Soft versus Hard interactions

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-Introduction

-Are there more hard than soft interactions as the energy or centrality increases?

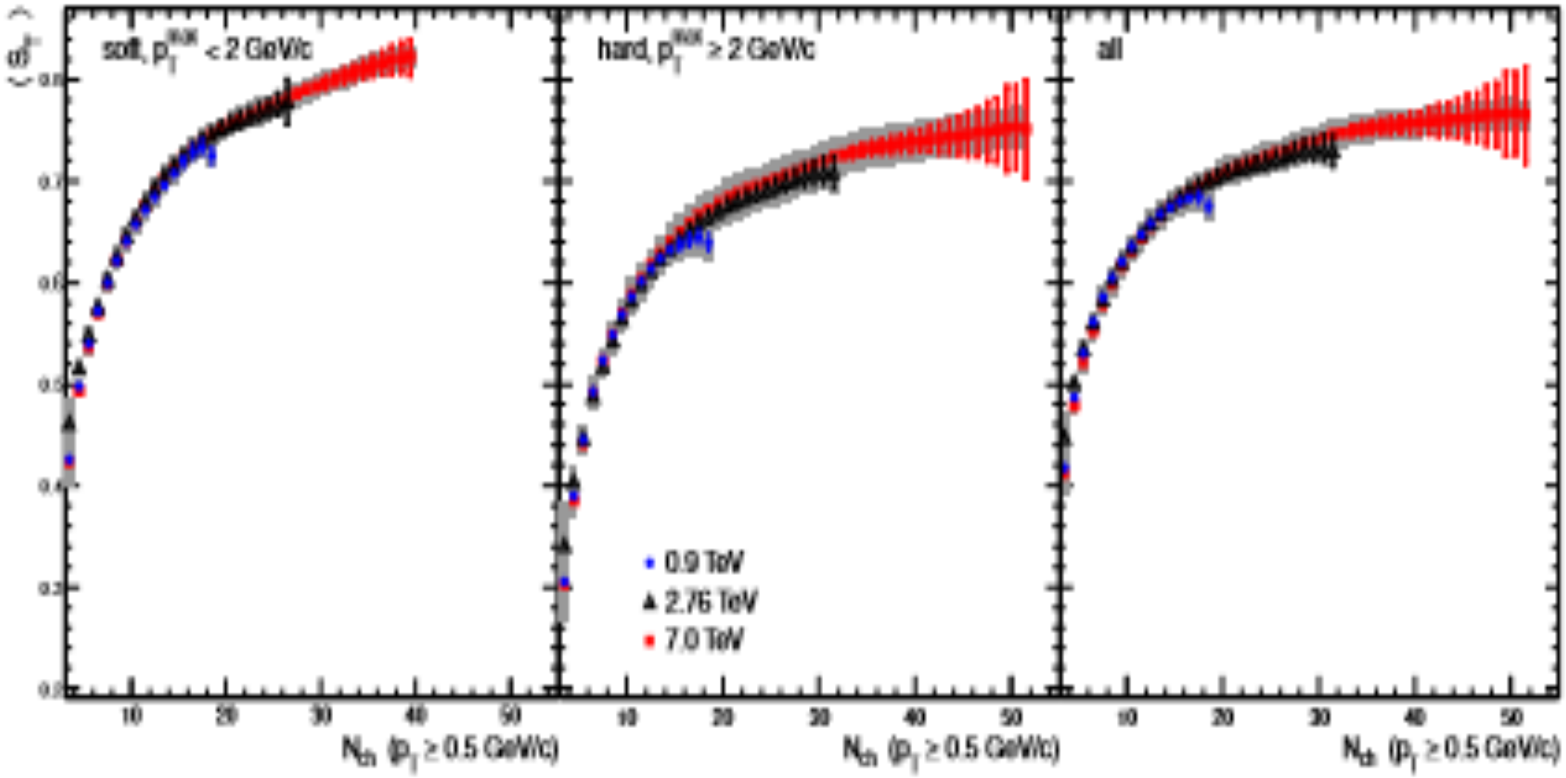
-Sphericity versus multiplicity(G.Paic,A.Ortiz)

-Geometrical scaling for pt<Qs

--Results on integrated soft interactions in pp, and AA at different centralities

