A simulation study for one-pion exchange contribution on very forward neutron productions in ATLAS-LHCf common events

K. Ohashi, H. Menjo (ISEE, Nagoya Univ.), Y. Itow (KMI and ISEE, Nagoya Univ.), T. Sako (ICRR, Univ. of Tokyo)

I. Introduction

Mass composition of Ultra-high energy cosmic rays are key to understand their origin. However, interpletations of mass compositions in experiments have large uncertainties owing to hadronic interaction models.

Recently, LHCf experiments found differences between data and predictions by hadronic interaction models as shown in Fig. 1 [1].

If these differeces are caused by

diffractive / Non-diffractive collisions

=> affects both $\langle X_{\max} \rangle$ and $\langle X^{\mu}_{\max} \rangle$ [2]

One-pion exchange

Which connects **high-energy pion-proton collisions. Possibility of measurments of pion-proton collisions using this process.**

=> affects muon components in air shower [3]

Fig. 2 illustrates the forward neutron spectrum of the one-pion exchange process (black line) and hadronic interaction models. Fig. 3 illustrate the Feynman diagram for the one-pion exchange process.

In this study, we develop a method for measuring cross-sections and multiplicity of the one-pion exchange contributions.

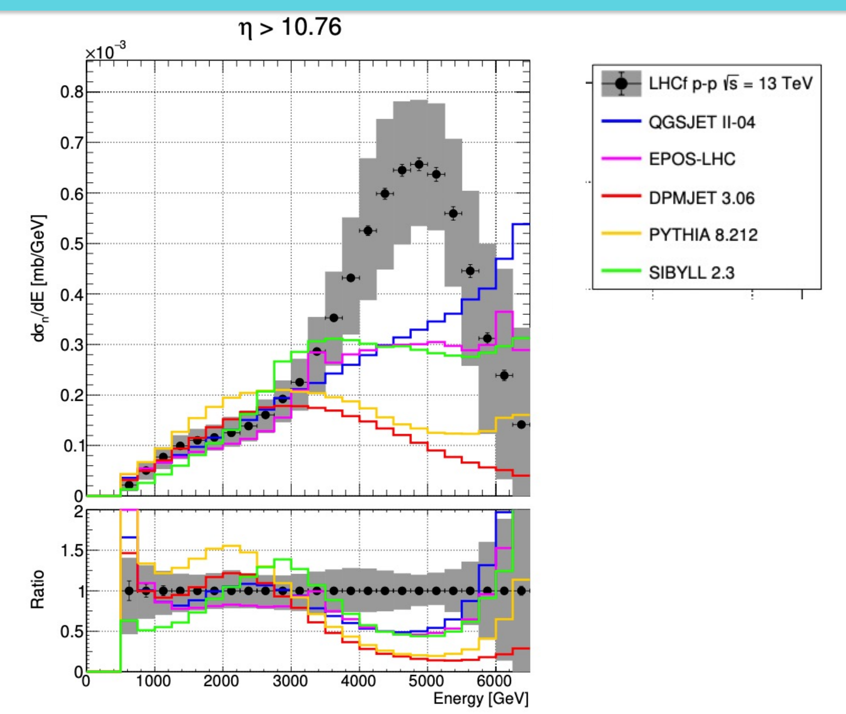

Fig. 1: Forward neutron spectrum in $\eta > 10.76$ measured by LHCf [1]

