

NA61/SHINE and Cosmic Ray Physics

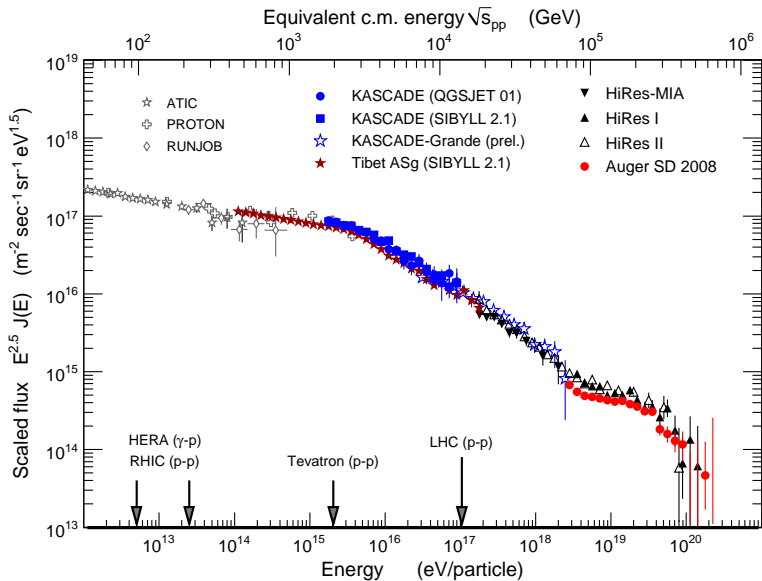
Ralf Ulrich

Karlsruhe Institute of Technology

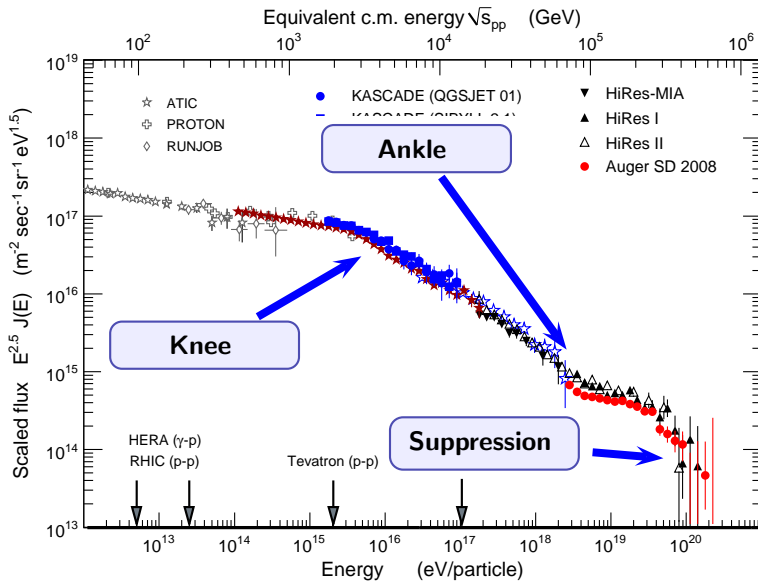
V Polish Workshop on Relativistic Heavy-Ion Collisions
SHIN(E)ING Physics

