RESULTS FROM PYTHIA AT LHC ENERGIES

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Minimum bias proton–proton events at LHC energies (3.15+3.15 TeV per nucleon for A–A, 8+8 TeV per nucleon for p–p) have been generated using PYTHIA, which was tuned to existing SppS and Tevatron data. A simple convolution has been made to build minimum bias and central A–A events, up to Pb–Pb. Rapidity and \( p_T \) distributions for several particle species are presented.

1. INTRODUCTION

The purpose of the ECFA Working Group on Heavy Ion Physics at the Large Hadron Collider is to evaluate the physics potential of this machine with colliding beams up to lead at a nucleon–nucleon center of mass energy of about 6.3 TeV.

More specifically, event generators are needed to simulate the general conditions of such collisions, providing estimates of (among other things) particle densities and transverse momentum spectra. The general conditions are needed both to estimate the energy densities and temperatures which could be reached, and to evaluate backgrounds from conventional physics to the interesting observables which could signal the formation of quark–gluon plasma (among them, dilepton invariant mass spectra).

The basic idea of the present work is to use a well established event generator (PYTHIA) to simulate minimum bias p–p events at LHC energy, and then to use a simple convolution rule for extrapolation to minimum bias or central A–A collisions.

2. PYTHIA FOR p–p COLLISIONS

The Lund Monte Carlo program PYTHIA, originally developed to describe high \( p_T \) hadronic physics, has been extended to cover also low \( p_T \) interactions; a picture in which hadronic events contain a variable number of parton–parton interactions, depending on the impact parameter, has been developed [1].

Recently, PYTHIA was tuned [2,3] to reproduce the main features of present collider data, namely those of UA5 [4] and UA1 [5] at the CERN \( p\bar{p} \) collider, and E735 [6] and CDF [7] at the FNAL Tevatron.

Specifically, the observed average charged multiplicity \( < N_{CH} > \) was used to fix the value of \( p_{T0} \), the scale for the transition from perturbative QCD hard scattering to low \( p_T \) interactions (\( p_{T0}=1.9 \) GeV). The correlation between \( < p_T > \)
and $N_{CH}$ was used to fix the structure of the secondary (non-hardest) parton-parton interactions (10% $q\bar{q}$ scattering, 81% $gg$ scattering with minimal string length and 9% $gg$ scattering with maximal string length).

We have used the above parameter values to generate $p$-$p$ events at $\sqrt{s}$ of 6.3 TeV (LHC ion-ion) and 16 TeV (LHC proton-proton). PYTHIA 5.3 has been used together with JETSET 7.2 for the fragmentation. In addition, events at $\sqrt{s}$ of 53, 200, 900 and 1800 GeV have been generated for comparison with existing data.

Some features of charged particle distributions as a function of $\sqrt{s}$ are presented in fig. 1–3. The linear increase of $<N_{CH}>$ in a restricted pseudorapidity interval ($|\eta| \leq 2.5$) with $\ln s$ is reproduced by PYTHIA and extended up to LHC energies (fig. 1).

A linear increase with $\ln s$ of $(dN_{CH}/d\eta)_{\eta=0}$ is predicted by PYTHIA (fig. 2), in good agreement with the linear fit of CDF to their data and UA5 data [7] ($0.27 \ln s - 0.32$, dashed line) and in contrast with the quadratic fit [7] ($0.023 \ln^2 s - 0.25 \ln s + 2.5$, full line) which would predict higher pseudorapidity densities.

The $<p_T>$ of charged particles in $|\eta| \leq 2.5$ is also reasonably well reproduced by PYTHIA (fig. 3). The $dN_{CH}/d\eta$ distributions of CDF data and PYTHIA at $\sqrt{s}=1800$ GeV are compared in fig. 4.

The $dN/d\eta$ distributions of charged particles, $\pi$, $K$ and $\bar{p}$ for minimum bias $p$-$p$ events at $\sqrt{s}$ of 6.3 TeV are presented in fig. 5. The $dN/dy$ distribution for the net baryon number is presented in fig. 6. The average rapidity shift of the protons is $\Delta y=1.28$. The baryon free region, defined as the available rapidity gap minus four times the shift, is 12.5 units (the available rapidity gap is $\Delta y=17.6$).

The transverse momentum distributions of produced charged particles, $\pi$, $K$ and $\bar{p}$ are shown for the full $\eta$ range in fig. 7, and for $|\eta| \leq 2.5$ in fig. 8. The average particle composition of an event and the $<p_T>$ of the various particles are listed in table 1 (note that all hyperons have been allowed to decay).

| Particle | $<N>$ | $<p_T>$ (GeV/c) | $<p_T>$ ($|\eta| \leq 2.5$) |
|----------|-------|----------------|--------------------------|
| charged  | 68.2  | .445           | .507                     |
| $\pi^\pm$| 56.3  | .413           | .466                     |
| $K^\pm$  | 5.95  | .598           | .724                     |
| $p$      | 3.28  | .624           | .947                     |
| $\bar{p}$| 2.09  | .724           | .931                     |

Table 1
Fig. 1

Fig. 2

Fig. 3

Fig. 4
3. CONVOLUTION OF p–p COLLISIONS

A simple scaling law was found to hold for the average charged multiplicity in proton–emulsion experiments as a function of the average charged multiplicity in p–p collisions [8]:

\[
< N_S >_{pEm} = 2.34 < N_{CH} >_{pp} - 4.12 \quad (E_{LAB} = 1 - 800 \text{GeV}) \quad (1)
\]

