Photon and photon+jet probes of small and large collision systems with ATLAS

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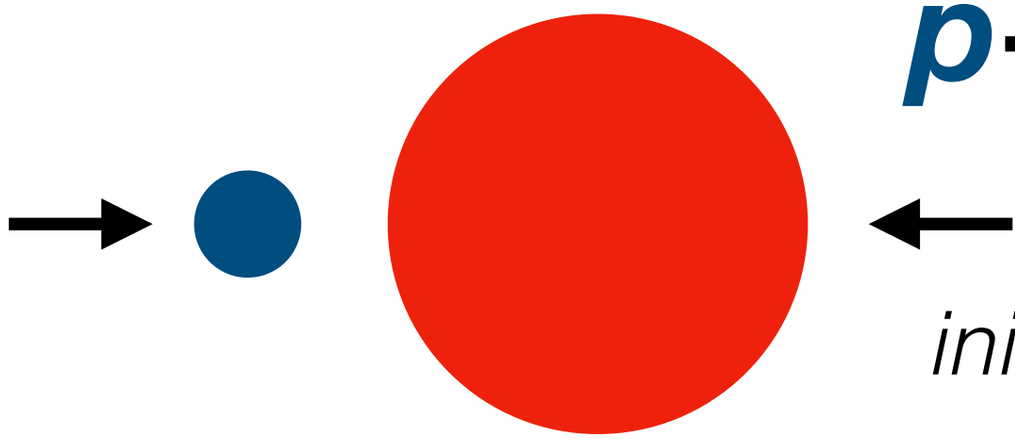
p+p

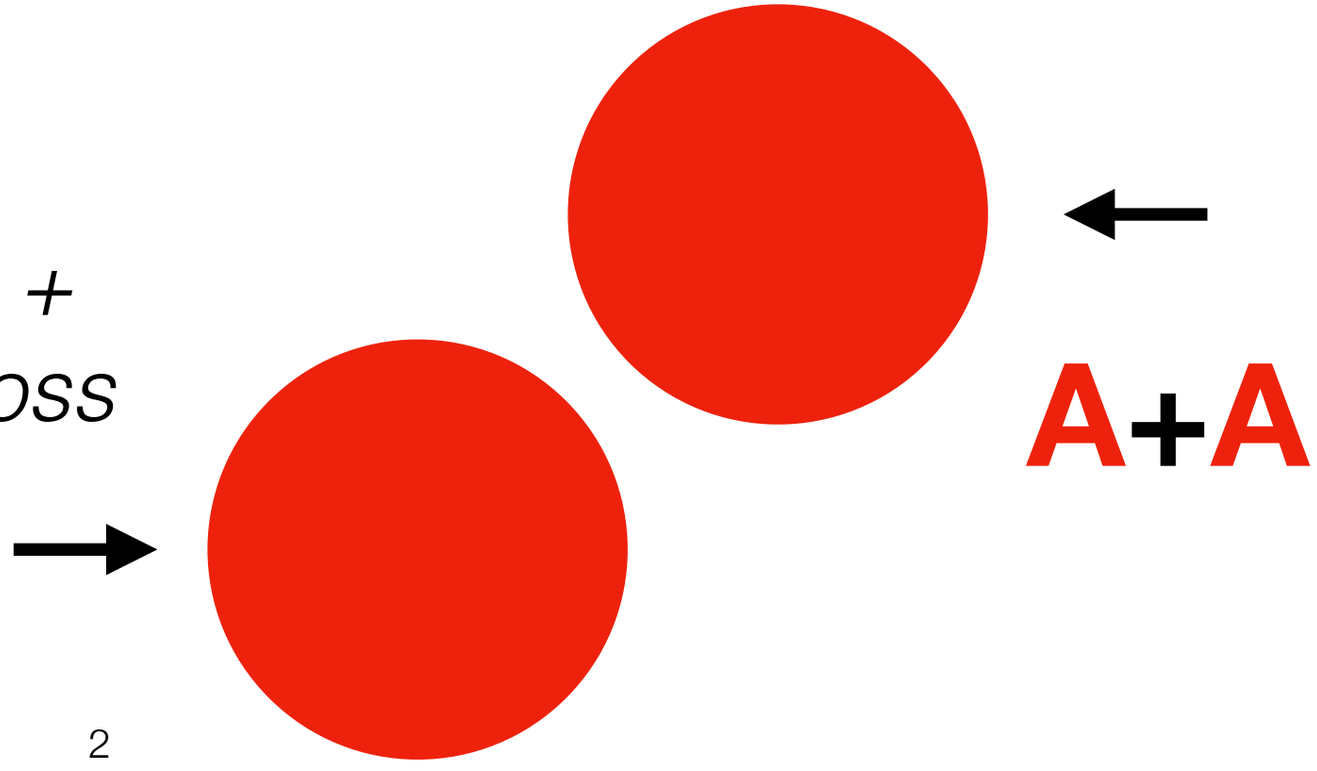
pQCD baseline for isolated photon spectra / photon+jet topologies

p+A



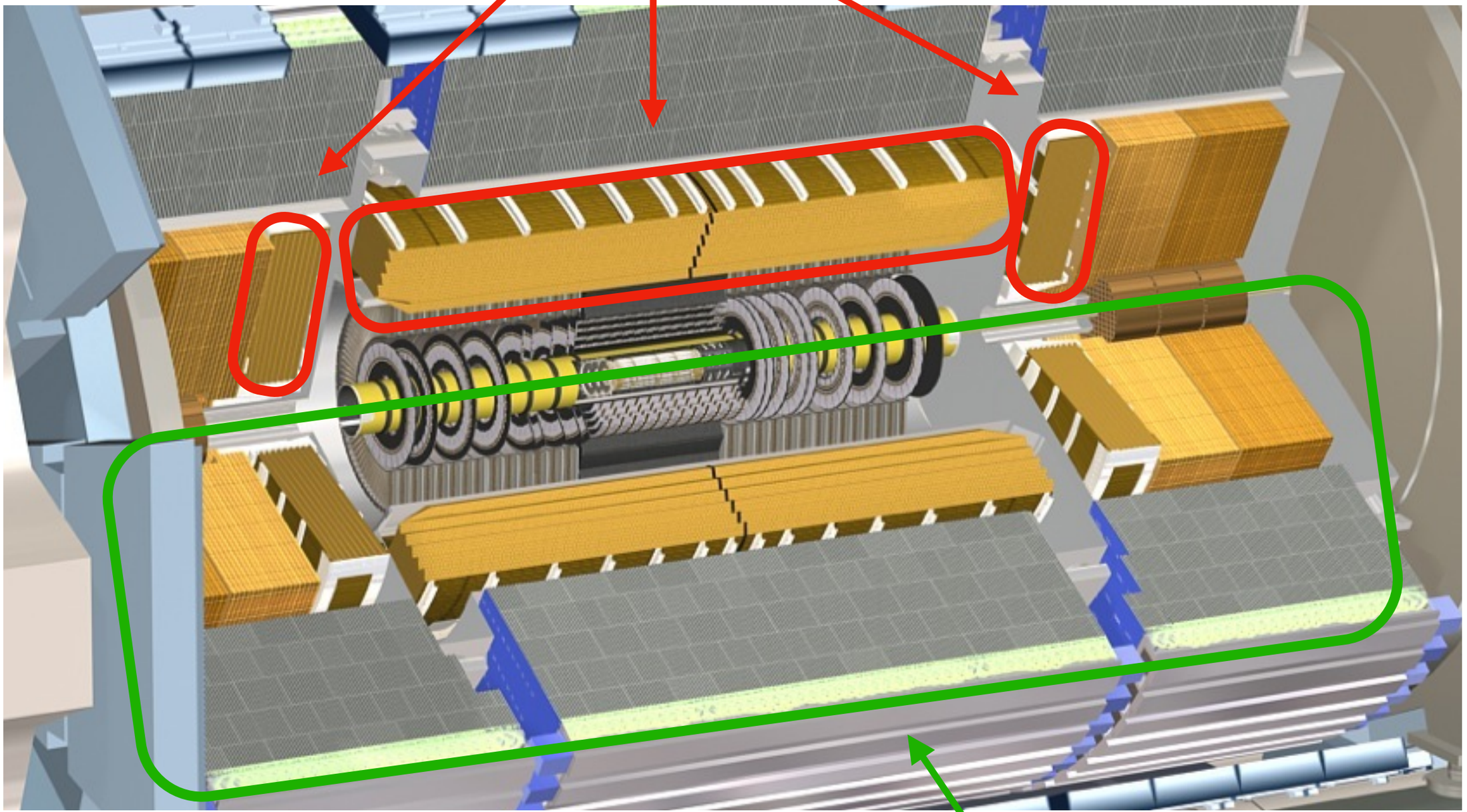
initial state effects

initial state effects + final-state energy-loss



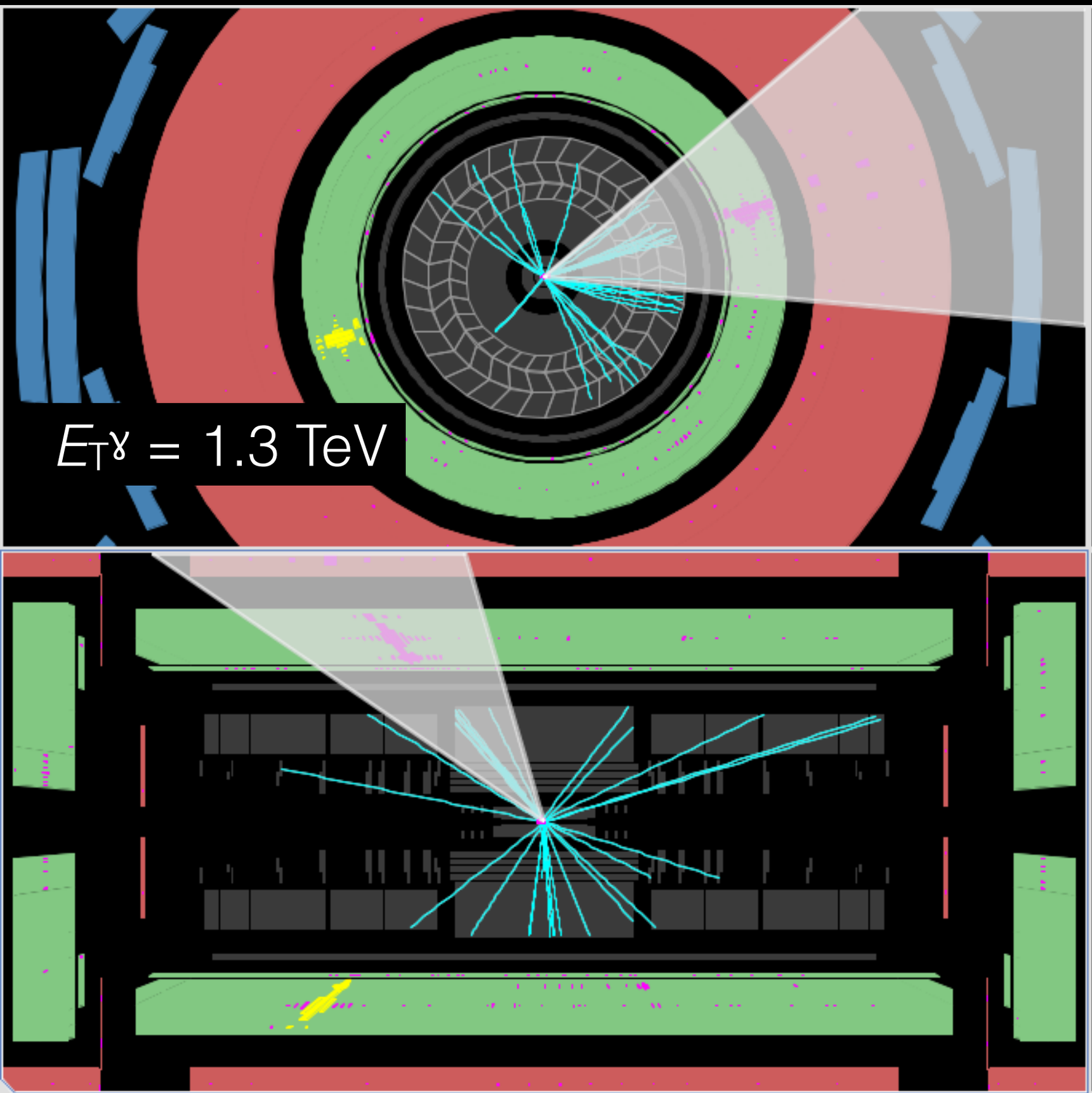
A+A

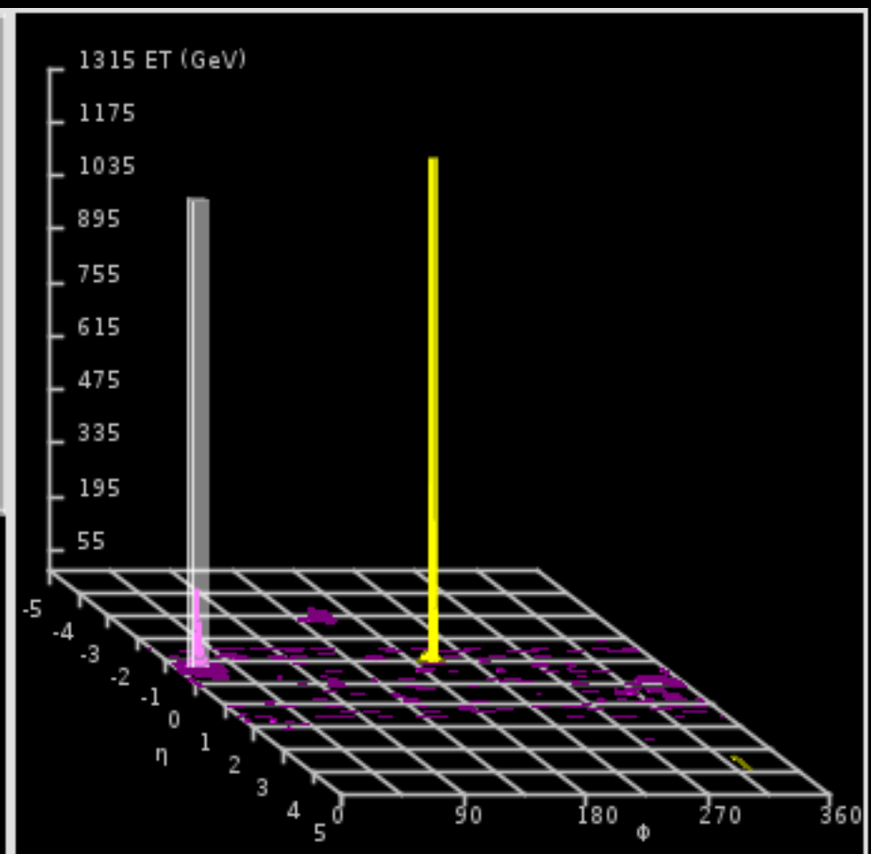
Photons in EM Barrel ($|\eta| < 2.37$)
and EM Endcap ($1.56 < |\eta| < 2.37$)



Jets in calorimeter system ($|\eta| < 4.9$),
but typically $|\eta| < 2.8$ in Heavy Ions,
or $|\eta| < 2.1$ for fragmentation functions ($|\eta^{trk}| < 2.5$)

γ+jet event, 13 TeV *pp*





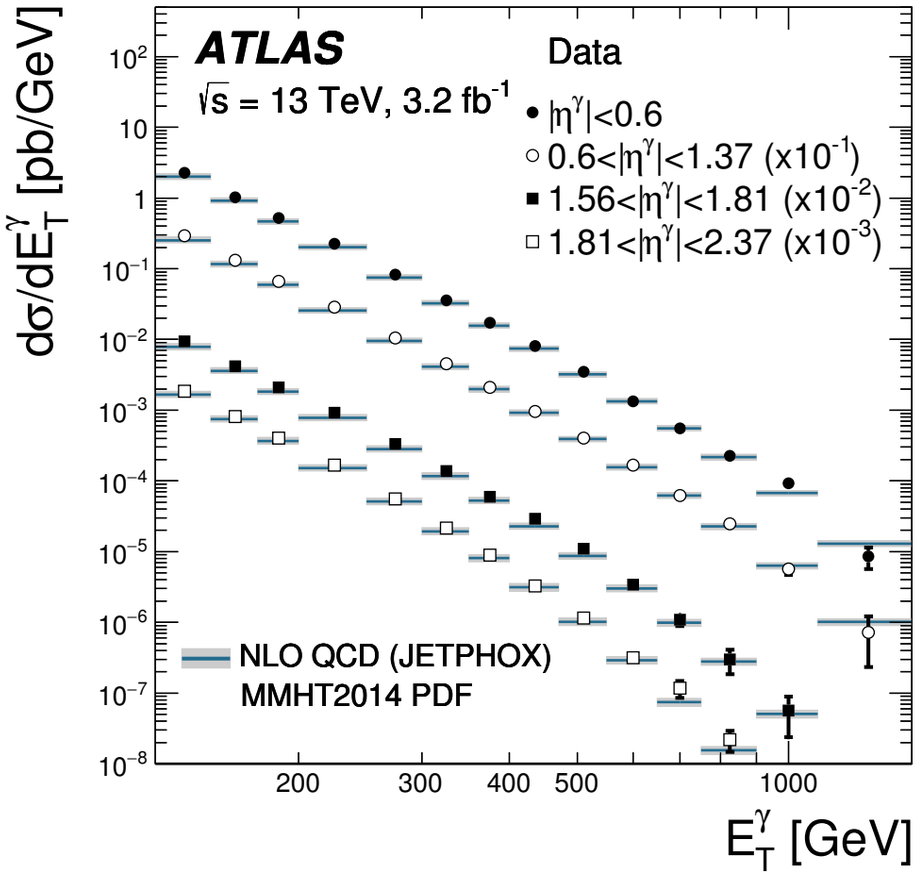
ATLAS EXPERIMENT

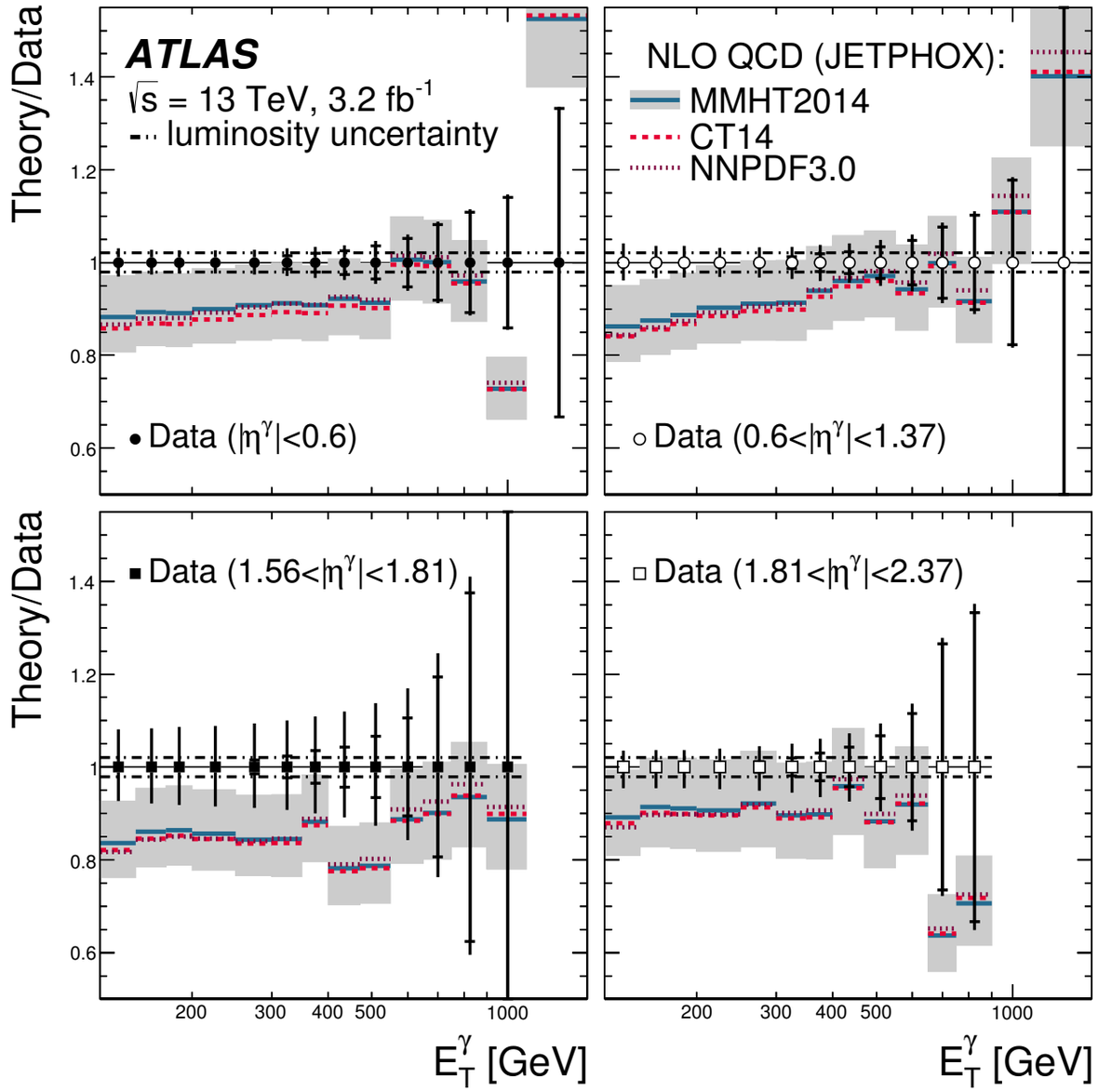
Run Number: 279284, Event Number: 768612867

Date: 2015-09-14 11:28:05 UTC

Isolated photon cross-sections

Phys. Lett. B 770 (2017) 473



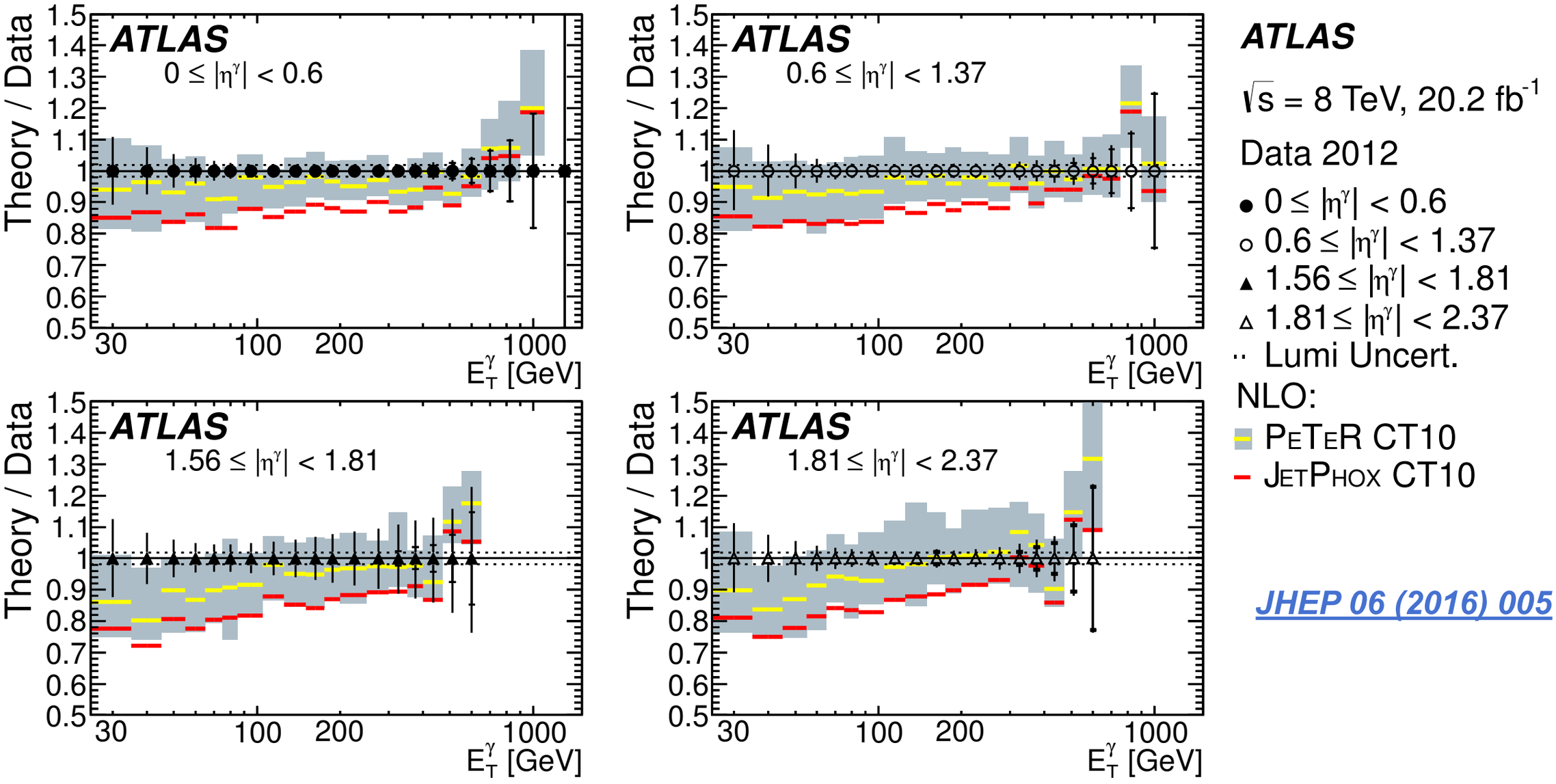


Kinematically broad measurements at 7 TeV, 8 TeV, 13 TeV (shown here)

- Early (7 TeV) data compatible w/ theory given large exp. uncertainties
- Newer data systematically higher than central JETPHOX (NLO pQCD)

  ➡ does not seem to be covered by “spread” of modern PDF sets

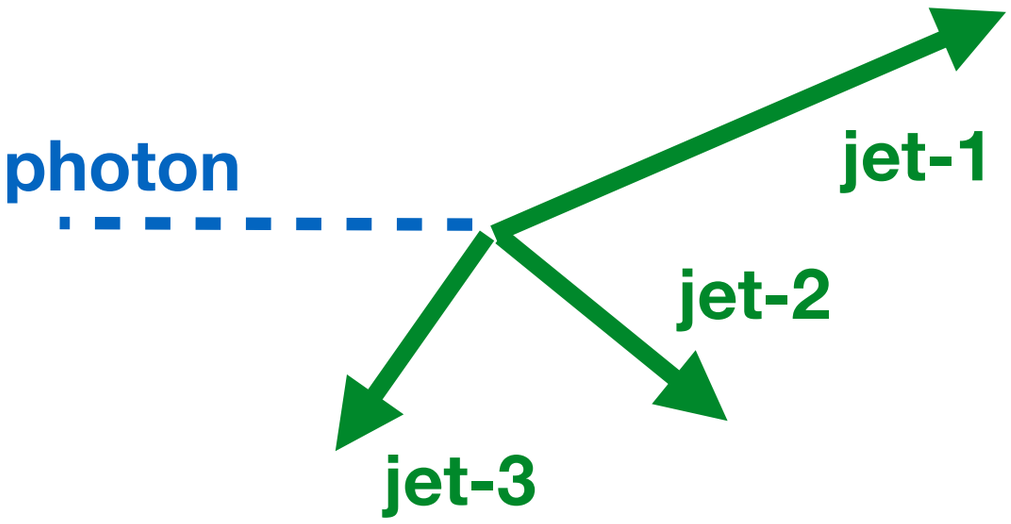
Isolated photon cross-sections



JHEP 06 (2016) 005

- Data / theory diff. larger at lower E_T, outside nominal scale unc.
  - ➡ no true NNLO photon+jets calculation, but can use for example PeTeR ("NNLO-like")
- Data more precise than state-of-the-art in theory…
  - ➡ important to have *pp* reference data for HI measurements…

