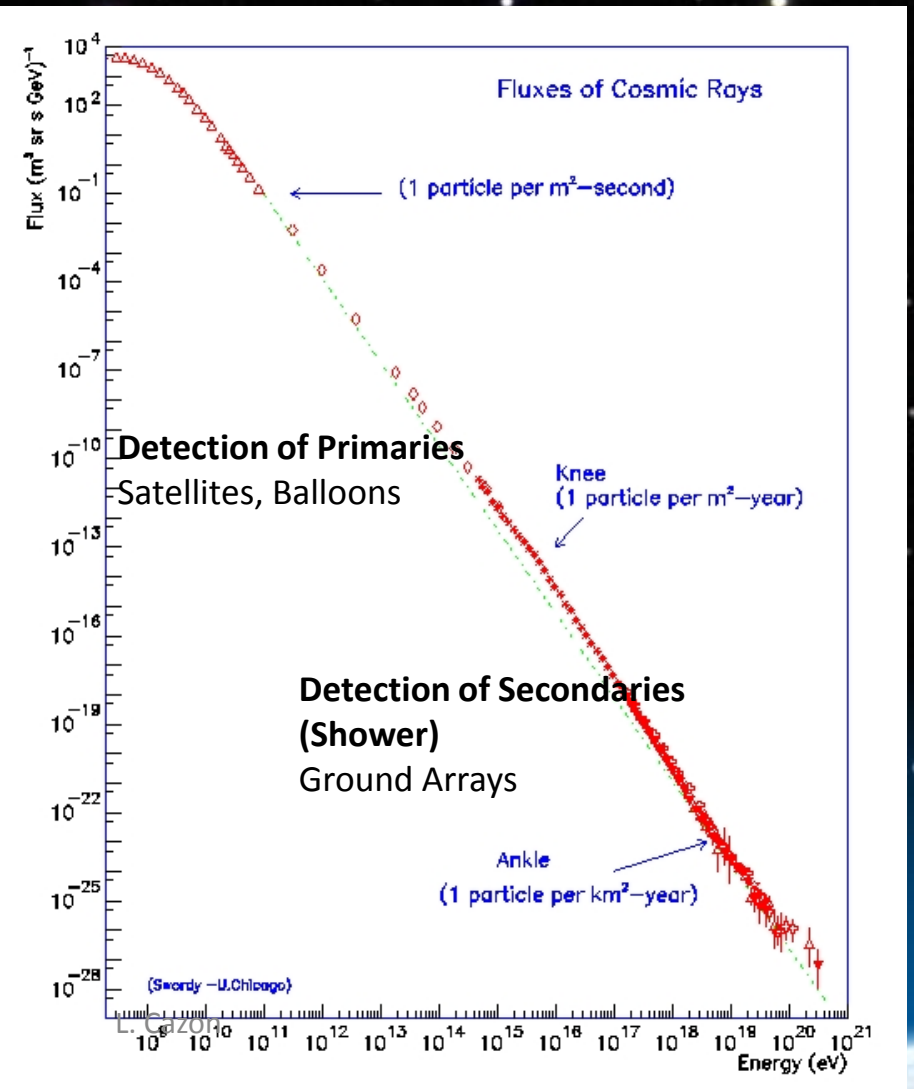
Ultra High Energy Cosmic Rays a 100 years puzzle

