JetQGP - Jet Quenching and the Nature of the Quark-Gluon Plasma

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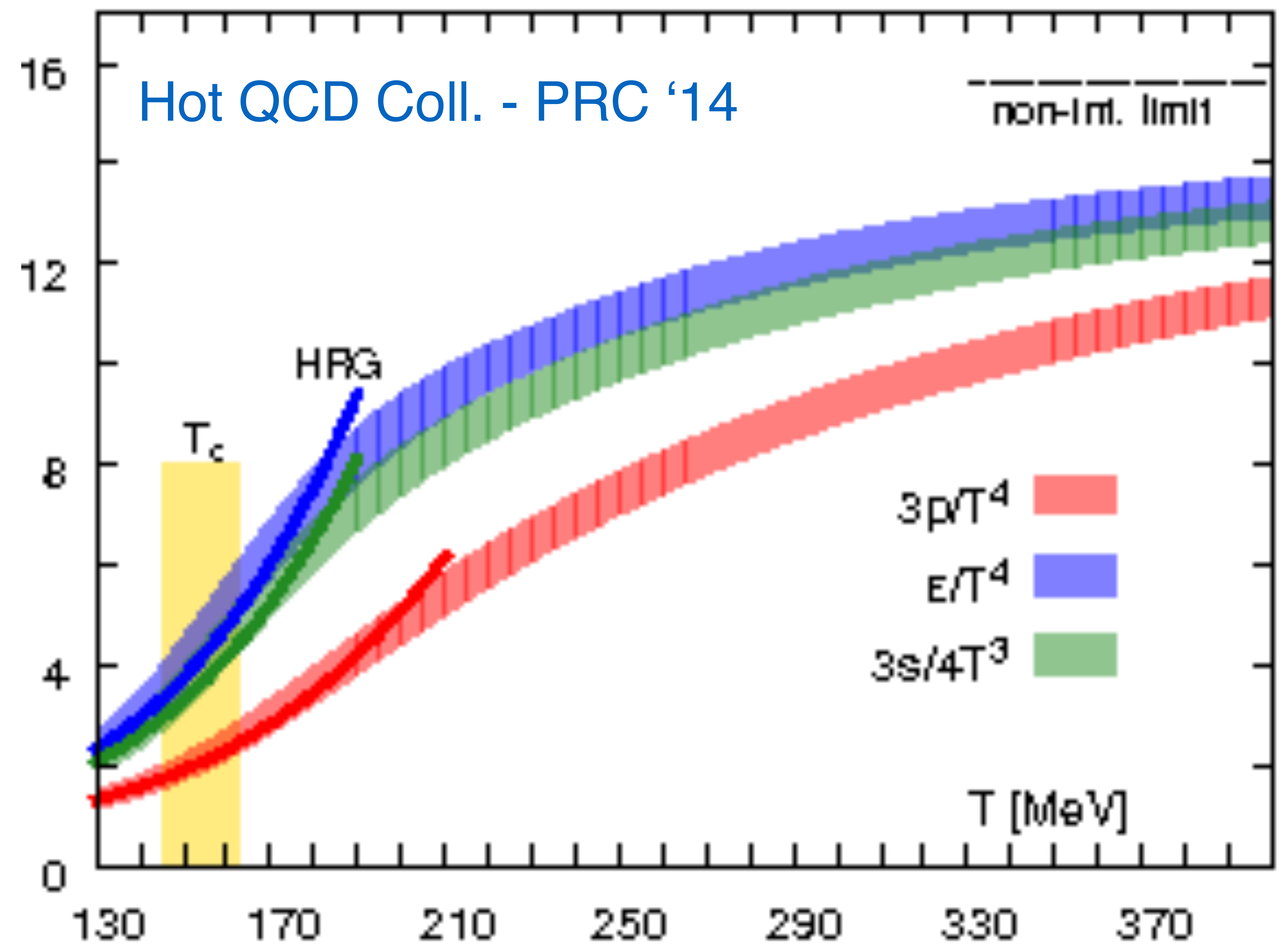
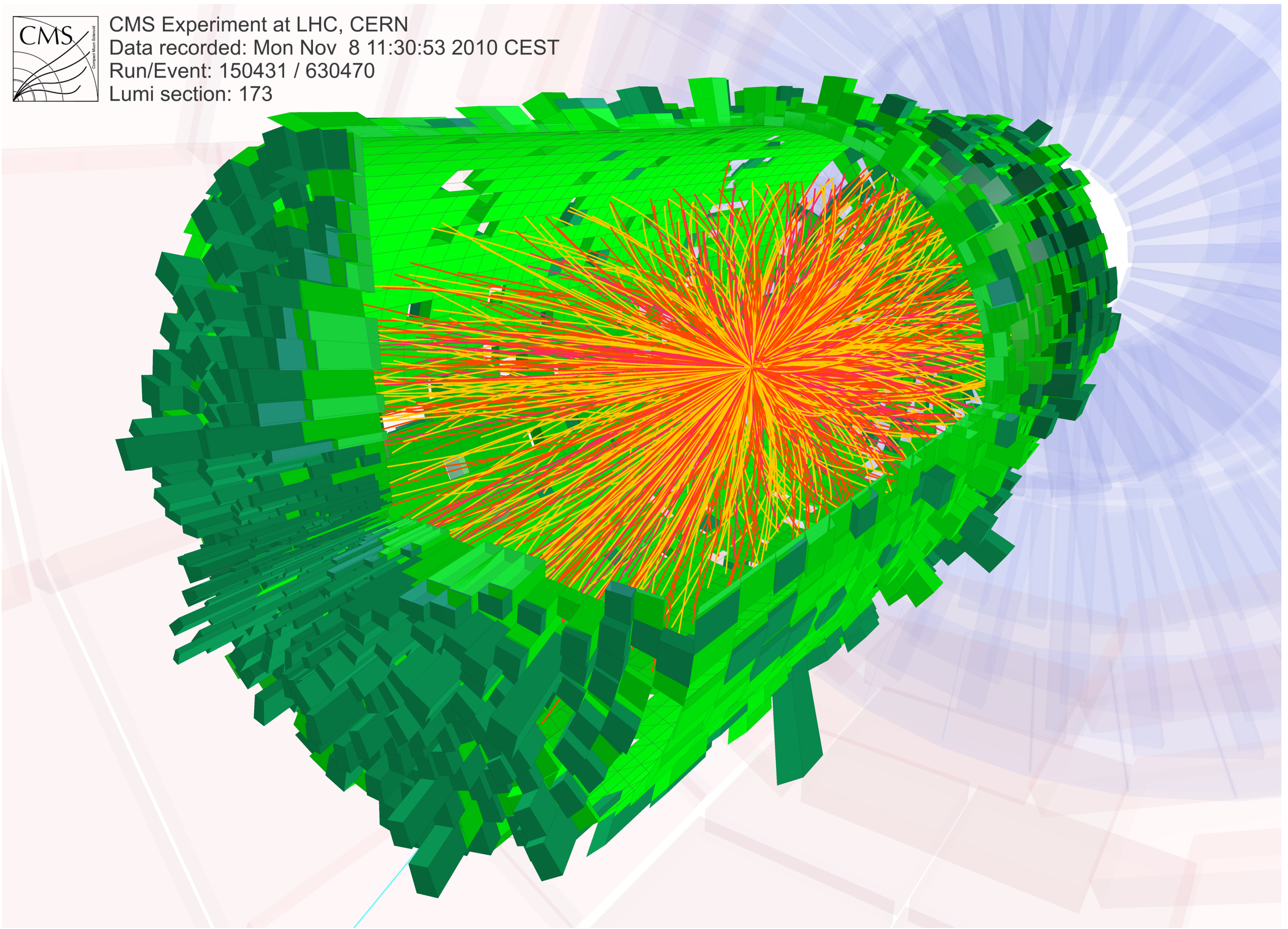
FELLINI General Meeting
14th Feb. 2023

