ATHIC2023

Groomed Substructures of Heavy Flavor Jets in pp and PbPb collisions at $\sqrt{s} = 5.02$ TeV

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Apr. 24, 2023, Japan

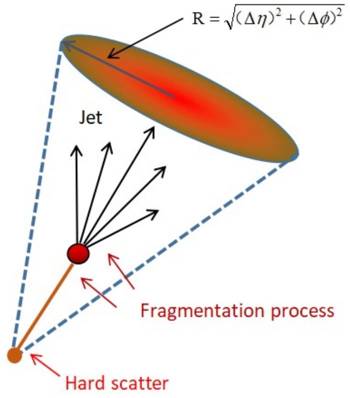
- **Qing Zhang**, Zi-Xuan Xu, Wei Dai, Ben-Wei Zhang, Enke Wang, Substructures of heavy flavor jets in pp and PbPb collisions at $\sqrt{s} = 5.02$ TeV, arXiv: 2303.08620 [nucl-th]
- Lei Wang, Jin-Wen Kang, **Qing Zhang**, Shuwan Shen, Wei Dai, Ben-Wei Zhang and Enke Wang, Jet radius and momentum splitting fraction with dynamical grooming in heavy-ion collisions, Chin. Phys. Lett. 40 (2023) no.3, 032101

Outline

- Motivation
  - Heavy flavor jets: heavy quark or heavy meson tagged jets
  - Groomed jet substructures
- Framework
  - Simulating Heavy quark Energy Loss with Langevin equations (SHELL)
- Jet substructures in pp collisions at $\sqrt{s} = 5.02$ TeV
- Jet substructures in PbPb collisions at $\sqrt{s} = 5.02$ TeV
- Summary

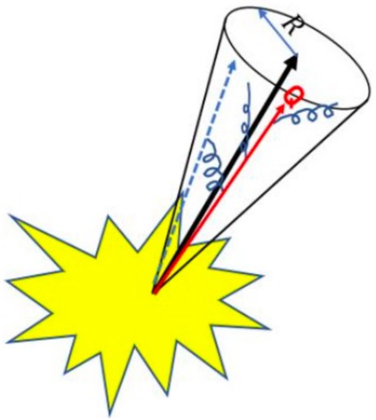
Background

➢ Jet



➢ Heavy Flavor Jets

- ➢ Dead Cone effect: $\Theta \lesssim m_Q/E$
- ➢ energy loss hierarchy: $\Delta E_b < \Delta E_c < \Delta E_q < \Delta E_g$



Jet tagged by heavy quark or heavy-flavored hadron

➢ Jet Grooming

① Jet reconstruction:

- ➢ anti-k_T algorithm

② reclustering the jet constituents:

- ➢ Cambridge-Aachen (C/A) algorithm

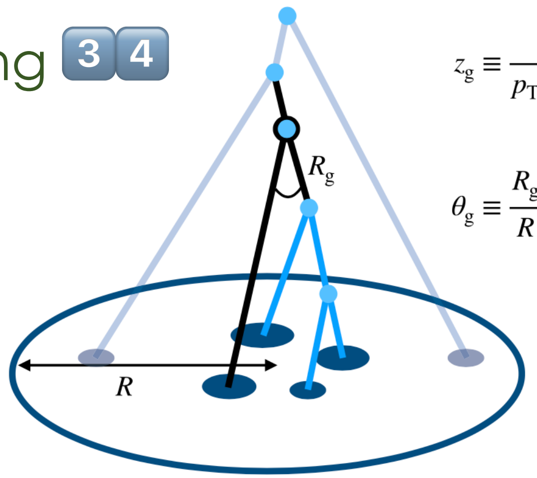
③ declustering the jet splittings:

- ➢ undone C/A

④ Soft-Drop condition:

- ➢ $z > z_{cut}\theta^{\beta}$

⑤ Repeating 3 4

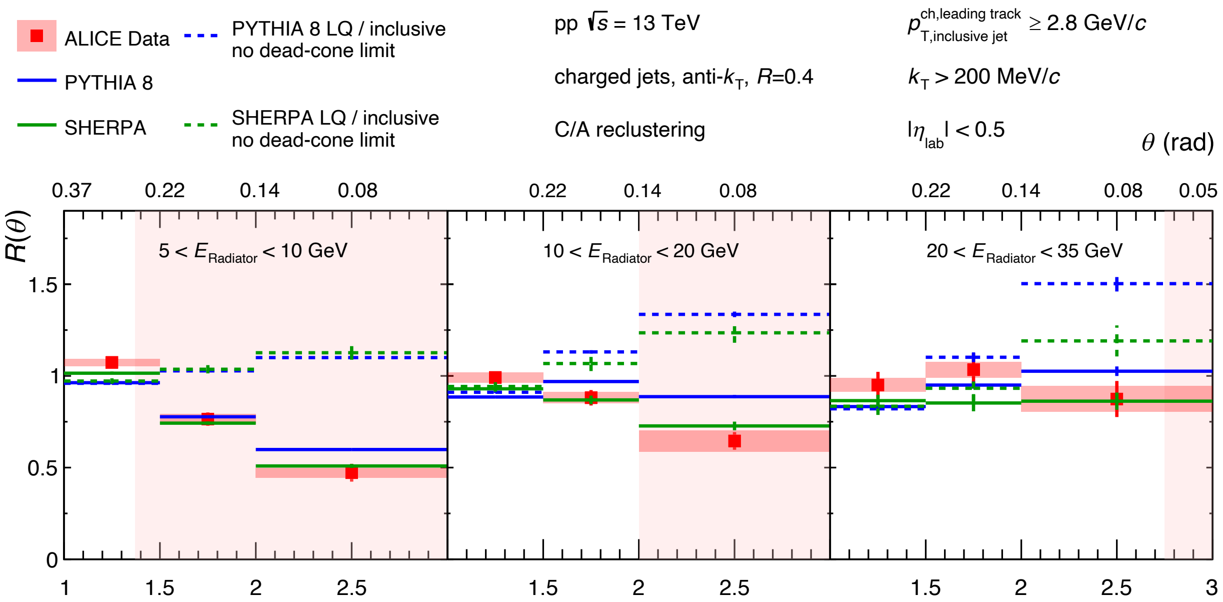


$$z_g \equiv \frac{p_{T,\text{subleading}}}{p_{T,\text{leading}} + p_{T,\text{subleading}}}$$

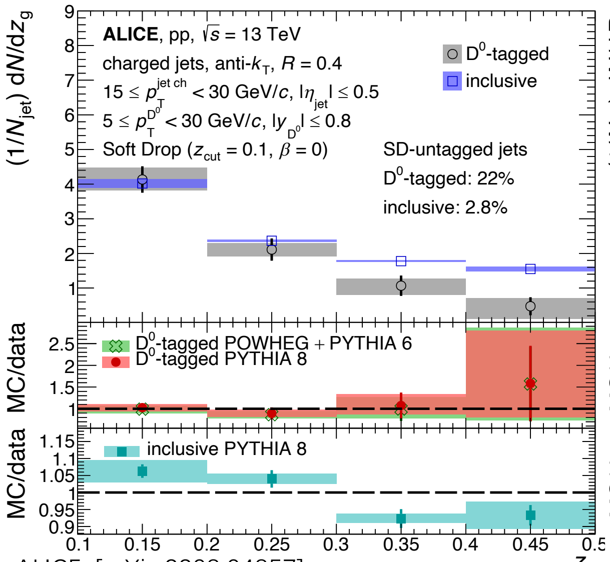
$$\theta_g \equiv \frac{R_g}{R} \equiv \frac{\sqrt{\Delta y^2 + \Delta\varphi^2}}{R}$$

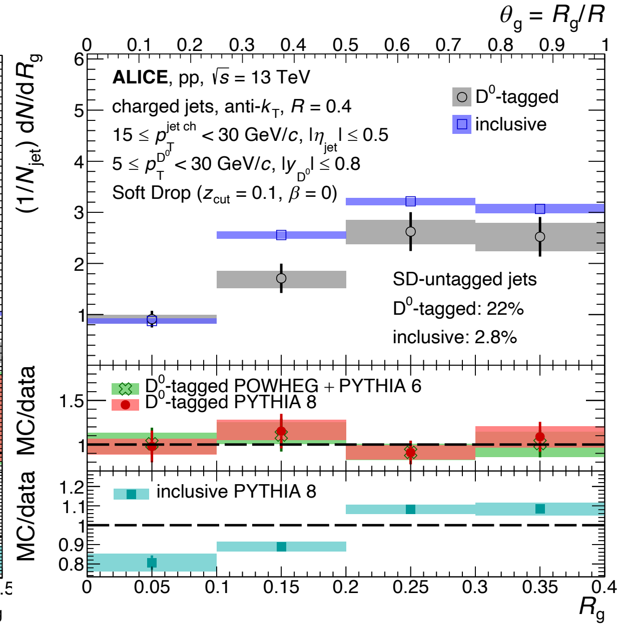
ALICE： *Phys.Rev.Lett. 128 (2022) 10, 102001*

