Hard probes of heavy ion collisions with ATLAS

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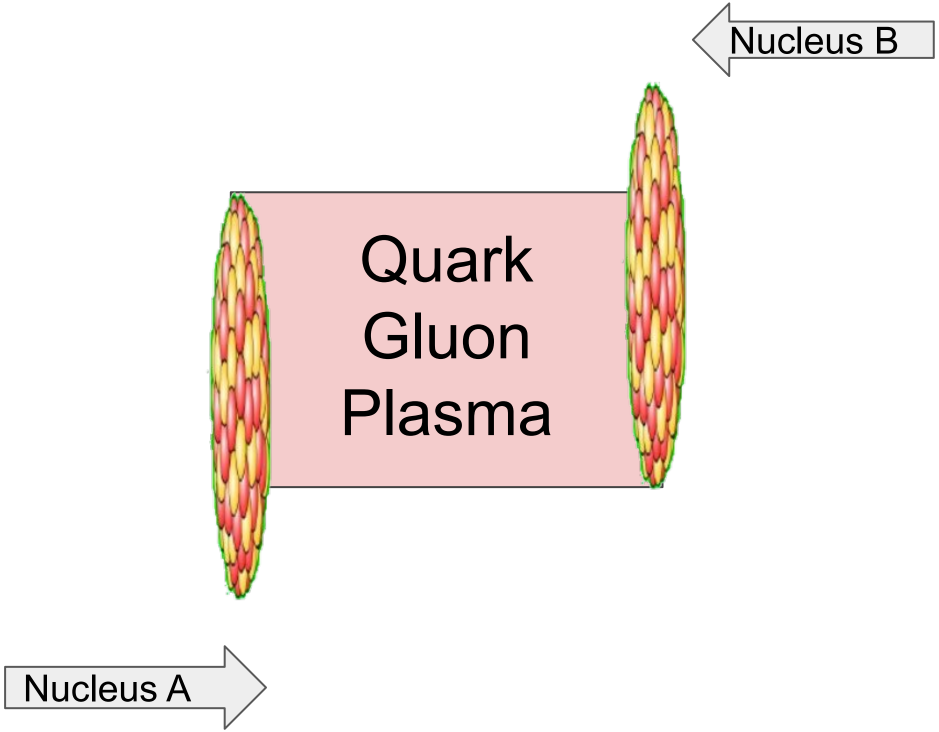
QCD22 Montpellier

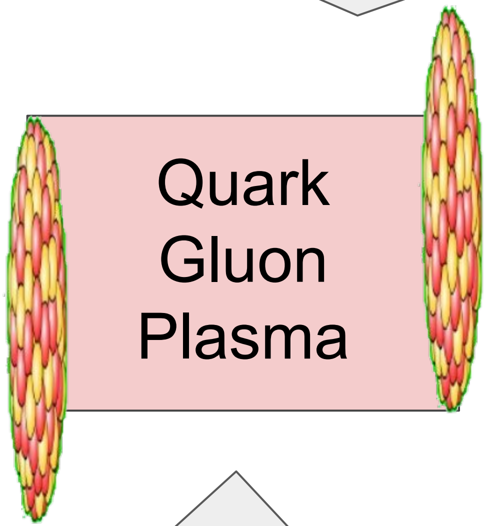
Introduction



Introduction

Properties and degrees of freedom of QGP?

How does the color charge interact and lose energy in the medium?



Is there flavour or mass dependence of the energy loss?

How does the hadronization process work?

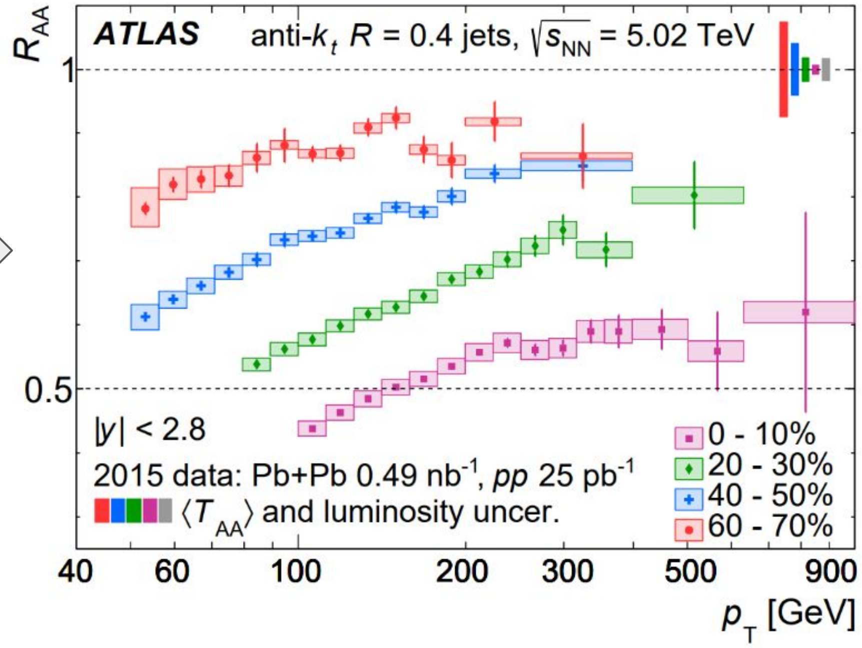
What is the resolution scale of the medium?

Inclusive jet production

Physics Letters B 790 (2019) 108–128

Nuclear modification factor:

$$R_{AA} = \frac{\text{Yield}(\text{Pb}\ \text{Pb})}{N_{coll} \times \text{Yield}(\text{p}\ \text{p})}$$

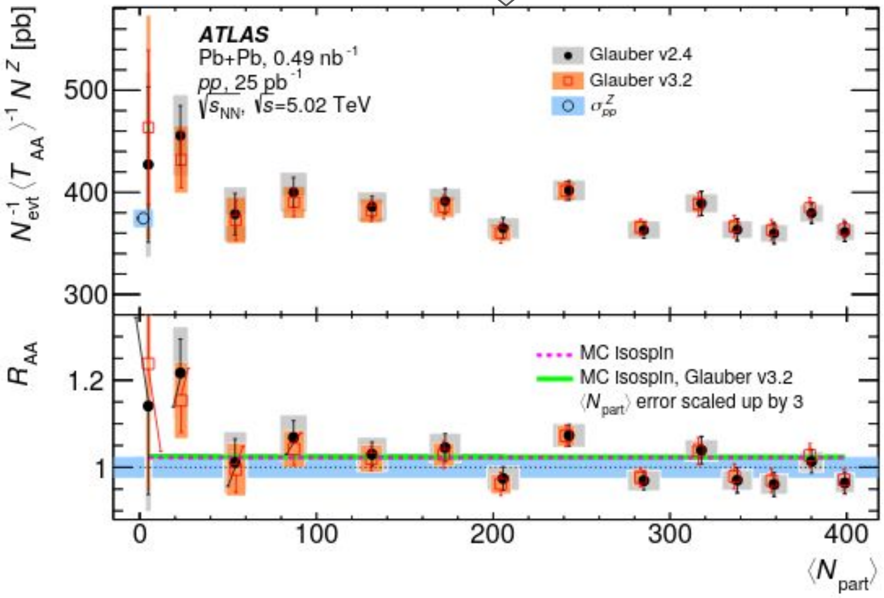


- $R_{AA} < 1 \rightarrow$ suppression.
- Suppression is stronger for more central collisions.
- While jets are strongly suppressed vector bosons remain unsuppressed (next slide)