Photon+multijet dynamics in *pp*

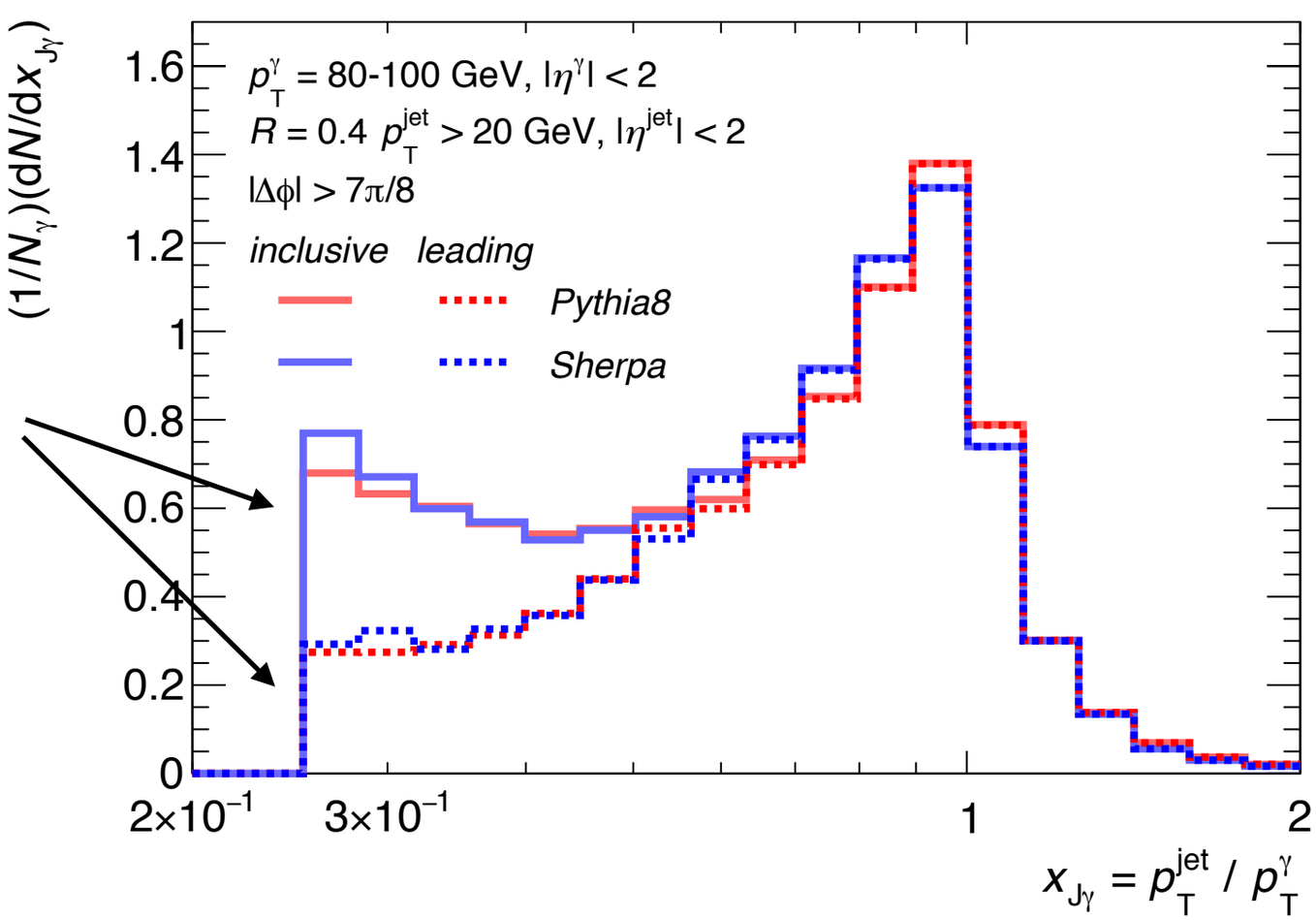


Tests fundamental production & radiation/hadronization dynamics

- ➡ handle on direct vs. fragmentation processes (in an LO sense)
- ➡ color connection / coherence effects between radiating partons

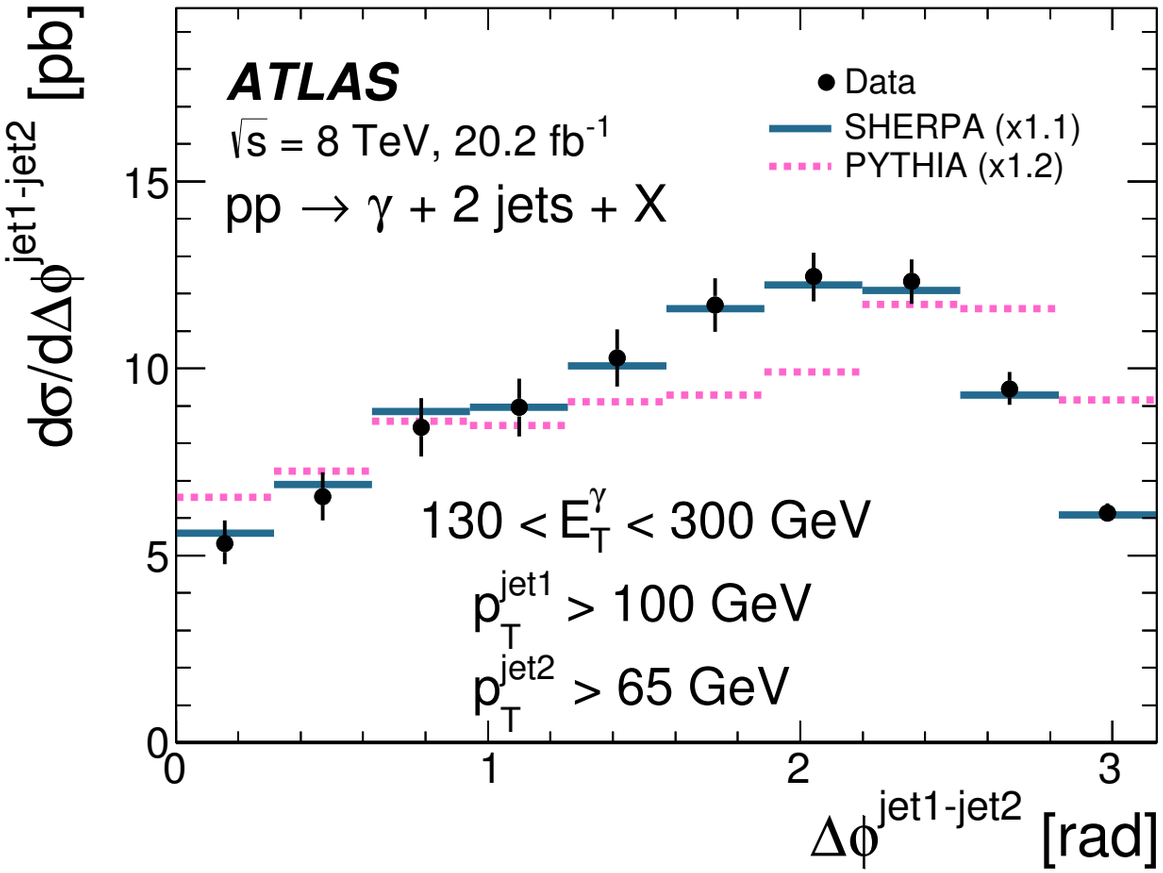
For HI measurements, large difference in low-p_T jet yield for *inclusive* vs. *leading* selection…

- ➡ different q/g fraction, different $\Delta\phi$ distribution, etc.
- ➡ can complicate interpretation of the data

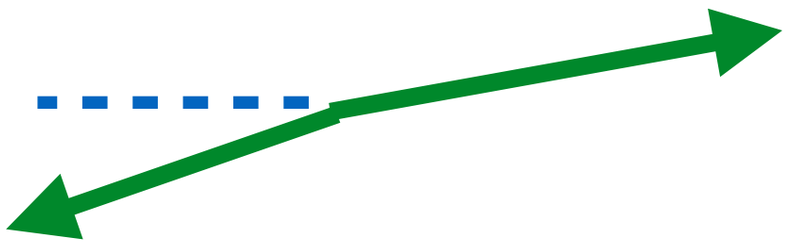


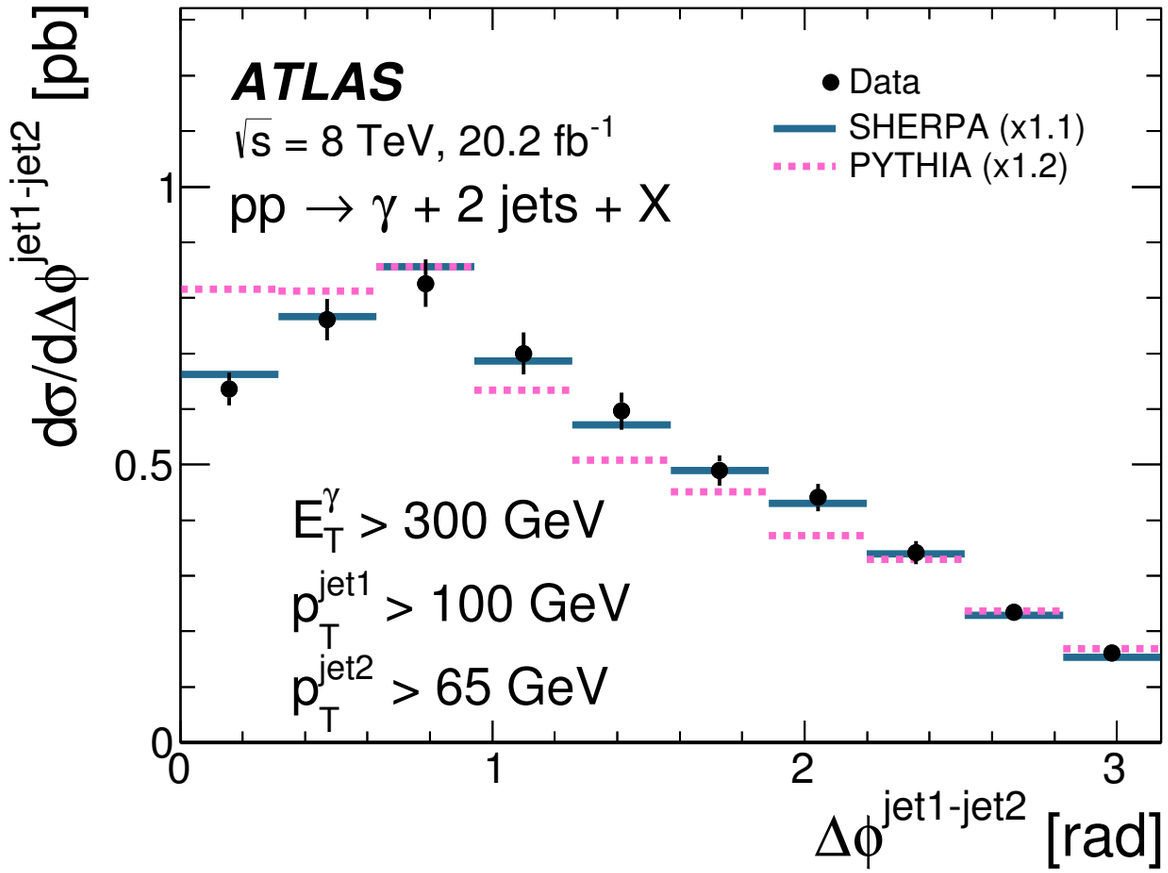
Photon+multijet dynamics in *pp*

"where is the 2nd jet most likely to be?"

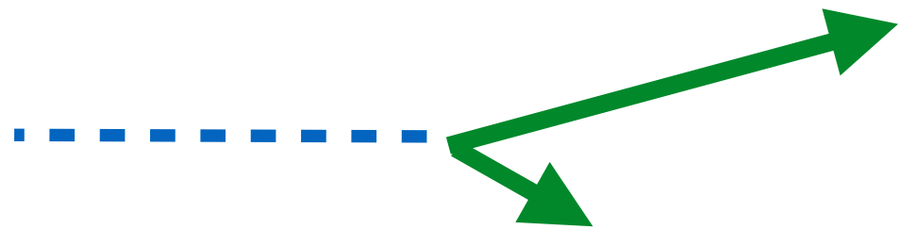


for larger $p_T^{jet\text{-}2}$ / p_T^{γ}, it is opposite the first jet…





for smaller $p_T^{jet\text{-}2}$ / p_T^{γ}, it is near the first jet…



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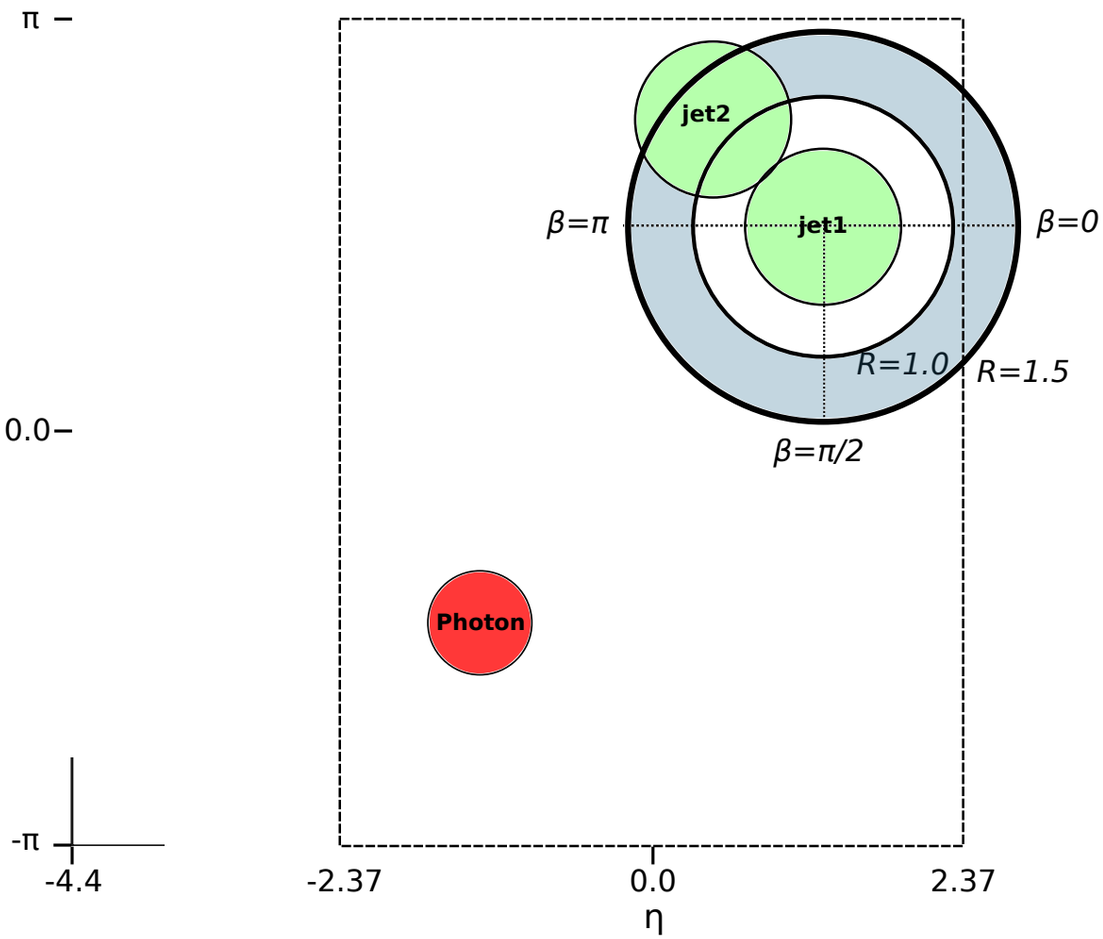
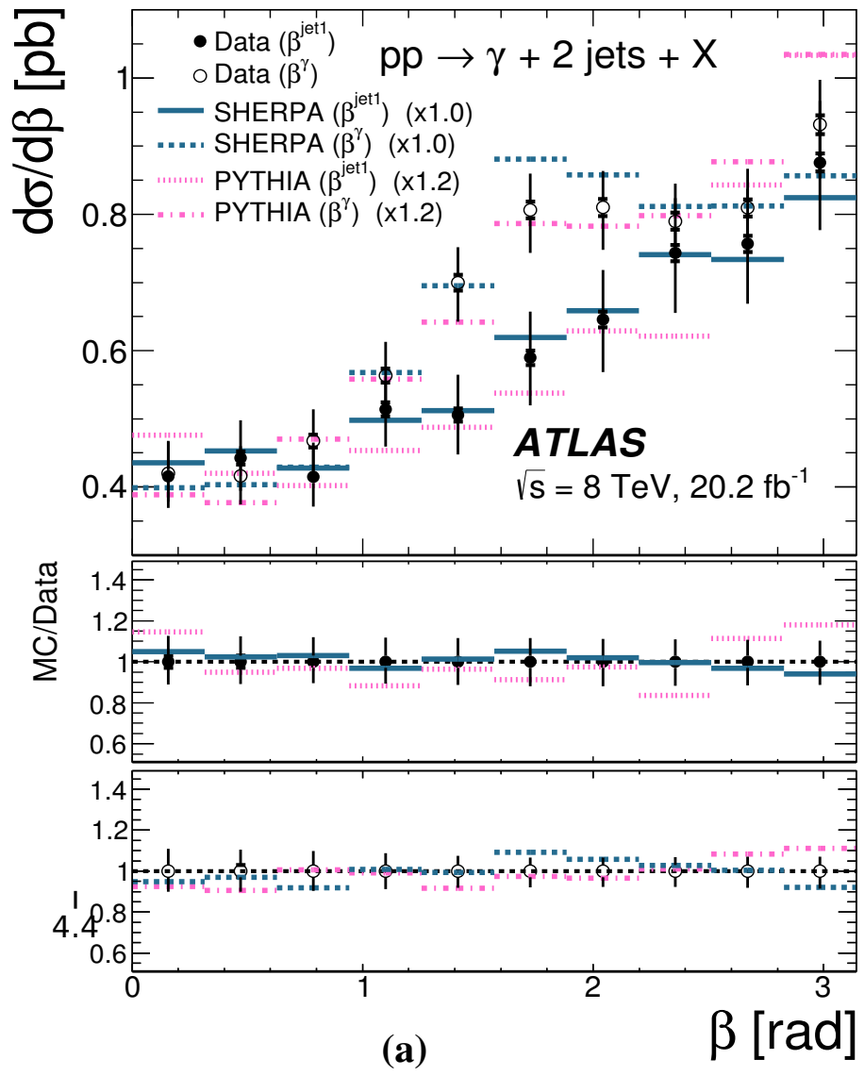
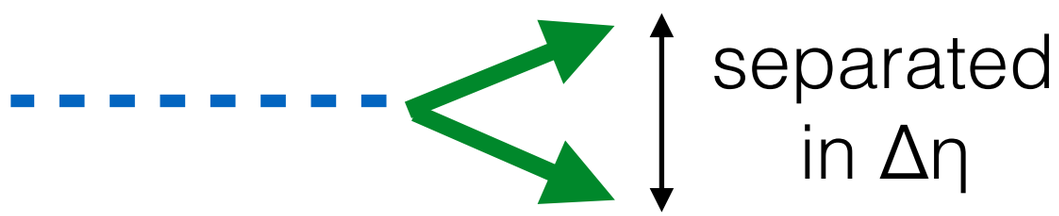
Photon+multijet dynamics in *pp*





For a second jet near the first jet:

➡ the two jets are more likely to be separated along the *η* direction (have similar $\Delta\phi^{\gamma+\text{jet}}$) than along ϕ …



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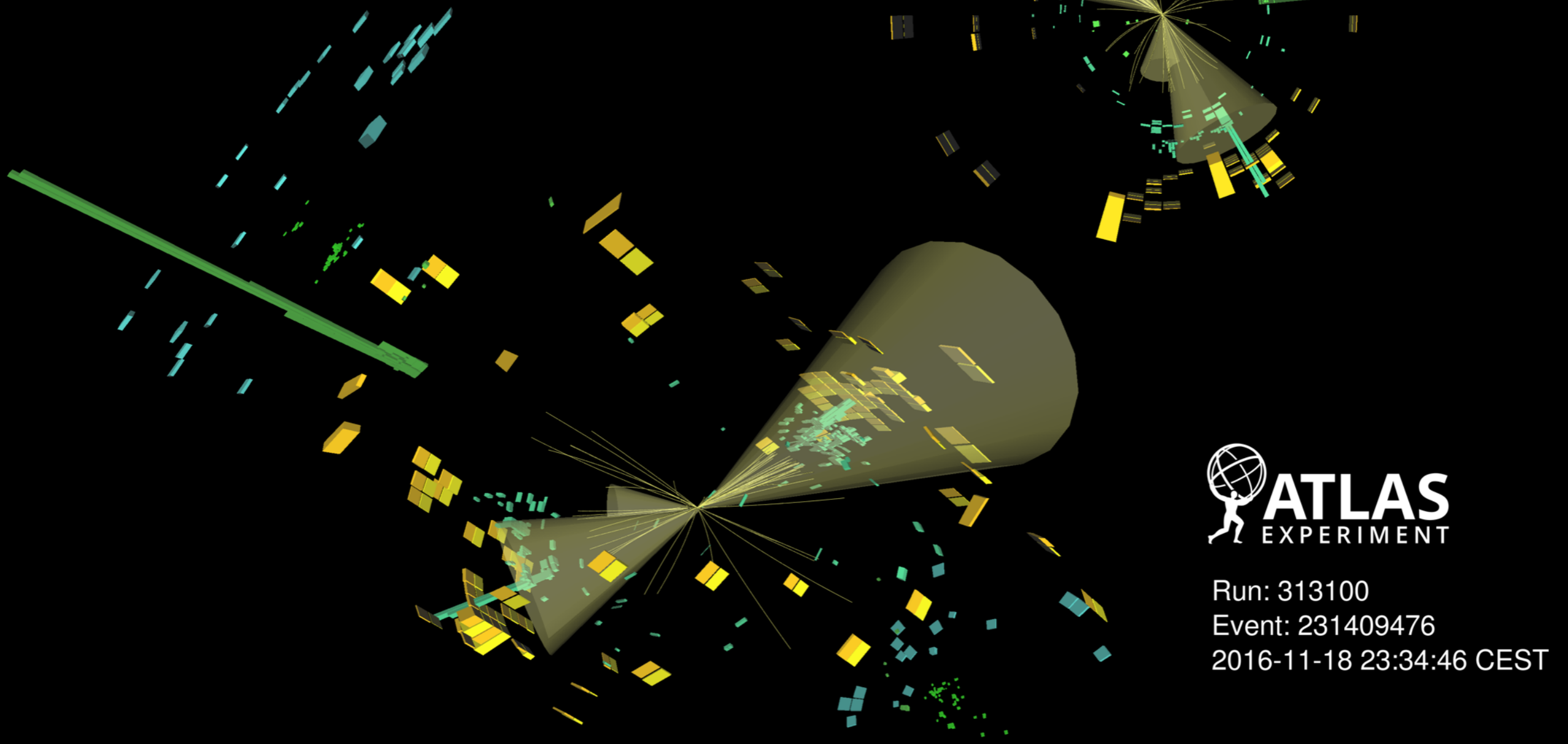
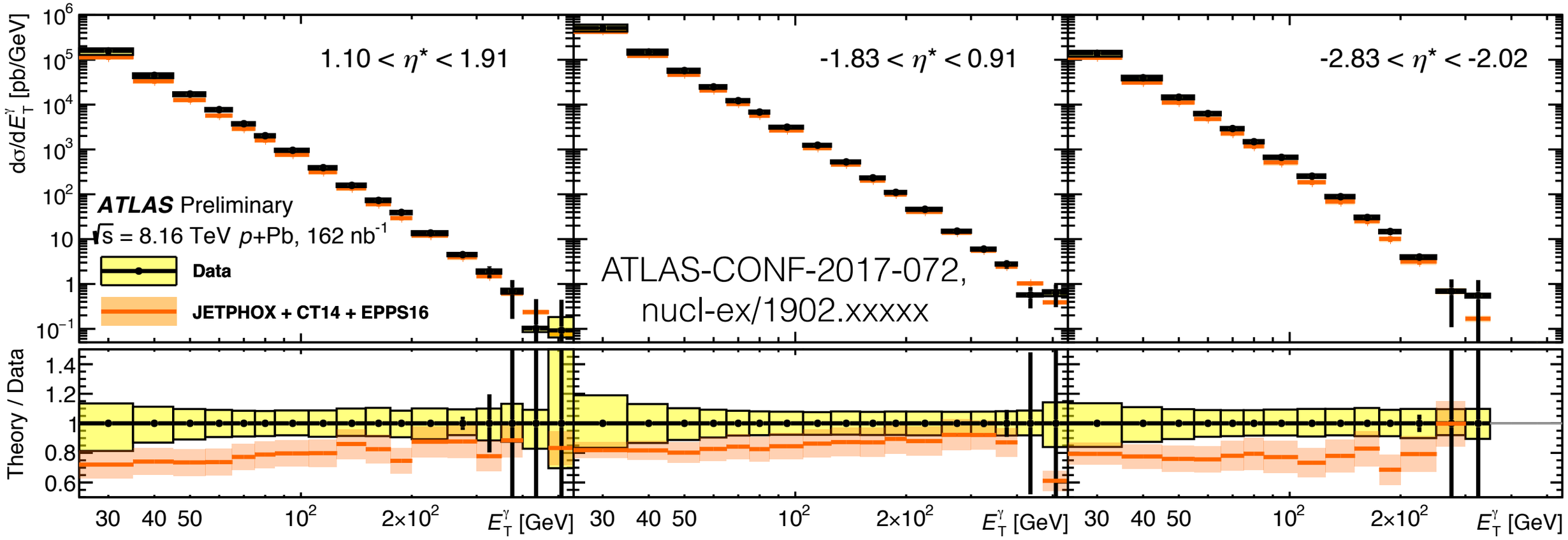
Photon+multijet event
p+Pb $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV, $\sum E_{\mathrm{T}}^{\mathrm{Pb}}$ = 33.1 GeV
photon: p_{T} = 154 GeV, η = -2.07, ϕ = 2.96
jet 1: p_{T} = 214 GeV, η = 0.63, ϕ = 0.58
jet 2: p_{T} = 110 GeV, η = -0.54, ϕ = -2.05
jet 3: p_{T} = 48 GeV, η = -0.72, ϕ = -1.58



ATLAS EXPERIMENT

Run: 313100
Event: 231409476
2016-11-18 23:34:46 CEST

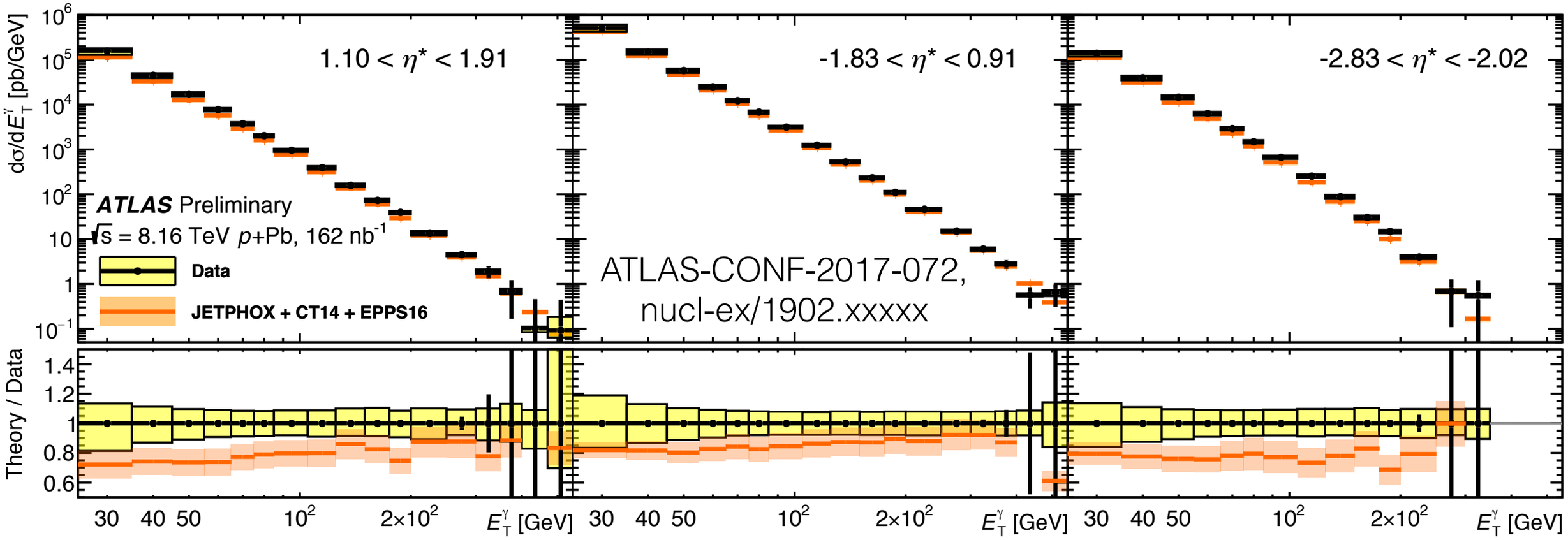
Isolated photon cross-section in *p*+Pb



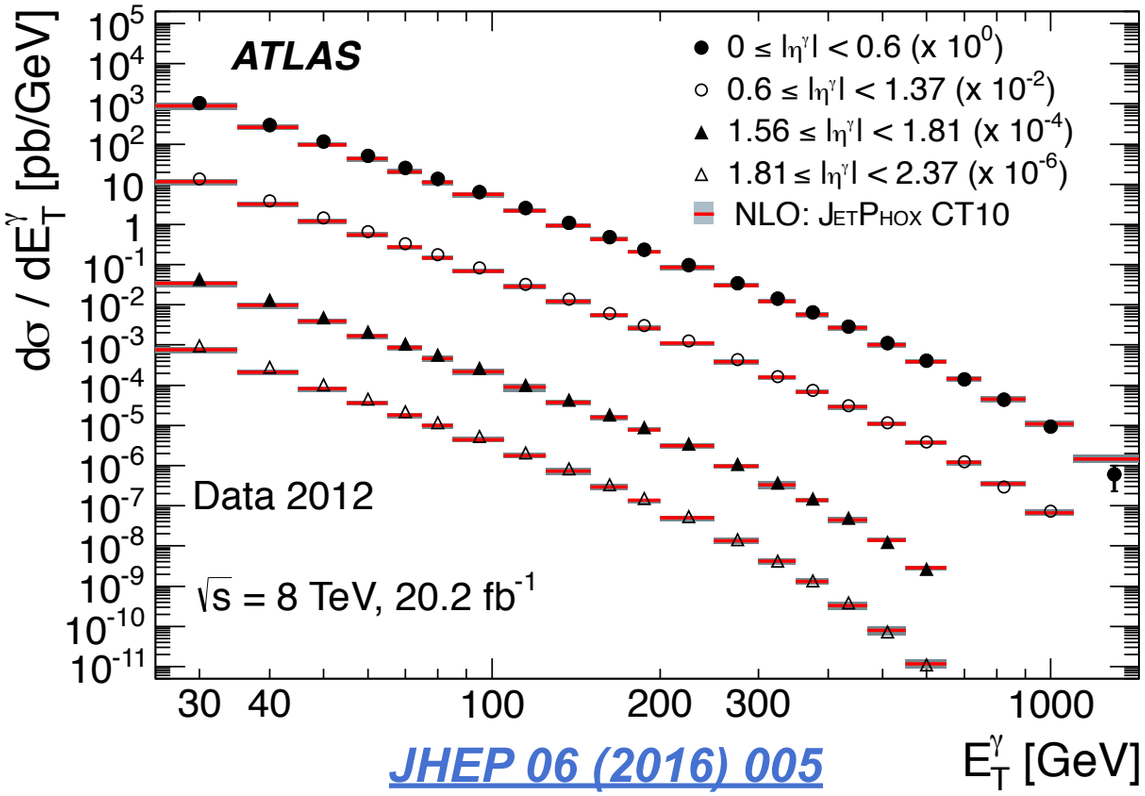
forward (p-going) *backward (Pb-going)*

- Broad measurement (p_T = 20-500 GeV) of isolated photon production
  - ➡ as in *pp*, under-prediction by NLO calculations (w/ nuclear effects)
- In Preliminary results shown here, ~7% p+Pb luminosity uncertainty is dominant in some kinematic regions!
  - ➡ for final results (soon to appear), this has been reduced to ~2.5%