Motivation



ALICE： *Nature 605 (2022) 7910, 440-446*



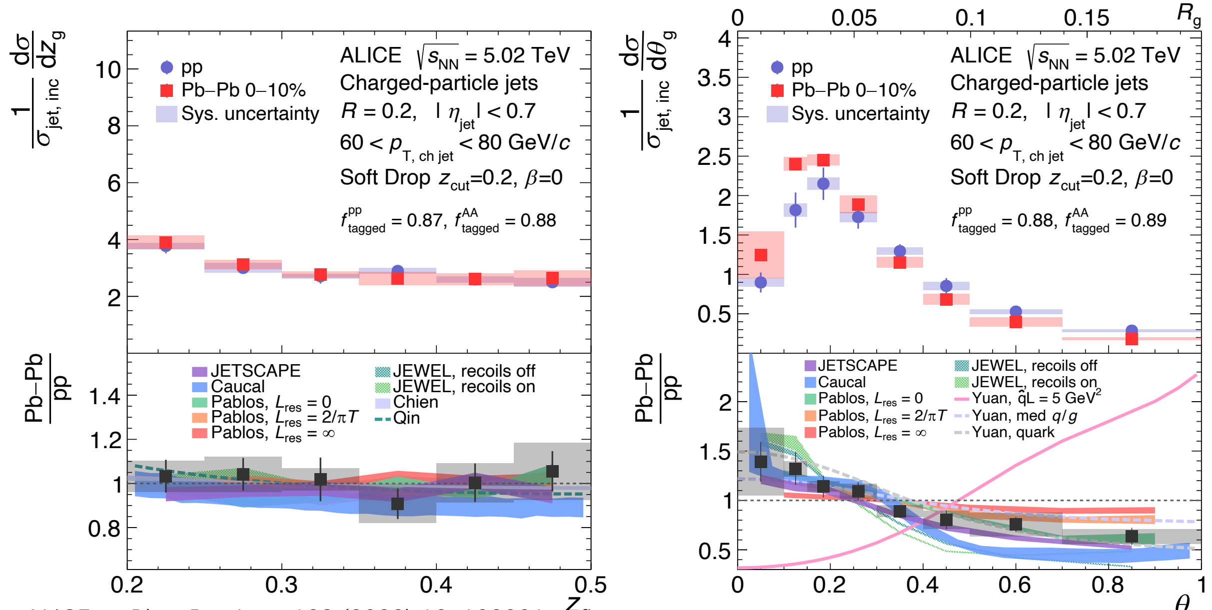


ALICE: [arXiv:2208.04857]

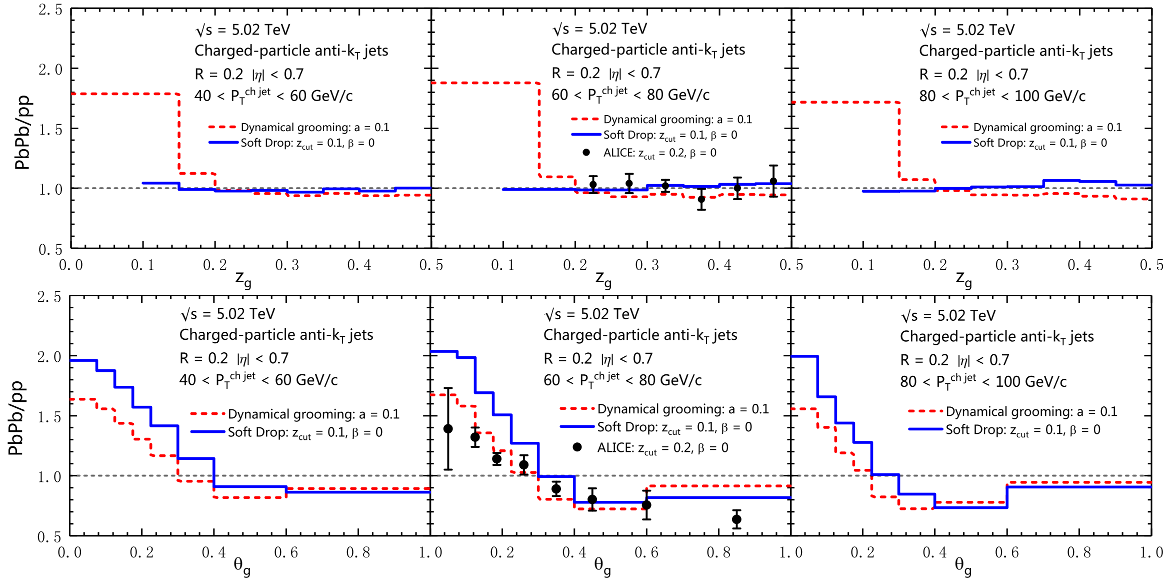
- ➢ Direct observation of the dead-cone effect by ALICE
  - ➢ Nature 605 (2022) 7910, 440-446
- ➢ Dead-cone effect in AA collisions
  - ➢ arXiv:2205.14668 [hep-ph]
- ✓ jet splitting structure
- ✓ $5 < p_T^{ch\ jet} < 50\ \text{GeV}/c$

- ➢ hardest branching of jet
- ➢ $15 \leq p_T^{ch} < 30\ \text{GeV}/c$
- ✓ z_g: D^0-tagged jets have fewer symmetric splittings than inclusive jets
- ✓ R_g: D^0-tagged jets have less large-angle splittings than inclusive jets
- ✓ parton mass effect and Casimir color factor difference

Motivation



ALICE： *Phys.Rev.Lett. 128 (2022) 10, 102001*



Chin. Phys. Lett. 40 (2023) no.3, 032101

- ➢ hardest branching of inclusive jets
  - ➢ Phys.Rev.Lett. 128 (2022) 10, 102001
- ➢ hardest branching of light-flavor jets
  - ➢ Chin. Phys. Lett. 40 (2023) no.3, 032101
- ➢ $60 < p_T^{ch\ jet} < 80\ \mathrm{GeV}/c$

↓

? hardest branching of inclusive jets, D^0-tagged jets, B^0-tagged jets in pp and AA collisions

- ➢ $m_c = 1.28 \pm 0.02\ \mathrm{GeV}/c^2$
- ➢ $m_b = 4.18^{+0.03}_{-0.02}\ \mathrm{GeV}/c^2$

Framework

- Heavy-meson Tagged Jets
  - $m_{D^0} = 1.86\ \mathrm{GeV}/c^2,\ m_{B^0} = 5.28\ \mathrm{GeV}/c^2$
  - $5 \leq p_{\mathrm{T}}^{\mathrm{HQ}} < 30\ \mathrm{GeV}/c, 15 \leq p_{\mathrm{T}}^{ch} < 30\ \mathrm{GeV}/c$
- MC event generator
  - PYTHIA 8.2
    - ✓ Comput.Phys.Commun. 191 (2015) 159-177
- Jet reconstruction
  - FastJet 3.2.1
    - ✓ Eur.Phys.J.C 72 (2012) 1896
  - anti-k_T (R = 0.4)
    - ✓ JHEP 04 (2008) 063
  - C/A algorithm
    - ✓ JHEP 08 (1997) 001
  - Soft Drop condition ($z_{cut} = 0.1, \beta = 0$)
- Hydrodynamics
  - CLVisc (3+1)D viscous hydrodynamics model
    - ✓ Phys. Rev. C 97 (2018) no.6, 064918
- Jet quenching model
  - SHELL

    Simulating Heavy quark Energy Loss with Langevin equations

    - ✓ Chin.Phys.C 44 (2020) 104105
    - ✓ Eur.Phys.J.C 79 (2019) 9, 789
    - ✓ Nucl.Phys.A 1005 (2021) 121787
    - ✓ Chin.Phys.C 45 (2021) 6, 064105
    - ✓ Eur.Phys.J.A 58 (2022) 7, 135

Framework

Simulating Heavy quark Energy Loss with Langevin equations (SHELL)

- the modified discrete Langevin transport equations,
  - ✓ Phys.Rev.C 88 (2013) 044907
  - ✓ Phys.Rev.C 71 (2005) 064904

$$\vec{x}(t+\Delta t) = \vec{x}(t) + \frac{\vec{p}(t)}{E}\Delta t \quad (1)$$

$$\vec{p}(t+\Delta t) = \vec{p}(t) - \Gamma(p)\,\vec{p}\,\Delta t + \vec{\xi}(t)\,\Delta t - \vec{p}_g \quad (2)$$

