Scaling properties of particle production in p+p collisions measured by PHENIX at $\sqrt{s}$=200 GeV

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THE DATA

An important part of the RHIC physics program is the measurement of the p+p collisions to uncover the origin of the proton spin.

It is also critically important to have a solid p+p baseline to understand the physics of the Heavy Ion interactions.

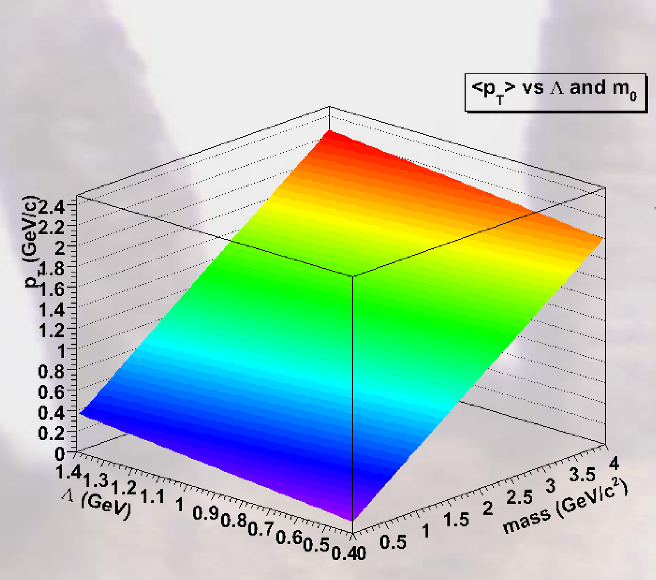
RHIC experiments gathered an immense amount of data on the identified particles production in the p+p interactions, and these data need to be understood and systematized.

This work is presents a common approach to describe particle production in p+p collisions and suggests that all identified particles in p+p follow the same universal p_T distribution with the minimal number of parameters, which can be found from the data. The shape of the particle spectra follows the Levy distribution which can be written as below:

$$E\frac{d^3\sigma}{dp^3} = \frac{\sigma}{2\pi}\frac{dN}{dy}\times\frac{(n-1)(n-2)}{(\Lambda+m_0(n-1))(\Lambda+m_0)}\times\left(\frac{\Lambda+m_T}{\Lambda+m_0}\right)^{-n}$$

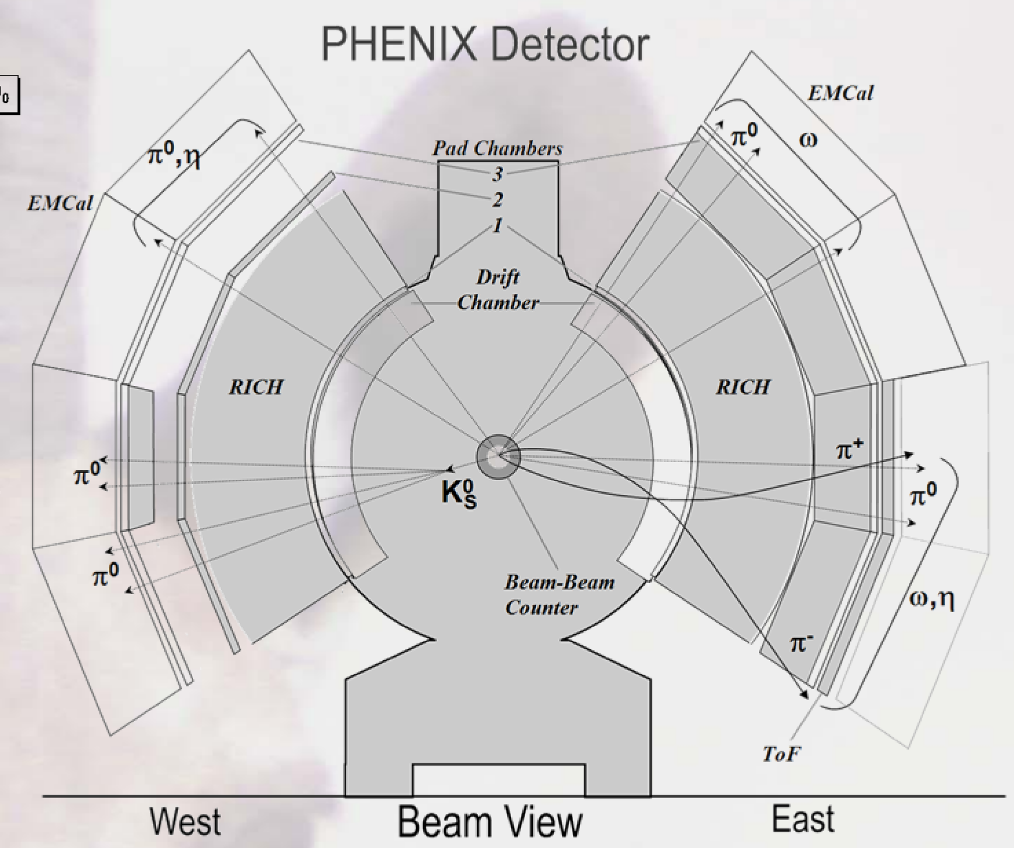
where "m_0" is the particle mass, "n" is the power and "Λ" is the width parameter.

