Hadronic interaction and air shower development

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Outline

- Motivation

  Excess of muon in Extensive Air Shower experiments

- Shower development and Macroscopic parameters

  Inelastic cross section, Multiplicity, Elasticity

- Method to modify the macroscopic parameters

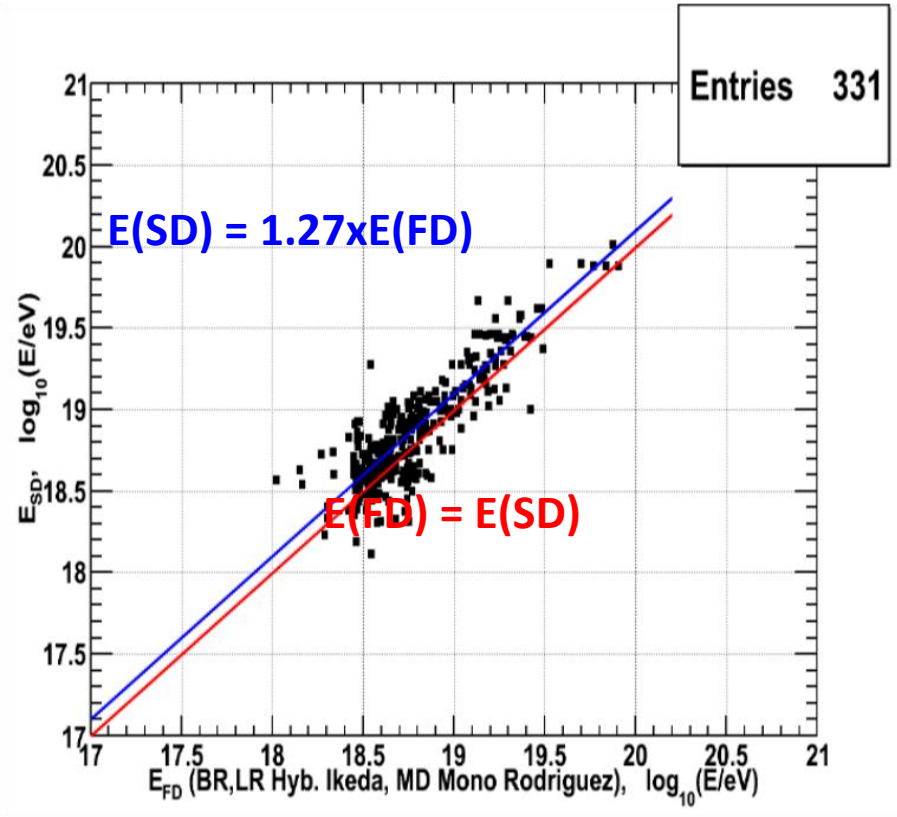
  Based on Ulrich, but extended to treat the 3-D shower development.

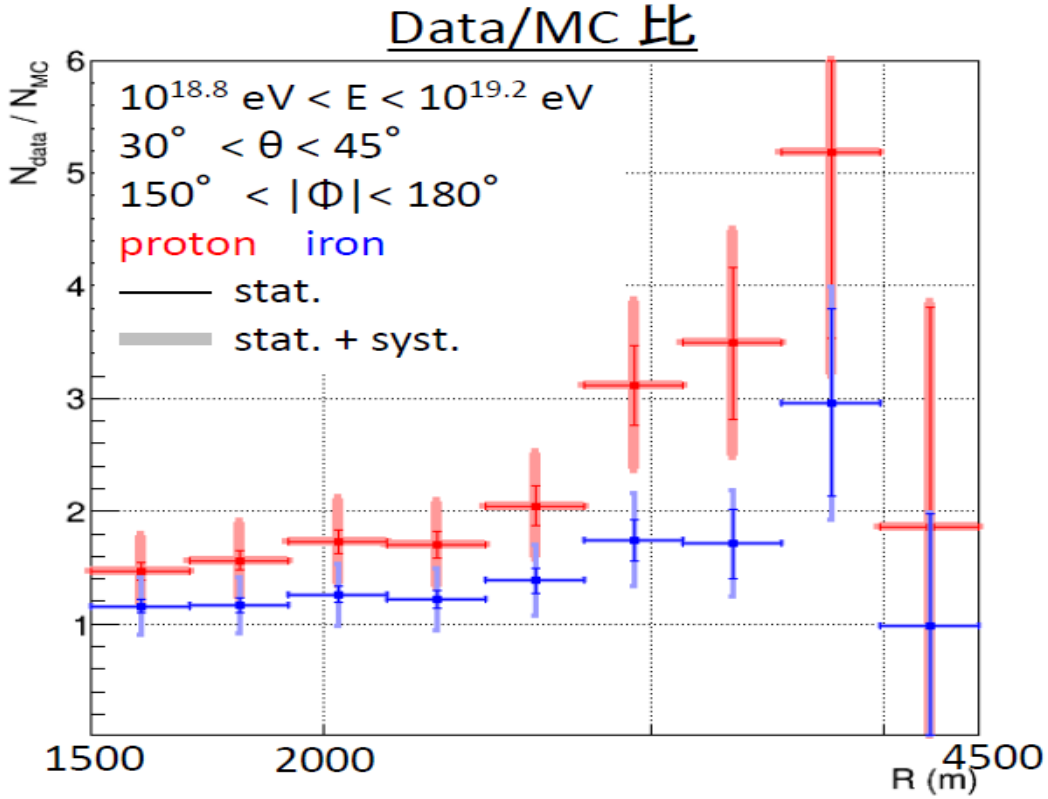
- Air shower simulation

  Influence on lateral distribution, muon production depth.

- Delayed neutron as information of hadron component in EAS

Motivation : Excess of muon on the ground





(R. Takeishi Doctor Thesis)

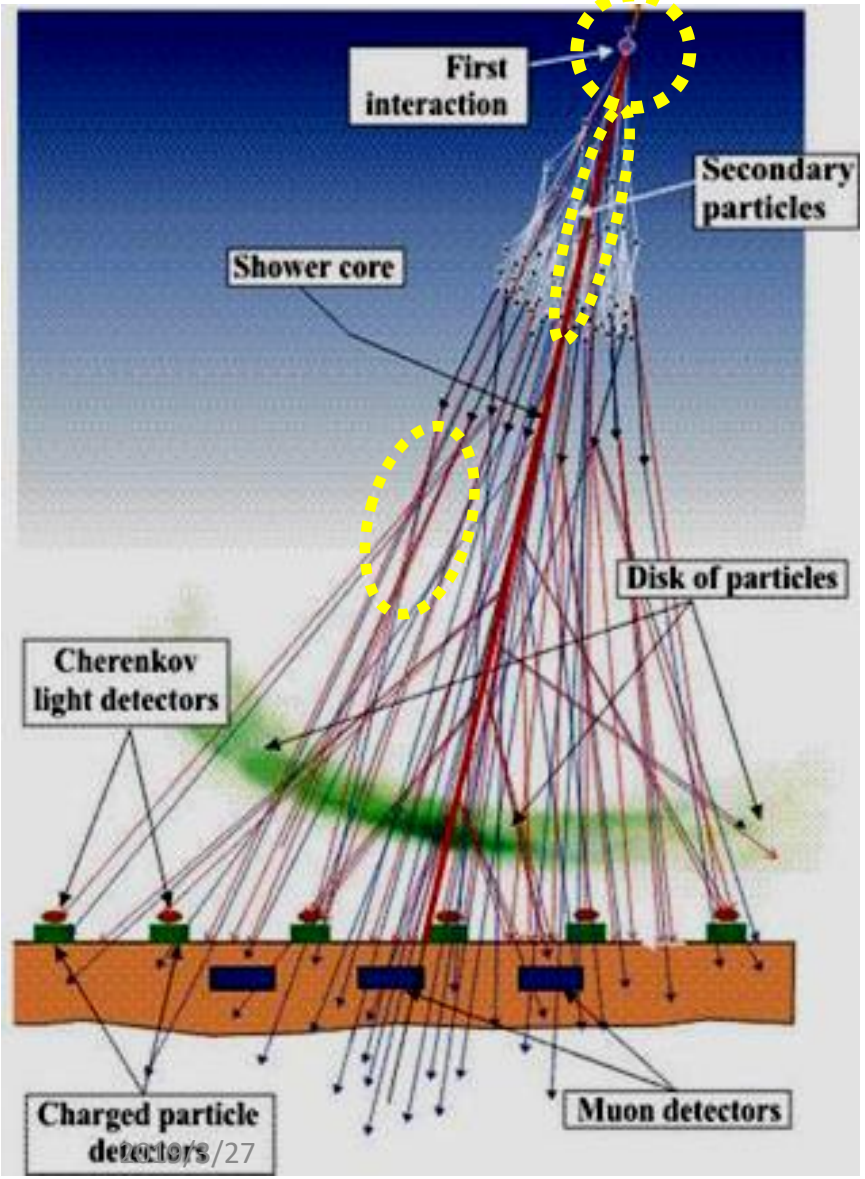
TA shows…

Particle density @ 800m is 27% larger than the prediction

Large signal excess far from the core

・・・ E_{prim}=10EeV, R=2000m Data/MC≒2

Macroscopic parameters of hadronic interaction



① Inelastic cross section σ_{inel}

If large σ: rapid development
If small σ: deep penetrating

② Multiplicity N_{multi}

If large, rapid development
If small, deep penetrating

③ Elasticity $\kappa = \frac{E_{leading}}{E_{total}}$

If small κ (π^0s carry more energy)
rapid development
If large (baryons carry more energy)
deep penetrating

Modification method of macroscopic parameters

(by Ulrich et al.)