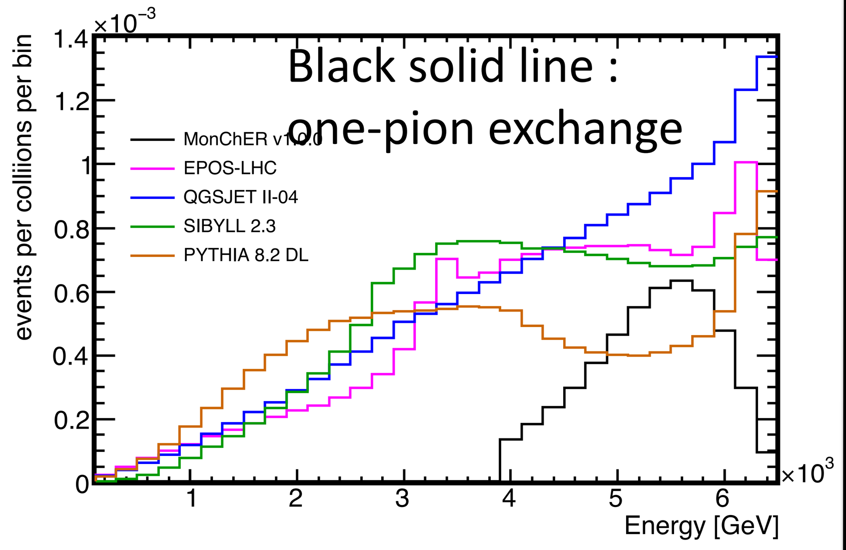

Fig. 2: Predictions of Forward neutron spectrum in $\eta > 10.76$ by one-pion exchange (black line) and hadronic interaction models.

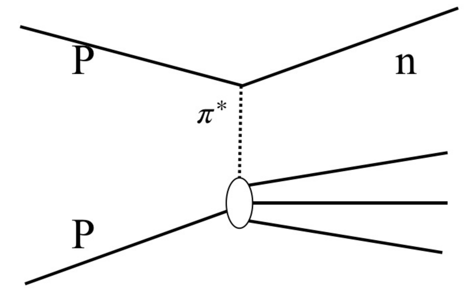

Fig. 3: Feynman diagram for the one-pion exchange process

II. ATLAS and LHCf detectors

ATLAS inner tracker :

Covers pseudo-rapidity $|\eta| < 2.5$ measuring charged particles with $p_T > 100$ MeV/c

LHCf detector :

Sampling calorimeters measuring neutral particles at 140m away from the interaction point.

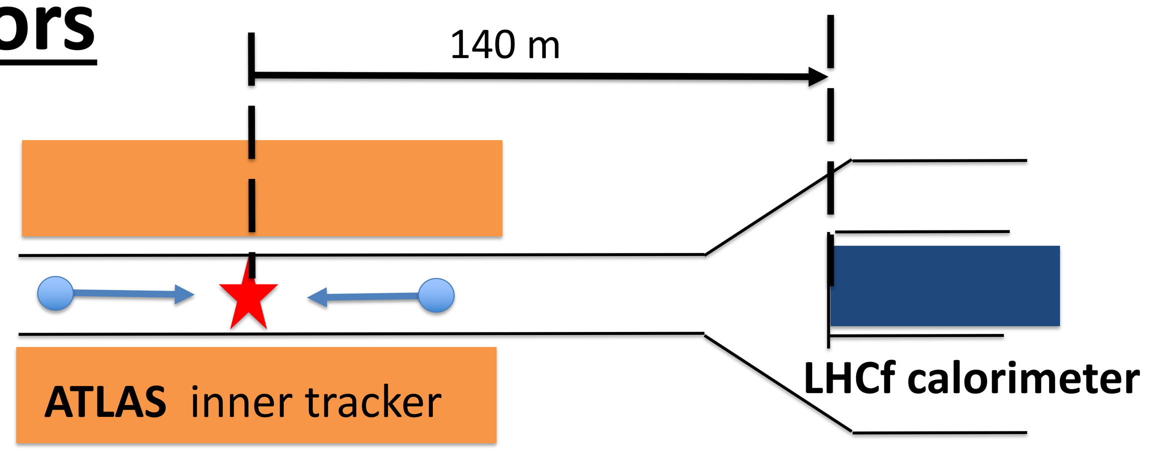

Fig. 4: The schematic view of detectors and colliding particles at the interaction point 1 of the Large Hadron Collider.

N_{charged} : Number of charged particles $p_T > 100$ MeV/c in the region coverd by the ATLAS Inner tracker.

Simulation : proton-proton, $\sqrt{s} = 13$ TeV

MonChER[4] (**signal**) : simulation of the one-pion exchange process

SIBYLL 2.3, EPOSLHC, QGSJET II-04, PYTHIA 8.2 DL (**backgrounds**): simulation of diffractive and non-diffractive collisions.

In figs 2-6, vertical axis is normalized to "per inelastic collisions"

III. A method to saparate one-pion exchange contribution

A simple extension of the previous study in Ref. [5]

Criteria :

ATLAS inner tracker: $N_{\text{charged}} > 10$,

LHCf : Neutrons in $\eta > 10.76$,

$E_n > 3500$ GeV

With this criteria, **large non-diffractive backgrounds are expected for some models.**

⇒Cannot separate the contributions.

