D^0 meson production in jets in pp and PbPb collisions with the CMS detector

Michael Peters on behalf of the CMS Collaboration

Hard Probes 2018
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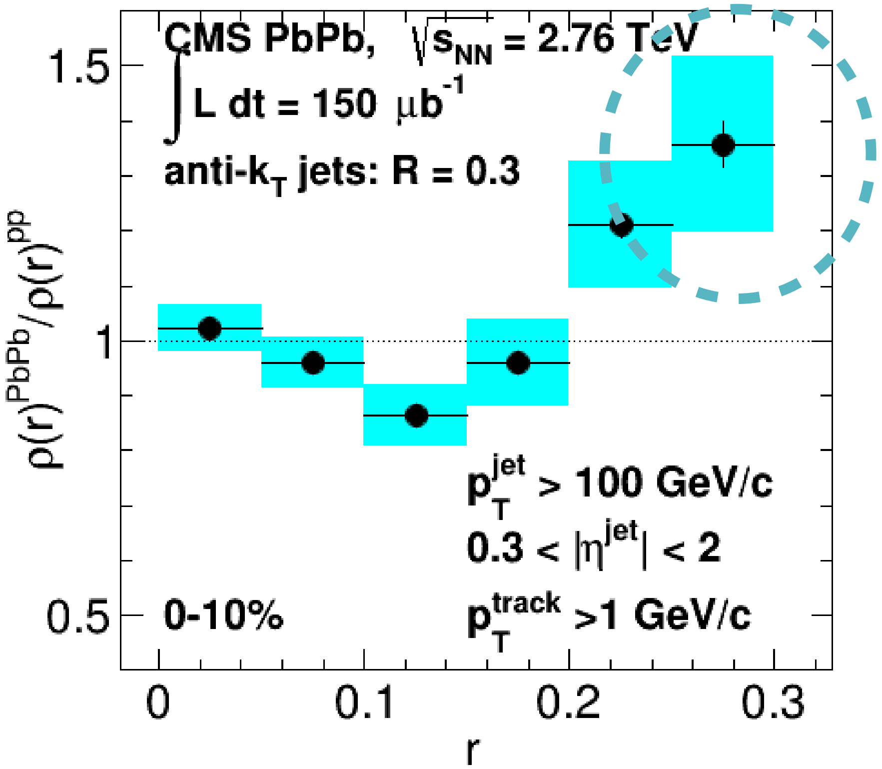
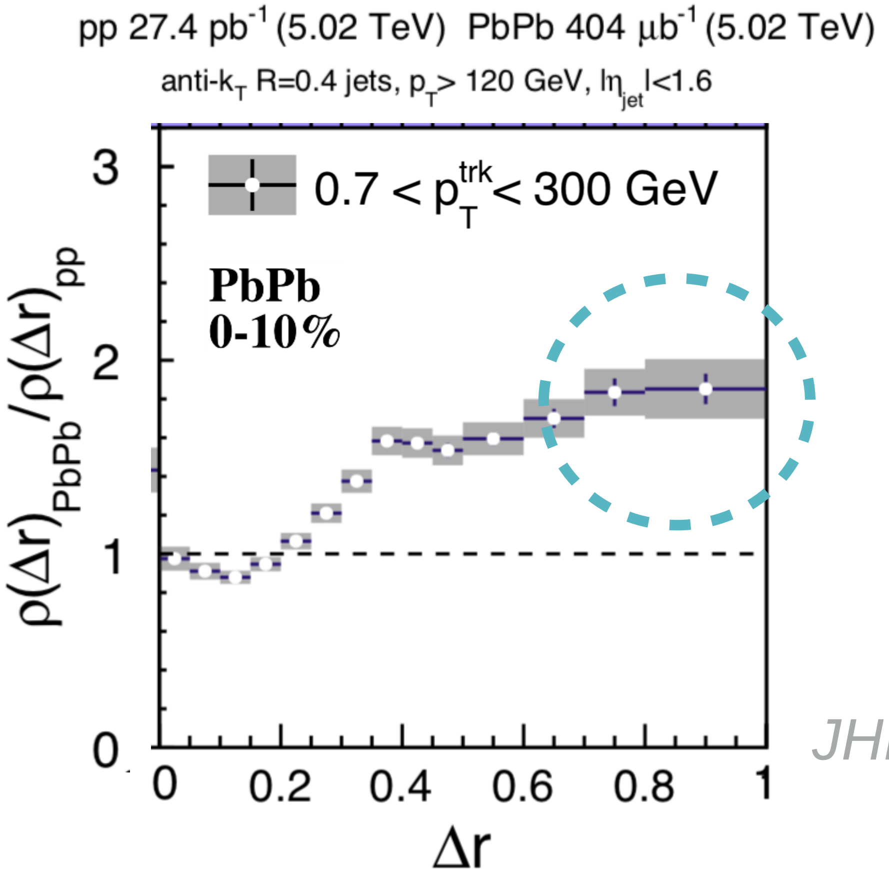
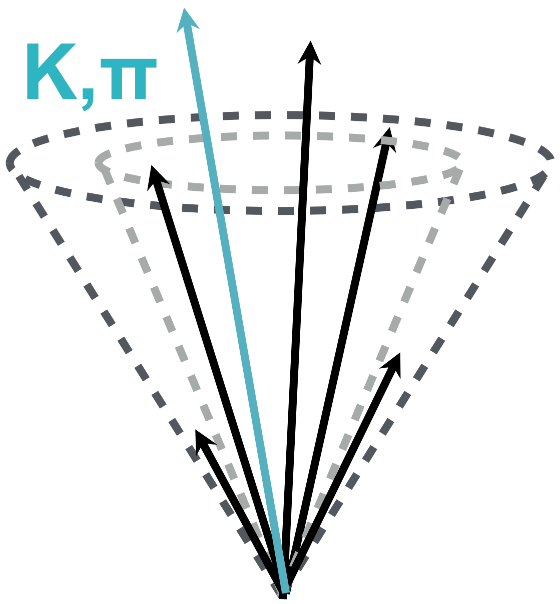
Aix-les-Bains, France

Why study D^0 meson production in jets?

Phys. Lett. B 730 (2014) 243







JHEP 05 (2018) 006

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

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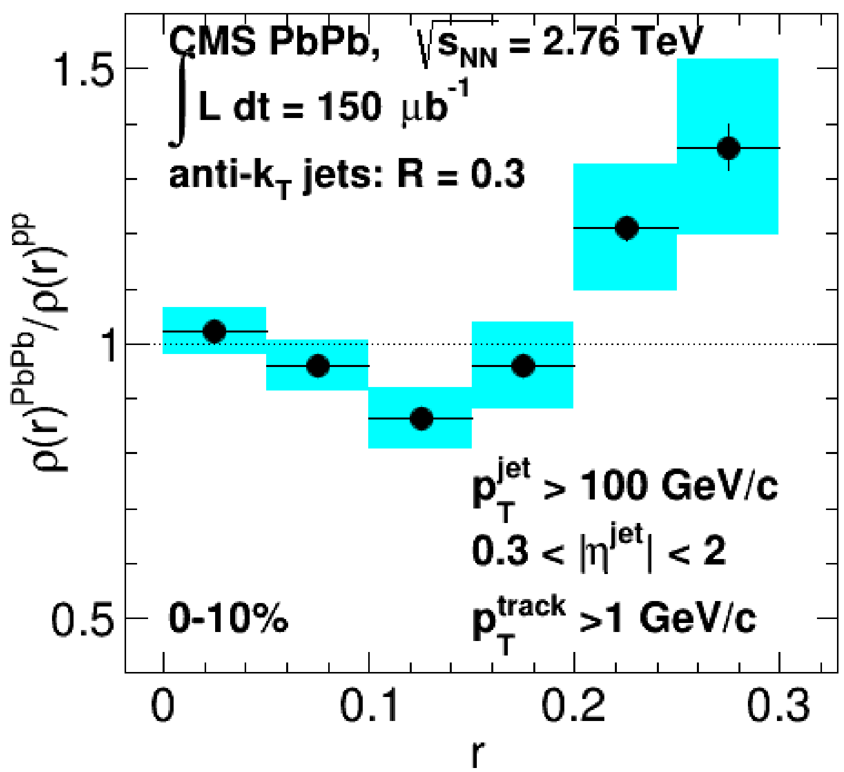

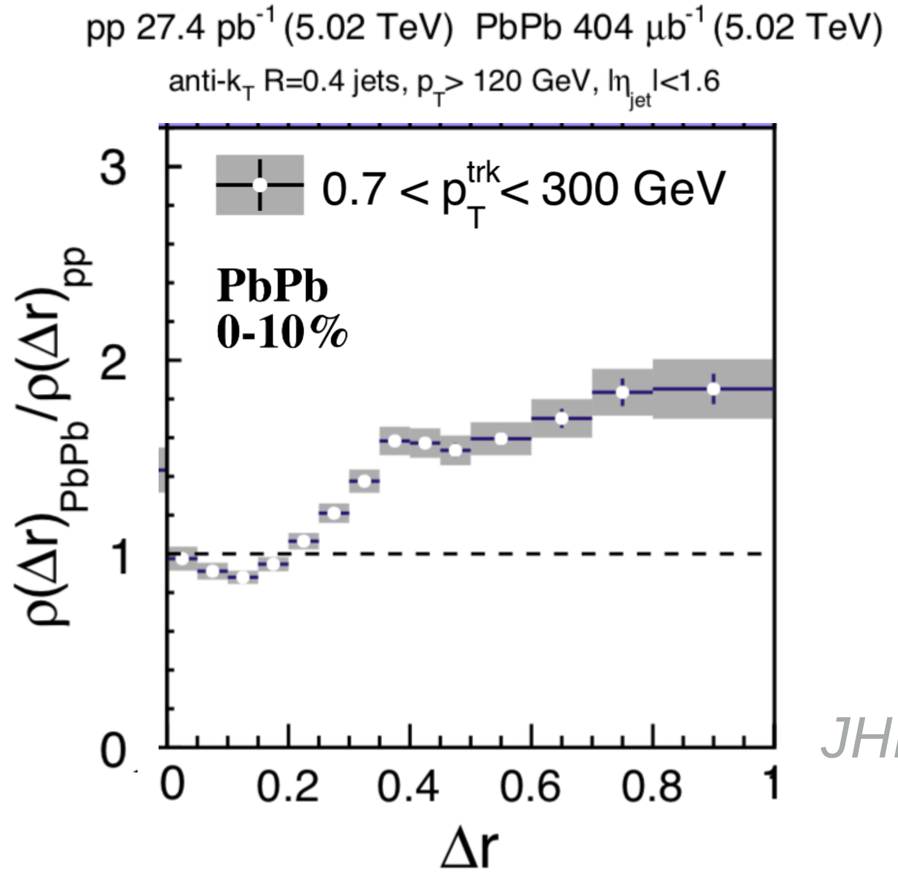

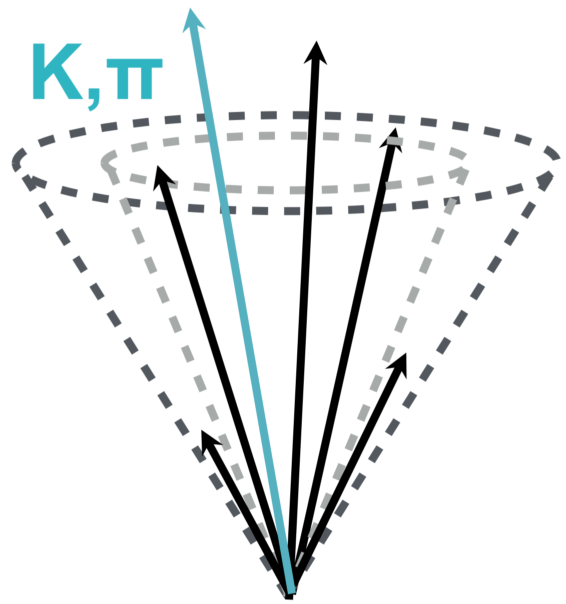

JHEP 05 (2018) 006

- Enhancement of low p_T light hadrons at large angles about jets
  - Light hadron jet shape analysis
- **How to explain this?**
  - medium-induced gluon radiation?
  - medium response?
  - modification of jet splitting function?
  - ……

Why study D^0 meson production in jets?