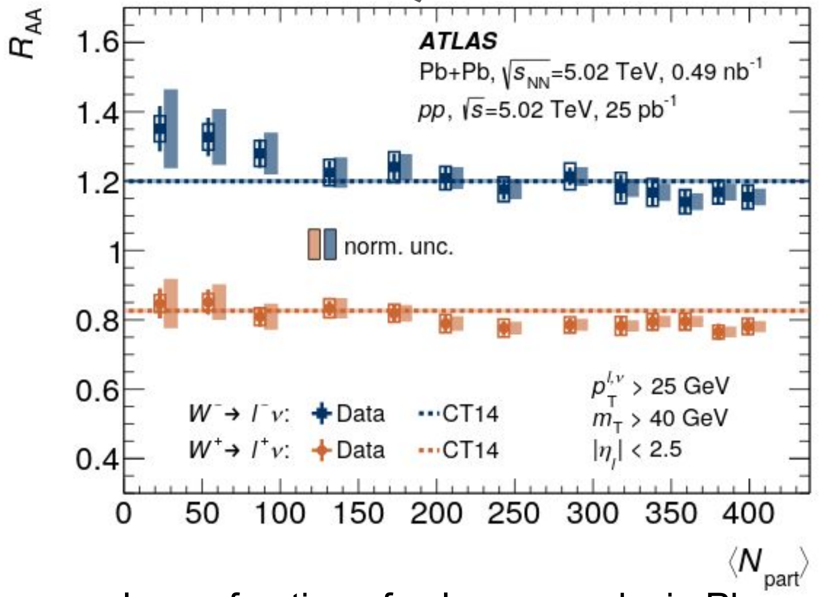
W and Z bosons

W: arXiv:1907.10414, Z: arXiv:1910.13396

Z



W



- Z^0 consistent with unity

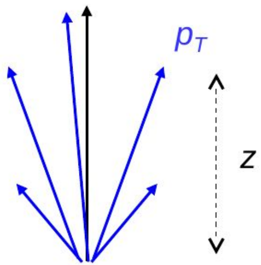
- larger fraction of valence-quarks in Pb nuclei than in protons →
- Deviation from unity → **isospin effect**

$$u\bar{d} \rightarrow W^+ \text{ and } d\bar{u} \rightarrow W^- \text{ processes}$$

$D(p_T)$ and $D(z)$ distributions

arXiv:1805.05424 (5.02TeV), PRC 98 (2018) 024908, EPJC 77 (2017) 379

To understand the large jet suppression we need to measure modifications of the jet substructure



$$z \equiv \frac{p_T}{p_T^{\mathrm{jet}}} \cos \Delta R$$

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

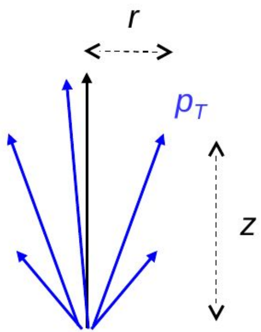
D(p_T) and D(z) distributions

arXiv:1805.05424 (5.02TeV), PRC 98 (2018) 024908, EPJC 77 (2017) 379

$$R_{D(z)} \equiv \frac{D(z)_{\mathrm{PbPb}}}{D(z)_{pp}}$$

$$R_{D(p_\mathrm{T})} \equiv \frac{D(p_\mathrm{T})_{\mathrm{PbPb}}}{D(p_\mathrm{T})_{pp}}$$

To understand the large jet suppression we need to measure modifications of the jet substructure



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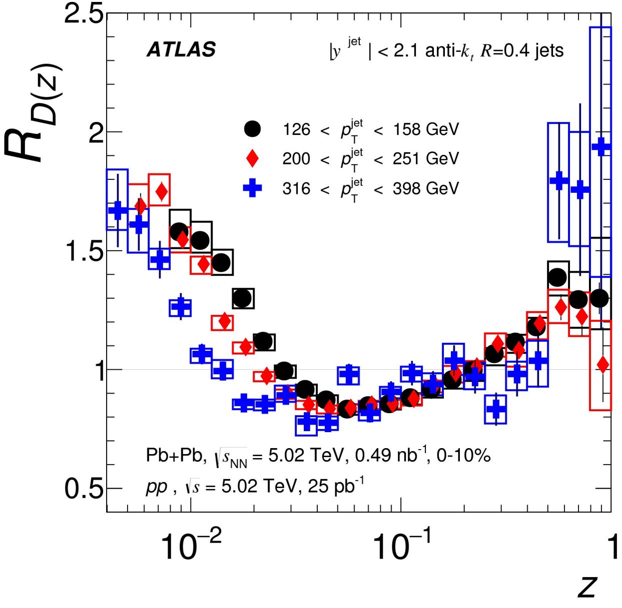
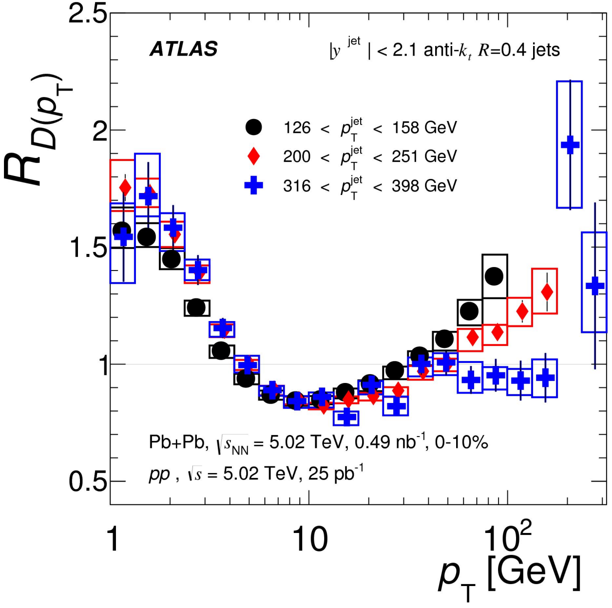




Enhancement -> Suppression -> Enhancement

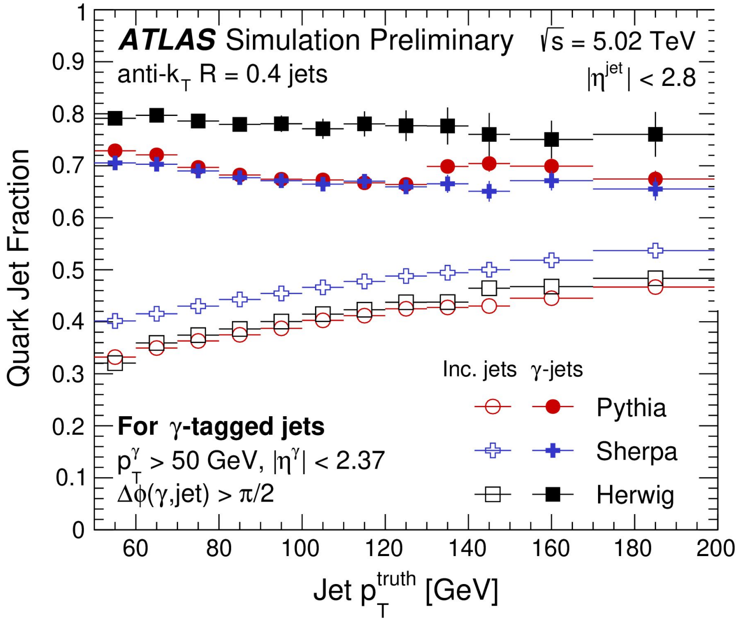
γ-tagged jets

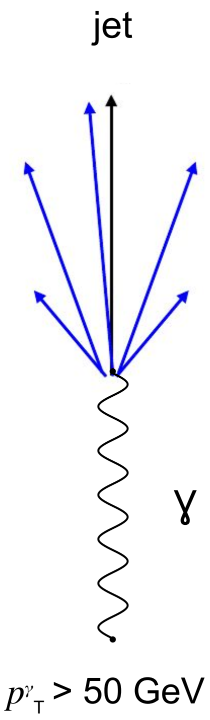
ATLAS-CONF-2022-019

- **Q**: Is there flavour dependence of the energy loss?

- Motivation:
  - Get lower in p_T
  - Removes the survival bias
  - ɣ-tagging constrains the jet flavor

- Quark initiated jets are dominant





γ-tagged jets

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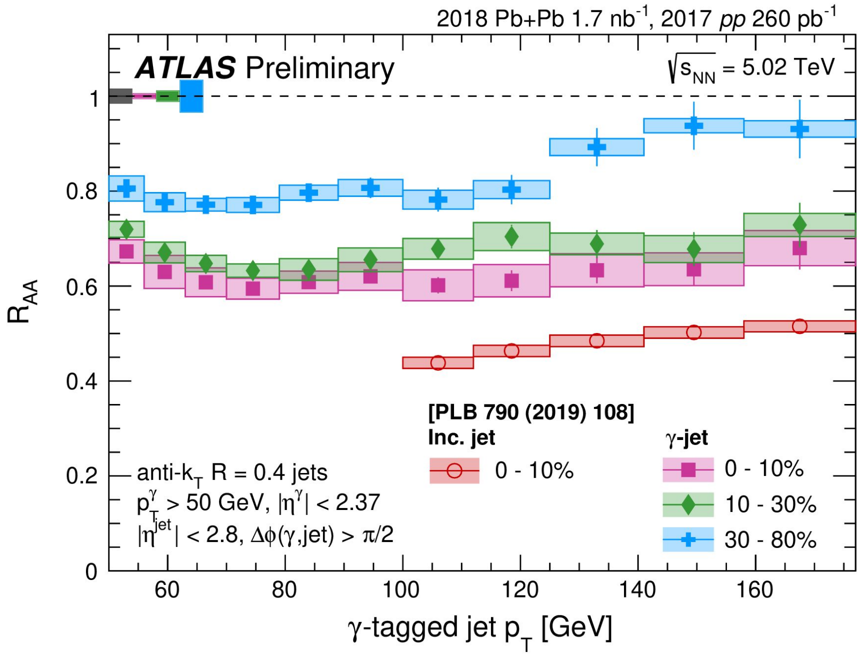

