Deciphering yield modification of hadron-triggered semi-inclusive recoil jets in heavy-ion collisions

Yang He (何杨)
Shandong University
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Collaboration with Maowu Nie, Shanshan Cao, Rongrong Ma, Li Yi, Helen Caines

Based on: *Phys. Lett. B 854 (2024) 138739*

Outline

Delve into hadron-triggered semi-inclusive recoil jets (h+jet) with LBT model

Part 1. Introduction on h+jet measurements

Part 2. Explore "surface bias" of trigger particles

Part 3. Decipher the suppression of recoil jets

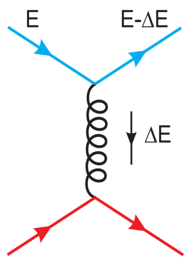
Part 4. Summary

Evidence for QGP in HIC: Jet quenching

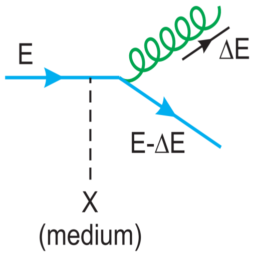
Jet: a collimated spray of hadrons produced by energetic quark or gluon

Jet production in vacuum calculable with pQCD

Parton energy loss in medium



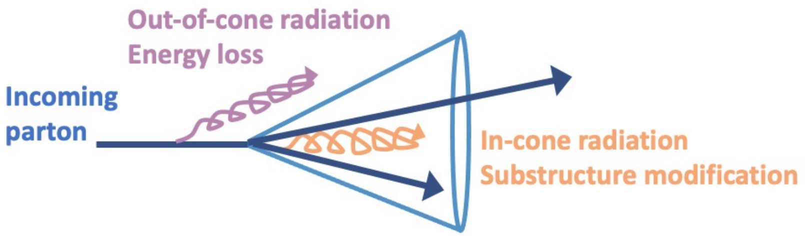
collisional energy loss



radiative energy loss

Jet quenching phenomenon

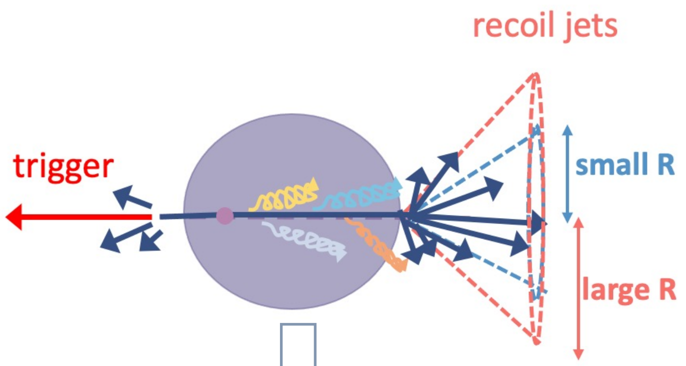
- Energy loss
- Acoplanarity
- Substructure modification



Jet quenching phenomenon can be used to probe QGP properties

h+jet to study jet quenching

Jets recoiling from a high-p_T trigger hadron

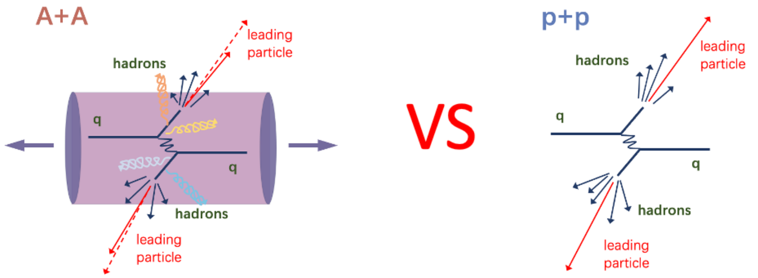


Suppress un-correlated background jets

Trigger: surface bias
Recoil jet: larger path length than inclusive jets

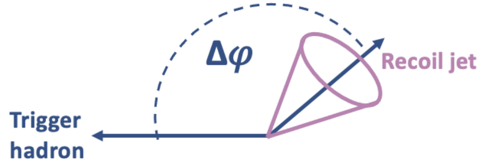
☐ Energy loss

Yield suppression



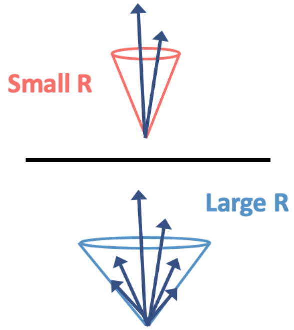
☐ Acoplanarity

Trigger-jet azimuthal correlation



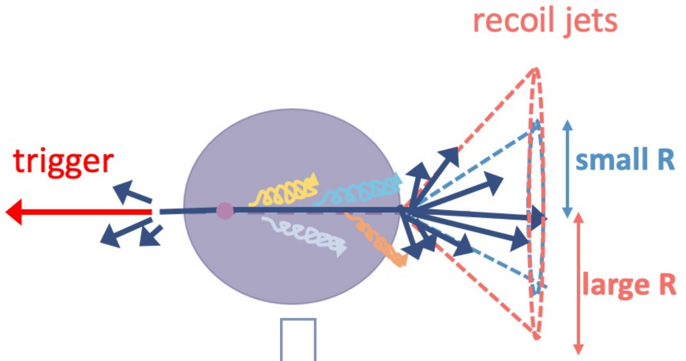
☐ Substructure modification

Yield dependence on jet R
Other substructure observables…



h+jet yield ratio (I_{AA})

Jets recoiling from a high-p_T trigger hadron

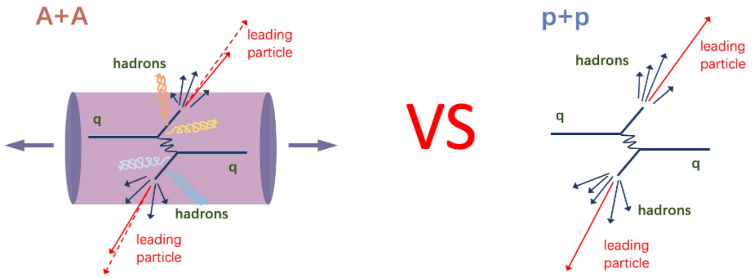


Suppress un-correlated background jets

Trigger: surface bias
Recoil jet: larger path length than inclusive jets

☐ Energy loss

Yield suppression



Trigger-normalized yield

$$\frac{1}{N_{trig}^{AA}} \cdot \frac{d^3 N_{\rm jet}^{\rm AA}}{dp_{\rm T,jet}^{\rm ch} d\Delta\phi d\eta_{\rm jet}}\Bigg|_{p_{\rm T,trig}} = \left(\frac{1}{\sigma^{\rm AA\to h+X}} \cdot \frac{d^3\sigma^{\rm AA\to h+jet+X}}{dp_{\rm T,jet}^{\rm ch} d\Delta\phi d\eta_{\rm jet}}\right)\Bigg|_{p_{\rm T,trig}}$$

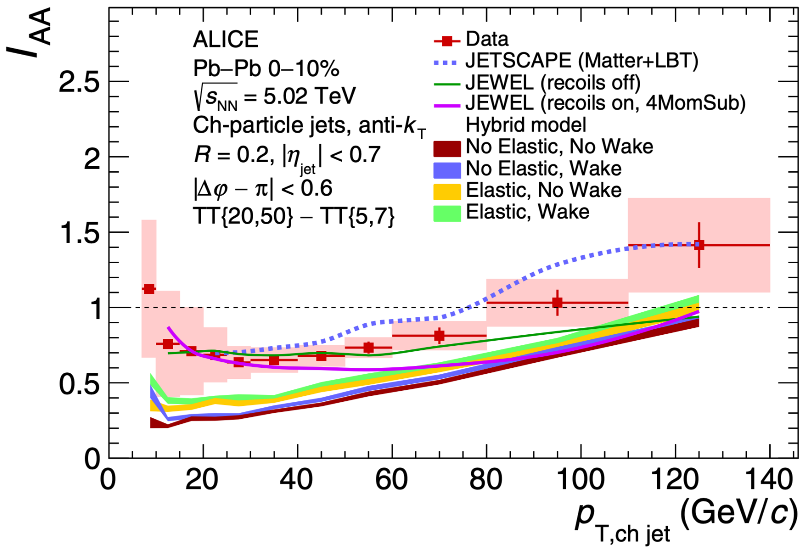
Jet quenching observable

$$I_{\rm AA} = \frac{Y^{A+A}}{Y^{p+p}}$$

h+jet yield ratio (I_{AA})

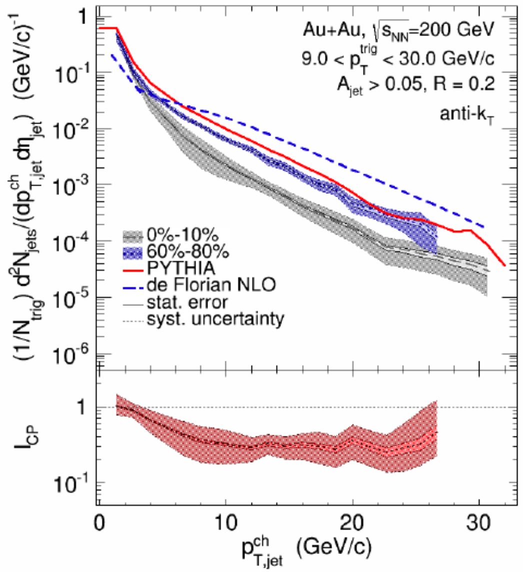
Experimental results

Pb+Pb@5.02 TeV



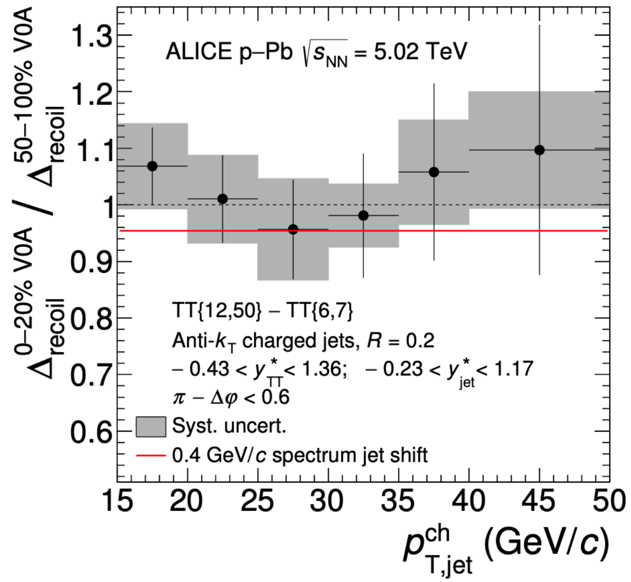
ALICE, Phys. Rev. C 110 (2024) 1, 014906

