HP2024
NAGASAKI

Hard Probes 2024, 長崎

LO, NLO, and NP parton collision kernels: Effects on the jet substructures

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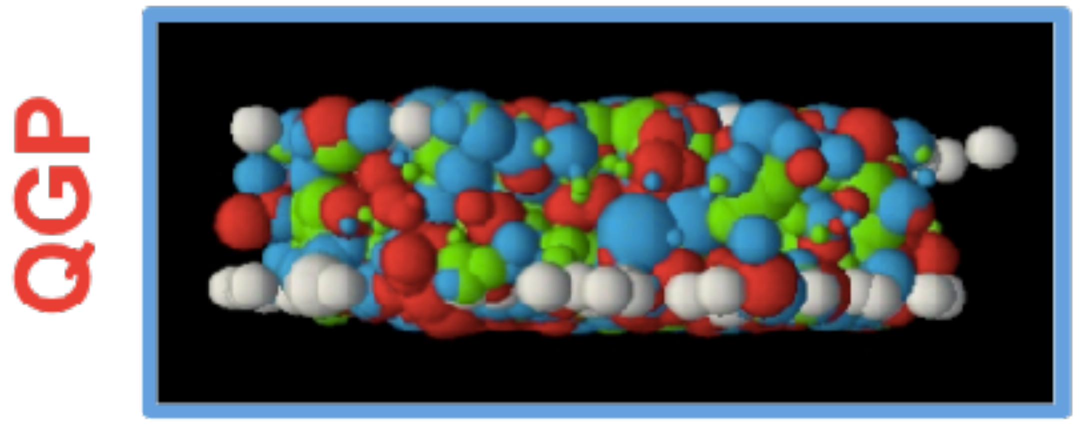
refs: [PhysRevC.106.064902 + 2407.19966]

Tomography of QGP

Jet Quenching:

particles w/ high momentum $(E > 10\ \mathrm{GeV}) \gg (k_B T \sim 160\ \mathrm{MeV})$

nucl.+nucl. (init.) = p+p



nucl.+nucl. (fin.)

Needs accurate hard-soft interaction to precisely probe the QGP properties.

energy loss of hard particles

AMY splitting rate

$$\frac{\mathrm{d}\Gamma^{\mathrm{AMY}}_{i\to jk}}{\mathrm{d}z}(P,z) = \frac{\alpha_s P_{i\to jk}(z)}{[2Pz(1-z)]^2} f_j(zP) f_k((1-z)P)$$
$$\times \int \frac{\mathrm{d}^2\mathbf{p}_\perp}{(2\pi)^2}\, \mathrm{Re}\left[2\mathbf{p}_\perp \cdot \mathbf{g}_{(z,P)}(\mathbf{p}_\perp)\right] \;,$$

$$2\mathbf{p}_\perp = i\delta E(z,P,\mathbf{p}_\perp)\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) + \int \frac{\mathrm{d}^2\mathbf{q}_\perp}{(2\pi)^2}\, \bar{C}(q_\perp)$$
$$\times \Big\{ C_1[\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) - \mathbf{g}_{(z,P)}(\mathbf{p}_\perp - \mathbf{q}_\perp)]$$
$$+ C_z[\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) - \mathbf{g}_{(z,P)}(\mathbf{p}_\perp - z\mathbf{q}_\perp)]$$
$$+ C_{1-z}[\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) - \mathbf{g}_{(z,P)}(\mathbf{p}_\perp - (1-z)\mathbf{q}_\perp)] \Big\} \,.$$

Arnold-Moore-Yaffe:

JHEP: 11(2001)057, 12(2001)009, 06(2002)030

energy loss of hard particles

AMY splitting rate

$$\frac{\mathrm{d}\Gamma^{\mathrm{AMY}}_{i\to jk}}{\mathrm{d}z}(P,z) = \frac{\alpha_s P_{i\to jk}(z)}{[2Pz(1-z)]^2} f_j(zP) f_k((1-z)P) \times \int \frac{\mathrm{d}^2\mathbf{p}_\perp}{(2\pi)^2}\, \mathrm{Re}\left[2\mathbf{p}_\perp \cdot \mathbf{g}_{(z,P)}(\mathbf{p}_\perp)\right] ,$$

collisions kernel

$$2\mathbf{p}_\perp = i\delta E(z,P,\mathbf{p}_\perp)\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) + \int \frac{\mathrm{d}^2\mathbf{q}_\perp}{(2\pi)^2} \boxed{\bar{C}(q_\perp)} \times \Big\{ C_1[\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) - \mathbf{g}_{(z,P)}(\mathbf{p}_\perp - \mathbf{q}_\perp)] + C_z[\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) - \mathbf{g}_{(z,P)}(\mathbf{p}_\perp - z\mathbf{q}_\perp)] + C_{1-z}[\mathbf{g}_{(z,P)}(\mathbf{p}_\perp) - \mathbf{g}_{(z,P)}(\mathbf{p}_\perp - (1-z)\mathbf{q}_\perp)] \Big\} .$$

at leading order:

$$C_{\mathrm{LO}}\left(\mathbf{q}_\perp\right) = \frac{g_s^2 T^3}{q_\perp^2\left(q_\perp^2 + m_D^2\right)} \int \frac{\mathrm{d}^3 p}{(2\pi)^3} \frac{p - p_z}{p} \times [2C_A n_B(p)(1 + n_B(p')) + 4N_f T_f n_F(p)(1 - n_F(p'))] .$$

Arnold-Moore-Yaffe:

