Generator-level studies for Z/photon-tagged jet measurements and effects of angular resolution driven by HI background

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γ-tagged jets at LHC

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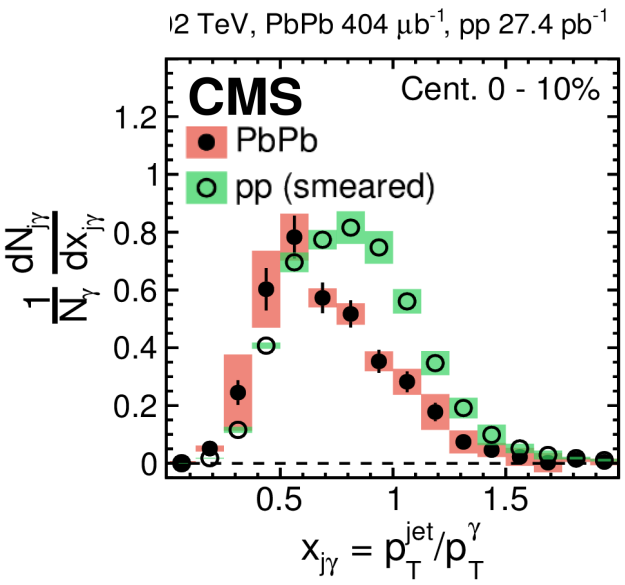
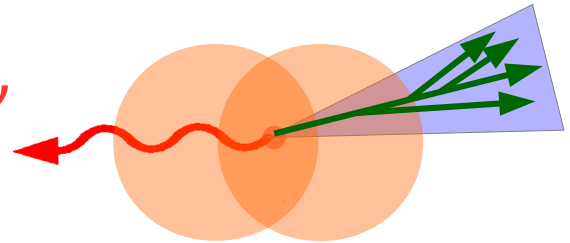
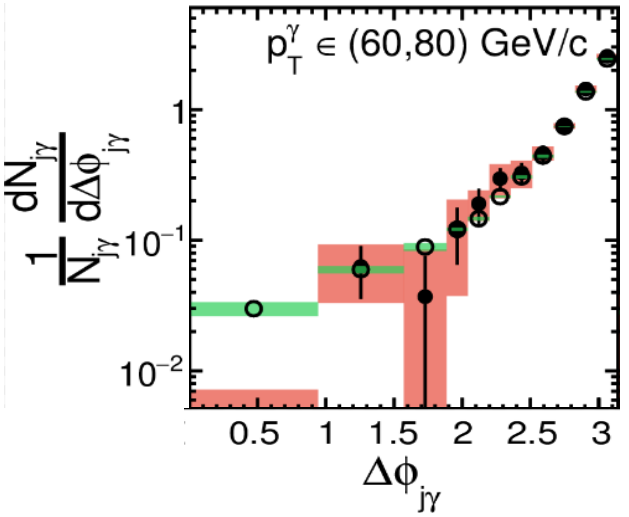
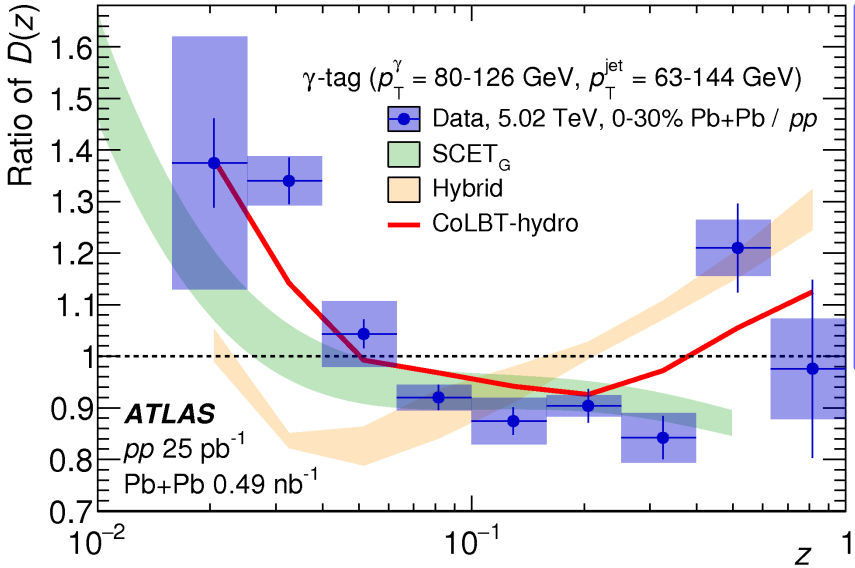


Bulk observables
Wide distributions already in pp
How to understand the shapes ?





arXiv:1902.10007

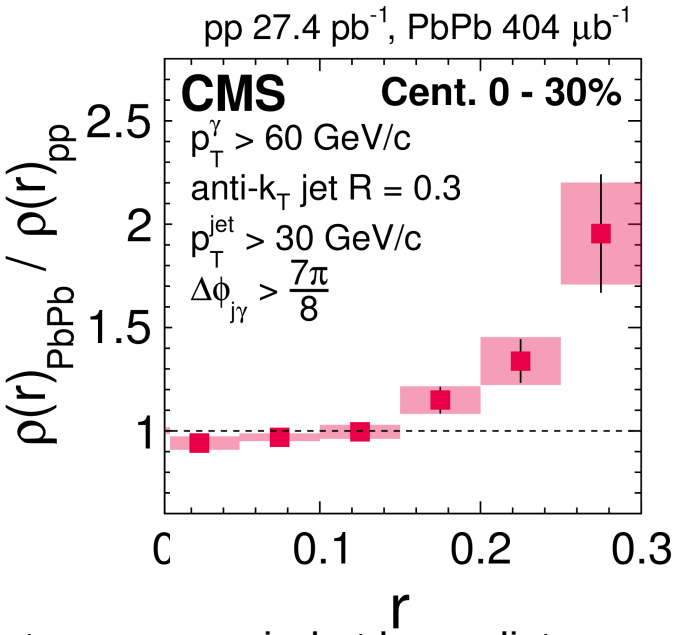


excess (depletion) of low-p_T (high-p_T) particles

Substructure obs.
Sensitive to resolutions driven by HI background

Focus on
angular resolution and
how to reduce its effect ?

arXiv:1809.08602



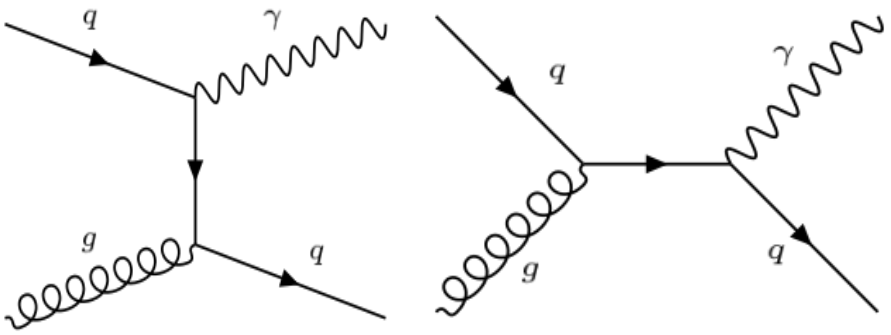
larger fraction of jet energy carried at large distances

γ+jet Production

γ+jet in Pythia 8

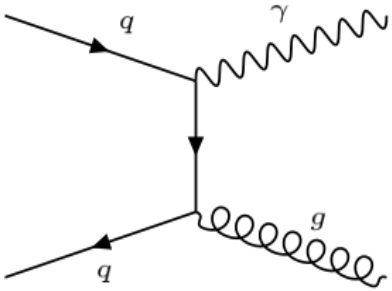
γ+quark

dominantly via QCD Compton scattering

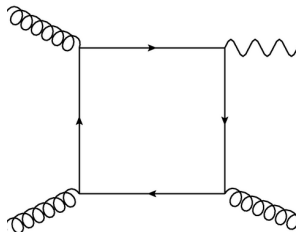


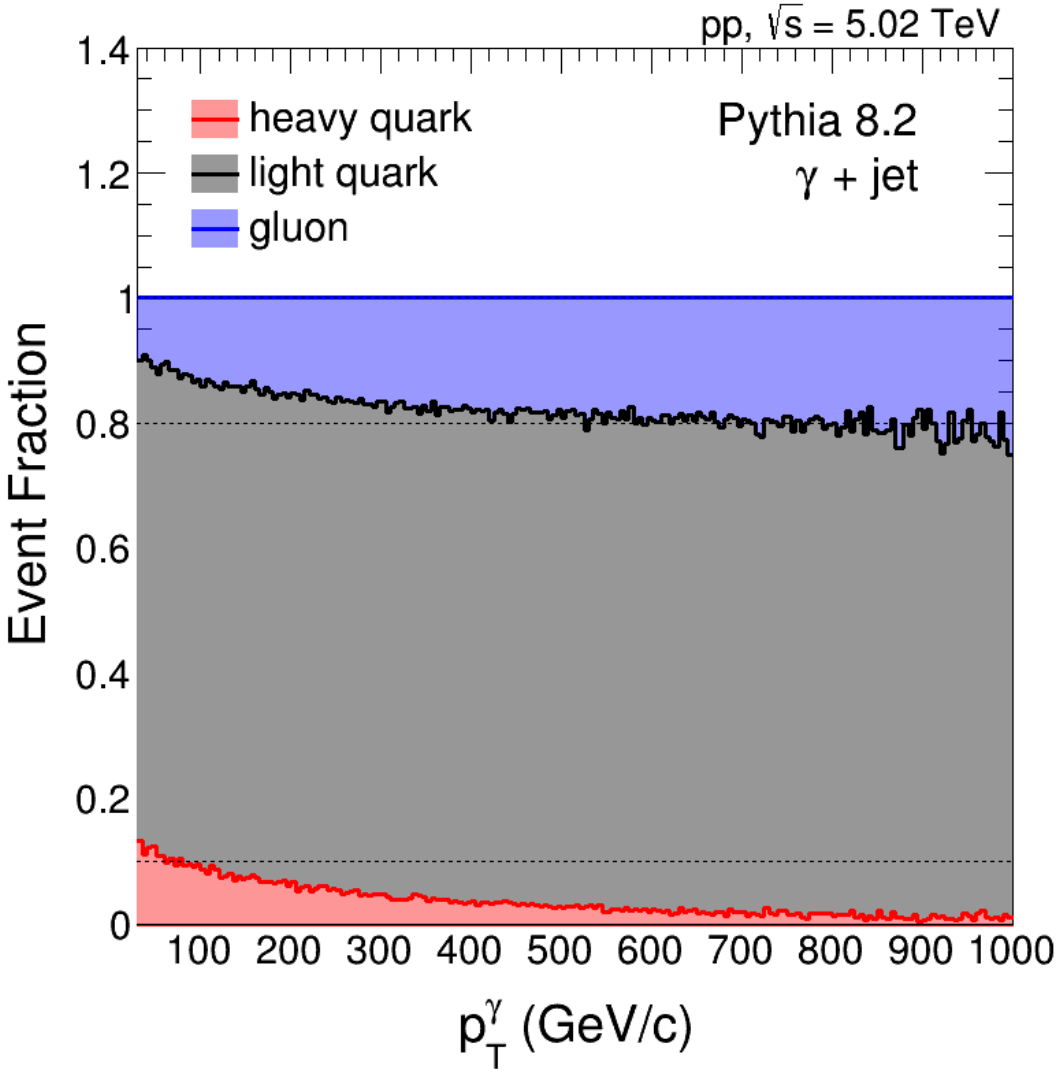
γ+gluon

dominantly via qqbar annihilation



subdominantly via



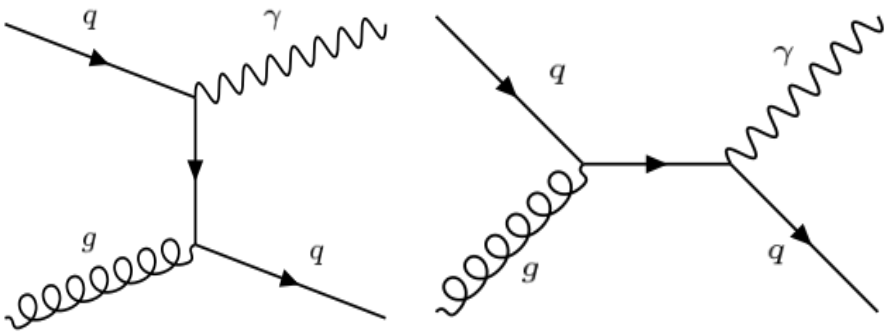


Process here is prompt photon (not isolated photon)
Quark dominated across the spectrum
80-90% from p_T ~ 50 GeV to ~ 1 TeV

Mapping γ+jet to PDF

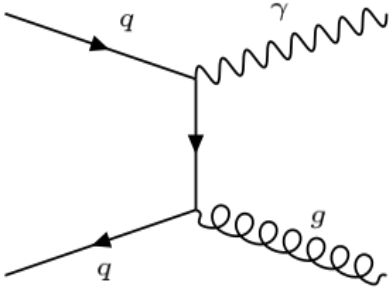
γ+quark

dominantly via QCD Compton scattering

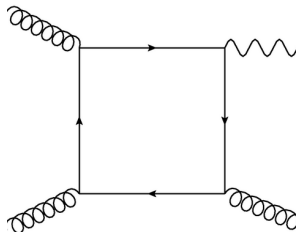


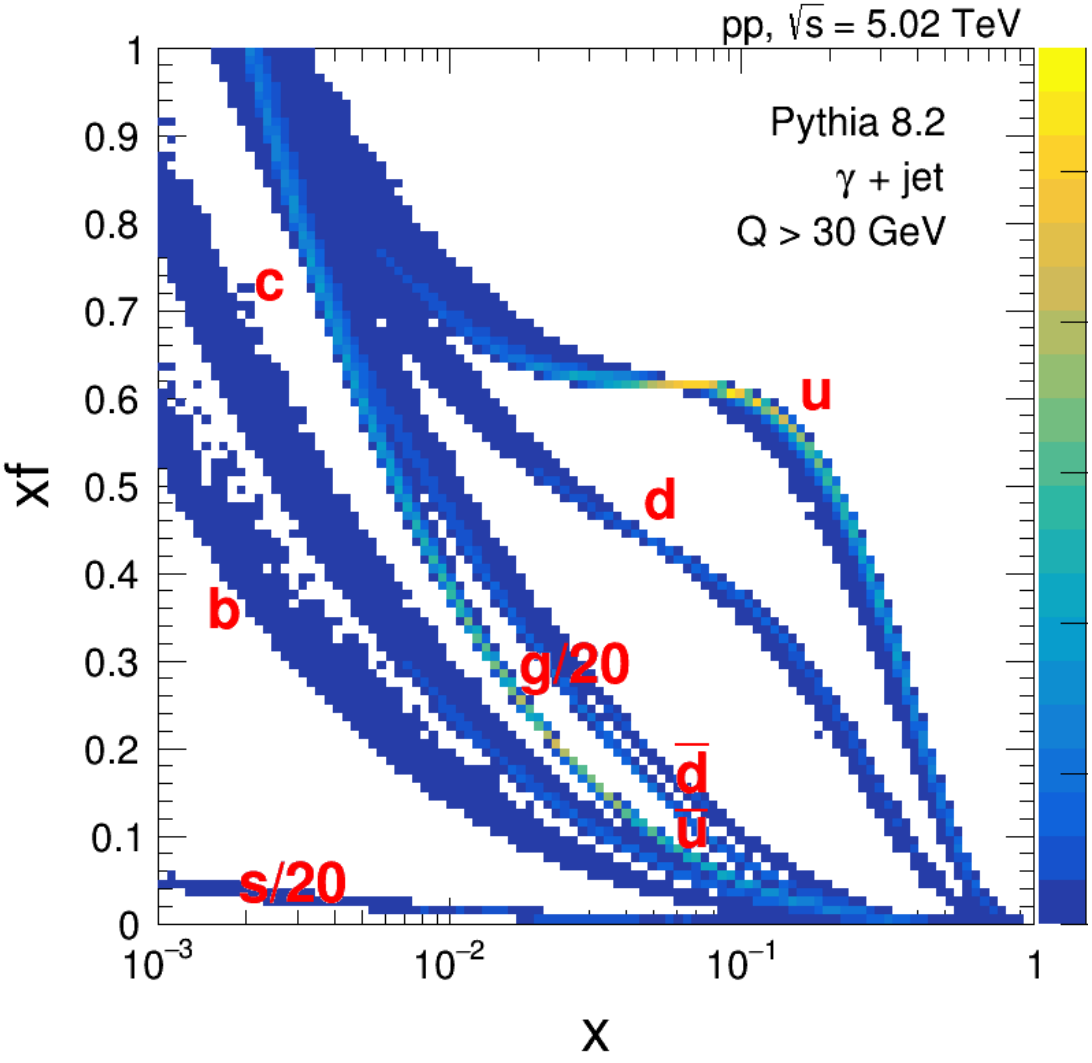
γ+gluon

dominantly via qqbar annihilation



subdominantly via



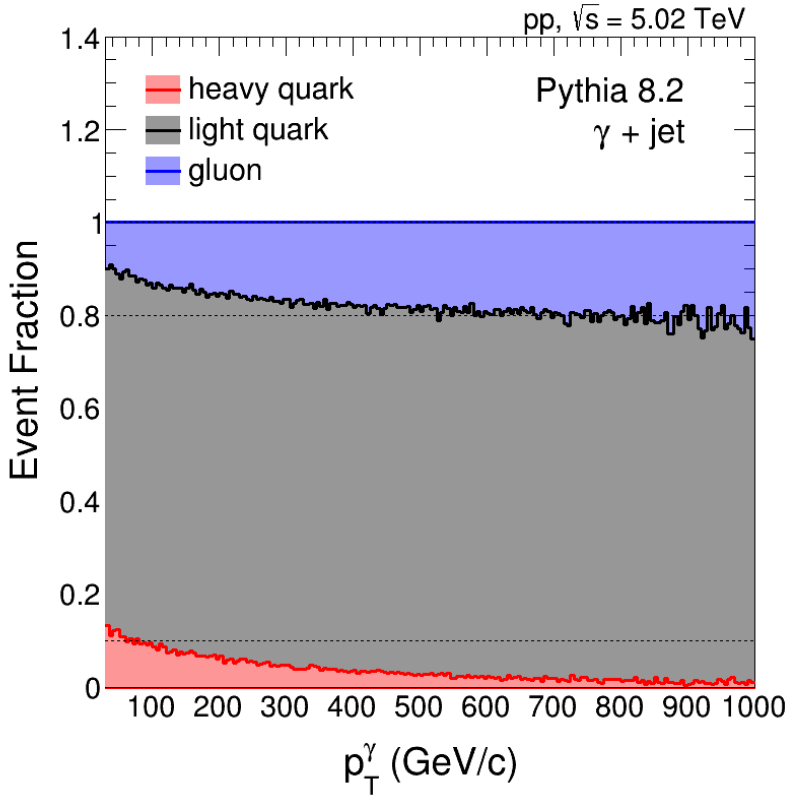


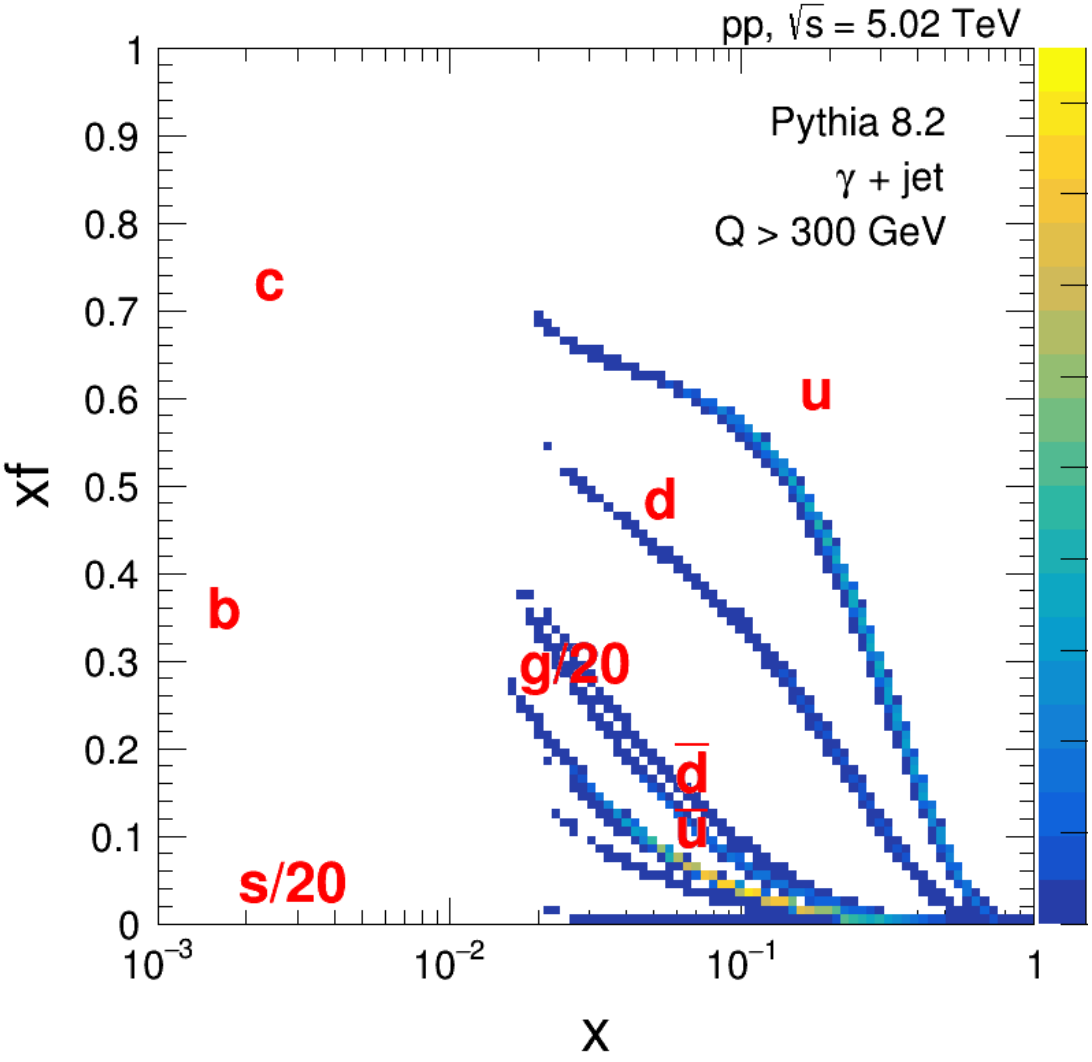
PDF vs x explored in photon+jet events

Mapping γ+jet to PDF – large Q

High momentum transfer – > large x

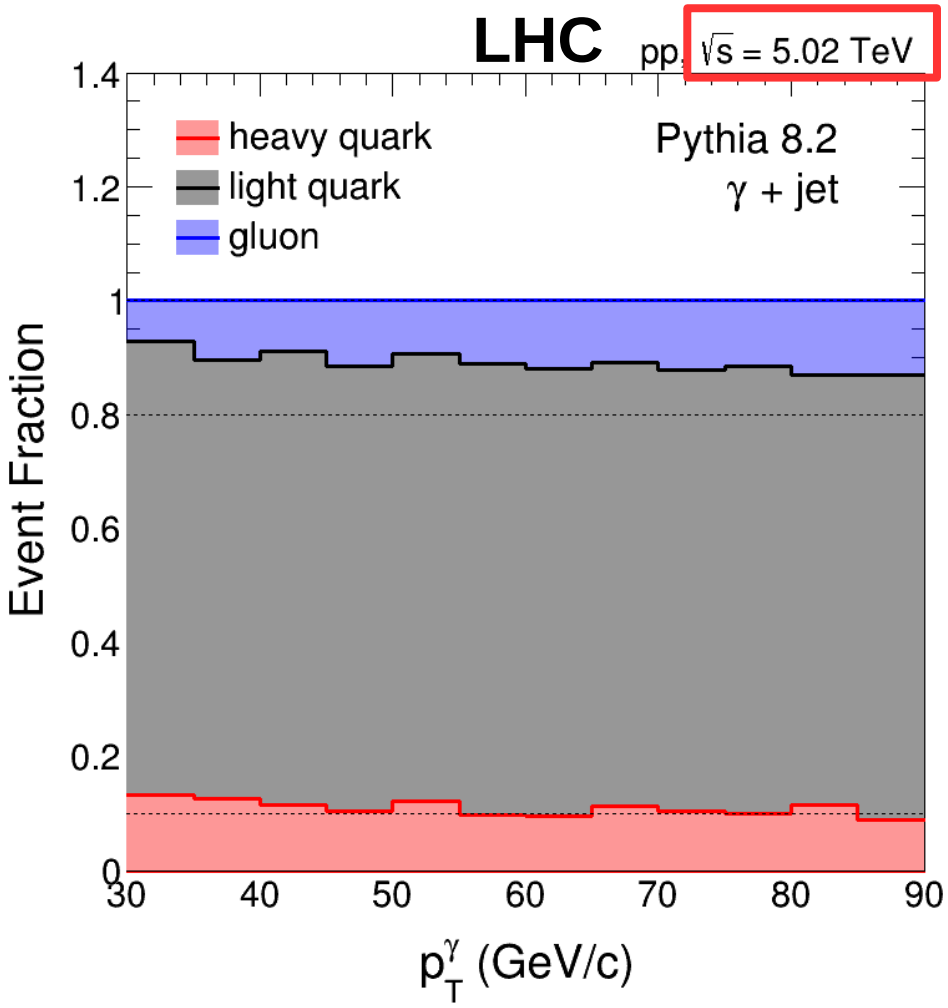
Gluon PDF falls faster with x
==>
Gluon initiated processes decrease
==>
Quark jet fraction decreases

