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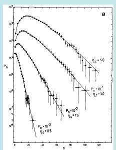
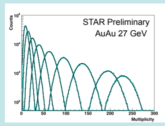
Beam Energy Dependence of Clan Multiplicity at RHIC

Q-Y. Shou. & A. Tang (for the STAR Collaboration)
Contact : A. Tang, Brookhaven National Lab,USA (aihong@bnl.gov)

The Success of Negative Binomial Distributions



UA5 Collab. Phys. Lett. 160B 193 (1985)
(and many others ……)



Negative Binomial (NB) has been widely used to describe particle productions in high energy collisions, and it can also describe particle productions at RHIC very well.

Transformation to Clan Parameters

Recall the negative binomial pdf , $f(n) = C^{n}_{k+n-1}(1-p)^n p^k$

Its mean is given by $\mu = \frac{(1-p)k}{p}$

and variance $\sigma^2 = \frac{(1-p)k}{p^2}$

In order to interpret the wide occurrence of the negative-binomial charged-particle multiplicity distribution, a parameterization alternative to the standard NB parameters has been proposed[1]. They are, namely, the average number of groups of particles of common ancestor (average number of clans, $\overline{N} = k\ln\left(1+\frac{\mu}{k}\right)$) and the average number of particles per clan, $\overline{n}_c = \mu/\overline{N}$.

With this transformation of parameters, it turns out that clans in various classes of events in a collision are independently produced, whereas particles within each clan are distributed according to a logarithmic distribution.

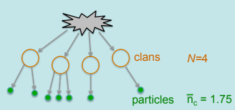


Illustration of clan and particle production.

The mathematical justification for such transformation is given below.

The generating function of logarithmic distribution is :

$$G_{\ln}(x) = \frac{\ln(1-zx)}{\ln(1-z)} \quad \text{where z is set to be } z = \frac{\mu}{\mu+k}$$

Because clans are independent of each other, they can be described by a Poisson distribution, for which the generating function is :

$$G_{poisson}(x) = e^{\overline{N}(x-1)}$$

The generating function of the compound distribution is then given by :

$$G_{poisson}(G_{\ln}(x)) = e^{\overline{N}(G_{\ln}(x)-1)} = \bullet\bullet\bullet = \left(\frac{\frac{k}{\mu}}{1+\frac{k}{\mu}-x}\right)^k$$

by which we recover the generating function of negative binomial distribution.

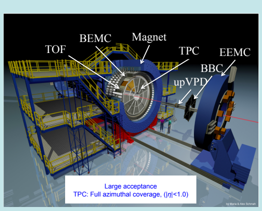
With the introduction of the clan concept, the NB distribution, if rearranged properly, yields a similarity to the grand-canonical partition function. Such analogy leads to "clan thermodynamics" [2]. Here, adopting the concept of clan does not necessary imply that we endorse "clan thermodynamics".

Clan concept describes clustering characteristics, and the clan parameters have been used to identify abnormalities due to a phase transition.[3-8]

In this study, we examine the average charged particles per clan as a function of collision energy.

(1) A. Giovanni, L. Van Hove, Z. Phys. C30 391 (1986)
(2) Giovannini, Lupia and Ugoccioni, PRD 65 094028 (2002)
(3) UA5 : Phys. Rep.154, 247(1987).
(4) EMC: Z. Phys. C 35, 335 (1987) [Erratum-ibid.36, 512 (1987)
(5) NA22 : Z. Phys. C37, 215 (1988)in heavy ion collisions :
(6) E802 : Phys. Rev. C 52, 2663 (1995)
(7) NA35 : Z. Phys. C 57 541 (1993)
(8) PHENIX: Phys. Rev. C 78 044902, (2008)].

STAR Detector Setup, Datasets and Cuts



Energy (GeV)	Year	Total # of events (M)
7.7	2010	4.4
11.5	2010	7.2
19.6	2011	44
27	2011	80
39	2010	37
62.4	2010	25
200	2010	25

Event-wise cuts

|Vz|<30 cm
Vr < 2 cm
Should have at least one TOF matched track

Track-wise cuts

numHitsFit>=15
1.02 > ratio = (nHitsFit/ nHitsPoss) > 0.52
|eta|<0.5 for particle of interest

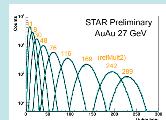
For 62.4 and 200 GeV, use low luminosity data (BBCX<25k)

PID cut is based on 2 sigma cut on TPC dE/dx.

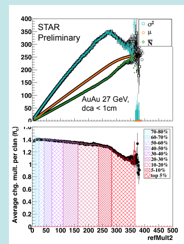
Centrality, Reference Multiplicity2, and the Calculation of Average Charged Multiplicity per Clan

For the study of the multiplicity distribution

For the definition of centrality and reference multiplicity (refMult2)



multiplicity distribution in |η|<0.5 fitted with NB.



Black : σ^2 μ from direct calculation
Colored : σ^2 μ from fitting NB

We are interested in produced particles only, thus protons and heavier positive particles are excluded.

To avoid the additional fluctuation from a wide multiplicity bin, which can significantly bias the variance, the analysis is performed with the finest refMult2 binwidth, and the final result for a centrality is presented by taking the average over fine bins.

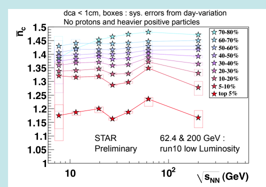
$$f(n) = C^{n}_{k+n-1}(1-p)^n p^k$$

$$p = \frac{\mu}{\sigma^2} \quad k = \frac{\mu p}{1-p}$$

$$\overline{N} = -k\ln p$$

$$\overline{n}_c = \frac{\mu}{\overline{N}} = \frac{1-p}{-p\ln p}$$

Energy Dependence of Average Charged Multiplicity per Clan



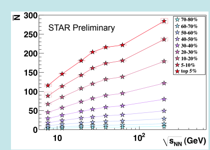
Interesting structure in energy dependence,

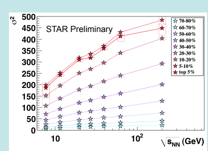
Most prominent in central collisions.

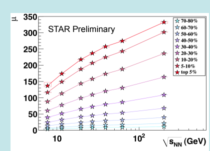
Cannot be explained by efficiency variations (not shown).

For the discussion on the effect of the efficiency on the multiplicity distribution, please refer to :
Tang & Wang, Phys. Rev. C 88, 024905 (2013).
For its implementation in this analysis, please refer to A. Tang's WWND 2014 slides
(https://indico.cern.ch/event/275088/contribution/59/material/slides/0.pdf)

Other Parameters







Conclusions

- A proper transformation of the NB parameters gives insights into the clan cluster production.

- Clan parameters have been measured in RHIC BES to study phase transitions.

- For the mean number of particles per clan we observed a reduction between 19.6 GeV and 62.4 GeV, with the minimum around 27 GeV. The structure is visible for most centralities, and most prominent for central collisions. So far we haven't identified a non-physical source for the structure.

- Looking forward to checking with more BES energies.