Some Open Questions in Cosmic Ray Physics

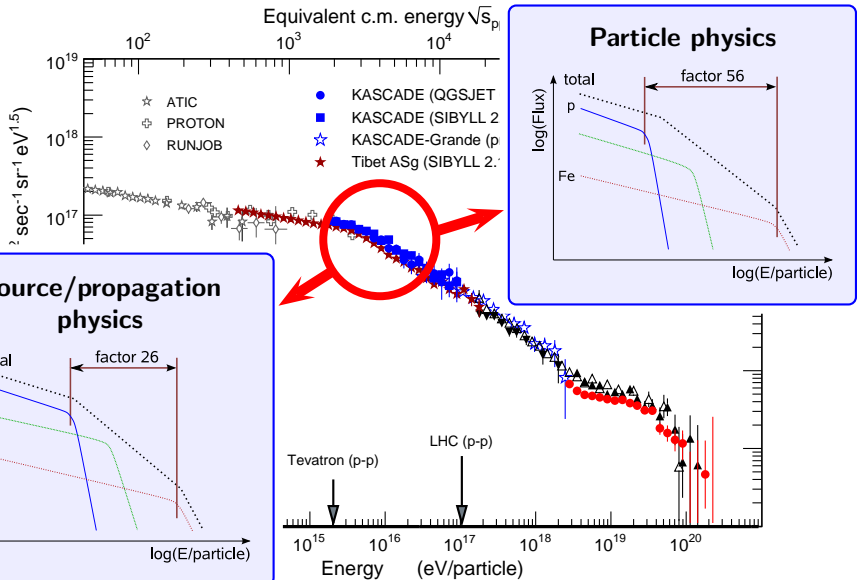
Flux of Cosmic Ray Particles



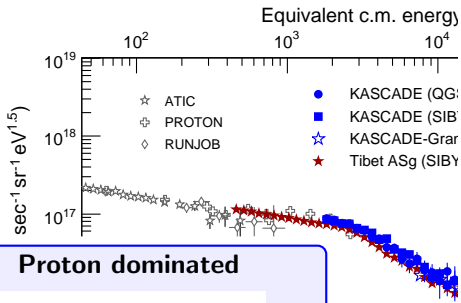
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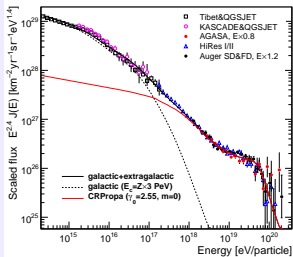
The Knee - Feature of Galactic Cosmic Rays ?



The Ankle - Transition to Extra-Galactic Cosmic Rays ?

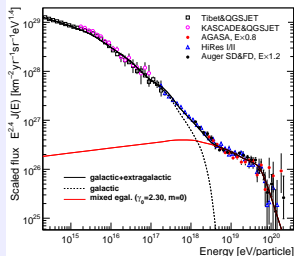


Proton dominated

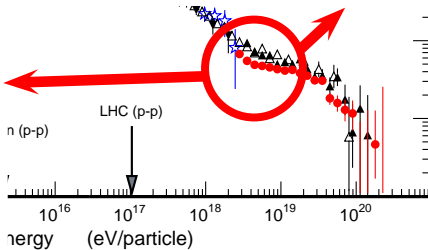


(M. Unger, ECRS 2008)

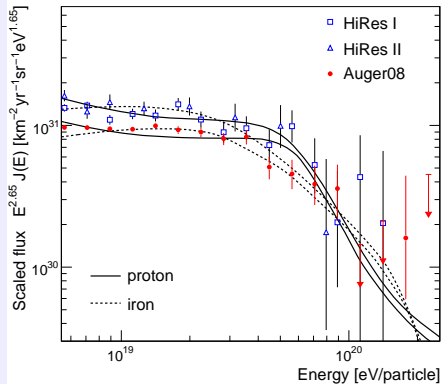
Mixed composition



(M. Unger, ECRS 2008)



Flux Suppression - End of the Cosmic Ray Spectrum ?

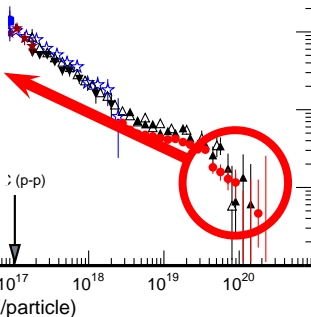


(M. Unger, ECRS 2008)

$y\sqrt{s}_{pp}$ (GeV)

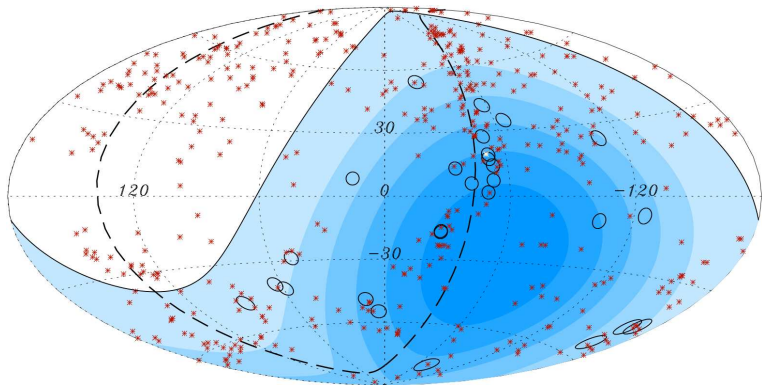
10^5 10^6

\blacktriangledown HiRes-MIA
 \blacktriangle HiRes I
 \triangle HiRes II
 \bullet Auger SD 2008



- Photo-pion production ?
- Photo-dissociation ?
- Maximum energy of accelerators ?

