Recent achievements from the Pierre Auger Observatory

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Fermilab

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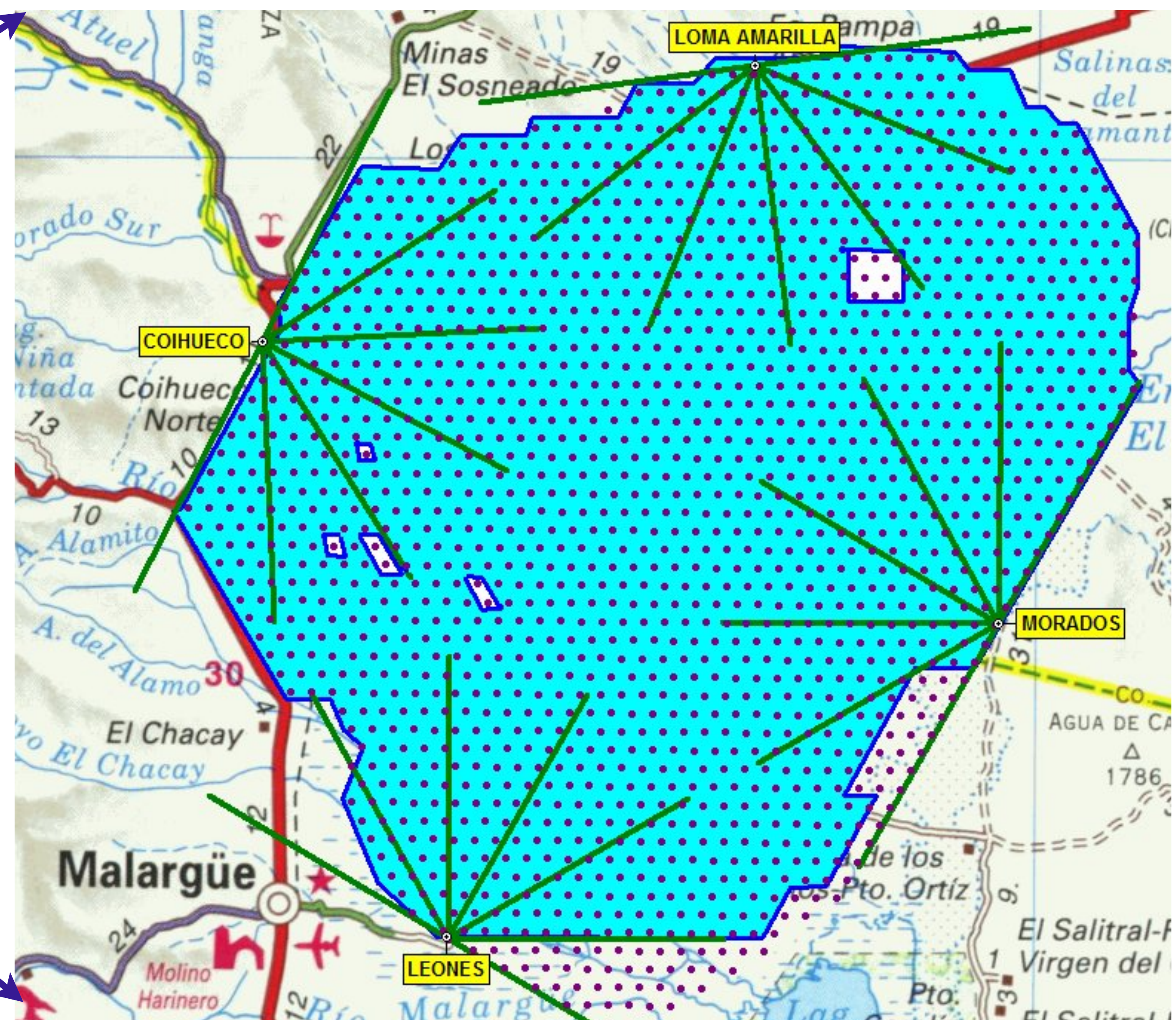
The Pierre Auger Observatory

Observe, understand, characterize the ultra high energy cosmic rays and probe particle interactions at the highest energies

- Malargüe, Mendoza, Argentina ~ 3000 km^2
  - Hybrid: 4 air fluorescence detector sites & 1600 water Cherenkov detectors
  - Enhancements and R&D ongoing, upgrade to run beyond 2015 planned