JHEP: 11(2001)057, 12(2001)009, 06(2002)030

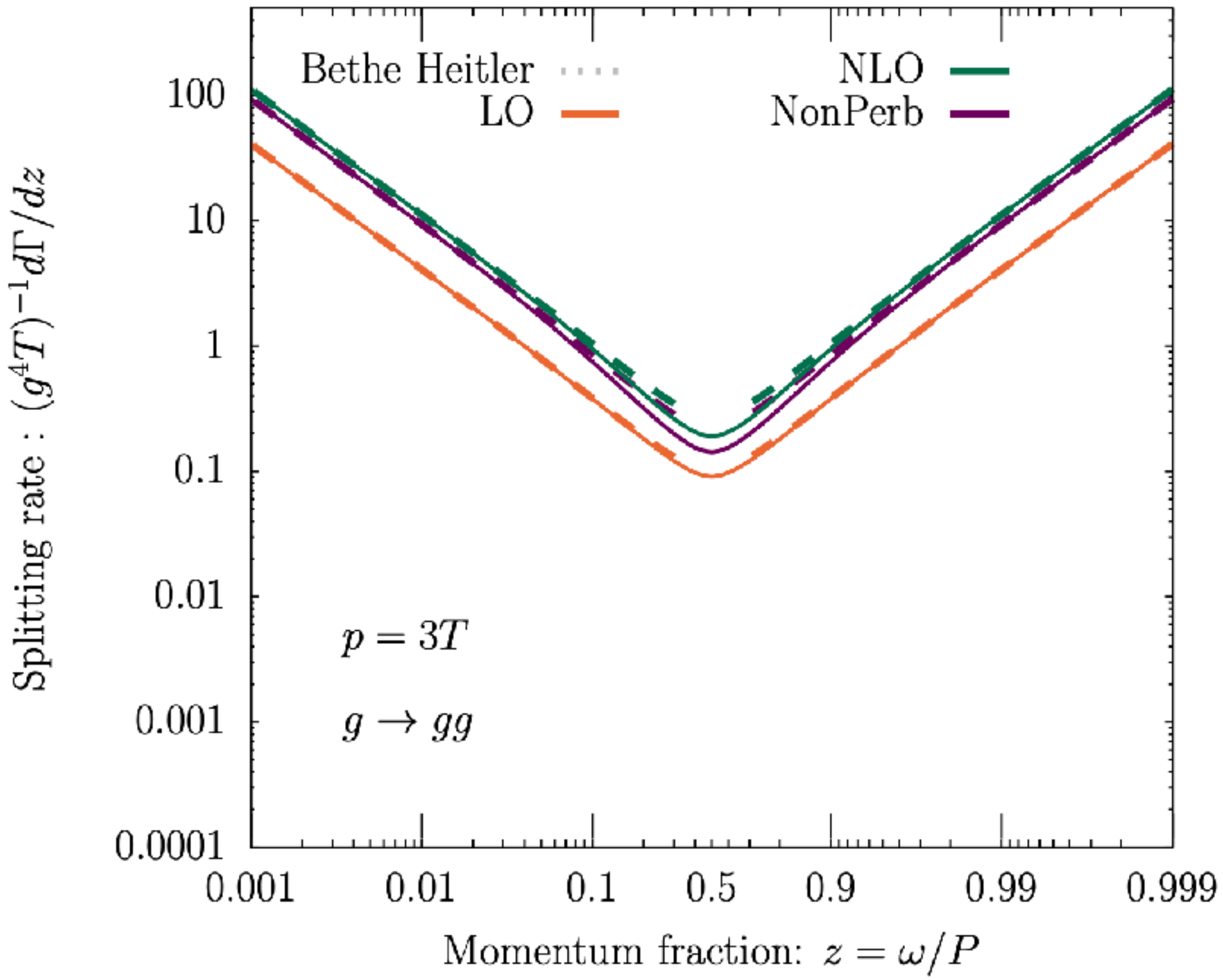
AMY rates w/ NLO and Non-Pert. kernels

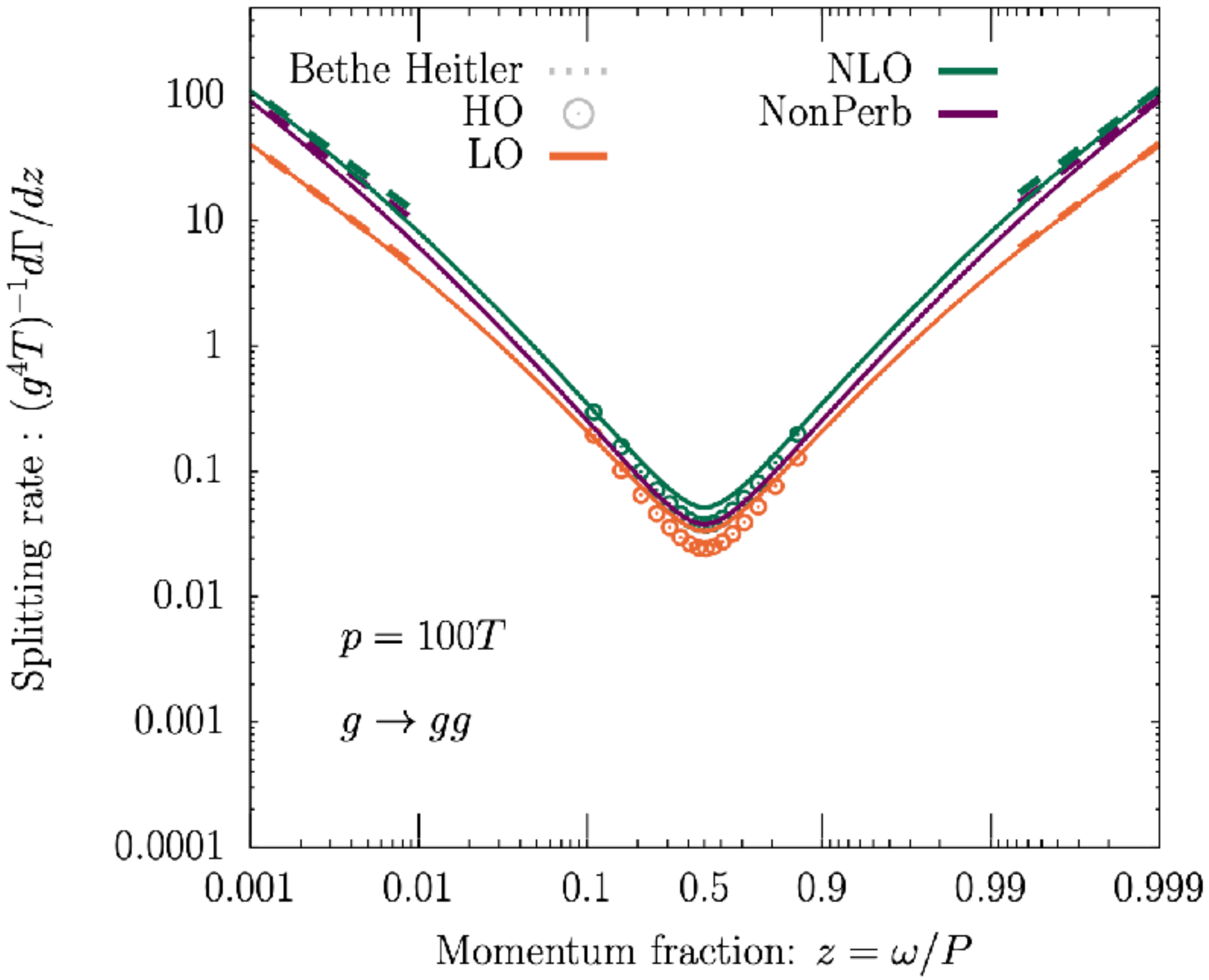
AMY rates w/ LO, NLO and non-perturbative kernels are calculated in

[*Caron-Huot*, PhysRevD.79.065039 (2009)]

[*Moore, Schlichting, Schlusser,* and *Soudi*, JHEP 10(2021)059]

splitting rates



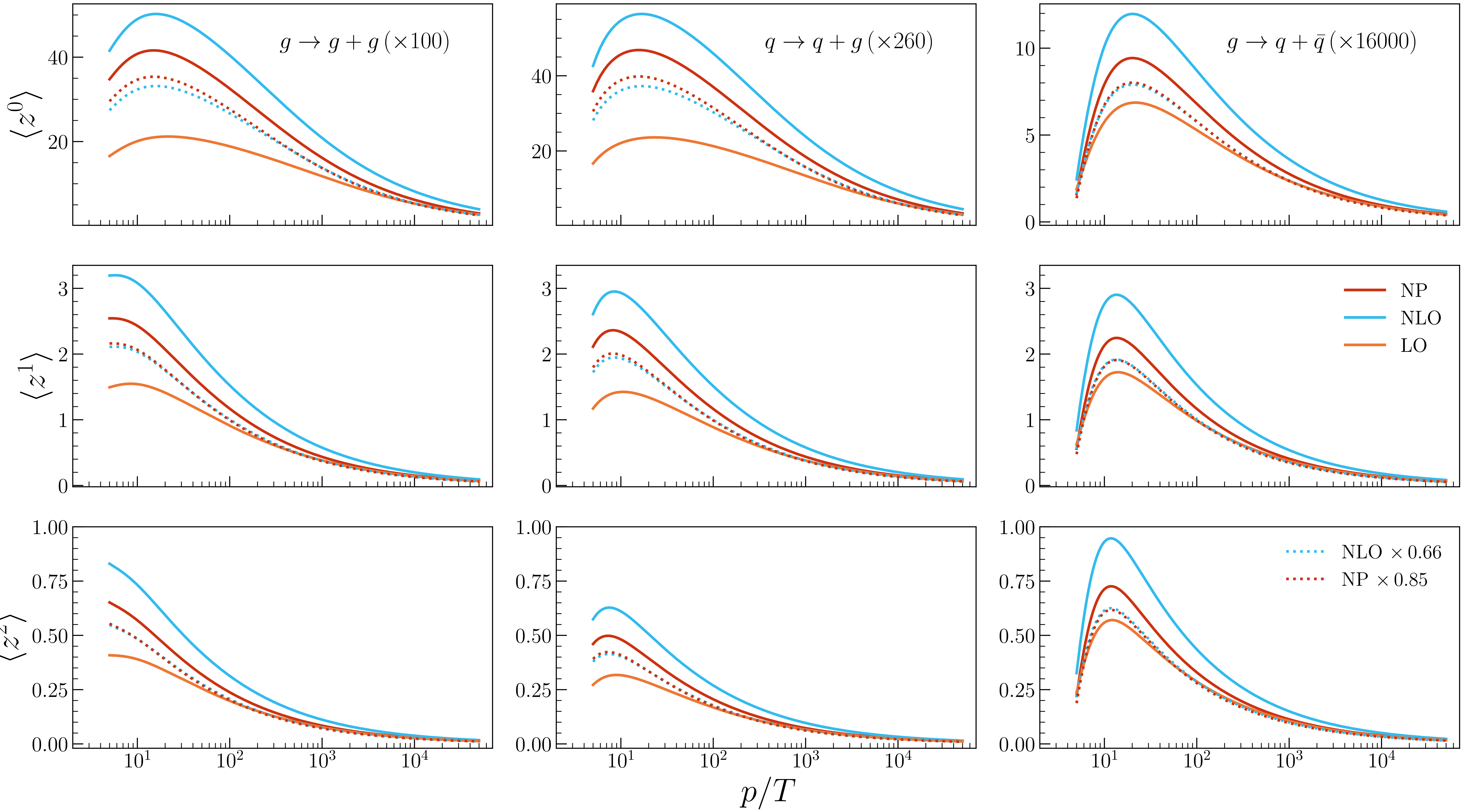


AMY rates w/ NLO and Non-Pert. kernels

we find: the differences can be absorbed by rescaling α_s

moments of splitting rates

$$\langle z^k \rangle \propto \int z^k \frac{\mathrm{d}\Gamma}{\mathrm{d}z}\mathrm{d}z$$