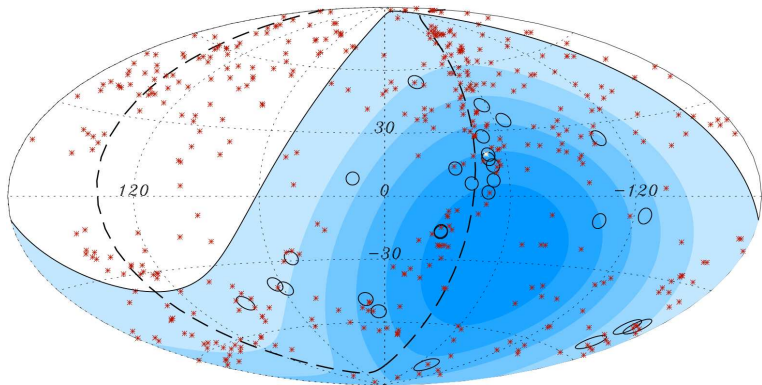
Arrival Directions at Ultra-High Energies



(Pierre Auger Collaboration, *Science* **318**:938-943, 2007)

- ⇒ Cosmic ray events above 56 EeV correlate within 3.1° with a selection of astrophysical objects within a sphere of 75 Mpc
- ⇒ Given a galactic magnetic field of $\sim \mu\text{G}$ only protons are able to explain this

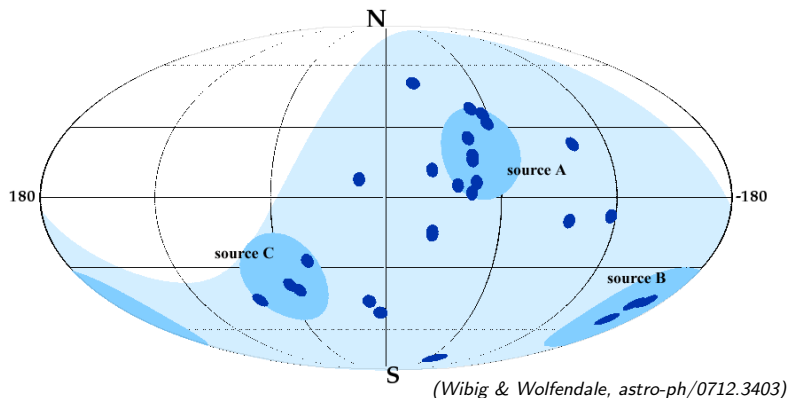
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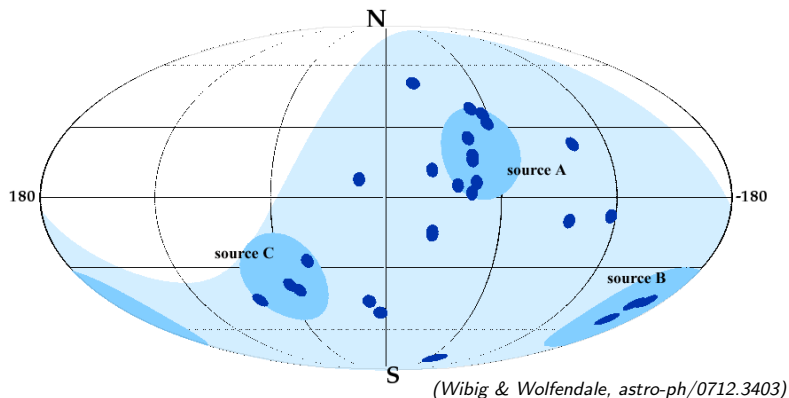
Arrival Directions at Ultra-High Energies



⇒ Only few dominant and close-by sources are relevant

⇒ Very heavy mass composition is possible

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- ⇒ Only few dominant and close-by sources are relevant
- ⇒ Very heavy mass composition is possible

