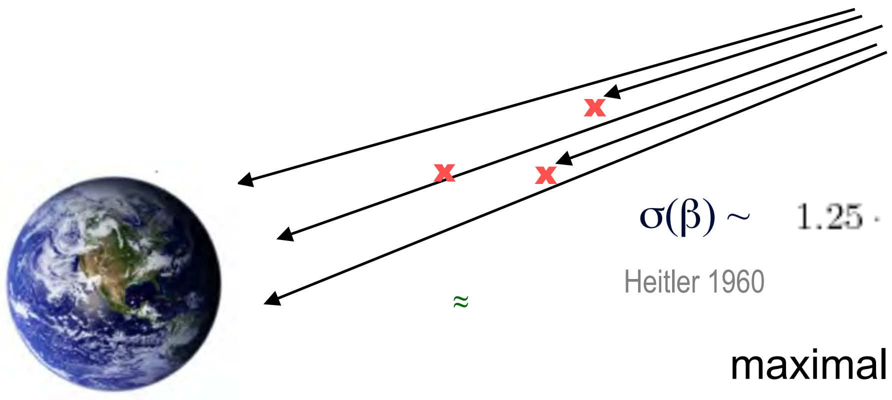
$$\lambda = \frac{1}{\sigma_{p\gamma}\,\rho_{CMB}}$$

$$\approx 6\ \mathrm{Mpc}$$



Propagation of γ-rays in the Universe





dominant process for absorption:

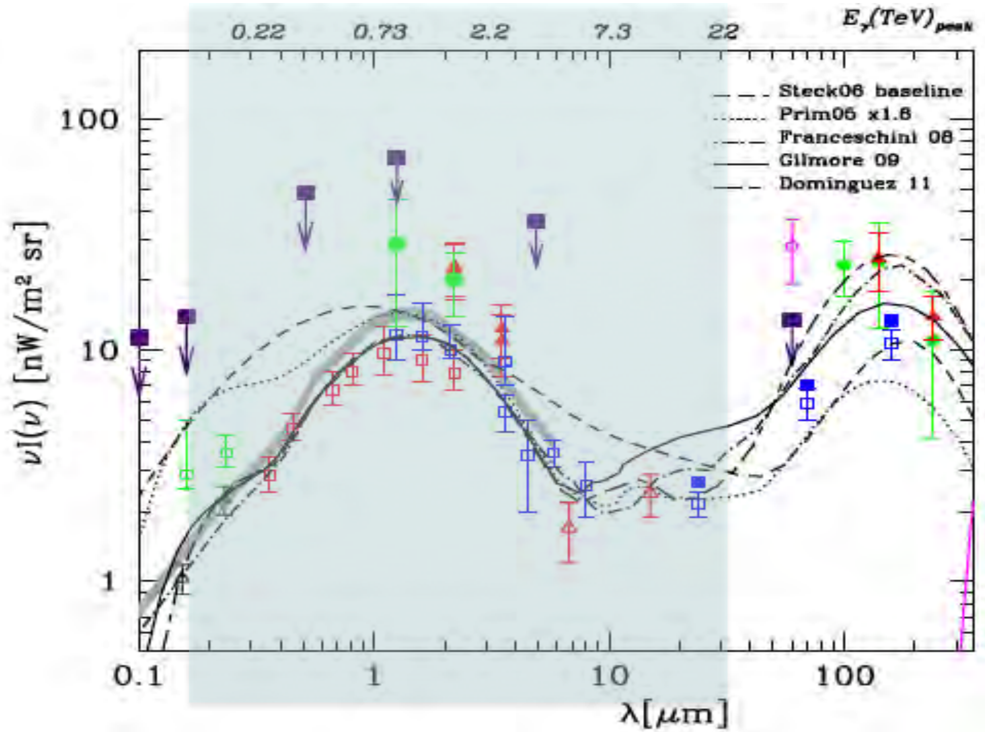
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

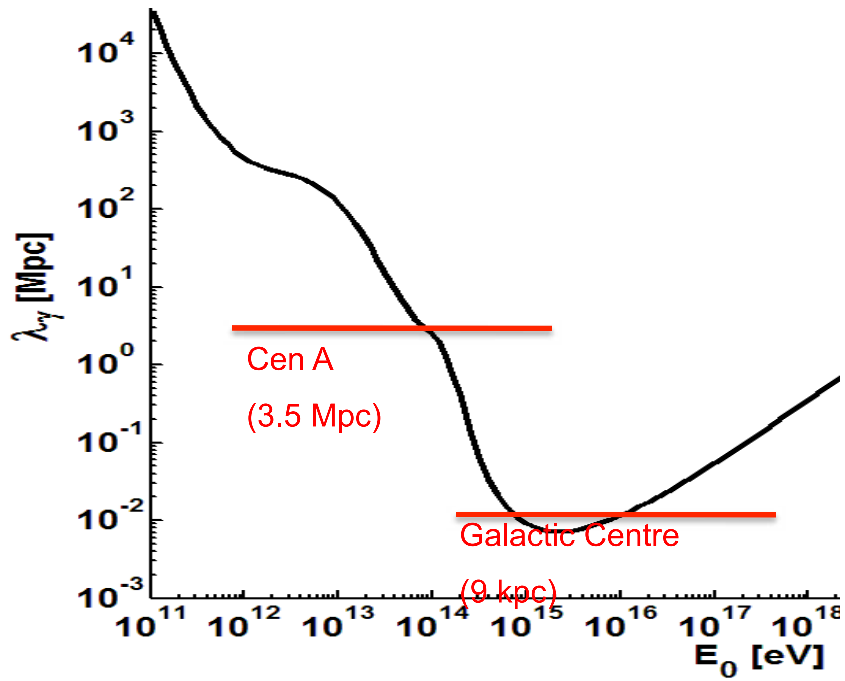
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

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



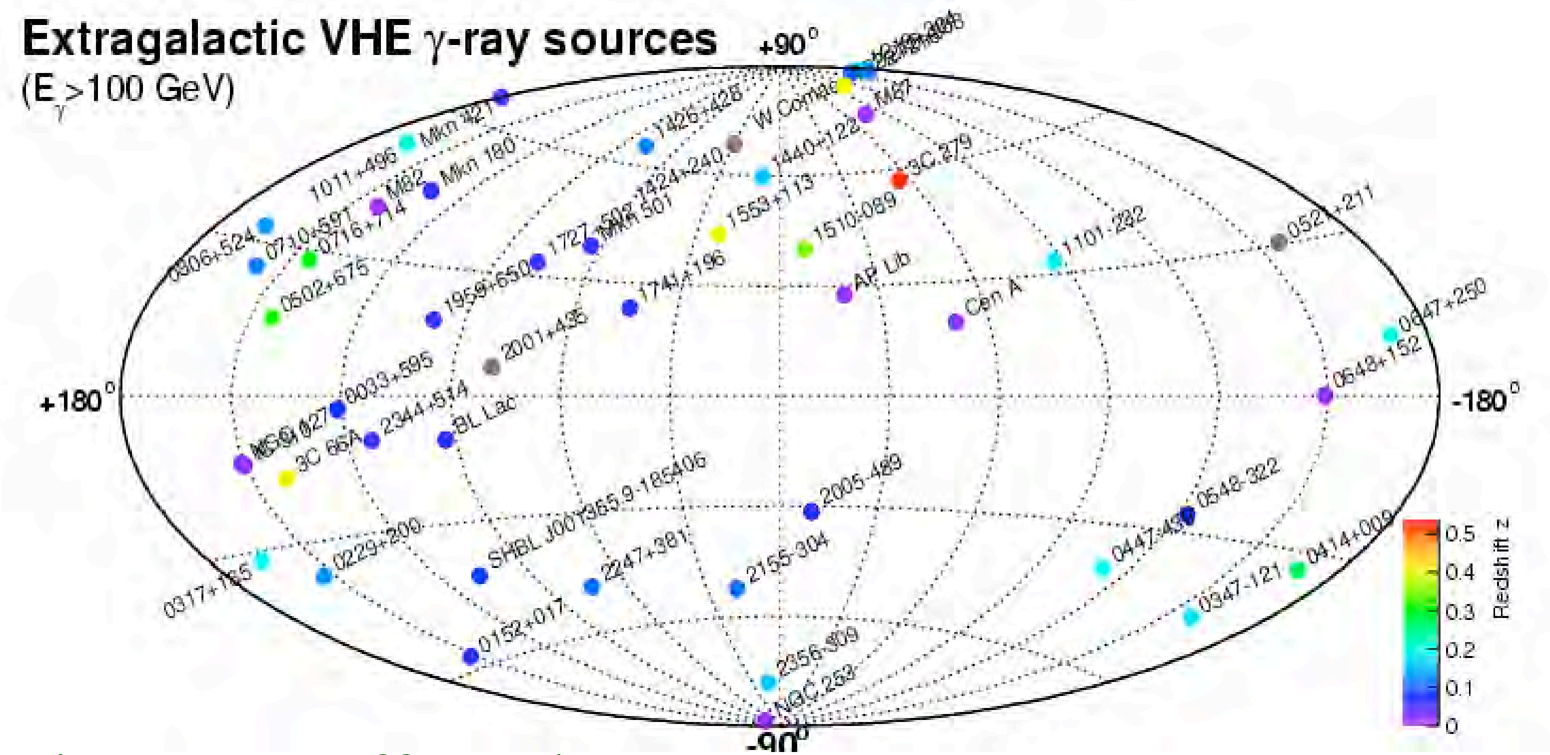


Extragalactic Sources

~60 Sources

…

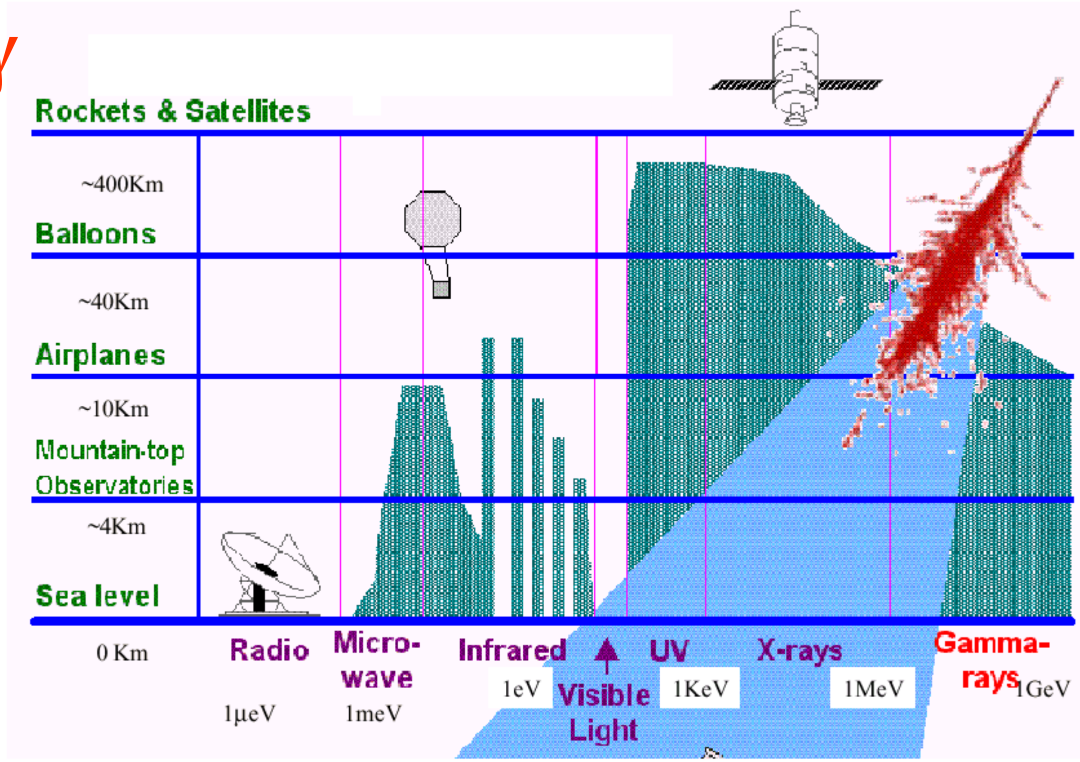
1ES 1011+496 z=0.21		**MAGIC 2007**
1ES 0414+009 z=0.29		HESS/Fermi 2009
S5 0716+71	**z=0.31±0.08**	**MAGIC 2009**
1ES 0502+675 z=0.34		VERITAS 2009
PKS 1510-089 z=0.36		HESS 2010
4C +21.43	**z=0.43**	**MAGIC 2010**
3C 66A	**z=0.44**	**VERITAS 2009**
3C 279	**z=0.54**	**MAGIC 2008**



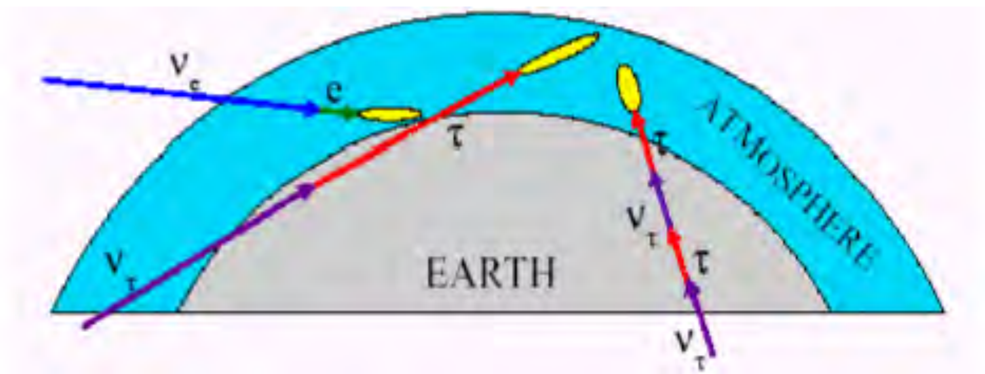
Neutrinos ~ unaffected

Interaction in the atmosphere/Earth

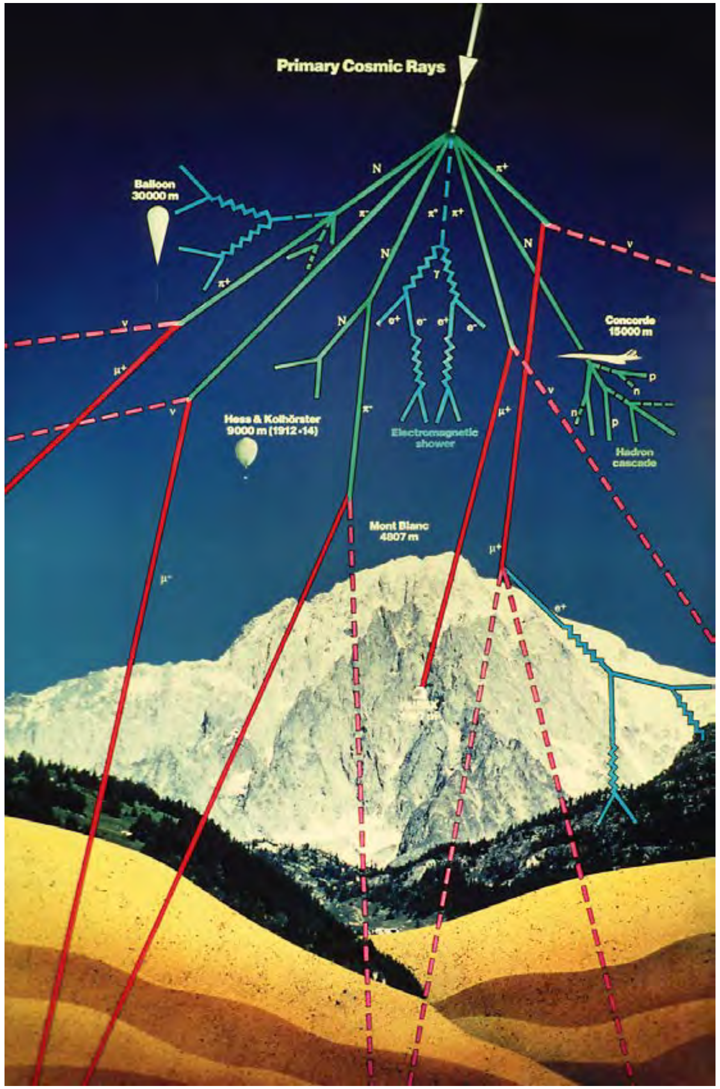
γ



ν



p/nucleus/gamma/e+-



The events: Cosmic rays “rain”

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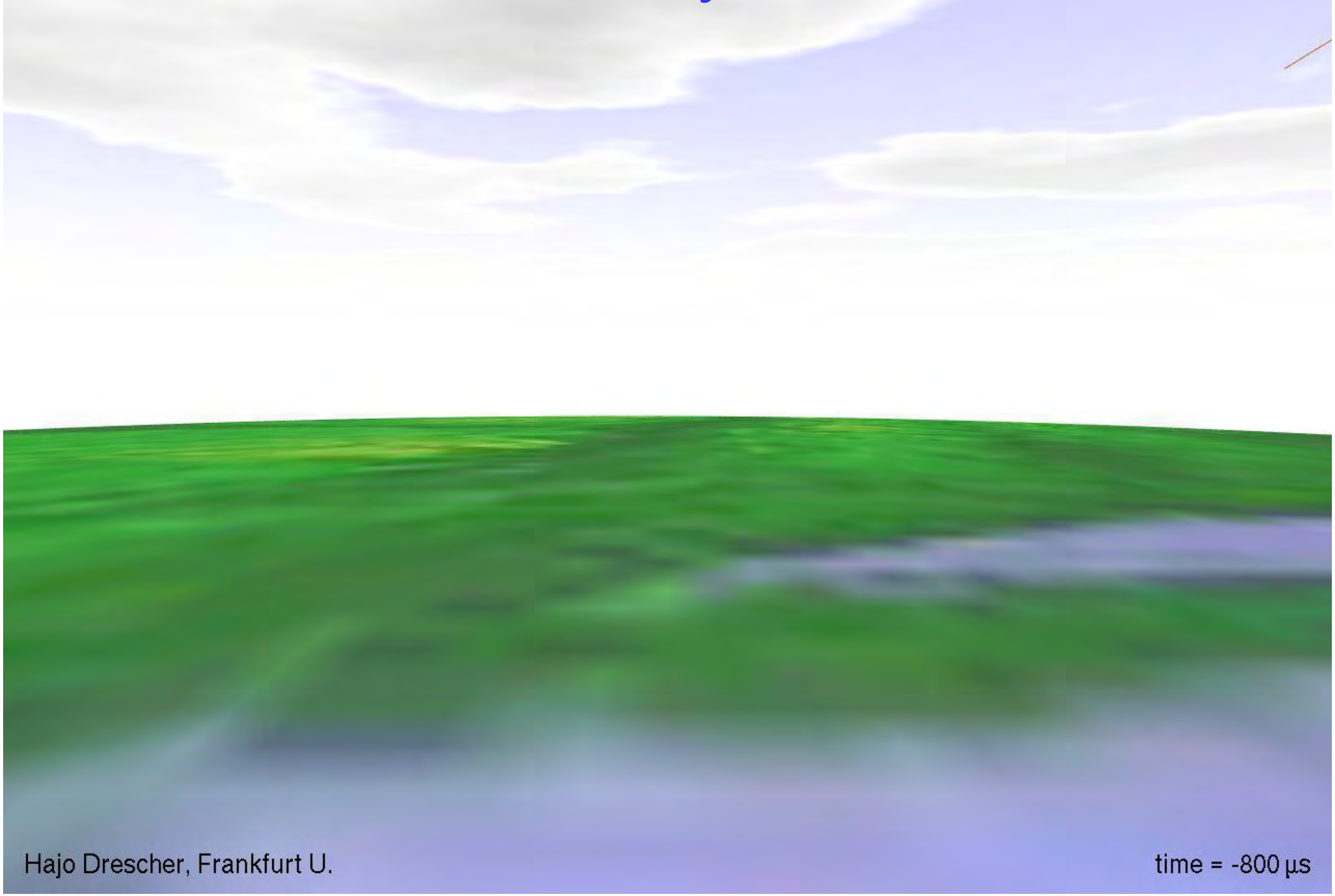

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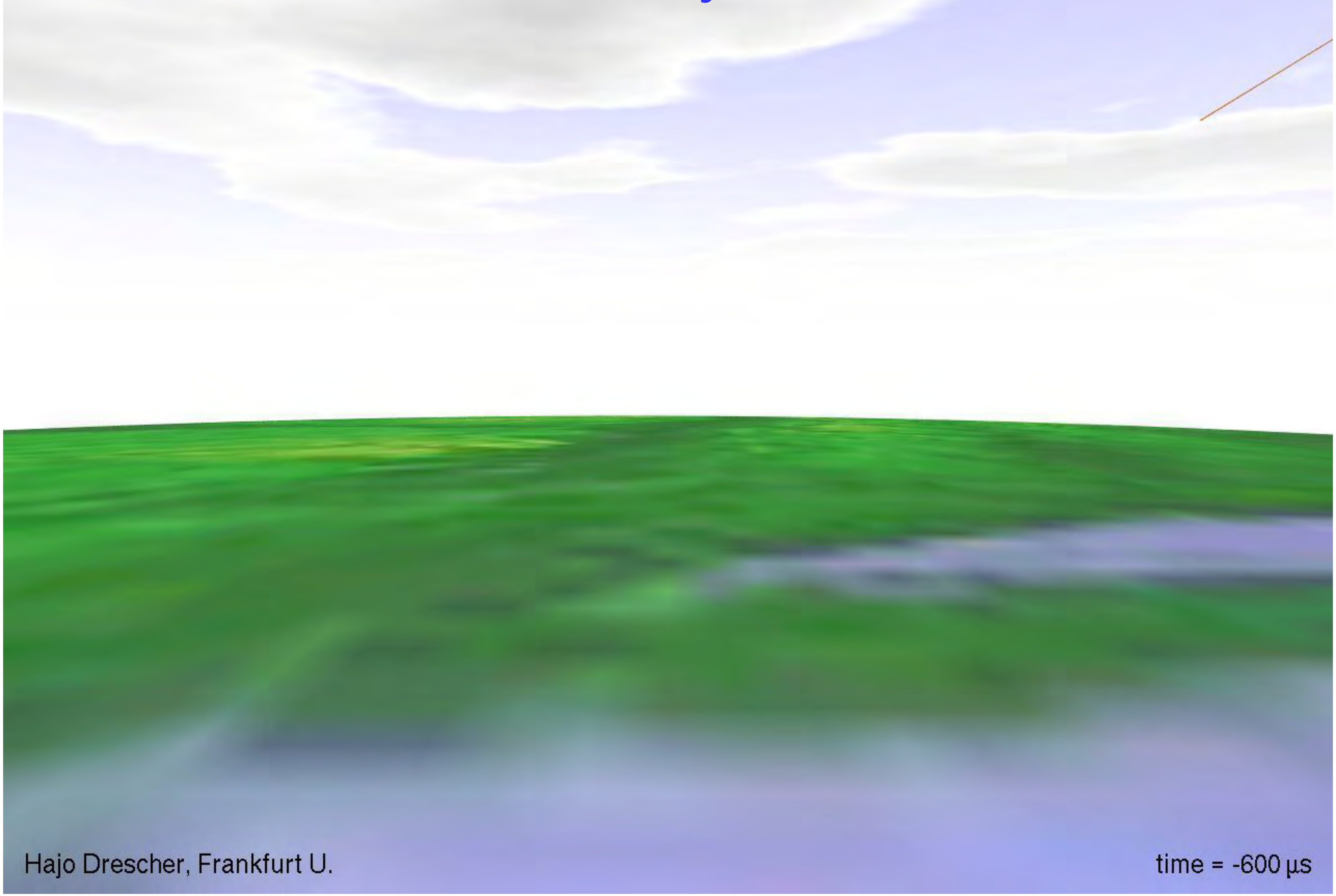
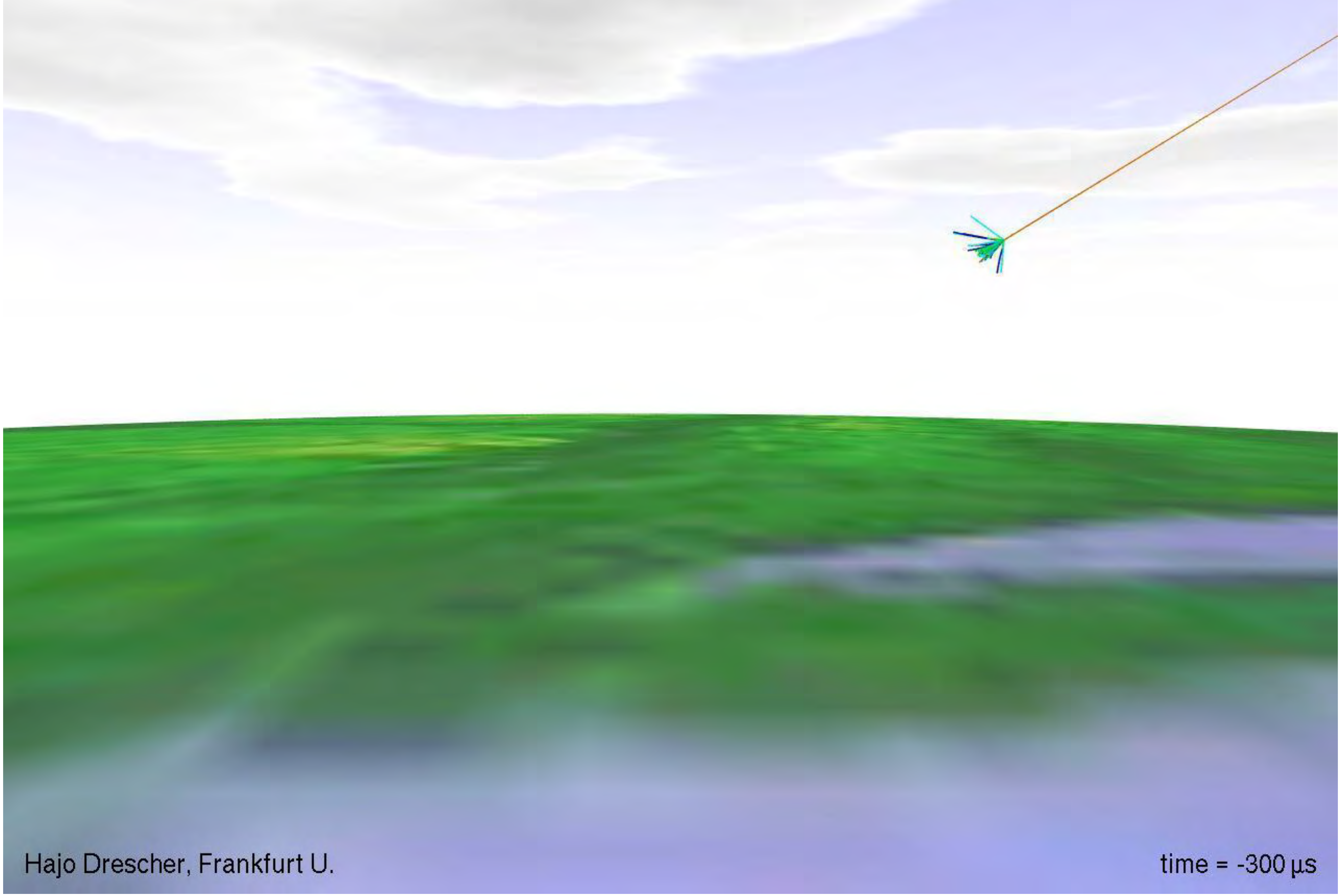


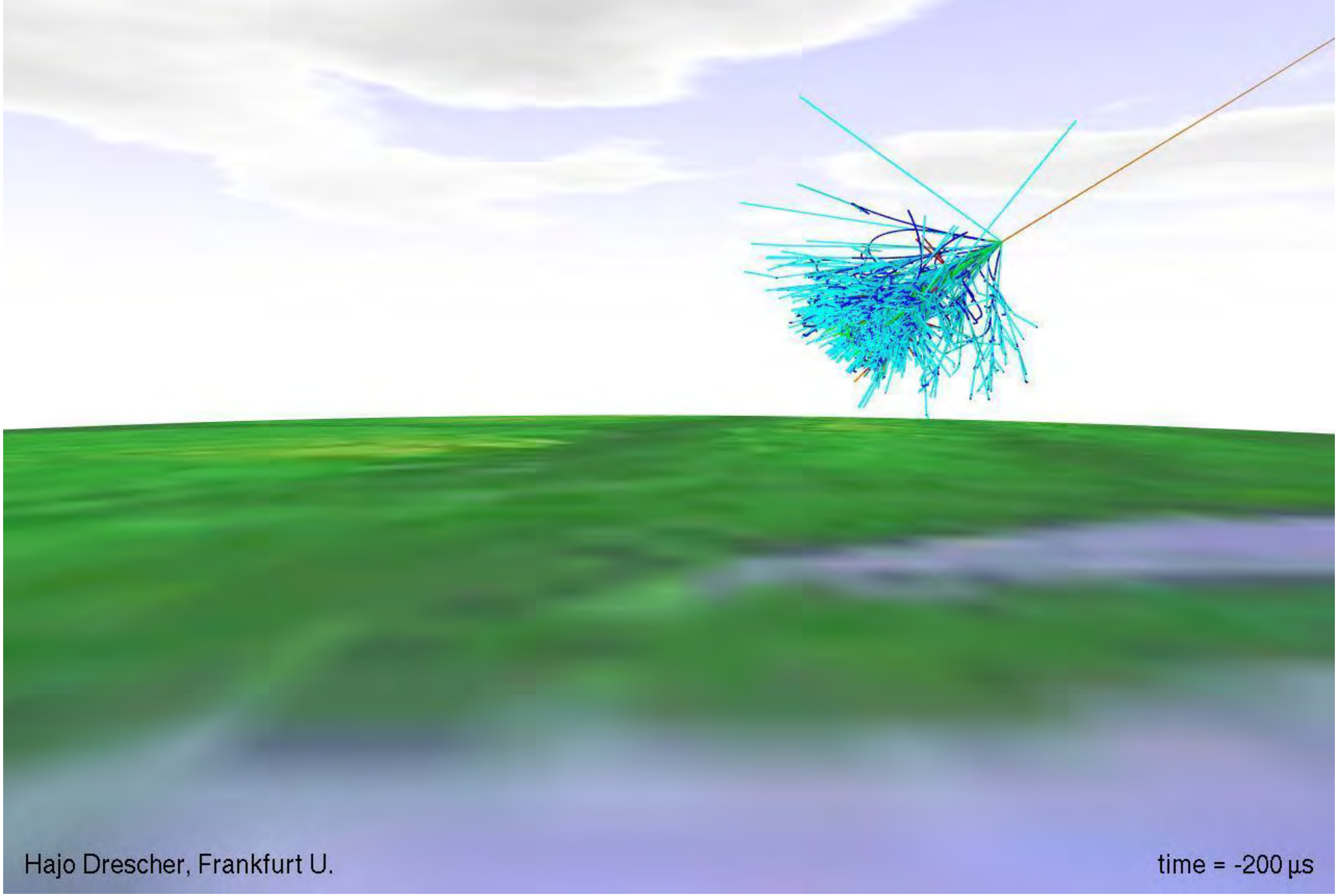
The events: Cosmic rays “rain”

The events: Cosmic rays “rain”

