Fragmentation of jets containing J/ψ mesons in pp collisions with CMS

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On behalf of CMS collaboration

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UCLA, Los Angeles, CA
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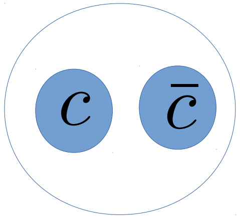
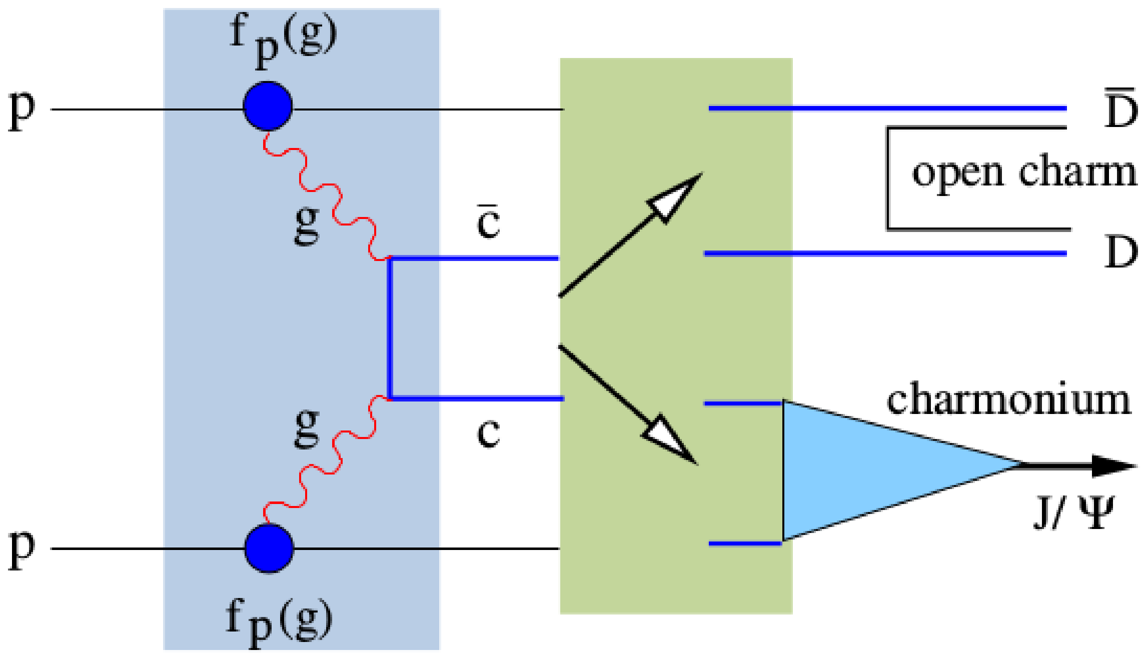
J/ψ vector meson production

- November 11, 1974 – SLAC and BNL discovered a new particle;

  It was interpreted as a bound state of ccbar pair

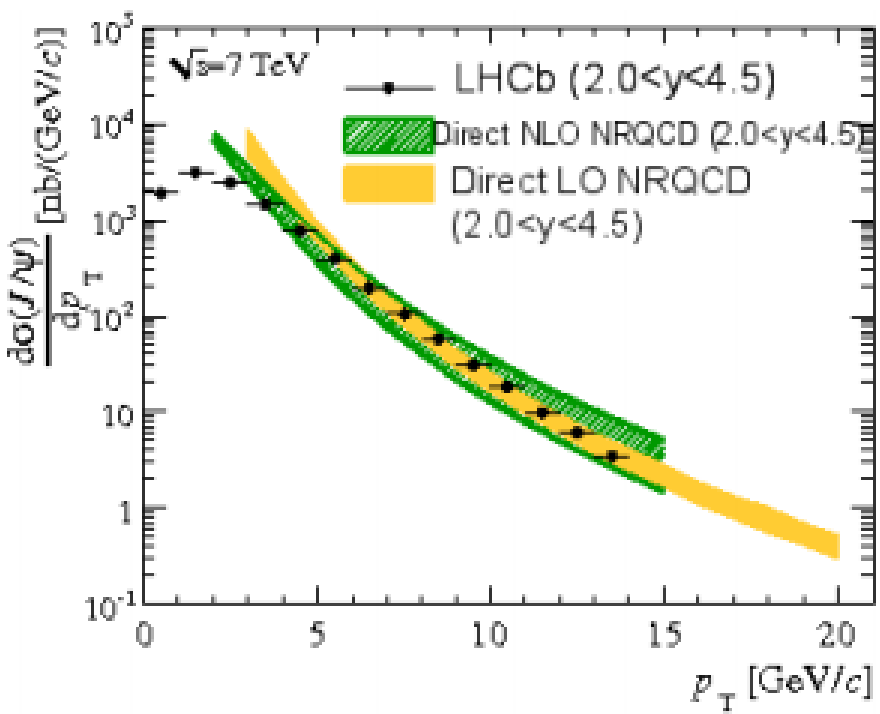


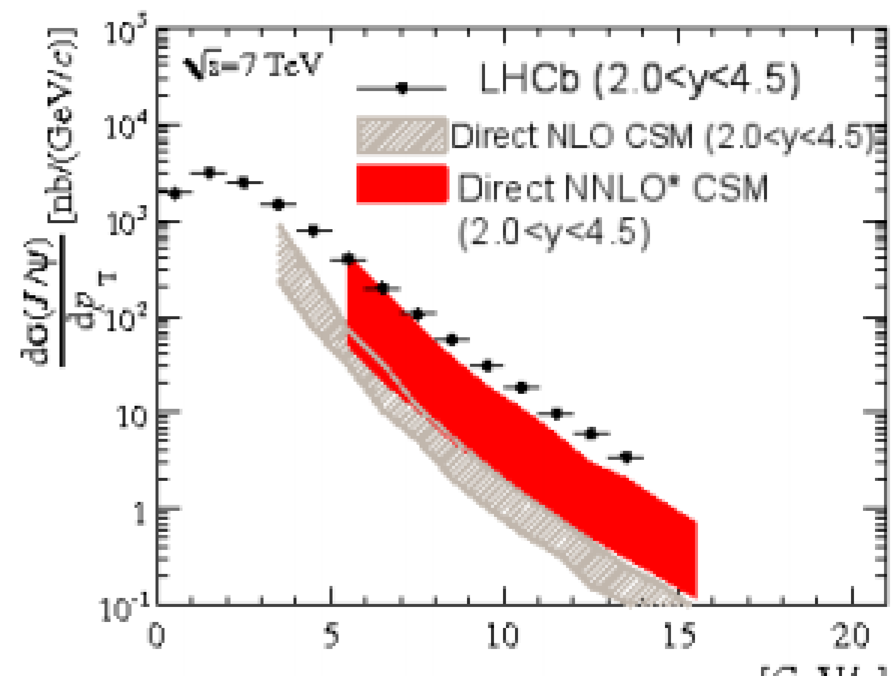
- NRQCD calculations sum over the color-singlet (CS) and color-octet (CO) states
  - Long-distance matrix elements are fitted from data and reflect the probability of a heavy quark-antiquark pair to evolve into a heavy quarkonium state
- Color-singlet model (CSM) doesn't allow contributions from CO states



