Recent ALICE jet study highlight

Wenqing Fan on behalf of the ALICE Collaboration

2nd workshop on advancing the understanding of non-perturbative QCD using energy flow, 11/09/2023

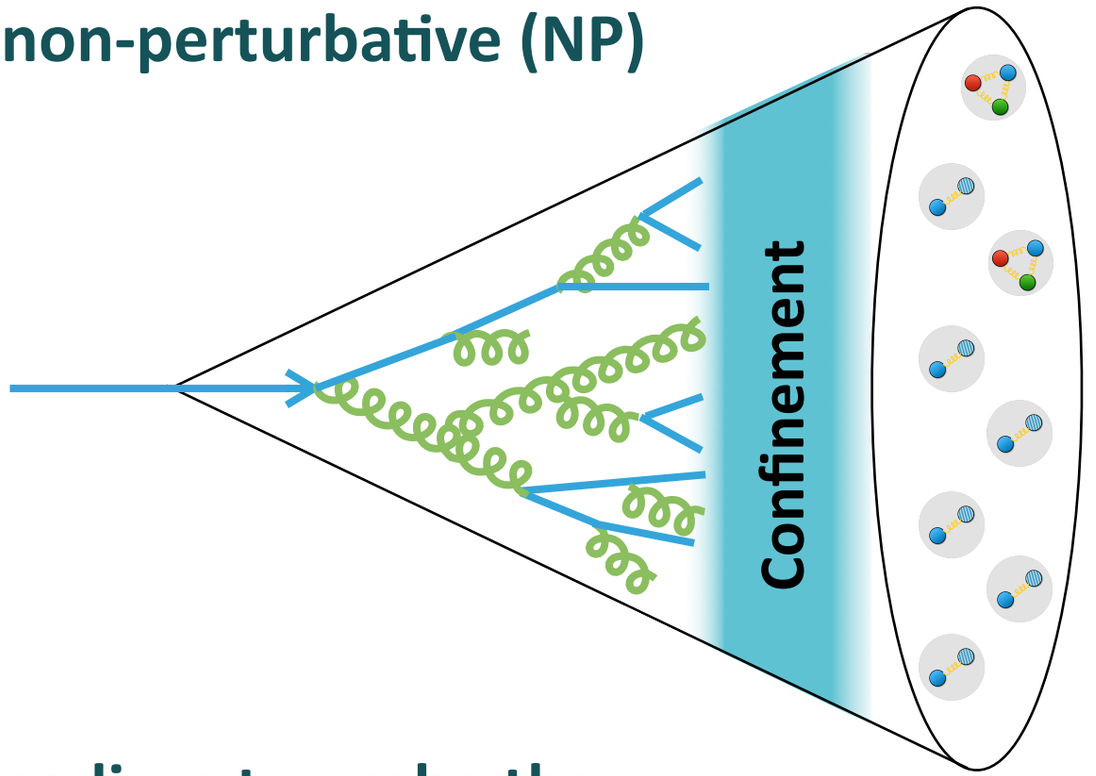
Center for Frontiers in Nuclear Science

BERKELEY LAB

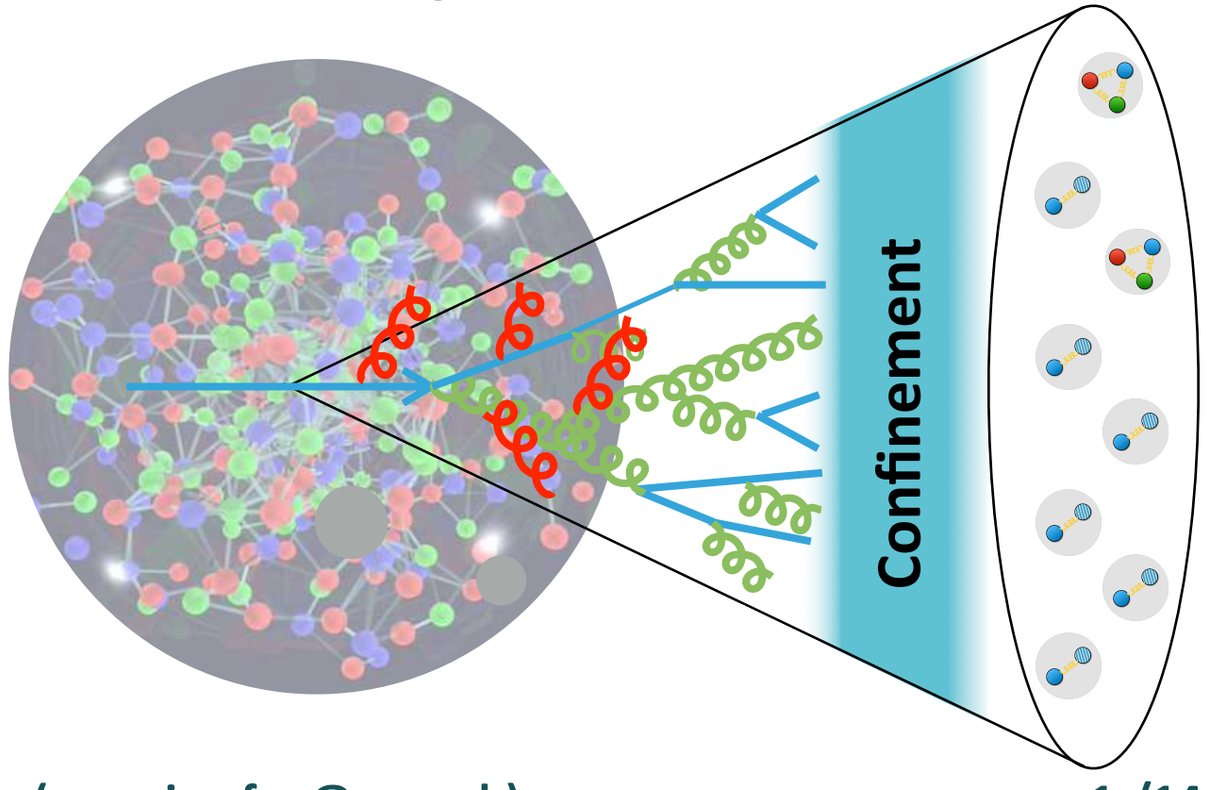
ALICE

Jet as object and probe

- **p+p: precision study of the perturbative and non-perturbative (NP) aspects of QCD in vacuum**
  - **What can we learn about perturbative interactions between q/g?**
  - **What can we learn about the NP effects (hadronization)?**
  - **What is the role of color charge and mass?**

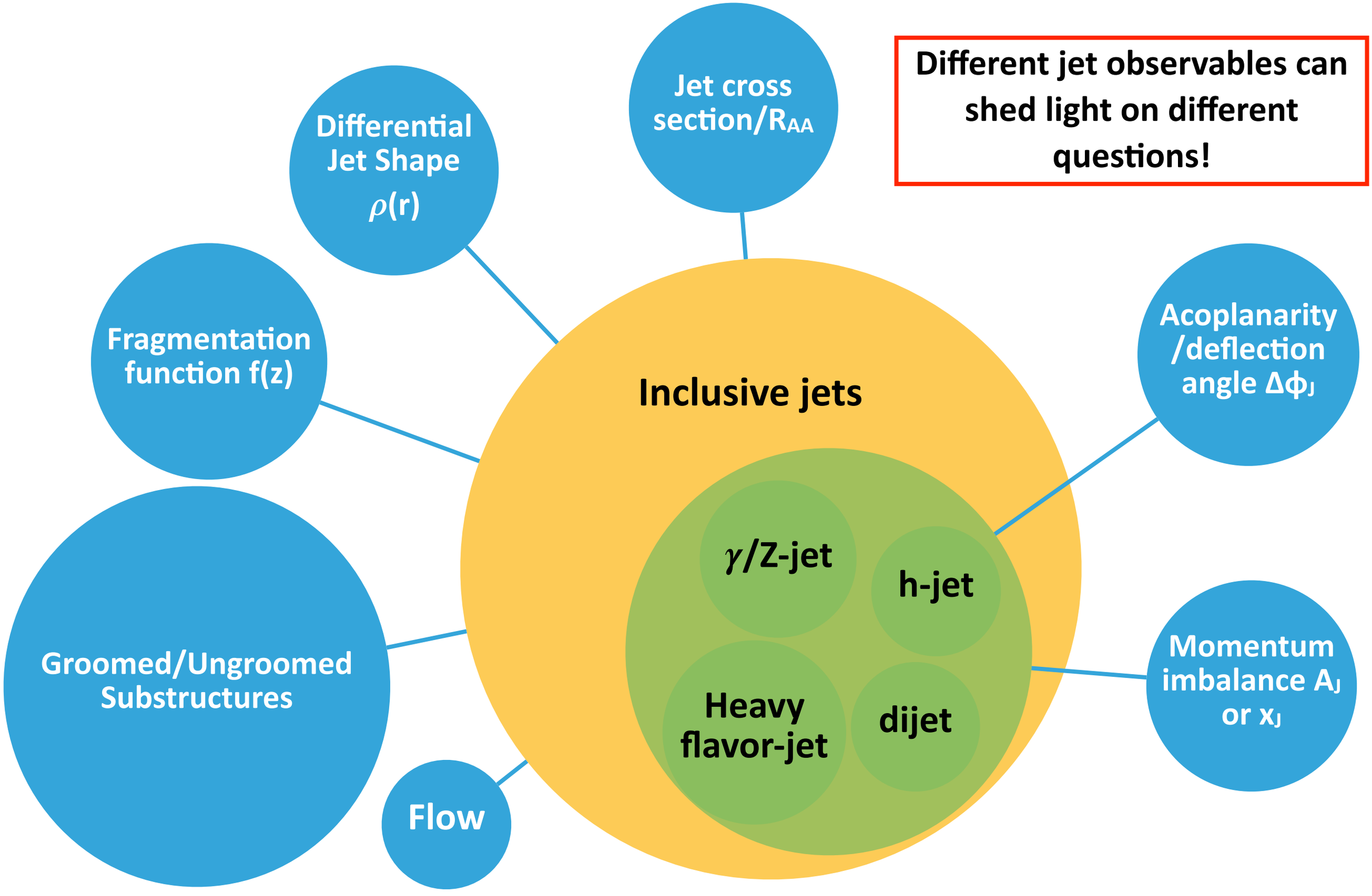


- **A+A: use the interplay between jet and the medium to probe the properties of QGP**
  - **How does the medium modifies the jet?**
  - **What is the path-length dependence? What is the role of parton color charge and mass?**
  - **Properties of QGP: medium size, transport coefficient, coherence length, quasi-particles?**