- the fluctuation-dissipation relation,
  - ✓ Phys.Rev.D 92 (2015) 11, 116003

$$\kappa = 2ET\Gamma = \frac{2T^2}{D_s} \quad (3)$$

$$D_s(2\pi T) = 4 \ \in (3.7 \sim 7) \quad (4)$$

- the stochastic term $\vec{\xi}(t)$ obeys Gaussian distribution,

$$W[\vec{\xi}(t)] = N \cdot exp\left[\frac{\vec{\xi}(t)^2}{2\kappa\Delta t}\right] \quad (5)$$

- radiative energy loss $\vec{p}_g$,
  - ✓ Phys.Rev.Lett. 85 (2000) 3591-3594
  - ✓ Phys.Rev.Lett. 93 (2004) 072301
  - ✓ Phys.Rev.D 85 (2012) 014023

$$\frac{dN}{dxdk_\perp^2dt} = \frac{2\alpha_s C_s P(x)\hat{q}}{\pi k_\perp^4} sin^2\left(\frac{t-t_i}{2\tau_f}\right)\left(\frac{k_\perp^2}{k_\perp^2 + x^2M^2}\right)^4 \quad (6)$$

- the jet transport coefficient $\hat{q}$,

$$\hat{q} \propto q_0\left(\frac{T}{T_0}\right)^3 \quad (7)$$

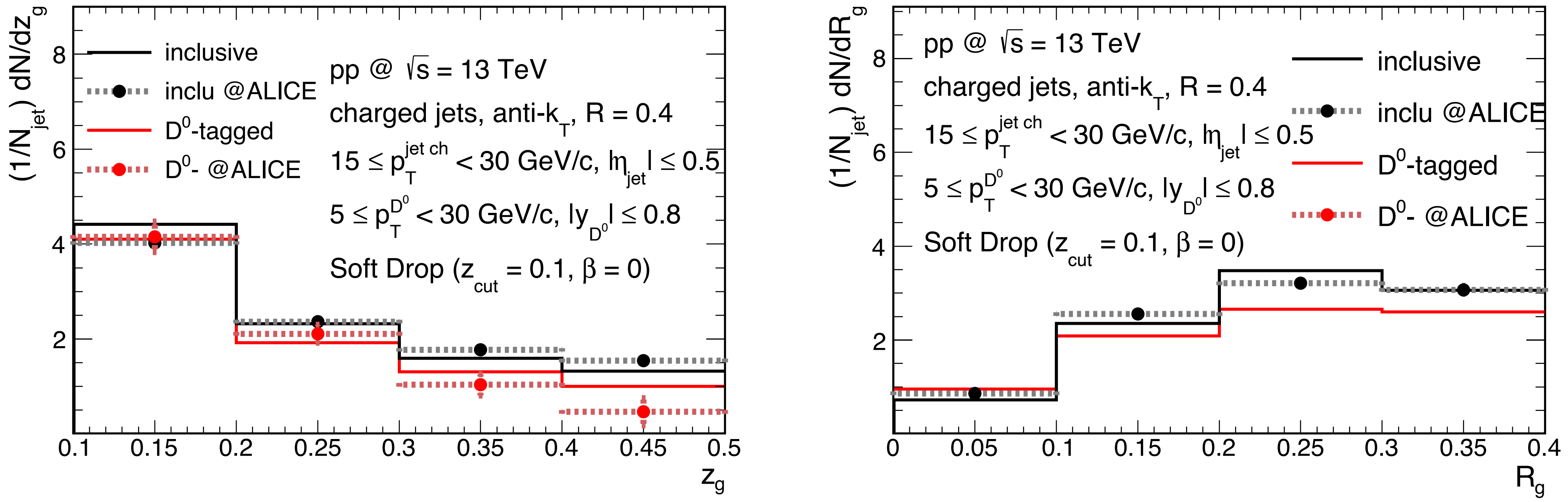
- pQCD calculation at HTL approximation,
  - ✓ Phys.Rev.D 83 (2011) 065012
  - ✓ Phys.Lett.B 726 (2013) 251-256

$$\frac{dE}{dz} = \frac{\alpha_s C_s \mu_D^2}{2} ln\frac{\sqrt{ET}}{\mu_D} \quad (8)$$

pp collisions at $\sqrt{s} = 13$ TeV

- $p_{\rm T}^{\rm D^0} \geq 5$ GeV/c → $p_{\rm T,inclusive\ jets}^{\rm ch,leading\ track} \geq 5.33$ GeV/c
- Normalization: **total** number of jets

ALICE: [arXiv:2208.04857]



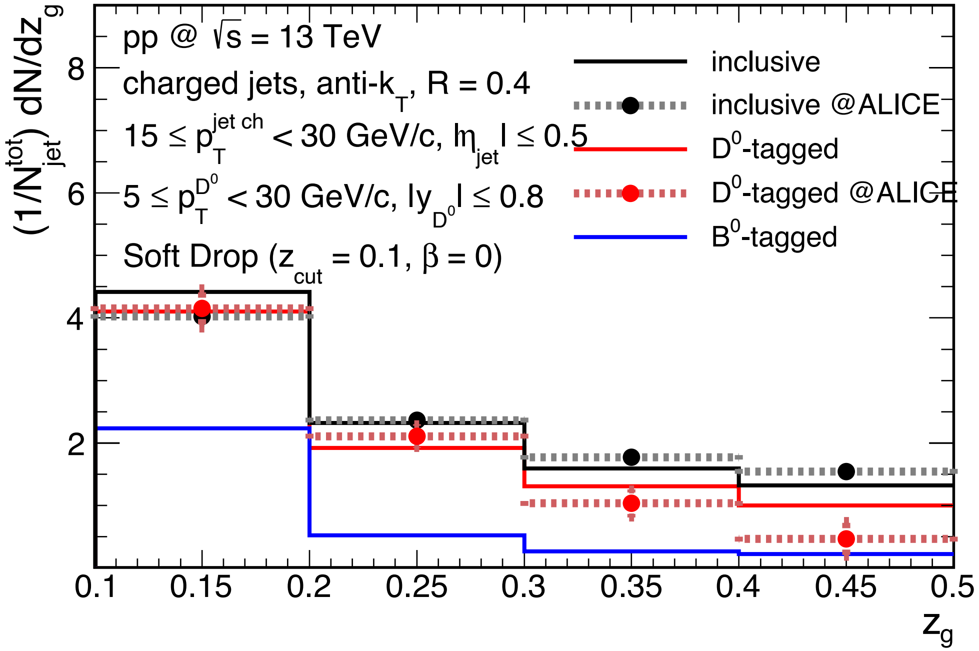
✓ z_g distributions of both D^0-tagged jets and inclusive jets decrease with increasing z_g;

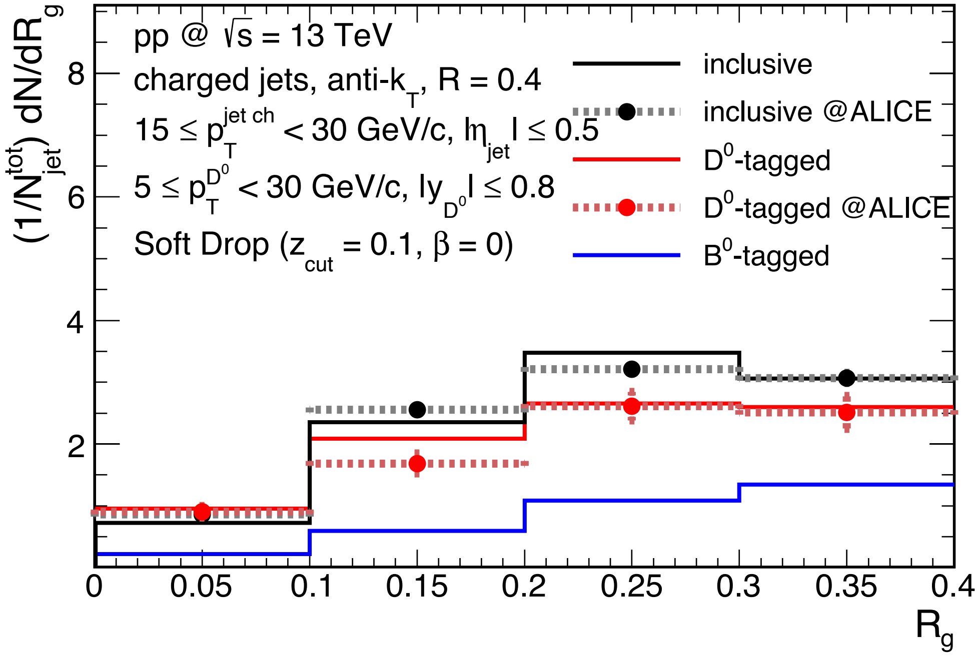
✓ At large z_g, distributions of D^0-tagged jets are suppressed than those of inclusive jets;

