The 1st Workshop on Jet and Heavy Quark Physics (JAQ2026)

Probing jet angular broadening and its flavor/mass dependence in heavy-ion collisions

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2026/01/24 Wuhan

Outline

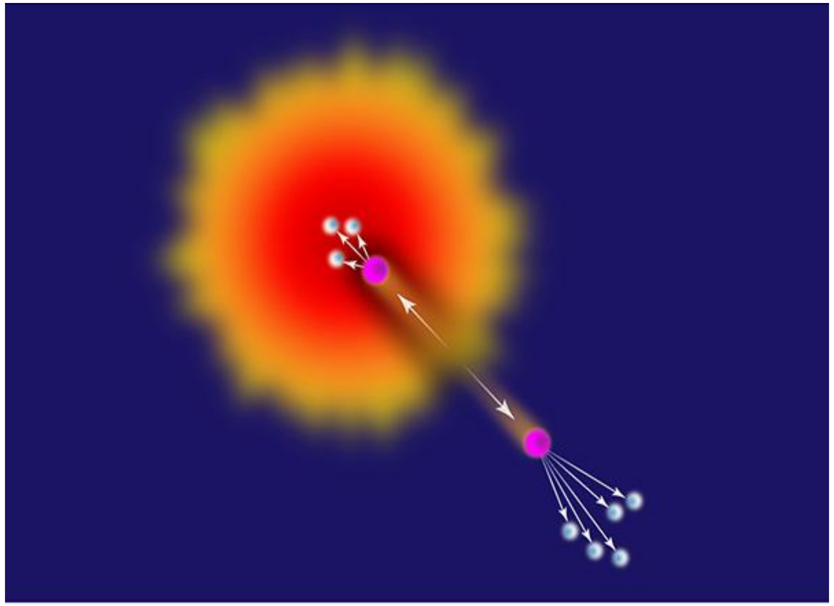
1 Background and motivation

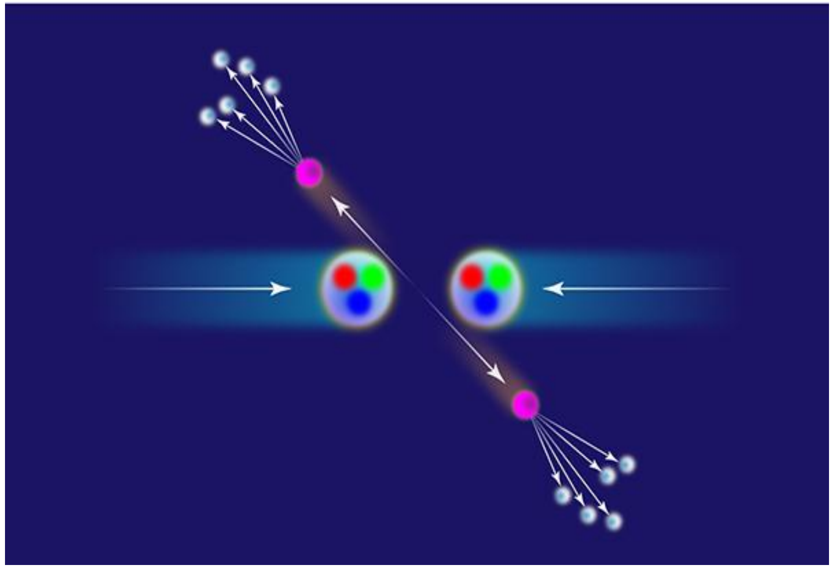
2 Theoretical framework

3 Results and discussion

4 Summary and outlook

Jet-QGP interactions

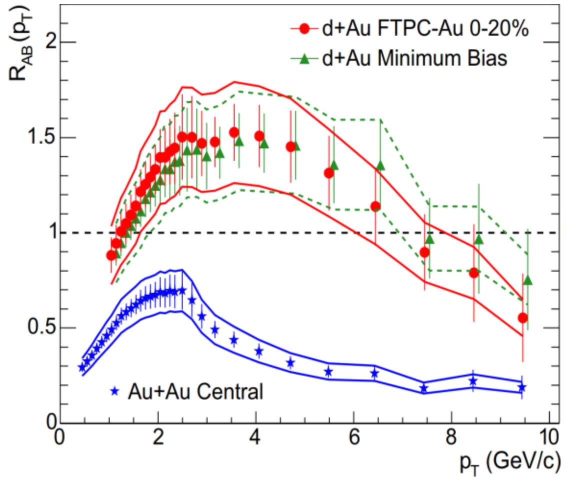


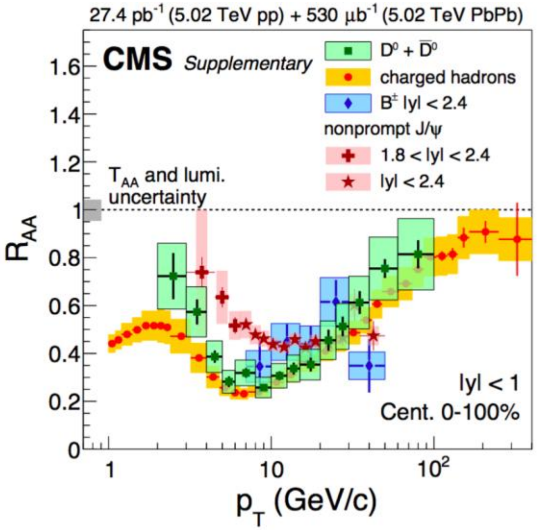


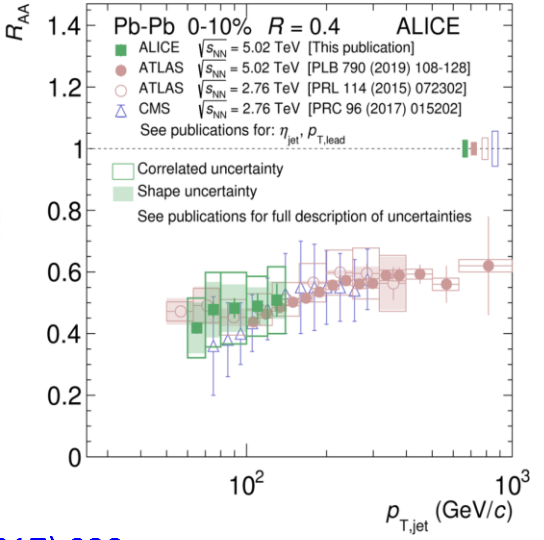
Jet transport coefficient : $\hat{q} = \frac{\mathrm{d}\langle p_\perp^2 \rangle}{\mathrm{d}t}$

Energy loss : $\frac{\mathrm{d}E}{dt}$

p_T-broadening : $\frac{\mathrm{d}p_\perp}{dt}$

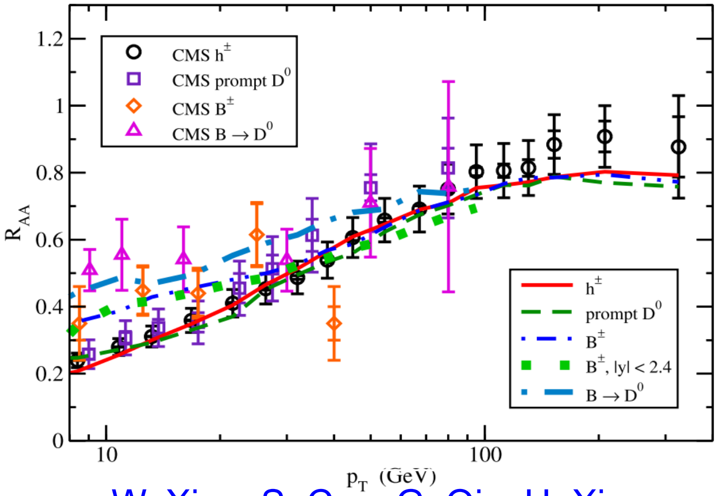




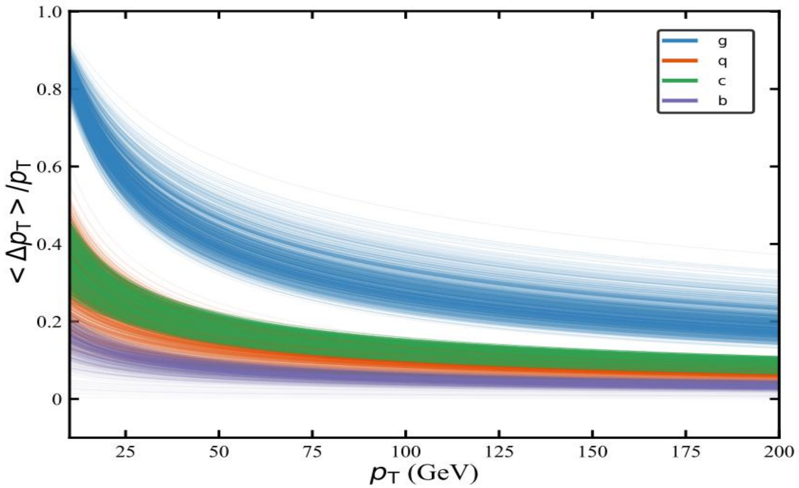


STAR, PRL 91(2003)072304
CMS, PRL 119 (2017) 152301
ATLAS, PLB 790 (2019) 108-128
ATLAS, PRL 114 (2015) 072302
CMS, JHEP 04 (2017) 039
CMS, PLB 782 (2018) 474
CMS, PRC 96(2017) 015202

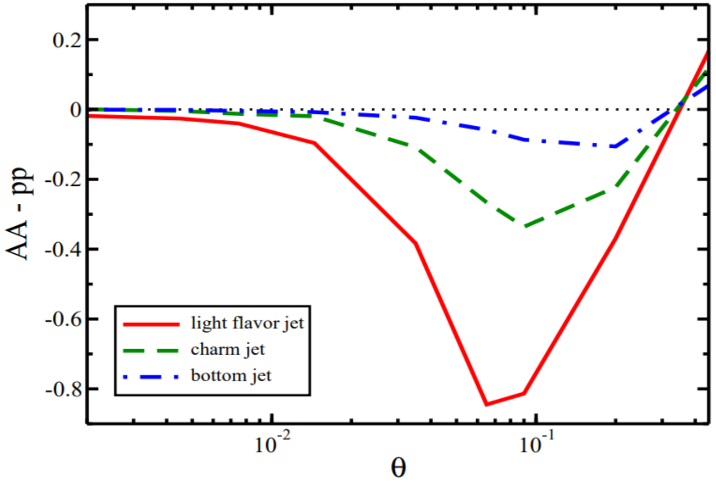
Mass hierarchy of jet energy loss



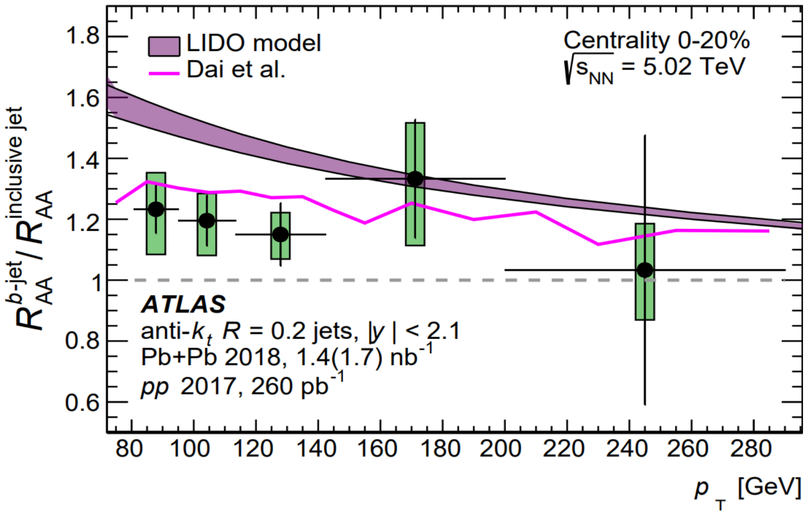
W. Xing, S. Cao, G. Qin, H. Xing, PLB (2020)



