Measurement of the neutral pion cross section in proton-proton collisions at $\sqrt{s}=200$ GeV with PHENIX

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The inclusive cross section for neutral pion production in the range $1 < p_T < 13$ GeV/c in $|\eta| < 0.35$ has been measured by the PHENIX experiment in proton-proton collisions at $\sqrt{s}=200$ GeV. An NLO pQCD calculation is, within the experimental and theoretical uncertainties, consistent with the measurement.

1. Introduction

A detailed understanding of hadron production in proton-proton collisions is essential to both the heavy-ion and spin physics programs at the Relativistic Heavy Ion Collider(RHIC). For the heavy-ion program, proton-proton data provide the reference to which hadron production in heavy-ion collisions can be compared so that novel phenomena, such as jet energy loss or suppression, can be distinguished from the proton-proton results. In the spin physics program, hadron production is a key probe of transverse and longitudinal spin structure functions and thus an understanding of the unpolarized cross section with next-to-leading order(NLO) perturbative QCD calculations provides the theoretical underpinnings for the physics interpretation of the polarized data.

2. Experimental Setup

The PHENIX detector[1][2] consists of two central arm spectrometers, two muon arm spectrometers, and other detectors for triggering. This work used the electromagnetic calorimeters (EMCal) in the central arms, each of which have an azimuthal coverage of 90° and pseudo-rapidity coverage of ± 0.35. This detector consists of 6 lead scintillator sampling calorimeter (PbSc) sectors and 2 lead glass (PbGl) sectors. In this paper, we will report only the measurement done with the 5 PbSc sectors, which have a nominal energy resolution of $8.2\%/\sqrt{E\ (\mathrm{GeV})} \oplus 1.9\%$ and a position resolution of $5.7\ \mathrm{mm}/\sqrt{E\ (\mathrm{GeV})} \oplus 1.6$ mm.

The data were collected during the proton-proton run in 2001–2002 at RHIC using the minimum bias (MB) and the newly installed EMCal triggers. The MB trigger was made with beam–beam counters (BBC) which covered pesudo-rapidity range from 3.0 to 3.9. The analysis imposed a cut of ± 30 cm on the vertex. The EMCal trigger was essential to enhance the sample of neutral pions at high p_T. This trigger consisted of two types:

*for the full PHENIX Collaboration author list and acknowledgements, see Appendix "Collaborations" of this volume.

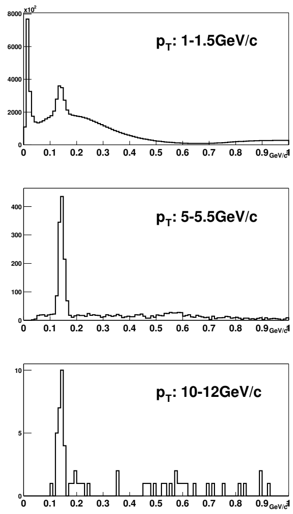

Figure 1. Invariant mass spectrum for p_T range of 1 to 1.5 GeV/c (top), 5 to 5.5 GeV/c (middle), and 10 to 12 GeV/c (bottom).

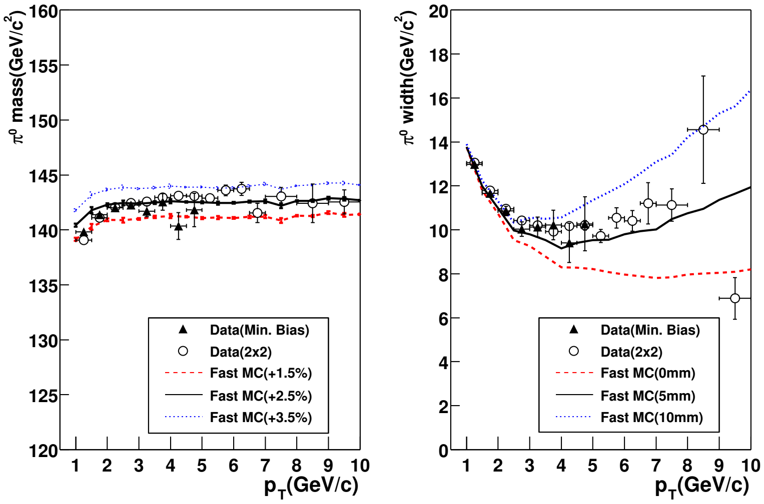

Figure 2. [left] The π^0 peak position from MB (star) and 2x2 trigger (open circle) samples as a function of p_T compared with the Monte Carlo simulation in which the energy scale is corrected by 1.5% (dash), 2.5% (solid), and 3.5% (dot), and [right] The π^0 width compared with the same MC when the position resolution is increased quadratically from the nominal one by 0 mm (dash), 5 mm (solid), and 10 mm (dot).

