A two component generalized multiplicity distribution and associated phenomenologically analogous Lee-Yang phase transition

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Abstract

We use a two component Generalised Multiplicity Distribution (GMD) to describe multiplicity data at LHC energies and consider the evolution of Lee-Yang zero plots with increasing energy. The distribution describes the multiplicity well up to 7 TeV, and also in various pseudorapidity cuts.

In agreement with earlier observations at lower energies, we observe the formation of the ear structure but note that the formation of an ear structure previously associated with increasing energy is affected by the pseudorapidity cut and truncation cut-off in the Lee-Yang phase transition approach.

Introduction

The GMD introduced by Chan and Chew [1] has been shown to be a solution of the stochastic branching equation that governs the dynamics of multiparticle production. It is given by:

$$P_{GMD}(n;k,k') = \frac{\Gamma(n+k)}{\Gamma(n-k'+1)\Gamma(k'+k)} \times \left(\frac{\bar{n}-k'}{\bar{n}+k}\right)^{n-k'} \left(\frac{k+k'}{\bar{n}+k}\right)^{k+k'} ,$$

where $\bar{n}$ is the mean multiplicity, and k and k' refer to average initial number of quarks and gluons respectively. The GMD is general in the sense that when the parameters k and k' are taken to the appropriate limits, the other familiar multiplicity distributions can be recovered. When $k' \to 0$, the GMD reduces to the NBD [2]; in the further limiting case where $k' \to 0$ and $k \to \infty$, the GMD reduces to the Poisson distribution. When $k \to 0$, the FYD [3] is recovered. The GMD is therefore able to describe multiplicity data at lower energies where the Poisson distribution provides a good description, to higher energies where the NBD provides a good description, and possibly beyond.

In order to account for the development of the KNO violating shoulder structure that forms in LHC energies, we propose the two component GMD, P_{tot}, which can be written as:

$$P_{tot} = \alpha_{hard} P_{hard}(\bar{n}_{hard}, k_{hard}, k'_{hard}) + (1-\alpha_{hard}) P_{soft}(\bar{n}_{soft}, k_{soft}, k'_{soft}),$$

where α_{hard} is the parameter that determines the relative contribution of the hard component to the total multiplicity distribution. Similar two component NBD models have been reviewed in [4].

Lee-Yang Zeroes

The factorial moment generating function is useful in studying the statistical properties of multiplicity distributions. It is given by:

$$G(z) = \sum_{n=0}^{\infty} P_{tot} z^n ,$$

where P_{tot} is the two component multiplicity distribution defined above.

Capella and Dremin suggested that the generating function is analogous to the grand canonical partition function of statistical mechanics, with z taking the role of fugacity [5]. In the Lee-Yang phase transition in statistical mechanics, the grand partition function is truncated at some N_{max} and its roots plotted in the complex plane. This is known as a Lee-Yang zero plot and in the limit $N_{max} \to \infty$, the roots tend towards the positive real axis, indicating a first order phase transition [6,7].

In particle collisions, while the nature of this phase transition is at present unclear, it is possible that it could shed some light on the as-yet elusive hadronisation mechanism. Lee-Yang zeroes have also been used recently to study correlations in anisotropic flow [8,9] and the truncated fugacity series from net-baryon multiplicities [10].

Selected Results

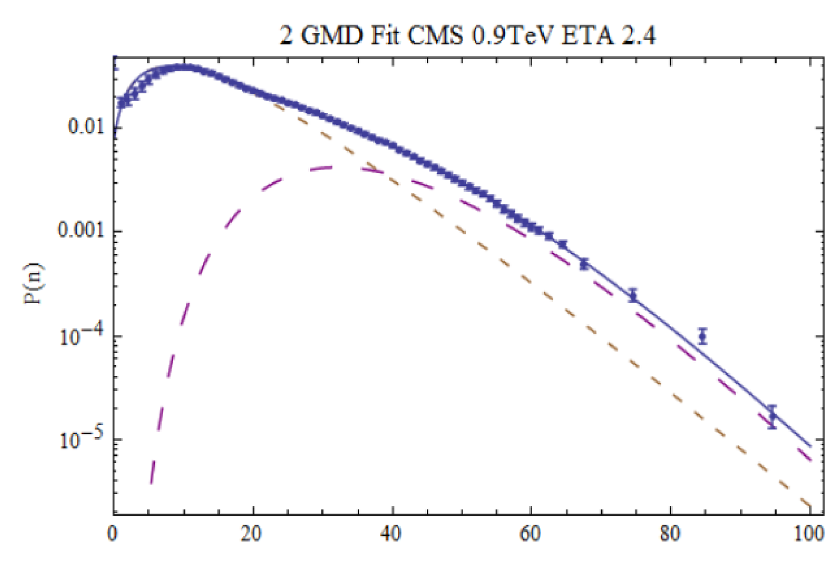
The table and multiplicity plots below show the best fit parameter values for the two component GMD for charged particle multiplicities for $\sqrt{s}$ = 0.9, 2.36 and 7 TeV at $|\eta| \leq 2.4$ from CMS [11].

