Exploring the QCD color charge dependence of jet quenching with photon+ jet events in ATLAS

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University Colorado Boulder

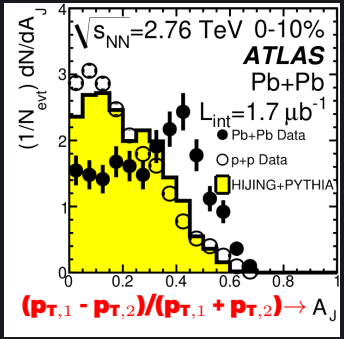
Hard Probes, Aschaffenburg

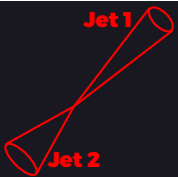
29 March 2023

ATLAS EXPERIMENT

Jet Measurements in QGP

PRL 105 (2010) 252303





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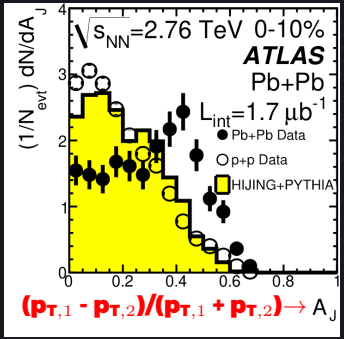

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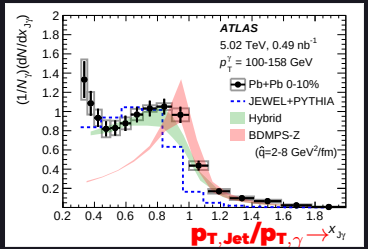

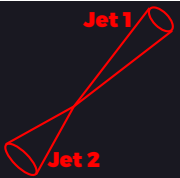

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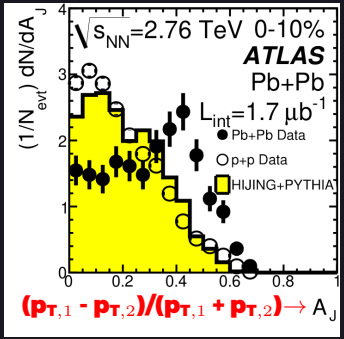

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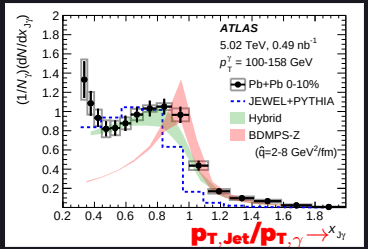
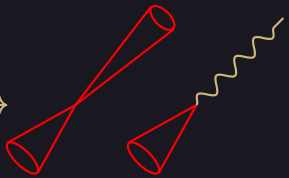
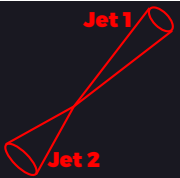


Today

1. Compare R_{AA}'s





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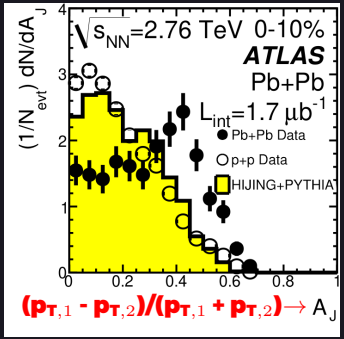

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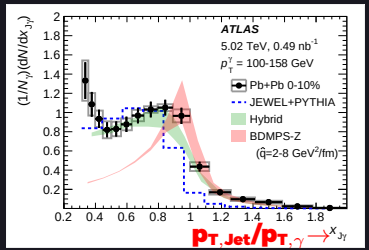

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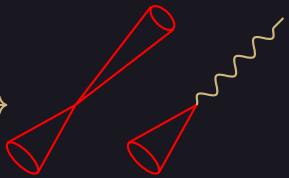
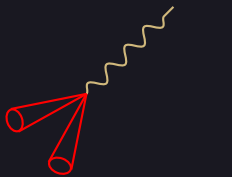
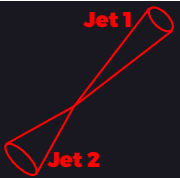
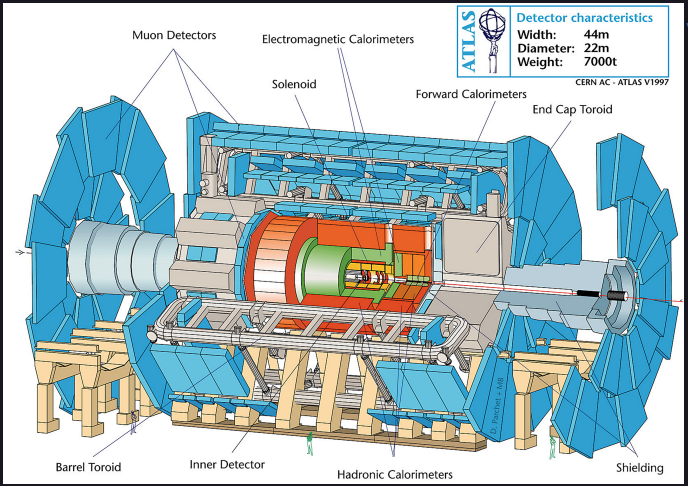


