# Cold nuclear matter effect on charmonium($c\bar{c}$) production in fixed target pA collisions

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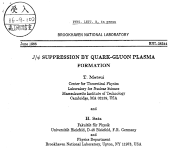
# Outline

1. Introduction
2. Brief Theoretical formalism to measure CNM effect in $J/\psi$
3. Experimental Data on $J/\psi$
4. Results and Discussion
5. Prediction for future experiment
6. Conclusion

# Motivation

- **T.Matsui and H.Satz** first predicted $J/\psi$ suppression as a signature of QGP,1986.
- Several experiments were done at CERN SPS like NA38 followed by NA50,NA60,... after the successful discovery of QGP in laboratory.
- The Charmonia production cross section in pA collisions increases less than linearly with the number of binary collisions $\Longrightarrow$ **Normal nuclear absorption or CNM effect**
  CNM effect is a convolution of several effect
  a.**Initial state effect** b.**Final state effect**
- Among several other effects, initial state energy loss would have a significant contribution as partons lose energy in QCD matter, as suggested by **M. Gyulassy et al. and R. Baier et al.**


PHYS. LETT. B, in press
BROOKHAVEN NATIONAL LABORATORY
June 1986 BNL-38344
$J/\psi$ SUPPRESSION BY QUARK-GLUON PLASMA FORMATION
T. Matsui
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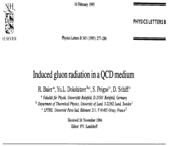
Volume 243, number 4 PHYSICS LETTERS B 5 July 1990
Jet quenching in dense matter
Miklos Gyulassy and Michael Plümer
Nuclear Science Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA
Received 2 March 1990
The quenching of hard jets in ultrarelativistic nuclear collisions is estimated emphasizing its sensitivity to possible changes in the energy loss mechanism in a quark-gluon plasma.


16 February 1995
PHYSICS LETTERS B
Physics Letters B 345 (1995) 277-286
Induced gluon radiation in a QCD medium
R. Baier, Yu.L. Dokshitzer, S. Peigné, D. Schiff
Received 24 November 1994
Editor: P.V. Landshoff

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- Useful for studying the effect of energy loss in hot and dense deconfined medium which is produced by relativistic heavy-ion collision.
- And also very crucial for identifying genuine QGP-specific suppression in charmonia production.

# How Charmonia(*here.* $J/\psi$) interact with nuclear matter??

- charmonia are produced by two step factorizable process in a nuclear collision.
  $\Longrightarrow$ Color $c\bar{c}$ production by perturbative process
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- Depending on the collision energy and the system size, each region would have its contribution for the charmonia production.

# Brief Theoretical Formalism of $J/\psi$ production

- The frame work employed to derive the $J/\psi$ absorption cross-section have two factorizable contributions:
  1. **Charmonia production cross-section**

$\Longrightarrow$ **CEM**

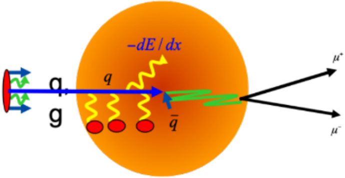
$$\frac{d\sigma_i}{dx_F} = 2F_i \int_{2m_c}^{2m_D} m \frac{d\sigma^{c\bar{c}}}{dx_F\, dm^2}\, dm \tag{1}$$

$$\frac{d\sigma^{c\bar{c}}}{dx_F\, dm^2} = \int_0^1 \delta(x_1 x_2 s_{NN} - m^2)\, \delta(x_F - x_1 + x_2)$$
$$\Bigg\{ f_g^A(x_1, m^2) f_g^B(x_2, m^2) \sigma_{gg}(m^2) + \sum_{q=u,d,s} \Big[ f_q^A(x_1, M^2)$$
$$f_{\bar{q}}^B(x_2, M^2) + f_{\bar{q}}^A(x_1, M^2) f_q^B(x_2, M^2) \Big] \sigma_{q\bar{q}}(m^2) \Bigg\}\, dx_1\, dx_2 \tag{2}$$

