Charmonium dissociation in matter: perspectives from CERN to JLab

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J/Ψ in matter.

Phenomenology with Tony

$\simeq$20 published paper.

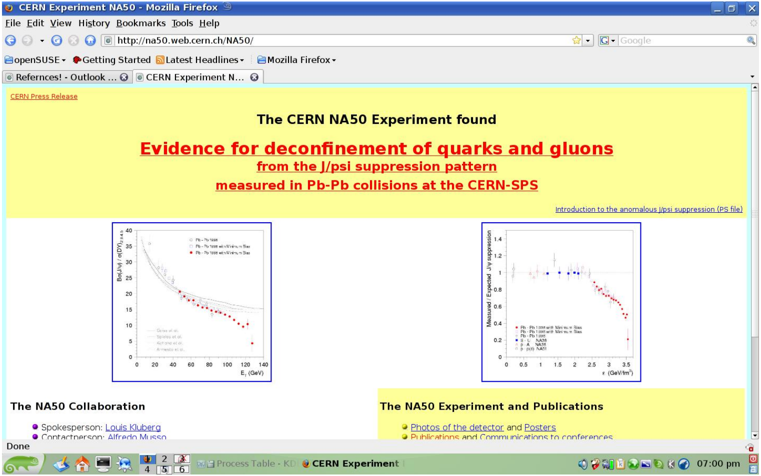
5 about charm and charmonium in matter

Relevance:

a) CERN discovery of the Quark Gluon Plasma.
b) GSI project PANDA on studying D and $\bar{D}$ meson production in antiproton-nucleus collisions.
c) J/Ψ dissociation at PANDA
d) Charmonium photoproduction from proton close to threshold at HALL D at JLab.
e) Perspectives on J/Ψ photoproduction from nuclei at JLab.

CERN Press Release

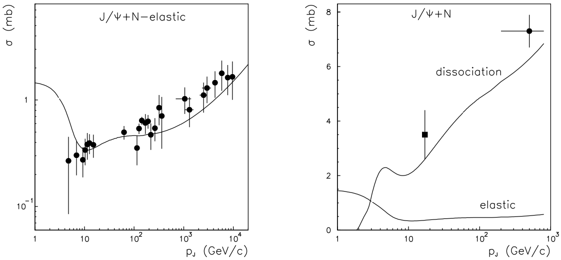
M. C. Abreu et al. (NA50 Collaboration), Phys. Lett. B 477 (2000) 28.



J/Ψ suppression in matter.

The suppression of J/Ψ production observed in $p{+}A$ up to central $S{+}U$ collisions, has been well understood in terms of charmonium absorption on nucleons in the nuclear medium.

The status of $J/\Psi{+}N$ interaction: A.S., K. Tsushima and A.W. Thomas, Phys. Rev. C63 (2001) 044906.



Left: elastic cross section. The circles are obtained by VDM from the data on J/Ψ photoproduction on proton. Right: absorption. The circle is evaluated from data on J/Ψ photoproduction off nuclei, while the square is obtained from proton-nucleus.

Anomalous results from CERN

The heavy ion simulations from different groups account for the charmonium absorption due to $J/\Psi + N$ interaction.

However, the experimental results from $Pb + Pb$ collisions reported by NA50 Collaboration at CERN show a considerably stronger charmonium suppression.

J/Ψ suppression was predicted as a consequence of color screening in a QGP which should keep the charmed quark -antiquark pairs from binding. Suppressing the J/Ψ requires temperatures which are about 30% above the color deconfinement temperature, or energy densities $\simeq$3 GeV/fm^3.

It was tried to reproduce the data by assuming that the charmonia are destroyed solely by final state interactions with surrounding nucleons. None of these attempts can account for the shape of the centrality dependence of the observed suppression.

Expectations from RHIC

On the other hand, the interpretation of this pattern in terms of color screening by deconfined quarks and gluons leads to the prediction of a similar suppression pattern at RHIC in much smaller nuclei.

Nevertheless, in an attempt to explain this anomalous suppression of J/Ψ production, many authors have studied one of two possible mechanisms, namely hadronic processes and the formation of QGP.

J/Ψ dissociation on meson comovers

In the hadronic dissociation scenario the J/Ψ interacts with pions and ρ-mesons in matter, forming charmed mesons through the reactions, $\pi+J/\Psi\rightarrow D^*+\bar{D}, \bar{D}^*+D$ and $\rho+J/\Psi\rightarrow D+\bar{D}$. The absorption of J/Ψ mesons on pions and ρ-mesons has been found to be important in general and absolutely necessary in order to fit the data on J/Ψ production. It should certainly play a more important role in $S+U$ and $Pb+Pb$ experiments, where hot, high density mesonic matter is expected to be achieved.