2. γ + 2 jets + X





ATLAS Detector and Data



Via CDS

p p

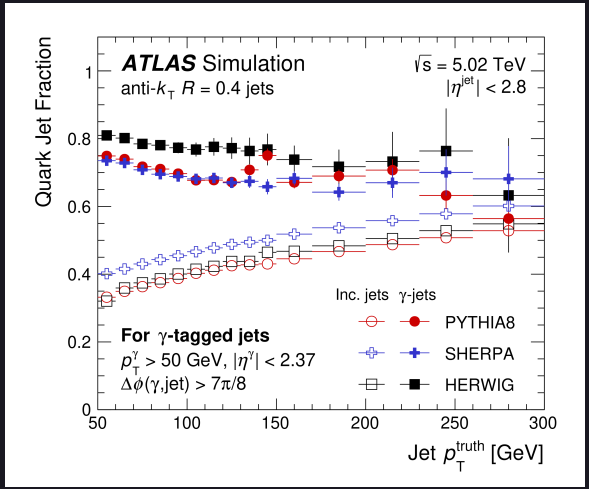
pp collected in 2017
260 pb^{-1} int. lumi.

Pb Pb

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

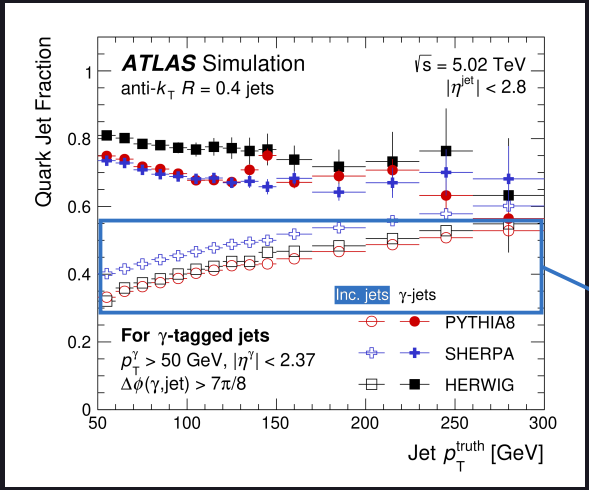
- Jets are reconstructed w/ EMCal and HCal
- Photons are reconstructed w/ EMCal
- Centrality (nuclear overlap) is determined by FCal

Motivating γ-tagged R_{AA}



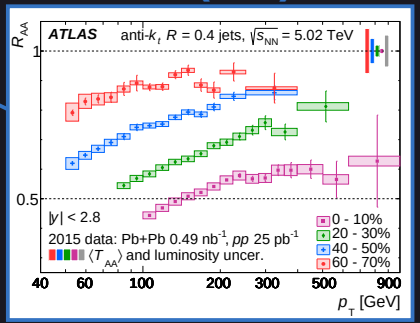
Submitted PLB

Motivating γ-tagged R_{AA}



Submitted PLB

PLB 790 (2019) 180



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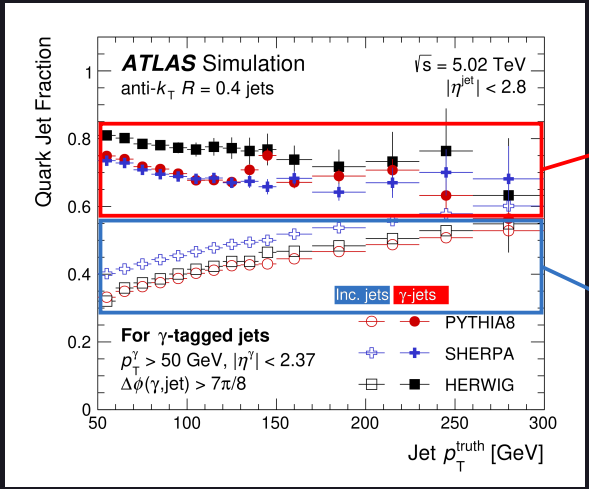