--Associated distributions of hard interactions

--Conclusions



soft, p_T^{max} < 2 GeV/c
hard, p_T^{max} ≥ 2 GeV/c
all
0.9 TeV
2.76 TeV
7.0 TeV
N_{ch} (p_T ≥ 0.5 GeV/c)
N_{ch} (p_T ≥ 0.5 GeV/c)
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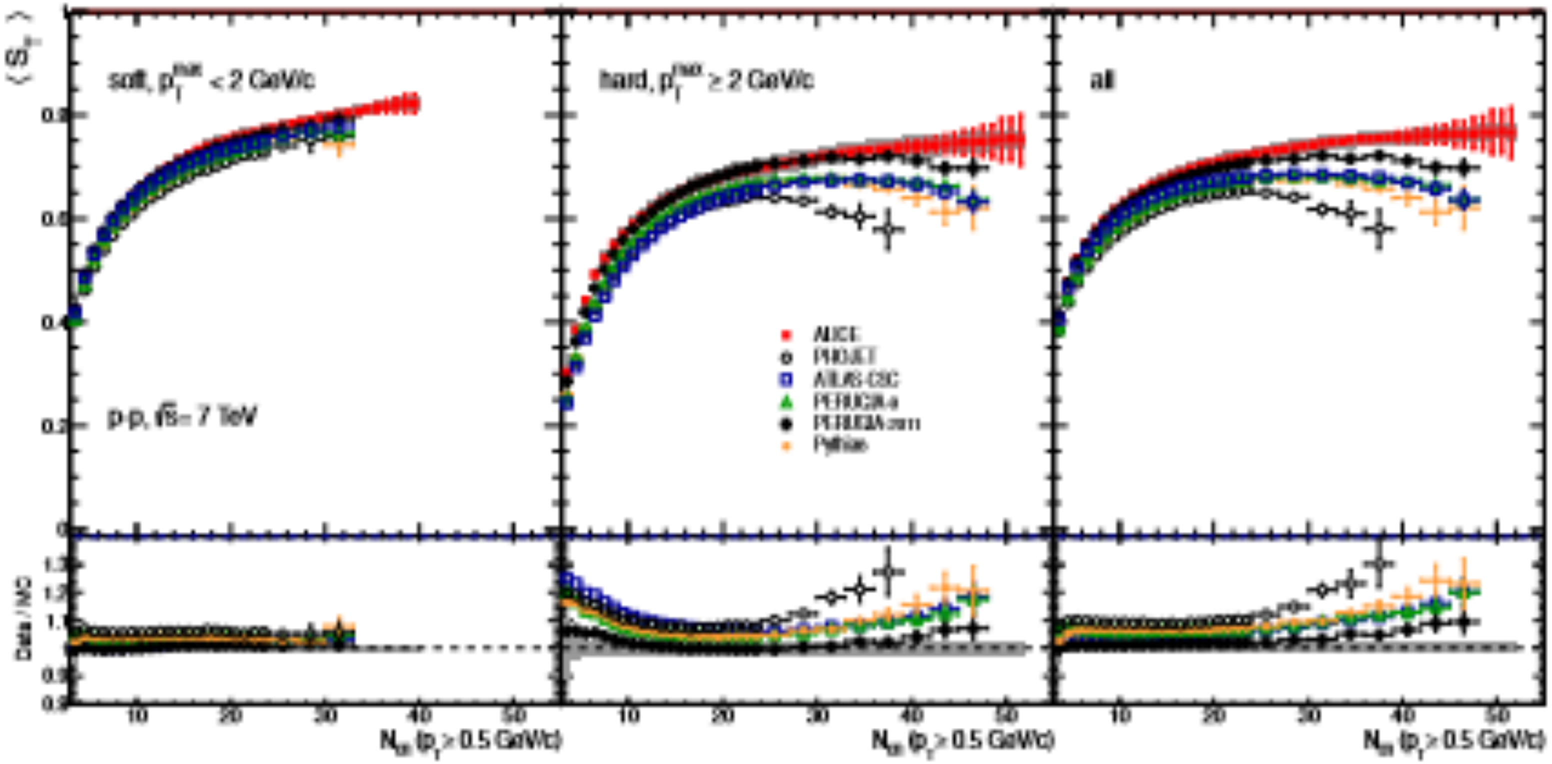