Suppression is present

γ-tagged jets

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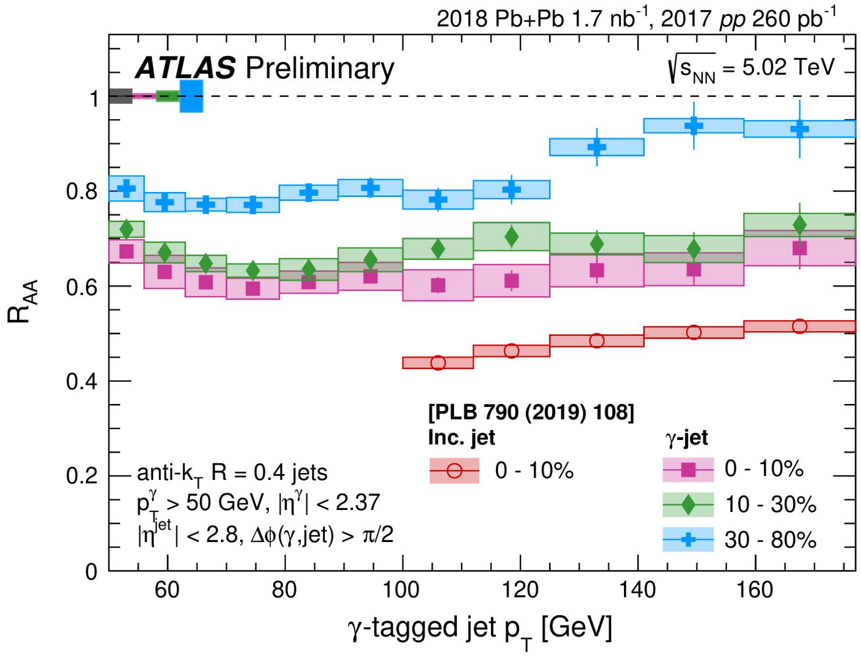
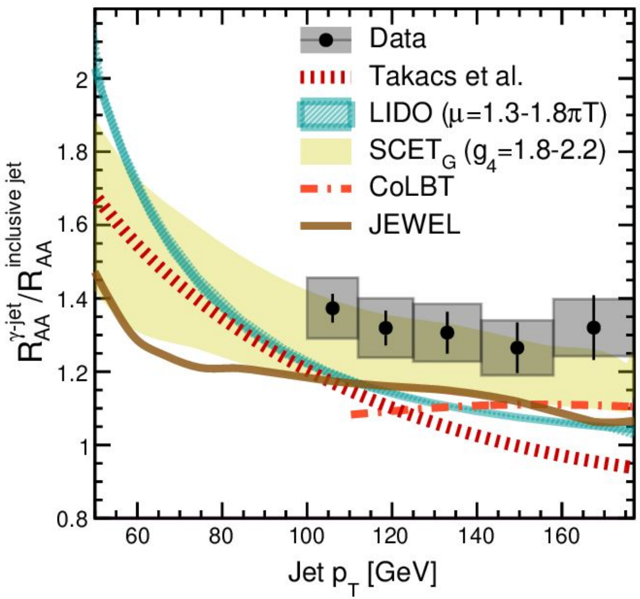


Suppression is present



- Ratio > 1 → visible effect from colour difference
- Quarks lose less energy than gluons

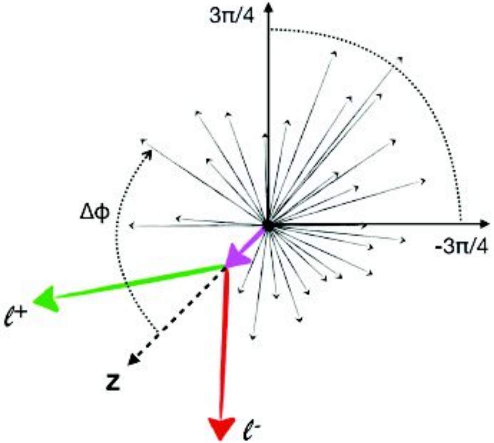
Z-tagged charged particles

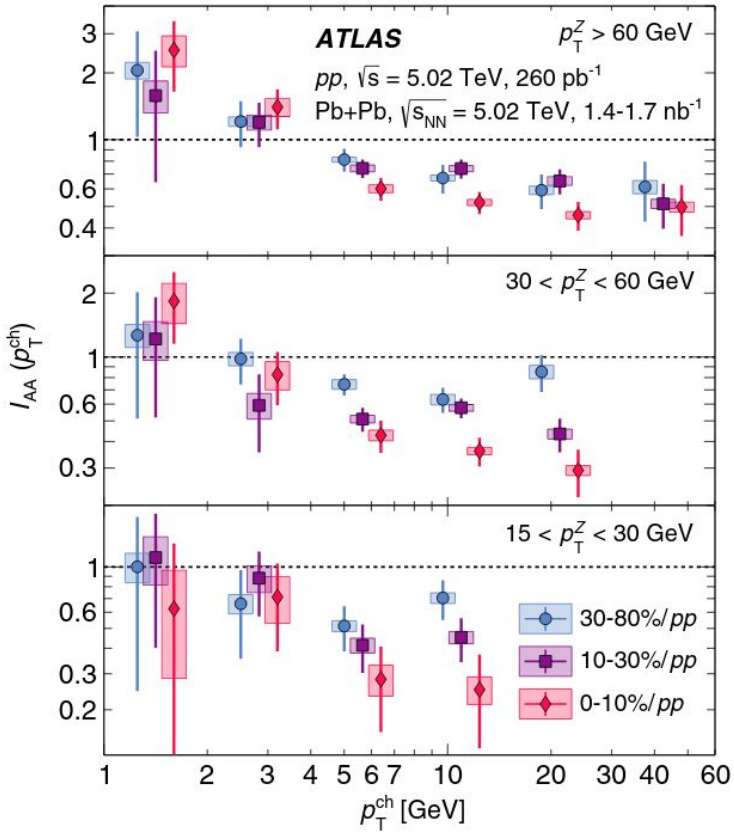
Phys. Rev. Lett. 126, 072301

- Motivation:
  - Get lower in p_T
  - Removes the survival bias
  - Z-tagging constrains the jet flavor
- Ratio of per-Z yields:

$$I_{AA} = Y_{Pb+Pb}/Y_{pp}$$

- No explicit jet required





Z-tagged charged particles

Phys. Rev. Lett. 126, 072301

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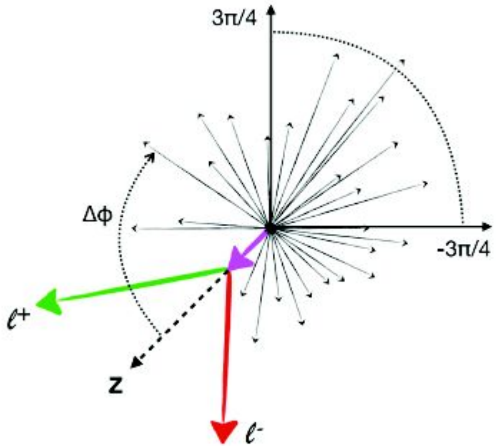
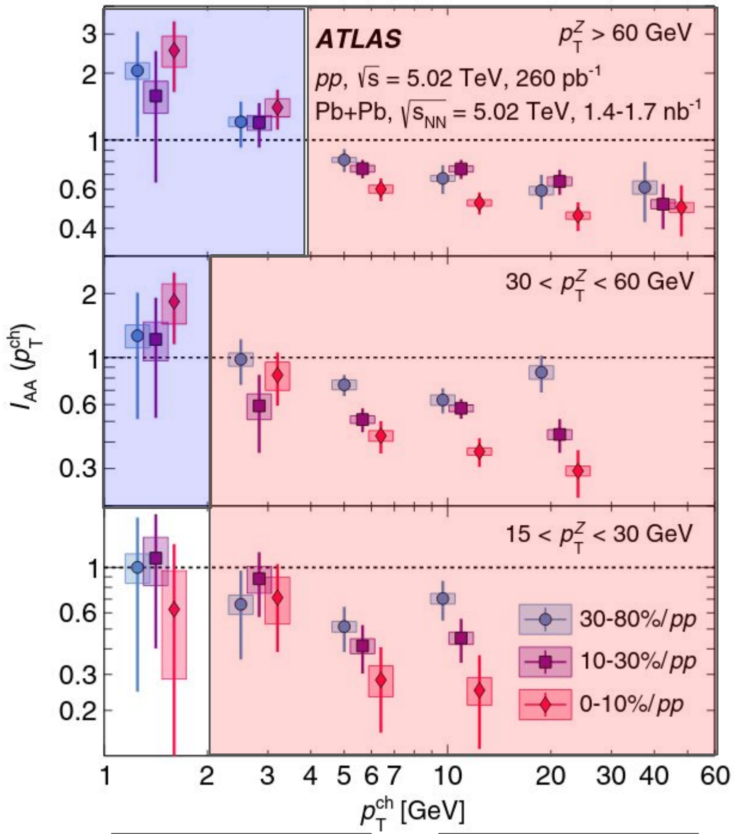




