Jet fragmentation and charmonium production at 5.02 Tev

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17 June 2024

Summary

1. Introduction and state of art
2. Quick overview of the theory regarding J/ψ production in jets
   - J/ψ hadroproduction
   - Non Relativistic Quantum ChromoDynamics (NRQCD)
   - What is a jet ?
   - Plan
3. Implementation with Pythia 8 and analysing the MC predictions at generator level using Rivet
   - What is Rivet ?
   - Predictions using Pythia 8.1
   - Predictions using Pythia 8.3 **(Onia Showers)**
4. Outlook and conclusion
   - Some improvements but still a long way to go
   - Analysing Jet substructure observables
   - Conclusion

Introduction and state of art

Motivation

- The production mecanisms of quarkonia are not well understood
- Up to now, we thought that J/ψ was produced early after hard parton scatterings
- BUT Data analysis regarding J/ψ in jets $\longrightarrow$ less isolated than we thought

In this presentation

- Presentation of the **Onia Showers** mode implemented in Pythia 8.3
- Results regarding J/ψ with Pythia 8.3
- First study of jet substructure using **Onia Showers** !

Fragmentation function observable

$$z = \frac{p_{T,J/\psi}}{p_{T,Jet}}, \; z \longrightarrow 1 \; : \; J/\psi \textit{ isolated}$$

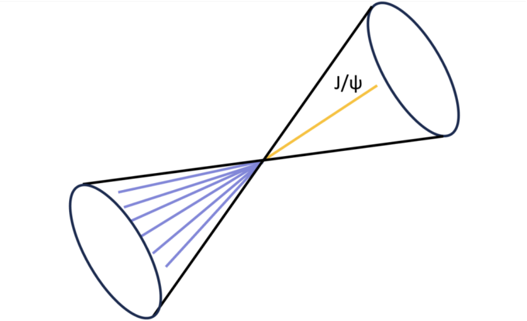


Fig. 1: From *NRQCD in Parton Showers*

Introduction and state of art

Pythia 8.1 confronts data from LHCb and CMS

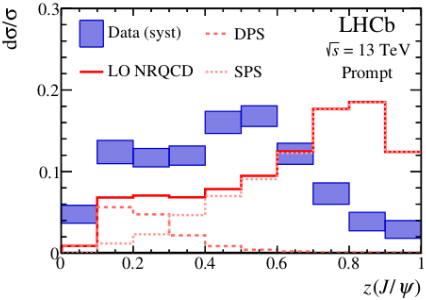


Fig. 2: From *Study of J/ψ production in jets*

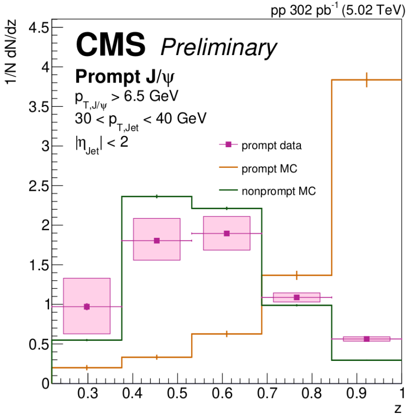


Fig. 3: From
Fragmentation of jets containing a prompt J/ψ[...]

Recents Improvements implemented by Naomi Cooke in Pythia 8.3 $\longrightarrow$ **Better agreement with LHCb data**

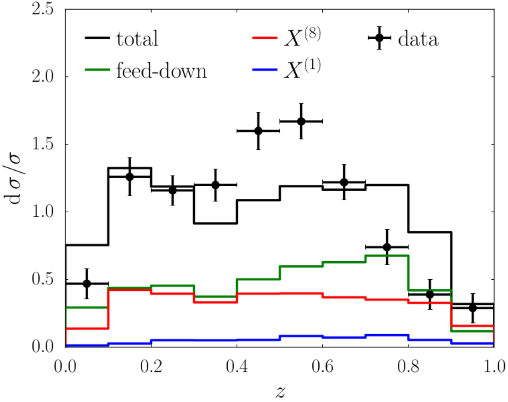


Fig. 4: From *NRQCD in Parton Showers*

Prompt J/ψ

J/ψ coming from the hadronization of a $c\bar{c}$ pair either directly or via the decay of an excited state (feed-down)

Non Prompt J/ψ

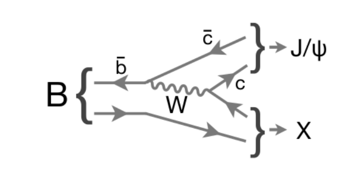


Fig. 5: A Feynman diagram of a LO contribution to the weak decay of a B hadron into a J/ψ

Can be separeted experimentally because of the macroscopic $c\tau_B$ of Non Prompt

Purpose of NRQCD

Describe how a $c\bar{c}$ pair with given color and quantum numbers can hadronize (color singlet) to a charmonium with definite quantum numbers.

