x_T scaling in Au+Au collisions at $\sqrt{s_{NN}}$=130 and 200 GeV for π^0 and charged hadrons from PHENIX

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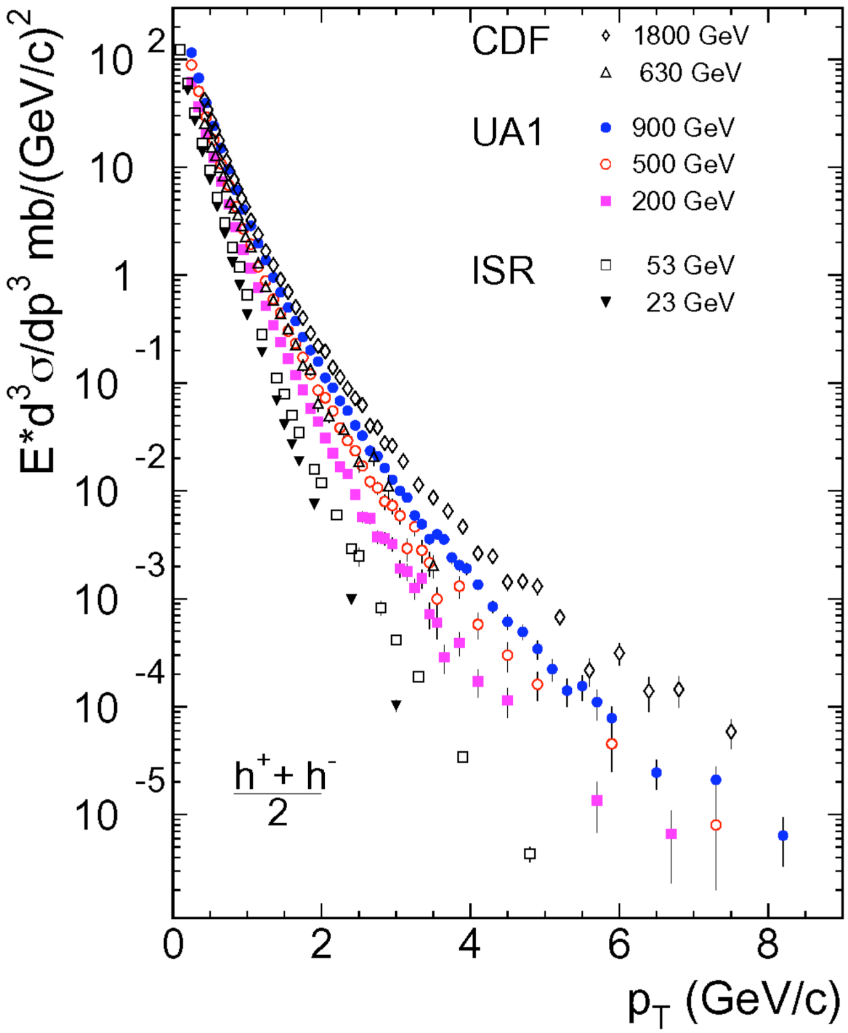
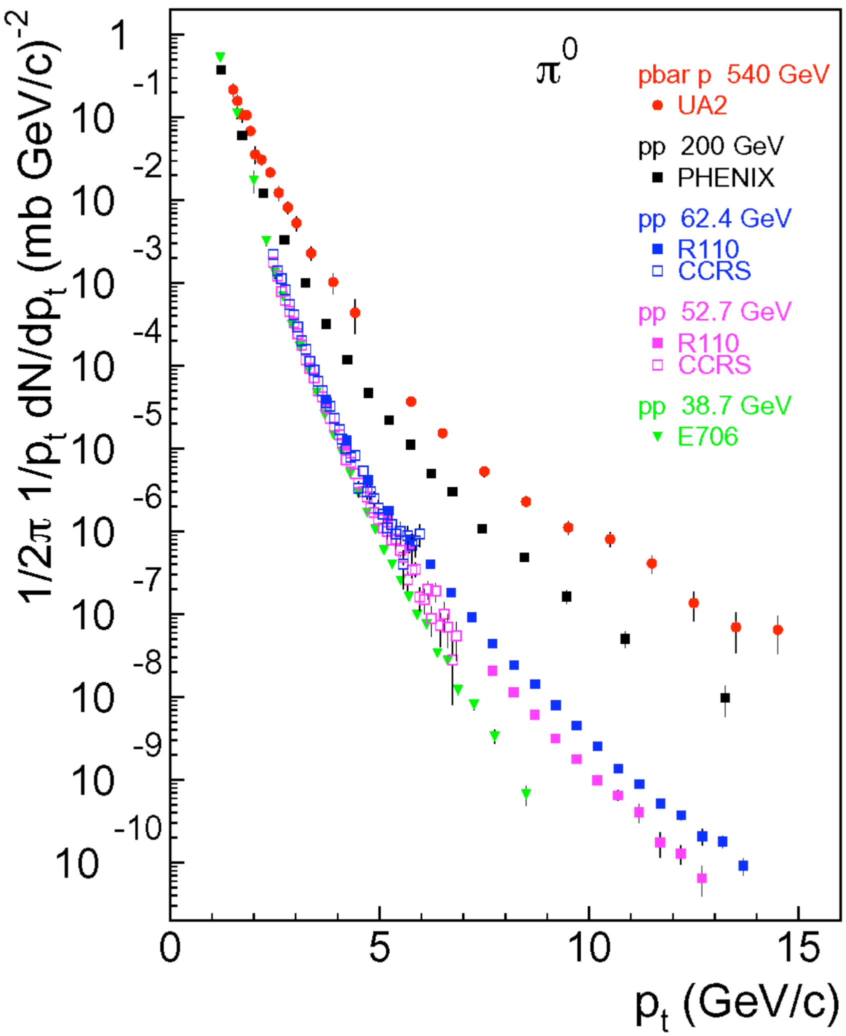
Inclusive single hadron high p_T spectra in p-p all s





