PROCEEDINGS OF SCIENCE

Zero degree neutron energy spectra in $\sqrt{s} = 13$ TeV proton–proton collisions at LHC

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The Large Hadron Collider forward (LHCf) experiment is designed to verify the hadronic interaction models used in cosmic-ray physics. We measured forward particle spectra with $\sqrt{s} = 13$ TeV proton-proton collisions at LHC in 2015. In this paper, we report the neutron energy spectra for LHC $\sqrt{s} = 13$ TeV proton-proton collisions in pseudorapidity $\eta > 10.76$ region. We also obtained x_F spectra which is made by normalized energy spectra with half of collision energy $\sqrt{s}/2$. The spectrum was compared with the one by $\sqrt{s} = 7$ TeV proton-proton collisions and we confirmed that they are consistent in error size. This result support the existence of collision energy dependence on the forward neutron energy spectra in high energies.

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†A footnote may follow.

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1. Introduction

Forward particle production in the hadronic interactions is one of the crucial points to understand the development of cosmic-ray air showers. The Large Hadron Collider forward (LHCf) experiment is designed to verify the hadronic interaction models used in cosmic-ray physics[1]. It measures neutral particles, mainly photons and neutrons, emitted in very forward region of the LHC. The measurement of neutron production in hadronic interaction enables us to know inelasticity.

Neutron energy spectra in proton-proton collisions at lower energies have been investigated by the measurement at the Intersecting Storage Rings (ISR) [3] and the PHENIX experiment[4]. The PHENIX experiment reported that x_F spectrum which were normalized by collision energies, and showed that they are independent of collision energies. However, the LHCf result at $\sqrt{s} = 7$ TeV proton-proton collisions shows break of the scaling[2]. The LHCf experiment measured the particle production at $\sqrt{s} = 13$ TeV proton-proton collisions at LHC. In this paper, we show the procedure and x_F spectrum with $\sqrt{s} = 13$ TeV proton–proton collisions.

2. The LHCf detectors

The LHCf experiment has two independent detectors named Arm1 and Arm2. In this paper, we show the result of the Arm1 detector. LHCf Arm1 detector is made of two calorimeter towers. The transverse dimensions of the calorimeter towers are 20 mm $\times$ 20 mm and 40 mm $\times$ 40 mm. Both calorimeters are composed of 16 layers of sampling scintillation panels interleaved with tungsten plates and position sensitive detectors. Position sensitive detectors are made of four pairs of X–Y position layers. Each layers consists of Gd_2SiO_5(GSO) scintillator bars[5].

3. The performance of the LHCf detectors for hadronic showers

The performance for the measurement of hadronic showers was studied with old detecters[6]. But we upgraded our detecter before $\sqrt{s} = 13$ TeV, we need calibration again. So we had a calibration test by using 250 to 350 GeV proton beams at the CERN-SPS H4 beam line. The position resolution is 0.9 mm, 1.0 mm and 1.2 mm with 250 GeV, 300 GeV and 350 GeV proton beams, respectively. And the energy resolution is 41.7 % with 350 GeV proton beam. We also confirmed that the energy resolution is almost independent from incident beam energy.

4. Analysis and result

4.1 Data reconstruction

Using LHCf data, we can determine the position and energy of the incident particle. The transverse hit position was reconstructed by fitting the lateral distribution measured by GSO-bars in position layers. Also, energy was reconstructed from the sum of the energy deposit in the detecters.

4.2 Event selection

Firstly we applied the selection which required more than energy threshold for successively three continuous layers. Then we select the events which hit in the circle centered on the beam center. The radius of the circle was set as 3 mm, which correspond to pseudorapidity $\eta > 10.76$. After that we selected only neutron events using the parameter L_{2D}. L_{2D} is a parameter defined as Here, $L_{20\ \%}$ and $L_{90\ \%}$ parameters represent the calorimeter depths containing 20 % and 90 % of the total deposited energy in the detecter, respectively.