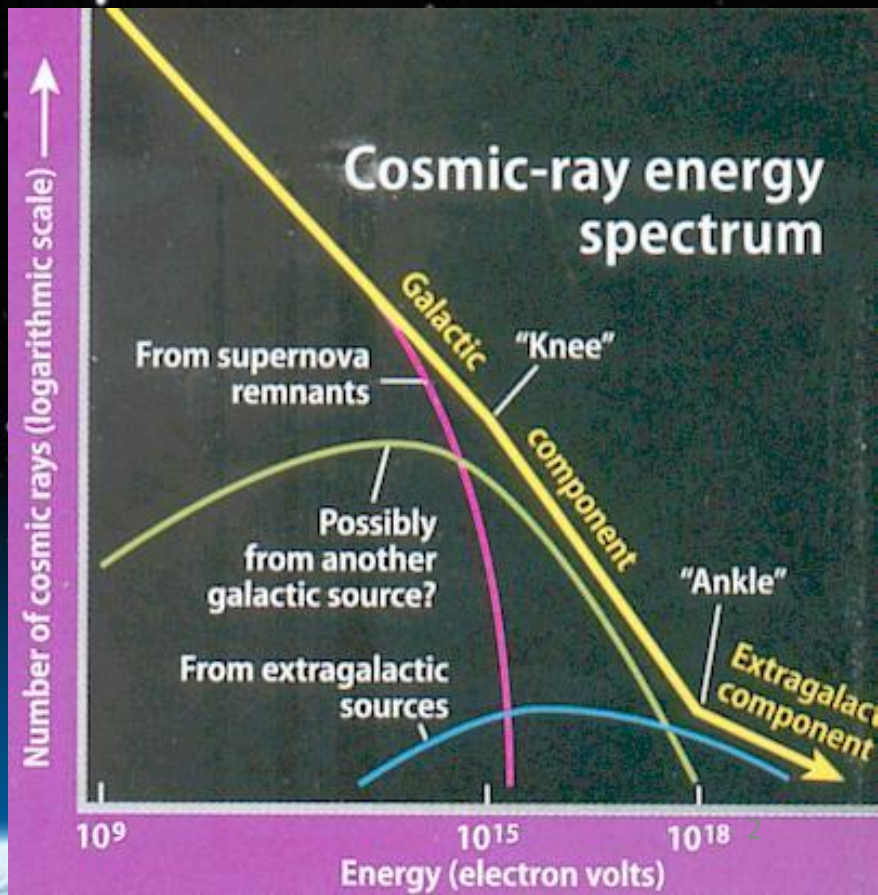
L. Cazon

Cosmic Ray Spectrum



Detection of Primaries
Satellites, Balloons

Detection of Secondaries (Shower)
Ground Arrays



A comparison

1.5 eV

10 000.0 eV

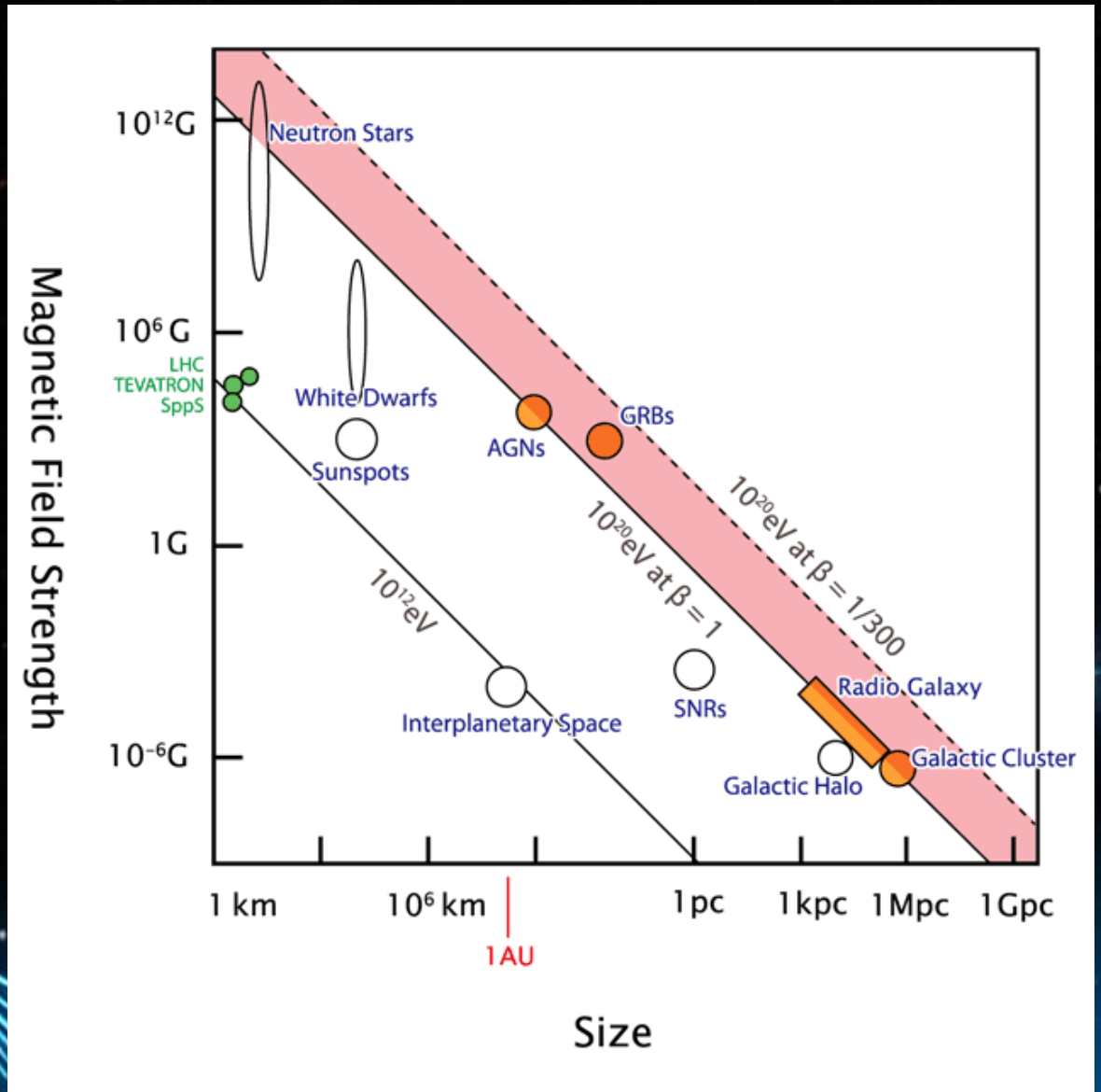
6 500 000 000 000.0 eV

300 000 000 000 000 000 000.0 eV

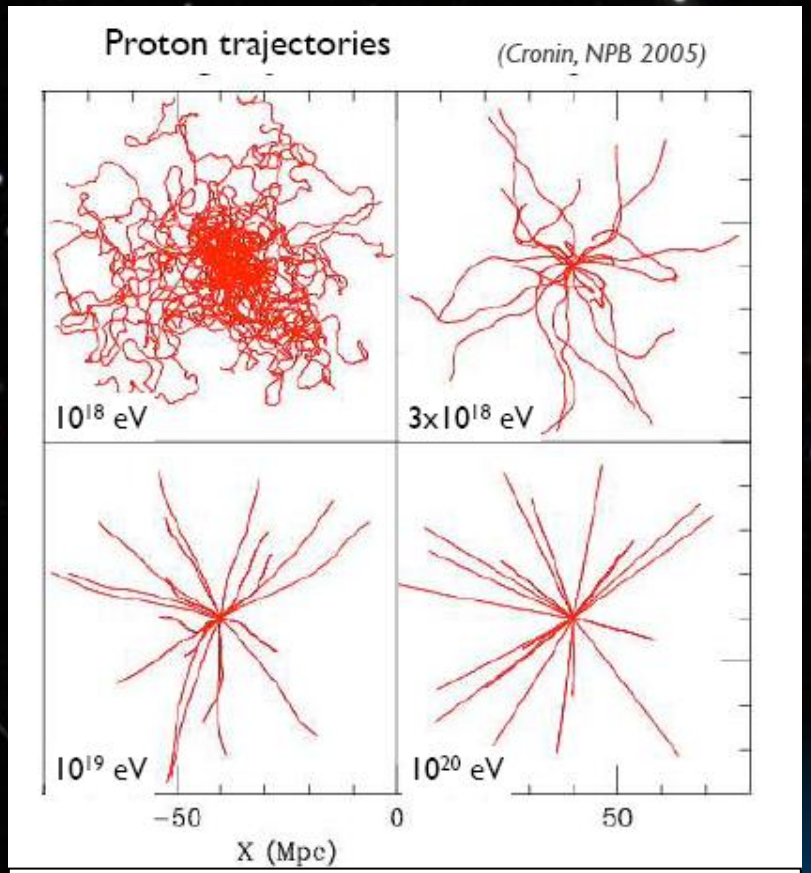
Gigantic energies

- The energy of 10 g (rest mass) of the highest energy cosmic rays is the equivalent of 100 times the energy of all world's fossil fuel reserves.

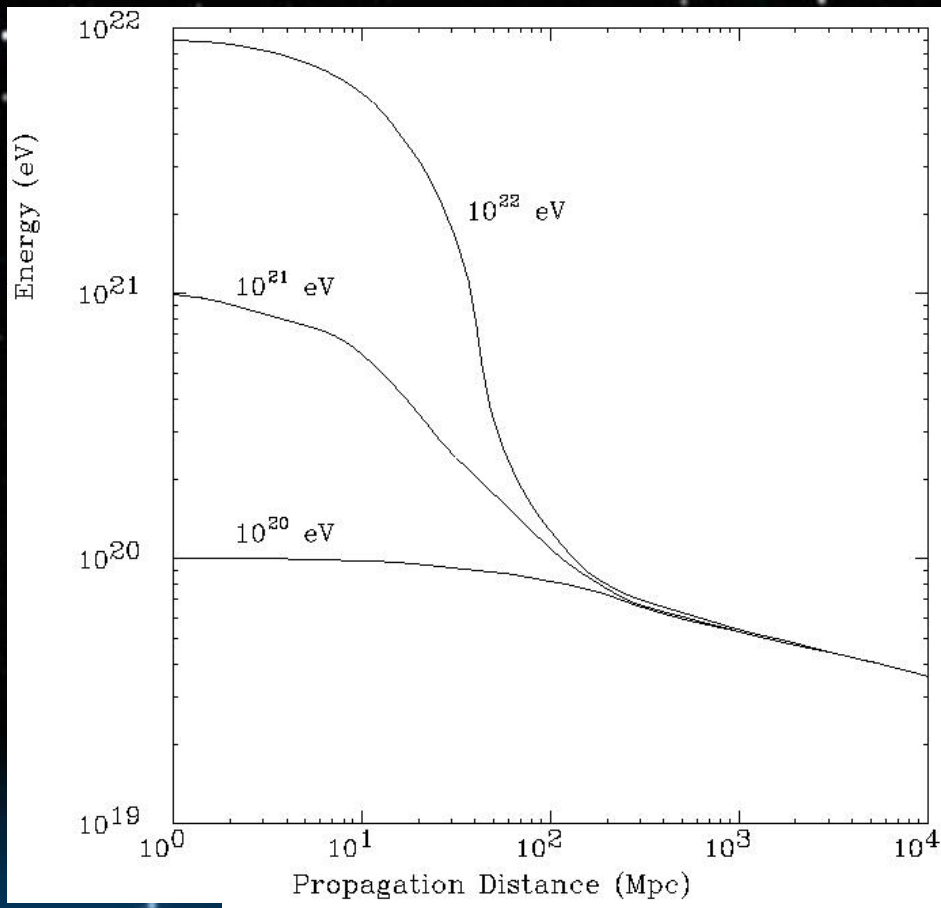
Super-Powerful Accelerators in Nature



Intergalactic B field and GZK cutoff



Simple model for extragalactic B. B=1 nG, Lcoh=1 MPc



$$\gamma_{\rm CMB} + p \to \Delta^+ \to p + \pi^0,$$

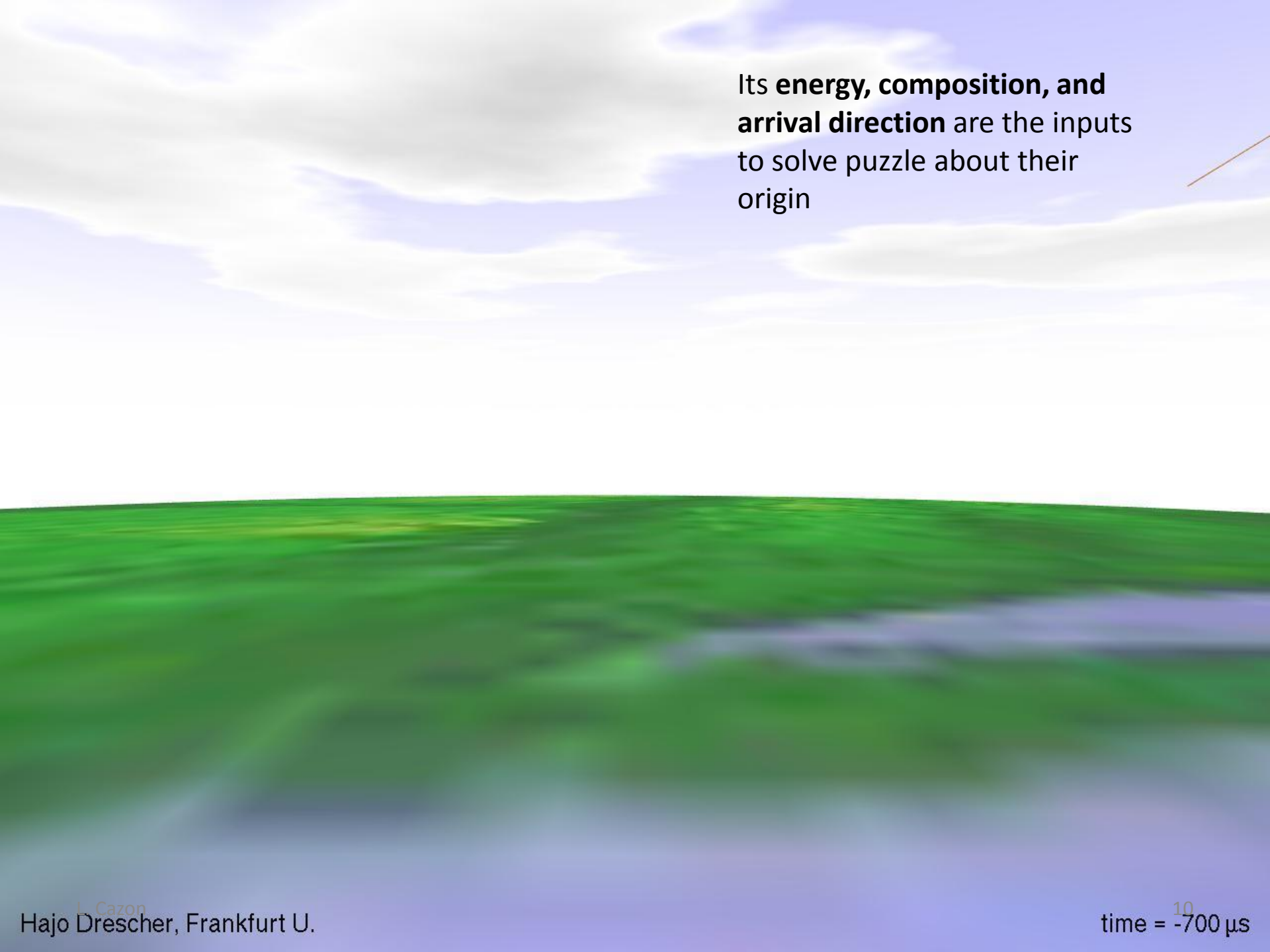
$$\gamma_{\rm CMB} + p \to \Delta^+ \to n + \pi^+.$$

