Charm and intermediate mass dimuons in In-In collisions

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We present preliminary results on the production of intermediate mass dimuons in 158 A·GeV In-In collisions at the CERN SPS. NA38 and NA50 observed a strong excess in this region in S-U and Pb-Pb interactions with respect to the dimuon production rate expected from p-A data. Thanks to the use of a pixel vertex telescope, NA60 can separate the prompt dimuons from the pairs resulting from open charm decays and show that the excess dimuons are of prompt origin.

One of the most interesting findings of the experiments studying heavy ion collisions in view of Quark-Gluon Plasma search is the excess of dimuons in the intermediate mass region (IMR, 1.2–2.7 GeV/c^2) observed in S-U and Pb-Pb collisions by NA38/NA50 [1] and in S-W collisions by HELIOS-3 [2]. The continuum between the ϕ and J/ψ peaks is well described in p-A collisions by the superposition of Drell-Yan dimuons and muon pairs from simultaneous semi-muonic decays of D and $\overline{\mathrm{D}}$ mesons [1]. Since the Drell-Yan contribution can be normalized from the high mass region, an excess in heavy-ion collisions is more likely to be due to the increase of *open charm* production (difficult to explain in the framework of pQCD) or to the appearance of the long-sought *thermal dimuons*, considered to be one of the most direct signatures of QGP formation [3]. It could also be due to the modification of the Drell-Yan mass spectrum due to higher-twist effects in nucleus-nucleus collisions [4]. To make progress it is crucial to separate the *open charm* contribution from prompt dimuons. The NA60 experiment can do this by measuring the offset of the muons from the interaction vertex, exploiting the long lifetime of D mesons: $c\tau = 312\ \mu$m for D^+ and 123 μm for D^0 [5].

The NA60 setup [6] consists of a Muon Spectrometer (MS) and a Zero Degree Calorimeter (ZDC), both inherited from NA50, a Vertex Telescope (VT) made from silicon pixel planes [7,8] embedded in a 2.5 T dipole magnetic field, and a Beam Tracker (BT) measuring the transverse position of the incoming ion before its interaction in the target.

By matching the muons reconstructed in the MS to the tracks measured in the VT we obtain the muon kinematics unaffected by the scattering in the hadron absorber. The matching is done by computing the weighted distance squared (χ^2) between these two tracks in the space of angles and inverse momenta, taking into account the error matrices. This procedure improves the mass resolution from 70–80 MeV/c^2 to 20–25 MeV/c^2 at M$\sim$1 GeV/c^2 and allows us to relate the muon to the interaction vertex. Fig. 1a shows the dispersion between the transverse position of the fit vertex and that of the BT prediction with resolution $\sigma_{\mathrm{BT}} = 20\mu$m as a function of the number of tracks associated with the vertex. The corresponding vertex resolution (also shown) is better than 10 μm in X (bending plane) and 15 μm in Y over most of our multiplicity range. Since at our energies the J/ψ is always prompt, we can use it to control the resolution of the muon offset with respect to the vertex. To account for the momentum dependence of the offset resolution, the *weighted offset* is used, defined as $\Delta_\mu = \sqrt{\Delta x^2 V_{xx}^{-1} + \Delta y^2 V_{yy}^{-1} + 2\Delta x \Delta y V_{xy}^{-1}}$ for the single muons and $\Delta_{\mu\mu} = \sqrt{(\Delta_{\mu 1}^2 + \Delta_{\mu 2}^2)/2}$ for dimuons, where the V^{-1} is the inverted error matrix from the vertex fit and the muon extrapolation. Fig. 1b shows the measured X and Y offset resolutions as a function of the inverse momentum. The (dimensionless) *weighted offset* distribution (top points) is also shown, scaled by a factor 100.

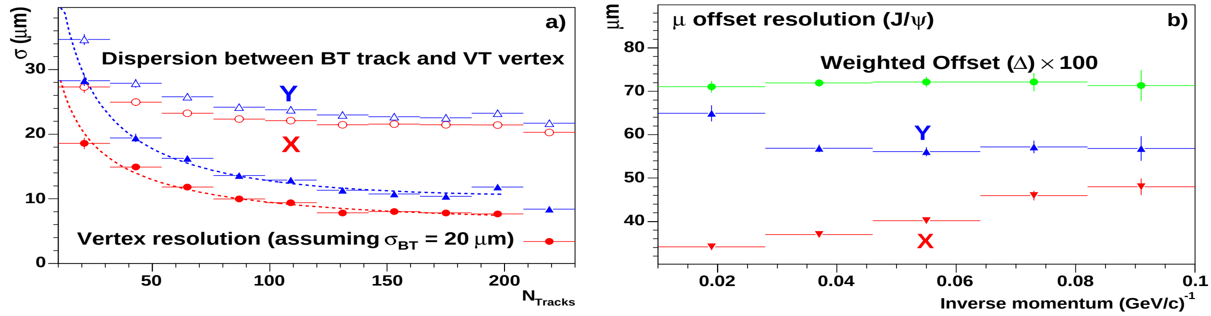

Figure 1. Transverse coordinate resolution of the interaction vertex as a function of multiplicity **(a)** and muon offset resolution as a function of inverse momentum **(b)**.

