Flavor dependence of jet quenching in heavy-ion collisions

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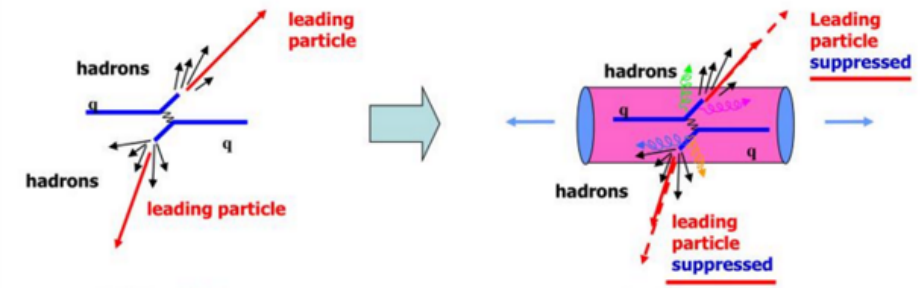
Outline

Jet quenching

- The Quark-gluon plasma (QGP), predicted by QCD and confirmed at RHIC and LHC, is a hot and dense medium.
- Jet quenching: energy loss when a jet propagates in the medium G.Y.Qin and X.N.Wang, Int.J.Mod.Phys.E 24, 9no.11, 1530014



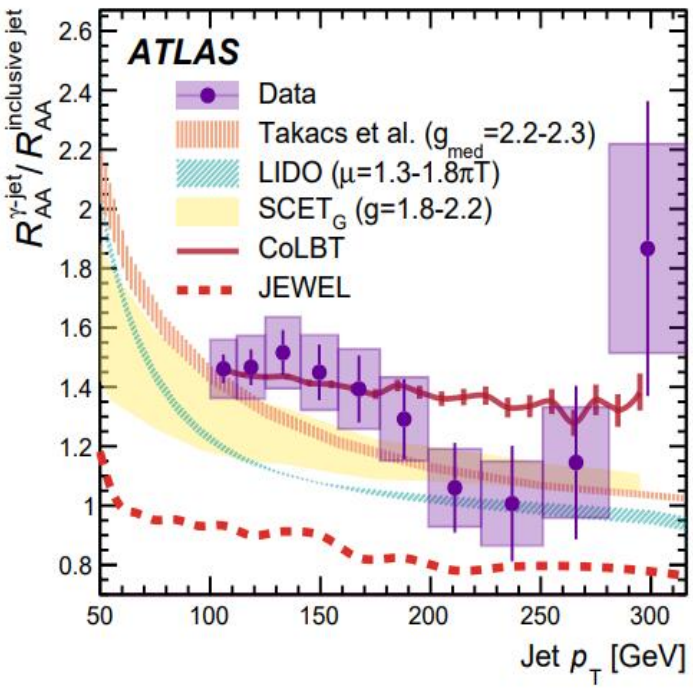
a very powerful hard probe to investigate the properties of QGP. Apolinario *et al.*, arXiv:2203.16352

- Nuclear modification factor: RevModPhys.90.025005

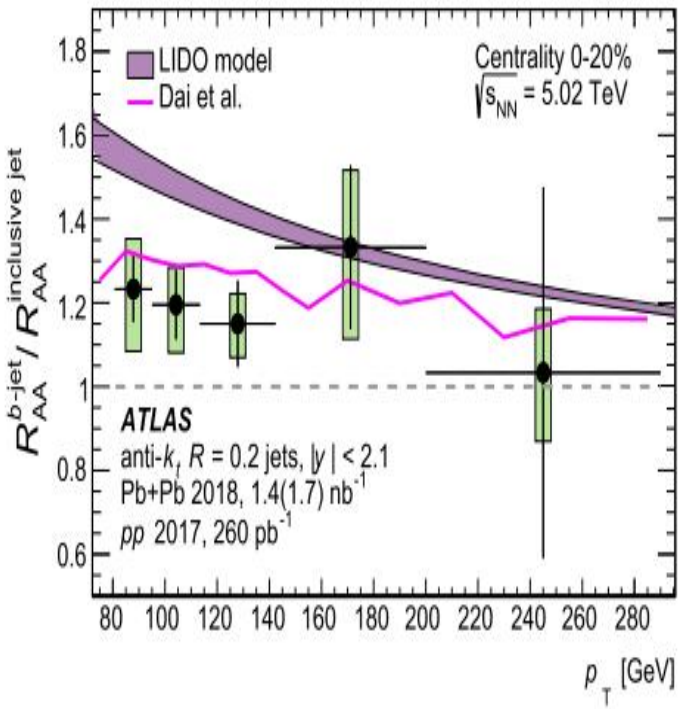
$$R_{AA} = \frac{1}{\langle N_{coll}^{AA} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta}$$