An Air Shower

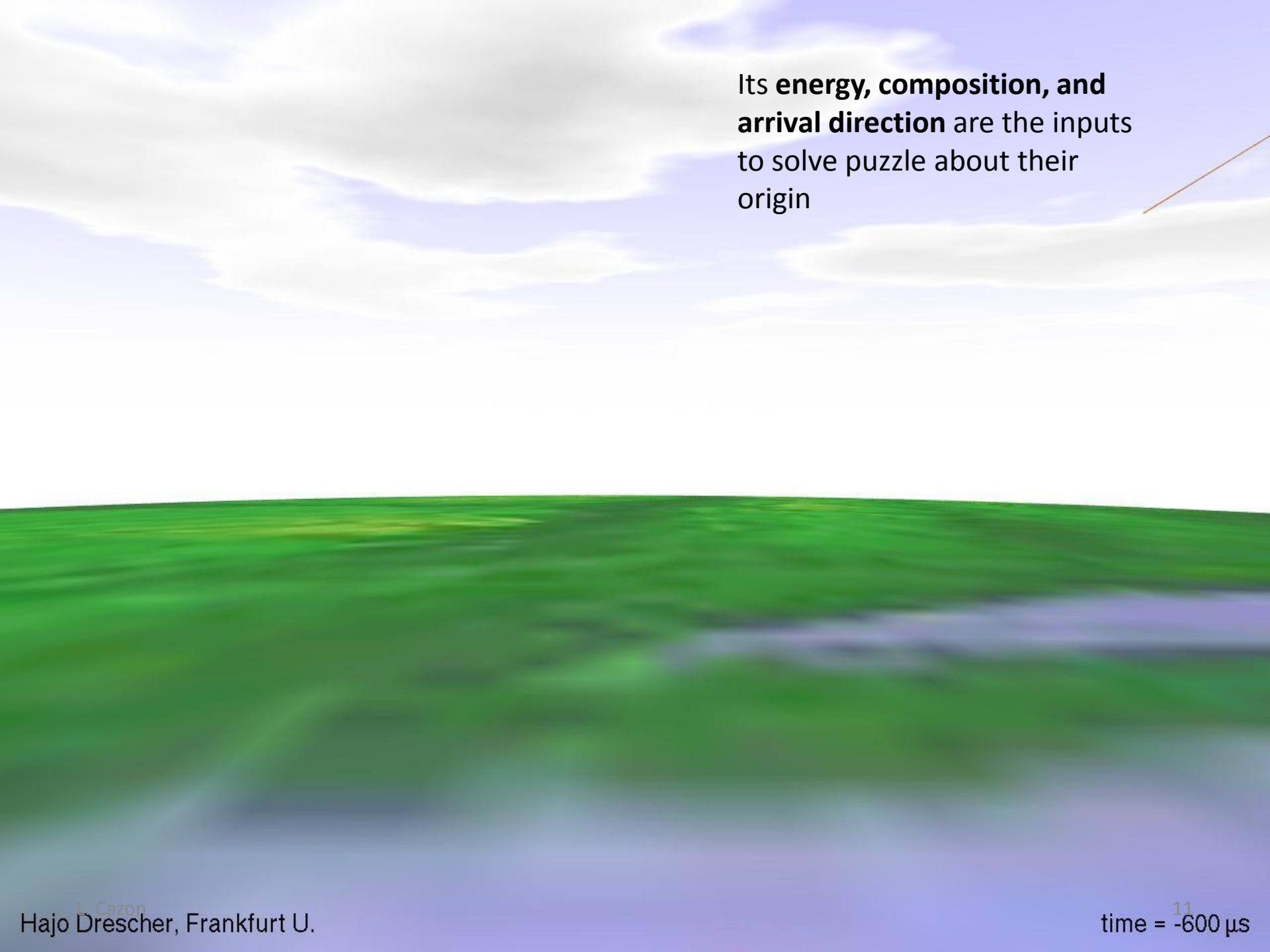
An Air Shower

An Air Shower

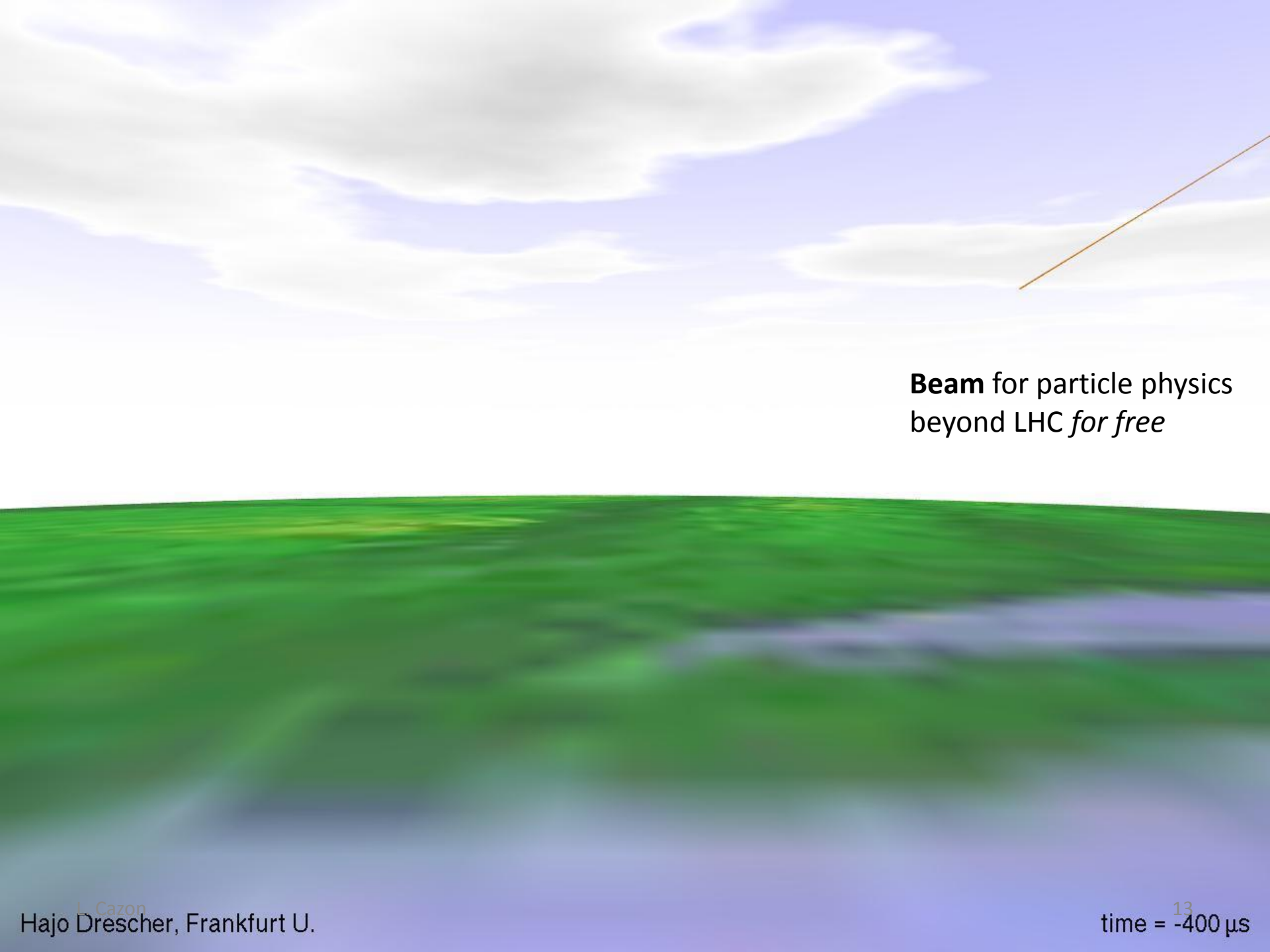
Its **energy, composition, and arrival direction** are the inputs to solve puzzle about their origin

