Hadron production spectra in Collider Experiments

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There exists a large body of high precision experimental data on hadron production in high energy particle collisions.

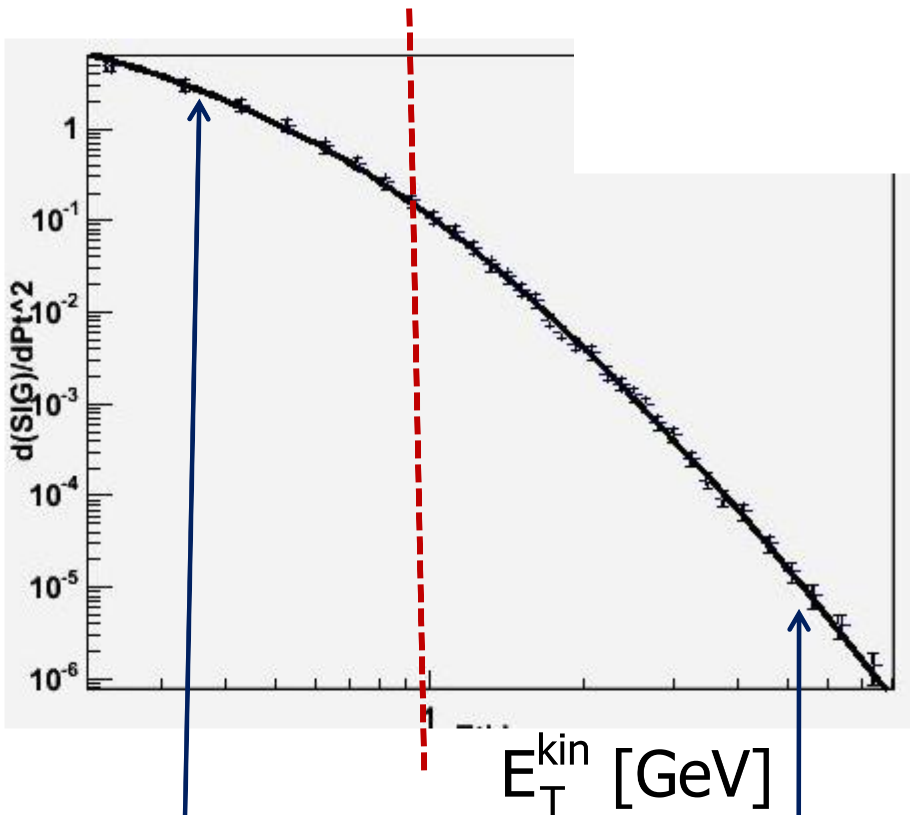
Collisions	Energy Range	Experiments
Proton – Proton	23 – 2360 GeV	ISR, SppS, CDF, CMS
Gamma - Proton	200 GeV	H1, ZEUS, Omega
Gamma - Gamma	100 GeV	Opal, L3
DIS	120 – 213 GeV $7 < Q^2 < 28$ GeV^2	H1, ZEUS
Aurum - Aurum	200 Gev	RHIC

Transverse Momentum Spectra of Charged Particles

(Differential Invariant Cross-Section)

$$E\frac{d^3\sigma}{d^3p}(y\approx 0)=\frac{A}{(1+\frac{E_T^{kin}}{T\cdot N})^N}$$

