Recent results on hard processes in *p*+Pb, Pb+Pb, and γ-γ collisions from the ATLAS Experiment at the LHC

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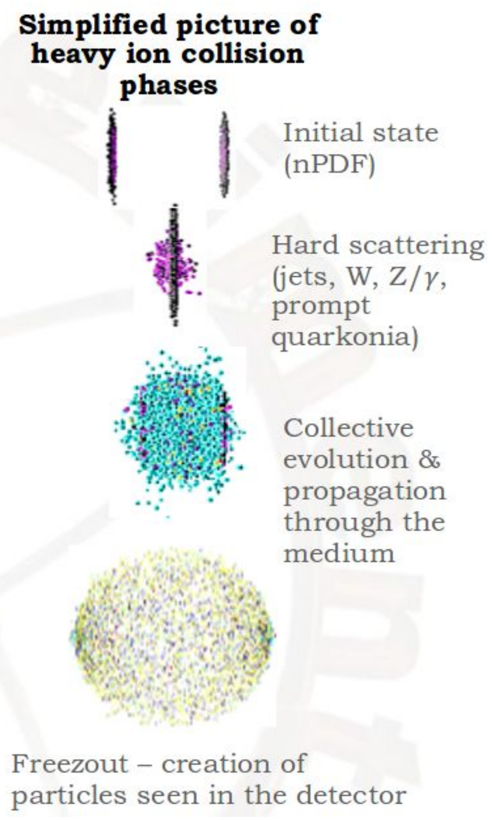
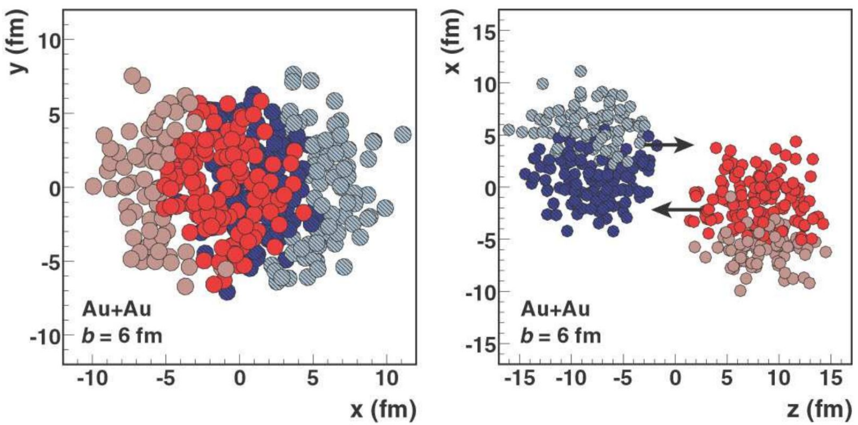
Goals of HI collisions

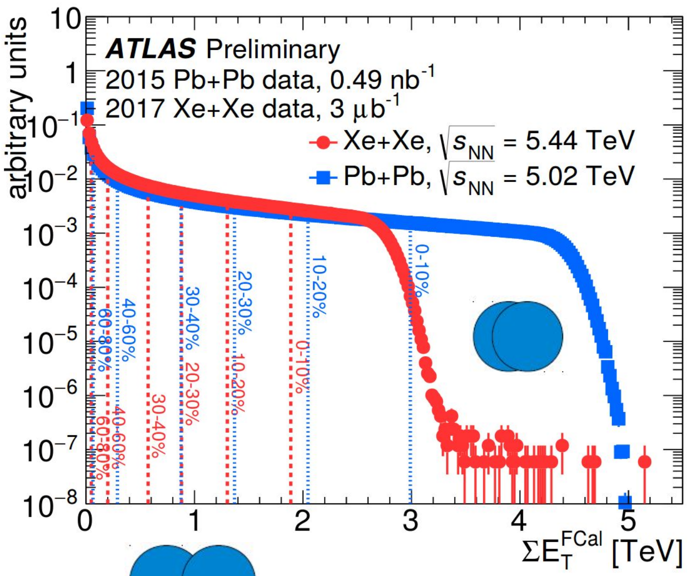
Study the properties of quark gluon plasma (QGP), the most extreme case of matter (in terms of density & temperature) which is created in heavy ion collisions.

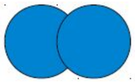
- How? By using probes at different scales:
  - Soft – global characteristics, collective expansion, correlations and fluctuations.
  - Hard – jet modification in QGP, heavy-quark production, calibration via electroweak bosons.
- Data from other colliding systems are necessary to understand physics in Pb+Pb:
  - *pp* - Serve as baseline.
  - *p*+Pb - importance of the initial state effects.
- Use different center-of-mass energies.
- For the first time Xe+Xe recorded in Oct 2017 ~ 6 hours.



Centrality in HI collisions



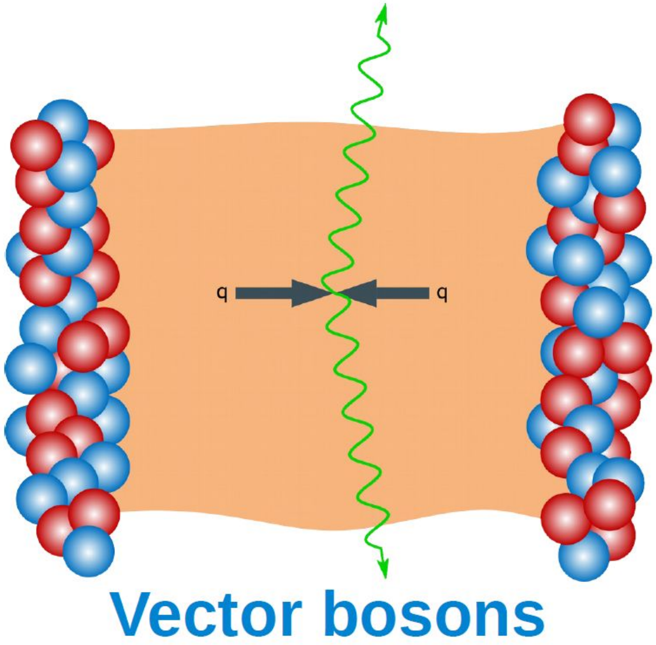




- Centrality is a measure of overlap of two colliding nuclei
- Determined by the sum of the transverse energy deposited in the Forward calorimeters
- It is closely related to the average number of participant nucleons N_{part} and number of binary inelastic collisions N_{coll}
- Events divided into successive percentiles of the $\sum E_{\mathrm{T}}^{\mathrm{FCal}}$
- Central collisions: Large overlap, high number of participating nucleons N_{part}
- Peripheral collisions: Small overlap, low number of participating nucleons N_{part}

Characterization of QGP

Different hard probes interact with medium differently.

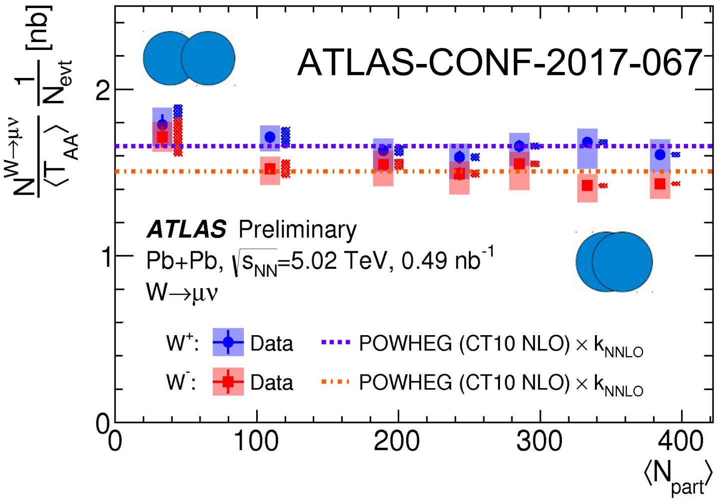


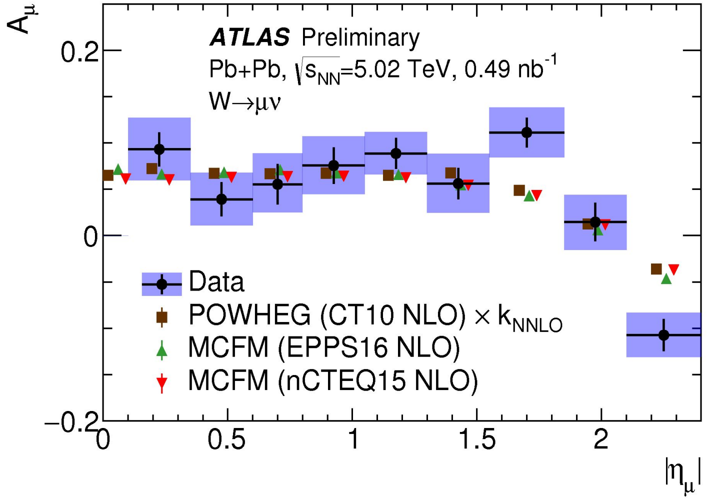
- Measurements of photons, Z and W bosons.
- Electro-weak bosons don't interact strongly with the medium so expect no modification to their production rates.
- Provide information about the initial state → nuclear PDFs.

EW boson production

- W bosons per event yield measured in muon channel in Pb+Pb collisions at 5.02 TeV.
- The yields scaled by T_{AA} (left) have no dependence on number of participating nucleons.
- W^+ yield by 10% larger than W^- yield.
- Lepton charge asymmetry (right) consistent with theory with some small deviations in the forward direction.

$$A_\ell(\eta_\ell) = \frac{dN_{W^+\to\ell^+\nu}/d\eta_\ell - dN_{W^-\to\ell^-\bar{\nu}}/d\eta_\ell}{dN_{W^+\to\ell^+\nu}/d\eta_\ell + dN_{W^-\to\ell^-\bar{\nu}}/d\eta_\ell}$$





Nuclear modification factor R_{AA}

Partons lose energy through interactions with the medium $\rightarrow$ **jet quenching**

$R_{AA} = \frac{1}{N_{\mathrm{coll}}}$  / 

QCD in medium

Yields in A+A

$$= \frac{1}{N_{\mathrm{coll}}} \frac{\frac{\mathrm{d}N_{AA}}{\mathrm{d}p_{\mathrm{T}}}}{\frac{\mathrm{d}N_{pp}}{\mathrm{d}p_{\mathrm{T}}}} = \frac{1}{T_{AA}} \frac{\frac{\mathrm{d}N_{AA}}{\mathrm{d}p_{\mathrm{T}}}}{\frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}p_{\mathrm{T}}}}$$

QCD in vacuum

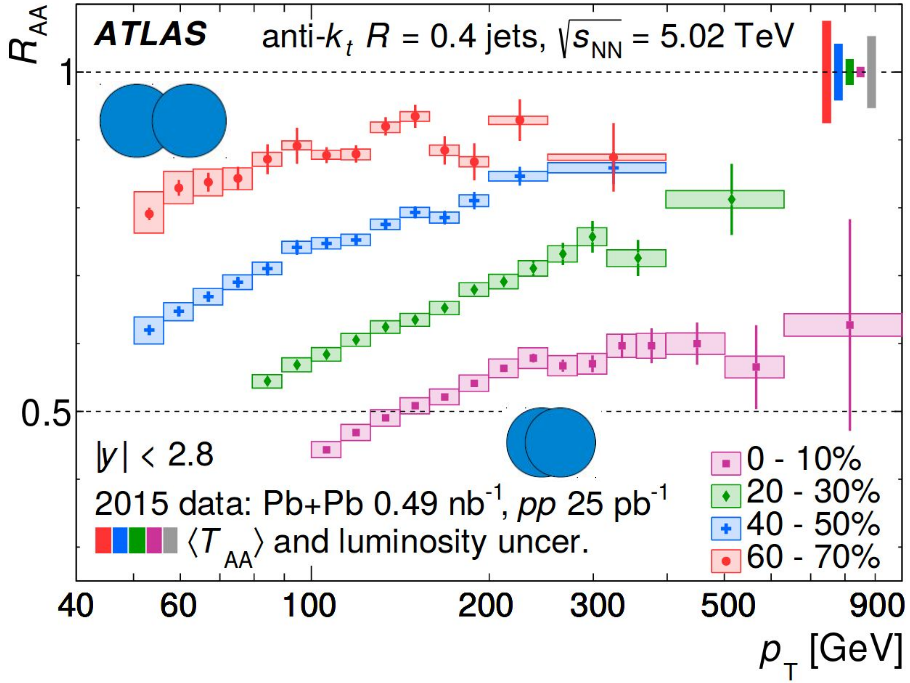
pp reference

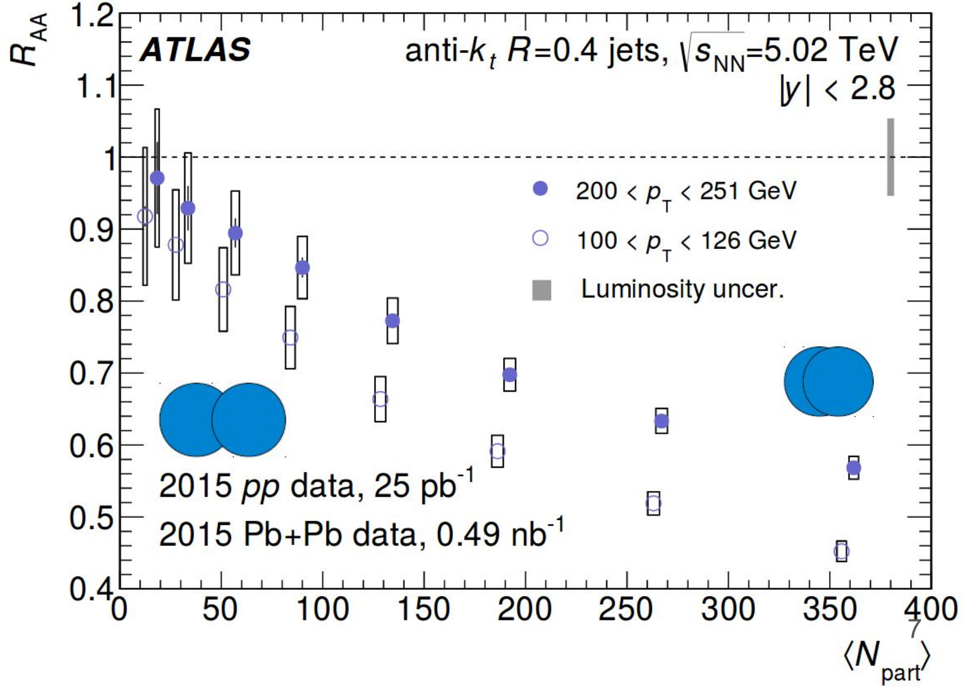
- Compares HI and *pp* collisions and removes the geometrical scaling.
- Jet nuclear modification factor quantifies the magnitude of jet suppression, which arise mainly from final-state interactions with constituents of the medium.

Jet R_{AA} vs p_T and N_{part} @ 5.02 TeV

- Central events: only modest grow with p_T, flattening for $p_T > 200$ GeV.
- Peripheral events: Still significant suppression even in 60-70%.