Heavy-Ion Collisions (HIC): The Little Bangs



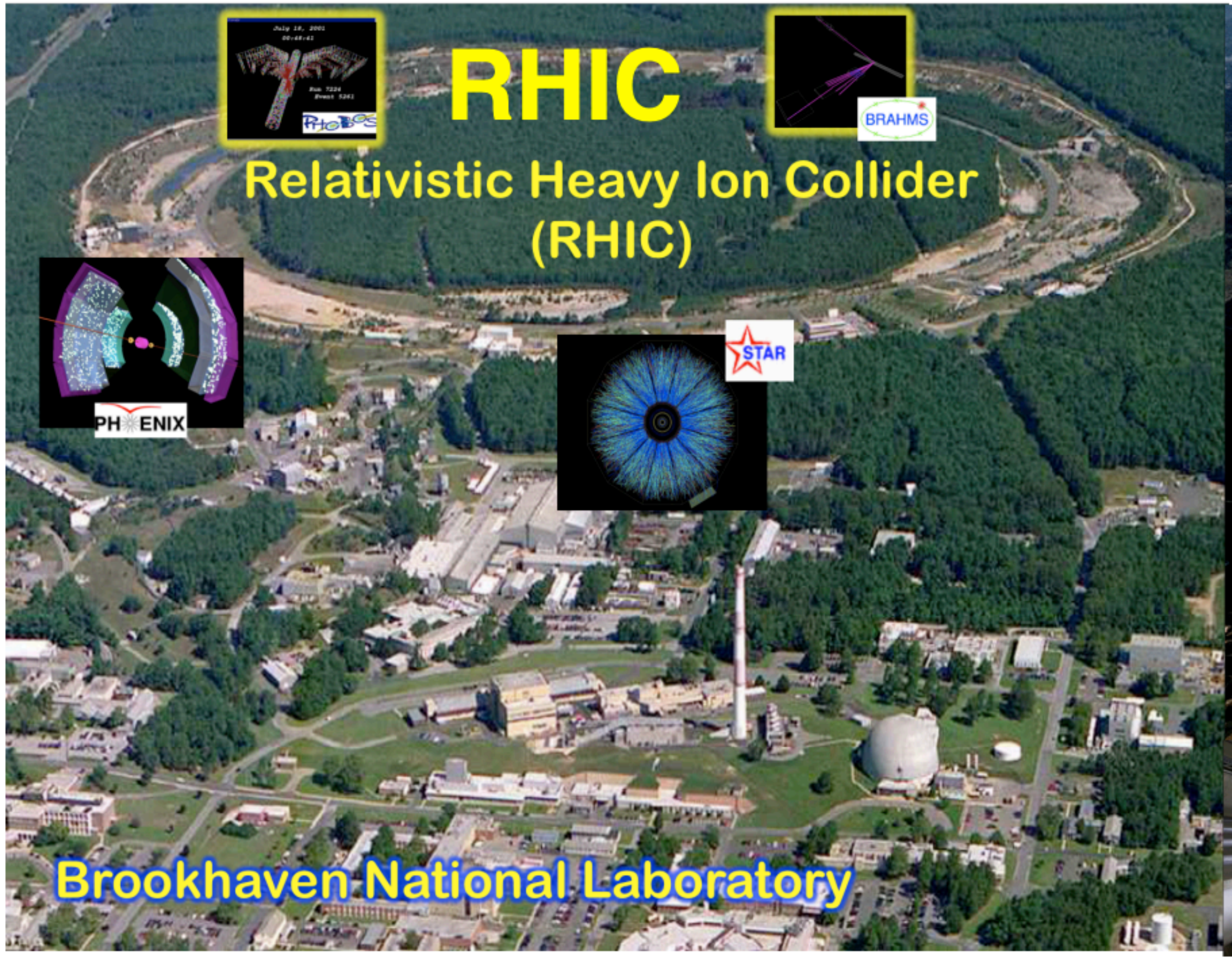


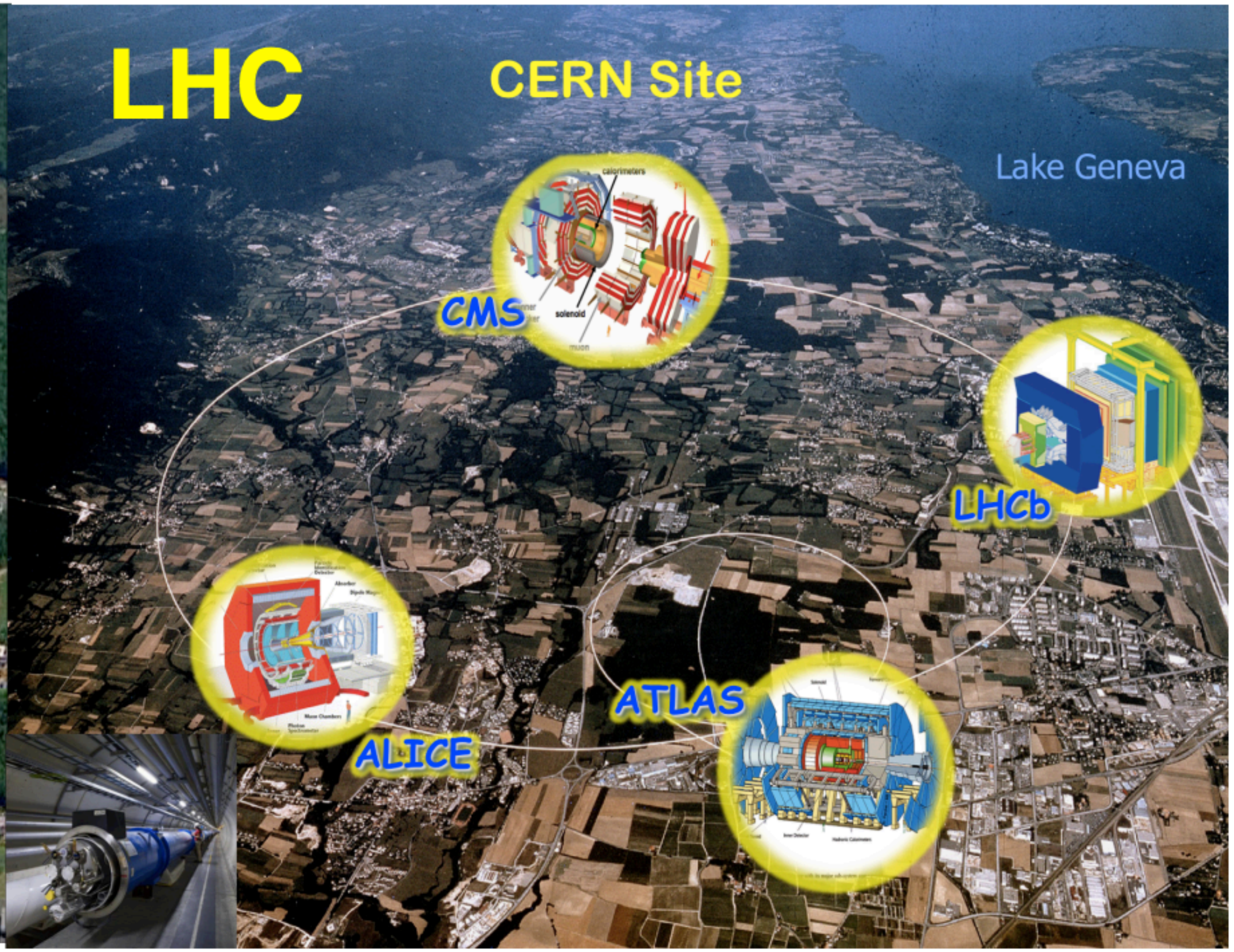
RHIC $\sqrt{s} \sim 0.2\,\mathrm{ATeV}$

LHC $\sqrt{s} \sim 4\,\mathrm{ATeV}$

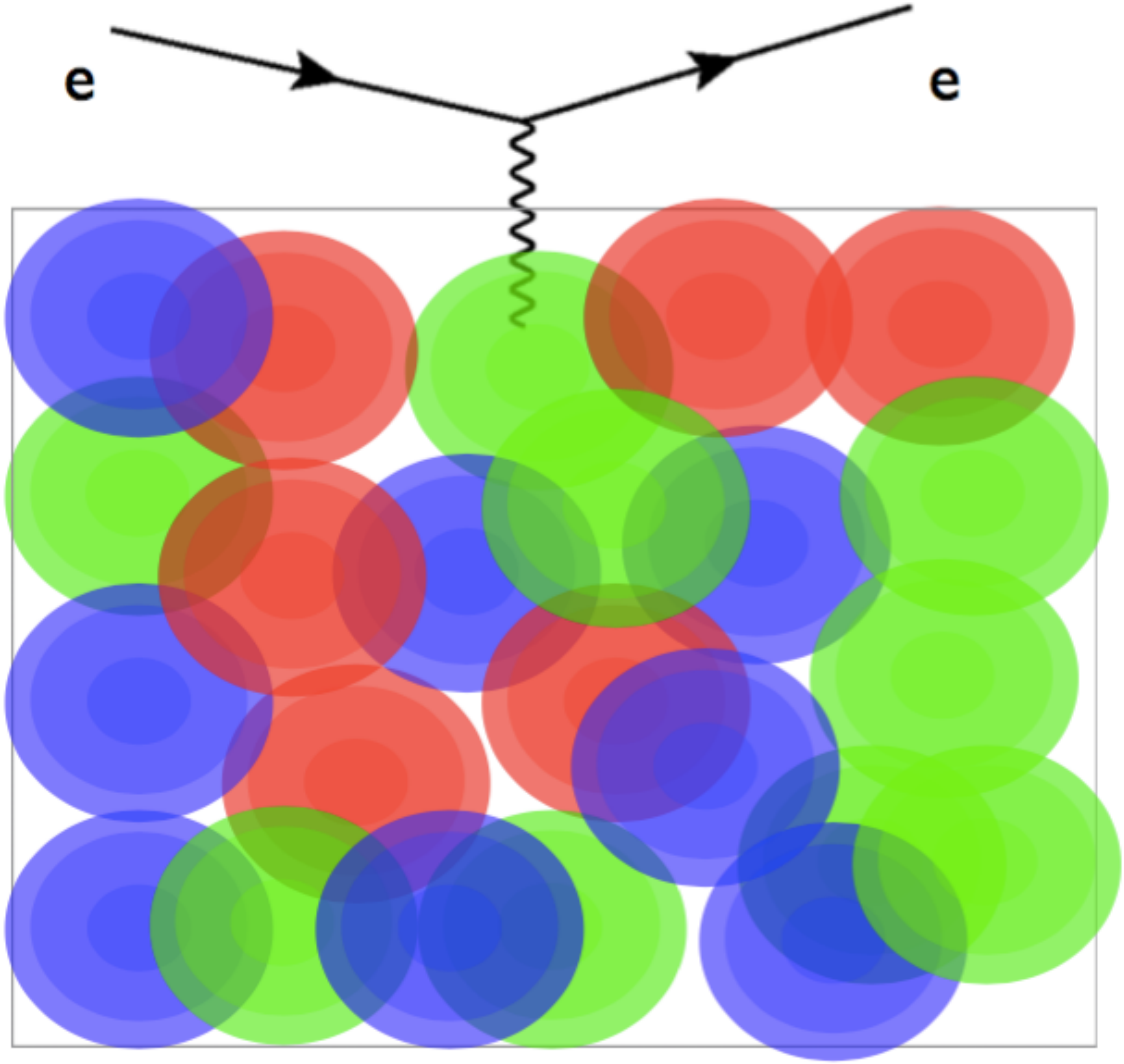
- Deconfined matter in experiments:
  - Very strong collective effects.
  - Thousands of particles correlated according to initial geometry.
  - Hydrodynamic explosion!

Heavy-Ion Collisions (HIC): The Little Bangs

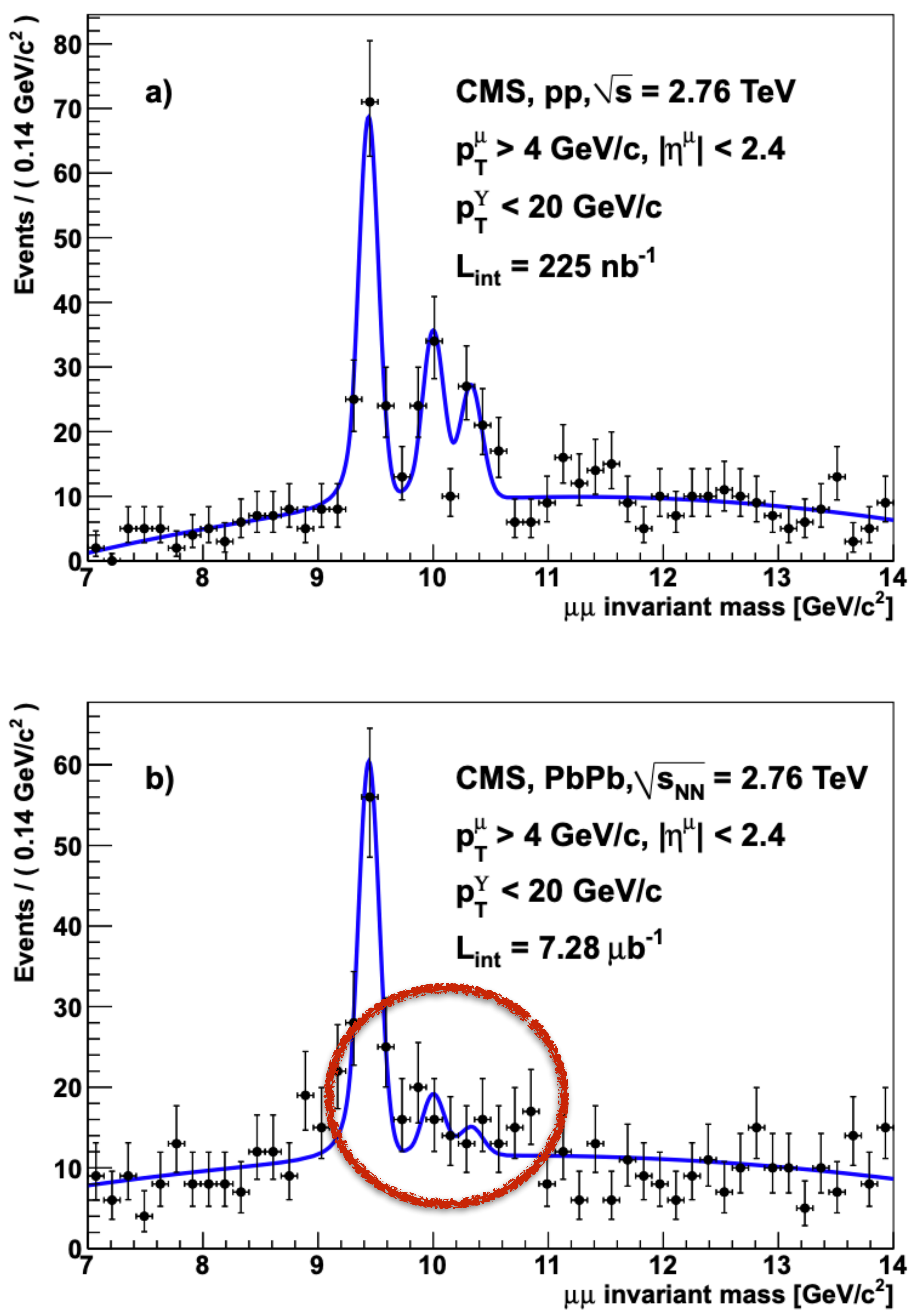




How Can We Probe the QGP?

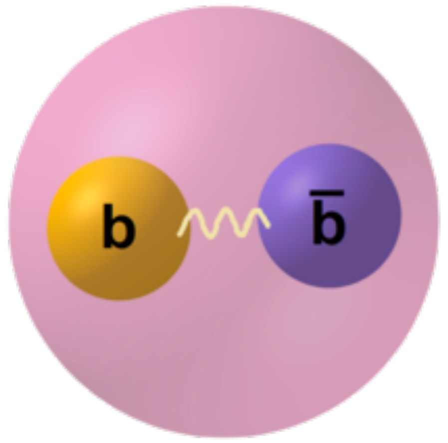


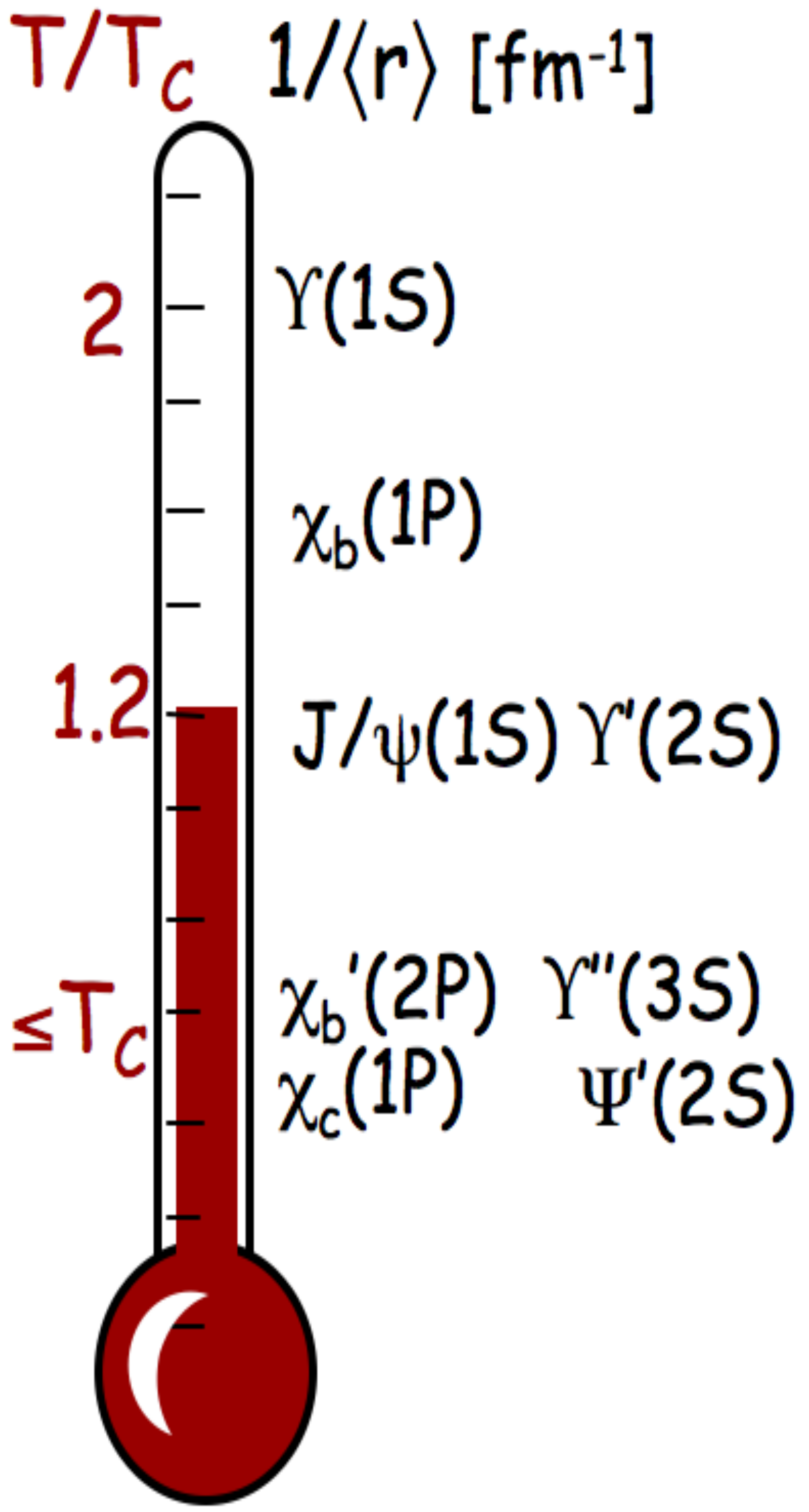
Quarkonium Suppression



- Potential between quark-antiquark pairs becomes screened at finite temperature (Matsui & Satz '86).

- Sequential suppression of bottomonium states due to their different binding energy: "QGP-Thermometer".





- Modern framework: Open Quantum Systems.

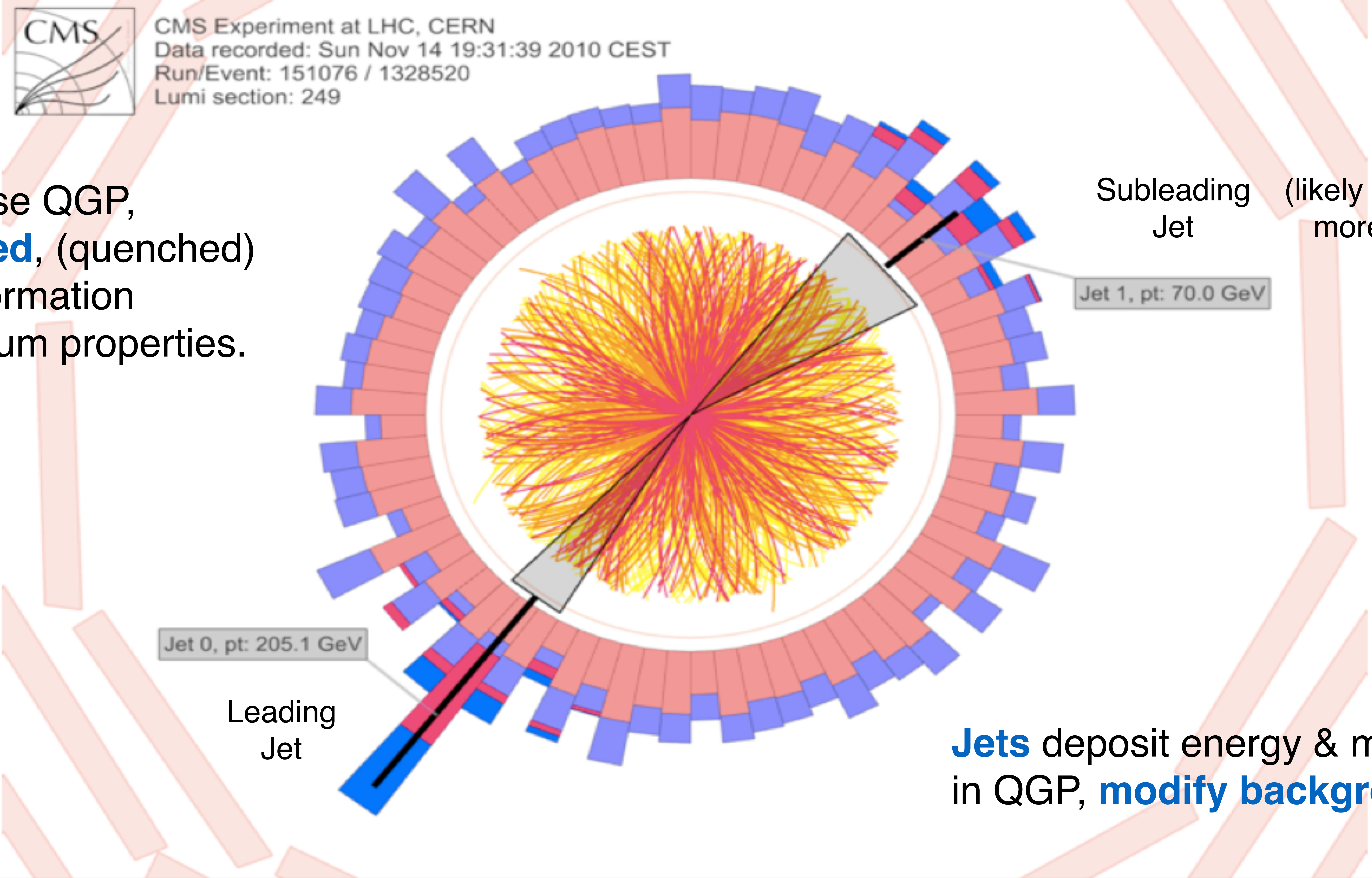
$$\frac{d\rho}{dt} = -i[H,\rho] + \sum_n \left(C_n\,\rho\,C_n^\dagger - \frac{1}{2}\{C_n^\dagger C_n, \rho\} \right)$$

Lindblad eq.

