Cosmic ray composition measurements

and

cosmic ray background free γ-ray observations

with

Cherenkov telescopes

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University of Geneva

… and D.Semikoz, Ie.Vovk, R.Mirzoyan, **arXiv:1610.01794** (Phys.Rev. D)

Overview

Introduction / motivation: how rejection of cosmic ray background and measurement of cosmic ray composition in space detectors and in the air shower arrays

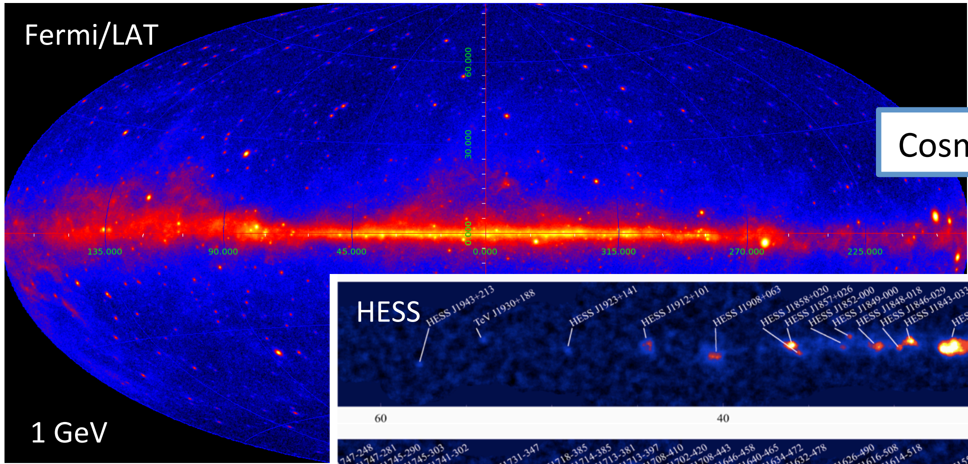
Muon component of strongly inclined air showers

Imaging of Cherenkov light of the muon component

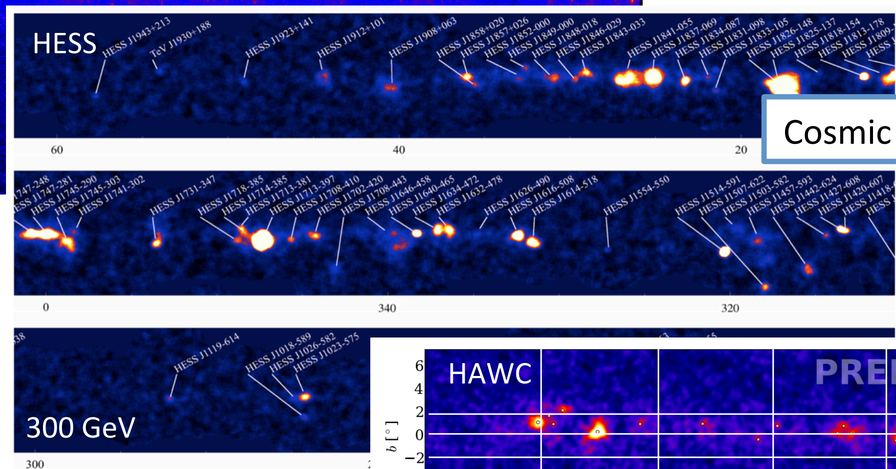
Rejection of cosmic ray background in imaging Cherenkov telescopes, based on the imaging of the muon component of the air showers

Cosmic ray composition in the PeV-EeV range with imaging Cherenkov telescopes

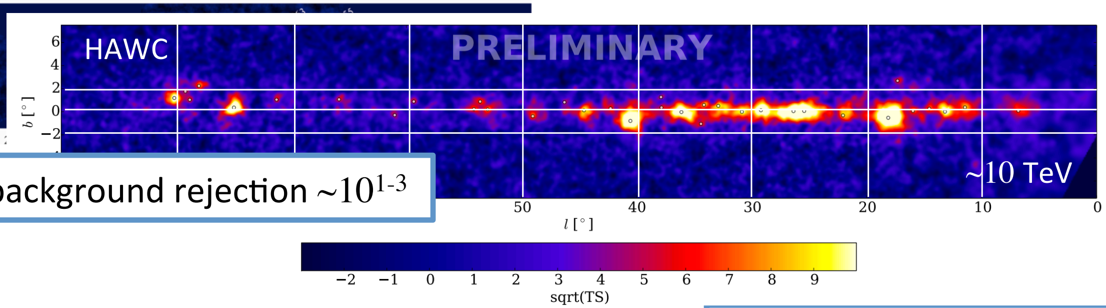
Suppression of cosmic ray background for γ-ray observations



Cosmic ray background rejection ~10^6



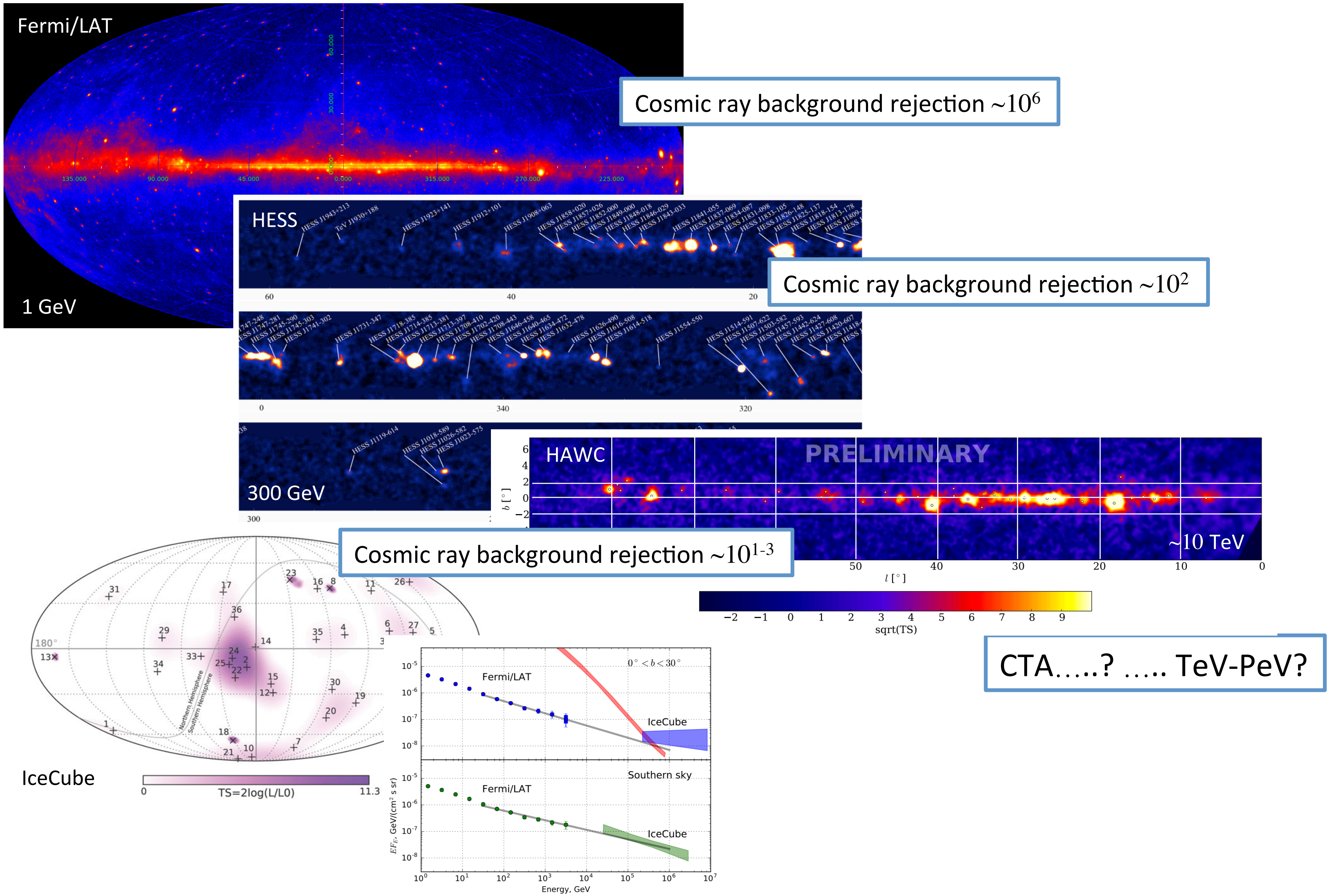
Cosmic ray background rejection ~10^2



Cosmic ray background rejection ~$10^{1\text{-}3}$

CTA…..? ….. TeV-PeV?