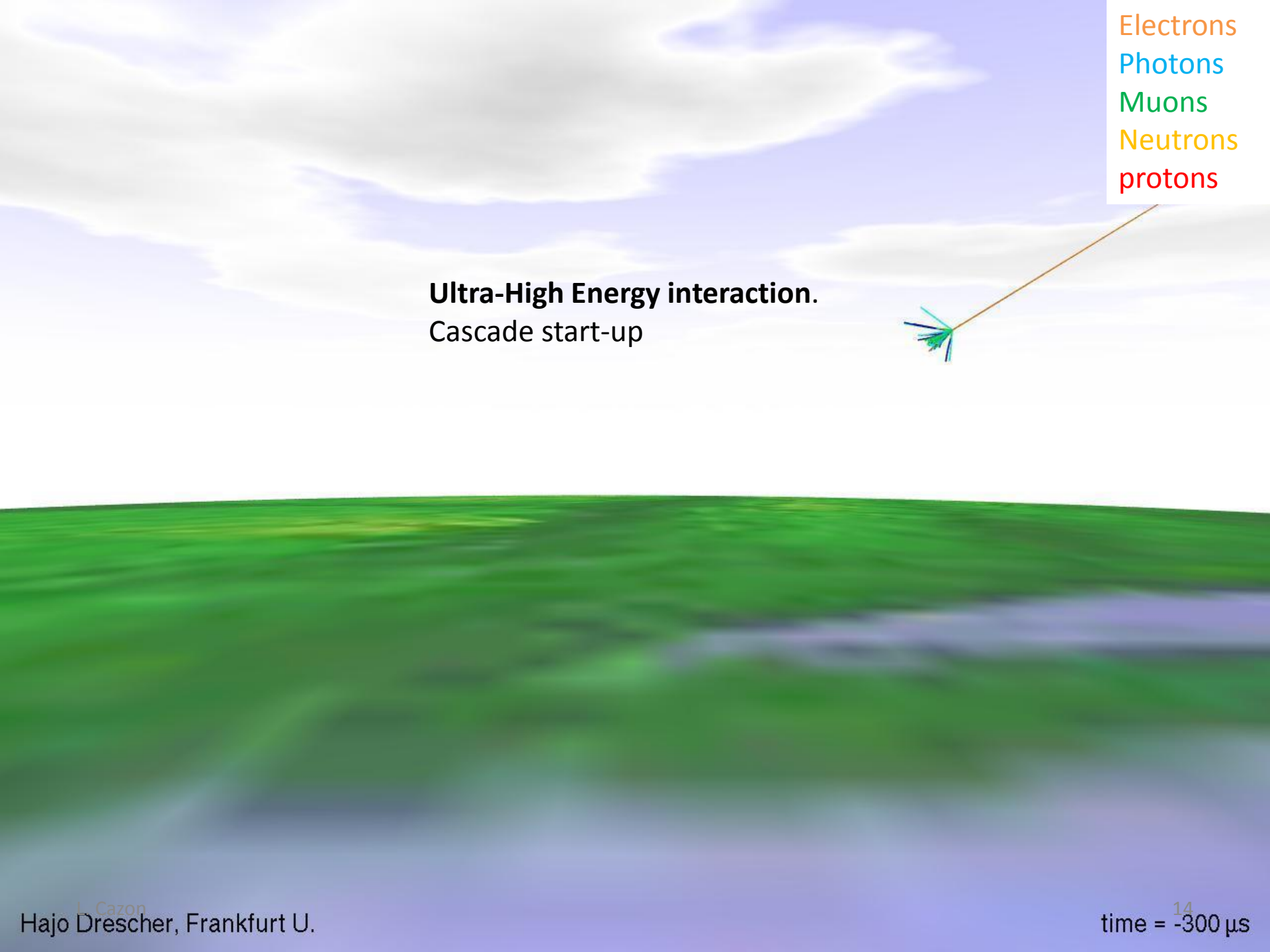


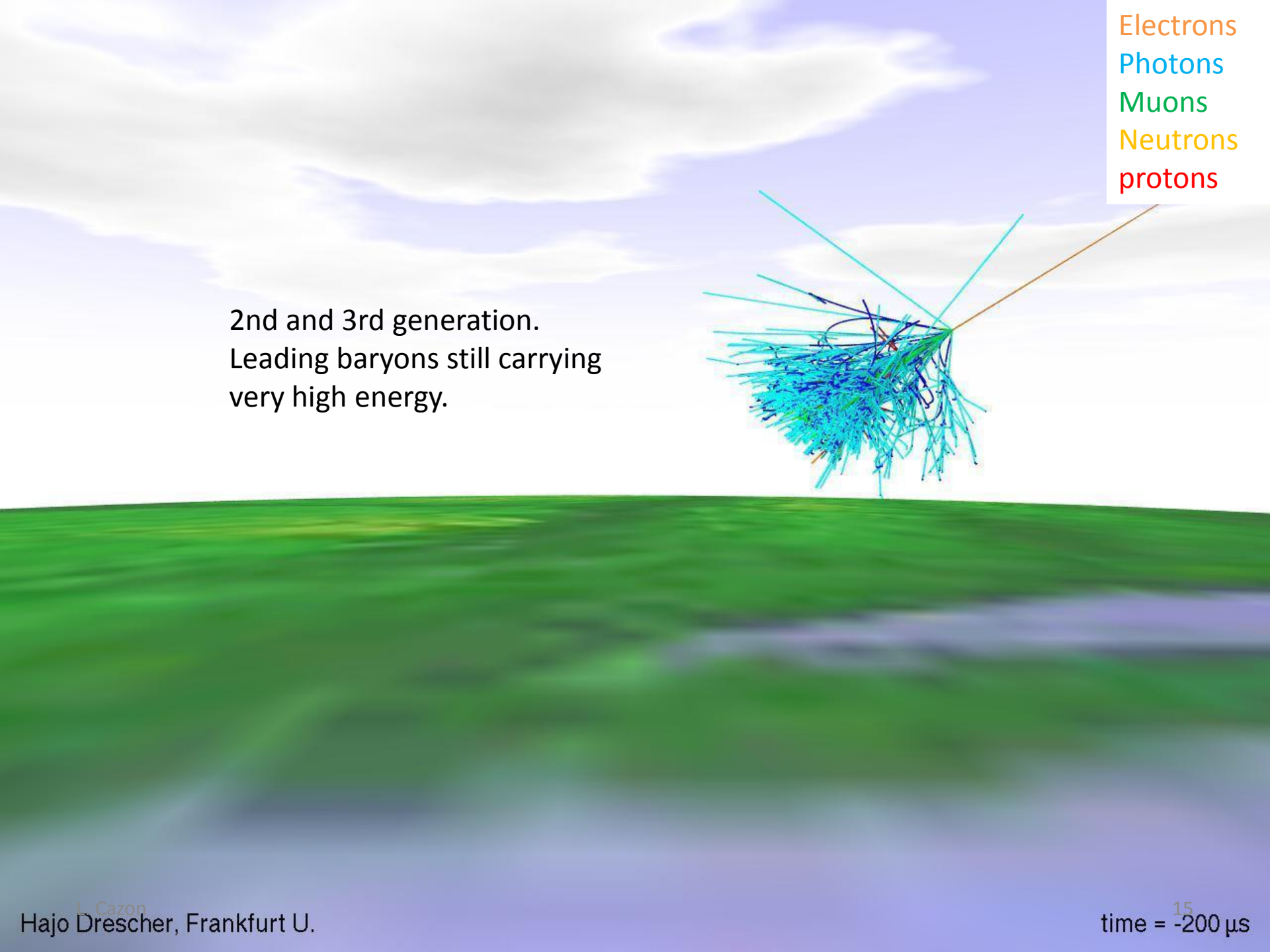
Its **energy, composition, and arrival direction** are the inputs to solve puzzle about their origin