Isolated photon cross-section in *p*+Pb

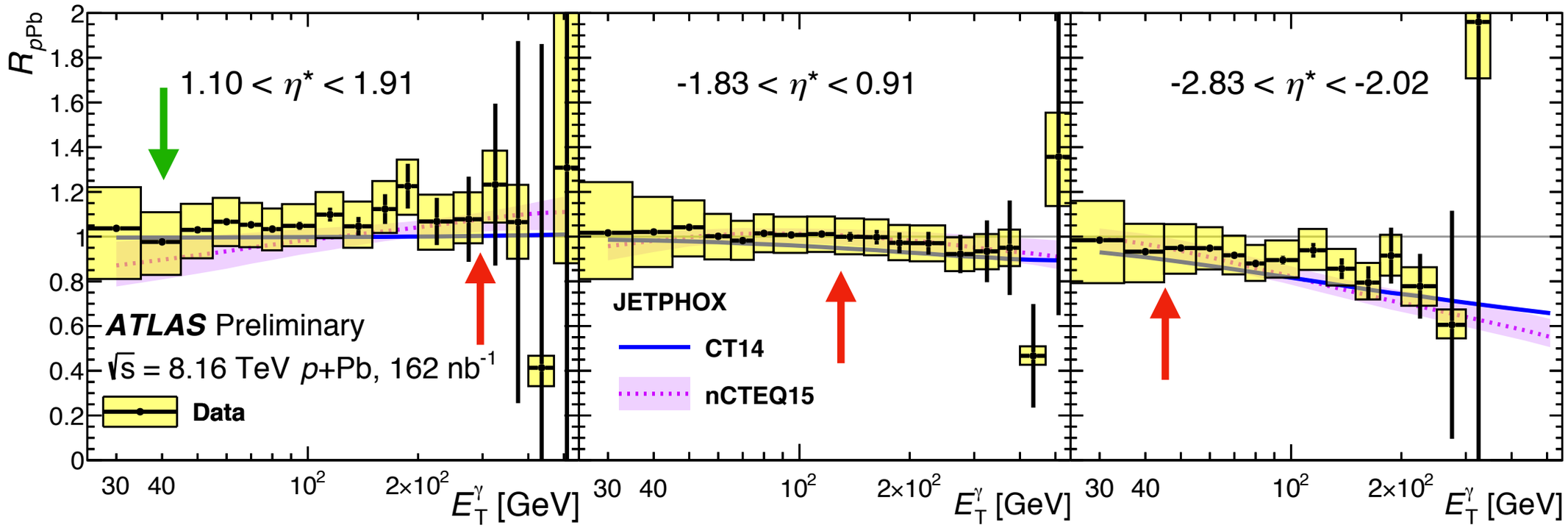


- Use 8 TeV *pp* data for reference in photon $R_{p\mathrm{Pb}}$
  - ➡ well-controlled corrections for (1) different $\sqrt{s}$ and (2) COM boost of *p*+Pb



[JHEP 06 (2016) 005]

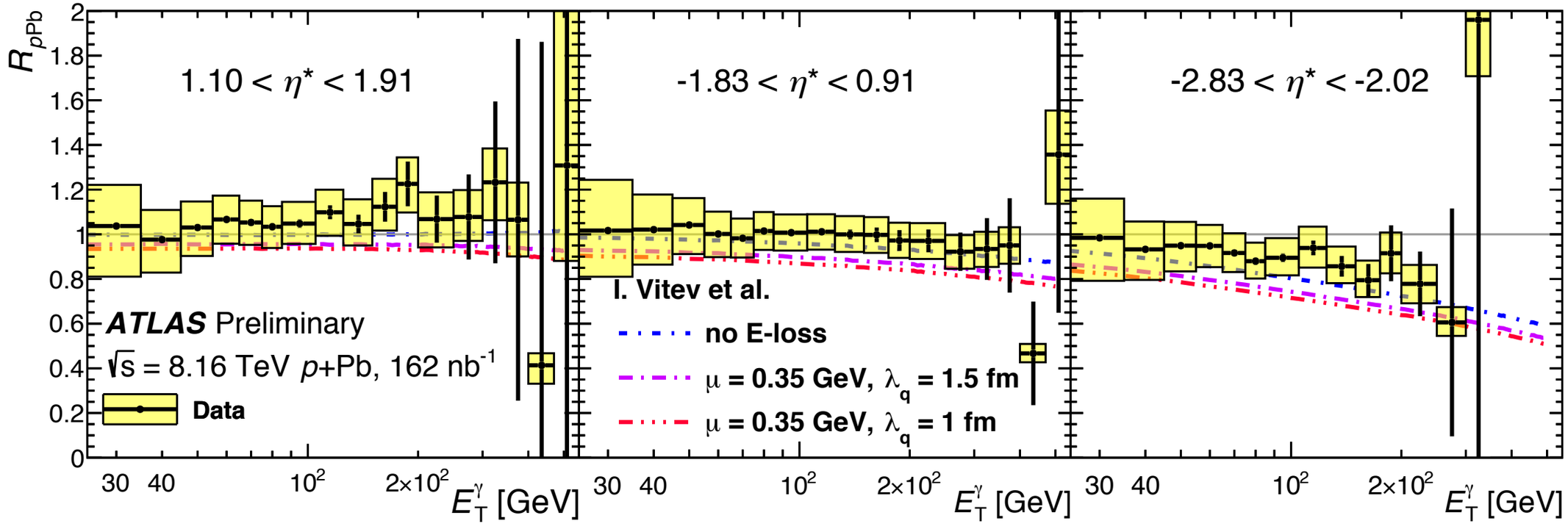
R_{pPb}



- Data favors **anti-shadowing** modification in line with global nPDF fits, less obvious in **shadowing** region

➡ (more apparent in final results w/ reduced uncertainties)

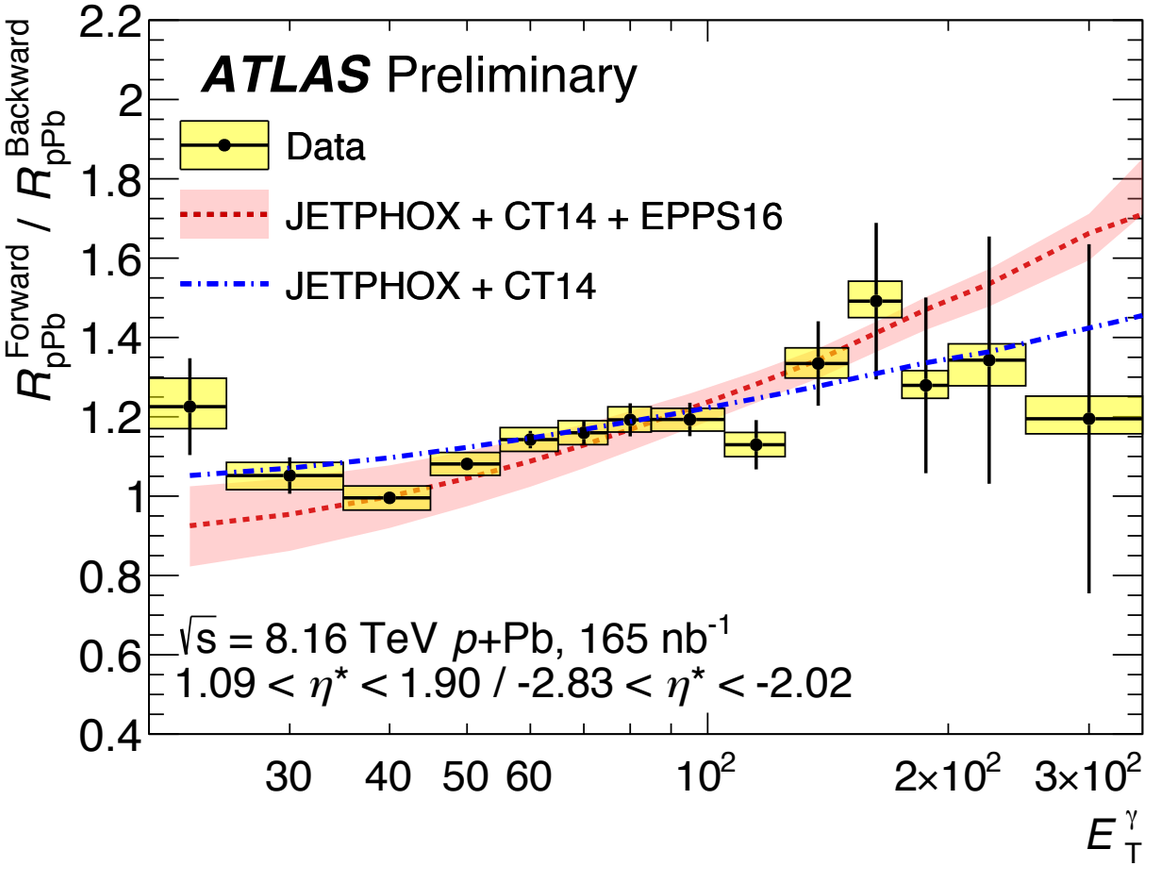
R_{pPb}

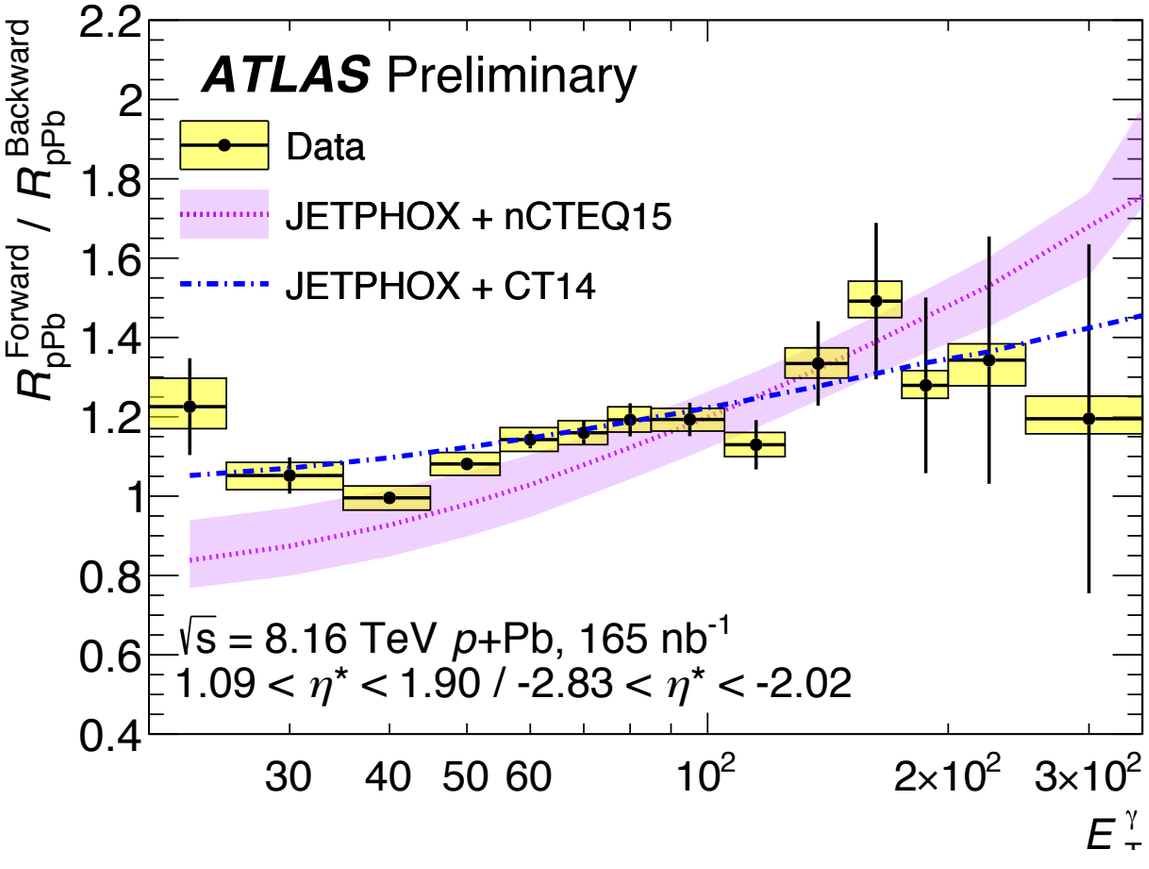


- Disfavors large initial state E-loss

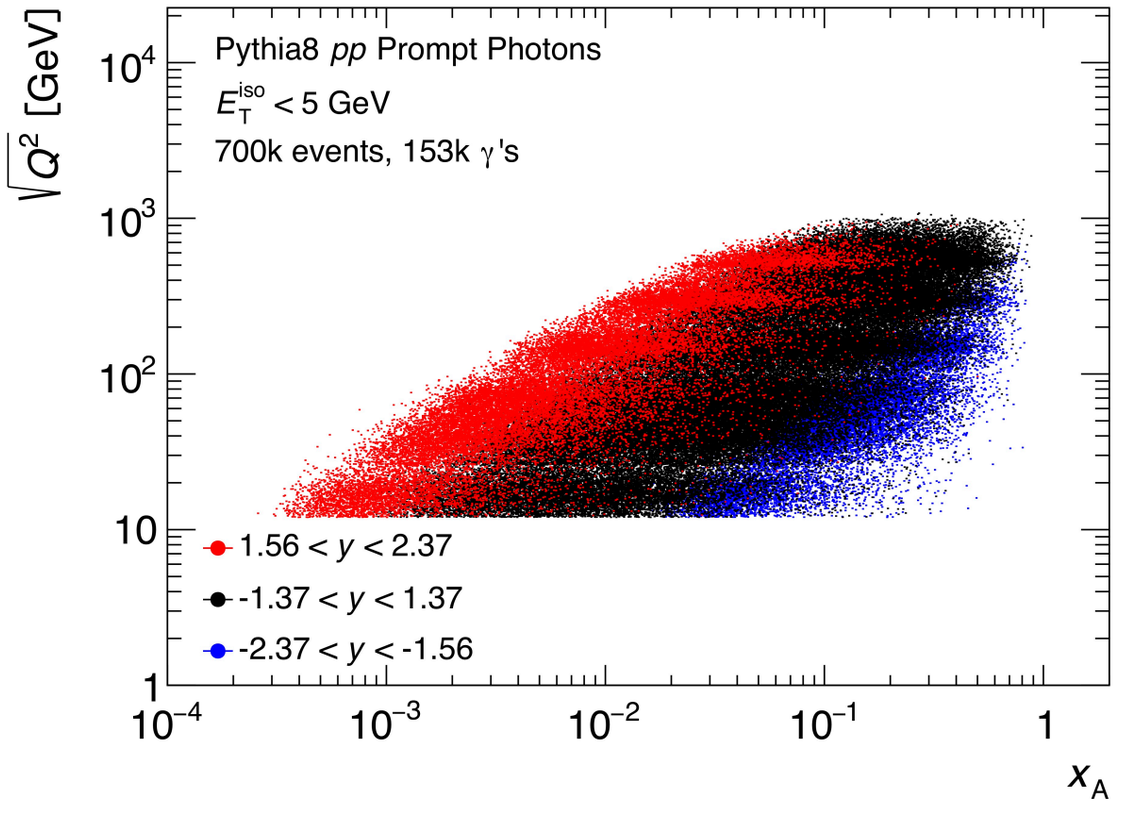
ATLAS-CONF-2017-072,
nucl-ex/1902.xxxxx

Forward / backward $R_{p\mathrm{Pb}}$ ratio vs. p_{T}

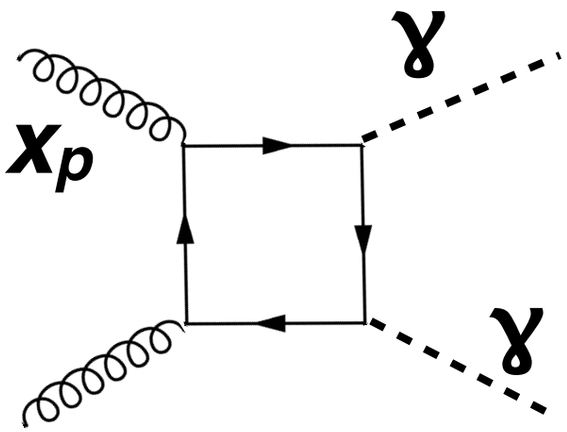




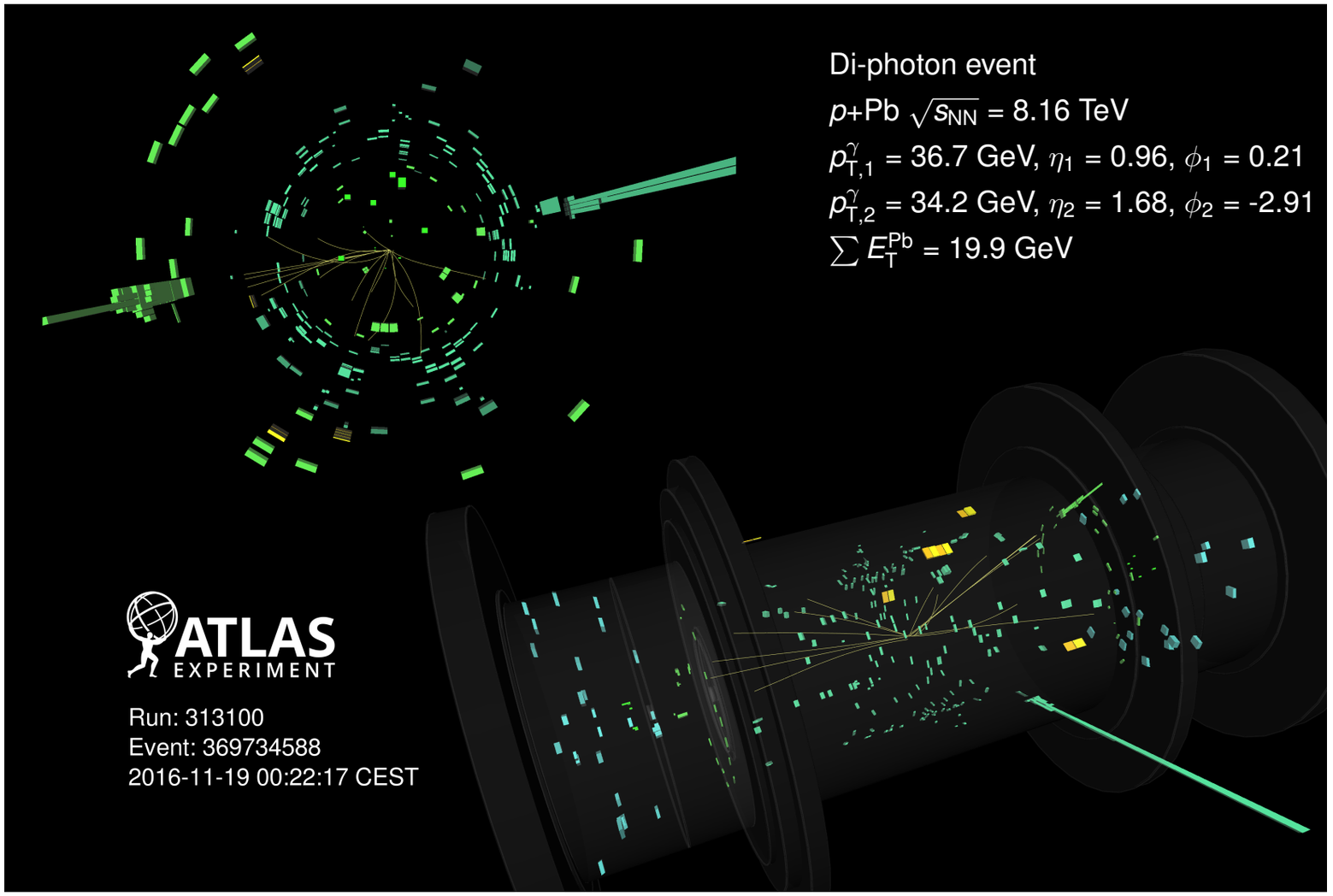
- At low-E_{T}, data almost compatible with free nucleon PDFs
  - ➡ region nominally sensitive to *gluon* shadowing / *quark* anti-shadowing
  - ➡ more generally, information for global nPDF fits

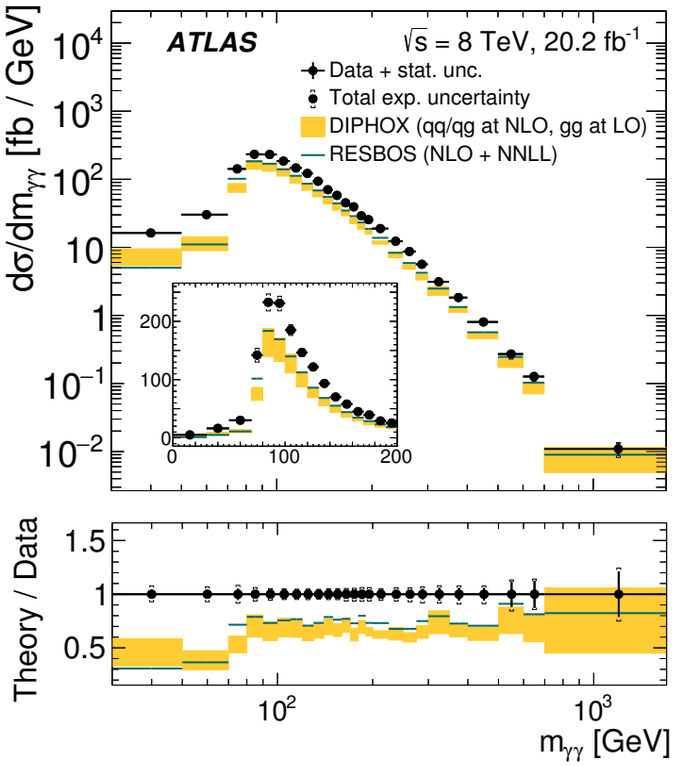


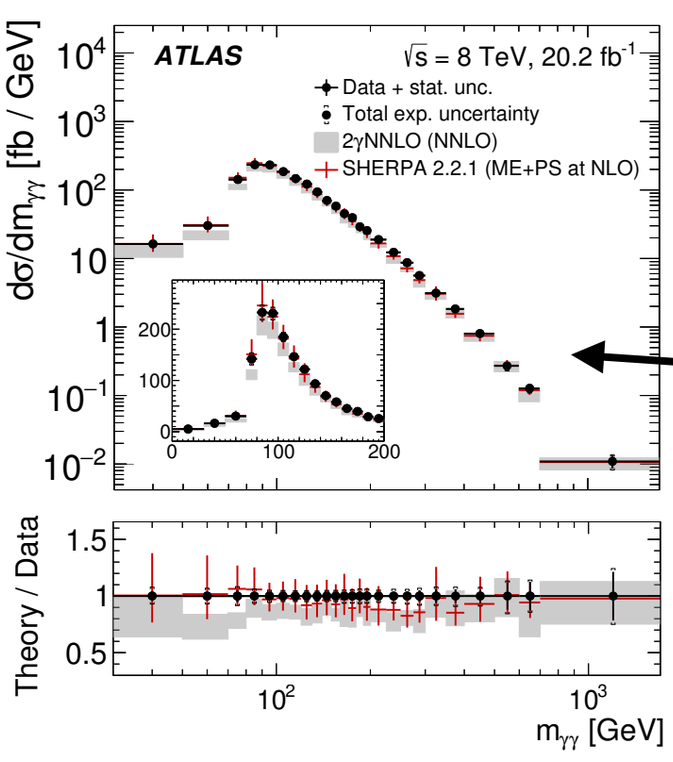
di-photon production @ LHC



low-x_A





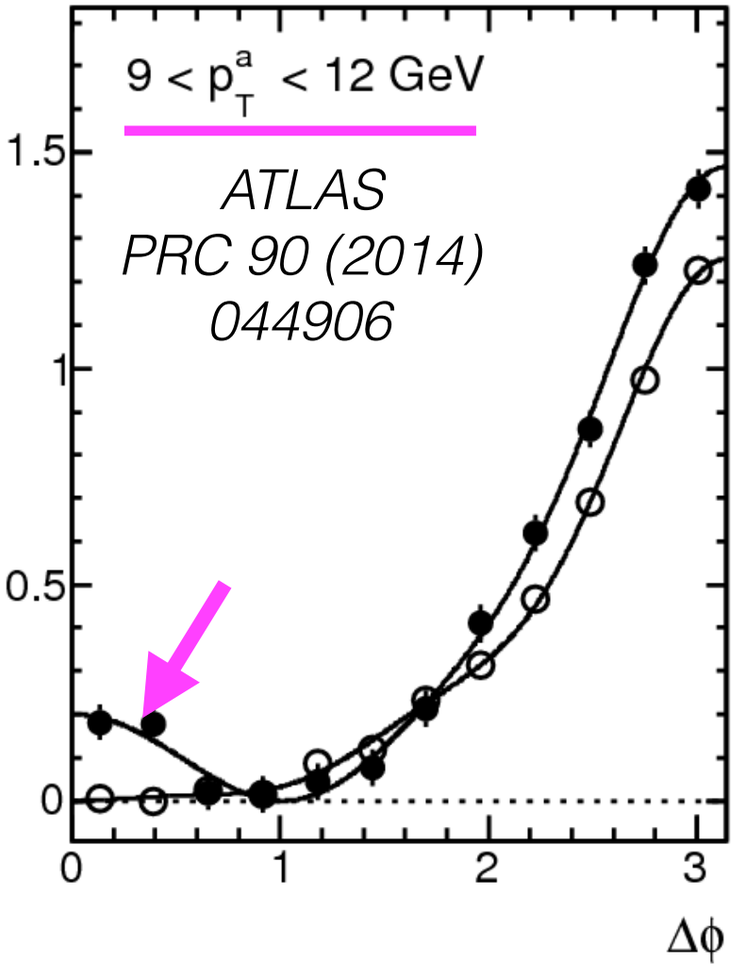


- Detailed reference measurements at 8 TeV
- $m_{\gamma\gamma}$ compared to DIPHOX, RESBOX, NNLO, Sherpa

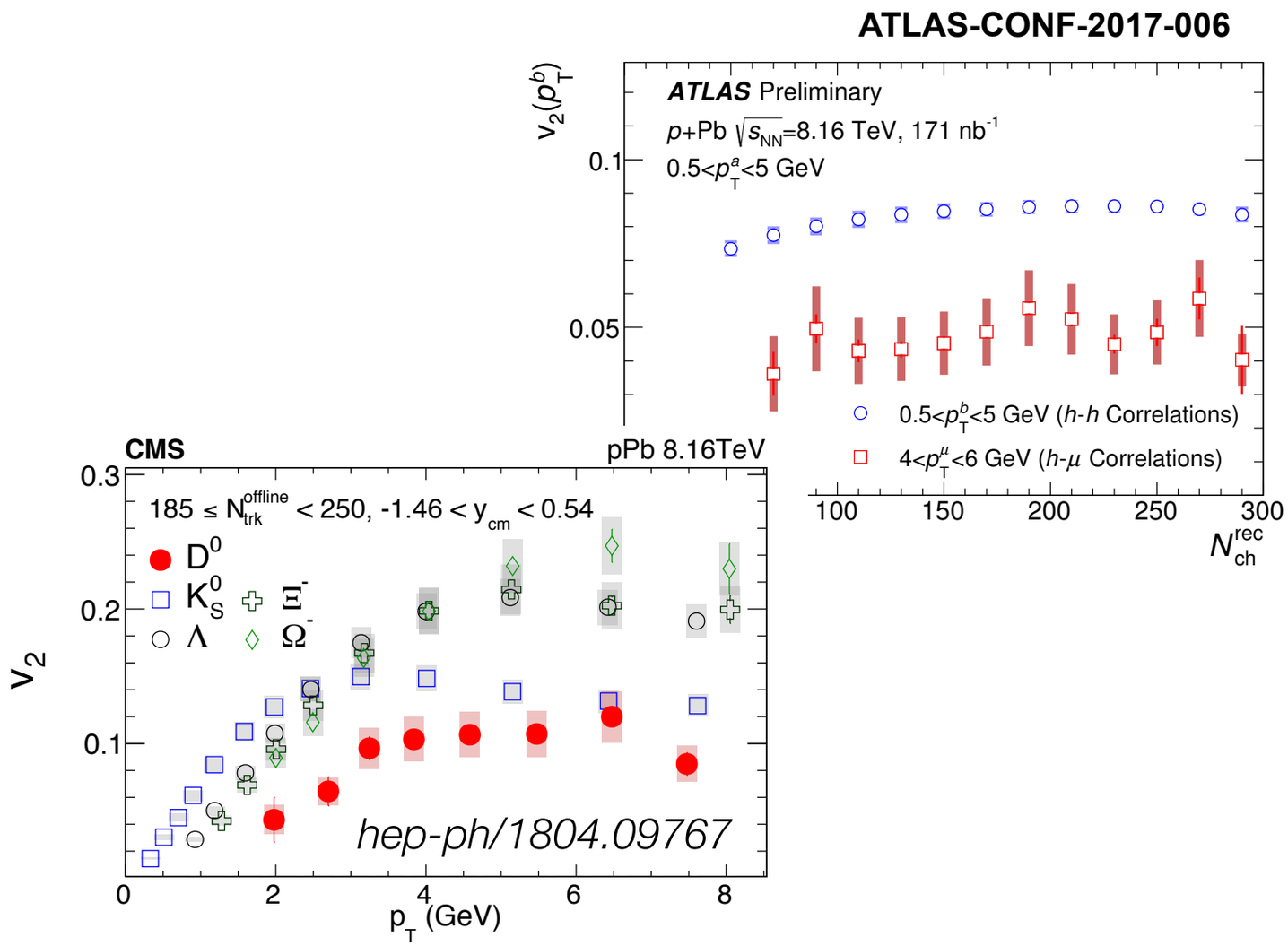
➡ should estimate nPDF effects!