$$E_T^{kin}=\sqrt{p_T^2+m_\pi^2}-m_\pi$$



Nonperturbative thermodynamics

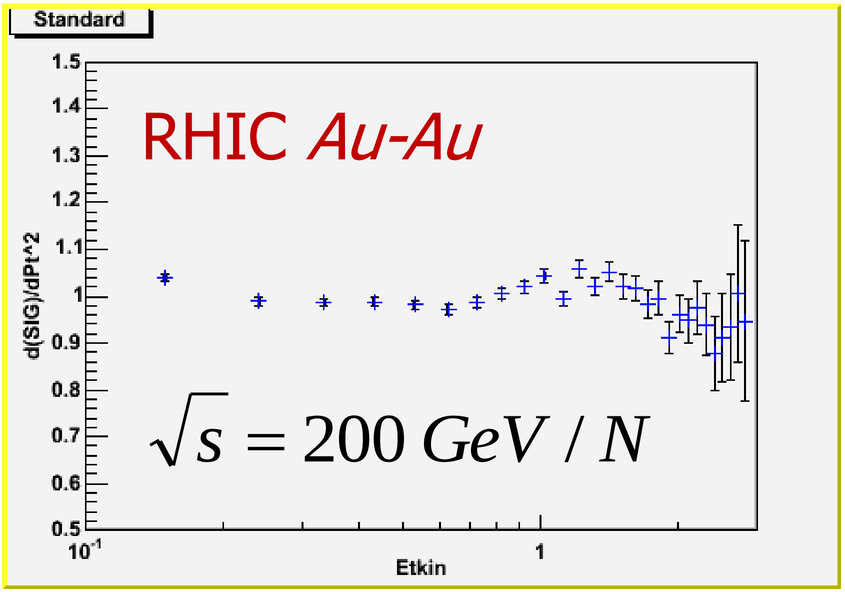
pQCD

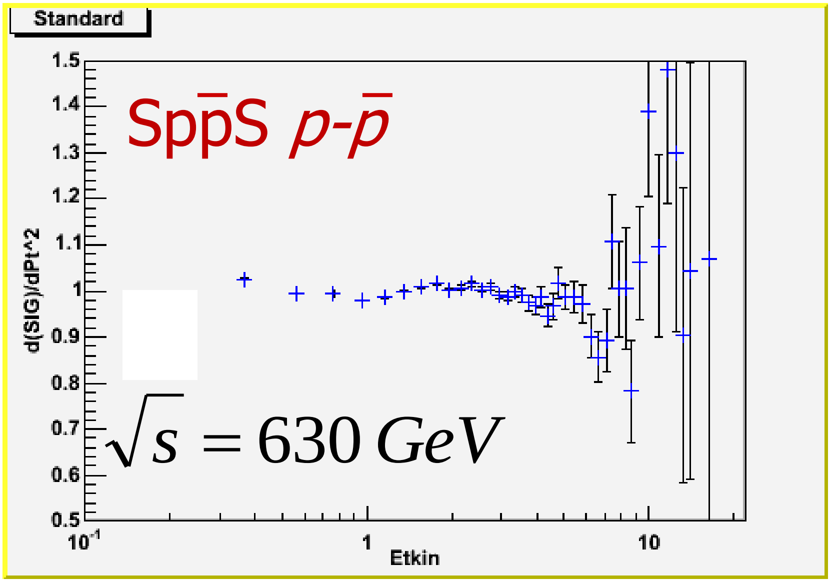
A single smooth Tsallis-type function for the whole kinematical region

A common statistical distribution in the Nature.

Does Tsallis-type power law distribution really describe the hadron production spectra?

To answer this question let's plot a ratio = data / fit function





On both plots one observes a shallow dip at $E_{\mp}$ values below 1 GeV followed by a broad bump above 1 GeV.

These defects are hidden on usual logarithmic plots!

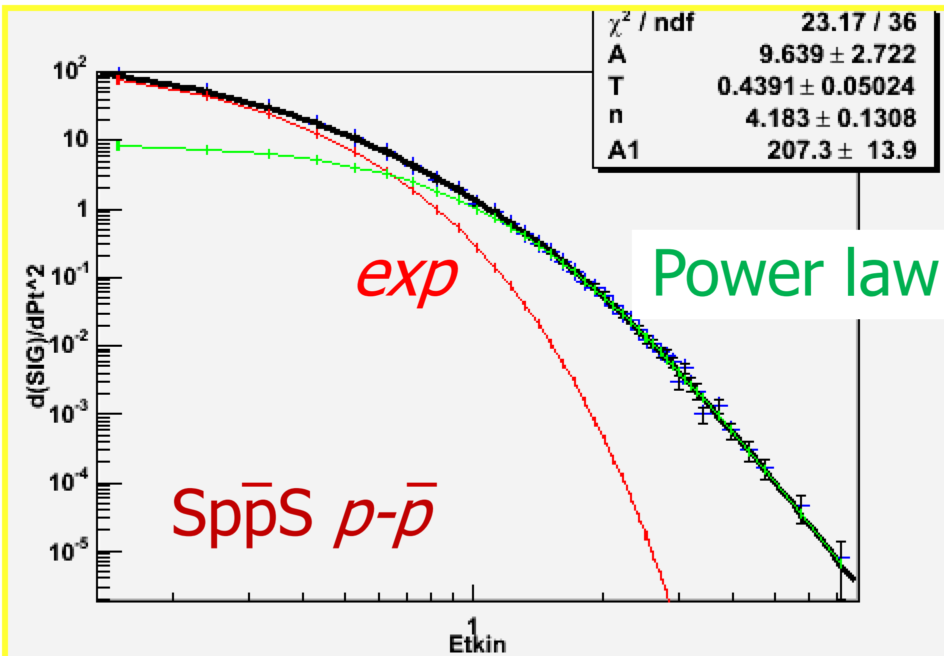
Observed systematic defects require to modify the fit function

A modification of the Tsallis function

Take two contributions: Exponential + Power law functions

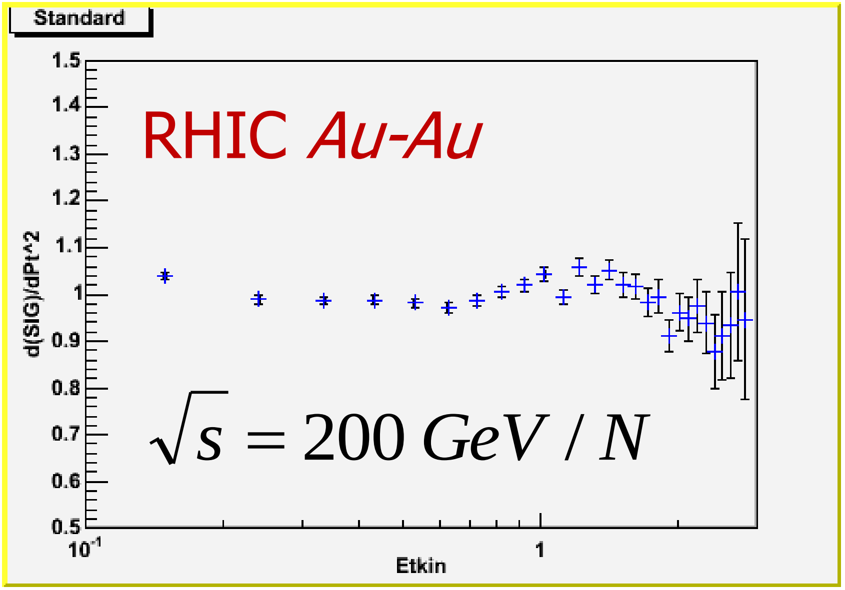
Generalized forms: $\exp(-F(P_T)/T_e)$ $1/(1+F'(P_T)/TN)^N$