Example

Basically, It gives the probability of such process :

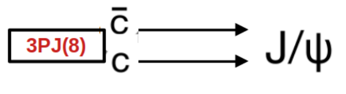


Fig. 6: 3PJ(8) state leading to J/ψ 3S1(1)

Quick overview of the theory regarding J/ψ production in jets

Non Relativistic Quantum ChromoDynamics (NRQCD)

Hypothesis

- Factorization theorem :

$$\sigma_{J/\psi} = \sigma_{pQCD(gg \longrightarrow c\bar{c})} * \sigma_{Hadronization(NRQCD)}$$

- Velocity of the the onium state $v << c$: $v = 0.3 \longrightarrow$ OK

Important result

- Fock states expansion for a given charmonium state (for instance J/ψ) :

$$|J/\psi\rangle = |3S_1^1\rangle\,\mathcal{O}(1) \;+\; |3P_J^1 g\rangle\,\mathcal{O}(v) \;+\; |3S_0^8 g\rangle\,\mathcal{O}(v^2) \;+\; |3S_1^8 gg\rangle\,\mathcal{O}(v^2) \;+\; \ldots$$

- the $\mathcal{O}$'s = Long Distance Matrix Elements$\longrightarrow$ **Parameters extracted from experimental data**

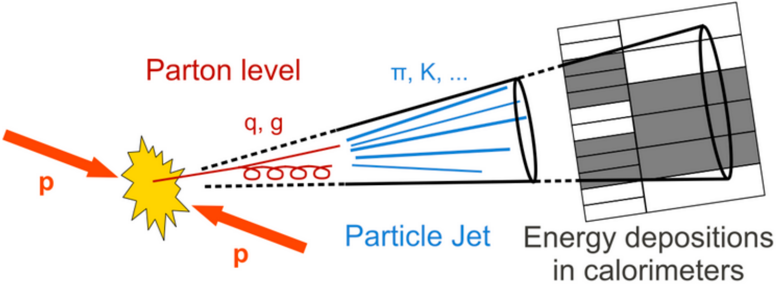


Fig. 7: From *Jets at CMS and the determination of their energy scale*

Jet definition

Not a unique definition : Jet = clustering algorithm(Anti kt, Cambridge-Aachen(C/A),...) + phase space volume R

In our study

- $R = 0.4$ where $R^2 = \eta^2 + \phi^2$ (Standard value)
- Anti kt algorithm $\longrightarrow$ favors pairwise clusterings involving at least one hard particle

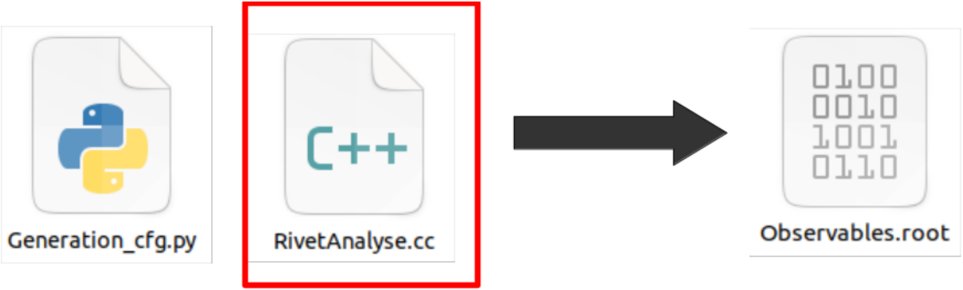
Quick reminder

$$z = \frac{p_{T,J/\psi}}{p_{T,Jet}},\ z \longrightarrow 1\ :\ J/\psi\ isolated$$

Plan

Compare the CMS data regarding the z observable with the results given by Pythia 8.3 Onia Showers at the generator level

"A system for validation of Monte Carlo event generators"



Implementation with Pythia 8 and analysing the MC predictions at generator level using Rivet

What is Rivet ?

```
void init() {
    FinalState fs;
    VetoedFinalState jet_input(fs);
    jet_input.vetoNeutrinos();
    declare(FastJets(jet_input, FastJets::ANTIKT, 0.4), "Jets04");

    // Select final state particles with J/psi
    const UnstableParticles jpsi_fs(Cuts::abspid == PID::JPSI);
    declare(jpsi_fs, "Jpsis");
```

```
void analyze(const Event& event) {


    const Jets jets = apply<FastJets>(event, "Jets04").jetsByPt(Cuts::pT > 30*GeV);
    const UnstableParticles& jpsi_fs = apply<UnstableParticles>(event, "Jpsis");
```

