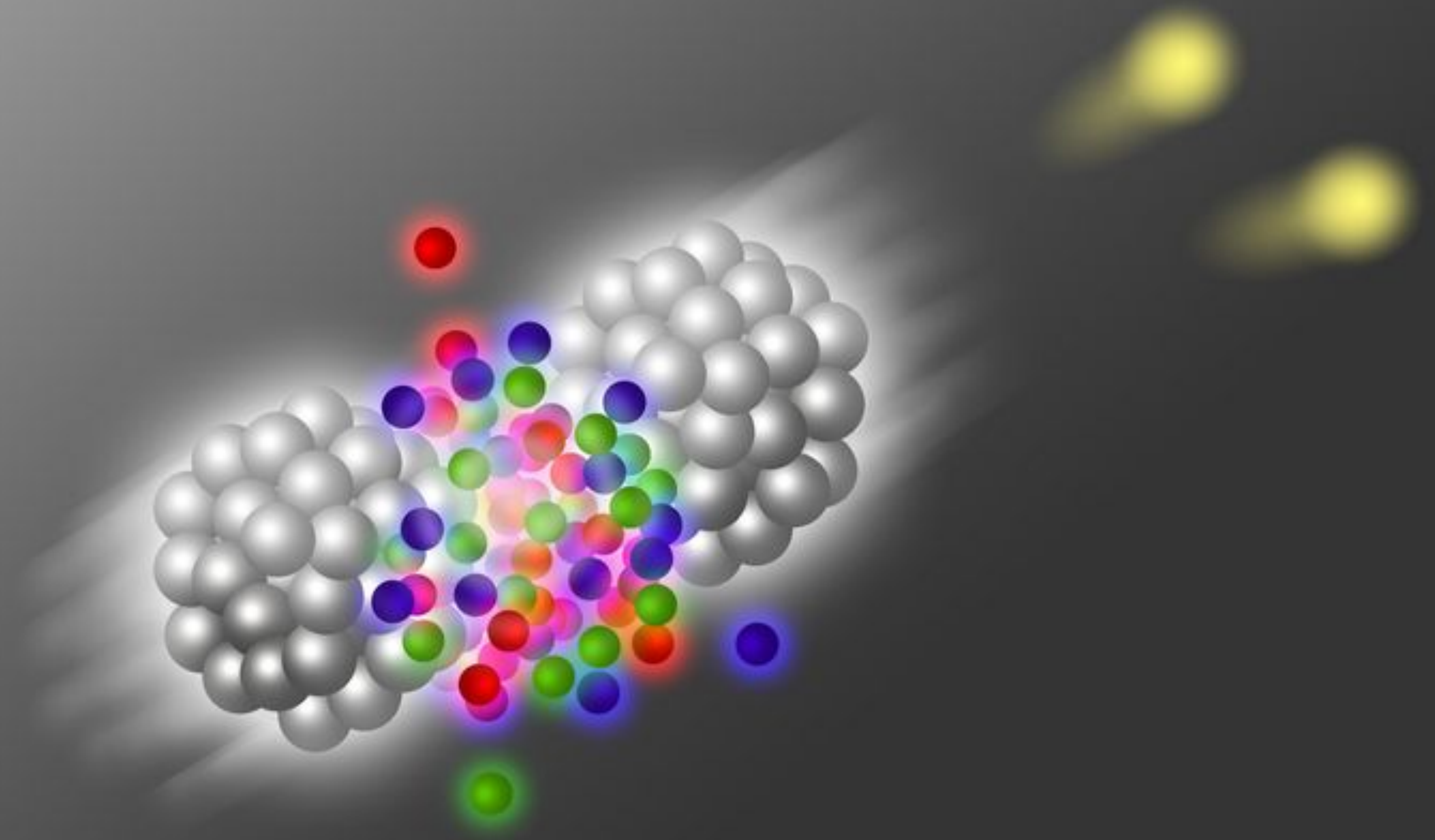
Opportunities and Future directions for Heavy-Ions



Liliana Apolinário

Guilherme Milhano

LIP

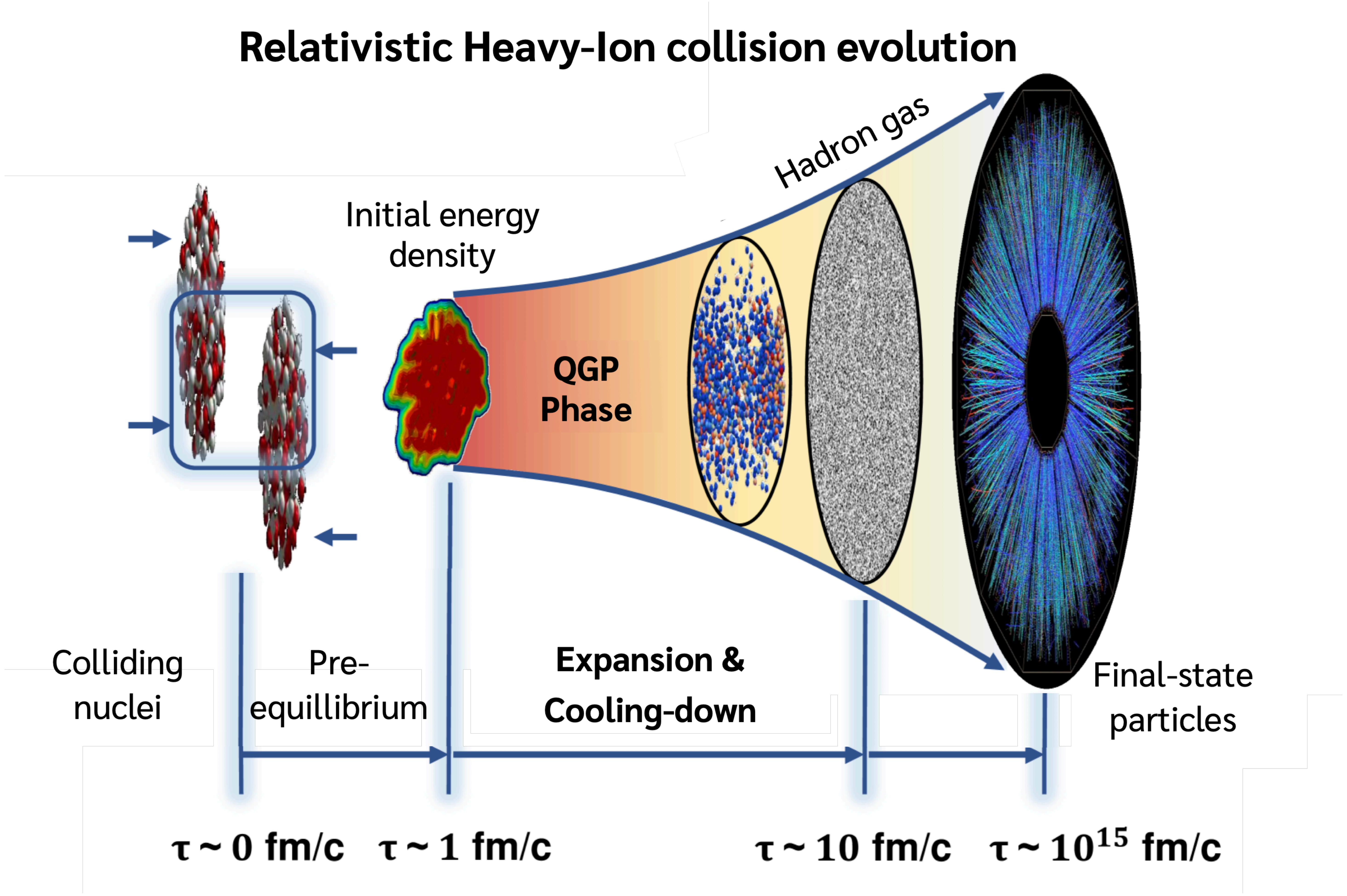
TÉCNICO LISBOA

Portuguese Discussion on the ESPP

Monday, January 20th

Heavy-Ion Collisions

- Ultra-relativistic heavy-ion collision
  - **Quark-Gluon Plasma (QGP)**: new state of QCD matter made of quarks and gluons



Heavy-Ion Collisions

- Ultra-relativistic heavy-ion collision
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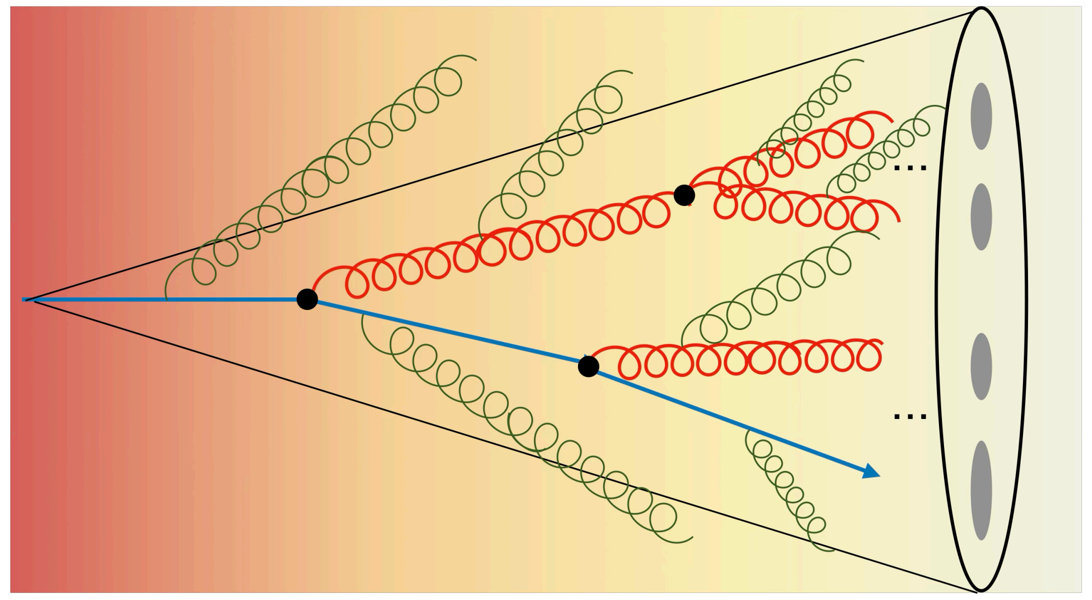
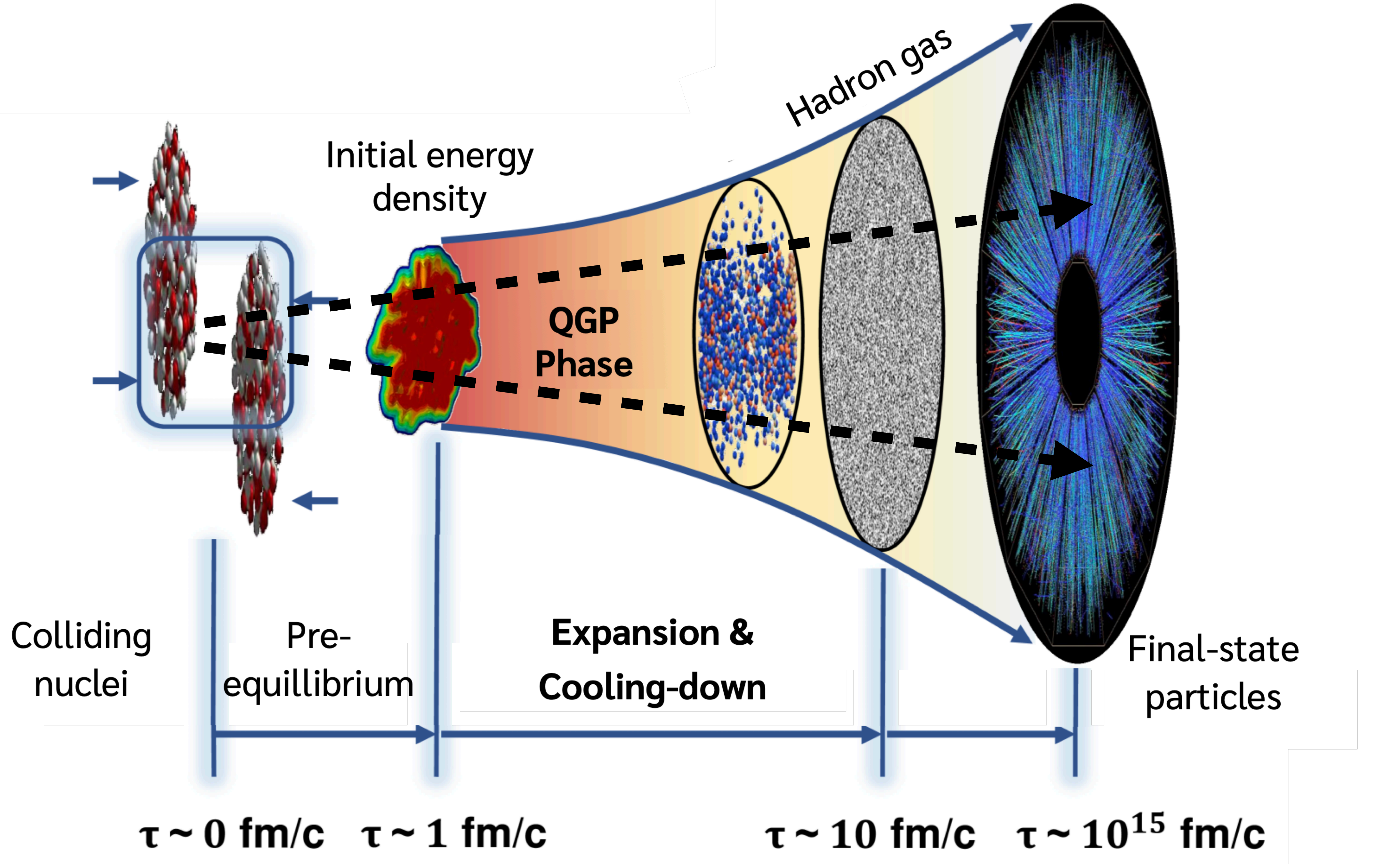
*Jets will propagate and interact with the produced QGP resulting into **jet energy loss** and **changes** on **jet substructure***



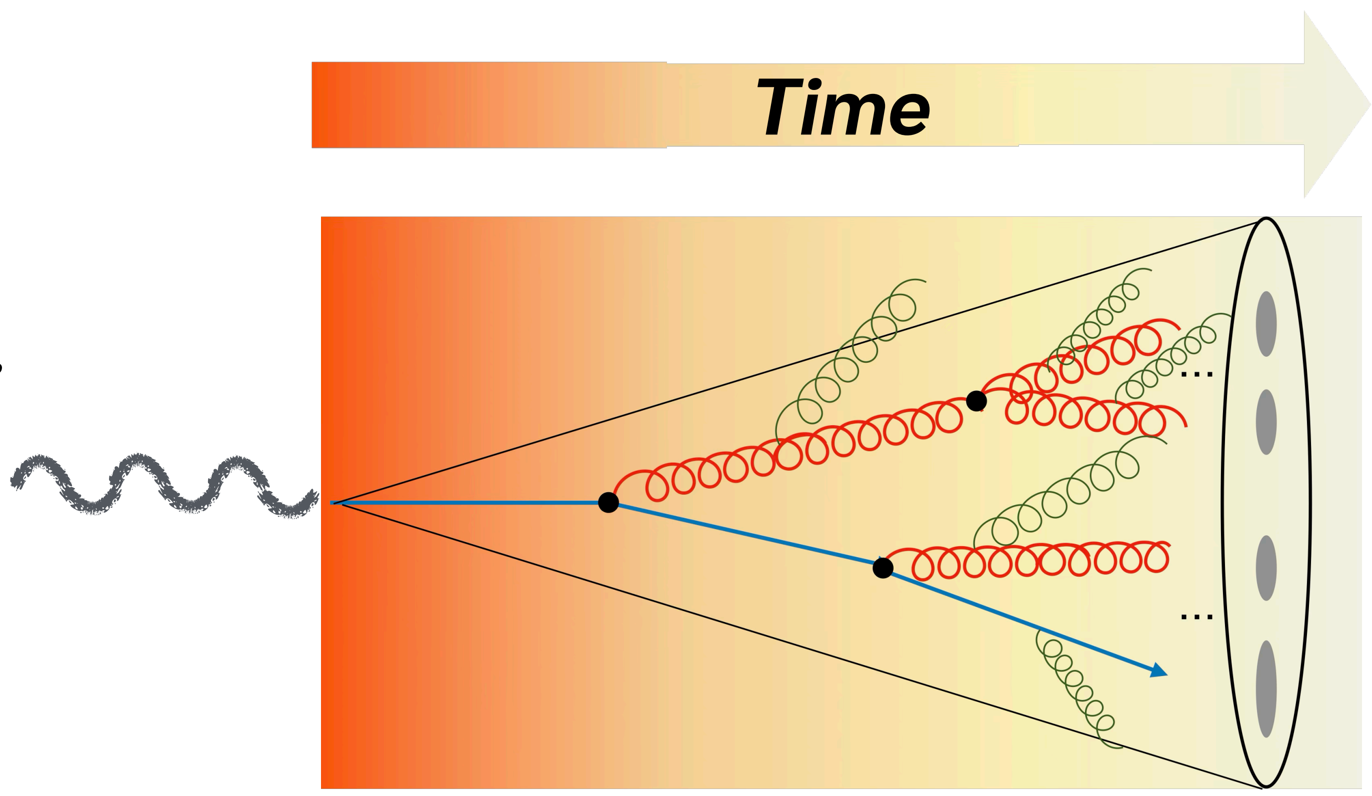
Jet Quenching

Relativistic Heavy-Ion collision evolution

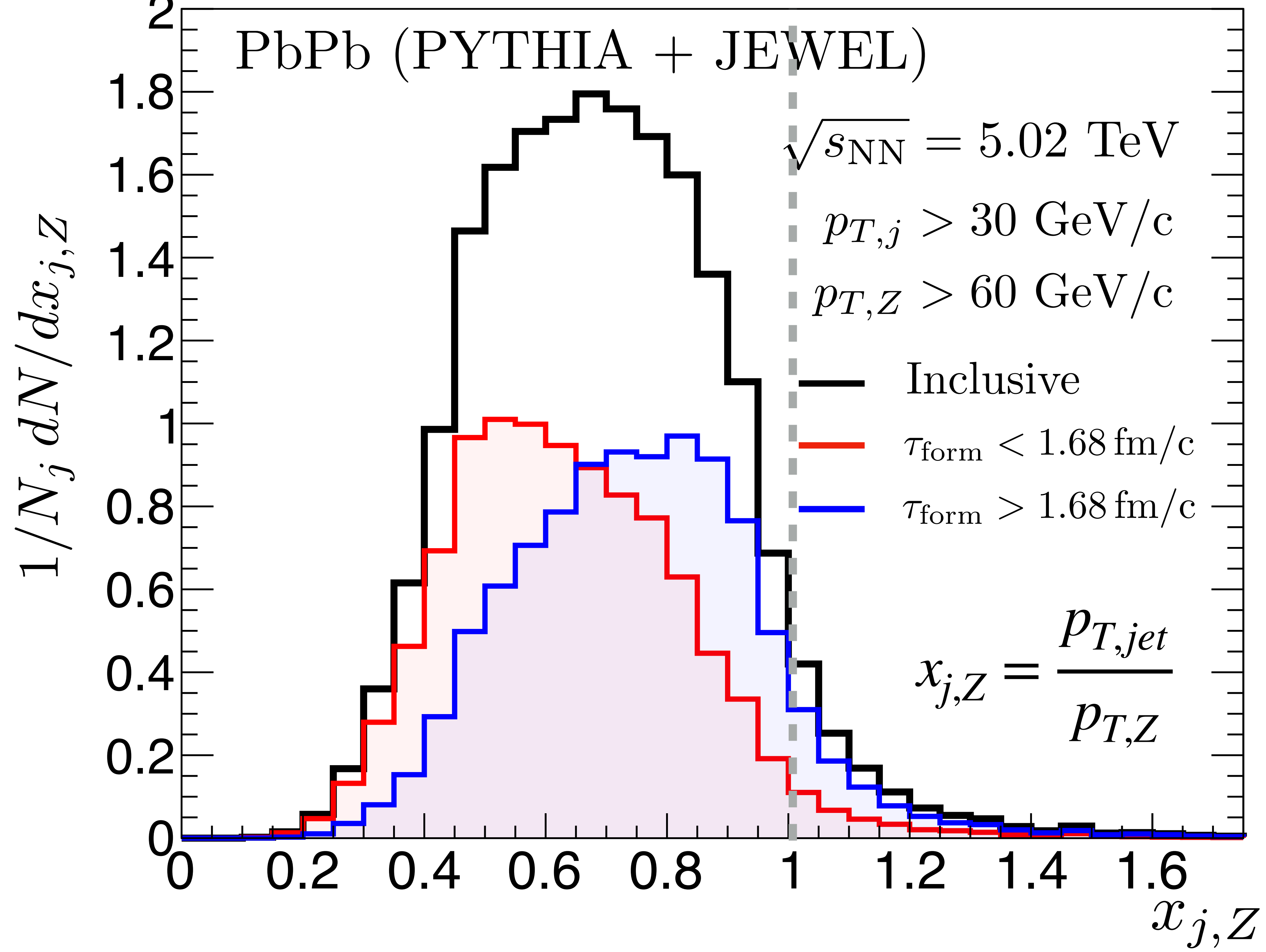


Jet τ Reclustering

- In heavy-ion collisions, formation time allows to **select jets strongly modified by the QGP**



