J/ψ production in jets

Qian Yang （杨 钱）
Shandong University

Outline

- Motivation
- J/ψ-jet Fragmentation function study in p+p system
- Impact of J/ψ in jet production in A+A system
- Summary

J/ψ production process

- J/ψ is a non-relativistic QCD system(v^2<<1): one of the simplest systems in QCD

Production of the $c\bar{c}$
(large momentum transfer)

→

Evolution of the $c\bar{c}$ pair into J/ψ
(small dynamical scale)

pQCD process

non-pQCD process

Model

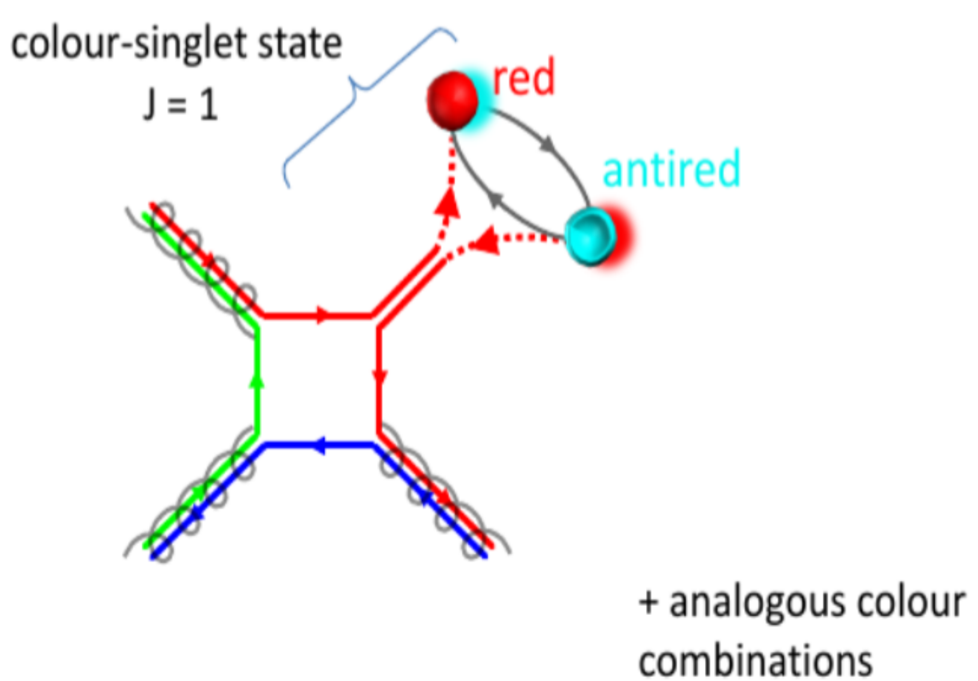
- Difficulty:involving both perturbative and non-perturbative processes

J/ψ production models

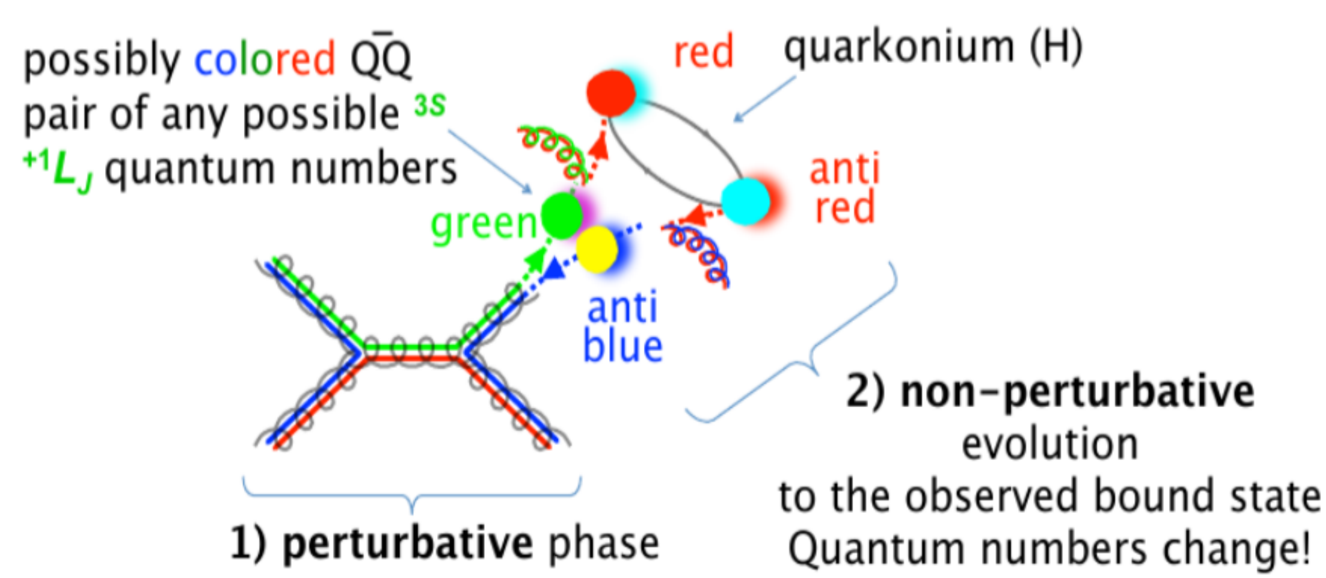
Models differ in the treatment of hadronization:

- Color Singlet Model
- Improved Color Evaporation Model et.al
- NRQCD approach (CGC+NRQCD at low p_T)
  - ➜ Long distance matrix elements (LDMEs)

Color-singlet



Color-octet

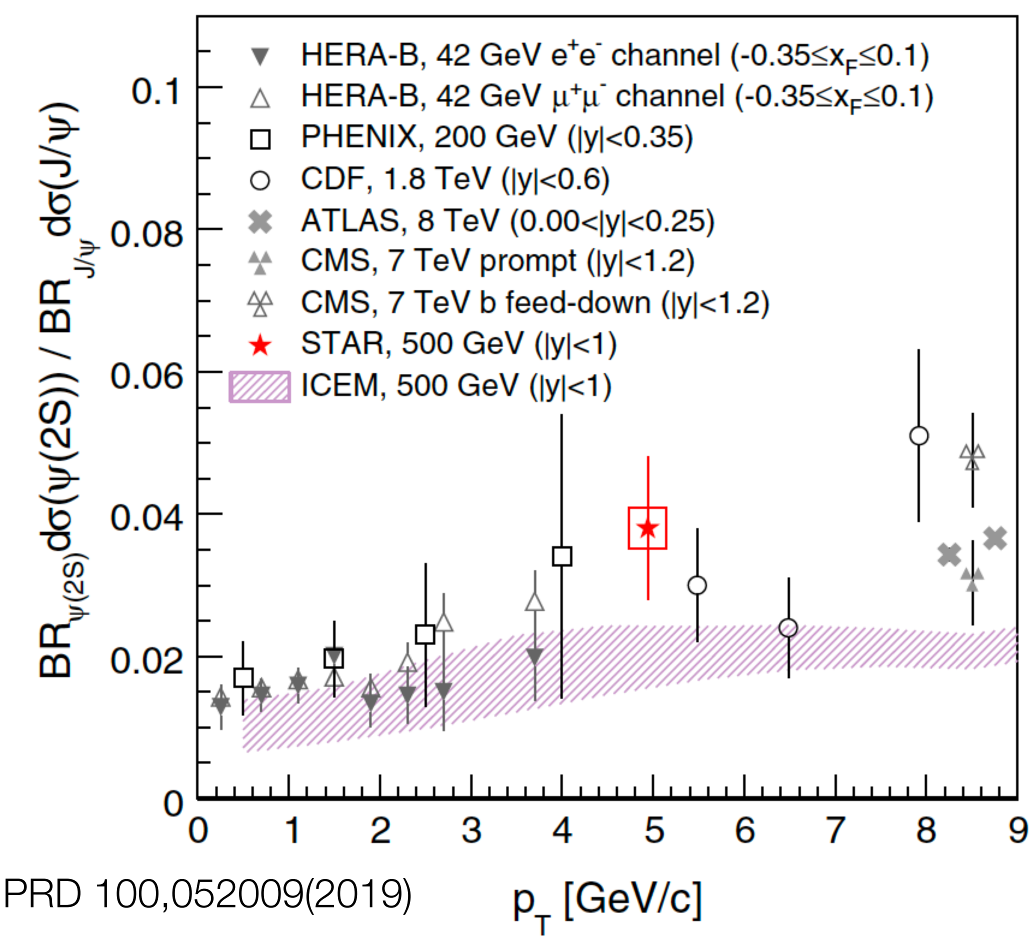


[P. Faccioli, Polarization in LHC physics, Course on Physics at the LHC 2014]

Feed-down contribution

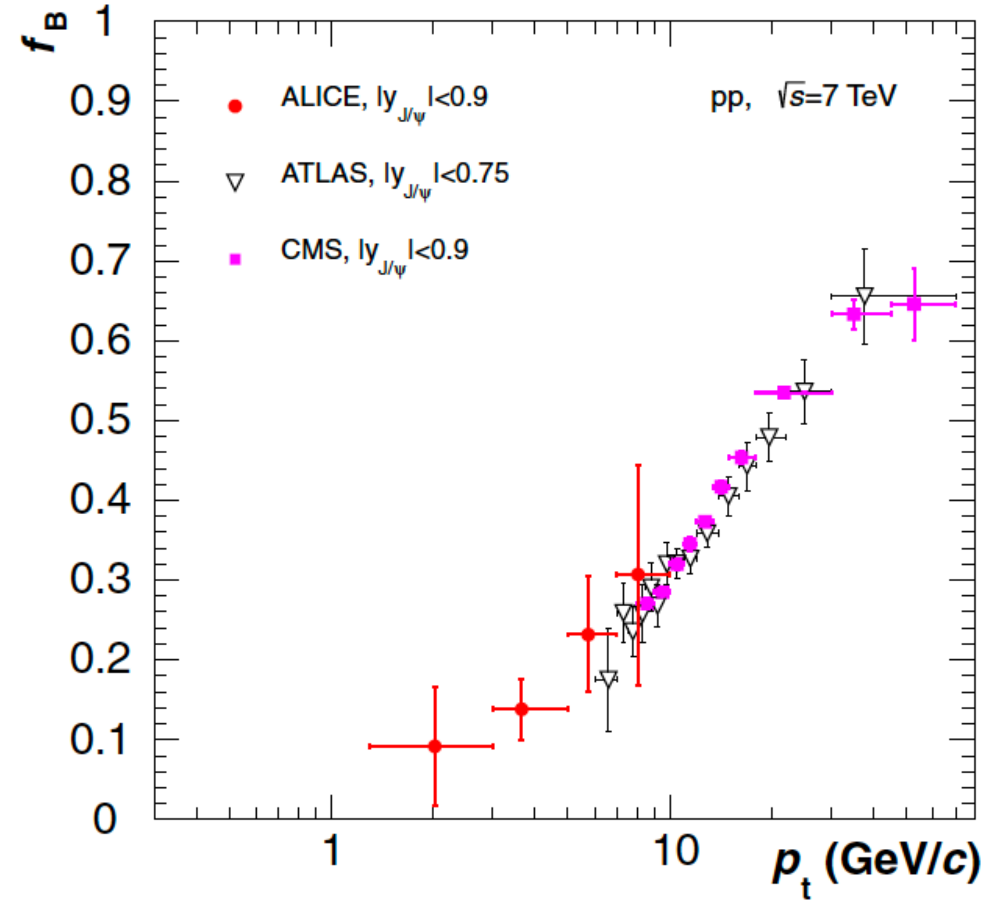
Inclusive J/ψ: prompt J/ψ (direct and excited states decay) and non-prompt J/ψ (from B-hadron)