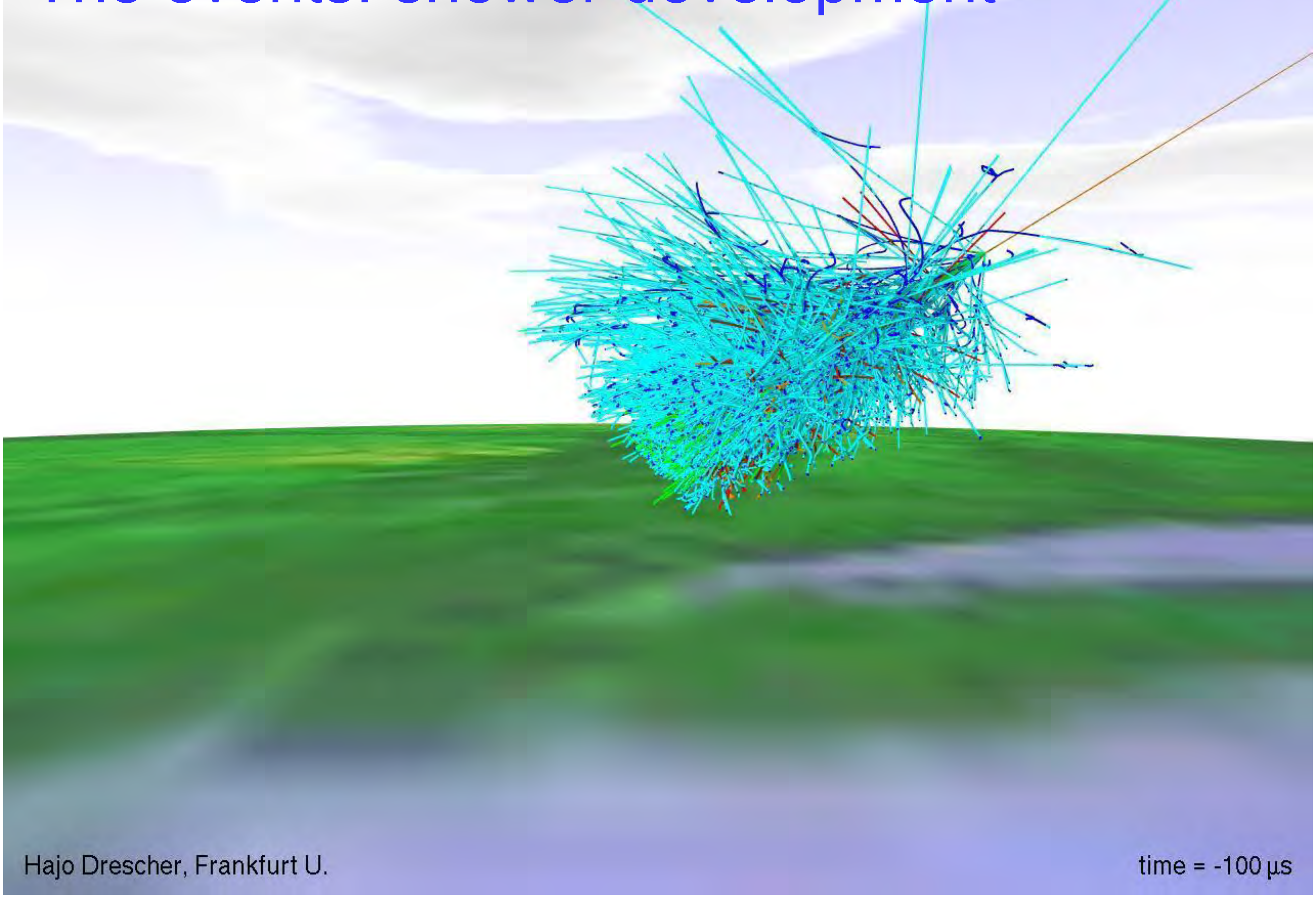
The events: first interaction



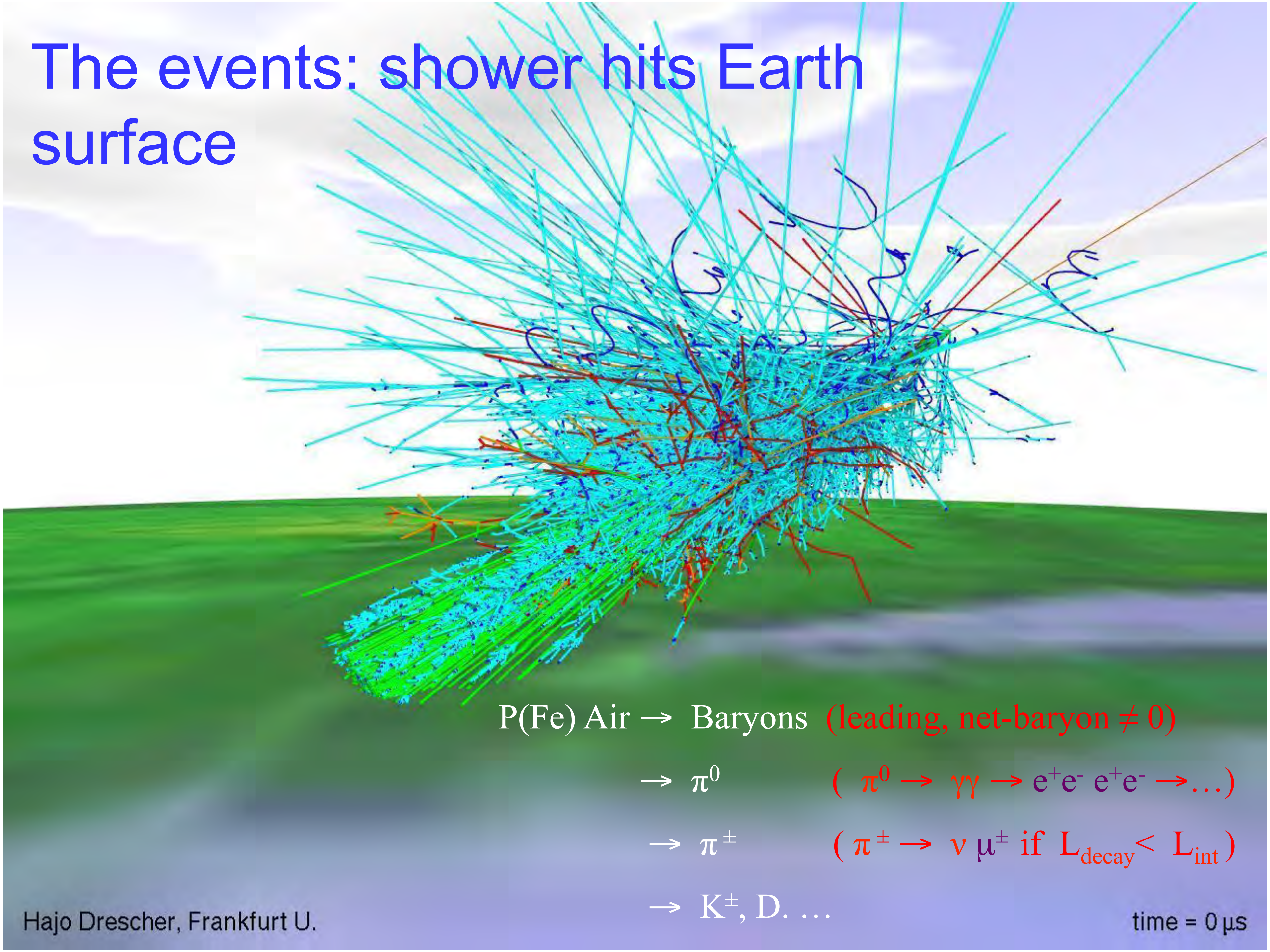
The events: shower development



The events: shower development



The events: shower hits Earth surface



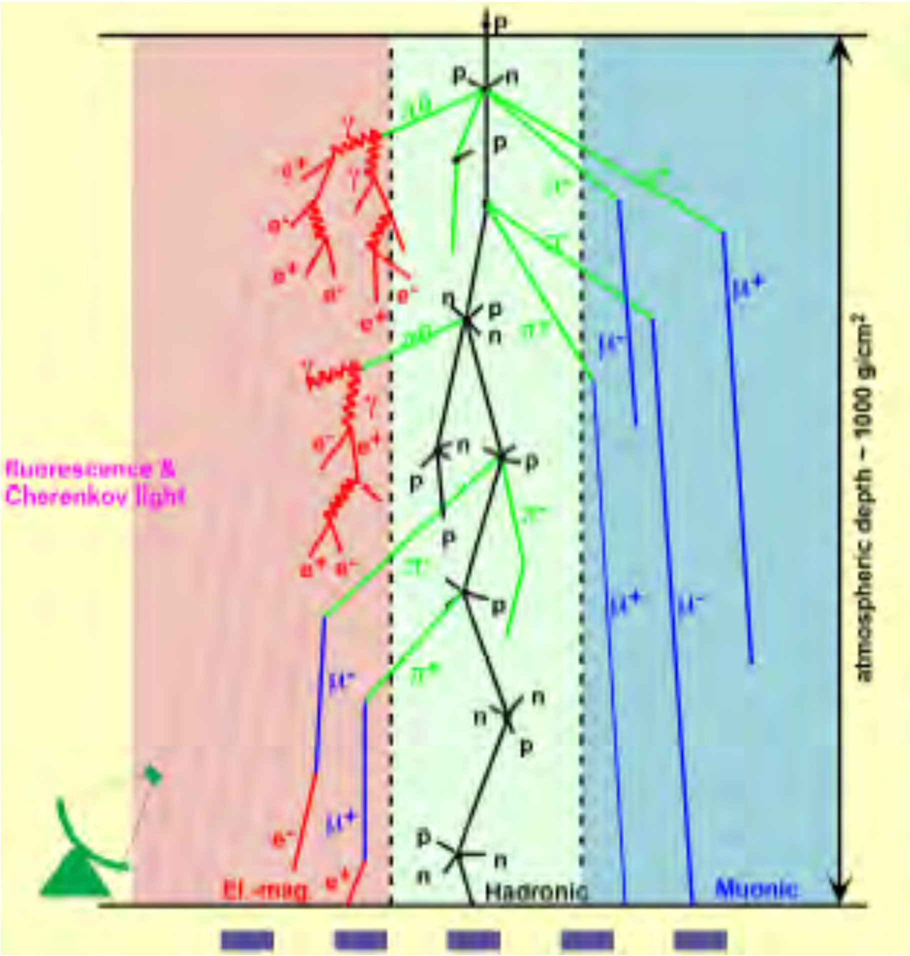
P(Fe) Air $\rightarrow$ Baryons (leading, net-baryon $\neq 0$)

$\rightarrow \pi^0$ $(\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^- e^+e^- \rightarrow \ldots)$

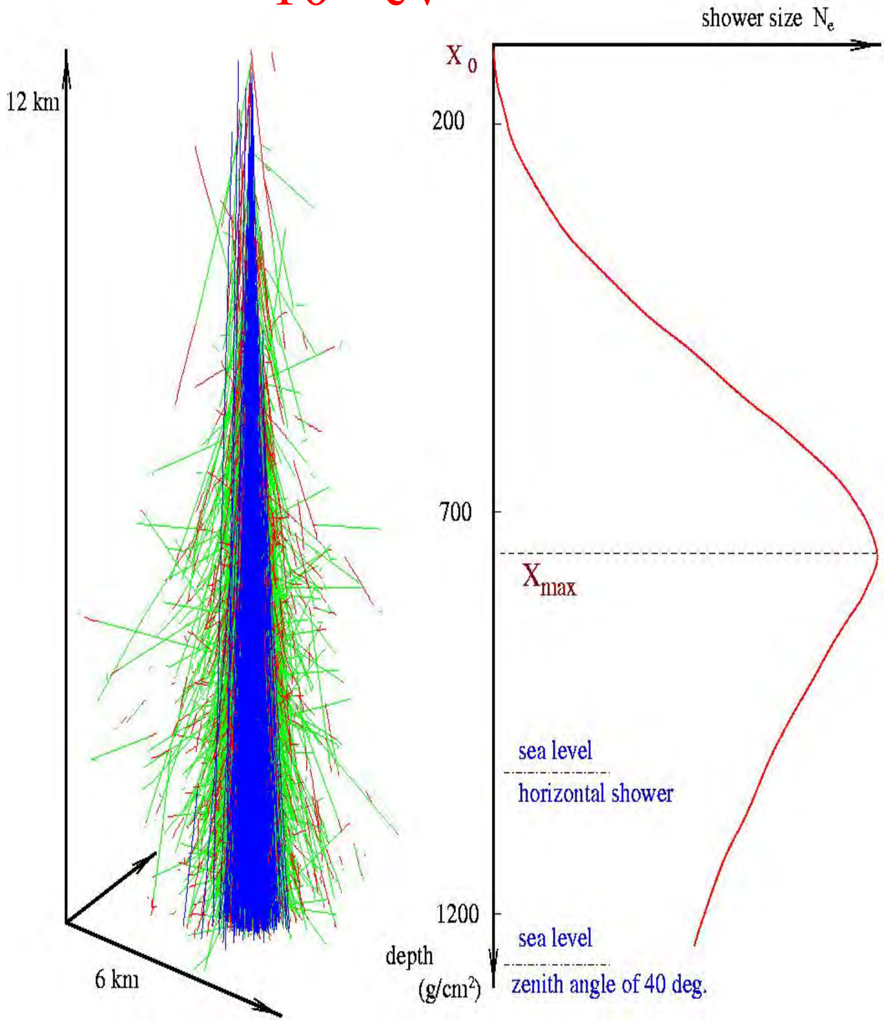
$\rightarrow \pi^\pm$ $(\pi^\pm \rightarrow \nu\, \mu^\pm$ if $L_{decay} < L_{int})$

$\rightarrow K^\pm$, D. …

Extensive Air Showers (EAS)



10^{19} eV



Electromagnetic showers

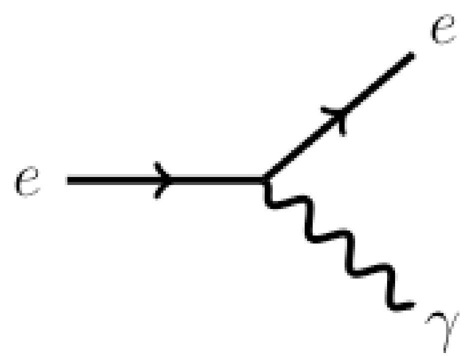
- When a high-energy e or γ enters an absorber, it initiates an em cascade as pair production and bremsstrahlung generate more e and γ with lower energy
- The ionization loss becomes dominant < a critical energy E_c
  - E_c ~ 88 MeV in air, ~ (550/Z)MeV
    - Approximate scaling in $y = E/E_c$
  - The longitudinal development ~scales as the radiation length in the material: $t = x/Xo$ (~440 m in air at NTP)
  - The transverse development scales approximately with the Moliere radius R_M ~ (21 MeV/E_c) Xo
    - In average, only 10% of energy outside a cylinder w/ radius R_M
    - In air, R_M ~ 80 m; in water R_M ~ 9 cm
- Electrons/positrons lose energy by ionization during the cascade process
- Not a simple sequence: needs Monte Carlo calculations

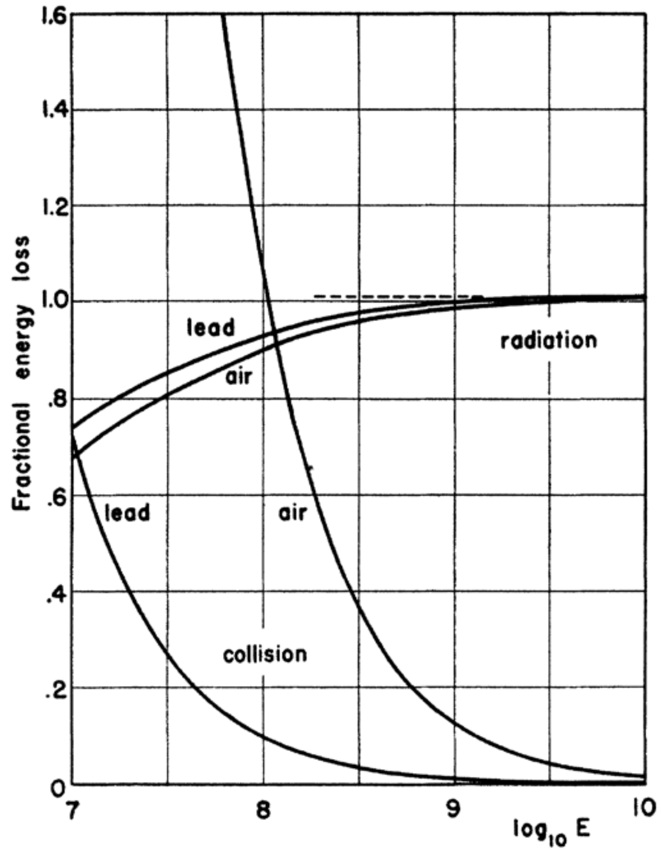
QED HE processes: bremsstrahlung for electrons…

- (and pair production for photons). Forbidden in vacuo by 4-momentum conservation
  - Require interaction with the medium
- Bremsstrahlung (braking radiation): photons of momentum $q<E_e$ emitted with probability ~proportional to 1/q
  - (and collimated: ~ m_e/E)

  ie, energy emission is ~constant for each interval of photon energy; total is propto E
  - The dependence on the material appears through the radiation length Xo:

    $$dE_e/dx = -1/Xo$$
  - Xo can be found in tables. It is ~440 m for air at NTP, ~43 cm for water; for density 1 g/cm^3 roughly proportional to A/Z^2
- Collision energy loss is almost constant (plateau)

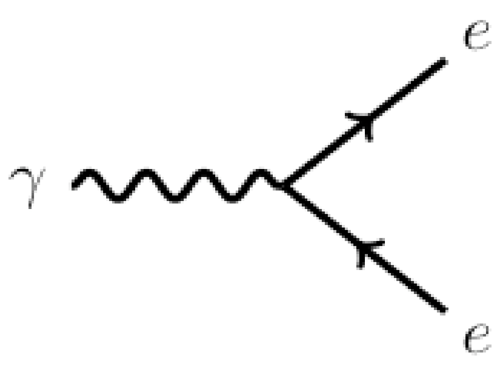


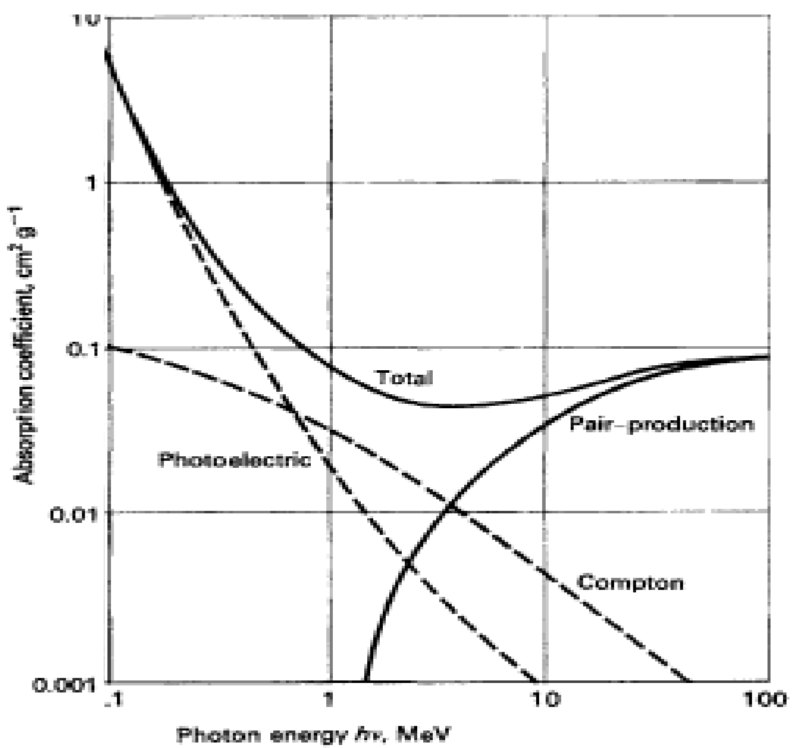


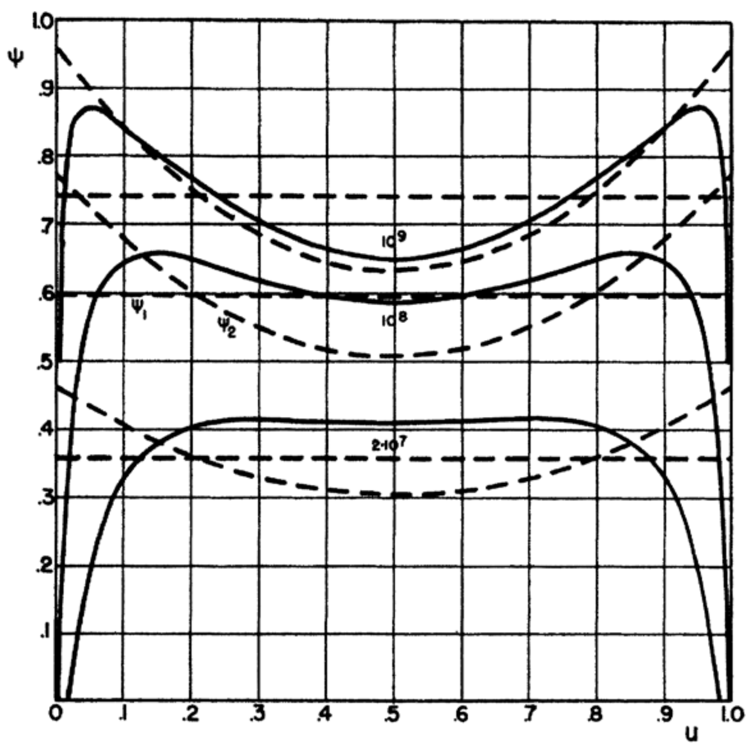
QED HE processes: …pair production for photons

- Pair production:
  $\lambda = (9/7)\, X_o$ for $E_\gamma \gg 2m_e$

  Energy spectrum ~ flat

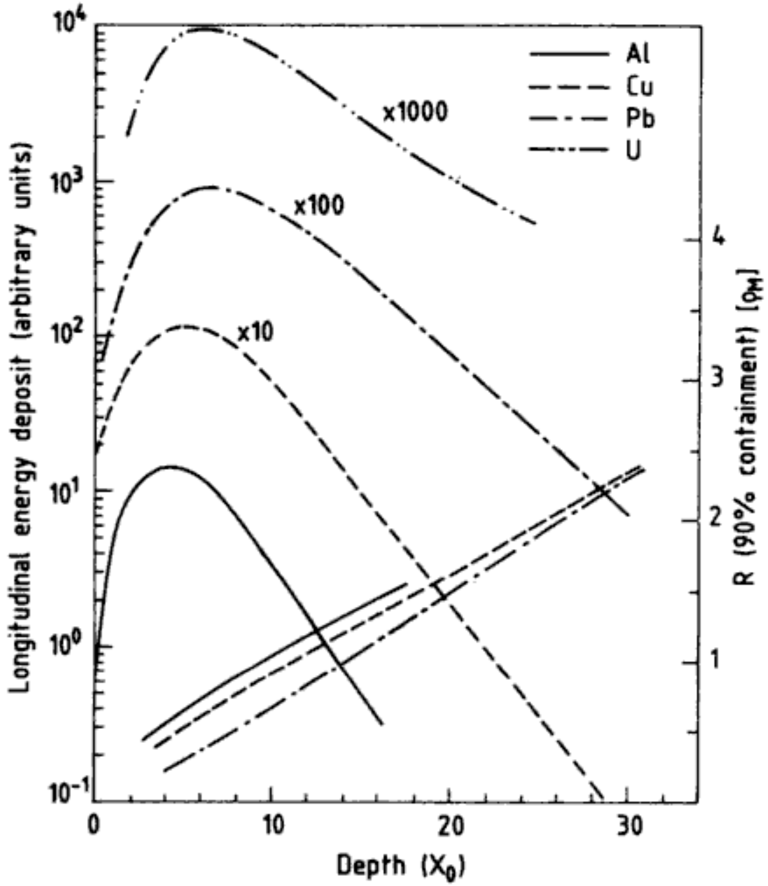






An analytic model: Rossi's "approximation B"

- Rossi in 1941 published an analytical formulation for the shower development as a set of 2 integro-differential equations under the approximation that:
  - Electrons lose energy by ionization & bremsstrahlung; asymptotic formulae hold
  - Photons undergo pair production only; asymptotic formulae hold ($E > 2\,m_e$)
- Very good approximation until $E \sim E_c$

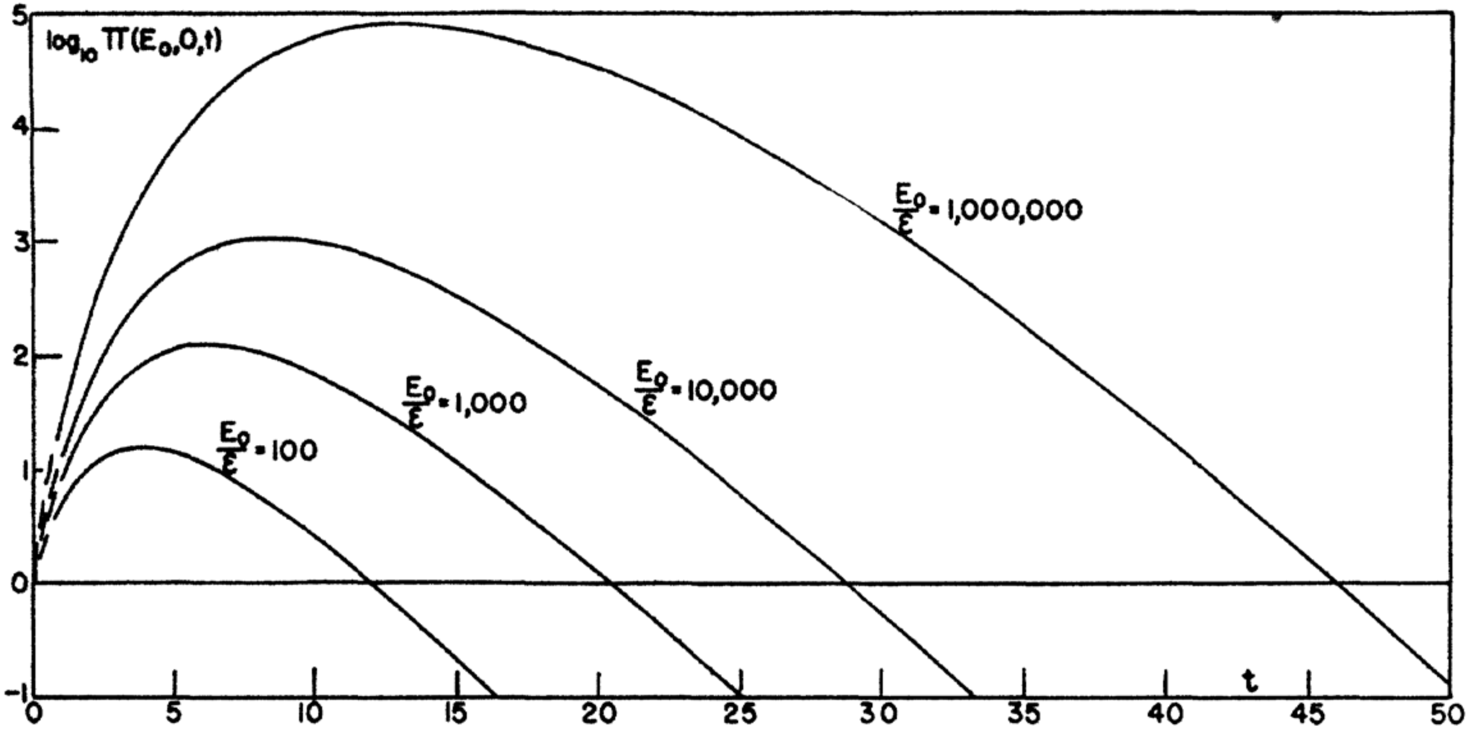


	Incident electron	Incident photons
Peak of shower, t_{max}	$1.0 \times (\ln y - 1)$	$1.0 \times (\ln y - 0.5)$
Centre of gravity, t_{med}	$t_{max} + 1.4$	$t_{max} + 1.7$
Number e^+ and e^- at peak	$0.3\,y \times (\ln y - 0.37)^{-1/2}$	$0.3\,y \times (\ln y - 0.31)^{-1/2}$
Total track length T	y	y

A snapshot of Rossi's equations (you can solve them, but…)

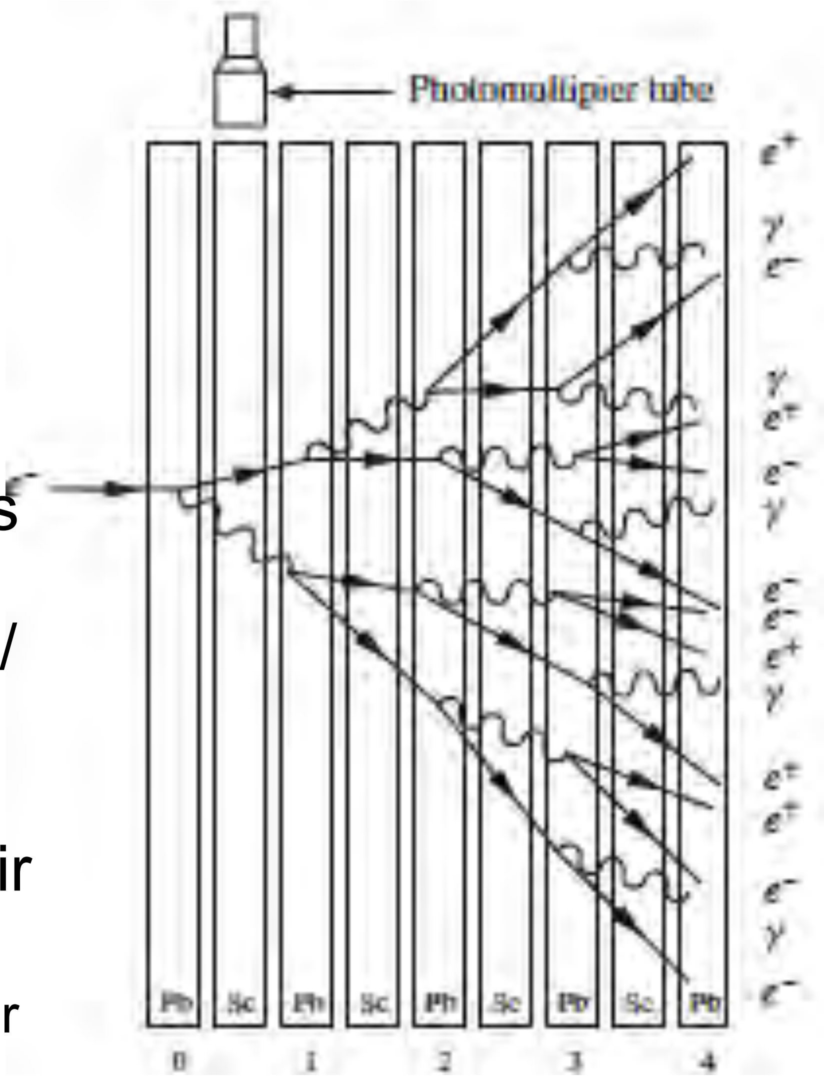
$$\frac{\partial\pi(E,t)}{\partial t}=2\int_0^1\gamma\left(\frac{E}{u},t\right)\psi_0(u)\frac{du}{u}-\int_0^1\left[\pi(E,t)-\frac{1}{1-v}\pi\left(\frac{E}{1-v},t\right)\right]\varphi_0(v)dv+\epsilon\frac{\partial\pi(E,t)}{\partial E}$$

$$\frac{\partial\gamma(W,t)}{\partial t}=\int_0^1\pi\left(\frac{W}{v},t\right)\varphi_0(v)\frac{dv}{v}-\sigma_0\gamma(W,t)$$



A simplified approach (Heitler)

- Qualitative features may be obtained from a simple model
  1. Each electron with $E>E_C$ travels 1 Xo and then gives up half of its energy to a bremsstrahlung photon
  2. Each photon with $E>E_C$ travels 1 Xo and then creates an e+e- pair with each particle taking E/2
  3. Electrons with $E<E_C$ cease to radiate and lose the rest of their energy by collisions
     - Ionization losses are negligible for $E>E_C$



Results from the simplified approach

- If the initial electron has energy $E_0 >> E_C$, after t Xo the shower will contain 2^t particles. ~equal numbers of e+, e-, γ, each with an average energy

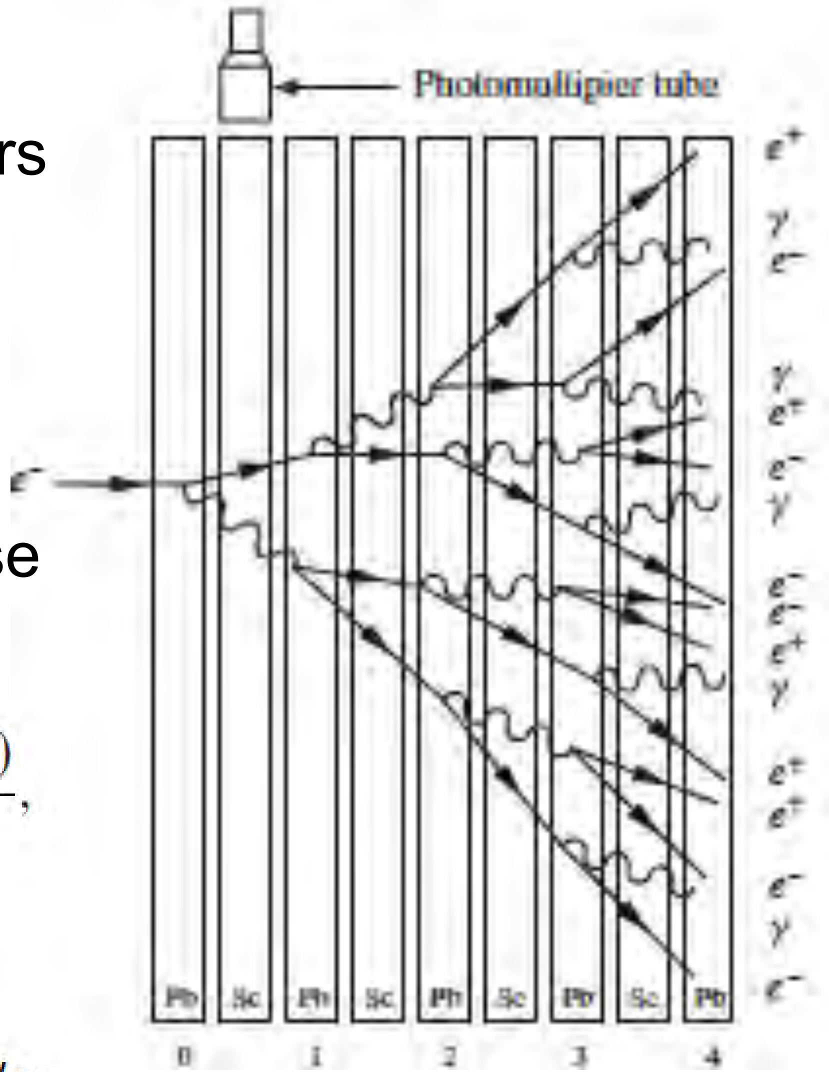
$$E(t) = E_0/2^t$$

- The multiplication process will cease when $E(t)=E_C$

$$t_{max} = t(E_C) \equiv \frac{\ln(E_0/E_C)}{\ln 2},$$

and the number of particles at this point will be

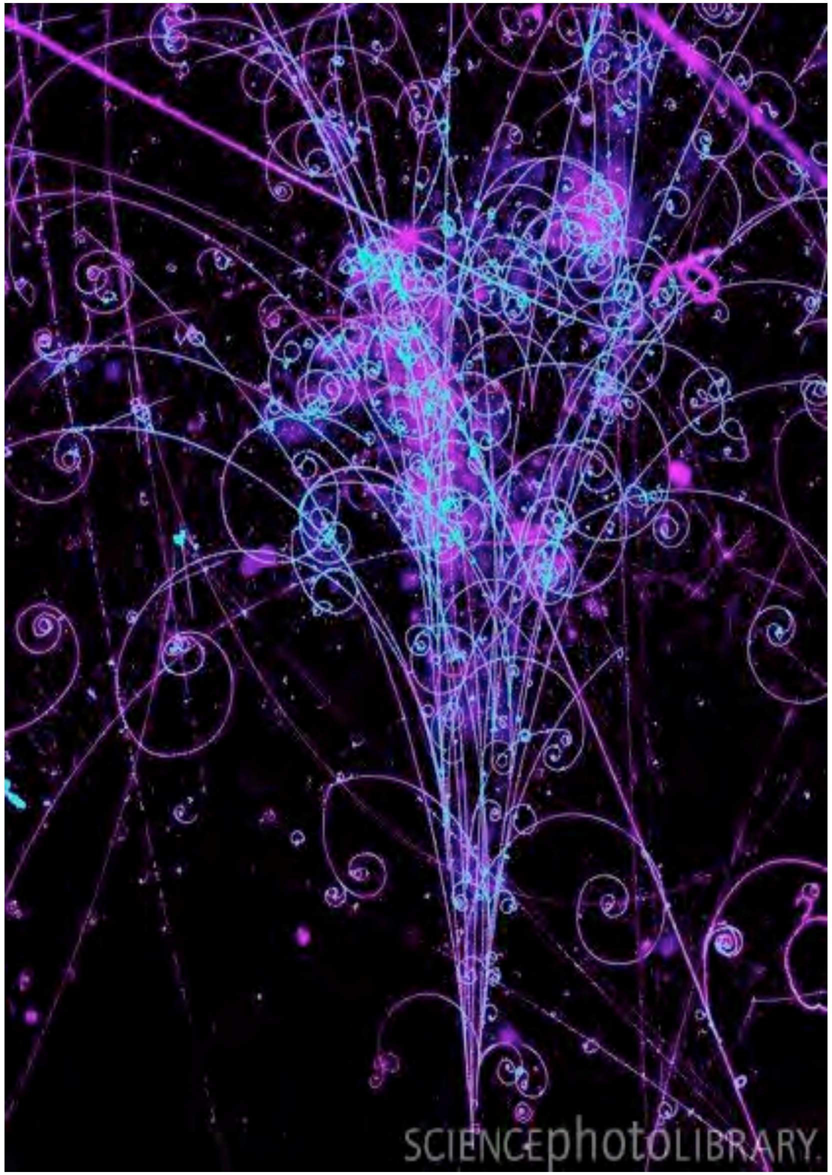
$$N_{max} = \exp(t_{max} \ln 2) = E_0 / E_C$$



Energy measurement

– Errors asymptotically dominated by statistical fluctuations:

$$\frac{\sigma_E}{E} \cong \frac{k_E}{\sqrt{E}} \oplus c$$

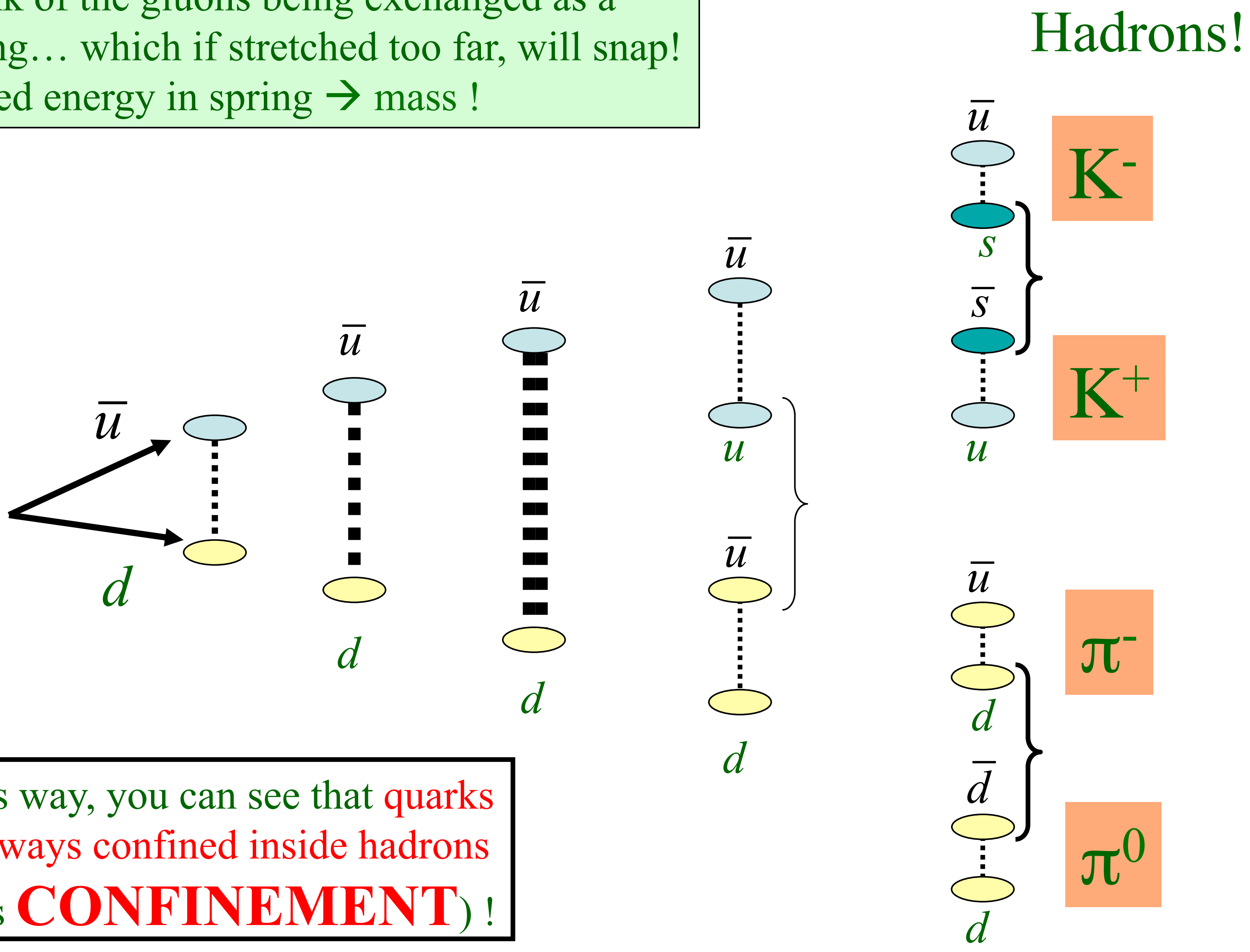


Hadronic showers

- Although hadronic showers are qualitatively similar to em, shower development is more complex because many different processes contribute
  - Larger fluctuations
- Some of the contributions to the total absorption may not give rise to an observable signal in the detector
  - Examples: nuclear excitation and leakage of secondary muons and neutrinos
- Depending on the proportion of π^0s produced in the early stages of the cascade, the shower may develop predominantly as an electromagnetic one because of the decay $\pi^0 \rightarrow \gamma\ \gamma$
- The scale of the shower is determined by the nuclear absorption length λ_H
  - Typically λ_H > Xo
  - Larger lateral width

String fragmentation

Think of the gluons being exchanged as a spring… which if stretched too far, will snap! Stored energy in spring → mass !



