Comparison between $dN/d\eta$ and dN/dy

Au+Au Collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$, 0–5% central events

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What it is about

Peter Christiansen and I submitted our results [1, 2] on identified charged hadron yields $dN/dy(\pi, K, p)$ to publication (PRL). These yields are based on the data taken with the BRAHMS spectrometers (MRS and FS) for Au+Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ and the 5% most central events. Independently, a measurement of the charged particle multiplicity $dN_{ch}/d\eta$ (non identified particles) was already available [3]. As a consistency check, one can therefore convert the yields dN/dy to $dN/d\eta$ for pions, kaons and protons, sum them up and compare with $dN_{ch}/d\eta$.

Issue

Peter and I have worked in the (y, p_T) space, namely rapidity–transverse momentum, whereas $dN_{ch}/d\eta$ has been worked out in the pseudo–rapidity η space. Let's review some definitions:

$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right) \tag{1}$$

$$E = m_T \cosh y = \sqrt{p_T^2 + m^2}\,\cosh y \tag{2}$$

$$\eta = \frac{1}{2}\ln\left(\frac{p+p_z}{p-p_z}\right) \tag{3}$$

$$= -\ln\left(\tan\frac{\theta}{2}\right) \tag{4}$$

where E is the total energy of the particle $E^2 = p^2 + m^2$, m its mass, $p_z = p\cos\theta$ the longitudinal component of the momentum p, and θ the emission angle of the particle w.r.t. the beam line. The pseudo–rapidity η is used when e.g. particle identification (PID) is not available, in which case only θ is needed. Ok, nothing new.

The issue brought up recently is the following: B. Back from the PHOBOS experiment has extrapolated $dN_{ch}/d\eta$ from Peter's and my $dN/dy(\pi, K, p)$ and compared with the PHOBOS results on $dN_ch/d\eta$. He found a large discrepancy at rapidities away from $y = 0$, in the order of 30% (lower than the PHOBOS data) at $y = 3$. The way Back has proceeded is not completely known to me. I unfortunately do not have any electronic figure to incorporate here (only a FAX from Flemming V.). Ramiro Debbe has taken a stab at it. He adopted another approach (as far as I know about Back's procedure): he took all p_T spectra (pion and kaon spectra are available here [4]) and converted each d^2N/dp_Tdy bin to a $d^2N/dp_Td\eta$ with the help of the Jacobian (see further). Figure 1 is what he ended up with. So apparently, we have a serious problem.

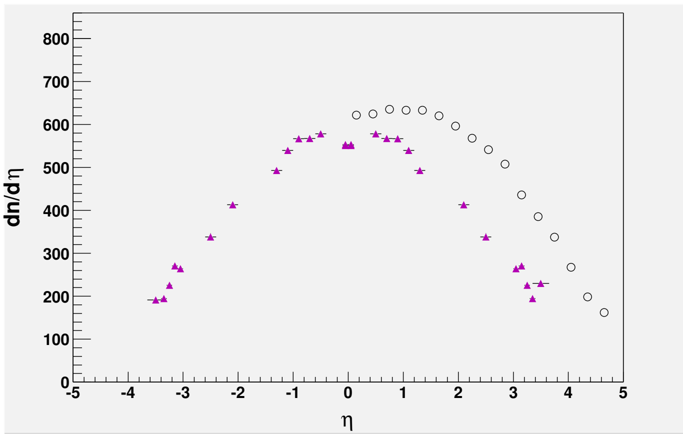

Figure 1: Extrapolation $dN/dy(\pi, K, p) \rightarrow dN_{ch}/d\eta$ by Ramiro Debbe, using the transformation $d^2N/dydp_T \rightarrow d^2N/d\eta dp_T$ in each spectrum bin.

My comparison

The previous approach looked reasonable at first glance but I suspected something was ignored. I kind of knew that it would be almost impossible without crude assumptions to derive $dN_{ch}/d\eta$ from dN/dy, simply because of an acceptance issue. Indeed, you can check by yourself that a straight slice in the (y, p_T) space looks totally skewed in the (η, p_T) space, especially for massive particles at forward rapidities and low p_T regions (I made a plot but removed it together with the root macro by accident...).

