Structure of the multiparticle events

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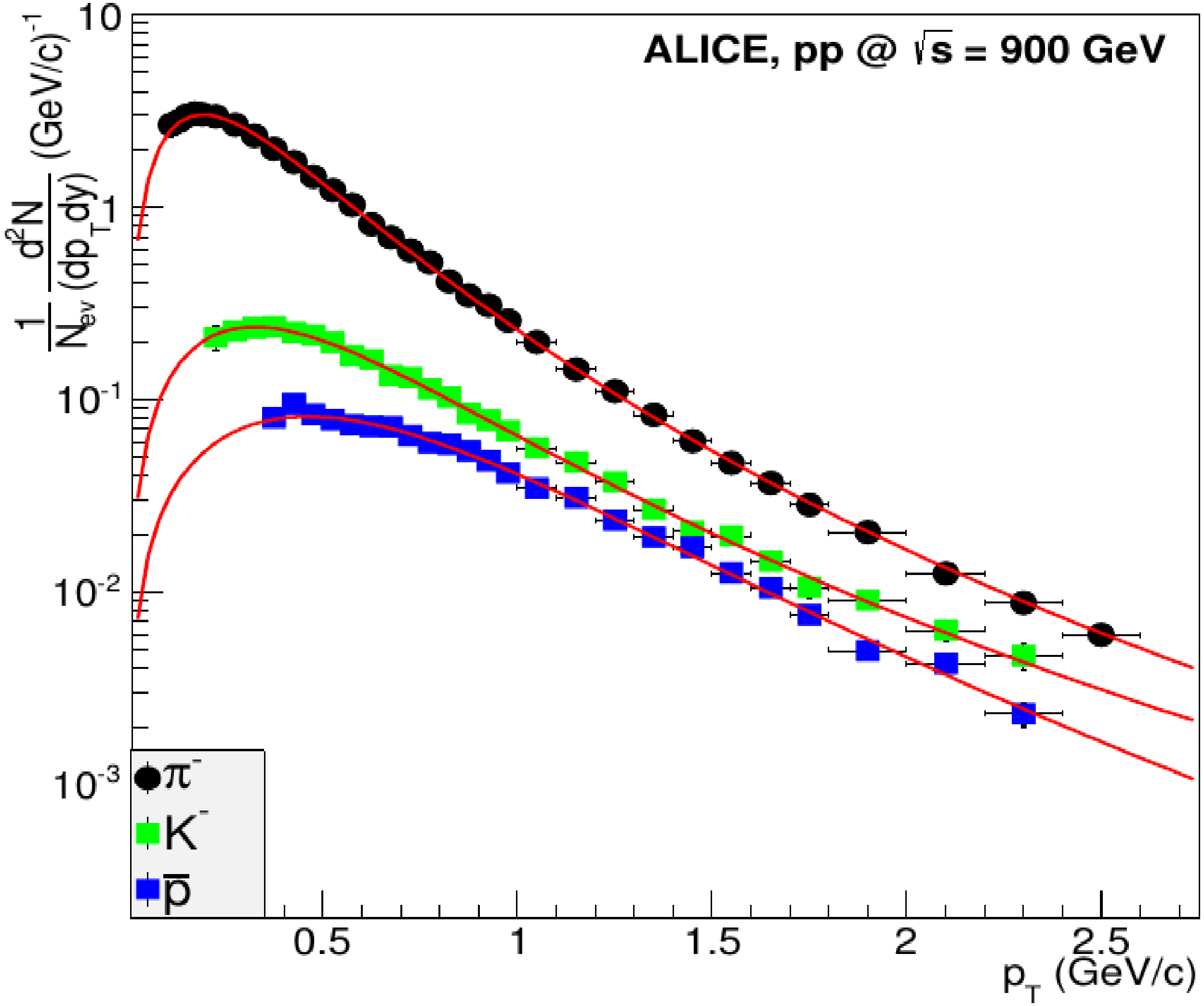
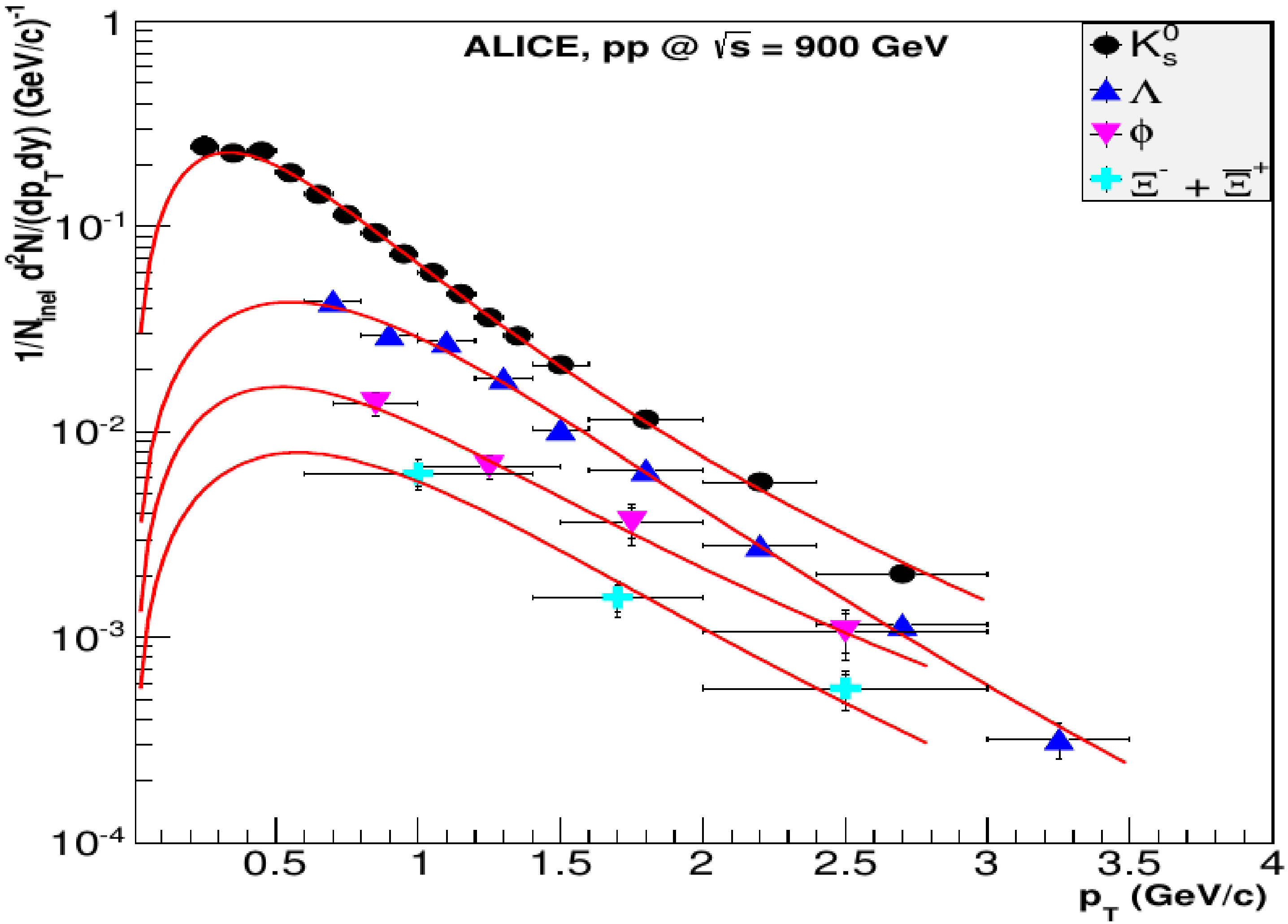
Dubna
16.09.2014