Can use transport coefficients from holography

Jets in HIC

Jets traverse QGP,
get modified, (quenched)
provide information
about medium properties.

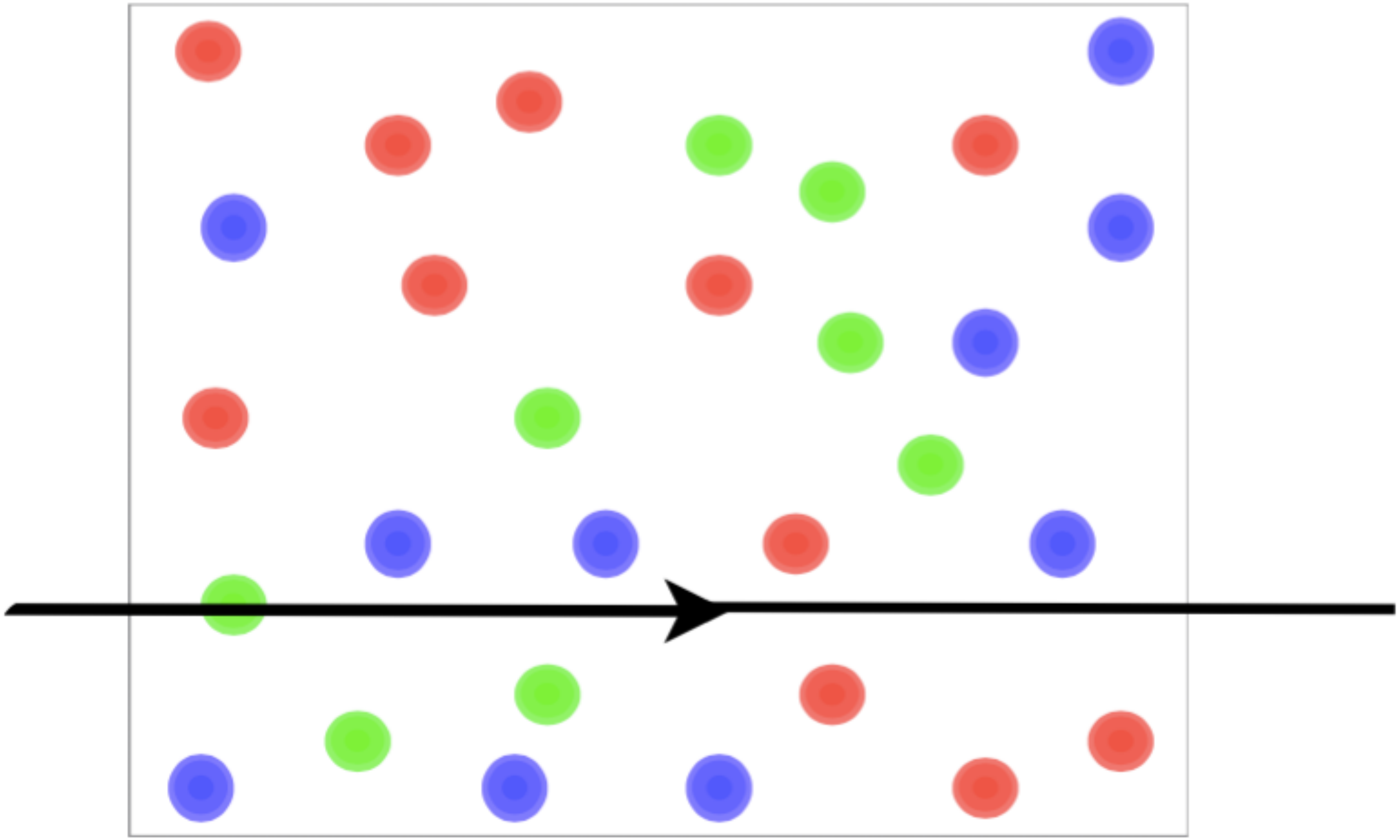


Subleading Jet (likely traversed more QGP)

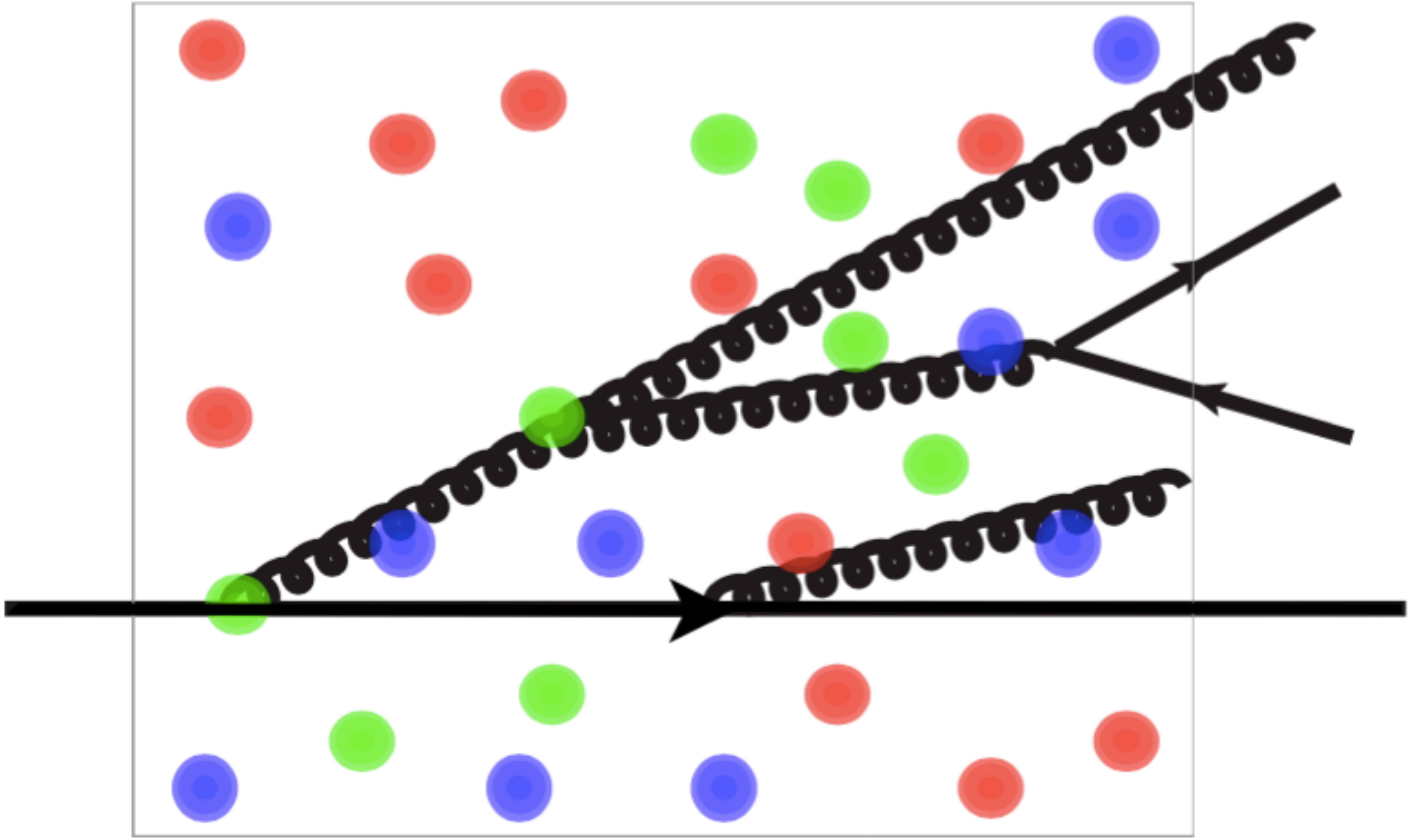
Leading Jet

Jets deposit energy & momentum in QGP, **modify background**.

In-Medium Jet Propagation



In-Medium Jet Propagation



Coherence Effects

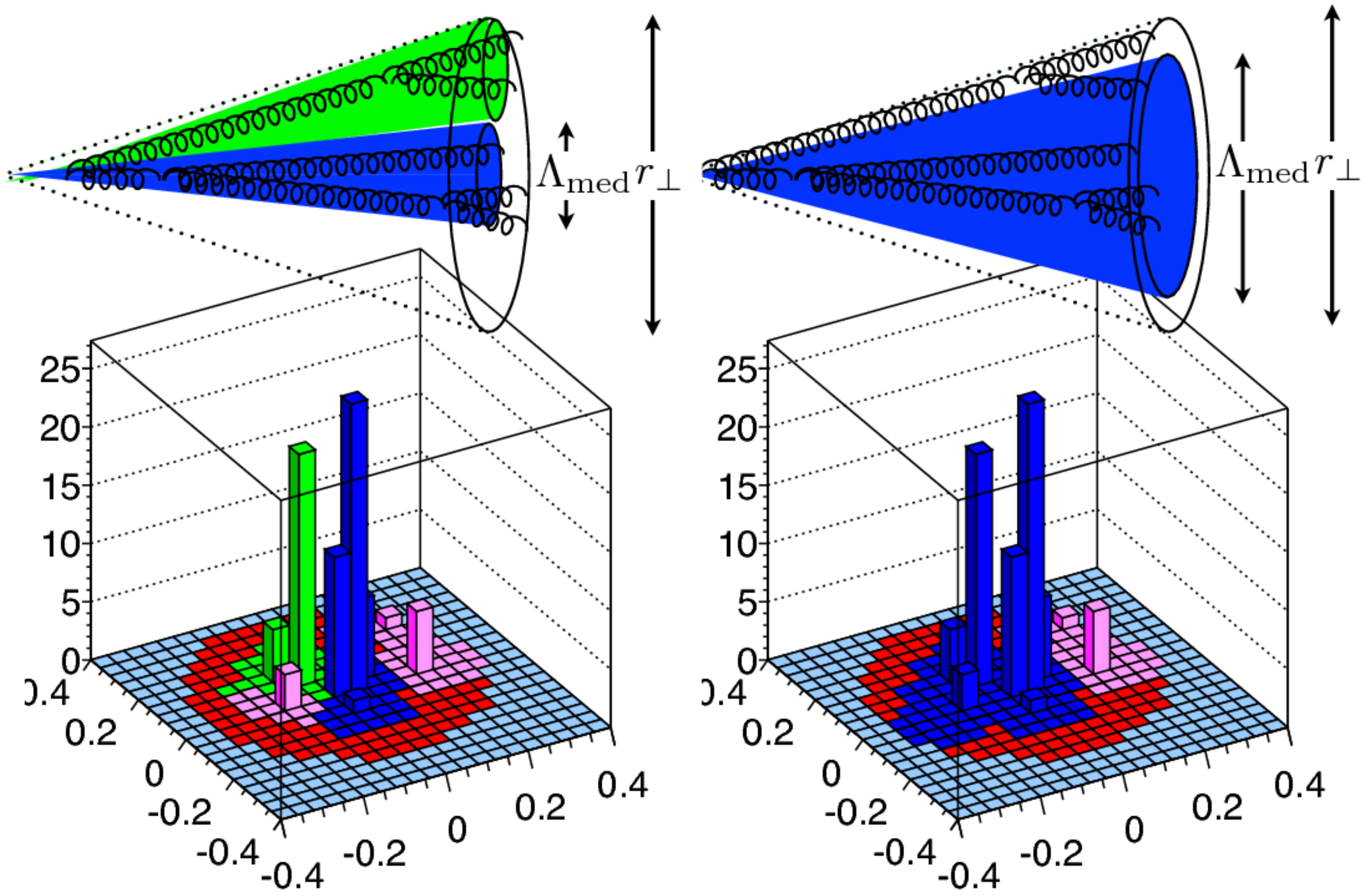
QGP resolution length:

minimal distance between two coloured charges such that they engage with the plasma independently. → The medium perceives a parton shower as a collection of effective probes.

At weak coupling:
connection between resolution length and energy loss.

At strong coupling:
no such connection (yet).