To remedy this technical issue, I went back to the double differential yields $d^2N/dydp_T$. Indeed, one can evaluate what η is for a given pair of p_T and y :

$$m_T = \sqrt{p_T^2 + m^2} \quad (5)$$

$$p_z = m_T \sinh y \quad (6)$$

$$\rightarrow p = \sqrt{p_z^2 + p_T^2} \quad (7)$$

$$\rightarrow \eta = \frac{1}{2} \ln \left(\frac{p + p_z}{p - p_z} \right) \quad (8)$$

Now that we know η, we want to know how $d^2N/dydp_T$ transforms to $d^2N/d\eta dp_T$. It turns out to be a simple equation:

$$\frac{d^2N}{d\eta dp_T} = \beta \frac{d^2N}{dydp_T} \quad (9)$$

which becomes, in terms of p_T and y only:

$$\frac{d^2N}{d\eta dp_T} = \sqrt{1 - \frac{m^2}{(p_T^2 + m^2)\cosh^2 y}} \frac{d^2N}{dydp_T} \quad (10)$$

With these equations, I can convert the double differential yields. The result can be seen in Fig. 2. Note how the acceptances are alike in the (η, p_T) space, the particle mass does not

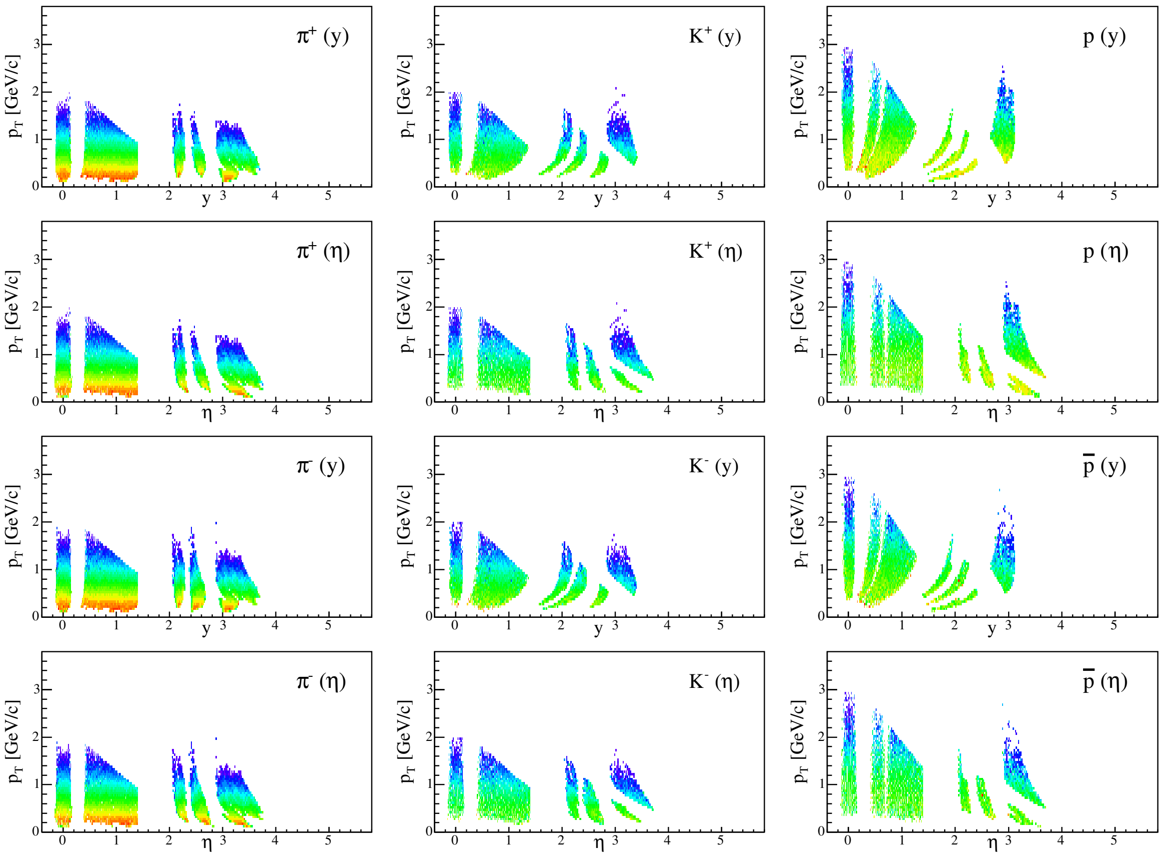

Figure 2: Double differential yields of $\pi^{\pm}, K^{\pm}, p, \bar{p}$ in the (y, p_T) and (η, p_T) spaces.