There are two types of background in NA60. Muons from uncorrelated π and K decays create the *combinatorial background* (CB). Additionally, some fraction of the muons from the MS can be wrongly matched to hadronic tracks in the VT, thus creating the *fake matches background*. Both types of background are subtracted by *mixed events technique*. First, the CB spectrum is built by combining into muon pairs two single muons from different like-sign dimuons in such a way that the obtained dimuons respect the acceptance and trigger conditions of NA60. Since this procedure does not distinguish between the fake and correct matches, after the subtraction of this spectrum only signal dimuons (both with correct and fake matches) remain. Then the spectrum of dimuons containing the *fake matches* (FB), is created by matching the MS muons from one event with VT tracks from a different event and mixing them in a special way with the matches from data events. This spectrum contains the *fake matches* both for the signal and combinatorial pairs. To separate the former contribution, we build the *fake combinatorial dimuons* (FCB) in the same way as it is done for the CB but using the single muons from the like-sign FB. The correctly matched signal spectrum is obtained as *Data - CB - (FB - FCB)*. Fig. 2a shows the measured opposite-sign dimuons' mass spectrum together with the two different types of background and the extracted signal. Only matches with $\chi^2 < 1.5$ are selected.

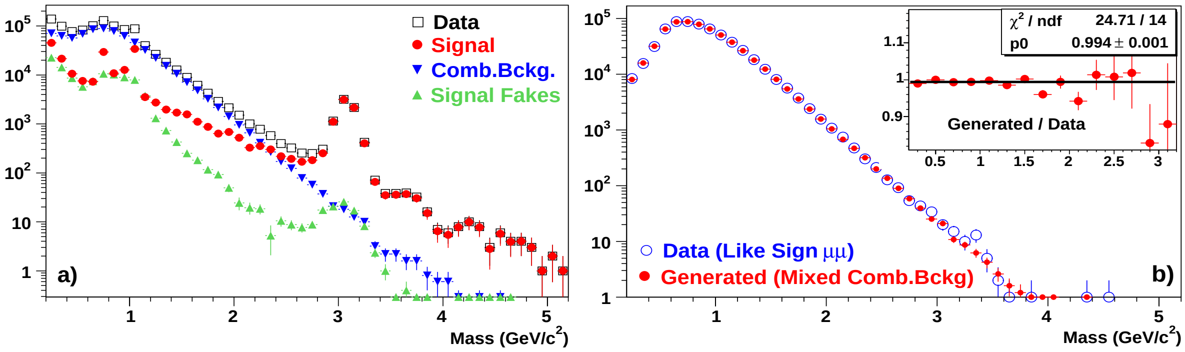

Figure 2. **(a)** Opposite-sign dimuon data, *combinatorial background* (CB), *fake signal* and final correctly matched signal; **(b)** Measured and generated like-sign CB spectra.

The quality of the mixed CB can be controlled by comparing the generated like-sign spectrum with the measured one, Fig. 2b. As one can see, the measured spectrum is reproduced within ∼1%, which, taking into account signal to background ratio of ∼1/10, means ∼10–20% systematic error on the final signal.

To fit the obtained spectra, the Drell-Yan and open charm contributions were generated by Pythia 6.2 using CTEQ6M PDFs with EKS98 nuclear modifications. To fix the relative normalization of these contributions, a K-factor of 1.8 was applied to Pythia's Drell-Yan cross section, in order to reproduce the high-mass cross section measured by NA50 [9]. The $c\bar{c}$ cross-section was taken to be 12 μb/nucleon, to reproduce the NA50 analysis of the 450 GeV p-A data. Note that this is almost twice higher than the *world average* cross section at this energy [10]. The absolute Drell-Yan normalization as a function of the collision centrality is obtained from the number of the observed J/ψ events, the J/ψ suppression pattern and the expected ψ/DY ratio [11]. The data are analyzed in the kinematic domain $0 < y_{\rm CM} < 1$ and $|\cos\theta_{\rm CS}| < 0.5$ and $1.2 < {\rm M}_{\mu\mu} < 2.7$.

First we check if the superposition of the expected Drell-Yan and open charm contributions can describe the mass spectrum of NA60. Fig. 3a shows the result of the fit with the normalization factors fixed within ±10% of their expected values. There is a big excess in the IMR, considerably higher than the expected DY yield (Fig. 3b). Letting the open charm normalization free improves the fit, leading to 80–90% more charm than expected, as shown in Fig.3c. This is consistent with the observation of NA50 that a charm yield enhanced by a factor of 3 is needed to describe the spectrum from central Pb-Pb collisions.