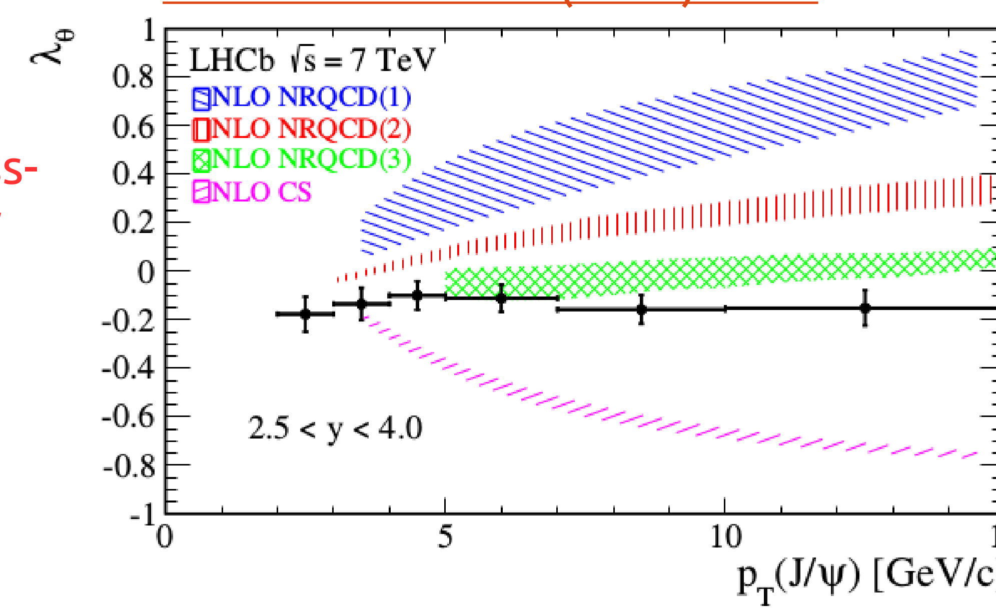
J/ψ cross-section and polarization

Eur. Phys. J. C 71 (2011) 1645





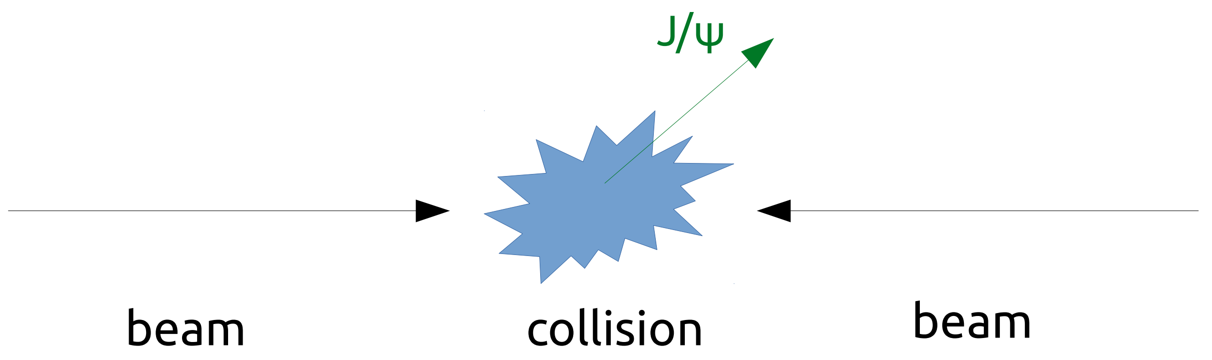
EUR. PHYS. J. C73 (2013) 2631



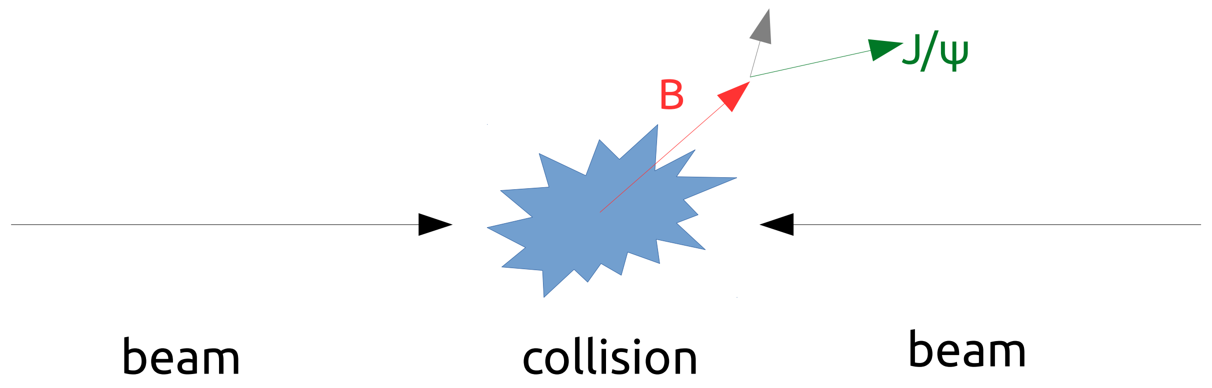
Existing models do not describe J/ψ cross-section and polarization simultaneously

J/ψ production

- <u>Prompt</u> : vertex is not displaced in the detector
  J/ψ originates directly from pp collision or via decay of heavier charmonium states (e.g. χ_c)

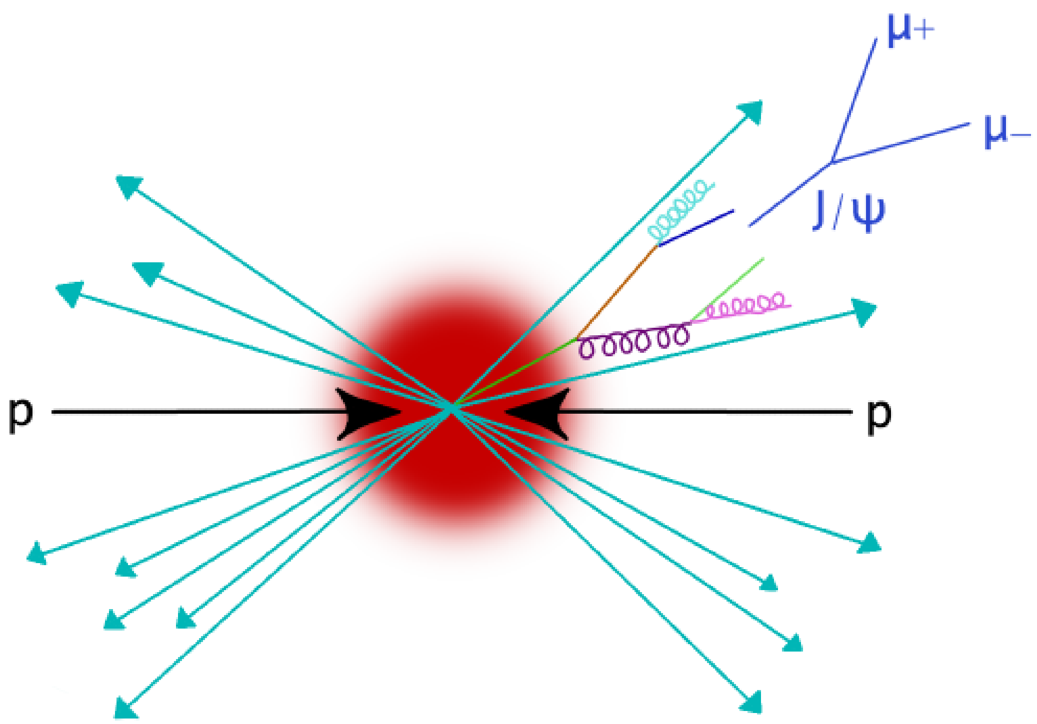


- <u>Non-prompt</u> : displaced vertex in the detector
  J/ψ comes from a decay of B-hadron



Jets fragmenting into J/ψ

To learn more about the production mechanism of J/ψ →
study how J/ψ is produced when it is a product of jet fragmentation

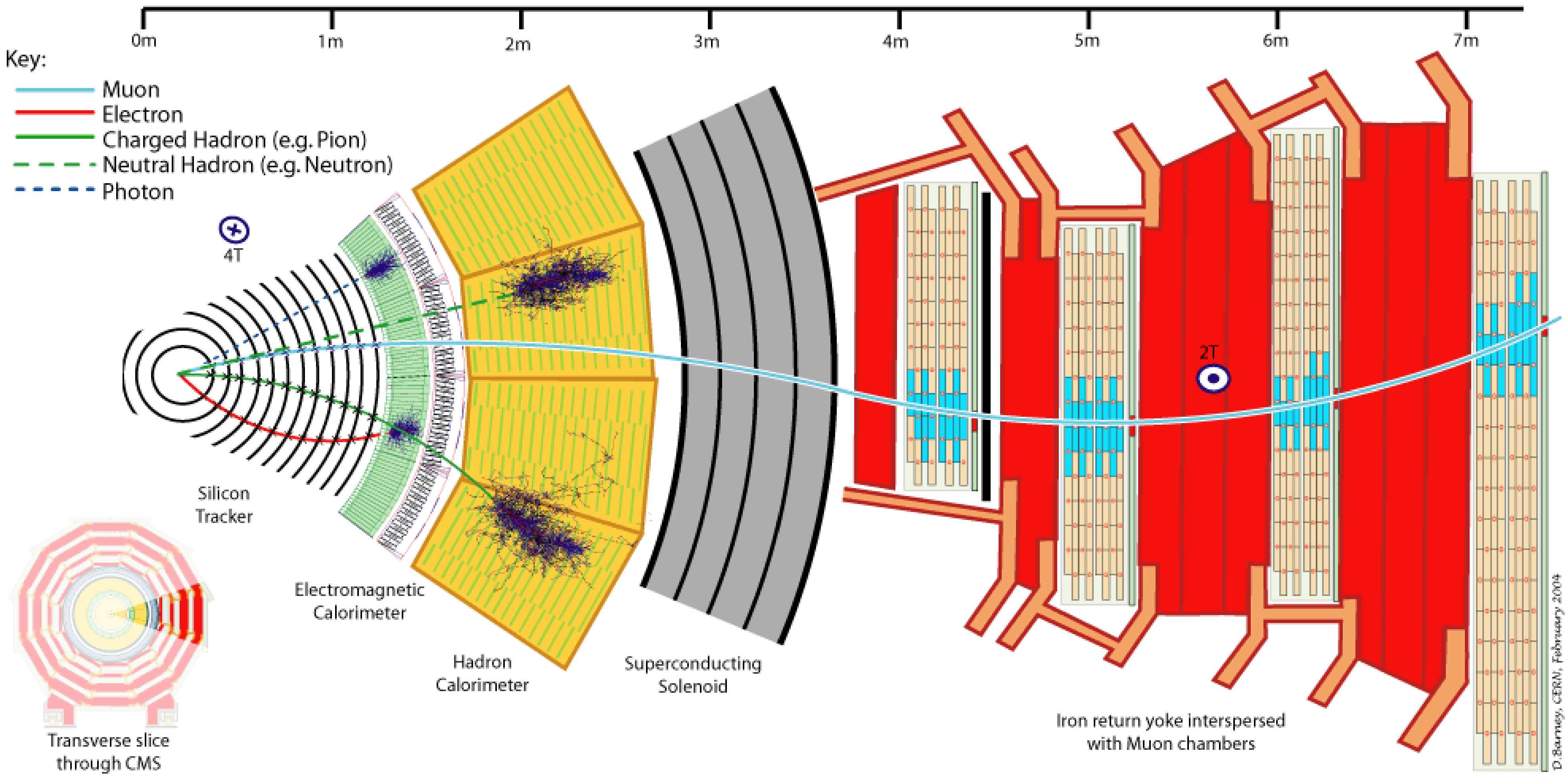


"J/ψ in jets" in CMS :

- $J/\Psi \to \mu^+\mu^-$
- Fragmentation function $z = \frac{p_{T,\ J/\Psi}}{p_{T,\ jet}}$
- Fraction of J/ψ mesons produced in jets