Phys. Rev. D 95 (2017) 112005

photon-tagged *E*-loss in *p*+A?



appreciable modulation of high-p_T hadrons in <1% p+Pb…



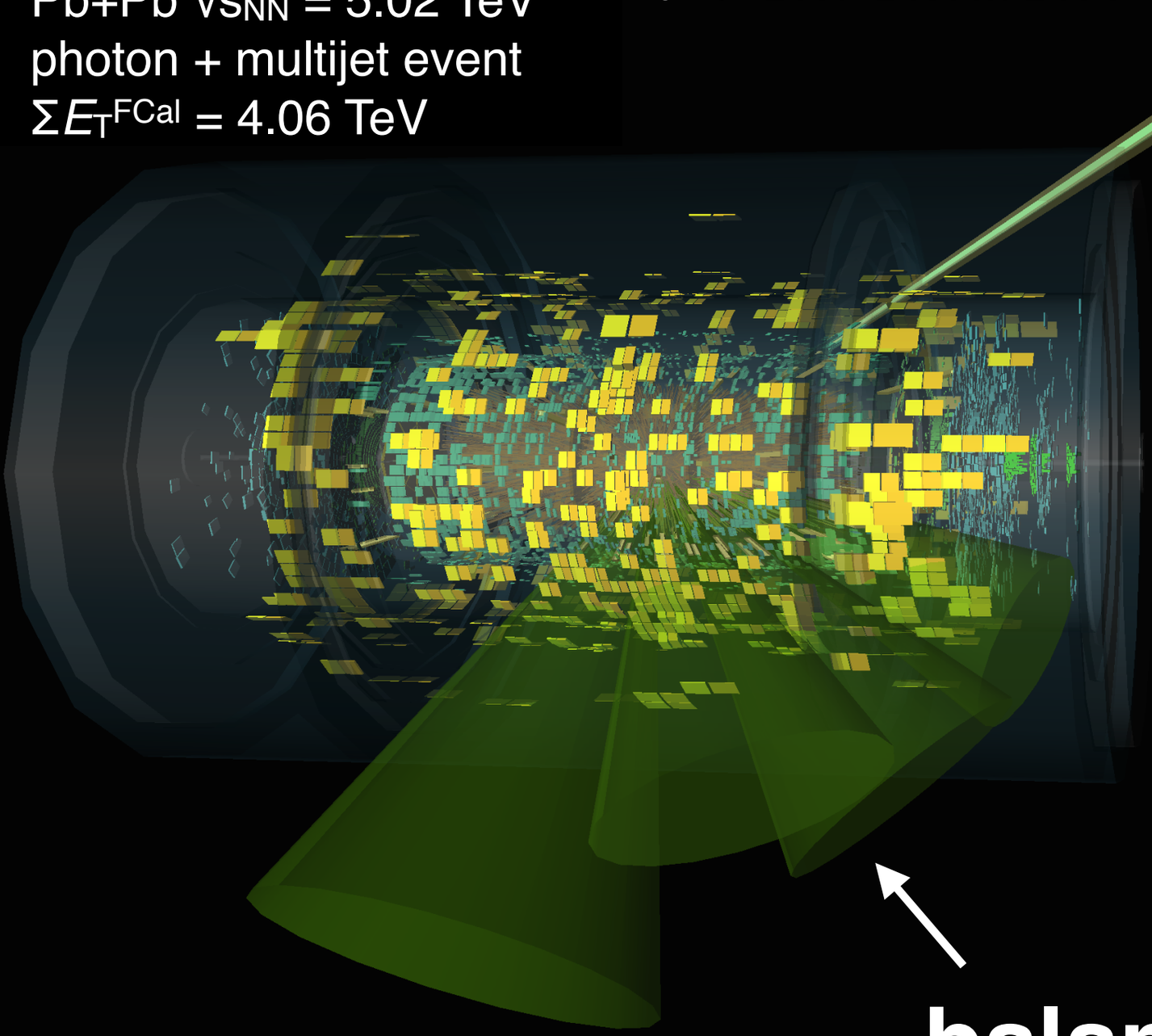
collective behavior of HF decay leptons & HF hadrons

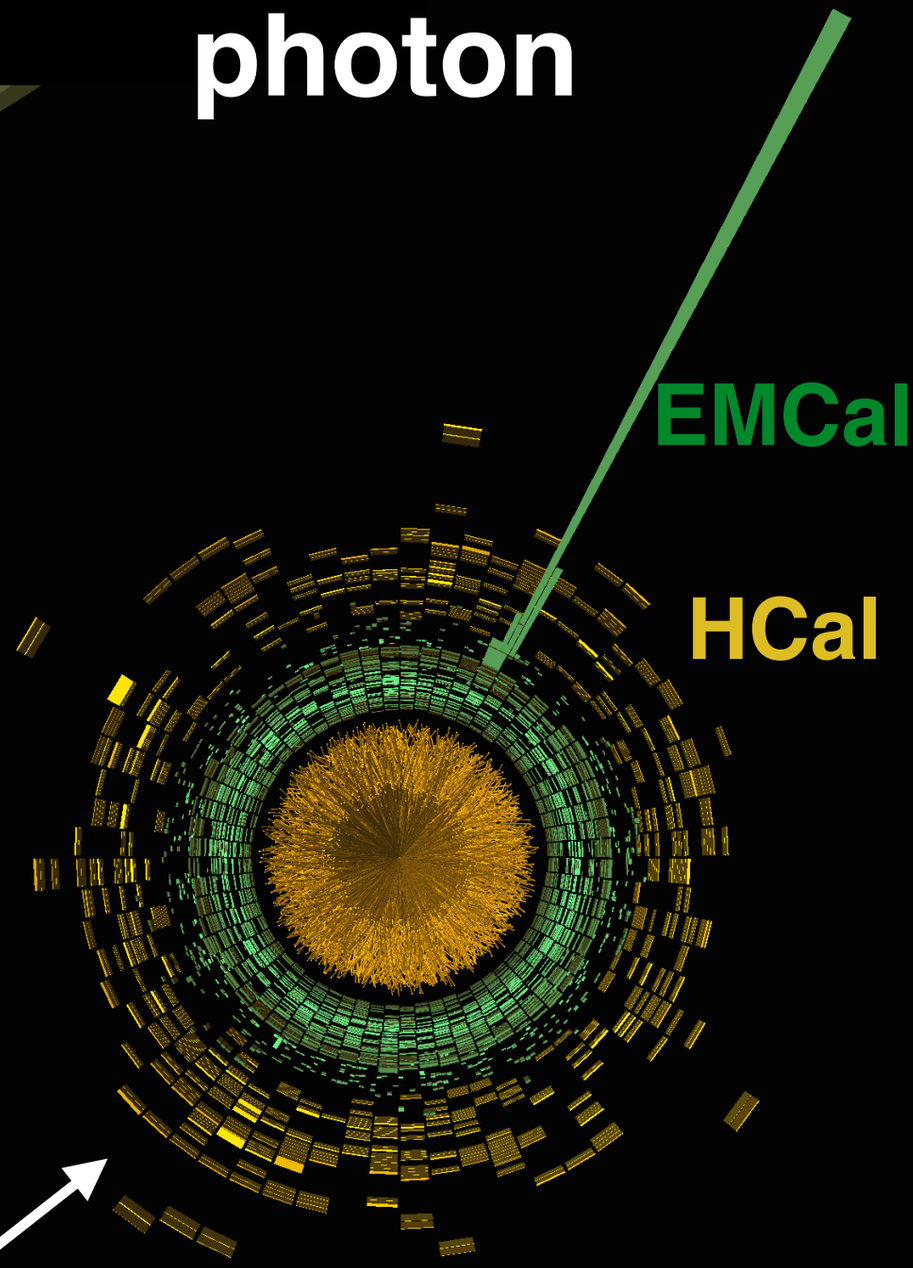
- If there is a QGP with fluid dynamics, can we constraint / observe jet modification with photon-jet / photon+hadron?
  - ➡ 0.5 M isolated photons in this data with $p_T^{\gamma} \geq$ 35-40 GeV

Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST
Pb+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
photon + multijet event
ΣE_T^{FCal} = 4.06 TeV

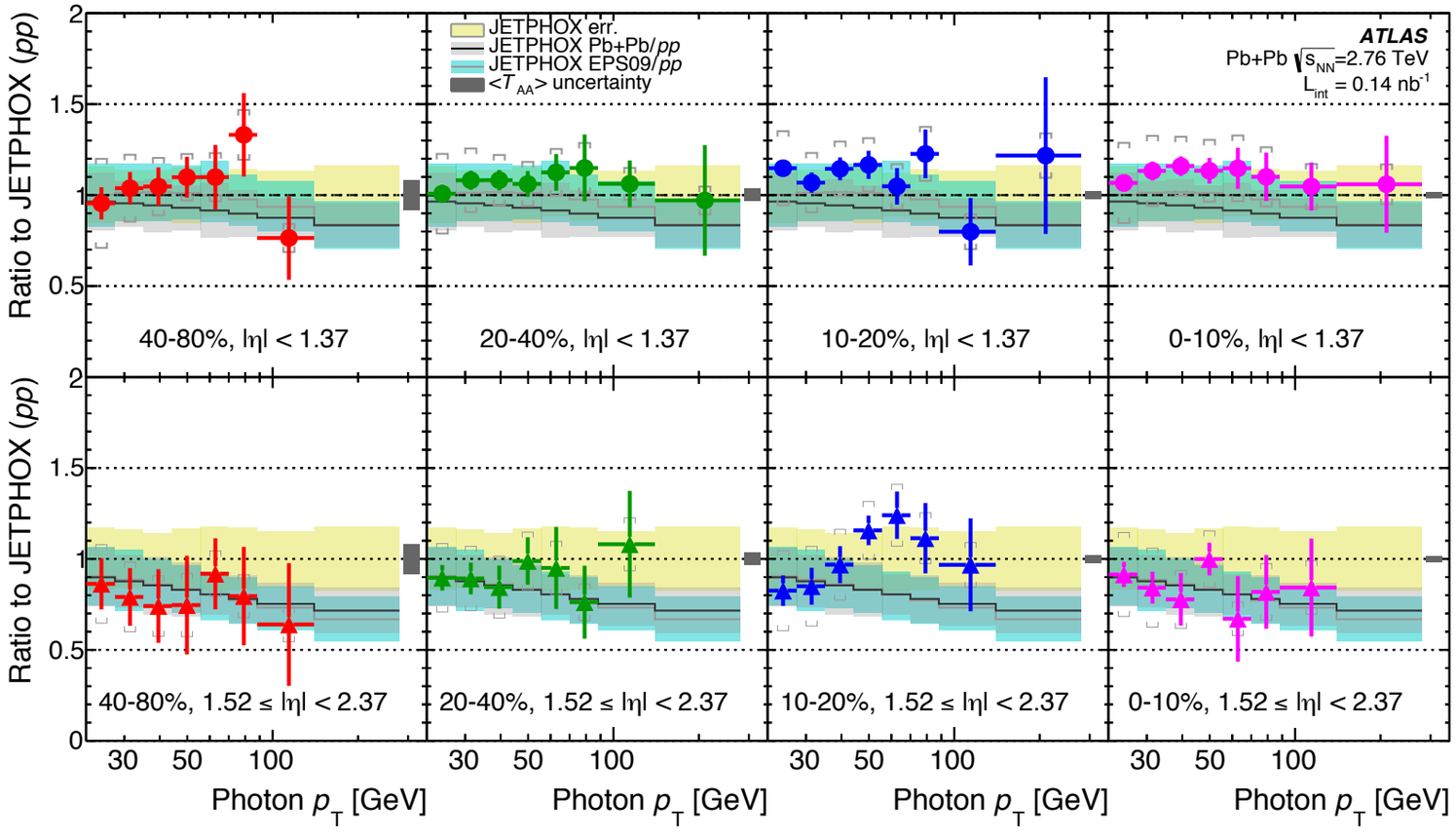
ATLAS EXPERIMENT

p_T = 200 GeV photon





balancing jet(s)?

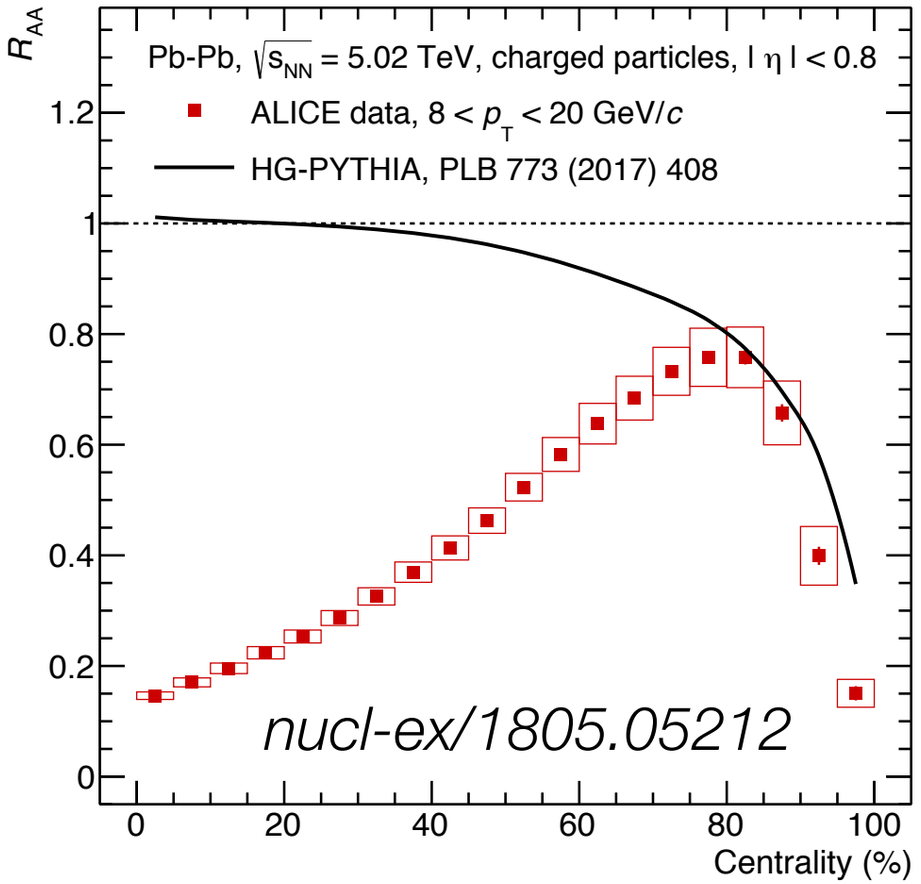


Photon yields in Run 1 (2.76 TeV) Pb+Pb collisions

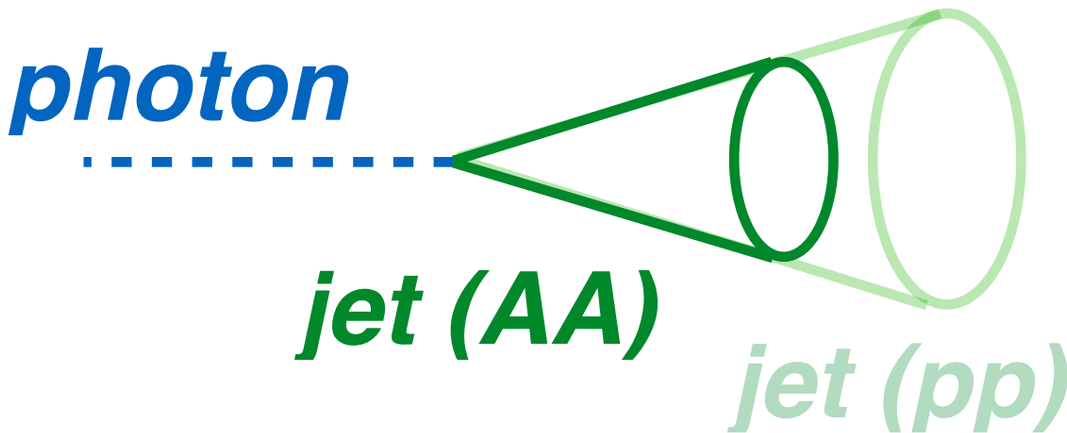
"triple differential" in p_T, η, centrality

Phys. Rev.C 93 , 034914 (2016)

- Expect > 20x statistics in 2018 Pb+Pb data
  - ➡ can address recent questions about hard scattering biases in peripheral events
    - ➡ i.e. does jet quenching "turn off" sooner than expected…



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



Photon + (inclusive) **jet** p_T-balance

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

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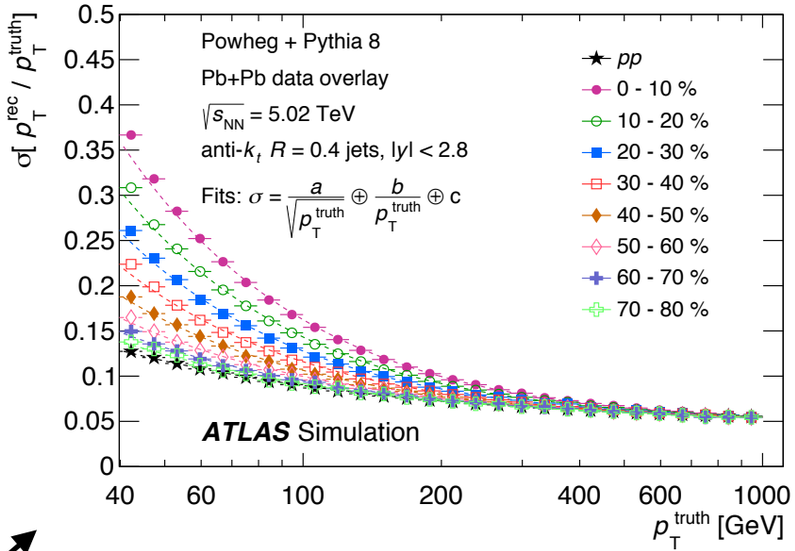
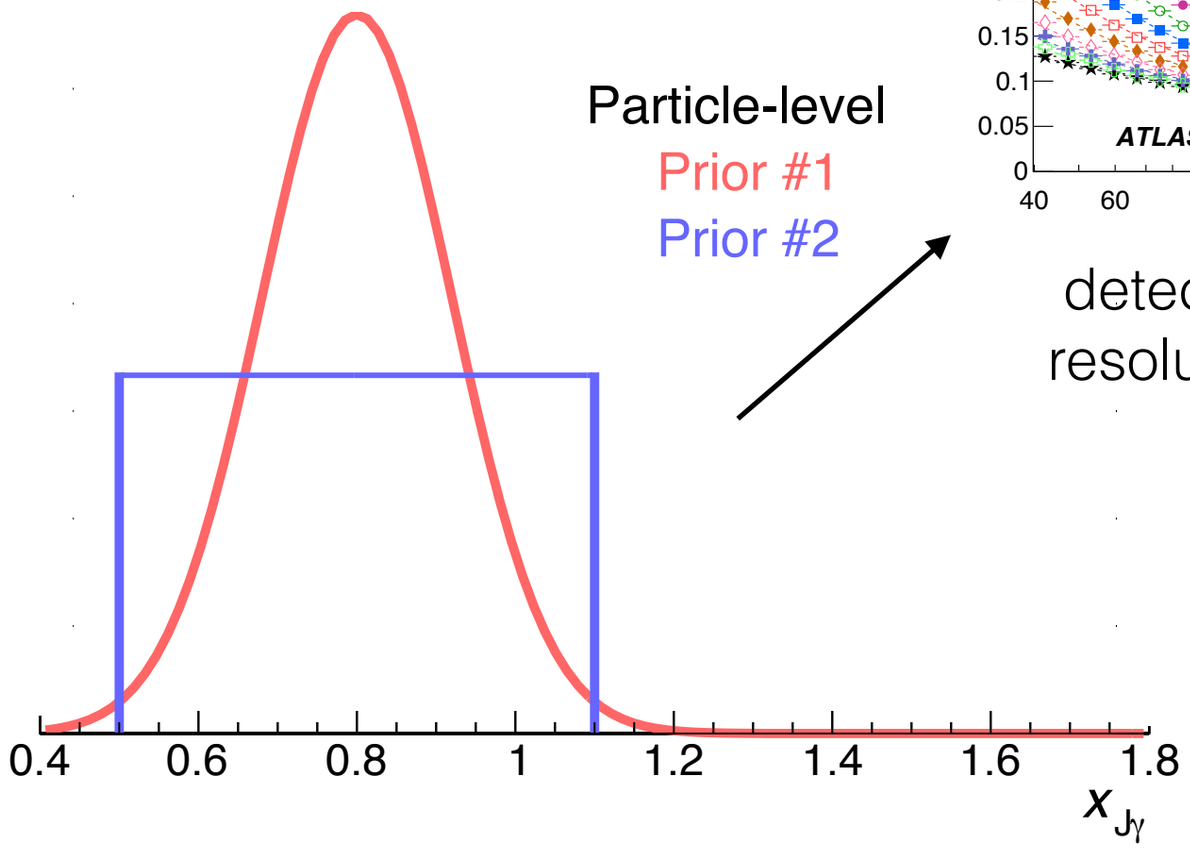
Results are *fully corrected* ("unfolded") for detector effects:

- ➡ "detector-free" data-theory comparisons
- ➡ data-data comparisons (LHC-LHC, LHC-RHIC, etc.)
- ➡ recover interesting features in data, e.g. *distributions* of *E* loss (Milhano & Zapp hep-ph/1512.08107, Hu, Peng & Wang nucl-th/1808.05310, etc.)

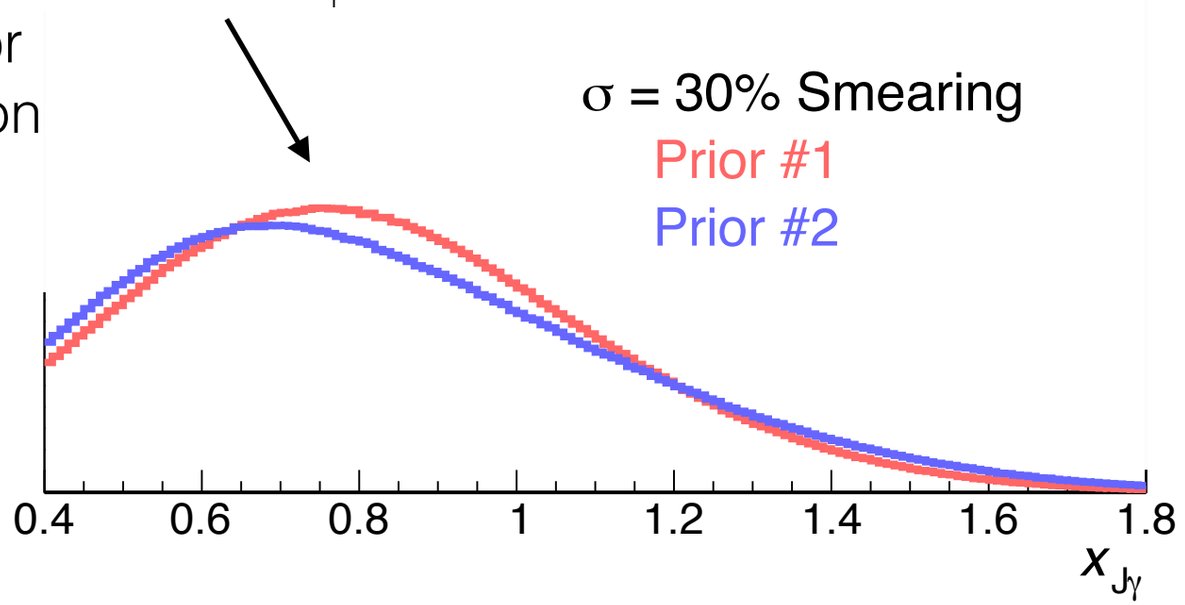
Very different particle-level distributions…