In order to study the impact of these parameters in AS development,
I modified the outputs of hadronic interaction models in CORSIKA.

In case of “Inelastic cross section”

$\sigma'_{inel} = f(E, f_{19}) \times \sigma_{inel}$ f_{19} : Modification factor @ 10EeV

$$f(E, f_{19}) = 1 + (f_{19} - 1)F(E)$$

$$F(E) = \begin{cases} 0 & E \leq 1\mathrm{PeV} \\ \log_{10}(E[\mathrm{PeV}]/1\mathrm{PeV}) \,/\, \log_{10}(10\mathrm{EeV}/1\mathrm{PeV}) & E > 1\mathrm{PeV} \end{cases}$$

Inelastic cross section

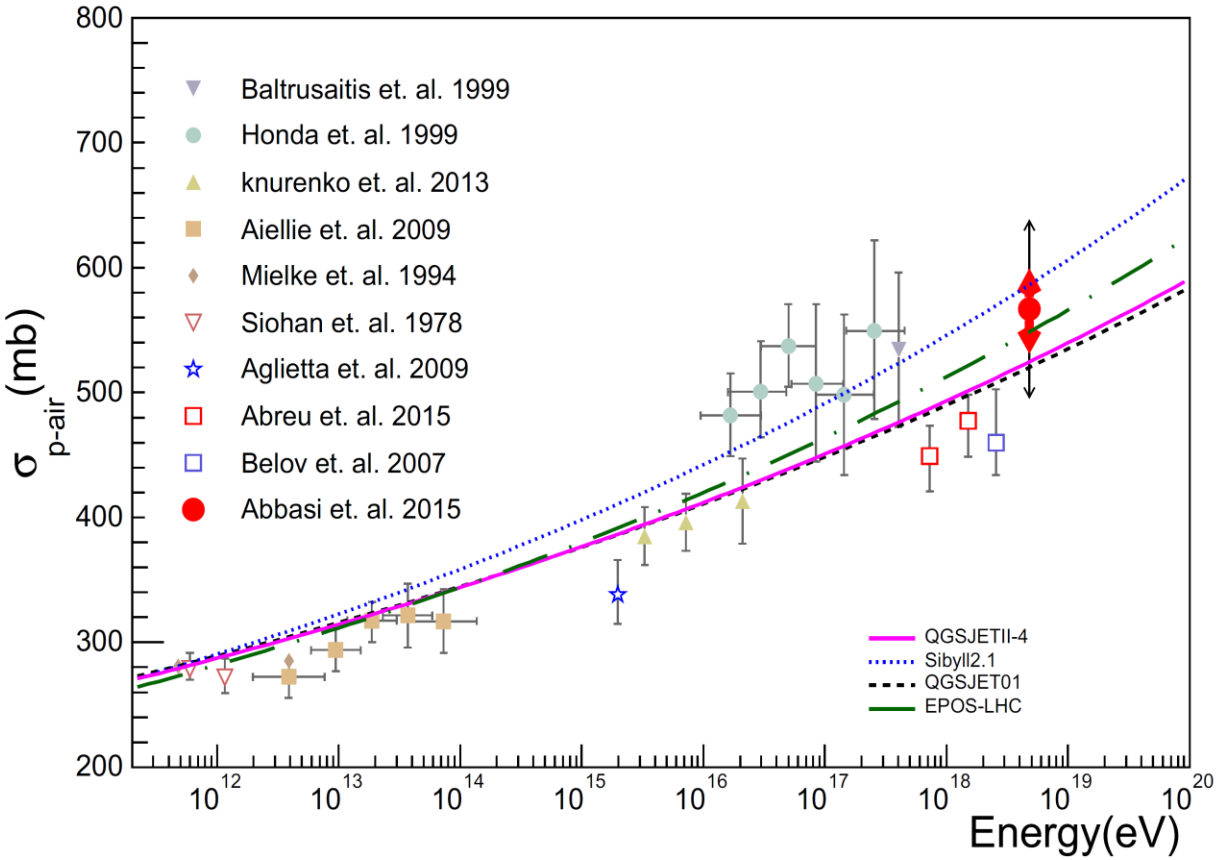
Cross sections of P-Air, p-p, π-p, K-p interactions are modified.

$f_{19} = 0.3, 0.5, 1.0, 2.0, 3.0$

TA result shows larger $\sigma_{p\text{-}Air}$ than 2 post-LHC models.

c.f. EPOS-LHC > QGSJET II-04

p-Air cross section (by R. Abbasi)



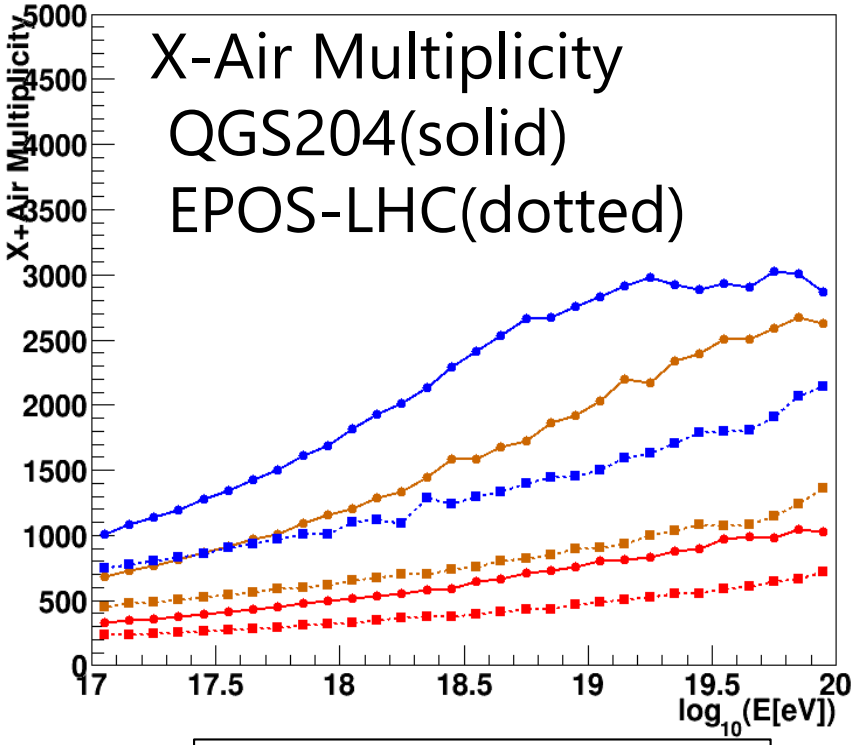
Multiplicity

of particles produced by hadronic interaction

$$N'_{mult} = f(E, f_{19}) \times N_{mult}$$

※ Total energy of each particle type is conserved.
However, The leading particle is excluded to conserve the elasticity.
※ Total charge is conserved.
※ Total energy is conserved.

c.f. QGSJET II-04 > EPOS-LHC



BLUE: IRON
BROWN: NITROGEN
RED: PROTON

Elasticity

Ratio of the leading particle energy to the total energy.

$$\kappa' = f(E, f_{19}) \times \kappa$$

※**Upper limit of modification**:
All particles except for the Leading particle have only mass energy