Submitted PLB

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

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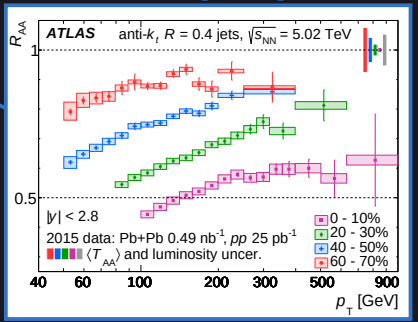
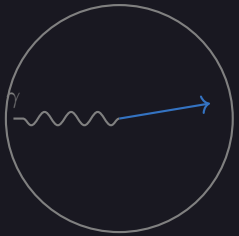


Measuring γ-tagged Jet Spectra

At least one γ:

1. p_T^{γ} > 50 GeV
2. $|\eta|$ < 1.37 OR 1.52 < $|\eta|$ < 2.37
3. Passes Tight ID
4. Isolation < 3.0 GeV

R=0.4 jets with:



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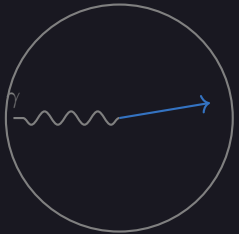

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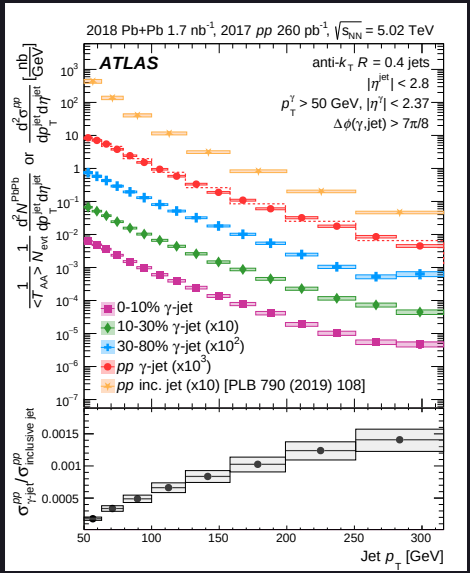
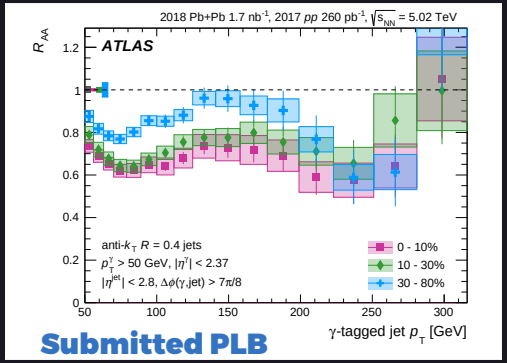


Submitted PLB

γ-tagged R_{AA}



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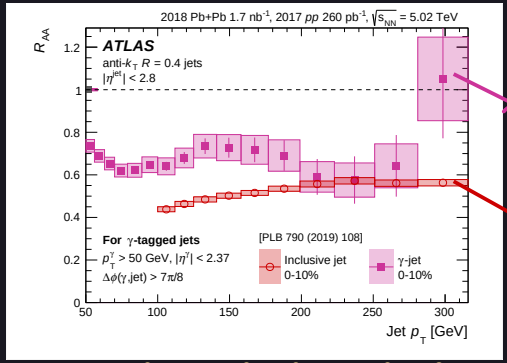
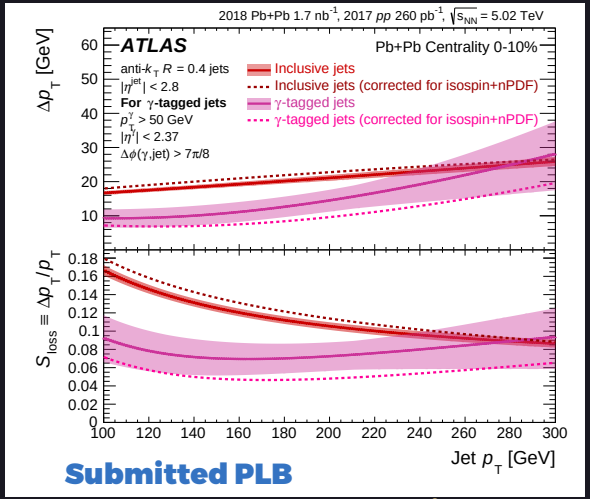


Comparison with inclusive jets

- **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**

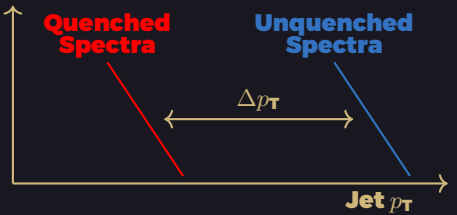
Estimating per-Jet Energy Loss



Submitted PLB

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.

