Exposing the Dead-cone Effect and Constraining In-medium Splitting Functions in Heavy Ion Collisions

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outline

Uncovering the QCD Dead-cone

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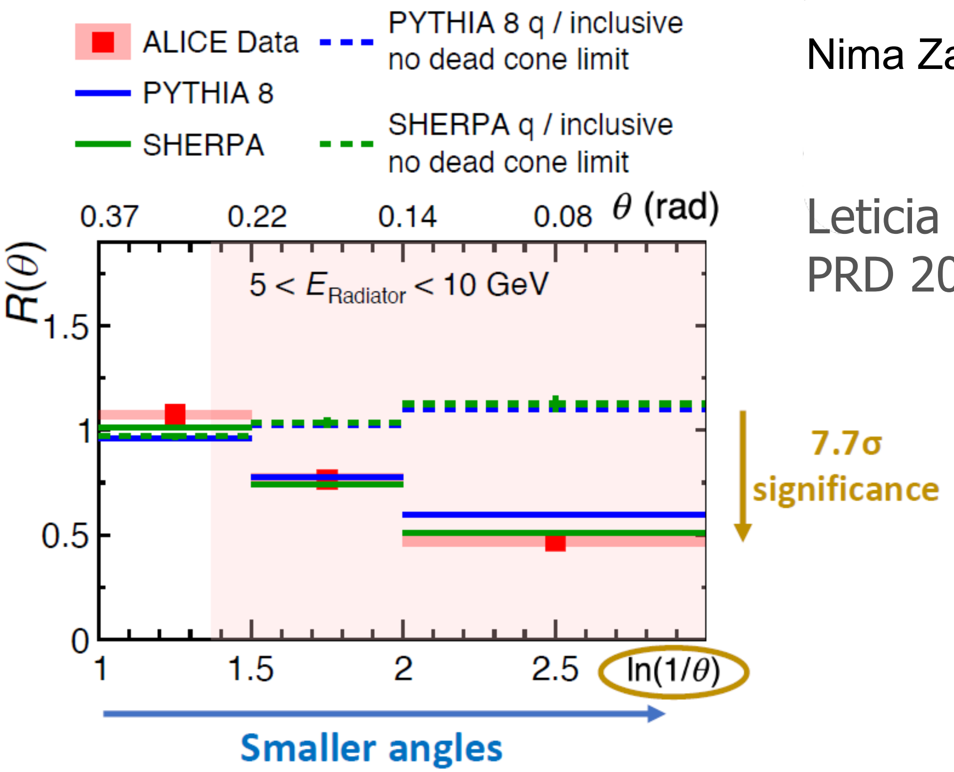

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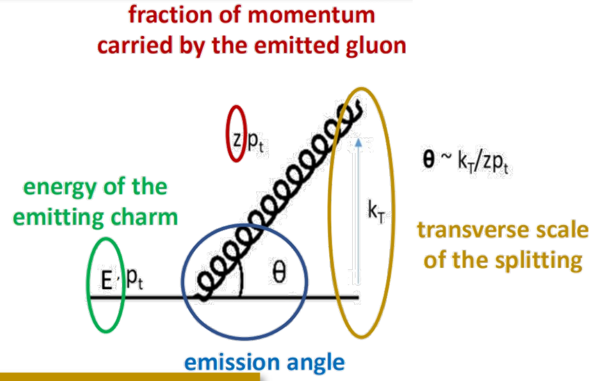


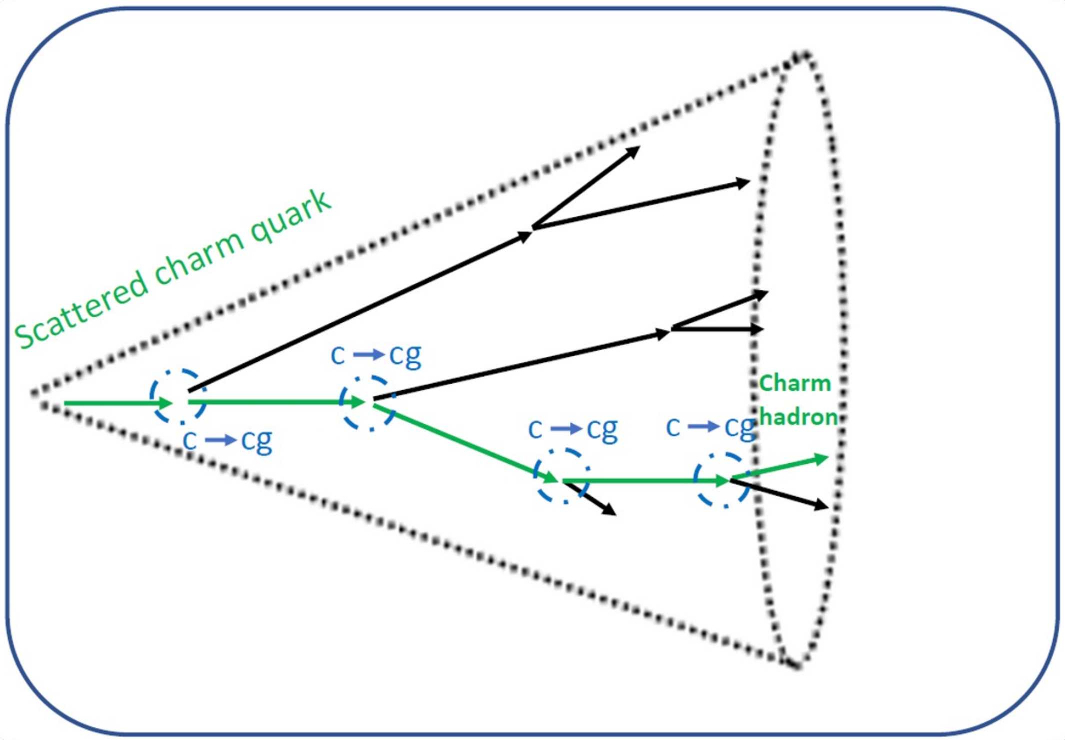
The dead cone is uncovered through a direct measurement of the emission angle

Small angle emissions supressed for charm quarks compared to light quarks and gluons

$$R(\theta) = \frac{1}{N^{\mathrm{D^0\,jets}}} \frac{\mathrm{d}n^{\mathrm{D^0\,jets}}}{\mathrm{d}\ln(1/\theta)} \Big/ \frac{1}{N^{\mathrm{inclusive\,jets}}} \frac{\mathrm{d}n^{\mathrm{inclusive\,jets}}}{\mathrm{d}\ln(1/\theta)} \Bigg|_{k_{\mathrm{T}},\, E_{\mathrm{Radiator}}}$$

Compare the angular distribution of charm-quark emissions to those of light quarks and gluons

Key Features for Dead-Cone Observation



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Specific transverse momentum of charged jets (mass effect plays an important role);