LA, Cordeiro, Zapp, EPJC 2021
LA, Guerrero-Rodriguez, Zapp, EPJC 2024



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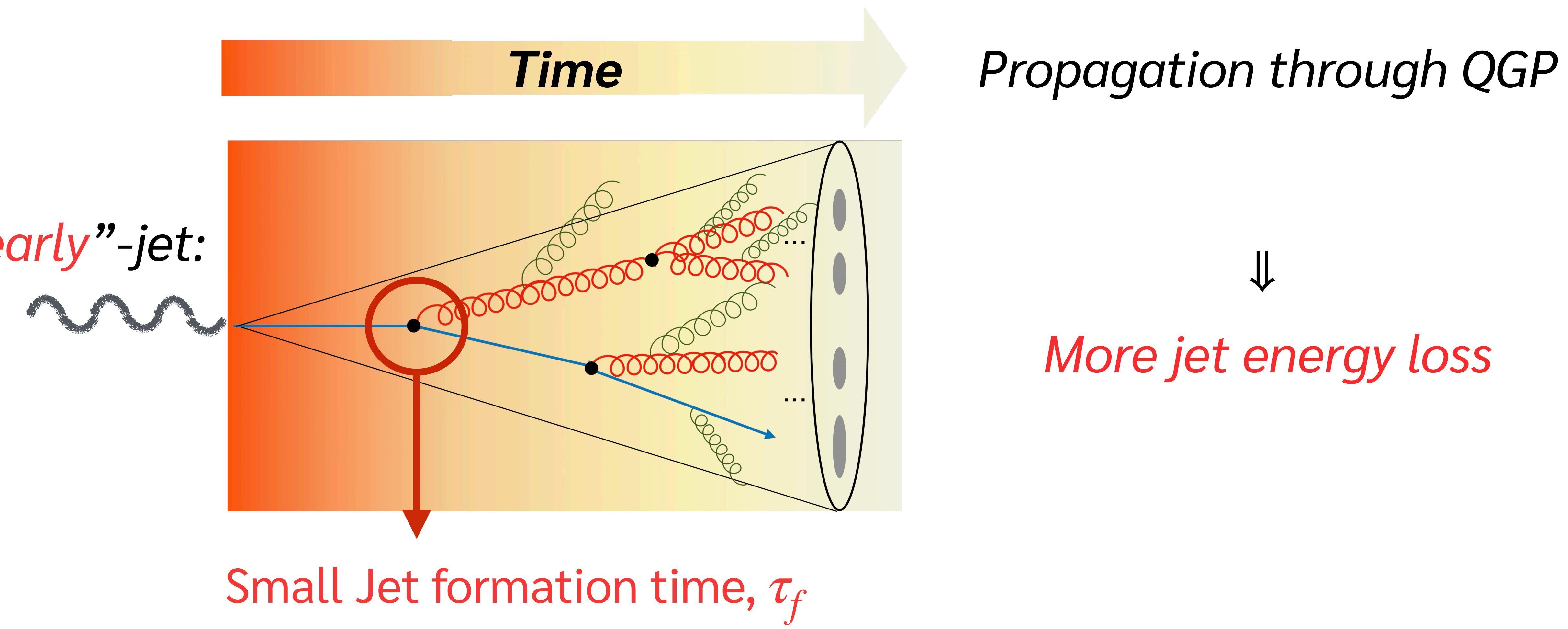

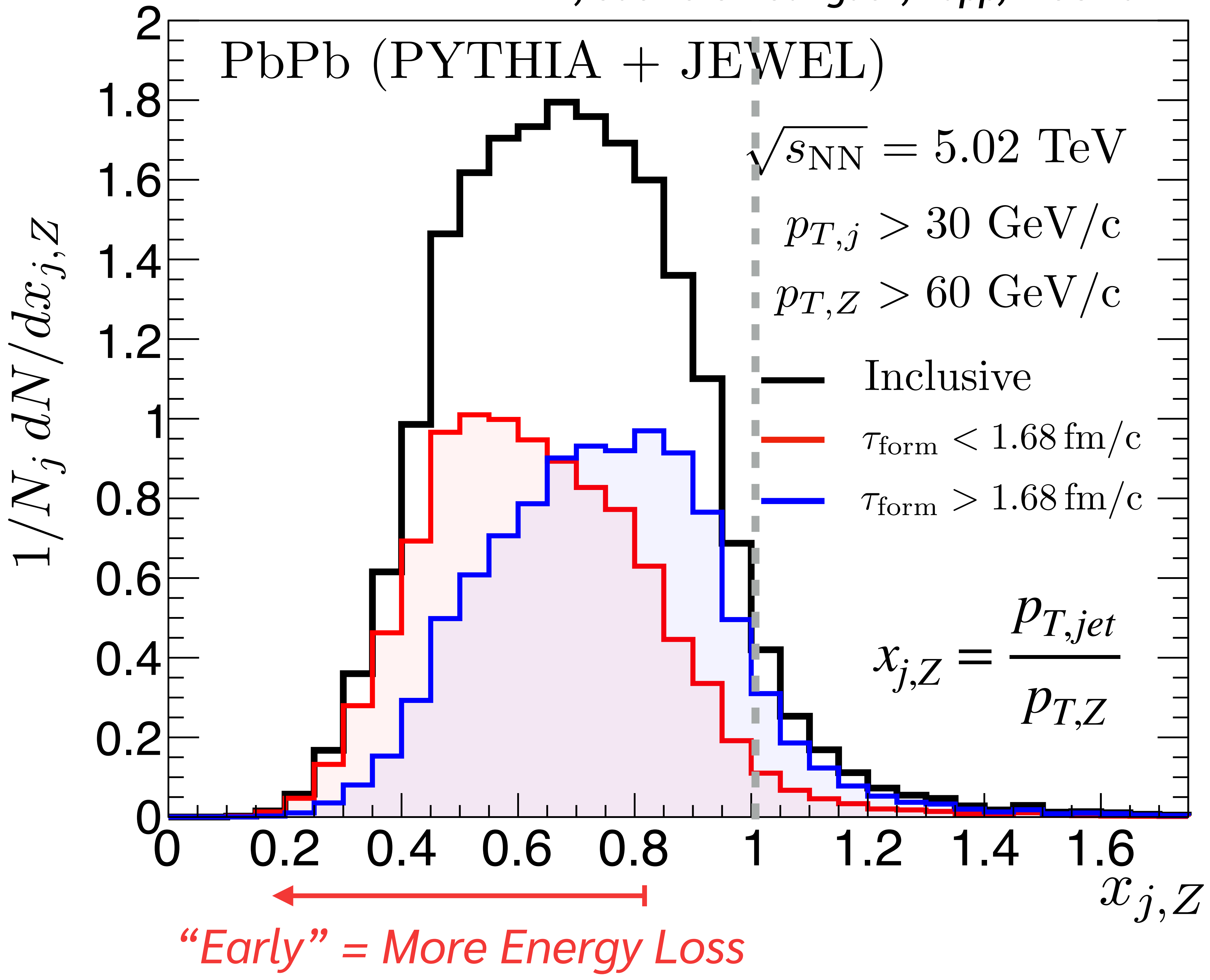

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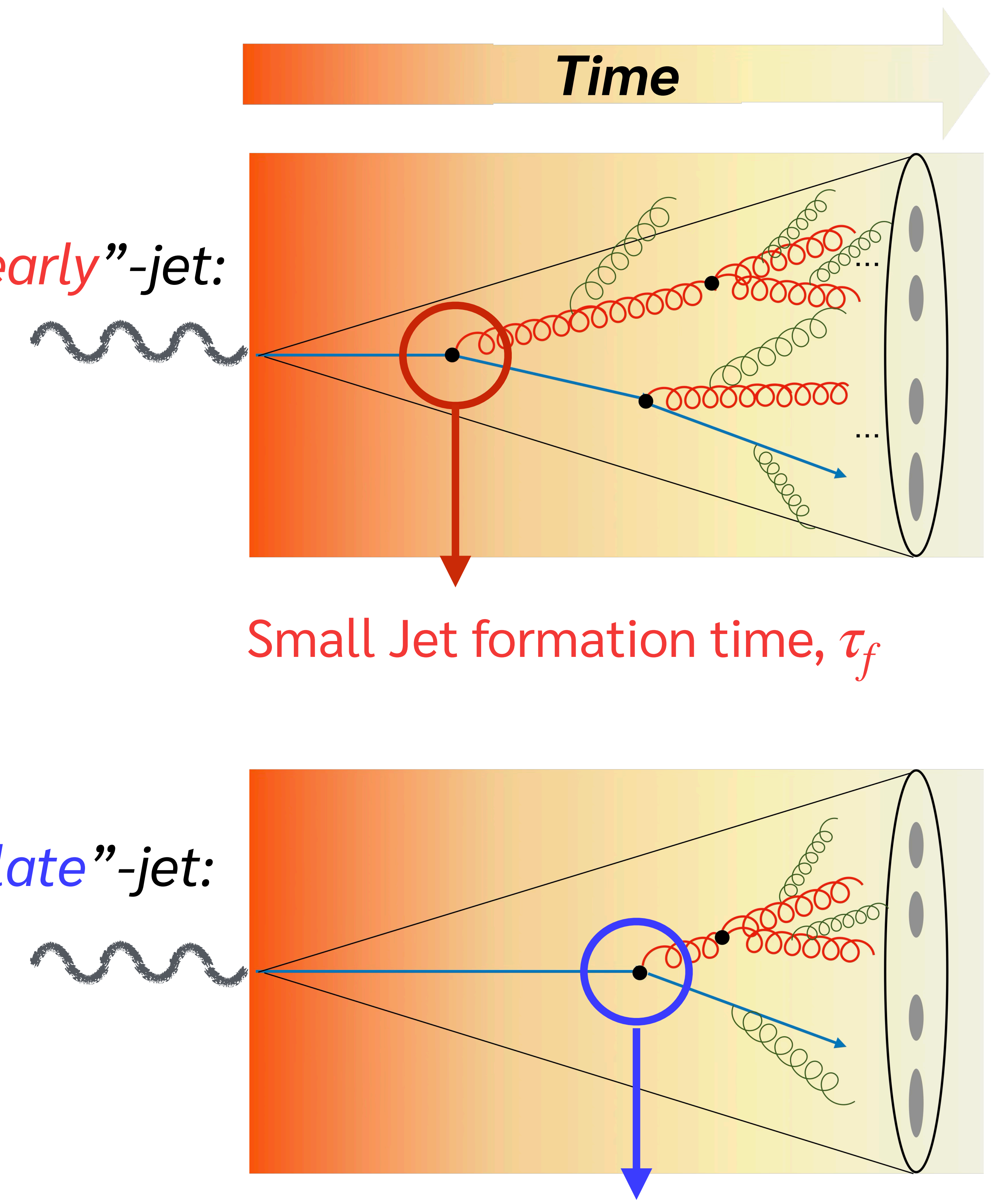

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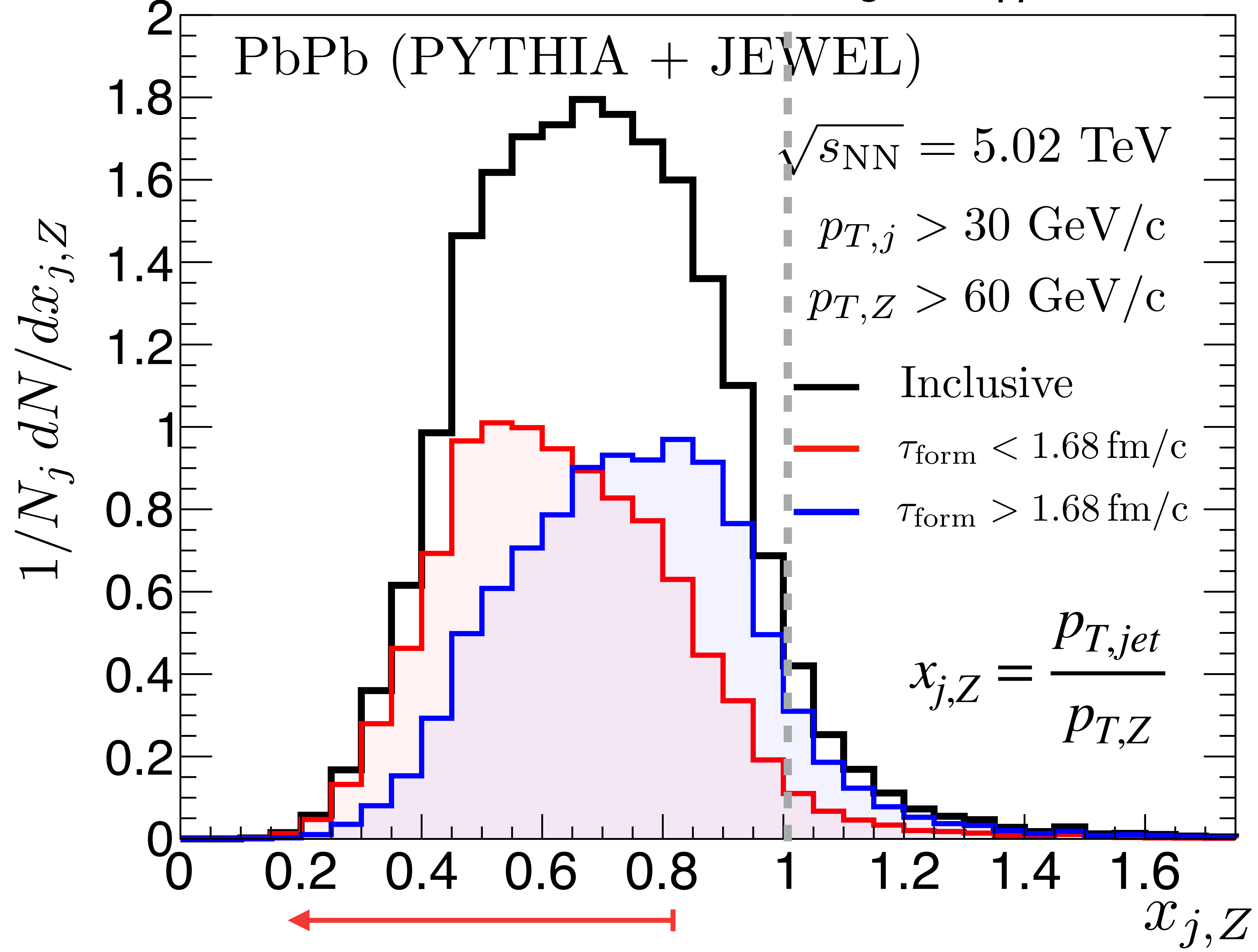