The invariant cross section for the single-particle inclusive reaction $p + p \rightarrow C + X$ where particle C has transverse momentum p_T near mid-rapidity, was given by the general scaling form [54]:

$$\boxed{E\frac{d^3\sigma}{dp^3} = \frac{1}{p_T^n} F\left(\frac{2p_T}{\sqrt{s}}\right) \quad \text{where} \quad x_T = 2p_T/\sqrt{s}}$$

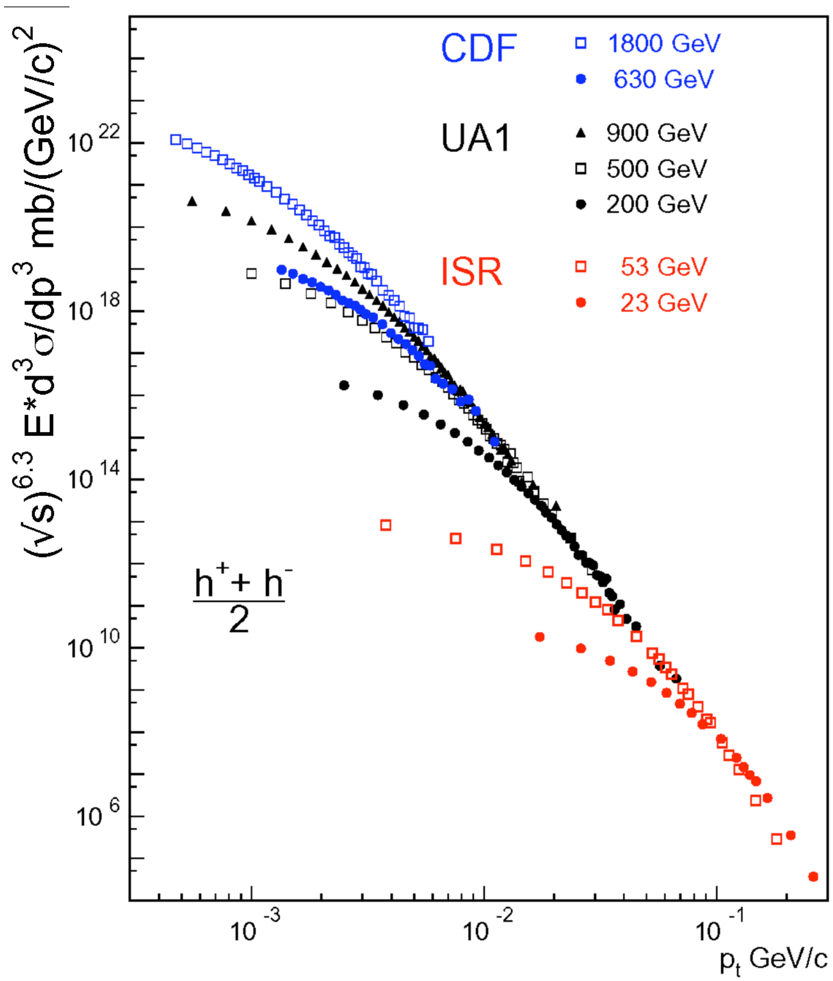
There are 2 factors: a function F which depends only on the ratio of momenta, and a dimensioned factor, p_T^{-n}, where n depends on the quantum exchanged in the hard-scattering. For QED or Vector Gluon exchange [53], $n = 4$. For the case of quark-meson scattering by the exchange of a quark [54], n=8.