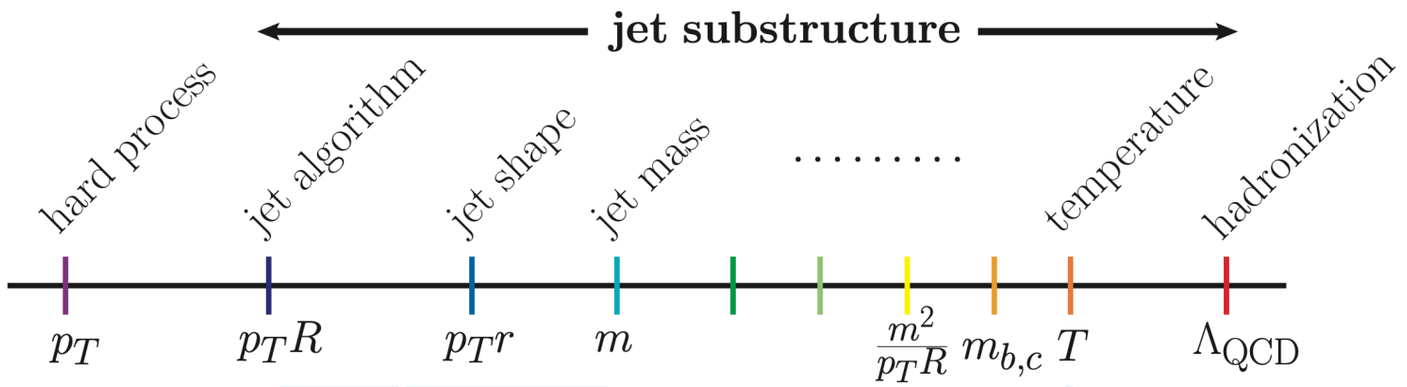
A (incomplete) roadmap of jet measurements

Different jet observables can shed light on different questions!



Unravel different QCD scaled with jet substructures

YangTing Chien QM18



Access different QCD scales with jet substructures

Inclusive jets

Groomed/ Ungroomed Substructures

- r_g or θ_g
- z_g
- $k_{T,g}$
- Jet charge
- Lund plane
- Energy correlators
- Angle between jet axes
- Angularity

Fragmentation fu…(z)