ψ(2s) to J/ψ ratio



STAR, PRD 100,052009(2019)

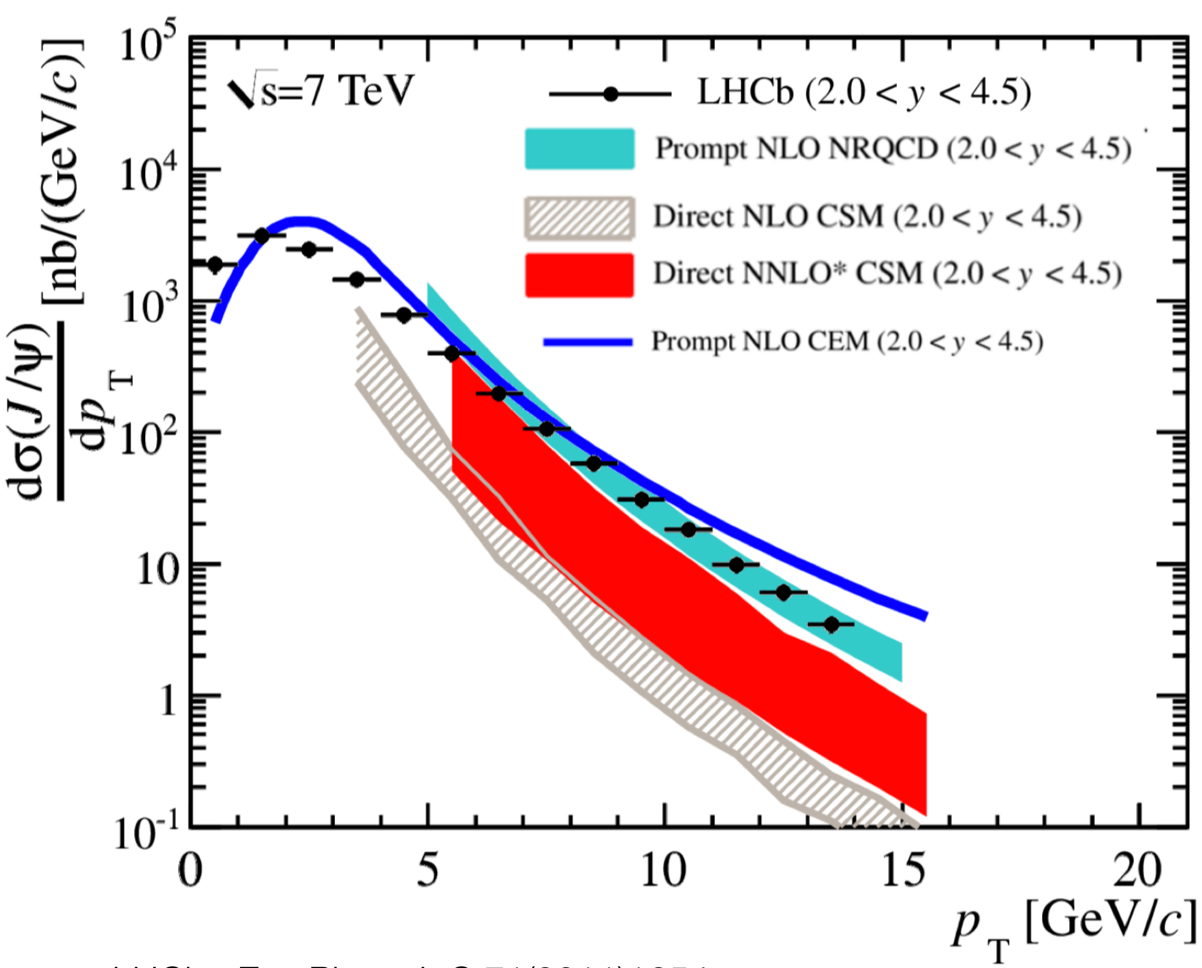
B→J/ψ to inclusive J/ψ ratio



A. Andronic et.al EPJC, (2016) 76:107

Feed-down complicated the understanding of J/ψ production

J/ψ production cross section



LHCb, Eur. Phys. J. C 71(2011)1654

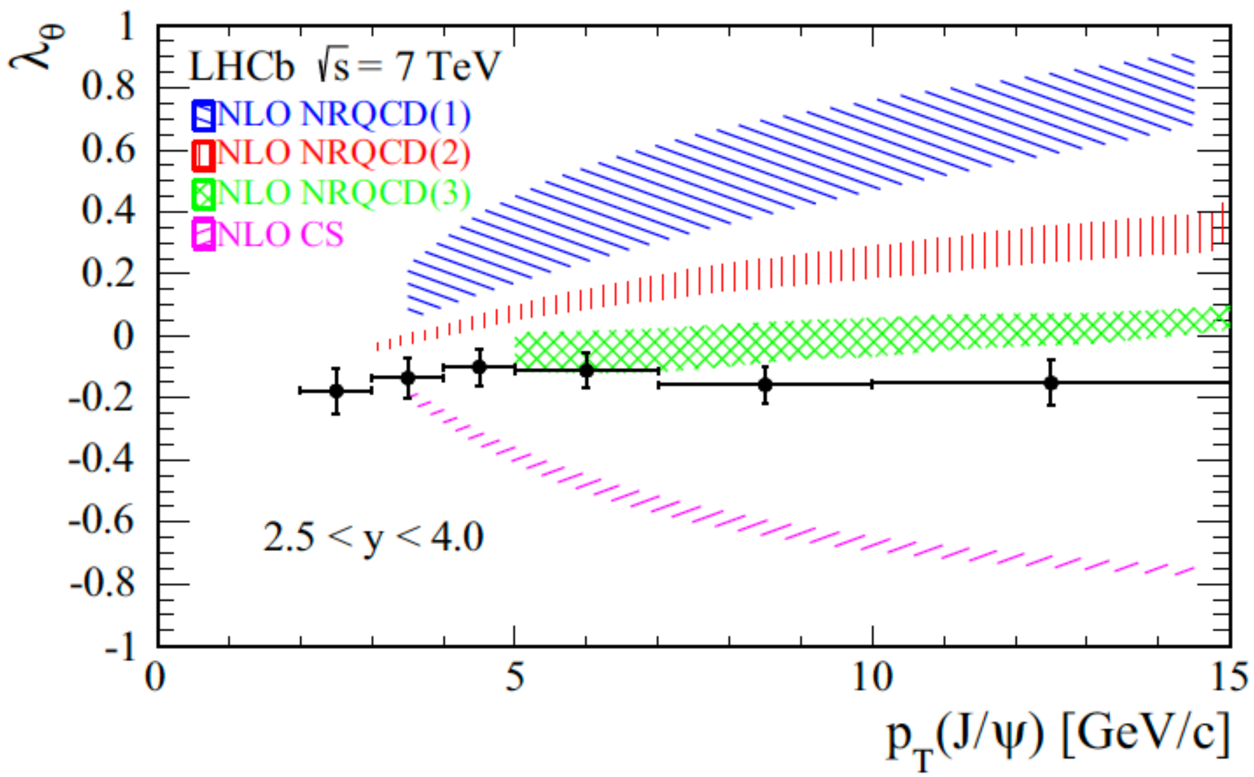
LDMEs

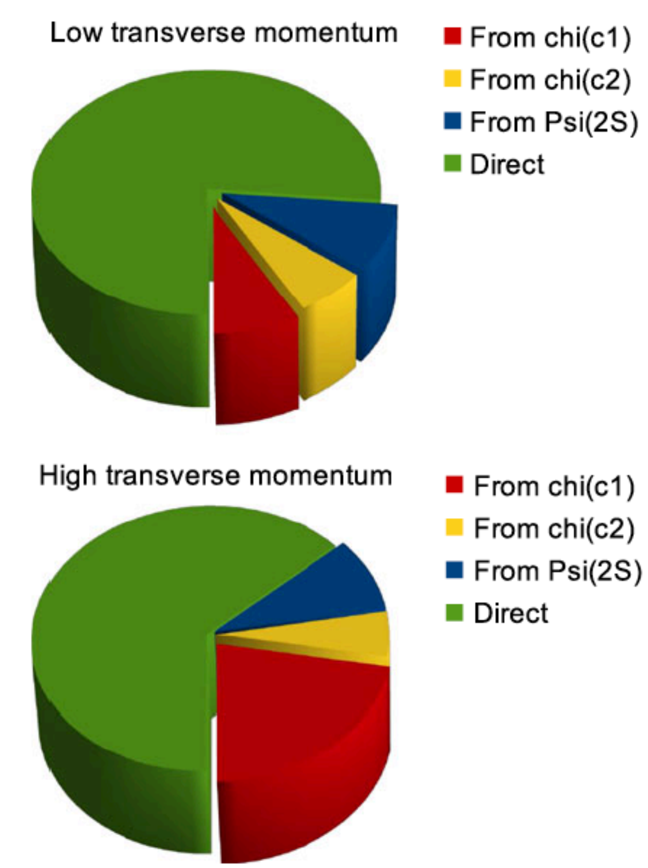
	B&K et. Al	Bodwin et. Al	Chao et.Al
Fit range	Extend to low-pT	High-pT	High-pT
Data-set	$p+p(\bar{p})$,e+e et.al	$p+p$	$p+p$
Correction	-	fragmentation contributions	-

NRQCD predictive power based on LDMEs which must be extracted from the data

- A good description of cross section with NRQCD approach
- Different approach to obtain LDMEs at different group

J/ψ polarization





LHCb, Eur. Phys. J. C 73(2013)2631

- J/ψ polarization is consistent with zero polarization for measurement
- Transverse polarization trend for J/ψ from NRQCD model prediction

J/ψ production puzzle

	B&K et. Al	Bodwin et. Al	Chao et.Al
p_T-differential cross section	✔	✔ (high-pT)	✔ (high-pT)
Polarization	✗	✔	✔
Universality	-	✗	✗

	${}^3S_0^{[1]}$	${}^1S_0^{[8]}$	${}^3S_1^{[8]}$	${}^3P_0^{[8]}$
Bodwin et al	-	9.9	1.1 (error 100%)	1.1 (error 100%)

- The extracted matrix elements are sufficiently inaccurate
  - New observables to further constrain LDMEs