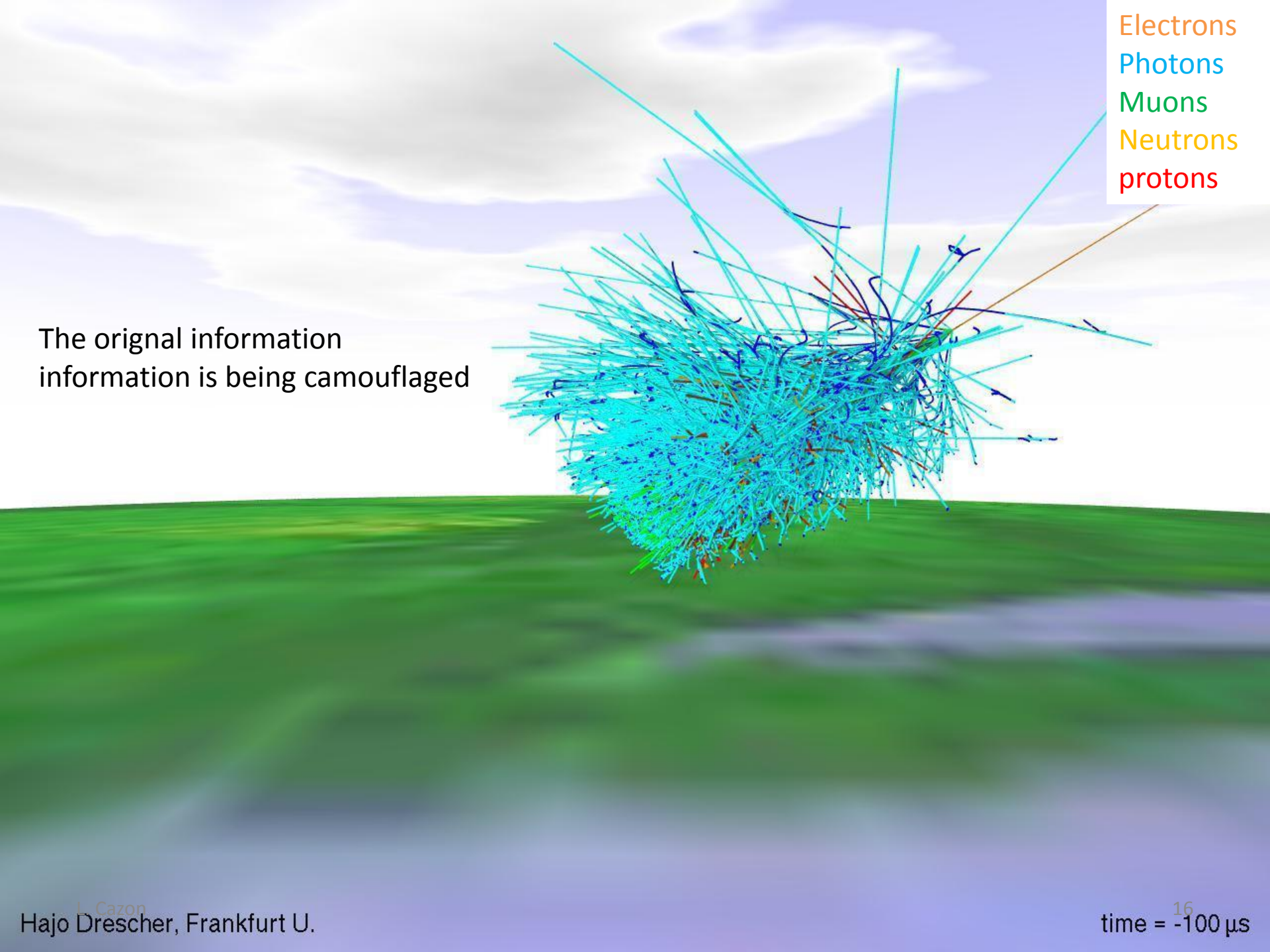


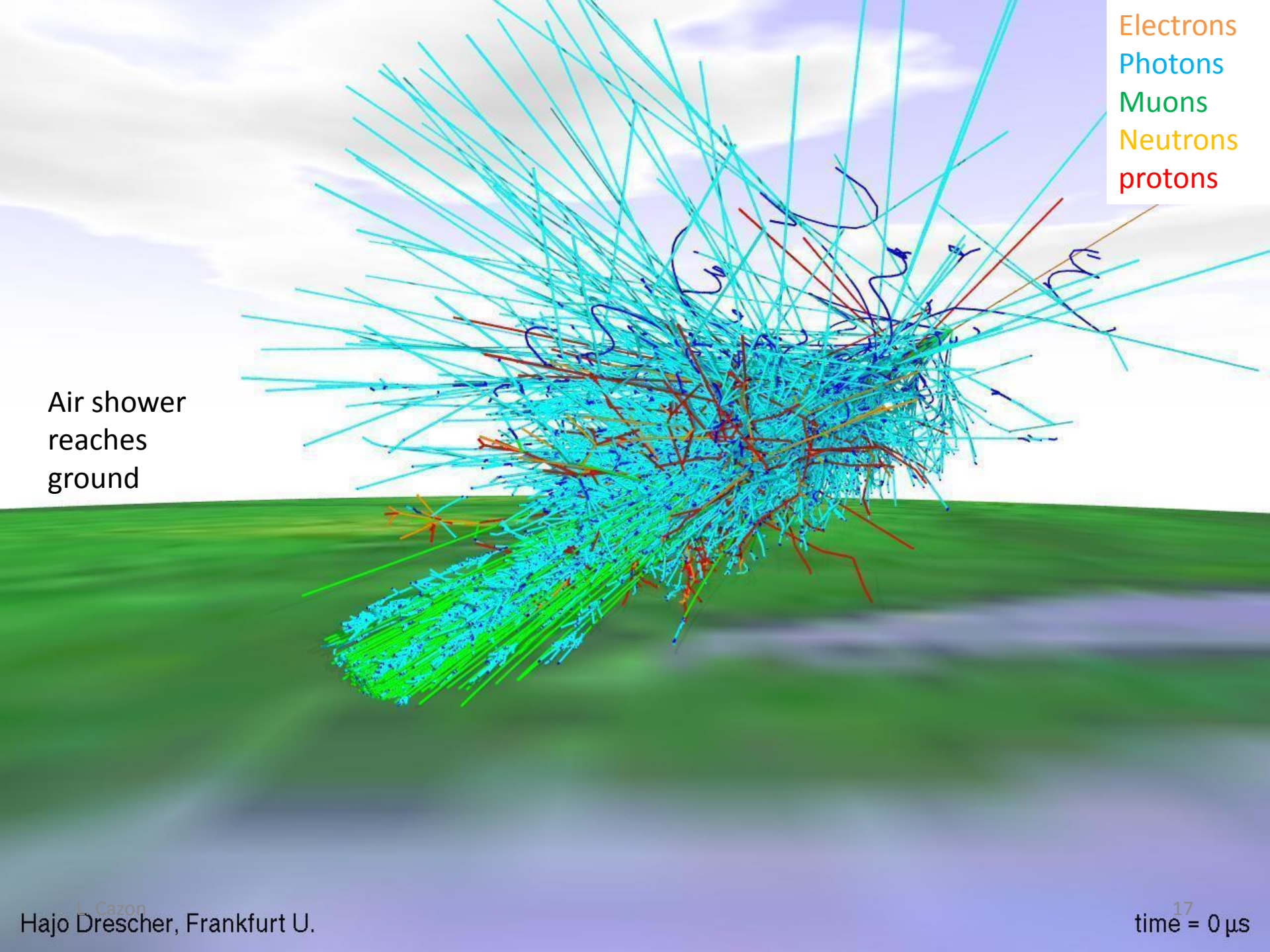

Beam for particle physics
beyond LHC *for free*
Hajo Drescher, Frankfurt U.
time = -500 µs


Beam for particle physics
beyond LHC *for free*
Hajo Drescher, Frankfurt U.
time = -400 µs


Electrons
Photons
Muons
Neutrons
protons
Ultra-High Energy interaction.
Cascade start-up
Hajo Drescher, Frankfurt U.
time = -300 µs

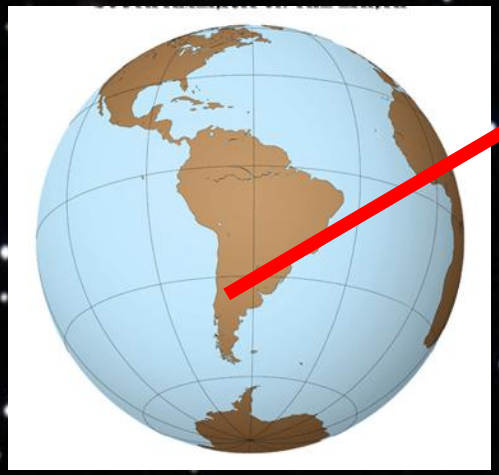

Electrons
Photons
Muons
Neutrons
protons
2nd and 3rd generation.
Leading baryons still carrying
very high energy.
Hajo Drescher, Frankfurt U.
time = -200 µs

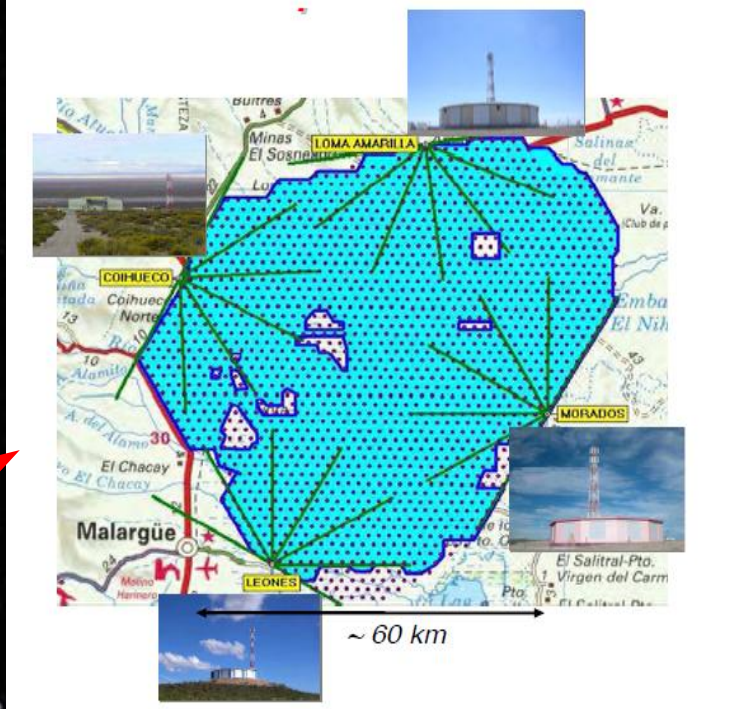

Electrons
Photons
Muons
Neutrons
protons
The orignal information
information is being camouflaged
Hajo Drescher, Frankfurt U.
time = -100 µs


Electrons
Photons
Muons
Neutrons
protons
Air shower reaches ground
Hajo Drescher, Frankfurt U.
time = 0 µs

The Pierre Auger Observatory

- Malargüe. Mendoza
- Latitude 35 S – Longitude 69 W
- 1400m a.s.l. X=870 g cm^2
- Data taking since 2004
- Installation completed in 2008





Surface Detector (SD)
1600 Cherenkov stations spaced 1.5 km
Area of 3000 km^2
100% duty cycle
Provides Large Statistics

Fluorescence Detector (FD)
4 building with 6 telescopes each
Telescope f.o.v. 30 x 30 deg
~10% duty cycle
Provides High Accuracy

+ Enhancements: AMIGA, HEAT, Radio, etc
+Atmospheric monitoring: LIDAR, LDF, cloud monitors

The Pierre Auger Observatory

PIERRE AUGER OBSERVATORY

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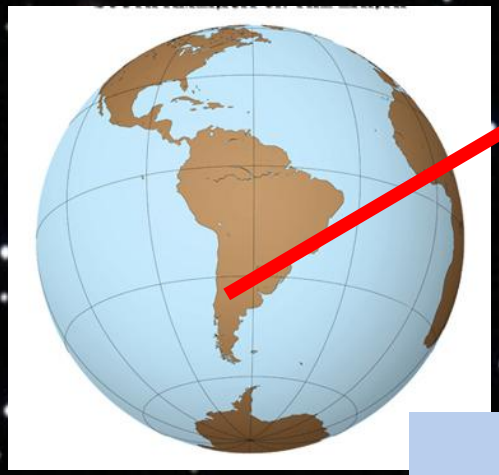

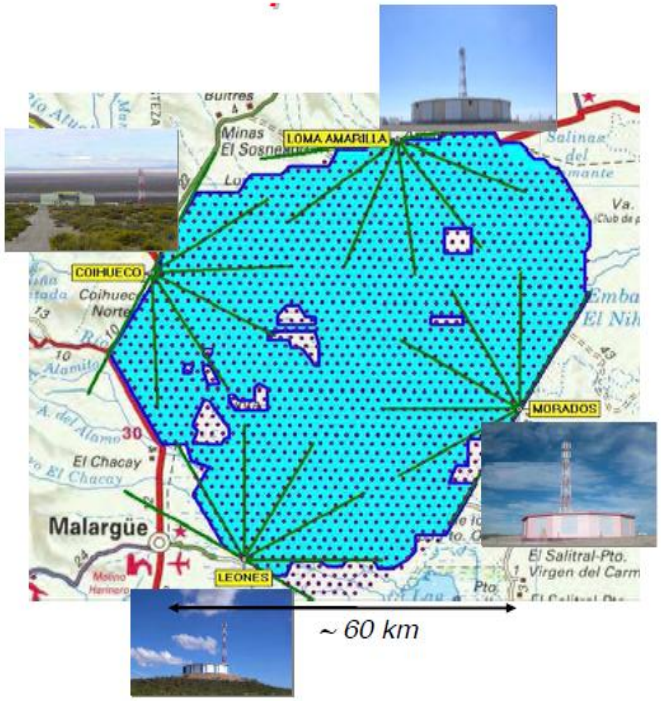

Surface Detector (SD)
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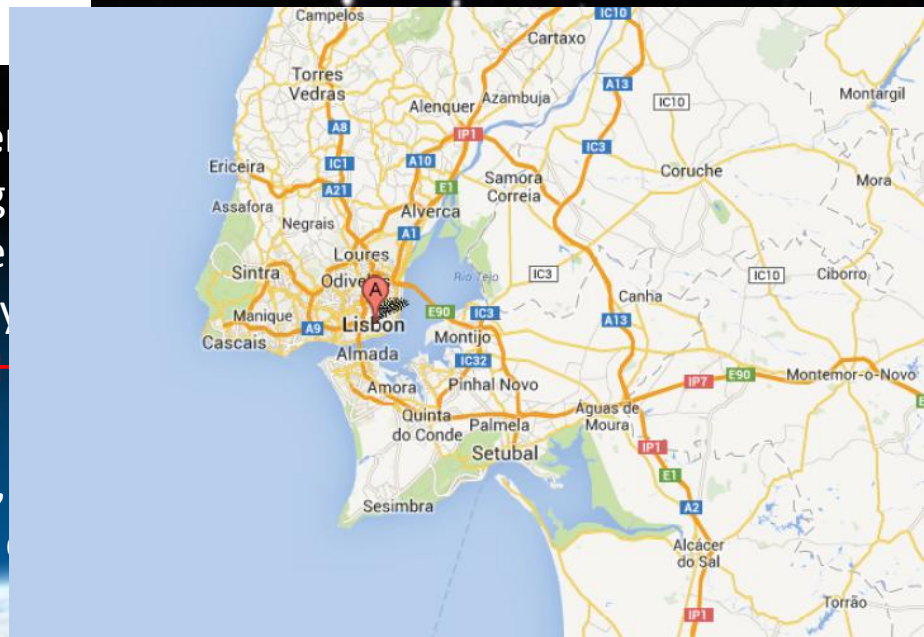
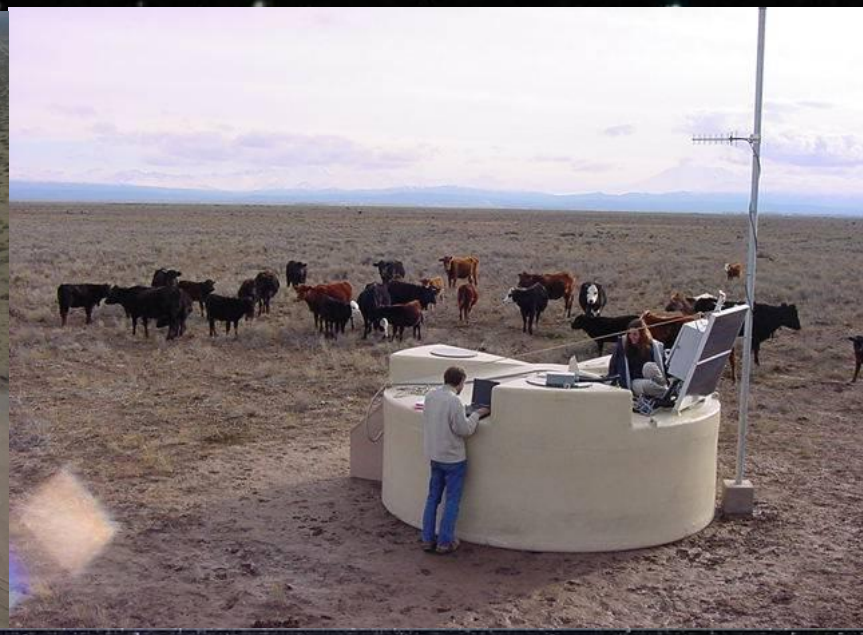
Area of 3000 km^2
100% duty cycle
Provides Large Statistics