Enhanced

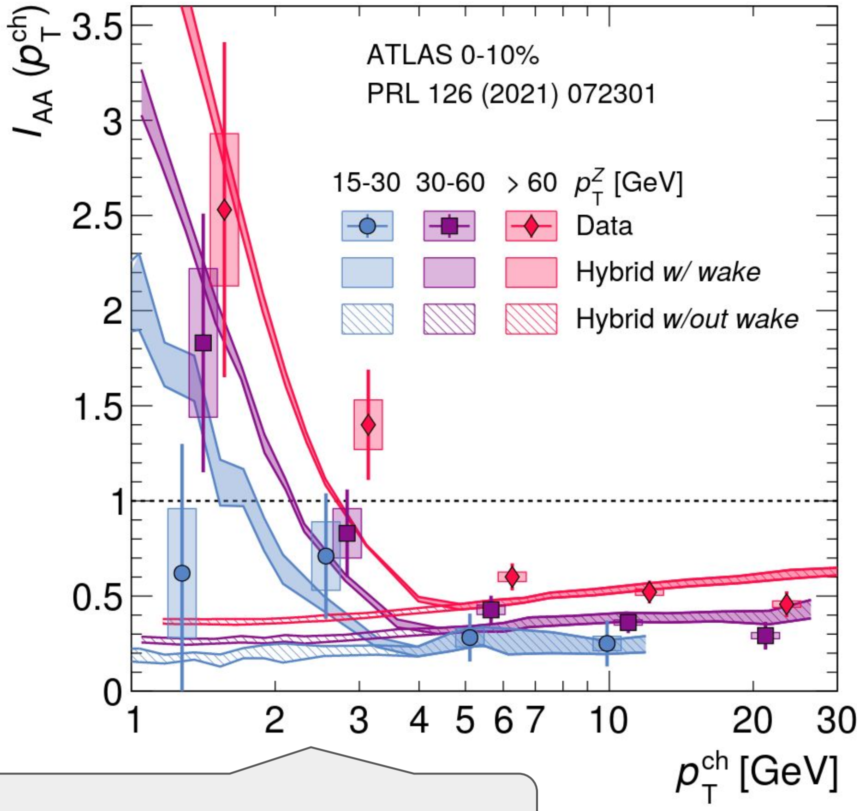
Suppressed

Z-tagged charged particles

Phys. Rev. Lett. 126, 072301

- **Larger amplitude**
  - smaller Z p_T

- 0-10% centrality JEWEL theoretical prediction describes the trends



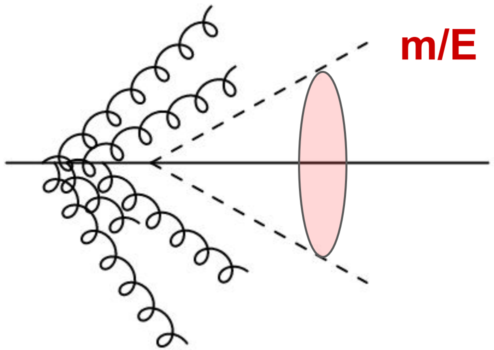
Wake is important in low p_T region

b-tagged jets

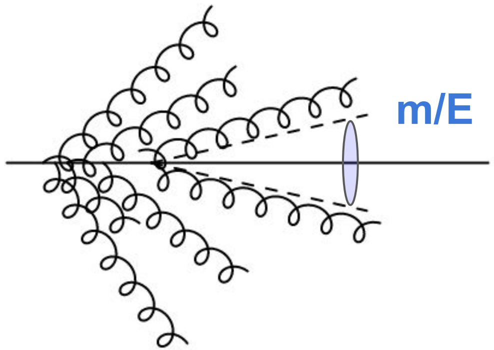
arXiv:2204.13530

Q: Is there mass dependence of the energy loss?

Dead cone effect:



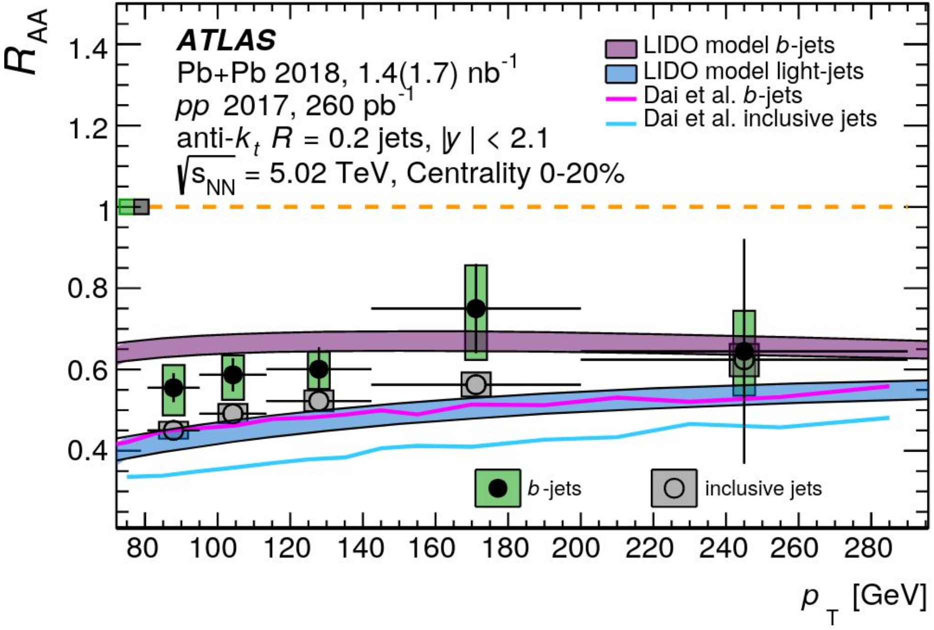
Heavy-tagged jets



Inclusive jets - lighter quarks

b-tagged jets

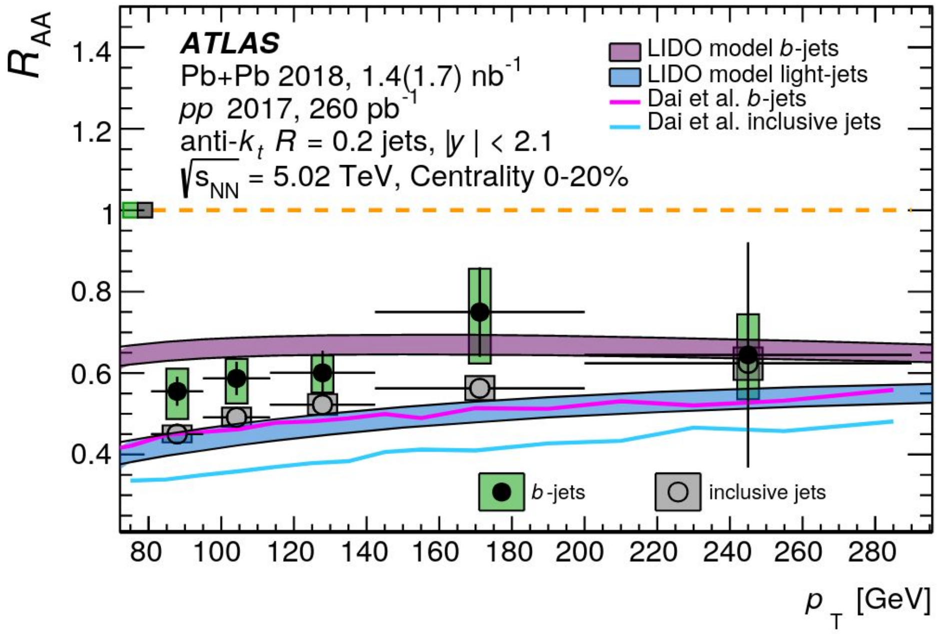
arXiv:2204.13530

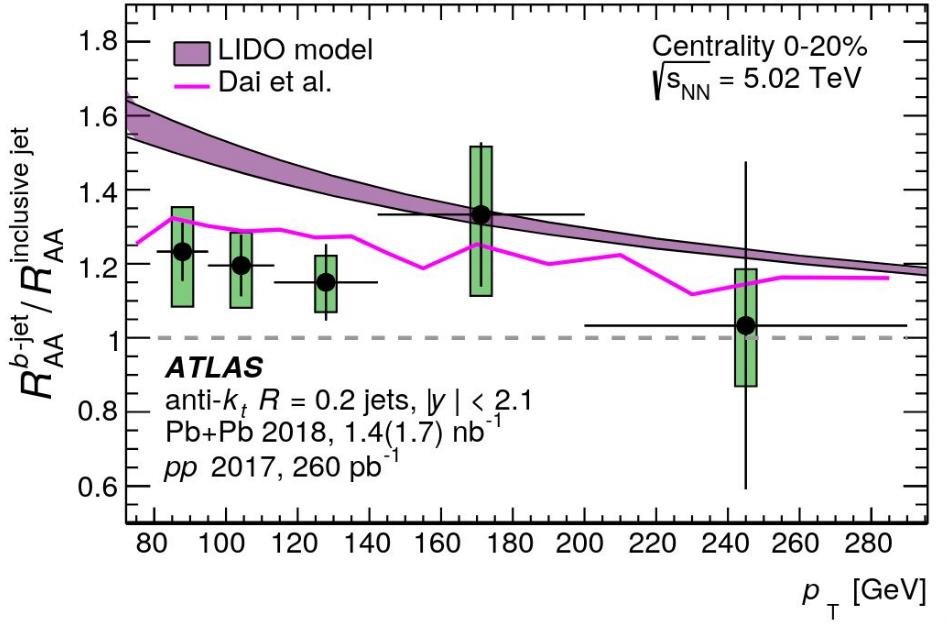


Less suppression of b-jets than inclusive jets

b-tagged jets

arXiv:2204.13530





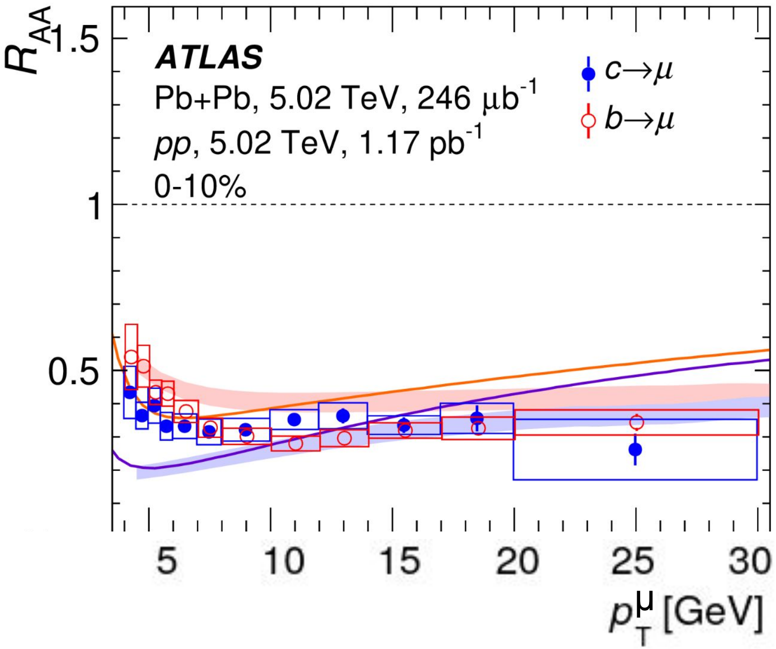
Less suppression of b-jets than inclusive jets

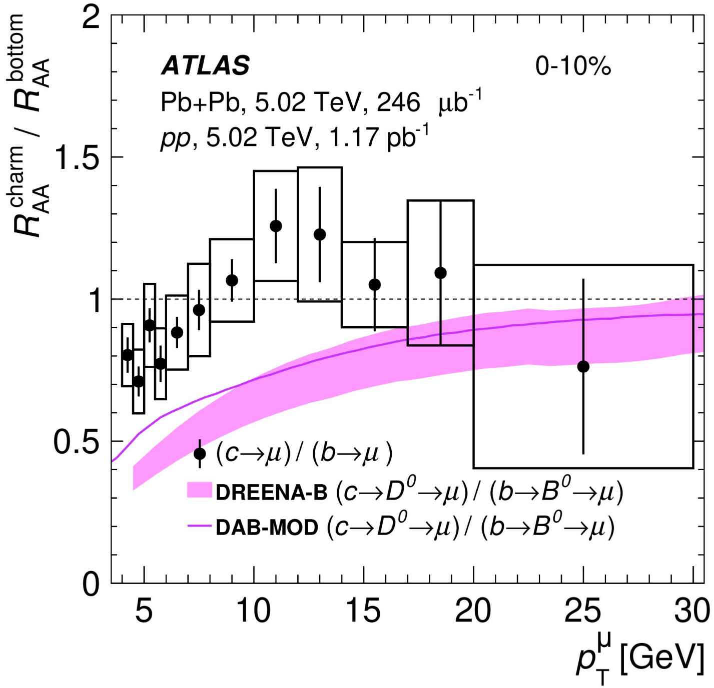
R_{AA} (b-jet) / R_{AA} (inc. jet) ~20% above unity

R_{AA} of muons from D and B meson decays

ATLAS-CONF-2021-020

Central collisions: 0 - 10%





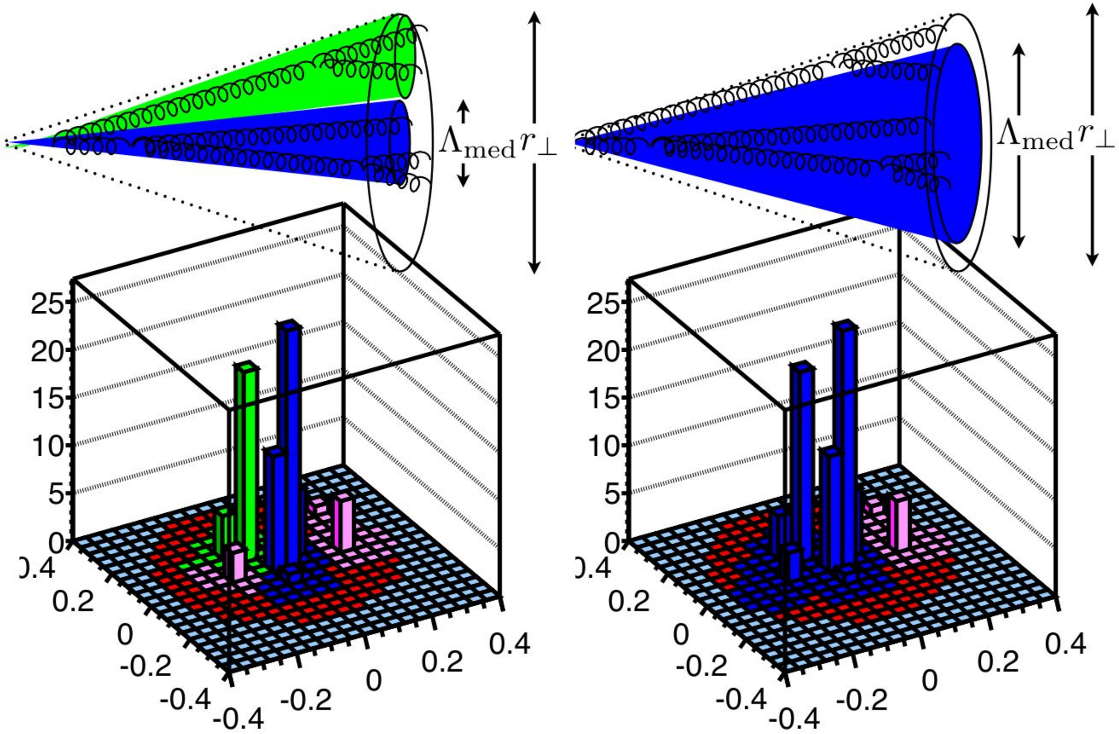
- Low p_T : charmonia suppressed more than B-hadrons
- High p_T: About the same suppression (mass is less important)

- Underprediction at low p_T from charmonia model

Dependence of suppression on jet structure

ATLAS-CONF-2022-026

Q: What is the resolution scale of the medium?