Charged particles

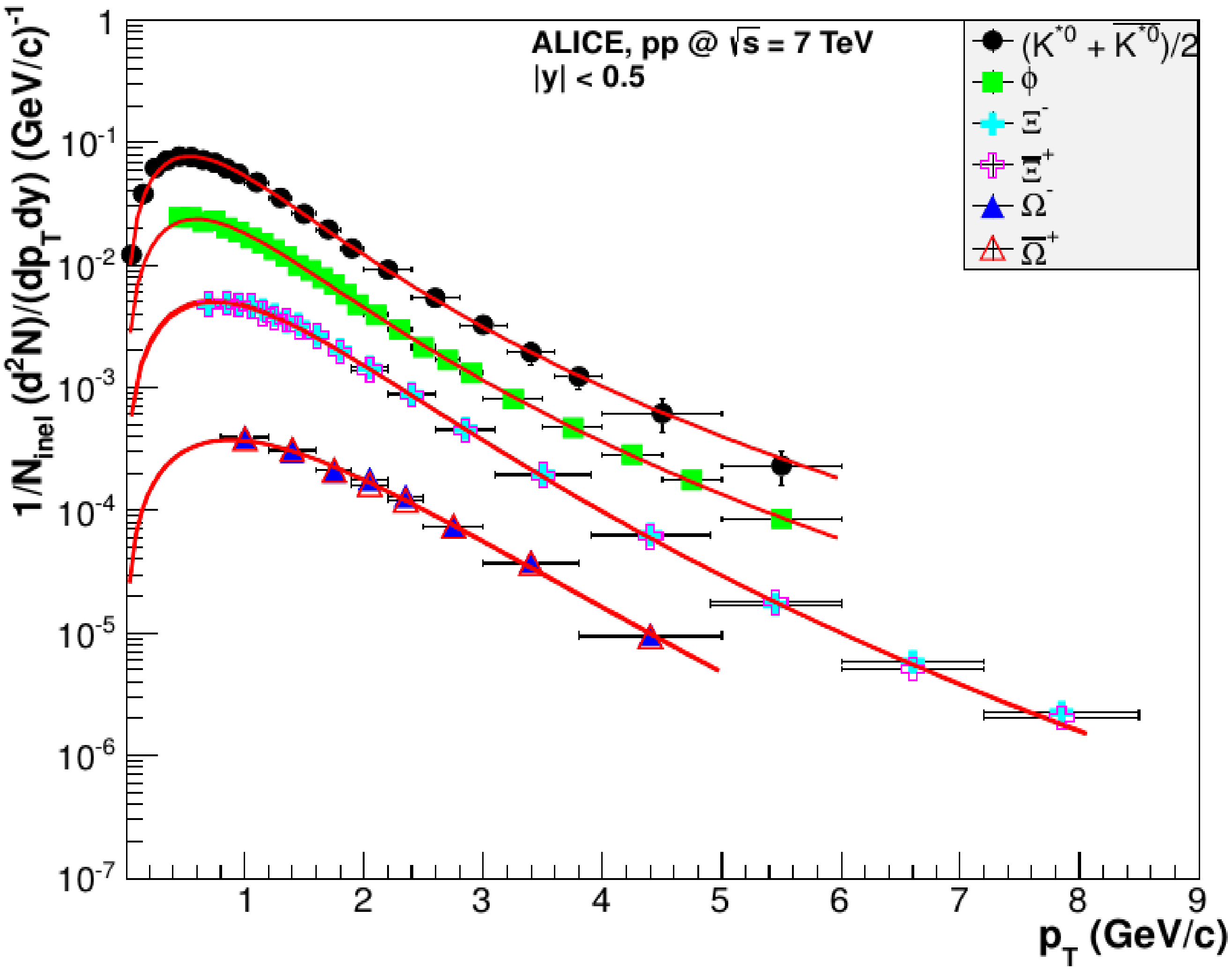
J.Cleymans CERN 2014



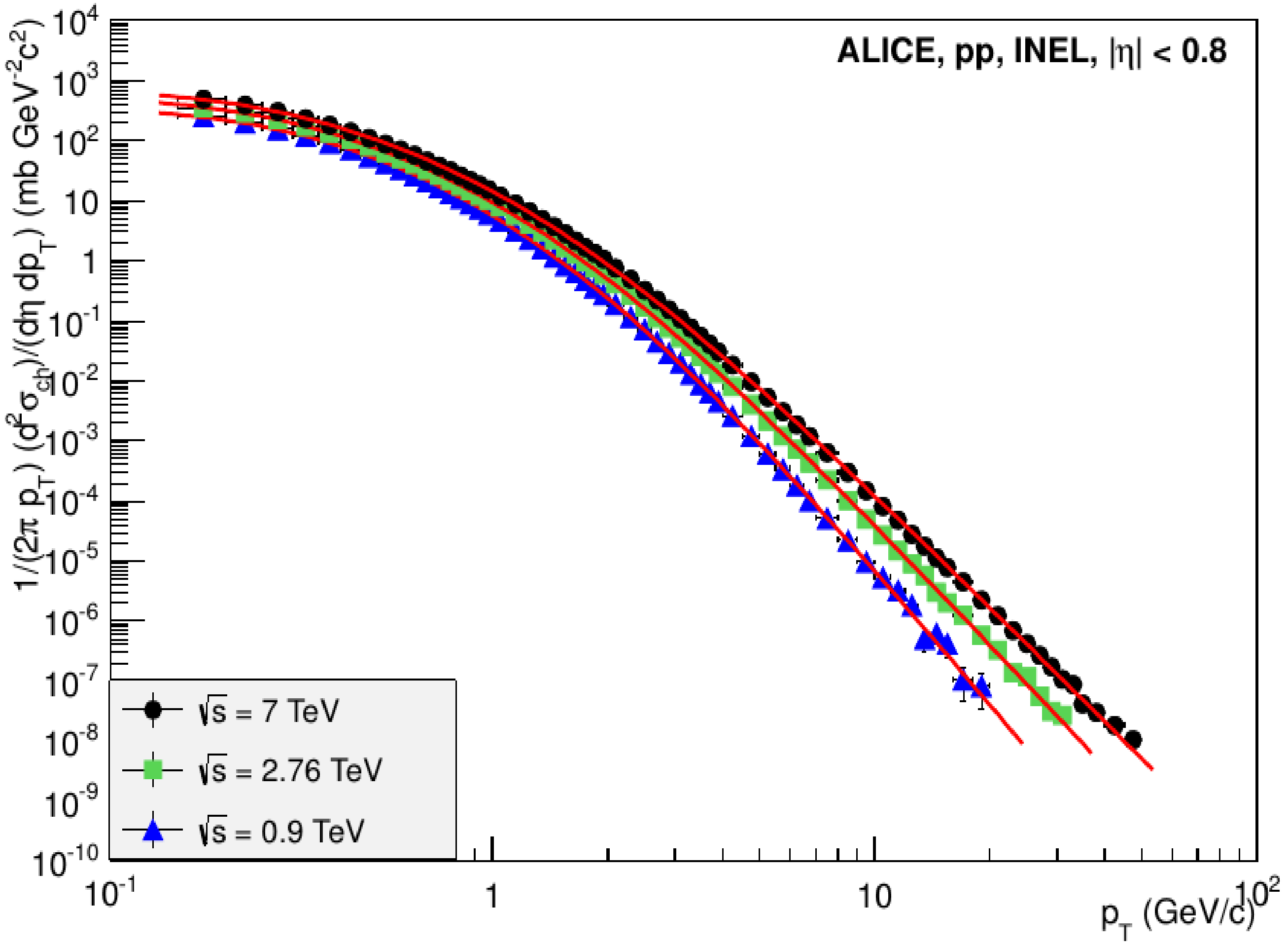
Strange particles



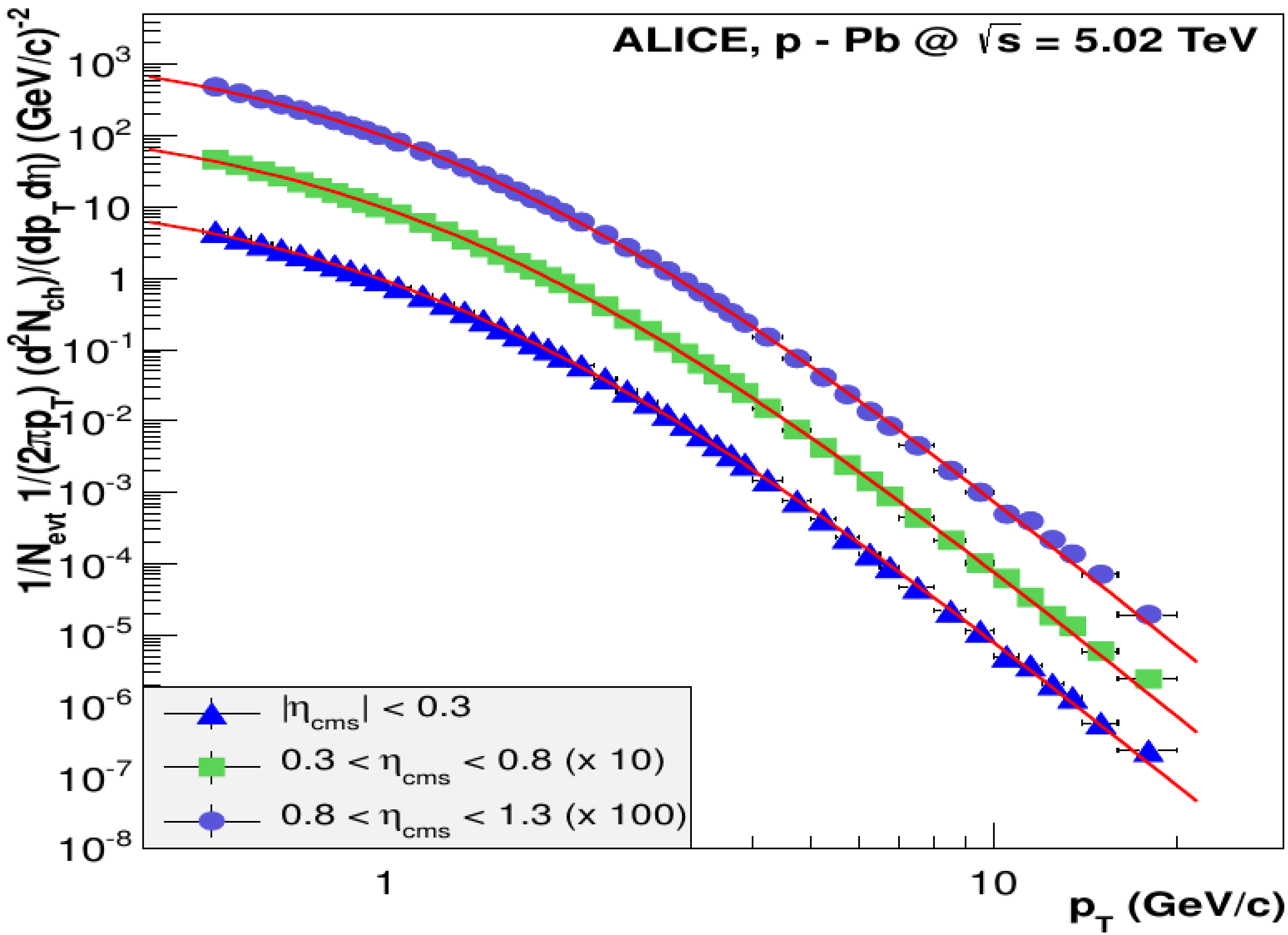
ALICE at √s =7 TeV



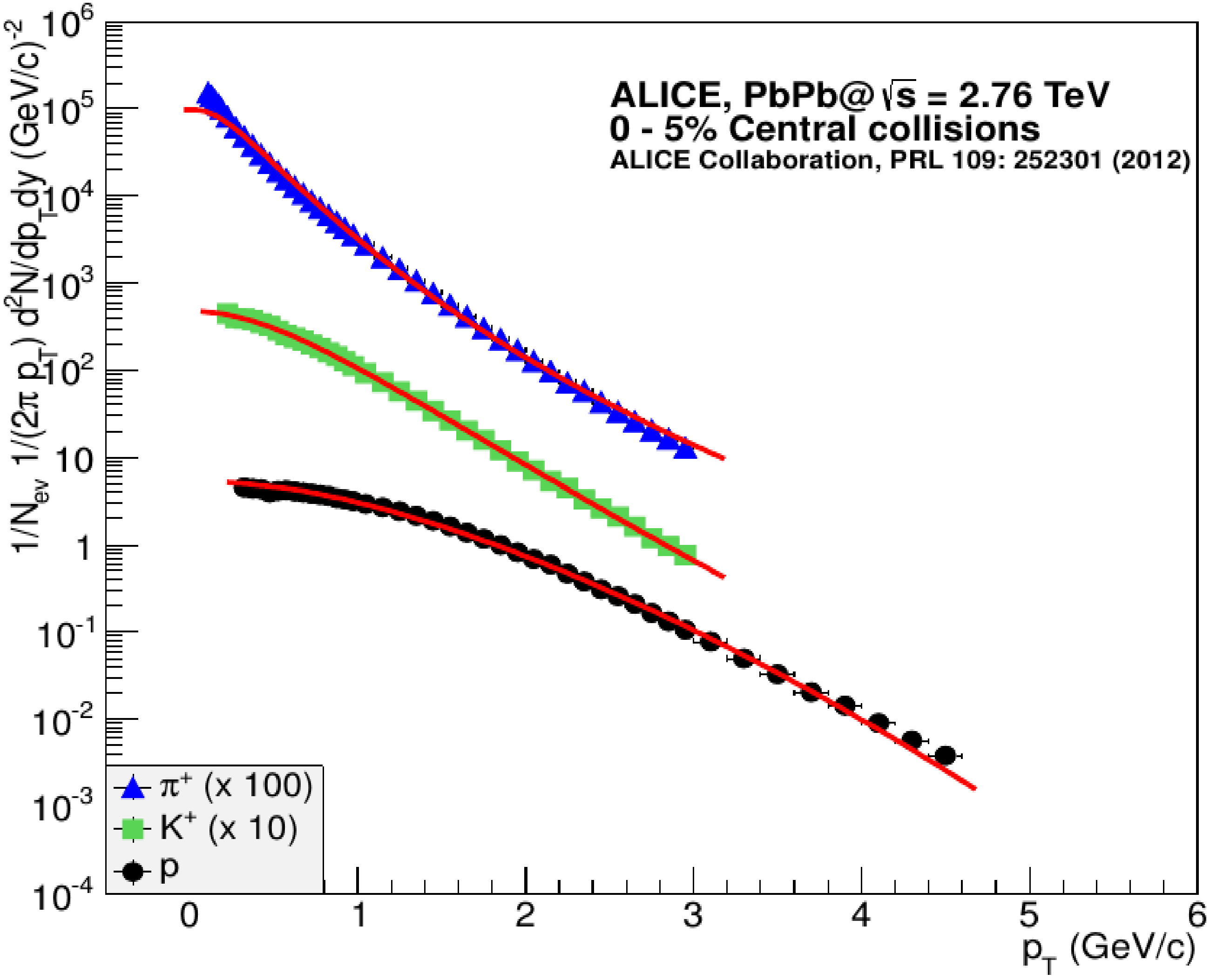
Colliding energies



pPb collisions



PbPb collisions



Tsallis distribution

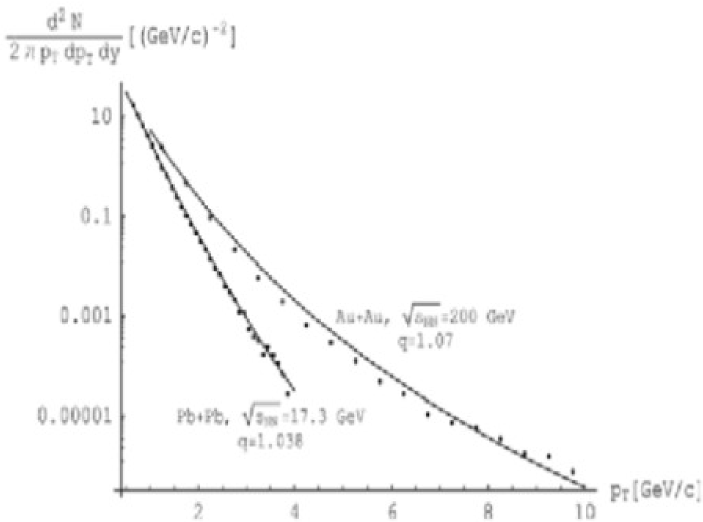
J.Cleymans. and D. Worku, J. Phys. G39 (2012) 025006;
arXiv:1203.4343[hep-ph].

$$\frac{d^2N}{dp_T dy} = gV \frac{p_T m_T}{(2\pi)^2} \left[1 + (q-1)\frac{m_T}{T}\right]^{-\frac{q}{q-1}}$$

where T and μ are the temperature and the chemical potential,
V is the volume and g is the degeneracy factor

Low energy

Eur. Phys. J. A 40, 313 (2009)



