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RESULTATS OBTENUS SUR LES DILEPTONS ET PERSPECTIVES

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Invited talk presented at the 6$^{\text{èmes}}$ Journées d' Etudes SATURNE
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Abstract.

Experimental results (mostly from the DLS collaboration at LBL) and model calculations of dielectron production in pp/pd/pBe (1-5 GeV) and CaCa (1-2 GeV/A) are presented. Dileptons appear to be a suitable probe to approach ***in-medium properties of hadrons*** in nuclear matter. At the present time, the ρ/ω region looks the most promising. Oncoming programs are briefly presented, in particular the HADES project at GSI.

Introduction.

The use of dileptons as a probe of nuclear matter at intermediate energies has been discussed on many occasions. Figure 1 shows the basic processes that lead to a dilepton in the final state. The impression may be that the situation is rather complex. At first, it is necessary to have an adequate quantitative understanding of the corresponding cross sections, which is not the case at the present stage, even though it is improving, as we will see below.

The physics interest of dileptons holds in the simple formula that they provide a *penetrating probe* of nuclear matter, with however a serious experimental difficulty due to the very low production rates. Consequently, they should be well suited to the study of *in-medium properties of hadrons*, via pA/e^-A collisions (normal density, cold nuclear matter) and AA collisions (hot and dense nuclear matter).

Depending upon phase space, projectile/target combination and production yield, some of the basic processes of figure 1 can be considered. For instance, the ρ/ω mass region is evidently a domain of most clean situation for both pA and AA collisions, full identification of the Δ Dalitz decay can only be envisionned in light pA systems, and nucleon form factor studies via the pn bremsstrahlung process would be best efficient in pN/pA interactions. In fact, it is not needed to have a full experimental identification of the processes when relative production yields are large enough, then the signal can be interpreted in the way of model simulation. Even though AA collisions may look more promising/challenging because of stronger/more exotic effects, pA studies are complementary and perhaps the only possibility in some cases.

In the following sections, we are going to present *(i)* experimental data (mostly from the DLS collaboration), *(ii)* typical theoretical results (mostly in comparison to the DLS data), *(iii)* experimental prospects at the Bevalac, Saturne and the Sinchrophasotron/Nuclotron, and the HADES project at SIS in some more details.

Let's warn the reader that all of the figures presented at the meeting are not included herein, sometimes available references are given, and the comments are rather briefly reproduced.

Experimental results.

The DLS (DiLepton Spectrometer) collaboration$^{(1)}$ at the LBL Bevalac has first produced data on pBe (1-5 GeV) and CaCa (1-2 GeV/A) collisions that have been published (see for instance ref. 2 and 3). The pBe measurements were intended/supposed to be equivalent to pp. In fact, these first data and the many relevant model calculations quickly demonstrated the need for direct measurements of the basic cross sections. As an example, figures 3 to 6 from Xiong *et al.*$^{(4)}$ (not reproduced herein) clearly suggest a problem with the pn bremsstrahlung contribution estimate. In the mean time, high energy results from RISK and HELIOS experiments$^{(5)}$ indicated dominant contributions from various Dalitz decays, in particular of the η meson, that had been underestimated for the many years of the so-called "low mass/low pt dilepton anomaly".

Since 1989, the DLS collaboration has undertaken systematic measurements of the reactions pp and pd $\longrightarrow e^+e^- +$ X between 1 and 5 GeV. Due to unexpected normalization difficulties, the data is still preliminary but reliable enough to already shed light on some of the previous controversies. As η Dalitz decay is now one of the prominant candidate for dielectron production at invariant masses below 500 MeV, special emphasis has been put on scanning a projectile energy range around the η production threshold at 1.25 GeV.

Figure 2 shows the mass distributions of opposite sign, same sign and true pairs from pp and pd at 4.9 GeV, with some normalization but no acceptance correction. These plots illustrate the improved statistics of the new data compared to what we were abble to obtain in the first series of experiments. Figure 3 exhibits the drastic change in mass distribution shape for both pp and pd when crossing the η threshold. Ratios of the pd to pp dielectron yields are given in figure 4. As a function of mass at given projectile energy (actually 1.0 and 1.6 GeV), the rise can more likely be interpreted as a simple Fermi momentum effect. The excitation function of the ratio for the π^0 Dalitz decay contribution (low mass region) is rather flat, while the ratio decreases from about 9 at 1.0 GeV to about 1.5 at 4.9 GeV for the rest of the mass spectrum.

