Hard-Soft correlations in hadronic collisions

Steffen Weber
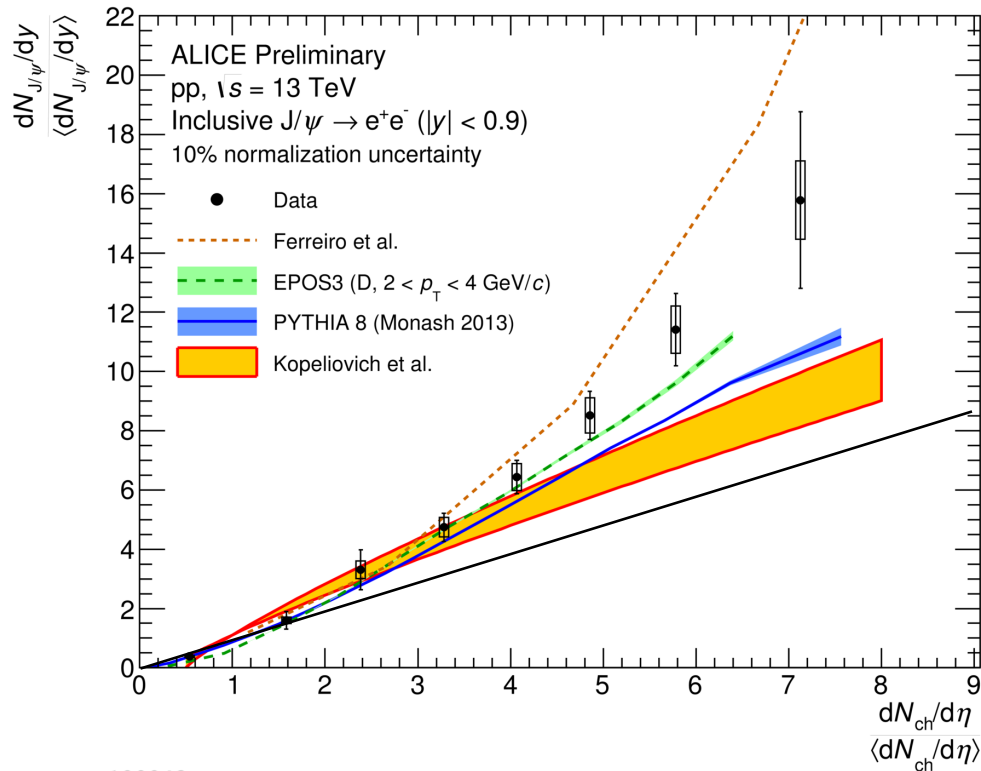
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Charmonium production versus multiplicity in PYTHIA8

Motivation

ALI-PREL-128843

ALICE Preliminary
pp, $\sqrt{s}$ = 13 TeV
Inclusive J/$\psi \to$ e$^+$e$^-$ ($|y|$ < 0.9)
10% normalization uncertainty

- Data
- Ferreiro et al.
- EPOS3 (D, 2 < p_T < 4 GeV/c)
- PYTHIA 8 (Monash 2013)
- Kopeliovich et al.

Preliminary ALICE results
- pp @ 13 TeV
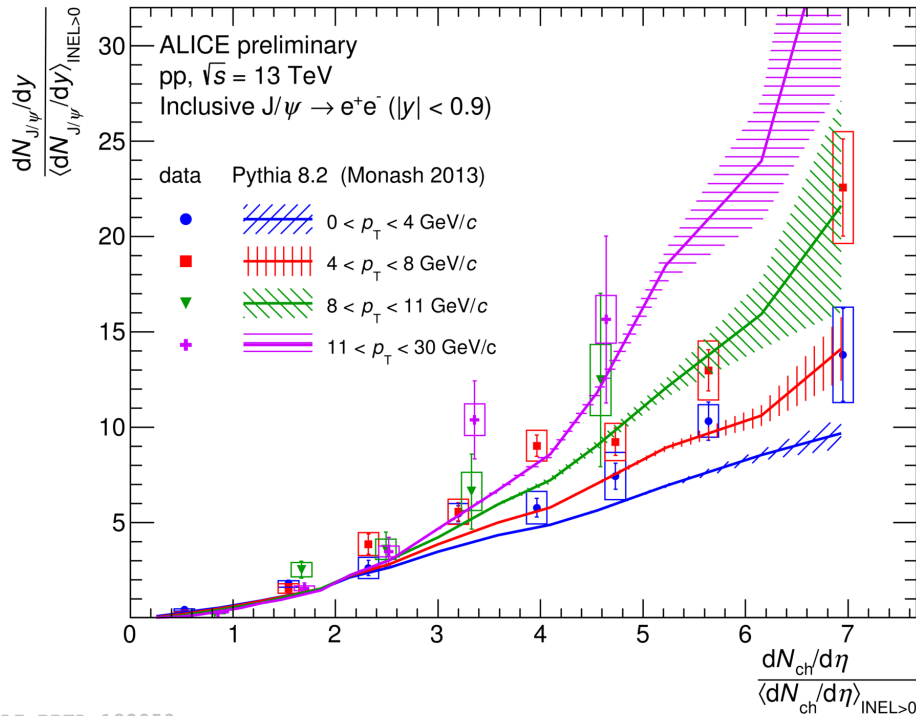- Inclusive J/ψ at |y| < 0.9
- multiplicity at |η| < 1.0

Stronger than linear increase observed

Models describe data well:

- Ferreiro: Overlapping strings → saturation of soft particle production, hard probes unaffected

- Kopeliovich: Use analogy between high multiplicity pp an pA collisions

- EPOS3: Hydrodynamic expansion reduced particle multiplicity

- PYTHIA

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Motivation

ALI−PREL−132858

Increase gets stronger at higher p_T

reproduced by PYTHIA

Preliminary ALICE results
- pp @ 13 TeV
- Inclusive J/ψ at |y| < 0.9
- multiplicity at |η| < 1.0

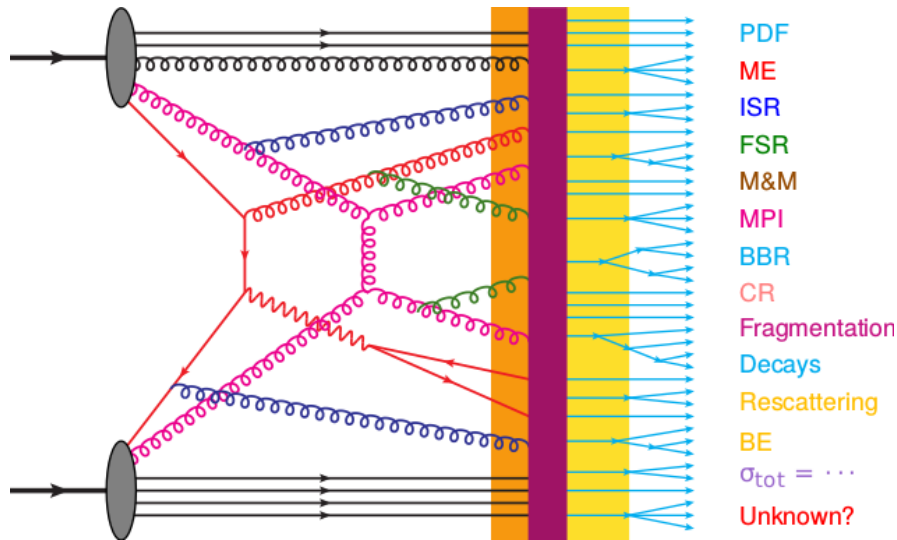# Outline

Investigate effects of

- MultiParton Interactions (MPI)

- Colour Reconnection (CR)

- Auto-correlation

Technicalities:
- PYTHIA8.230
- J/ψ forced to decay in dielectron channel
- non-diffractive events
- No $N_{ch}>0$ normalization as in data

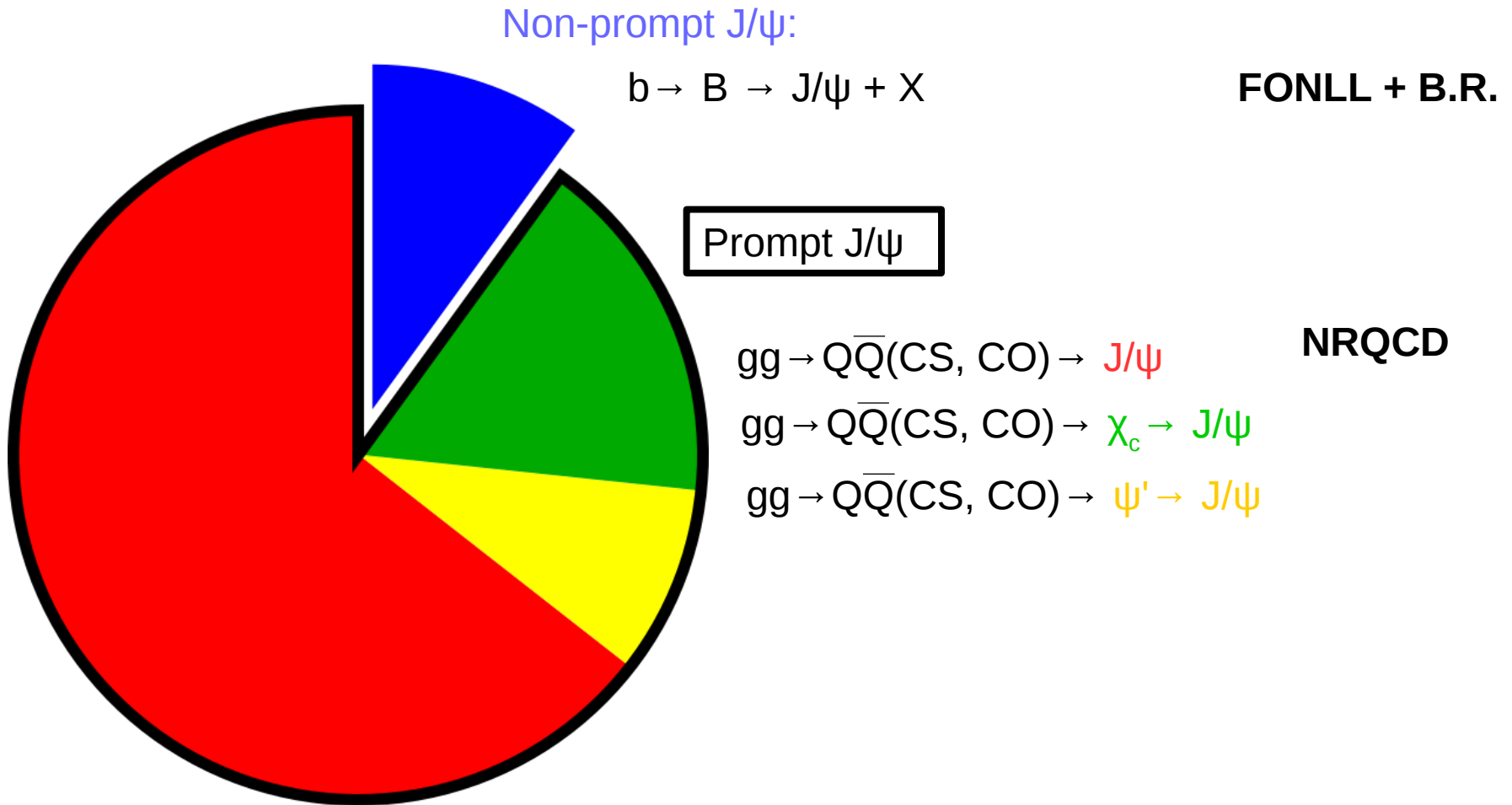TECHNISCHE
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PYTHIA