Rivet

- 30 lines of code ⟶ histogram in root file format
- Easy C++ framework well documented with standard analyses
- **A strong tool to show theoretical predictions at the generator level**

J/ψ production with Pythia 8.1

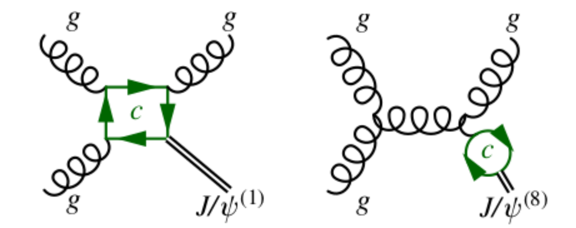


Fig. 8: From *NRQCD in Parton Showers*

- Lowest order diagrams leading to J/ψ (or an excited state)
- Jet = ISR + FSR + standard underlying event + J/ψ $\longrightarrow$ isolated J/ψ

Pythia 8.1 configuration file

```
processParameters = cms.vstring(
    'Charmonium:all = on',
    '443:onMode = off',
    '443:onIfAny = 13 -13',
```

- Hard process = Charmonium:all
- Only Prompt
- J/ψ decay in dimuon (CMS)
- Tune = CP5

Implementation with Pythia 8 and analysing the MC predictions at generator level using Rivet

Predictions using Pythia 8.1

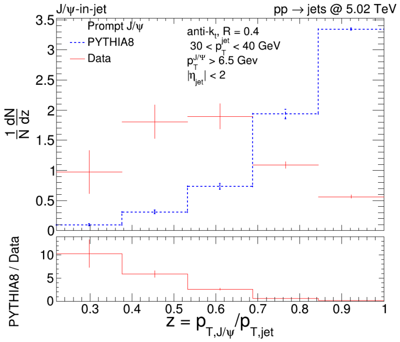


Fig. 9: Pythia 8.1 predictions using Rivet

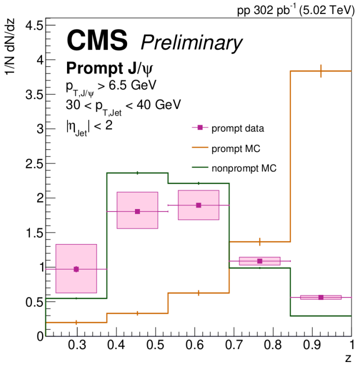


Fig. 10: From *Fragmentation of jets containing a prompt J/ψ[...]*

Parton Shower

Simulation of emission of arbitrary number of particles, usually ordered in angle or p_T

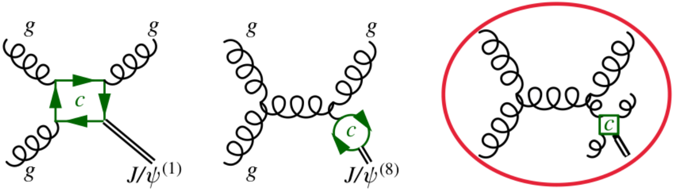


Fig. 11: From *NRQCD in Parton Showers*

Improvements

- Higher order channels
- Expect more radiation
- A shift to lower z values

Implementation with Pythia 8 and analysing the MC predictions at generator level using Rivet

Predictions using Pythia 8.3 **(Onia Showers)**

Pythia 8.3 configuration file

```
processParameters = cms.vstring(
    'HardQCD:all = on',
    'CharmoniumShower:all = on',
    'OniaShower:ldmeFac = 100.',
    '443:onMode = off',
    '443:onIfAny = 13 -13',
```

- Hard process = HardQCD:all
- **Onia Showers = on**
- Prompt and Non-Prompt
- Boost J/ψ production by boosting σ_{NRQCD}
- Tune = CP5

Implementation with Pythia 8 and analysing the MC predictions at generator level using Rivet

Predictions using Pythia 8.3 **(Onia Showers)**

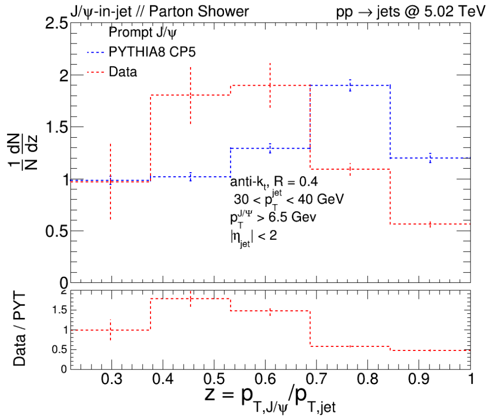


Fig. 12: Pythia 8.3 (Parton Shower mode) predictions using Rivet

Results

- A shift to lower z values
- Still not matching the uncertainty bars
- Still a lack of radiation
- **But a better ratio !**

Conclusion

- Pythia 8.3 does a better job describing quarkonia production in jets !
- J/ψ are not isolated : you have to seek for more radiation

What about the substructure of Jets containing J/ψ ?