Experimental neutral pion invariant yields in central Pb+Pb collisions at $\sqrt{s_{NN}}$ = 17.3 GeV and in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV compared with the modified thermal distribution shape by using non-extensive statistics

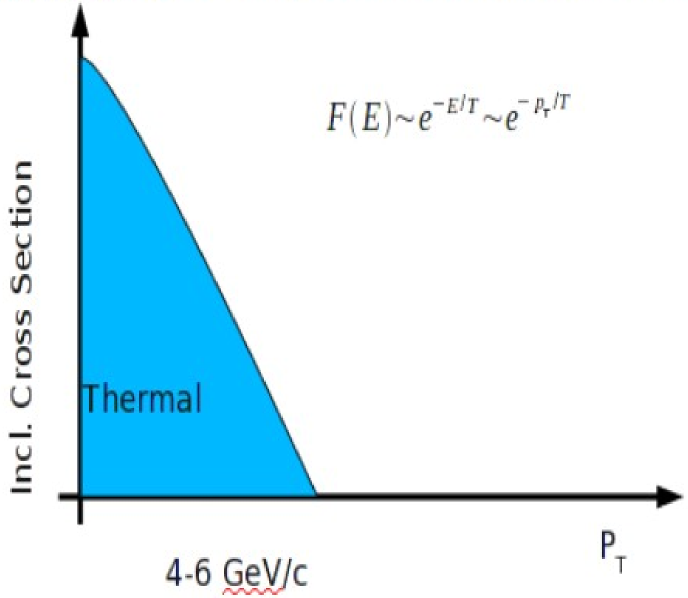
(q = 1.038 for Pb+Pb and q = 1.07 for Au+Au collisions.)

$$\frac{\mathrm{d}^2 N}{2\pi p_\perp \mathrm{d}p_\perp \mathrm{d}y} = C\, m_\perp \left[1 - (1-q)\frac{m_\perp}{T}\right]^{1/(1-q)}$$

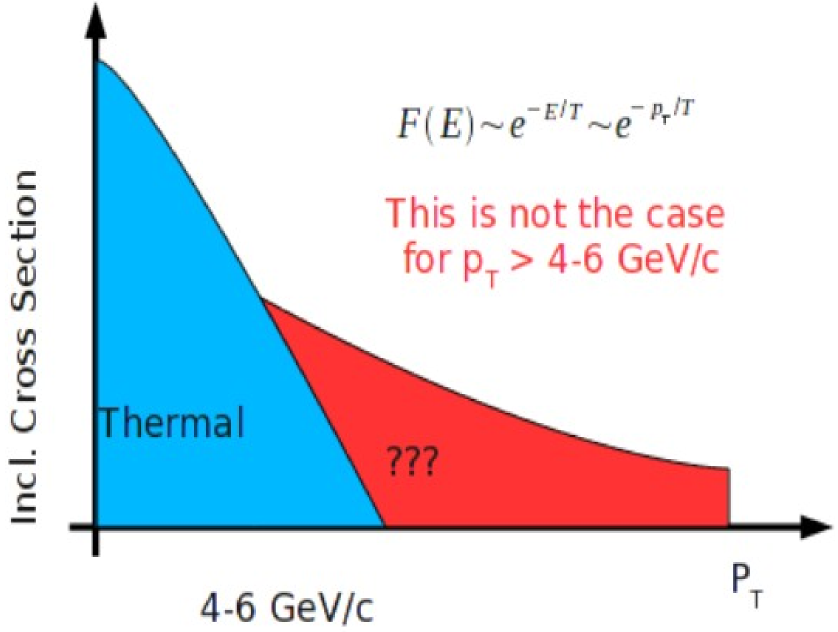
Boltzmann-Gibbs and ...

G.G. Barnaföldi: Tsallis Distribution in High-Energy Heavy Ion Collisions

- Thermalised system: spectra follow Boltzmann-Gibbs

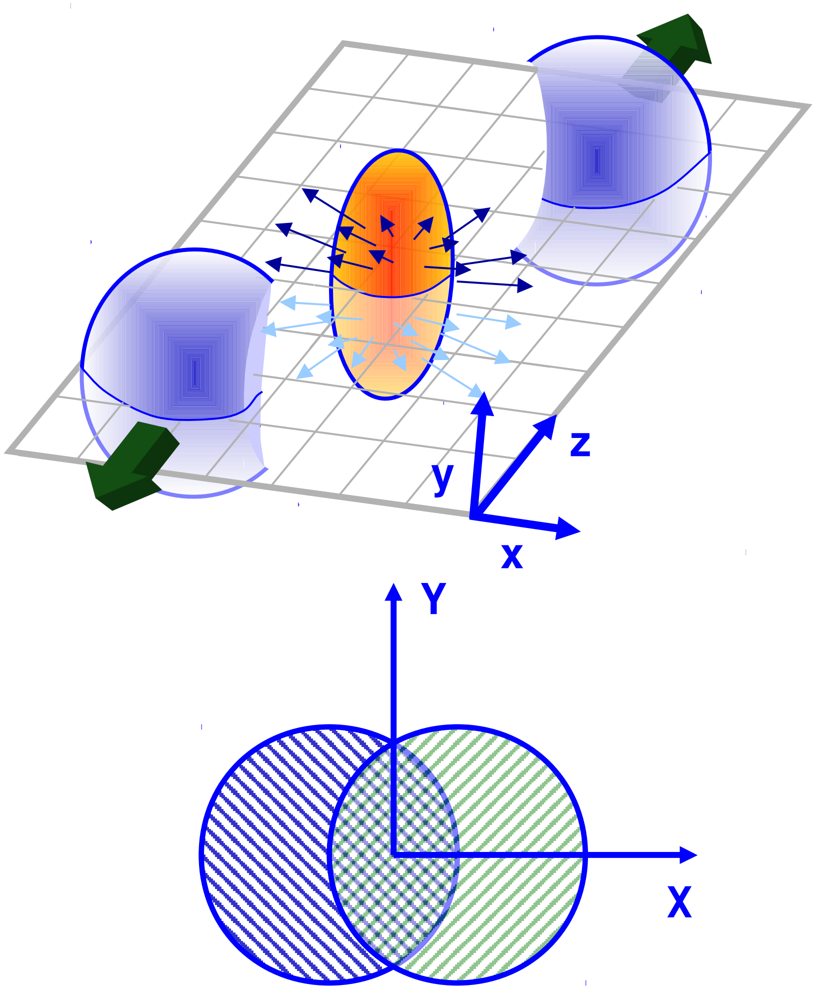


- But in HIC this is quite different...