Au+Au@200 GeV



STAR, Phys. Rev. C 96 (2017) 2, 024905

p+Pb@5.02 TeV



ALICE, PLB 783 (2018) 95-113

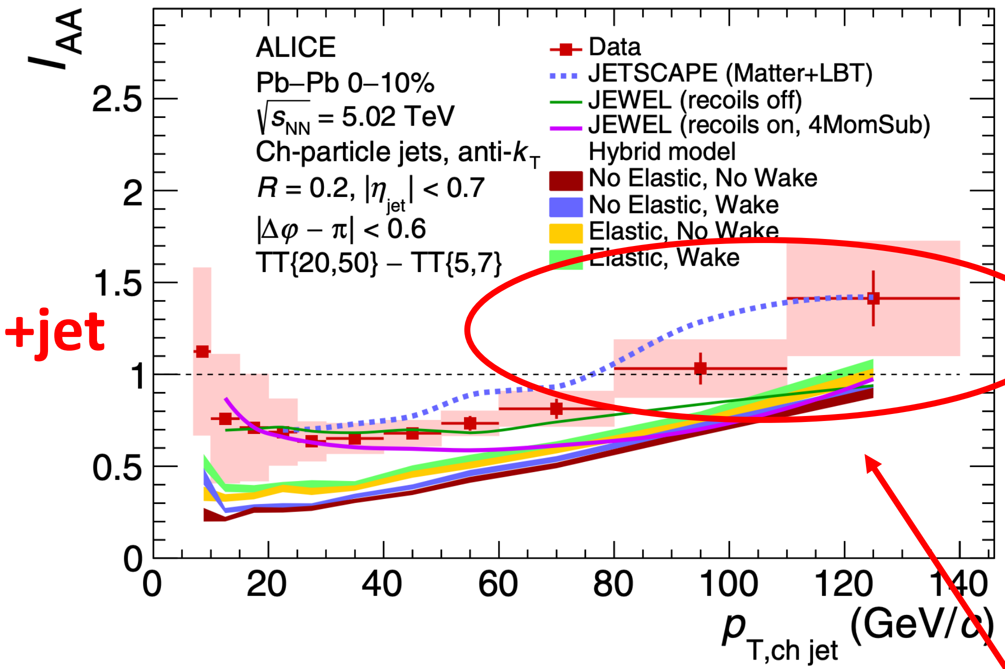
Plenty of I_{AA} measurements in different collision systems

What does I_{AA} > 1 mean?

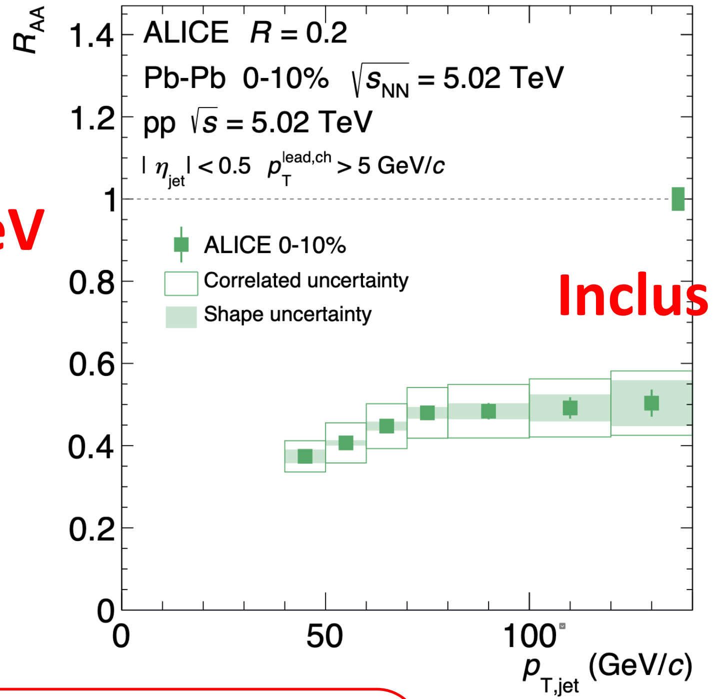
Experimental results

ALICE, Phys.Rev.C 110 (2024) 1, 014906

h+jet



ALICE, Phys. Rev. C 101 (2020) 034911



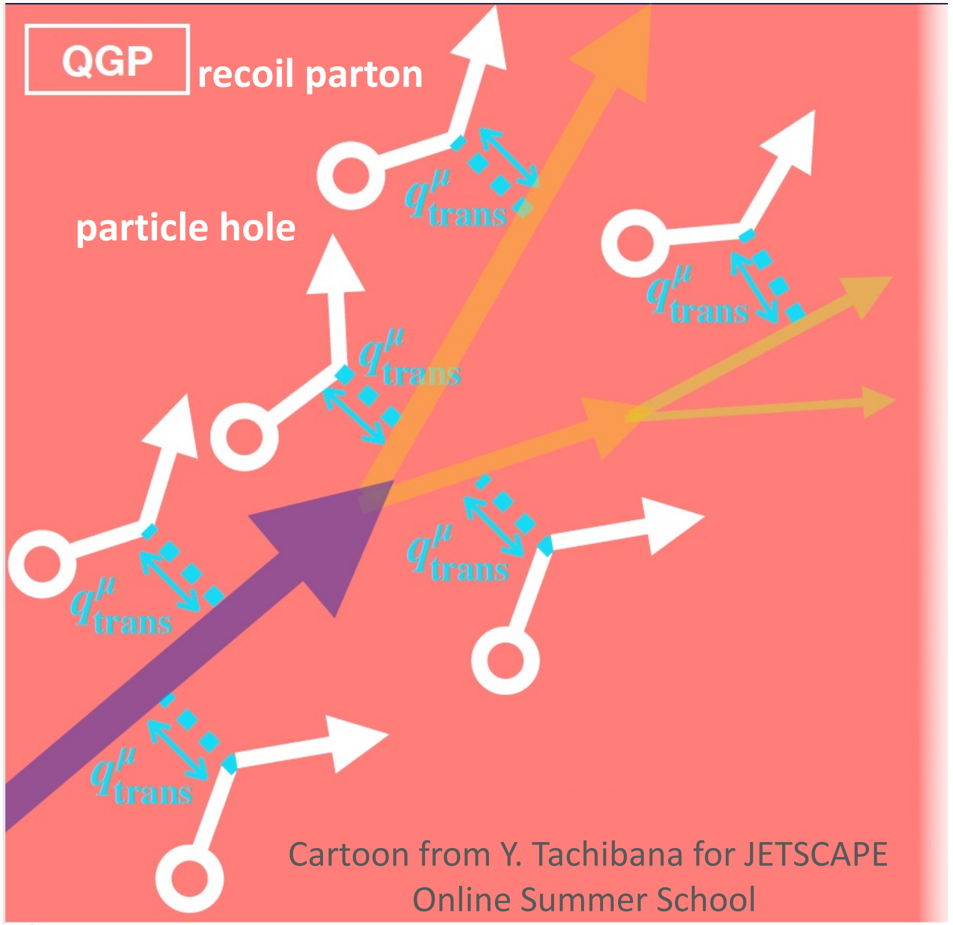
Inclusive jet

Pb+Pb@5.02 TeV
0-10% R=0.2

I_{AA} > 1? Consistent with inclusive jets?
Is there still any energy loss?

Linear Boltzmann Transport (LBT) model

Cao, Luo, Qin, Wang, Phys. Rev. C 94 (2016) 1, 014909



The LBT model is developed for studying jet evolution inside the QGP

Medium modification of jet shower:

Medium-induced in-cone and out-of-cone splittings

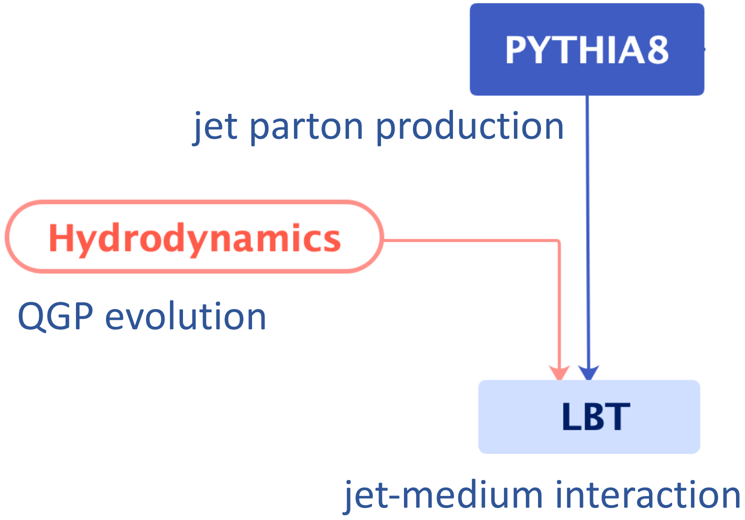
Medium response:

