EUROPEAN LABORATORY FOR PARTICLE PHYSICS

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NA60 status report

The NA60 Collaboration

Abstract

In this report the main results obtained from the analysis of the NA60 data during 2007 are reviewed. Also the future perspectives for the analysis activity during 2008 are considered.

1 The low and intermediate dimuon mass regions in Indium-Indium collisions: first evidence of dilepton radial flow

As discussed in the previous report, in the mass region below 2.6 GeV an excess over the expected sources has been isolated.

The left panel of Fig. 1 shows in detail the excess in the low mass region resulting from the subtraction of the known pseudoscalar and vector mesons contributions [1].

In the intermediate mass region, the detailed analysis of the offset distributions (also discussed in the previous report) showed that the observed open charm yield is consistent with the extrapolation from the NA50 p-A data. Thus, no enhanced open charm production is observed. The excess comes from a prompt source and it is 2.4 times the expected Drell-Yan yield. The left panel of Fig. 2 shows the dimuon excess mass distribution observed in the intermediate mass region, which is steeper than the Drell-Yan.

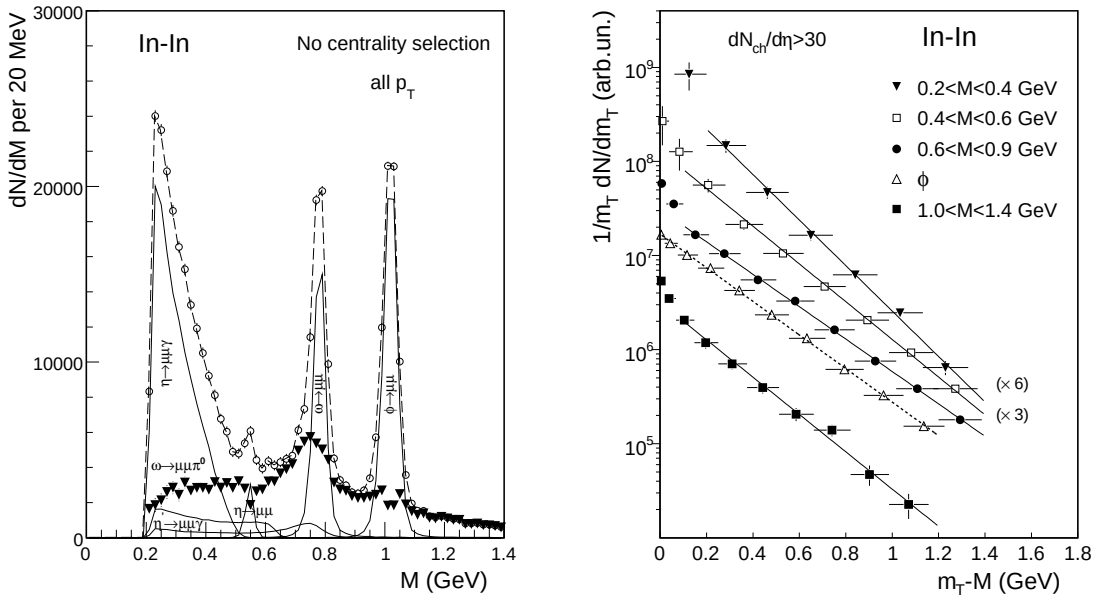

Figure 1: Left: Isolation of an excess above the electromagnetic decays of neutral mesons in the low mass region. Total data (open circles), individual cocktail sources (solid), difference data (thick triangles), sum of cocktail sources and difference data (dashed). Right panel: Transverse mass spectra of the excess for four mass windows summed over centralities (excluding the peripheral bin) in comparison to the ϕ.