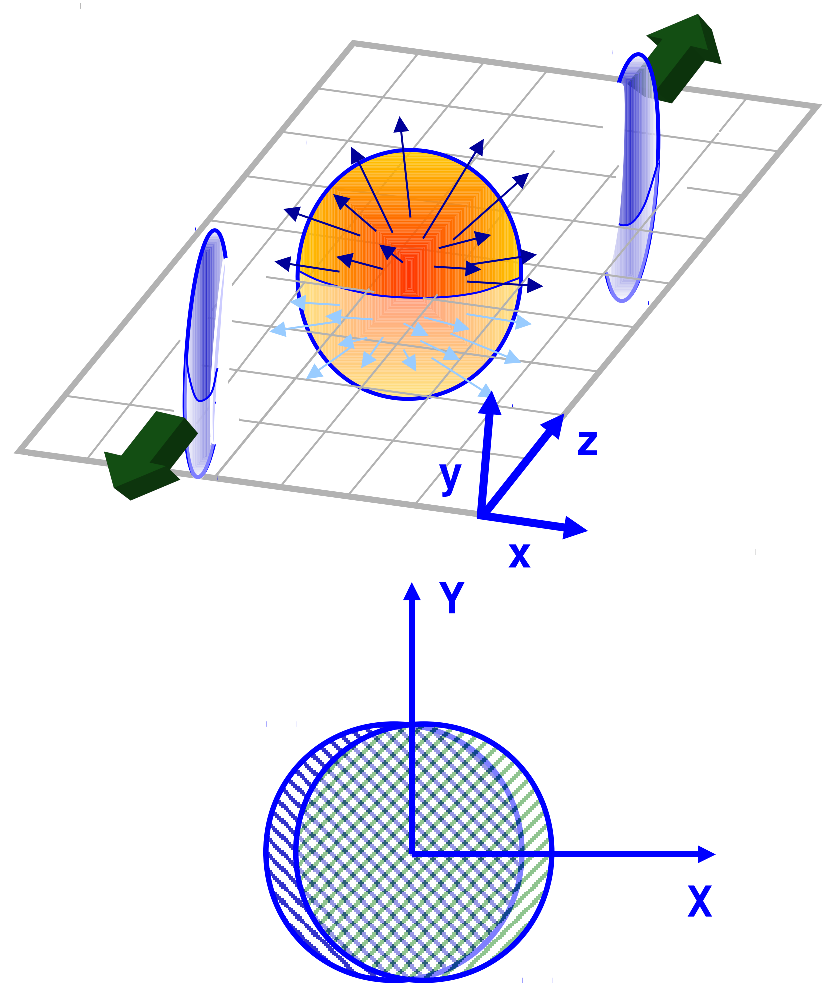


Collectivity

Peripheral Collision

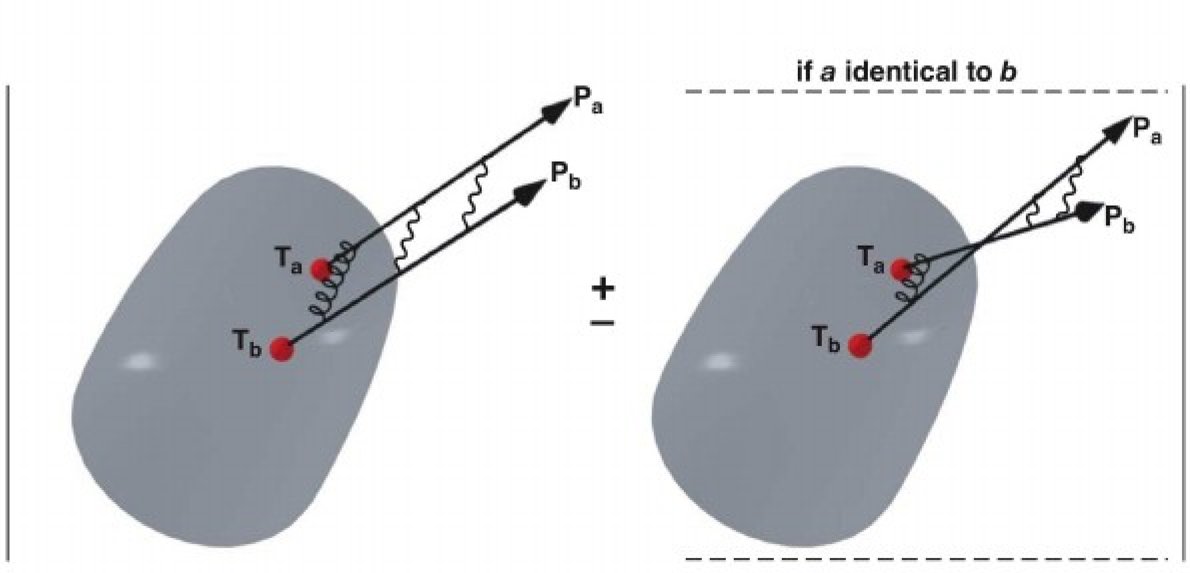


(near) Central Collision



Femtoscopy

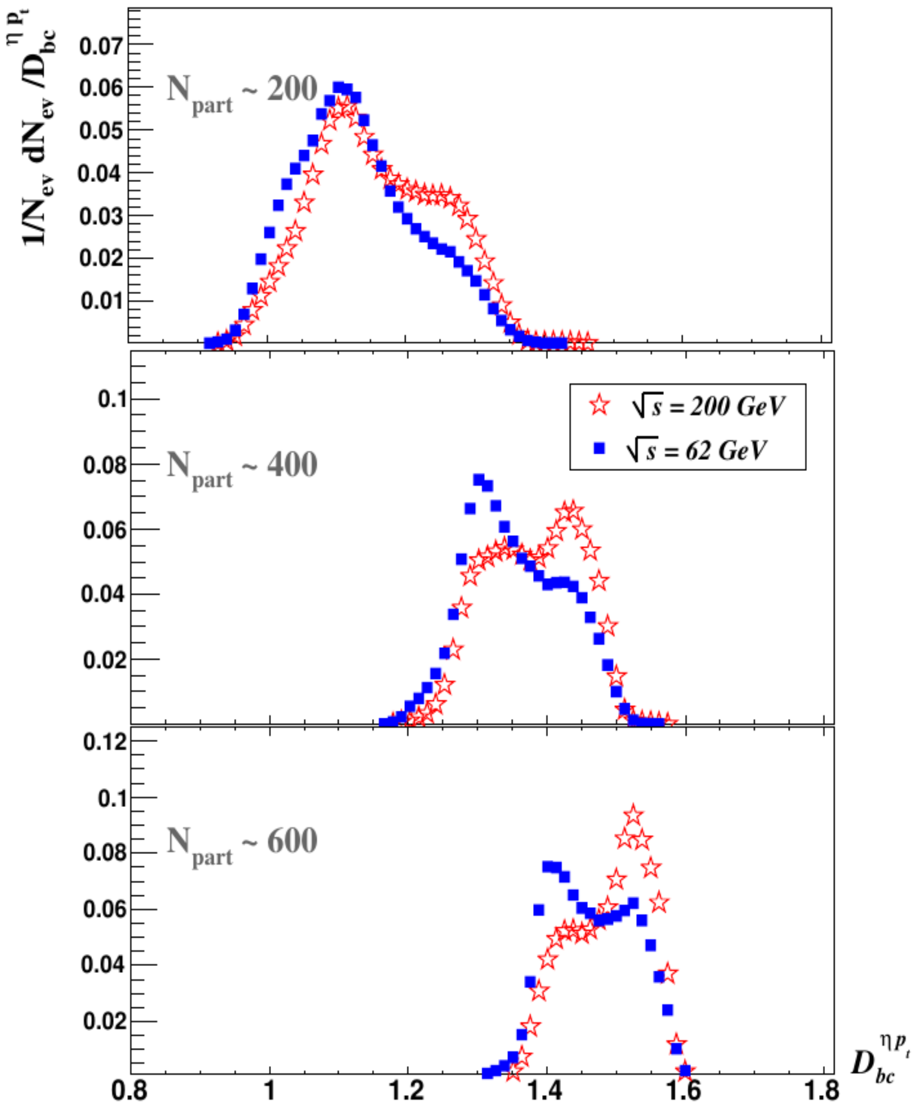
arXiv:nucl-ex/0505014v1

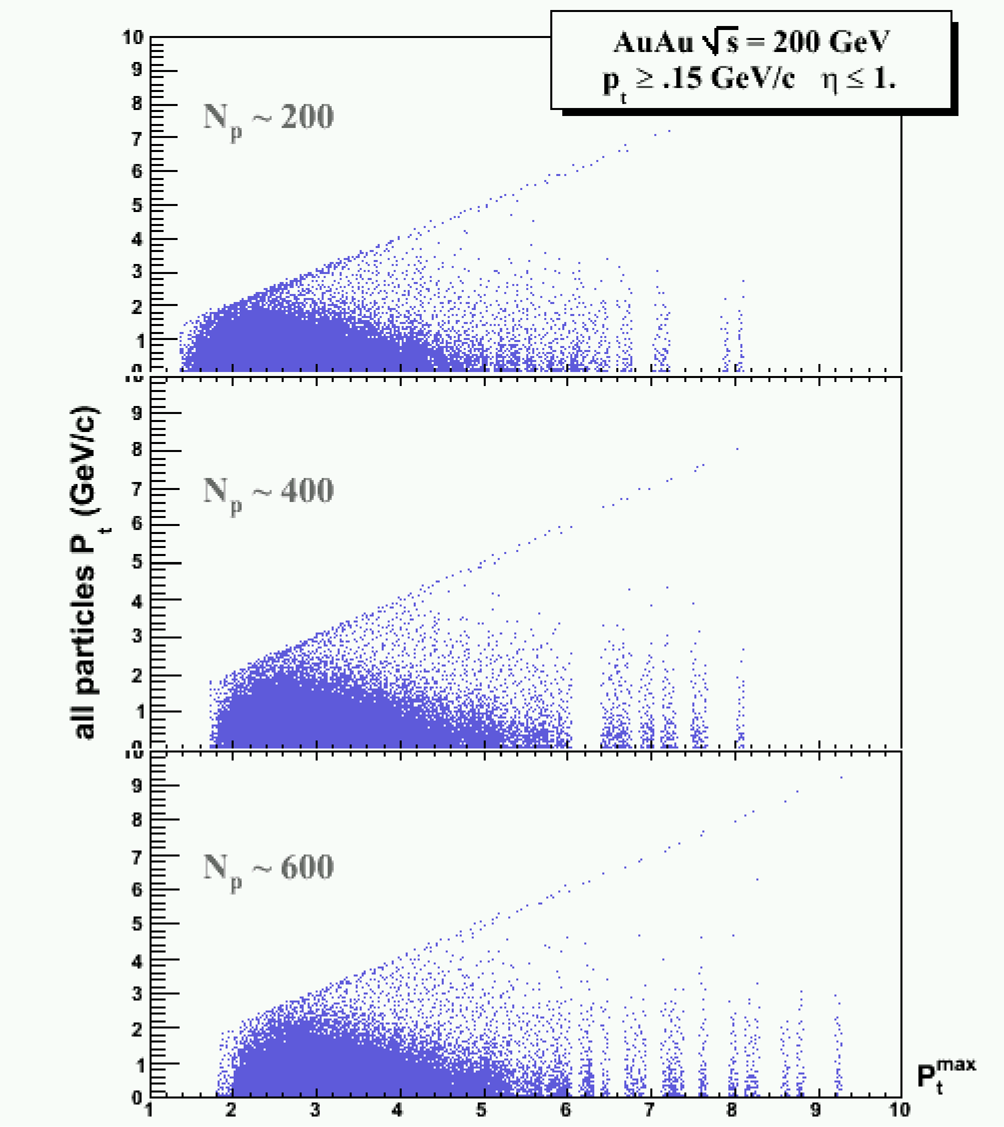


representation of the squared emission amplitude for two particles emitted independently from the grey-shaded source region and