Energy dependence of J/ψ production in pp collisions with the PACIAE model

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More details, see arXiv: 2310.12627

Outline

1. Background and motivations
2. The PACIAE model
3. Method
4. Results and discussions
5. Summary

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Background and Motivation

- J/ψ is the lightest vector charmonium meson.
- The suppression of J/ψ production was proposed as a probe to QGP created in HI collisions.
- The J/ψ production could also be suppressed due to the CNM effects, such as modifications of nuclear PDFs.
- In order to disentangle the hot and cold medium effects, it is necessary to understand the J/ψ production in pp collisions where the initial state effects are absent.

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Background and Motivation

- The J/ψ production was extensively investigated at colliders such as the Tevatron, RHIC and LHC.
- The ALICE collaboration had published the inclusive J/ψ production in the fwd- and mid-rapidity regions in pp collisions.

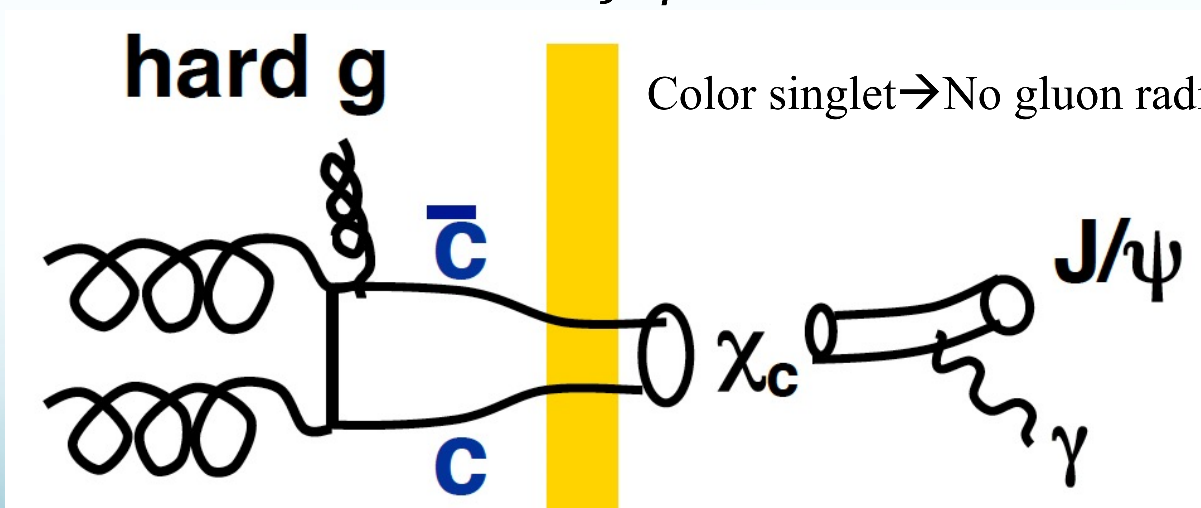
$\sqrt{s}$	forward rapidity ($2.5 < y < 4$)	mid-rapidity ($-0.9 < y < 0.9$)
2.76 TeV	Phys. Lett. B 718, 295 (2012).	–
5.02 TeV	Eur. Phys. J. C 77, 392 (2017).	J. High Energy Physics 10, 84 (2019).
7 TeV	Eur. Phys. J. C 74, 2974 (2014).	Phys. Lett. B 704, 442 (2011).
8 TeV	Eur. Phys. J. C 76, 184 (2016).	–
13 TeV	Eur. Phys. J. C 77, 392 (2017).	Eur. Phys. J. C 77, 392 (2017).

Inclusive J/ψ =direct J/ψ+ the feed-down from heavier charmonium decay+beauty hadrons weak decay

Background and Motivation

- Several theoretical approaches, such as CSM, COM and CEM have been utilized to describe the experimental data.
- They differ mostly in the treatment of non-perturbative evolution of the $c\bar{c}$ pair into the bound state J/ψ.

Color Singlet



Color singlet→No gluon radiation

taken from A. Kraan's slides

Phys. Lett. B 102, 364 (1981). perturbative non-perturbative

Background and Motivation

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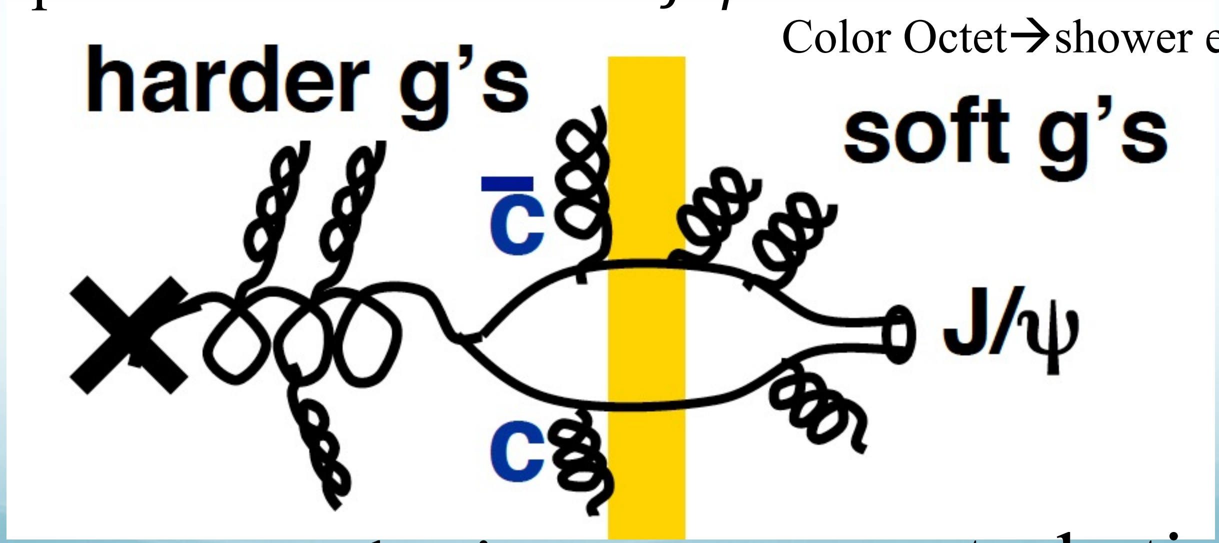
Color Octet→shower expected

