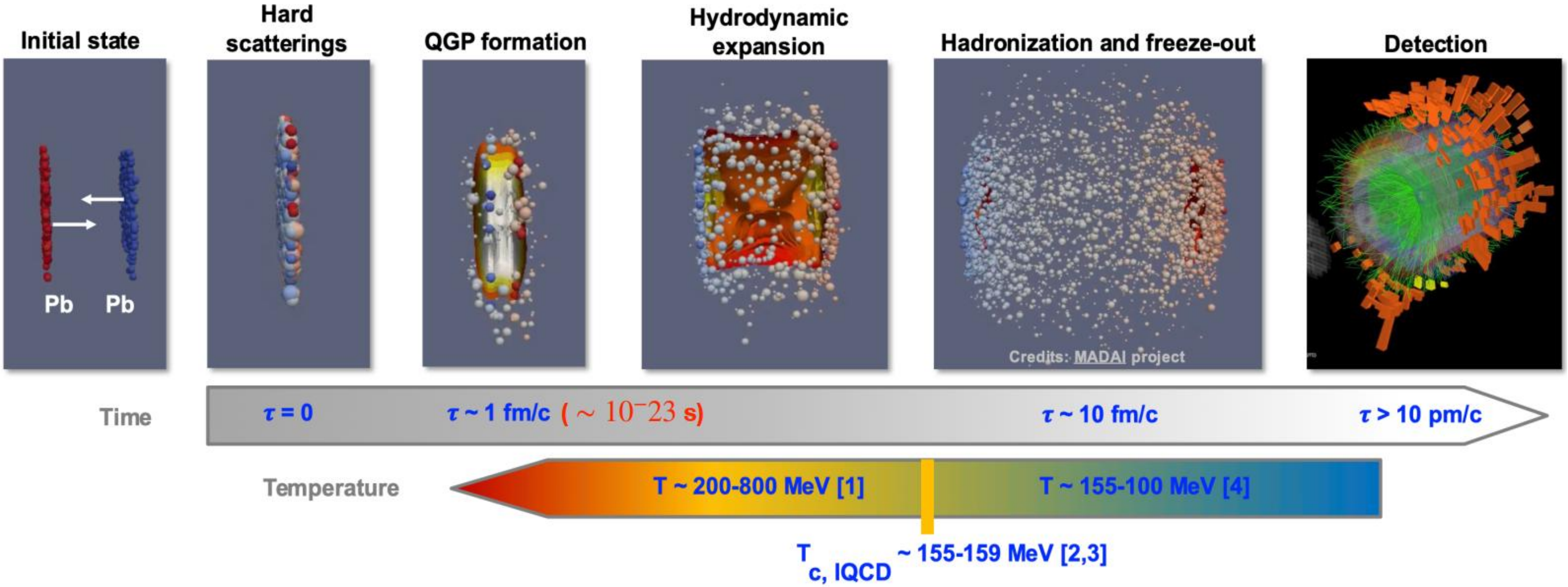
CHINA THREE GORGES UNIVERSITY

中国物理学会高能物理分会第十二届
全国会员代表大会暨学术年会

高能核碰撞中喷注子结构的介质诱导展宽

王洒
三峡大学
2026-07-15 • 广州

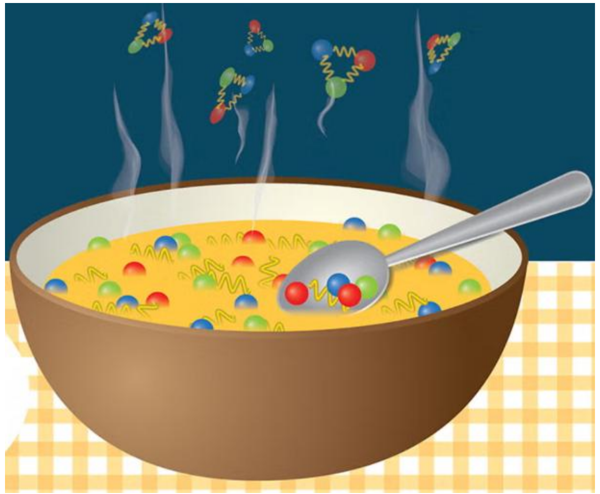
Relativistic heavy-ion collisions



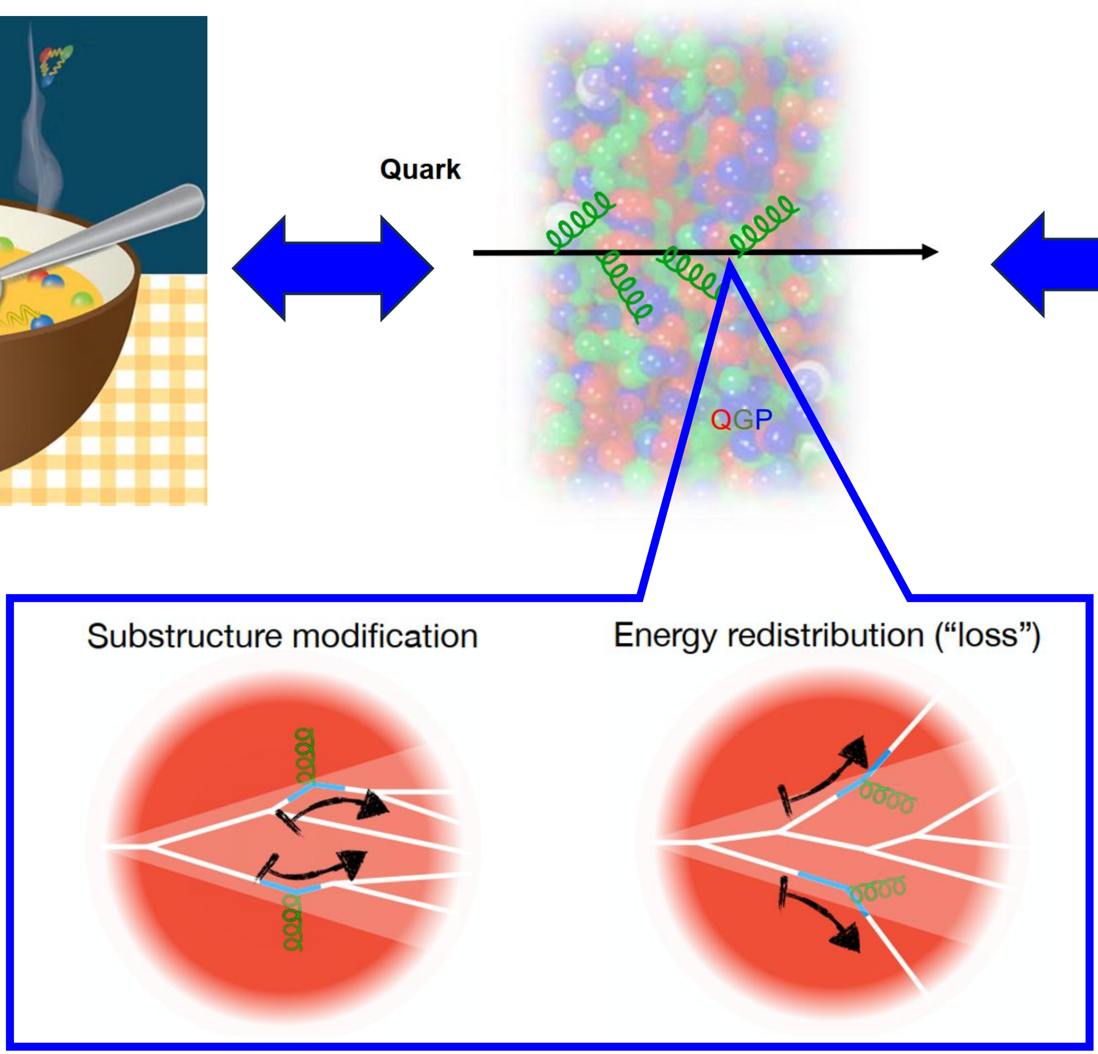
Ralf Averbeck, Quark Matter 2025

Jet quenching

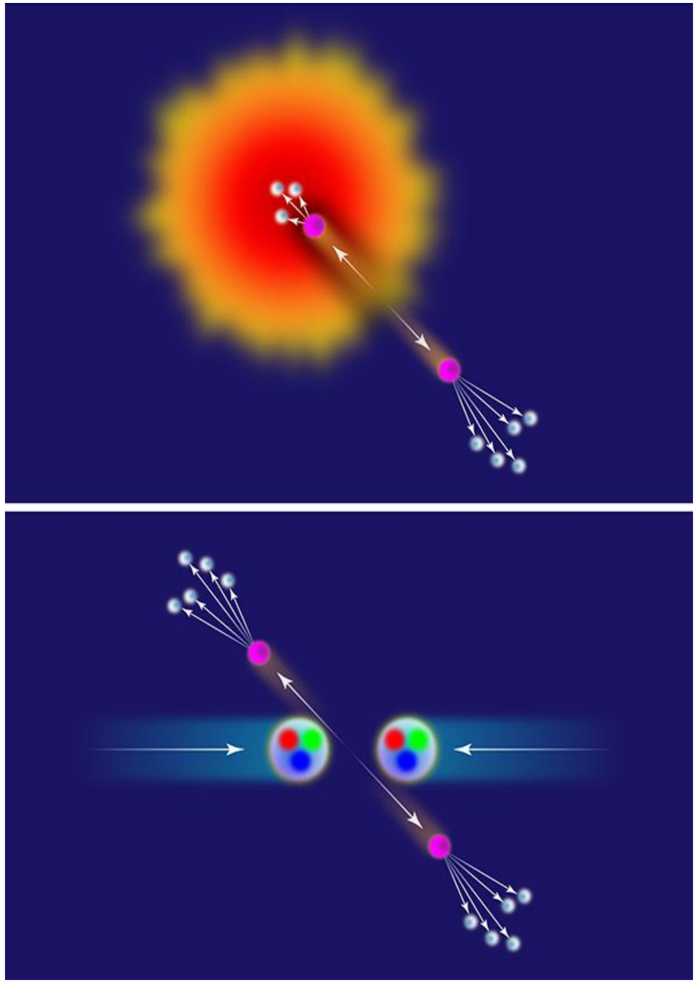
