# Dilepton observables at the CERN super proton synchrotron

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Invariant-mass ($M$) spectra of dileptons in relativistic heavy-ion collisions (HICs) provide direct information on the electromagnetic (EM) current correlation function in the hot and dense medium throughout its entire evolution.

In the vacuum, as known from $e^+e^-\to$hadrons, the EM correlator is well described by the light vector mesons (most notably the ρ-meson) for invariant masses $M$<1.5GeV, and by a perturbative QCD continuum at $M$>1.5 GeV. Thus, to understand the dilepton signal in HICs one has to assess the in-medium modifications of the light vector mesons. At high temperatures and densities QCD predicts a phase transition from a chirally broken to a symmetric state, at a critical temperature of $T_c$=160-190 MeV at vanishing baryon density. This implies a softening of hadronic spectral functions and a degeneracy among chiral-partner states.

Employing many-body theory based on effective hadronic models [1], we have analyzed recent high-precision NA60 data [2] on dimuon $M$ and transverse-momentum ($q_T$) spectra in 158AGeV In-In collisions [2]. Our approach includes a detailed description of the light vector mesons including mesonic and baryonic interactions in the medium and results in a massive broadening especially for the ρ meson, with small mass shifts. The pertinent EM current correlator determines the dilepton emission rate which has to be integrated over the thermal evolution of the medium, which we modeled by a homogeneous thermal fireball with radial flow. The temperature evolution is extracted utilizing an equation of state for an ideal gas of light quarks and gluons above $T_c$ and for a hadron resonance gas below $T_c$. In the hadronic phase hadron-chemical potentials are introduced to conserve the particle-number ratios which are fixed at chemical freeze-out temperatures of $T_{\mathrm{ch}}\approx$160-175 MeV (consistent with thermal-model fits to heavy-ion data).

Our earlier model predictions [3] show good agreement with inclusive NA60 dimuon $M$-spectra in semi-/central In-In collisions [4], but underpredict the experimental $q_T$ spectra (and corresponding slope parameters) above $q_T\sim$1 GeV. We therefore have conducted a systematic study of sources for hard dileptons, including radiation from (i) t-channel-meson exchange in thermal $\pi\rho\to\pi\gamma$ scattering, (ii) decays of hard ρ mesons, which are produced in primordial N-N collisions, undergoing jet quenching but not equilibration, (iii) decays of ρ mesons after thermal freeze-out ($T_{fo}$=120-140 MeV), which in the earlier models [1,3] were approximated by an extra 1 fm/$c$ of fireball lifetime; the spectra from a thermal source are, however, softer by a Lorentz factor $1/\gamma=M/q_0$ ($q_0$: dilepton energy) compared to the decay of freely streaming ρ mesons due to relativistic time dilation [2]. We also have taken into account (iv) Drell-Yan annihilation in primordial N-N collisions, extrapolated to small $M$ using constraints from the real-photon point.

Although the t-channel-meson exchange contributions are the hardest among all thermal sources, their absolute magnitude cannot explain the observed slopes of the $q_T$ spectra above 1 GeV. The comparison improves including the other sources of hard dileptons listed above. However, to reproduce the large measured effective slopes in the low-mass region ($M$<1 GeV) an increase of the radial acceleration of the fireball is necessary, leading to larger blue shifts of the $q_T$-spectra (especially for ρ decays after thermal freeze-out). The slopes at larger invariant masses are less affected since the dominant contribution in this region mostly originates from larger temperatures, i.e., earlier stages of the fireball evolution. It is important to note that the refinements of the model concerning hard dilepton sources do not spoil the previously found agreement [3] in the description of the $M$-spectra, dominated by thermal radiation which is most relevant at lower $q_T$<1 GeV (left panel of Fig. 1). We furthermore have verified that the (earlier and recent) dielectron spectra by CERES/AN45 [5] in central 158 AGeV Pb-Au collisions are well described within our updated approach. In particular, the large enhancement at very low $M<2m_\pi$ is consistent with our predictions and underlines the importance of baryon effects in the medium modification of the light vector mesons (middle panel of Fig. 1).

Finally we have studied the sensitivity of the model to the equation of state (EoS) by varying (i) the critical temperature according to recent lattice-QCD results [6], $T_c$=160-190 MeV, and (ii) the chemical-freezeout temperature according to thermal-model fits to hadron data in HICs [7]. In addition to our standard scenario with $T_c=T_{\rm ch}$=175 MeV (labelled EoS-A in Fig. 1), we studied a case with $T_c=T_{\rm ch}$=160 MeV (EoS-B), as well as $T_c$=190 MeV and $T_{\rm ch}$=160 MeV (EoS-C). The latter is characterized by chemical equilibrium in the hadronic phase for $T$=160-190 MeV. We find that the $M$-spectra are quite insensitive to these variations in the EoS, due to the fact that the underlying dilepton rates for QGP (hard-thermal loop improved quark-antiquark annihilation) and hadron gas (hadronic many-body vector-meson spectral functions) are very similar in the vicinity of the phase boundary, interpreted as a "quark-hadron duality" [1].

Another important observation (and direct consequence of quark-hadron duality) is that the current uncertainty in $T_c$ prevents a conclusion on whether dilepton emission for 1 GeV<$M$<1.5 GeV is predominantly of partonic or hadronic (multi-pion) origin, since both the QGP- (EoS-B) and hadron-dominated (EoS-C) scenarios describe the measured $M$-and $q_T$-spectra and effective slopes comparably well.

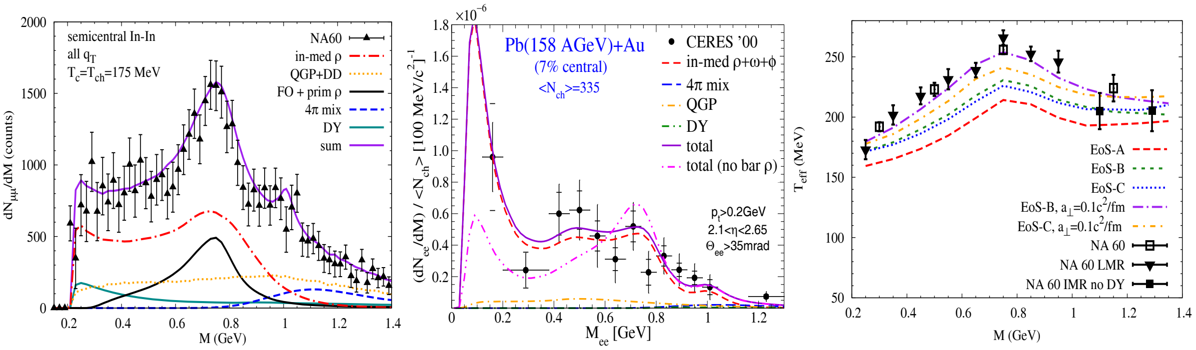

**Figure 1**. Left panel: dimuon excess spectrum of our approach [2] compared to NA60 data [4] from semicentral 158 AGeV In-In collisions; middle panel: the same model applied to compute dielectron excess spectra in 158 AGeV Pb-Au collisions confronted with CERES/NA45 data [5]; right panel: effective slope parameters of dimuon-$q_T$ spectra in semicentral 158 AGeV In-In assuming different equations of state and transverse acceleration of the thermal fireball expansion (see the text for details), compared to NA60 data [4].

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