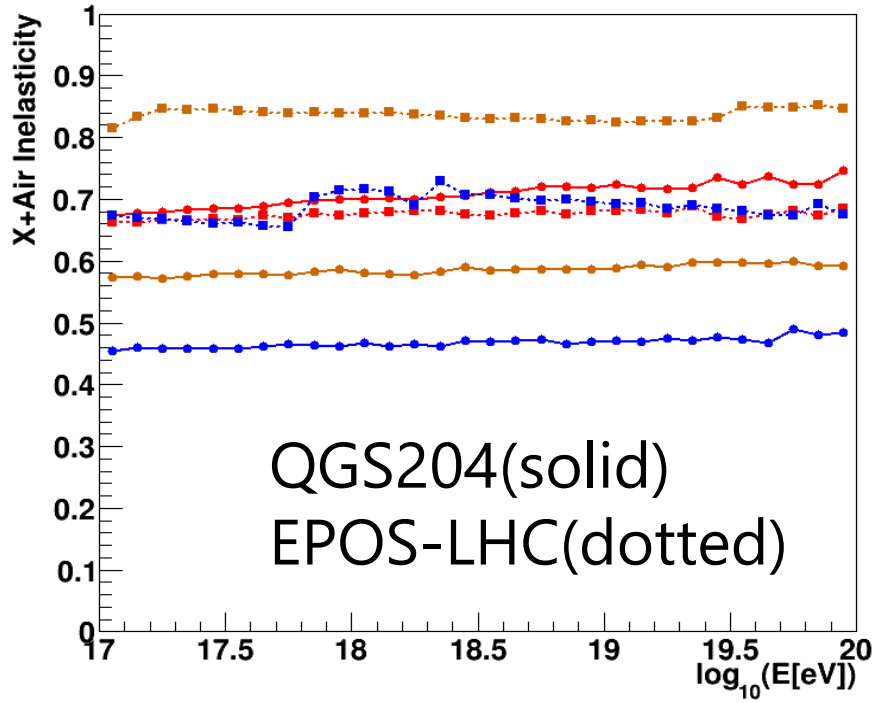
※ **Lower limit of modification**:
All of the secondary particles have the same energy.

※ # of particles, the total energy and particle types are conserved.

c.f.) In p-Air interaction,

QGSJET II-04 > EPOS-LHC

X-Air Inelasticity ($1 - \kappa$)



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Air shower simulation w/ modified interaction model.

4 Modification factors f_{19} = 0.3,0.5,2.0,3.0

Original source code: Corsika ver.7.570

Original hadronic interaction model: QGSJET-II-04

Primary particle : proton

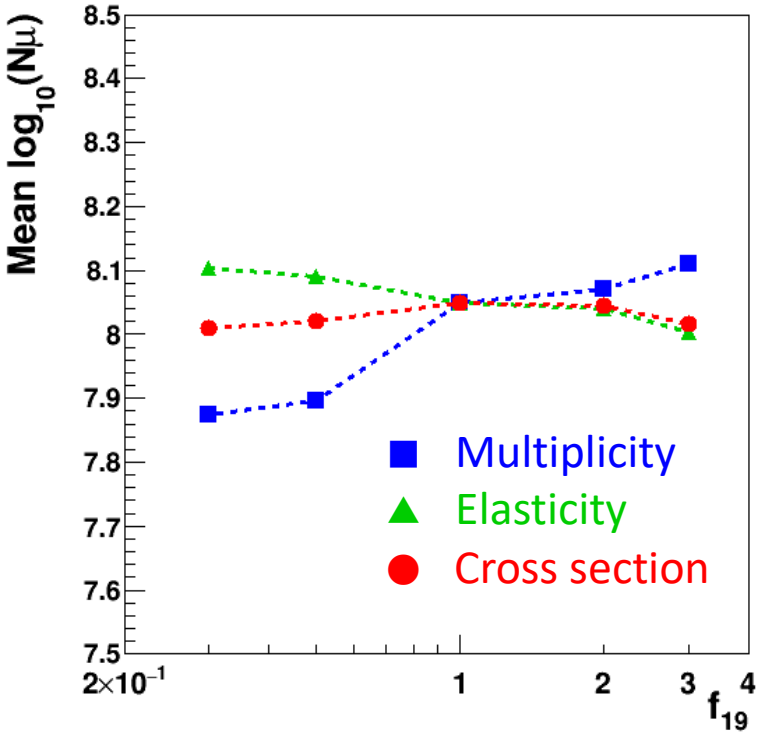
Primary energy : 10^19.5 eV

Zenith angle : 0 ～ 60deg.