In this way, you can see that quarks are always confined inside hadrons (that's **CONFINEMENT**) !

Neutrino interactions: no interaction in space; with Earth

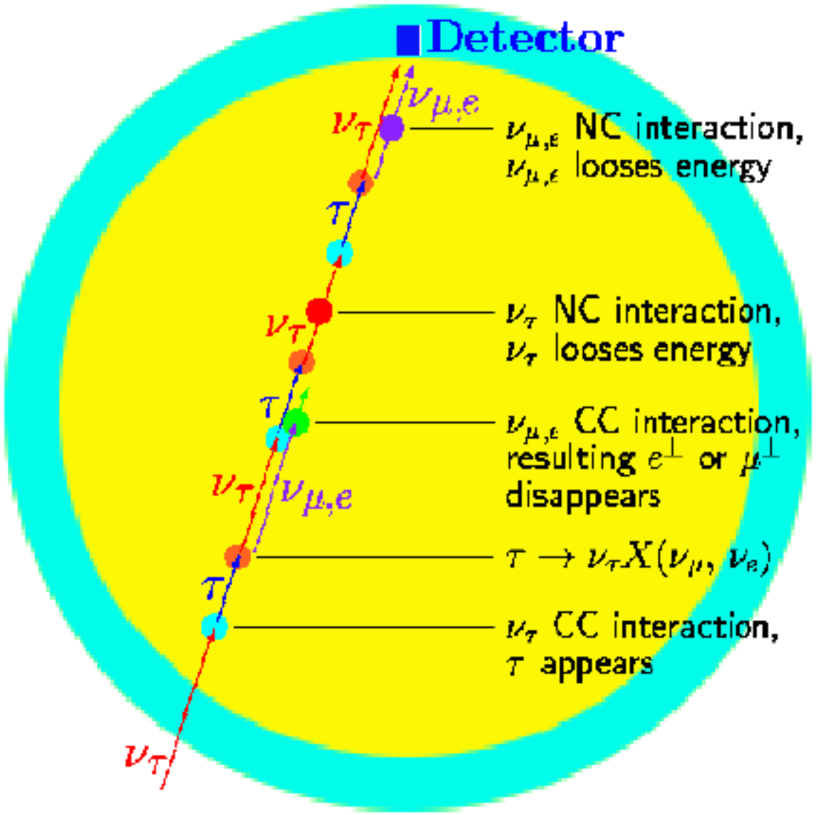
$\nu_\tau \rightarrow \tau \rightarrow \nu_\tau \rightarrow \ldots$

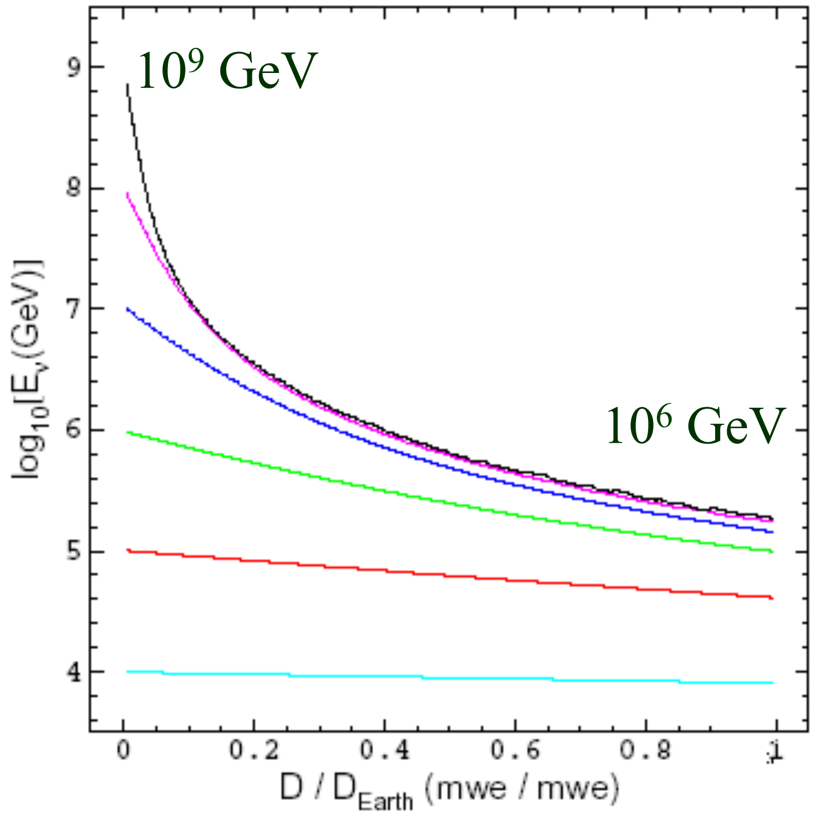
ν_τ energy degradation

$\sigma_\nu \nearrow E_\nu$

The Earth is opaque to $\nu_e\, \nu_\mu$

Above $E_\tau \sim 10^7$ GeV: $L_{\tau int} < L_{\tau decay}$

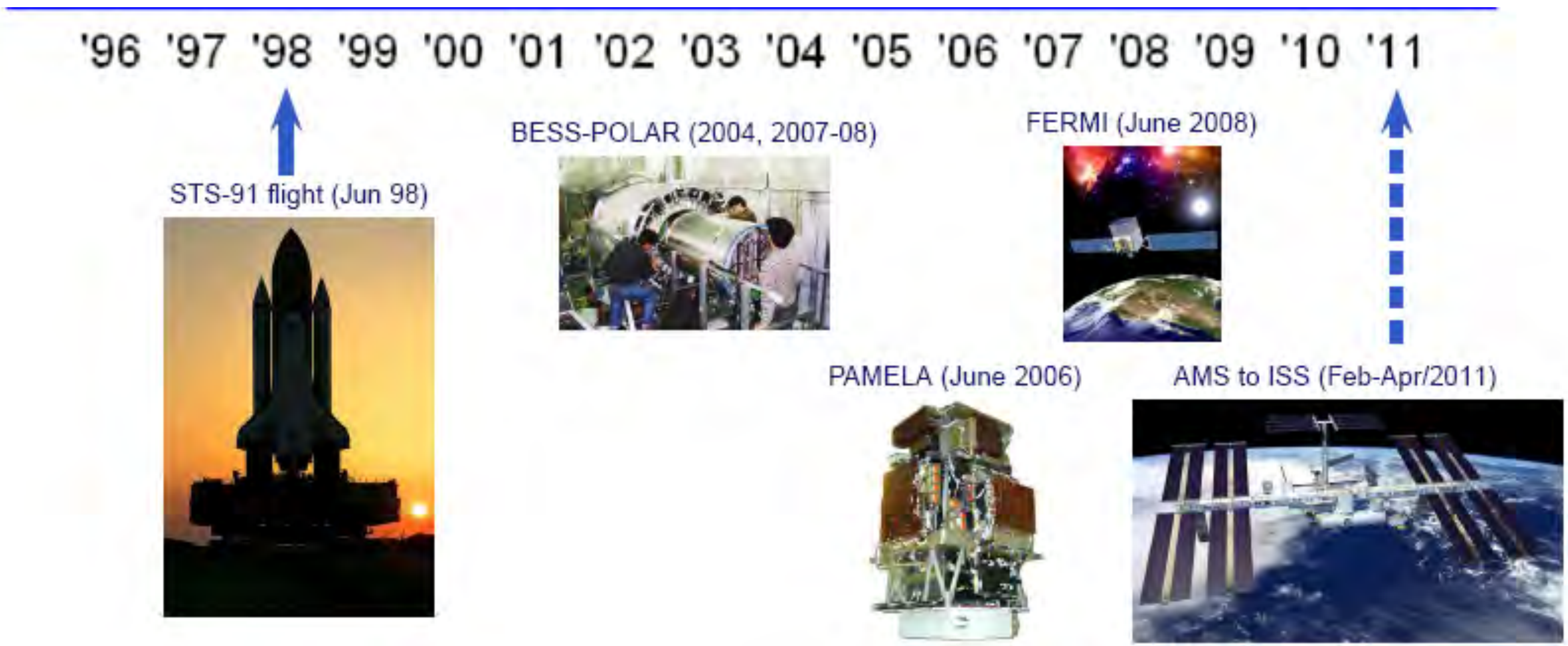




Fraction of Earth diameter

THE DETECTION

Cosmic ray detection in space

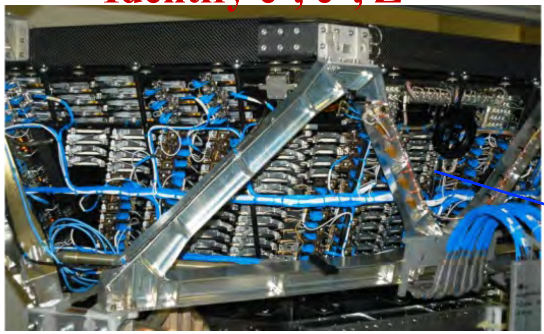


AMS: A TeV precision, multipurpose spectrometer

Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

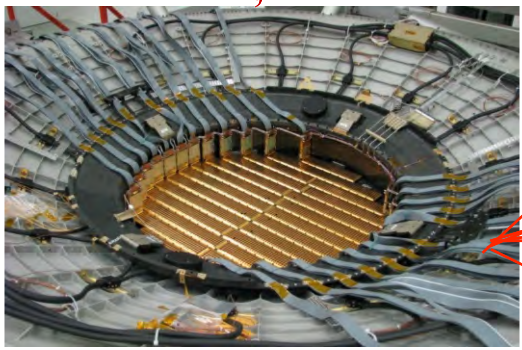
TRD

Identify e^+, e^-, Z



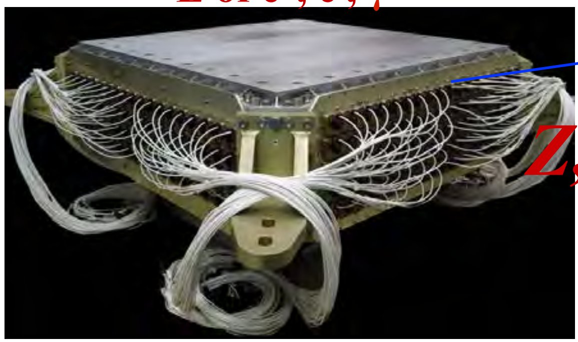
Silicon Tracker

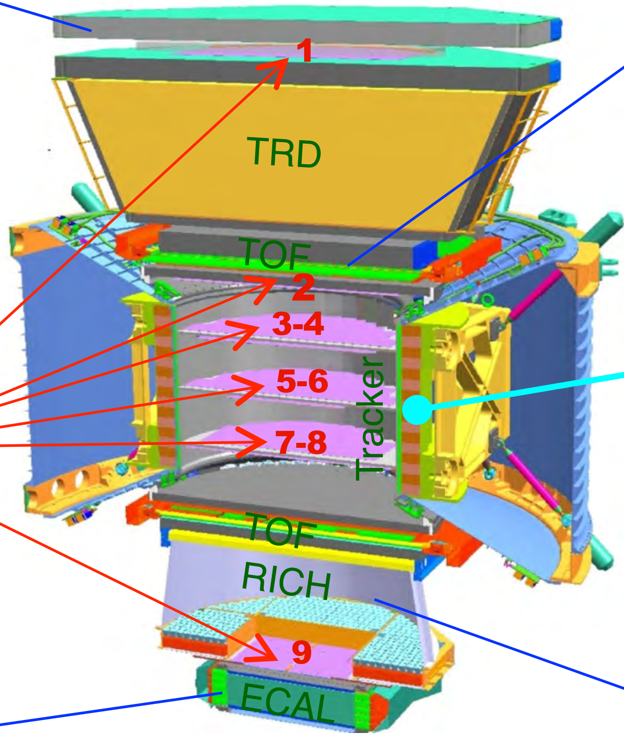
Z, P



ECAL

E of e^+, e^-, γ



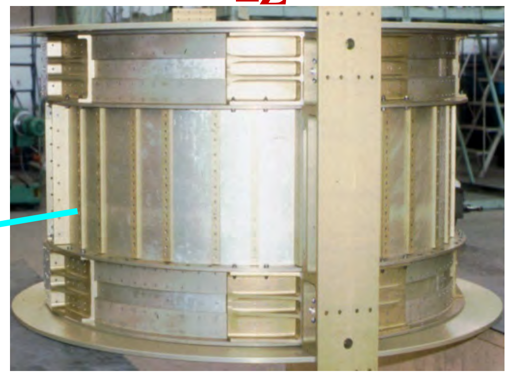


TOF

Z, E

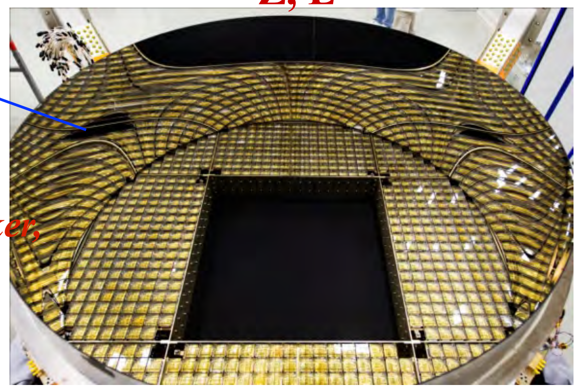
Magnet

±Z



RICH

Z, E

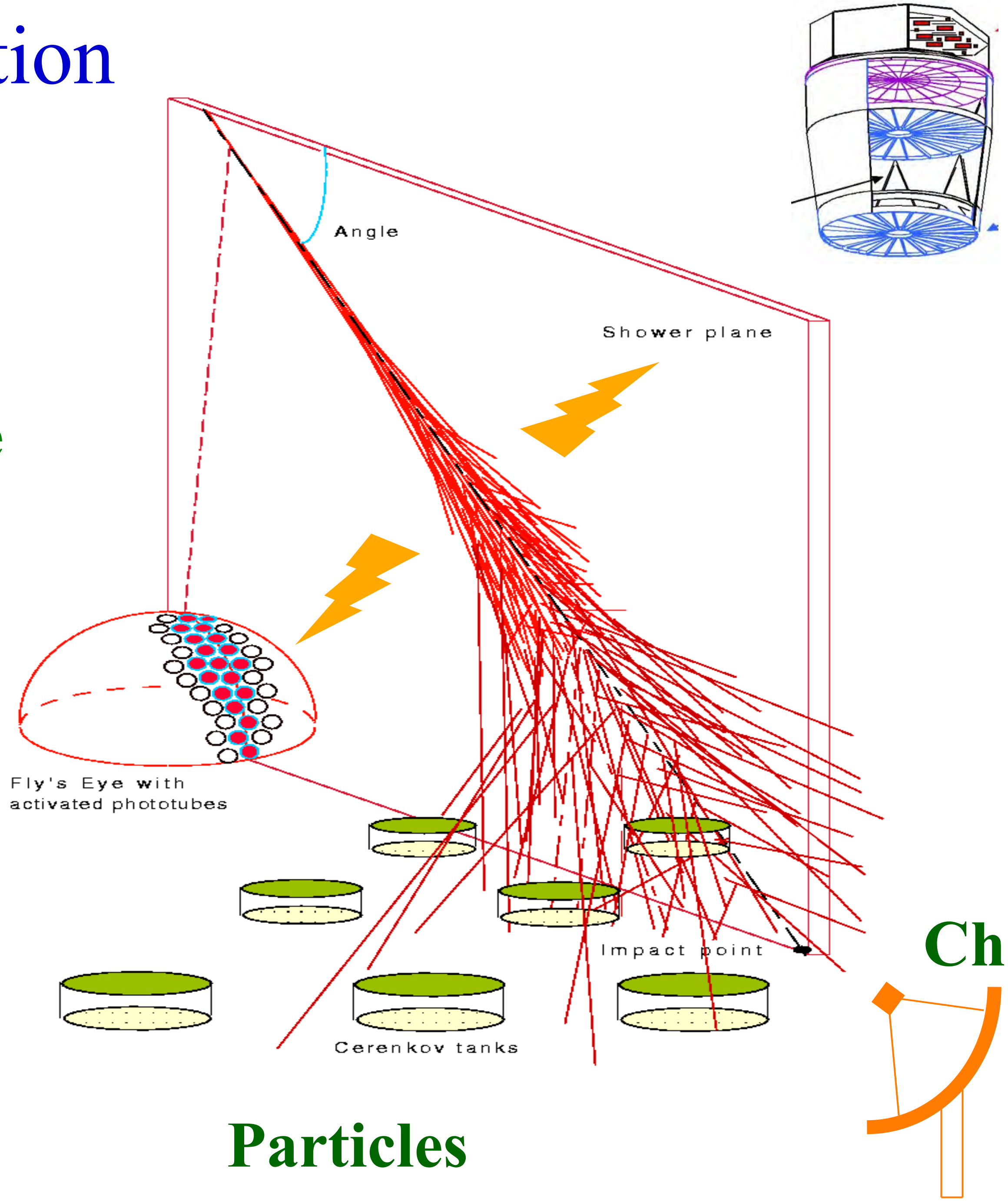


***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*

EAS detection

Fluorescence

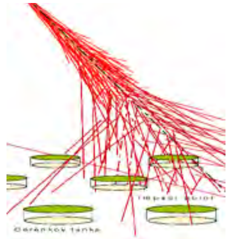
electrons excite
N_2 molecules

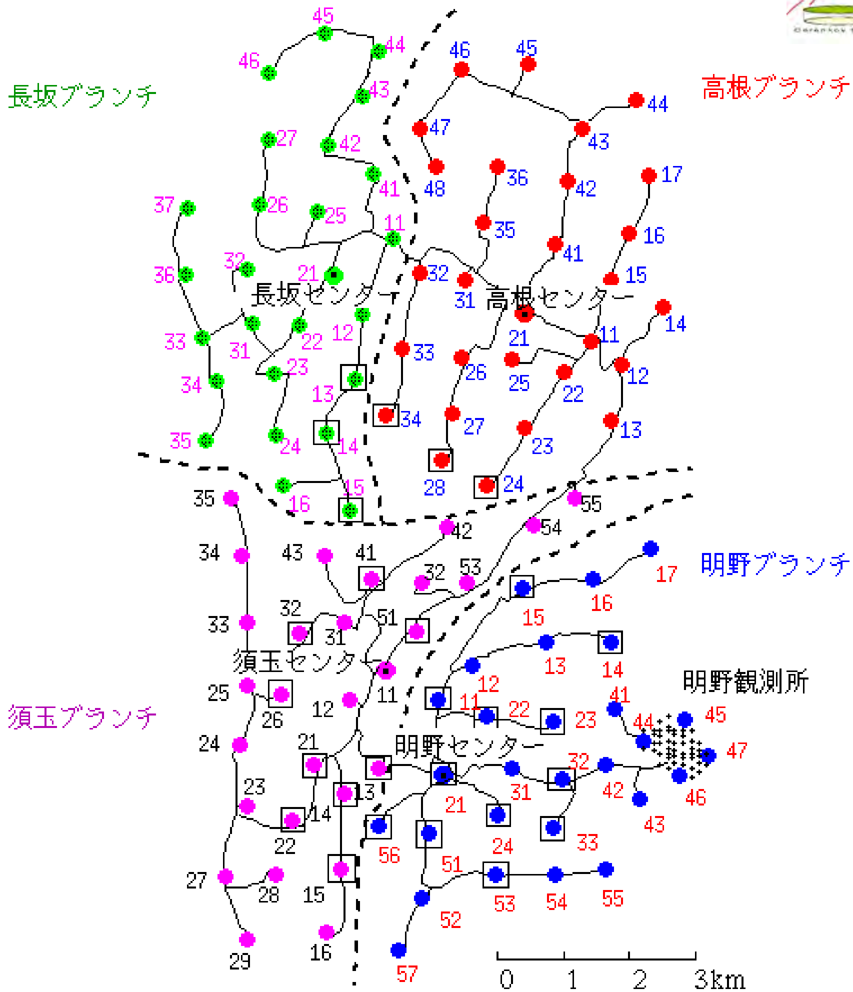


Cherenkov

Particles

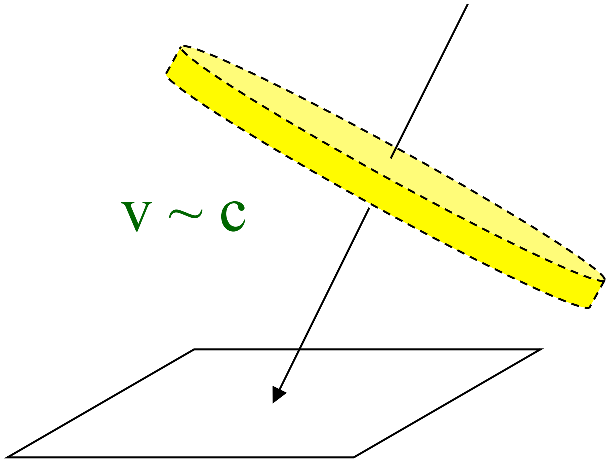
AGASA



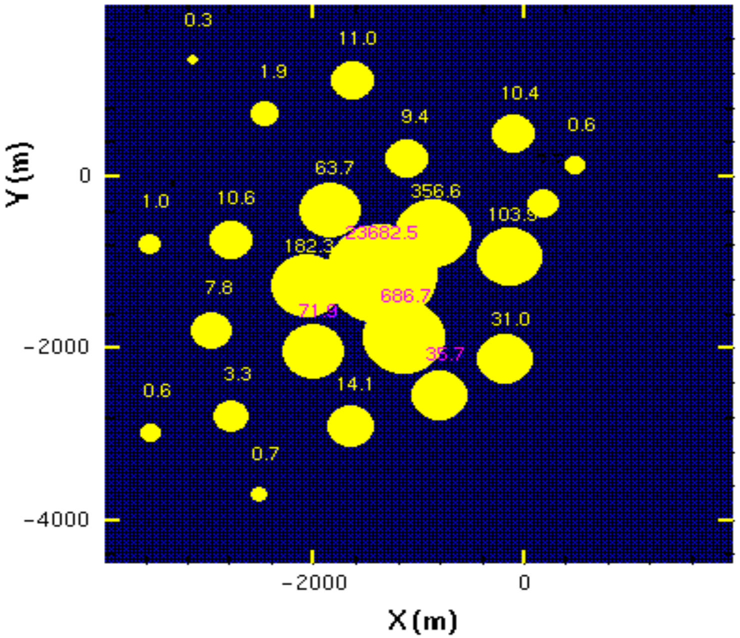


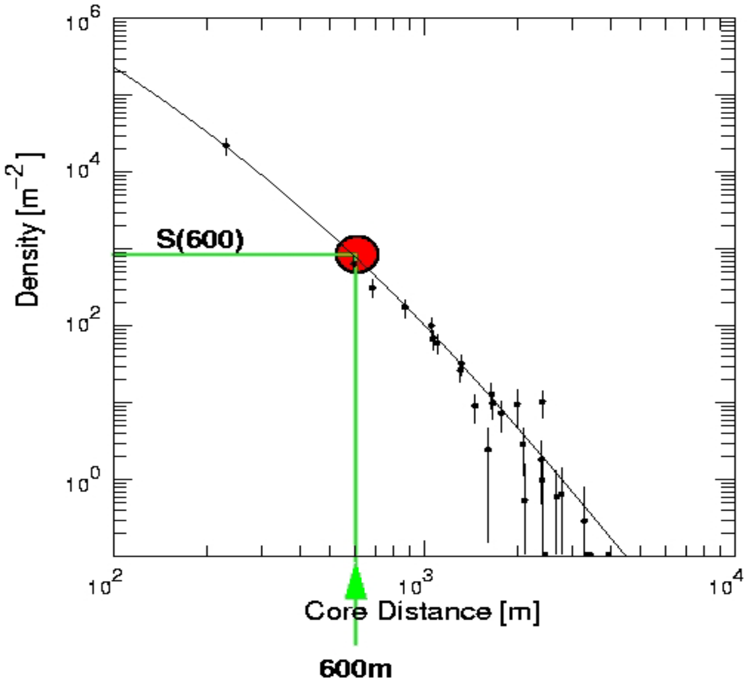
111 detectors for electrons

Ground arrays measurements



From (n_i, t_i):
The direction
The core position
The Energy



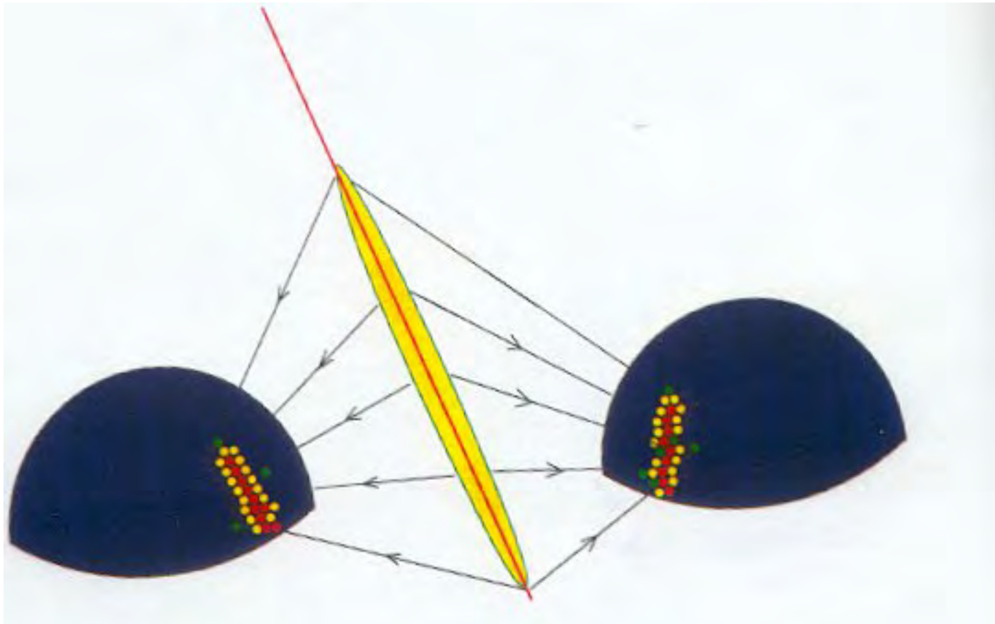


Fluorescence detectors:

Fly's Eye

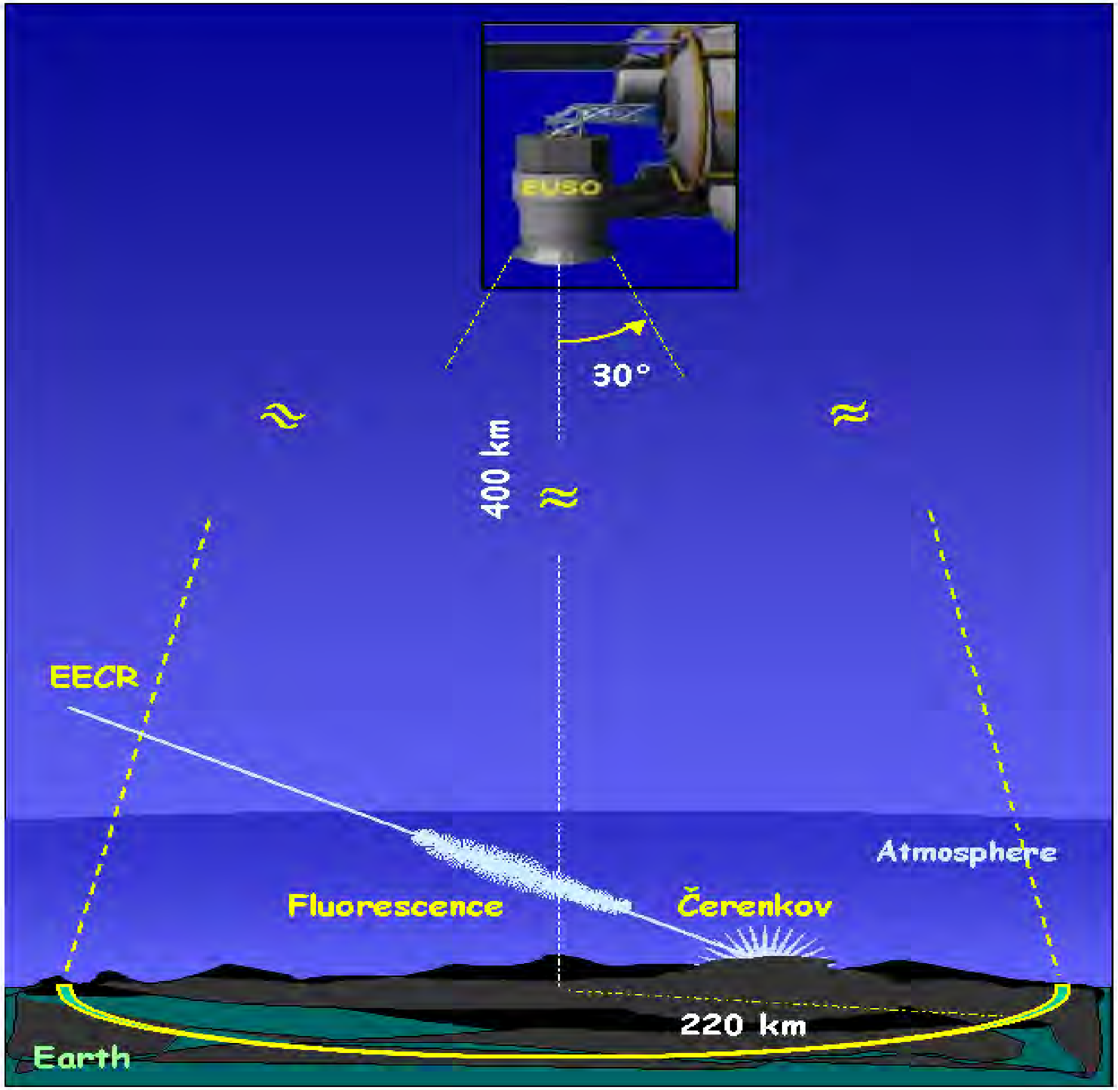
HiRes

Air shower
stereo image



Fluorescence from space

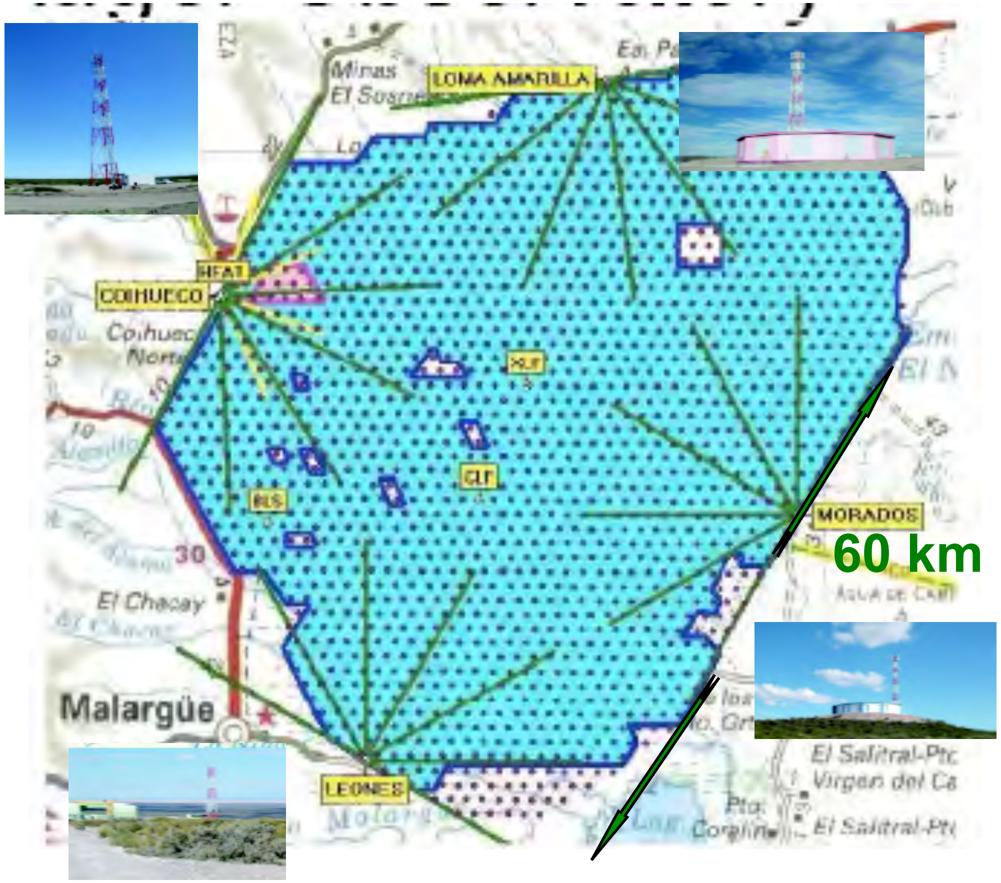
JEM-EUSO



The Pierre Auger Observatory

South Hemisphere

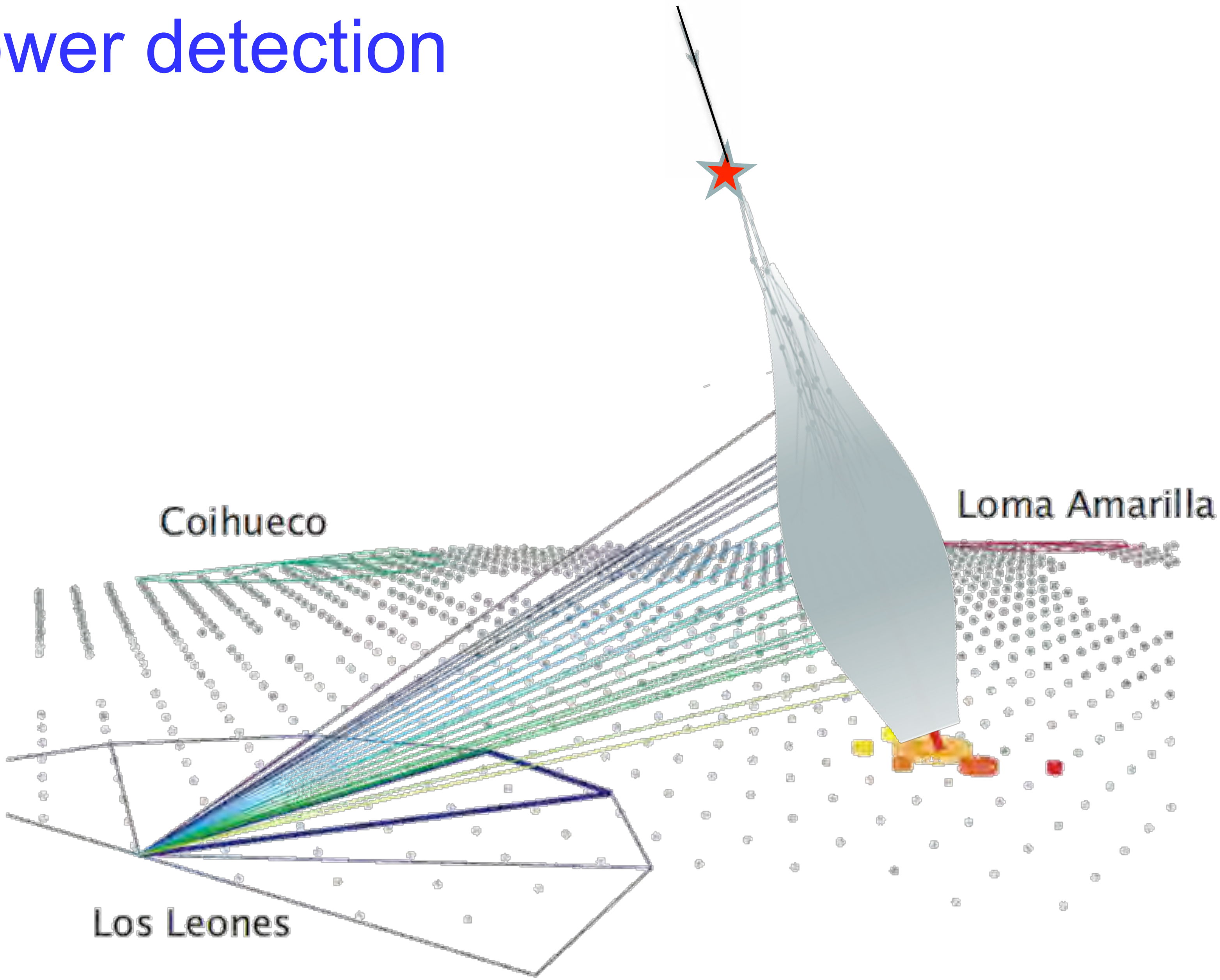
Area ~ 3000 km2
24 fluorescence telescopes
1600 water Cerenkov detectors



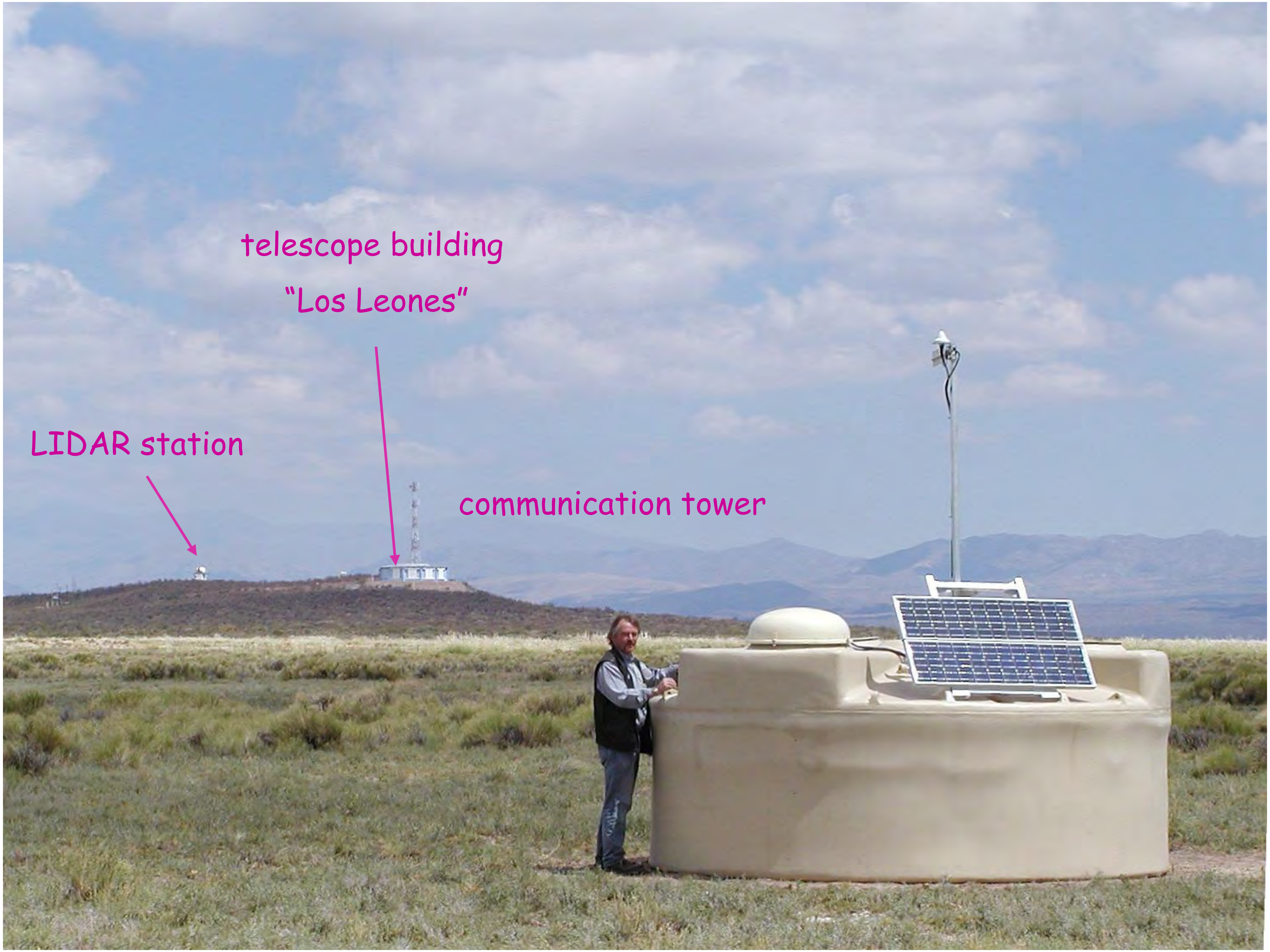
Malargüe, Argentina

Nov 2009

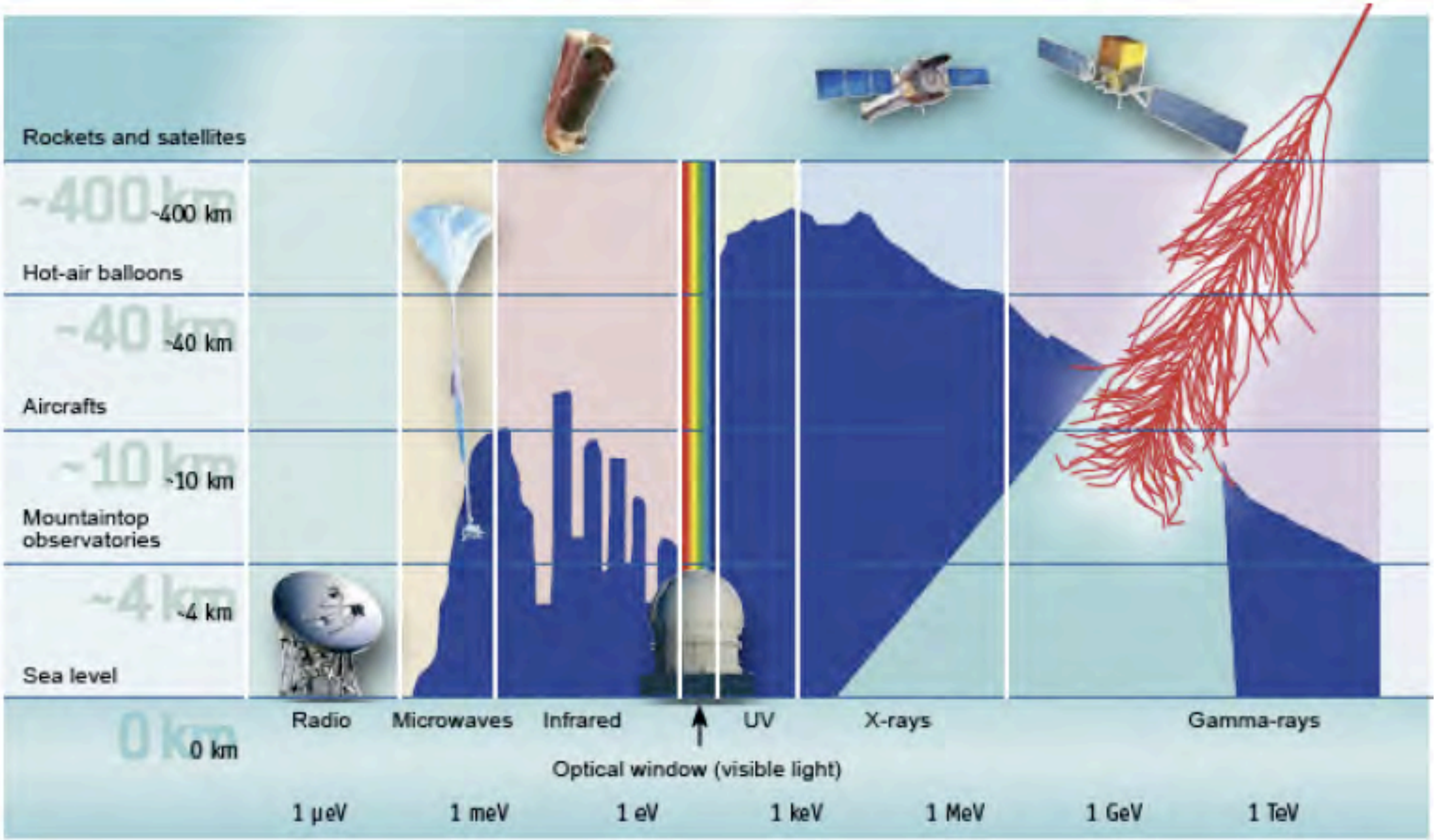
Shower detection




The Pierre Auger Observatory


telescope building
"Los Leones"
LIDAR station
communication tower

Gamma ray detection



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

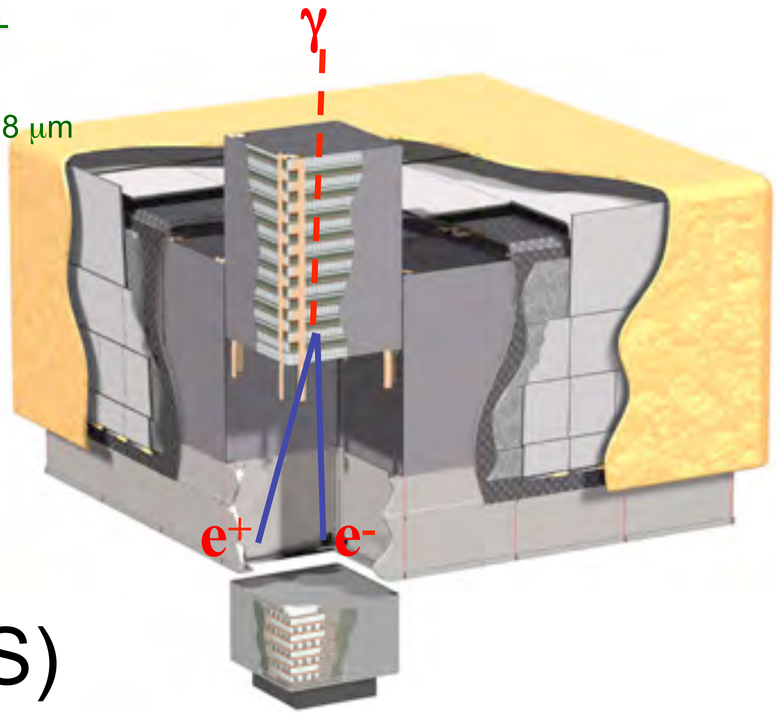
Detectors

Precision Si-strip Tracker (TKR)

18 XY tracking planes

Single-sided silicon strip detectors 228 µm pitch, 8.8 10^5 channels

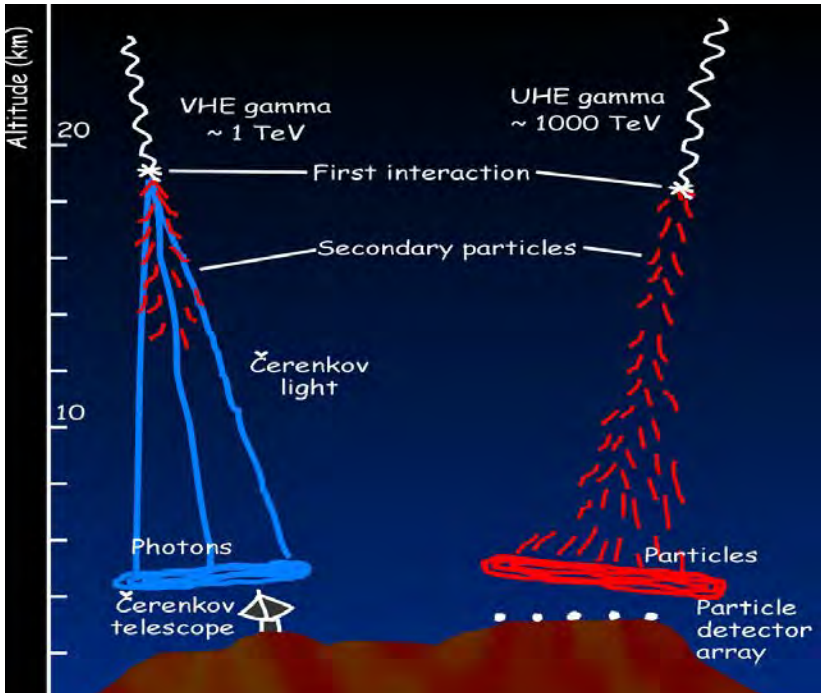
Mea n direction



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

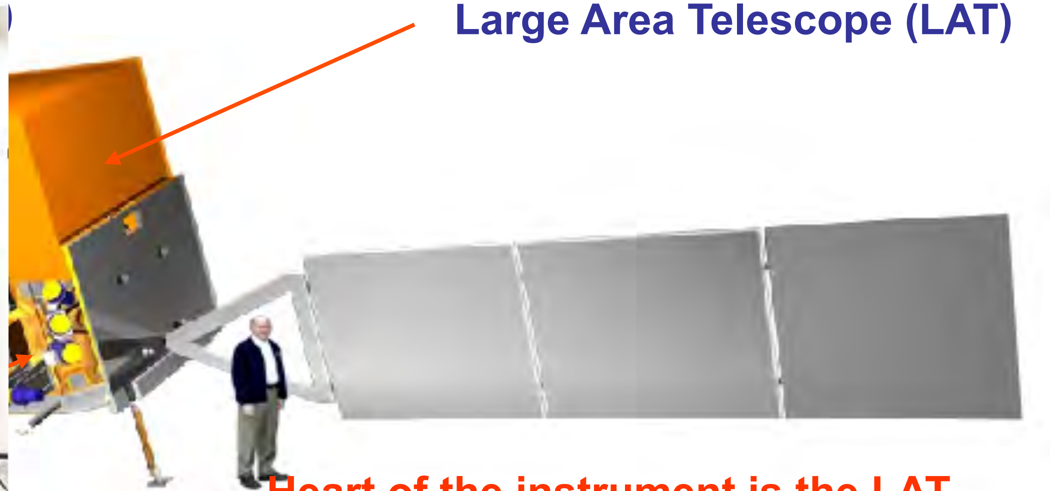
- Cherenkov telescopes (H.E.S.S., MAGIC, VERITAS)

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



HEP detectors!

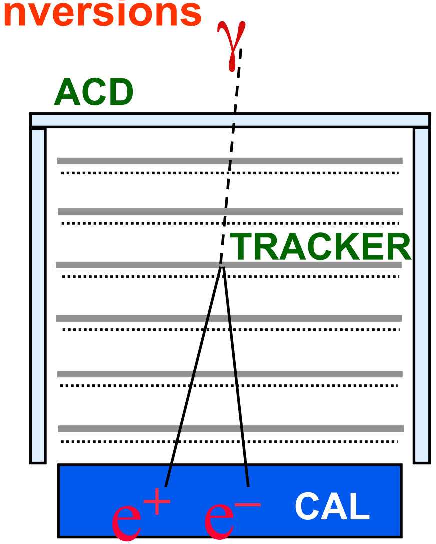
The GLAST/Fermi observatory and the LAT



e Center

min)

Heart of the instrument is the LAT, detecting gamma conversions



International collaboration USA-Italy-France-Japan-Sweden
(it has a small precursor: the all-Italian AGILE)

LAT overview

Si-strip Tracker (TKR)

18 planes XY ~ 1.7 x 1.7 m^2 w/ converter

Single-sided Si strips 228 μm pitch, ~10^6 channels

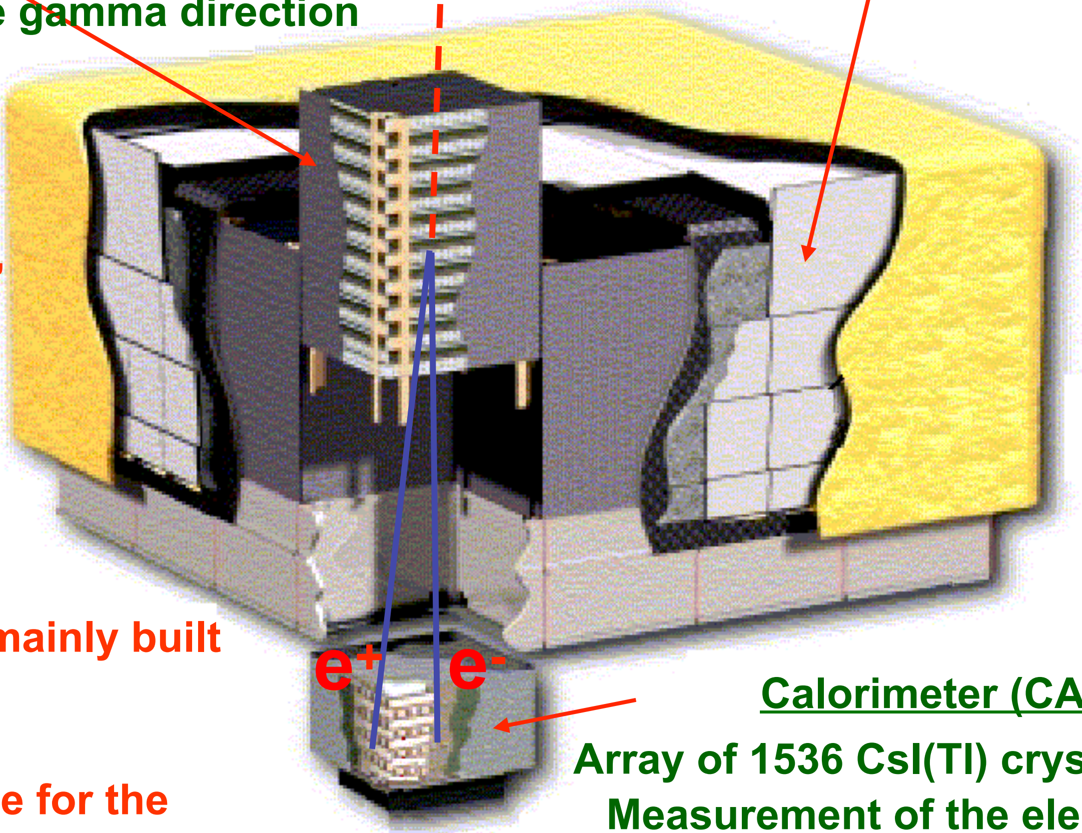
Measurement of the gamma direction

AntiCoincidence Detector (ACD)

89 scintillator tiles around the TKR

Reduction of the background from charged particles

Astroparticle groups INFN/University Bari, Padova, Perugia, Pisa, Roma2, Udine/Trieste



The Silicon tracker is mainly built in Italy

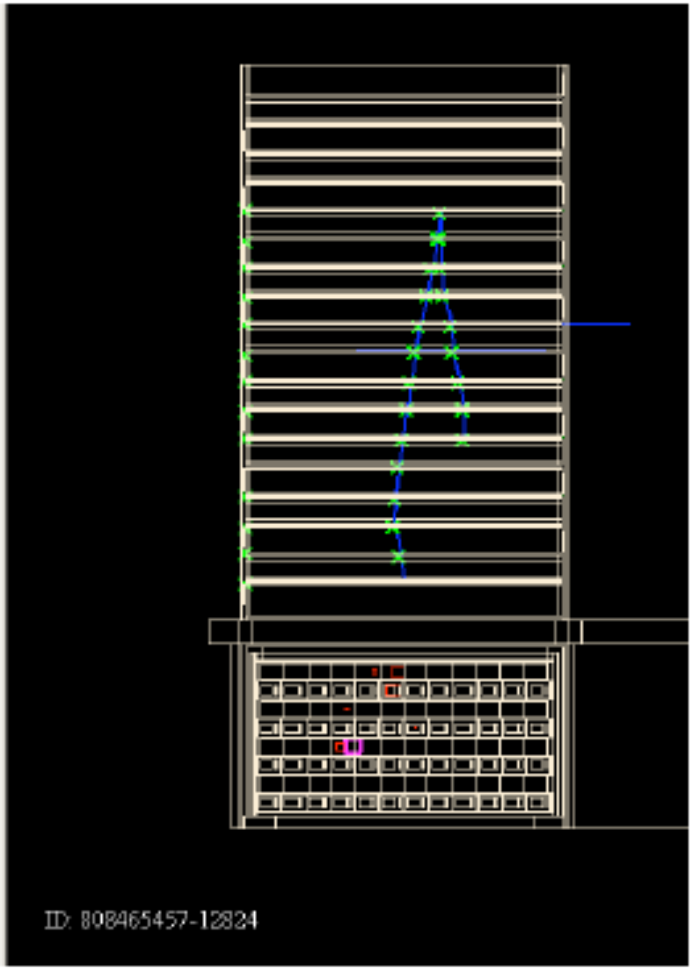
Italy is also responsible for the detector simulation, event display and GRB physics

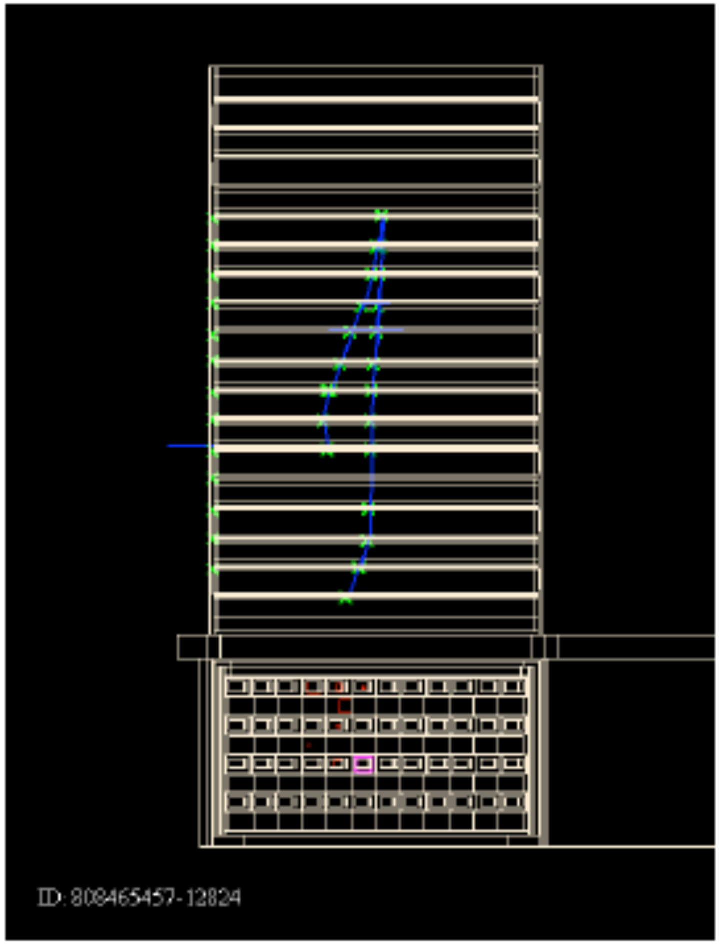
Calorimeter (CAL)

Array of 1536 CsI(Tl) crystals in 8 layers

Measurement of the electron energy

Detection of a gamma-ray





Ground-based telescopes still needed for VHE…

- Peak eff. area of Fermi: 0.8 m^2

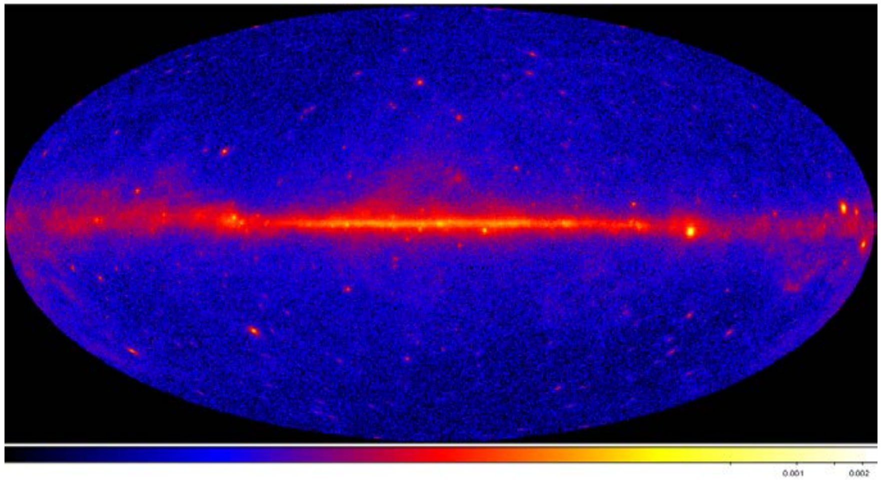
  From strongest flare ever recorde of very high energy (VHE) γ-rays:

  1 photon / m^2 in 8 h above 200 GeV

  (PKS 2155, July 2006)

- The strongest *steady* sources are > 1 order of magnitude weaker!
- Besides: calorimeter depth $\leq 10\ X_0$

$\Rightarrow$ VHE astrophysics (in the energy region above 100 GeV) can be done only at ground



EAS

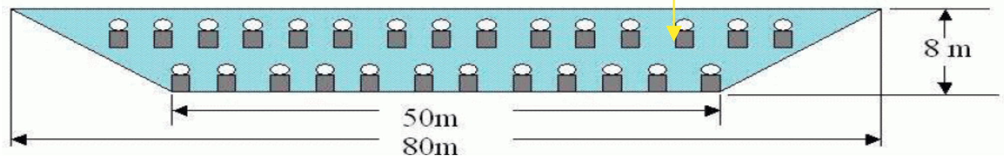
MILAGRO (New Mexico@2600m)

water Cherenkov,

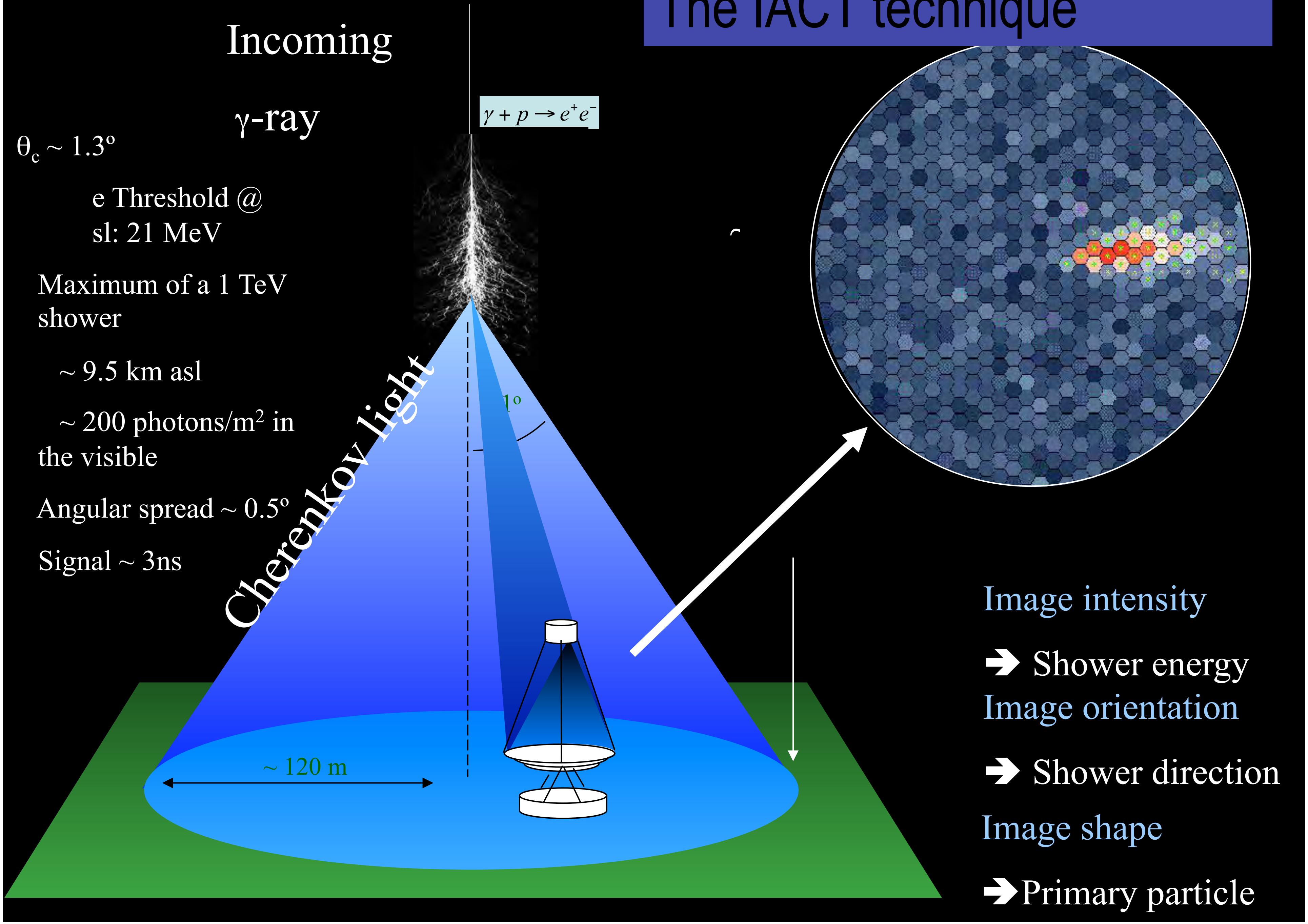
60x80m^2 + outriggers,

γ/h: Muon-identification

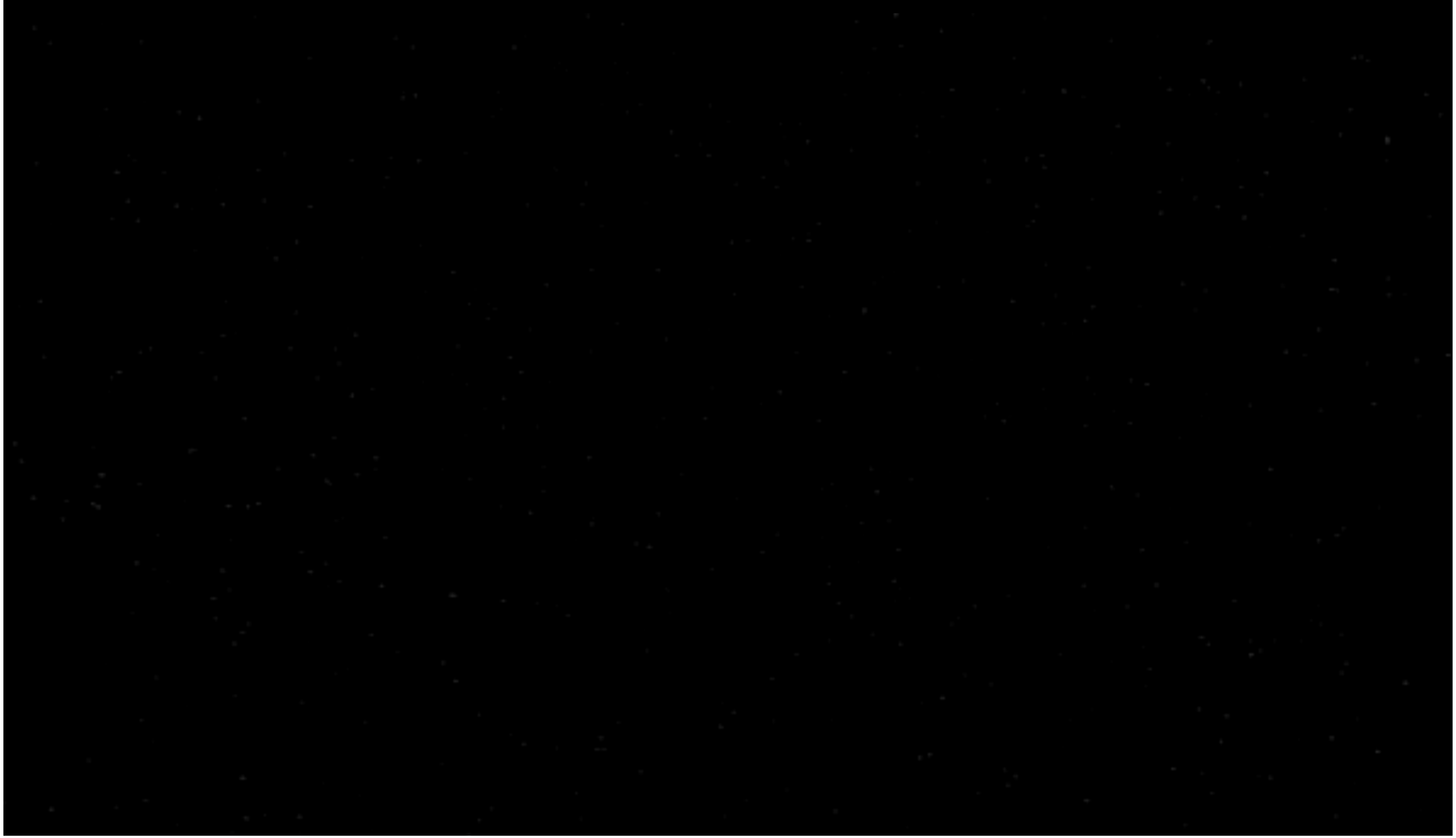
in second layer)