Color Octet

$g \rightarrow c\bar{c}^{(8)}$



perturbative non-perturbative

taken from A. Kraan's slides

Phys. Rev. D 51, 1125 (1995)

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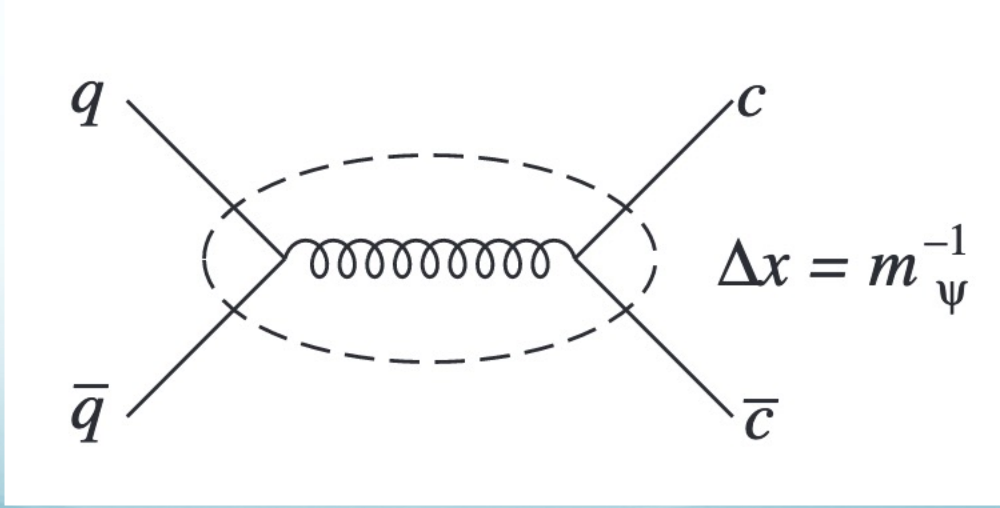
Color Evaporation