Energy deposition: recoil parton

Energy depletion: particle hole

Simulation procedure

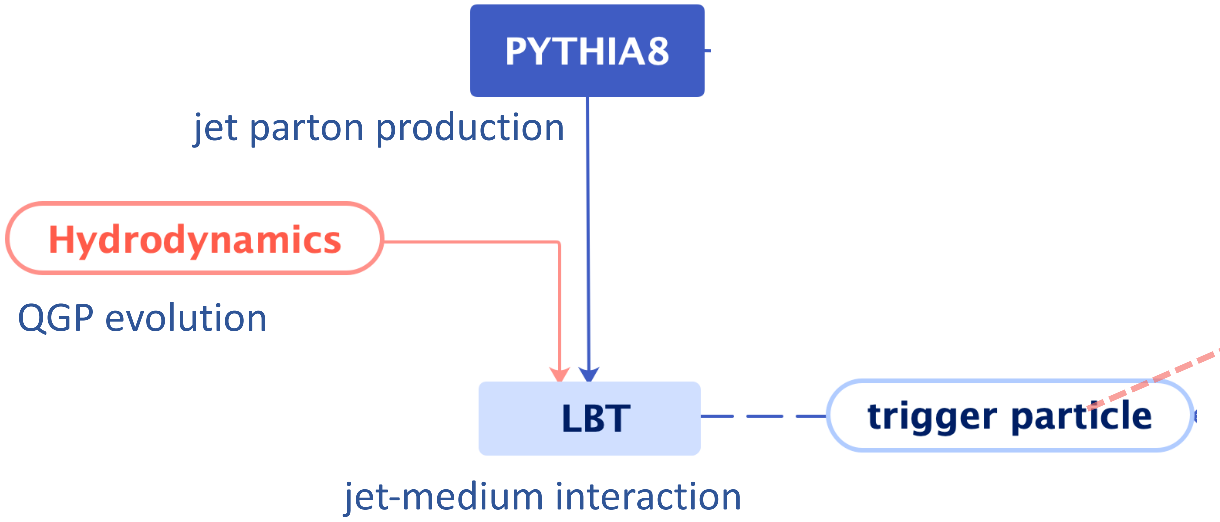
LBT simulation

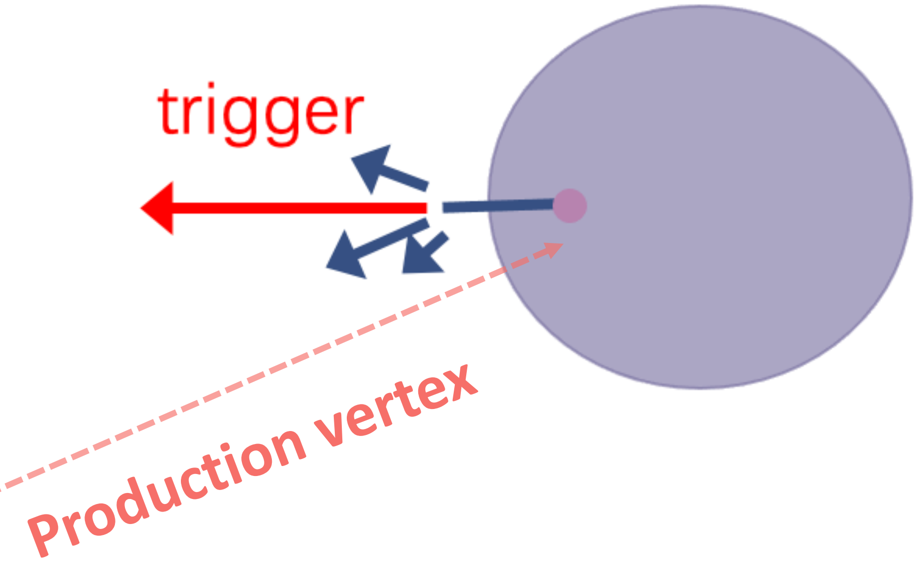


***Note: parton level study**

Explore "surface bias" of high p_T trigger

LBT simulation



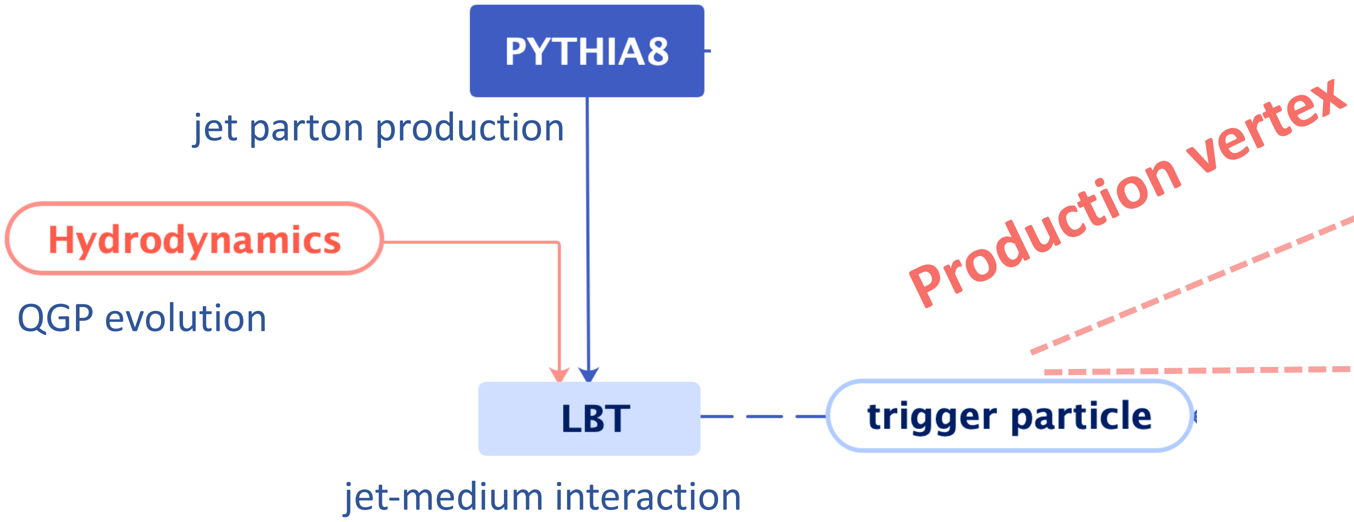


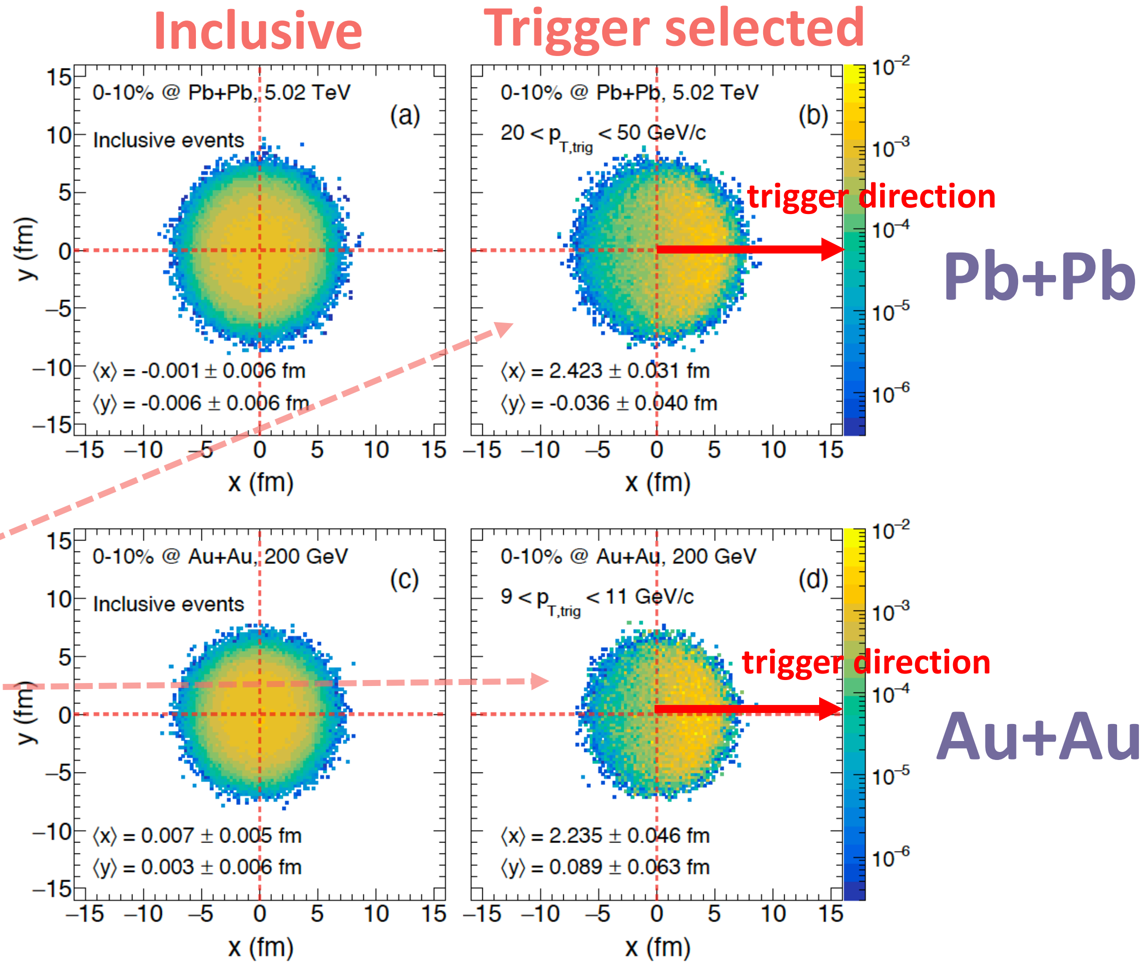
Are the triggers produced near the edge of the QGP?

