Associated $J/\psi + \gamma$ production in the high-energy limit of QCD

Alimov L. E.[1]
Saleev V. A.[1,2]

1. Samara National Research University
2. Joint Institute for Nuclear Research

SPD collaboration meeting
25/10/2023

Outline

- Introduction
- PRA
- ICEM
- NRQCD
- Models testing
- Results

Introduction

Motivation:

- "... clean probe of the gluon distribution ..."
- No $J/\psi + \gamma$ measurements.
- Need predictions in different approaches.

PRA introduction

⇒ Lipatov's Effective Field Theory

Reggeized gluons and quarks ⇒ Feynman rules

L. N. Lipatov (1995); L. N. Lipatov and M. I. Vyazovsky (2001).

Required matrix element $|\bar{M}|^2_{pra}(R + R \to c\bar{c}[^3S_1^{(1)}] + \gamma)$ was calculate by using FeynArt's model file **ReggeQCD** by **Maxim Nefedov**

PRA PDFs

Kimber, Martin, Ryskin and Watt (KMRW) PDF

DGLAP ($\sim log(\mu^2)$) and BFKL ($\sim log(1/x)$) are taken into account

M. A. Kimber, A. D. Martin, and M. G. Ryskin (2001); G. Watt, A. D. Martin, and M. G. Ryskin (2003).

MMRK modification

Exact normalization :

$$\left[\int_0^{\mu^2} dt\Phi_i(x,t,\mu^2) = xf_i(x,\mu^2)\right] \equiv \left[\Phi_i(x,t,\mu^2) = \frac{d}{dt}[T_i(t,\mu^2,x)xf_i(x,t)]\right]$$

From the equivalence requirement between normalization equation and KMRW prescription

PRA factorization formula

$$\sigma = \int \frac{dx_1}{x1}\frac{d^2q_{1T}}{\pi}\int \frac{dx_2}{x2}\frac{d^2q_{2T}}{\pi}\Phi(x_1,t_1,\mu^2)\times$$

$$\Phi(x_2,t_2,\mu^2)\hat{\sigma}(R+R\to J/\psi+\gamma)$$

$$\hat{\sigma} = \frac{(2\pi)^4}{(2\pi)^{3n}}\delta^{(4)}(q_1+q_2-\sum p_i)\frac{|\bar{M}|^2_{pra}}{2x_1x_2s}\prod\frac{d^3p_i}{2p_i^0}$$

$$q^\mu_{1,2} = x_{1,2}P^\mu_{1,2}+q^\mu_{1,2T}, \quad q_{1,2T}\neq 0 \quad q^2_{1,2} = q^2_{1,2T} = -\vec{q}^{\,2}_{1,2T}$$

For additional about MMRK and general about PRA see

M.A. Nefedov, V.A. Saleev (2020)

Improved color evaporation model

Processes

$R + R \to c + \bar{c} + \gamma$, $Q + \bar{Q} \to c + \bar{c} + \gamma$, where $Q = s, u, d$

ICEM phenomenological cross-section

$$\sigma = F_{J/\psi} \times \int\limits_{m^2_{J/\psi}}^{4m_D^2} \frac{d\sigma}{dM^2} dM^2, \; p_{T\,J/\psi} = \frac{m_{J/\psi}}{M} p_{T\,c\bar{c}}$$

Color evaporation model (CEM): H. Fritzsch (1977); F. Halzen (1977)
Improved CEM: Cheung V., Vogt R. (2017)

A. A. Chernyshev, V. A. Saleev (2022)

Fit $pp \to J/\psi X$: $F_{J/\psi}(\sqrt{s}) = 0.012 + 0.952\sqrt{s}^{-0.525}$

NRQCD

$$d\hat{\sigma}(a+b \to C+X) = \sum_n d\hat{\sigma}(a+b \to c\bar{c}[n]+X)\langle O^c \rangle$$

where n - color, spin, orbital and angular momentum quantum number.