- QCD inspired MC event generator

- Hard partonic interactions plus parton showers

- Soft particle production in string fragmentation

- Crucial: MultiParton Interactions: MPI

  - proton-proton collisions consist of several hard interactions (with associated parton showers)

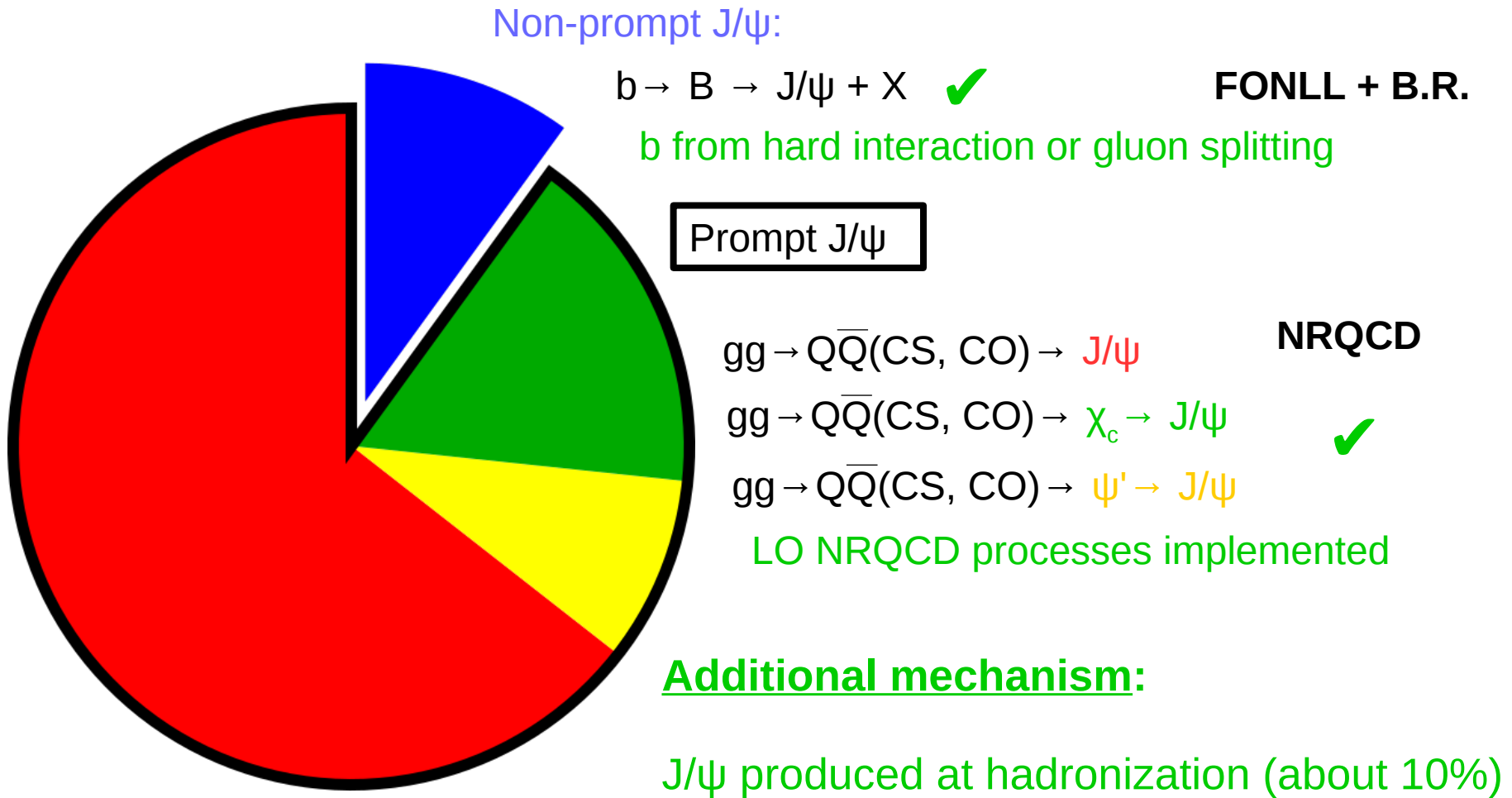   → possibility to produce several hard probes in one collision
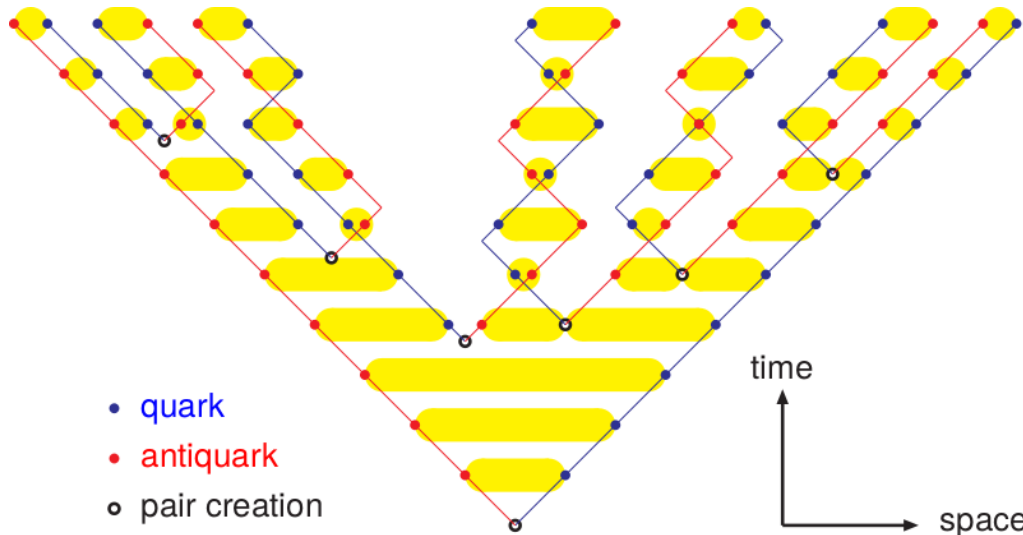
J/ψ production in hadronic collisions

Non-prompt J/ψ:

$b \rightarrow B \rightarrow J/\psi + X$

FONLL + B.R.

Prompt J/ψ

$gg \rightarrow Q\overline{Q}(CS, CO) \rightarrow J/\psi$

$gg \rightarrow Q\overline{Q}(CS, CO) \rightarrow \chi_c \rightarrow J/\psi$

$gg \rightarrow Q\overline{Q}(CS, CO) \rightarrow \psi' \rightarrow J/\psi$

NRQCD

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J/ψ production in PYTHIA

Non-prompt J/ψ:

b → B → J/ψ + X ✔ **FONLL + B.R.**

b from hard interaction or gluon splitting

Prompt J/ψ

NRQCD

$gg \to Q\overline{Q}(CS, CO) \to$ J/ψ

$gg \to Q\overline{Q}(CS, CO) \to \chi_c \to$ J/ψ ✔

$gg \to Q\overline{Q}(CS, CO) \to \psi' \to$ J/ψ

LO NRQCD processes implemented

Additional mechanism:

J/ψ produced at hadronization (about 10%)

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Hadronization in PYTHIA

String fragmentation:

- quark
- antiquark
- pair creation

no heavy quarks produced in pair creation!

Special cases for short strings:

- Clusters decay: only one pair creations → two mesons produced
- Cluster collapse: no pair creation → initial quarks bound to hadron
  → if c and $\bar{c}$ → charmonium produced