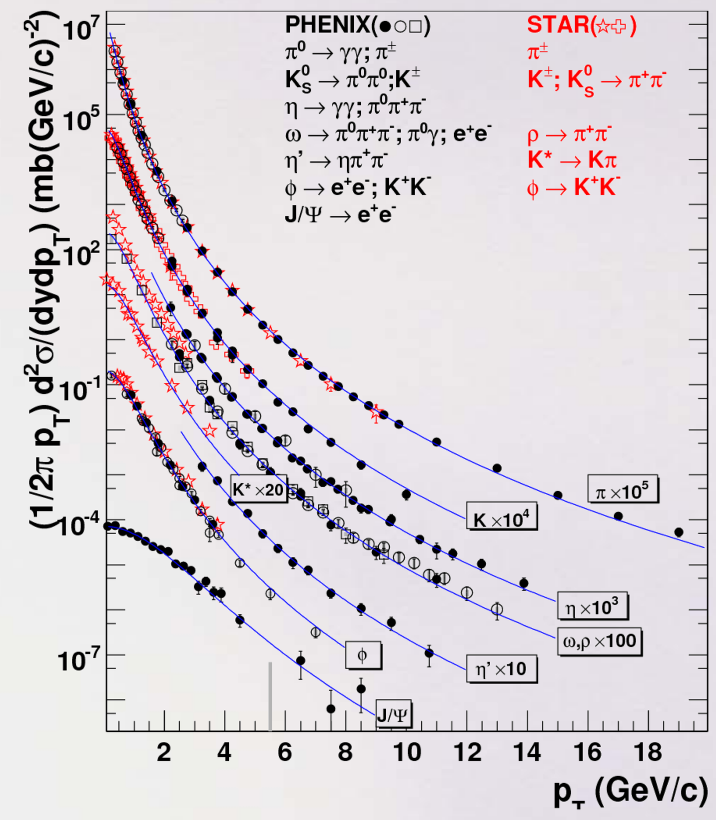
Levy @ high p_T → Power law
Levy @ mass = 0 → Hagedorn



One cannot write the <p_T> of Levy function in analytic form, however a simple numeric exercise shows that for the fixed parameter "n" the mean p_T linearly grows with the particle mass

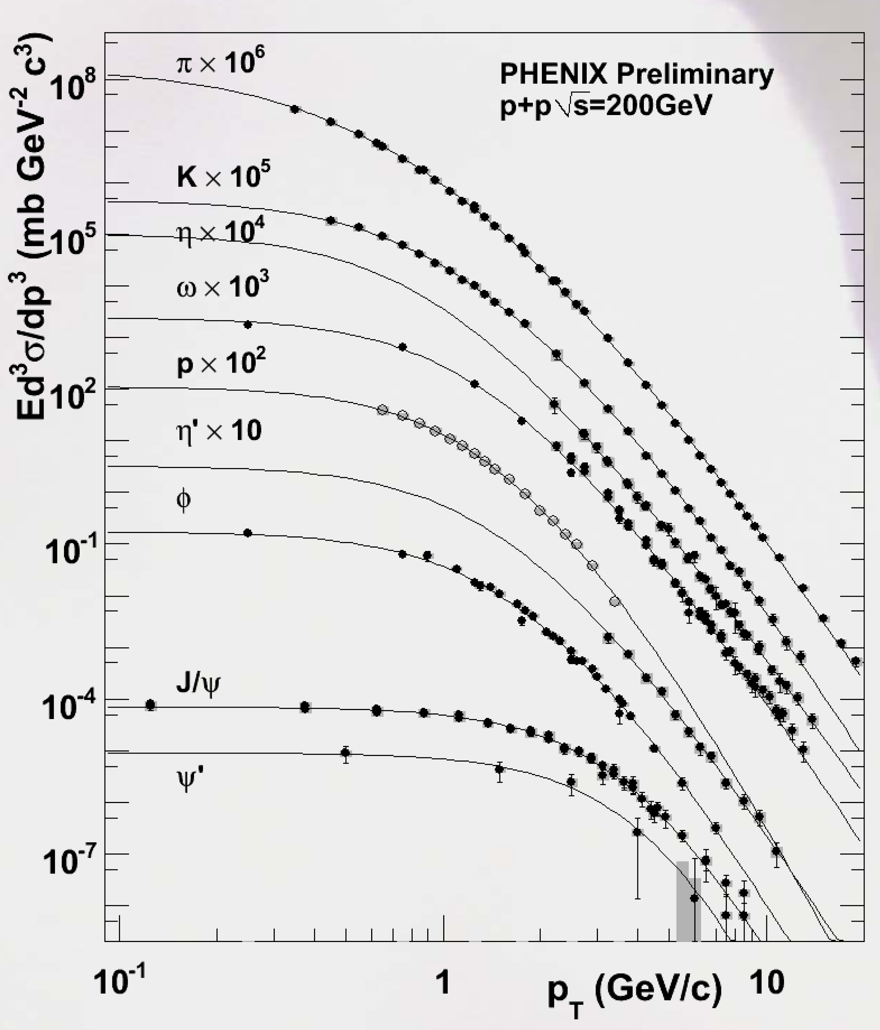
$$\langle p_T\rangle \approx \alpha\cdot\Lambda + \beta\cdot m_0$$





