Measurement of D mesons in jets in pp and PbPb with the CMS detector

Jing Wang on behalf of the CMS Collaboration

2018 Workshop on Probing Quark-Gluon Matter with Jets
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Brookhaven National Laboratory (Upton)
Why study D meson production in jets?

- **Enhancement of low $p_T$ light hadrons at large angles about jets**
  - Light hadron jet shape analysis

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Why study D meson production in jets?

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- **How to explain**
  - medium-induced gluon radiation?
  - medium response?
  - multiple scatterings?
  - ......

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Jing Wang (MIT), D meson production in jets, BNL jet workshop (Upton)
Why study D meson production in jets?

Enhancement of low $p_T$ light hadrons at large angles about jets
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How to explain
- medium-induced gluon radiation?
- medium response?
- multiple scatterings?

Vary mass of the associated hadrons
- Heavy flavor!
Why study D meson production in jets?

Even more …

Production mechanism of charm
• The role of gluon splitting
• Recombination in the medium

Heavy quark behavior and interactions in the medium
• Energy loss
  • Inclusive measurements:
    ➔ heavy-flavor hadrons spectra, azimuthal anisotropy, heavy flavor tag jets
  • Details on interaction of heavy quarks about jet directions
• Diffusion
Dataset and observables

- **Jet-triggered** events in $pp$ (27.4 pb$^{-1}$) and $PbPb$ (404 μb$^{-1}$) collisions at $\sqrt{s_{NN}} = 5.02$ TeV collected in 2015 with the CMS detector

- **MinimumBias** events are used for background subtraction

- Cross-checked with **D-triggered events**
Dataset and observables

- **Jet-triggered** events in **pp** (27.4 pb$^{-1}$) and **PbPb** (404 μb$^{-1}$) collisions at $\sqrt{s_{NN}} = 5.02$ TeV collected in 2015 with the CMS detector

- Radial distribution of $D^0$ with respective to the jet axis:
  \[
  \frac{1}{N_{JD}} \frac{dN_{JD}}{dr}
  \]

- The final distribution is normalized to unity in $r < 0.3$

- No $p_T$ weight as light-hadron jet shape analysis

\[ r = \sqrt{\Delta \phi_{JD}^2 + \Delta \eta_{JD}^2} \]
D and jets reconstruction and selections

- **Jet-triggered** events in **pp** (27.4 pb$^{-1}$) and **PbPb** (404 μb$^{-1}$) collisions at $\sqrt{s_{NN}} = 5.02$ TeV collected in 2015 with the CMS detector

- D$^0 \rightarrow K\pi$
- D$^0$ vertex reconstruction
  - pairing two tracks
  - kinematic fitter
- Topological selections
  - Pointing angle ($\alpha$) < ~0.04
  - 3D decay length ($d_0$) normalized by its error > ~3
  - Secondary vertex prob > ~0.05
- $|y^{D0}| < 2$
- Two $p_T$ bins
  - 4 < $p_T^{D0}$ < 20 GeV
  - $p_T^{D0}$ > 20 GeV
D and jets reconstruction and selections

- Jet-triggered events in **pp** (27.4 pb\(^{-1}\)) and **PbPb** (404 μb\(^{-1}\)) collisions at \(\sqrt{s_{\text{NN}}} = 5.02\) TeV collected in 2015 with the CMS detector

- Particle flow jets
- anti-\(k_T\), \(R = 0.3\)
- \(p_{T\text{jet}} > 60\) GeV/c
- \(|\eta_{\text{jet}}| < 1.6\)

- D\(^0\) → Kπ
- D\(^0\) vertex reconstruction
  - pairing two tracks
  - kinematic fitter
- Topological selections
  - Pointing angle (\(\alpha\)) < ~0.04
  - 3D decay length (\(d_0\)) normalized by its error > ~3
  - Secondary vertex prob > ~0.05
- \(|y_{\text{D}}| < 2\)
- Two \(p_T\) bins
  - 4 < \(p_T^{\text{D}}\) < 20 GeV
  - \(p_T^{\text{D}} > 20\) GeV
Analysis strategy

- **Reconstruct** jets and D\(^0\) candidates
- **Jet energy correction**
- **Pair** selected D\(^0\) candidates with *every* selected jet in the same event
- Extract raw yield via **fitting invariant mass** in bins of \(r\)
- Correct **acceptance** and **efficiency** by simulations in bins of \(r\)
- **Subtract background** via event mixing technique
- Correct the **resolution effect** by the jet resolution from simulations
Raw D⁰ yield extraction