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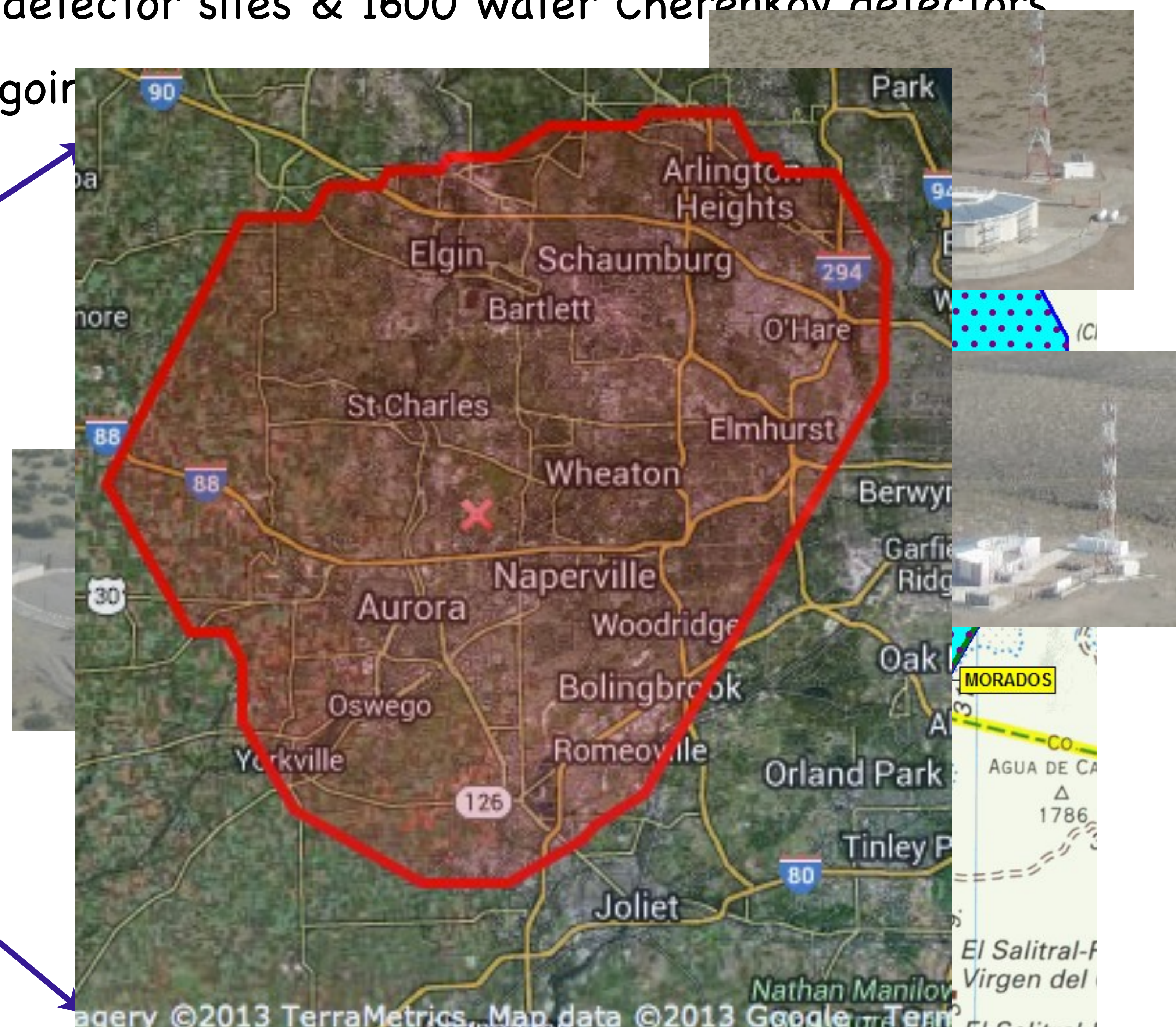