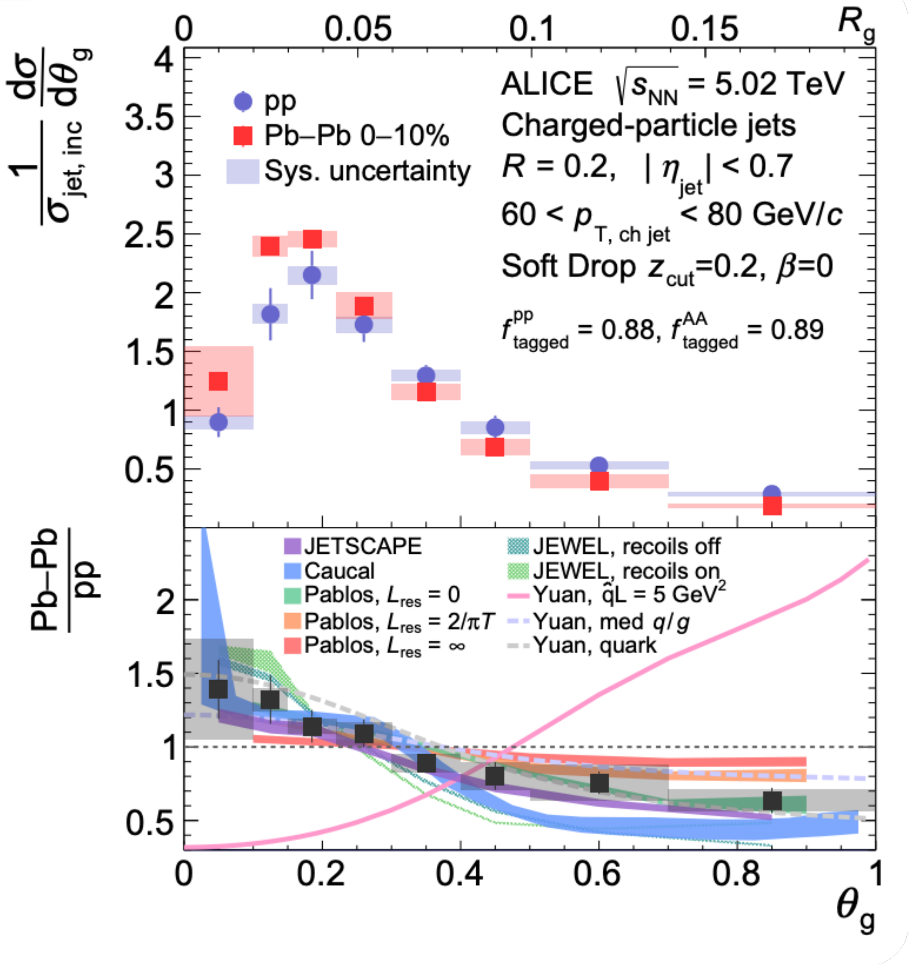
De-clustering method can reveal the most basic splitting structure in a vacuum from final state jets;

Tracking the hardest branches, then the splitting angle (emission angle) can be calculated;

The radiator’s energy, emission angle, and transfer scale are proposed as observables;

Dead-cone Effect: a long-telling theoretical story is first and directly manifest in measurements.

Groomed jet radius in A+A



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Why jet quenching will lead the jets to be wider?

Can measurements be closer to the QCD processes?

Can there be splitting observables for jet quenching?

Motivation

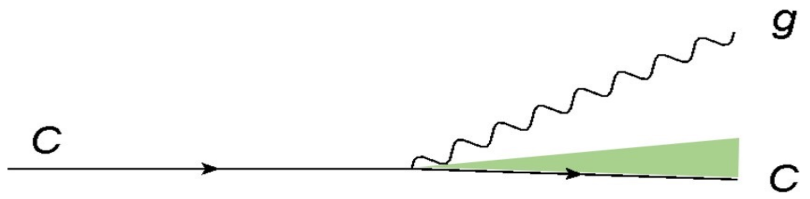
1. What is it like for the QGP medium-modified basic splitting structures;

2. The declustering method used in a vacuum is still helping when revealing medium-modified structure?

3. Can the Dead-cone effect in jet quenching still be directly observed using the exact same method ?

4. Can the splitting observable better constrain the jet quenching models since it is even closer to the basic processes?

Theoretical Definition of Dead-cone



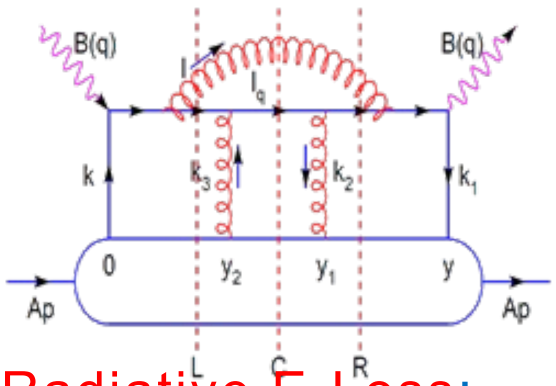
Gluon radiation , with dead-cone
Angle $\theta = m/E$

bremsstrahlung radiation spectrum
off a light quark in vacuum:

$$dP_0 \simeq \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{dk_\perp^2}{k_\perp^2}$$

radiated gluon spectrum off a heavy quark in vacuum:

$$dP_{HQ} \simeq \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{k_\perp^2 dk_\perp^2}{(k_\perp^2+\omega^2\theta_0^2)^2} = dP_0\left(1+\frac{\theta_0^2}{\theta^2}\right)^2$$



In Medium Radiative E-Loss:

higher-twist approach implemented both in SHELL and LBT

$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2\alpha_s P(x)\hat{q}}{\pi k_\perp^4} Sin^2\left(\frac{t-t_i}{2\tau_f}\right)\left(\frac{k_\perp^2}{k_\perp^2+x^2M^2}\right)^4$$

$$k_\perp = \omega\theta$$
$$\omega = xE$$

$$f_{Q/q} = \left(1+\frac{\theta_0^2}{\theta^2}\right)^{-4}$$

SHELL : in-medium E-loss Collisional

- For heavy quark, the discrete Langevin transport equations are used to describe the propagating of HQ in the QGP.[Phys.Rev. C71 (2005) 064904, Eur.Phys.J. C71 (2011) 1666, Phys.Rev. C88 (2013) 044907].

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

$$\vec{p}(t+\Delta t) = \vec{p}(t) - \Gamma(p)\vec{p}\Delta t + \vec{\xi}(t)\Delta t$$

