Jet quenching measurements with electroweak boson topologies

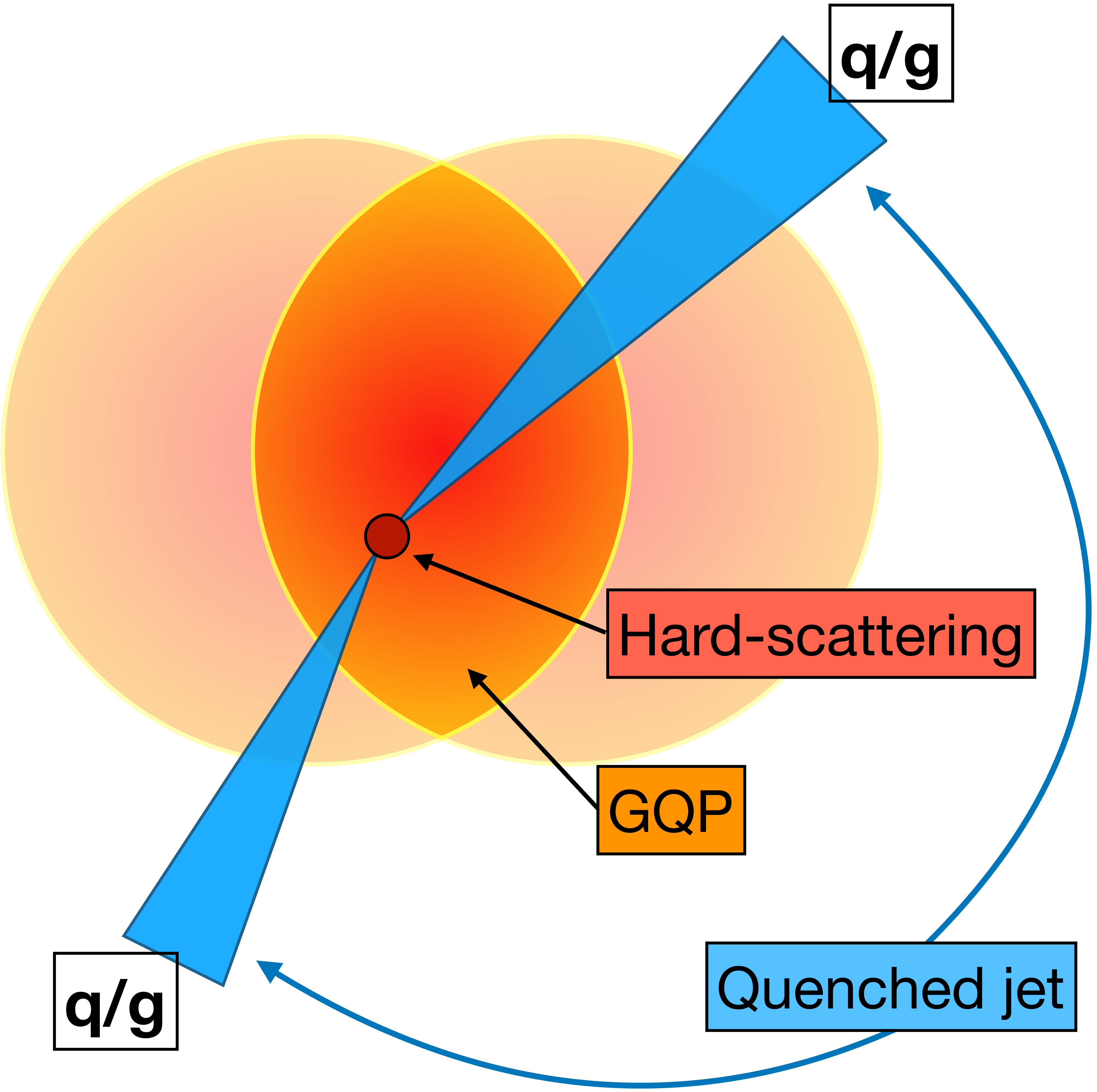
Sebastian Tapia Araya
Iowa State University

Jet Quenching In The Quark-Gluon-Plasma

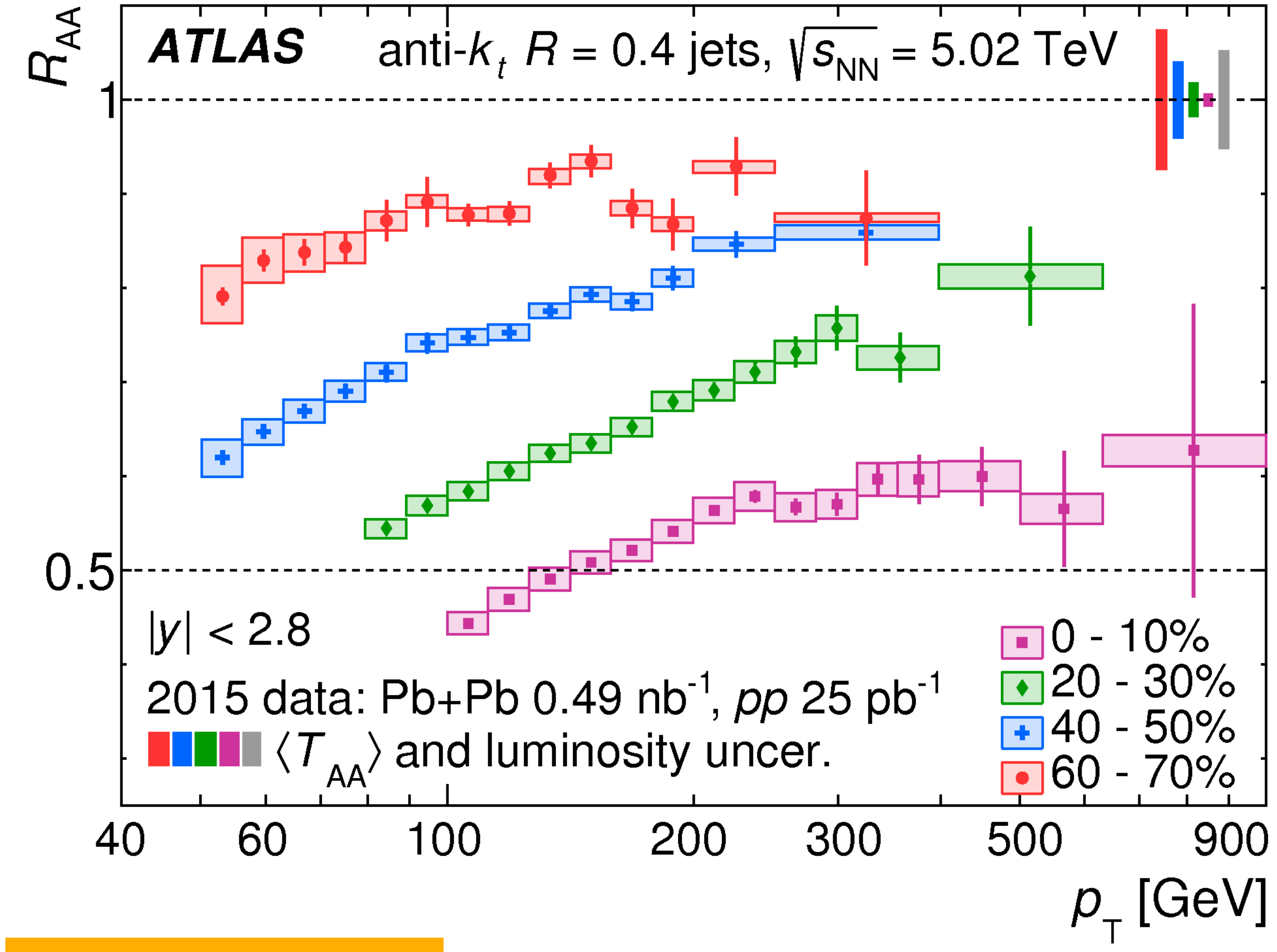
15 Jun 2022

Motivation

Jets are known to lose energy when going through the Quark-Gluon-Plasma



Inclusive jets R_{AA}

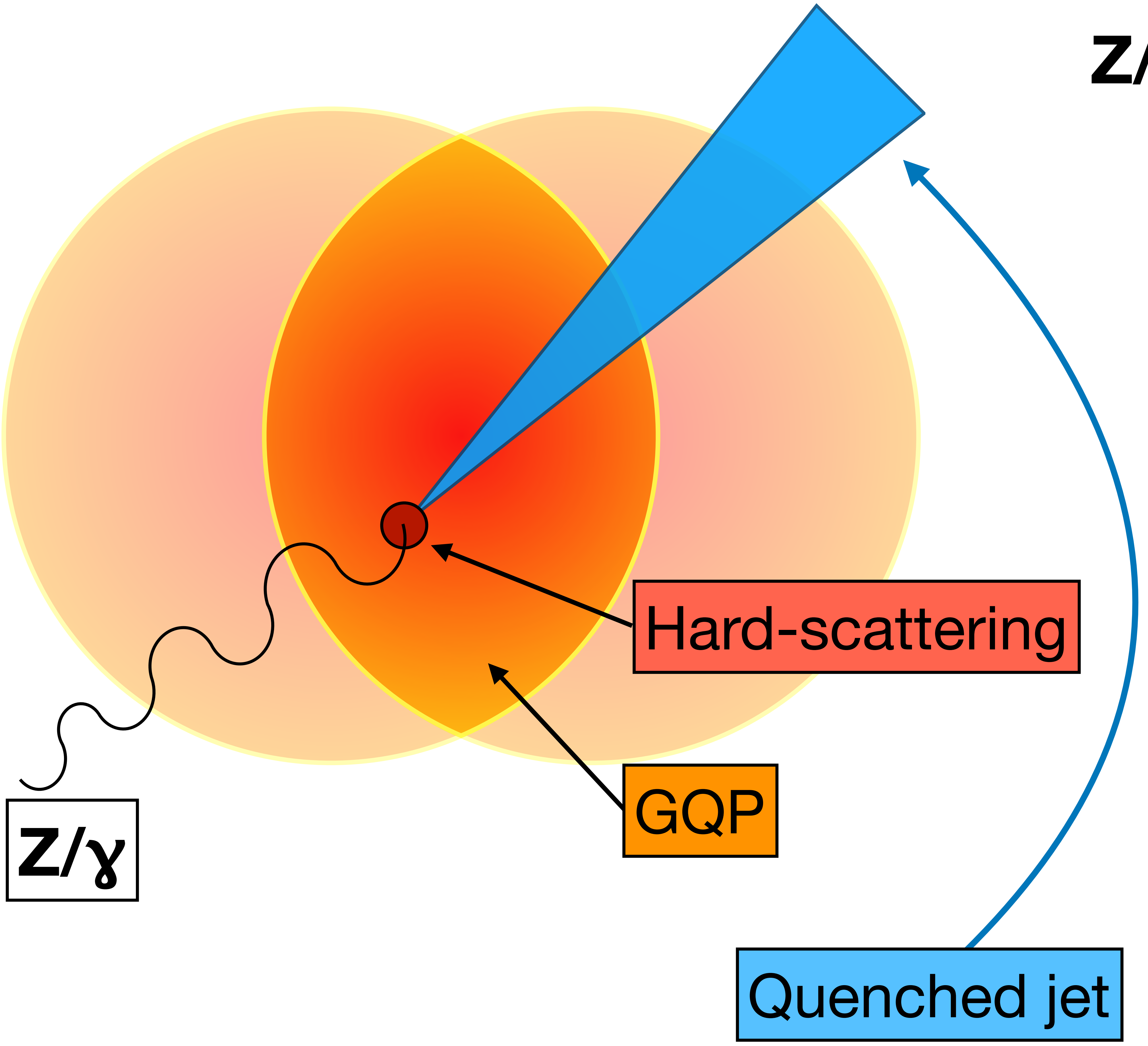


Phys. Lett. B 790 (2019) 108

Motivation

Jets are known to lose energy when going through the Quark-Gluon-Plasma

What can we do to improve our understanding of energy loss in QGP?

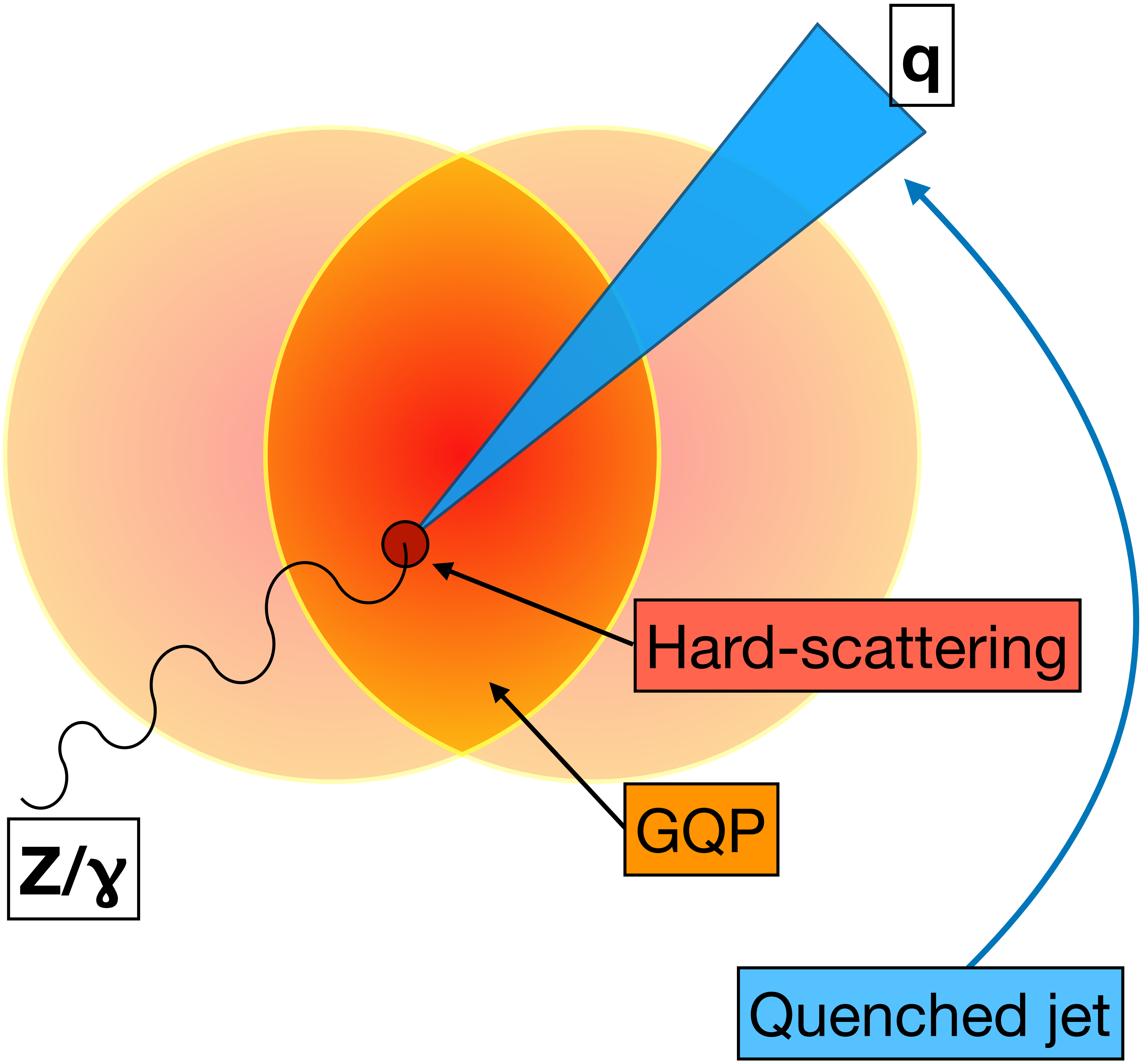


Z/ɣ-tagged jets are useful for two reasons:

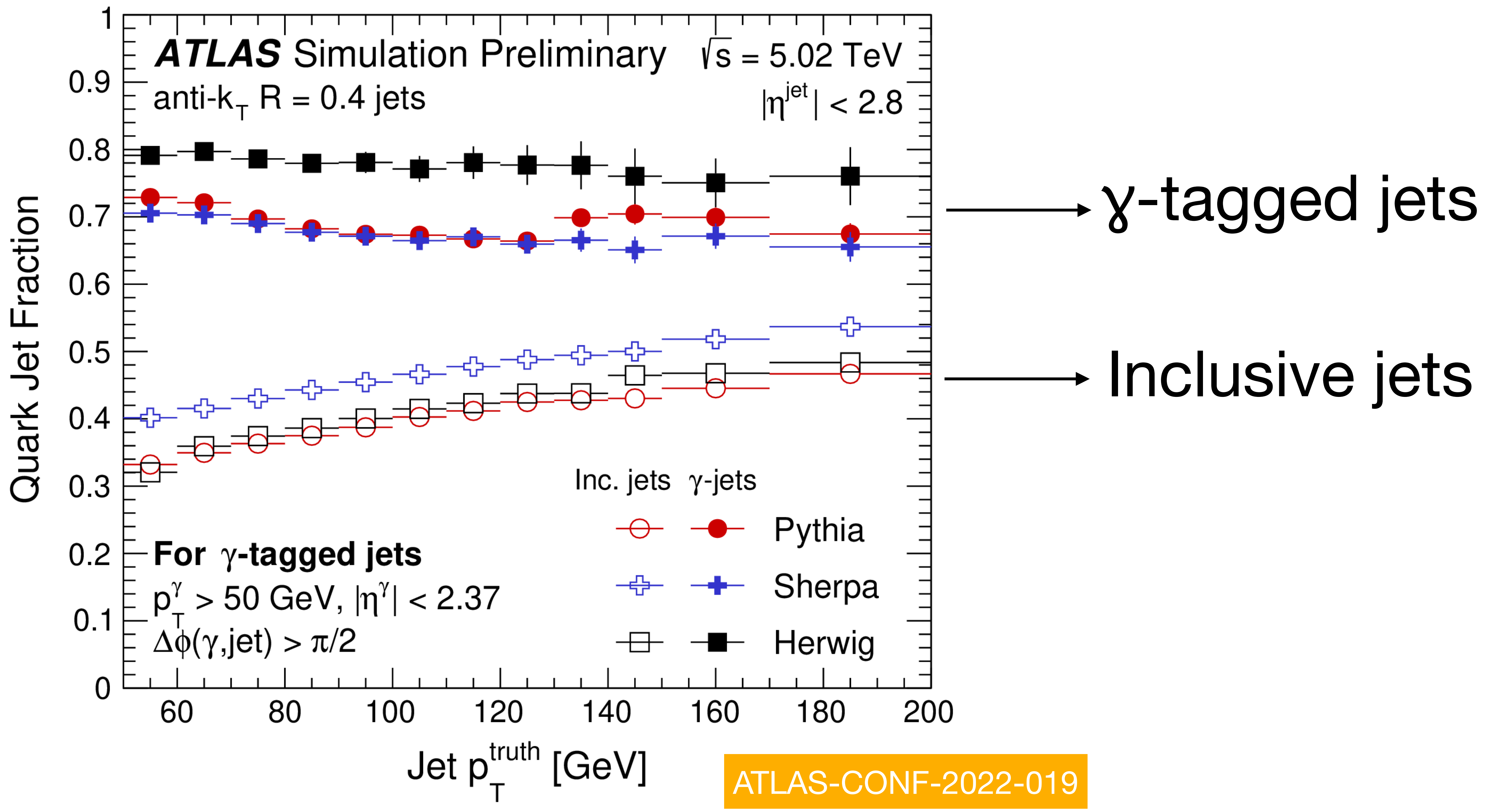
Motivation

Jets are known to lose energy when going through the Quark-Gluon-Plasma

What can we do to improve our understanding of energy loss in QGP?



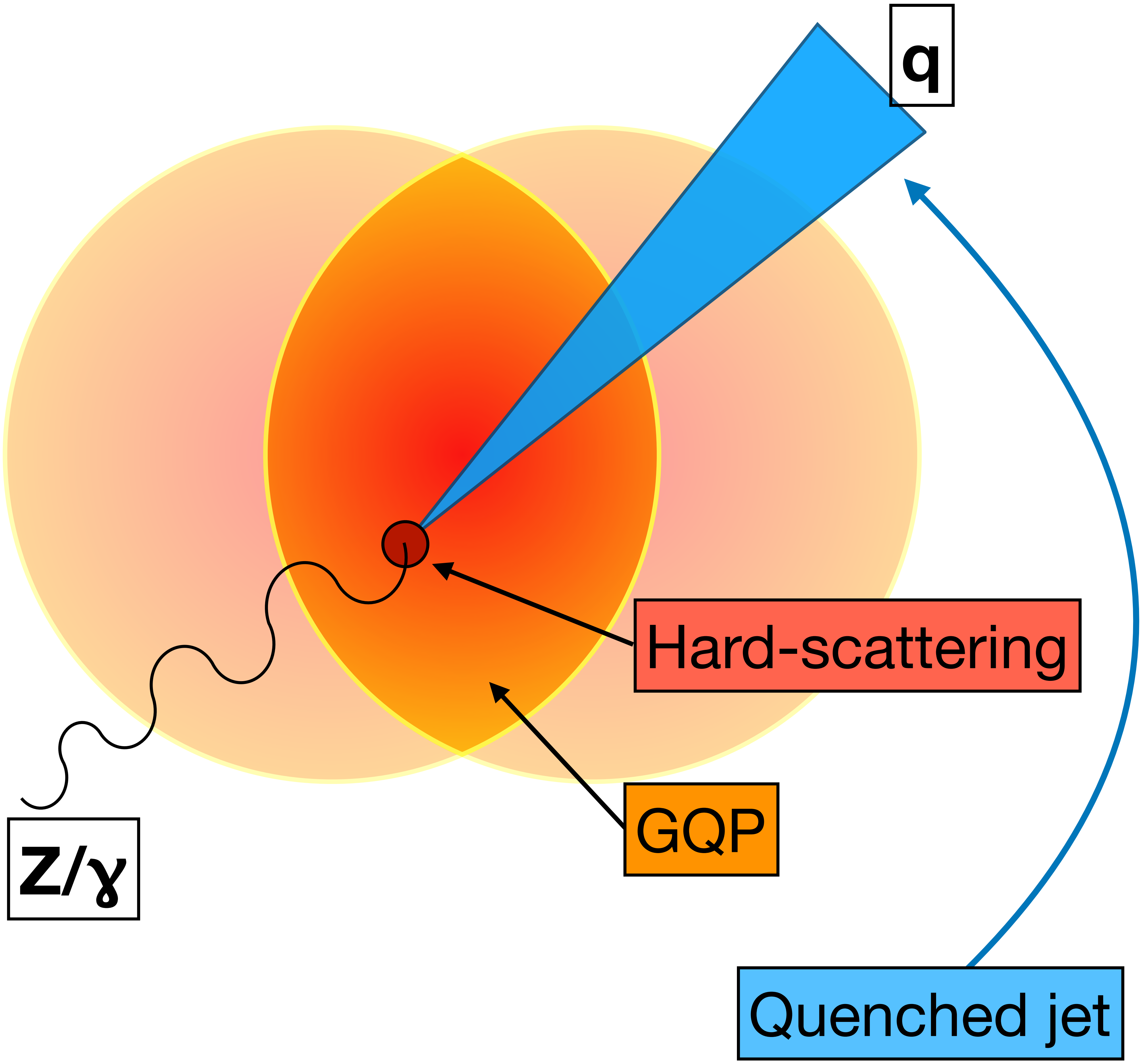
Z/γ-tagged jets are useful for two reasons:
1) Constraining the jet flavor