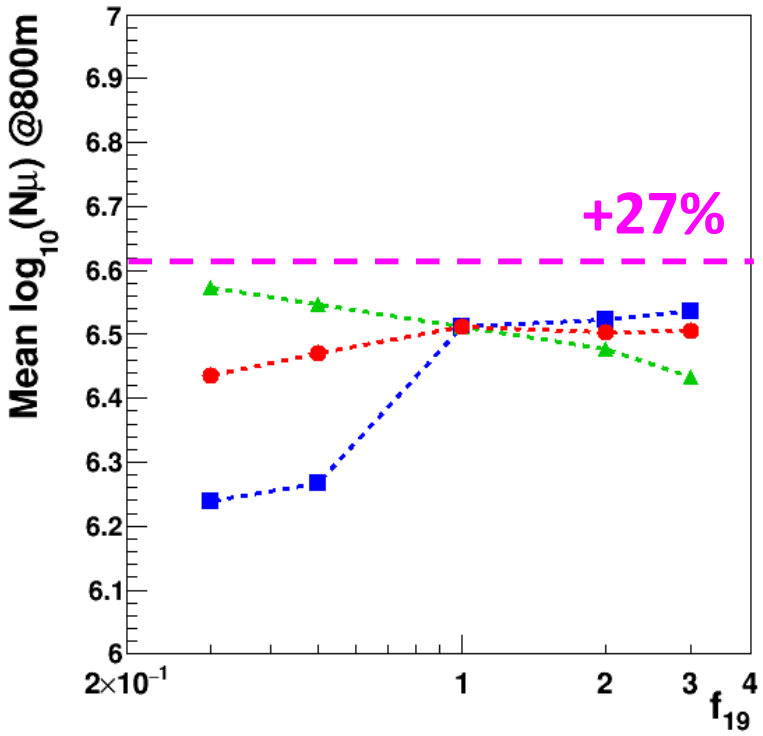
# of event : 250

of muons on the ground（E>1GeV） vs. f_{19}

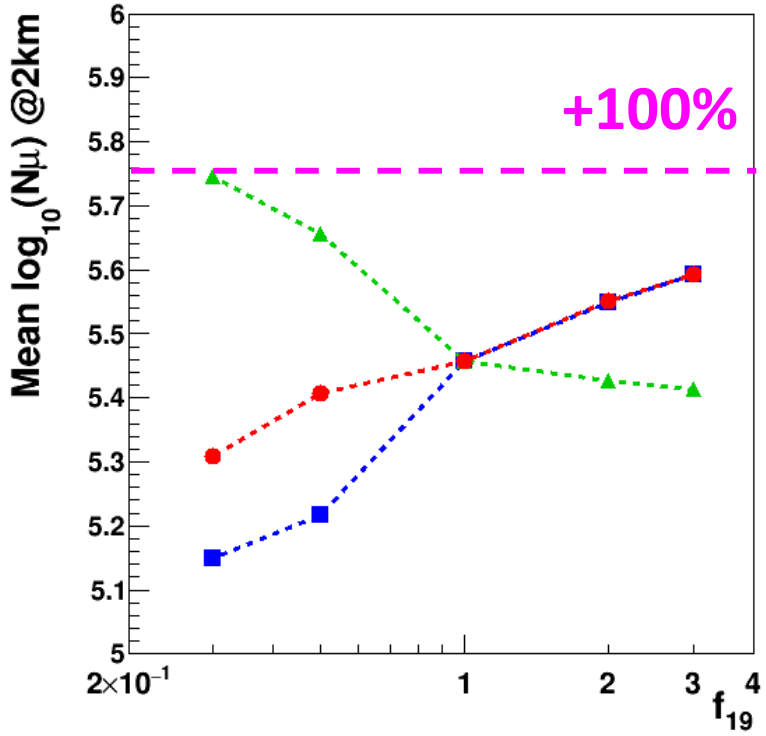
All distance



R=800m



R=2000m



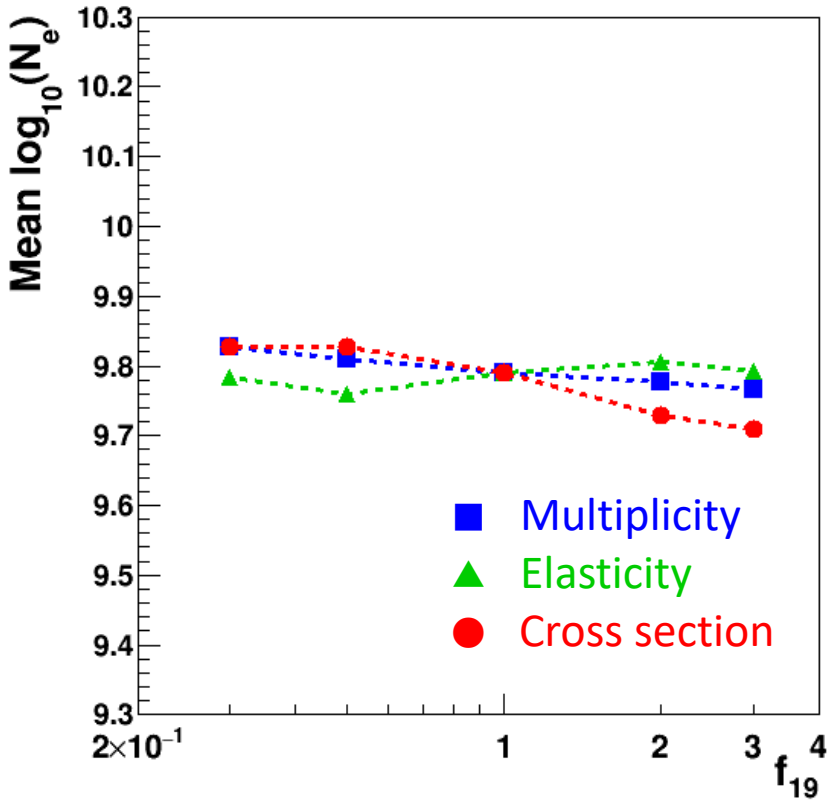
Influence of modification depends on the core distance.

Decrease Elasticity ➔ **Increase energy of π group**

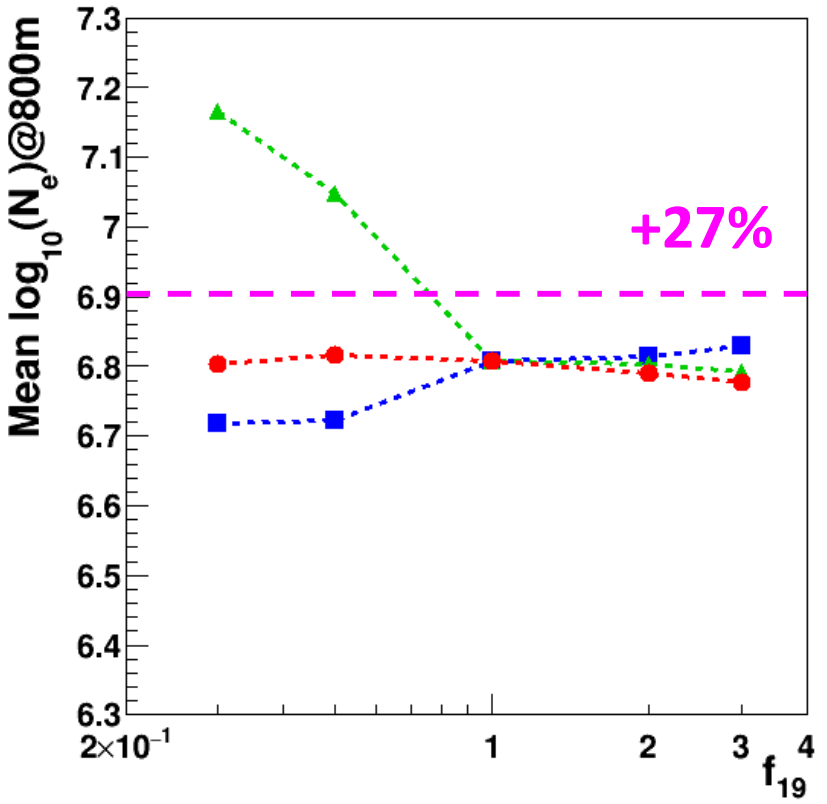
➔ Increase muons far from the core

of electrons on the ground (E>10MeV) vs. f_{19}

All distance



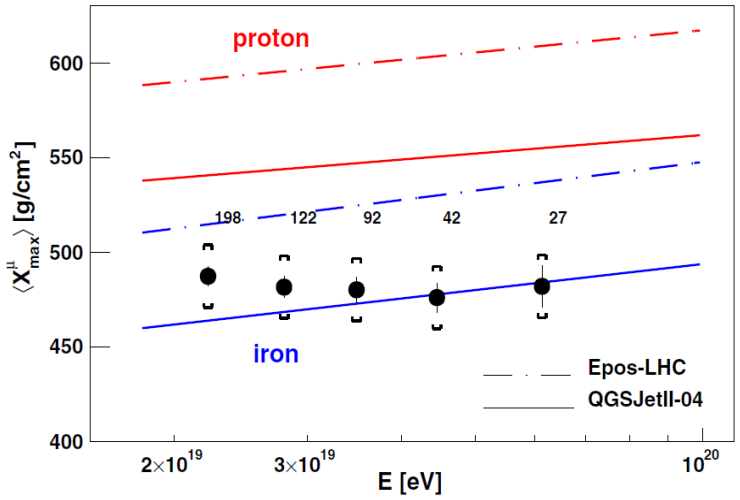
R=800m

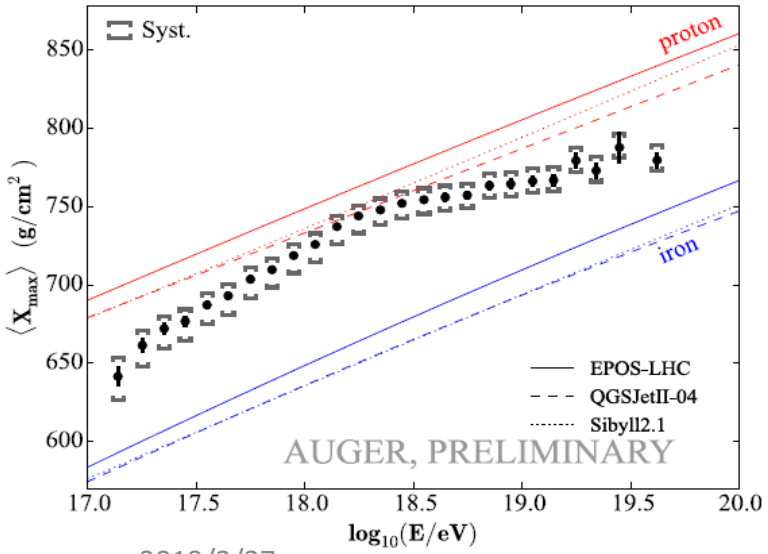


# of electron increase too much…

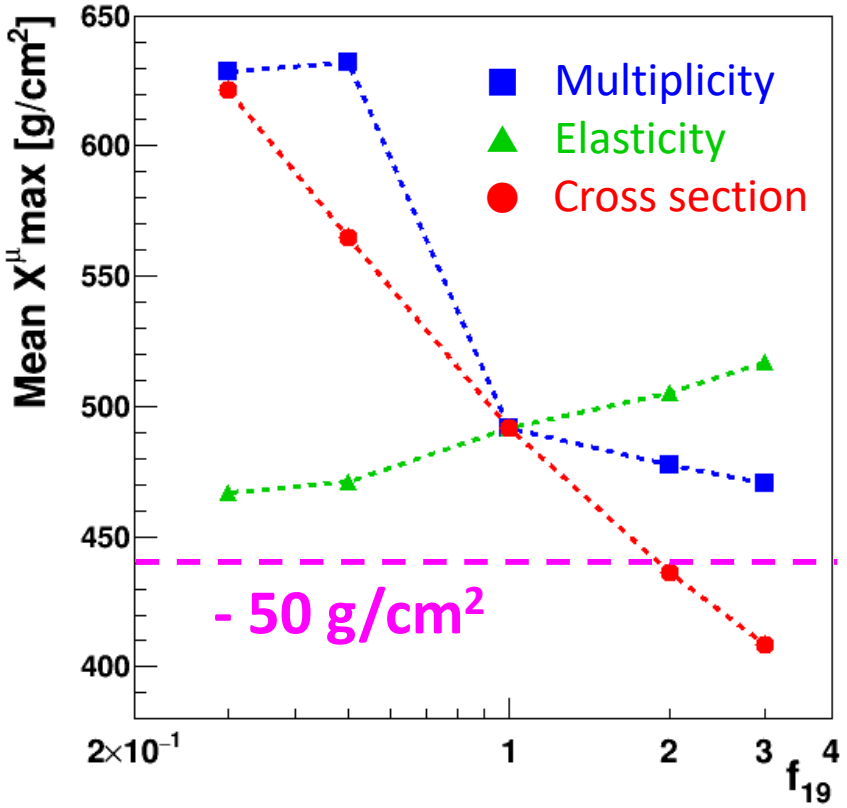
Muon production depth X^{μ}_{max}

Auger results





$X^{\mu}max$ vs. f_{19}



Increase muon far from the core
➔ Decrease MPD

※ Xmax also becomes small.