count anymore. From that on, one can choose η intervals, make particle spectra and integrate these in order to obtain $dN/d\eta$ for each particle type. The final step is to sum up at a given η multiplicities of all particle types. This is what I did. I chose the following intervals:

- $\eta = 0.0 \pm 0.1$
- $\eta = 1.0 \pm 0.1$
- $\eta = 2.3 \pm 0.2$
- $\eta = 3.25 \pm 0.15$

You can find in appendix the spectra, fits and extrapolated $dN/d\eta$ for each particle type and charge. Note that I only wanted a reasonable estimation, so I did not spend time trying to get the best fit (cf. proton at low p_T). Finally, Fig. 3 shows the comparison between my estimation of $dN_{ch}/d\eta$ and the measurement from the multiplicity arrays (MA) and the beam–beam counters (BB).

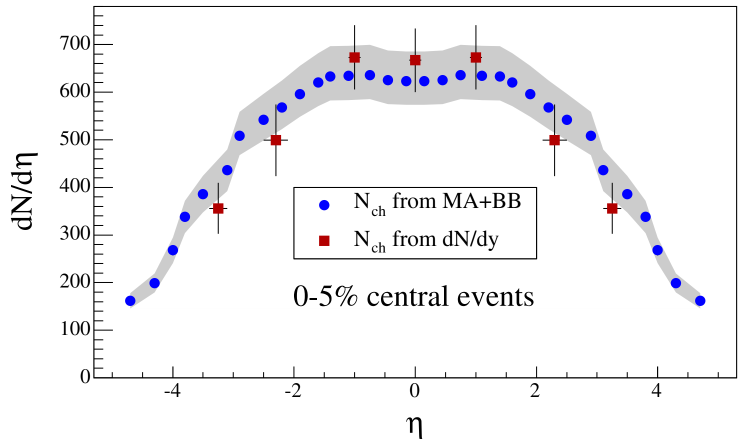

Figure 3: Comparison between multiplicity arrays and beam–beam counter measurements and my estimation from dN/dy.

The band delimits the systematic errors (MA and BB). Note that these are independent (MA acceptance is $-3 < \eta < 3$). The error bars on my estimation are systematic errors as well (roughly 10% in the MRS and 15% in the FS). The discrepancy at $y = 3.25$ between measurement and estimation is at most 15%, much better than the crude approximations from Back or Ramiro.

Conclusion

Given the fact that the spectrometer data were not corrected for feed down ($K_s^0 \rightarrow 2\pi$'s, etc), I conclude from this exercise that we are not in such a trouble. Of course, there remains issues about some different systematic in the MRS (higher than MA+BB) and FS (lower) but again, the systematic errors do not move altogether in the same way but somehow depend on the detector system we look at (MRS, FS, MA or BB).

References

[1] I. G. Bearden et al., *nucl-ex/0312023*, 2003.

[2] I. G. Bearden et al., *nucl-ex/0403050*, 2004.

[3] Phys. Rev. Lett. **88**, 202301 (2002).

[4] http://www4.rcf.bnl.gov/brahms/WWW/publication_data/mesonAuAu200

Appendix: Particle Spectra

In the following are the spectra I got at four different η intervals. Since I could not sum up all double differential yields before slicing the η axis (due to missing data sets for some particles, and PID cuts particle dependent - cf. RHIC), I had to first fit each particle spectrum individually. For pions, I chose a power law $A\,(1+p_T/p_0)^n$, for kaons a single exponential m_T and for protons, a Boltzmann in m_T. The latter is not always optimal but still better than the expo. or the Gaussian fits.

Pion Spectra

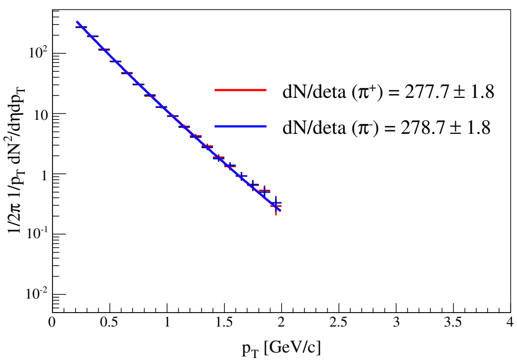

Figure 4: Spectra $1/2\pi d^2N/p_T dp_T d\eta$ for pions at $\eta = 0 \pm 0.1$.