Can study string splitting in holography



Casalderrey et al. - PLB ‘13

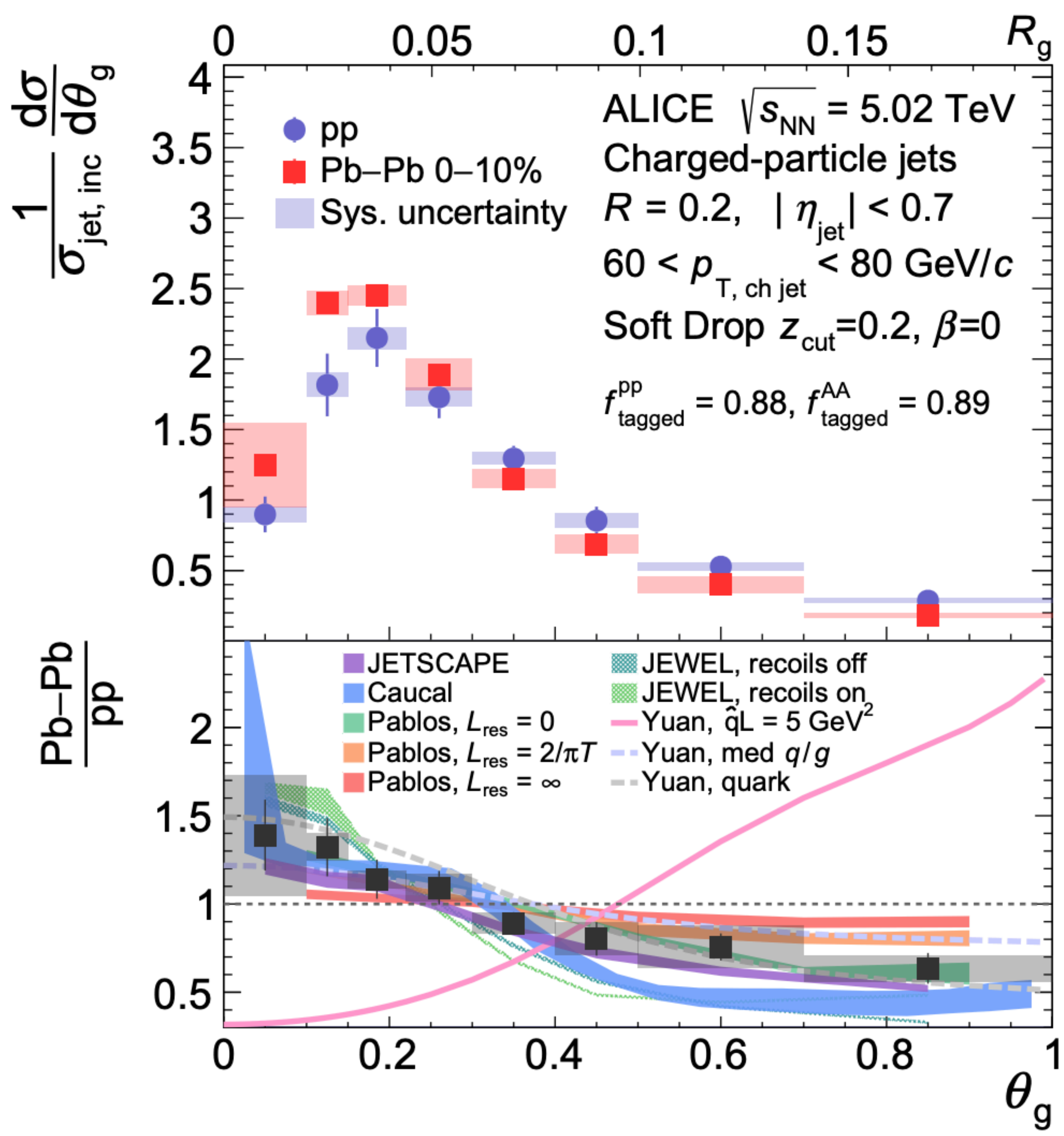
At weak coupling:
Antenna can lose coherence due to color rotations via multiple soft scatterings with the medium.

Decoherence time $t_{\rm coh}(\theta_{q\bar{q}}) \equiv \left(\frac{4}{\hat{q}\theta_{q\bar{q}}^2}\right)^{1/3}$

For maximum possible length L, minimal angle

$$\theta_c \equiv 2/\sqrt{\hat{q}L^3}$$

Narrowing of Jet Substructure



ALICE - PRL ‘22

Example: Groomed radius.

Many Monte Carlo models get similar results.

Bias towards narrower, less active jets.

Medium q/g can also account for the signal.

Strong suppression of gluon jets (factor 4 w.r.t. pp).

Qiu et al. - PRL ‘19

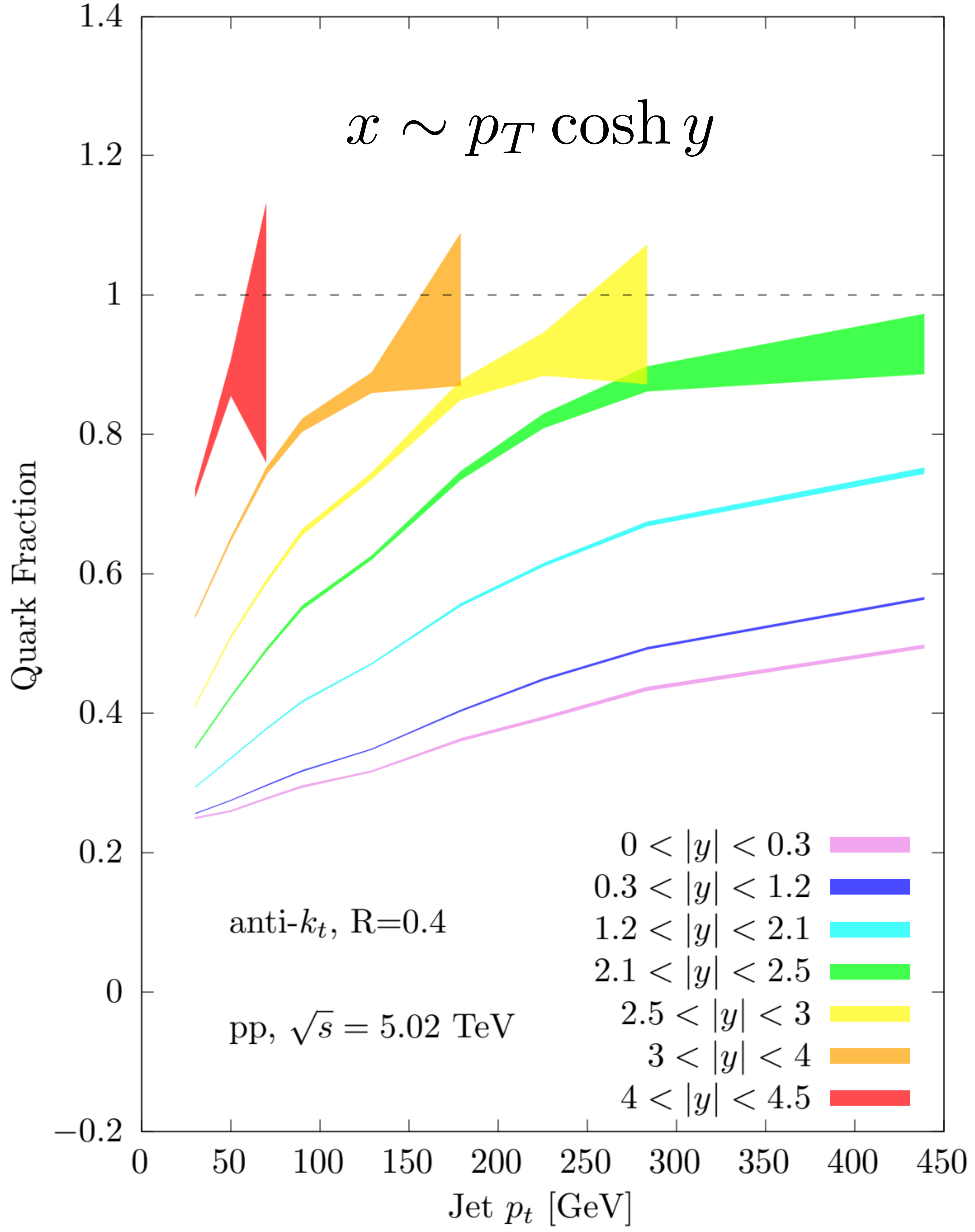
Medium q/g + p_T broadening fails.

Not accounting for selection bias, while broadening emissions, results in a broader jet ensemble.

Ringer et al. - PLB ‘19

Rapidity Evolution of Quark Fraction

DP & A. Soto-Ontoso - 2210.07901



- Quark enriched samples can be obtained from e.g. inclusive b-tagged jets, semi-inclusive boson-jets.
- Here: exploit rapidity evolution of quark fraction to engineer quark enriched samples.

Extended rapidity coverages available in future detector upgrades.

ALICE3

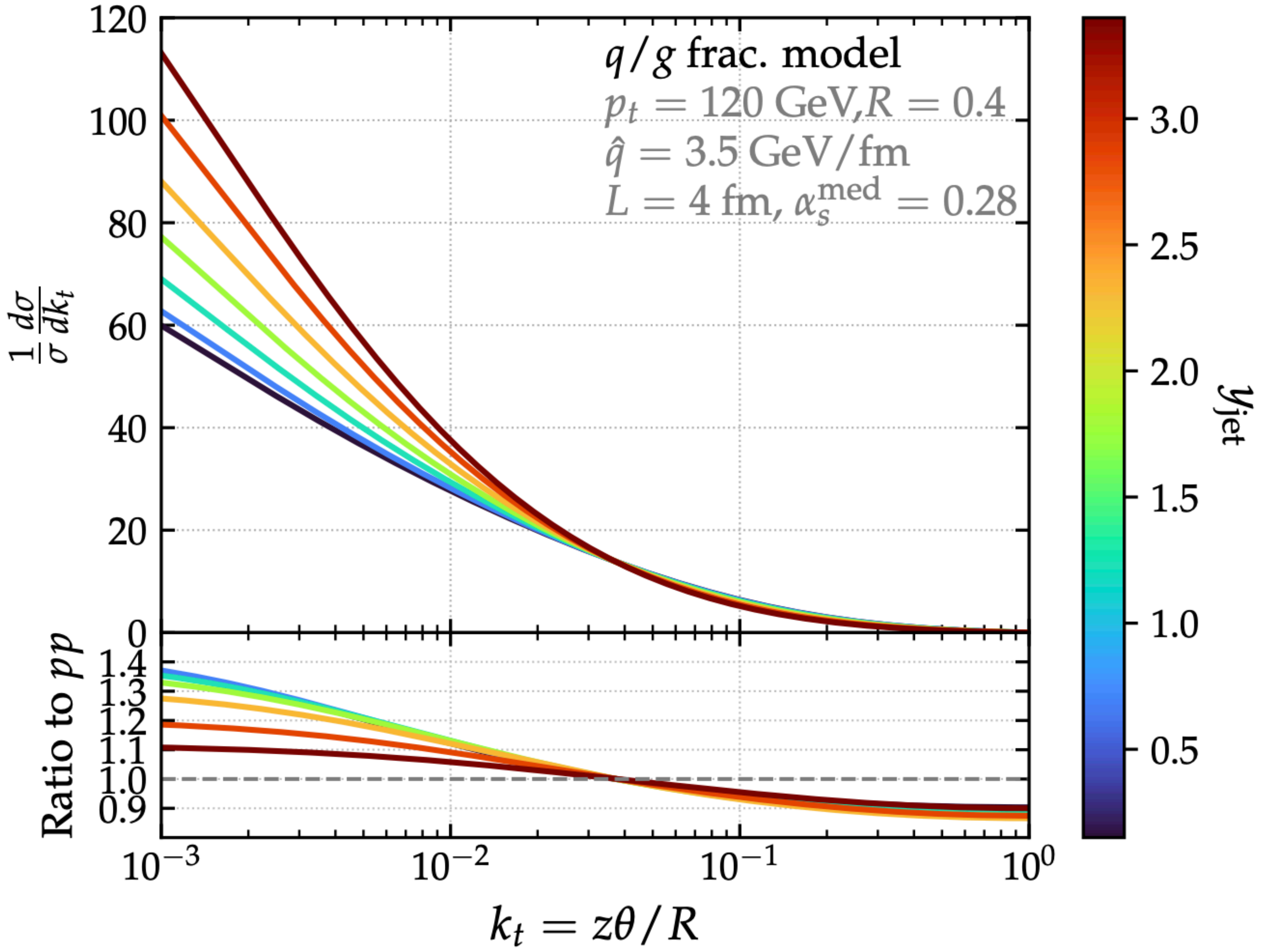
Run 5 with |η|<4
and great p_T resolution.

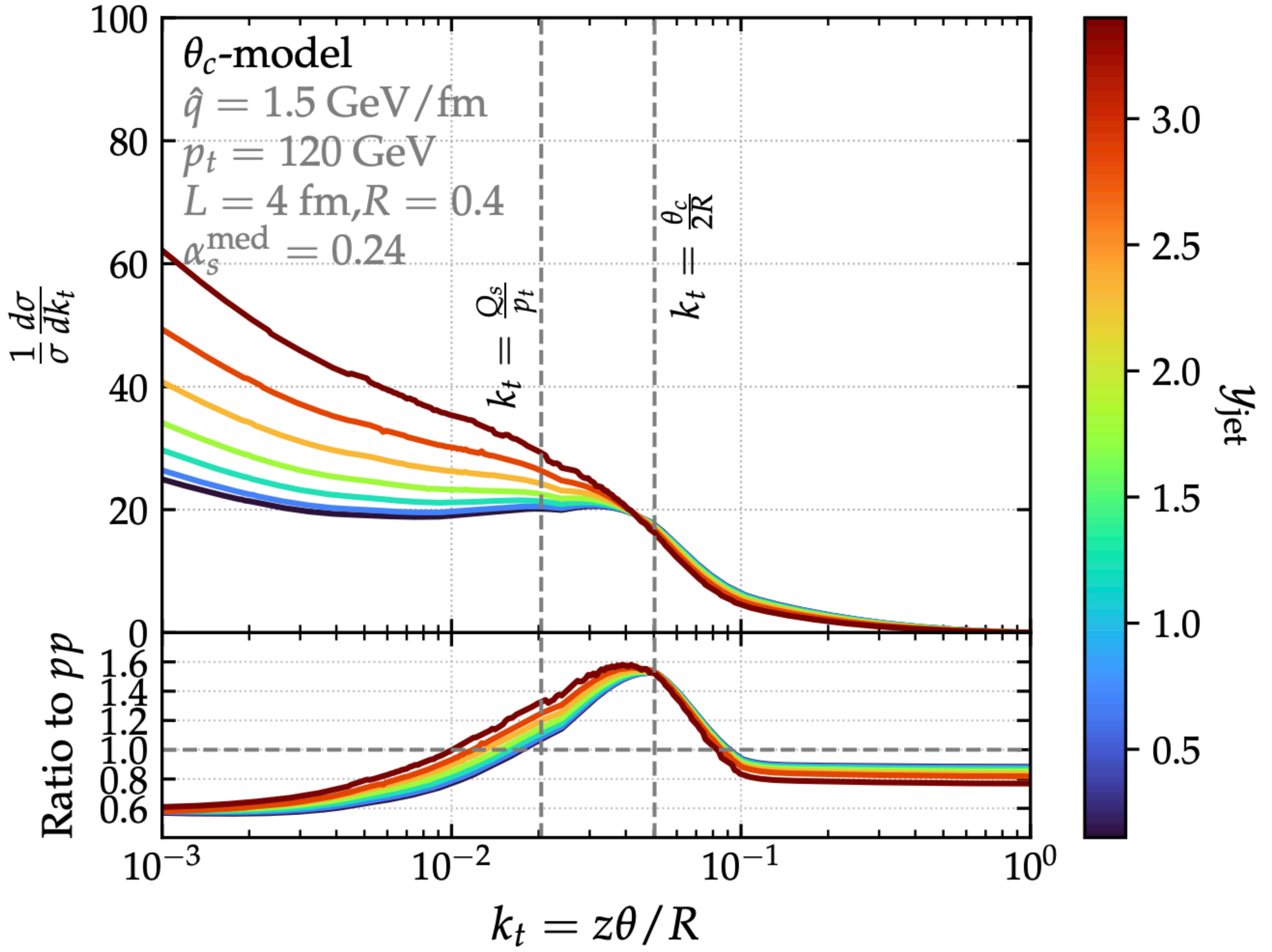
CERN-LHCC-2022-009

Also ATLAS and CMS.

Analytic Estimates at DLA - Summary

DP & A. Soto-Ontoso - 2210.07901





q/g frac model:

→ Quenching of leading charge only.

Less narrowing with increasing rapidity.