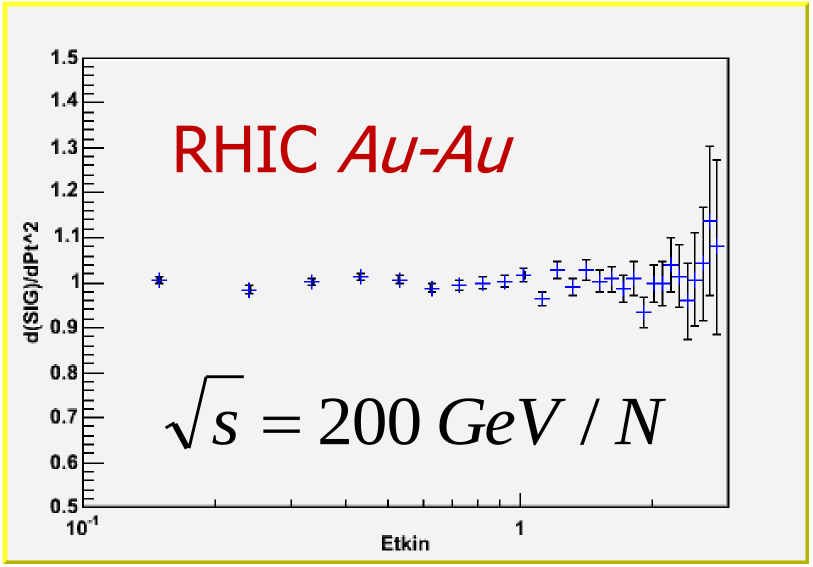
With scalar $F, F' = P_T^2$ or E_T^{kin} (not P_T or P_T^3)

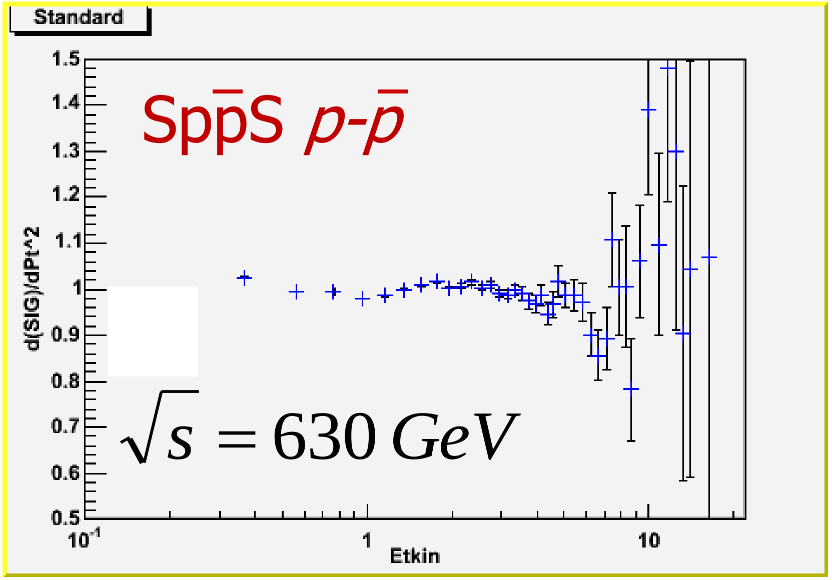


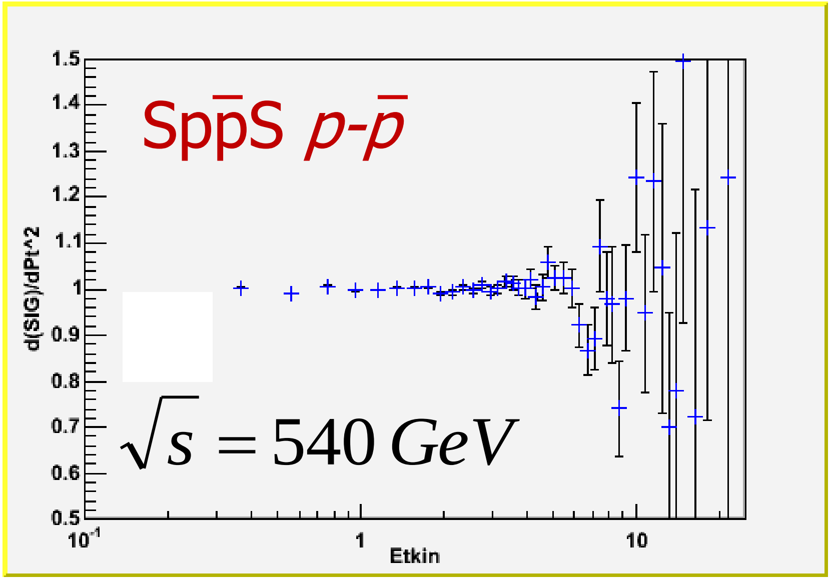
The best fits are given by $A_e \cdot \exp(-E_T^{kin}/T_e) + A/(1+P_T^2/TN)^N$