Fluoresce
4 building
Telescope
~10% duty
Provides H

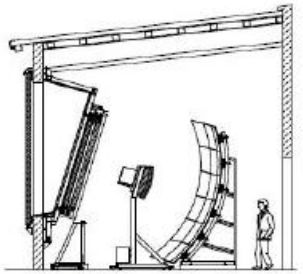
+ Enhancements: AMIGA, HEAT, Radio,
+Atmospheric monitoring: LIDAR, LDF,

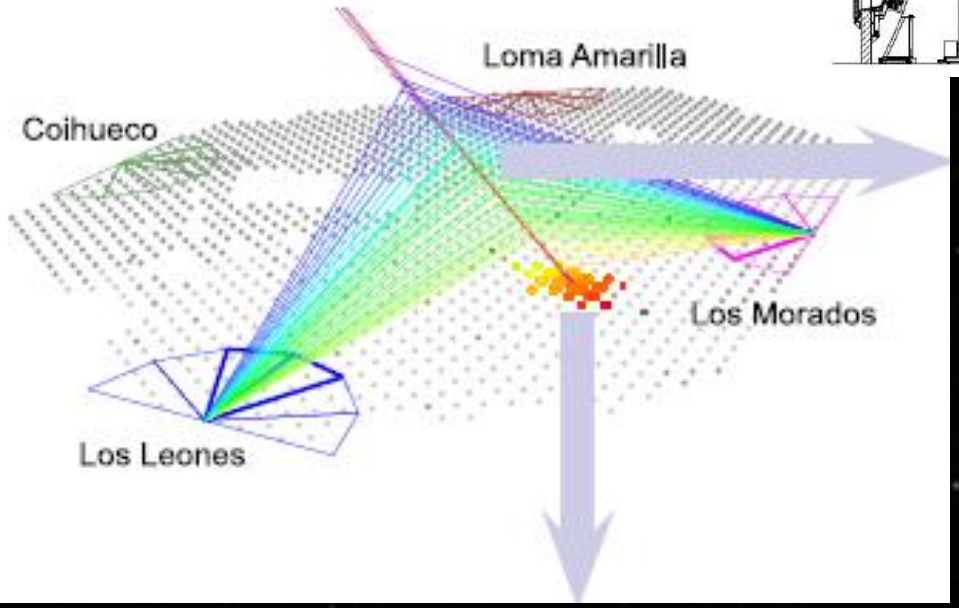


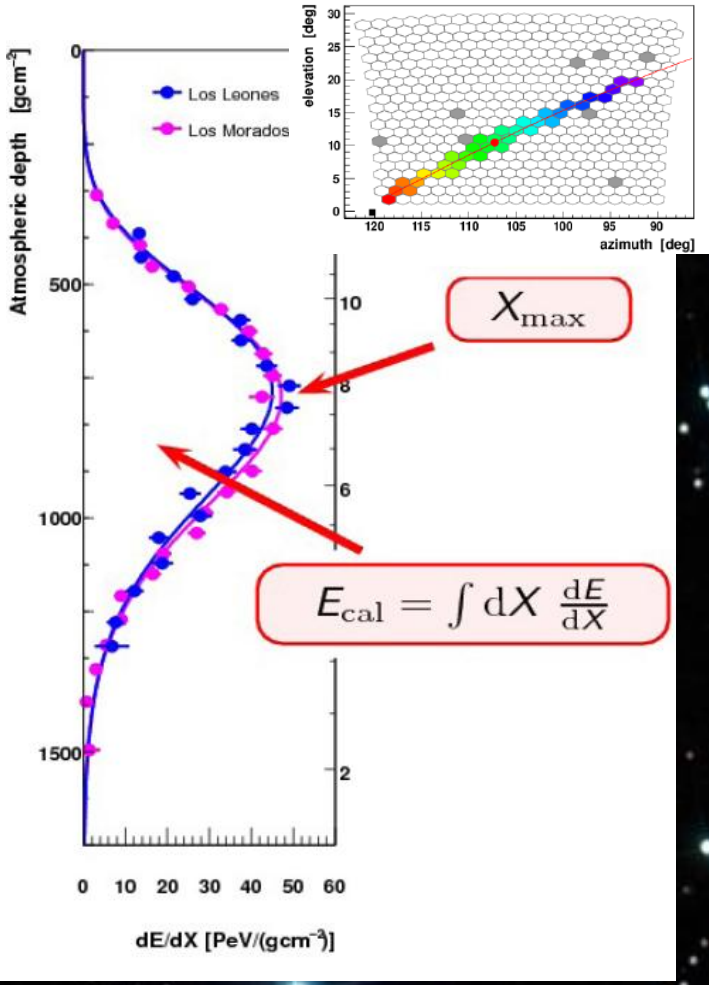
A wild enviroment

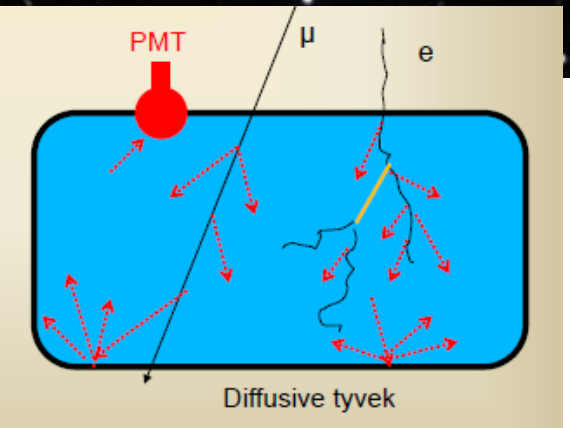


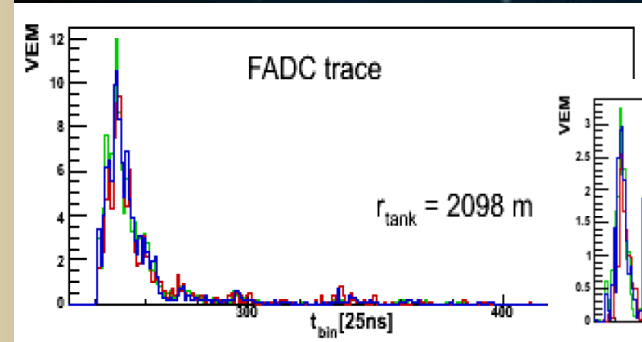
Hybrid detector

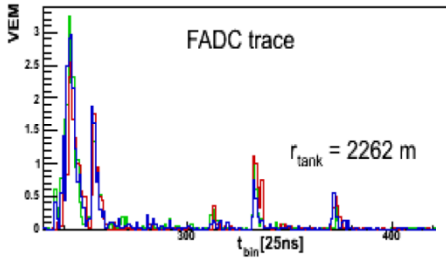


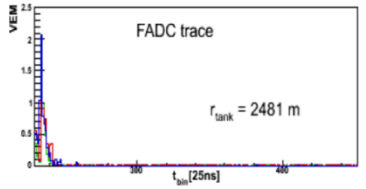






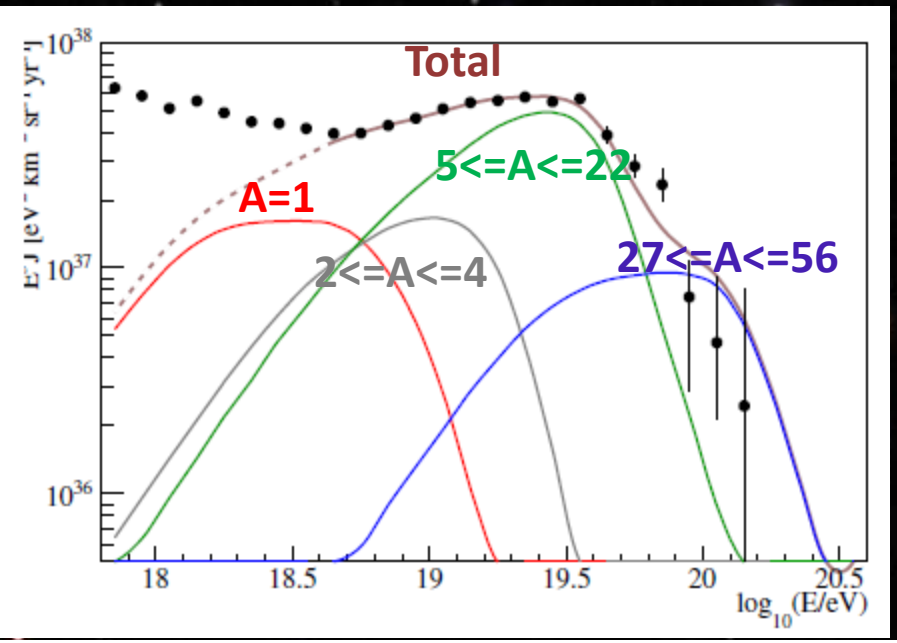


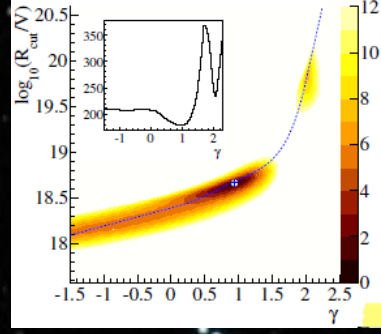