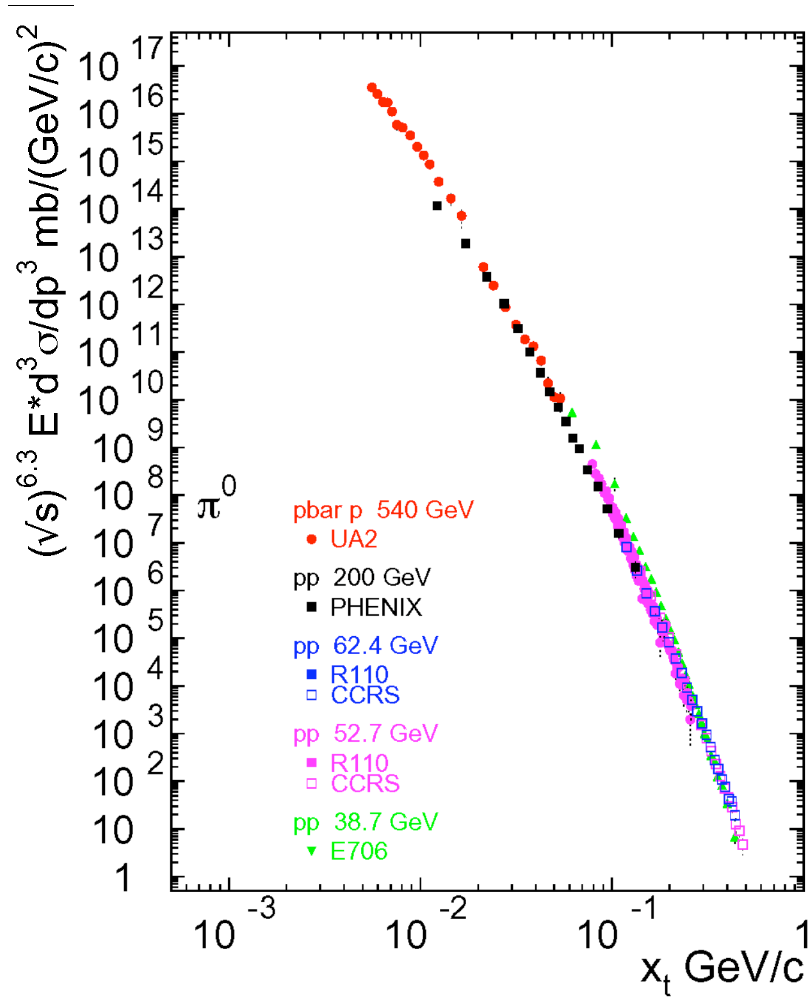
Inclusion of QCD [58] into the scaling form led to the x_T-scaling law

$$\boxed{E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^{\,n(x_T,\sqrt{s})}} G(x_T)}$$

where the "x_T-scaling power" $n(x_T, \sqrt{s})$ should equal 4 in lowest order (LO) calculations, analogous to the $1/q^4$ form of Rutherford Scattering in QED. The structure and fragmentation functions, which scale as the ratios of momenta are all in the $G(x_T)$ term. Due to higher order effects such as the running of the coupling constant, $\alpha_s(Q^2)$, the evolution of the structure and fragmentation functions, and the initial state k_T, measured values of $n(x_T, \sqrt{s})$ in $p + p$ collisions are in the range from 5 to 8.

x_T scaling in p-p collisions x~0.05-0.10



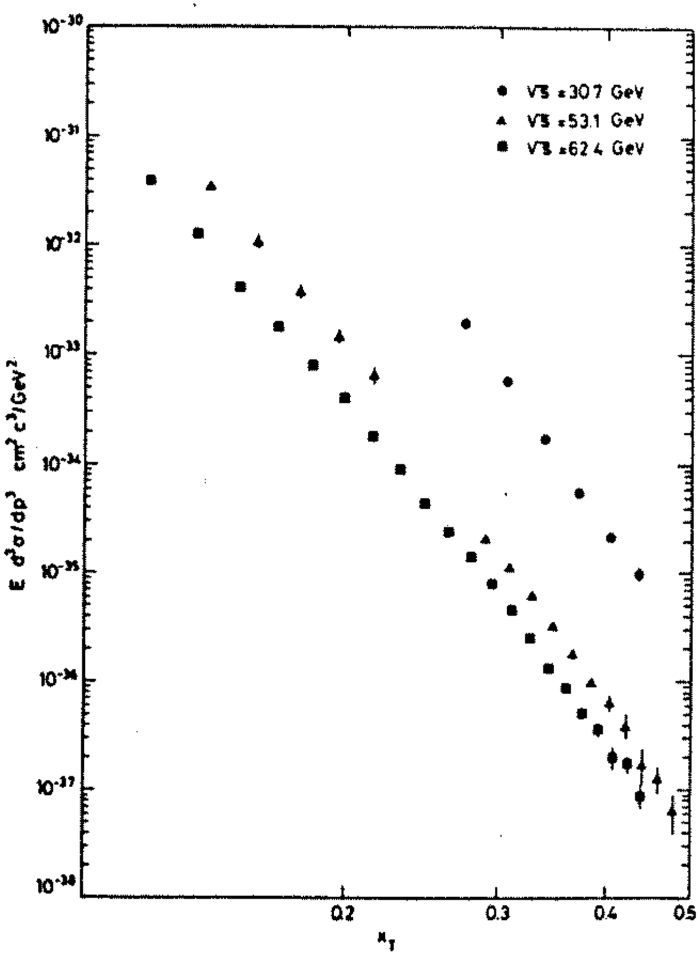


The x_T-scaling of the single particle inclusive data is nicely illustrated by a plot as a function of x_T, with $n(x_T, \sqrt{s}) = 6.3$ of:

