12th International workshop on Multiple Partonic Interactions at the LHC
11-15 October 2021

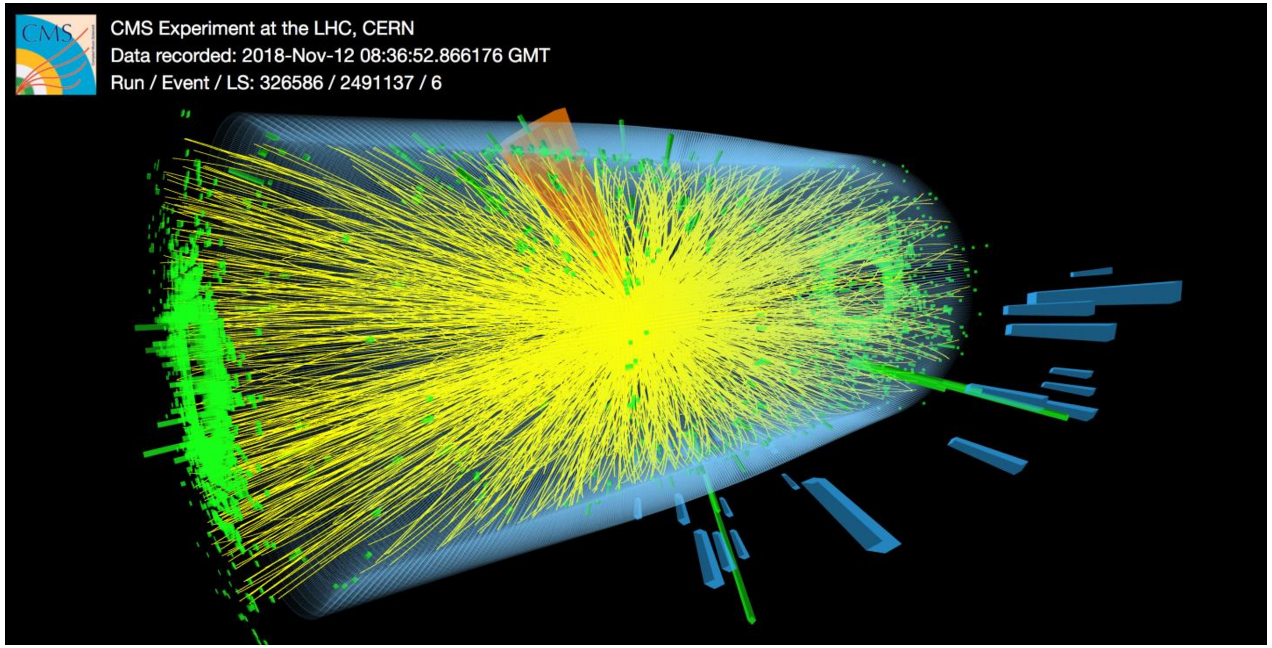
12th MPI at LHC

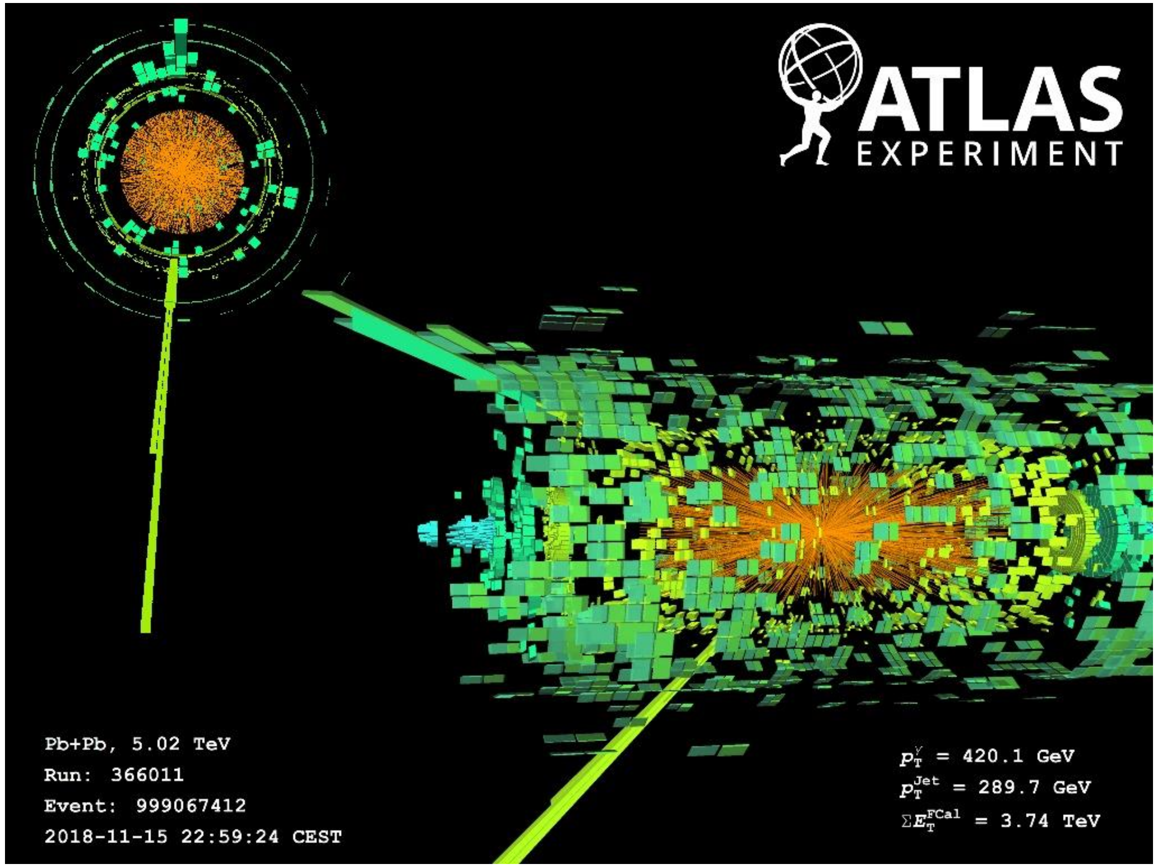
Overview talk on Jets and UPC physics in heavy-ion collisions at the LHC

Hassane Hamdaoui
Mohammed V University
For the ALICE, ATLAS, and CMS collaborations

photon+jet

Z+Jet





Jets in heavy-ion collisions