Look back at the Ratios = data / fit function





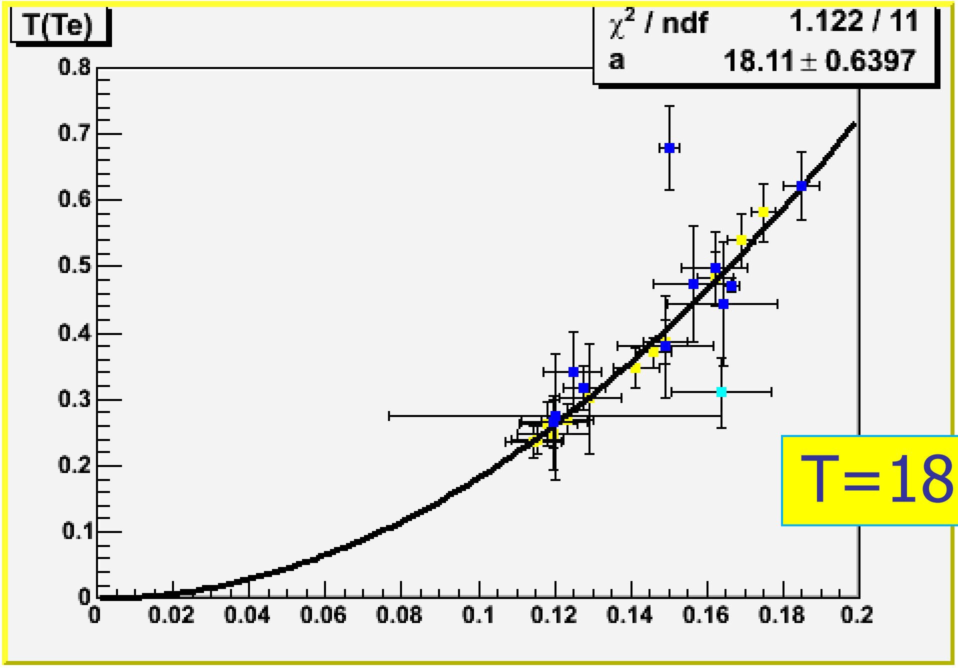




A strong correlation between the fit-function parameters

Fit-function: $$A_e \cdot \exp(-E_T^{kin} / T_e) + A/(1 + P_T^2 / TN)^N$$

T [GeV^2]



$T = 18.11 T_e^2$

T_e [GeV]

The observed correlation might indicate that the exponential and power law terms are integral parts of more complicated function describing the statistical distribution.

Modified spectrum fit-function. Interpretation.

Exponential term – “thermolized” hadrons, or a hadronic cloud accompanying the interactions. Boltzmann-type.

Power-law term – originates from partonic hard interactions?

The modified function could be rewritten as:

$$\frac{d\sigma}{dP_T^2}(y \approx 0) = A_e \cdot \exp(-E_T^{kin}/T_e) + A/(1+P_T^2/TN)^N =$$

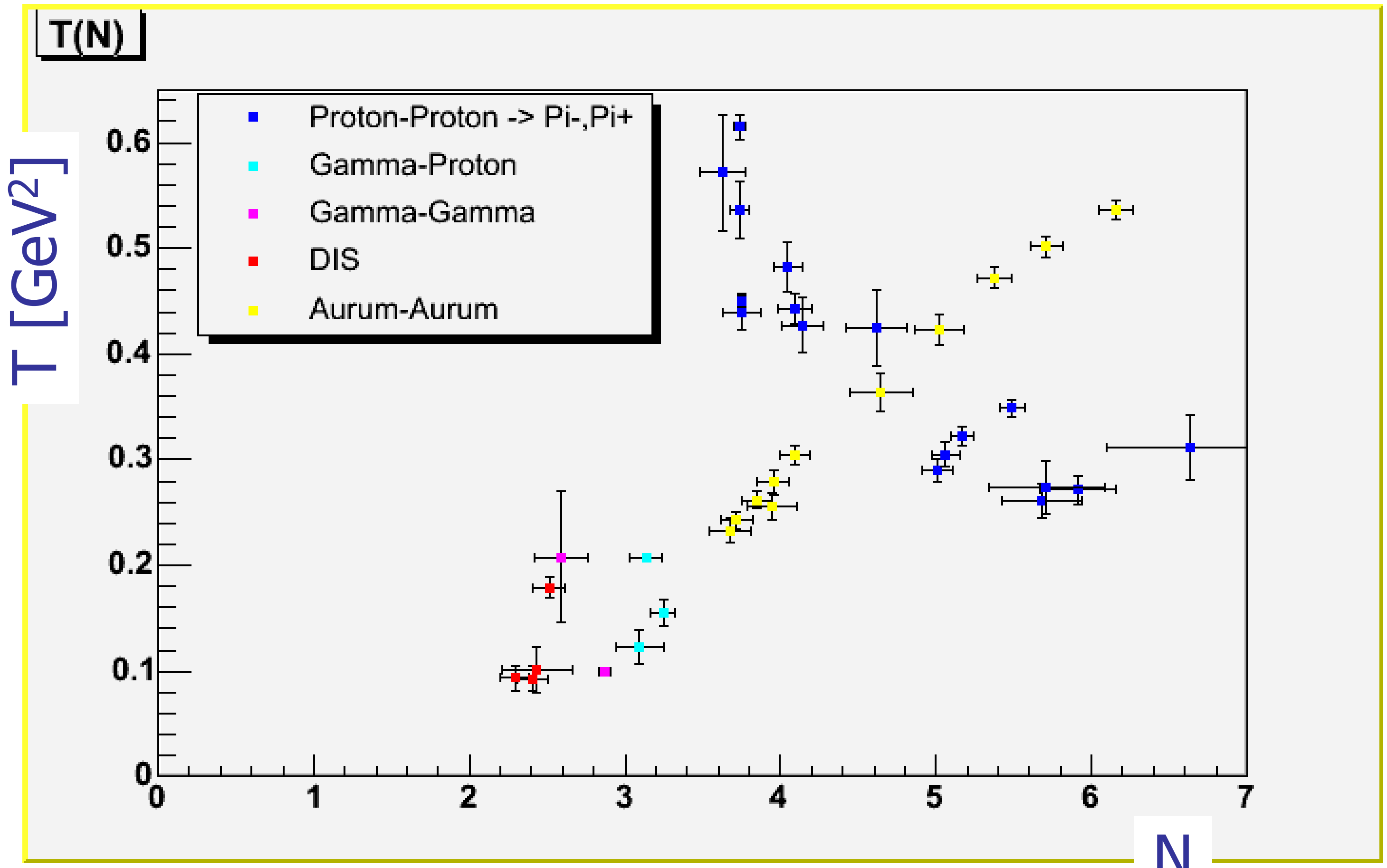
$$= A_e \cdot \exp(-\varepsilon) + A/(1+\varepsilon^2/bN)^N$$