$$\sqrt{s}^{\,n(x_T,\sqrt{s})} \times E\frac{d^3\sigma}{dp^3} = G(x_T)$$

n(x_T,   s~60 GeV) WORKS, n□ 5=4^{++}

Invariant cross section plotted vs x_T=2p_T/ s p-p collisions



Calculate n from ratio of Invariant cross sections at fixed x_T

n=5.1± 0.4
including all systematic errors

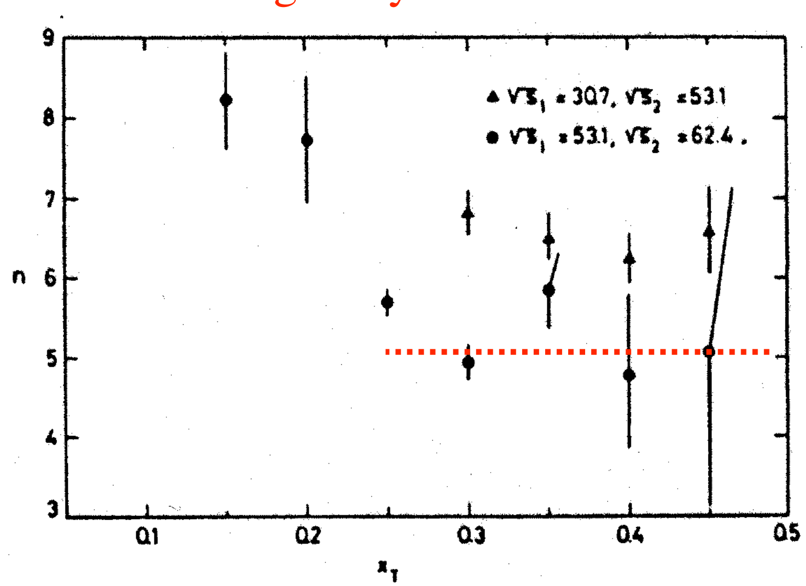
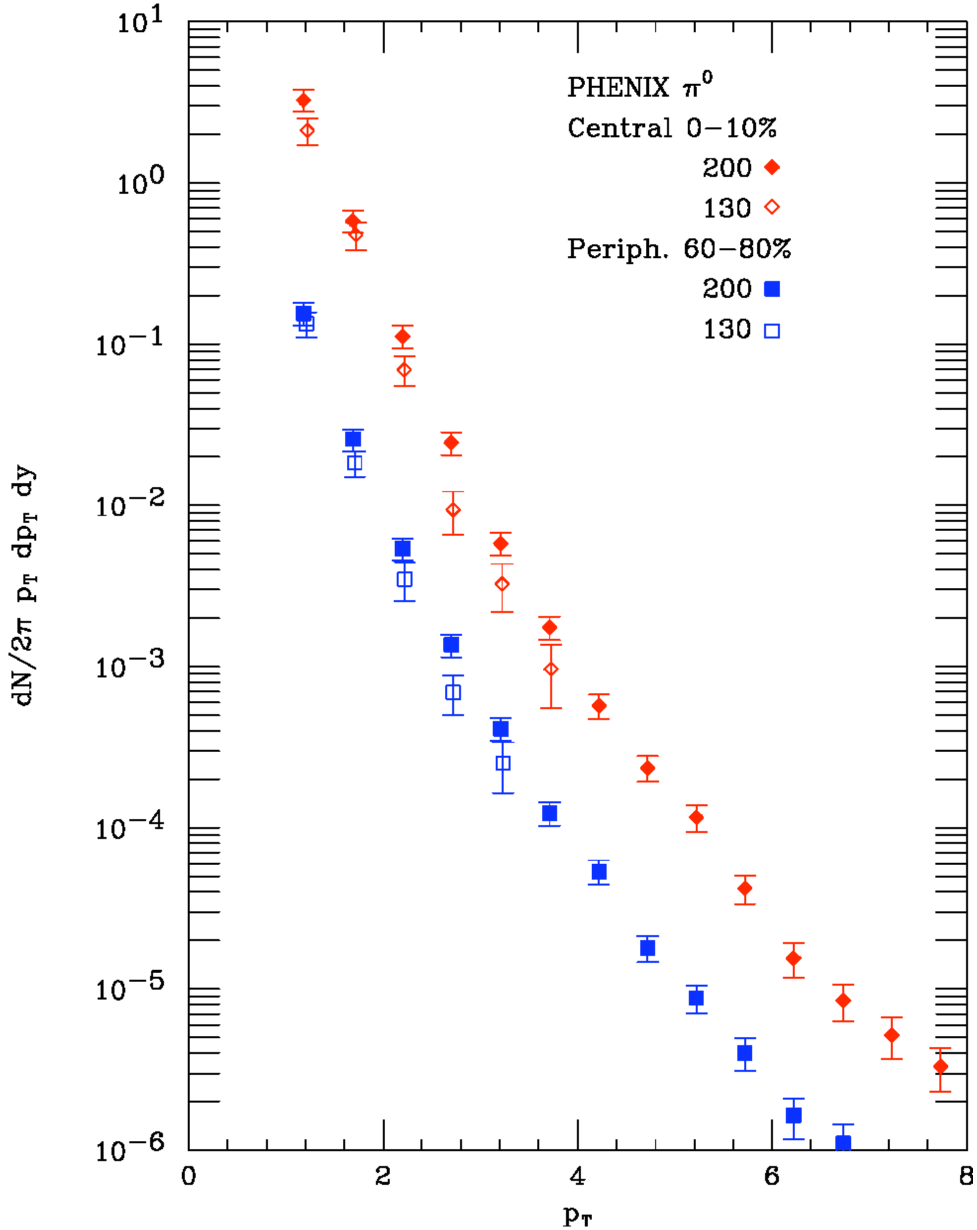


