Influence of parton shadowing on J/ψ-to-Drell-Yan ratio @ SPS and FAIR

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Introduction: J/ψ and its suppression

❖J/ψ suppression is classical signature of de-confinement in relativistic nuclear collisions

❖Suppression also seen in p+A collisions due to cold nuclear matter (CNM): needs to be precisely estimated to isolate the genuine hot medium effects

❖Requires comparison of p+A measurements in the same energy and kinematic domain of A+A data

❖Till date no J/ψ data in A+A collisions below top SPS energy, some sparse p+A data sets

❖CBM experiment at FAIR SIS-100: opportunity for detailed investigation of charmonium production in p+A and small size A+A (eg: Ni+Ni, …) collisions

❖We investigate different CNM effects at SPS and make prediction at FAIR

J/ψ production in nuclear collisions

Calculations performed within two-component QVZ model

(J. Qui, J.P. Vary and X. Zhang, Phys. Rev. Lett. 88, 232301 (2002))

Production in hadronic collisions is a factorizable two step process:

- First stage: production of a cc-bar pair with relative momentum q^2
  - gg fusion and qq-bar annihilation in LO pQCD
  - Higher order via K factor

- Second stage: transition to color neutral physical bound state , non-perturbative transition probability $F(q^2)$ parameterized using different functions:

Gaussian form:

$$F^{(\mathrm{G})}_{c\bar{c}\rightarrow \mathrm{J}/\psi}(q^2) \;=\; N_{\mathrm{J}/\psi}\,\theta(q^2)\,\exp\left[-q^2/(2\alpha_F^2)\right]$$

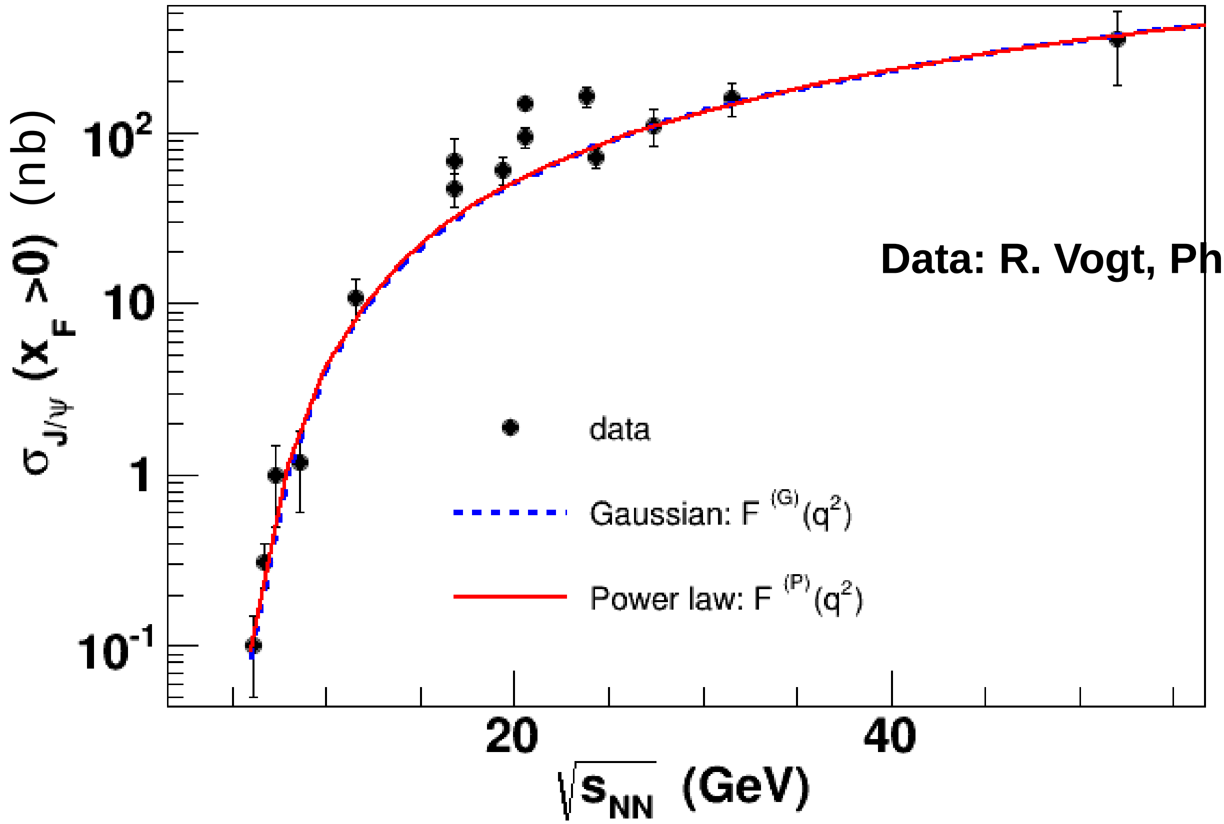
$F^{(G)}(q^2)$ mimics CSM, does not accommodate gluon radiation