$$with \quad \varepsilon = \frac{E_T}{T_e}$$

The fit-function parameter map

$$\frac{d\sigma}{dP_T^2} = A_e \cdot \exp(-E_T^{kin} / T_e) + A/(1 + P_T^2 / TN)^N$$

T=18.11T_e^2



Observations made with the fit parameter map

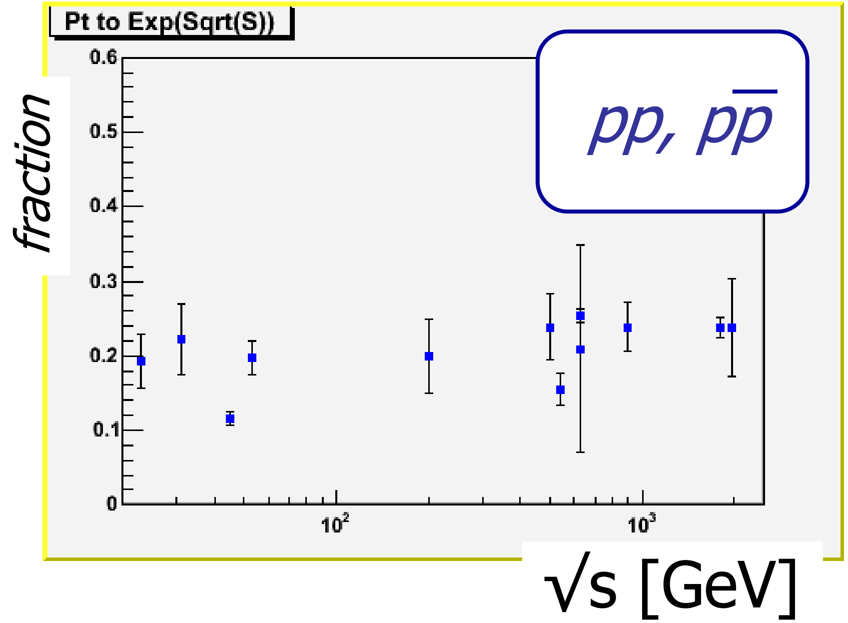
1. There are two distinct trends:
   - with change of $\sqrt{s}$ in pp
   - for different colliding particles and fixed $\sqrt{s}$
2. The two trends cross each other in a point
   - with $\sqrt{s}$ = 200 GeV in pp and Au-Au
   - for minimum bias centrality in Au-Au
3. DIS, γp, $\gamma\gamma$ sit on the same band as Au-Au with different centralities and look similar to very peripheral Heavy Ion interactions

Surprise:

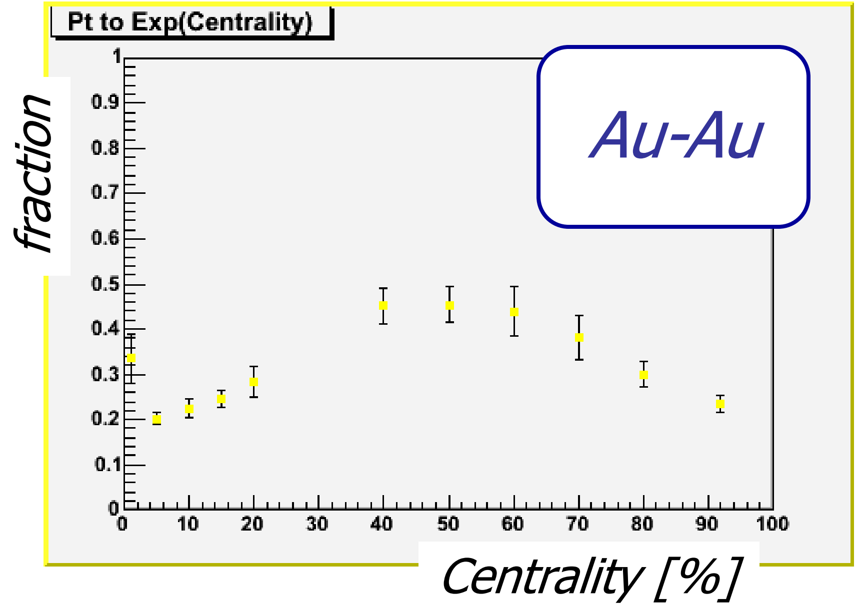
Heavy Ion low centrality (multiplicity) presumably very peripheral interactions differ significantly from single pp-interactions and at the same time are "close relatives" of interactions with photons.