Figure 5: Left: CCOR invariant cross section vs x_T=2p_T/ s. Right: n(x_T,   s) derived from the combinations indicated. *The systematic normalization at   s=30.6 has been added in quadrature. Note that the absolute scale uncertainty cancels!*



PHENIX Semi-Inclusive π_0

$\boxed{\text{Au+Au}}$

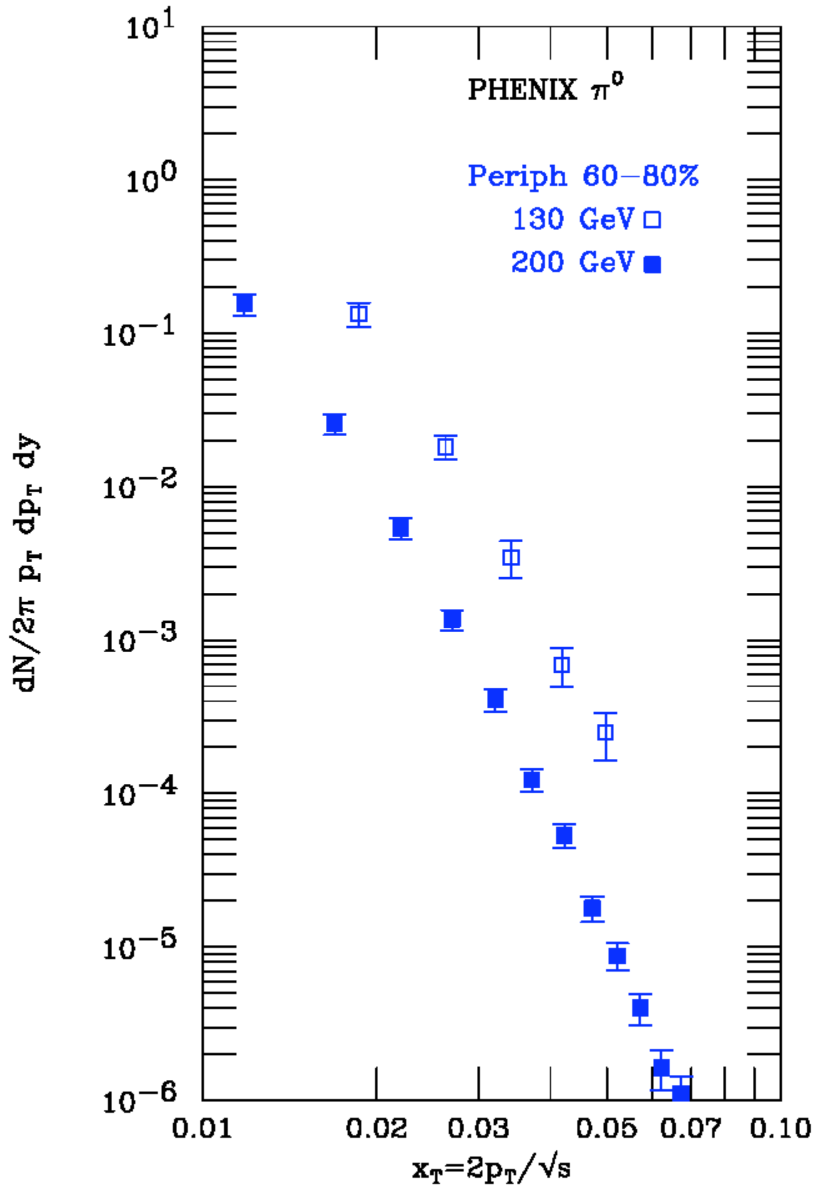
s_{NN}=130 and 200 GeV