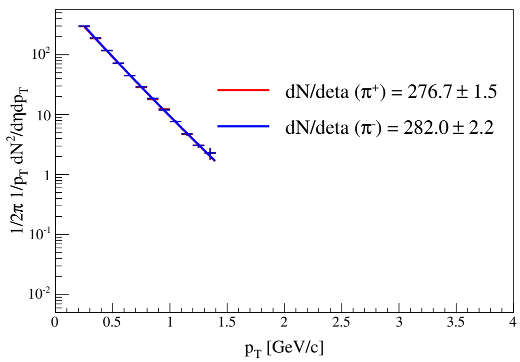

Figure 5: Same as Fig. 4 at $\eta = 1 \pm 0.1$.

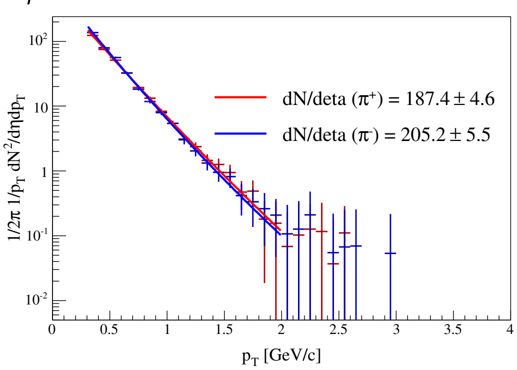

Figure 6: Same as Fig. 4 at $\eta = 2.3 \pm 0.2$.

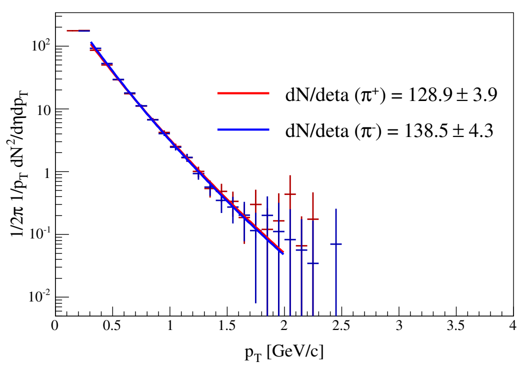

Figure 7: Same as Fig. 4 at $\eta = 3.25 \pm 0.15$.

Kaon Spectra

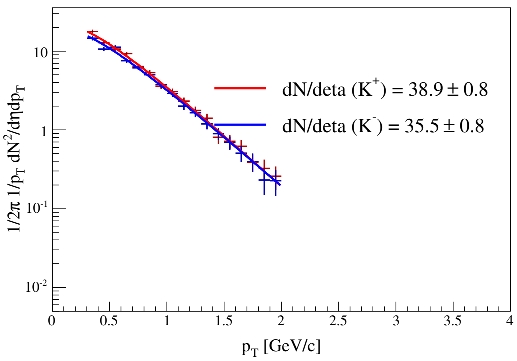

Figure 8: Spectra $1/2\pi d^2N/p_T dp_T d\eta$ for kaons at $\eta = 0 \pm 0.1$.

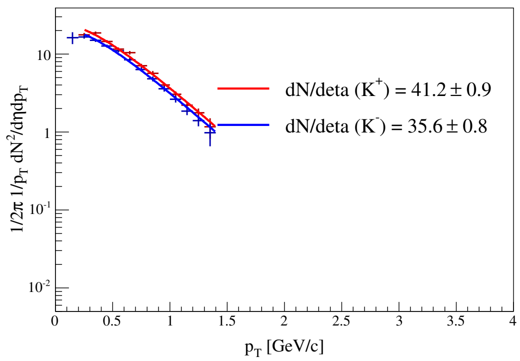

Figure 9: Same as Fig. 8 at $\eta = 1 \pm 0.1$.