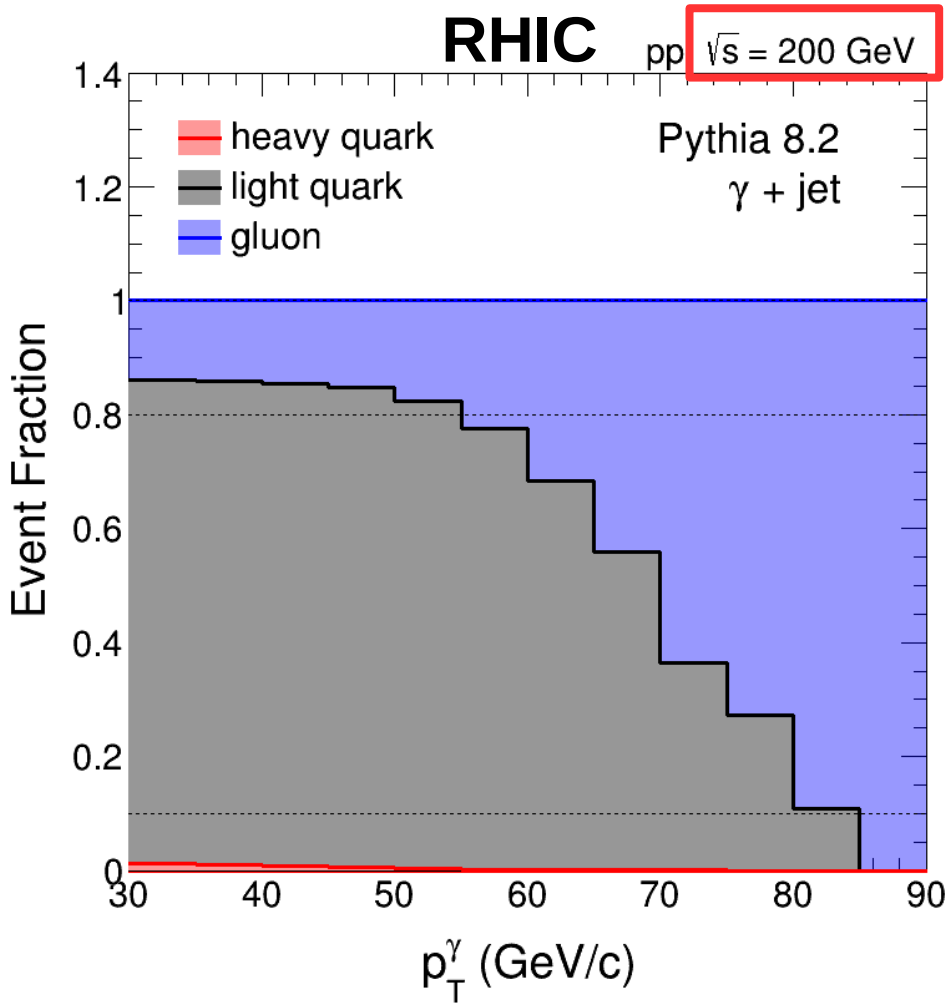




PDF vs x explored in photon+jet events

q/g fraction – γ+jet at LHC vs RHIC





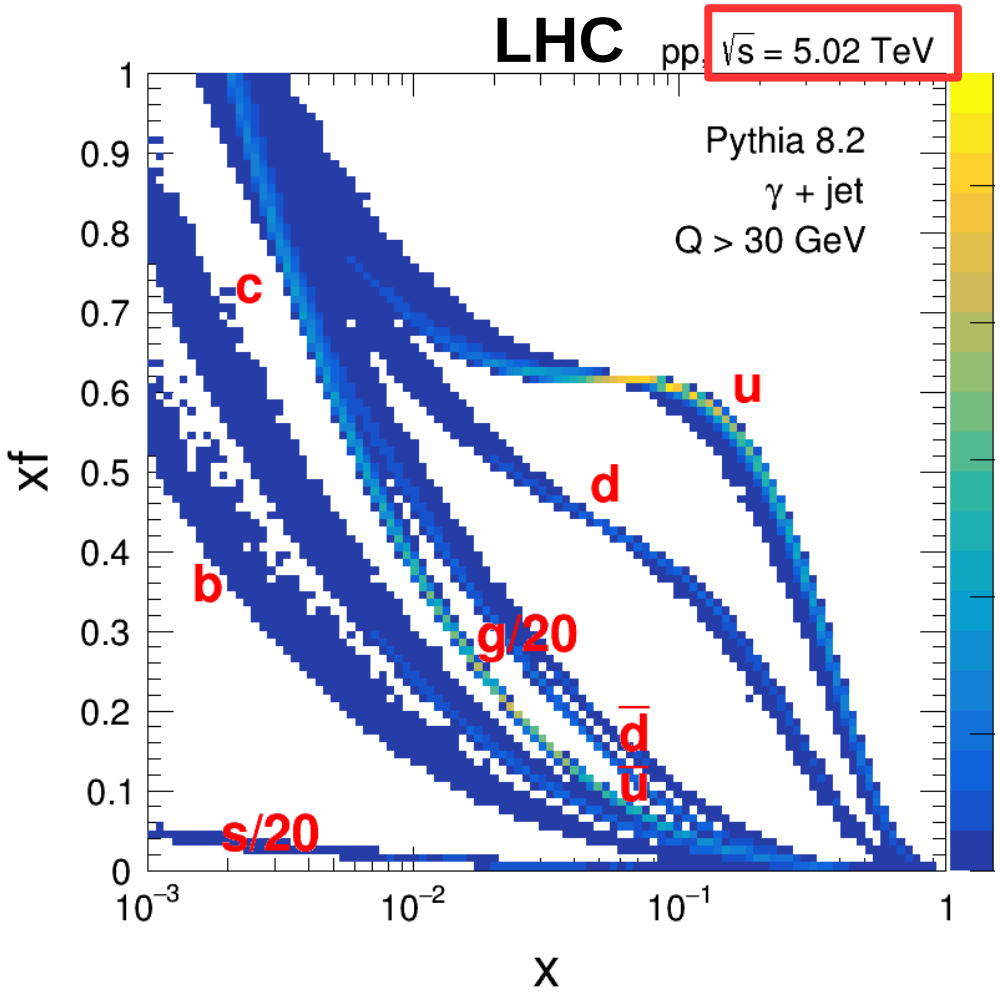
Almost no heavy quark events

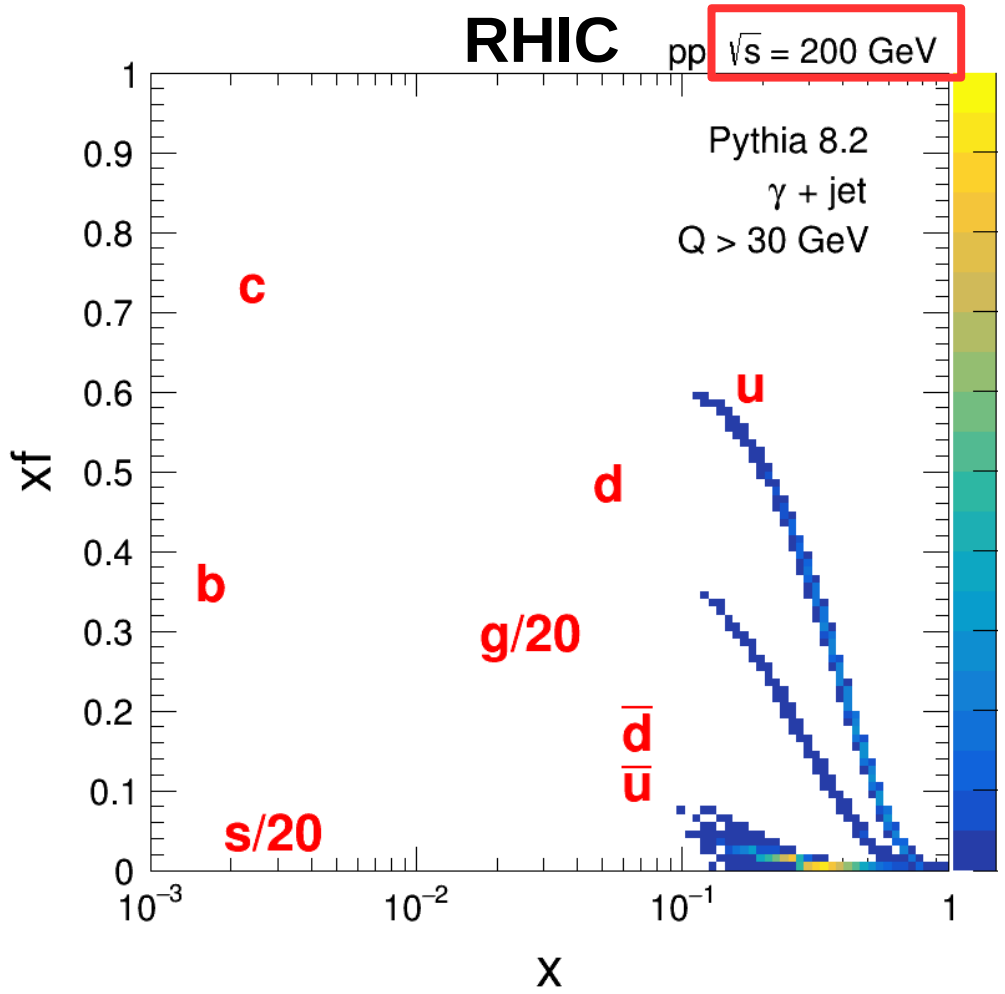
Rapid decrease in quark fraction after p_T ~ 50 GeV

sPHENIX not expected to go beyond that p_T

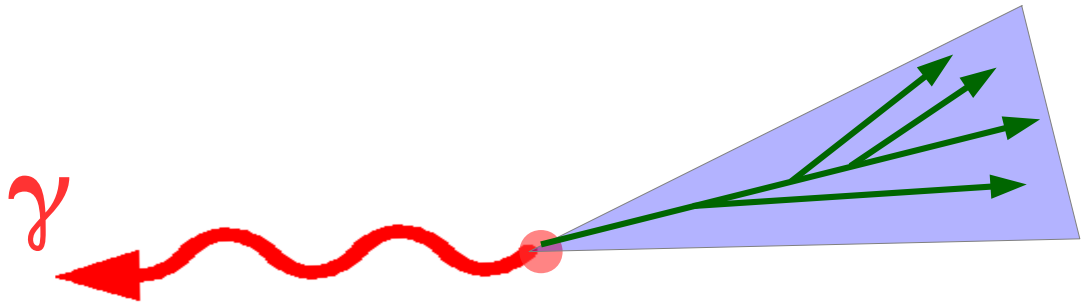
See HP2018 talk

Map to PDF – γ+jet at LHC vs RHIC





B/c phase space is squeezed into high x



Bulk observables

Shape of momentum imbalance

Processes in the evolution of hard scattering
- **Multiparton interactions (MPI)**
- **Initial-state radiation (ISR)**
- **Final-state radiation (FSR)**

Turn off these processes one by one.
Their absence reveals the impact on the observable.

Left (Right) tail from **FSR** (**ISR**)

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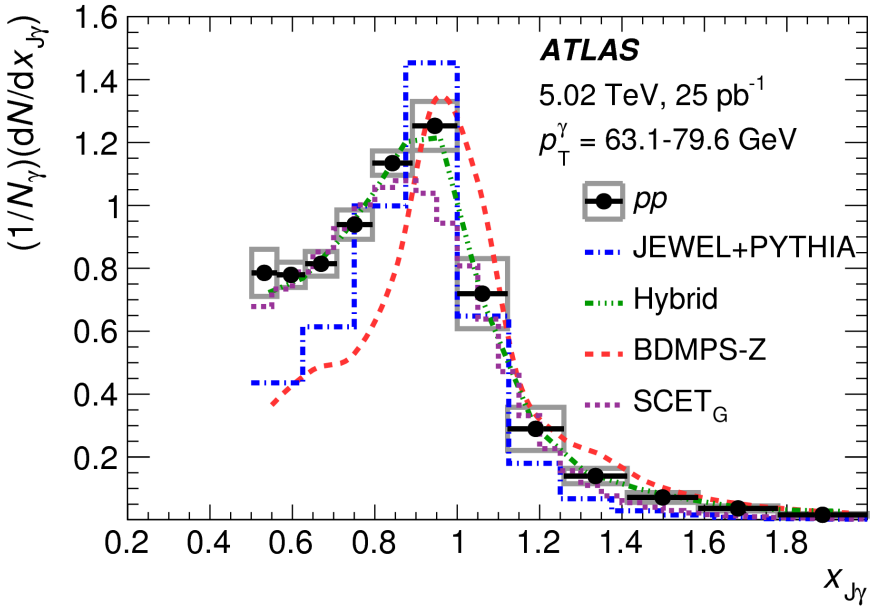
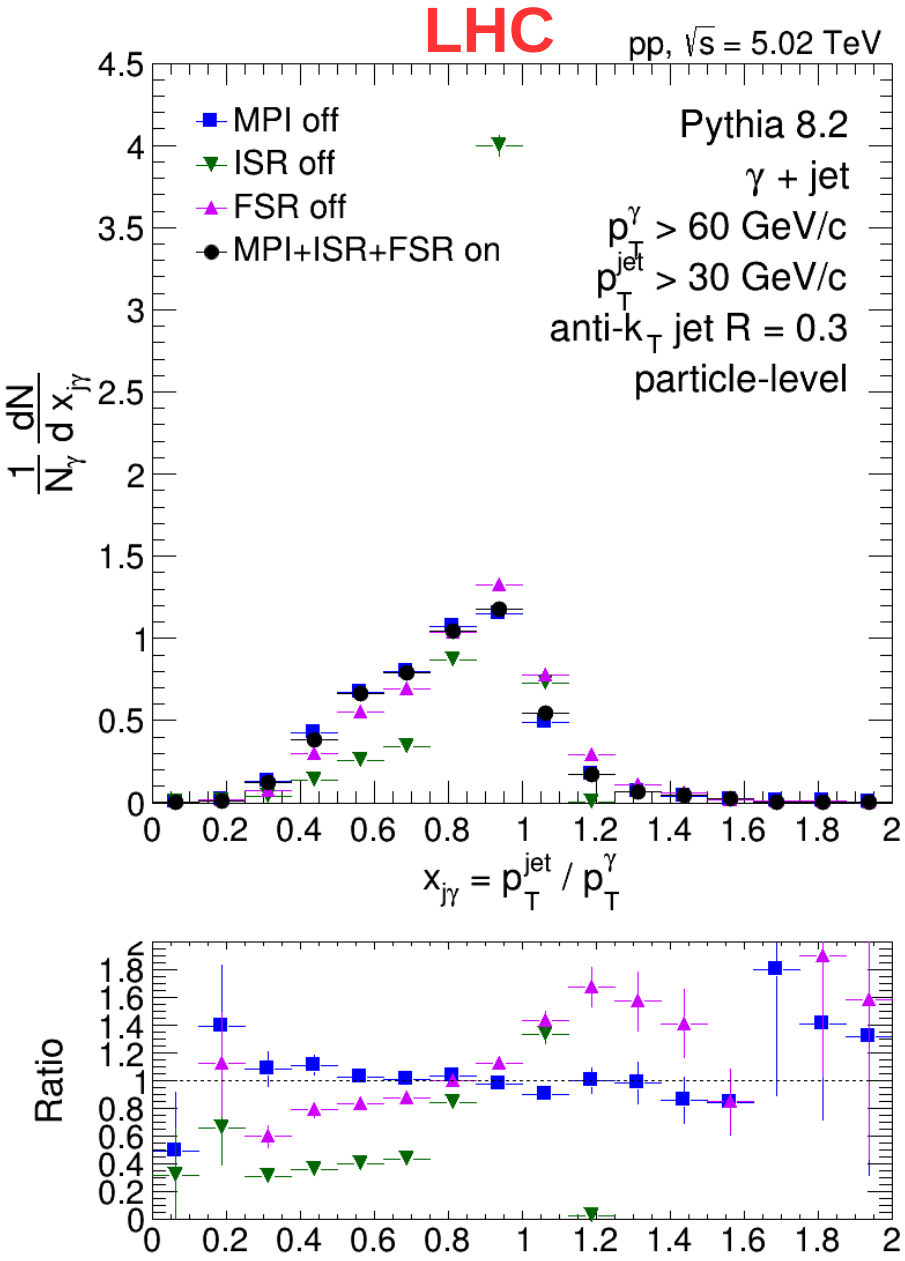


LHC

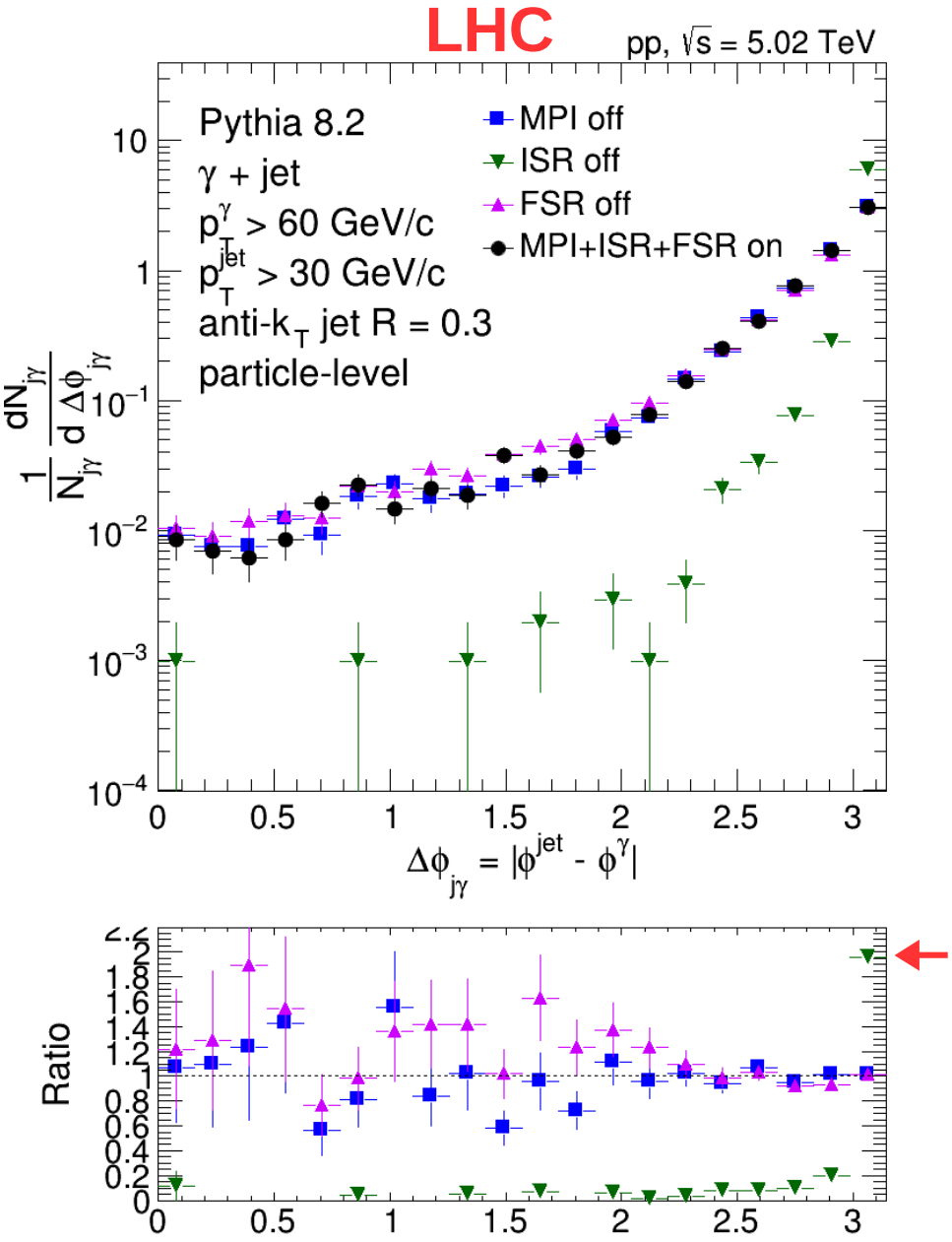


Shape of angular correlation

Processes in the evolution of hard scattering
- **Multiparton interactions (MPI)**
- **Initial-state radiation (ISR)**
- **Final-state radiation (FSR)**

Turn off these processes one by one.
Their absence reveals the impact on the observable.

ISR is the process that widens azimuthal angle correlation.