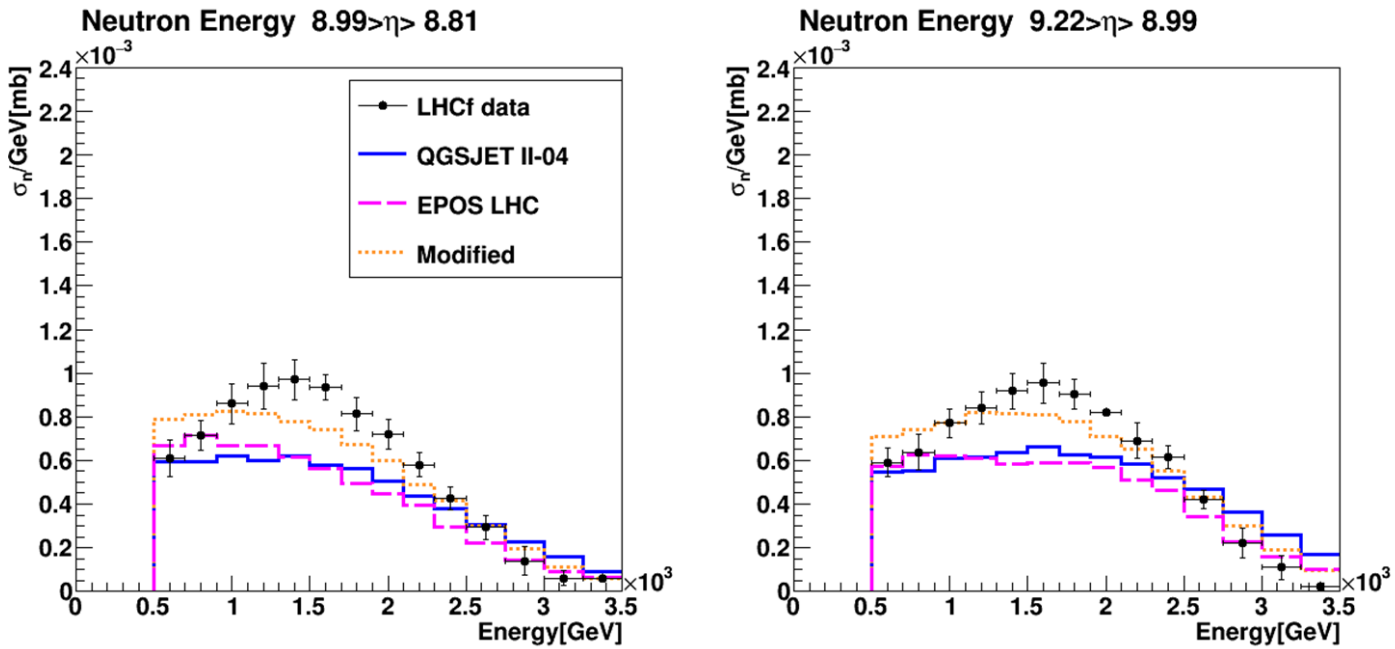
Baryons in EAS

- Baryon can carry large part of energy as the leading particle.
- Secondary baryons can interact and produce charged pions.

➔ μ production.

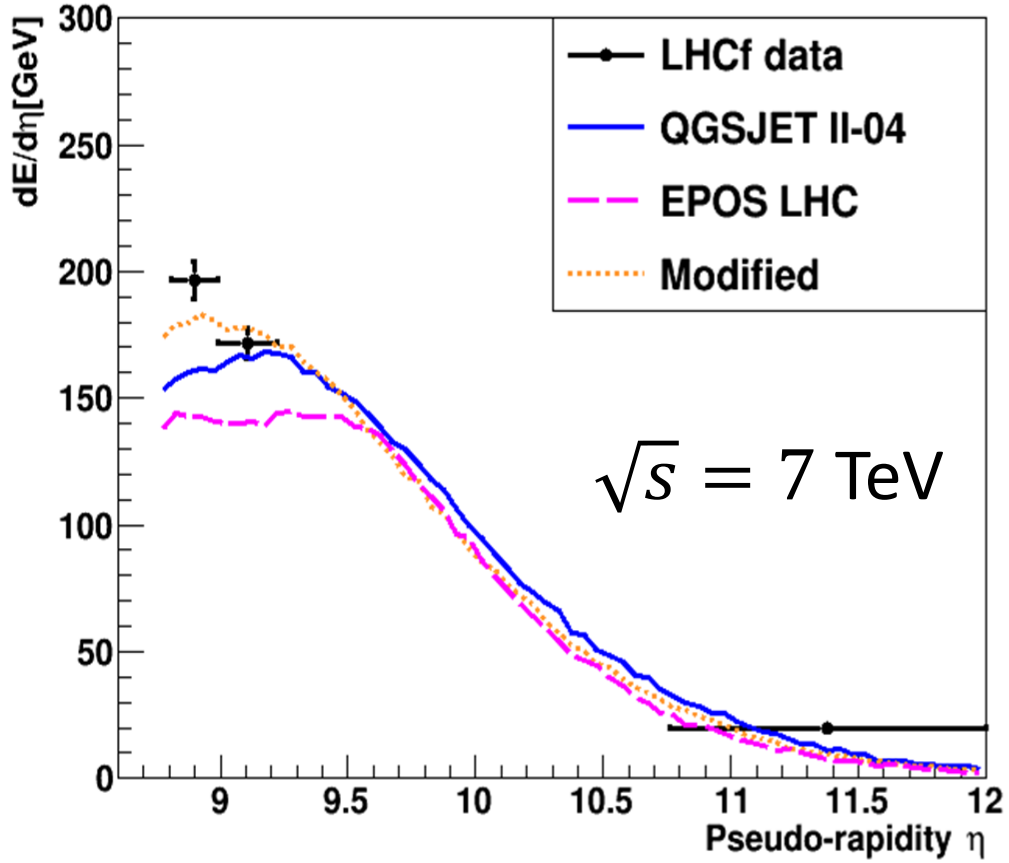
LHCf result shows :

Forward neutral baryon have much more energy than the predictions of post-LHC models.