Importance of Accelerator Measurements

**Mass composition important for
cosmic ray source and propagation scenarios**



Modern cosmic ray experiments:
High quality and statistics of data



Indirect measurements of extensive air showers



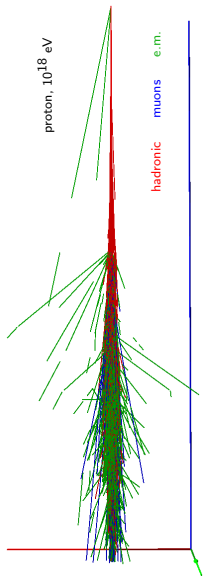
Strong model dependence
due mainly to muon production in air showers



Pion/kaon production at fixed target experiments

**Mass Composition of Cosmic Rays
and
Model Dependence**

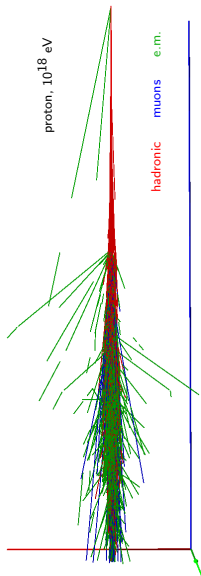
Mass Composition from Air Shower Ground Arrays



Air Shower Simulations:

- Particle tracking in magnetic field of Earth
- Particle tracking in differential atmosphere
- Interactions over ~ 10 orders of magnitude in lab. energy:

Mass Composition from Air Shower Ground Arrays



Hadronic Interactions

low energies:

- GHEISHA (*Fesefeldt*)
- FLUKA (*Fasso, Ferrari, Ranft, Sala*)
- UrQMD (*Bass, Bleicher et al.*)

→ mostly parametrizations of data

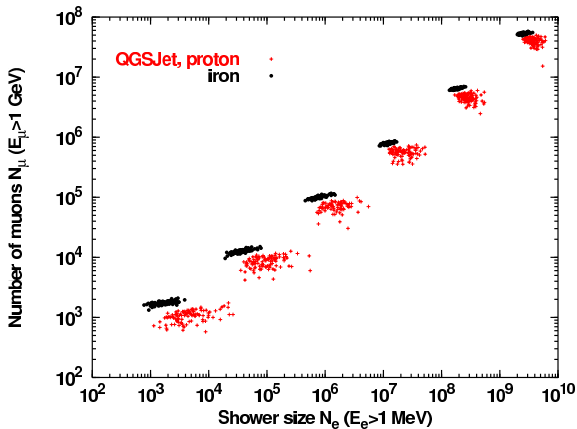
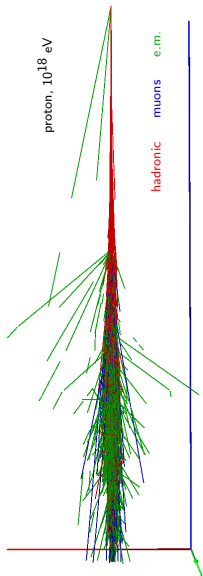
high energies:

- DPMJET II.5 (*Ranft & Roesler*)
- QGSJET 01/II (*Kalmykov & Ostapchenko*)
- SIBYLL2.1 (*Engel, Fletcher, Gaisser, Lipari & Stanev*)
- EPOS 1.61 (*Pierog & Werner*)

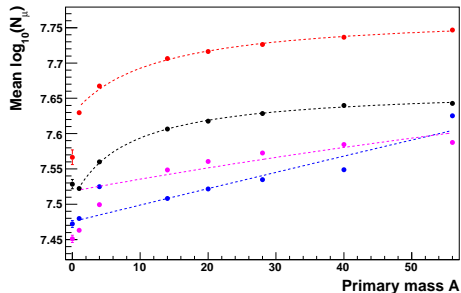
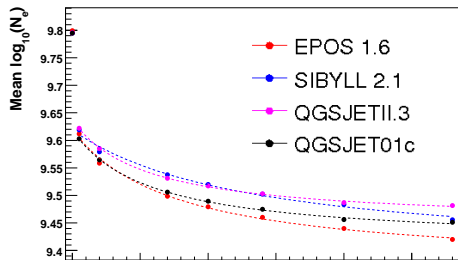
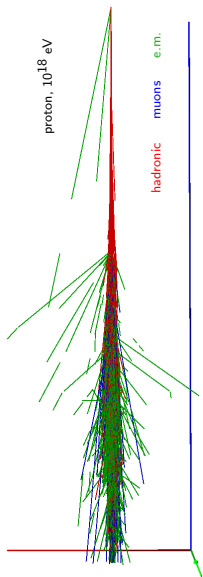
→ all QCD-inspired models (minijets)