More work is needed before precise conclusions can be drawn. If it is confirmed that η contribution is dominant above about 2 GeV incident energy, this combined with acceptance effect could then be the reason for the bump around 300 MeV invariant mass observed in the previous DLS data. At this stage, it can at least be said that pp is not suppressed compared to pn above 2 GeV projectile energy, which is in strong disagreement with present theoretical pn bremsstrahlung estimates.

To end this section on experimental results, we'd like to mention a study performed at Dubna in the 70's, prior to the DLS program, on πp and πA reactions in between 164 and 380 MeV. The goal was the determination of nucleon and pion form factors in the time-like region of 4-momentum transfers. From diagrams such as those at the bottom of figure 1, they could obtain (independently) both pion and nucleon form factors. An illustration of their results is given in figure 7 of ref. 6 (not reproduced here). It seems they did not get any evidence of in-medium effect because of systematical uncertainty and model dependent analysis$^{(7)}$.

Theoretical results.

Figure 5 shows the various dilepton contributions obtained in a BUU approach by Wolf *et al.*$^{(8)}$. From these results, it follows that η contribution is dominant at low mass below 450 MeV, Δ and pn at intermediate mass for pBe, and the cleanest place is the ρ/ω mass region for CaCa. Neither pion in-medium effect nor proton form factor were used in these calculations. QMD results from the Frankfurt Group$^{(9)}$ support the same general conclusions, with however some significant differences in absolute yields with the BUU calculation.

The possibility of using dileptons as a probe of pion dynamics in nuclear matter has been first discussed by Gale and Kapusta$^{(10)}$, and Xia *et al.*$^{(11)}$. Their estimates have been revised by Korpa *et al.*$^{(12)}$. The issue is not settled yet, and it is not clear whether or not any signal could be observable in the mass threshold region of $\pi\pi$ annihilation (300 MeV), where instead several other processes contribute.

Results by Chanfray *et al.*$^{(13)}$ and Herrmann *et al.*$^{(14)}$ on the ρ-meson mass distribution are not in very good agreement as for shift or widening of the resonance. However, they suggest that in-medium effect should be already observable at normal nuclear density, and quite significant at few times normal density.

Introducing in-medium changes of the pion annihilation component in CaCa at 1 GeV/A, and proton form factor in the pn bremsstrahlung component of pBe at 2.1 GeV, Wolf *et al.*$^{(8)}$ obtain the curves shown in figure 6 (notice that the top plot here is from ref. 14). These graphs illustrate once more the sensitivity of the dilepton mass spectra to those effects in the invariant mass domain around 700-800 MeV, under the assumption that statistical accuracy can reach an adequate level. Let's add here that the projectile/target mass dependence of the dilepton signal is most likely one more possibility to constrain model calculations.

The ϕ-meson may be accessible in relativistic heavy ion collisions, with some experimental difficulty due to low rate that can be inferred from figure 3 of ref. 15 (not reproduced here). Strangeness production in nuclei is discussed by another speaker$^{(16)}$.

First theoretical results are becoming available on pp and pd reactions, see figures 1 and 2 of ref. 17 (not reproduced here). It is much too early to draw conclusions, however it is seen again that the point is on pn bremsstrahlung at the highest energy.

Prospects.

On the theoretical side, there is much activity in the community and it can be expected that the basic processes of dilepton production (in particular the suppression of pn bremsstrahlung at high energy) are reasonably well understood within some (short) time. As for in-medium properties of hadrons, there is an obvious need for high statistics/good resolution/wide phase space experimental data.