Suppression of cosmic ray background for γ-ray observations



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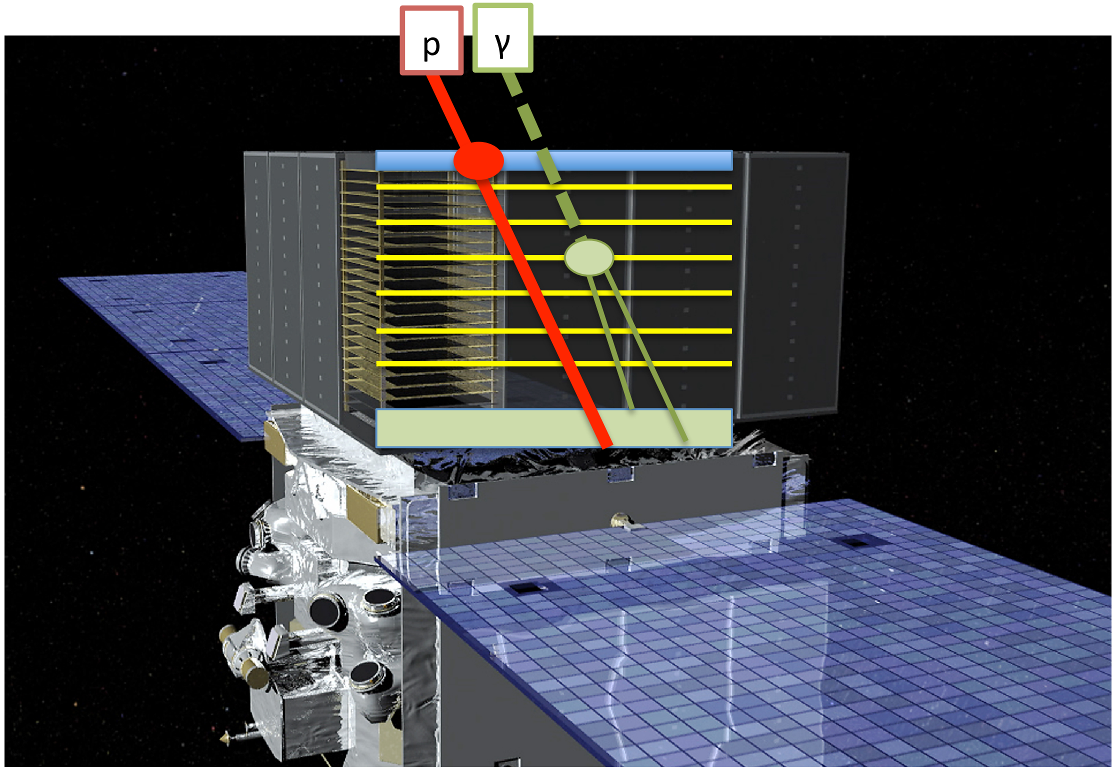
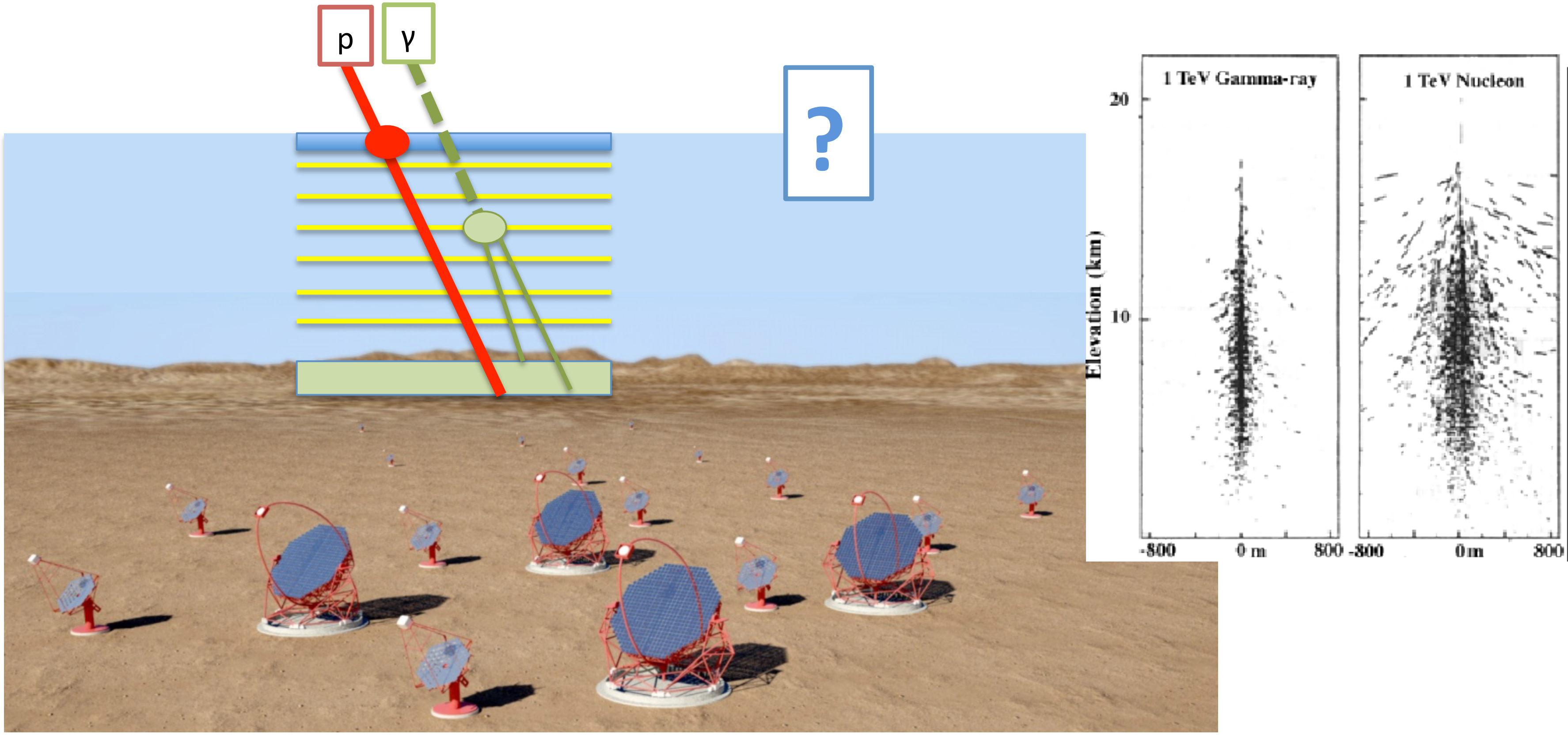


Fermi-LAT reaches a rejection factor $\sim 10^{-6}$ for the cosmic ray background through the use of

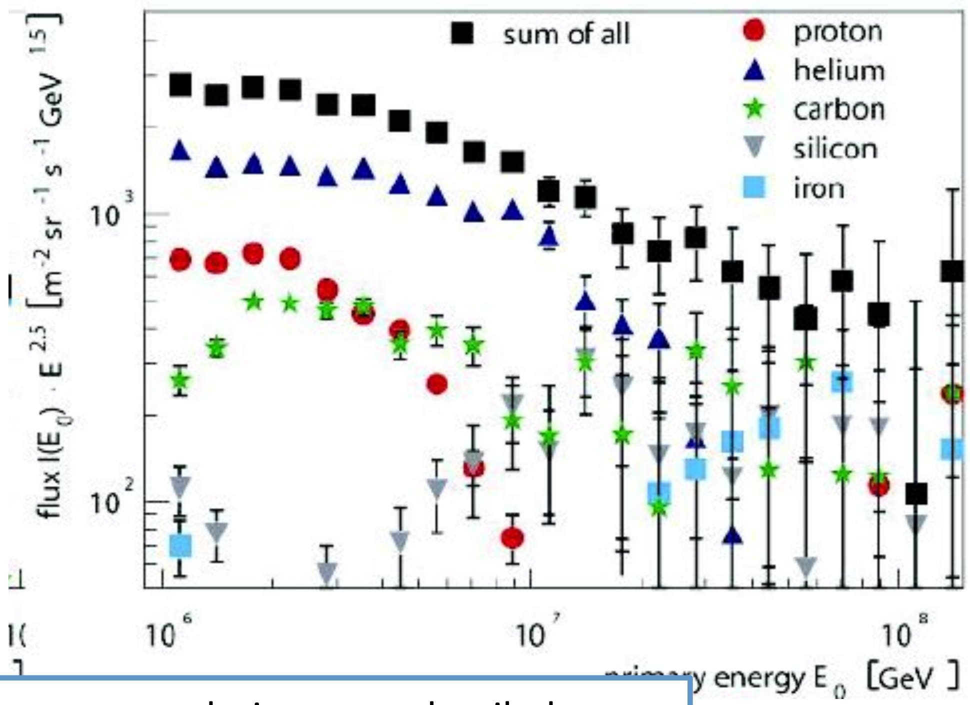
(a) anti-coincidence shield
(b) limited measurement of particle ID in the tracker and calorimeter

Suppression of cosmic ray background for γ-ray observations



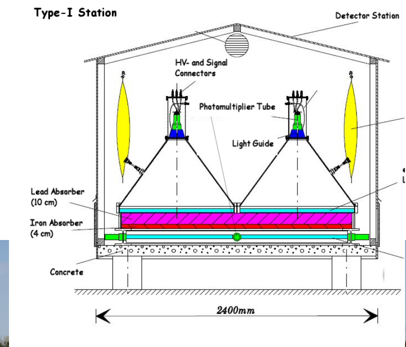
"Anti-coincidence shield" at the top of the atmosphere is hardly possible, but information on the primary particle ID helps to reduce the cosmic ray background in ground-based gamma-ray observations.

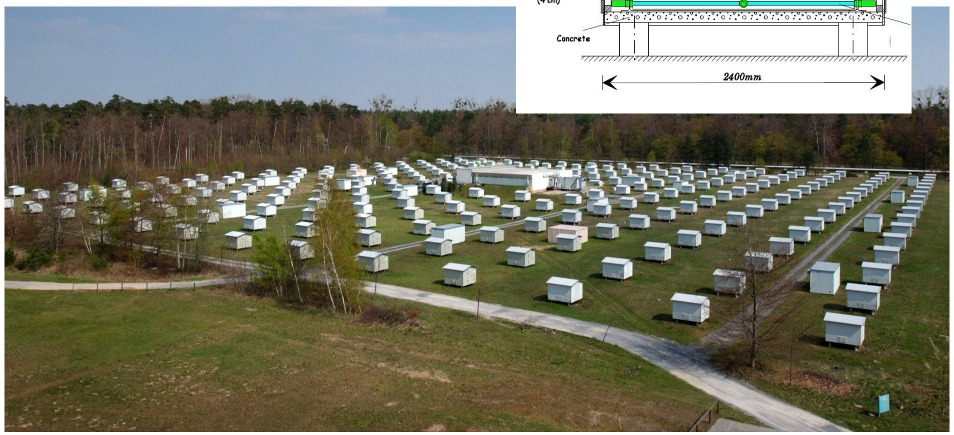
Measurements of particle ID for cosmic rays



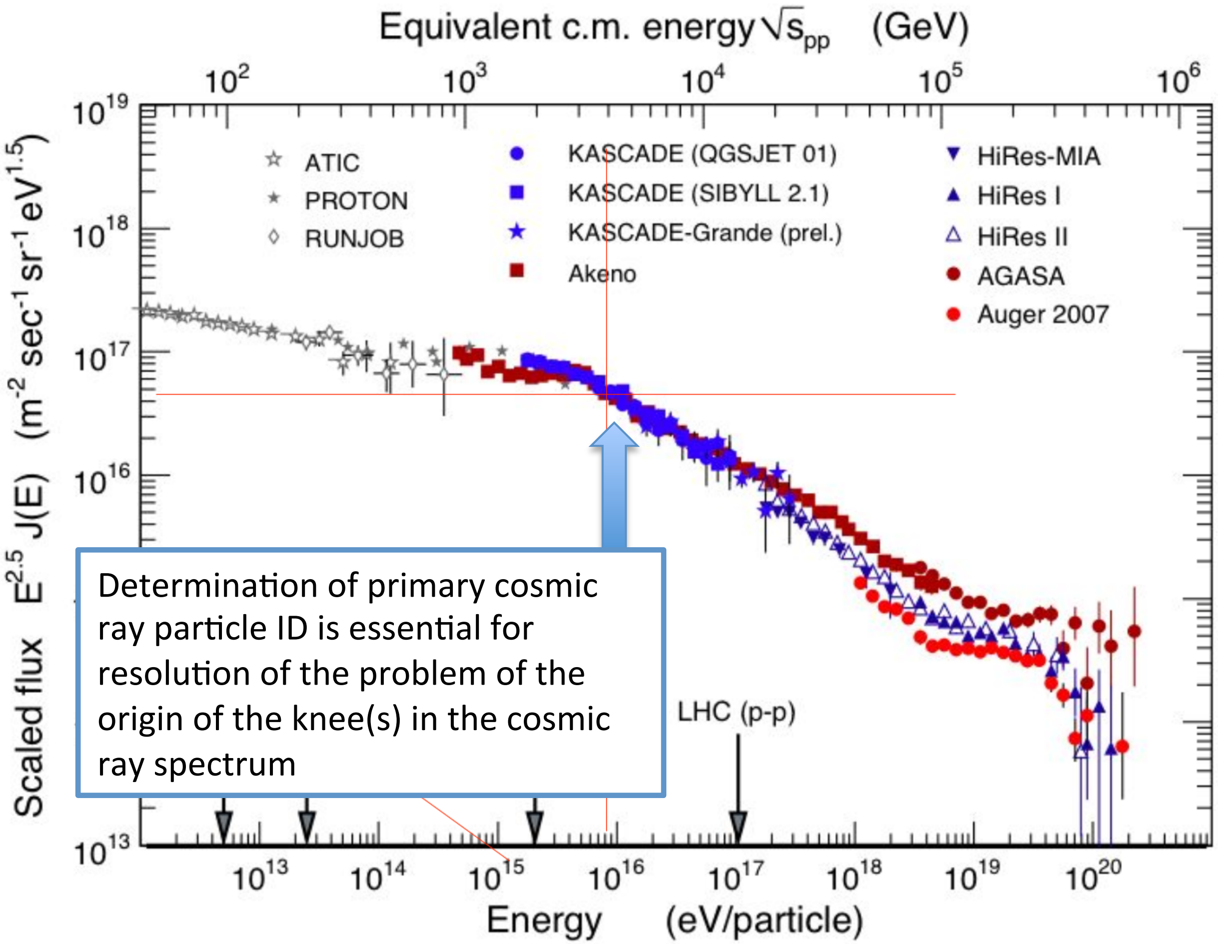
Air shower arrays derive more detailed primary particle ID based on the measurement of

