

JAQ 2026

首届喷注与重夸克物理研讨会 (JAQ 2026)

The 1st Workshop on Jet and Heavy Quark Physics

🕒 2026 / 1 / 23 - 26

📍 华中师范大学, 武汉 (CCNU, Wuhan)

Particle Correlations in Jets

Wenbin Zhao

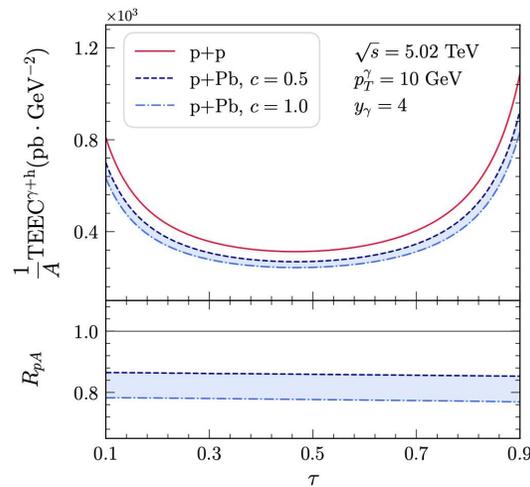
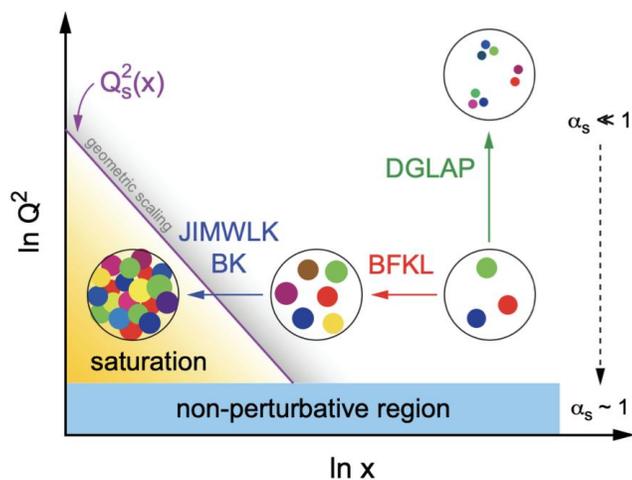
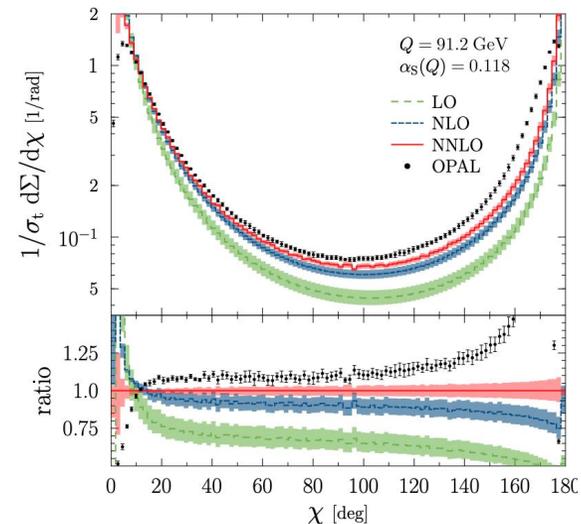
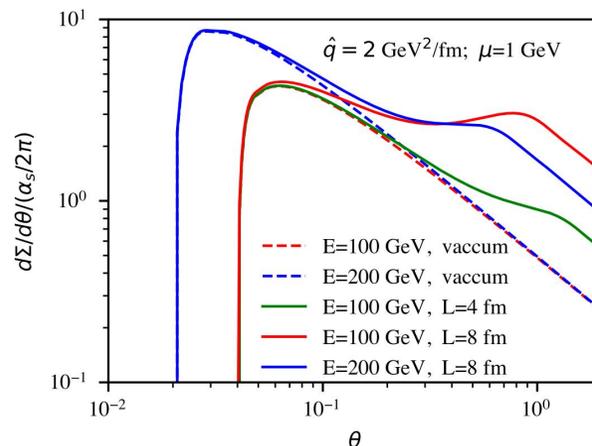
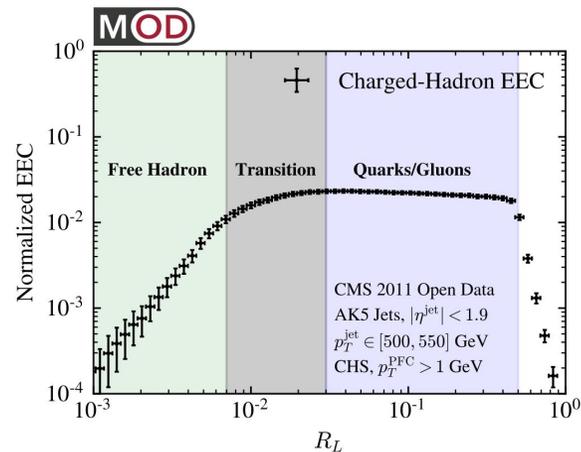
Central China Normal University

01.23-26, 2026, Wuhan, China



Energy-Energy Correlator

$$\frac{d\langle\text{EEC}(\theta)\rangle_{\text{full}}}{d^2\theta} = \frac{1}{N_{\text{jet}}} \sum_{\text{jets } J} \sum_{i \neq j \in J} \frac{E_i E_j}{E_J^2} \delta^{(2)}(\vec{\theta} - (\vec{\theta}_i - \vec{\theta}_j)) ,$$



- C. Berger et al. (PLUTO), Phys. Lett. B 99, 292 (1981).
- C. L. Basham, L. S. Brown, S. D. Ellis, and S. T. Love, PRL. 41, 1585 (1978).
- P. T. Komiske, I. Mout, J. Thaler, and H. X. Zhu, (2022), arXiv:2201.07800
- Z. Yang, Y. He, I. Mout, and X.-N. Wang, Phys. Rev. Lett. 132, 011901 (2024)
- Z. B. Kang, R. Kao, M. Li and J. Penttala, Phys. Rev. D 112 (2025) no.7, 076006
- I. Mout and H. X. Zhu, (2025), 2506.09119.
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EEC inside the jet

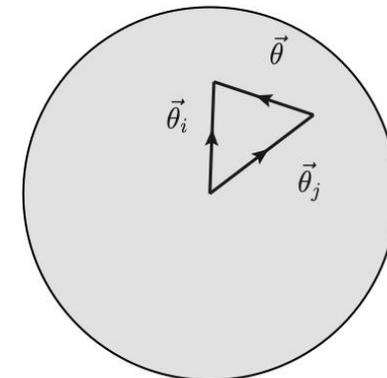
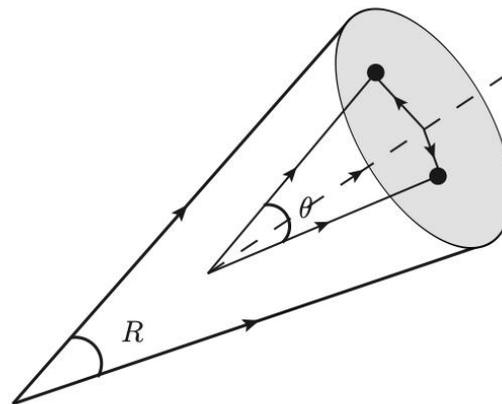
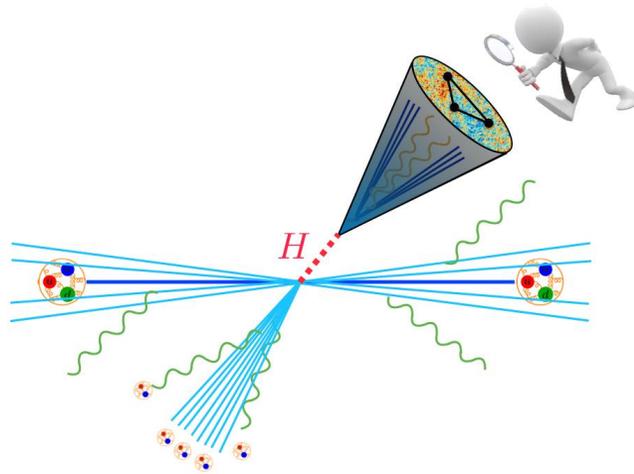
- The **full EECs** inside the jet is defined as

$$\frac{d\langle\text{EEC}(\theta)\rangle_{\text{full}}}{d^2\theta} = \frac{1}{N_{\text{jet}}} \sum_{\text{jets } J} \sum_{i \neq j \in J} \frac{E_i E_j}{E_J^2} \delta^{(2)}(\vec{\theta} - (\vec{\theta}_i - \vec{\theta}_j)) ,$$