J/ψ vs number of MPI
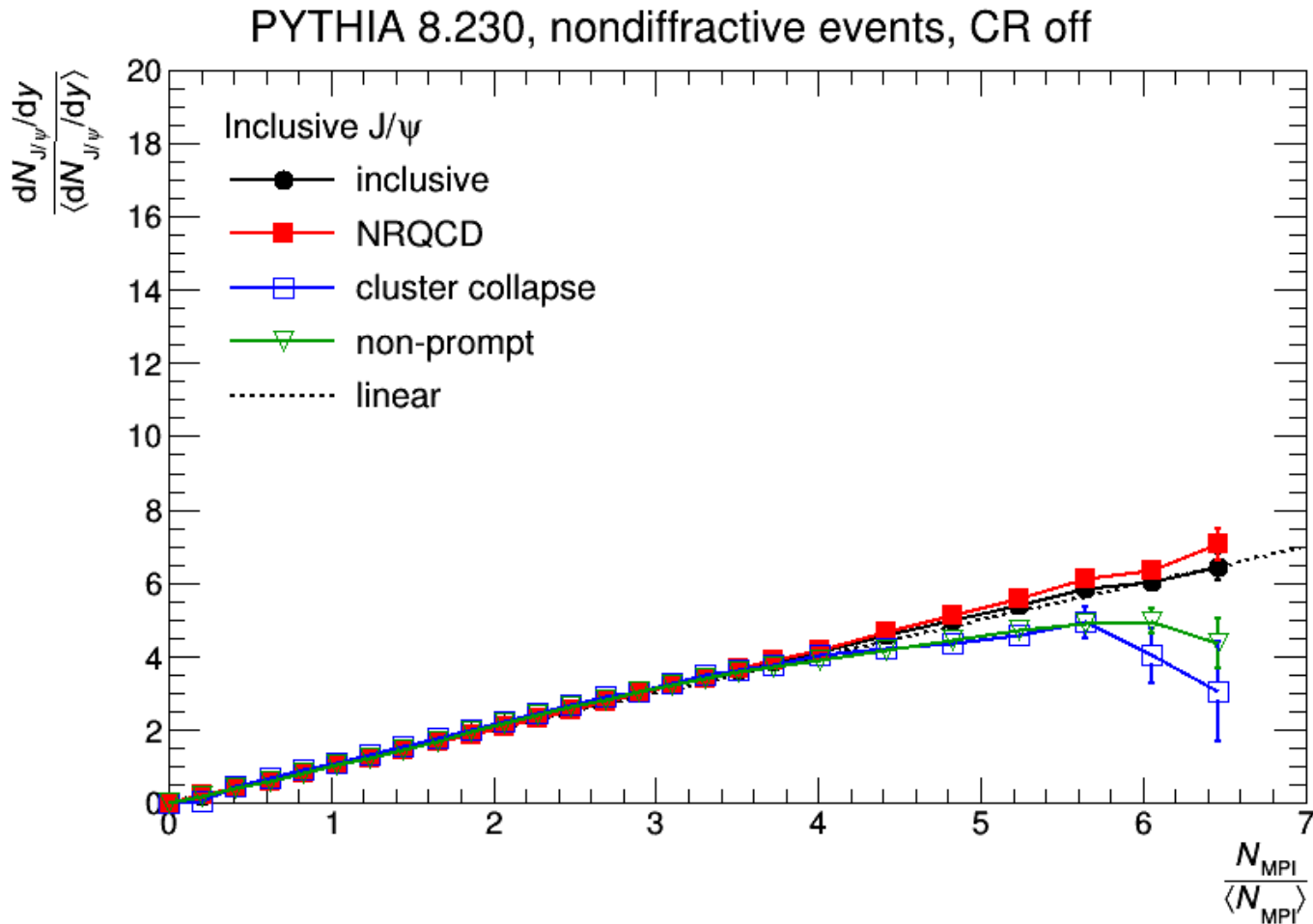
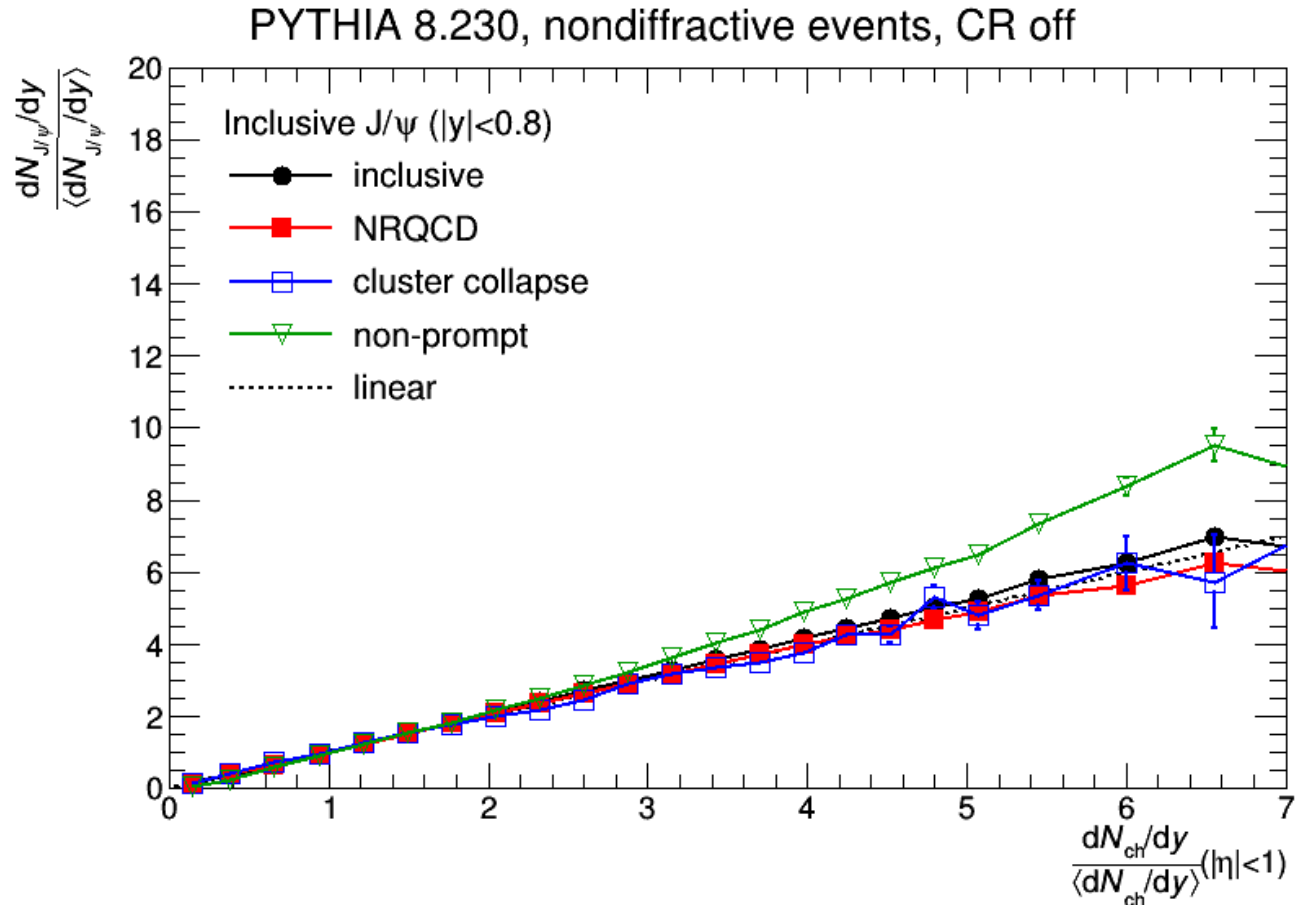
Total J/ψ yield in 4π scales linearly with N_{MPI}

J/ψ vs multiplicity

PYTHIA 8.230, nondiffractive events, CR off

Inclusive J/ψ (|y|<0.8)
- inclusive
- NRQCD
- cluster collapse
- non-prompt
- linear

J/ψ at mid-rapidity vs. multiplicity at mid-rapidity: stronger-than-liner increase of non-prompt J/ψ → auto-correlation (will be investigated later)

Colour Reconnection

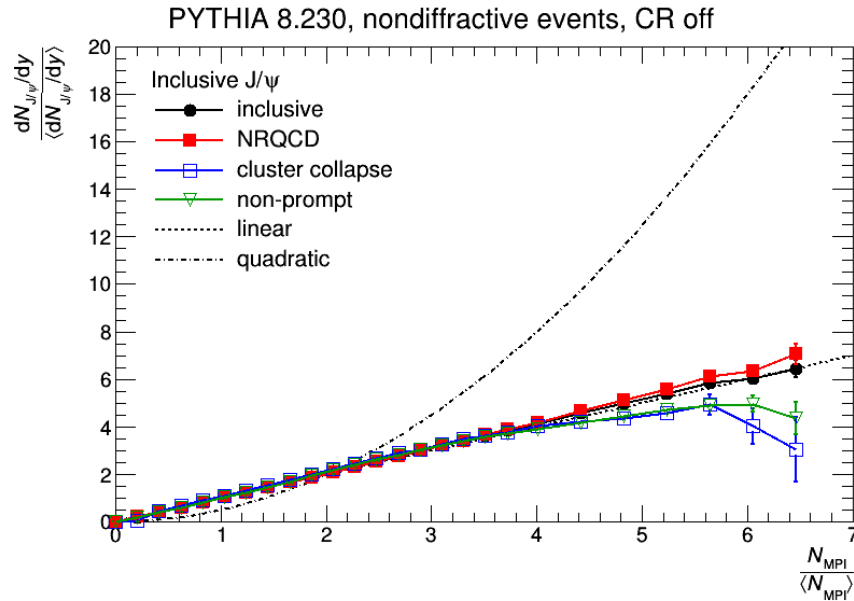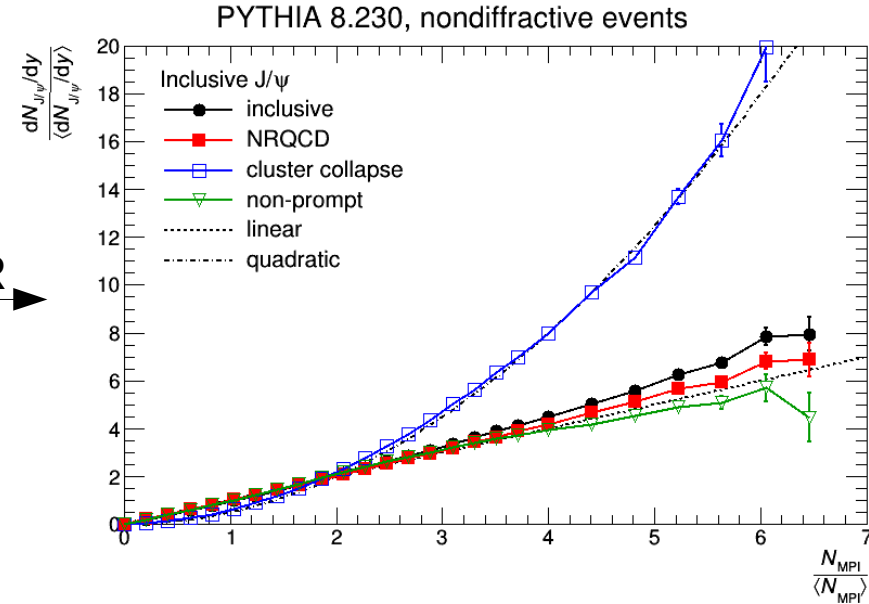- Rearrangement of string topology in order to reduce total string length
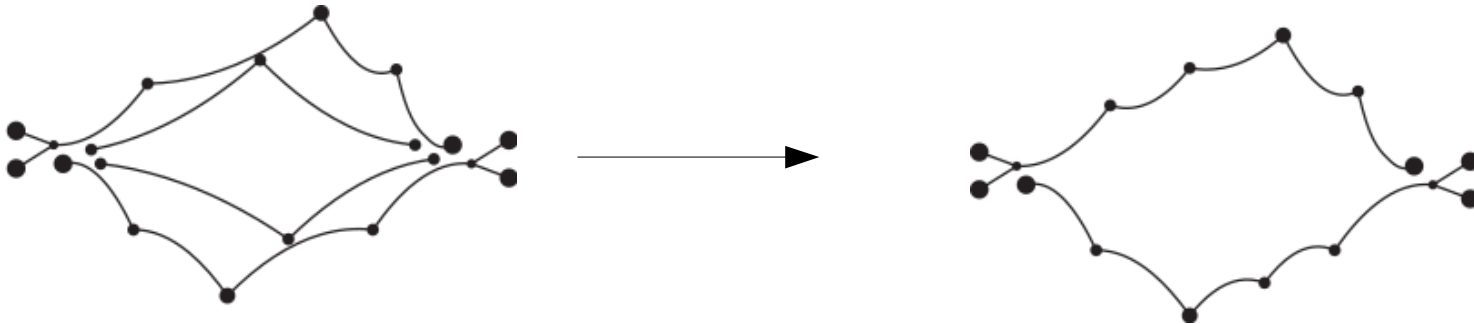
Two effects:

- partons from different MPIs get connected

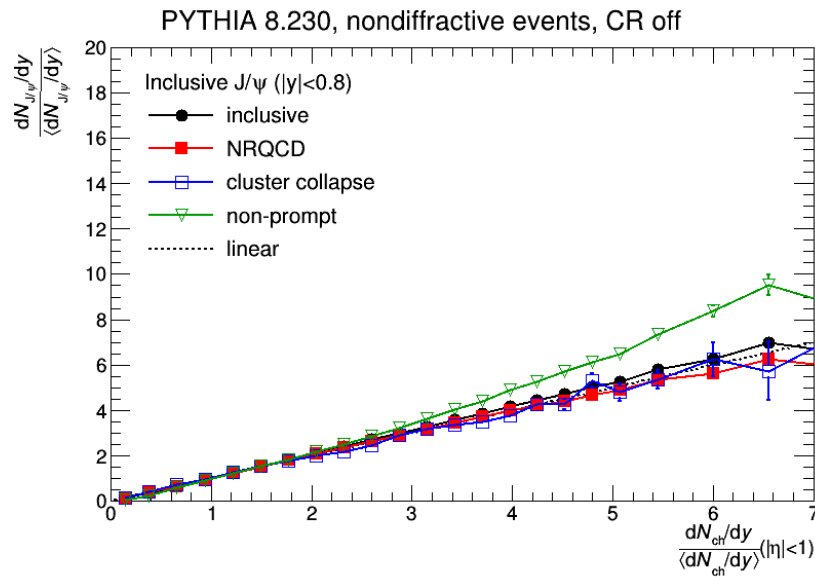- Total string length reduced → total multiplicity reduced

Colour reconnection

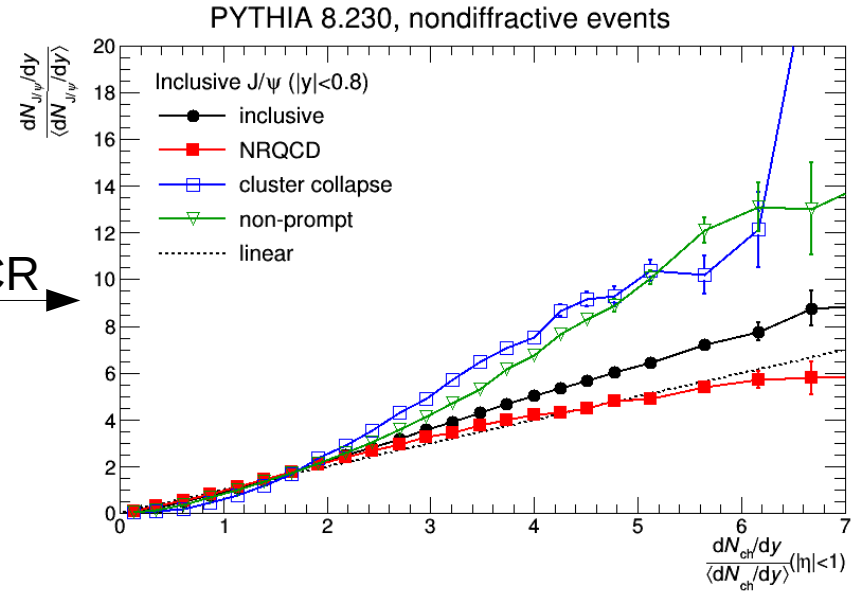PYTHIA 8.230, nondiffractive events, CR off

PYTHIA 8.230, nondiffractive events

Inclusive J/ψ
- inclusive
- NRQCD
- cluster collapse
- non-prompt
- linear
- quadratic

CR →

- Normal J/ψ production: hard process, independent of strings
  → not affected by CR

- J/ψ from cluster collapse: with CR also c and $\bar{c}$ from different MPI can combine → quadratic increase with N_{MPI}
  - Overall fraction of total yield rises from ~2% to ~10%

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Colour reconnection

PYTHIA 8.230, nondiffractive events, CR off
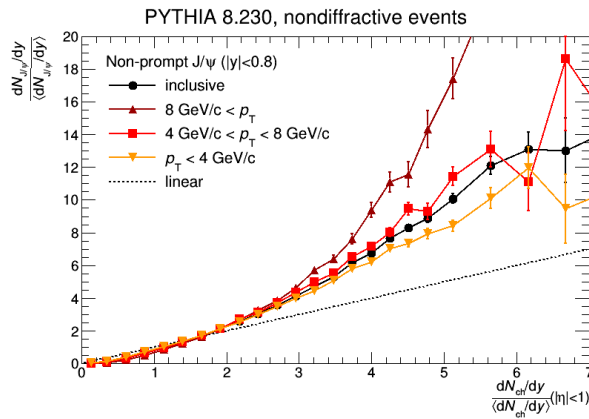
PYTHIA 8.230, nondiffractive events

CR →

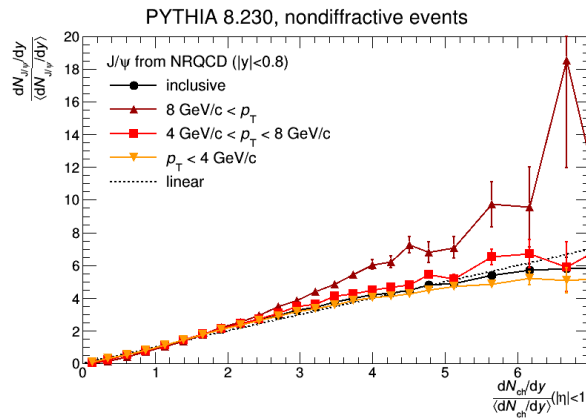CR reduces charged particle multiplicity → slightly stronger than linear increase of non-prompt J/ψ gets enhanced
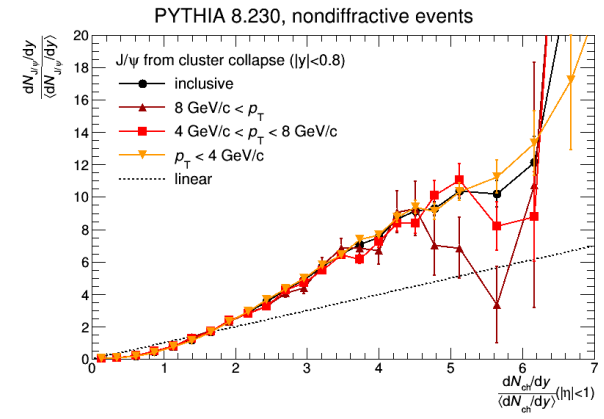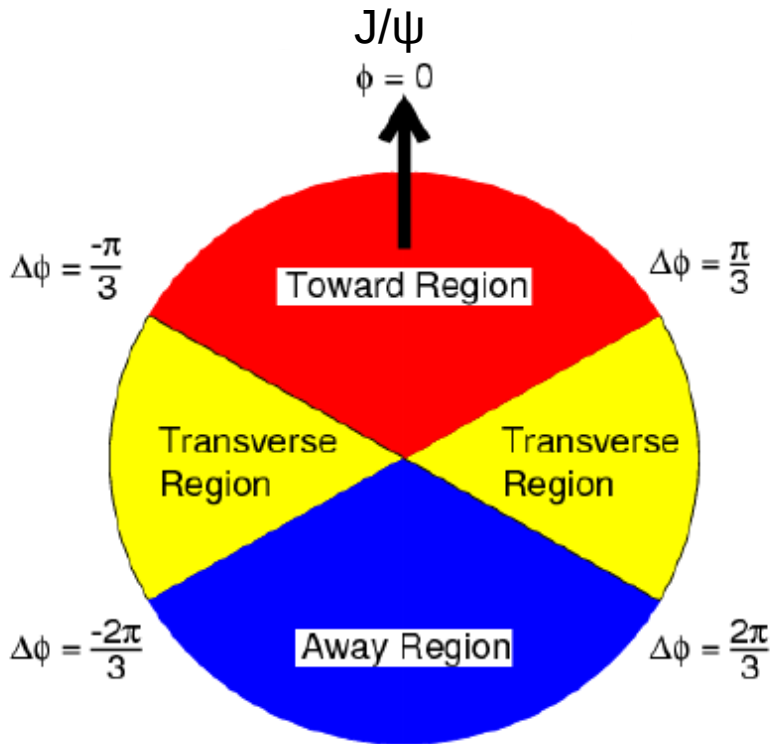
Transverse momentum bins