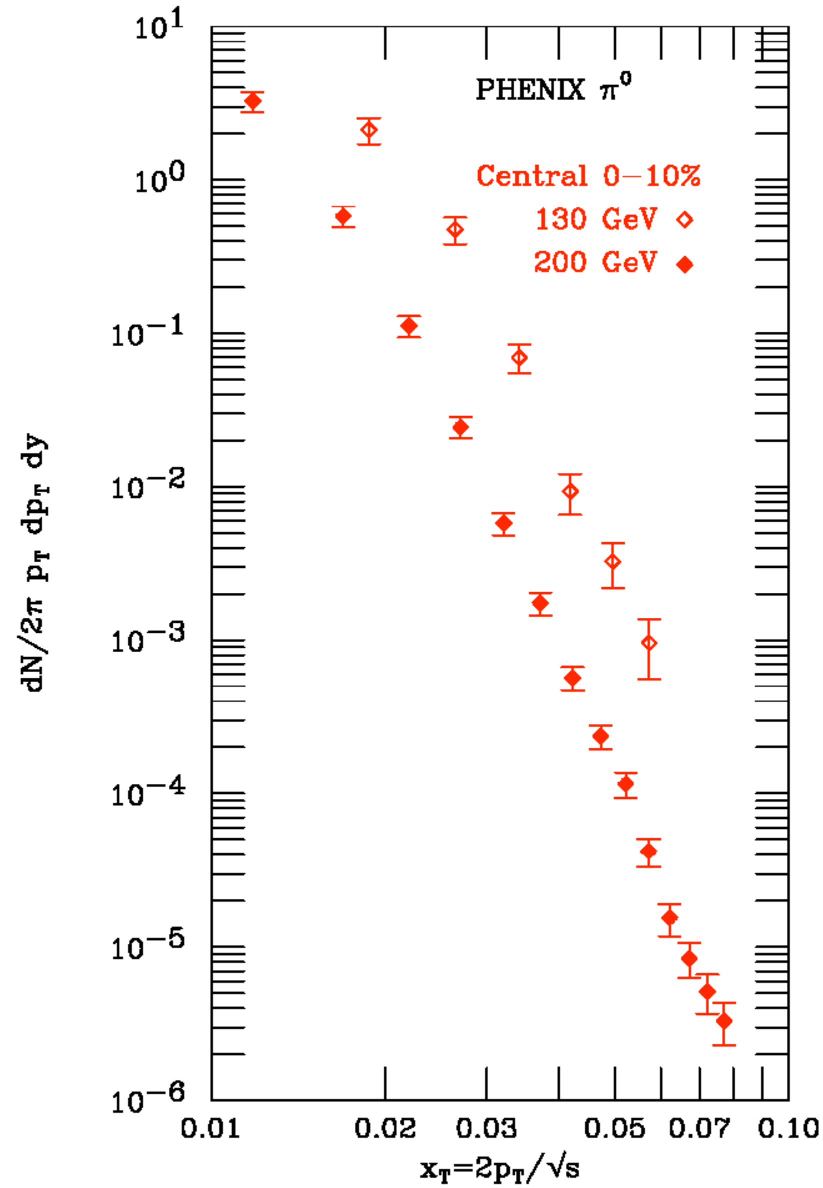
vs p_T

Peripheral 60 -- 80%

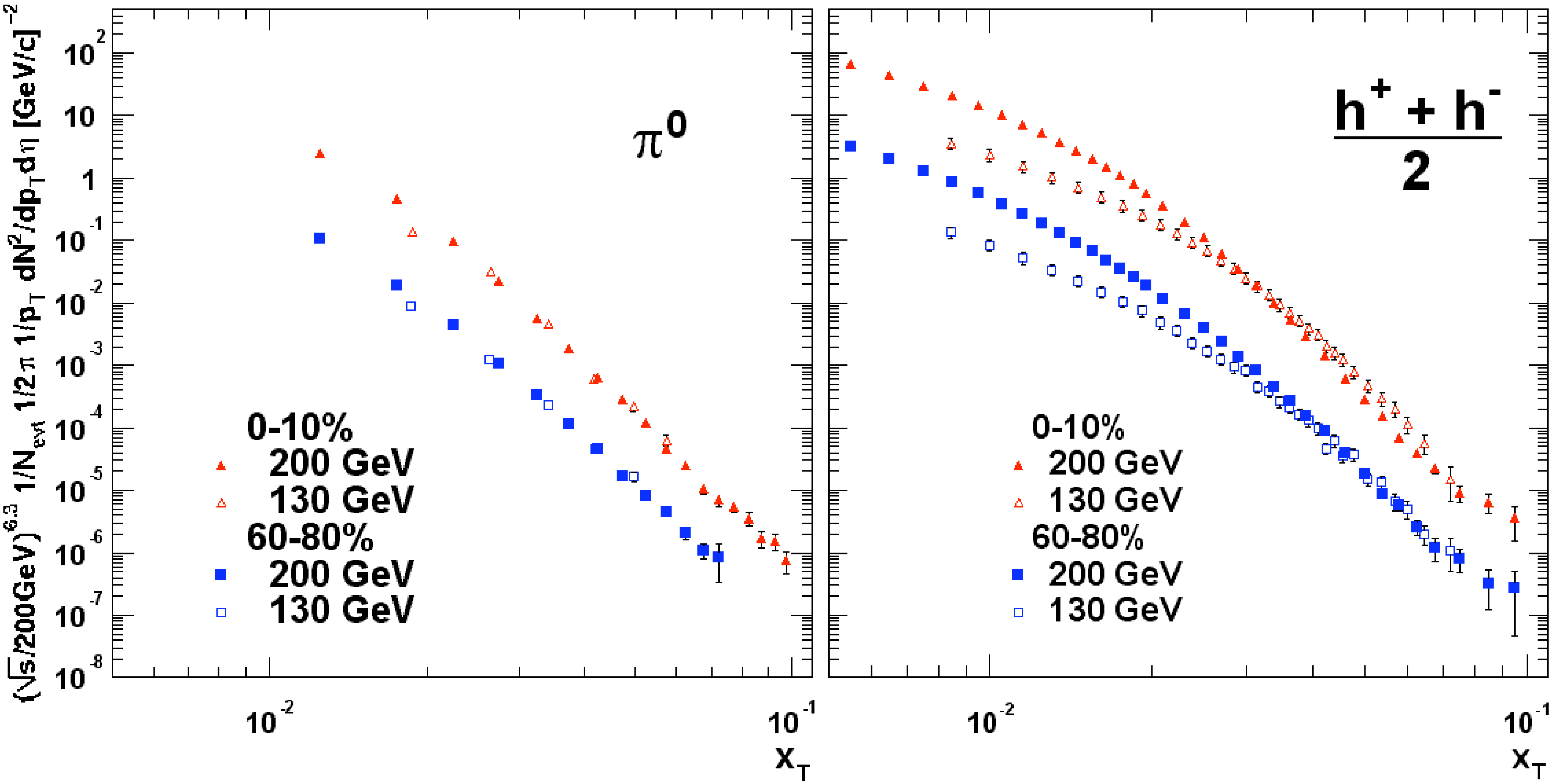
Central 0-10%

Same data vs x_T on log-log plot





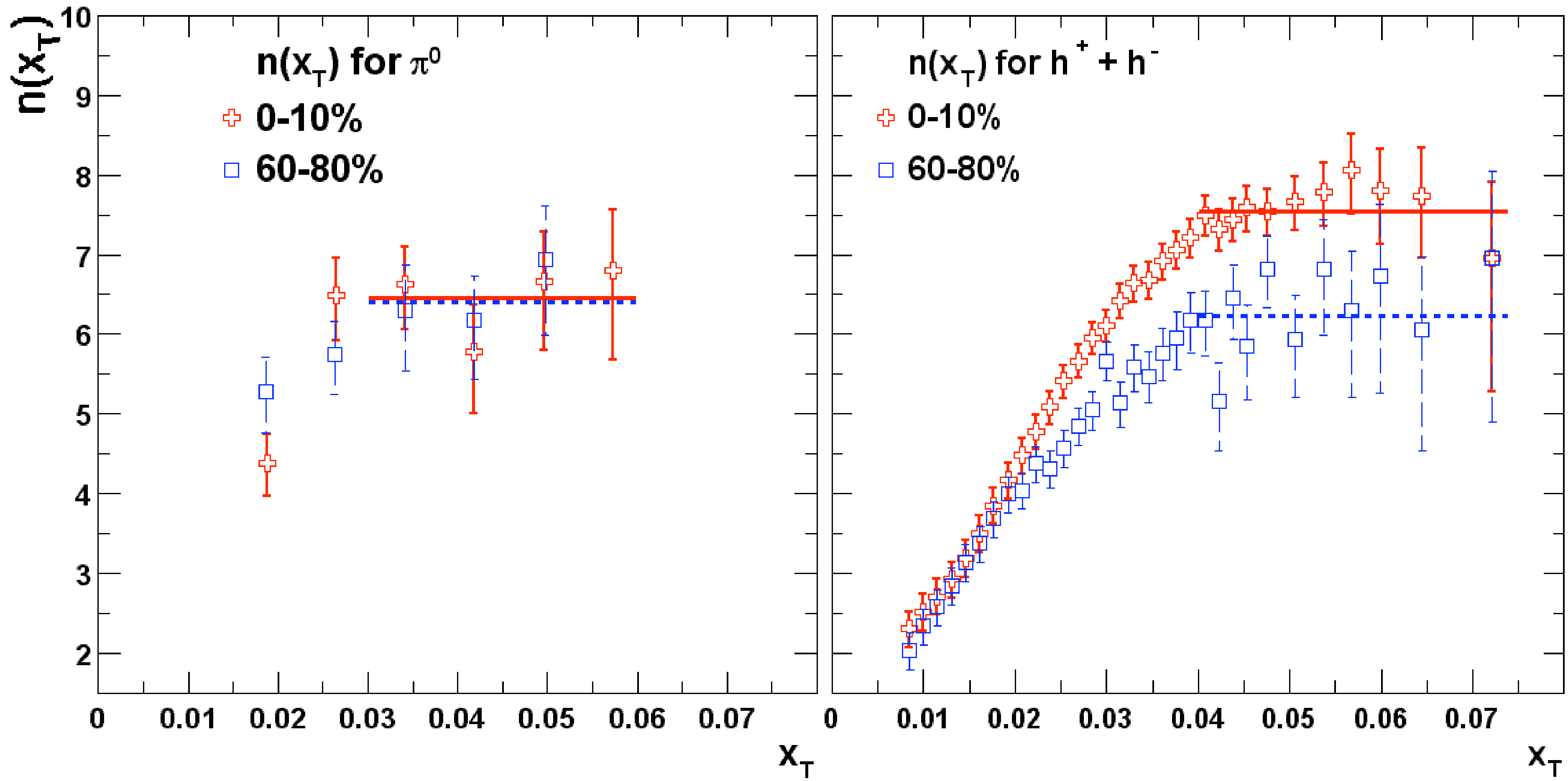
π^0 and $(h^+ + h^-)/2$ x_T scaled n=6.3



- Can calculate $n(x_T)$ point-by-point by the ratio of σ_{inv} at fixed x_T for 2 different $\sqrt{s}$

$$\left(\frac{\sqrt{s_1}}{\sqrt{s_2}}\right)^{n(x_T,\sqrt{s})} = \frac{\frac{Ed^3\sigma}{dp^3}(x_T,\sqrt{s_2})}{\frac{Ed^3\sigma}{dp^3}(x_T,\sqrt{s_1})}$$

$n(x_T)$ point-by-point 200/130



- π^0 x_T scales in both peripheral and central Au+Au with same value of n=6.3 as in p-p
- $(h^+ + h^-)/2$ x_T scales in peripheral same as p-p but difference between central and peripheral is significant

Precision values of n(x_T)