- Trivial two particle distributions** from single particle distributions

$$\frac{d}{d^2\theta} \langle\text{EEC}(\theta)\rangle_{\text{trivial}} = N_{\text{trivial}} \int d^2\theta_1 d^2\theta_2 \times \frac{d\langle\text{E}(\theta_1)\rangle}{d^2\theta_1} \frac{d\langle\text{E}(\theta_2)\rangle}{d^2\theta_2} \delta^{(2)}(\vec{\theta} - (\vec{\theta}_1 - \vec{\theta}_2)) ,$$

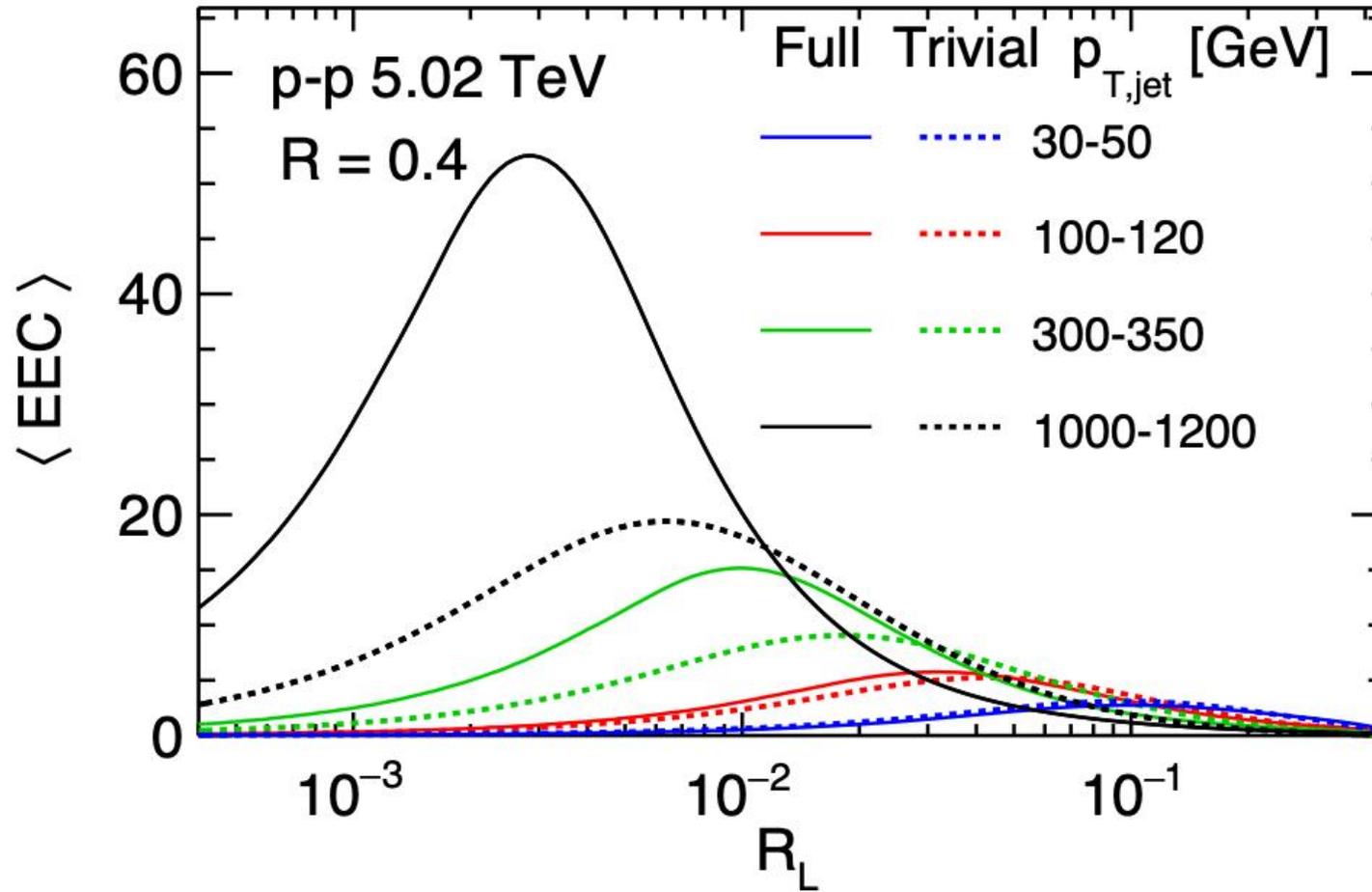
$$N_{\text{trivial}} \approx 0.85$$



I. Moutl and H. X. Zhu, (2025), 2506.09119

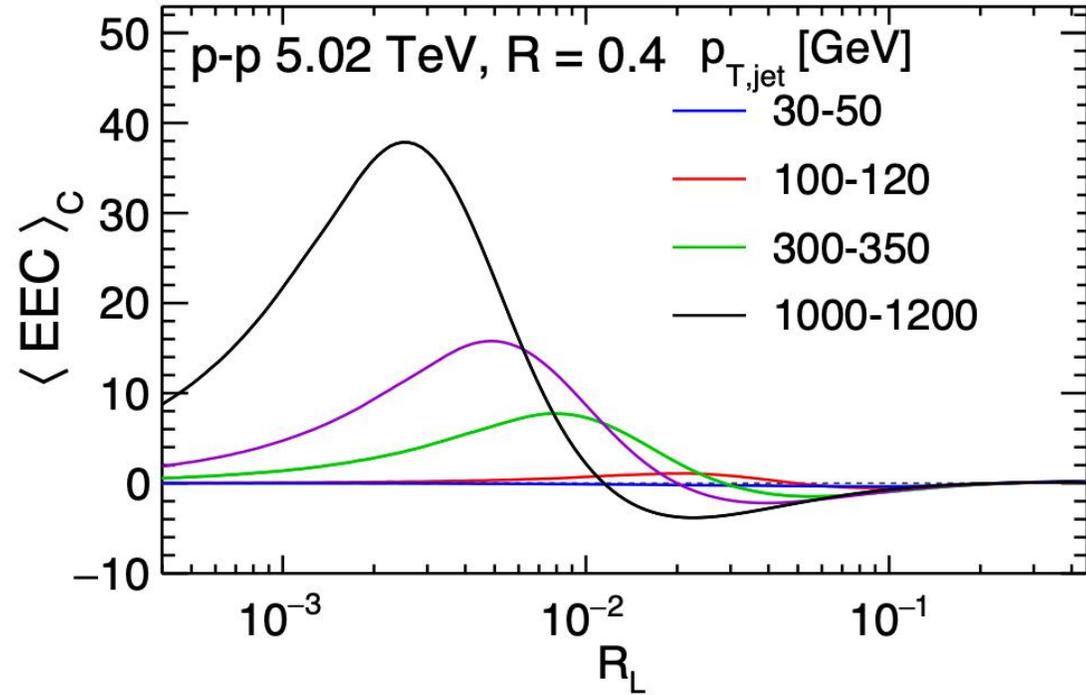
W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