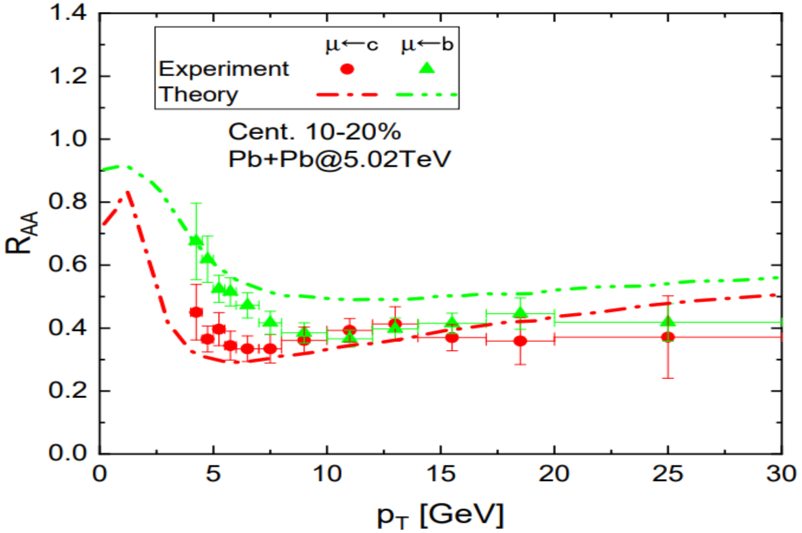
S. Zhang, J. Liao, G. Qin, E. Wang, H. Xing, Sci.Bull. (2023)



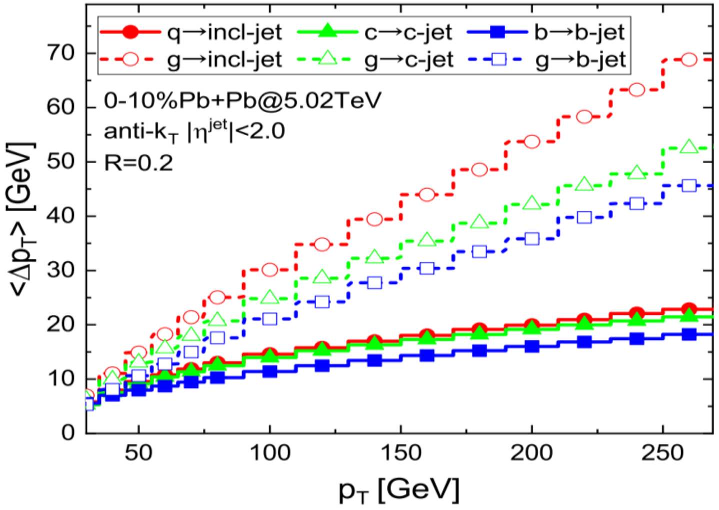
W. Xing, S. Cao, G. Qin, X.N. Wang, PRL (2025)



ATLAS, EPJC(2023)



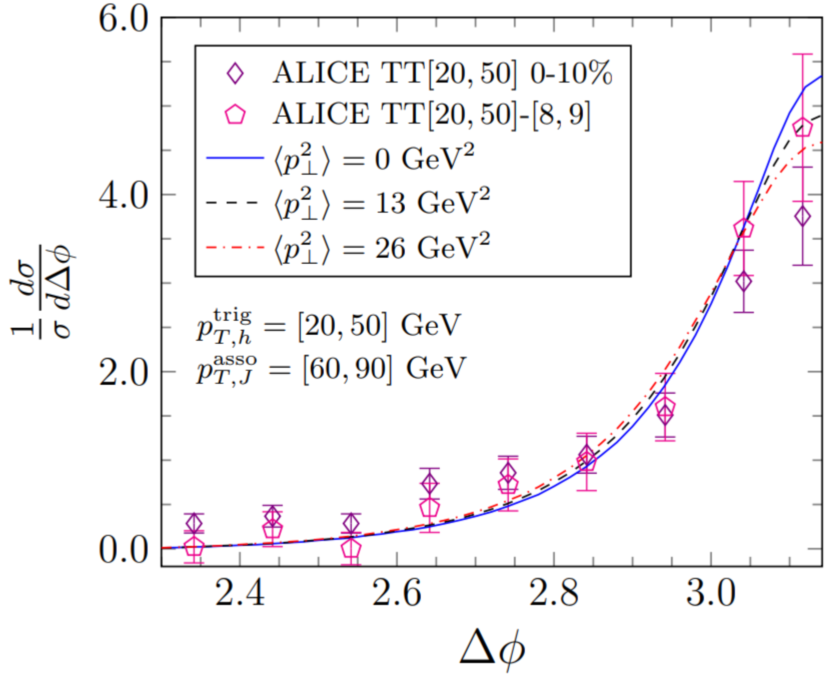
S. Wang, B.W. Zhang, E.K. Wang, PRC(2025)



S. Wang, S. Li, Y. Li, B.W. Zhang, E.K. Wang, CPC(2025)

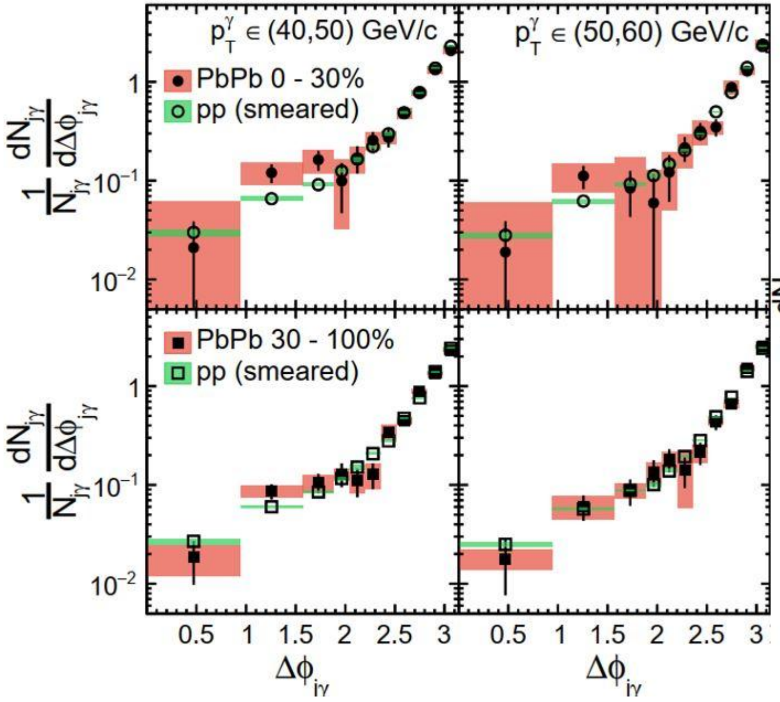
Probing jet broadening with angular correlations

dijet



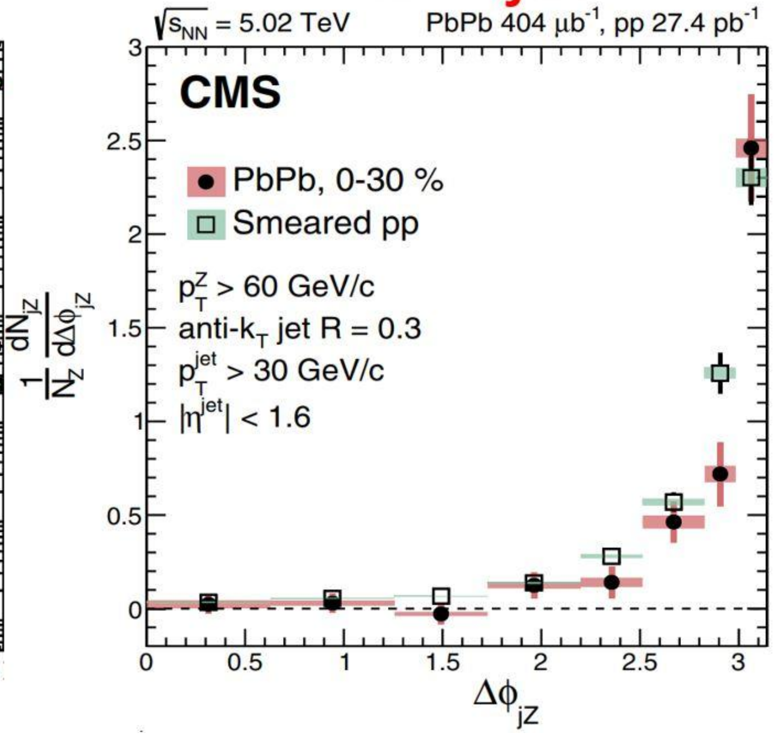
ALICE, JHEP (2015) 170
L. Chen, G.-Y. Qin, S.-Y. Wei,
B.-W. Xiao, H.-Z. Zhang, PLB (2017)

photon+jet



CMS, PLB (2018)
CMS, PLB (2013)

Z^0+jet



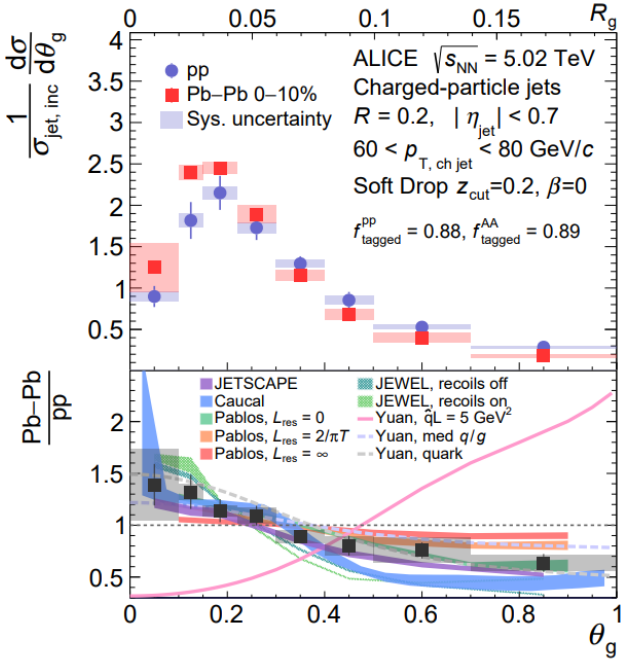
CMS, PRL (2017)

No significant nuclear modification of jet angular correlations!