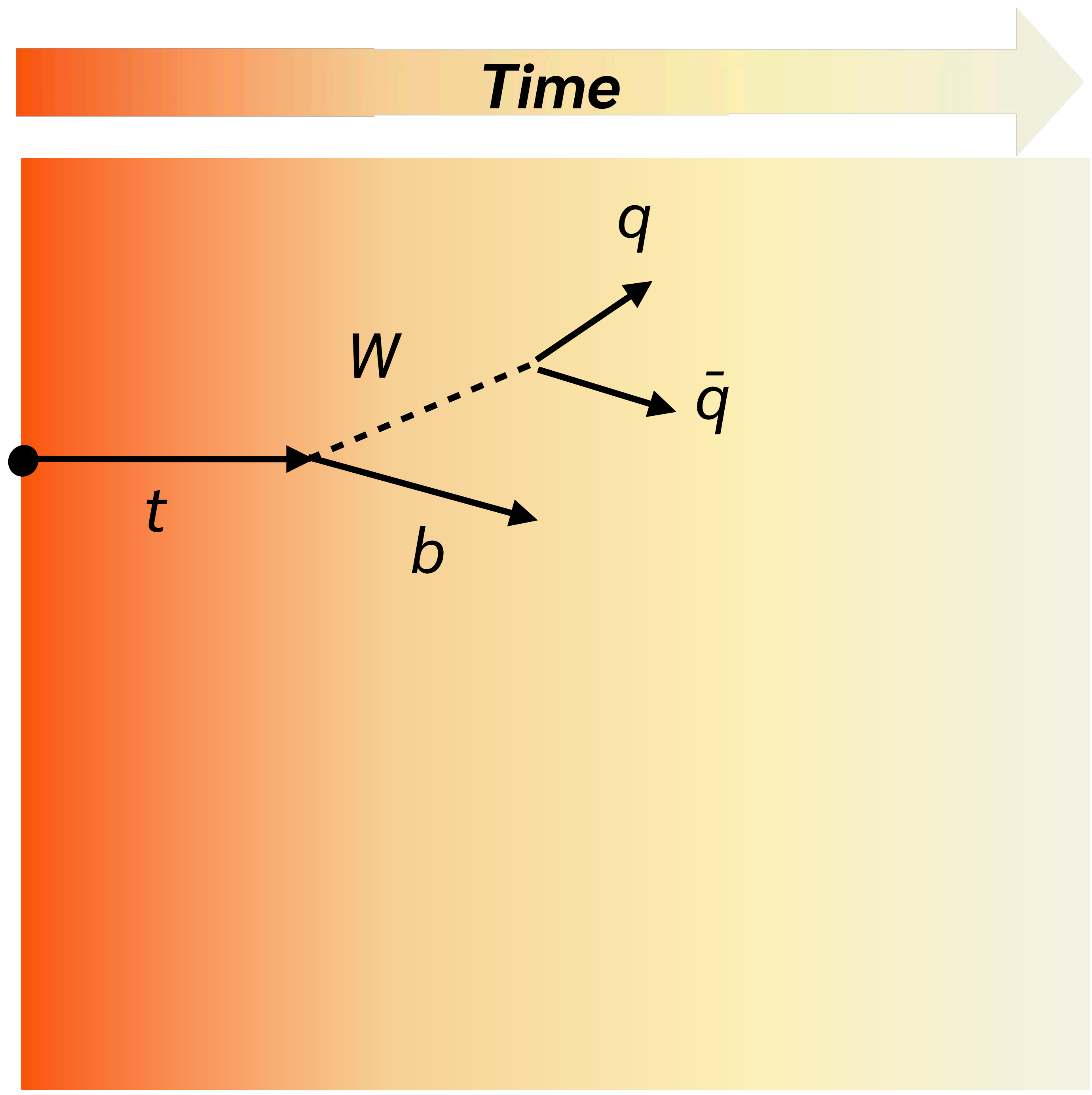
"Early" = More Energy Loss

"Late" = Less Energy Loss

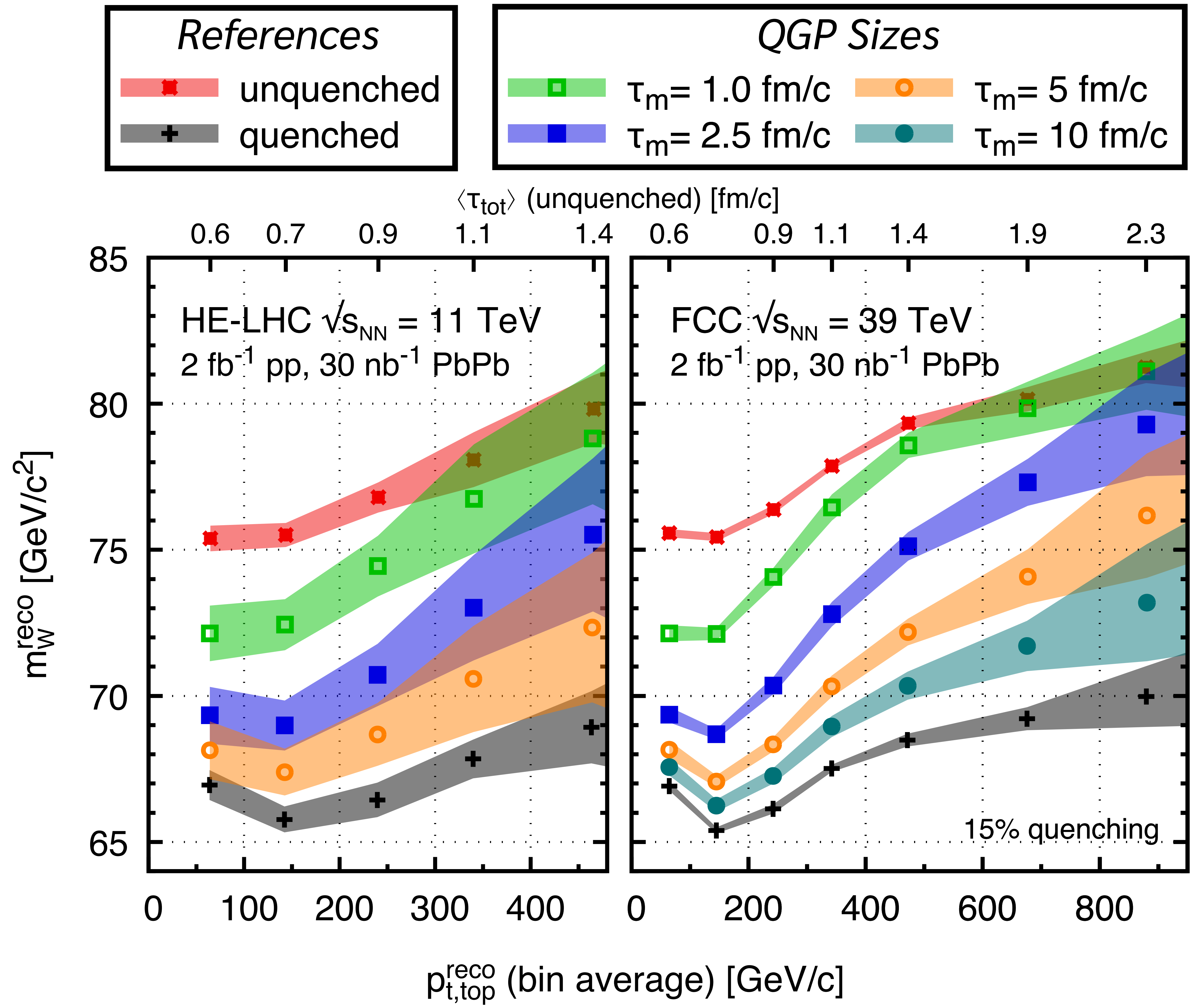
Boosted tops

- Time at which hadronic particles start to "see" QGP will depend on the boost of the top quark

LA, Milhano, Salgado, Salam, PRL 2019



Decay inside the QGP



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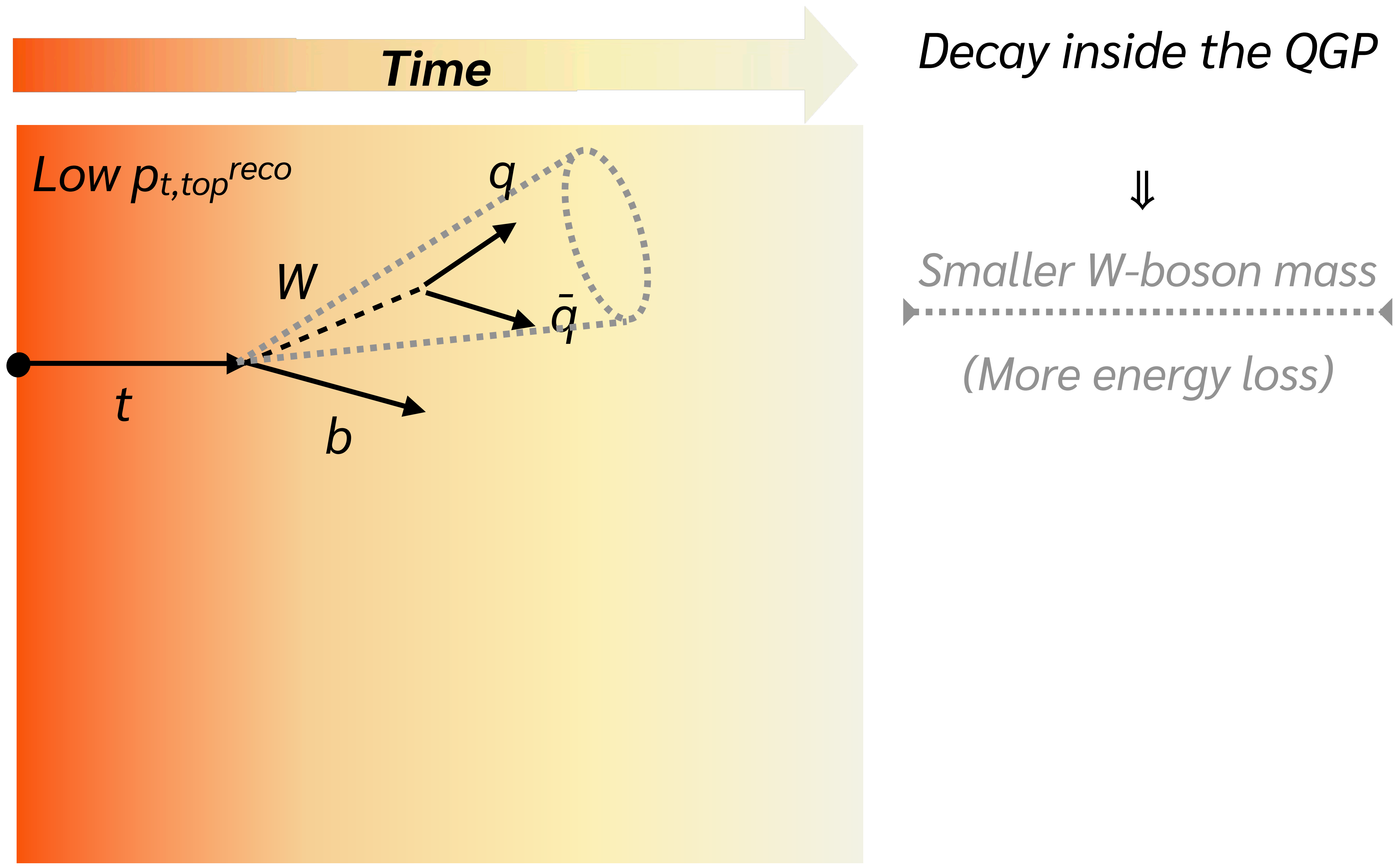

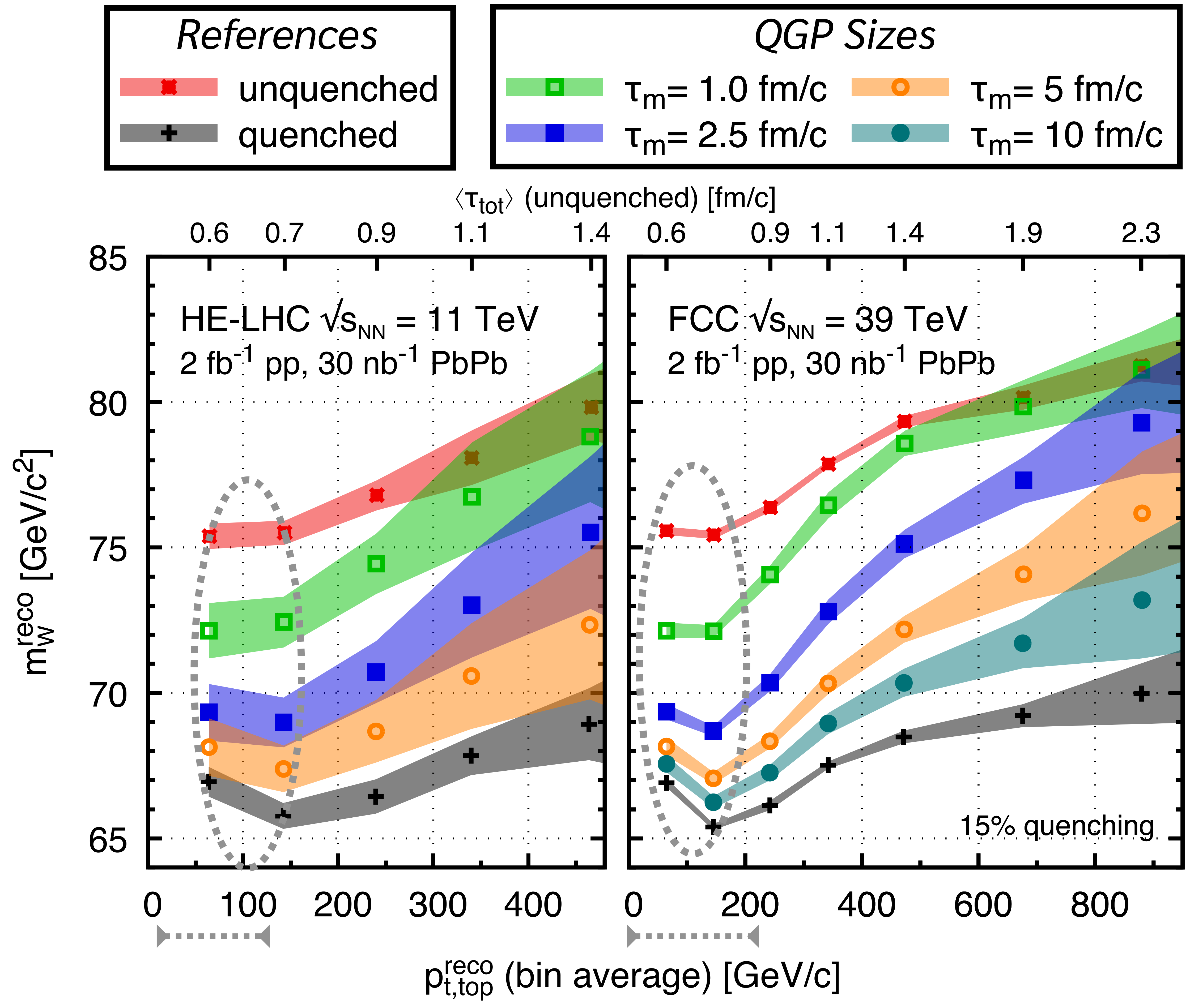

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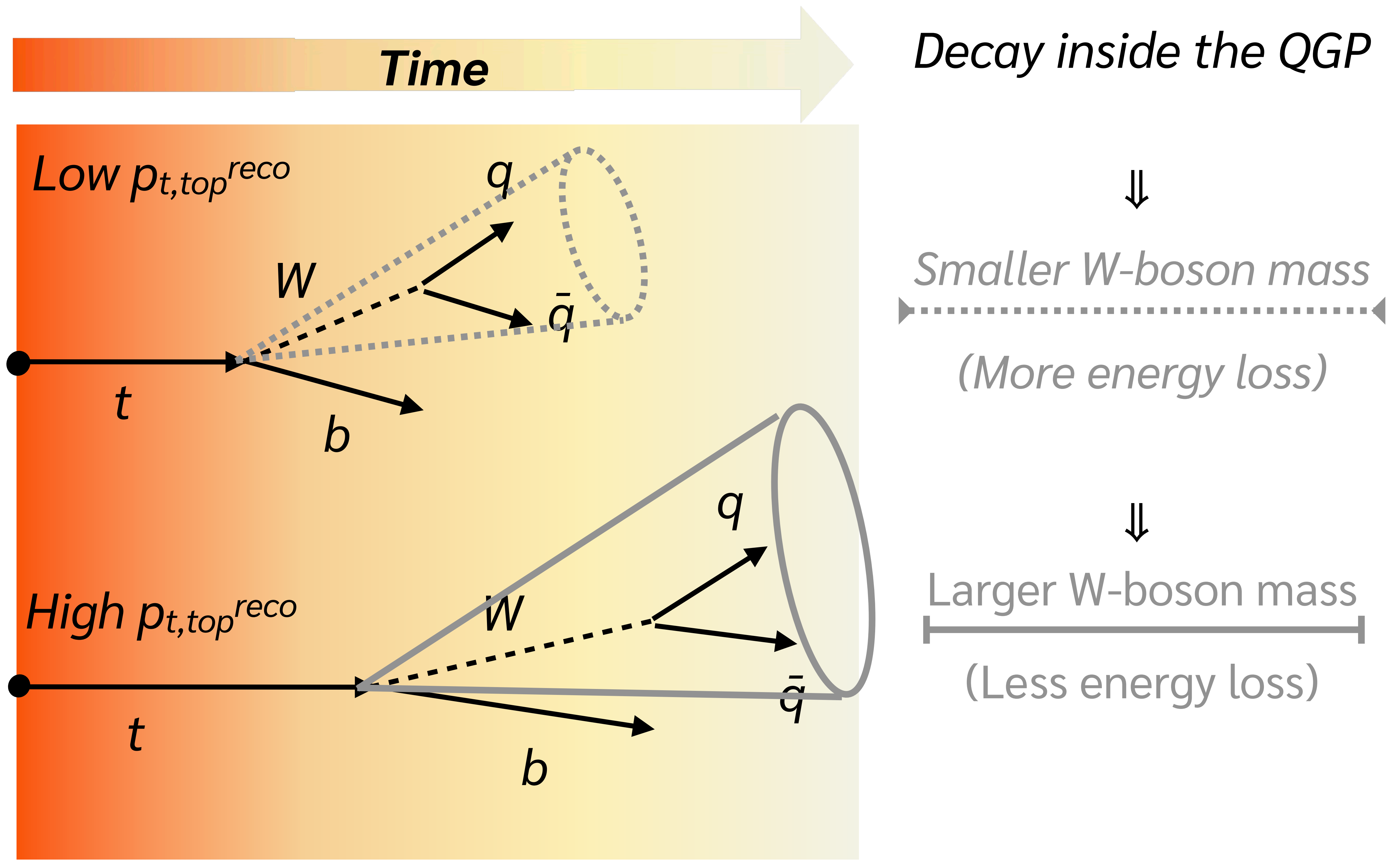
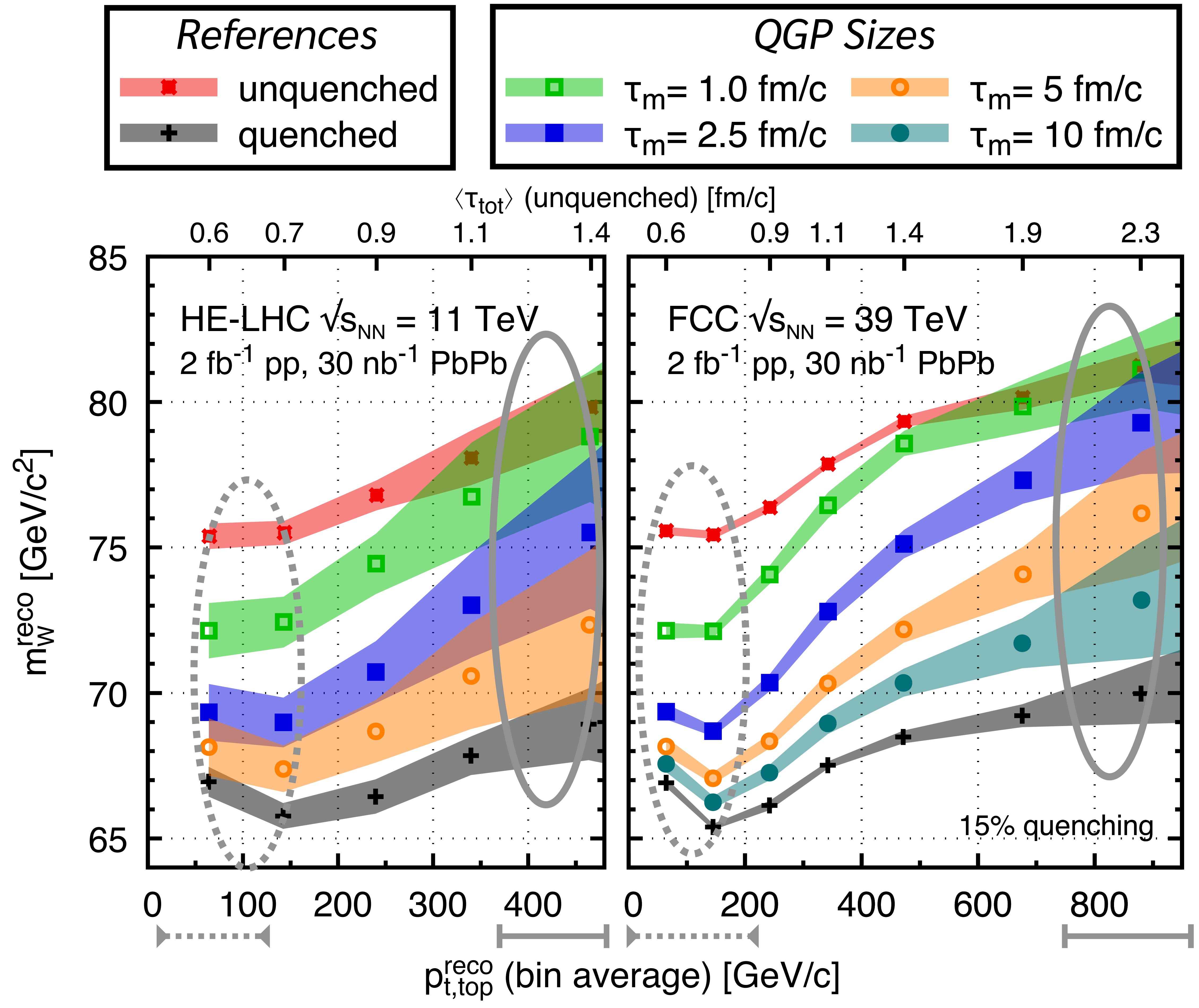
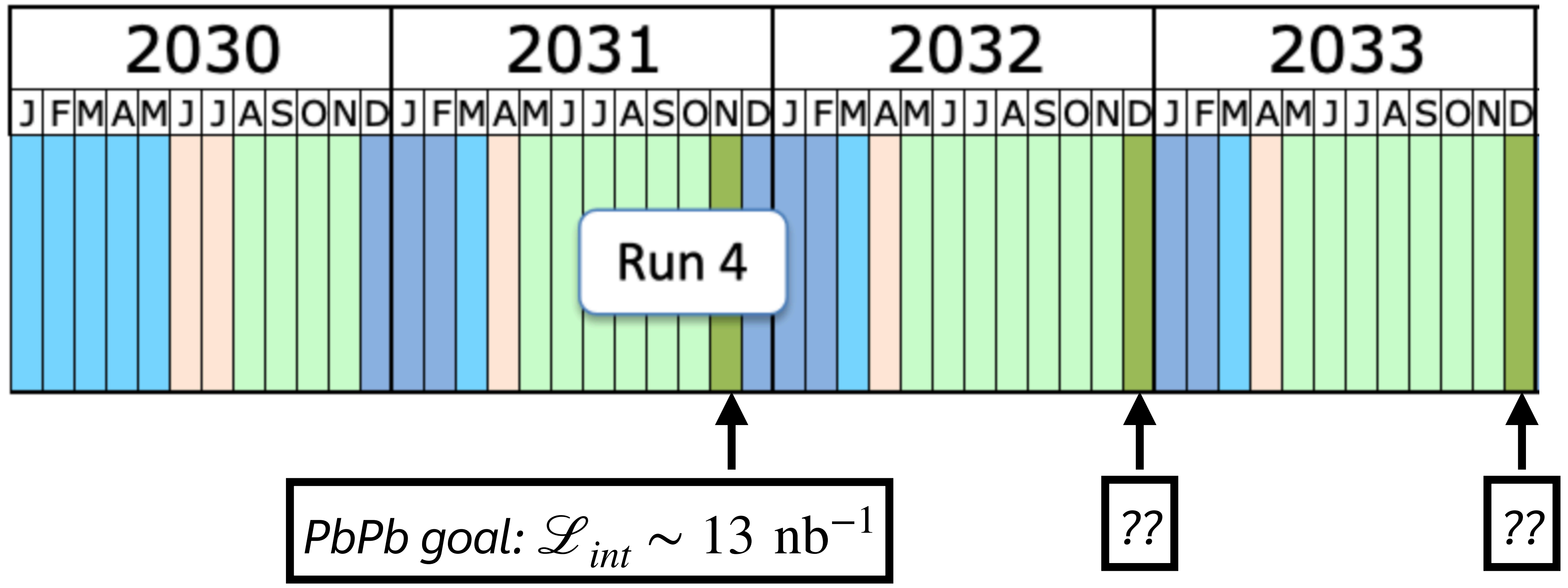