Acoplanarity /deflection angle $\Delta\phi_J$

γ/Z-jet

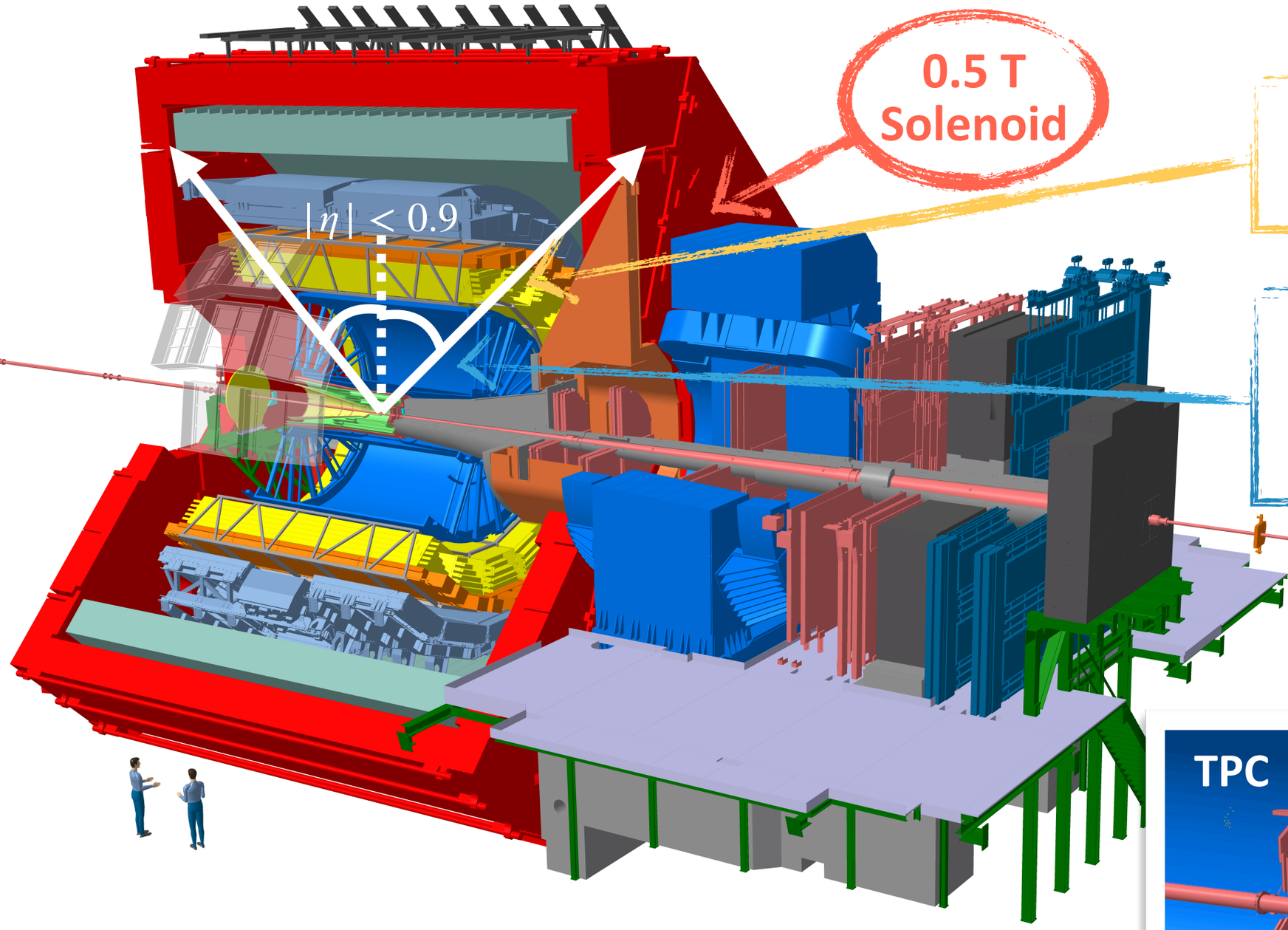
h-jet

Heavy flavor-jet

dijet

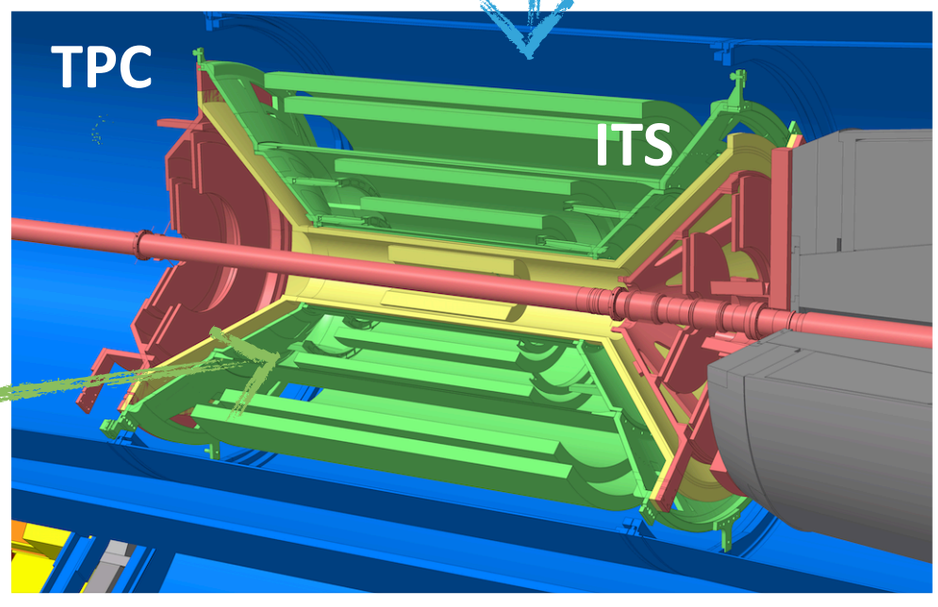
Momentum imbalance A_J or x_J

ALICE detector



Time of flight (TOF): PID via time of flight

Time projection chamber (TPC): tracking and PID via dE/dx

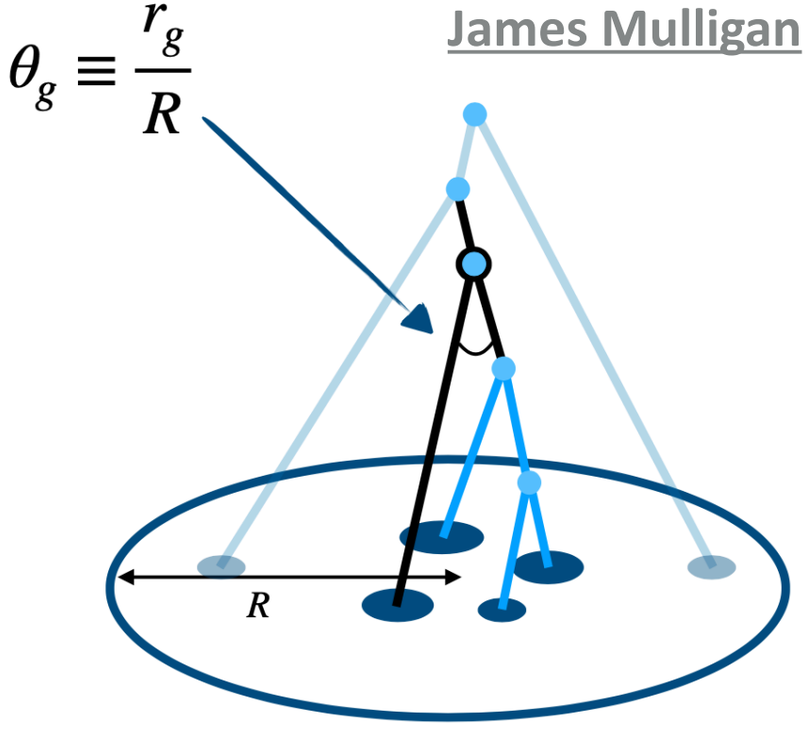


Inner tracking system (ITS): tracking and vertexing

Groomed jet radius

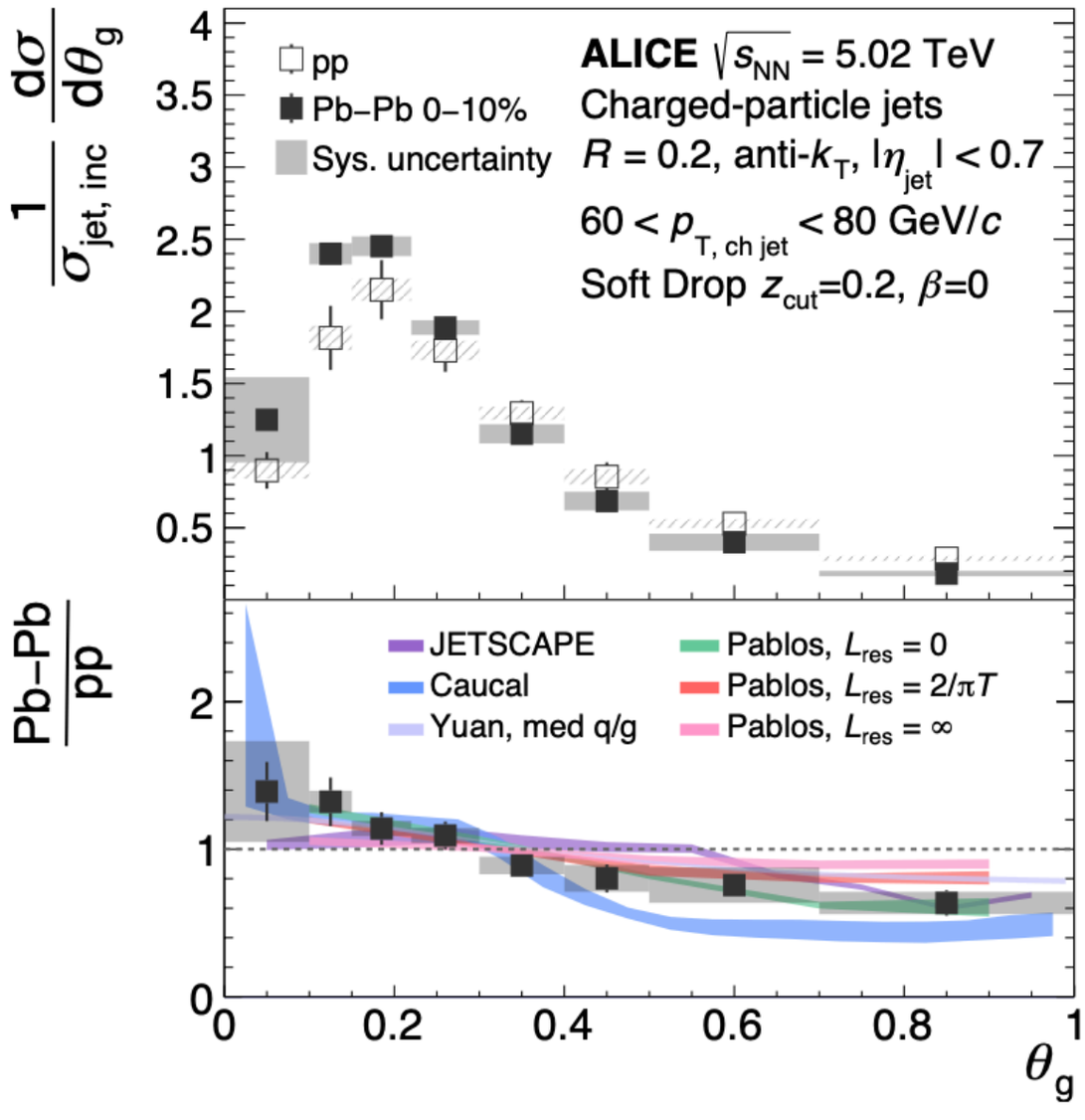
- How the hard splitting core of jet is modified? Does the jet quenching magnitude depends on that?
- Grooming: access to the hard parton structure of a jet
  - Remove the large angle soft radiation (suppress UE)

Figure credit:
James Mulligan



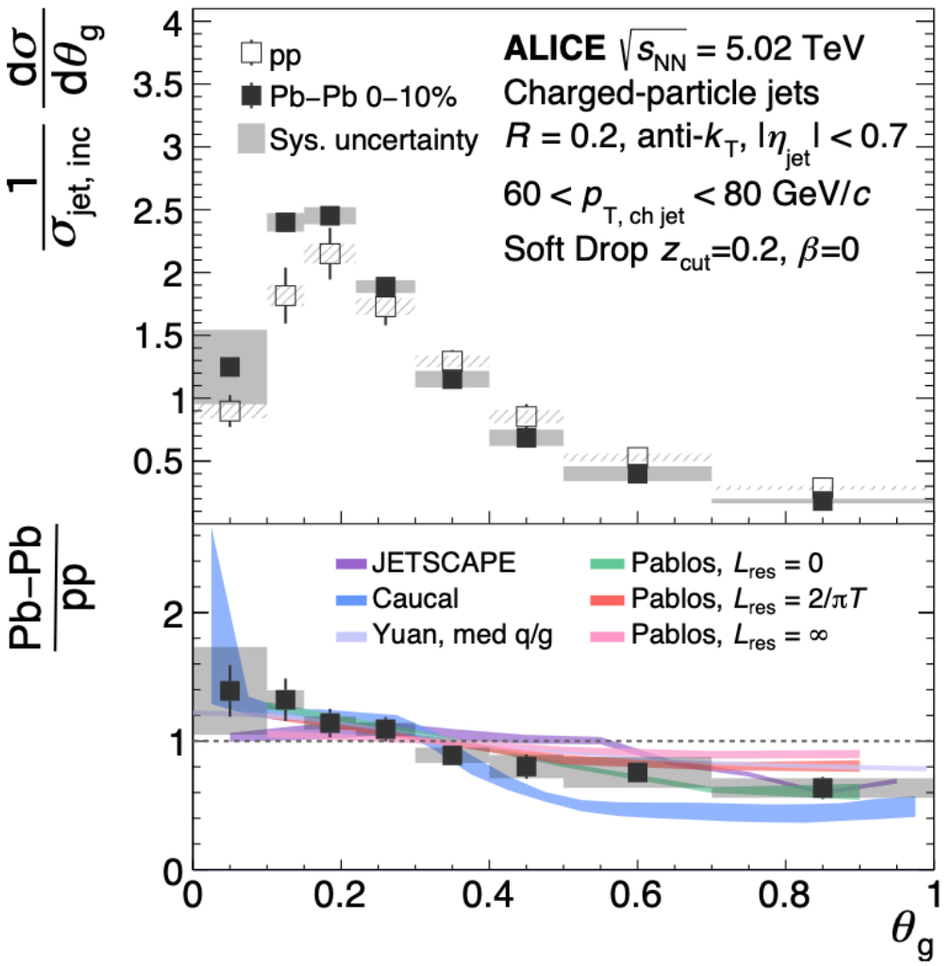
The cores of jets are narrower in PbPb compared to pp

PRL 128, 102001 (2022)