Power law form:

$$\begin{aligned} F^{(\mathrm{P})}_{c\bar{c}\rightarrow \mathrm{J}/\psi}(q^2) \;&=\; N_{\mathrm{J}/\psi}\,\theta(q^2)\,\theta(4m_D^2-4m_C^2-q^2) \\ &\times\; \left(1-q^2/(4m_D^2-4m_C^2)\right)^{\alpha_F} \;, \end{aligned}$$

$F^{(P)}(q^2)$ mimics COM, accommodates soft gluon radiation for color neutralization

Comparison with data: p+p collisions



Data: R. Vogt, Phys. Report, 1999

Both functional forms of the transition probability $F(q^2)$ fit the data over a wide energy range

Two model parameters $f_J = K \times N_{J/\psi}$ and α_F extracted from fitting

Cold nuclear matter effects

In p+A collisions CNM effects come into play**:**

- Modification of nuclear parton densities in the initial stage

  (ignored in the original QVZ prescription)

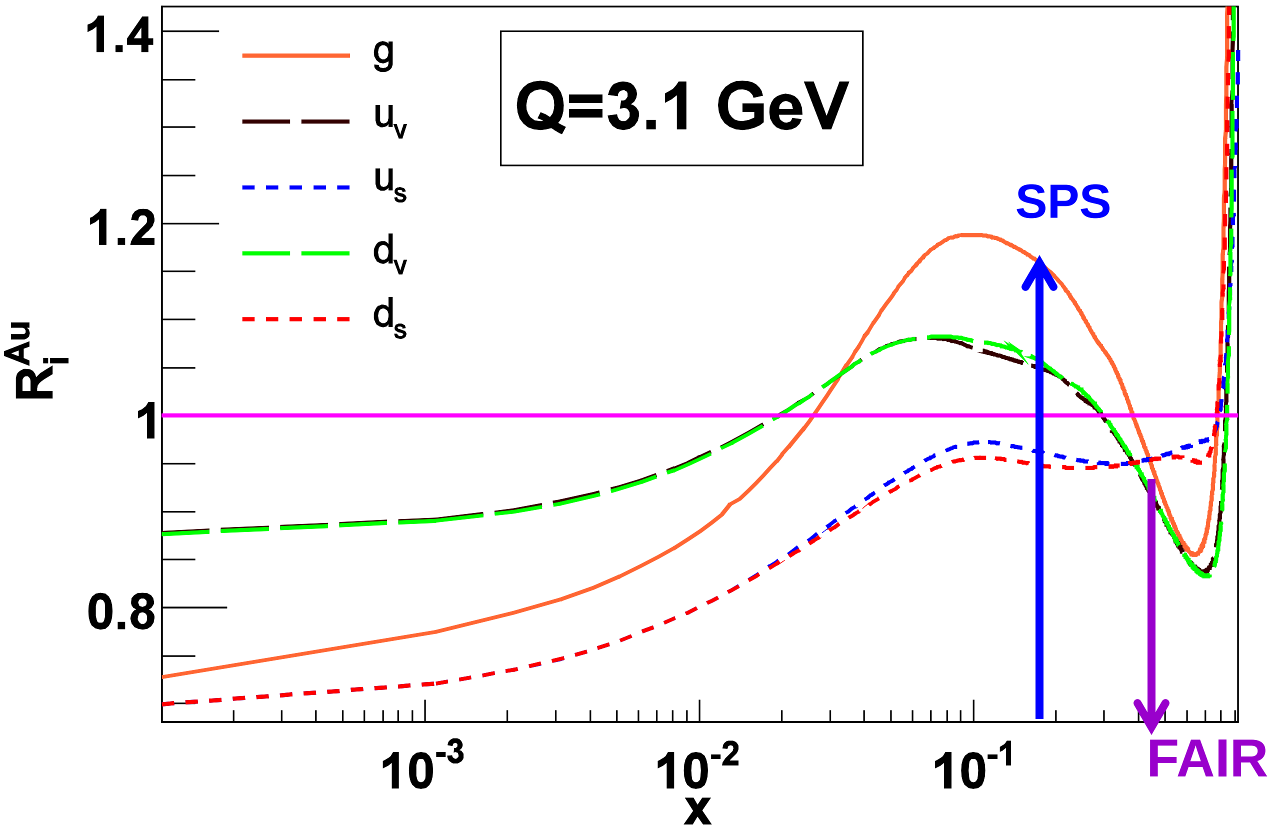
- Dissociation of the nascent cc-bar pairs in the final stage via:
  - multiple soft scattering of the cc-bar pairs inside nuclear medium
  - modifies the formation probability: $F(q^2) \Rightarrow F(q^2 + \varepsilon^2 L)$
  - reduction in charmonium production cross section