Phys. Lett. B 790 (2019) 108

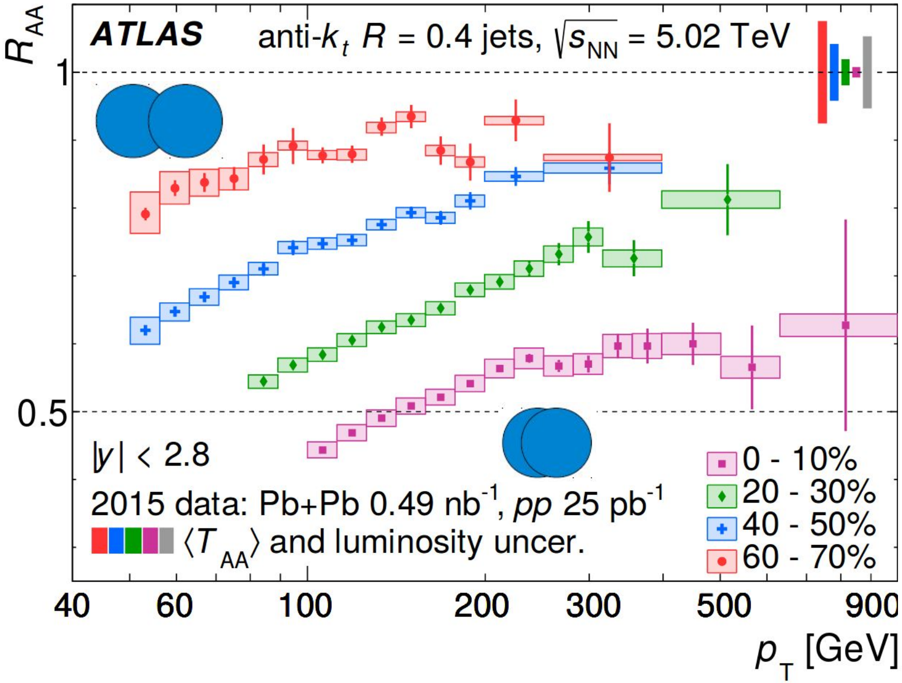


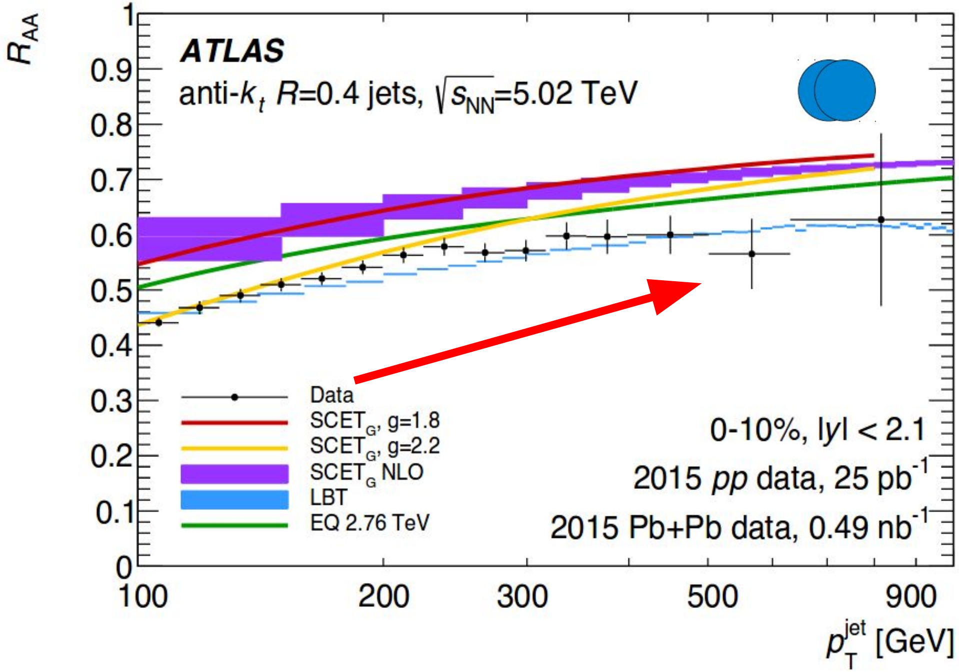


Jet R_{AA} vs p_T and N_{part} @ 5.02 TeV

- Central events: only modest grow with p_T, flattening for $p_T > 200$ GeV.
- Different theoretical models can describe trends seen in the data.

Phys. Lett. B 790 (2019) 108





Jet mass measurement @ 5.02 TeV

- Do jets of different widths lose energy differently? How does R_{AA} depend on m/p_T?
- m/p_T is related to the angular width of the jet. Information about transverse structure of jet, connection to virtuality of initial parton.
- Distribution of m/p_T is measured, where m is the norm of jet four-momentum from calo towers ($\Delta\eta$ x $\Delta\varphi$ = 0.1 x 0.1):

$$m = \sqrt{\Big(\sum_{i \in J} E_i\Big)^2 - \Big(\sum_{i \in J} \vec{p}_i\Big)^2}$$

- First fully-unfolded measurement of jet mass in Pb+Pb and *pp* collisions at 5.02 TeV by ATLAS.

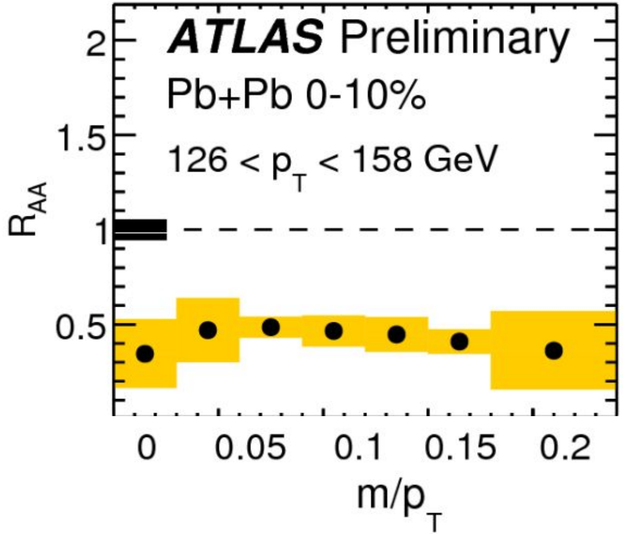
$$R_{\mathrm{AA}}(m/p_{\mathrm{T}}, p_{\mathrm{T}}) = \frac{\left.\frac{1}{N_{\mathrm{evt}}}\frac{\mathrm{d}N_{\mathrm{jet}}^{\mathrm{Pb+Pb}}}{\mathrm{d}(m/p_{\mathrm{T}})}(p_{\mathrm{T}})\right|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}}\rangle \frac{\mathrm{d}\sigma_{\mathrm{jet}}^{pp}}{\mathrm{d}(m/p_{\mathrm{T}})}(p_{\mathrm{T}})}$$

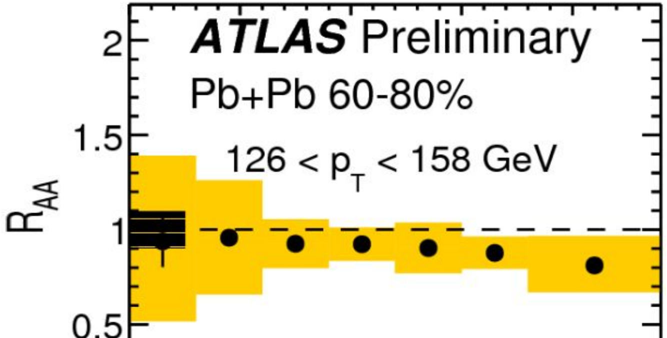
Measured in Pb+Pb

Measured in *pp*

Jet mass R_{AA} vs m/p_T @ 5.02 TeV

- Jet mass R_{AA} measured differentially in centrality and over a wide kinematic range of $100 < p_T < 500$ GeV.
- No significant modification of $R_{AA}(m/p_T)$ observed.
- Next step: reducing the systematic uncertainties and measure rapidity dependence to observe the quark/gluon fractions.

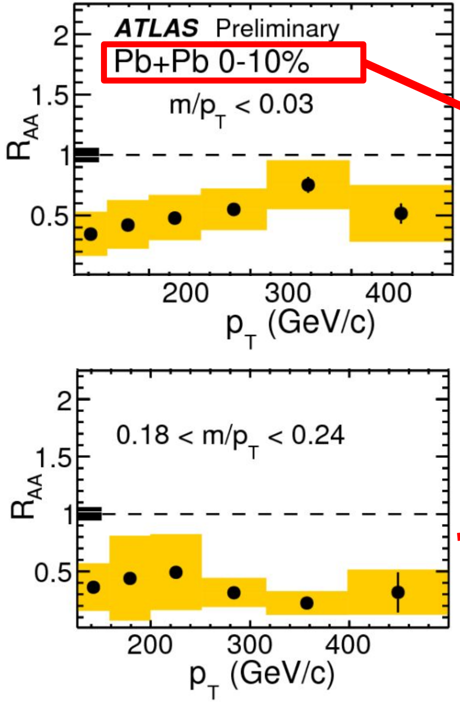


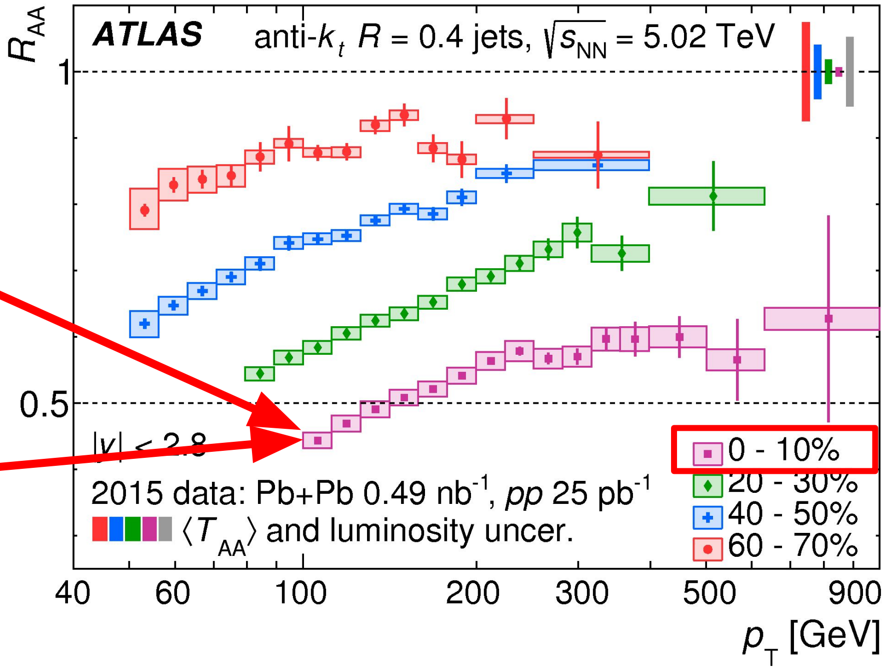


ATLAS-CONF-2018-014

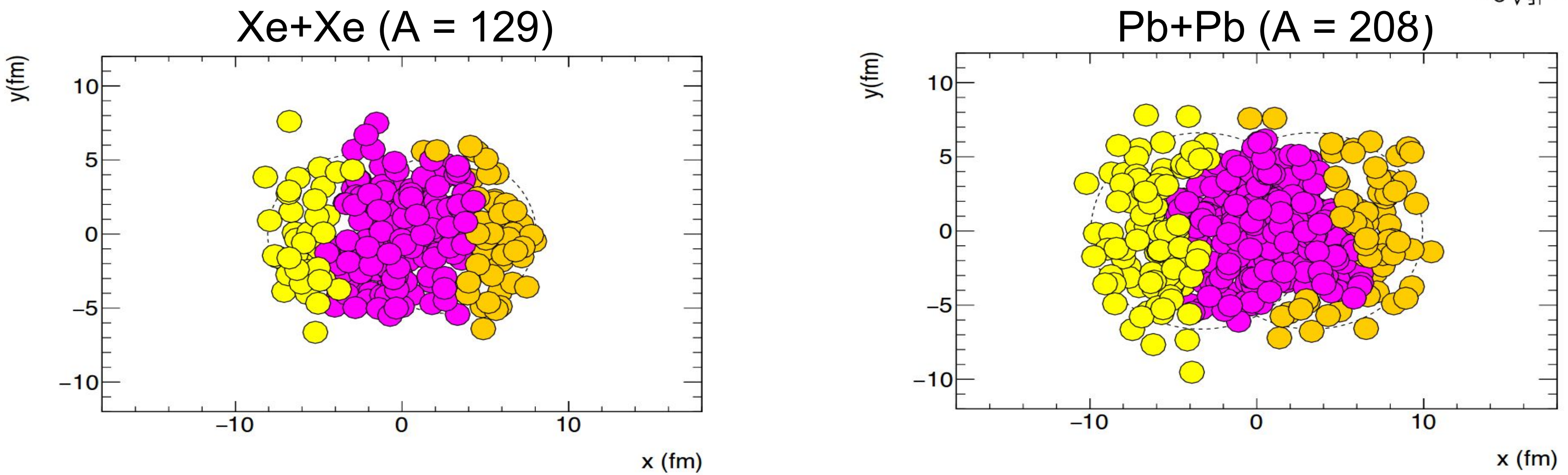
Jet mass R_{AA} vs p_T @ 5.02 TeV

- Jet mass R_{AA} measured differentially in centrality and over a wide kinematic range of $100 < p_T < 500$ GeV.
- All m/p_T bins consistent with inclusive jet $R_{AA}(p_T)$.



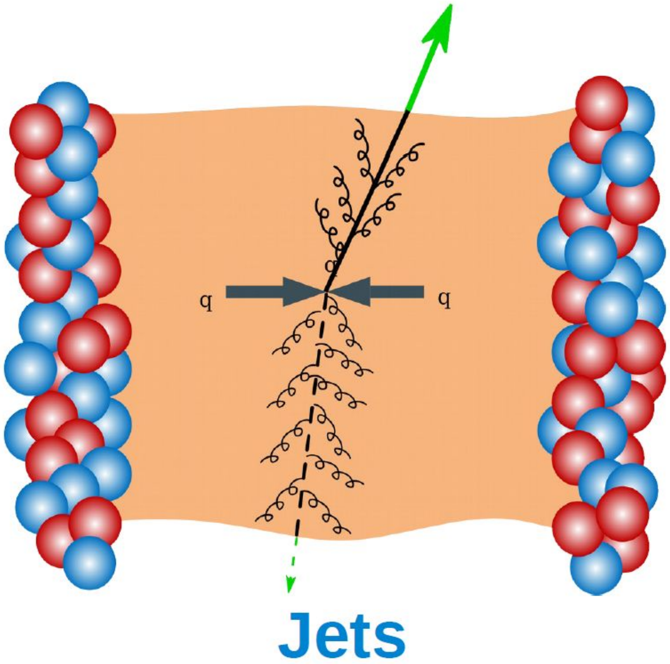


Xe+Xe vs. Pb+Pb



- *Hard Probes*: Xe+Xe collisions have typically a shorter path length through medium (formed in overlap region). Smaller jet suppression expected.
- *Soft Probes*: Smaller Xe+Xe system has fewer participants overall, and thus larger typical fluctuations of initial shape.