For $M < 1$ GeV the dimuon excess yield is dominated by the process $\pi^+\pi^- \to \rho \to$

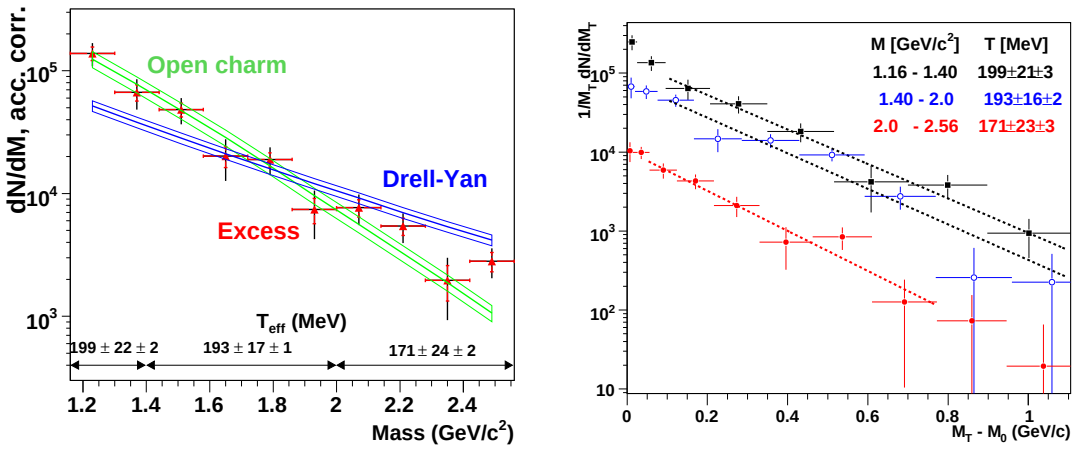

Figure 2: Left: excess mass distribution in the intermediate mass region and comparison to Drell-Yan and open charm. Right: Transverse mass spectra of the excess for three mass windows summed over centralities.

$\mu^+\mu^-$ with a strongly modified intermediate ρ. Different many-body hadronic models are able to describe the data with a strongly broadened intermediate ρ without any mass shift.

On the other hand, there is not a unique interpretation for masses above 1 GeV. There are models able to describe this region in terms of partonic processes (the long sought thermal radiation from the plasma) [2], others where the predominant processes are hadronic (4 pion annihilation or higher processes) [3]. This ambivalence reflects what is usually called parton-hadron duality.

In order to try to clarify this situation, NA60 has now focused the attention on the transverse momentum spectra, which encode information on the source temperature and on the collective motion (radial flow) that takes place during the fireball expansion. When the spectra are fitted with the simple Boltzmann-like function $dN/dp_T = p_T \exp(-m_T/T_{eff})$, the *effective* temperature extracted from the spectra is not any longer the source temperature. It is blue shifted (boosted) by the collective motion and acquires a linear dependence on mass. Since dimuons are emitted continuously during the whole fireball lifetime, they probe regions where the source temperature was high and the flow was small (early phases of the fireball with a low effective temperature close to the real source temperature), or regions where the temperature was low and the flow was high (later phases of the fireball lifetime with

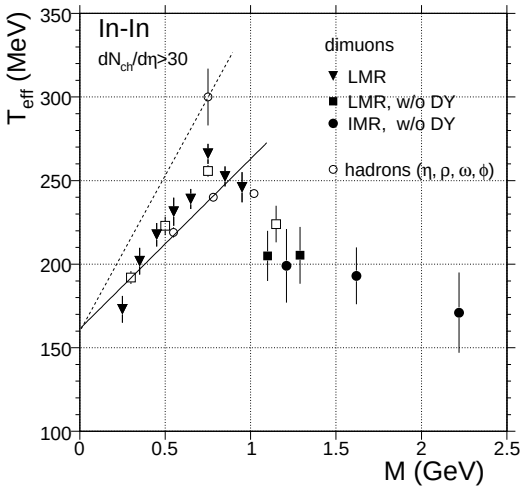

Figure 3: Inverse slope parameter T_{eff} vs. dimuon mass M for $dN_{ch}/d\eta > 30$.

a larger effective temperature because the increasing flow boost predominates over the fireball cooling). In this way, dimuon transverse momentum spectra can be used as a diagnostic tool to access the emission region and may differentiate between a hadronic or a partonic nature of the source.

The acceptance-corrected transverse momentum spectra of the excess were measured for several mass intervals from threshold up to 2.6 GeV. The results are shown in detail in the right panels of Fig. 1 and Fig. 2. They were fitted with the Boltzmann-like exponential function given above. The effective temperature T_{eff} as a function of the dimuon invariant mass is shown in Fig. 3. For comparison, also the temperature of the stable hadrons η, ω and ϕ, as measured by the same experiment, are shown (open circles). Several striking features are seen. First, the effective temperature of the excess shows an almost linear rise with mass up to $M = 1$ GeV, as for the hadrons. As mentioned above, this is a rather clear evidence of radial flow.

