Hadron Cross-Section predicted by CORSIKA for the LHCf experiment

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***Abstract*. At CERN, a new experiment will be planed to obtain the differential cross-section of neutral pions and neutrons emitted at very forward region. The equivalent energy of the accelerator corresponds to 10^{17}eV and forthcoming results will be very important for understanding cosmic ray phenomena near the GZK cut-off energies; it provides a precious milestone for the extrapolation to the GZK energy from $\sqrt{s} = 14$ TeV beyond 400 TeV. The expected cross-sections in the forward region by the LHCf experiment have been provided being based on the DPMJET3, QGSJET 1 and 2, SYBILL and EPOS models which are implemented in CORSIKA. We investigate here some questions which have not been yet considered, such as the $diffractive\ component$ and the relative contribution of the non-diffractive component, taking account of the relation between $< Pt >$ and rapidity distributions: the structure functions of valence quark and see quarks.**

***Keywords*: multiple production, LHC, CORSIKA**

I. INTRODUCTION

The results of the CERN collider and the so called collider physics implemented in cosmic ray simulations gave the opportunity of significant progress in the interpretation of cosmic ray data during the last two decades. However the measurements of colliders cannot give informations on the forward region very important for the development of hadronic cascades and EAS. Only the measurements of the UA7 experiment [1] provided the forward neutral pion calibration near 10^{14} eV. Furthermore, we have poor informations on p-A collisions above >1TeV, whereas the total collider data remains under 2×10^{15} eV. Extrapolations higher by 6 orders of magnitude than the equivalent laboratory energy of the Tevatron are now requested for experiments with giant air showers in the GZK energy region. Therefore the experiment LHCf is going to perform the measurements of the γ rays in the very forward fragmentation energy region (above 8.4 units of pseudo rapidity) and also the registration of the most energetic neutrons. Those new informations at 10^{17} eV shall help the adjustment of the parameters of hadronic interaction models and the extrapolations in higher energy in cosmic ray Monte Carlo codes for cosmic rays.

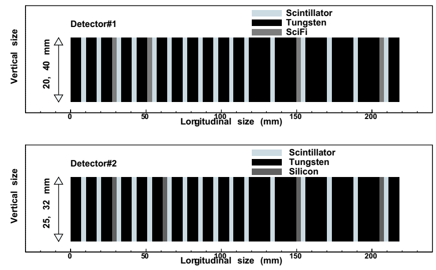


Fig. 1: Longitudinal structure of detector 1(top) and detector 2(bottom); grey, light blue,orange and red indicate the layers of tungsten,plastic scintillator, SciFi and silicon strip sensor, respectively.

II. LHCF DETECTOR AND FRAGMENTATION REGION

The LHCf experiment is characterized by one pair of shower calorimeters installed on both sides of the interaction point at a distance of ± 140m and centered on the zero degree crossing angle beam line. Both LHCf detectors are located in target neutral absorbers (TAN) [2].

The longitudinal (along the beam direction) structure of the calorimeter is shown in Figure 1. Each calorimeter consists of 16 layers of tungsten plates interleaved with 3mm thick plastic scintillators for measuring the deposited energy. The thickness of the tungsten plates is 7mm for the first 11 layers and 14mm for the rest. Including the position sensors the total length is 220 mm. In units of radiation and hadron interaction lengths the total length of a calorimeter is $44X_0$ and 1.7λ, respectively. The transverse sizes of the calorimeters are $20\text{mm}\times 20\text{mm}$ and $40\text{mm}\times 40\text{mm}$ for detector 1 and $25\text{mm}\times 25\text{mm}$ and $32\text{mm}\times 32\text{mm}$ for detector 2. The cross sections of two detectors are shown in Figures 2 and 3. Because of the small Moliere radius of tungsten (9 mm), electro-magnetic showers are well contained even for such small calorimeters. In addition the incident position provided by the position sensitive layers is used to correct for shower-leakage. Each plastic scintillator is viewed by an acrylic light guide and then read out by a PMT (HAMAMATSU R7400U) through 1mm diameter optical fibers. The signals from the PMTs are amplified and sent to the counting room (USA15). The experiment is expected to start late in 2009.

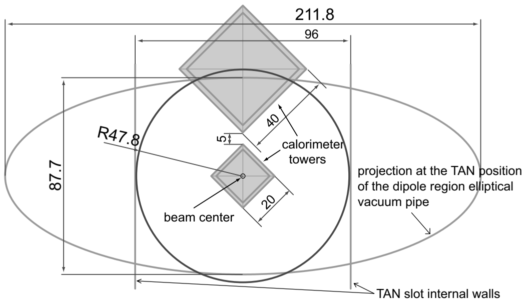


Fig. 2: Cross section of detector 1. Grey squares indicates the calorimeter in the detectors. Vertical and elliptical blue lines indicate the physical aperture limited by the walls of the TAN and the beam pipe respectively.