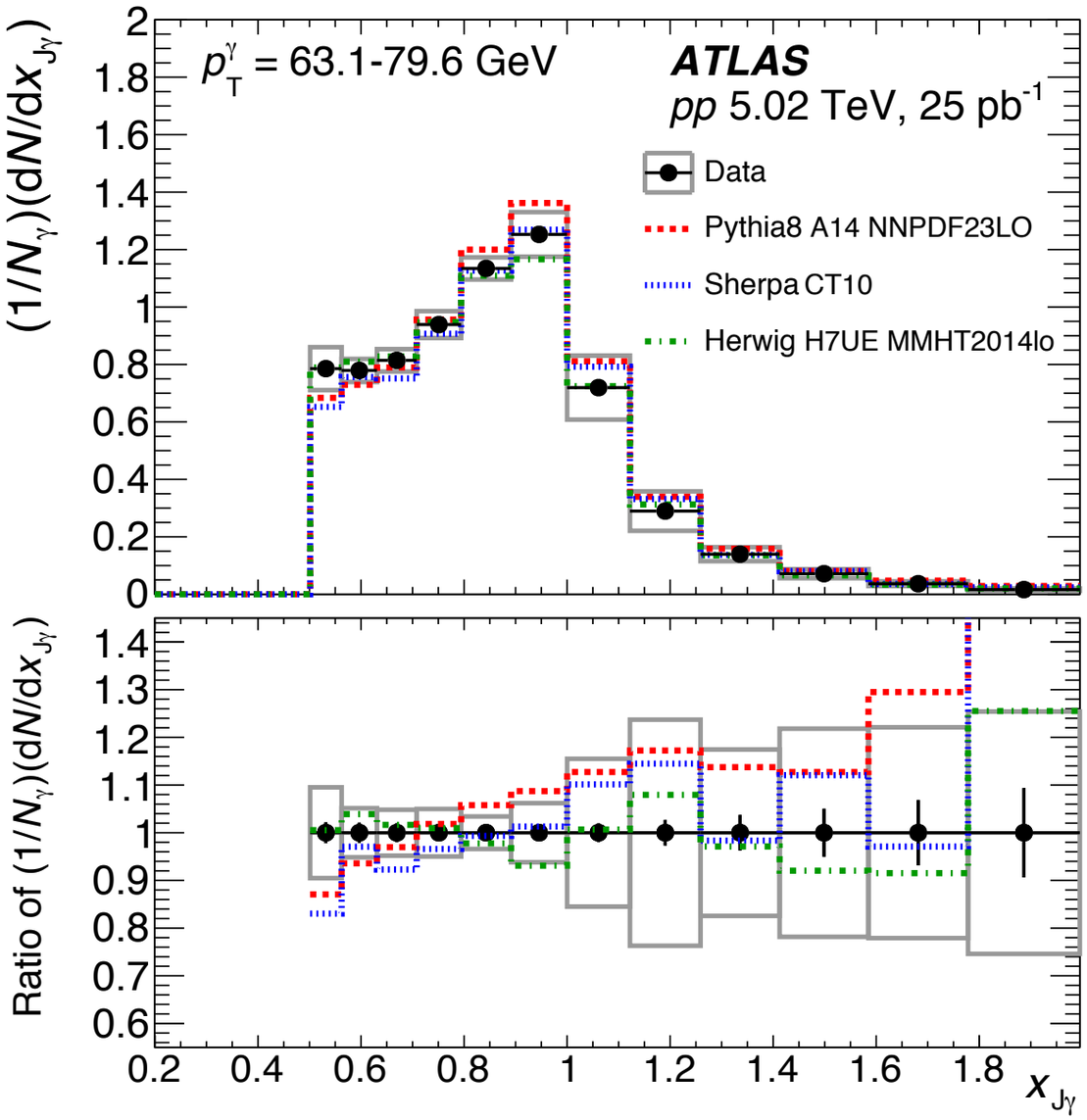


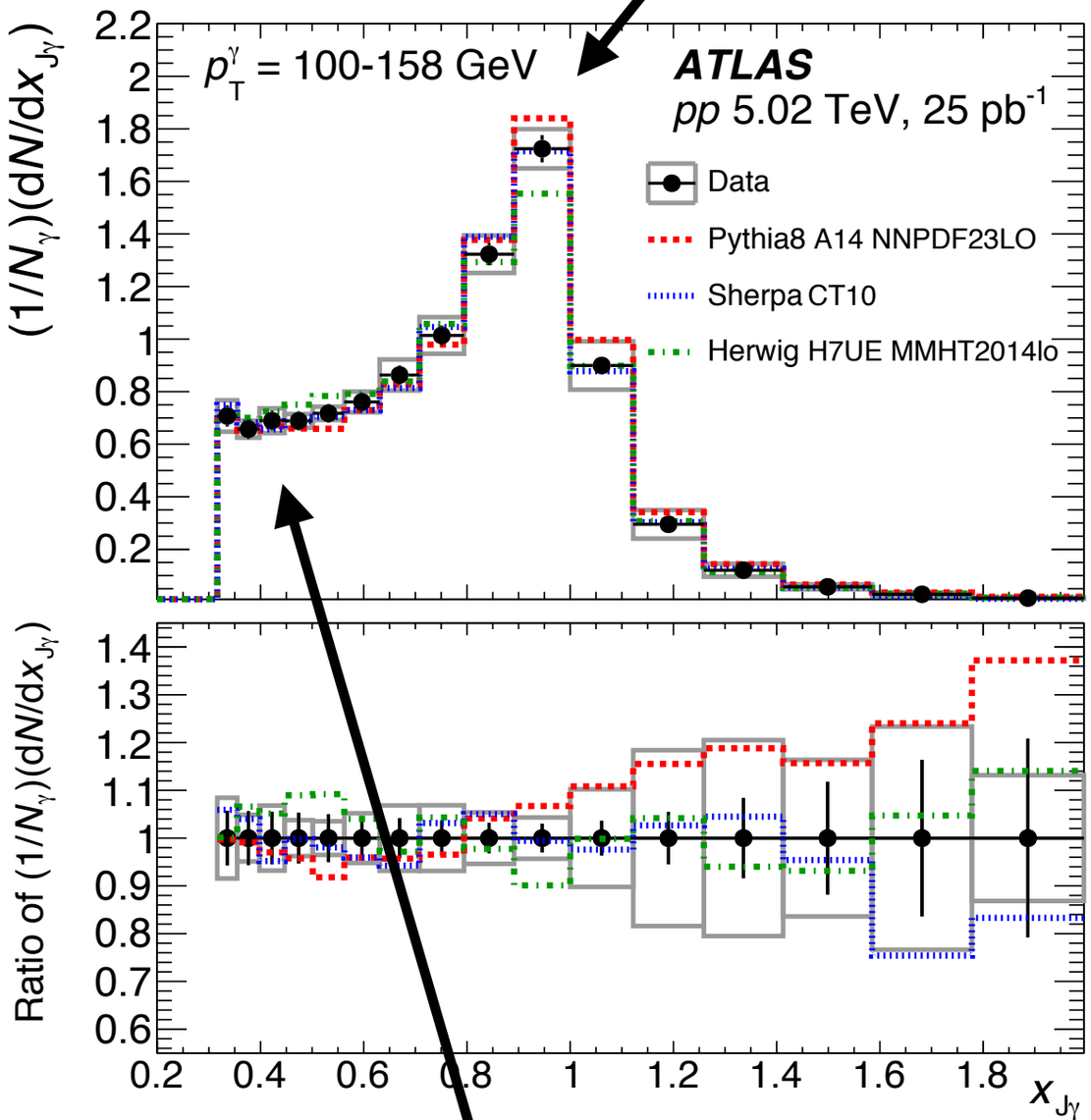
detector resolution

… smearing occludes the differences in shape



Photon+jet p_T balance in *pp*





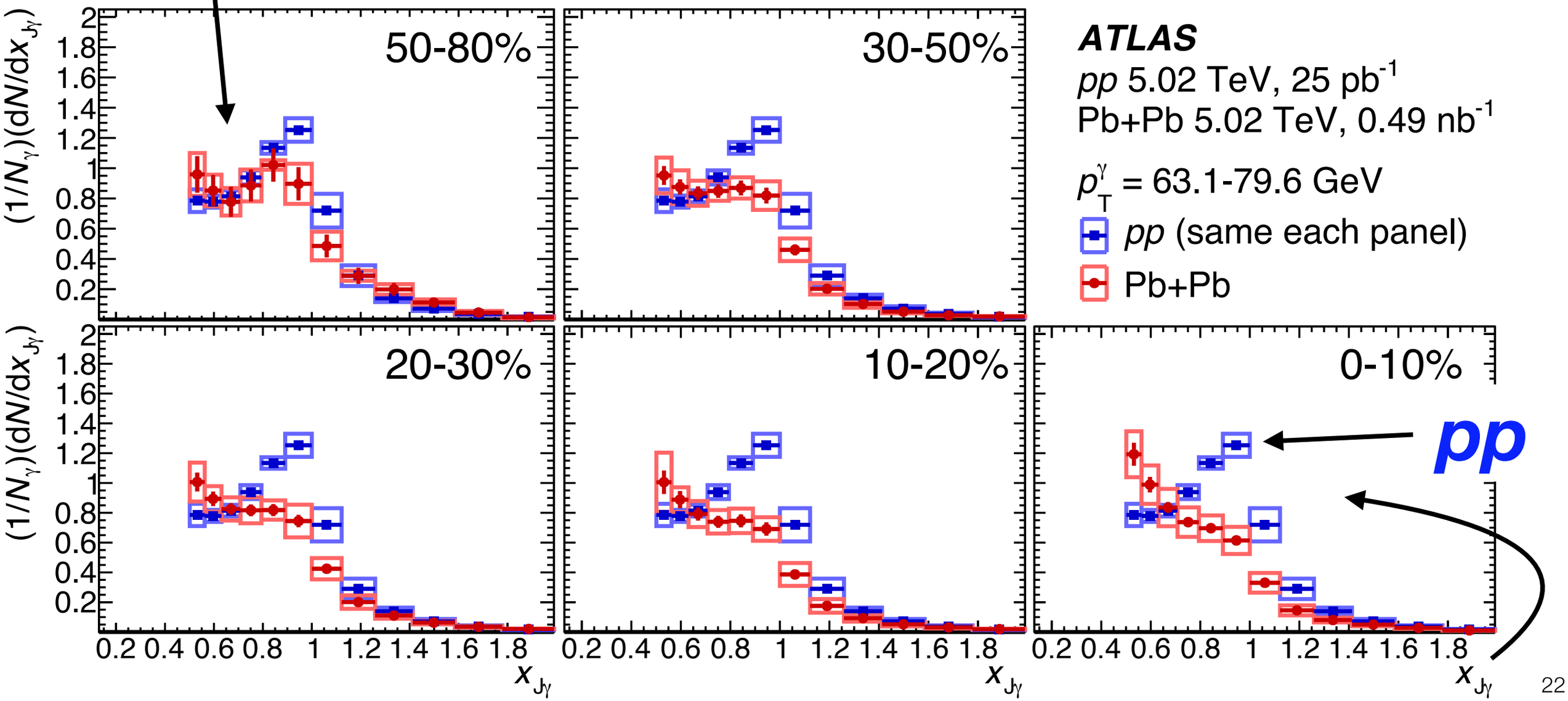
unfolding recovers sharp peak…

Compare directly to MC generators at particle-level: **Pythia 8 Sherpa Herwig 7**

but note contribution from FSR jets

peak returns in ***50-80%*** *Pb+Pb events*

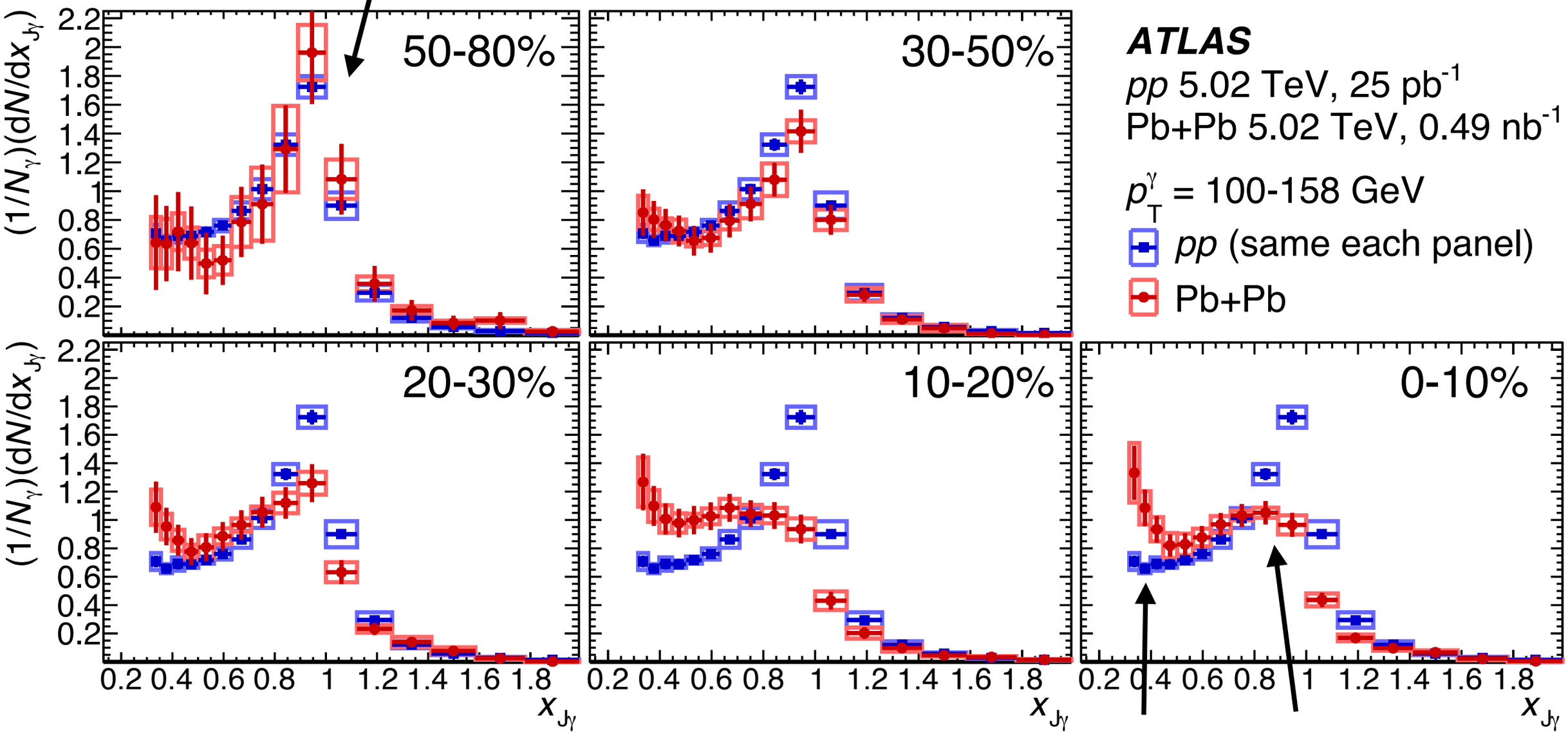
Results: p_T^{γ} = 63.1-79.6 GeV



peaked structure destroyed in ***0-10%*** *Pb+Pb*

50-80% *Pb+Pb events compatible with* ***pp***

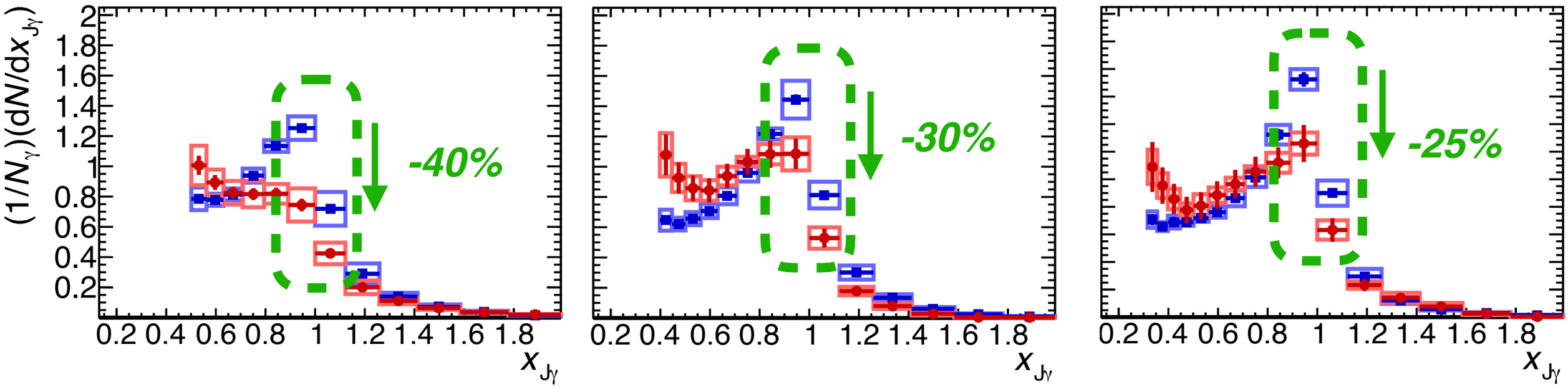
Results: p_T^{γ} = 100-158 GeV



P(E$_{lost}$ = large) > 0 ***P(E$_{lost}$ = 0) > 0***

visible peak even in ***0-10%*** *Pb+Pb!*

20-30% Pb+Pb centrality

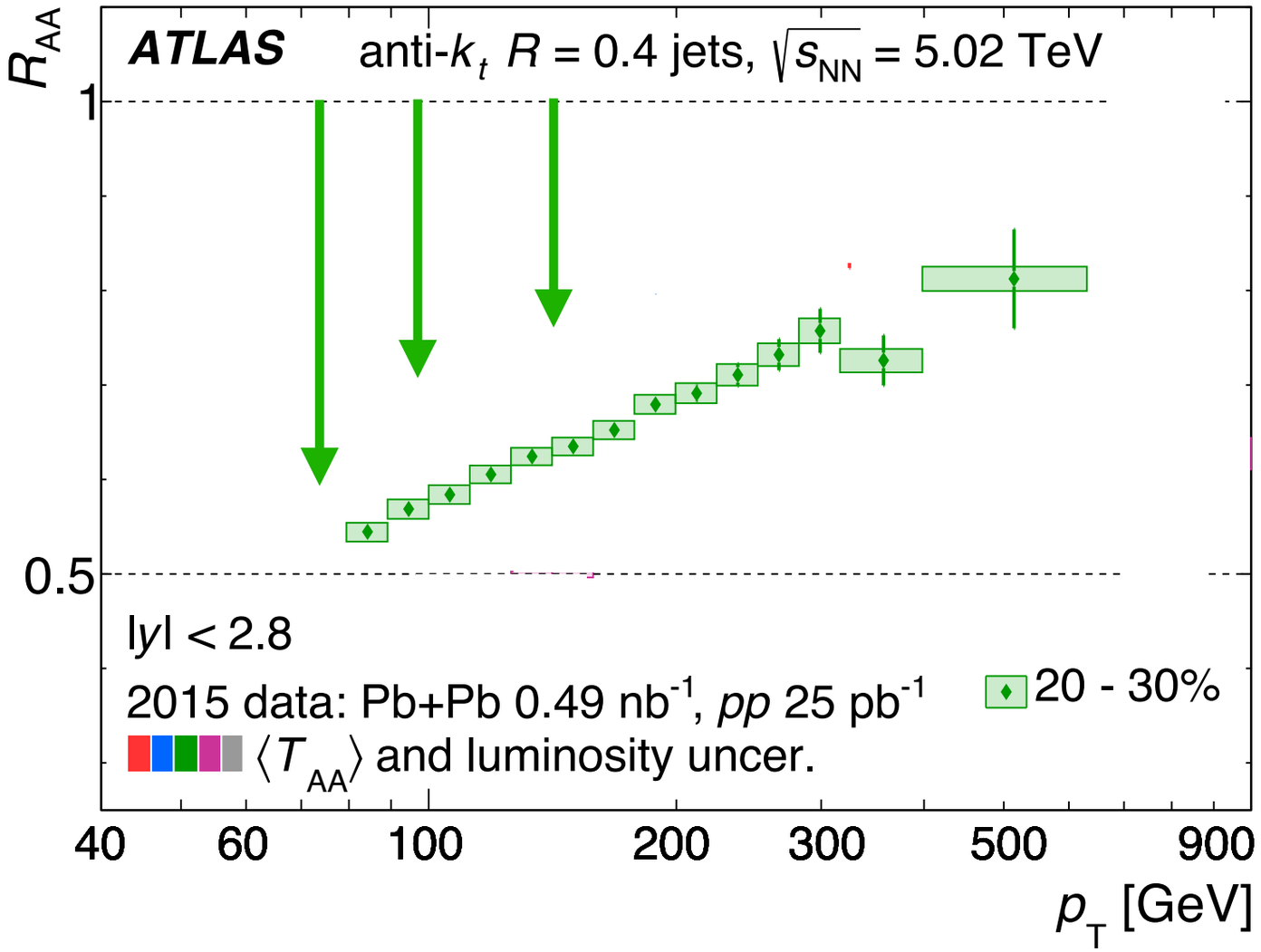


Consider a picture of energy loss as arising from a few discrete scatterings

➡ jets either lose no energy (R_{AA} =1) or a lot (R_{AA} = 0), constrain from high-side tail

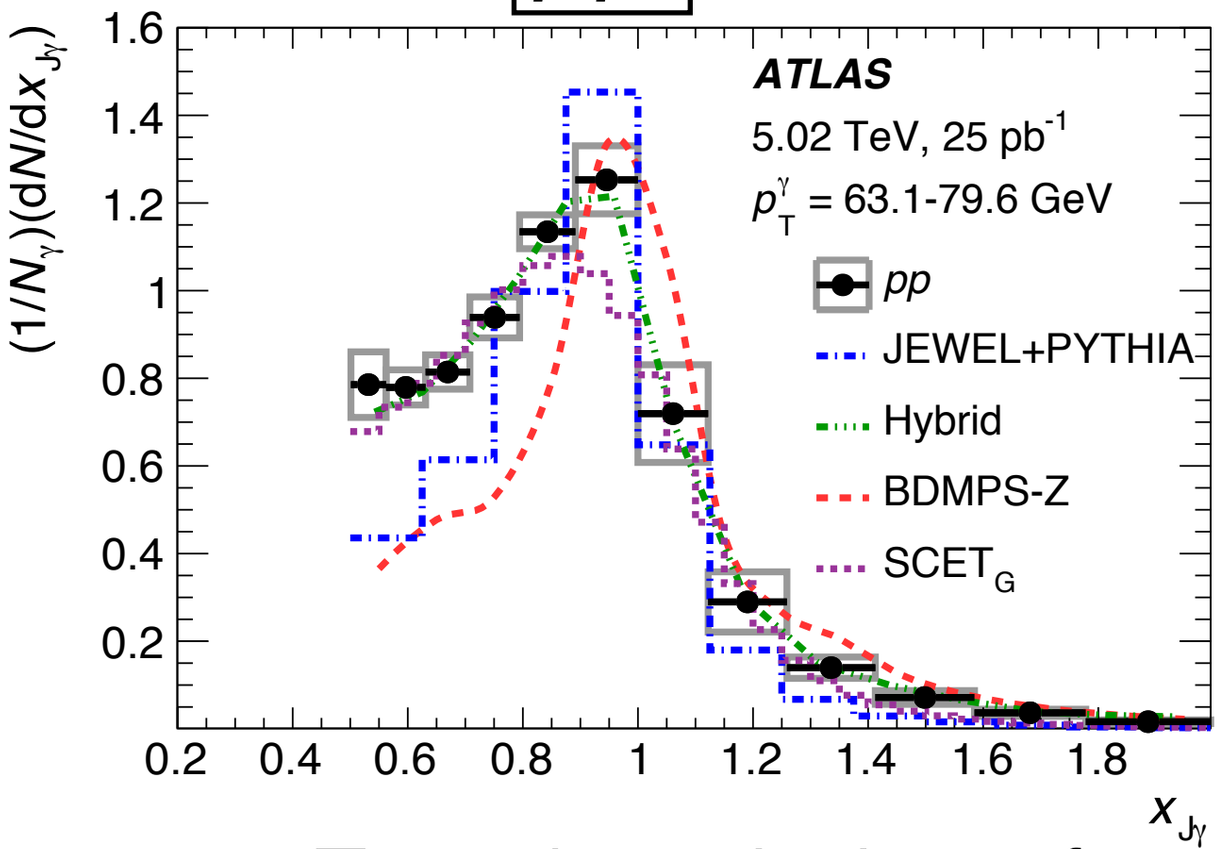
➡ this picture "underpredicts" suppression in jet R_{AA}

➡ presumably quarks less quenched than gluons



Direct comparisons to theory (no smearing)

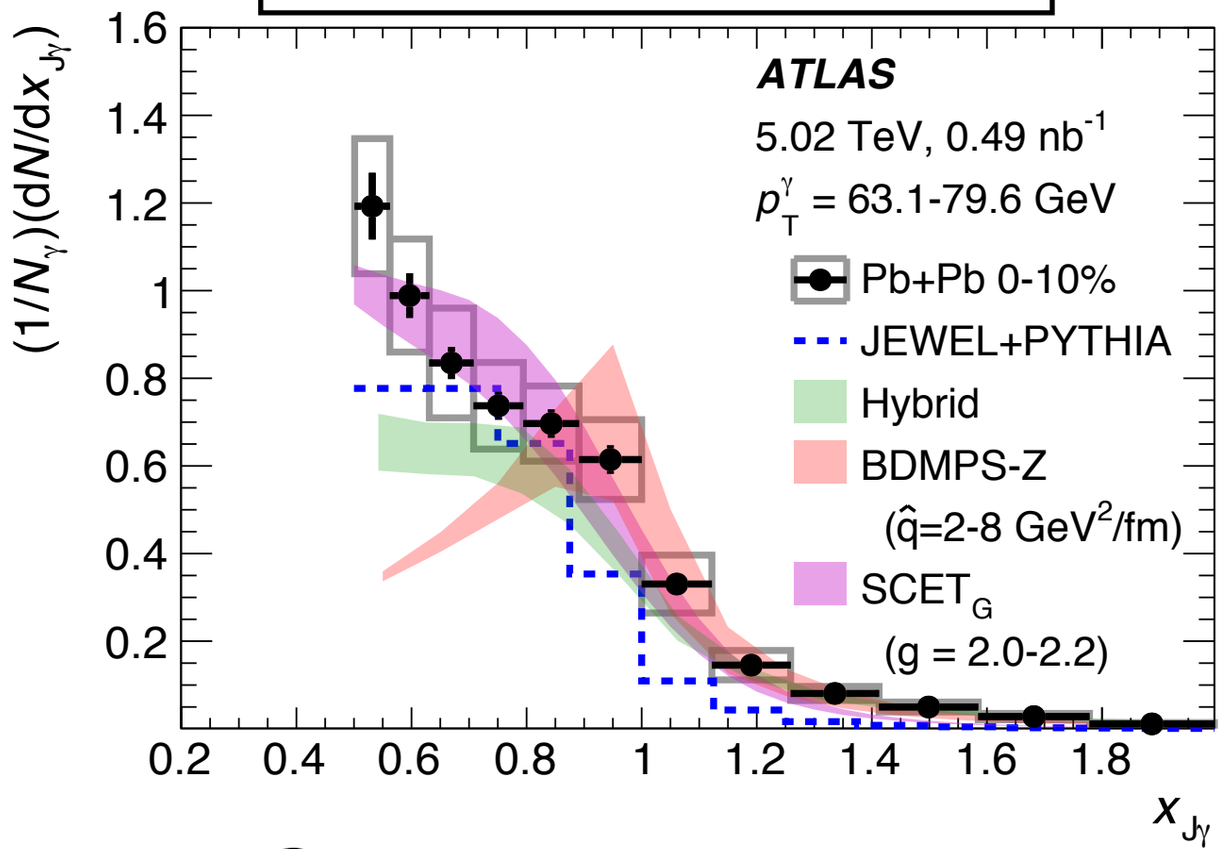
pp



Test description of vacuum (*pp*) baseline

Models with Pythia vacuum distribution (e.g. **Hybrid**) tend to do well…

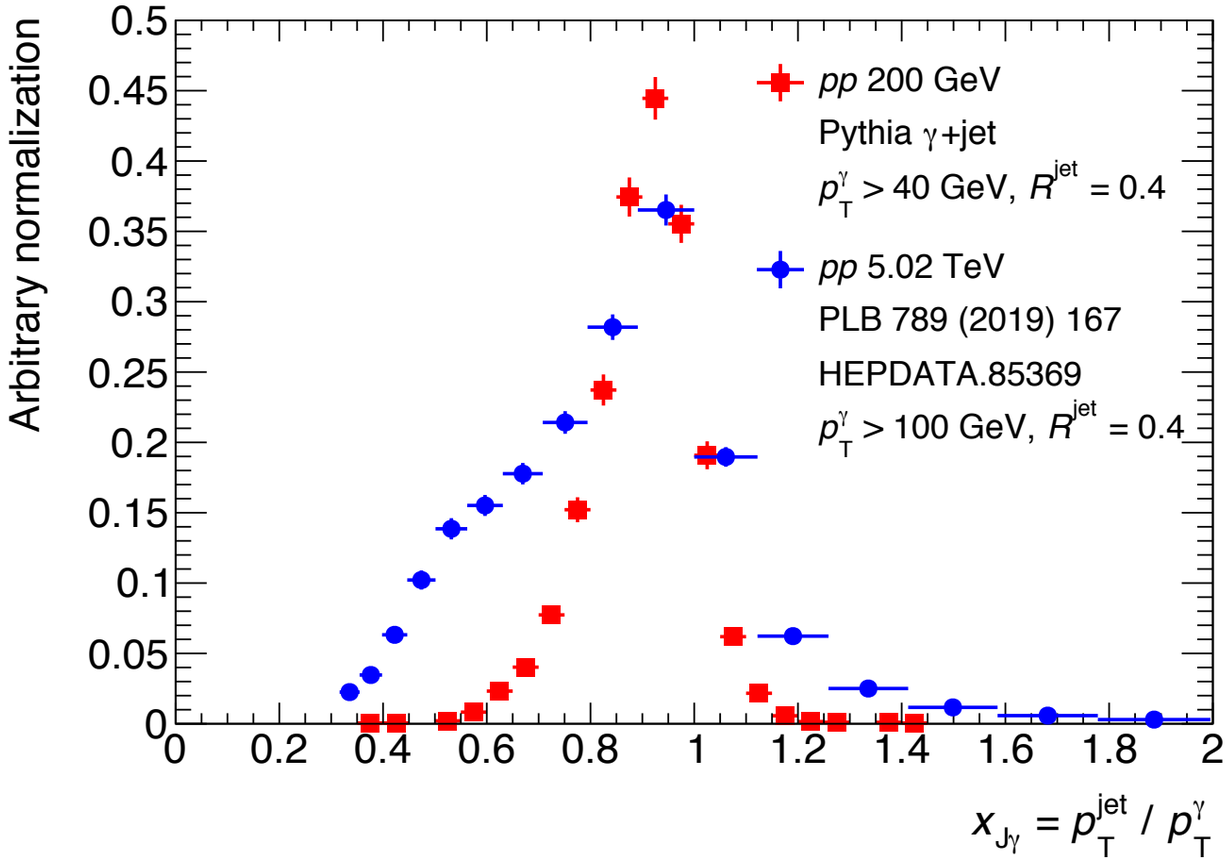
0-10% Pb+Pb

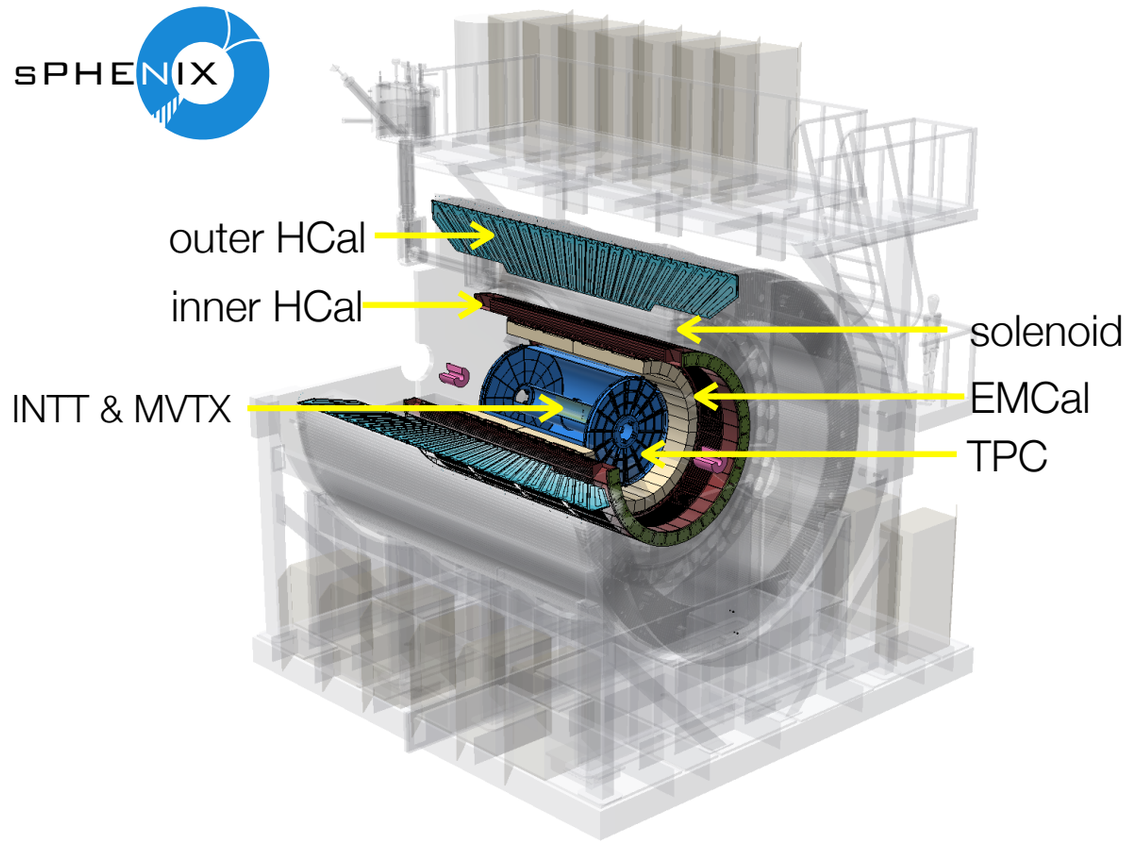


Can models describe centrality / p_T^{γ} evolution?