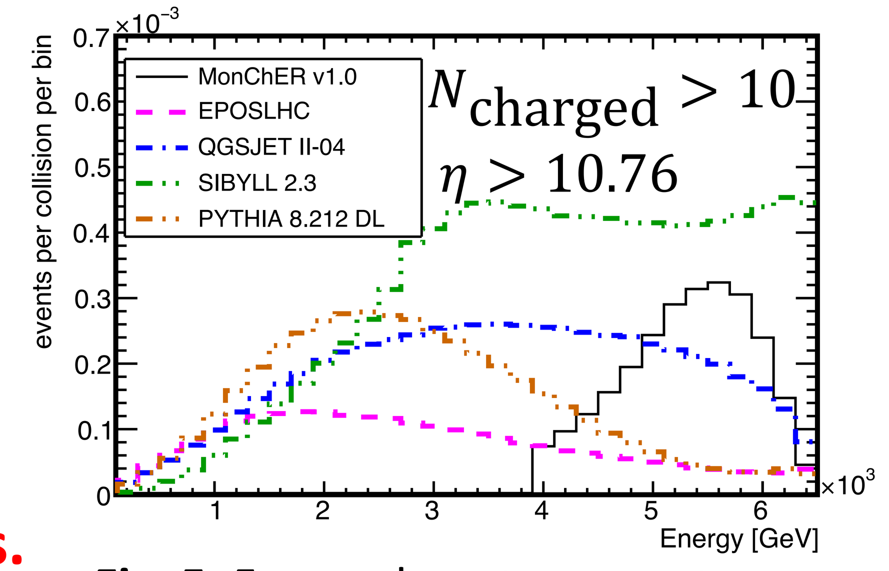

Fig. 5: Forward neutron spectrum.

A method to sapare contributions

New Criteria :

Previous Criteria + $N_{\text{charged}} > 60$

Except for SIBYLL 2.3, we can find **two peacks** in energy spectrum

⇒separate events into **the signal sample** and **the non-diffractive background sample.**

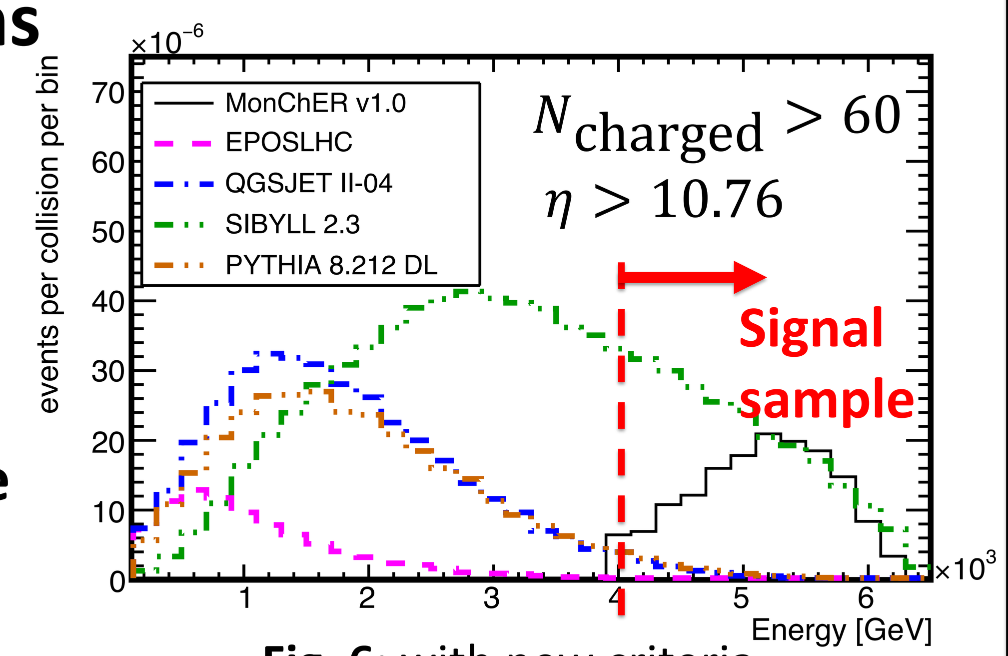

Fig. 6: with new criteria.