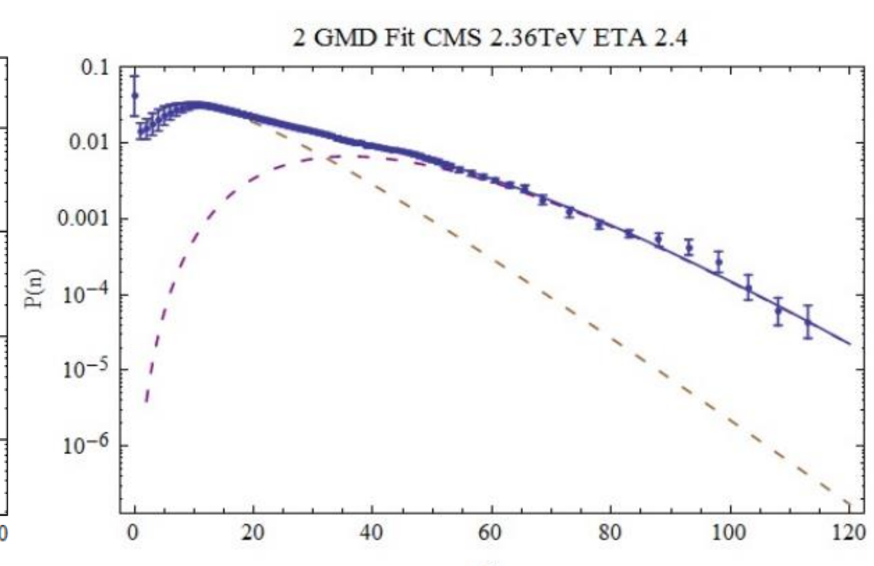
$\sqrt{s}$ (TeV)		$\bar{n}$	k	k'	α_{hard}	χ^2
0.9	hard	14.9	2.36	3.43×10^{-3}	0.850	0.937
	soft	37.8	0.555	5.99		
2.36	hard	15.7	2.36	1.42×10^{-6}	0.722	0.316
	soft	42.8	5.62	0.878		
7	hard	16.0	2.09	6.63×10^{-9}	0.562	0.137
	soft	49.6	2.60	0.879		