# Introduction of energy loss

- In presence of energy loss: $x'_{1q(g)} \longrightarrow x_{1q(g)}$

$$x'_{1q(g)} = x_{1q(g)} + \Delta x_{1q(g)}$$



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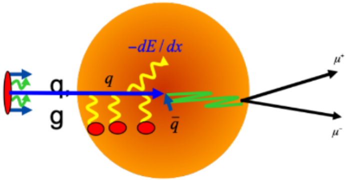
- Now: $\Delta x_{1q} = \frac{\Delta E_q}{E_h} \quad \Delta x_{1g} = (9/4)\Delta x_{1q}$
- BH formalism: $\Delta x_{1q} \approx \frac{\alpha}{E_h} < L_A >$
- BDMPS formalism: $\Delta x_{1q} \approx \frac{\beta}{E_h} < L_A^2 >$




2.Survival probability of the nascent charmonium($c\bar{c}$)states $\Longrightarrow$**Glauber Model**

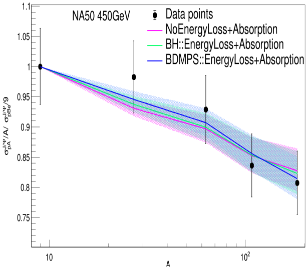
$$\sigma_{PA}^{J/\psi} = \frac{\sigma_0}{\sigma_{abs}^{J/\psi}} \int db_A[1 - (1 - T_A(b_A)\sigma_{abs}^{J/\psi})^A] \quad (3)$$

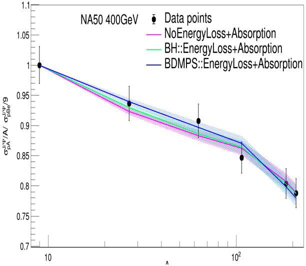
# Experimental data

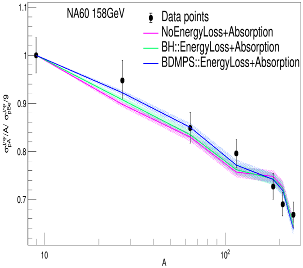
- $J/\psi$ data from **NA50,NA60** at CERN SPS and **E866** at FERMILAB .

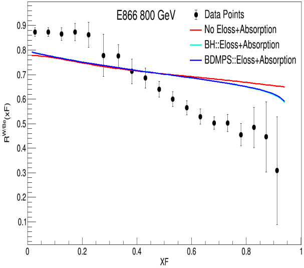
| Expt. $E_{LAB}(GeV)$ | Collision system | Phase space |
|---|---|---|
| NA50 450 | $p-Be, Al, Cu, Ag, W$ | $-0.5 < y_{cms} < 0.5$ |
| NA50 400 | $p-Be, Al, Cu, Ag, W, Pb$ | $-0.425 < y_{cms} < 0.575$ |
| NA60 400 | $p-Be, Cu, In, W, Pb, U$ | $-0.17 < y_{cms} < 0.33$ |
| NA60 158 | $p-Be, Al, Cu, Ag, W$ | $0.28 < y_{cms} < 0.78$ |
| E866 800 | $p-Be, Fe, W$ | $-0.34 < x_F < 0.14$ |

