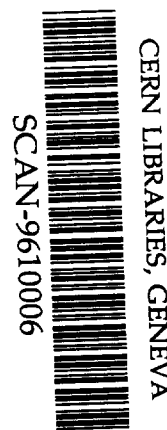


**ERNEST ORLANDO LAWRENCE  
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Nucleus + Nucleus Collisions  
at 1.05 GeV/nucleon**

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## Dielectron Production in Nucleus+Nucleus Collisions at 1.05 GeV/nucleon

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## INTRODUCTION

Measurements of dielectron production in heavy-ion collisions are valuable probes into the dynamics of the collision process. While the hadronic participants of the collision are subject to strong final state interactions, the coupling of the electron-positron pair to the collision medium is electromagnetic. Dielectrons, therefore, suffer little rescattering leaving the interaction and can retain information about their production origins, probing even the early stages in the evolution of the collision. The DiLepton Spectrometer (DLS) collaboration's original measurements of dielectron production established the existence of the signal at Bevalac energies<sup>1,2,3</sup>. The 1992-93 DLS measurements in nucleus+nucleus collisions at a kinetic beam energy of 1.05 *GeV/nucleon* are the subject of this presentation.

While the promise in the measurements of dielectron production is to probe the collision process, untangling the physics content of the signal is made complicated by the number of sources which can produce electron-positron pairs. Specifically, the multiplicity of the sources can impede the unambiguous determination of the mechanisms responsible for the signal in regions of the measured pair variables ( $m, p_t, y, \theta_D, \phi_D$ ) in which more than one process contributes significantly to the yield. For example, early model estimates suggested that the signal in the low pair mass region ( $< 0.4 \text{ GeV}/c^2$ ) is due to a combination of bremsstrahlung from  $p+n$  scatterings and  $\Delta$  Dalitz decays<sup>4</sup>.

**Table 1.** Summary of DLS Dielectron Data Sets

	System	Beam Energy ( <i>GeV/nucleon</i> )	Experiment Dates
1st Generation	p+Be	1.05, 2.1, 4.9	Dec 1986-Jan 1988
DLS data	Ca+Ca	1.05, 2.10	Dec 1987-Jan 1988
	Nb+Nb	1.05	May 1989
2nd Generation	p+p, p+d	1.0, 1.25, 1.6, 1.8, 2.1, 4.9	Sep 1990-June 1992
DLS data	Ca+Ca	1.05	Sep 1992
	C+C, $\alpha$ +Ca, d+Ca	1.05	Jan 1993

More recent calculations suggest that the signal in this region also includes a large contribution from the Dalitz decays of the  $\eta$  meson<sup>5,6</sup>. Furthermore, since dielectrons are produced during all stages of the collision,  $e^+e^-$  pairs originating from the later stages of the interaction can obscure the signal emerging from earlier phases of the collision. The electromagnetic decays of long lived mesons (e.g.  $\pi^0$ ,  $\eta$ , and  $\omega$ ) are examples of final state particles which produce dielectron pairs. While the study of these sources can yield important physics information, they do not directly probe the entirety of the collision. The goal of the DLS collaboration was to obtain dielectron production measurements from a set of colliding systems ( $p+p$  to  $A+A$ ) which could best reveal the physics information contained in the dielectron signal. The complete list of systems from which the DLS has measured dielectron production is shown in Table 1.

### Sources for Dielectron Production

A comparison between the first generation DLS cross section measurements from  $p+Be$  and  $Ca+Ca$  collisions at the beam energy of 1.05 *GeV/nucleon* as a function of pair mass was reported in the publication of the  $Ca+Ca$  results<sup>2</sup>. An enhancement in the cross section at large pair masses from the  $Ca+Ca$  collisions suggested the presence of a mechanism(s) not existing in the  $p+Be$  system. This result was considered to be consistent with the existence of a  $\pi^+\pi^-$  annihilation process which would not be expected in the nucleon+nucleon scatterings of the  $p+Be$  collisions. The 1988 DLS cross section measurement from  $Ca+Ca$  collisions at 1.05 *GeV/nucleon* is shown in Figure 1 along with a model calculation of the signal components. The very lowest mass region ( $< 0.135$  *GeV/c*<sup>2</sup>) is expected to be dominated by the Dalitz decays of the  $\pi^0$  meson. However, the large dielectron yield from this source is restricted to a domain in  $m$ ,  $p_t$ , and  $y$  in which the spectrometer has very limited acceptance. The results from the model calculation by Wolf *et al.*<sup>6</sup> indicate that, while the signal in the mass region just above the  $\pi^0$  mass comes from a combination of bremsstrahlung and  $\Delta$  and  $\eta$  Dalitz decays, the  $\pi^+\pi^-$  annihilation process dominates the signal for masses above about 0.5 *GeV/c*<sup>2</sup>. This result is consistent with the observations from the original comparison between the signal from the  $p+Be$  and  $Ca+Ca$  systems.