J/Ψ dissociation on meson comovers, combined with the absorption on nucleons, is the main mechanism proposed as an alternative to the dissociation of the J/Ψ in a QGP. Note that both the hadronic and QGP scenarios predict J/Ψ suppression but no mechanism has yet been found to separate them experimentally.

Within the hadronic scenario the crucial point is the required dissociation strength. In particular, one needs a total cross section for the $\pi,\rho+J/\Psi$ interaction of around $1.5\div3$ mb in order to explain the data in heavy ion simulations.

Novel features of J/Ψ dissociation in matter

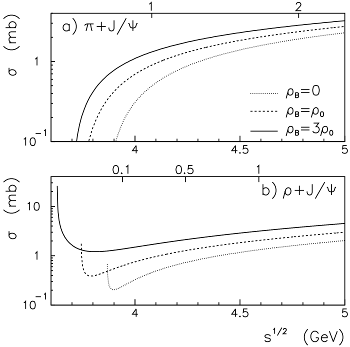
On the other hand, there may be other mechanisms which produce an increase in J/Ψ absorption in a hot, dense medium. We are particularly interested in the rather exciting suggestion, based on the quark-meson coupling (QMC) model, that the charmed mesons, D, $\bar{D}$, D^* and $\bar{D}^*$, should suffer substantial changes in their properties in a nuclear medium.

This might be expected to have a considerable impact on charm production in heavy ion collisions.

P.A.M. Guichon, Phys. Lett. B 200 (1989) 235;
K. Tsushima, D.H. Lu, A.W. Thomas, K. Saito and R.H. Landau, Phys. Rev. C 59 (1999) 2824;
A. Sibirtsev, K. Tsushima and A.W. Thomas, Eur. Phys. J. A 6 (1999) 351.

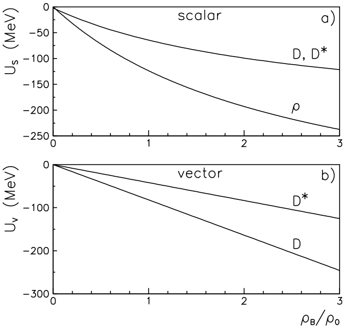
Novel features of J/Ψ dissociation in matter

The reactions $\pi+J/\Psi\rightarrow D+\bar{D}^*$, $\bar{D}+D^*$ and $\rho+J/\Psi\rightarrow D+\bar{D}$, based on D exchange.



$\pi+J/\Psi$ (a) and $\rho+J/\Psi$ (b) dissociation cross sections as functions of the invariant collision energy, $s^{1/2}$. Results are shown for vacuum (the dotted line), ρ_0 (the dashed line) and $3\rho_0$ (the solid line).

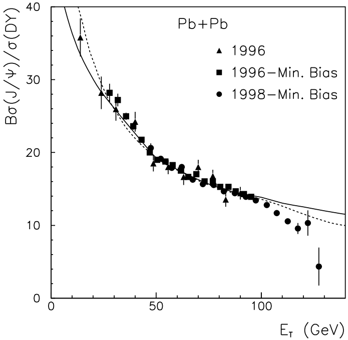
D and D^* mesons in matter



The scalar (a) and vector (b) potentials for the D and D^* mesons, calculated for nuclear matter as functions of the baryon density, in units of the saturation density of nuclear matter, ρ_0=0.15 fm^{-3}. Scalar potentials for D and D^* are indistinguishable.

Note that the total D^--meson potential is repulsive, while the D^+ potential is attractive, which is analogous to the case for the K^+ and K^- mesons, respectively

CERN data and our calculations



The ratio of the J/Ψ over Drell-Yan cross sections from $Pb{+}Pb$ collisions as function of the transverse energy E_T. Data are from NA50. The solid line shows our calculations with the density dependent cross section for J/Ψ absorption on comovers. The dashed line indicates the calculations with phenomenological cross section $\langle\sigma v\rangle\simeq$1 mb. For both calculations the nuclear absorption cross section was taken as 4.5 mb.

The results

Our results on Novel features of J/Ψ dissociation in matter were published close after the CERN Press Release in

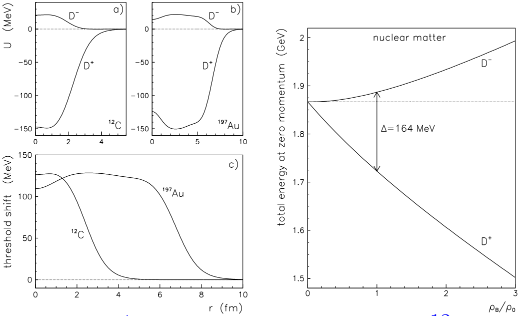
A. Sibirtsev, K. Tsushima, K. Saito and A. W. Thomas, Phys. Lett., B 484 (2000) 23.