J/ψ production in jets

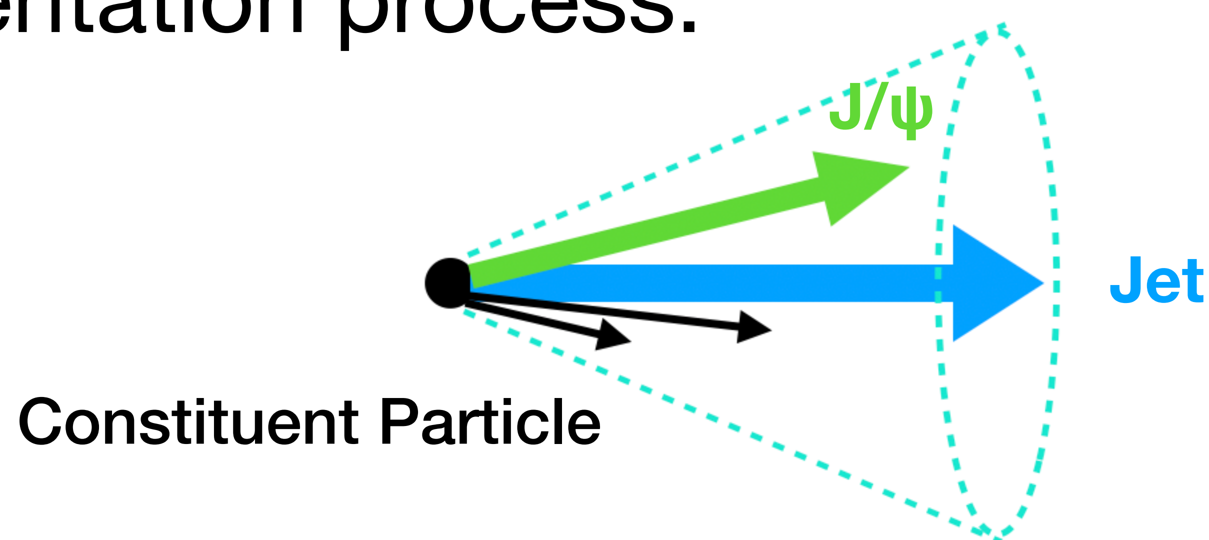
Inclusive process:

$$p + p \rightarrow J/\psi + X$$

Cross-section or polarization

Part of J/ψ hadronization information

Fragmentation process:

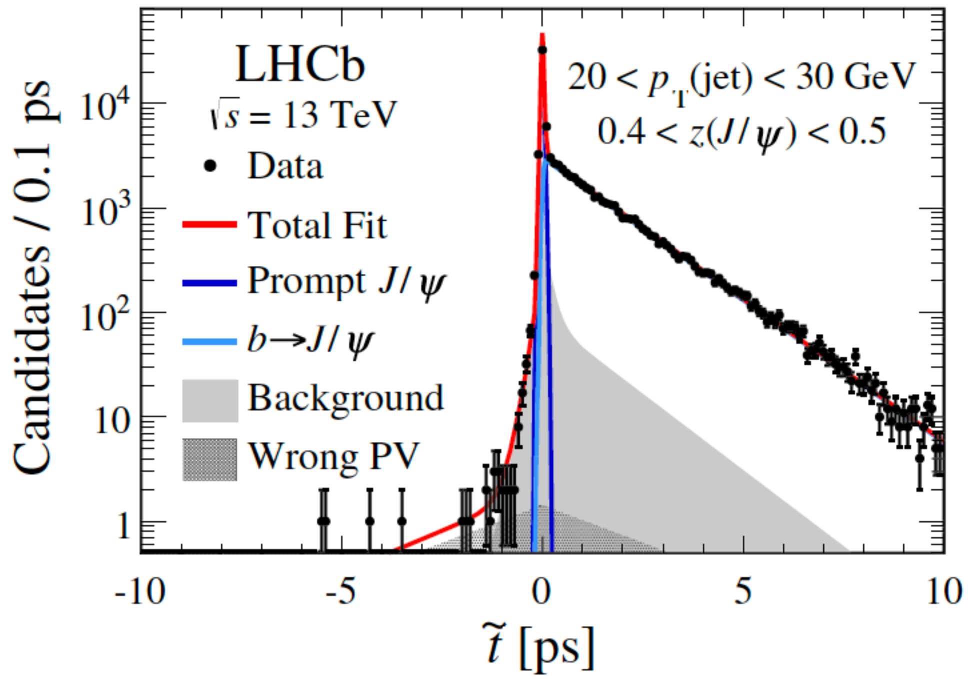


Hadronization in jet, more comprehensive information about J/ψ production

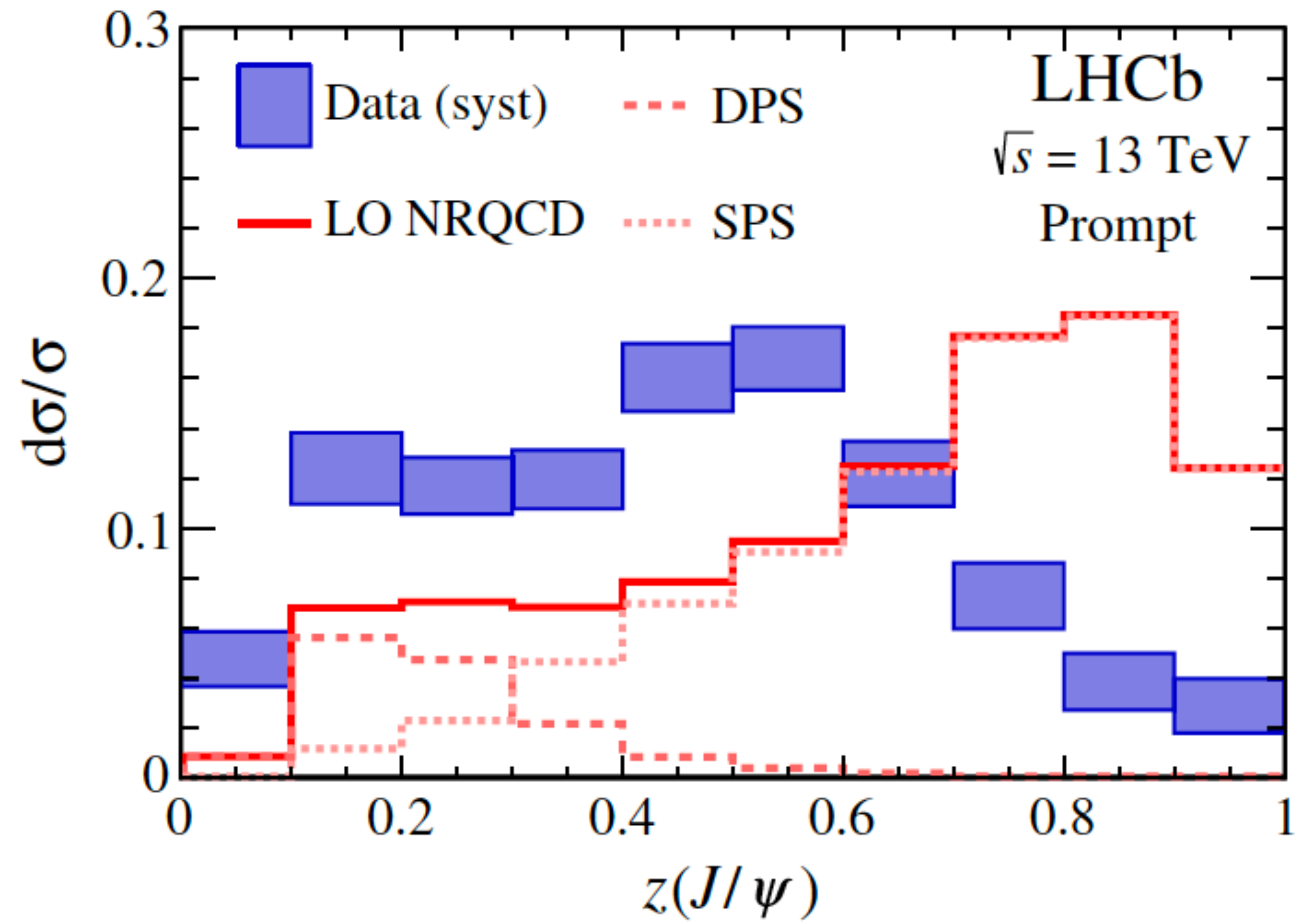
Prompt J/ψ in jets at LHCb

p_T (jet) > 20 GeV/c, 2.5 < η(jet) < 4.0, R= 0.5

muon: 2.0 < η(jet) < 4.5, p>5 GeV/c, pT>0.5 GeV/c

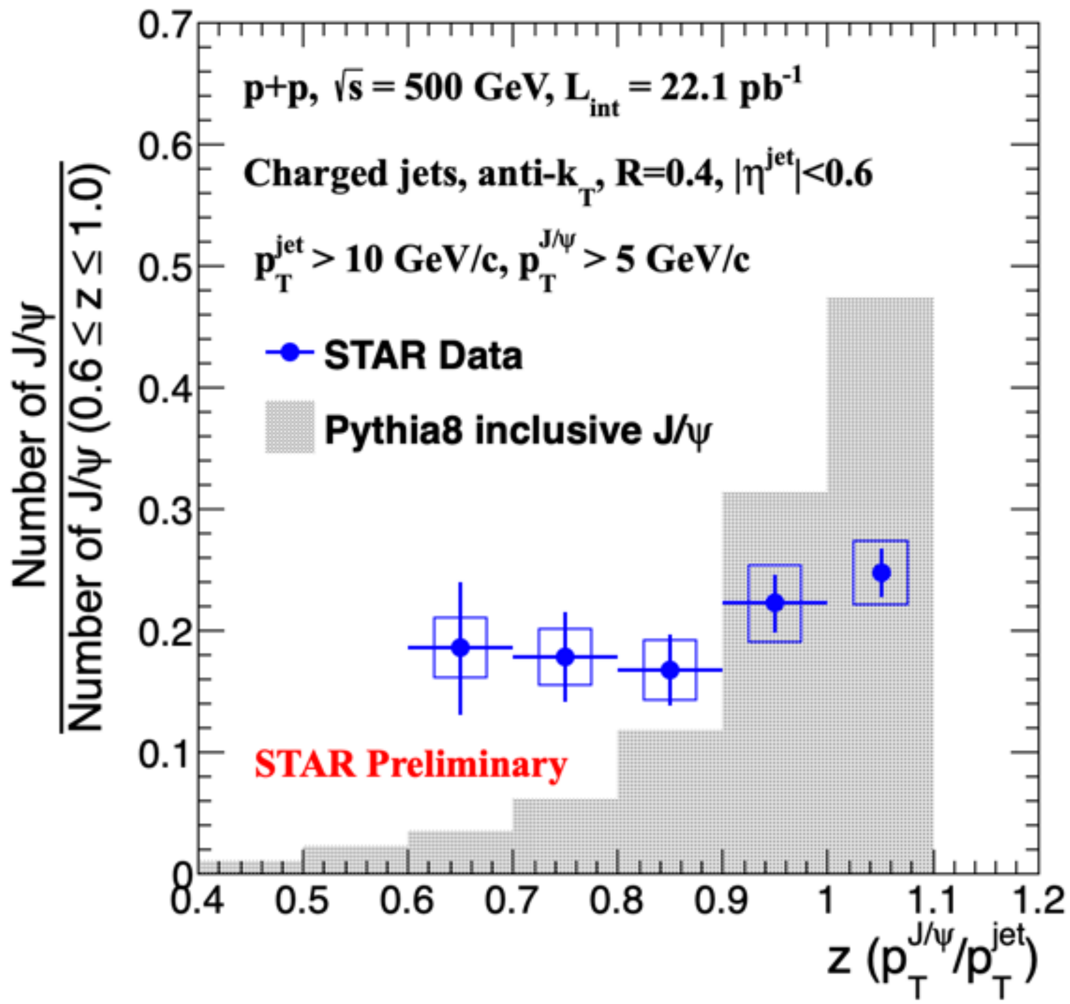


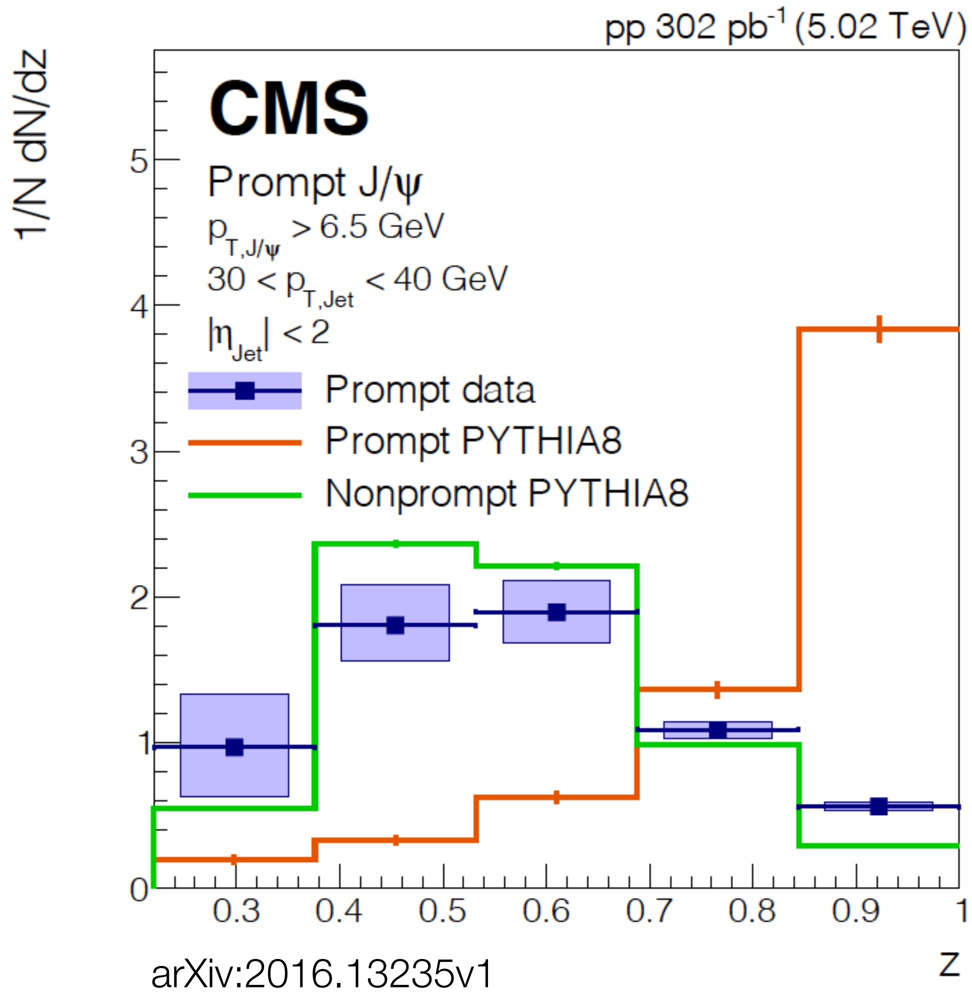
LHCb, PRL 118,(2017)192001



- Prompt J/ψ in data is produced much less isolated than Pythia8 prediction
- LO NRQCD (Pythia8): LO SDMEs ($c\bar{c}$ production) + LO LDMEs

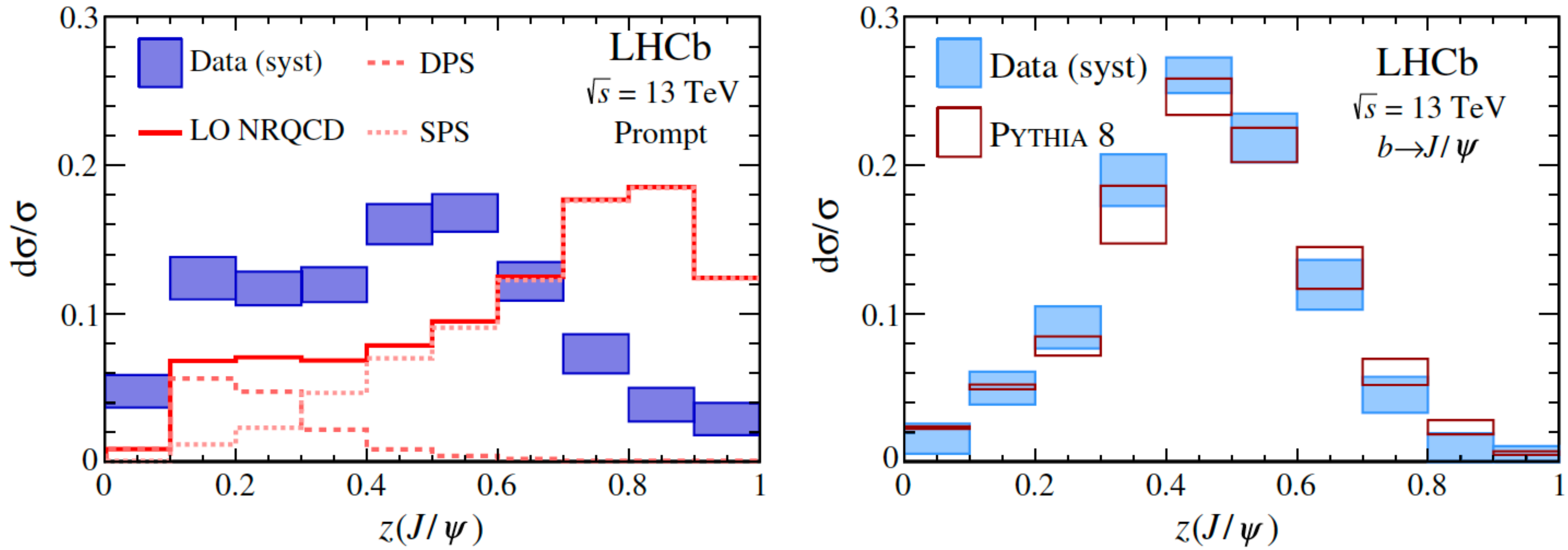
p_T-integrated FJF





- Despite of the different in jet measurements
  - Charged jet at RHIC vs. full jet at LHC
  - Different kinematics range
- Both show a less isolated production scenario at RHIC and LHC energies

J/ψ production in jets at LHCb

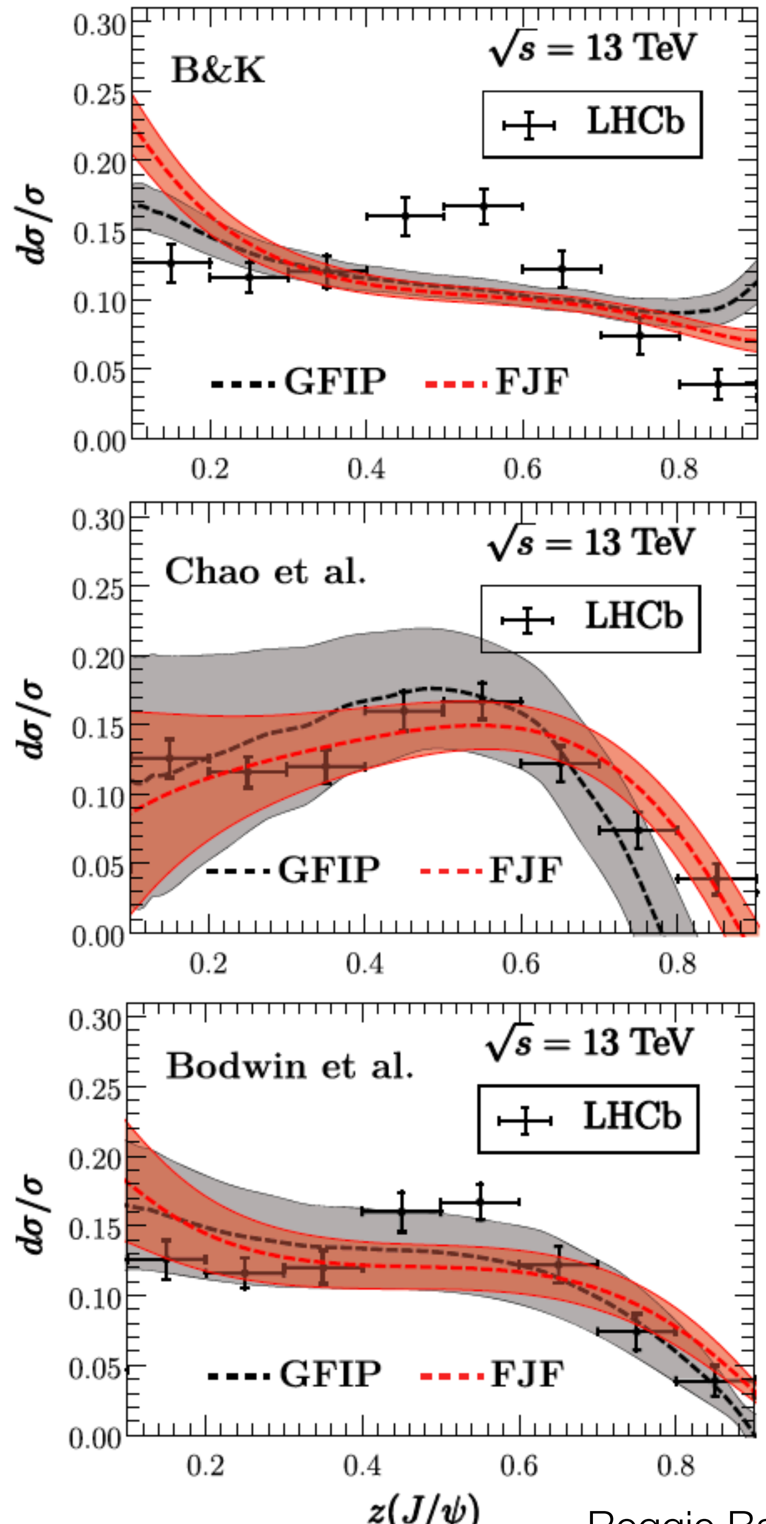


LHCb, PRL 118,(2017)192001

- Prompt J/ψ meson in data are observed to be much less isolated than predicted
- Data and theory are consistent for J/ψ mesons produced in b-hadron decays

➜ Something wrong with the fragmentation process of parton to J/ψ

Data v.s Models

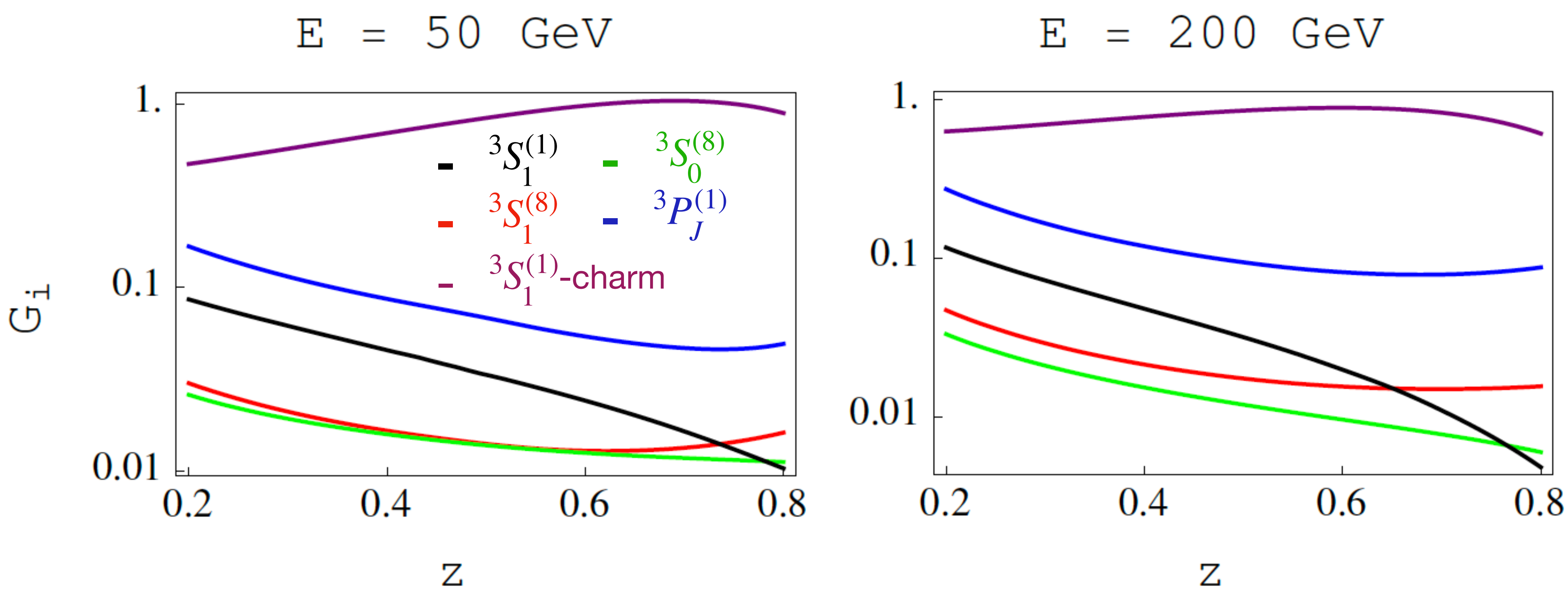


GFIP: Gluon Fragmentation Improved Pythia
FJF: Fragmentation Jet Functions (GDLAP equation to evolve fragmentation functions to $2m_c$)