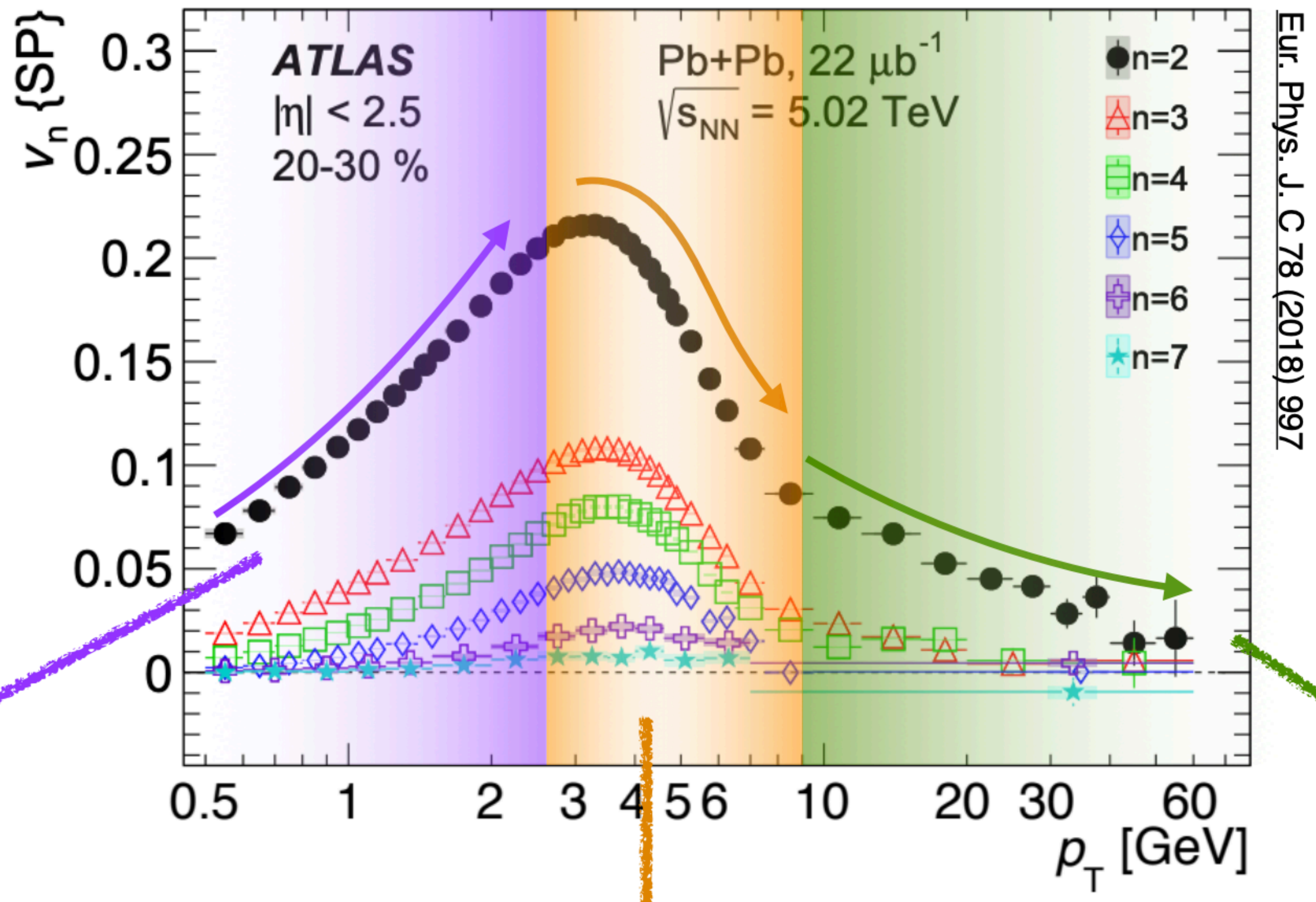
θ_c model:

→ Quenching of leading and tagged prongs if resolved (i.e. with $\theta > \theta_c$).

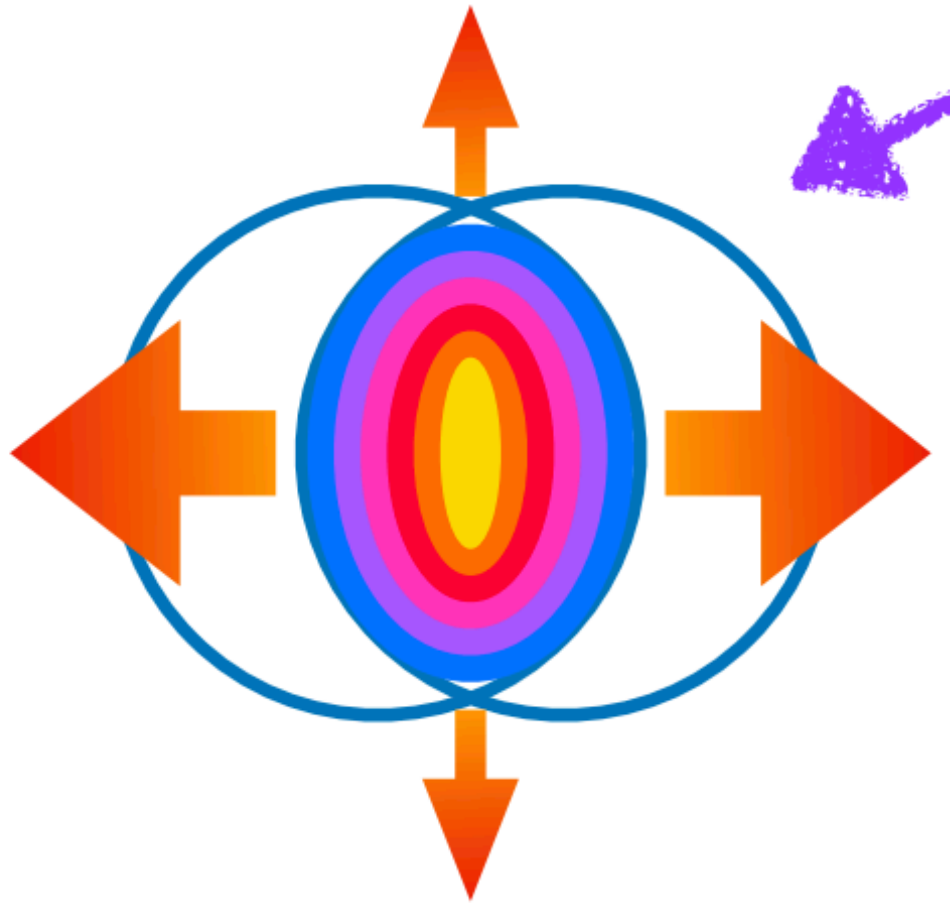
Narrowing persists also at forward rapidities.

Jet Azimuthal Anisotropy

Slide from
K. Hill at QM'19

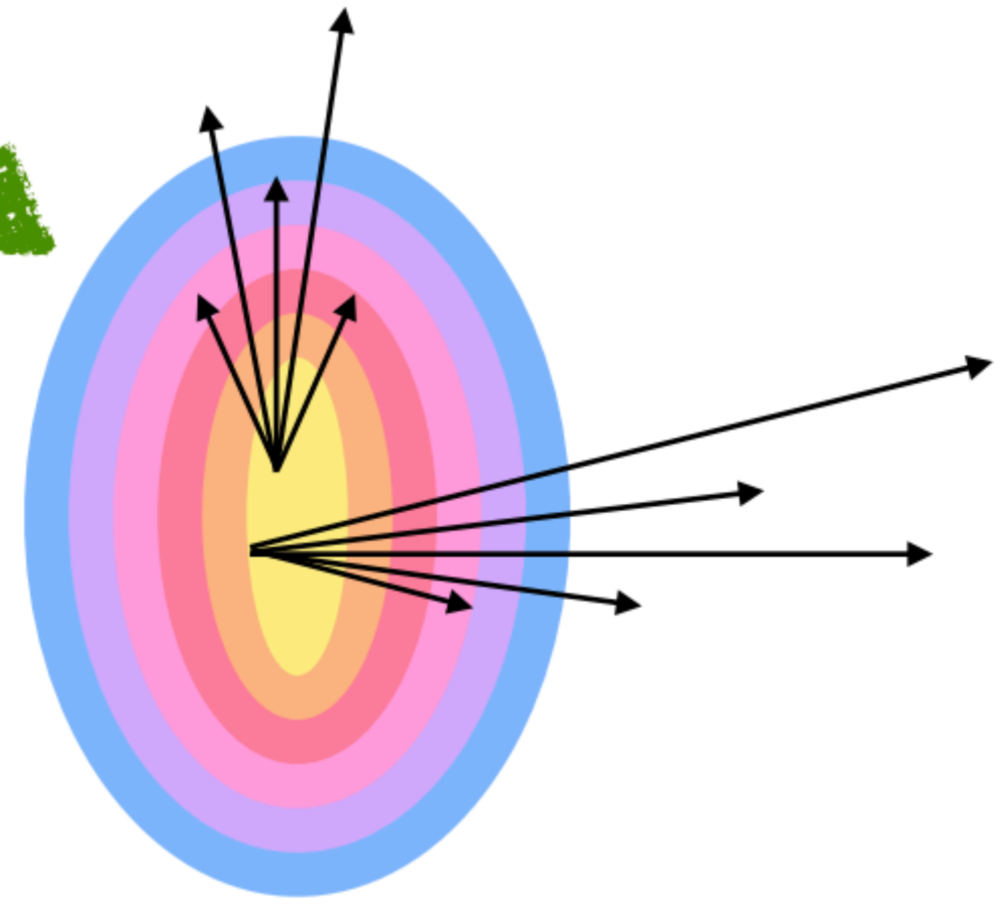


Hydrodynamics



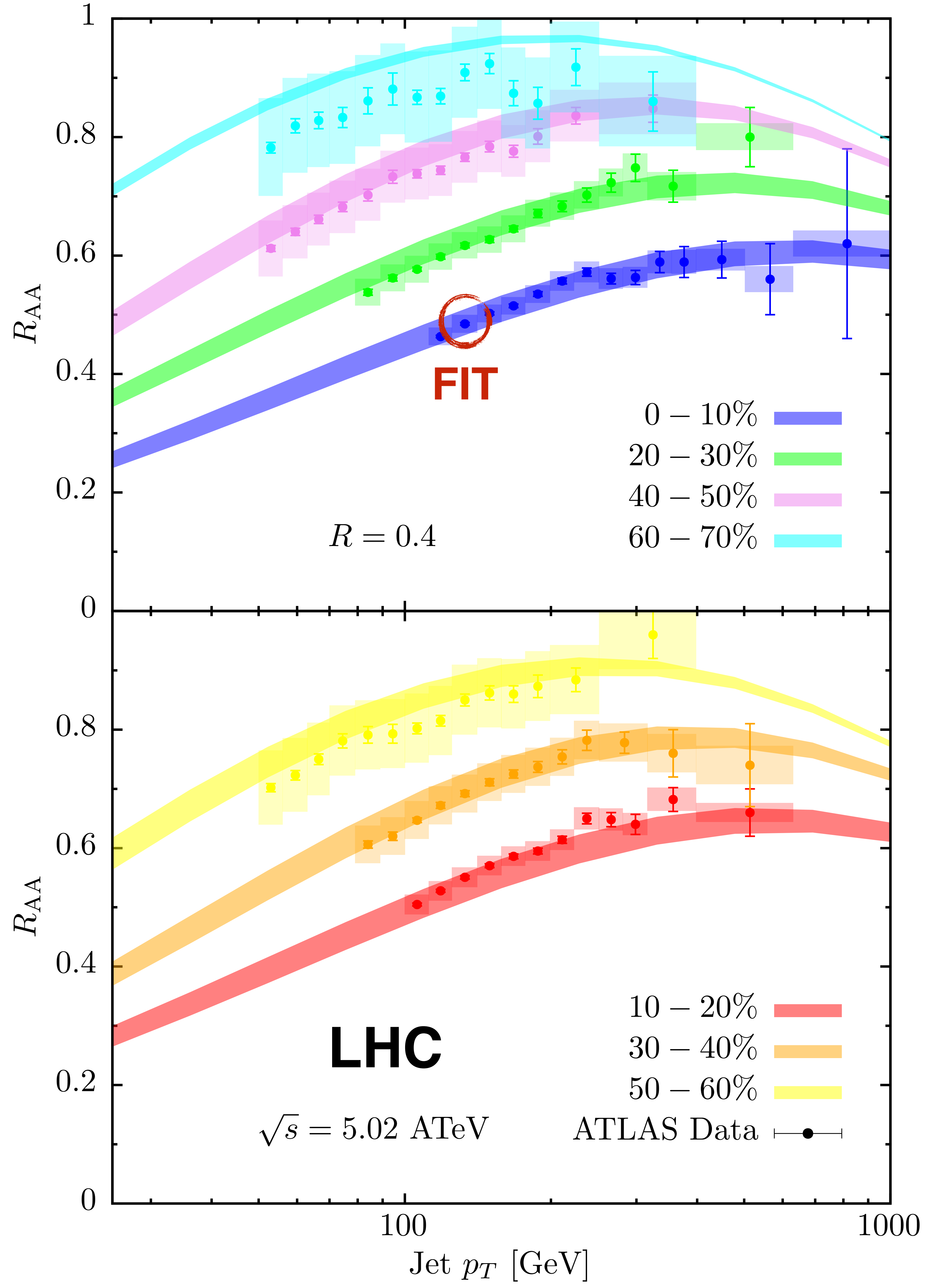
Transition region

Differential energy loss



Jet Suppression at LHC

Mehtar-Tani, DP, Tywoniuk - PRL '21



- Embed framework into realistic heavy-ion environment:
  - Glauber sampling, random azimuthal orientation.
  - Compute event-by-event relevant quantities, e.g.: (in local fluid rest frame)

$$L = \int_{\Gamma(t)} dx_F \qquad \hat{q}_0 \propto \frac{1}{L}\int_{\Gamma(t)} dx_F\, T^3(x)\left(\frac{p \cdot u(x)}{p^0}\right)$$

Path of jet through hydro. profile (VISHNU) down to T_c

- $g_{\rm med}$ fit to ATLAS R=0.4 around p_T~120 GeV at 0-10%
  - $g_{\rm med} \in \{2.2,\, 2.3\}$

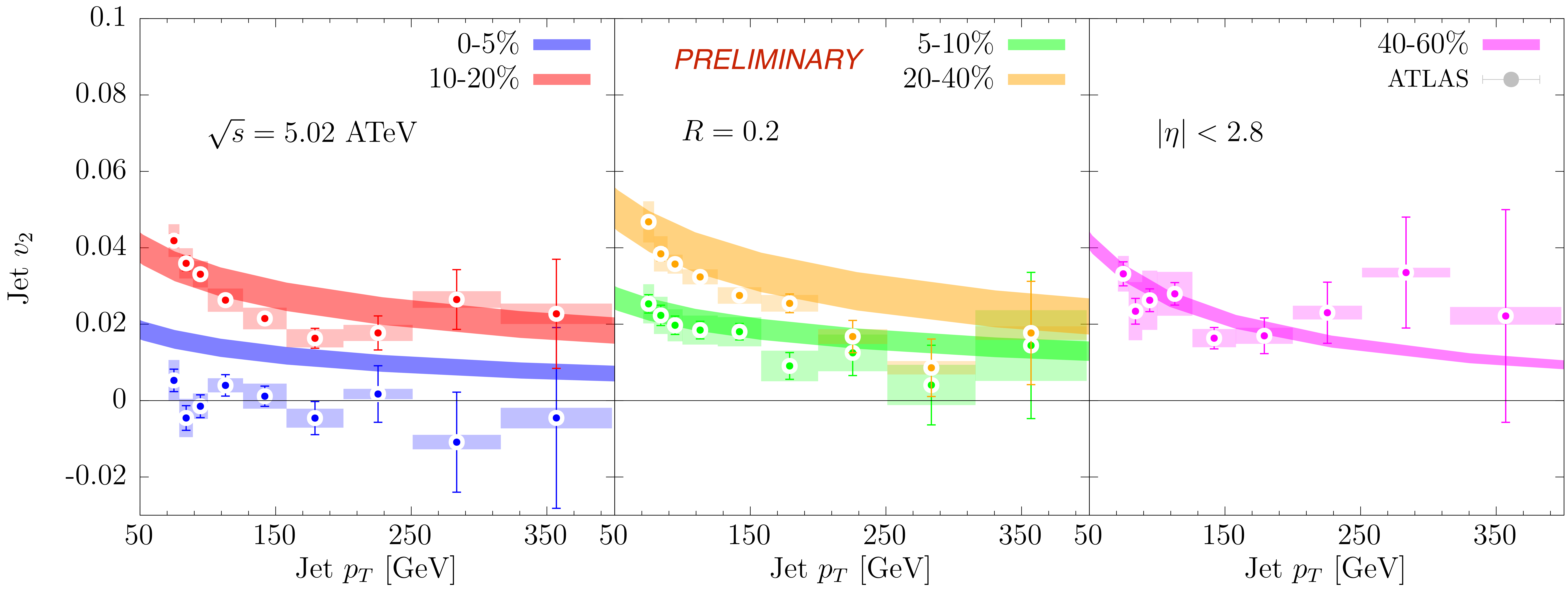
$$\langle \hat{q}_0 \rangle \simeq 0.41 \;\; \mathrm{GeV^2/fm}$$

$$\hat{q} = 2.46 \;\; \mathrm{GeV^2/fm}$$

due to logarithmic corrections.