ATLAS measurements of γ/b-jet R_{AA}

PLB 846(2023)138154



EPJC 83(2023)5,438



- $R_{AA}^{\gamma\text{-jet}} > R_{AA}^{\text{jet}}$, color factor dependence of parton-QGP interaction.
- $R_{AA}^{b\text{-jet}} > R_{AA}^{\text{jet}}$, suggest a role for mass and colour-charge effects in partonic energy loss.

Flavor decomposition of jet R_{AA}

Nuclear modification factor R_{AA}

$$R^{C}_{\rm AA} = \frac{\sum_i R^{i,C}_{\rm AA} d\sigma^{i}_{\rm pp}}{\sum_i d\sigma^{i}_{\rm pp}} = R^{g,C}_{\rm AA} + \sum_{i\neq g}(R^{i,C}_{\rm AA} - R^{g,C}_{\rm AA}) f_i \tag{1}$$

where $f_i = d\sigma^{i}_{pp}/\sum_i d\sigma^{i}_{pp}$ is the fraction of parton i initiated jet.
The flavor dependent $R^{i,C}_{AA}$

$$R^{i,C}_{\rm AA}(p_{\rm T}) = \frac{\int d\Delta p_{\rm T}\, d\sigma^{i}_{\rm pp}(p_{\rm T}+\Delta p_{\rm T}) \otimes W^{i,C}_{\rm AA}(x)}{d\sigma^{i}_{\rm pp}(p_{\rm T})}, \tag{2}$$

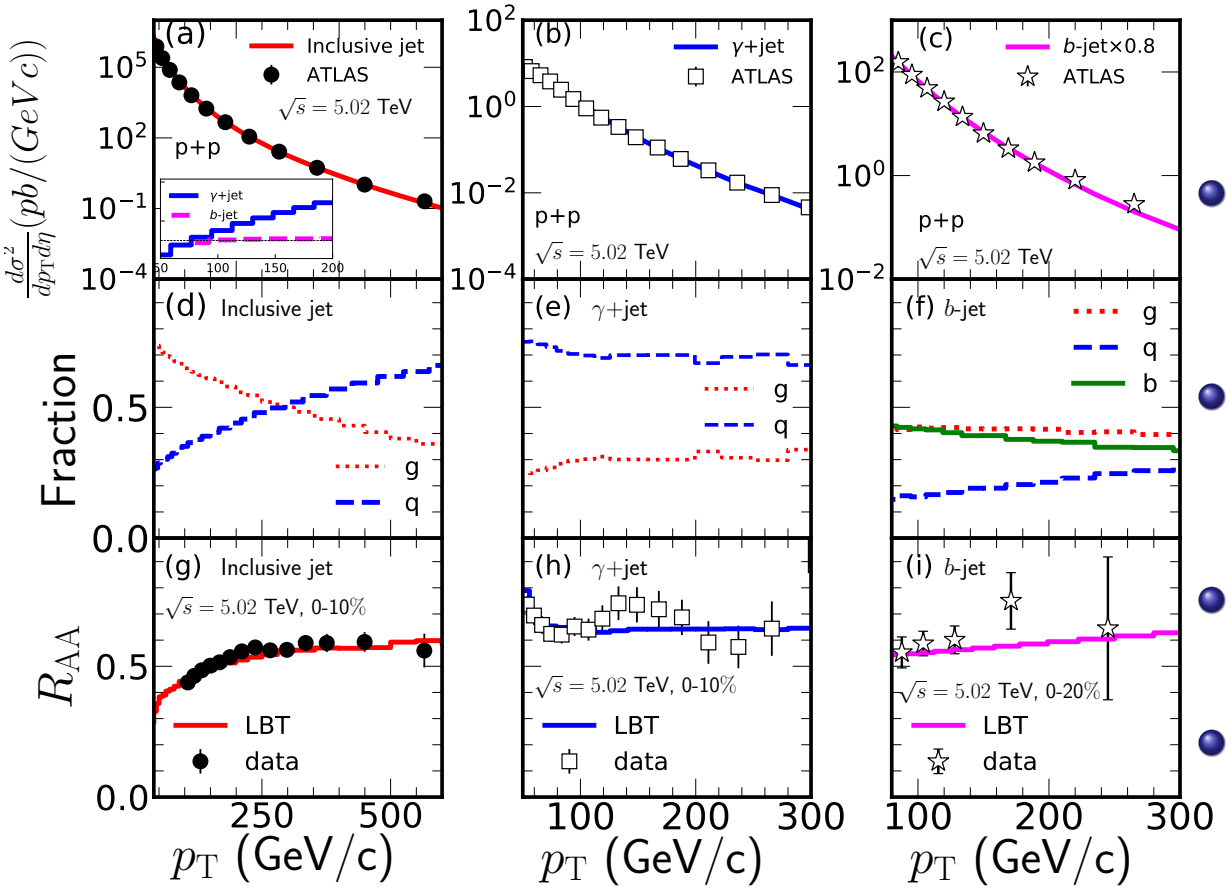
Energy loss distributions Y.He, L.G.Pang and X.N.Wang, PhysRevLett.122.252302

