HIGHLIGHTS FROM THE NA60 EXPERIMENT

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The NA60 experiment is a fixed-target experiment at the CERN SPS. It has measured the dimuon yield in Indium–Indium collisions with an In beam of 158 AGeV/c and in p-A collisions with a proton beam of 400 and 158 AGeV/c. The results allow to address three important physics topics, namely the study of the ρ spectral function in nuclear collisions, the clarification of the origin of the dimuon excess measured by NA50 in the intermediate mass range, and the J/ψ suppression pattern in a collision system different from Pb-Pb. An overview of these results will be given in this paper.

The NA60 experiment. The measurement of dimuon production is a key tool to gain insight into ultra-relativistic nuclear collisions. However, the importance of the dimuon data depends strongly on the resolution of the experimental apparatus. While the NA50 experiment measured the J/ψ suppression pattern as a function of centrality in Pb–Pb collisions, its mass and vertexing resolutions were not sufficient to address two other important physics topics, namely the shape of the in-medium spectral function of the ρ meson and the origin of the dimuon excess observed by NA50 in the intermediate mass region (IMR, 1.2-2.7 GeV/c^2).

The NA60 experiment inherited from NA50 the muon spectrometer (MS) for muon triggering and tracking, and the Zero Degree Calorimeter (ZDC), which measures the energy carried forward (at 0°) by the spectator nucleons, to evaluate the centrality of A–A events. Two components were added: before the target, a beam scope (BS) made of two pairs of cryogenic silicon strip detectors determines the beam impact point on the target transverse plane with a 20 μm resolution; after the target, a vertex tracker (VT), made of 16 planes of radiation-hard silicon pixel detectors embedded in a 2.5 T dipolar magnetic field, measures tracks and their momenta before they suffer multiple scattering in the absorber (for details on the NA60 apparatus see[1]).

Tracks in the VT are matched (both in momenta and in coordinate space) to tracks measured in the muon spectrometer. This procedure greatly improves the mass resolution, particularly in the low-mass range (20 MeV/c^2 at the ω mass, to be confronted with NA50 80 MeV/c^2). This allows to resolve and evaluate the different contributions to the dimuon spectrum below 1.2 GeV/c. Moreover, it is possible to determine the offset between muon tracks and the primary interaction vertex with a precision of ~40 μm for 20 GeV/c muons. This is sufficient to discriminate between muons coming directly from the fireball and muons originated by secondaries decays in the intermediate mass range.

The results reported in this paper were obtained from the analysis of data taken in 2003 for In–In collisions at 158 AGeV/c, and in 2004 for p–A collisions at 158 GeV/c. The choice of a colliding system different from Pb–Pb makes it possible to search for the scaling variable which drives the onset of the J/ anomalous suppression. Moreover, p{A data at 158 GeV allow to compare p{A to A{A data without systematic errors deriving from the energy rescaling.

The low mass region. The net opposite-sign dimuon spectrum below 1.4 GeV/c^2 has been obtained from the raw mass spectrum by subtraction of combinatorial background and of signal fake matches between tracks in the MS and in the VT. Four centrality classes were de ned via the charged particle multiplicity measured by the VT. Most peripheral data (4 < dN_{ch}=d < 30) are well reproduced by the cocktail of expected electromagnetic decays of the neutral mesons, while for more central collisions a strong excess appears, whose shape is not known a priori. Thanks to the high data quality, it is possible to isolate this excess by subtracting from the data a hadron cocktail without the (see[2]), whose spectral shape is expected to be modi ed in the reball. The resulting excess is shown in Fig.1 (left) for semicentral collisions (110 < dN_{ch}=d < 170): it is characterized by a peaked structure centered on the nominal mass, which broadens and increases with centrality and resides on a wide continuum. However, a quantitative analysis of the excess (for details see[3]) demonstrates that the ratio between the continuum-subtracted peak and the obtained from the cocktail t decreases by almost a factor 2 from most peripheral to most central bin. This means that the excess can not be simply interpreted as the cocktail on top of a continuum.