Dijet asymmetry

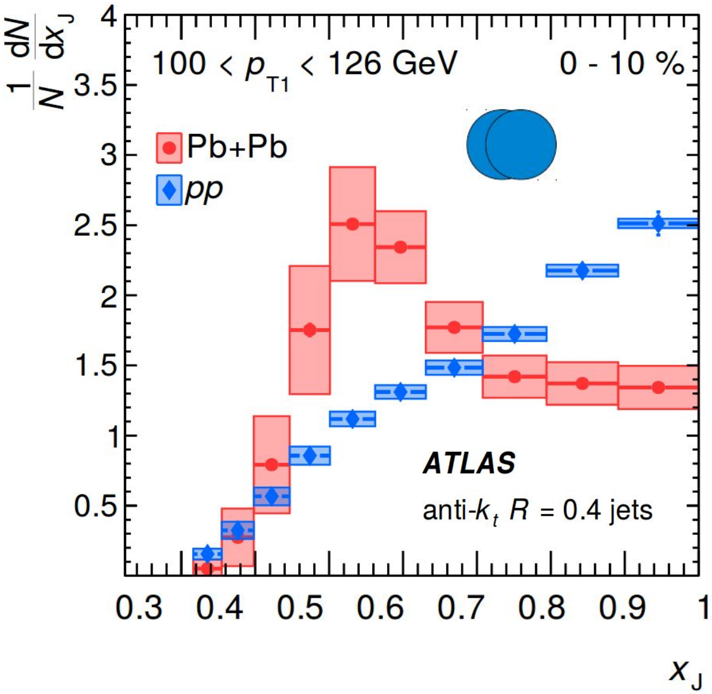


- Dijets in *pp* collisions are approximately balanced in energy
- In Pb+Pb the two jets lose different amounts of energy because of they travel different paths in the plasma or they are caused by jet-by-jet fluctuations in the energy loss
- Use ratio of the lower jet p_T (sub-leading jet) to the higher jet p_T (leading jet):

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

- Compare Pb+Pb to *pp* dijets where we expect the x_J ~1

Reminder: Dijet asymmetry in Pb+Pb & *pp* @ 2.76 TeV

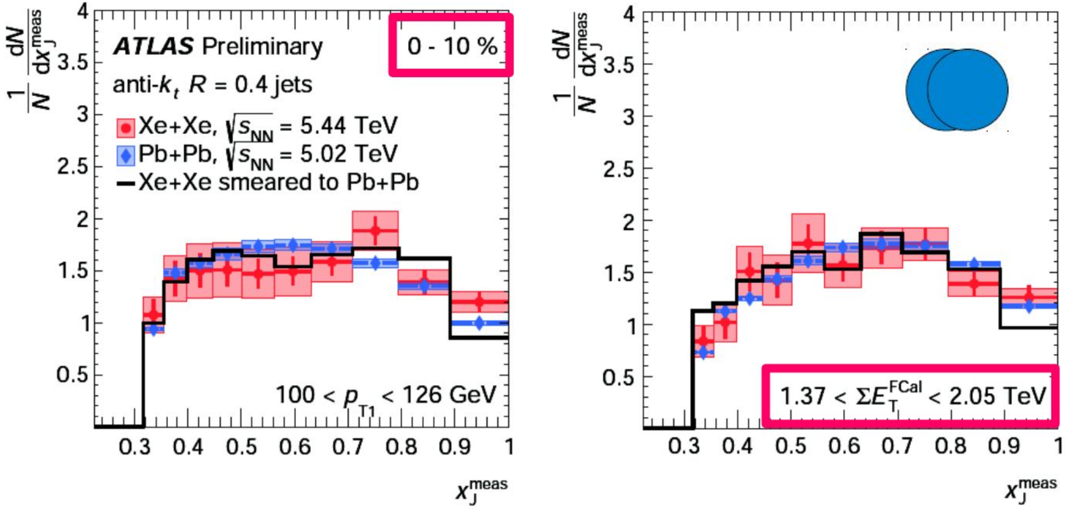


PBL 774 (2017) 379

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

- **Measured for:**
  - $p_{T,\text{subleadning}}$ >25 GeV,
  - $p_{T,\text{leadning}}$ >100 GeV (various bins),
  - $|\Delta\varphi| > 7\pi/8$
  - $|\eta| < 2.1$
  - R=0.4, R=0.3 jets

Dijet asymmetry:
Xe+Xe @ 5.44 TeV vs Pb+Pb @ 5.02 TeV

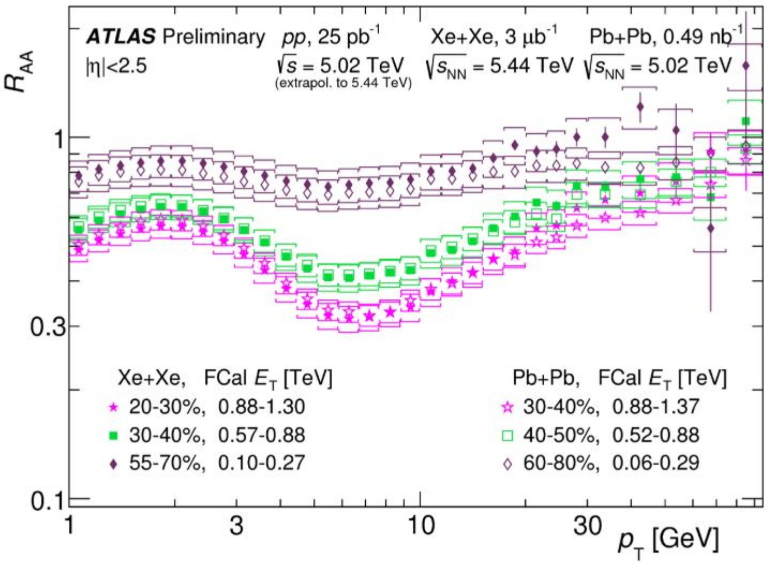


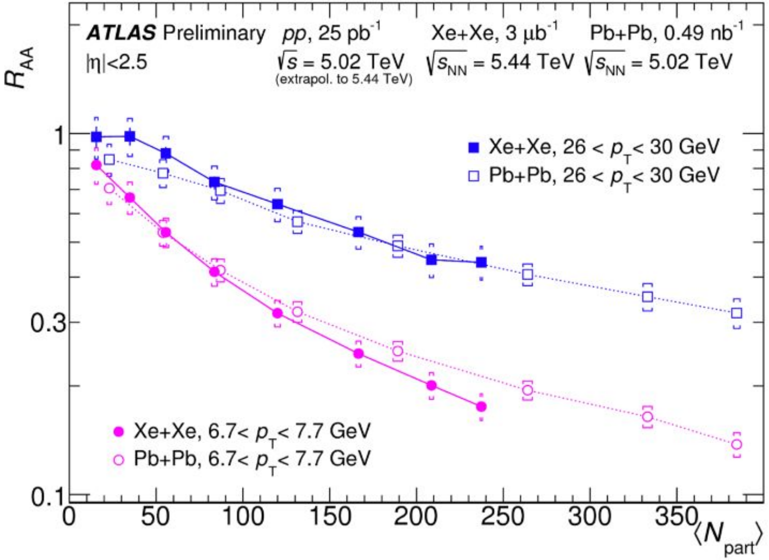
[ATLAS-CONF-2018-007]

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

- Left: Xe+Xe consistent with Pb+Pb in same centrality percentiles.
- Right: Xe+Xe consistent with Pb+Pb in the same event activity class (same FCal E_T bin).
- <u>Not yet unfolded</u>, but Xe smeared to match Pb UE fluctuations.
- No clear preference for geometry vs. density.

Charged hadron R_{AA} in Xe+Xe and Pb+Pb



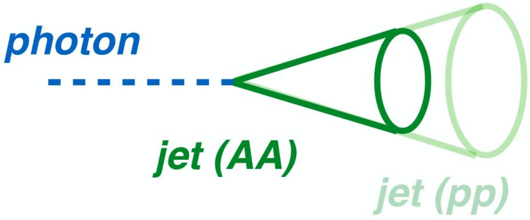


ATLAS-CONF-2018-007

- Measurement of charged-hadron spectra in **Xe+Xe** collisions at **5.44 TeV** and **Pb+Pb** at **5.02 TeV**.
- R_{AA} in Xe+Xe collisions shows a centrality-dependent suppression with characteristics qualitatively similar to that observed in Pb+Pb collisions.
- In central events, hadron yields in Xe collisions are more suppressed to those in Pb, while in peripheral events, milder suppression observed in Xe+Xe than Pb+Pb collisions.
- Baseline estimated from *pp* data with 5.02 TeV and extrapolated to the Xe+Xe center-of-mass energy.

Photon-tagged jet studies in Pb+Pb @ 5.02 TeV

- What is the (absolute) amount of energy lost in cone?

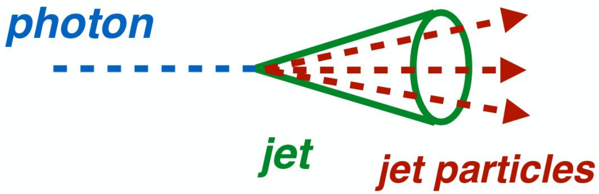


Photon-jet p_T asymmetry:

$x_{J\gamma} = p_T^{jet} / p_T^{\gamma}$ (for $\Delta\Phi > 7\pi/8$)

Phys. Lett. B 789 (2019) 167

- How is the parton shower in cone modified by hot and dense medium?



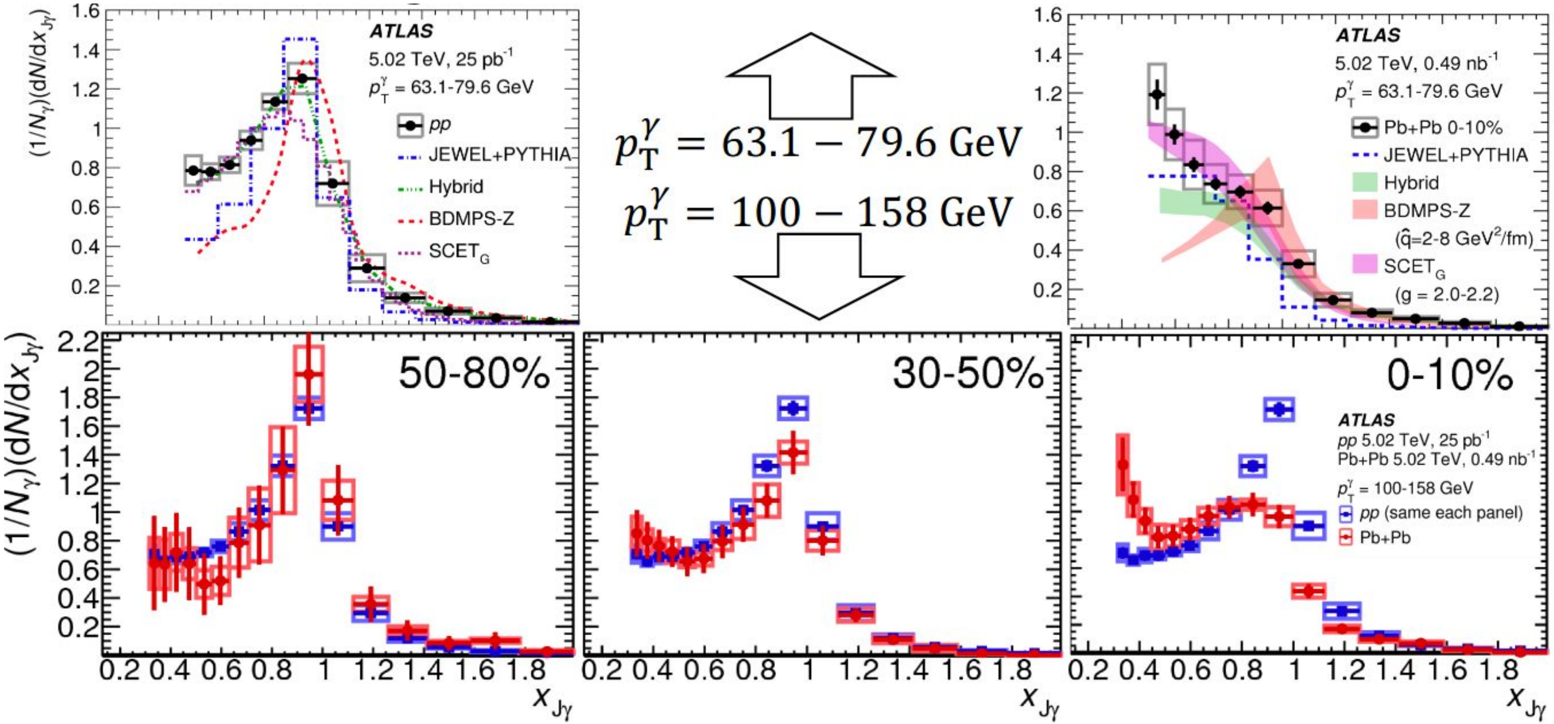
Photon-tagged fragmentation function
(with respect to the jet):
$D(p_T^h)$ or $D(z = p_T^h / p_T^{jet})$
ATLAS-CONF-2017-074

Kinematic selection intended to pick out only leading (dominantly quark) jets:

$p_T^{\gamma} = 79.6 - 125$ GeV $\quad p_T^{jet} = 63.1 - 144$ GeV

γ-jet asymmetry in *pp* and Pb+Pb @ 5.02 TeV

- ***pp*** peaks at $x_{J\gamma} \sim 1$ compared to central events in **Pb+Pb** at $x_{J\gamma} \sim 0.5$.



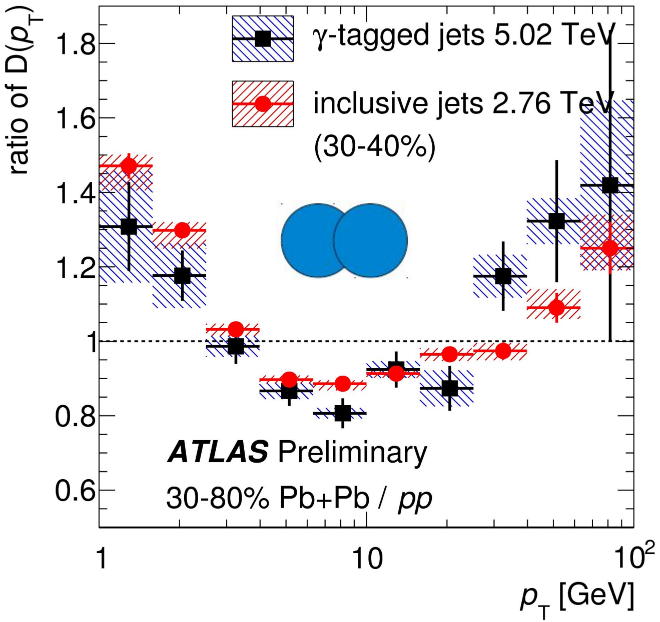
$$x_{J\gamma} = \frac{p_{T,\mathrm{jet}}}{p_{T,\gamma}}$$

- Peripheral **Pb+Pb** events are similar to ***pp*** collisions.