Quark soup



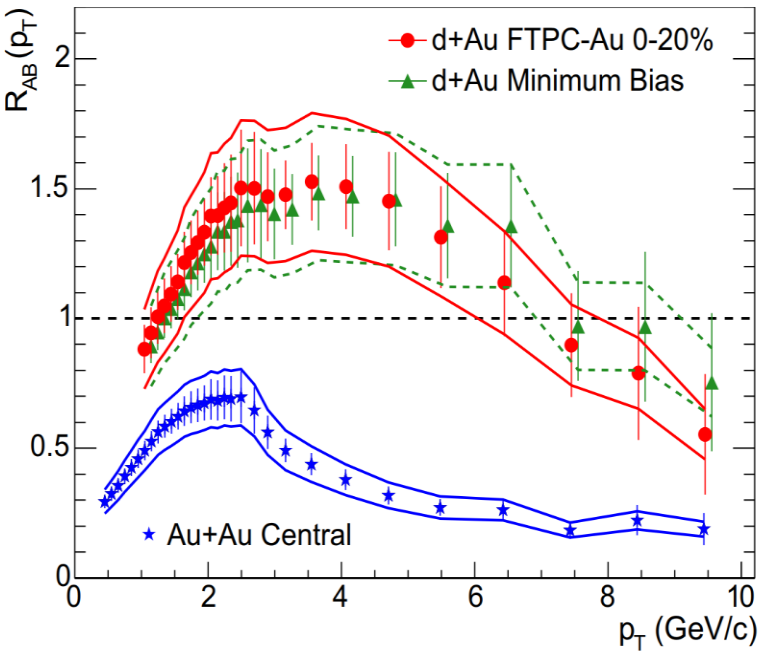
Hard probes



Medium modification



Energy loss of high-p_T parton/jet



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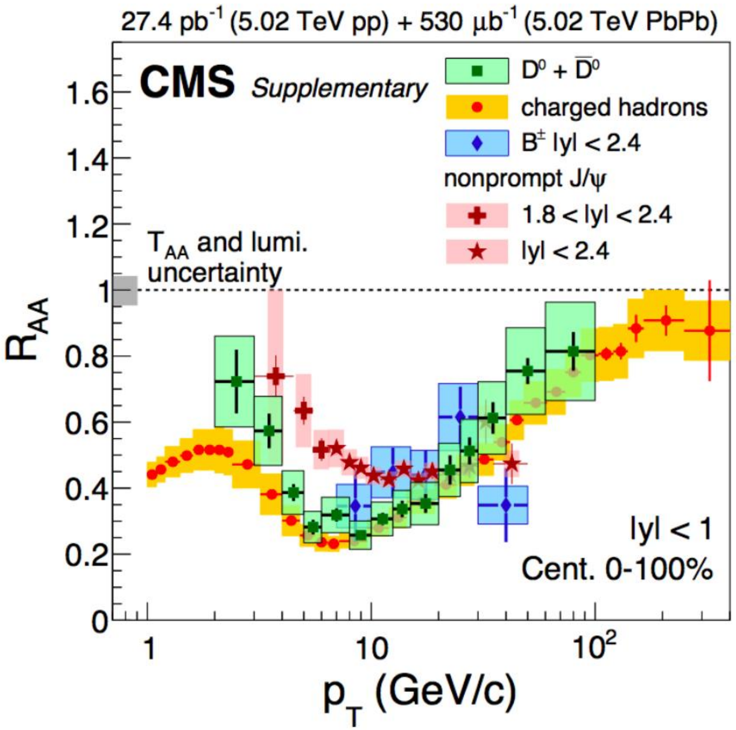

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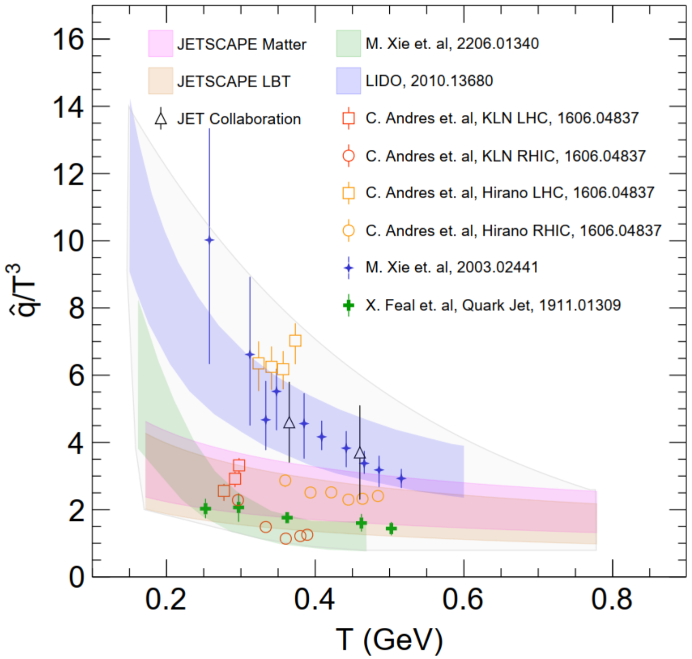