- Different from conventional Glauber approach:
  - final state dissociation quantified by an absorption cross section σ_{abs}
  - Survival probability :$S \sim e^{-\rho\ \sigma abs<L>}$

Initial state parton shadowing

- EPS09 set of nuclear parton distribution function (nPDF)

$$f_i(A, x, Q^2) = R_i(A, x, Q^2) \times f_i^p(x, Q^2)$$



x_{SPS} ~ 0.18 enhancement @ SPS

x_{FAIR} ~ 0.45 depletion @ FAIR

Effect of local shadowing

Variation of the shadowing function $\boldsymbol{S}^{AA}$ with b

SPS: Pb+Pb @ 158 A GeV

CBM: Au+Au @ 30 A GeV

❖Implementation of local shadowing, with shadowing parameter dependent on local density

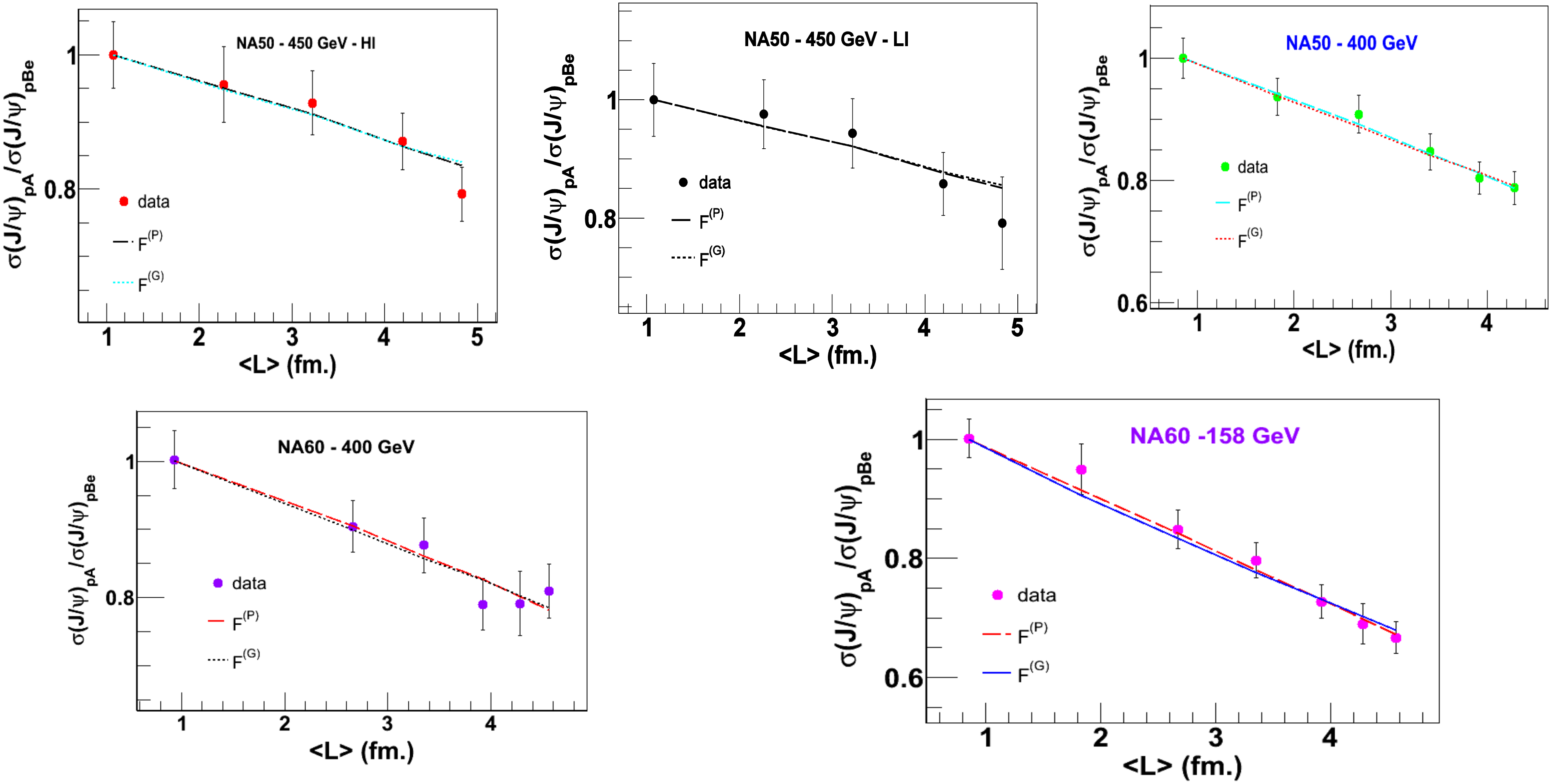
❖Enhancement of the gluon densities inside target and projectile nucleons:
Anti-shadowing effects in J/ψ production @ SPS