On the experimental side, the DLS collaboration is going to complete the pp/pd study in June-July and collect at least 1000 true pairs, multiplicity tagged, in CaCa at 1 GeV/A in the Fall of this year. At Saturne, dilepton measurements (with different physics goals) have been presented by other speakers$^{(18)}$, and it must be stressed that the pp/pd $\longrightarrow \eta +$ X experiments$^{(19)}$, which have their own interest, are also very useful in terms of dilepton production mechanisms and should be pursued at the highest possible proton energy. Along this line, the η measurements in progress at SIS by the TAPS collaboration$^{(20)}$ are relevant to the same physics as the one presented in the introduction section. The SPHERE collaboration at the JINR Synchrophasotron/Nuclotron(21) intends to measure pA/AA $\longrightarrow e^+e^- +$ X up to 10 GeV and 5 GeV/A (CaCa).

Ths HADES collaboration(22) just submitted a letter of intent "A High-Acceptance Di-Electron Spectrometer for SIS" at the GSI. The main goal of the project is to allow high statistics high resolution dielectron studies of the heaviest systems at the highest SIS energies(text from the letter of intent):

- the system should be abble to safely identify electrons in an environment of high hadronic and photon background;
- the system should have flat acceptance in mass, transverse momentum and rapidity;
- the invariant mass resolution should be good enough to clearly identify and separate the ρ and ω mesons;
- the system should be abble to run at an interaction rate of up to 10^6 per spill.

In addition to nucleus-nucleus collisions, the experiments would cover proton-nucleus reactions to study the influence of compression and heat. It would also be desirable to study dilepton production in the nucleon-nucleon system itself. An additional option would be the combination of HADES with the photon spectrometer TAPS, thereby allowing direct measurements of Dalitz decays, in particular of the η meson. The general layout of the spectrometer is shown in figure 7 and the whole project will be presented in more details by Paul Kienle at round table discussions.

Footnotes and references.

(1) The DLS collaboration - Lawrence Berkeley Laboratory: L. Heilbronn, H. Huang, G.F. Krebs, A. Letessier-Selvon, H.S. Matis, J. Miller, C. Naudet, J. Panetta, J. Porter, J. Rians, L. Schroeder (spokesperson), P.A. Seidl, W.K. Wilson; University of California at Los Angeles: S. Beedoe, J. Carroll, G. Igo; The Johns Hopkins University: T. Hallman, L. Madansky, R. Welsh; Louisiana State University: P. Kirk, Z.F. Wang; Northwestern University: D. Miller; Université Blaise Pascal: M. Bougteb, F. Manso, M. Prunet, G. Roche; CEBAF: A. Yegneswaran: other contributors at earlier stages of the project: J. Bystricky, J. Cailiu, G. Claesson, P. Force, J.-F. Gilot, J. Gordon, D. Hendrie, E. Lallier, G. Landaud, T. Mulera, H. Pugh; engineers: R. Fulton and D. Nesbitt (LBL), P. Oillataguerre (UCLA).

(2) C. Naudet *et al.*, Phys. Rev. Lett. **62**, 2652 (1989).

(3) G. Roche *et al.*, Phys. Lett. **B226**, 228 (1989).

(4) L. Xiong *et al.*, Phys. Rev. **C41**, R1355 (1990).

(5) See for instance G. London's presentation at the 4th Journées des Théoriciens, Laboratoire National Saturne, November 22-23, 1990.

(6) G.D. Alekseev *et al*, Sov. J. Nuc. Phys. **46**(5), 801 (1987).

(7) T. Blokhintseva, private communication.

(8) Gy. Wolf *et al.*, private communication.

(9) See for instance L. Winckelmann *et al.*, GSI Scientific Report 1990, p. 103.

(10) C. Gale and J. Kapusta, Phys. Rev. **C35**, 2107 (1987).

(11) L.H. Xia *et al.*, Nuc. Phys. **A485**, 721 (1988).

(12) C.L. Korpa *et al.*, Phys. Lett. **B246**, 333 (1990).

(13) G. Chanfray, see a previous talk at the same meeting.

(14) M. Herrmann *et al.*, GSI-92-15 Preprint, March 1992.

(15) L.P. Kaptari *et al.*, JINR Preprint E2-90-543, 1990.

(16) J.M. Laget, see a previous talk at the same meeting.

(17) B. Kämpfer *et al.*, ZfK Rossendorf Preprint ZfK-753, December 1991.

(18) M. Garçon and J. Poitou, see previous talks at the same meeting.

(19) G. Dellacasa, see a previous talk at the same meeting.

