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LHCf plan for p-Pb forward particle measurement

T. Sako[1,2,a], O. Adriani[3,4], L. Bonechi[3], M. Bongi[3], G. Castellini[3], R. D'Alessandro[3,4], M. Haguenauer[5], T. Iso[1], Y. Itow[1,2], K. Kasahara[6], K. Kawede[1], K. Masuda[1], H. Menjo[2,3], G. Mitsuka[1], Y. Muraki[1], K. Noda[7], P. Papini[3], A.-L. Perrot[8], S. Ricciarini[3], Y. Shimizu[6], T. Suzuki[6], T. Tamura[9], S. Torii[6], A. Tricomi[7,10] and W.C. Turner[11]

[1] *Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan*
[2] *Kobayashi-Maskawa Institute for the Origin of Particles and the Universe, Nagoya University, Nagoya, Japan*
[3] *INFN Section of Florence, Italy*
[4] *University of Florence, Italy*
[5] *Ecole-Polytechnique, Palaiseau, France*
[6] *RISE, Waseda University, Japan*
[7] *INFN Section of Catania, Italy*
[8] *CERN, Switzerland*
[9] *Kanagawa University, Japan*
[10] *University of Catania, Italy*
[11] *LBNL, Berkeley, California, USA*

Abstract. LHCf is planning to measure very forward particle emission in the LHC p-Pb collisions foreseen at the end of 2012. The measurement is expected to constrain the nuclear effect in the forward particle emission relevant to the CR-Air interaction. Model discrimination power of this measurement is presented together with some detail in technical feasibility.

1. INTRODUCTION

Experimental data from high energy accelerators provide crucial benchmarks for the hadronic interaction models used in the simulations for Extensive Air Showers (EAS). The Large Hadron Collider forward (LHCf) is a dedicated experiment for this purpose by measuring very forward particles emitted in the LHC hadron collisions [1–3].

So far, including LHCf, rich data from p-p (or $\bar{p}$) collisions is available for the model development while data from nuclear collisions is sparse. In spite of the importance of nuclear interaction in the EAS study, the effect is not extensively discussed.

The effect of nuclear collision with respect to the nucleon collision is usually expressed as the nuclear modification factor, R. The STAR collaboration at RHIC showed that the forward hadron productions in $\sqrt{s_{NN}} = 200\,\text{GeV}$ d-Au collisions [4], having large pseudo-rapidity (η) and being important for EAS, are largely suppressed by nuclear effect.

[a] e-mail: sako@stelab.nagoya-u.ac.jp

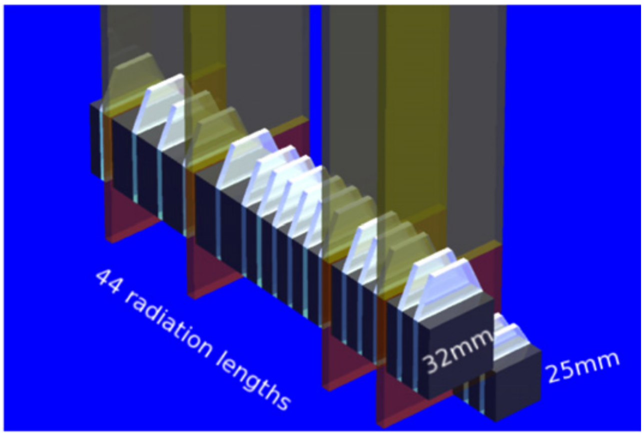

Figure 1. Schematic view of the LHCf Arm2 detector.

LHC is planning p-Pb collisions at $\sqrt{s_{NN}} = 4.4\,\text{TeV}$ at the end of 2012. Although Pb is too heavy to represent the atmosphere, the nuclear effect is simply enhanced when compared with p-Nitrogen collisions [5]. In this paper we first study the feasibility of the p-Pb data taking using the existing LHCf detector and compare the predictions from the different hadron interaction models.