Second, the effective temperature exhibits a sudden drop of almost 50 MeV at $M = 1$ GeV. In addition, for masses beyond 1 GeV, T_{eff} remains at an approximately constant value. This feature reflects seemingly a condition of rather small or no flow. This observation could suggest, for $M > 1$ GeV, that dimuons are emitted from a source which was dominant in an early stage of the fireball evolution, as the *partonic* process $q\bar{q} \rightarrow \mu^+\mu^-$.

All these results have been finalised. A paper has been submitted to Physical Review Letters. A more extensive paper mainly focused on the excess found in the

intermediate mass region is ready for submission.

2 J/ψ suppression in Indium-Indium collisions

The results on the J/ψ suppression, discussed in the previous report, have been finalised and published in Physical Review Letters. The suppression pattern is shown in the left panel of Fig. 4 and compared with the NA50 results relative to Pb-Pb collisions. The two suppression patterns are compatible within the common range of number of participants and clearly show that the J/ψ is suppressed beyond normal nuclear absorption at SPS energies. A similar effect has been recently observed also in Au-Au collisions at RHIC ($\sqrt{s} = 200$ GeV/nucleon).

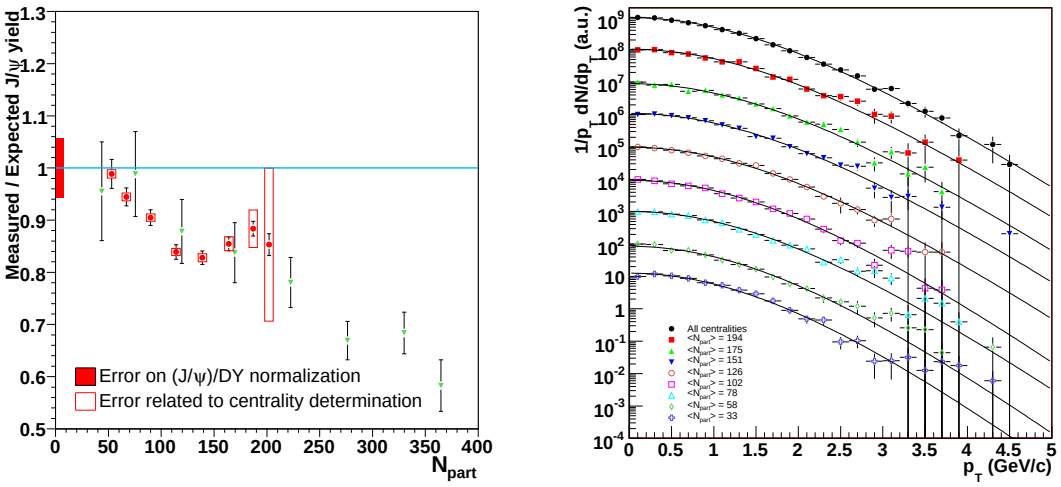

Figure 4: Left: Comparison between the In-In (NA60, circles) and Pb-Pb (NA50, triangles) suppression patterns. The box on the left shows the 6% systematic error related to the normalization procedure of the In-In points. Right: J/ψ transverse momentum spectra for several centrality bins.

Further results have been obtained from the study of the differential spectra. The transverse momentum distributions have been studied in several centrality bins and are shown in the right panel of Fig. 4. The effective temperature, integrated over centrality, is $T_{J/\psi} = 231 \pm 2$ MeV. A broadening of the transverse momentum spectra as a function of centrality is observed, consistent with the broadening due to gluon scattering in the initial state. Also the J/ψ rapidity distribution has been measured. Data are consistent with a gaussian distribution roughly independent of centrality and having a width of 0.68 ± 0.02.

The J/ψ polarization in the helicity reference frame has been studied as a function of transverse momentum, rapidity and centrality. This measurement has considerable interest since the quarkonium polarization is a key test for different production models. Moreover, it was speculated that deconfinement could lead to a significant

polarization. The present results show that the polarization is consistent with zero, independent of centrality or any kinematic variable.