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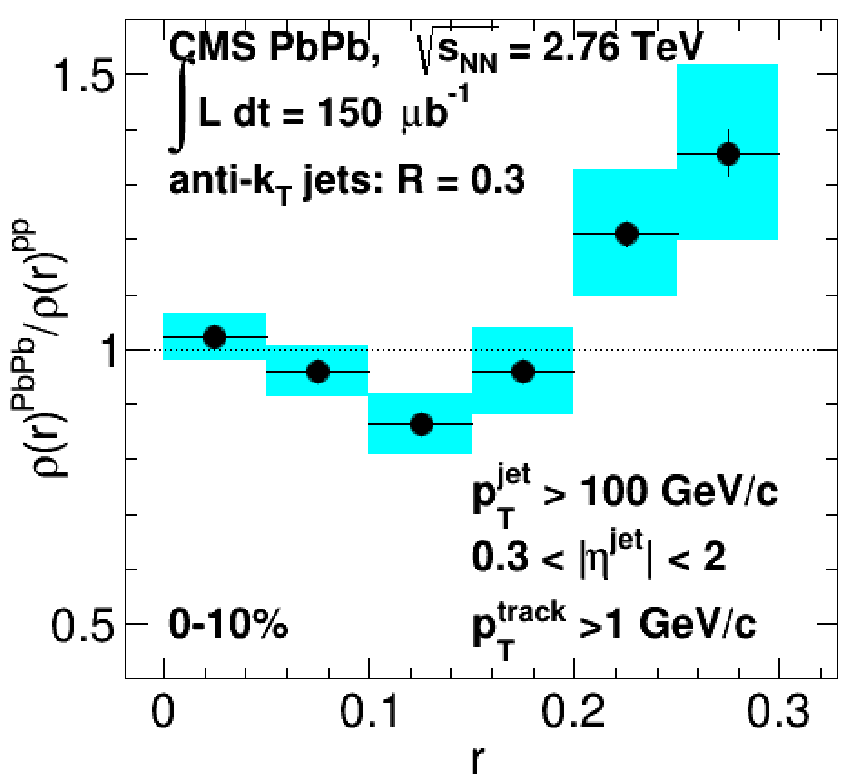

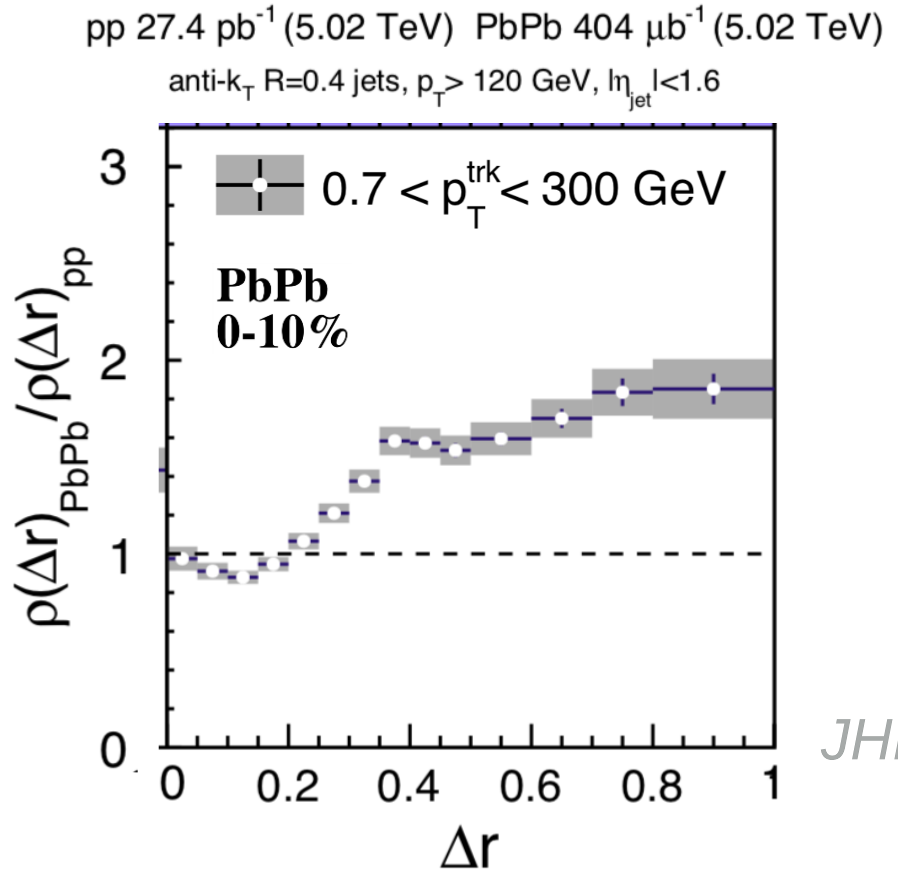

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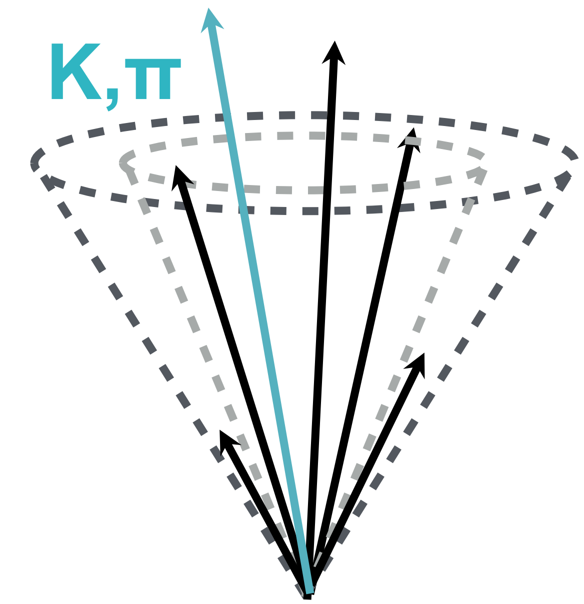
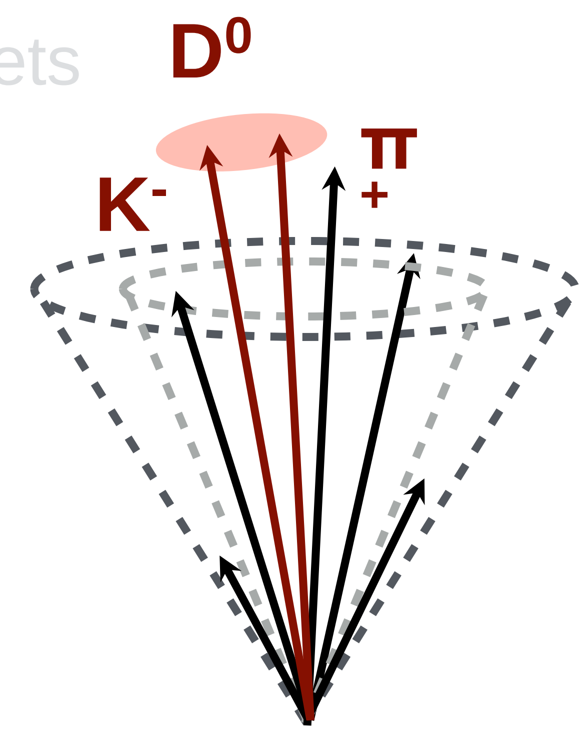


- Enhancement of low p_T light hadrons at large angles about jets
  - Light hadron jet shape analysis
- How to explain this?
  - medium-induced gluon radiation?
  - medium response? $m_c \gg T_{QGP}$: suppressed!
  - modification of jet splitting function?
  - ……
- **Vary mass of the associated hadrons**
  - **Heavy flavor!**



Why study D^0 meson production in jets?

Even more …

Production of charm and D^0 in QGP

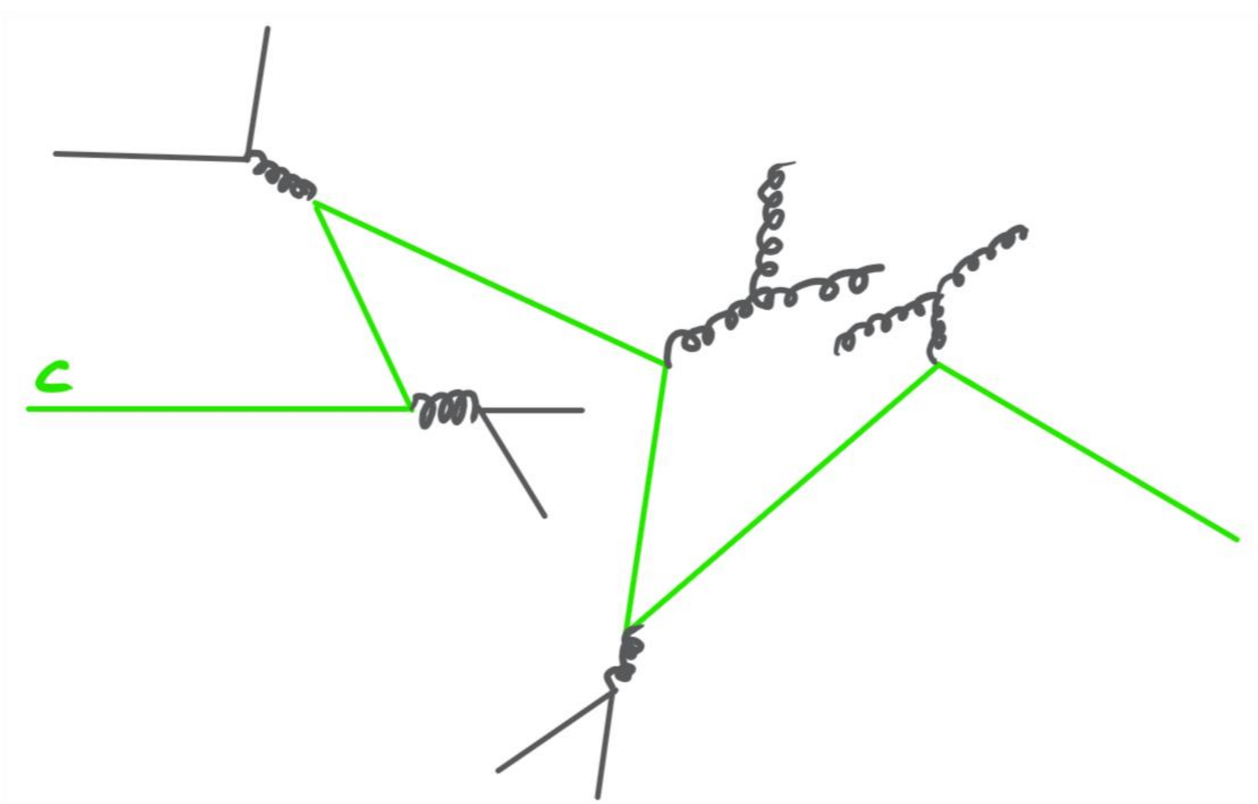
- Mechanisms of charm production:
  - Hard scattering
  - Decay of b quarks
  - Gluon splitting
- Mechanisms of D^0 production in jets:
  - Hadronization of charm (or bottom) quark jet
  - Decay of B meson
  - Hadronization after gluon splitting
- Different mechanisms of D^0 production probe different **production times!**

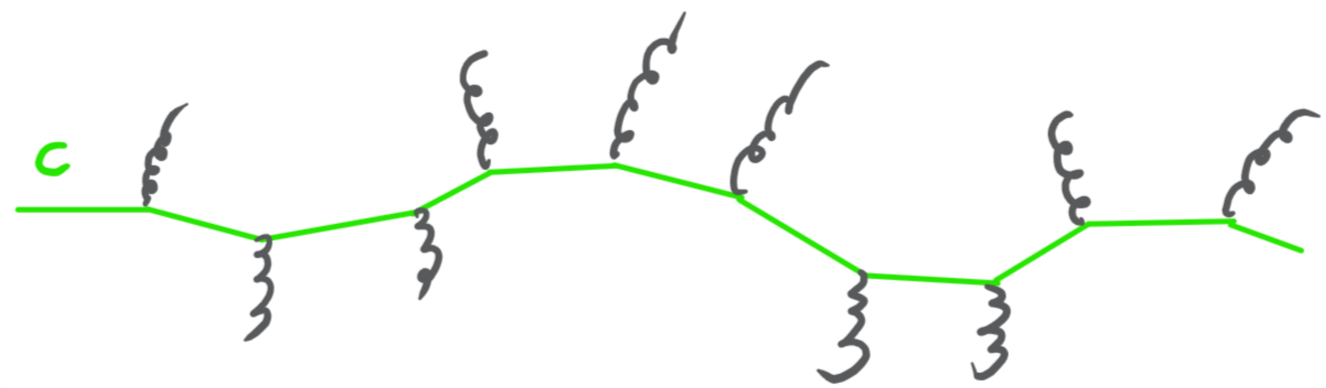
Why study D^0 meson production in jets?

Even more …

Heavy-flavor energy loss due to medium interactions

<u>Collisional Energy Loss</u> vs. <u>Radiative Energy Loss</u>





- **Lower** longitudinal drag
- **Harder** individual interactions
- <u>**More** broadening of radial profile</u>

- **Higher** longitudinal drag
- **Softer** individual interactions
- <u>**Less** broadening of radial profile</u>

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^0-triggered events**

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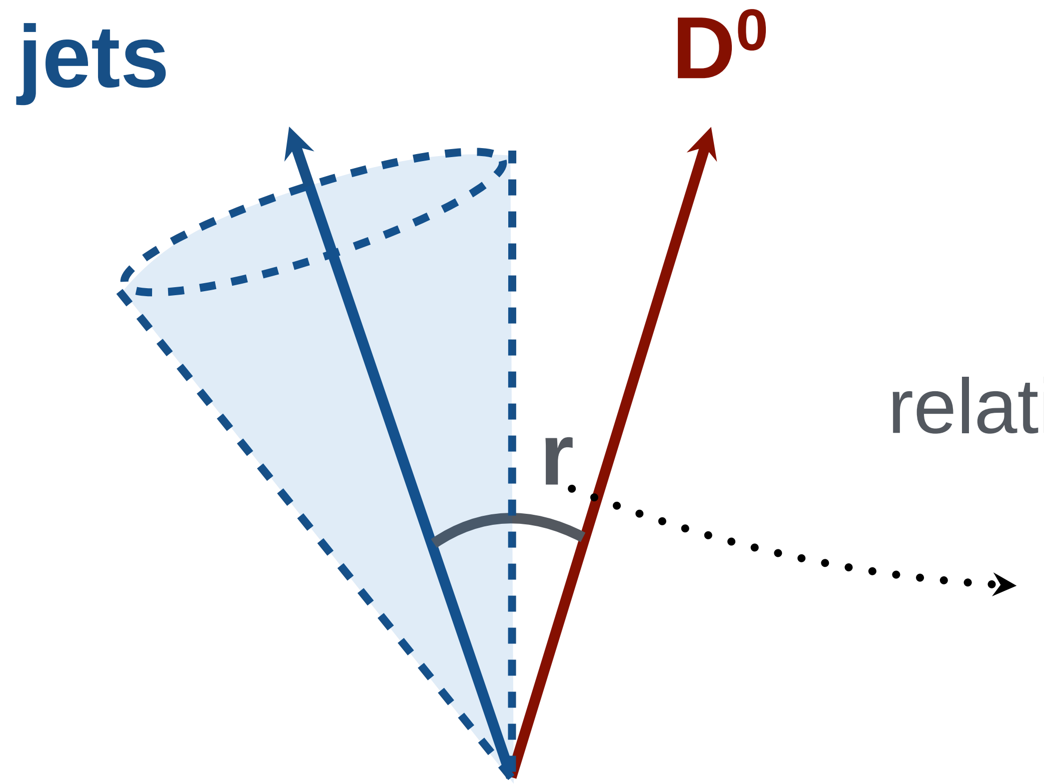