Further observations: relative contributions of the exponential and power-law terms in the spectra

Power law term fraction in pp spectra as function of √s

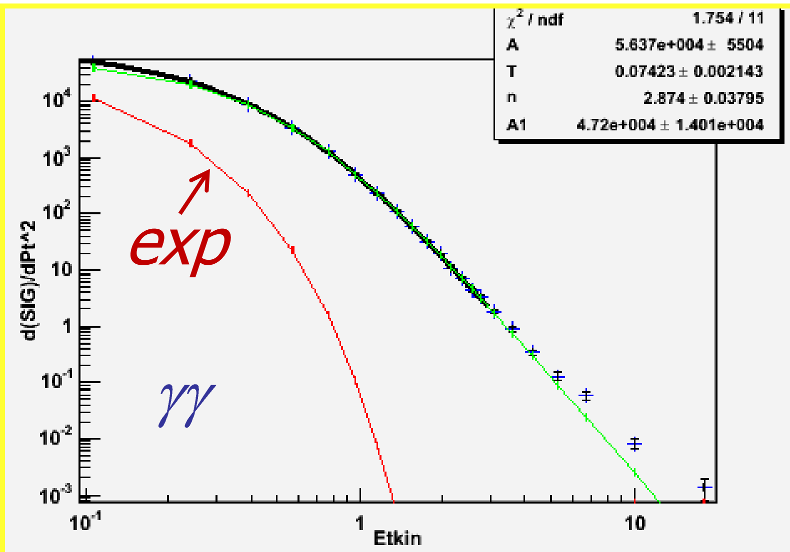


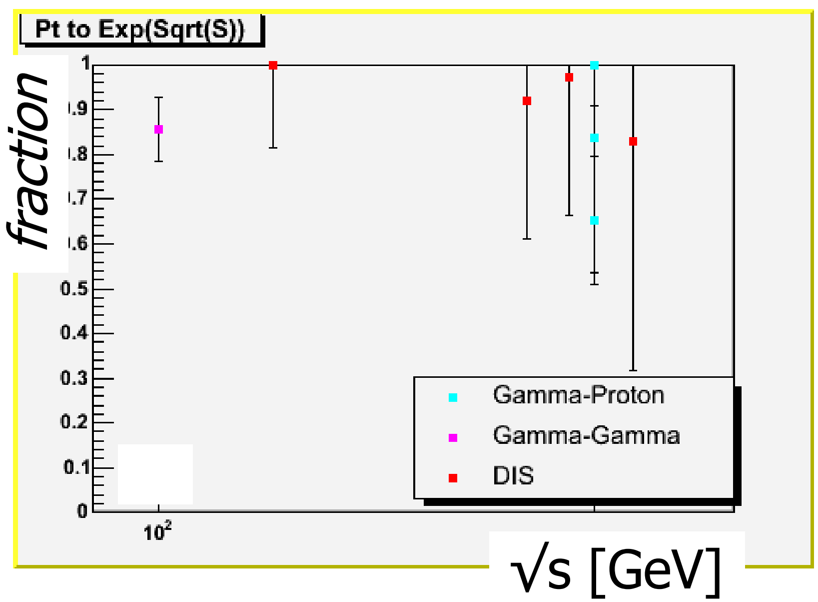
Power law term fraction as function of centrality in Au-Au at √s=200 GeV



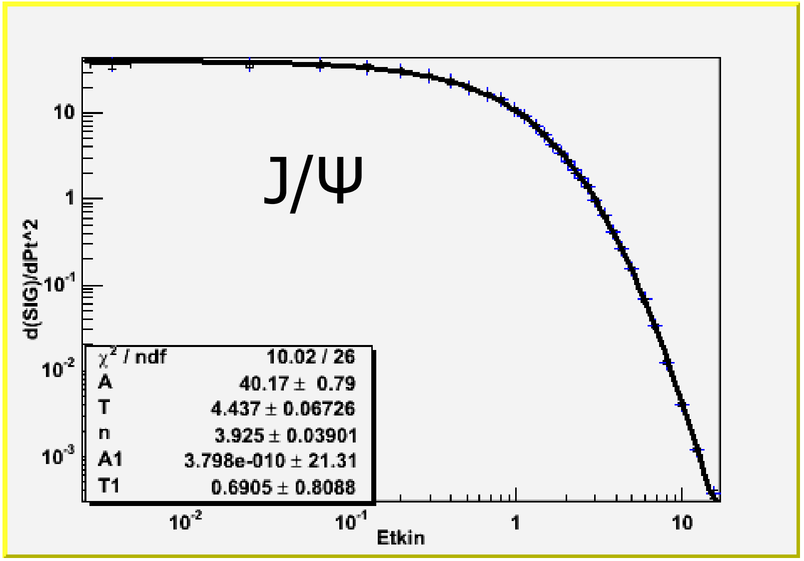
- In pp interactions: exp / power-law ≈ 4 independent of √s
- Power-law fraction has maximum at mid centralities in Heavy Ion int.
- What is about "point-like" ineractions?

