TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Mathematik und Naturwissenschaften, Fachrichtung Physik

Higgs Production in the atmosphere of the earth

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ATLAS EXPERIMENT

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Science Life and Physics

Nature's hadron collider produces Higgs bosons all the time, high in the sky

Cosmic rays provide a free source of high-energy collisions, which have been used in the past to discover new particles. A recent study calculates how often they produce Higgs bosons

Artists impression of cosmic rays entering Earth's atmosphe

Jon Butterworth

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To answer that question, you need an estimate of the number of cosmic rays with sufficient energy that impact upon the Earth's atmosphere. On a recent trip to CERN, a colleague pointed me at the Batchelor's thesis of Josua Unger of the Technical University of Dresden, which addresses exactly that question. The estimate Unger comes up with, under various reasonable assumptions, that a Higgs boson is produced somewhere in the atmosphere about once every 8 seconds[1]. For These Higgs bosons are produced mainly when gluons, inside the various produced hadrons, collide and fuse together. And they would be highly boosted - that is, travelling very, very fast.

Even the most boring collisions at the Large Hadron Collider tell us something - this time about cosmic rays

Read more

That is not a very high Higgs rate, and the news gets worse, because to have a chance of seeing them, the bosons would have to decay to something distinctive - preferably muons. They do this sometimes, and we have measured Higgs bosons decaying to muons (via W or Z bosons) at the LHC, but the fraction of them that do so is tiny.

Of course, you would also have to cover the whole world with muon detectors something like the one in our lab at UCL, or probably better, because you would have to measure their energy and direction quite precisely to reconstruct the Higgs boson. Overall, it is quicker, simpler and cheaper to build a hadron collider.

Nevertheless, I find it strangely reassuring that nature is steadily making Higgs bosons, up there in the sky, without our help.

Useful for public talks

- Bachelor thesis Josua Unger
  - TU Dresden, Nov 2014
  - CERN-THESIS-2014-313
    https://cds.cern.ch/record/2019394
- Recently covered in
  - Guardian (article)
  - Reference Frame (article)
  - Science Mag (article)
  - Computer Oiger (article)
  - Schattenblick (article)

Main input

Spectrum of Cosmic Rays

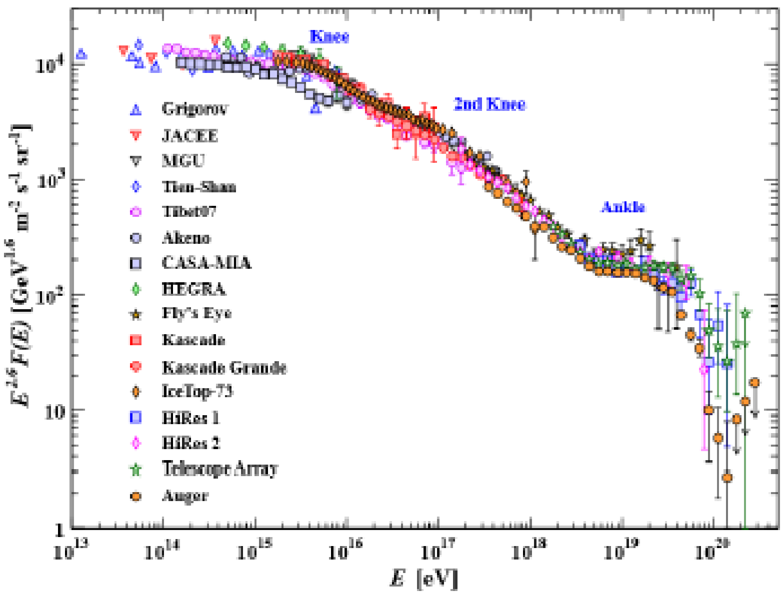

Figure: Energy Spectrum of CR

- Approximately described by power laws:

$$N(E)\mathrm{d}E \propto E^{-\gamma}\mathrm{d}E$$

- GZK cutoff results from interaction with cosmic microwave background

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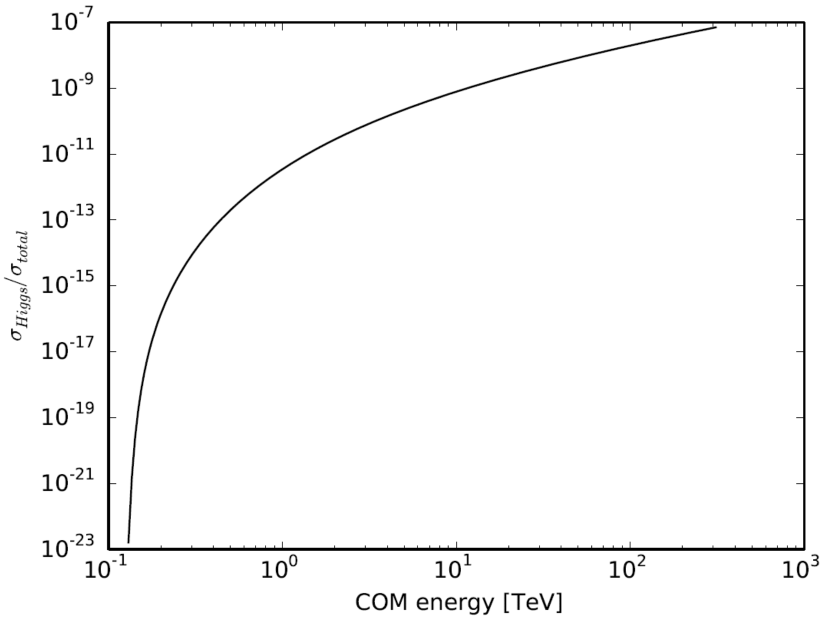
Total Higgs production rate