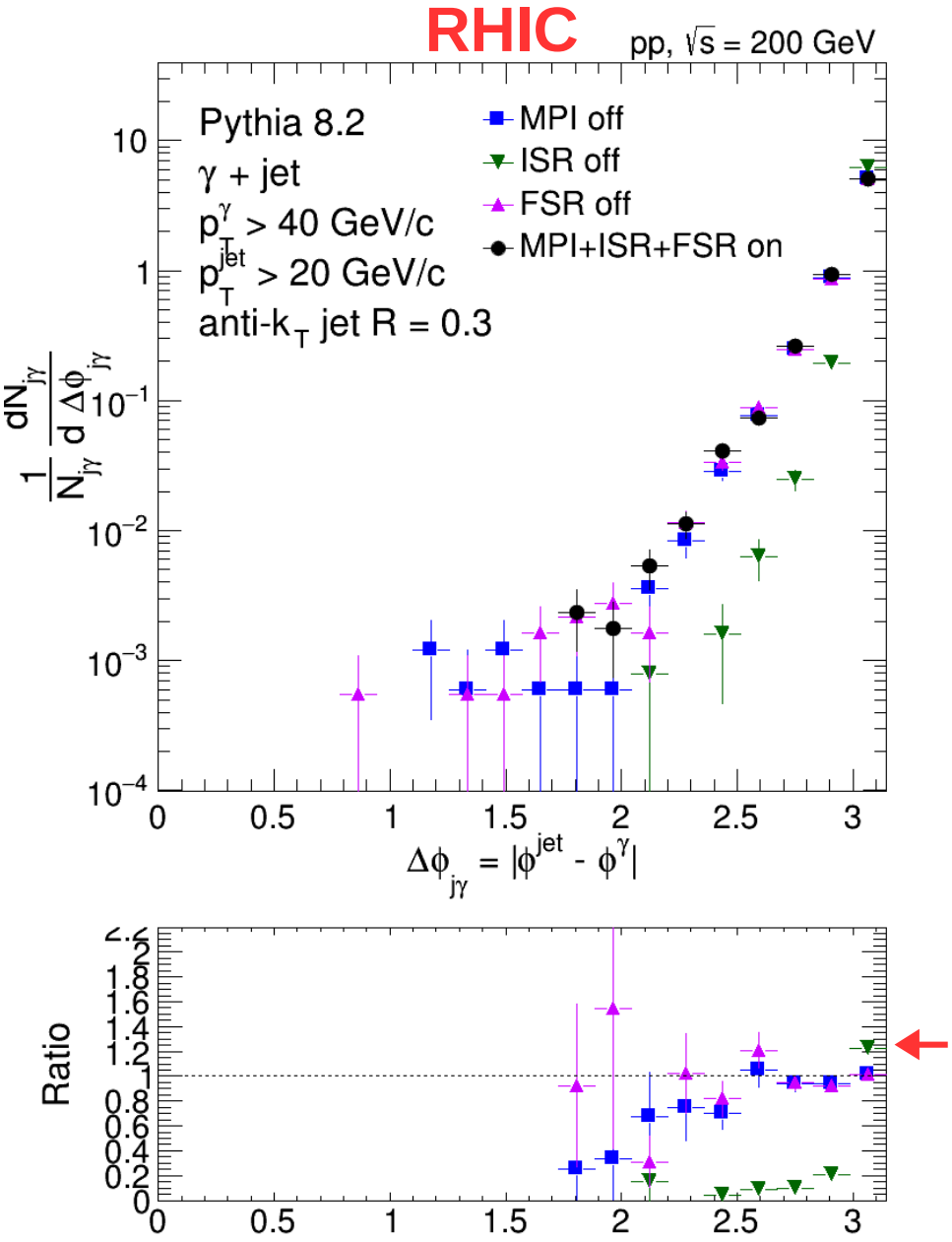


Shape of angular correlation at RHIC

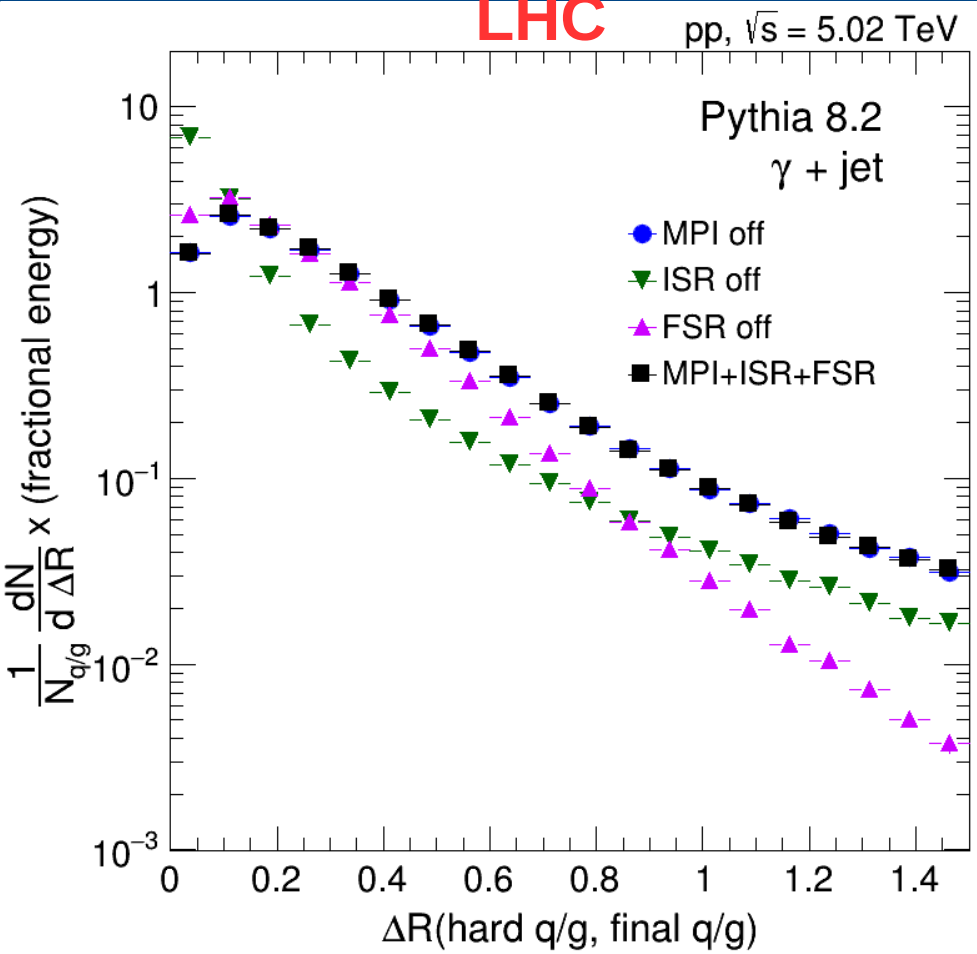
Processes in the evolution of hard scattering
- **Multiparton interactions (MPI)**
- **Initial-state radiation (ISR)**
- **Final-state radiation (FSR)**

Turn off these processes one by one.
Their absence reveals the impact on the observable.

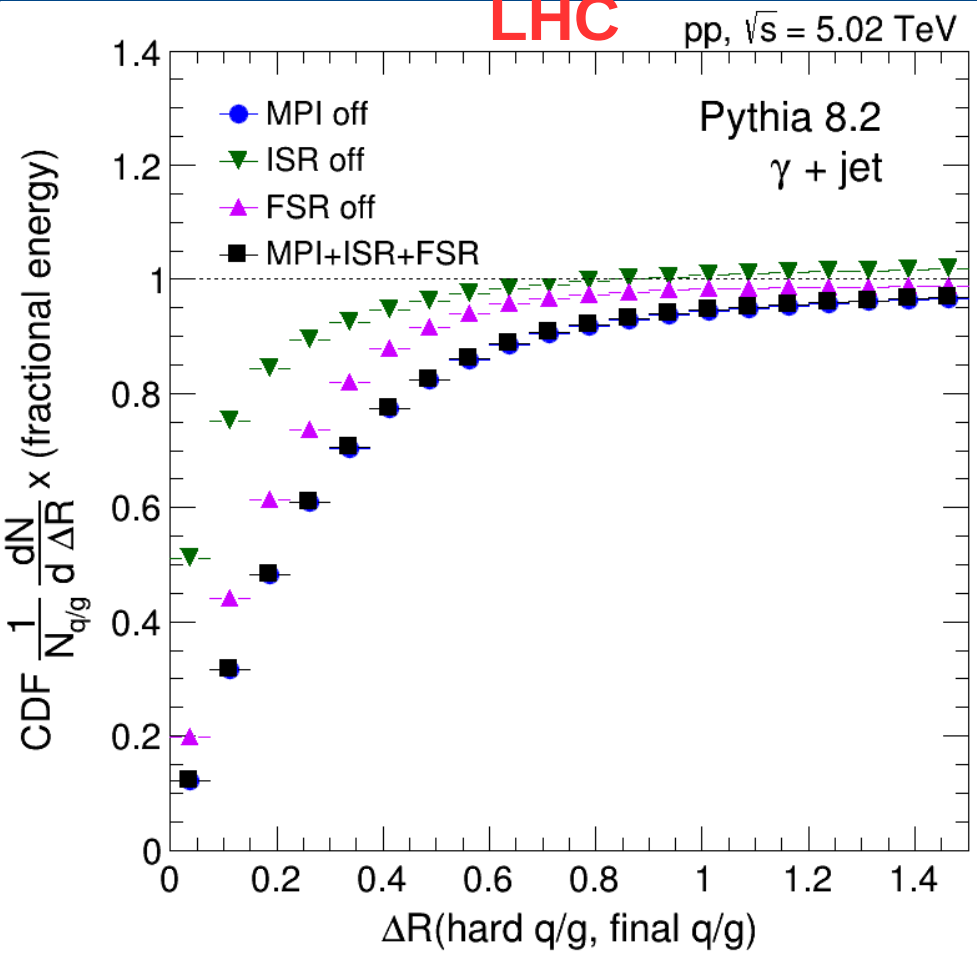
Sharper angular correlation at RHIC
ISR has a smaller effect



Hard parton radiates to large angles



Fraction of energy radiated **at** angle ΔR

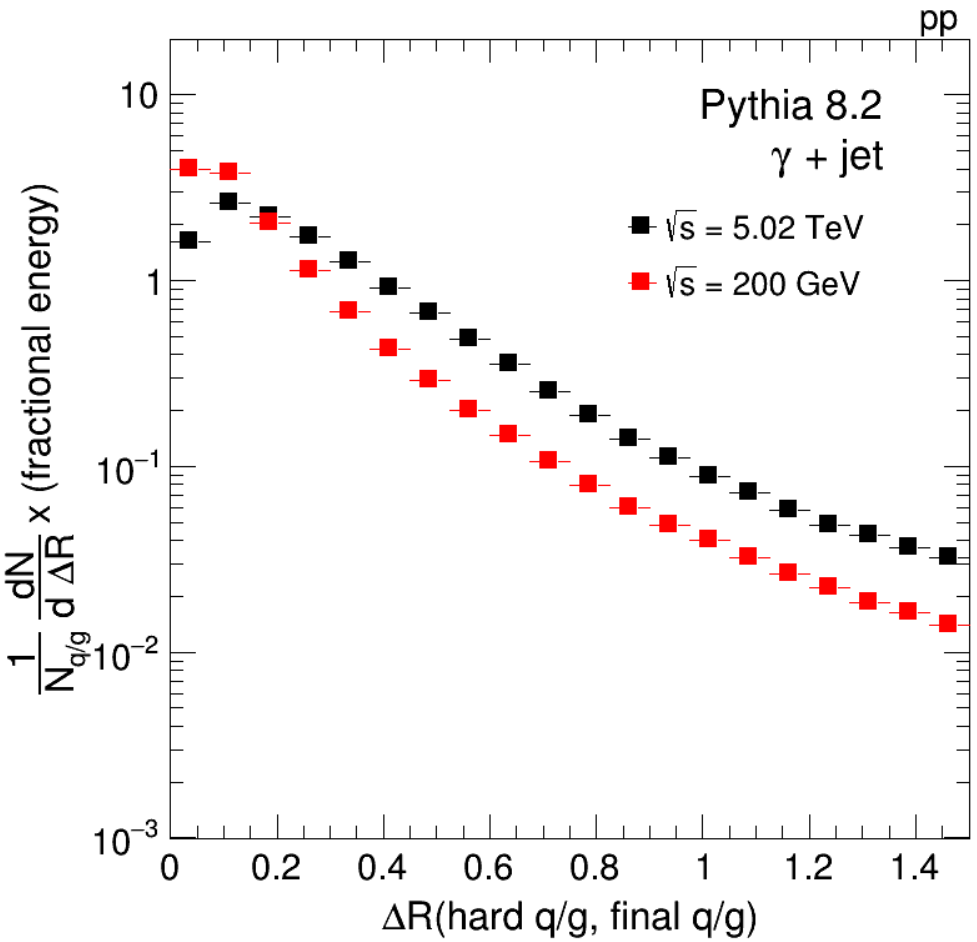


Fraction of energy **inside** ΔR

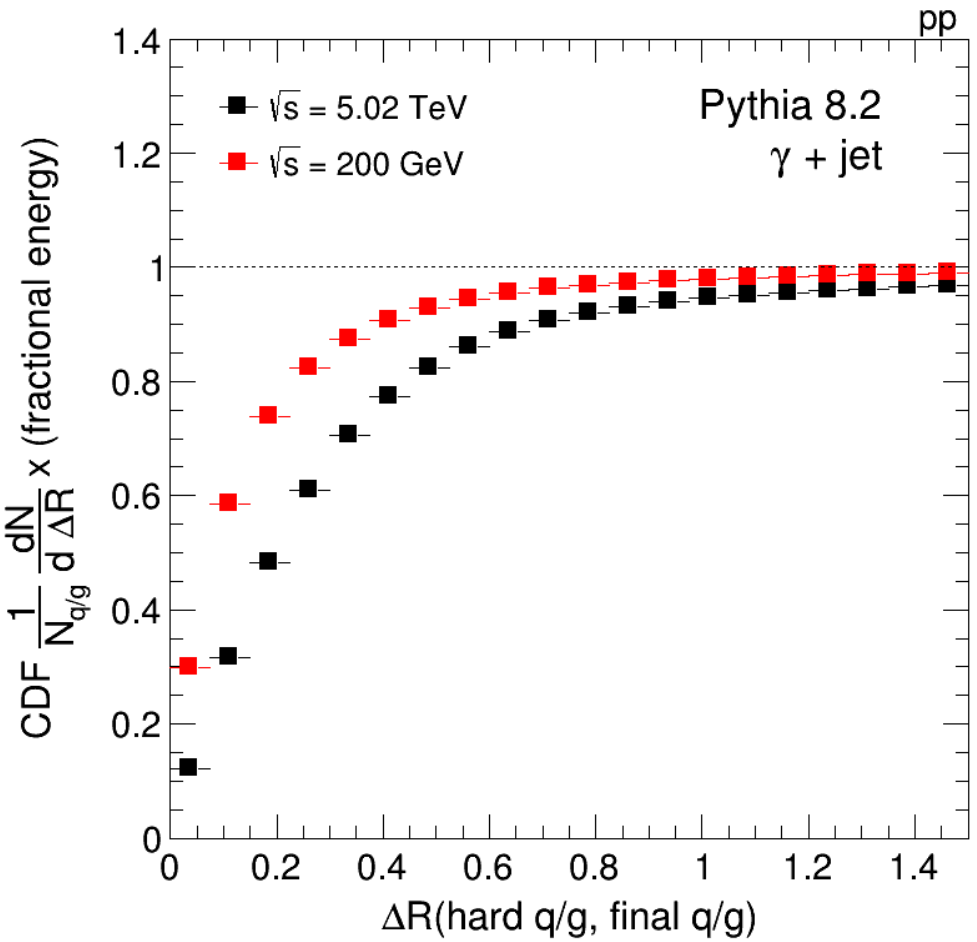
Radiation up to large angles (ΔR ~ 1.5)

Hard – > parton produced at hard scattering
Final – > daughters of “hard” partons right before hadronization

Radiation to large angles – LHC vs RHIC



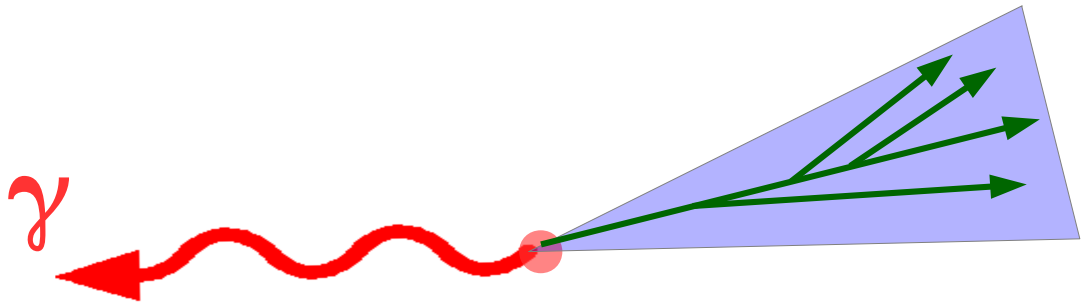
Fraction of energy radiated **at** angle ΔR



Fraction of energy **inside** ΔR

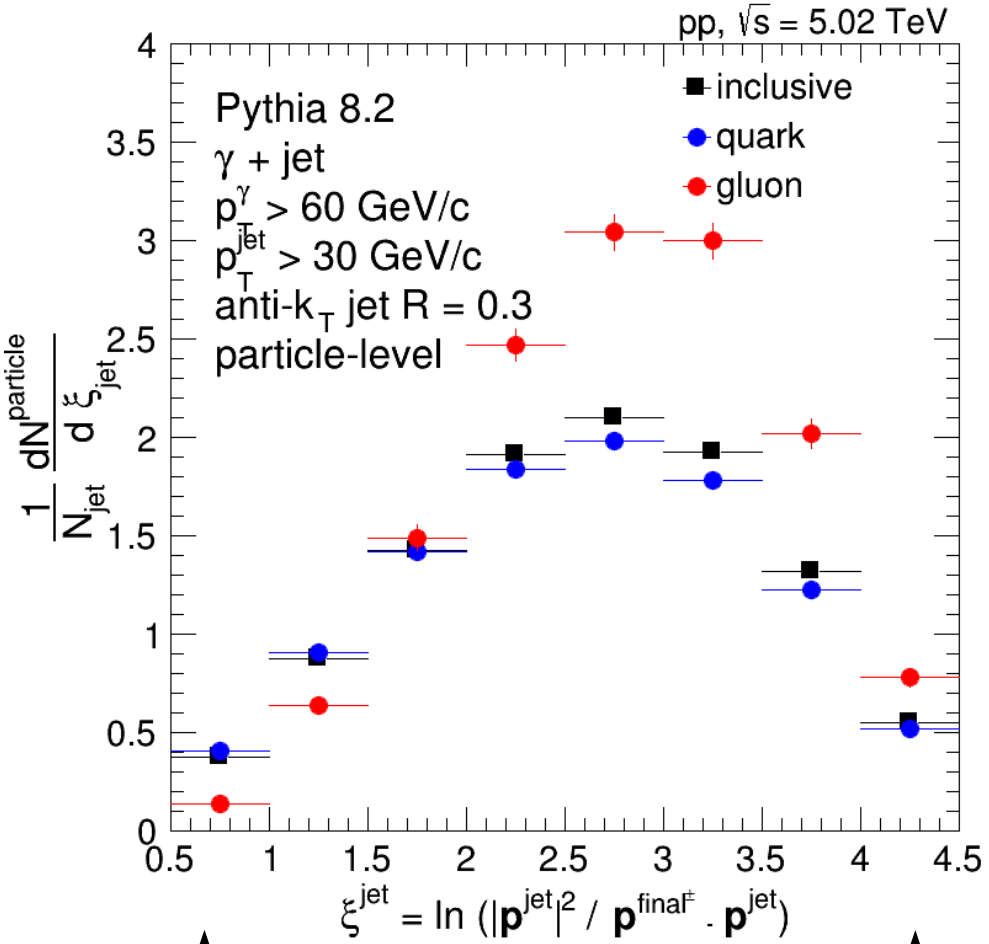
Recover 80% of parton energy at
ΔR~0.4 for LHC
ΔR~0.25 for RHIC

Hard – > parton produced at hard scattering
Final – > daughters of “hard” partons right before hadronization



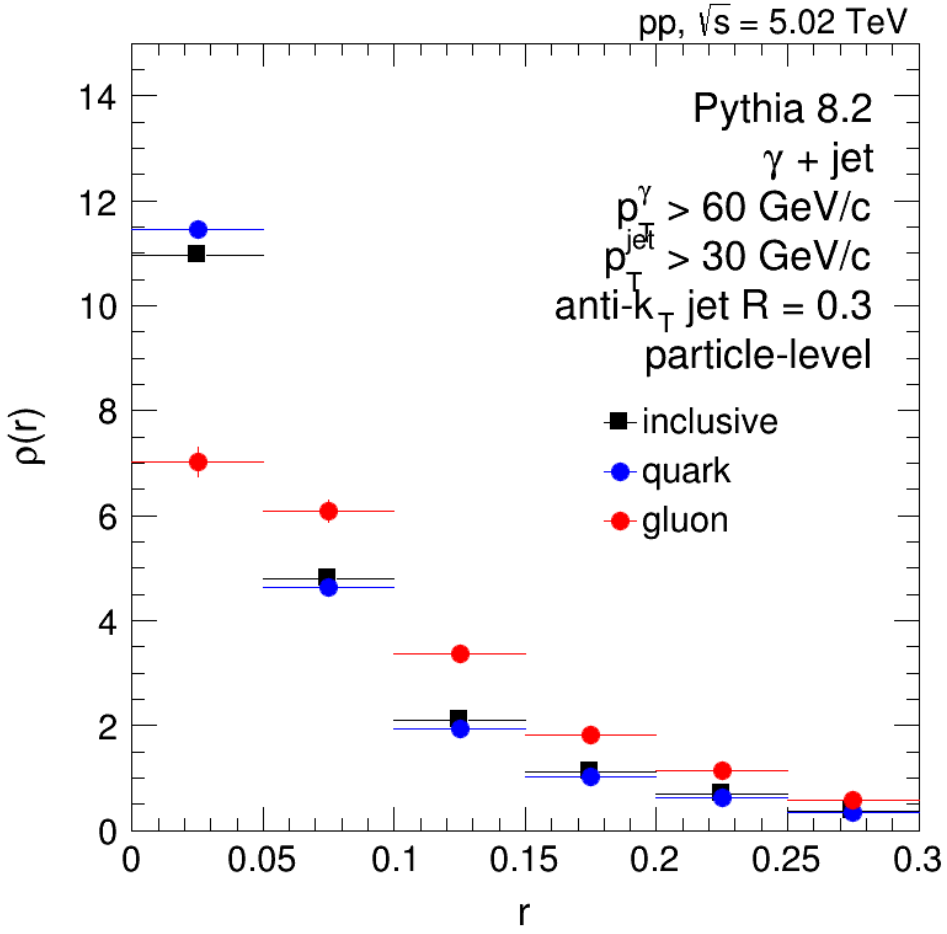
Substructure

Fragmentation function and jet shape



high-p_T particles

low-p_T particles



$$r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2}$$

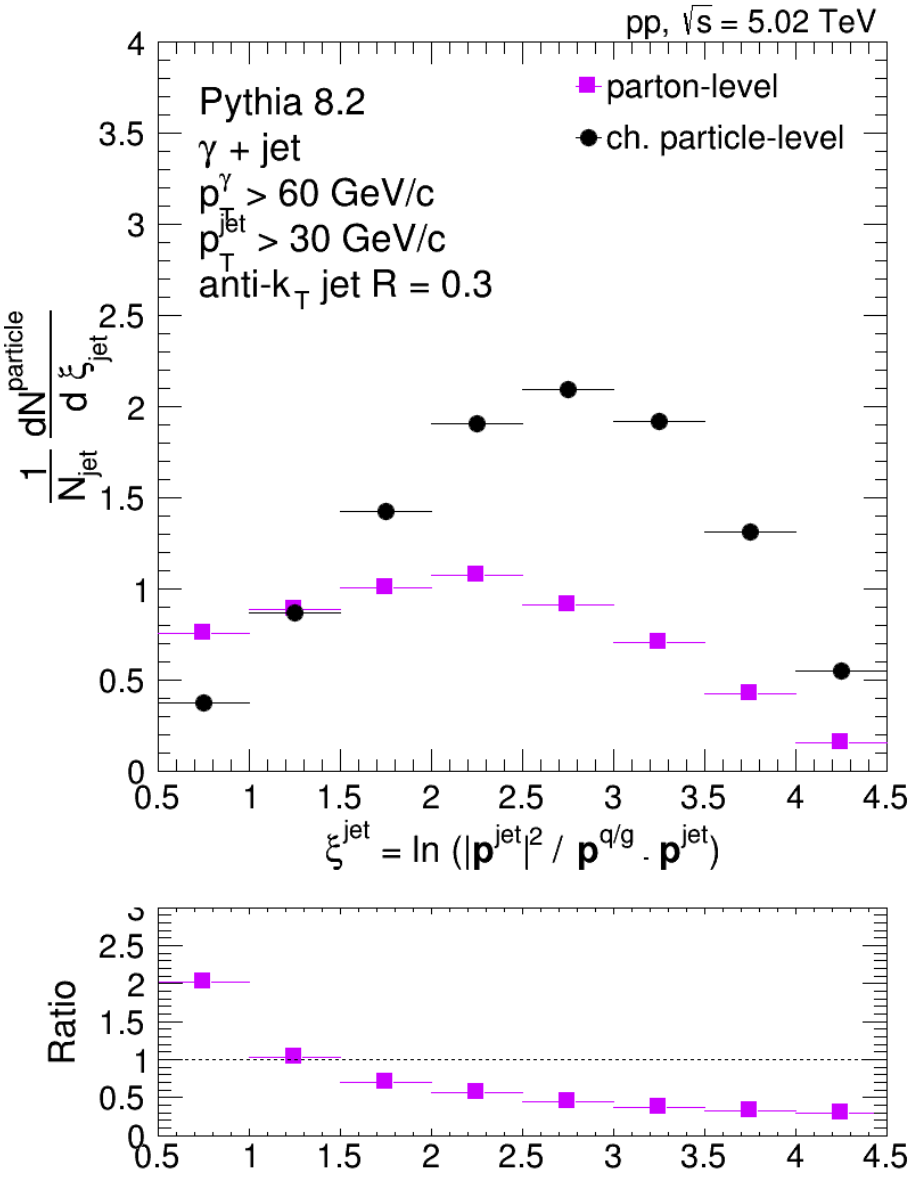
$$\rho(r) = \frac{1}{\delta r} \frac{\sum_{\text{jets}} \sum_{\text{trk} \in [r_a, r_b)} (p_T^{\text{trk}} / p_T^{\text{jet}})}{\sum_{\text{jets}} \sum_{\text{trk} \in [0, r_f)} (p_T^{\text{trk}} / p_T^{\text{jet}})}$$