relative η,Φ between D^0 and jets

$$r = \sqrt{\Delta\phi^2_{JD} + \Delta\eta^2_{JD}}$$

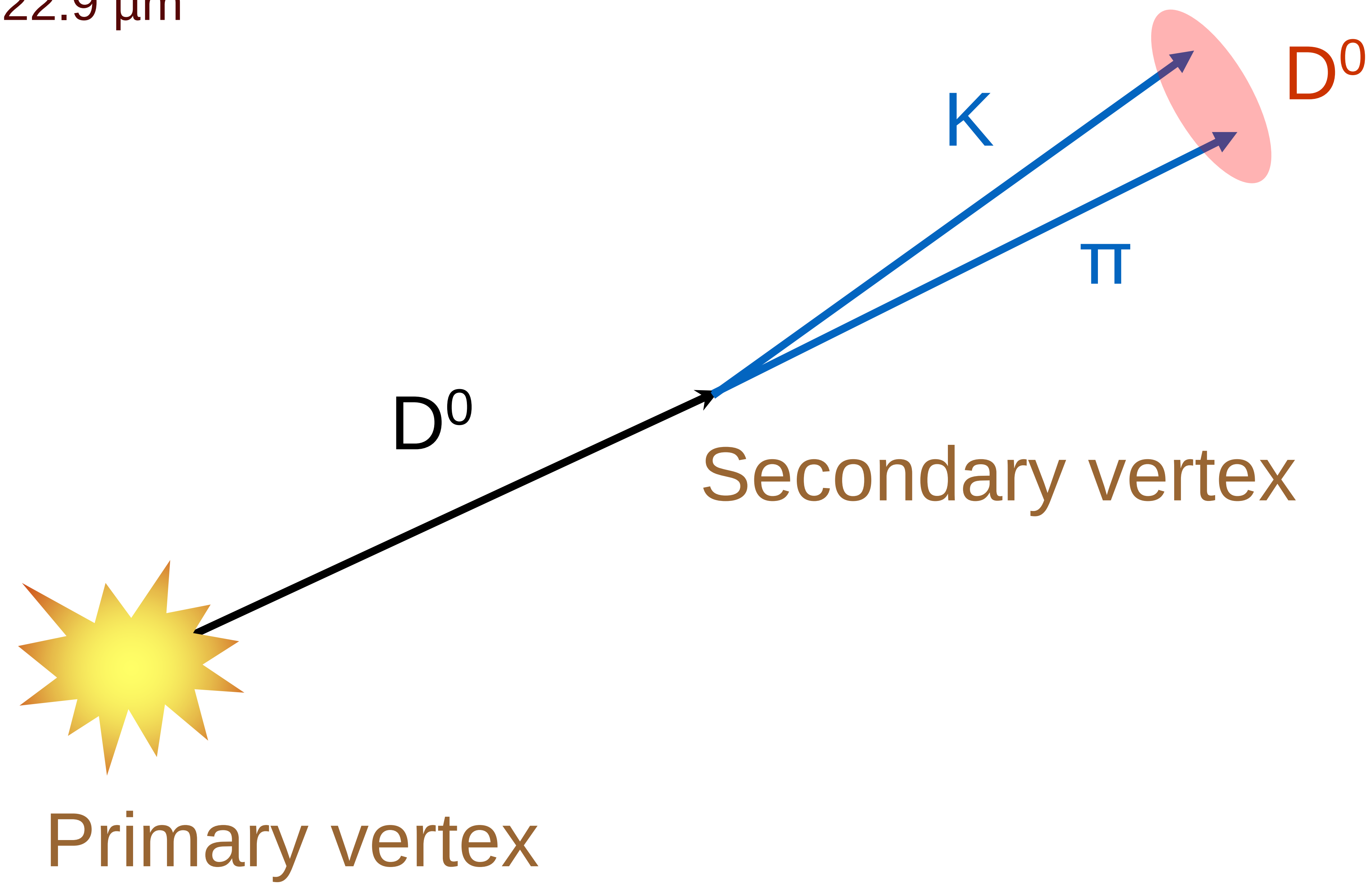
- **Radial distribution of D^0 with respect to the jet axis:**

$$\frac{1}{N_{JD}} \frac{dN_{JD}}{dr} = \frac{1}{N_{JD}\Delta r} \frac{N_{JD}|_{\Delta r}}{\alpha \times \epsilon}$$

- The final distribution is normalized to unity in $r < 0.3$
- No p_T weight as light-hadron jet shape analysis

D^0 meson production

- $c \rightarrow D^0$: O(50%) of c cross-section
- $D^0 \rightarrow K\pi$: 3.93 ± 0.04%
- D^0 $c\tau$ = 122.9 µm



D^0 and jets reconstruction and selections

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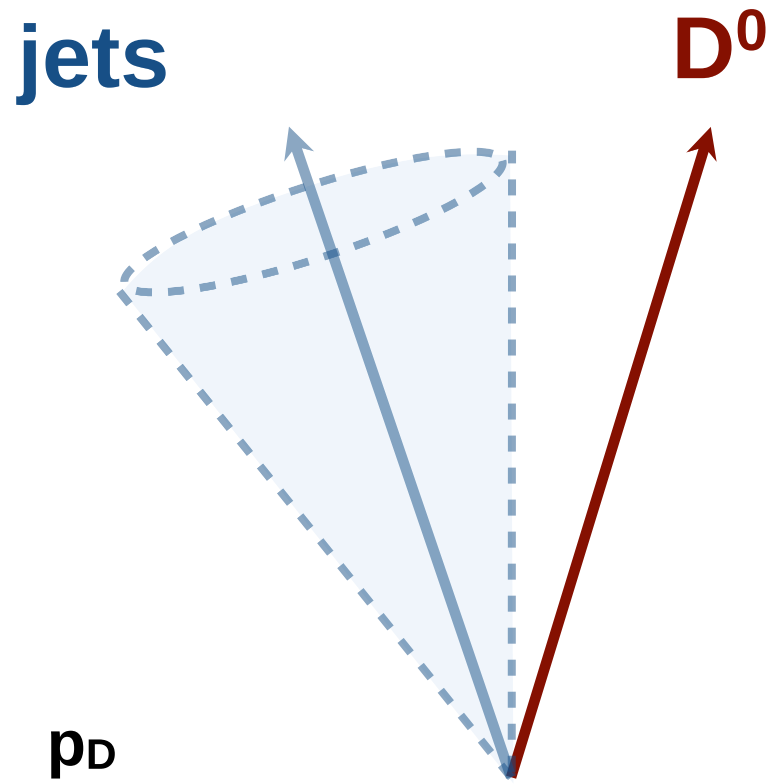

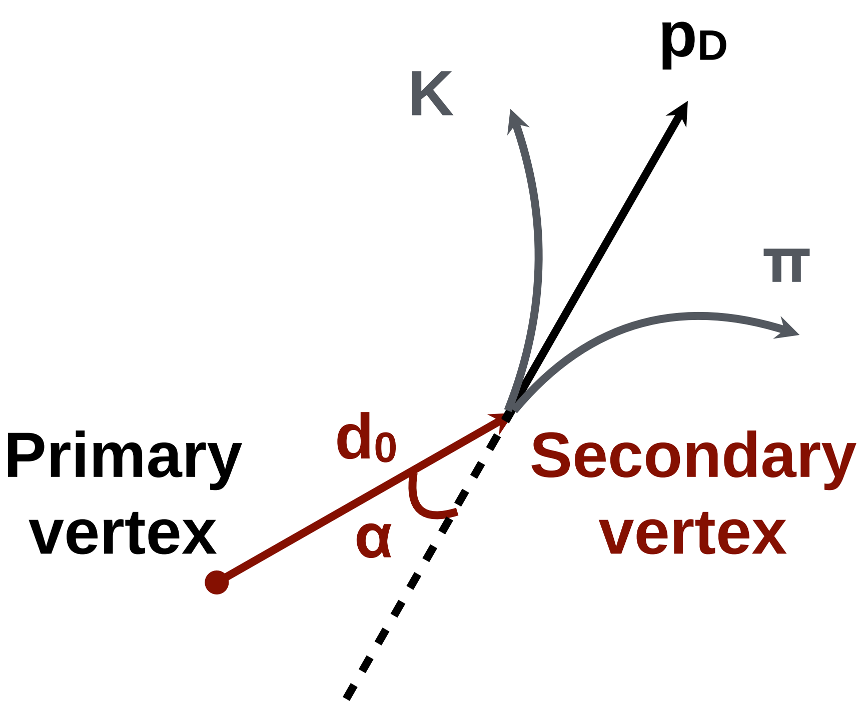

- $D^0 \rightarrow K\pi$
- D^0 vertex reconstruction
  - pairing two tracks
  - kinematic fitter
- Topological selections
  - Pointing angle (α) < ~0.04
  - 3D decay length (d_0) normalized by its error > ~3
  - Secondary vertex prob > ~0.05
- $|y^D| < 2$
- Two p_T bins
  - $4 < p_T^D < 20$ GeV
  - $p_T^D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

D^0 and jets reconstruction and selections

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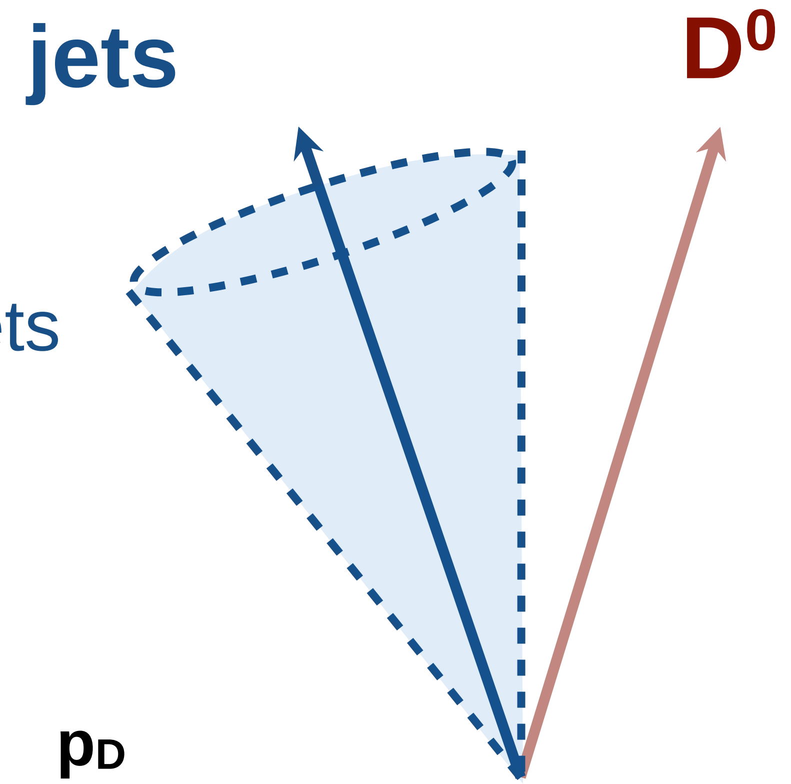
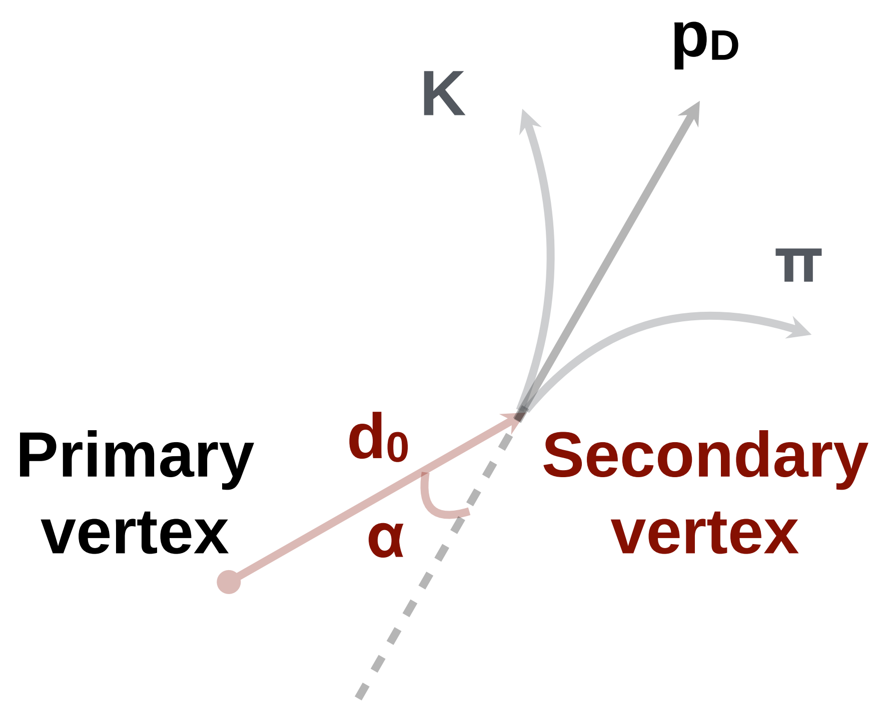


- Iterative PU-subtracted PF jets
- anti-k_T, R = 0.3
- $p_T^{jet} > 60$ GeV/c
- $|\eta^{jet}| < 1.6$



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Analysis strategy

- **Reconstruct** jets and D^0 candidates
- **Jet energy correction**
- **Pair** all selected D^0 candidates with all selected jets 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 jet resolution from simulations

