Di-lepton production in p+p collisions at $\sqrt{s} = 200$ GeV from STAR

Bingchu Huang (for the STAR Collaboration)
Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China
Brookhaven National laboratory, Upton NY 11973, USA
E-mail: huangbc@bnl.gov

Abstract. The di-electron mass continuum in the mass range $0 < M_{ee} < 3.3$ GeV/c has been measured at midrapidity ($|y| < 1$) by the STAR experiment in p+p collisions at $\sqrt{s} = 200$ GeV. We will compare the measured di-lepton continuum to a hadronic cocktail simulation. In addition, the omega yields via di-leptonic decays have been measured for $0 < p_T < 1.6$ GeV/c.

1. Introduction
Di-leptons production is a crucial probe of strongly interacting matter with high energy density matter[1] created in Relativistic Heavy Ion Collider(RHIC). Since di-leptons are not affected by the strong interaction, and can escape from the hot dense matter, di-leptons can probe the whole time evolution and dynamics of the heavy ion collisions. In-medium properties of low-mass vector mesons can be studied via their di-lepton decays. The observation of in-medium modifications of vector mesons may relate to the possibility of Chiral symmetry restoration. In the intermediate mass range($1.1 < M_{ll} < 3.0$ GeV/c$^2$), the di-leptons production are directly linked to the thermal radiation of the QGP [2, 3]. The di-electron production measurements in p+p collisions provide a crucial baseline for the future measurements in Au+Au collisions at STAR [4]. Benefit from the newly installed Time-of-Flight detector (TOF) at STAR, we are able to identify electrons with high purity, high acceptance, and high efficiency [5] from low to intermediate transverse momentum ($p_T$) [6]. We combine the TOF and Time Projection Chamber (TPC) [7] for electron identification (eID). The EMC was used for eID at high $p_T$ (¿2 GeV/c). The di-electron continuum which come from 200 GeV p+p collisions in 2009 is presented in this article. We also present the cocktail simulations and compare the results with the data. The $\omega \rightarrow e^+e^-$ yields were obtained and compared to previously published results.

2. Data analysis and Results
2.1. Detector and data sample
In this analysis, we have three major detectors that are used for the eID: the TPC, the TOF, and the Barrel Electron-magnetic Calorimeter (EMC) [8]. The TPC is the primary tracking device of the STAR detector providing energy loss, momenta and path-lengths measurements of particles created in the collisions. The energy loss is used for particle identification [9, 10]. At STAR, 72% of the TOF system was installed in year 2009, it could extend the identification of $\pi$ and $K$ up to 1.6 GeV/c and the $p(\bar{p})$ up to 3 GeV/c [11, 12]. Each track included in the
di-electron analysis was required to pass cuts of the velocity(\(\beta\)) from the TOF and the \(dE/dx\) from the TPC. Electrons can be clearly identified from low to intermediate \(p_T\) by combining the TOF and TPC. In addition, the EMC is used for triggering on high energy photons and electrons based on the energy deposited in the detector.

The p+p data used in this analysis were 107 million events that were required to have a collision vertex within 50 cm from TPC center along the beam line. The electron candidates were obtained with 99% purity by applying velocity and \(p_T\) dependent \(dE/dx\) cuts on tracks with \(p_T > 0.2\) GeV/c and \(|\eta| < 1\). The velocity was required as \(|1/\beta - 1| < 0.03\). The di-electron invariant mass distribution was generated by pairing all possible \(e^+\) and \(e^-\) tracks from the same event, which is marked as unlike-sign distribution. In order to understand the combinatorial and correlated background, we reconstructed the backgrounds by both mixed-event technique and like-sign technique. In the like-sign technique, the invariant mass was calculated by pairing two tracks with same charge from the same events. The mixed-event background was reconstructed by two opposite charge sign electrons from different events. The two events were only mixed if they had collision vertices within 5 cm of each other in the beam line direction.