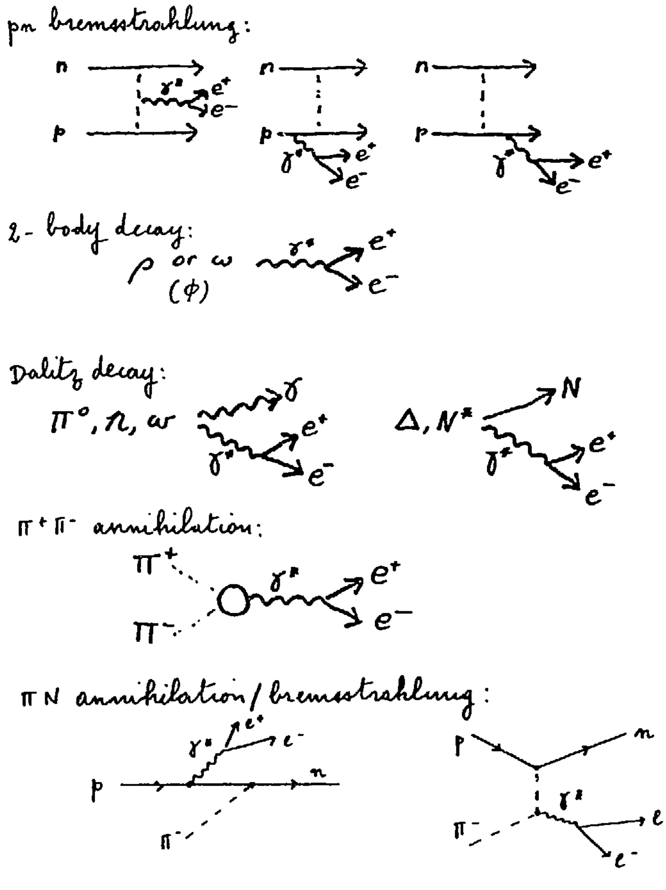
(20) V. Metag, see a previous talk at the same meeting.

(21) Proposal of the experiments for the SPHERE spectrometer on JINR Synchrophasotron and Nuclotron in Dubna, 1991 (spokesperson: A.I. Malakhov).

(22) The HADES collaboration: H. Hlavac (Bratislava); G. Paic, F. Piuz (CERN); M. Bougteb, F. Manso, L. Meritet, H. Meunier, M. Prunet, G. Roche (Clermont-Ferrand); A. Brenschede, V. Hejny, W. Kühn (spokesperson), V. Metag, R. Novotny, St. Riess (Gießen); H. Bokemeyer, W. Karig, P. Kienle, W. Koenig, H. Neumann, R. Schicker, R.S. Simon, H. Stelzer, H. Tsertos (GSI Darmstadt); A. Balanda, P. Salabura (Krakow); V. Alekseev, V. Busigin, S. Cherepnya, T. Aybergenov (Moskow LPI); A.F. Iyudin, F.M. Sergeeff, V.A. Kanzerov, Yu.A. Volkov, A.K. Ponosov, M.A. Guzenko, A.V. Nikitin, I. Grigoriev, S.E. Belenko, N.A. Starinski, Yu.N. Mishin, I.S. Stepanov, A.V. Zazolin (Moskow MEPI); F. Braems, B. Erazmus, T. Reposeur (Nantes); J. Friese, P. Kienle, K. Zeitelhack (TU München).

Figure 1:

<u>Sources of e^+e^- Pairs</u>
<u>at beam energies near 1 GeV</u>



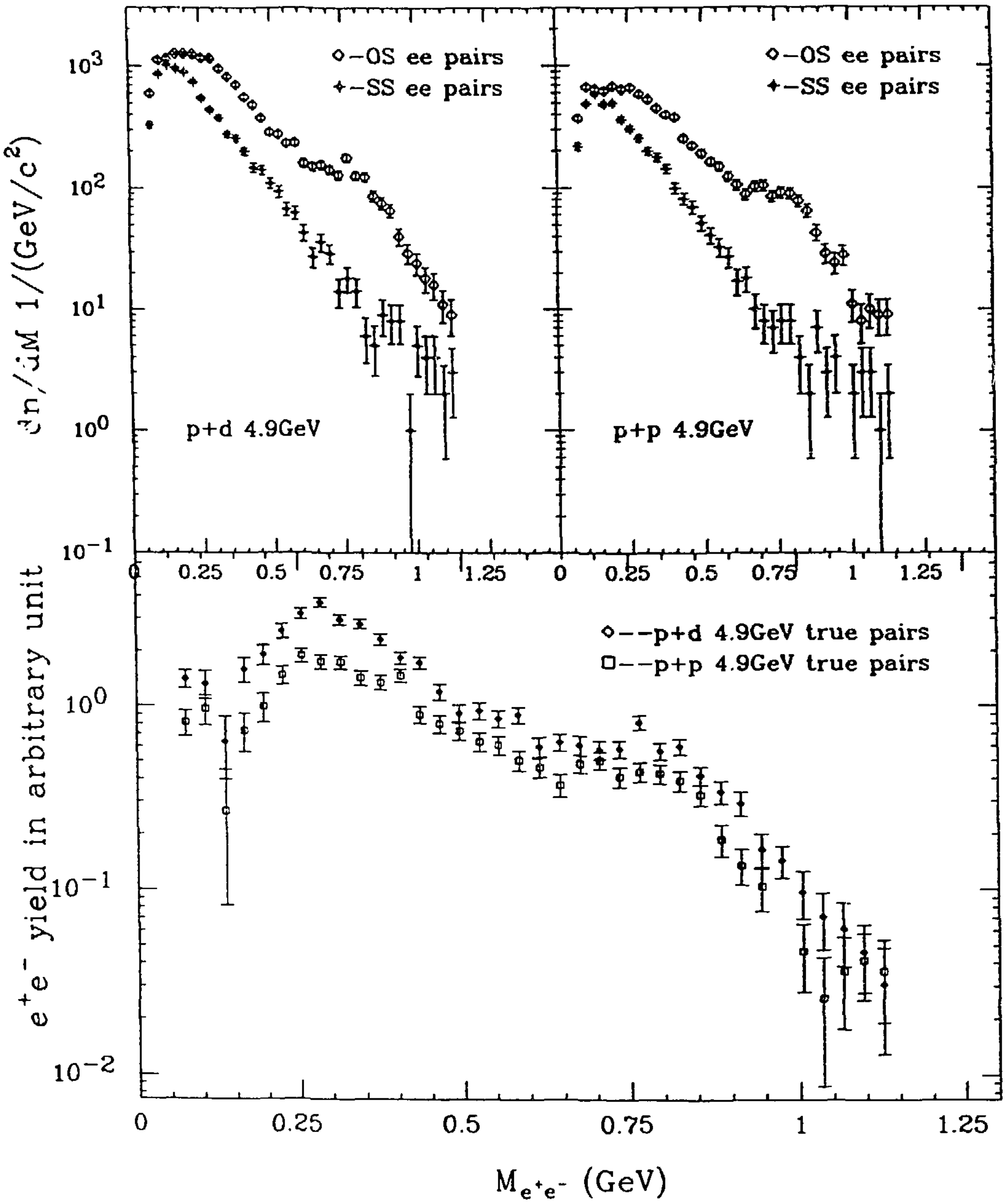
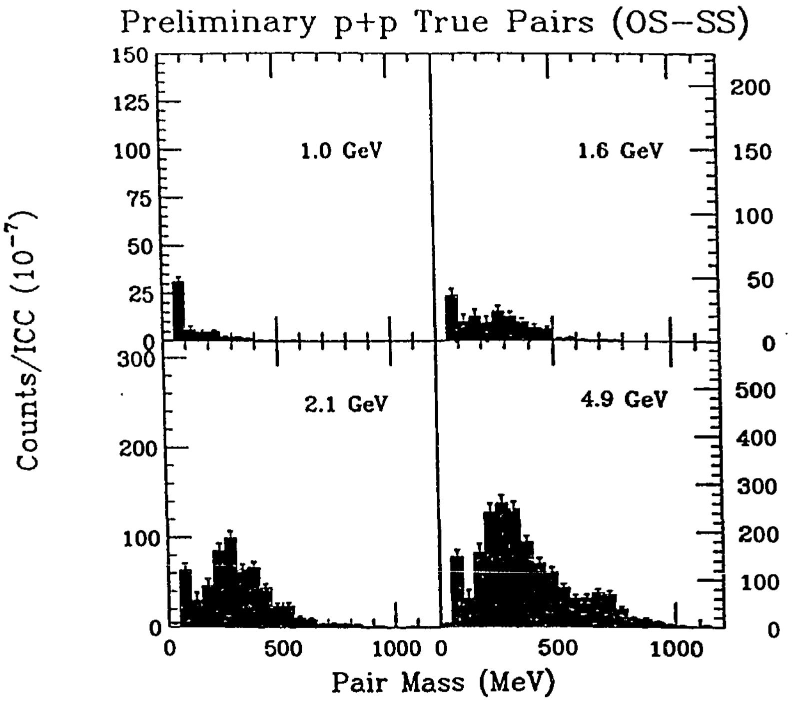