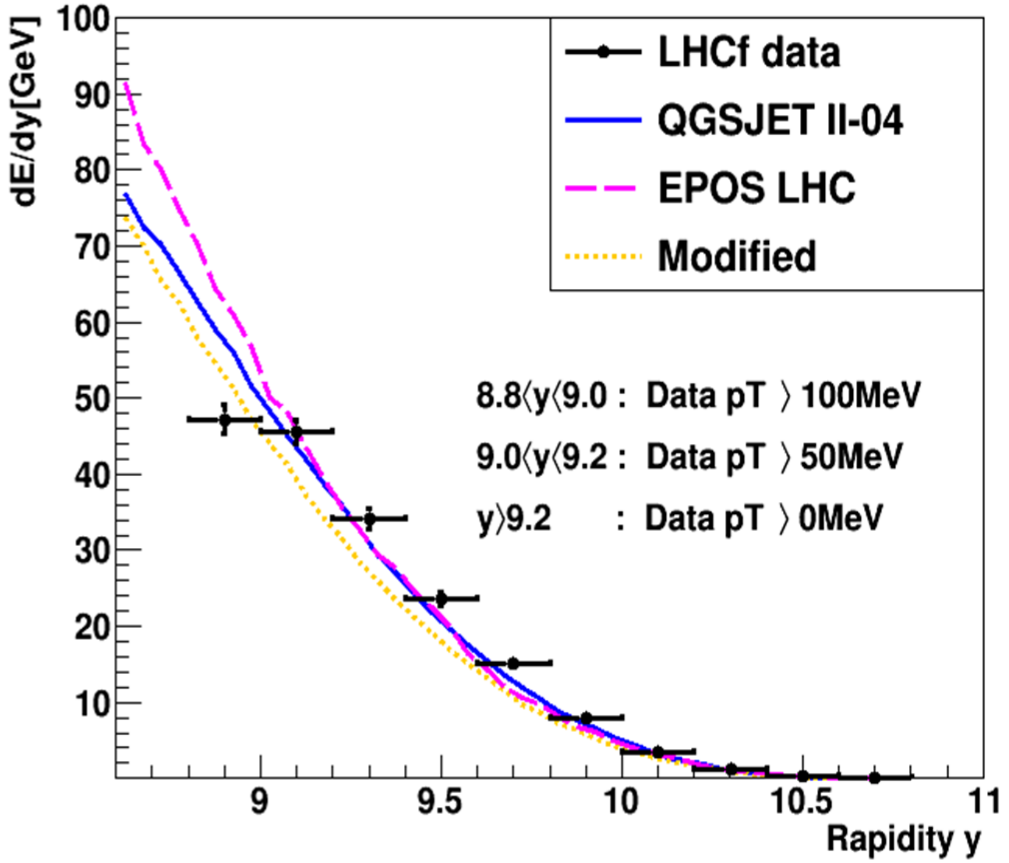


Change the energy flow of forward baryon

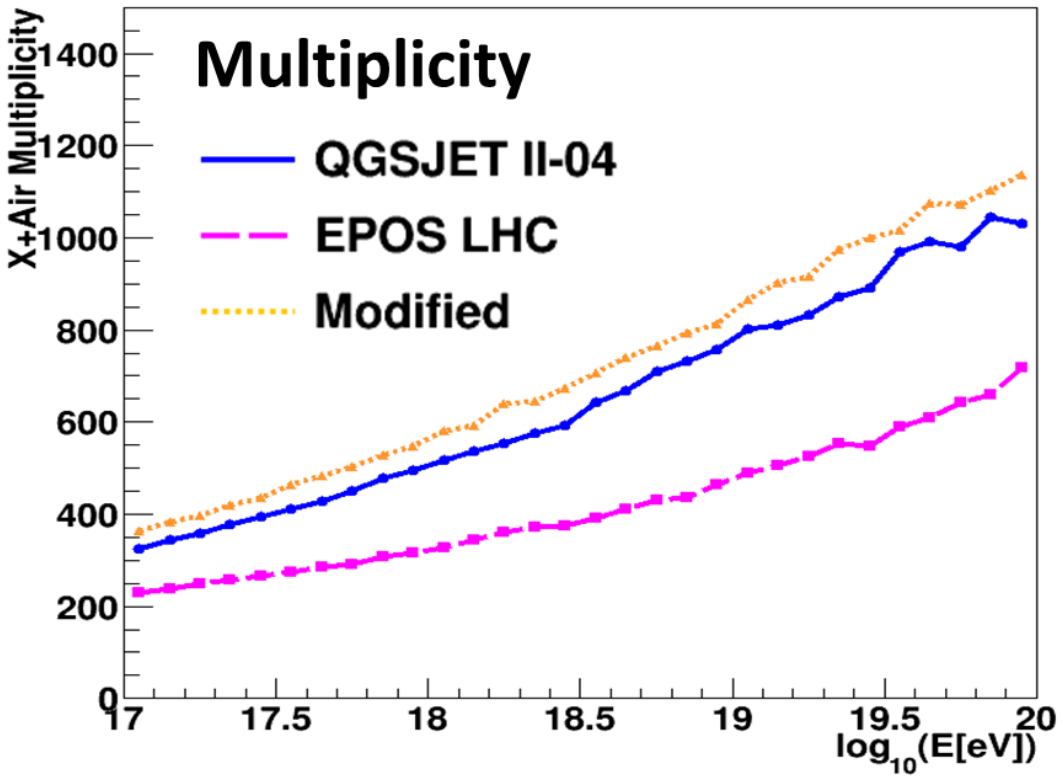
Forward Neutron

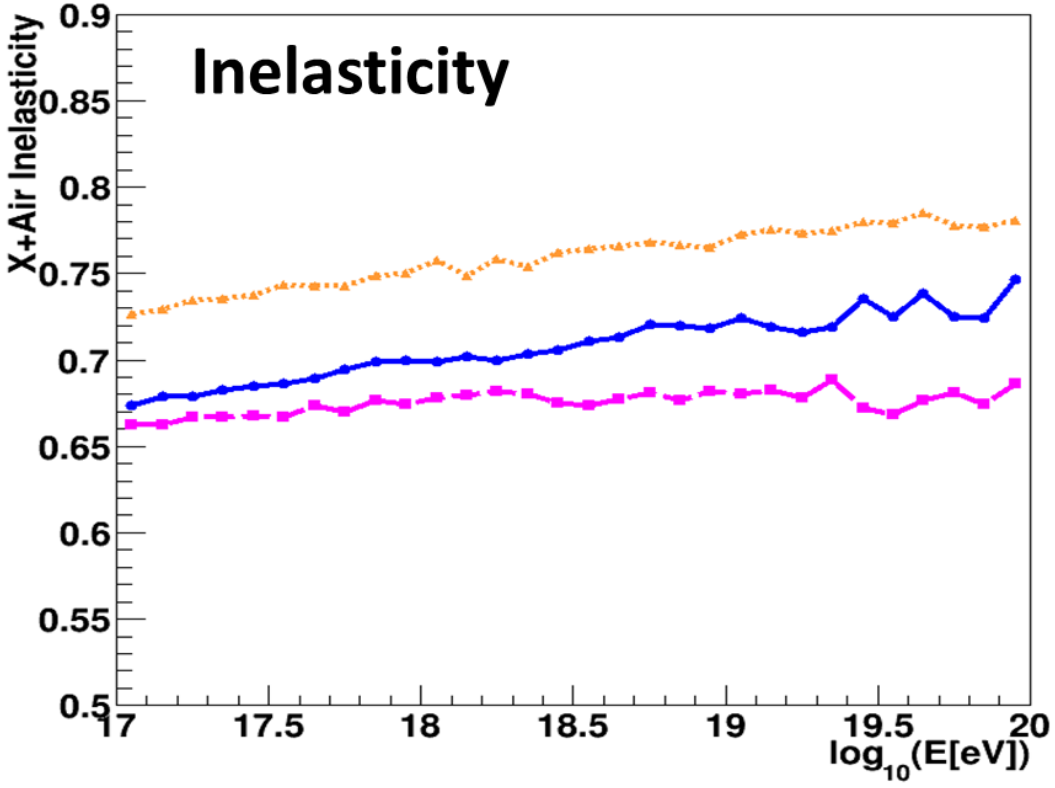


Forward π0

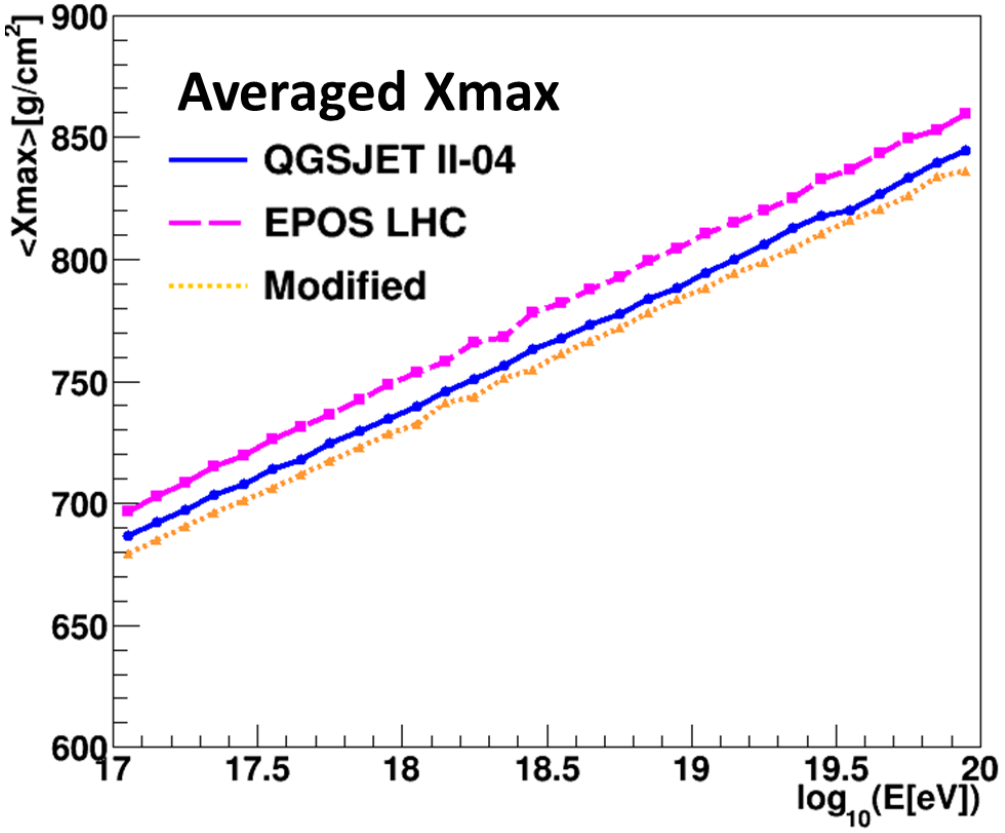


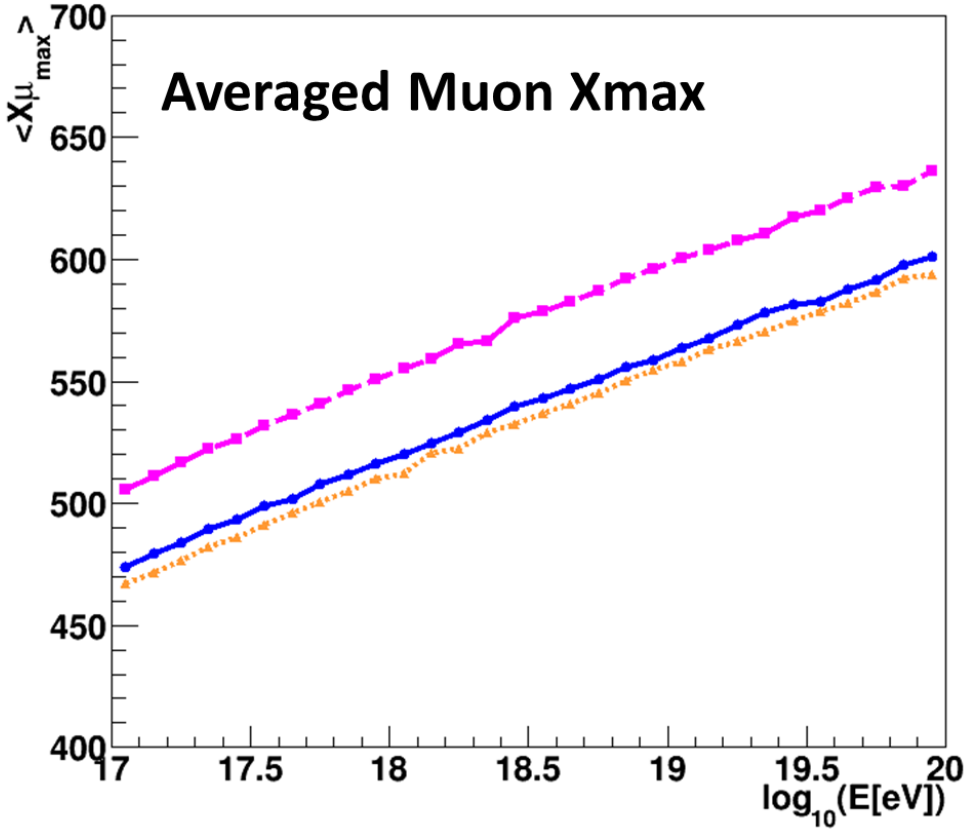