Motivation

Jets are known to lose energy when going through the Quark-Gluon-Plasma

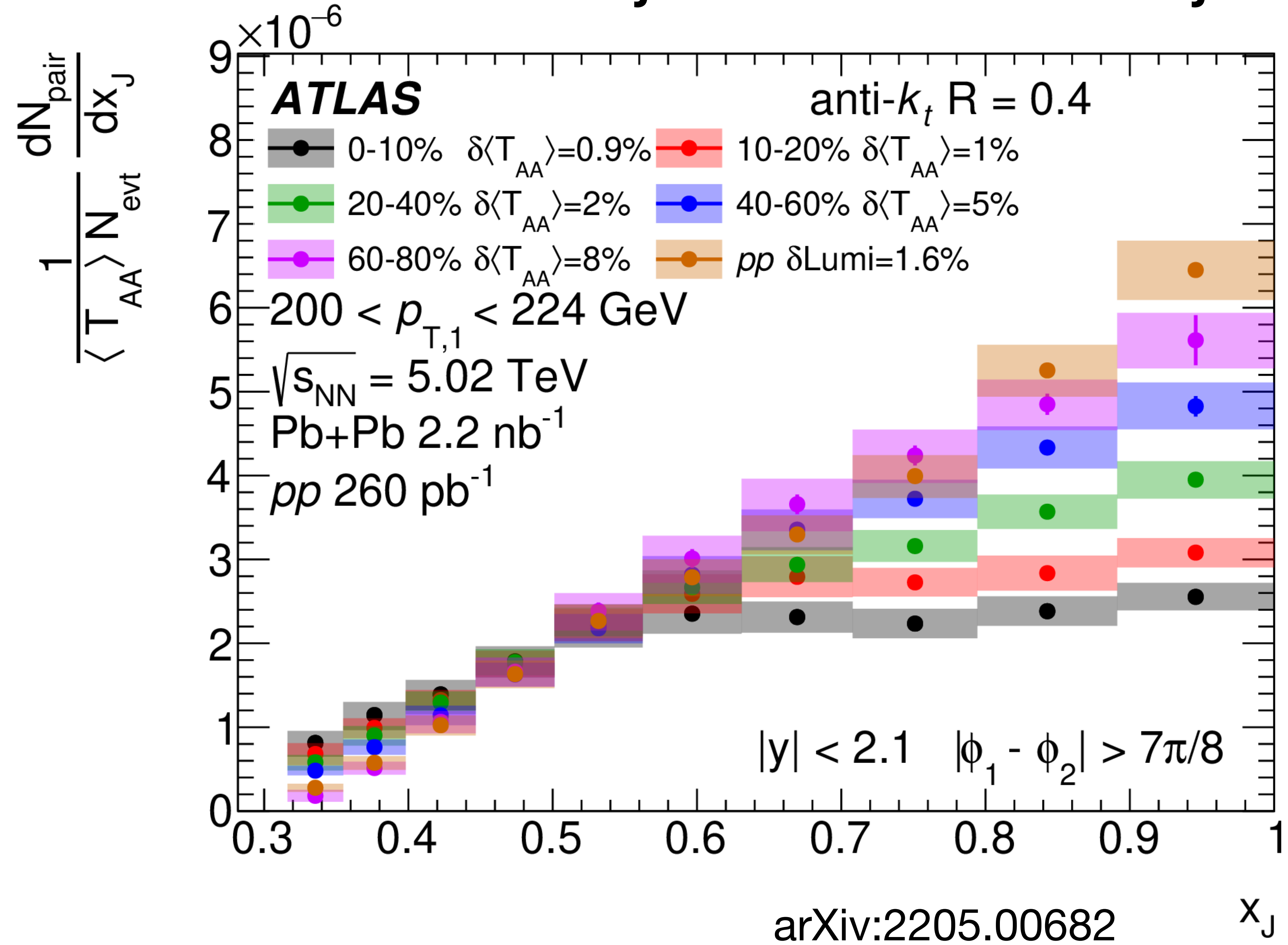
What can we do to improve our understanding of energy loss in QGP?



Z/ɣ-tagged jets are useful for two reasons:

2) Constraining initial the jet momentum

- E/W bosons do not interact strongly with QGP
- Different than di-jets where both jets are quenched

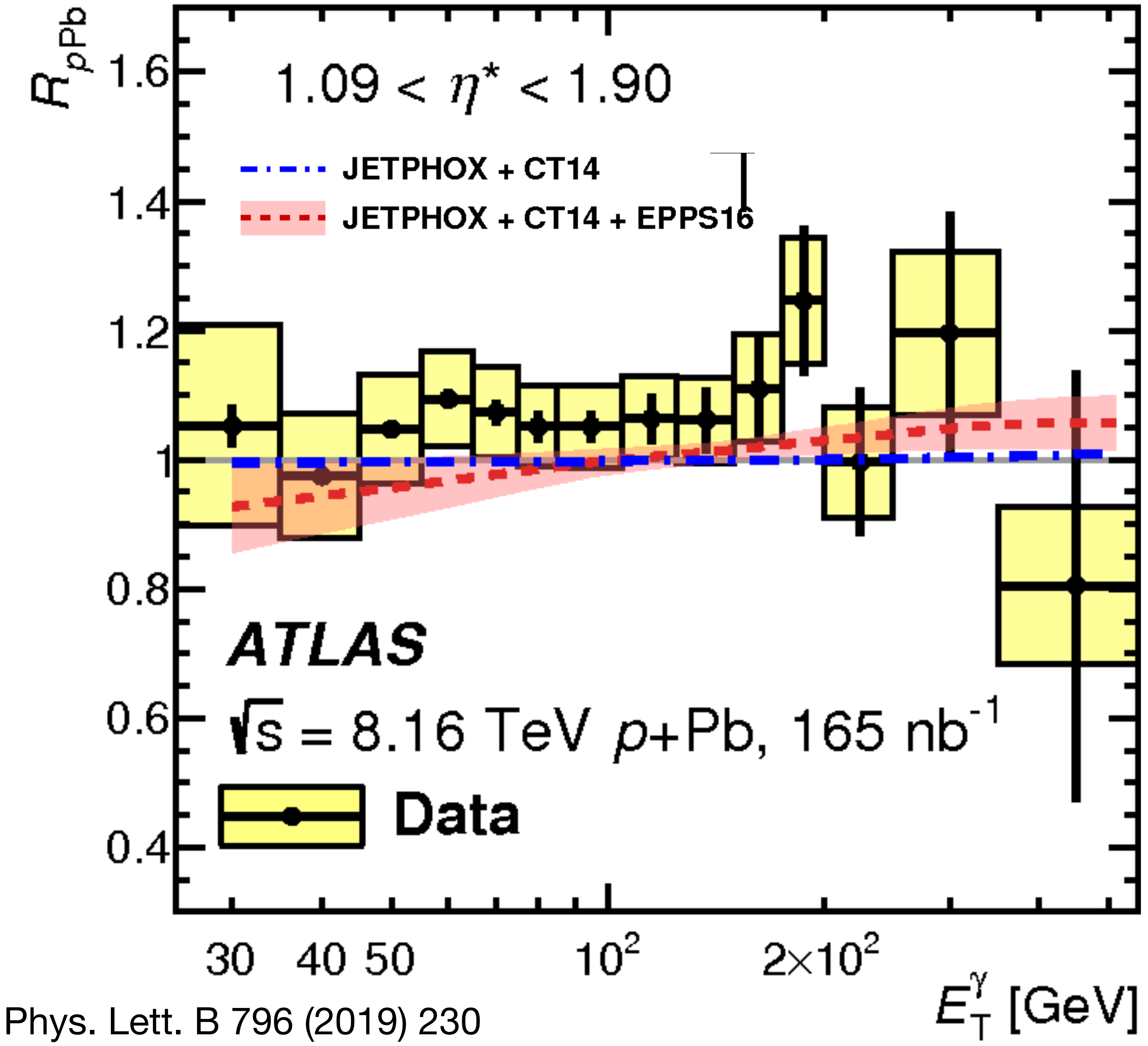


$$x_j = \frac{p_T^{sub-lead}}{p_T^{lead}}$$

arXiv:2205.00682

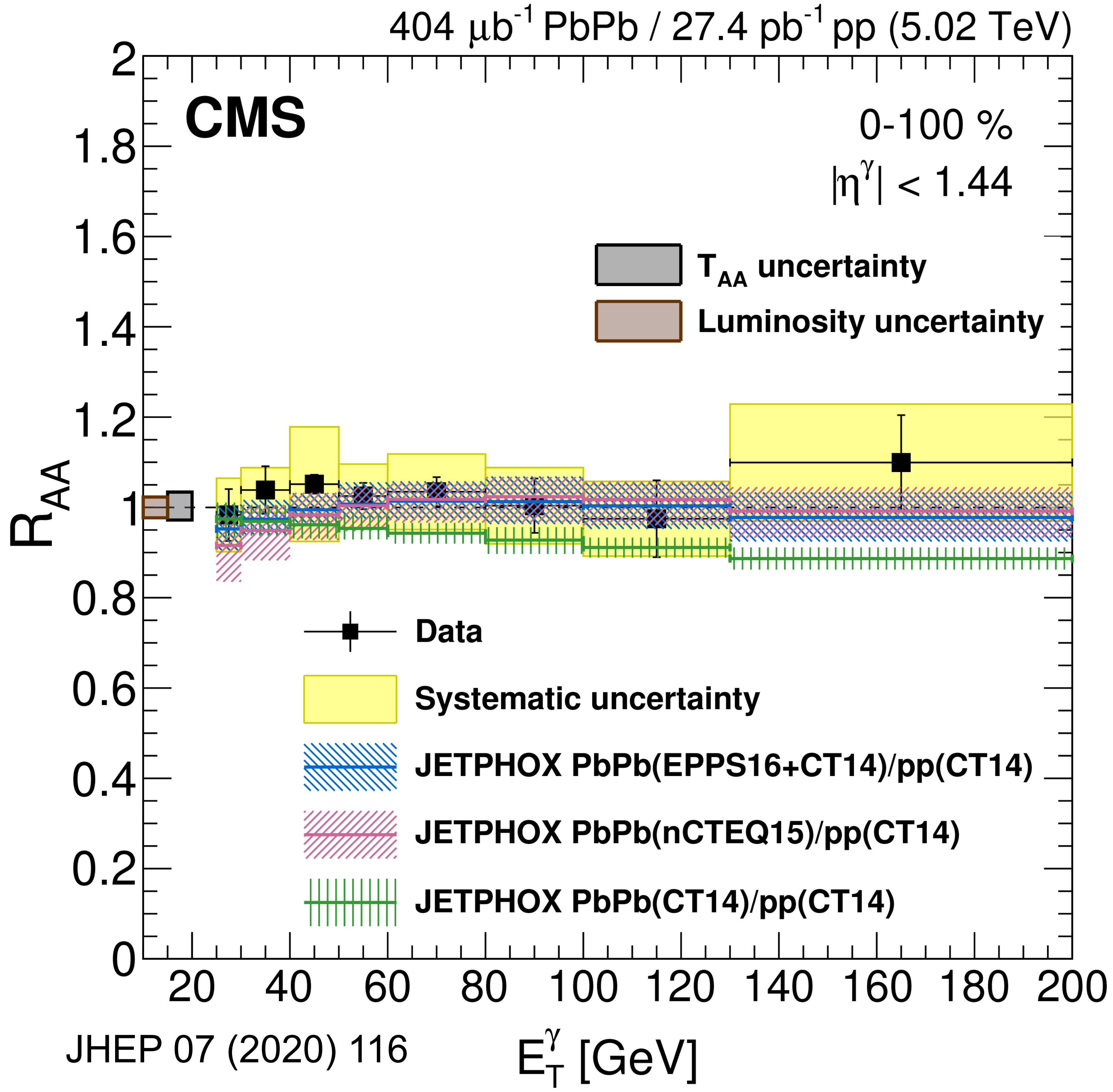
Isolated γ R_{AA}

γ R_{pPb} p+Pb collisions



Phys. Lett. B 796 (2019) 230

γ R_{AA} Pb+Pb collisions

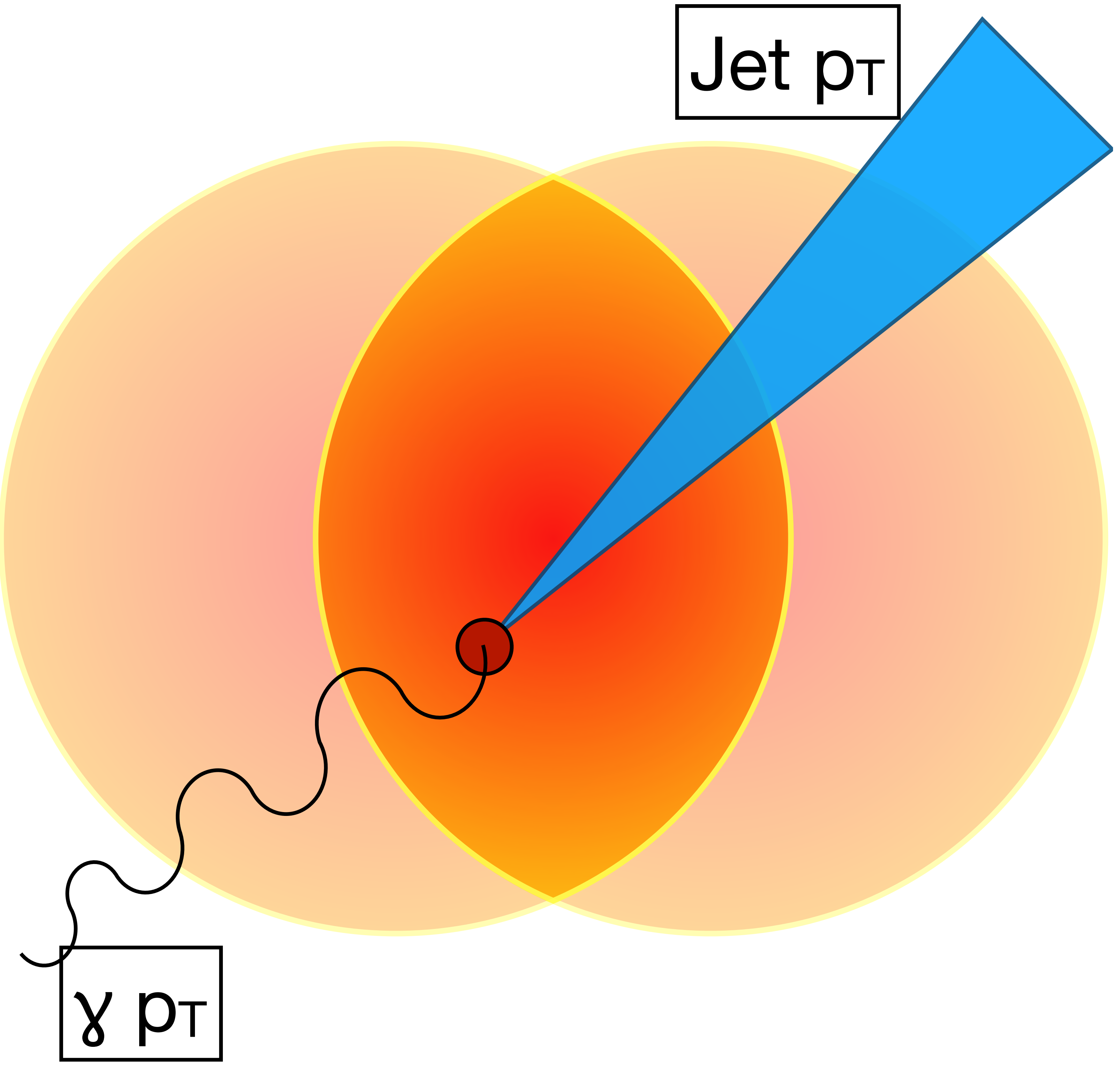


JHEP 07 (2020) 116

- R_{AA} consistent with unity ==> means no Eloss, can be used to tag initial energy in γ-jets events
- Good understanding of isolated E/W production in p+Pb and Pb+Pp collisions
- Provides a direct way to test perturbative QCD and nPDFs

Energy loss — using momentum imbalance

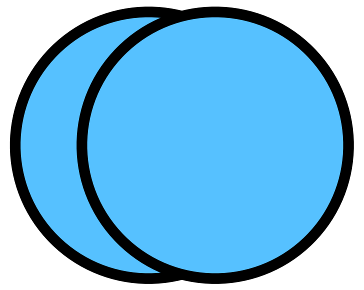
Energy loss — using momentum imbalance

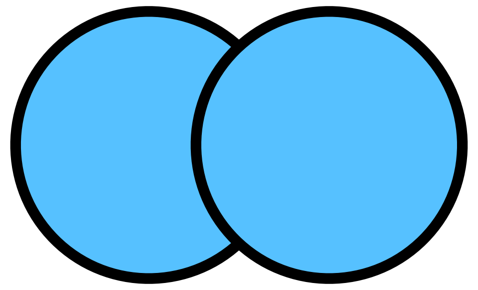


Momentum imbalance:

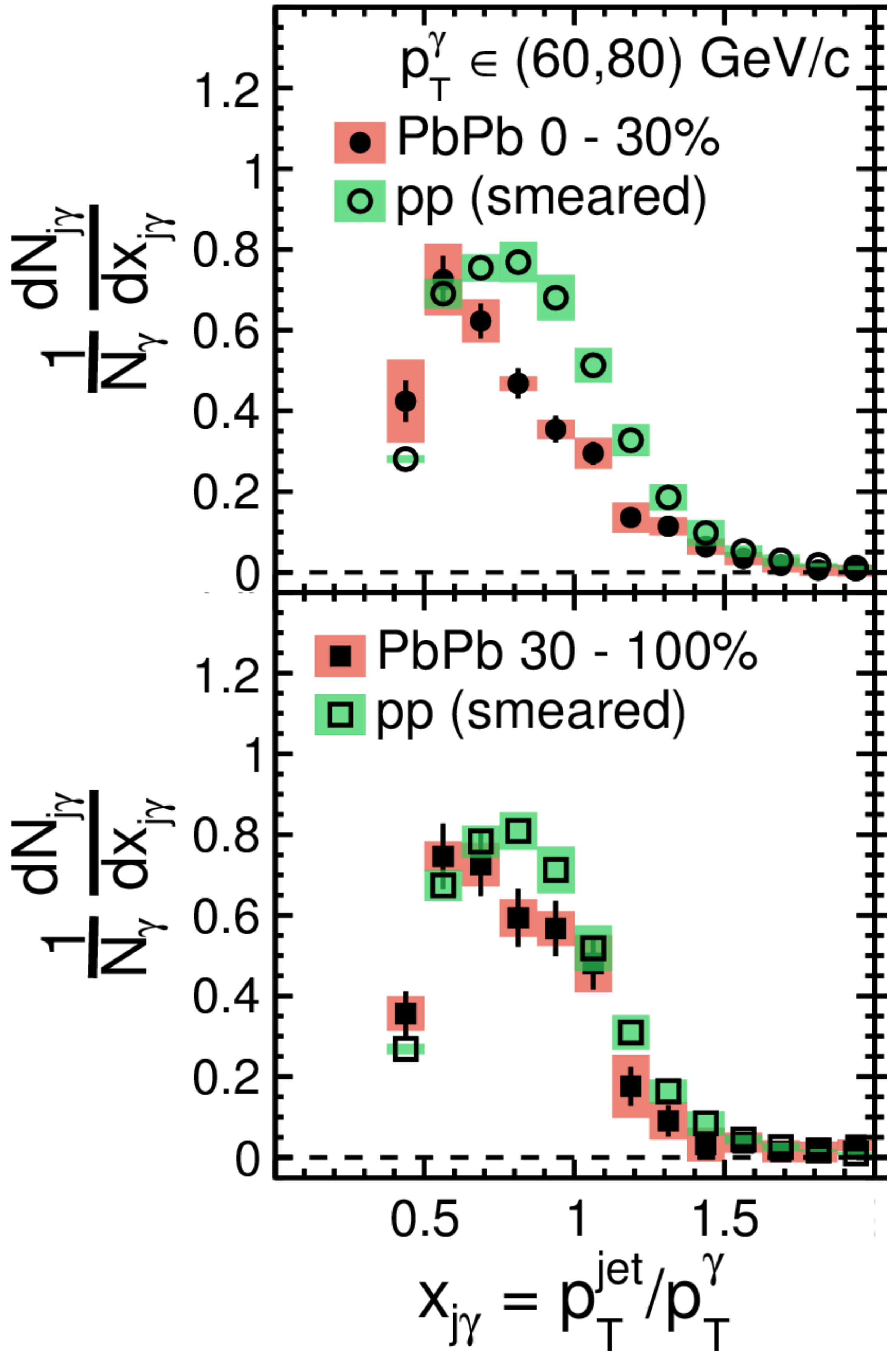
$$x_{j\gamma} = p_T^{jet}/p_T^{\gamma}$$

- Consistent results between detectors
- Jets loss more energy in central collisions