❖Depletion of the gluon and quark densities inside target and projectile nucleons
Shadowing effects @ FAIR

Strongest effects in central collisions

Calibration of the model at SPS

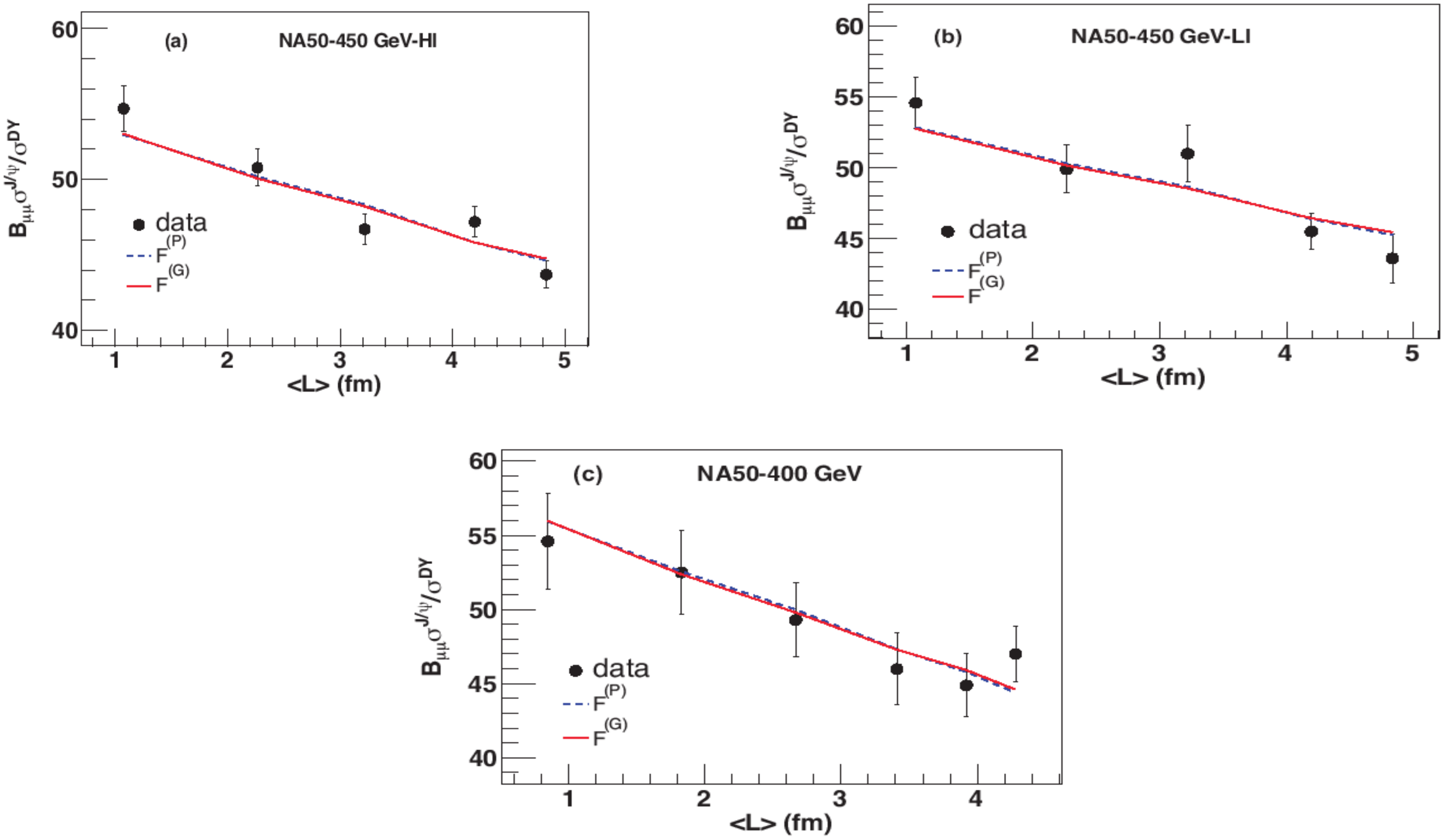
Phys. Rev. C 84, 054914 (2011)