Probing intra-broadening with jet substructures

Groomed radius

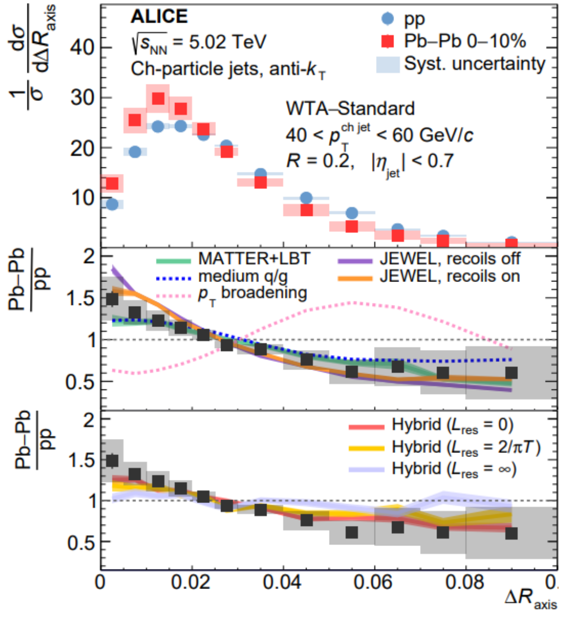
$$\frac{\min(p_{T,1}, p_{T,2})}{p_{T,1}+p_{T,2}} > z_{cut}\left(\frac{\Delta R_{1,2}}{R}\right)^{\beta}$$



[ALICE, PRL(2022)](#)

Angle between jet axis

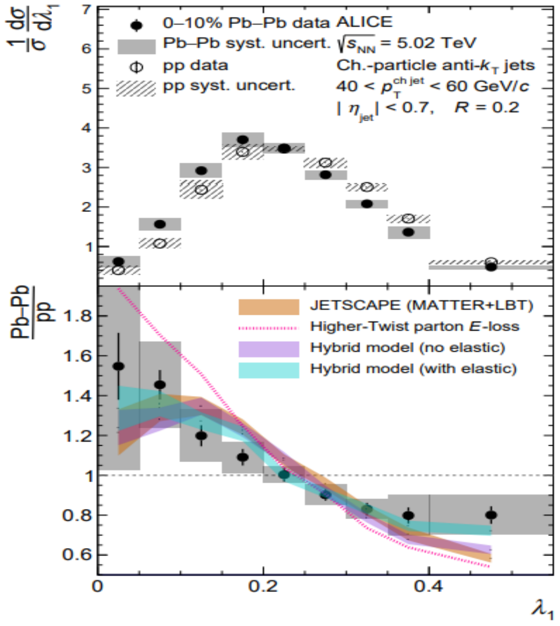
$$\Delta R^{a-b}_{axis} = \sqrt{(y^a_{axis} - y^b_{axis})^2 + (\phi^a_{axis} - \phi^b_{axis})^2}$$



[ALICE, 2303.13347](#)

Jet angularity

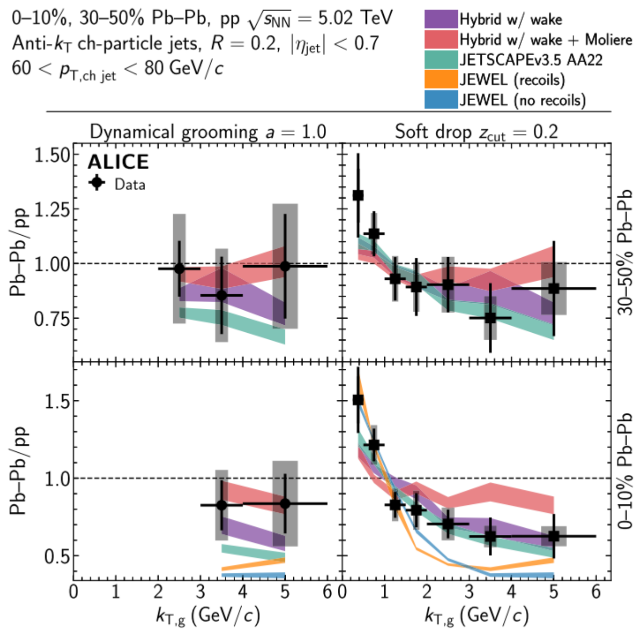
$$\lambda^{\kappa}_{\alpha} \equiv \sum_{i\in jet}\left(\frac{p_{T,i}}{p_{T,\,jet}}\right)^{\kappa}\left(\frac{\Delta R_i}{R}\right)^{\alpha}$$



[ALICE, PLB(2025)](#)

Relative p_T between subjets

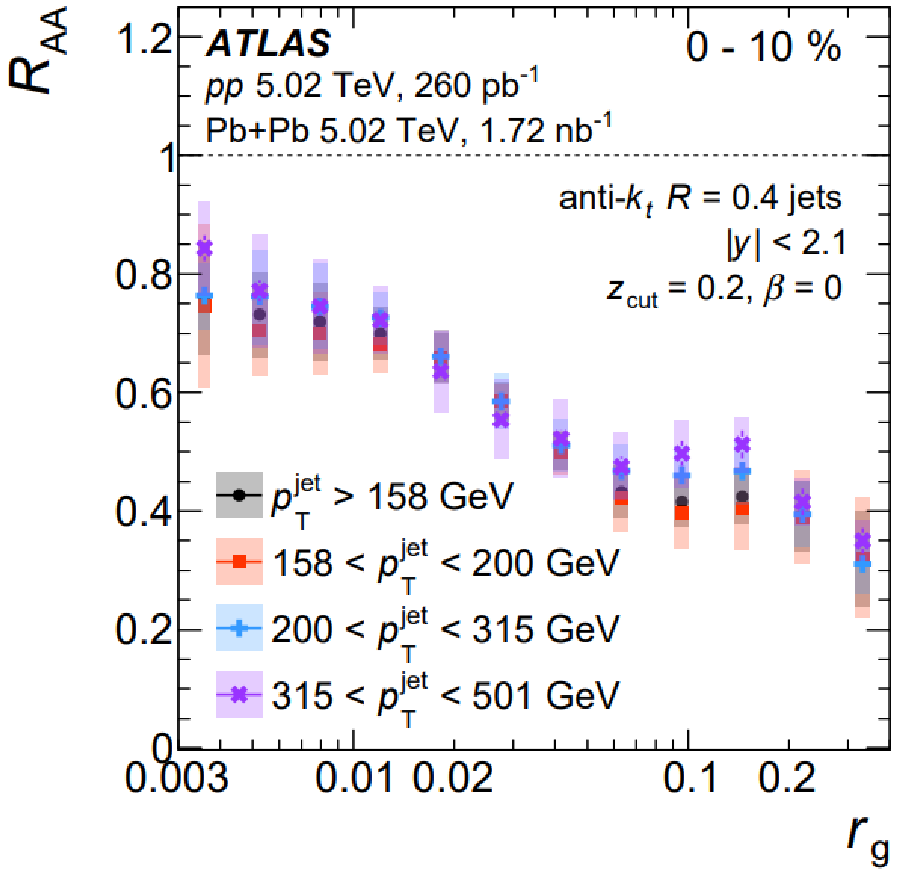
$$k_{T,g} = p_{T,2} \cdot \sin R_g$$



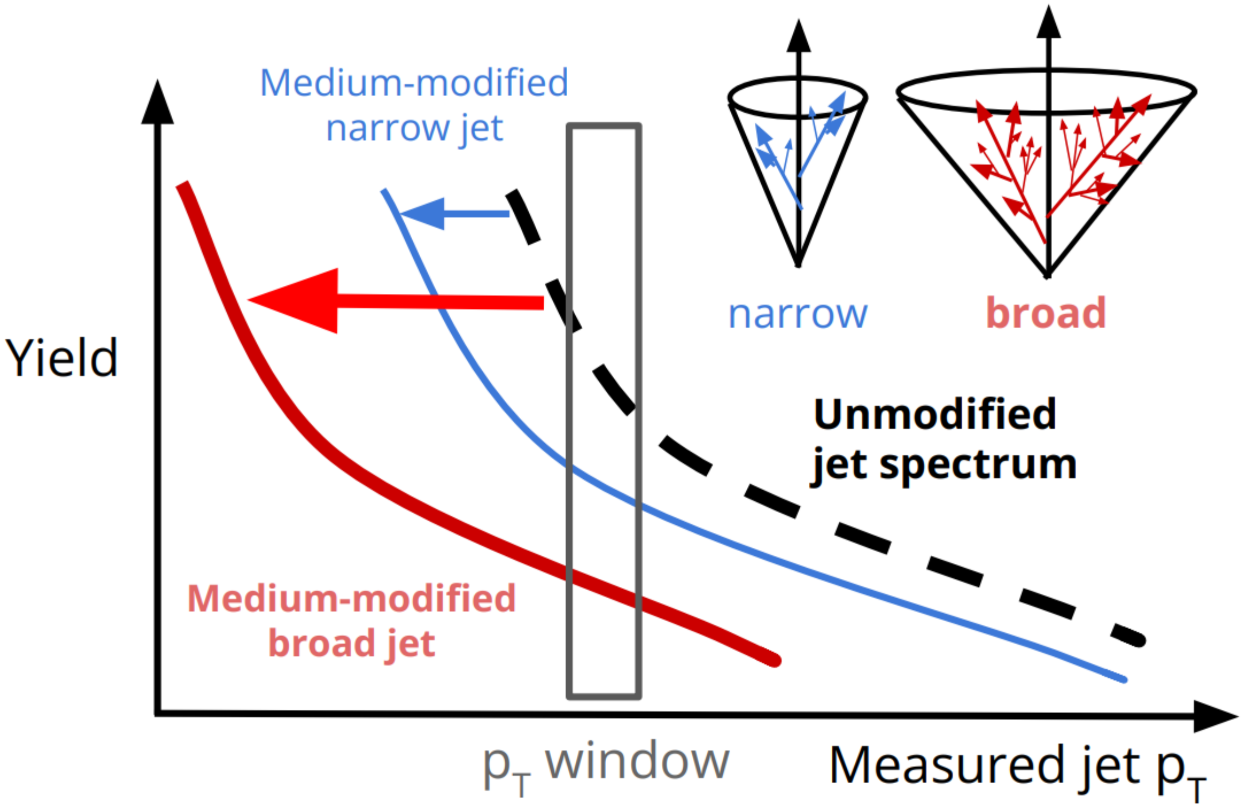
[ALICE, PRL(2025)](#)

Narrowing instead of broadening observed in experiment!