In addition, also the ψ' suppression pattern has been measured. While it is presently thought that the J/ψ could survive well above the deconfinement critical temperature (up to $2T_c$), the relatively loose bound states ψ' and χ_c should melt for temperatures around T_c. This study is limited by the statistics which amounts to 300 ψ' in the total sample. The yield is normalized to the Drell-Yan and studied in three centrality bins. An anomalous suppression is observed, in good agreement with the Pb-Pb results.

Presently the suppression pattern is being studied as a function of rapidity and transverse momentum. In addition, also the measurement of the J/ψ absolute cross section is under way.

3 ϕ production in In-In collisions

The results on the ϕ differential spectra have been finalised and a paper draft is in preparation. The inverse T slopes extracted from transverse momentum spectra, as discussed in the previous report, are in rather good agreement with NA49. When the fit is restricted to the NA50 transverse momentum range ($p_T > 1$ GeV), the observed slopes are slightly smaller (a hint of radial flow) though not enough to agree with the NA50 values. The study of the differential spectra was completed by the measurement of the rapidity distribution and the polarization. The data are consistent with a gaussian rapidity distribution roughly independent of centrality and having a width of 1.15 ± 0.06. The polarization was extensively measured in different reference systems (Collins-Soper, Gottfried-Jackson and helicity). In all of the three reference frames the polarization is compatible with zero.

The largest effort in the past months was devoted to the absolute yield measurement. This is important in order to try to shed light on the long-standing discrepancy, know as ϕ *puzzle*, between the results found in Pb-Pb collisions by NA49 (which measured the ϕ in the kaon channel) and NA50 (which measured the ϕ in the muon channel). The yield measured in the muon channel by NA50 is 2-3 times higher than the yield measured in the kaon channel by NA49. Theoretical models tried to explain it assuming kaon absorption and rescattering in the hot and dense medium, which would suppress the observed ϕ yield in the kaon channel. In addition, the absolute yield measurement in NA60 now provides a normalization also for other processes in the low mass region, which is essential for quantitative comparisons to theoretical models.

The measurement is performed following two independent methods. The first is based on the luminosity determination, exploiting the beam counters provided by the ZDC and the Beam Tracker detectors. In the second approach, the number of observed J/ψ (corrected for anomalous suppression and nuclear absorption) or Drell-Yan events are used to estimate the number of interactions by using the known J/ψ

or Drell-Yan elementary cross sections (cross sections per binary collision). The first preliminary results seem to indicate that the ϕ yield in In-In (in the muon channel) is also higher than the one measured by NA49. On the other hand, the observed ϕ enhancement in In-In saturates already at a number of participants corresponding to Pb-Pb semi-peripheral collisions. This fact, together with the smaller system size in In-In which would lead to a smaller ϕ yield with respect to Pb-Pb, could indicate qualitative agreement with the NA50 results. The first preliminary results from NA60 may be shown in the oral presentation.

4 Elliptic flow of charged particles and J/ψ In-In collisions

The results on the charged particles and J/ψ elliptic flow discussed in the previous report have been finalised and a paper draft is in preparation.

5 Results from p-A 2002 data

The results from p-A data collected in 2002, mainly focused on the ω and ϕ production have been finalised and a paper is ready for submission.

6 p-A 2004 reconstruction and analysis

The p-A data can be divided in two samples, both collected with seven different targets (Al, Be, Cu, In, W, Pb and U). Data were taken with a 158 GeV/c beam (four days) using a vertex tracker made of 13 ALICE pixel planes, 2 ATLAS pixel planes and 2 BNL microstrip planes. In the remaining data taking period, a 400 GeV/c beam was used, with a few different setups of the vertex tracker including also ATLAS microstrip planes.

The analysis of the data collected with the 158 GeV/c beam is ongoing. The objective is to measure the nuclear dependence of the J/ψ absorption cross section at the same energy as the In-In data. The total sample consists of $\sim$ 11000 J/ψ dimuons. In a preliminary analysis, the ratio $\sigma_{J/\psi}/\sigma_{DY}$ averaged over the targets has been measured and compared to previous results as a function of L, the mean path of the J/ψ in nuclear matter. In the left panel of Fig. 5 a compilation of pA measurements, taken at various energies and rescaled at 158 GeV/c, is shown. The new NA60 point is in rather good agreement. This seems to indicate that the rescaling of the elementary production cross section, which was so far used in the determination of the nuclear absorption reference, is indeed correct. The next step will be the measurement of the absorption cross section.