Non-prompt

NRQCD

Cluster collapse

- Strong p_T dependence for non-prompt J/ψ

- Some p_T dependence for J/ψ from NRQCD

- No p_T dependence for J/ψ from cluster collapse

Auto-Correlation

J/ψ
φ = 0

$\Delta\phi = \frac{-\pi}{3}$ $\Delta\phi = \frac{\pi}{3}$

Toward Region

Transverse Region   Transverse Region

$\Delta\phi = \frac{-2\pi}{3}$ $\Delta\phi = \frac{2\pi}{3}$

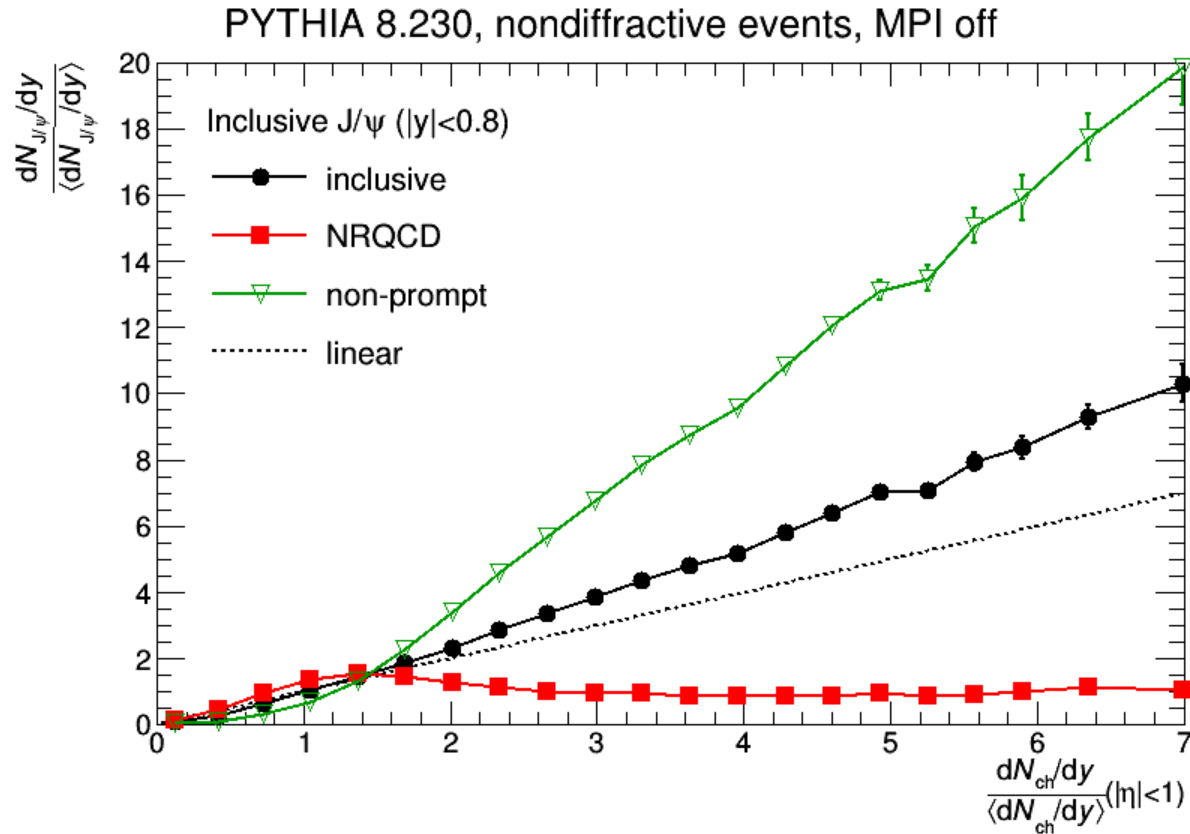Away Region

- Jet bias and additional decay products (non-prompt J/ψ)

- Investigate multiplicity in three φ regions

- Investigate multiplicity at mid and forward rapidity

- Should be best visible for simulation without MPI

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Situation without MPI

PYTHIA 8.230, nondiffractive events, MPI off

Inclusive J/ψ (|y|<0.8)
- inclusive
- NRQCD
- non-prompt
- linear

$\frac{dN_{J/\psi}/dy}{\langle dN_{J/\psi}/dy\rangle}$
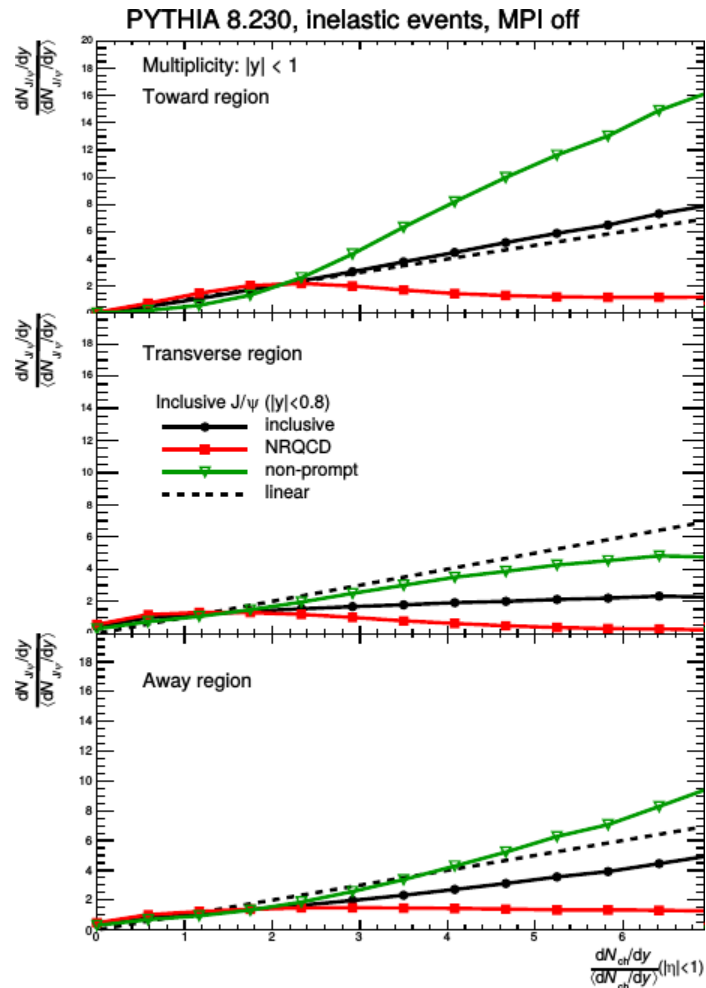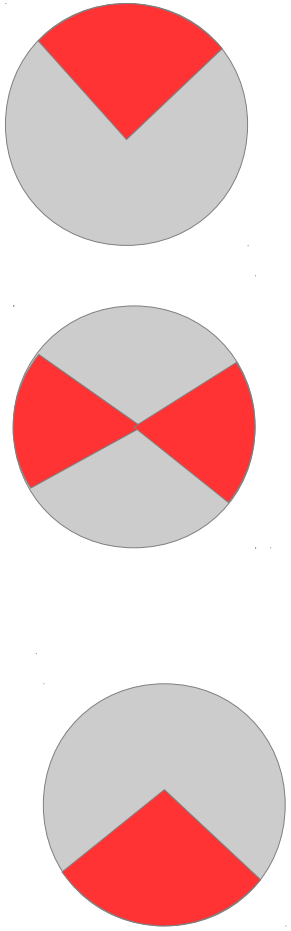
$\frac{dN_{ch}/dy}{\langle dN_{ch}/dy\rangle}(|\eta|<1)$

Without MPI:
- Prompt J/ψ production largely independent of multiplicity
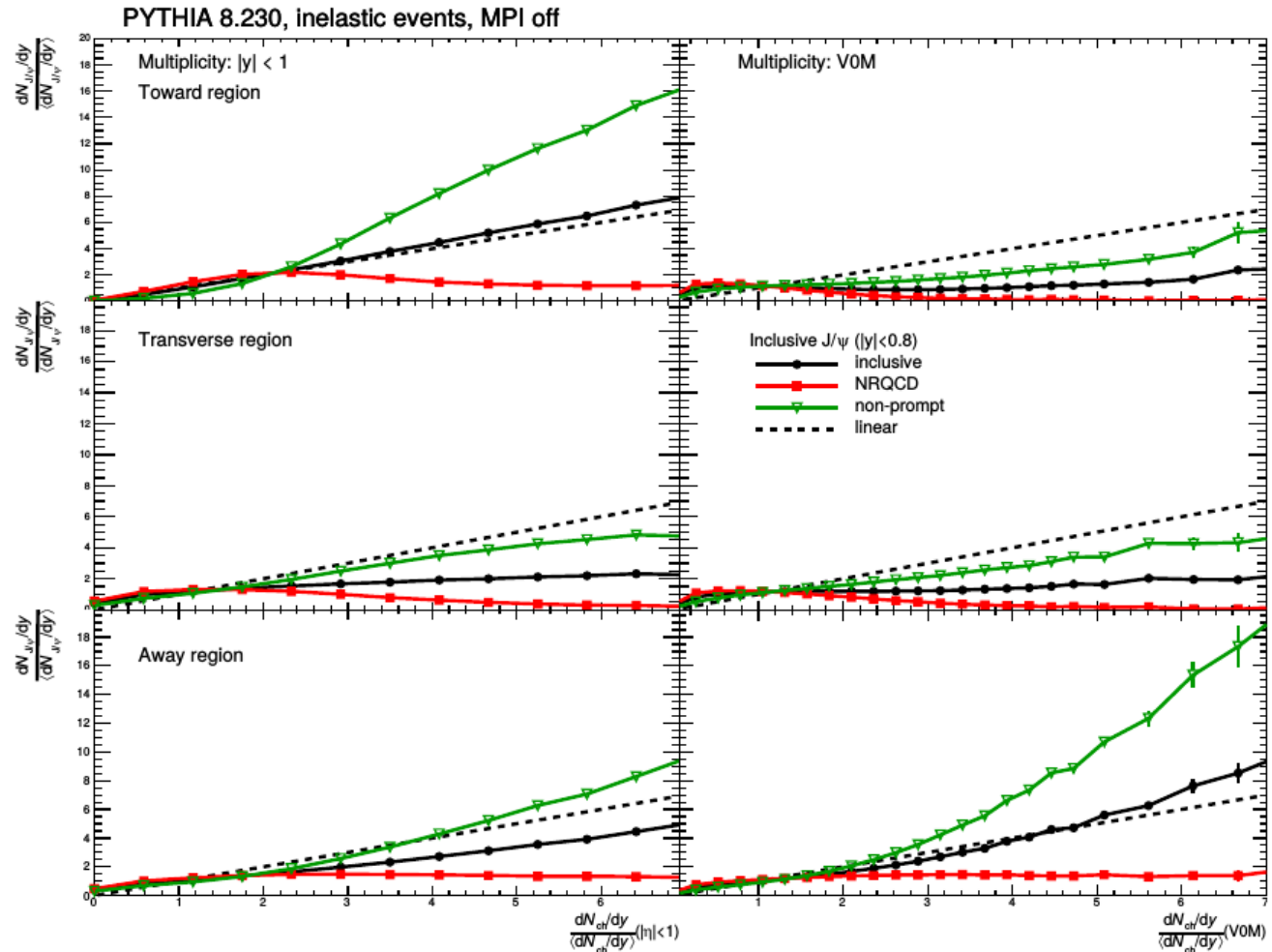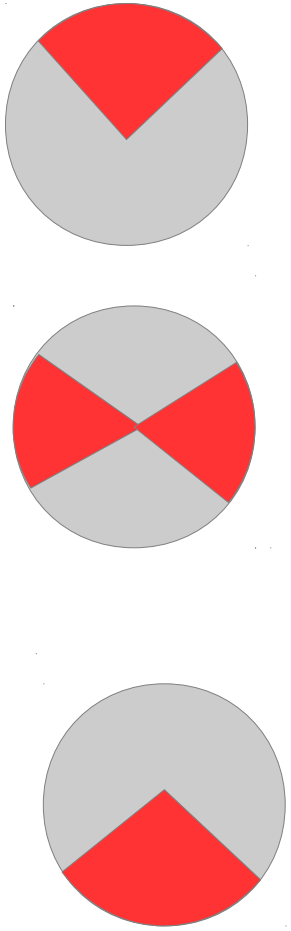- Non-prompt J/ψ: multiplicity dependence stronger than in full simulation