***Note: parton level study**

Explore "surface bias" of high p_T trigger

LBT simulation



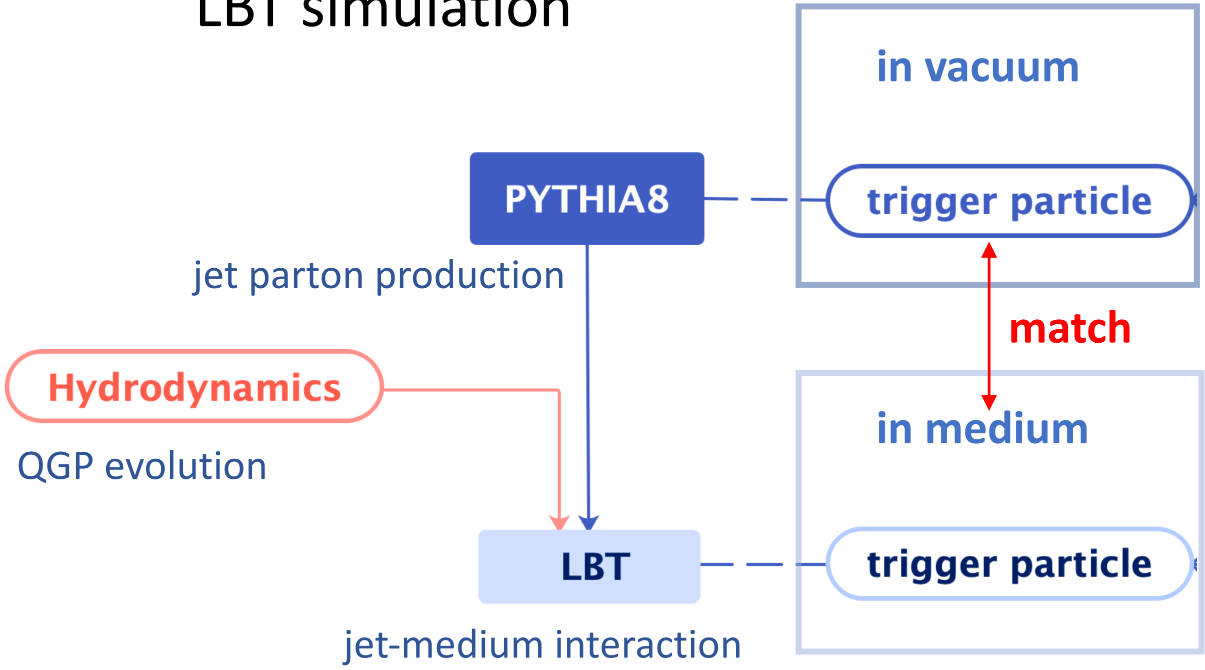


***Note: parton level study**

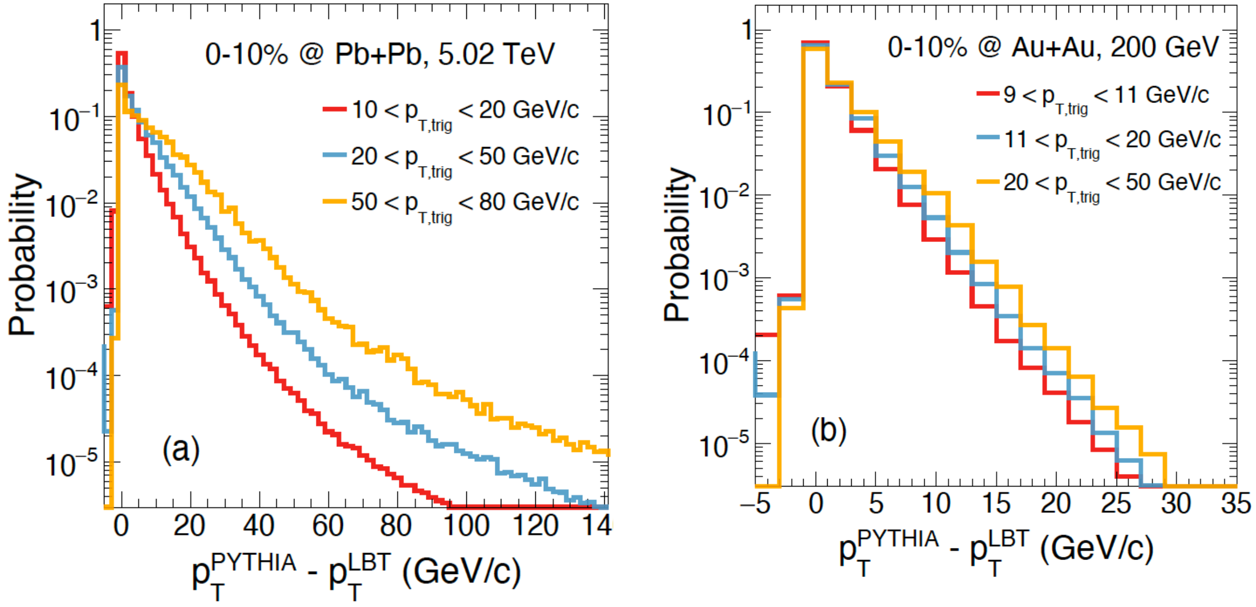
- Deviates from the center by about 2 fm
- Still a large fraction of triggers lose energy

Quantify energy loss of trigger partons

LBT simulation



Pb+Pb   Au+Au



The fraction of triggers losing energy > 1 GeV/c

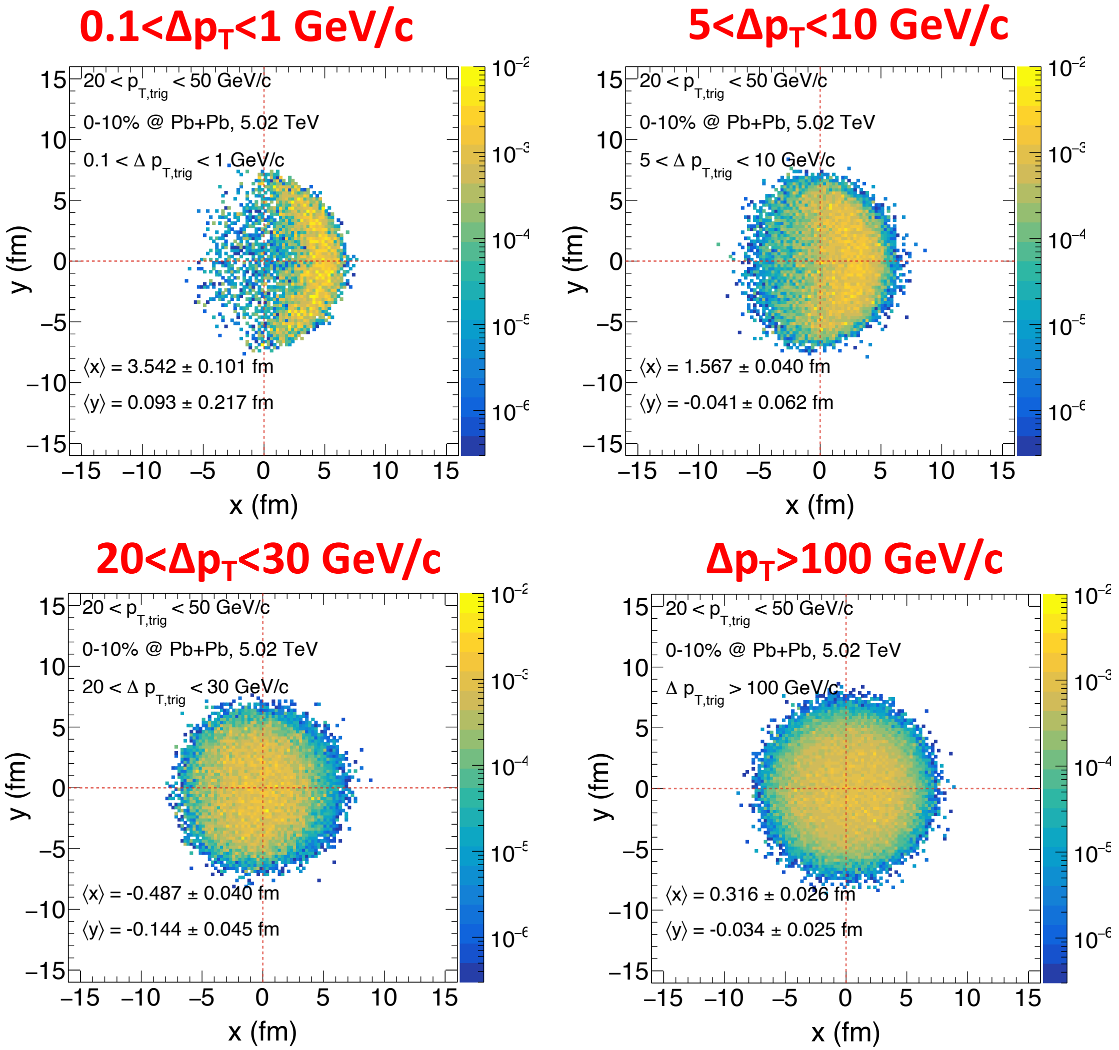
Pb + Pb: 63% for the selection of $20 < p_{T,trig} < 50$ GeV/c

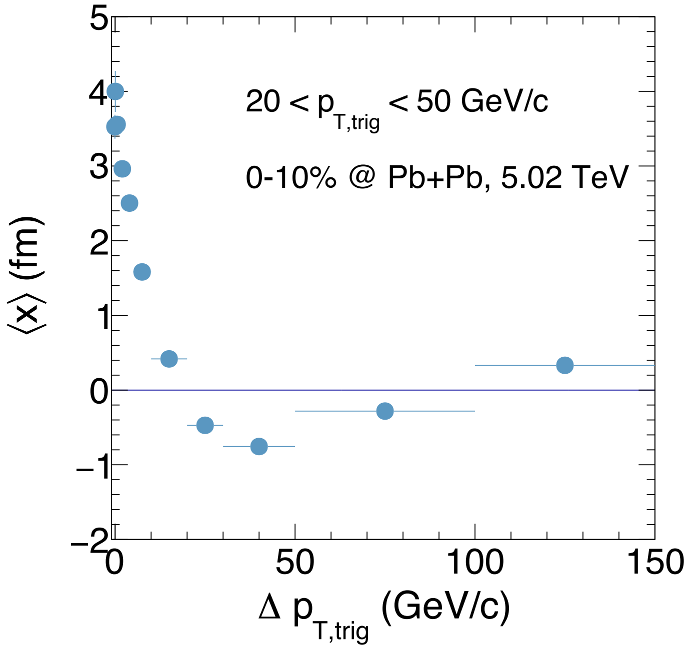
Au + Au: 30% for the selection of $9 < p_{T,trig} < 11$ GeV/c