(a) muon content of the showers



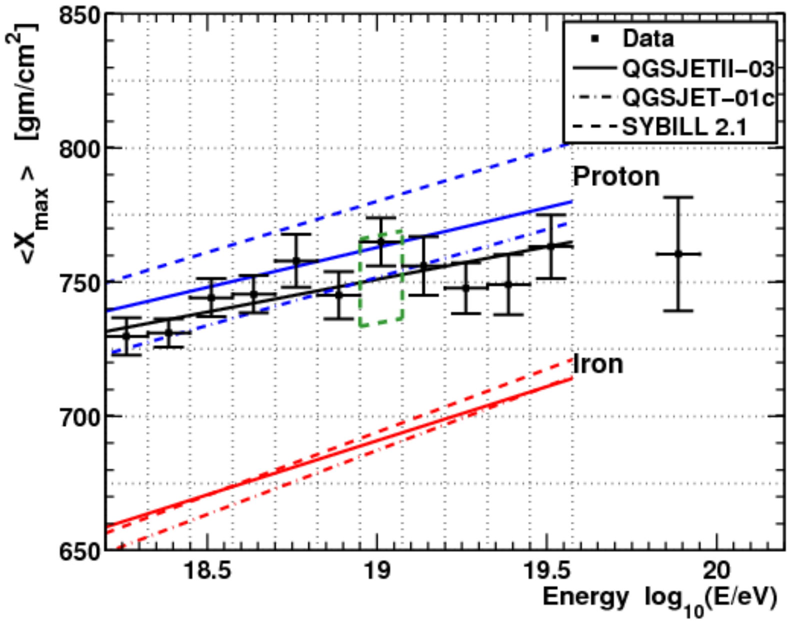


Measurements of particle ID for cosmic rays



Determination of primary cosmic ray particle ID is essential for resolution of the problem of the origin of the knee(s) in the cosmic ray spectrum

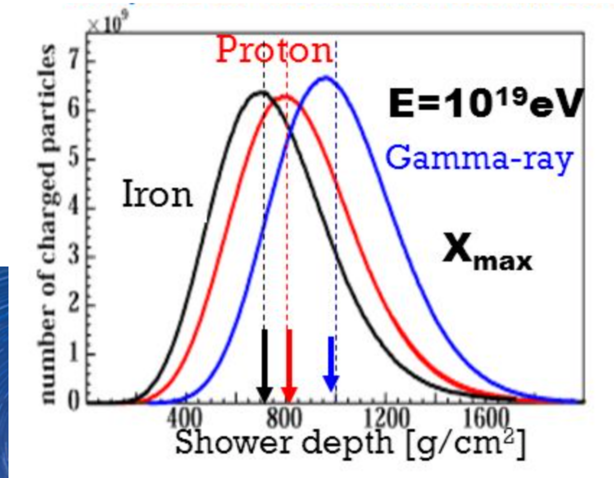
Measurements of particle ID for cosmic rays

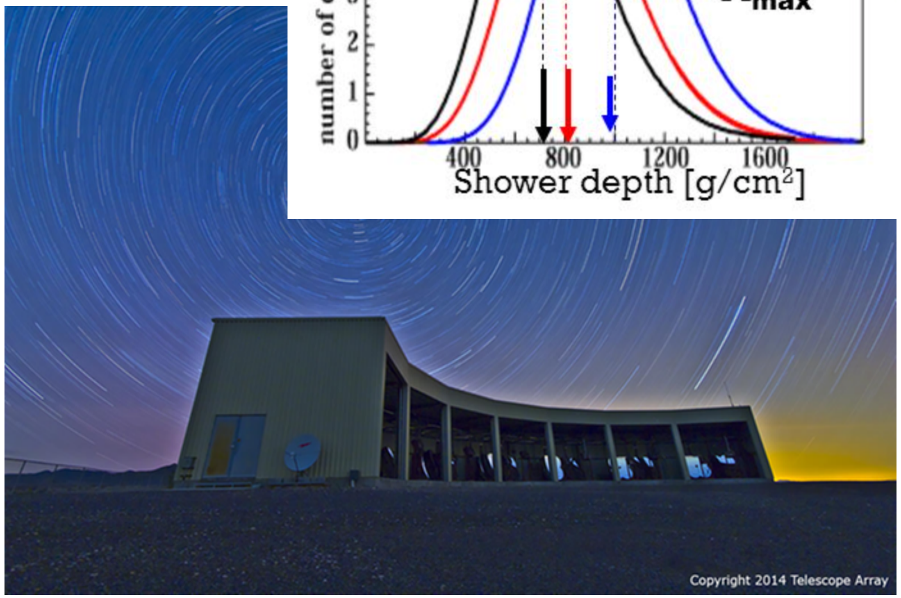


Air shower arrays derive more detailed primary particle ID based on the measurement of

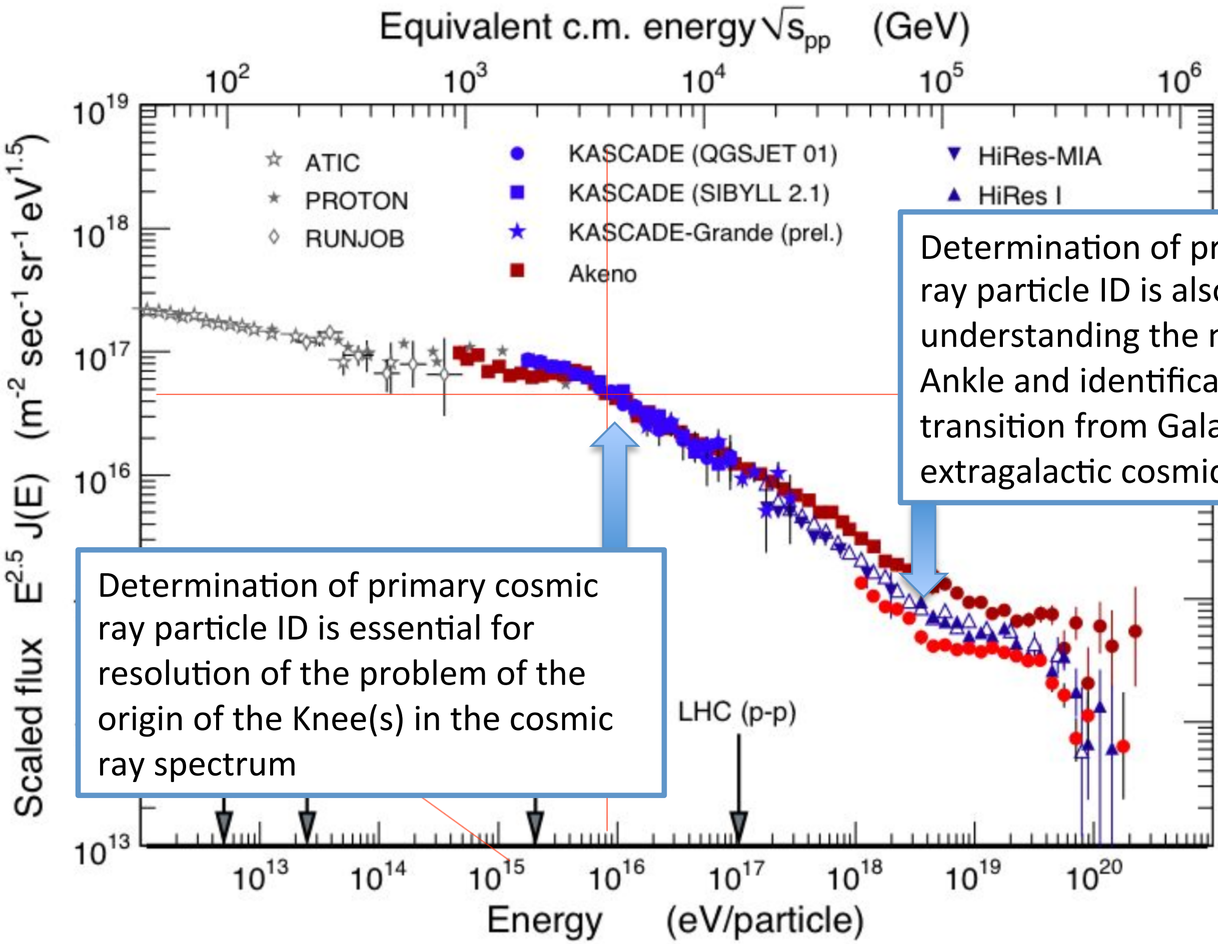
(a) muon content of the showers

(b) measurement of the depth of the shower maximum.





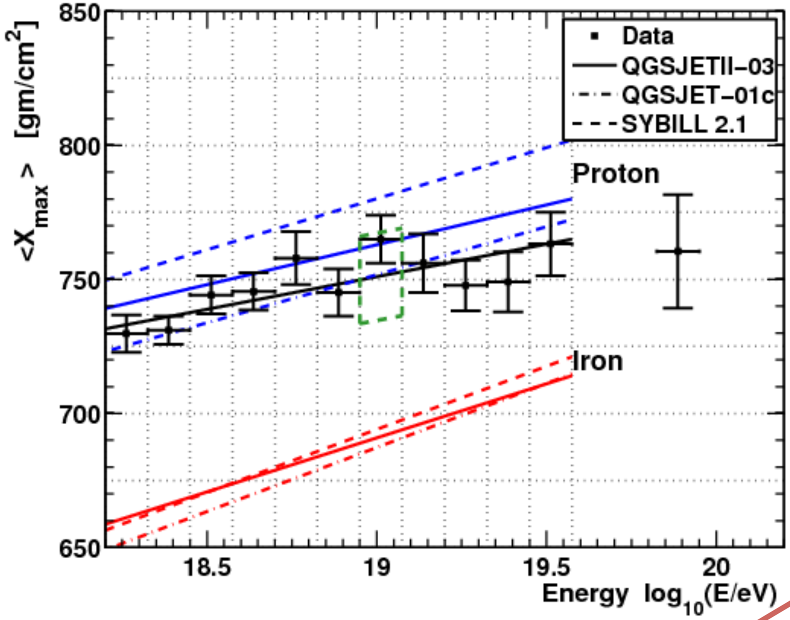
Measurements of particle ID for cosmic rays



Determination of primary cosmic ray particle ID is also essential for understanding the nature of the Ankle and identification of transition from Galactic to extragalactic cosmic ray flux.