Dependence of suppression on jet structure

ATLAS-CONF-2022-026

Grooming procedure:

Anti-k_T jet → Track-calo-cluster constituents of the jet → Recluste with Cambridge-Aachen → Decluster for two sub-jets

Soft-drop condition:

$$\frac{\min(p_T^{sj_1}, p_T^{sj_2})}{p_T^{sj_1} + p_T^{sj_2}} > z_{\mathrm{cut}} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

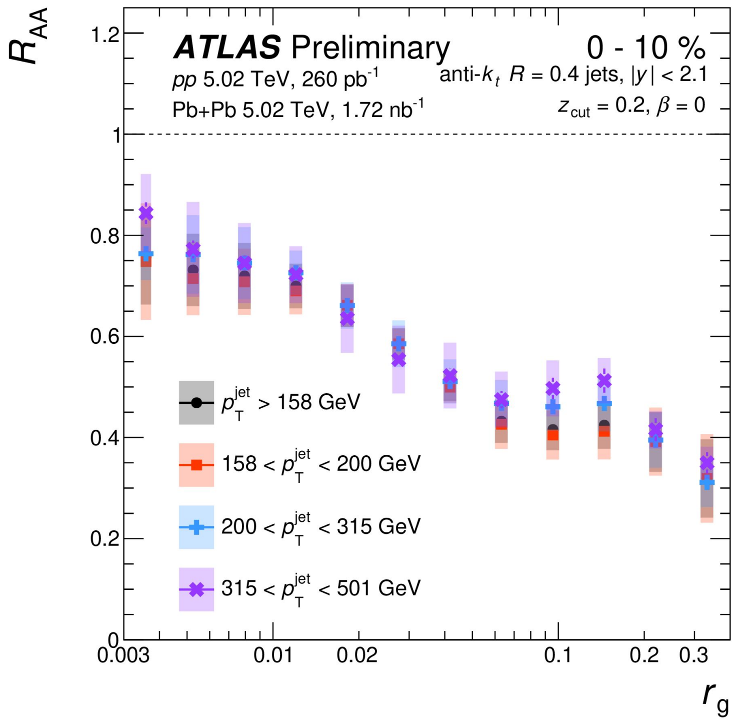
$r_g = \Delta R_{j1,j2}$ → $r_g > 0$ → jet has substructure

→ $r_g = 0$ → jet does not have substructure

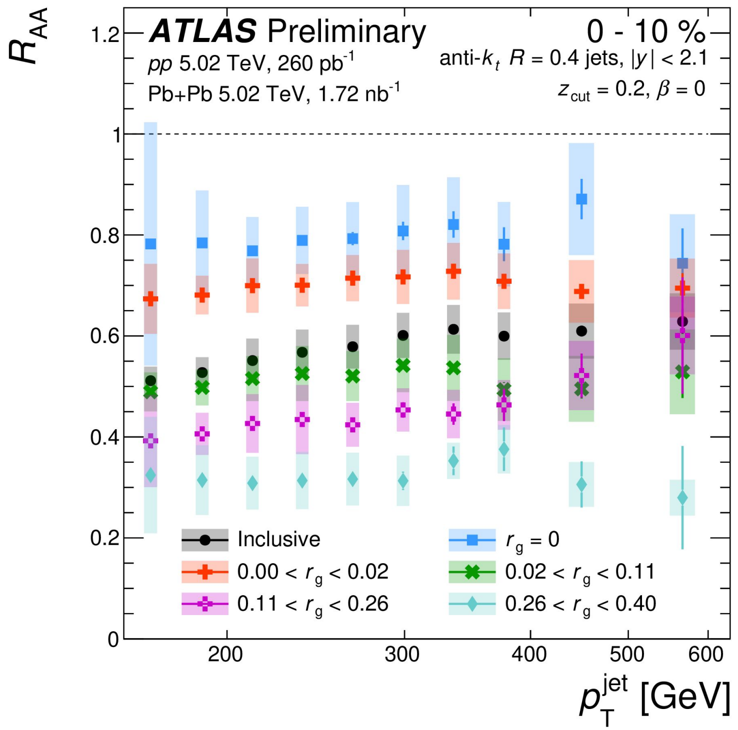
$$\Delta R_{12} = \sqrt{\Delta\eta_{12}^2 + \Delta\phi_{12}^2}$$

Dependence of suppression on jet structure

ATLAS-CONF-2022-026



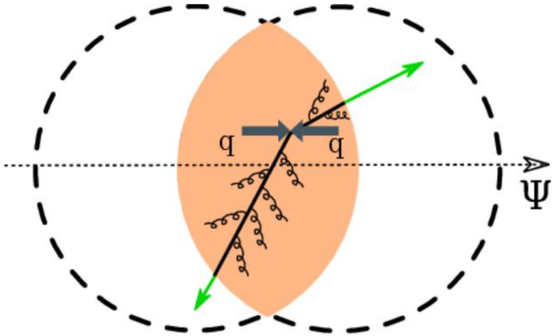
Strong r_g dependence



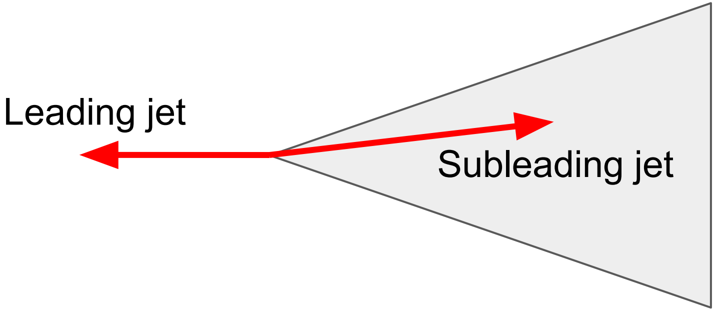
Weak p_T dependence

Dijet balance

arXiv:2205.00682



Path length energy loss



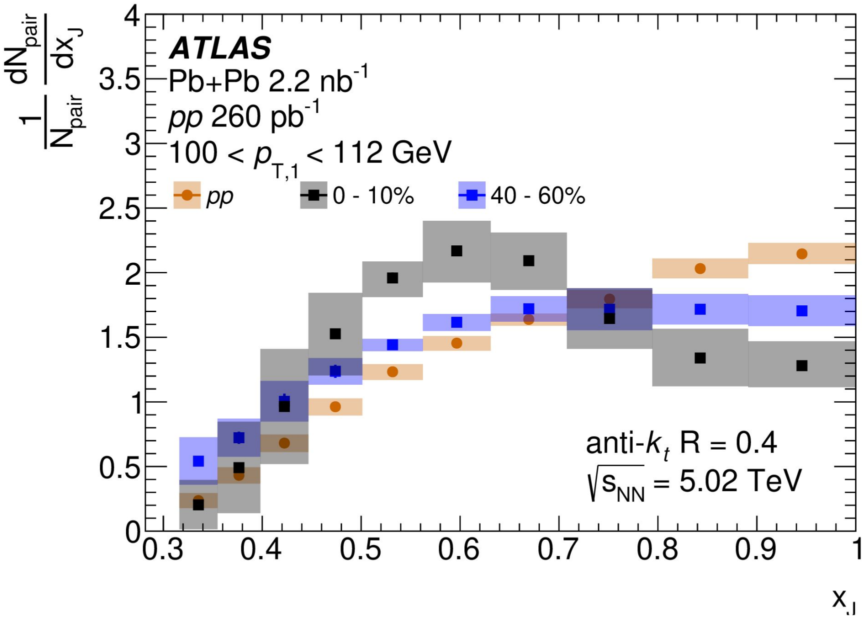
$\Delta\phi = \frac{7}{8}\pi$ opposite leading jet