✓ R_g distributions of both D^0-tagged jets and inclusive jets increase with increasing R_g;

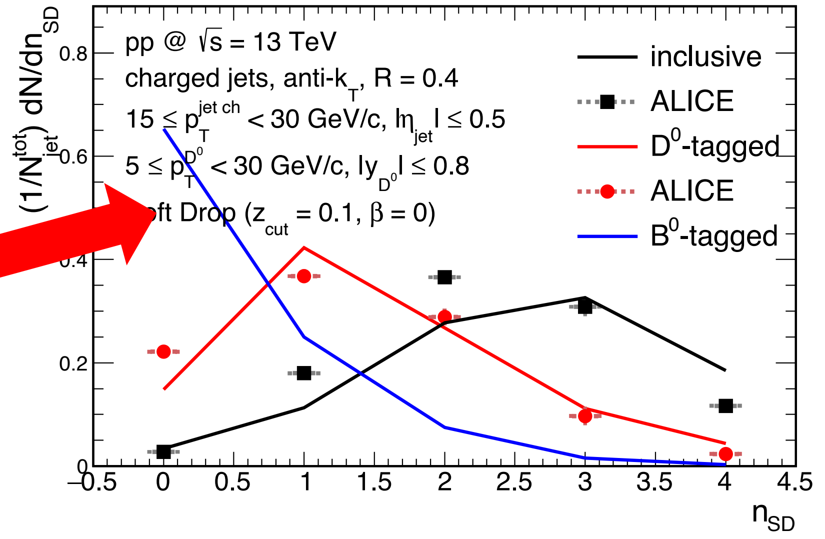
✓ At large R_g, distributions of D^0-tagged jets are suppressed than those of inclusive jets.

pp collisions at $\sqrt{s}$ = 13 TeV



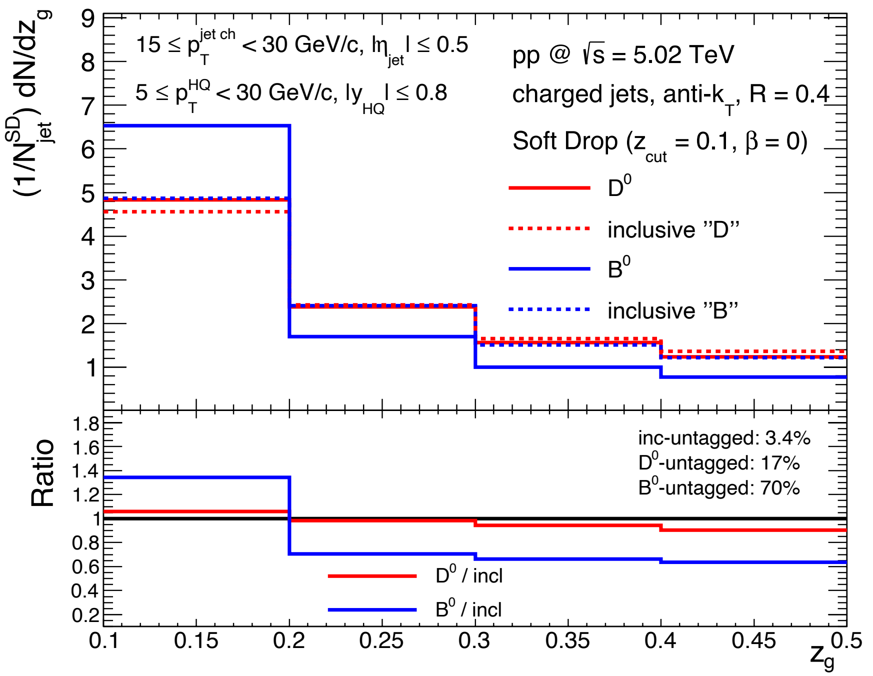


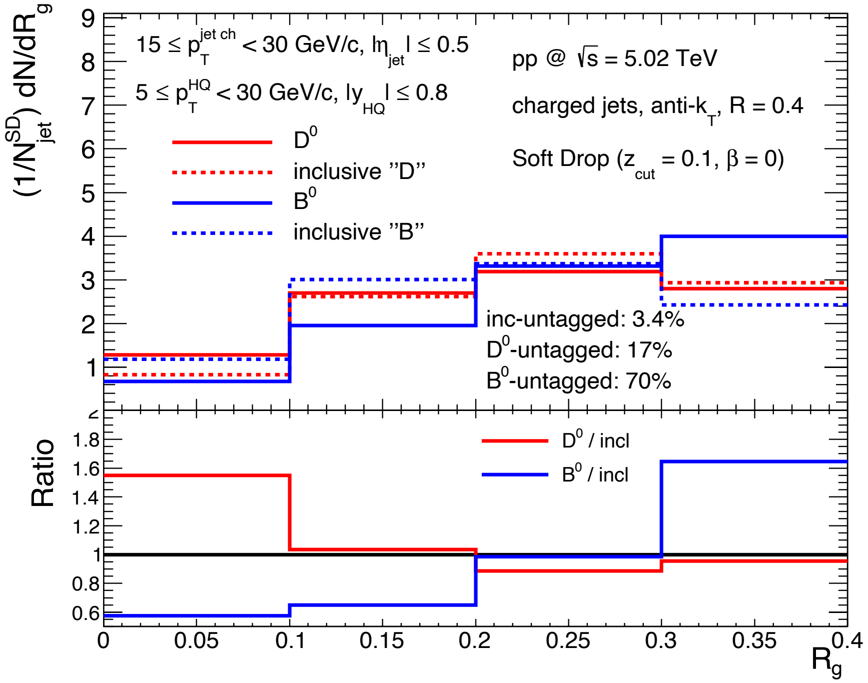
- Soft-drop untagged fraction:
  - inclusive-untagged: 3.4%
  - D^0-untagged: 17%
  - B^0-untagged: 68%
- Normalization: **"total"** number of jets $N_{\text{jet}}^{\text{tot}}$ → **"SD"** jets $N_{\text{jet}}^{\text{SD}}$



pp collisions at $\sqrt{s} = 5.02$ TeV

- **inclusive "D"** : $p_{\mathrm{T}}^{\mathrm{D}^0} \geq 5\ \mathrm{GeV}/c \rightarrow p_{\mathrm{T,inclusive\ jets}}^{\mathrm{ch,leading\ track}} \geq 5.33\ \mathrm{GeV}/c$
- **inclusive "B"** : $p_{\mathrm{T}}^{\mathrm{B}^0} \geq 5\ \mathrm{GeV}/c \rightarrow p_{\mathrm{T,inclusive\ jets}}^{\mathrm{ch,leading\ track}} \geq 7.27\ \mathrm{GeV}/c$
- **Normalization :** number of Soft-Drop jets $N_{\mathrm{jet}}^{\mathrm{SD}}$