CMS-PAS-HIN-18-012

Compact muon solenoid experiment



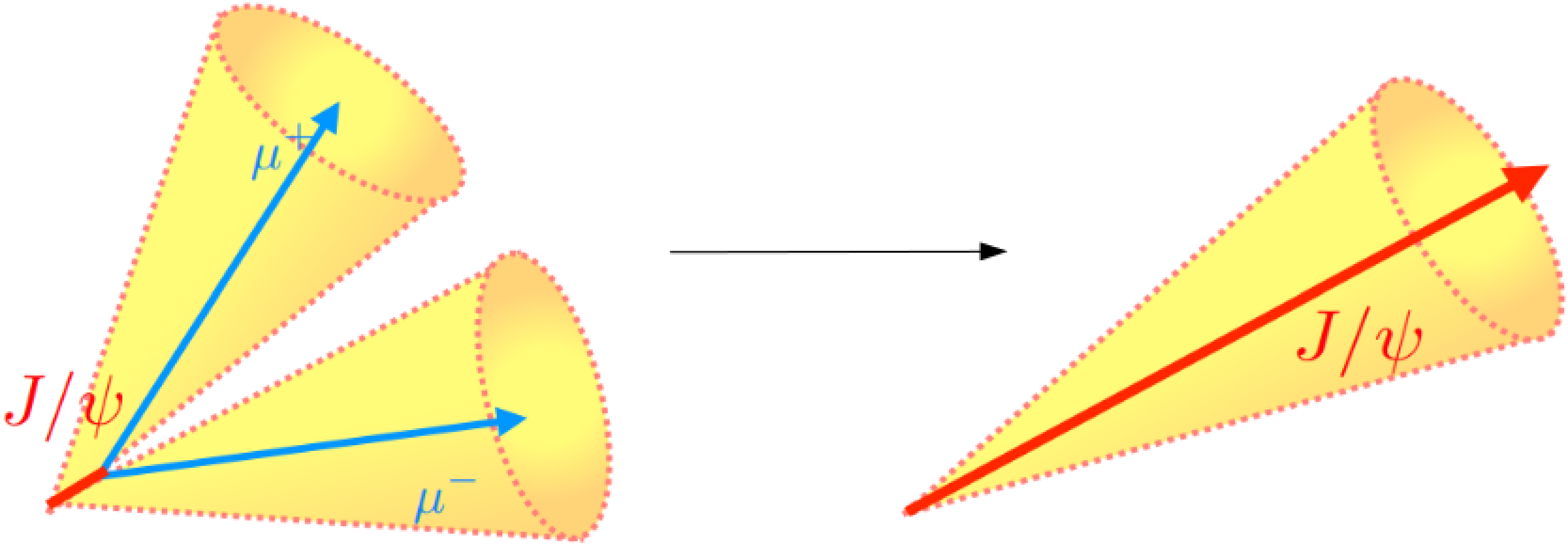
Muons from $J/\Psi \rightarrow \mu^{+}\mu^{-}$ = very clean signature in the detector.
Acceptance for "J/ψ in jets" analysis : $|y_{J/\Psi}| < 2.4,\ 3 < p_{T,\ J/\Psi} < 35\ \mathrm{GeV}$

Jet = collimated spray of particles, originating from quarks and gluons.
Jet leaves signals in the tracker, the electromagnetic and hadronic calorimeters

Jet clustering

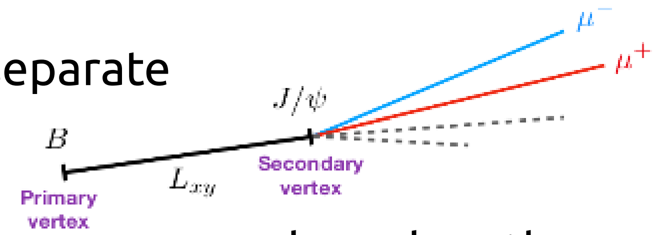
Opening angle of J/ψ decay could be large → muons might end up in different jets

Jets were reclustered with the J/ψ meson instead of muons

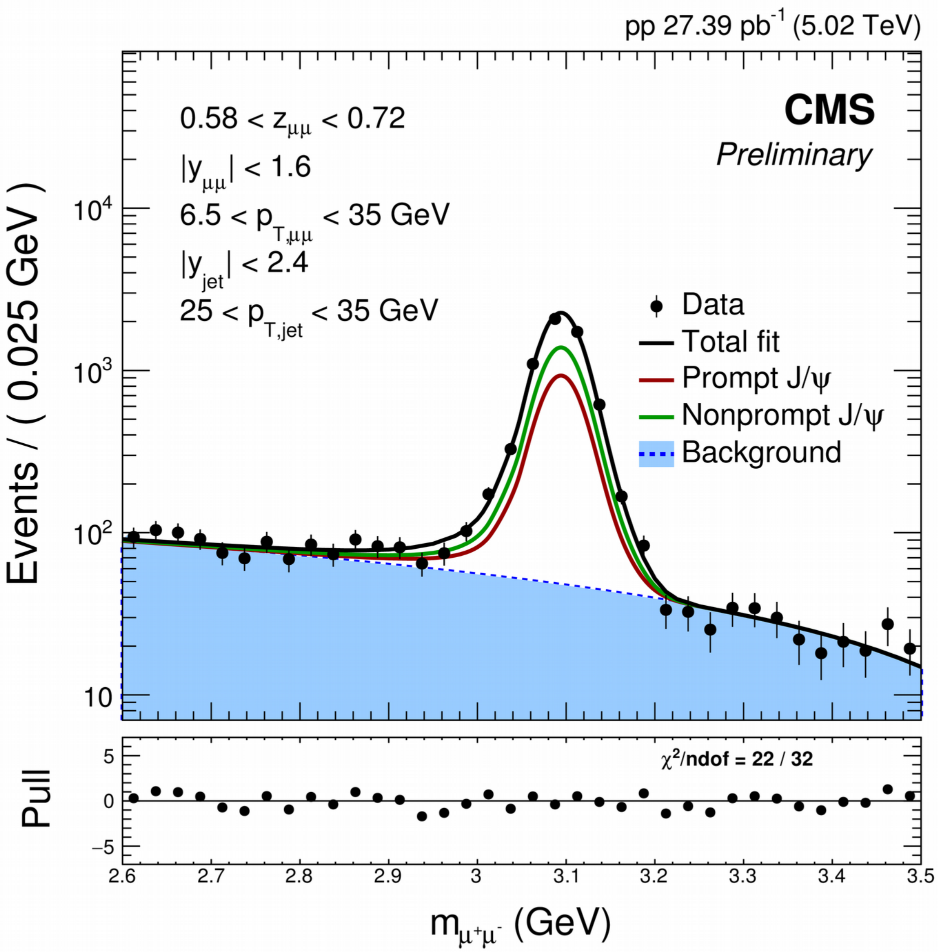


J/ψ separation : prompt vs non-prompt

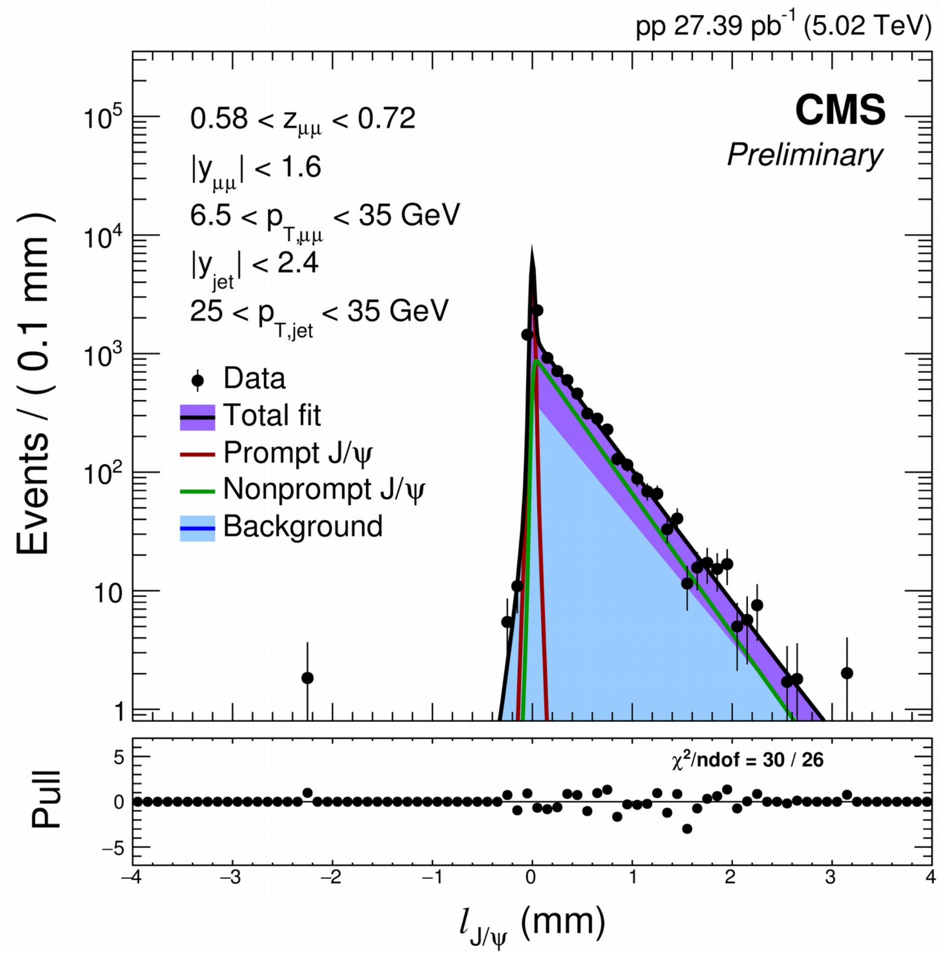
2D fits of invariant mass and decay length used to separate prompt and non-prompt J/ψ mesons