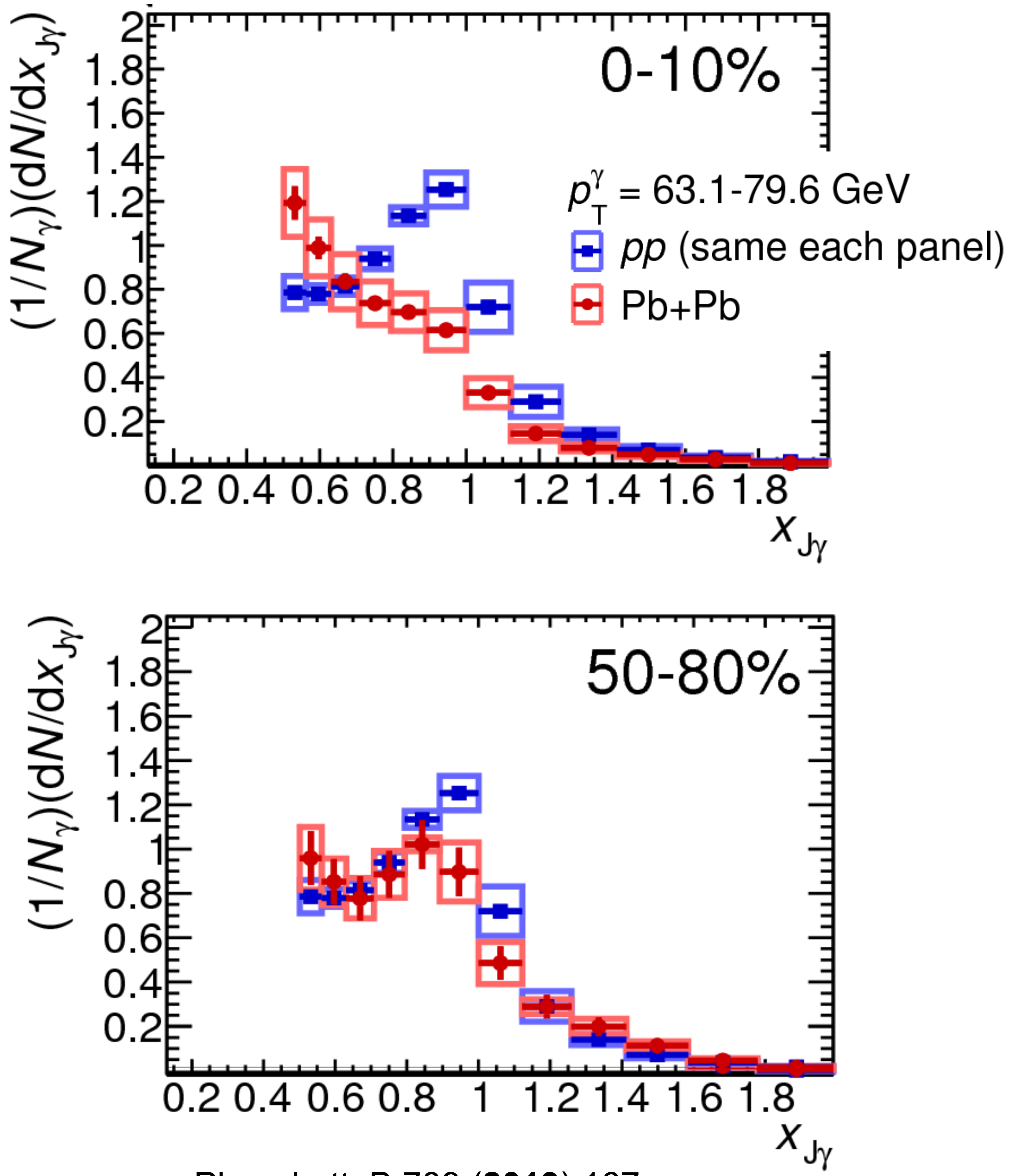


CMS $\Delta\phi > 7\pi/8$ $p_T^{jet} > 30\ GeV$ $|\eta^{jet}| < 1.6$ $|\eta^{\gamma}| < 1.44$



Phys. Lett. B 785 (**2018**) 14

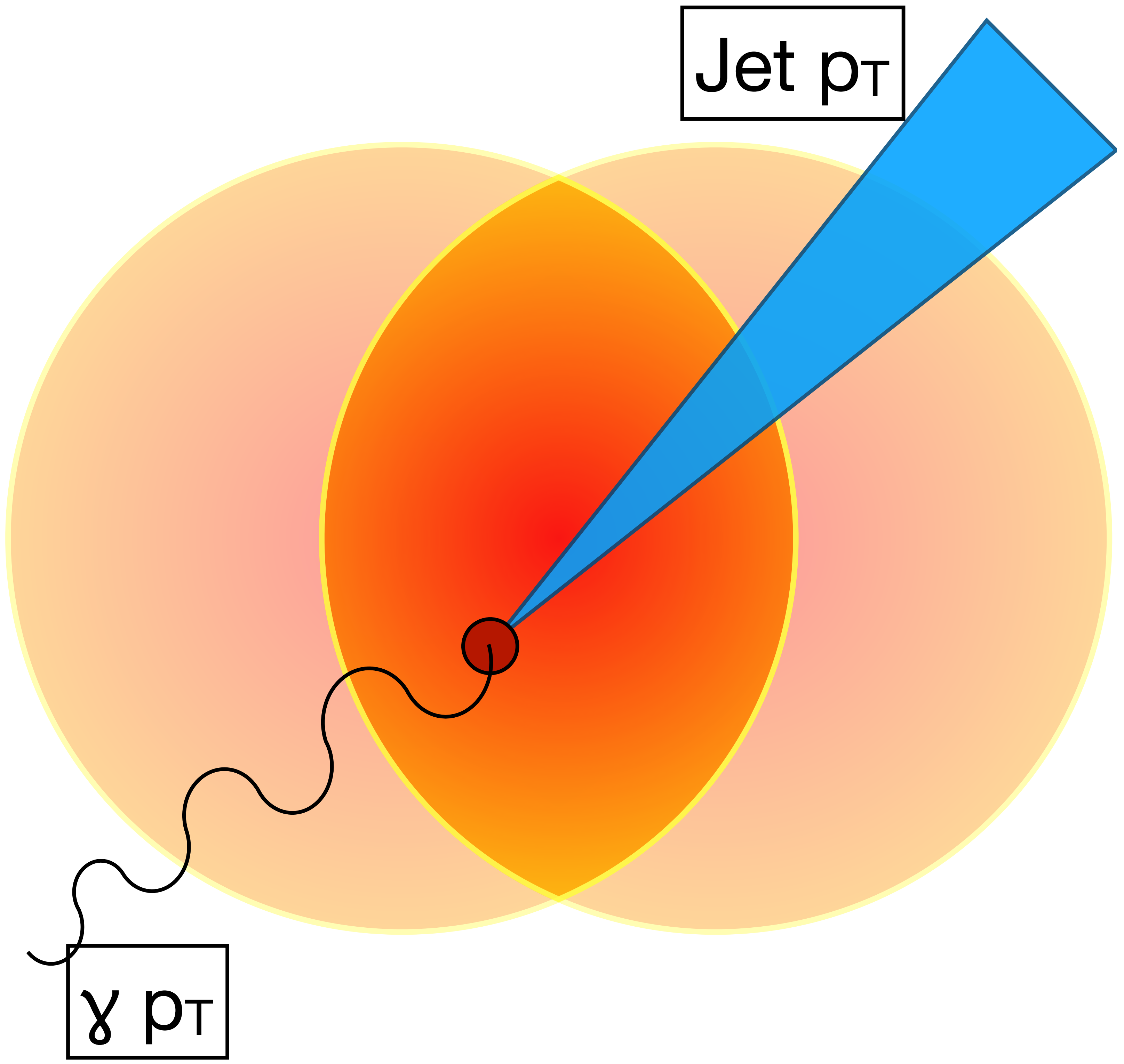
ATLAS $\Delta\phi > 7\pi/8$ $p_T^{jet} > 31.6\ GeV$ $|\eta^{jet}| < 2.8$ $|\eta^{\gamma}| < 2.37$



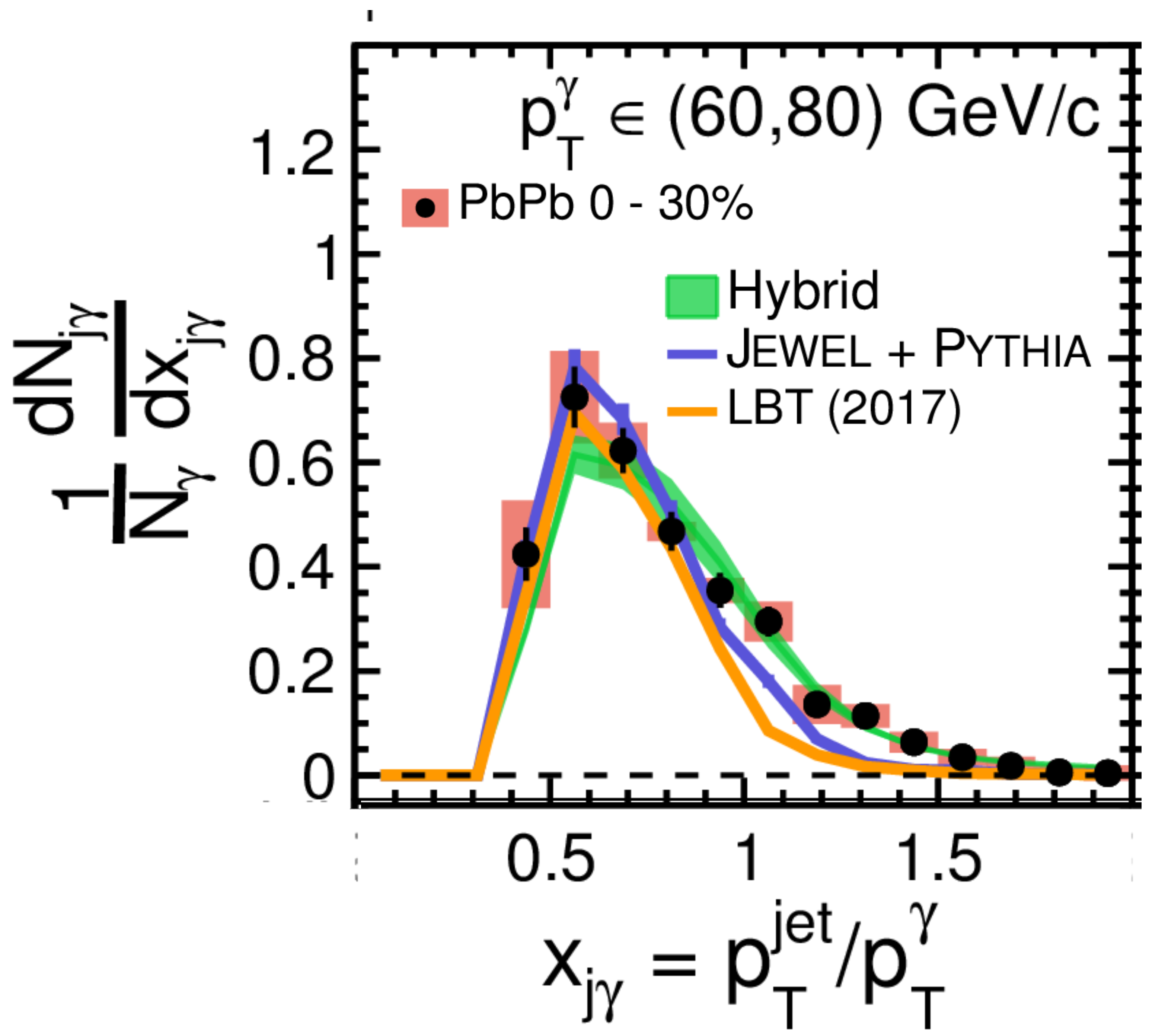
Phys. Lett. B 789 (**2019**) 167

Energy loss — using momentum imbalance

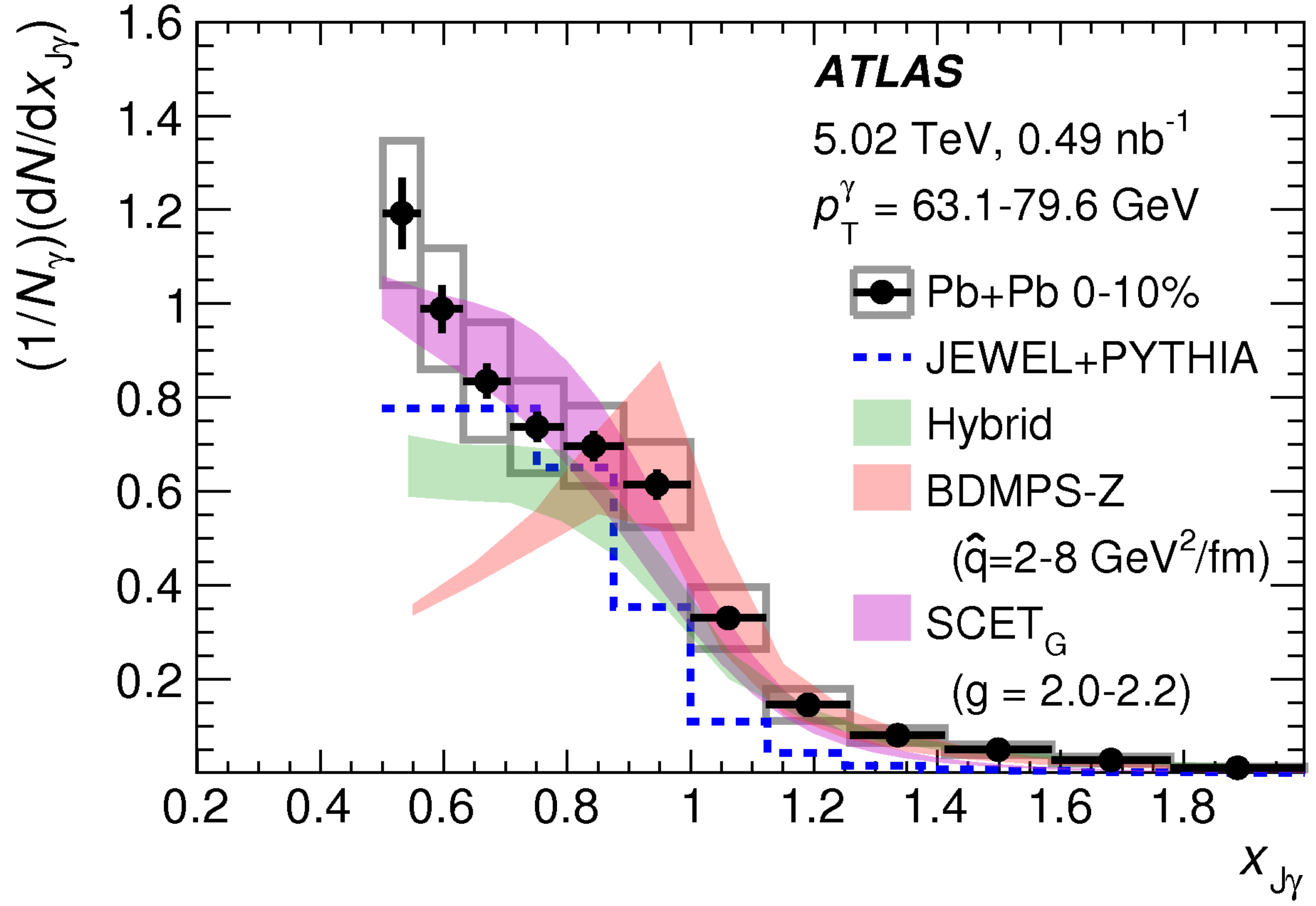
Phys. Lett. B 789 (2019) 167
Phys. Lett. B 785 (2018) 14



CMS $\Delta\phi > 7\pi/8$ $p_T^{jet} > 30\ GeV$ $|\eta^{jet}| < 1.6$ $|\eta^{\gamma}| < 1.44$



ATLAS $\Delta\phi > 7\pi/8$ $p_T^{jet} > 31.6\ GeV$ $|\eta^{jet}| < 2.8$ $|\eta^{\gamma}| < 2.37$

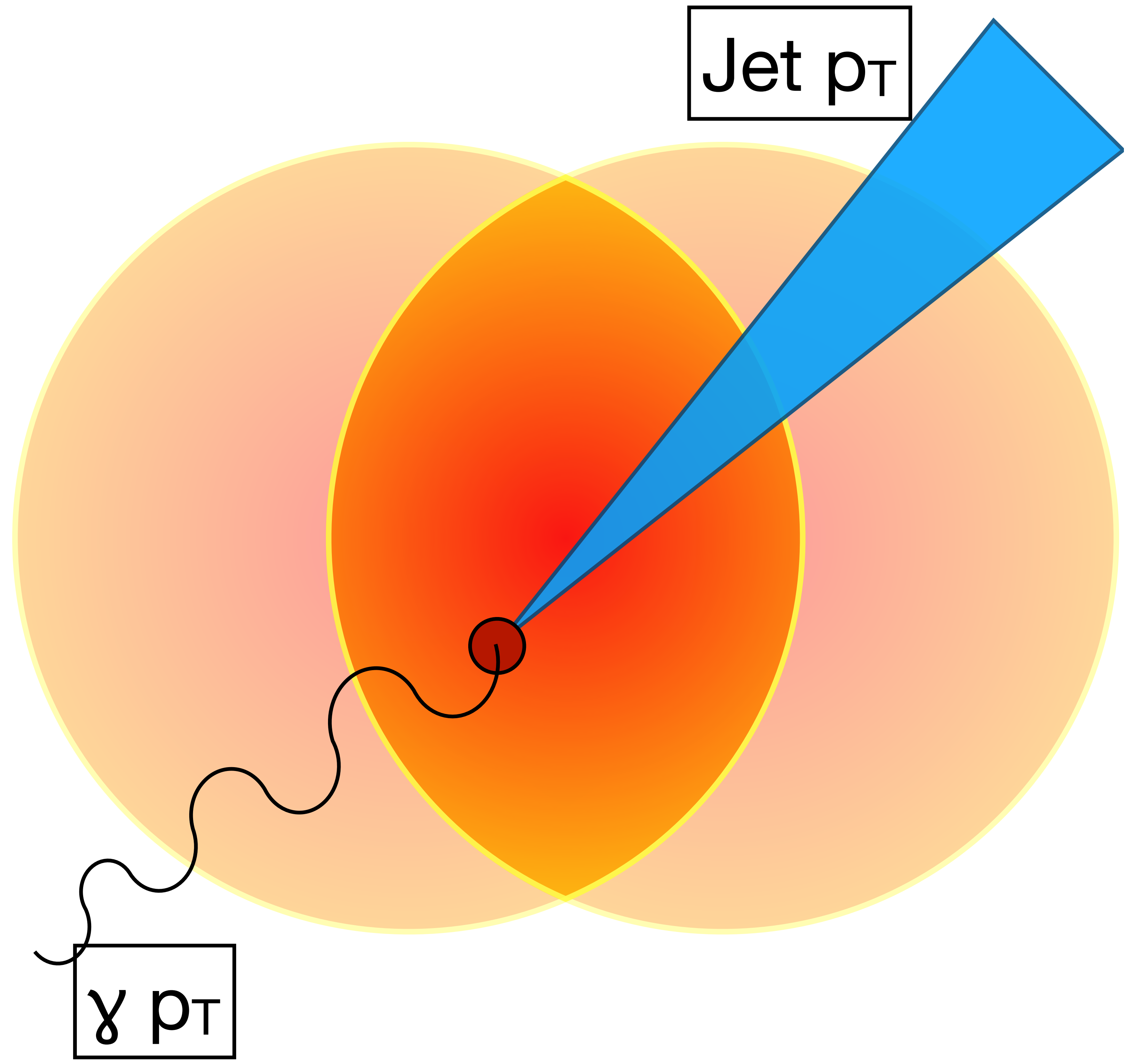


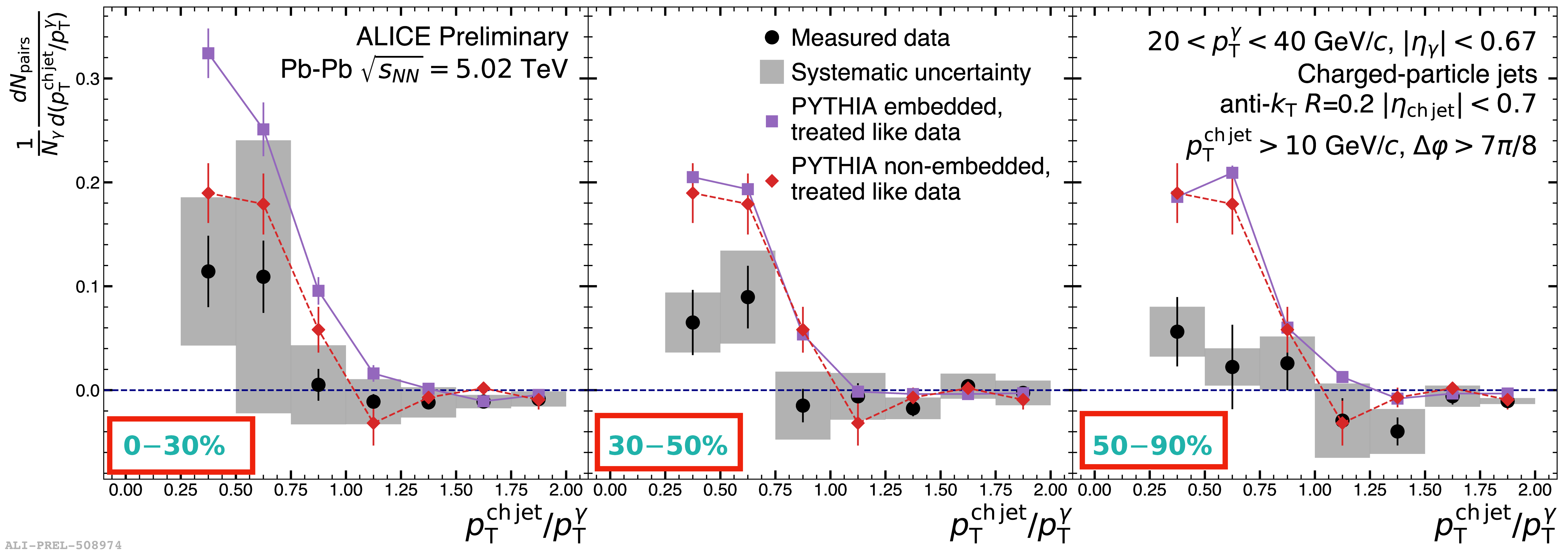
Momentum imbalance:

$$x_{j\gamma} = p_T^{jet}/p_T^{\gamma}$$

- Consistent results between detectors
- Jets loss more energy in central collisions
- **Qualitatively good agreement with theoretical calculation**