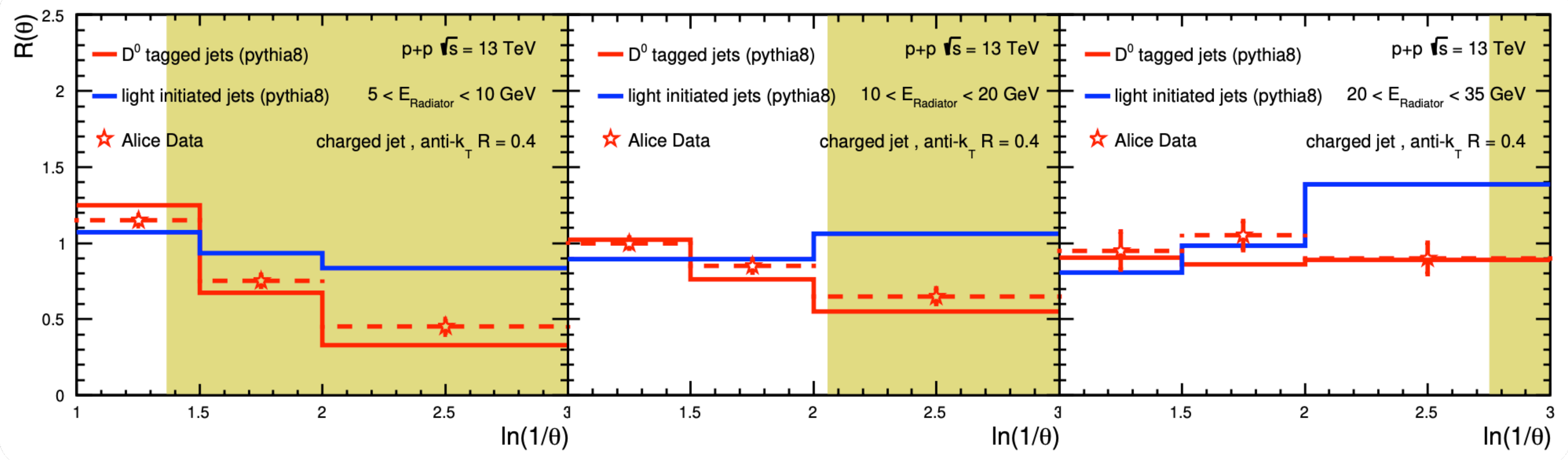
The fluctuation-dissipation relation $\kappa = 2ET\Gamma = \frac{2T^2}{D_s}$. Based on the LQCD calculation [Phys.Rev. D92 (2015) no.11, 116003], D_s is fixed at $2\pi T D_s = 4$.

- For light parton, the collisional energy loss is described by the calculation at Hard Thermal Loop (HTL) approximation.[Phys.Rev. D83 (2011) 065012, Phys.Lett. B726 (2013) 251-256].

$$\frac{dE}{dz} = \frac{\alpha_s C_i m_D^2}{2} ln \frac{\sqrt{ET}}{m_D}$$

- Evolution of the bulk medium is produced by the iEBE-VISHNU hydro model[Comput.Phys.Commun. 199 (2016) 61-85].

P+P Set-tups



$$R(\theta) = \frac{1}{N^{D^0 jets}} \frac{dn^{D^0 jets}}{dln(1/\theta)} / \frac{1}{N^{inclusive\ jets}} \frac{dn^{inclusive\ jets}}{dln(1/\theta)} \Big|_{k_T, E_{Radiator}}$$

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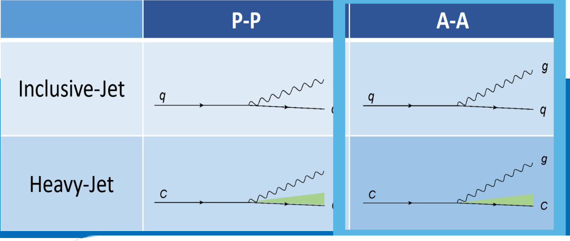
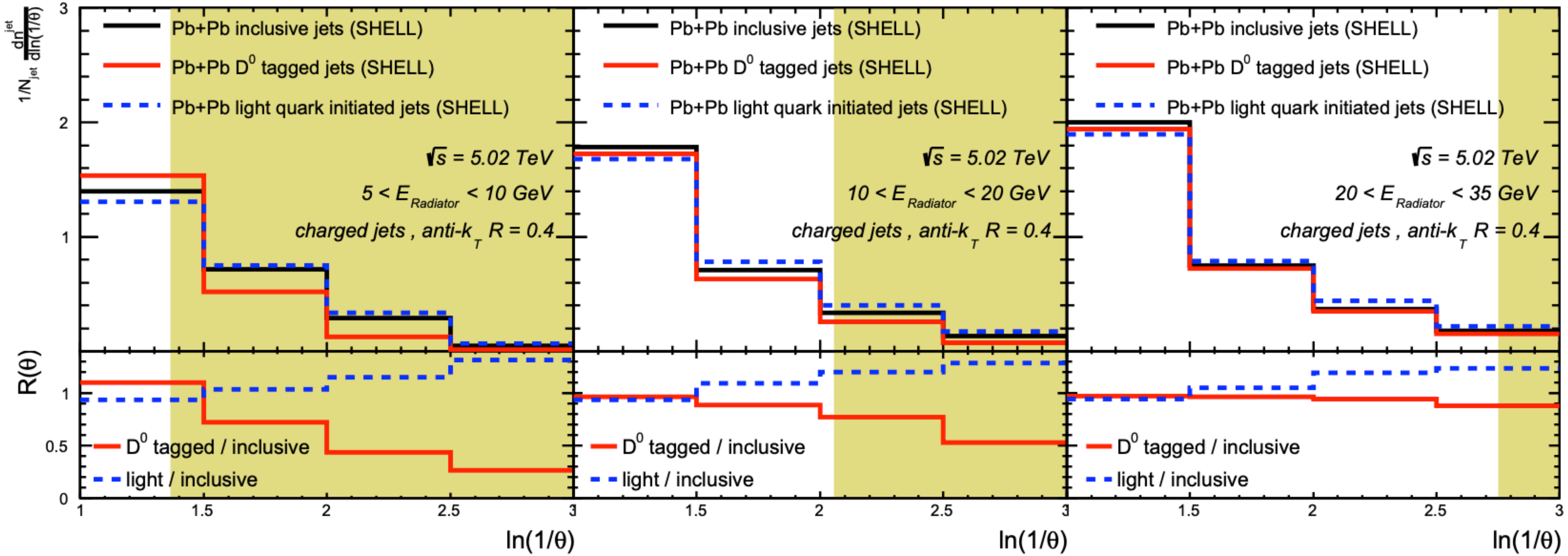
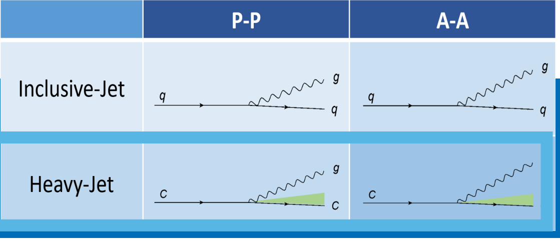