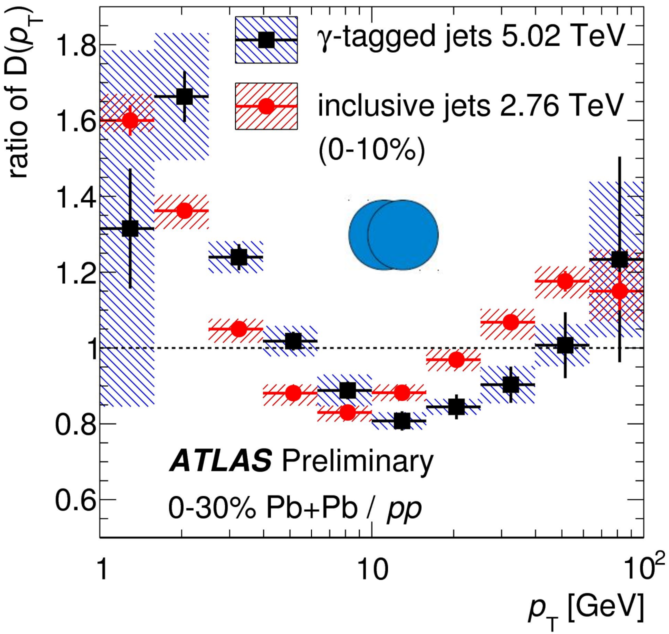
Phys. Lett. B 789 (2019) 167

Photon-tagged jet FF ratios in Pb+Pb @ 5.02 TeV

30-80% Pb+Pb / *pp*



0-30% Pb+Pb / *pp*

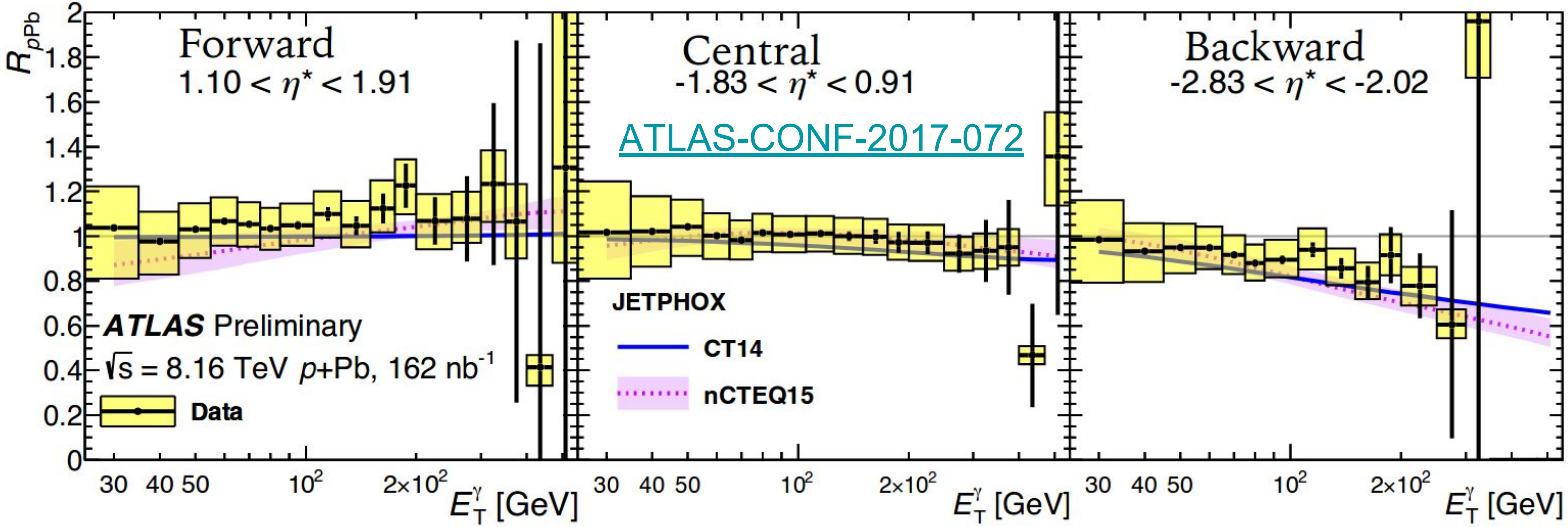


- In peripheral (left): similar behaviour for photon-tagged and inclusive jets.
- In central (right): differences between photon-tagged and inclusive jet FF - additional suppression at high p_T and enhancement at low p_T.

ATLAS-CONF-2017-074

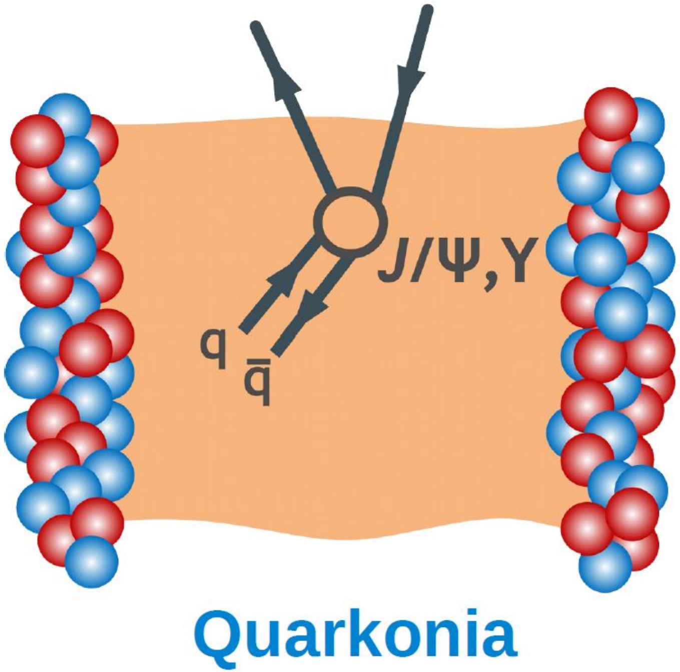
Inclusive photons in *p*+Pb

- Measurement of inclusive prompt photons in *p*+Pb collisions at 8.16 TeV:
  - At forward and central rapidity, R_{pPb} consistent with unity.
  - At backward rapidity, R_{pPb} < 1 due to isospin effects.
- Comparison to JETPHOX with nPDF from EPPS16, nCTEQ15:
  - With the current uncertainties, the data is unable to constraint nPDF.
  - Ongoing work to reduce uncertainties.

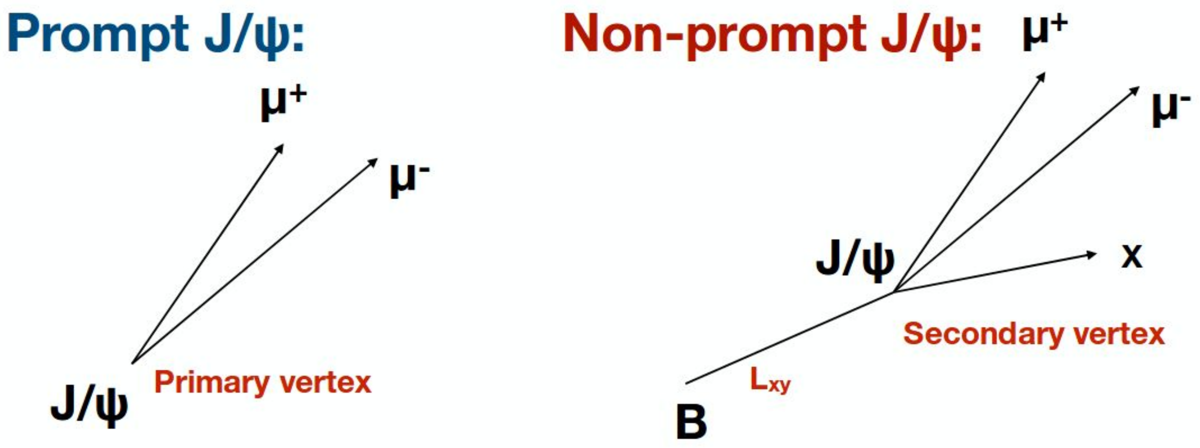


Quarkonia production in HI collisions

Charmonia are bound states of c and $\bar{c}$ quarks. An important probe to study the hot, dense system created in nucleus-nucleus (A+A) collisions.



Prompt and non-prompt quarkonia production



Inclusive J/ψ

=

Prompt J/ψ
(direct production, feed-down from excited states)

→ **Modified by color screening and regeneration in the QGP**

+

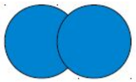
Non-Prompt J/ψ
(decays from B-hadrons)

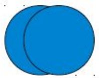
→ **Energy loss of *b*-quarks in the medium**

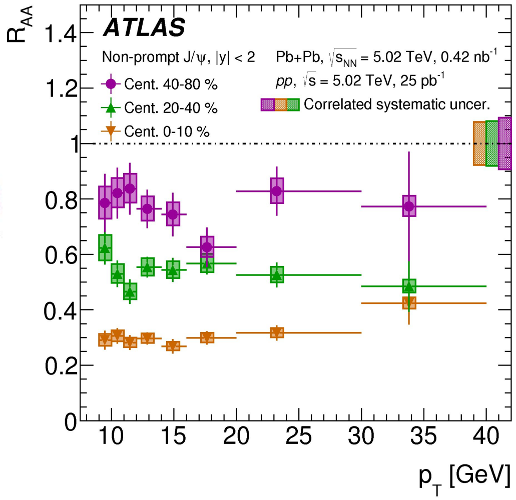
Quarkonia production in Pb+Pb @ 5.02 TeV

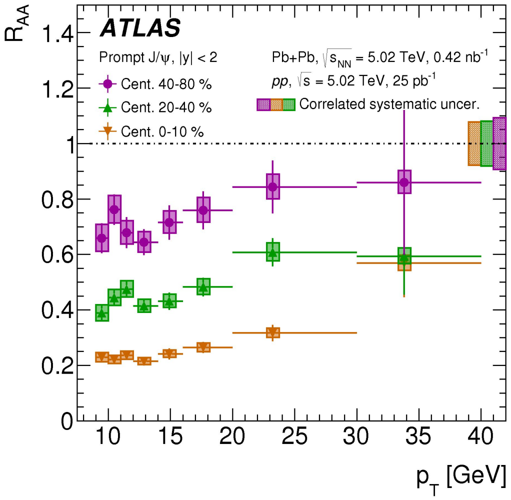
- Measurement of per-event yields of prompt and non-prompt production of J/ψ and ψ(2S) for different centrality classes.
- Meson kinematics determined from a dimuon system: $9 < p_T < 40$ GeV and $|y| < 2$.
- J/ψ R_{AA} as a function of p_T, rapidity and N_{part} for both prompt and non-prompt component.
- Strong suppression is found for both J/ψ and ψ(2S) and increasing with centrality.
- R_{AA} dependence of prompt and non-prompt J/ψ on centrality seems to be quite similar.
- For 0-10% centrality, $R_{AA} \sim 0.25$.

Eur. Phys. J. C 78 (2018) 762









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- Meson kinematics determined from a dimuon system: $9 < p_T < 40$ GeV and $|y| < 2$.
- J/ψ R_{AA} as a function of p_T, rapidity and N_{part} for both prompt and non-prompt component.
- Strong suppression is found for both J/ψ and ψ(2S) and increasing with centrality.
- R_{AA} dependence of prompt and non-prompt J/ψ on centrality seems to be quite similar.
- Result largely consistent with colour screening and colour transparency and parton energy-loss predictions.

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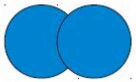
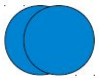
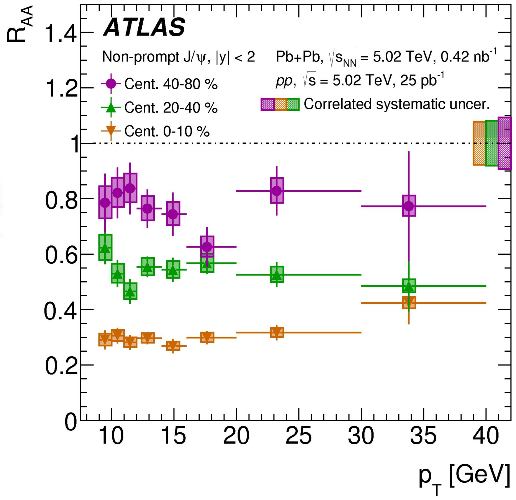
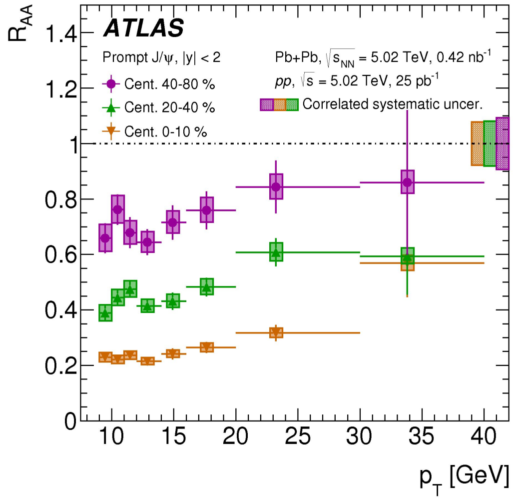
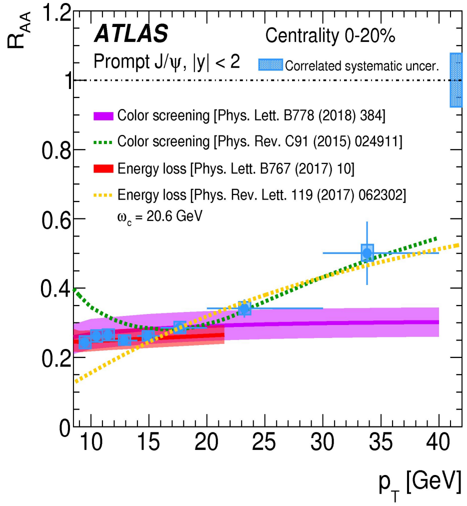




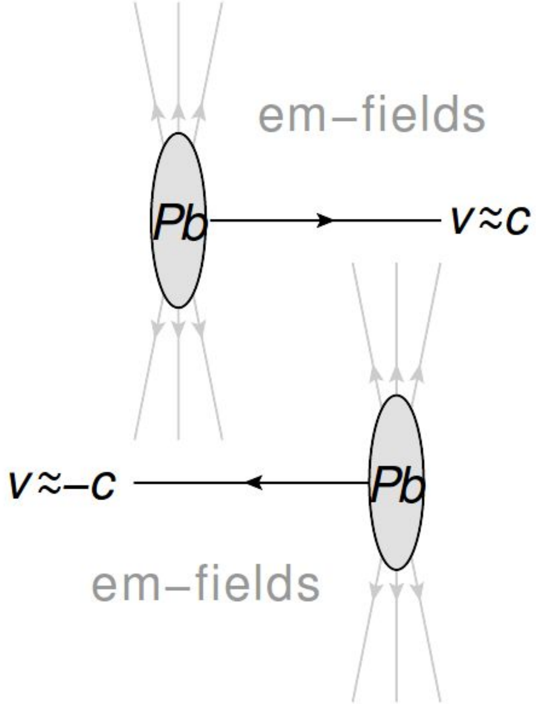






UPC and non-UPC Pb+Pb collisions

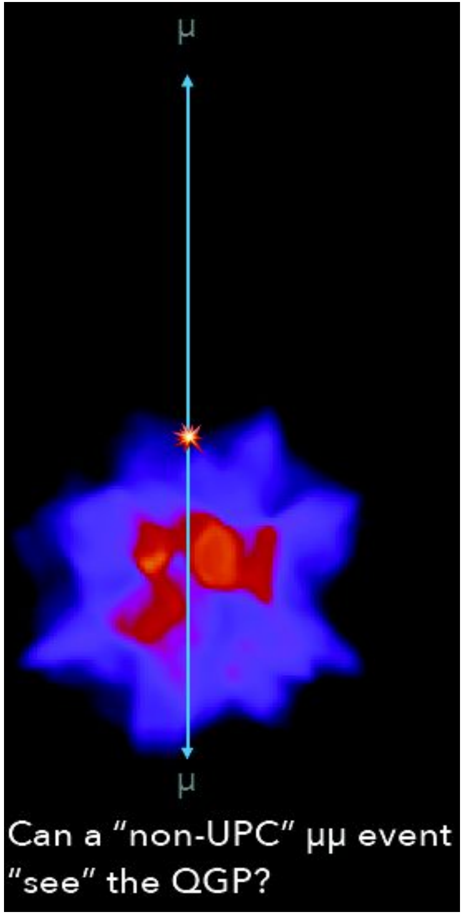
- Ultra peripheral (UPC) collisions ($b>2R$):
  - the EM processes dominate, and have a very clean signature.
  - Equivalently, sources of photons w/ high flux extending to >~ 50 GeV
  - Use to probe "initial state" of Pb+Pb collisions using γ+A collisions
- non-Ultra peripheral collisions ($b<2R$):
  - EM processes are still present and are background to hadronic interactions.