Jets: colored probes from partons that interact strongly with medium

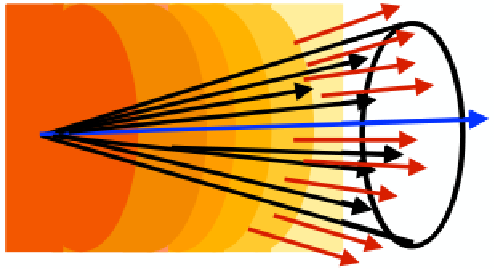
$$R_{AA} = \frac{\text{Pb-Pb}}{\text{scaled}\otimes\text{pp}}$$

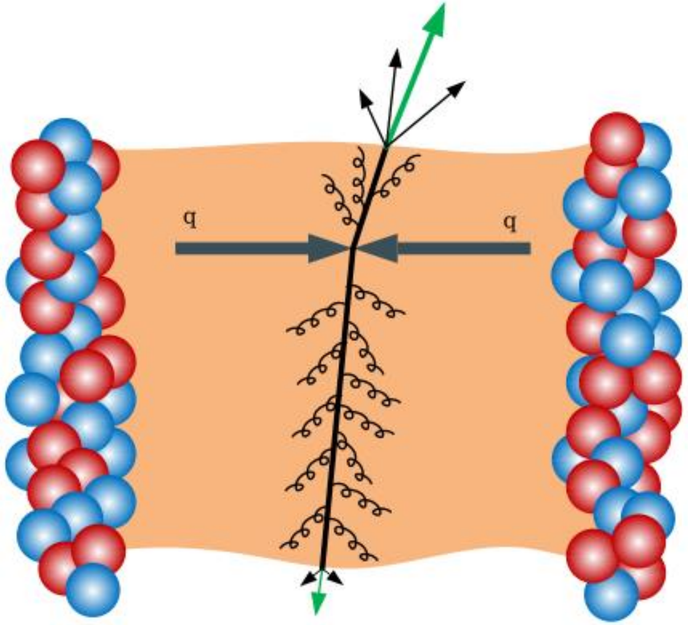
Jet quenching: partons in heavy-ion (HI) collisions interact with the medium to produce:

➞ jet energy loss (suppression of high pT jet yields, correlation)
➞ jet substructure modification (jet structure and substructure measurement)