Colorless leaden order of NRQCD series named CSM

$$d\hat{\sigma}(g+g \to {}^3S_1^{(1)}+\gamma) = \langle O^{J/\psi}[{}^3S_1^{(1)}]\rangle d\hat{\sigma}(g+g \to c\bar{c}[{}^3S_1^{(1)}]+\gamma)$$

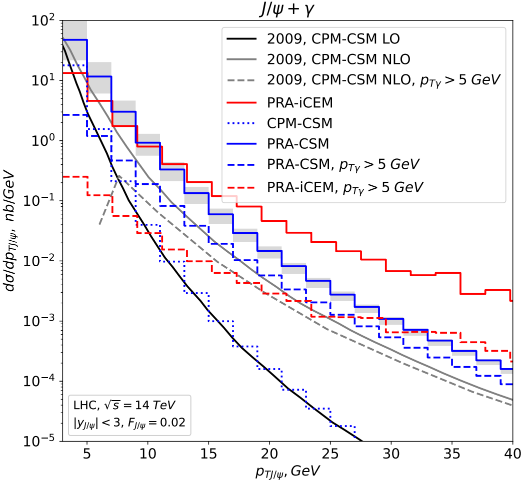
where $\langle O^{J/\psi}[{}^3S_1^{(1)}]\rangle = 1.3\ GeV^3$ is singlet long distance matrix element.

In the leading order, the singlet contribution prevails over the prompt contribution.
M. A. Doncheski, C. S. Kim (1993)

So leading order in parton reggeization approach

$$d\hat{\sigma}(R+R \to {}^3S_1^{(1)}+\gamma) = \langle O^{J/\psi}[{}^3S_1^{(1)}]\rangle d\hat{\sigma}(R+R \to c\bar{c}[{}^3S_1^{(1)}]+\gamma)$$

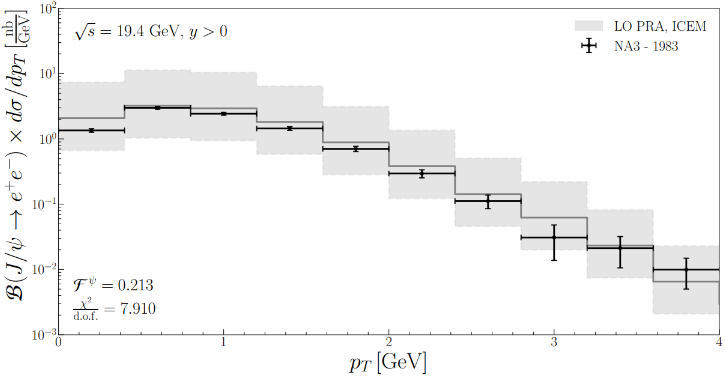
At high energies



PRA-CSM $\simeq$ NLO CPM-CSM [previous calculations by R. Li, J.X. Wang (2009)]

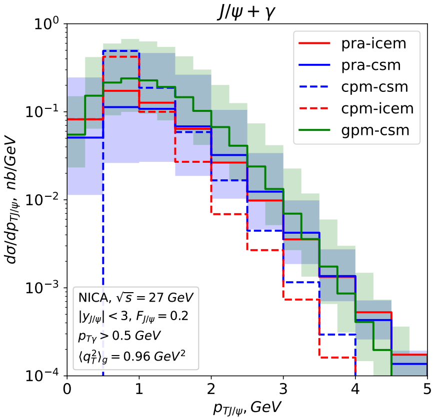
$\sigma_{CPM-NLO} = 61\ nb$
$\sigma_{PRA-CSM} = 128\ nb$
$\sigma_{PRA-iCEM} = 43\ nb$
$p_{T\gamma} > 5$:
$\sigma_{CPM-NLO} = 1.1\ nb$
$\sigma_{PRA-CSM} = 9.4\ nb$
$\sigma_{PRA-iCEM} = 1\ nb$

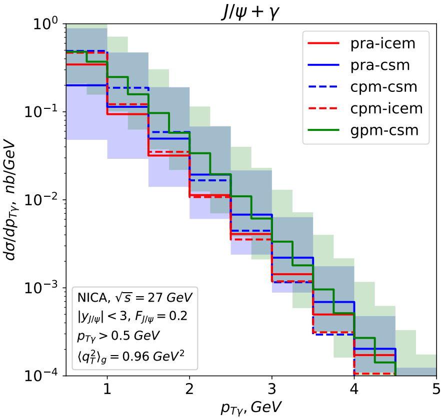
Inclusive J/ψ at low energies



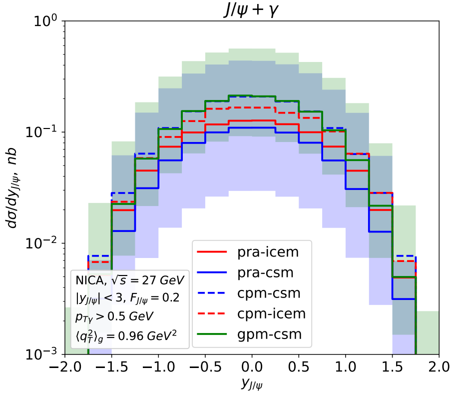
A. A. Chernyshev, V. A. Saleev (2022)