[PhysRevC.106.064902]

AMY rates w/ NLO and Non-Pert. kernels

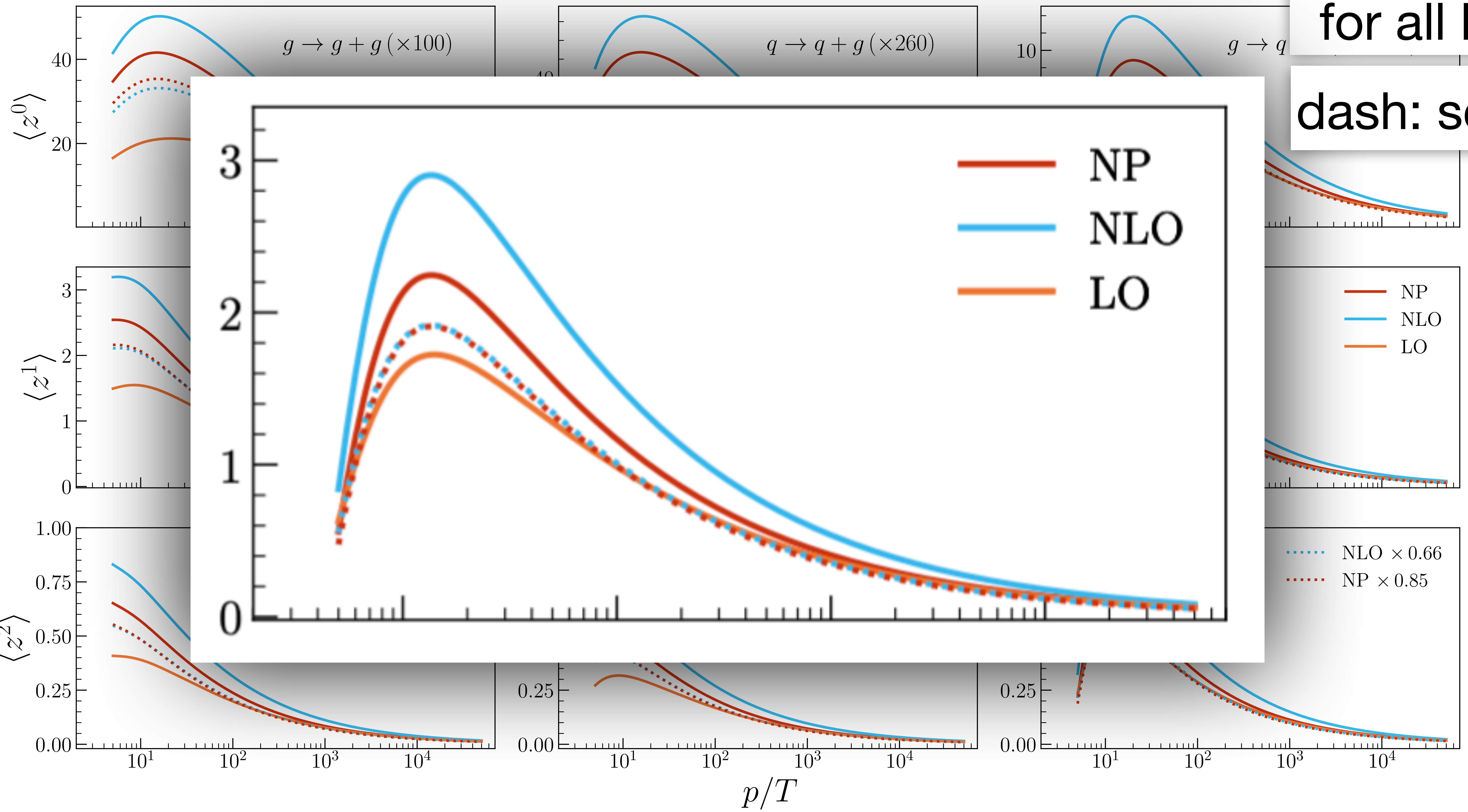
we find: the differences can be absorbed by rescaling α_s

solid: same α_s
for all kernels

dash: scaled α_s

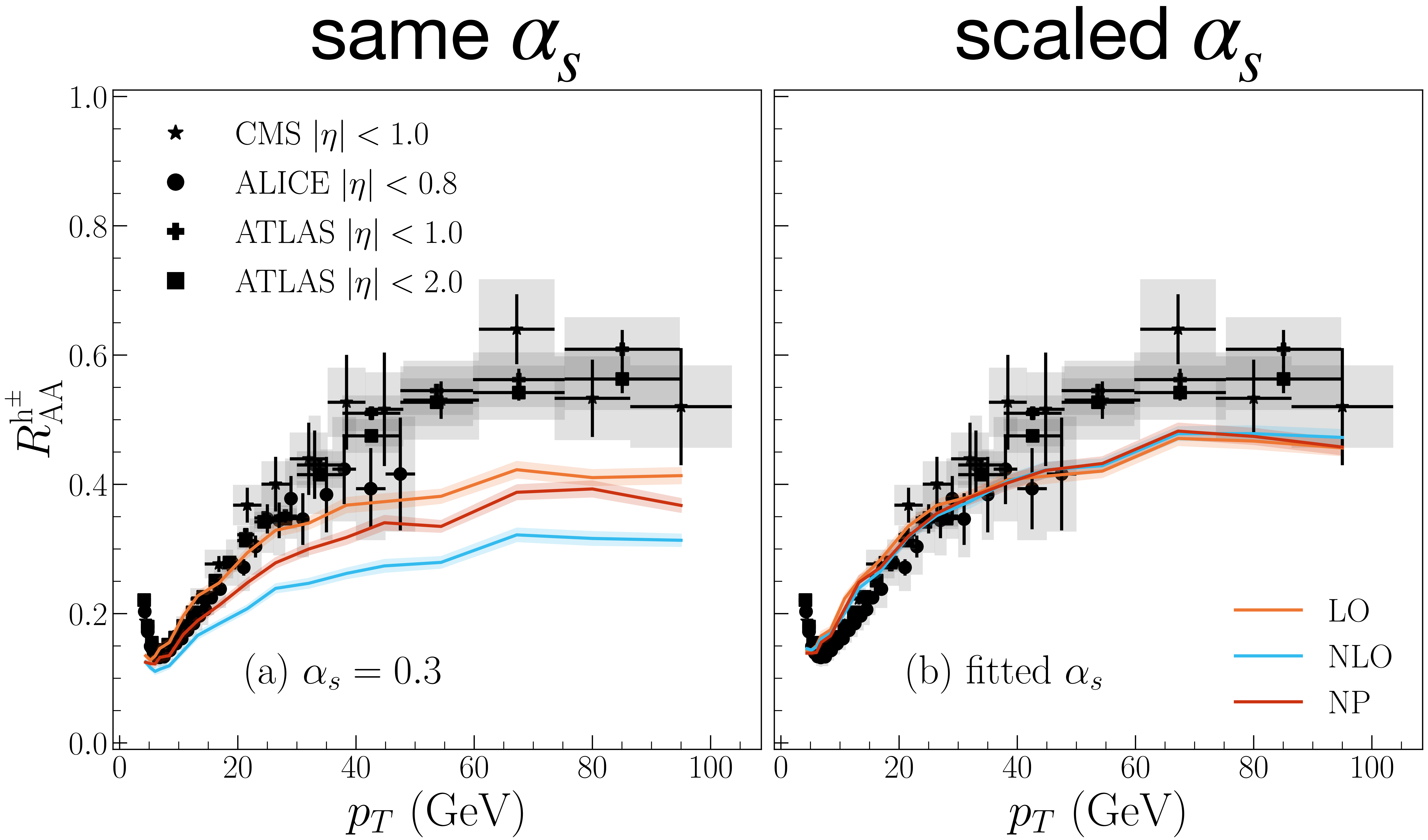
moments of splitting rates

$$\langle z^k \rangle \propto \int z^k \frac{d\Gamma}{dz} dz$$



[PhysRevC.106.064902]