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Auto-correlation: sources

Auto-correlation: sources

Auto-correlation: non-prompt, p_T bins

mid-multiplicity

fwd-multiplicity

PYTHIA 8.230, inelastic events, MPI off

Multiplicity: |y| < 1
Toward region

Multiplicity: V0M

Transverse region

Non-prompt J/ψ (|y|<0.8)
— inclusive
— 8 GeV/c < p_T
— 4 GeV/c < p_T < 8 GeV/c
— p_T < 4 GeV/c
- - - linear

Away region
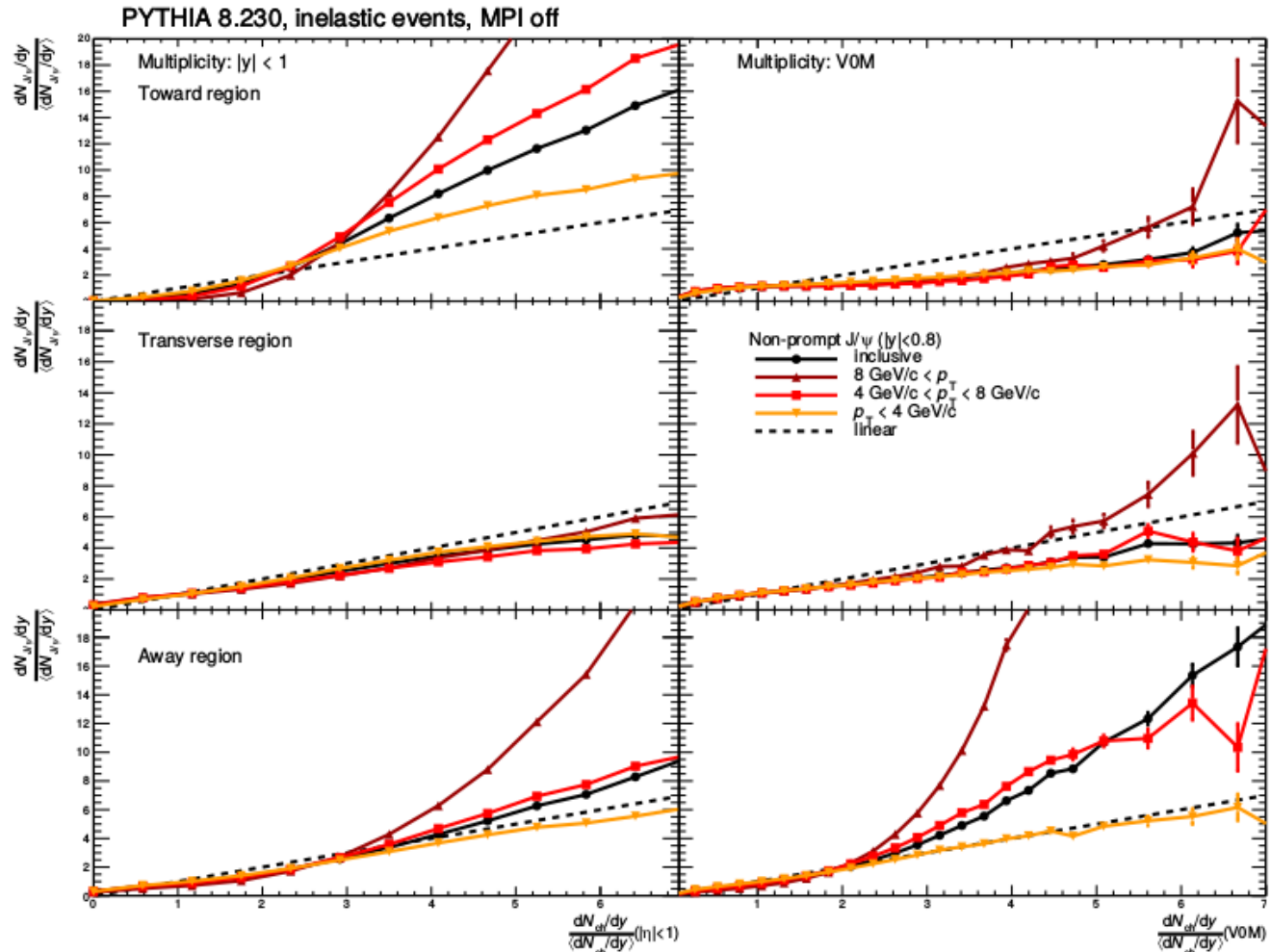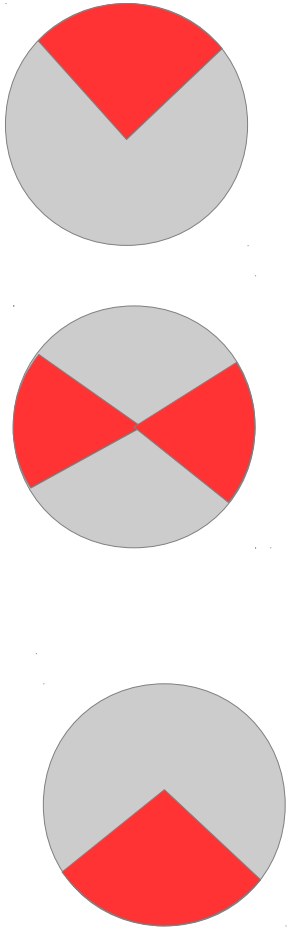
Auto-correlation

- Strong multiplicity dependence of non-prompt J/ψ without MPI largely due to correlation with multiplicity in φ region around the flight direction of the J/ψ or opposite to it

- η gap between J/ψ and multiplicity removes strong correlation with towards-region multiplicity, but not with away-region multiplicity

- Effect strongly p_T dependent

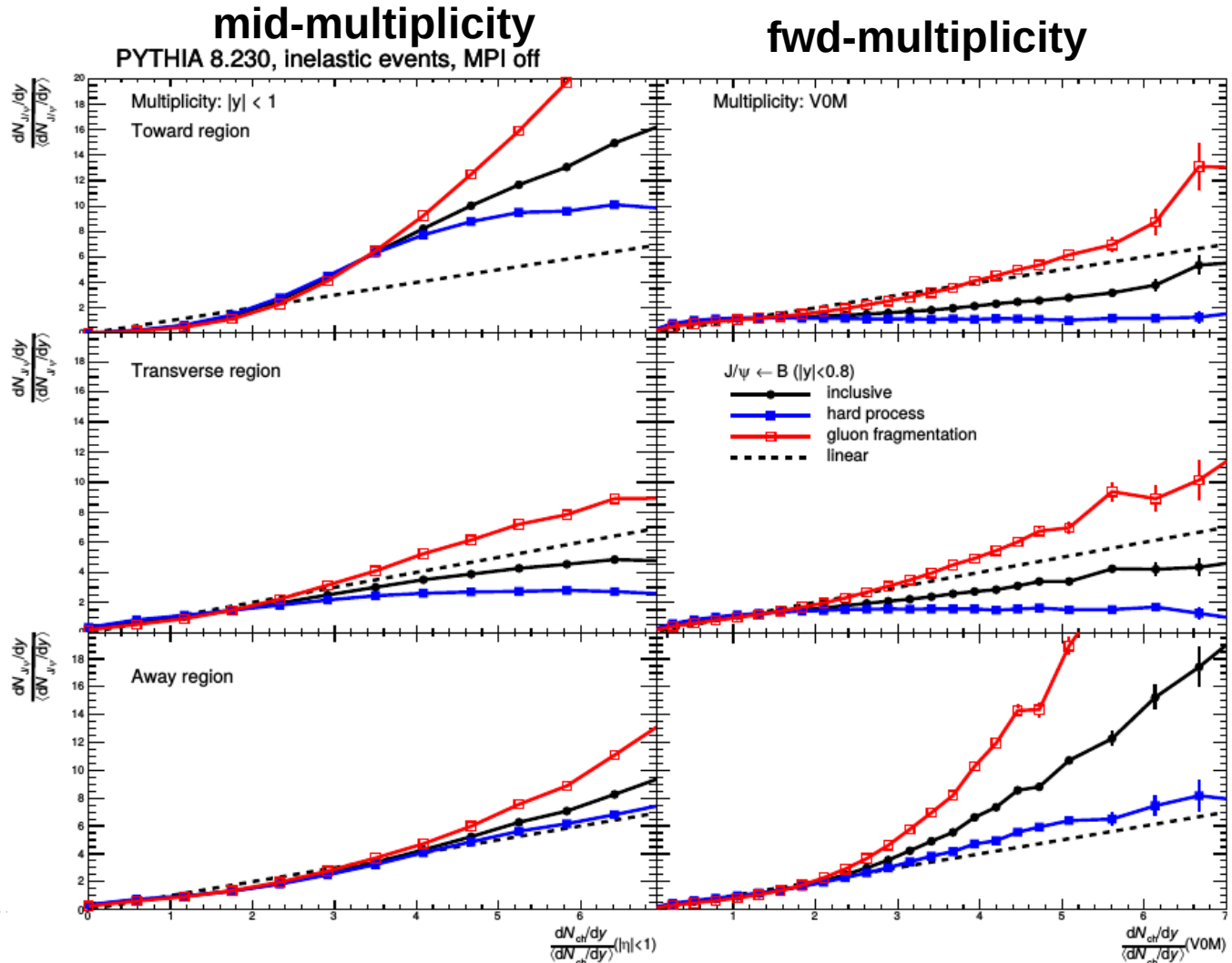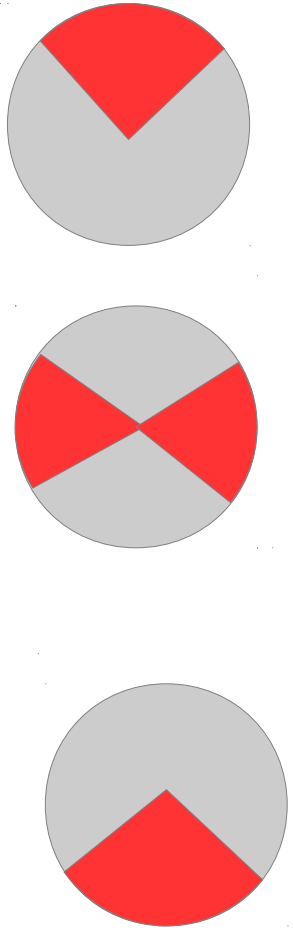   → bias due to jet fragmentation, decay daughters

