

Studies of jet quenching and medium response using photon+jet events with ATLAS

Christopher McGinn

Quark Matter, Houston
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MIT HIG group's work was
supported by US DOE-NP



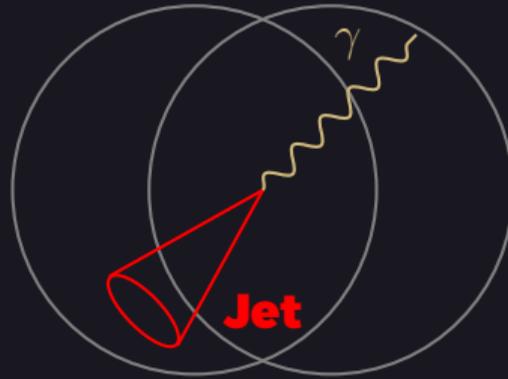
University
Colorado
Boulder



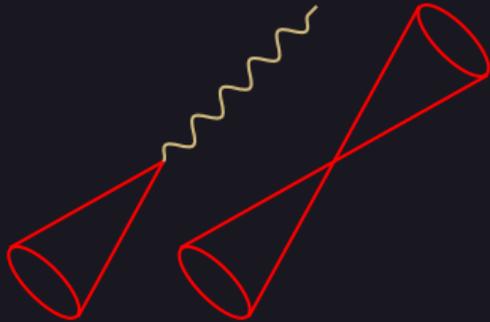
Photon+jets in QGP



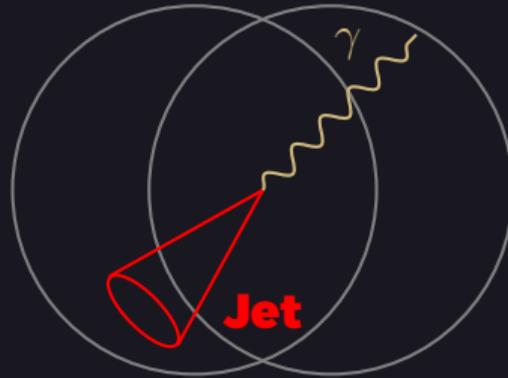
Photon+jets in QGP



1. Compare R_{AA}

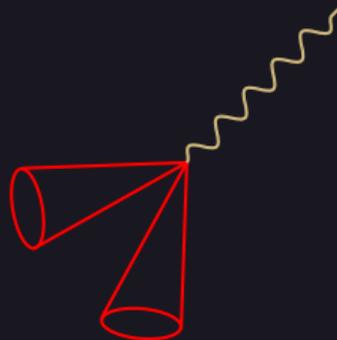
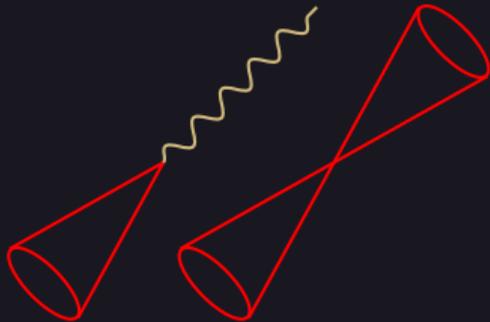


Photon+jets in QGP

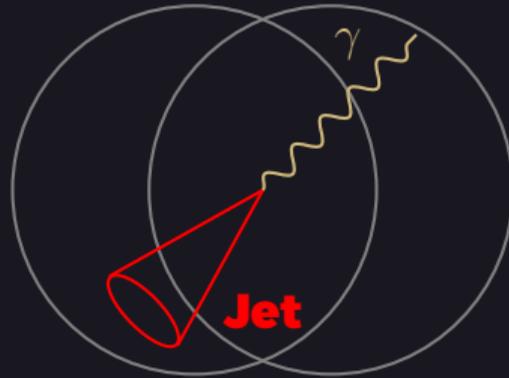


1. Compare R_{AA}

2. $\gamma+2$ jets + X



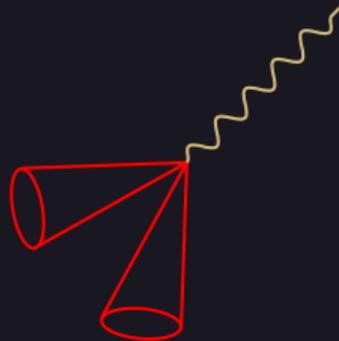
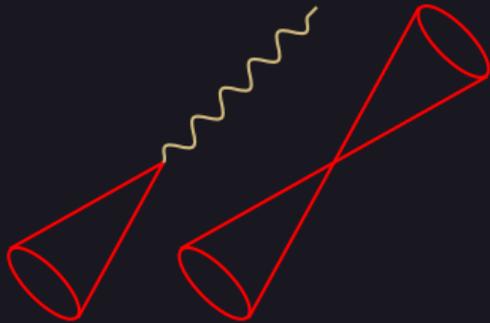
Photon+jets in QGP



1. Compare R_{AA}

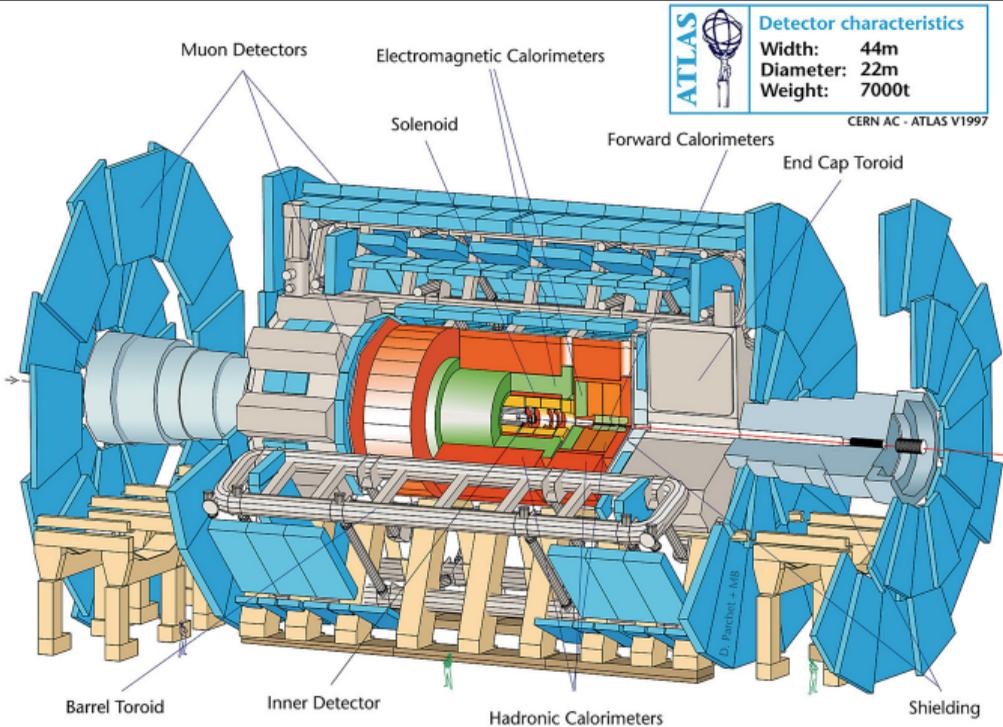
2. $\gamma+2$ jets + X

3. Diffusion Wake!



ATLAS Detector and Data

Via CDS



$p\ p$

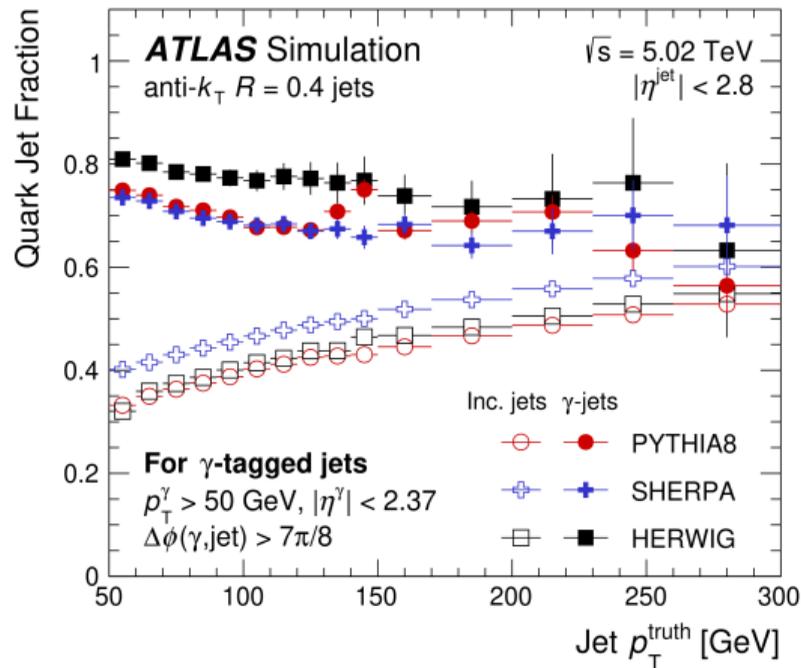
**pp collected in 2017
260 pb^{-1} int. lumi.**