Small Systems @ LHC

Reveal the critical conditions for QGP formation



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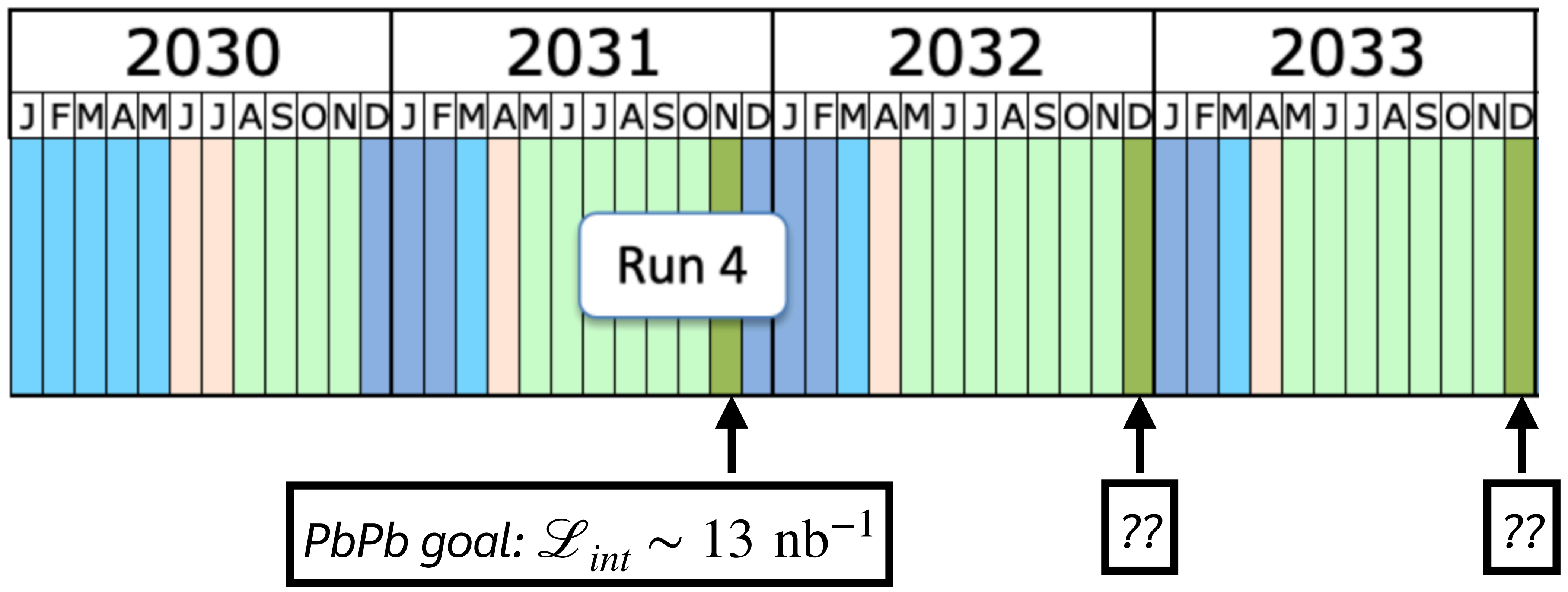

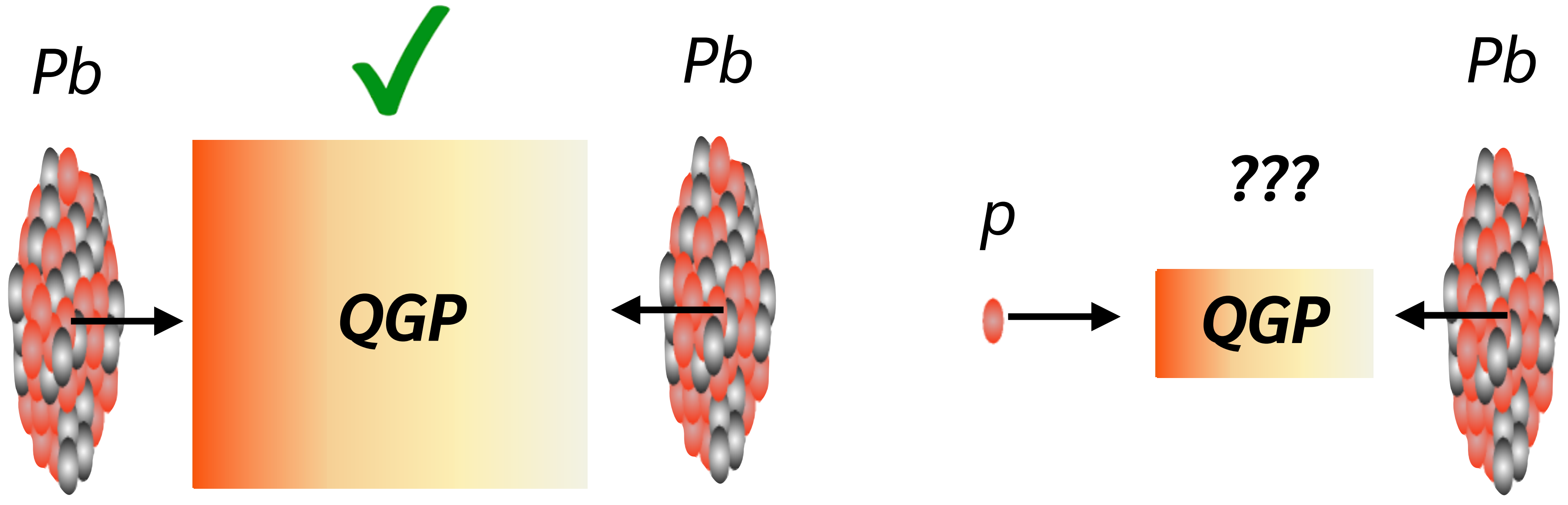

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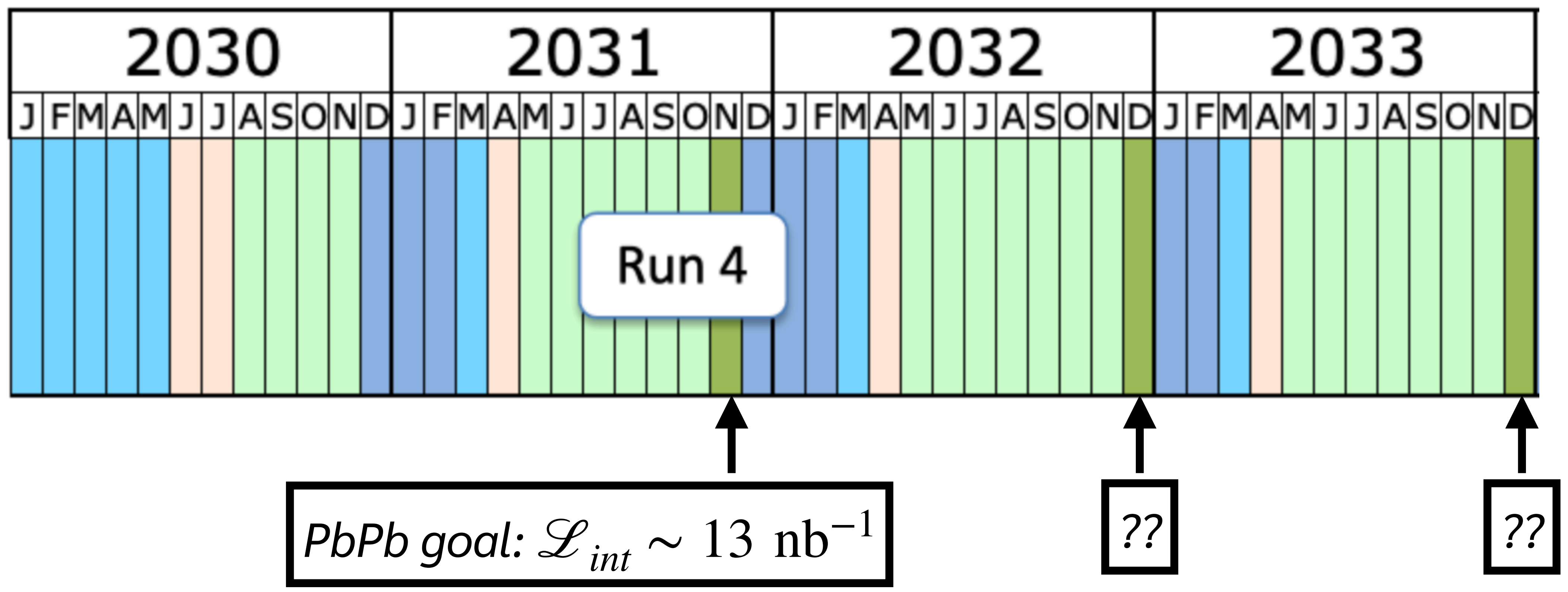
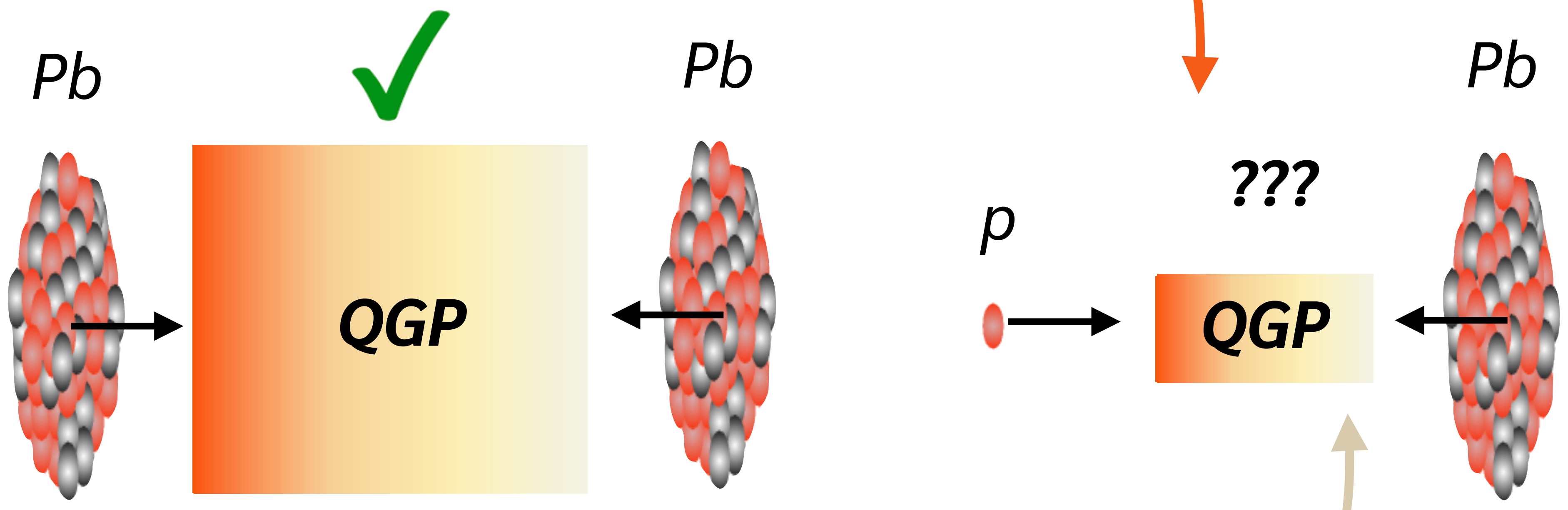


τ-Reclustering: Early QGP-tomography



Boosted tops: Delayed QGP-tomography

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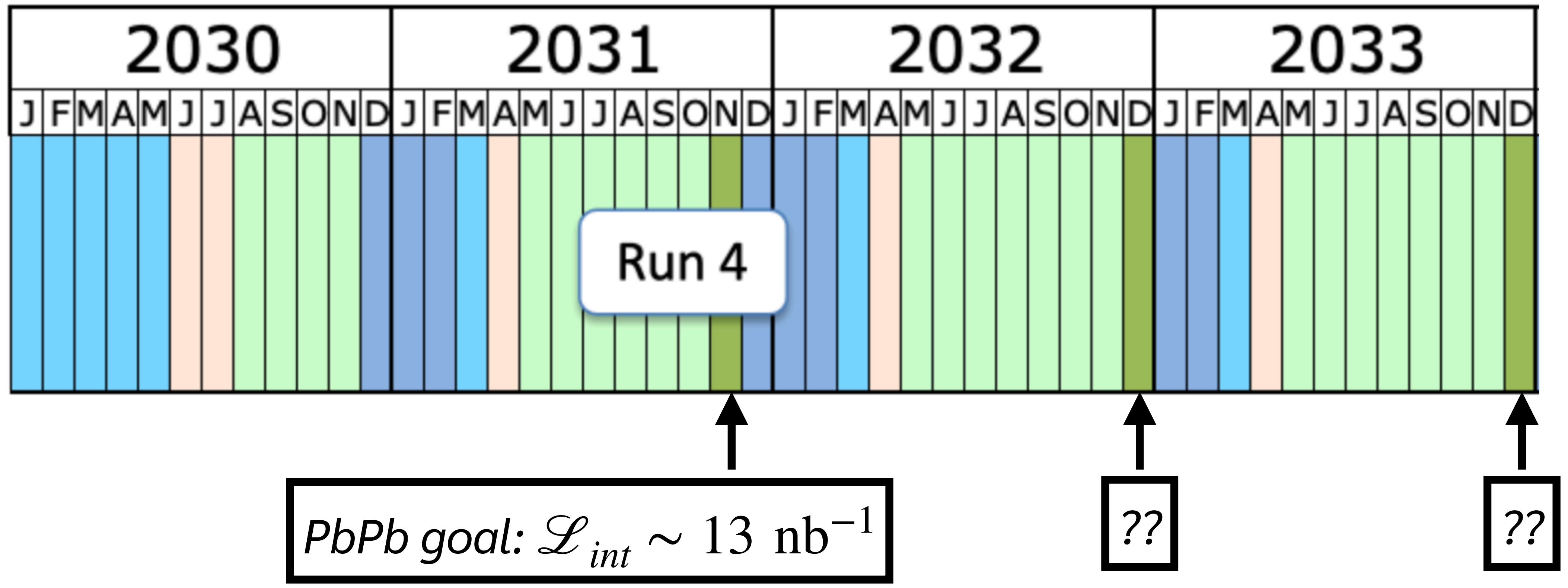