2. FEASIBILITY OF LHCF OPERATION

A plan for LHCf to take data during LHC p-Pb collisions foreseen in 2012 [6] is approved. In the 2012 operation, LHCf will install one of the two detectors called Arm2 at 140 m from the ATLAS interaction point to the direction of the ALICE. Unique installation slot enables to measure particles emitted very forward including 0 degree, or pseudo-rapidity $\eta > 8.4$. The LHCf Arm2 detector, illustrated in Fig. 1, is composed of two compact sampling calorimeters with transverse sizes of $25\,\text{mm} \times 25\,\text{mm}$ and $32\,\text{mm} \times 32\,\text{mm}$. The longitudinal 44 radiation lengths of Tungsten can fully contain the multi TeV electromagnetic showers while corresponding 1.6 hadron interaction lengths give limited performance to the hadronic shower measurement. The shower particles are sampled by 16 layers of plastic scintillators and four X-Y pairs of silicon strip sensors provide the lateral shape of the showers developed in the calorimeters. More detail performance of the LHCf Arm2 detector can be found elsewhere [7–9].

Compared with p-p collisions, ion collisions generally produce larger number of secondary particles. A constraint is given from the geometry of the calorimeters. In case multi particles hit a single calorimeter, LHCf cannot correctly reconstruct the information of the incident particles. Particle multiplicity in the p-Pb collisions are studied by means of Monte Carlo simulations using EPOS and DPMJET-III hadron interaction models for the small and large calorimeters, and for the photon and neutron incidents. Figure 2 shows the results at the proton-remnant side (direction of the proton beam). The probability of more than 1 particle entering in a single calorimeter is almost at the 1% level of the single particle event. We concluded there is no significant effect of the multi-hit events. On the other hand, in the Pb-remnant side as shown in Fig. 3 very large multiplicity is expected from neutrons because the spectator (non-interacting) neutrons in nuclei are emitted along the beam. From the multi-hit study, LHCf decided the observation of the p-remnant side as a prime target and the Pb-remnant side as optional. LHC will circulate the proton beam in the clockwise direction (directing from interaction point to LHCf Arm2) first and then switch to the opposite direction. This is reasonable when we consider proton primary cosmic rays interact with the atmospheric nuclei.

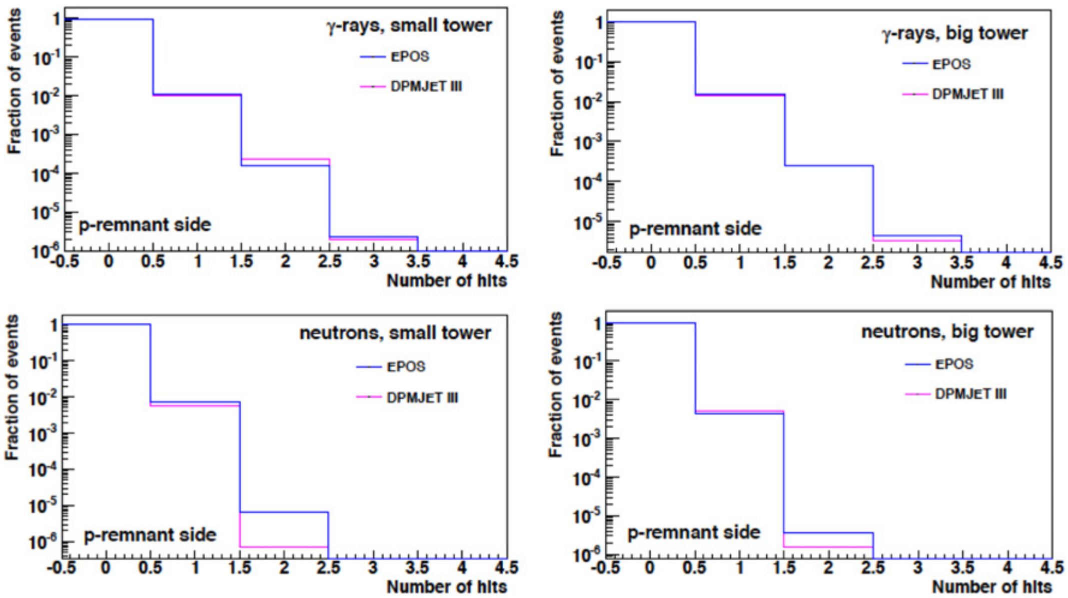

Figure 2. Particle multiplicities in a LHCf calorimeter at p-Pb collisions (proton remnant side). Left for the small calorimeter and right for the large calorimeter. Top and bottom show the results for photon and neutron incident, respectively.