Mass distributions fitted by
- Double gaussian (Signal)
- 3rd order polynomial (Combinatorial)
- Single gaussian (K-π swapped)
  - Candidates with wrong mass assignment
Event mixing technique

- **Signal**: jets and $D^0$ mesons from the same hard scattering
- **Background**: fake jets, jets and $D^0$ mesons in underlying events, …
Event mixing technique

- Correlate $D^0$ mesons and jets in \textbf{triggered events (raw)} and \textbf{MB events (bkg)}
Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

```
Raw D — MB D

= Raw jets

= MB jets

raw D signal jet
```
Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

**Raw D**

- Correlate $D^0$ mesons and jets in triggered events (raw) and MB events (bkg)

**MB D**

**Raw jets**

**MB jets**
Event mixing technique

- Correlate $D^0$ mesons and jets in **triggered events (raw)** and **MB events (bkg)**

Raw $D$

- Raw $D$
- Raw jets

MB $D$

- MB $D$
- MB jets

raw $D$ signal jet

bkg $D$ signal jet

signal $D$ signal jet
Background subtraction

- **Signal** = Raw - Background
- Background contributions are much smaller than signal
Results

**Low D $p_T$: $4 < p_T^{D} < 20$ GeV/c**

- $4 < p_T^{D} < 20$ GeV/c
- $|y^{D}| < 2$
- $|p_T^{jet}| > 60$ GeV/c
- $|\eta^{jet}| < 1.6$

Low $D$ $p_T$: reach maximum at $0.05 < r < 0.1$

**High D $p_T$: $p_T^{D} > 20$ GeV/c**

- $p_T^{D} > 20$ GeV/c
- $|y^{D}| < 2$
- $|p_T^{jet}| > 60$ GeV/c
- $|\eta^{jet}| < 1.6$

High $D$ $p_T$: fall rapidly as a function of $r$

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CMS-PAS-HIN-18-007
Results

Low D $p_T$: $4 < p_T^D < 20$ GeV/c

- Predictions from PYTHIA 8
  - Low D $p_T$: produce a wider radial profile than measurements
  - High D $p_T$: agree with measurements

High D $p_T$: $p_T^D > 20$ GeV/c
Results

Low $D_{p_T}$: $4 < p_T^D < 20$ GeV/c

- The ratio of PbPb over pp:
- Low $D_{p_T}$: increases as a function of $r$
  → Hint that $D^0$ are further from jet axis in PbPb than pp
- High $D_{p_T}$: consistent with unity

High $D_{p_T}$: $p_T^D > 20$ GeV/c

CMS Preliminary

$D^0 +$ jet

$N_{dN/dr}$ vs. $r$

PbPb / pp
Summary

- First measurement of the **radial profile of D⁰ mesons in jets** in PbPb and pp
  - Hint of wider D⁰ radial profile in PbPb collisions at 4 < p⁰_T < 20 GeV/c
  - Ratio of PbPb/pp is consistent with unity at p⁰_T > 20 GeV/c
- Provides new experimental constraints on
  - heavy-flavor production
  - heavy quark energy loss and diffusion

The MIT group's work was supported by US DOE-NP
Thanks for your attention!
Raw D⁰ yield extraction

**pp**

![Graph for pp collision](image)

CMS Preliminary

- Data
- Fit
- Signal
- Combinatorial
- K-π swapped

0.05 < r < 0.1

**PbPb**

![Graph for PbPb collision](image)

CMS Preliminary

- Data
- Fit
- Signal
- Combinatorial
- K-π swapped

0.05 < r < 0.1

27.4 pb⁻¹ (5.02 TeV pp)

404 μb⁻¹ (5.02 TeV PbPb)

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CMS-PAS-HIN-18-007
Background subtraction

- Raw = signal + background
- Four correlations
  - Raw jet + Raw D
  - MB jet + Raw D
  - Raw jet + MB D
  - MB jet + MB D
Analysis strategy

- raw reco D
- raw reco jet
- raw reco D
- raw reco jet
- raw reco D
- reco jet
- gen D
- reco jet
- signal gen D
- signal reco jet
- signal gen D
- signal sgen jet
- signal gen D
- signal gen jet

- Residual JEC
- Invariant mass fit + Acc x Eff correction
- Background subtraction event-mixing method
- Residual correction for non-closure
- Resolution correction
D⁰ meson production

- c→D⁰: O(50%) of c cross-section
- D⁰→Kπ: 3.93 ± 0.04%
- D⁰ cτ = 122.9 μm
The MIT group's work was supported by US DOE-NP
Outlook

• Higher statistics with 2018 PbPb data
• Centrality dependence of the radial profile of $D^0$ mesons
• Fragmentation function of $D^0$ mesons in jets