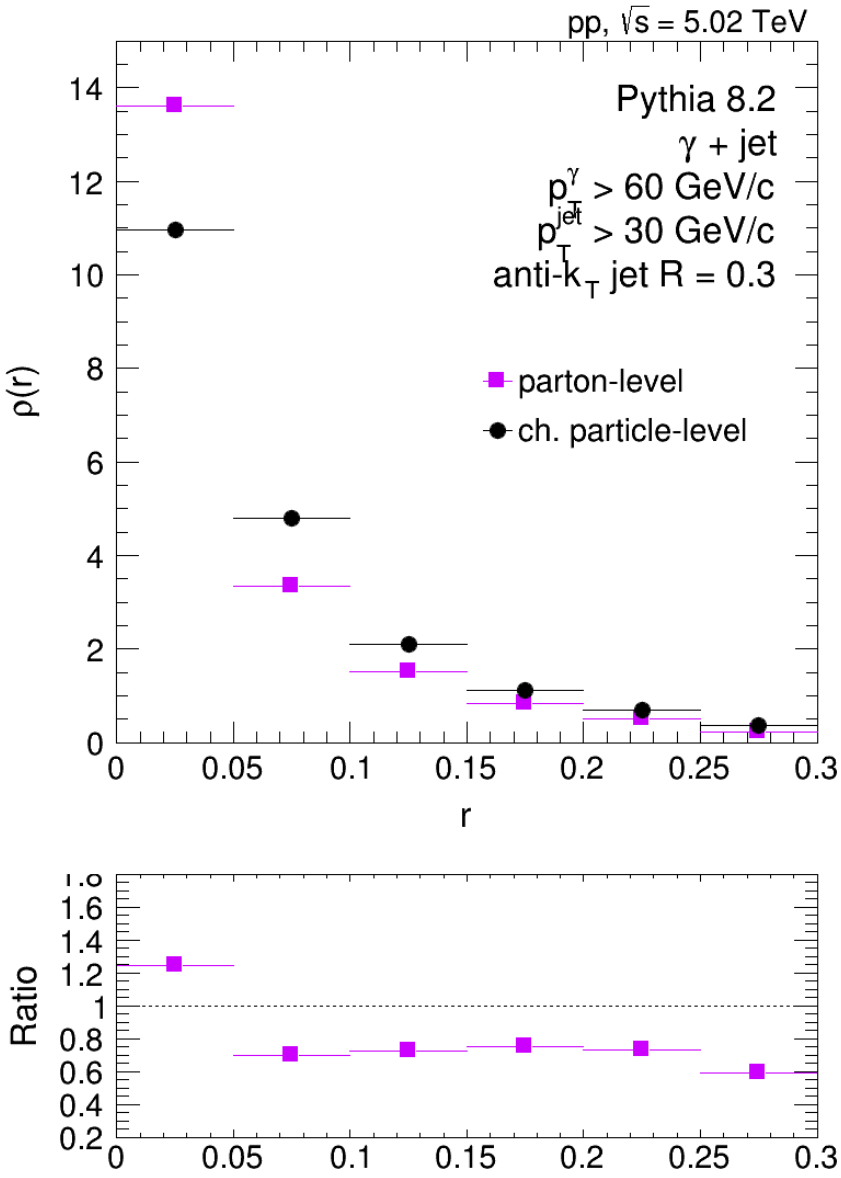
p_T > 1 GeV/c for all particles

Fragmentation function (FF)
Distribution of longitudinal momentum over particles

Jet shape (JS)
Energy fraction radiated to transverse direction

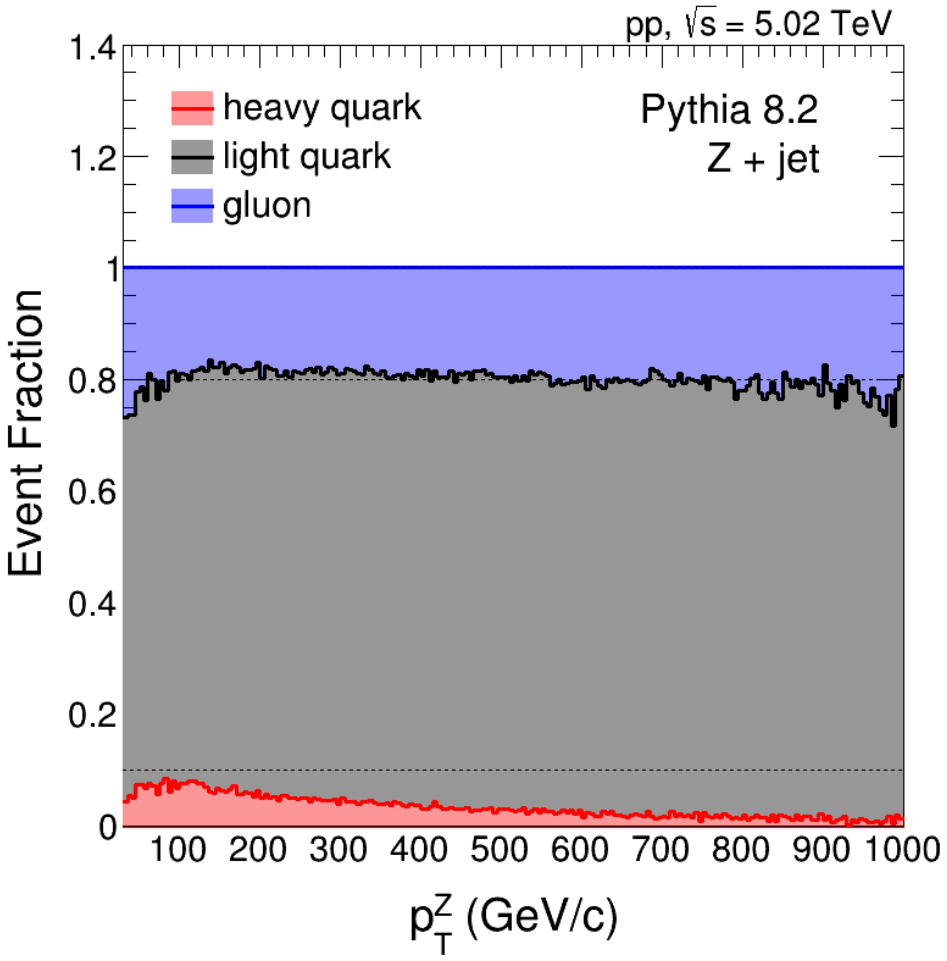
FF vs JS – Sensitivity to Hadronization



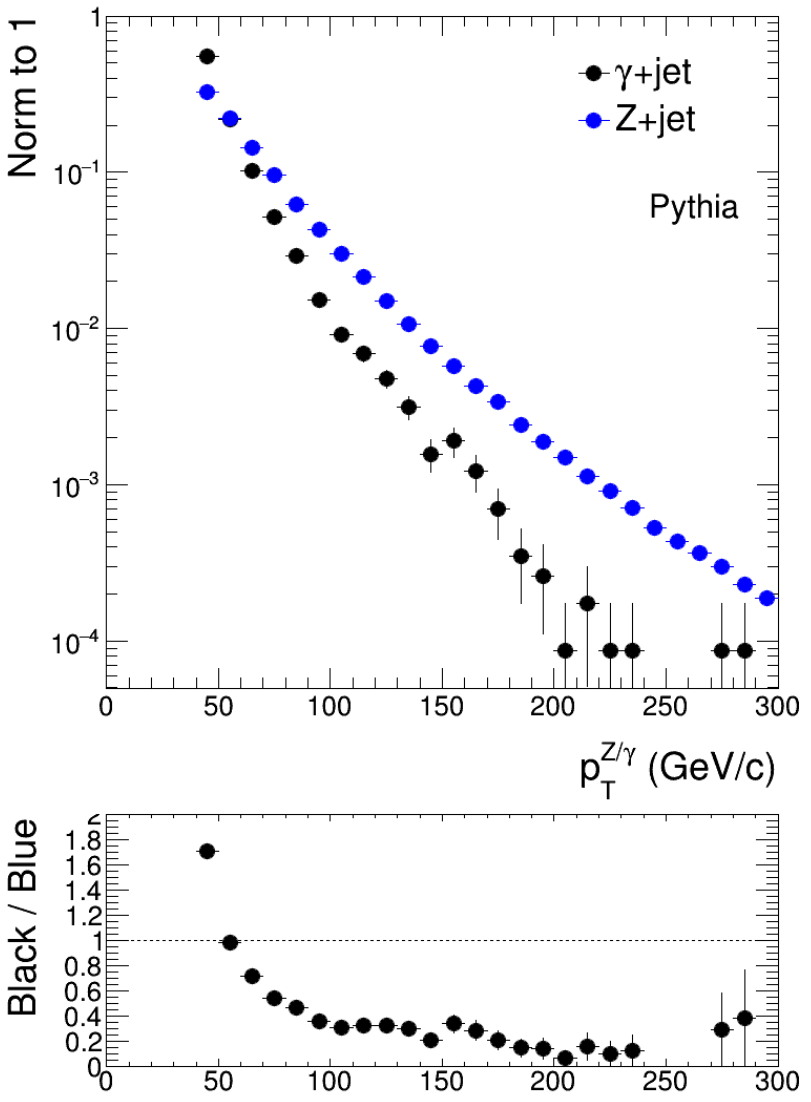


FF more sensitive to hadronization

Z+jet

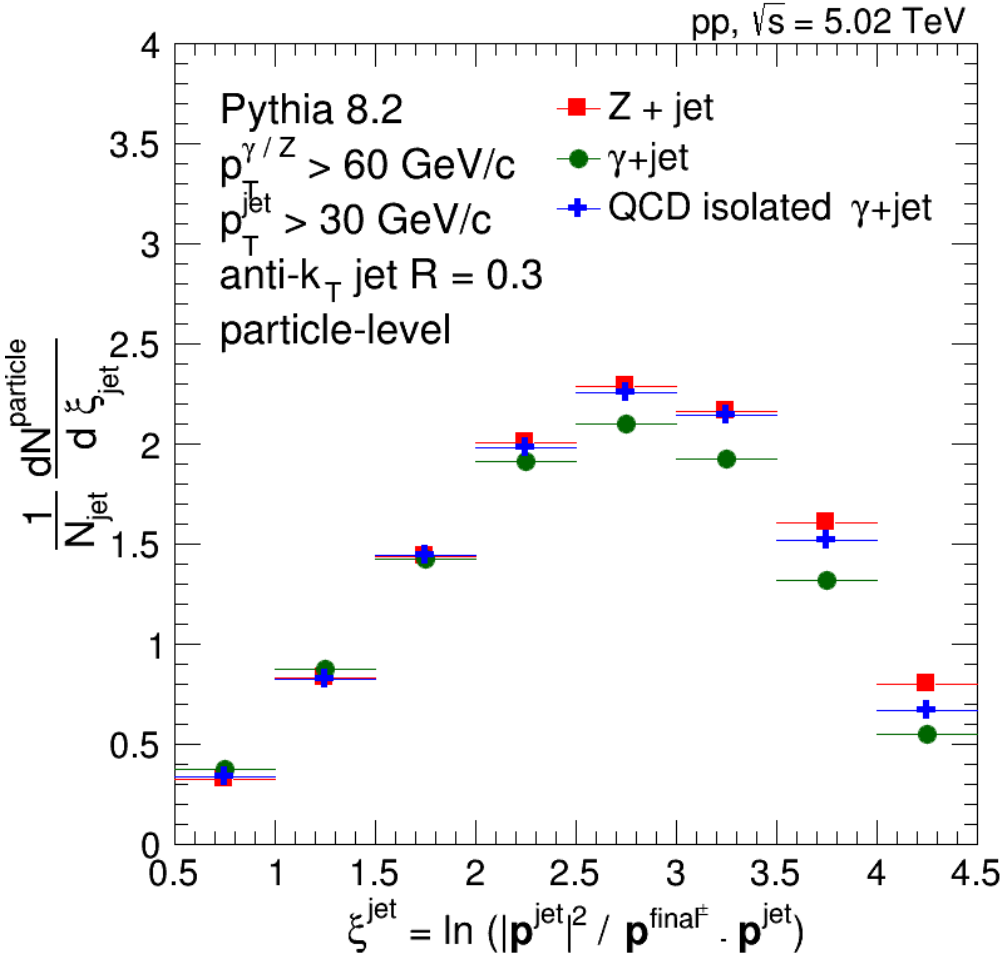


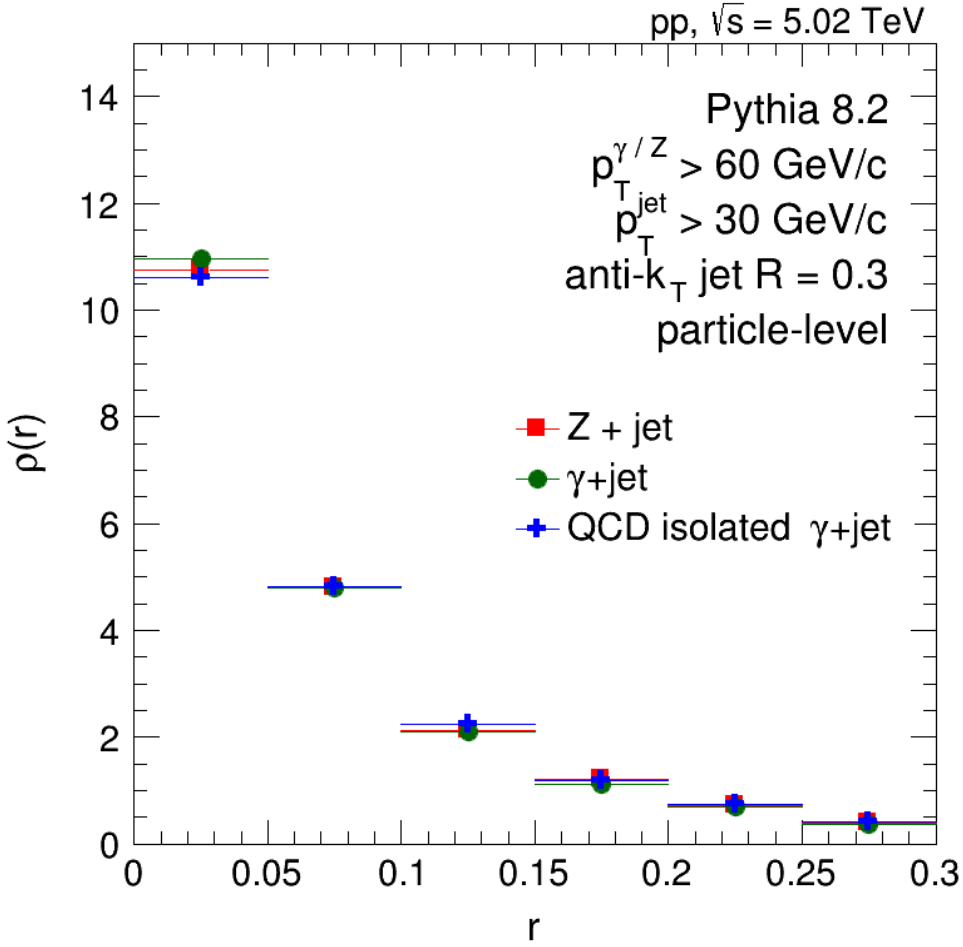
Similar Q/G fraction as prompt photon



Z is massive – > Wider p_T spectrum

Z+jet vs γ+jet: FF and JS



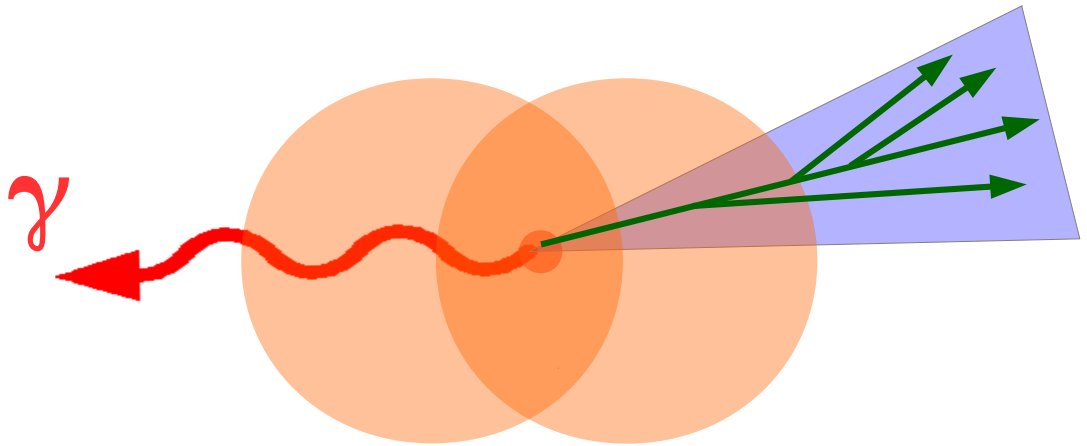


Isolated photon+jet

represents the experiment sample better

more similar to **Z+jet** than **prompt photon**

All three similar



Substructure
in Heavy Ion Background

We ~know how to correct/subtract some things
e.g. energy, multiplicity
Generally --> scalar quantities – > along 1D, direction of change is known

Background subtraction for charged particles

isolated-photon+jet event

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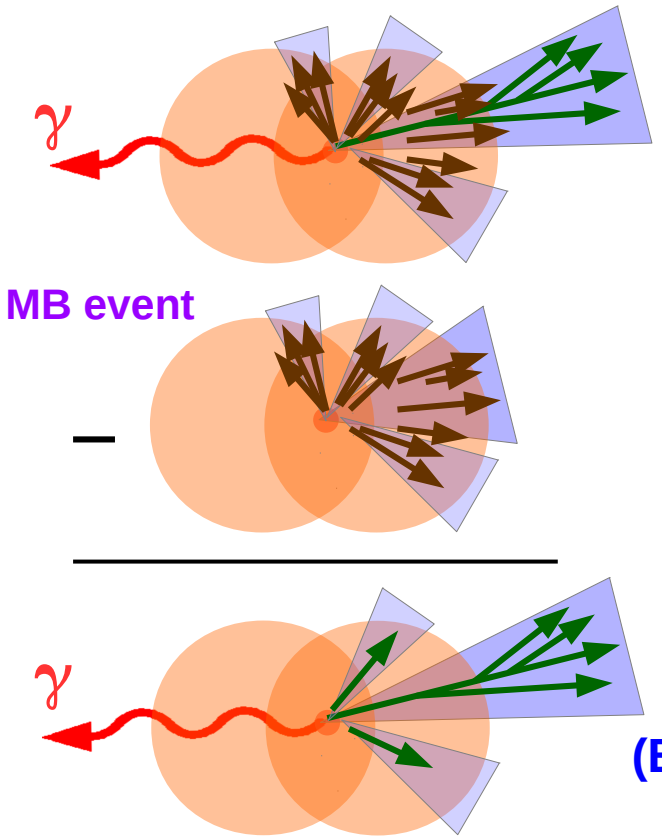
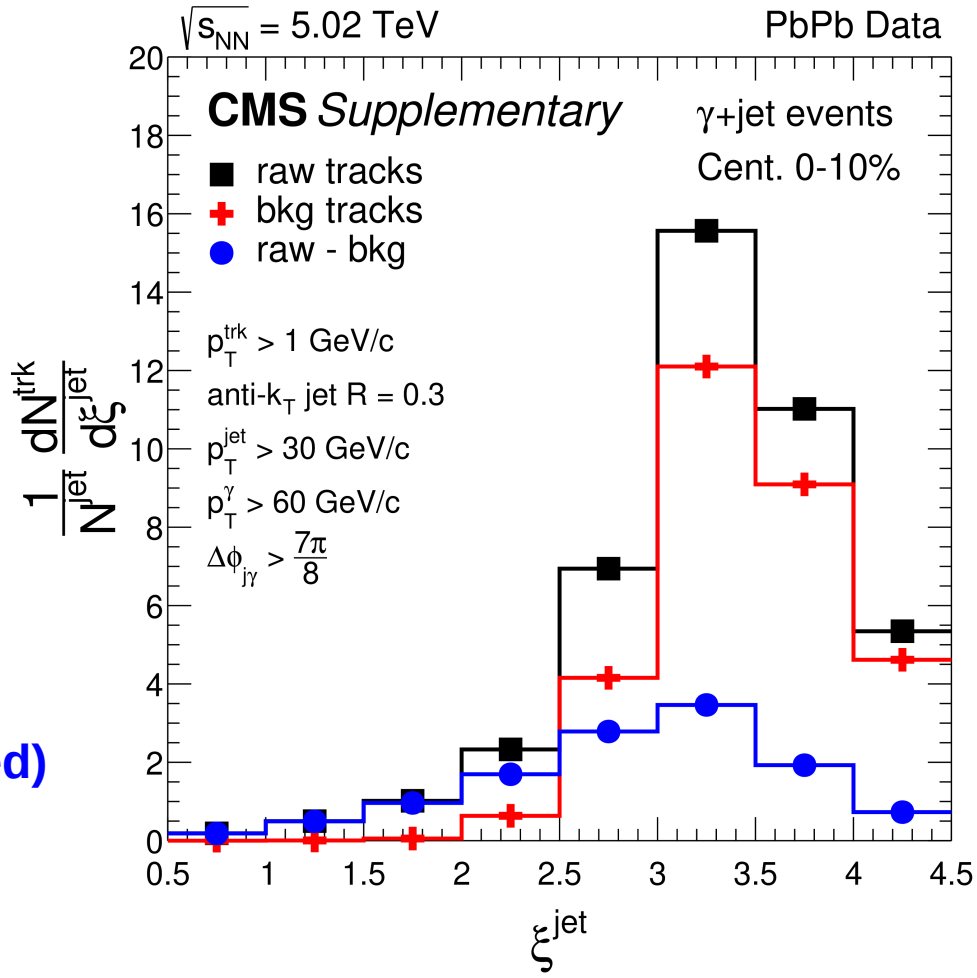