charged hadron R_{AA}

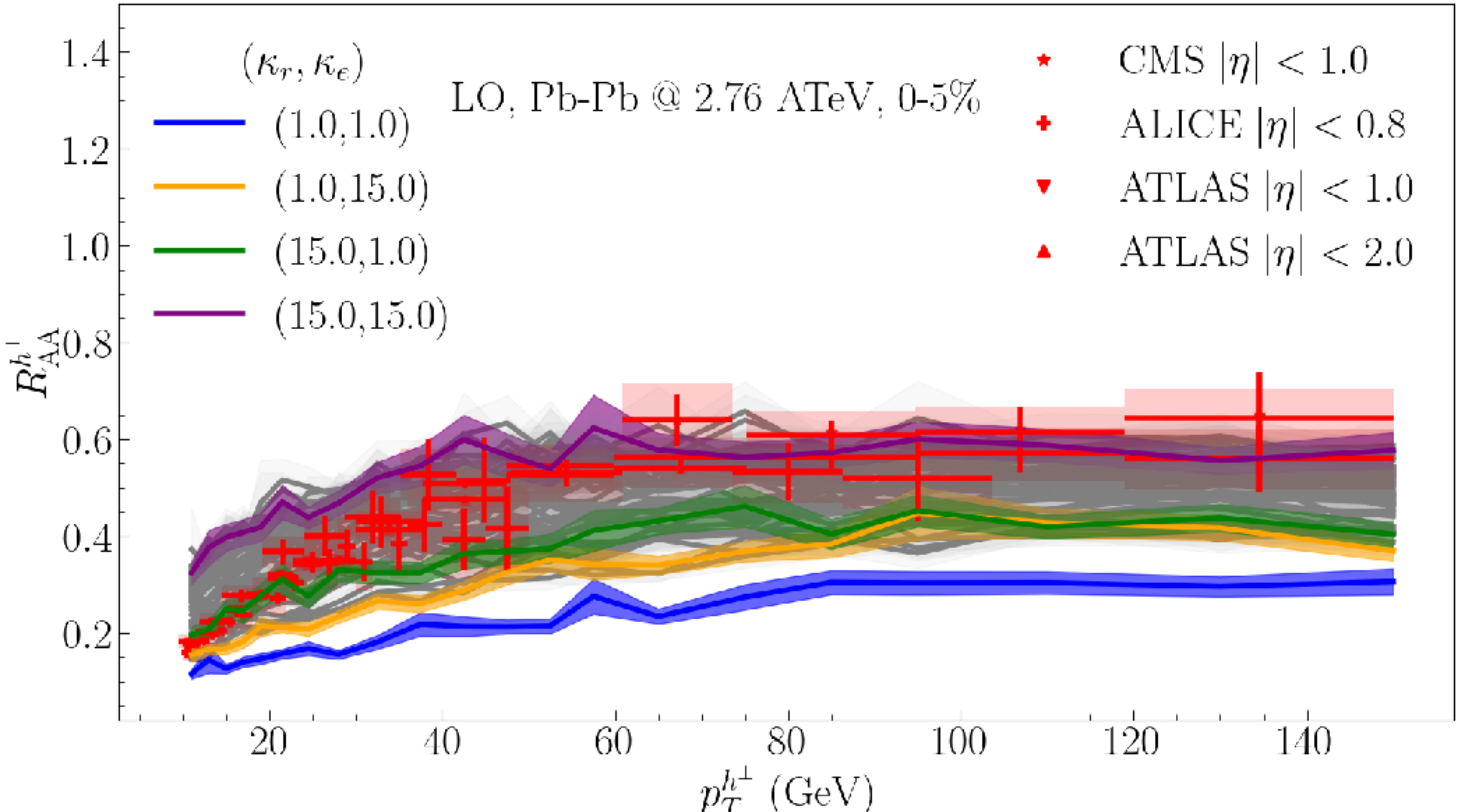


Difference in R_{AA} absorbed by rescaling α_s

[PhysRevC.106.064902]

charged hadron R_{AA}

scan parameters controlling the running of α_s

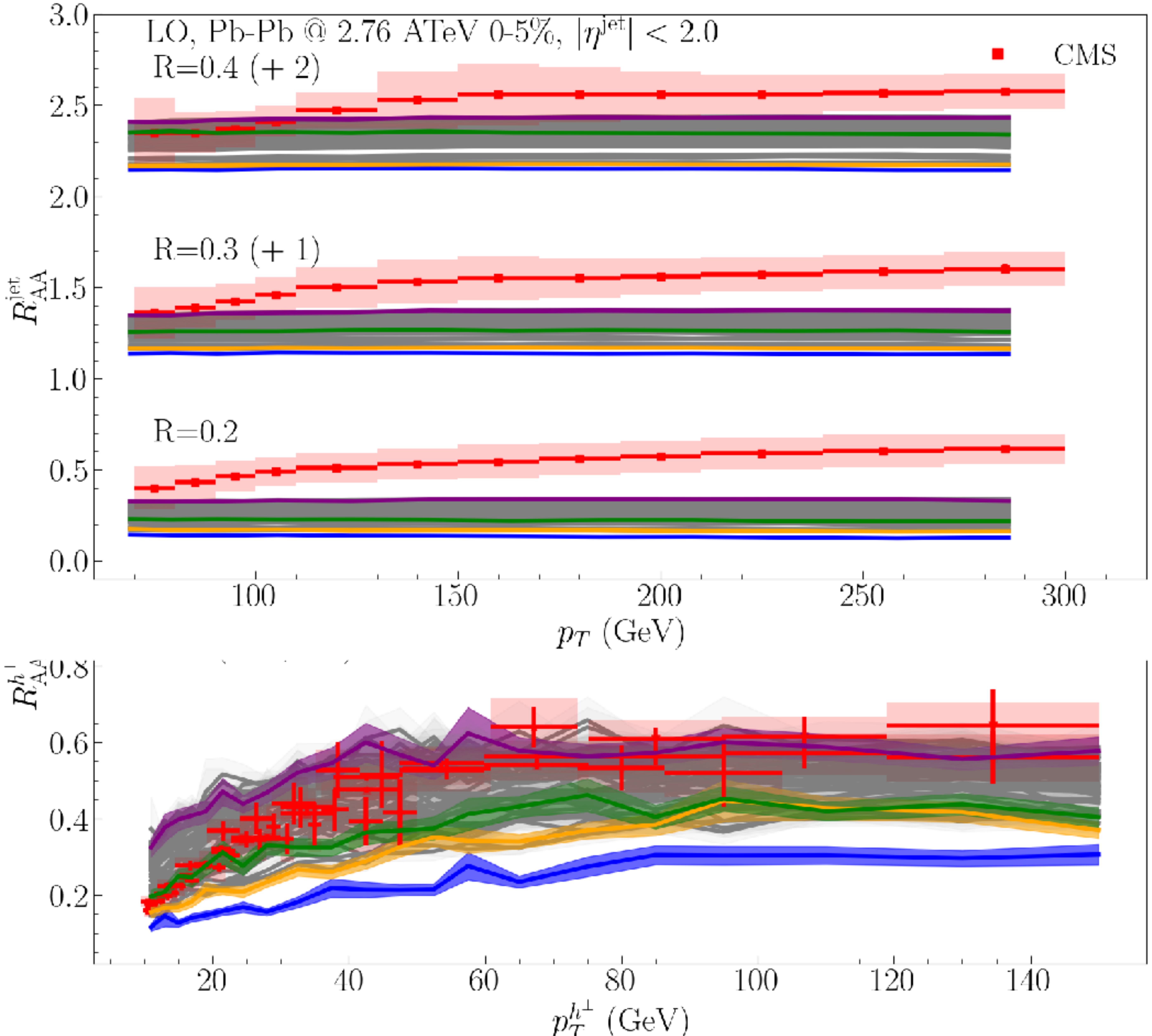


good coverage of $R^{h\pm}_{AA}$

colored: four corners in the parameter space

gray: other parameters

a surprise in the jet R_{AA}



scan parameters controlling the running of α_s

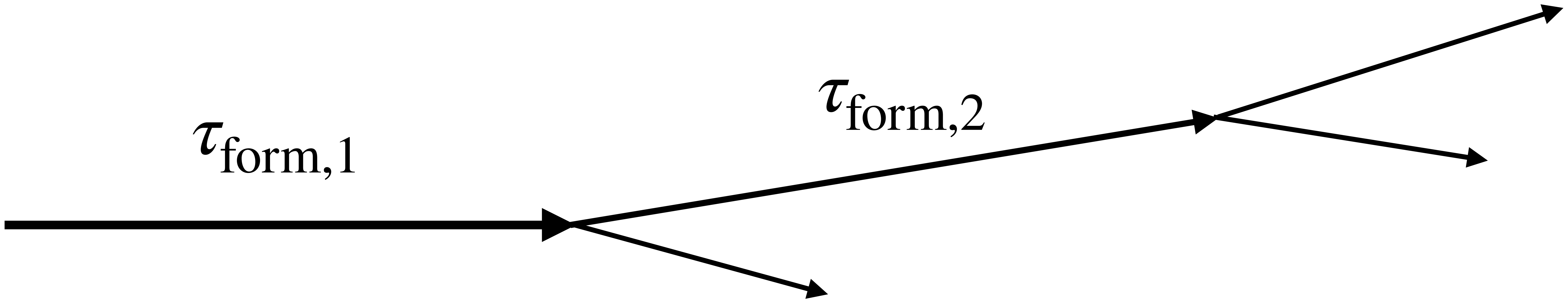
Jets are always over-quenched!!!