transition low/high energies: 80 – 200 GeV

Mass Composition from Air Shower Ground Arrays

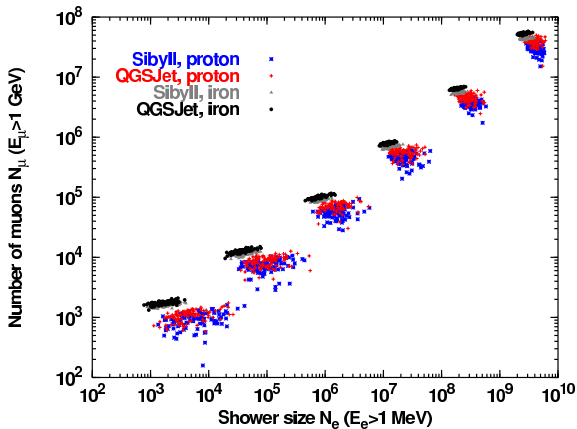
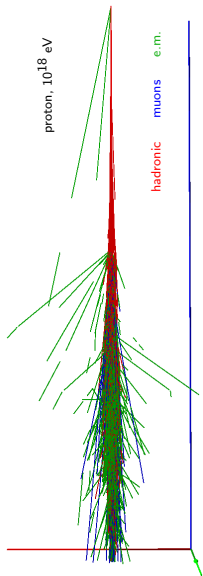


Mass Composition from Air Shower Ground Arrays



(R. Ulrich, PhD thesis)

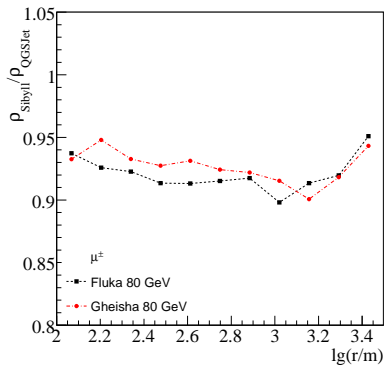
Mass Composition from Air Shower Ground Arrays



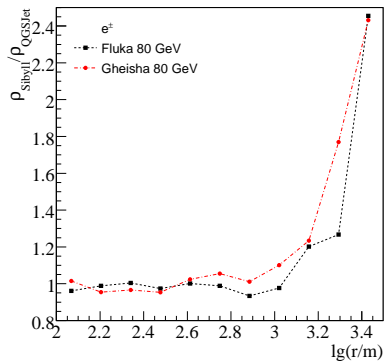
Lateral Particle Densities

Impact of High Energy Model

Muons



Electrons

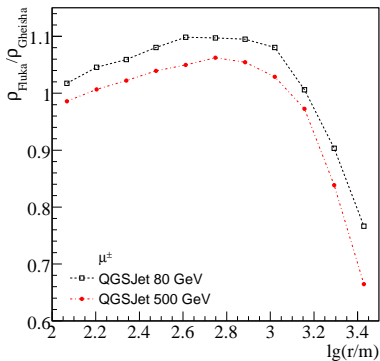


(I. Maris et al., ISVHECRI 2008)