Determination of primary cosmic ray particle ID is essential for resolution of the problem of the origin of the Knee(s) in the cosmic ray spectrum

Measurements of particle ID for cosmic rays



Air shower arrays derive more detail
primary particle ID based on the
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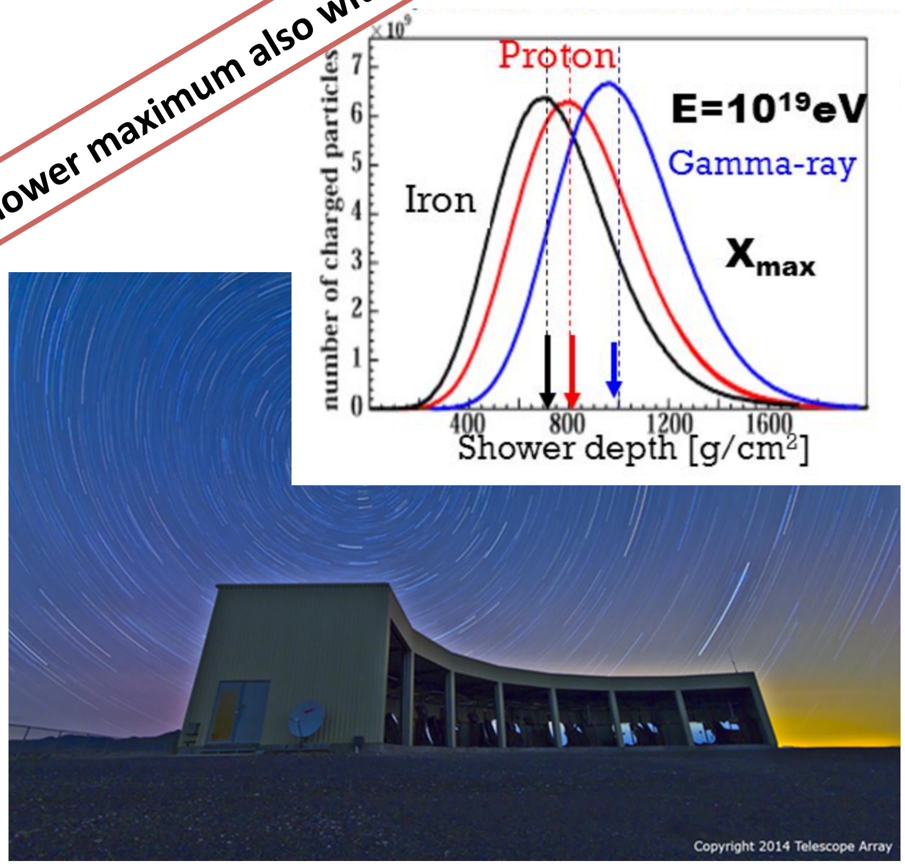
(a) muon content ... showers

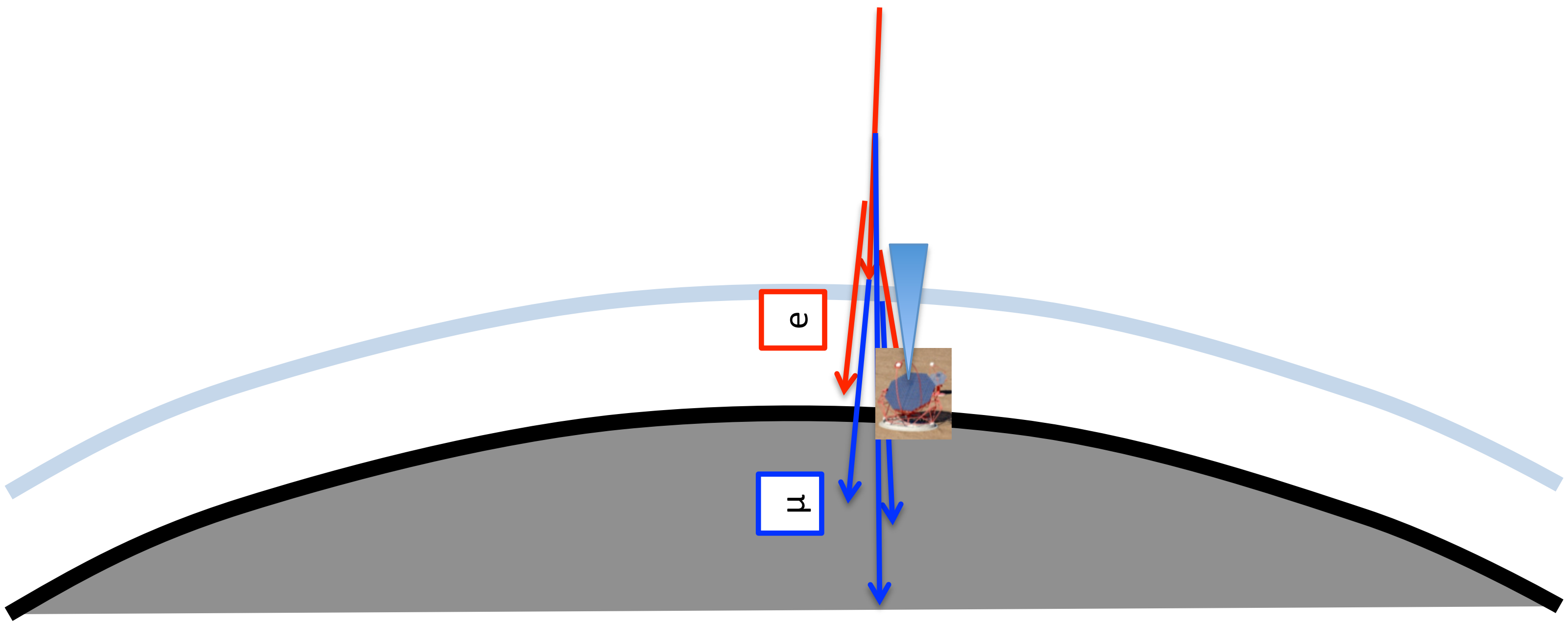
(b) measure... the depth of

the sh... aximum.

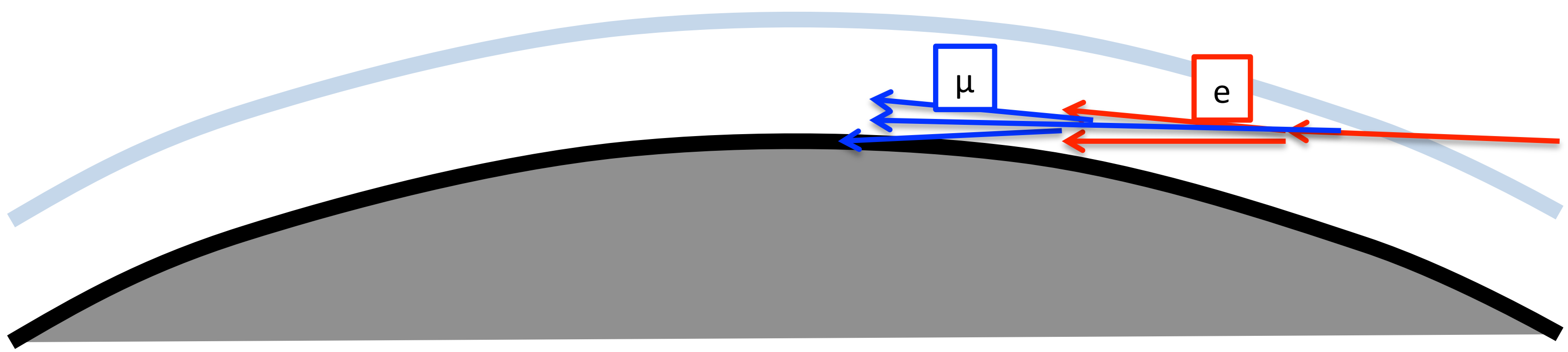
Could we measure muon content and the depth of the shower maximum also with Cherenkov telescopes?



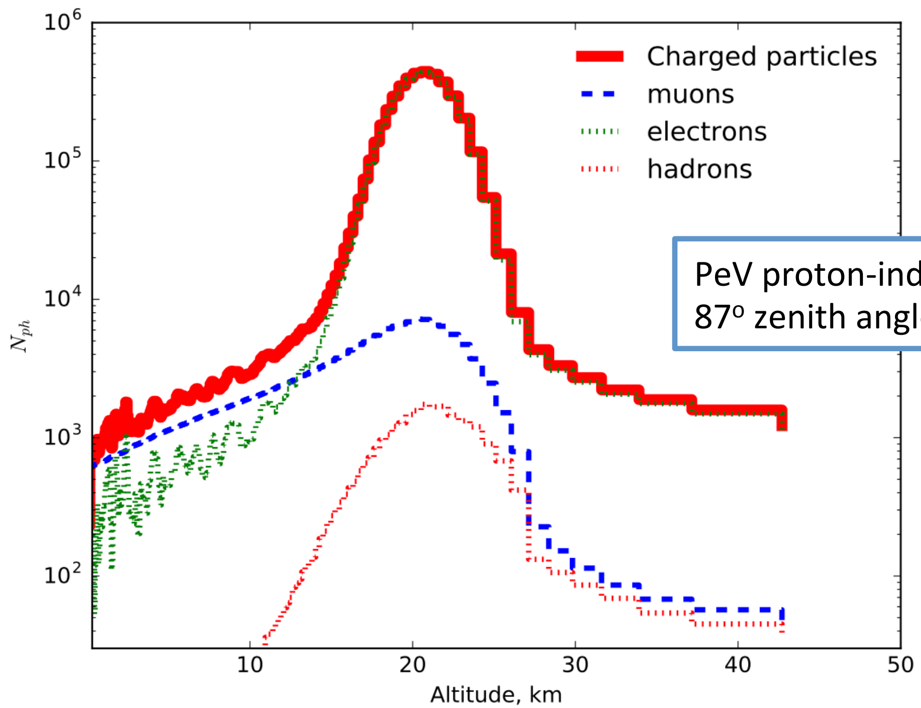
Cherenkov light from muon component of the air shower



Muon component of the air shower



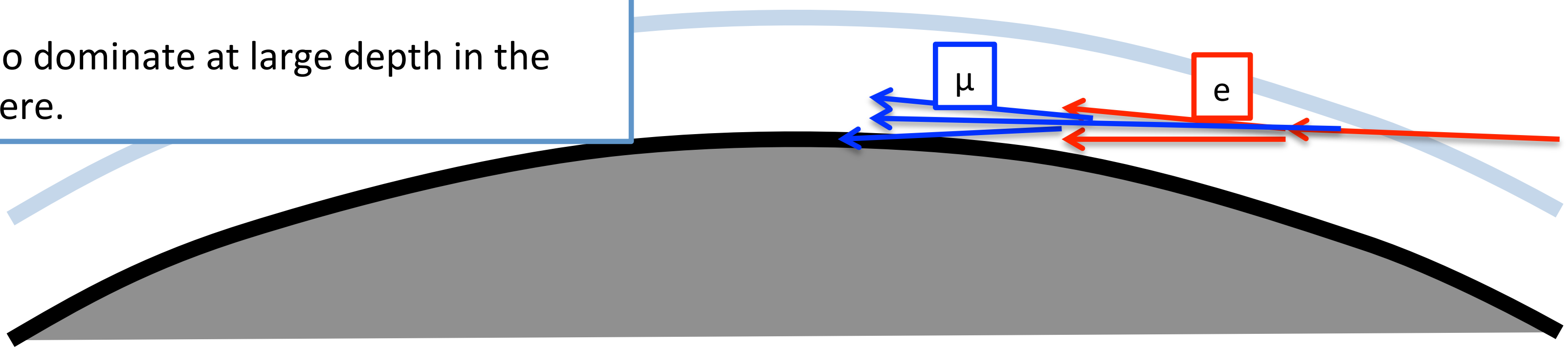
Muon component of the air shower



PeV proton-induced shower incident at 87° zenith angle

Muon component is largely sub-dominant in the shower maximum region.