Momentum broadening

Medium response





Push toward
lower pT : (ALICE)
➞ Connection to RHIC
➞ Probes different scales and modification expected to be different
➞ Quark and gluon fractions vary
and large R :
➞ Possible recovery of the jet energy because of out-of-cone radiation
➞ Possible difference in modification for larger jets

Large R Jets in heavy-ion collisions

Inclusive jet suppression: large R=0.2 to 1.0!
➞ Possible recovery of the jet energy because of out-of-cone radiation
➞Possible difference in modification for larger vs smaller jets

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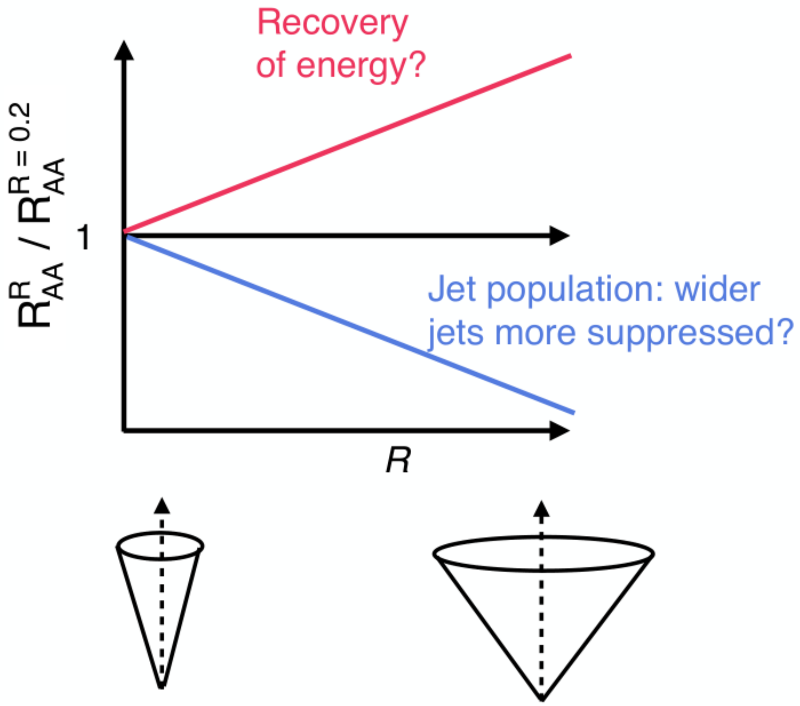
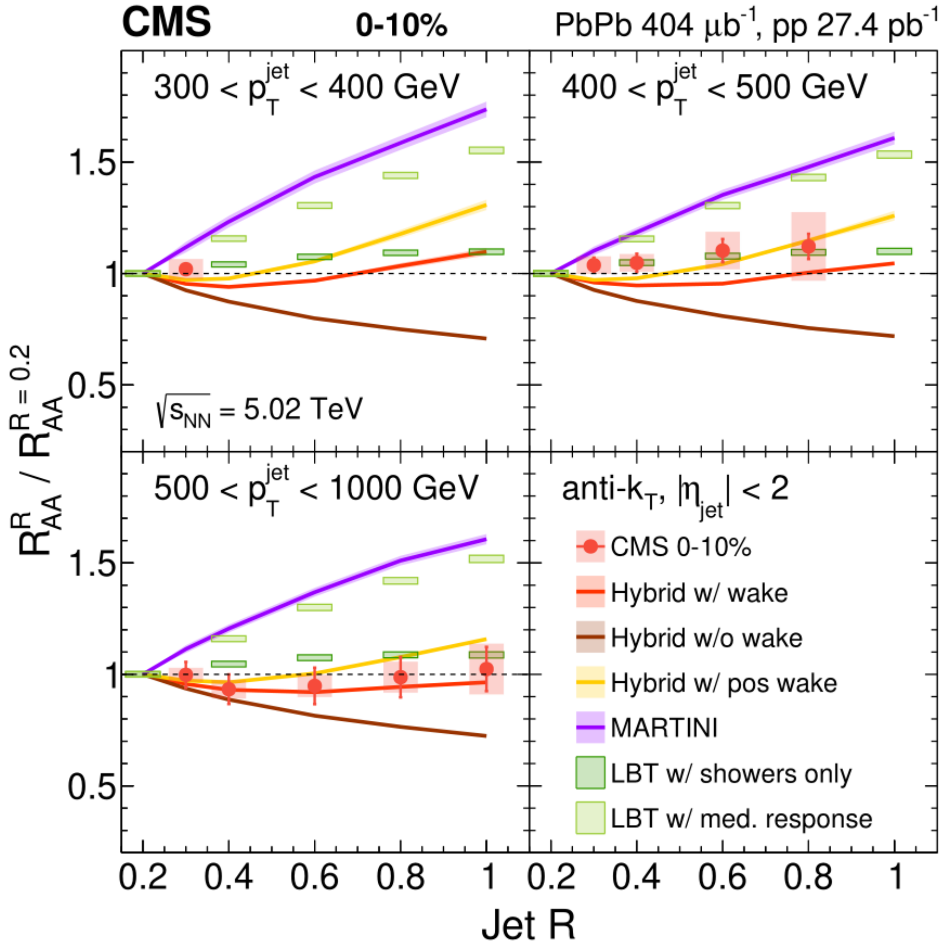
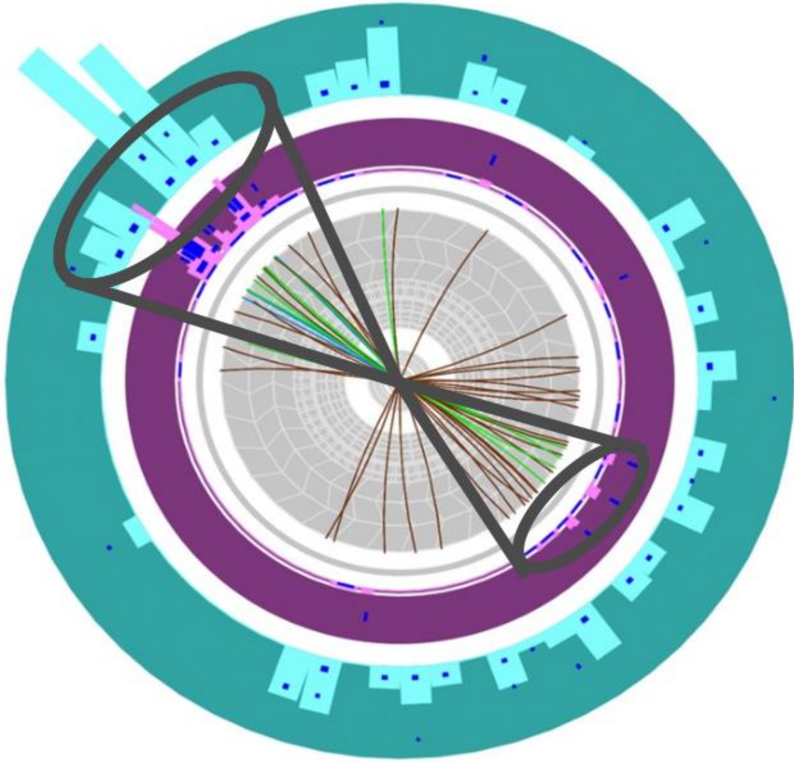