Biased jet selection in heavy-ion collisions

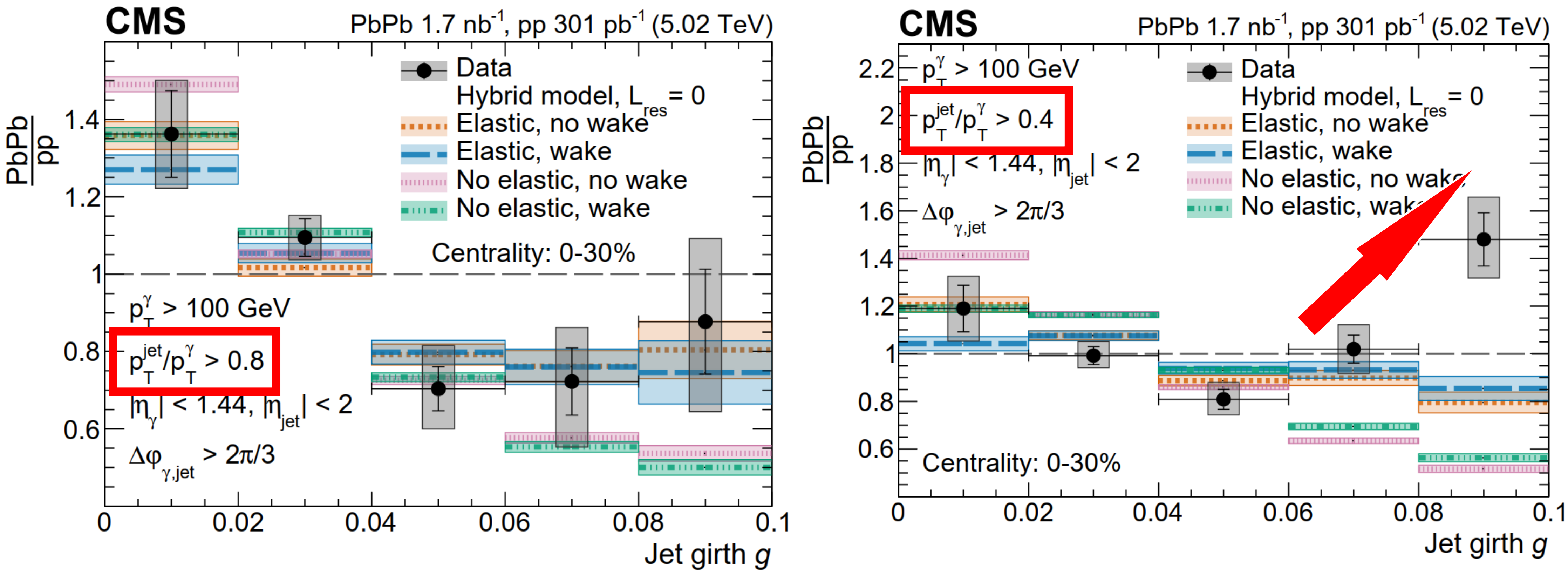


ATLAS, Phys.Rev.C 107 (2023) 5, 054909



Due to energy loss in QGP, effectively quenched jets may be less likely to pass the pT selection threshold in A+A collisions, while some jets with insufficient quenching may still survive.

Medium-modified substructure of photon-tagged jets



CMS, Phys.Lett.B 861 (2025) 139088

➢ Signal of jet substructure broadening observed for jets with lower energy threshold in Pb+Pb collisions.

Simulating Heavy and Light quark jet Energy Loss

Collisional energy loss: **pQCD@HTL**

$$\frac{dE_{\rm coll}}{dL} = -\frac{C_i}{4}\left(1+\frac{N_f}{6}\right)\alpha_s(ET)g_s^2(\alpha_s^{\rm eff})T^2 \times \ln\left(\frac{q_{\rm max}}{q_{\rm min}}\right)\left(\frac{1}{v}-\frac{1-v^2}{2v^2}\ln\frac{1+v}{1-v}\right)$$

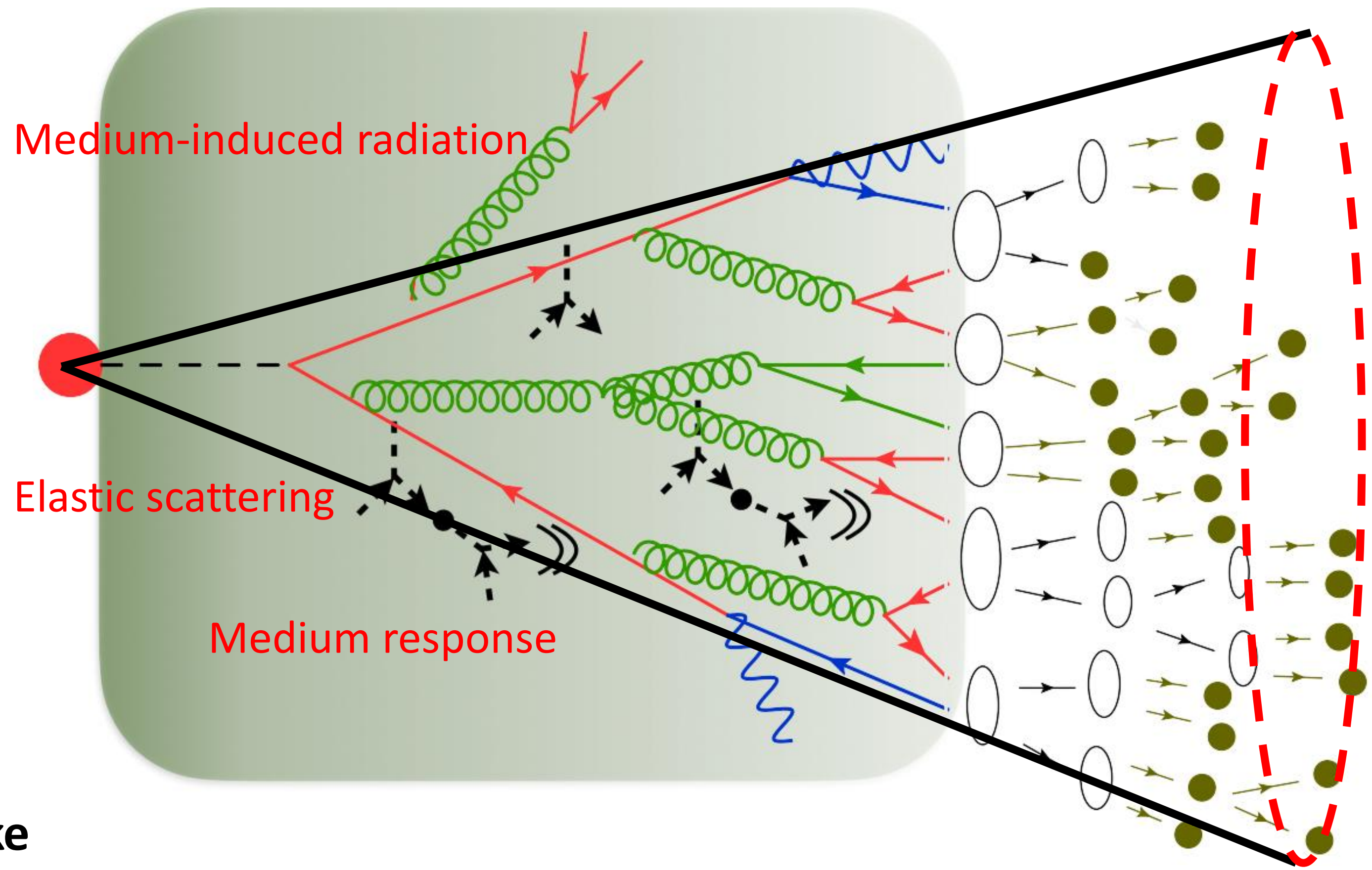
Radiative energy loss: **Higher-Twist formalism**

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

$$\hat{q} = C_i\frac{42\zeta(3)}{\pi}\alpha_s(\mu^2)\alpha_s^{\rm eff}T^3\ln\left[\frac{cET}{4m_D^2}\right]$$

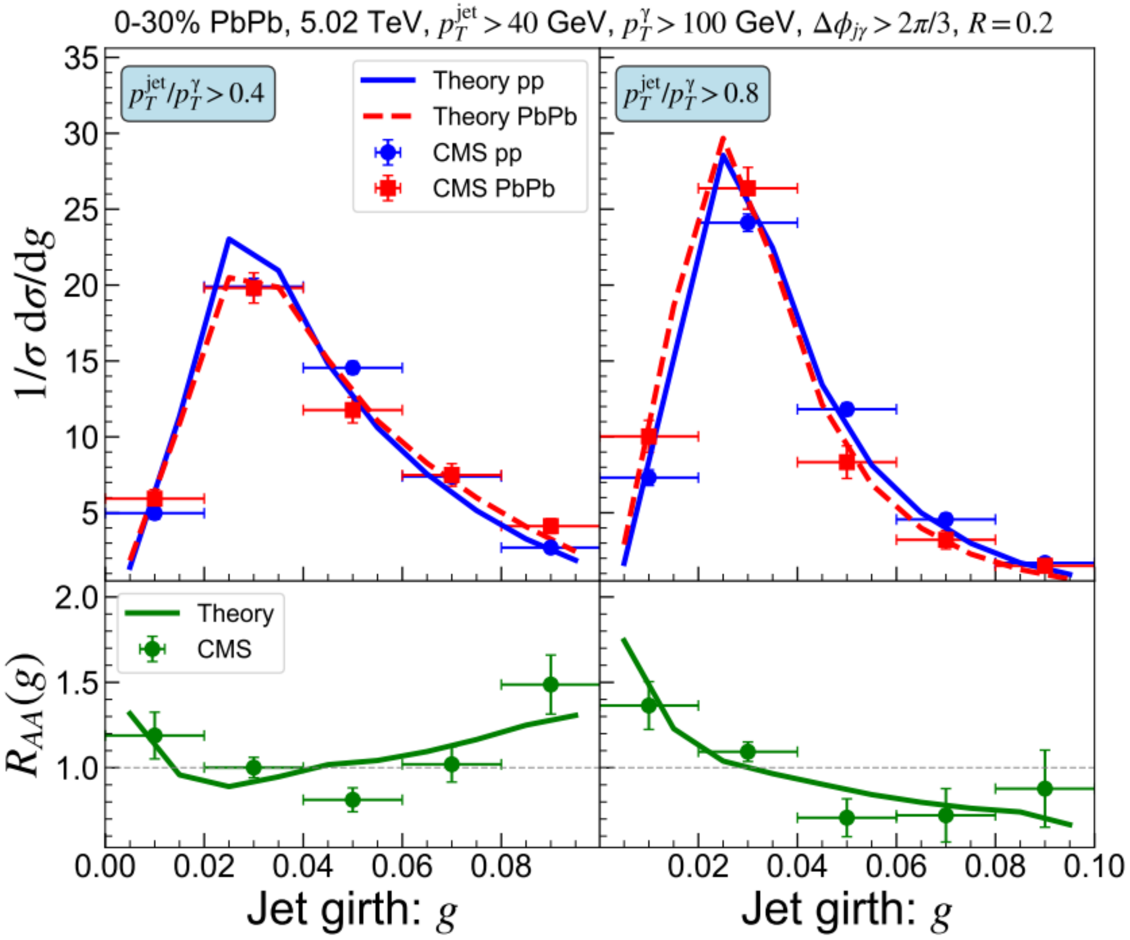
Medium response: **Perturbed Hydrodynamic Wake**