Particle	Mode	Run	p_T, m_T, E_k	Status	Reference
PHENIX					
π^0	γγ	5	0.6-19	Final	PRD 76, 051106(R) (2007)
$\pi^+ \pi^-$	ToF	3	0.35-2.6	Final	PRC 74, 024904 (2006)
$K^+ K^-$	ToF	3	0.45-1.8	Final	PRC 74, 024904 (2006)
p p-bar	ToF	3	0.65-3.4	Final	PRC 74, 024904 (2006)
J/Ψ	e^+e^-	5	0.125-8.5	Final	PRL 98, 232002 (2007)
ω	$\pi^0\pi^+\pi^-$	3	2.75-9.25	Final	PRC 75, 051902(R) (2007)
ω	πγ	3	2.5-6.5	Final	PRC 75, 051902(R) (2007)
ω	$\pi^0\pi^+\pi^-$	5	2.25-13.0	Preliminary	
ω	πγ	5	2.5-11	Preliminary	
ω	$\pi^0\pi^+\pi^-$	5	2.25-4.75	Preliminary	
K_0^S	$\pi^0 \pi^0$	5	2.25-10.0	Preliminary	
K_0^S	$\pi^0 \pi^0$	5	2.25-4.25	Preliminary	
η	γγ	3	2.75-11	Final	PR C75, 024909 (2007)
η	$\pi^0\pi^+\pi^-$	3	3-8	Final	PRC 75, 024909 (2007)
φ	hh	5	1.3-7	Preliminary	
φ	hK	5	0.9-3.6	Preliminary	
φ	e^+e^-	5	0.25-3.5	Preliminary	
ω	e^+e^-	5	0.25-3.5	Preliminary	
η'	η $\pi^+\pi$	5	3.25-10.8	Preliminary	
η	γγ	5	2.21-13.8	Preliminary	
STAR					
$K^+ K^-$	ToF		0.46-1.5	Final	PLB 616, 8 (2005)
$\pi^+ \pi^-$	ToF		0.35-9.0	Final	PLB 637, 161 (2006)
p,p-bar	ToF		0.47-6.5	Final	PLB 637, 161 (2006)
K*	Kπ		0.1-3.5	Final	PRC 71, 064902, (2005)
φ	K^+K^-		0.45-3.75	Final	PLB 612, 181, (2005)
π	$\pi^+\pi^-$		0.3-2.7	Final	PRL 92 092301 (2004)
Σ, Σ-bar	Λπ		0.17-2.0	Final	PRL 97 132301 (2006)
Λ,Λ-bar	pK		0.06-0.99	Final	PRL 97 132301 (2006)
Ω	ΛK		1.05-2.83	Final	PRC 75, 064901 (2007)
Ξ,Ξ-bar	Λπ		0.67-3.33	Final	PRC 75, 064901 (2007)
K_0^S	$\pi^+\pi^-$		0.26-4.73	Final	PRC 75, 064901 (2007)
$K^+ K^-$	kink		0.25-2.2	Final	PRC 75, 064901 (2007)
Λ,Λ-bar	p π		0.35-4.75	Final	PRC 75, 064901 (2007)
$\pi^+ \pi^-$	ToF		0.225-0.775	Submitted	arXiv:0808.2041v1
$K^+ K^-$	ToF		0.225-0.725	Submitted	arXiv:0808.2041v1
p,p-bar	ToF		0.375-1.125	Submitted	arXiv:0808.2041v1