$$x_J = \frac{p_{T_2}}{p_{T_1}}$$

Dijet balance

$x_J \equiv p_{T_2}/p_{T_1}$

arXiv:2205.00682

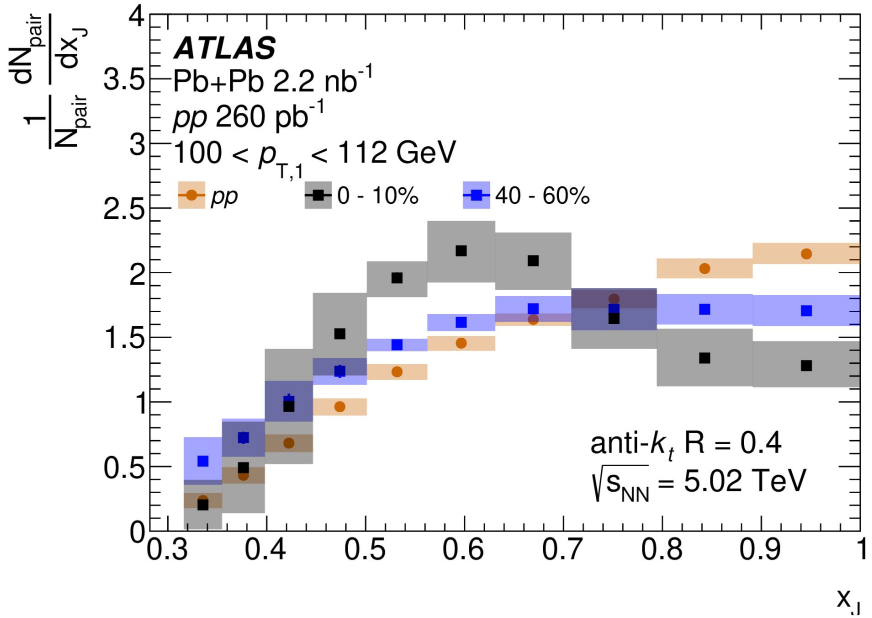


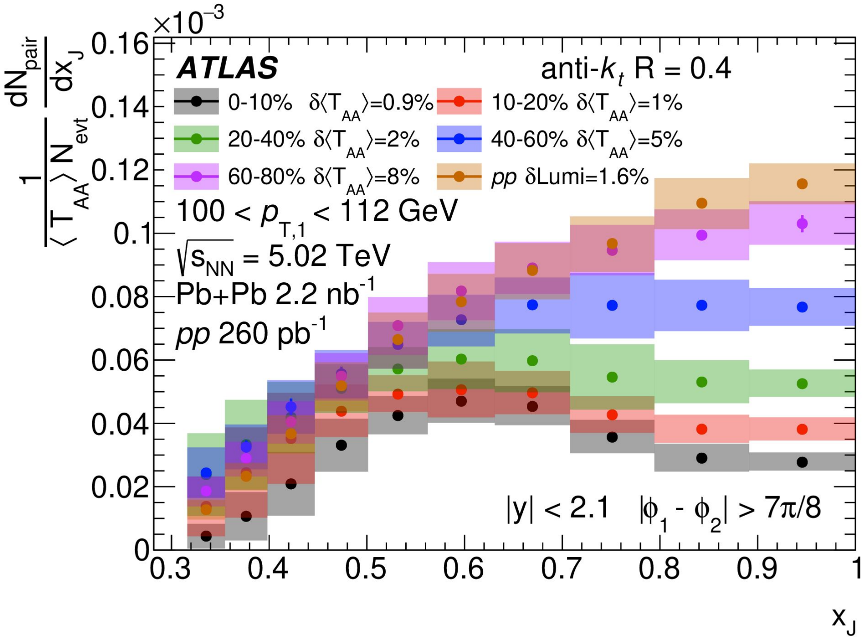
- Broadening of x_J for low cent. and p_T
- High p_T → no visible broadening. (not shown)

Dijet balance

$x_J \equiv p_{T_2}/p_{T_1}$

arXiv:2205.00682





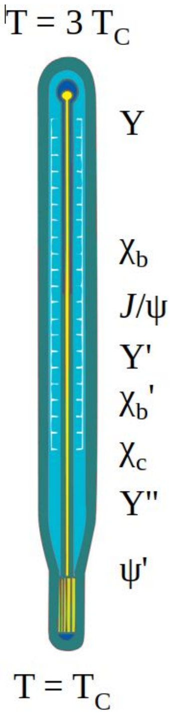
- Broadening of x_J for low cent. and p_T
- High p_T → no visible broadening. (not shown)

- Not low x_J increase, but rather high x_J decrease

Upsilon suppression

ATLAS-CONF-2019-054, *Eur. Phys. J. C 78 (2018) 762*

- The theory predicts sequential melting dependent on the binding energy
- Good analogy with Debeye screening



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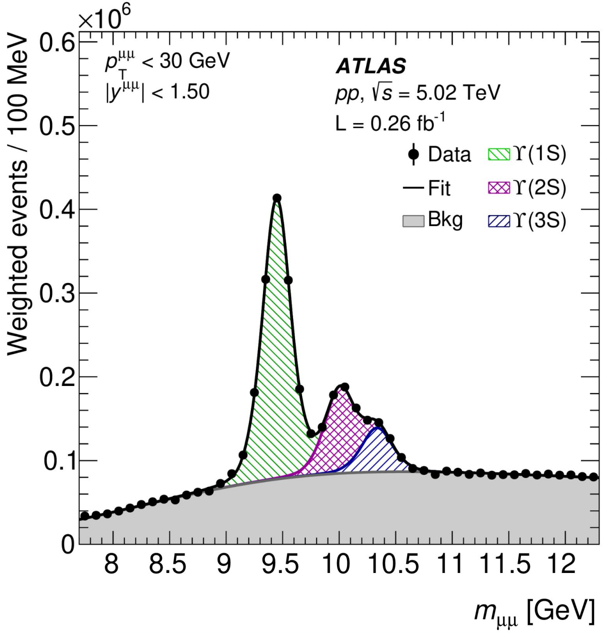
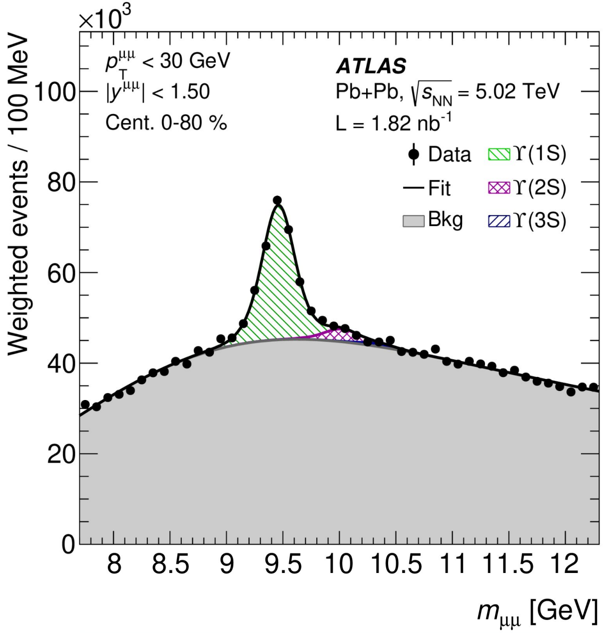
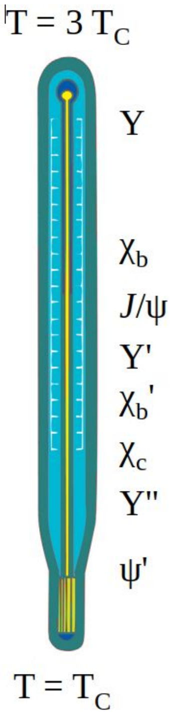


