The influence of very forward hadron production in air shower development

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Introduction

Anomalies in AS observation and LHCf results
Introduction: Air shower observations

• From Telescope Array,
\[ E(\text{FD}) = E(\text{SD})/1.27 \]

• From PAO,
\[ \mu \text{ on the ground is larger than predictions} \]

Shower development is not completely understood.
Difference b/w E(FD) and E(SD)

Longitudinal development

Lateral distribution

Proton \(10^{14} \text{ eV} \)

\( h^{\text{fast}} = 17642 \text{ m} \)

hadrons \(\rightarrow\) muons

neutrons \(\rightarrow\) electrons

Made by A. Oshima (Chubu U.)
Introduction: Very forward hadron production

- Energy flow distribution of pp @ $\sqrt{s} = 7$[TeV]

To understand shower development, pion and nucleon production in very forward region is essential.
Introduction: $\pi^0$ result of LHCf experiment

- LHCf group has published $\pi^0$ pT spectra at $11 > y > 8.9$ in pp 7TeV collisions.

- EPOS-LHC reproduces data.
- QGSJET-II-04 is also good.
Introduction: $\pi^0$ result of LHCf experiment

- Calculate energy flow from published data and compare with prediction of models.

$\pi^0$ energy flow is not far from the post-LHC model predictions.
Introduction: neutron result of LHCf experiment

- Compare the LHCf neutron results with post-LHC models and DPMJET3.

In these figures, the distance from collision point and detector is not taken into account. So, decay neutrons are not included.
Introduction: neutron result of LHCf experiment

- Calculate energy flow from published data and compare with prediction of models.

Neutron energy flow is about 30% larger than the post-LHC model predictions.
Modification of QGSJET-II-04
Modification method

• In order to increase energy flow of neutron at very forward region, the interaction in which the leading particle is neutron is increased.
  1. Select Non-diffractive event whose leading particle is not neutron.
  2. 10% of selected events are converted to Single diffractive events or double diffractive events whose leading particles are neutrons.

neutron : +30%
proton : +2%
Charged $\pi$ : -4%
$\pi^0$ : -4%
Result of Modification ($\eta > 10.76$)

Original QGSJET-II-04

Sum = 21.7GeV

Modified

Sum = 28.2GeV
Result of Modification ($9.22 > \eta > 8.99$)

Original QGSJET-II-04

Sum = 31.7GeV

Modified

Sum = 40.5GeV
Result of Modification (8.99 > \eta > 8.81)

Original QGSJET-II-04

Energy (GeV)

\begin{itemize}
\item Sum = 23.6 GeV
\end{itemize}

Modified

Energy (GeV)

\begin{itemize}
\item Sum = 28.9 GeV
\end{itemize}
π0 energy flow at $y<8.0$ is decreased about 10%.
Neutron energy flow increased about 30% at the peak.
Summary of model modification

• Output of QGSJET-II-04 is modified to increase the leading neutron.

• Neutron energy flow in LHCf acceptance is increased.
  • $\eta>10.76$ : 30% larger than the measured value.
  • $9.22>\eta>8.99$ : Almost same as data
  • $8.99>\eta>8.81$ : 25% smaller than the measured value

• Energy distributions become harder, although real data shows softer distribution.

• Energy distribution of neutron from diffractive interaction is too hard.
Air shower simulation

Proton primary, 1EeV, Vertical
Simulation condition

• Cosmos Ver7.645 is used as the air shower simulator.
  • http://cosmos.n.kanagawa-u.ac.jp/cosmosHome/index.html
  • 3D simulation is essential for the lateral distribution.
  • ~4 hours for 10^{18}eV proton shower data production

• Primary particle is 10^{18}eV vertical proton.

• Modification is applied to interactions above 10^{13}eV.
Longitudinal development

Increase of high rapidity particle slows the shower development. Xmax changes +5g/cm^2 by this modification.
Lateral distribution

# of Electron

- +2% at core
- -0.5% at 600m away

# of Muon

- ~+2% at core
- -1% at 1000m away
Summary of air shower simulation

• Proton primary, $10^{18}$eV, Vertical
• $X_{\text{max}}$ is changed only $+5g/cm^2$
• Lateral distribution is changed $\sim$ few %.
  • # of particle around shower core is increased.
• This lateral distribution change is the opposite direction to the observation of TA.
  • TA shows the higher particle density than the prediction at 800m away from the core.
• This modification does not solve the muon excess.
Summary & prospects

• TA observation shows the 27% difference between FD/SD energy scale.

• One of the candidate of the source is the lateral distribution of secondary particles.

• To modify the lateral distribution, the LHCf neutron data and COSMOS air shower simulator is used.

• LHCf neutron results shows the higher energy flow than the predictions of post-LHC models.

• QGSJET-II-04 output is modified to increase the leading neutron.
  • Neutron energy flow at peak increases about 30%.
  • Neutron spectra at LHCf acceptance become harder than the observation results.
Summary & prospects

• Increase of the leading neutron does not affect the lateral distribution.
• Lower energy neutron should be increased to fit the data. (Next step)
  → Large multiplicity of neutron will result the increase of muon.
• pp 13TeV data will give us the information of π0 around the peak of energy flow distribution.