invariant mass

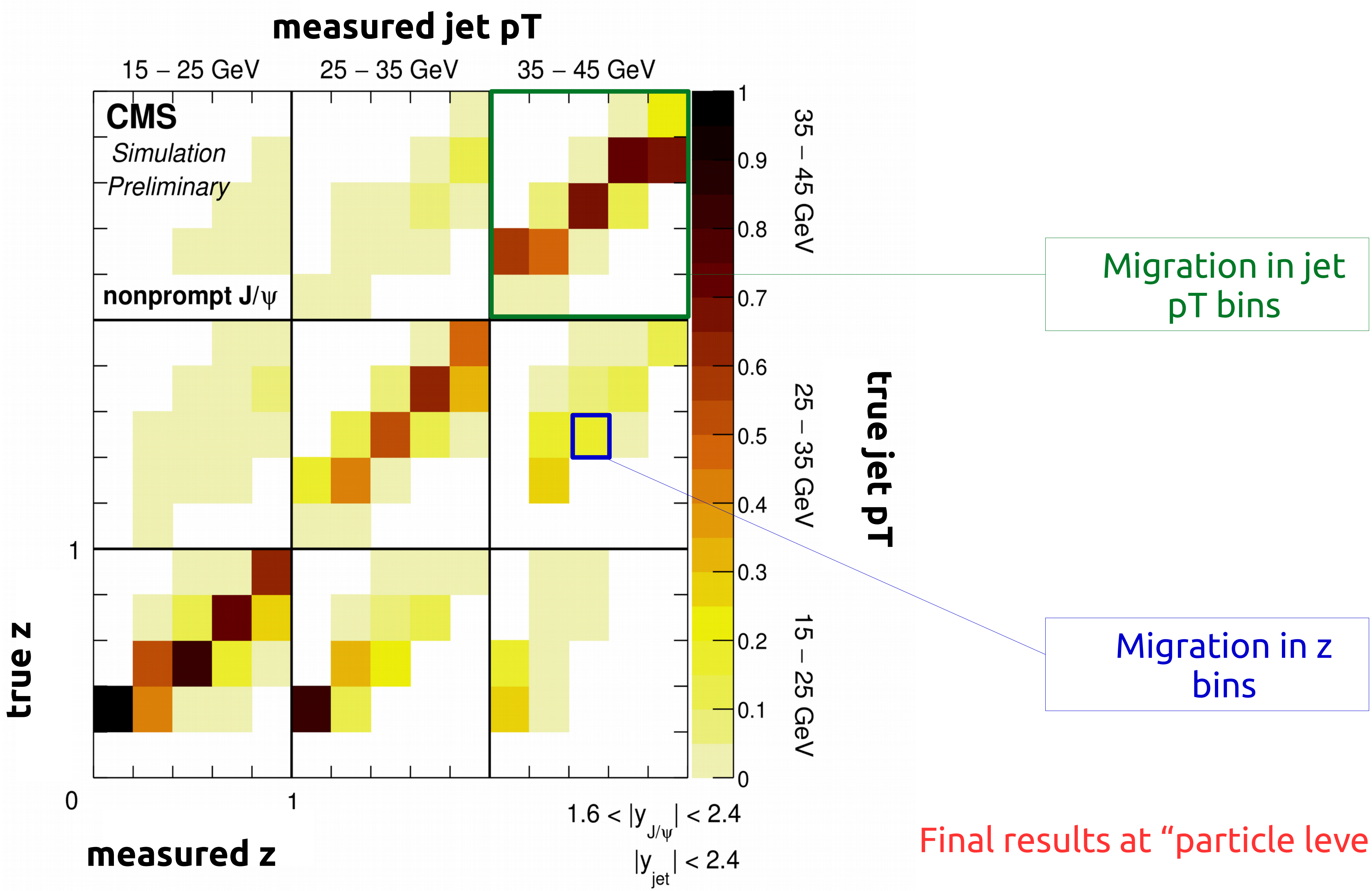


decay length



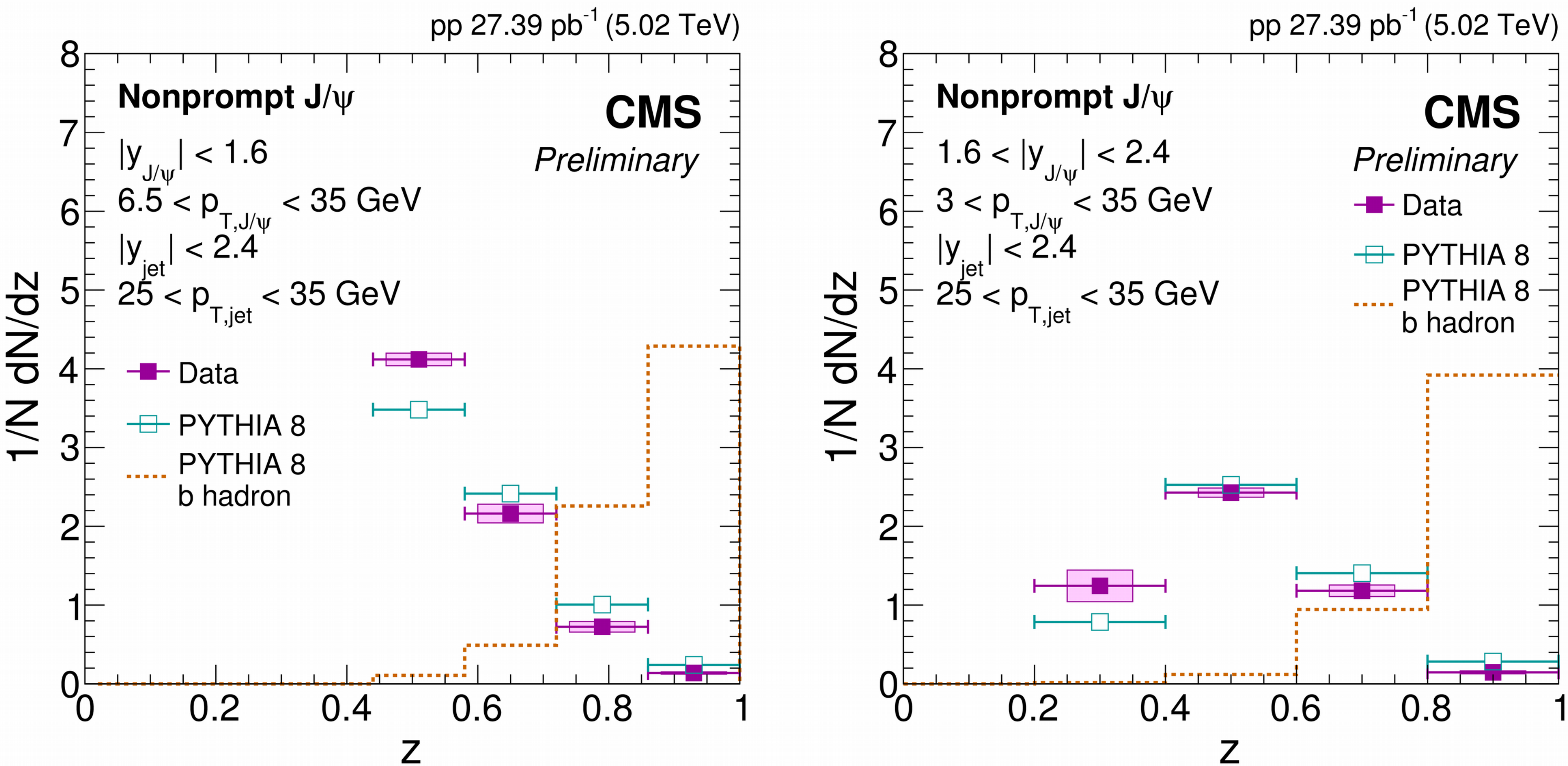
Correction for detector effects

Migration across z bins due to finite jet pT resolution is corrected using <u>unfolding</u>
Detector response from MC simulations



Final results at “particle level” !