$Pb\ Pb$

**Pb+Pb collected in 2018
1.72 nb^{-1} int. lumi.**

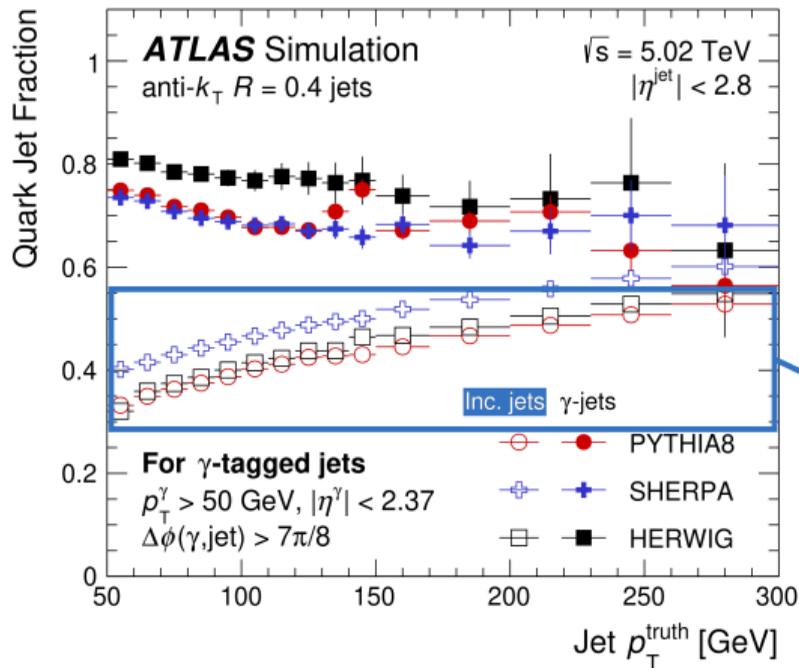
- **Jets are reconstructed w/ EMCal and HCal**
- **Photons are reconstructed w/ EMCal**
- **Centrality (nuclear overlap) is determined by FCal**

Motivating γ -tagged R_{AA}

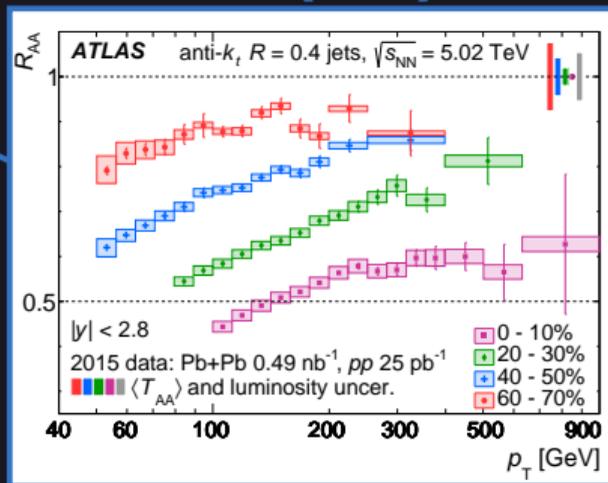


Accepted PLB

Motivating γ -tagged R_{AA}

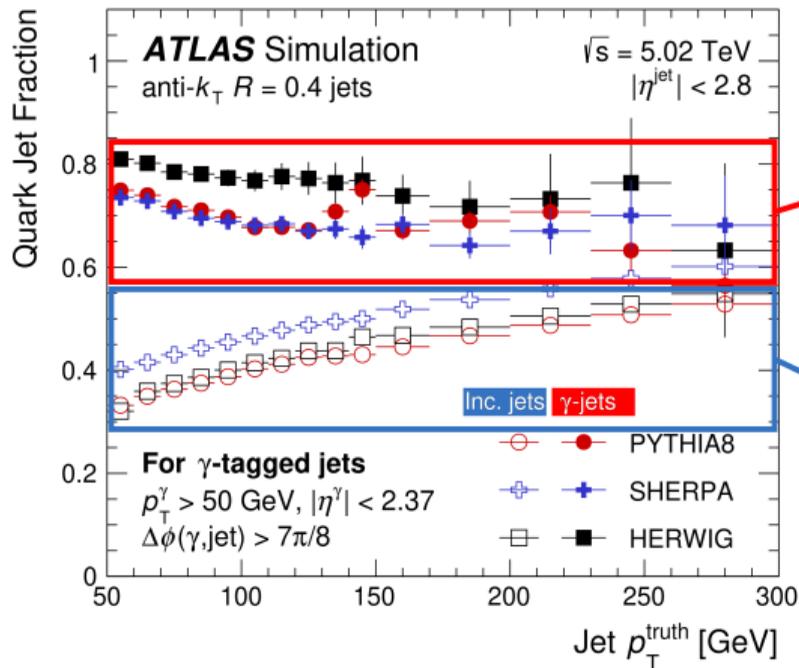


PLB 790 (2019) 180



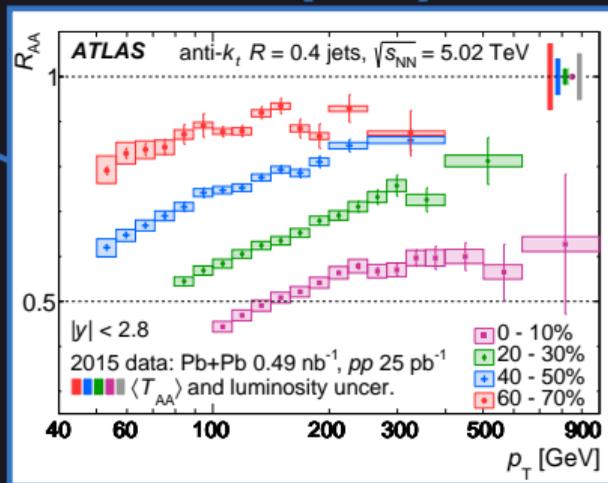
Accepted PLB

Motivating γ -tagged R_{AA}



Can we make a comparable measurement and observe q/g flavor dependence?

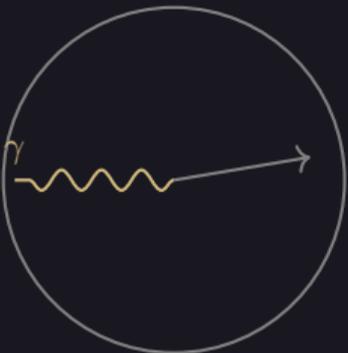
PLB 790 (2019) 180



Accepted PLB

Measuring γ -tagged Jet Spectra

At least one γ :



1. $p_T^\gamma > 50$ GeV
2. $|\eta| < 1.37$ OR $1.52 < |\eta| < 2.37$
3. Good shower shape
4. γ is isolated

R=0.4 jets with:



1. $p_T > 50$ GeV
2. $|\eta_{\text{Jet}}| < 2.8$
3. $\Delta\phi_{\gamma, \text{Jet}} > 7\pi/8$

Construct Raw Distributions

Subtract Mixed Event

Apply Purity Correction

Unfold For Detector Effects

Final Results

Measuring γ -tagged Jet Spectra

At least one γ :