Multiplicity & Inelasticity





Impact on air shower development





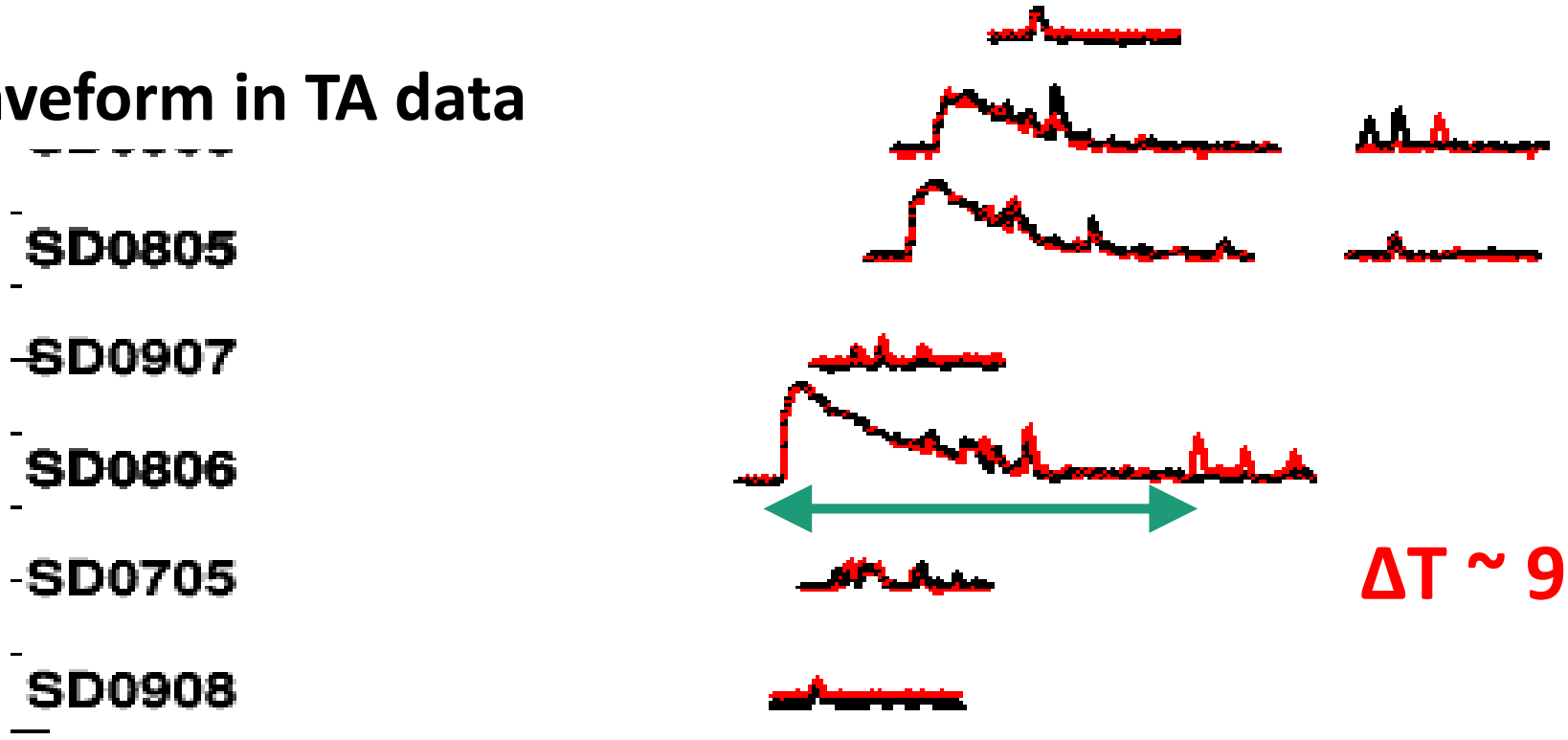
Delayed neutron

The fraction of neutron in the secondary particle is very small.

➔ **Signal time delay** and **Energy deposit** in the detector can be used to extract neutron signals from data.