❖Both $F^P(q^2)$ & $F^G(q^2)$ describe the available data reasonably well

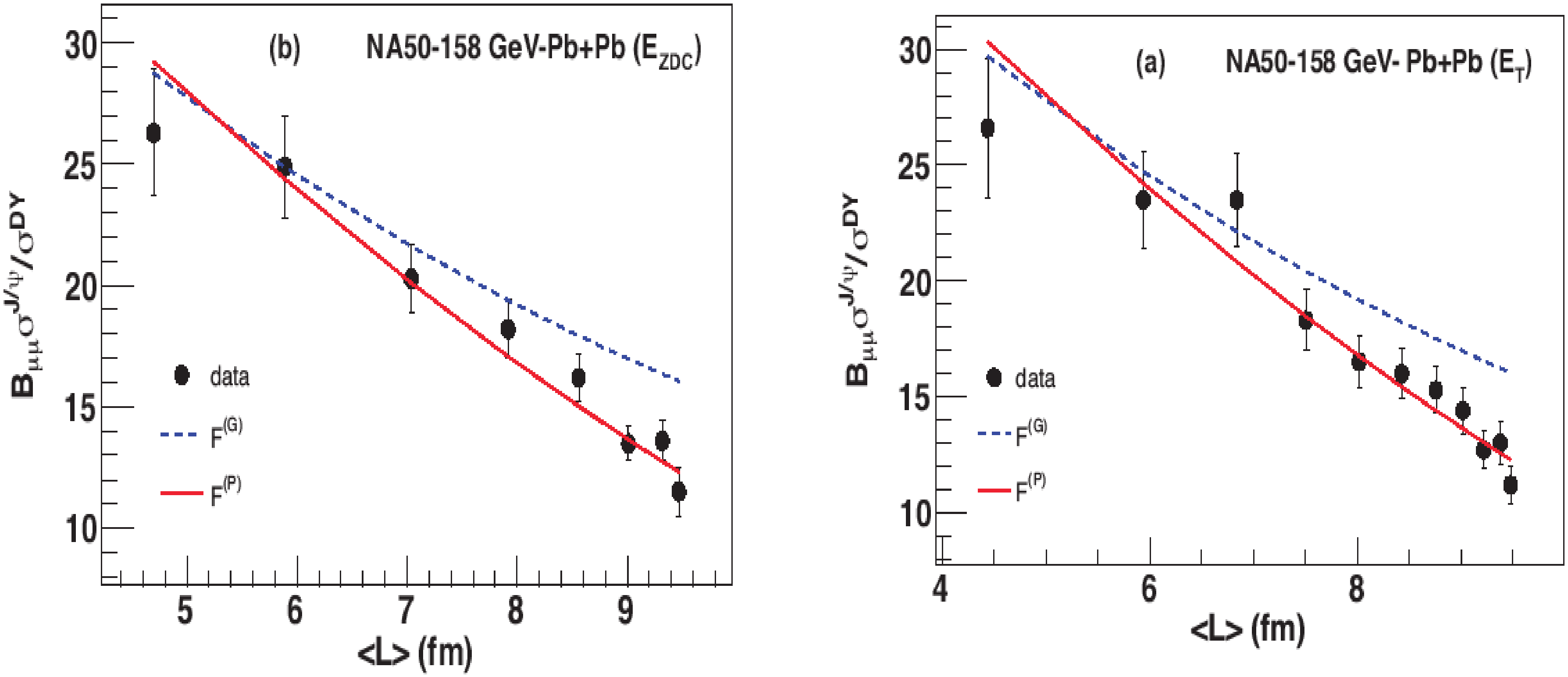
❖Extracted ε^2 values characterizing final state dissociation in the model show a non-negligible dependence on the energy of the incident proton beam