![Graph](image)

**Figure 1.** (top-left panel) The electron-pair invariant mass distributions for unlike-sign pairs, like-sign, and mixed-event background in minimum-bias p+p collisions. (top-right panel) The ratio of like-sign over mixed-event distributions in minimum-bias p+p collisions. (bottom panel) The ratio of like-sign over mixed-event distributions in EMC triggered p+p collisions.

2.2. Background subtraction

Figure. 1 (top-left panel) shows the invariant mass distribution for unlike-sign pairs, like-sign, and mixed-event background. The mass range of the mixed-event distribution normalized to
the like-sign distribution is $0.4 - 1.5$ GeV/$c^2$. Correlated background are at low mass region, which comes from double Dalitz decays followed by a conversion of the decay photon, or two-photon conversions. Such background included in the like-sign distribution but not in the mixed-event background. We subtracted like-sign background at $M_{ee} < 0.7$ GeV/$c^2$, and subtracted normalized mixed-event background at $M_{ee} > 0.7$ GeV/$c^2$. As shown in the ratio plot in Fig. 1 (top-right panel), the shape of like-sign and mixed-event distributions matched reasonably well. The ratio like-sign over mixed-event distributions is around unity for $p_T > 0.2$ GeV/$c$ [13]. To study the difference of like-sign and mixed event distribution at high mass, we made the two backgrounds by using EMC triggered events which triggered on at least one electron track which has $p_T > 2$ GeV/$c$. We found that the shape of like-sign and mixed-event distributions matched in the mass region of $1 - 3$ GeV/$c^2$, as shown in the bottom panel of Fig. 1. This indicates that the jet contribution is negligible within the STAR acceptance. PYTHIA simulations to estimate the jet contributions are on-going. The di-electron continuum after background subtraction is shown in Fig. 2. The errors are statistical only. The systematic uncertainties on the normalization and background subtraction are still under study.

\[ \frac{dN}{dM} \left( 10 \text{ MeV/c} \right)^2 \]

\[ 10^0 \quad 10^1 \quad 10^2 \quad 10^3 \quad 10^4 \]

\[ M_{ee} \ (\text{GeV/c}^2) \]

\[ 0 \quad 0.5 \quad 1 \quad 1.5 \quad 2 \quad 2.5 \quad 3 \quad 3.5 \]

**Figure 2.** The comparison for di-electron continuum between data and simulation in 200 GeV minimum-bias p+p collisions. The di-electron continuum from simulations with different source contributions are also shown. The statistical errors are shown as bars.

### 2.3. Cocktail simulation

The dominant sources of di-electron signals are hadron decays. For example, light flavor hadrons, $\pi^0$, $\eta$, and $\eta'$ Dalitz decays: $\pi^0 \rightarrow \gamma e^+e^-$, $\eta \rightarrow \gamma e^+e^-$, and $\eta' \rightarrow \gamma e^+e^+$; vector meson decays: $\omega \rightarrow \pi^0 e^+e^-$, $\omega \rightarrow e^+e^-$, $\rho^0 \rightarrow e^+e^-$, $\phi \rightarrow \eta e^+e^-$, $\phi \rightarrow e^+e^-$, and $J/\psi \rightarrow e^+e^-$. Heavy flavor hadron semi-leptonic decays: $c\bar{c} \rightarrow e^+e^-$ and $b\bar{b} \rightarrow e^+e^-$; and Drell-Yan contributions most dominant at high mass region. We fit the invariant yields of measured mesons with the Tsallis blast-wave functions [14], and use the fit functions as inputs of the simulations. We decayed the input mesons into di-electrons GEANT using STAR year 2009 geometry. The same cuts were applied in the simulation as well as in the data. The different contribution sources had same number of events and rapidity ranges as used in the data analysis. The gamma conversion $\gamma \rightarrow e^+e^-$ was not rejected and its contribution to di-electron continuum was simulated with the same method. The Dalitz decays of $\pi^0 \rightarrow \pi^0 e^+e^-$, $\omega \rightarrow \pi^0 e^+e^-$ and $\eta' \rightarrow \gamma e^+e^-$ were obtained.
by using the Kroll-Wada expression [15]. The $\rho^0 \to e^+e^-$ line shape was convoluted with the Boltzmann phase space factor [16, 17]. Fig. 2 shows the total contribution from the simulation as black solid curve which is found to be consistent with the data over all measured mass region. The uncertainties of the simulations are about 30%, mainly coming from the uncertainties of the invariant yield of input sources. The invariant yield of $\pi^0$ is taken as the average of $\pi^+$ and $\pi^-$ [12, 18]. The yields of $\phi$ [19] and $\rho^0$ [17] are from STAR while $\eta$ [20], $\omega$ [21] and $J/\psi$ [22] are from PHENIX. In this simulation, the $c\bar{c}$ cross section was an input and constrained by the measurement from STAR [6, 23]. The $\chi^2/NDF$ of the comparison between data and simulation is 36/30 in the mass region of 0.1-3.2 GeV/$c^2$. In the intermediate mass region, di-electron continuum is dominated by the $c\bar{c}$ contribution. It is unable to distinguish STAR’s measured charm cross section from PHENIX’s [6, 24] with current data precisions.