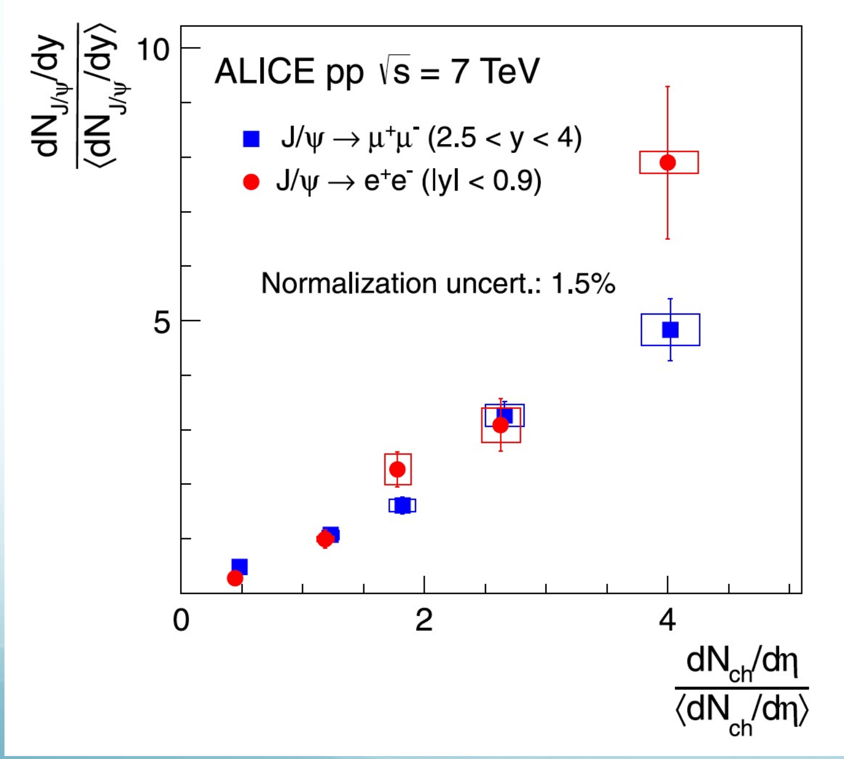


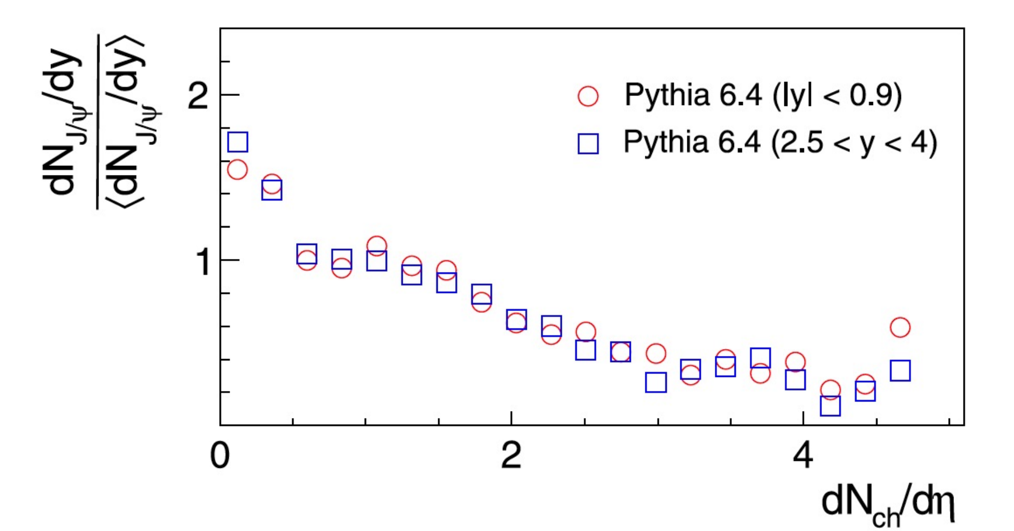
$q\bar{q}$ annihilation into $c\bar{c}$

PLB 390, 323-328, 1997

Background and Motivation

- The J/ψ production was also investigated by Monte Carlo simulations



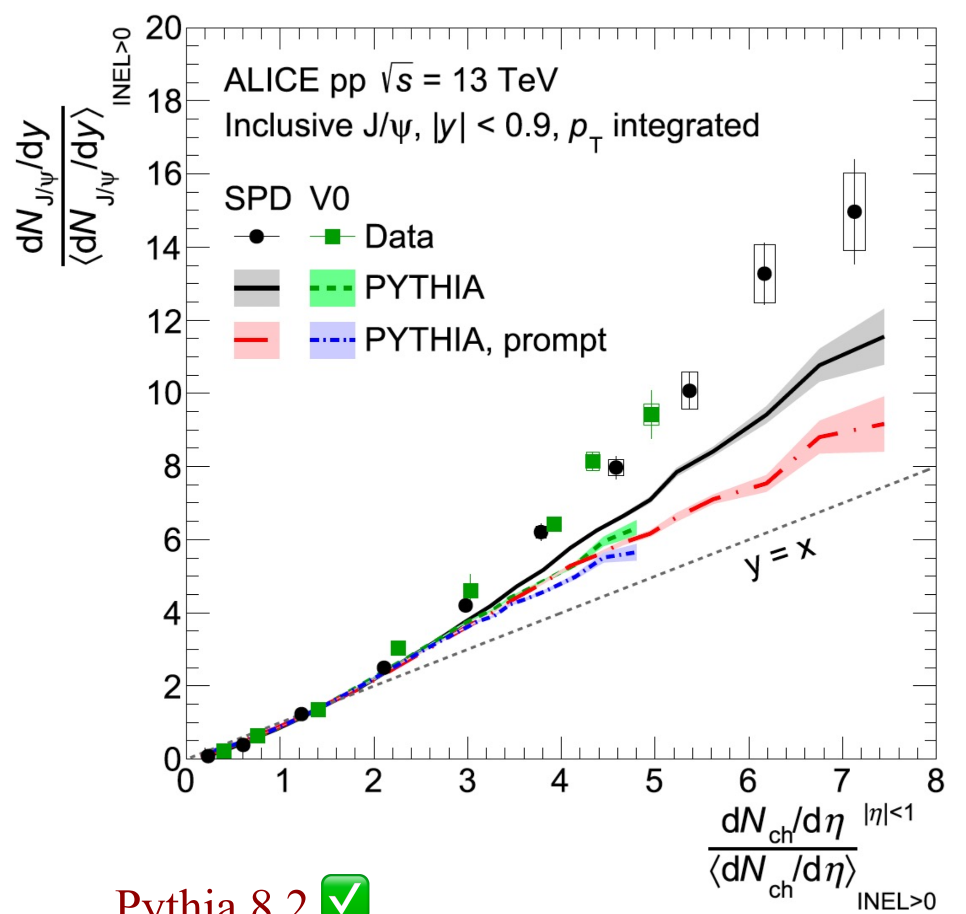


Pythia 6.4 ✕

Background and Motivation

- The J/ψ production was also investigated by Monte Carlo simulations

Different treatment of MPI in PYTHIA 6 and PYTHIA 8



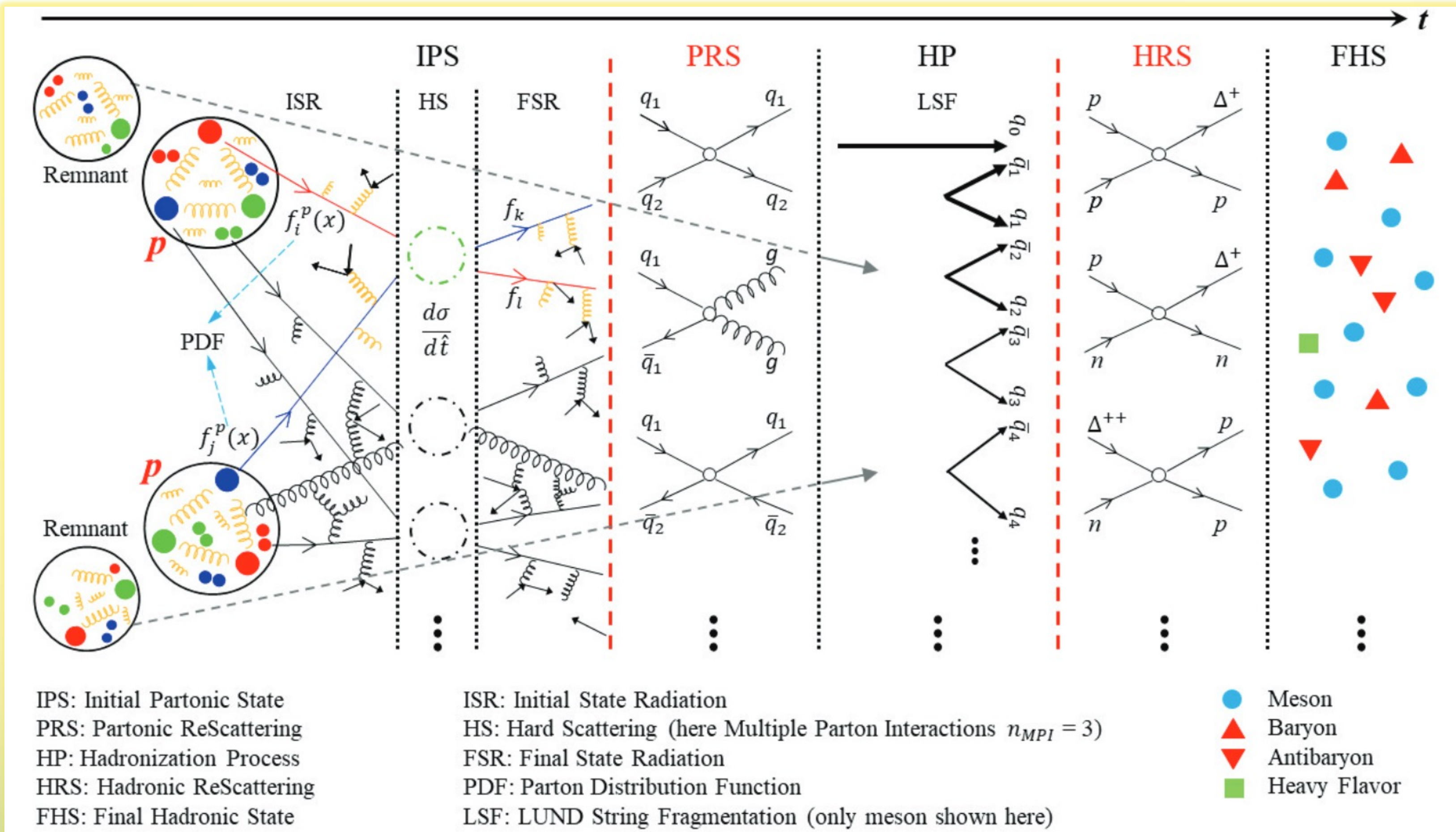
Pythia 8.2 ✅

Physics Letters B 810 (2020) 135758

Background and Motivation

- As a complementary study, we use a parton and hadron cascade model PACIAE 2.2a to investigate the J/ψ production in pp collisions at $\sqrt{s}$ =2.76, 5.02, 7, 8, and 13 TeV.
- In the model the J/ψ production QCD process will be selected specially and a bias factor will be introduced for the simulation sample correspondingly.