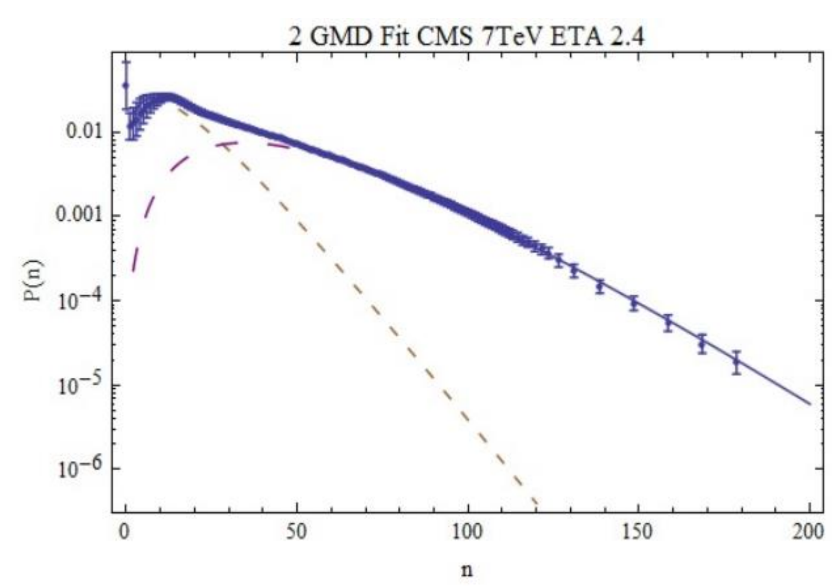
Table: Summary of best fit parameters

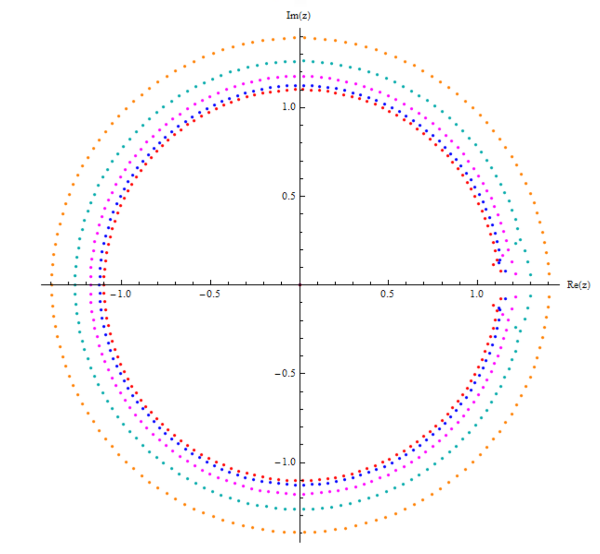
The Lee-Yang circle plots below are for $\sqrt{s}$ = 0.9, 2.36 and 7 TeV, with $|\eta| \leq 0.5, 1.0, 1.5, 2.0$ and 2.4 , showing a convergence towards a unit circle at larger pseudorapidity cuts.

Plots

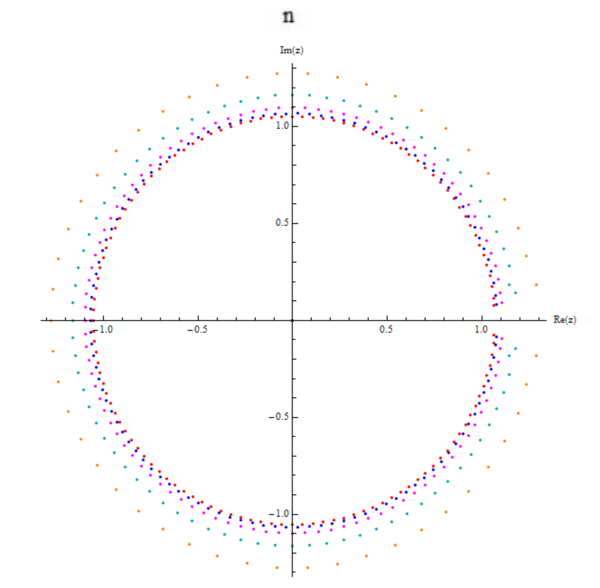




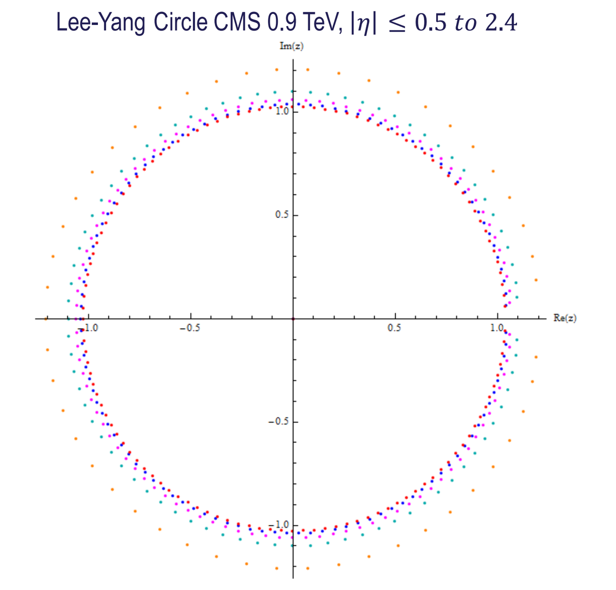




Lee-Yang Circle CMS 0.9 TeV, $|\eta| \leq 0.5$ to 2.4



Lee-Yang Circle CMS 2.36 TeV, $|\eta| \leq 0.5$ to 2.4



Lee-Yang Circle CMS 7 TeV, $|\eta| \leq 0.5$ to 2.4

Conclusion

The two component GMD provides a good description of the multiplicity data at LHC energies. We see a decrease in α_{hard} as energy increases, suggesting higher contributions from soft particle production. In addition, k'_{hard} remains small, indicating the hard component is effectively described by a NBD. In agreement with previous observations, there does appear to be an analogous Lee-Yang phase transition that occurs with increasing energy in pp collisions. For each energy level, the Lee-Yang circles demonstrate that the ear structure appears at lower $|\eta|$ cuts, disappearing with wider pseudorapidity ranges.

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