# Analysis Results



# Discussion

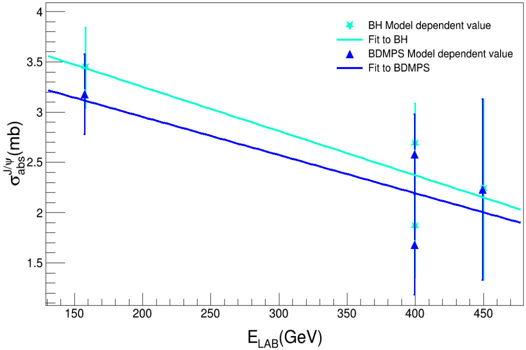
- EPPS21 nuclear PDFs has been taken to account shadowing-antishadowing effect
- Three parametrization along with final state absorption has been employed

| Experiment($E_{LAB}(GeV)$) | Model | $\sigma_{abs}^{J/\psi}(mb)$ |
|---|---|---|
| NA50 (450) | No Eloss | 4.56±1.0 |
| | BH Eloss | 2.23±0.9 |
| | BDMPS Eloss | 2.17±0.9 |
| NA50 (400) | No Eloss | 5.13±0.4 |
| | BH Eloss | 2.68±0.4 |
| | BDMPS Eloss | 2.52±0.4 |
| NA60 (158) | No Eloss | 6.85±0.4 |
| | BH Eloss | 3.44±0.4 |
| | BDMPS Eloss | 3.12±0.4 |

- In presence of energy loss, final state absorption $\sigma_{abs}^{J/\psi}$ decreasing

# Prediction for future experiment

- A linear fit for $\sigma_{abs}^{J/\psi}$ vs $E_{LAB}$
- Extrapolate it to the energies of upcoming experiments $NA60+$ at CERN SPS and CBM at FAIR




- At CBM beam energy 30 GeV $J/\psi$ absorption cross-section around **4.2 mb** and that is around **3.8 mb** for 80 GeV beam energy of $NA60+$ experiment.

# Summary and Conclusion

- We Introduce the initial state energy loss of incoming partons on $J/\psi$ production process in proton induced nuclear collision.
- Decouple the initial state energy loss effect convoluted in the final state absorption
- With lowering the beam energy final state $J/\psi$ absorption increasing.
- Some quantitative prediction has been given for the upcoming experiments $NA60+$ at CERN SPS and CBM at FAIR.
- Our model is unable to explain the data of E866 from FERMILAB.
- Need to be improvement for higher energy experiments......

# References


- T. Matsui and H. Satz, Phys. Lett. B **178**, 416-422 (1986)
- B. Alessandro *et al.* [NA50], Eur. Phys. J. C **33**, 31-40 (2004)
- B. Alessandro *et al.* [NA50], Eur. Phys. J. C **39**, 335-345 (2005)
- R. Arnaldi *et al.* [NA60], Conf. Proc. C **060726**, 430-434 (2006)
- M. J. Leitch *et al.* [NuSea], Phys. Rev. Lett. **84**, 3256-3260 (2000)
- S. J. Brodsky and P. Hoyer, Phys. Lett. B **298**, 165-170 (1993)
- R. Baier, Y. L. Dokshitzer, A. H. Mueller, S. Peigne and D. Schiff, Nucl. Phys. B **484**, 265-282 (1997)
- K. J. Eskola, P. Paakkinen, H. Paukkunen and C. A. Salgado, Eur. Phys. J. C **77**, no.3, 163 (2017)
- M. Gyulassy and M. Plumer, Phys. Lett. B **243**, 432-438 (1990)

# Thank you!

**For your kind attention!**

# Backup Slide

- $\Delta x_1$ Characteristic Length of gluon
- $\Delta x_1$ The broadening of squared transverse momentum
- $-\Delta E = \frac{1}{4}\alpha_s C_R \hat{q} L^2$
- $\hat{q} \approx 0.8\hat{q}_0, \hat{q}_0 \approx 0.07 - 0.09 GeV^2/fm.$
- Baier-Dokshitzer-Mueller-Peigné-Schiff(BDMPS)
- ratio has been taken to reduce the systematic uncertainty as well as the experiment does no give individual cross section rather give ratio
- formation legth of the $J/\psi$

$$d_{0(R)} = \beta\gamma c\tau_{0(R)} = \frac{p_L}{M}\tau_{0(R)}$$

$\tau_0 \approx 0.25 fm$

$\tau_R \approx 0.35 fm (4)$