The PACIAE Model



PACIAE is based on PYTHIA 6.4 but further considers the partonic rescattering before hadronization and the hadronic rescattering after hadronization.

A.-K. Lei et al., arXiv: 2309.05110

The PACIAE Model

- The initial partonic states are created by temporarily switching off the string fragmentation in PYTHIA, breaking down these strings and splitting up the diquarks (anti-diquarks) randomly.

- Together with the ISR and FSR, this partonic matter then undergoes hard scatterings and parton rescatterings, where the LO pQCD parton-parton interaction xs are employed.

The PACIAE Model

- A *K* factor is introduced to consider higher order effects and non-perturbative corrections.
- After the parton rescattering, the partonic matter is converted into hadrons by the string fragmentation or the coalescence model.
- Then followed is the hadronic rescattering where the method of two-body collision is utilized to rescatter hadrons until the kinetic freeze-out happens.

The Method

- A 'menus' of subprocesses for the J/ψ production is composed.
- The 'color-octet' processes are not considered, as we only focus

on the production of J/ψ in the low and intermediate p_{T} range.

color-singlet processes

ISUB =	86	$gg \rightarrow J/\psi g$
	87	$gg \rightarrow \chi_{0c} g$
	88	$gg \rightarrow \chi_{1c} g$
	89	$gg \rightarrow \chi_{2c} g$
	104	$gg \rightarrow \chi_{0c}$
	105	$gg \rightarrow \chi_{2c}$
	106	$gg \rightarrow J/\psi\gamma$

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The Method

- The selection of the J/ψ production processes will introduce a bias sampling.

$$\frac{\left.\frac{\mathrm{d}\sigma_{J/\psi}}{\mathrm{d}y}\right|_{\mathrm{sim}}}{\int p_{\mathrm{T}} \left.\frac{\mathrm{d}^2\sigma_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{\mathrm{sim}} \mathrm{d}p_{\mathrm{T}}} = \frac{\left.\frac{\mathrm{d}\sigma_{J/\psi}}{\mathrm{d}y}\right|_{\mathrm{exp}}}{\int p_{\mathrm{T}} \left.\frac{\mathrm{d}^2\sigma_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{\mathrm{exp}} \mathrm{d}p_{\mathrm{T}}}.$$

Bias factor

$$B = \frac{\int p_{\mathrm{T}} \left.\frac{\mathrm{d}^2\sigma_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{\mathrm{exp}} \mathrm{d}p_{\mathrm{T}}}{\int p_{\mathrm{T}} \left.\frac{\mathrm{d}^2\sigma_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{\mathrm{sim}} \mathrm{d}p_{\mathrm{T}}} = \frac{\int p_{\mathrm{T}} \left.\frac{\mathrm{d}^2\sigma_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\right|_{\mathrm{exp}} \mathrm{d}p_{\mathrm{T}}}{\int p_{\mathrm{T}} \left.\frac{\mathrm{d}^2 N_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \cdot \frac{\sigma_{J/\psi}}{N_{J/\psi}}\right|_{\mathrm{sim}} \mathrm{d}p_{\mathrm{T}}}$$

