ALICE Results on Jets and Photons

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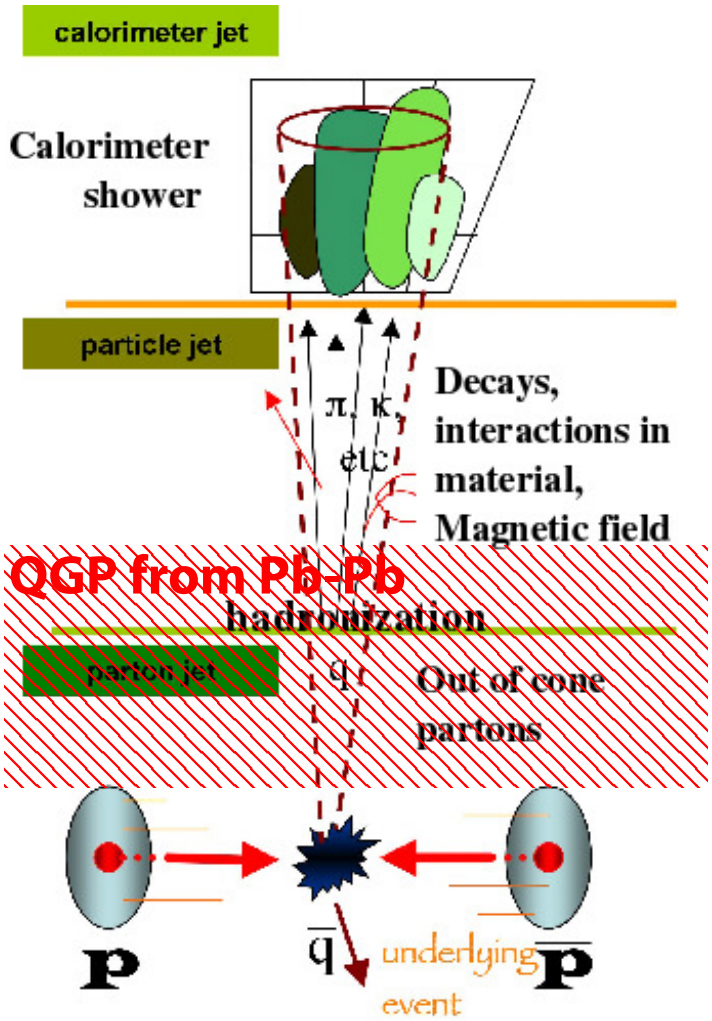
Introduction

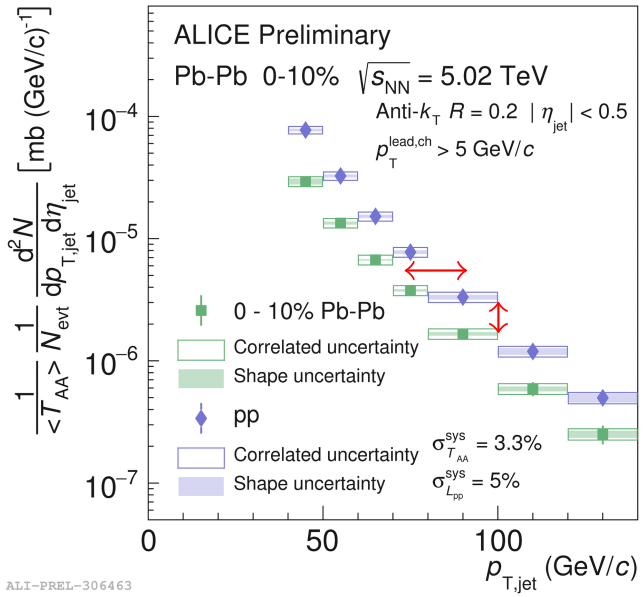


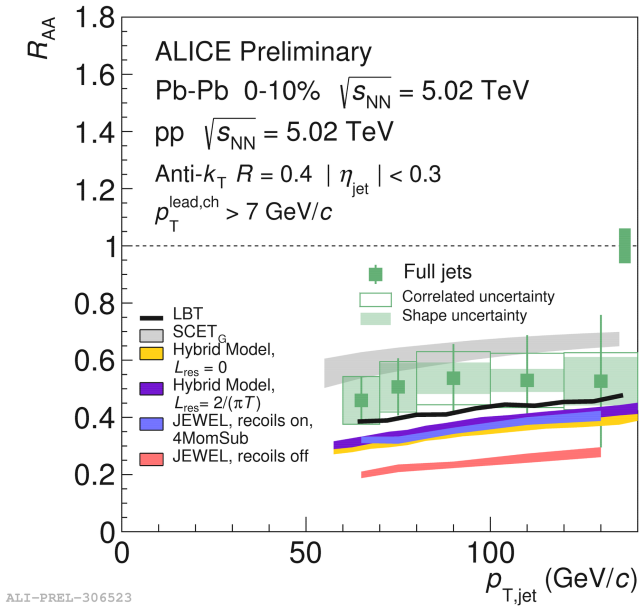
S. D. Ellis, et al., Prog. Part. Nucl. Phys. 60, 484 (2008)

- Jets: Remnants from surviving quark and gluons, after interaction with the plasma, produced plentifully
- Asymptotic freedom causes flux tube to "rip" and hadronizes into a spray of particles
- I will talk about results with
  - Jet spectra and R_{AA}
  - Substructure (color coherence when forming jets)
  - Identified deuterons (do hadrons coalesce into composite particles?)
  - Photons

Inclusive Jets/R_{AA}

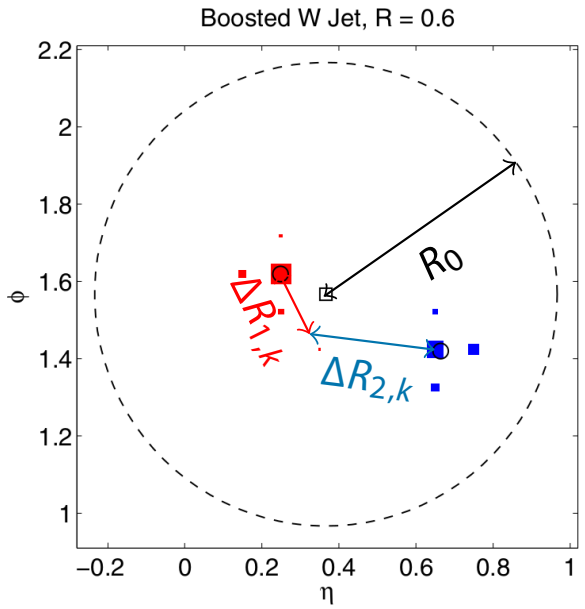
- R_{AA} = rate relative to superposition (of independent nucleon-nucleon binary collisions)
- $R_{AA} < 1$ can result from a shift in energy, and is not necessarily an observable for survival probability
- Result marginally consistent with pQCD energy loss models (models tend to be tuned not too far off R_{AA})
  - "Hybrid" applies AdS-CFT energy loss to PYTHIA, and energy lost is assumed to be isotropic/no correlation with jets
  - Remaining models implement pQCD physics: SCET/JEWEL single or few gluon mission, LBT multiple emission with transport model