The pion annihilation process is of particular interest for understanding the dynamics of the collision process. The annihilation rate is dependent upon the pion densities reached during the collision and the dynamical properties of the pions within the dense hadronic system. However, the prospect for determining specific information about the collision from this process underscores the need to know the contributions to the signal

in this mass region from mechanisms associated with *non-collective* nucleon+nucleon scatterings. As shown in the model calculation of Figure 1, the dielectron signal in the lower pair mass region may come from such binary processes. Of particular interest is the contribution from the  $\eta$  Dalitz decays. This interest follows from the fact that  $\eta$  production is subthreshold at this beam energy. The prominence of this subthreshold process raises the question whether the dielectron yield at higher masses could also be due to subthreshold processes. The signal from such processes will be suppressed in the  $p+Be$  collisions where the projectile proton can carry no Fermi momentum. Therefore, the sources for dielectron production within a nucleon+nucleon scattering framework need to be evaluated not only at the beam energy of the nucleus+nucleus system but at higher energies as well.

The DLS collaboration has performed a series of measurements of dielectron production in  $p+p$  and  $p+d$  colliding systems in order to determine the contributions to the cross section from processes of nucleon+nucleon scattering origins. These data sets are listed in Table 1. For the purpose of identifying contributions to the  $e^+e^-$  signal in the nucleus+nucleus systems from subthreshold processes, the selection of the beam energies included the threshold energies for  $\eta$  and  $\rho/\omega$  production (1.25 GeV and 1.8 GeV). The data from the  $p+p$  and  $p+d$  systems have been published in the form of the dielectron yield ratios ( $p+d/p+p$ ) at each beam energy<sup>7</sup> and the cross sections for the 4.9 GeV data<sup>8</sup>. The measurements have been instrumental in fostering refinements in the model estimates of the dominant nucleon+nucleon scattering mechanisms for dielectron production<sup>3</sup>. The production cross sections from the other beam energy systems are near completion. These measurements will be powerful aids in unfolding the content of the dielectron measurements obtained from the nucleus+nucleus systems.

## Nucleus+Nucleus Measurements

The DLS measurements of the dielectron differential mass cross section in nucleus+nucleus collisions at 1.05 GeV/nucleon are presented in Figure 2. The  $Ca+Ca$ ,  $C+C$ ,  $\alpha+Ca$ , and  $d+Ca$  systems were chosen to study the origins of the dielectron signal. A primary goal for the nucleus+nucleus program was to obtain a statistically large pair sample from the heaviest system that could be measured with the spectrometer while maintaining control of the systematic corrections to the measurement. The  $Ca+Ca$  system satisfied this criterion and the current pair yield of  $4783 \pm 148$  net pairs (after subtraction of the combinatorial background) represents nearly 20 times more pairs than obtained in the 1988 DLS measurement in this system. The measurement obtained from the lighter  $C+C$  system allows for exploring the dependence of the dielectron cross section on the size of the system and the densities achieved during the collisions. The  $\alpha+Ca$  and  $d+Ca$  measurements were performed in order to make the connection between the signals from  $p+p$  and  $p+d$  collisions and the symmetric nucleus+nucleus systems. That is, unlike the  $p+p$  and  $p+d$  colliding systems, the internal motion of the nucleons are present in both the projectile and target nuclei of the  $\alpha+Ca$  and  $d+Ca$  collisions. This may allow for the occurrence of subthreshold processes not available to the  $p+p$  and  $p+d$  systems but present in the  $Ca+Ca$  interactions. However, the  $\alpha+Ca$  and  $d+Ca$  collisions will not produce the extensive hot hadronic system possible in the  $Ca+Ca$  collisions. The full set of measurements will help distinguish between competing processes responsible for the dielectron signal.