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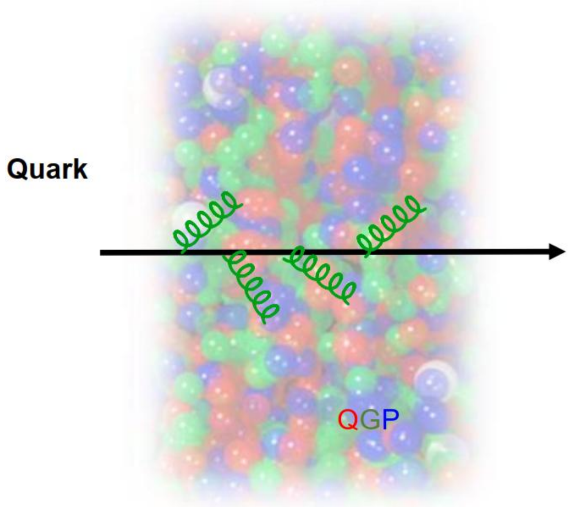
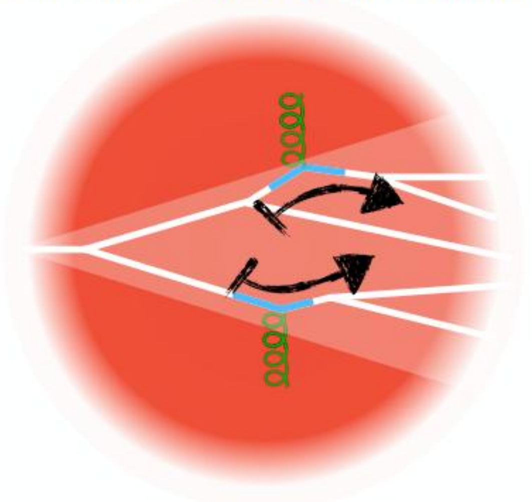
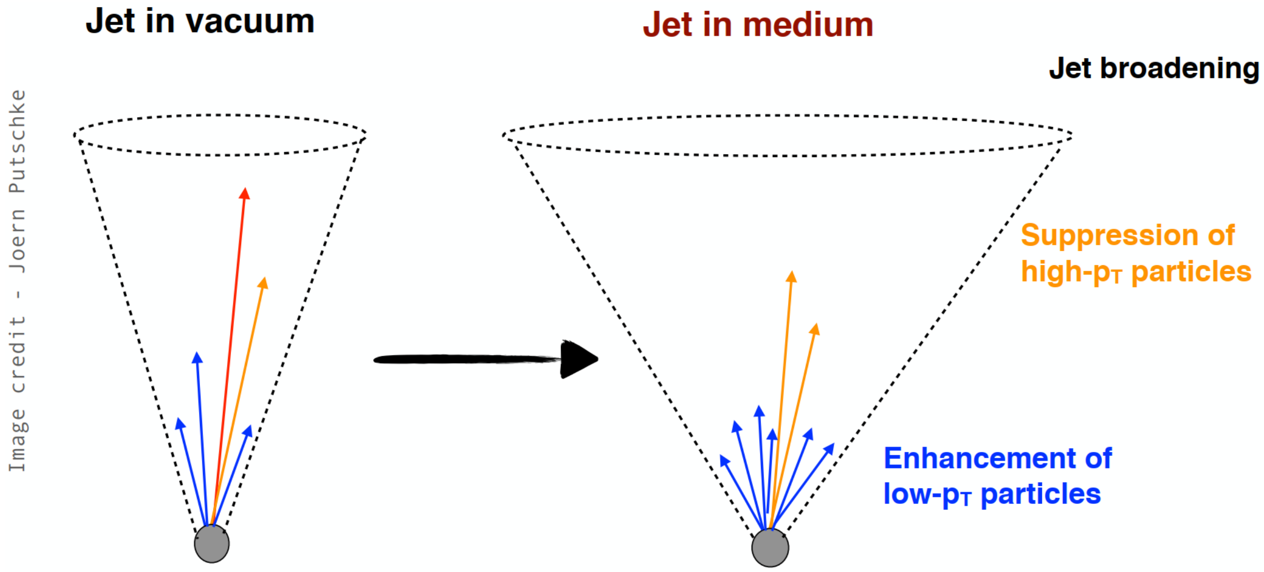
Medium-induced jet broadening