$N_{J/\psi}$ is total J/ψ yield in simulation

$\sigma_{J/\psi}$ is J/ψ cross section in one pp collision at a given energy

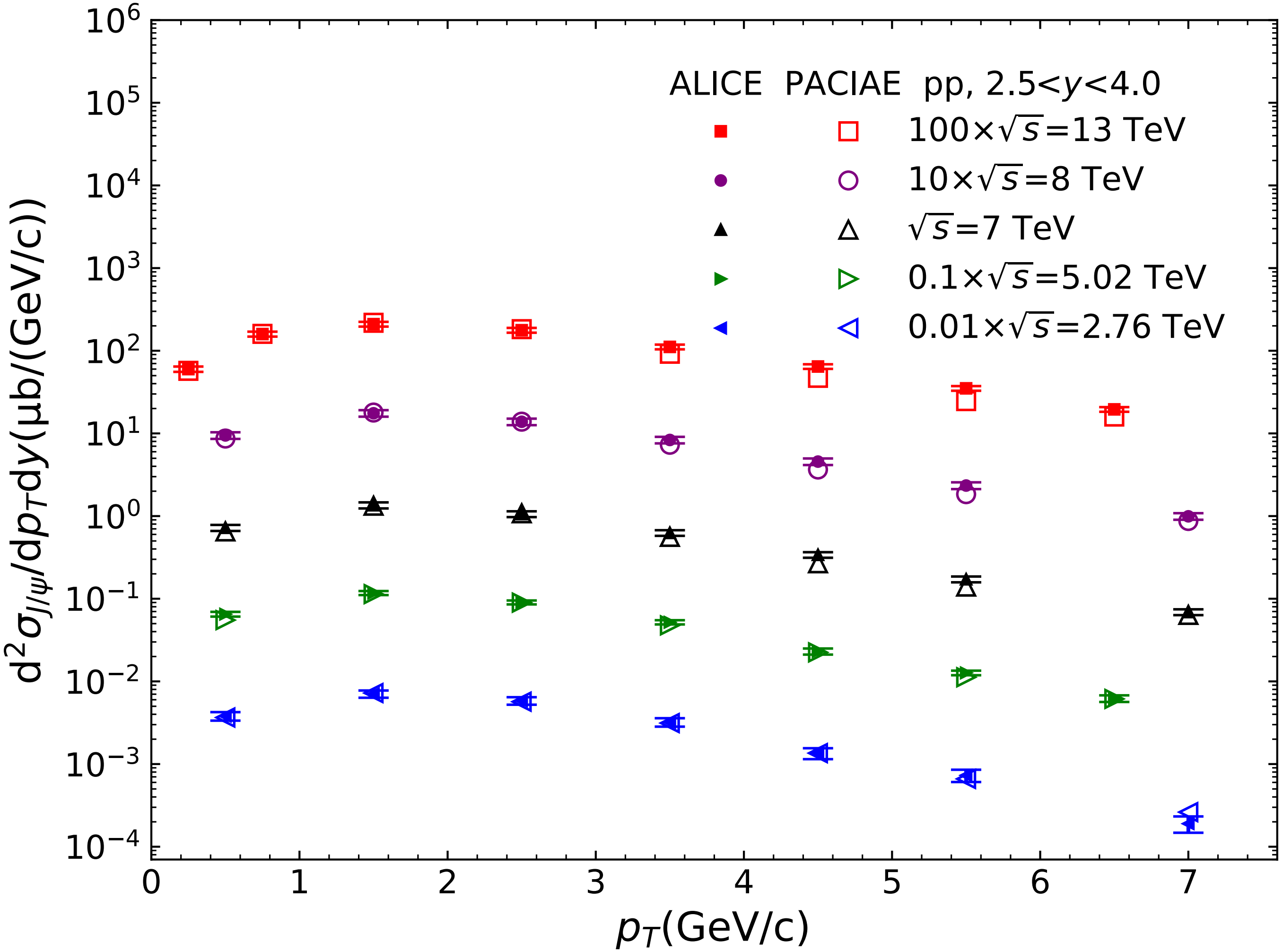
The Method

- In PACIAE, the model parameters are chosen as the default values in PYTHIA 6.4, except for the K factor.
- The K factor is determined by fitting the simulation to the experimental data with a least χ^2 method.

K	2.76 TeV	5.02 TeV	7 TeV	8 TeV	13 TeV
			χ^2/ndf		
1.1	5.39/6	14.06/6	23.85/6	17.09/6	66.34/7
1.2	4.74/6	10.93/6	19.57/6	16.77/6	71.67/7
1.3	6.11/6	17.25/6	**16.62/6**	16.40/6	63.80/7
1.4	4.81/6	13.55/6	18.87/6	17.08/6	60.94/7
1.5	6.86/6	11.44/6	21.23/6	**13.40/6**	58.07/7
1.6	**3.46/6**	13.10/6	19.18/6	13.71/6	58.83/7
1.7	5.92/6	**10.92/6**	19.54/6	14.85/6	**54.86/7**
1.8	7.04/6	14.89/6	19.25/6	14.37/6	65.33/7
1.9	5.96/6	15.22/6	20.05/6	14.94/6	71.83/7