N-subjetiness

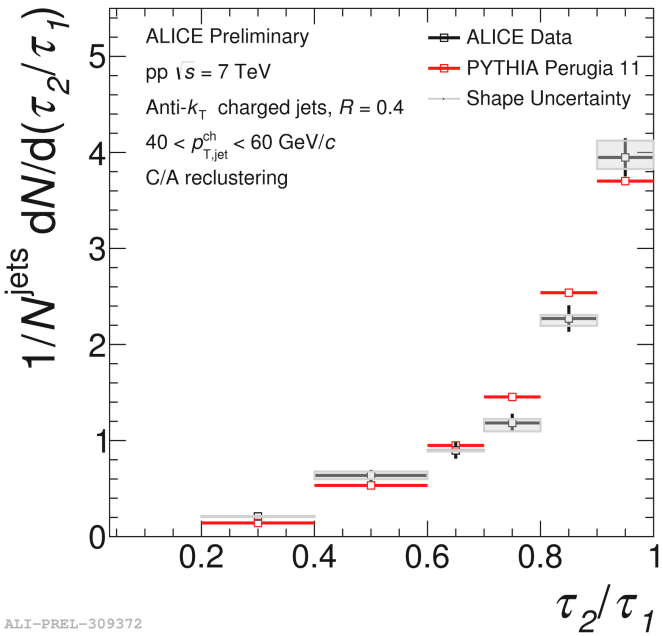
- Thaler, Van Tilburg (JHEP 1103:015, 2011)
- N candidate subjets: $\dfrac{\sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \ldots, \Delta R_{N,k}\}}{\sum_k p_{T,k} R_0}$
- Statistical measure of the the degree which a jet has N or fewer hard cores
- R_0 the characteristic radius (e.g. the dashed circle below)



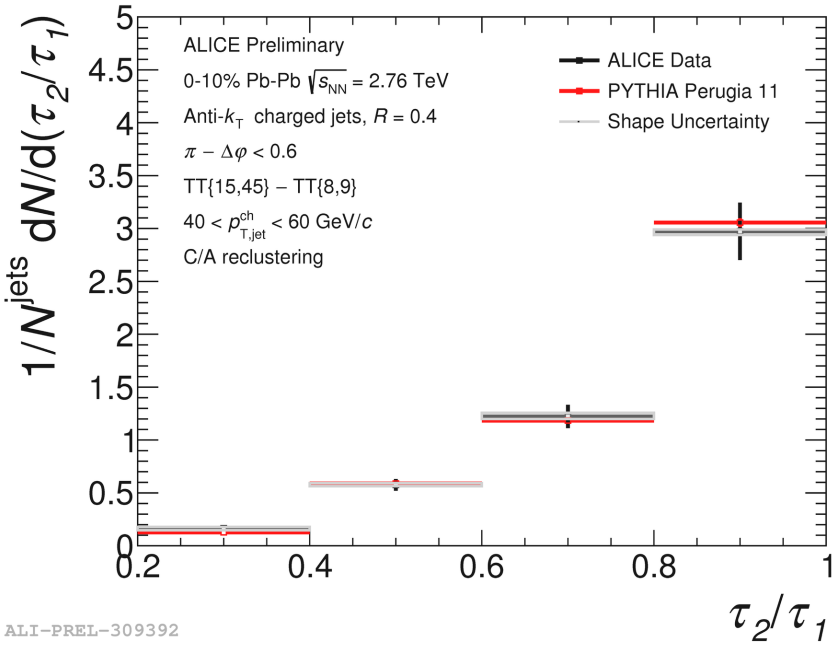
- $\tau_N \approx 0$: everything lines up, N or fewer subjets (open circle symbols)
- $\tau_N \gg 0$: energy away from N subjets, at least $N+1$ subjets

J. Thaler, K. Van Tilburg, JHEP 1103:015 (2011)

N-subjetiness (C/A)



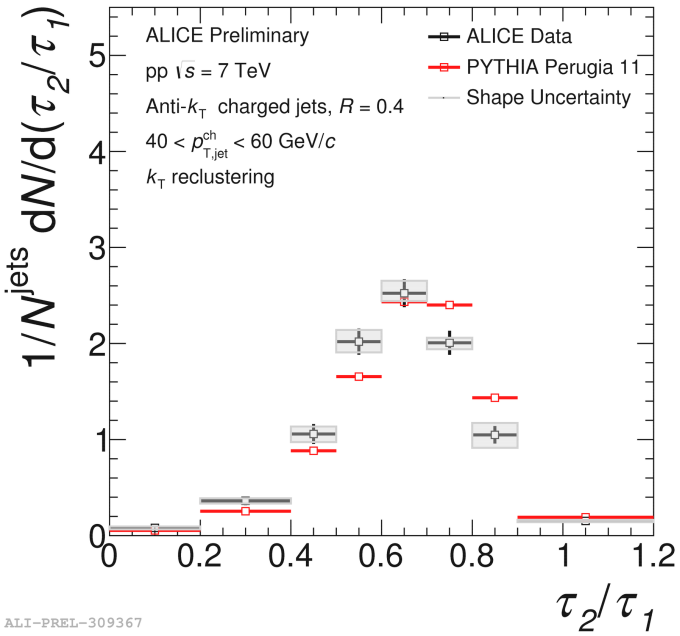
pp $\sqrt{s} = 7$ TeV

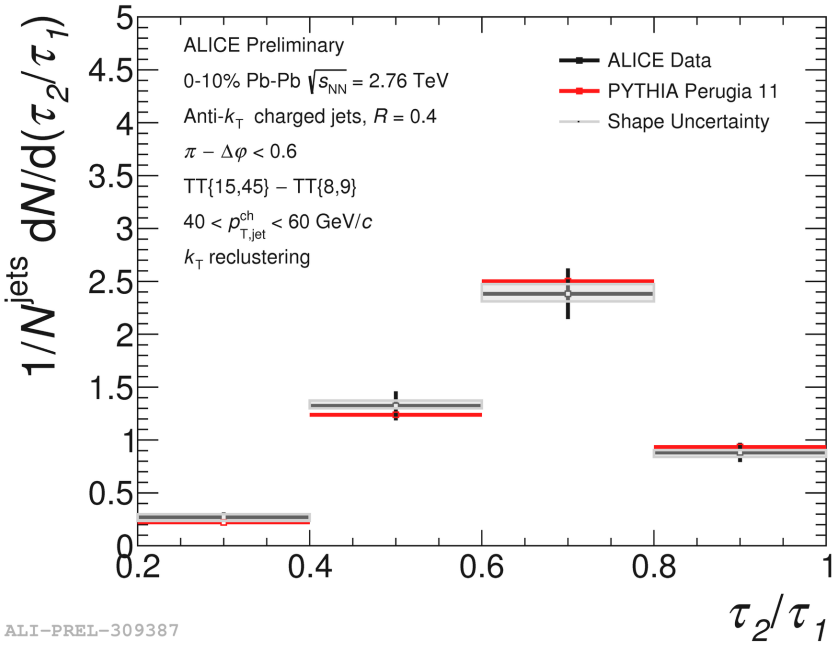


Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV

- Recoil jet against a high-p_T "TT" = trigger track only
- Cambridge-Aachen deconstruction
- Agreement with MC (PYTHIA) is marginal at $\sqrt{s} = 7$ TeV for pp — note that Perugia 2011 has been tuned to $\sqrt{s} = 1.96$ TeV Tevatron data, but not $\sqrt{s} = 7$ TeV LHC
- Agreement with the Pb-Pb jets is good, appears unmodified (and $\sqrt{s_{NN}} = 2.76$ TeV is closer to the tuned $\sqrt{s}$ of Perugia 2011)