interacting with each other in the final states. For identical bosons (+) and fermions (-), correlation also involves interference between the paths.

Fractal analysis

O.R. ICHEP 2006

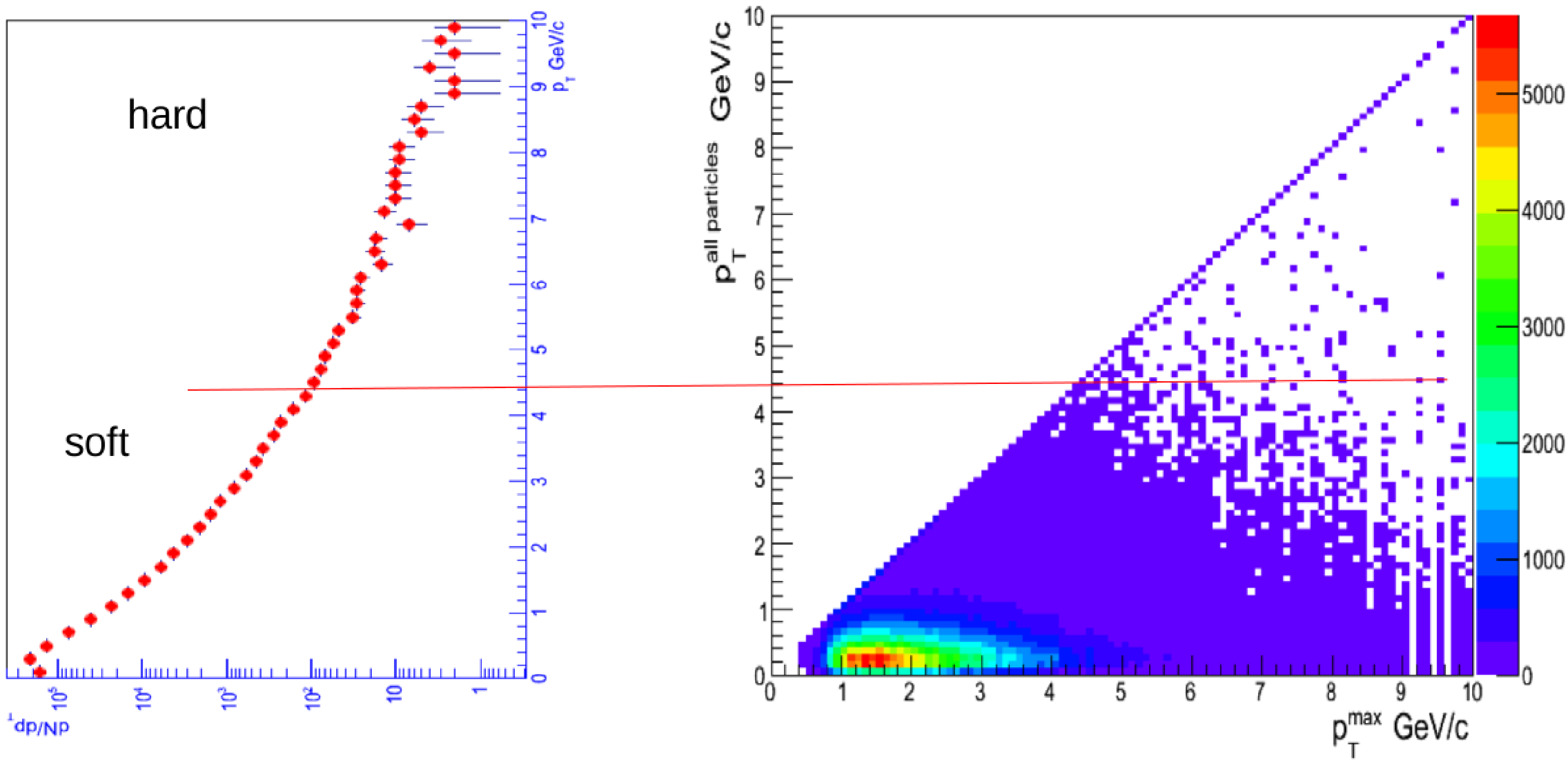




Hard and soft physics

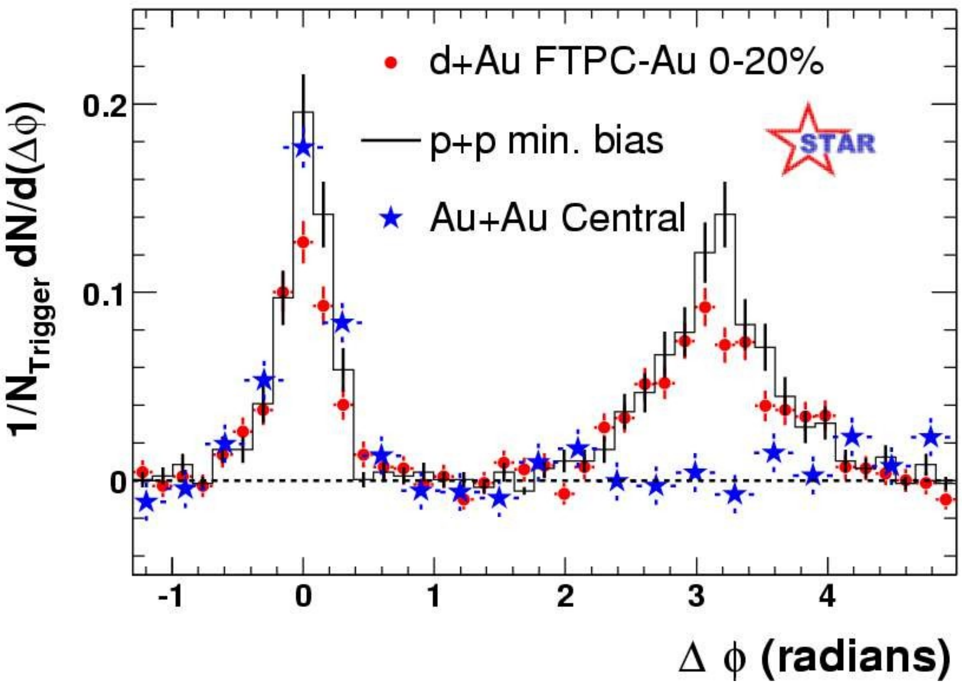
Pythia v.6-424

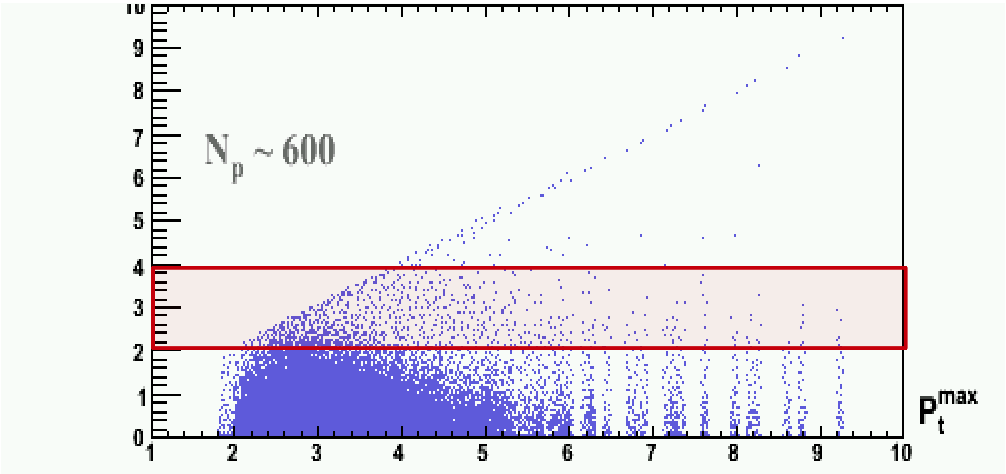
10K events √s =7 TeV
All charged particles