Full and Trivial Correlations

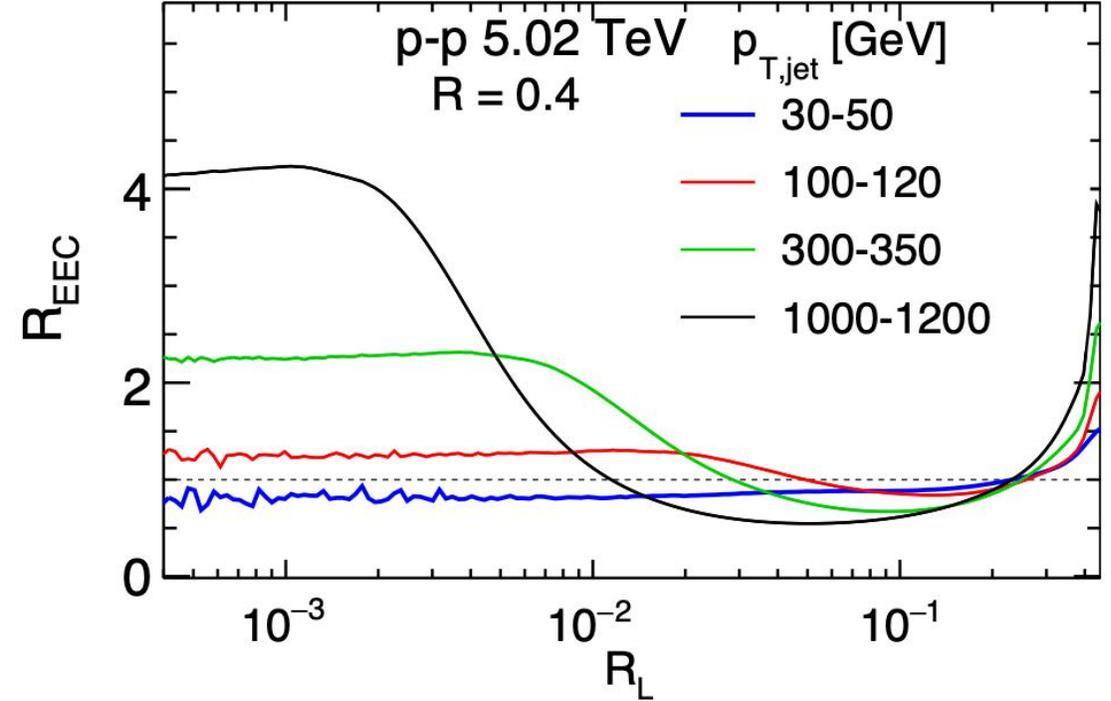


W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

Ratio and difference between Full and Trivial Correlations



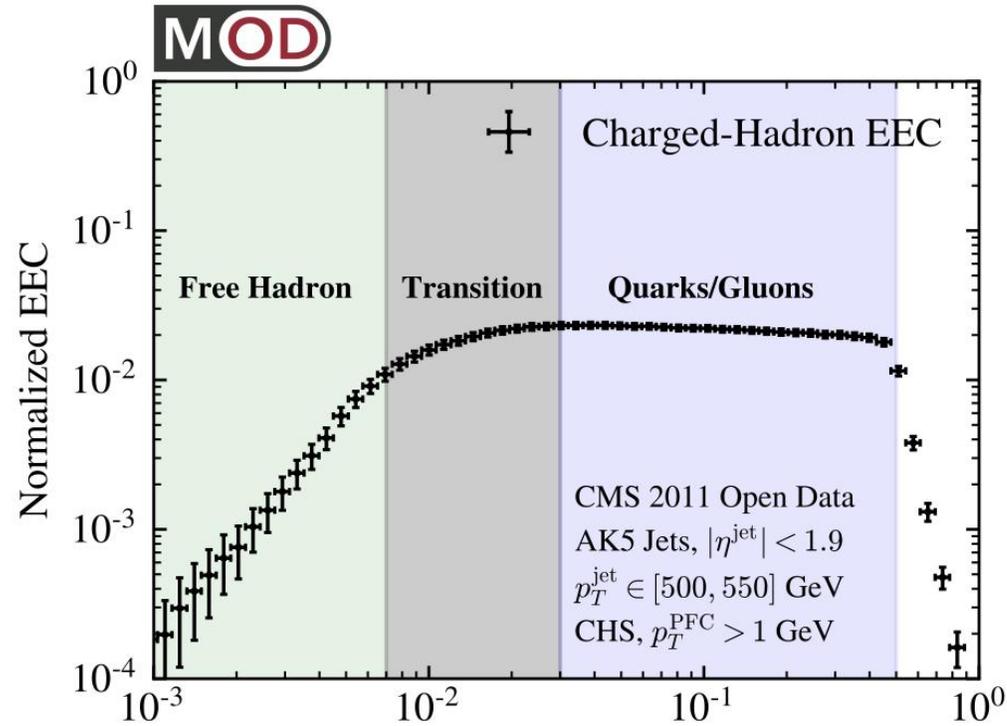
$$\langle \text{EEC}(\theta) \rangle_C = \frac{d\langle \text{EEC}(\theta) \rangle_{\text{full}}}{d^2\theta} - \frac{d\langle \text{EEC}(\theta) \rangle_{\text{trivial}}}{d^2\theta}$$



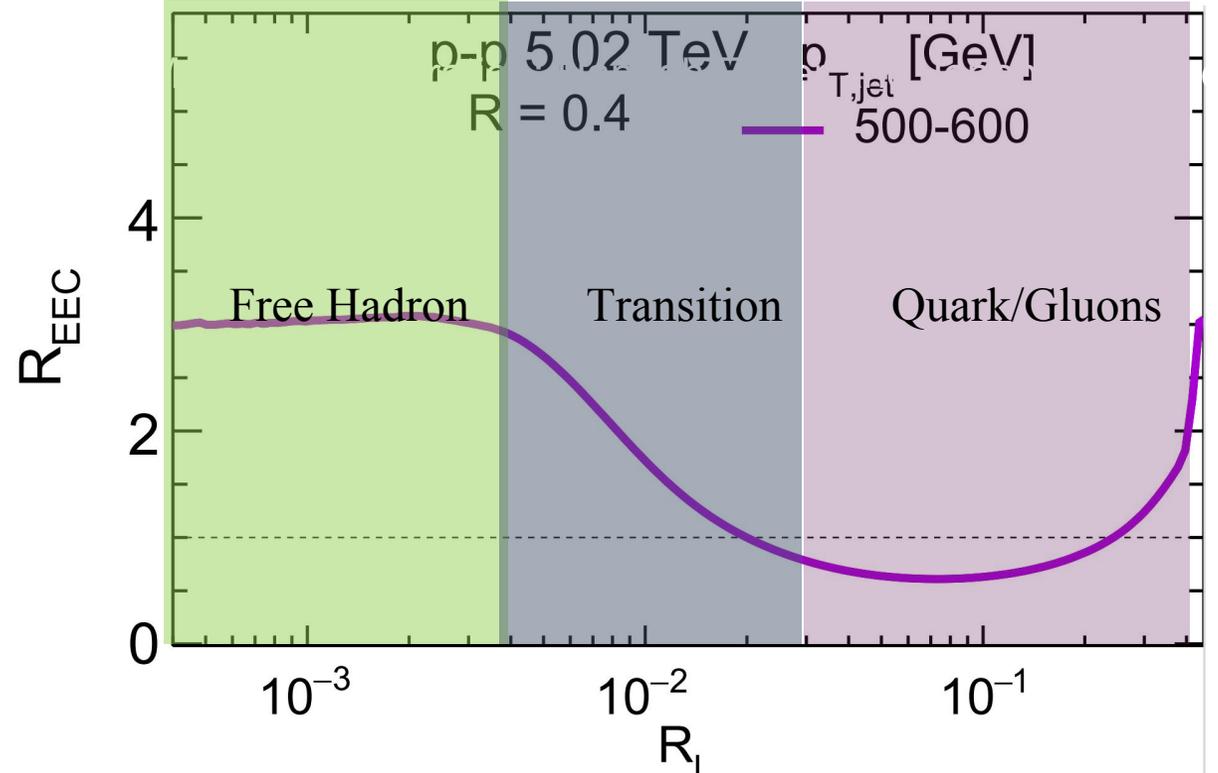
$$\mathcal{R}_{\text{EEC}}(\theta) = \frac{d\langle \text{EEC}(\theta) \rangle_{\text{full}}}{d^2\theta} / \frac{d\langle \text{EEC}(\theta) \rangle_{\text{trivial}}}{d^2\theta},$$