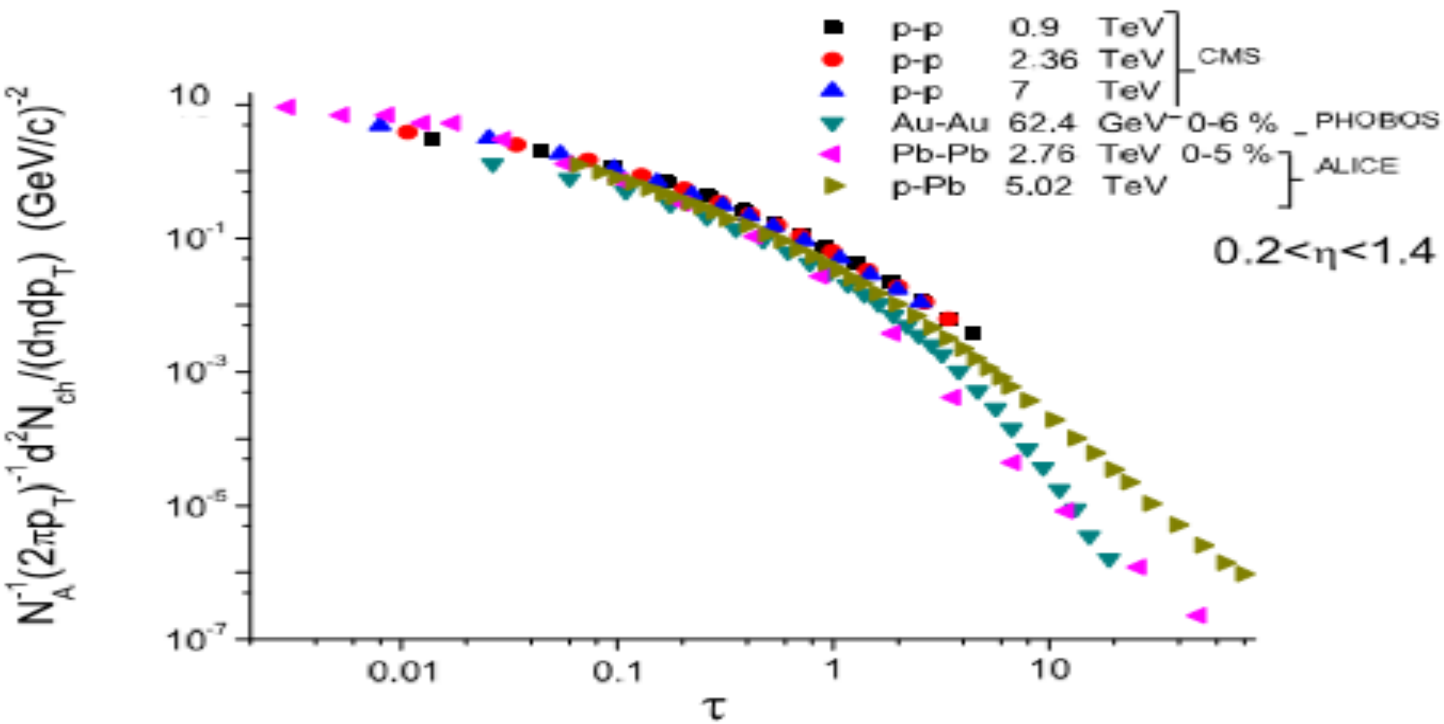
Fig. 8. (Color online) Mean transverse sphericity versus multiplicity for inclusive (right), "hard" (middle) and "soft" (left) pp collisions at $\sqrt{s} = 7\,\text{TeV}$. The ALICE data are compared with different MC models: PHOJET, PYTHIA 6 (tunes: ATLAS-CCS, PERUGIA-0 and PERUGIA-2011) and PYTHIA 8. The statistical errors are displayed as error bars and the systematic uncertainties as the shaded area. Figure reproduced from Ref.[24]