N-subjetiness (k_T)





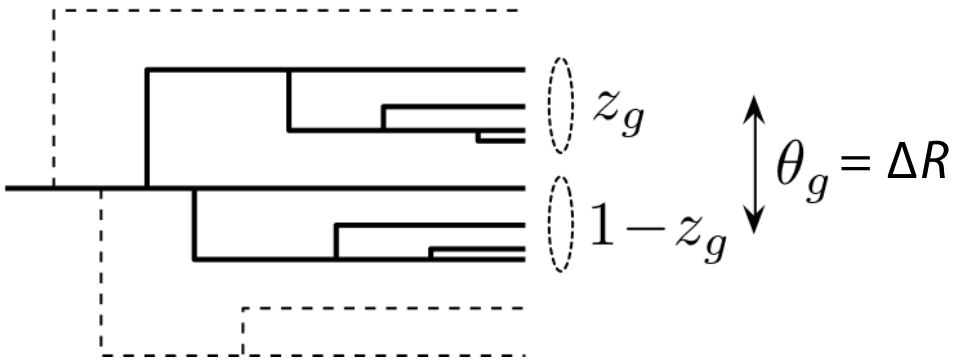
pp $\sqrt{s} = 7$ TeV

Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV

- Modest amount of difference also seen in k_T deconstruction
- Agreement is marginal in Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV to Perugia 2011
- Comparison at $\sqrt{s} = 7$ TeV shows that many jet substructure may need better PYTHIA tunes

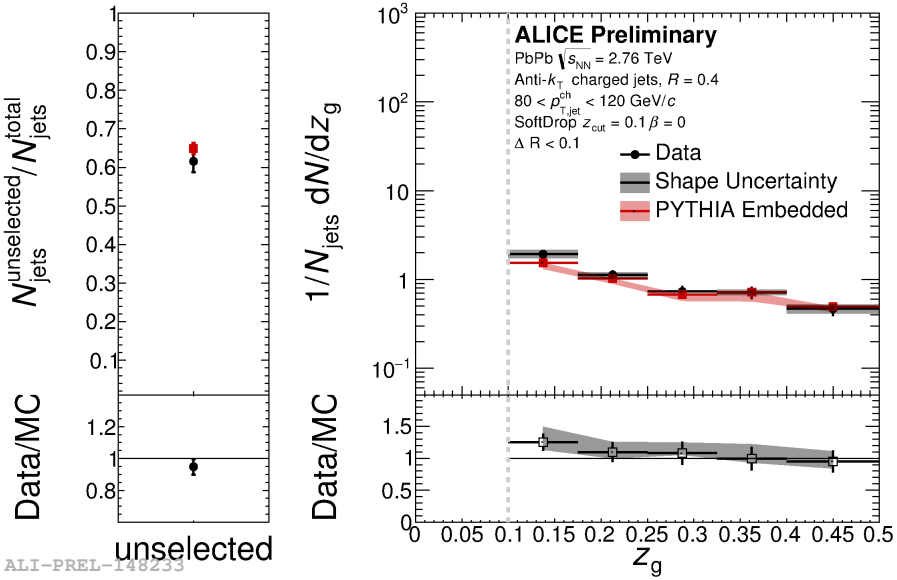
SoftDrop Shared Momentum Fraction

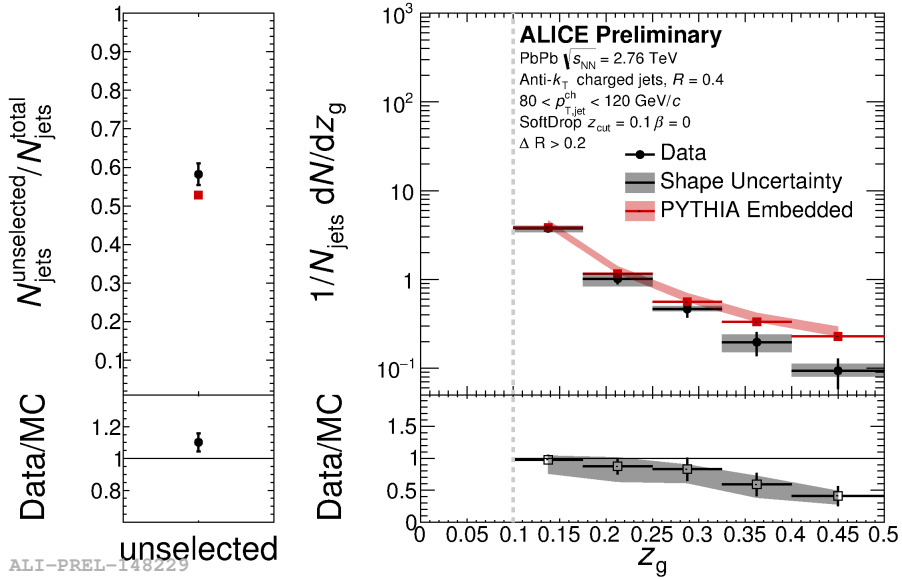
- Larkoski, Marzani, Thaler (Phys. Rev. D 91, 111501, 2015)
- SoftDrop condition $\frac{\min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} > z_{\text{cut}} \left(\frac{\Delta R_{ij}}{R_0} \right)^{\beta}$
- Default $z_{\text{cut}} = 0.1$, $\beta = 0$
- If the SoftDrop condition is satisfied, obtain $z_g = \frac{p_{T,2}}{p_{T,1} + p_{T,2}}$ and add to histogram
- Found to behave like the (symmetrized and flavor averaged) splitting function **in pp** $\sum_{i=q,g} P_i(z) + P_i(1-z)$
- See what happens in Pb-Pb, which may be sensitive to other effects than the splitting function (e.g. energy loss in both split partons)