The IACT technique



Signal duration: ~ 3ns



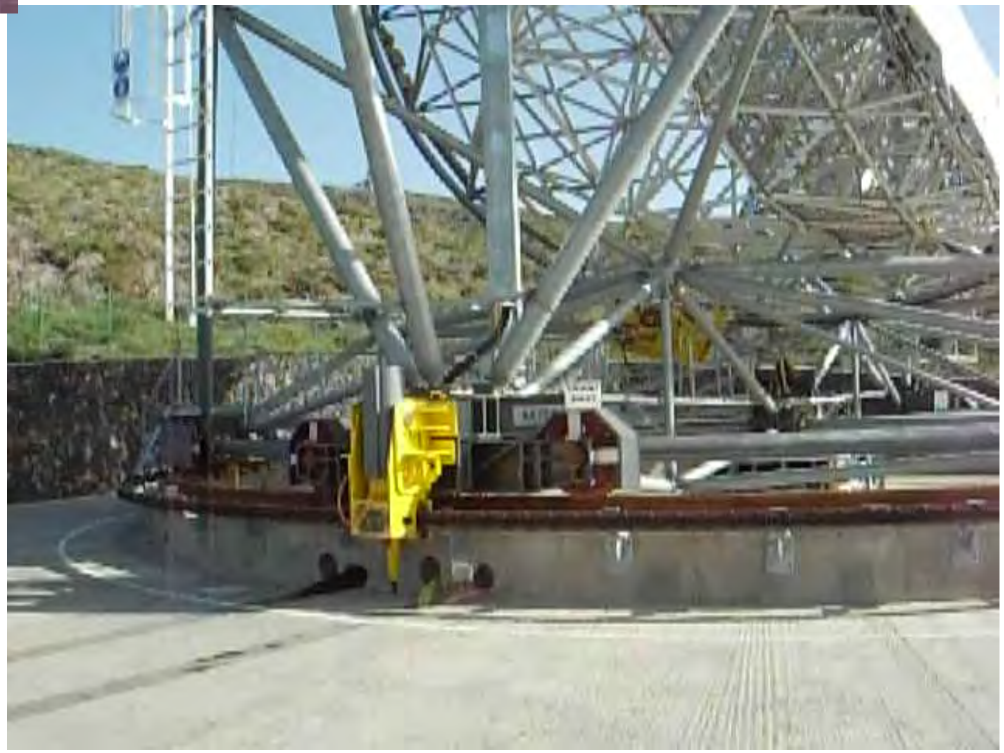
MAGIC at La Palma

(2 x 17 meters diameter telescopes)

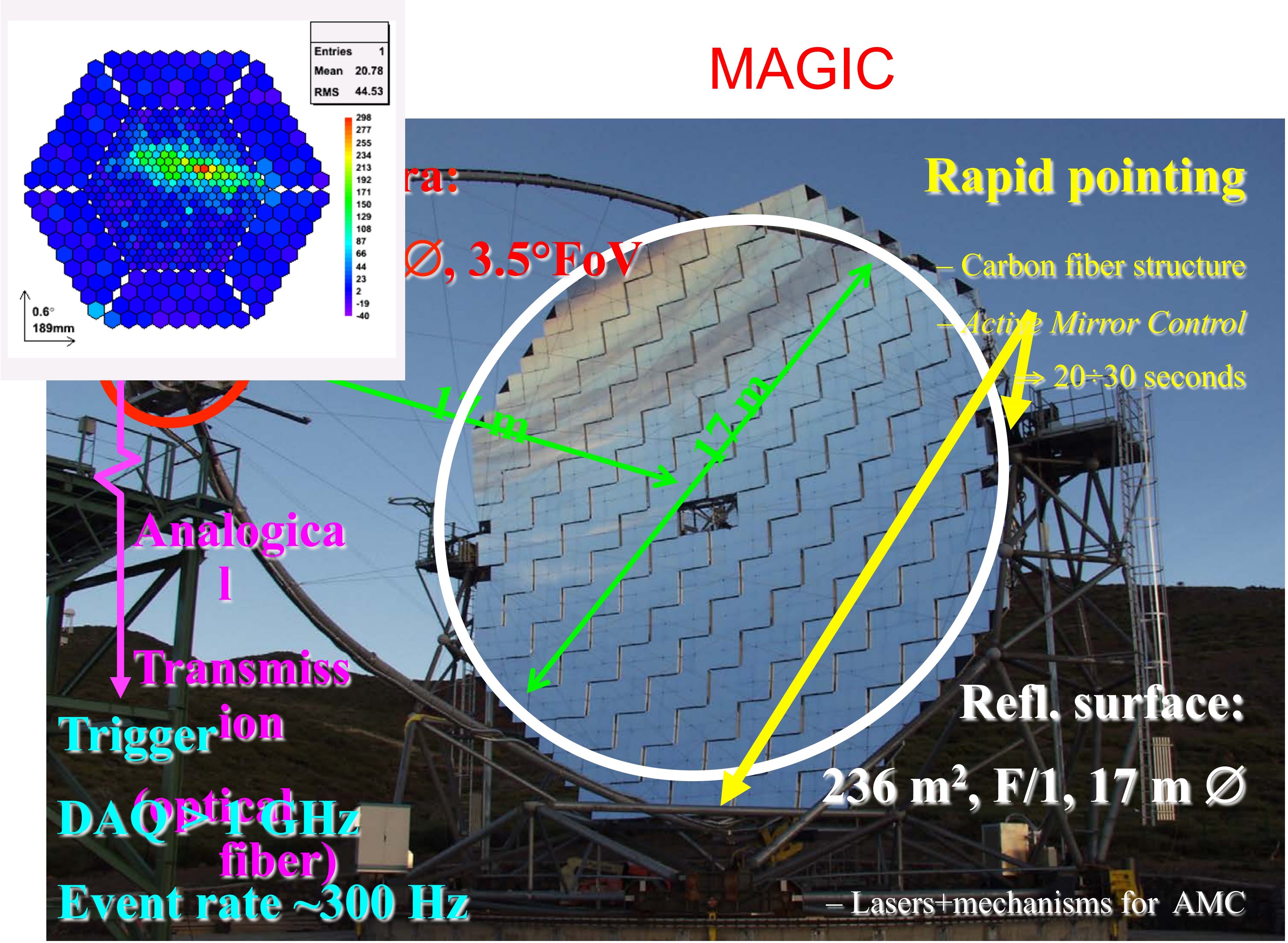
An international collaboration of 160 scientists from institutes in Germany, Italy, Spain, Japan, Switzerland, Finland, Poland, Bulgaria, Croatia

Commissioned as a stereo system since May 2010

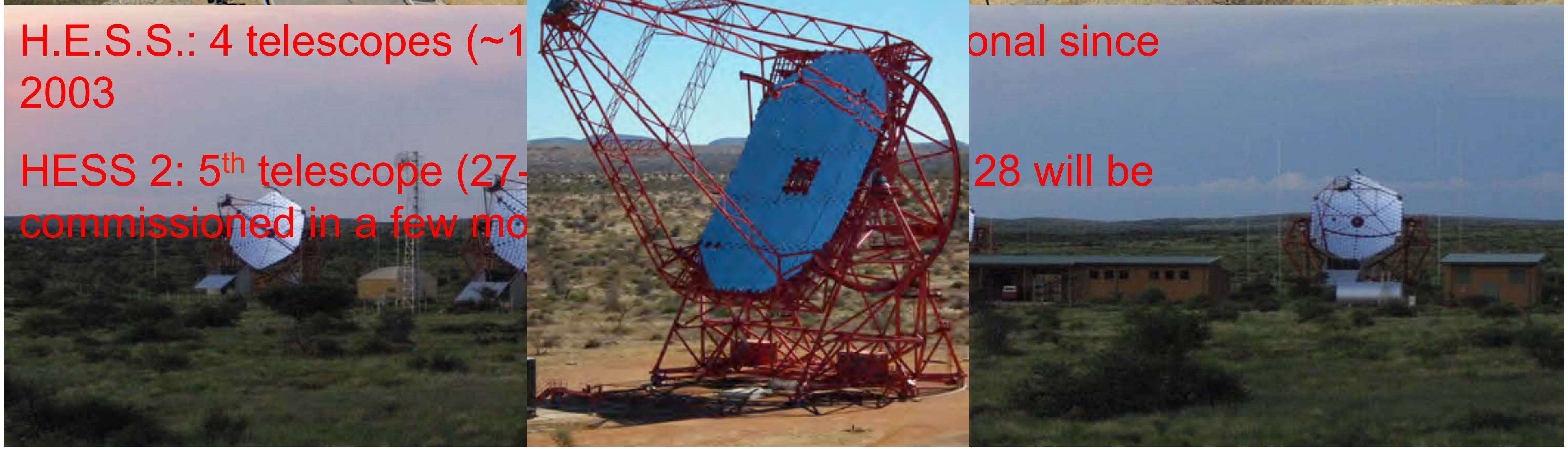
(was mono since 2004)



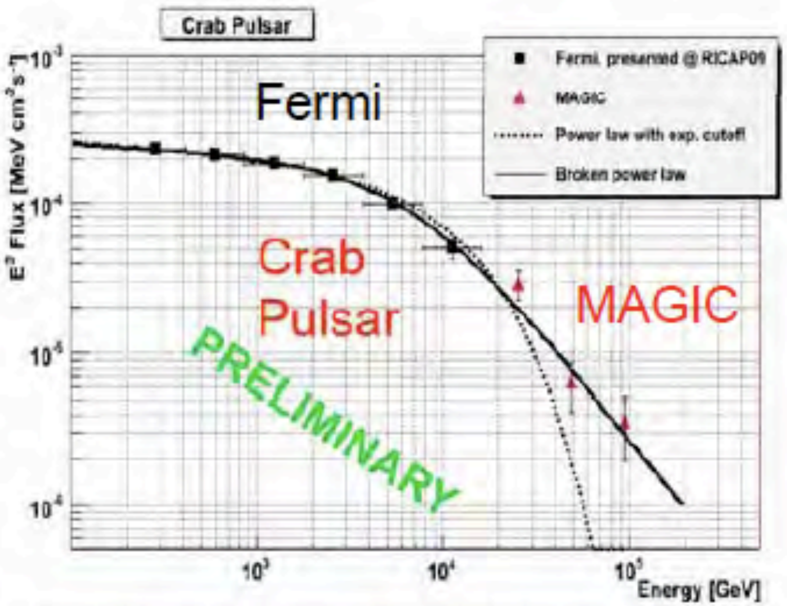
MAGIC

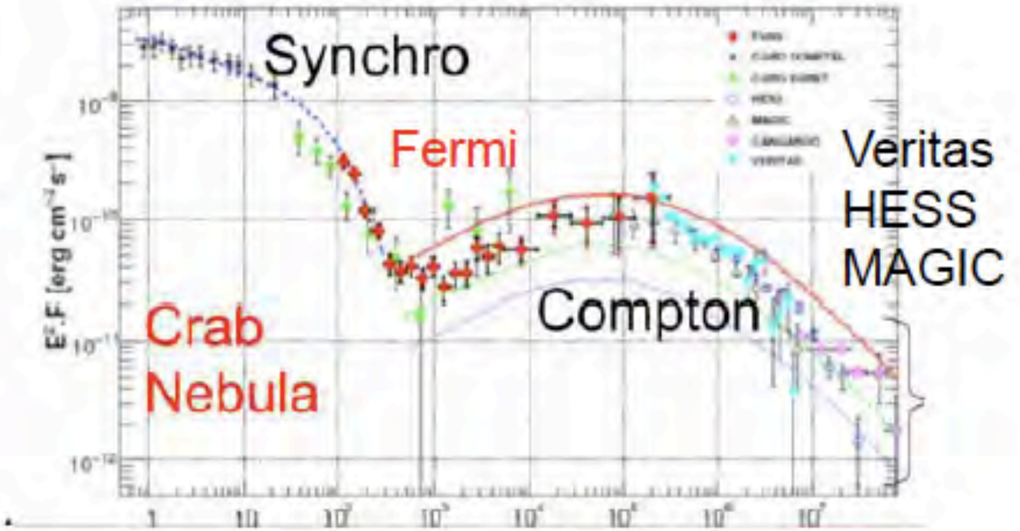

Entries 1
Mean 20.78
RMS 44.53
298
277
255
234
213
192
171
150
129
108
87
66
44
23
2
-19
-40
0.6°
189mm
ra:
∅, 3.5°FoV
17 m
17 m
Rapid pointing
– Carbon fiber structure
– Active Mirror Control
⇒ 20÷30 seconds
Analogical Transmission (optical fiber)
Trigger
DAQ > 1 GHz
Event rate ~300 Hz
Refl. surface:
236 m², F/1, 17 m ∅
– Lasers+mechanisms for AMC

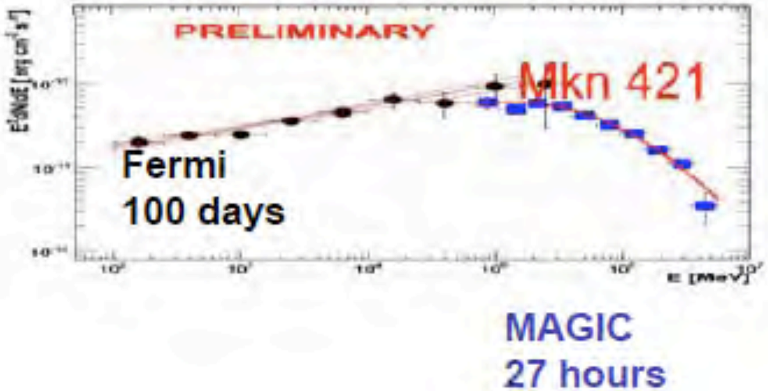
Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7

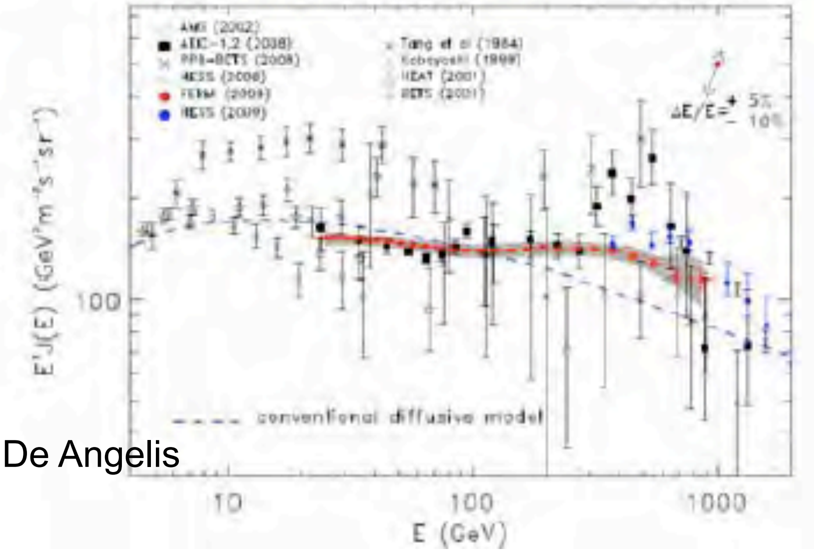


Complementarity IACT/Fermi

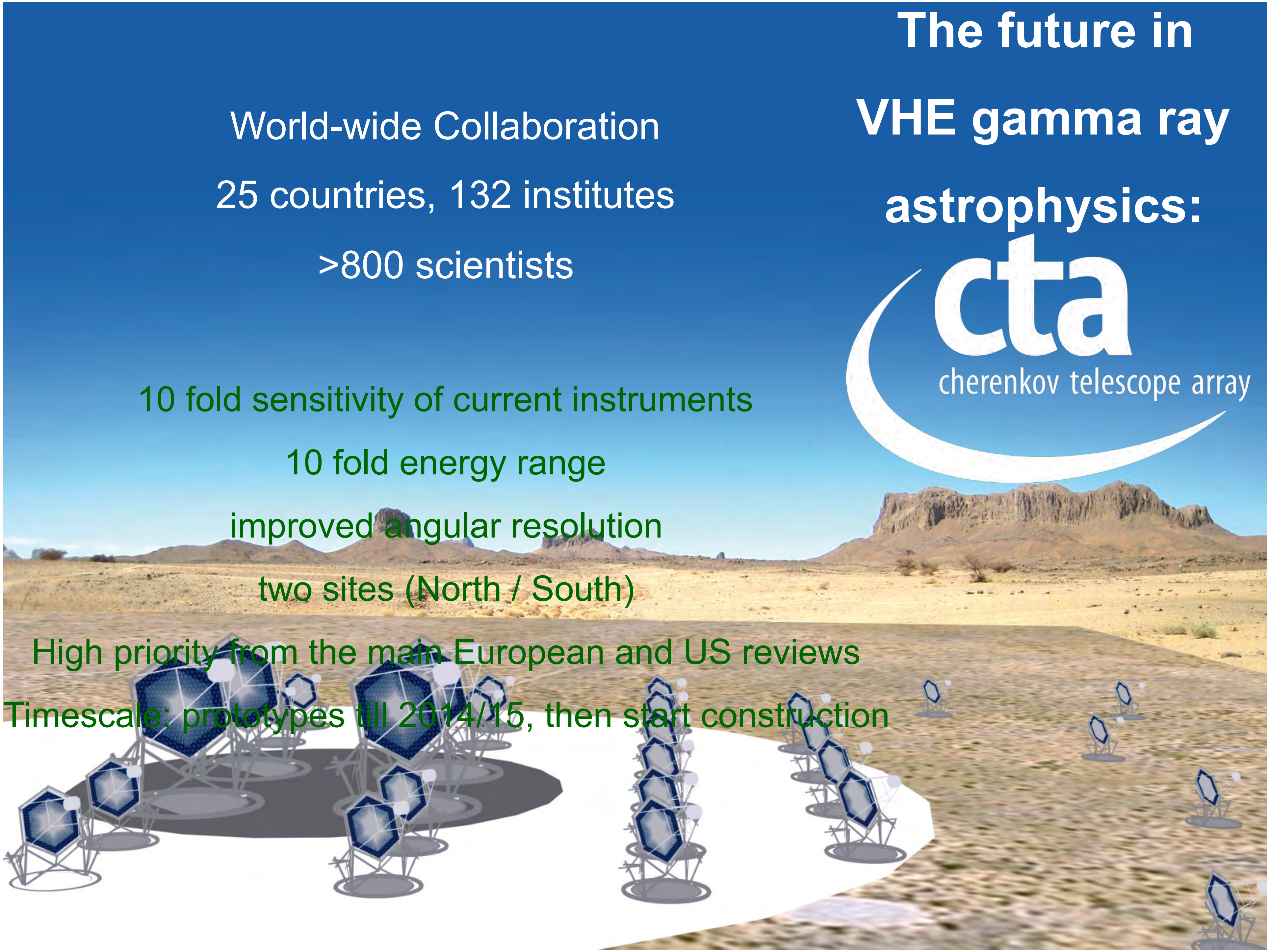


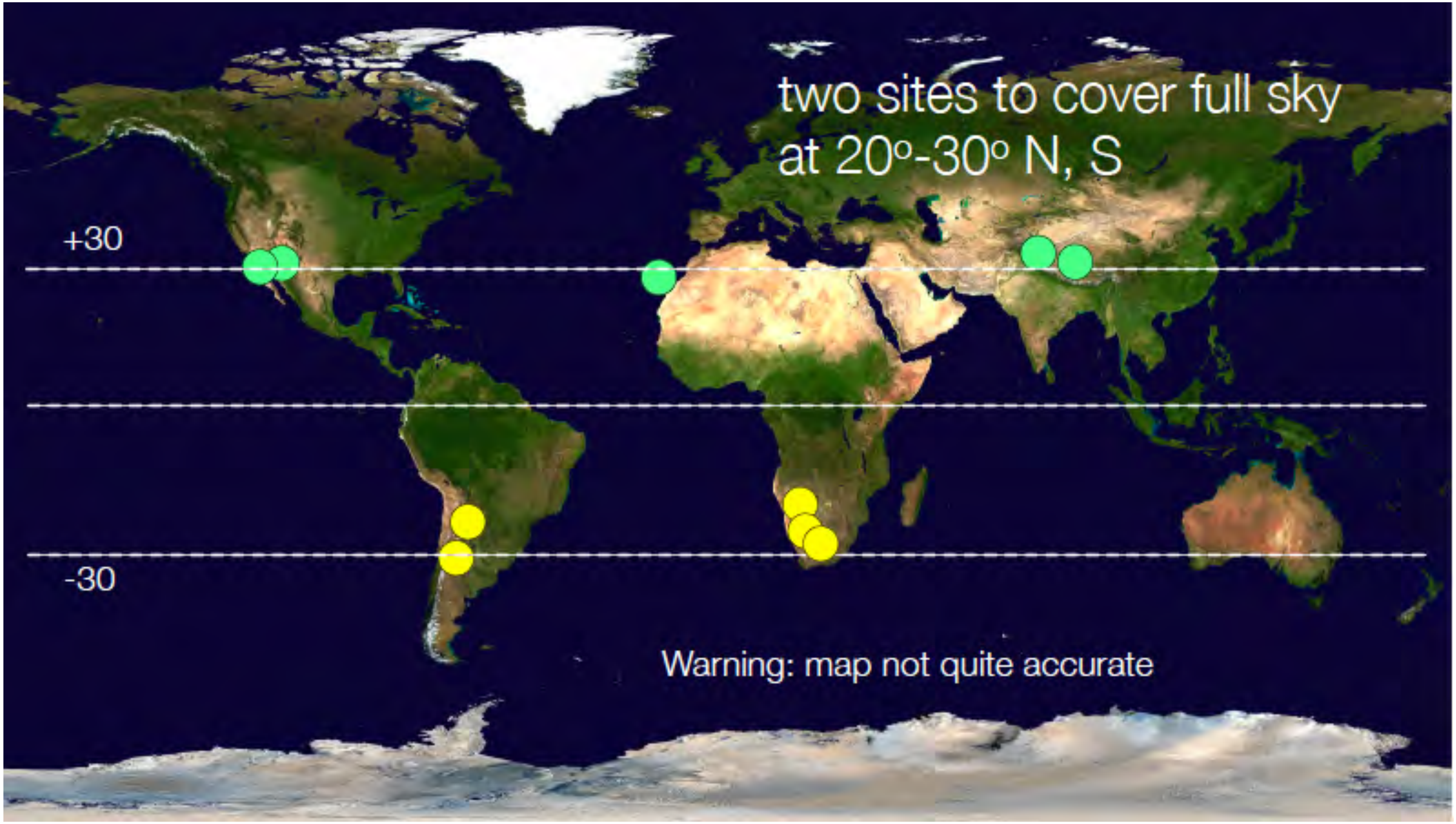


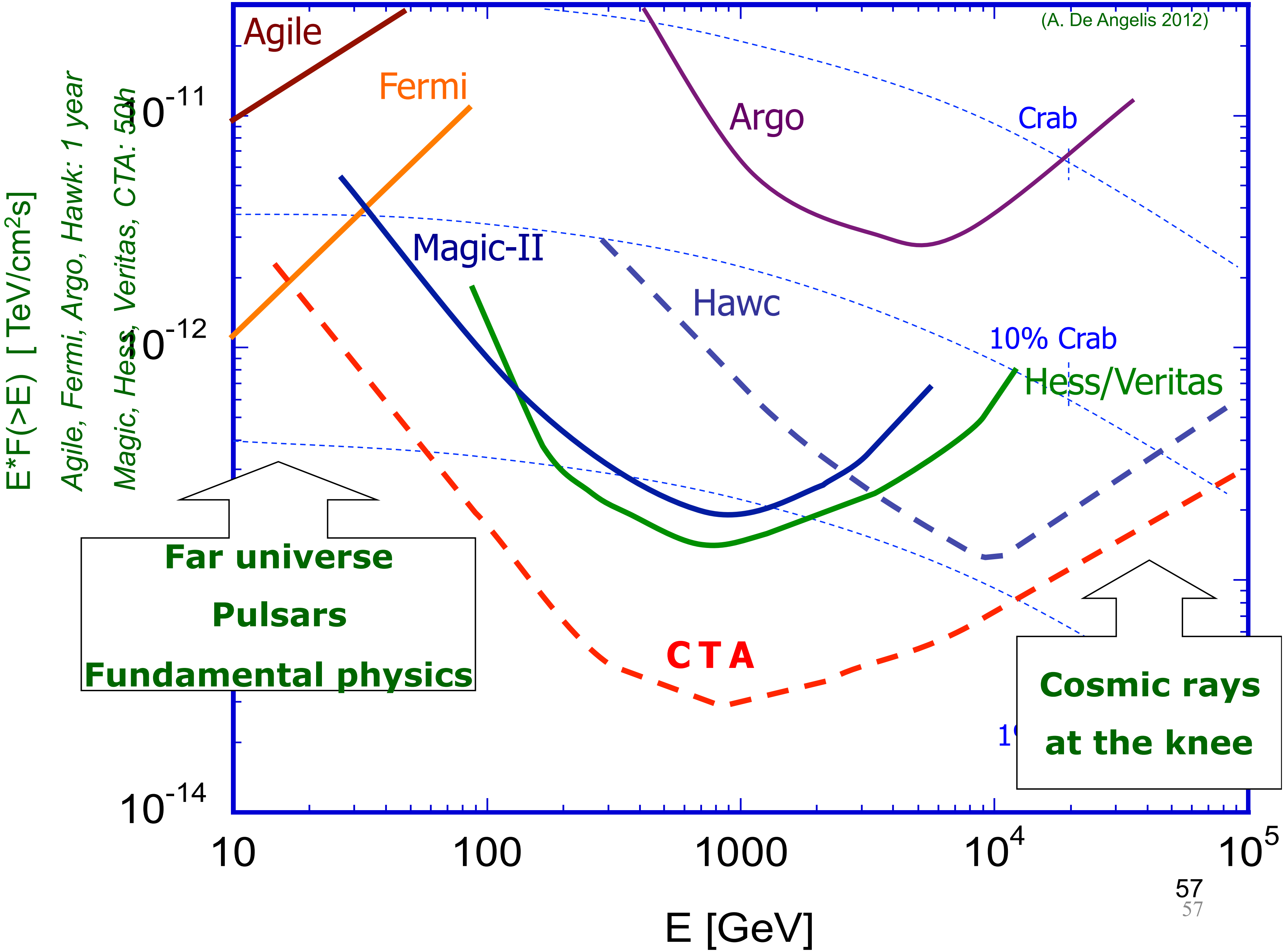




Alessandro De Angelis


The future in
VHE gamma ray
astrophysics:
cta
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)
High priority from the main European and US reviews
Timescale: prototypes till 2014/15, then start construction


two sites to cover full sky
at 20°-30° N, S
+30
-30
Warning: map not quite accurate


(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]

57

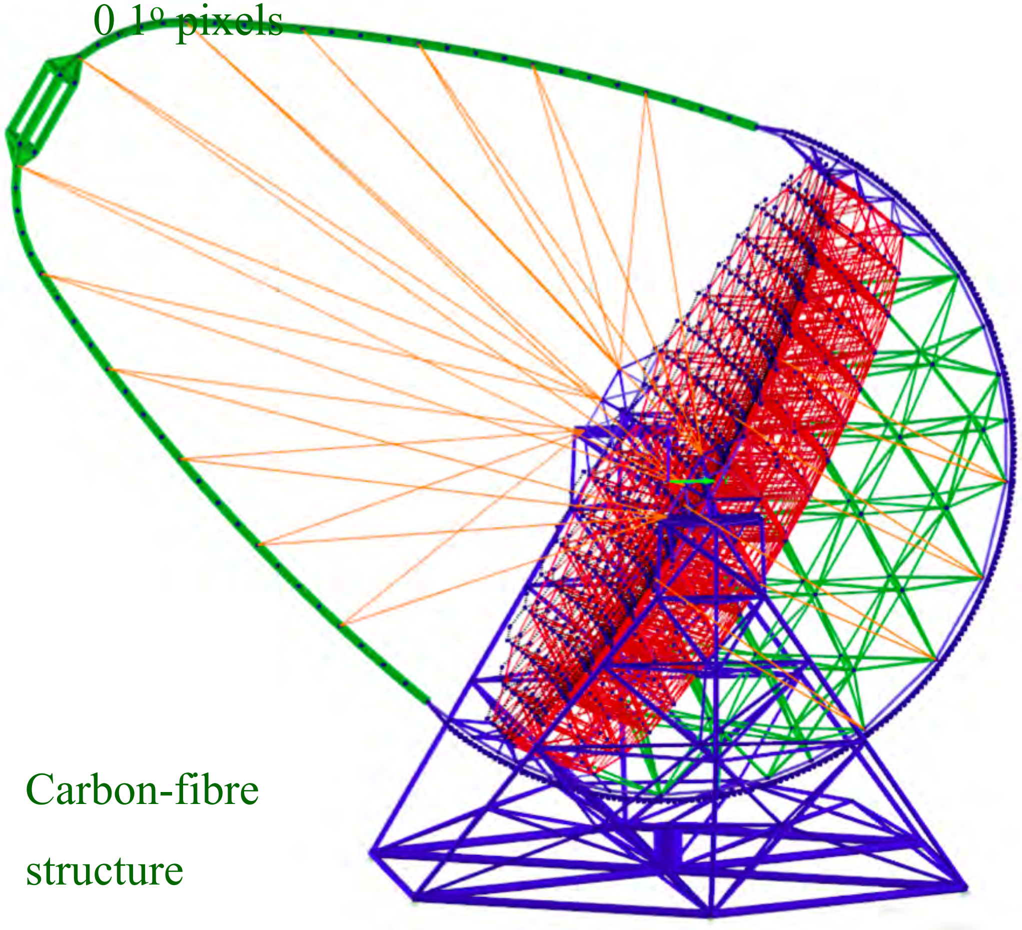
Design: 23 m Large Telescopes

optimized for the range below 200 GeV

27.8 m focal length

4.5° field of view

0.1° pixels

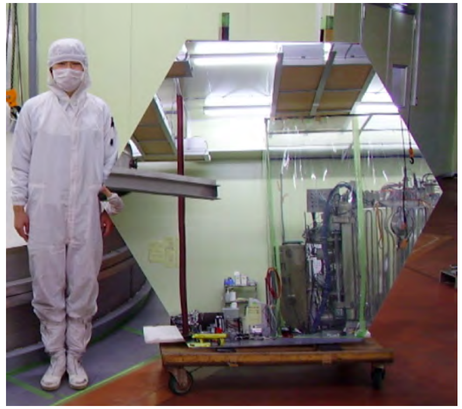


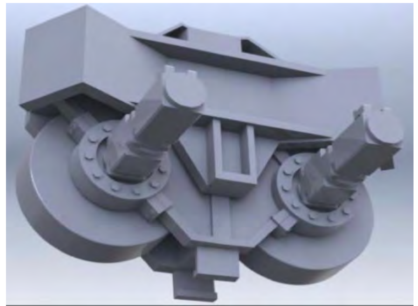
Carbon-fibre structure

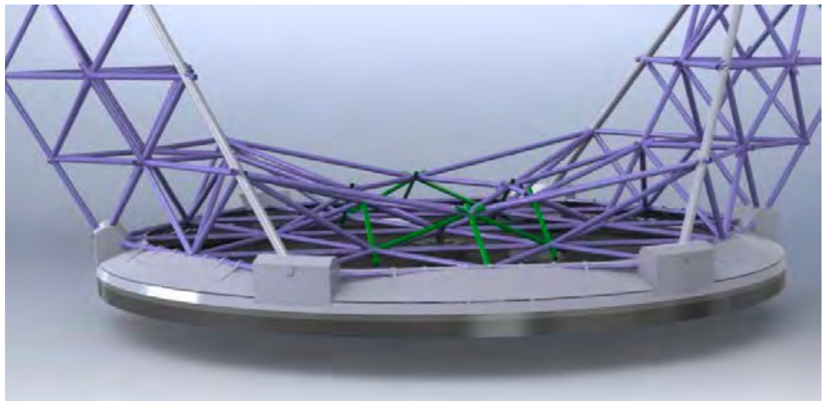
400 m^2 dish area

1.5 m sandwich mirror facets

On (GRB) target in < 20 s



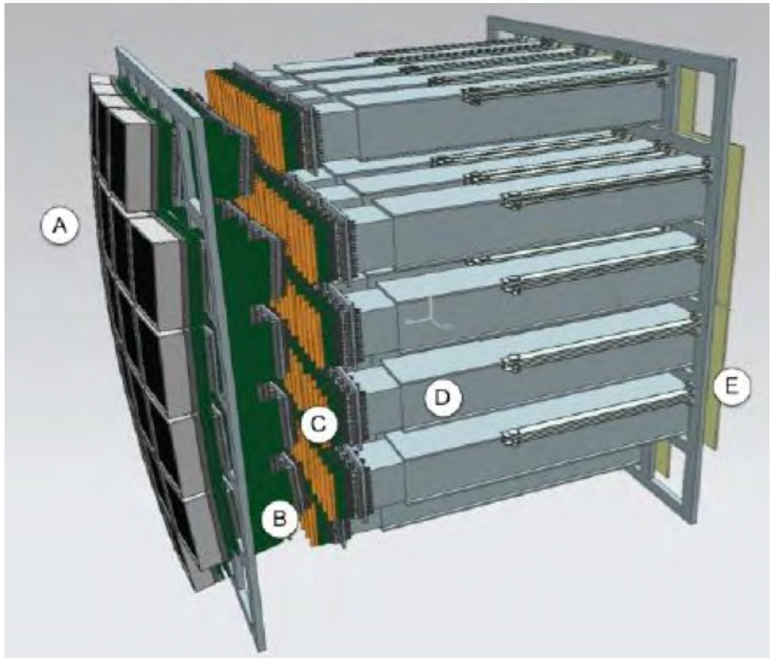




Design: Small 4-6 m Telescopes

cover the range above few TeV across 10 km^2

Multi-Anode PMT camera option



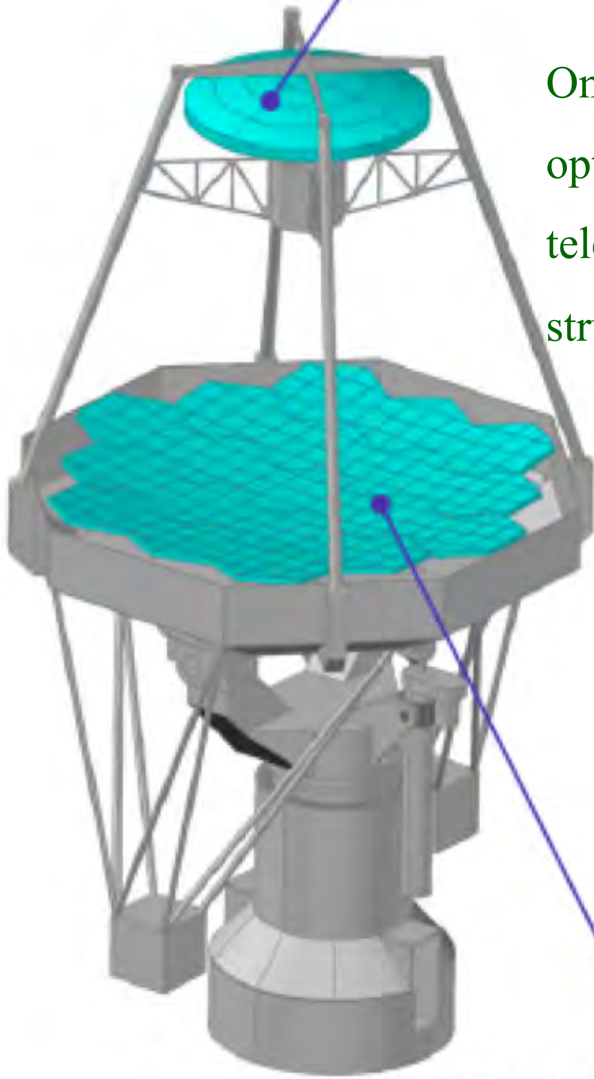
Under study:

dual-mirror optics with compact photo sensor arrays

single-mirror optics

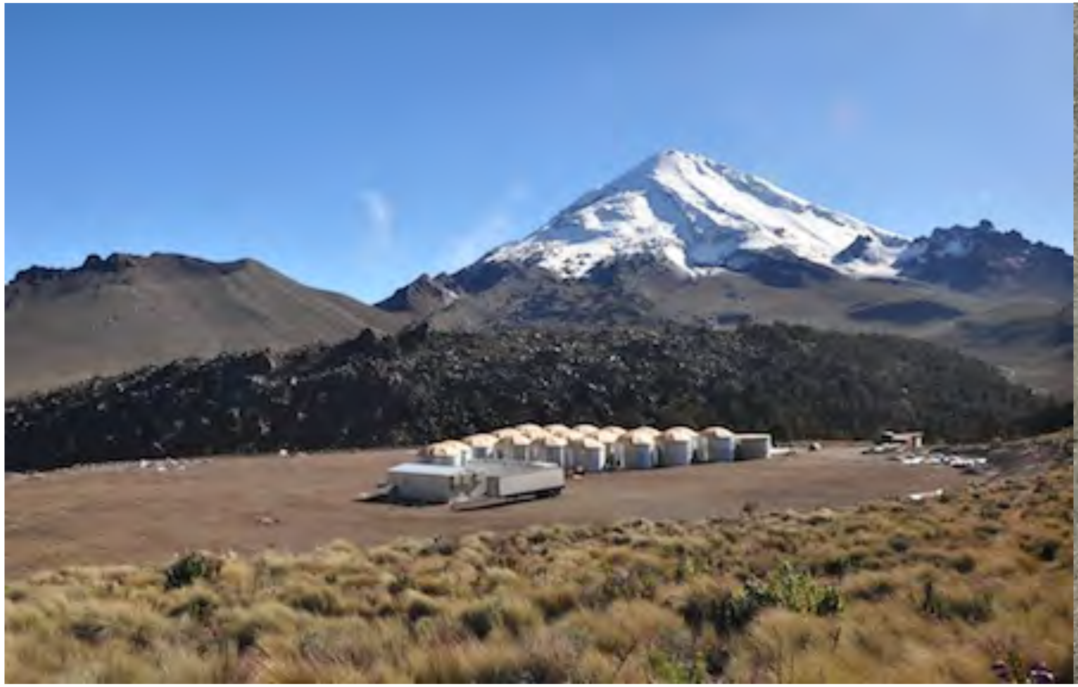
PMT-based and silicon-based sensors

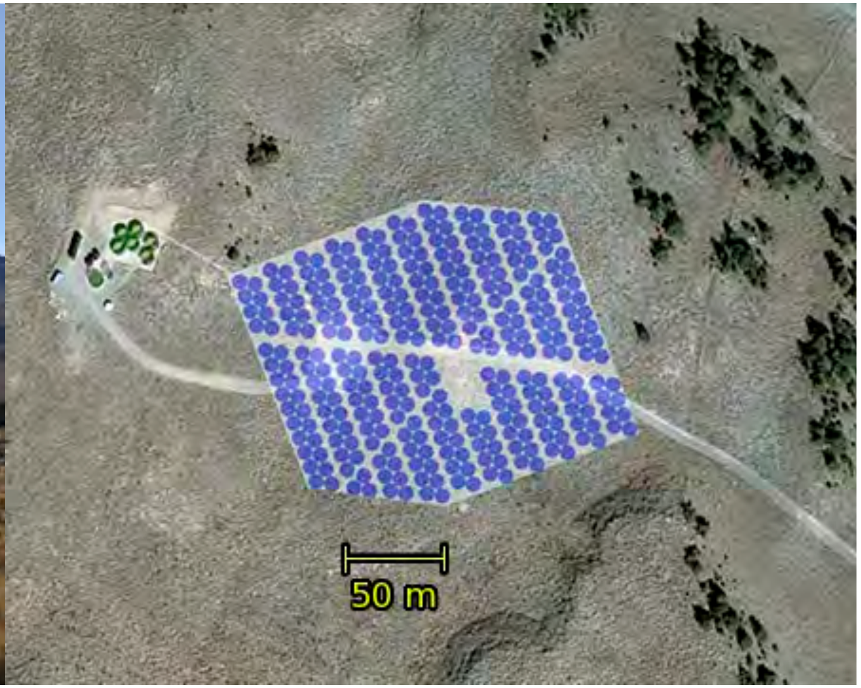
➜ Not yet conclusive which solution is most cost-effective



Future in EAS detectors: HAWC

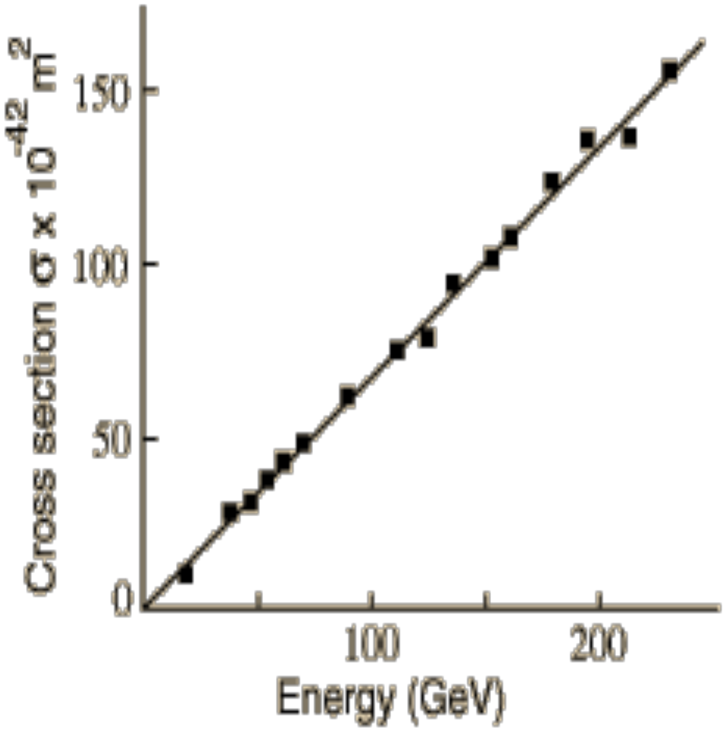
- EAS detectors have advantages on Cherenkov: duty cycle, serendipitous searches
- But the EAS up to now (Argo, Milagro, Tibet) were not sensitive enough
- The High-Altitude Water Cherenkov Observatory, or HAWC, is a facility designed to observe TeV gamma rays and cosmic rays with large FOV, with sensitivity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





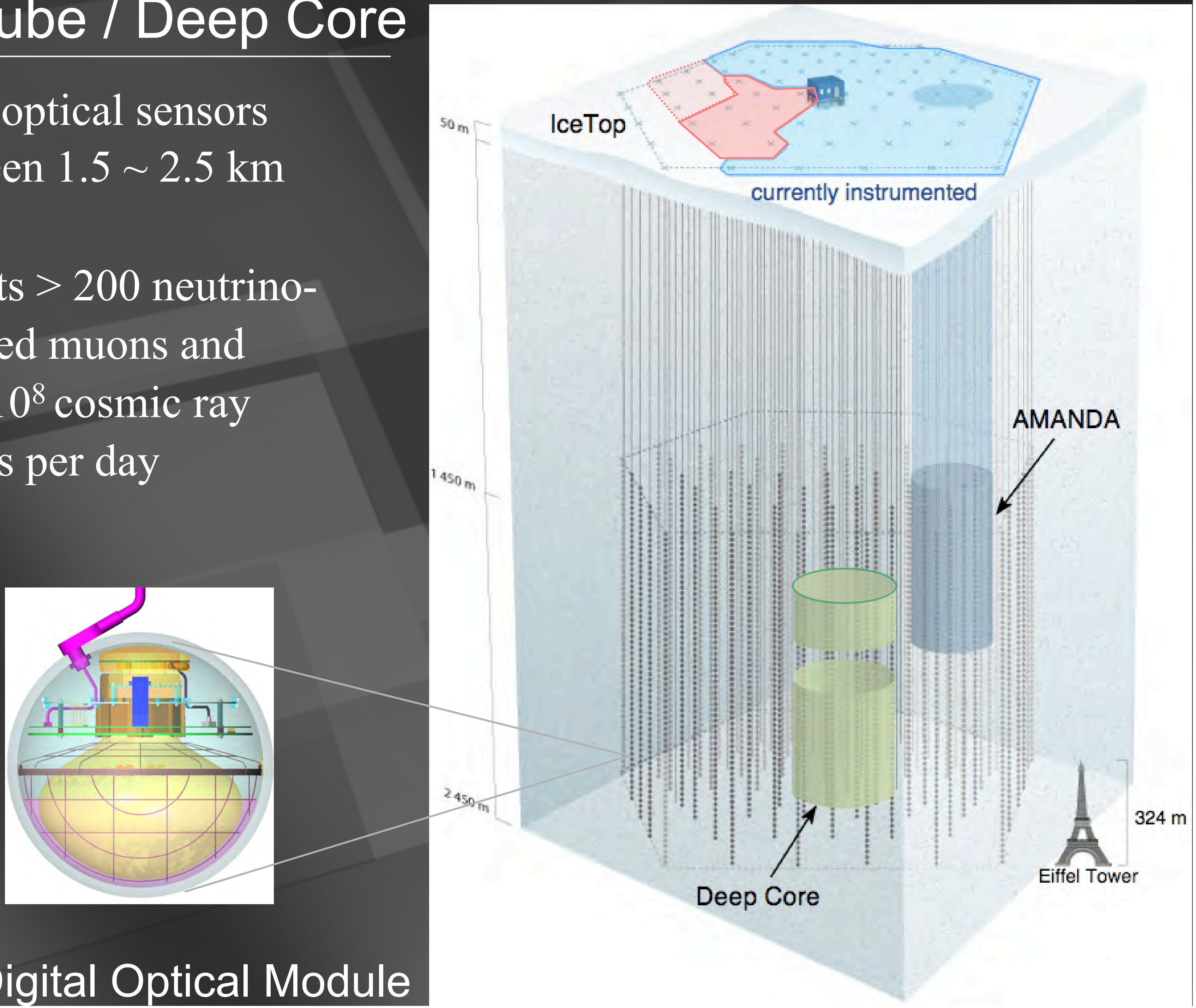
Neutrino detection

- Since cross section is small, needs large converters (and large detection volumes)
  - Use the Earth as converter
  - Make Cherenkov detectors using as fluids the sea and the Antarctica ices



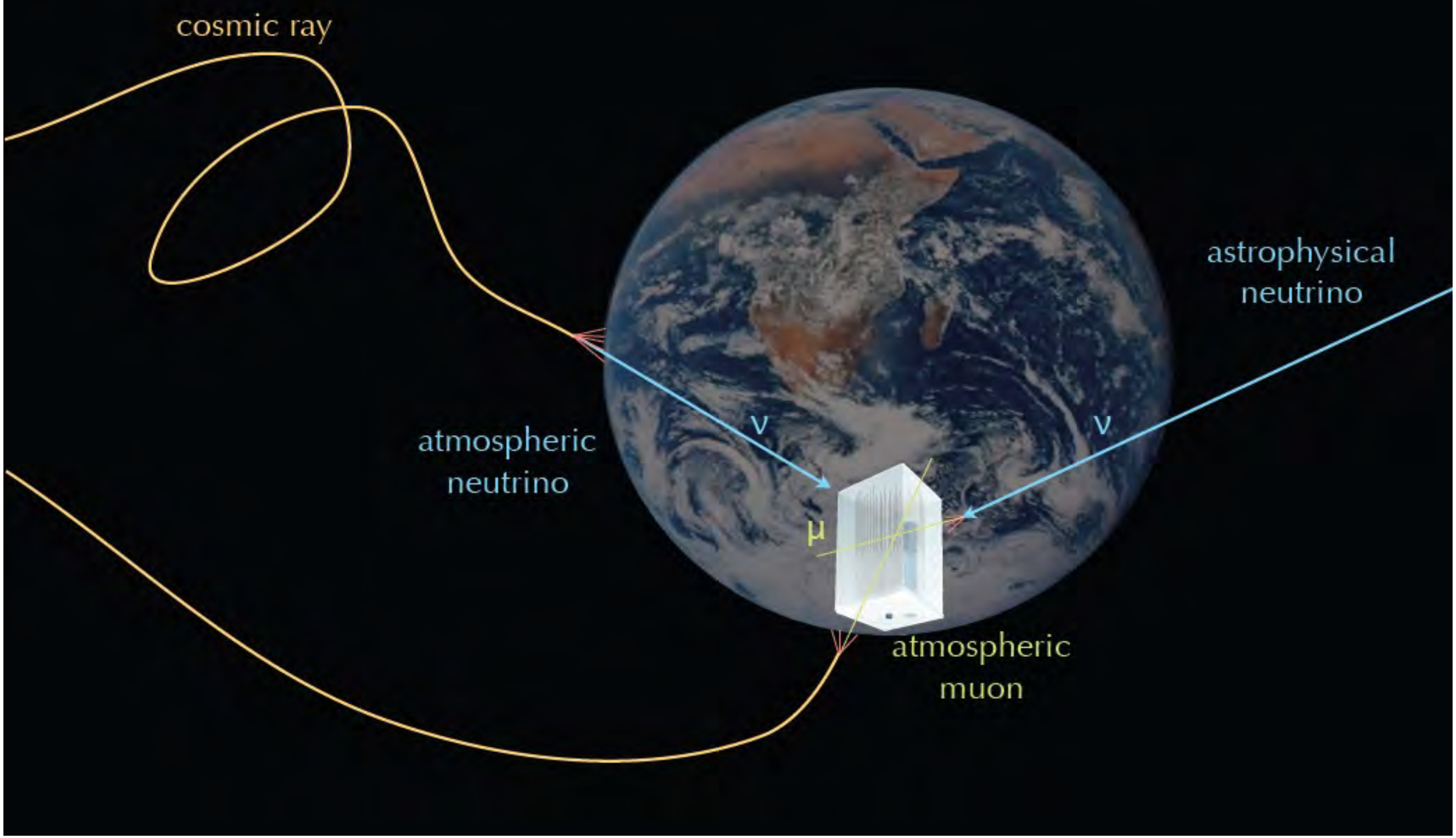
IceCube / Deep Core

- 5160 optical sensors between 1.5 ~ 2.5 km
- detects > 200 neutrino-induced muons and ~ 2 x10^8 cosmic ray muons per day

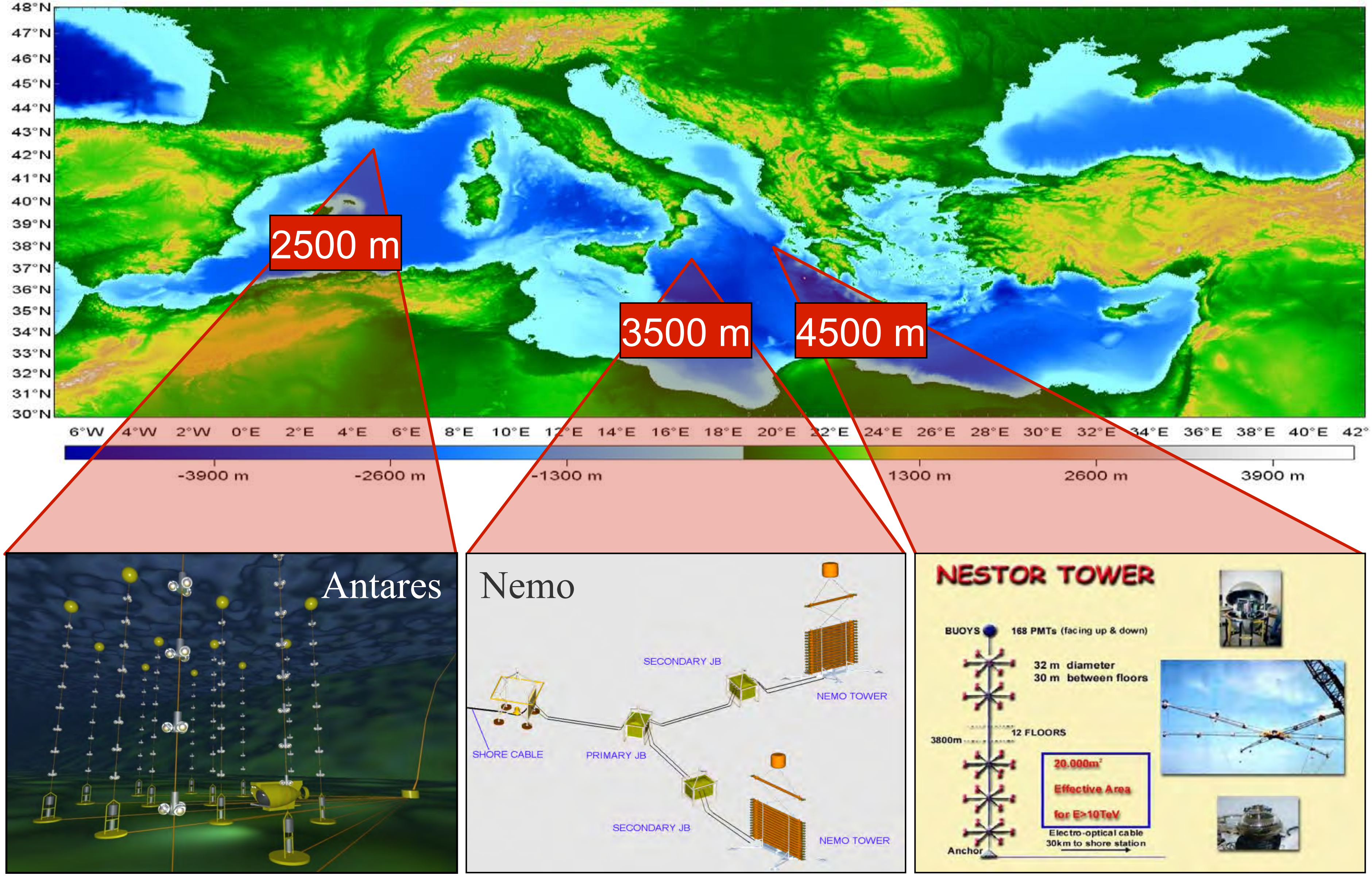


DOM-Digital Optical Module

Signals and Backgrounds



Three Mediterranean Pilot Projects



OPEN QUESTIONS

Main open problems on VHE photons
(with emphasis on fundamental physics)

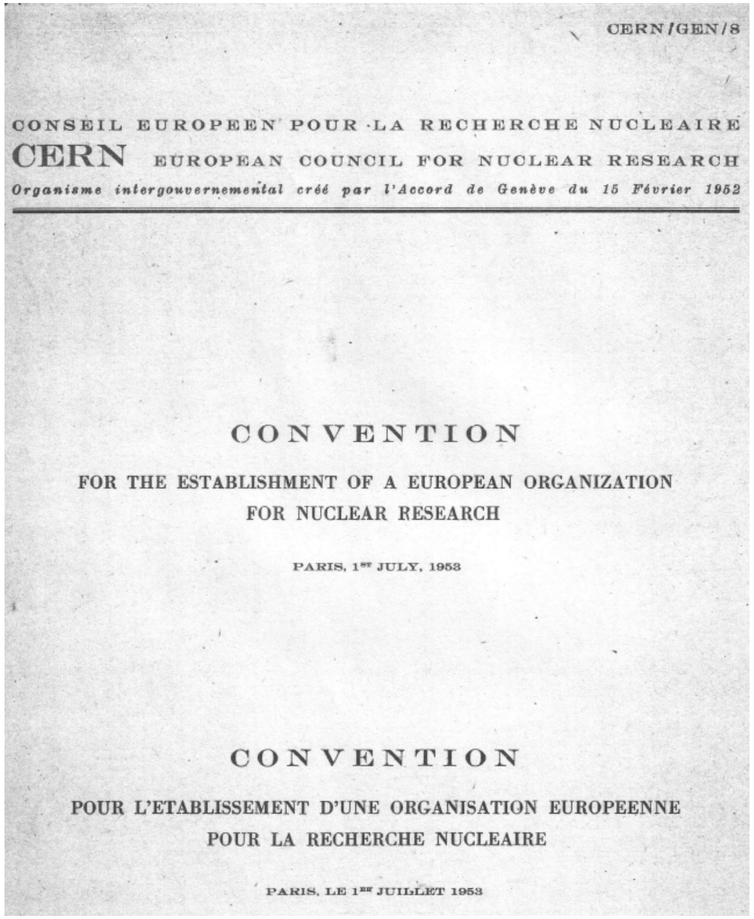
- Cosmic Rays

- Transparency of the Universe;

  Tests of Lorentz Invariance;

  Axion-Like Particles

Dark matter & new particles


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

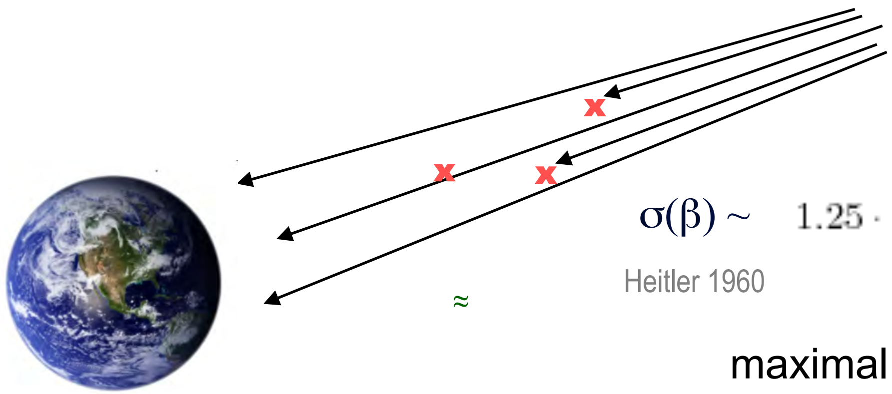
PARIS, LE 1ER JUILLET 1953

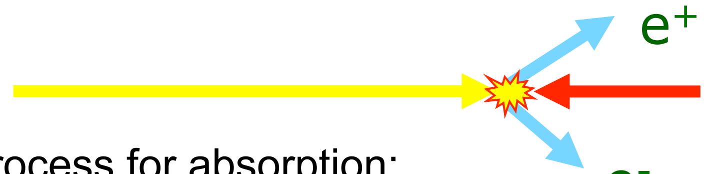
Questions on Cosmic Rays

- CR at 100 TeV x 10 come from SNR; still >1 decade from the knee…
- Are the other galactic sources of gamma rays important for the formation of CR?
  - Binaries accreting galactic BH
  - …
  - Pulsars and electron-positron pairs
- How are CR accelerated in AGN?
- Are they accelerated also in GRB?

(Need improvement of energy range, PSF, stat)

Propagation of γ-rays





dominant process for absorption:

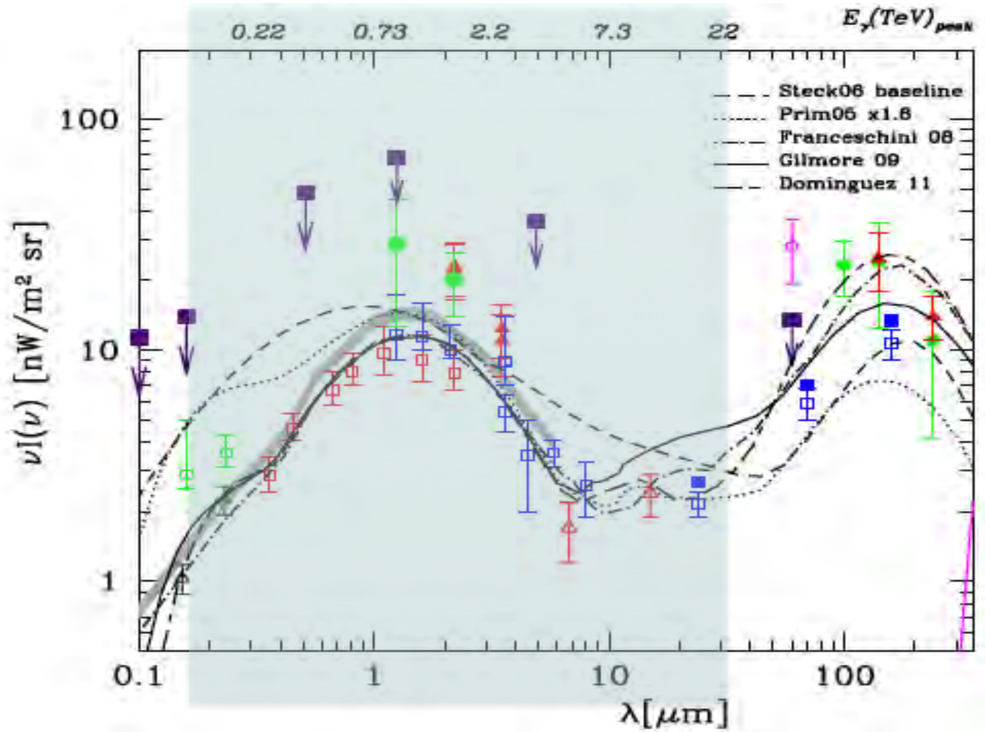
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

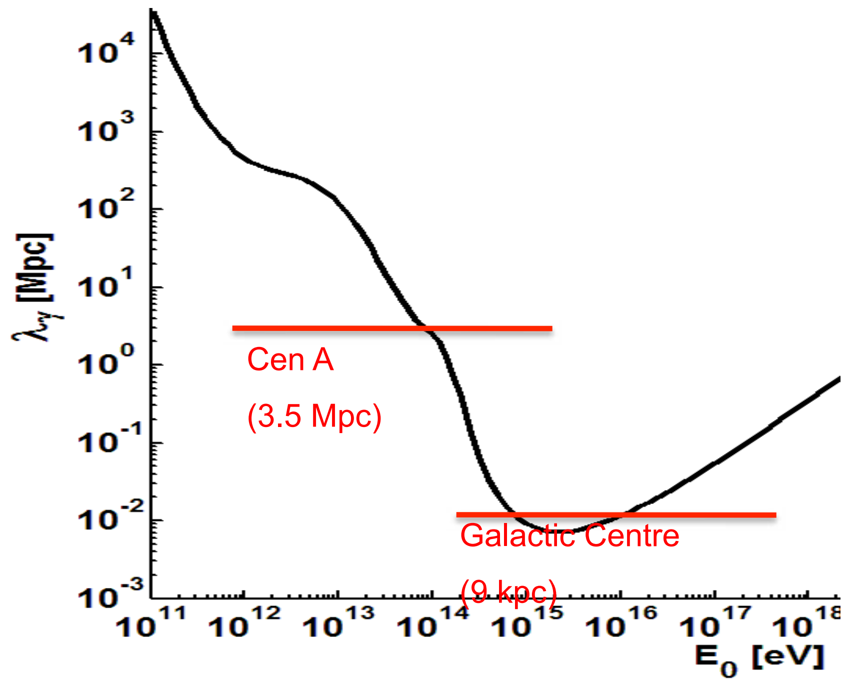
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

Heitler 1960

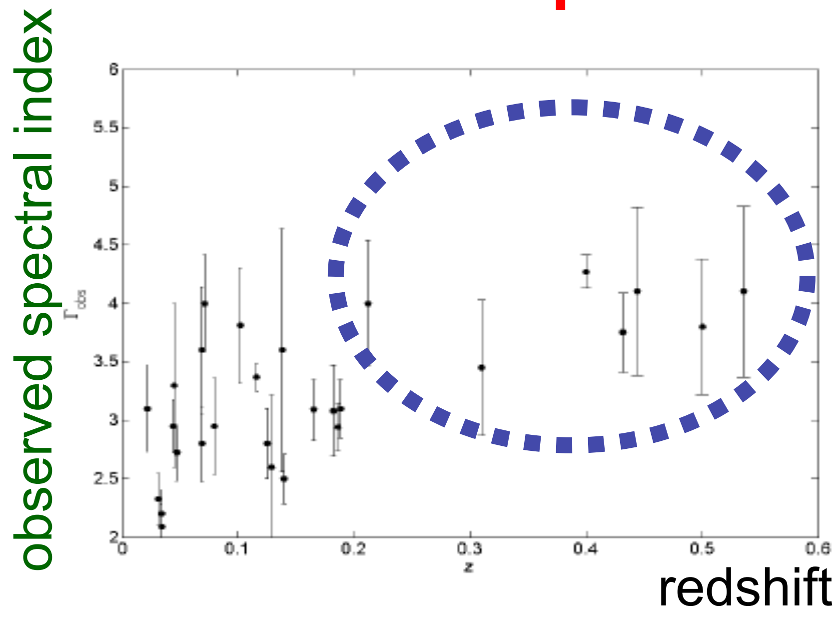
maximal for: $$\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\ \mathrm{GeV}}{E}\right)\mathrm{eV}$$

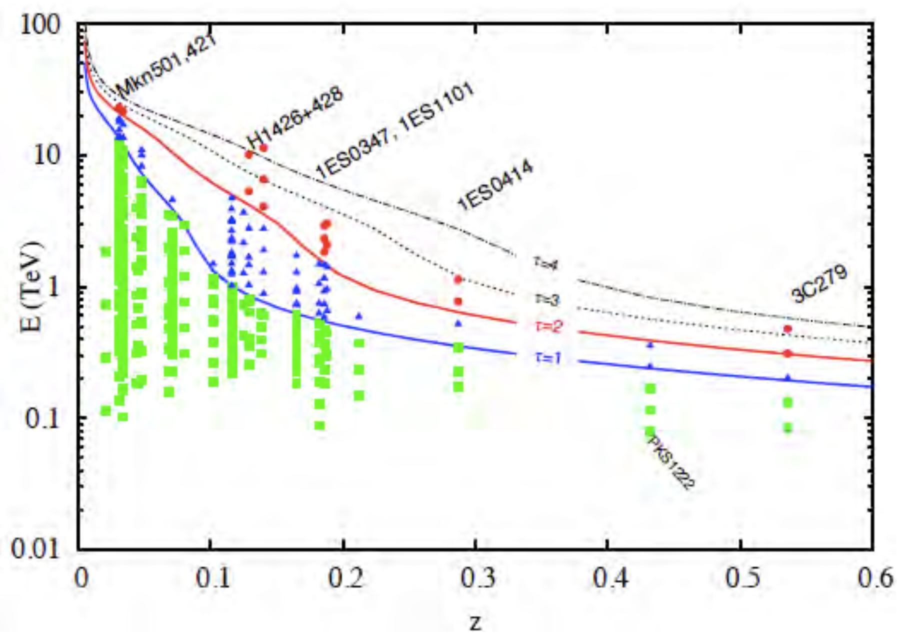
- For gamma rays, relevant background component is optical/infrared (EBL)
- different models for EBL: minimum density given by cosmology/star formation