- High-z enhanced in measured range
  - Biased to c-quark initiated jets contribution
- Better agreement with LHCb measurement
  ➜Fragmentation process not right in Pythia8
- LDMEs from global fits (B&K) give worse agreement than LDMEs from high-pT fitting (Chao et al. and Bodwin et al.)
  ➜Large uncertainty at low-z range

Reggie Bain et.al, PRL 119, (2017)032002

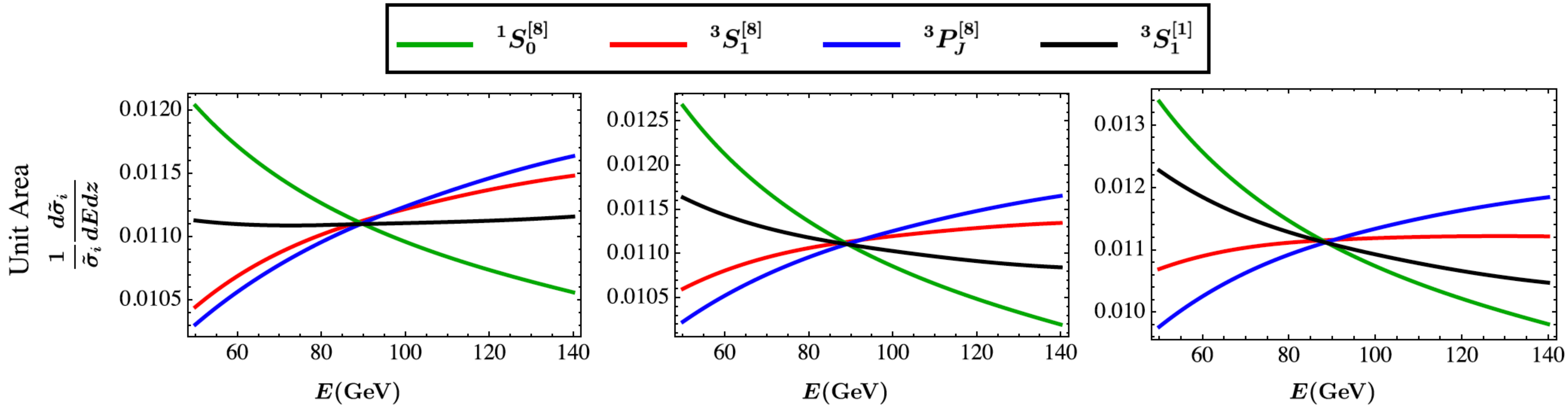
Energy dependence of FJF



Matthew Baumgart et.al, JHEP11(2014)003

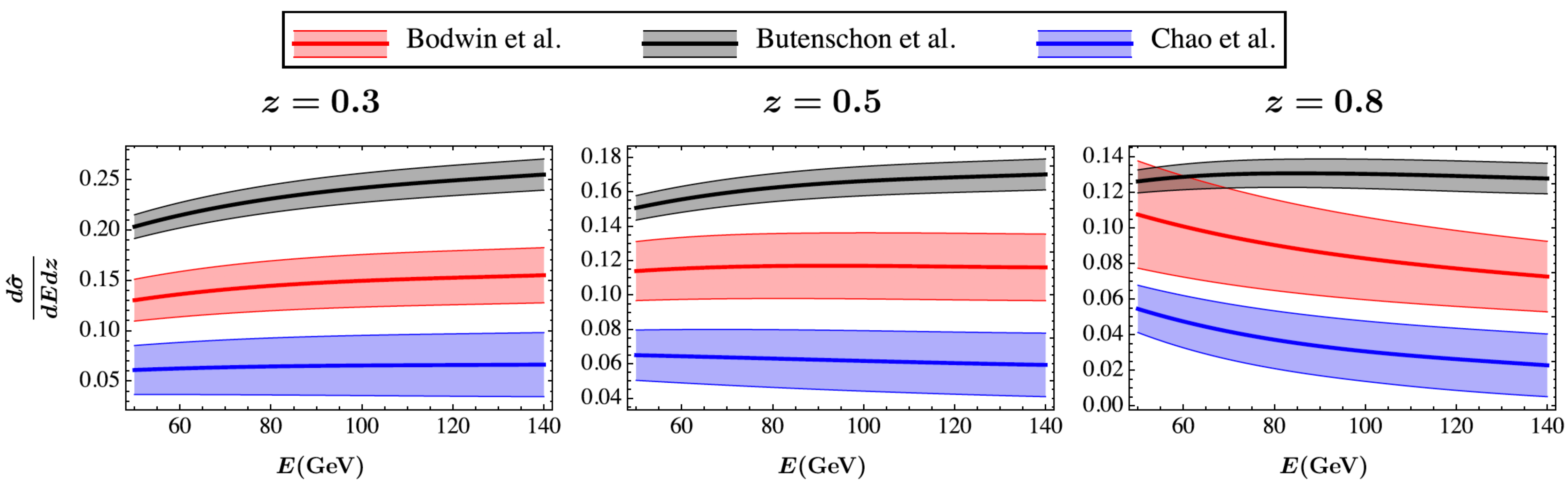
- Dramatic differences in FJF for different $c\bar{c}$ status
- The FJF changes a lot at different jet energy
  - The jet energy integrated FJF may not very sensitive to LDMEs

Energy dependence of FJF at fixed z

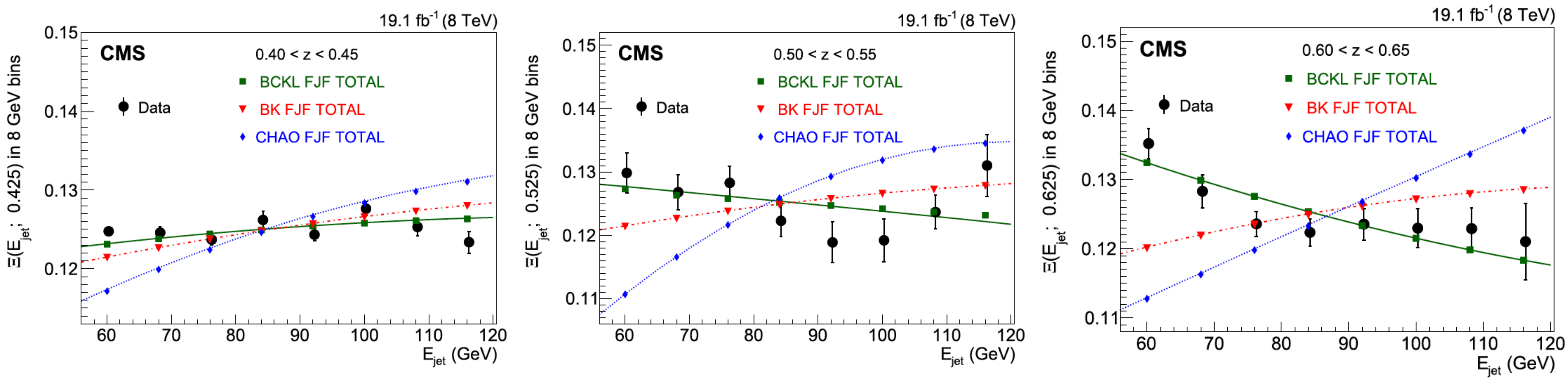


- Energy dependence of FJF at fixed z are quite distinct for different $c\bar{c}$ status especially for z> 0.5