good coverage of $R_{AA}^{h\pm}$

colored: four corners in the parameter space

gray: other parameters

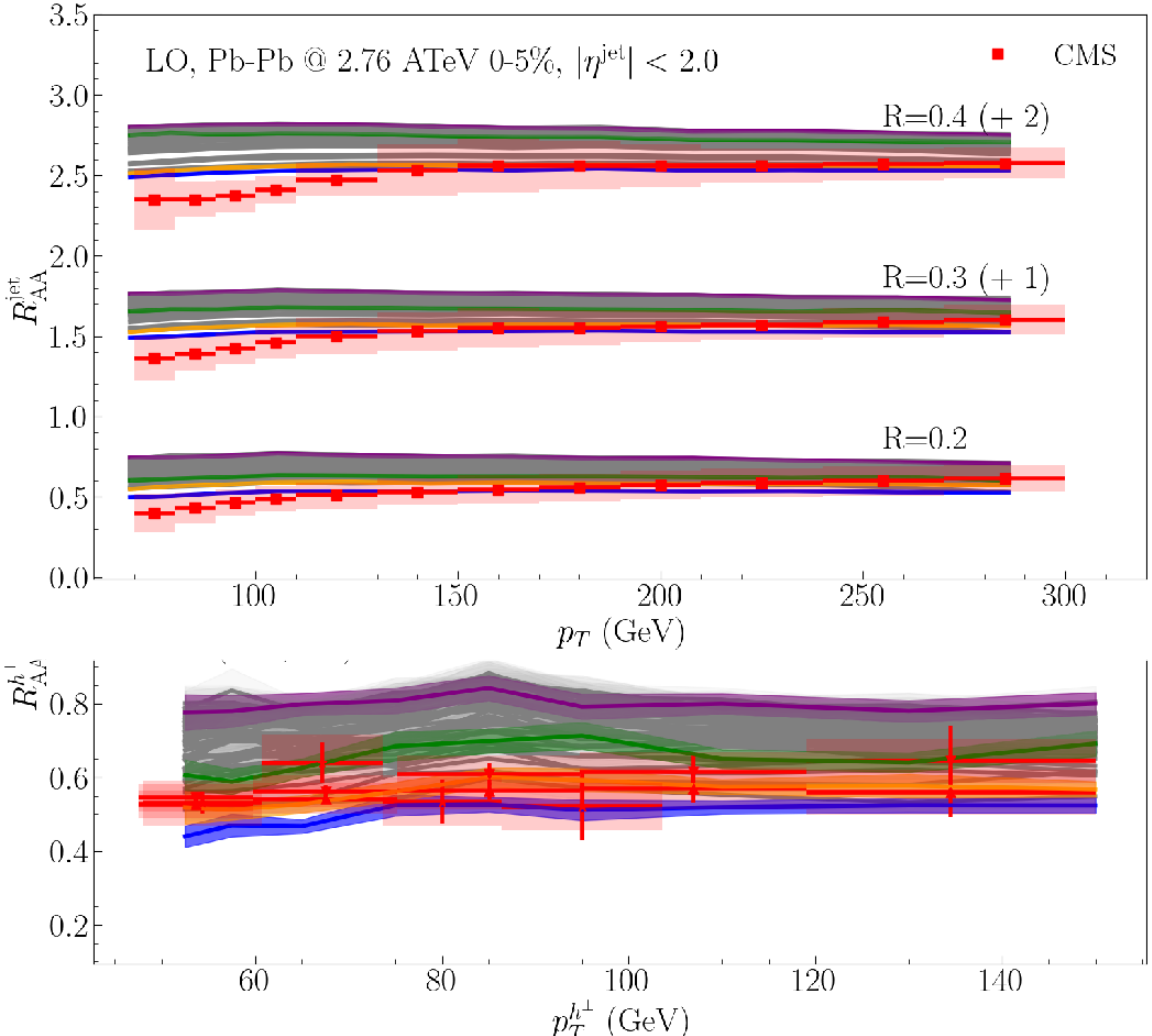
introduction of formation time



formation time estimated by virtuality: $$\tau_{\text{form},i} = \frac{2E_i\ x_i(1-x_i)}{k_{\perp,i}^2}\,,$$

sum over the "family tree": $$\tau_{\text{form}} = \sum_i \tau_{\text{form},i}\,.$$

introduction of formation time



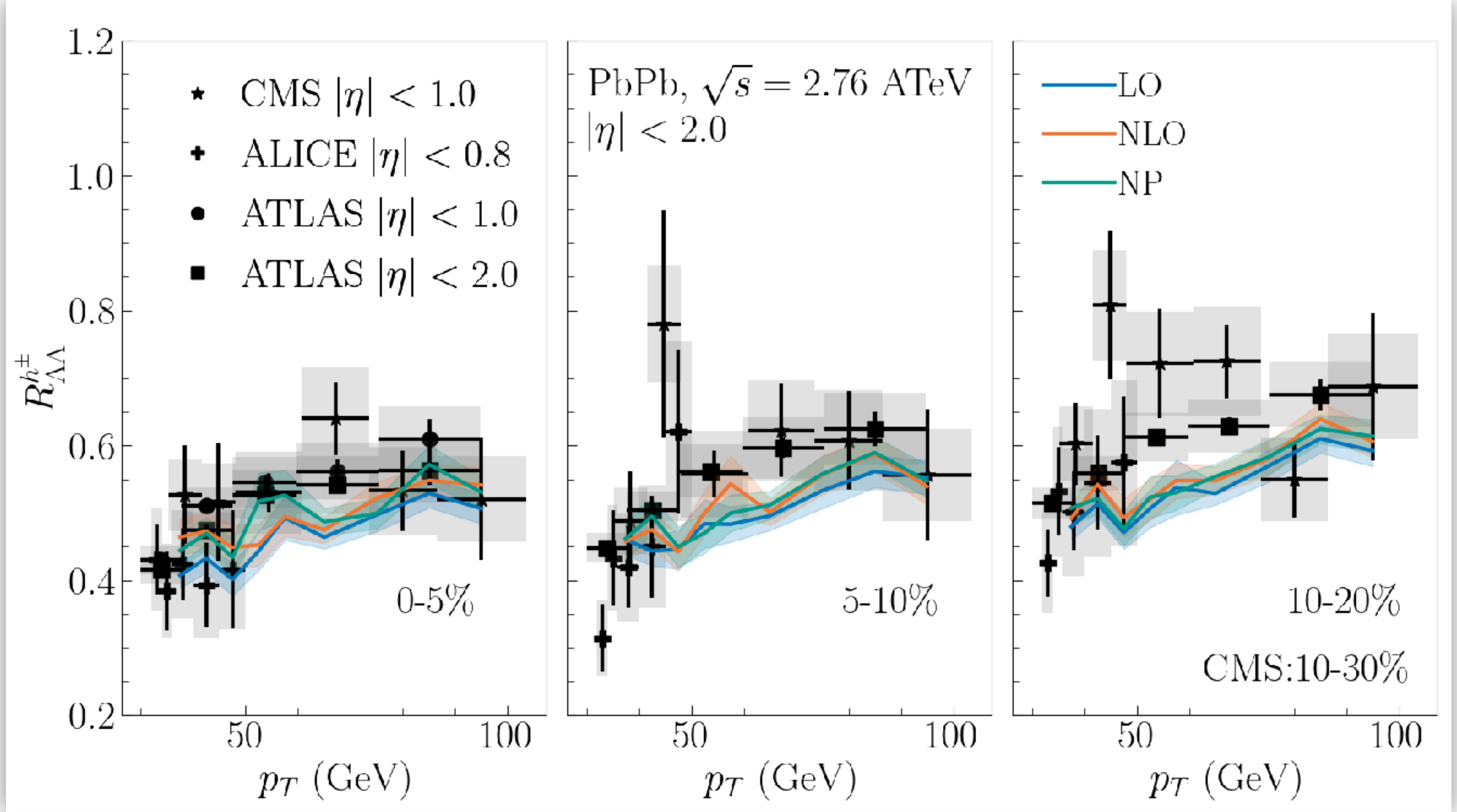
scan parameters controlling the running of α_s

tension btw/ $R_{AA}^{h\pm}$ and R_{AA}^{jet} resolved!