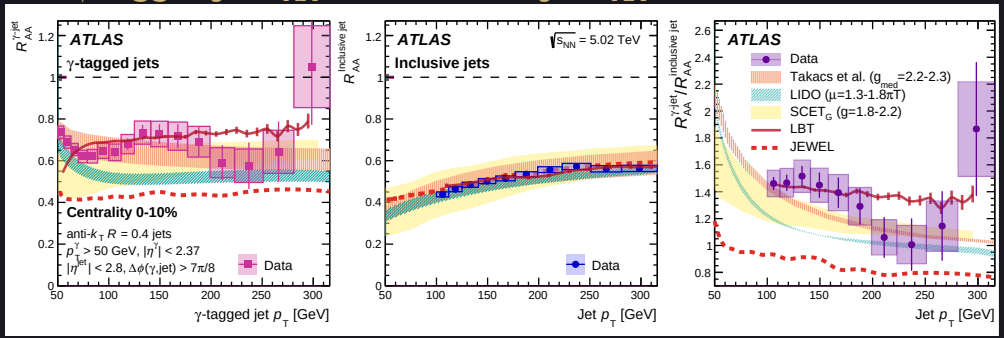


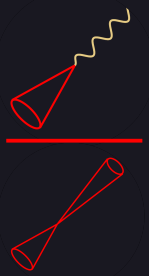
Remove spectral shape, isospin and nPDF effects for fair comparison between inclusive and γ-tagged jets

See also Dr. Maya Shimomura's talk for application in PHENIX w/ pions

Comparisons with Theory

γ-tagged jet R_{AA} | Inclusive jet R_{AA} | Ratio



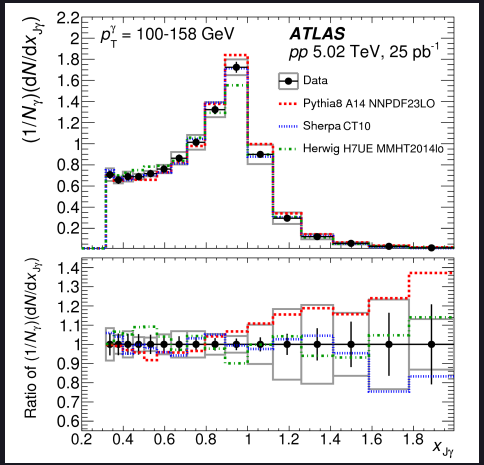


Submitted PLB

- 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 quantitatve discrepencies exist