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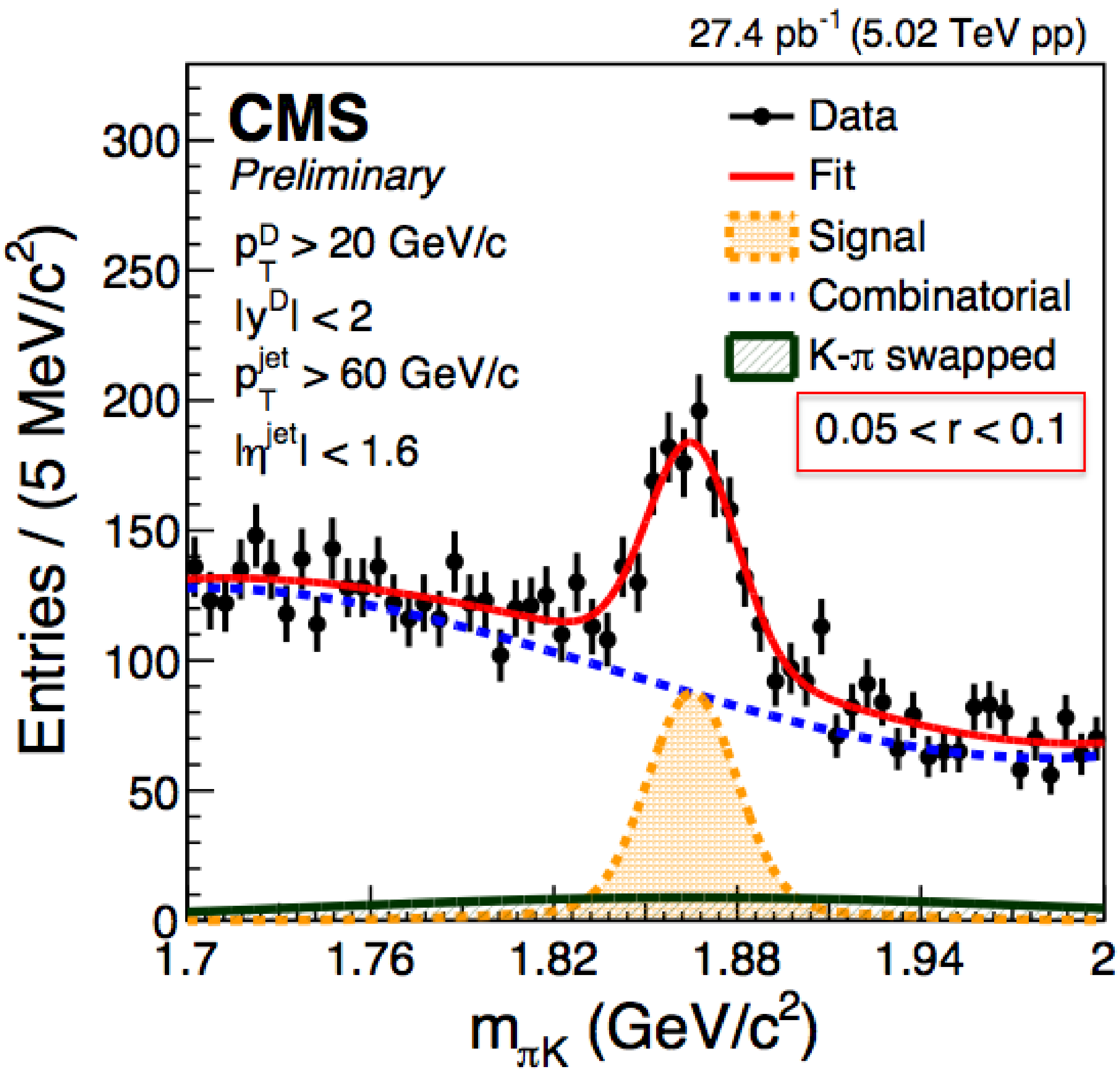
Raw D^0 yield extraction



Mass distributions fitted by

- Double gaussian (Signal)
- 3rd order polynomial (Combinatorial)
- Single gaussian (K-π swapped)
  - Candidates with wrong mass assignment

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Event mixing technique

- **Signal**: jets and D^0 mesons from the same hard scattering
- **Background**: fake jets, fake D^0, jets and D^0 mesons in underlying events, jets and D^0 mesons from different hard scatterings …
- Must extract signal D^0 and signal jet from 4 populations:
  - **Raw** (D-triggered) and **MB** D^0 mesons
  - **Raw** (D-triggered) and **MB** jets

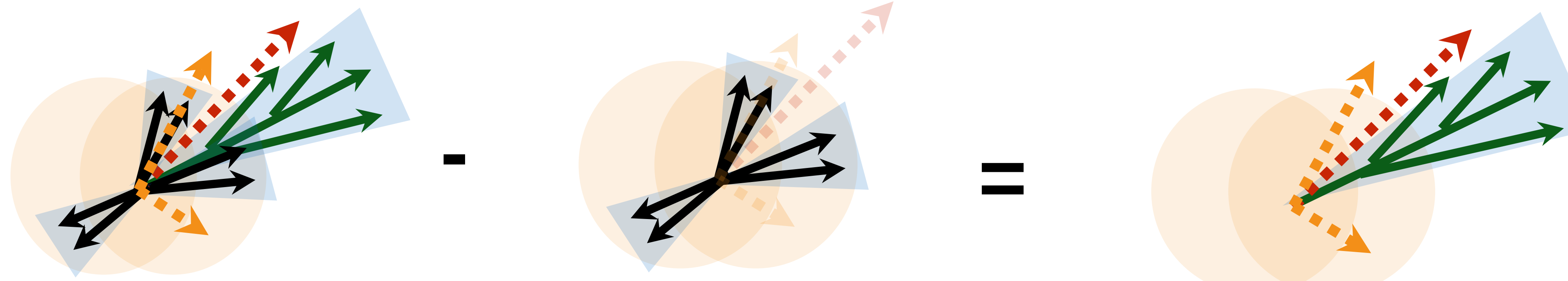
Event mixing technique

- Extract signal using event mixing:
  - Match raw events with MB events that share:
    - PV position
    - HF energy
    - event plane
  - Pair D^0 and jet samples in all possible ways:
    - (raw D^0, raw jet)
    - (MB D^0, raw jet)
    - (raw D^0, MB jet)
    - (MB D^0, MB jet)
  - Subtract radial profiles using a 3-step procedure:

before subtraction pure signal

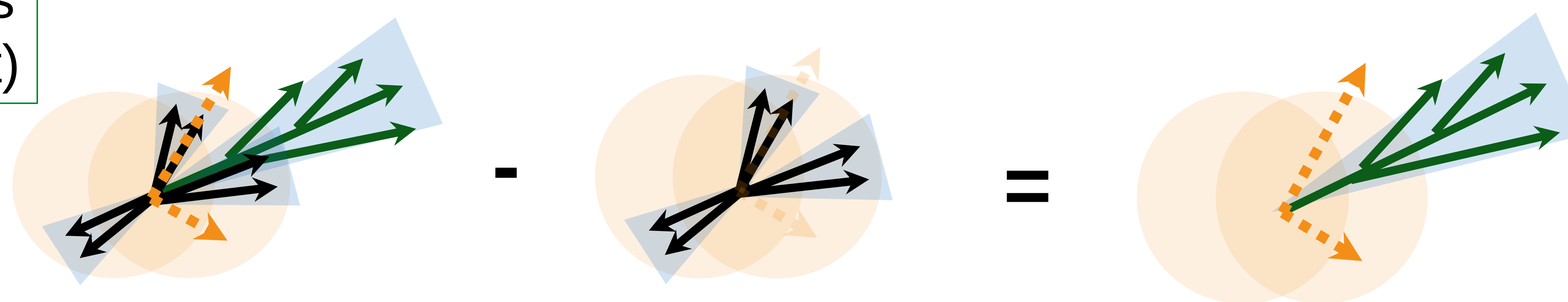
Event mixing technique

1. Remove bkgd jets from (raw D^0, raw jet)



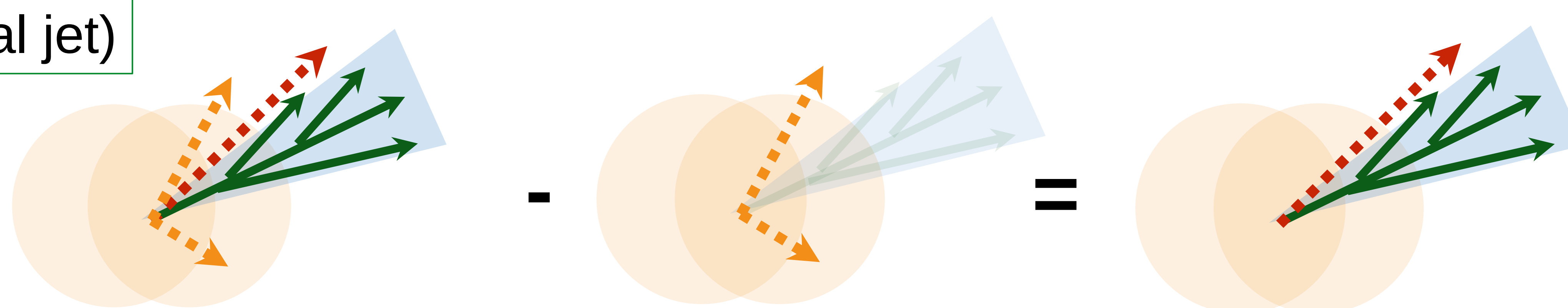
(Raw D^0, Raw Jet) - (Raw D^0, MB Jet) = (Raw D^0, Signal Jet)

2. Remove bkgd jets from (MB D^0, raw jet)



(MB D^0, Raw Jet) - (MB D^0, MB Jet) = (MB D^0, Signal Jet)

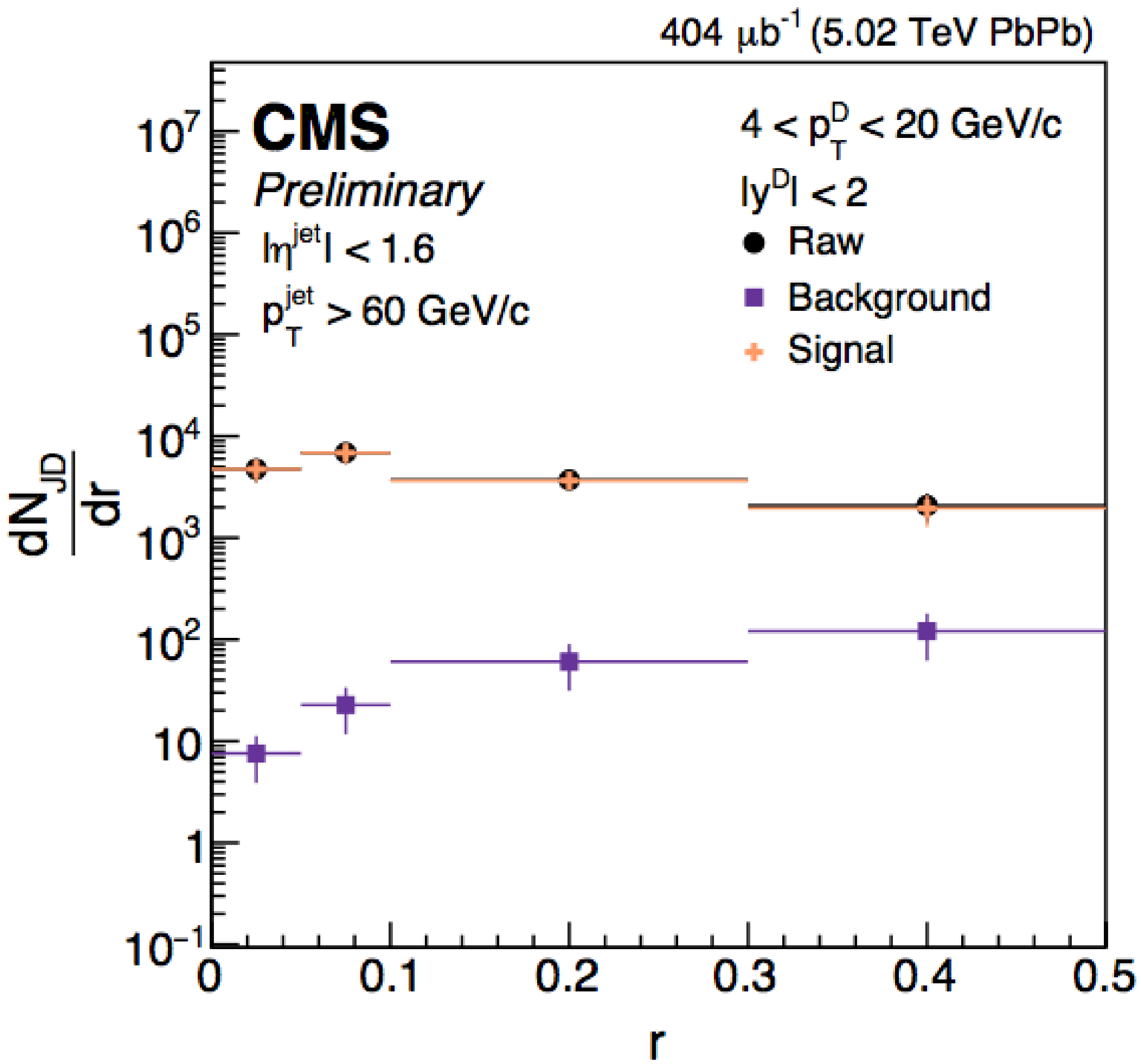
3. Remove bkgd D^0 from (raw D^0, Signal jet)



(Raw D^0, Signal Jet) - (MB D^0, Signal Jet) = (Signal D^0, Signal Jet)