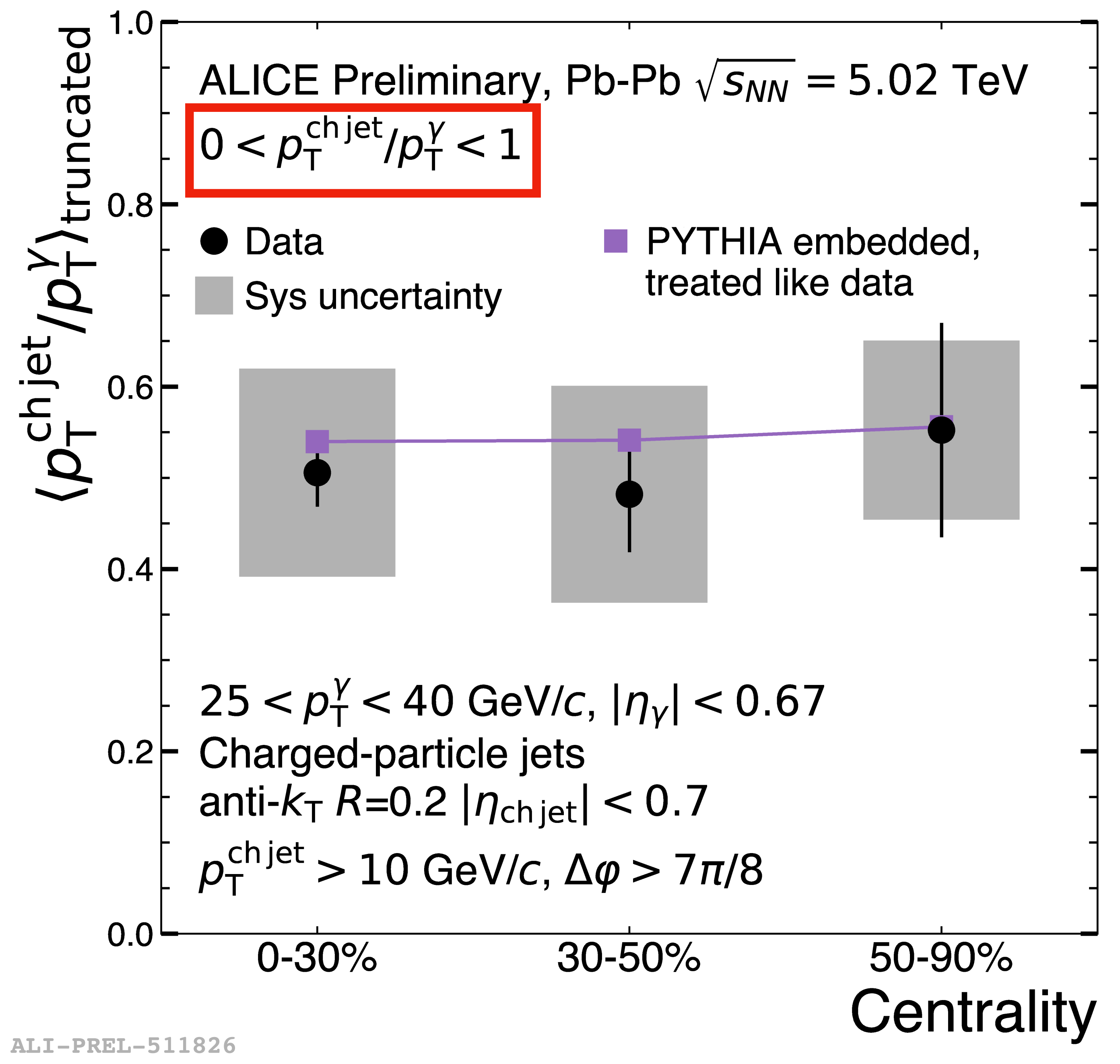
Energy loss — using momentum imbalance





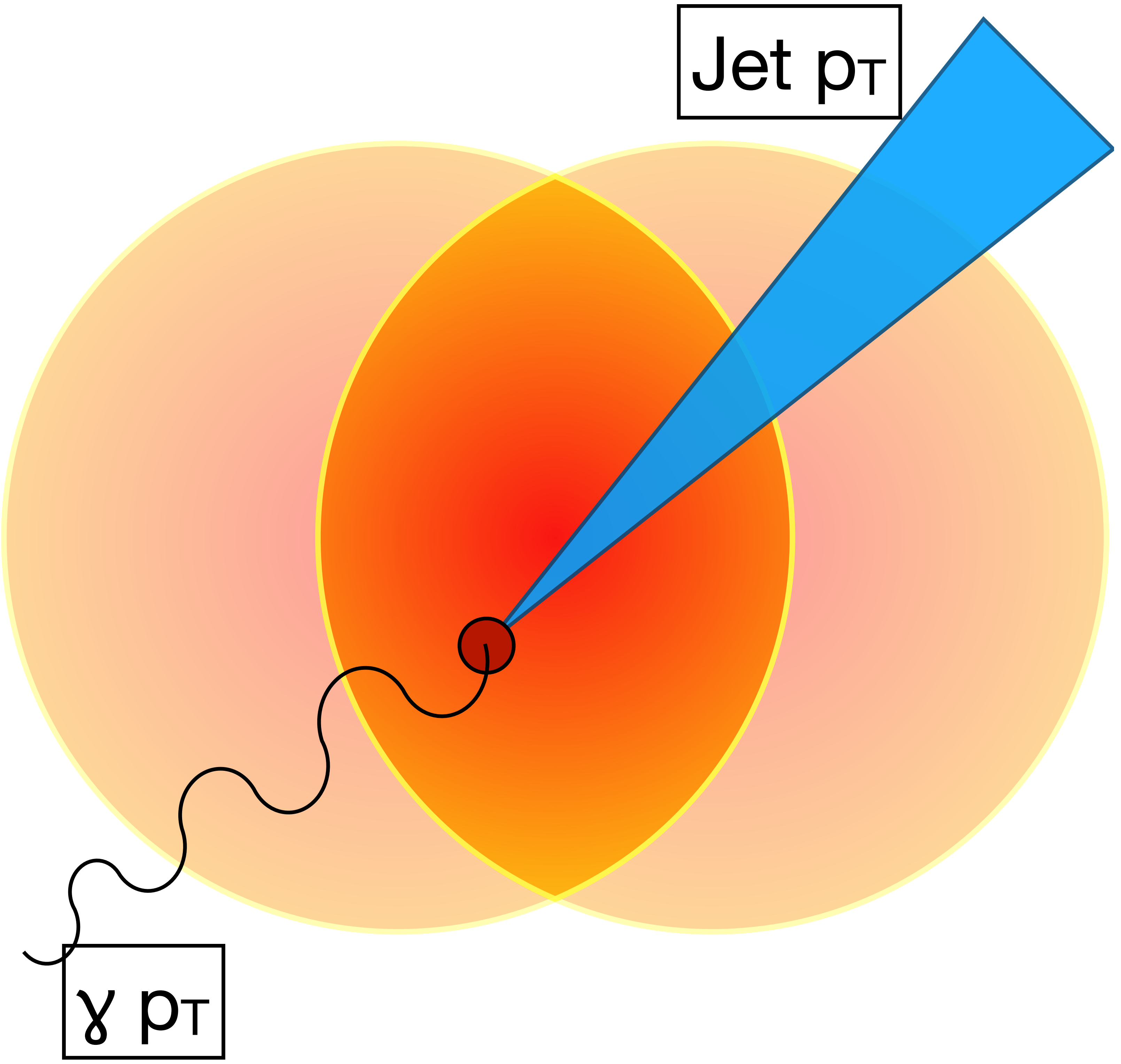
Momentum imbalance:

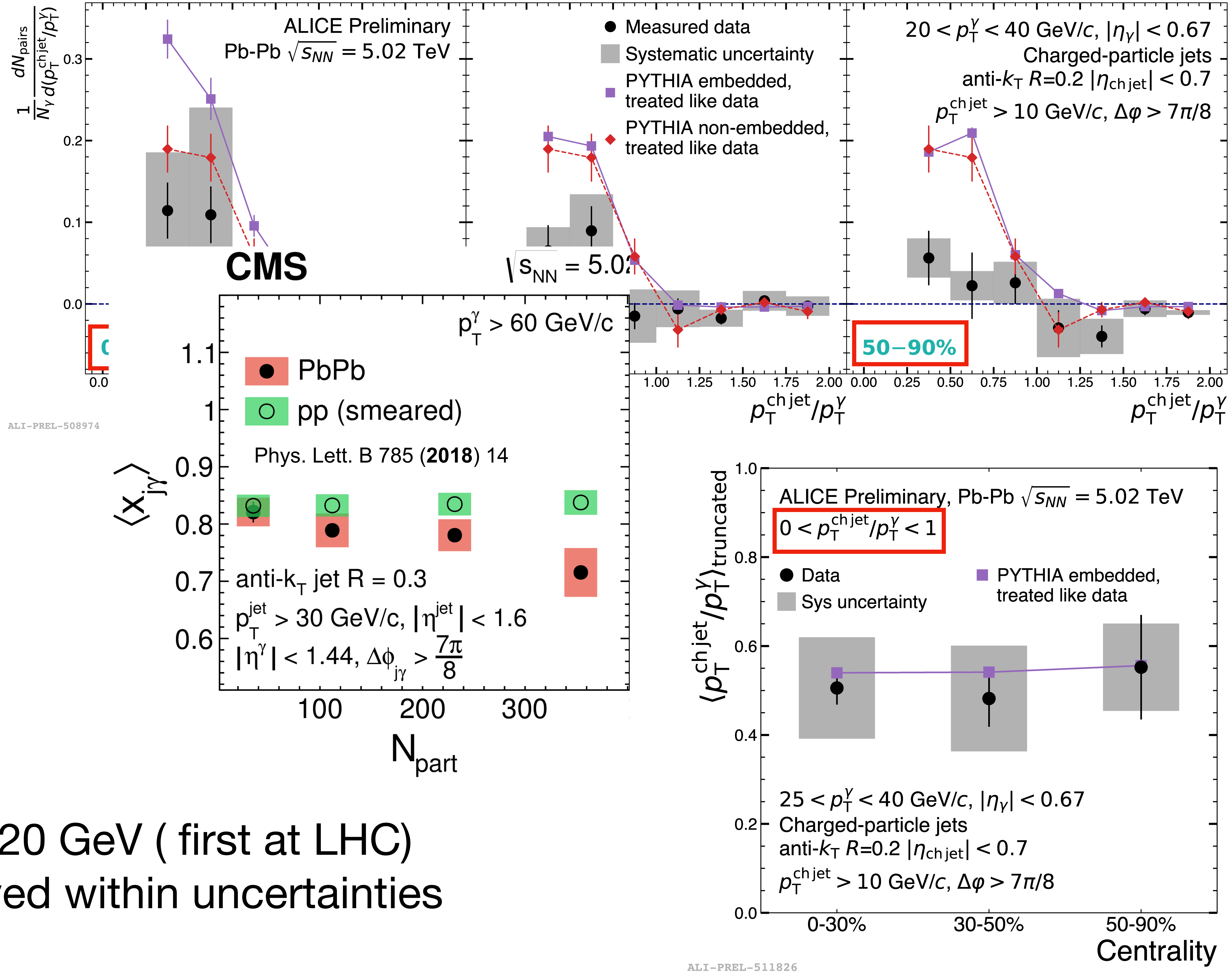
$$x_{j\gamma} = p_T^{jet}/p_T^{\gamma}$$



- γ-jet measurement down to p_T = 20 GeV (first at LHC)
- No centrality dependence observed within uncertainties

Energy loss — using momentum imbalance





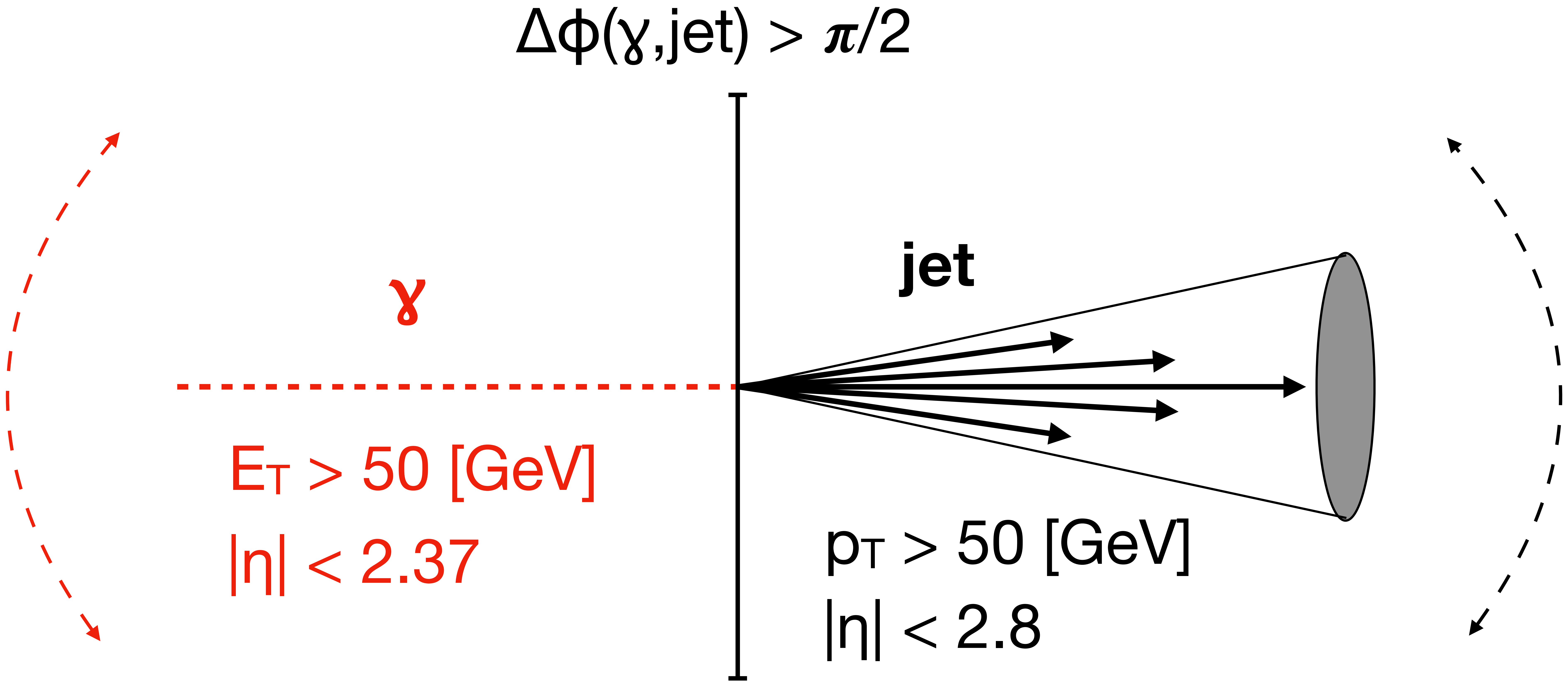
Momentum imbalance:

$$x_{j\gamma} = p_T^{jet}/p_T^{\gamma}$$

- ɣ-jet measurement down to p_T = 20 GeV (first at LHC)
- No centrality dependence observed within uncertainties
  - **Tension with ATLAS/CMS?**

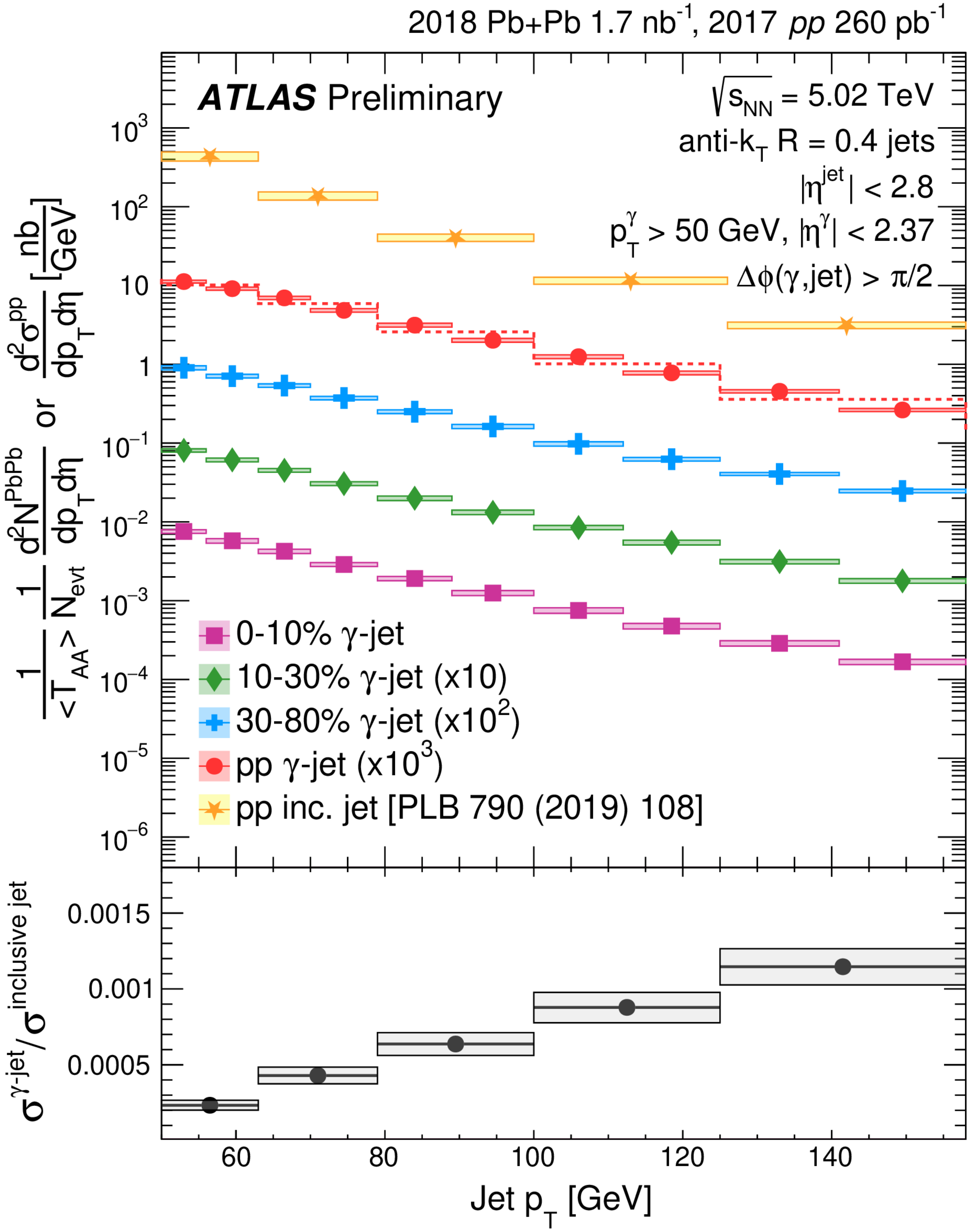
Energy loss — using nuclear modification factor

Energy loss — using nuclear modification factor



- γ is used **only** for tagging the event
  - Enhanced quark fraction
- No strong back-to-back requirement
  - The motivation is to compare with inclusive jet R_{AA} ==> quark vs gluon energy loss

γ-tagged jets vs inclusive jets in *pp* and Pb+Pb collisions



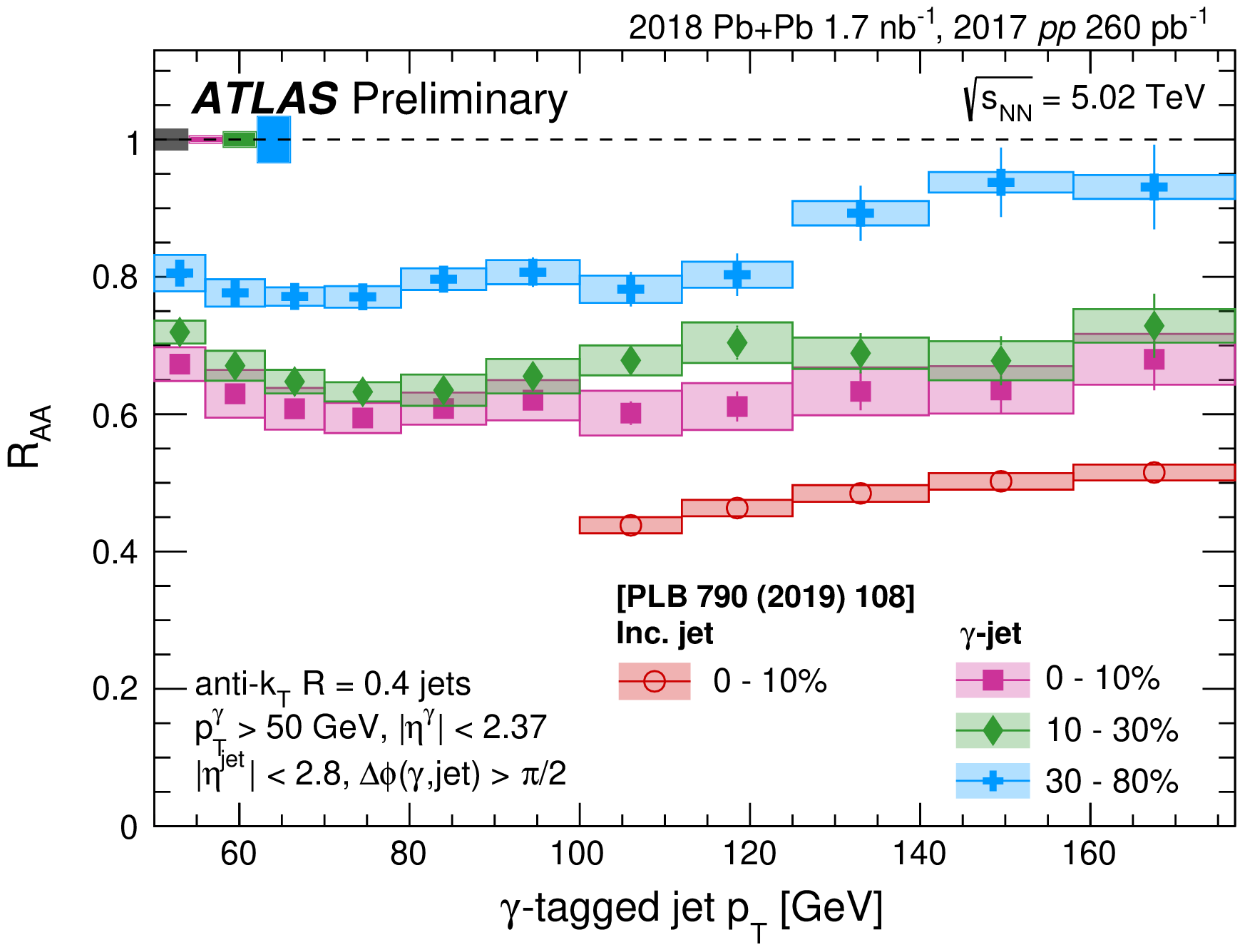
γ-tagged jets measured for three centralities classes in Pb+Pb data

γ-tagged jets to inclusive *R*=0.4 cross-section ratio:

- Relevant for R_{AA} modification interpretation
  - Inclusive jet spectra steeper than γ-tagged jets —> less suppression for γ-tagged jets
  - Isospin/nPDF effect also plays an important role —> larger suppression for γ-tagged jets
  - The two effects are expected to have similar magnitude but opposite sign

Inclusive jets from *PLB 790 (2019) 108*

ɣ-tagged jets vs inclusive jets in Pb+Pb collisions



Nuclear modification factor, R_{AA}, measured for ɣ-tagged jets and inclusive jets from *PLB 790 (2019) 108*:

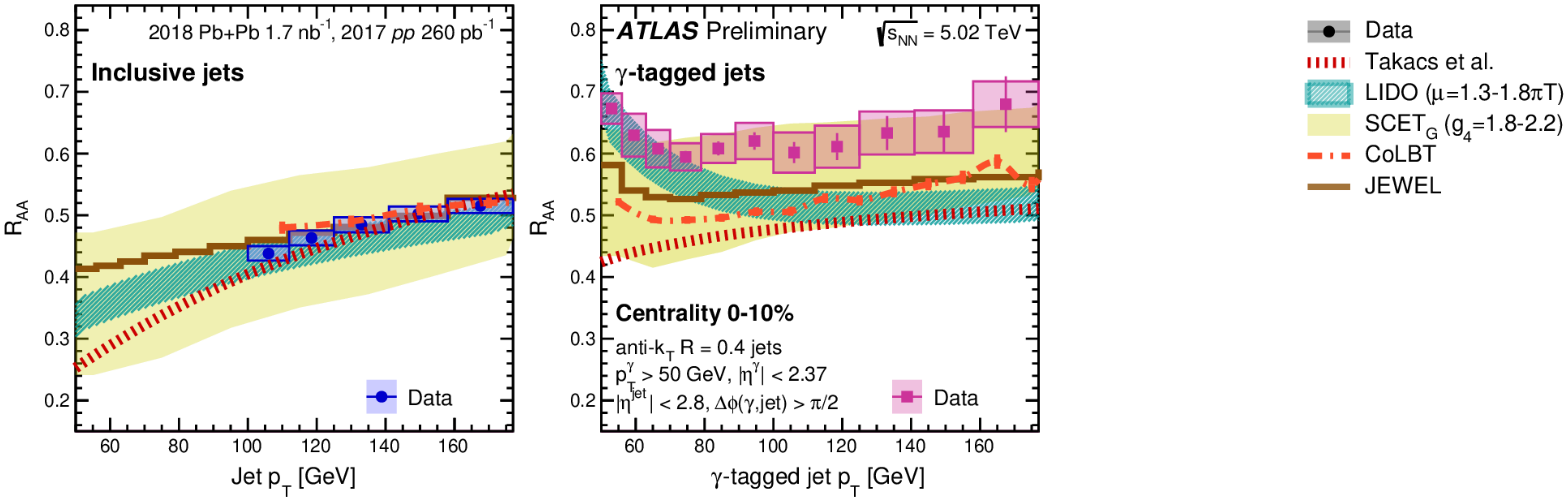
- ɣ-tagged jets R_{AA} measured for three centrality classes, central R_{AA} more suppressed than peripheral
- ɣ-tagged jets (quark-jet dominant) **found to be less suppressed** than inclusive (gluon-jet dominant) jets in central collisions