It starts to dominate at large depth in the atmosphere.



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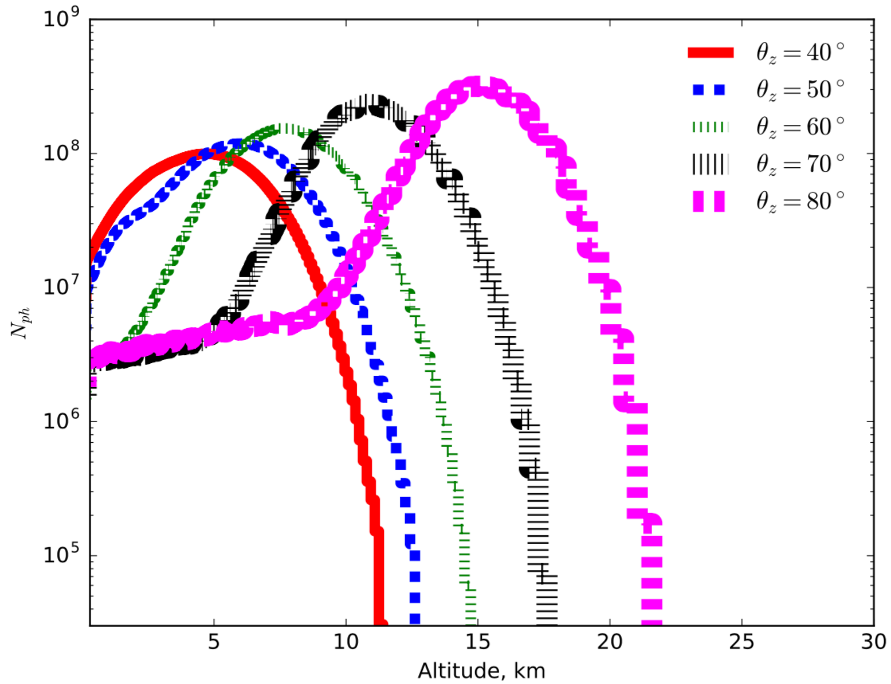
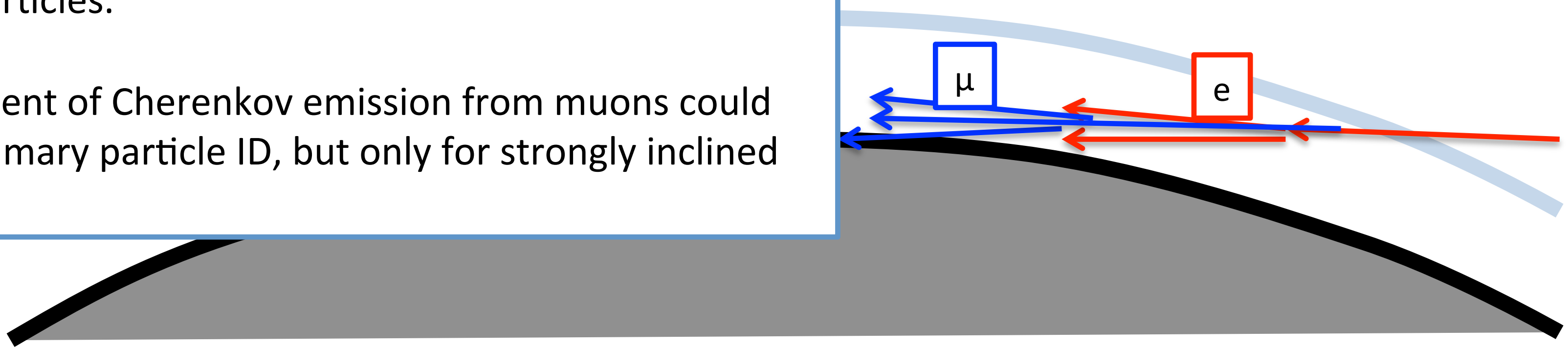


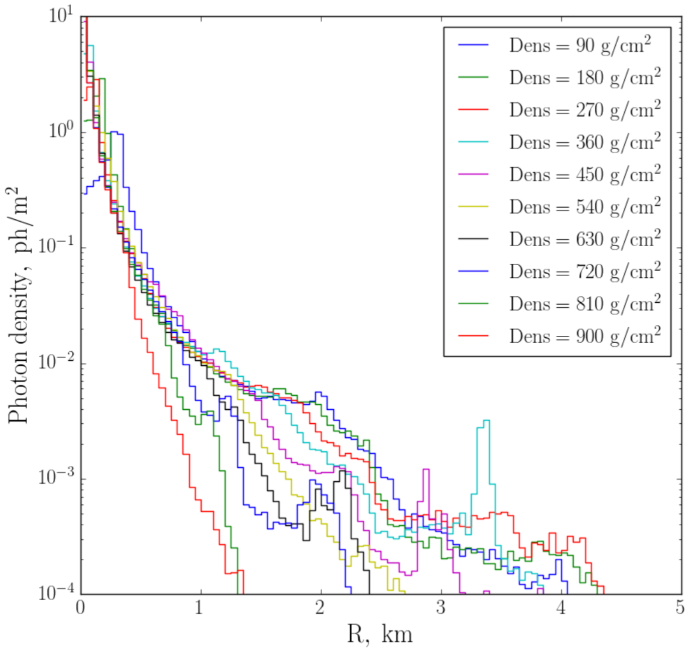
Muons emit Cherenkov light, similarly to electrons.

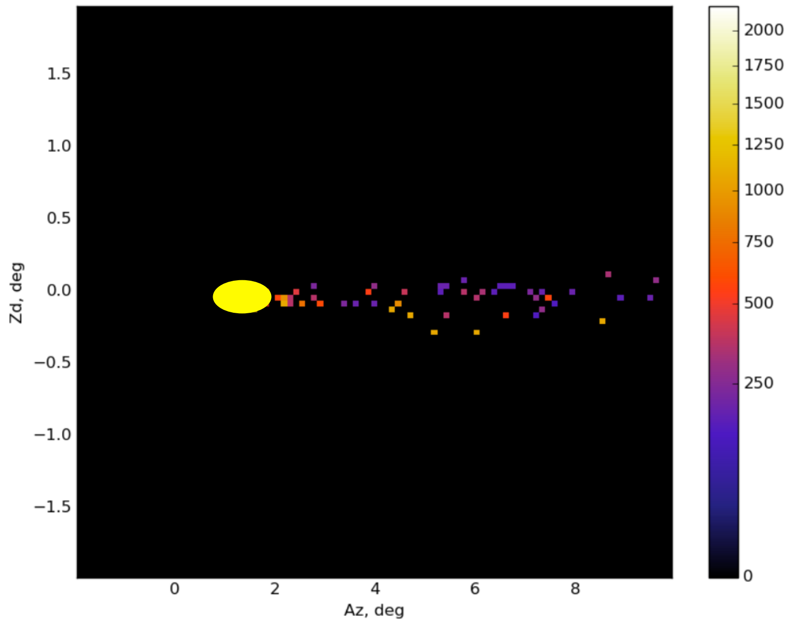
Muon Cherenkov emission is widely different for different primary particles.

Measurement of Cherenkov emission from muons could provide primary particle ID, but only for strongly inclined showers.



Imaging of Cherenkov light from muon component of the air shower



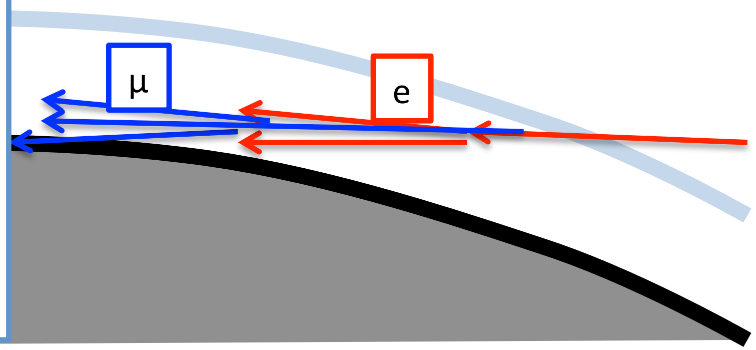


Muons from strongly inclined showers reach the ground and are spread over large distance range.