***Note: parton level study**

Energy Loss and path length

Pb+Pb, 20<$p_{T,trig}$<50 GeV/c

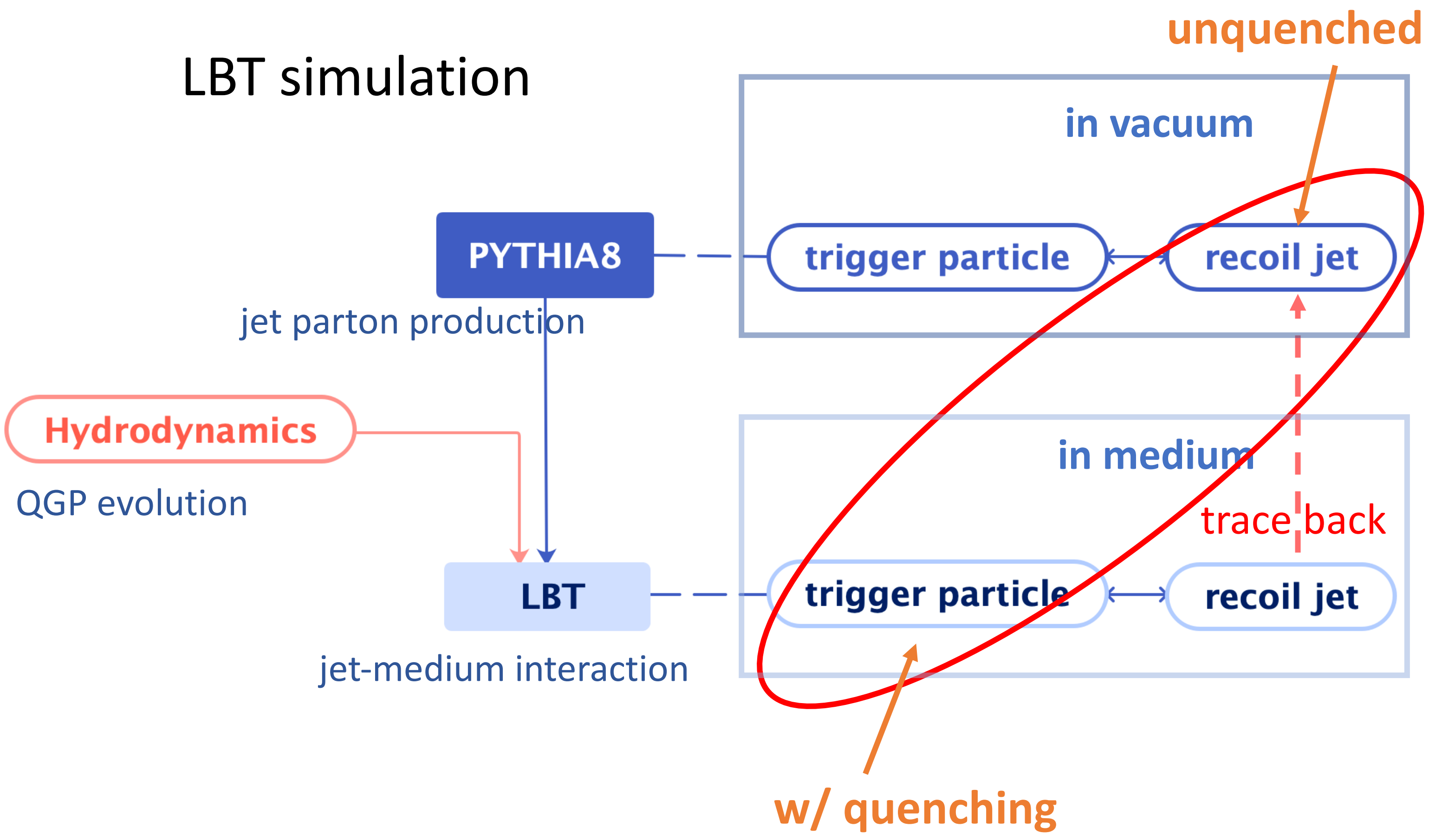




- <x> decreases with increasing energy loss
- Extremely large energy loss arises predominantly from fluctuations

How do quenched triggers impact I_{AA} ?

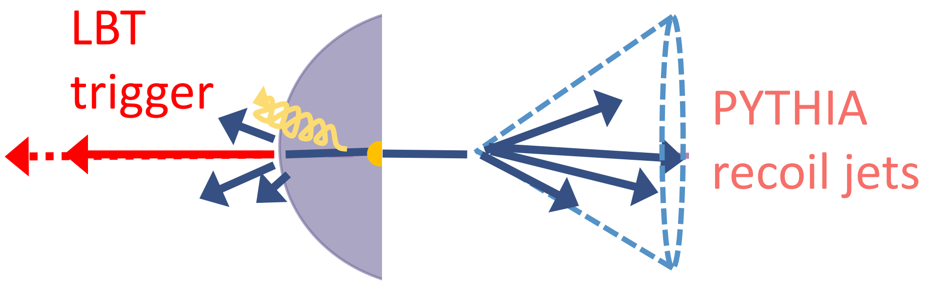
LBT simulation



Construct hybrid sample:

energy loss for trigger partons

no energy loss for recoil jets



How do quenched triggers impact I_{AA} ?

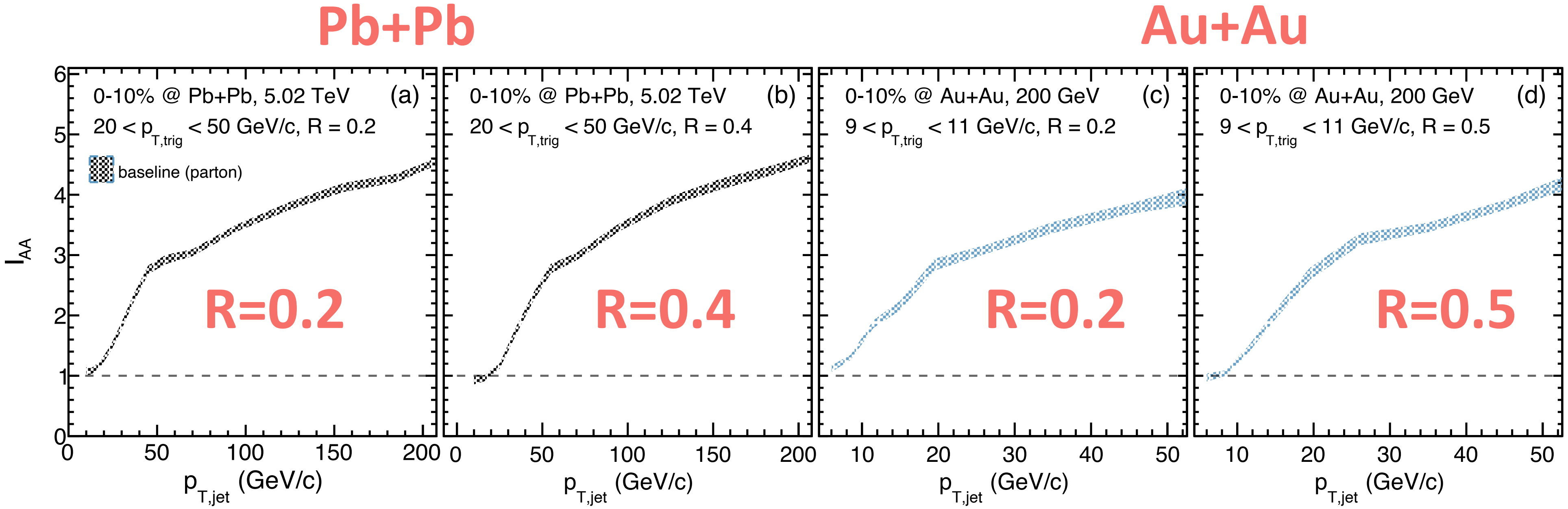
“True” baseline

$$I_{AA}^{\mathrm{baseline}} = \frac{1/N_{\mathrm{trig}}^{\mathrm{LBT}} dN_{\mathrm{jet}}/dp_{\mathrm{T,jet}}^{\mathrm{PYTHIA}}}{1/N_{\mathrm{trig}}^{\mathrm{PYTHIA}} dN_{\mathrm{jet}}/dp_{\mathrm{T,jet}}^{\mathrm{PYTHIA}}}$$

hybrid sample

PYTHIA sample

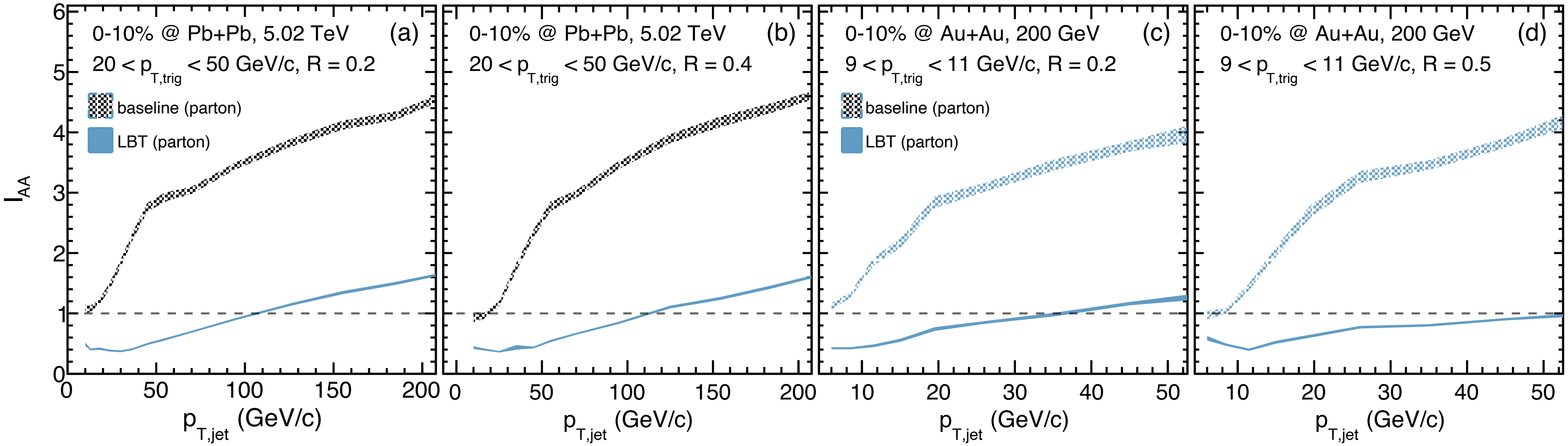
Trigger energy loss only!