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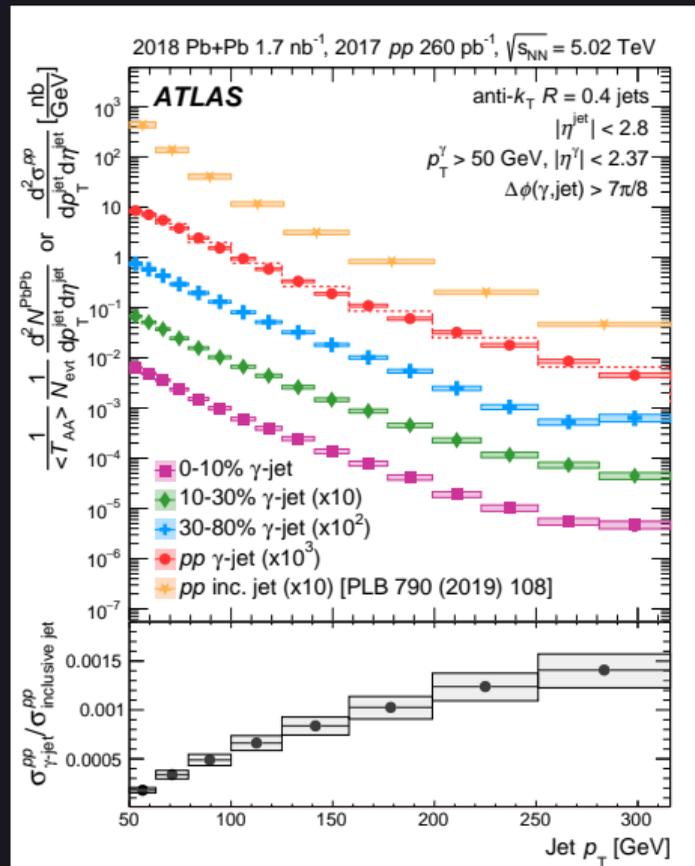
R=0.4 jets with:



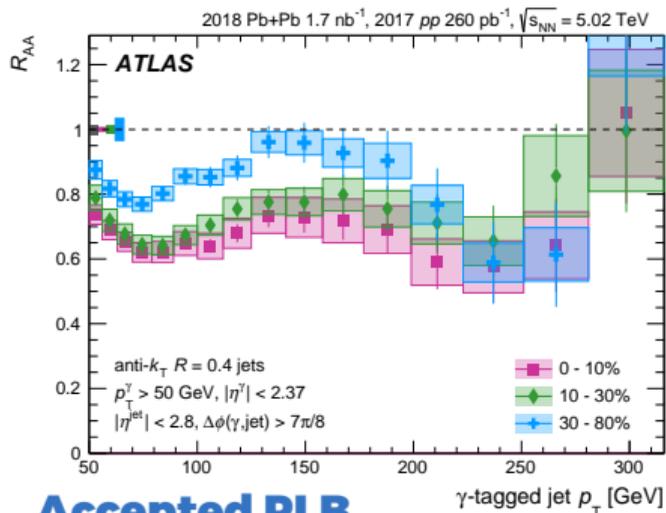
1. $p_T > 50$ GeV
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Accepted PLB

Christopher McGinn

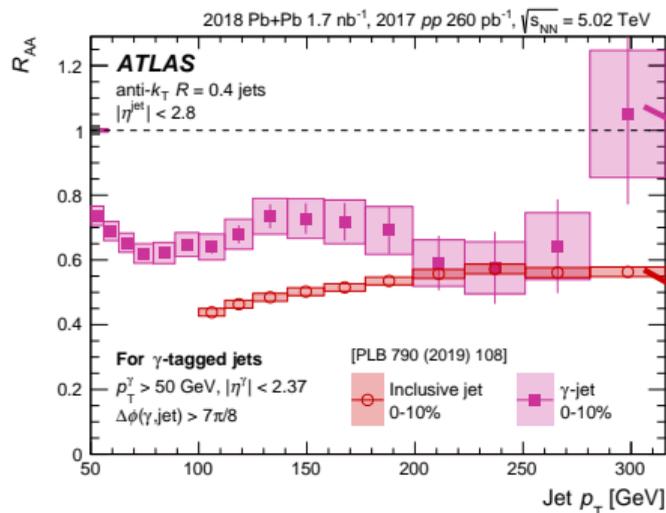


γ -tagged R_{AA}



Accepted PLB

γ -tagged R_{AA}

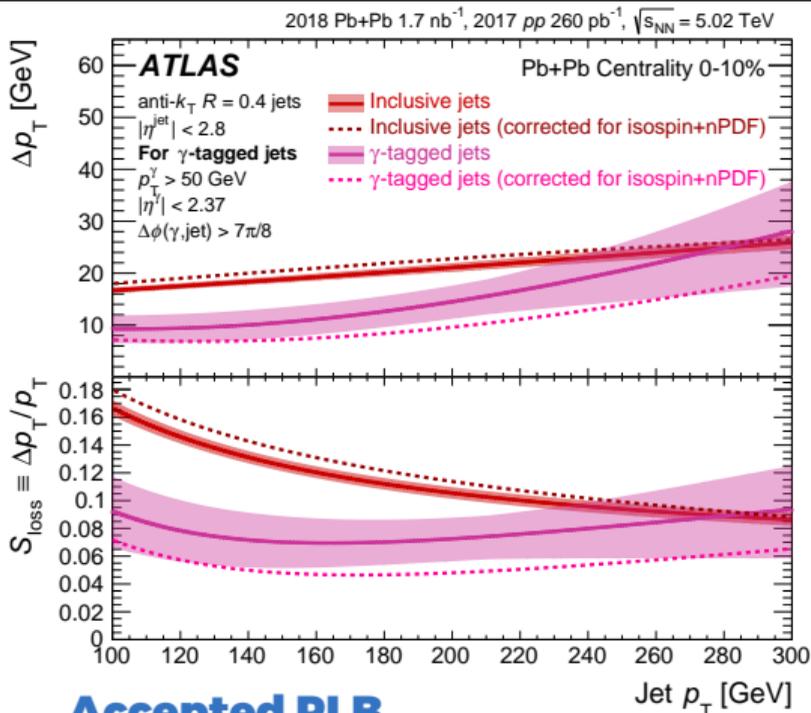


Comparison with inclusive jets

- Observe centrality ordered suppression (left), 0-10% most suppressed
- 0-10% γ -tagged jet $R_{AA} >$ inclusive jet R_{AA} ! (right)
- Quark v. Gluon medium interactions one possible explanation
 - Slope of spectra in pp differ enough to cause a 10% effect
 - Isospin and nPDF effects cause another 10% but opposite in sign

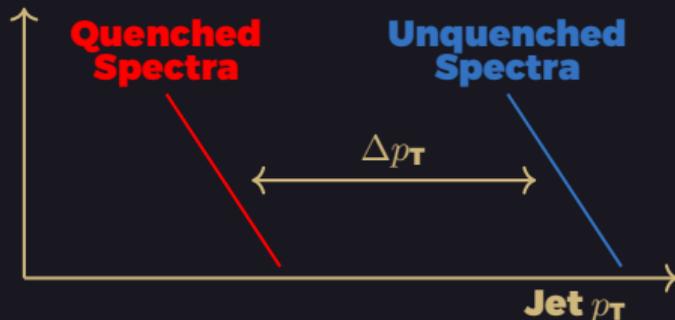


Estimating per-Jet Energy Loss



Δp_T and S_{Loss} calculation

Following PHENIX PRC 93 024911 (2016):
 Calculate per-jet energy loss from spectral shift needed to produce observed R_{AA} , i.e.