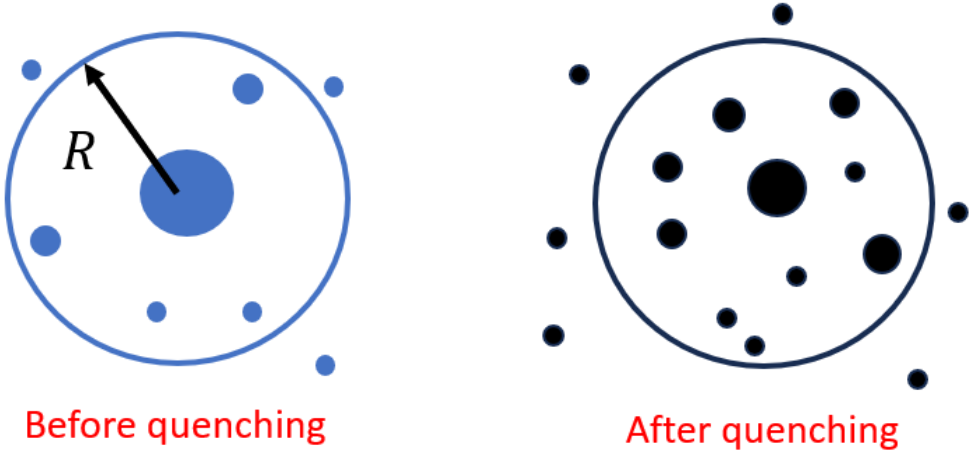
Partonic scattering



Substructure modification

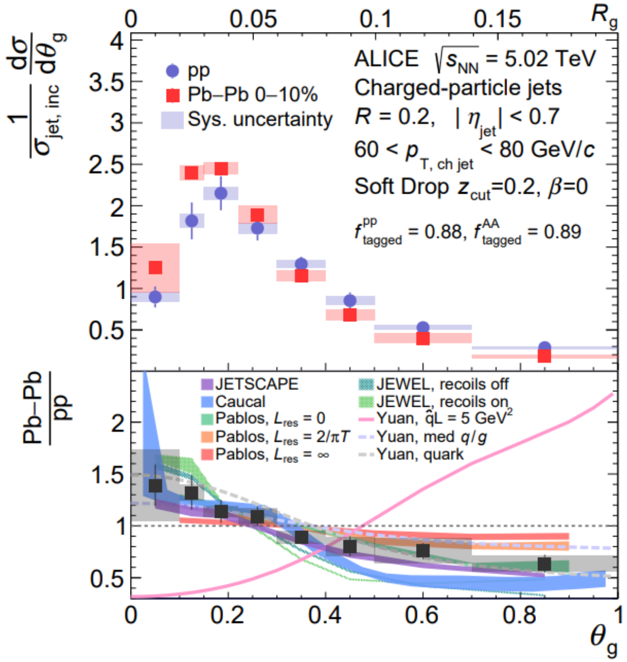


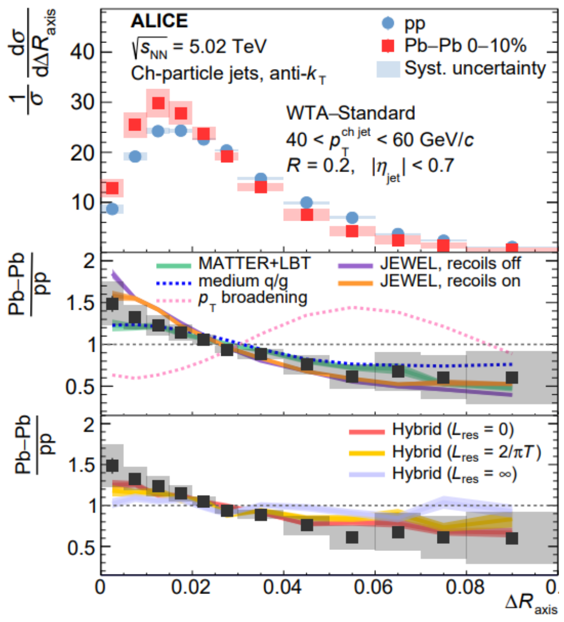


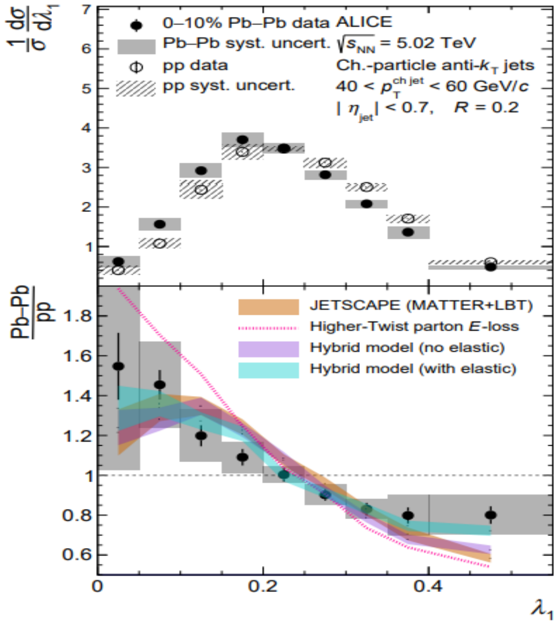


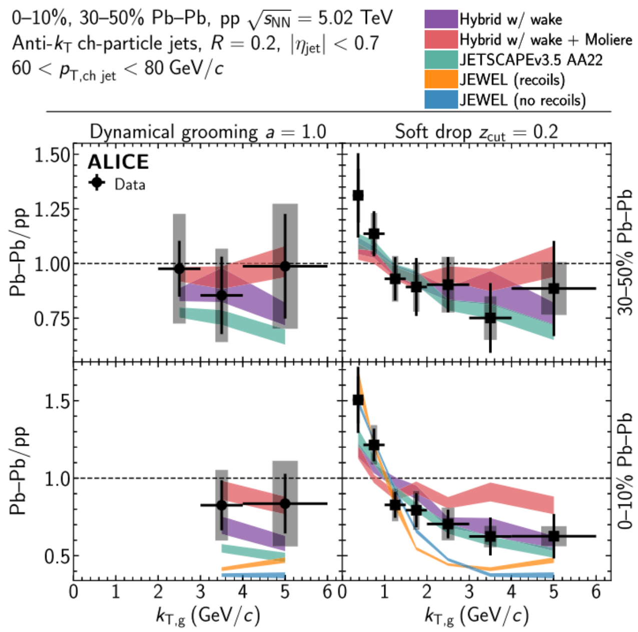
Jet substructures in A+A collisions

Groomed radius	Angle between jet axis	Jet angularity	Relative p_T between subjets
$\frac{\min(p_{T,1},p_{T,2})}{p_{T,1}+p_{T,2}} > z_{cut}\left(\frac{\Delta R_{1,2}}{R}\right)^{\beta}$	$\Delta R_{axis}^{a-b} = \sqrt{(y_{axis}^a - y_{axis}^b)^2 + (\phi_{axis}^a - \phi_{axis}^b)^2}$	$\lambda_\alpha^\kappa \equiv \sum_{i\in jet}\left(\frac{p_{T,i}}{p_{T,jet}}\right)^\kappa\left(\frac{\Delta R_i}{R}\right)^\alpha$	$k_{T,g} = p_{T,2}\cdot\sin R_g$





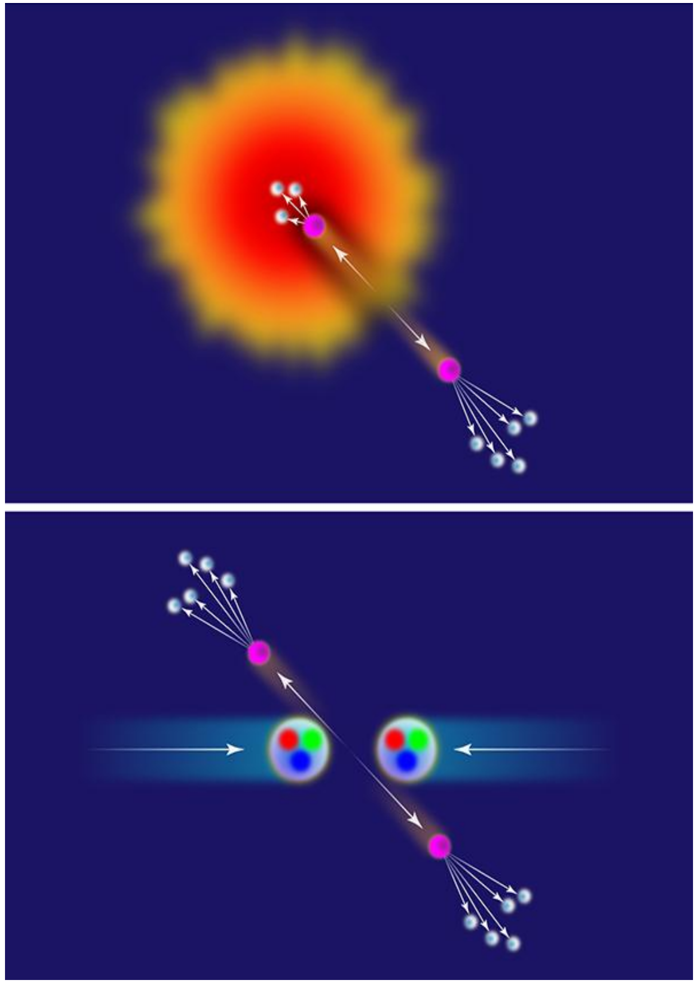


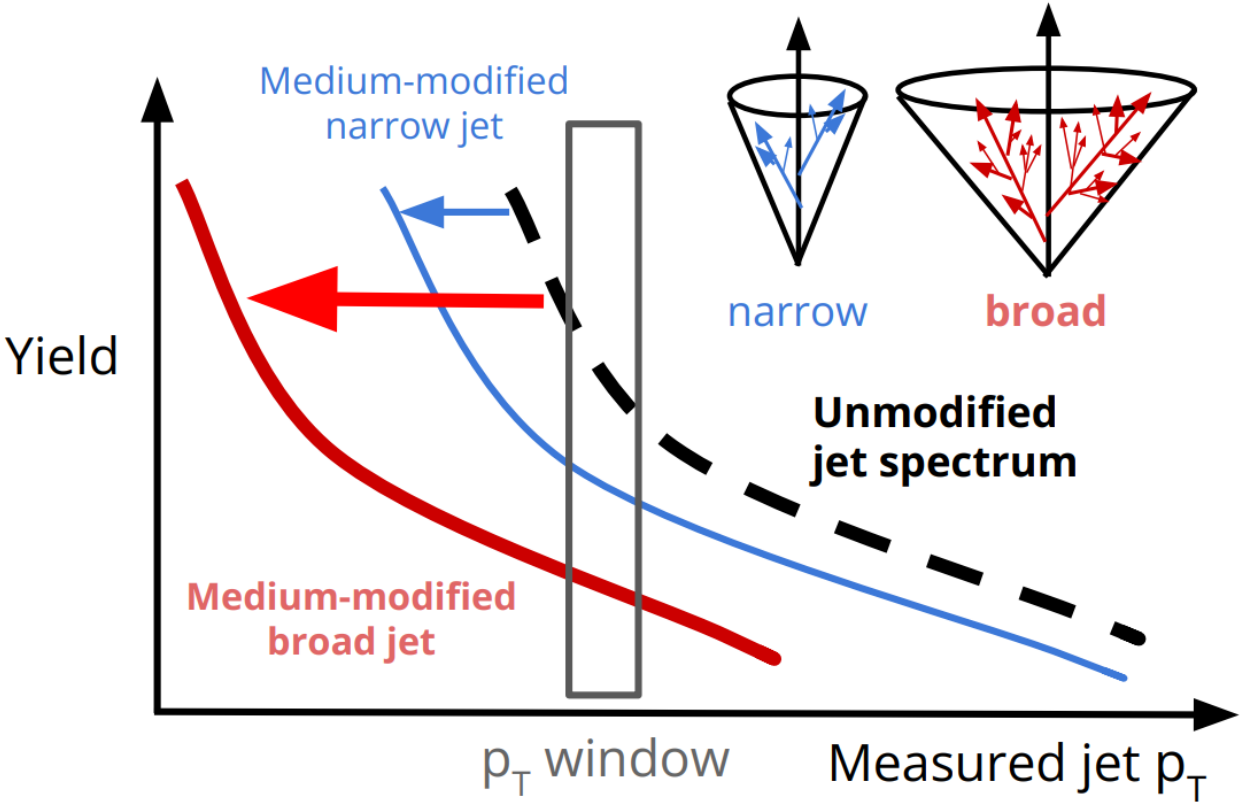


ALICE, PRL(2022) ALICE, PRC(2026) ALICE, PLB(2025) ALICE, PRL(2025)

Narrowing instead of broadening observed in experiment!

