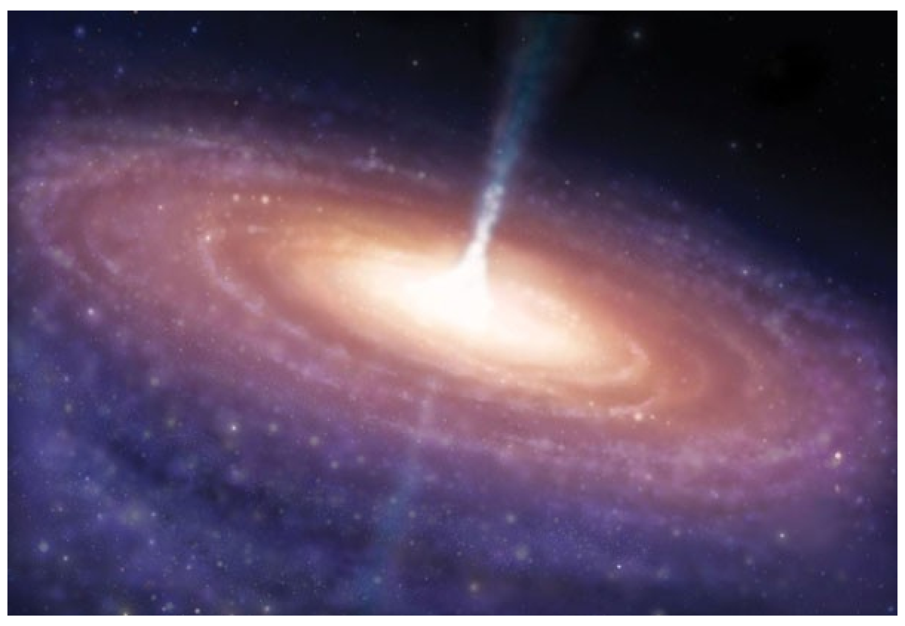
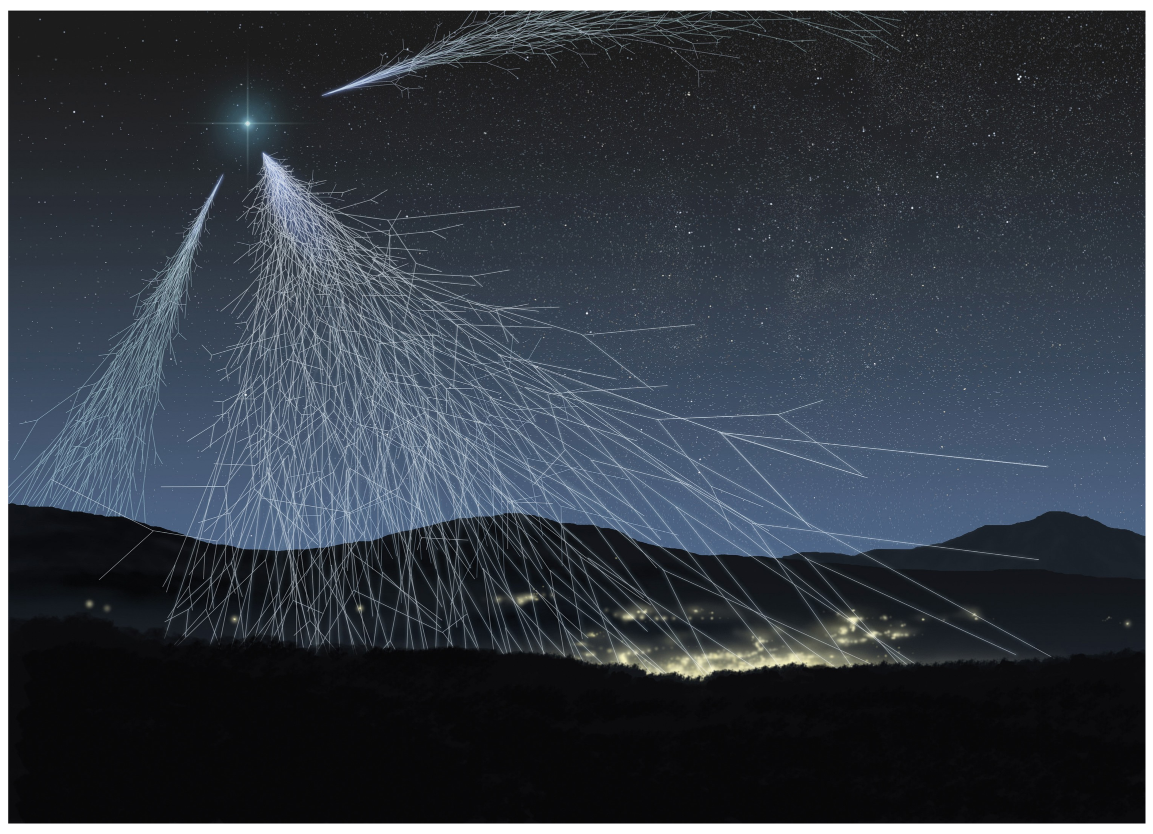
Hadron Production Measurements with NA61/SHINE for the Interpretation of Ultra-High Energy Cosmic Ray Air Showers