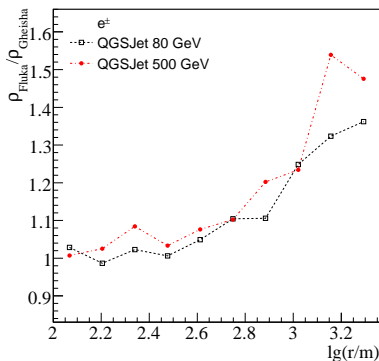
SIBYLL vs. QGSJET

Impact of Low Energy Model

Muons



Electrons

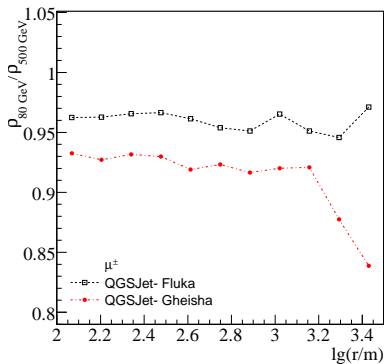


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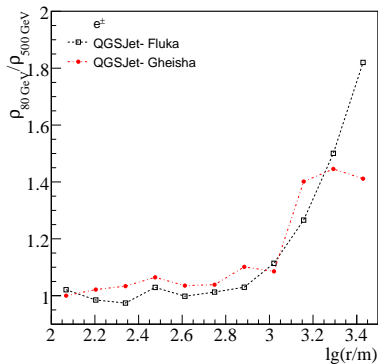
FLUKA vs. GHEISA

Impact of Transition Energy for Low/High-Energy Model

Muons



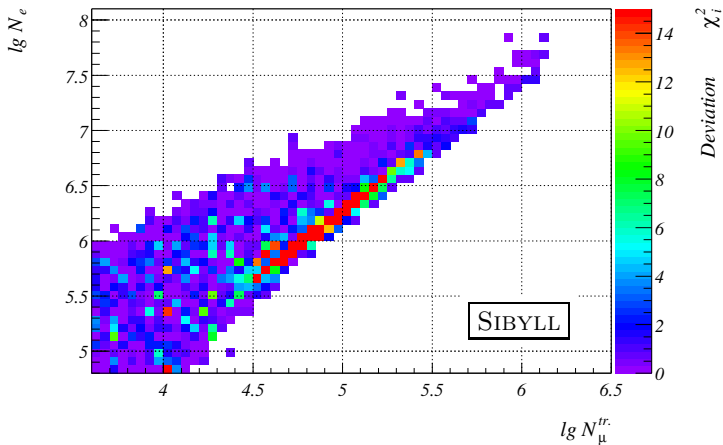
Electrons



(I. Maris et al., ISVHECRI 2008)

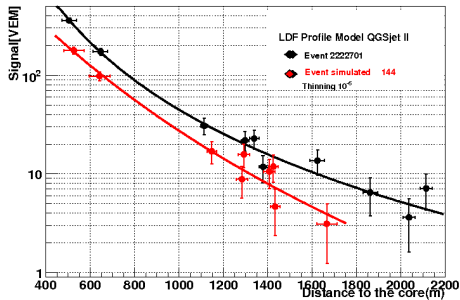
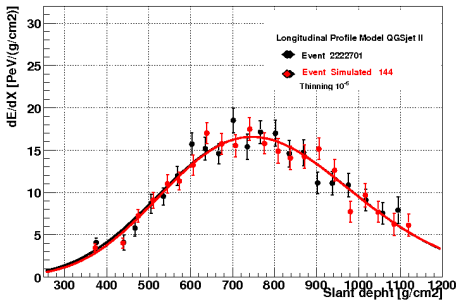
80 GeV vs. 500 GeV

Model Inconsistencies in Air Shower Interpretation



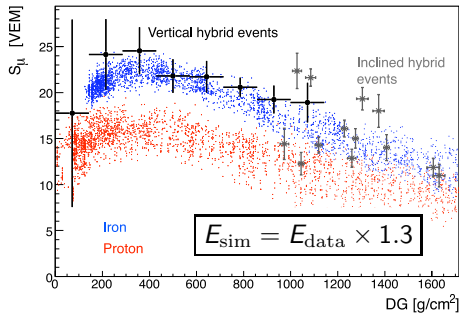
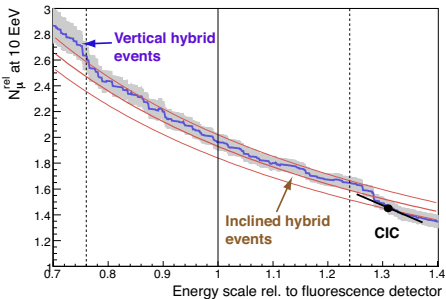
(KASCADE, *Astropart.Phys.*24:1,2005)

Distribution of χ^2 of deconvoluted N_e/N_μ -spectra to data



(F. Messar, diploma thesis)

- Perfect description of longitudinal development
 - Underestimation of particle densities at ground. Worse at:
 - large lateral distances
 - large distances of X_{max} from ground
- **Muon deficit in simulations ?**