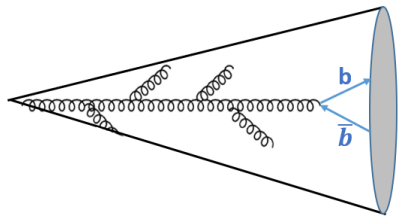
$$W^{i}(x) = \frac{\alpha_i^{\alpha_i} x^{\alpha_i - 1} e^{-\alpha_i x}}{\Gamma(\alpha_i)}, \begin{cases} x = \Delta p^{i}_{\rm T}/\langle \Delta p^{i}_{\rm T}\rangle \\ \langle \Delta p^{i}_{\rm T}\rangle = \beta_i (p_{\rm T}/p^{0}_{\rm T})^{\gamma_i} \log(p_{\rm T}/p^{0}_{\rm T}) \end{cases} \tag{3}$$

Three parameters in the above for each parton type: $[\alpha_i, \beta_i, \gamma_i]$
Bayesian analysis:

$$P(\theta|data) = \frac{P(\theta)P(data|\theta)}{P(data)} \tag{4}$$

Cross sections in p+p and in Pb+Pb

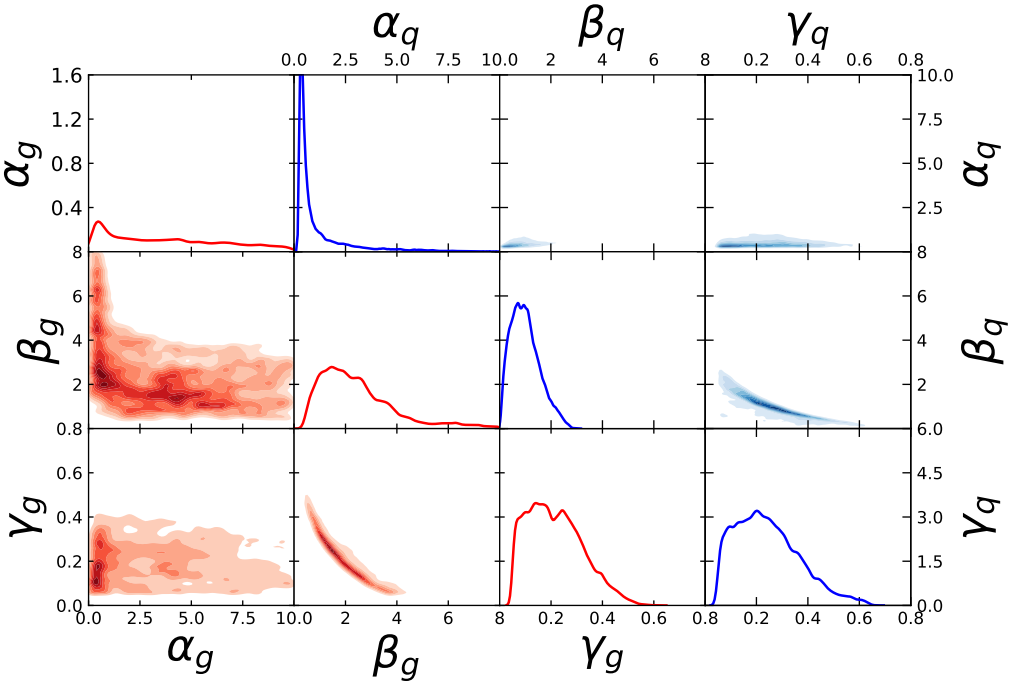




- Inclusive jet spectrum is steeper than γ+jet, similar as *b*-jet.
- Incl. jet: gluon(quark) jet dominates in low (large) p_T.
- γ+jet: quark initiated jet dominates ($\sim 80\%$).
- *b*-jet: gluon initiated jet contributes about 40%.