There exists a discrepancy in the overall normalization between the 1988 and 1992 DLS cross section measurements from the  $Ca+Ca$  system at  $1.05\text{ GeV/nucleon}$ . Specifically, the current cross section measurement is a factor of  $6.2\pm 1.5$  (*statistical*) larger than the 1988 measurement. The systematic uncertainty in the current measurement is  $\pm 30\%$ . The uncertainty in the original measurement was reported as  $+70\%/-20\%$ , a large portion of which originated within the trigger electronics in place during the early DLS measurements. The inefficiencies in that setup were later found to have been intensified by a micro-time structure in the Bevalac beam current. Indications of the problem at the time of publication lead to the  $+70\%$  uncertainty specified for this measurement and to a major overhaul of the trigger systems prior to the second generation DLS data sets. Additional modifications to both the data acquisition electronics and the beam quality control systems were implemented during the  $p+p$  and  $p+d$  running periods. The result of these modifications on the  $p+p$  and  $p+d$  data sets was quantified with measurements at several beam intensities. After the final modifications were in place (prior to the final nucleus+nucleus running periods), the DLS performed a measurement of the  $p+p$  elastic scattering cross section at  $1.25\text{ GeV}$ . This measurement is in complete agreement with the existing measurements of this process<sup>9</sup>.

The difference in the overall normalization between the 1988 and 1992 DLS measurements from the  $Ca+Ca$  system leaves the published model calculations<sup>5,6</sup> (as in Figure 1) underestimating the cross section. However, the  $\eta$  production cross section was not well known at the time these calculations were performed. Recent measurements of  $\eta$  production in  $p+p$  and  $p+d$  collisions near threshold<sup>10</sup> and in  $Ar+Ca$  at  $1.0\text{ GeV/nucleon}$ <sup>11</sup> may modify the estimated contribution from this source. In addition, a recent calculation<sup>12</sup> compared to the DLS dielectron measurement from  $p+p$  collisions at  $4.9\text{ GeV}$  found a non-negligible  $e^+e^-$  yield from  $\rho$  mesons produced in the decays of baryon resonances which do not nominally have enough mass to produce a  $\rho+N$ . These decays are allowed by the overlapping of the mass distributions between the baryon and  $\rho$  resonances. For example, while the nominal mass of the  $N(1520)$  resonance is only  $580\text{ MeV}/c^2$  above the nucleon mass, a 15%-25% branching ratio is known for the  $N(1520)\rightarrow\rho+N$  decay channel<sup>13</sup>. The full evaluation of such processes may be needed to account for the current DLS measurements in the nucleus+nucleus systems.

In order to investigate the dielectron signal from the nucleus+nucleus systems, a comparison of the pair mass dependence between these measurements can be performed. The ratio of the cross sections from the  $Ca+Ca$  system to that from the  $C+C$  system is shown in Figure 3. Only the statistical errors are included in the plot. The line drawn in the figure is at the value for the ratio of the product of the projectile and target numbers from the two systems,  $(A_p \cdot A_t)_{CaCa}/(A_p \cdot A_t)_{CC}$ . Since both systems are symmetric ( $A_p=A_t$ ), this ratio is equivalent to the ratio of the impact parameter averaged number of projectile nucleons participating in the collision ( $\bar{N}_p$ ) times the similar quantity for the target nucleus ( $\bar{N}_t$ ) evaluated on a geometrical basis. The plot shows that the lower mass pair region is well represented by this ratio. This scaling is shown not to hold for the larger pair masses. Rather, an enhancement above the scaling factor is indicated for the signal from the  $Ca+Ca$  system which may reflect a dependence in the signal on the densities achieved during the collisions. Further comparisons with the other two systems,  $\alpha+Ca$  and  $d+Ca$ , await a determination of any effects on these signals due to the acceptance of the spectrometer which arise from differences in the center of mass rapidity for these systems. However, the preliminary results from such comparisons confirm the  $\bar{N}_p \cdot \bar{N}_t$  scaling in the lower pair mass region.



## Conclusions

The sensitivity of the dielectron probe into nucleus+nucleus collisions has been enhanced with the second generation DLS data sets. First, the measurements from the  $p+p$  and  $p+d$  systems map the excitation function over the Bevatron energies. Second, the DLS data sets from nucleus+nucleus systems have much greater statistical precision than the earlier measurements thereby improving their use in discriminating between the results from efforts to account for the dielectron signal. Finally, the measurements from the four different nucleus+nucleus systems at the  $1.05 \text{ GeV/nucleon}$  beam energy allow for exploration of the dependence in the signal on the size and densities of the hot hadronic systems produced during the collision process. Preliminary results from the nucleus+nucleus systems indicate that the lower pair mass signal scales as the  $\bar{N}_p \cdot \bar{N}_t$  product. The cross section in the larger pair mass region from the  $Ca+Ca$  system is enhanced above this scaling. The complete set of the second generation DLS measurements will help probe the dynamical properties of heavy-ion collisions and continue to stimulate the theoretical investigations into these processes.