A. Larkoski et al., Phys. Rev. Lett. 119, 132003 (2017)

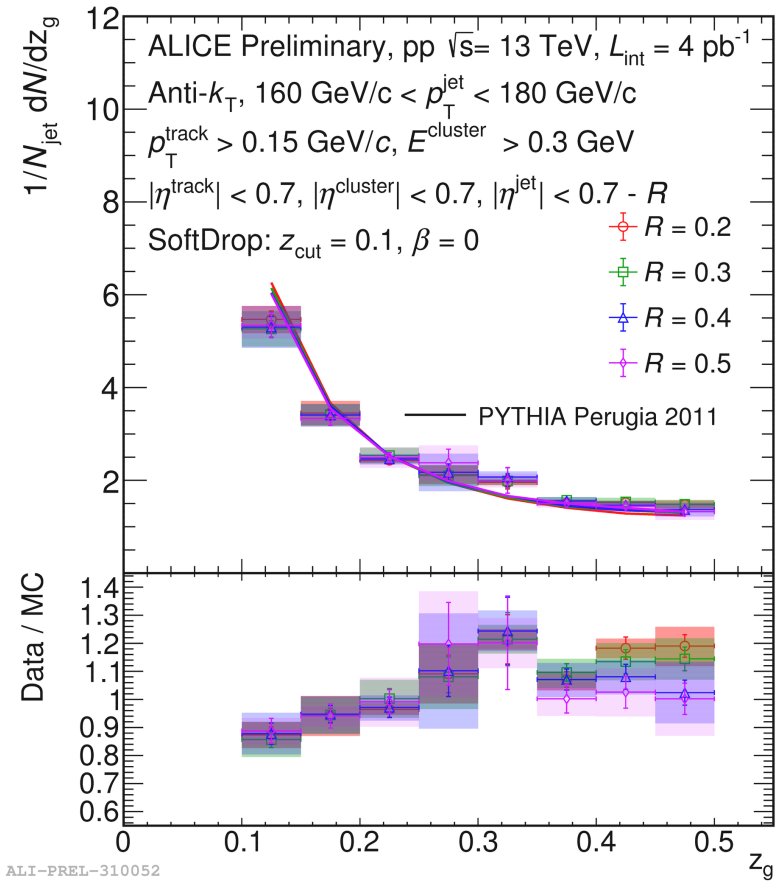
SoftDrop Shared Momentum Fraction

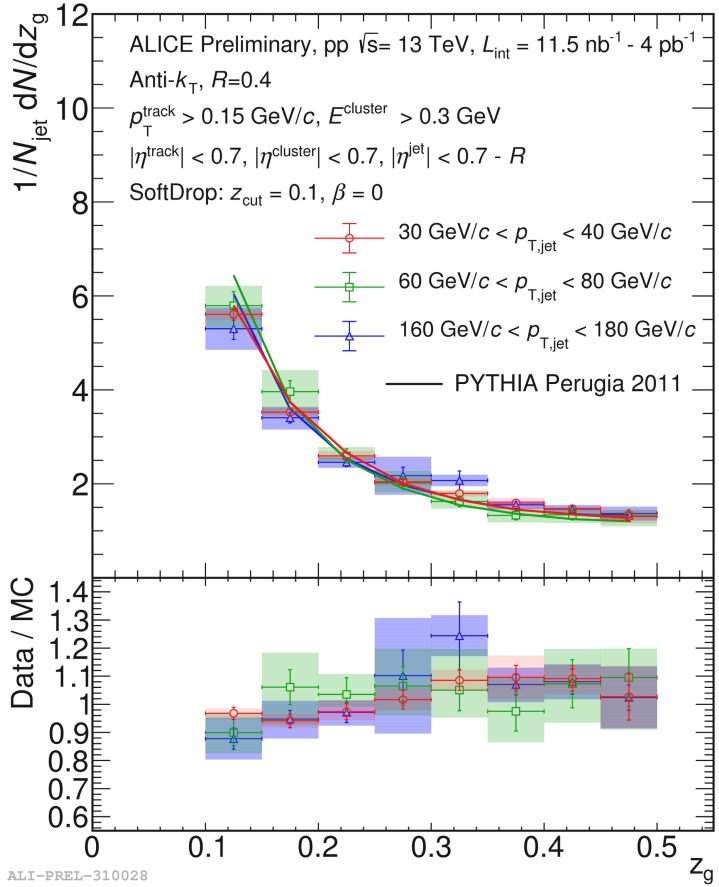




- In Pb-Pb **track only**, a significant (-30%) modification data/PYTHIA at the higher z_g was observed for large angle (right)
- ALICE specifically observes suppression of symmetric subjets with large separation angle, but the behavior does not extend to small separation angles