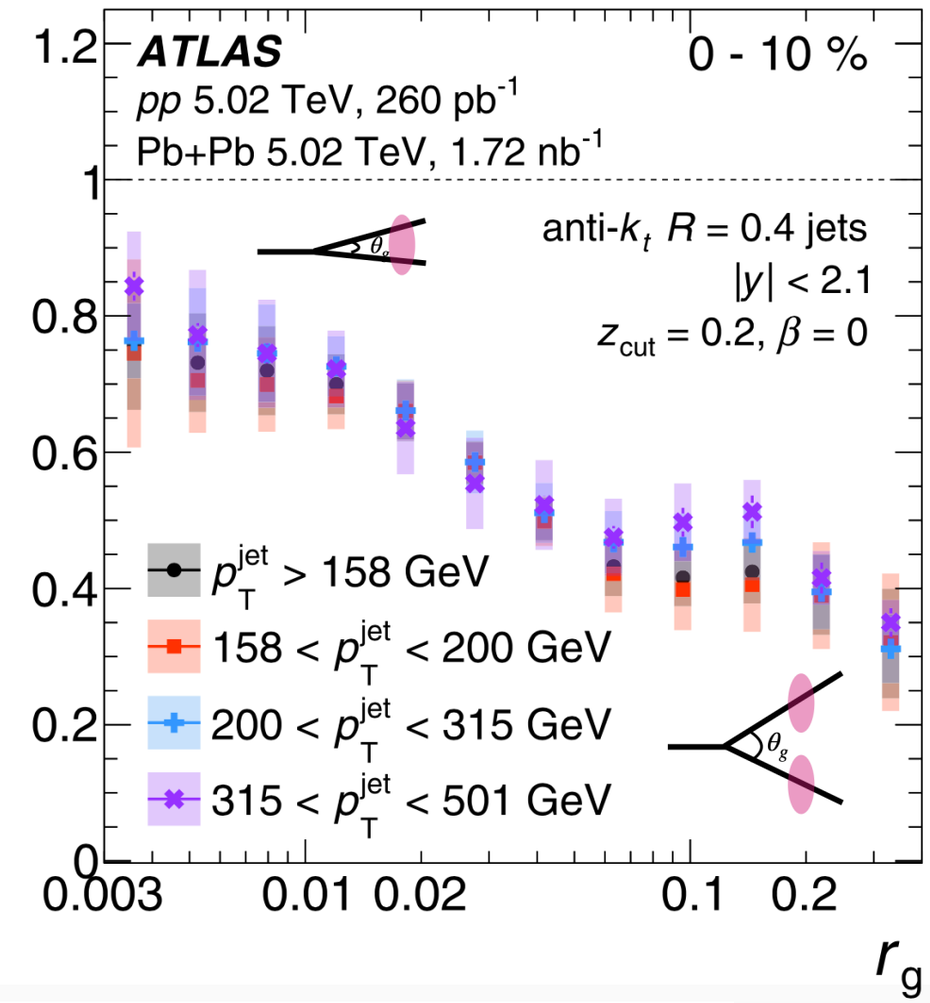
Jets with wider cores wider are more suppressed?

PRL 128, 102001 (2022)



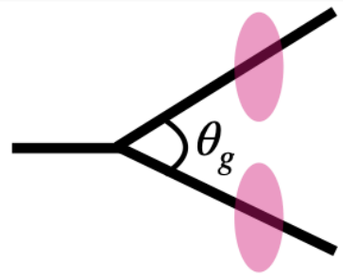
Narrowing of jet core: jets with wider cores are more suppressed

Phys. Rev. C 107, 054909 (2023)



- Two possible explanations:
  - Wider jets are more resolved by medium: sensitive to QGP resolution scale (θ_c)
  - Wider gluon jets are more suppressed as compared to narrower quark jets: color charge difference

$\theta_g > \theta_c$



$\theta_g < \theta_c$

Energy-Energy Correlators (EECs): energy correlation inside jets

$$\frac{\mathrm{d}\sigma_{\mathrm{EEC}}}{\mathrm{d}R_{\mathrm{L}}} = \sum_{i,j} \int d\sigma(R'_{\mathrm{L}}) \frac{p_{\mathrm{T},i}\, p_{\mathrm{T},j}}{p^2_{\mathrm{T,jet}}} \delta(R'_{\mathrm{L}} - R_{\mathrm{L},ij})$$

Energy weight

Angular distance

$$R_{\mathrm{L}} = \sqrt{\Delta\varphi_{ij}^2 + \Delta\eta_{ij}^2}$$

Step 1. Jet clustering

Step 2. Count number of weighted track pairs as function of R_L

$\langle \Psi | \mathcal{E}(\hat{n}_1) \cdots \mathcal{E}(\hat{n}_k) | \Psi \rangle$

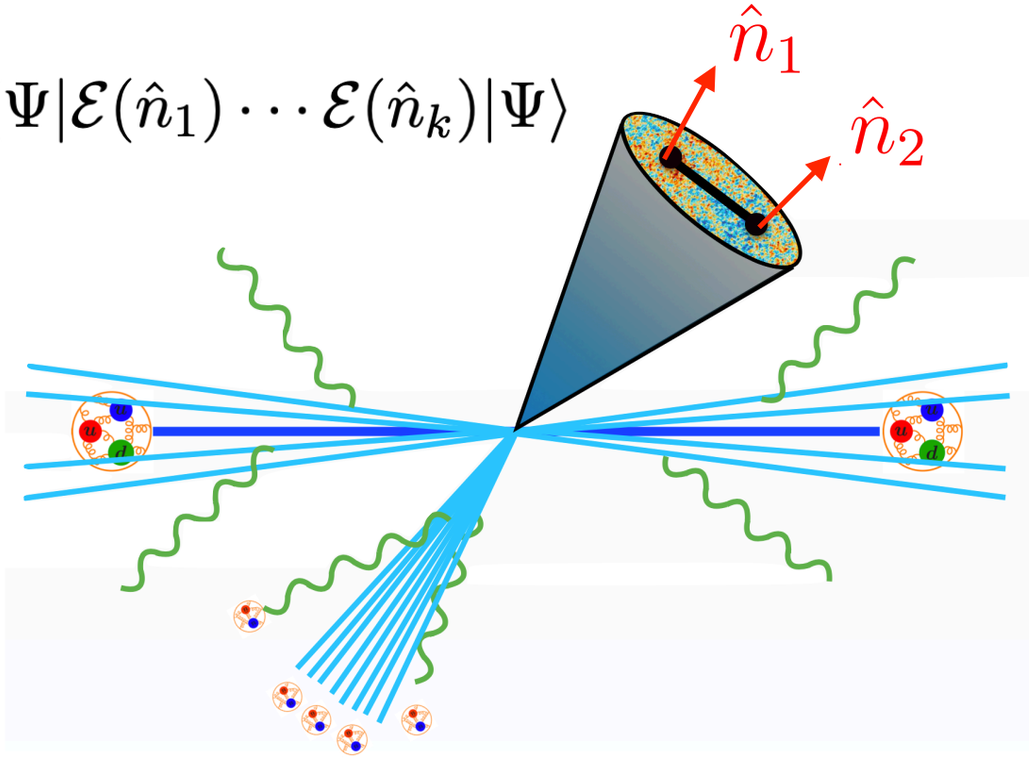
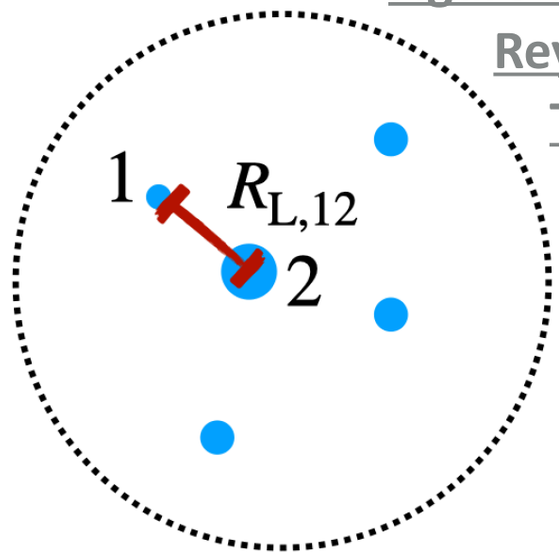
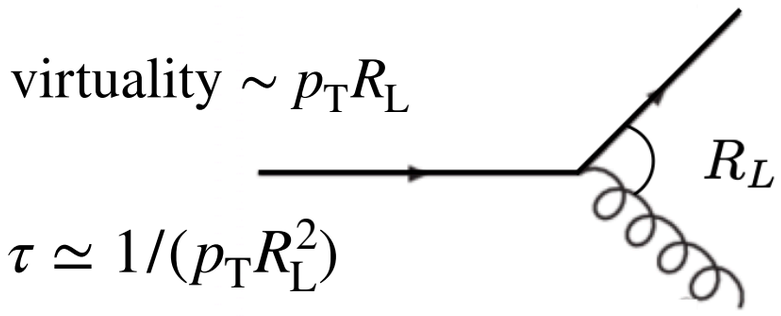


Figure credit: Rey Cruz Torres

$$\frac{p_{\mathrm{T},1}\, p_{\mathrm{T},2}}{p^2_{\mathrm{T,jet}}}$$



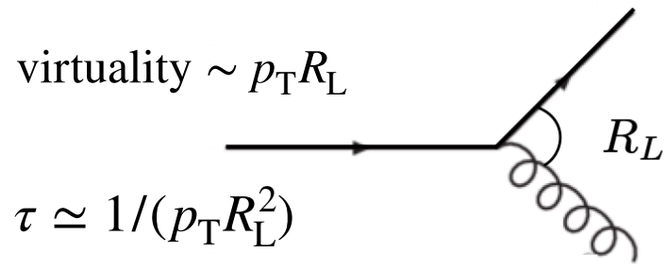
- **IRC safe and well-defined in QFT: correlation functions of the energy flux**
  - **pQCD calculation available for p+p**
  - **Soft radiation suppressed by energy weight**
  - **Probing fixed scale with fixed R_L**