- $R_{AA}^{\gamma+\text{jet}} / R_{AA}^{\text{jet}} > 1$, a mix effect of the initial spectra and color-charge.
- $R_{AA}^{b\text{-jet}} / R_{AA}^{\text{jet}} > 1$, the mixture of mass effect and color effect.

Bayesian data-driven method

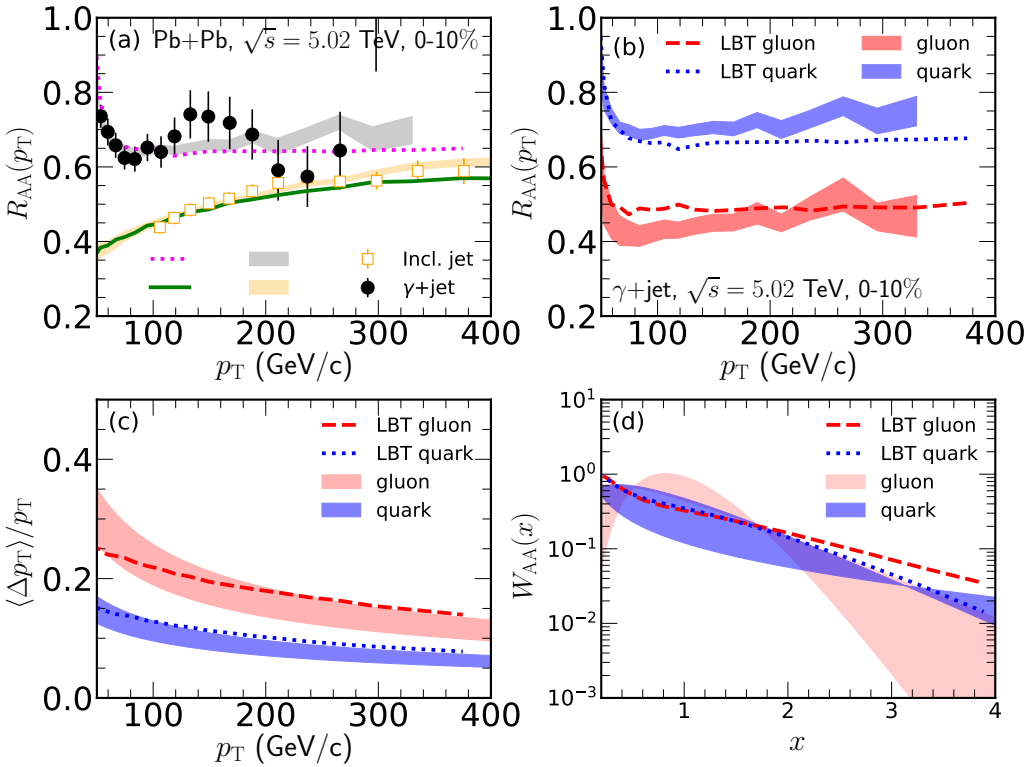


- Uniform prior distribution for $[\alpha_i, \beta_i, \gamma_i] \in [(0, 10), (0, 8), (0, 0.8)]$
- 2M MCMC steps for training, then 2M steps for scanning the parameter space
- All parameters are well constrained.

Extracted parameters for parton energy loss distributions

$(0-10\%)$5.02 TeV			
	α	β	γ
gluon	4.36±2.07	1.78±0.38	0.25±0.03
quark	0.5±0.07	0.39±0.17	0.32±0.13