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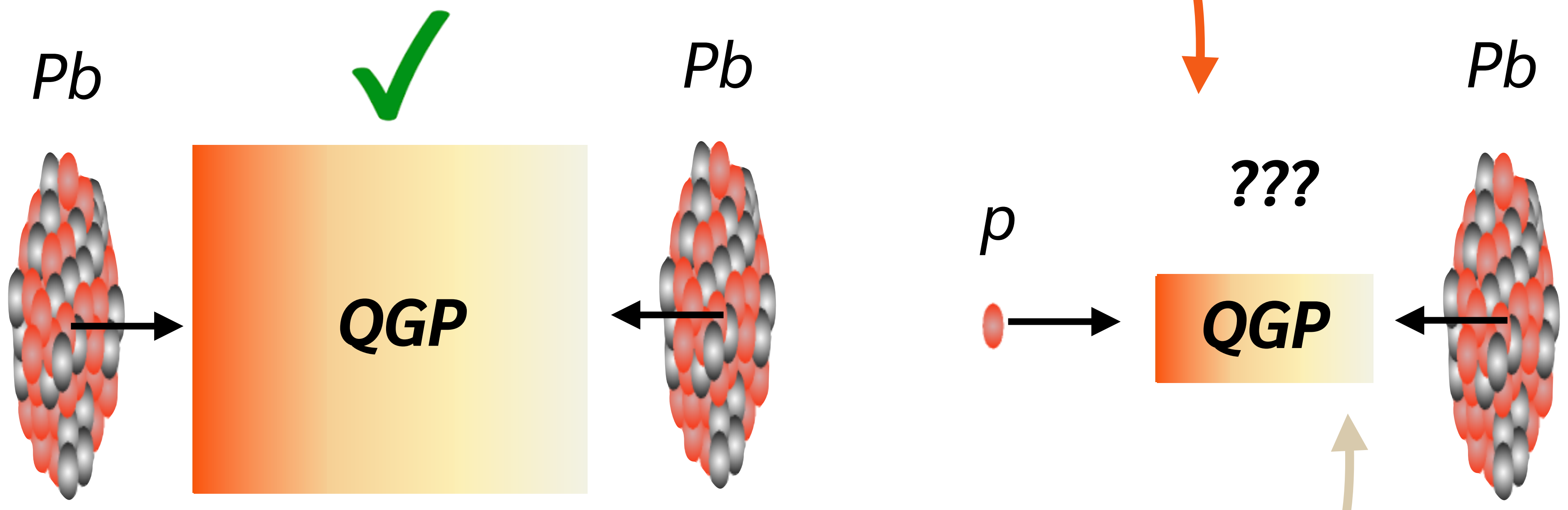
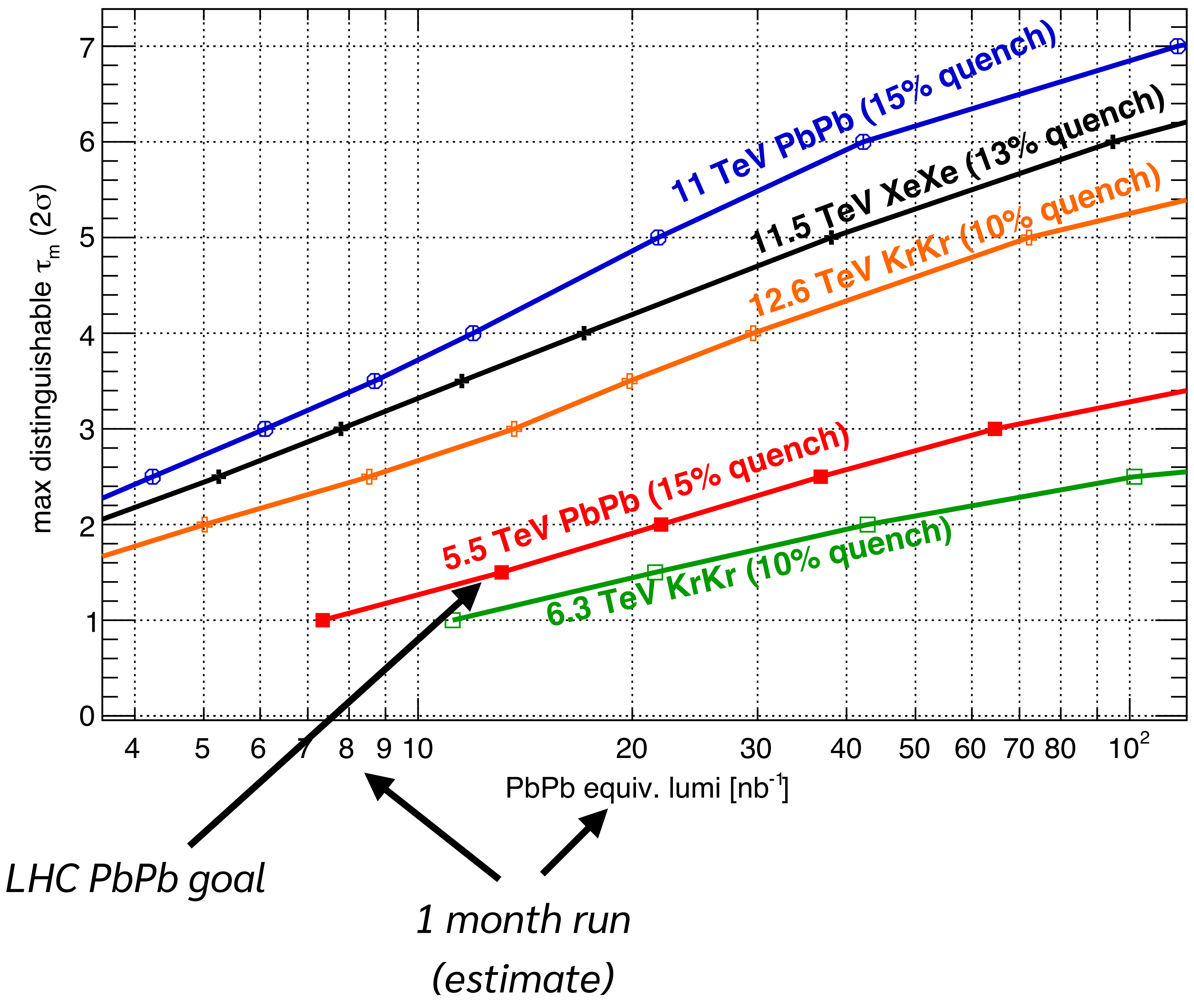


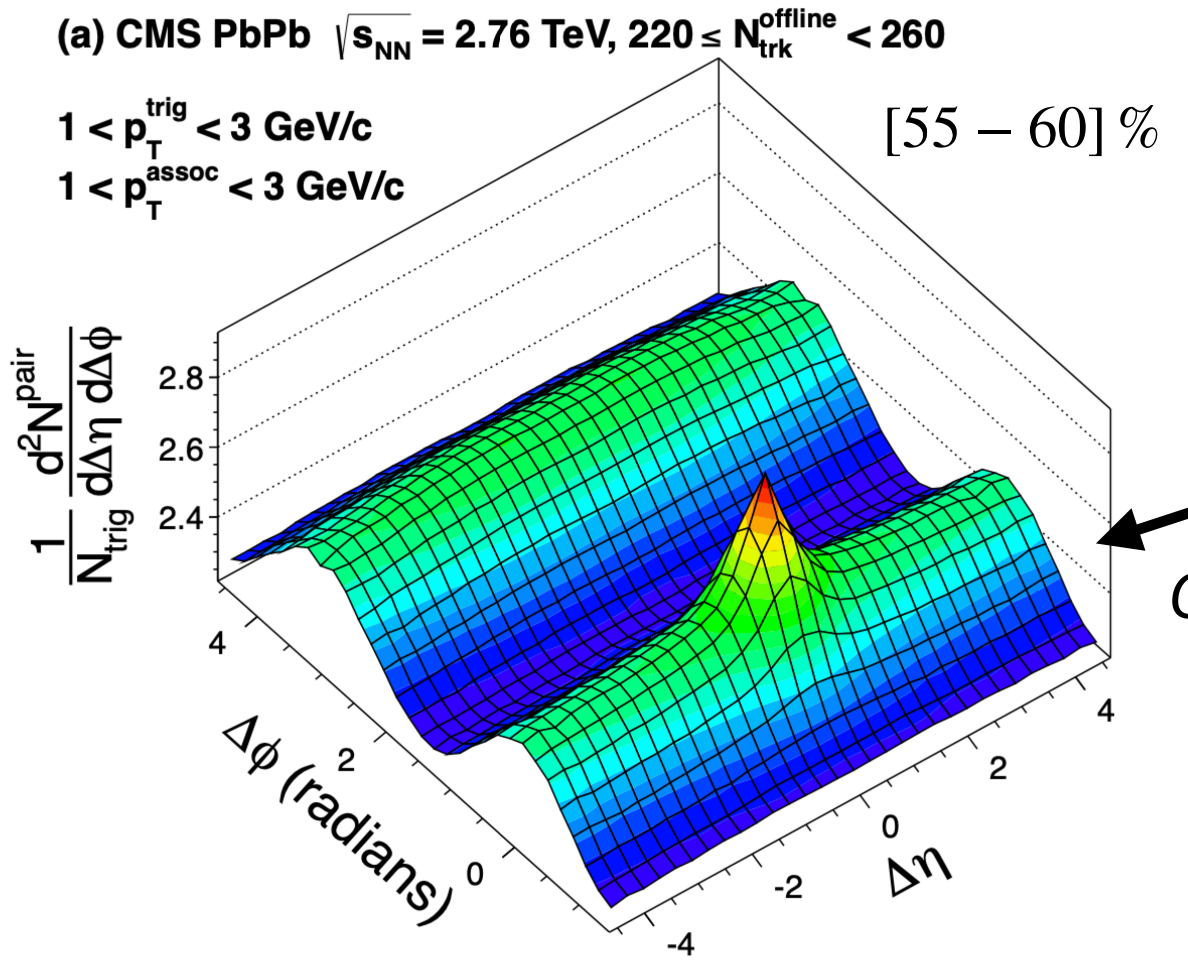
Boosted tops: Delayed QGP-tomography

Citron, LA, Milhano et al., CERN Yellow Rep.Monogr. 7 (2019)



FCC

Reference for QGP studies



Ridge:
Collectivity effects
✓

FCC

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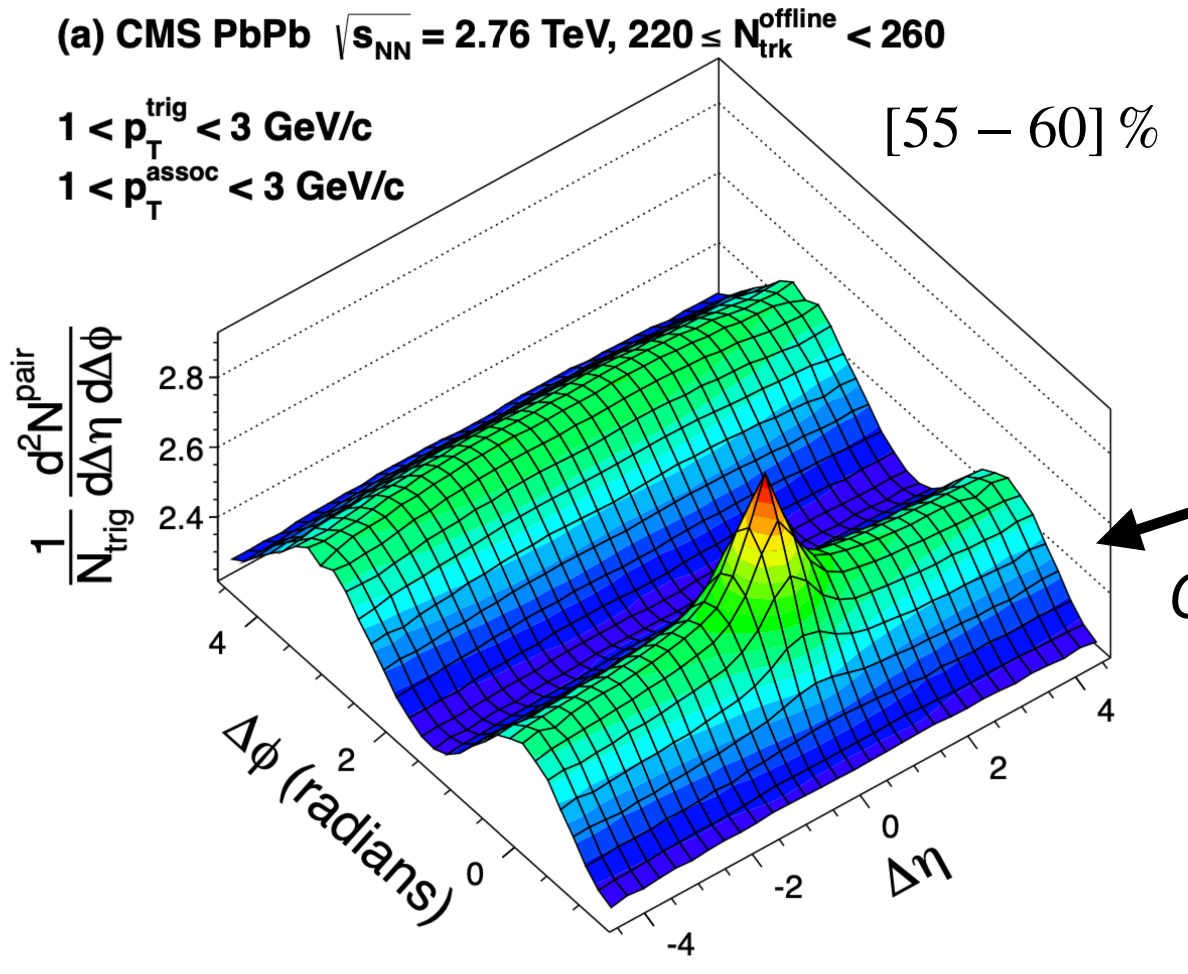

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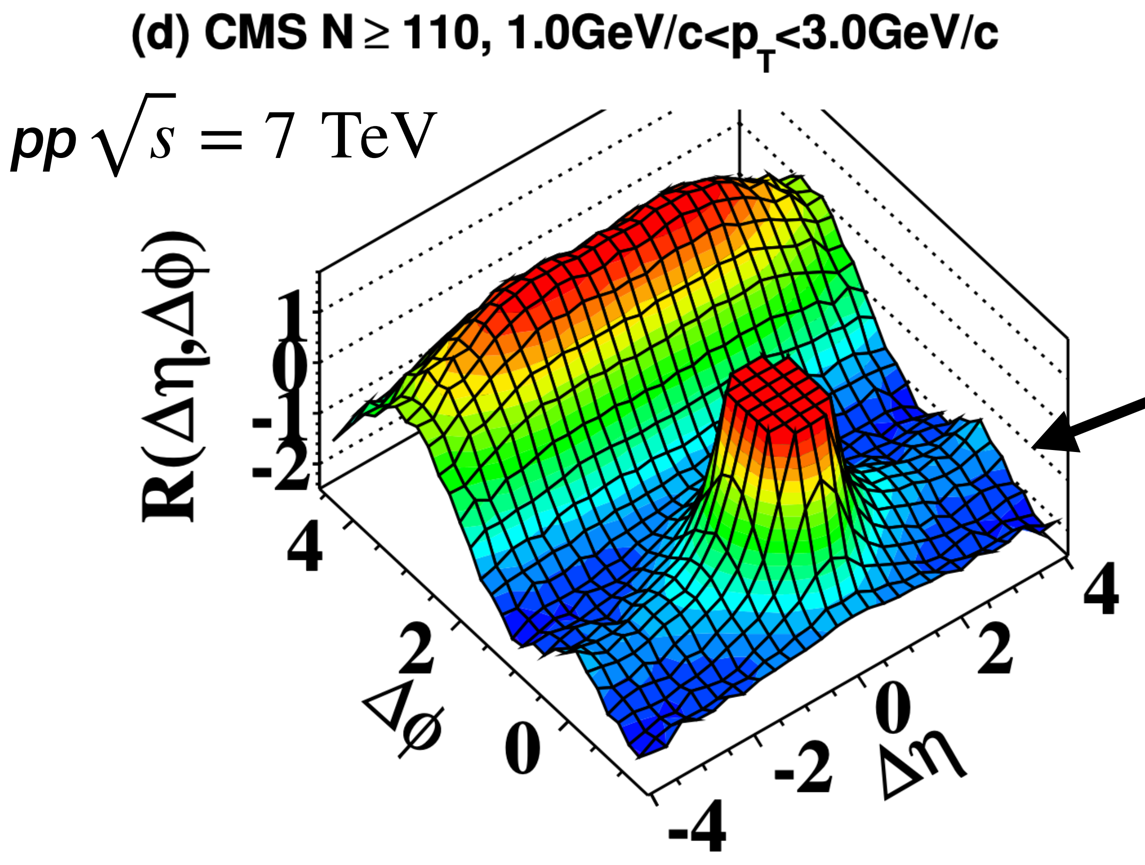
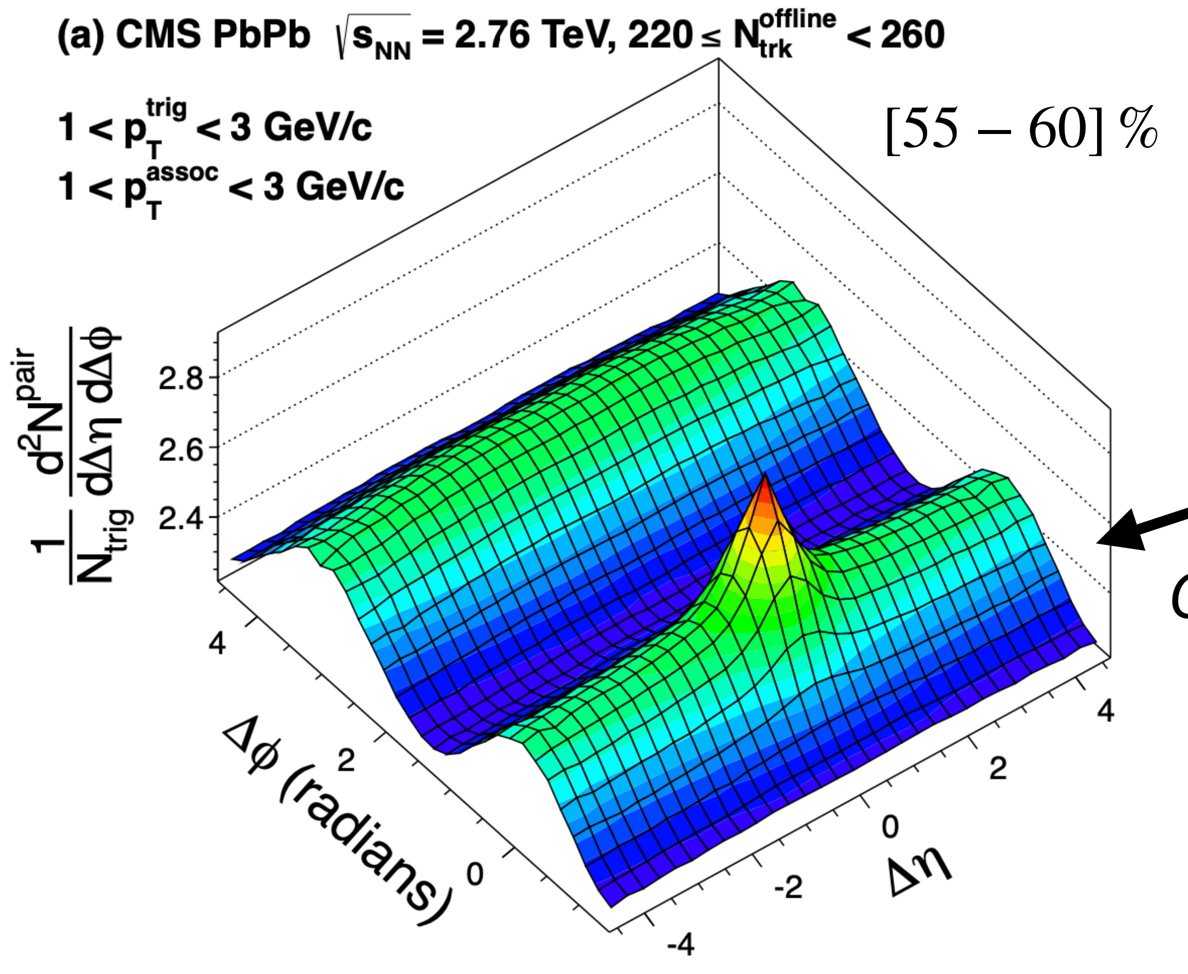


Ridge:
???