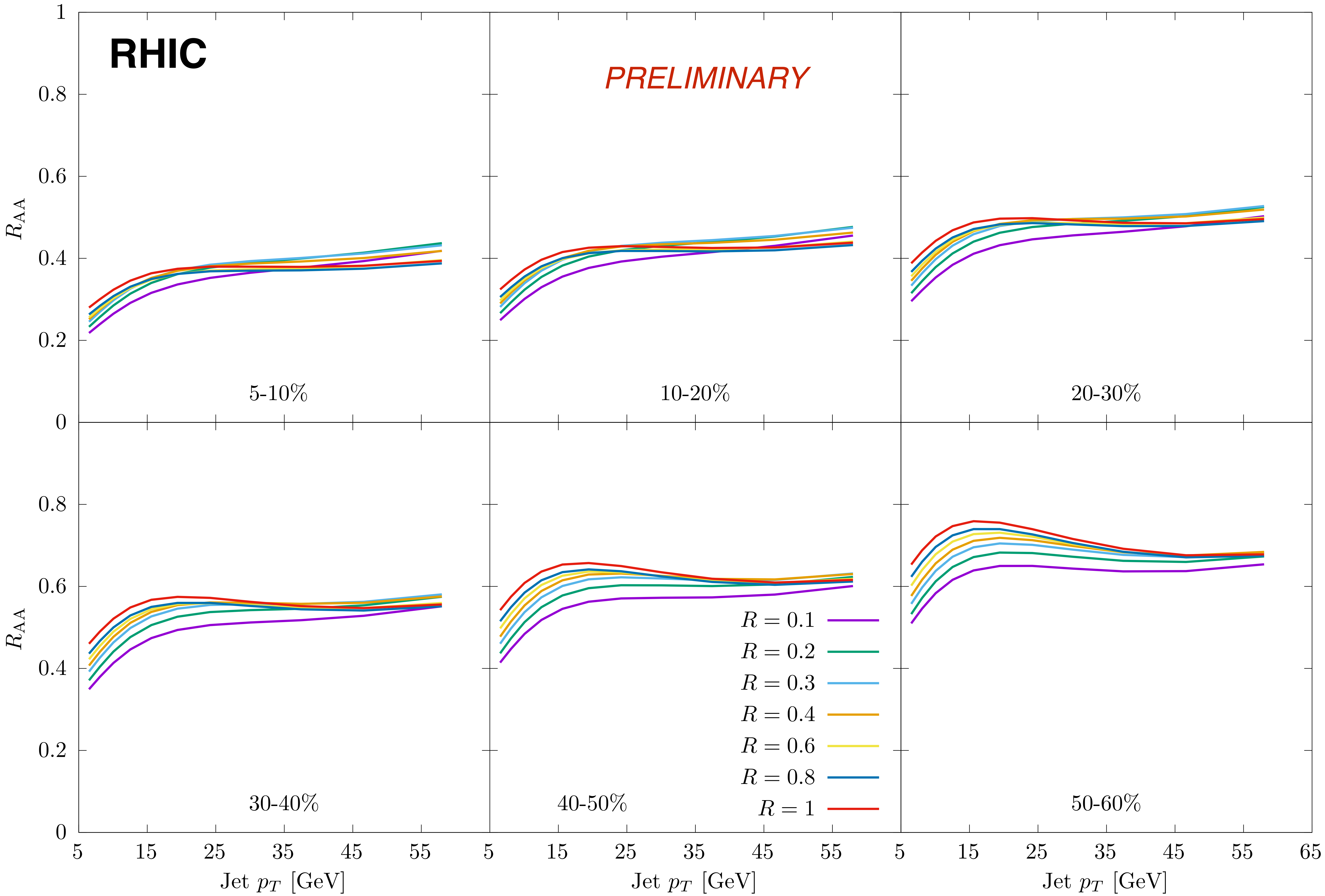
Jet v_2 at LHC for R=0.2

Mehtar-Tani, DP, Tywoniuk - in preparation



Jet R_{AA} at RHIC

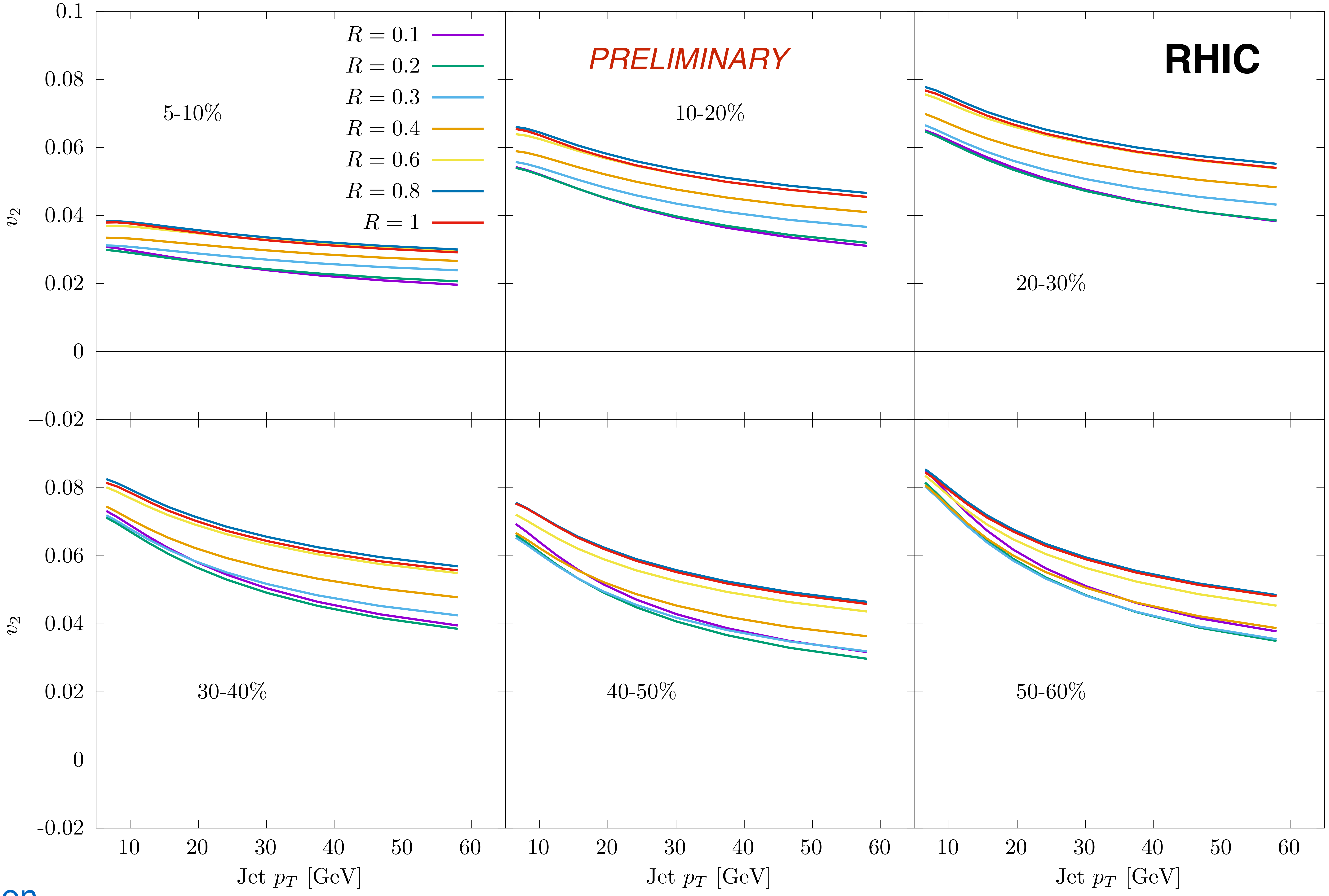
- Even milder R dependence than at LHC.
- In agreement with STAR data.



Mehtar-Tani, DP, Tywoniuk - in preparation

Jet v_2 at RHIC

- Interesting grouping in v_2 for different R.
- R=0.3, and especially R=0.4, migrate as a function of centrality.