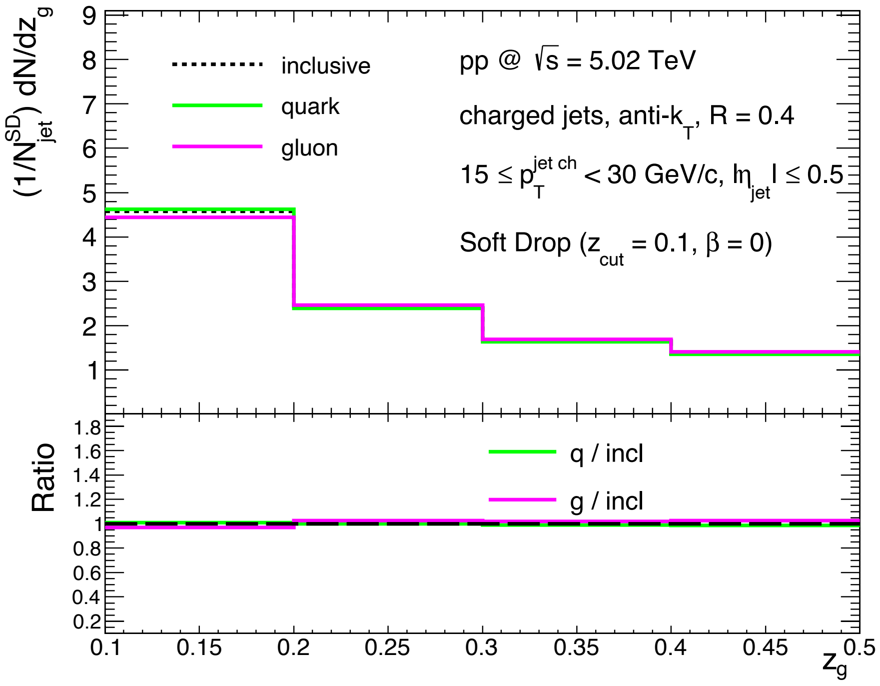
✓ Mass hierarchy in z_g distributions

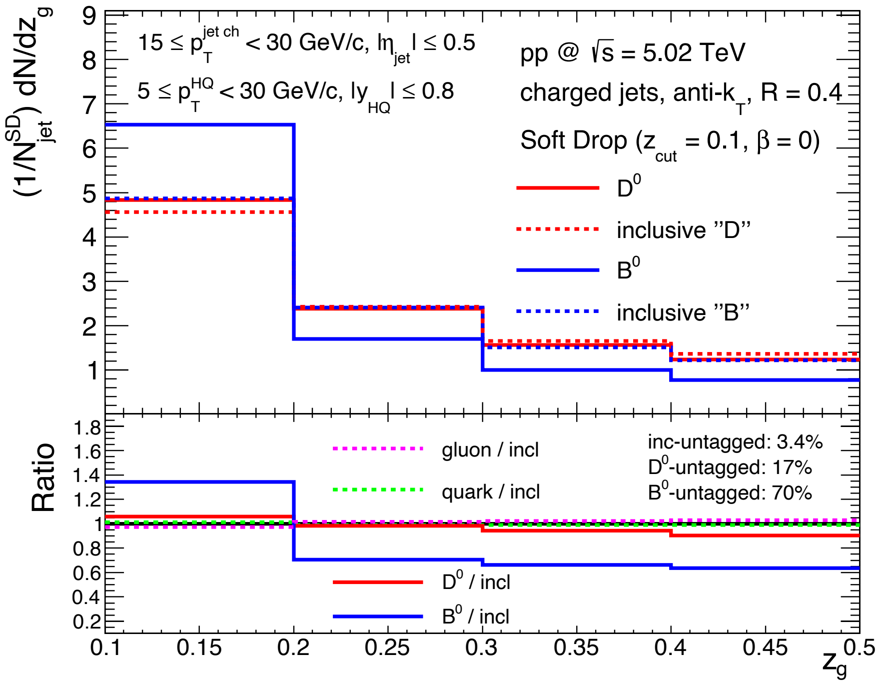
✓ D^0-tagged jets and B^0-tagged jets

✓ Mass hierarchy is not maintained in R_g distributions

① z_g distributions

- ➢ pure light-quark initiated jets
- ➢ pure gluon initiated jets



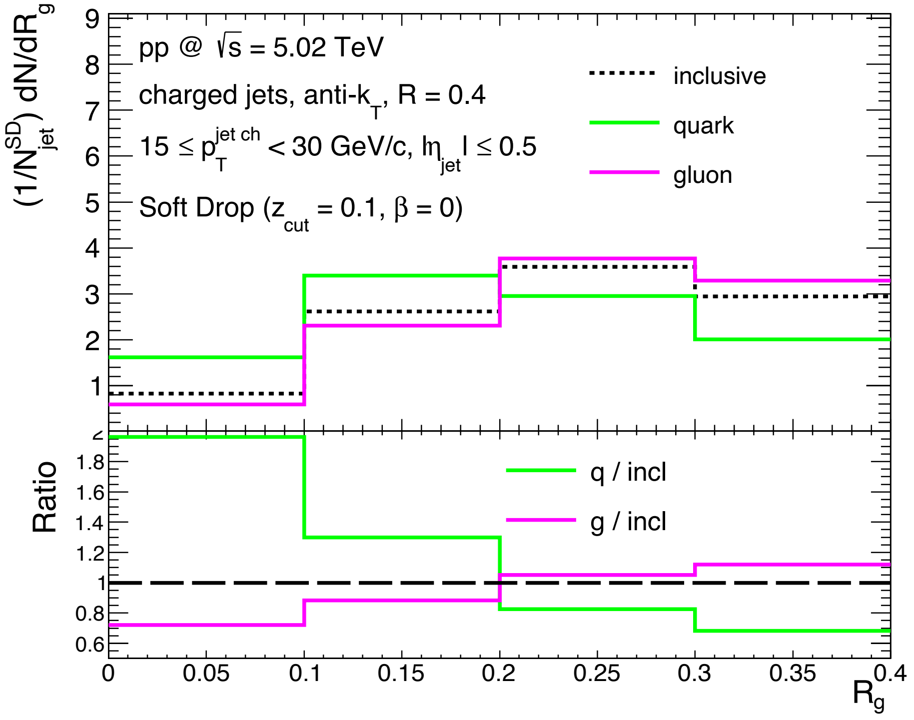


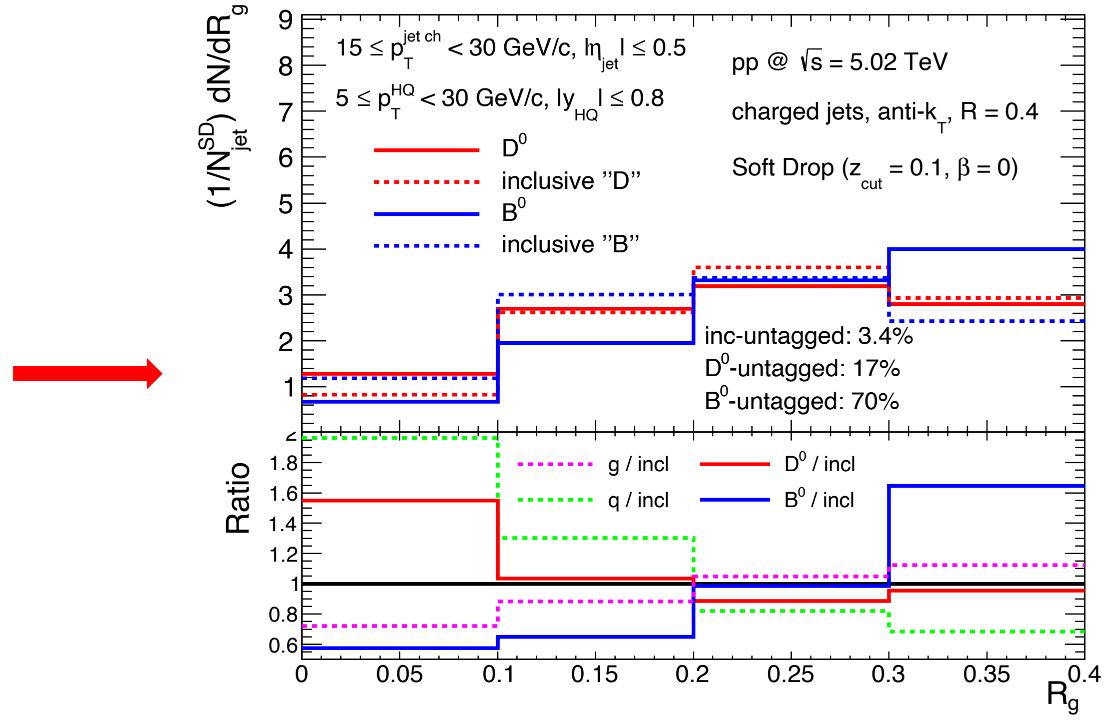
✓ Difference in Casimir color factor

✓ parton mass effects

② R_g distributions

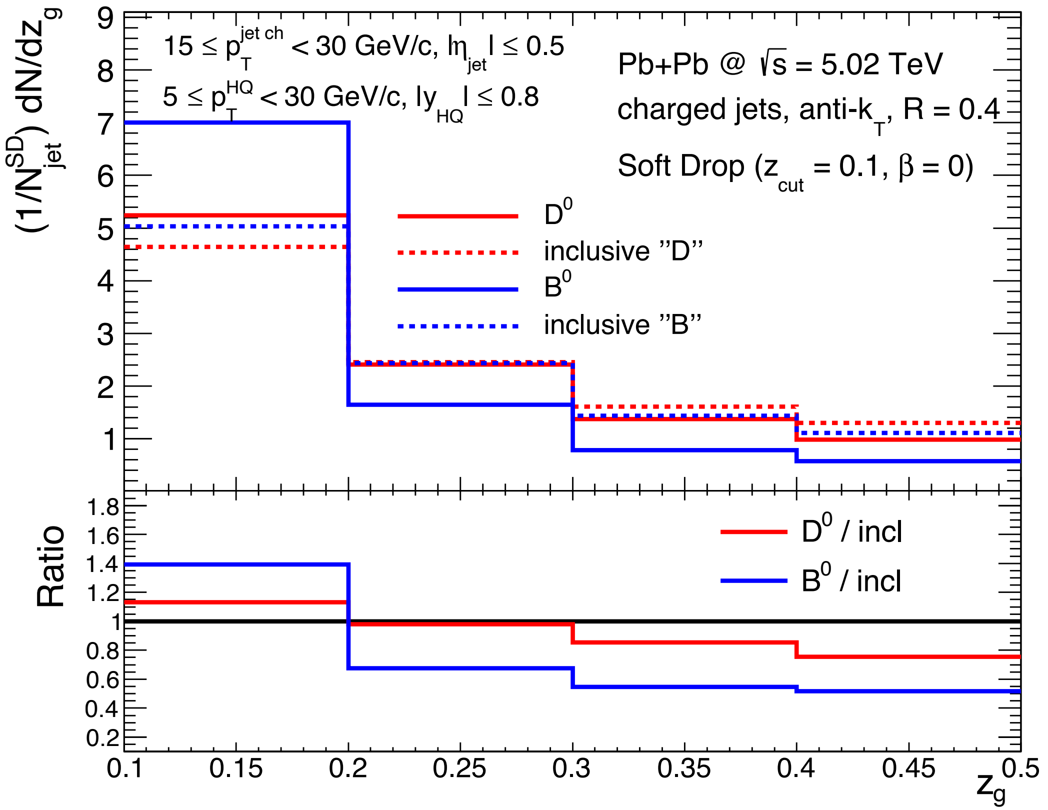
- pure light-quark initiated jets
- pure gluon initiated jets