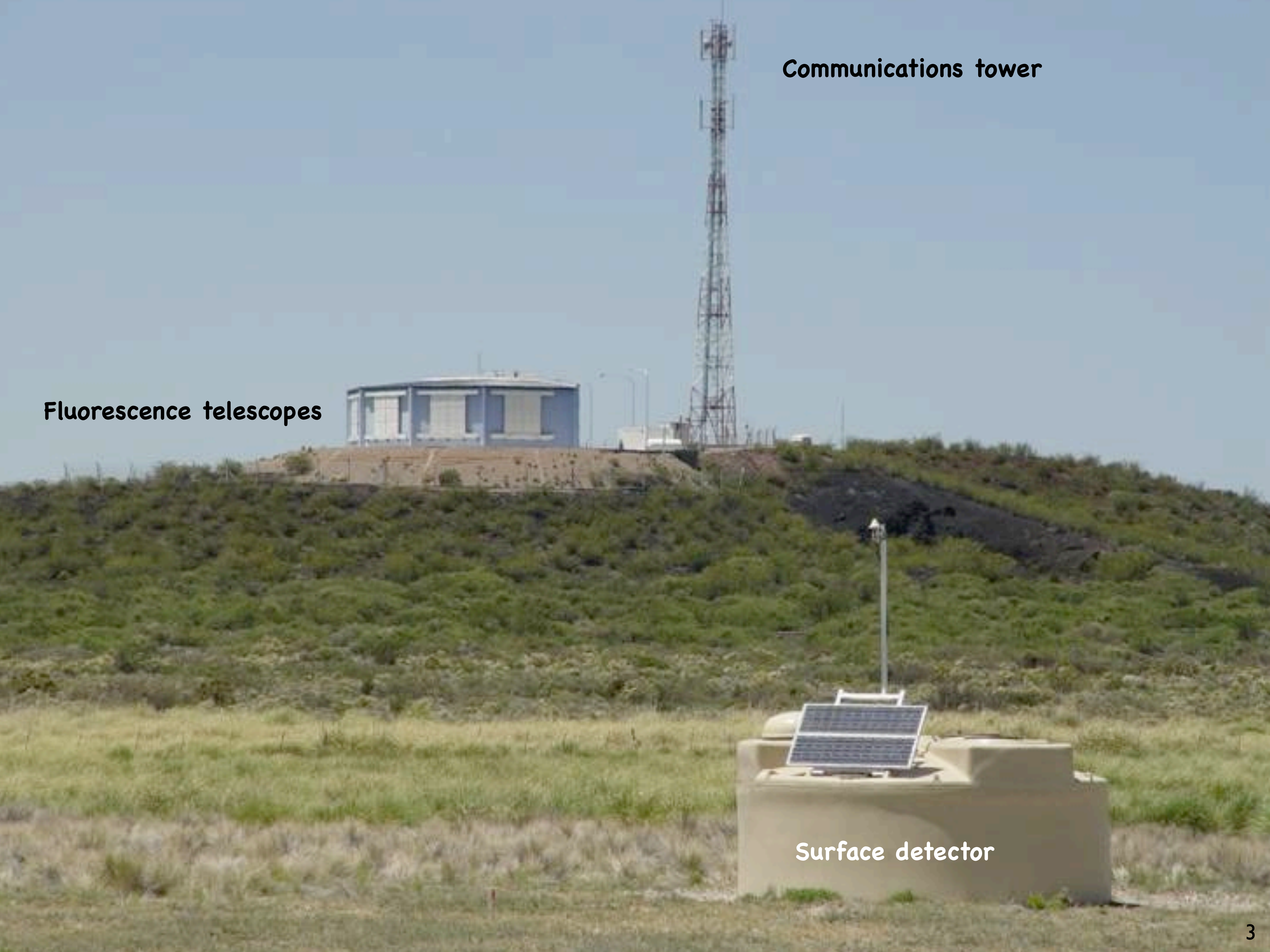
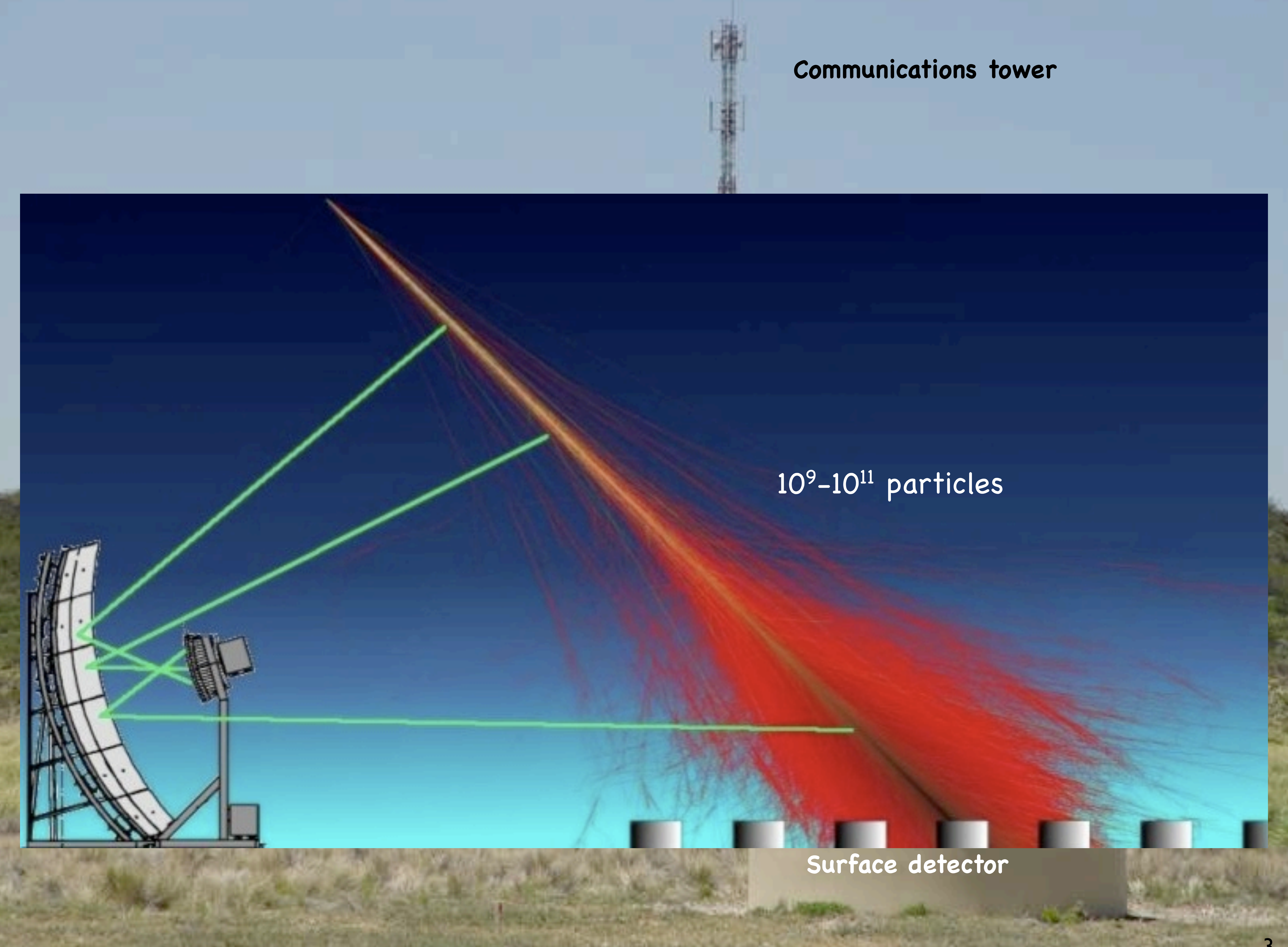
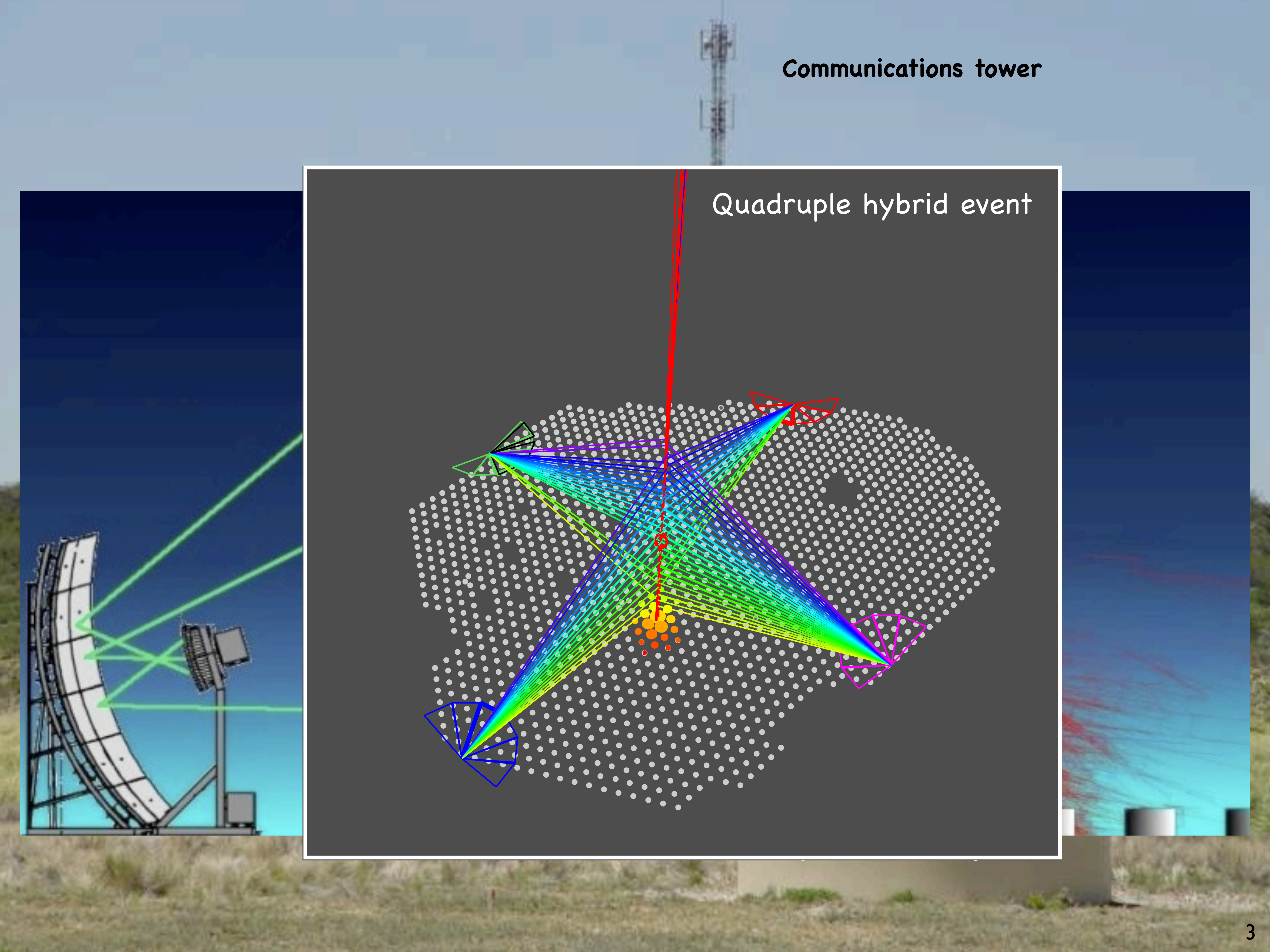