Lin Dai et.al, PRD 96 (2017) 036020



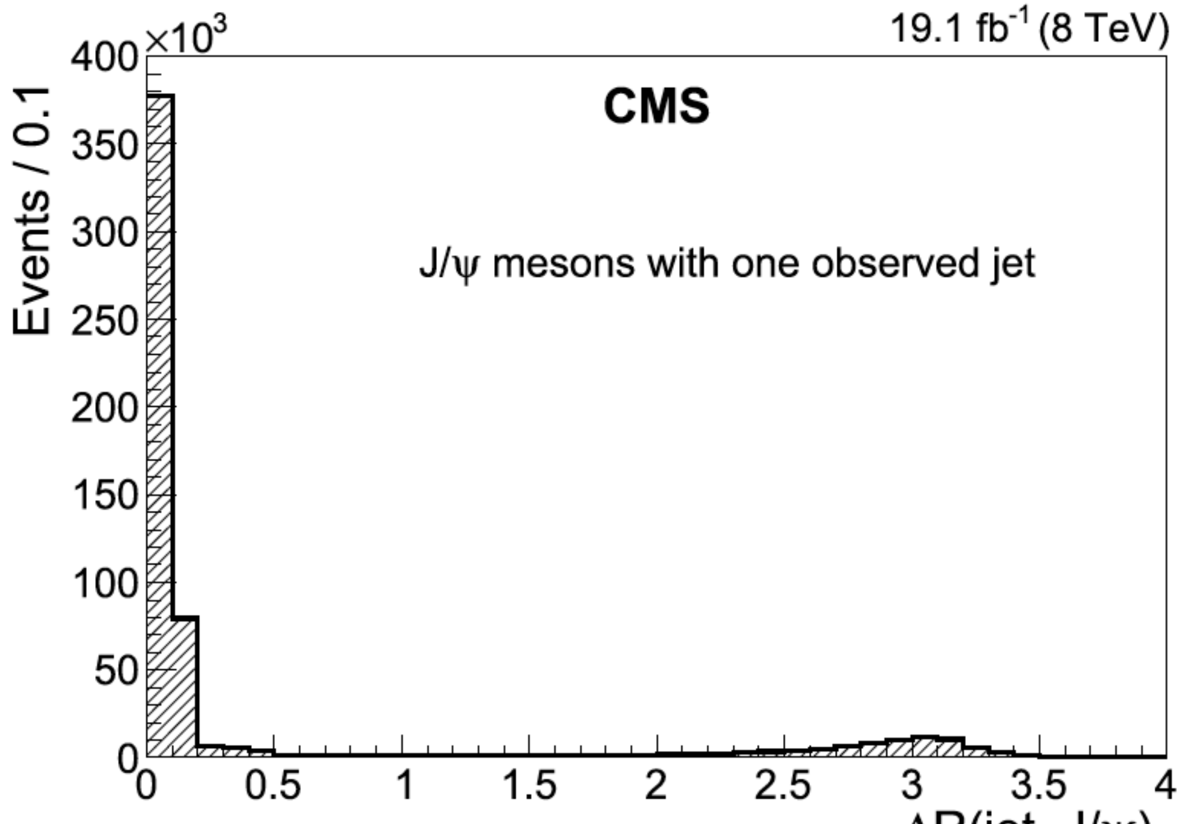
Energy dependence of FJF

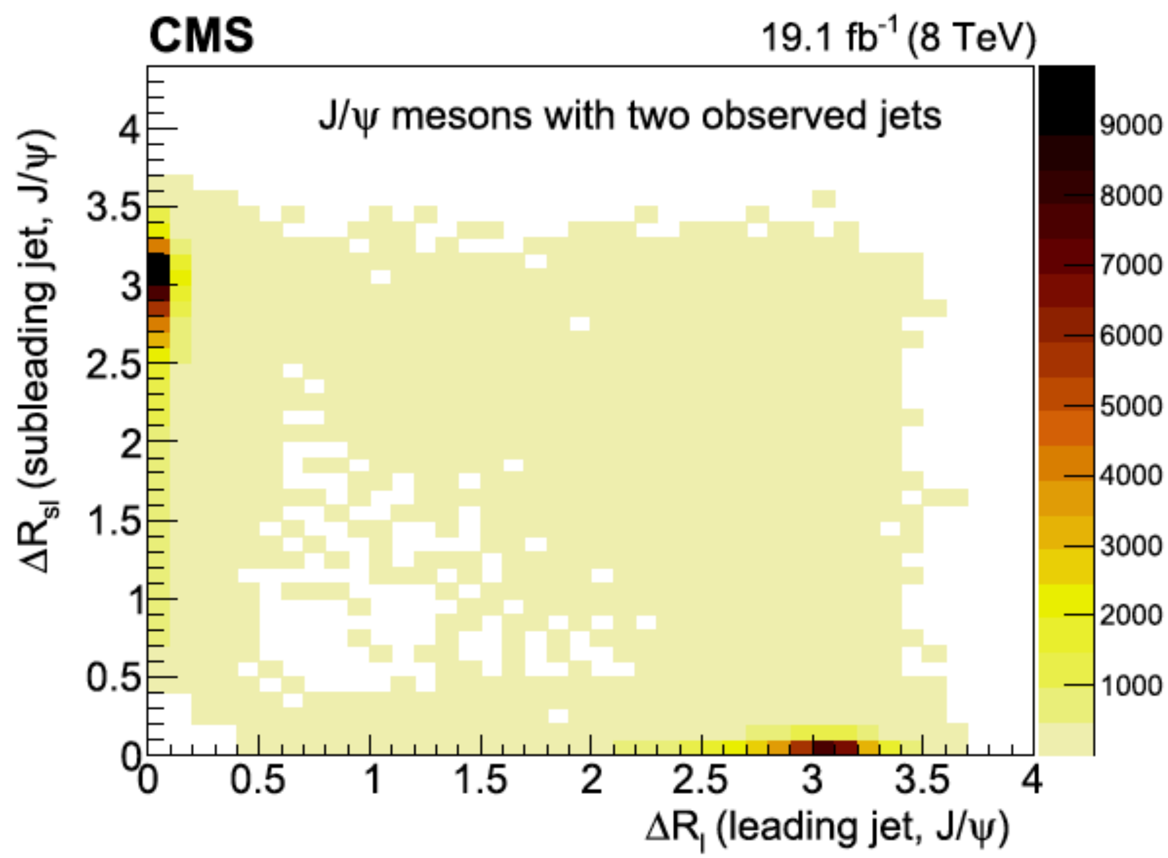


CMS, PLB 804(2020) 135409

- The measurement consistent with the FJF predictions for the BCKL (Bodwin et. al) LDME parameter set, and not favor other two set of LDMEs
- LDMEs from Bodwin et. al
  - Describes cross-section, polarization as well as the FJF at high-pT in p+p
  - Remind — Disagree HERA J/ψ photoproduciton, pT-integrated J/ψ hadroproduction as well as J/ψ production in e+e- collisions

J/ψ production associated with Jet

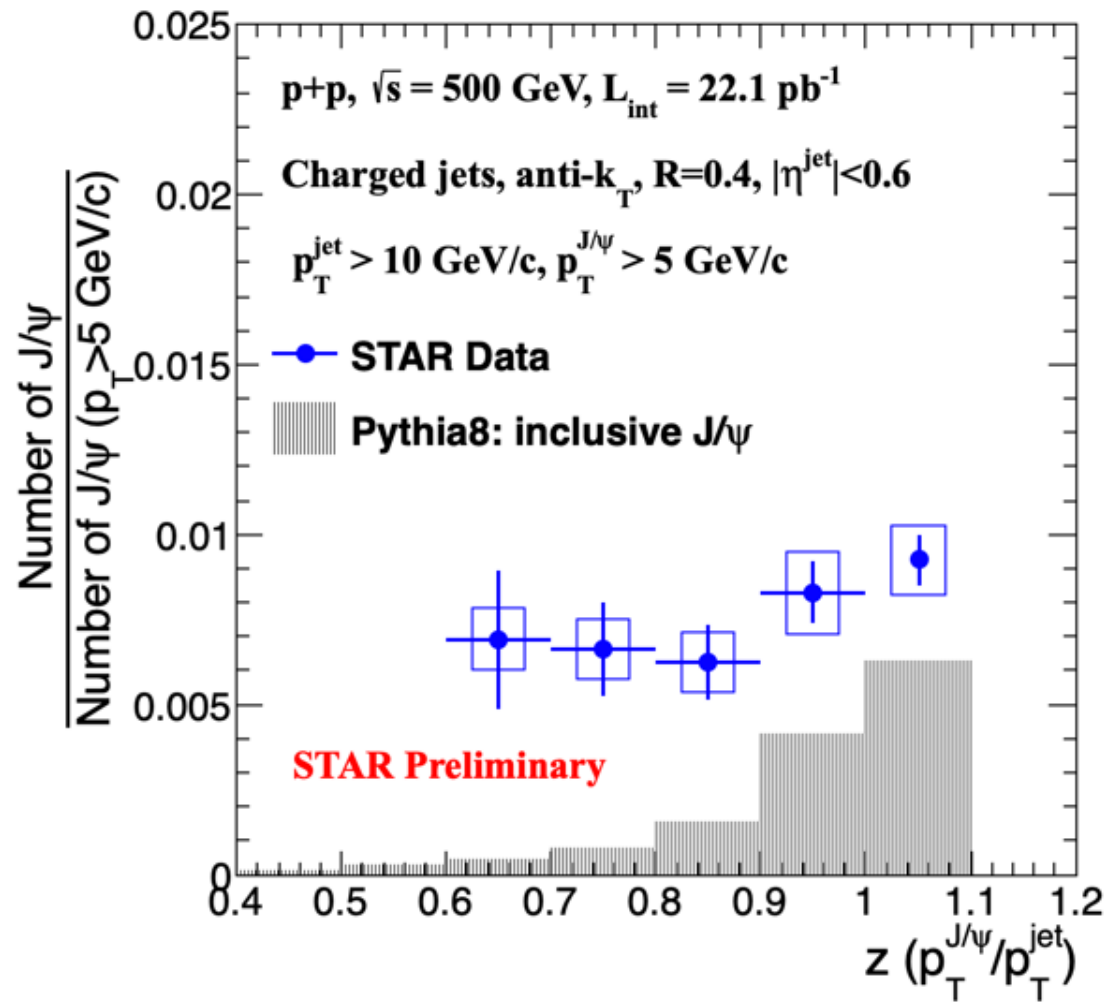




CMS, PLB 804(2020) 135409

- Jet fragmentation accounts for almost all (> 83%) prompt J/ψ mesons produced at large-p_T range (J/ψ p_T>10 GeV/c)
  - ${}^1S_0^{[8]}$ dominated?
- Does the fraction still significant at low-pT range? Does LDMEs from Bodwin et. al still work at low-pT for FJF?