In DIS, γp, γγ the power-law contribution dominates (~100%)

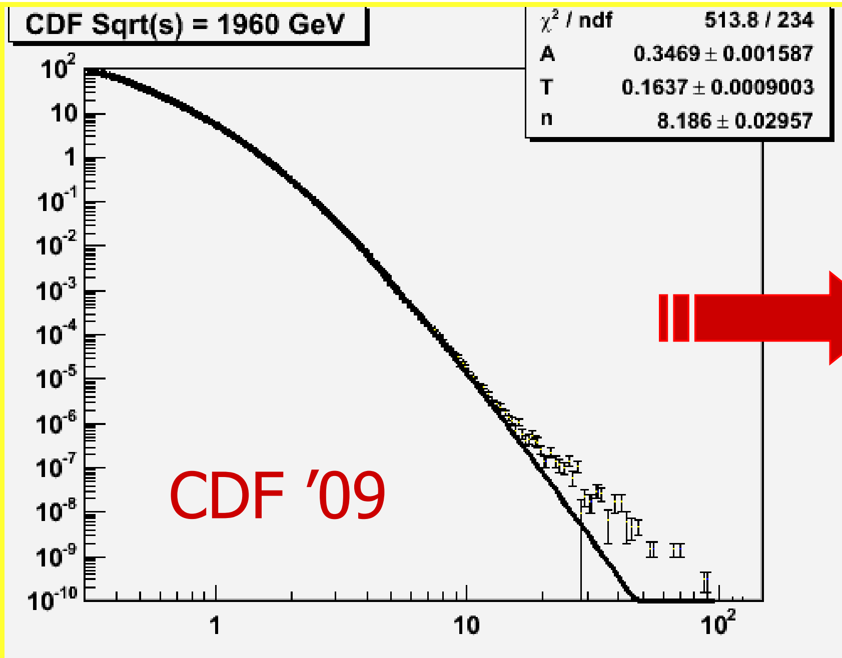


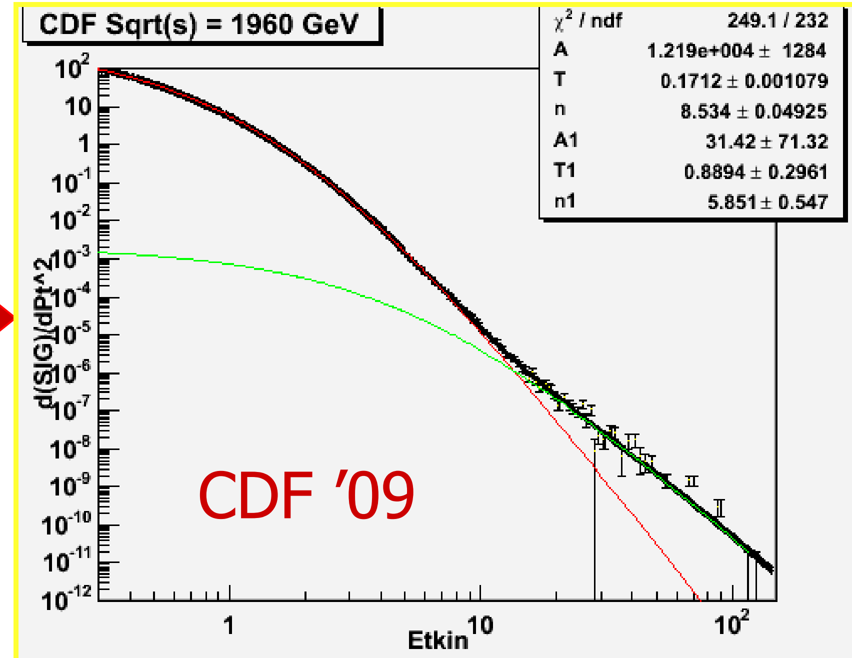


Inclusive J/Ψ production doesn't leave any room for the exponential term in the spectrum shape



More surprises in high-Pt data





χ^2/ndf = 513.8/234

χ^2/ndf = 249.1/232

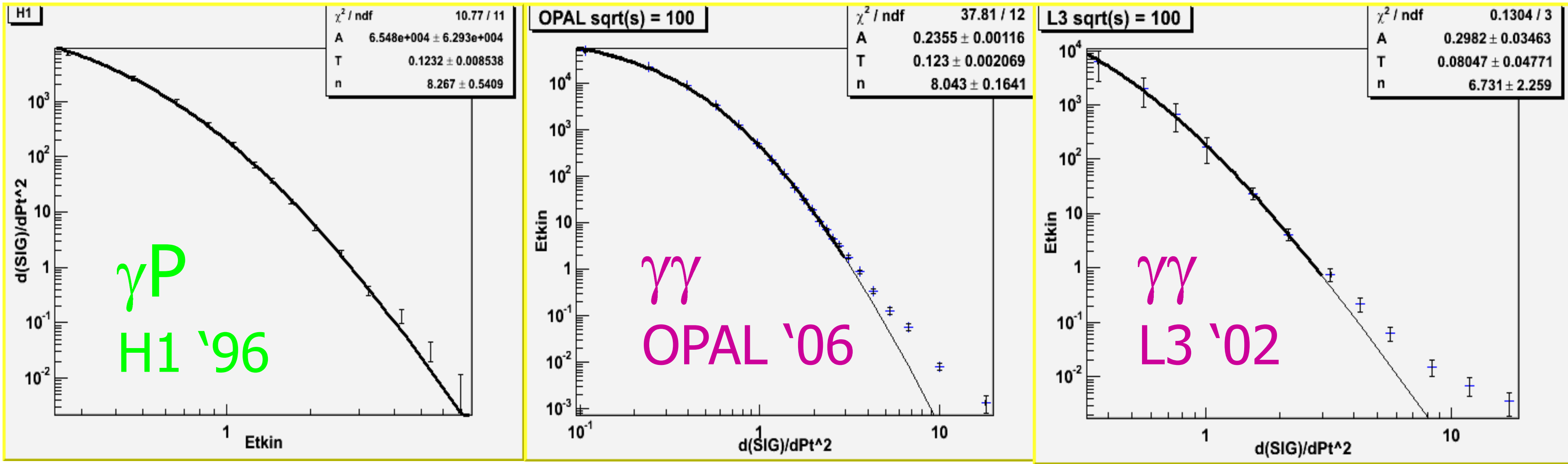
$$\frac{d\sigma}{dP_T^2} = A_1 \cdot (1 + E_T^{kin} / T_1 / N_1)^{N_1} + A_2 \cdot (1 + E_T^{kin} / T_2 / N_2)^{N_2}$$

$$A_1 / A_2 \approx 10^3; \quad T_1 = 0.17 \;\; T_2 = 0.89\, GeV; \quad N_1 = 8.5 \; N_2 = 5.8$$