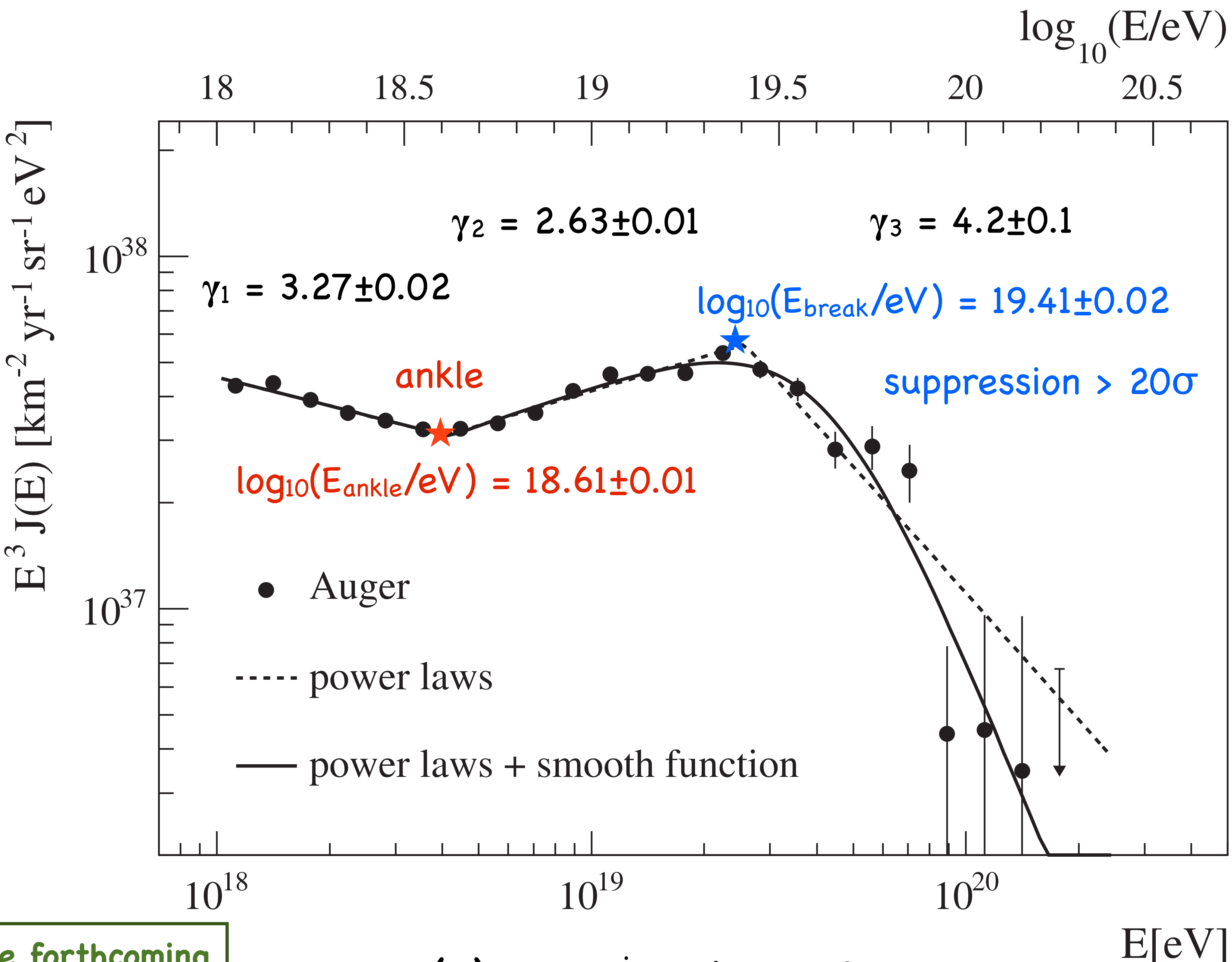

Communications tower
Fluorescence telescopes
Surface detector


Communications tower
10^9–10^{11} particles
Surface detector


Communications tower
Quadruple hybrid event

I. Energy spectrum

- Best statistics, ankle and suppression features clearly shown



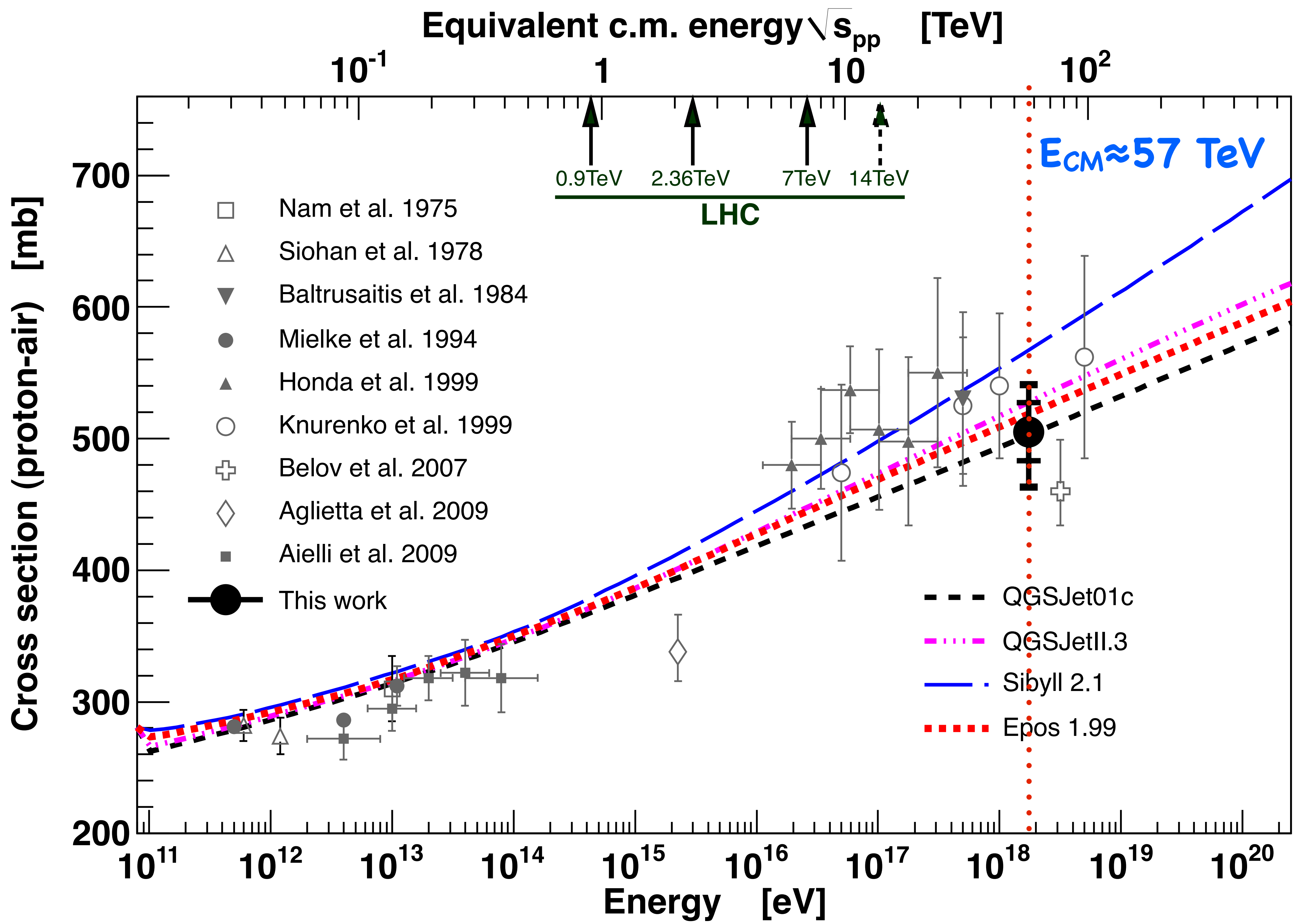
χ^2/ndof = 37.8/16 = 2.4

Update forthcoming at ICRC2013

$J(E) \propto E^{-\gamma_i}$, i = 1, 2, 3

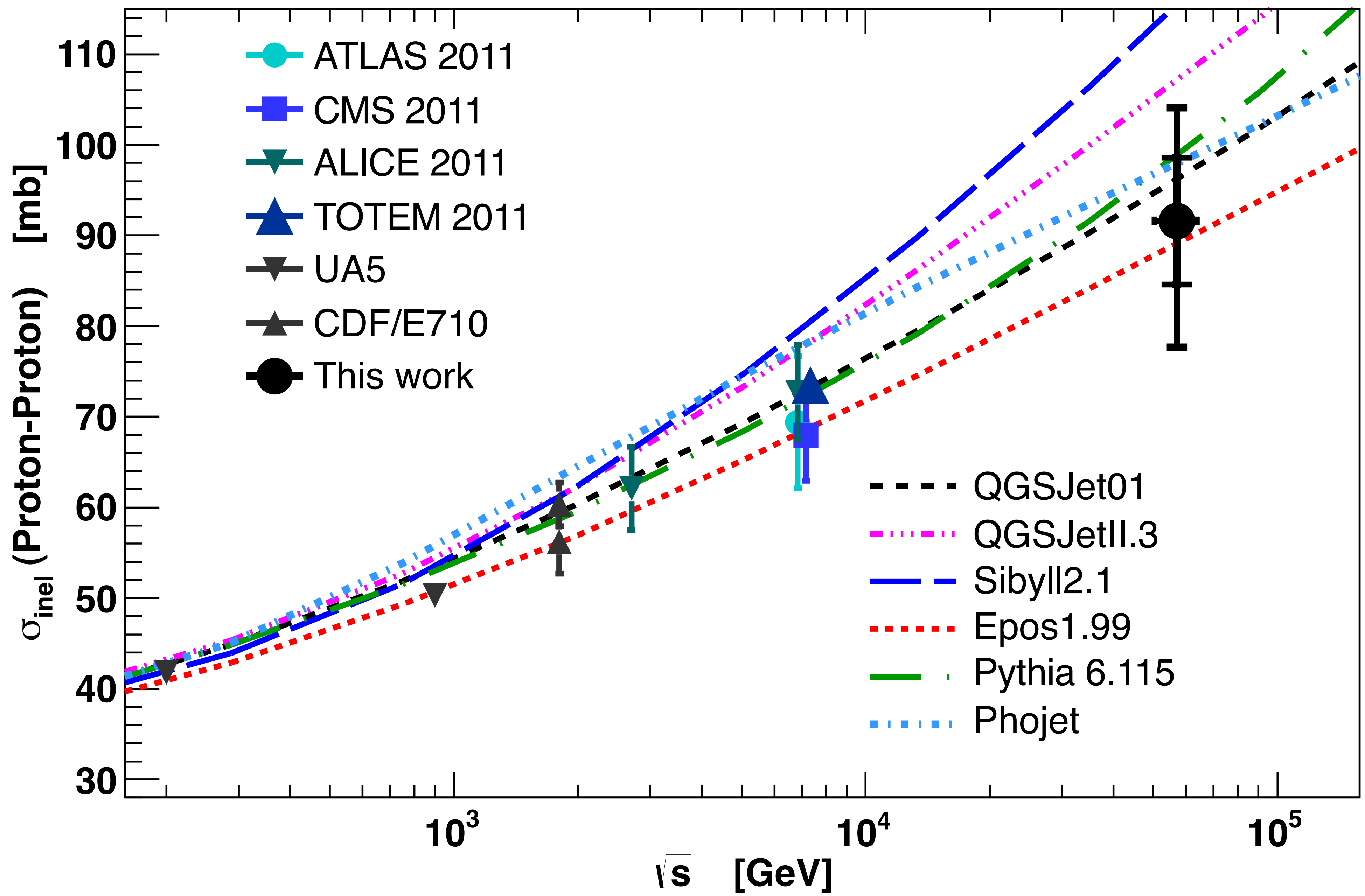
II. Proton-air, proton-proton cross section