Figure 2: the dielectron yield from p+d and p+p collisions at 4.9 GeV



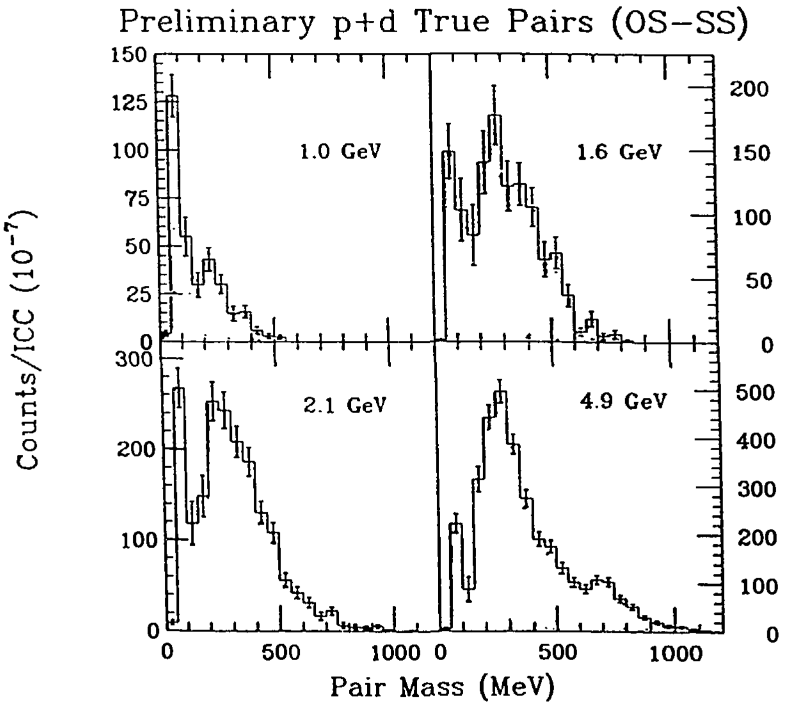
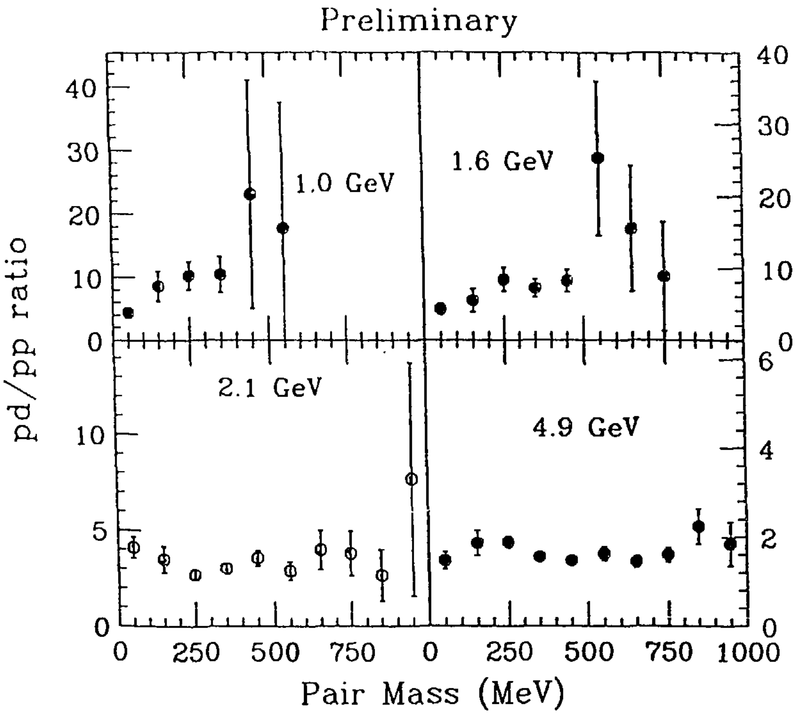