**Figure 3.** The $M_{ee}$ distribution after the mixed-event background subtraction at $0.65 < M_{ee} < 0.95$ GeV/$c^2$ in p+p collisions at $\sqrt{s} = 200$ GeV. The fit is to obtain the $\omega \to e^+e^-$ raw yields in three different $p_T$ bins shown in the plot. The fit range is $0.7 < M_{ee} < 0.85$ GeV/$c^2$. The dashed green line represents the residual background. Errors on data points are statistical.

**Figure 4.** The efficiency including STAR acceptance for $\omega \to e^+e^-$ at $|y| < 1$ in p+p collisions at $\sqrt{s} = 200$ GeV.
Figure 5. The $\omega \rightarrow e^+e^-$ invariant yields, divided by its branch ratio, in non-singly diffractive p+p collisions at $\sqrt{s} = 200$ GeV. The open circles represent PHENIX published results [25]. The bars are statistical errors and boxes are systematic uncertainties. The line represents the yields of $\omega$ from Tsallis blast-wave function fit to high $p_T$ $\omega$ yields through hadronic decays in 200 GeV p+p collisions.

2.4. $\omega$ yields

To extract the $\omega \rightarrow e^+e^-$ signal, we used two components to fit the distribution of $M_{ee}$ at $0.7 < M_{ee} < 0.85$ GeV/$c^2$: the $\omega \rightarrow e^+e^-$ signal and the residual background. The residual background shape and magnitude were from simulation. The systematic uncertainties of the $\omega \rightarrow e^+e^-$ raw yields were derived by the magnitude of the background and it is in the order of 30% due to the uncertainties of the input invariant yields. Figure 3 shows the fit to the $M_{ee}$ distribution at $0.7 < M_{ee} < 0.85$ GeV/$c^2$ in three different $p_T$ bins in p+p collisions at $\sqrt{s} = 200$ GeV. Combining the TPC tracking, TOF acceptance and response, and the $dE/dx$ cut efficiency, the total efficiency including the STAR acceptance for $\omega \rightarrow e^+e^-$ at $|y| < 1$ is shown in Fig. 4. The $\omega \rightarrow e^+e^-$ invariant yields are shown as stars in Fig. 5 in non-singly diffractive p+p collisions at $\sqrt{s} = 200$ GeV. The open circles represent PHENIX published results [25]. The bars are statistical errors and boxes are systematic uncertainties, which were dominated by the fit and efficiency correction factors. Our measured $\omega$ yields through di-leptonic decays are consistent with previously published results [25] and the Tsallis function fit to the high $p_T$ $\omega$ yields [14] reconstructed from their hadronic decays.

3. Summary

The di-electron continuum is measured in 200 GeV p+p collisions at STAR. The cocktail simulations are consistent with the data in 200 GeV p+p collisions. The di-electron mass
distribution provide a reference for the future Au+Au. The newly installed TOF system enables this study. The $\omega$ invariant yields are consistent with the previously published results.

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