Proton-air production cross section



$$\sigma^{prod}_{p-air} = 505 \pm 22_{stat}\ (+28/-36)_{sys}\ \text{mb}$$

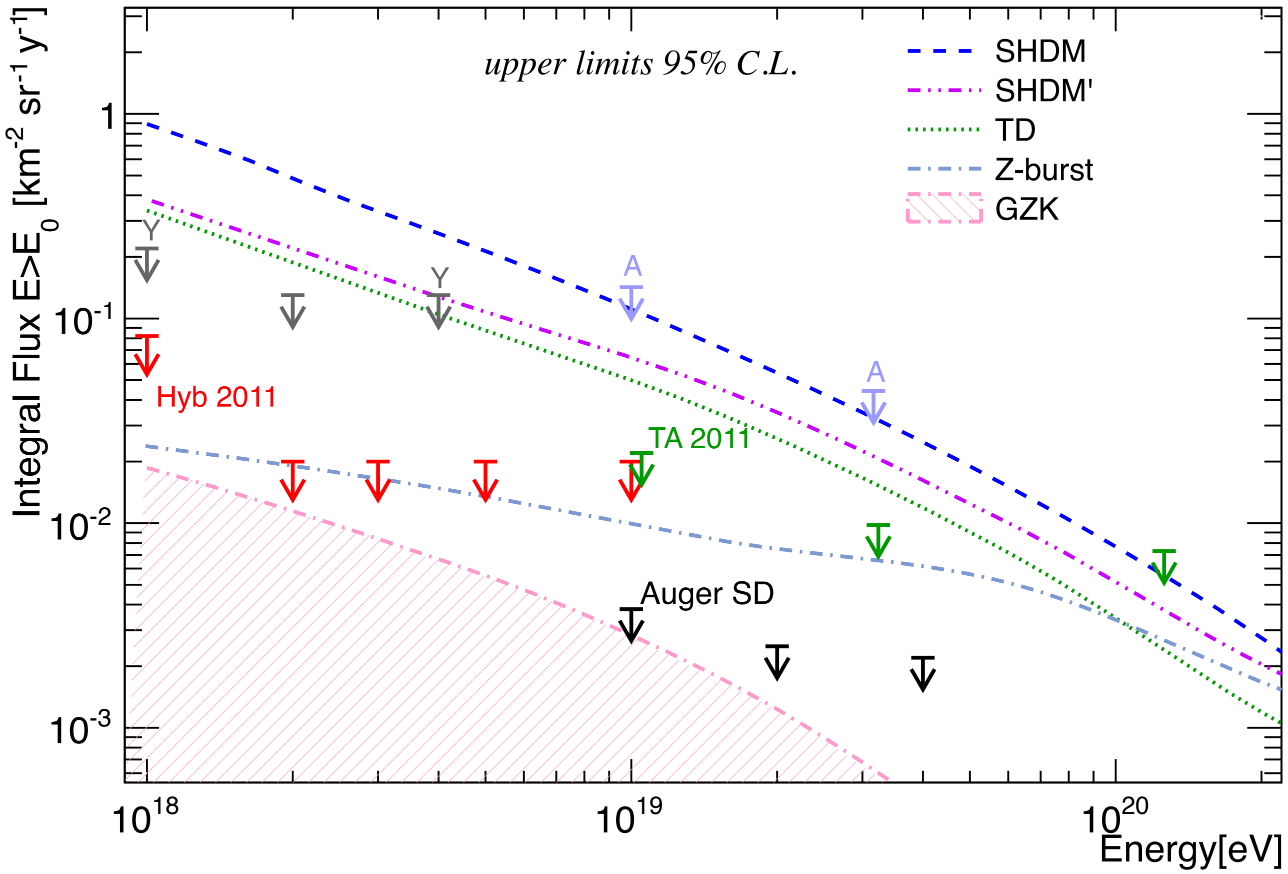
Proton-proton cross section, with Glauber modelling