And after us were confirmed by many others calculations!
The story about Quark Gluon Plasma discovery at CERN finally was discussed as a possible indication of QGP observed by NA50 Collaboration.

We did this first and in time and did prevent further speculations.
Thank you Tony!

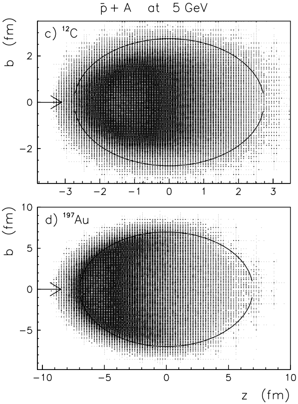
On Studying Charm in Nuclei through Antiproton Annihilation.

We examine the production of open charm in antiproton annihilation on finite nuclei. The enhancement of the subthreshold production cross section, even in a nucleus as light as carbon, should provide a clean signature of the reduction in the masses of these mesons in-medium.



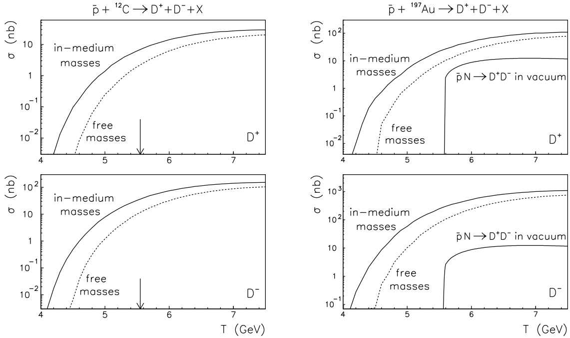
Left. The D^- and D^+ potentials calculated for ^{12}C (a) and ^{197}Au (b) as a function of the nuclear radius. We also show the downward shift in the threshold for D^+D^- production.

Annihilation.



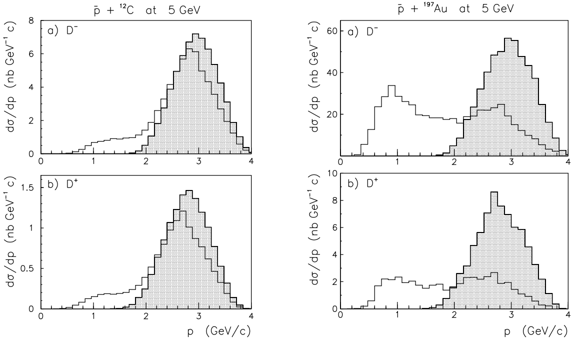
The plot of the annihilation zone for $\bar{p}+^{12}C$ (a) and $\bar{p}+^{197}Au$ (b) reactions at a beam energy of 5 GeV. The solid line indicates the r.m.s. radius of the target nucleus. The arrows show the direction of the antiproton beam.

Open charm production in annihilation.



The total cross section for D^+ and D^--meson production in $\bar{p}C$ and $\bar{p}Au$ annihilation as a function of the antiproton energy. The results are shown for calculations with free (dashed lines) and in-medium masses (solid lines) for the D-mesons. The arrow indicates the reaction threshold on a free nucleon.

Determination of the DN interaction



The momentum spectra of D^- and D^+ mesons in the laboratory system and from the $\bar{p}C$ and $\bar{p}Au$ annihilation at 5 GeV. Hatched histograms show the primary spectra from the antiproton annihilation at the bound nucleon. Solid histograms are the final spectra.

The results

Our results on On Studying Charm in Nuclei through Antiproton Annihilation were published in

A. Sibirtsev, K. Tsushima and A. W. Thomas, Eur. Phys. J., A6 (1999) 351.

This is part of the GSI project PANDA on studying modification of the D and $\bar{D}$ meson through the production in antiproton-nucleus collisions.

Our results on Charmonium absorption by nucleons were published in

A. Sibirtsev, K. Tsushima and A. W. Thomas, Phys. Rev., C63 (2001) 044906.

This is part of the GSI project PANDA on studying charmonium dissociation in antiproton-nucleus interaction.

Charmonium photoproduction.

The available data on J/Ψ photoproduction were analyzed in terms of pomeron exchange, two gluon exchange and photon-gluon fusion models.