Disappearance of away-side correlations

nucl-ex/0403018

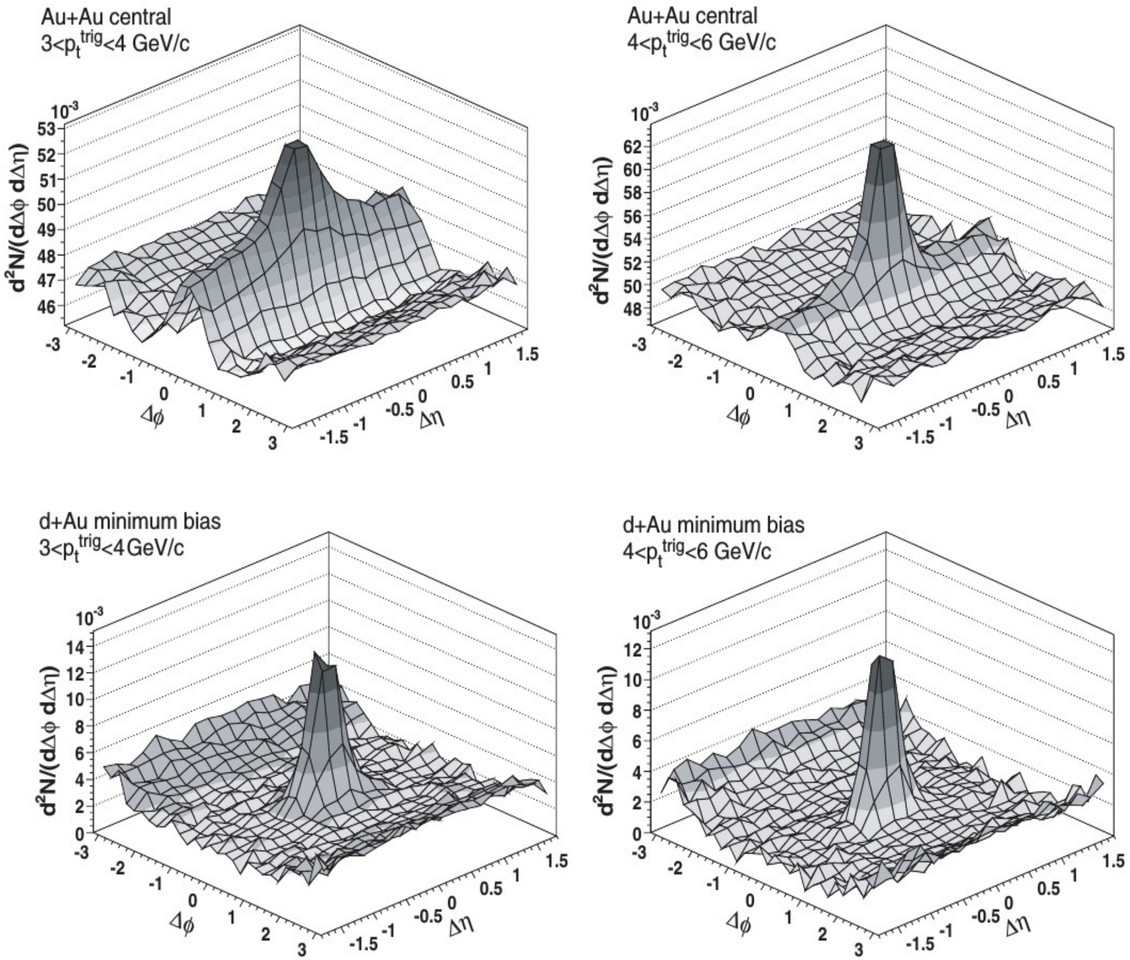




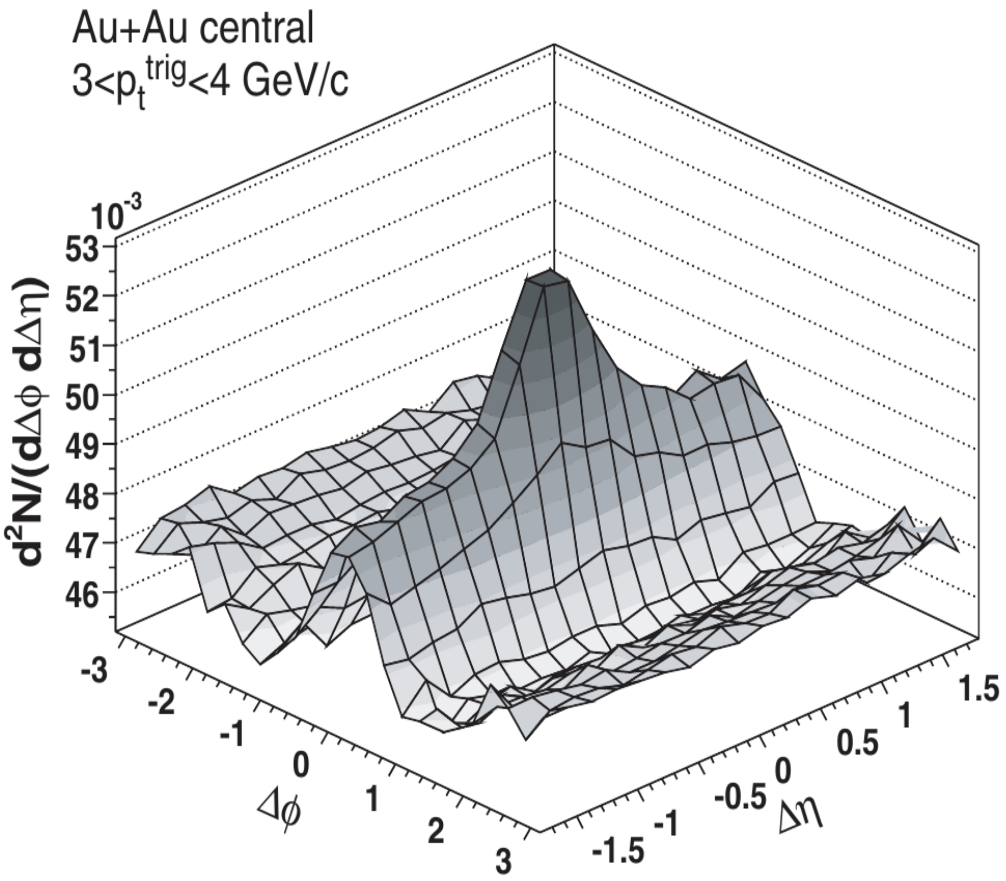
Trigger: highest pT track with pT>4 GeV
Δφ distribution: 2 GeV < pT < pTtrigger
Normalize to number of trigger particles

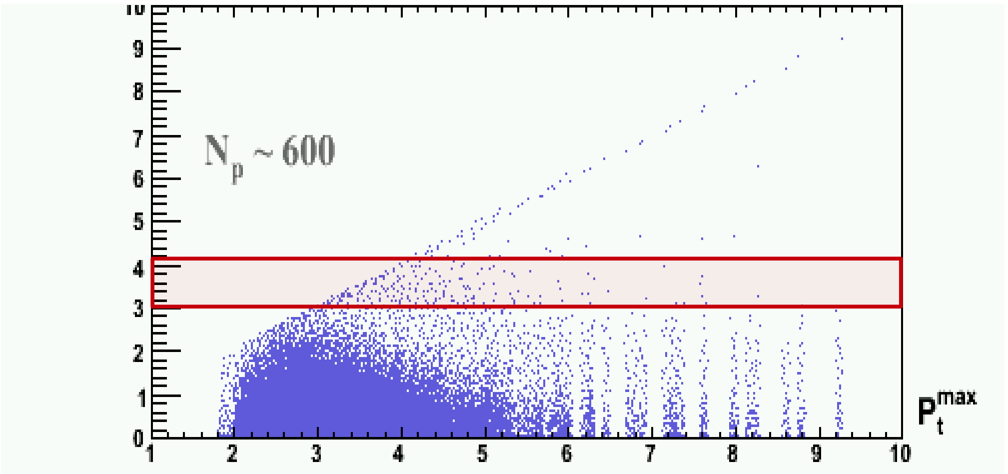
Ridge effect in AuAu

PHYSICAL REVIEW C 80, 064912 (2009)