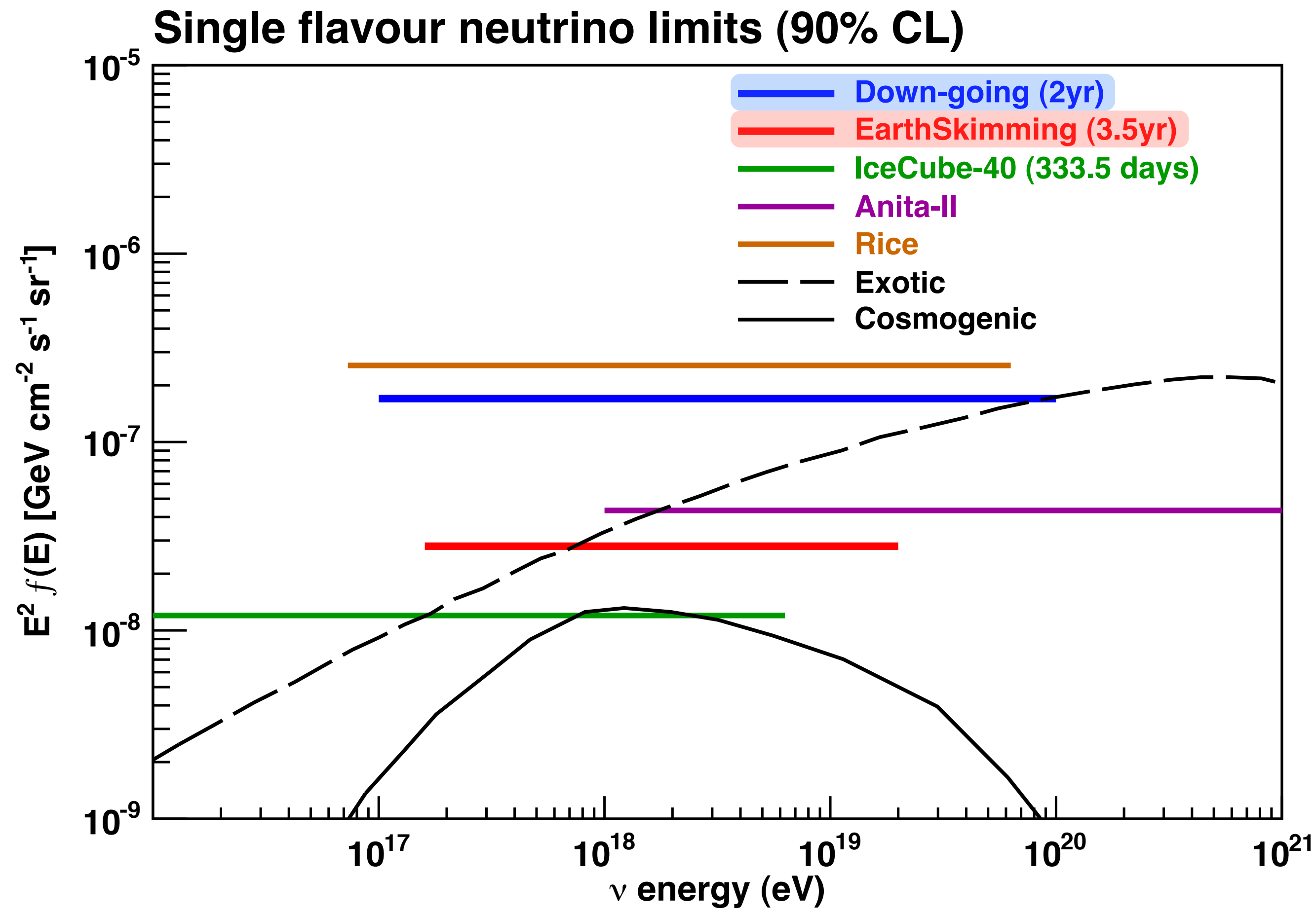


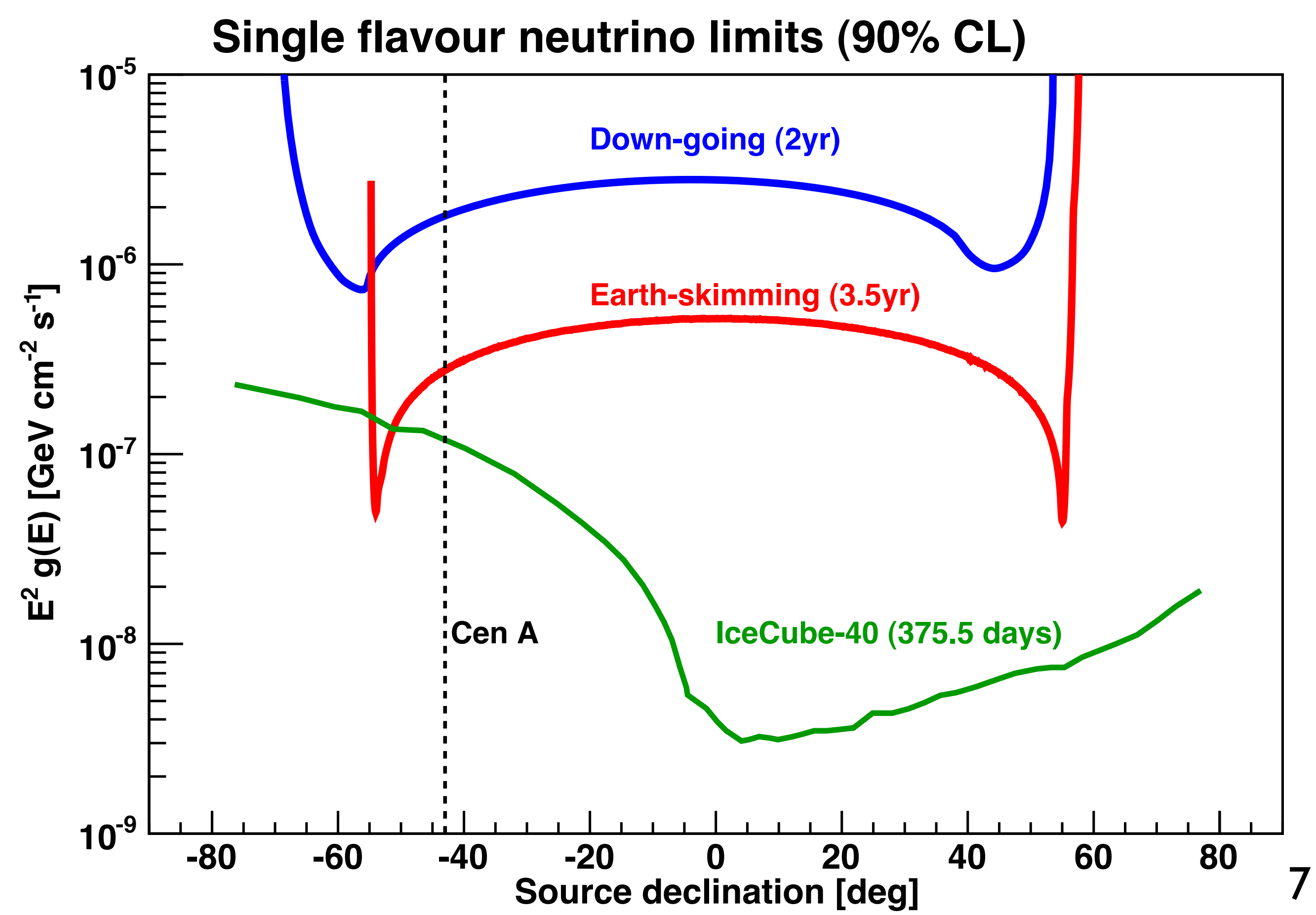
$$\sigma_{p-p}^{inel} = 90 \pm 7_{stat}\ (+9/-11)_{syst} \pm 7_{glauber}\ \text{mb}$$

$$\sigma_{p-p}^{tot} = 133 \pm 13_{stat}\ (+17/-20)_{syst} \pm 16_{glauber}\ \text{mb}$$

III. Limits on photons and neutrinos







- Photon limits:
  - most stringent
  - constrain top-down models, soon to reach GZK limit
- Neutrino limits: deeply penetrating horizontal & Earth-skimming showers
  - high sensitivity close to horizon
  - no neutrino candidate

Updates forthcoming at ICRC2013

IV. Composition

Observe, understand, characterize the ultra high energy cosmic rays and probe particle interactions at the highest energies

- Understand what these UHECRs are

  -> understand the sources of these UHECRs

- Obtain insight into hadronic interactions at these energies ($E_{CM} >> 14$ TeV)

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  -> understand the sources of these UHECRs
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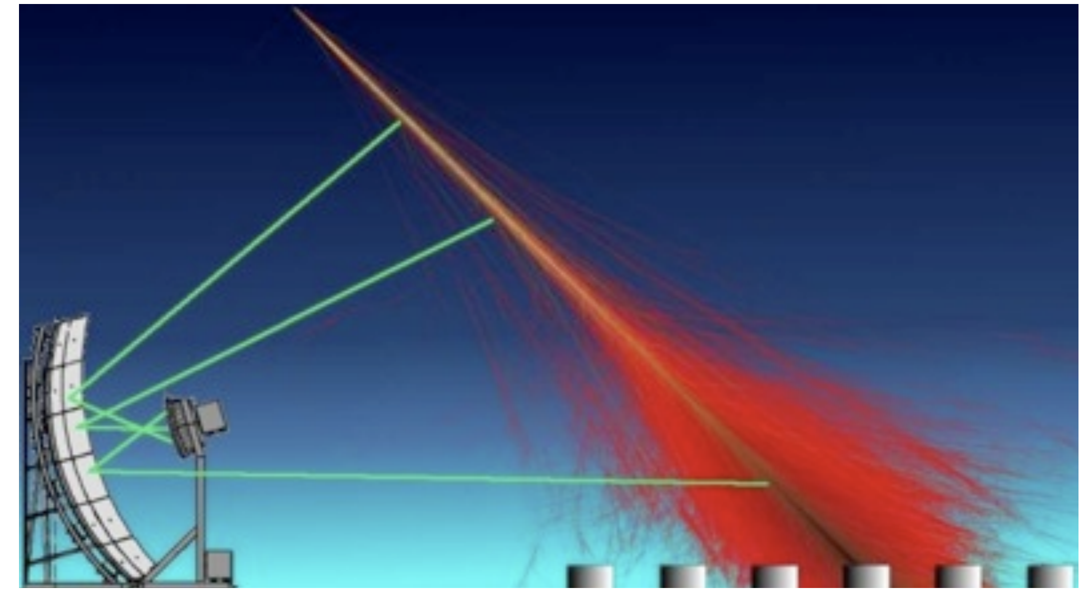
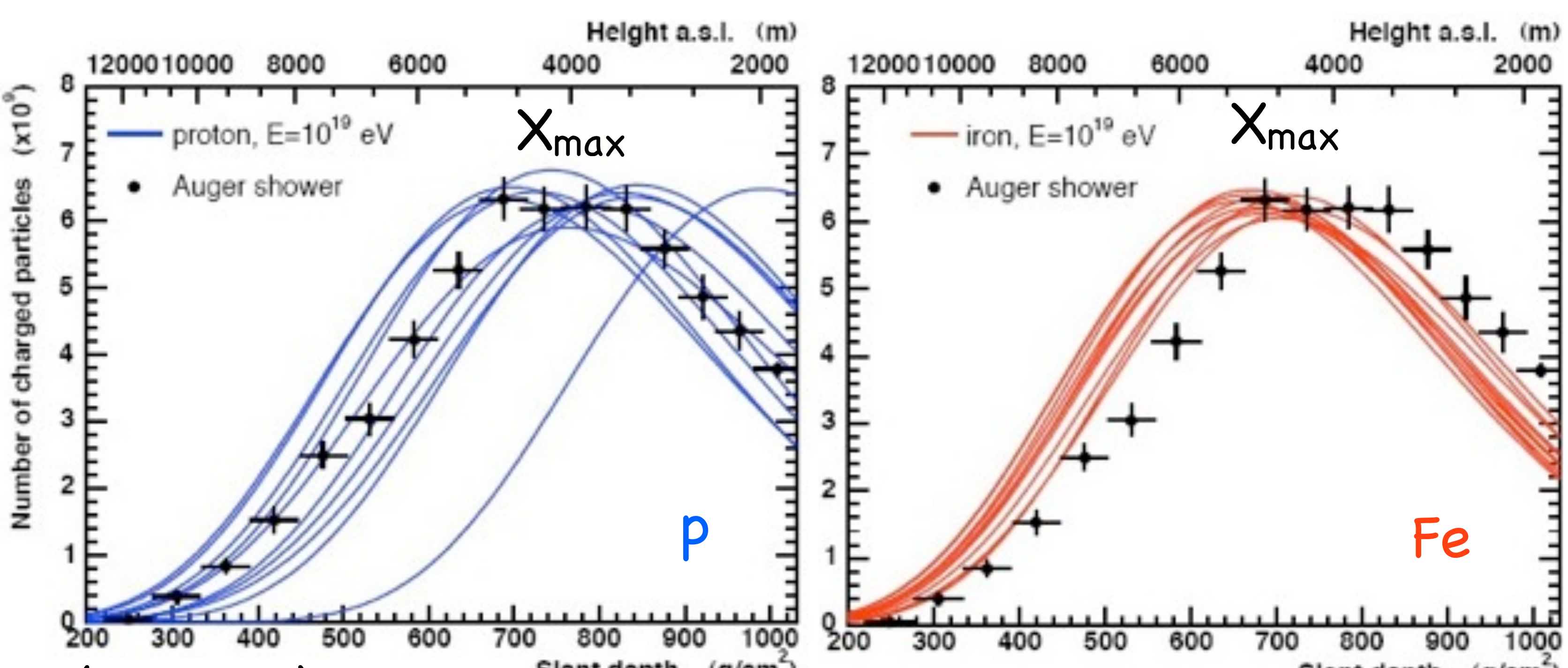
❖ Brief history of UHECR composition