Background subtraction

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



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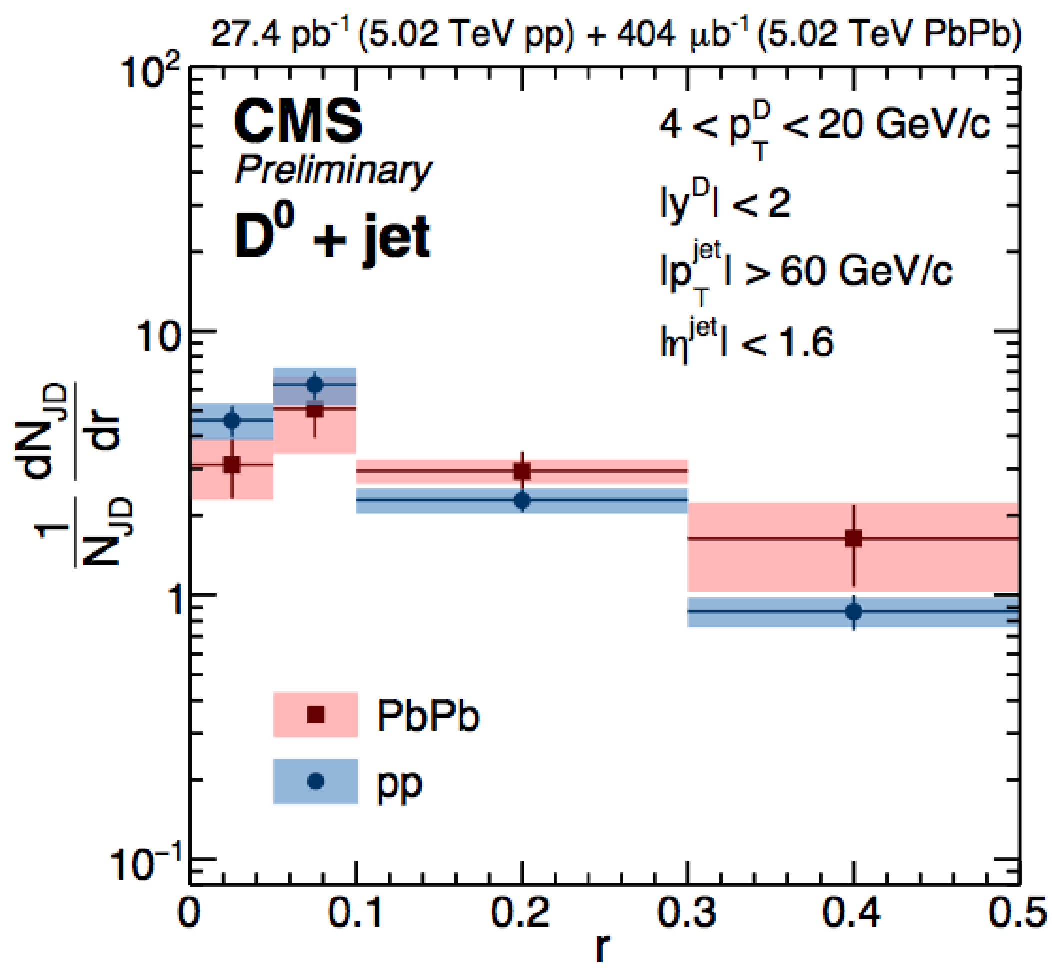
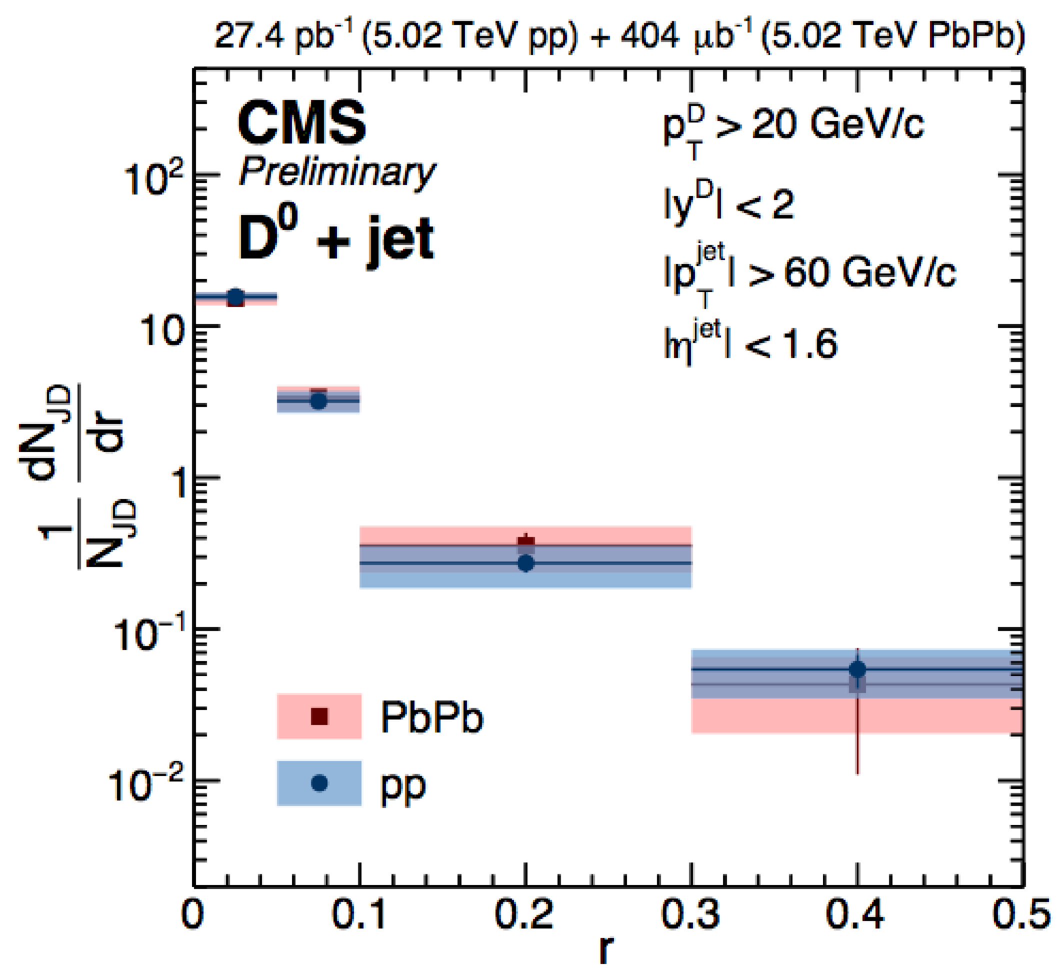
Results

Low D⁰ pT: $4 < p_T^D < 20$ GeV/c



High D⁰ pT: $p_T^D > 20$ GeV/c



- Low D^0 p_T: reach maximum at $0.05 < r < 0.1$
- High D^0 p_T: fall rapidly as a function of r

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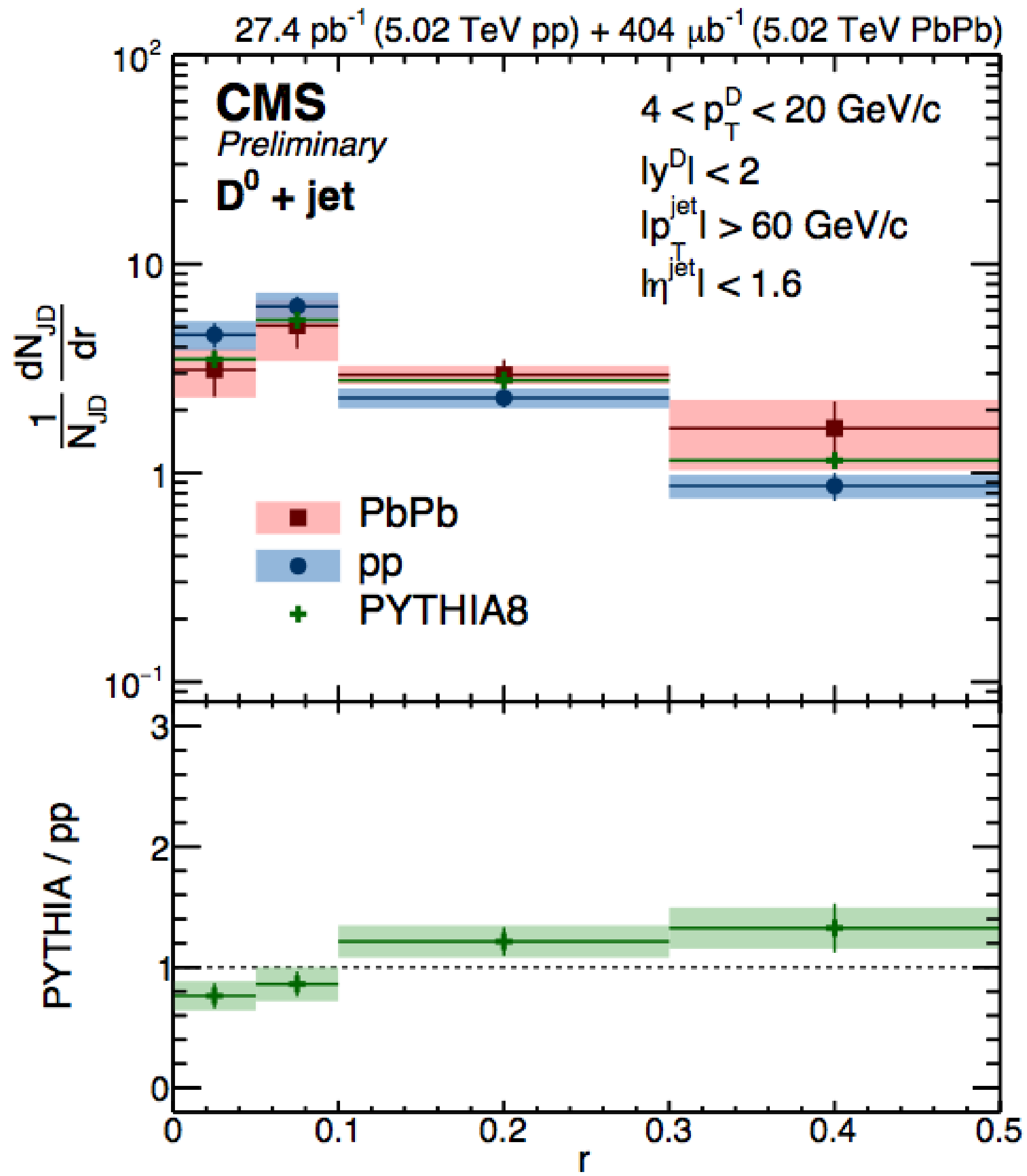
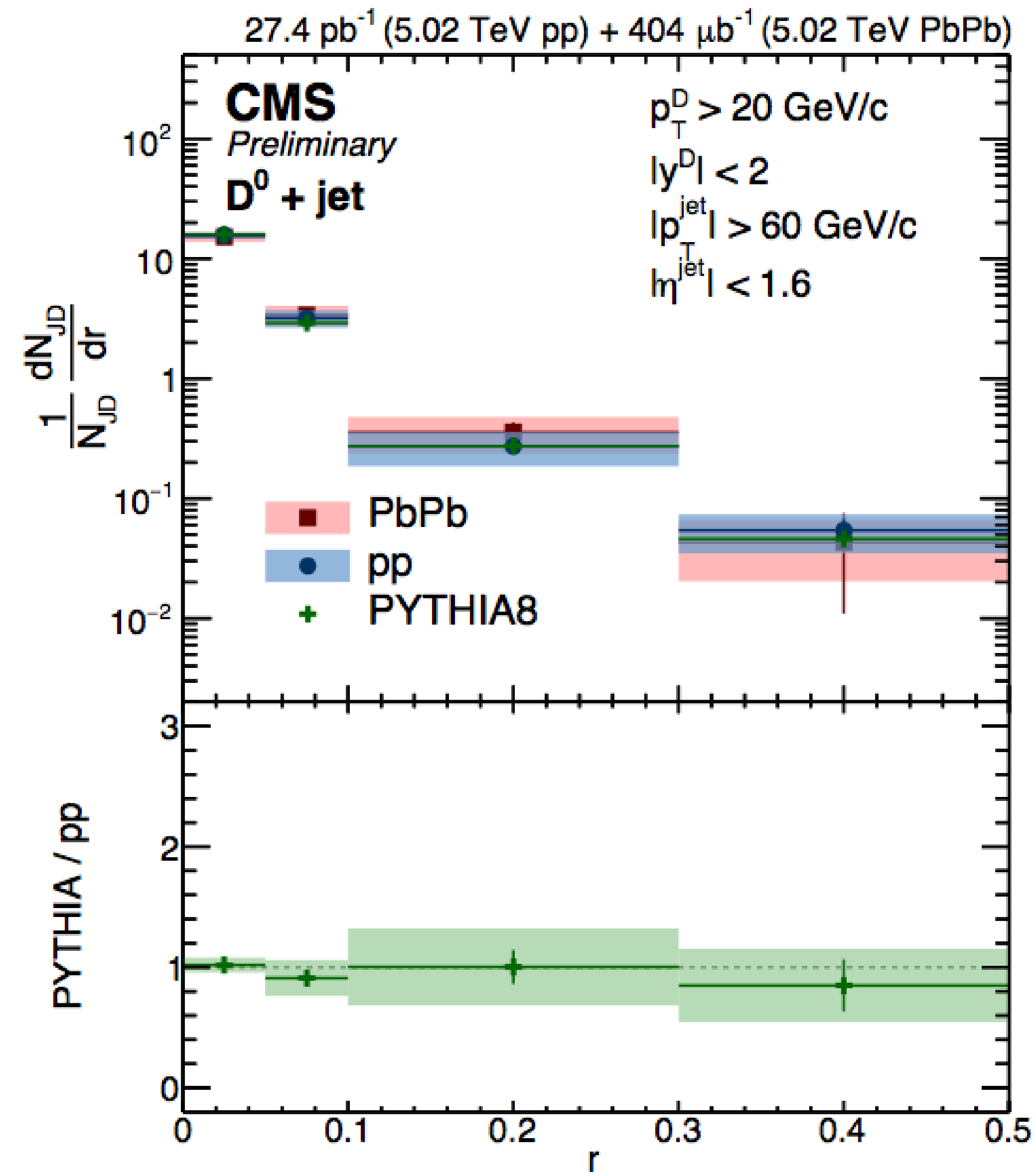
Results

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



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



- predictions from PYTHIA 8
  - Low D^0 p_T: produce a wider radial profile than measurements
  - High D^0 p_T: agree with measurements