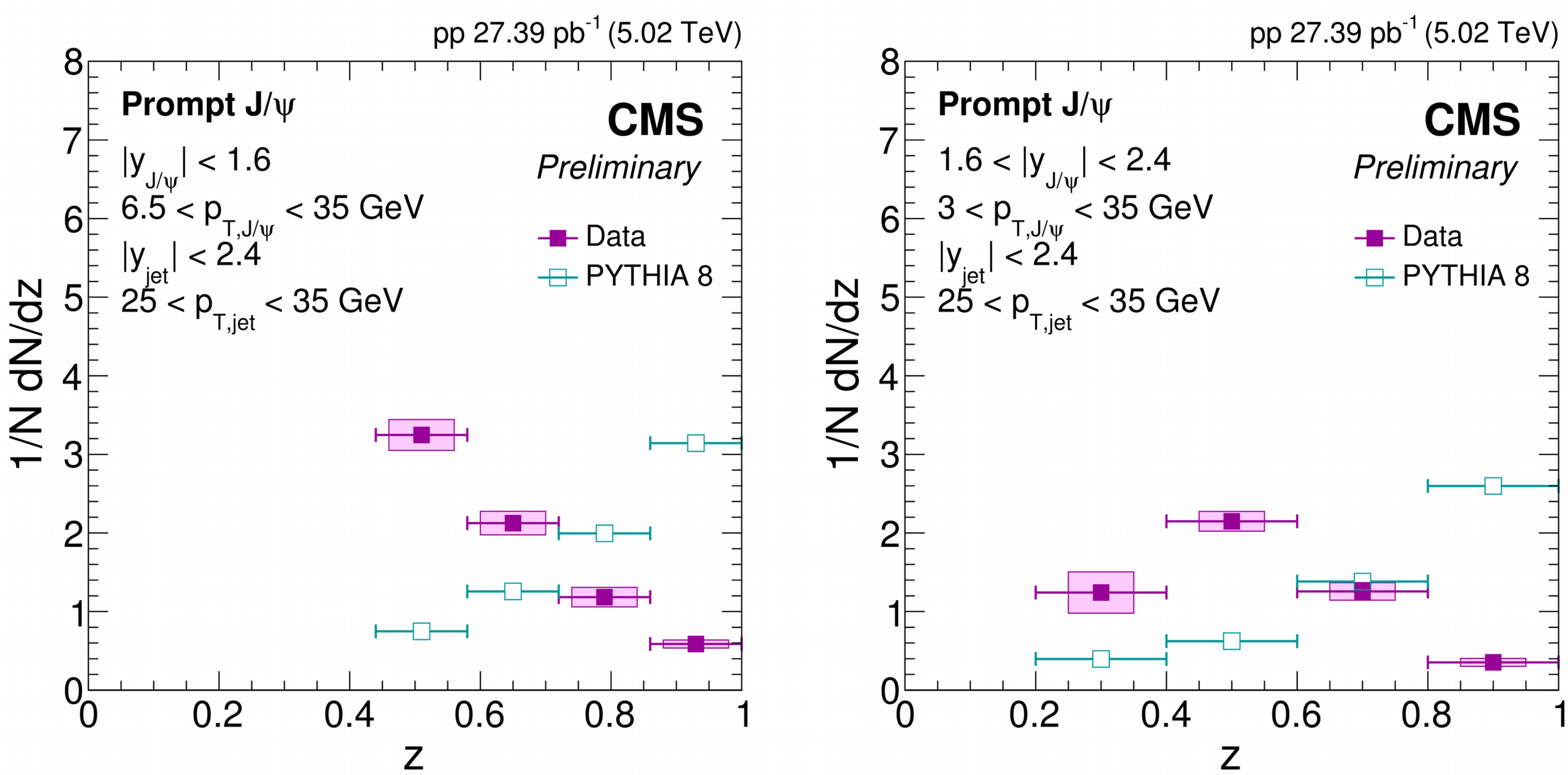
Results: non-prompt J/ψ



Similar behaviour in data and Pythia

Fragmentation of the b-hadron is described well in Pythia

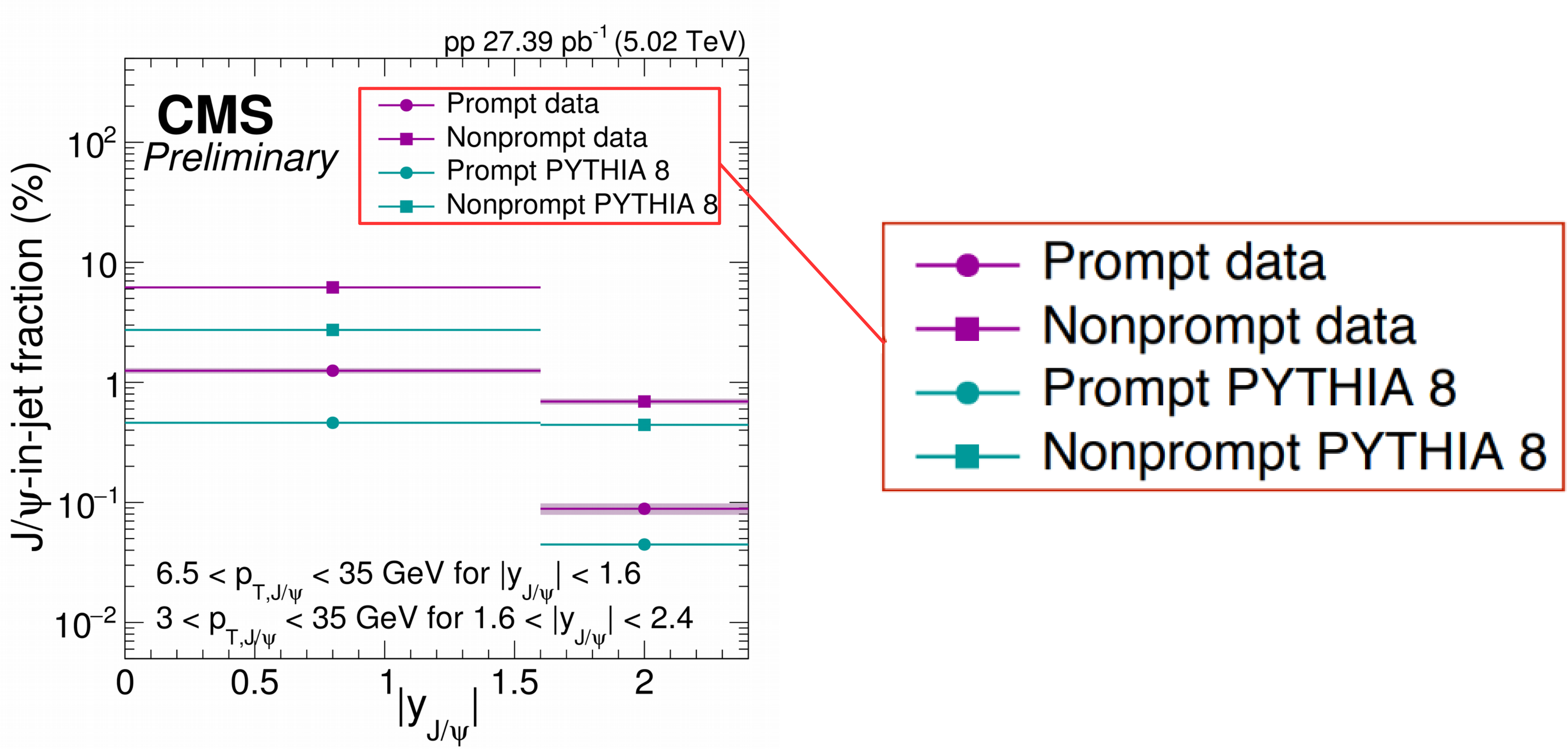
Results: prompt J/ψ



z distribution is too hard in Pythia : the jet activity accompanying J/ψ is underestimated

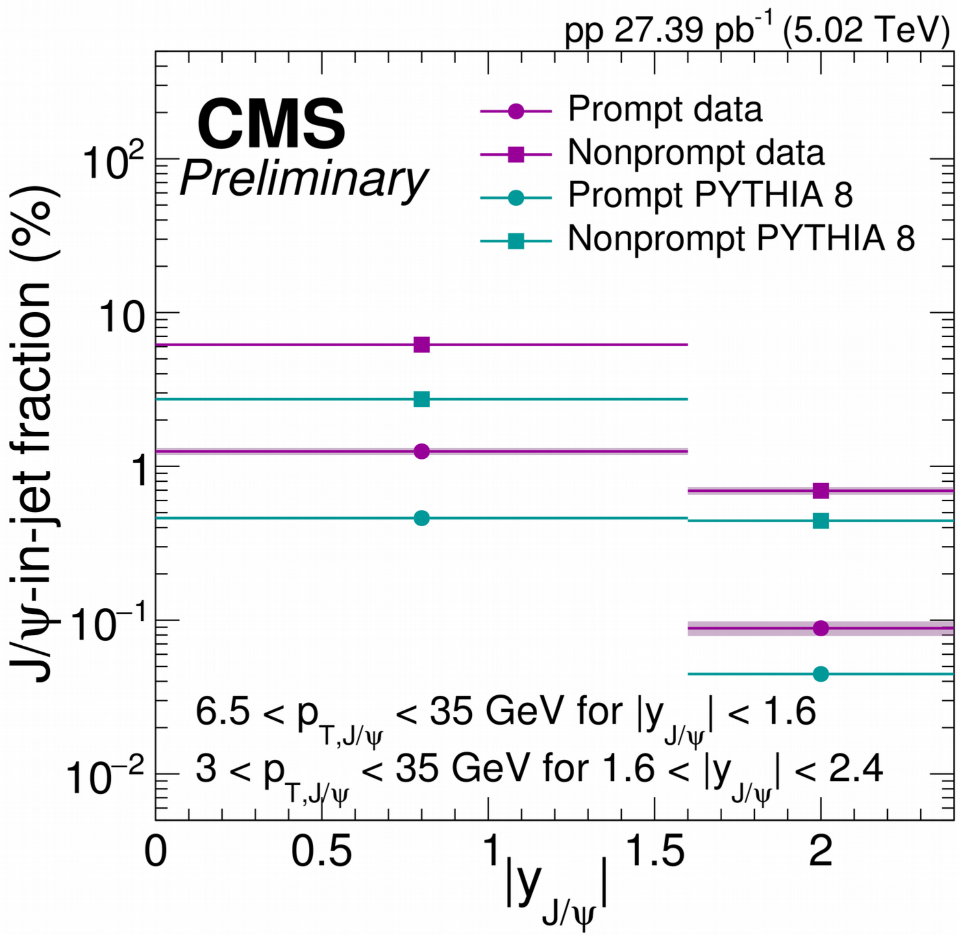
Data looks very similar to non-prompt z distribution