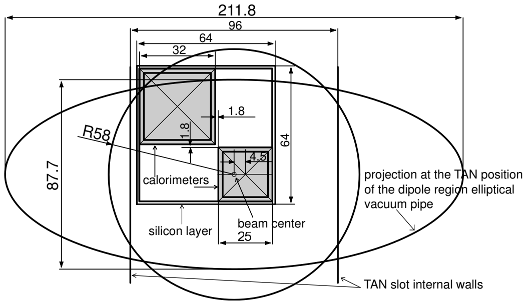


Fig. 3: Cross section of detector 2. Grey squares indicates the calorimeter in the detectors while green square shows the coverage of the silicon strip sensor.

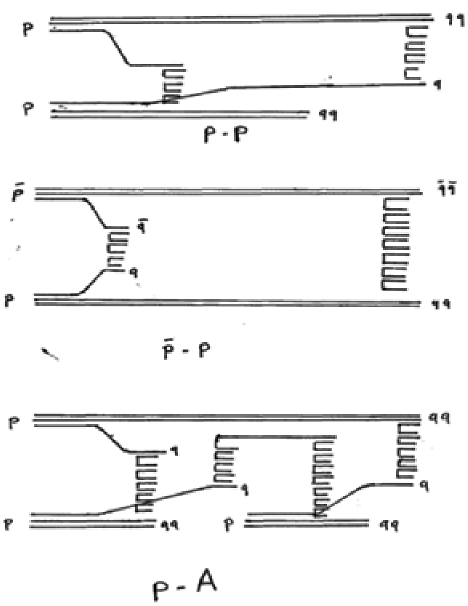


Fig. 4: Diagram Parton models, from top p-p collision, $\overline{p}-p$ collision, p-A collision

III. Monte Carlo Collision generators adapted from CORSIKA for LHCf

The interaction models implemented in CORSIKA as well as the M.C. codes used in collider physics are commonly based and Gribov Regge Theory and string parton models. A classic representation is contained in the diagrams of the dual parton model [3]. The diagram for $p-\bar{p}$ collisions as in LHC is characterized by a long diquark-antidiquark string and a short quark-antiquark string ; in contrast a $p-p$ collision is determined by a pair of symmetric strings between valence quarks and diquarks from projectile and target (Fig. 4. A different arrangement of strings has again to be considered for $p-A$ collisions. Such topologies affect the central part, especially in the pseudo-rapidity distributions; some difficulties may appear when the parameters of the microscopic models are adjusted on accelerator data under 1 TeV and on collider data in the 100 TeV-100 PeV energy band for colliders to describe further p-Air collisions in all the cosmic ray energy band. Another arrangement [4] is used for the diffractive component (the different graphs are presented here only with the most important processes, without rescattering).

For a better approach of the forward fragmentation region seen in LHCf in parallel with to cosmic ray events, we are elaborating a very fast Monte Carlo generation procedure based on the inverse integral method (with a dedicated numerical algorithm) to produce the respective momenta of valence quarks and sea quarks as well as for gluons.

The generation for valence quarks down and sea quarks is presented for example on Fig.5(a) and Fig.5(b), corresponding to the structure functions [5]:

$$xd_v(x) = 0.7\ x^{0.5}\ (1-x)^4, \tag{1}$$

$$xs(x)\ =\ 0.2\ (1-x)^8. \tag{2}$$

The average transverse momentum of the quarks are determined following Schwinger theory as indicated by Wong [8] and our procedure [4] as

$$\sqrt{< p_t >^2} = \sqrt{\frac{\kappa}{\pi}}, \tag{3}$$

κ being the string tension. Such relation provides the classical values of $< p_t >= 0.25 GeV/c$ for quarks and $0.35 GeV/c$ for the pions where the pairs $q-\bar{q}$ are recombined.