Figure 3: mass distributions (not corrected for acceptance) in pp and pd at four different energies.



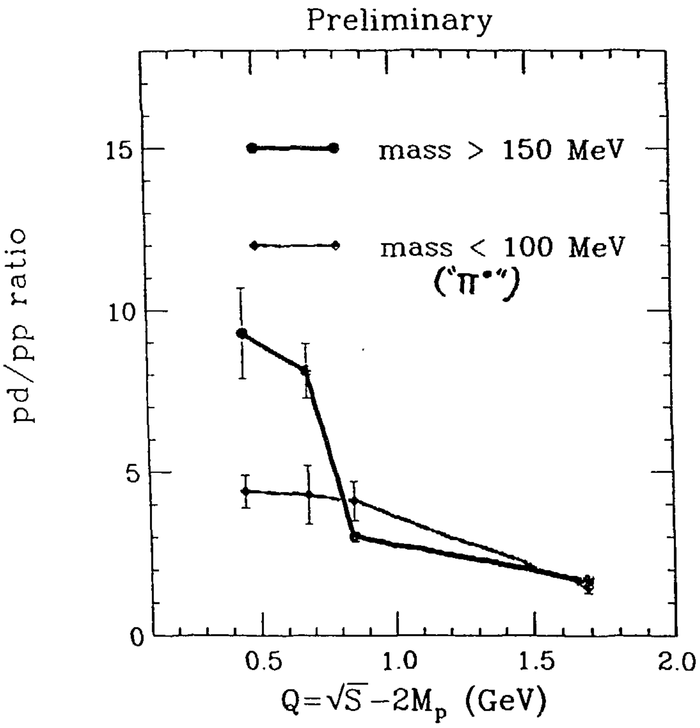


Figure 4: ratios of the pd to pp dielectron yields, as a function of invariant mass and as an excitation function.

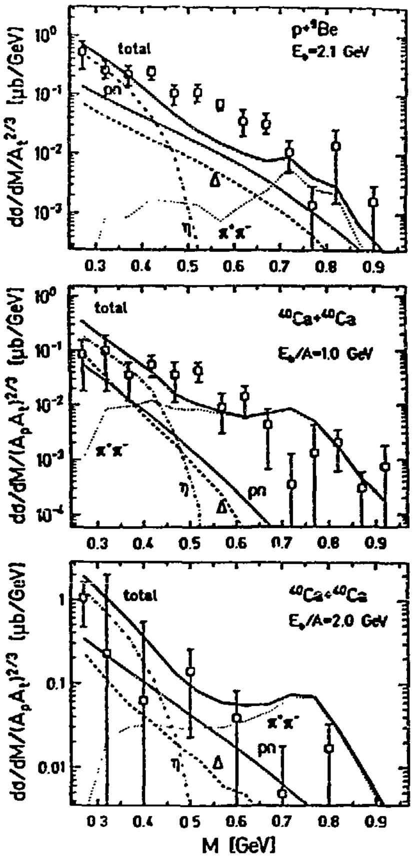


Figure 5: dilepton invariant mass spectra for $p+^9Be$ at 2.1 GeV and for $^{40}Ca+^{40}Ca$ at 1 and 2 GeV/A bombarding energies. Solid line: *pn* bremsstrahlung; dot-dashed: η Dalitz-decay; dotted: $\pi^+\pi^-$ annihilation; dashed: Δ Dalitz-decay; thick solid line: sum of all contribution. Data points from the DLS.