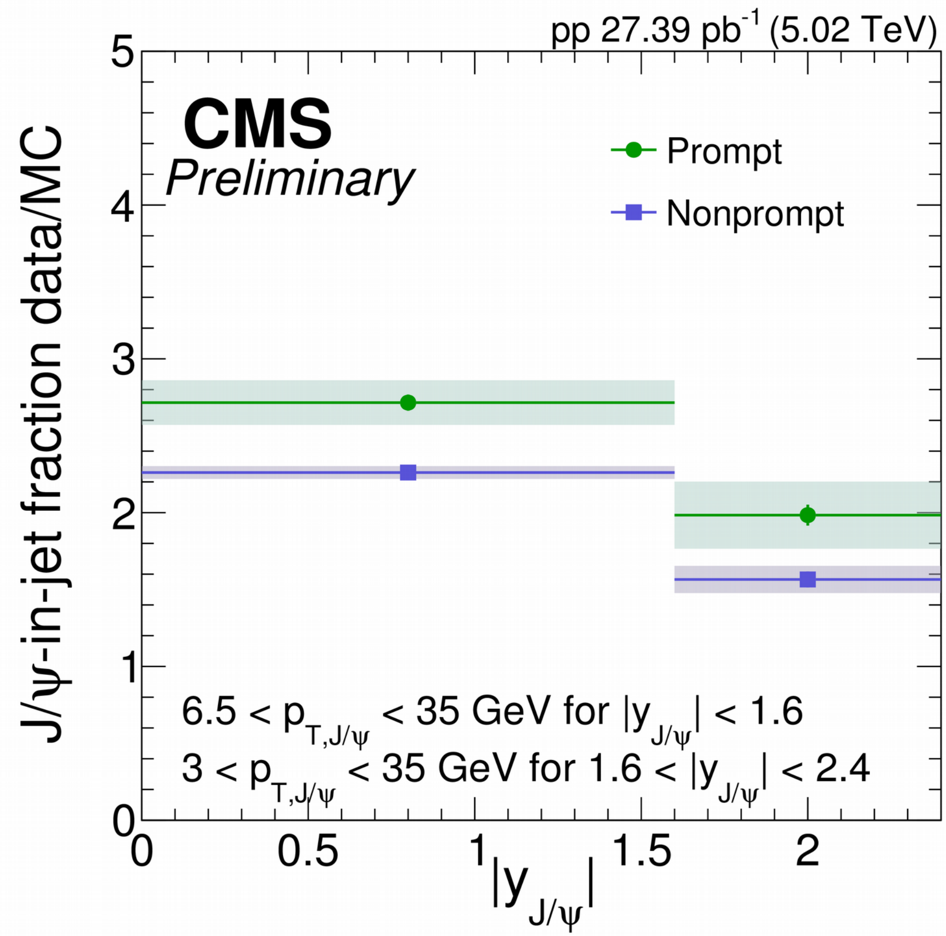
Results: fraction of J/ψ produced in jets



Almost 7% of J/ψ produced in jets

Results: fraction of J/ψ produced in jets

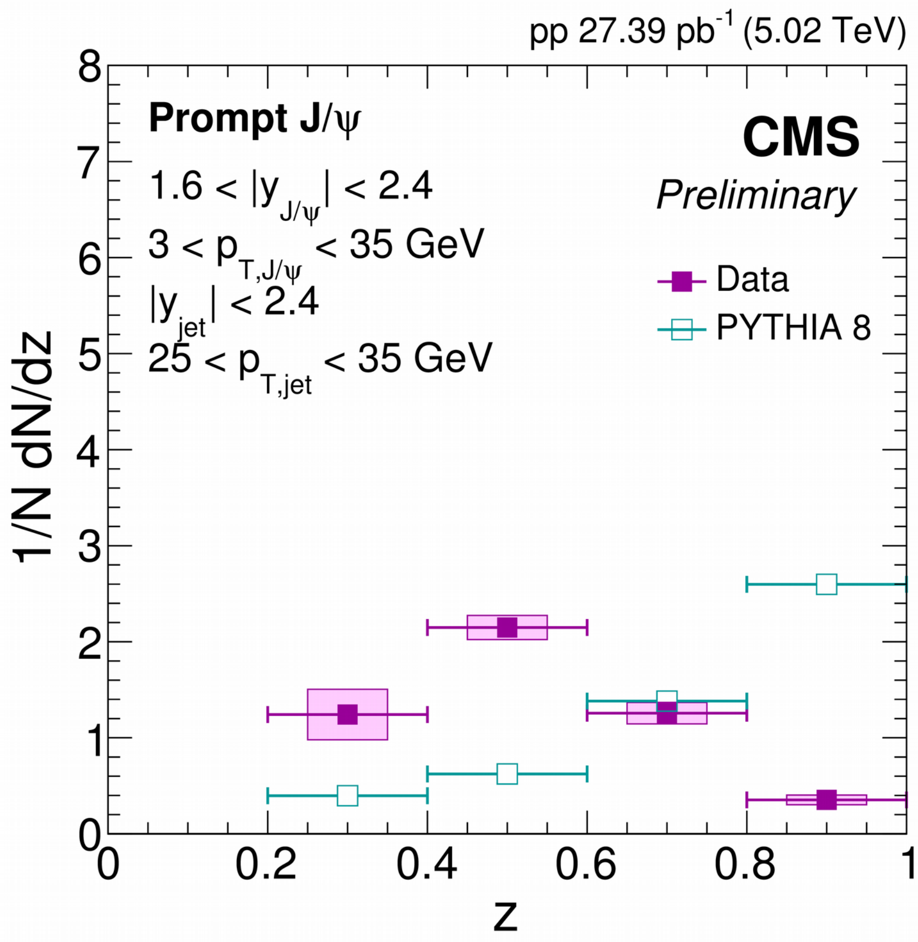




Almost 7% of J/ψ produced in jets

Under-predicted in Pythia both for prompt and non-prompt !

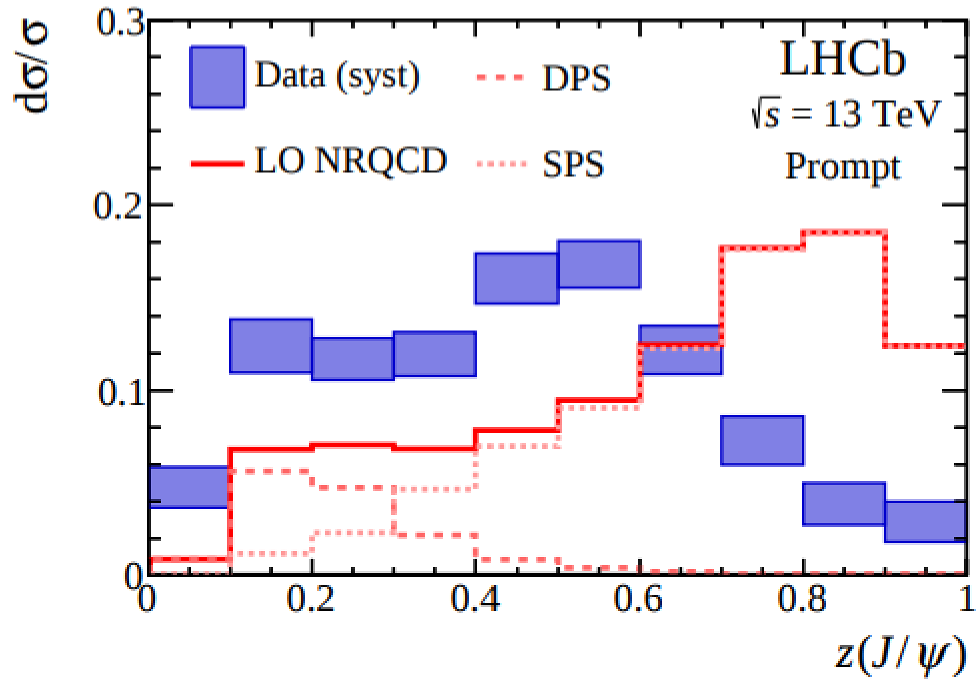
Results compared to LHCb



[PRL 118, 192001]

$$2.0 < |\eta_{J/\Psi}| < 4.5,\ p_{T,\ \mu} > 0.5\ \text{GeV}$$

$$2.5 < |\eta_{jet}| < 4.0,\ p_{T,\ jet} > 20\ \text{GeV}$$



Similar results in CMS and LHCb in different kinematic regions

Further theoretical developments

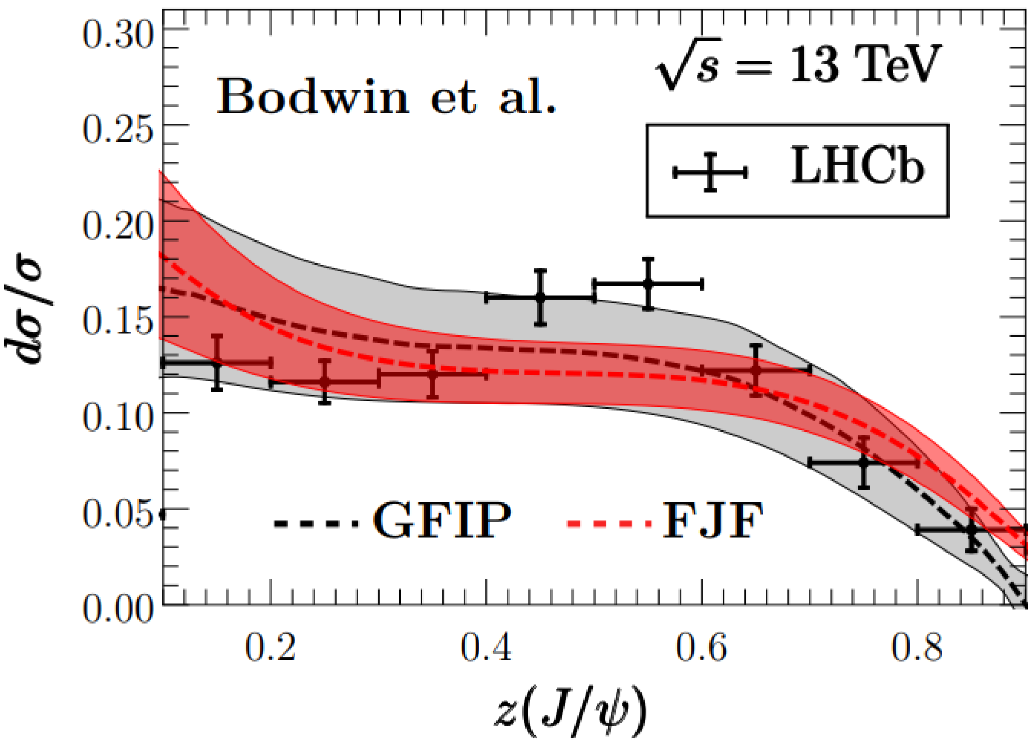
In Pythia qq is produced in a CS or CO process :

- CS : qq → J/ψ and no gluon emission
- CO : qq showers with the splitting function peaking at 1.
  At the end of the shower CO qq emits gluon to become CS J/ψ

New developments :