Small R_L ← **Increasing τ / decreasing μ** → **Large R_L**

Clear separation of parton region and hadron region

When the virtuality approaches $\mathcal{O}(\Lambda_{QCD})$, EEC undergo transition into confinement region



Ananya Rai
Thursday 11:50 am

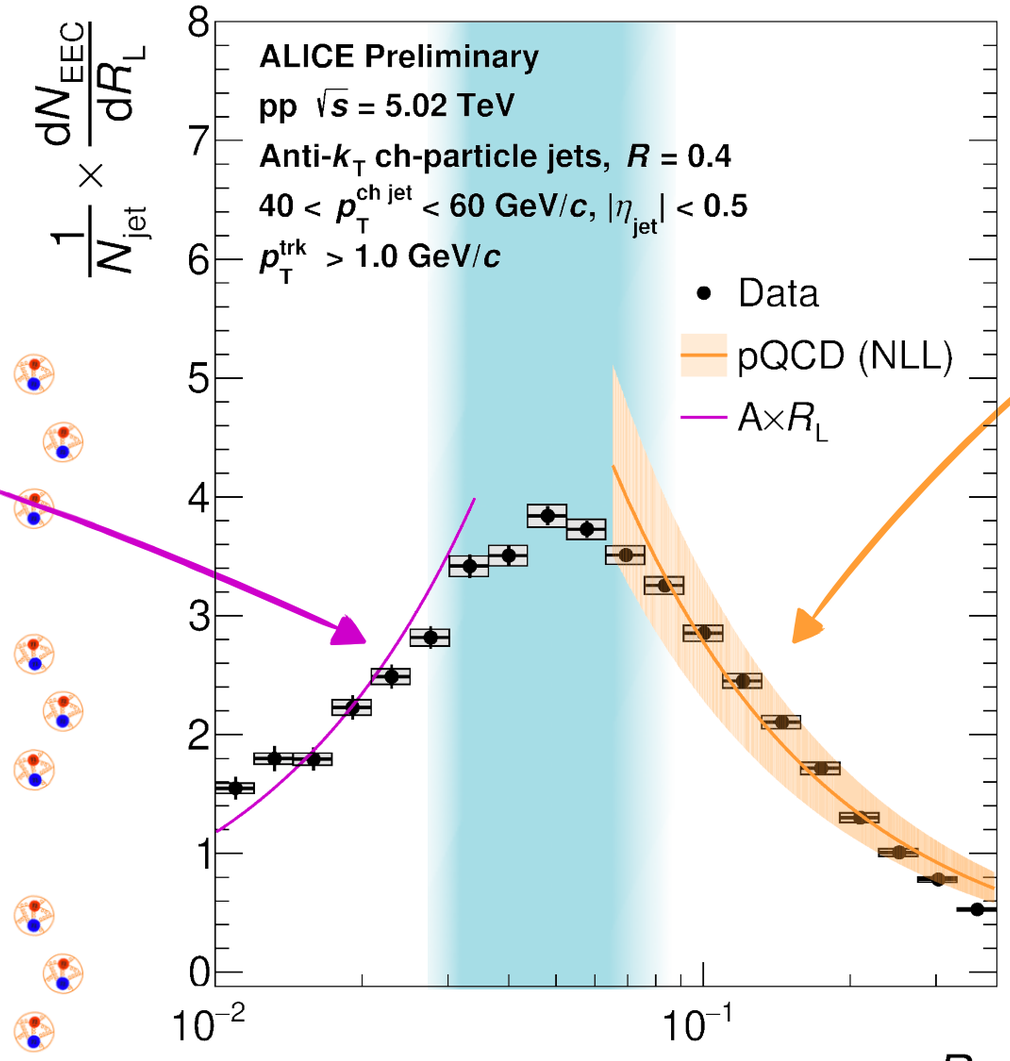
Andrew Tamis
Tuesday 17:00 pm

Confinement

Free hadron scaling (hadronic degree of freedom)

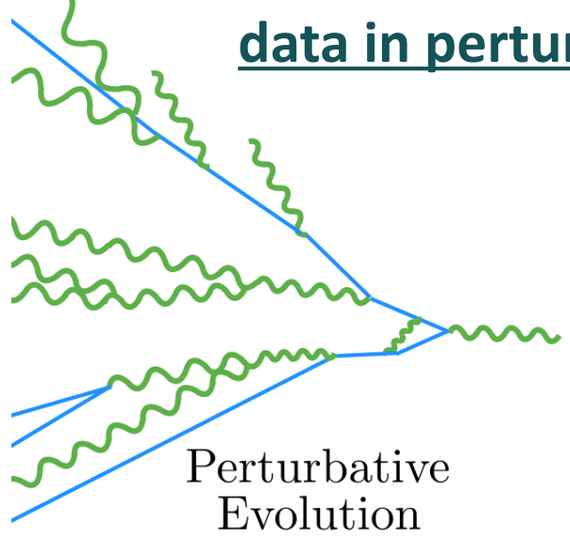
$$\frac{d\sigma}{dR_L^2} = \text{constant}$$

$$\rightarrow \frac{d\sigma}{dR_L} \propto R_L$$



pQCD scaling (partonic degree of freedom)

***pQCD prediction (arXiv:2205.03414) are normalized to data in perturbative region**



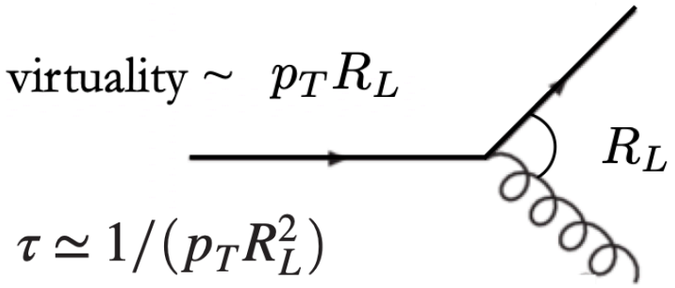
increasing time

Small angle ← → **Large angle**

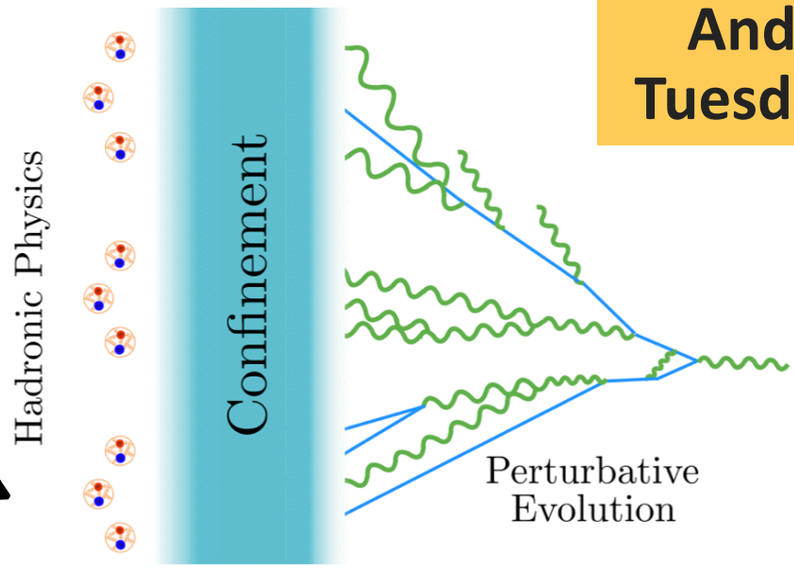
decreasing energy scale

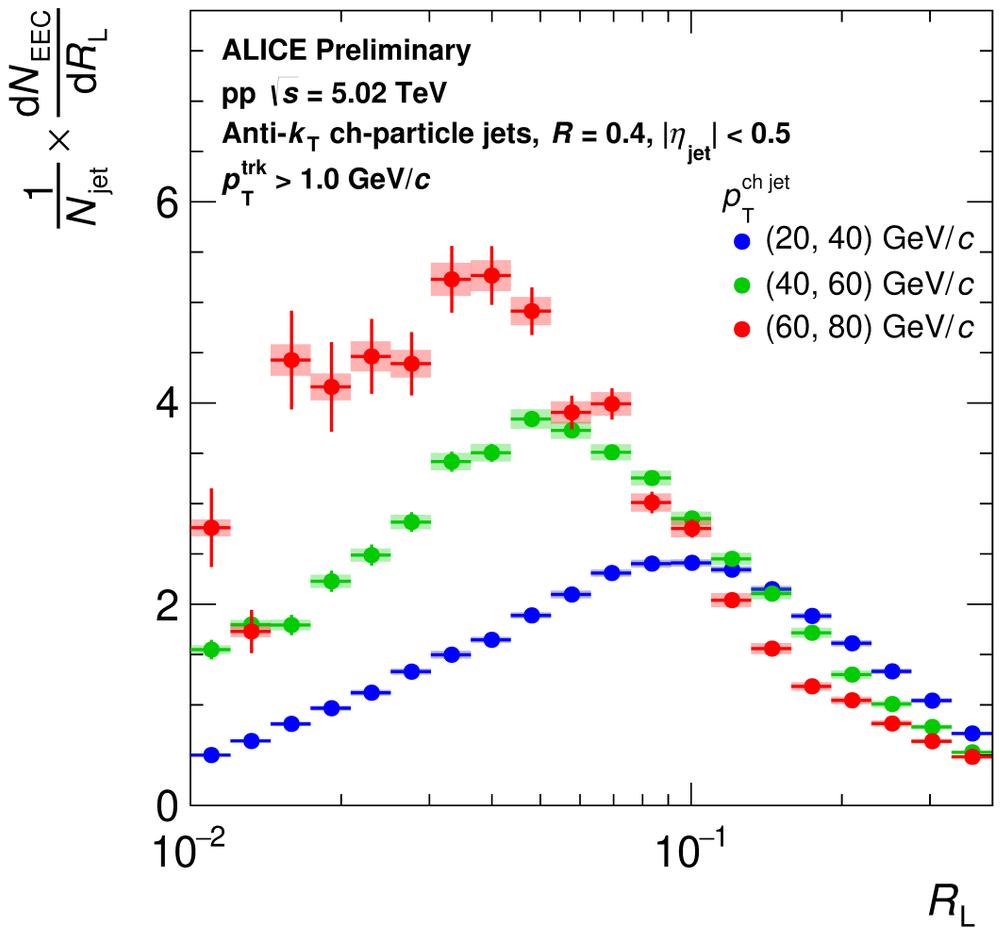
Universal behavior of the transition region