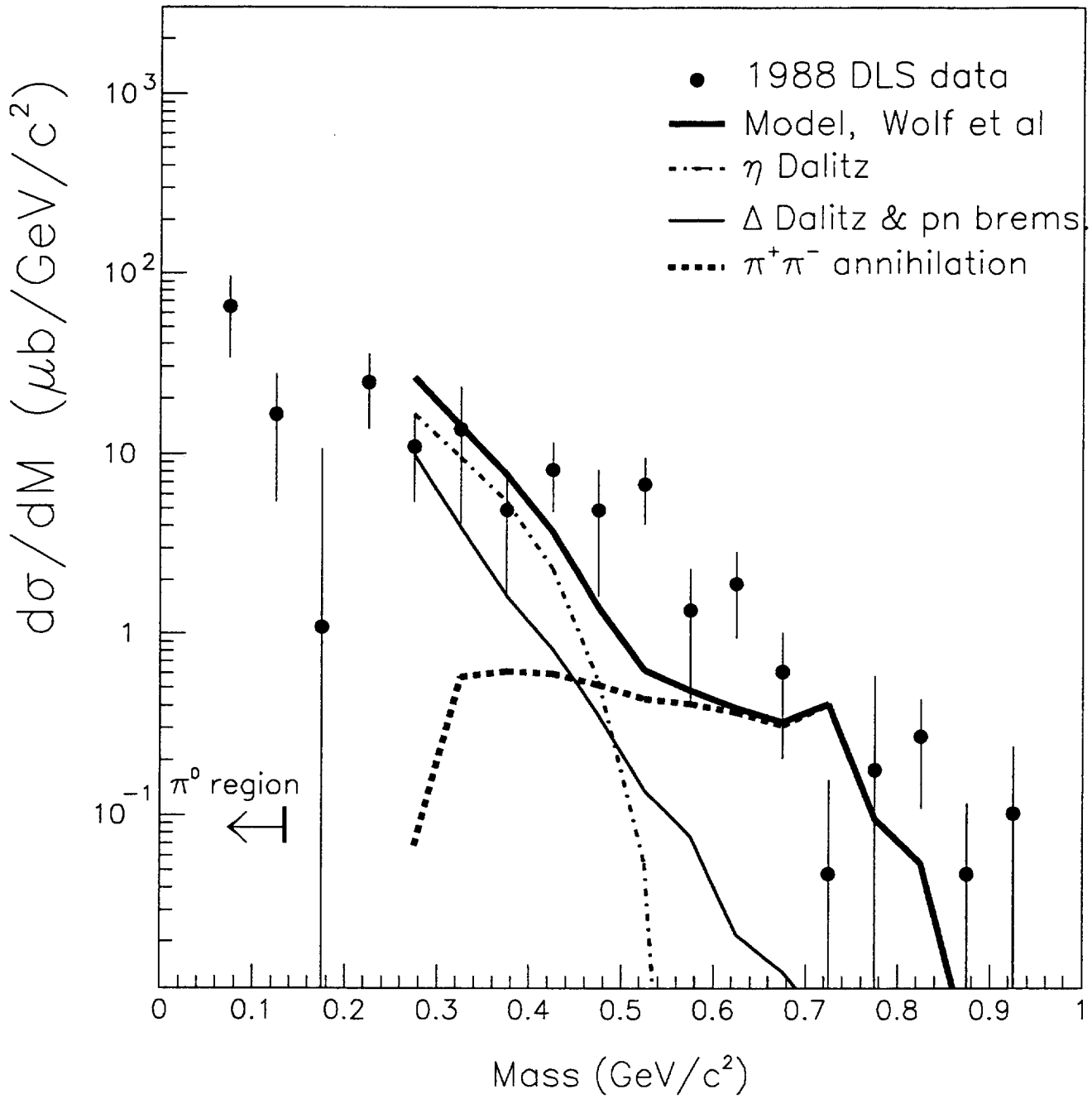
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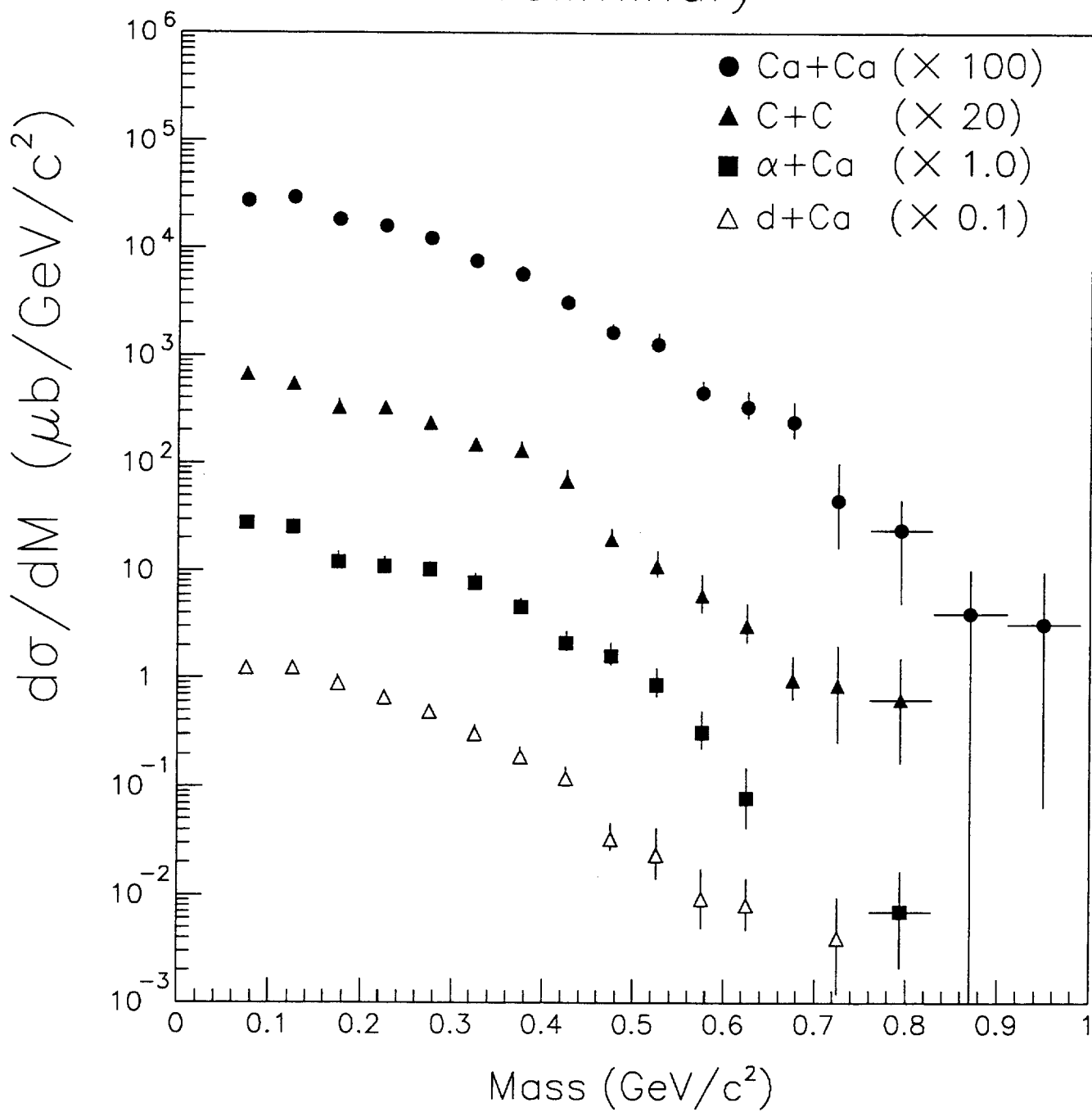
**Figure 1.** DLS measured  $e^+e^-$  cross section<sup>2</sup> and model calculation<sup>6</sup>,  $Ca+Ca$  at 1.05  $GeV/nucleon$ .

**Figure 2.** 1992-93 DLS cross section measurements in nucleus+nucleus at 1.05  $GeV/nucleon$ .

**Figure 3.** Ratio of dielectron cross section from  $Ca+Ca$  and  $C+C$  as a function of pair mass.



Preliminary



Preliminary