If there is a problem





Explanations from the standard ones

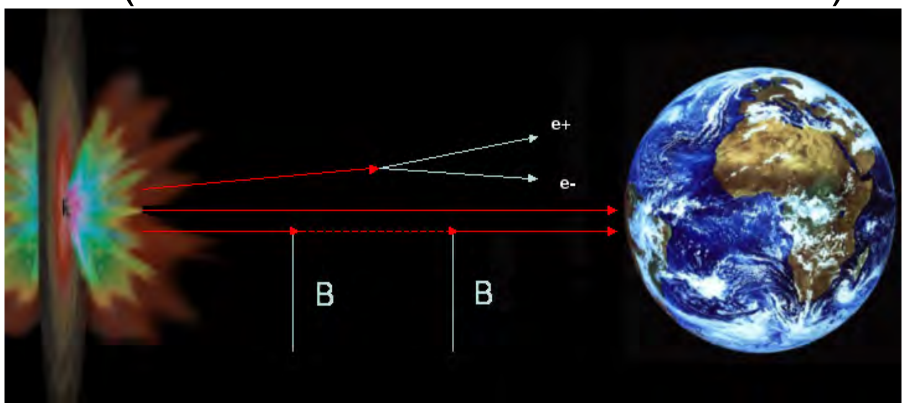
- very hard emission mechanisms with intrinsic slope < 1.5 (Stecker 2008)
- Very low EBL, plus observational bias, plus a couple of "wrong" outliers

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)



Moving to very fancy explanations of unexpected results on the transparency of the Universe

- Emission models are more complicated than we think (but only for sources far away: nearby sources behave well)
- VHE photons are generated on the way (interaction of cosmic rays, neutrinos and photons with intergalactic medium: Sigl, Essey, Kusenko, …)
- Something is wrong in the $\gamma\gamma$ -> e+e- rate calculation
  - Vacuum energy (new sterile particles coupling to the photons): DARMA, …
    - For example an ALP: consistent values for m, g=(1/M) in a range not experimentally excluded ("Se non e' vero e' ben pensato")
  - $\gamma\gamma$ -> e+e- cross section

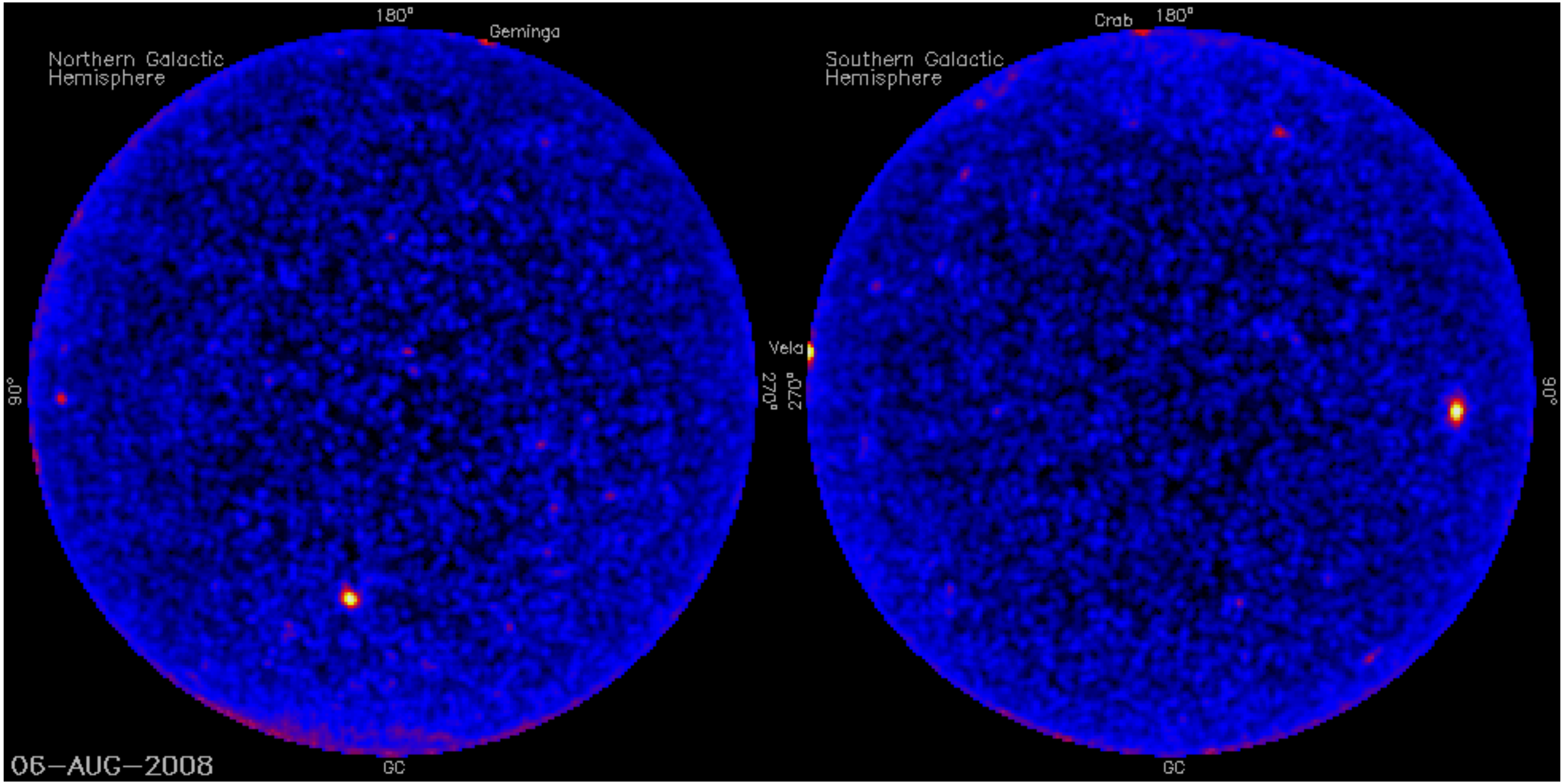
    QED calculations appears to be in a safe region; then it must be
    - the boost (Lorentz transformations; relativity)

Is Lorentz invariance exact?
Due to large E, d astroparticles are a crash test

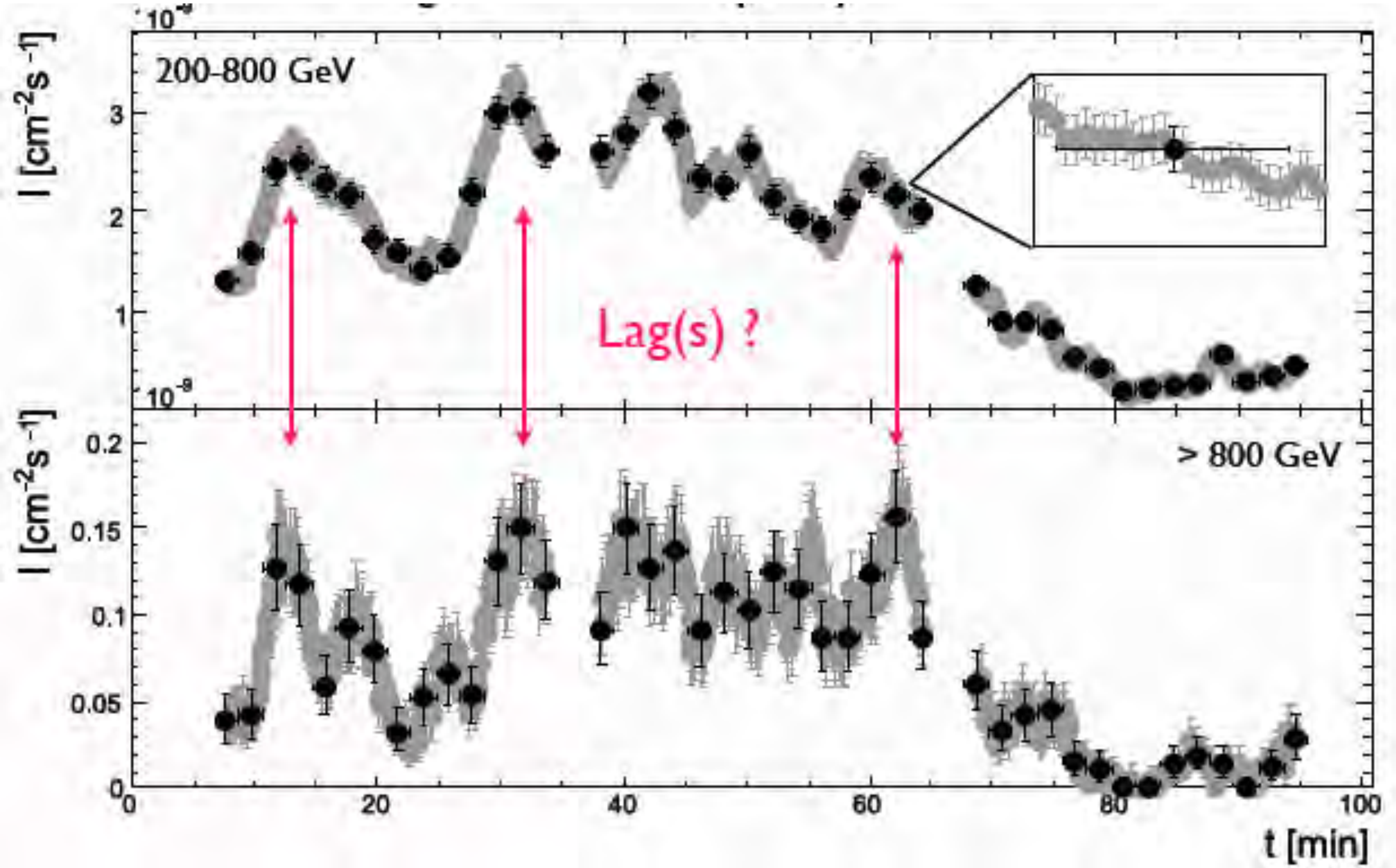
- For longtime violating Lorentz invariance/Lorentz transformations/Einstein relativity was a heresy
  - Is there an aether? (Dirac 1951)
  - Many preprints, often unpublished (=refused) in the '90s
    - Gonzales-Mestres, ADA, Jacobson, …

- Then the discussion was open
  - Trans-GZK events? (AGASA collaboration 1997-8)
  - LIV => high energy threshold phenomena: photon decay, vacuum Cherenkov, GZK cutoff (Coleman & Glashow 1997-8)
  - GRB and photon dispersion (Amelino-Camelia et al. 1997)
  - Framework for the violation (Colladay & Kostelecky 1998)
  - LIV and gamma-ray horizon (Kifune 1999)
  - …

Variability



Tests of Lorentz violation: the name of the game

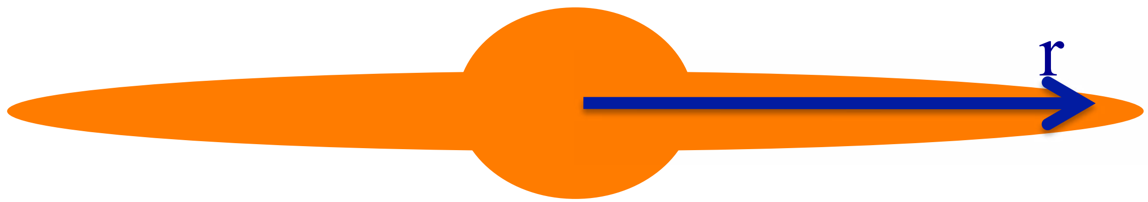


No signal uo to now, ~Mp

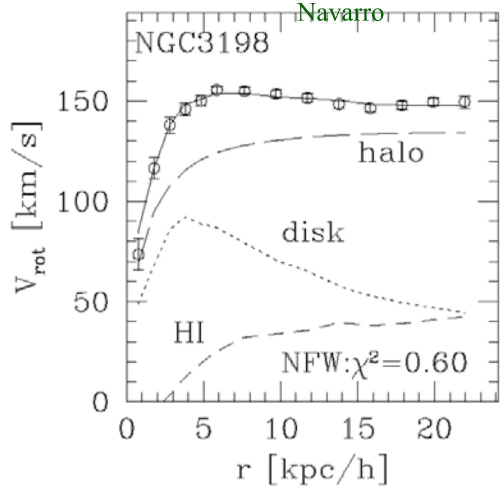
HESS, PKS 2155

The Dark Matter Problem

Measure rotation curves for galaxies:



Begelman/
Navarro

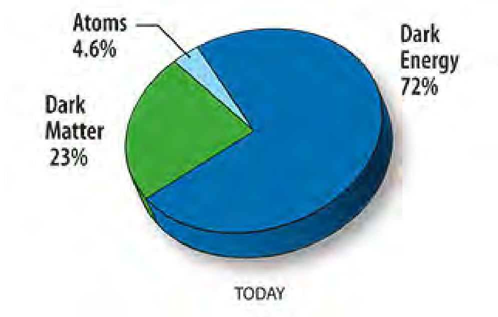


For large r, we expect:

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

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?

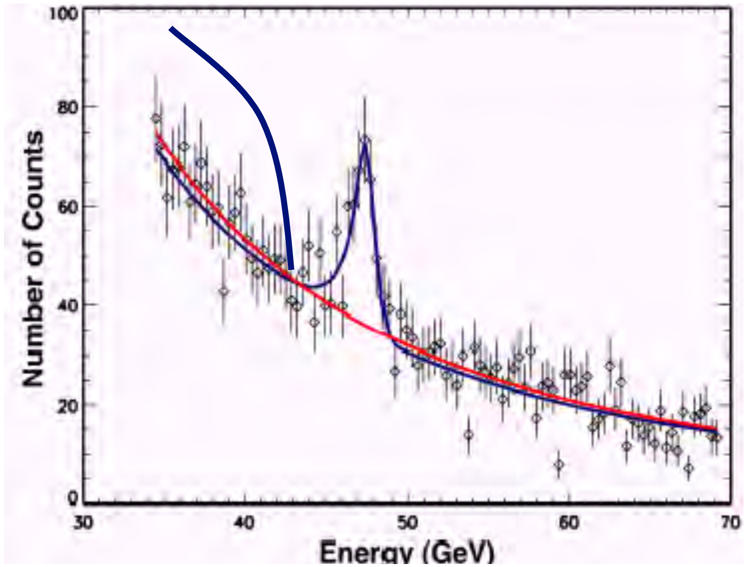
- Self-annihilating WIMPs, if Majorana (as the neutralino in SUSY), can produce:
  - Photon lines (γγ, γZ)
  - Photon excess at E < m from hadronization
- Excess of antimatter (annihilation/decay)
- Excess of electrons, if unstable

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

from particle physics

from astrophysics

Look to the closest point with M <<L



Alessandro De Angelis

Many Places to Seek DM!

Galactic Center

Good statistics but source confusion/diffuse background

Satellites

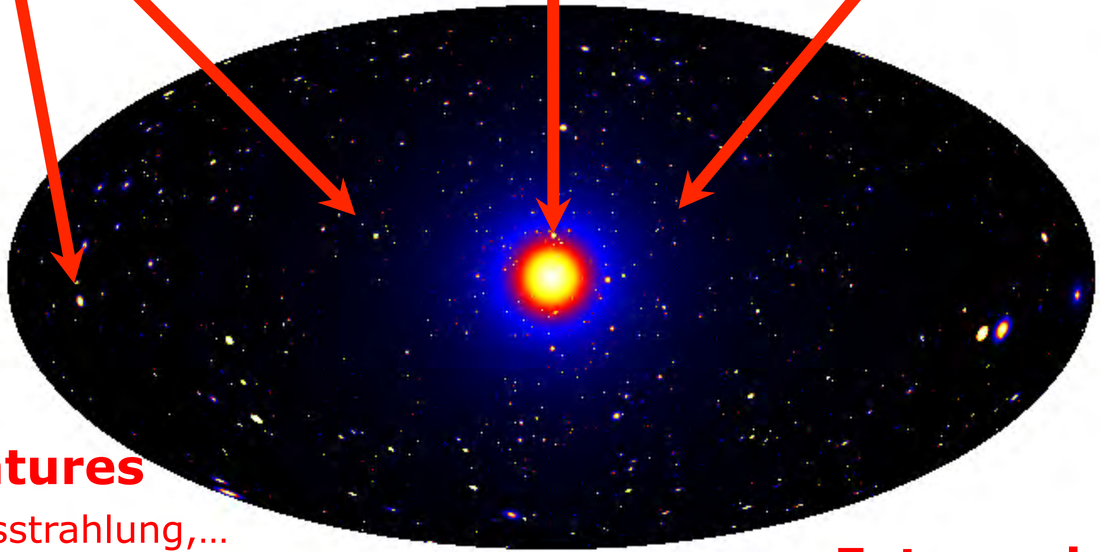
Low background and good source id, but low statistics, astrophysical background

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,...

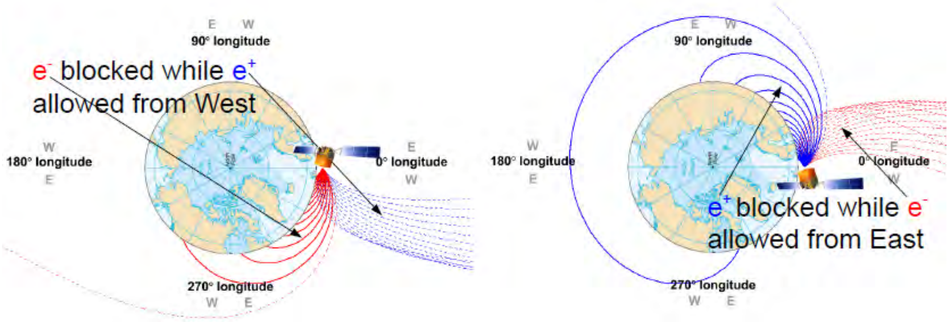
No astrophysical uncertainties, good source Id, but low sensitivity because of expected small BR

Extra-galactic

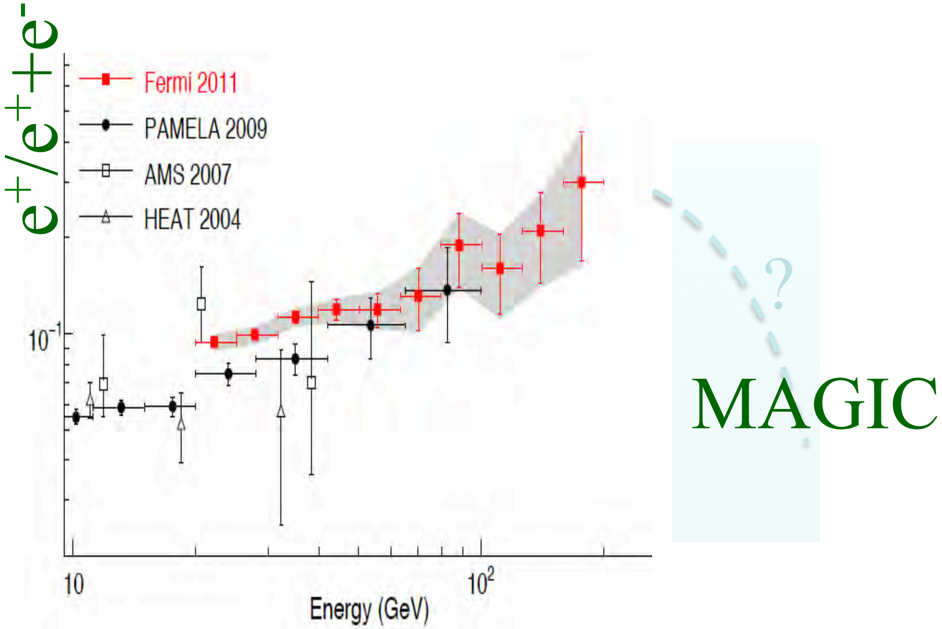
Large statistics, but astrophysics, galactic diffuse backgrounds

No signal from possibly expected sources, yet

Cosmic rays: the PAMELA anomaly



Unexpected increase in e^+/e^- ratio (PAMELA) confirmed by Fermi

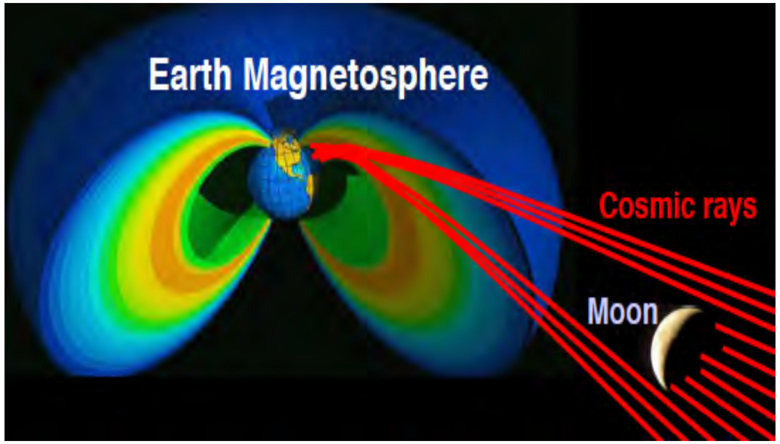


Moon shadow observation mode developed for the MAGIC telescopes [MAGIC ICRC 2011]

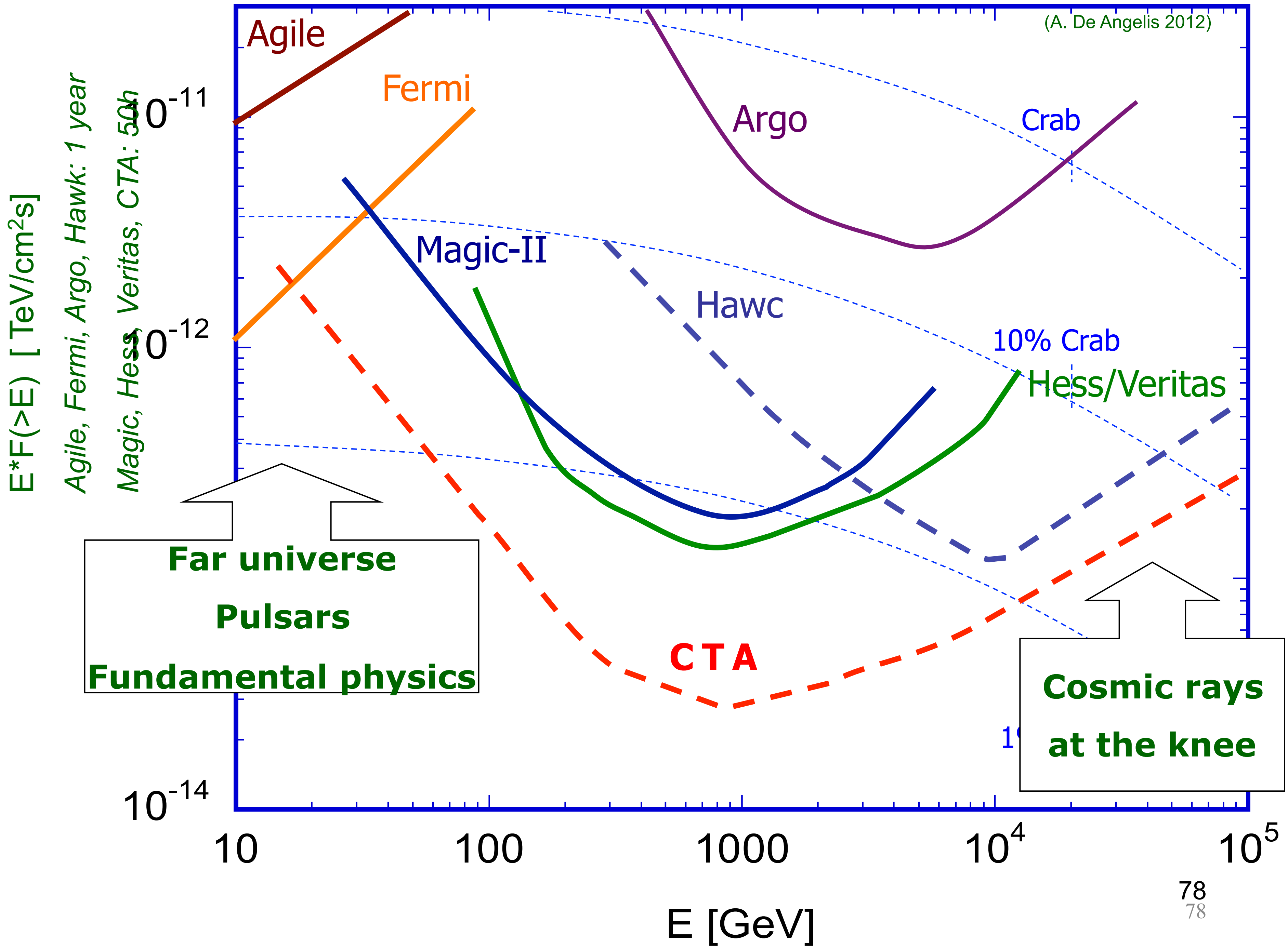
sensitivity (50h): 300-700GeV: ~4.4% Crab

measurement possible in few years

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



Alessandro De Angelis



(A. De Angelis 2012)
Agile
Fermi
Argo
Crab
Magic-II
Hawc
10% Crab
Hess/Veritas
CTA
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]
Far universe
Pulsars
Fundamental physics
Cosmic rays
at the knee

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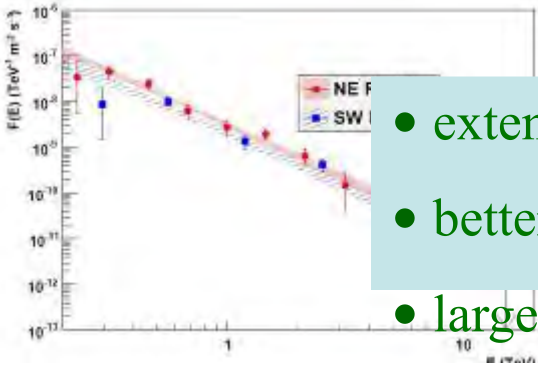
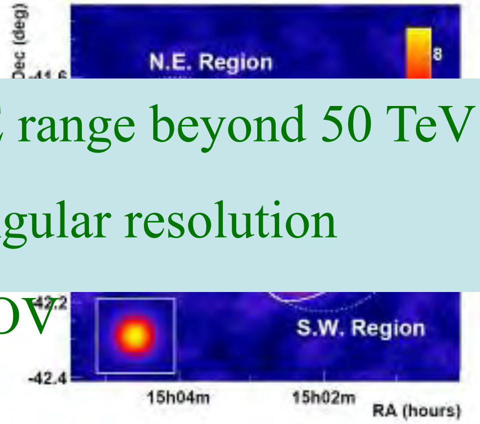
A wish list for the future

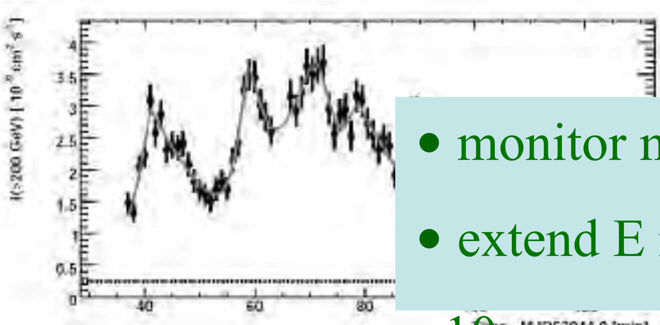
- Galactic sources & CR





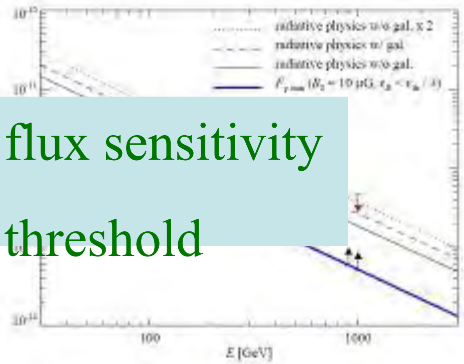
- extend E range beyond 50 TeV
- better angular resolution
- larger FOV

- AGN & gamma prop.