Energy loss of trigger particles in A+A collisions results in them having originated from higher-Q^2 processes, and thus ”true” baseline exceeds unity

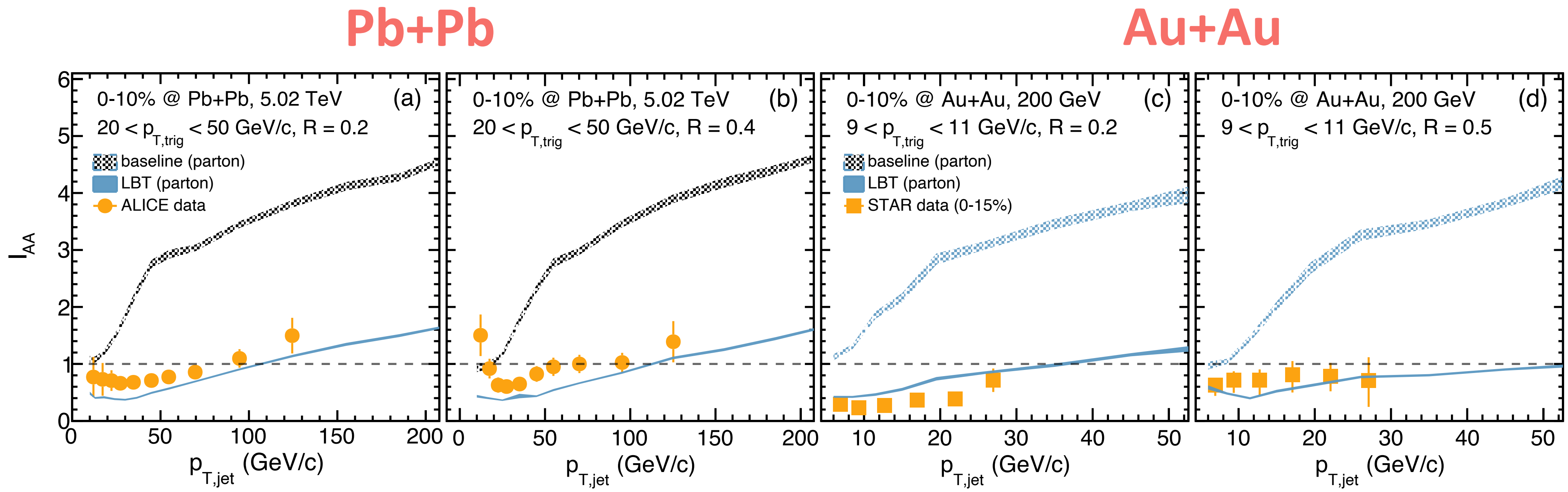
Decipher $I_{AA} > 1$ observed in experiments

Pb+Pb **Au+Au**



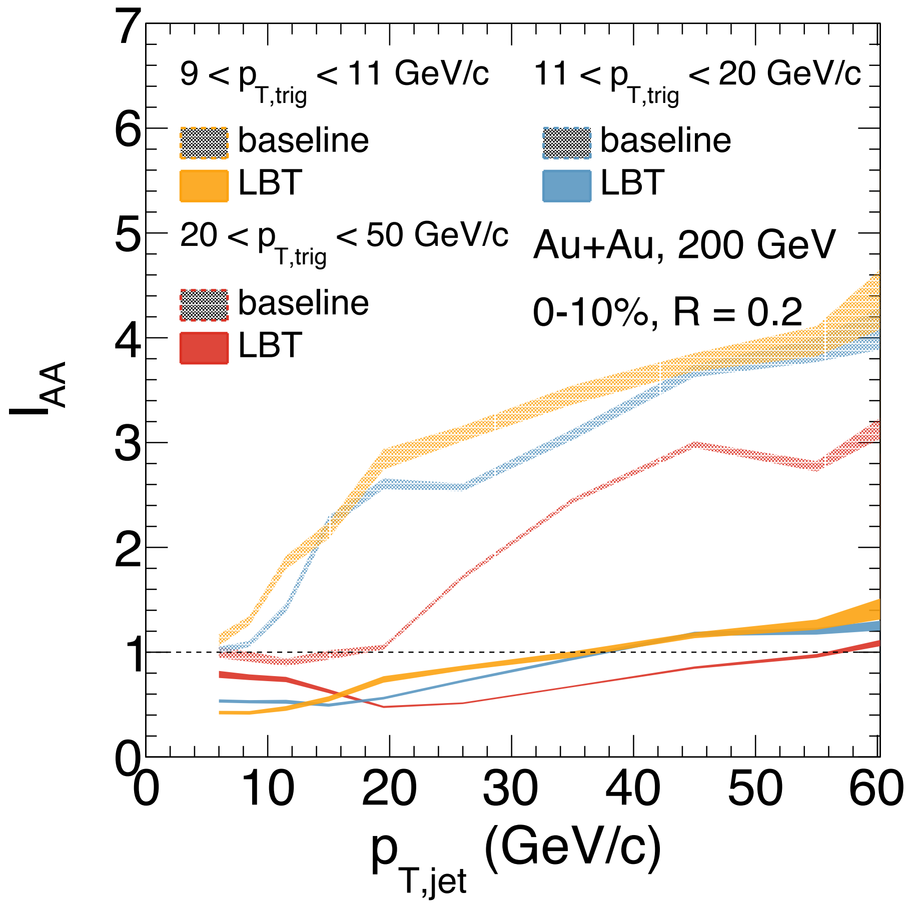
- The enhanced baseline indicates that $I_{AA} > 1$ could still signal jet quenching

Decipher $I_{AA} > 1$ observed in experiments



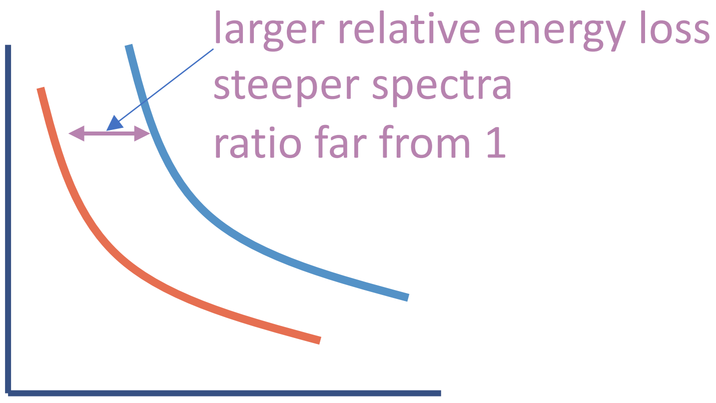
- The enhanced baseline indicates that $I_{AA} > 1$ could still signal jet quenching
- Rising trend of I_{AA}, especially as observed in the ALICE data, can be qualitatively reproduced by the LBT model

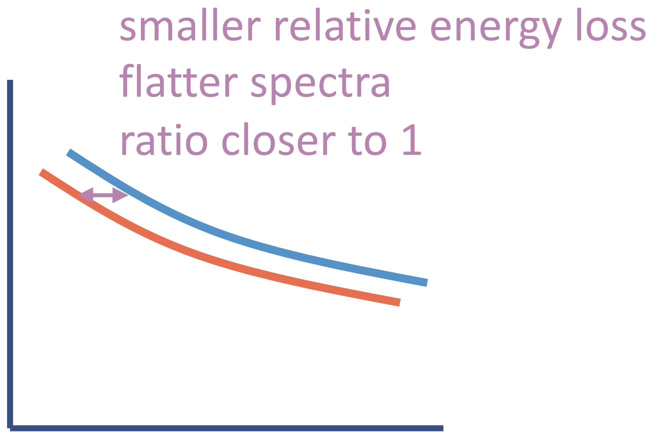
Exploration on trigger p_T dependence



The baseline gets closer to one with increasing trigger p_T

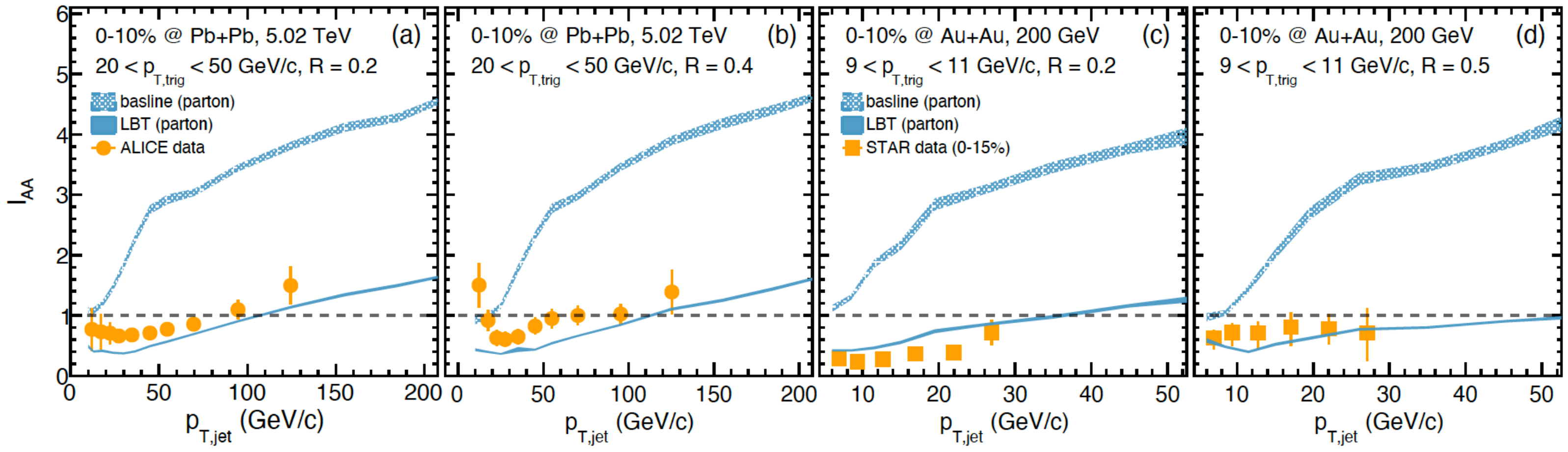
Combined effects of flatter jet spectrum and smaller relative energy change of higher p_T trigger