Tune signal and background models using the control samples

⇒Reduce uncertainty in models.

⇒Allow us to subtract non-diffractive backgrounds.

event-by-event selection & Background subtraction

Measurements of cross-section and multiplicity of the one pion exchange contribution for higher multiplicity regions where diffractive backgrounds are negligible.

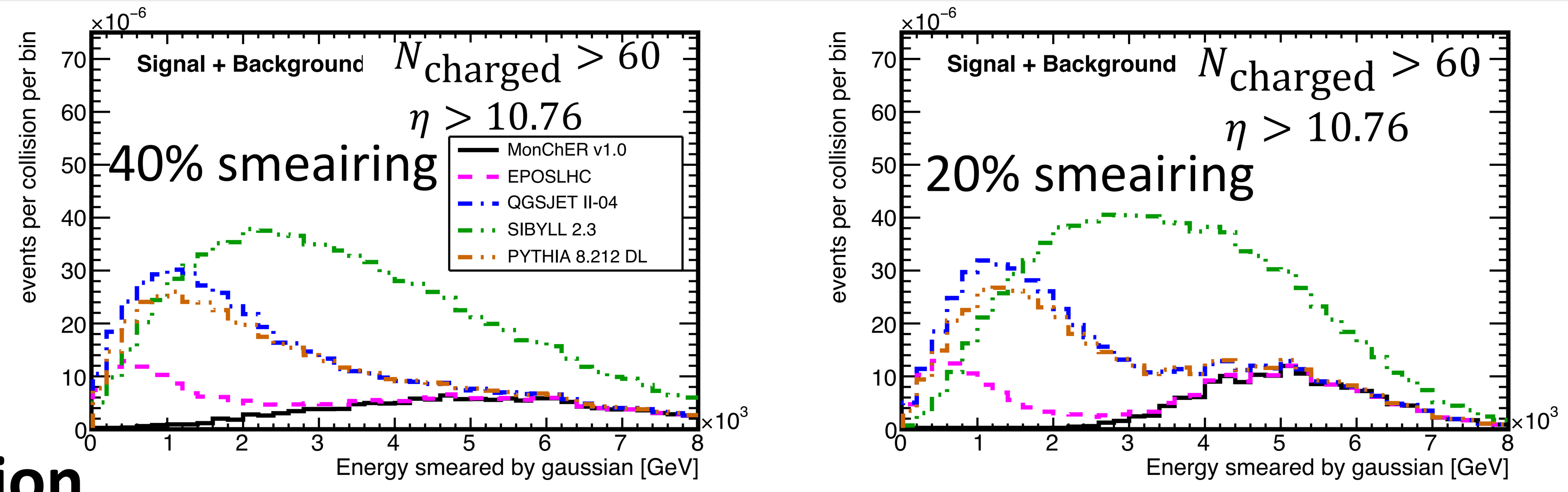

Fig. 7: Neutron enegy spectra. For spectra of hadronic interaction models, the one-pion exchange contributions are artificially added.

IV. Energy and position resolution of detectors

Detector resolutions of LHCf for neutron:
28-38% for energy and 0.1-0.3 mm for positoins
Energy resolution **In Run 3 (LHCf + ATLAS ZDC)** : 20%
To consider resolutions, we apply gaussian smearing for position (0.3mm std. dev.) and neutron energy (20% or 40%).

Resolution of LHCf detector (Fig. 7, left plot) :

Not enough to see the two peak structure even if there are clear differences in true level.

Expected resolution in LHC-Run 3 (right plot) :

We have **possiblitity to find the two peak structure** and separate into signal and background samples.

V. Summary

In this study, we demonstrate the method for separating the one-pion exchange contribution in event-by-event bias.
With event-by-event selections of the one-pion exchange and non-diffractive contributions, we can measure cross-sections and multiplicity distributions for higher multiplicity regions where diffractive backgrounds are negligible.

VI. References

[1] LHCf Collaboration, JHEP 11(2018)073
[2] K. Ohashi et al, Prog. Theor. Exper. Phys. Volume 2021, Issue 3, March 2021, 033F01
[3] T. Pierog, EPJ Web of Conference 208, 02002 (2019)
[4] R.A Ryutin et al, arXiv:1106.2076; https://moncher.hepforge.org/
[5] V.A. Petrov et.al, Eur. Phys. J. C (2010) 65: 637-647