J/ψ-to-DY ratio in p+A collisions at NA50-SPS



Model with parameters calibrated from absolute J/ψ cross sections can also explain the J/ψ-to-DY ratio data

J/ψ-to-DY ratio in 158 A GeV Pb+Pb collisions at NA50

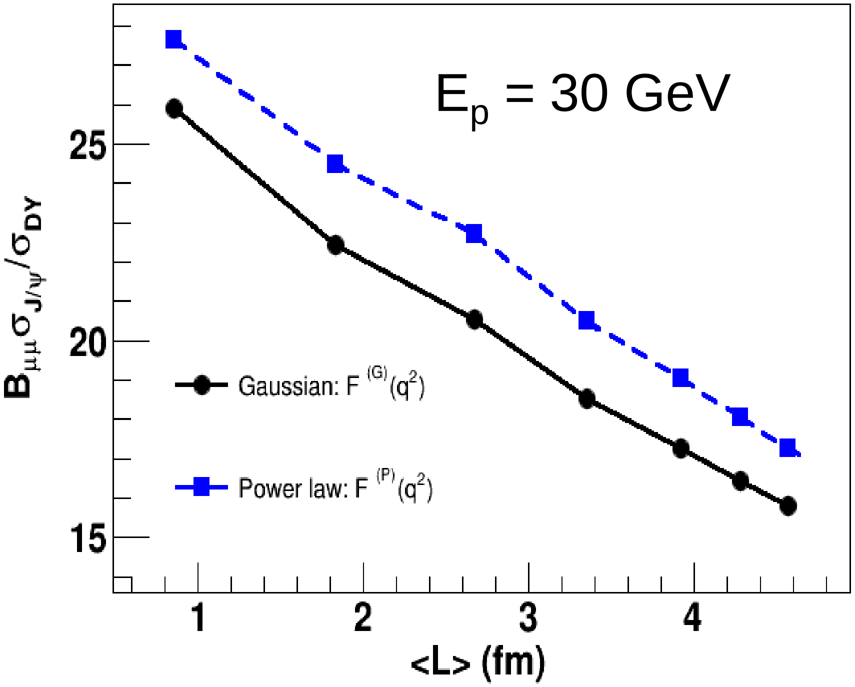


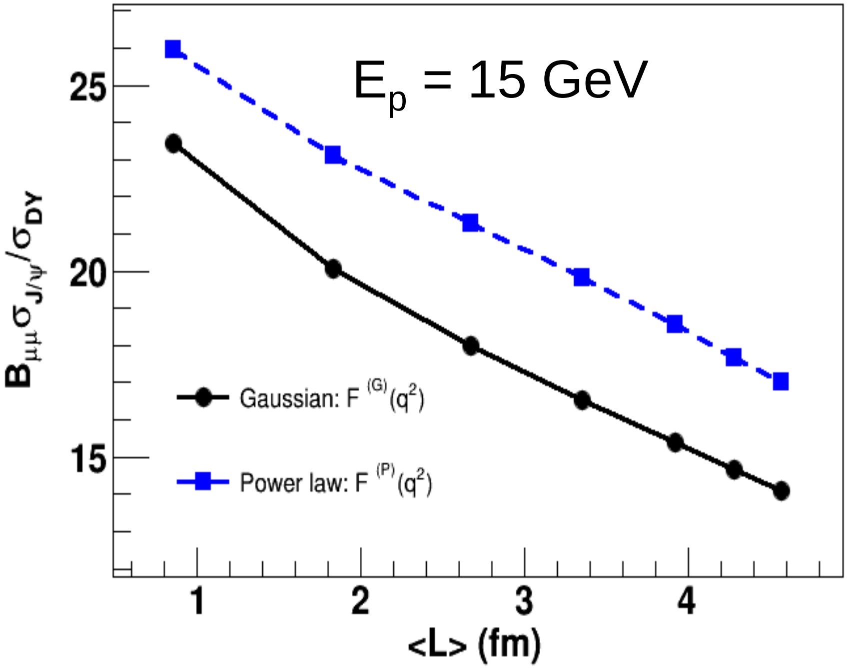
Gaussian probability fails to generate enough suppression for large system