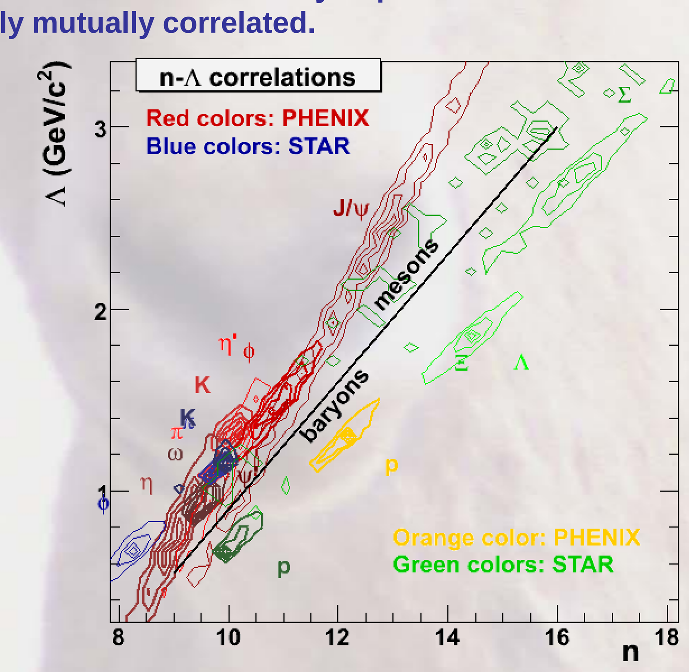
THE ANALYSIS

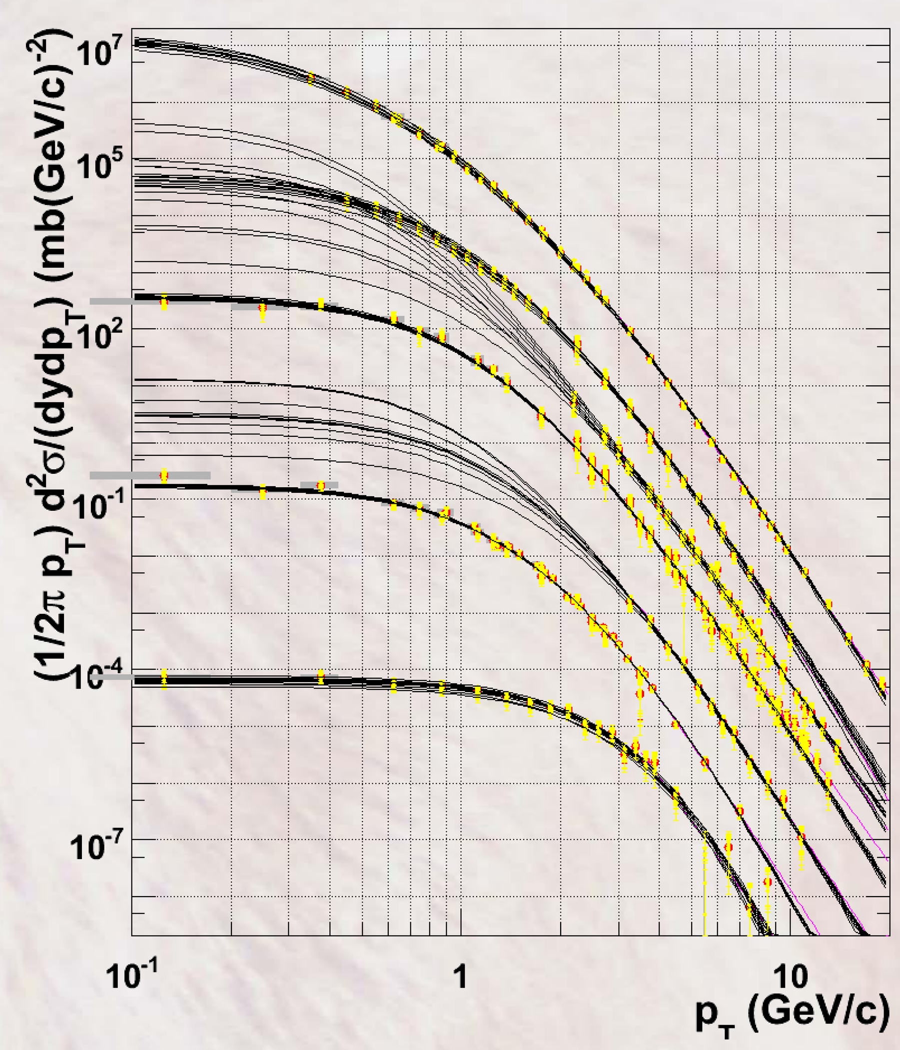


Fitting Levy function to the data works very well, but the fit parameters are different for different particles. One needs to establish whether each particle has its own set of parameters, or it is driven by uncertainties of the measurements?

The errors must be taken into account, therefore we do multiple fits varying the points within systematic uncertainties and define mean and RMS of each parameter from the procedure like it is shown in the right plot.

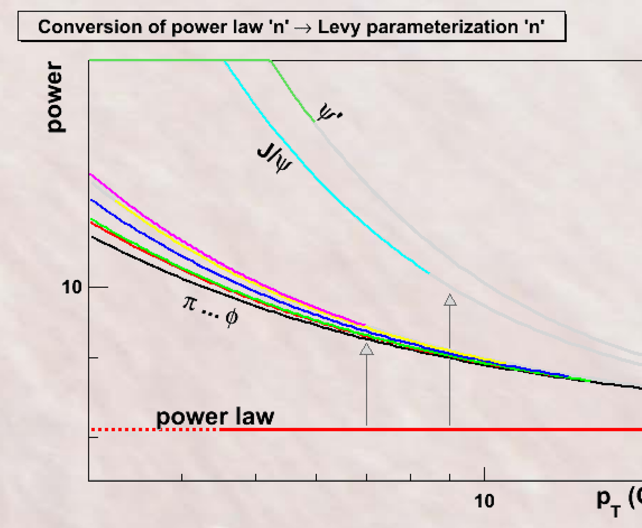
It becomes clear that the Levy fit parameters "n" & "Λ" are strongly mutually correlated.