Mark A. Garlick, www.space-art.co.uk

Cosmic rays are charged particles from space that continuously bombard the atmosphere of Earth. The energies of the particles reach far beyond the ones achievable in man-made accelerators and the highest energy events observed so far exceed 10^{20} eV. The origin of these **ultra-high energy** cosmic rays is still unknown, but they are most probably of extragalactic origin. Active galaxies with a **super-massive black hole** in their center (illustrated on the left) are potential astrophysical sources.

When entering the atmosphere, the primary cosmic ray particles collide with nuclei in the air and initiate an avalanche of elementary particles, a so called **air shower.** Among the produced secondary particles are hadrons, photons, electrons and muons. Air showers develop deeply into the atmosphere up to ground level. The pene- tration depth increases with the energy per nucleon of the cosmic ray.



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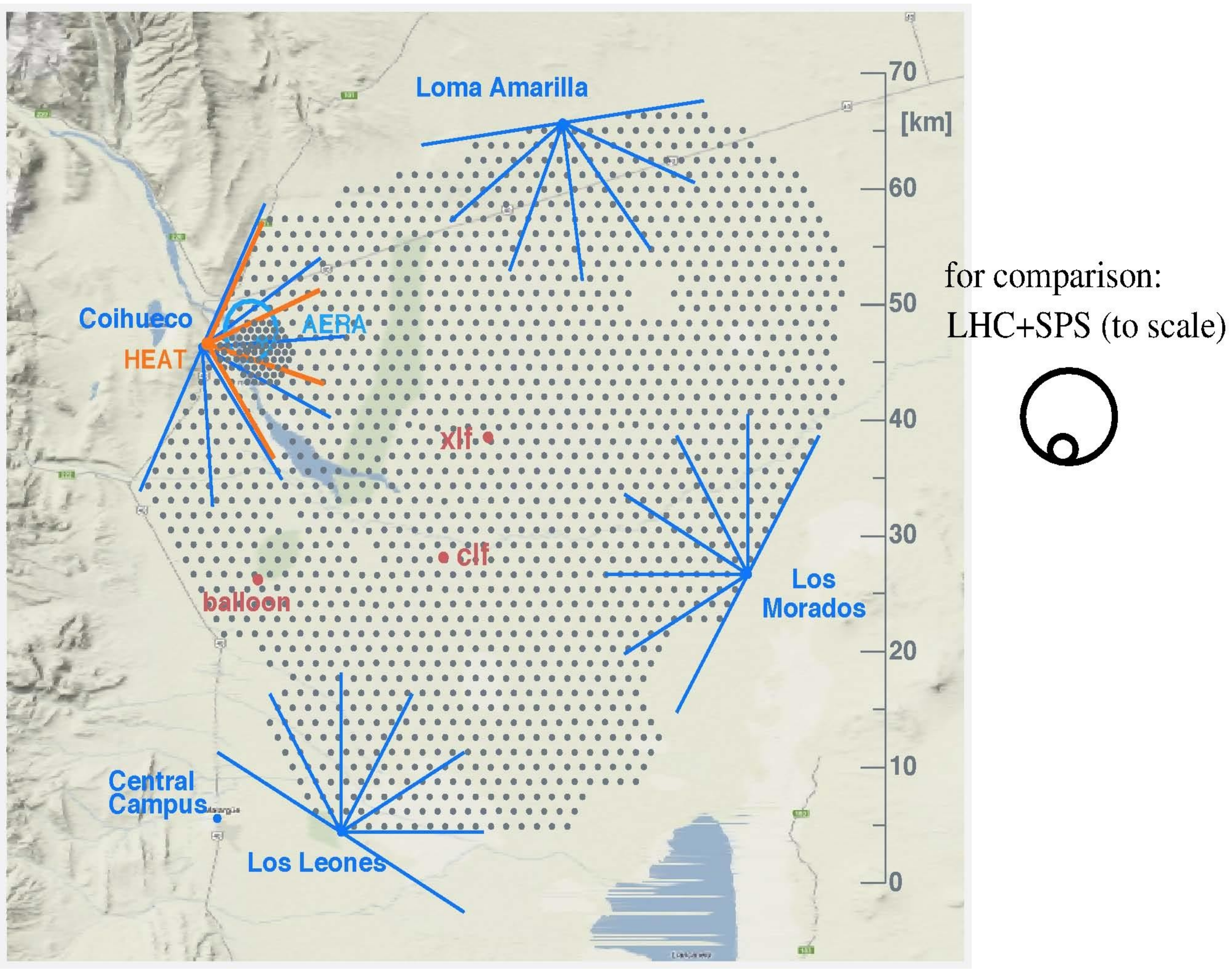
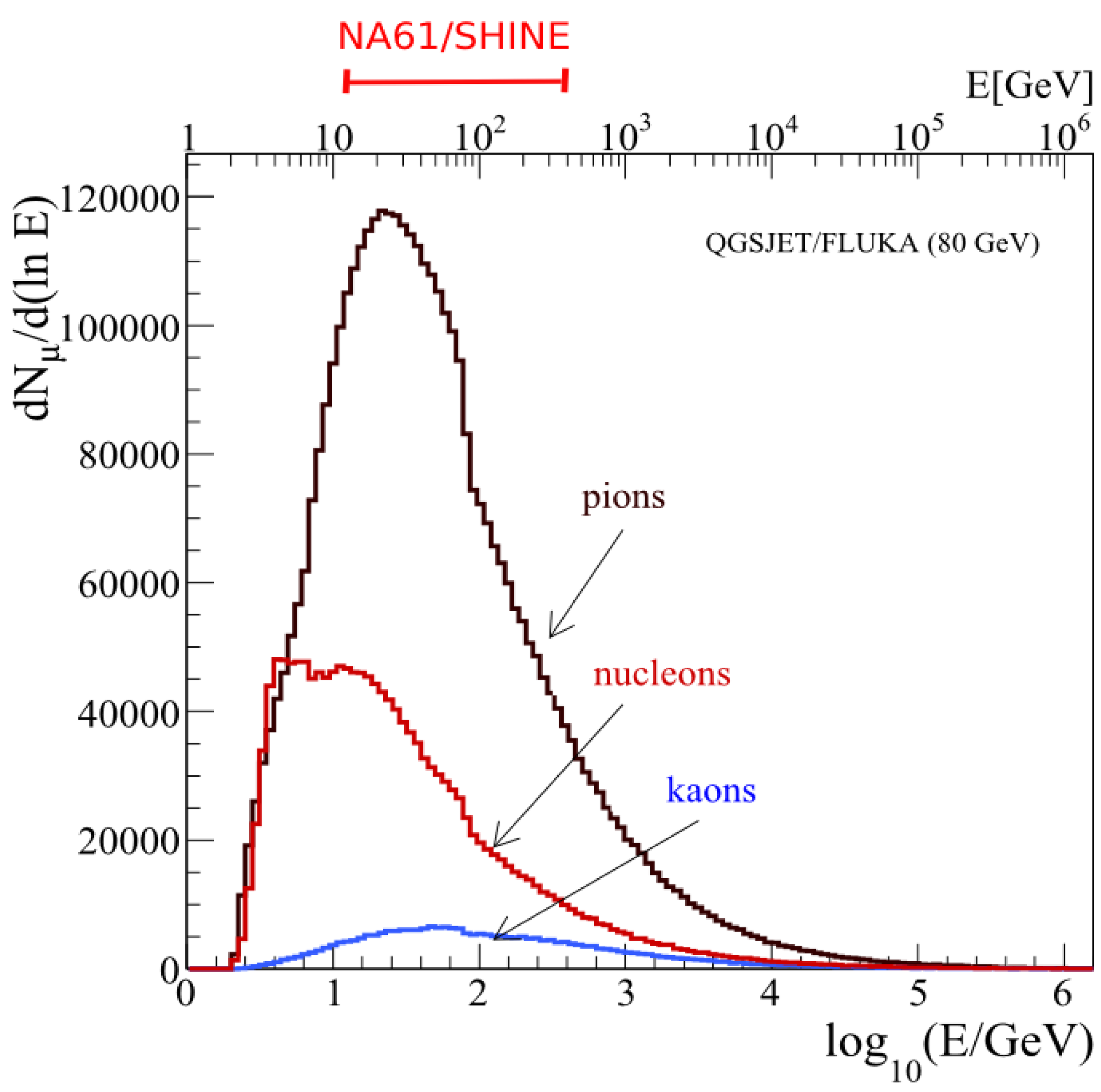
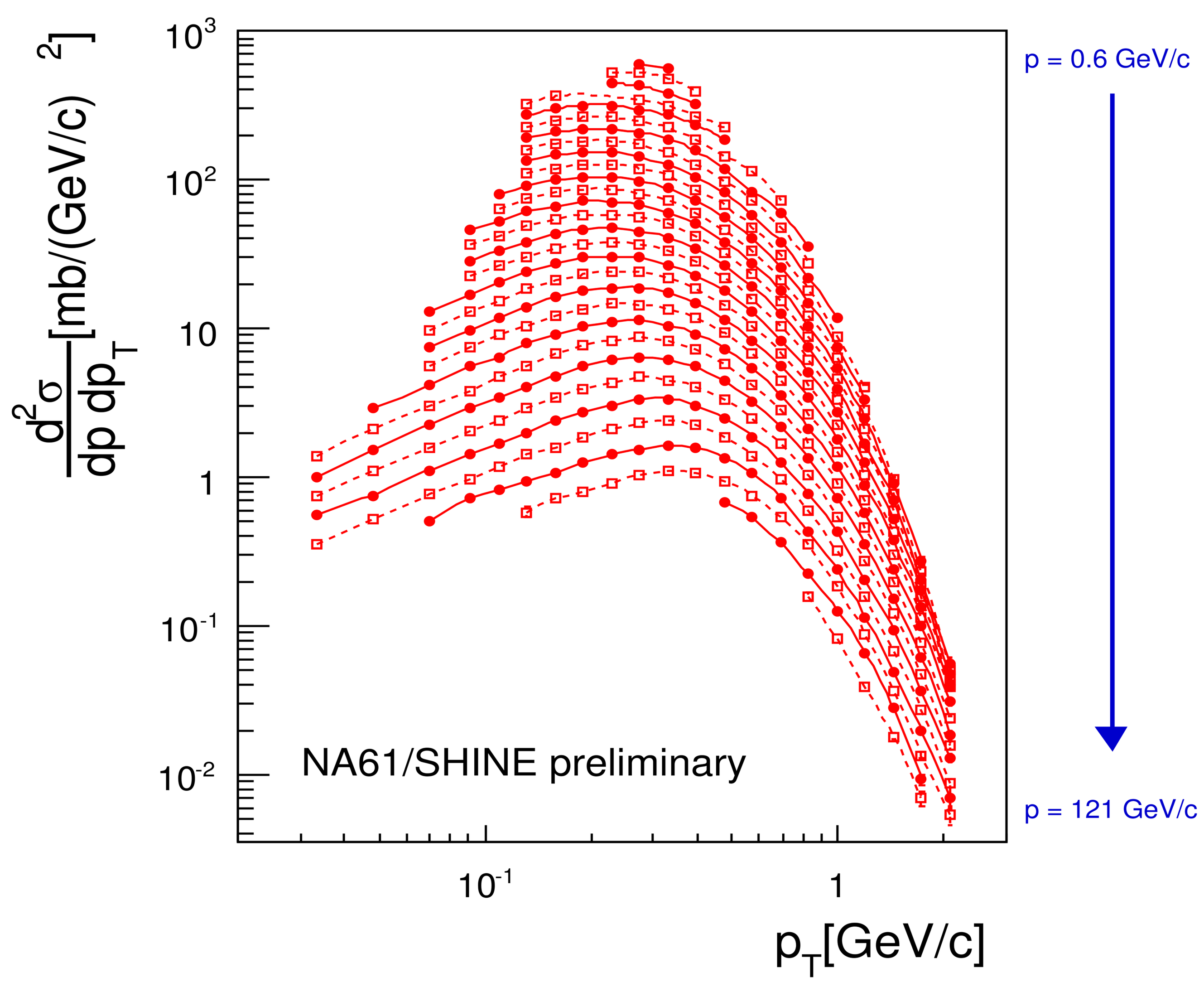


Since the flux of ultra-high energy cosmic rays is very small (less than 1 particle per century and square kilometer), a large detection area is needed to collect a sizable number of events. The **Pierre Auger Observatory** in Malargüe, Argentina, is the largest cosmic ray detector ever built. It features a 3000 km^2 array of particle detectors and optical telescopes to observe the secondary particles at ground and the fluorescence light emitted by air showers as they pass through the atmosphere. The layout of the observatory is shown to the left and its size is compared to the Large Hadron Collider.



The incomplete knowledge of **hadronic interactions** taking place during the development of an air shower constitutes a major challenge for the measurement of the primary energy and mass of cosmic rays. To understand the muonic signal at ground level, it is important to study the interactions that are relevant for the production of the parent particles of these muons. Simulations suggest that the majority of muons detected by the Pierre Auger Observatory originate from pion interactions in the range of SPS fixed target experiments (see right figure for an air shower with E=10^{19} eV).



In 2009, **NA61/SHINE** recorded more than 8 million interactions of pions on carbon at 158 and 350 GeV/c for the purpose of providing **particle production measurements** for the tuning of hadronic interaction models used to interpret air shower data. Preliminary results on the production of positively charged hadrons at 350 GeV/c are shown to the left.