Concerning the 400 GeV/c data sample, approximately 15% of the total statistics has been reconstructed and the analysis is ongoing. This fraction corresponds to a

set-up where the first ATLAS microstrip planes were replaced by pixel planes. The first physics results are expected by the end of this year. Selecting events with one dimuon correctly associated to a vertex in the target region, the total statistics of opposite sign muon pairs amounts to $\sim$ 100000, 6 times more than the statistics collected in 2002. The right panel of Fig. 5 shows the preliminary dimuon invariant mass spectra for the different nuclear targets. Fitting the ω, ϕ and J/ψ peaks with gaussian functions, the measured mass resolution is $\sigma_\omega = 35$ MeV, $\sigma_\phi = 37$ MeV, $\sigma_{J/\psi} = 104$ MeV. In the same figure the like-sign mass distribution ($\sim$ 5000 events) is also shown.

For what concerns the reconstruction of the remaining data sample, the alignment of the microstrip planes proved to be a rather delicate problem. In particular, the usual alignment method based on the minimization of residuals failed almost completely. A new method has been developed, based on the simultaneous search of correlations in the x, y coordinates between tracks reconstructed with the pixel planes and microstrips. The results obtained with this new method are satisfactory and a semi-automatic tool for the final alignment is under development. We expect to increase significantly the reconstructed data sample by the end of the year.

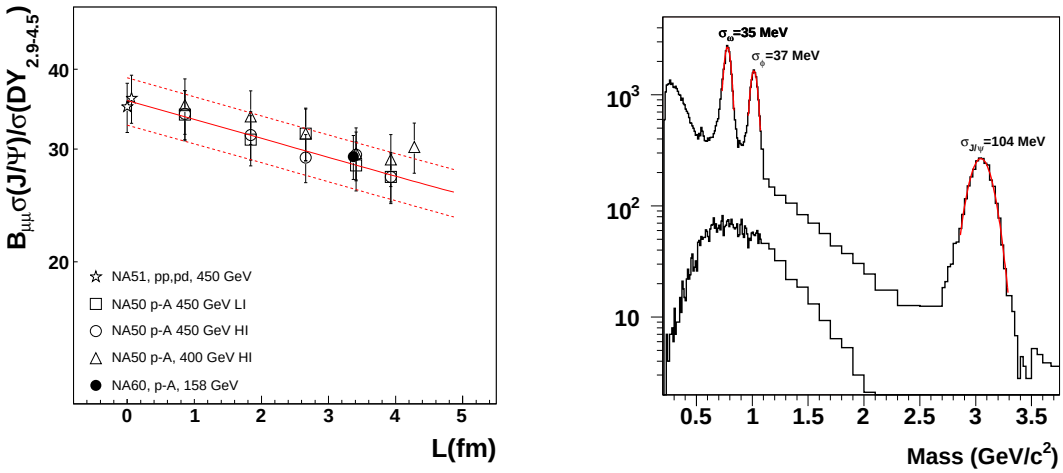

Figure 5: Left panel: Compilation of the $\sigma_{J/\psi}/\sigma_{DY}$ values measured in pA and nucleus-nucleus collisions at the SPS, rescaled, when necessary, to 158 GeV/c^2. The lines indicate the results of a Glauber fit to the p-A data and the size of the error. The full circle indicates the preliminary NA60 result for pA collisions at 158 GeV/c^2. Right panel: Dimuon invariant mass spectra, integrated over the different nuclear targets, for 15% of the total 400 GeV/c statistics.

The lack of sufficient manpower prevented so far the analysis of the proton data in parallel with the indium data. Since the analysis of the indium data will be largely terminated by the end of 2008, the proton data analysis will then receive the full attention and the collaboration will put the highest effort into the completion of the corresponding physics program.

7 Future plans

7.1 Near Term Priority topics

1. In-In analysis. The time estimate to complete each of the following analyses, which will lead to about 10 paper, is $1 - 1.5$ person-years.