W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

“Free hadrons” to “transition” to “collinear” regions



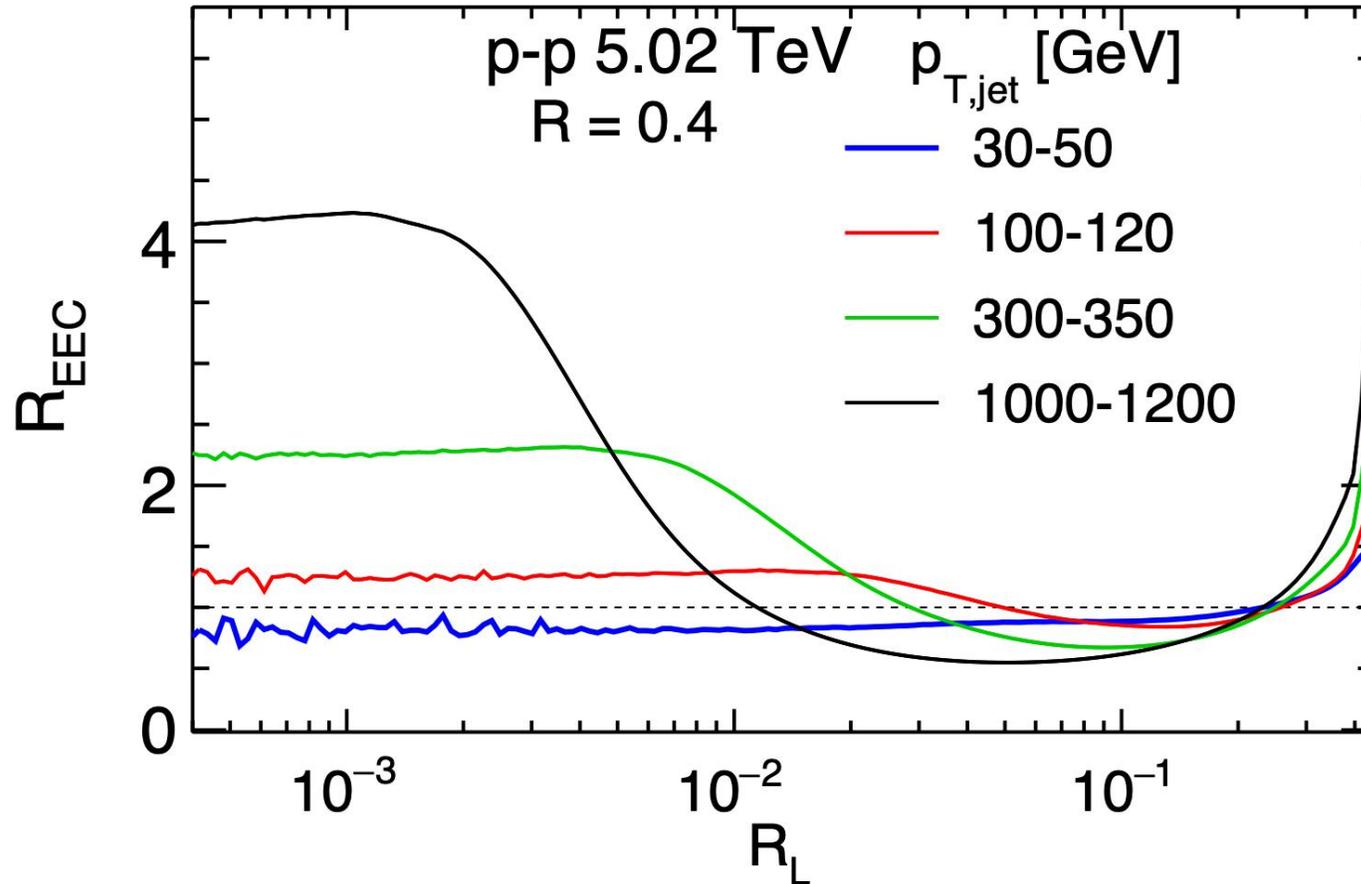
P. T. Komiske, I. Moutl, J. Thaler and H. X. Zhu, Phys. Rev. Lett. 130, 051901 (2023).



W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

- **Small angles:** REEC is **flat**, unmodified hadron emissions with negligible collinear effects;
- **Moderate angles** (the “Transition Region”), REEC **decreases**, the onset of collinear dynamics and hadronization processes.
- **Large angles** (the “Collinear Region”), REEC **rises**, driven by perturbative-QCD collinear splittings that enhance correlations.

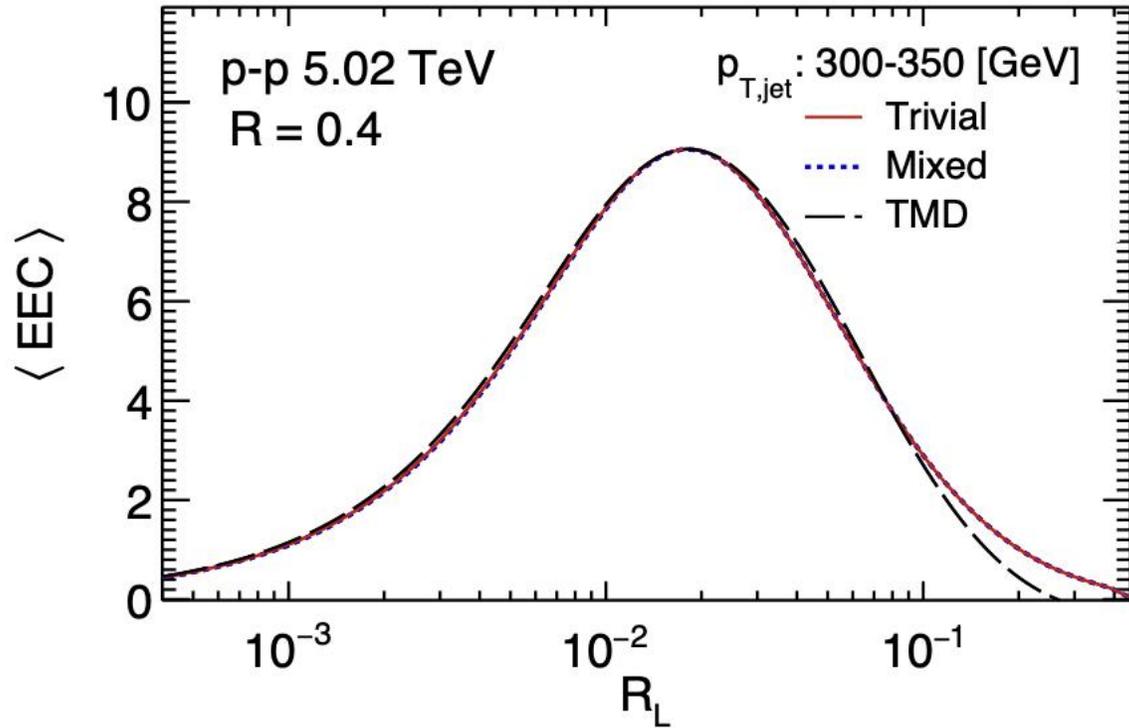
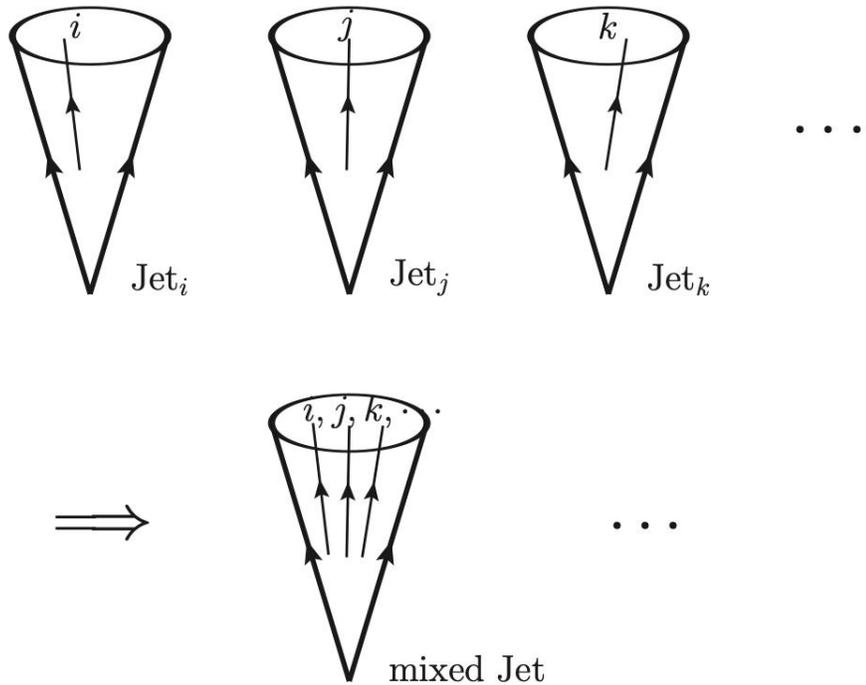
Jet P_T dependence



- “Free hadron” region becomes **smaller for higher P_T jet**.
- $R_{\text{EEC}} < 1$ for the low P_T jet, partially caused by the **different gluon and quark jets fractions**.
- **The platform at small angle increases with the jet P_T .**

W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

Mixed events and “trivial” Correlations



- The EEC from mixed events agree with that obtained from the product of the single energy flows (“trivial” Correlations).