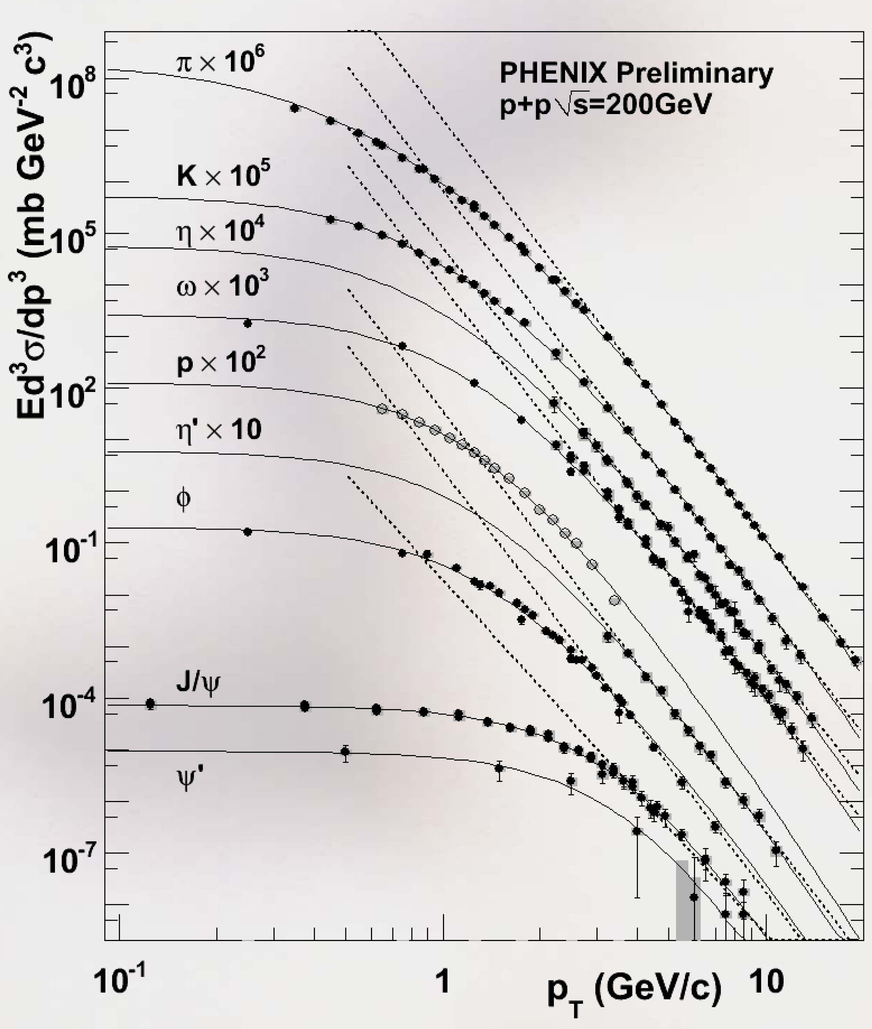




However, the choice of the parameter "n" in Levy fit Is not arbitrary. We know that the pQCD calculations predict the power-like behavior of the spectra at high p_T and it is confirmed by the fact that the particle ratios measured at high p_T are constant. This is only possible if power of all particle remains the same.

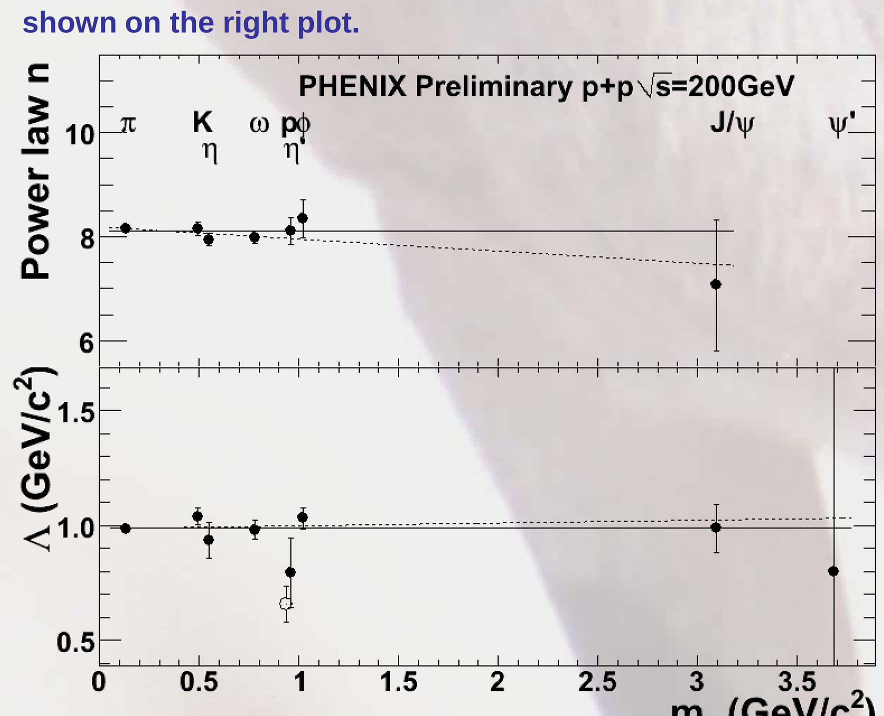
The two parameters "n" in the power law and in the Levy function are linked to each other and such correspondence is demonstrated with the figure below. Using the power law fit at high p_T one can put a constrain on the parameter "n" in Levy fit.