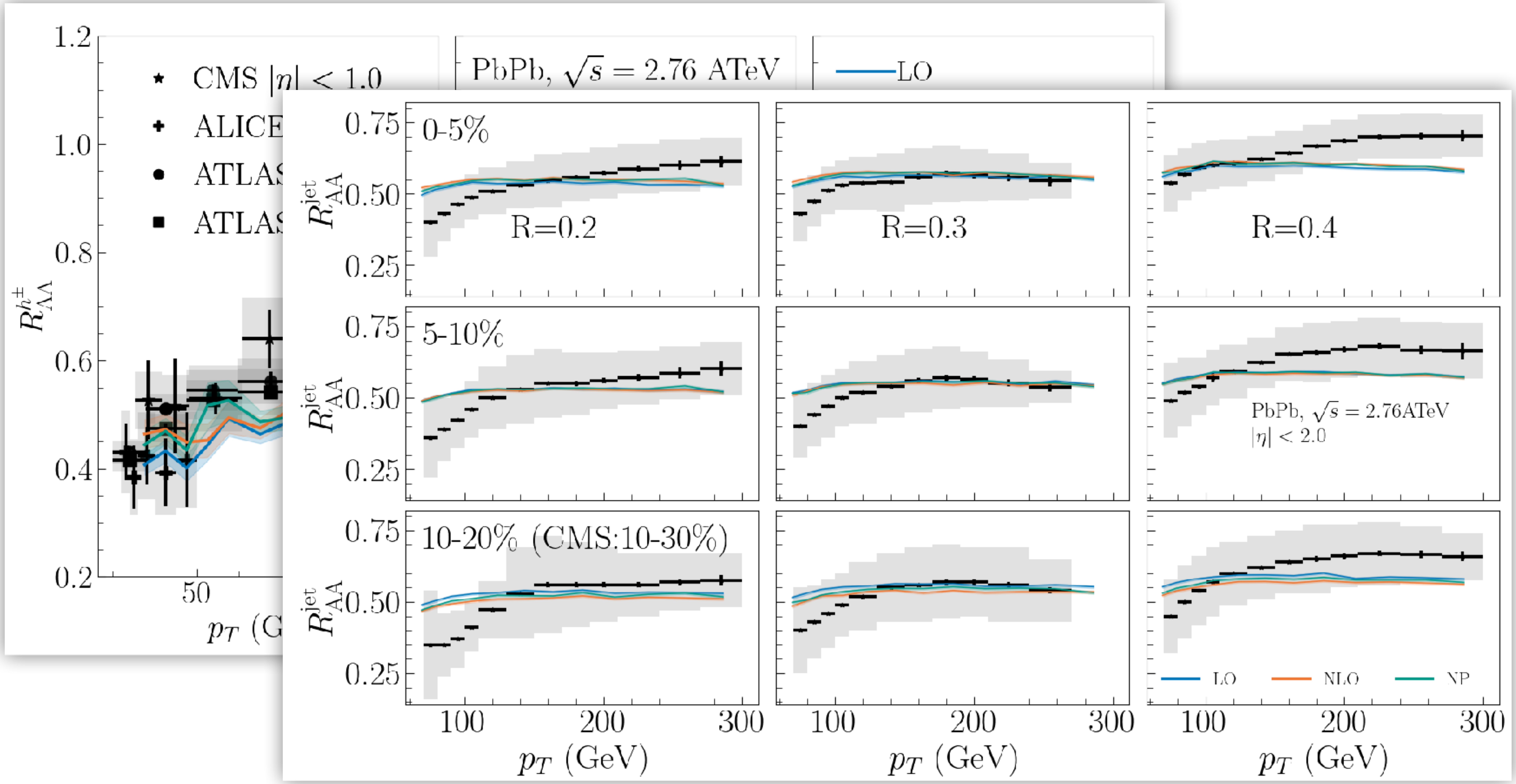
colored: four corners in the parameter space