Exclusive dimuons in non-UPC Pb+Pb collisions

- In this search, look for exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ production in MinBias events in non-Ultra-Peripheral collisions.
- Muons are back-to-back in azimuth Φ.
- Acoplanarity, α, is defined as: $\alpha = |1 - \Delta\Phi / \pi|$.

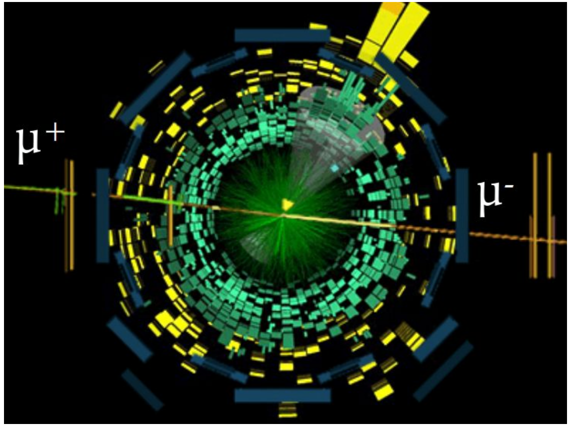
- What happens to acoplanarity in the QGP?

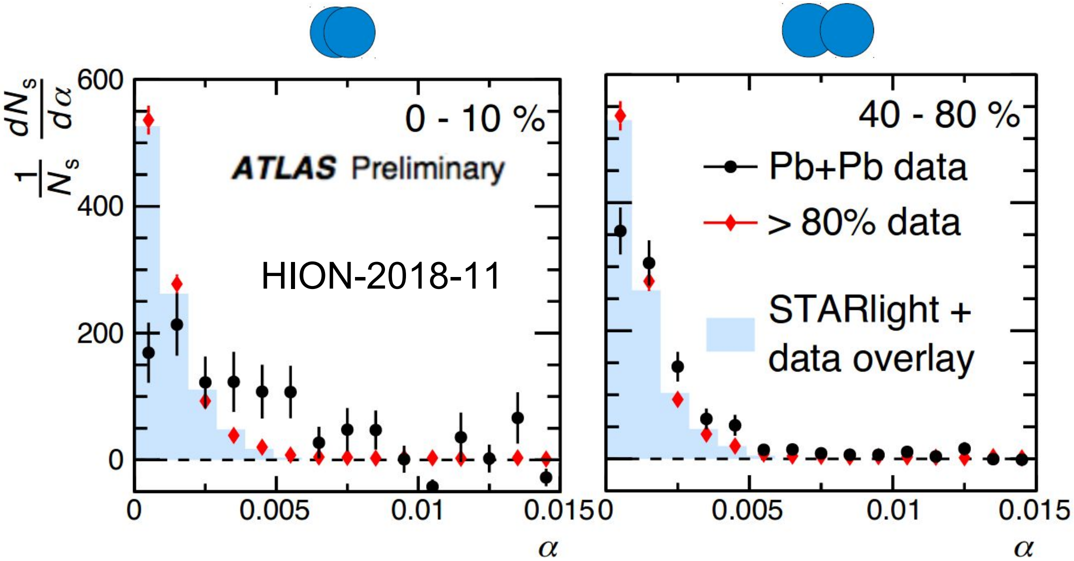


ATLAS EXPERIMENT

Exclusive dimuons in non-UPC Pb+Pb collisions

- Exclusive production of $\mu^+\mu^-$ pairs in non-Ultra-Peripheral collisions.
- Muons are back-to-back in azimuth *Φ.*
- Acoplanarity, α, is defined as: $\alpha = |1 - \Delta\Phi / \pi|$
- What happens to acoplanarity in the QGP?





- A clear centrality-dependent broadening is observed for α distribution.
- Modification qualitatively consistent with re-scattering of muons in the QGP.
- MC model (signal from STARlight+MB event from data) does not describe the data in the central events.
- First observation of EM interactions with the QGP?

Conclusions

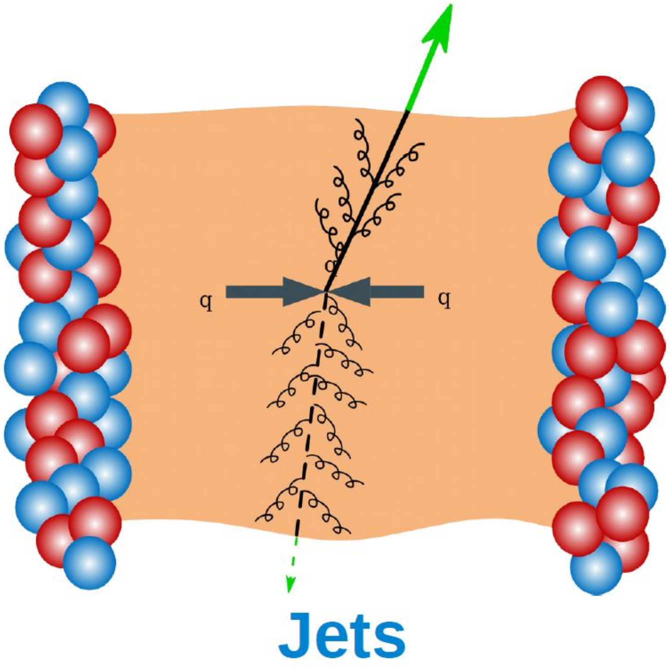
- EW boson measurements improve our understanding of the geometry.
- Inclusive jet suppression in 5.02 TeV Pb+Pb collisions:
  - Significant suppression seen up to ~1 TeV with weak p_T dependence.
- Mass of jets measured in Pb+Pb & *pp* collisions at 5.02 TeV:
  - No dependence of R_{AA} on m/p_T of jets observed.
- Dijet asymmetry in 5.44 TeV Xe+Xe collisions:
  - No differences in comparison to Pb+Pb collisions observed.
- Measured spectra and nuclear modification factor for charged hadrons in Xe+Xe collisions:
  - The suppression is similar to that measured in Pb+Pb collisions.
- Photon-jet fragmentation functions:
  - Different modification in central events compared to inclusive jets FF.
- Strong suppression is found for both J/ψ and ψ(2S).
- Observation of broadening of acoplanarity distribution for muons from γγ->μμ process.

ATLAS public results

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

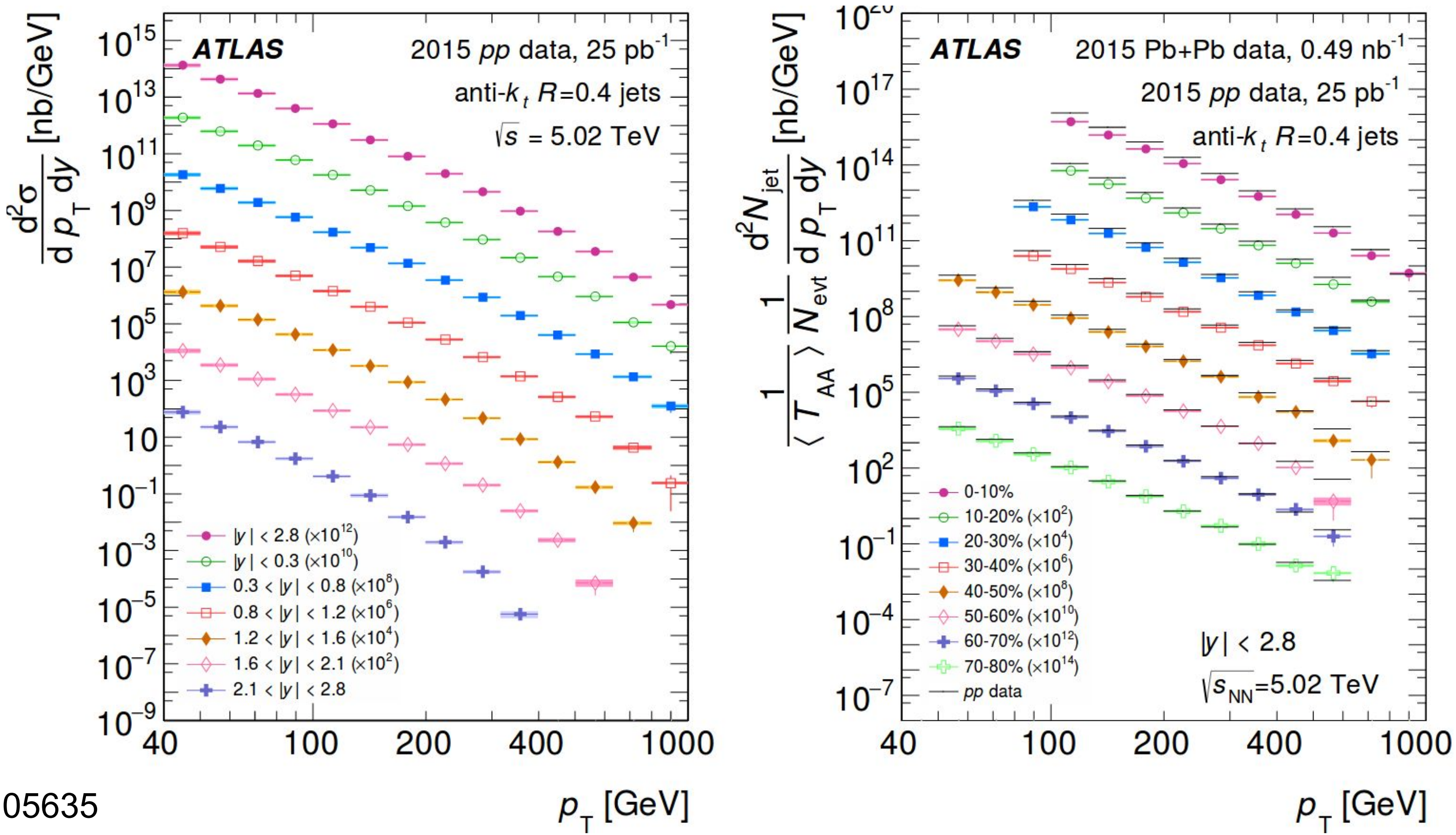
Characterizing the QGP using jets

Different hard probes interact with medium differently.



- Produced early in the collision where the initial state is well understood such that any differences from *pp* in the final state are from interactions with the medium.
- Interactions of medium and colored probe (elastic scattering, induced radiation).
- Partons lose energy through interactions with the medium $\rightarrow$ **jet quenching**

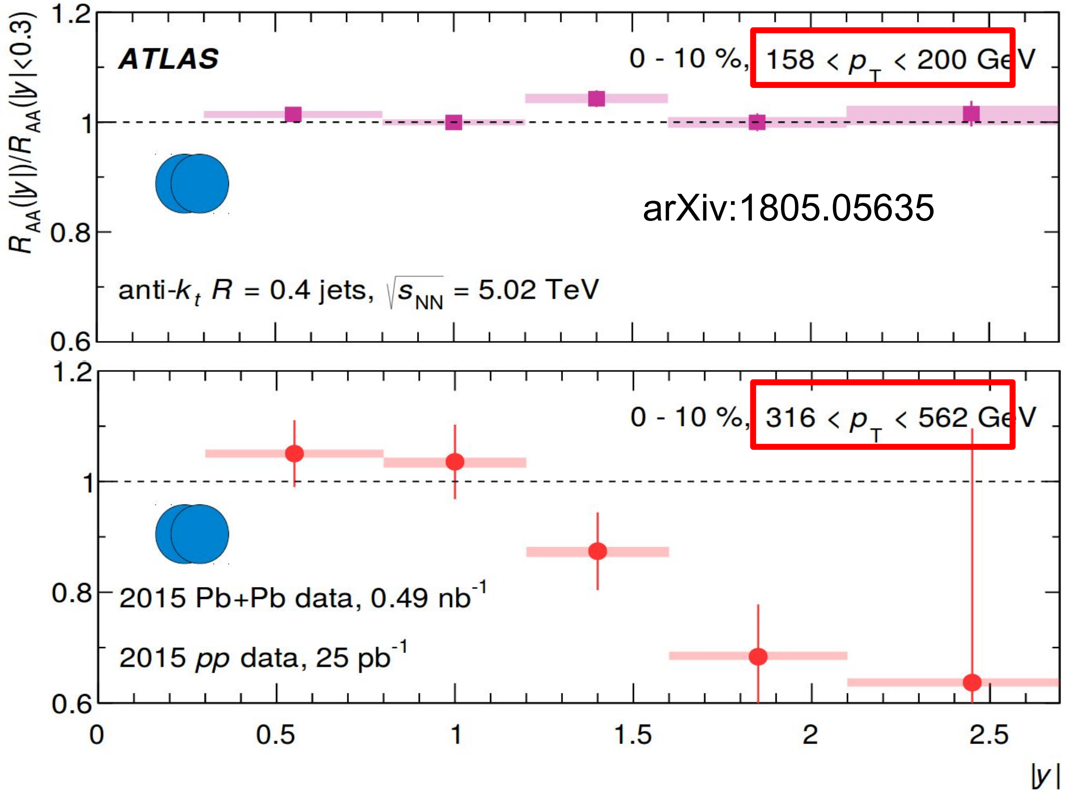
Jet cross-section in pp and yields in Pb+Pb