- Calculated folding various terms

$$\frac{dN_H}{dt} = \int_{0.13\ \mathrm{TeV}}^{433\ \mathrm{TeV}} \frac{\sigma_{gg\to H}(E_{CM})}{\sum_i \sigma_{PP\to i}(E_{CM})} \cdot \frac{d^4\phi(E_{RSE}(E_{CM}))}{dt \cdot dA \cdot d\Omega \cdot dE_{RSE}} \cdot A \cdot 4\pi \cdot \frac{dE_{RSE}}{dE_{CM}} \cdot dE_{CM}$$

- Increasing fraction of Higgs production as f(E_{CM}):
  - E_{CM} =0.5 TeV: 10^{-13}
  - E_{CM} =1.0 TeV: 5×10^{-12}
  - E_{CM} =2.0 TeV: 2×10^{-11}
  - E_{CM} =4.0 TeV: 10^{-10}
  - E_{CM} =10 TeV: 10^{-9}
  - E_{CM} =50 TeV: 10^{-8}
  - …



Total Higgs Boson Production Rate

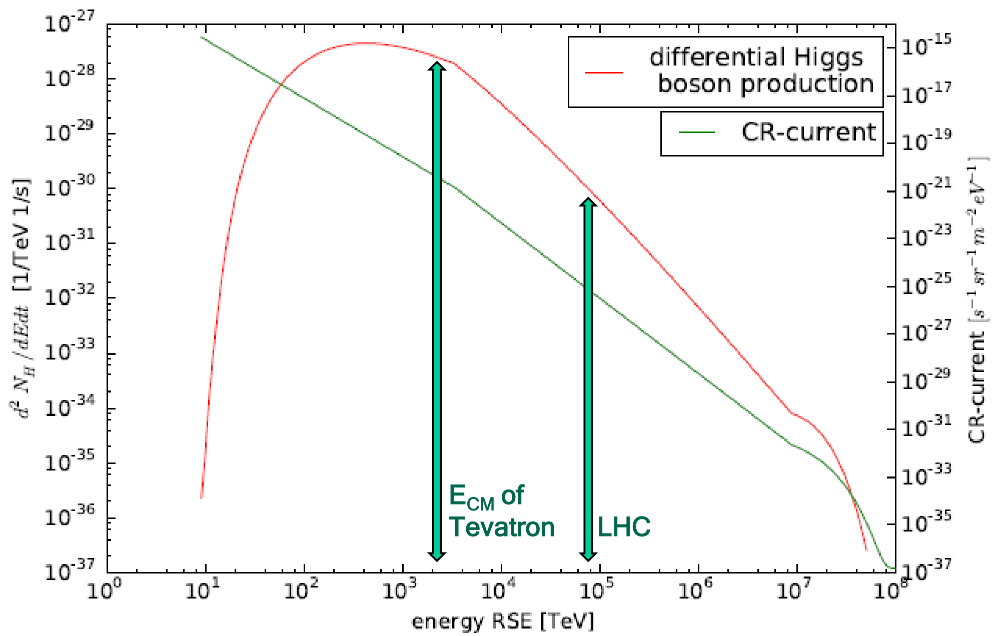


Figure: Differential Higgs Boson Production and the CR-flux in the rest frame of the earth

$$\frac{dN_H}{dt} = 0.12^{+0.03}_{-0.09}\ \mathrm{s}^{-1}$$

Facts to note

- Production rate
  - Primary CR produce 1 Higgs ~ every 8 seconds in the atmosphere
  - This is about 3 times more than the LHC did during runtime 2012
  - Production by secondary CR was not considered, would further increase the atmopheric rate by ...(?)
- Energy Range
  - By far most of the production happens with incoming protons of 100 TeV < E_{proton} > 2000 TeV corresponding to 0.45 TeV < E_{CM} (pp) < 2 TeV center of mass energy
  - This is lower E_{CM} (pp) than Tevatron, and much lower than LHC (for E_{CM} (pp) of LHC, cosmic Higgs are already ~ factor 500 below max)
  - → Flux helps nature over x-section (only 10^{-11}–10^{-13} of all incoming protons produce a Higgs at max)
- There are more details in CERN-THESIS-2014-313 https://cds.cern.ch/record/2019394
  - Uncertainties
  - Height of production (max at ~ 25 km above ground)
  - Momentum distribution