For a more quantitative analysis, the $Au + Au$ data for a given centrality and hadron selection are fitted simultaneously for $\sqrt{s_{NN}} = 130$ and 200 GeV to the form,

$$E\frac{d^3\sigma}{dp^3}(x_T, \sqrt{s}) = \left(\frac{A}{\sqrt{s}}\right)^n (x_T)^{-m}$$

Fitting results for π^0 over $0.03 < x_T < 0.06$		
parameters	0-10% centrality bin	60-80% centrality bin
A	0.973 ± 0.232	0.843 ± 0.3
m	8.48 ± 0.17	7.78 ± 0.22
n	$6.41 \pm 0.25(stat)$	$6.33 \pm 0.39(stat)$
	$\pm 0.49(sys)$	$\pm 0.37(sys)$
Fitting results for $h^+ + h^-$ over $0.04 < x_T < 0.074$		
A	2.30 ± 0.44	0.62 ± 0.27
m	8.74 ± 0.28	8.40 ± 0.43
n	$7.53 \pm 0.18(stat)$	$6.12 \pm 0.33(stat)$
	$\pm 0.40(sys)$	$\pm 0.36(sys)$

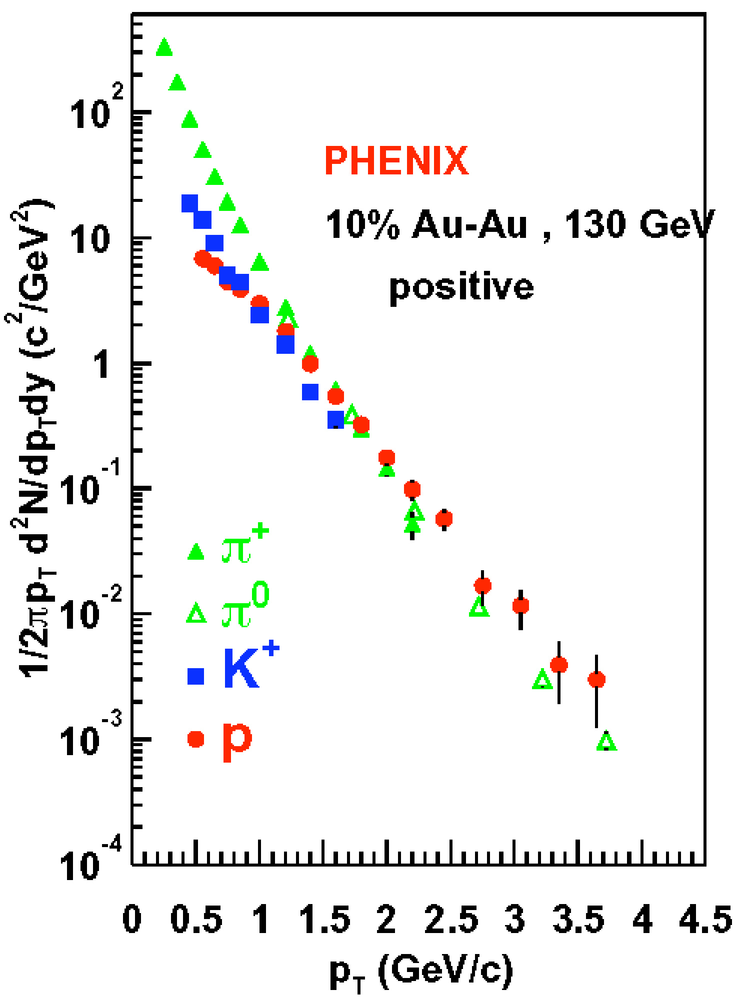
- □$n=n_{cent} - n_{periph}= 1.41\pm0.43$ for $(h^+ + h^-)/2$ ***significant***
- □$n=n_{cent} - n_{periph}= 0.09\pm0.47$ for □^{0}

Conclusions

- x_T scaling in peripheral Au+Au collisions at $\sqrt{s_{NN}}$ =130 and 200 GeV for both π^0 and $(h^+ + h^-)/2$ with the same value of n~6.3 as in p-p collisions in this x_T $\sqrt{s}$ range indicates that hard-scattering is the dominant production mechanism for high p_T particles in Au+Au collisions.
- π^0 production exhibits x_T scaling with the same value of n~6.3 in both central and peripheral Au+Au collisions
- This implies that the dynamics of suppressed high p_T π^0 production in Au+Au collisions is consistent with hard-scattering according to pQCD with scaling structure and fragmentation functions as in p-p collisions.
- Perhaps a little puzzling since this indicates that the energy loss of the parton scales with its energy, if energy loss. However, scaling is consistent with gluon-saturation.

Conclusions, continued

- For $(h^+ + h^-)/2$ the difference in n between central and peripheral collisions is significant: $\Delta n = 1.41 \pm 0.43$ and is consistent with the large proton and anti-proton enhancement compared to charged pions, which appears to violate x_T scaling from 130 to 200 GeV:
  - » The range $0.04 < x_T < 0.074$ corresponds to $2.6 < p_T < 4.8$ GeV/c at 130GeV and $4 < p_T < 7$ GeV/c at 200GeV
    But protons are enhanced for the same p_T range $2 < p_T < 4.5$ GeV/c for both 130 and 200 GeV



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