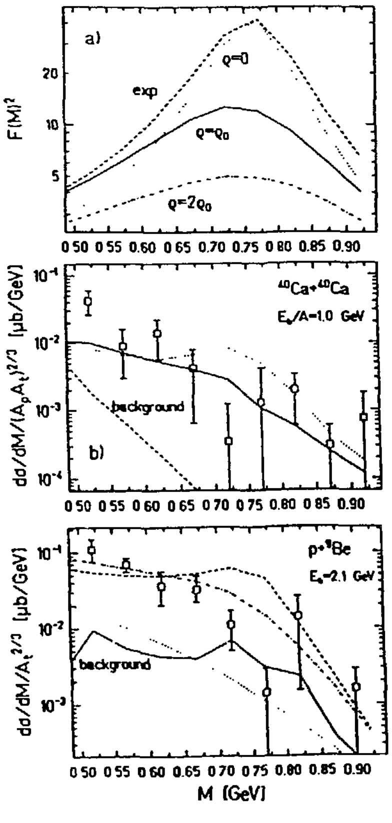


Figure 6: a) The electromagnetic form factor of the pion as a function of density(from Herrmann et al.). b) In-medium changes of the pion-annihilation component for $^{40}Ca+^{40}Ca$ at 1 GeV/A. c) Effects of the proton form factor on the dilepton spectra for $p+^9Be$.

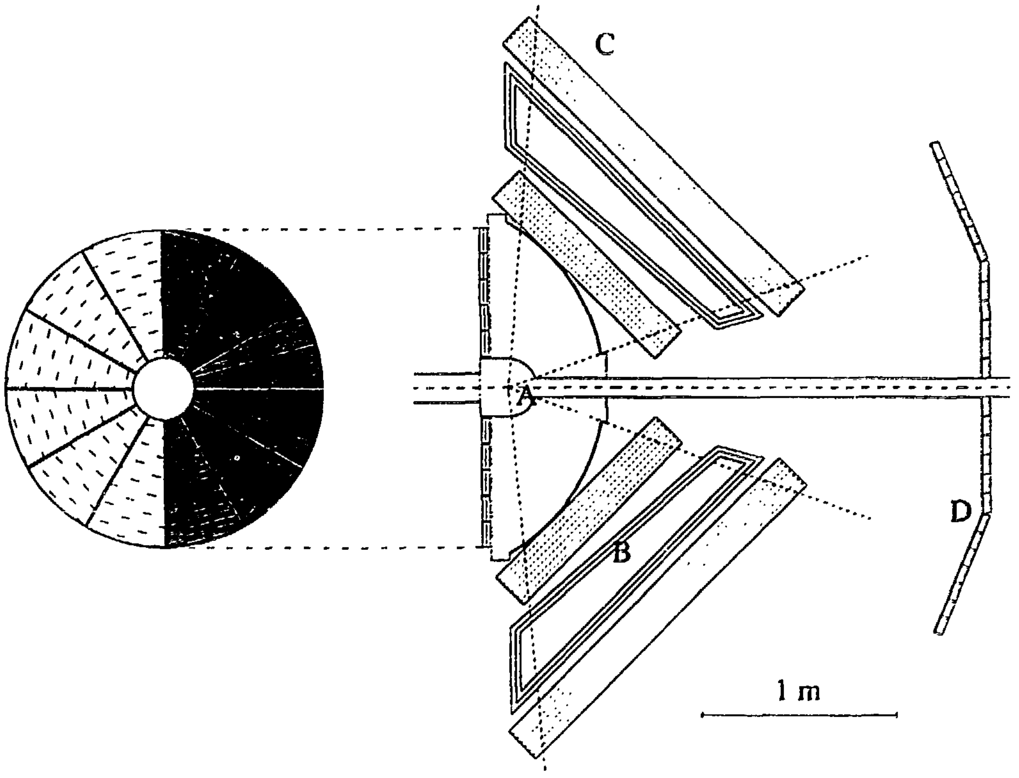


Fig. 7:
General layout of HADES. The electrons are identified in a RICH detector (A). The Cherenkov photons are detected in a UV detector with solid photo - cathode. A magnetic field of toroidal shape is produced by superconducting coils (B). Drift chambers before and after (C) the field serve to measure the electron momenta. A forward wall of plastic scintillators is used for trigger purposes and impact parameter selection.