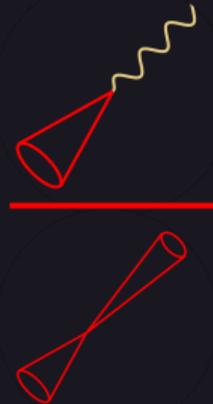
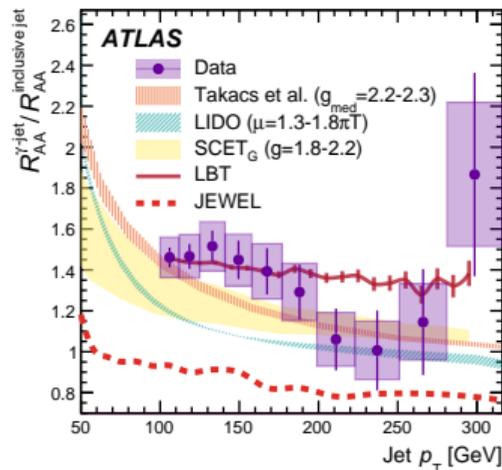
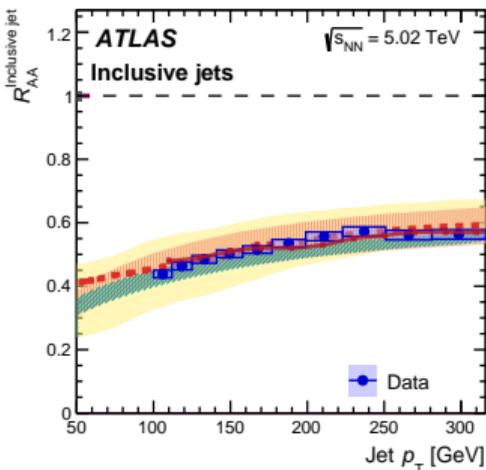
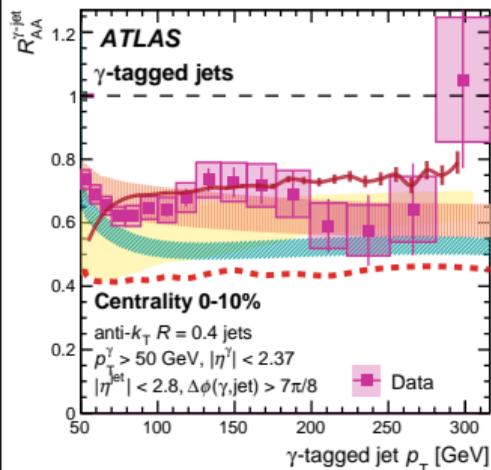
Remove spectral shape, isospin and nPDF effects for fair comparison between inclusive and γ -tagged jets

Comparisons with Theory

γ -tagged jet R_{AA}

Inclusive jet R_{AA}

Ratio

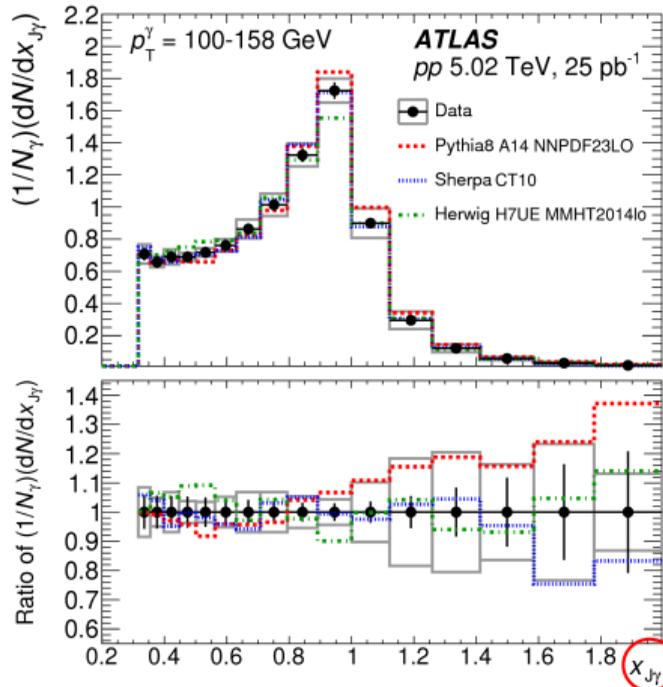


Accepted PLB

- All calculations describe inclusive jet R_{AA} well
- Most calculations tend to undershoot data for γ -tagged jet R_{AA}
- Data shows the ratio of the two R_{AA} above 1 everywhere
 - Theory replicates this qualitatively, but quantitative discrepancies exist

Motivating γ +multijet

Phys. Lett. B 789 (2019) 167



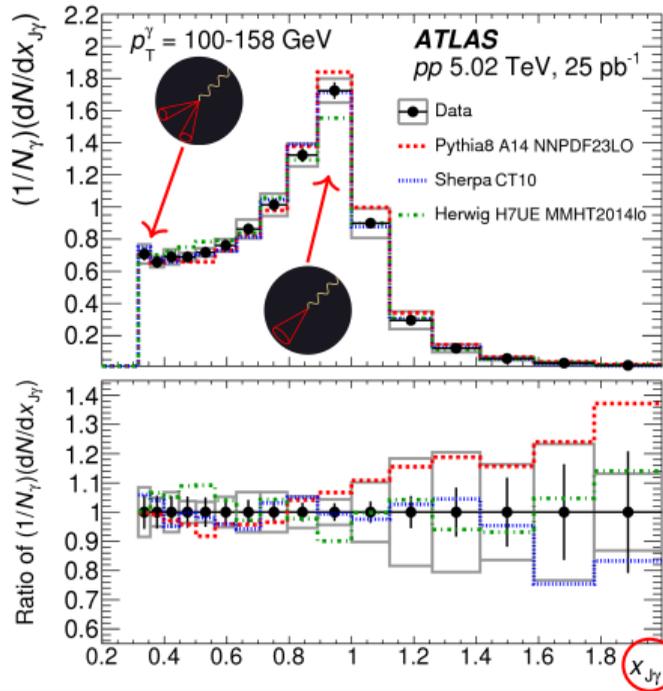
$$x_{J\gamma} = \frac{p_T^{\text{Jet}}}{p_T^\gamma}$$

γ -jet balance in pp

Motivating γ +multijet

Phys. Lett. B 789 (2019) 167

- pp measurements of $x_{J\gamma}$ are a combination of γ + single and multijet



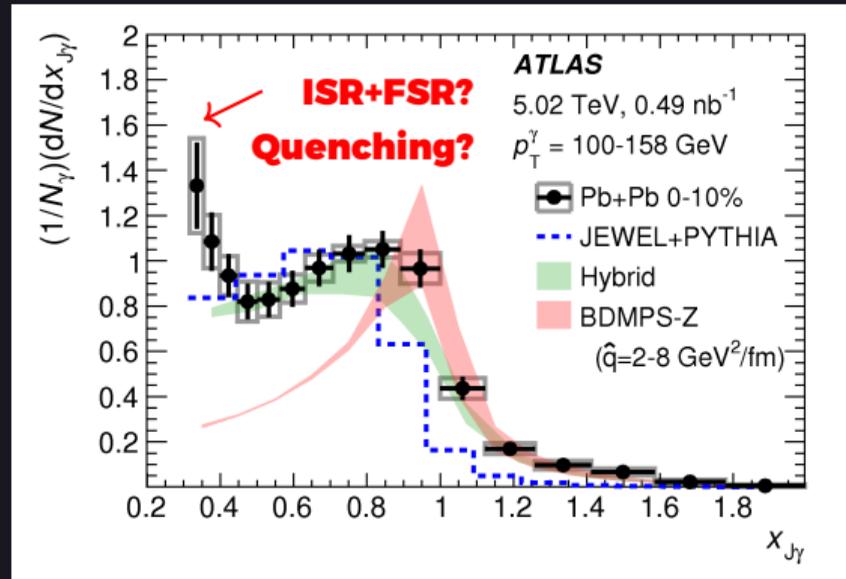
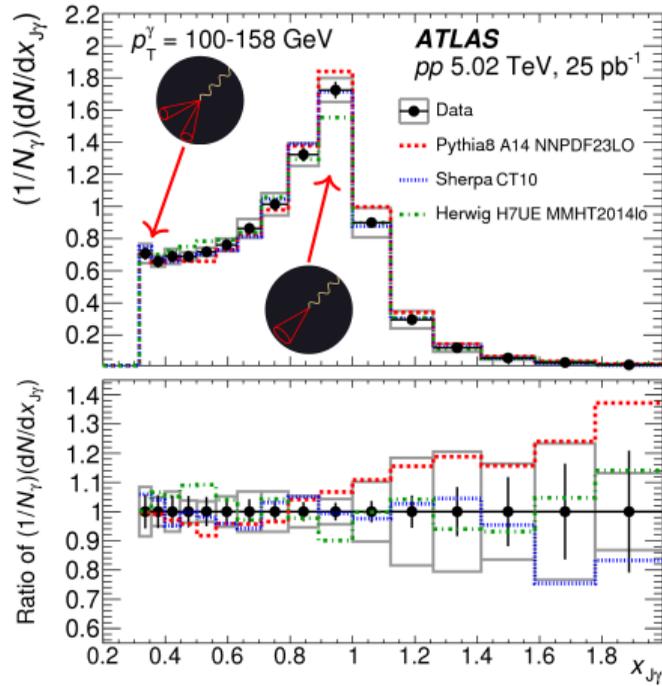
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γ -jet balance in pp

Motivating γ +multijet

Phys. Lett. B 789 (2019) 167

- pp measurements of $x_{J\gamma}$ are a combination of γ + single and multijet
- In Pb+Pb, this is convoluted w/ quenching
 - Can we disentangle w/ data?