Dead-Cone exposure in A+A

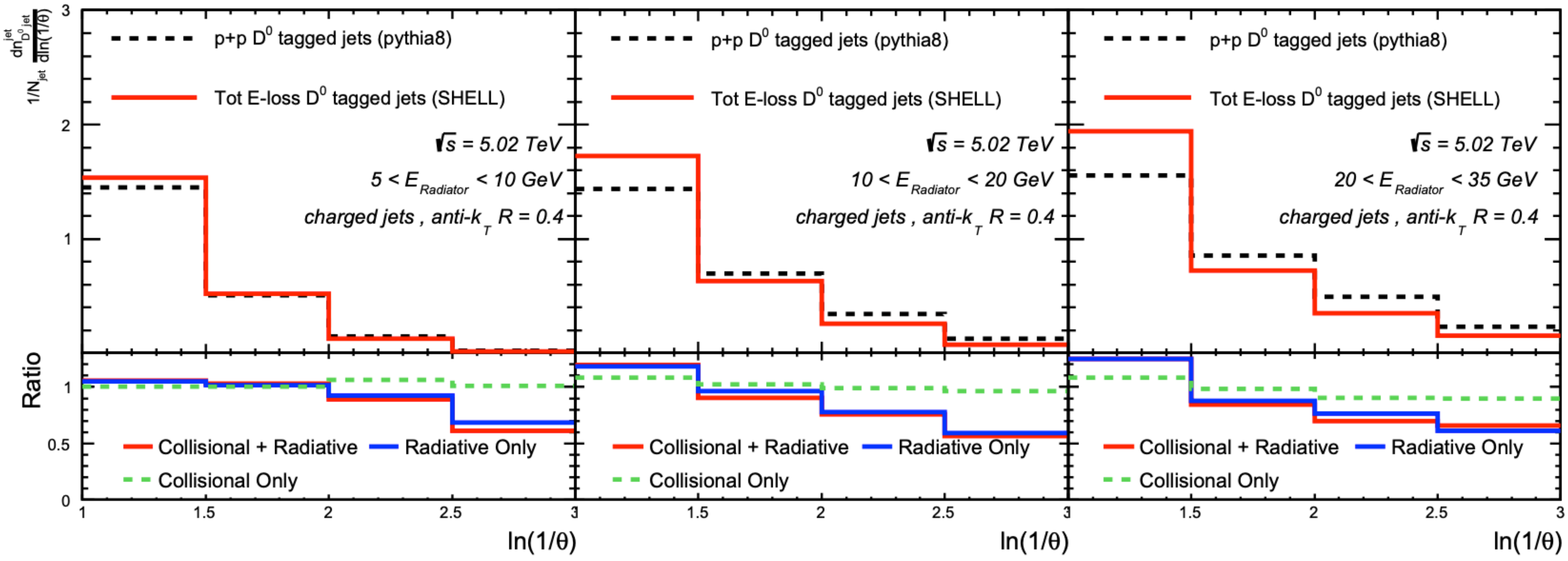


Similar suppression at the $\theta_{dc} < m_c/E_{Radiator}$ regions as in the case of p+p is observed.

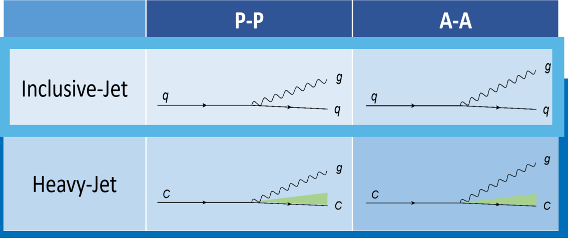
Such suppression begins to vanish when the energy of the radiator increases



The splitting structures in A+A : I



The collisional energy loss mechanism has a negligible impact on the medium modification to the emission angle distribution of the charm-quark initiated splittings for D0 meson-tagged jets.



The splitting structures in A+A: II

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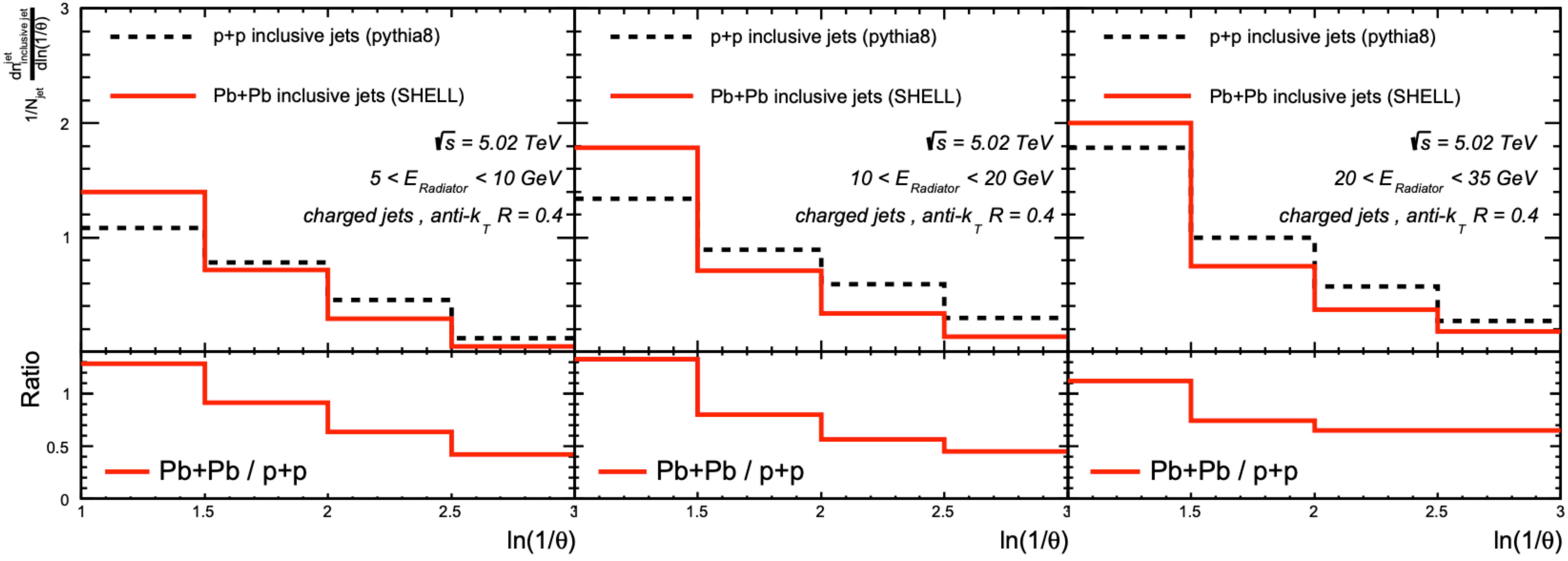

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Comparison of $< \theta >$

Normalized To Number Of Jet

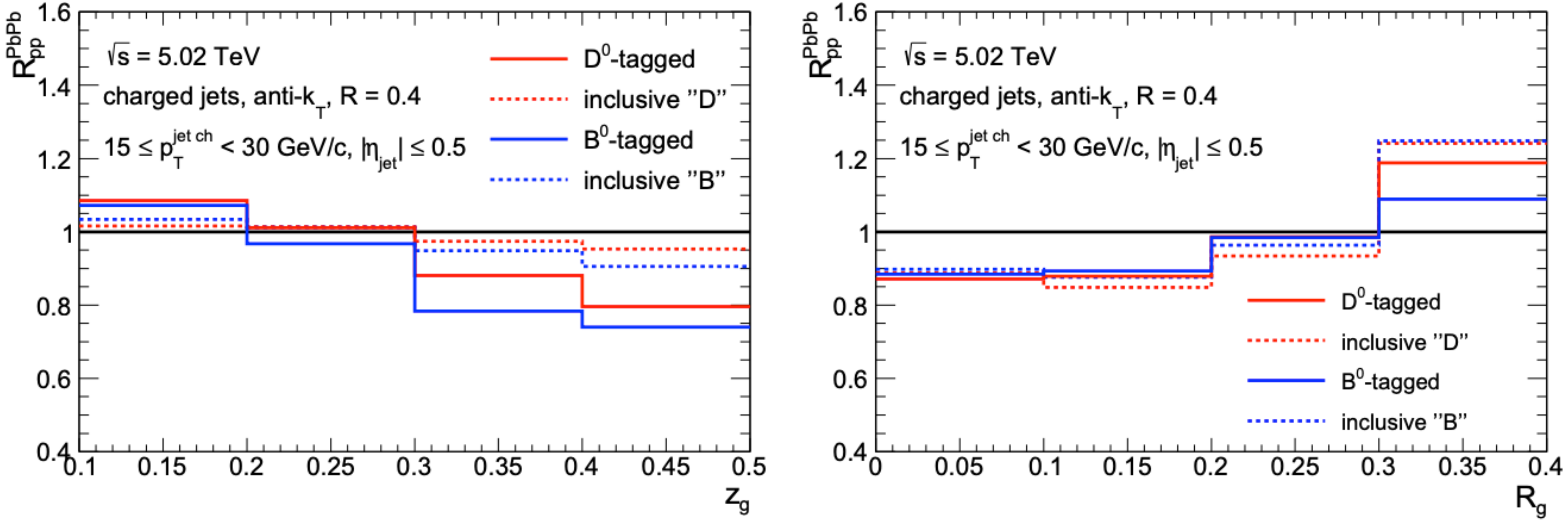
E_{Radiator}	Inclusive jets $\langle\theta\rangle_{\text{jets}}$	D^0 jets $\langle\theta\rangle_{\text{jets}}$	
5 – 10 GeV	0.31	0.34	pp
	0.36	0.36	AA
10 – 20 GeV	0.40	0.37	pp
	0.45	0.42	AA
20 – 35 GeV	0.47	0.42	pp
	0.49	0.47	AA