   - Low Mass / thermal radiation
     - Acceptance-corrected mass spectra and spectral moments
     - Polarisation of the ω and the continuum
     - Elliptic flow of the continuum
     - Hadrons: electromagnetic transition form factors (η, ω Dalitz)

     Responsible: S. Damjanovic, H.J. Specht (part time)

   - Low mass / hadrons
     - Absolute calibration of NA60
     - ϕ analysis
     - Charged particle multiplicity
     - Flow analysis

     Responsible: M. Floris, G. Usai

   - J/ψ
     - Anomalous suppression as a function of p_T and y.
     - Finalisation of differential spectra and polarization
     - Absolute cross section

     Responsible: R. Arnaldi, E. Scomparin

2. Calibration and reconstruction of p-A data

   Responsible: R. Shahoyan, P. Martins (PhD), P. Parracho (PhD), P. Ramalhete (PhD), P. Cortese, M. Floris, C. Lourenco, J. Seixas, F. Manso

   Time estimate: 1/2 - 3/4 year

7.2 Further important analysis topics

1. p-A analysis

   - Low mass hadrons
     - Nuclear dependence of particle ratios
     - ρ/ω interference
   - J/ψ
     - Nuclear dependence at 400 and 158 GeV
     - Transverse momentum spectra
   - Open charm in p-A
     - Cross sections - Nuclear dependence
   - χ_c in p-A
     - Nuclear dependence

2. Ultra-peripheral collisions in In-In

3. Λ and D^0 production in In-In

There are more topics than people presently available for these analyses.

8 Requests to CERN

The NA60 collaboration will continue the analysis activity at least until the end of 2009. For this reason, we would like to request the support from the CERN IT division at the present level. In particular, the analysis work makes use of the raw data stored on the CASTOR system. In addition, we would like to keep the offices which are presently assigned.

References

[1] R. Arnaldi et al. (NA60), Phys. Rev. Lett. **96** (2006) 162302.
[2] J. Ruppert, T. Renk, arXiv:hep-ph:0612113
[3] H. van Hees and R. Rapp. Phys. Rev. Lett. **97** (2006) 102301

Papers published and in progress - 2007

1. J/ψ production in Indium-Indium collisions at 158 GeV/nucleon. Phys. Rev. Lett. 99 (2007) 132302. Available in the arXiv: arXiv:0706.4361

2. First measurement of radial flow of thermal dileptons in high energy nuclear collisions. Submitted to Physics Review Letters.

3. Production of dimuons in the mass region between the ϕ and the J/ψ in indium-indium collisions at the SPS. Paper in preparation, to be submitted to European Physics Journal.

4. ϕ meson production in indium-indium collision at 158 AGeV incident beam energy. Paper in preparation, to be submitted to European Physics Journal.

5. ϕ, ω and dimuon production in proton-nucleus collisions at 400 GeV. Paper in preparation, to be submitted to The Journal of High Energy Physics.

6. Elliptic flow of charged particles and J/ψ in indium-indium collisions. Paper in preparation, to be submitted to European Physics Journal.

7. New results from NA60 and other SPS experiments (G. Usai et al.), J. Phys. G **34** (2007) S233

8. NA60 results on charm and inermediate mass dimuons production in In-In 158 GeV collisions, (R. Shahoyan et al.), J. Phys. G **34** (2007) S1029

9. New results on the ρ spectral function in Indium-Indium collisions, (J. Seixas et al.), J. Phys. G **34** (2007) S1023

10. J/ψ production in In-In and p-A collisions. (E. Scomparin et al.), J. Phys. G **34** (2007) S463

11. Quantifying the prompt intermediate mass dimuon excess in the In-In collisions measured by NA60. (A. David et al.), Nucl. Phys. A **783** (2007) 205

12. J/ψ suppression in In-In collisions at 158-GeV/nucleon. (R. Arnaldi et al.), Nucl. Phys. A **783** (2007) 261

13. NA60 results on the rho spectral function in In-In collisions. (S. Damjanovic et al.), Nucl. Phys. A **783** (2007) 327

14. First Measurement of the ρ Spectral Function in Nuclear Collisions (S. Damjanovic et al.). Eur. Phys. J. C **49** (2007) 235

15. ϕ production in NA60 (M. Floris et al.) Eur. Phys. J. C **49** (2007) 255