For P_T > 80 GeV is of order of inclusive jet cross section

Only at CDF?

The onset of high-Pt power-law tail in gamma collisions



The onset of the high-P_T power-law term is visible for:

$P_T > 10$ GeV in pp - collisions

$P_T > 4$ GeV in γp - collisions

$P_T > 3$ GeV in $\gamma\gamma$ - collisions

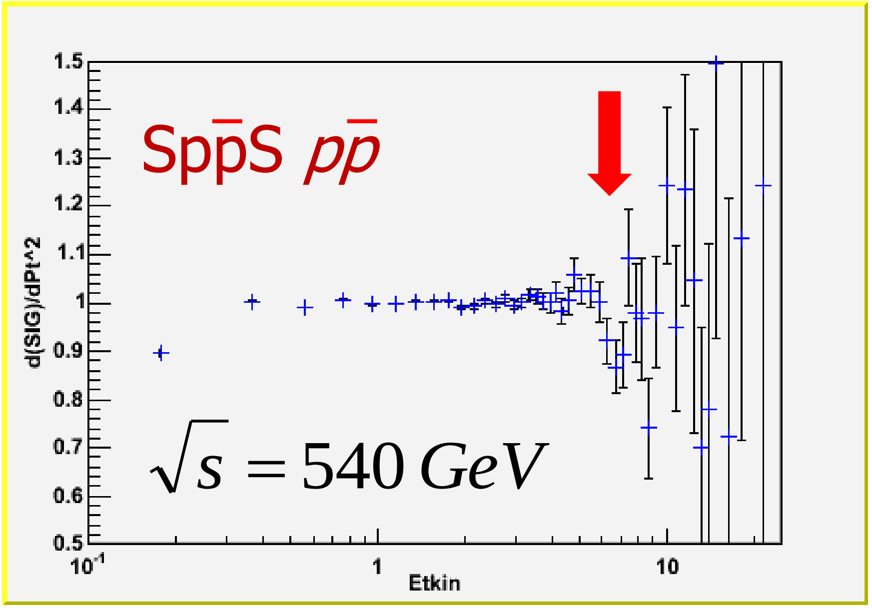
Disagreement with CDF jet spectrum & Fragmentation (A.S.Yoon et al)

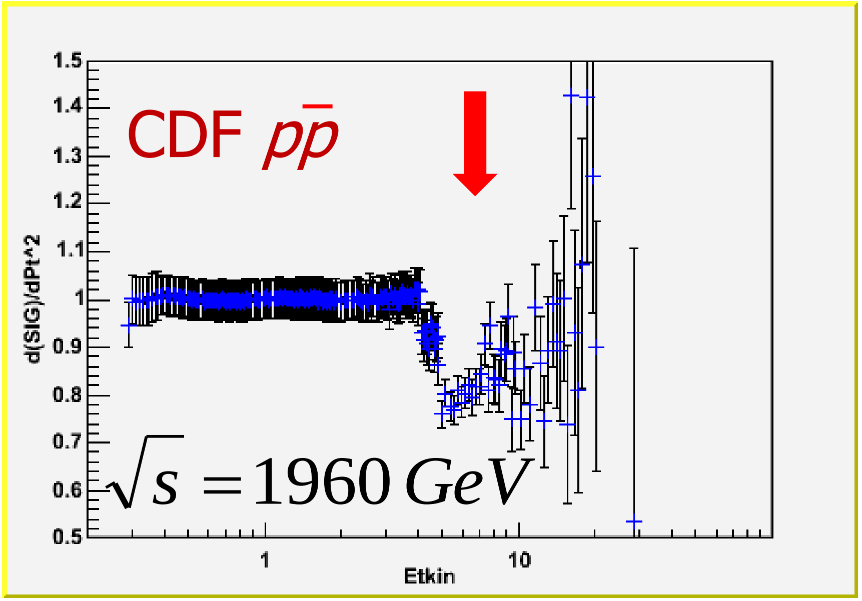
Two different regimes for charged hadron production?

Diffraction-type dips in the inclusive particle spectra?

Provocative examples of the data to fit ratio:

The only two accurate sets of *pp*-data extended to high P_T





Looking forward to see the LHC (7 GeV) spectra soon.

Conclusions:

- the large body of high precision data on hadron production in collider experiments allow systematic measurements of the fine details of the spectra shape;
- a simple power law type statistical distribution (Tsllis, kappa, Levy,…) provides a good approximation, but fail to describe the details of spectra shape both al low and high Pt;
- a modified statistical distribution is proposed
- despite the hadron spectra have been studied for decades, there is a number of puzzles to be solved:

1. *Hadron production parameter map*
2. *High PT tails*
3. *Dips*

Wanted:

High statistics LHC charged particle spectra.