ɣ-tagged jets vs inclusive jets in Pb+Pb collisions

Central collisions nuclear modification factor, R_{AA}, of **inclusive jets**, ɣ-tagged jets, and ratio:

- **Inclusive jets R_{AA}**, is well modeled by theoretical calculations

γ-tagged jets vs inclusive jets in Pb+Pb collisions



Central collisions nuclear modification factor, R_{AA}, of inclusive jets, **γ-tagged jets**, and ratio:

- Inclusive jets R_{AA}, is well modeled by theoretical calculations
- **γ-tagged jets R_{AA}**, in general, under-estimated by theoretical calculations
- SCET$_G$ reproduces both, this results could help constrain the parameter space

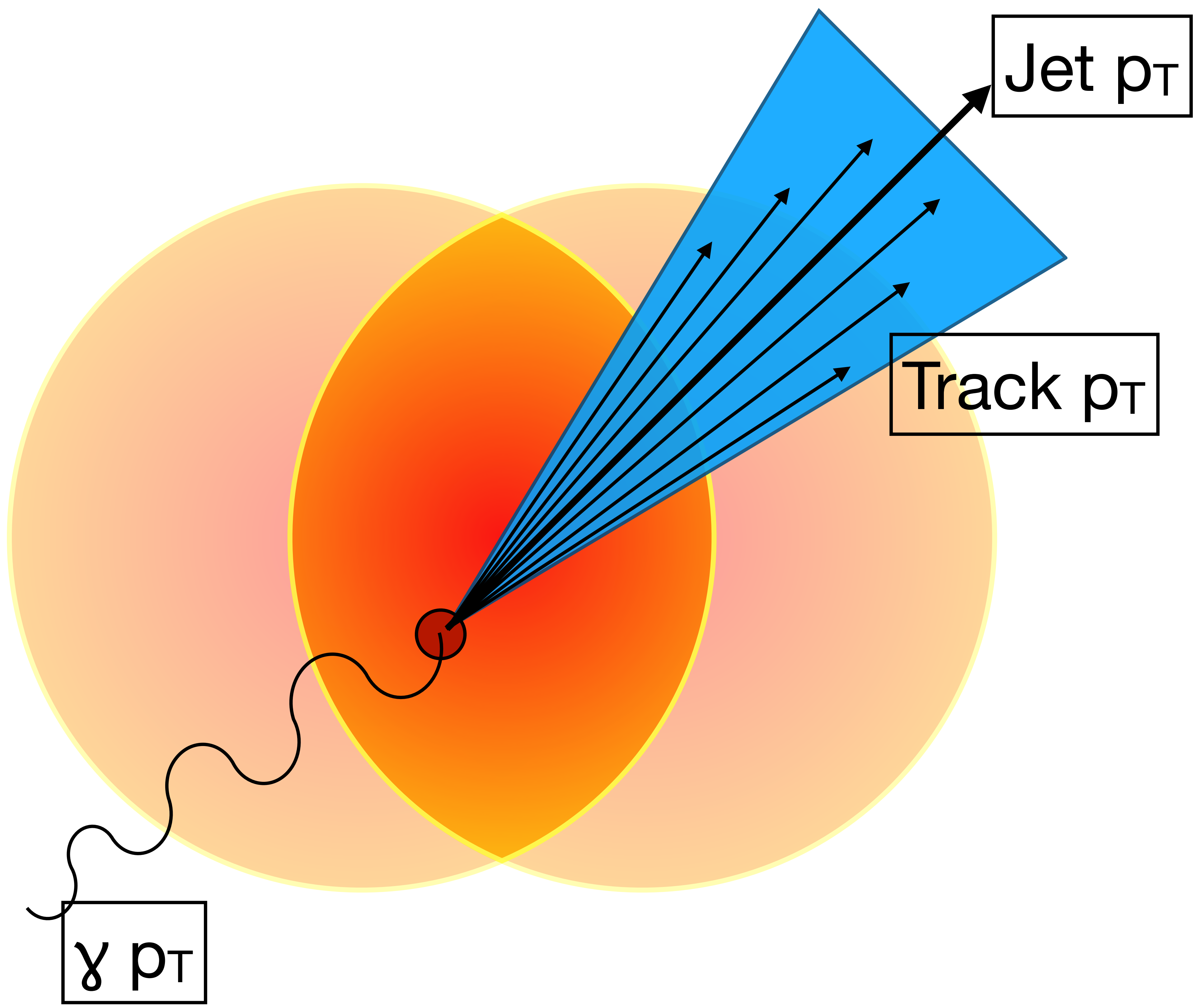
ɣ-tagged jets vs inclusive jets in Pb+Pb collisions

ATLAS-CONF-2022-019

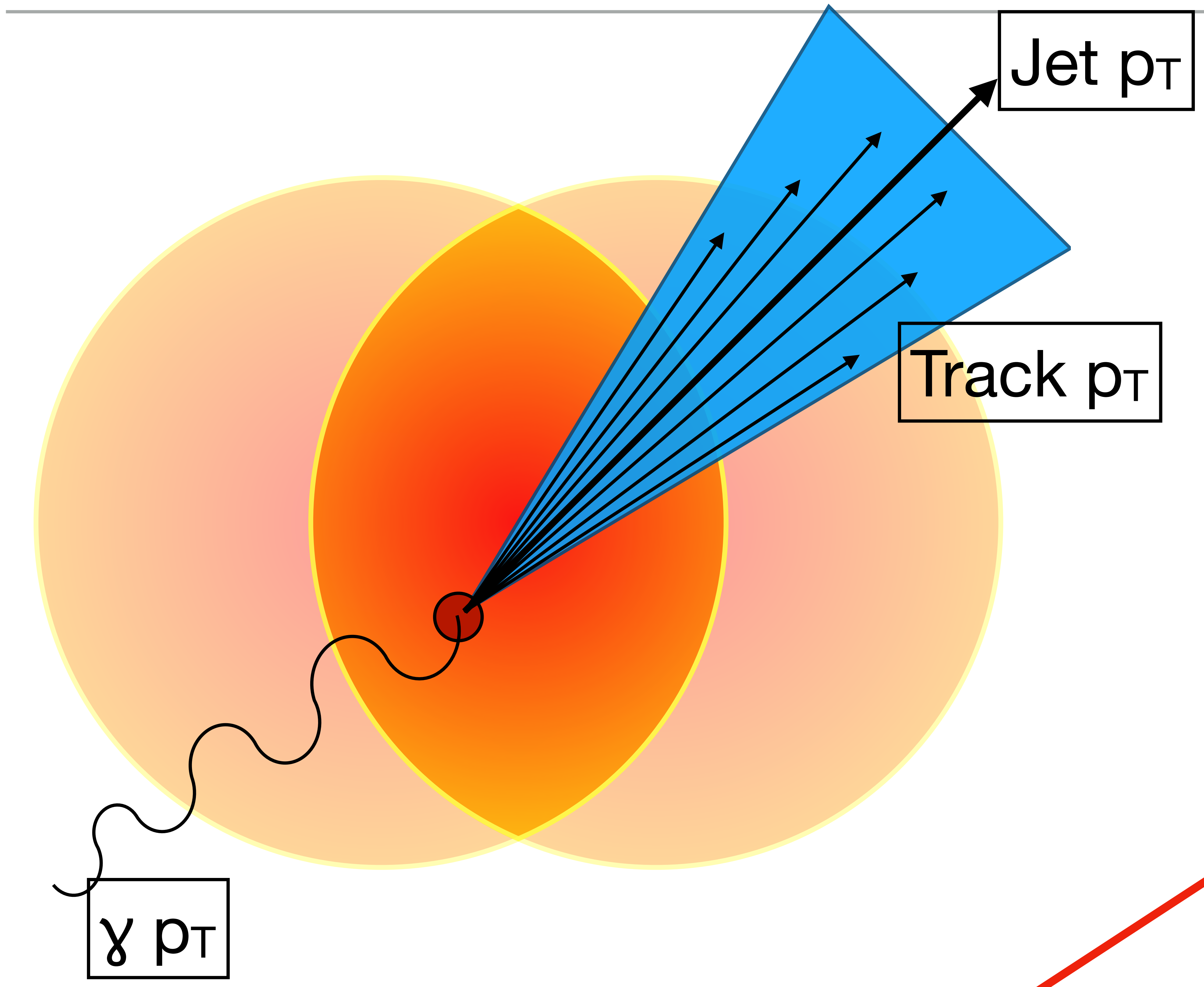
Central collisions nuclear modification factor, R_{AA}, of inclusive jets, ɣ-tagged jets, and **ratio**:

- Inclusive jets R_{AA}, is well modeled by theoretical calculations
- ɣ-tagged jets R_{AA}, in general, under-estimated by theoretical calculations
- $SCET_G$ reproduces both, this results could help constrain the parameter space
- **R_{AA} ratio ~30% above unity in central collisions**

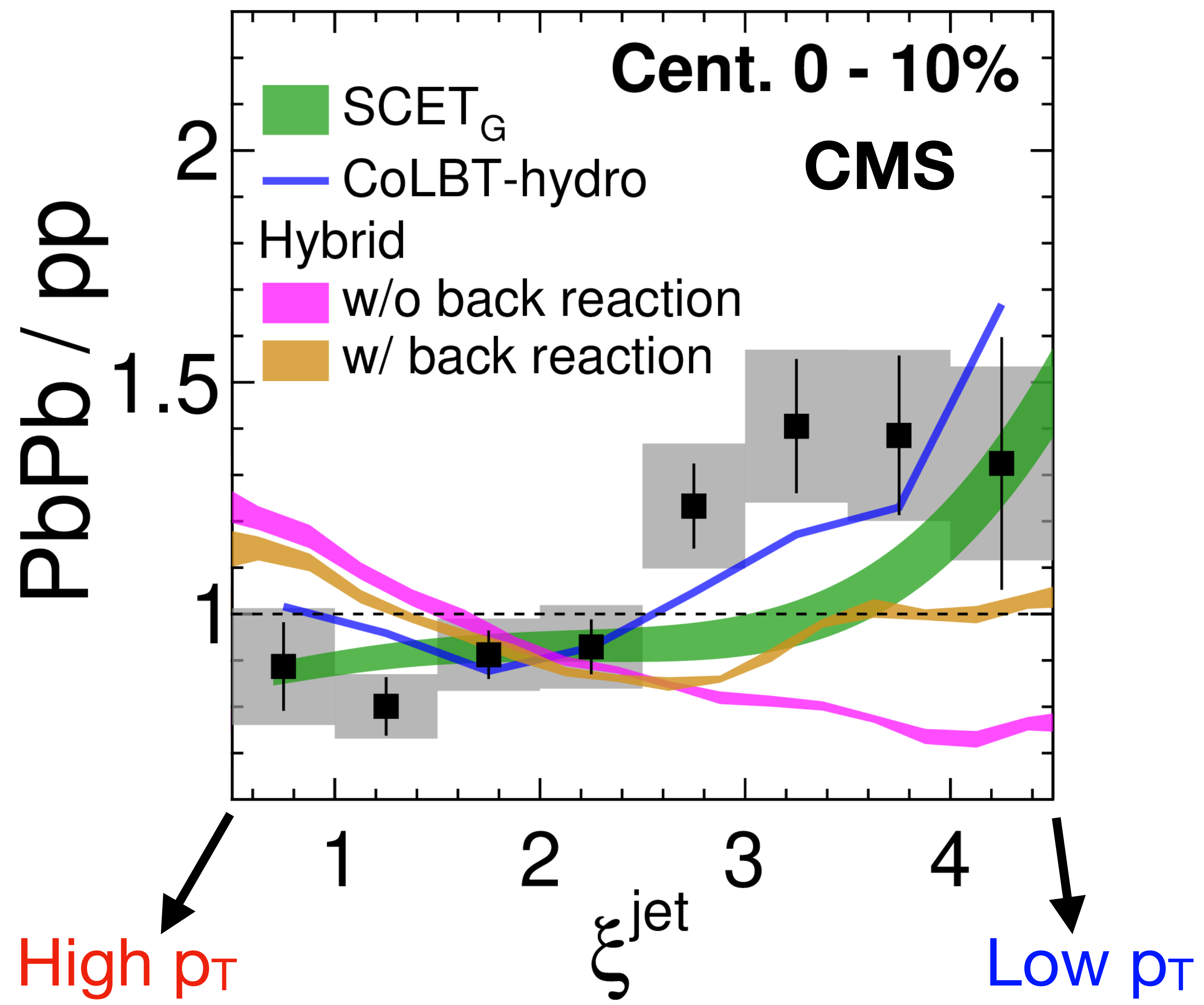
Where is the energy going? — with reconstructed jets



Where is the energy going? — with reconstructed jets



PRL 121 242301 (2018)

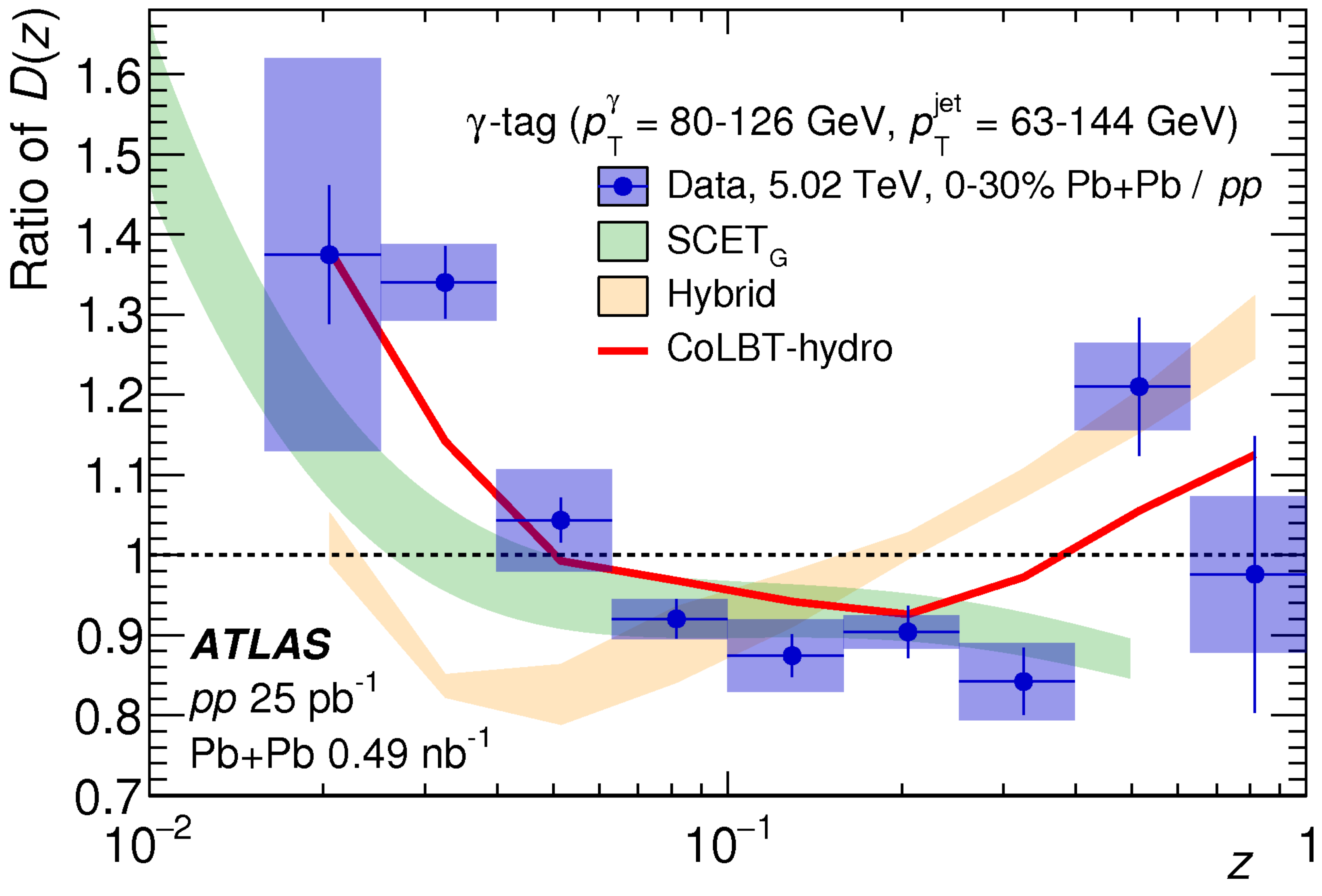


$p_T^{jet} > 30\ GeV$

$p_T^{\gamma} > 60\ GeV$

Fragmentation function:

$$\xi^{jet} = ln\frac{|\overrightarrow{p}_T^{jet}|^2}{\overrightarrow{p}_T^{jet} \cdot \overrightarrow{p}_T^{trk}} \qquad z = \frac{\overrightarrow{p}_T^{jet} \cdot \overrightarrow{p}_T^{trk}}{|\overrightarrow{p}_T^{jet}|^2}$$



PRL 123 (2019) 042001

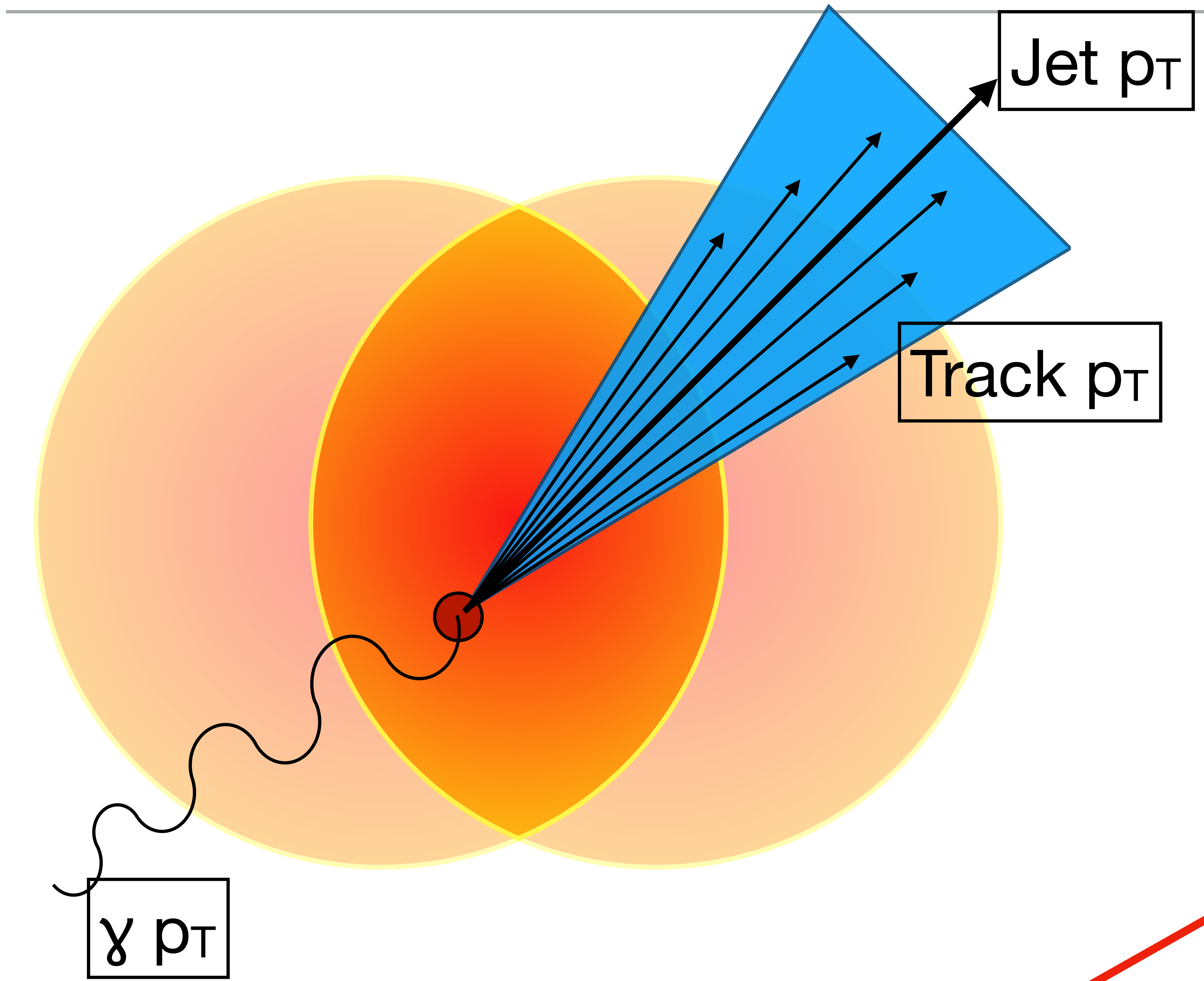
$p_T^{jet} : 64 - 144\ GeV$

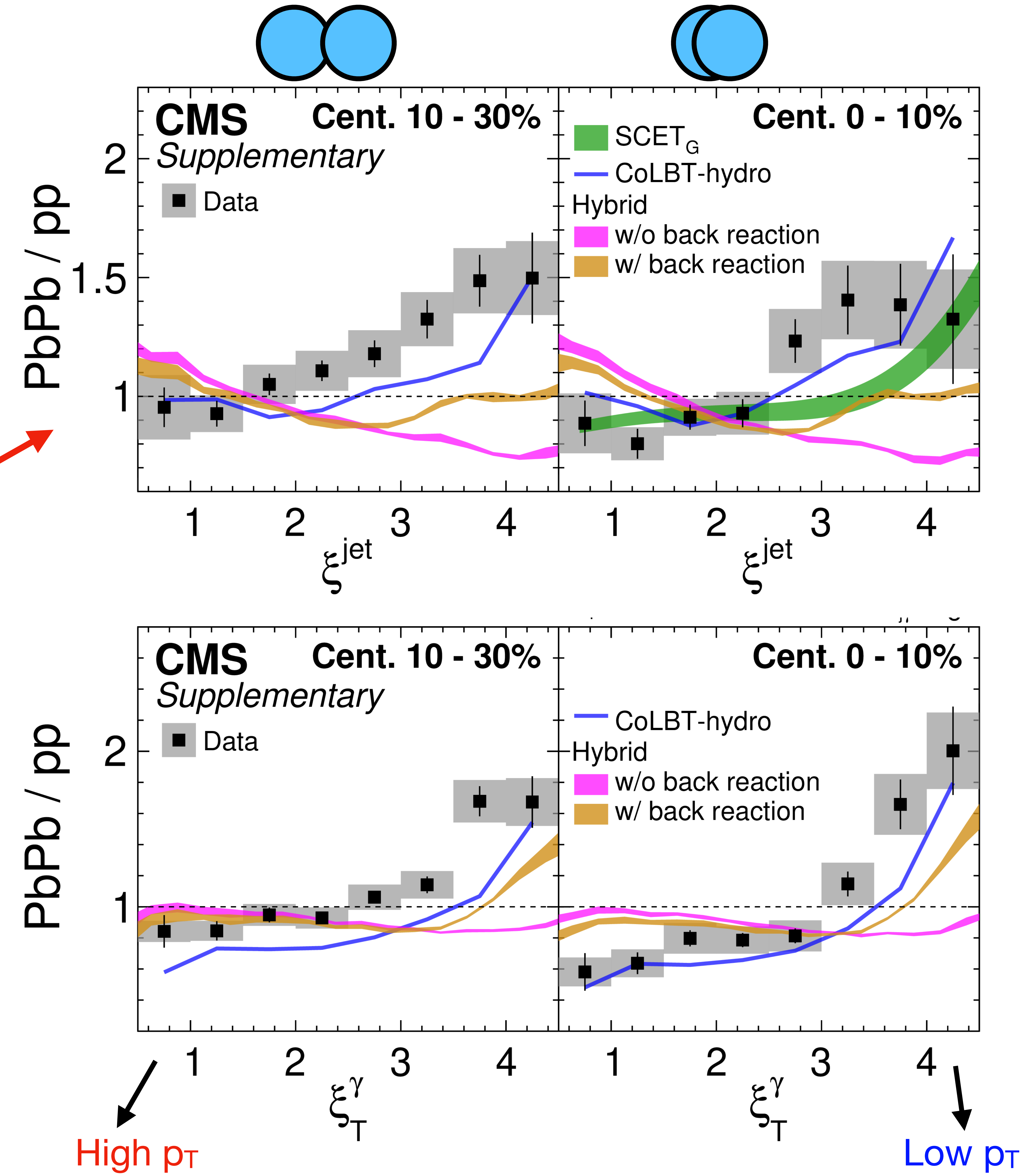
$p_T^{\gamma} : 80 - 126\ GeV$

- Consistent results between detectors
- Enhanced low-p_T and depletion of high-p_T particles