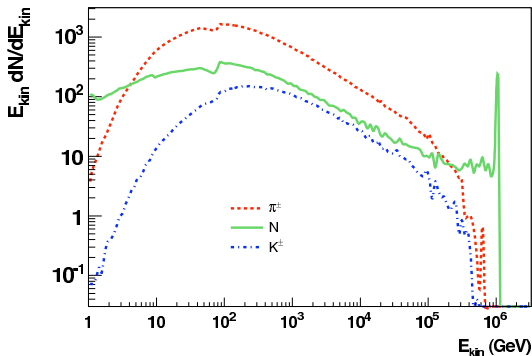
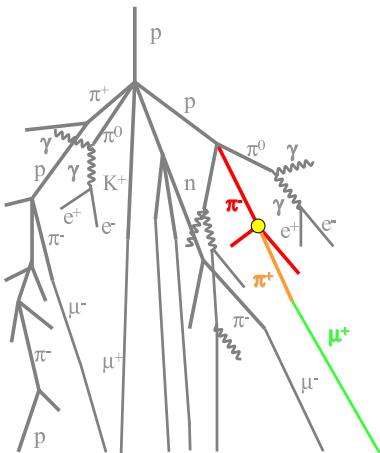


(Auger Collaboration, ICRC 2007)

- Energy scale ?
- Muon deficit in simulations ?

Muon Production in Air Showers

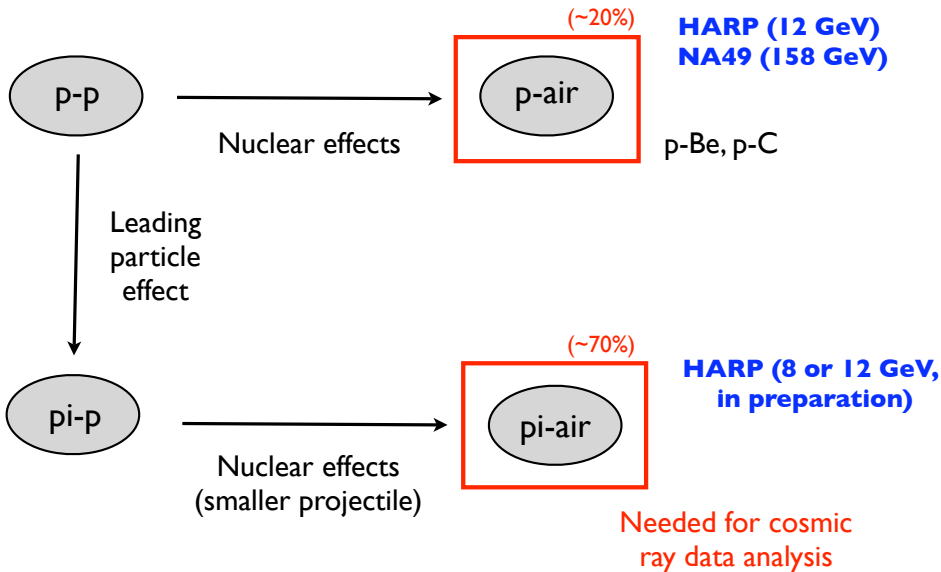
Relevant Interactions in Air Showers for Muon Production



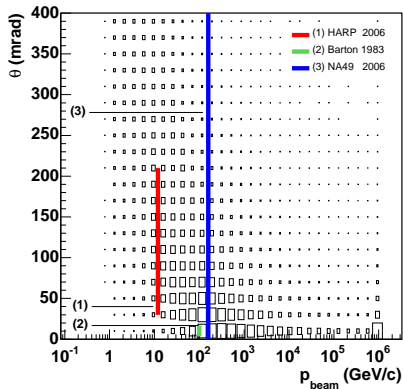
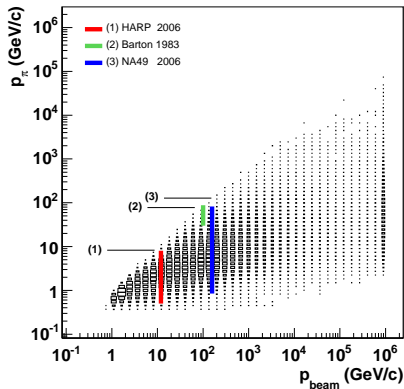
Important energies: **10 - 1000 GeV**

	beam particle	secondary
pion	72.3 %	89.2 %
nucleon	20.9 %	
kaon	6.5 %	10.5 %

Relevant Target: Air (^{14}N , ^{16}O , ...)