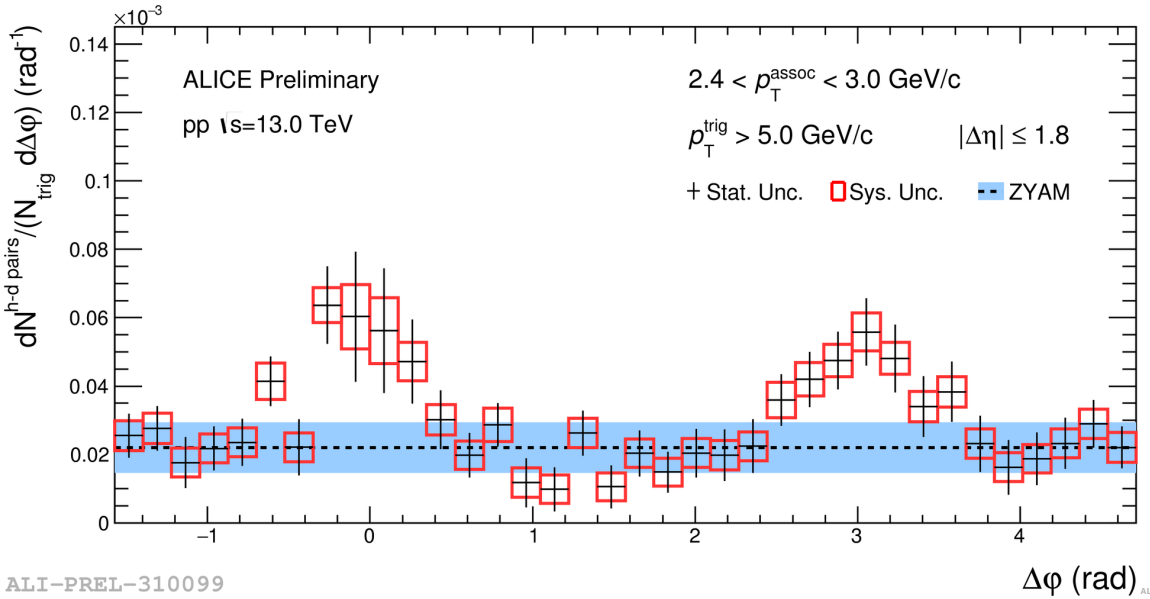
SoftDrop Shared Momentum Fraction

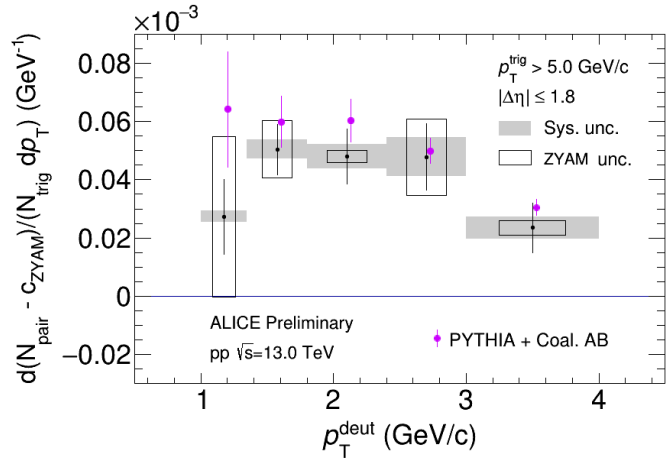




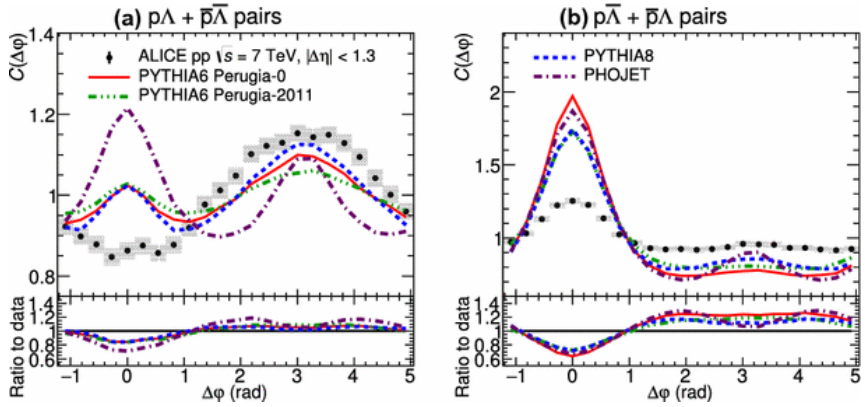
- In pp (but at $\sqrt{s} = 13$ TeV) the data/PYTHIA is increasing with z_g
- No p_T dependence is observed (as expected if z_g is related to the pQCD splitting function)

Deuterons in Jets



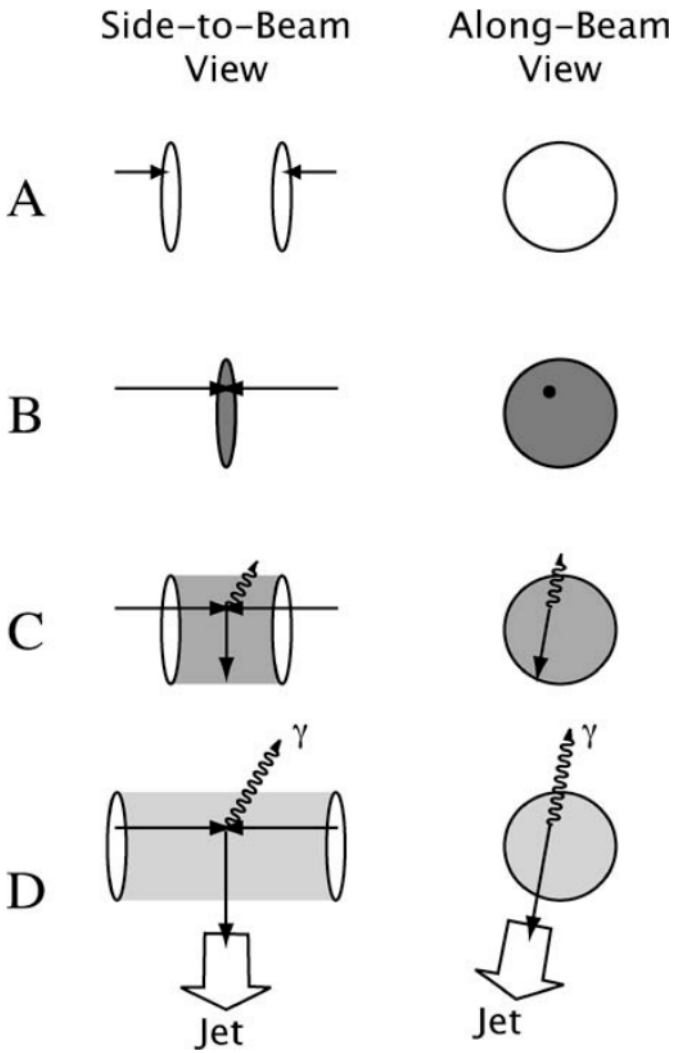


- Data vs. coalescence or thermal production model is probe whether the source is thermalized (or simply having a high baryon density)
- Jets are sources of dense baryon production, and test for coalescence model
- Observed deuterons are in alignment with the dijet geometry
- Hadrons coalescence into deuterons well-described by PYTHIA with afterburner in ALICE-PUBLIC-2017-010



EPJC 77, 569 (2017)