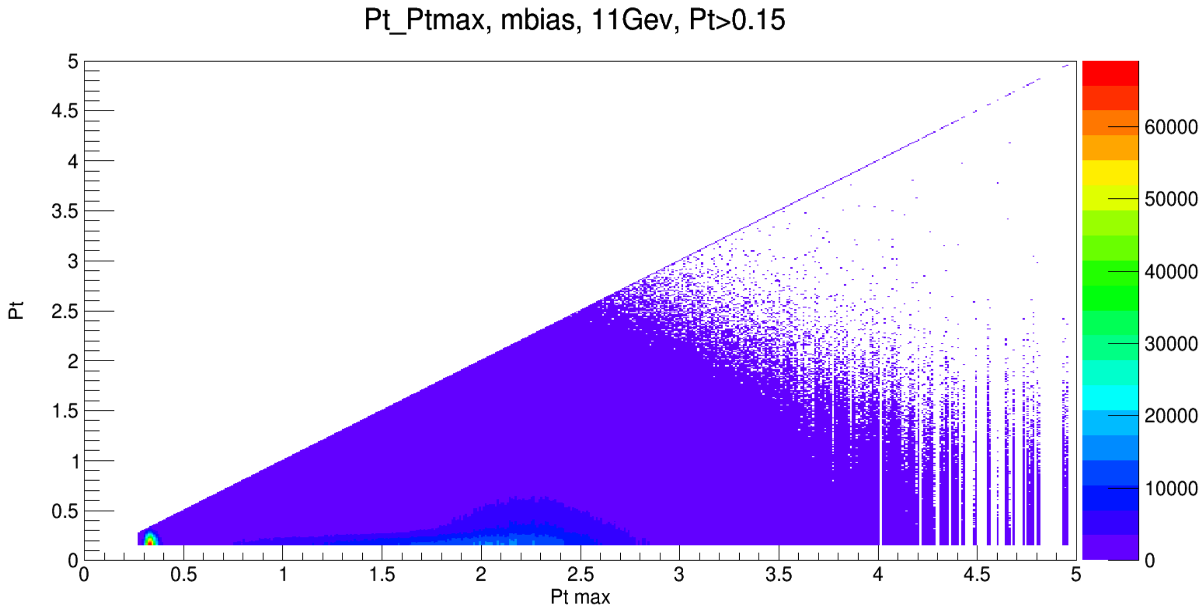


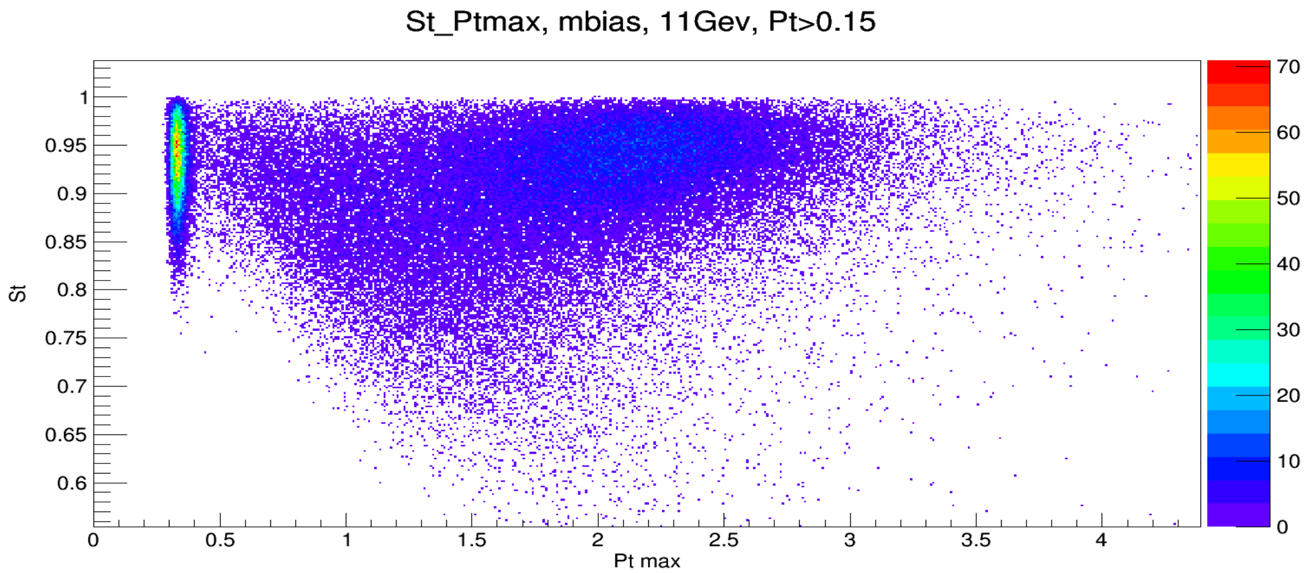
Ridge position



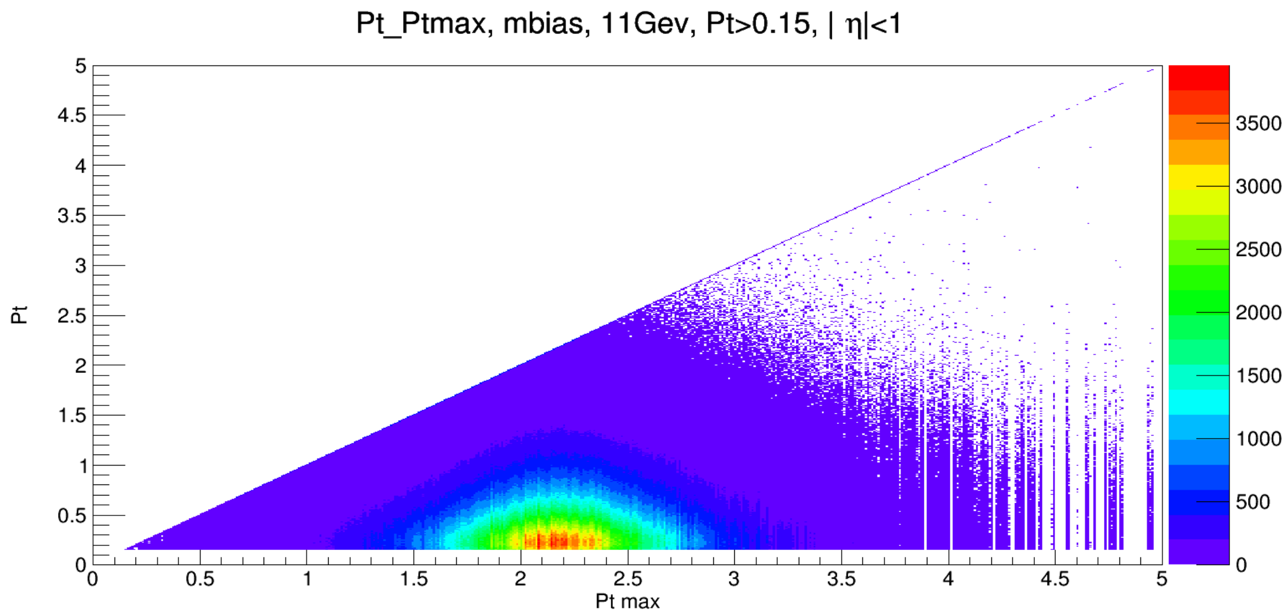


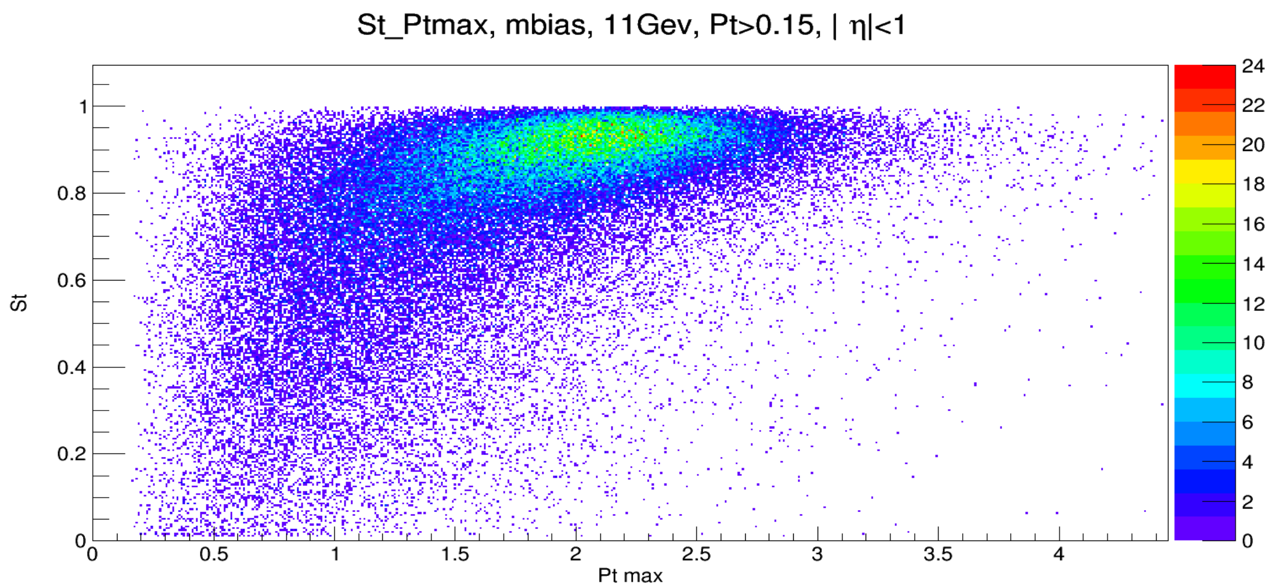
Events sphericity



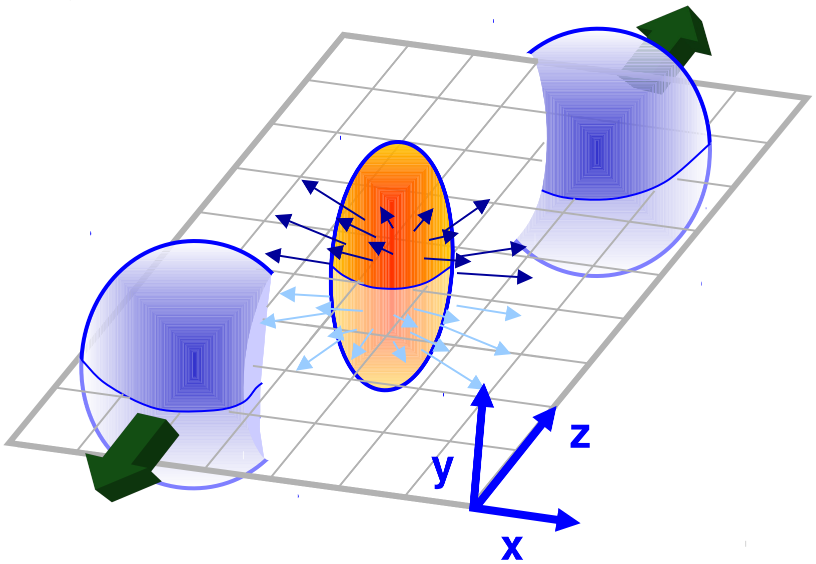


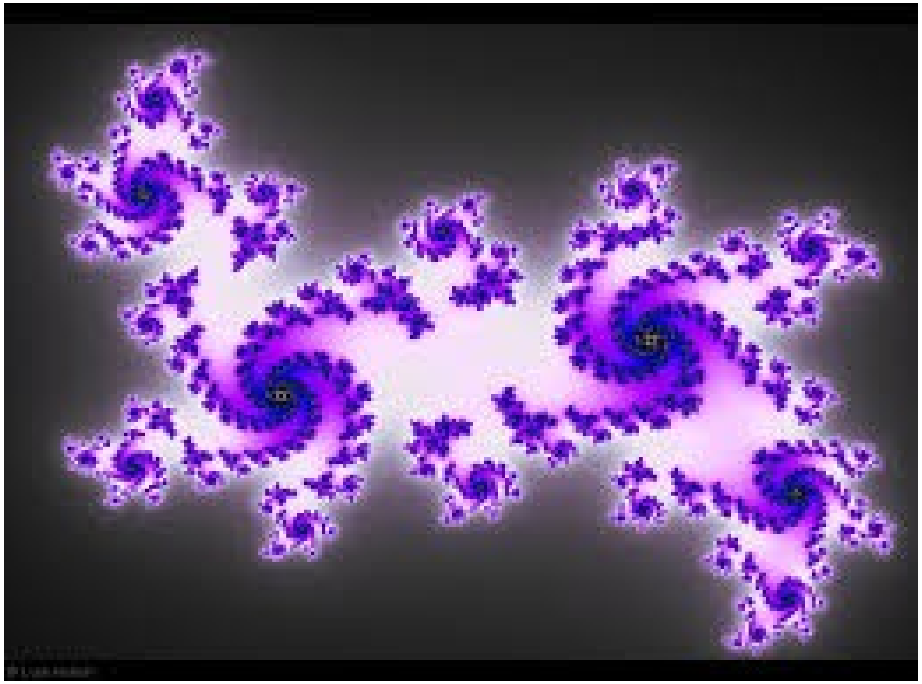
With acceptance





Summary





Event structure of multiparticle collision reveals itself by the features in the inclusive spectra and various correlation phenomena