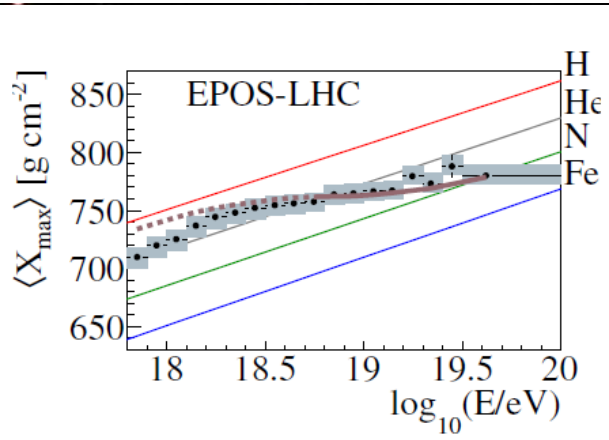

AT A GLANCE
RESULTS

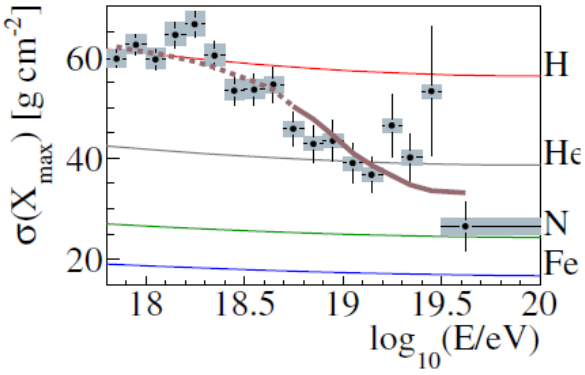
Spectrum & Composition

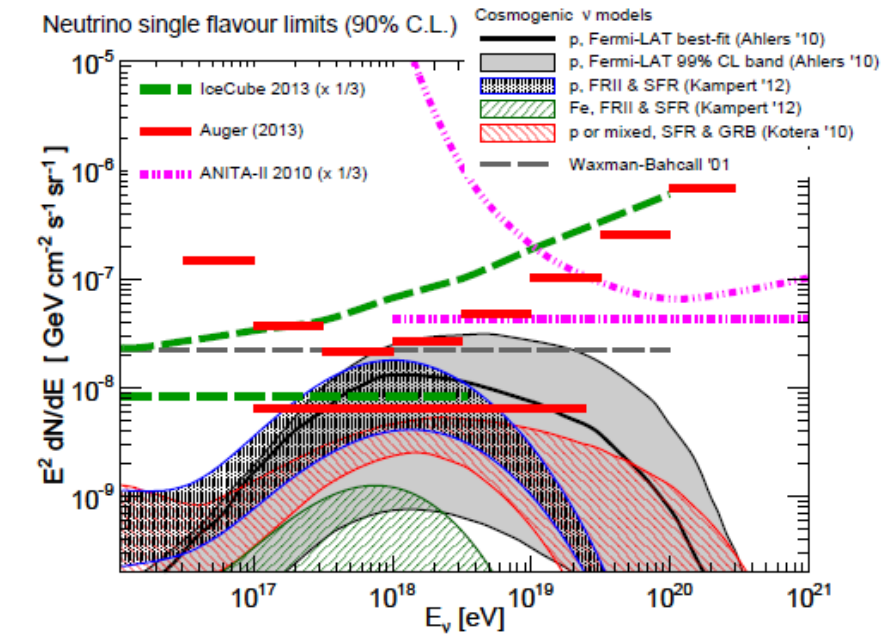


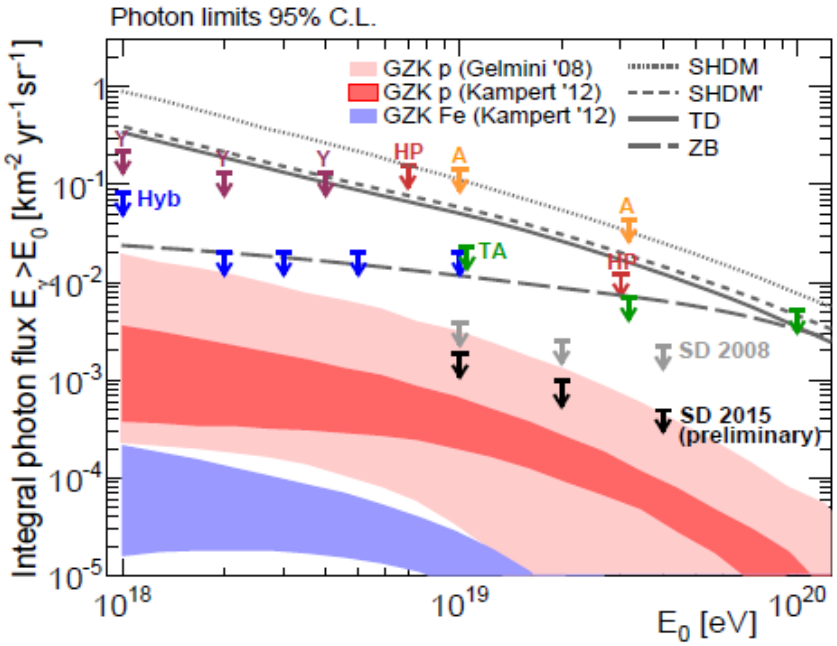


- Best fit with very hard injection spectra ($\gamma \leq 1$)
- Flux limited by maximum energy at the sources
- High Metallicity







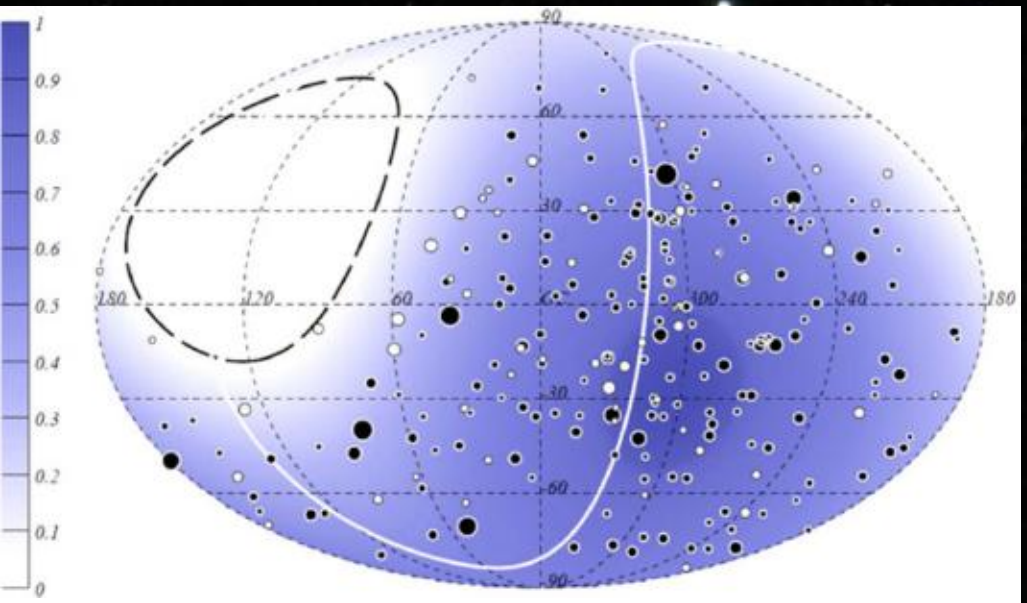


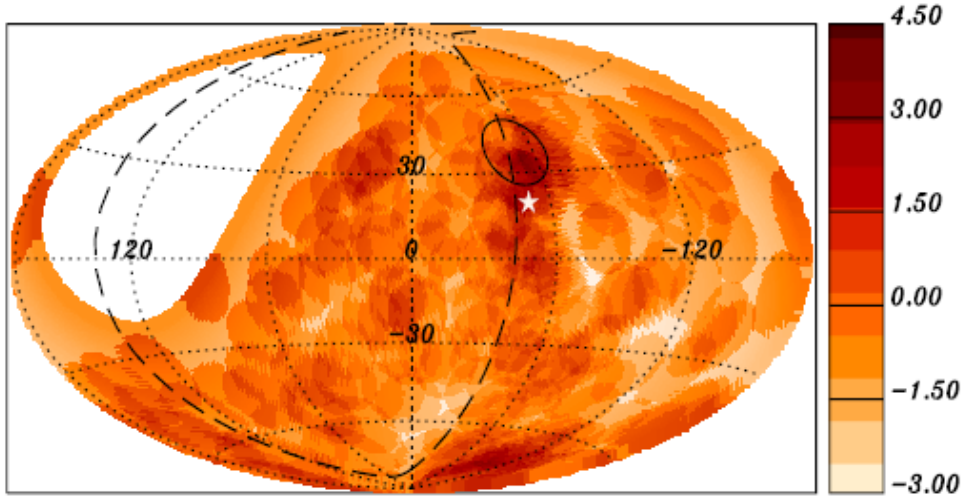
Photon & neutrino limits

They disfavour most of the exotic decay scenarios to produce UHECR and favour acceleration in astrophysical scenarios