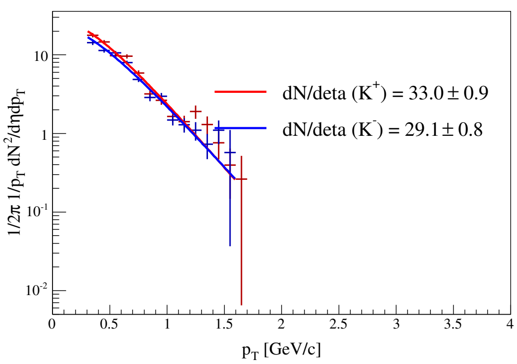

Figure 10: Same as Fig. 8 at $\eta = 2.3 \pm 0.2$.

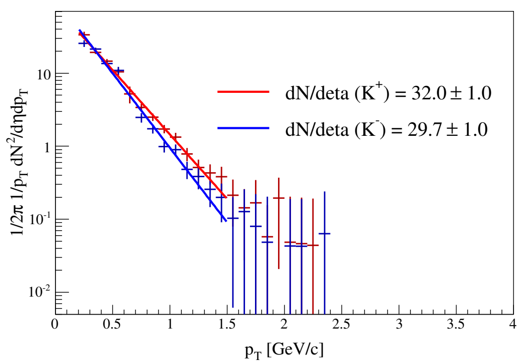

Figure 11: Same as Fig. 8 at $\eta = 3.25 \pm 0.15$.

Proton Spectra

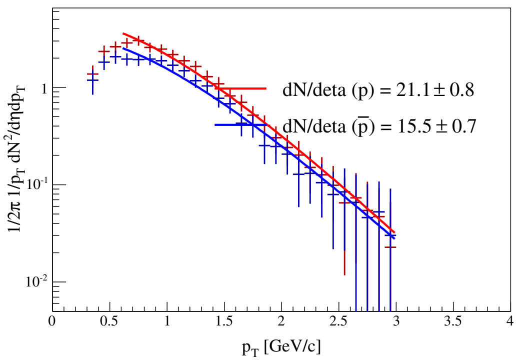

Figure 12: Spectra $1/2\pi d^2N/p_T dp_T d\eta$ for protons at $\eta = 0 \pm 0.1$.

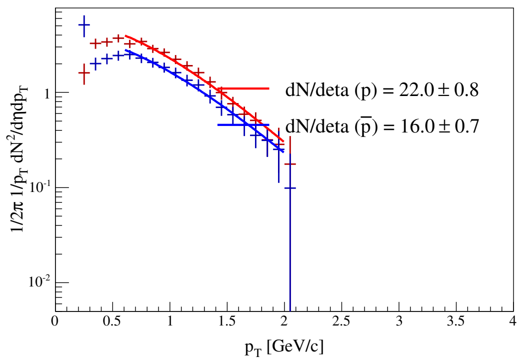

Figure 13: Same as Fig. 12 at $\eta = 1 \pm 0.1$.

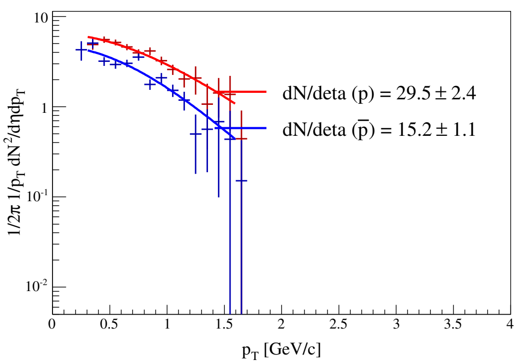

Figure 14: Same as Fig. 12 at $\eta = 2.3 \pm 0.2$.

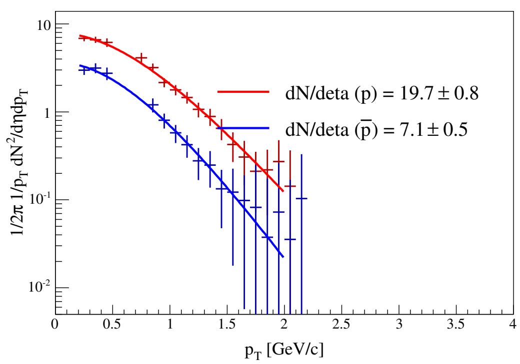

Figure 15: Same as Fig. 12 at $\eta = 3.25 \pm 0.15$.