proton-proton

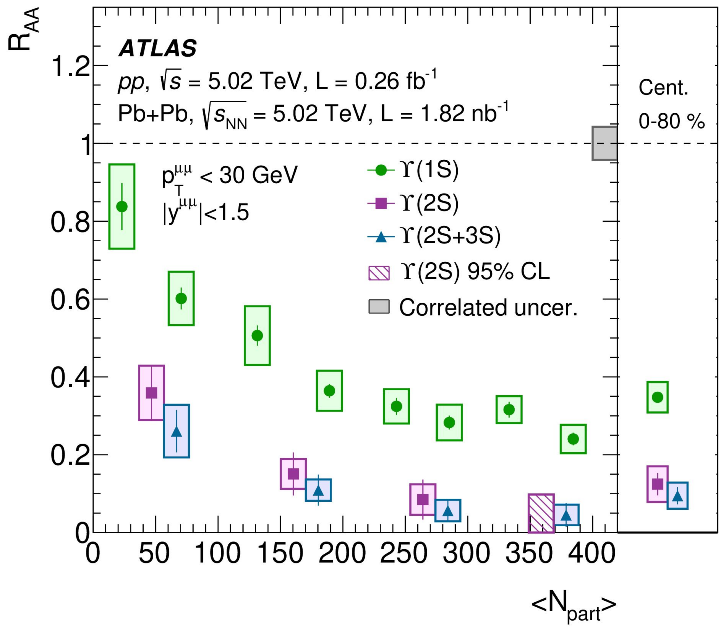


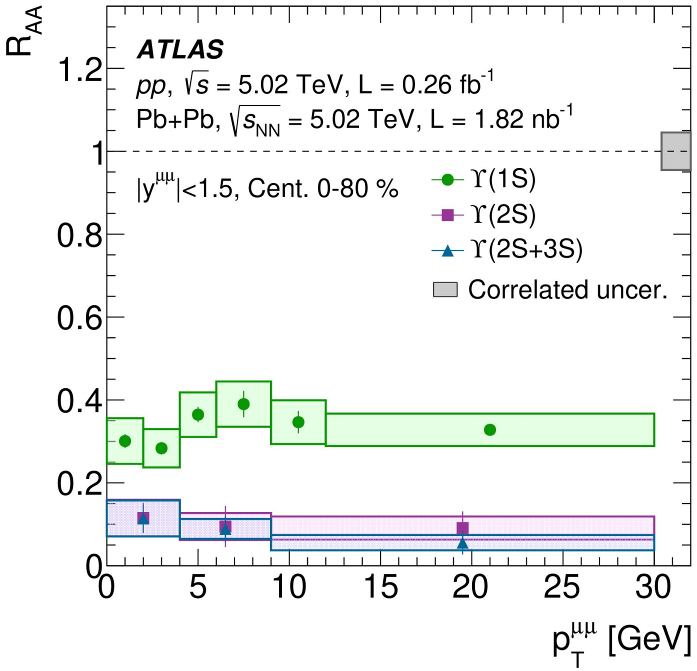
Pb+Pb



Upsilon suppression

ATLAS-CONF-2019-054





- Expected suppression hierarchy confirmed: 1S < 2S < (2+3)S

- No strong p_T or |y| dependence is observed.

Summary

- Presence of QGP is affecting produced particles in the scattering process
- Significant suppression in Pb+Pb wrt pp collisions reported for:
  - inclusive jets, γ-tagged jets, and b-tagged jets
  - B and D mesons
  - charmonia and bottomonia
- Substructure of the jets is studied to better understand the mechanism of energy loss
- To understand the role of fluctuations and path-length in the jet quenching the dijet suppression is quantified

Thank you for your attention

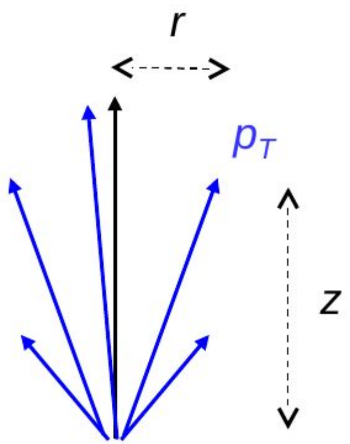
Questions?

Backup slides

Measuring fragmentation function

PRC 98 (2018) 024908, EPJC 77 (2017) 379

To understand the large jet suppression we need to measure modifications of the jet substructure



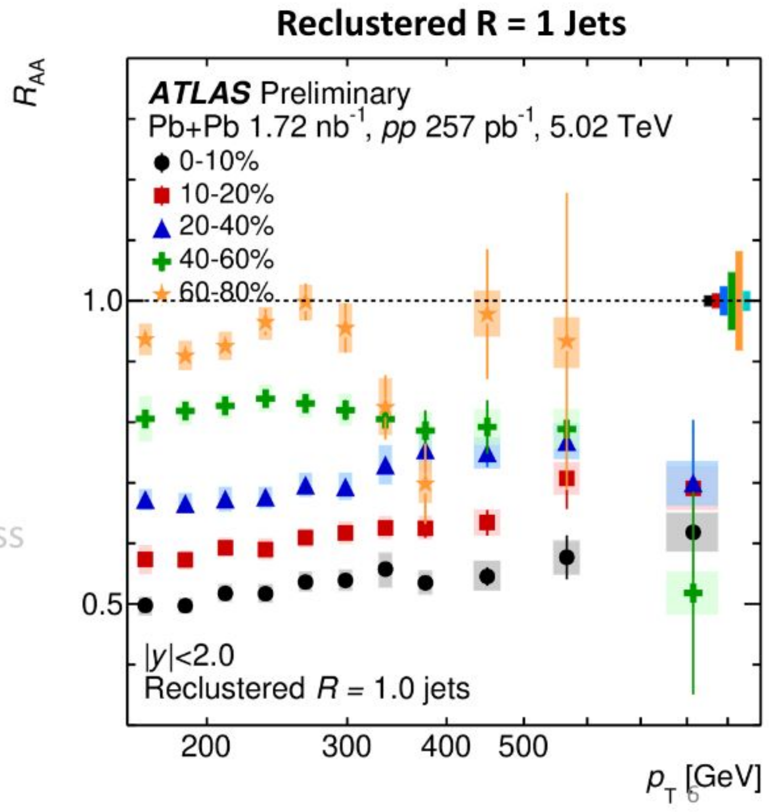
$$D(z) = \frac{1}{N_{jet}} \frac{\mathrm{d}N}{\mathrm{d}z}$$

$$D(p_T) = \frac{1}{N_{jet}} \frac{\mathrm{d}N}{\mathrm{d}p_T}$$

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

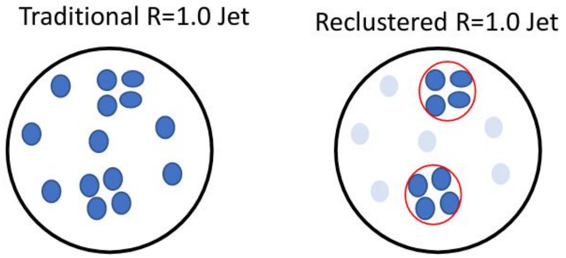
Dependence of suppression on jet structure

ATLAS-CONF-2019-056



- First measurement of large-R heavy-ion jets
- R=0.2 jets with p_T > 35 GeV reclustered using anti-k_T
  - Soft contribution removed
  - Recluster with anti-k_T
  - Allows to study k_T splitting scale
- Observe suppression up to 1 TeV

$$\sqrt{d_{12}} = \min(p_{T,1}, p_{T,2}) \cdot \Delta R_{12}$$



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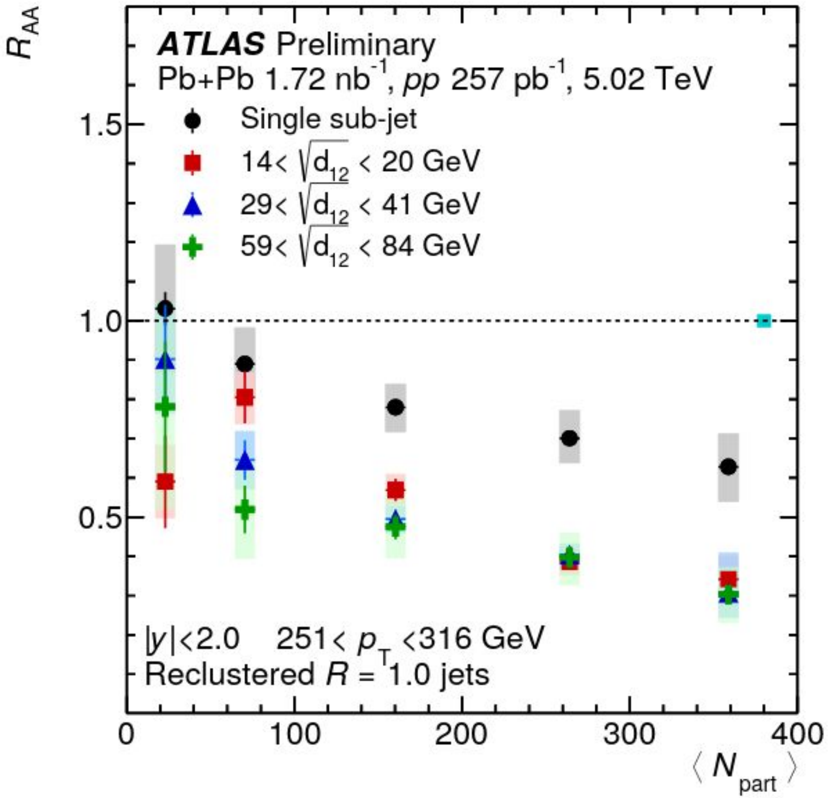
ATLAS-CONF-2019-056



- Jets with single sub jet are less suppressed

$$\sqrt{d_{12}} = \min(p_{T,1}, p_{T,2}) \cdot \Delta R_{12}$$