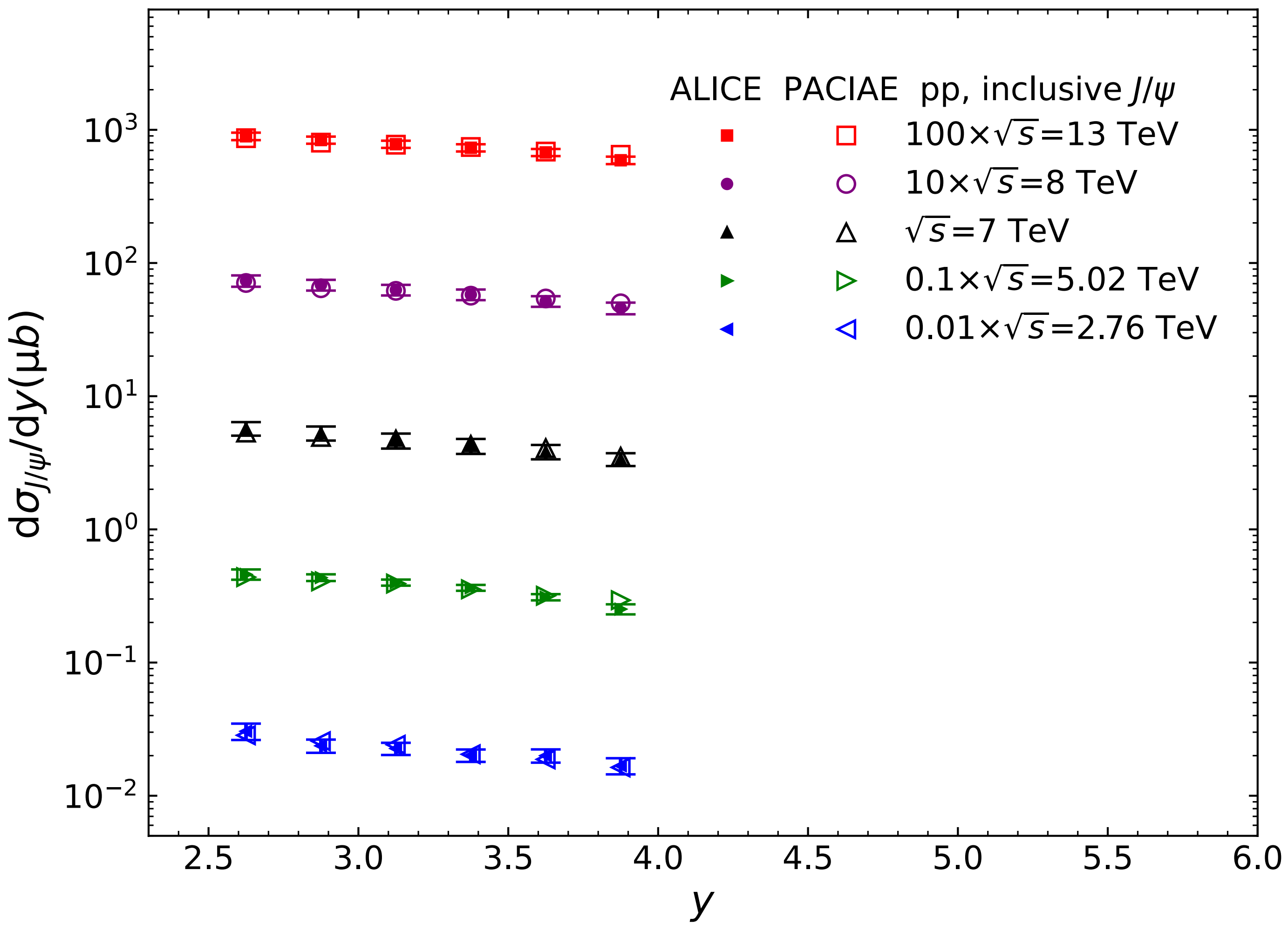
Results and Discussions

Forward rapidity



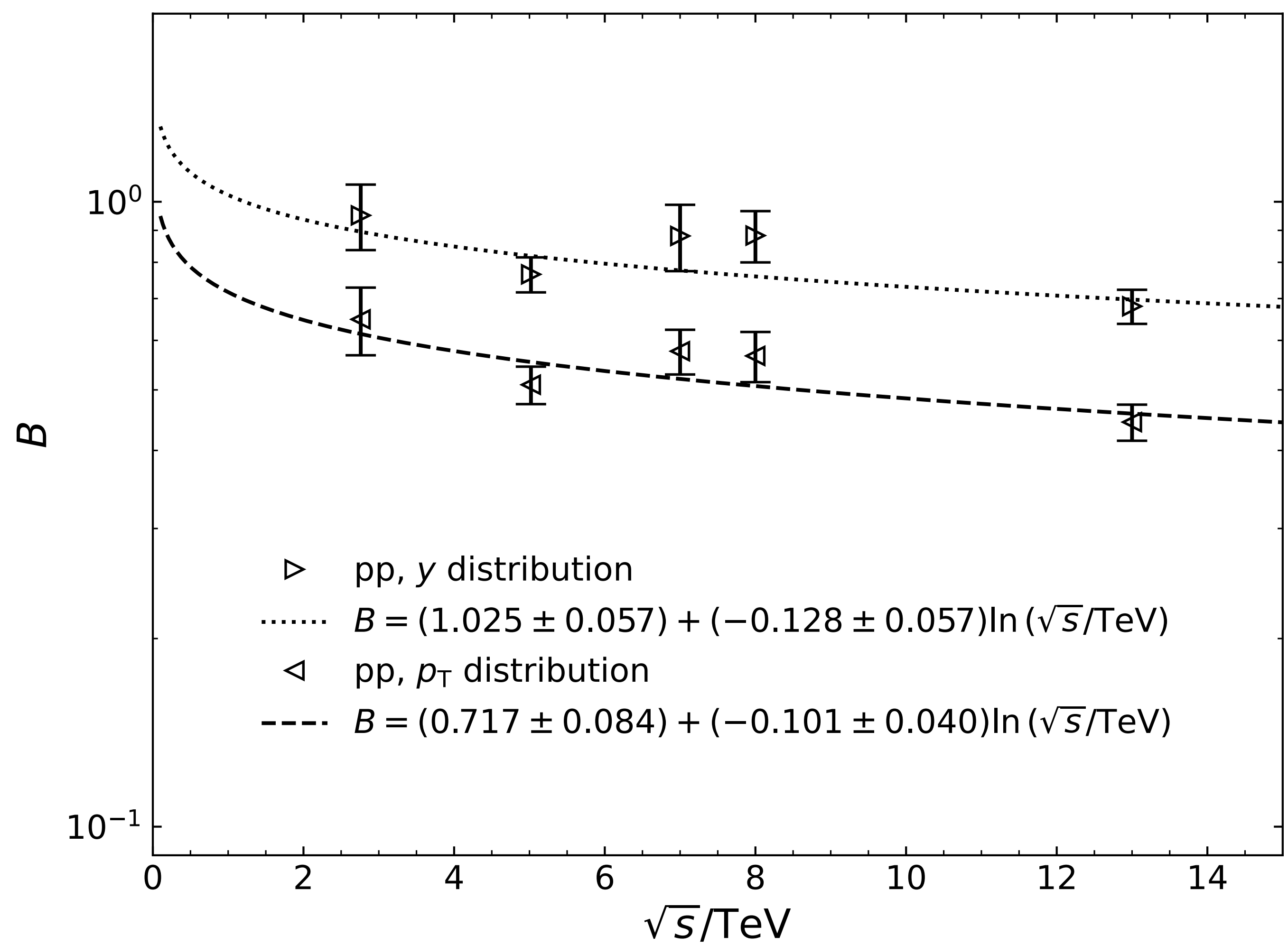
Results and Discussions

Forward rapidity



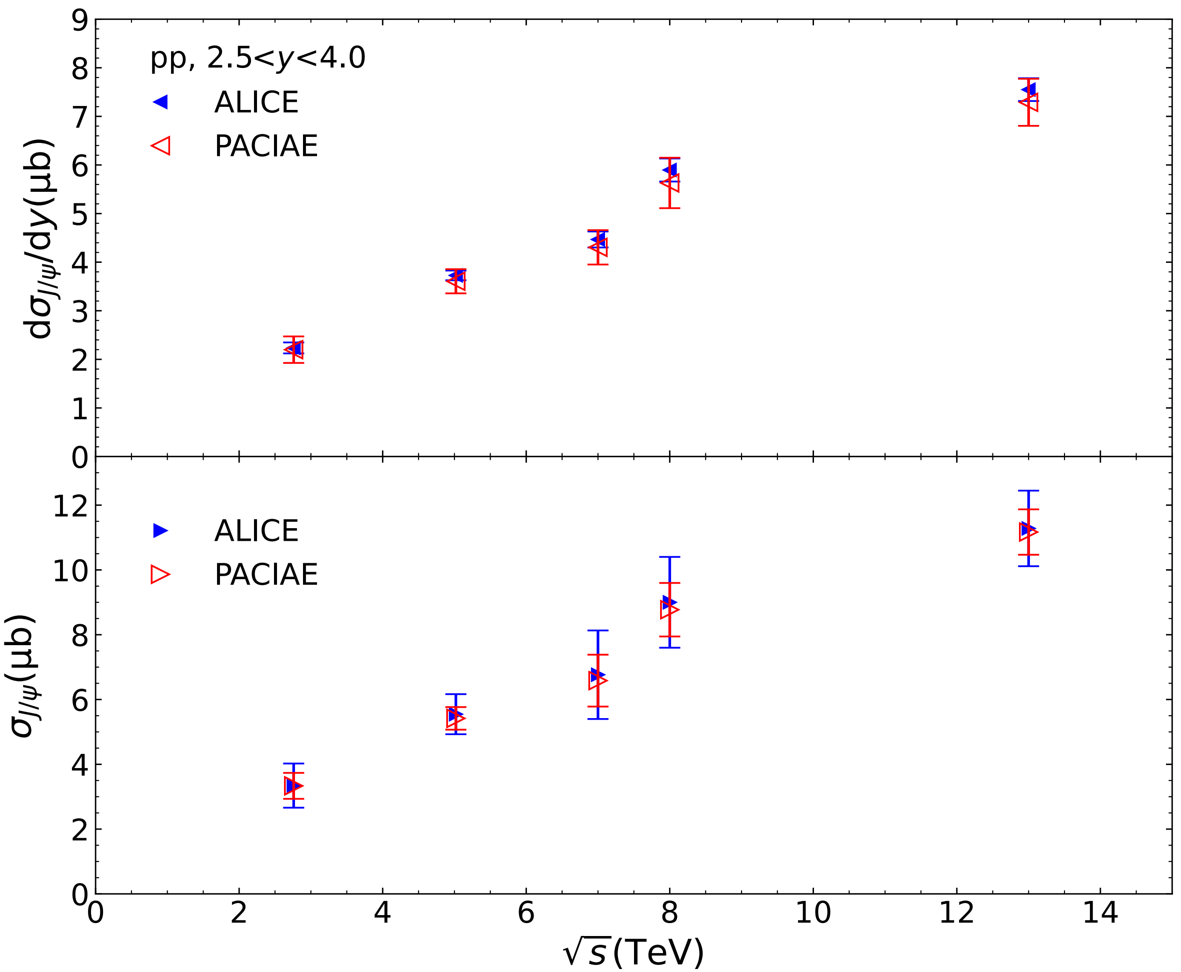
Results and Discussions