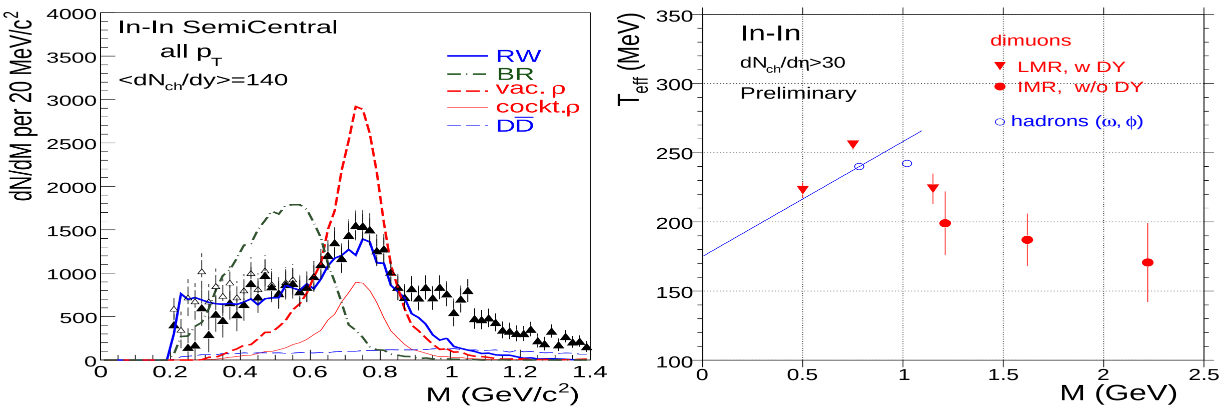

Figure 1: Left: comparison of excess mass spectrum (black triangles) with no p_T cut to model predictions made for In-In at dN_{ch}=d = 140 (semicentral bin). Cocktail (thin solid), unmodi ed (dashed), in-medium broadening [5], in-medium moving related to [4] (dashed-dotted), uncorrelated charm (thin dashed). Errors are purely statistical. The open data points show the excess resulting from a decrease of the subtracted yield by 10%. Right: T_{eff} from an exponential t to the p_T window 0:6 2 GeV/c vs. mass. The open circle points are the ! and temperatures. Full circle points are obtained from a di erent analysis of the IMR up to 2.5 GeV/c^2 (see g.2). The line is the expected temperature on the basis of a linear dependence on meson mass as determined by the NA49 systematics[7].

As shown in g1 (left), the moving mass model related to Brown/Rho (BR) scaling is ruled out. The qualitative features of the excess mass spectra are consistent with the interpretation as direct thermal radiation from the reball, dominated by annihilation. Models based on the in-medium broadening scenario and which take into account the role of baryons in the broadening[5] are able to reproduce quantitatively the data below 0.9 GeV/c. For the mass region above 0.9 GeV, data seem to be described equally well by introducing 4 hadronic processes sensitive to vector-axialvector mixing (and therefore to chiral symmetry restoration) or in terms of partonic processes dominated by $q\bar{q}$ annihilation. This feature could be a manifestation of parton-hadron duality.

The study of p_T spectra presents further interesting features. The trend at small p_T is opposite to the attening expected from radial ow of hadrons produced at kinetic freeze-out, while it attens as expected in the mass bin. Moreover, the T_{eff}, obtained from ts of the

m_T spectra (see g.1 right) and plotted as a function of mass, shows a maximum in the like region. This may be attributed to the produced at freeze-out, which experiences the largest blue-shift and thus the highest e ective temperature. Besides that, it is worth noting that the continuum above 0.9 GeV/c is cooler than the continuum below 0.6 GeV/c: this seems to indicate that the two regions are fed by qualitatively di erent sources. It is hoped that a ner theoretical understanding of p_T spectra could serve as a handle to disentangle partonic from hadronic sources (breaking parton-hadron duality). For details see [6].

Intermediate mass region. To understand the origin of the excess measured by NA50 in the IMR, NA60 has measured the o set of the muon tracks with respect to the main interaction vertex. This distribution has been weighted by the inverted error matrix from the vertex t and the muon extrapolation (the combinatorial background was subtracted by event mixing). The resulting distribution is composed of two components, the Drell-Yan (i.e. prompt) and the open charm (o vertex) events. To evaluate each contribution, their shapes were obtained from Pythia (details are given in [8]); then, the o set distribution was tted as a superposition of prompt and o -vertex contributions. The t parameters are the coe cients by which each contribution should be scaled in order to describe the data.

The t fails to reproduce the data if the prompt yield is forced to 1.1 the expected Drell-Yan yield, and the open charm is left free. In the left panel of g.2 both contributions are left free: in this way, an accurate representation of data is achieved. The t parameters indicate that the prompt contribution is two times larger than expected: we can then conclude that the excess is due to a prompt source.

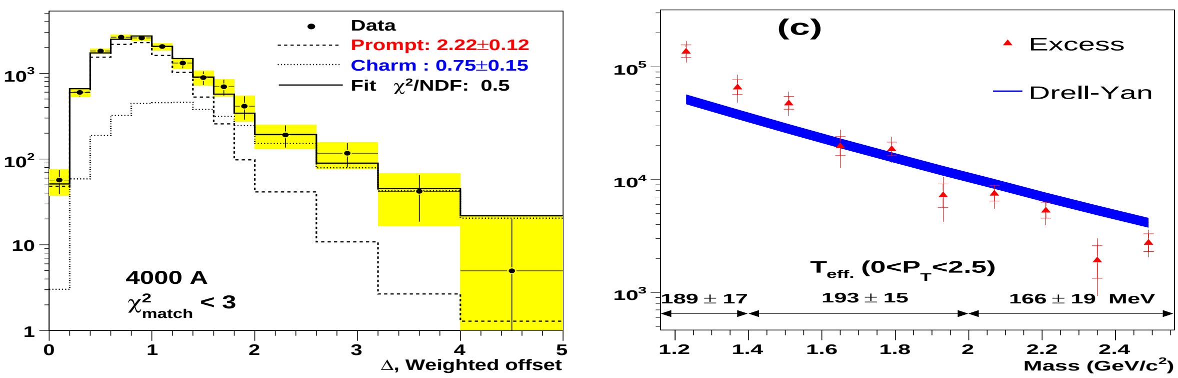

Figure 2: Left panel: t to the weighted o set distribution where both the prompt and the open charm yields are free parameters ($1{:}16 < m < 2{:}56$). Right: mass spectra of Drell-Yan and excess. The e ective temperature of the excess tted in the $0 < p_T < 2{:}5$ range for the mass bins of 1:16 1:4, 1:4 2:0 and 2:0 2:56 GeV$=c^2$ is also shown.