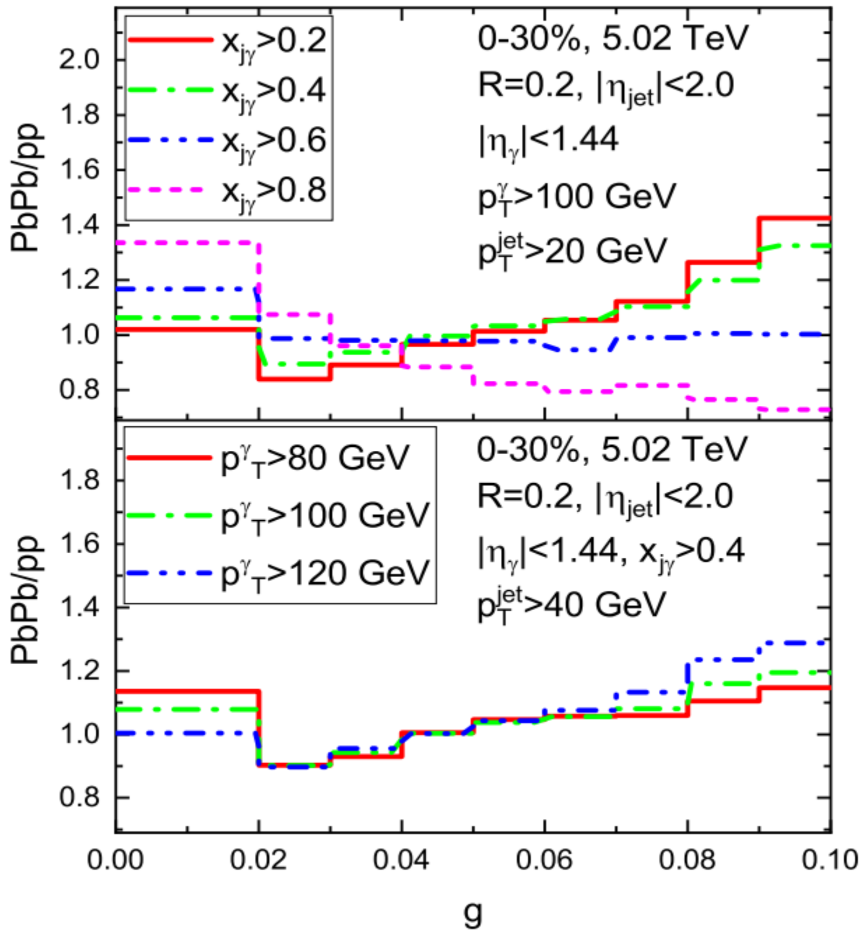
$$E\frac{d\Delta N}{d^3p} = \frac{m_T}{32\pi T^5}\cosh(\Delta y)\exp\left[-\frac{m_T}{T}\cosh(\Delta y)\right] \times\left\{p_T\Delta P_\perp\cos(\Delta\phi)+\frac{1}{3}m_T\Delta M_T\cosh(\Delta y)\right\}$$

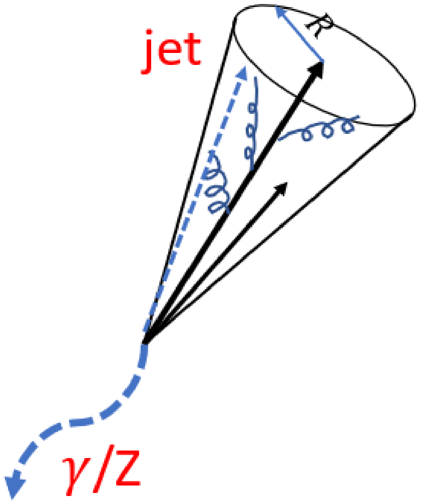


Phys.Rev.D 44 (1991) 9, R2625
Phys.Rev.D 77 (2008) 114017
Phys.Rev.C 82 (2010) 024906
JHEP 03 (2017) 135
Phys. Rev. Lett. 85 (2000) 3591
Nucl. Phys. A 720, 429-451 (2003)
Phys. Rev. Lett. 93 (2004) 072301
Phys.Rev.C 94 (2016) 1, 014909

Theoretical calculations of γ + jet girth





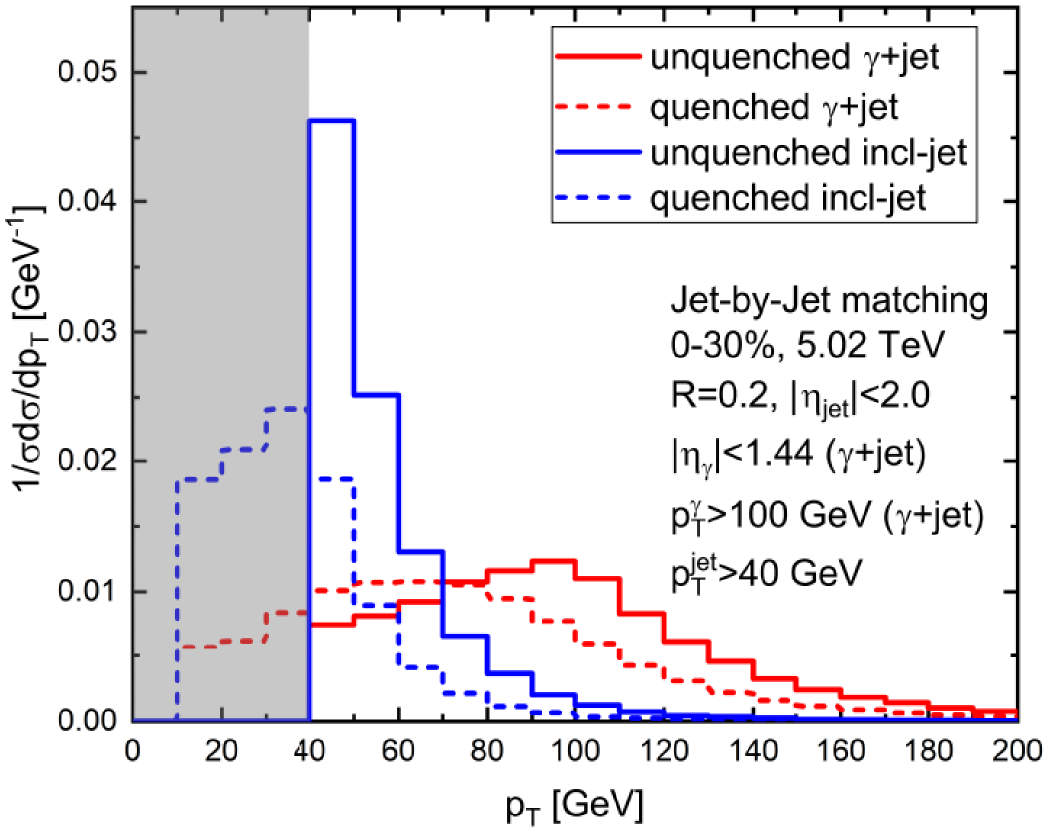


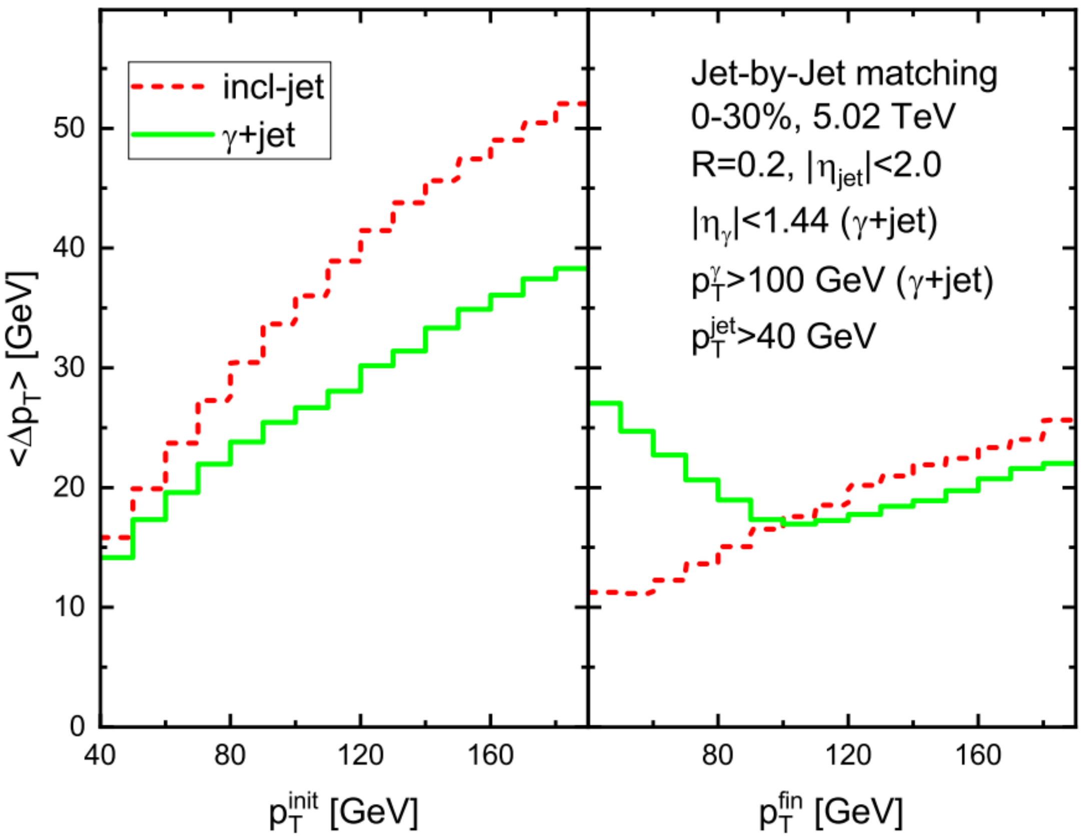
$$x_{j\gamma} = \frac{p_T^{jet}}{p_T^{\gamma}}$$

- ➢ Theoretical calculations of jet girth modification pattern are consistent with CMS data, show a clear p_T threshold dependence of modification pattern.

SW, Y Li, JW Kang, BW Zhang, arXiv:2408.10924, NST(2026)

Advantages of γ + jet to capture jet broadening



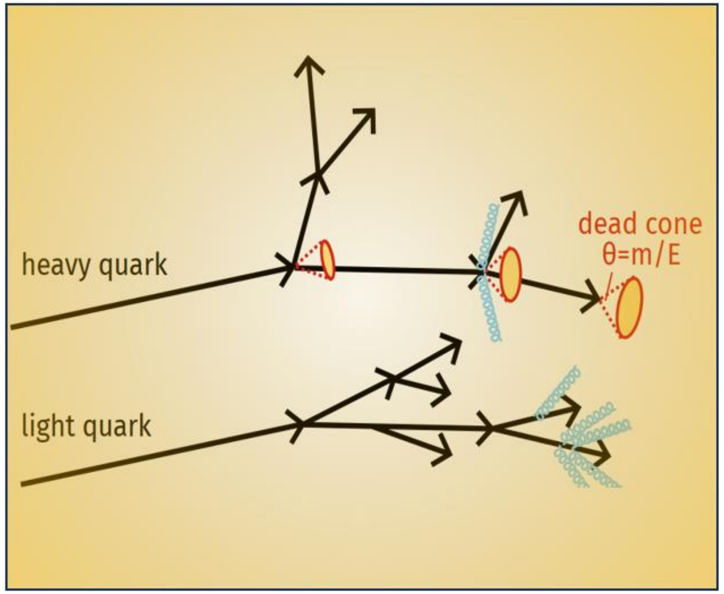


- γ + jet reduces selection bias and can effectively select jets sufficiently quenched, which is crucial to capture the jet angular broadening.