W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

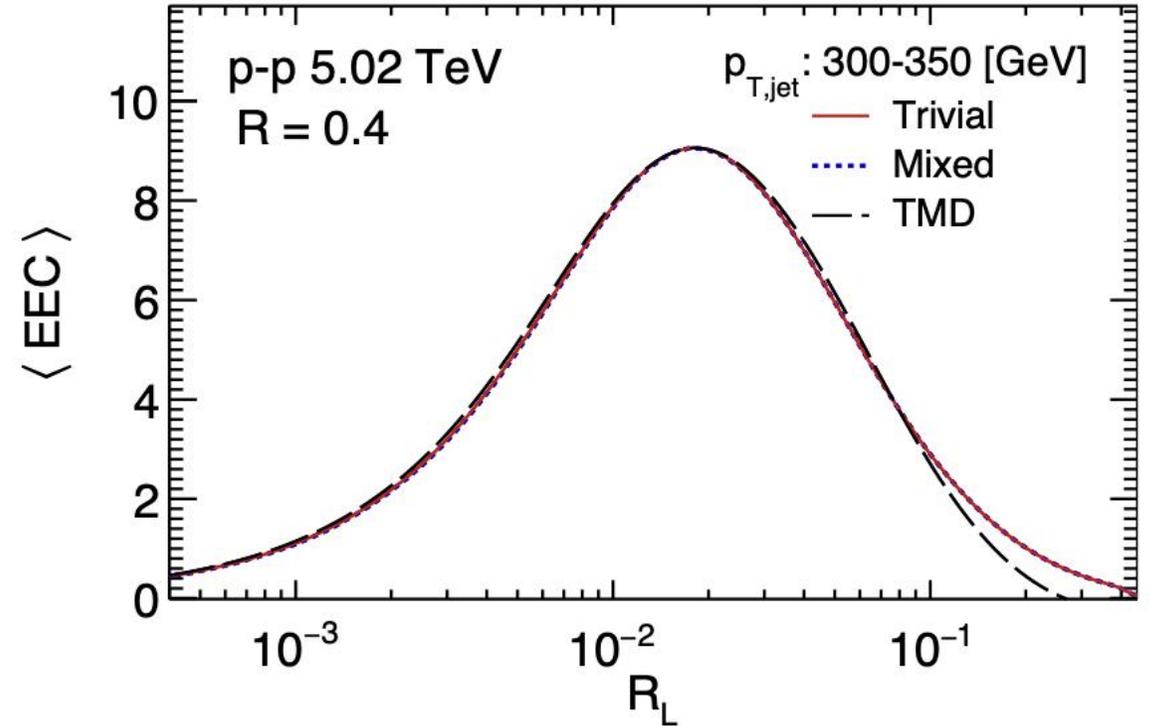
TMD calculations

$$\frac{d\langle E(\theta) \rangle}{d^2\theta} = \mathcal{N}_1 c_1^2 E^2 \sum_h \int dz_h z_h D_{q/g}^h(z_h, P_{h\perp}; \zeta_E),$$

$$D_{q/g}^h(z_h, P_{h\perp}; \zeta_E) = \int \frac{d^2 b_T}{(2\pi)^2} e^{i \frac{P_{h\perp} \cdot b_T}{z_h}} D_{q/g}^h(z_h, \mu_b) \times e^{-\frac{S_{q/g}(c_2 E, b_T)}{2}}, \quad (\text{B2})$$

$$\begin{aligned} & \frac{d}{d^2\theta} \langle \text{EEC}(\theta) \rangle_{\text{trivial}} \\ &= \tilde{\mathcal{N}} c_1^2 E^2 \int db b J_0(c_1 E b \theta) e^{-S_{q,g}(c_2 E, b)}, \end{aligned}$$

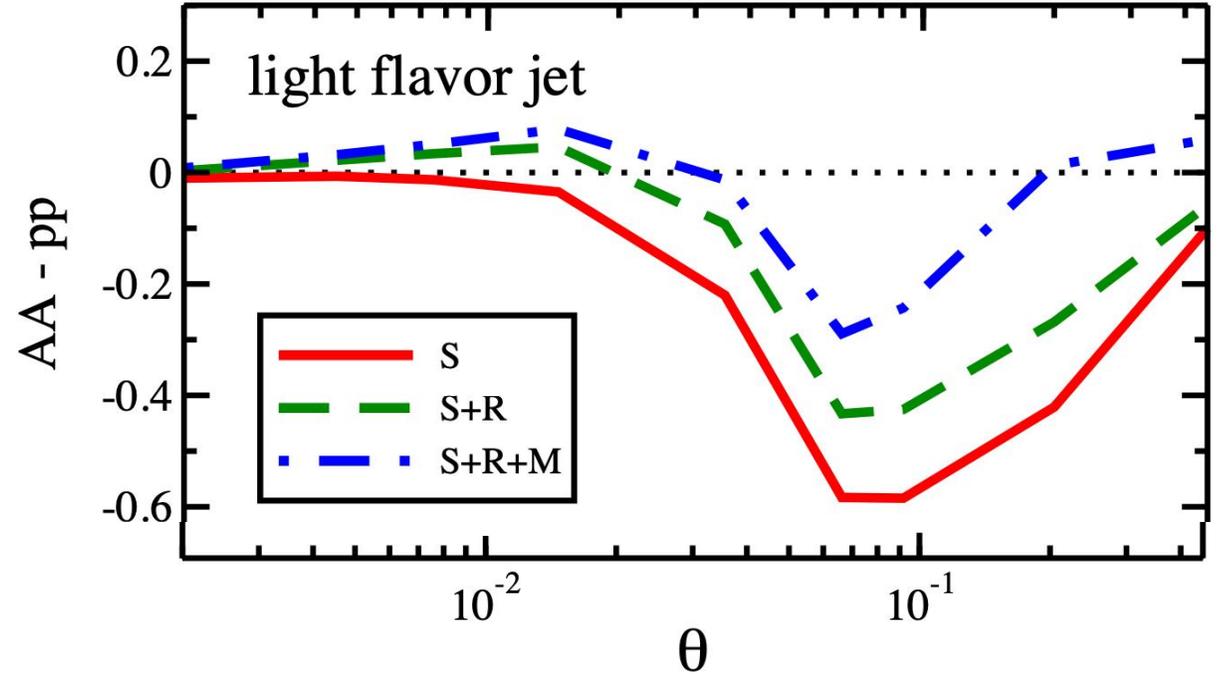
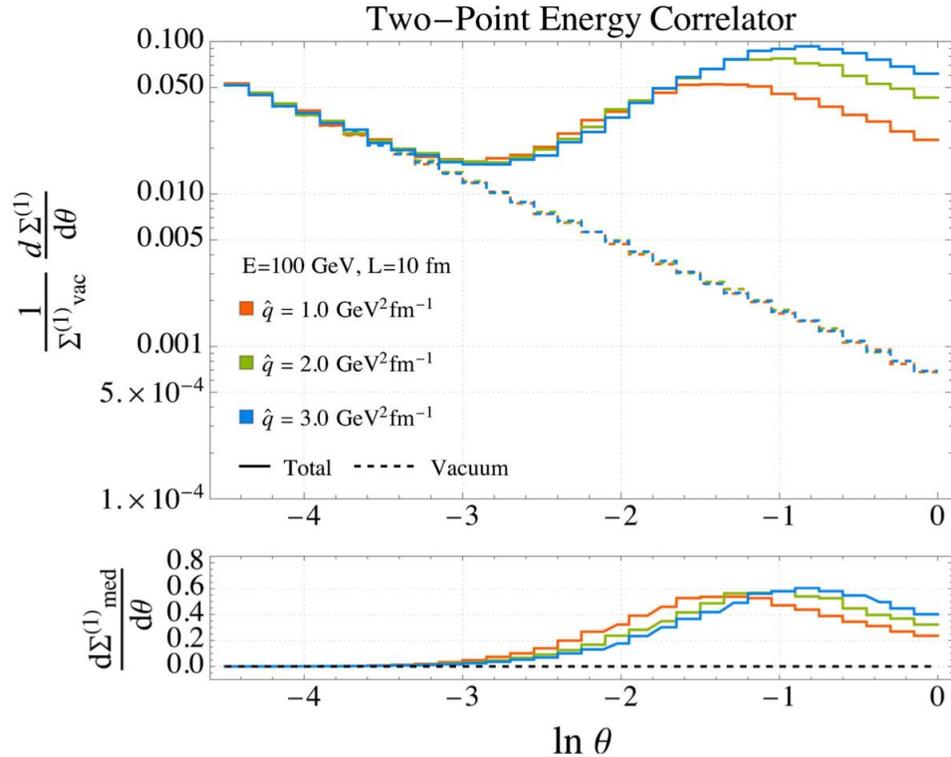
- TMD model calculations capture the main behavior of the trivial correlators at small angles.