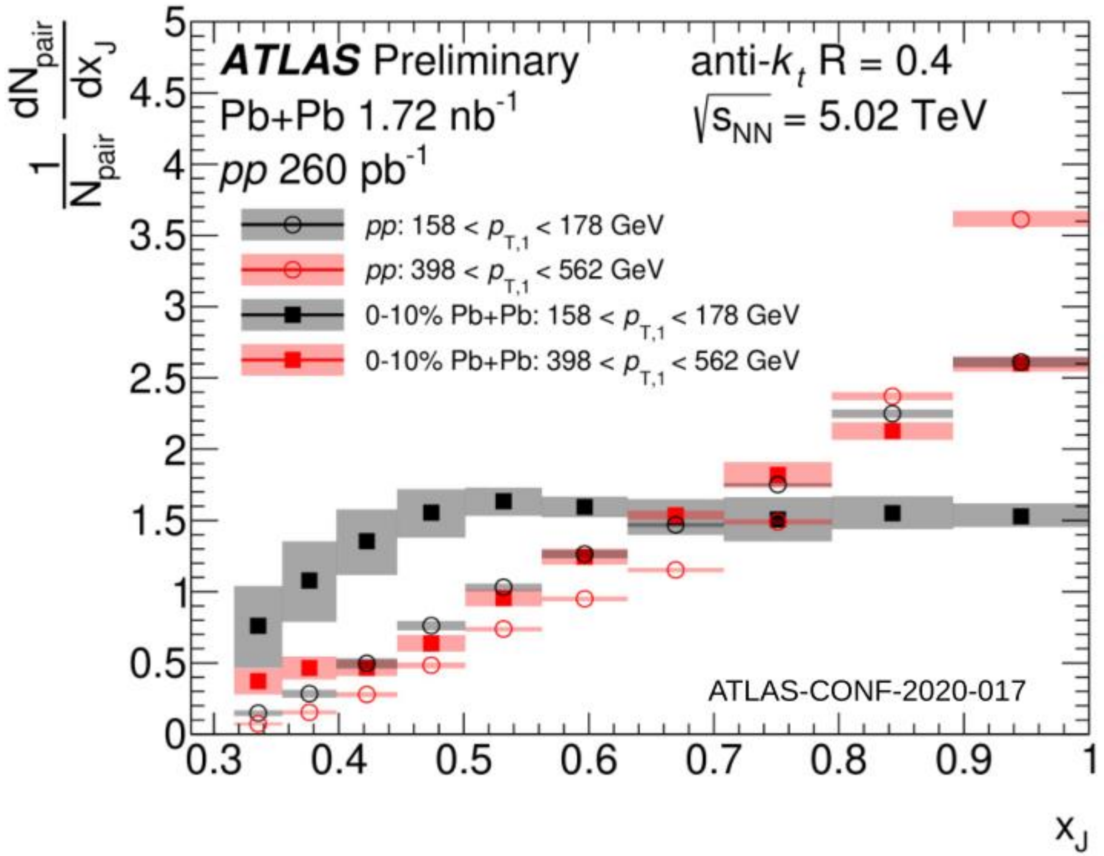


Di-jet balance

ATLAS-CONF-2020-017

Probes path-length dependence and per-jet fluctuations of the jet quenching.





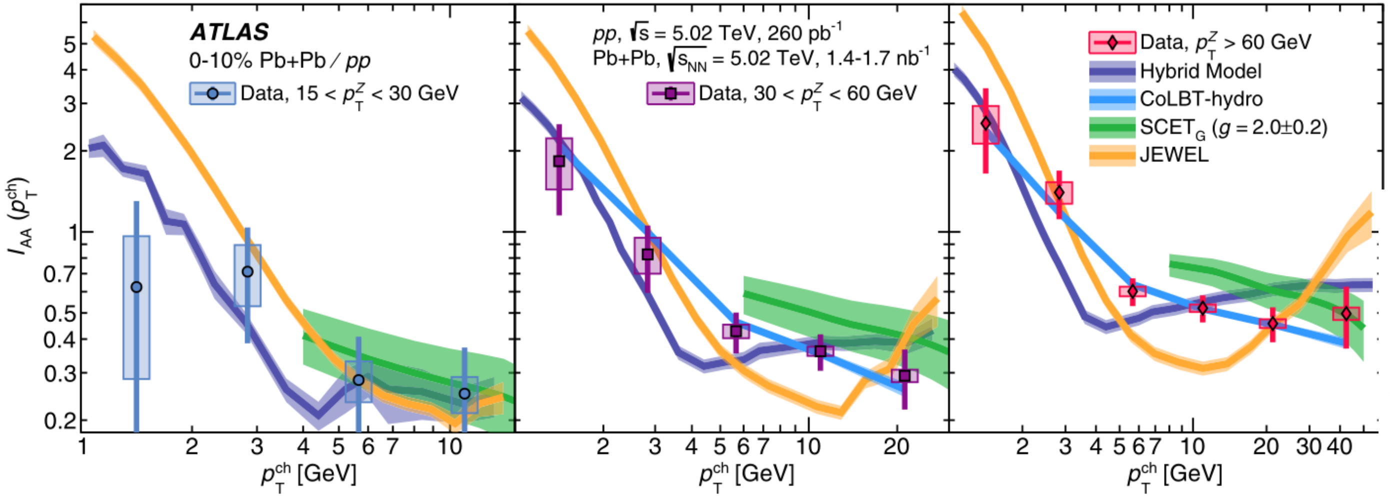
$$x_J \equiv p_{T_2}/p_{T_1}$$

- An asymmetry at lower pT
- Less difference between pp and Pb+Pb at high pT
- Could be explained by changes of flavor or energy lose fluctuation

Z-hadron correlations in Pb+Pb and pp collisions

- What is the new information compared to the inclusive measurement ?
- Quark dominated jet sample.
- Testing role of parton virtuality when comparing Z- and Ɣ-tagged measurements.
- Access to low pT (jet) region.