Sphericity

$$S_T \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

where: $\lambda_1 > \lambda_2$ are the eigenvalues of the transverse momentum matrix:

$$\mathbf{S^L_{xy}} = \frac{1}{\sum_i p_{Ti}} \sum_i \frac{1}{p_{Ti}} \begin{pmatrix} {p_{xi}}^2 & p_{xi}p_{yi} \\ p_{xi}p_{yi} & {p_{yi}}^2 \end{pmatrix}$$

Entropy: Tsallis vs Boltzmann

The Boltzmann entropy is given by

$$S^B = -g \sum_i \left[f_i \ln f_i - f_i \right], \tag{1}$$

The Tsallis entropy is given by

$$S_T^B = -g \sum_i \left[f_i^q \ln_q f_i - f_i \right], \tag{2}$$

which uses

$$\ln_q(x) \equiv \frac{x^{1-q} - 1}{1 - q}, \tag{3}$$

often referred to as q-logarithm.
By maximizing the entropy one obtains expressions for particle density, energy density and pressure.

In the grand canonical ensemble the particle number, energy density and pressure are given by

$$\begin{aligned} N &= gV \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E-\mu}{T}\right), \\ \epsilon &= g \int \frac{d^3p}{(2\pi)^3} E \exp\left(-\frac{E-\mu}{T}\right), \\ P &= g \int \frac{d^3p}{(2\pi)^3} \frac{p^2}{3E} \exp\left(-\frac{E-\mu}{T}\right), \end{aligned}$$

where T and μ are the temperature and the chemical potential, V is the volume and g is the degeneracy factor.

Consider a quantum system with state (Hilbert) space H. For simplicity, let the Hamiltonian H of the system have discrete spectrum so that there exists a basis $|n\rangle$ with $n=0,1,2,\ldots$ for the state space consisting of eigenvectors of the Hamiltonian. Let ϵn denote the energy corresponding to each eigenvector $|n\rangle$, namely$H|n\rangle=\epsilon n|n\rangle$Now, it may happen that one or more of the energy eigenvectors $|n\rangle$ have the same energy. In this case, we say that their corresponding shared energy eigenvalue is degenerate. It is therefore often convenient to have a the concept of the energy levels Ej of the system which are simply defined as the sequence of distinct energy eigenvalues in the spectrum of the Hamiltonian. So, whereas one can have $\epsilon n=\epsilon m$ if $n\neq m$, one cannot have $En=Em$ if $n\neq m$. Moreover, it is often convenient to label the energy levels in increasing index order so that $Em<En$ whenever $m<n$.

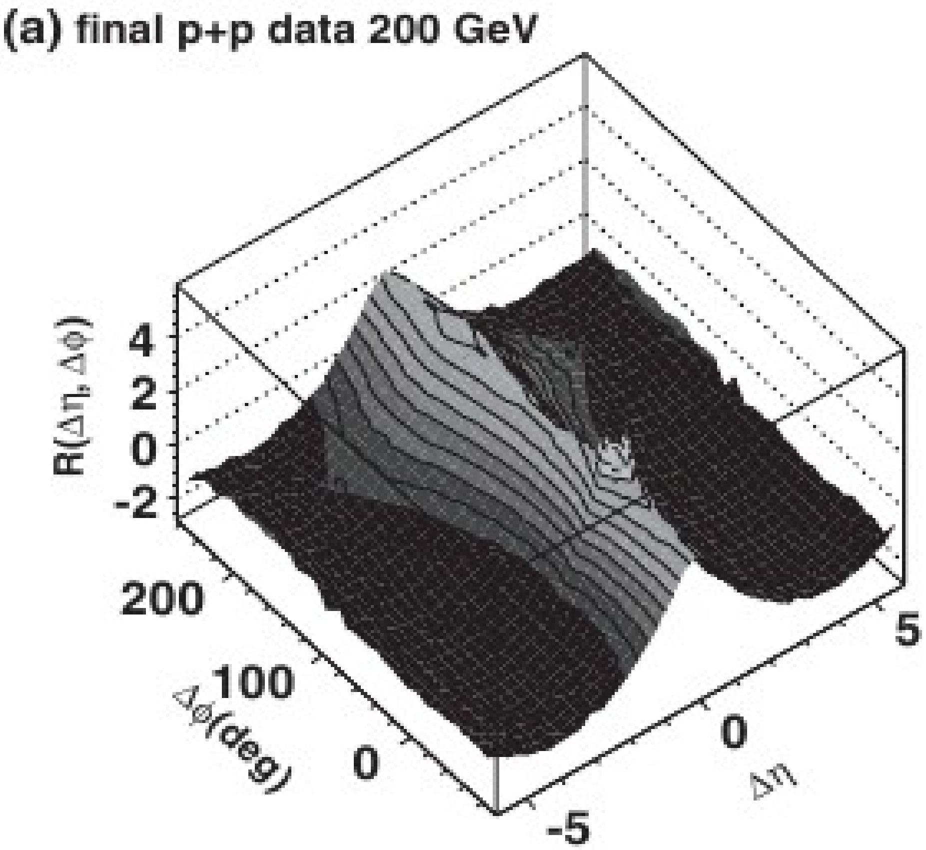
The degeneracy gn of the energy level En is defined as the number of distinct energy eigenvalues $\epsilon m$for which $\epsilon m=En$. For simplicity, we assume that none of the levels is infinitely degenerate so that $gn\geq 1$ is integer for all n.

The partition function of a system in the canonical ensemble is given by$Z=\sum ne-\beta\epsilon n$In other words, the sum is over the state labels, not over the energy levels. However, noting that whenever there is degeneracy, sum of the terms in the sum will be the same, we can rewrite the partition function as a sum over levels$Z=\sum ngne-\beta En$The degeneracy factor is precisely what counts the number of terms in the sum that have the same energy.

As for a simple example, consider a system consisting of two, noninteracting one-dimensional quantum harmonic oscillators. The eigenstates of this system are $|n1,n2\rangle$ where $n1,n2=0,1,2,\ldots$ and the corresponding energies are$\epsilon n1,n2=(n1+n2+1)\hbar\omega$.The canonical partition function is given by$Z=\sum n1,n2=0\infty e-\beta\epsilon n1,n2=e-\beta\hbar\omega$(C)(D)(B)(A)(E)(E)$n1=0,n2=0+e-\beta(2\hbar\omega)$(C)(D)(B)(A)(E)(E)(E)(E)$n1=1,n2=0+e-\beta(2\hbar\omega)$(C)(D)(B)(A)(E)(E)(E)(E)$n1=0,n2=1+\cdots$If you think about it for a moment, you'll notice that, in fact, the energy levels of this composite system are$En=n?\omega,n1+n2=n$and that the degeneracy of the nth energy level is$gn=n$so that the partition function can also be written in the form that uses energy levels and degeneracies as follows:$Z=\sum n=1\infty gne-\beta En=e-\beta\hbar\omega$(C)(D)(B)(A)(E)(E)$n=1+2e-\beta(2\hbar\omega)$(C)(D)(B)(A)(E)(E)(E)(E)(E)(E)$n=2+3e-\beta(3\hbar\omega)$(C)(D)(B)(A)(E)(E)(E)(E)(E)(E)$n=3+\cdots$

Ridge @ 200 GeV

PHYSICAL REVIEW C **75**, 054913 (2007)



$3 < |\eta| < 4.5$

$-180^\circ < \varphi < 180^\circ$

5×10^5 200-GeV and 8×10^5 410-GeV p+p events

$|z_{vtx}| < 10$ cm along the beam axis.

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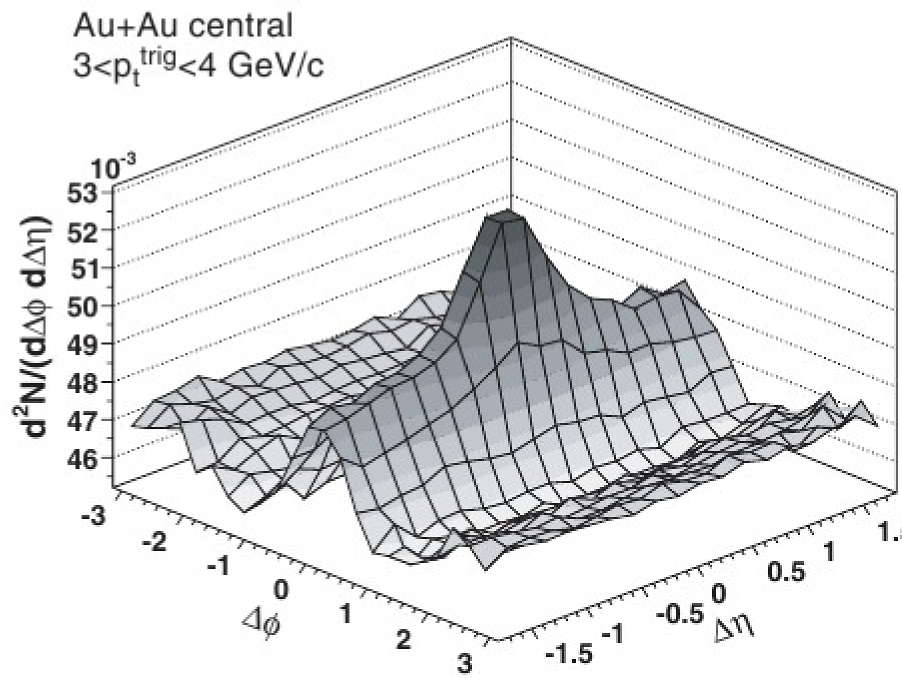

2 GeV/c $< p_T^{assoc} < p_T^{trig}$