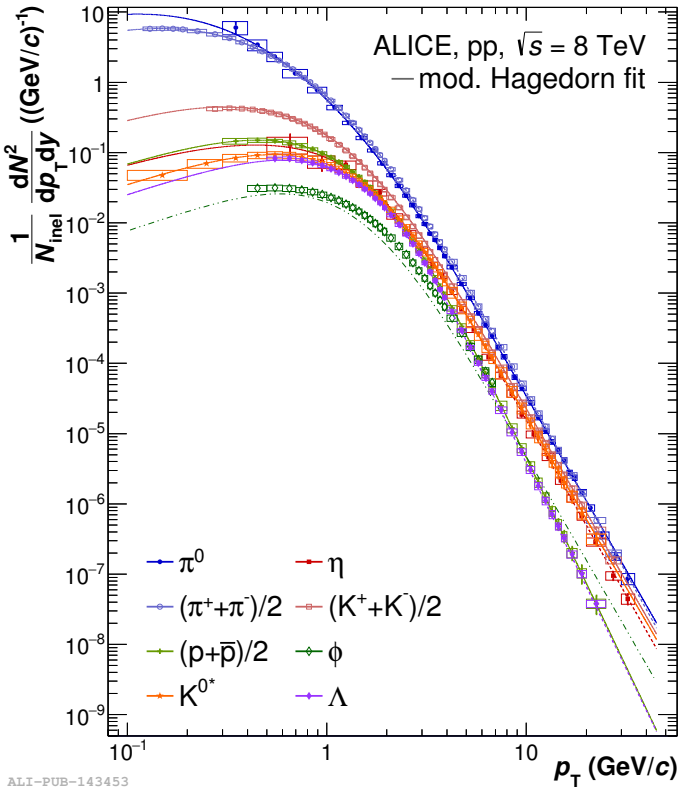
Direct (Prompt + Thermal) Photon

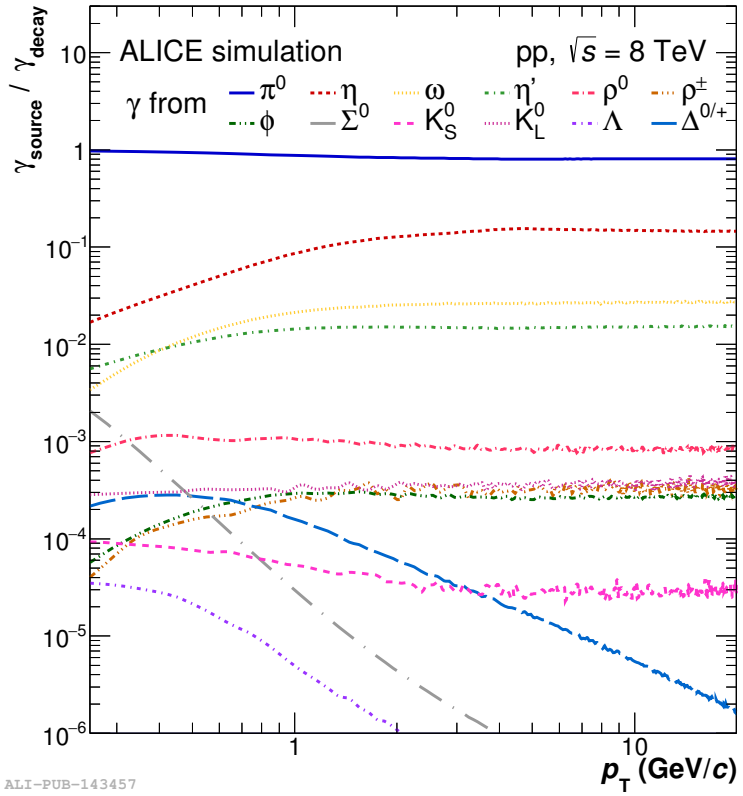


P. Stankus, Ann. Rev. Nucl. Part. Sci. 55, 517 (2005)

- Thermal photons: Photons radiating from hot matter
- Prompt photons: Rare (suppressed by α_{EM}) kinematic tags for strong interacting with the plasma
  - (Non-isolated) low-p_T direct (prompt + thermal) photon spectra in pp and p-Pb
  - Direct photon azimuthal anisotropy/elliptic flow in Pb-Pb
  - Isolated prompt photon + hadron correlation

Low p_T Direct (Prompt + Thermal) Photon

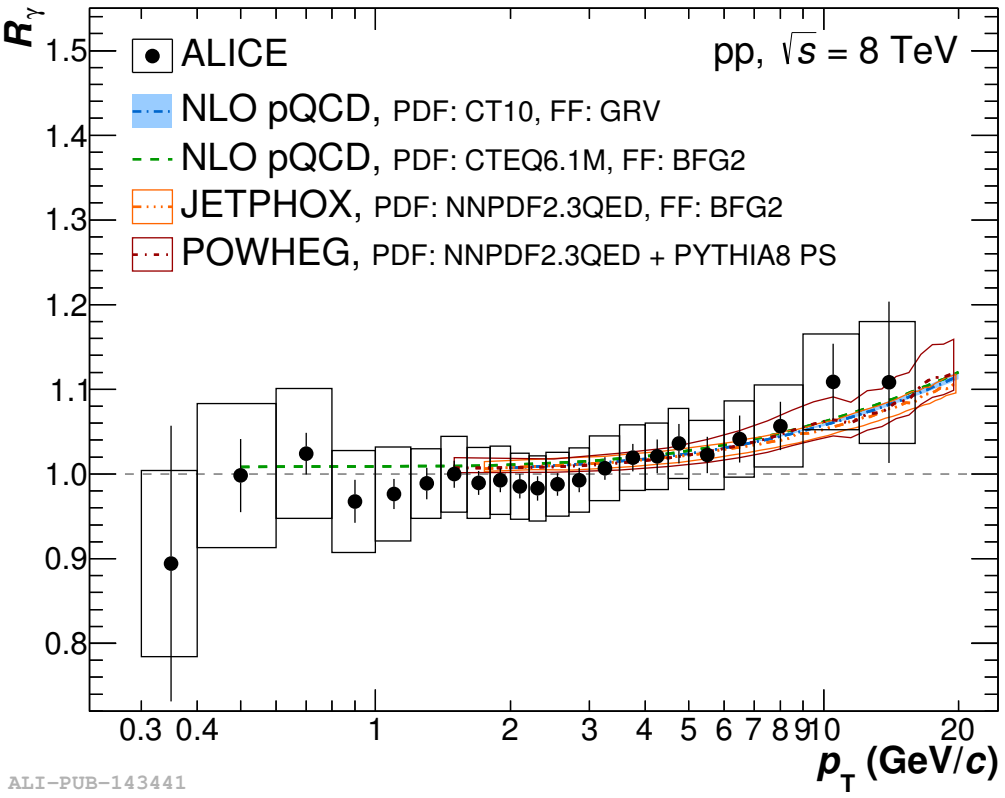


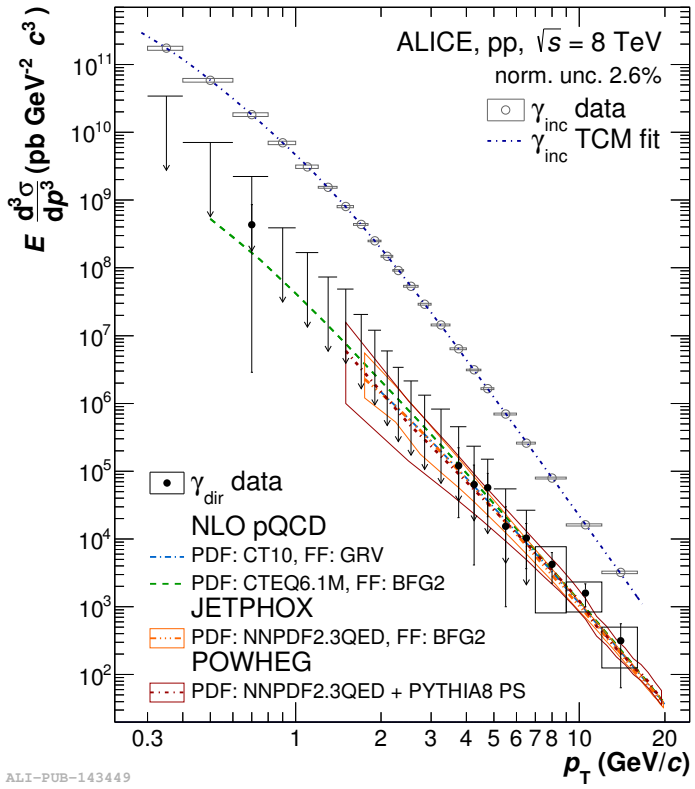


arXiv:1803.09857 (accepted by PRC)

- Inclusive direct (prompt + thermal) photons are measured by first measuring all possible hadron yield, and determine decay contribution