2x2 non-overwrapping tower sum (0.8 GeV threshold), and 4x4 overwrapping tower sum (2 and 3 GeV thresholds). For higher p_T, this work is based upon the data collected via the 2x2 trigger whose rejection factor was 90.

3. Analysis Procedure

The cross sections for the two trigger samples were computed as the ratio of the π^0 yield corrected for efficiency, acceptance, and smearing ($\mathcal{N}_{\pi^0}^{MB}$,$\mathcal{N}_{\pi^0}^{2\times 2}$) to the integrated effective luminosity ($\mathcal{L}^{MB}$,$\mathcal{L}^{2\times 2}$) which were computed as:

$$\mathcal{N}_{\pi^0}^{MB} = \frac{N_{\pi^0}^{MB}(p_T)\cdot C_{\pi^0}^{reco}(p_T)}{\varepsilon_{\pi^0}^{MB}(p_T)} \qquad \frac{1}{\mathcal{L}^{MB}} = \sigma^{pp}\times\frac{\varepsilon_{trig}^{MB}}{N_{trig}^{MB}}$$

$$\mathcal{N}_{\pi^0}^{2\times 2} = \frac{N_{\pi^0}^{2\times 2}(p_T)\cdot C_{\pi^0}^{reco}(p_T)}{\varepsilon_{\pi^0}^{MB}(p_T)\cdot\varepsilon_{\pi^0}^{2\times 2}(p_T)} \qquad \frac{1}{\mathcal{L}^{2\times 2}} = \frac{1}{\mathcal{L}^{MB}}\times\frac{N_{trig}^{MB\&2\times 2}}{N_{trig}^{2\times 2}}$$

Figure 1 shows sample invariant mass spectra for two photons. Above a p_T of ~ 3 GeV/c, the ratio of the combinatorial background to the signal was $\sim 10\%$. To extract the number of π^0 [$N_{\pi^0}^{MB}(p_T)$ & $N_{\pi^0}^{2\times 2}(p_T)$] in each p_T bin, several functions – including a gaussian and some order of polynomial – were used to fit to the combinatorial background over a variety of fit ranges. The systematic error was estimated from the variation in these fits and the run-to-run stability of the yield.

The acceptance, efficiency, and smearing correction [$C_{\pi^0}^{reco}(p_T)$] was obtained by a Monte Carlo simulation which was tuned using results from the test beam measurements and

Table 1
The p_T dependent systematic error.

Correction Term	Source	Estimate
N_{π^0}	Background subtraction	5%
	Hot/Warm towers	2-3%
	Run dependence	10%(MB) 6%(2x2)
$C^{reco}_{\pi^0}(p_T)$	Fast MC statistical error	1%
	Edge towers	5%
	Position resolution	0-1%
	Energy absolute calibration	3-8%
	Energy non-linearity	0-10%
	Energy resolution	3%
$\varepsilon^{2\times2}_{\pi^0}(p_T)$	2x2 high p_T trigger threshold	10%

the data itself. Figure 2 compares the measured π^0 mass and width against the Monte Carlo simulations with different parameter sets. The systematic error was estimated from the change in the correction factor when the parameters were varied within their errors.

Using the MB data, the π^0 efficiency of the 2x2 trigger [$\varepsilon^{2\times2}_{\pi^0}(p_T)$] was determined to plateau at 80% above a p_T of $\sim$3 GeV/c. A systematic error of 10% was assigned to this quantity by comparing it to the result from a Monte Carlo simulation which included the measured efficiencies for the tiles in the trigger. The bias for π^0 detection arising from the MB trigger condition [$\varepsilon^{MB}_{\pi^0}(p_T)$] was measured to be 75%, independent of p_T up to a p_T of $\sim$5 GeV/c using the data sample collected with a 4x4 trigger which, unlike the 2x2 trigger, did not impose the MB requirement. This value was consistent with an estimate from a PYTHIA+GEANT simulation and thus also used to correct the data at higher p_T. All of the systematic errors are summarized in Table 1.