Biased comparison between pp and AA

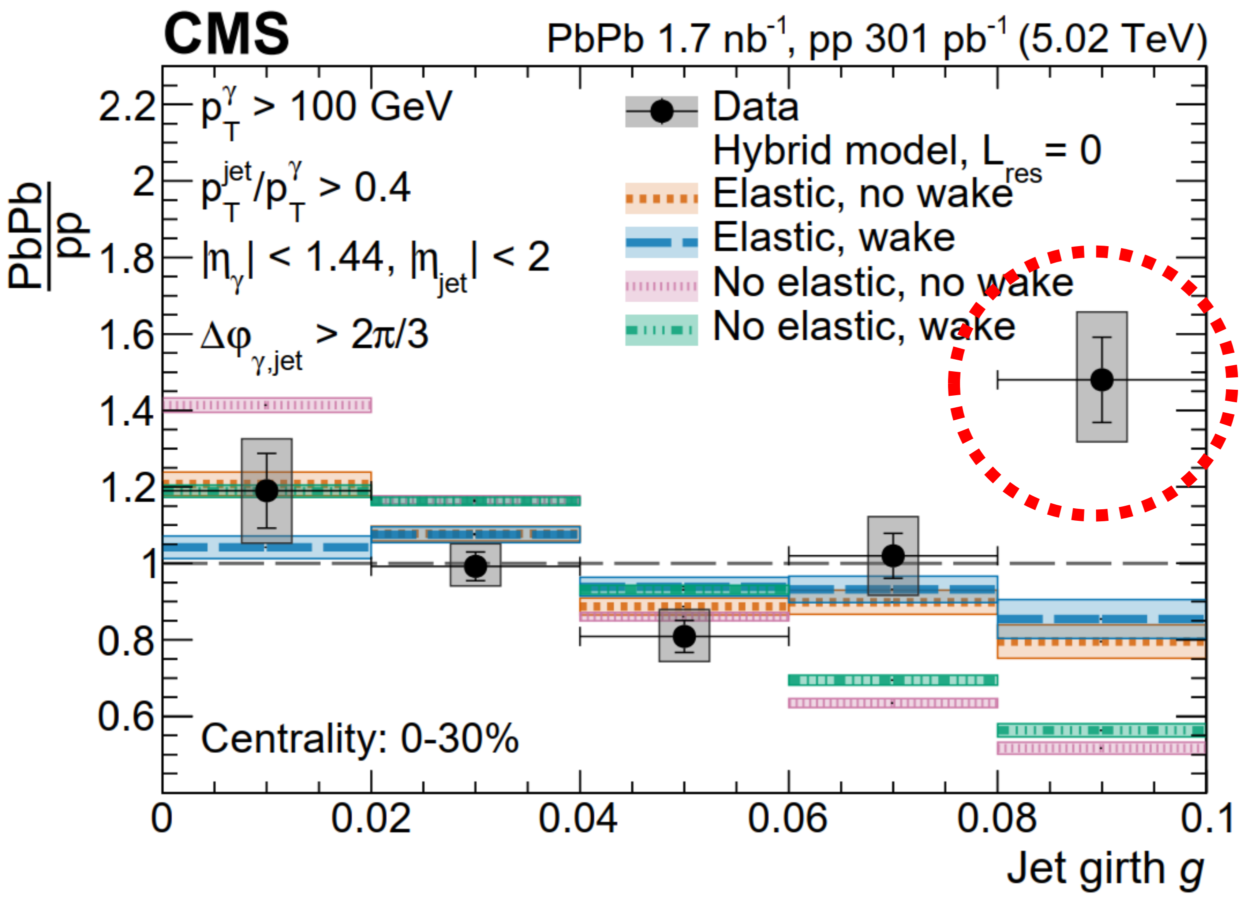


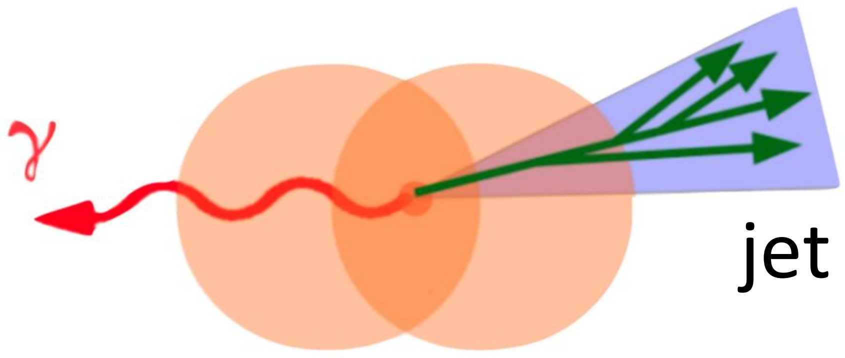


[CMS, Phys.Lett.B 861 (2025) 139088](#)

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

New opportunity: photon-tagged jet (γ+jet)