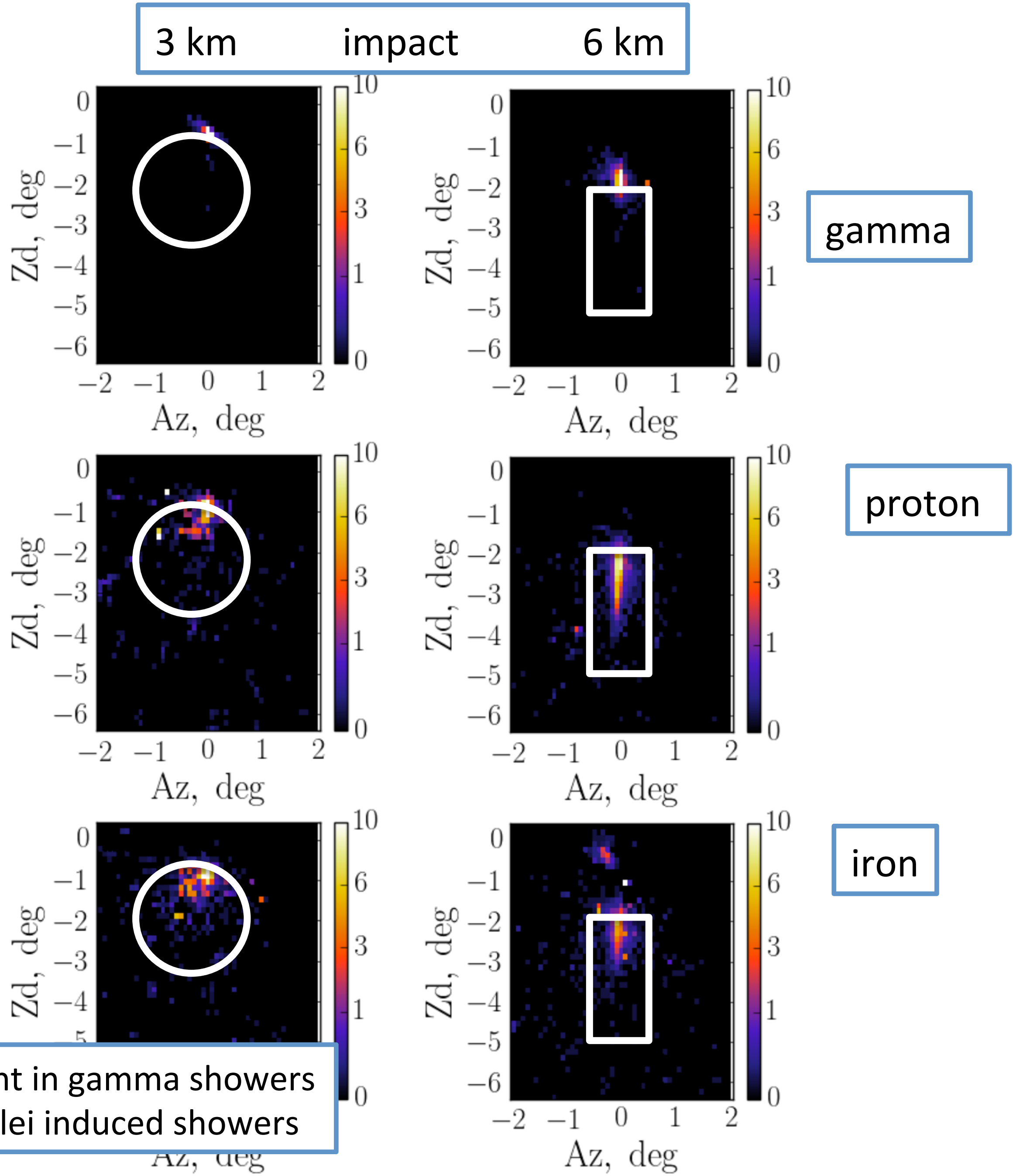
Superimposed fragments of "muon rings" of individual muons form a many-degree-long "tail" image.

To the contrary, image of electromagnetic component of the shower is compact

Gamma-ray induced showers are muon-poor and, therefore, do not exhibit the "muon tail".

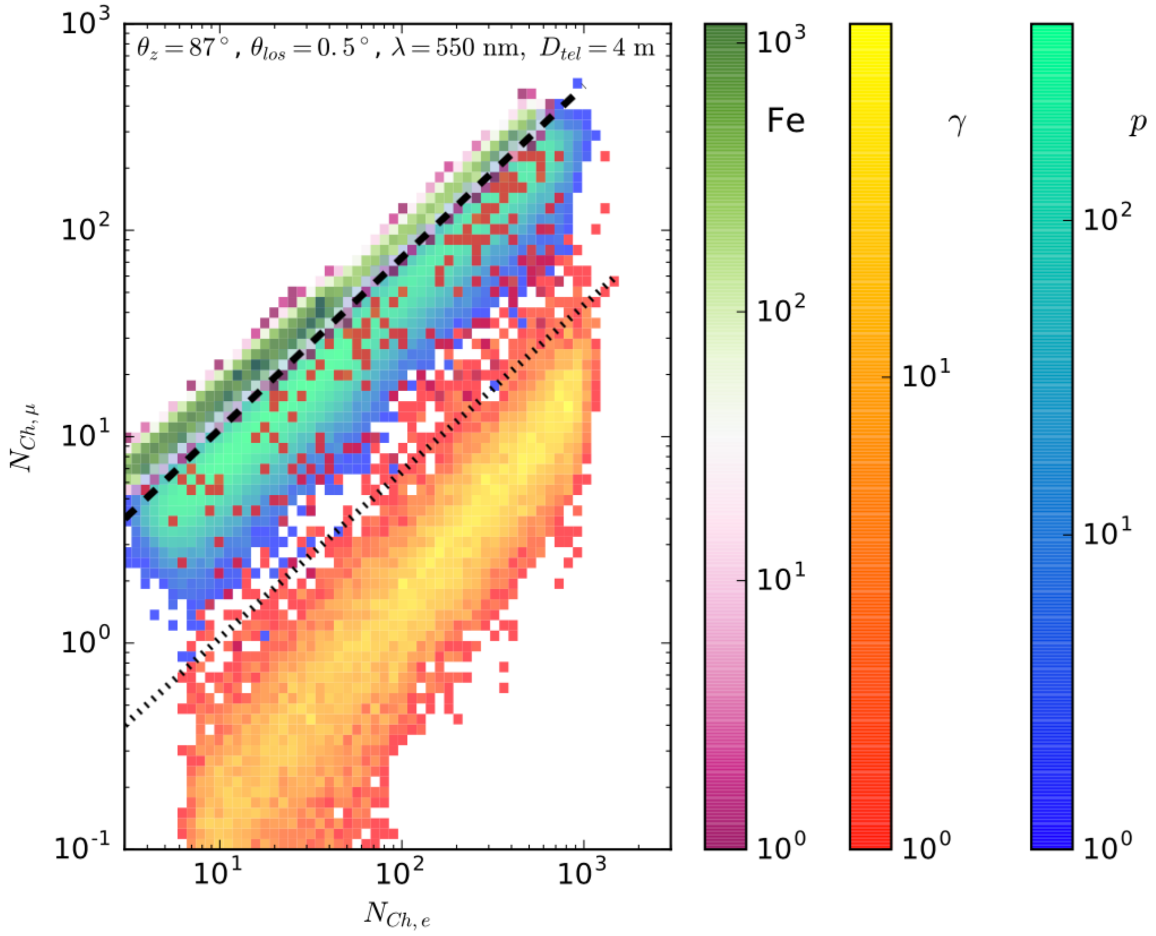


Imaging of Cherenkov light from muon component of the air shower



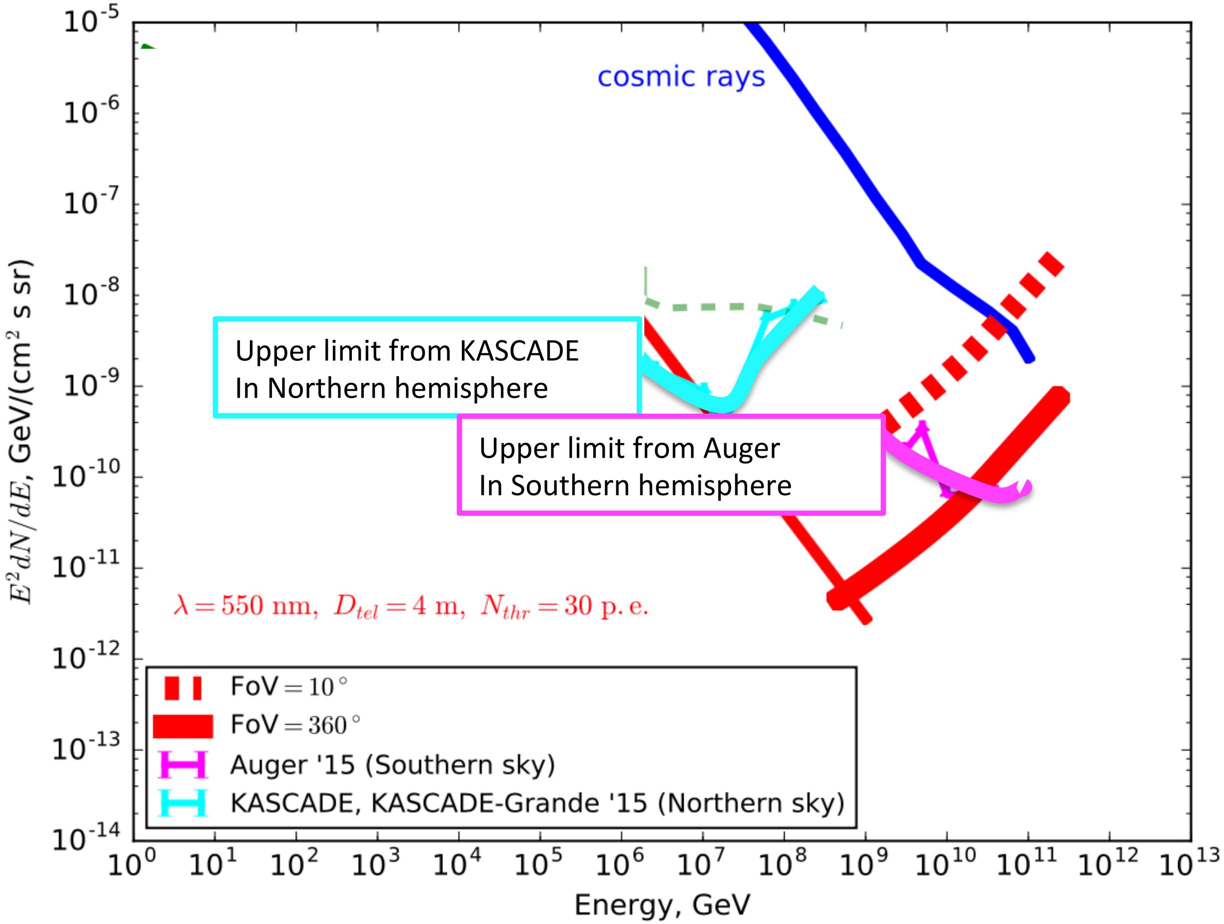
Muon "tail" or "halo" is absent in gamma showers but is present in proton / nuclei induced showers

Cosmic ray background rejection for gamma-ray observations



Proton and nuclei induced highly inclined shower images are strongly dominated by muon tail component. Gamma-ray shower images are compact. Requirement of non-detection of muon tail down to certain (energy-dependent) fraction of the electromagnetic shower size suppresses cosmic ray backgorund by a factor up to **10^5**.