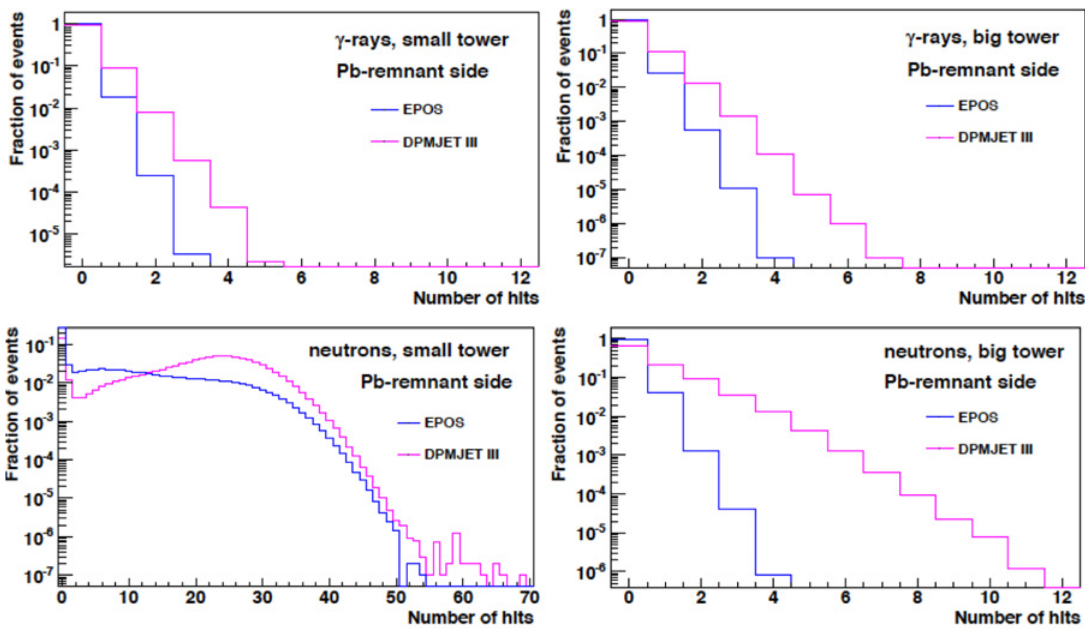

Figure 3. Particle multiplicities in a LHCf calorimeter at p-Pb collisions (Pb remnant side). Left for the small calorimeter and right for the large calorimeter. Top and bottom show the results for photon and neutron incident, respectively.