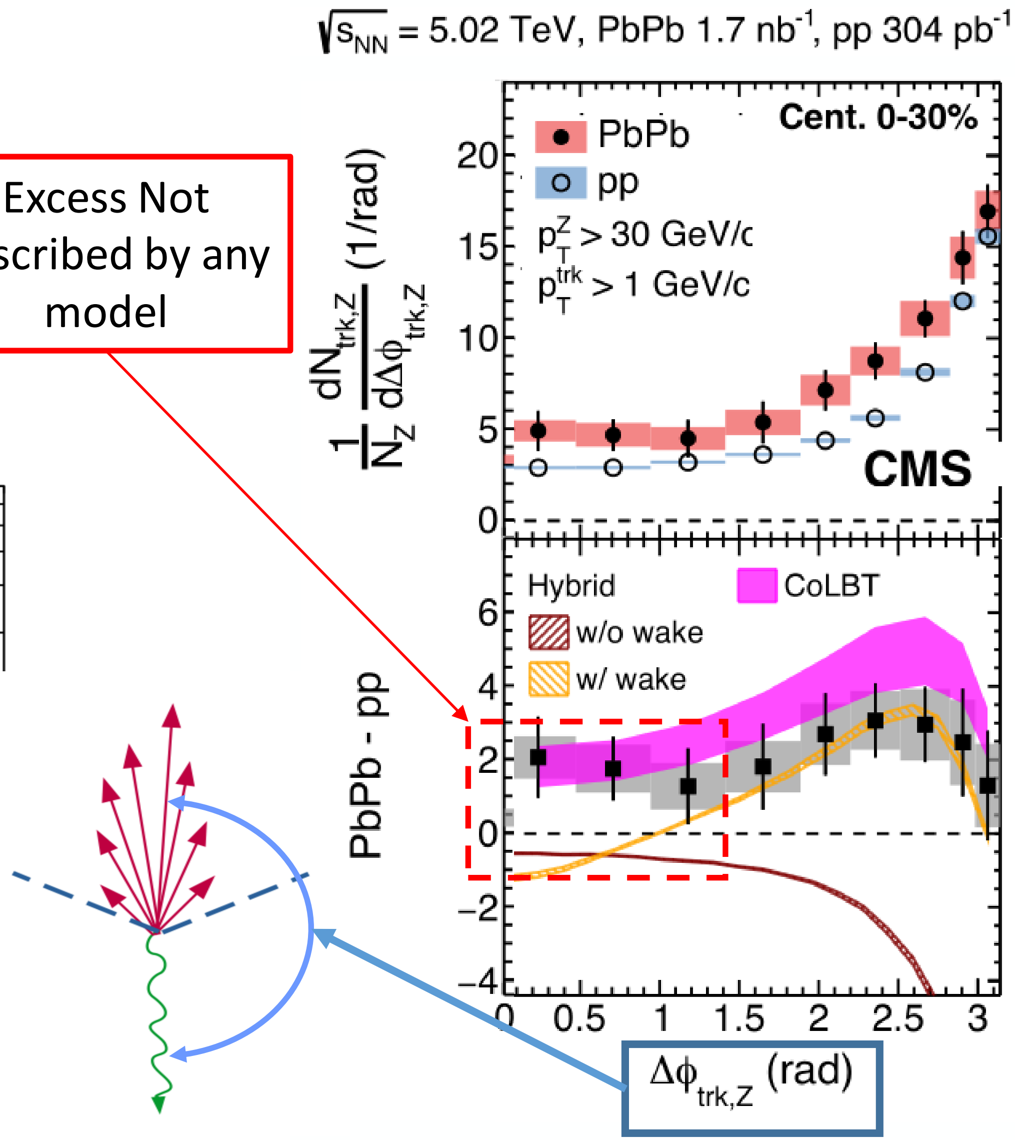
Phys. Rev. Lett. 126 (2021) 072301



Similar trend to what we see in photon tagged jets.