b quark production process

- Hard processes: flavour creation, flavour excitation, ... : 65%

- Gluon (from hard process or ISR/ FSR) splitting into $b\bar{b}$: 35%

- beam remnant: negligible at mid-rapidity

PYTHIA 8.230, nondiffractive events, MPI off
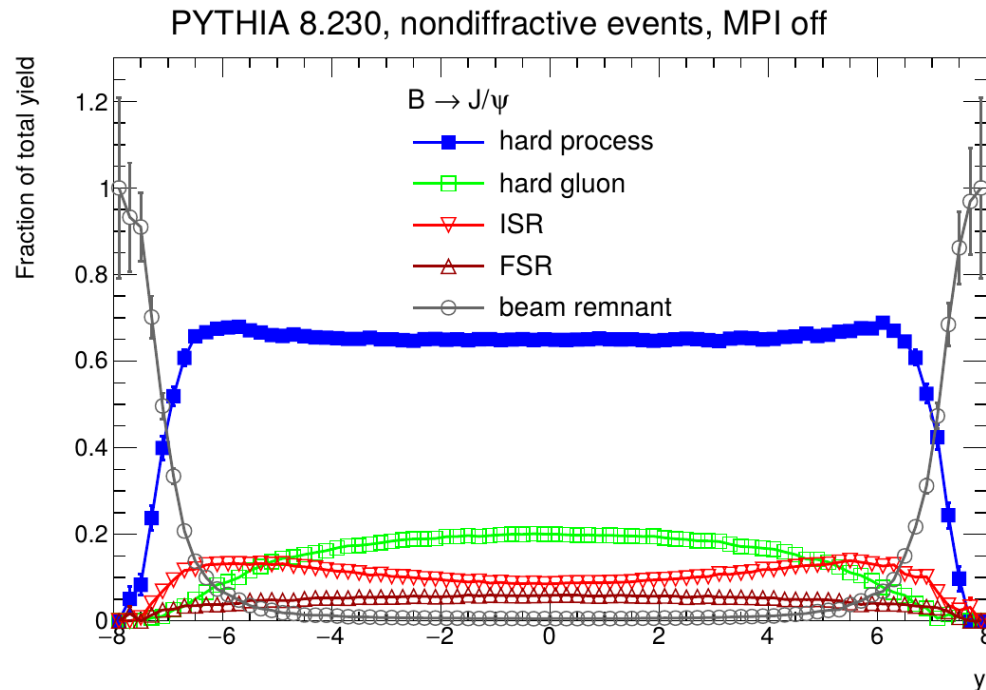
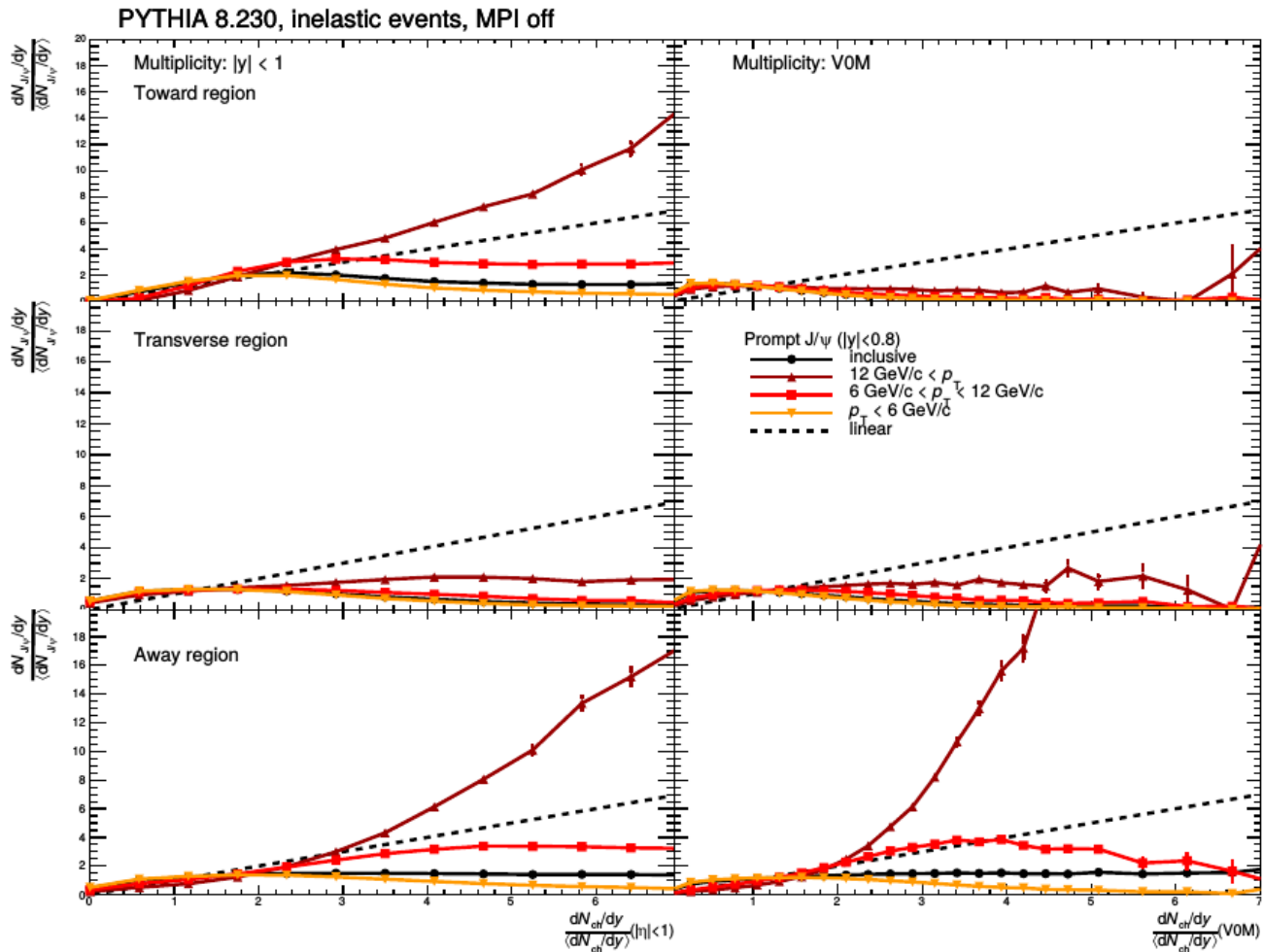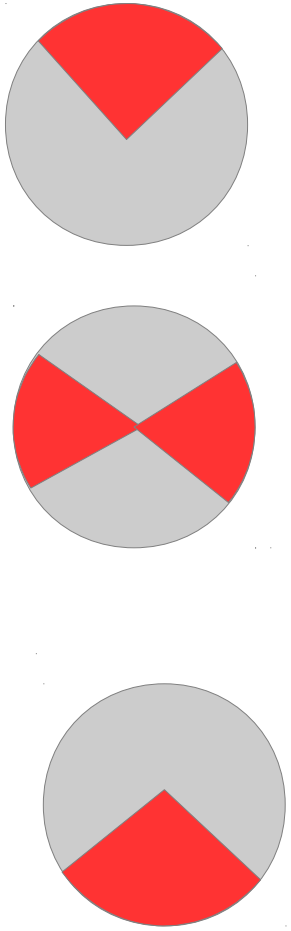# Auto-correlation: J/ψ ← B