Summary

- We explore the origin of I_{AA} larger than 1 at high p_T region with model study, and identify the **trigger energy loss as the cause**
- We find that "true" baseline for I_{AA} can well exceed 1 at high p_T for quenched trigger particle
- Due to the enhancement of "true" baseline, **I_{AA} > 1 can still signal jet quenching**
- I_{AA} provides strong constraints on model to describe both trigger and recoil jet energy loss



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Back up

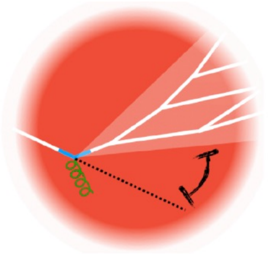
Outlook

Case using colored partons as trigger is explored. How about other particle species?
Is the baseline for colorless gamma or Z boson I_{AA} = 1?

Trigger effect is studied at parton level. Will the same observation hold at hadron level?

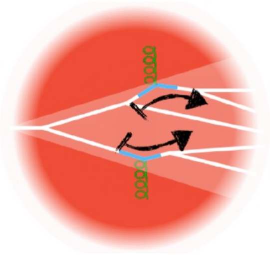
Trigger energy loss effect on I_{AA} is explored. What's its effect on other observables?

Jet acoplanarity :



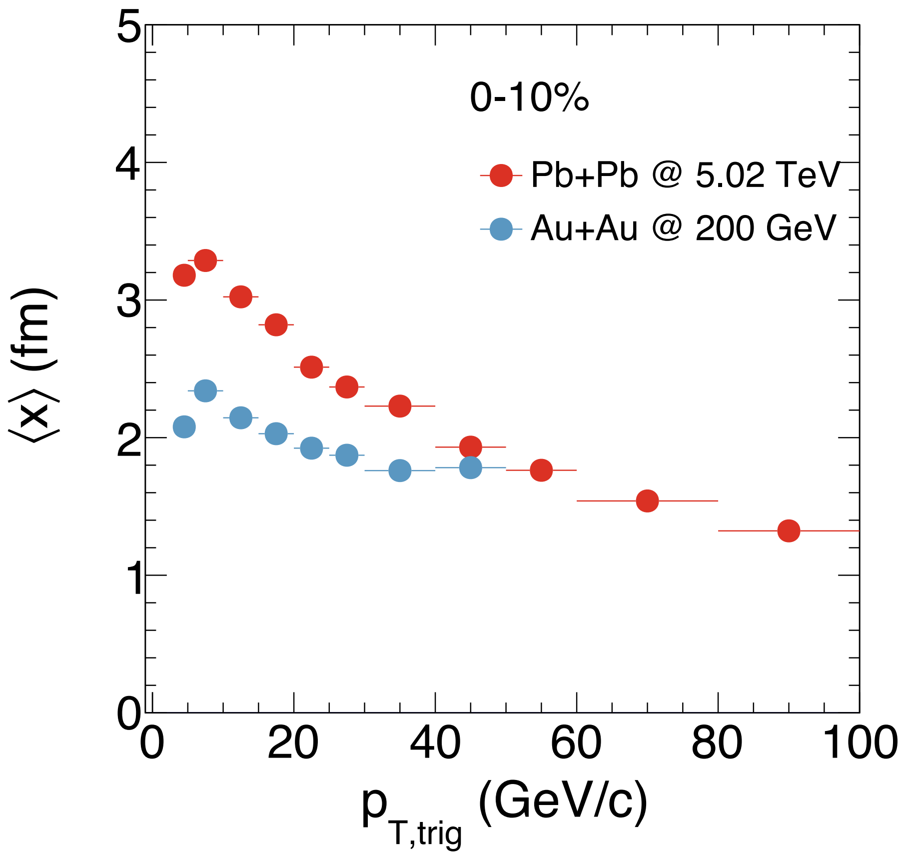
Medium deflects jet to large angle? (medium effect)
Harder jets are more difficult to deflect? (trigger effect)

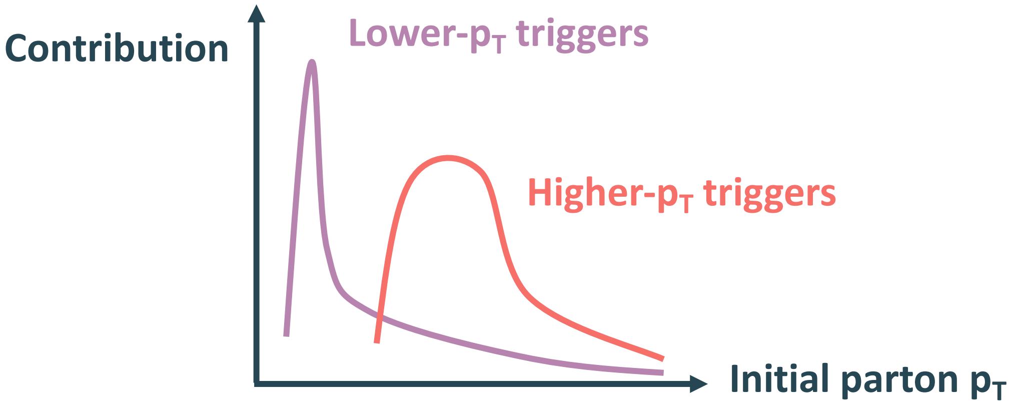
Jet substructure:



Interaction with medium broadens the jet? (medium effect)
Harder jets are more collimated? (trigger effect)
How do they interplay?

Trigger p_T and path length





Flatter parton spectrum at higher p_T

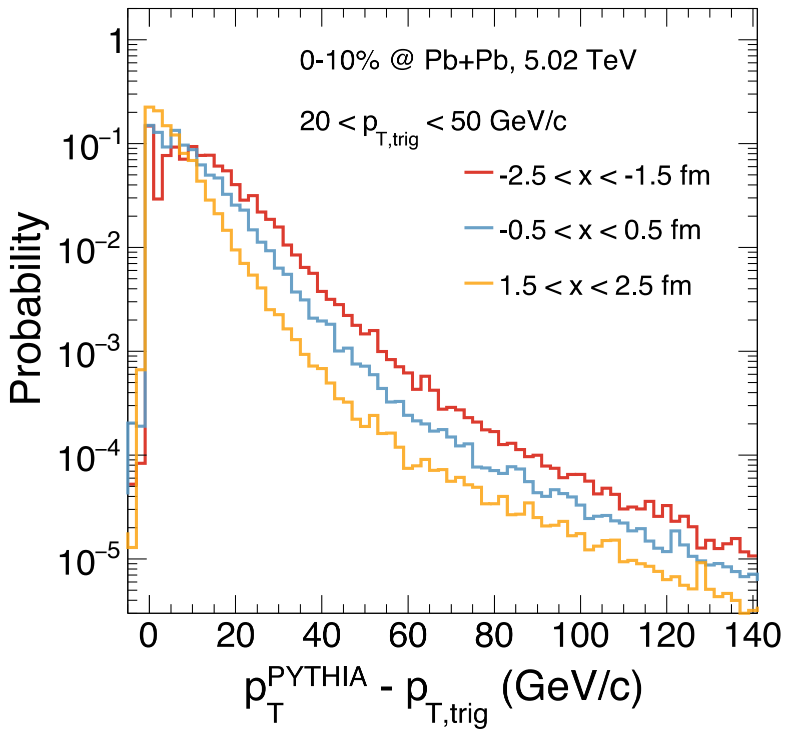
⇩

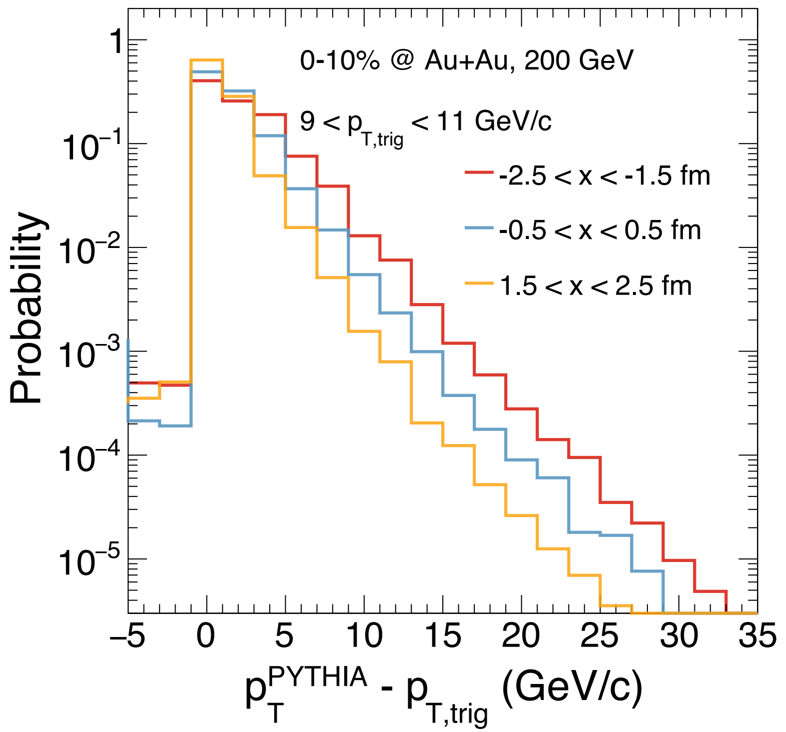
Higher-p_T triggers get more contribution from even higher- p_T initial partons with stronger energy loss