Power law form can reasonably explain data for all centralities

No room for additional suppression

CNM suppression in p+A collisions@ FAIR SIS-100





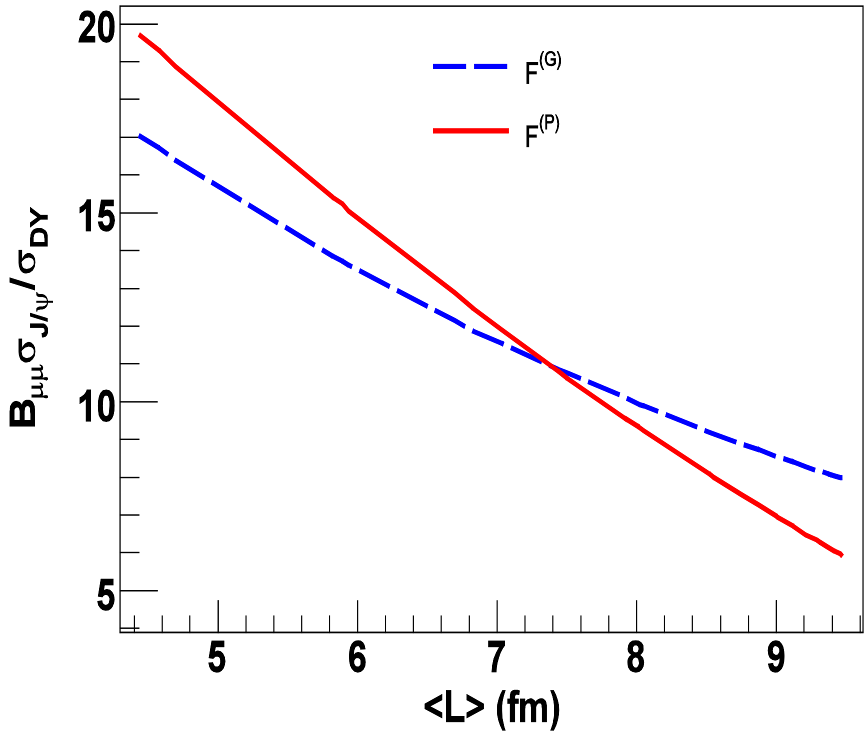
Larger suppression @ FAIR energy domain compared to SPS

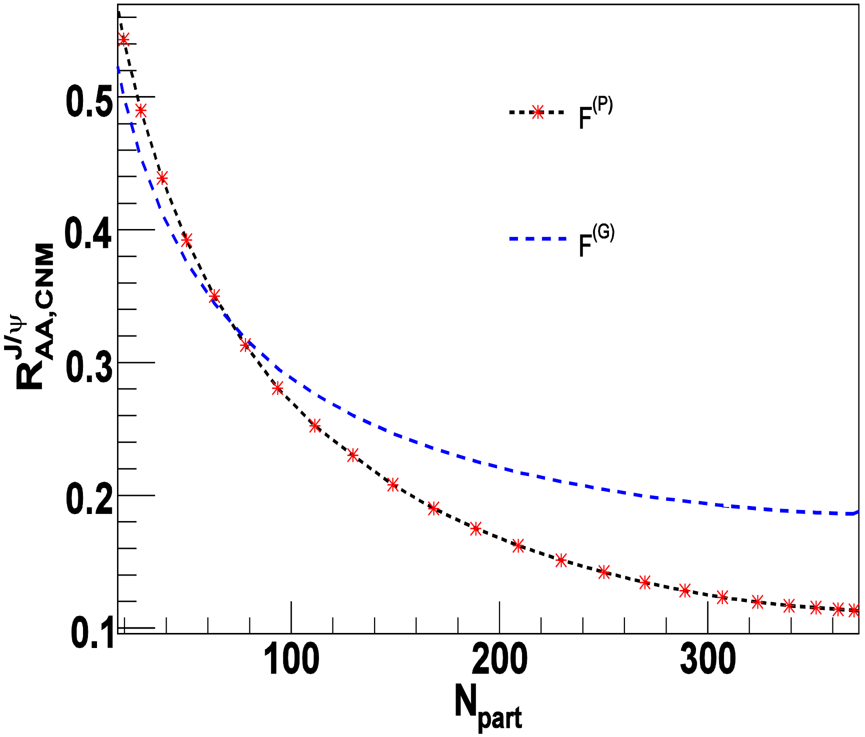
Depletion of the target parton densities in the initial state; larger dissociation in the final state (σ_{abs} ~ 10 - 12 mb @ 15 GeV)