FCC

Reference for QGP studies

Uncover hadronization mechanisms and QCD confinement



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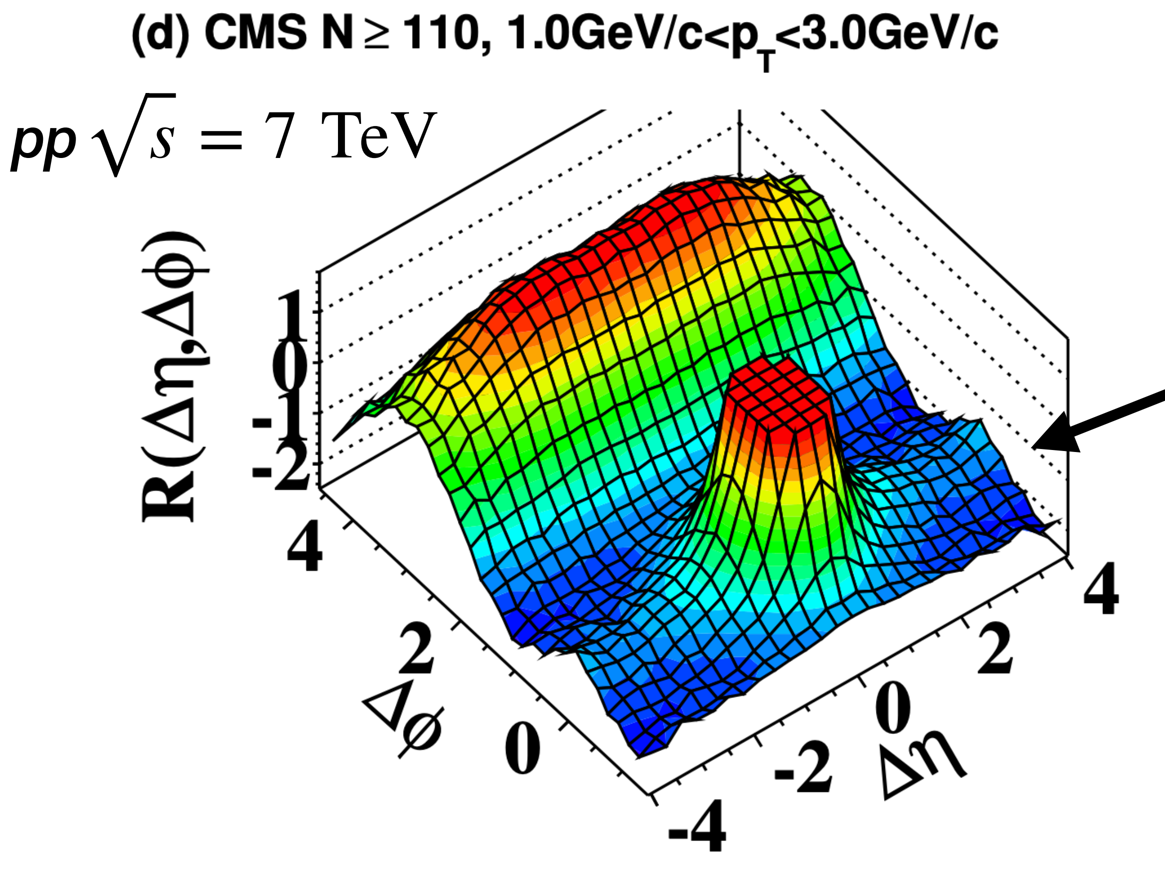
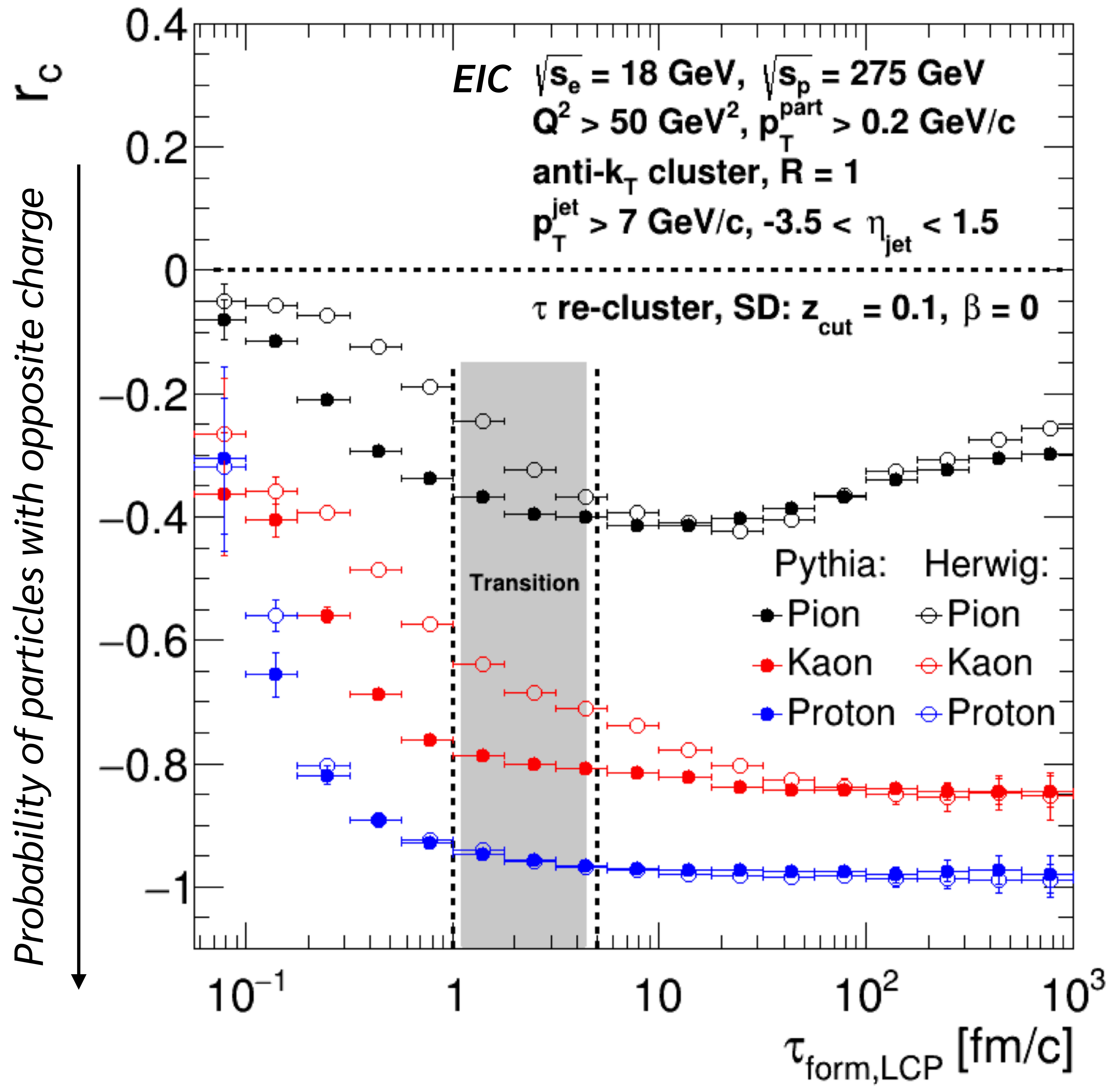
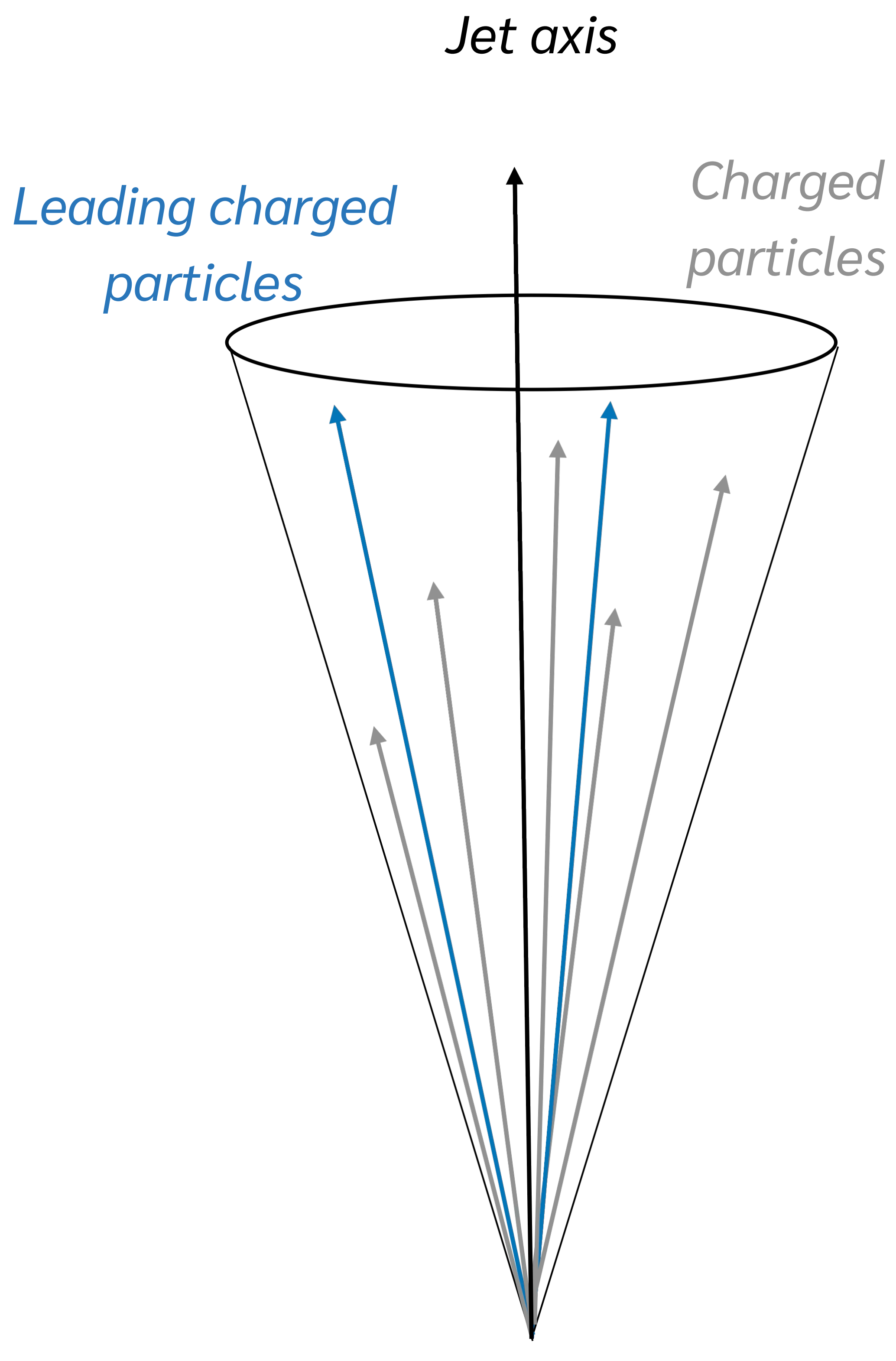


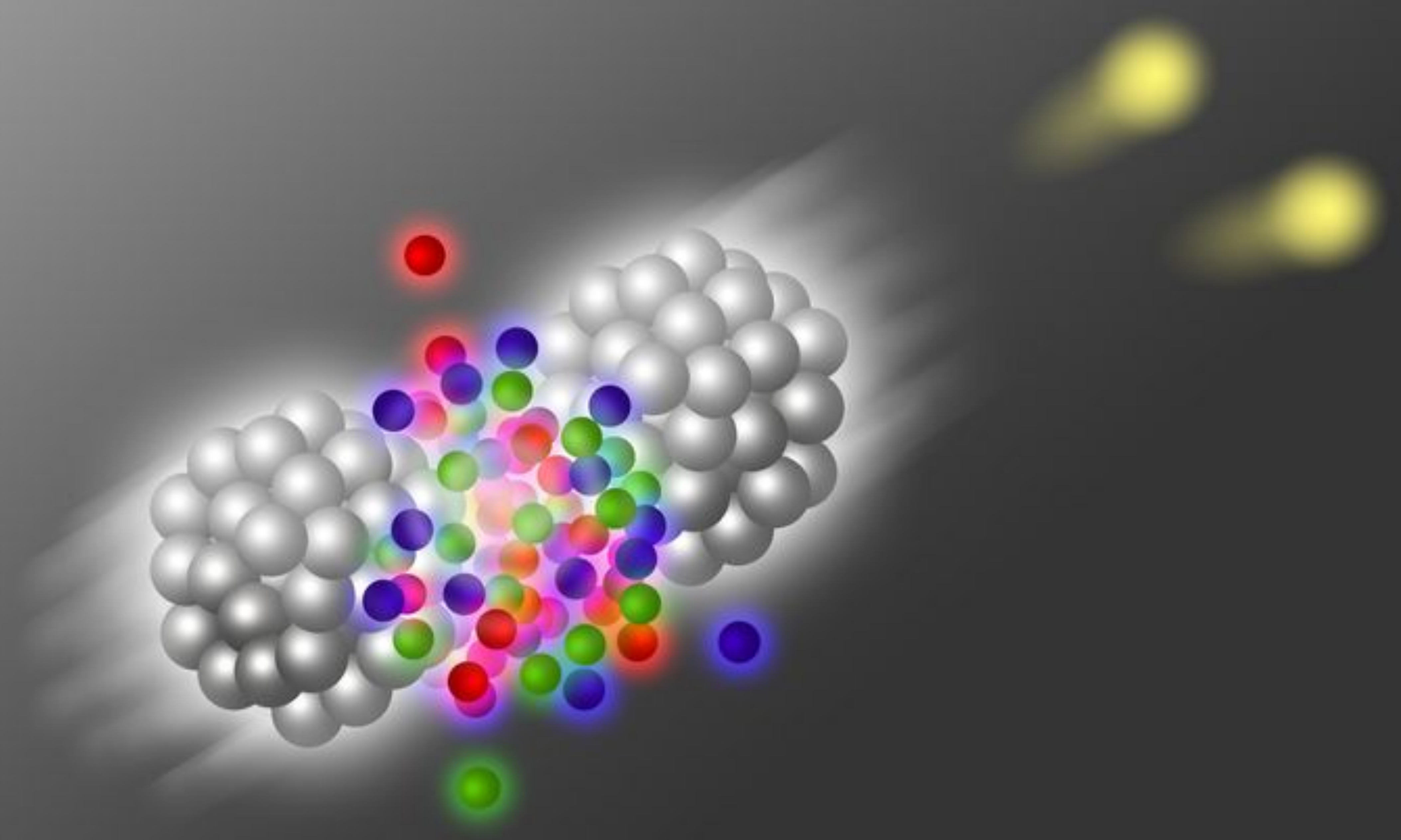
Ridge:
???

LA, Elayavalli, Olavo, submitted to PRD



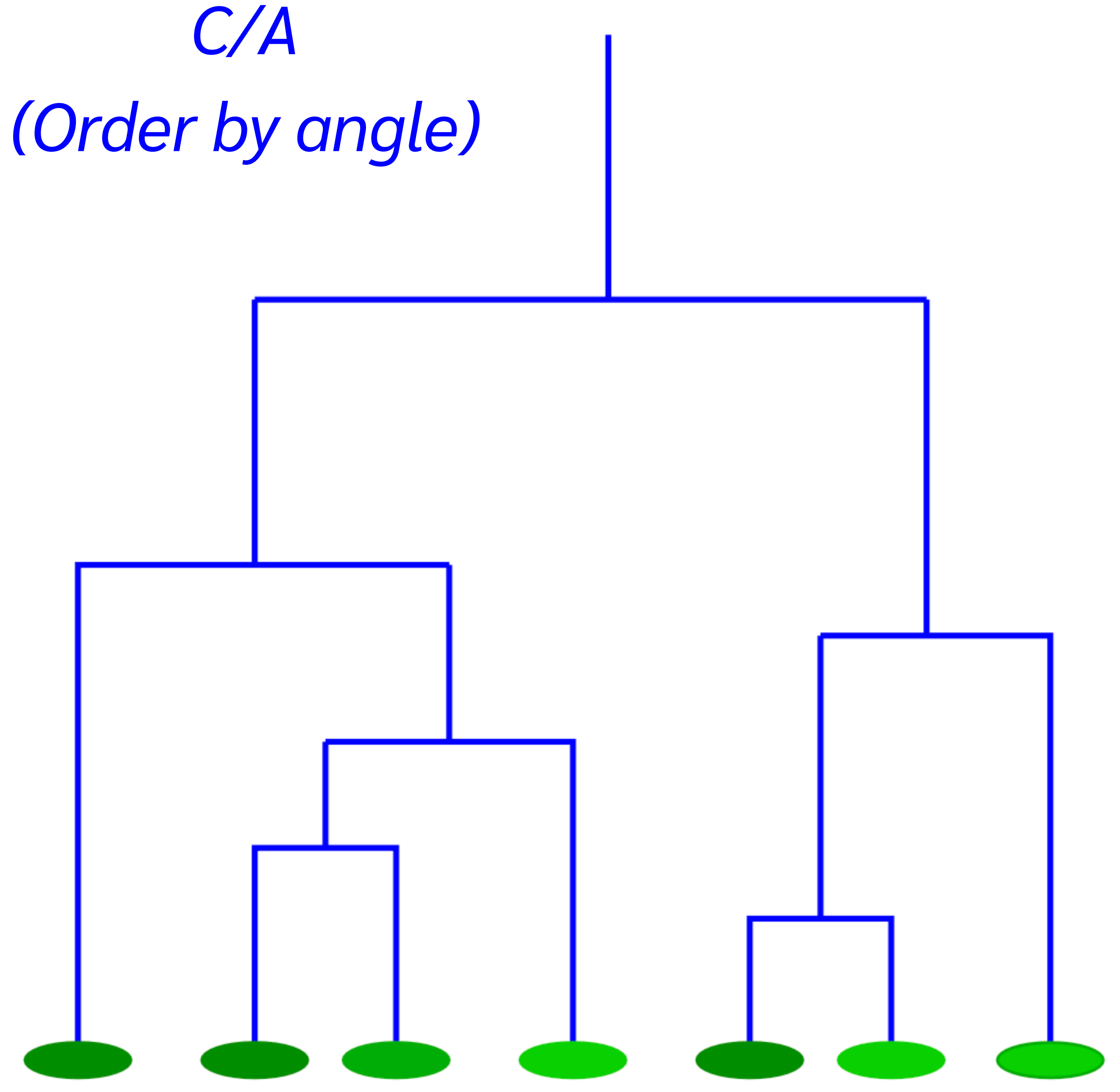


Backup Slides



Jet τ-algorithm

- Jet algorithms are a set of rules in which clustering steps follow a given metric order:



From: K. Zapp (21)

Iterative distance between 2 pseudo-jets:

(Generalized-k_T family)

$$d_{ij} = \min(p_{T,1}^{2p}, p_{t,j}^{2p})\frac{\Delta R_{ij}^2}{R^2}$$

p = 0: Cambridge/Aachen (C/A)

$$d_{ij} \propto \theta_{ij}^2$$

Dokshitzer, Leder, et al, JHEP 1997

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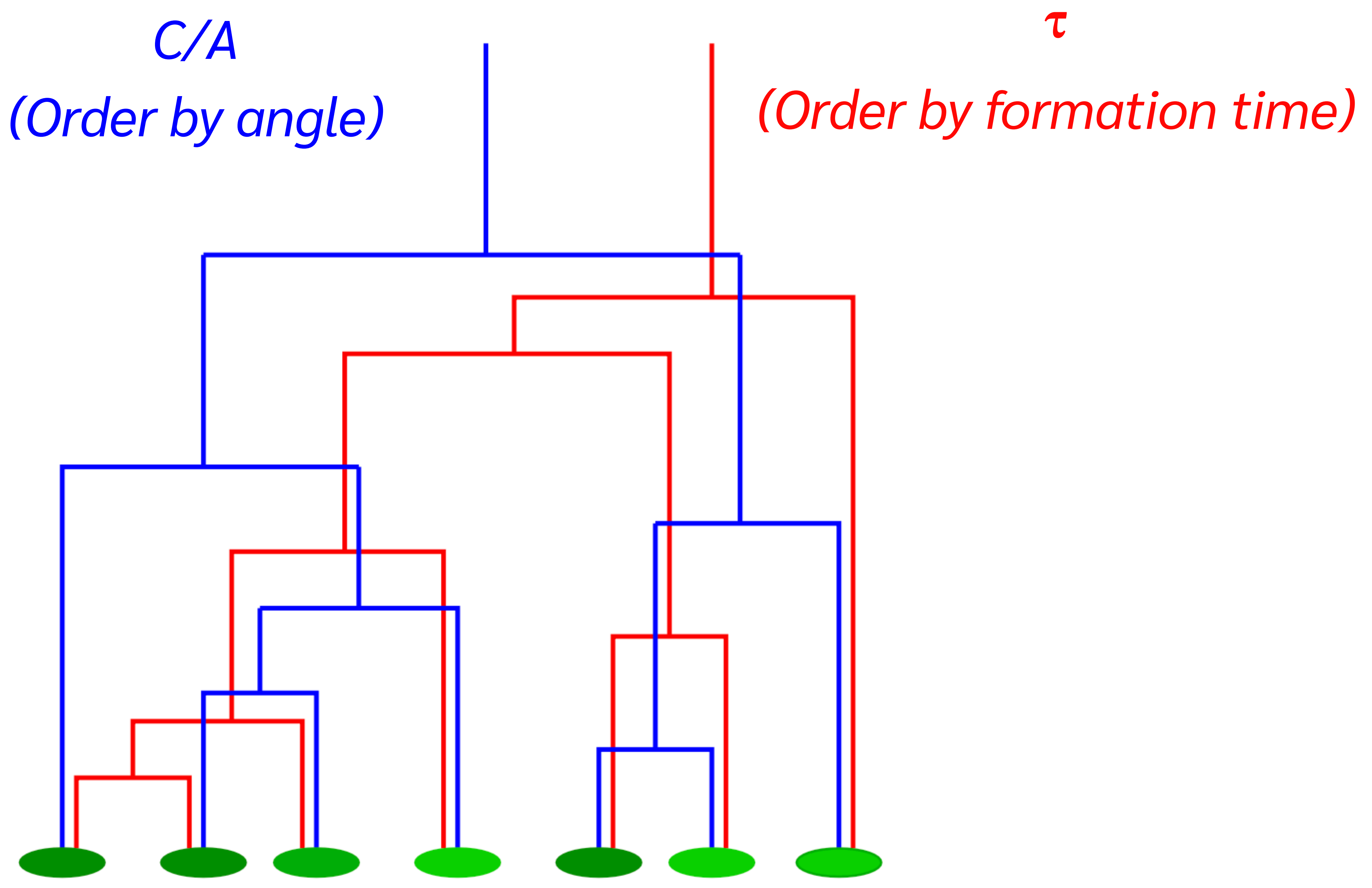
QGP is an extended medium



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Dokshitzer, Leder, et al, JHEP 1997

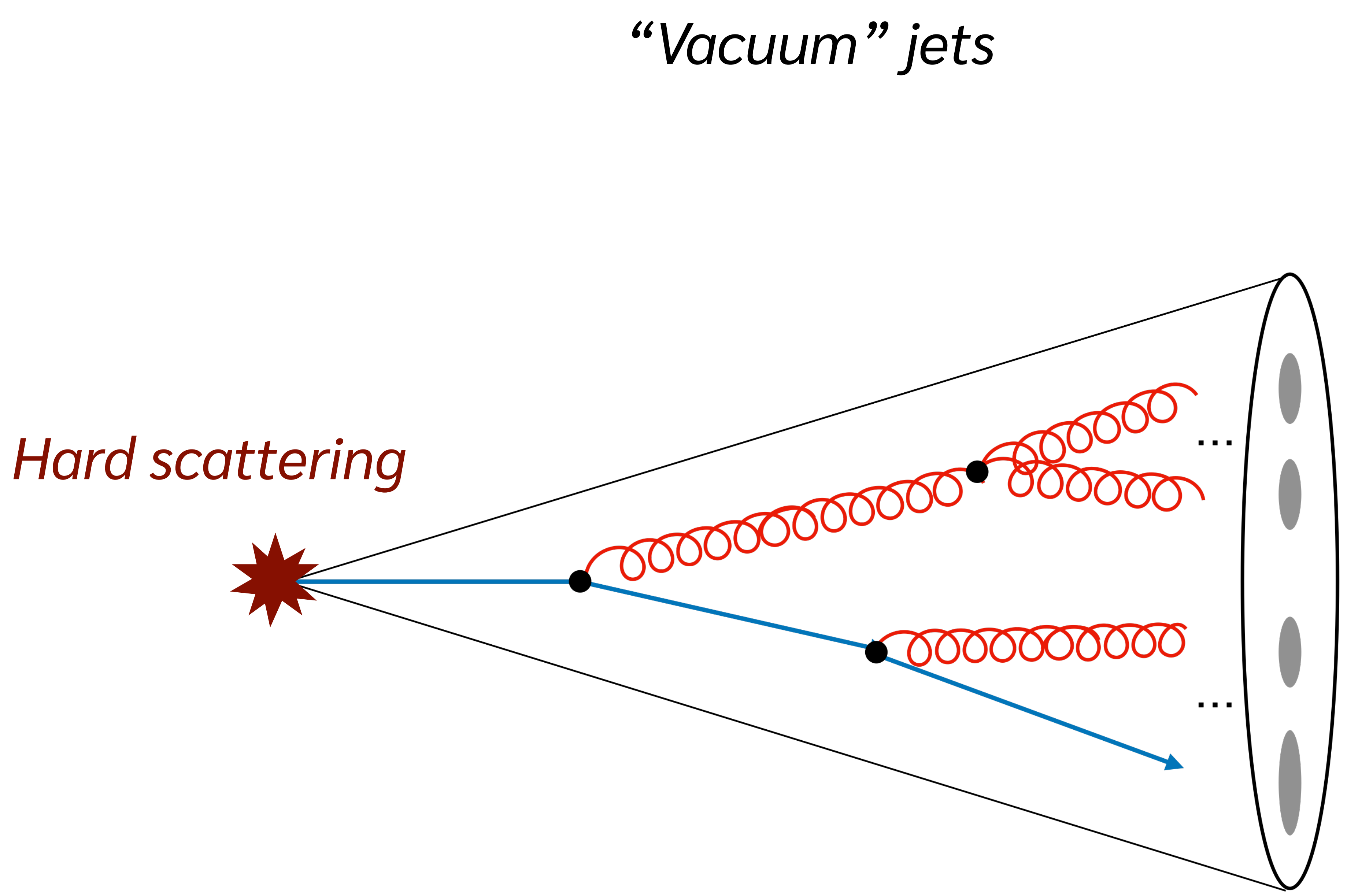
p = 1/2: Inverse formation time (τ)

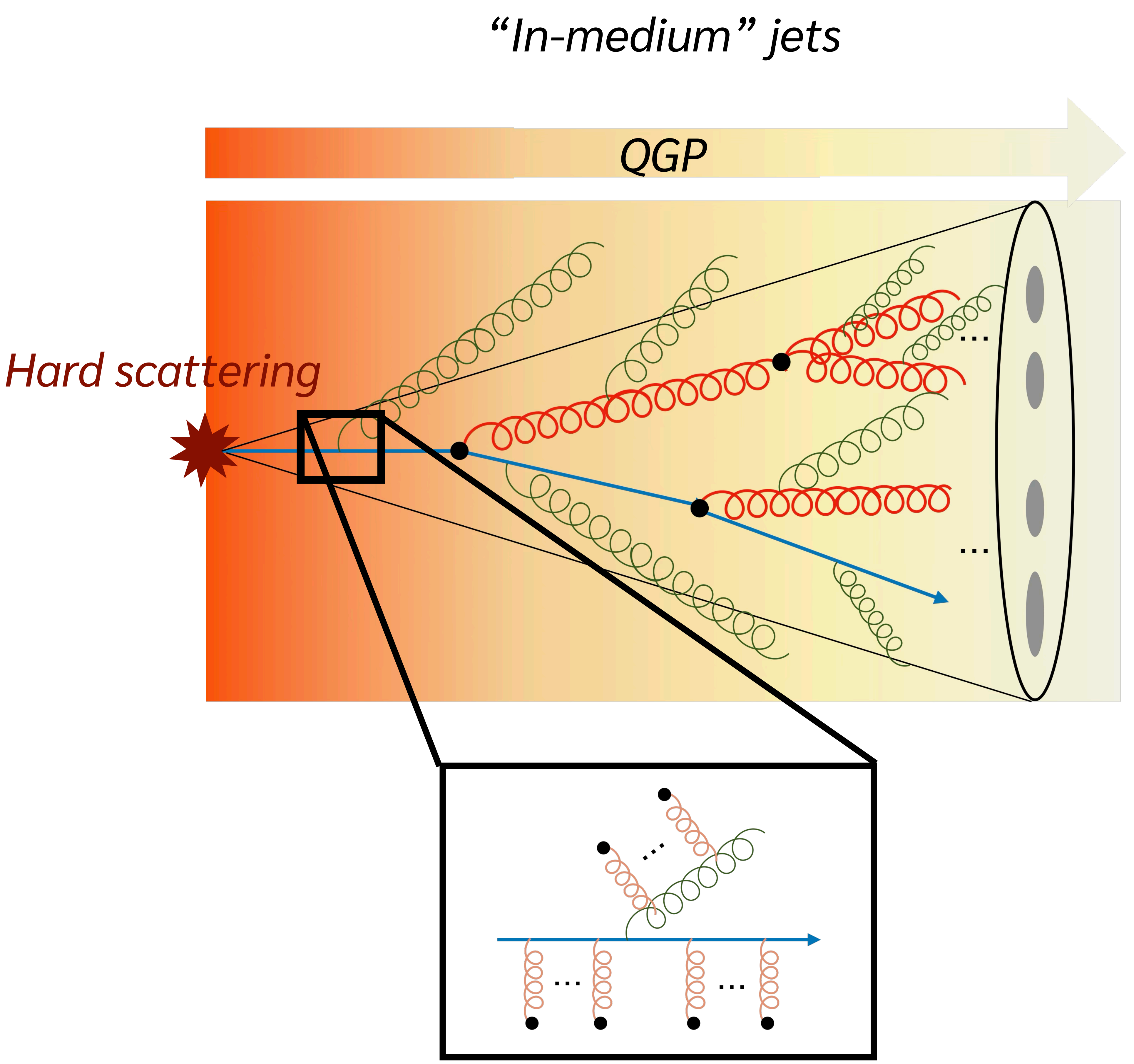
$$d_{ij} \propto \tau_{form}^{-1} \simeq p_{T,i}\,\theta_{ij}^2$$

LA, Cordeiro, Zapp, EPJC 2021

Jet Energy Loss

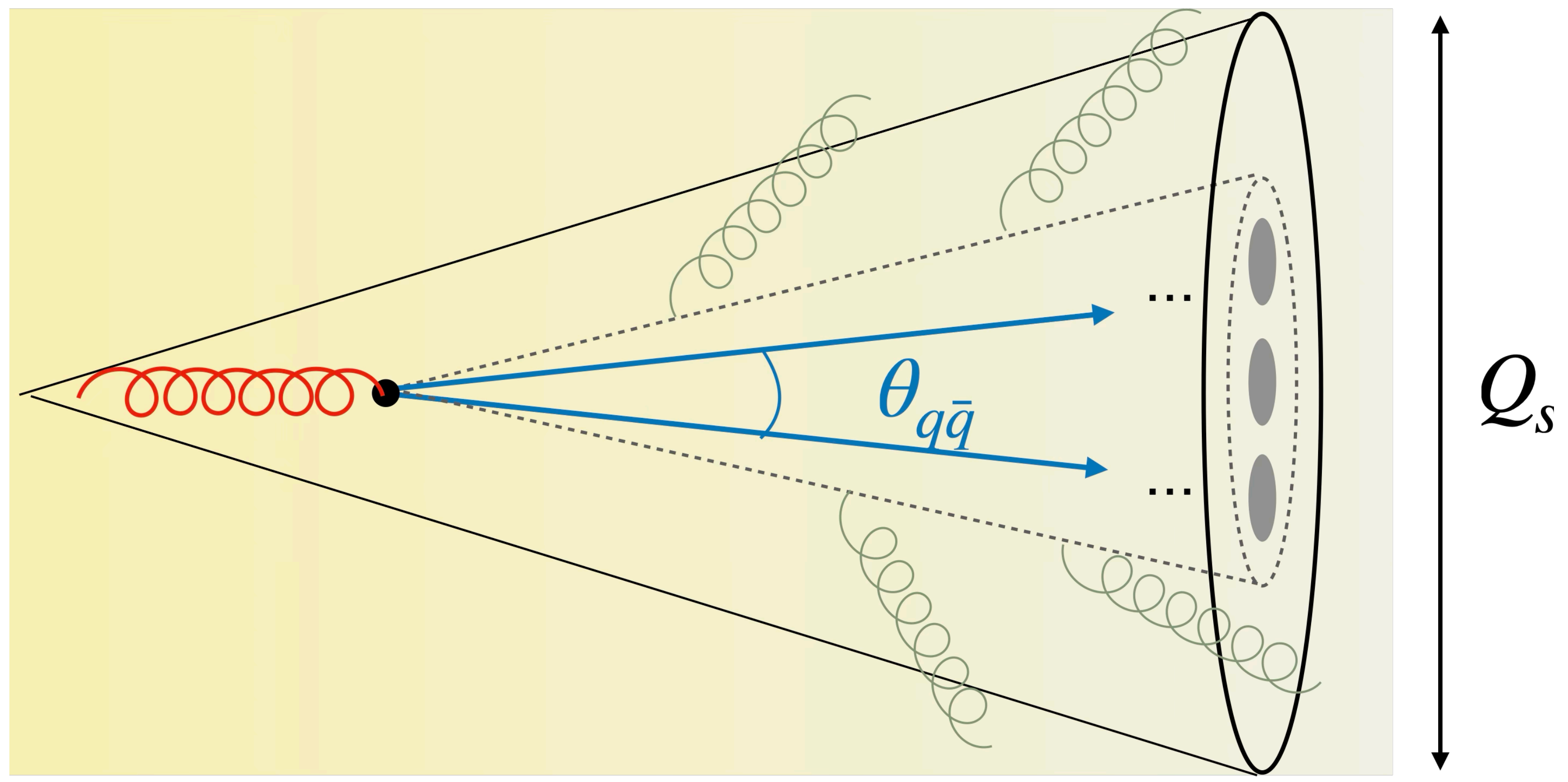
- In-medium interactions will induce additional QCD radiation:





Color (De)Coherence

- In-medium interactions can break expected angular ordering pattern
  - Magnitude of the effect will depend on interplay between medium resolution and QCD-antenna opening angle



$Q_s \geq \theta_{q\bar{q}}$

Medium "sees" quark and anti-quark as a single emitter

Coherent loss of energy

Medium saturation scale: $Q_s^2 = \hat{q}L$

Transport coefficient: $\hat{q}$

Medium length: L

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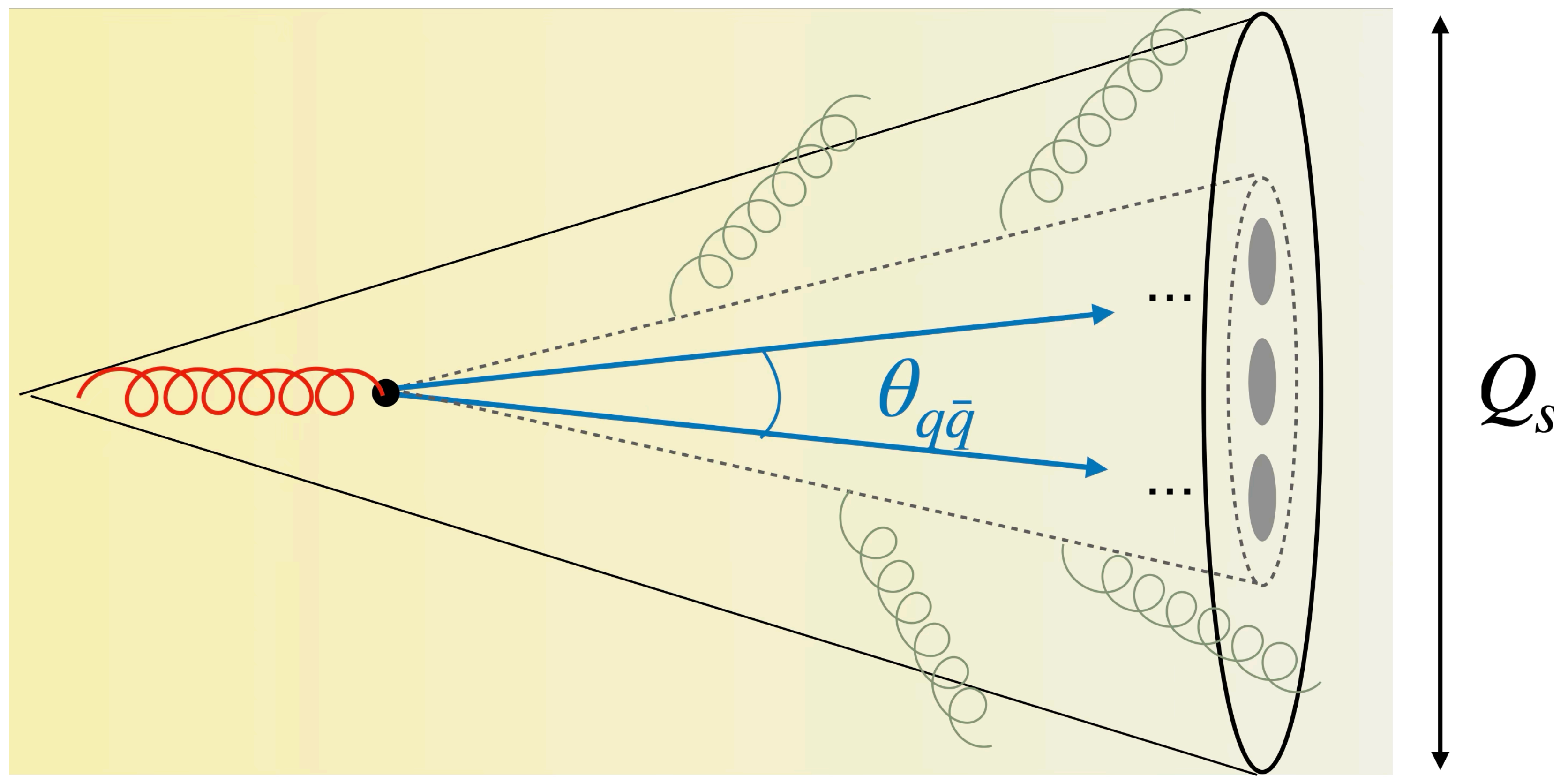