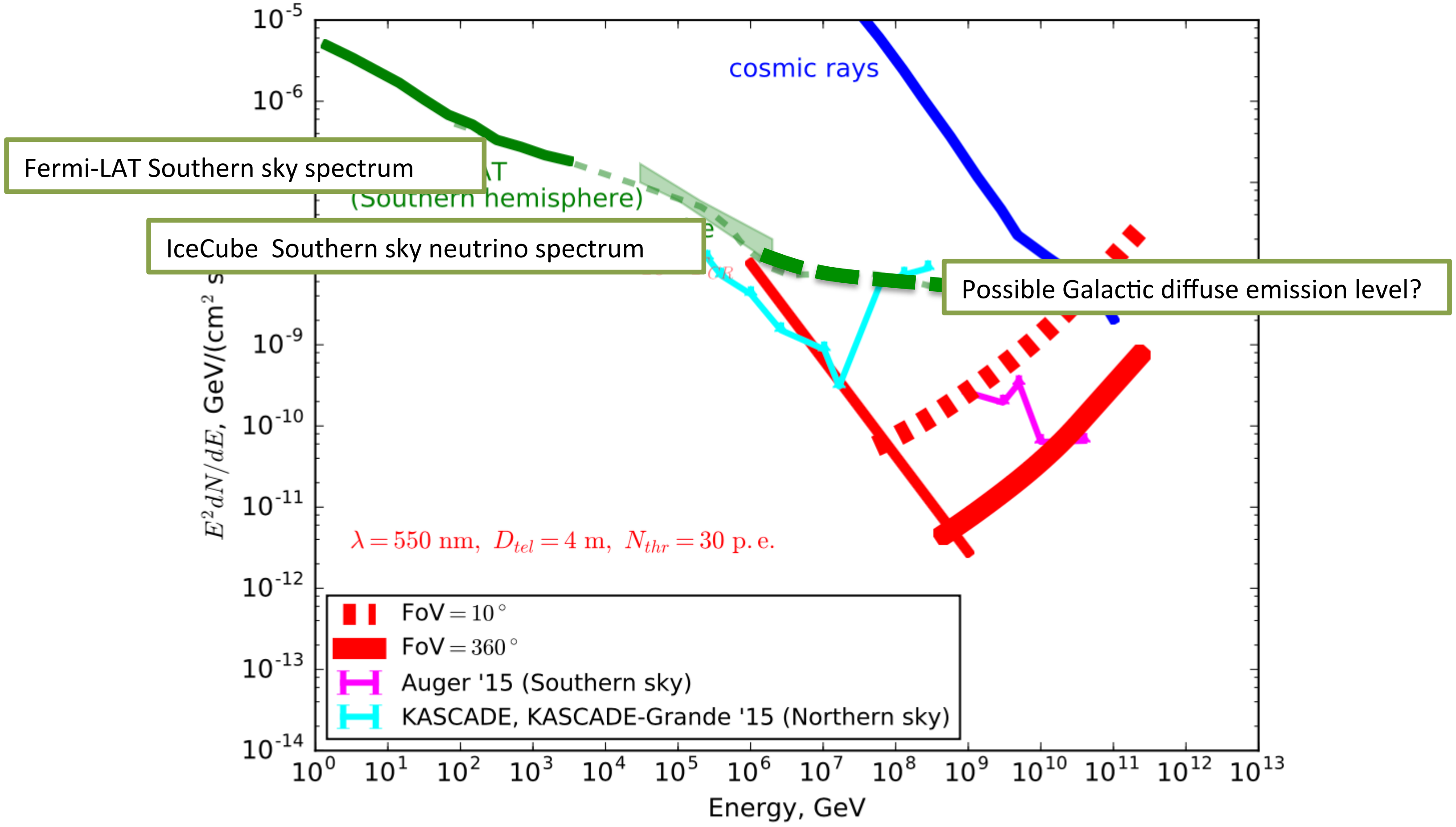
PeV gamma-ray sky



The energy threshold for observations of nearly horizontal showers with 4 m class Cherenkov telescopes is rather high. The 10^{-5} suppression factor for the cosmic ray background could be achieved only in the PeV range.

No gamma-ray sources have previously been observed in this energy band…….

PeV gamma-ray sky



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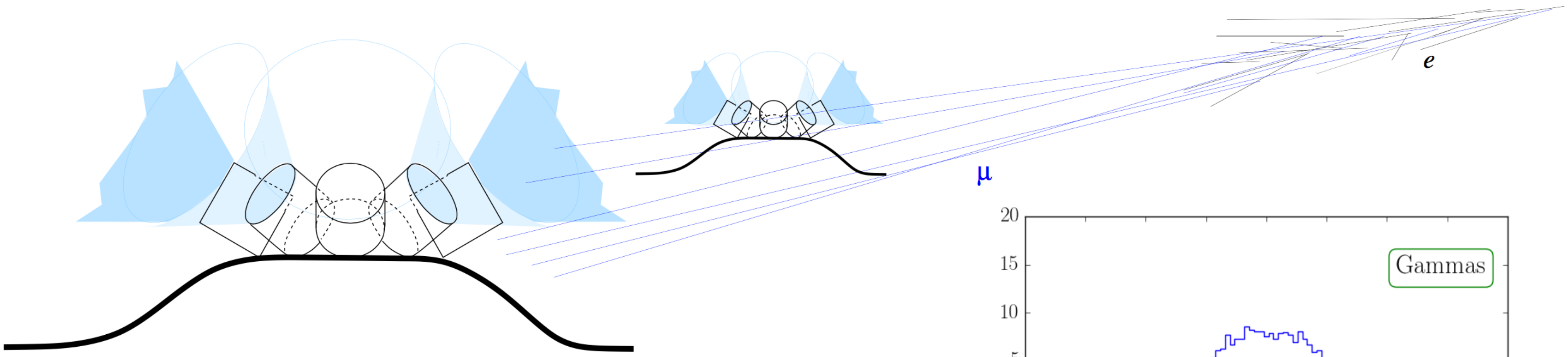
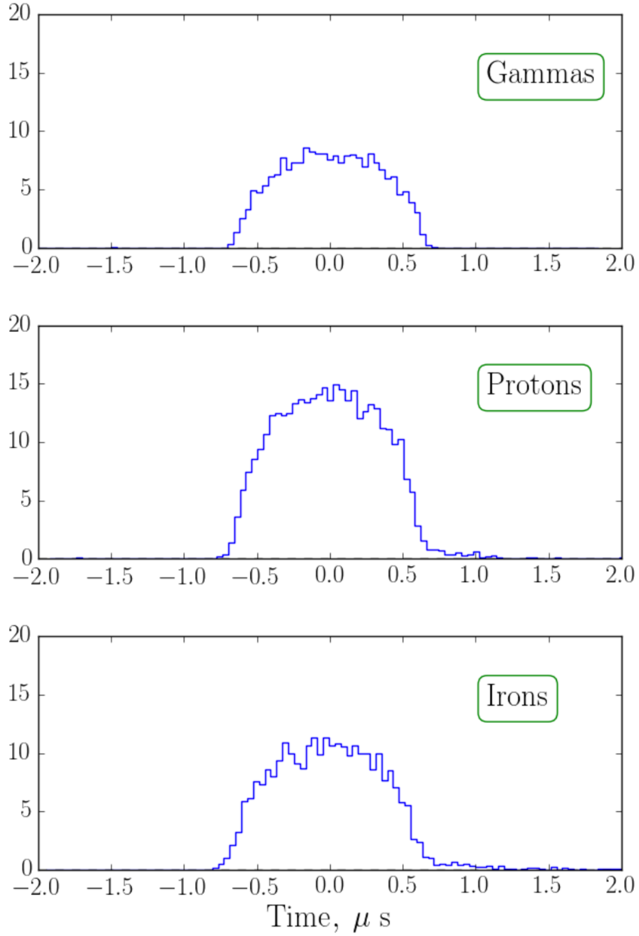
Observations of nearly horizontal air showers

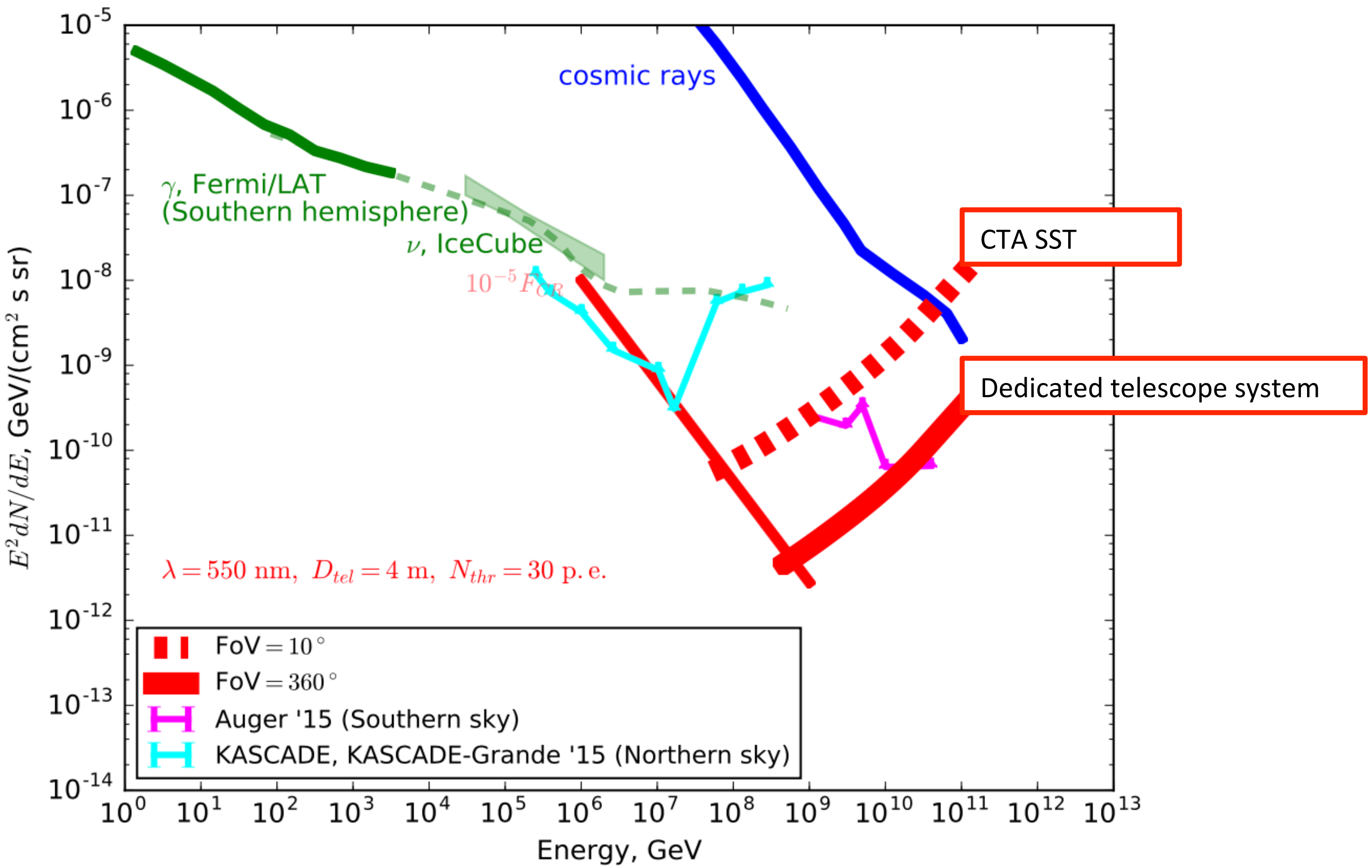




A setup optimized for observations of PeV diffuse emission in background-free regime should consist of a system of telescopes overlooking the entier 360^{o} strip along the horizon.

Trigger and readout system should be optimized for relatively long time scale of the signal: ~ 1 μs.