- Fragmentation jet function evaluated at the jet energy scale. It controls z dependence of the cross-section
- Hard gluon produced in a short-distance process → it showers to a gluon with virtuality 2mc → hadronizes into J/ψ
- Reproduces better experimental results

PRL 119, 032002

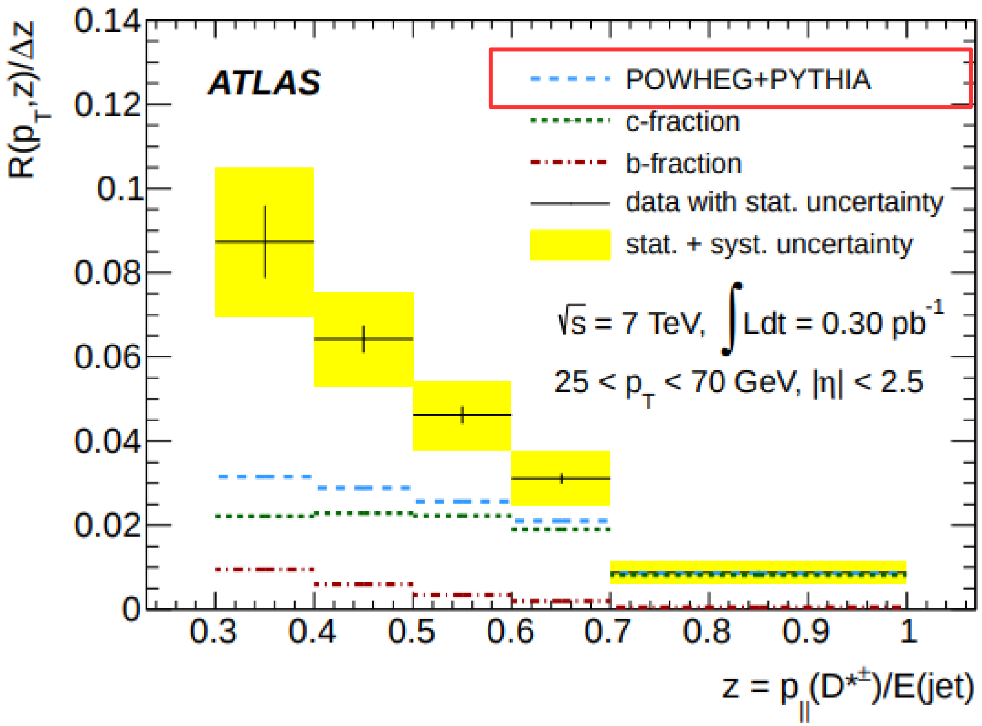


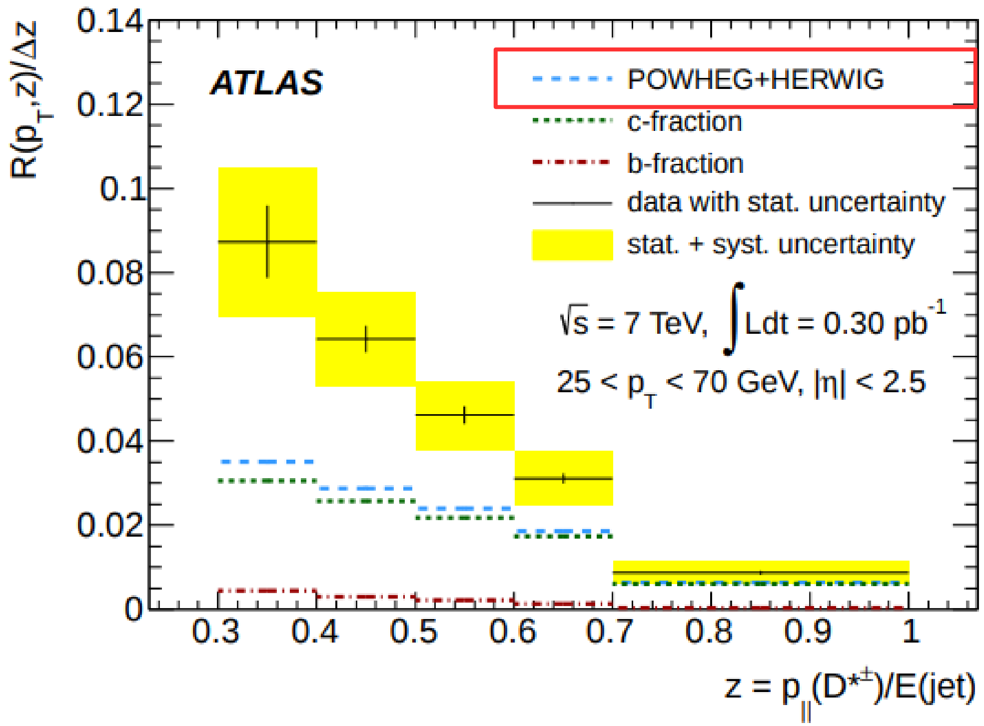
This might be important for J/ψ production in heavy ion collisions, as jet quenching might play a role in quarkonia suppression

“D meson production in jets” in ATLAS

The ratio of “D in jets” to inclusive jets : $\mathcal{R}(p_{\mathrm{T}}, z) = \frac{N_{D^{*\pm}}(p_{\mathrm{T}}, z)}{N_{\mathrm{jet}}(p_{\mathrm{T}})}$

Phys. Rev. D85 (2012) 052005





Large discrepancies are observed between data and MC at low z

Might have the same origin as the discrepancy observed in J/ψ analysis : gluon fragmentation to D is underestimated ?

Conclusion and prospects

- Both CMS and LHCb conclude that J/ψ are produced in a jettier environment than implemented in Pythia
- Possible indication of prompt J/ψ is being produced in a parton shower
- The discrepancy was also observed in open heavy flavor; it might have the same origin as the one seen in J/ψ measurements : gluon fragmentation is underestimated?...
- In CMS, “J/ψ in jets” study will be done with 10 times larger pp statistics and extended to PbPb collisions. Any predictions for PbPb are available or ongoing?

Backup slides

“Quenching of Hadron Spectra in Heavy Ion Collisions at the LHC”

PRL 119, 062302 (2017)

An analytic model based on a single process – radiative energy loss – to describe the quenching of single hadrons at large pT

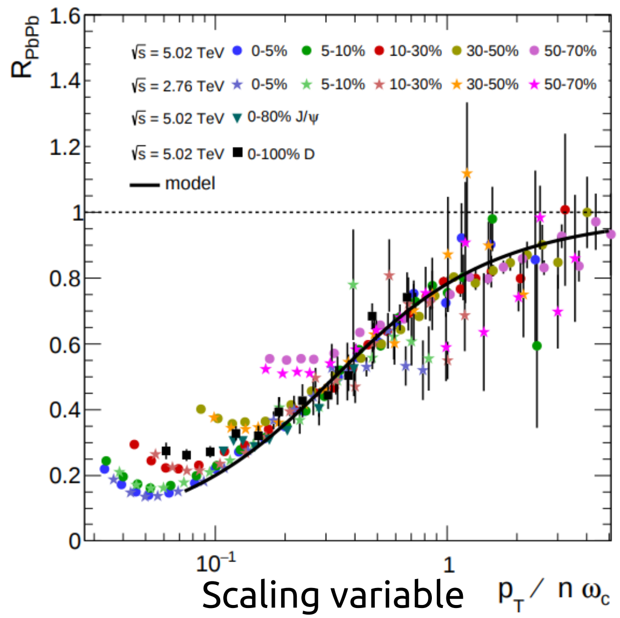


Figure 2: R_{AA} of $h^{\pm}$, D and J/ψ as a function of $p_{\perp}/n\omega_c$ in PbPb collisions at $\sqrt{s}$ = 2.76 TeV and $\sqrt{s}$ = 5.02 TeV in different centrality classes.