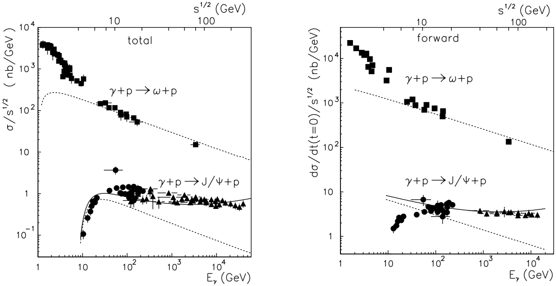
Allowing the pomeron-quark interaction to be flavour dependent and introducing the soft and hard pomerons it is possible to reproduce the data at $\sqrt{s}>$10 GeV and small $|t|$.

The two gluon exchange calculations indicate strong sensitivity to the gluon distribution function. The results obtained with the most modern MRST2001 and DL PDF reproduce the forward J/Ψ photoproduction cross section at $\sqrt{s}>$10 GeV.

The calculations with the photon-gluon fusion model and with MRST2001 and DL PDF are also in reasonable agreement with the data on the total J/Ψ photoproduction cross section.

Charmonium photoproduction. Results.

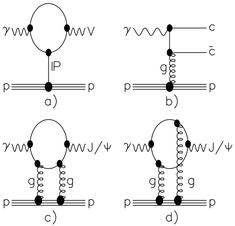
We compare ω and charmonium photoproduction in order to analyse the difference of the underlying reaction mechanism.

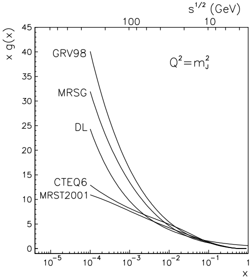


Reduced ω and J/Ψ total (left) and forward (right) photoproduction cross sections as a function of photon energy. The dashed lines show the calculations with soft pomeron exchange alone, while the solid lines are the sum of soft and hard pomeron contributions.

Gluon PDF.

To compare the two gluon exchange model with data on J/Ψ photoproduction we need to specify the gluon parton distribution function.

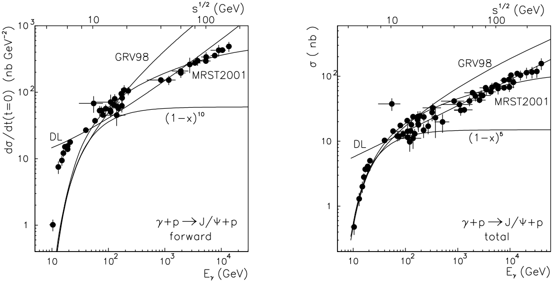




The gluon distribution functions as a function of x at $Q^2{=}m_J^2$. Upper axis shows the relevant invariant collision energy given as $\sqrt{s}{=}m_J/\sqrt{x}$.

Results with gPDF.

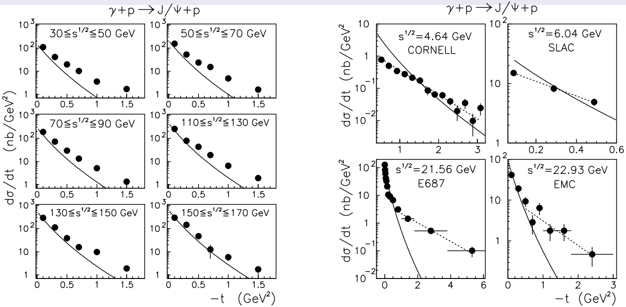
The results were published: A. Sibirtsev, S. Krewald and A. W. Thomas, Systematic analysis of charmonium behavior Program photoproduction tion, J. Phys., G30 (2004) 1427.



The forward J/Ψ and total photoproduction cross section as a function of photon energy, E_γ. The lines show the pQCD calculations by two gluon exchange model (left) and photon gluon fusion model (right) with the gluon distribution functions The upper axis indicates the invariant collision energy.

Anomalous exchange.

We allocate the J/Ψ photoproduction at low energies and large $|t|$ to the mechanism different from pomeron or two gluon exchanges. We consider that this might be axial vector trajectory exchange that couples to the axial form factor of the nucleon.



The $\gamma+p\rightarrow J/\Psi+p$ differential cross section as a function of four momentum transfer squared t measured at different invariant collision energies $\sqrt{s}$. The solid lines show the calculations including both soft and hard pomeron exchanges.

Conclusions.

We did start almost 10 years ago with exciting CERN results on Quark Gluon Plasma. But we found other and most appropriate explanation for NA50 observations.

As a results we did propose a good part of physics on charm and charmonium in matter. This is now part of the Programm of PANDA Collaboration at GSI.

At some stage around 2004 we started the project on charmonium photoproduction. With systematic analysis of the world data and available phenomenology we detect that close to threshold data indicate some unexpected behaviour.

That is now the part of the future programm at HALL D at JLab.

Thanks

Although Tony was always extremely busy at JLab, it was always possible to find a proper time for discussions!

Happy Birthday, Tony!