Auto-correlation: prompt, p_T bins

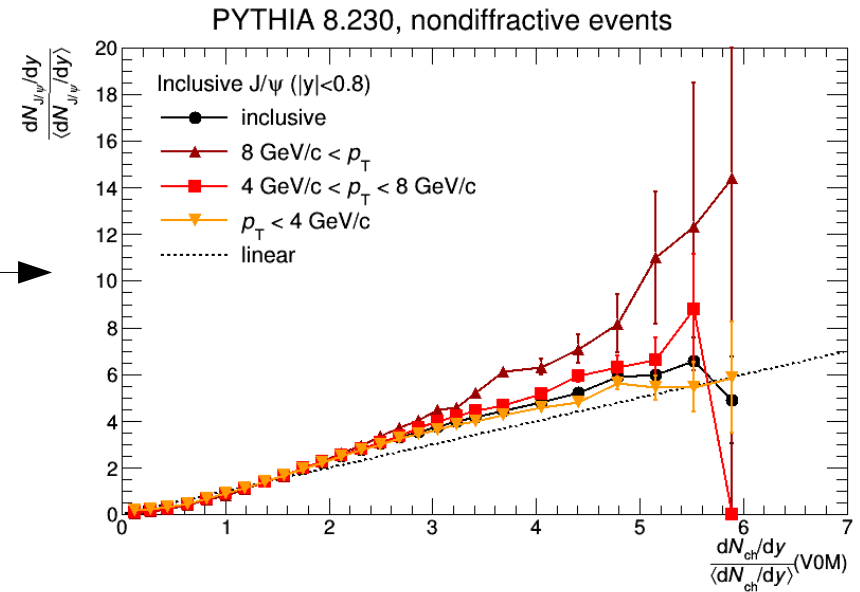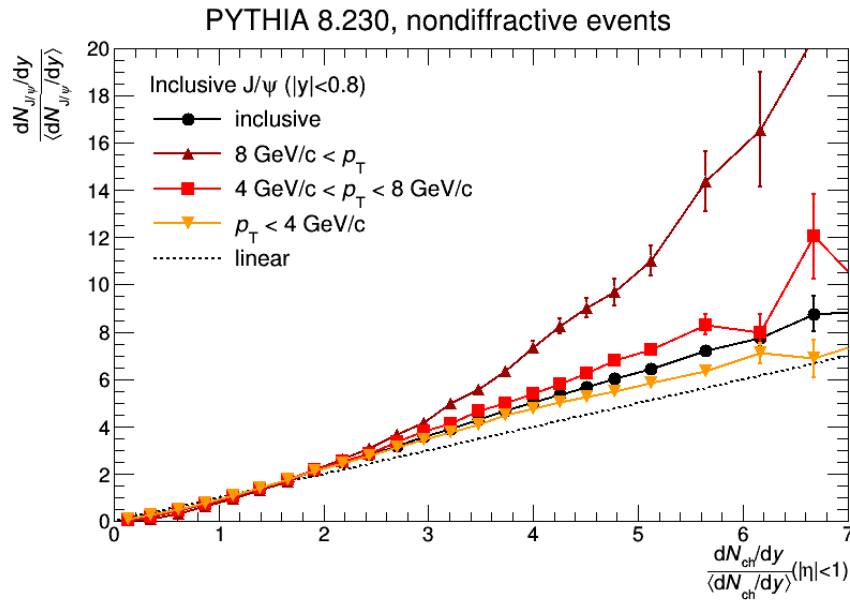**mid-multiplicity**

fwd-multiplicity

Auto-correlation

- Signature even clearer when only considering non-prompt J/ψb where b quark was produced in hard interaction

  → yield almost independent of multiplicity in transverse region of in towards region at different rapidity

- Auto-correlation effect also seen for prompt J/ψ, but starting at higher p_T
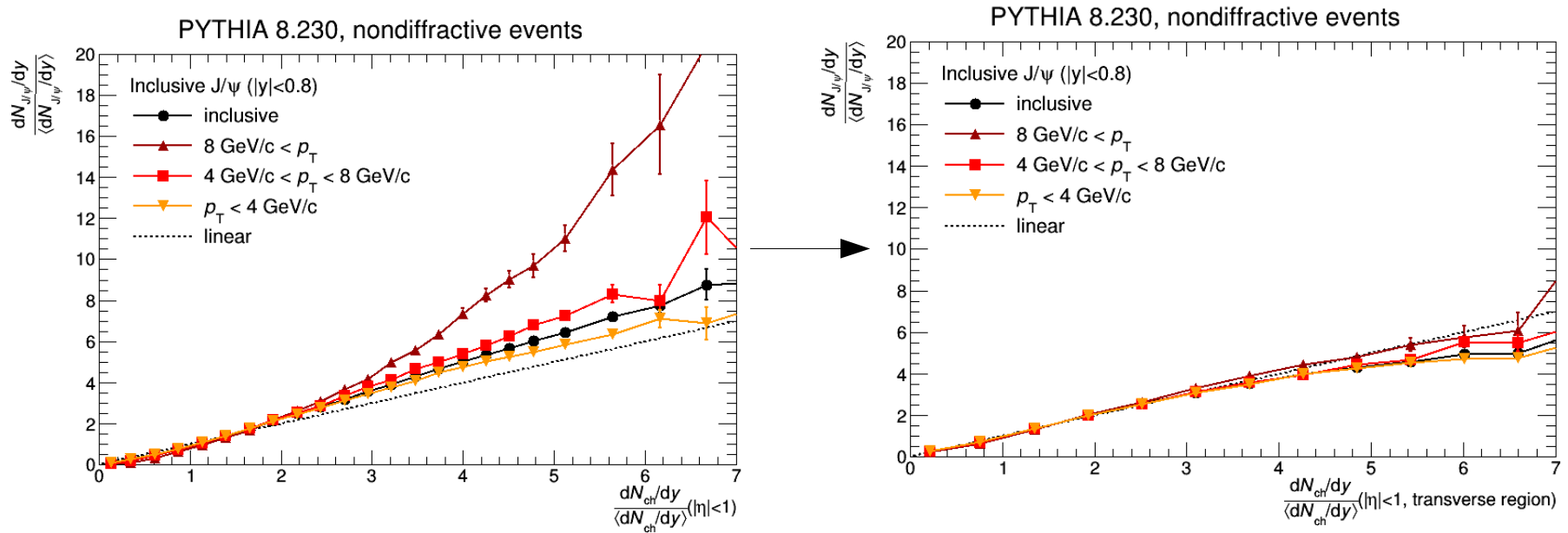
Consequences for full simulation: η gap

PYTHIA 8.230, nondiffractive events

Inclusive J/ψ (|y|<0.8)
- inclusive
- 8 GeV/c < p_T
- 4 GeV/c < p_T < 8 GeV/c
- p_T < 4 GeV/c
- linear

- Increase of inclusive J/ψ still stronger than linear when measured as a function of forward multiplicity

- Increase is p_T dependent

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Consequences for full simulation: φ gap

PYTHIA 8.230, nondiffractive events

Inclusive J/ψ (|y|<0.8)
- inclusive
- 8 GeV/c < p_T
- 4 GeV/c < p_T < 8 GeV/c
- p_T < 4 GeV/c
- linear

- (Slightly weaker than) linear increase of inclusive J/ψ when measured as a function of multiplicity in transverse region

- Increase independent of p_T

Consequences for full simulation: φ gap
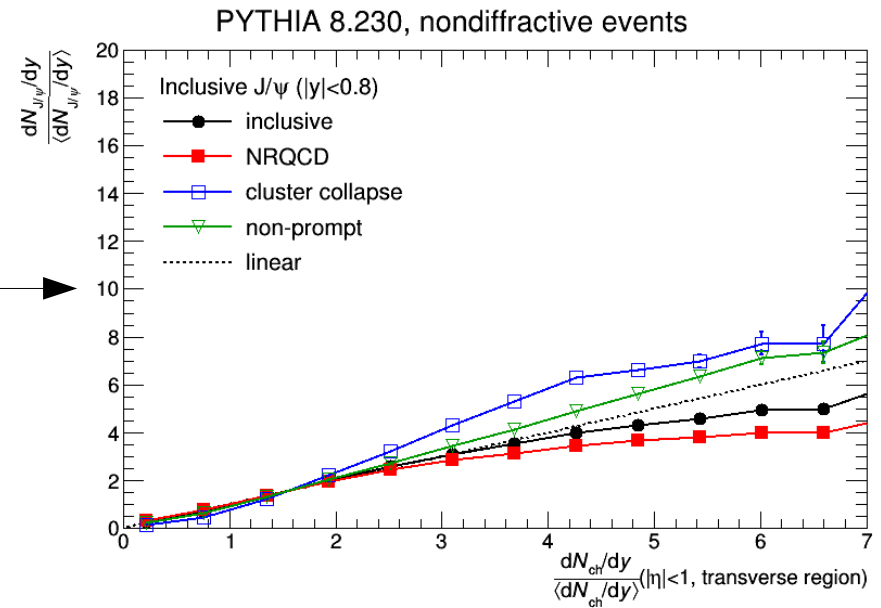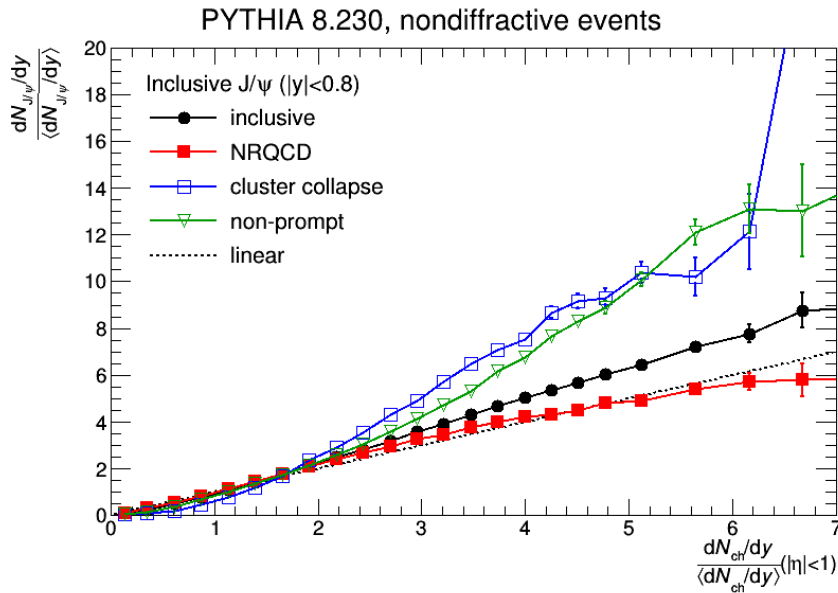
- Non-prompt J/ψ production most effected by restriction to transverse region

Summary

- Linear increase of J/ψ production with number of MPI

- In Addition:

  - Quadratic increase of cluster collapse component

  - Charged particle reduction via colour reconnection

  - Auto-correlation effects in non-prompt component

- Propose multiplicity measurement in transverse region:

  - Remove auto-correlation

  - Linear increase with multiplicity without p_T dependence expected

  - Especially interesting for open heavy flavour measurements

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