W. Zhao, V. Koch and F. Yuan, [arXiv:2507.18790].

Particle Correlations in Heavy-Ion Collisions

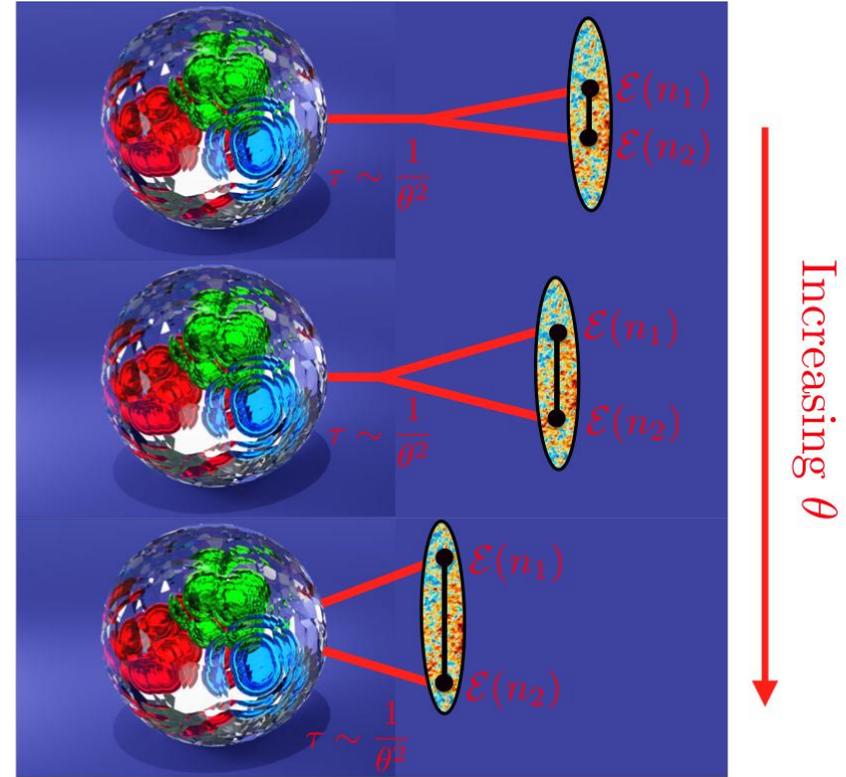
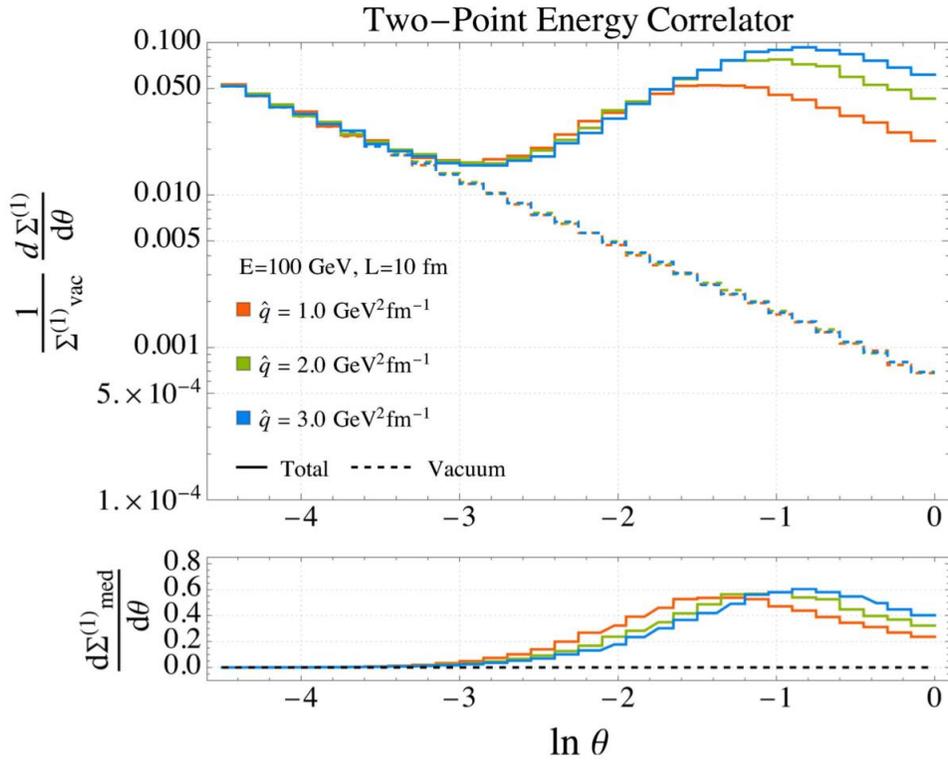
Deciphering the nuclear modification mechanism



S: shower partons; **R:** medium-induced radiations;
M: medium response

- **Small angle:** same as the vacuum result
- **Large angle:** Having an excess due to medium effects.
- Realistic model simulation shows the energy loss will **reduce the energy correlators at large angle.**

Deciphering the nuclear modification mechanism



- **Small angle:** same as the vacuum result
- **Large angle:** Having an excess due to medium-induced radiation.
- Realistic model simulation shows the energy loss will **reduce the energy correlators at large angle.**
- Medium: **can't resolve the small angle correlations** $\theta \sim \mu_{\text{Debye}} / E_{\text{jet}}$