gray: other parameters

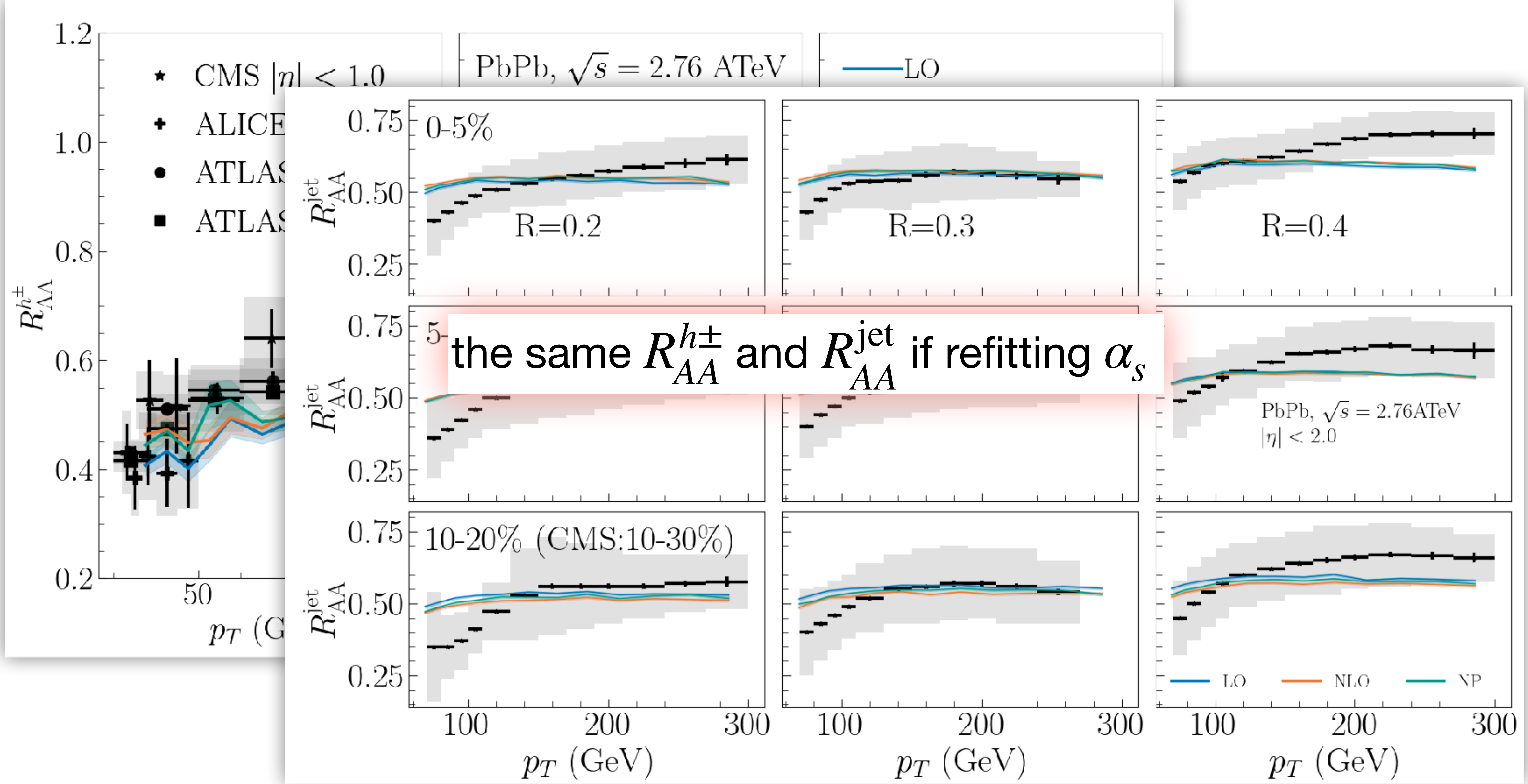
comparison of different kernels



comparison of different kernels

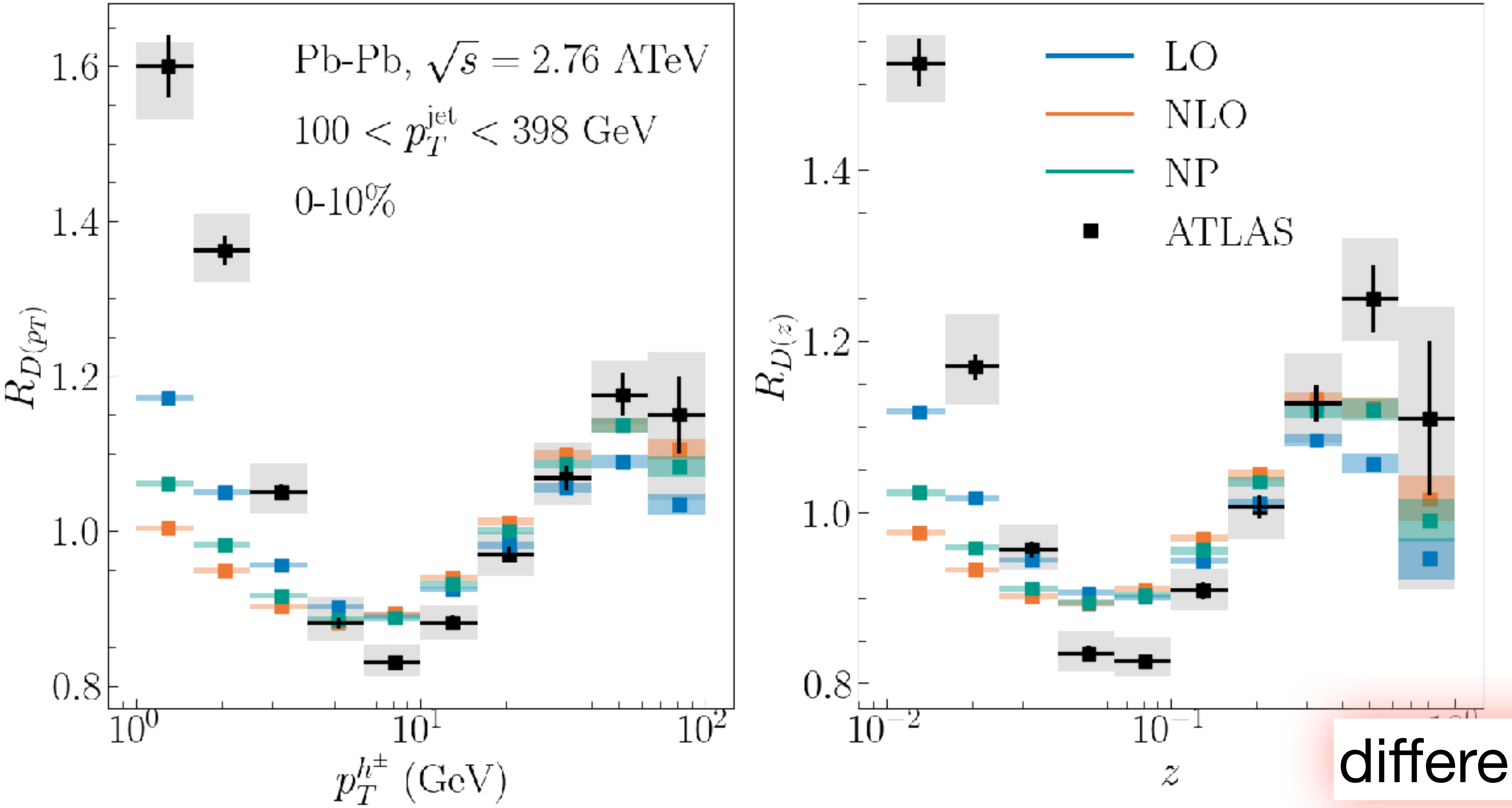


comparison of different kernels

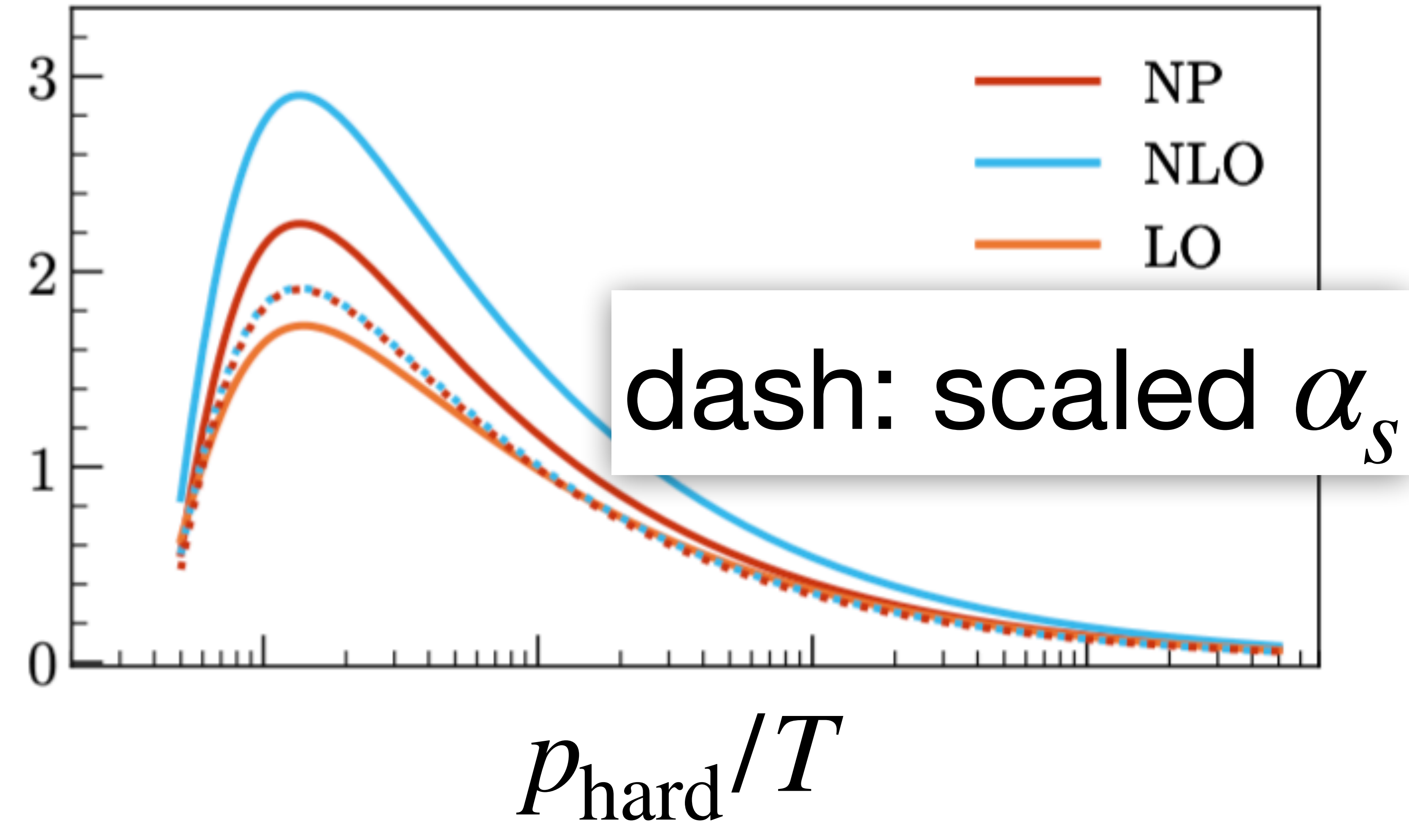


the same $R_{AA}^{h\pm}$ and $R_{AA}^{\rm jet}$ if refitting α_s

comparison of different kernels



$$\langle z^1 \rangle \propto \int z \frac{d\Gamma}{dz} dz$$



dash: scaled α_s

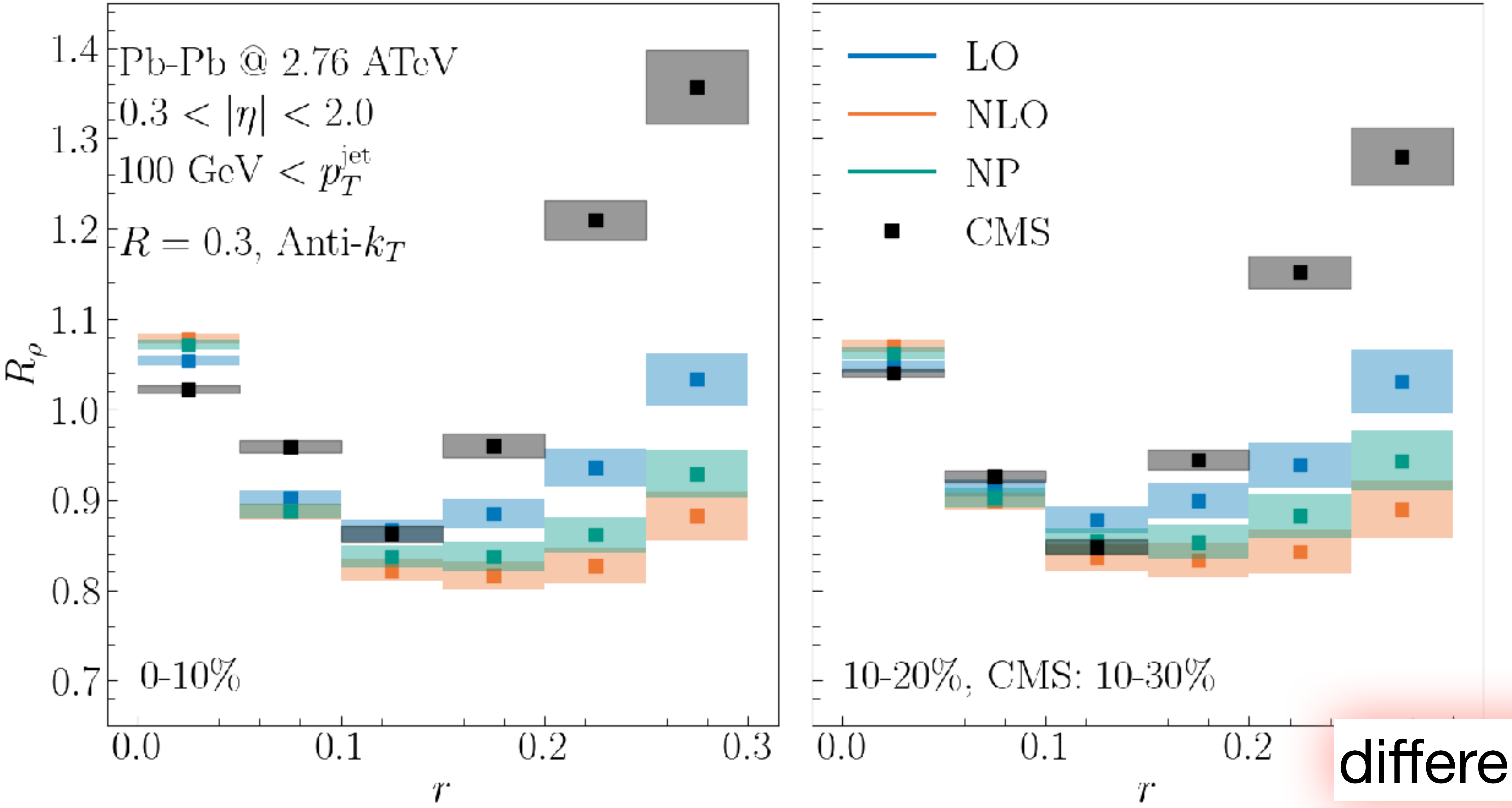
different kernels distinguishable

LO: less EL at tail

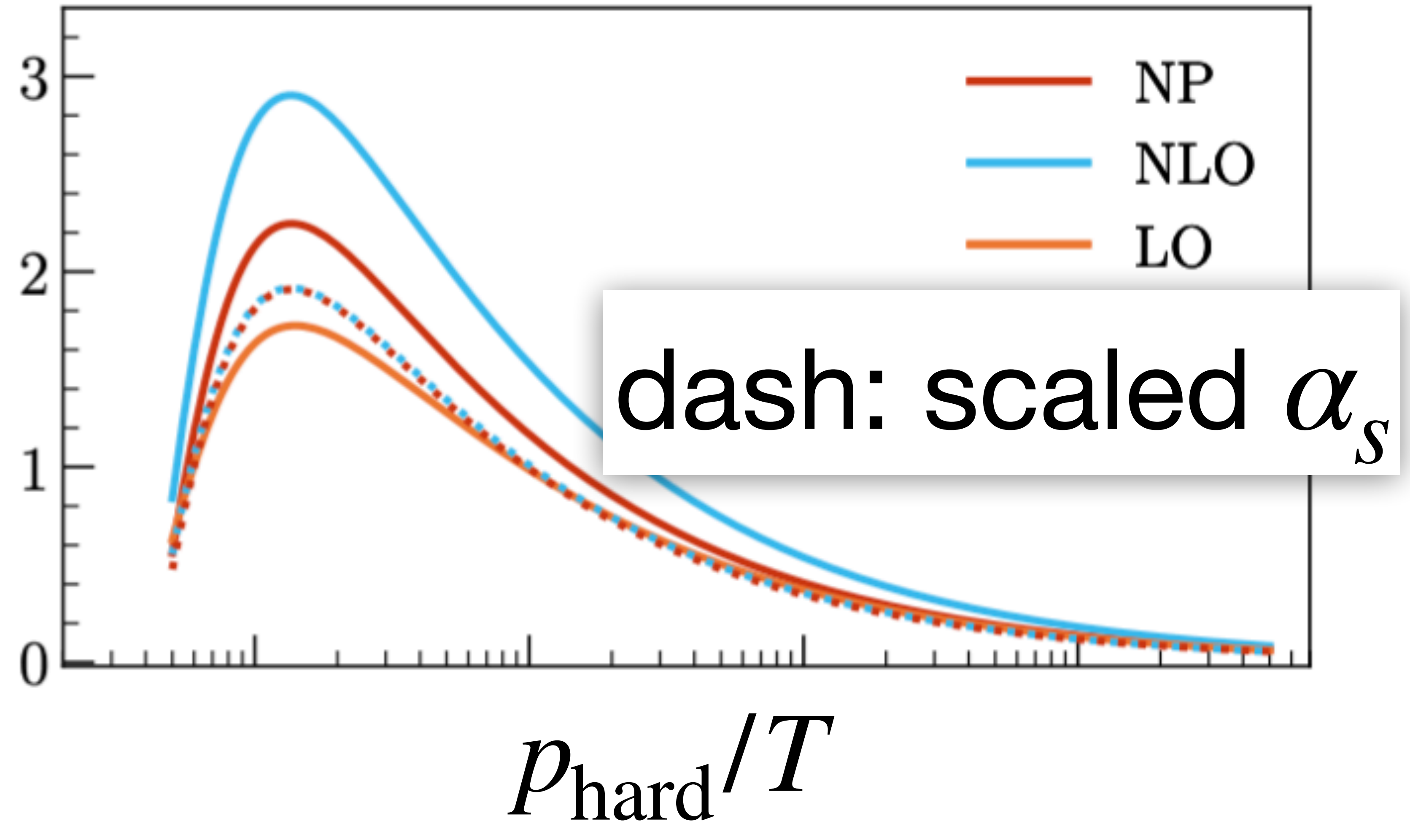
ratio of fragmentation function

$$z_h \equiv \frac{p_h \cdot p_{\rm jet}}{p_{\rm jet}^2}$$