Andrew Tamis
Tuesday 17:00 pm



Scaling angle R_L by jet p_T and normalize y scale





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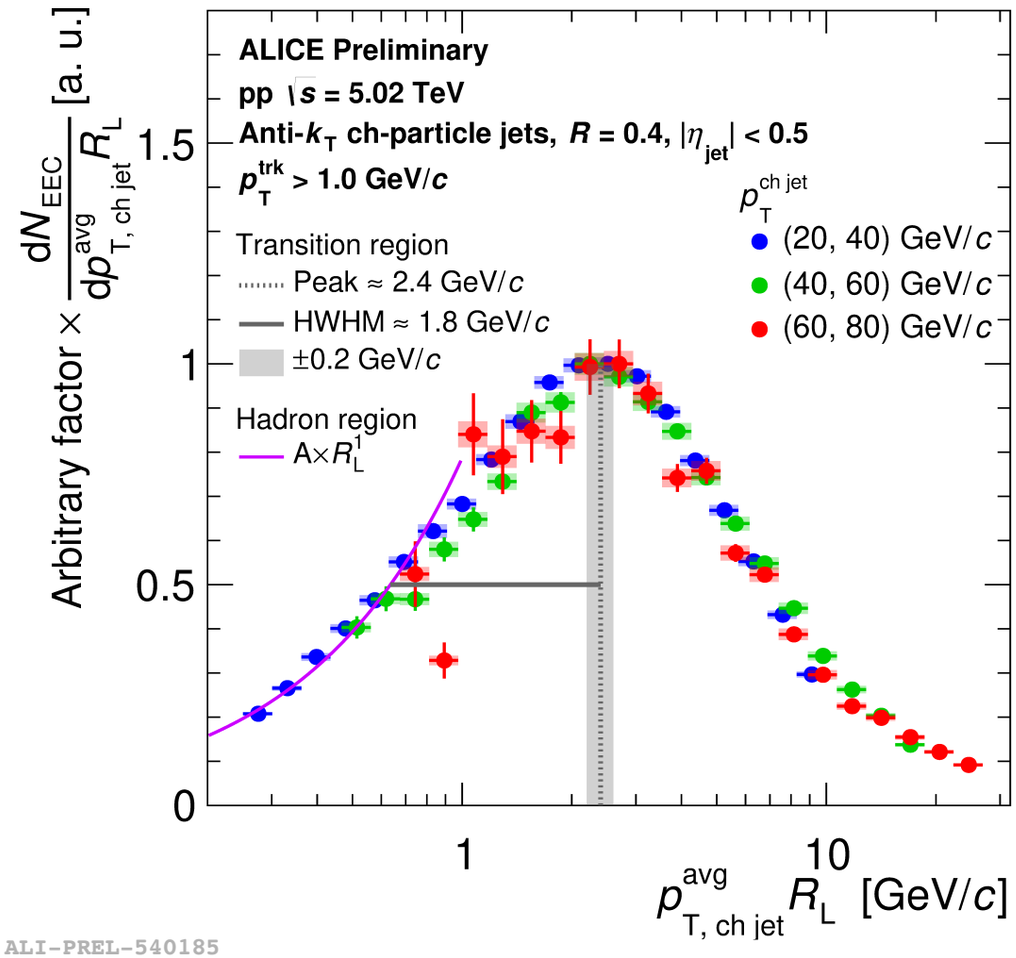
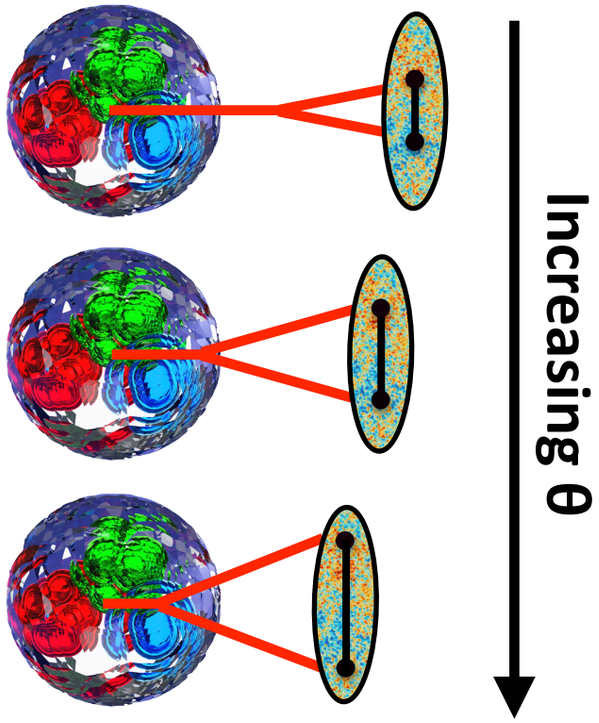


ALI-PREL-540185

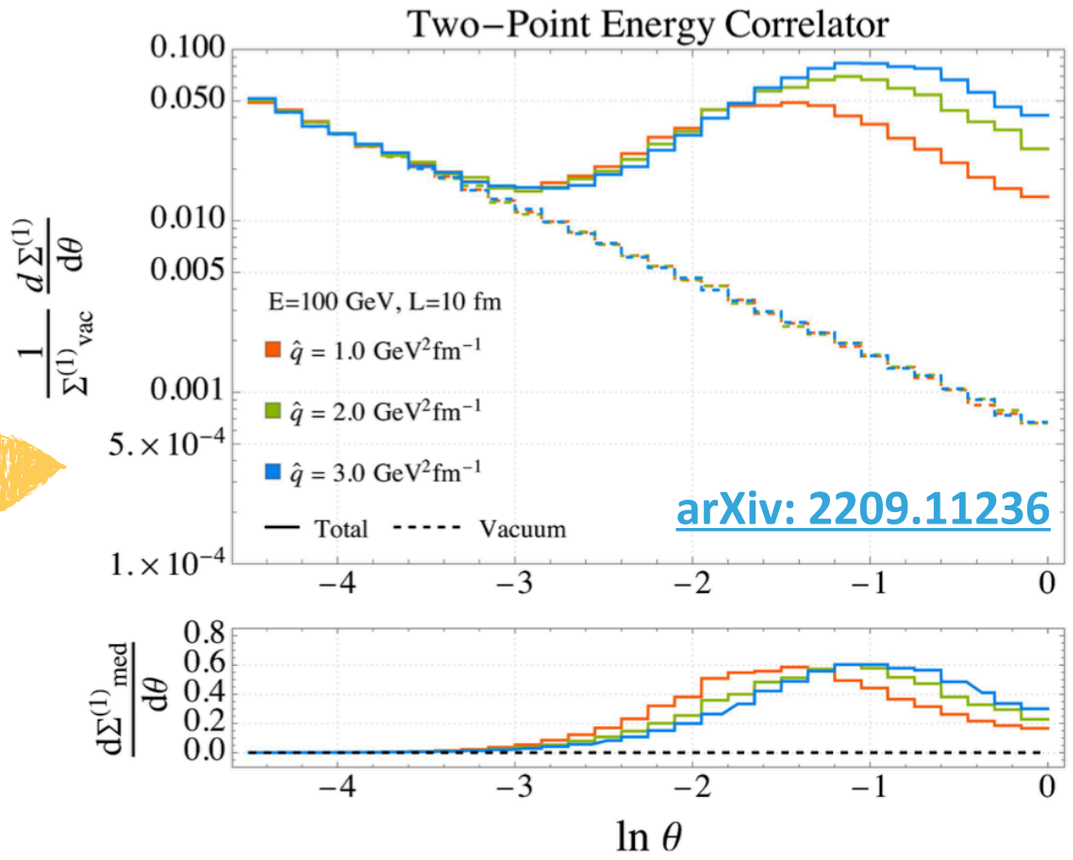
EEC distributions in different jet p_T bin have similar shape