I. Mout, slides, 2025.

Deciphering the nuclear modification mechanism

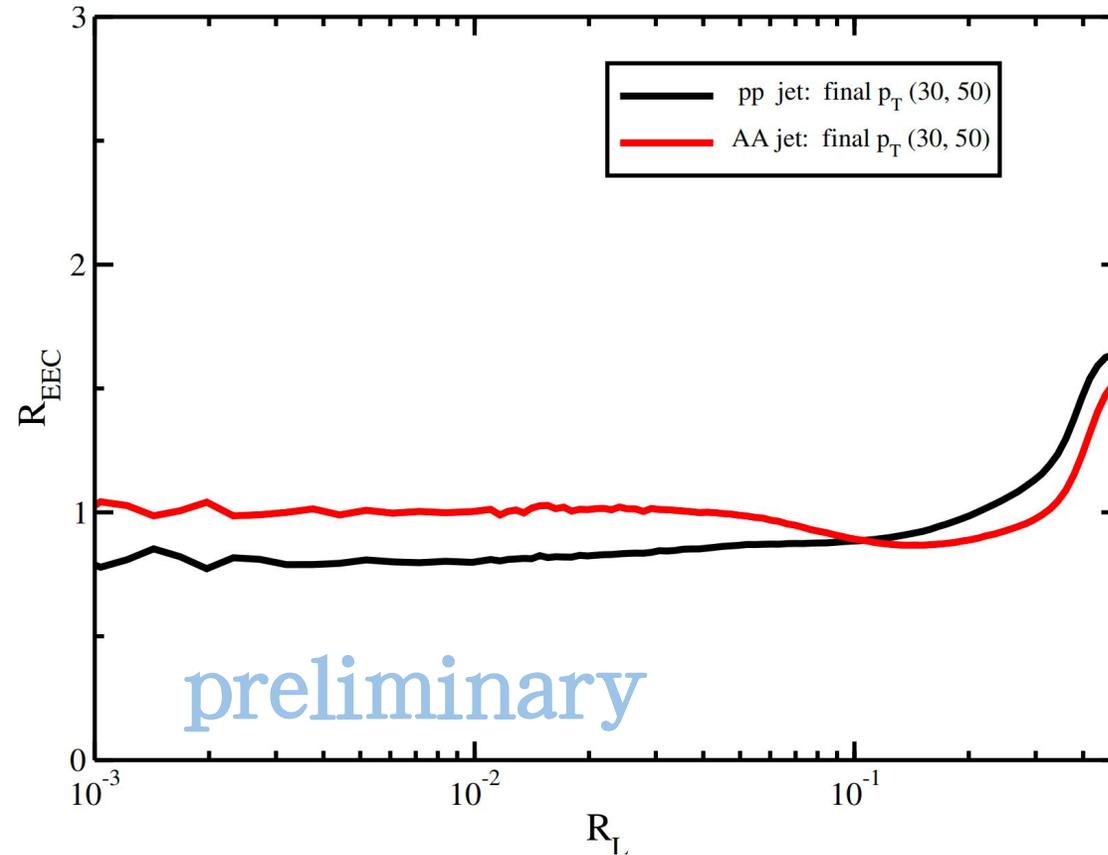
- Double difference $\Delta\langle\text{EEC}\rangle^{AA}(\theta) = \langle\text{EEC}(\theta)\rangle_C^{AA} - \langle\text{EEC}(\theta)\rangle_C^{pp}$,

$$\langle\text{EEC}(\theta)\rangle_C = \frac{d\langle\text{EEC}(\theta)\rangle_{\text{full}}}{d^2\theta} - \frac{d\langle\text{EEC}(\theta)\rangle_{\text{trivial}}}{d^2\theta}$$

- Double ratio: $\mathcal{R}_{\text{EEC}}^{AA}(\theta) = \frac{\frac{d\langle\text{EEC}(\theta)\rangle_{\text{full}}^{AA}}{d^2\theta} / \frac{d\langle\text{EEC}(\theta)\rangle_{\text{trivial}}^{AA}}{d^2\theta}}{\frac{d\langle\text{EEC}(\theta)\rangle_{\text{full}}^{pp}}{d^2\theta} / \frac{d\langle\text{EEC}(\theta)\rangle_{\text{trivial}}^{pp}}{d^2\theta}}$.

- **Small angle:** jet energy loss, **quantitatively extract** the jet energy loss.
- **Large angle:** medium modification of the parton splitting.
- **Medium response will be canceled out** in **Double difference** in AA, it has no particular angular dependence.

Heavy-Ion Collisions (LBT simulations)

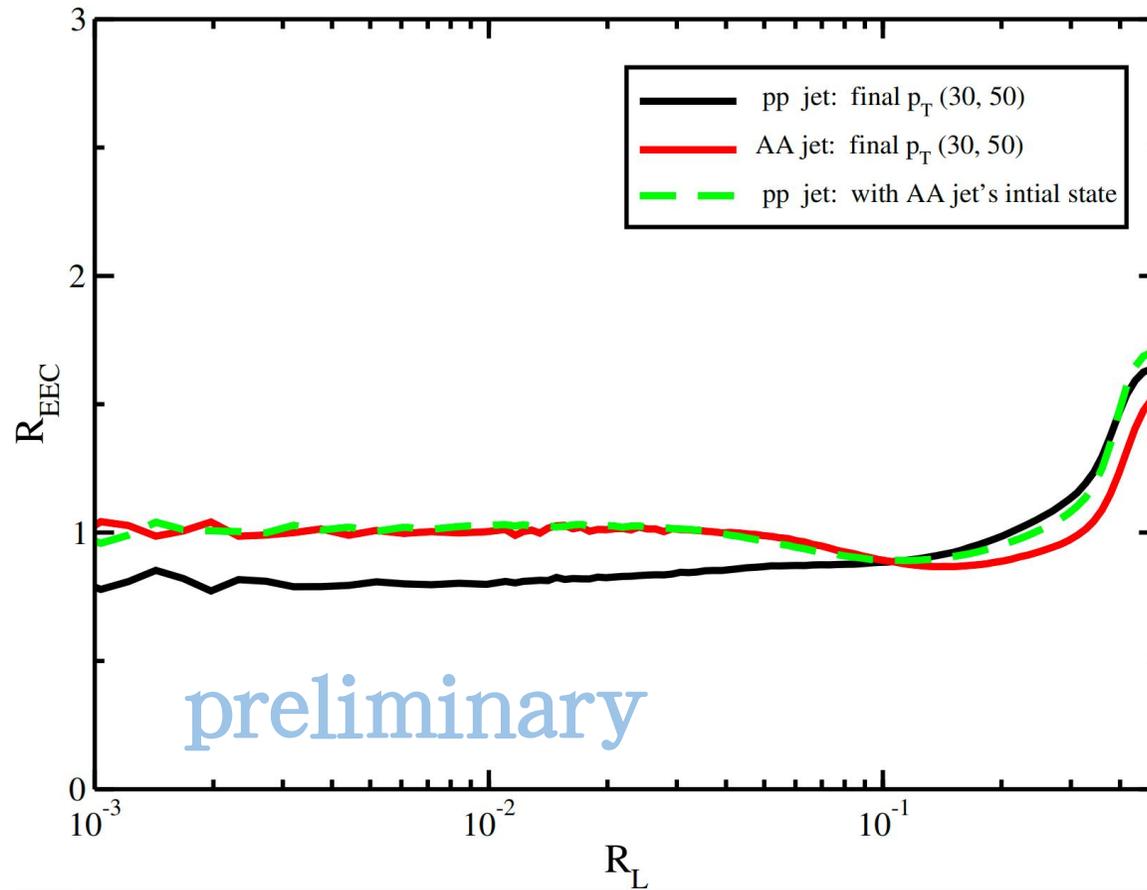


From Wenjing Xing

- **Small angle:** AA (PbPb 0-10%) has the **higher platform** than p-p at the same jet P_T .
- **Moderate and large angles :** AA is smaller than p-p, due to energy loss.

W. Xing, L. Li, W. Zhao, W. Ke, V. Koch, G. Qin, X. Wang, F. Yuan. in progress.

Remove selection bias (LBT simulations)

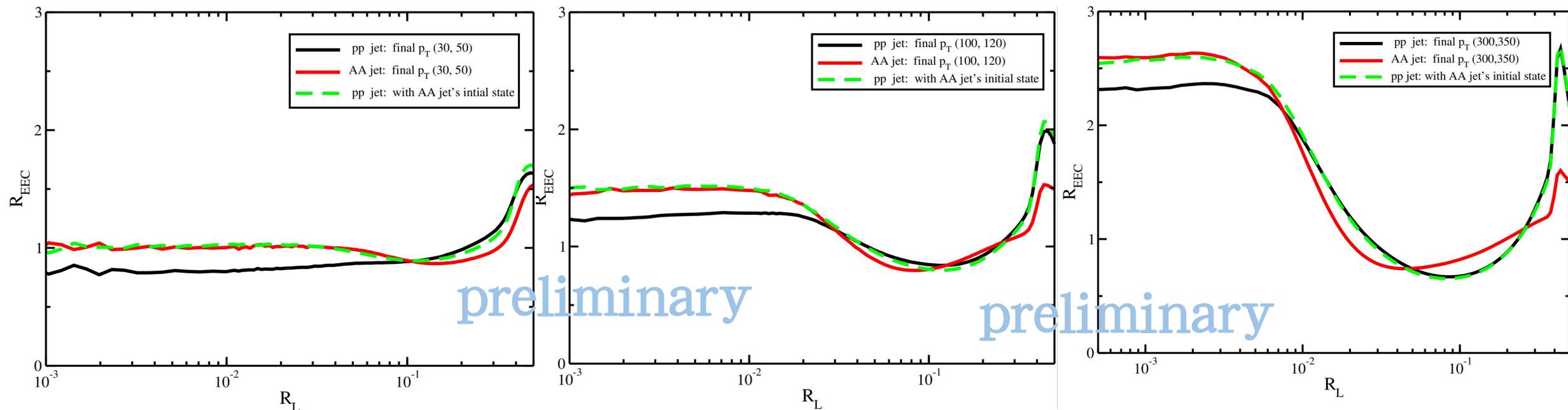


From Wenjing Xing

- **Small angle:** selected p-p has the **same platform** as AA, **extracted the reduced jet P_T** .
- **Moderate and large angles :** selected p-p is the same as p-p.