Where is the energy going? — using reconstructed jets

PRL 121 242301 (**2018**)



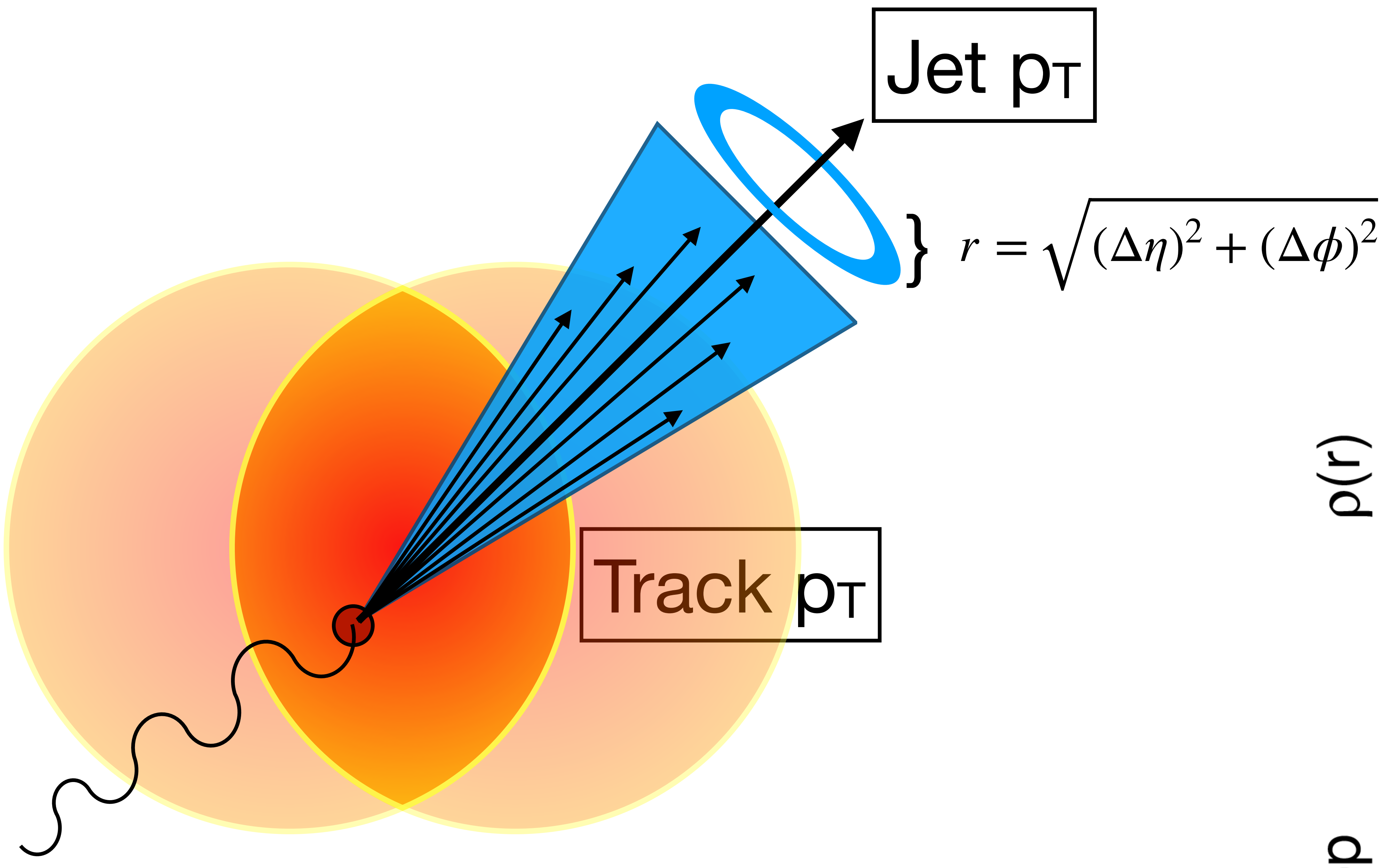


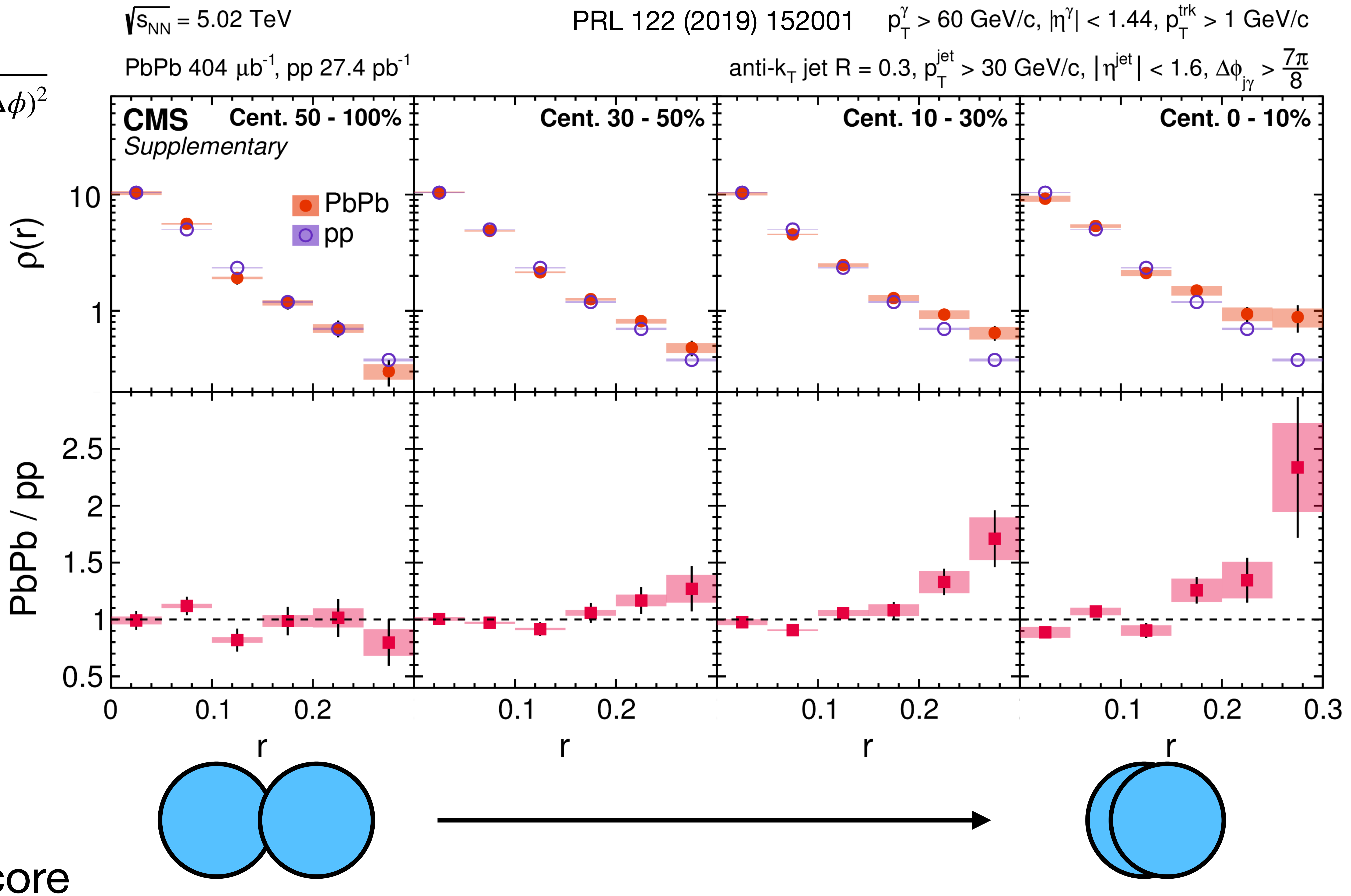
Fragmentation function:

$$\xi^{jet} = ln\frac{|\vec{p}_T^{\,jet}|^2}{\vec{p}_T^{\,jet}\cdot\vec{p}_T^{\,trk}} \qquad \xi_T^{\gamma} = ln\frac{-|\vec{p}_T^{\,\gamma}|^2}{\vec{p}_T^{\,\gamma}\cdot\vec{p}_T^{\,trk}}$$

- Consistent results for **jet** and **ɣ** p_T normalization
- Enhanced low-p_T and depletion of high-p_T particles

Where is the energy going? — with reconstructed jets



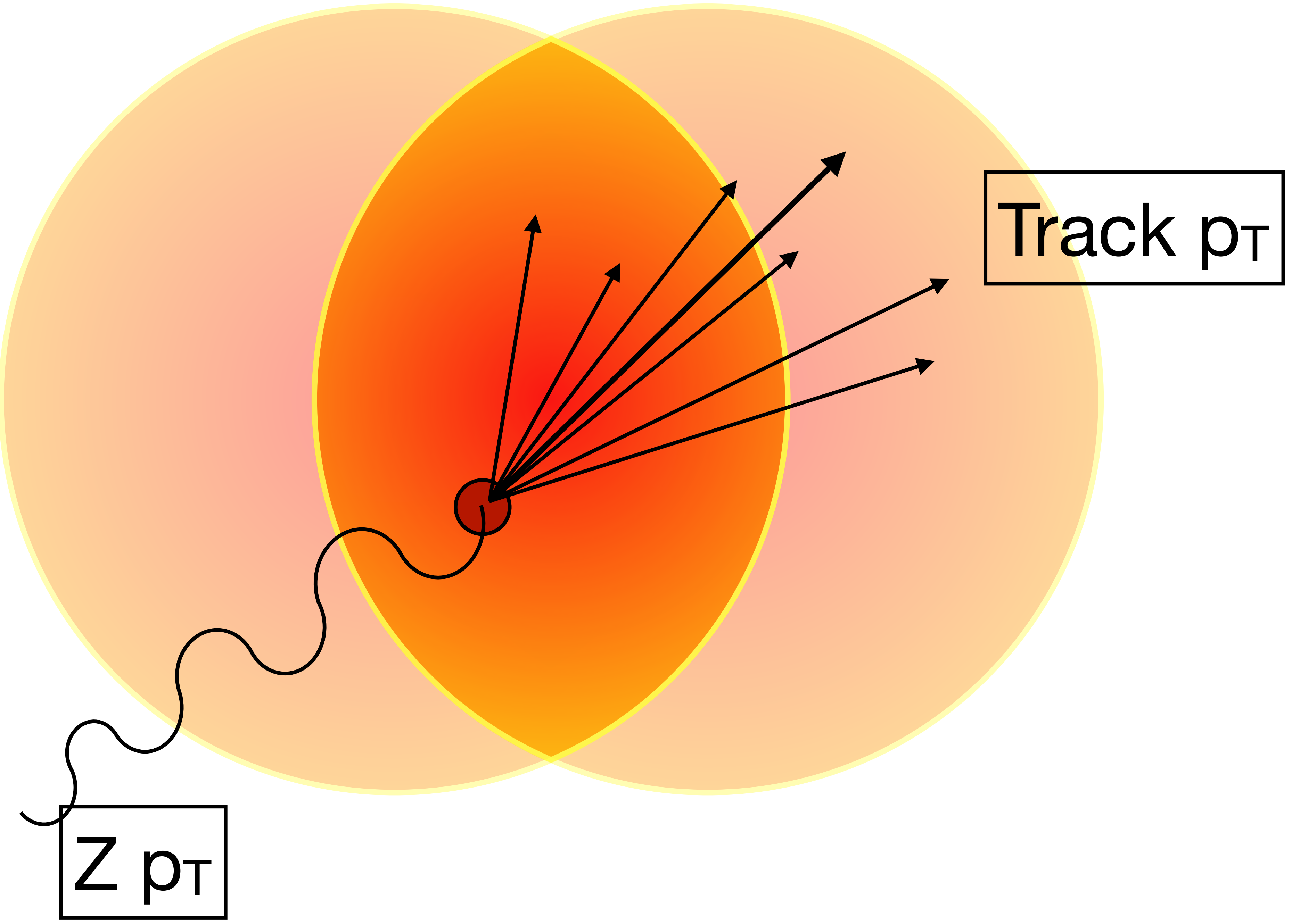


Radial momentum density:

$$\rho(r) = \frac{1}{\delta r} \frac{\sum_{jet} \sum_{r_a<r<r_b} p_T^{trk}/p_T^{jet}}{\sum_{jet} \sum_{r_a<r<r_f} p_T^{trk}/p_T^{jet}}$$

- Small relative modification of jet core
- Enhancement of particles away from jet axis

Where is the energy going? — without reconstructed jets



Why?

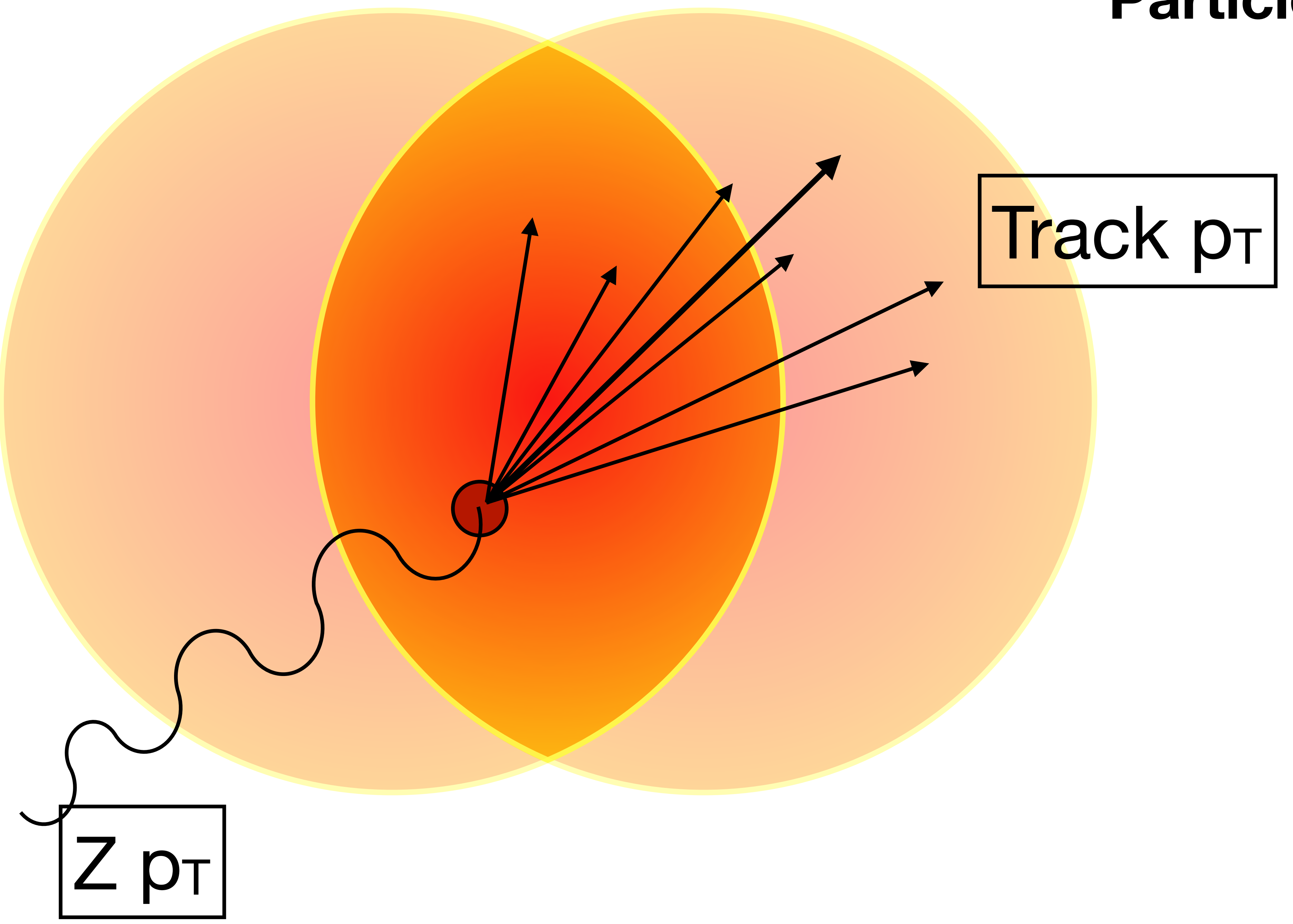
- To remove jet p_T bias

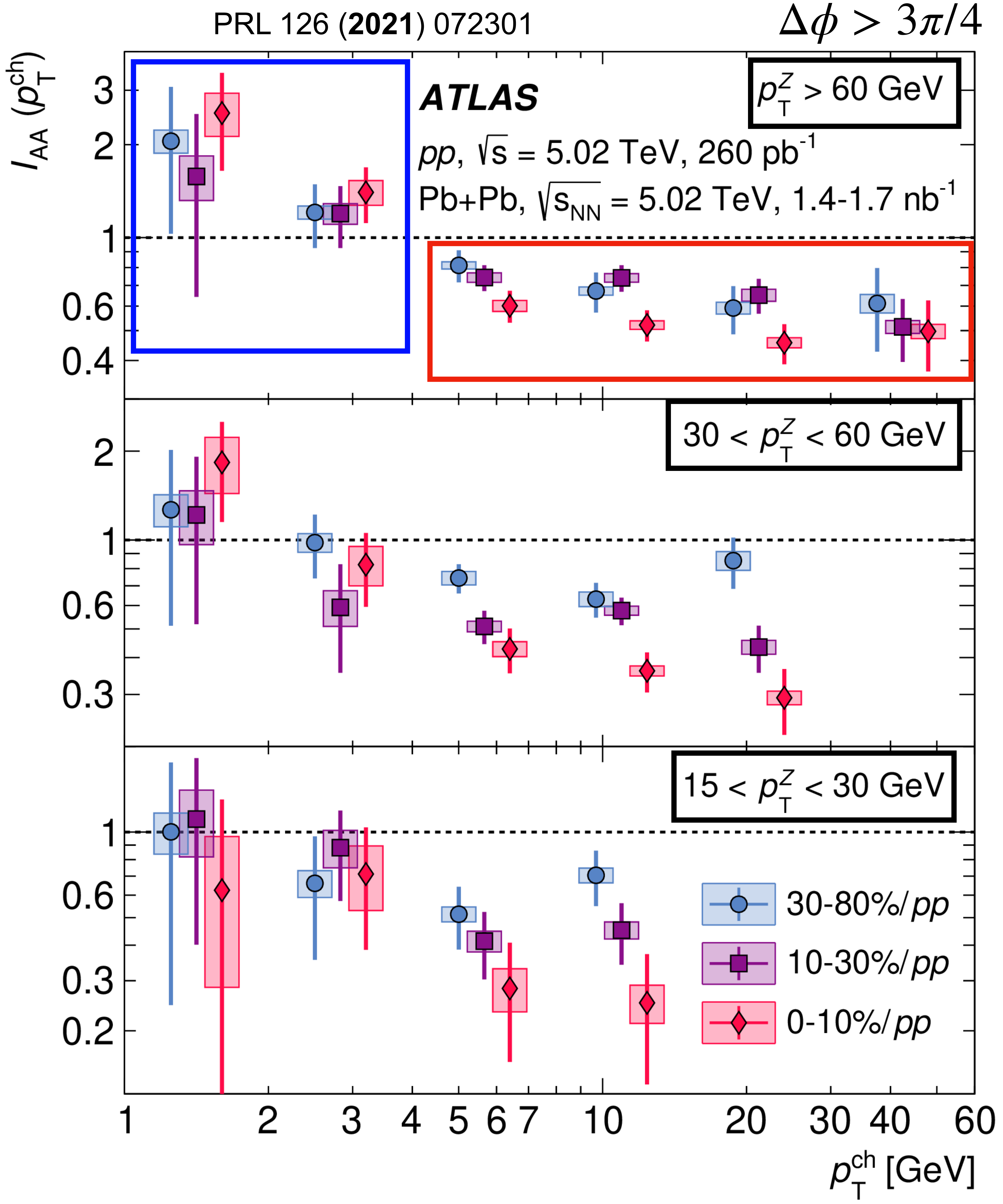
We use Z-boson (intead of γ)

- Almost no background

Where is the energy going? — without reconstructed jets

$$I_{AA} = \frac{\text{Particles per Z in Pb+Pb}}{\text{Particles per Z in p+p}}$$