Gluon and quark jet energy loss in Pb+Pb



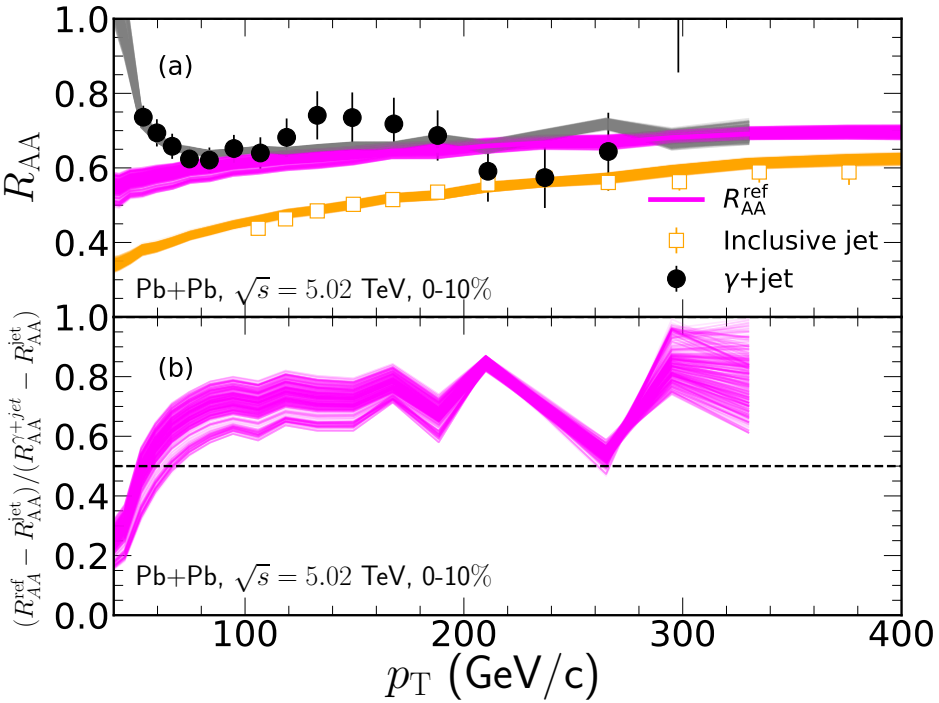
[arXiv:2303.14881]

The optimized results agree perfectly with data.

In turn, gluon and quark jet R_{AA} and energy loss distributions are extracted.

- Clear flavor hierarchy of jet energy loss, $\Delta E_g > \Delta E_q$.
- Quark jet energy loss shows a weaker p_T dependence.
- Agree with data and LBT results. PRC.91.054908, PRC.94.014909

Colour-charge dependence of R_{AA}

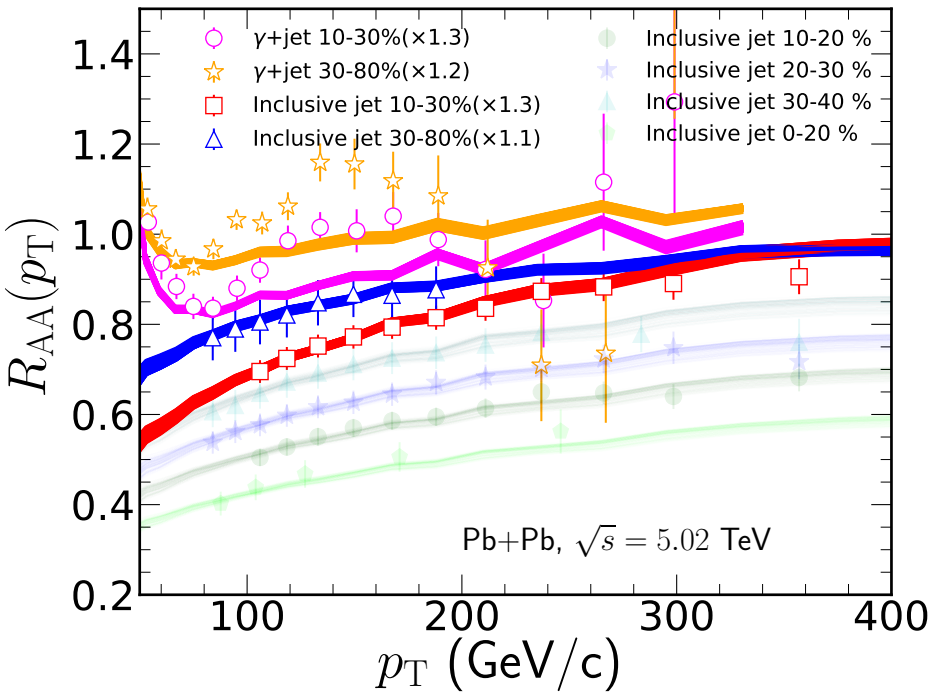


[arXiv:2303.14881]

R_{AA}^{ref} is shown by assuming that inclusive jet has the same quark fraction as γ+jet.

- Large quark-initiated jet fraction underlies $R_{AA}^{\gamma+jet}/R_{AA}^{jet}$ at large p_T
- The flat spectra give the dominate contribution to $R_{AA}^{\gamma+jet}/R_{AA}^{jet}$ at low p_T.