Motivating γ+multijet

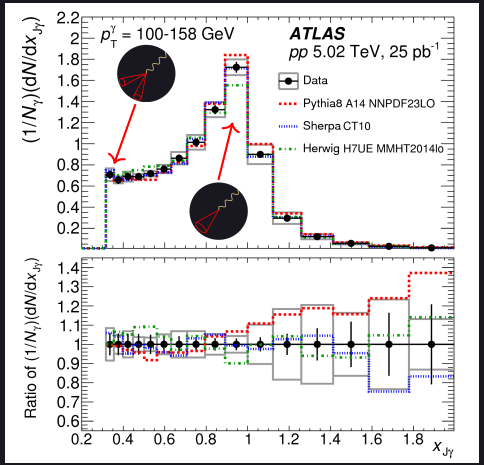
Phys. Lett. B 789 (2019) 167



γ-jet balance in pp

Motivating γ+multijet

Phys. Lett. B 789 (2019) 167



γ-jet balance in pp

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

Motivating γ+multijet

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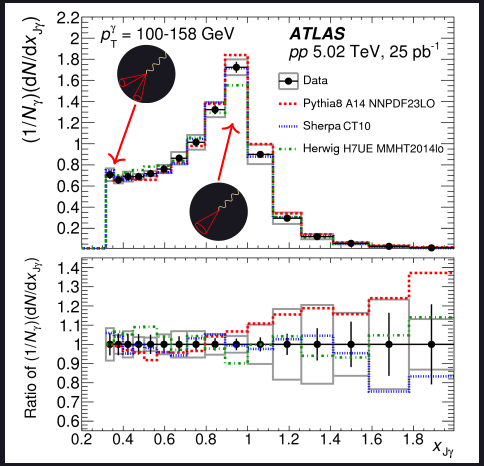
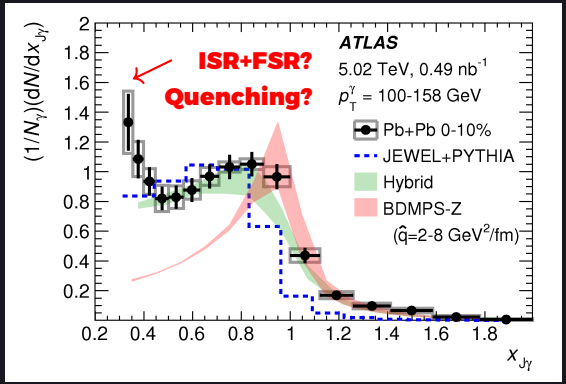


γ-jet balance in pp

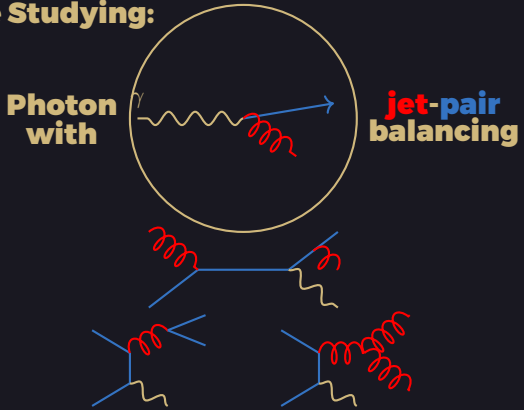
- pp measurements of $x_{J\gamma}$ are a combination of γ+ single and multijet
- In Pb+Pb, this is convoluted w/ quenching
  - Can we disentangle w/ data?



γ-jet balance in Pb+Pb

Multijet Observables

We are Studying:



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

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

Multijet Observables

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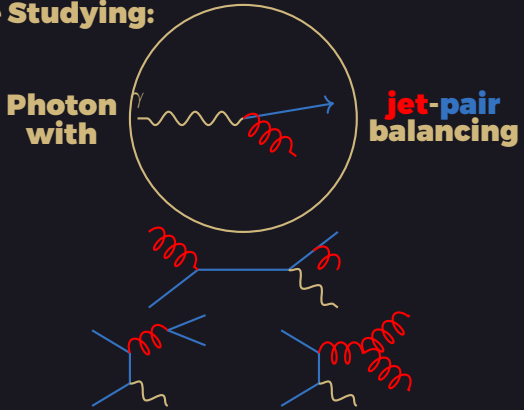


$$x_{JJ\gamma} = (\vec{p}_1 + \vec{p}_2)_T / p_T^{\gamma}$$

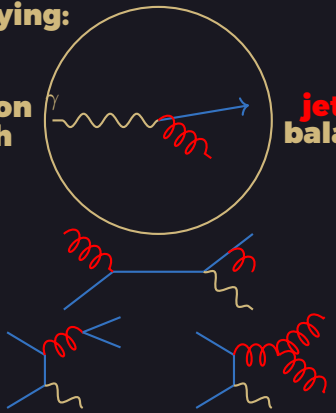
$$\Delta R_{JJ} = \sqrt{\Delta\phi_{1,2}^2 + \Delta\eta_{1,2}^2}$$

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

Multijet Observables

We are Studying:

Photon with jet-pair balancing



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

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

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

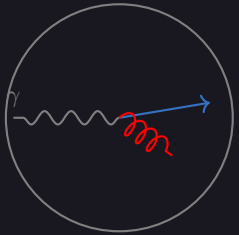
- $x_{JJ\gamma}$ - reduced impact of ISR/FSR on γ+jet balance
- ΔR_{JJ} - medium resolution of multiple color charges
- $A_{JJ\gamma}$ - sensitive to color-charge differences in q/g

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. Passes Tight ID
4. Isolation < 3.0 GeV

At least two R=0.2 jets with:



1. $p_T > 30$ GeV
2. $|\eta_{Jet}| < 2.8$
3. $\Delta\phi_{\gamma,Jet} > \pi/2$
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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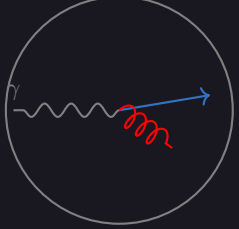