- beginning: photons or charged particles? -> **positively charged particles**
- afterwards: **protons** - most abundant and stable particle in Universe
  - extra-galactic astrophysical or top-down sources; GZK cutoff
- later: **protons** and **iron nuclei** - two most abundant & stable species
  - Galactic or extra-galactic astrophysical sources; particle propagation
- lately: **what are they?** Auger found composition is not as simple
  - probe hadronic interactions at UHE

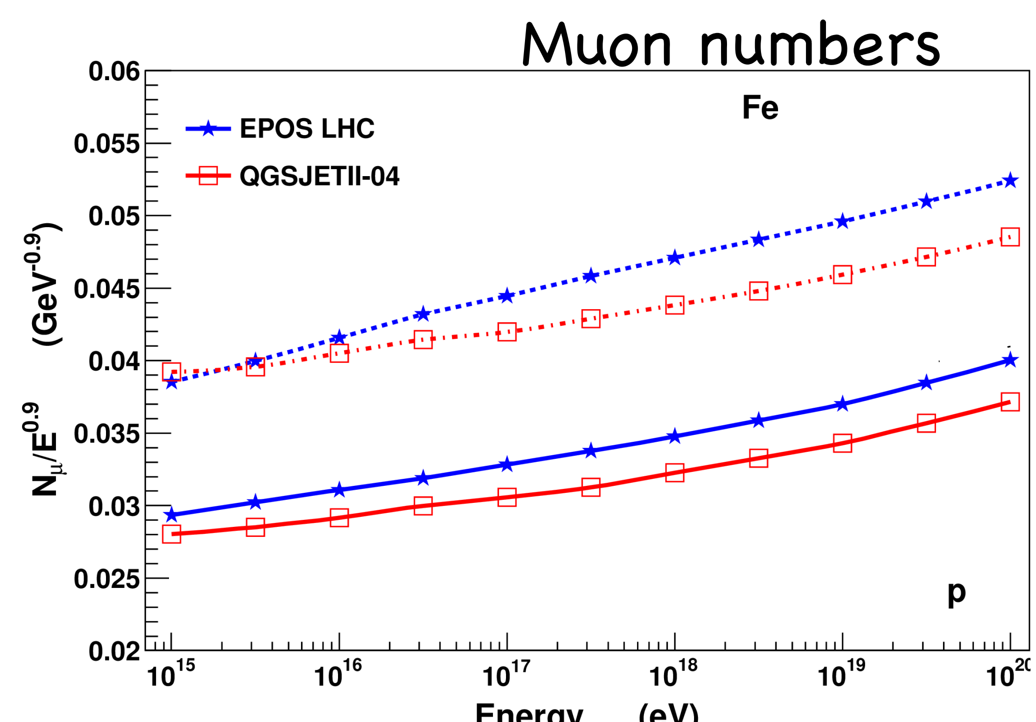
- ❖ Study air shower properties of different primary cosmic rays via simulations:
  - electromagnetic & hadronic interactions
    - hadronic interaction models have been updated with the LHC data
  - cascades in the atmosphere



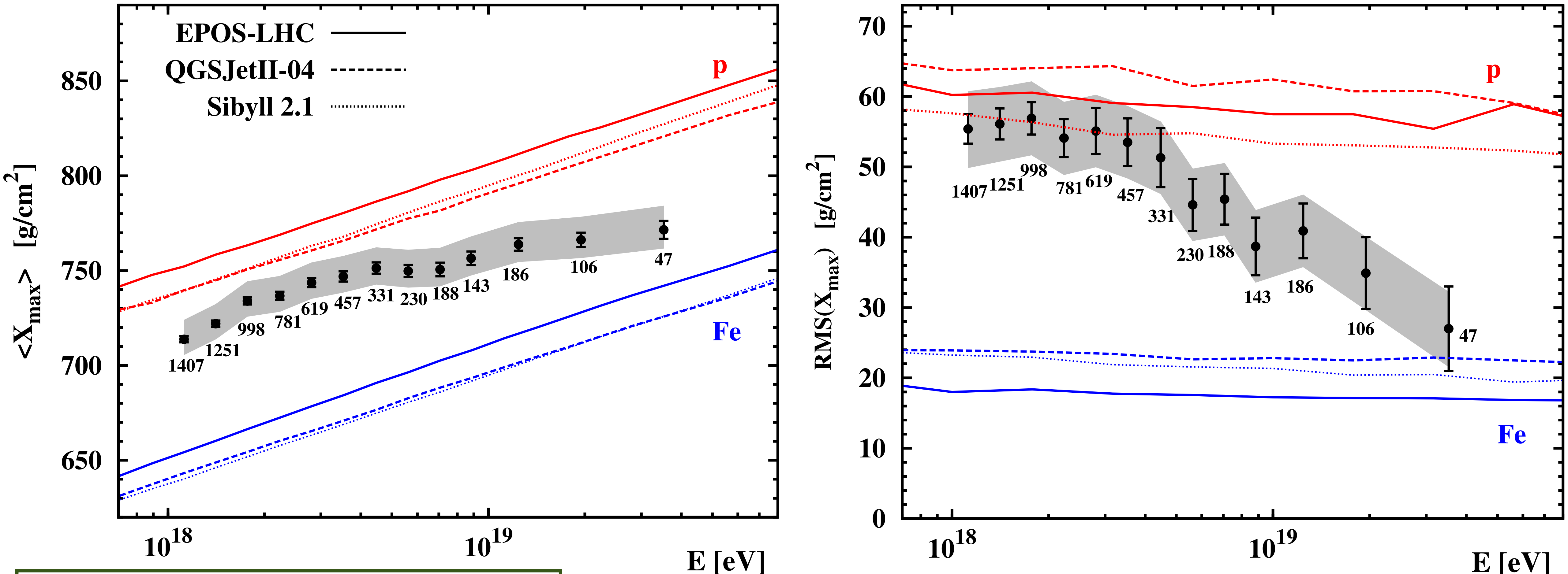
- ❖ Extract information on composition via shower observables
  - Electromagnetic component of air shower development in atmosphere (X_{max})
  - muon numbers on ground
  - muon production in the atmosphere



(Sibyll 2.1)



- Compositions appear to be more complex than a simple pure protons or pure iron nuclei