⇩

Higher-p_T triggers have less surface bias

Energy loss and production vertex

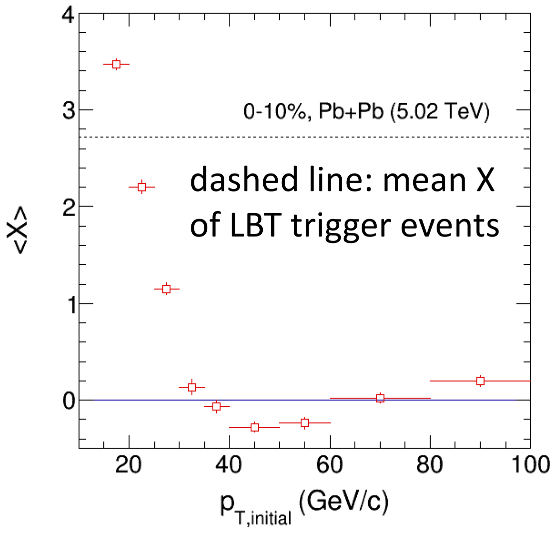




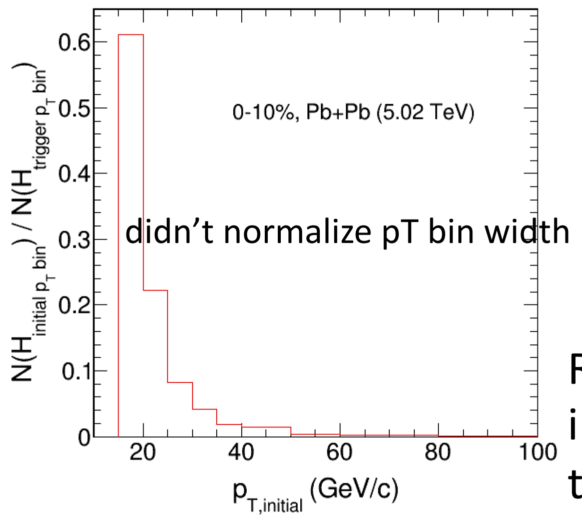
<X> distributions

15<LBT trigger pT<20 GeV/c

surface bias decrease with initial parton pT

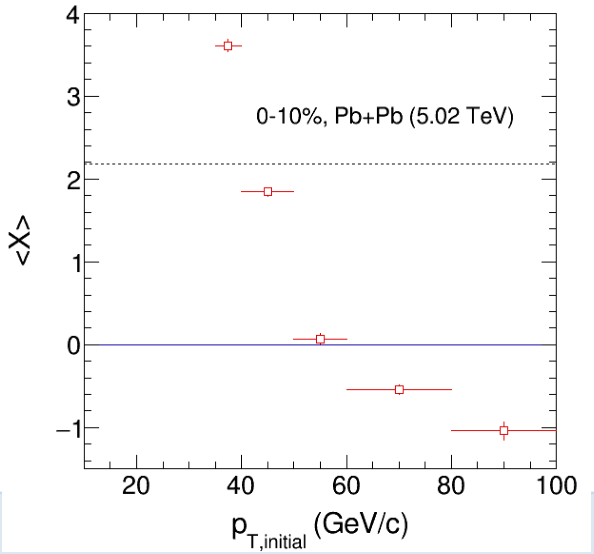


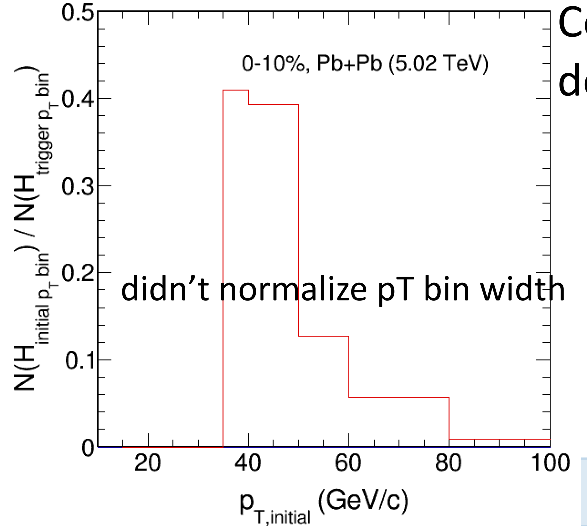
Y axis:(Integral of initial pT bin 2d plot) / (Integral of LBT trigger 2d plot)



Relative contribution from large initial pT bins increased with LBT trigger pT

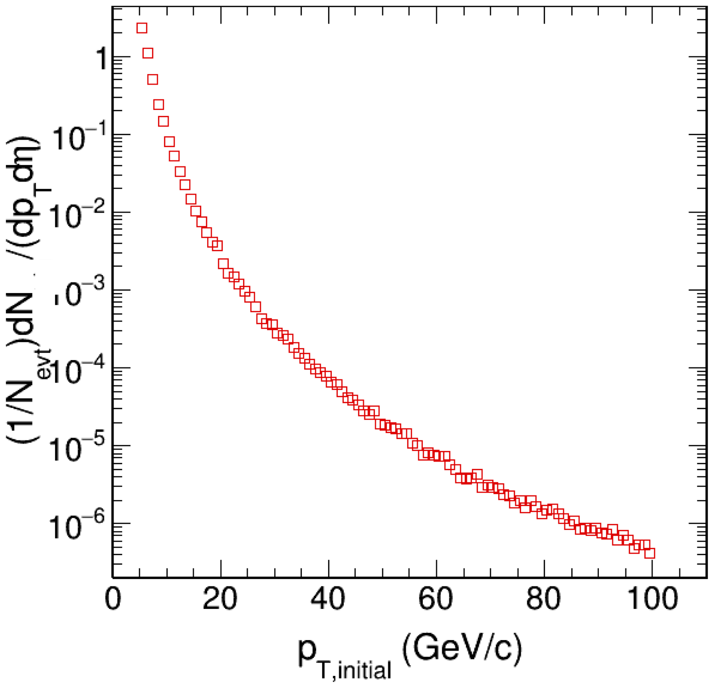
35<LBT trigger pT<40 GeV/c



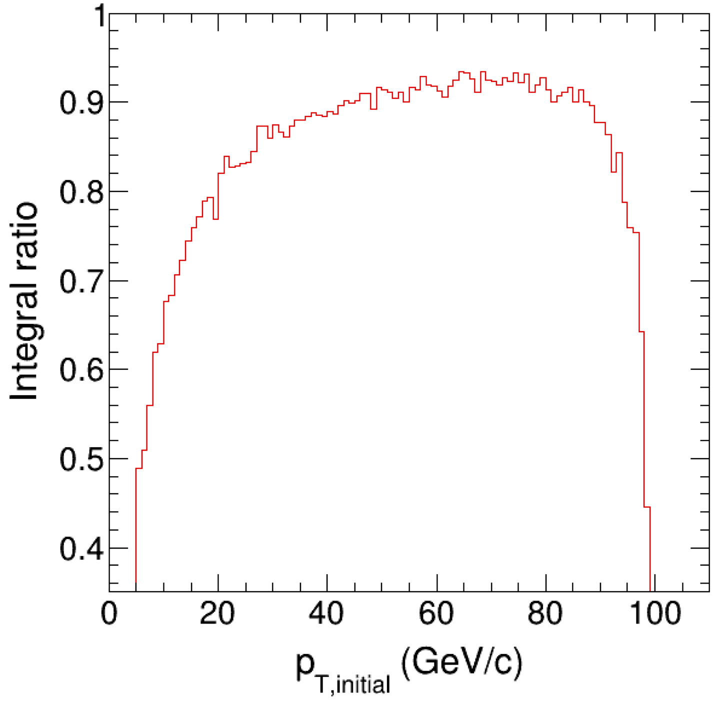


Could it be the reason for decreasing mean X?

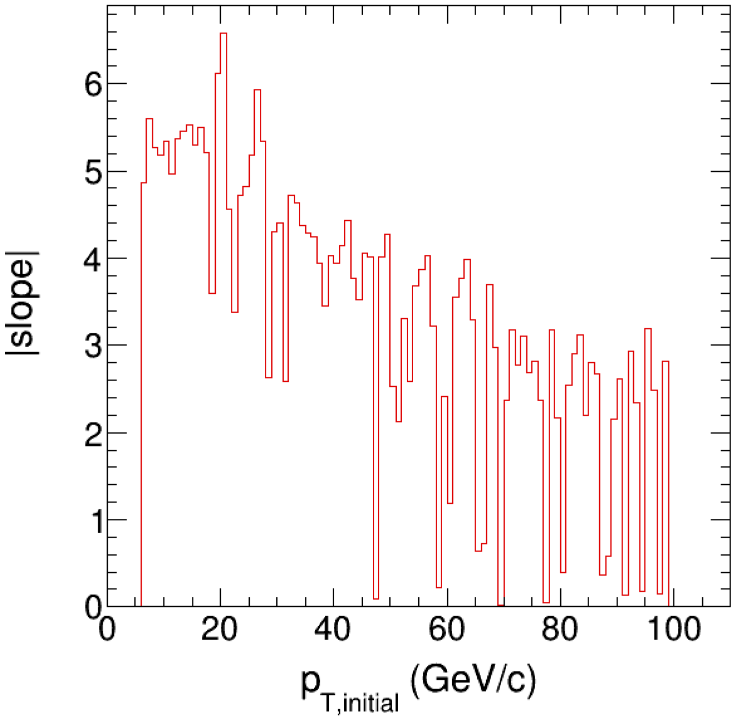
PYTHIA p_T distribution



Integral(bin_i+1, 100)/Integral(bin,100)



fit the three pt bins: bin_i-1, bin_i, bin_i+1 with a power-law distribution to get the slope



- Initial pT spectrum gets flatter
- Higher-pT triggers get more contribution from even higher initial pT partons whose lose more energy