Figure 1 shows the L_{2D} parameter distribution for the experimental data and MC simulation. From this figure, L_{2D} parameters of hadronic events shown in blue histogram has higher L_{2D} distribution than the ones of photon events shown in red histogram. Hadronic showers are more pen-

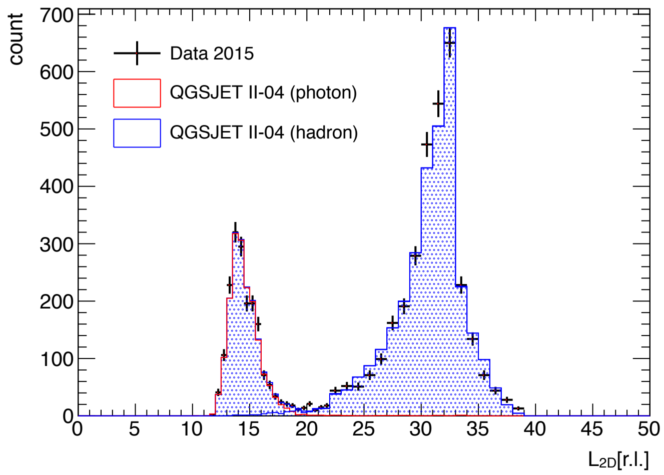

Figure 1: The L_{2D} parameter distribution. The horizontal axis shows the L_{2D} parameter and the vertical axis shows counts. Black points shows the experimental datas measured in 2015 and red and blue histograms shows the L_{2D} distribution obtained by MC simulation with QGSJetII-04. Red histogram shows photon result and blue histogram shows neutron result.

etrating than electromagnetically induced showers. Using L_{2D} parameter, we select only hadron events.

4.3 Result

Figure 2 shows the neutron energy spectra obtained after reconstruction and event selection. The red points represent the neutron energy spectra with $\sqrt{s} = 13$ TeV proton-proton collisions and the blue points represent the one with $\sqrt{s} = 7$ TeV proton-proton collisions[7] . The horizontal axis, x_F, means the neutron energy normalized by the half of the collision energy $\sqrt{s}/2$ and the vertical axis means the frequency of neutron detection. The errors include both systematic and statistical errors. Because this spectra includes detector's energy resolution, we can not compare directly to the measurement at the ISR and the PHENIX experiment. But we can compare with the

LHCf $\sqrt{s} = 7$ TeV data because the LHCf old detecter used in the $\sqrt{s} = 7$ TeV measurement has almost same energy resolution with the LHCf new detecter used in the $\sqrt{s} = 13$ TeV measurement. The spectra with $\sqrt{s} = 13$ TeV proton–proton collisions shows a shift to low x_F, but seems to be consistent with the spectra with $\sqrt{s} = 7$ TeV collisions in error size. This result means the x_F spectra with the $\sqrt{s} = 13$ TeV proton-proton collisions has energy dependence as same as the one with the $\sqrt{s} = 7$ TeV collisions with respect to the measurement at the ISR and the PHENIX results.

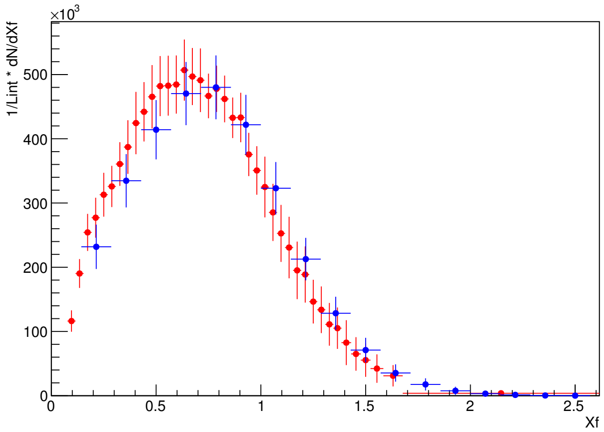

Figure 2: The neutron energy spectrum. The horizontal axis shows neutron energy normalized by half of collision energy $\sqrt{s}/2$. The red points means neutron energy spectrum with $\sqrt{s} = 13$ TeV proton-proton collisions and blue points means the neutron energy spectrum with $\sqrt{s} = 7$ TeV proton-proton collisions. The errors include the systematic error and statistical error.

5. Summary

The LHCf experiment measured very forward particle spectrum in $\sqrt{s} = 13$ TeV proton-proton collisions at LHC in 2015. The neutron spectra in $\sqrt{s} = 13$ TeV proton-proton collisions is consistent with $\sqrt{s} = 7$ TeV data in error size. This explain that neutron energy spectra in $\sqrt{s} = 13$ TeV collisions have energy dependence with respect to the PHENIX experiment spectrum. To compare the spectra directly, we need to remove the detector effect by unfolding.

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