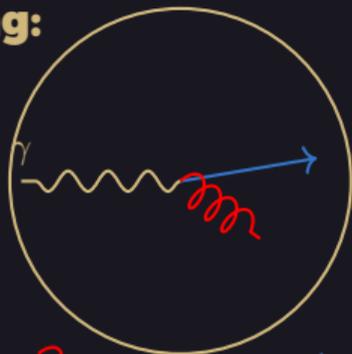
γ -jet balance in pp

γ -jet balance in Pb+Pb

Multijet Observables

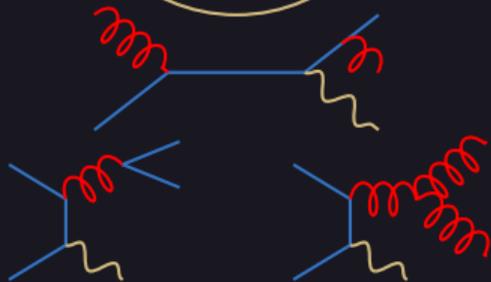
We are studying:

Photon
with



jet-pair
balancing

$$x_{JJ\gamma} = (\vec{p}_1 + \vec{p}_2)_T / p_T^\gamma$$

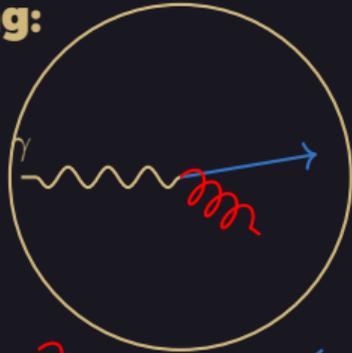


- $x_{JJ\gamma}$ - reduced impact of ISR/FSR on γ +jet balance

Multijet Observables

We are studying:

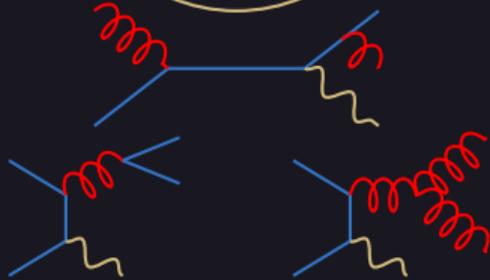
Photon
with



jet-pair
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$$\mathbf{x}_{JJ\gamma} = (\vec{p}_1 + \vec{p}_2)_T / p_T^\gamma$$

$$\Delta R_{JJ} = \sqrt{\Delta\phi_{1,2}^2 + \Delta\eta_{1,2}^2}$$

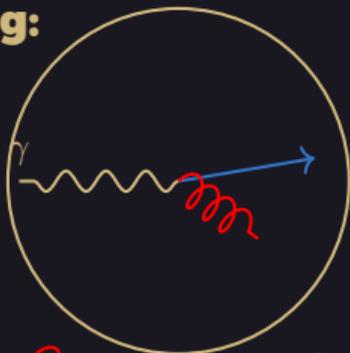


- $\mathbf{x}_{JJ\gamma}$ - reduced impact of ISR/FSR on γ +jet balance
- ΔR_{JJ} - medium resolution of multiple color charges

Multijet Observables

We are studying:

Photon
with

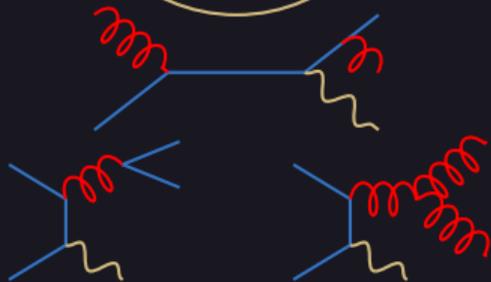


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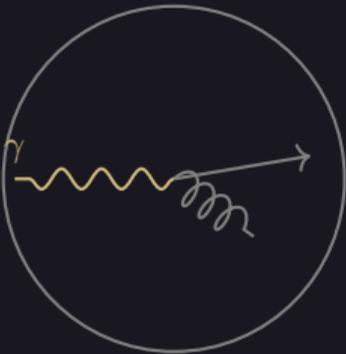
$$\mathbf{A}_{JJ\gamma} = (\mathbf{p}_{T,1} - \mathbf{p}_{T,2}) / p_T^\gamma$$



- $\mathbf{x}_{JJ\gamma}$ - reduced impact of ISR/FSR on γ +jet balance
- ΔR_{JJ} - medium resolution of multiple color charges
- $\mathbf{A}_{JJ\gamma}$ - sensitive to color-charge differences in q/g

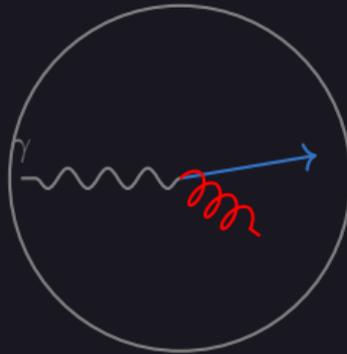
Measuring γ +multijet

At least one γ :



1. $90 < p_T^\gamma < 180$ GeV
2. $|\eta| < 1.37$ OR $1.52 < |\eta| < 2.37$
3. Good shower shape
4. γ is isolated

**At least two
R=0.2 jets with:**



1. $p_T > 30$ GeV
2. $|\eta_{\text{Jet}}| < 2.8$
3. $\Delta\phi_{\gamma, \text{Jet}} > \pi/2$
4. $\Delta R_{JJ} > 0.4$
5. $\Delta\phi_{JJ-\gamma} > 7\pi/8$

Construct Raw Distributions

Subtract Mixed Event

**Modified for
multijet**

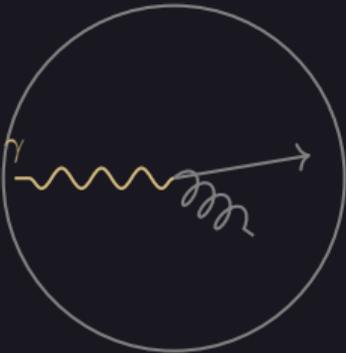
Apply Purity Correction

Unfold For Detector Effects

Final Results

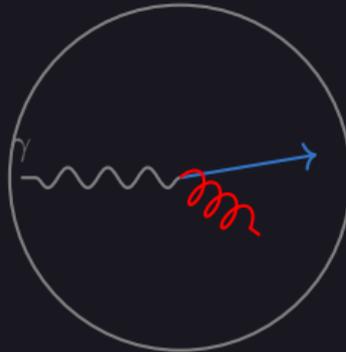
Measuring γ +multijet

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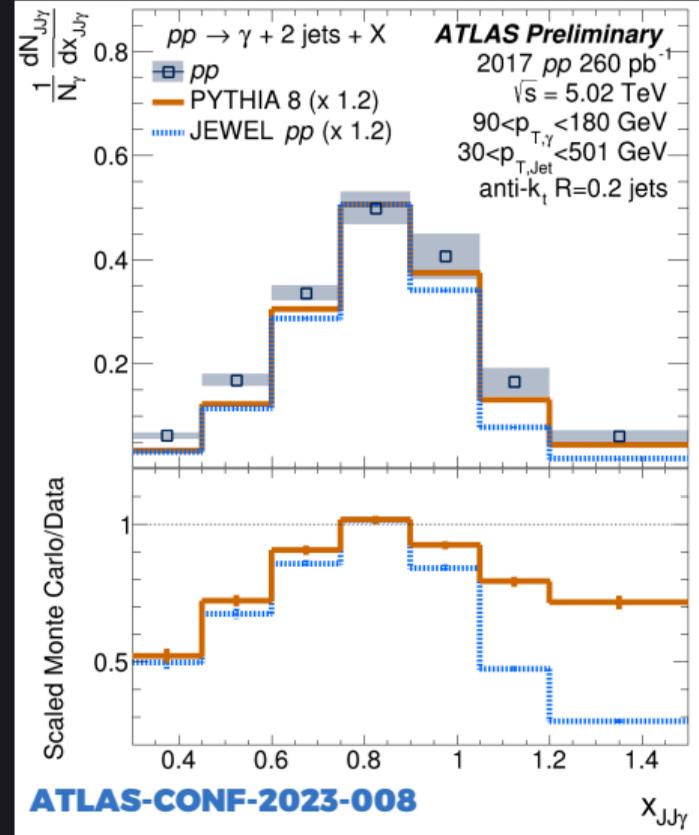