arXiv:1805.05635

Jet R_{AA} vs rapidity

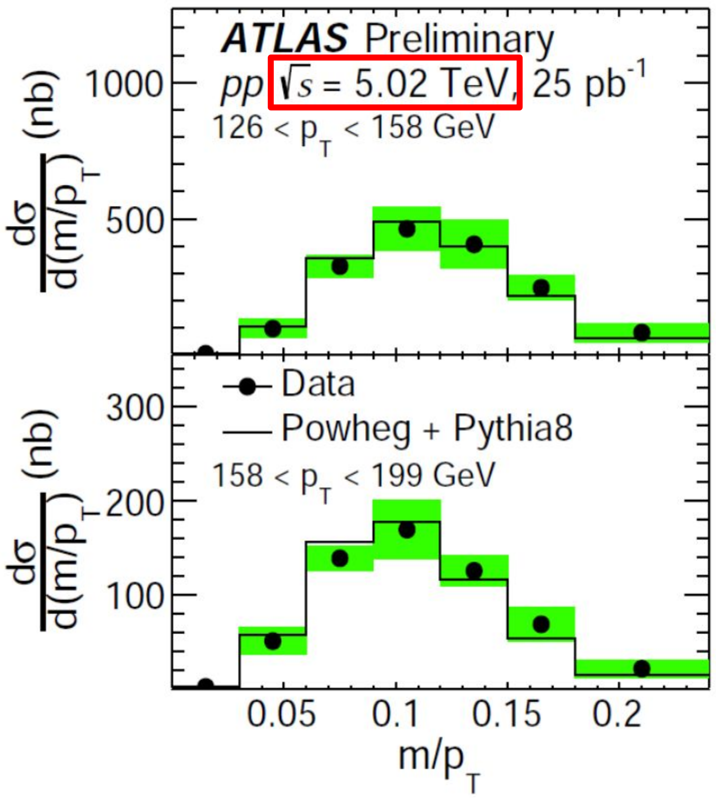
$$\frac{R_{AA}(|y|)}{R_{AA}(|y|<0.3)}$$

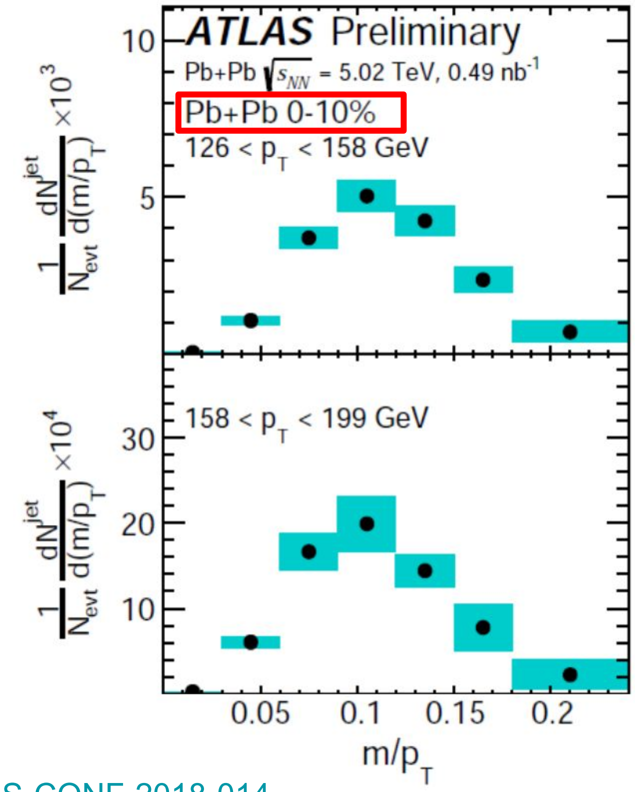


- Fraction of quark jets increases with $|y|$ at fixed jet p_T.
- Quark jets should lose less energy than gluon jets:
  - Increase R_{AA} with $|y|$
- Spectra become steeper with increasing |y|:
  - Decrease R_{AA} with $|y|$.

- For p_T > 316 GeV: The effects of the steeper spectra seems to dominate the measurement.

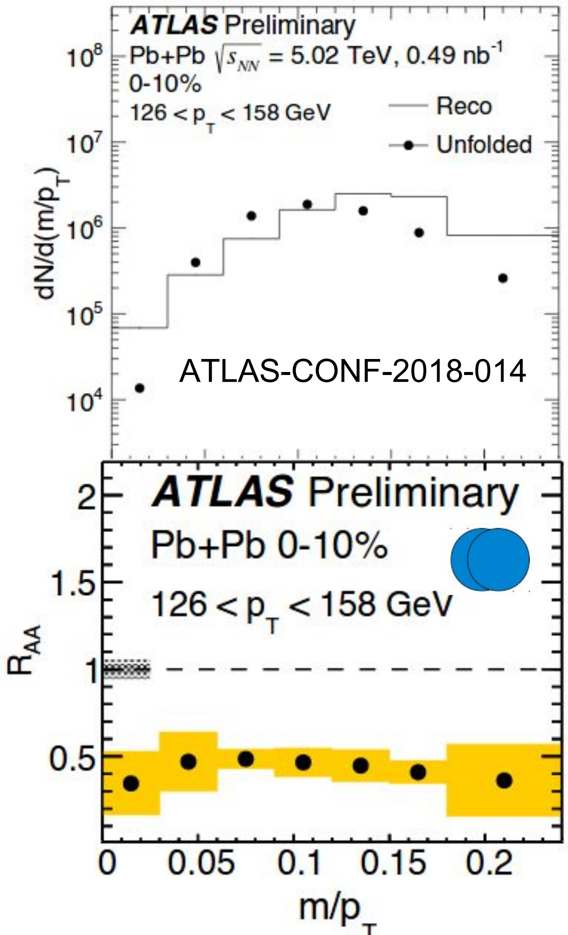
Jet mass distributions @ 5.02 TeV





ATLAS-CONF-2018-014

Jet mass in Pb+Pb @ 5.02 TeV



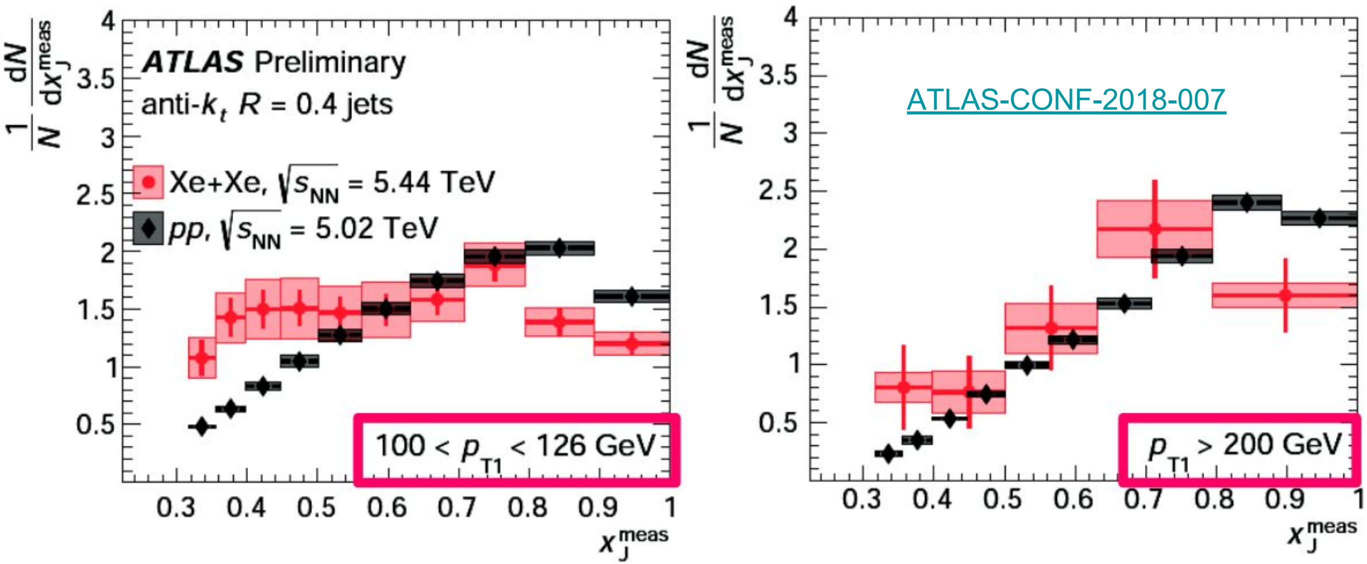
- First fully-unfolded measurement of jet mass in Pb+Pb/*pp* collisions at 5.02 TeV by ATLAS
- Jets: 126 < p_T < 500 GeV, $|y|$ < 2.1
- Distribution of m/p_T is measured, where m is the norm of jet four-momentum from calo towers

$$R_{AA}(m/p_T, p_T) = \frac{\left.\frac{1}{N_{evt}} \frac{dN_{jet}^{Pb+Pb}}{d(m/p_T)}(p_T)\right|_{cent}}{\langle T_{AA}\rangle \frac{d\sigma_{jet}^{pp}}{d(m/p_T)}(p_T)}$$

- R_{AA} has no significant dependence on m/p_T
- R_{AA} values are consistent with inclusive jet R_{AA}

Dijet asymmetry in Xe+Xe @ 5.44 TeV

Xe+Xe: smaller system, larger eccentricity … impact on jet suppression?

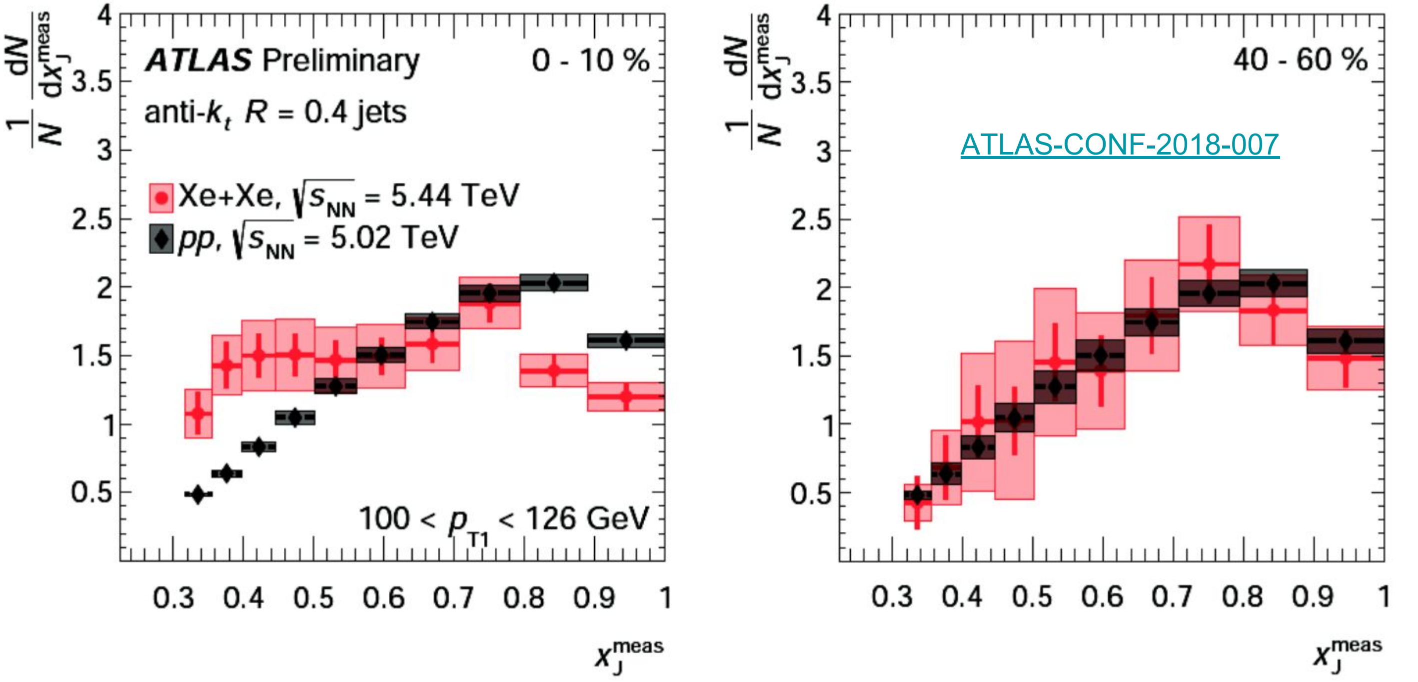


- Not unfolded for detector effects but still similar to Pb+Pb
- Larger dijet asymmetry decreases with increasing p_T

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

Dijet asymmetry in Xe+Xe @ 5.44 TeV

Xe+Xe: smaller system, larger eccentricity … impact on jet suppression?



- Not unfolded for detector effects
- x_J decreases with decreasing centrality

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

Fragmentation functions

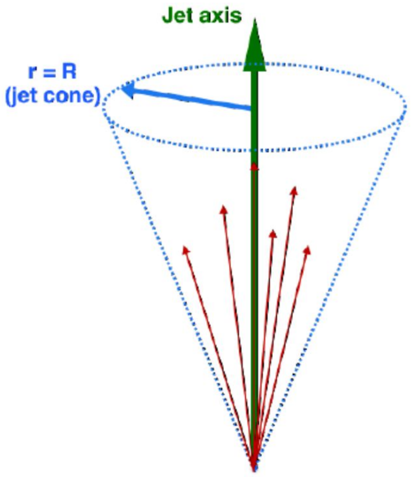
ATLAS studies of 3 colliding systems at different centre-of-mass energy:

pp @ 2.76 TeV & 5.02 TeV   *p*+Pb @ 5.02 TeV   Pb+Pb @ 2.76 TeV & 5.02 TeV

- How much is the jet structure modified?
- Jet fragmentation functions (FF) are defined as:

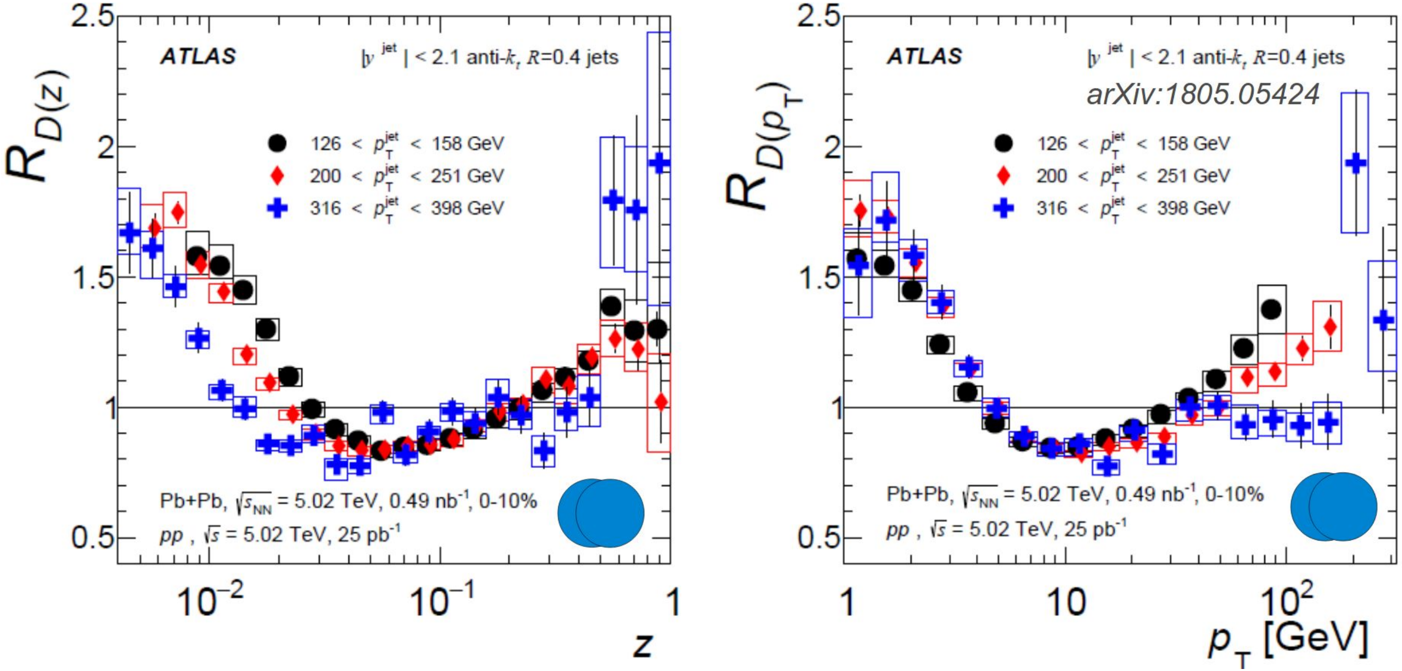
$$D(p_{\mathrm{T}}) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}p_{\mathrm{T}}^{\mathrm{ch}}} \qquad D(z) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}z} \qquad z = \frac{p_{\mathrm{T}}}{p_{\mathrm{T}}^{\mathrm{jet}}} \cos \Delta R$$

- N_{ch} is the number of charged particles associated to a jet
- Measurement was done for R = 0.4 jets differentially in η and p_T
- Jet substructure measured using charged tracks starting at p_T = 1 GeV
- FF are background subtracted, corrected for tracking efficiency and fully unfolded with 2D Bayesian unfolding



Jet p_T dependence to the FF modification

$$D(p_T) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dp_T} \quad D(z) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dz}$$, where $z \equiv p_T \cos r \ / \ p_T^{jet}$ $$R_{D(p_T,r)} = \frac{D(p_T,r)_{Pb+Pb}}{D(p_T,r)_{pp}}$$



- No dependence on jet p_T observed at high z for jets up to 400 GeV.
- Enhancement of soft fragments increases for high p_T jets.