Low p_T Direct (Prompt + Thermal) Photon

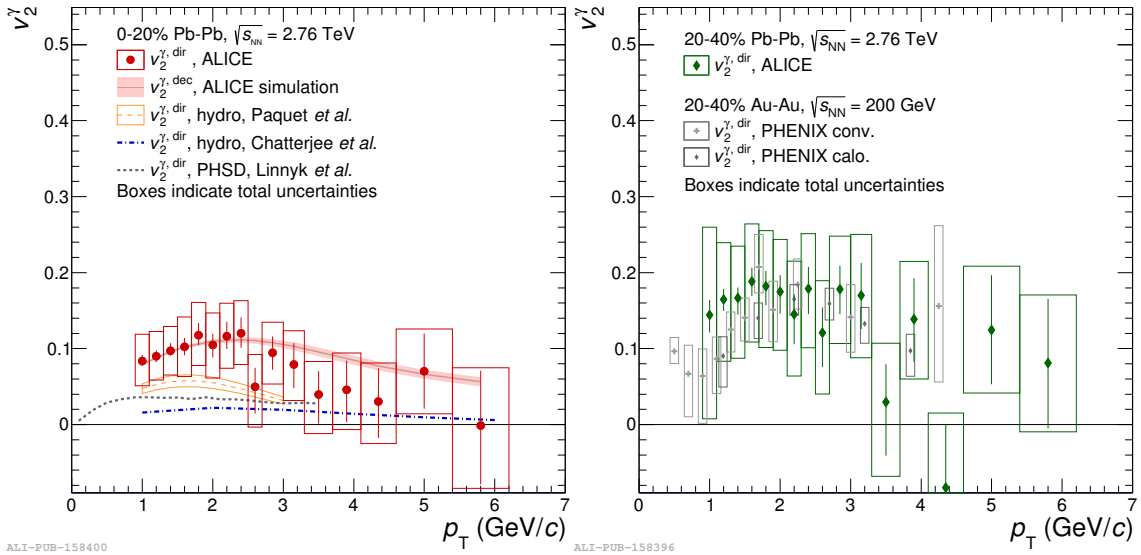




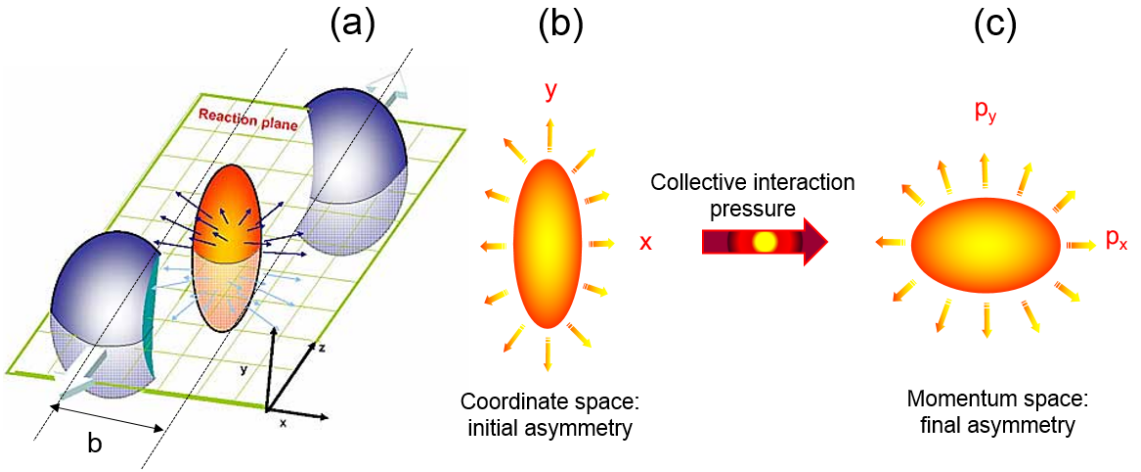
- $R_\gamma = \dfrac{\gamma_{\text{incl,meas}}}{\pi^0_{\text{meas}}} \dfrac{\pi^0_{\text{sim}}}{\gamma_{\text{decay,sim}}} \approx \dfrac{\gamma_{\text{incl,meas}}}{\gamma_{\text{decay,meas}}}$
- Below $p_T = 8$ GeV/c, only an upper bound can be extracted (due to the large π^0 background)
- Data consistent with NLO over entire range
- Systematics is strongly (but not fully) correlated

Direct (Prompt + Thermal) Photon v_2

- Similar method as used for direct photon spectra
- v_2 is the relative strength of the 2nd order Fourier component of $\frac{dN}{d\varphi}$ (over the 0th) how a particle is produced ($v_2 = 0$ if isotopic)
- $$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_n)$$
- At low p_T, direct photons are thermal emissions from hot matter, so finite v_2 expected from an anisotropic plasma
- At high p_T, direct photons originate predominantly at hard scatterings (produced isotropically), e.g. $q\bar{q} \to g\gamma$ and $qg \to q\gamma$, and do not interact with the plasma