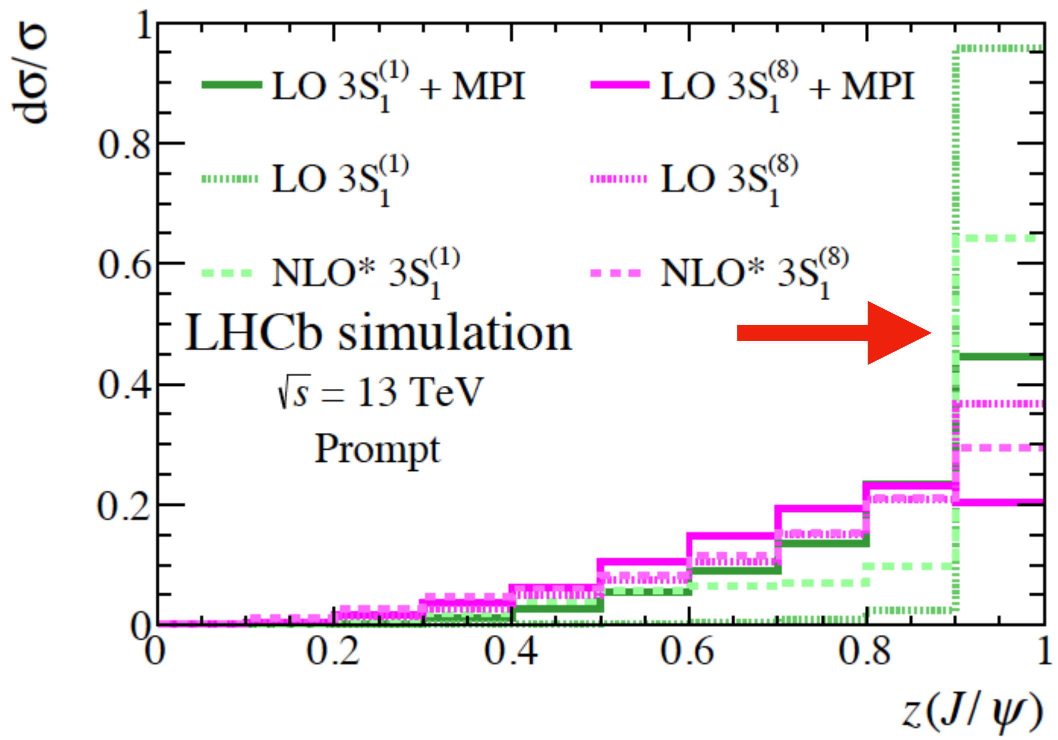
J/ψ production associated with Jet

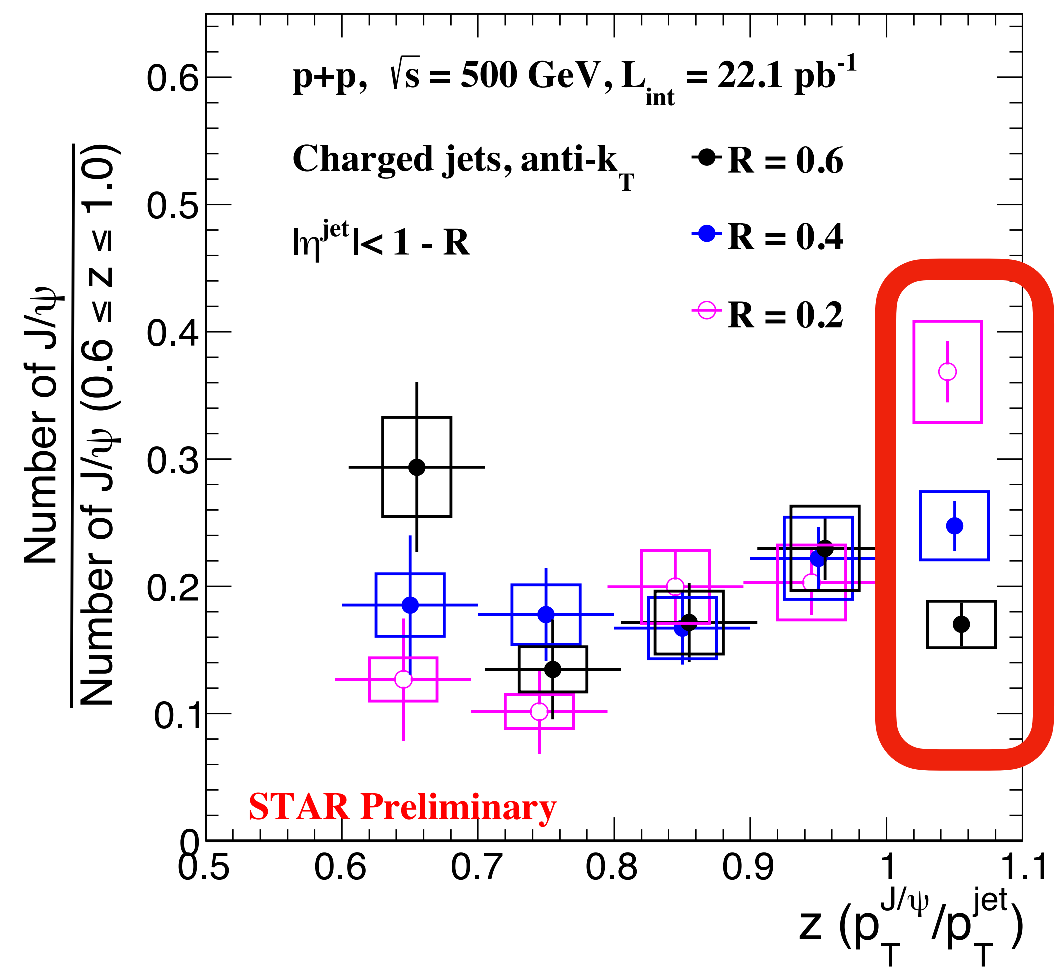


- The probability of producing a J/ψ in charged jet is systematically higher in data than in Pythia8 for the measured kinematics
  - 3.7% ± 0.3%(stat.) ± 0.2%(sys.) of J/ψ produced in jets
- A kinematic range that mixing J/ψ production in jet and out of jet
  - An ideal place to testing LDMEs

Isolated J/ψ

- Quantitative understanding various production channels with LDMEs
  - ➜Isolated production channel

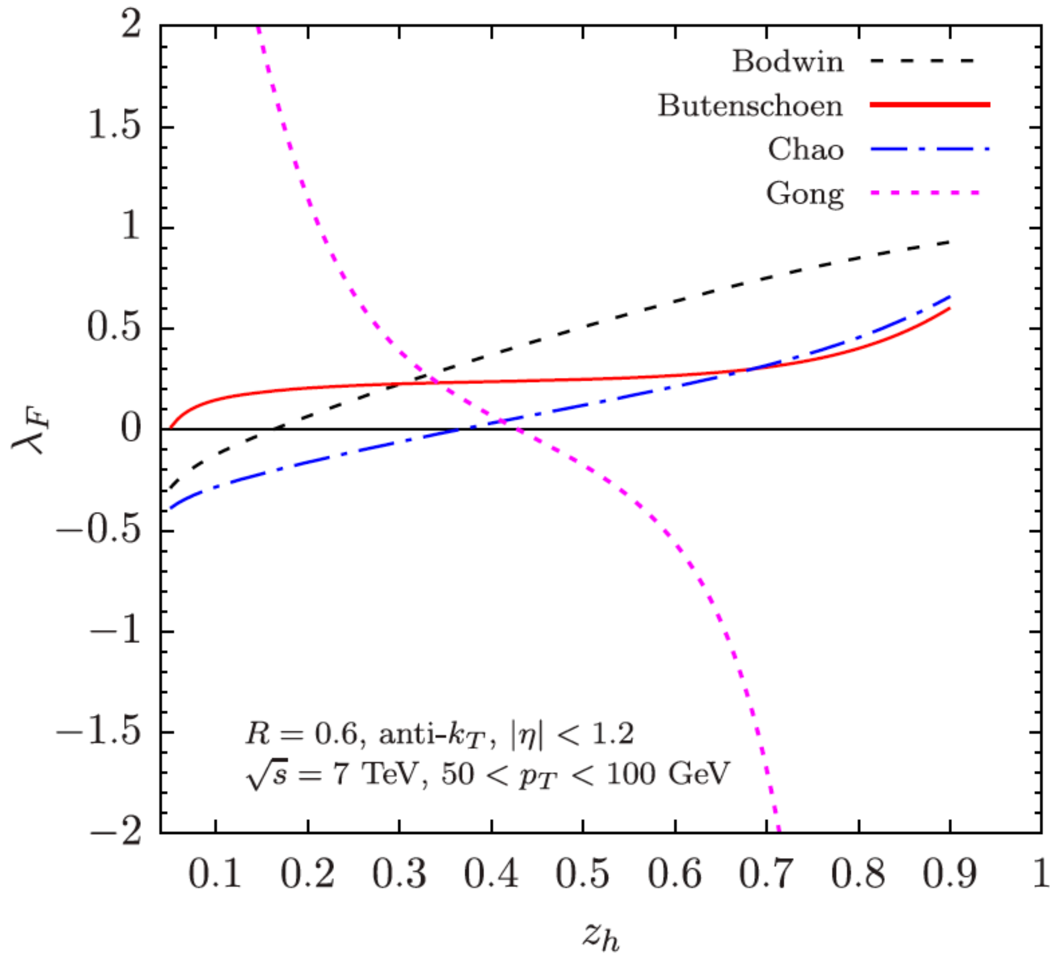


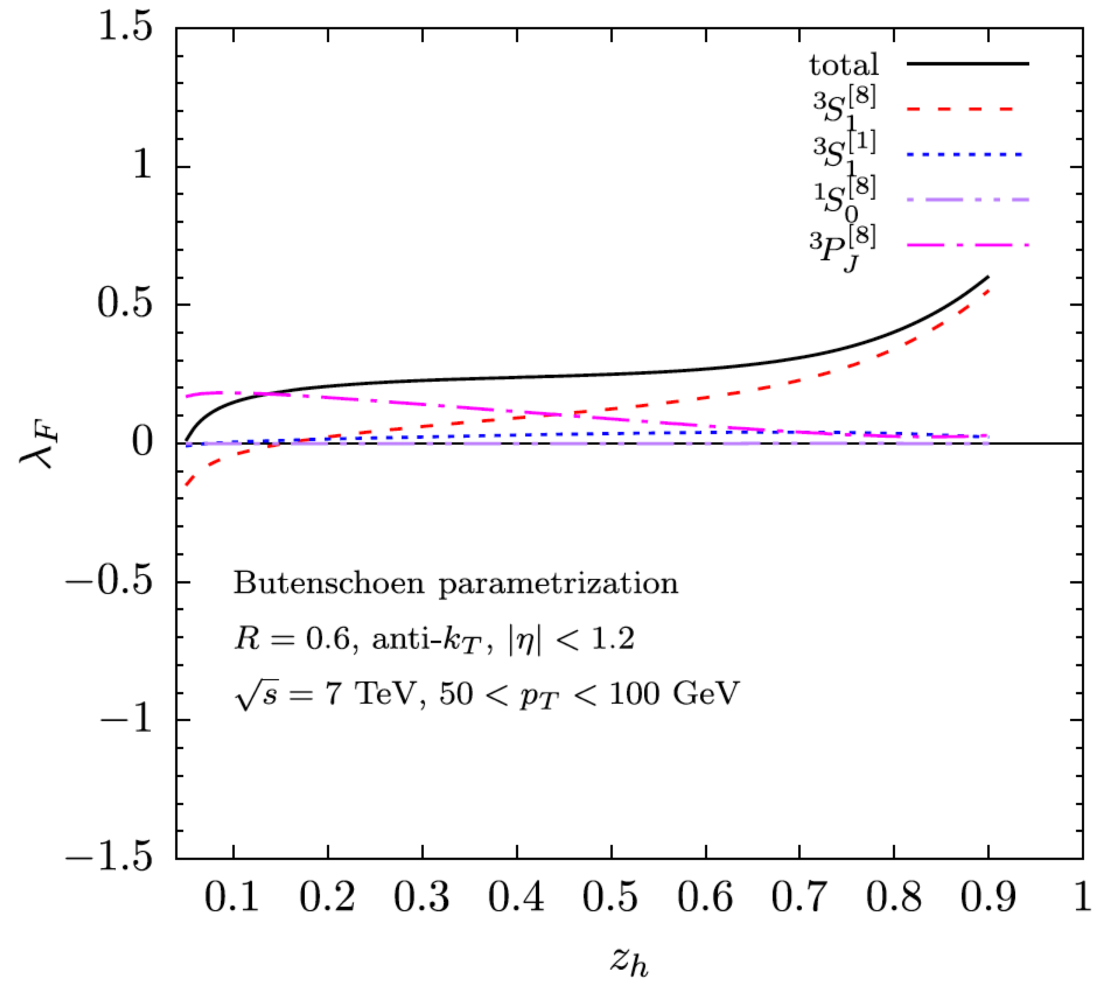


The evolution of isolated J/ψ production rate as a function of jet energy

➜ A proxy of color-singlet contribution

J/ψ polarization in jet





Zhong-Bo Kang et.al , PRL 119(2017) 032001

- Distinctive predictions for J/ψ polarization in jets with different sets of LDMEs
- Polarization also sensitive to production rate of different $c\bar{c}$ states