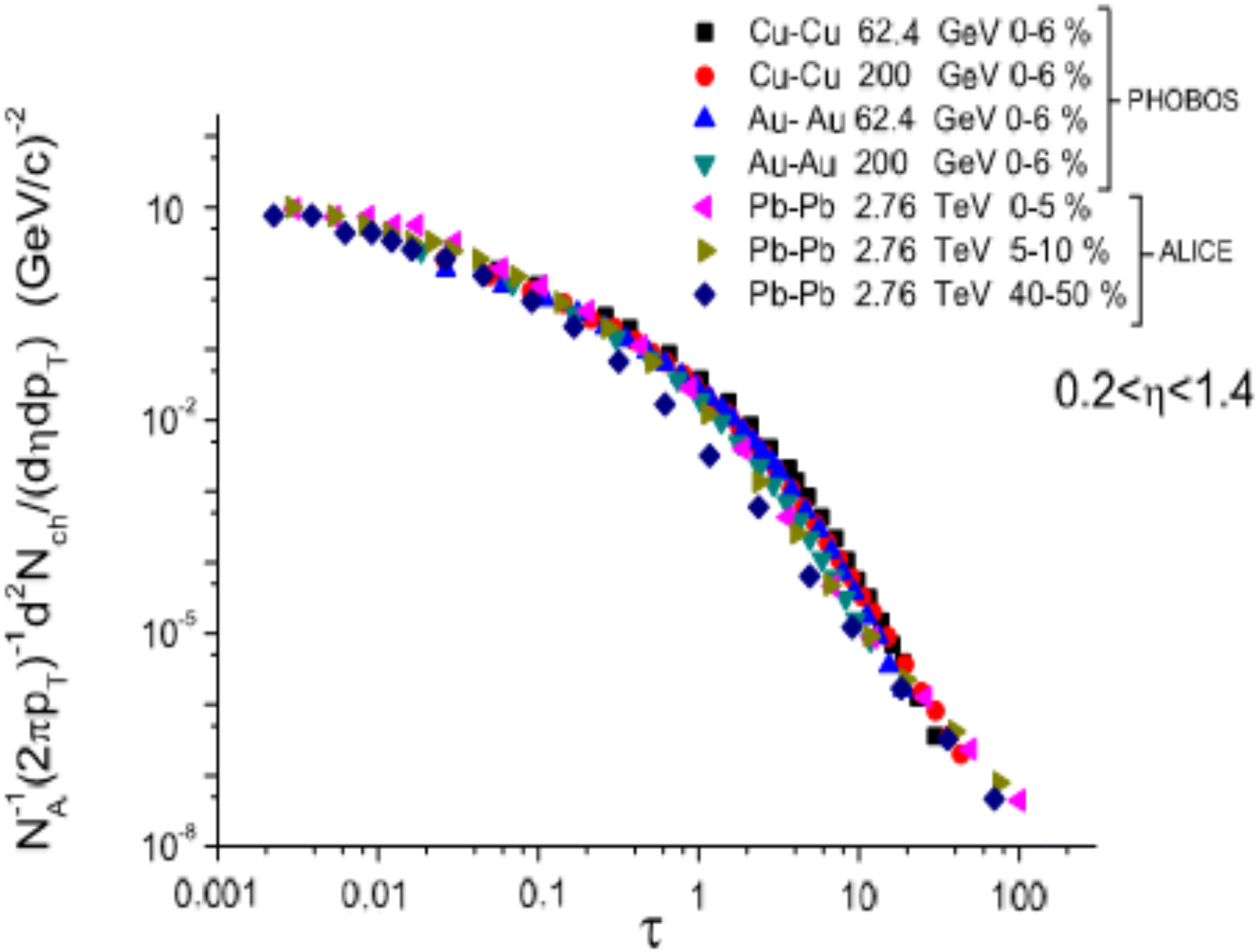
$$\left(Q_s^A\right)^2 = \left(Q_s^p\right)^2 N_A^{\beta(s)/2} A^{1/6} \left(\frac{A}{N_A}\right)^{1/3} \qquad \left(Q_s^p\right)^2 \equiv Q_0^2 \left(\frac{W}{p_T}\right)^{\lambda}$$

$$\beta(s) = \frac{1}{3}\left(1 - \frac{1}{1 + \ln\left(\sqrt{s/s_0} + 1\right)}\right).$$

where $W = \sqrt{s} \times 10^{-3}$ and $\lambda = 0.27$.

$$\tau \equiv p_T^2 / Q_s^2,$$





Cu-Cu 62.4 GeV 0-6 %
Cu-Cu 200 GeV 0-6 %
Au- Au 62.4 GeV 0-6 %
Au-Au 200 GeV 0-6 %
Pb-Pb 2.76 TeV 0-5 %
Pb-Pb 2.76 TeV 5-10 %
Pb-Pb 2.76 TeV 40-50 %
PHOBOS
ALICE
0.2<η<1.4
$N_A^{-1}(2\pi p_T)^{-1}d^2N_{ch}/(d\eta dp_T)$ $(GeV/c)^{-2}$
10
10^{-2}
10^{-5}
10^{-8}
0.001
0.01
0.1
1
10
100
τ

$$\frac{1}{N_A}\frac{dN_{ch}^{soft}}{d\eta} = \frac{1}{N_A}\int_0^{Q_s^2} \mathrm{d}p_T^2 \frac{dN_{ch}^2}{d\eta dp_T^2} = \frac{1}{N_A}\int_0^{Q_s^2} \mathrm{d}p_T^2 \frac{1}{Q_0^2}F(\tau)$$