Forward rapidity



Results and Discussions

Forward rapidity



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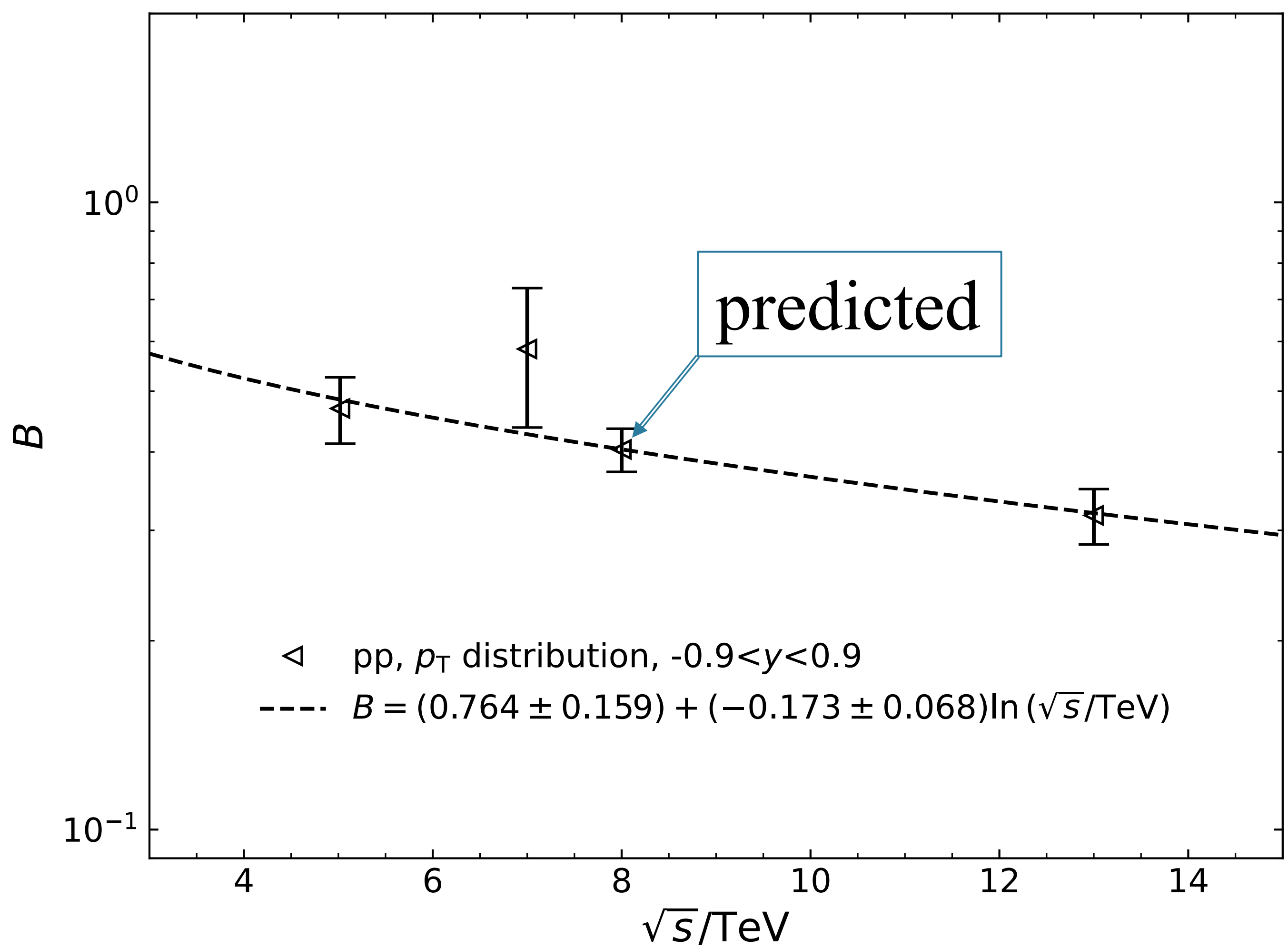
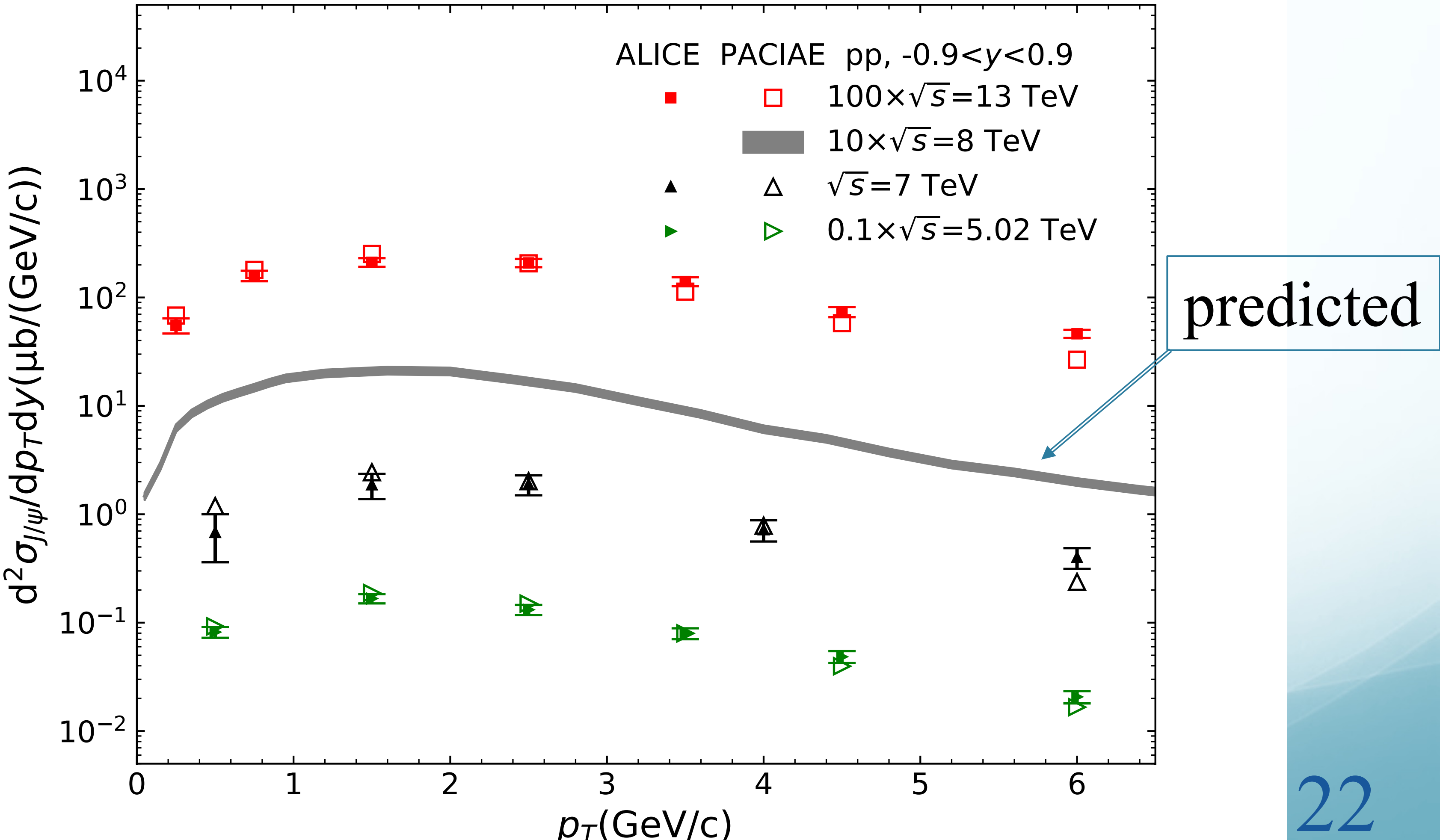
Results and Discussions