Soft Drop algorithm

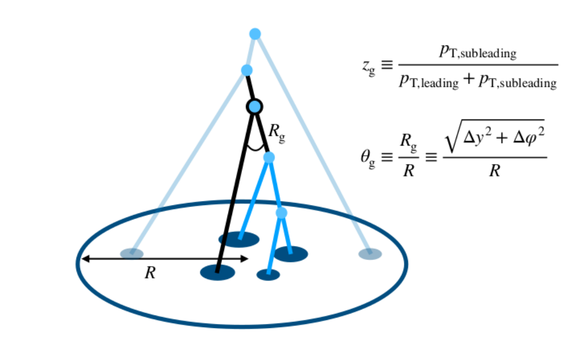


Fig. 13: From *Measurements of the groomed jet radius[...]*

- **Step 1 : Re-clustered using C/A algorithm**

Soft Drop algorithm

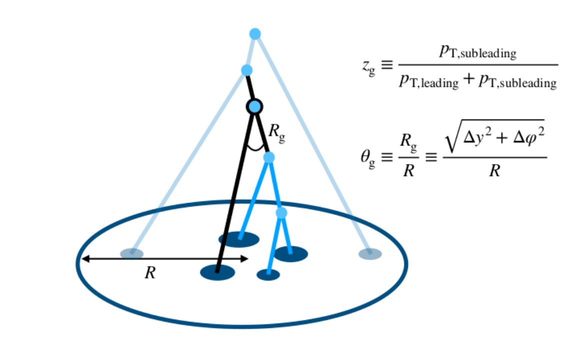


Fig. 14: From
Measurements of the groomed jet radius[...]

- Step 1 : Re-clustered using C/A algorithm
- **Step 2 : SD : while $z_g > z_{cut}$**
  Jet = SubJet with larger p_T

Soft Drop algorithm

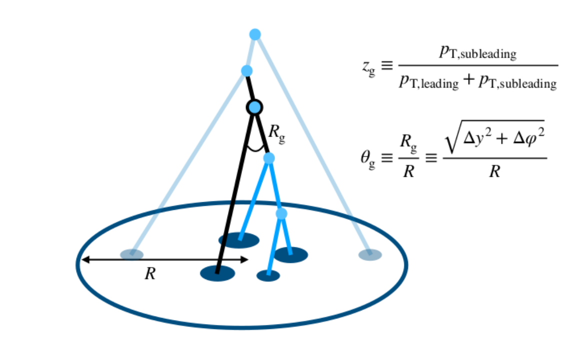


Fig. 15: From
Measurements of the groomed jet radius[...]

- Step 1 : Re-clustered using C/A algorithm
- Step 2 : SD algo : while $z_g < z_{cut}$ Jet = Jet with larger p_T
- **Step 3 : Compute z_g and R_g with the final groomed Jet**

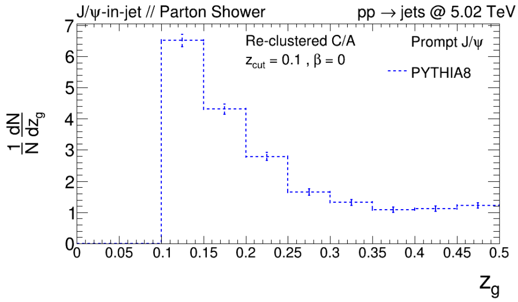


Fig. 16: Pythia 8.3 predictions regarding momentum splitting fraction for jets containing J/ψ (CP5)

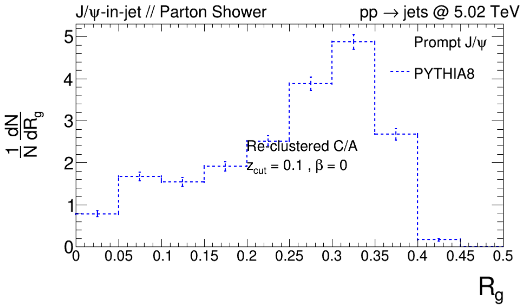


Fig. 17: Pythia 8.3 predictions regarding groomed jet radius for jets containing J/ψ (CP5)

Conclusion

What's next ?

- Try to extract from the data z_g and R_g
- Taking advantage of Rivet to make comparaisons with jets containing double open charm baryons
- **The Rivet analysis I made to plot the fragmentation function for J/ψ in jets is on its way to becoming public !**