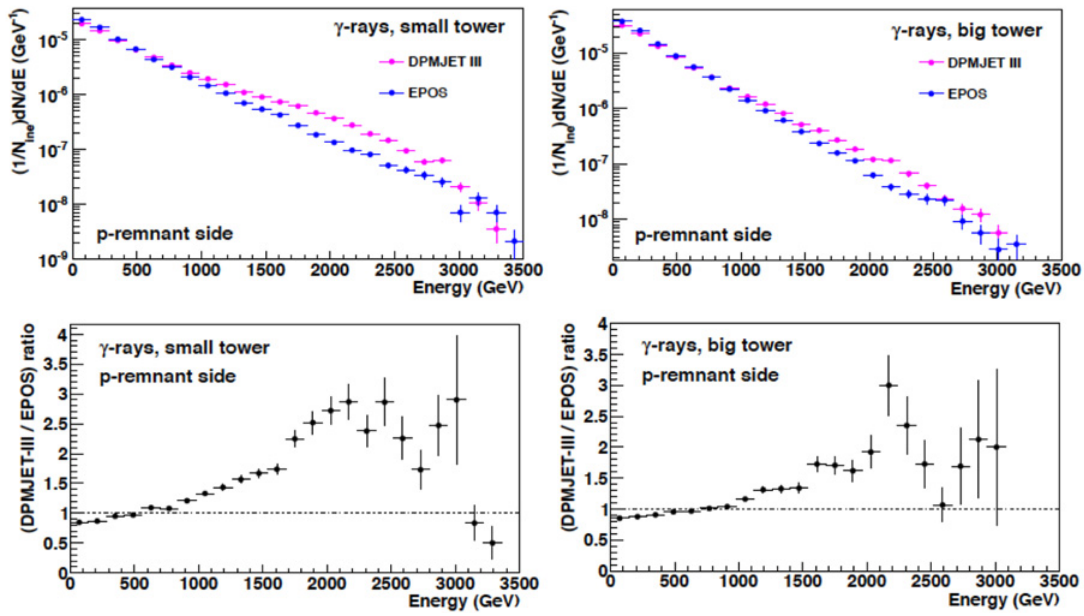

Figure 4. Expected energy spectra of photons at the proton remnant side using DPMJET-III and EPOS. Bottom plots show the ratio of two models.

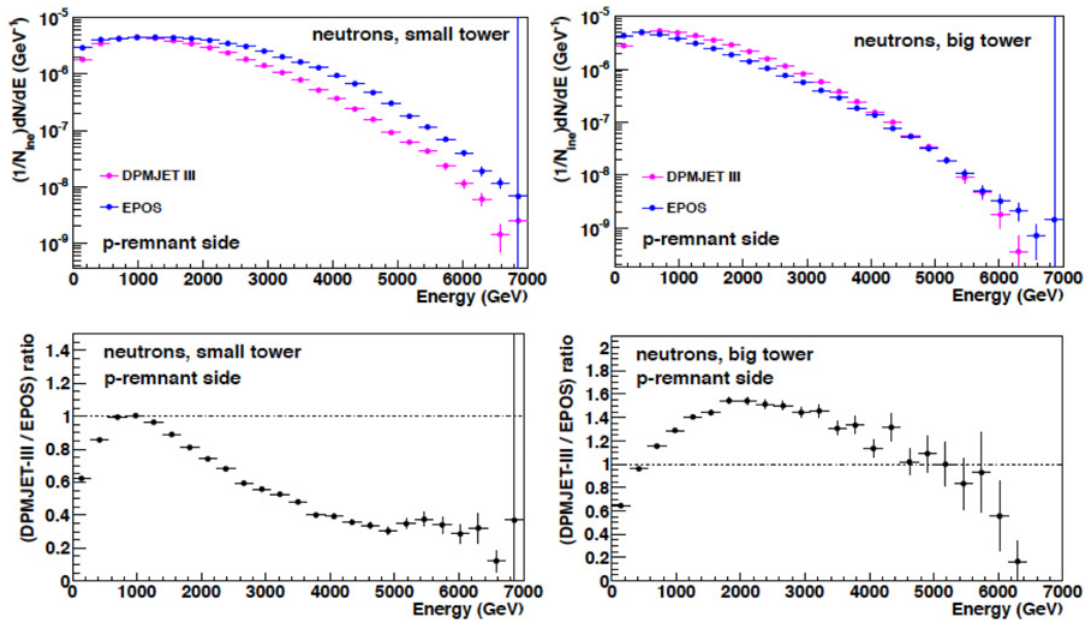

Figure 5. Expected energy spectra of neutrons at the proton remnant side using DPMJET-III and EPOS. Bottom plots show the ratio of two models.

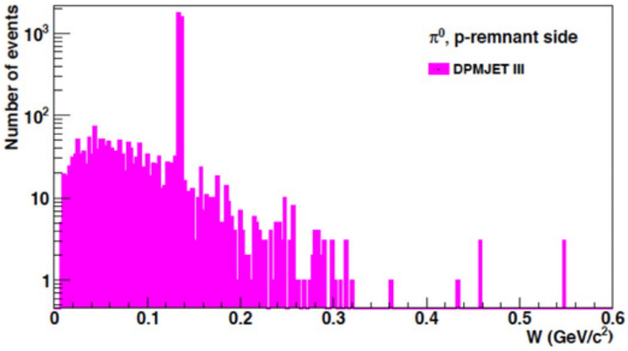

Figure 6. Expected invariant mass spectrum in the p-remnant side of p-Pb collisions. A clear peak at 0.135 GeV is due to the π^0 decay photons. Continuum is produced by the photon pairs of accidental coincidence.