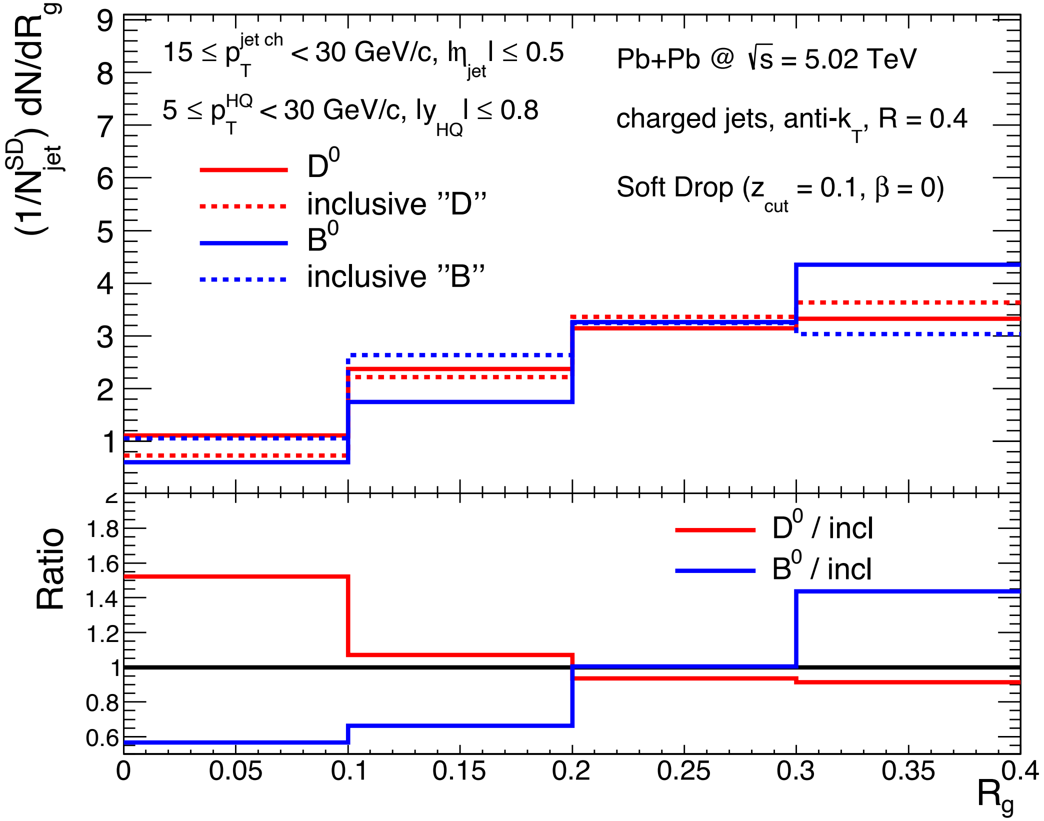




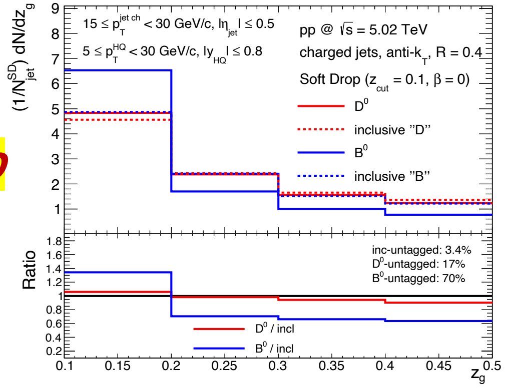
- ✓ gluon-initiated jets have wider splitting angles than quark-initiated jets due to larger Casimir color factor;
- ✓ R_g ratio of gluon jets over inclusive jets is closer to unity than that of quark jets over inclusive jets;
- ✓ mass hierarchy reemerges in the ordering of light-quark initiated, D^0-tagged jets, B^0-tagged jets.