Transition peak position ~2.4 GeV

Probing different scales in QGP with energy correlators

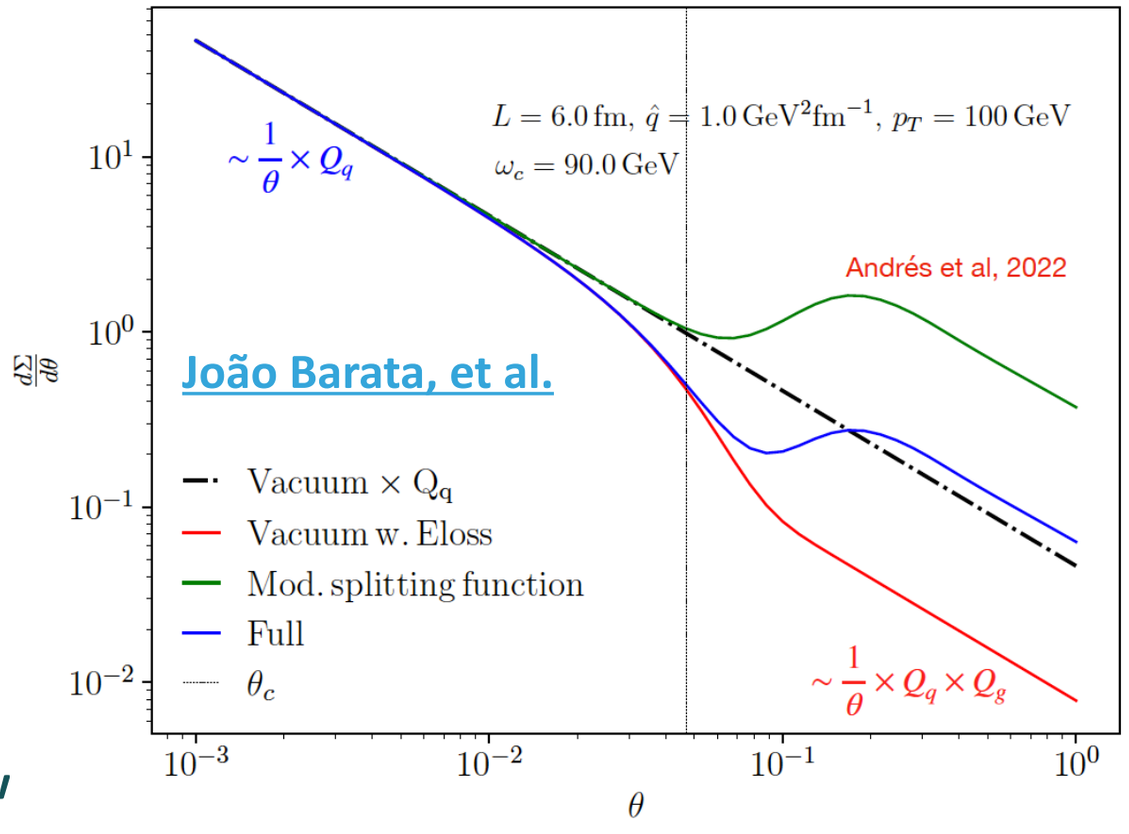


Onset of modification sensitive to medium size



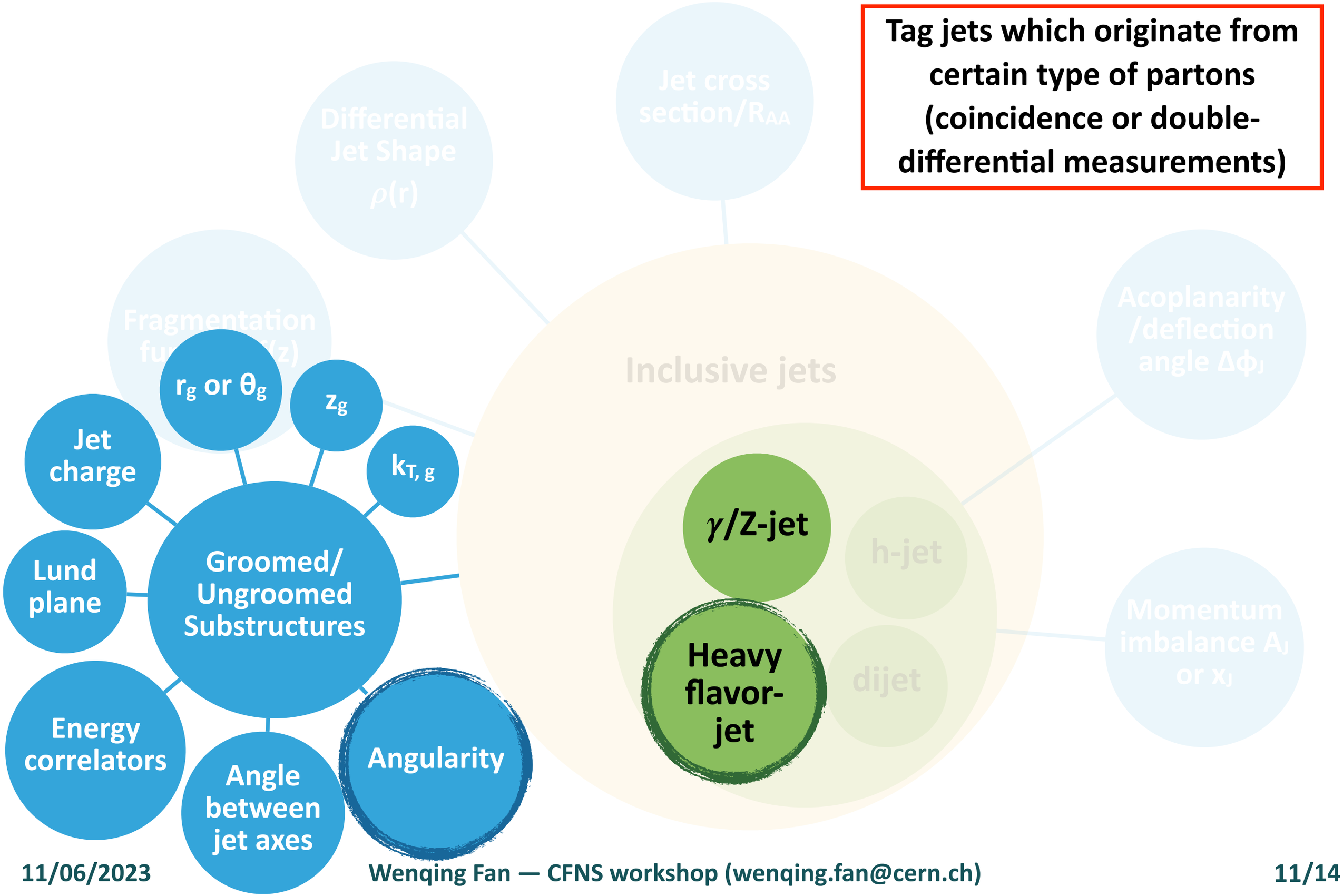
- **In the perturbative region:**
  - **Induced splitting when parton shower in the medium ➜ enhancement at large angle**
  - **Energy loss of the hard splitting ➜ suppression at large angle**
- **In the NP region: modified hadronization?**

PbPb data analysis ongoing!

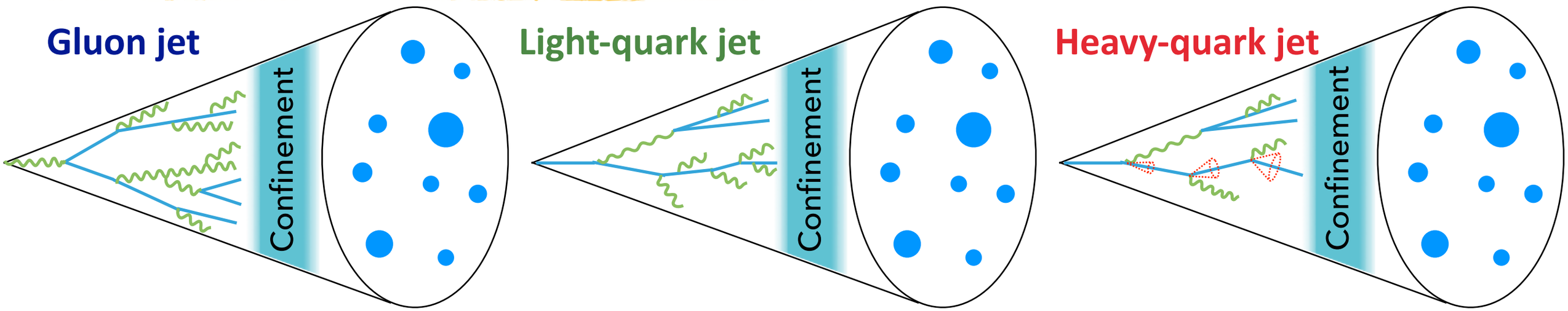


What is the role of parton color charge and mass?