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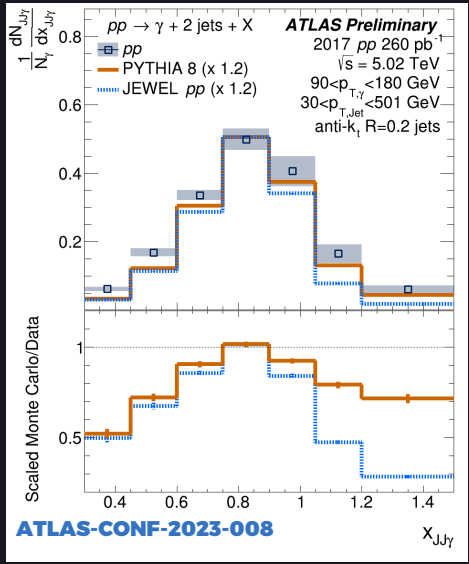

Multi-jet Mixed Event (I)

Mixed event subtracts off background contributions (red)

- 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:

1. **Signal**
   - b+c
2. **Signal with Background**
   - a+b
   - a+c
   - d+b
   - d+c
3. **Pure Background**
   - a+d

Step-by-step walkthru of mixing jet algo. in backup here

Results $x_{JJ\gamma}$

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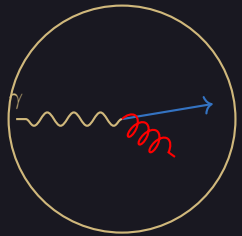
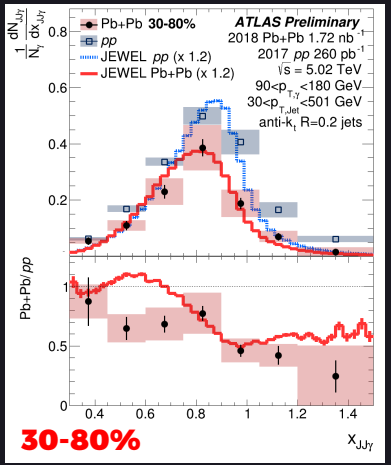
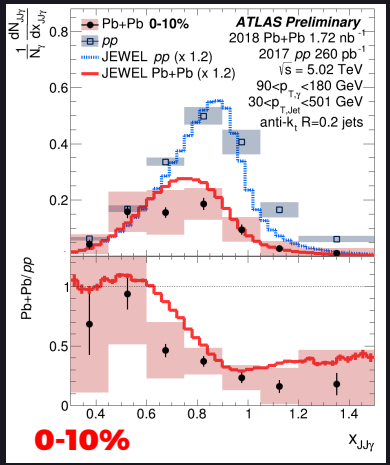


$$x_{JJ\gamma} = (\vec{p}_1 + \vec{p}_2)_T / p_T^{\gamma}$$





- **Monotonic increase in overall suppression as centrality → 0%**
- **Peak shifts left in Pb+Pb as centrality → 0%**

Results $A_{JJ\gamma}$

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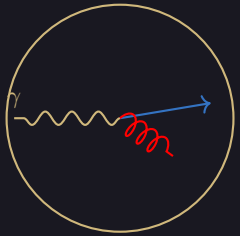
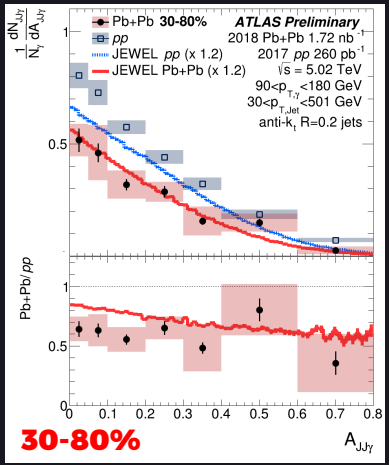
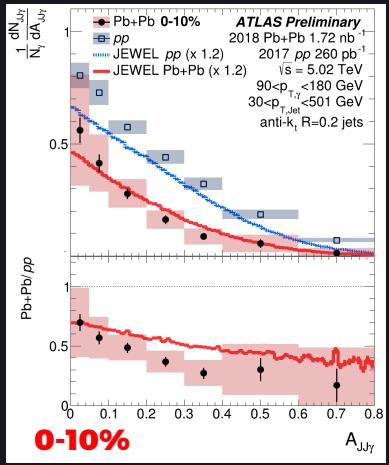