Extract quark/gluon jet R_{AA} in different Centrality

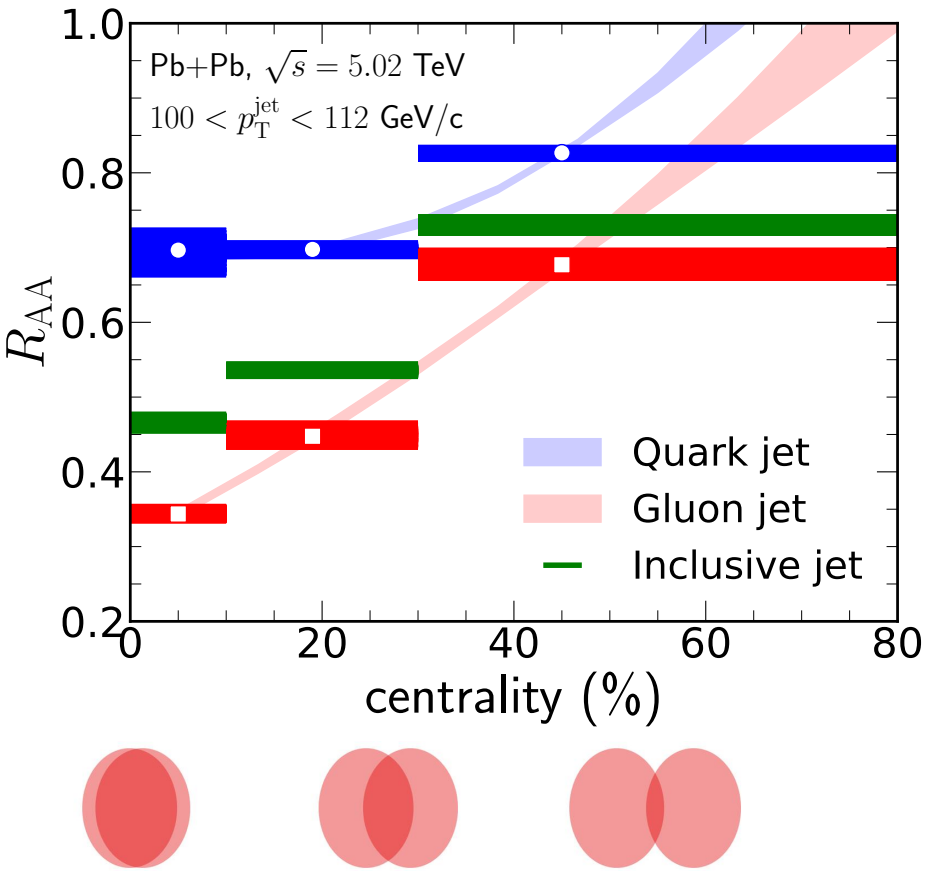


- Uniform prior distribution for $[\alpha_i, \beta_i, \gamma_i] \in [(0, 10), (0, 8), (0, 0.8)]$
- Fitting to inclusive jet R_{AA} and γ+jet R_{AA} in 10-30% and 30-80% centrality separately.
- The optimized results agree perfectly with data.
- R_{AA} for quark/gluon-initiated jets in 10-30%, 30-80% centrality are extracted.

Extracted parameters for parton energy loss distributions

		α_i	β_i	γ_i
10-30%	gluon	2.17±0.94	1.47±0.44	0.25±0.04
	quark	5.81±1.8	1.27±0.12	0.09±0.02
30-80%	gluon	4.78±1.87	1.16±0.17	0.11±0.03
	quark	6.4±2.63	0.7±0.05	0.09±0.01

Centrality dependent of quark/gluon jet R_{AA}



[arXiv:2303.14881]