and with the change of variables

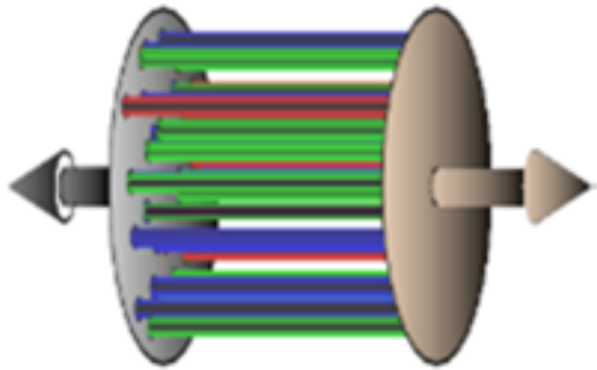
$$\frac{dp_T^2}{Q_0^2} = \frac{2}{2+\lambda}\left(\frac{W}{Q_0}\right)^{\frac{2\lambda}{2+\lambda}} \tau^{-\frac{\lambda}{2+\lambda}} N_A^{\delta(s)/2} A^{1/6}\left(\frac{A}{N_A}\right)^{1/3} d\tau,$$

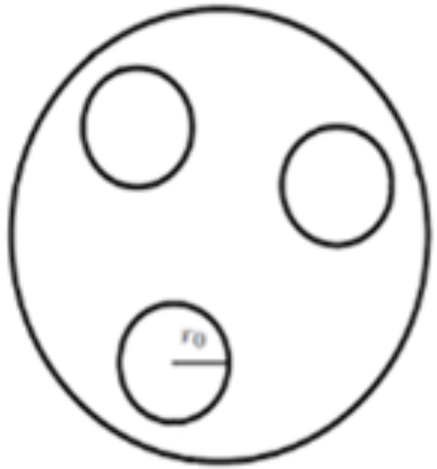
the fraction of soft and hard multiplicities over the total multiplicity results

$$R_s \equiv \frac{dN_{ch}^{soft}/d\eta}{dN_{ch}^{tot}/d\eta} = \frac{\int_0^1 \mathrm{d}\tau\, \tau^{-\frac{\lambda}{2+\lambda}} F(\tau)}{\int_0^\infty \mathrm{d}\tau\, \tau^{-\frac{\lambda}{2+\lambda}} F(\tau)}, \qquad R_h \equiv \frac{dN_{ch}^{hard}/d\eta}{dN_{ch}^{tot}/d\eta} = \frac{\int_1^\infty \mathrm{d}\tau\, \tau^{-\frac{\lambda}{2+\lambda}} F(\tau)}{\int_0^\infty \mathrm{d}\tau\, \tau^{-\frac{\lambda}{2+\lambda}} F(\tau)}$$

	Energy (TeV)	Centrality	R_s	R_h
p-p	0.9	minb	0.91	0.09
p-p	2.36	minb	0.90	0.10
p-p	7	minb	0.92	0.08
p-Pb	5.02	minb	0.93	0.07
Cu-Cu	0.0624	0-6 %	0.93	0.07
Cu-Cu	0.2	0-6 %	0.94	0.06
Au-Au	0.0624	0-6 %	0.93	0.07
Au-Au	0.2	0-6 %	0.96	0.04
Pb-Pb	2.76	40-50 %	0.98	0.02
Pb-Pb	2.76	0-5 %	0.98	0.02

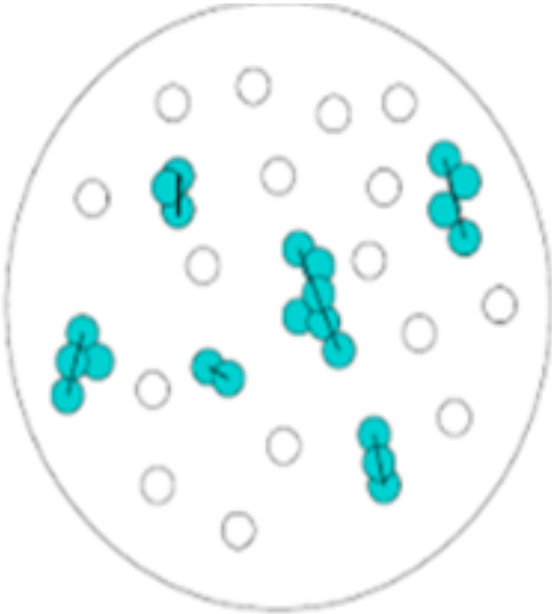
Physical picture





$r_0 = 0.2 - 0.25\ fm$

- Projectile and target interact via color field created by the constituent partons of the nuclei.
- Color field is confined in a region with transverse size $r_0 \sim \mathbf{0.2}\,\mathbf{fm}$.
- We can see them as small areas in transverse plane.
- These color "strings" break producing $q\bar{q}$ pairs (Schwinger mechanism) that subsequently lead to the observed hadrons.