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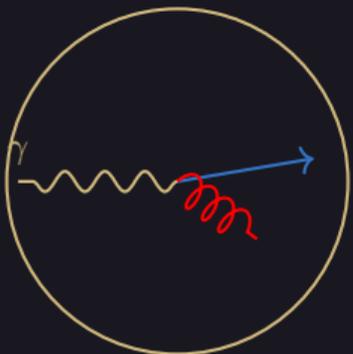


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5. $\Delta\phi_{JJ\gamma} > 7\pi/8$



Results $x_{JJ\gamma}$

ATLAS-CONF-2023-008

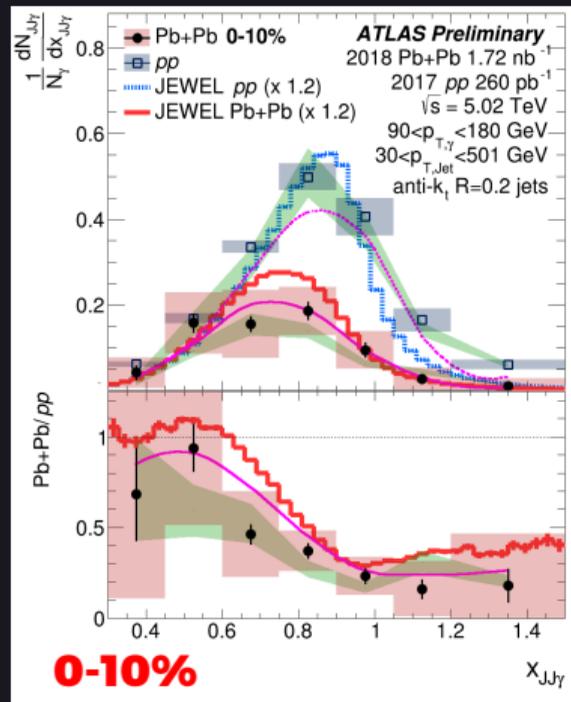


$$x_{JJ\gamma} = (\vec{p}_1 + \vec{p}_2)_T / p_T^\gamma$$

New Comparisons

JETSCAPEv3.5 AA22

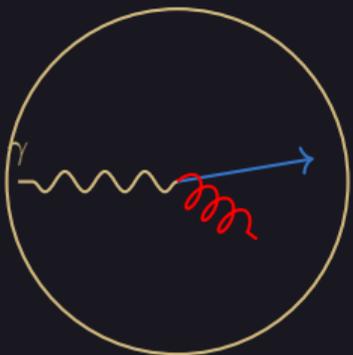
LBT



- **Monotonic increase in overall suppression as centrality → 0%**
- **Peak shifts to lower $x_{JJ\gamma}$ in Pb+Pb as centrality → 0%**

Results $A_{JJ\gamma}$

ATLAS-CONF-2023-008

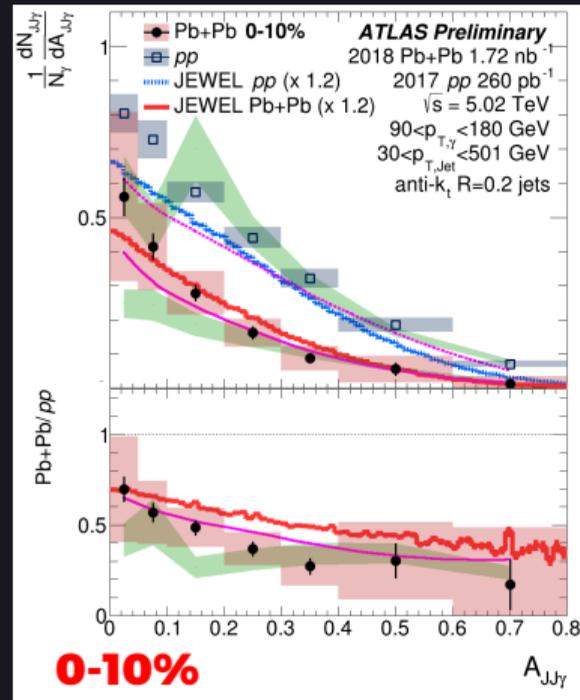


$$A_{JJ\gamma} = (\mathbf{p}_{T,1} - \mathbf{p}_{T,2}) / p_T^\gamma$$

New Comparisons

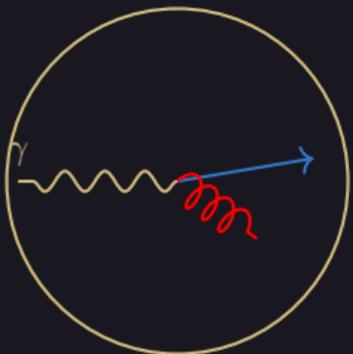


- As cent. \rightarrow 0%, $A_{JJ\gamma}$ Pb+Pb/pp develops a downward slope
- Suggests a greater suppression of asymmetric pairs



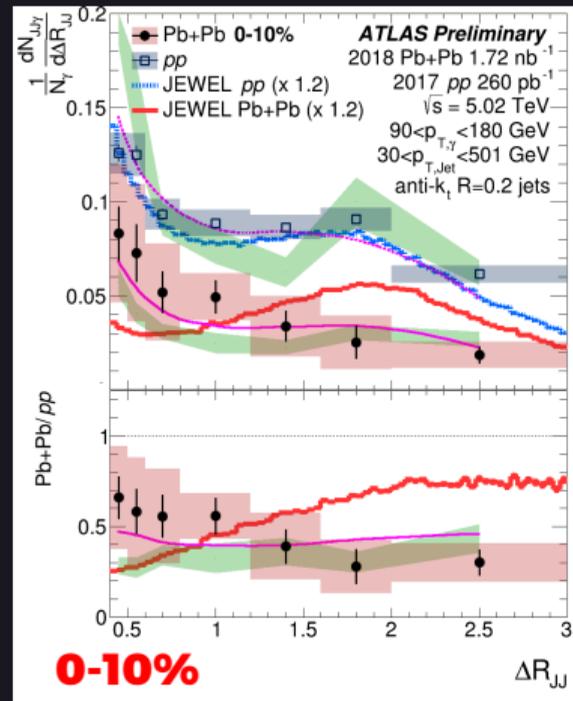
Results ΔR_{JJ}

ATLAS-CONF-2023-008



$$\Delta R_{JJ} = \sqrt{\Delta\phi_{1,2}^2 + \Delta\eta_{1,2}^2}$$

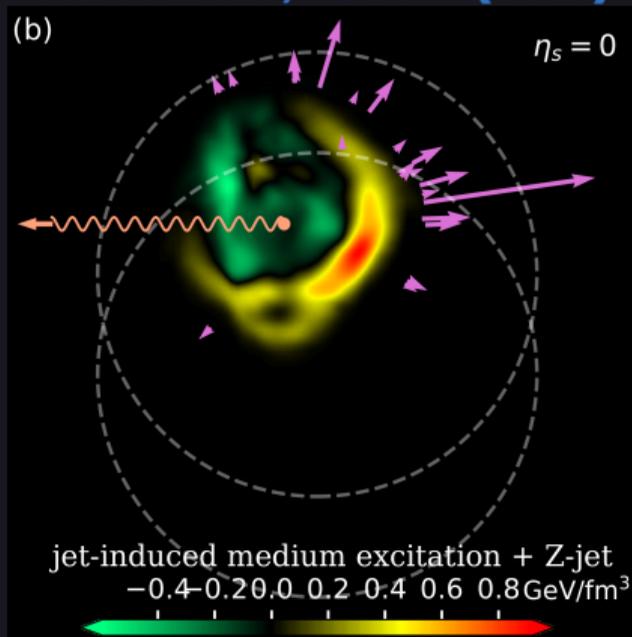
New Comparisons



- See hint of greater suppression at large ΔR_{JJ} in 0-10%
- JEWEL gets the slope of Pb+Pb/pp strikingly wrong