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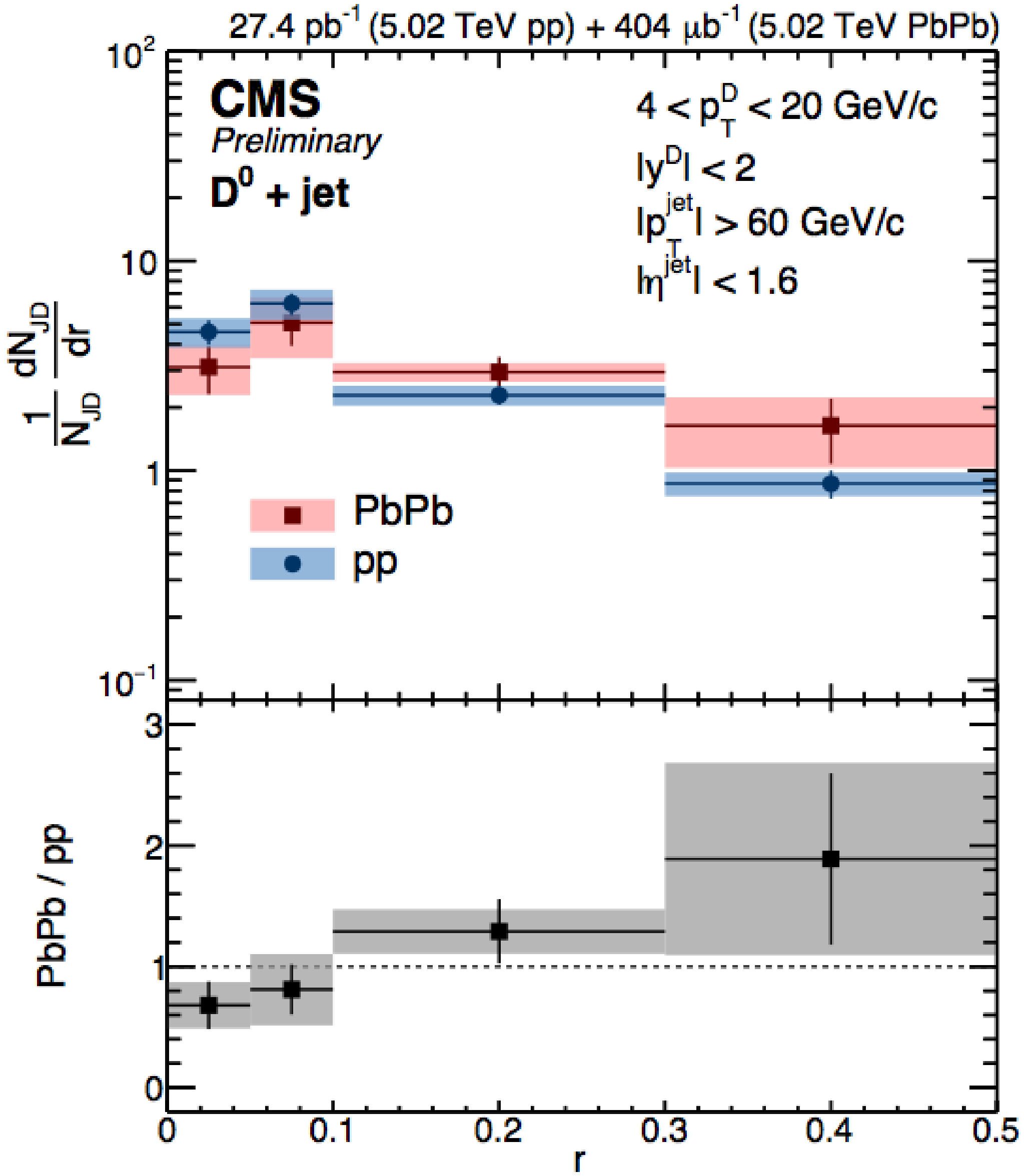
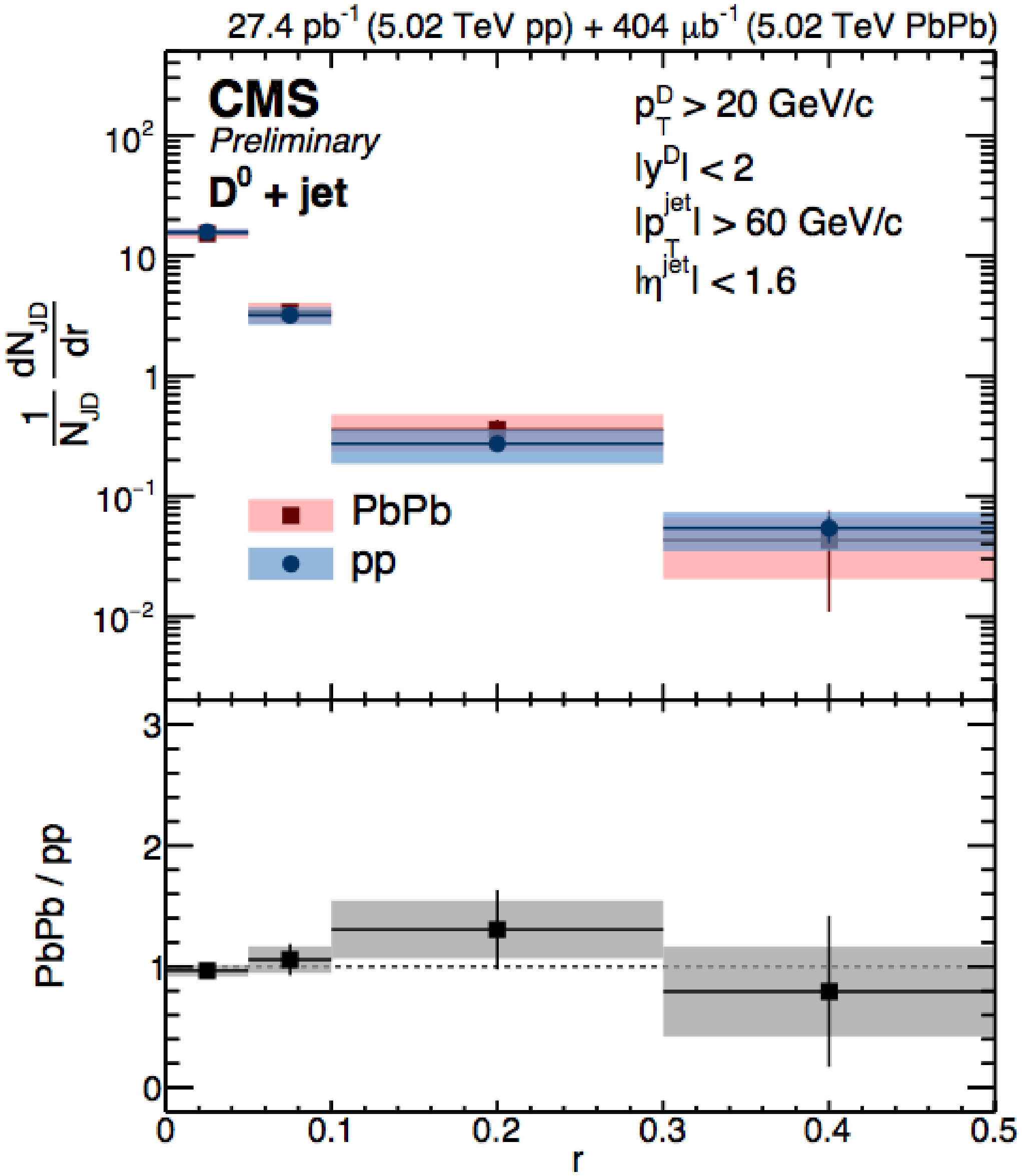
Results

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



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



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

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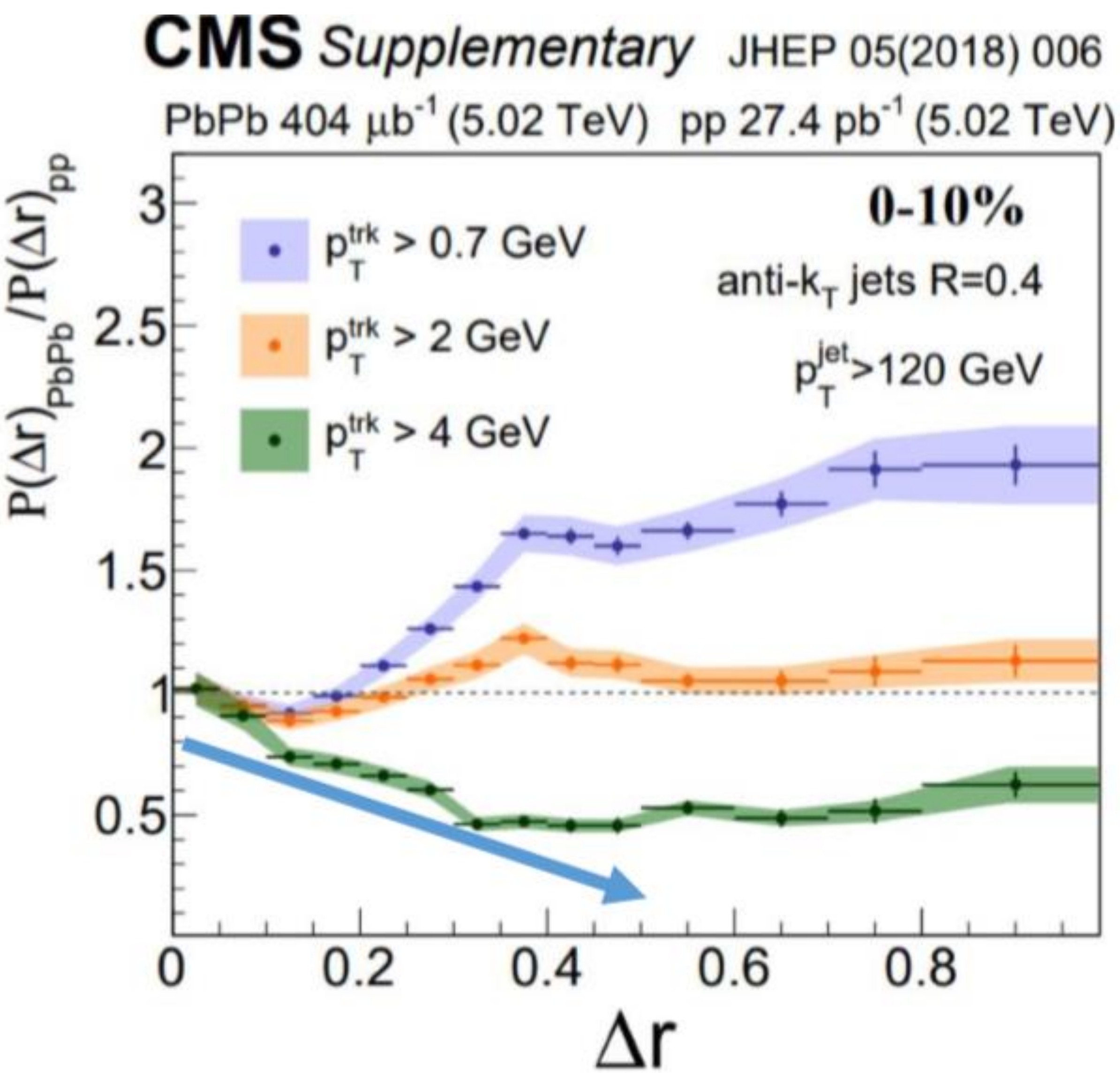
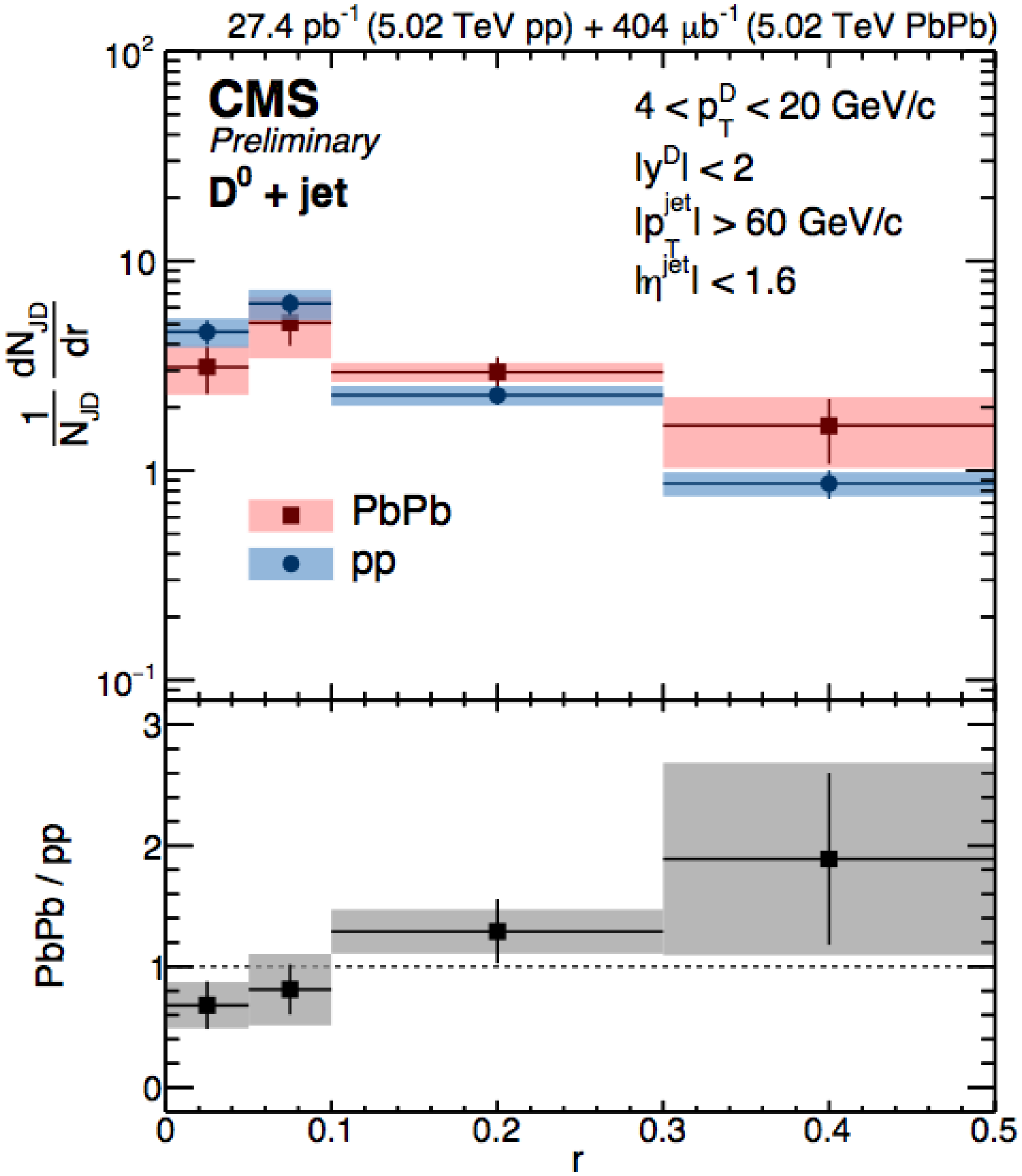
Results