The naive hypothesis that the excess could be due to an increased Drell-Yan yield is ruled out by the p_T dependence of the ratio between the excess and the Pythia-generated Drell-Yan (after acceptance correction). It ranges from 3 at low p_T, to 0.5 at high p_T, suggesting that the excess is qualitatively di erent from Drell-Yan. This di erence is con rmed by the comparison of the excess and Drell-Yan mass spectra, shown in the right panel of g.2. The temperatures shown in the gure are obtained from ts in the range $0 < p_T < 2{:}5$ GeV/c: the systematic error on the temperature determination has been evaluated from ts performed in di erent p_T ranges and turns out to be of the order of 10 MeV (see also [8]).

J/ suppression in In-In. To measure the amount of anomalous suppression, the J/ yield has to be compared to a reference process. Traditionally, the Drell-Yan yield above 4 GeV/c^2 has been used, but this choice increases the statistical error due to the DY limited statistics. To overcome this limitation and fully exploit the J/ sample, NA60 has calculated the reference spectrum expected in case of normal suppression only: the relative normalization between the calculated and measured spectra is set to the value resulting from the $_{J=}$ = $_{DY}$

analysis (see [9]). The resulting suppression pattern is shown in fig. 3 (left), compared to the results published by NA50 in Pb–Pb collisions: both sets of data depart from the normal nuclear absorption line for $50 < N_{part} < 100$, suggesting that N_{part} could be well suited as scaling variable between different colliding systems. The data have been compared to theoretical predictions tuned for NA60 In–In collisions: none of them was able to reproduce data, even if the magnitude of suppression is reasonably reproduced (further details in [9]).

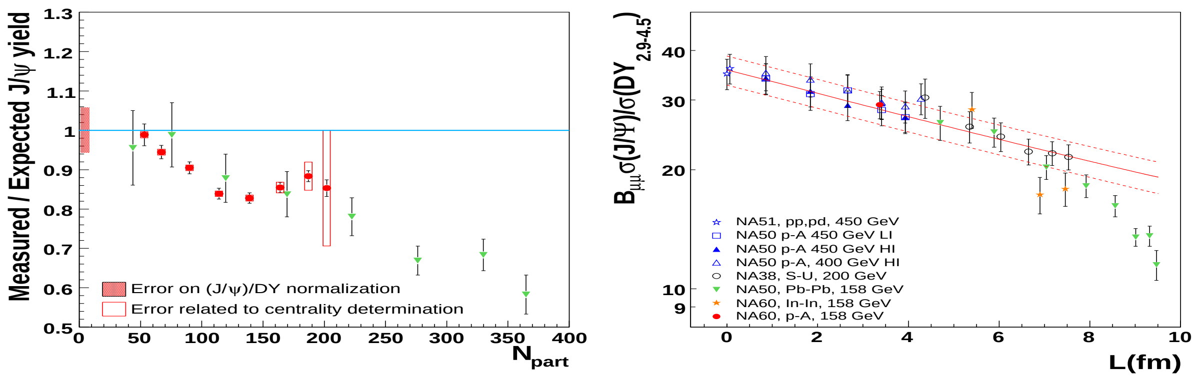

Figure 3: Left: comparison between the In-In (NA60: square points) and Pb-Pb (NA50: triangle points) suppression patterns. Right: Compilation of the $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ values measured in p–A and A-A collisions at the SPS, rescaled, when necessary, to 158 GeV/c: The lines indicate the results of a Glauber fit to the p–A data and the size of the error. The full circle indicates the preliminary NA60 result for p–A collisions at 158 GeV/c.

To evaluate correctly the anomalous suppression, the normal nuclear suppression (which can be extracted from p–A data) must be accurately known. However, up to 2004, p–A data were available only for proton energies of 400 and 450 GeV/c: this implied that the p–A results had to be rescaled to the energy of nuclei beams (158 AGeV/c), under the assumption that σ_{abs} would not change with the beam energy. In order to eliminate uncertainties associated with this assumption, NA60 has taken p–A data at the same energy of the Indium beam on a variety of targets (Be, Al, Cu, In, W, Pb and U). Up to now, a preliminary estimate of $\sigma_{J/\psi}/\sigma_{DY}$ has been obtained by averaging over the different targets. In fig. 3 right, it is shown a comparison of this result to the previous measurements (rescaled when necessary) as a function of the mean length of nuclear matter traversed by the J/ψ. The NA60 average point corresponds to a length $\langle L \rangle = 3.4$ fm and falls along the interpolating band, corroborating the correctness of the rescaling procedure and confirming the anomaly of the J/ψ suppression with respect to a pure nuclear absorption scenario.

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