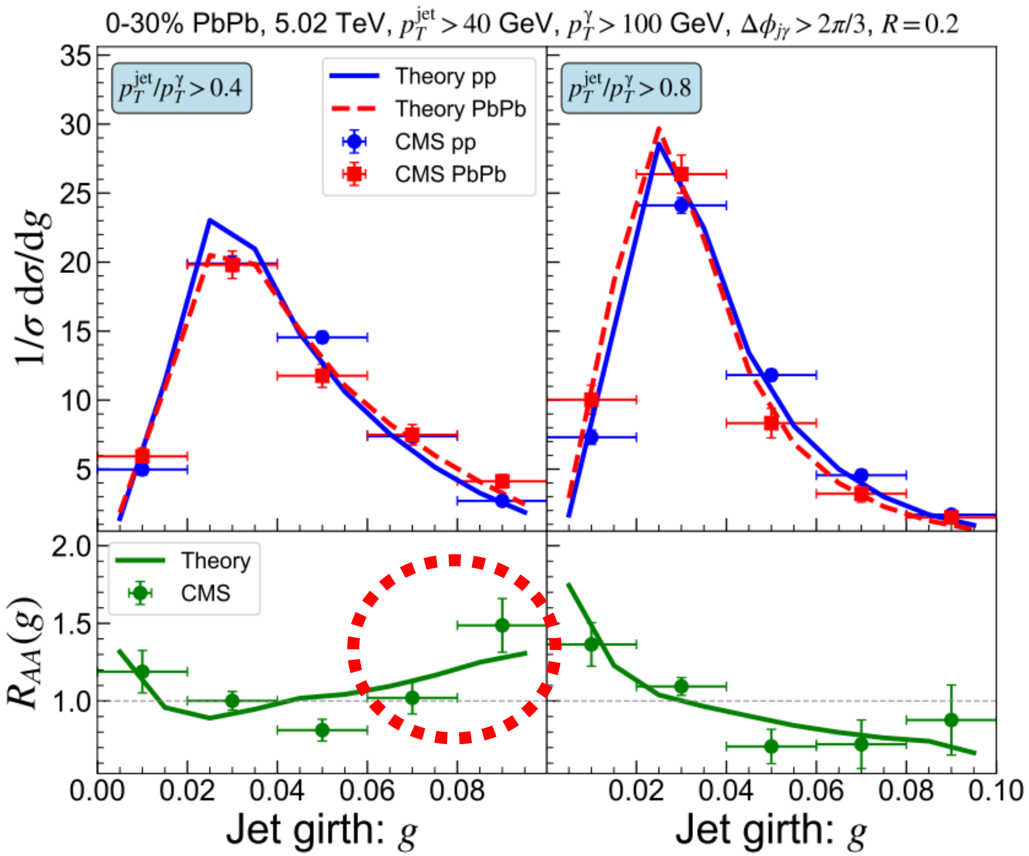


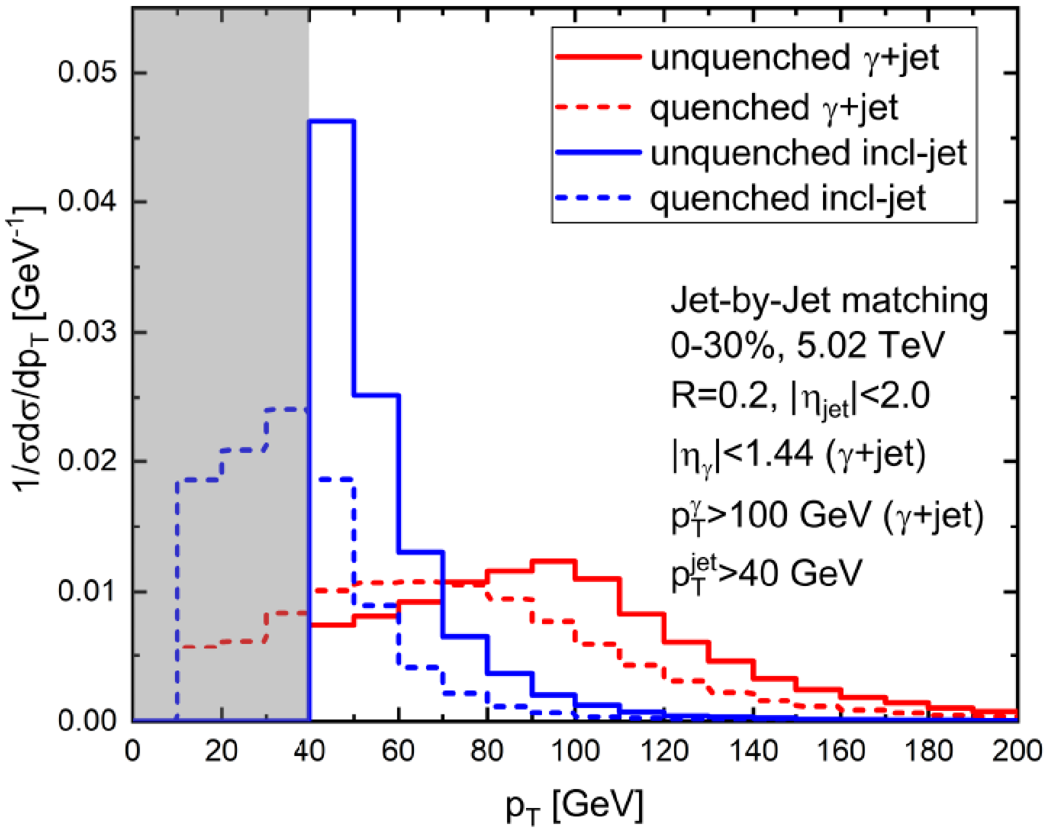
$$\lambda_{\alpha}^{\kappa} \equiv \sum_{i \in \text{jet}} \left(\frac{p_{\mathrm{T},i}}{p_{\mathrm{T,\,jet}}} \right)^{\kappa} \left(\frac{\Delta R_i}{R} \right)^{\alpha}$$

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

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

Advantages of γ+jet to capture jet broadening

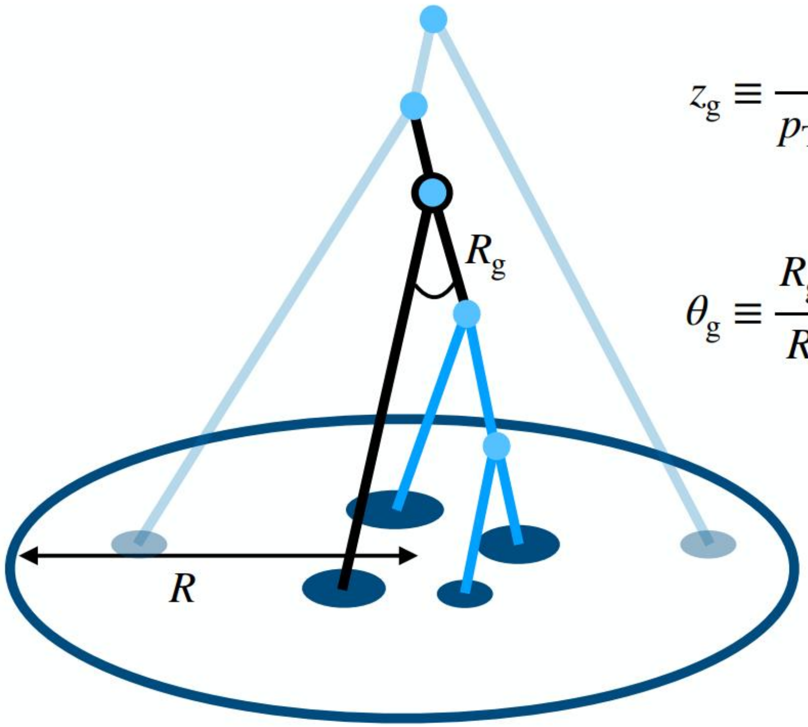




- γ + jet reduces selection bias and can effectively select jets sufficiently quenched, which is crucial to capture the jet angular broadening.

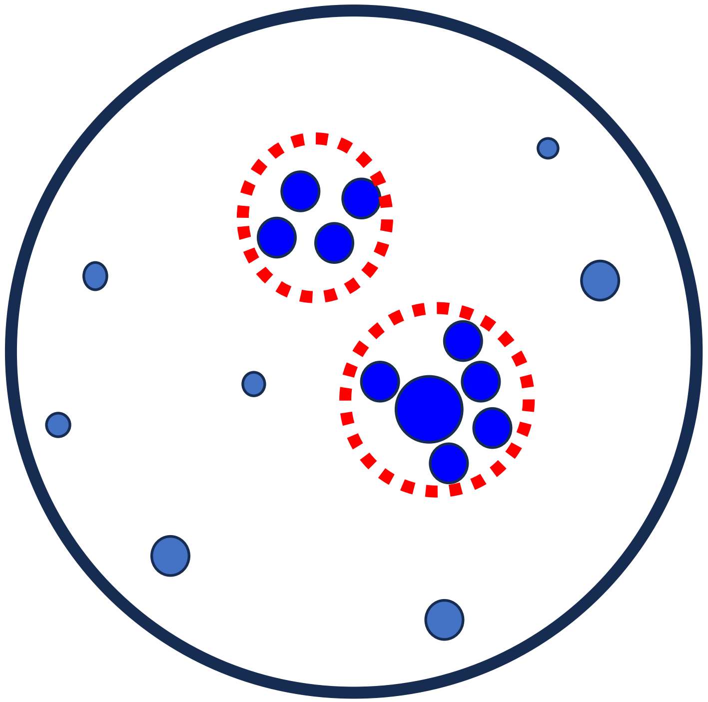
SW, Y Li, JW Kang, BW Zhang, Nucl.Sci.Tech. 37 (2026) 9, 168