Difficult to describe detailed shape! (**$SCET_G$** tends to do well…)

Comparisons to (future) HI data @ RHIC



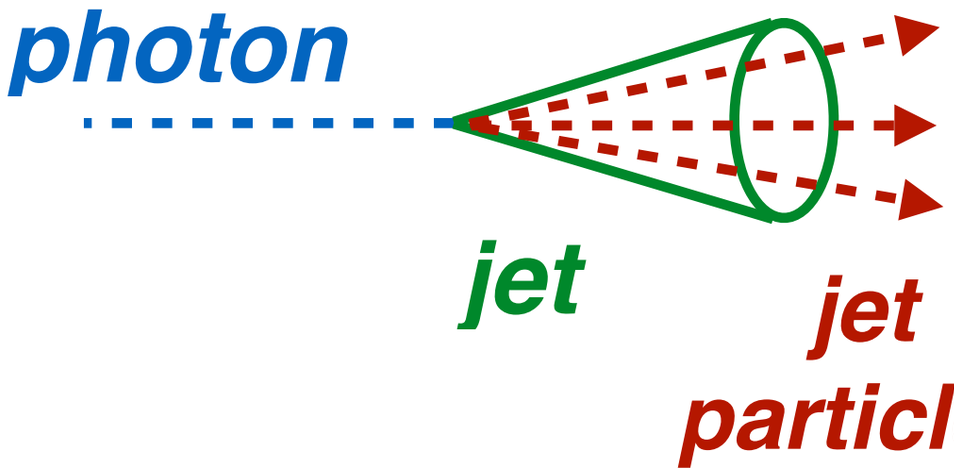


Major physics goal for the HI community: compare jets at RHIC & LHC with similar “unquenched” kinematics / flavor / cone size

➡ one good opportunity for this: select jets with high-p_T photons

➡ above: compare particle level **γ+inclusive-jet** @ RHIC-sPHENIX to **unfolded γ+leading-jet** @ LHC-ATLAS

How is the parton shower in cone modified by medium?



$D(p_T^h)$ *or*

$D(z = p_T^h / p_T^{jet})$

particles

Photon-tagged **frag. function**

(with respect to the **jet** p_T)

note: topological cuts select *leading jets* only

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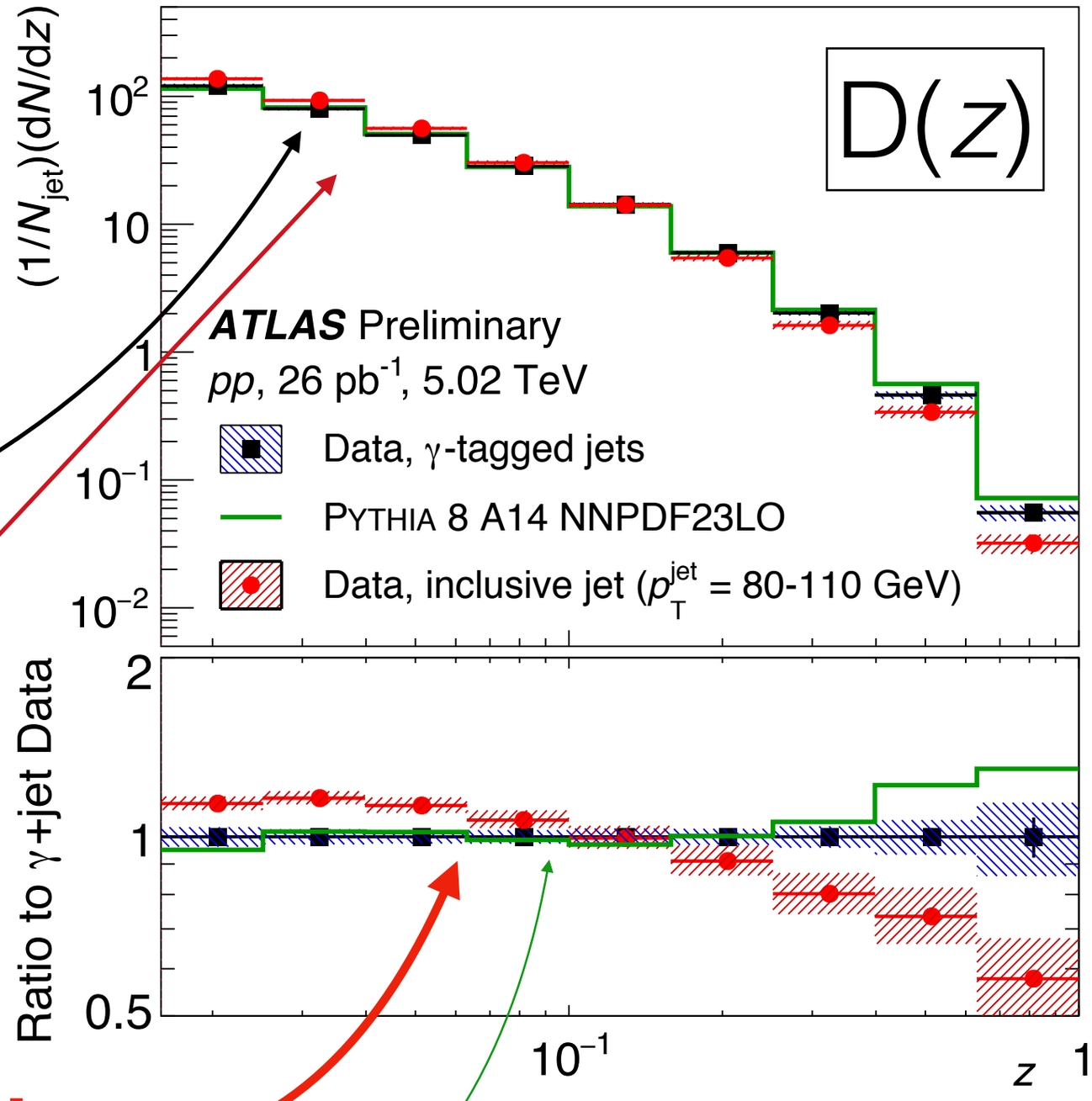
γ-tagged jet FF in *pp*

γ-tagged jet
(quark jet-dominant)

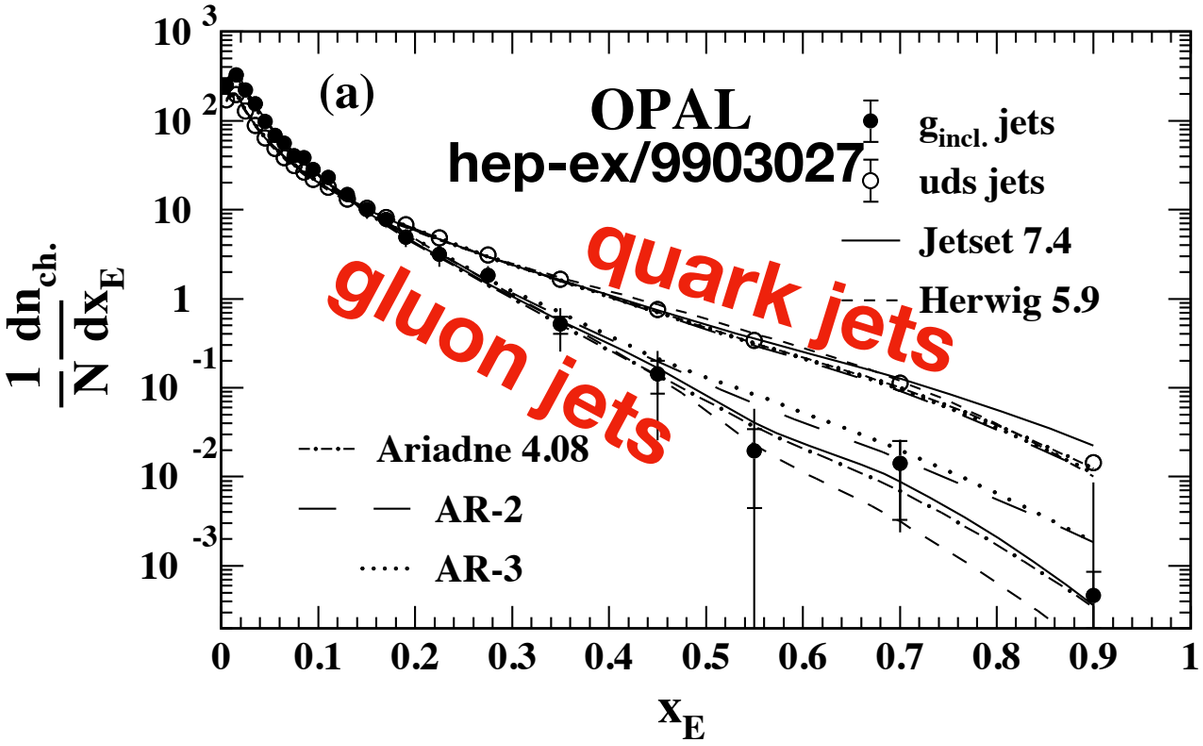
Inclusive jet
(gluon jet-dominant)

Inclusive / γ-tagged ratio

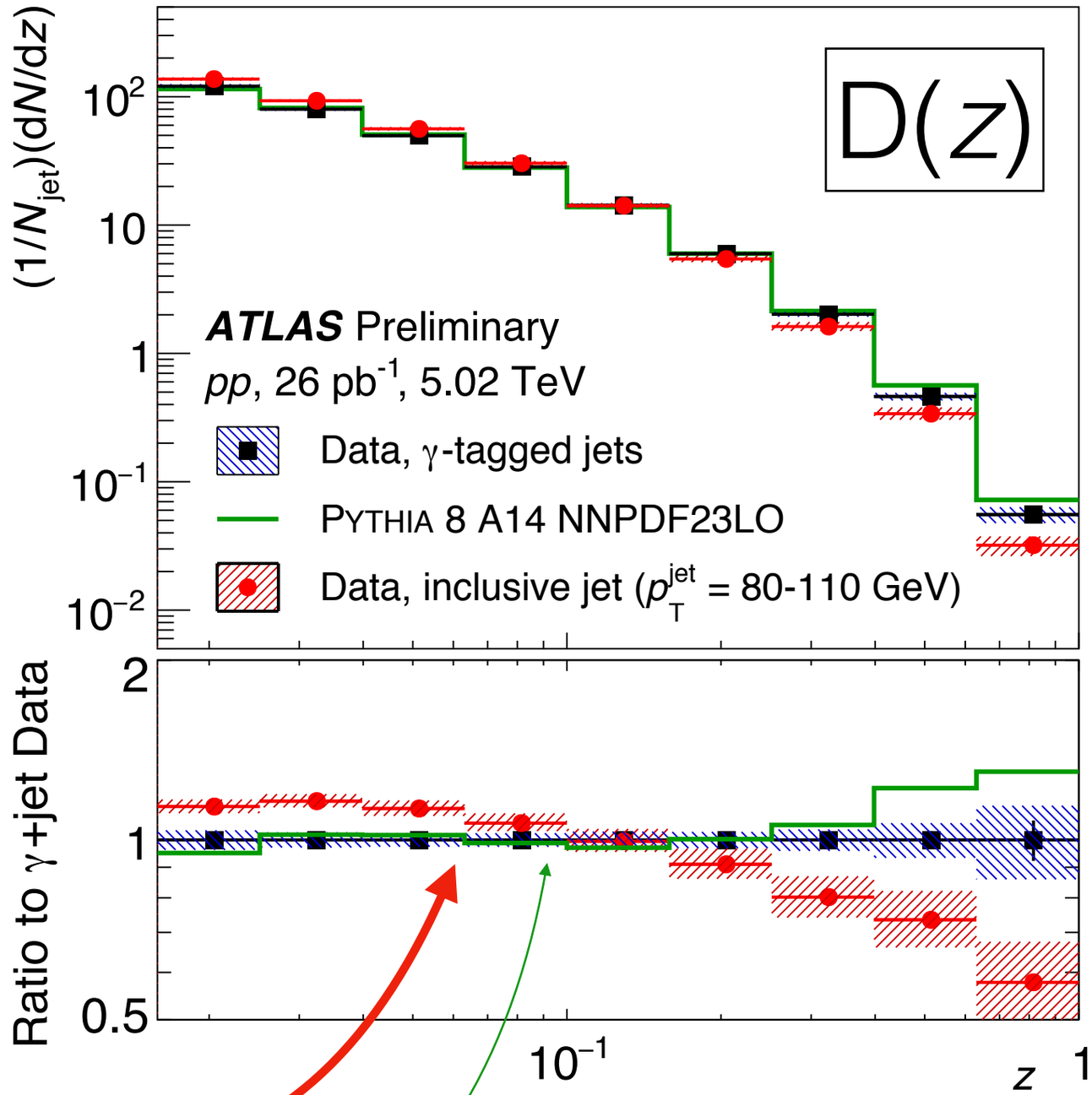
(also γ-tagged Pythia/data ratio)



γ-tagged jet FF in *pp*



Fragmentation difference as expected from, e.g. LEP

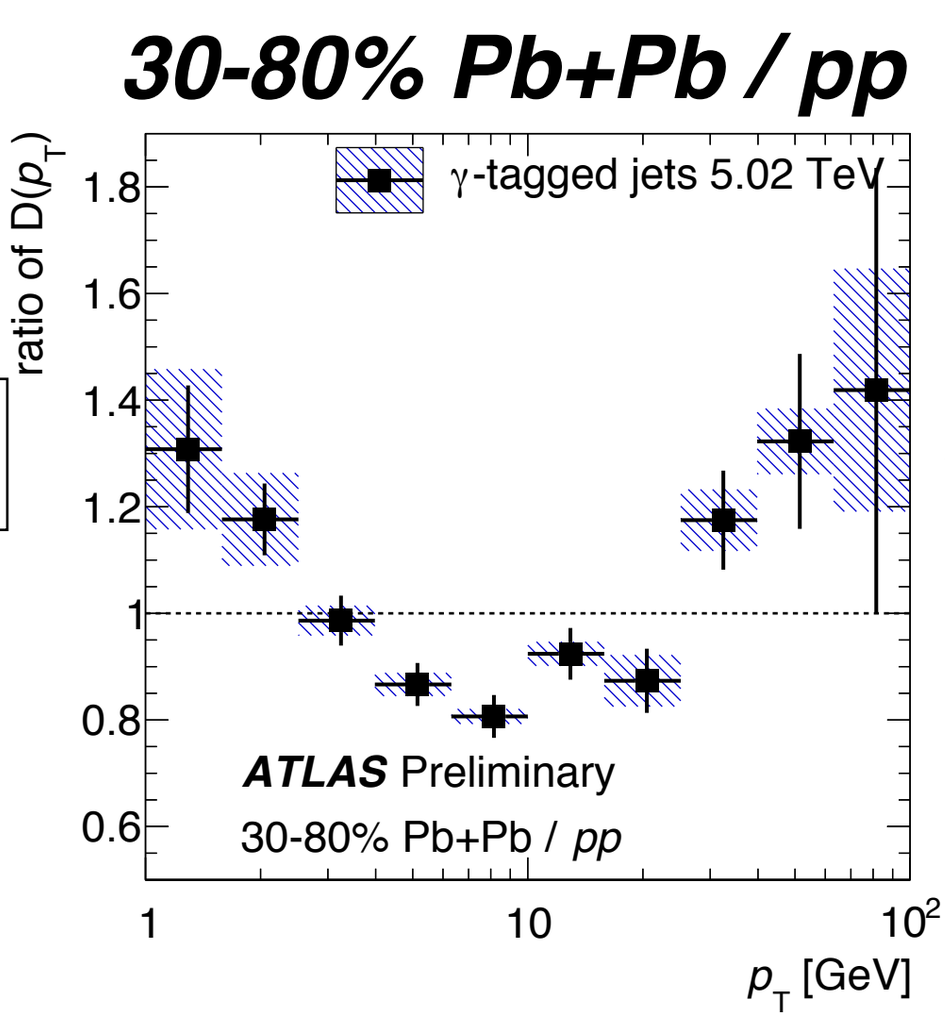


Inclusive / γ-tagged ratio

(also γ-tagged Pythia/data ratio)

γ-tagged jet FF in 30-80% Pb+Pb

D(p_T)



rise at large-z / p_T?

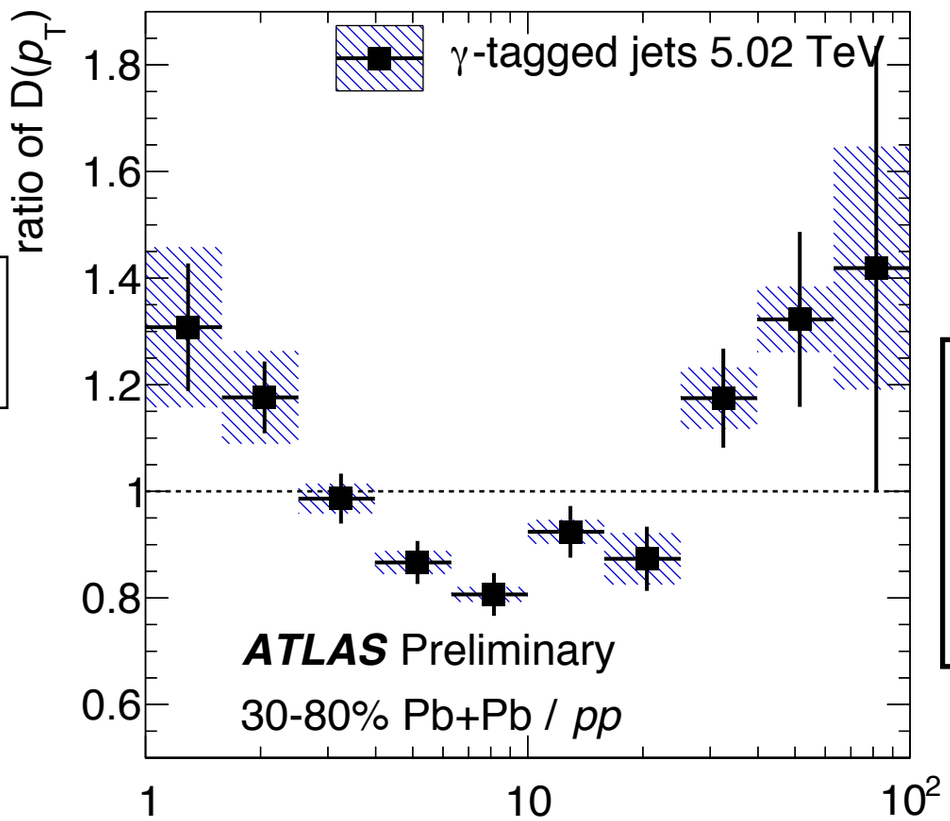
D(z)

less obvious here…

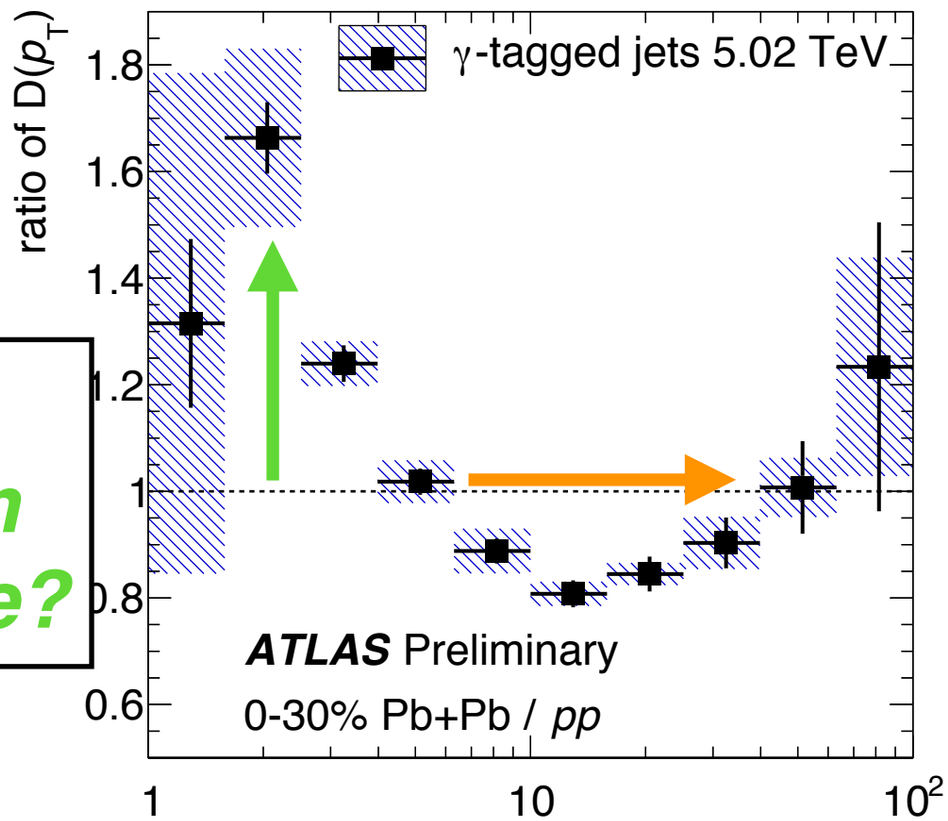
30-80% Pb+Pb / pp

0-30% Pb+Pb / pp

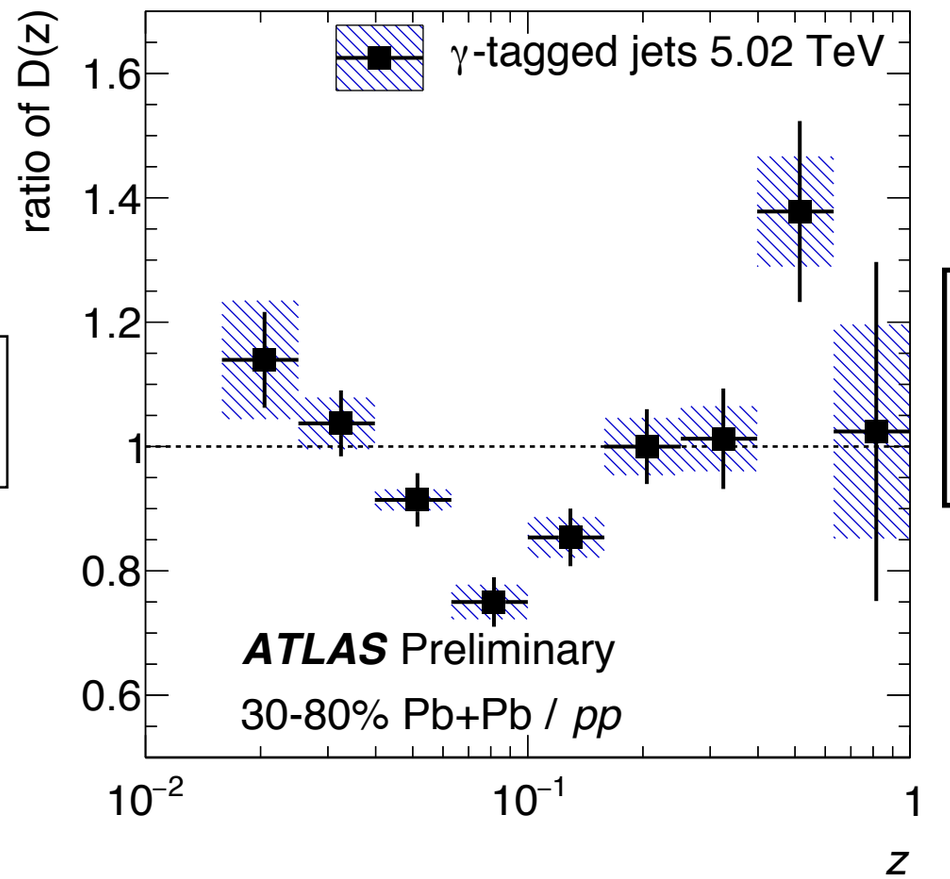
$D(p_T)$



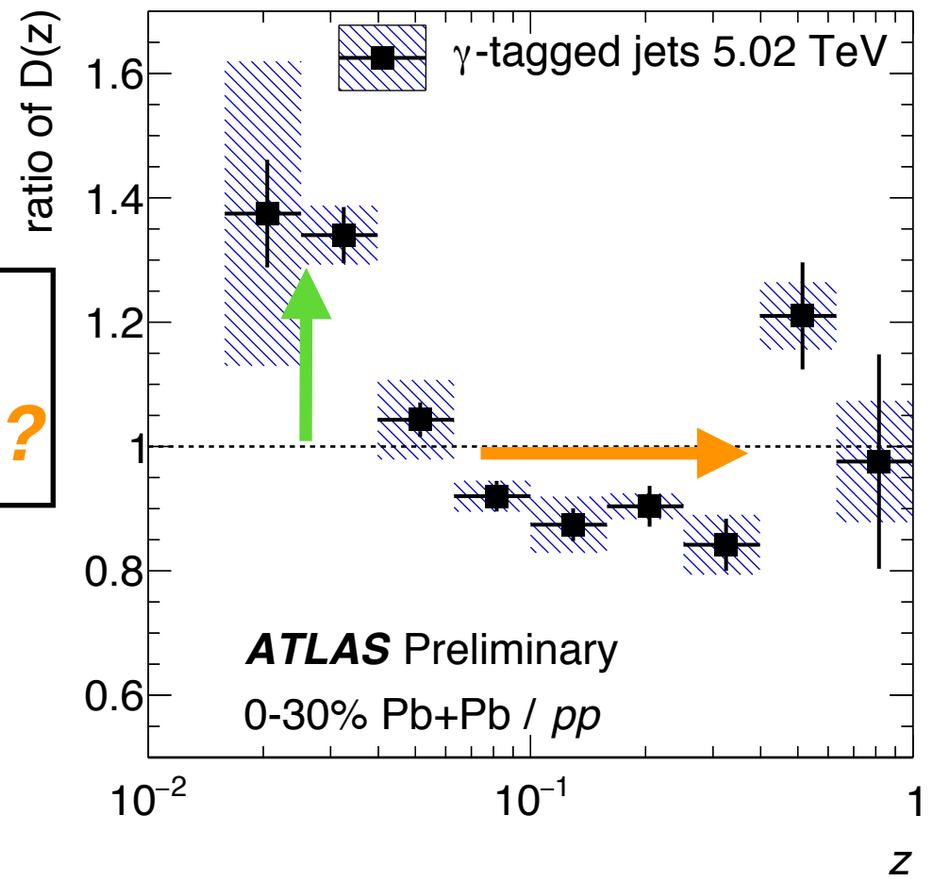
larger medium response?