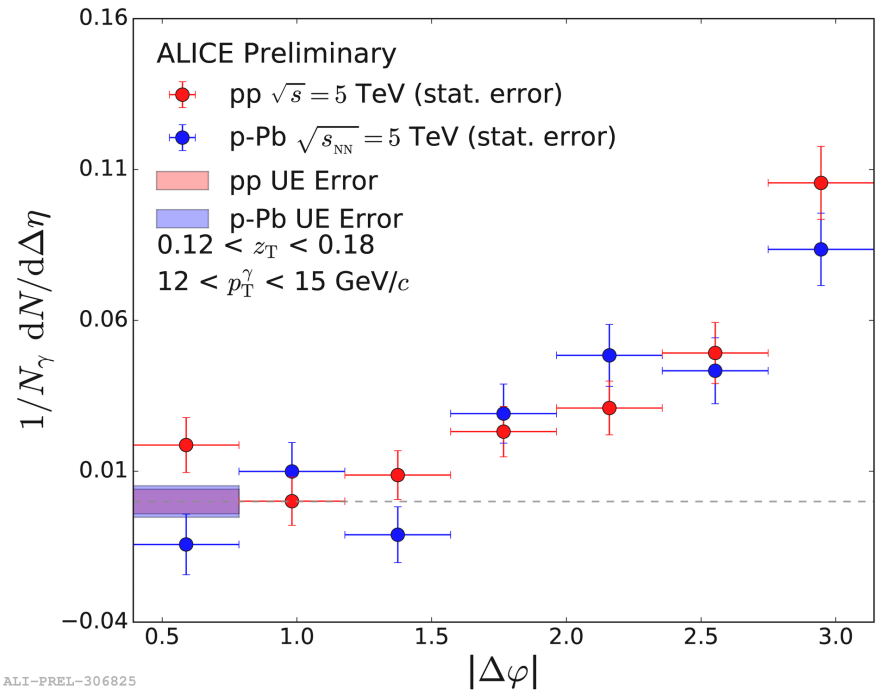


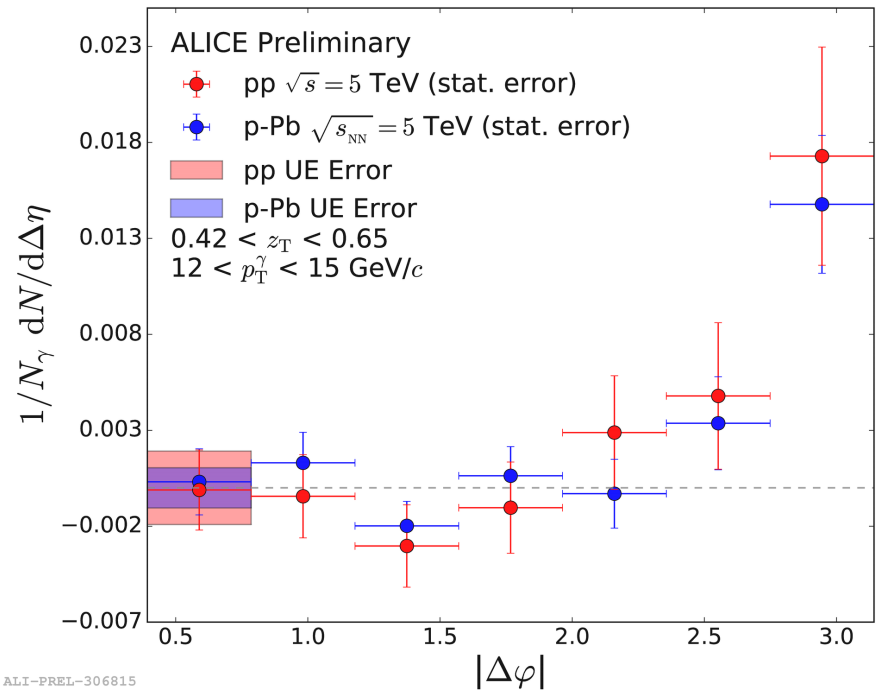
Phys. Lett. B 789, 308-322 (2019)



from arXiv:1611.01533

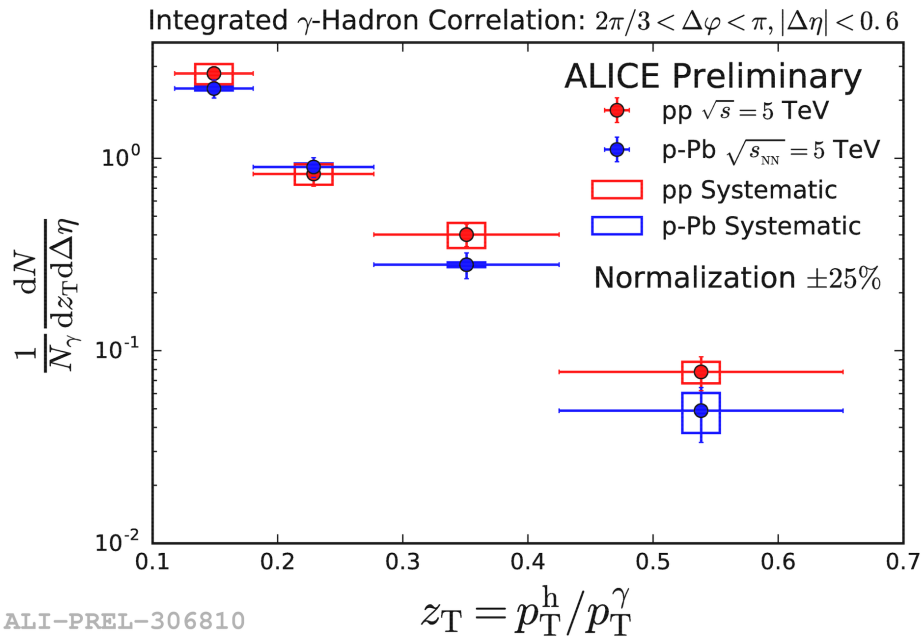
Isolated Photon + Hadron

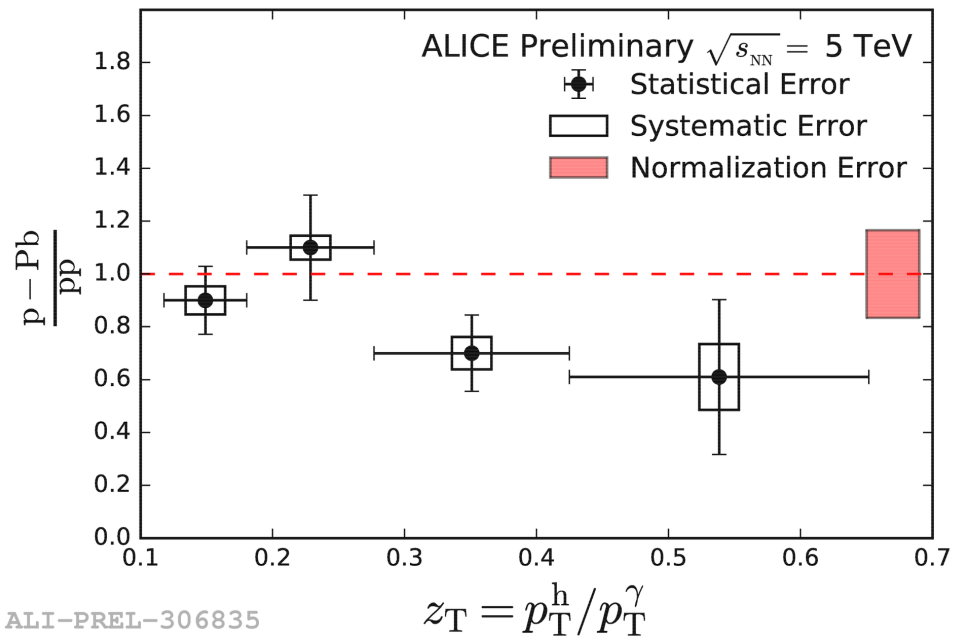




- Photon tags the Q^2 similarly as the scattered electron in deep inelastic scattering
- Measurement without jets, determine yield by integrating over correlated hadrons (a leading order approximation)
- Recoiling hadrons with $p_{\rm T} \approx 10$ GeV/c is strongly impacted by the plasma ($pc = kT \approx 300$ MeV), and photons with $E_{\rm T} < 20$ GeV at LHC is unique to ALICE due to the small radiation length in front of the EMCal
- Isolation cuts down on the rate and contribution of fragmentation and decay photons (surrounded by other jet fragments)
- No difference observed in $\Delta\varphi$ distribution for pp and p-Pb

Isolated Photon + Hadron





- Measurement in pp and p-Pb at $\sqrt{s_{\rm NN}} = 5$ TeV, baseline for Pb-Pb
- No significant difference observed between pp and p-Pb
- Innovative usage of ALICE Si tracking only + calorimeter, and calorimetric triggers

Conclusion

- Many measurements that investigates LHC heavy-ion physics, including unique kinematic ranges to ALICE
- Jets surviving the plasma at a given p_T are observed at a lower rate than simple superposition ($R_{AA} \approx \frac{1}{2}$)
- Jet substructure is only modestly modified by the plasma, and is comparable in magnitude to the $\sqrt{s}$ dependence of QCD fragmentation
- Only at large angle in groomed jets, suppression of symmetric subjets production
- Baryons in jets do coalesce into light nuclei
- First result using the new ALICE Si tracking only + calorimeter mode for rare, high p_T processes: isolated photon + hadron in pp and p-Pb, baseline measurement for Pb-Pb, no significant difference between pp and p-Pb