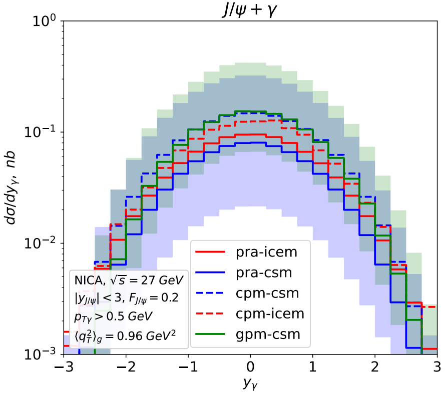
NICA, $\sqrt{s} = 27$ GeV, transverse momentum cross sections



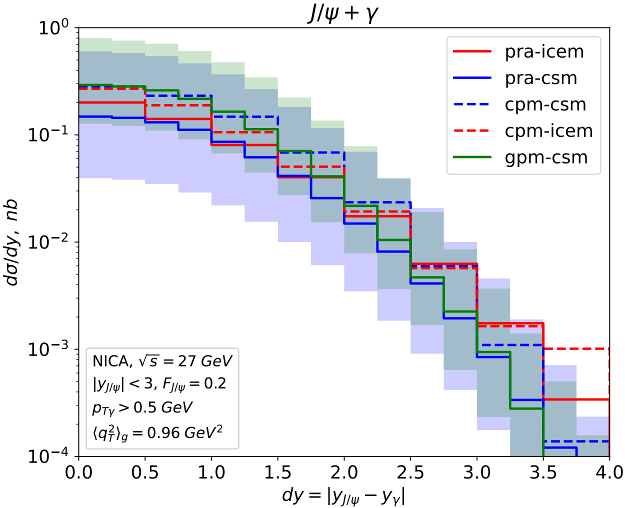


NICA, $\sqrt{s} = 27$ GeV, rapidity cross sections



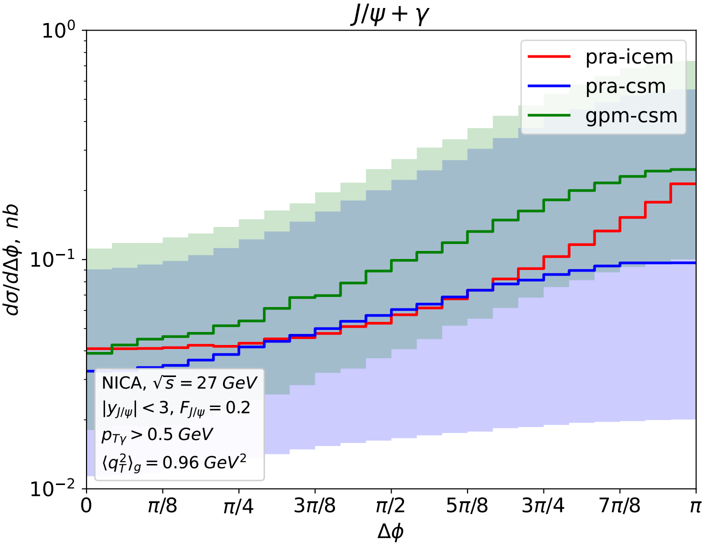


NICA, $\sqrt{s} = 27$ GeV, rapidity difference cross-section



$\sigma_{GPM-CSM} = 0.37\ nb$
$\sigma_{PRA-CSM} = 0.2\ nb$
$\sigma_{PRA-iCEM} = 0.24\ nb$

NICA, $\sqrt{s} = 27$ GeV, azimuthal correlations



Conclusions

- Our PRA-CSM result for LHC ($\sqrt{s} = 14\, TeV$) have good comparison with NEXT to leading order CPM-CSM computation. The implementation of this standard condition guarantees the correctness of the approach.
- A good description of the inclusive production data at low energies allows us to talk about the extensibility of the PRA. The extensibility argument of the PRA was used to predict differential cross sections at the energy of the NICA $\sqrt{s} = 27$ GeV.
- At low energies, we show that the predictions in different models are in good agreement with each other, but the behavior of the cross sections is different according to the difference of azimuthal angles. So it seems possible to test, to discriminate models.

Thank you for your attention!