Pb+Pb collisions at $\sqrt{s}$ = 5.02 TeV

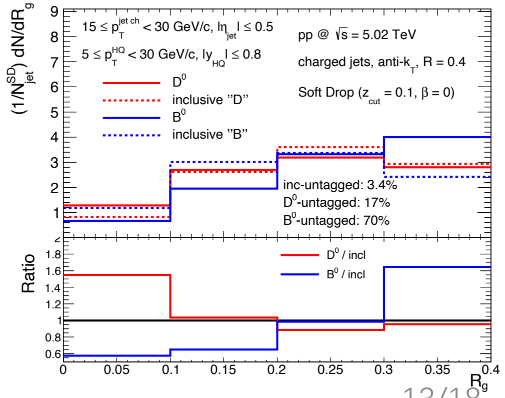




pp

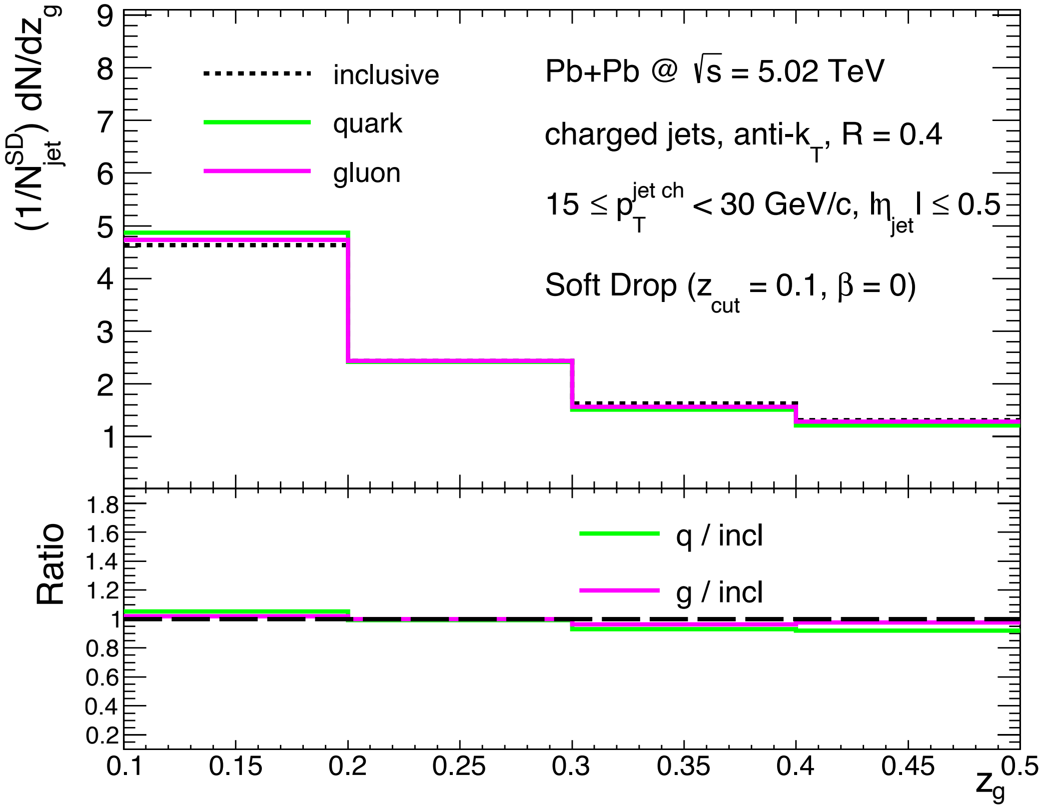


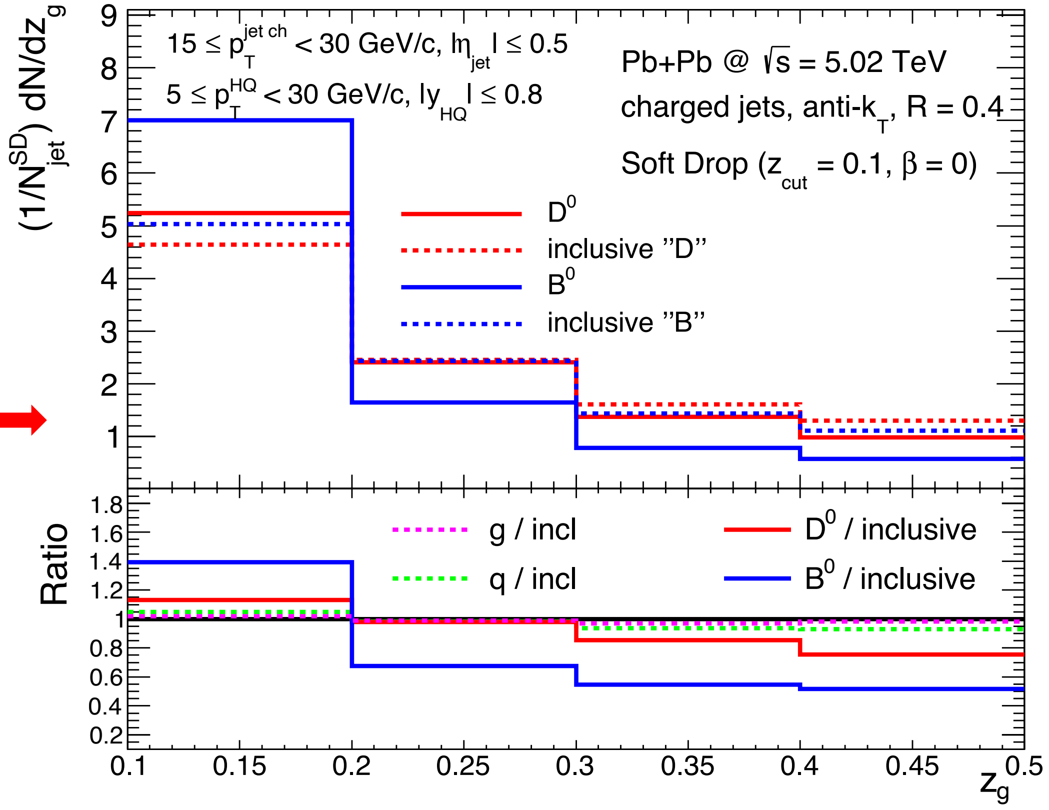
pp



① z_g distributions

- pure light-quark initiated jets
- pure gluon initiated jets



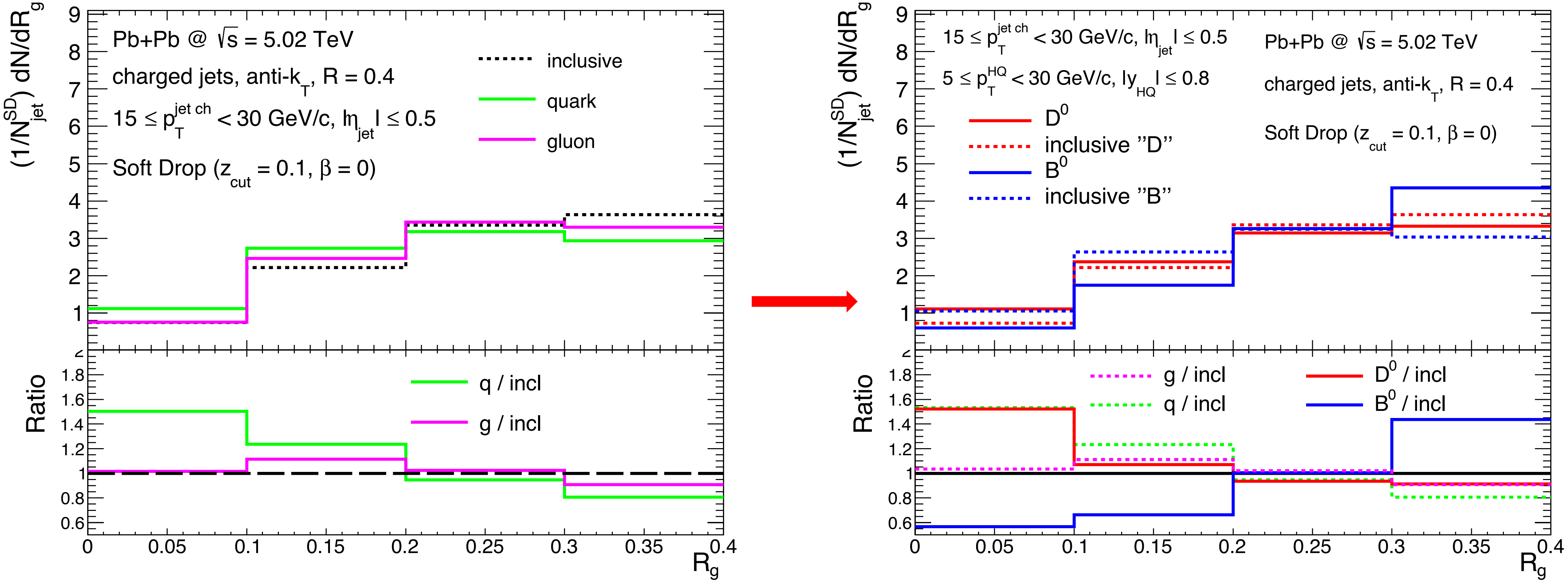


✓ Difference in Casimir color factor

✓ parton mass effects

② R_g distributions

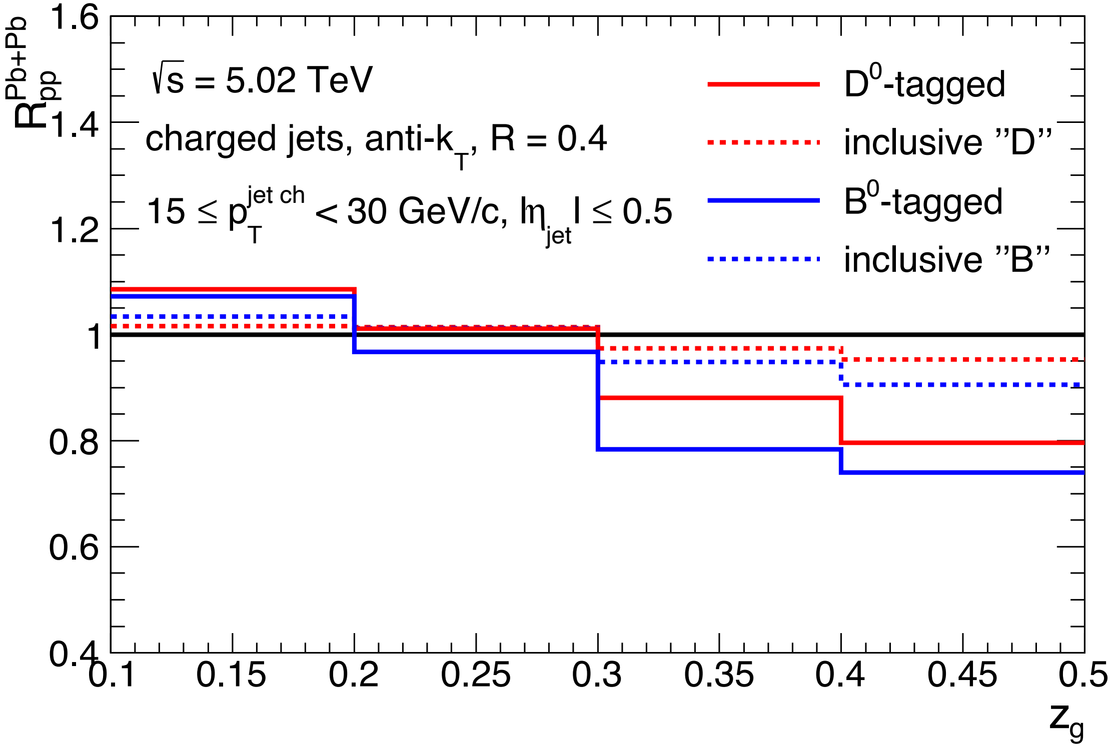
- pure light-quark initiated jets
- pure gluon initiated jets