SW, Y Li, JW Kang, BW Zhang, arXiv:2408.10924, NST(2026)

Flavor/mass dependence for jet broadening?

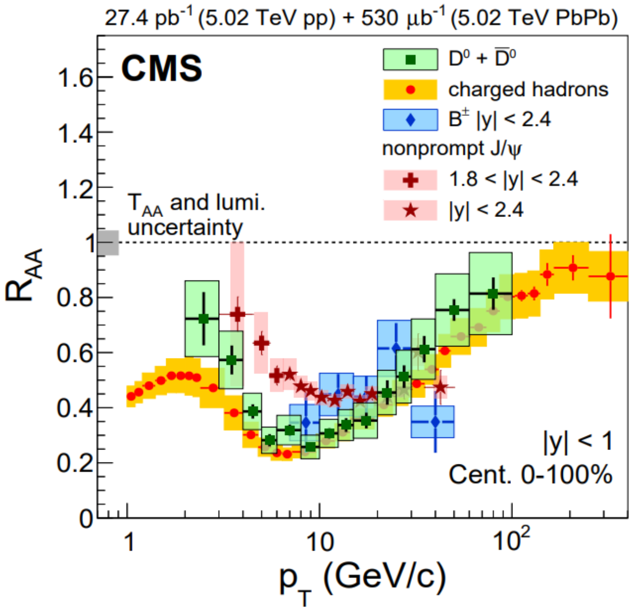
Energy loss : $\frac{\mathrm{d}E}{dt}$

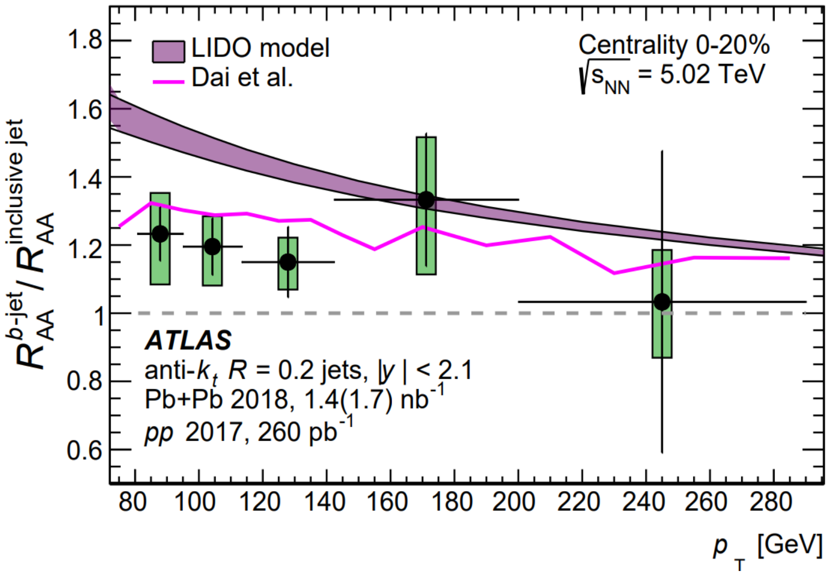


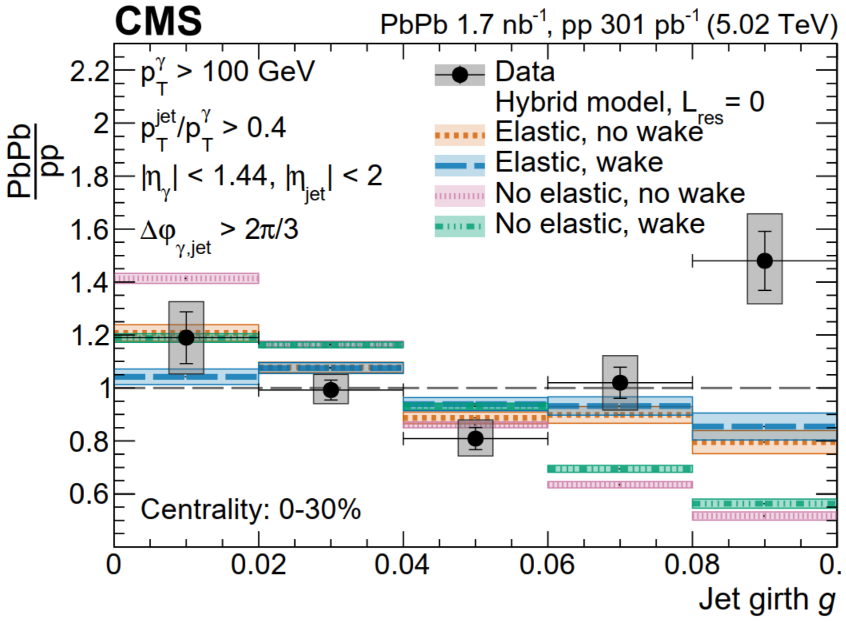
p_T-broadening : $\frac{\mathrm{d}p_\perp}{dt}$

ALICE, PLB (2018)
CMS, PRL (2017)
ATLAS, EPJC(2023)

CMS, PLB (2025)



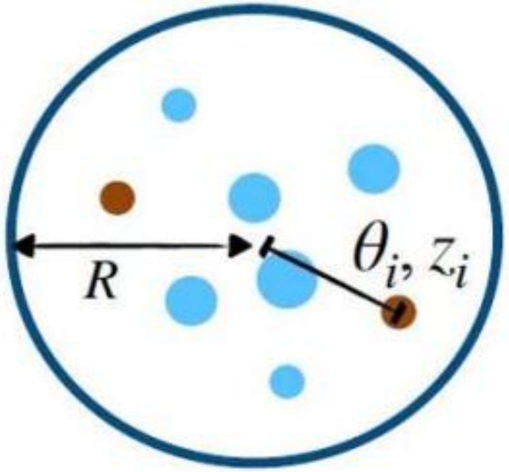




Generalized jet angularity

Angularity:

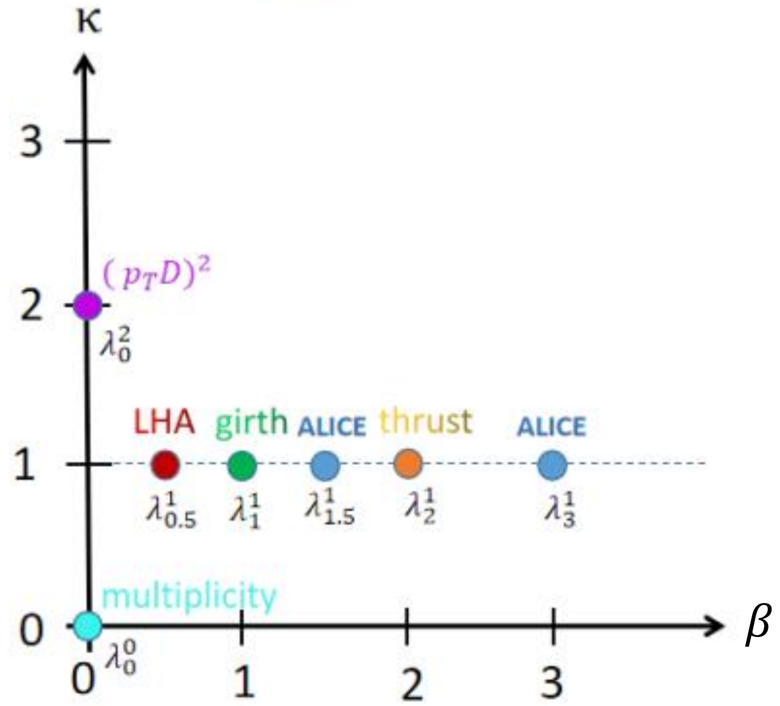
$$\lambda_\beta^\kappa = \sum_{i\in \text{jet}} \left(\frac{p_{T,i}}{p_{T,\text{jet}}}\right)^\kappa \left(\frac{\Delta R_{\text{jet},i}}{R_{\text{jet}}}\right)^\beta = \sum_{i\in\text{jet}} z_i^\kappa \theta_i^\beta$$



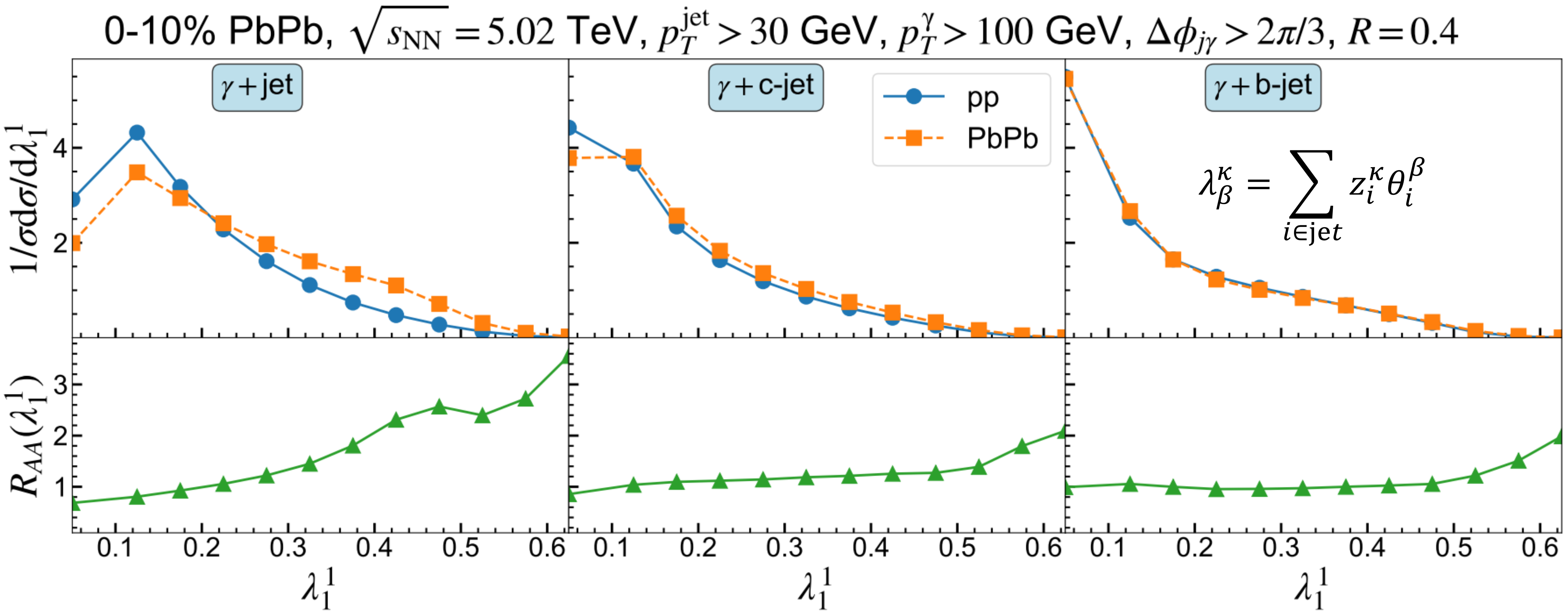
z_i : momentum fraction carried by jet constituents.