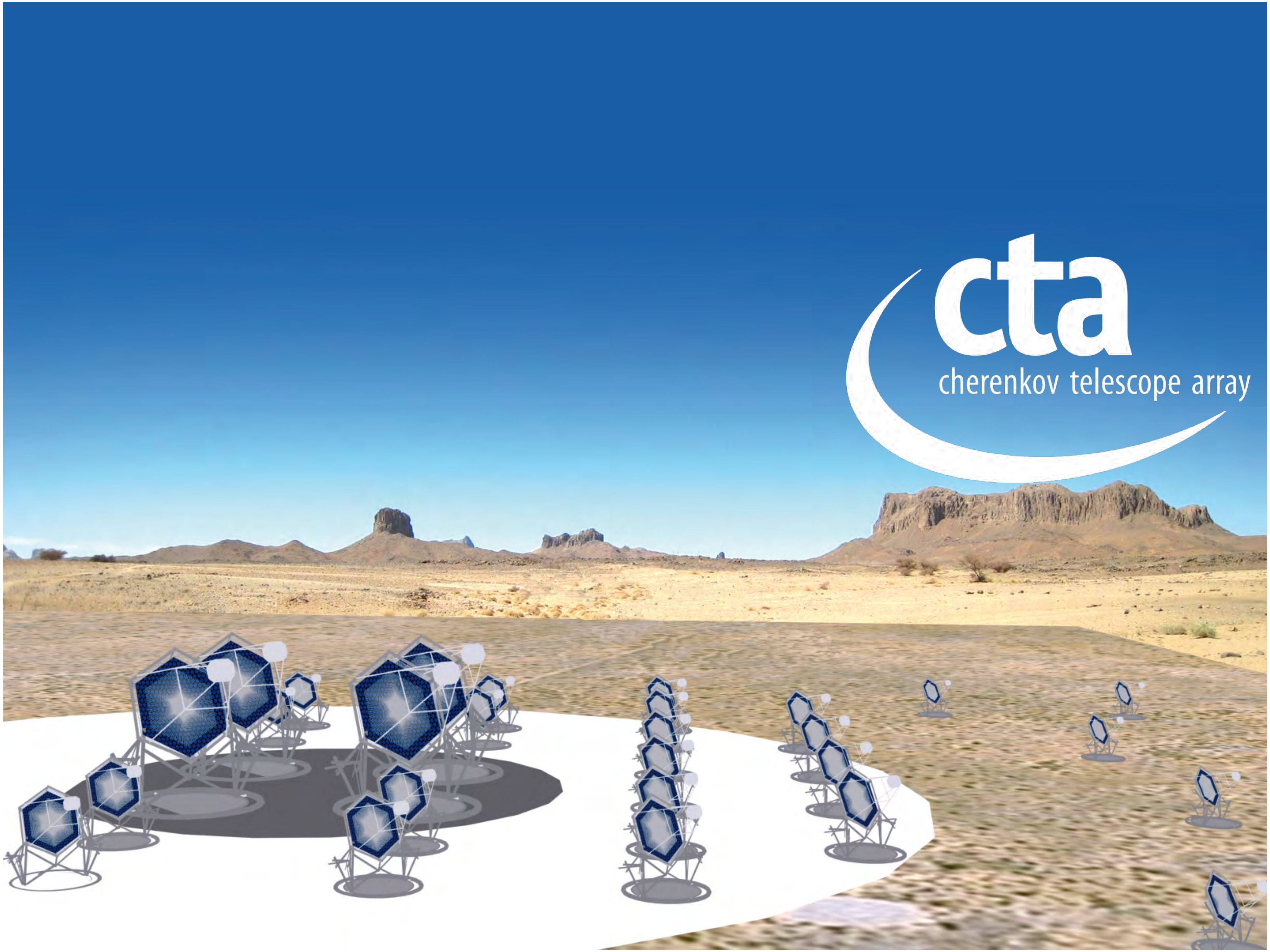


- monitor many objects simult.
- extend E range under 50 GeV
- 10x sources

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



- better flux sensitivity
- lower threshold

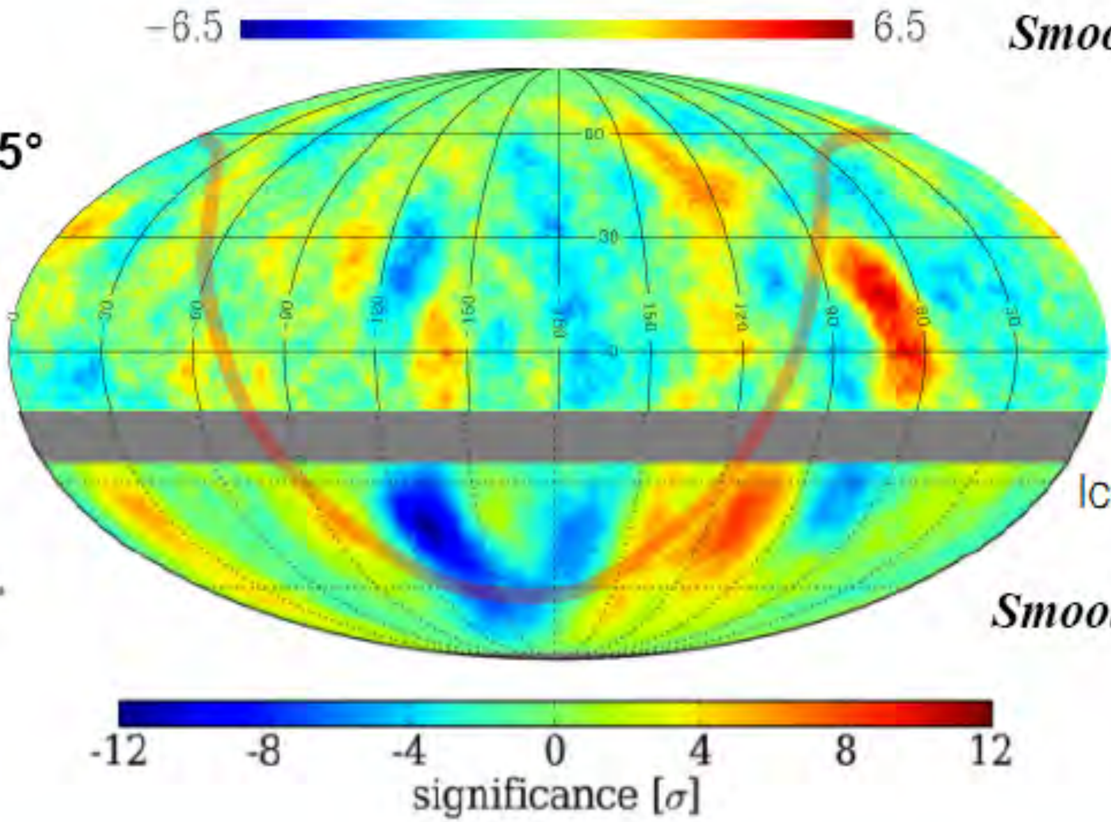

cta
cherenkov telescope array

Complete CR map of the entire TeV sky

ARGO-YBJ + IceCube-59

Smoothing radius 10°

3 hr = 45°



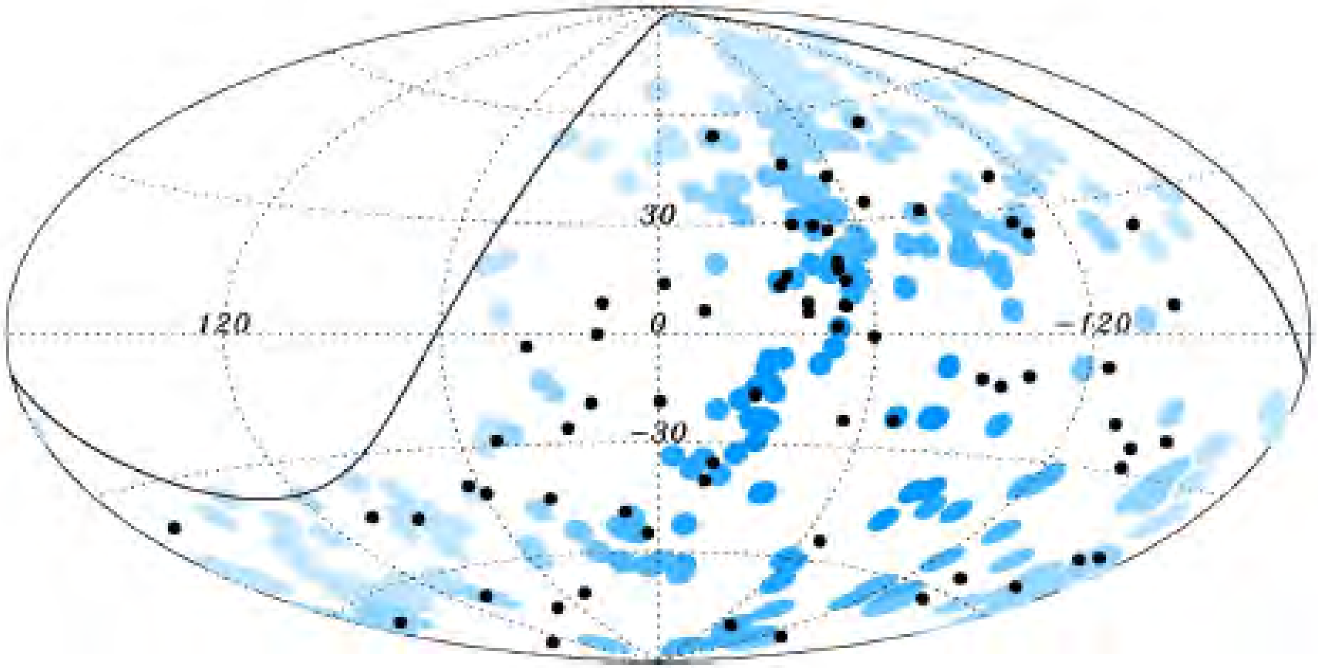
ARGO-YBJ
20 TeV

IceCube-59 20 TeV

4 hr = 60°

Smoothing radius 10°

Correlation with AGNs

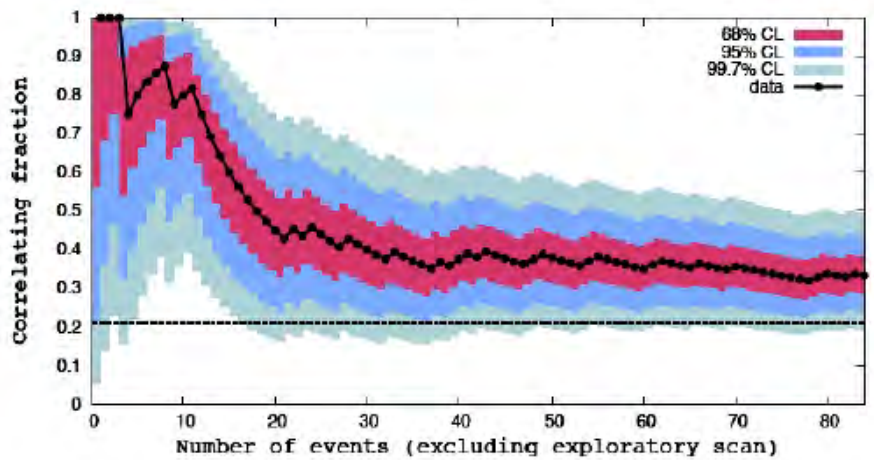


28 out of 84 correlates

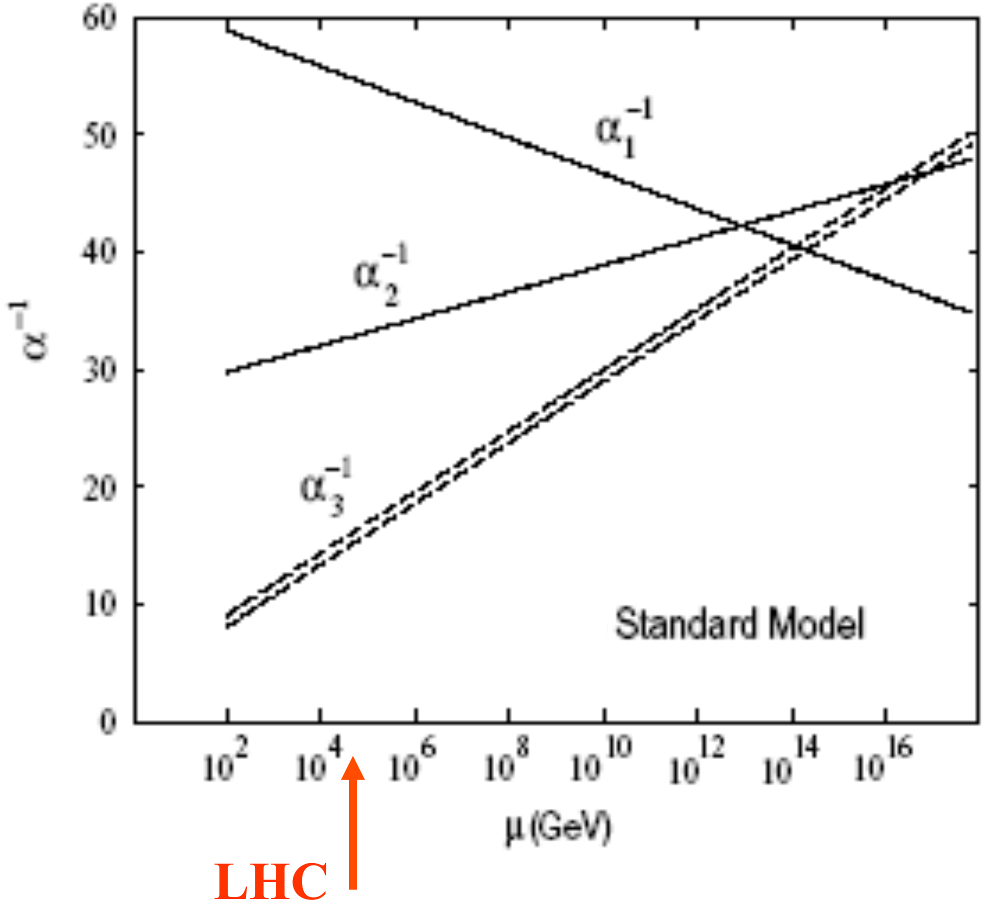
Vernon-Cetty-Vernon AGN catalog

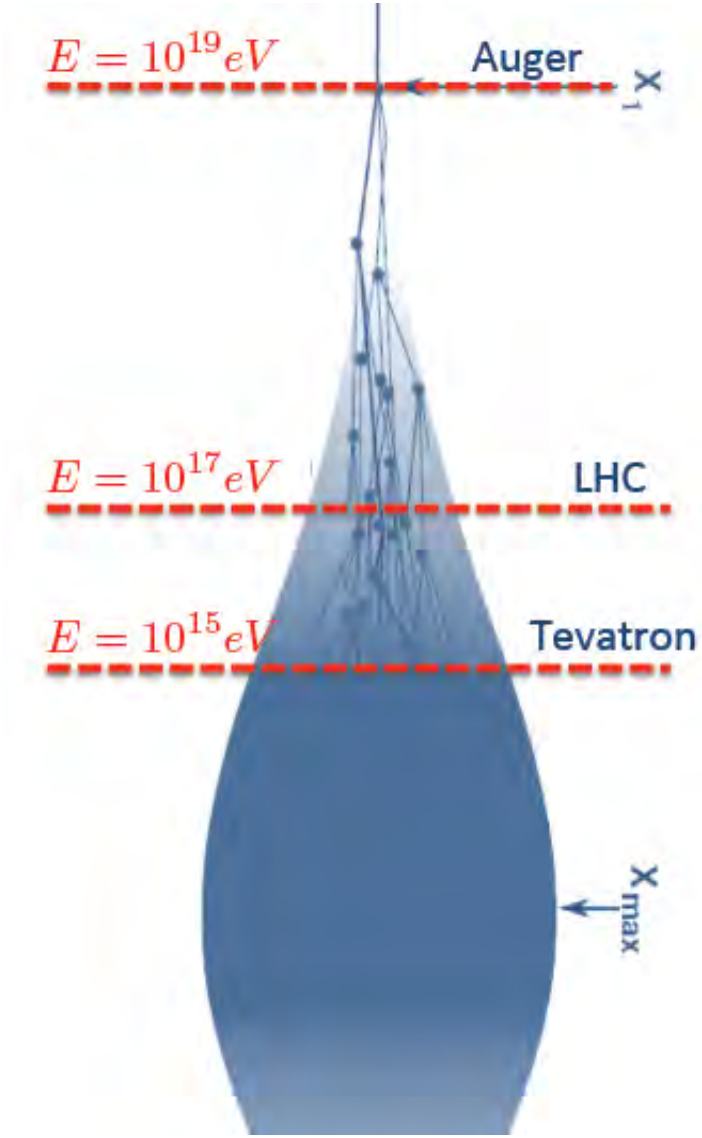
E> 57 EeV, z<0.018, distance < 3.1 deg.

P = 0.006, f = 33 ± 5%

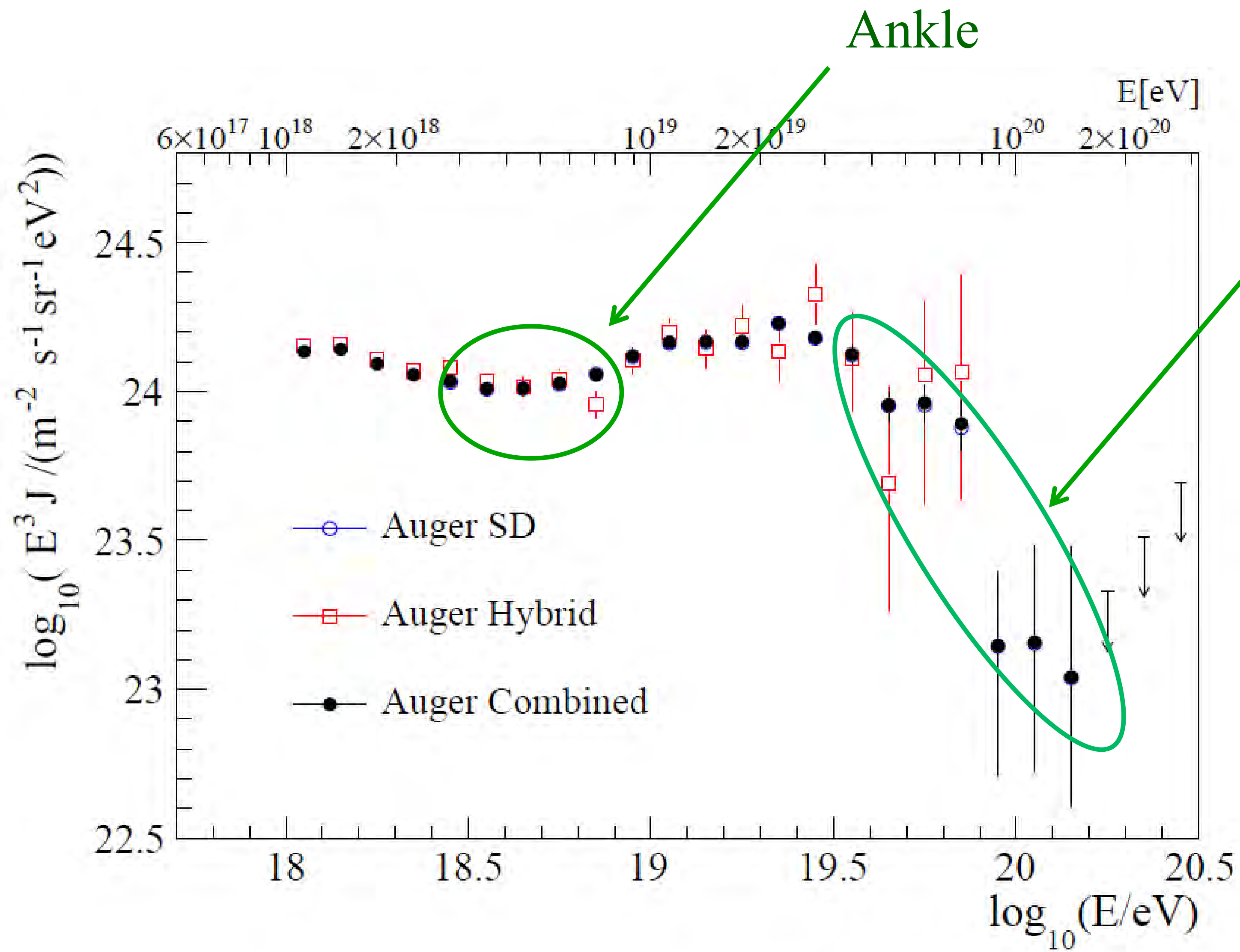


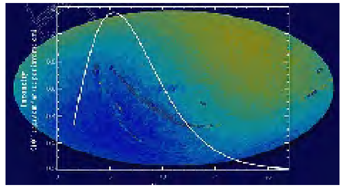
An opportunity to Particle Physics

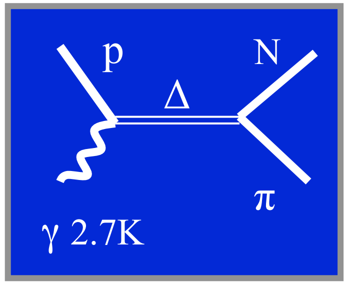




Energy spectrum



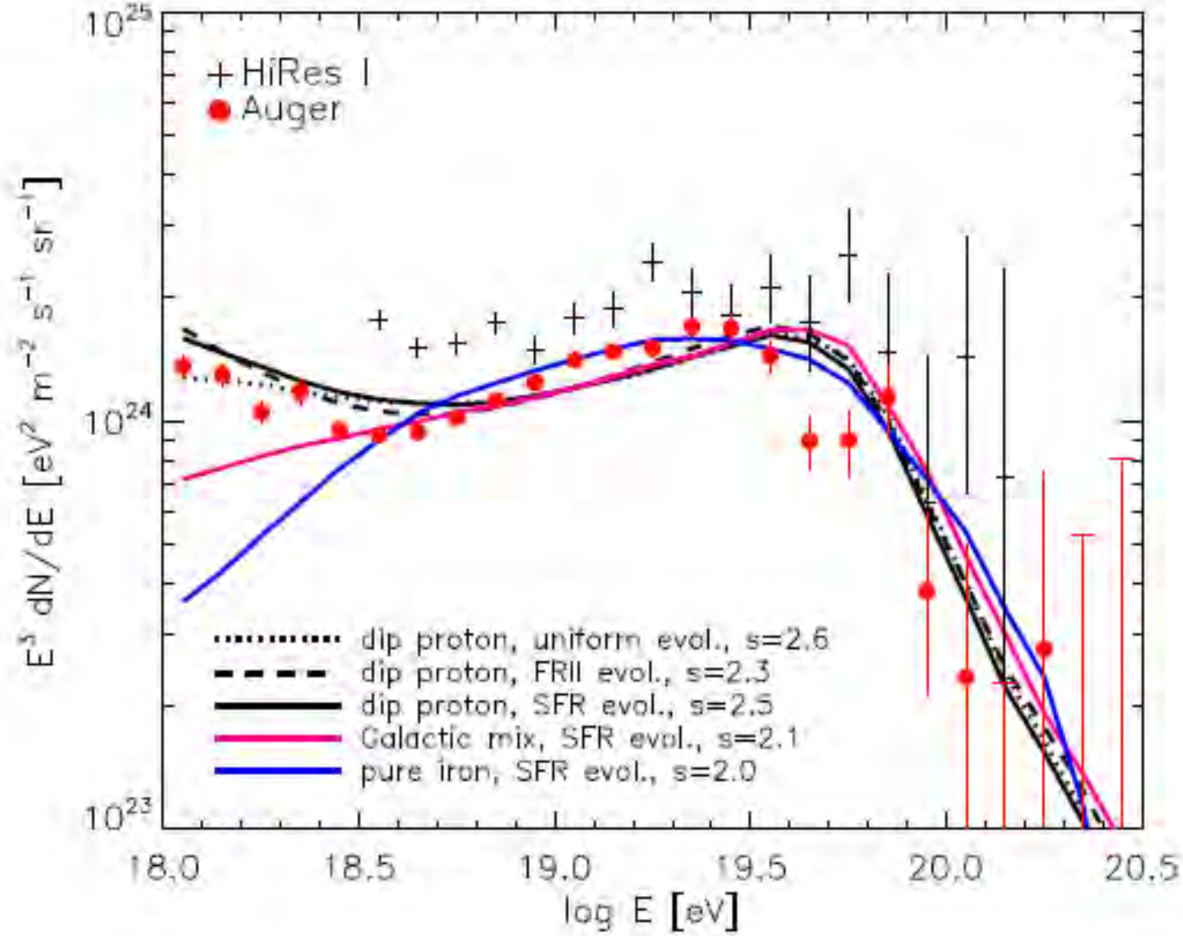




GZK like suppression !!!

Energy spectrum (interpretation)

Kotera &Olinto



GZK:

$p\,\gamma \rightarrow \Delta \rightarrow \pi\, N$

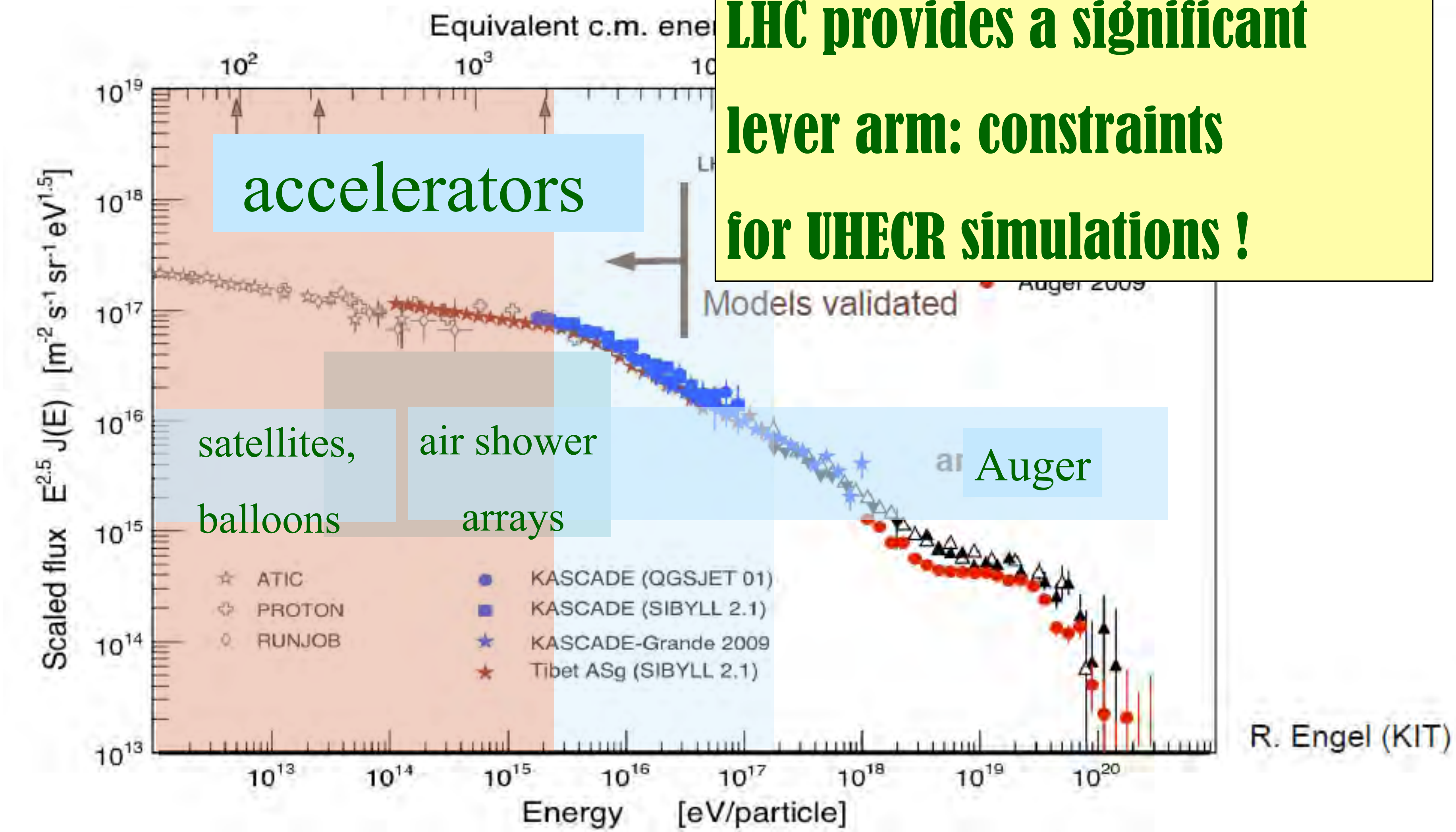
The "disappointing" model: heavy nuclei

Mixed models: fine tuning!

Spectrum of UHECRs multiplied by E^3 observed by HiRes I and Auger. Overlaid are simulated spectra obtained for different models of the Galactic to extragalactic transition and different injected chemical compositions and spectral indices, s.

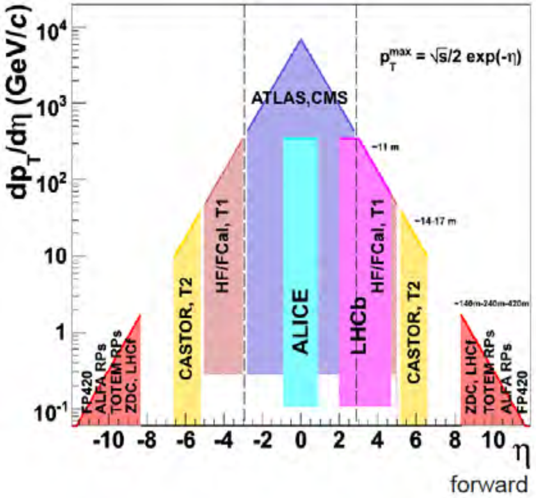
Cross section & composition

Cosmic Rays and LHC



LHC provides a significant lever arm: constraints for UHECR simulations !

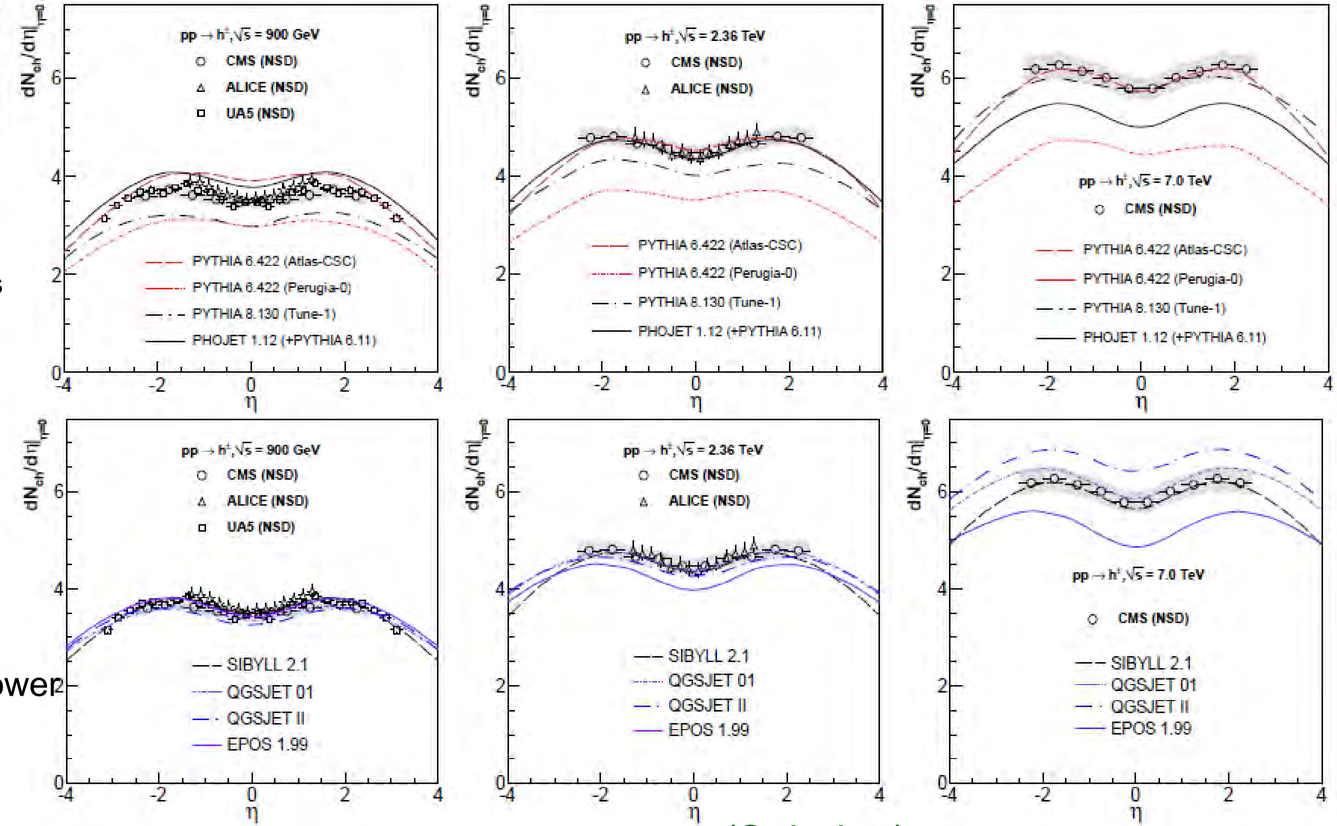
Small-x region (LHC as a pathfinder for CR, and vice-versa)



- LHC detectors cover all wide rapidity range
  - EAS models bracket accelerator data
  - no model perfect, but EAS models seem to do better than HEP models

- **HEP**
  High Energy Physics
  models

- **EAS**
  Extensive Air Shower
  models

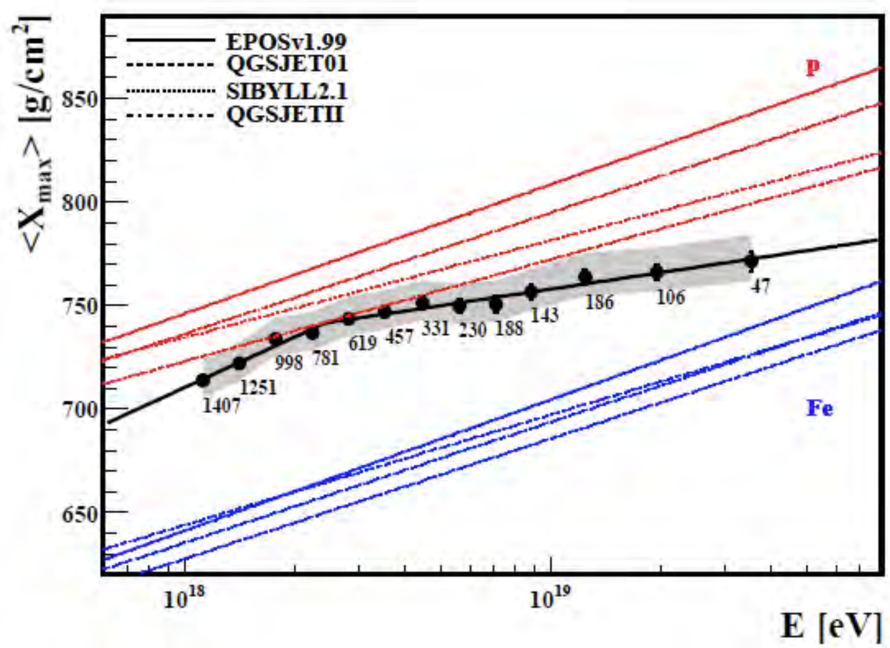


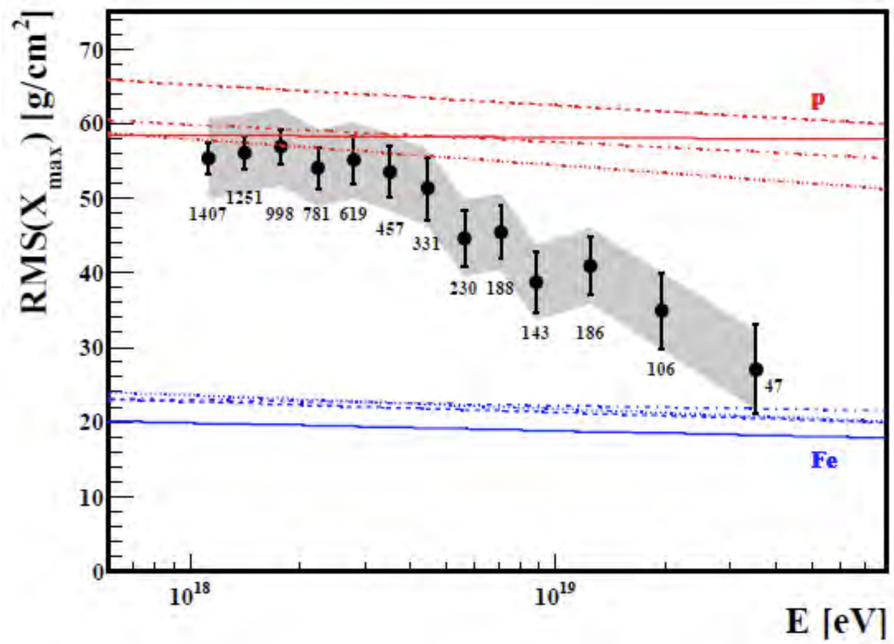
(Spiering)

Cross sections: something not understood in Auger

Shower Maximum X_{max}

(Pimenta)





These suggest high cross section and high multiplicity at high energy.

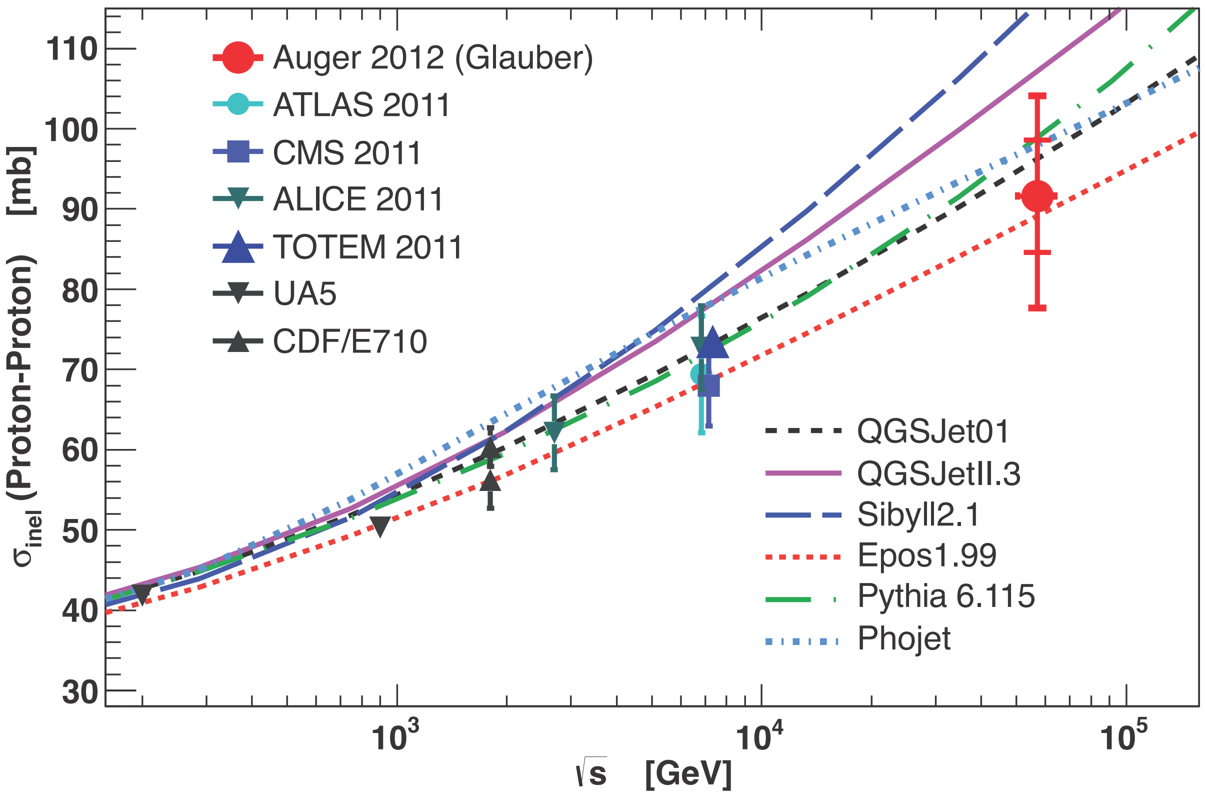
Heavy nuclei?

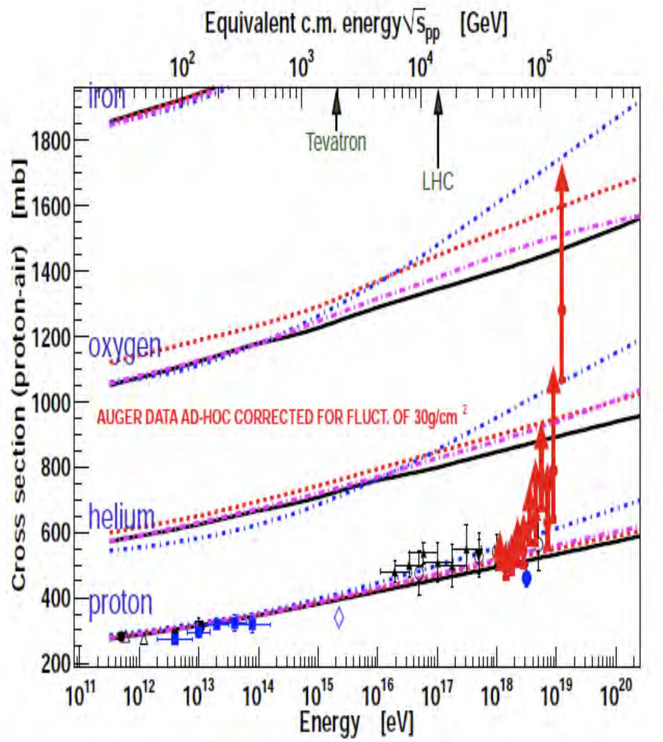
Or protons interacting differently than expected?

Information lacking for the EHE (anisotropic?) energy regime!

Cosmic Rays and LHC: total cross section

pp inel. cross section at sqrt(s)=57 TeV





- Tune EAS simulations

If protons, the

X-section rises

at ~100 TeV

=> A new physics scale?

In astroparticle physics we are exploring the 100 TeV energy scale, well beyond LHC, and maybe we are touching something fundamental!