(< \text{\textit{N}}_\text{S} \text{\textit{S}} > \text{\textit{S}} is the average shower particle multiplicity), and a similar law was later found for oxygen–emulsion experiments [9]:

\[
< N_S >_{OEm} = 10.1 < N_{CH} >_{pp} - 16.6 \quad (E_{LAB} = 2.1 - 200 \text{GeV/N}) \quad (2)
\]

Adamovich et al. [9] found that eq. (2) can be reproduced by multiplying eq. (1) by a suitable weighted average between the ratio of participants oxygen–emulsion/proton–emulsion (which is expected to be relevant if the formation time is long and individual nucleons fragment independently) and the ratio of binary collisions (which is expected to be relevant for short formation times):

\[
R_{OEm} = \frac{2}{3} \frac{P_{OEm}}{P_{pEm}} + \frac{1}{3} \frac{C_{OEm}}{C_{pEm}} \quad (3)
\]

The number of participant nucleons (from projectile and target) \( P = P_p + P_T \) and the number of binary nucleon–nucleon collisions \( C \), averaged over impact parameter, are given from simple geometrical considerations by:

\[
P_p = \frac{A_p \sigma_p A_T}{\sigma_p A_T}, \quad P_T = \frac{A_T \sigma_p A_T}{\sigma_p A_T}, \quad C = \frac{A_p A_T \sigma_{pp}}{\sigma_p A_T} \quad (4)
\]

This scaling law seems to indicate that the energy dependence of particle production is the same for p–p, p–A and A–B collisions. We may extend this approach to arbitrary A–B collisions, defining a ratio \( R_{AB} \) in analogy with \( R_{OEm} \) in eq. (3), and then writing:

\[
< N_S >_{AB} = R_{AB} < N_S >_{pEm} = \left( \frac{2}{3} \frac{P_{AB}}{P_{pEm}} + \frac{1}{3} \frac{C_{AB}}{C_{pEm}} \right) < N_S >_{pEm} \quad (5)
\]

where \(< N_S >_{pEm} \) is given by eq. (1).

The number of p–p interactions to be convoluted to reproduce the average multiplicity of an A–B collision, \( N_{AB} \), is obtained by requiring \(< N_S >_{AB} = N_{AB} < N_{CH} >_{pp} \):

\[
N_{AB}(\sqrt{s}) = R_{AB} \frac{2.34 < N_{CH} >_{pp}(\sqrt{s}) - 4.12}{< N_{CH} >_{pp}(\sqrt{s})} \quad (6)
\]

(the \( \sqrt{s} \) dependence of \( N_{AB} \) is weak for high \( < N_{CH} >_{pp} \)).
We computed $N_{AB}$ for minimum bias collisions using the definitions (4) with inelastic cross-sections parametrized as [9]:

$$\sigma_{pp} = 32.3 \, \text{mb}, \quad \sigma_{pA} = 38.17A^{0.719} \, \text{mb},$$

$$\sigma_{AB} = 109.2 \left( A^{0.29} + B^{0.29} - 1.39 \right)^2 \, \text{mb}$$

For central collisions $N_{AB}$ was estimated using the number of participants $P_{AB} = A + B$, and the number of binary collisions $C$ as calculated from the overlap integral. Some $1.5 \cdot 10^5$ p–p events at $\sqrt{s}$ of 6.3 TeV were then convoluted to simulate O–O, S–S and Pb–Pb events. The numbers used for the convolution and the charged rapidity densities obtained are summarized in table 2. Other systems can easily be treated using the same method.

The values of $$(dN_{CH}/dy)_{y=0}$$ obtained for central collisions are considerably higher than those extrapolated from the p–p value assuming an $A^\alpha$ dependence [10] with $\alpha=1.0$ without rescattering (column 6 in table 2) or $\alpha=1.1$ with rescattering (column 7). In fact, a fit to such a dependence using the value of $$(dN_{CH}/dy)_{y=0}$$ from the convoluted events (column 5) gives $\alpha \simeq 1.16$.

The $dN_{CH}/d\eta$ distributions for central and minimum bias S–S and Pb–Pb events at $\sqrt{s}$ of 6.3 TeV are presented in fig. 9 and 10. More detailed information can be extracted from figures 5–8 (proton–proton distributions) by taking into account the convolution factors $N_{AB}$ from table 2.

The picture of an ion–ion collision as a straight superposition of a number of p–p collisions is certainly too naïve. For example, the stopping is most probably higher in A–A collisions. A more realistic simulation should include at least a proper treatment of the nuclear geometry. This would require using PYTHIA to describe multiple collisions of a nucleon, at lower and lower values of $\sqrt{s}$. 
4. CONCLUSIONS

We have used a phenomenological convolution rule to simulate ion–ion events by superposition of proton–proton events generated with PYTHIA at $\sqrt{s}$ of 6.3 TeV.

Since PYTHIA was tuned to existing $pp$ and $p\bar{p}$ data up to $\sqrt{s}$ of 1.8 TeV, we believe that these event samples can provide a useful starting point for the estimation of general conditions and backgrounds in Pb–Pb collisions at LHC. In particular, it will be interesting to compare our results with those of generators which contain the full nuclear geometry, like for example VENUS [11].

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REFERENCES


2) G. Ciapetti and A. Di Ciaccio, Minimum bias models, these proceedings.
3) T. Sjöstrand, Summary of pp working group on event generators, these proceedings.


8) B. Andersson et al., Phys. Lett. 84B (1979) 469.


10) U. Heinz, General Conditions in Heavy Ion Collisions at LHC, these proceedings.

11) P. Cerello, P. Giubellino and K. Werner, Results from VENUS at LHC energies, these proceedings.