- With growing energy and/or atomic number of colliding particles, the number of **sources** grows → The **number of strings** grows with energy and/or atomic number.
- The **number of strings** also increases with increasing centrality.
- Strings are **randomly distributed** in transverse plane so they can overlap forming clusters.

$$\rho = N_s \frac{S_1}{S_A}$$

- At a certain critical density 1.2-1.5 a macroscopic cluster appears which marks the percolation transition.

- Mean fraction of the area covered by clusters

$$\left(1 - e^{-\rho}\right)$$

- Mean fraction of the area covered by clusters

$$A(\rho) = \frac{1}{1 + ae^{-(\rho-\rho_c)/}}$$

- So the basic equations concerning clusters are

$$\mu_n = N_s F(\rho) \mu_1, \quad \langle p_T^2 \rangle_n = \langle p_T^2 \rangle_1 / F(\rho)$$

where

$$F(\rho) = \sqrt{\frac{1 - e^{-\rho}}{\rho}}.$$

The decay of a cluster of many strings covers almost the whole phase space and therefore have sphericity close to 1.On the other hand as the energy or centrality or multiplicity increases, the fraction of the area covered by strings grows and the fraction of events with high sphericity should increase

Associated distribution to hard events

$$\sigma_n^{hA}(b) = \binom{A}{n}[\sigma_{tot}T(b)]^n[1-\sigma_{tot}T(B)]^{A-n},$$

$$\sigma_n^{hA}(s) = \int d^2b\, \sigma_n^{hA}(b).$$

$$\sigma_{tot} = \sigma_C + \sigma_N,$$

$$[T(b)\sigma_{tot}]^n = T^n(b)\sum_{i=0}^{n}\binom{n}{i}\sigma_C^i\sigma_N^{n-i}.$$

$$\sigma_{\mathrm{C}}^{hA}(b) = \sum_{n=1}^{A} \binom{A}{n} \left(\sigma_{\mathrm{tot}}^{n} - \sigma_{\mathrm{N}}^{n}\right)$$

$$\times\, T^{n}(b)\left[1 - T(b)\sigma_{\mathrm{tot}}\right]^{A-n}$$

$$= 1 - \left[1 - T(b)\sigma_{\mathrm{C}}\right]^{A} .$$

$$P_C(n) \simeq \frac{n\,P(n)}{\langle n \rangle}.$$

$$\langle n \rangle_C - \langle n \rangle = \frac{D^2}{\langle n \rangle}.$$

$$P(x) \rightarrow \frac{xP(x)}{< x >} .... \rightarrow \frac{x^k P(x)}{< x^k >} \rightarrow ...$$

Jona Lasinio renormalization group in probabilistic theory
The only stable distributions under these transformations are the generalized gamma functions

$$\Psi(z) = \frac{\mu}{\Gamma(\kappa)} \left[\frac{\Gamma(\kappa + 1/\mu)}{\Gamma(\kappa)} \right]^{\kappa\mu} \times z^{\kappa\mu - 1} \exp\left(- \left(\frac{\Gamma(\kappa + 1/\mu)}{\Gamma(\kappa)} z \right)^{\mu} \right).$$

$$W(N) = \frac{\gamma}{\Gamma(k)}(\gamma N)^{k-1}\exp(-\gamma N), \qquad \gamma = \frac{k}{\langle n \rangle}.$$

$$\frac{1}{k} = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle^2}.$$

The gamma function satisfies K.N.O scaling if k is constant

$$P(n) = \frac{1}{\langle n \rangle}\psi\left(\frac{n}{\langle n \rangle}\right)$$

Conclusions

--The fraction of hard events(pt>Qs) does not increase with energy or centrality.

--In string percolation,the larger string density the smaller room surface free for isolated hard collisions.This agrees with the results on the dependence of sphericity with multiplicity in pp cpllisions

--The associated distribution to hard collisions(distribution on number of parton collisions,both soft and hard) is the gamma function(generalized) which satisfies the KNO scaling