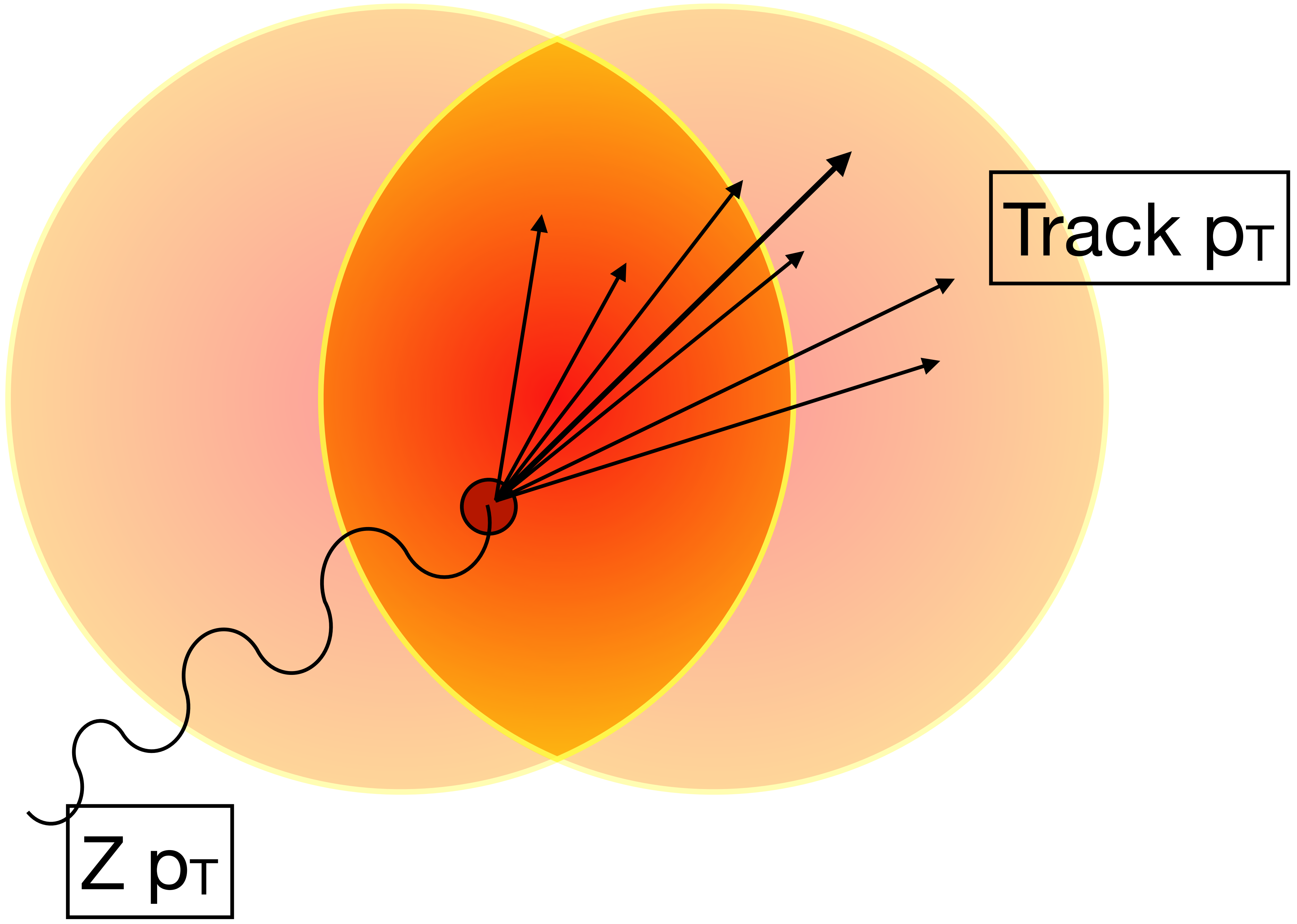




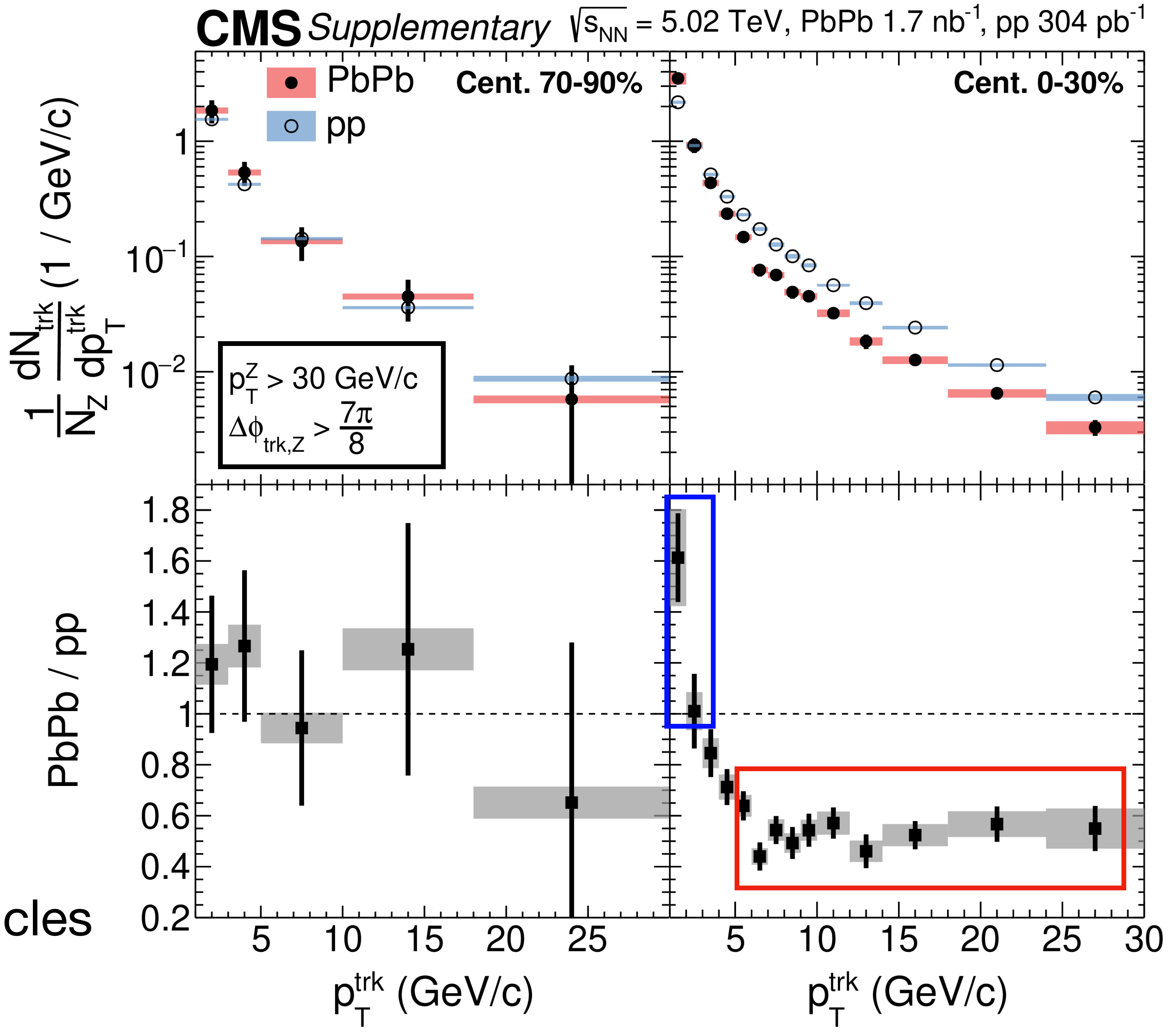
p_T spectrum: p_T^{Trk}

- Enhanced low-p_T and depletion of high-p_T particles

Where is the energy going? — without reconstructed jets



p_T spectrum: p_T^{Trk}

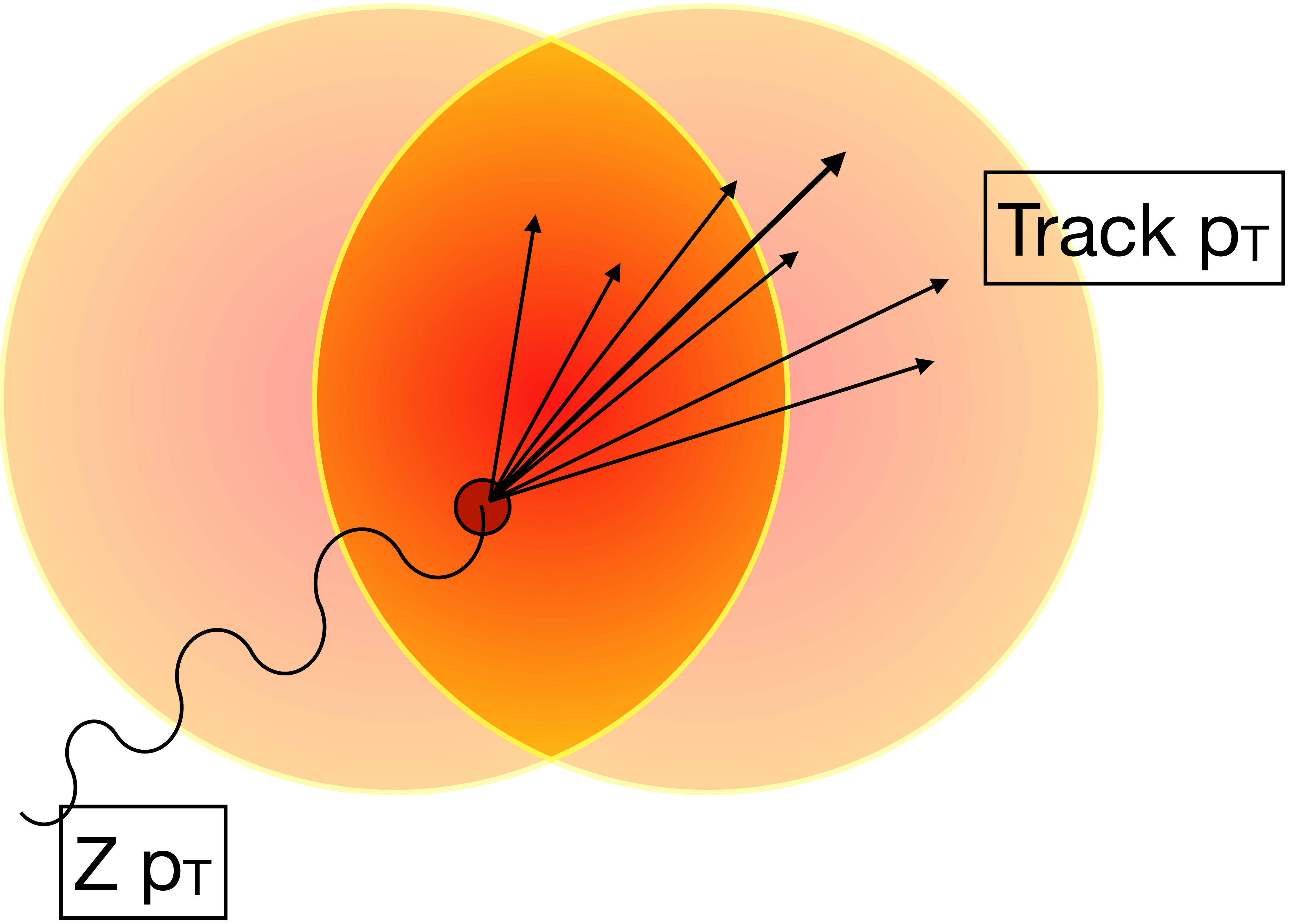


- Enhanced low-p_T and depletion of high-p_T particles
- Consistent results between detectors

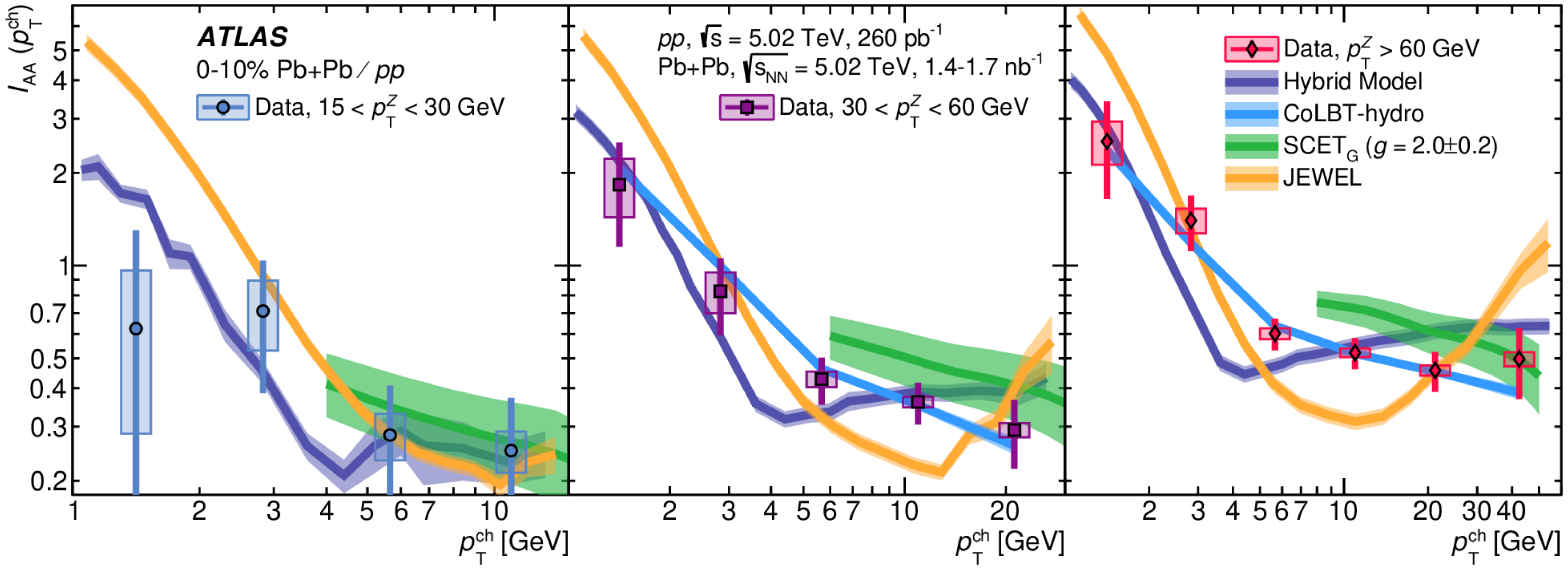
PRL 128 (**2022**) 122301

Where is the energy going? — without reconstructed jets

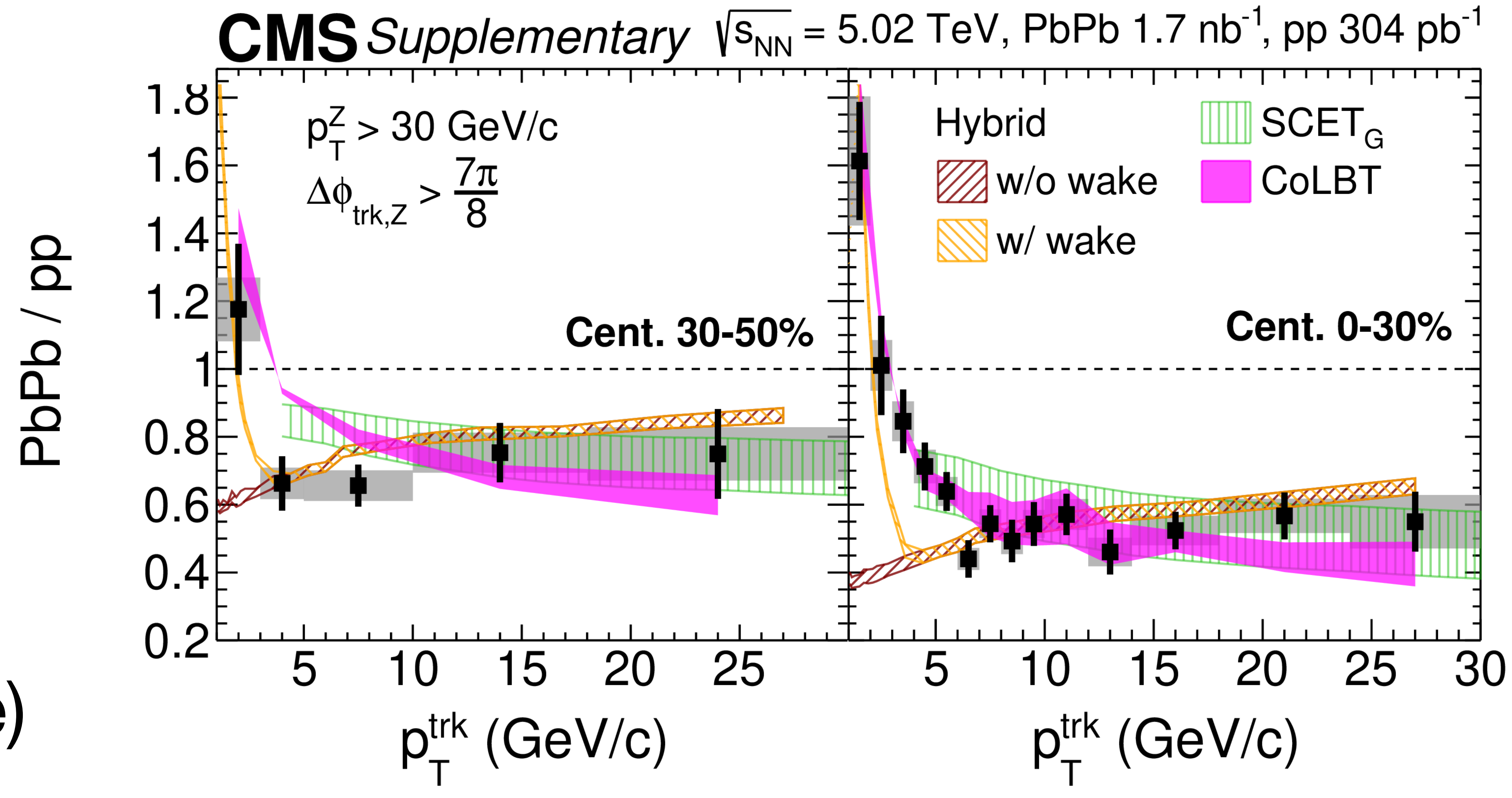
$$I_{AA} = \frac{\text{Particles per Z in Pb+Pb}}{\text{Particles per Z in p+p}}$$



PRL 126 (**2021**) 072301



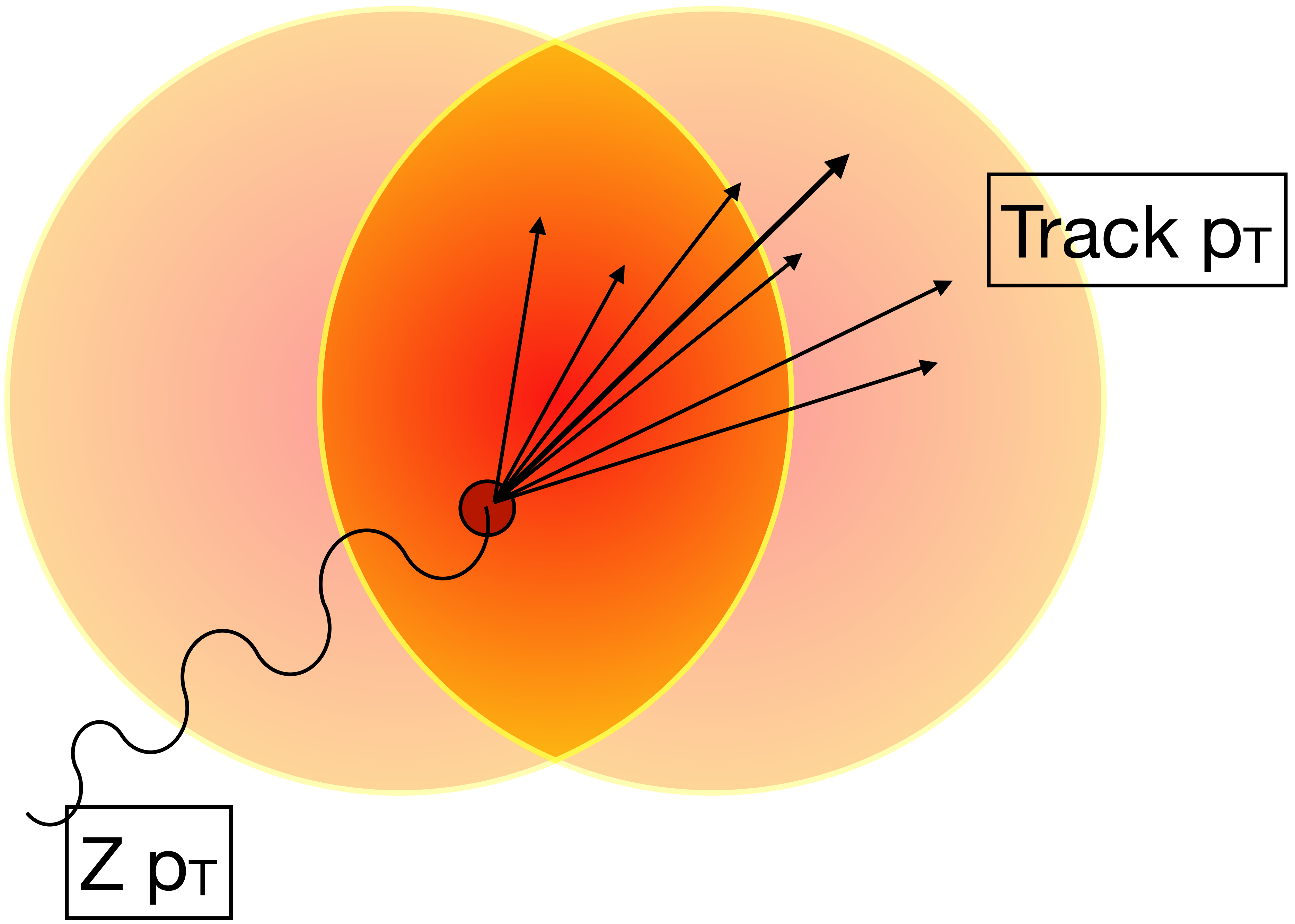
p_T spectrum: p_T^{Trk}



PRL 128 (**2022**) 122301

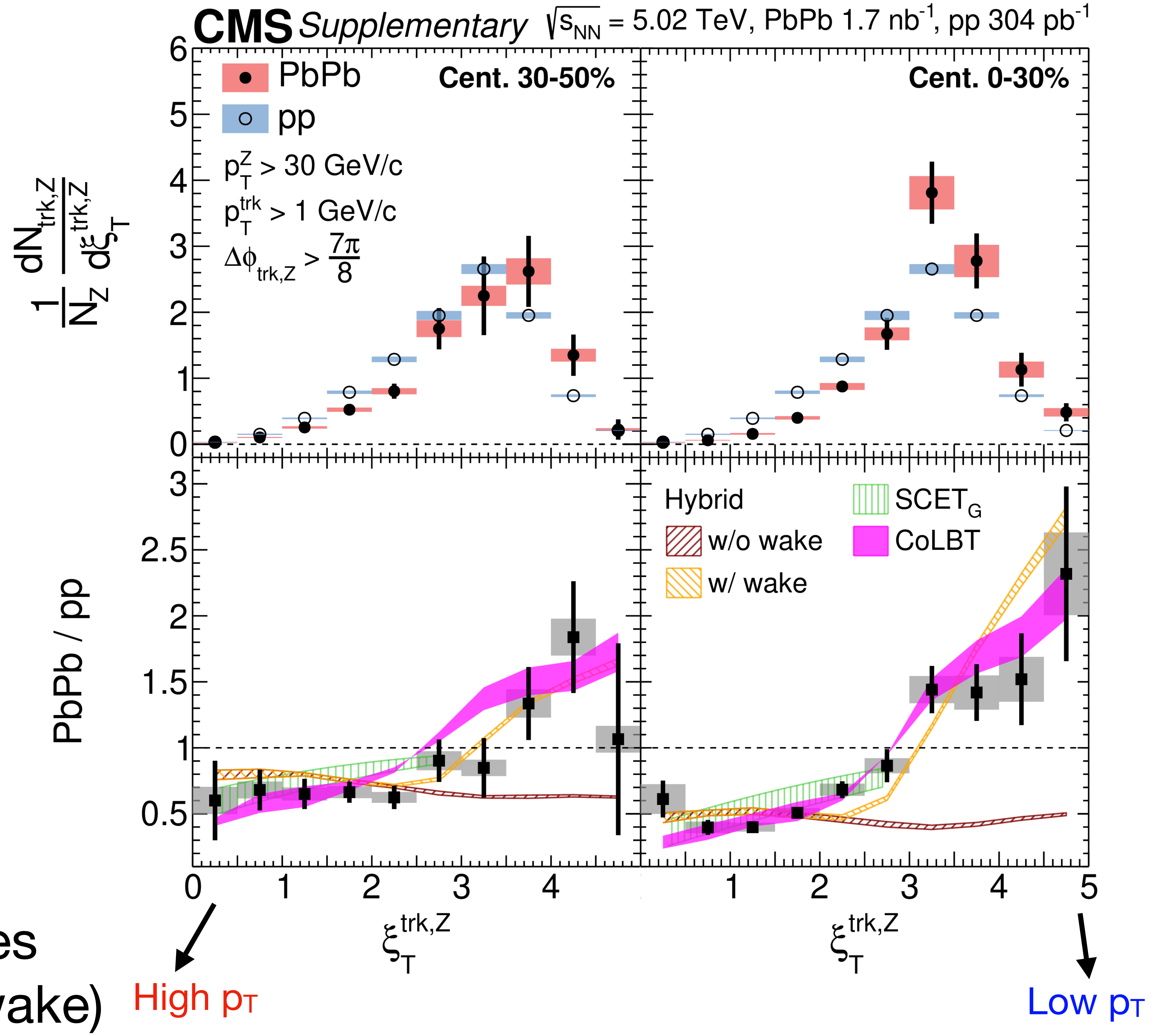
- Enhanced low-p_T and depletion of high-p_T particles
- Consistent results between detectors
- Low p_T hadrons, sensitive to medium response (wake)
  - Hybrid==> strong coupling regimes