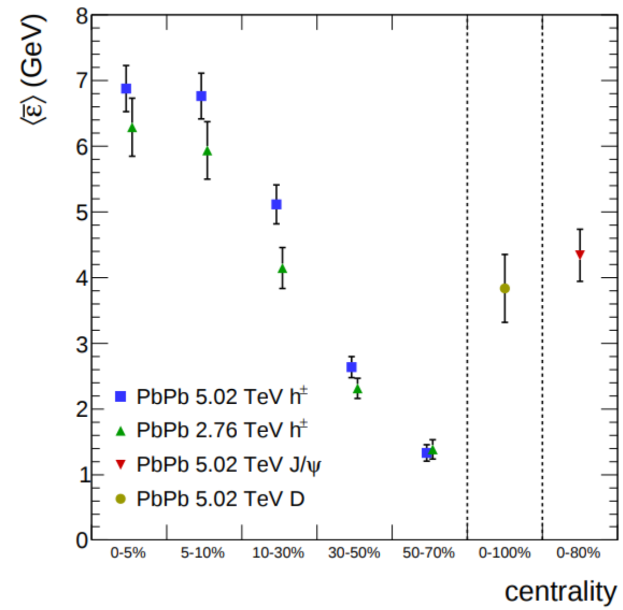
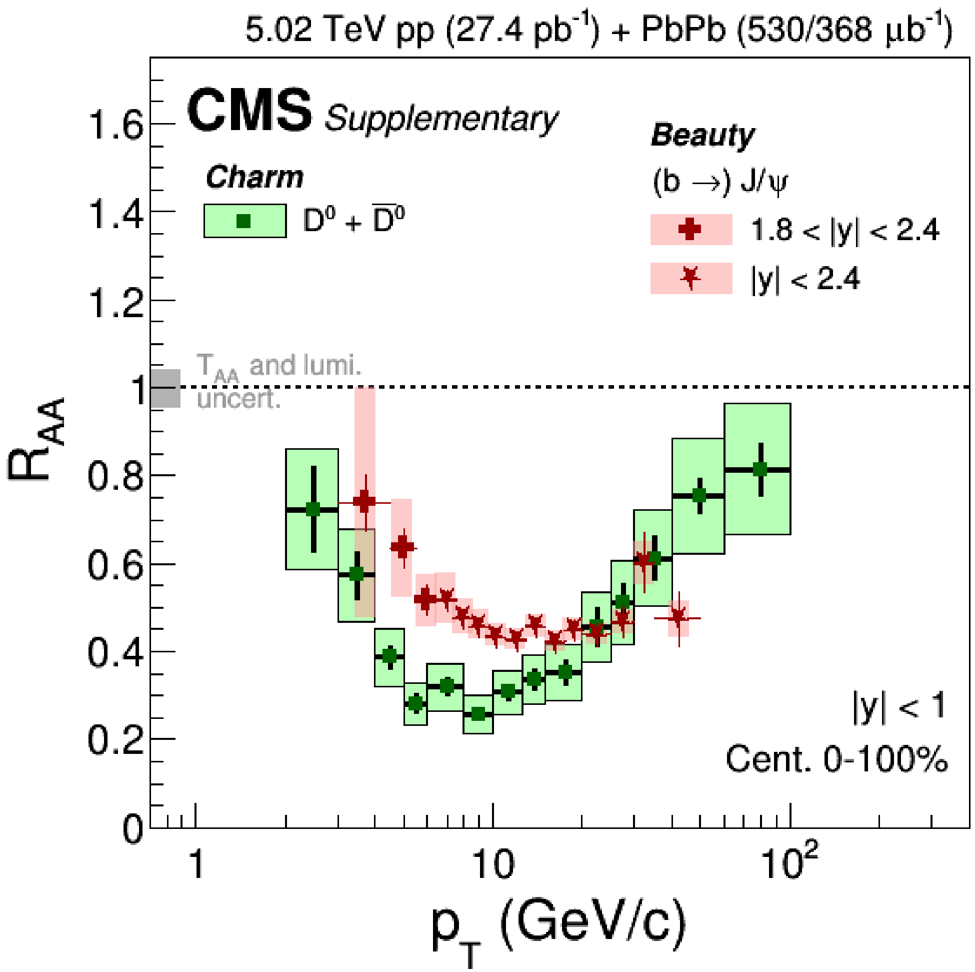


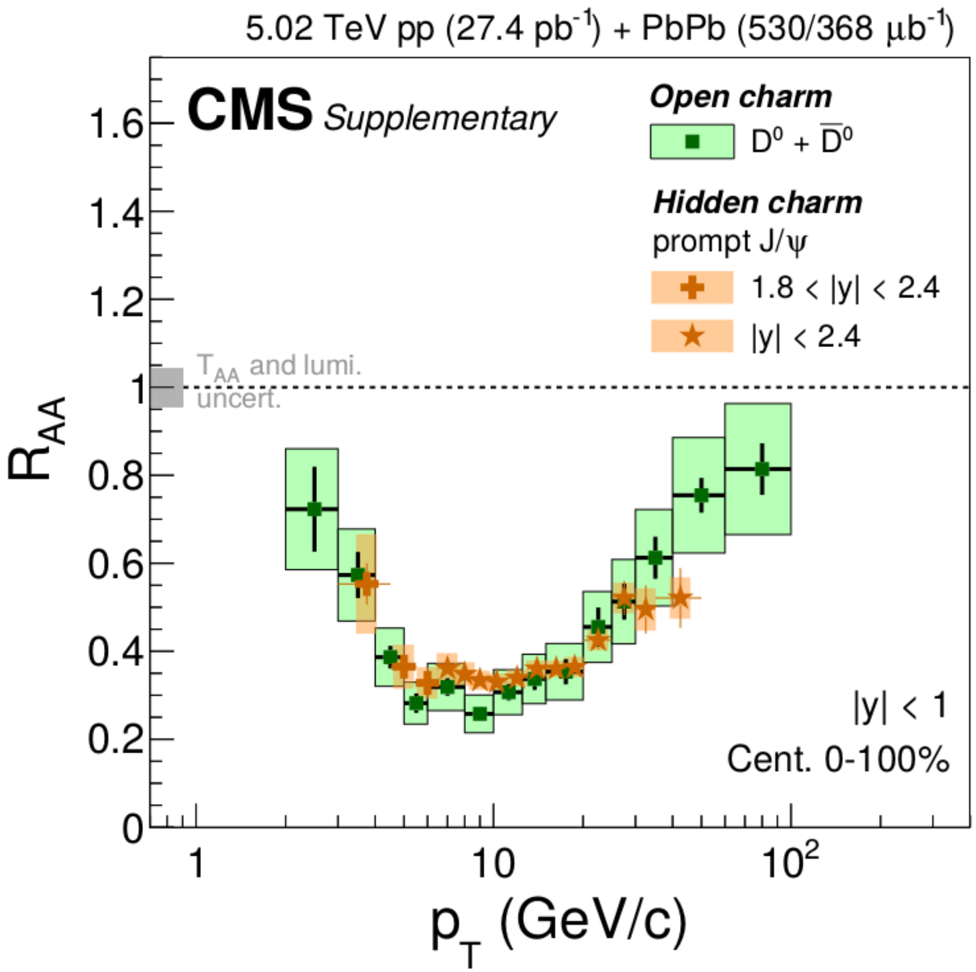
Figure 3: Mean energy loss extracted in PbPb collisions at $\sqrt{s}$ = 2.76 TeV (triangles) and $\sqrt{s}$ = 5.02 TeV (squares) from the quenching of $h^{\pm}$, D, and J/ψ.

Data lines up into a single shape: predicted in the energy loss model and observed in data. Supports the interpretation of a unique process responsible for the nuclear modification factors of all hadrons above a given pT in heavy-ion collisions at the LHC.

The quenching of heavy mesons (D and J/ψ) obeys the exact same pattern, suggesting that at large pT the same process affects similarly all hadron species, including bound states like heavy-quarkonia.

Current CMS results in PbPb





Fragmentation functions

PRL 119, 032002

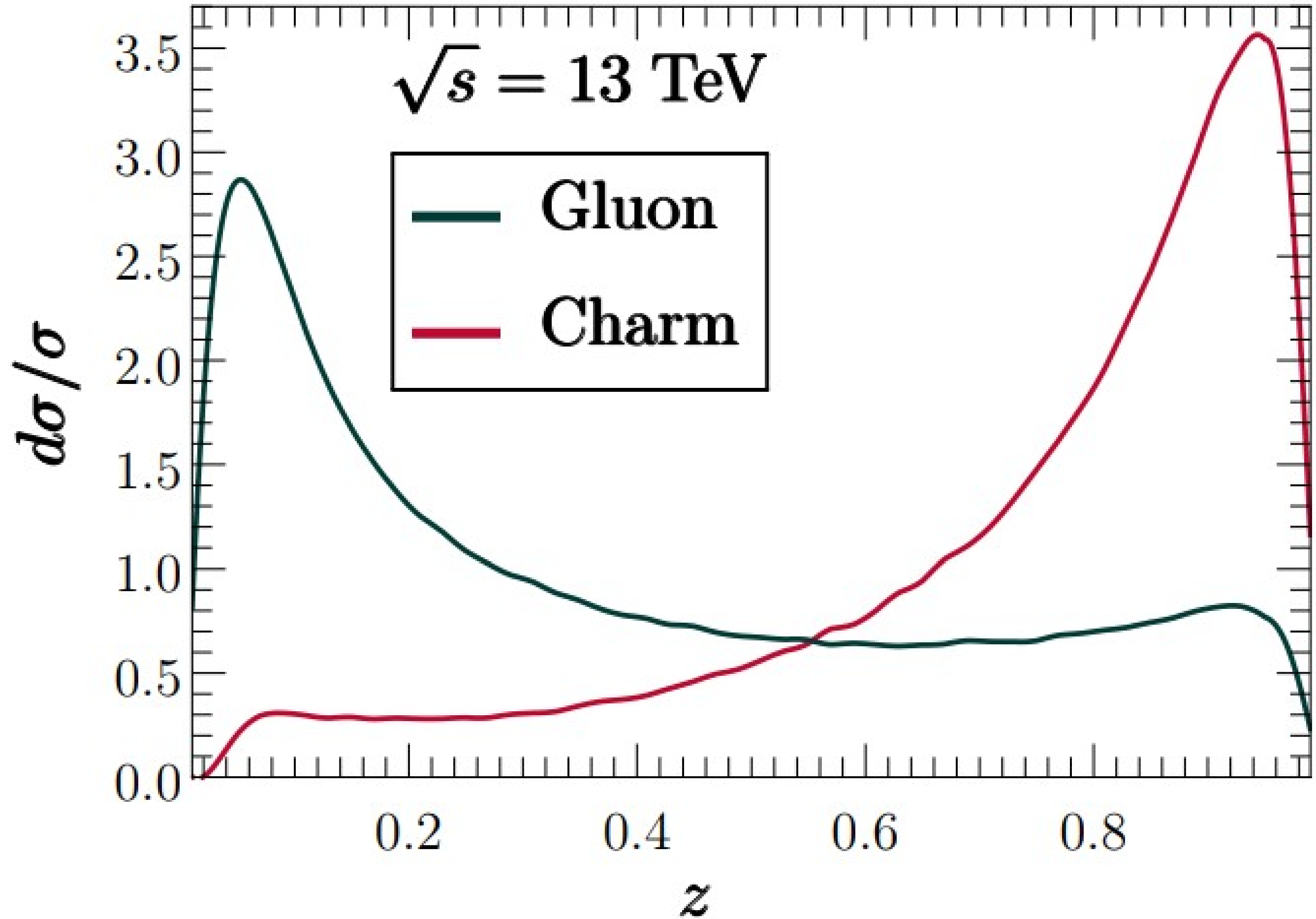


FIG. 1. PYTHIA predictions for c quark and gluon z distributions (where z is the fraction of the energy of the parton initiating the jet) after showering to the scale $2m_c$.