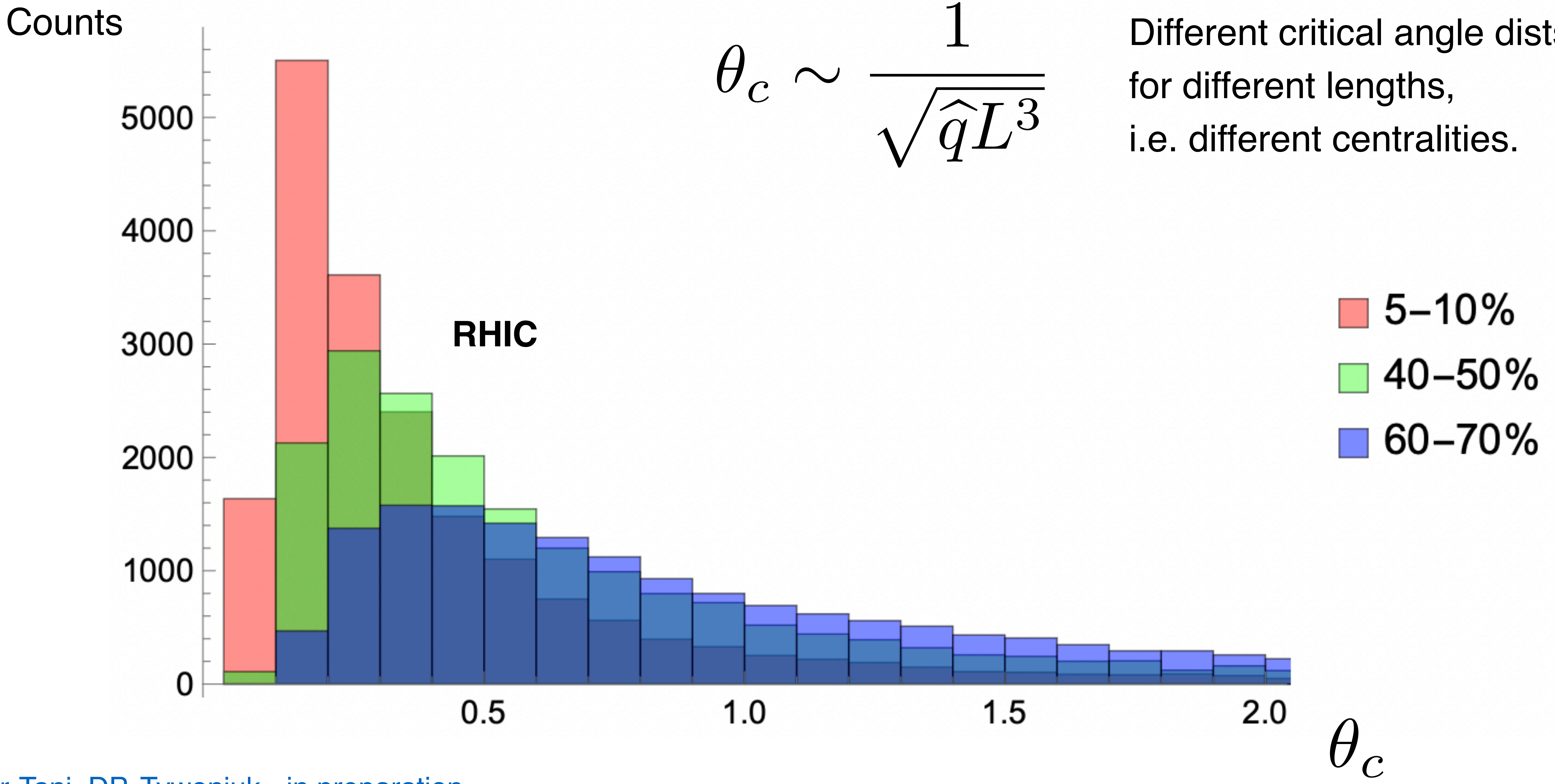


Mehtar-Tani, DP, Tywoniuk - in preparation

Coherence vs. Centrality

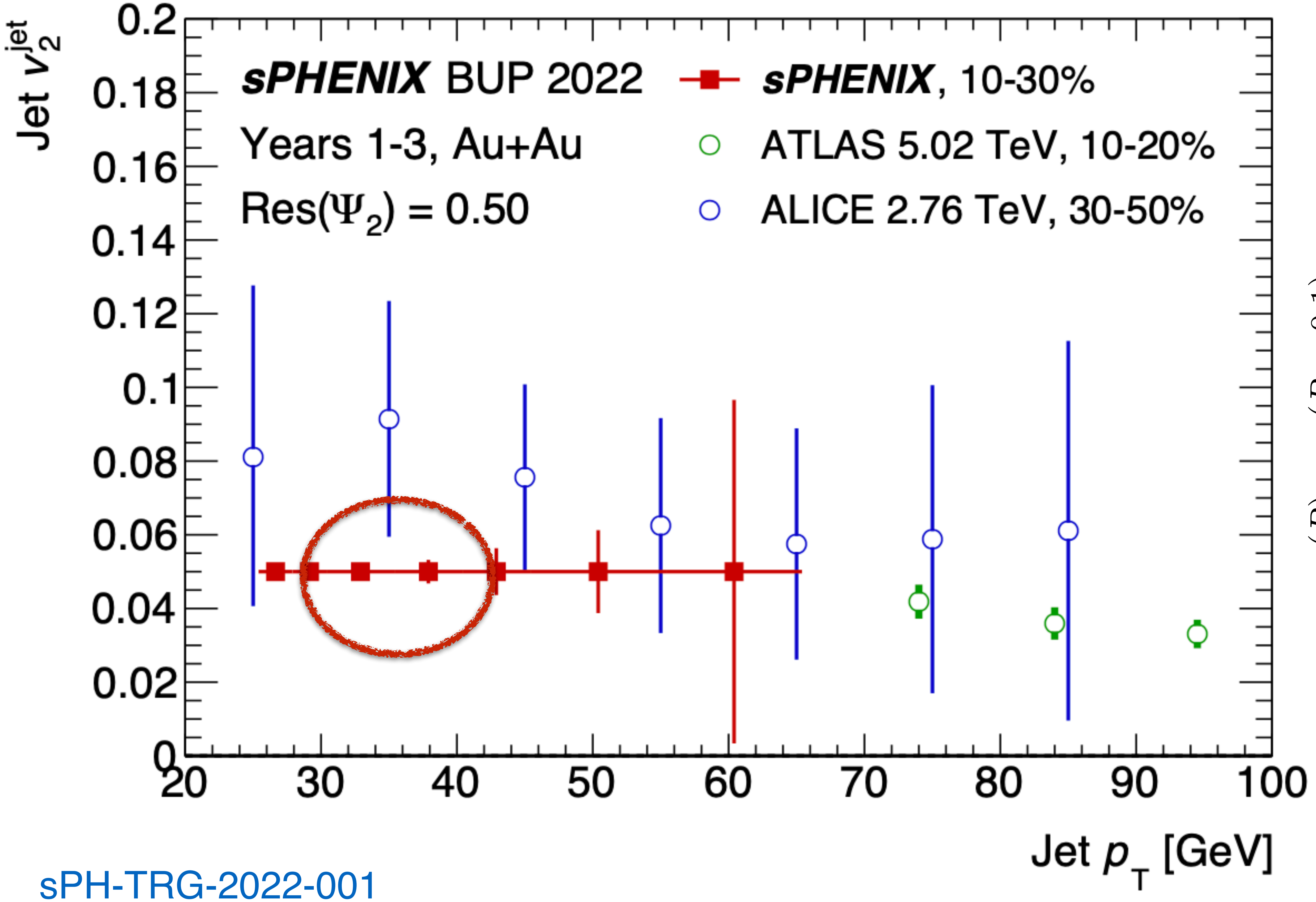
$$\theta_c \sim \frac{1}{\sqrt{\hat{q}L^3}}$$

Different critical angle dists.
for different lengths,
i.e. different centralities.



Mehtar-Tani, DP, Tywoniuk - in preparation

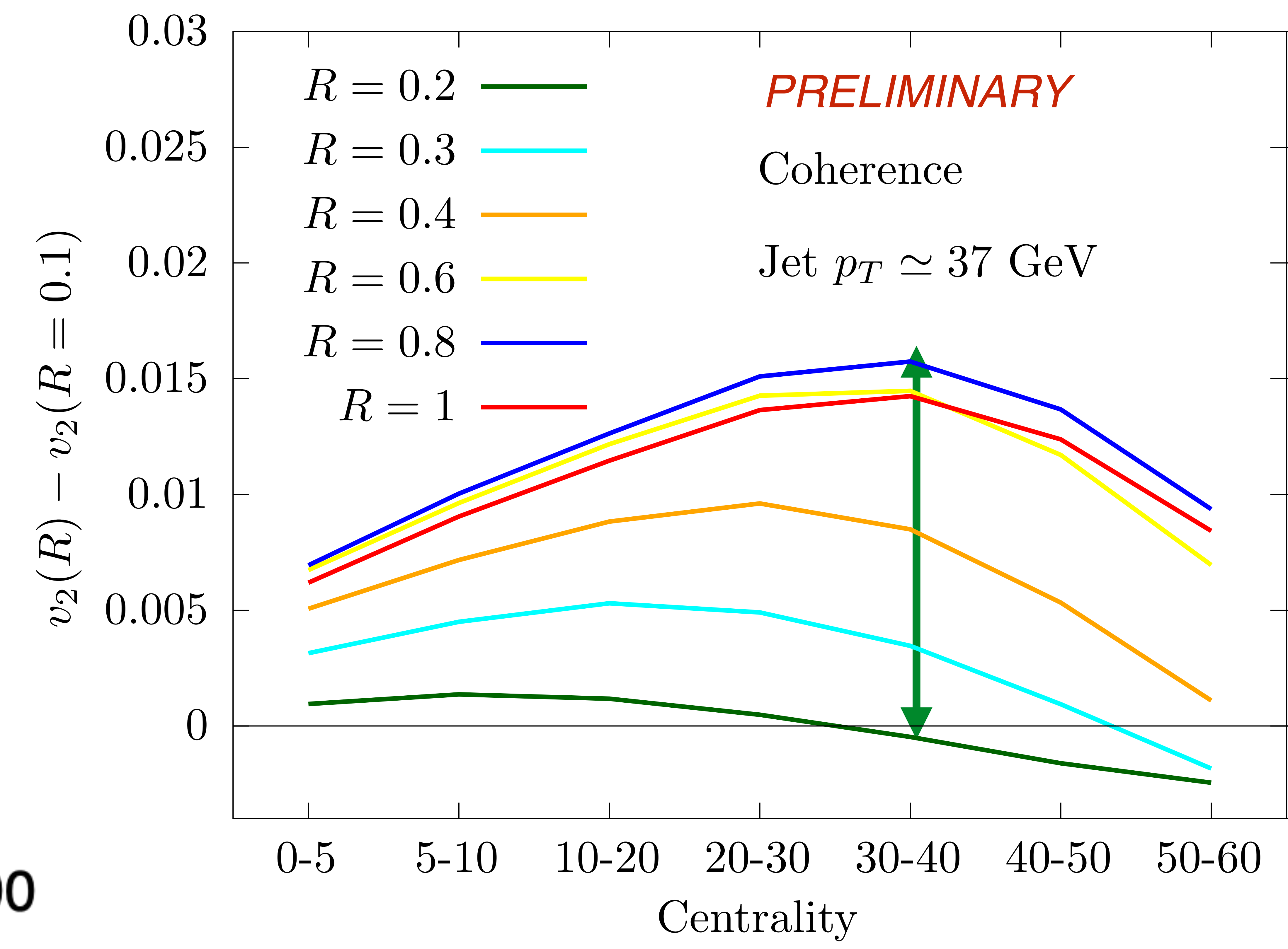
Jet v_2 & Coherence Effects



sPH-TRG-2022-001

Mehtar-Tani, DP, Tywoniuk - in preparation

RHIC



- Effect can be measured by sPHENIX.

$$\frac{v_2}{e} \approx \begin{cases} 0 & \text{for } R < \theta_c \\ \frac{3\bar{\alpha}}{2} \ln \frac{p_\perp}{\omega_c} (1 - Q_g) & \text{for } R > \theta_c \end{cases}$$

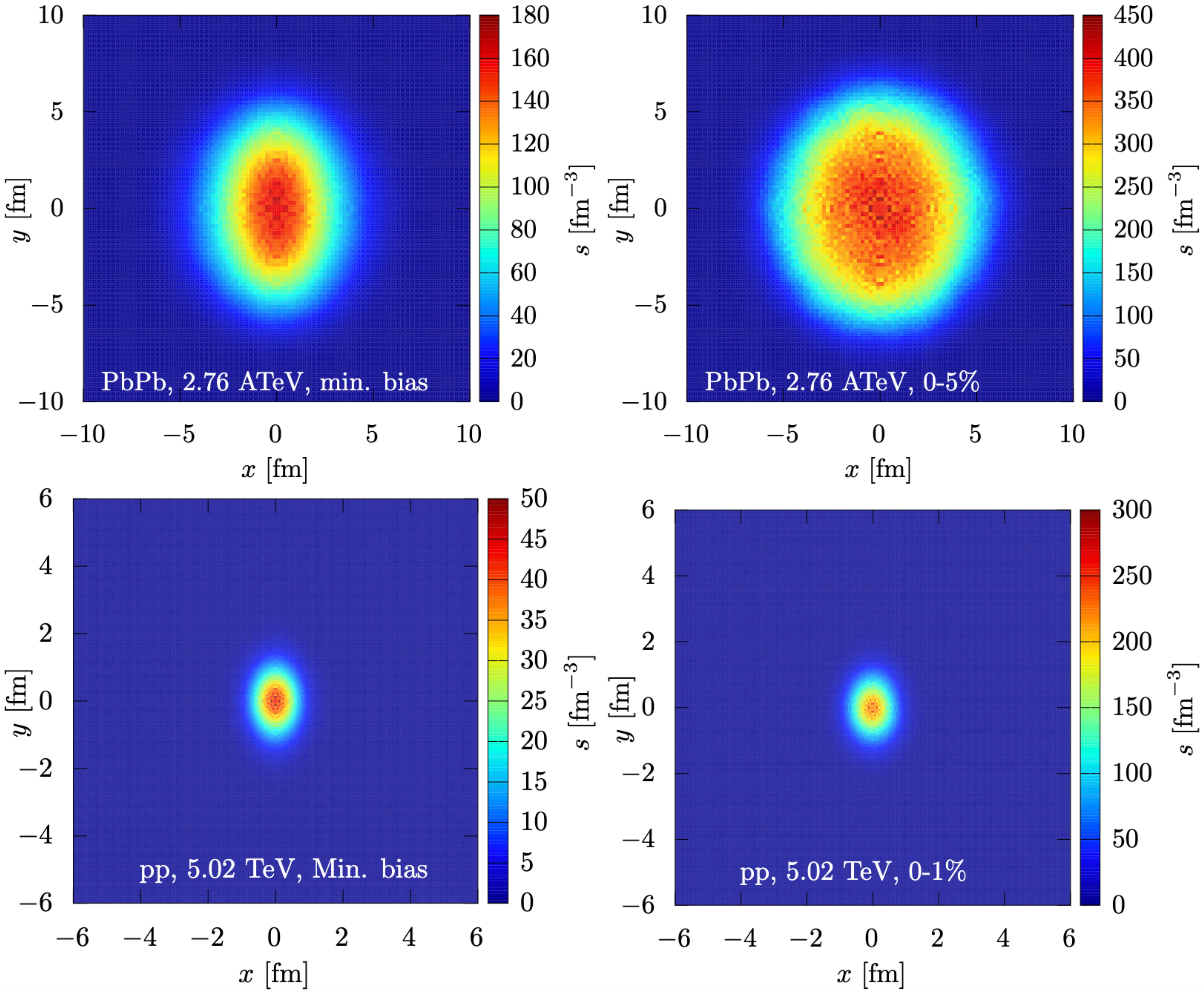
QGP in Small Systems

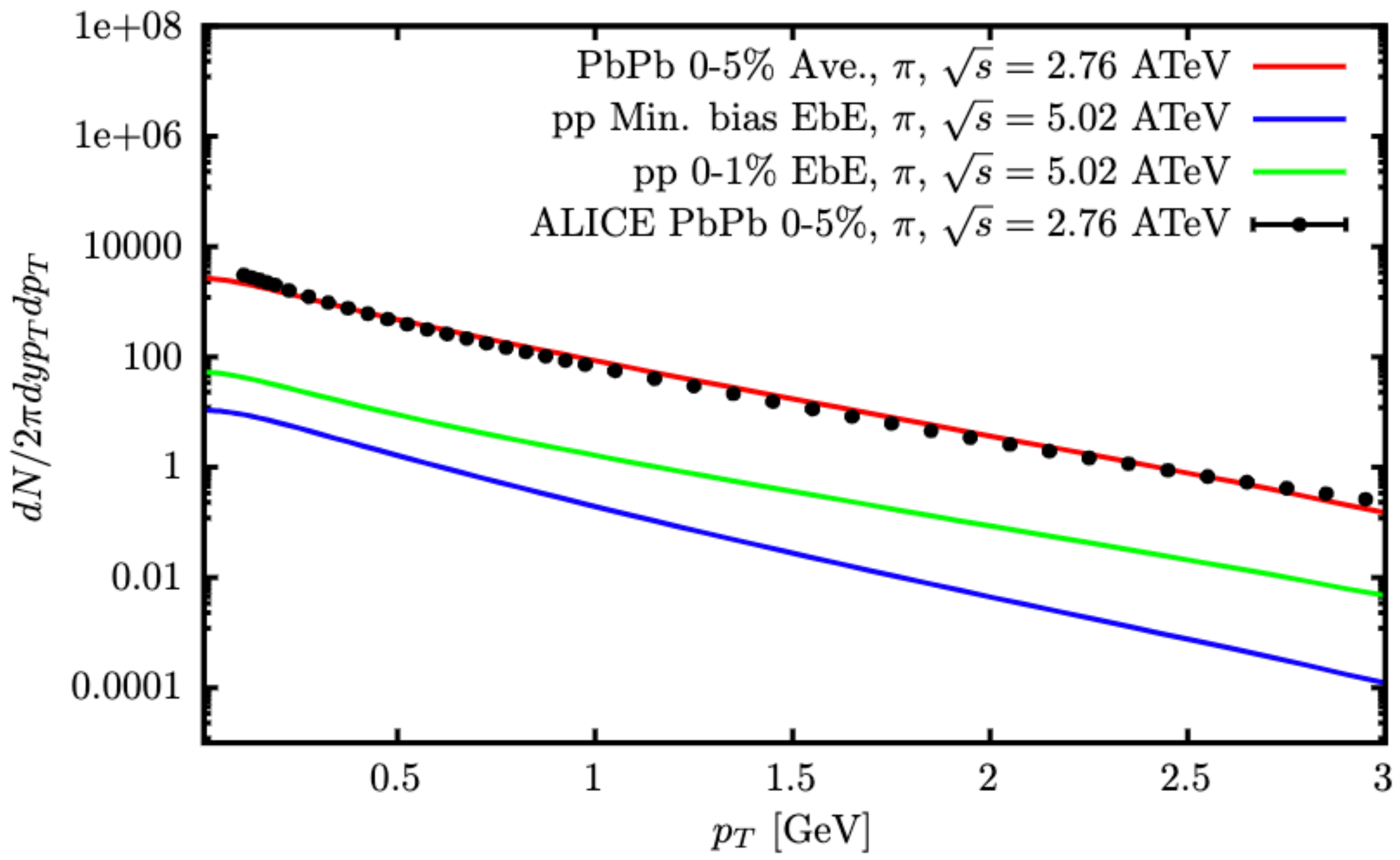
A. Beraudo, M. Monteno,
M. Nardi, DP,
A. De Pace, F. Prino
- in preparation