Normalized To Number Of Splitting

E_{Radiator}	Inclusive jets		D^0 jets		
	$\langle\theta\rangle_{\text{spl}}$	N_{spl}	$\langle\theta\rangle_{\text{spl}}$	N_{spl}	
5 – 10 GeV	0.227	1.358	0.277	1.233	pp
	0.256	1.405	0.280	1.280	AA
10 – 20 GeV	0.220	1.810	0.244	1.510	pp
	0.254	1.757	0.263	1.600	AA
20 – 35 GeV	0.232	2.040	0.232	1.822	pp
	0.249	1.977	0.251	1.860	AA

The story of the dead-cone phenomenon affecting heavy flavor is that the probability of heavy quark emitting gluon at a smaller angle is largely suppressed due to the dead-cone effect, leading it to be distributed at a larger angle. However, the possibility of emitting such gluon is suppressed due to this mass effect.

Jet quenching in such same groomed jets



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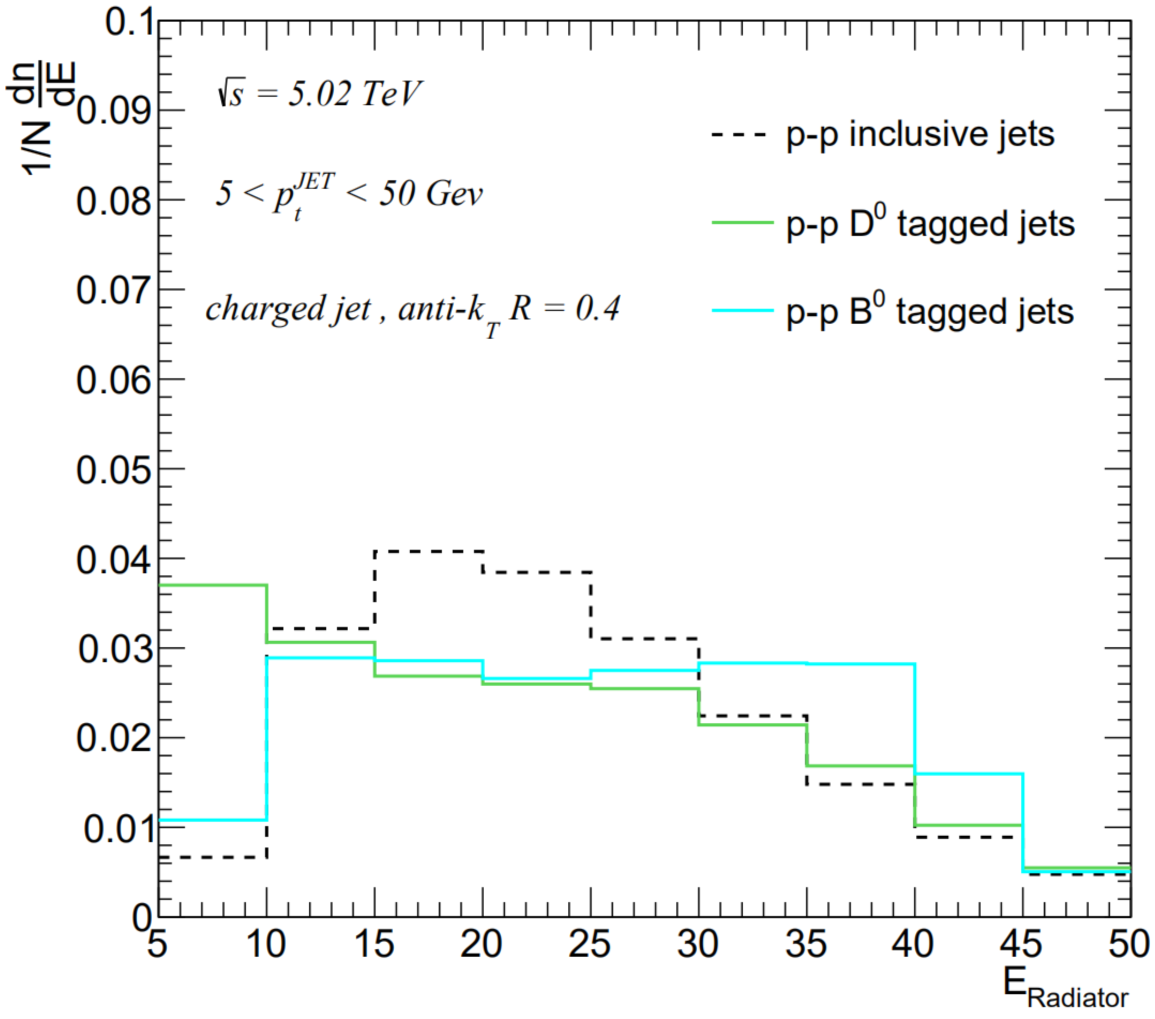
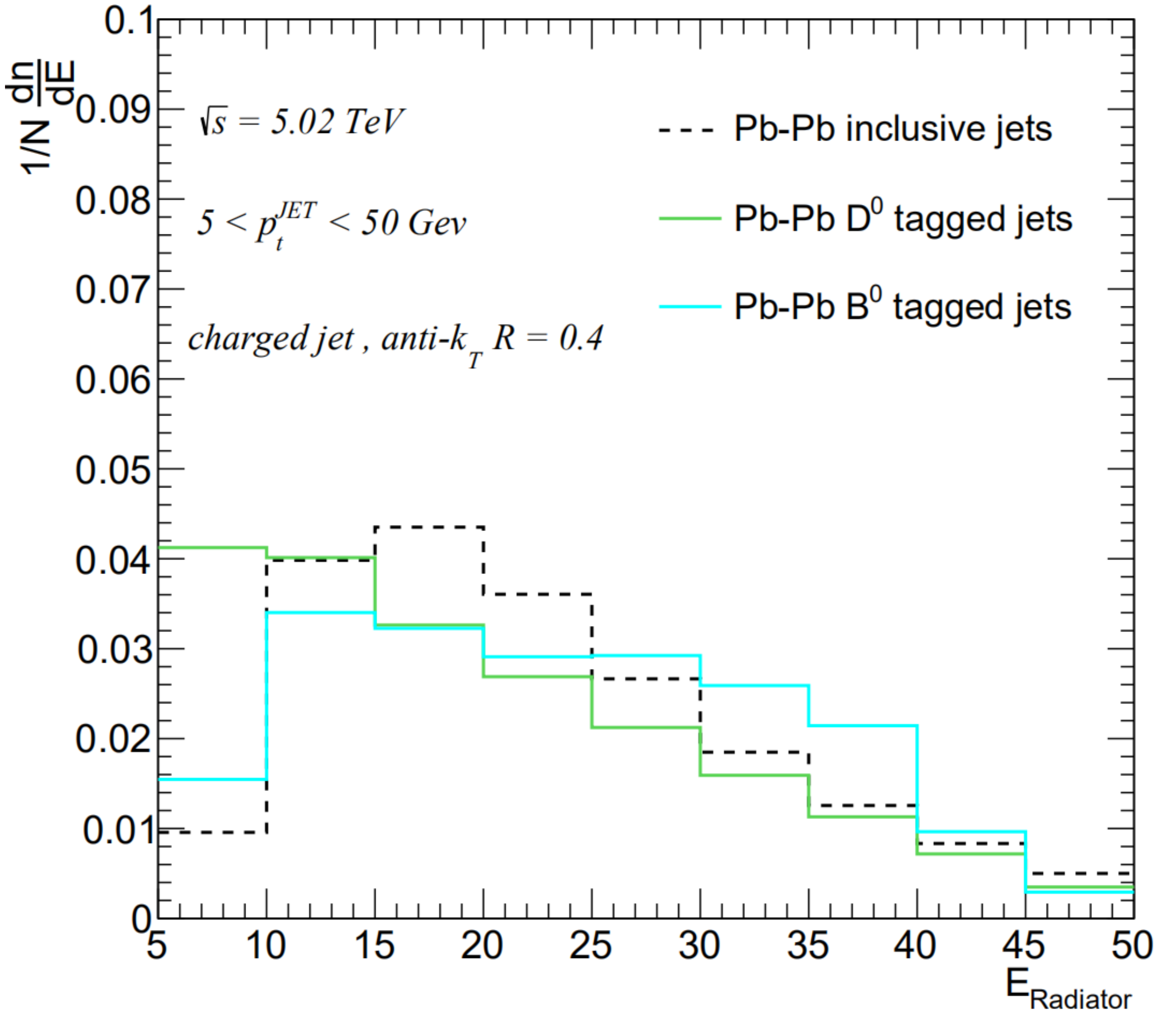
Detailed jet quenching in splittings