$A_{JJ\gamma} = (p_{T,1} - p_{T,2})/p_T^{\gamma}$





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

Results ΔR_{JJ}

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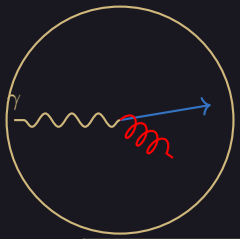
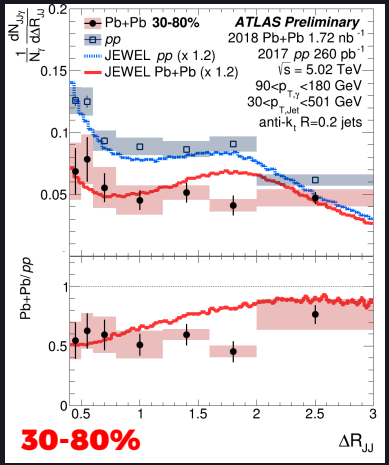
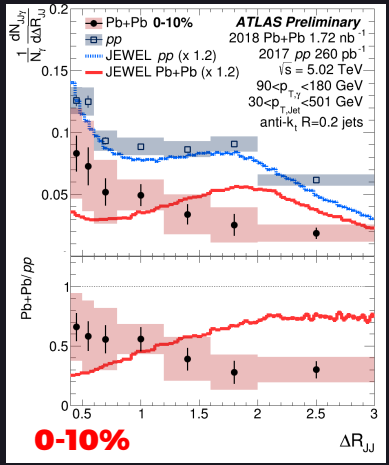


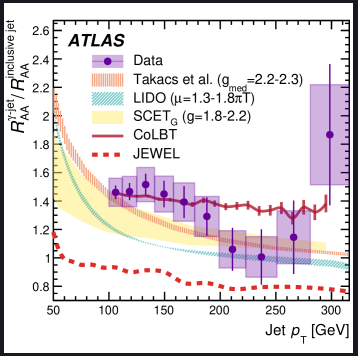
$$\Delta R_{JJ} = \sqrt{\Delta\phi_{1,2}^2 + \Delta\eta_{1,2}^2}$$

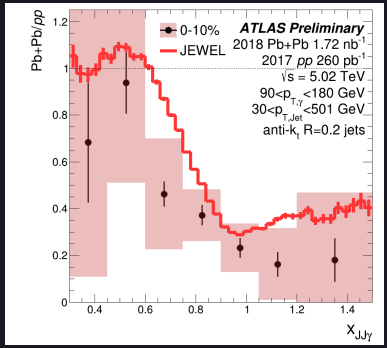




- **See hint of greater suppression at large ΔR_{JJ} in 0-10%**
- **JEWEL gets the slope of Pb+Pb/pp strikingly wrong**

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 γ+ 2 jets + X production

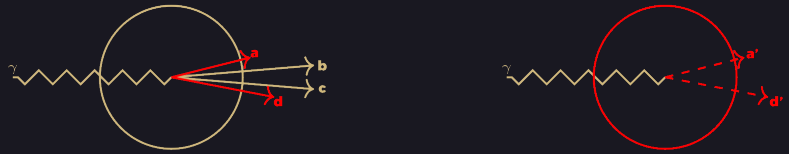
Backup

Mixing Algo. (I)

Assuming symmetric observable (think vector sum over p_{T}^{γ}):

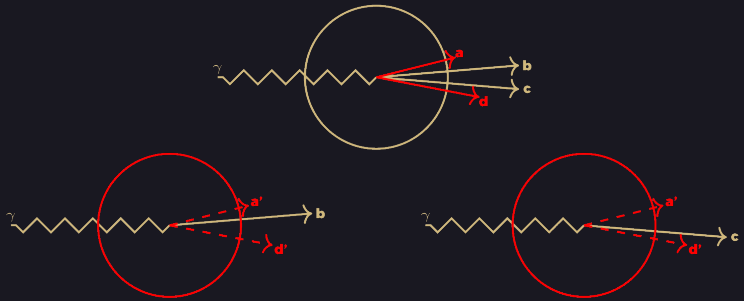
1. **Signal**
   - **b+c**
2. **Signal with Background**
   - **a+b**
   - **a+c**
   - **d+b**
   - **d+c**
3. **Pure Background**
   - **a+d**

Mixing Algo. (II)