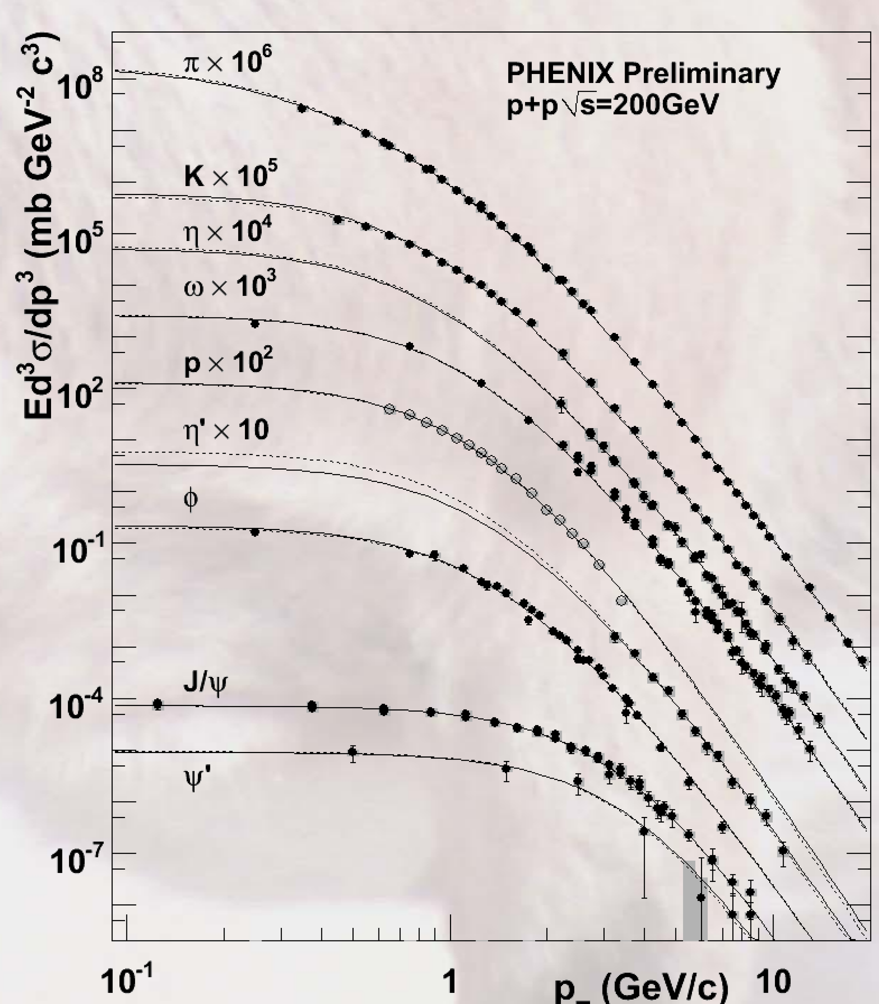


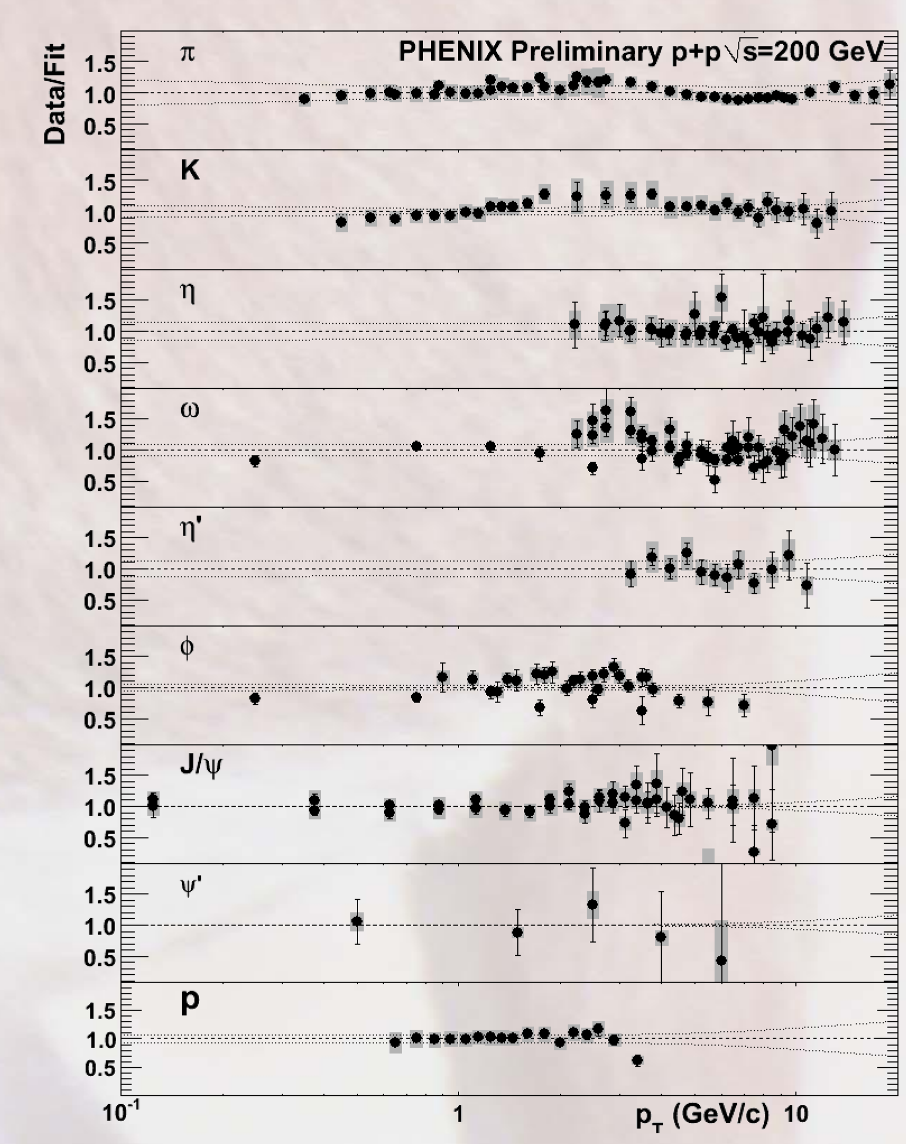


Power law fit yields the same parameter "n" for all particles which can be re-calculated into parameter "n" of the Levy fit. Both fits are shown on the left plot

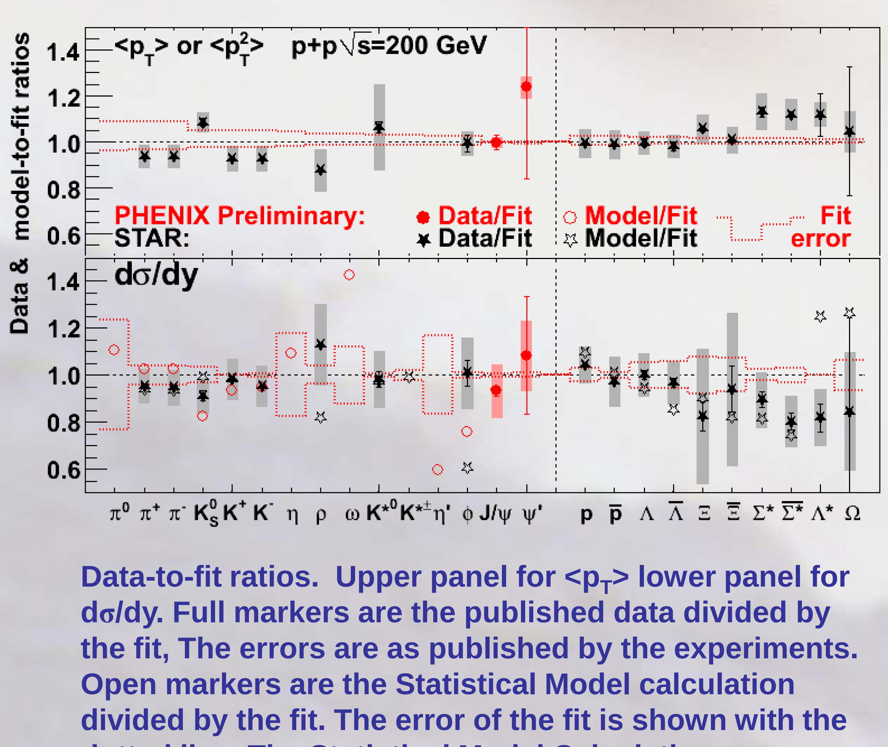
Once "n" is fixed in the fit, the Levy parameterization gives the same parameter "Λ" for all measured mesons, and different parameter "Λ" for baryons. See figure below. These values are used to further constrain the fit. This is shown on the right plot.