θ_i : scaled angular distance between jet constituents and jet axis.

Jet angularities (κ, β)
$(0,0)$: jet multiplicity
$(1,1)$: jet girth
$(1,2)$: jet mass
$(2,0)$: jet p_TD

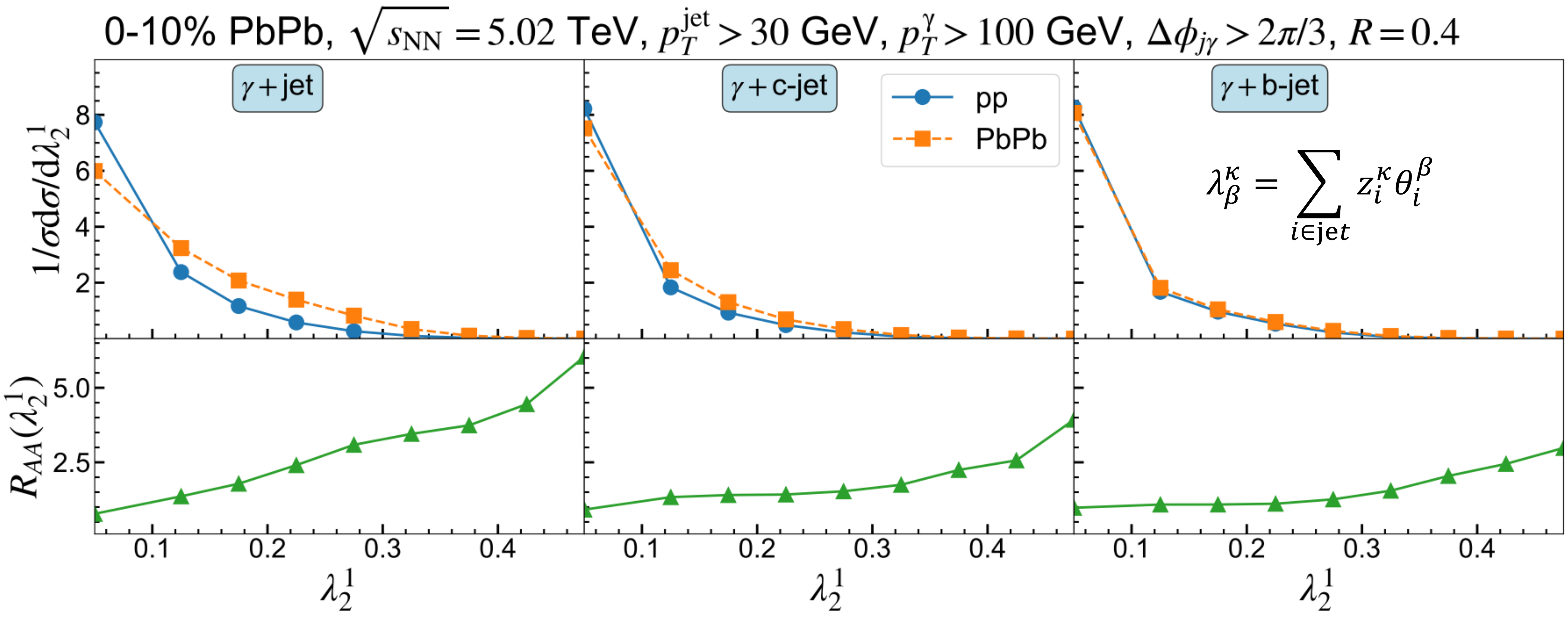


Jet angularity modification for γ + (Q)jets



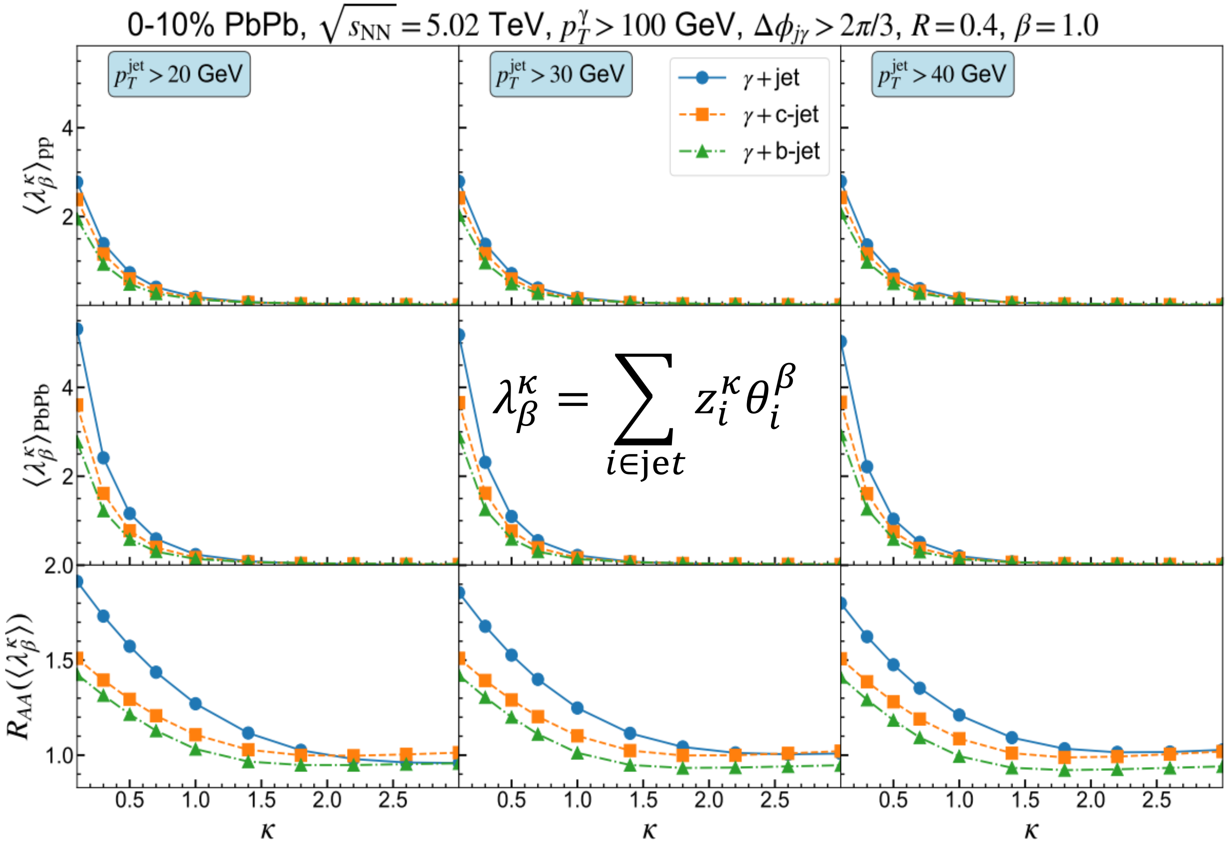
- ➢ Photon-tagged jets are less susceptible to selection bias compared to inclusive jets.
- ➢ Jet girth and jet mass of γ + jets show more significant broadening than that of γ + Q-jets in the same collision system.

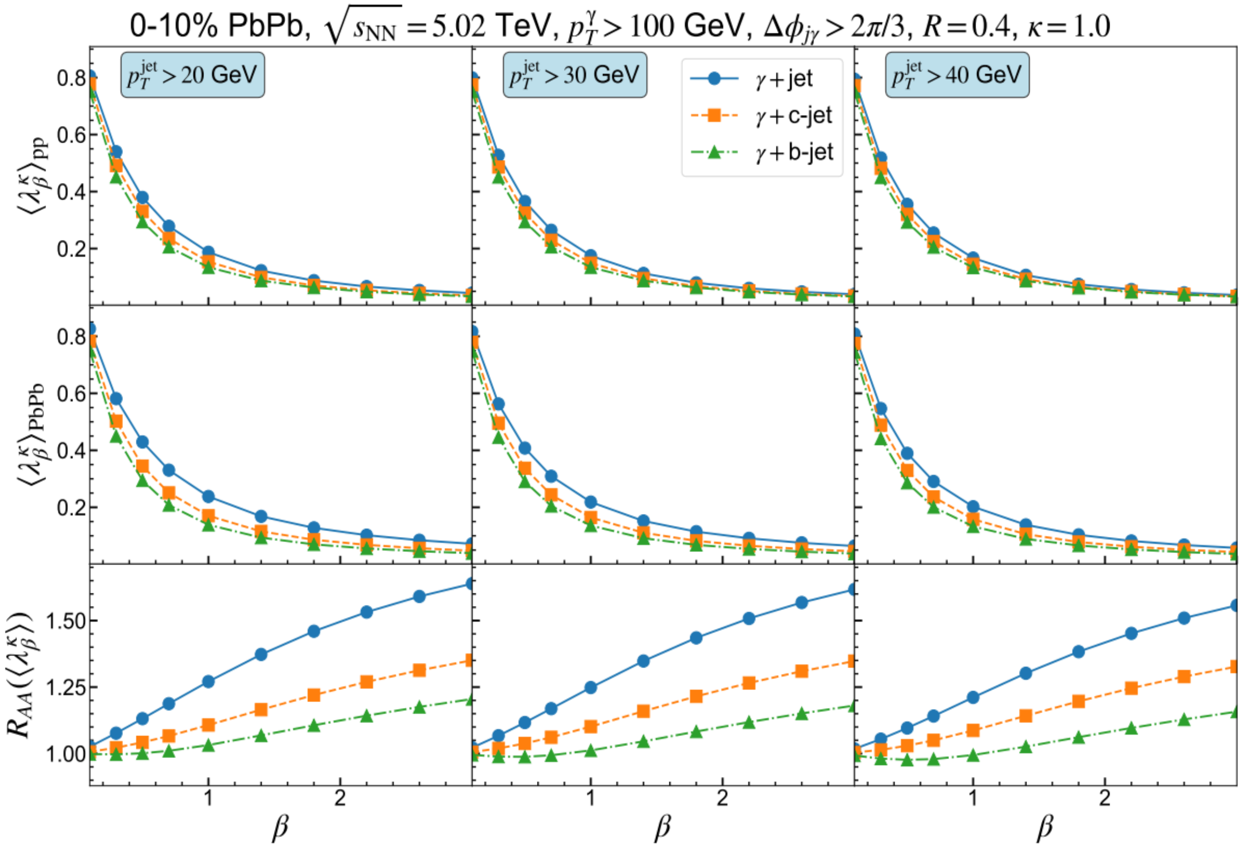
Jet angularity modification for γ + (Q)jets



➢ Photon-tagged jets are less susceptible to selection bias compared to inclusive jets.
➢ Jet girth and jet mass of γ + jets show more significant broadening than that of γ + Q-jets in the same collision system.