Raw tracks inside jet cone

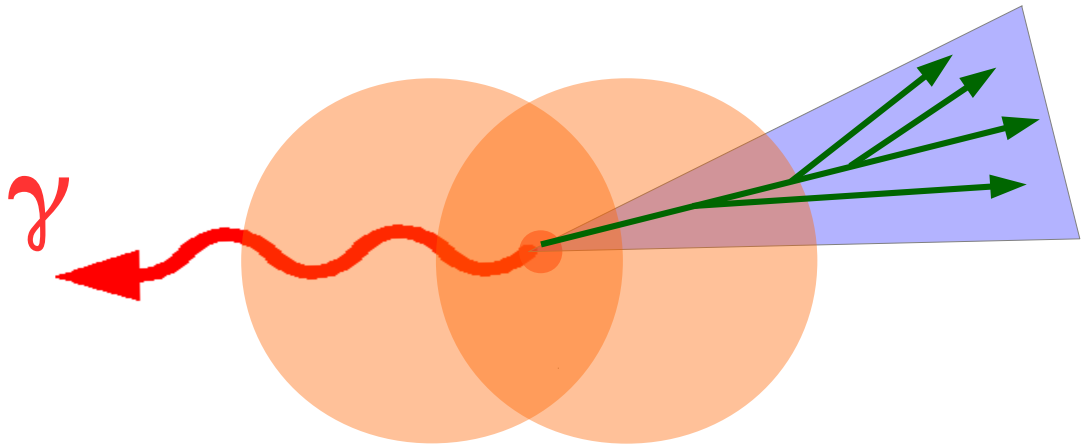
Bkg tracks inside jet cone

Raw – Bkg (Bkg track subtracted)



$$\xi^{\mathrm{jet}} = \ln \frac{|\mathbf{p}^{\mathrm{jet}}|^2}{\mathbf{p}^{\mathrm{trk}} \cdot \mathbf{p}^{\mathrm{jet}}}$$

Large ξ – > low p_T particle

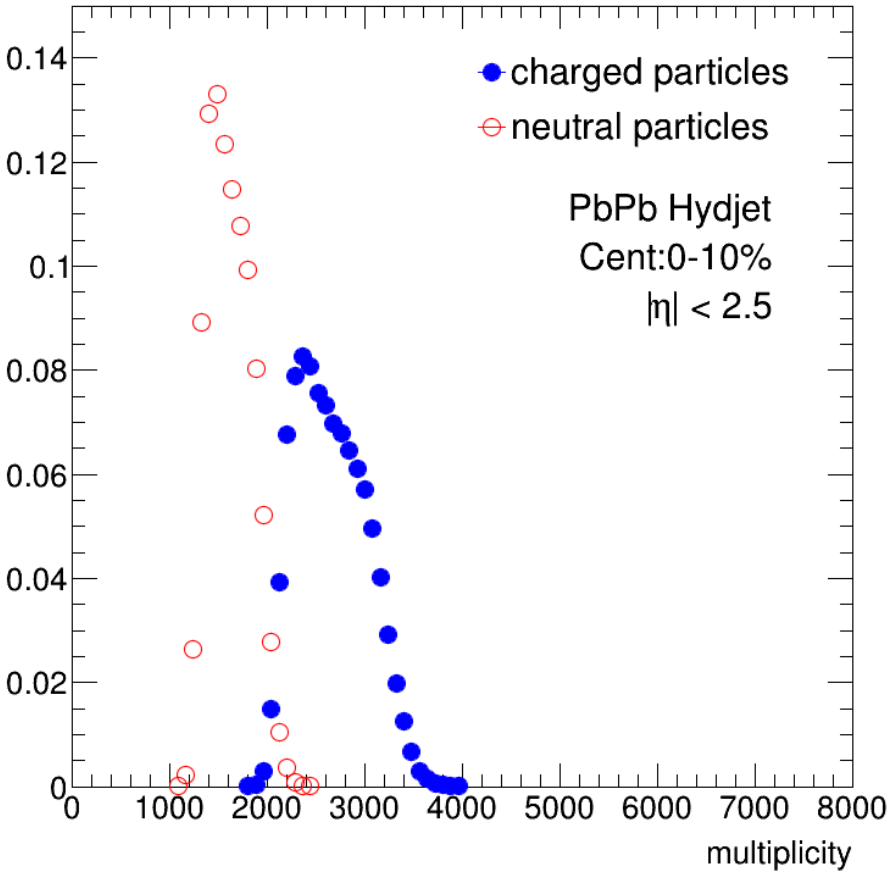


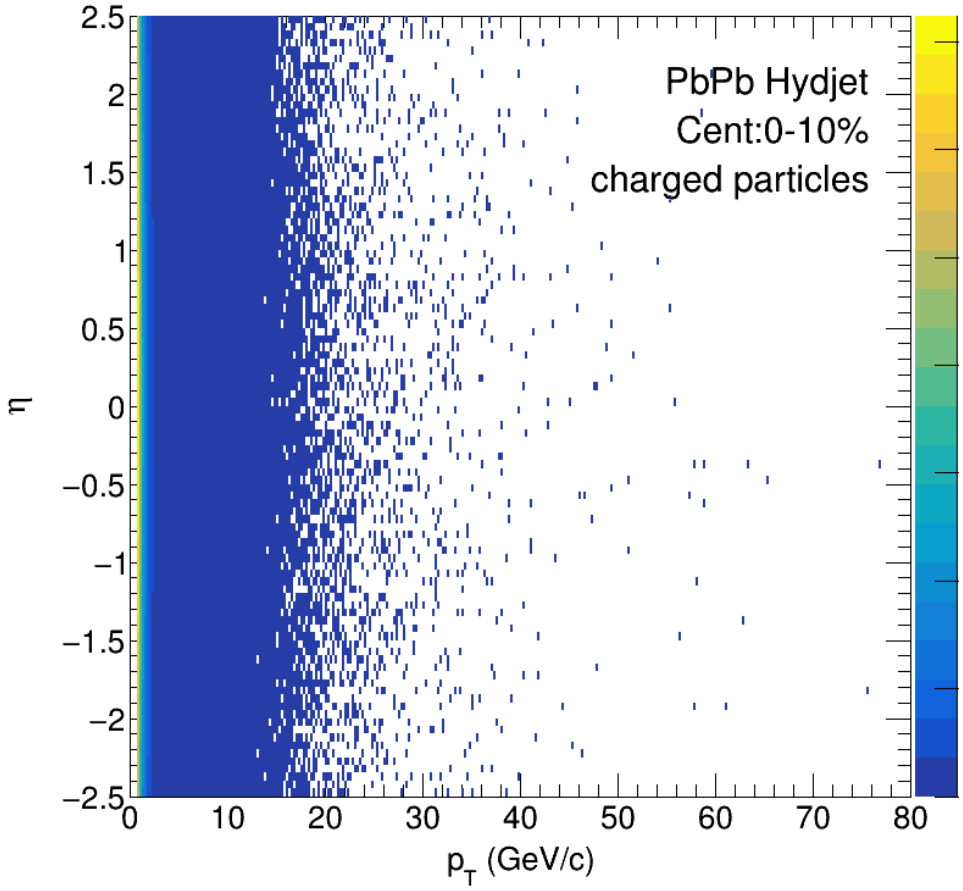
Substructure
in Heavy Ion Background

We ~know how to correct/subtract some things
e.g. energy, multiplicity
Generally --> scalar quantities – > along 1D, direction of change is known

What about vector quantities ?
e.g. direction in 2D plane
Might estimate the **magnitude** of the change
But what about **direction** ?

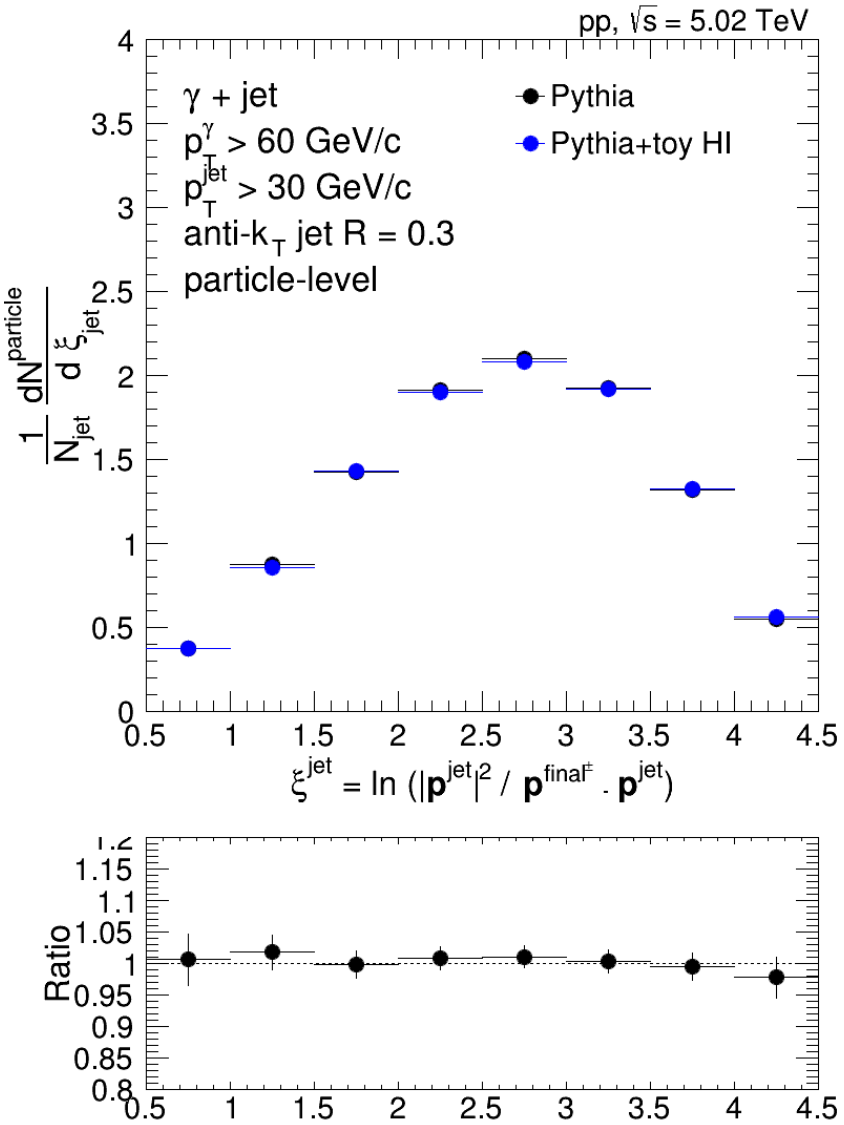
Creating a toy Underlying Event



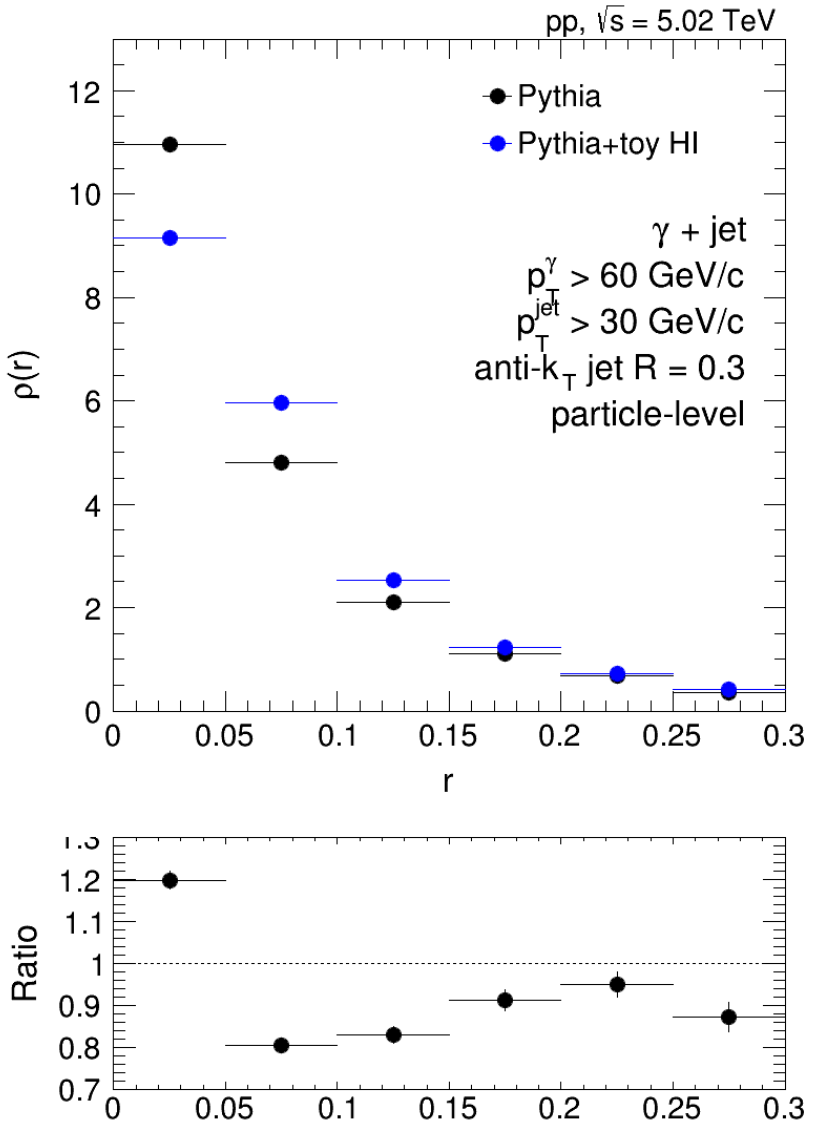


1. Sample toy particles from PbPb Hydjet
2. Shoot them into Pythia event
3. Cluster jets using all (Pythia+toy) particles
   Correct jet energy by subtracting energy of toy particles – > JES/JER factored out
4. Construct observables using Pythia particles only

FF and JS in toy UE

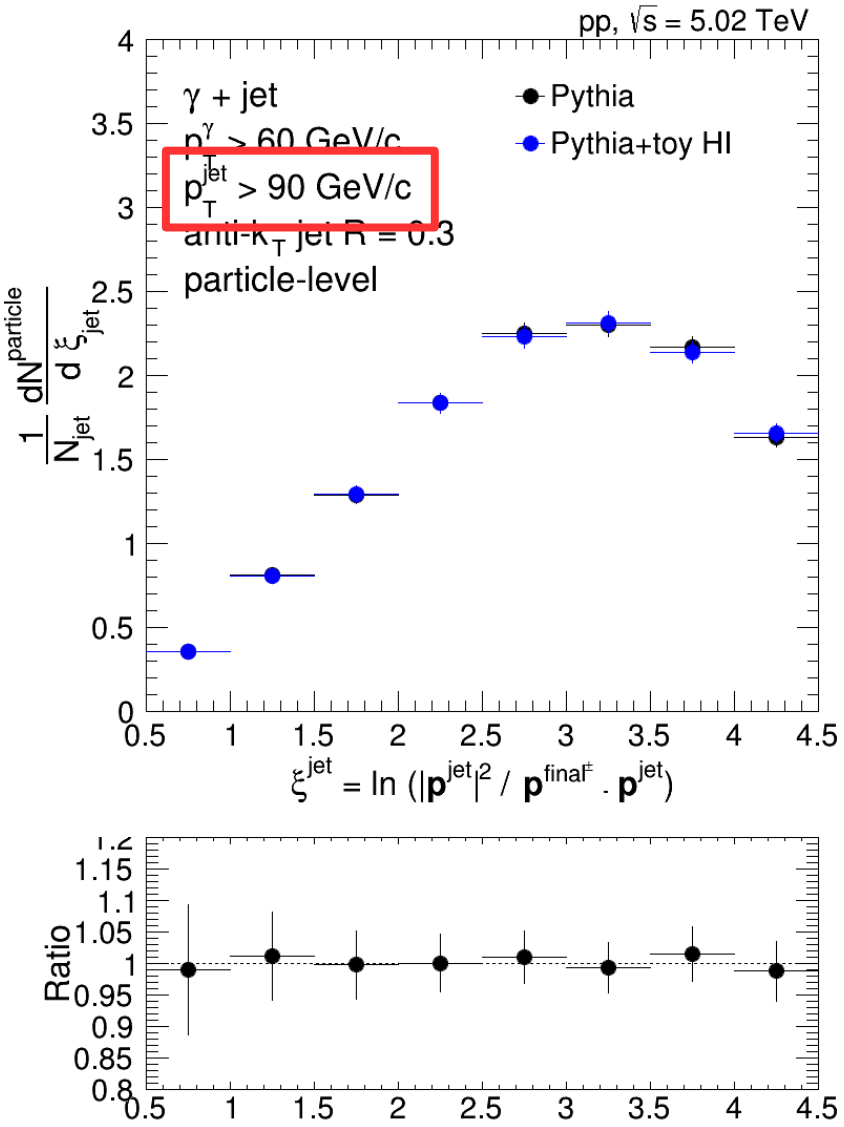


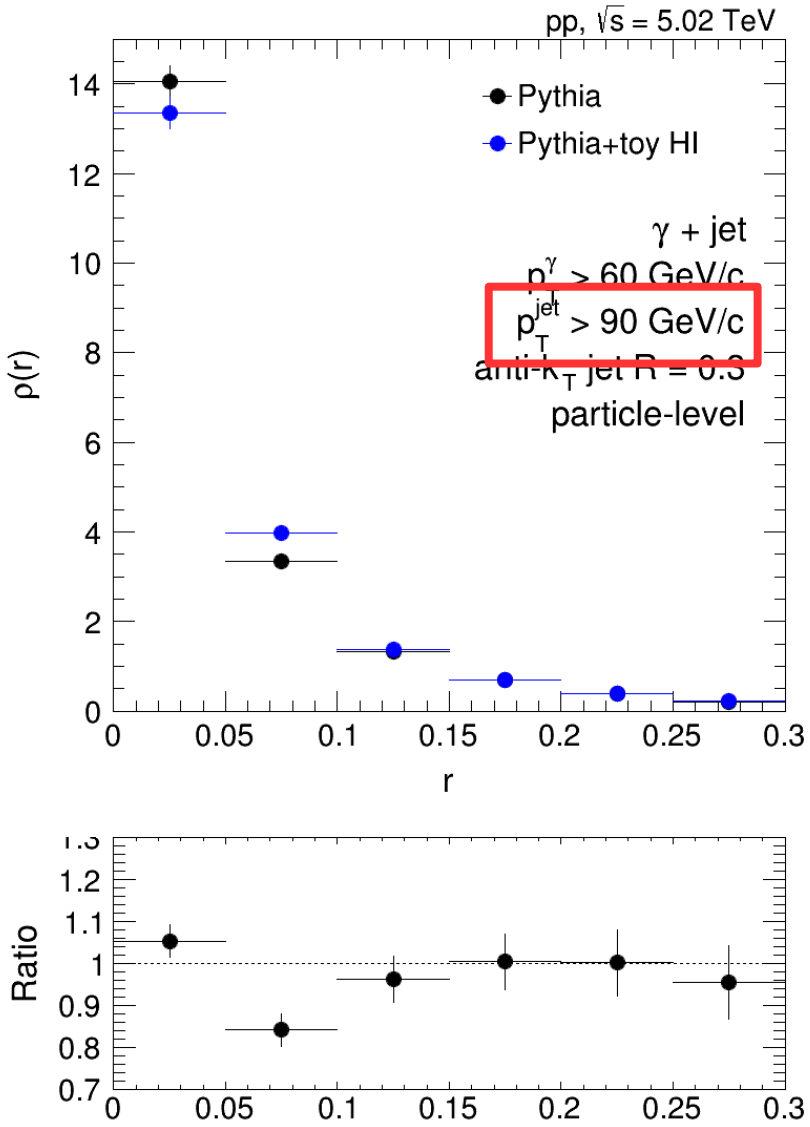
No significant change



~20% change at small r
== > Particles from UE **pull** the jet axis

FF and JS in toy UE – high p_T

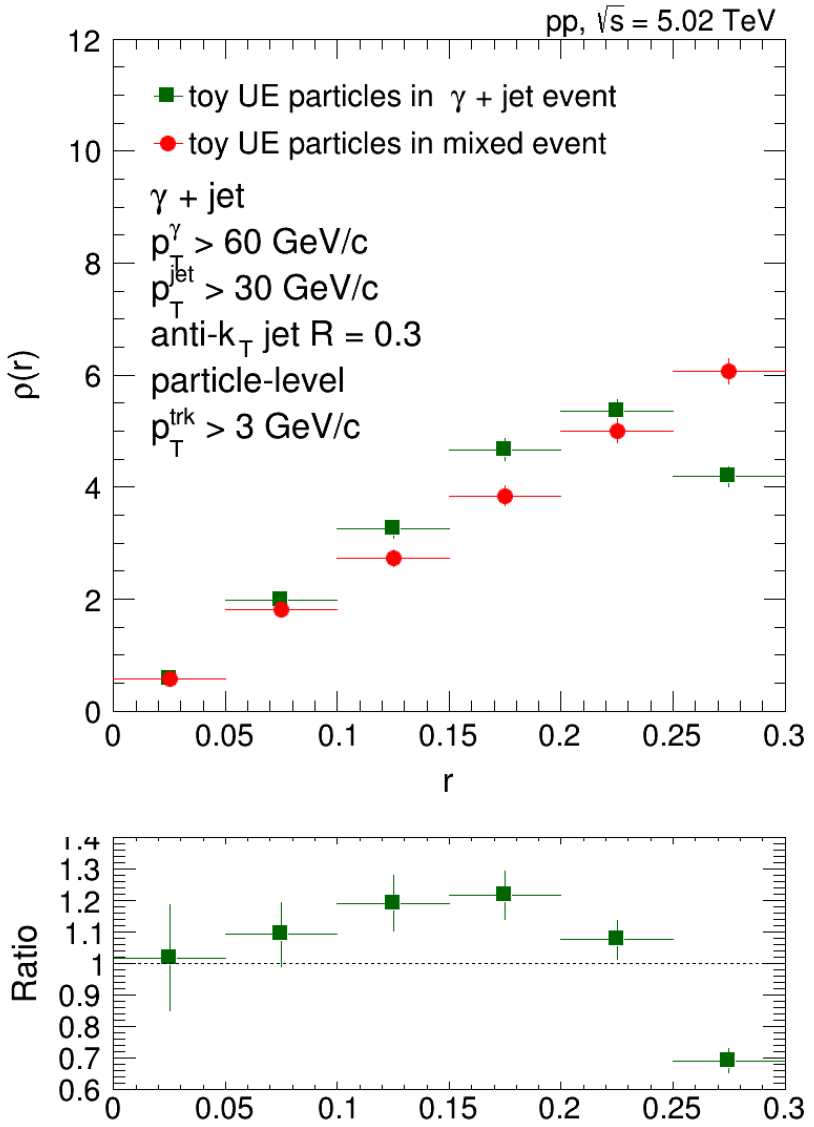




Effect reduced at higher jet p_T

Particles from UE and jet axis

- **High p_T particles from UE** pull the jet axis during clustering
- Different shape than with **particles from mixed event**
- What is distorted here is the jet axis, a vector
  - Direction of change ambiguous
- Correlated with the position of particles
  - Not reproduced by random smearing
- Need to redefine jet angle ?