Updates forthcoming at ICRC2013

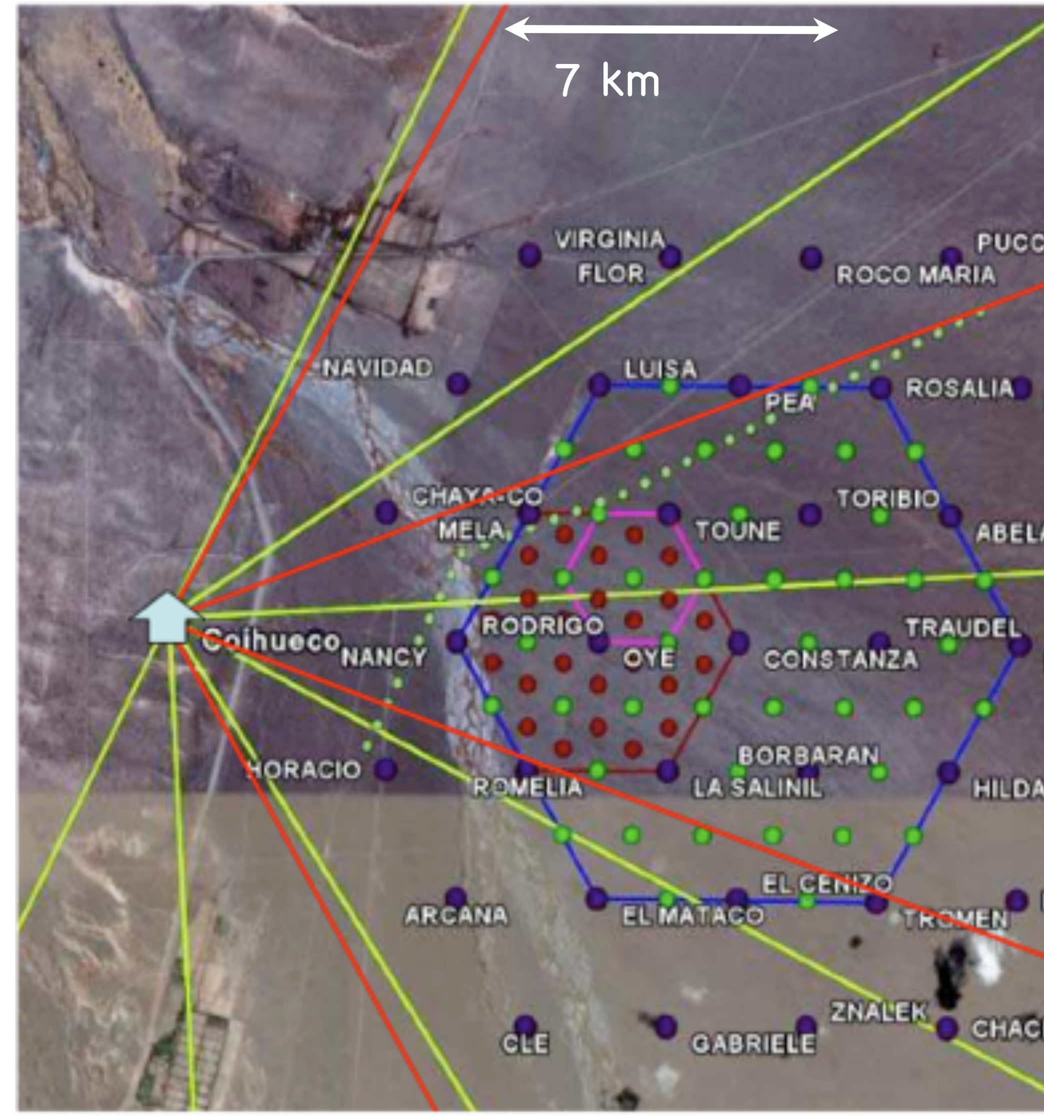
❖ **Fermilab group has led the composition analysis using a new method made possible by the unprecedented amount of Auger hybrid X_{max} data, resulting in crucial insights into composition and hadronic interactions. Result will be submitted very soon.**

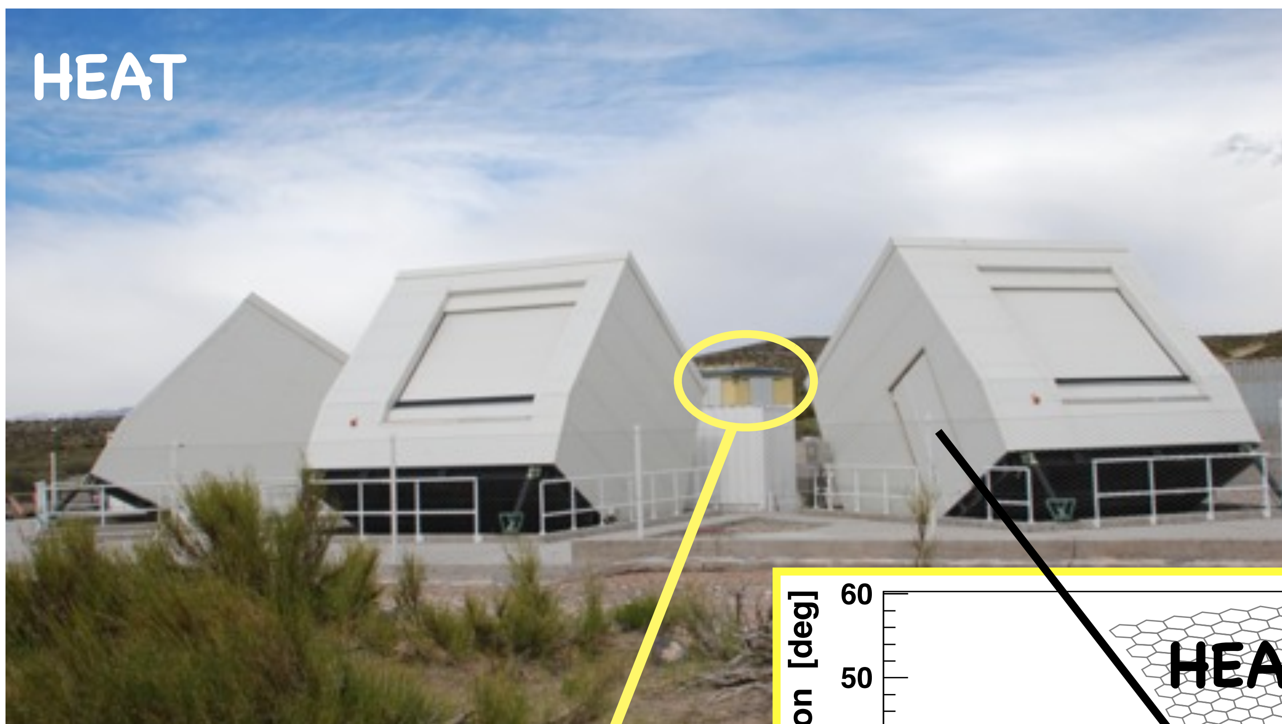
◉ Enhancements

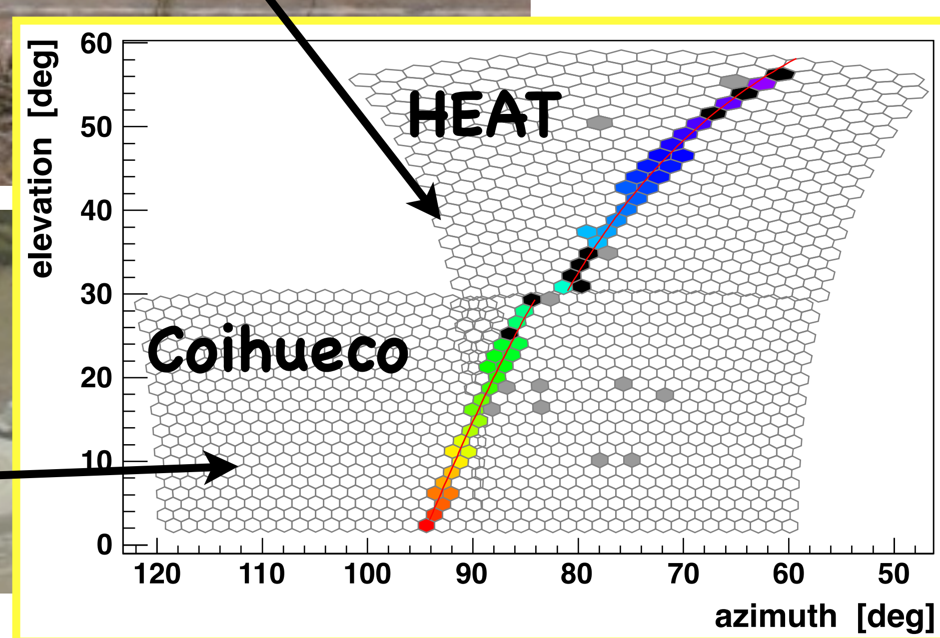
- High Elevation Auger Telescope (HEAT)
- Muons and infill (AMIGA)
  -> extend down to ~ 10^{17} eV,
  obtain better composition information

low energy hybrid trigger

- Complementary techniques with radio:
  Auger Engineering Radio Array (AERA)







Summary

- Auger has made significant contributions to the UHECR field with accurate measurements of CR properties above $E_{lab} = 10^{18}$ eV and unprecedented statistics:
  - energy spectrum with clear ankle and suppression features
  - proton-air cross section measurement
  - stringent photon and neutrino limits: constrain top-down scenarios
- Auger continues to make significant discoveries:
  - unravelling composition and hadronic interaction information at $E_{CM} > 50$ TeV
  - understanding the source of the UHECRs
- Enhancements extend energy down to $E_{lab} \approx 10^{17}$ eV
- 43 papers published, 193 PhDs (22 more papers in preparation)
- Upgrade preparations to run beyond 2015 are in progress