Charged-Particle Jet Shape

Low D^0 p_T: $4 < p_T^D < 20$ GeV/c





- D^0 radial profiles **do not show** the decreasing PbPb/pp trend seen in high-pt charged particles
- Possible hint of charm diffusion in medium; more statistics required to be conclusive

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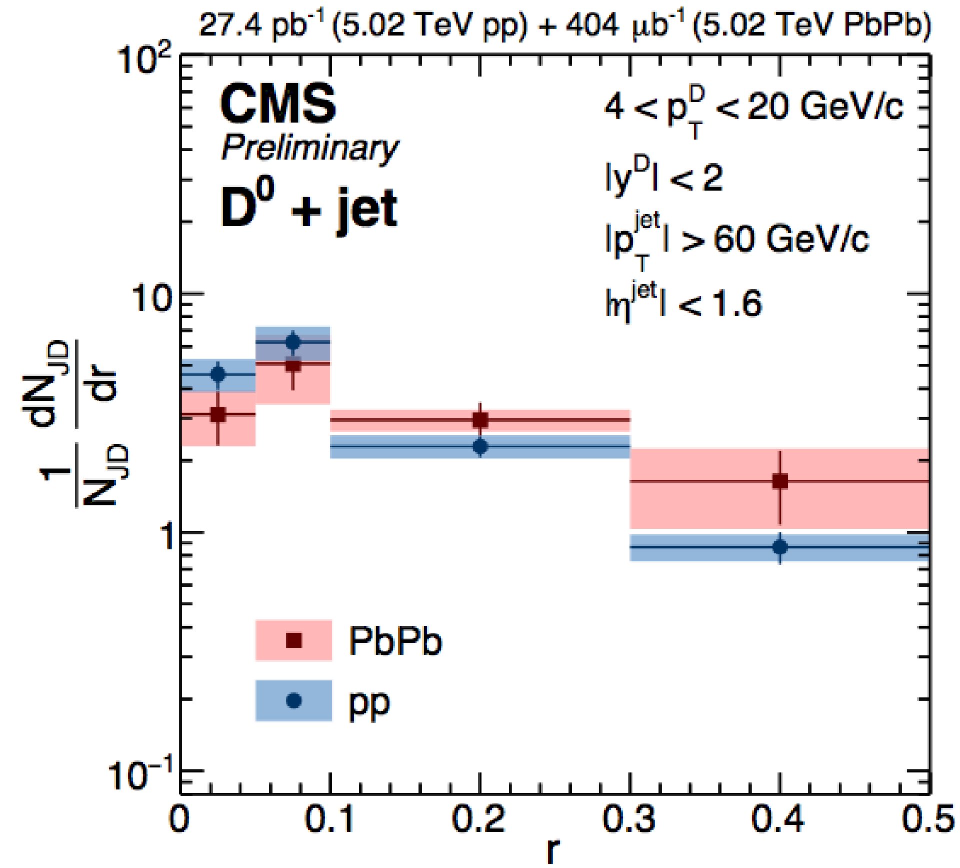
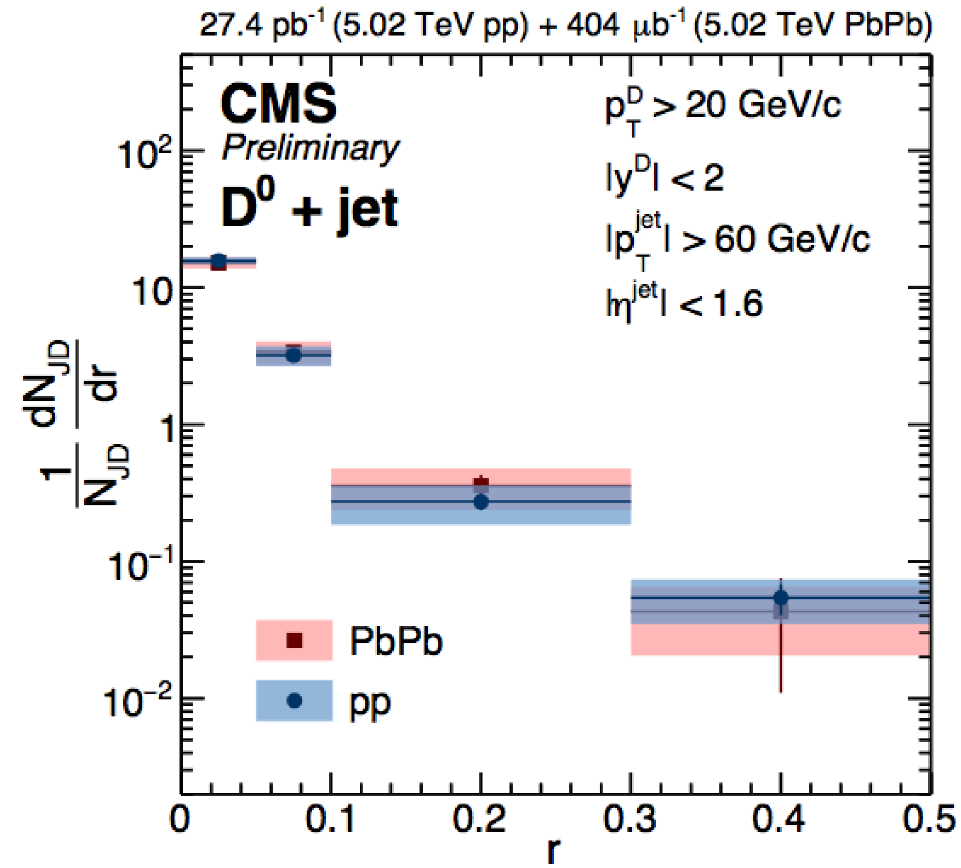
Summary

- First measurement of the **radial profile of D^0 mesons in jets** in PbPb and pp
  - Hint of wider D^0 radial profile in PbPb collisions at $4 < p_T^D < 20$ GeV/c
  - Ratio of PbPb/pp is consistent with unity at $p_T^D > 20$ GeV/c
- Provides new experimental constraints on
  - heavy-flavor production
  - heavy quark energy loss and diffusion



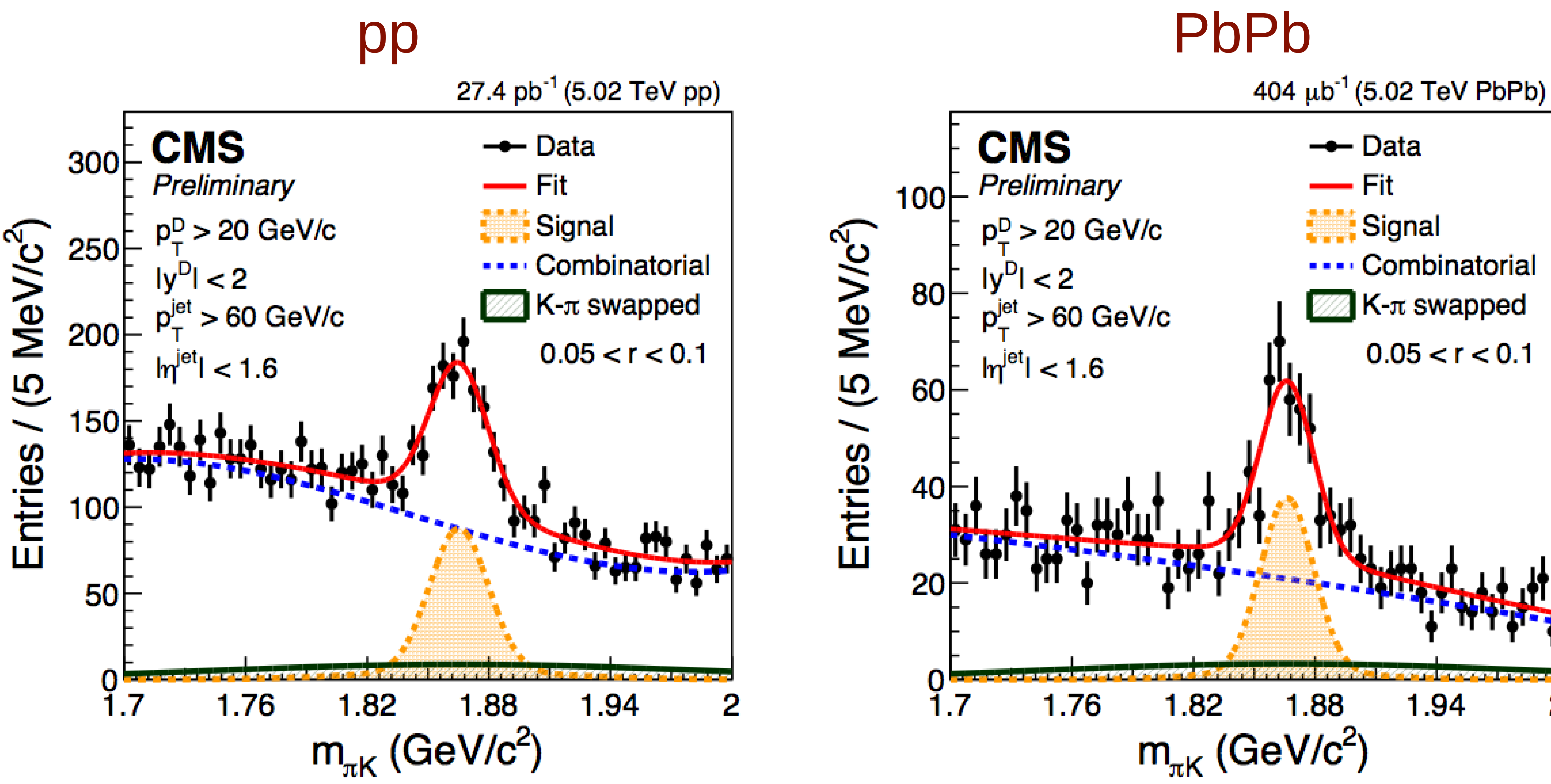


The MIT group's work was supported by US DOE-NP

Back up

Thanks for your attention!

Raw D^0 yield extraction



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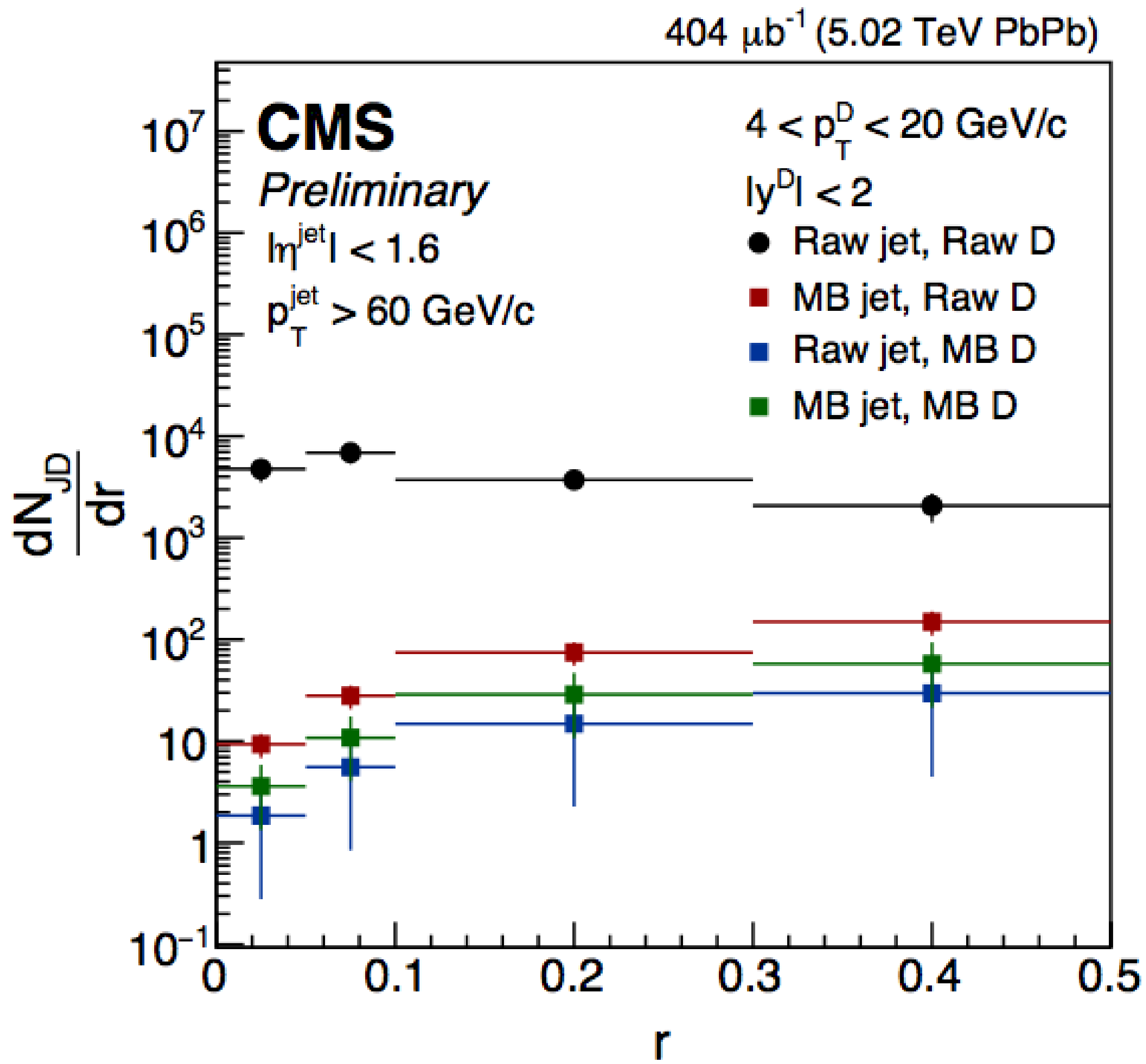
Background subtraction

- Raw = signal + background
- Four correlations
  - →Raw jet + Raw D
  - →MB jet + Raw D
  - →Raw jet + MB D
  - →MB jet + MB D