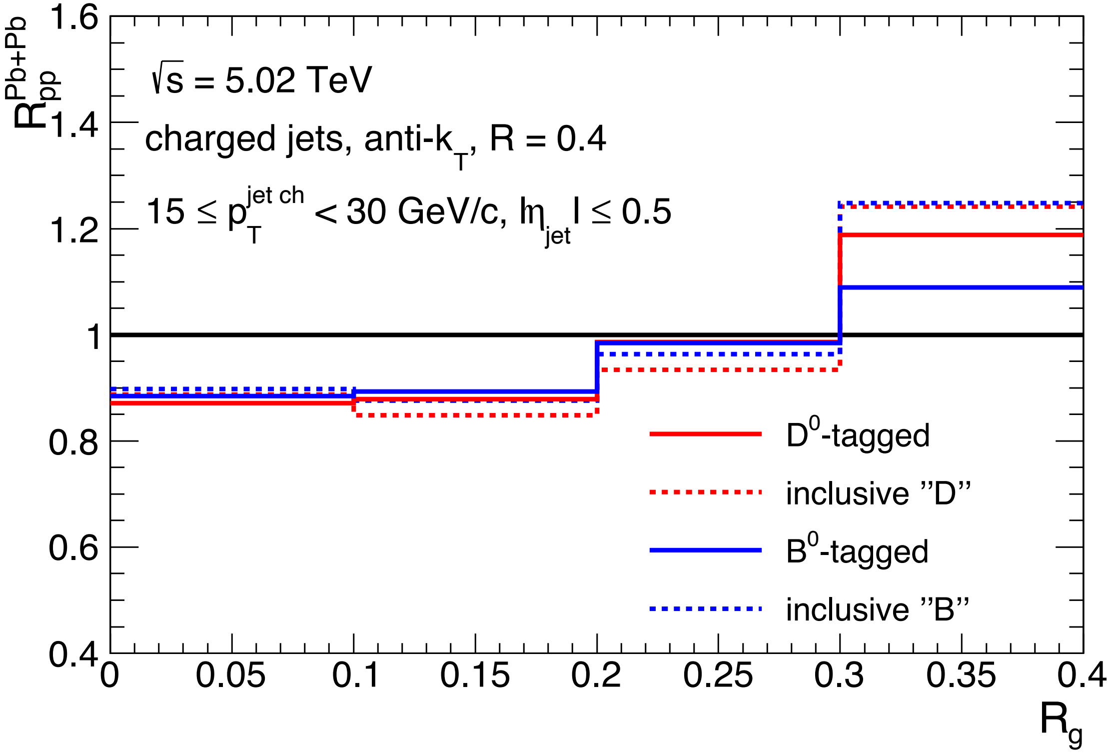


✓ Difference in Casimir color factor

✓ parton mass effect and Casimir color factor difference

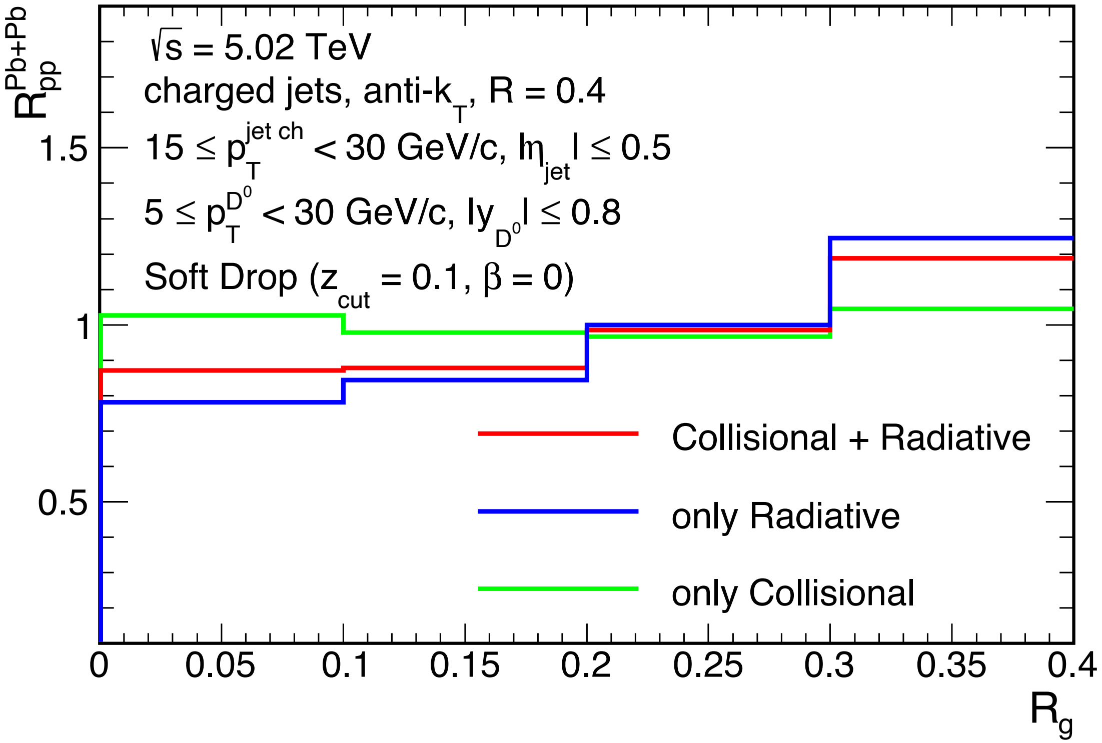
Medium Modifications: Pb+Pb/pp



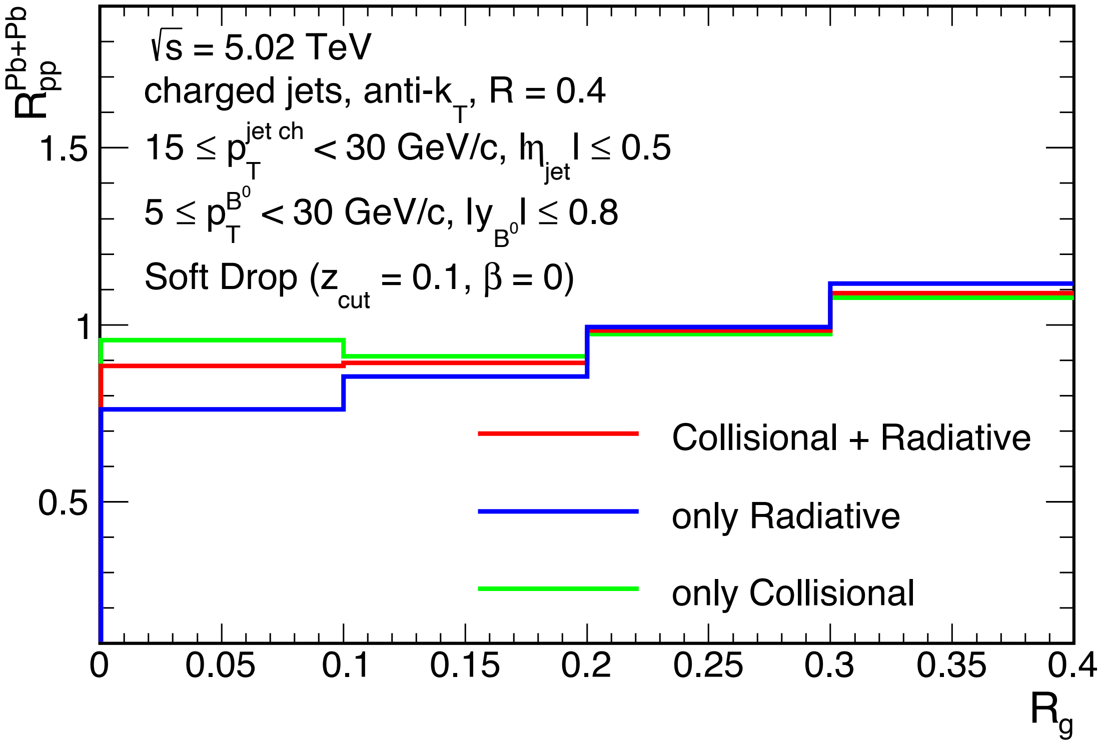


Energy Loss Mechanism

- Radiative energy loss
- Collisional energy loss



D^0-tagged jets



B^0-tagged jets

- R_g — Mostly from Rad contribution

Summary

- Predictions and analysis of $\mathbf{z_g}$ and $\mathbf{R_g}$ in pp and Pb+Pb collisions at $\sqrt{s} = 5.02$ TeV in the transverse momentum interval $15 \leqslant \mathbf{p_T^{ch}} < 30$ $\mathbf{GeV/c}$.
- In pp collisions:
  - z_g: larger the mass, less balanced the momentum fraction
  - R_g: Mass effects & Flavor effects
- Jet quenching effects:
  - Less balanced momentum
  - Wider splitting angle
- In Pb+Pb collisions:
  - z_g: mass hierarchy
  - R_g: Mass effects & Flavor effects

Thank You !