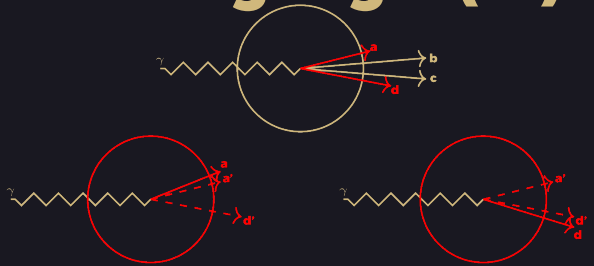
- Handled as in inclusive jet analysis
  - Add γ to MB event matched by global parameters
  - Correlate γ w/ all pairs of jets in-event
- Or:
  - Contribution of a+d cancelled by a'+d'

Mixing Algo. (III)



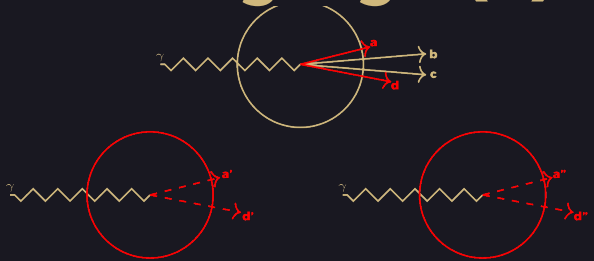
- Now embed γ with a single jet
- Correlate all jet pais w/ embedded γ+jet
  1. b+a' cancels b+a
  2. b+d' cancels b+d
  3. c+a' cancels c+a
  4. c+d' cancels c+d

Mixing Algo. (IV)



- We don't know which jets are real or fake!
- We must also embed γ + a,d
  - Note I've offset them in the embeds for clarity
- This gives additional combinations
  - a+a'
  - a+d'
  - d+a'
  - d+d'

Mixing Algo. (V)



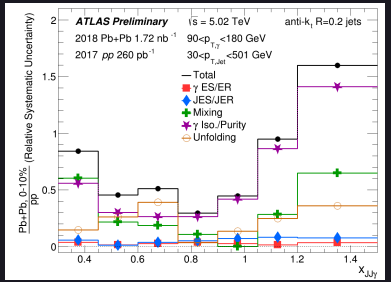
- What happened?
  - We took a photon correlated with an in-event fake jet and correlated with a jet from another event
  - To fix, double embed
- γ + a',d' are associated at first embed
- Each γ + jet pair from first embed are embedded again
  - a'+a" cancels a+a'
  - a'+d" cancels a+d'
  - d'+a" cancels d+a'
  - d'+d" cancels d+d'

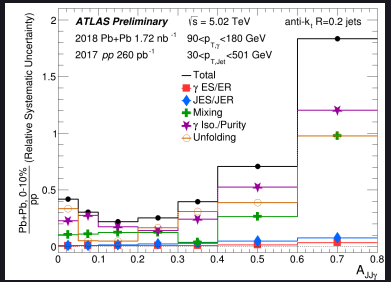
Mixing Algo. (VI)

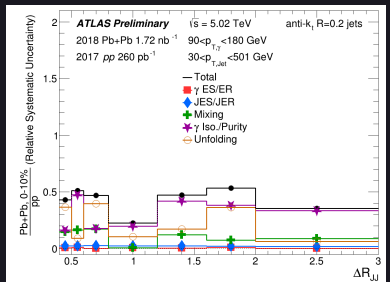
- a+d removed with γ in single event
- b+a removed with γ+b in single event
- b+d removed with γ+b in single event
- d+a removed with γ+d in single event
- d+d removed with γ+d in single event
- Double embed corrects for γ+jet in single event where the paired jet is fake
- Only b+c remains

Multijet Systematics

All figures 0-10%/pp



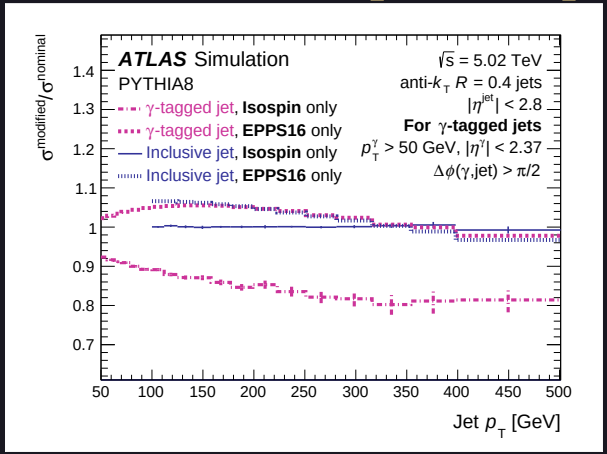




$x_{JJ\gamma}$ $A_{JJ\gamma}$ ΔR_{JJ}

- **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**