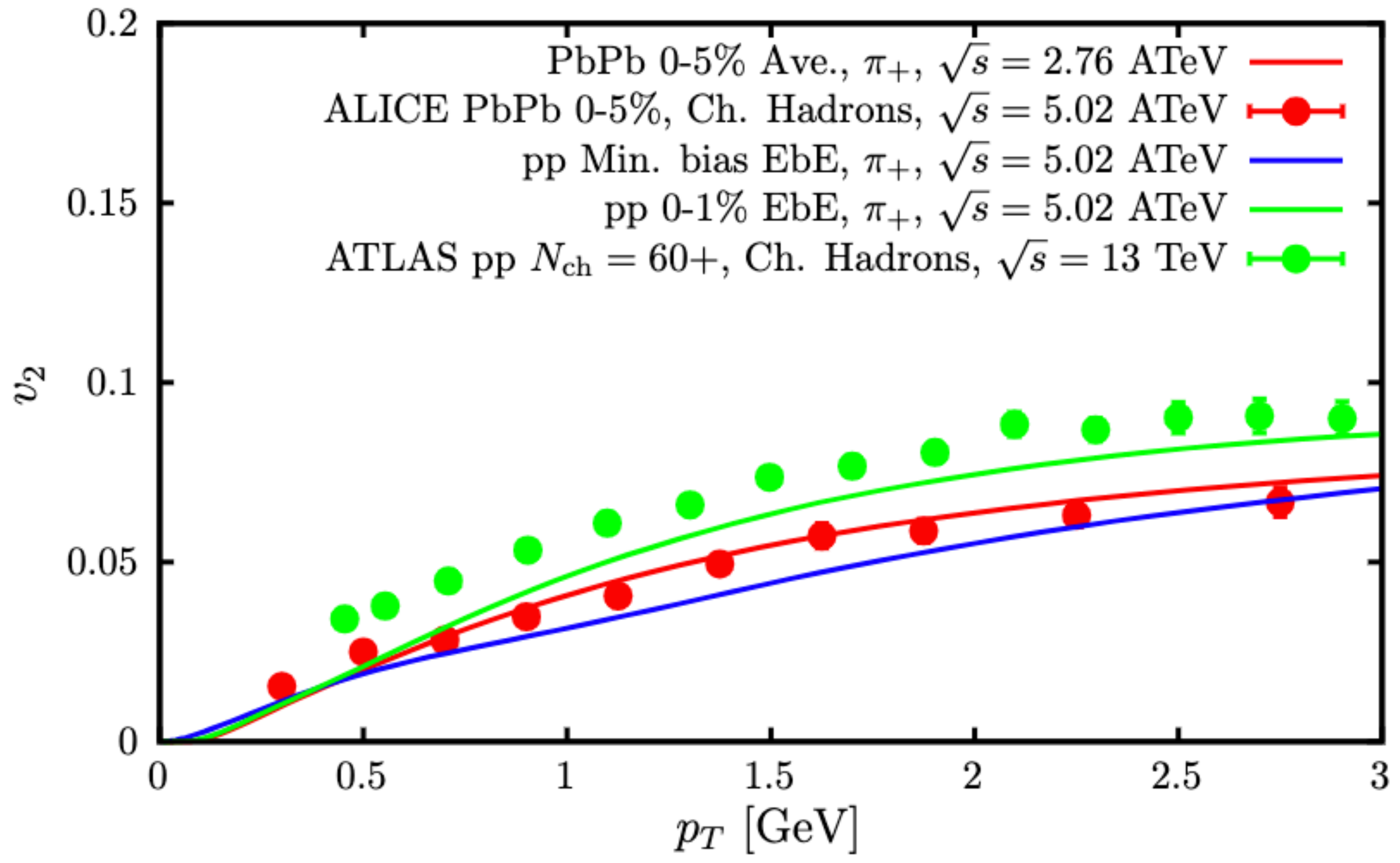
- Assume QGP formation (i.e. deconfined matter) also in proton-proton collisions.

- Hydro at work with large gradients: hydrodynamic attractors.

Example: averaged initial conditions





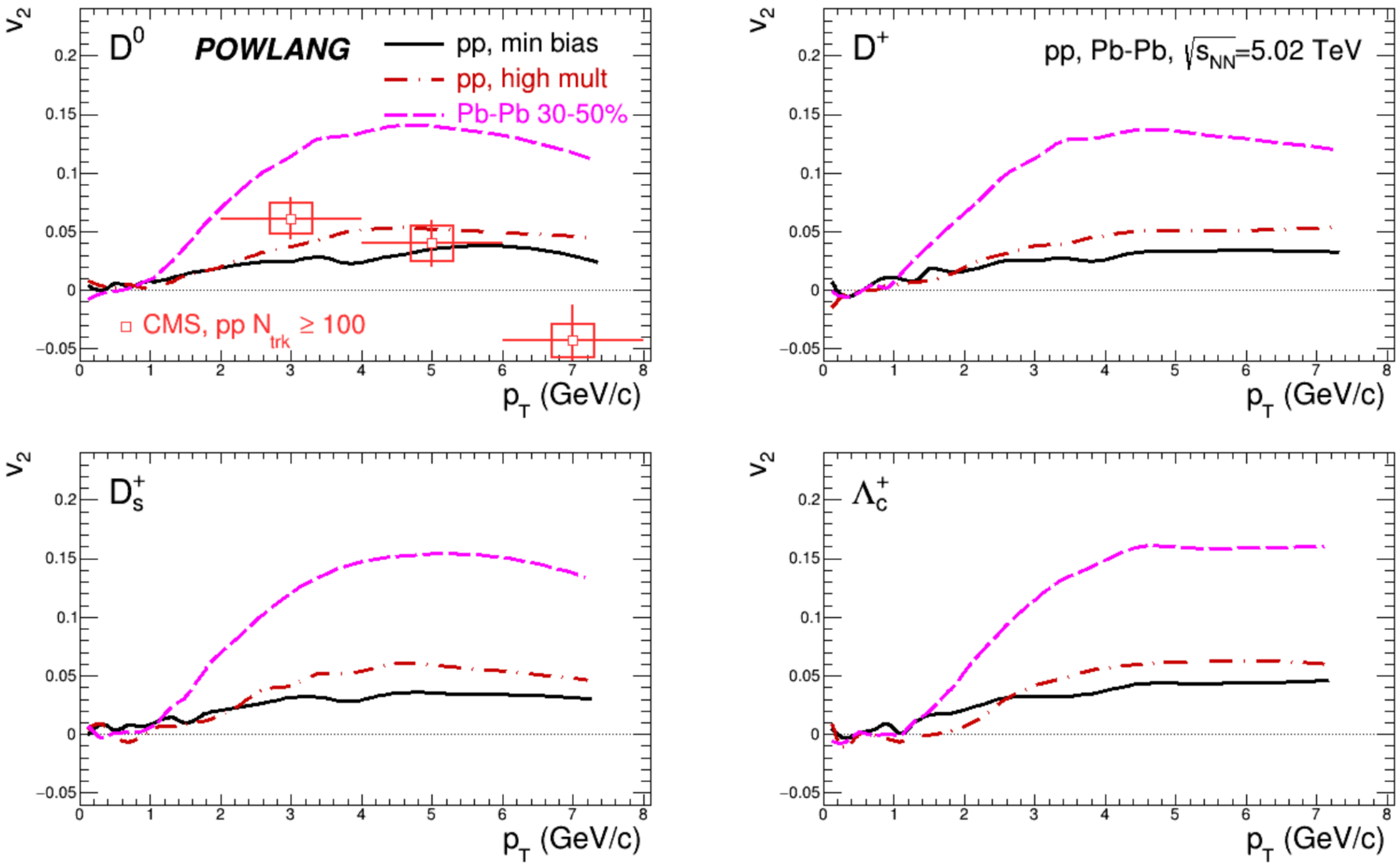


- Obtain good description of measured spectra and flow coefficients for charged particles.

A. Beraudo, M. Monteno,
M. Nardi, DP,
A. De Pace, F. Prino
- in preparation

Elliptic Flow of Charmed Hadrons in pp

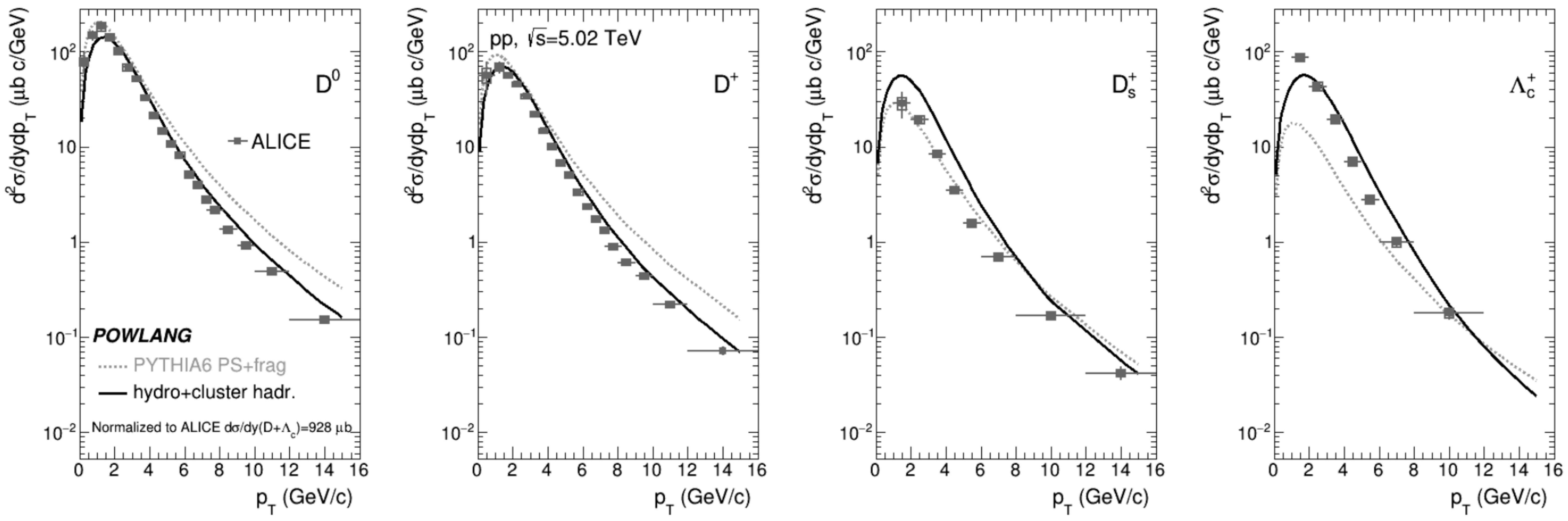
- New hadronization model: Create clusters with local reservoir of thermal colored objects (quarks, diquarks).



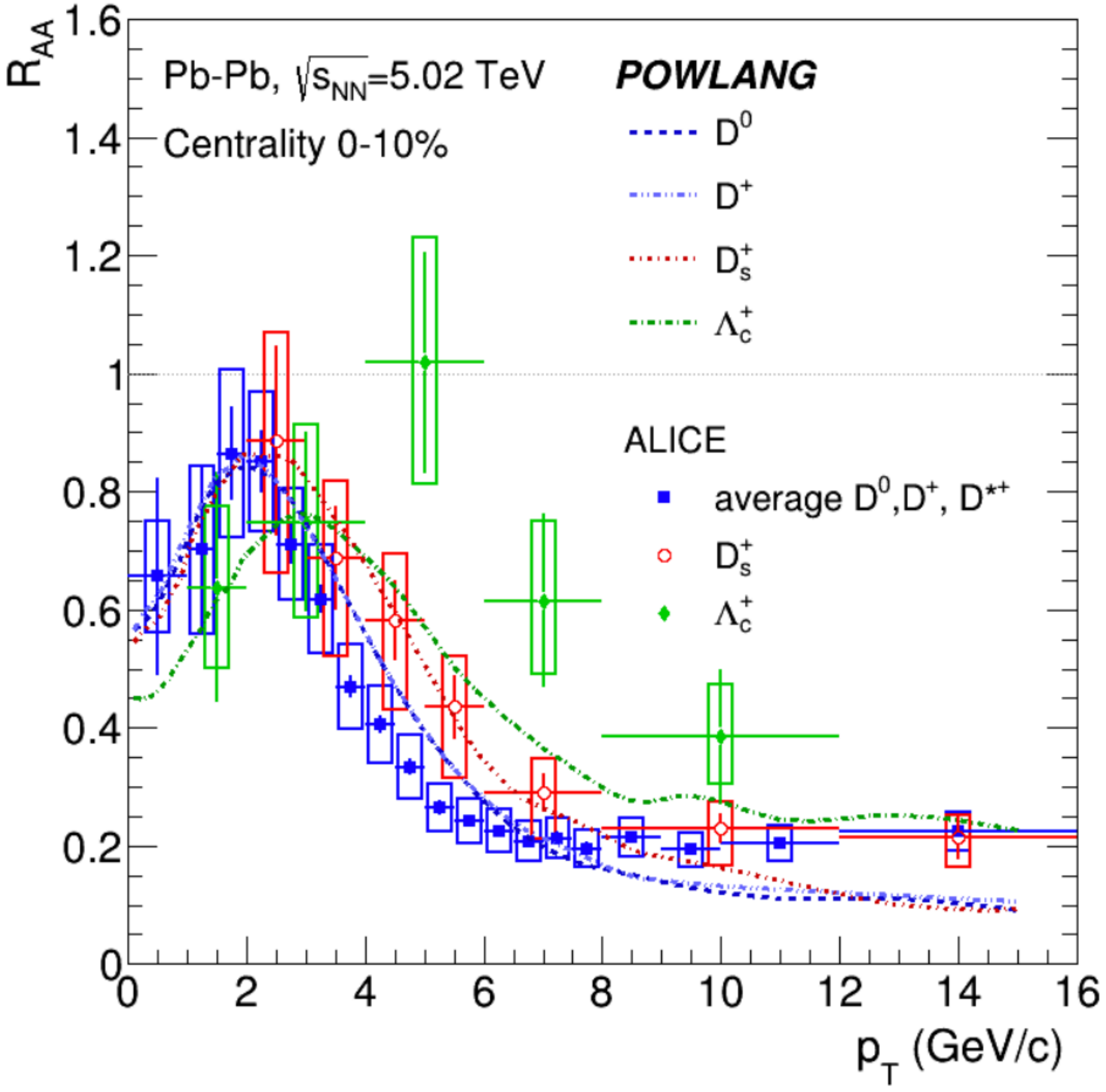
A. Beraudo, M. Monteno,
M. Nardi, DP,
A. De Pace, F. Prino
- in preparation

- Can describe elliptic flow of D meson in pp.
- Predictions for minimum bias pp and other hadrons.

Redefining Charmed Hadrons in pp



- Crucial improvement for spectra description in pp.



- Baseline for RAA calculations (PbPb over pp), Provides observed species dependence and radial-flow peak

A. Beraudo, M. Monteno, M. Nardi, DP, A. De Pace, F. Prino - in preparation

Summary

- Use quark enriched sample to disentangle physical biases. Exploit rapidity evolution of q-fraction.
  - → If there is still jet substructure narrowing in quark enriched sample, then medium can resolve jet substructure.

Improved detector acceptance in HL-LHC era.

- R-dependence of jet v_2 is quite sensitive to coherence physics.
  - → Average value of critical angle acts as a filter, groups curves into two classes.
  - → Motivates measuring R-dependent jet v_2 in future runs at RHIC and LHC.

- Can use holography to improve the phenomenology of strongly coupled probes:
  - → Transport coefficients of heavy quarks.
  - → Coherence physics via string splittings.

- Flowing medium seems to be present also in small systems, e.g. pp collisions.
  - → Can describe properties of charmed hadrons (spectra & elliptic flow).
  - → Recent progress on understanding the dynamics of *deconfined QCD matter*.