Mid-rapidity



Results and Discussions

Mid-rapidity



Conclusions

- We have investigated the J/ψ production in pp collisions at the LHC energy with PACIAE 2.2a.
- The J/ψ production QCD processes are selected specially, the bias factor is proposed and applied to the simulation sample correspondingly.
- The calculated J/ψ xs as a function of p_{T} and y agree with the experimental data reasonably well.
- The double differential xs of J/ψ at $\sqrt{s}=8$ TeV is predicted.
- The necessary of the individually investigating the partonic and hadronic rescattering effects, which will be presented in our next work.

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Back up

Summary of cross sections for each J/ψ 'color-singlet' selection process, σ_{sel}, in one pp collision at a given energy in PACIAE.

Processes	2.76 TeV	5.02 TeV	7 TeV	8 TeV	13 TeV	BR	Sampling probablity
	$\sigma_{\text{sel}}(\mu\text{b})$						
$gg \to J/\psi g$	32.871	62.654	64.798	83.623	132.548	100.0%	2.184%
$gg \to \chi_{0c} g$	241.830	499.519	533.856	700.603	1169.812	1.4%	21.054%
$gg \to \chi_{1c} g$	138.797	312.055	345.636	460.827	823.761	34.3%	5.000%
$gg \to \chi_{2c} g$	265.777	552.470	593.993	779.302	1302.222	19.0%	23.101%
$gg \to \chi_{0c}$	294.944	554.780	572.512	744.378	1202.169	1.4%	23.525%
$gg \to \chi_{2c}$	255.635	484.268	502.488	651.972	1060.098	19.0%	25.083%
$gg \to J/\psi\gamma$	0.929	1.872	1.856	2.588	4.232	100.0%	0.053%
$\sigma_{J/\psi}(\mu\text{b})$	28.631	57.349	60.822	79.524	132.111	–	–

Back up

- The total J/ψ cross section in one event at a given energy in simulation, $\sigma_{J/\psi}$, can be expressed as follows:

$$\sigma_{J/\psi} = \sigma^{ev}_{J/\psi} \frac{N_{J/\psi}}{N_{ev}} = \sigma^{ev}_{J/\psi} N^{per}_{J/\psi}$$

- $N_{J/\psi}$ (N_{ev}) is the number of J/ψ (events) in the simulation sample.
- For each energy, N_{ev} is set to be 10^6.
- ${N^{per}}_{J/\psi}$ is the number of J/ψs in one event, ${N^{per}}_{J/\psi} = N_{J/\psi}/N_{ev}$
- ${\sigma^{ev}}_{J/\psi}$ is the xs of producing one J/ψ in one event, ${\sigma^{ev}}_{J/\psi} = \sigma_{J/\psi}/{N^{per}}_{J/\psi}$

$$\frac{\mathrm{d}^2\sigma_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} = \frac{1}{N_{\mathrm{ev}}} \frac{\mathrm{d}^2 N_{J/\psi}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \sigma^{\mathrm{ev}}_{J/\psi} = \frac{\mathrm{d}^2 N_{J/\psi}}{\mathrm{d}p_T\mathrm{d}y} \frac{\sigma_{J/\psi}}{N_{J/\psi}}$$

Back up

- If MPI were mainly affecting processes involving only light quarks and gluons, as implemented e.g. in PYTHIA 6.4, processes like J/ψ and open heavy flavor production should not be influenced and their rates are expected to be independent of the overall event multiplicity.
- However, at the high center-of-mass energies reached at the LHC, there might be a substantial contribution of MPI on a harder scale which can also induce a correlation between the yield of quarkonia and the total charged particle multiplicity.