3. OPERATION PLAN

To collect sufficient data as discussed in Sec. 4, we require 10^8 inelastic collisions as a minimum set. Assuming the cross section of 2 barn, this corresponds to an integrated luminosity of 50 μb^{-1}. This can be achieved within 1.4 (140) hours of operation under the luminosity of 10^{28} (10^{26}) cm^{-2}s^{-1} which is a realistic (pessimistic) value. Even at the higher luminosity 10^{28} cm^{-2}s^{-1}, the effects of the collision pile-up (more than 1 collision in a bunch crossing) and signal overlap due to the events from successive collisions are negligible. The event rate of the LHCf will be 1 kHz or less at this luminosity. At that condition LHCf can record data under a moderate read out inefficiency. Several sets of data taking will be carried out under ideal collision conditions at different detector positions to cover calorimeter gap and with different PMT gains for systematics study.

The plan of opposite beam directions and p-p collisions at the corresponding collisions energy is still under discussion because the operation is limited only in one month. In any case, because of the small integrated luminosity required by LHCf, LHCf can collect useful data.

4. EXPECTED RESULTS

Energy spectra of photons and neutrons at the p-remnant side to be measured by the LHCf Arm2 calorimeters after 10^8 inelastic collisions are shown in Fig. 4 and Fig. 5 for two models DPMJET-III and EPOS. Here geometrical acceptance of the detector and energy resolutions (fixed at 35% for neutrons) are taken into account instead of simulating the detector response. Clear differences between two models are found. Note that the origin of the model dependence is not only the uncertainty in the nuclear effect but also in the p-p collision. Measurements of p-p collision at the same collision energy is strongly encouraged to clarify the nuclear effect.

From the events with a single photon in each calorimeter, invariant mass of the photon pair can be determined assuming they come from the decay at the interaction point. When the photon pair comes from a decay of π^0, the invariant mass becomes the mass of π^0 as demonstrated in the p-p collision data analysis [2]. As shown in Fig. 6, Monte Carlo simulations predicts a clear peak also in the p-Pb collisions. By extracting events from this peak, energy spectrum of π^0 can be determined as shown in Fig. 7. Even with a few thousands of π^0 in the 10^8 inelastic collisions, difference of models can be clearly observed.

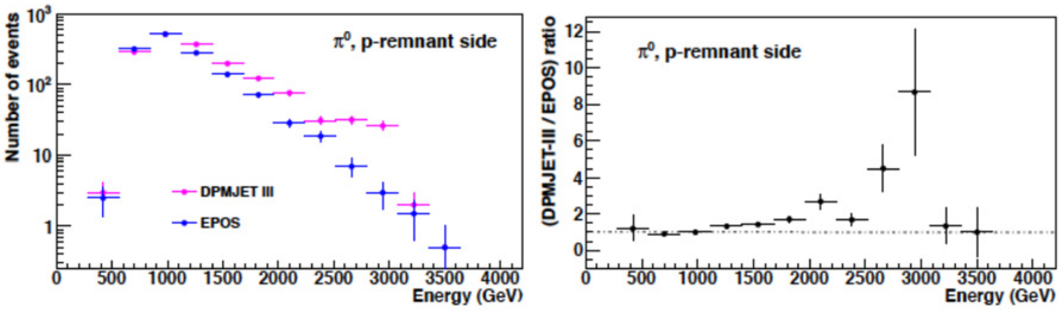

Figure 7. Expected energy spectrum of π^0 in the p-remnant side of p-Pb collisions and the ratio between the predictions of DPMJET-III and EPOS.

5. SUMMARY

LHCf is successfully providing very forward particle spectra from the LHC 900 GeV and 7 TeV p-p collision data. It promises the fruitful results from the 14 TeV p-p collisions foreseen from 2014 (physics operation from 2015). In this paper, we introduced a new LHCf plan to constrain the nuclear effect for the very forward particles using the LHC p-Pb collisions foreseen in 2012. LHCf can measure forward photons, neutrons and π^0s using the existing detector in proton-remnant side which is relevant to test the interaction between proton-primary cosmic rays and atmospheric nuclei. Even in the limited operation period of p-Pb collisions, LHCf can collect sufficient number of events. The data will be crucial calibrations to improve the hadronic interaction models and understanding the nature of UHECRs.

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