W. Xing, L. Li, W. Zhao, W. Ke, V. Koch, G. Qin, X. Wang, F. Yuan. in progress.

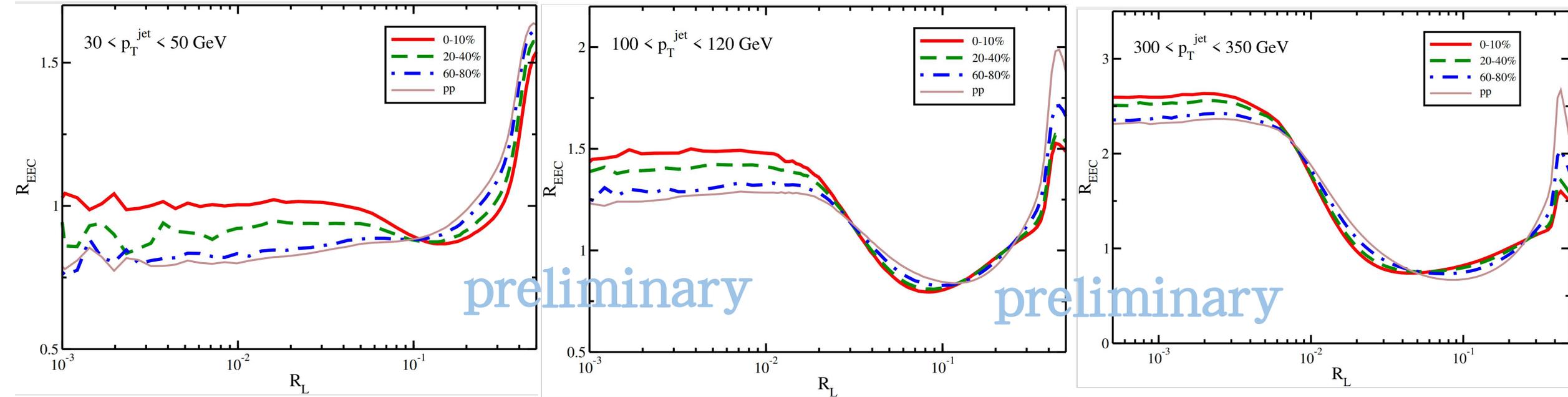
More jet P_T bins (LBT simulations)



- All jet P_T bins have the **consistent** results.
- It can be measured experimentally, and **extracted the reduced jet P_T quantitatively**.
- It's **free from the systematic uncertainties associated Ncoll**.

W. Xing, L. Li, W. Zhao, W. Ke, V. Koch, G. Qin, X. Wang, F. Yuan. in progress.

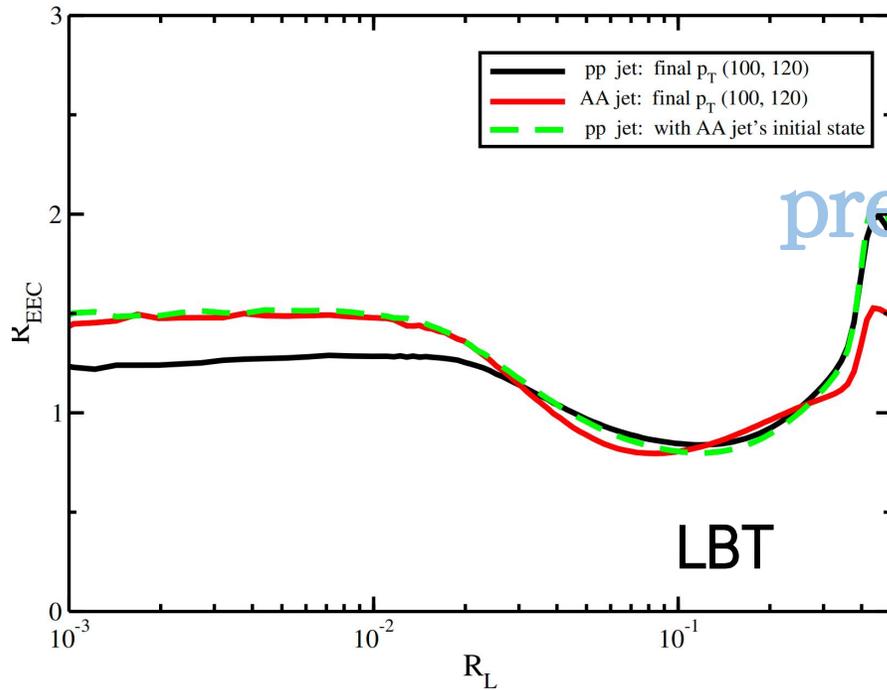
More centrality bins (LBT simulations)



- All centrality bins have the **consistent** results.
- AA approaches to p-p **from top to bottom**

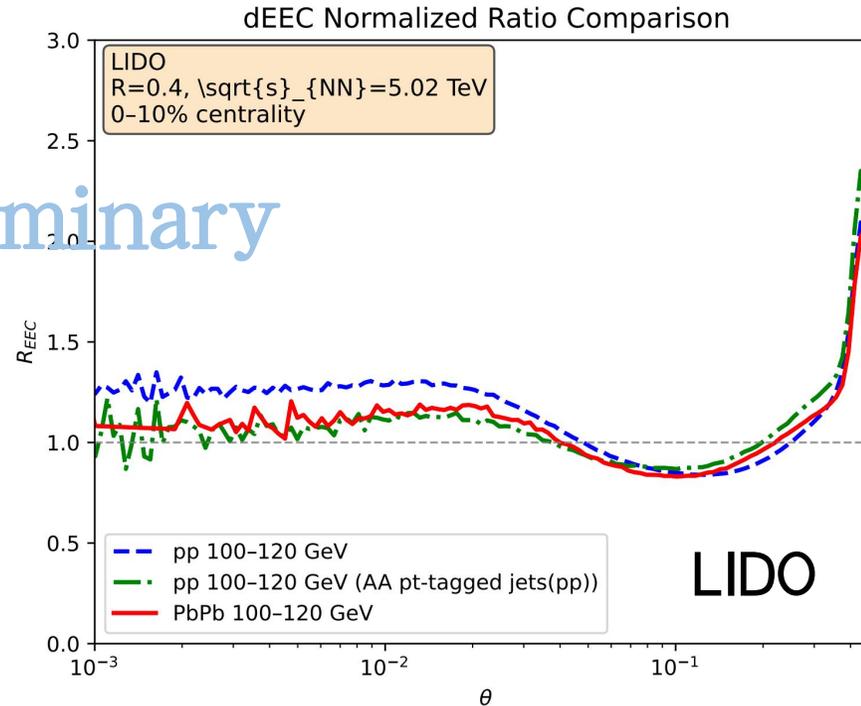
W. Xing, L. Li, W. Zhao, W. Ke, V. Koch, G. Qin, X. Wang, F. Yuan. in progress.

Heavy-Ion Collisions (LIDO simulations)



Wenjing Xing

preliminary



Lin Li

- In LIDO, AA seems below the pp at small angle.
- Both LBT and LIDO demonstrates that **medium don't affect the REEC at small angle.**
- The difference between LIDO and LBT needs to be understood.

W. Xing, L. Li, W. Zhao, W. Ke, V. Koch, G. Qin, X. Wang, F. Yuan. in progress.

Summary

- We propose a new particle correlation observable within high-energy jets to elucidate the underlying physics driving energy–energy correlators and to reveal hadronization effects in high energy jets
- We investigated the effects of a hot medium on particle correlations within jets, potentially enabling the **quantitative extraction of the reduced jet** transverse momentum.
- This can also apply to **small system**, like high multiplicity p-p, **free from the systematic uncertainties associated Ncoll**.
- The difference between LIDO and LBT still needs to be understood.

Thanks for Your Attention!