Jet grooming: probing hard jet splitting



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

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

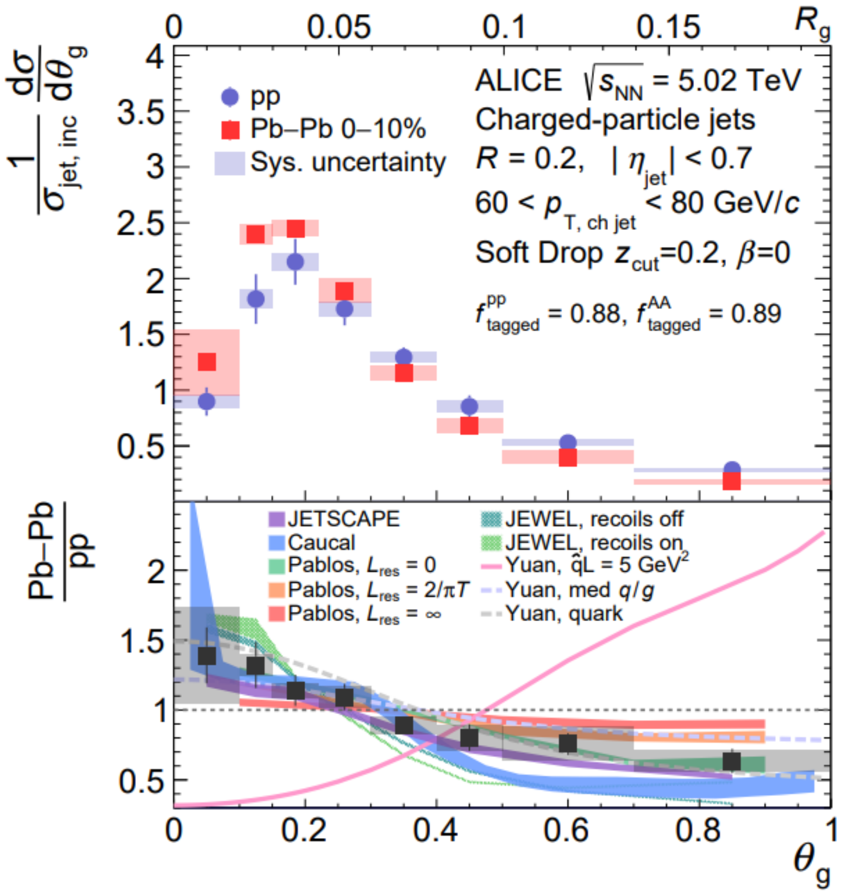


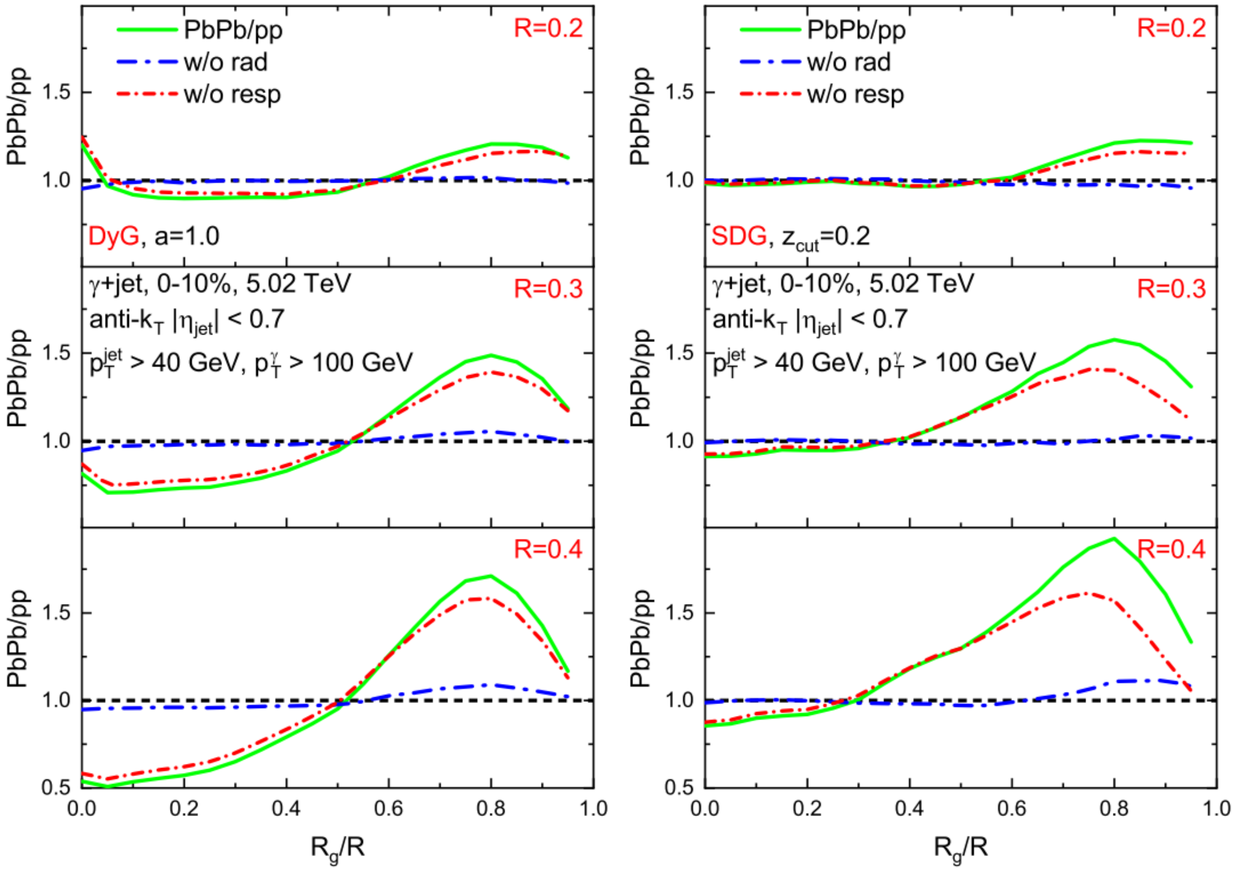
Anti- $k_T : d_{ij} = \min(p_{ti}^{2p}, p_{tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2}$ $\xrightarrow{\text{decluster}}$ C/A: $d_{ij} = \frac{\Delta R_{ij}^2}{R^2}$

Hard jet structure

- Grooming techniques remove the soft, wide-angle radiation, reducing the impact of non-perturbative contributions and preserving the characteristic of hard splitting.

Groomed jet radius of γ+jet in A+A collisions





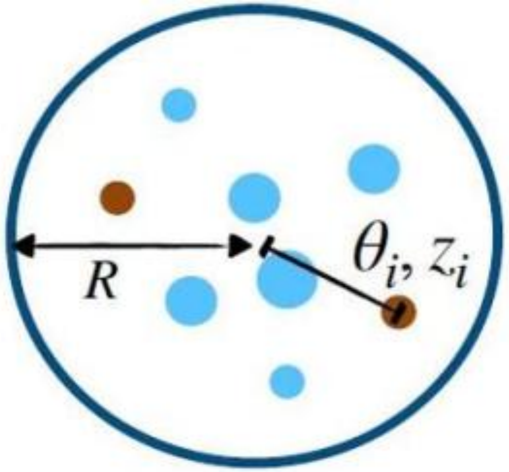
- γ + jet reduces selection bias and can effectively select jets sufficiently quenched, which is crucial to capture the jet angular broadening.