PeV gamma-ray sky



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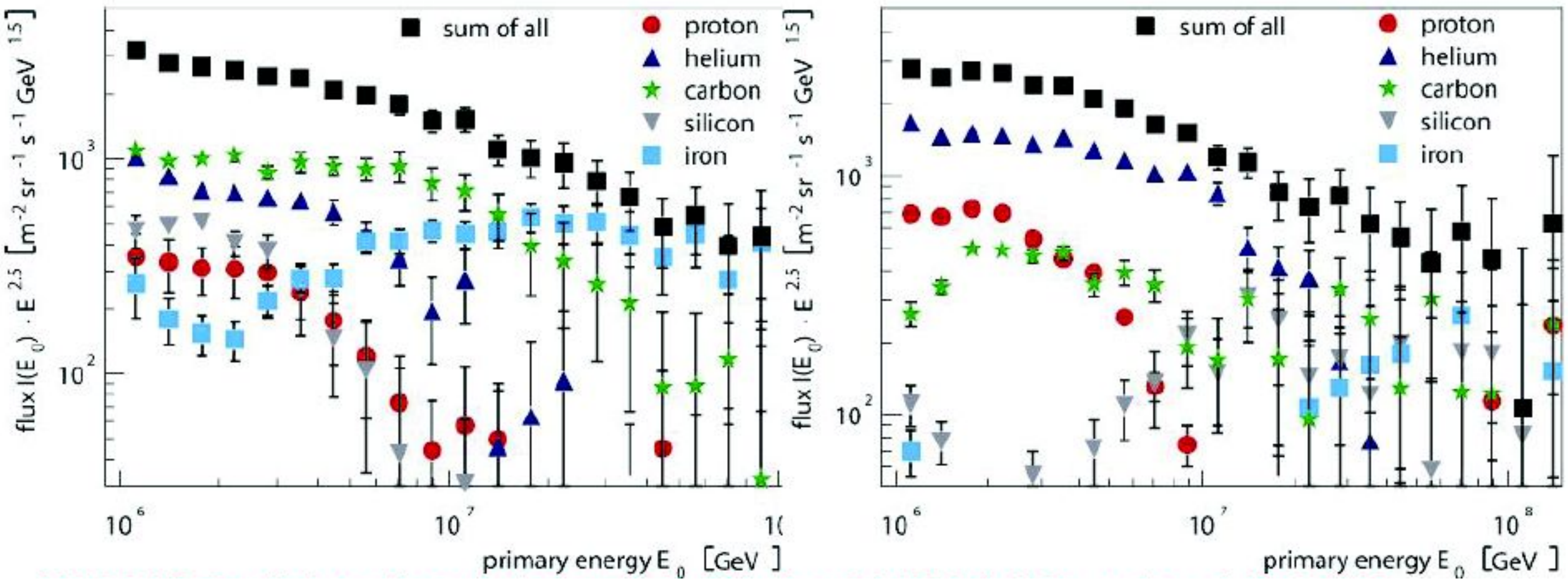
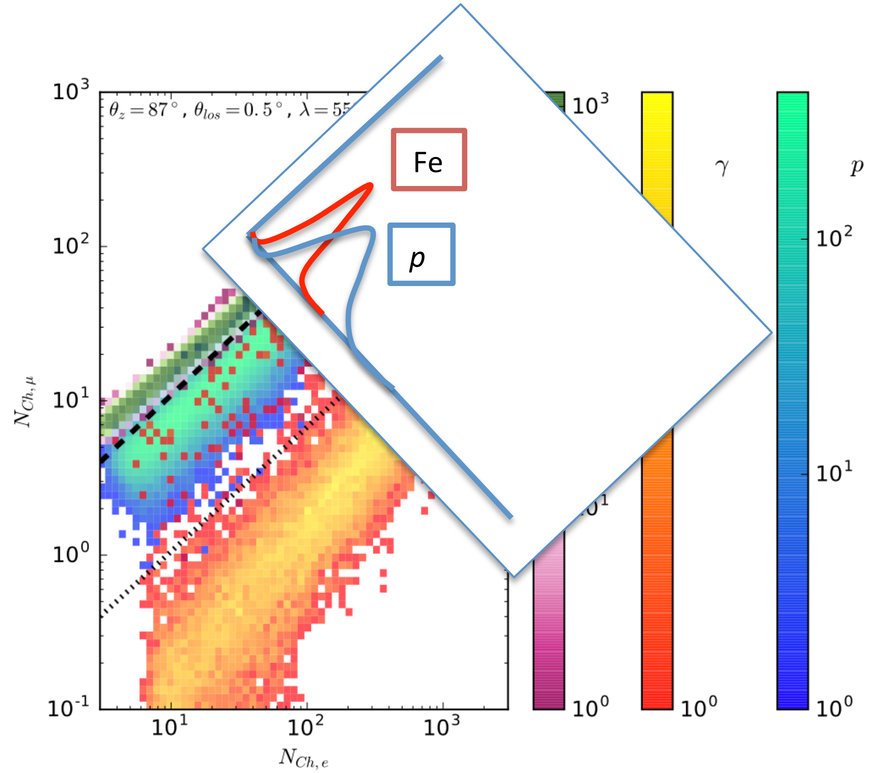
Cosmic ray composition measurements



KASCADE and KASCADE-Grande measurements of composition in the knee-ankle energy range show strong dependence on the hadronic interaction model used.

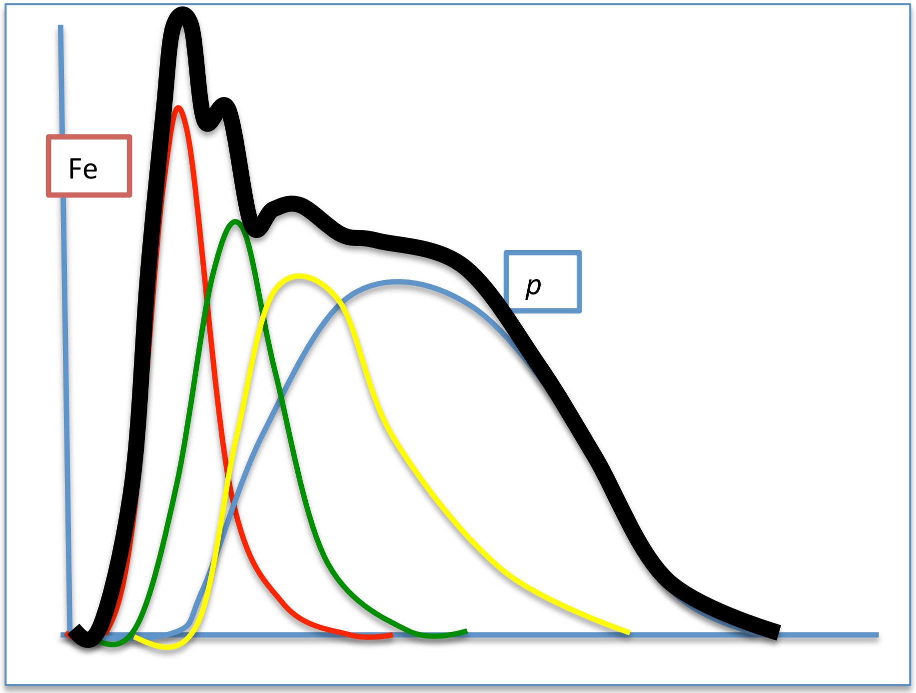
Account of LHC constraints did not improve the situation: ambiguity on details of light / heavy nuclei partial contributions to the flux persist.

Cosmic ray composition measurements



Measurement of muon content of strongly inclined showers also provides information on the primary particle ID for the cosmic ray nuclei.

Cosmic ray composition measurements

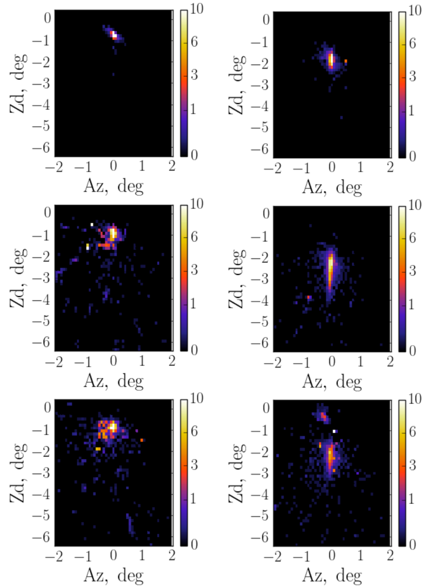


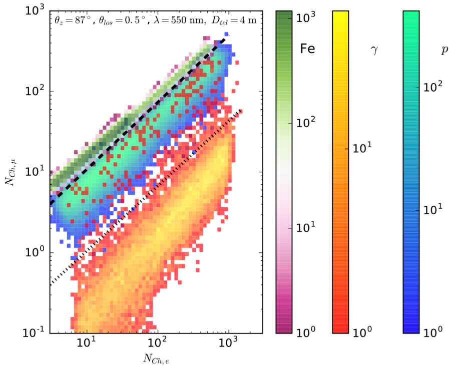
Measurement of muon content of strongly inclined showers also provides information on the primary particle ID for the cosmic ray nuclei.

This could be used to measure the detailed composition of the cosmic ray spectrum in the knee-ankle energy range in a way which is complementary to the KASCADE measurements: it does not rely on measurement of particles surviving to the ground level

Summary

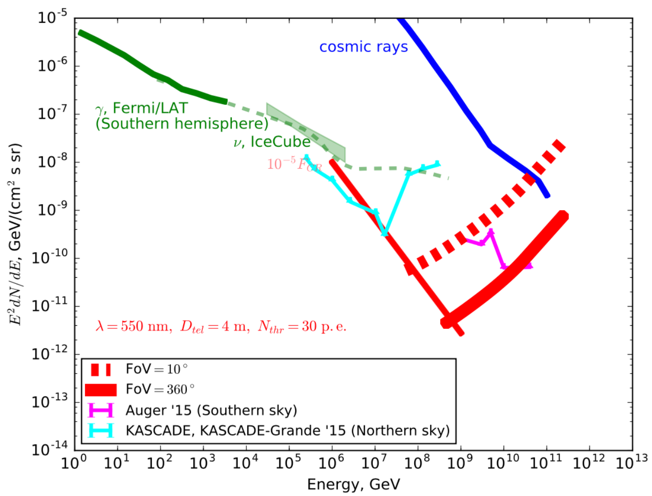
Images of strongly inclined air showers from primary cosmic ray nuclei have strong muon “tail” component

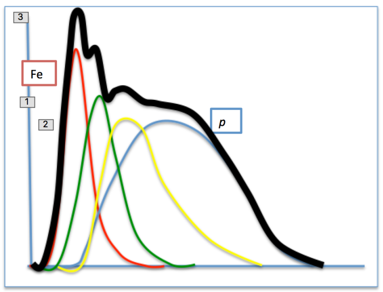




Vetoing of the tail component showers allows suppression of the cosmic ray background by up to 10^5 for gamma-ray observations

This provides a possibility for exploration of the PeV gamma-ray sky in backgorund-free regime





Measurement of the size of the muon component providesa possibility for the study of composition of cosmic ray spectrum above PeV energy