J/ψ in jets in A+A

J/ψ a sensitive probe to QGP

J/ψ : heavy mass (m_c = ~1.5 GeV/c^2)
➜ early creation
long lifetime

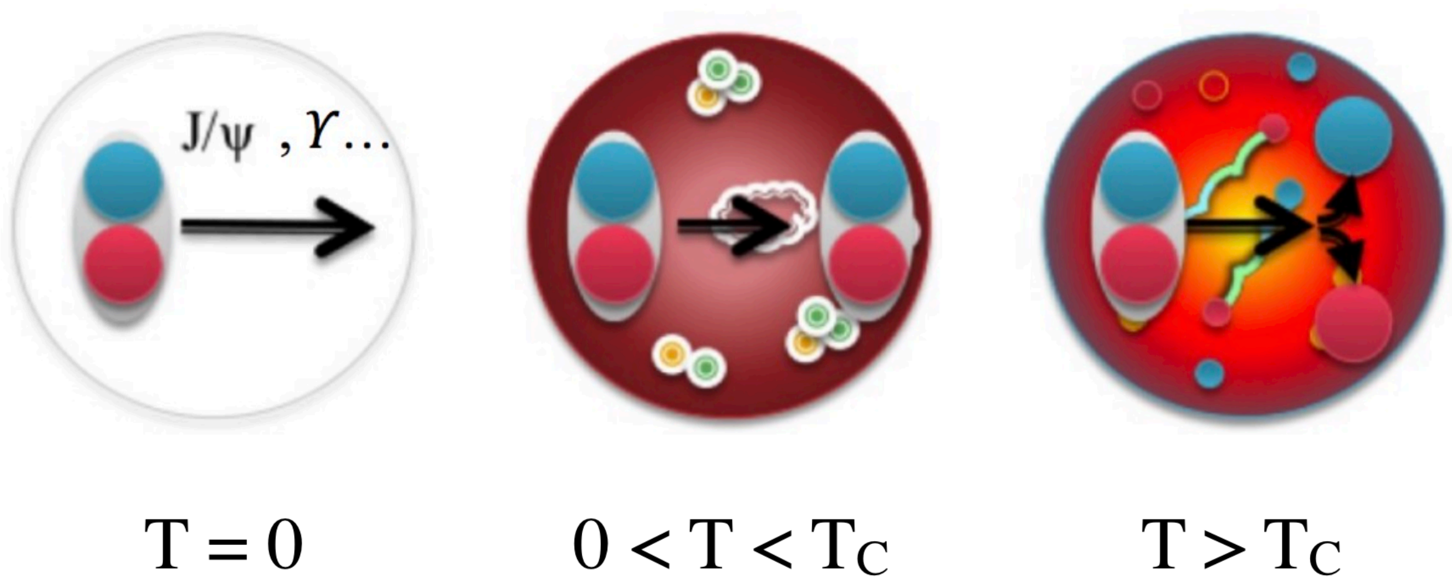


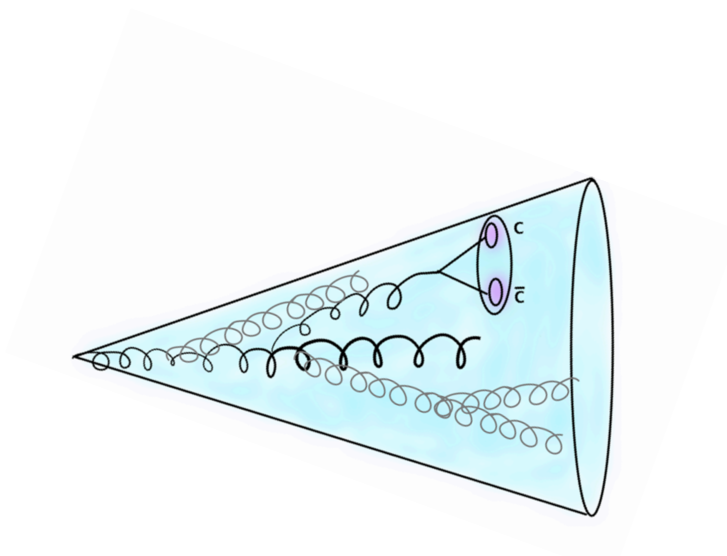
Illustration: A. Rothkopf

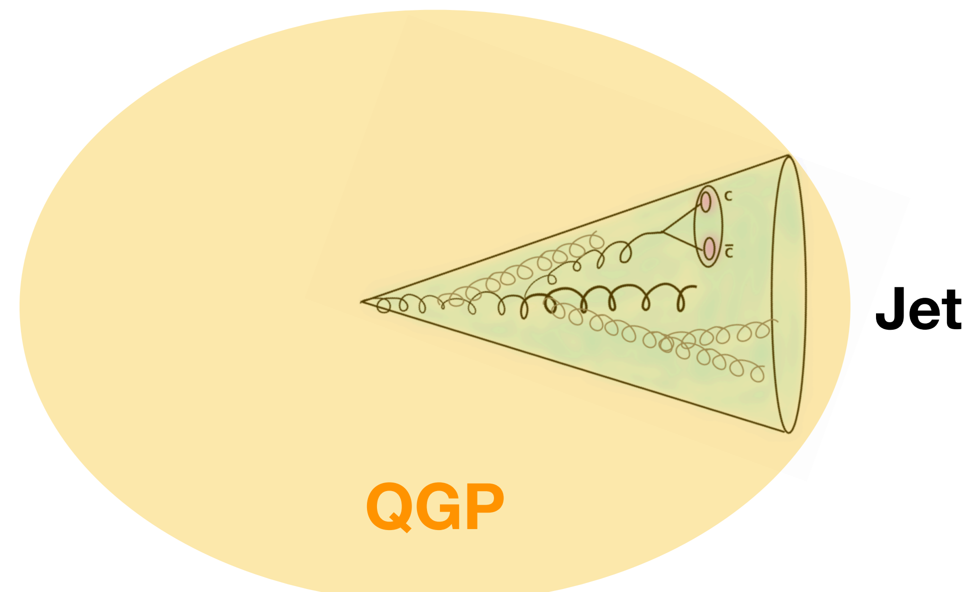
J/ψ is a sensitive probe of the de-confinement in the QGP: color screening dissociation

J/ψ production in jet

“Jet fragmentation accounts for almost all prompt J/ψ meson produced at large p_T (>15 GeV/c)”

- p+p @ 8 TeV CMS PLB,804 (2020) 135409

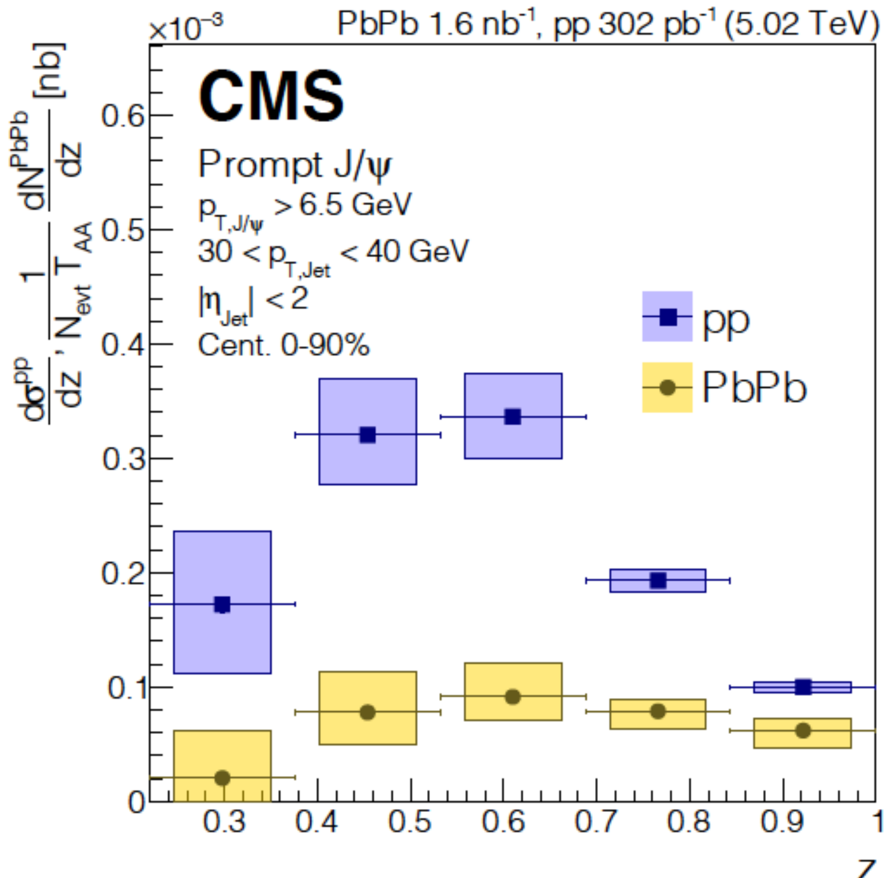


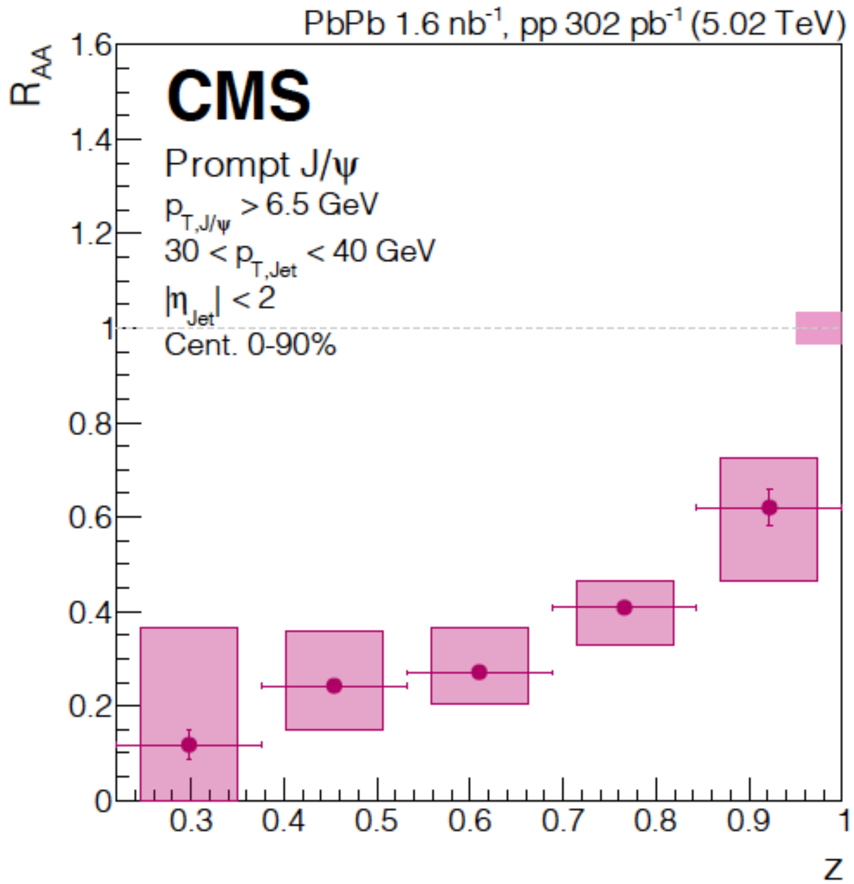


J/ψ produced later in parton showe

Parton: larger degree of interaction with QGP

J/ψ in jet R_{AA} in A+A





arXiv:2016.13235v1

- Prompt J/ψ are more populated at lower z values in p+p
  - J/ψ production late in parton showers
- The suppression is larger at low-z than high-z range in Pb+Pb system
  - Jet quenching mechanism is important in J/ψ suppression

Summary

- The J/ψ production mechanism is still unknown
- Progress is made by using J/ψ in jets observables to understand the production mechanism, but not full solve the problem
  - Fragmentation precess is not properly handled in Pythia8
  - High-pT (>10 GeV/c) J/ψ are mainly produced in jet.
  - LDMEs from Bowdin et. al with fragmentation correction describes FJF at high-pT range, and ${}^1S_0^{[8]}$ could be the main source of final J/ψ
  - Important to extend the study to low-p_T range
- The jet quenching is a important mechanism for J/ψ suppression in A+A system

Thanks!

Backup

TABLE I. J/ψ NRQCD LDMEs from four different groups.

	$\langle\mathcal{O}(^3S_1^{[1]})\rangle$ GeV^3	$\langle\mathcal{O}(^1S_0^{[8]})\rangle$ 10^{-2} GeV^3	$\langle\mathcal{O}(^3S_1^{[8]})\rangle$ 10^{-2} GeV^3	$\langle\mathcal{O}(^3P_0^{[8]})\rangle$ 10^{-2} GeV^5
Bodwin	0[a]	9.9	1.1	1.1
Butenschoen	1.32	3.04	0.16	−0.91
Chao	1.16	8.9	0.30	1.26
Gong	1.16	9.7	−0.46	−2.14

[a]Note: in [7], the contribution from the $^3S_1^{[1]}$ state is assumed to be small and excluded from the fit.