The MB trigger efficiency [ε^{MB}_{trig}] of 51% was obtained from a PYTHIA+GEANT simulation. We assigned a normalization error of 30% based on the difference between the cross section measurement from a van der Meer/vernier scan and the total (elastic+inelastic) p+p cross section.

4. Results and Discussion

Figure 3 shows the measured cross sections for the MB and the 2x2 trigger samples along with the p_T dependent systematic error. The results from the two samples are consistent within the error. The UA1 collaboration measured the $(h^+ + h^-)/2$ production cross section in the $p-\bar{p}$ collisions at $\sqrt{s} = 200$ GeV in the ± 2.5 rapidity range[3]. When scaled to our rapidity range and corrected for the particle composition using ISR results[4], our measurement is consistent with the UA1 measurement over their measured p_T range of 1 to 6 GeV/c.

Figure 4 shows a comparison with an NLO pQCD calculation[5] using the formalism of F. Adversa *et al.*[6] with the CTEQ5M parton distribution functions[7] and the PKK fragmentation functions[8]. The data for the lower p_T range is shown from the MB trigger samples to avoid the larger systematic error of the 2x2 trigger samples. Over the full p_T range, this calculation is consistent with our measurement within the systematic errors.

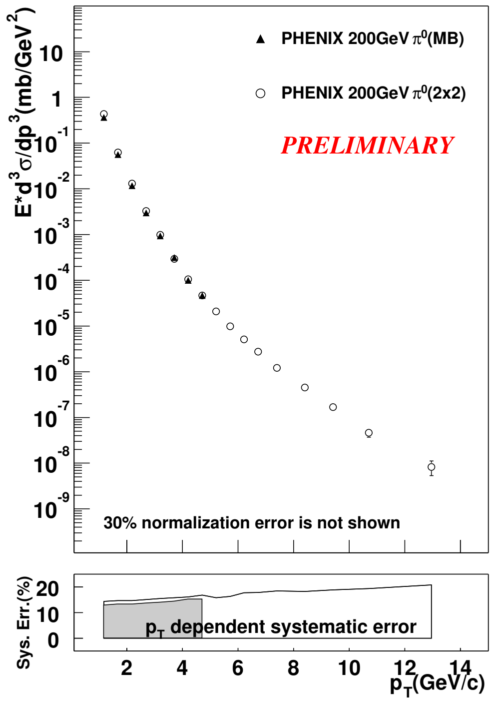

Figure 3. The inclusive neutral pion cross section for the MB trigger (filled triangle) and for the 2x2 trigger (open circle) as a function of p_T. The p_T dependent systematic error is shown in the lower box for the MB trigger (filled box) and for the 2x2 trigger (open box).

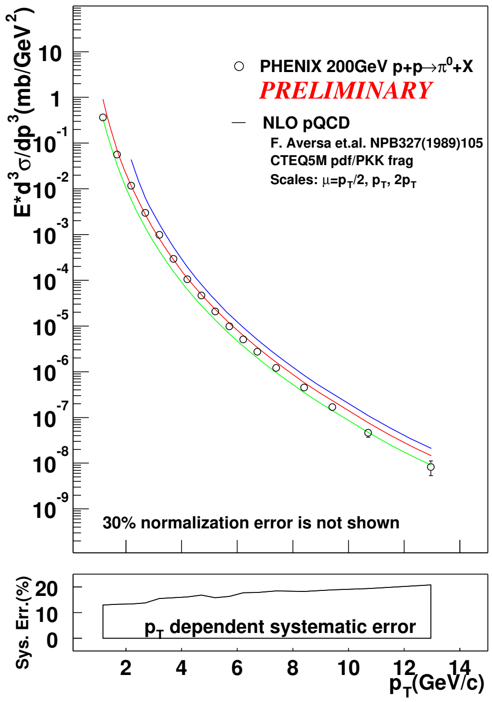

Figure 4. The inclusive neutral pion cross section (open circle) and comparison with NLO pQCD calculation using $p_T/2$ (top line), p_T (middle line), and $2p_T$ (bottom line) renormalization and factorization scales. The p_T dependent systematic error of the data is shown in the lower box.

5. Conclusion

The NLO pQCD calculation with a set of parton distribution and fragmentation function is consistent with our measurement over the full p_T range of 1-13 GeV/c within the systematic error and the scale selection. This measurement provides a baseline for high p_T heavy-ion physics[9].

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