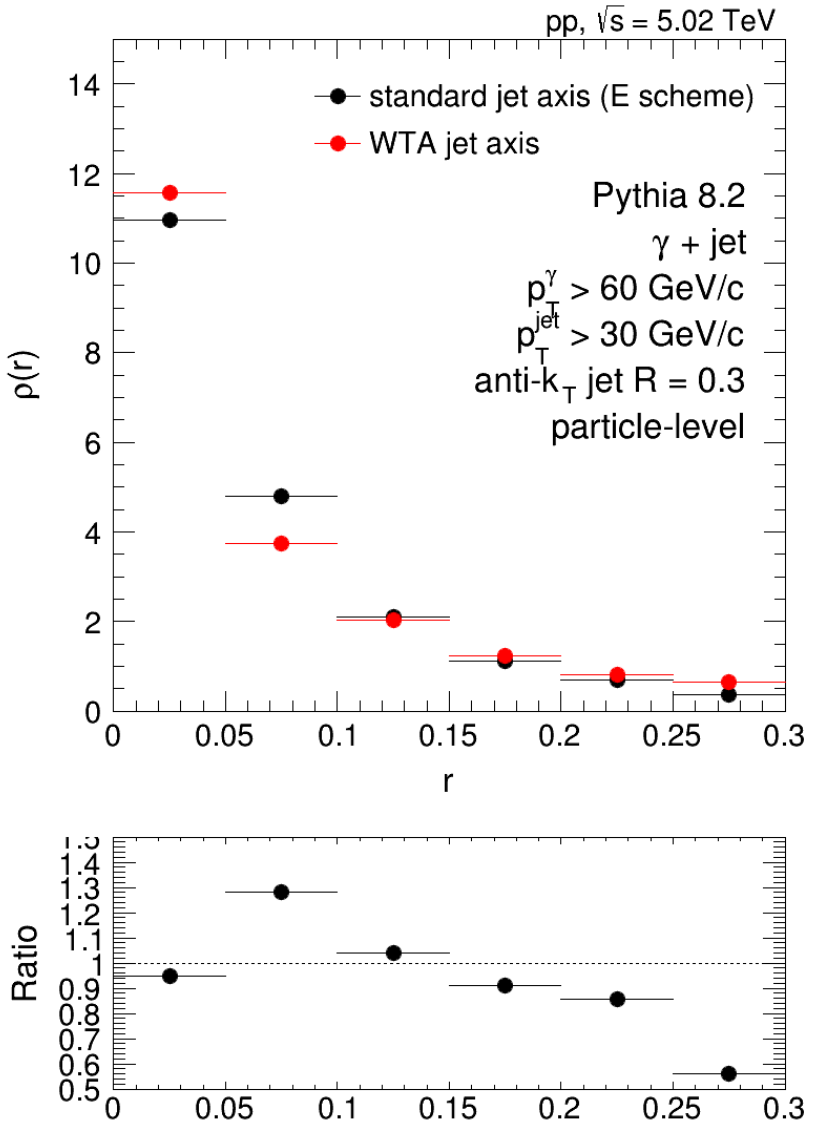
WTA recombination scheme - JS

- Standard jet axis determined via E-scheme
  - sum of 4-vec
- Winner-Take-All recombination scheme
  - In particular WTA-pt-scheme
  - Recombination p_r of p_i and p_j where

$$
\begin{aligned}
p_{t,r} &= p_{t,i} + p_{t,j} \,, \\
\phi_r &= (w_i\phi_i + w_j\phi_j)/(w_i + w_j) \,, \\
y_r &= (w_i y_i + w_j y_j)/(w_i + w_j) \,, \\
w_i &= p_t^n \qquad n \to \infty
\end{aligned}
$$

Ref. FastJet v3.2.2 Doc

== >
The new axis coincides with that of the harder component



Sharper JS with WTA

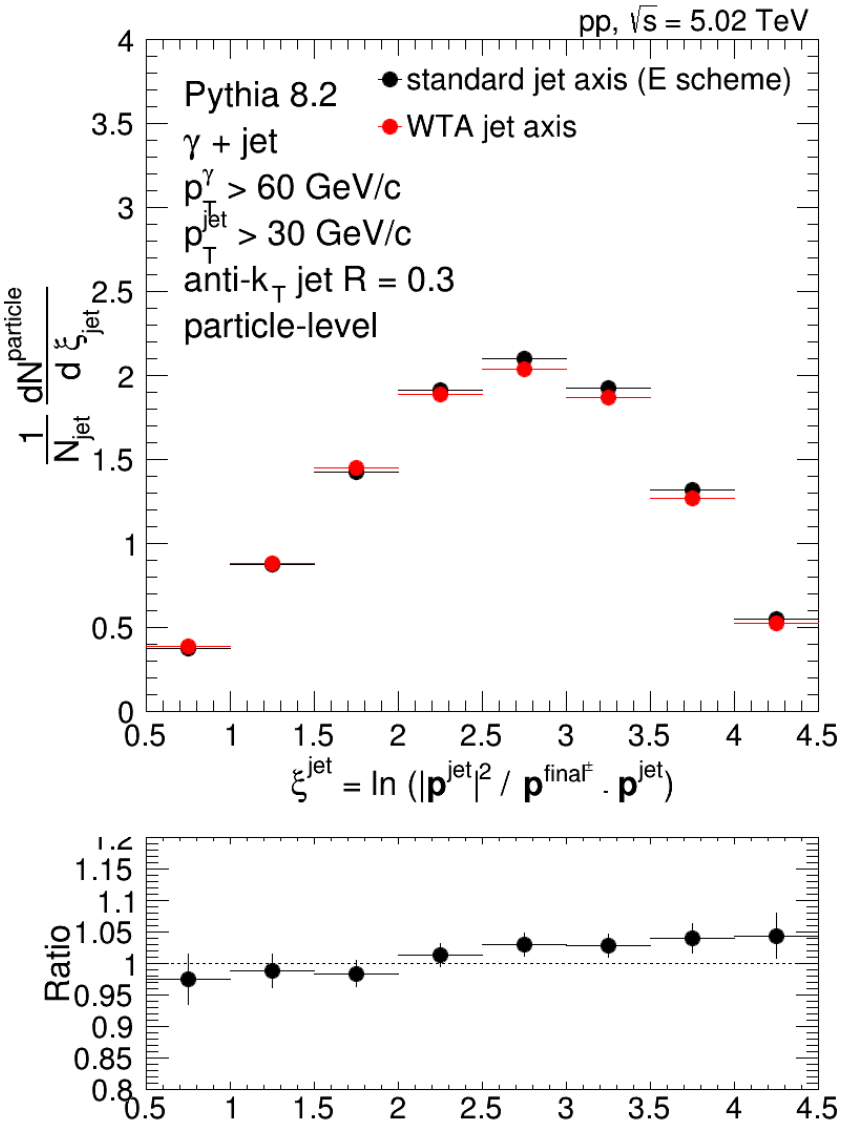
WTA recombination scheme - FF

- Standard jet axis determined via E-scheme
  - sum of 4-vec
- Winner-Take-All recombination scheme
  - In particular WTA-pt-scheme
  - Recombination p_r of p_i and p_j where

$$
\begin{aligned}
p_{t,r} &= p_{t,i} + p_{t,j} \,, \\
\phi_r &= (w_i\phi_i + w_j\phi_j)/(w_i + w_j) \,, \\
y_r &= (w_i y_i + w_j y_j)/(w_i + w_j) \,, \\
w_i &= p_t^n \qquad n \to \infty
\end{aligned}
$$

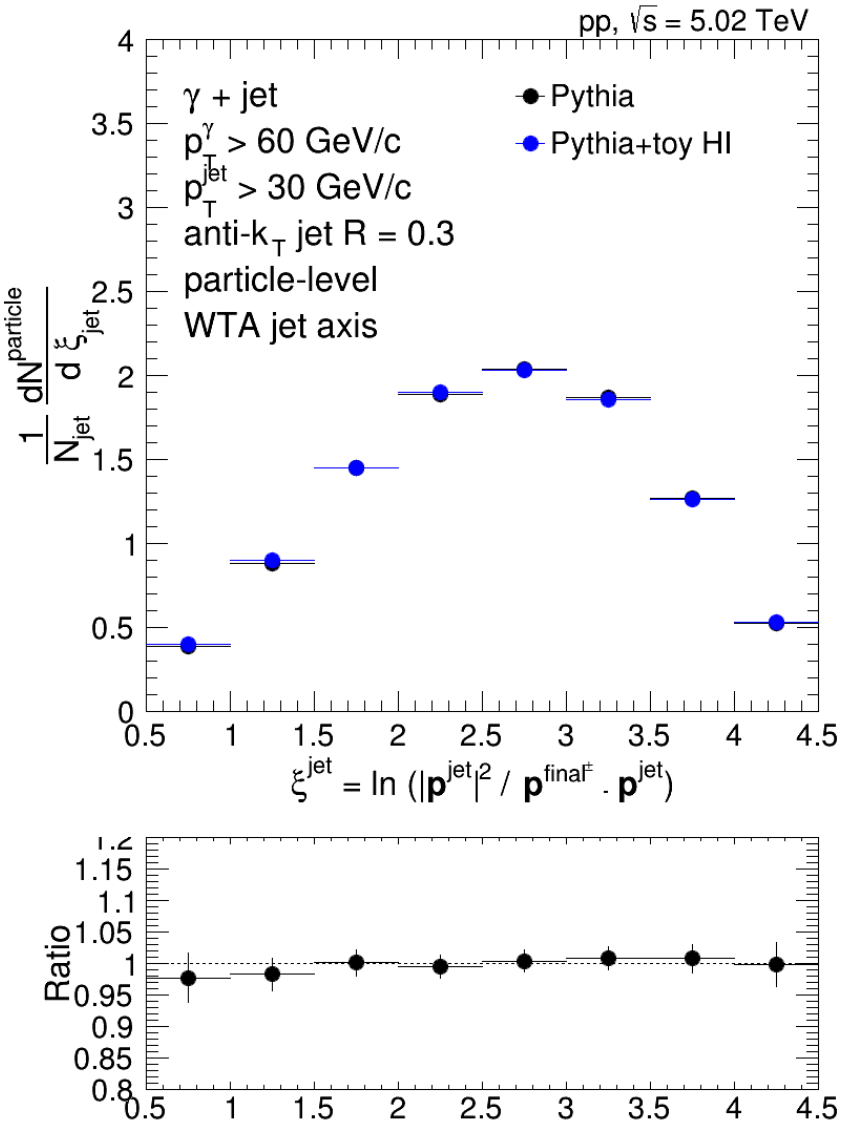
Ref. FastJet v3.2.2 Doc

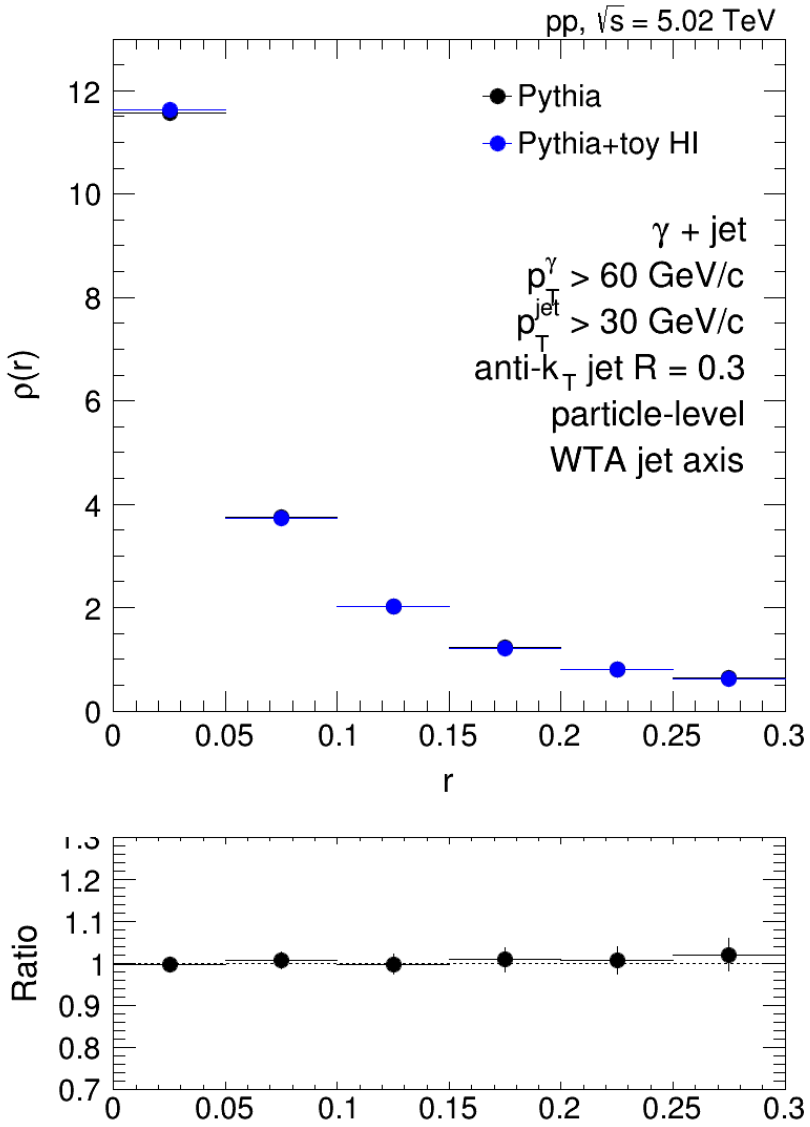
== >
The new axis coincides with that of the harder component



Soft particles slightly removed

FF and JS in toy UE – use WTA scheme

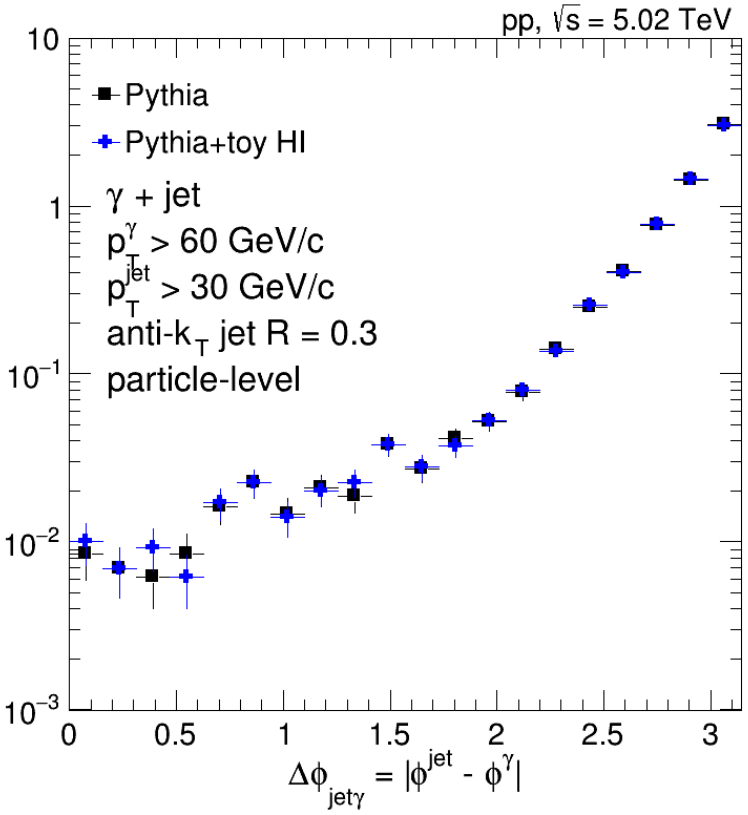




JS much more robust with WTA

Angular correlation in toy UE - LHC

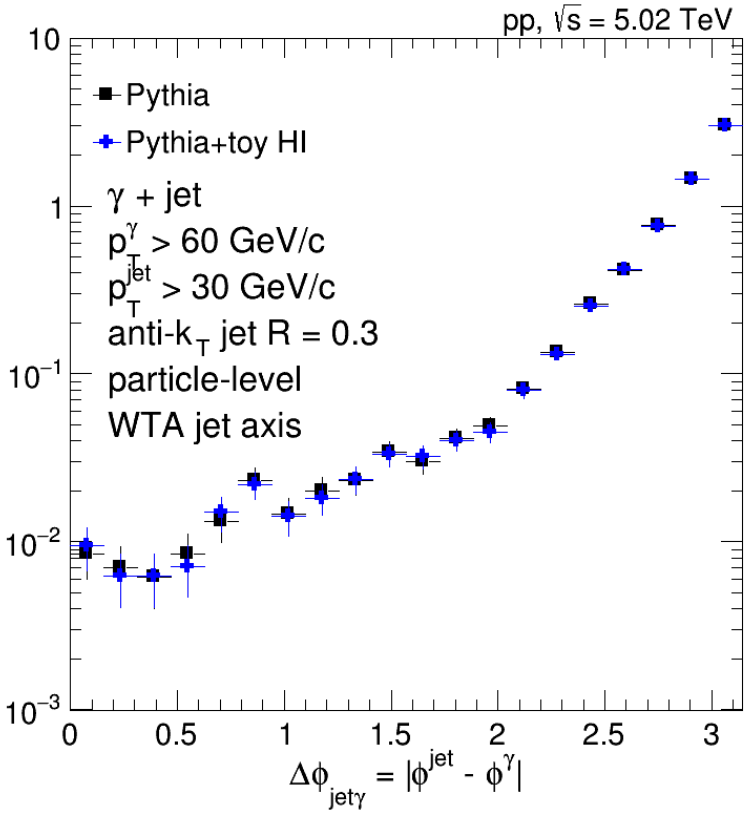
Standard jet axis (E scheme)



LHC

~2% deviation

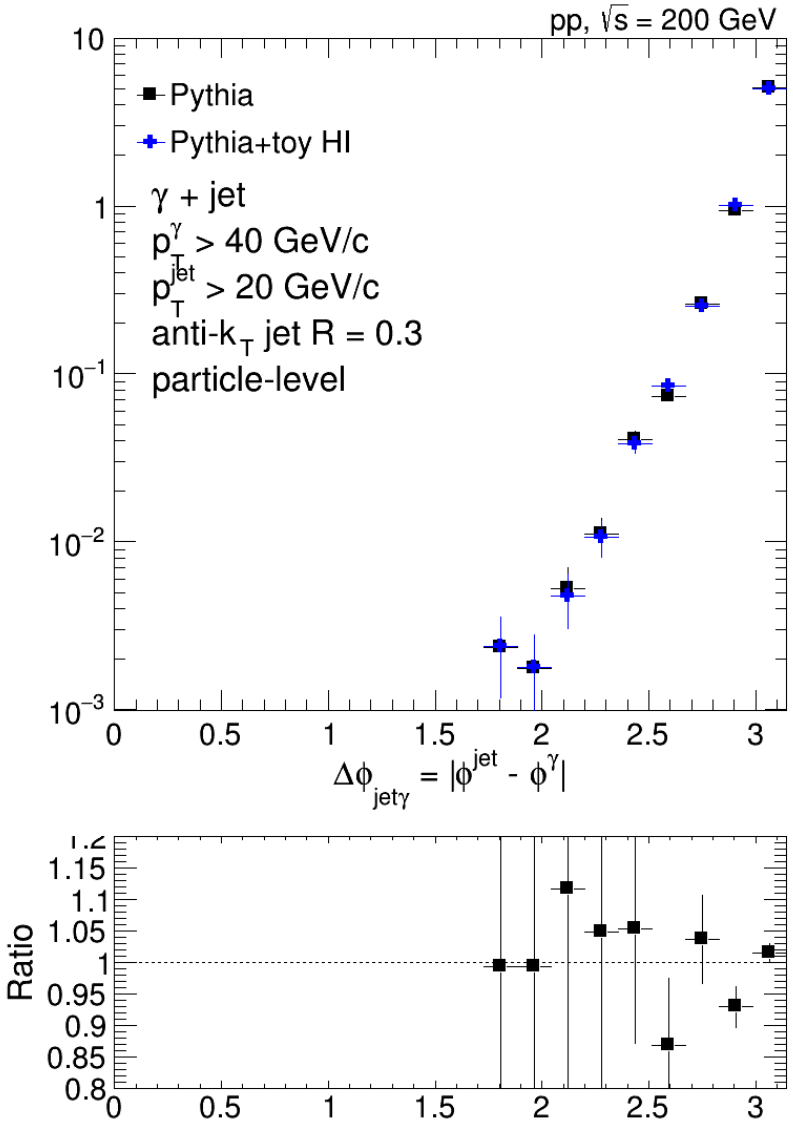
WTA jet axis



Slightly less distorted if WTA used

Angular correlation in toy UE - RHIC

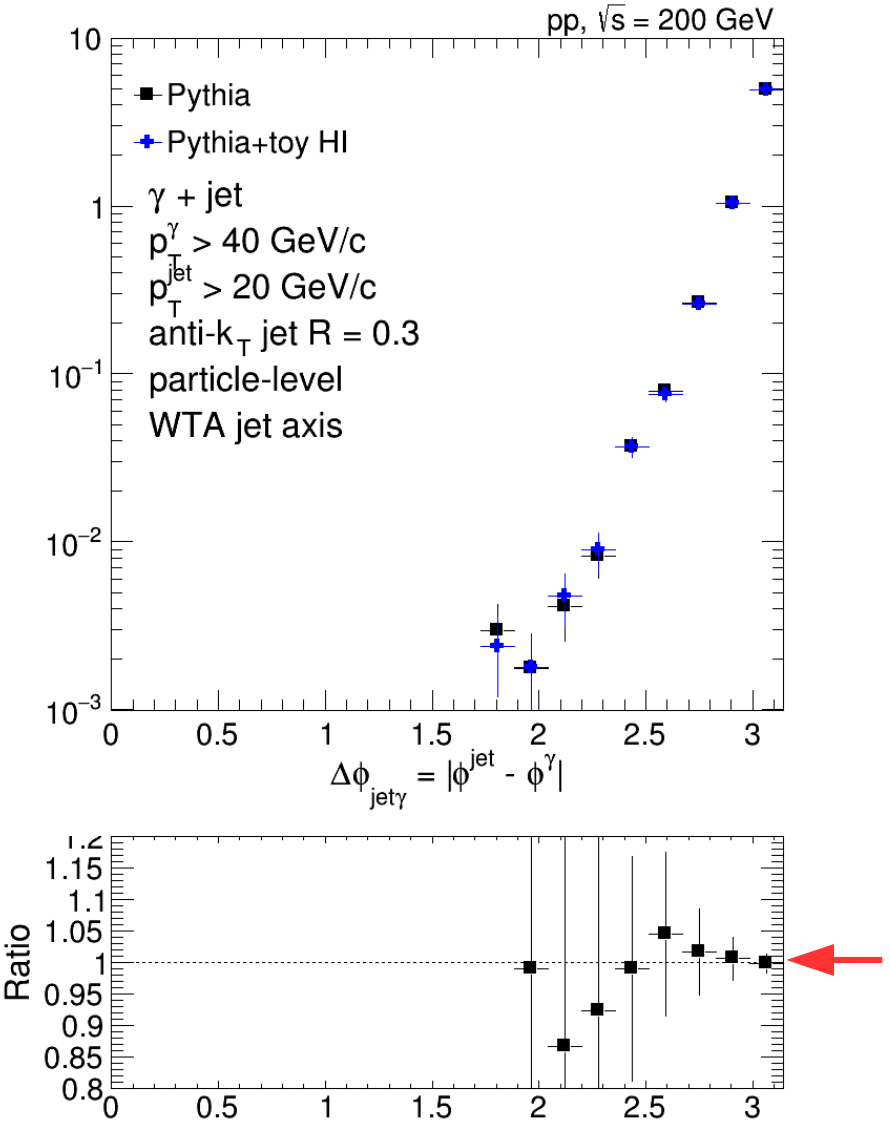
Standard jet axis (E scheme)