In the next step we fit the signal dimuons *weighted offset* distribution as a superposition of the prompt and open charm contributions. For the former the shape of the sum of the measured J/ψ and ϕ offsets is used, while for charm we use the Monte-Carlo shape, smeared to account for the difference between the Monte-Carlo and data observed in the J/ψ and ϕ signals. Fig. 4a shows the result of the fit with the prompt contribution normalized to the expected Drell-Yan and the open charm left free. The latter is too flat to describe the data. Letting both contributions vary freely, see Fig. 4b, gives a good description of the data, preferring the yield extrapolated from the NA50 p-A data, but requiring almost twice as many prompt dimuons as the expected Drell-Yan. Fig. 4c shows

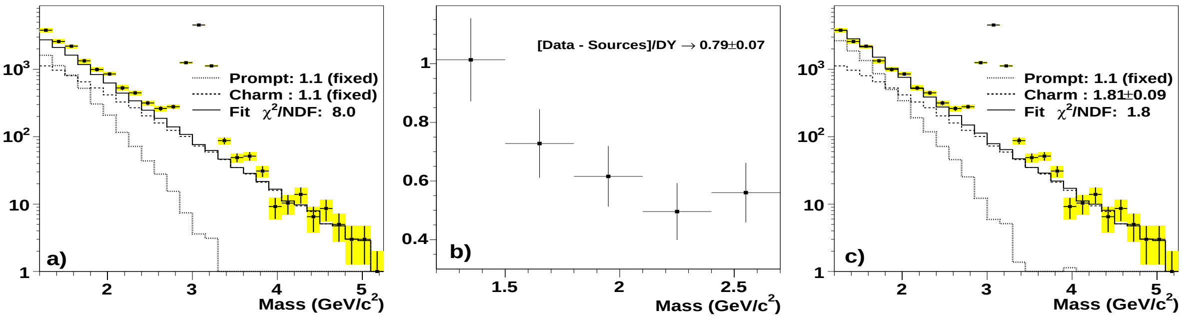

Figure 3. Fit of IMR mass spectrum to the superposition of Drell-Yan and open charm contributions: **(a)** both normalizations are fixed to be within 10% of expected value; **(b)** ratio of the excess from (a) to the Drell-Yan contribution; **(c)** open charm yield is let free.

the ratio of the excess to the number of participants (in arbitrary units since the latter is taken to be proportional to the observed ω yield) in three centrality bins.

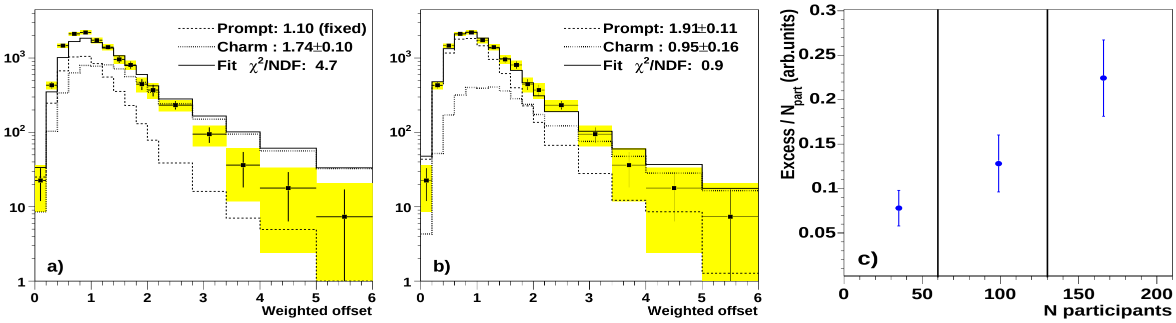

Figure 4. Fit of IMR dimuon *weighted offset* spectrum by the superposition of prompt (dashed) and open charm (dotted) contributions: **(a)** the prompts are fixed to the expected Drell-Yan level and the charm is free; **(b)** both contributions are free; **(c)** ratio of the excess to the number of participants (in arbitrary units) as a function of centrality.

In conclusion, this preliminary analysis of In-In collisions at 158 A·GeV shows an excess of IMR dimuons over the expected Drell-Yan and open charm contributions. It is caused by prompt dimuons and has a steeper mass distribution. The excess rises faster than linearly with the number of participants.

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REFERENCES

1. M.C. Abreu *et al.* (NA50 Coll.), Eur. Phys. J. **C14** (2000) 443.
2. A.L.S. Angelis *et al.* (HELIOS-3 Coll.), Eur. Phys. J. **C13** (2000) 433.
3. R. Rapp and E. Shuryak, Phys. Lett. **B473** (2000) 13.
4. J.W. Qiu and X.F. Zhang, Phys. Lett., **B525** (2002) 265.
5. S. Eidelman *et al.* (PDG), Phys. Lett. **B592** (2004) 1.
6. R.Arnaldi *et al.* (NA60 Coll.), Eur. Phys. J. **C43** (2005) 167.
7. K. Banicz *et al.*, Nucl. Instrum. Meth. **A539** (2005) 137.
8. G. Usai *et al.* (NA60 Coll.), Eur. Phys. J. **C43** (2005) 415.
9. M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B410** (1997) 337.
10. H. Wöhri and C. Lourenço, J. Phys. **G30** (2004) S315.
11. R. Arnaldi *et al.* (NA60 Coll.), these proceedings.