Where is the energy going? — without reconstructed jets



Fragmentation function:

$$z = \frac{\vec{p}_T^{\,Z} \cdot \vec{p}_T^{\,trk}}{|\vec{p}_T^{\,Z}|^2} \qquad \xi^Z = ln\frac{-|\vec{p}_T^{\,Z}|^2}{\vec{p}_T^{\,Z} \cdot \vec{p}_T^{\,trk}}$$

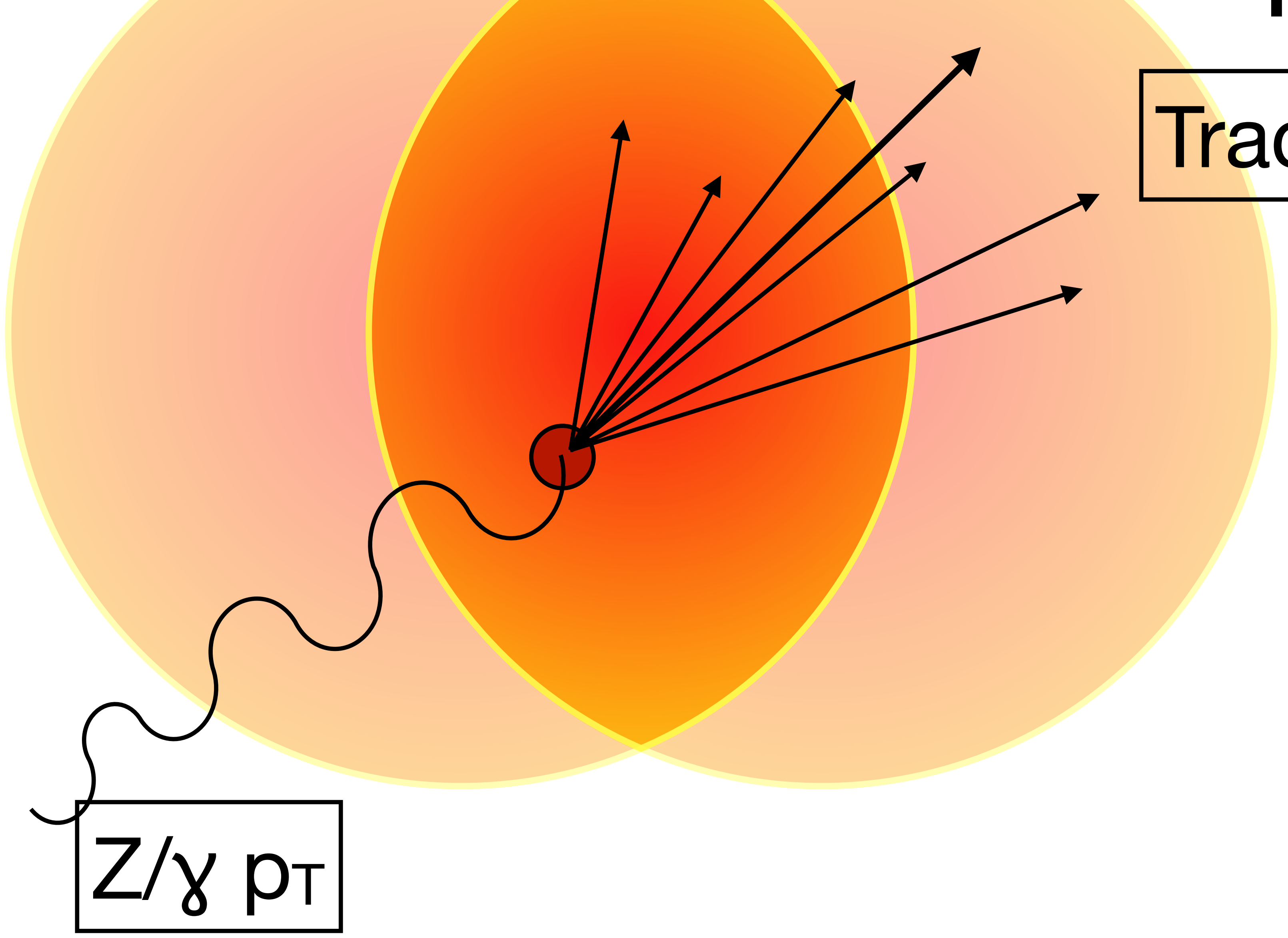


- Enhanced low-p_T and depletion of high-p_T particles
- Low p_T hadrons, sensitive to medium response (wake)
  - Hybrid==> strong coupling regimes

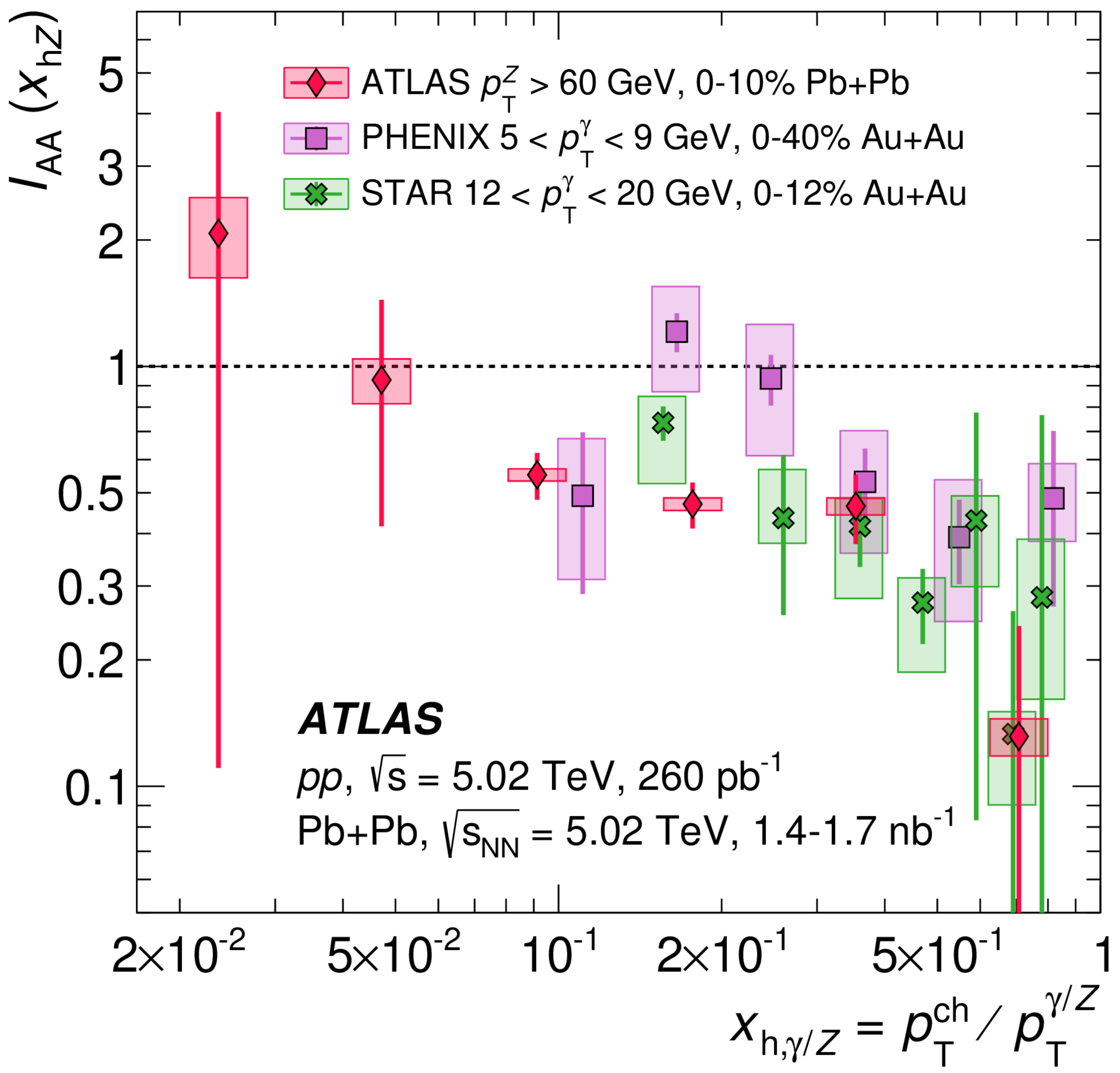
PRL 128 (**2022**) 122301

Where is the energy going? — without reconstructed jets

$$I_{AA} = \frac{\text{Particles per Z in Pb+Pb}}{\text{Particles per Z in p+p}}$$



PRL 126 (**2021**) 072301



Fragmentation function:

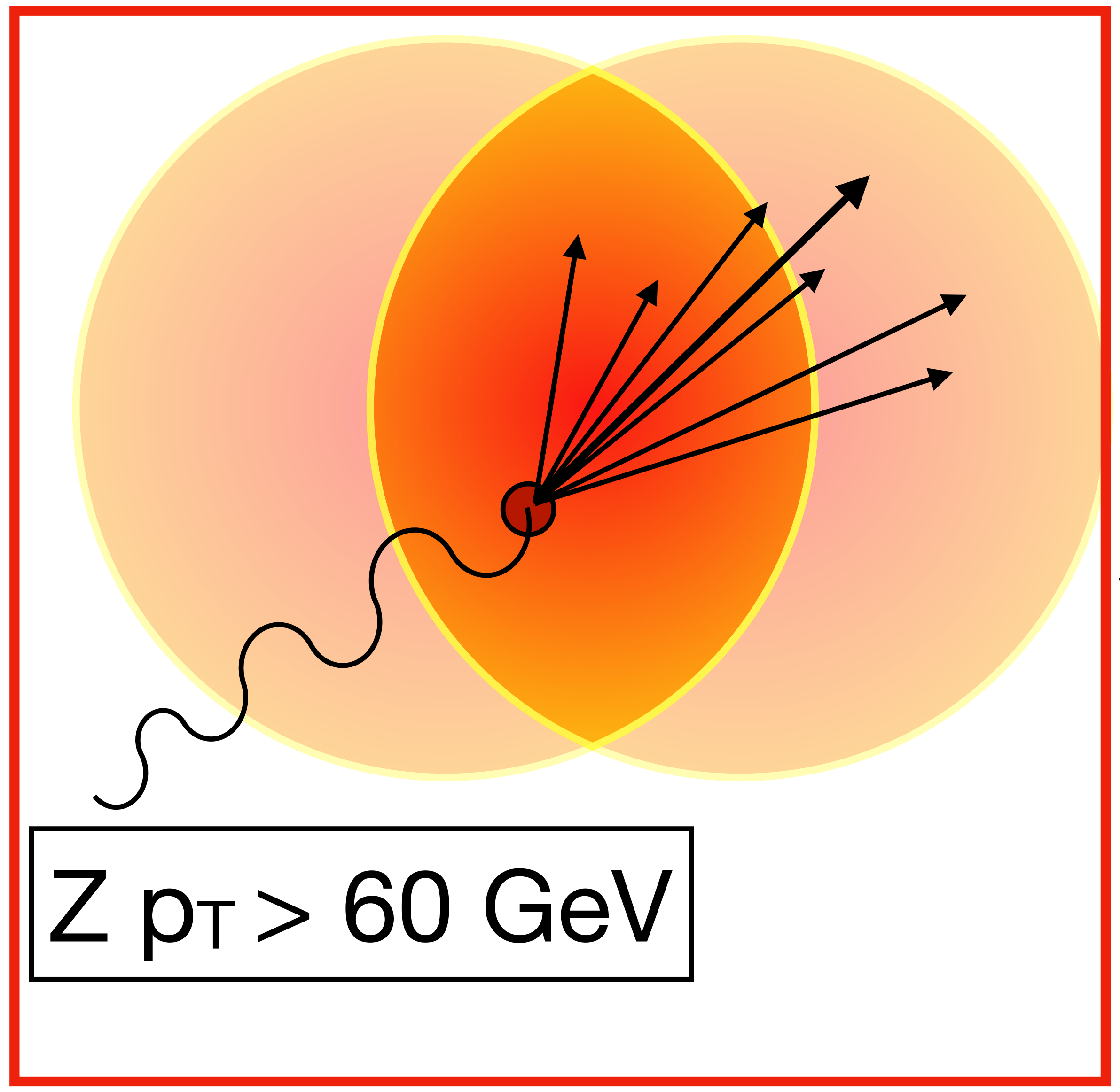
$$z = \frac{\vec{p}_T^{\,Z} \cdot \vec{p}_T^{\,trk}}{|\vec{p}_T^{\,Z}|^2} \qquad \xi^Z = ln\frac{-|\vec{p}_T^{\,Z}|^2}{\vec{p}_T^{\,Z} \cdot \vec{p}_T^{\,trk}}$$

- Qualitatively similar depletion of high-p_T particles between **LHC and RICH**
  - RICH significant Lower pT with respect to LHC

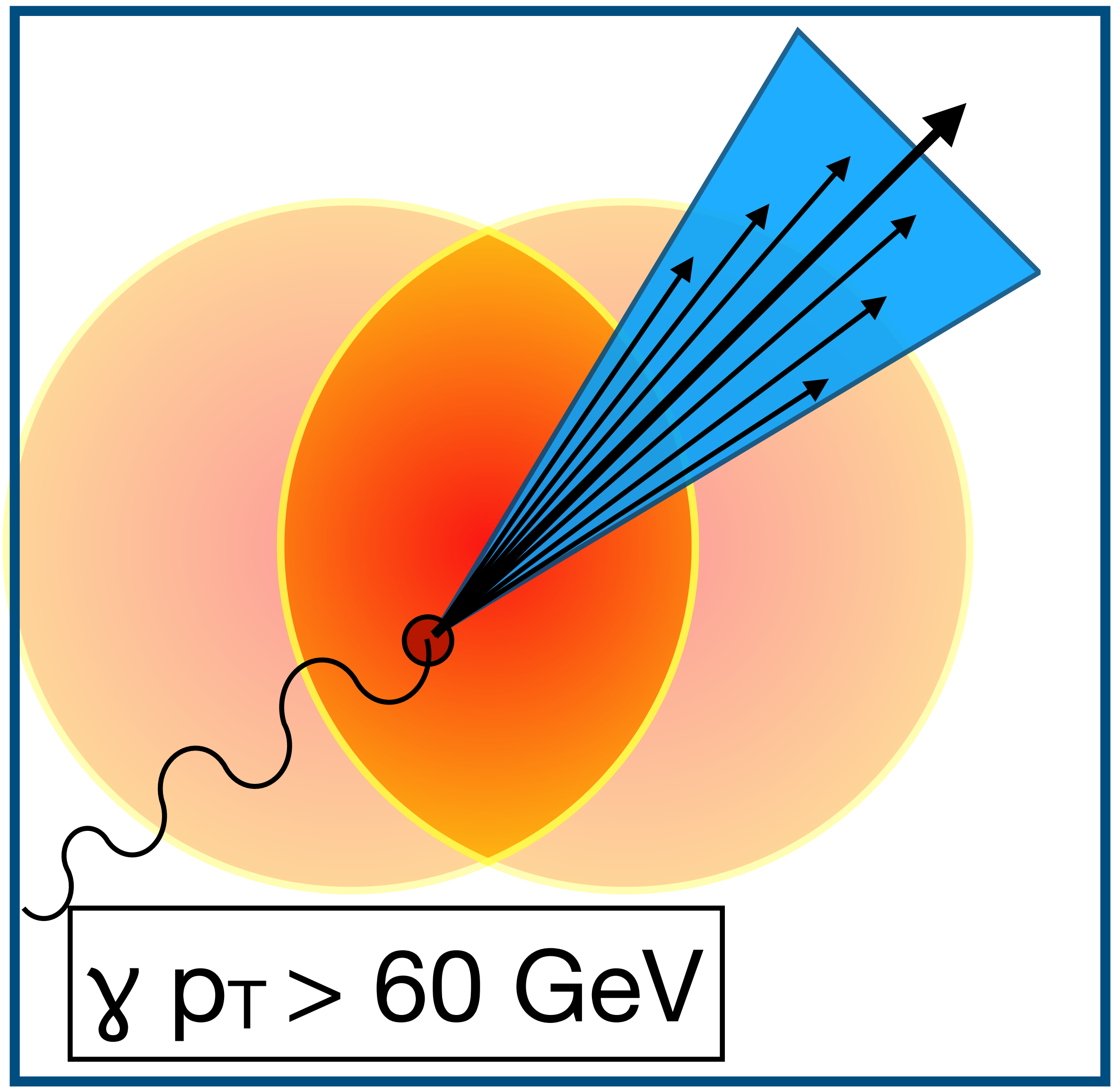
with and without reconstructed jets

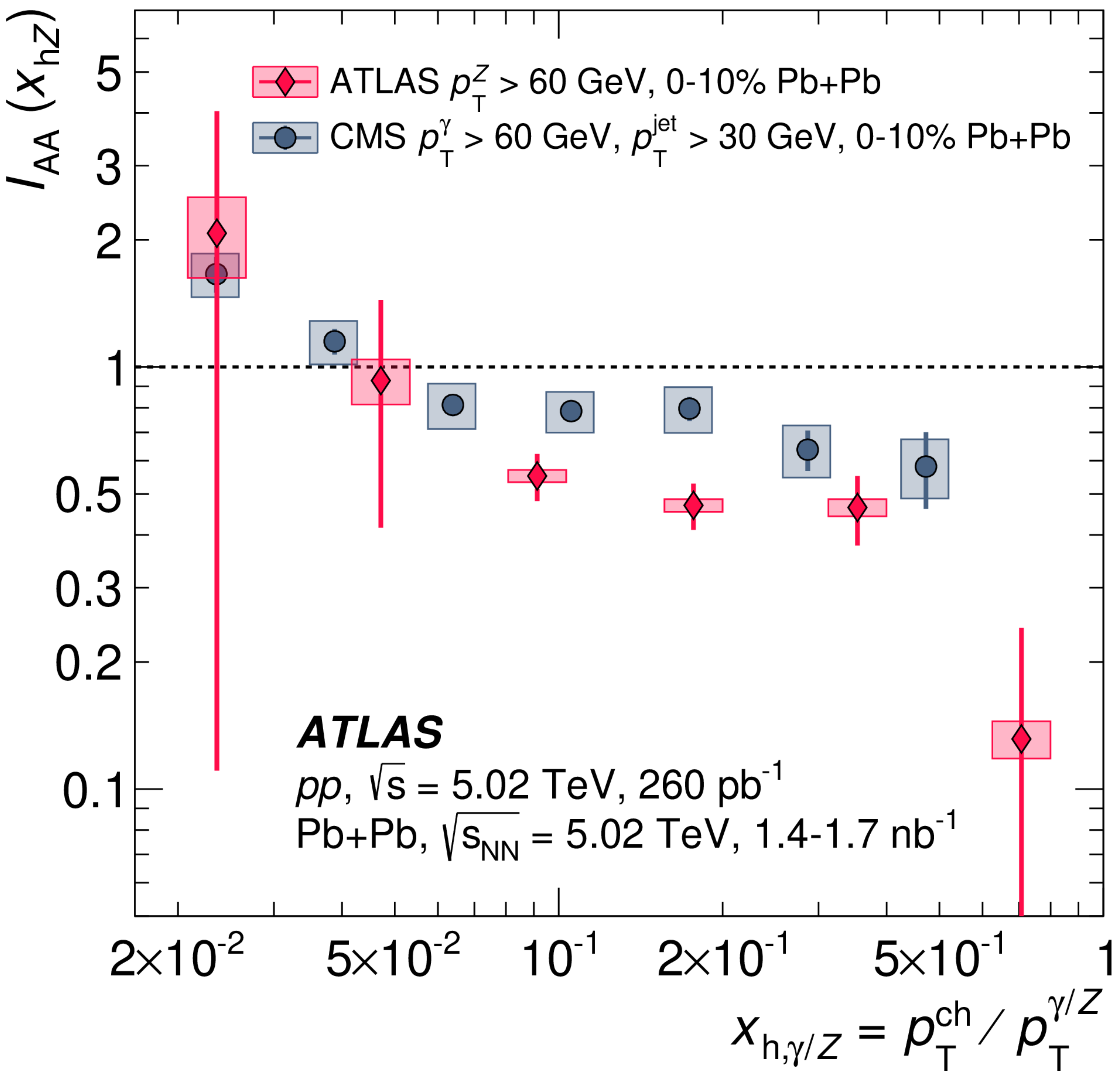
PRL 126 (**2021**) 072301

$$I_{AA} = \frac{\text{Particles per Z in Pb+Pb}}{\text{Particles per Z in p+p}}$$



v/s





Fragmentation function:

$$z = \frac{\vec{p}_T^{\,Z} \cdot \vec{p}_T^{\,trk}}{|\vec{p}_T^{\,Z}|^2}$$

- Similar pattern with and without reconstructed jet
- p_T > 30 GeV, may result in a selection bias against events with more energy loss … ?

Thank you!