RHIC

~5% deviation

WTA jet axis



Sharper angular correlation at RHIC – > more sensitive to resolution

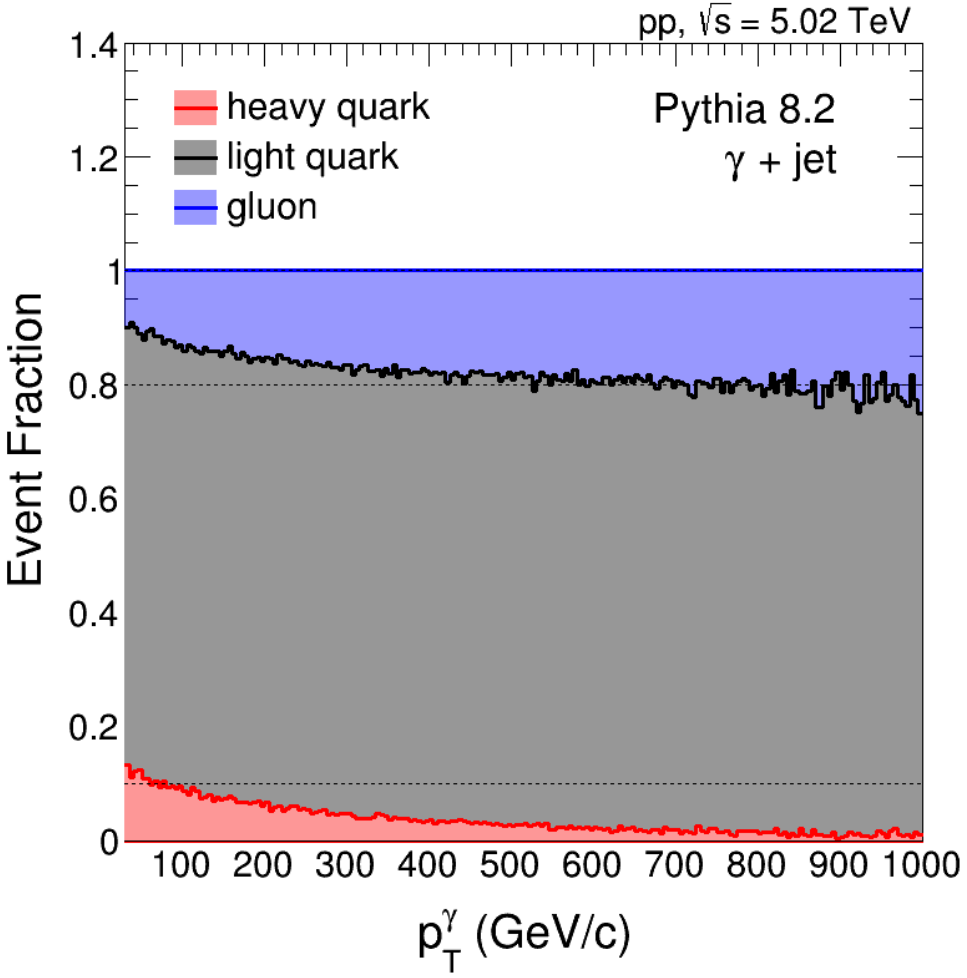
Summary

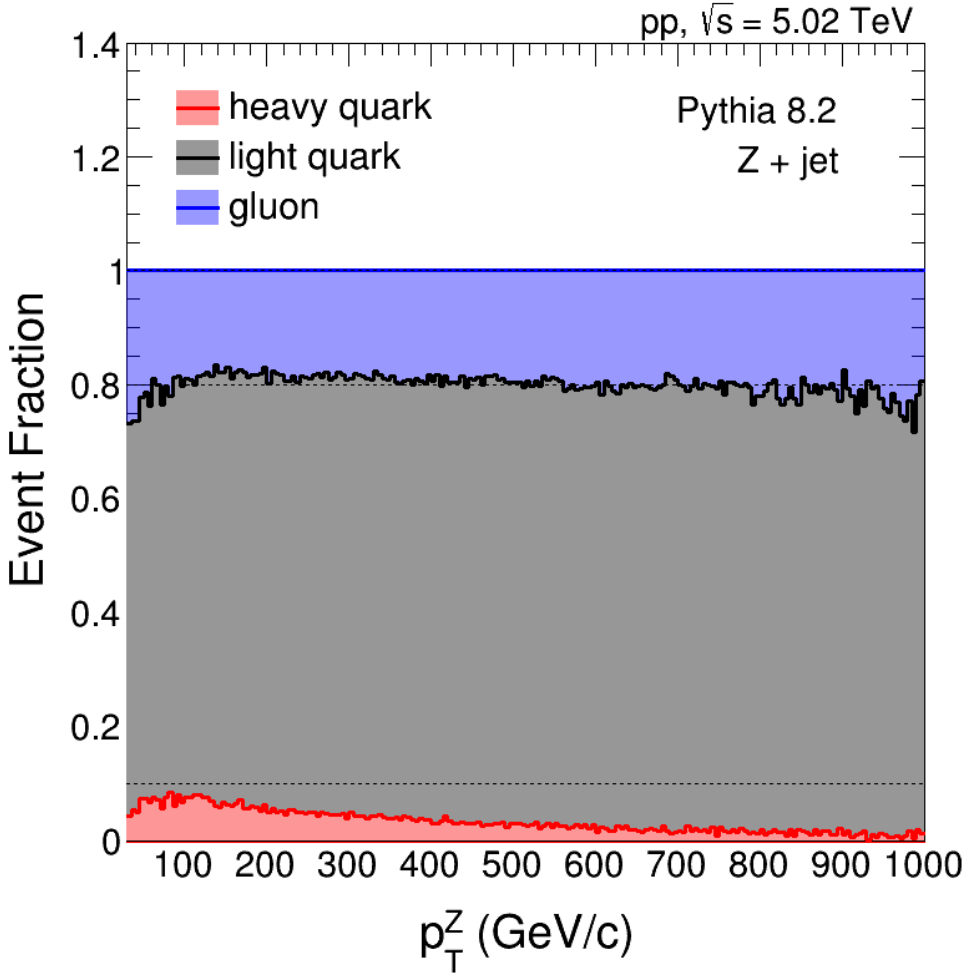
- **Photon+jet production mechanism**
  - Evolution of Q/G fractions can be understood via PDF
- **Processes in the evolution of hard scatterers**
  - Smear initial correlations, set the shape of bulk observables
  - ISR – > large effect for angular correlation, smaller at RHIC than at LHC
- Comparison of FF and JS observables
- **Background effects**
  - Harder to undo if **direction** is not known and things happen in a correlated way
  - Studied effects using gen-level Pythia and toy PbPb
  - UE particles pull jet axis.
  - One way to overcome – > change axis definition to WTA.
    - Reduces resolution effects for JS
    - Can be useful also for angular correlation

Acknowledgements : The MIT group's work was supported by US DOE-NP.

BACKUP

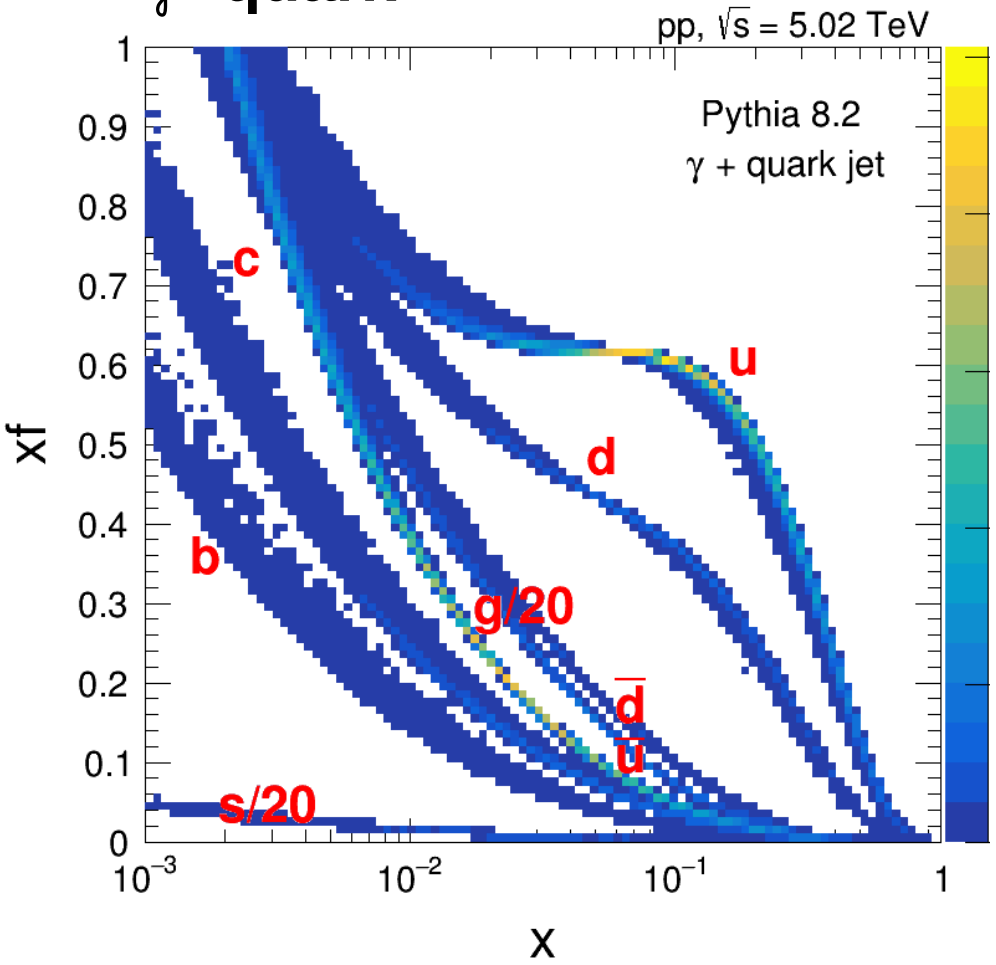
q/g fraction – γ+jet vs Z+jet





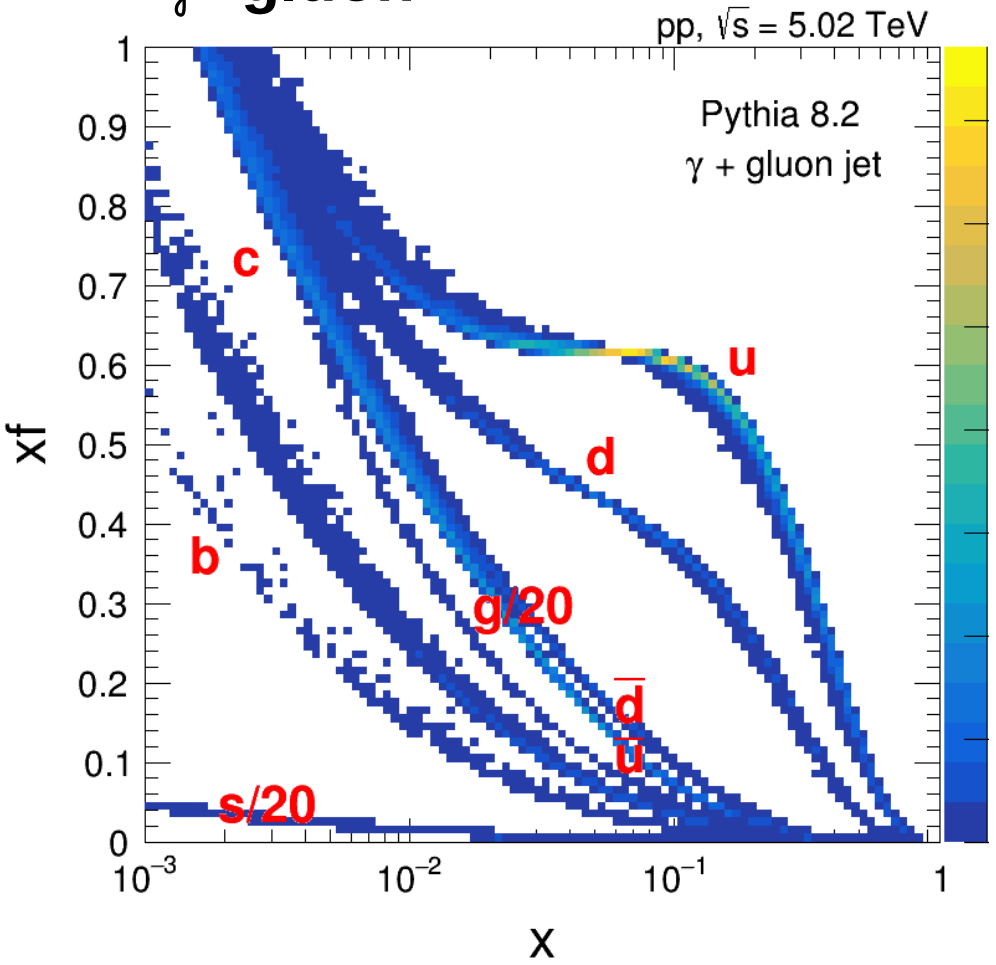
Mapping γ+jet to PDF – split q vs g

γ+quark



dominantly via QCD Compton scattering

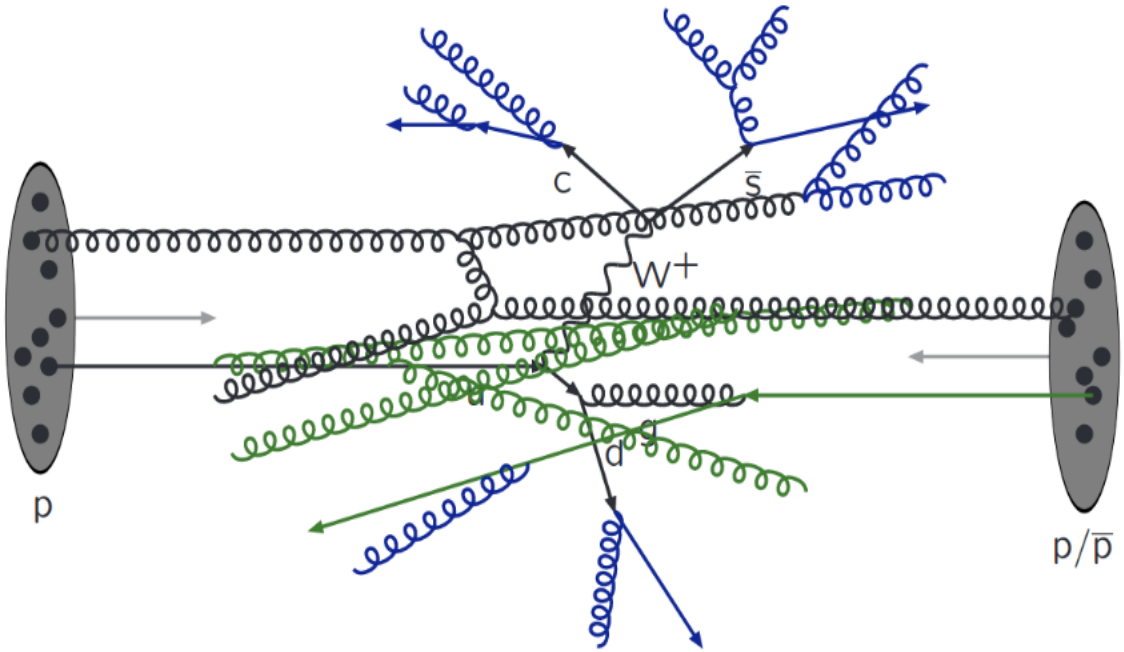
γ+gluon



dominantly via qqbar annihilation

Hard scattering evolution

CTEQ/MCnet School, Talk by T. Sjöstrand



A lot of things happen already in pp

MPI

Initial-state radiation (ISR)

Final-state radiation (FSR)

...

and

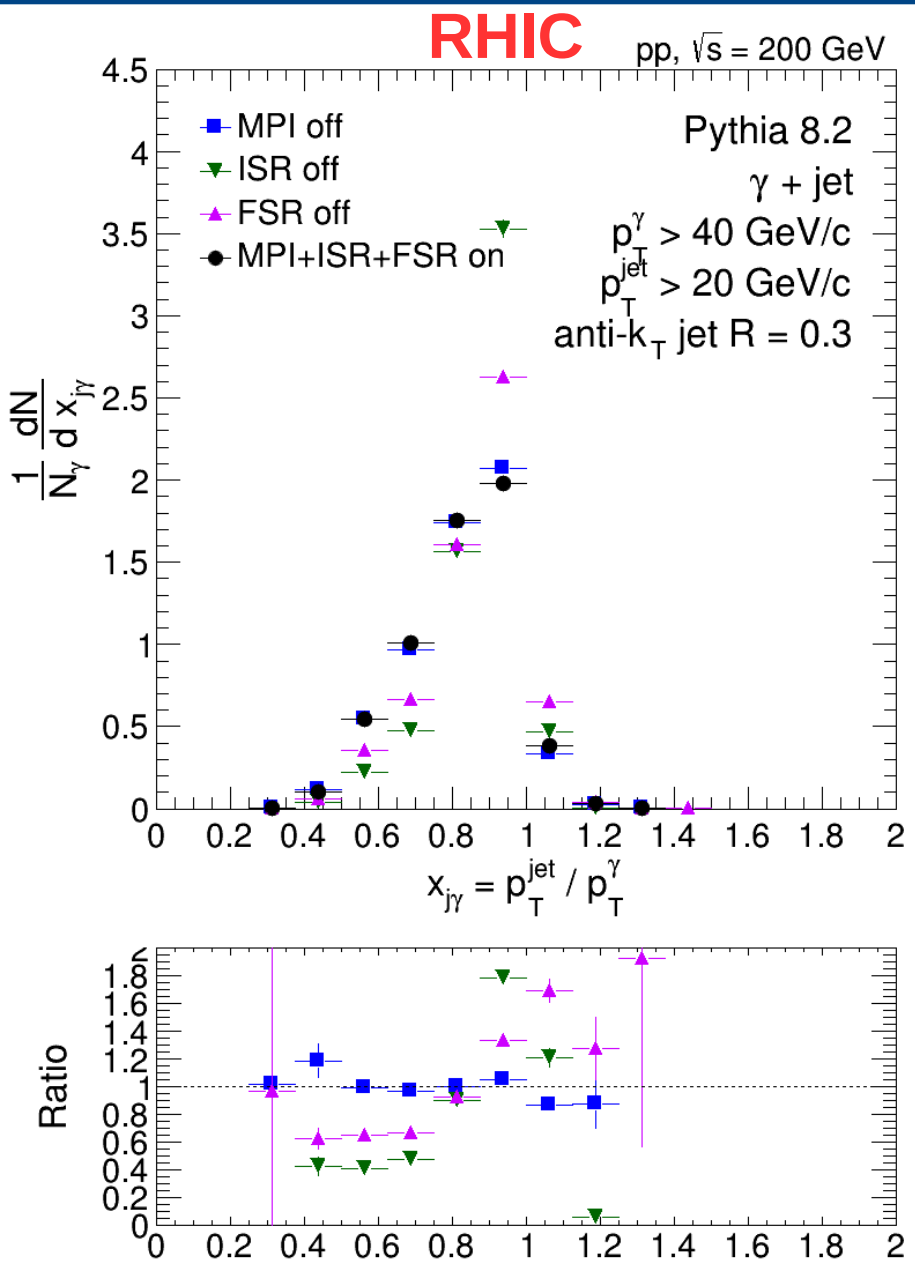
Beam Remnants (BR)

Shape of momentum imbalance - RHIC

Processes in the evolution of hard scattering
- **Multiparton interactions (MPI)**
- **Initial-state radiation (ISR)**
- **Final-state radiation (FSR)**

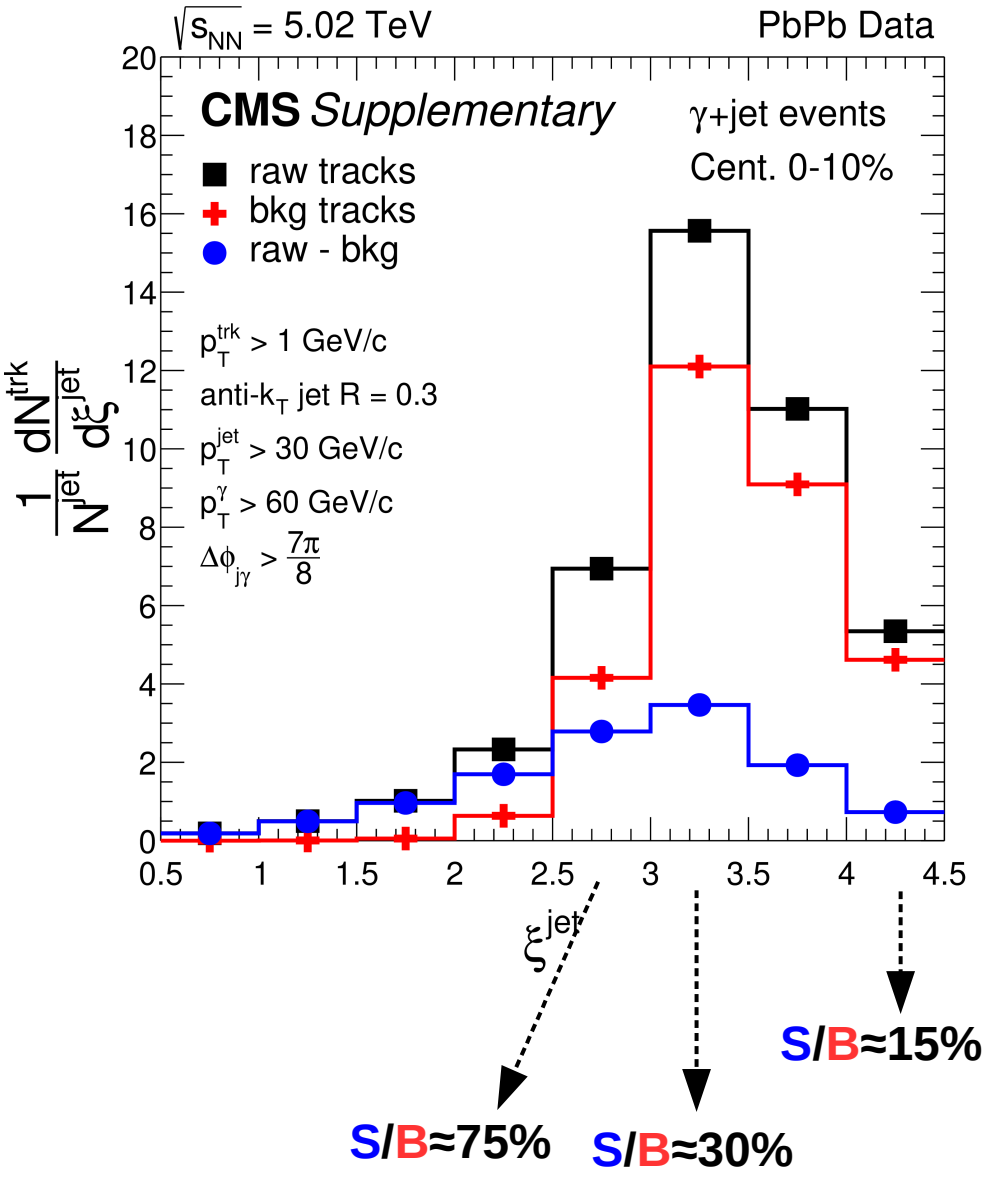
Turn off these processes one by one.
Their absence reveals the impact on the observable.