$D(z)$



more softening?

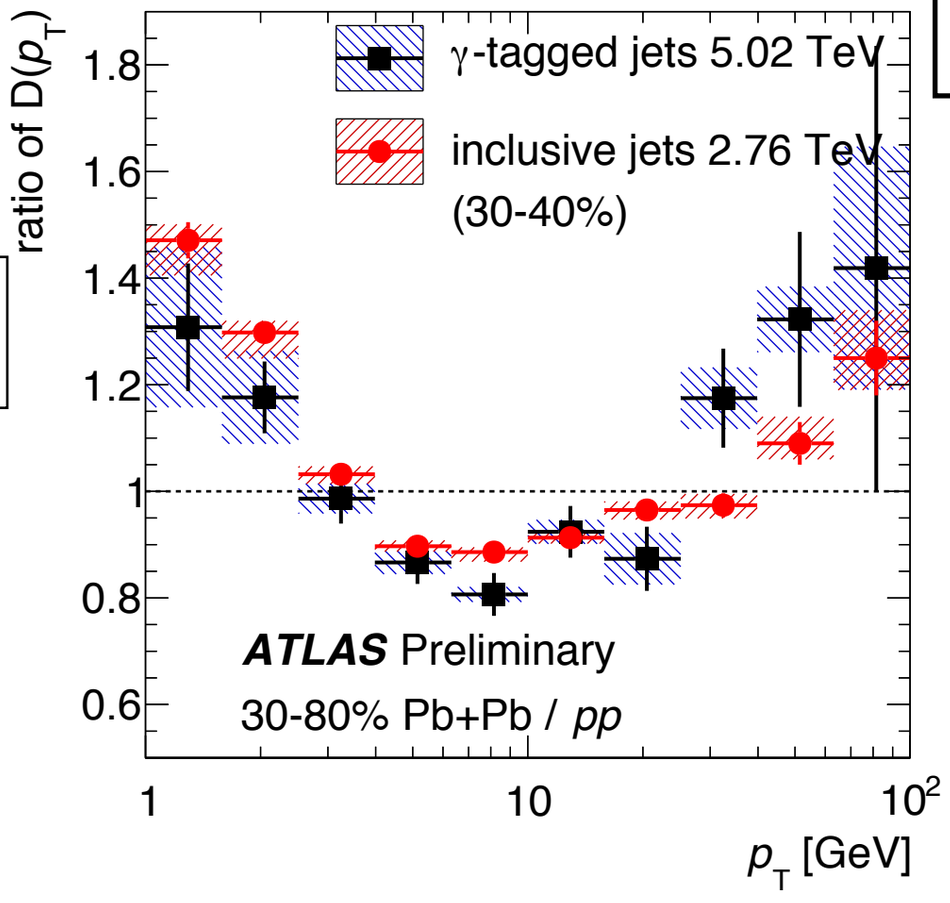


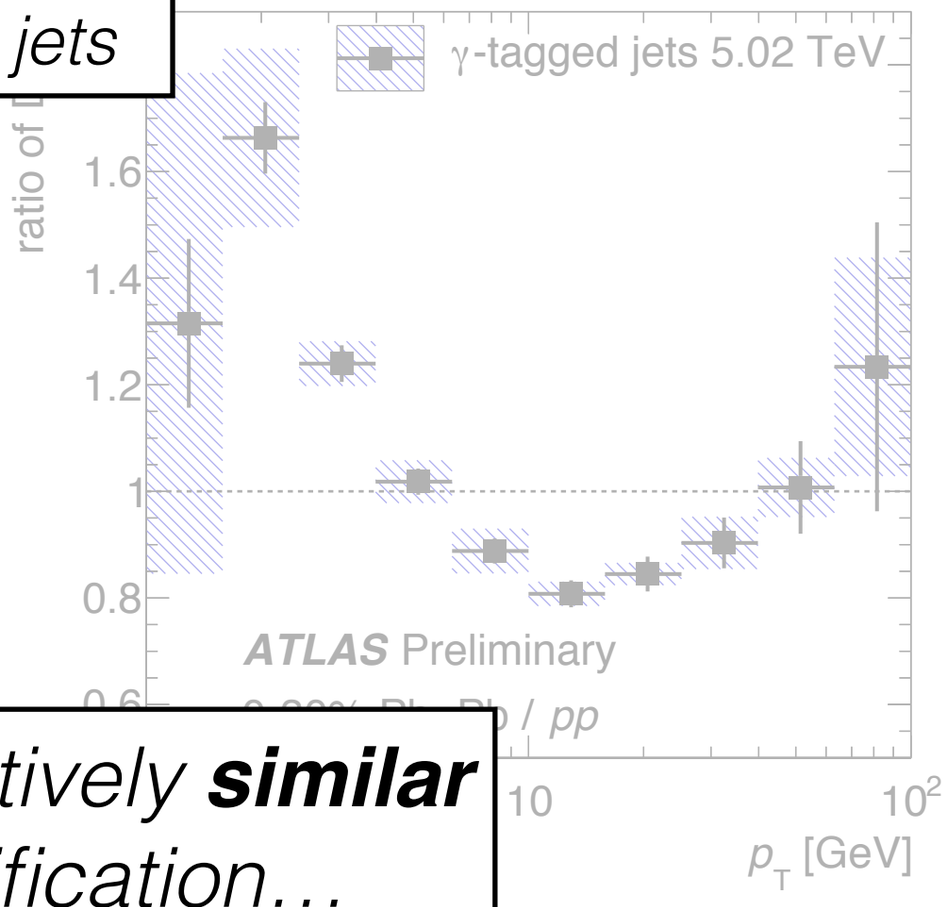
30-80% Pb+Pb / pp

inclusive (gluon-dominant) jets

0-30% Pb+Pb / pp

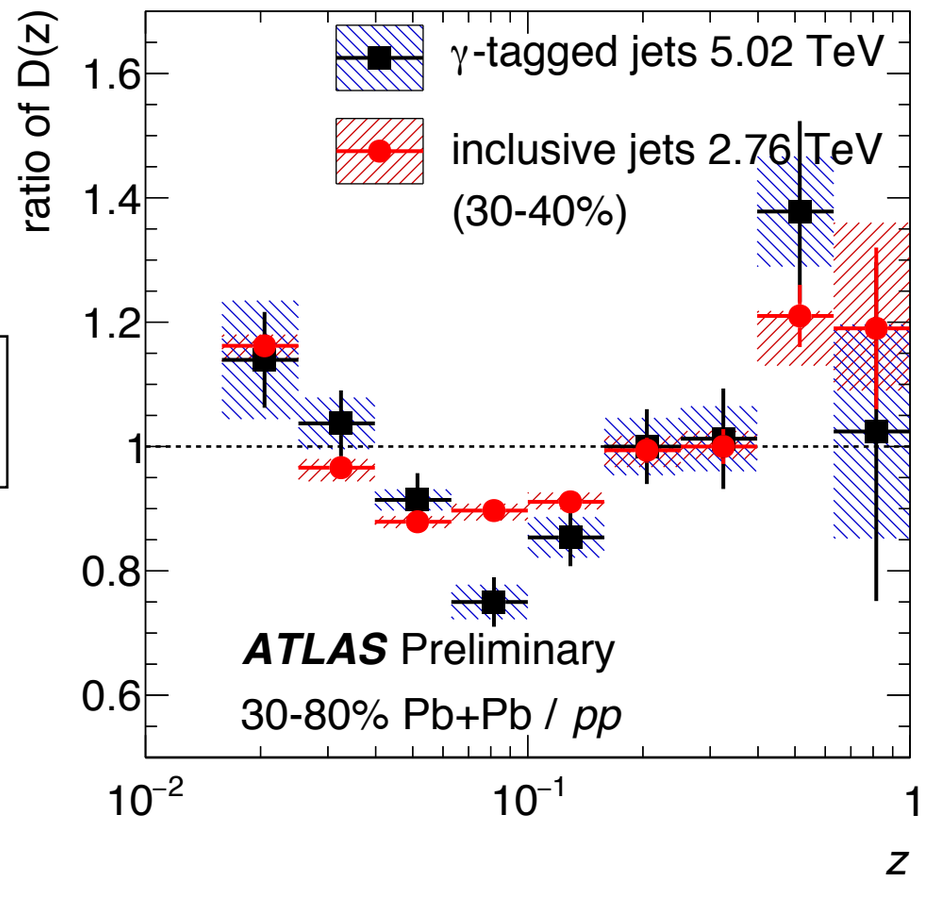
D(p_T)

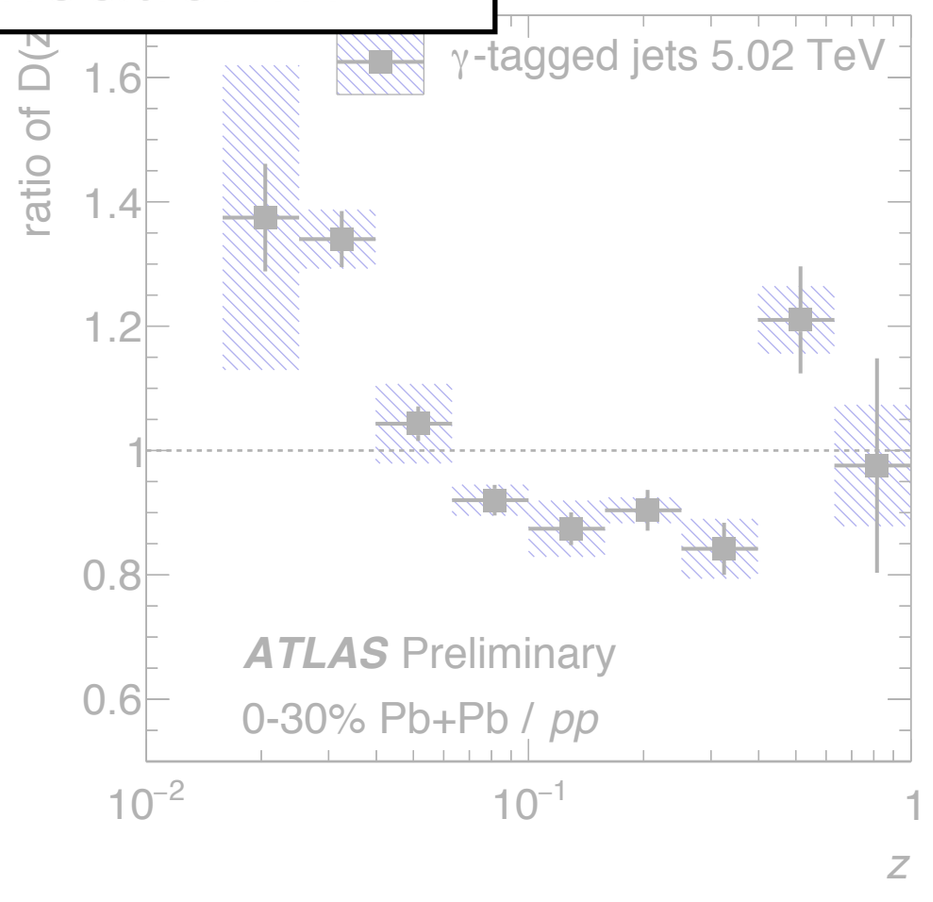




quantitatively ***similar*** *modification…*

D(z)



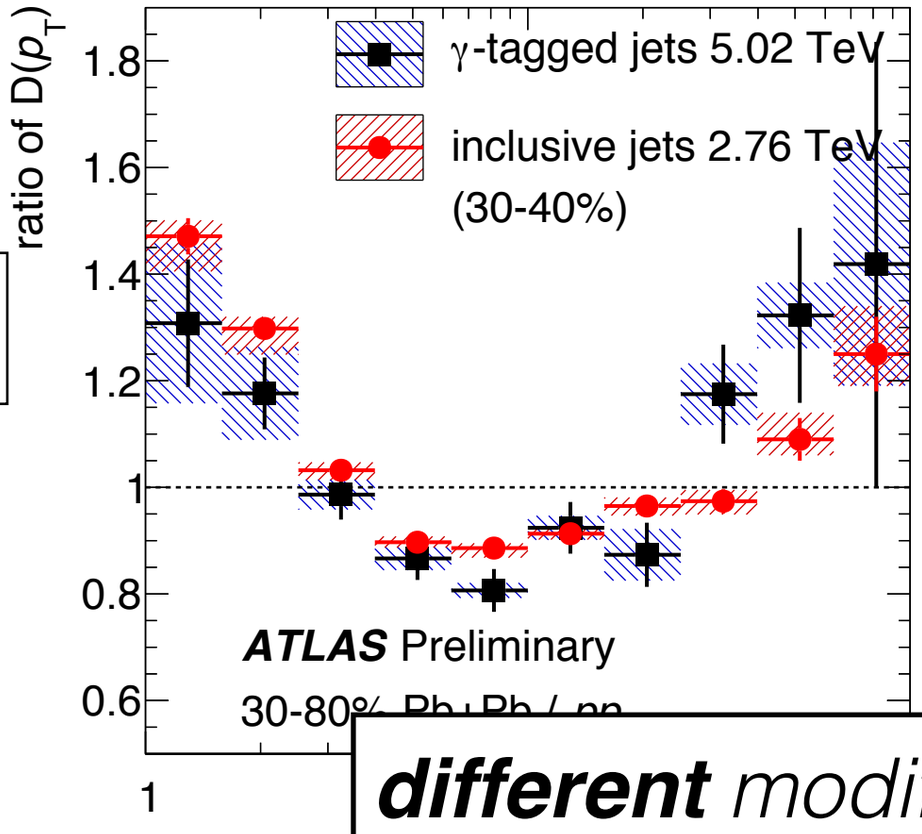


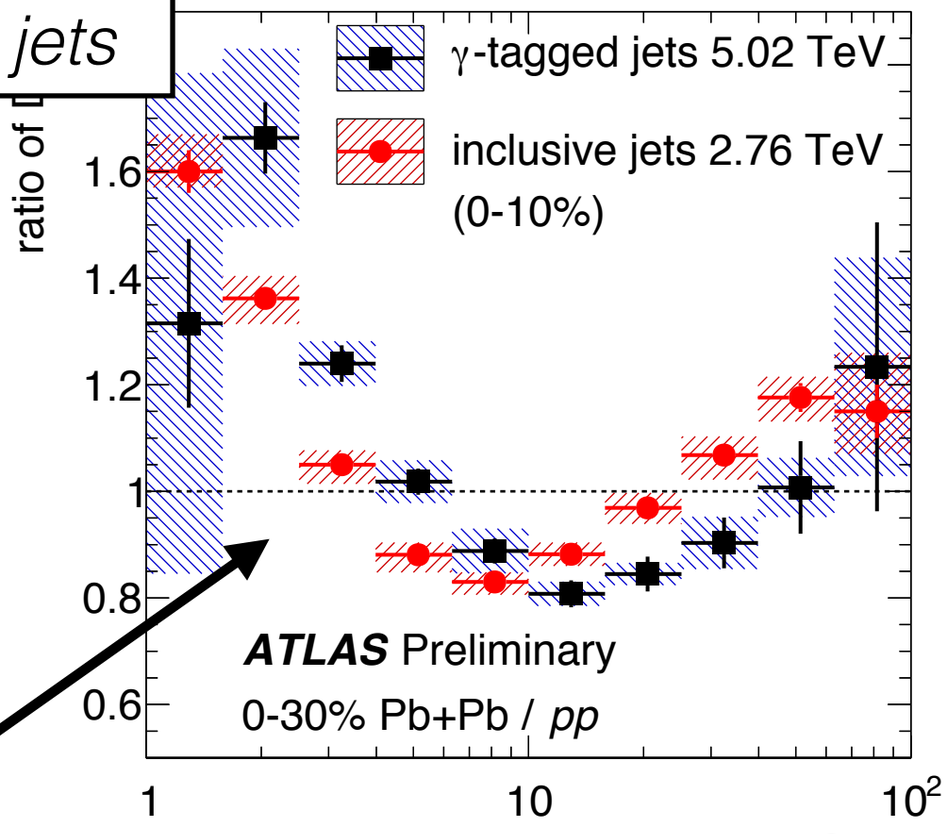
30-80% Pb+Pb / pp

inclusive *(gluon-dominant) jets*

0-30% Pb+Pb / pp

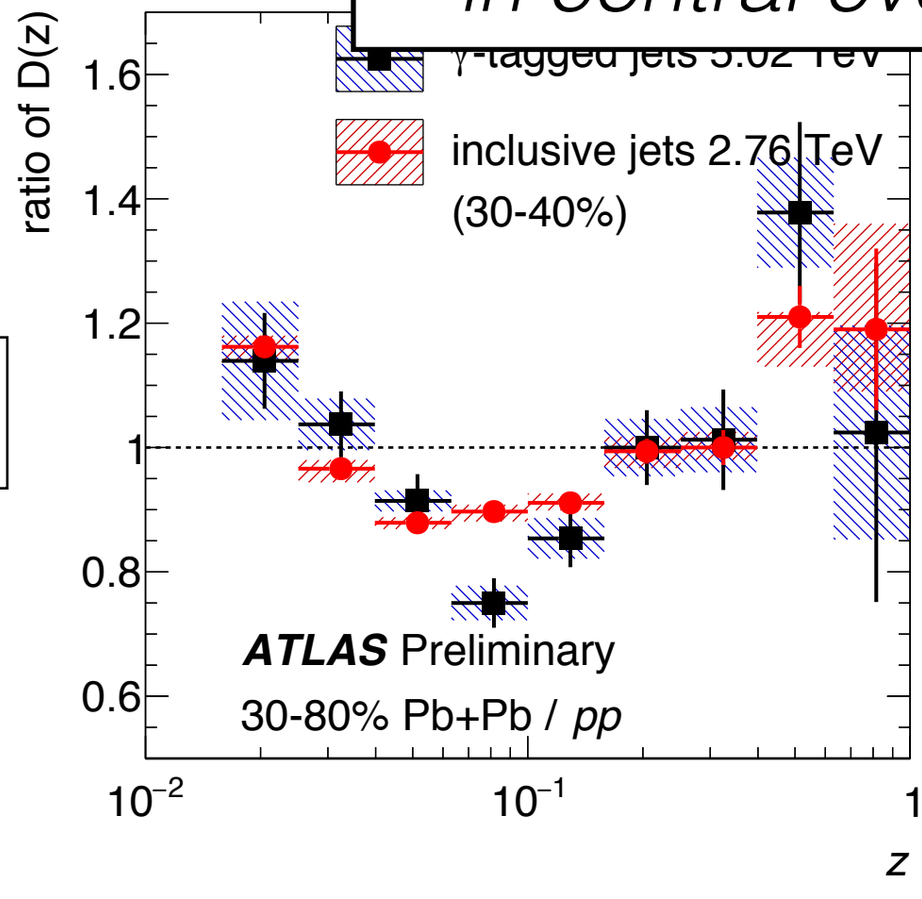
D(p_T)

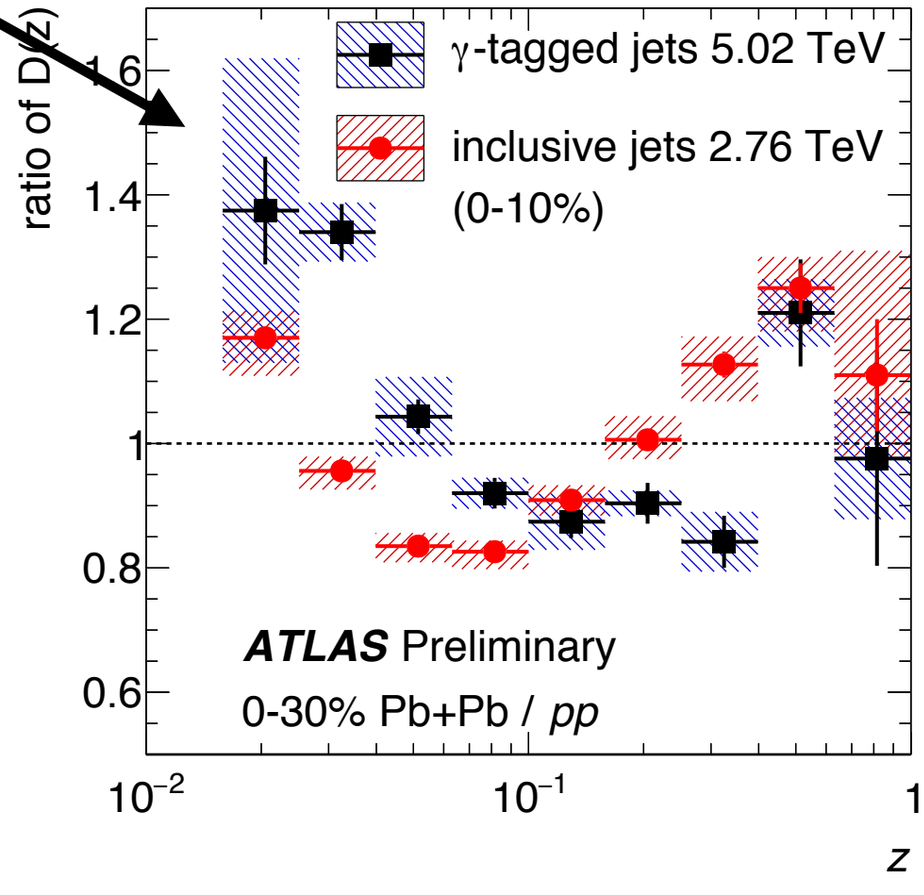




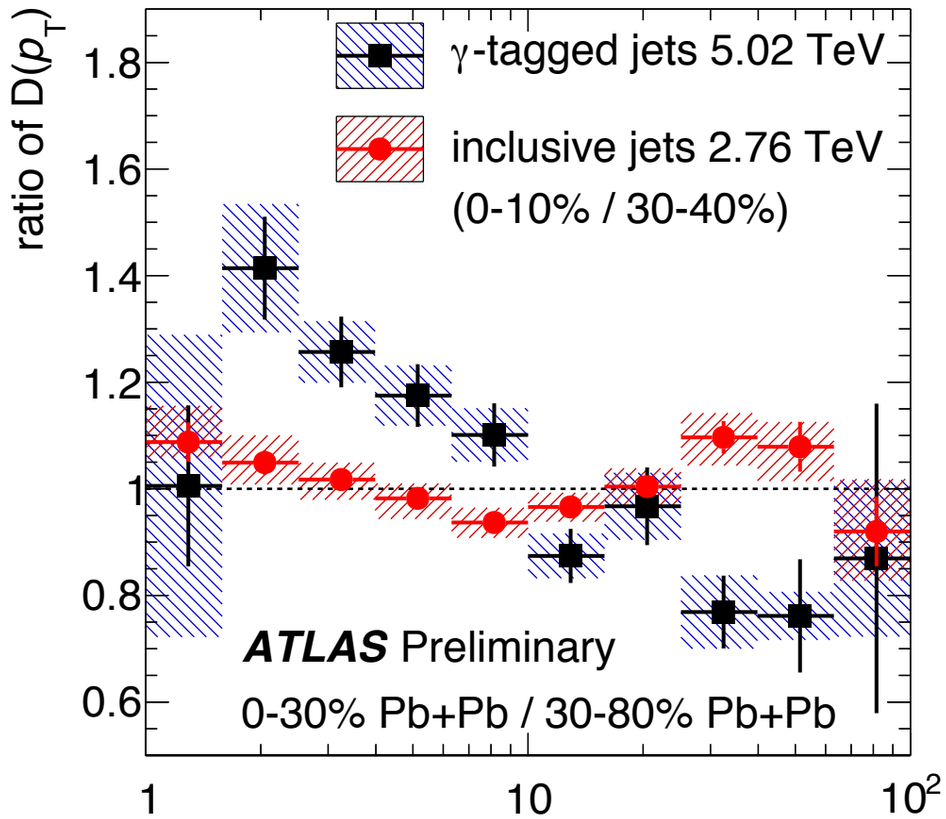
different *modification in central events!*

D(z)

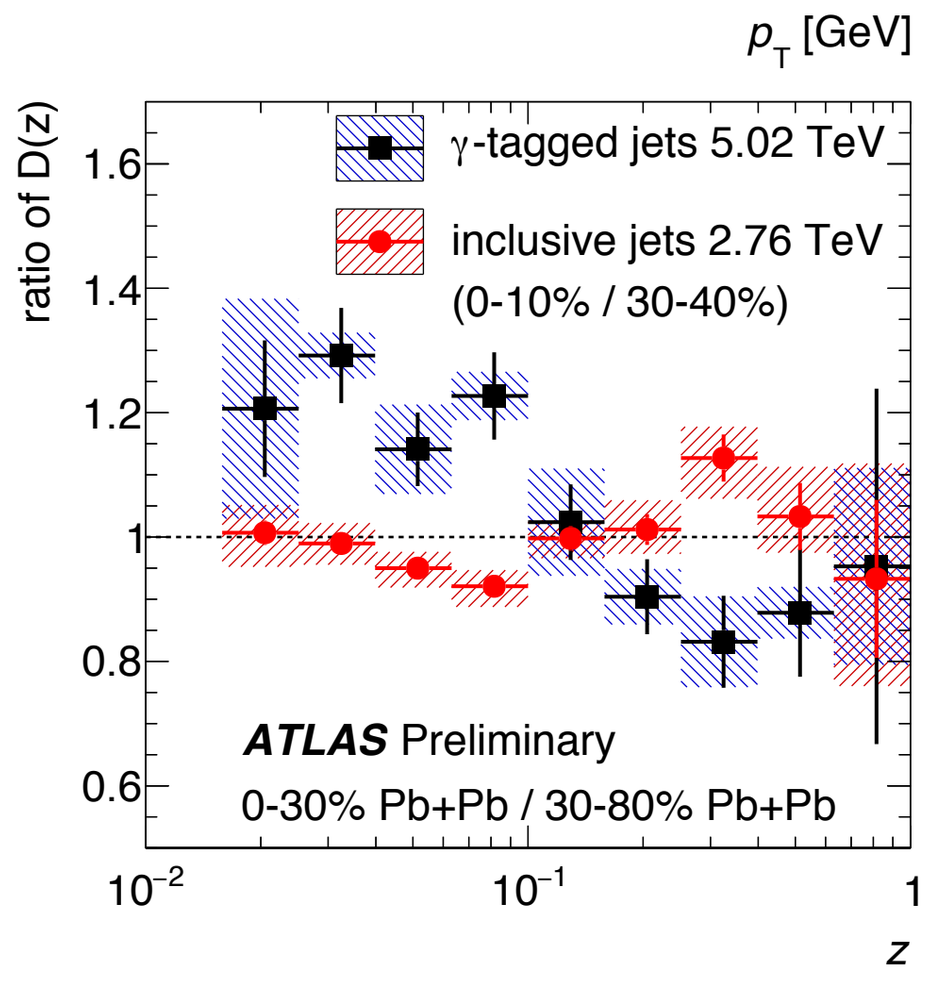




D(p_T)



D(z)