THE RESULTS



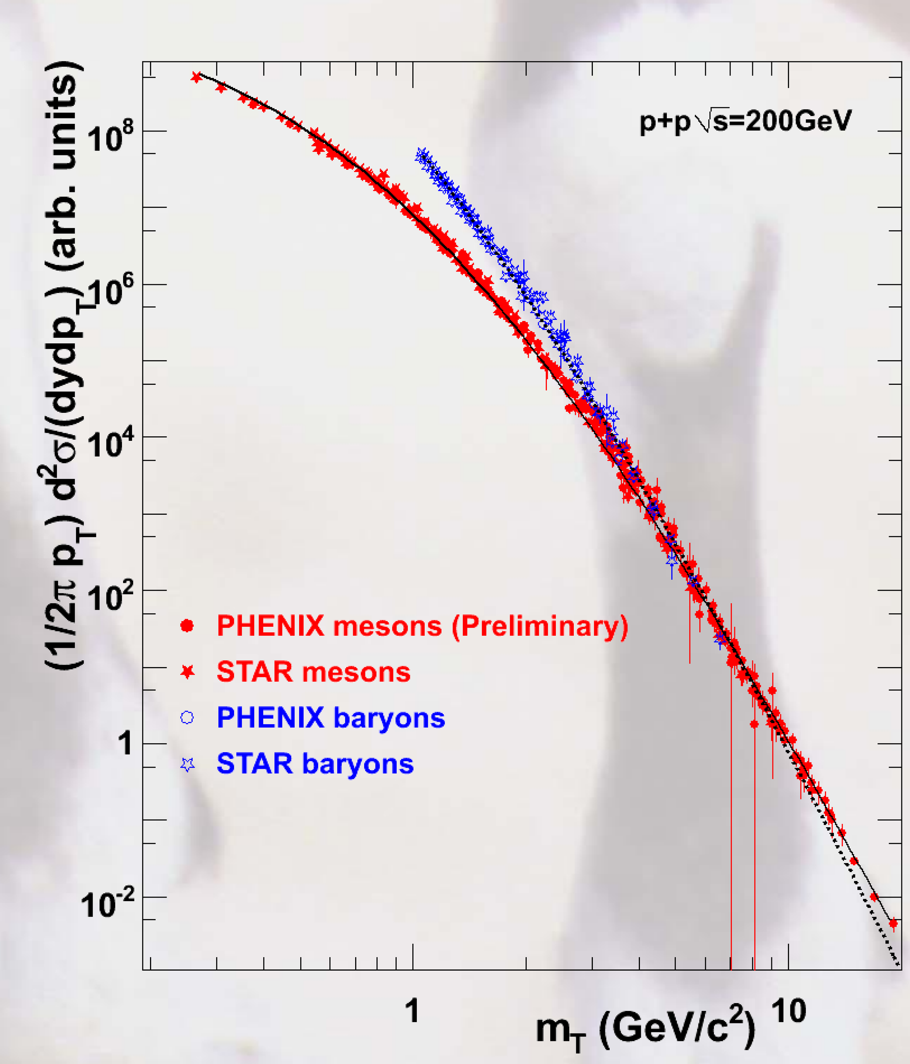
Data-to-fit ratios. Upper panel for <p_T> lower panel for dσ/dy. Full markers are the published data divided by the fit, The errors are as published by the experiments. Open markers are the Statistical Model calculation divided by the fit. The error of the fit is shown with the dotted line. The Statistical Model Calculations are provided by F. Becattini of *INFN* and are based on STAR's published results.

The Physics:

- There is a universal shape for the particle spectral distribution produced in p+p collisions. Two independent parameters plus normalization for each particle is sufficient to describe p_T spectrum of any particle at mid-rapidity.
- The <p_T> of all particles linearly depends on the mass.
- The slope of <p_T> vs. mass for mesons and baryons is the same, but the offset is different. Mesons have higher <p_T>'s than baryons of the same mass.
- The m_T scaling works well but is still an approximation. It does not describe data correctly within the existing errors.
- The Statistical model reasonably well describes all existing data and gives predictions for the particles which were not measured within better than 40% .

The Tools:

- One can extract the integrated yields of the particles which can be measured only at high-p_T. Virtually, one can extract a yield from a single point on a single p_T spectra.
- All particle ratios can be readily calculated from the universal shape.
- Feed down from different particles decay can be calculated using decay kinematics.
- One can use this approach to study particle production at different incident energies and extrapolate between them.



The m_T scaling was long time believed to correctly describe the particle spectra in p+p (shown n the left). Evidently , there is a large difference between mesons and baryons, however all available data at $\sqrt{s}$=200GeV seems to follow the scaling. This true only to the first approximation. Fitted to a Hagedorn shape (Levy @m_0=0) data shows much larger deviations from the universal shape (see below) when from the Levy does, as shown above.