SW, S Li, JW Kang, BW Zhang, EK Wang, Sci.China Phys.Mech.Astron. (2026)

Generalized jet angularity

Angularity:

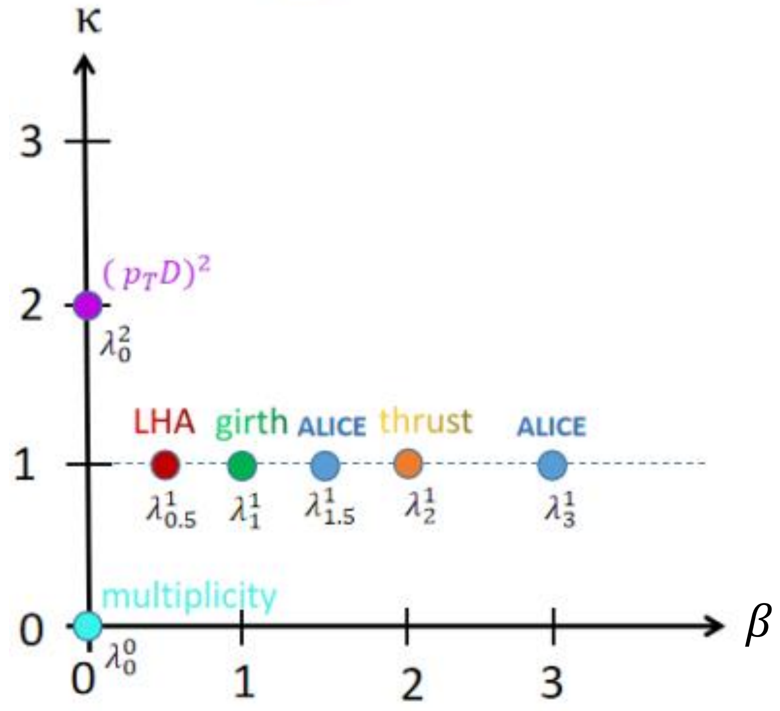
$$\lambda_\beta^\kappa = \sum_{i\in\text{jet}} \left(\frac{p_{T,i}}{p_{T,\text{jet}}}\right)^\kappa \left(\frac{\Delta R_{\text{jet},i}}{R_{\text{jet}}}\right)^\beta = \sum_{i\in\text{jet}} z_i^\kappa \theta_i^\beta$$



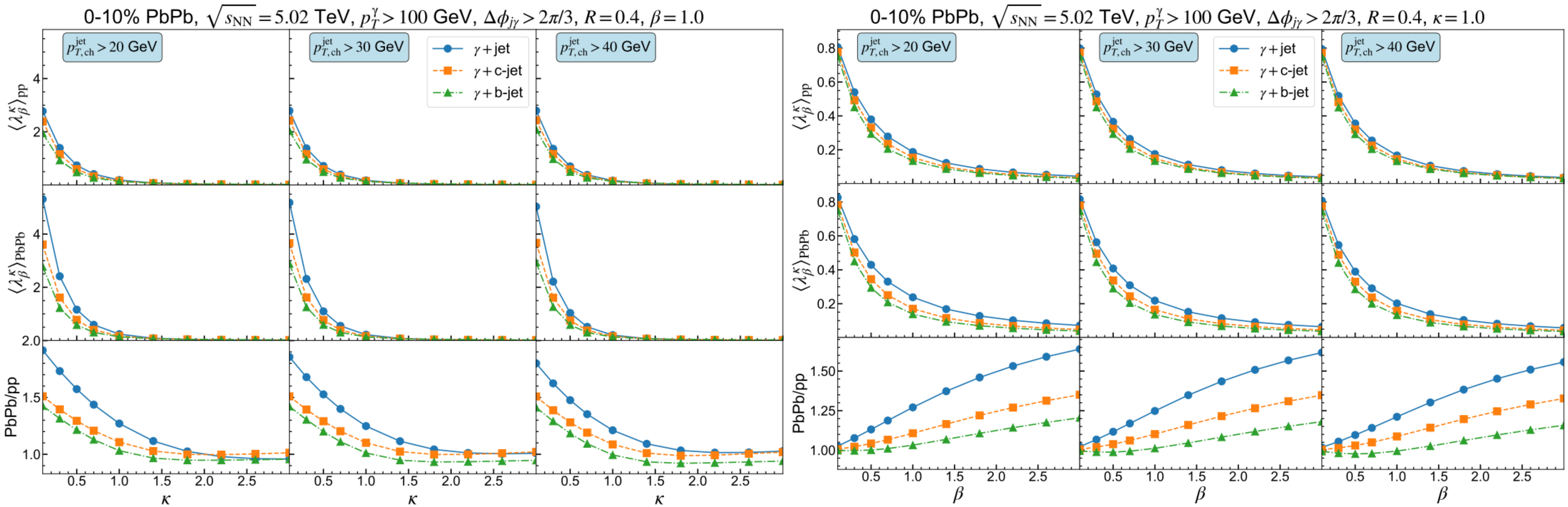
z_i : momentum fraction carried by jet constituents.

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



Mass-dependent broadening of γ + (Q-)jet



- ➢ A clear 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.

$$\lambda_\beta^\kappa=\sum_{i\in \rm jet} z_i^\kappa \theta_i^\beta$$

SW, S Li, BW Zhang, EK Wang, in preparation.

Summary and outlook

- How to eliminate selection bias to reveal the true jet substructure modification? γ+jet.
- What kind of observable is suitable for capturing signals of jet broadening? λ_β^κ.
- Does jet broadening exhibit a mass hierarchy effect? Yes.
- Difference between gluon- and quark-initiated jets?...

Thank you

Backup: simulation of in-medium jet transport

Collisional energy loss: **pQCD@HTL**

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

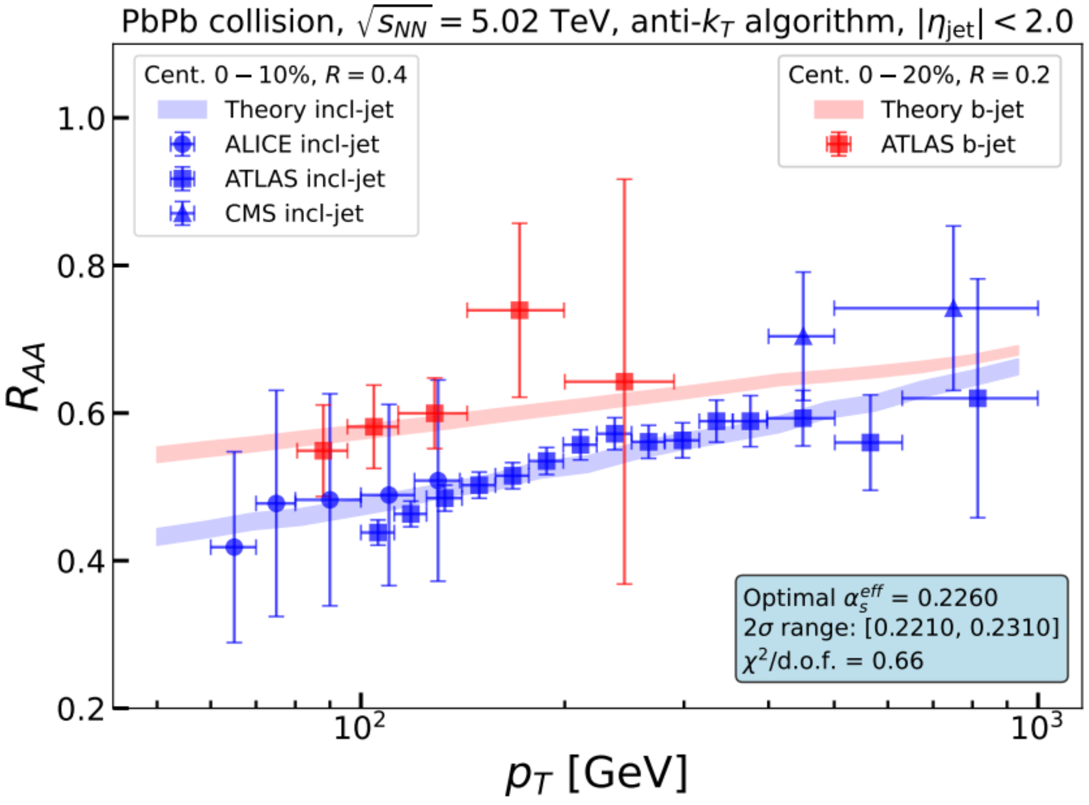
Radiative energy loss: **Higher-Twist formalism**

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

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

Medium response: **Perturbed Hydrodynamic Wake**

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



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