Diffusion Wake Search in γ +jets (I)

Via PRL 127, 082301 (2021)



Look at jet-hadron corr. in γ
hemisphere; Search via $x_{J\gamma}$

1. Select on γ +jet events

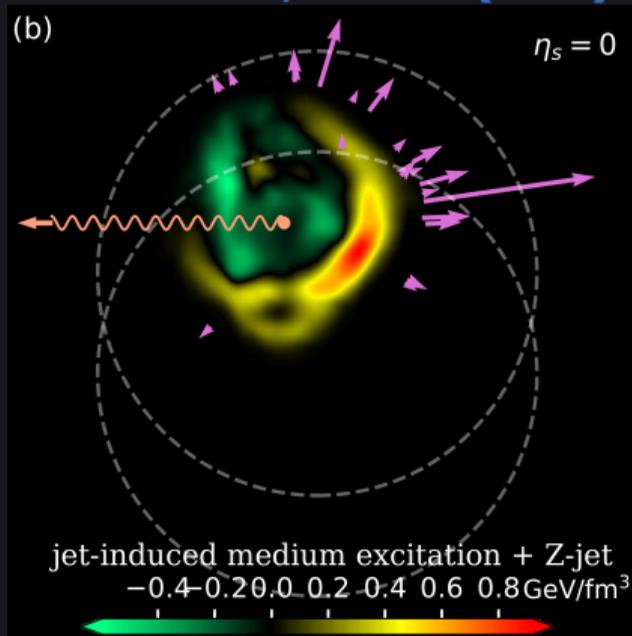
2. Jet-track correlations for $\Delta\phi_{\text{jet, trk}} > \pi/2$

3. Scan as function of $x_{J\gamma}$

4. If ratio deviates from 1? Diffusion wake!

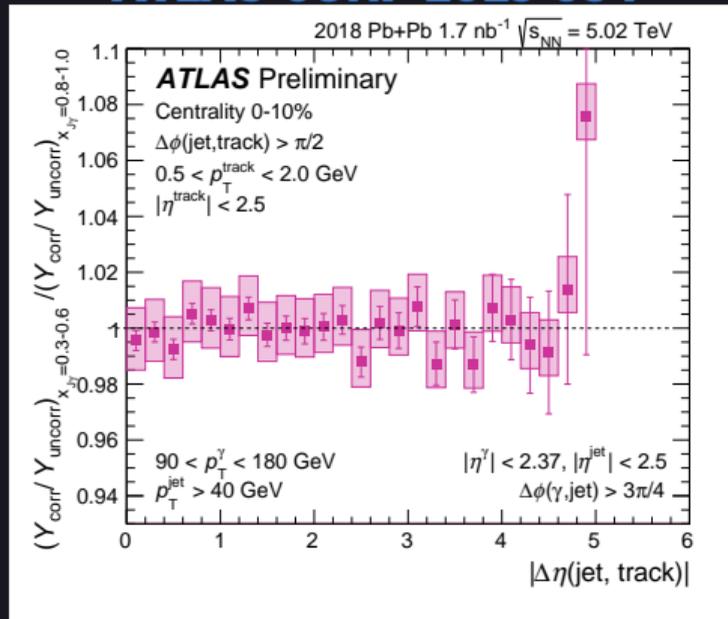
Diffusion Wake Search in γ +jets (II)

Via PRL 127, 082301 (2021)



Look at jet-hadron corr. in γ hemisphere; Search via $x_{J\gamma}$

ATLAS-CONF-2023-054

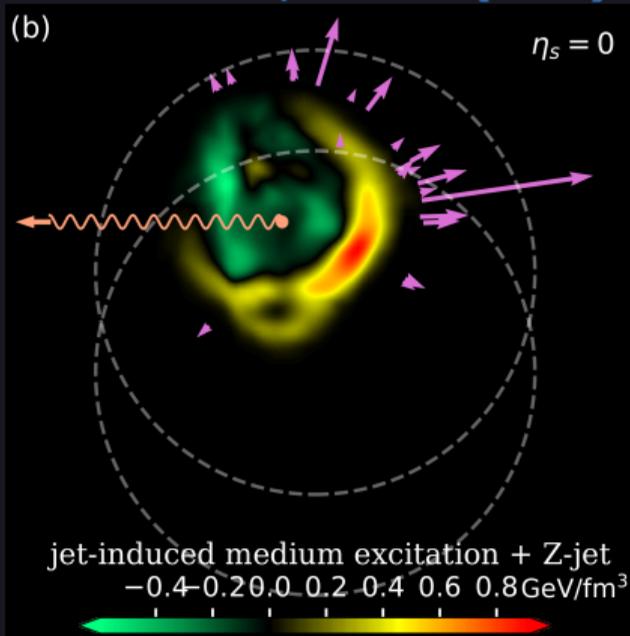


No observable $x_{J\gamma}$ dependence in yield within current uncertainties; NO WAKE

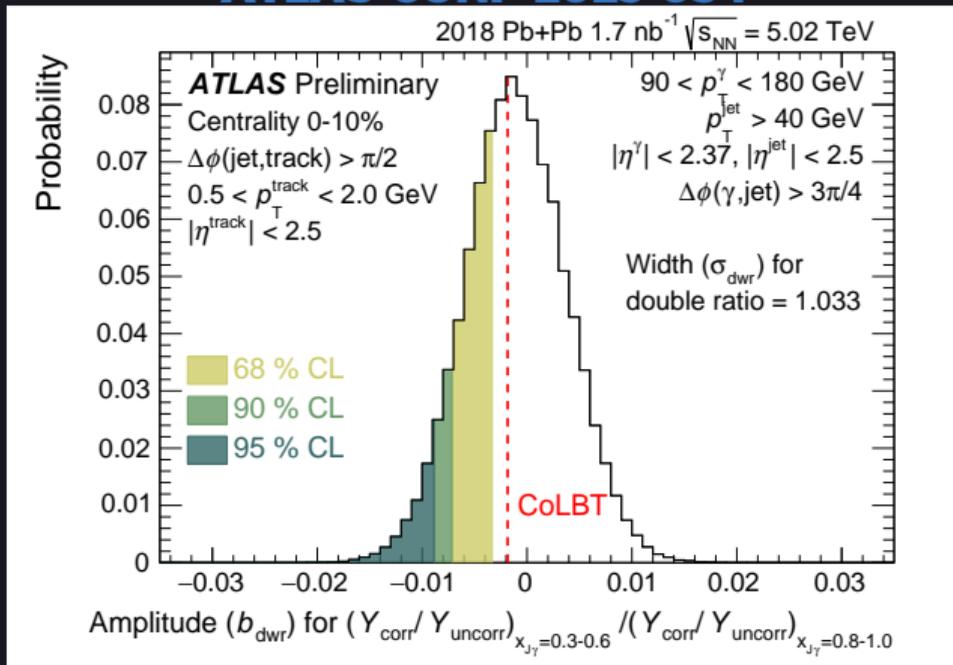
Diffusion Wake Search in γ +jets (III)

ATLAS-CONF-2023-054

Via PRL 127, 082301 (2021)