They are reaching the guaranteed cosmogenic fluxes

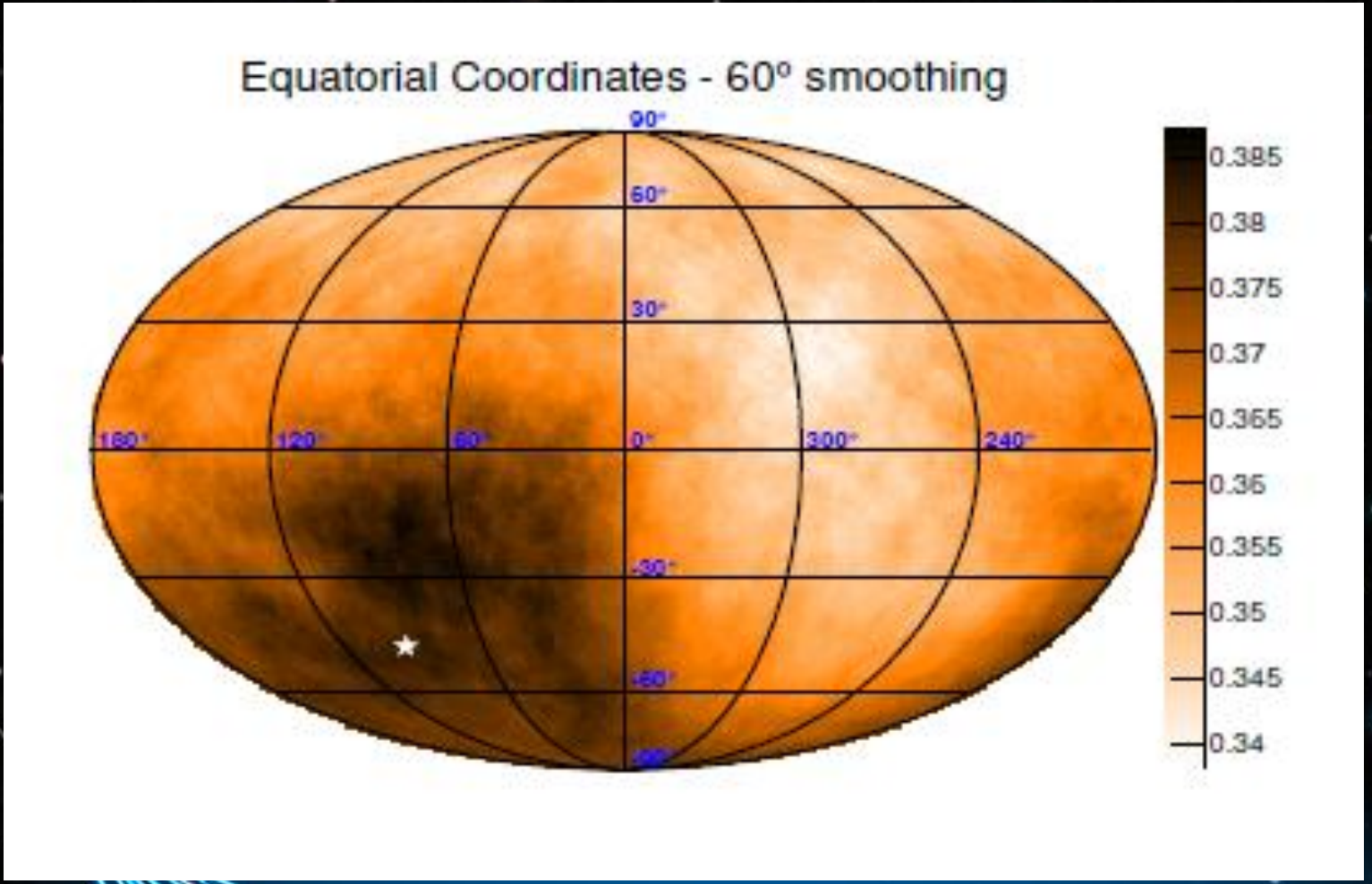
Where are the sources?



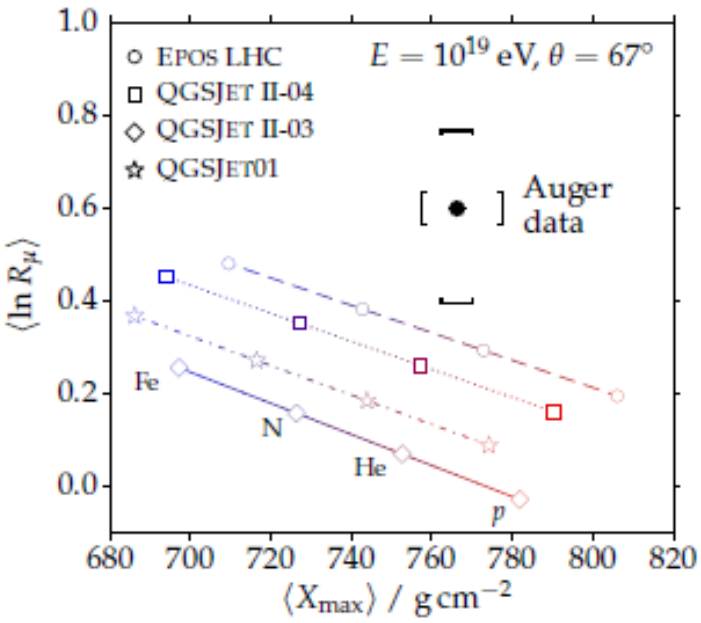


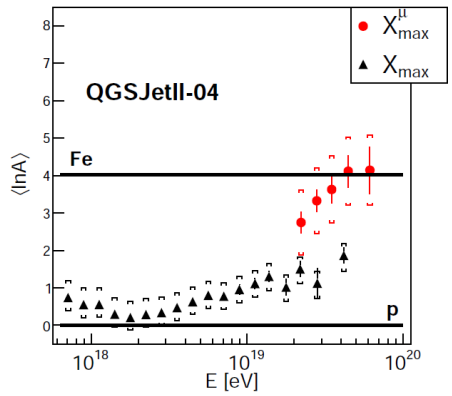
- Absence of anysotropies at the highest energies
- Hot spot around Cen-A, but not significant (yet?)

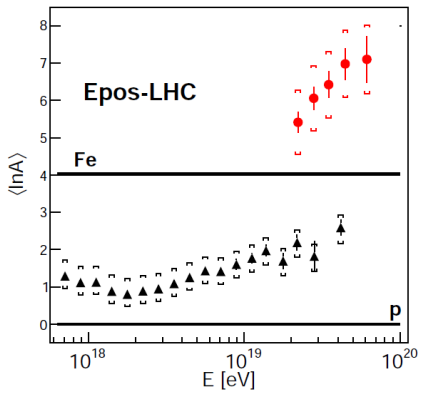
A misterious dipole at 10 EeV



Hadronic Physics







Our interpretation of air shower rely on unexplored physics: energies above LHC and forward regions

We know that something is missing in the current high energy hadronic models.

New physics?

A multidisciplinary field

Cosmology & Astrophysics

- Acceleration Scenarios
  - AGN, GRB,…
- Decay Scenarios
  - Super Heavy Dark Matter
  - Cosmic Strings
  - Relic Particles
- Propagation:
  - Galactic & Extragalactic magnetic fields
  - Source evolution
- Astrophysical Gamma Ray Sources
- GZK neutrinos
- Lorentz Violation

Particle Physics

- High Energy Hadronic Interaction Models
- LHC-complementarity measurements
- New phenomena
  - high density QCD
- Exotic particles
  - Magnetic Monopoles
  - Mini-Black Holes
  - R-Hadrons

A multidisciplinary field

Shower Phenomenology

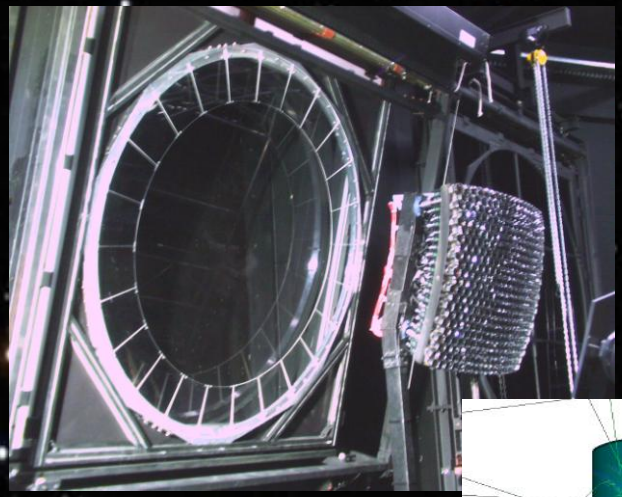
- Balance and evolution of the cascades
- EM radiation:
  - MHz (Geosyncrotron, Cerenkov)
  - GHz (Molecular Bremshtrahlung)
  - UV-light (Air Fluorescence, Cerenkov)
- Plasma formation
  - Radar detection, Molecular Bremstrahlung)

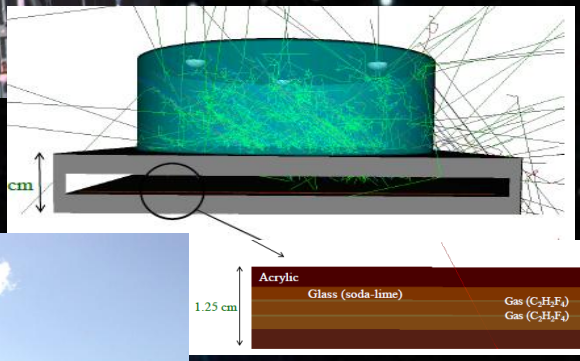
Earth Sciences

- Atmosphere
- Lighning
- Space weather
- Seismology
  - 1600 GPS stations tracking a large active area!

A multidisciplinary field

- Technology R&D
  - Particle Detectors
    - Cerenkov tanks
    - RPC's
    - Scintillators
  - DAQ
  - Electronics
  - Communications
  - LASERs , LIDARs
  - RADAR
  - Antenna Design
    - MHz
    - Microwaves
  - Optics:
    - Telescopes
    - Optoelectronics
  - Solar Pannels





Developed skills

- Physics
- Mathematics
- Technology (R&D)
- Software
  - C++, shell scripting, parallel computing…

- Data Science
  - Data mining
  - Monte Carlo
  - Machine learning
  - …
  - Synthesis and Display

Our currents trends (but not only)

Physics & data science

Understand air showers dynamics to access physics beyond the LHC energies.

Primary mass determination

Research and development

New generation of high-precission particle detectors. Applications to fundamental and applied science.


Enroll!
Thanks!!!