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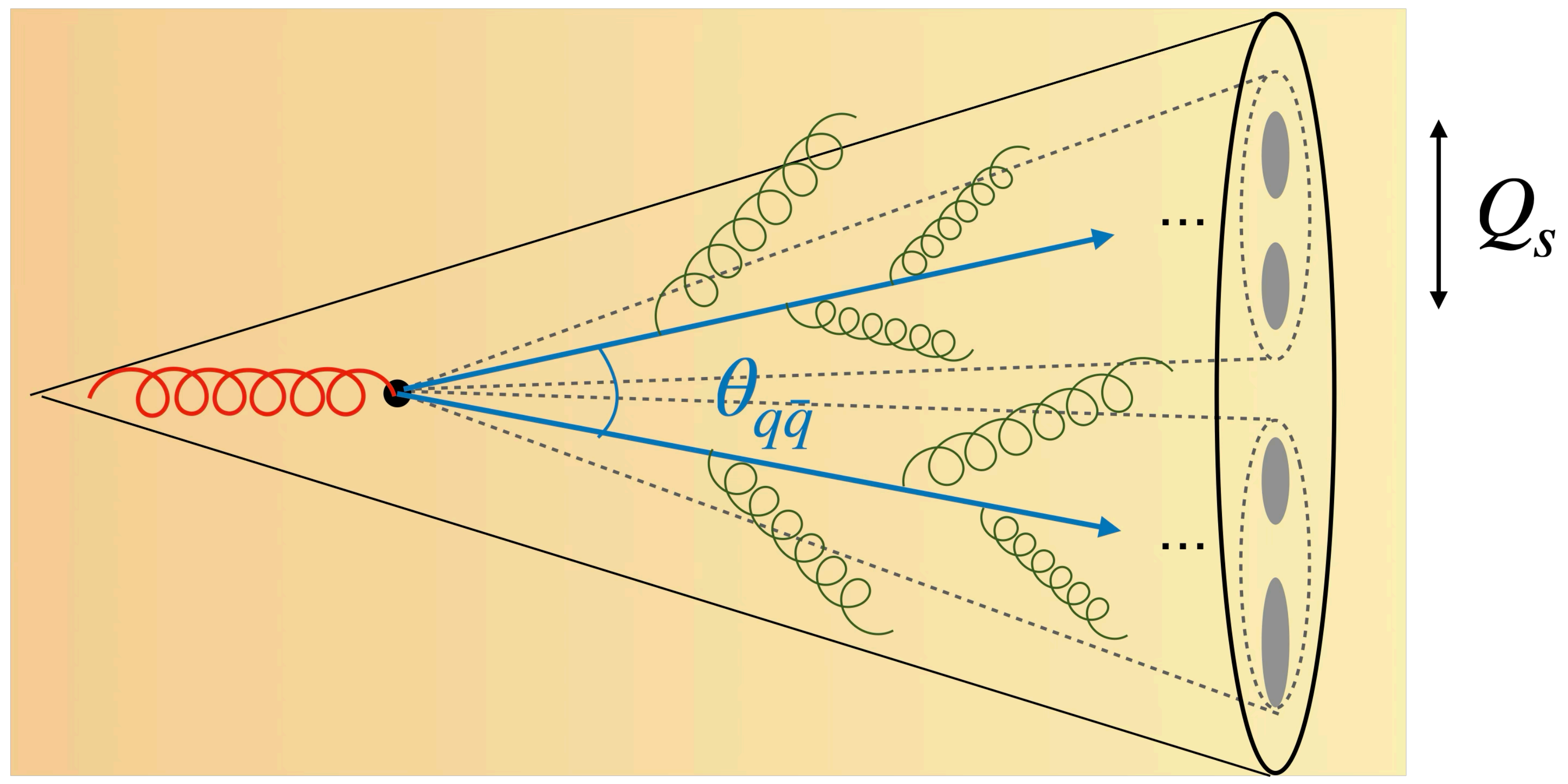

$Q_s \geq \theta_{q\bar{q}}$

Medium "sees" quark and anti-quark independently

Incoherent loss of energy

Medium saturation scale: $Q_s^2 = \hat{q}L$

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Medium length: L

(Anti-)Angular Ordering

- In-medium interactions can break expected angular ordering pattern
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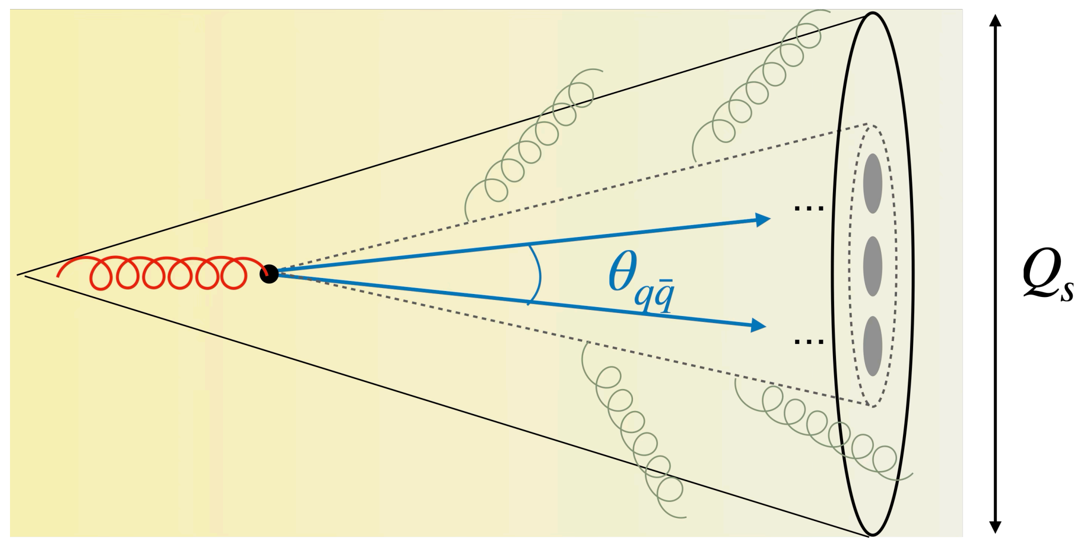
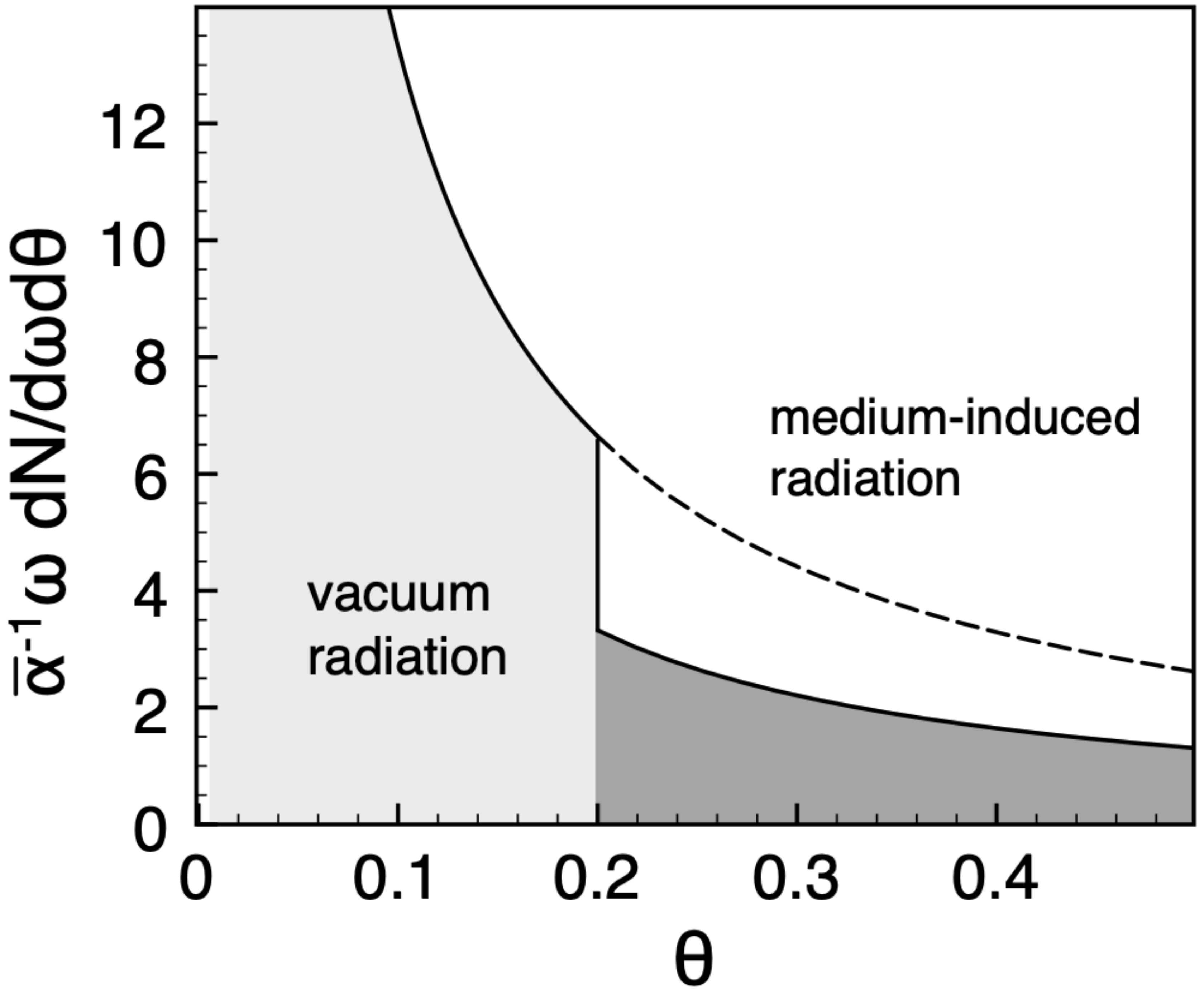
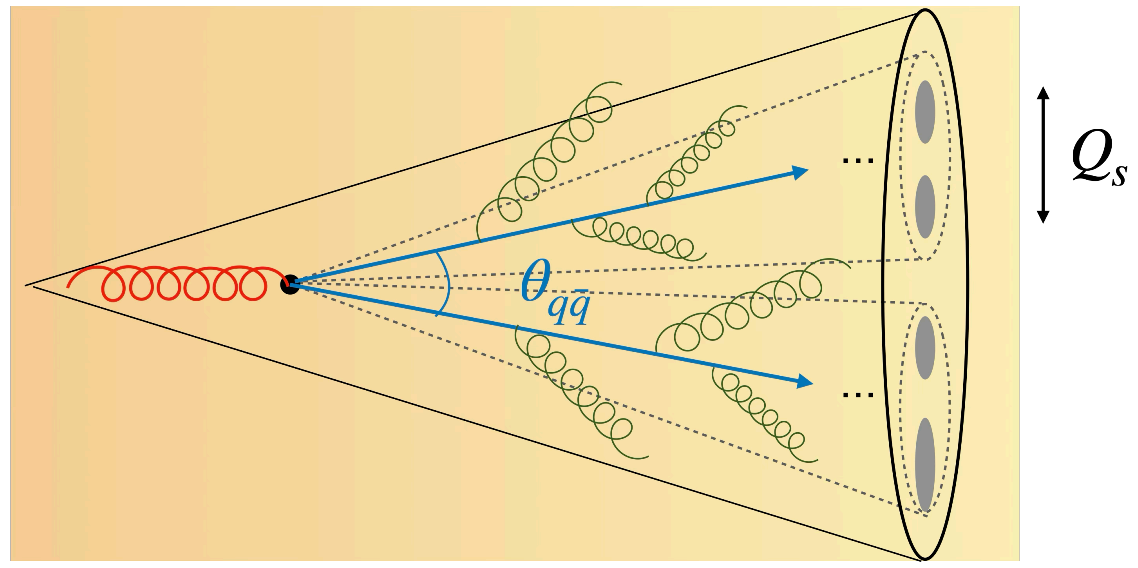


Mehtar-Tani, Salgado, Tywoniuk, PLB 2012

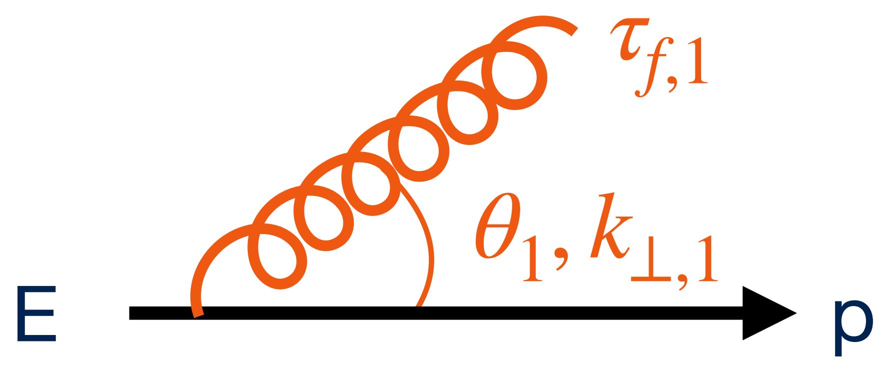




In the presence of a QGP, emissions do not need to follow angular ordering…

QCD Parton Formation time

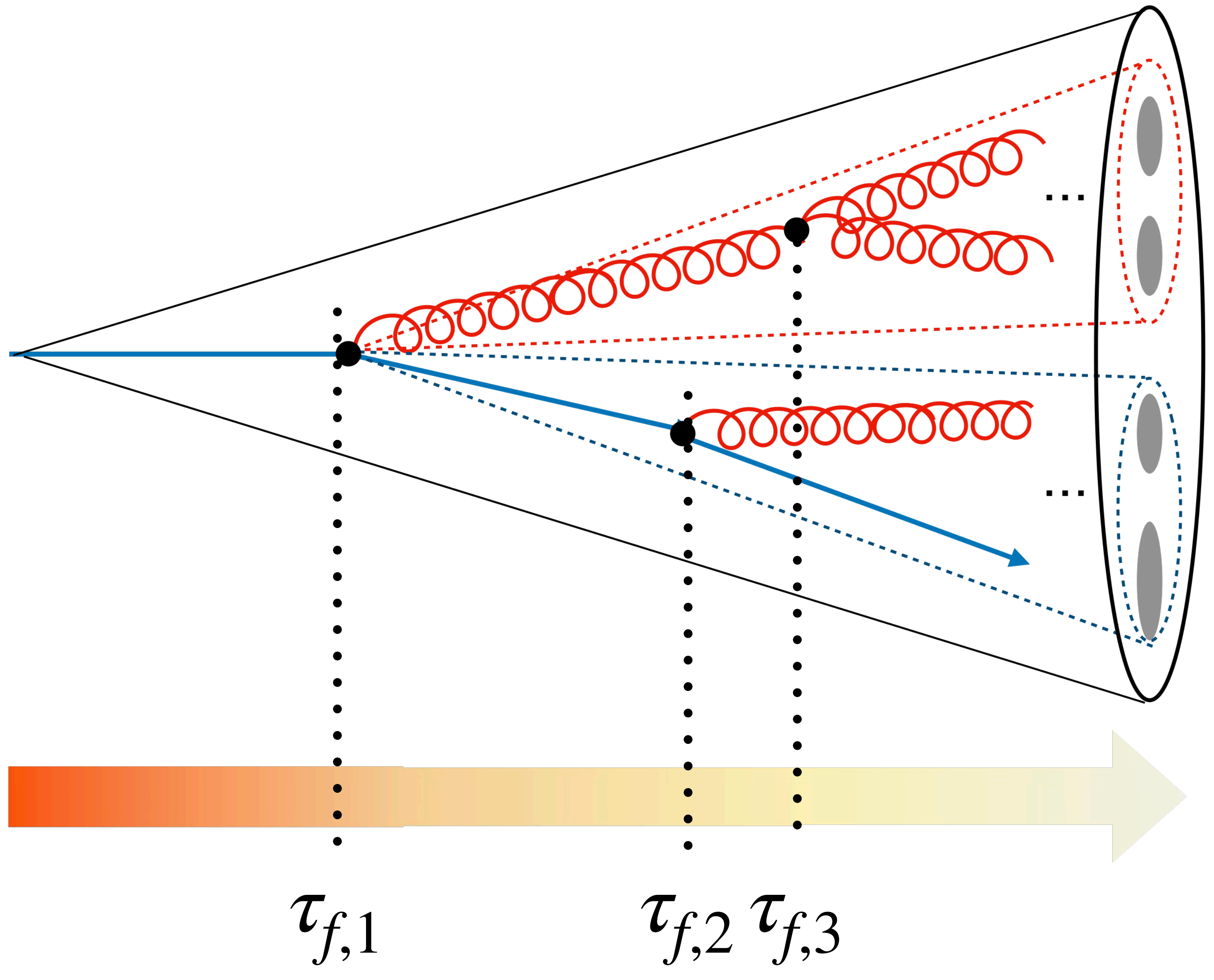
- QCD Parton Formation time understood as the time it takes for a quark/gluon to radiate

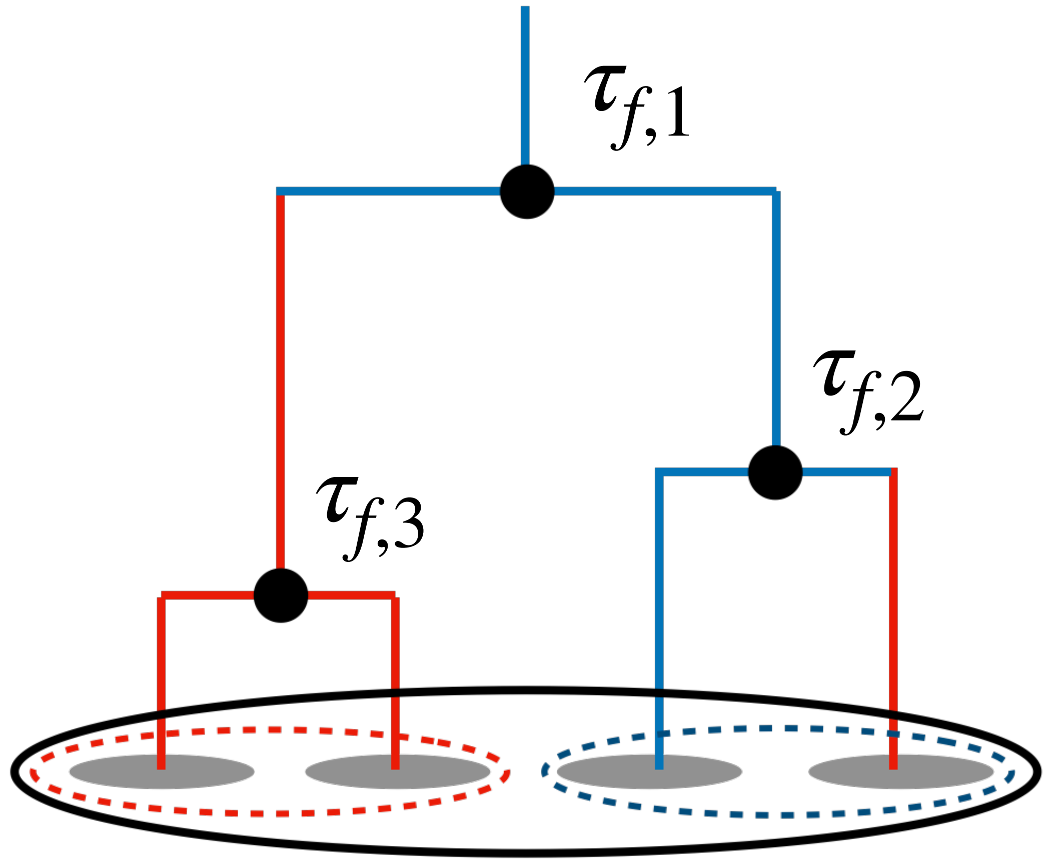


$$\tau_{form} \sim \frac{E}{M_{virt}} \frac{1}{M_{virt}}$$

(Estimated from Heisenberg uncertainty principle)

- When applied to a jet clustering tree yields $\tau_{f,1} < \tau_{f,2} < \tau_{f,3}$





First *unclustering step is the one with the* ***shortest formation time***