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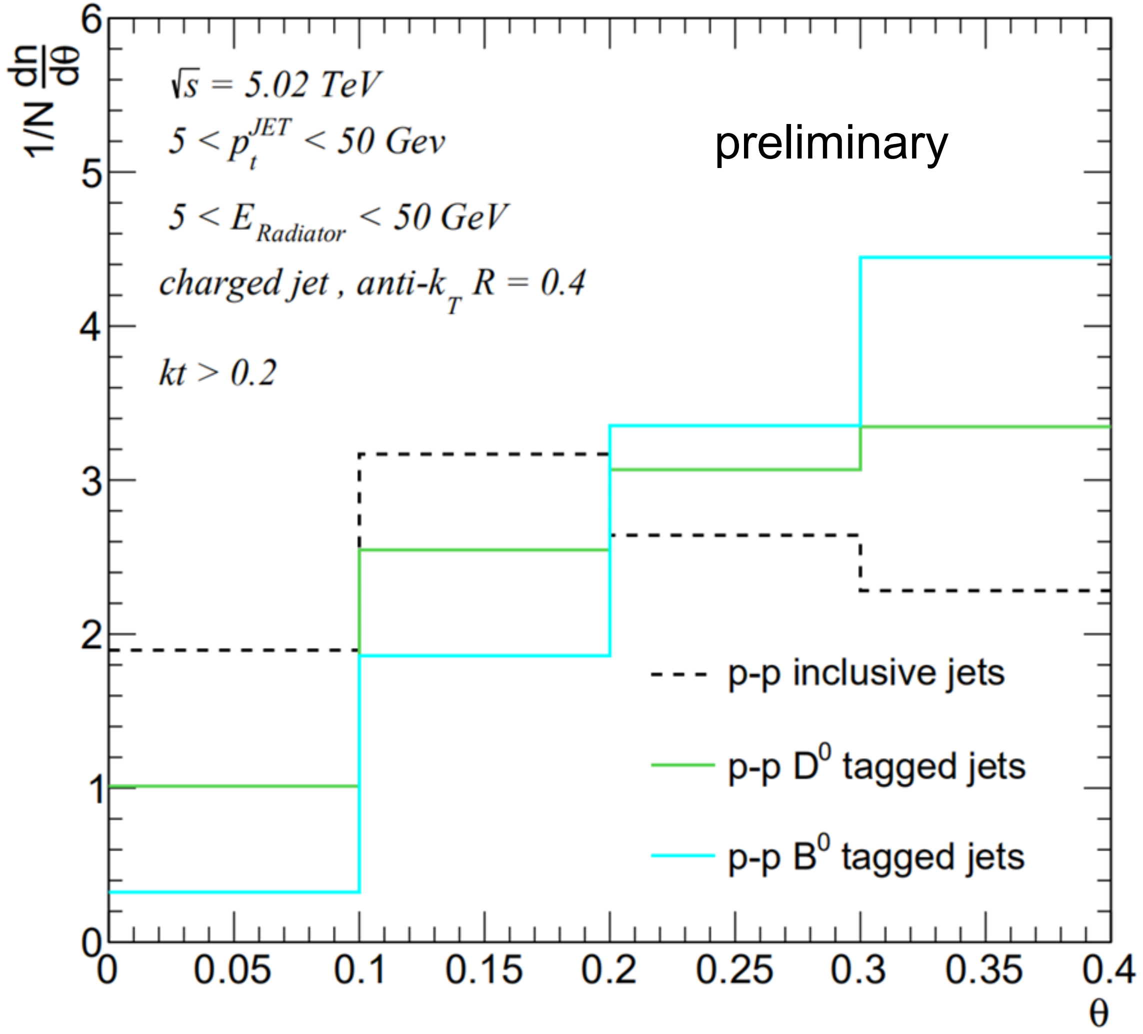