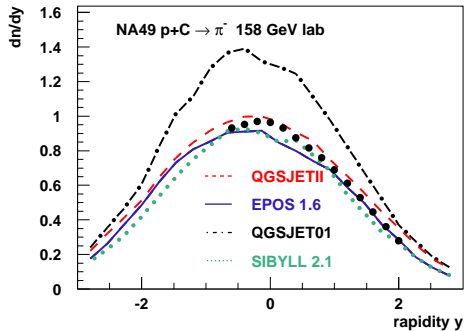
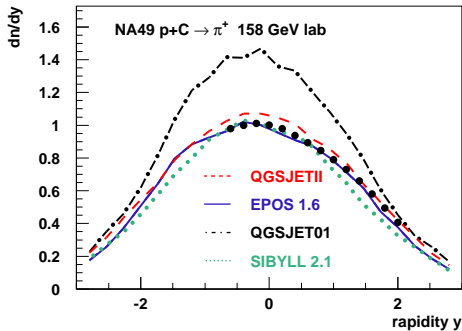


Existing p - ^{12}C Data



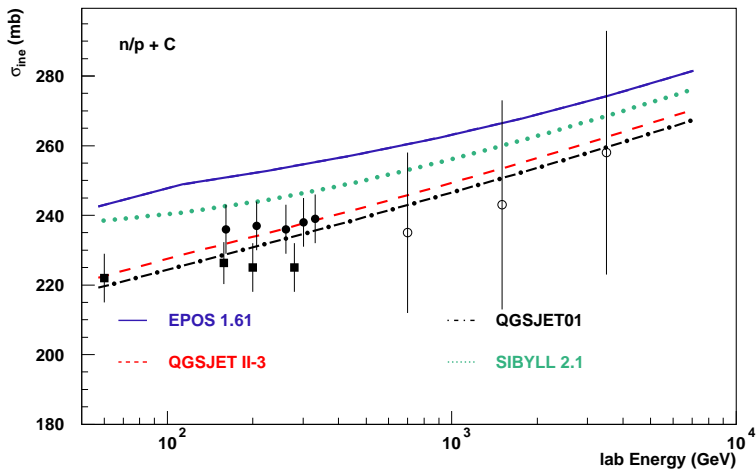
(C. Meurer et al., ISVHECRI 2006)

Comparison of NA49 Data to Models



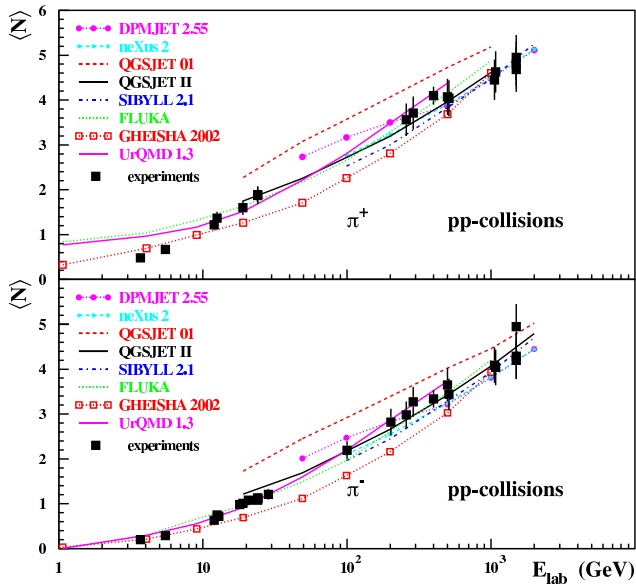
(Tanguy Pierog)

Inelastic Cross Sections



(Tanguy Pierog)

Multiplicity in the Transition Region



(D. Heck)

Important: Investigate particle production in
p-C and π -C interactions

Energy region around 100 GeV equally relevant for
low and high energy interaction models

NA61/SHINE is well suited for the task

Better understanding of hadronic physics in forward direction
⇒ **Major breakthrough in cosmic ray data analysis**