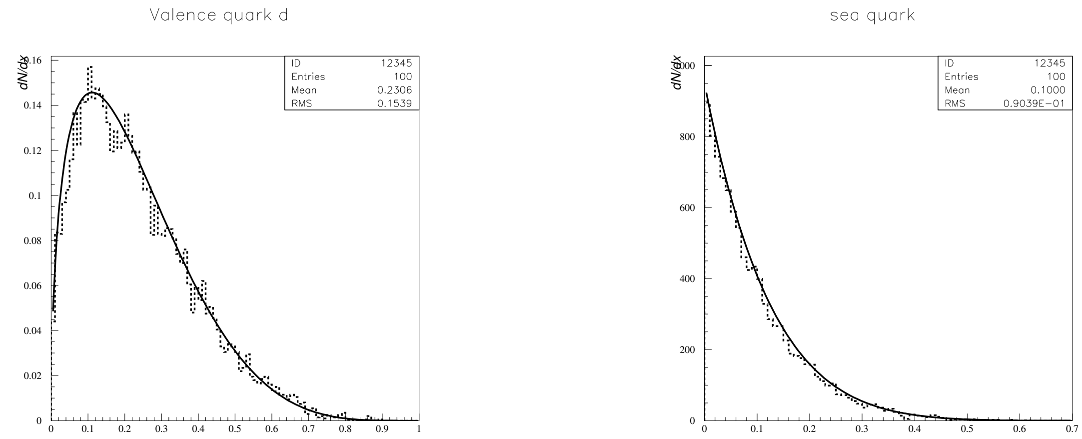
The Gaussian distributions of the p_t are inferred as :

$$\frac{dN}{dp_t} = exp[-\frac{\pi(m^2+p_t^2)}{\kappa}] \tag{4}$$

where m is the mass of the parton. The generation of transverse momenta is shown on Fig. 6 giving for example in the case of an average diquark transverse momentum $< p_t >= 0.35\ GeV/c$.

IV. Simulated events in CMS and Laboratory systems

Above the maximal energy of the LHC, about 10 events have been recorded in very large emulsion chambers at mountain altitude. Those events are observed in so called γ ray and hadron families in the laboratory system containing a proportion more or less important of



(a) Valence quark down structure function (b) sea quark structure function

Fig. 5: Momentum generation for valence quark down (left). Momentum generation for sea quarks (right).

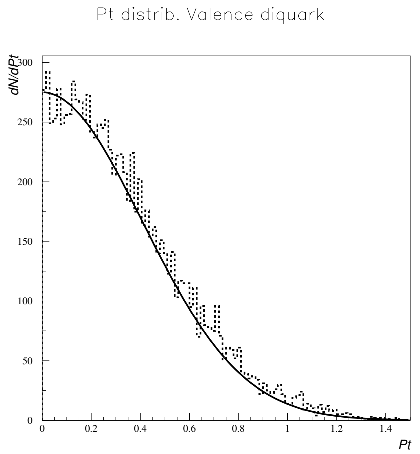


Fig. 6: Diquark p_t generation following Schwinger mechanism

secondaries generated directly in the forward fragmentation region. The cascading increases when the distance to the primary hadron-Air collision exceeds 4 km above the X ray emulsion chambers exposed at altitudes of $4-5$ km. The energy thresholds according to the properties of the X-ray films are usually of 2 TeV for γ's (this means electrons and photons in the chamber) and 6 TeV for hadrons.

The comparison will be possible only in the very forward fragmentation region and this is the case for LHCf registrating neutral secondaries at a distance of 140m from the primary interaction. We have carried preliminary simulations with the models involved in CORSIKA in the most simple conditions [6], separating the diffractive and non diffractive component (preliminary samples of 2000 events are presented).

The small diffractive masses correspond to particles emitted in the very forward region as it can be seen in Fig. 7. The center of mass of the diffractive mass moves progressively in direction of the central region together with the diffractive mass $<\eta>= 8.5 \rightarrow 6.5$ (Fig. 7).

Inside the NSD data, a special attention has been given to the semi-inclusive events and the pseudo rapidity distributions of the photons are shown on Fig.8.

The semi inclusive distributions correspond to values of the Koba-Nielsen-Olesen variable Zkno= 0.5 (small multiplicities), Zkno = 1. (average for NSD), Zkno = 2. (large multiplicities) where $Zkno = \frac{n}{<n>}$. The distribution of the distances of the γ's to the central beam line at the level of LHCf detectors is shown on Fig. 8 for the diffractive and non diffractive components.

The case of small diffractive masses is summarized on Table I.