Left (Right) tail from **FSR** (**ISR**)

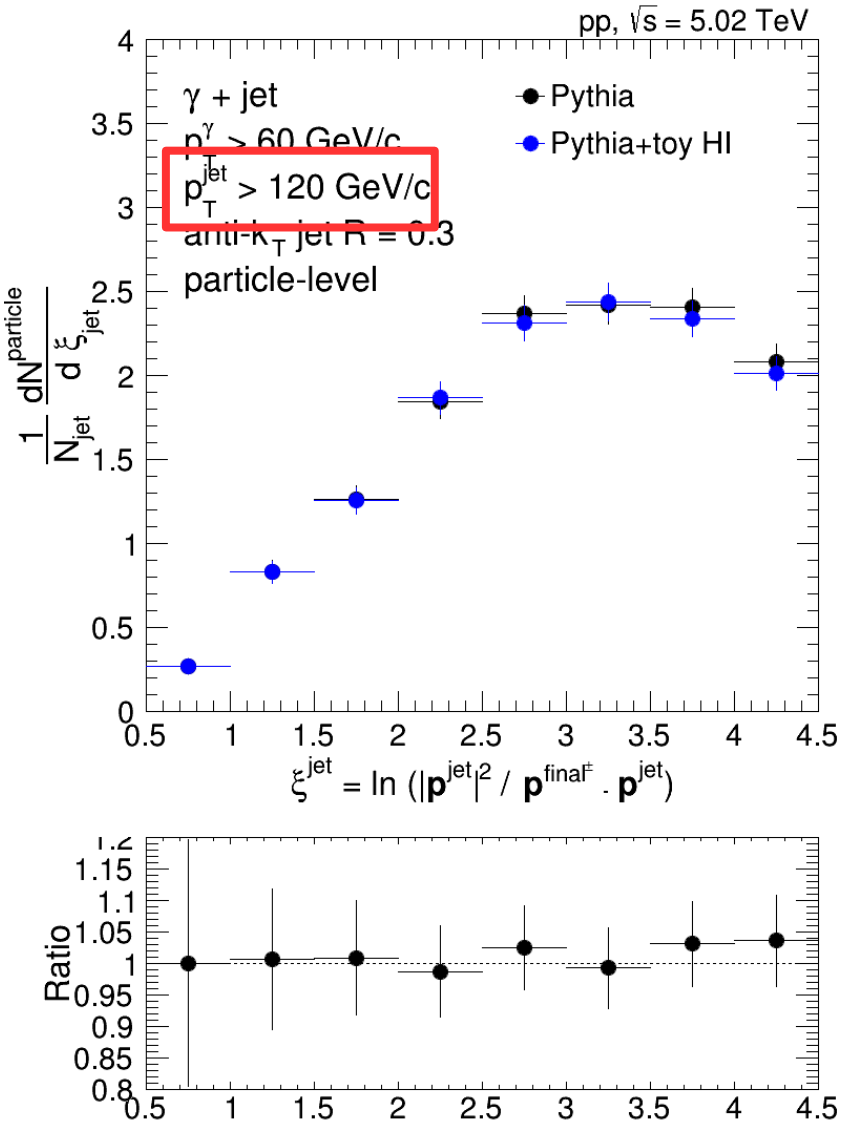


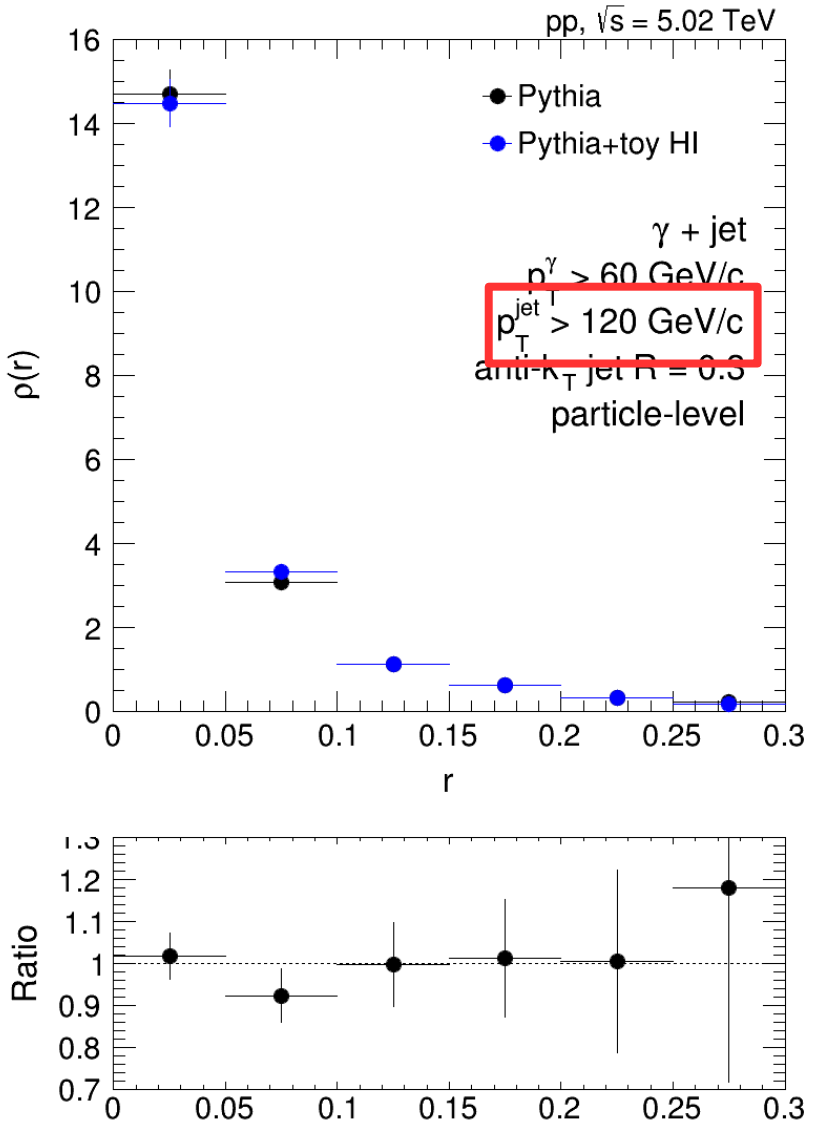
Size of background

PRL 121, 242301 (2018)



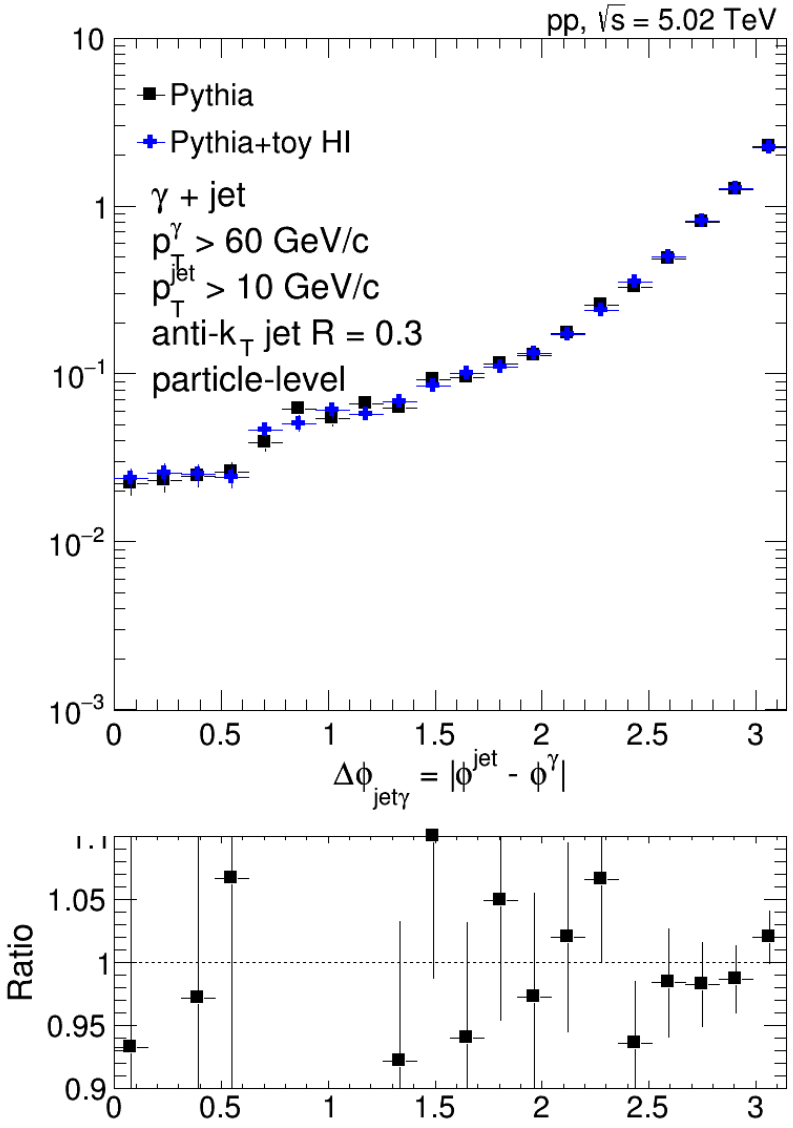
FF and JS in toy UE – high p_T





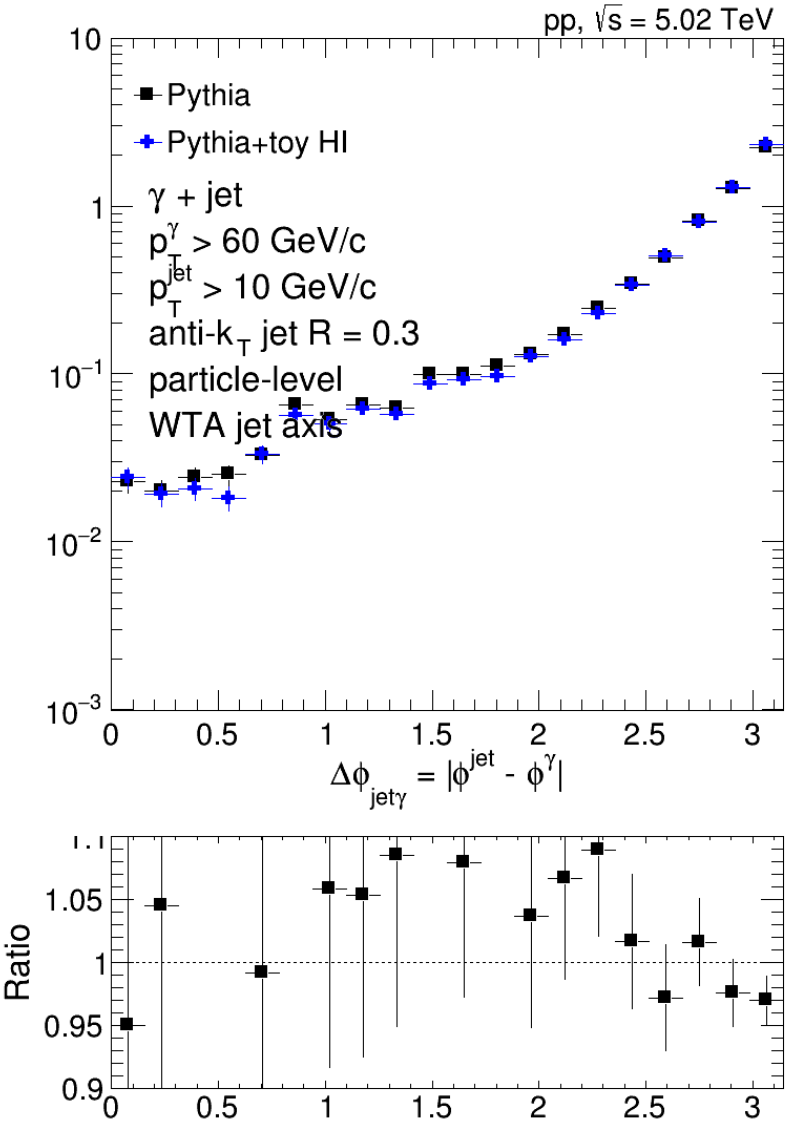
Angular correlation in toy UE – LHC – low p_T

Standard jet axis (E scheme)

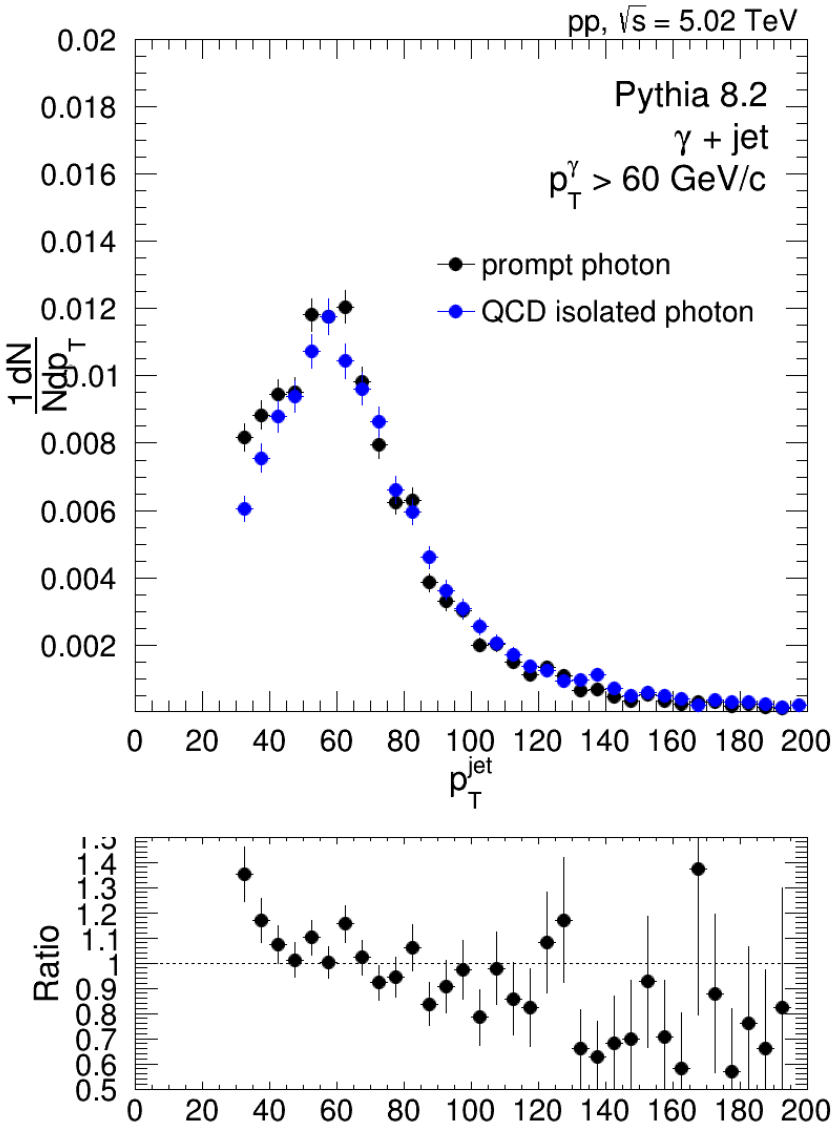


LHC

WTA jet axis

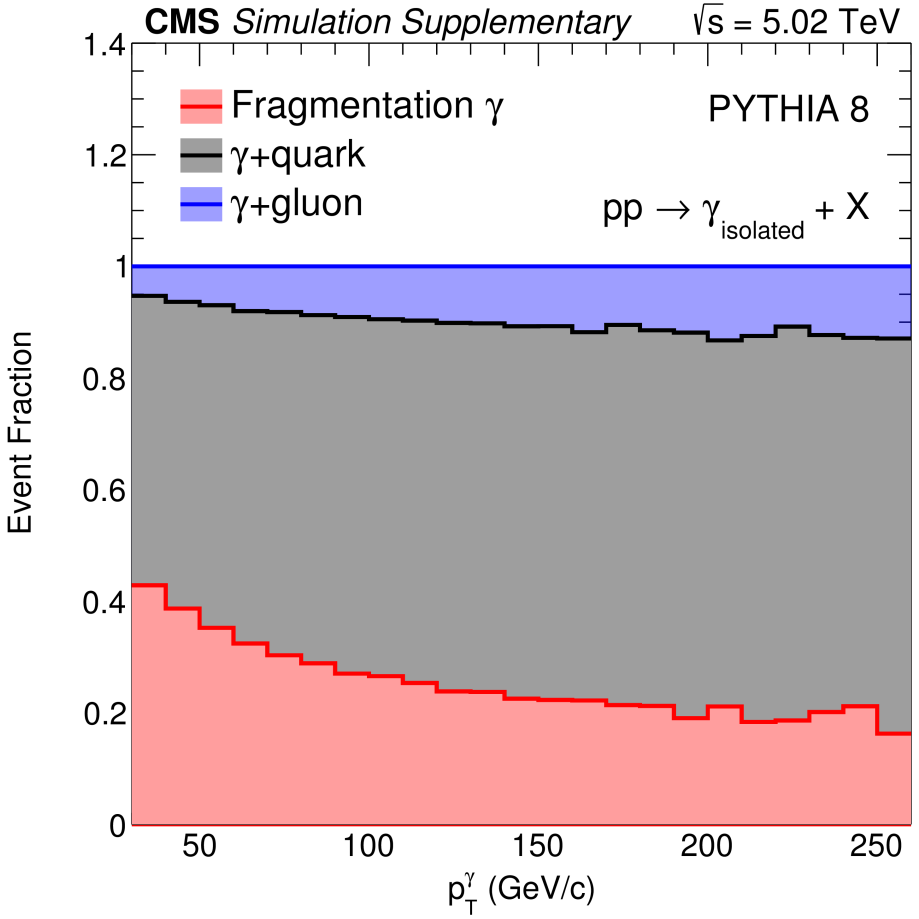


Prompt vs isolated γ+jet

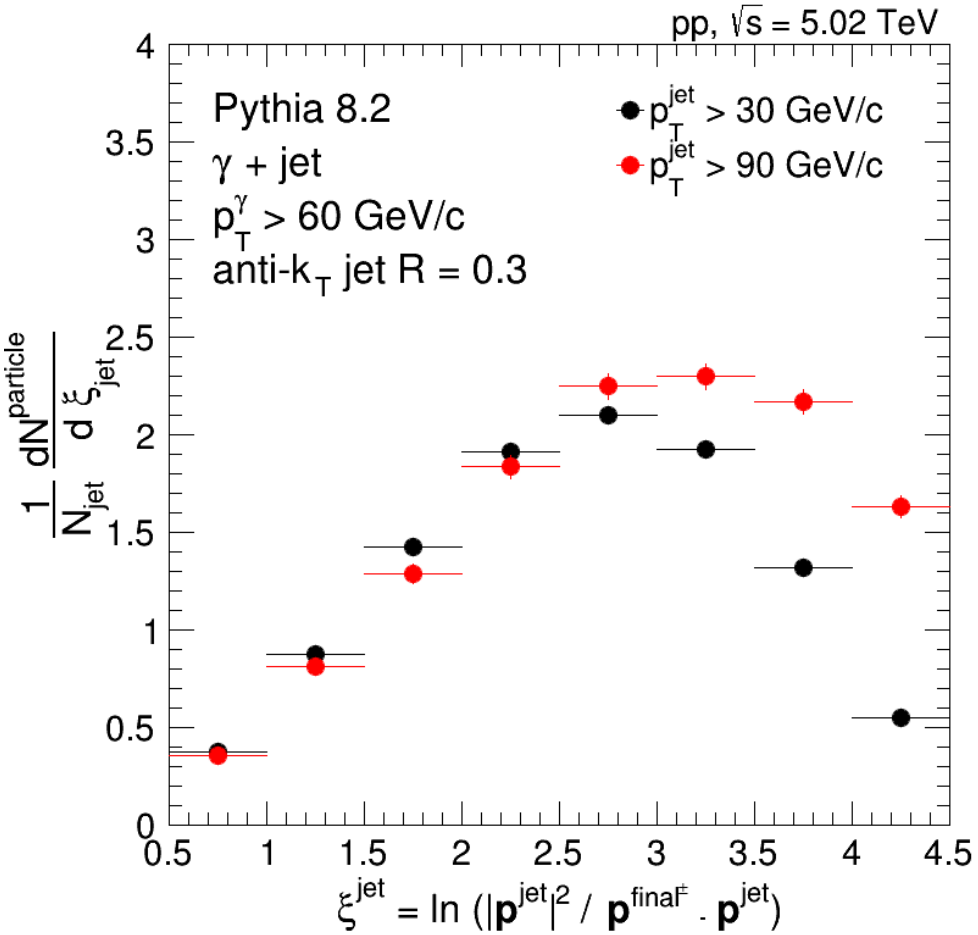


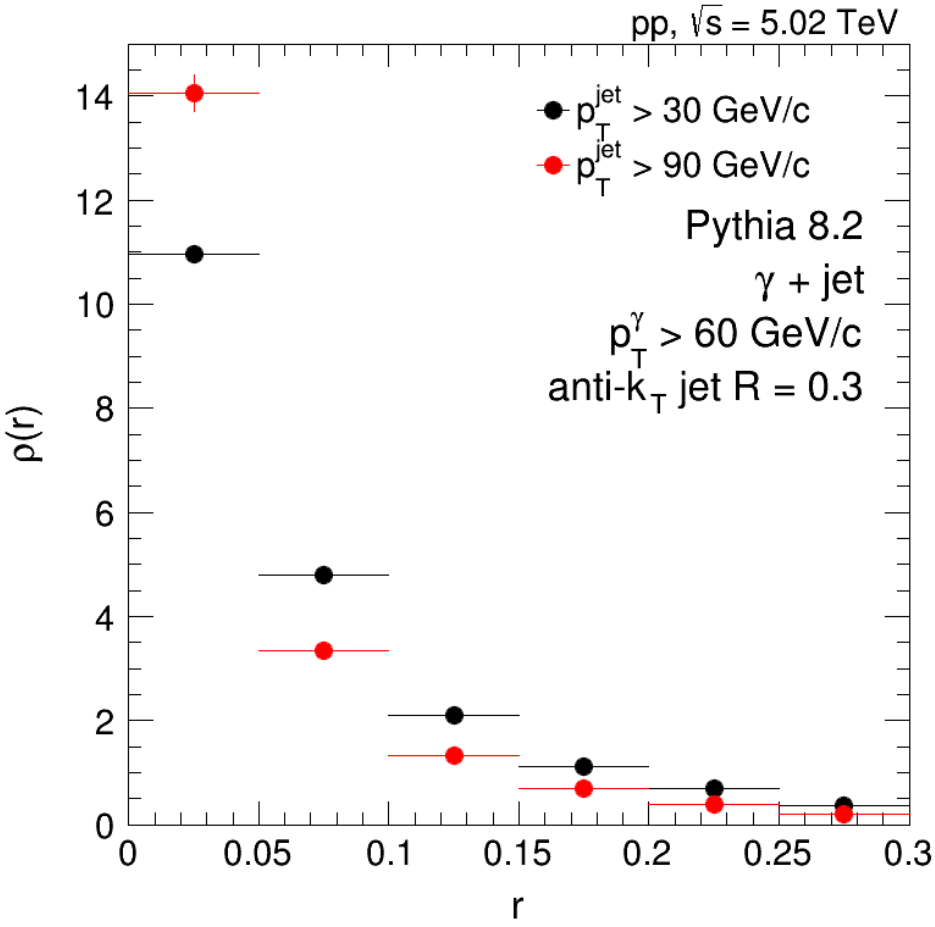
q/g fraction – isolated γ+jet

PRL 121, 242301 (2018)



High and low p_T





MPI, ISR, FSR effects