comparison of different kernels



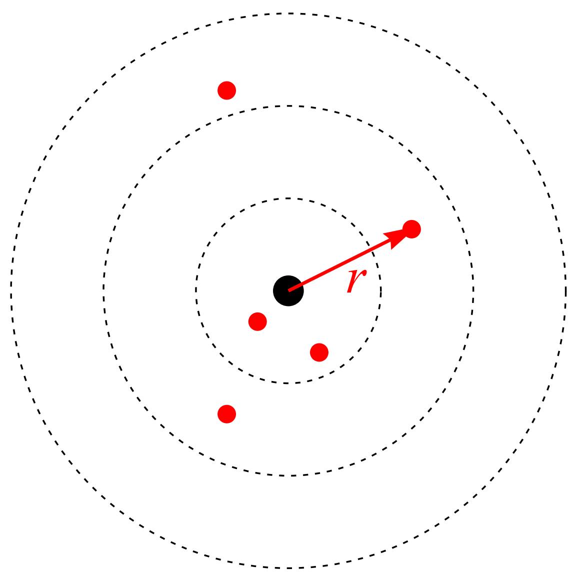
$$\langle z^1 \rangle \propto \int z \frac{\mathrm{d}\Gamma}{\mathrm{d}z} \mathrm{d}z$$



dash: scaled α_s

different kernels distinguishable

ratio of jet density



LO: stronger elastic e.l. to
compensate the rad. e.l.
=> more diffraction

summary and outlook

- LO, NLO, and NP kernels
  - the same $R_{AA}^{h\pm}$ and R_{AA}^{jet}
  - different jet shape and fragmentation function

- τ_{form} needed to resolve the tension btw/ $R_{AA}^{h\pm}$ and R_{AA}^{jet}

- energy loss of virtual particle is needed for more precise description of jet substructure.

back up slides

effect of formation time