Pb+Pb @ 5.02 TeV

Fragmentation functions measured at ATLAS

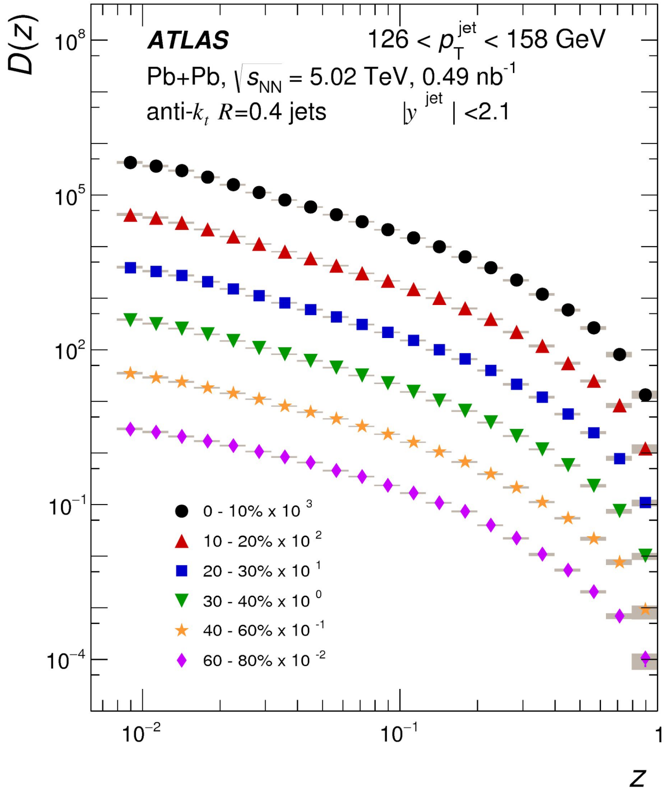
- FF @ 2.76 TeV:

  Pb+Pb central-to-peripheral ratio, *Physics Letters B 739 (2014) 320*
  Pb+Pb & *pp* reference, *Eur. Phys. J. C 77 (2017) 379*

- FF @ 5.02 TeV:

  p+Pb & *pp* reference, *arXiv:1706.02859*
  Pb+Pb & *pp* reference, *arXiv:1805.05424*
  r-dep in Pb+Pb & *pp* reference, *ATLAS-CONF-2018-010*
  Photon-tagged Pb+Pb & *pp* reference, *ATLAS-CONF-2017-074*

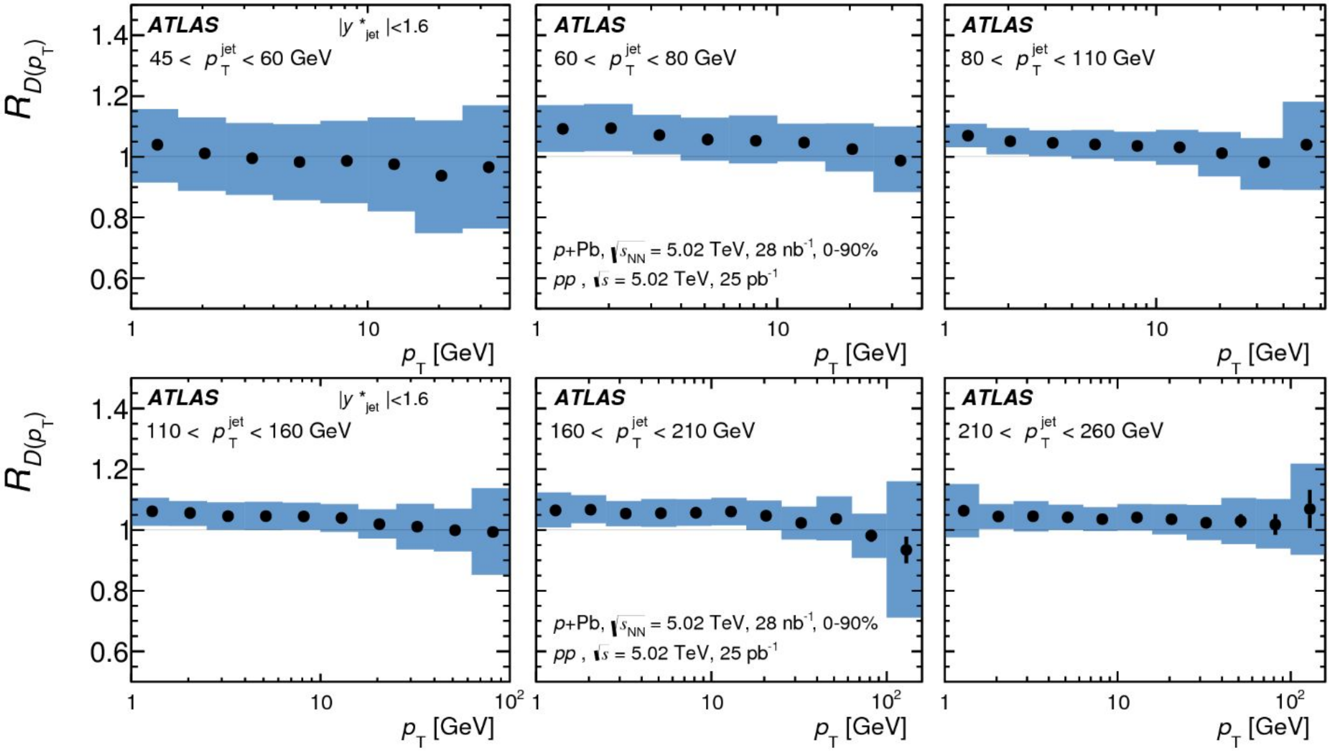
This talk



Jet p_T dependence to the FF modification

$$D(p_T) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dp_T} \qquad D(z) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dz}$$, where $z \equiv p_T \cos r \;\; / \, p_T^{jet}$

p+Pb @ 5.02 TeV



No modification of jet structure within experimental precision in the p+Pb system

Result consistent with unmodified hadron R_{pPb} measured with the 5.02 TeV pp reference data ATLAS-CONF-2016-108

Track-to-jet correlation

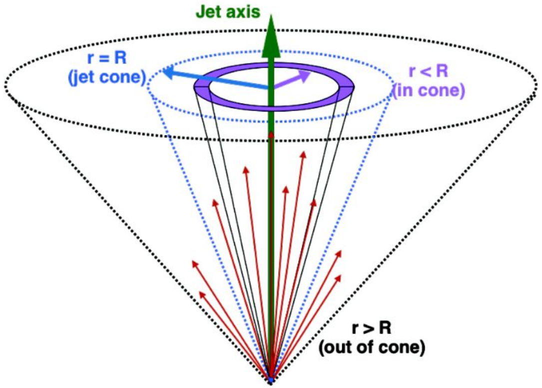
Reminder: measurement of the fragmentation functions:

$$D(p_T) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dp_T} \qquad D(z) \equiv \frac{1}{N_{jet}} \frac{dn_{ch}}{dz}$$

, where $z \equiv p_T \cos r \; / \; p_T^{jet}$

$$D(p_T, \boxed{r}) = \frac{1}{N_{jet}} \frac{1}{2\pi r} \frac{d^2 n_{ch}(r)}{dr \, dp_T}$$

where $r < 0.6$

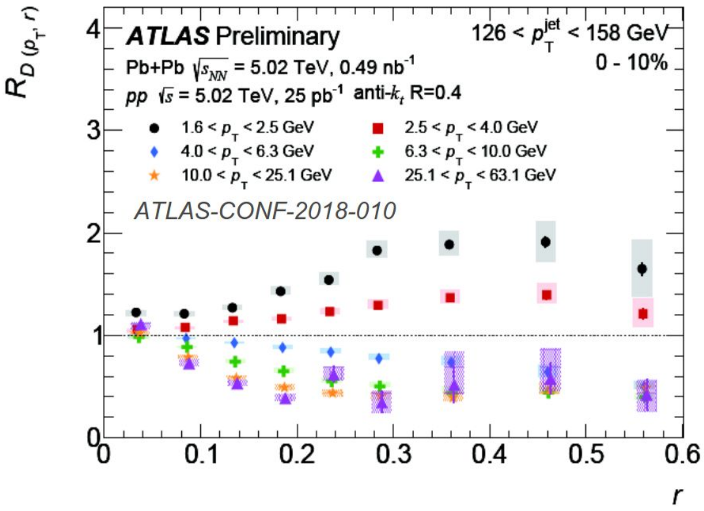


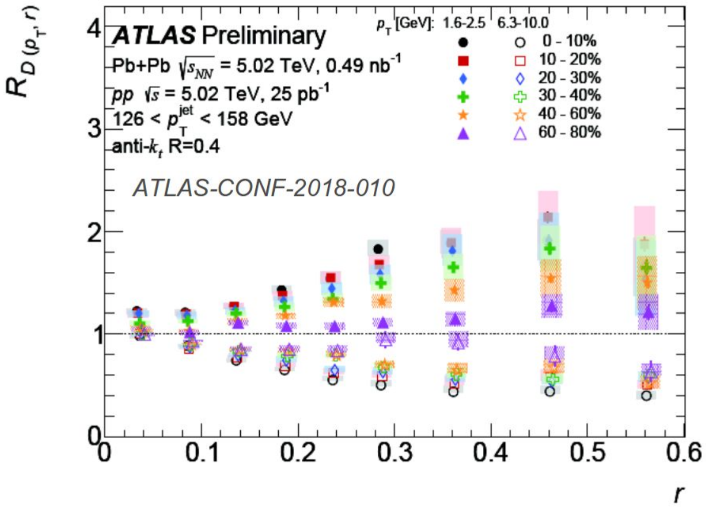
- Study distribution of charged particles inside and around the jet cone ($r < 0.6$) in Pb+Pb and *pp* collisions at 5.02 TeV
- Dependence on centrality, jet- and charged-particle p_T is extracted
- Quantities D(p_T, r) and ratios $R_{D(p_T,r)}$ are fully unfolded and can be compared to theory

Track-to-jet correlation

$$D(p_{\mathrm{T}}, r) = \frac{1}{N_{\mathrm{jet}}} \frac{1}{2\pi r} \frac{\mathrm{d}^2 n_{\mathrm{ch}}(r)}{\mathrm{d}r\,\mathrm{d}p_{\mathrm{T}}}$$

$$R_{D(p_{\mathrm{T}},r)} = \frac{D(p_{\mathrm{T}}, r)_{\mathrm{Pb+Pb}}}{D(p_{\mathrm{T}}, r)_{pp}}$$





$R_{D(p_{\mathrm{T}},r)}$ is above unity for particles with $1.6<p_{\mathrm{T}}<4$ GeV, and below unity for particles with $p_{\mathrm{T}} > 4$ GeV in 0-10% centralities

This observation is in agreement for $r < 0.4$ with the inclusive jet FF results

For a given particle p_{T} interval, $R_{D(p_{\mathrm{T}},r)}$ changes for $r < 0.3$ and then saturates

- Jets are broader in more central collisions. Smallest modification seen in the jet core.
- Increase of yields of soft fragments with increasing *r*. Decrease of yields of intermediate p_{T} particles with *r.*
- Energy lost by jets is being transferred to particles with $p_{\mathrm{T}}< 4.0$ GeV with larger radial

Track-to-jet correlation

$$D(p_{\mathrm{T}}, r) = \frac{1}{N_{\mathrm{jet}}} \frac{1}{2\pi r} \frac{\mathrm{d}^2 n_{\mathrm{ch}}(r)}{\mathrm{d}r\,\mathrm{d}p_{\mathrm{T}}} \qquad R_{D(p_{\mathrm{T}},r)} = \frac{D(p_{\mathrm{T}}, r)_{\mathrm{Pb+Pb}}}{D(p_{\mathrm{T}}, r)_{pp}}$$

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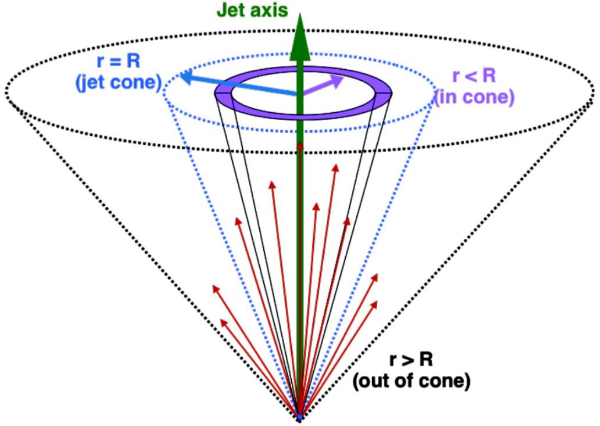

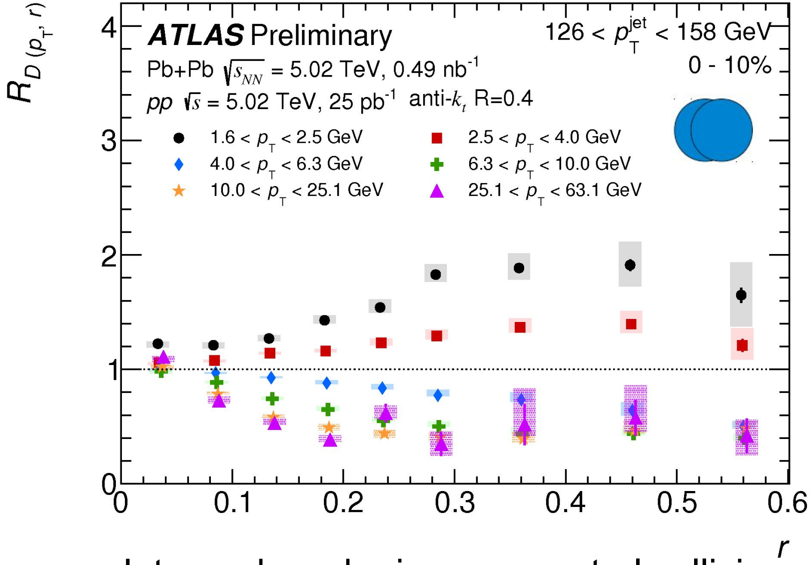

Jets are broader in more central collisions.
Smallest modification seen in the jet core.