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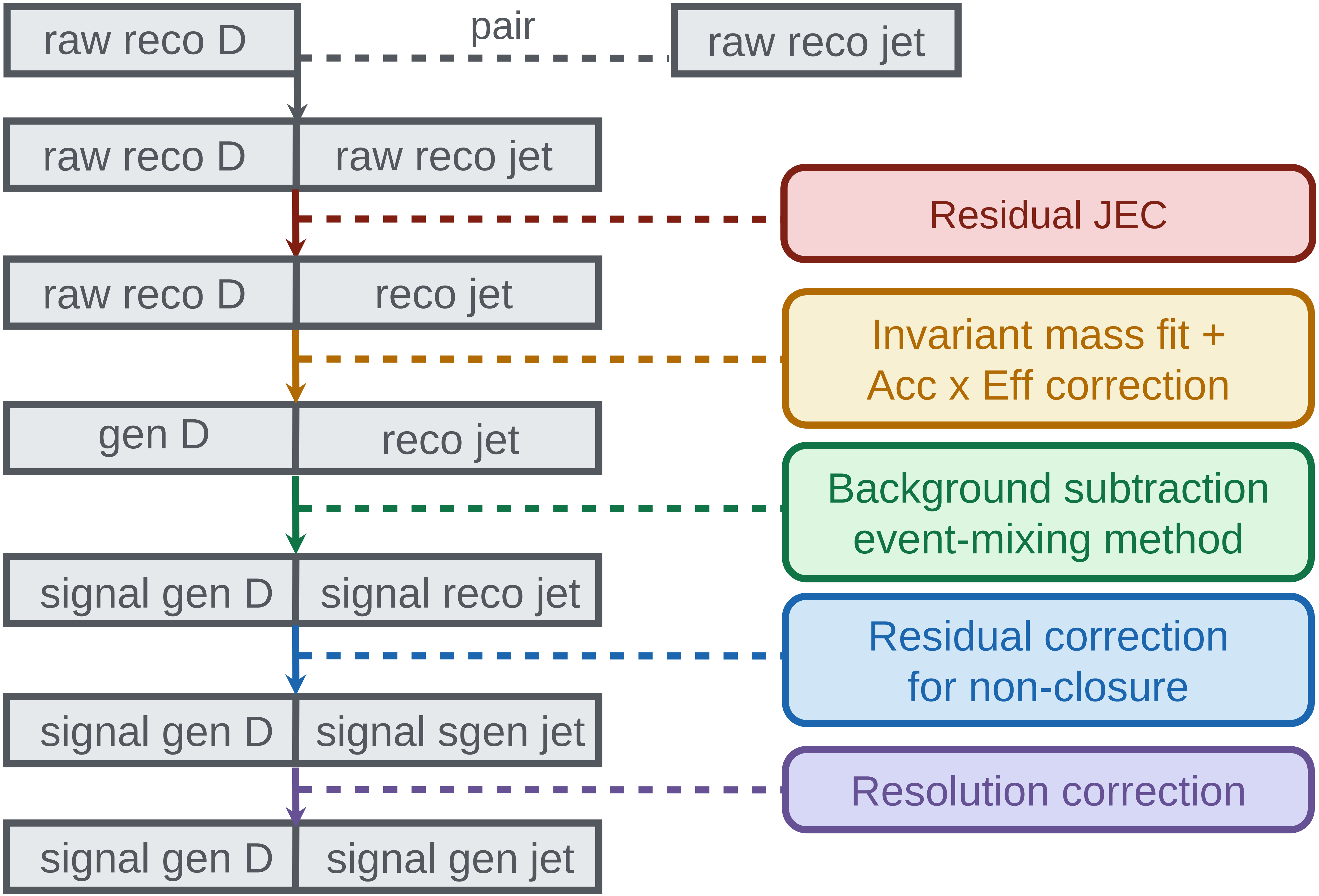
Analysis strategy

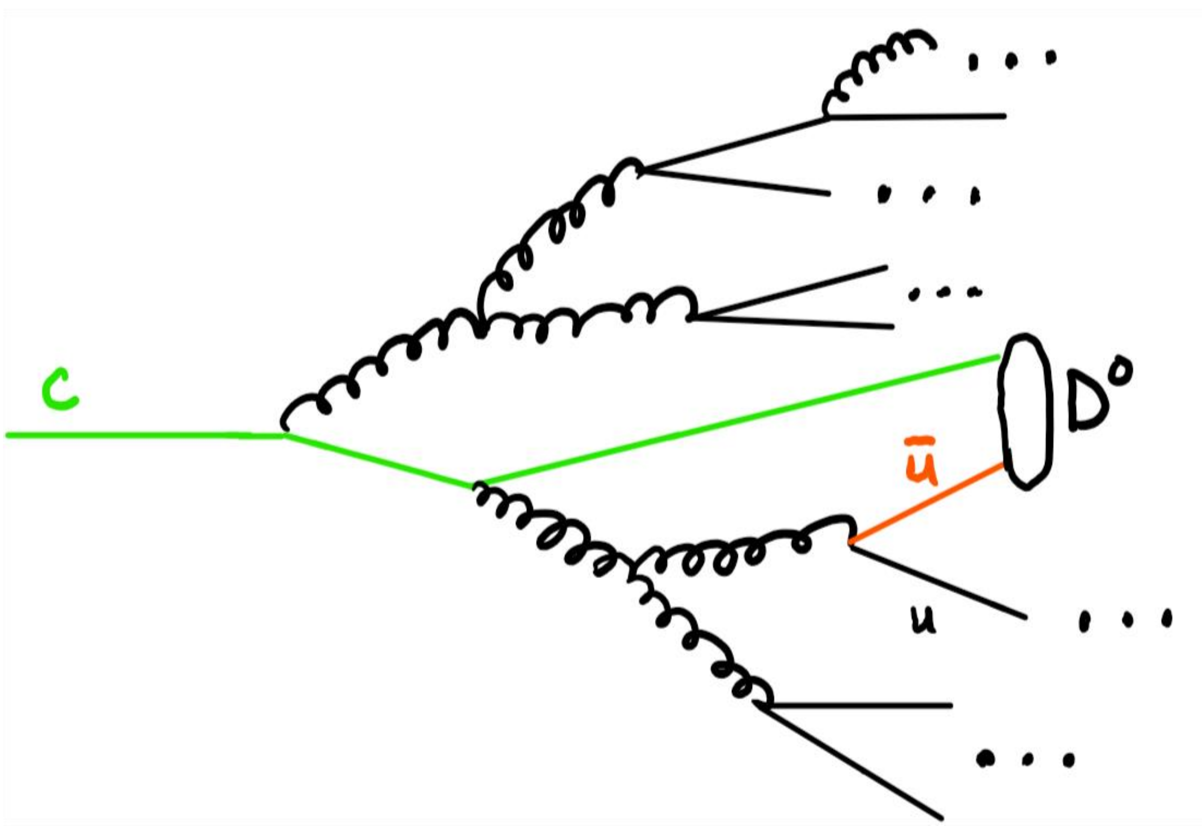


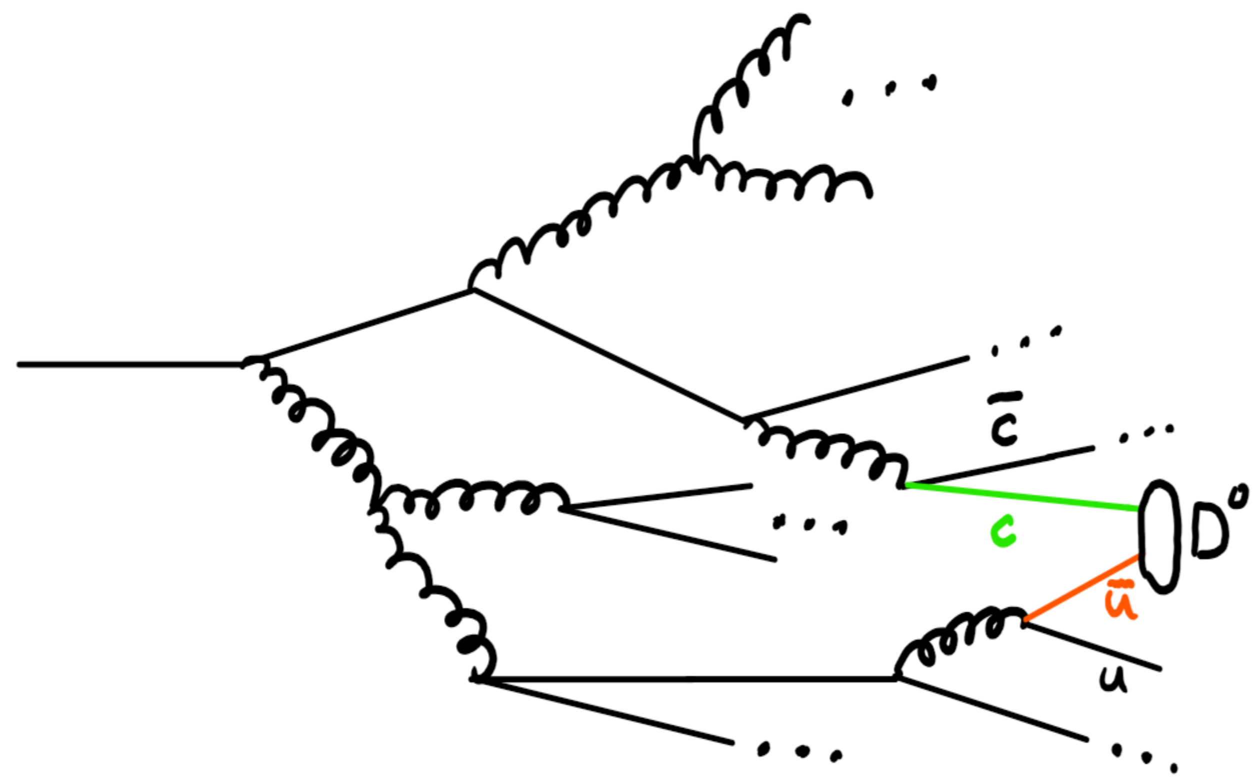
Why study D meson production in jets?

Even more …

Production mechanism of charm

Charm jets from hard scattering vs. Gluon splitting



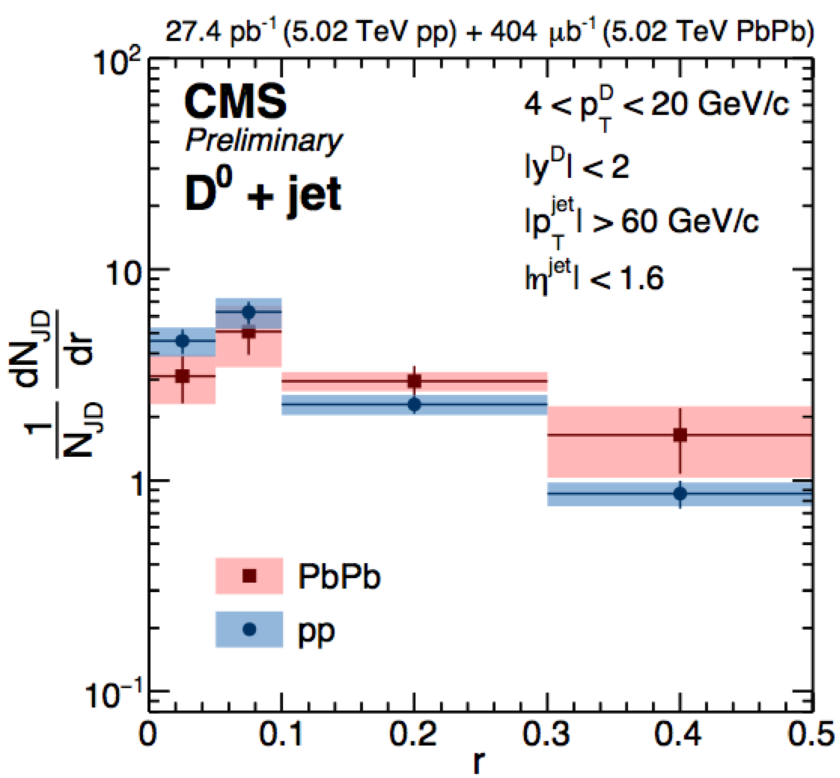


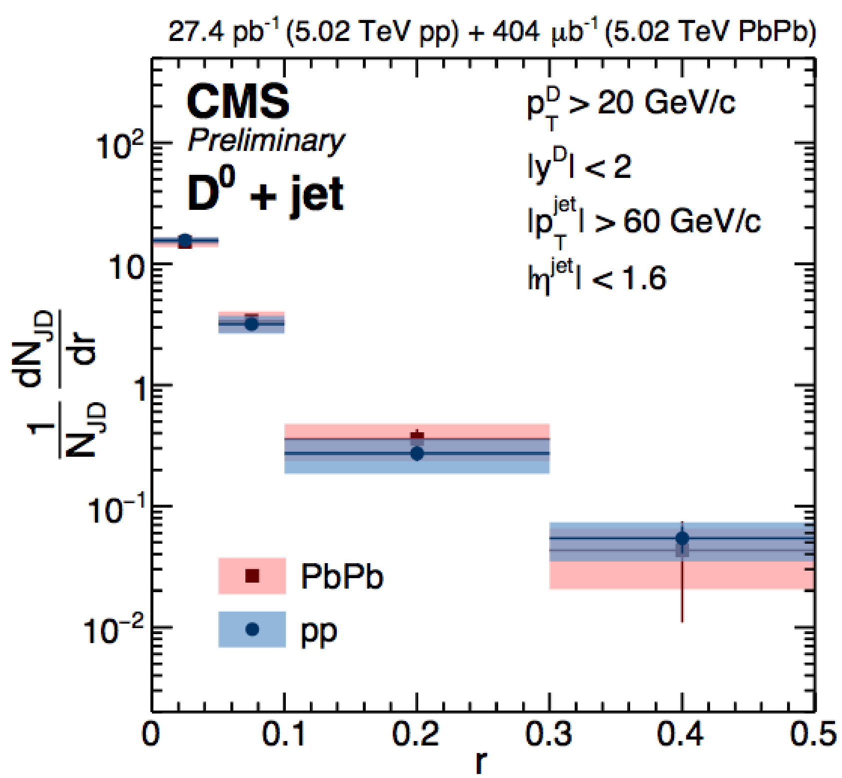
- Gluon splitting produces broader D^0 radial profile than a charm jet
- Radial profile measures relative contribution of each mechanism

Last slide

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





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