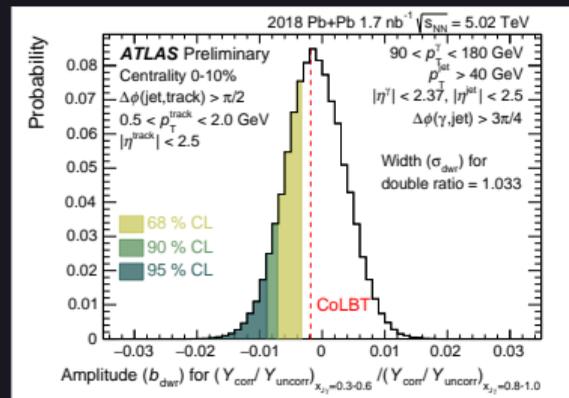
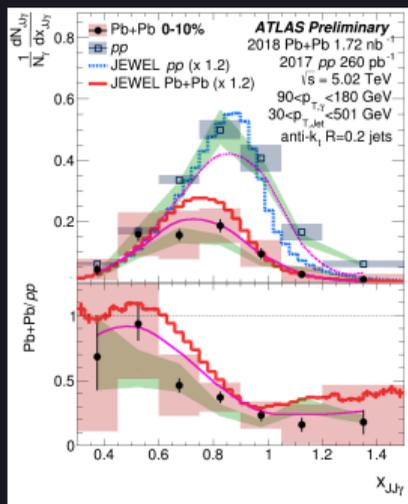
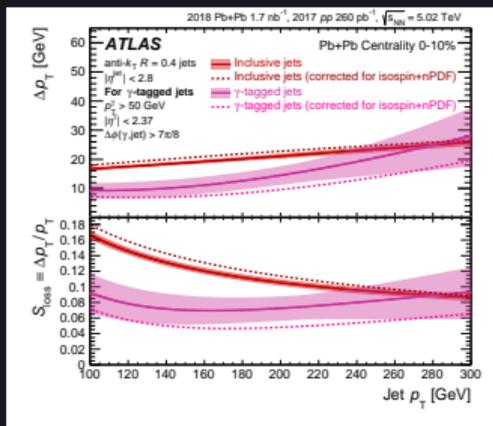


Look at jet-hadron corr. in γ hemisphere; Search via $x_{J\gamma}$



95% CL at 0.8% perturbation on bulk; CoLBT prediction is 0.2%

Conclusion



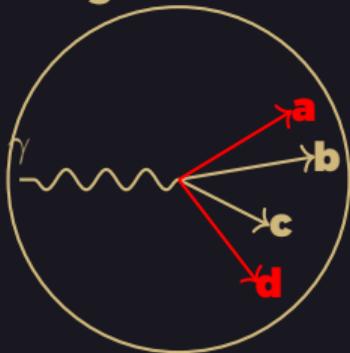
- γ -tagged jet R_{AA} finalized for publication; extended to higher p_T
- Observe quark-enhanced γ -tagged jet $R_{AA} >$ inclusive jet R_{AA}
- First analysis of γ -tagged multijet system in Pb+Pb (preliminary)
- Observe significant suppression of $\gamma + 2$ jets + X production
- 95% CL on diffusion wake set by γ +jet data!

Backup

Multi-jet Mixed Event (I)

Mixed event subtracts off background contributions (red)

Signal Event



Min. Bias Event 1



Min. Bias Event 2

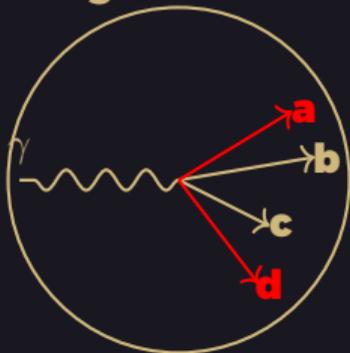


- **2 Min. Bias Events are needed per signal (minimum)**
- **Min. Bias chosen by matching global characteristics in signal:**
 - **Centrality matching (1% width bins)**
 - **Ψ_2 , or Event-plane ϕ , (8 bins)**

Multi-jet Mixed Event (II)

Using our example signal event, raw contributions are:

Signal Event



Min. Bias Event 1



Min. Bias Event 2



1. Signal

- $b+c$

2. Signal with Background

- $a+b$
- $a+c$
- $d+b$
- $d+c$

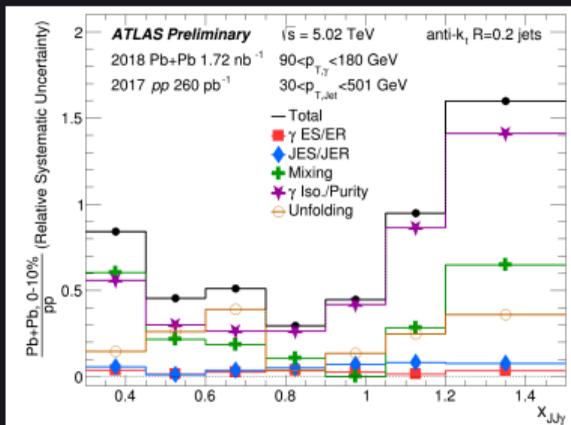
3. Pure Background

- $a+d$

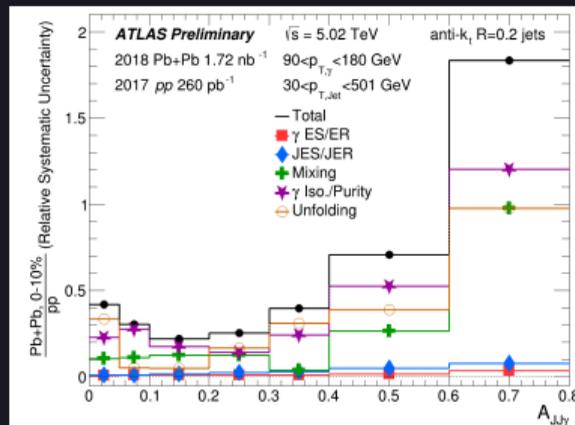
For a
step-by-step walkthru
of mixing jet algo.
come ask me!

Multijet Systematics

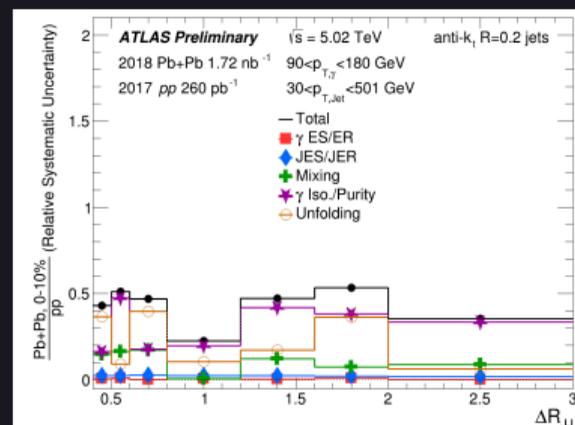
All figures 0-10%/pp



$X_{JJ\gamma}$



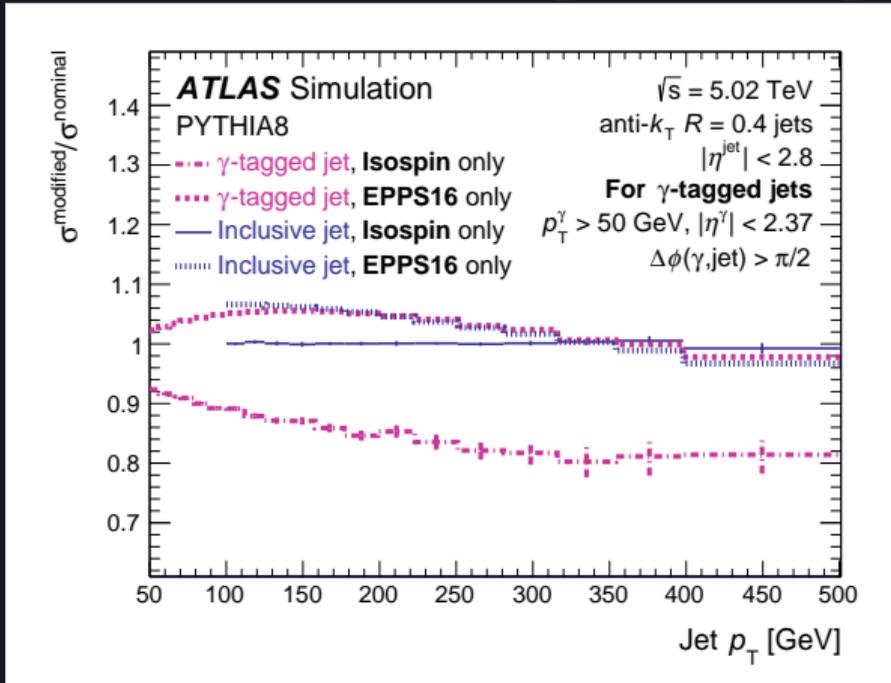
$A_{JJ\gamma}$



ΔR_{JJ}

- Multijet systematics for Pb+Pb 0-10% / pp
- Can reach 100% in the tails of the distributions

nPDF and Isospin Impact



- nPDF effect cancels between inclusive and γ -tagged
- Isospin effect significant