Tag jets which originate from certain type of partons (coincidence or double-differential measurements)



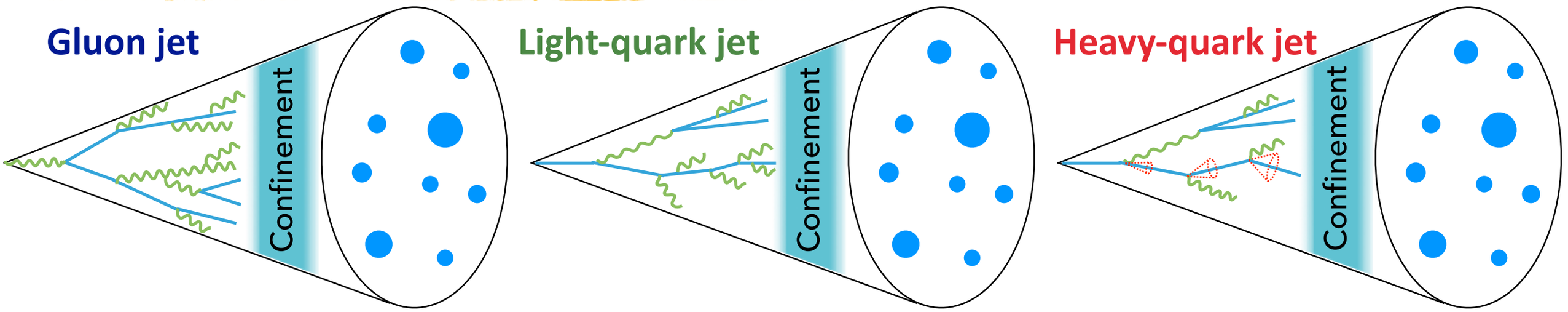
Probe mass and color effects with tagged charm jets



Casimir color effects (C_F/C_A = 9/4): a broader and softer fragmentation profile for gluons

Mass effects: gluon radiation suppressed along the heavy quark

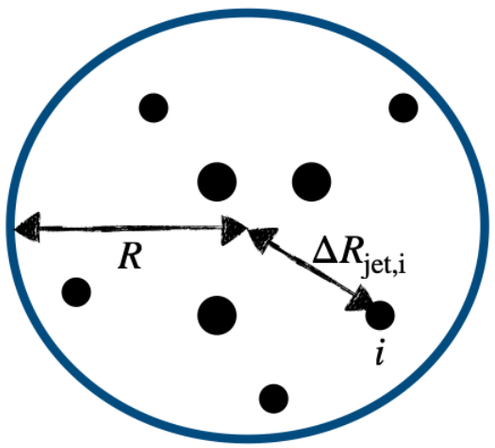
Probe mass and color effects with tagged charm jets



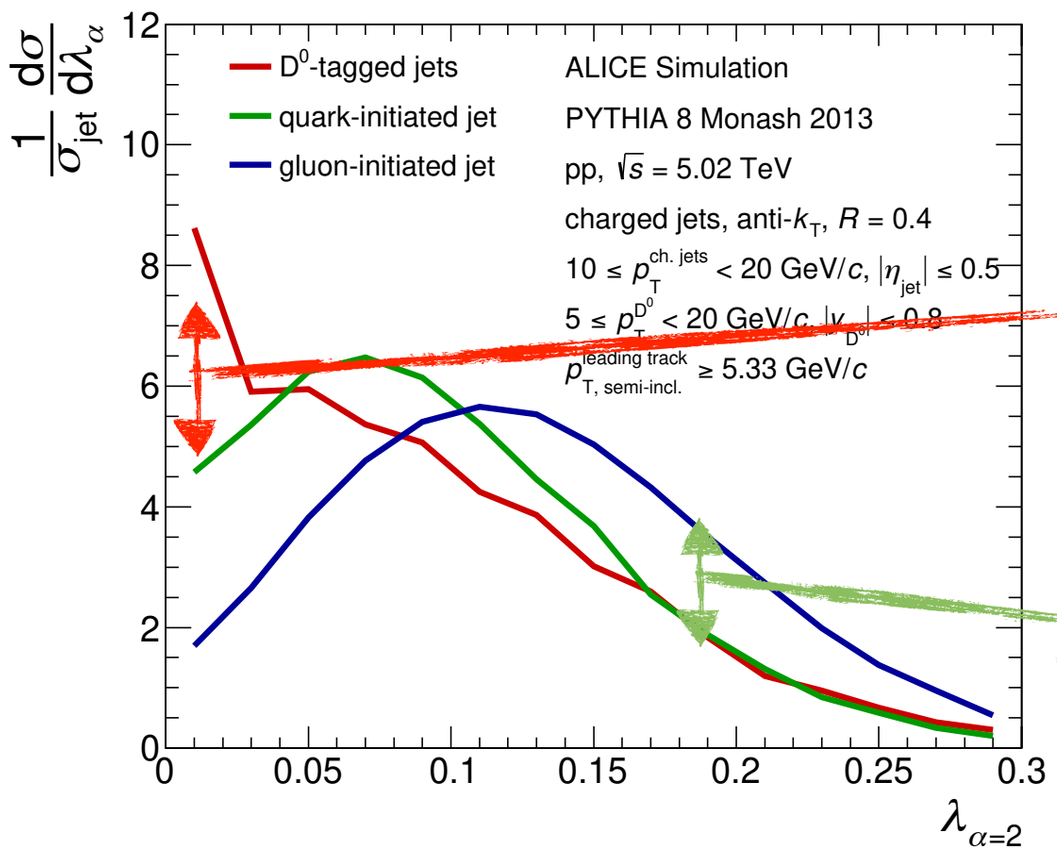
Casimir color effects (C_F/C_A = 9/4): a broader and softer fragmentation profile for gluons

Mass effects: gluon radiation suppressed along the heavy quark

$$\lambda_\alpha^\kappa = \sum_{i \in jet} \left(\frac{p_{T,i}}{p_{T,jet}} \right)^\kappa \left(\frac{\Delta R_{jet,i}}{R} \right)^\alpha$$



IRC safe for κ = 1 and α > 0



Sensitive to mass effect

Sensitive to Casimir color effects

ALI-SIMUL-540836

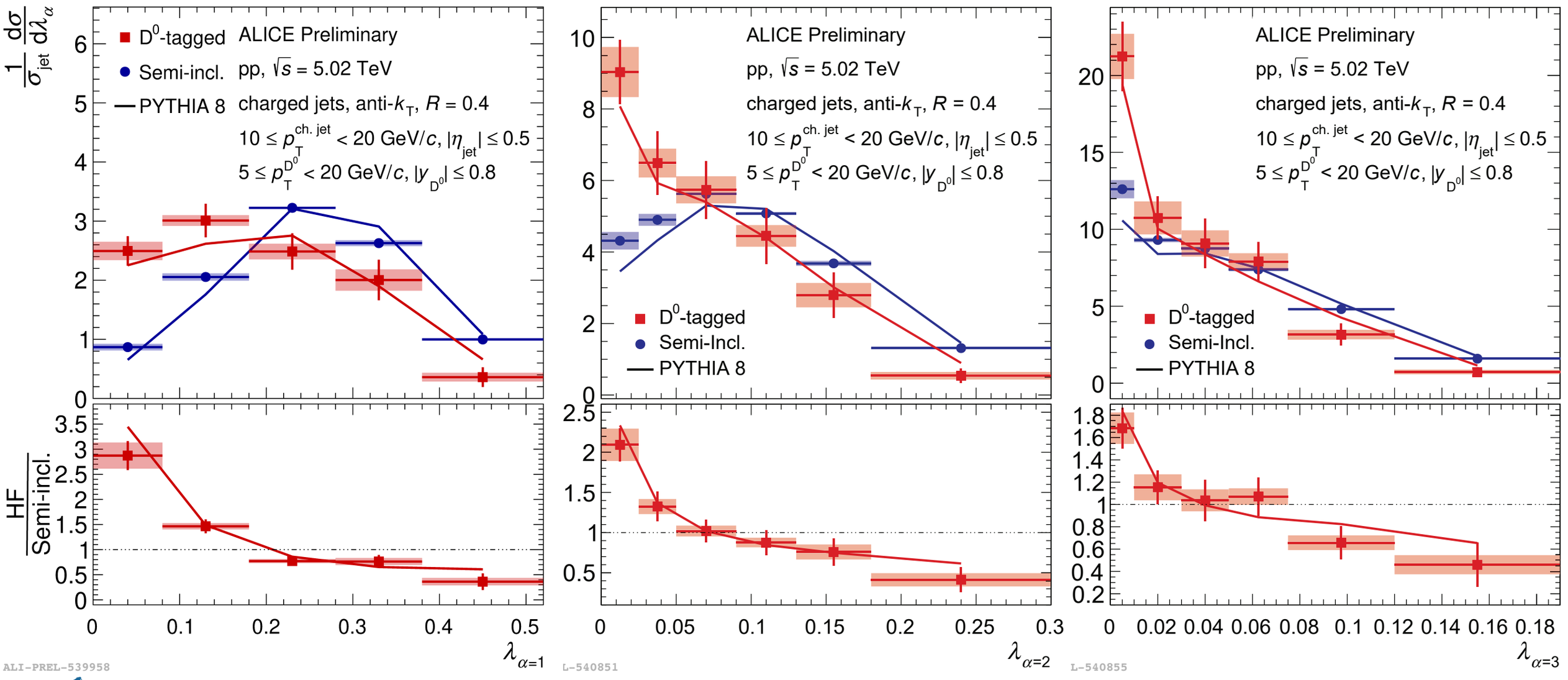
D⁰-tagged vs. semi-inclusive jet angularity

Increasing weight for radiation in the core

α

Increasing weight for large angle radiation

$\alpha = 1$ $\alpha = 2$ $\alpha = 3$



α

D⁰ tagged and inclusive jets more different in their cores

D⁰ tagged and inclusive jets distribution become similar towards wider angle

Summary and outlook

- **ALICE has performed many jet and jet substructures studies**
  - **Groomed jet radius to study the perturbative core of jets and observed narrowing effect from medium modification.**
  - **Novel observables, energy correctors, explored to look into the transition between perturbative and non-perturbative dynamics inside jet. Promising to shed light on modification at different scales in QGP.**
  - **D tagged charm jets used to probe the mass and color effect on the jet fragmentation. D tagged jets measurements in heavy ion collisions provide insights to the mass and color effect dependence of the energy loss.**

- **Run 3 data taking ongoing: stay tuned for more results from ALICE!**