(c.f. AGASA: ΔT > 4us && ΔE>3MIP)

Waveform in TA data

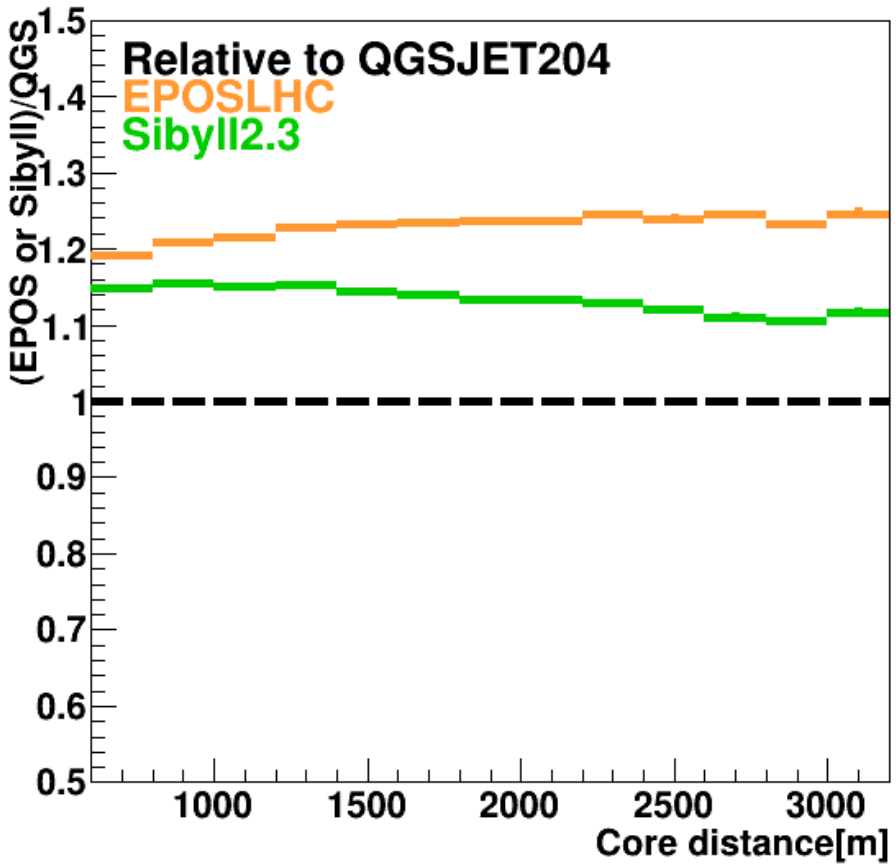


ΔT ~ 9us, ΔE~ 4MIP

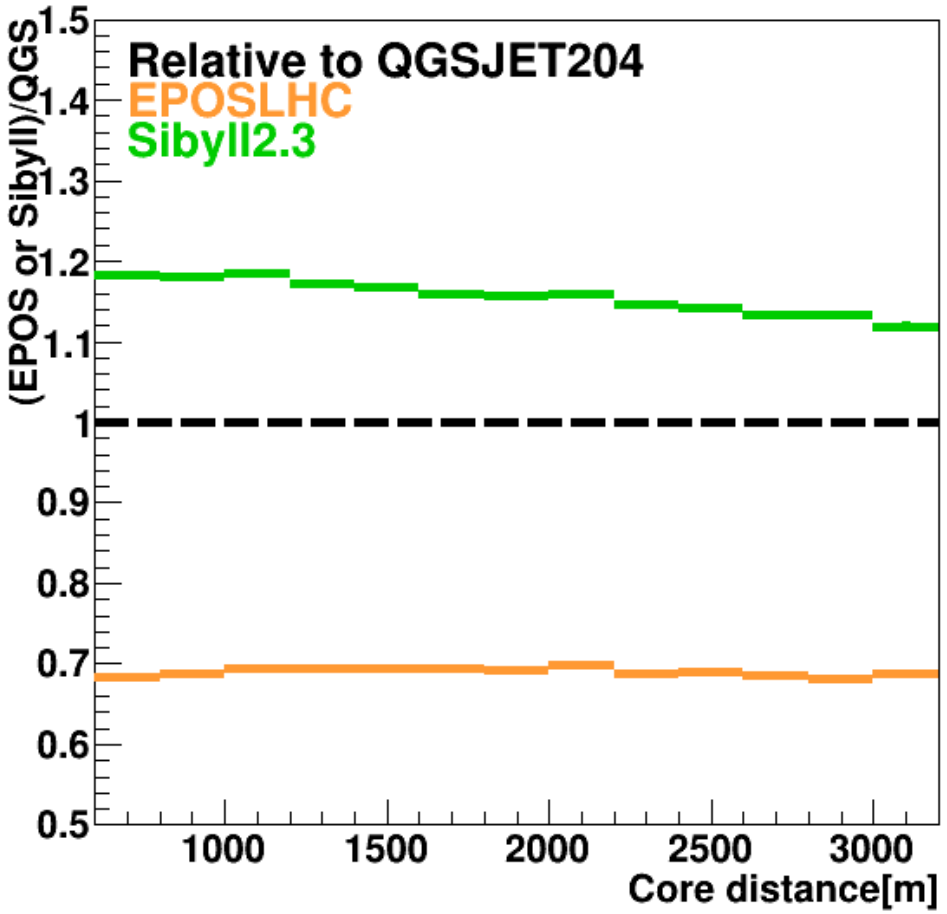
Model dependence

of delayed neutron (ΔT > 4 usec)

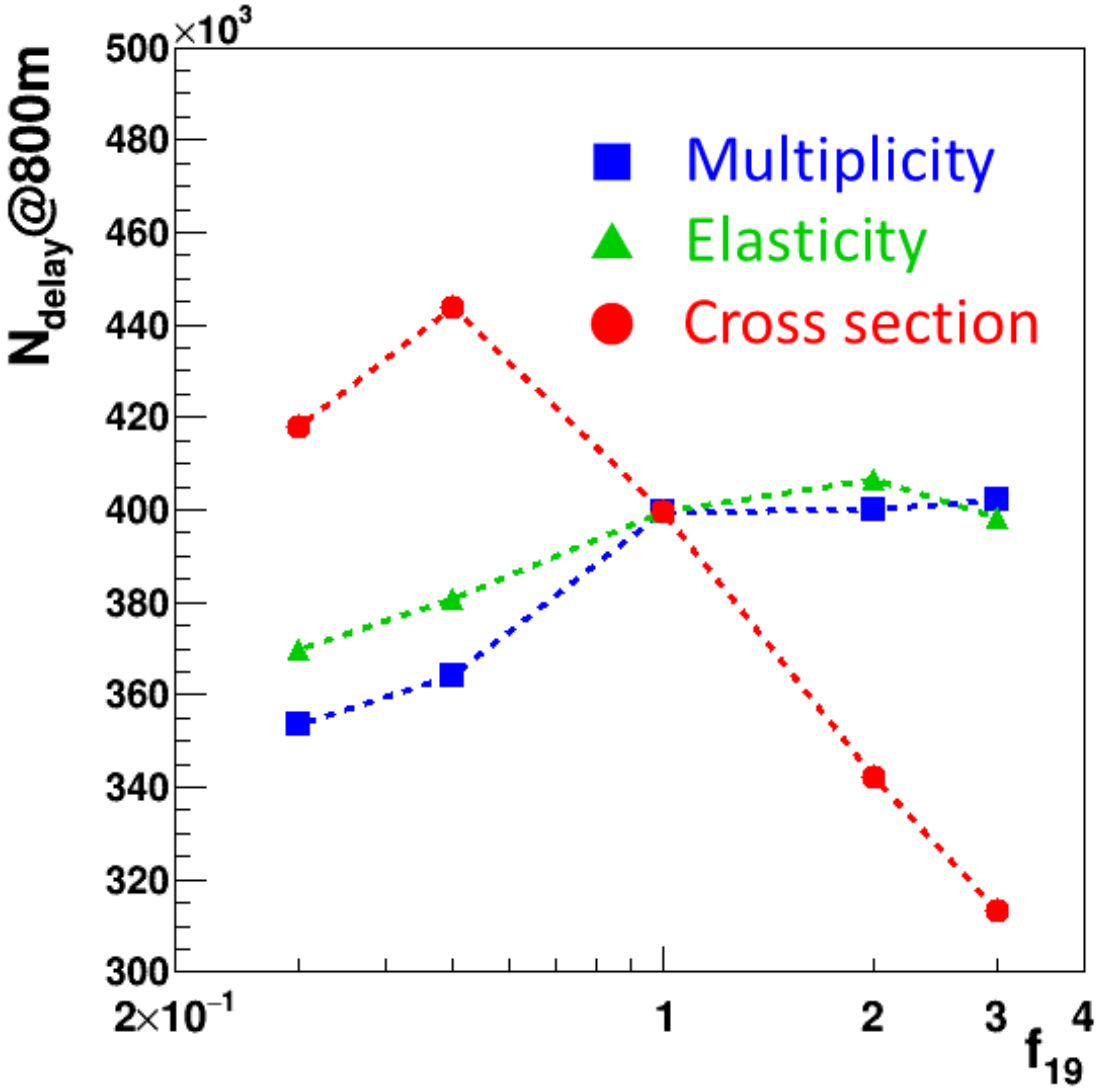
Proton primary



Iron primary



Macroscopic parameter dependence



Preliminary simulation study

Still going on….

We need high statistics.

Summary

of muons far from core increase by the decrease elasticity.

The muon excess does not contradict the small muon production depth.

By modificaton of the interaction model to reproduce the LHCf 7TeV results, # of muon increased.

Hadron component in EAS secondary particles also have model dependence.

Delayed particle can help us to obtain the information.