Lower be the beam energy higher is the difference between the amount of suppressions following two hadronization schemes

CNM suppression at FAIR SIS-300
30 A GeV Au+Au collisions

PPB, A.K. Chaudhuri and S. Chattopadhyay, Phys. Rev. C 85, 064911 (2012)
PPB, A.K. Chauduri and S. Chattopadhyay, Phys. Rev. C 89, 044912 (2014)





Cold matter effects are more vigorous @ FAIR compared to SPS:

i) *Effective shadowing of the nuclear pdfs (~ 15 % effect)*
ii) *Larger final state dissociation (ε^2 increases with decreasing E_b)*

Operative over a larger period due to larger collision time

Summary and Outlook

❖We analyzed the data on ψ-to-DY ratio in p+A and Pb+Pb collisions at SPS

❖Ratio found to be sensitive to the initial state nuclear modification of parton densities inside the nuclei.

❖Model calculations are extrapolated to FAIR energy domain

❖Much larger CNM suppression is anticipated in p+A collisions at FAIR

❖In A+A collisions, CNM effects appears to be most dominant source of J/ψ suppression

❖Future plans include

- apply the model for ψ’ production
- include the effect of parton energy loss
- investigate the effect of fluctuations

Thank You

Back ups

Initial state parton shadowing

- PDF in a nucleus is the sum of the proton & neutron parton densities

$$f_i^A = Z\ f_i^{p/A} + (A - Z)\ f_i^{n/A}$$

$f_i^{n/A}$ is obtained from $f_i^{p/A}$ from iso-spin conjugation

$$u^{n/A} = d^{p/A},\ d^{n/A} = u^{p/A},\ s^{n/A} = s^{p/A}$$

- DIS & Drell-Yan measurements showed parton densities inside a nucleus are significantly different relative to a free proton
- Depleted (shadowing) or enhanced (anti-shadowing) depends on (x, Q^2, A)
- Available parameterizations generates $R_i(x,Q^2,A)$ that converts free proton distributions into nuclear distribution assuming factorization

$$f_i^A(x, Q^2) = R_i(A, x, Q^2) \times f_i^{\mathrm{p}}(x, Q^2)$$

J/ψ production in nuclear collisions

Implementation of local shadowing

In a nuclear collision both target & projectile nucleons undergo shadowing effects
Depending on the impact parameter (b) either the halo or the core collide
Shadowing effects should be different in the centre (more) than in the surface (less)
Impact parameter dependent local shadowing
Shadowing function is assumed to be proportional to the local density:

$$R_{i,\rho}(A,x,Q^2,\mathbf{s},z) = 1 + N_\rho^A \left(R_i(A,x,Q^2) - 1\right) \frac{\rho_A(\mathbf{s},z)}{\rho_0}$$

Normalization N_ρ^A is fixed to ensure:

$$(1/A) \int d\mathbf{s} dz \, R_{i,\rho}(A,x,Q^2,\mathbf{s},z) = R_i(A,x,Q^2)$$

At large distance, $r^2 (= s^2 + z^2) >> R^2_A$ and $R_{i,\rho} \to 1$
At nuclear centre ($r \to 0$), $R_{i,\rho} >> R_i$

Beam energy dependence of ε^2

Power law form: $F^{(P)}(q^2)$

Gaussian form: $F^{(G)}(q^2)$

Parameterizing the E_{Lab} dependence of ε^2 and extrapolate to FAIR energy domain

More dissociation at lower energy collisions

Estimation of nuclear absorption

$$F^{(\mathrm{G})}_{c\bar{c}\to \mathrm{J}/\psi}(q^2) = N_{\mathrm{J}/\psi}\,\theta(q^2)\,\exp\left[-q^2/(2\alpha_F^2)\right]$$

$$q^2 \longrightarrow \bar{q}^2 = q^2 + \varepsilon^2\, L(A)$$

$$\Longrightarrow \quad \sigma_{pA\to \mathrm{J}/\psi}(\sqrt{s}) = \exp\left[-\frac{\varepsilon^2}{2\alpha_F^2}\,L(A)\right]\sigma_{NN\to \mathrm{J}/\psi}(\sqrt{s})$$

$$\sigma_{pA}^{J/\psi} = A\,\sigma_{NN}^{J/\psi}\, e^{-\sigma_{abs}^{J/\psi}\rho L}$$

$$\sigma_{\mathrm{abs}}(mb) = (10\times\varepsilon^2)/(2\times\alpha_F^2\times\rho_0)$$