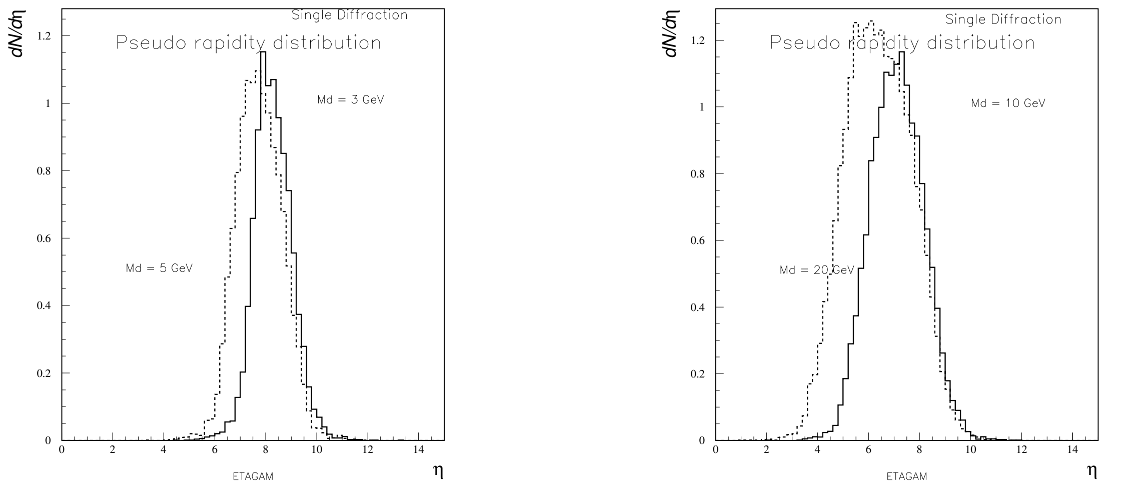
TABLE I: Forward diffraction, small diffractive masses and photon distributions

	$M_D = 3GeV$	$5GeV$	$10GeV$	$20GeV$
$<R>cm$	7.37	12.11	15.91	17.10
$<\eta_\gamma>$	8.29	7.76	7.11	6.40

An example of cosmic ray family simulated with CORSIKA is shown in [7]. The incident particle here is a proton of 130 PeV with the first interaction at 1.9 km above the detector. 49 PeV of the energy carried by the γ rays (visible energy) was deposited in the central part, a circle of a radius of 2 cm.

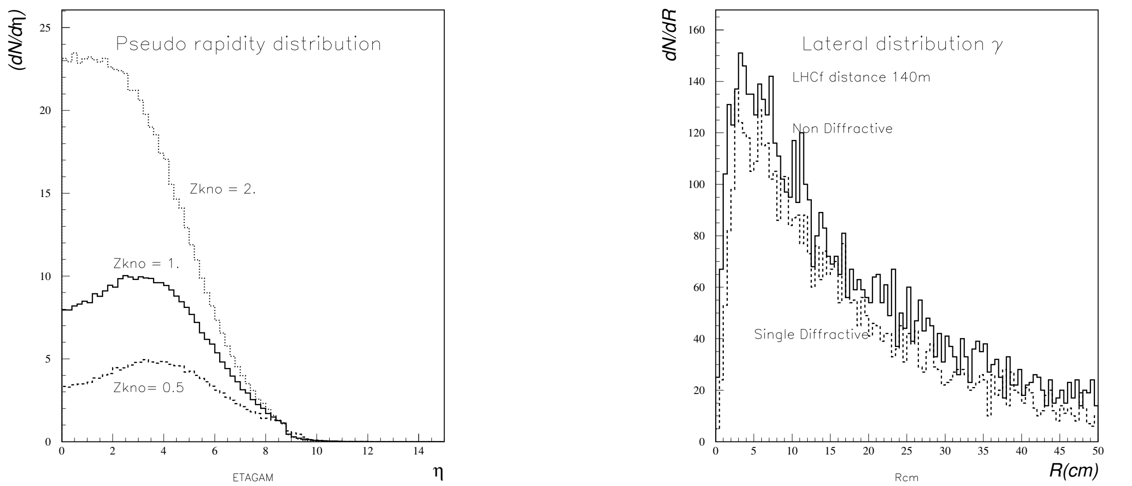
V. CONCLUSION

CORSIKA may be used in Center of Mass as well as in Laboratory system to compare events of the LHC and cosmic ray data. LHCf data will provide a good approach of the fragmentation region, especially for small diffractive masses and small multiplicities where the proportion of photons above 8.4 rapidity units is more important.



(a) diffractive masses of 3 and 5 GeV (b) diffractive masses of 10 and 20 GeV

Fig. 7: Pseudo rapidity of photons in forward single diffraction : small diffractive masses 3 (solid line)and 5 (dashed) GeV(left). Diffractive masses of 10(solid line) and 20(dashed) GeV (right).



(a) NSD Semi inclusive data (b) Photon lateral distribution

Fig. 8: Pseudo rapidity distributions of photons : NSD for Zkno = 0.5 (dashed), Zkno = 1(solid), Zkno = 2(dotted) (left). Lateral photon distribution NSD (solid hist.), SD(dashed) (right).

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