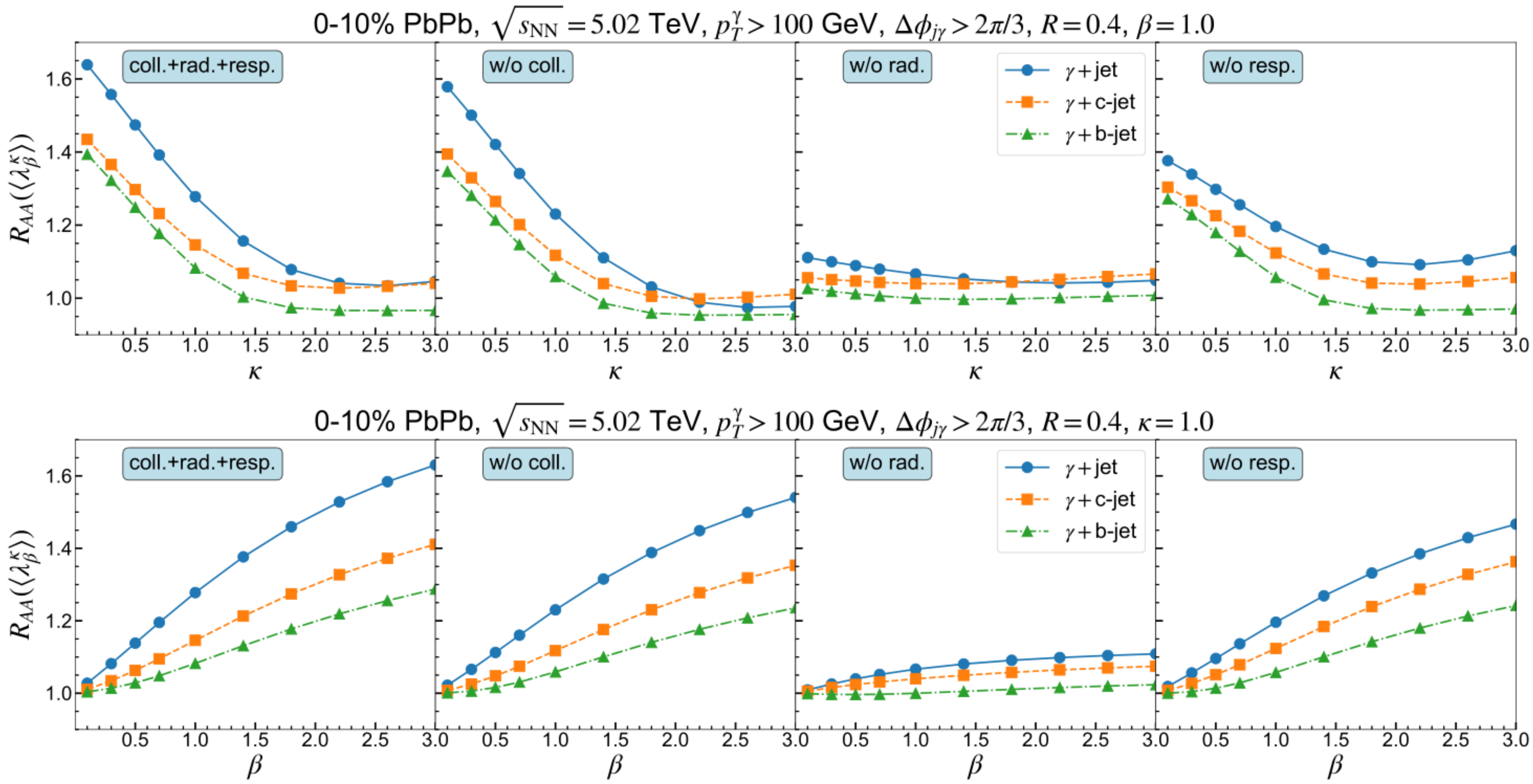
Mass-dependent jet angularity modification





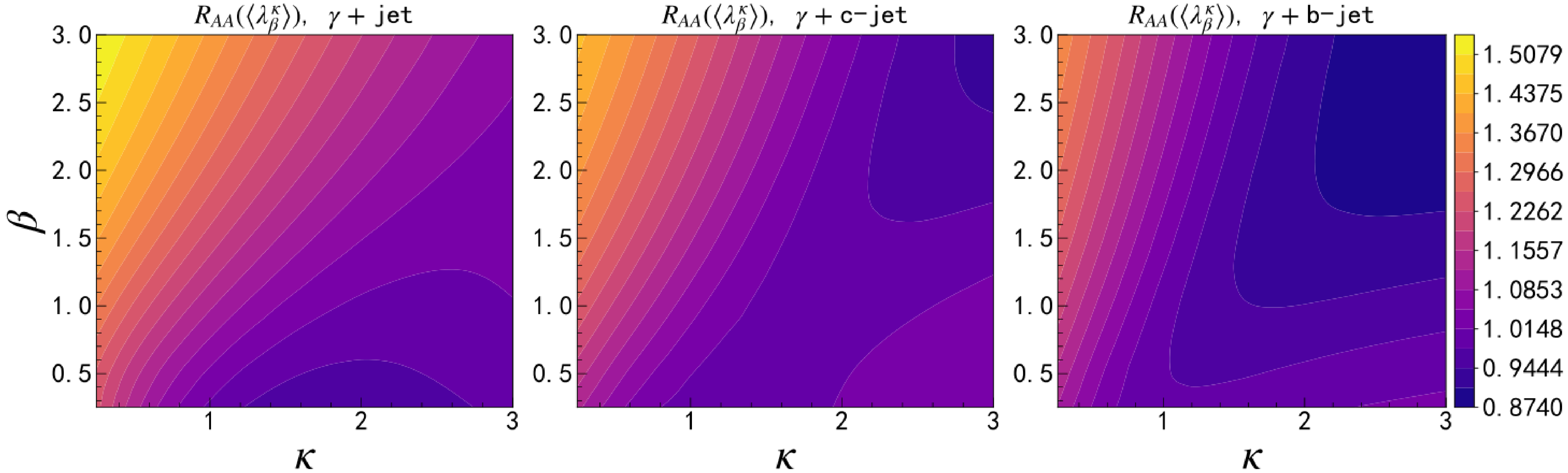
- We observe a mass-ordered broadening of jet angularity in heavy-ion collisions.
- $\langle\lambda_\beta^\kappa\rangle$ show different sensitivities to the variations of (κ, β) for light and heavy quark jets.

Mass-dependent jet angularity modification



- Medium-induced gluon radiation plays a critical role in the angularity broadening.
- A promising method to test the dead cone effect of heavy quarks in nucleus-nucleus collisions.

Global (κ, β) scanning for angularity modification



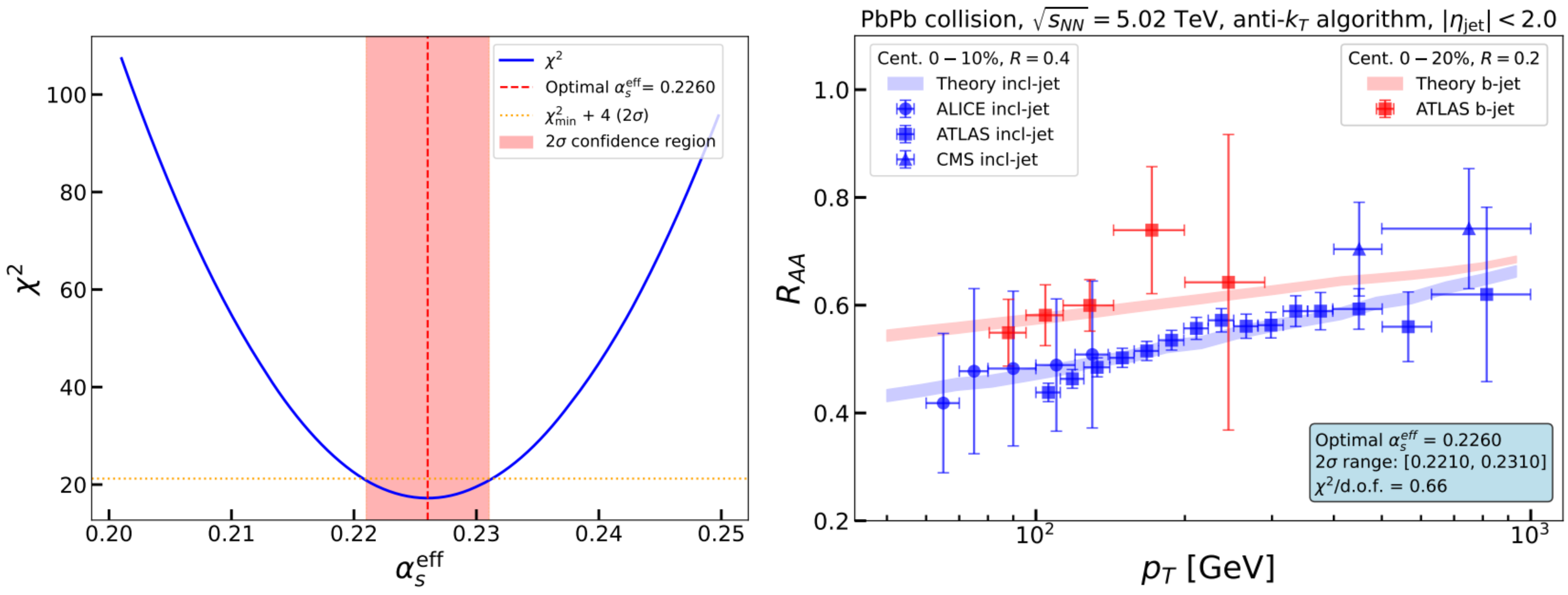
- Larger κ (β) suppresses the contribution of jet constituents with soft momenta (smaller angular distance to jet axis).
- Broadening/narrowing of angularity reveals sensitivity of the medium modified (z_i, θ_i) distribution of jet constituents to the parameters (κ, β).

Summary and outlook

- We find that γ+jet mitigates selection bias and effectively selects jets that are sufficiently quenched.
- Jet substructure observables in γ+jet events exhibit clear angular broadening, demonstrating sensitivity to the underlying jet–medium interaction mechanisms.
- We confirm a mass-ordered broadening of angularity in heavy-ion collisions.
- Systematic analysis of angularity's broadening/narrowing in response to (κ, β) variations could provide fresh perspectives on jet–QGP interaction mechanisms and the role of mass effects in medium-modified jet substructure.
- We plan to perform systematic investigations on the broadening of different substructure observables (R_g, $\Delta R_{\rm axis}$, EEC) of Z^0/γ + (Q)jets to test their flavor/mass or system-size/temperature dependence.

Thank you

Backup: determination of α_s^{eff}



- α_s^{eff} is the only one tunable parameter in our framework.
- χ^2 fitting of experimental R_{AA} data with 2σ confidence give best estimation of $\alpha_s^{\mathrm{eff}} = 0.226 \pm 0.005$.

Backup: profile of jet constituents in pp and PbPb