ATLAS EXPERIMENT

ATLAS-CONF-2018-010

Track-to-jet correlation

$$D(p_{\mathrm{T}}, r) = \frac{1}{N_{\mathrm{jet}}} \frac{1}{2\pi r} \frac{\mathrm{d}^2 n_{\mathrm{ch}}(r)}{\mathrm{d}r\, \mathrm{d}p_{\mathrm{T}}} \qquad R_{D(p_{\mathrm{T}},r)} = \frac{D(p_{\mathrm{T}}, r)_{\mathrm{Pb+Pb}}}{D(p_{\mathrm{T}}, r)_{pp}}$$

- Study distribution of charged particles inside and around the jet cone ($r < 0.6$) in Pb+Pb and *pp* collisions at 5.02 TeV.
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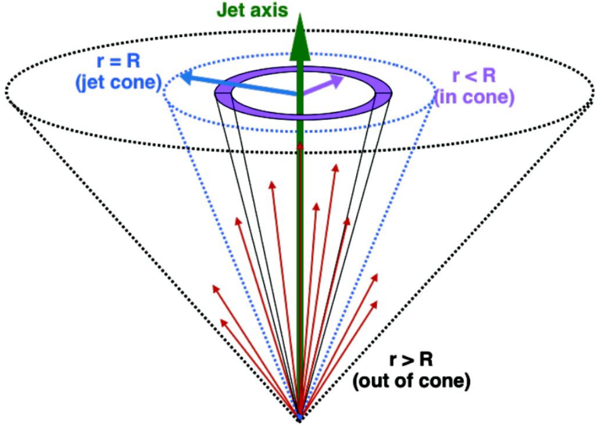
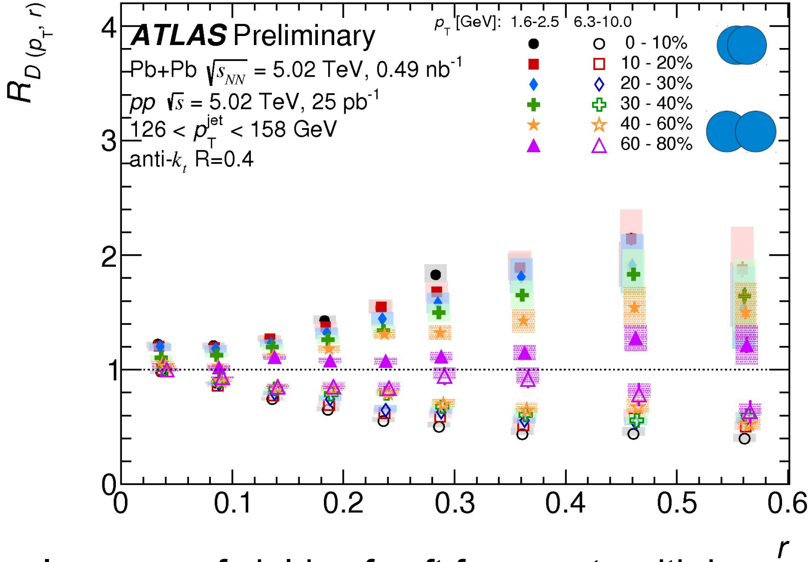




Increase of yields of soft fragments with increasing r.
Decrease of yields of intermediate p_T particles with r.

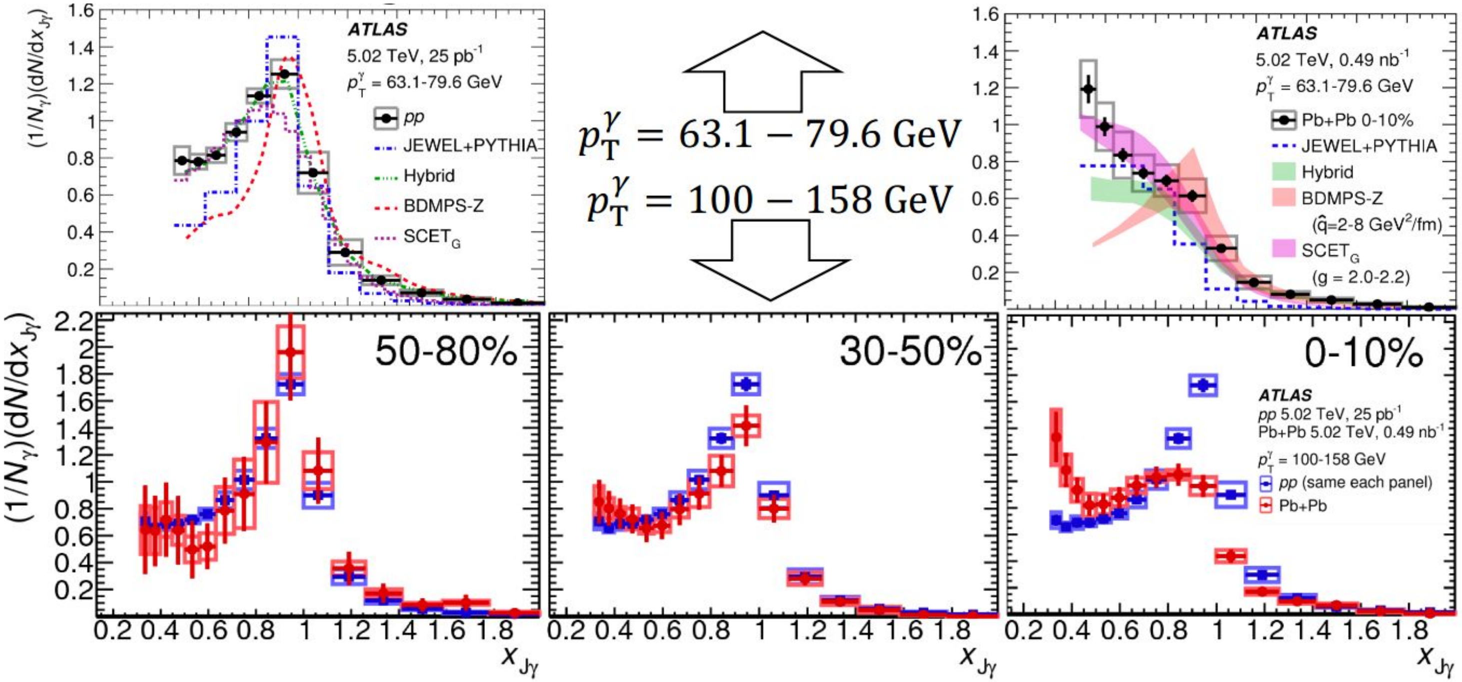
ATLAS EXPERIMENT

ATLAS-CONF-2018-010

γ-jet asymmetry in **Pb+Pb** and ***pp*** @ 5.02 TeV

- Central events in **Pb+Pb** peaks at $x_{J\gamma} \sim 0.5$ compared to ***pp*** at $x_{J\gamma} \sim 1$.
- Peripheral **Pb+Pb** events are similar to ***pp*** collisions.

PLB 789 (2019) 167



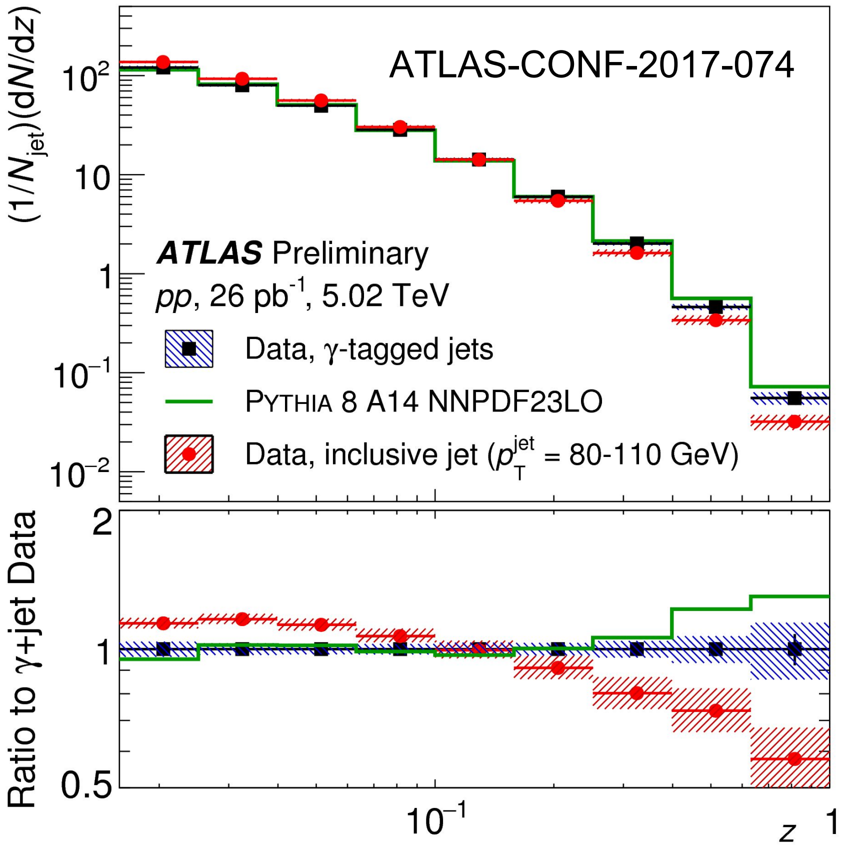
$$x_{J\gamma} = \frac{p_{T,\mathrm{jet}}}{p_{T,\gamma}}$$

Photon-tagged jet FF in *pp* @ 5.02 TeV

- Use photon-tagged jets with photons acting as unmodified probes in QGP

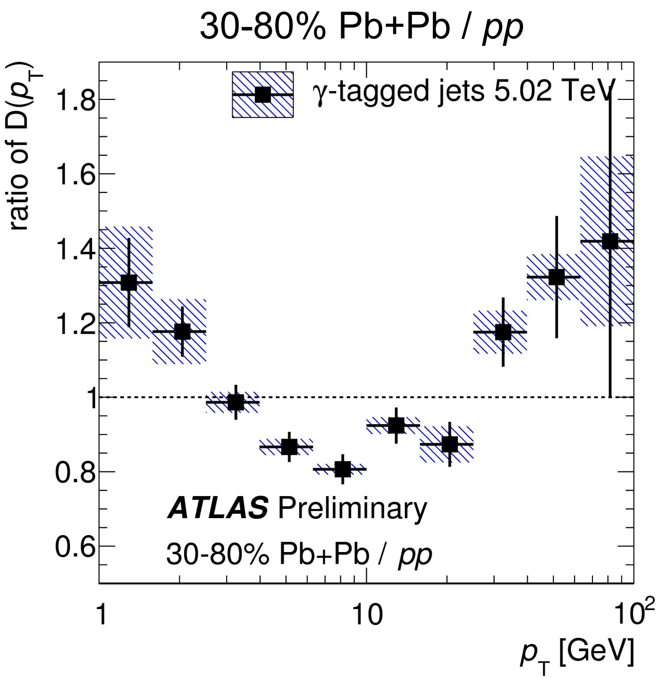
- Photon-tagged jets are more likely to be initiated by quarks, inclusive jets ale gluon jet-dominant

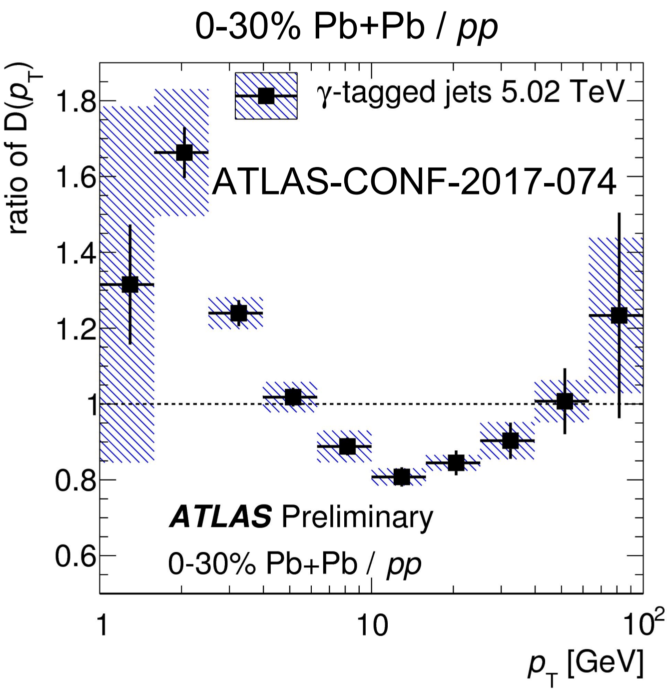
- Fully unfolded ratios of jet FF for photon-tagged and inclusive in Pb+Pb and pp systems



Inclusive to γ-tagged jet FF ratio

Photon-tagged jet FF ratios in Pb+Pb @ 5.02 TeV



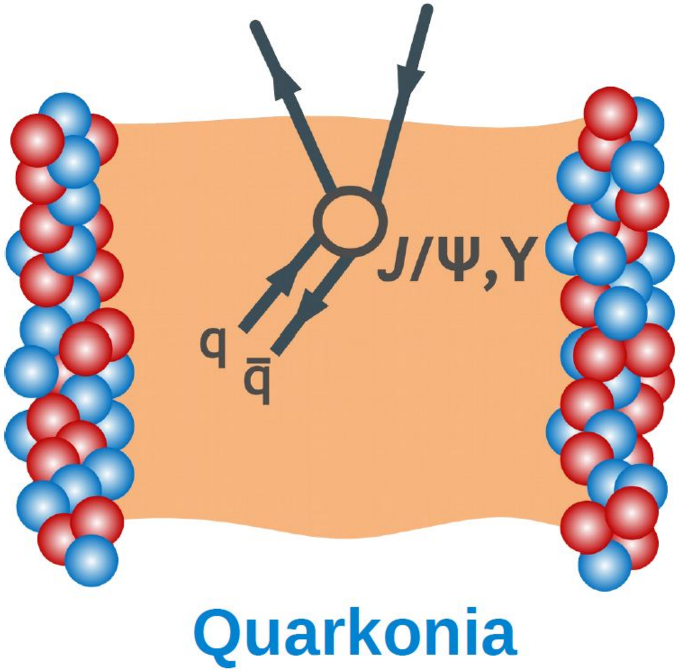


- Familiar pattern of modification for peripheral events wrt inclusive FF (left) but different pattern for central events (right)

Quarkonia production

Charmonia bound states of c and $\bar{c}$ quarks, could be a unique probe to study the hot, dense system created in nucleus-nucleus (A+A) collisions.

However, the full picture is much more complicated:
- Color-Screening: melting
- Color-exchange: absorption
- Medium induced energy loss
- Regeneration via statistical recombination
- Feed-Down of excited charmonium states and B-hadrons



Quarkonia production in p+Pb @ 5.02 TeV

EPJC 78 (2018) 171

- Measurement of cross-section for prompt and non-prompt production of J/ψ and ψ(2S) for different rapidity intervals and inclusive yields of Υ(nS), n =1, 2, 3.
- J/ψ cross-section are in agreement with NRQCD (prompt) and FONLL (non-prompt) predictions.
- J/ψ R_{pPb} is consistent with unity for p_T between 8 - 40 GeV.
- Υ(1S) R_{pPb} is found to be suppressed for p_T < 15 GeV.