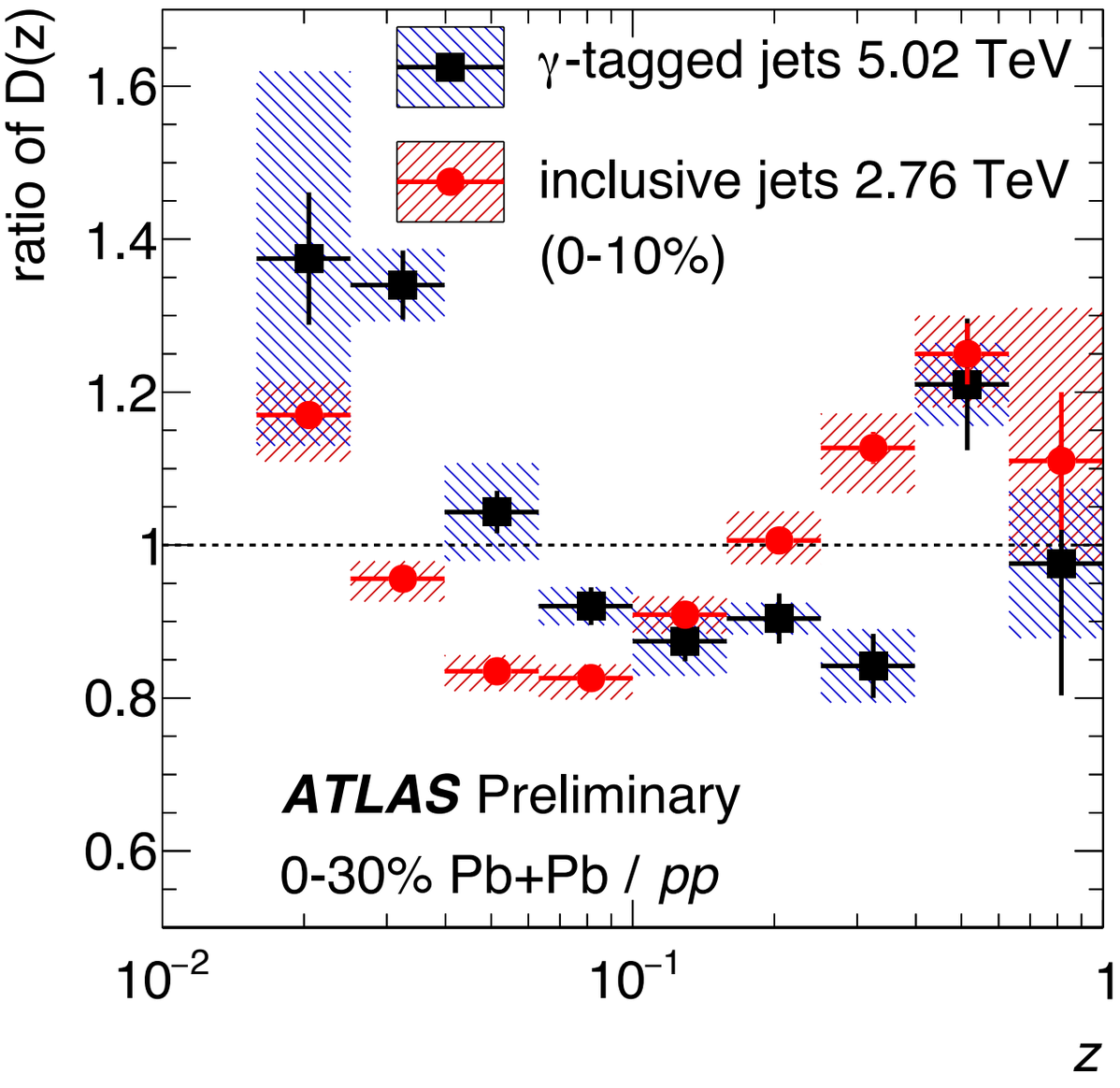


*take **0-30% Pb+Pb / 30-80% Pb+Pb** ratio*

(like an "R_{CP}")

*weak centrality dependence for **inclusive jets***

***photon-tagged jets** continue to be modified with centrality…*

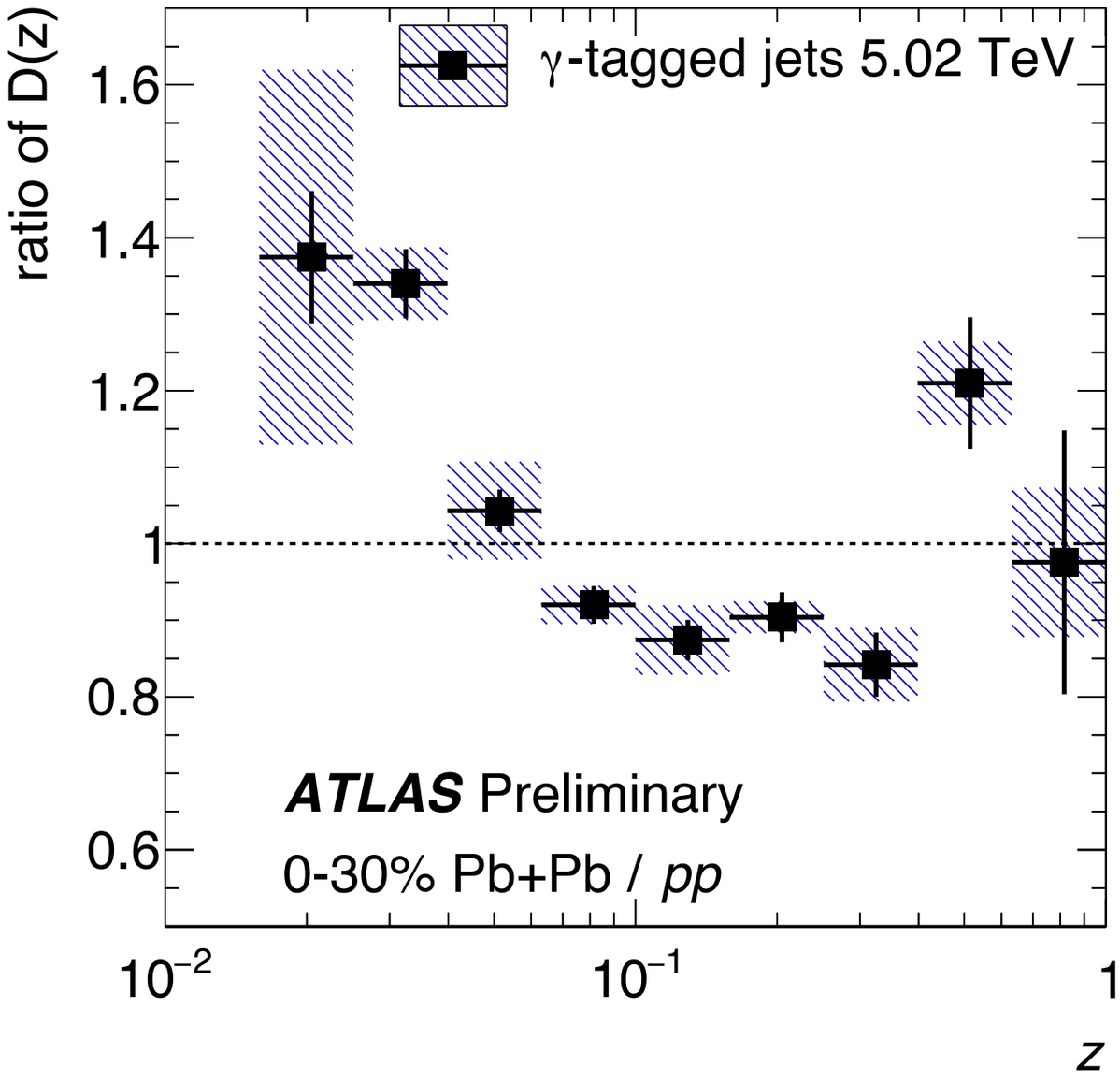


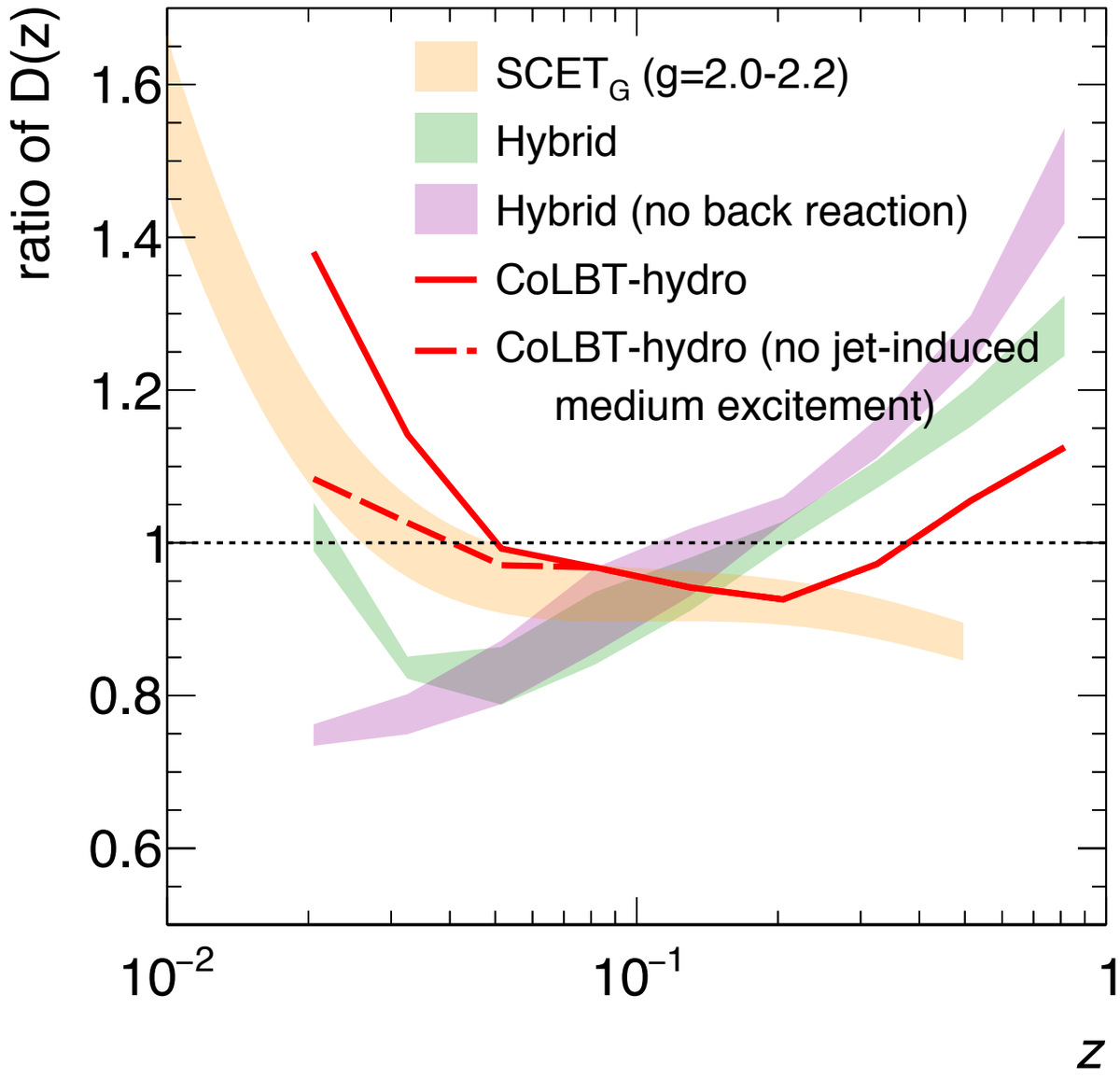
how much of this can be attributed just to flavor?

… and how much to selection effects?

(bias against strongly modified jets w/ ***inclusive selection****, but not with* ***photon tag****?)*

Theory comparison: γ-tagged

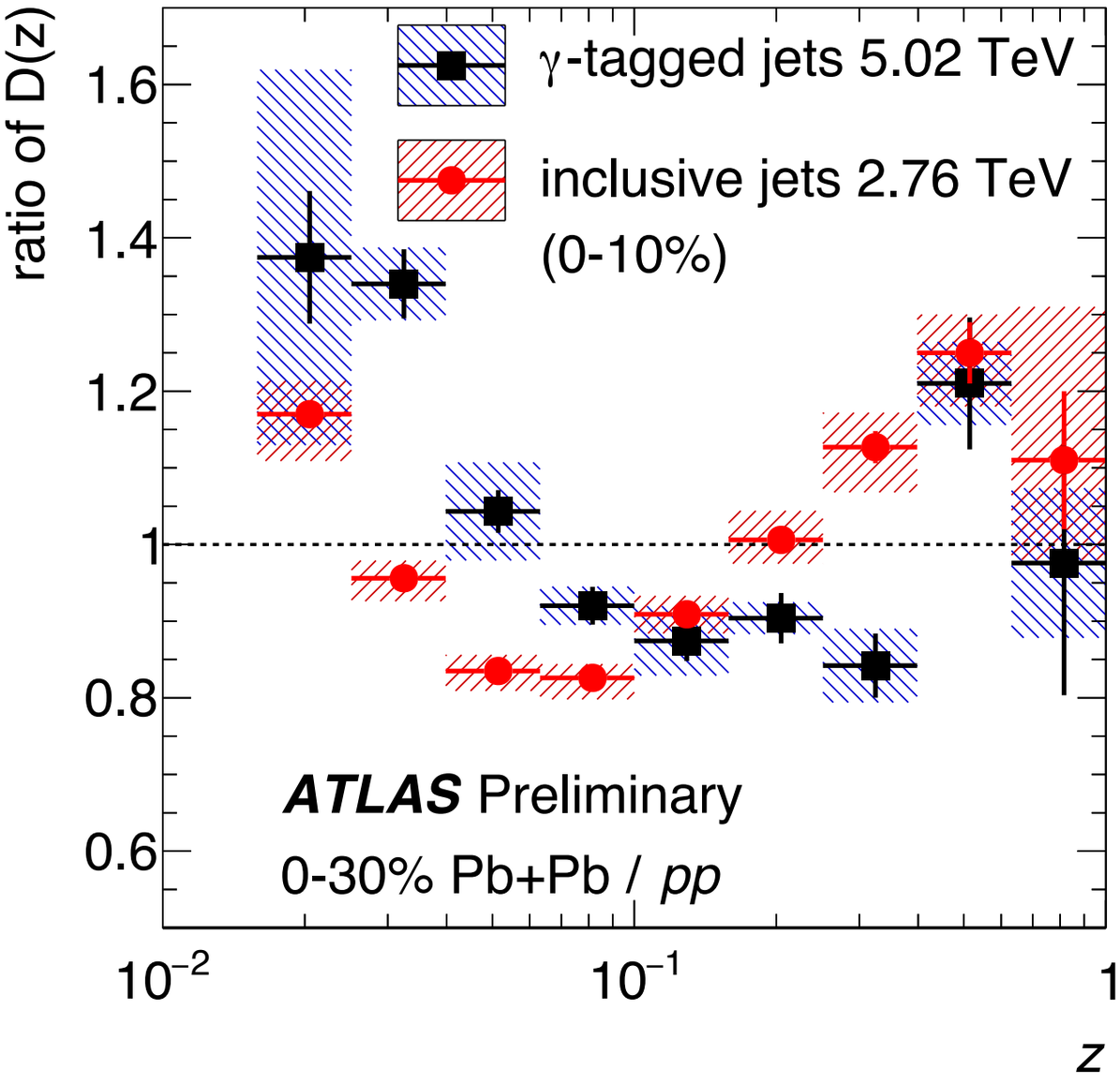


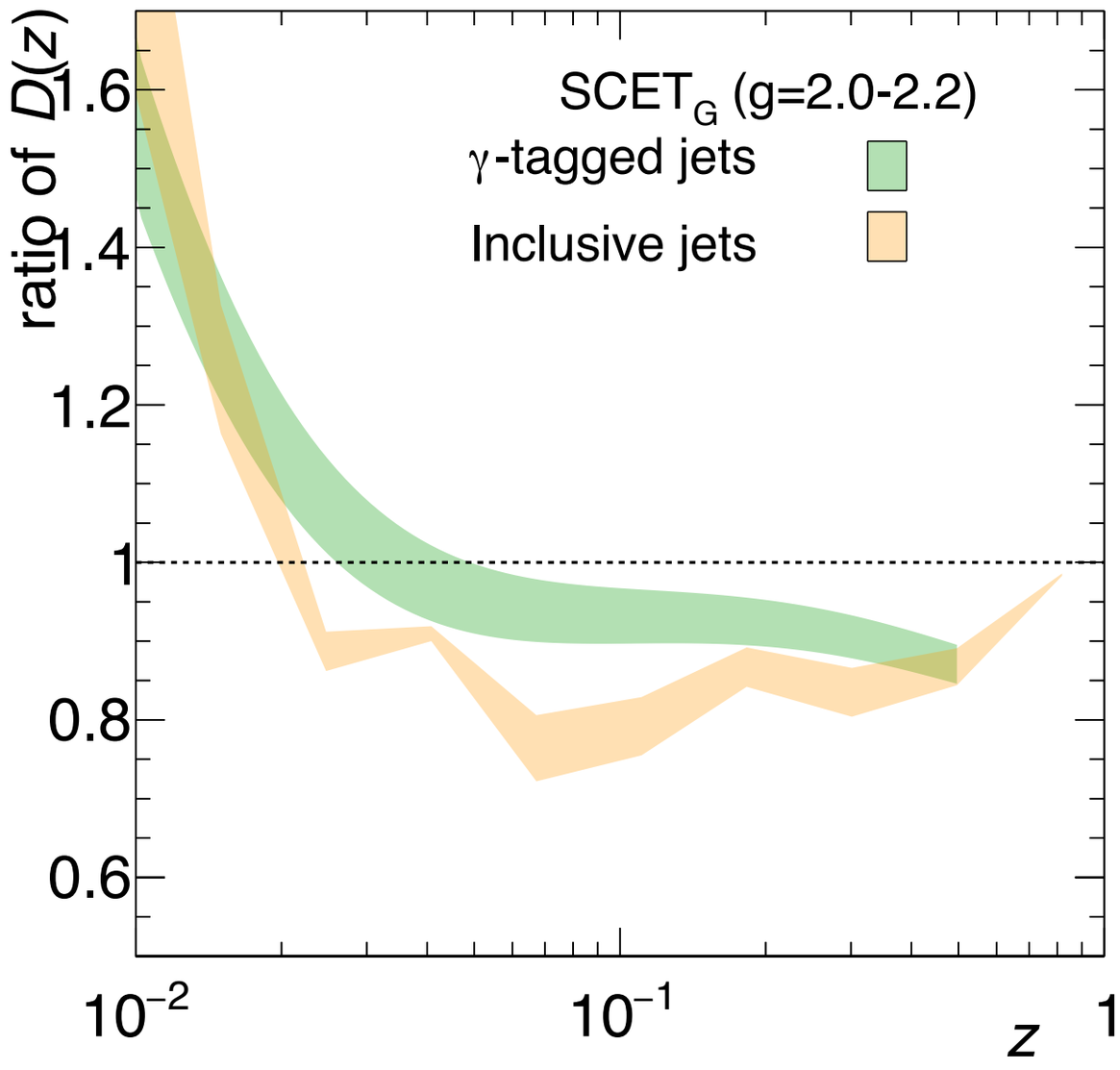


Some models correctly describe the low-*z* enhancement (**CoLBT-hydro** & $SCET_G$)

➡ particularly with back reaction / jet-induced medium effects…

Theory comparison: γ-tagged & inclusive





Simultaneous four-way data / theory / inclusive / γ-tagged comparison

➡ $SCET_G$ captures the γ-tagged vs. inclusive "ordering" for $z < 0.1$
— what physics in the calculation causes this?

Summary

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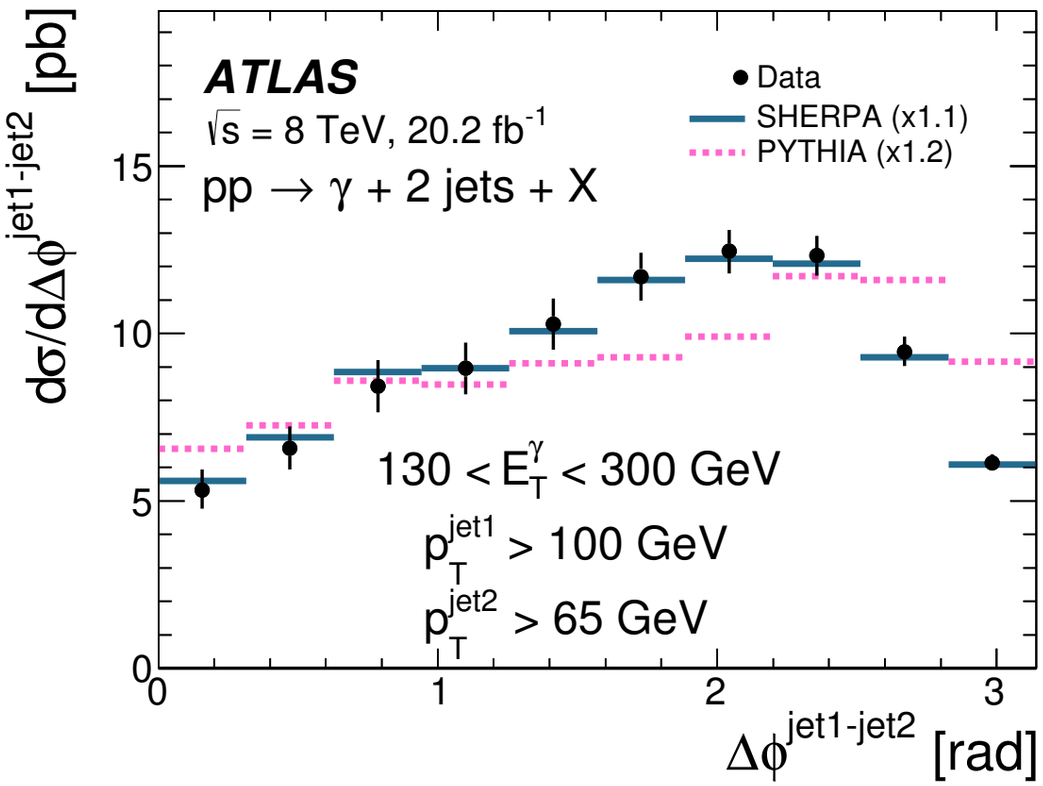

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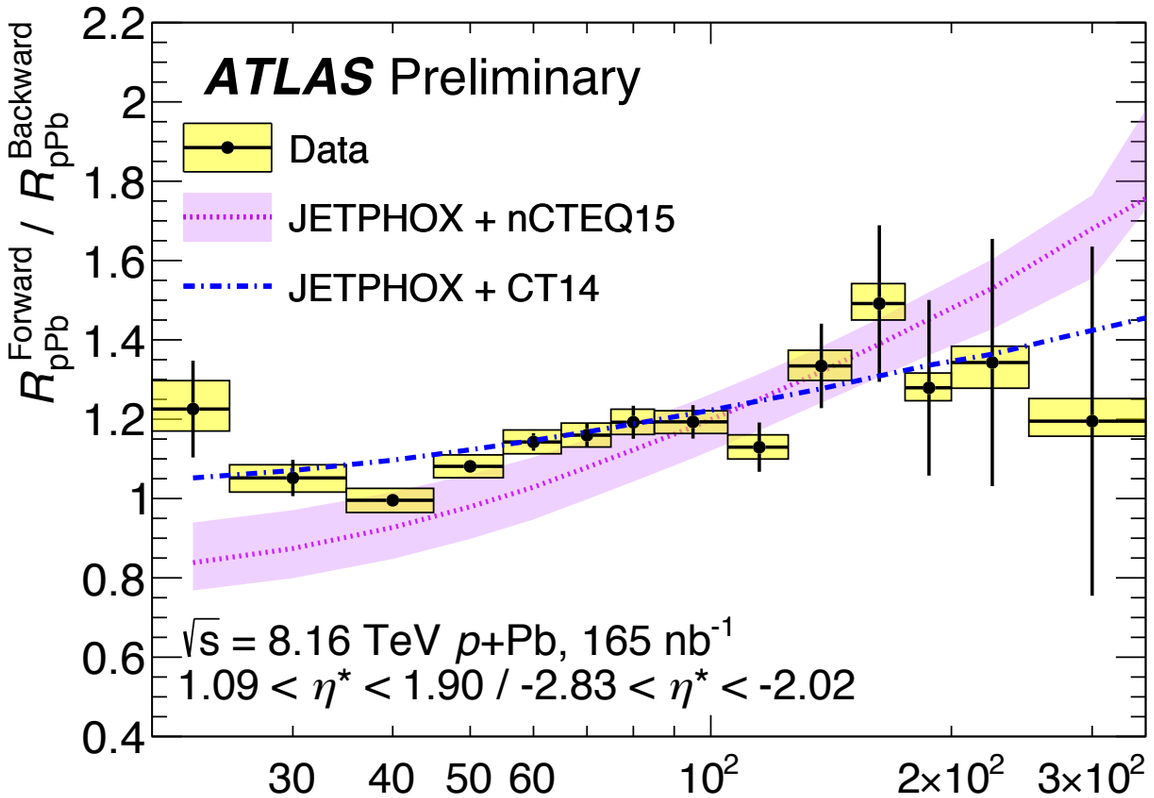

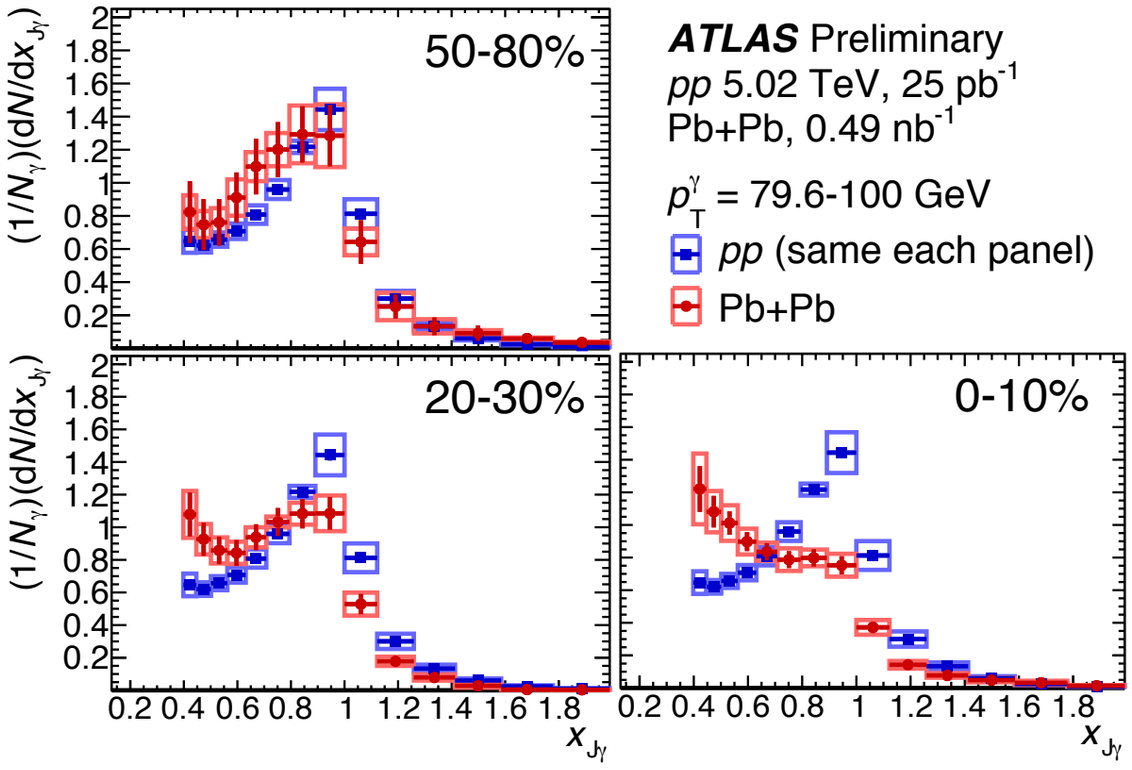

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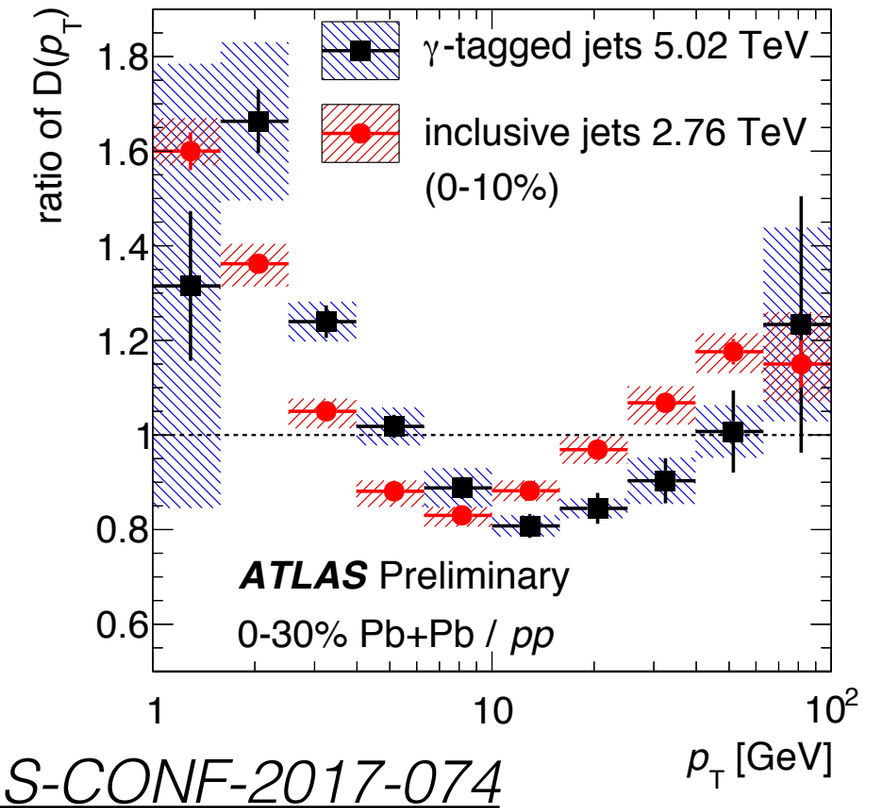

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