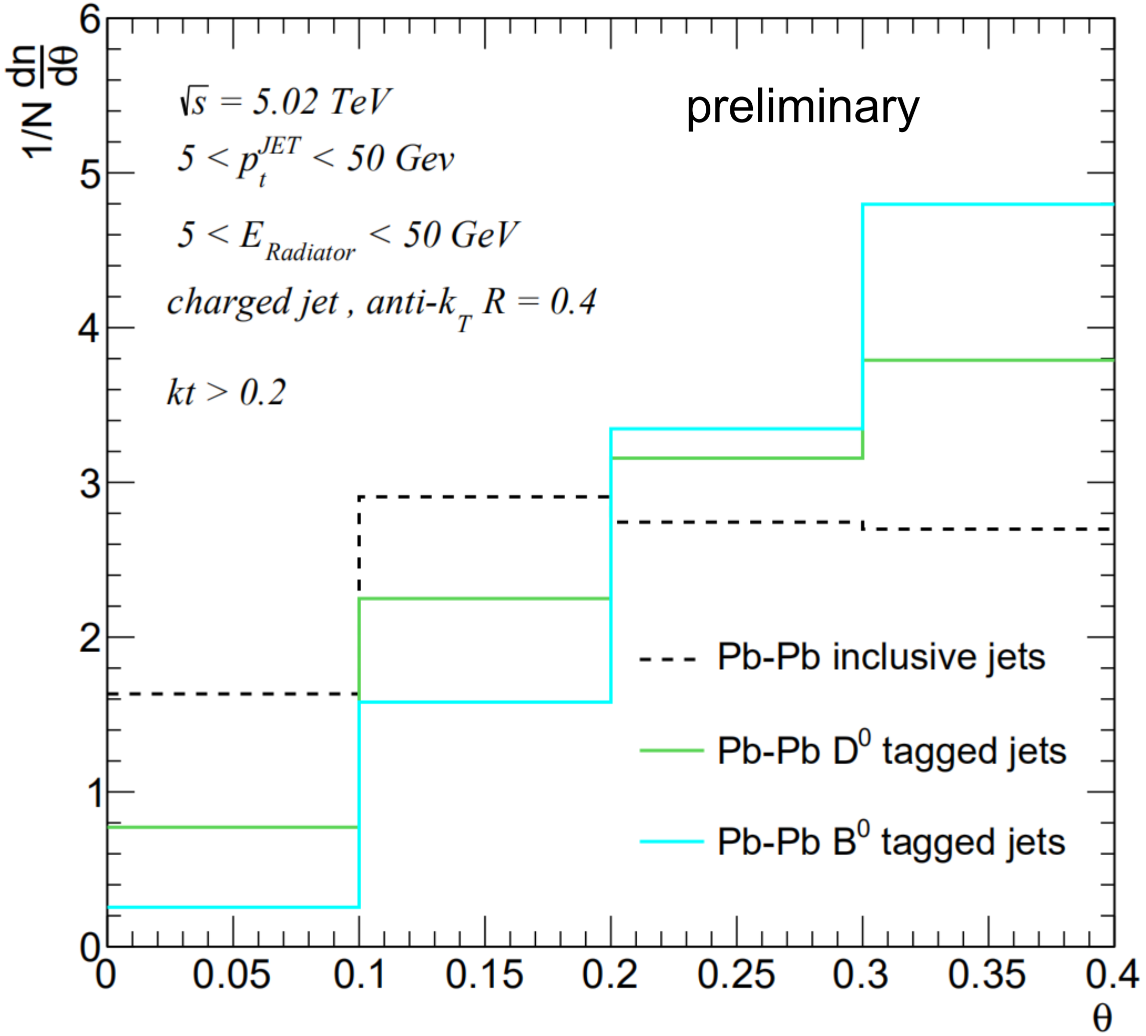

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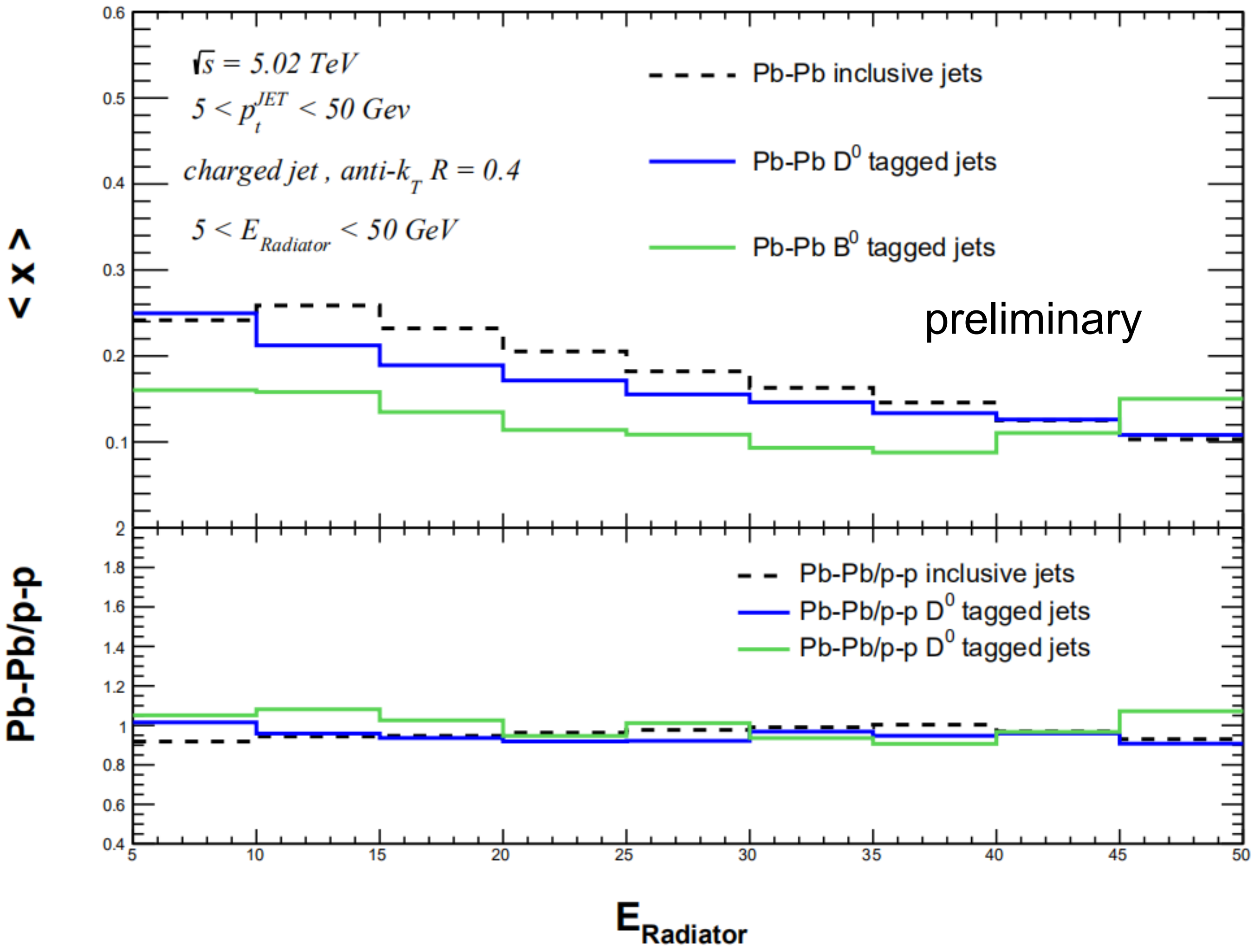
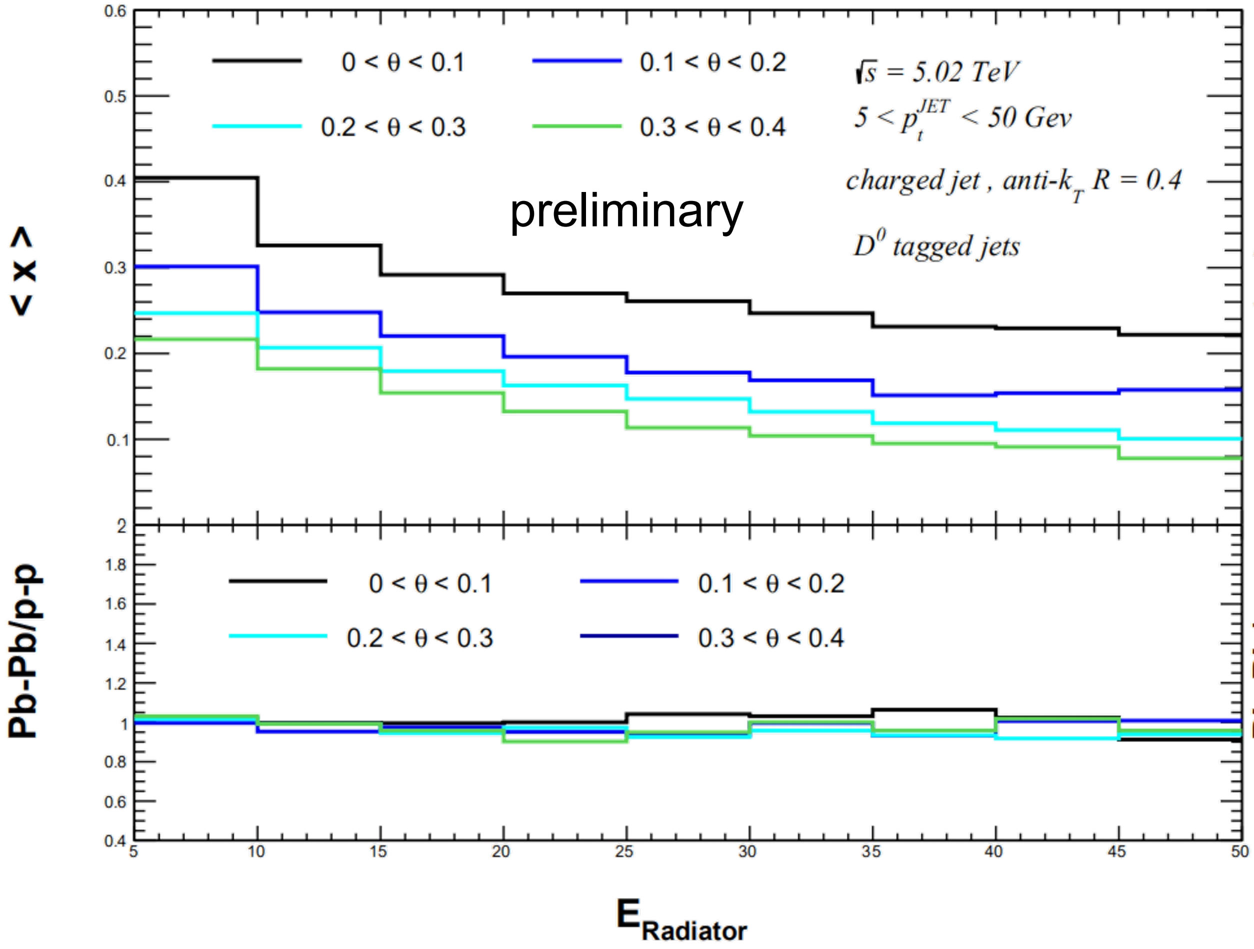
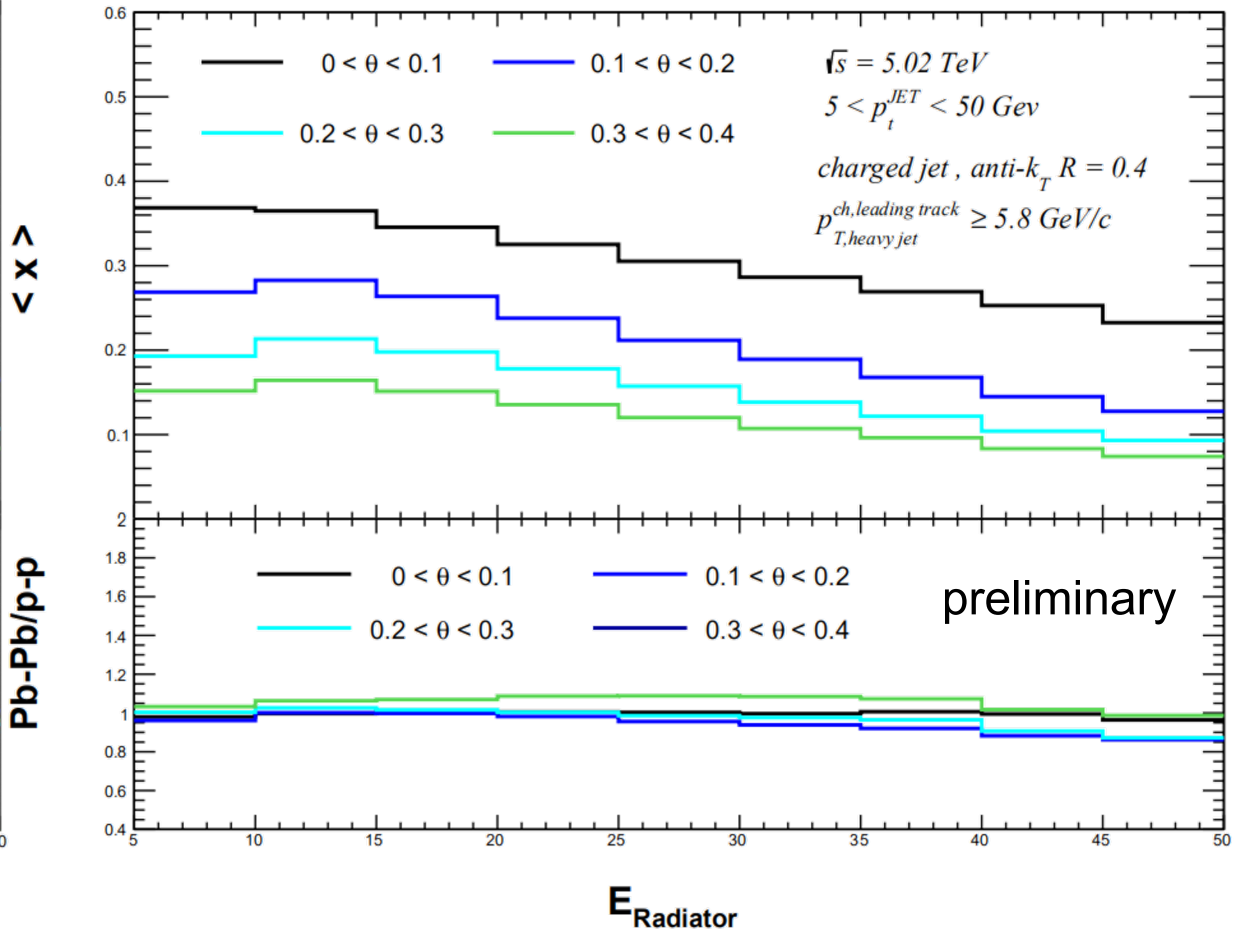


Detailed jet quenching in splittings





Conclusion

1. The dead-cone effect will broaden the emission angle of the splitting and reduce the possibility to occur such splitting, therefore leading the massive parton to lose less energy.

2. The dead-cone effect in medium-induced radiation can be directly observed.

3. The collisional energy loss mechanism will not compromise such observation.

4. The splitting observables provide insights of the details of the jet quenching and can be used to test against jet quenching models.

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Thanks