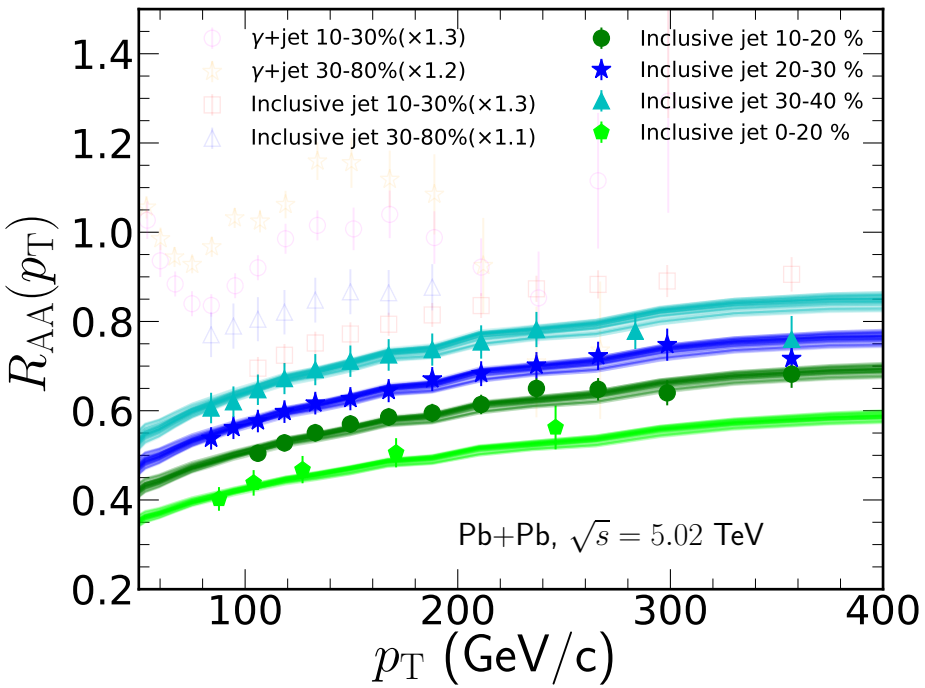
Fitting the centrality dependent R_{AA} of quark- and gluon- initiated jet via a simple parametrization:

$$h^i(C) = a_i C^2 + b_i C + c_i$$

	gluon	quark
a_i $(\times 10^{-5})$	12.39±2.83	3.36±2.45
b_i $(\times 10^{-3})$	-2.95±1.74	6.65±1.20
c_i	0.7±0.021	0.309±0.009

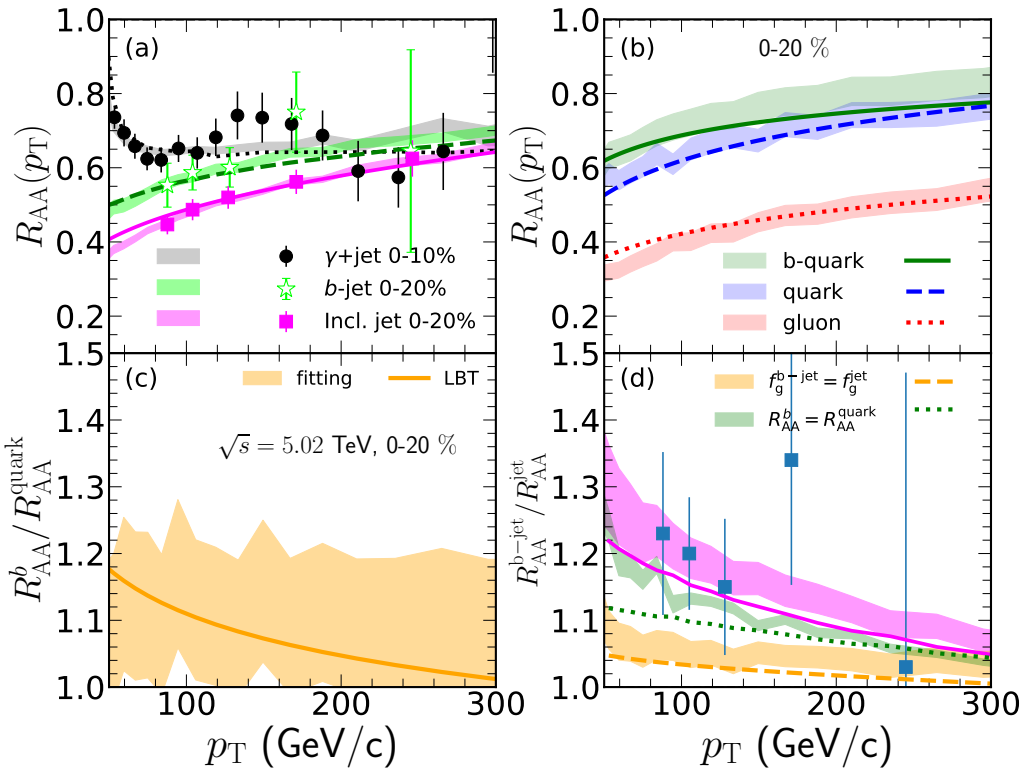
- Quark-initiated jet has weaker dependence on the centrality.
- Need more data to identify the jet R_{AA} in peripheral collisions ($> 60\%$).

Prediction of jet R_{AA} in PbPb



- Our extracted centrality dependence of quark and gluon jet energy loss distributions can describe the experimental data R_{AA} very well.

Extract flavor dependent jet energy loss in Pb+Pb



[arXiv:2303.14881]

$f^{b\text{-jet}} = f^{jet}$: assuming b-jet has the same fraction of gluon initiated jet as inclusive jet.

$R_{AA}^b = R_{AA}^{quark}$: b-quark jet lose the same fraction of energy as light-quark initiated jet.

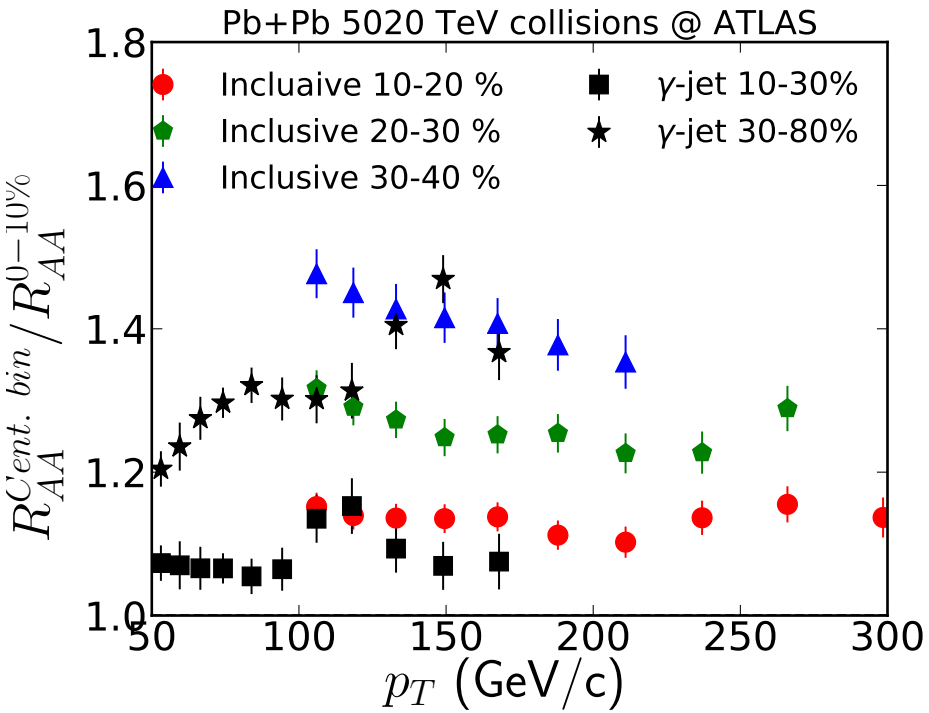
- Clear flavor hierarchy of jet energy loss, $\Delta E_g > \Delta E_q > \Delta E_b$.
- The color charge effect have greater impacts on the ratio $R_{AA}^{b\text{-jet}} / R_{AA}^{jet}$ than parton mass effect, which decrease moderately at $p_T \sim 300$ GeV/c.
- Agree with data and LBT results.

Summary

- The flavor-dependent jet energy loss distributions are extracted via a Bayesian data-driven method from experimental data.
- Clear flavor hierarchy of jet energy loss, $\Delta E_g > \Delta E_q > \Delta E_b$.
- The energy loss of quark-initiated jets shows weaker p_{T} and weaker centrality dependence.
- Large quark jet fraction underlies $R_{\mathrm{AA}}^{\gamma+\mathrm{jet}}/R_{\mathrm{AA}}^{\mathrm{jet}}$ at large p_{T}, while the flat spectra give the dominate contribution to $R_{\mathrm{AA}}^{\gamma+\mathrm{jet}}/R_{\mathrm{AA}}^{\mathrm{jet}}$ at low p_{T}.
- The color charge effect have greater impacts on the ratio $R_{\mathrm{AA}}^{b\text{-jet}}/R_{\mathrm{AA}}^{\mathrm{jet}}$ than parton mass effect, which decrease moderately at $p_{\mathrm{T}} \sim 300$ GeV/c.

Thanks!

Centrality dependent jet R_{AA}



- Inclusive jet R_{AA} show stronger dependence on centrality than γ+jet R_{AA}.
- different quark/gluon fraction or quark-initiated jet has weaker dependence on the centrality?