arXiv:2103.04377v1

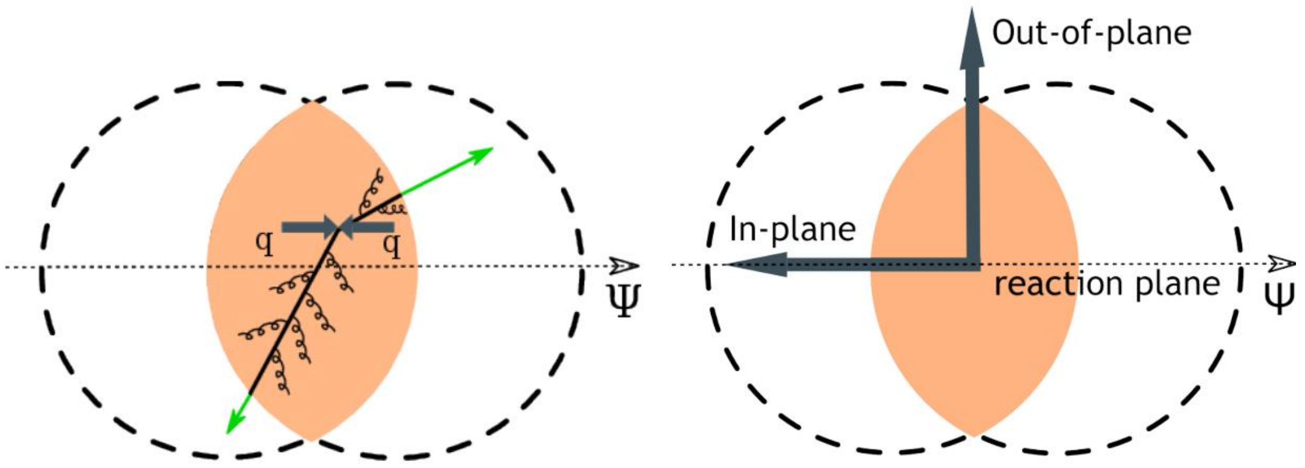
Excess Not described by any model

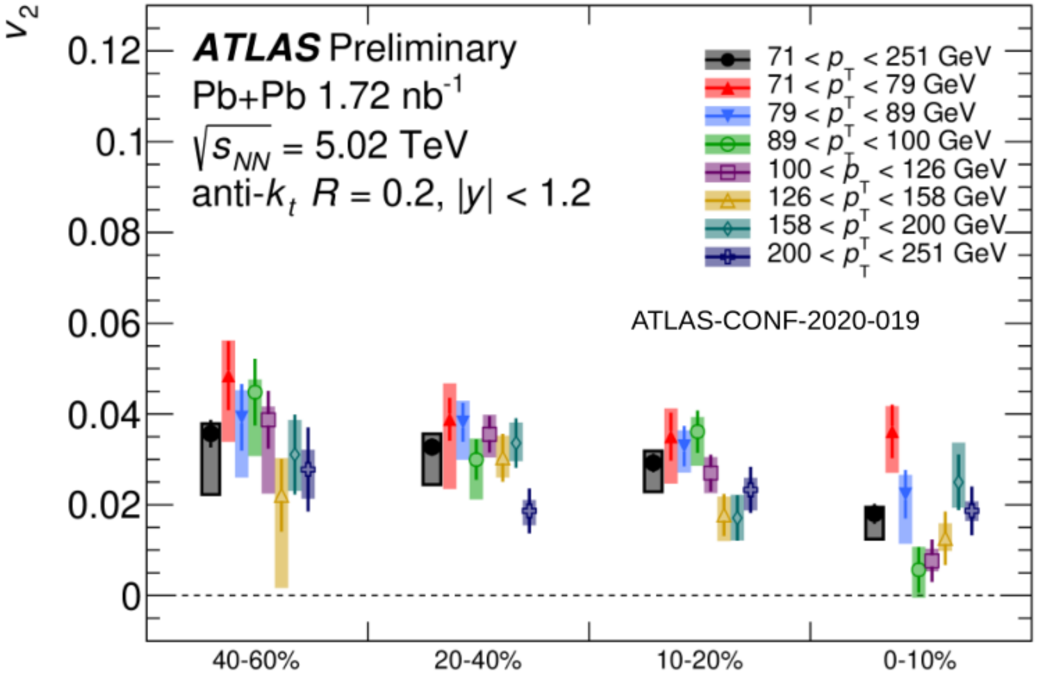


Jet antisotropies

ATLAS-CONF-2020-019

Deferential jet yields measurement w.r.t. reaction plane.





The angular distribution of jets is described via a Fourier expansion :

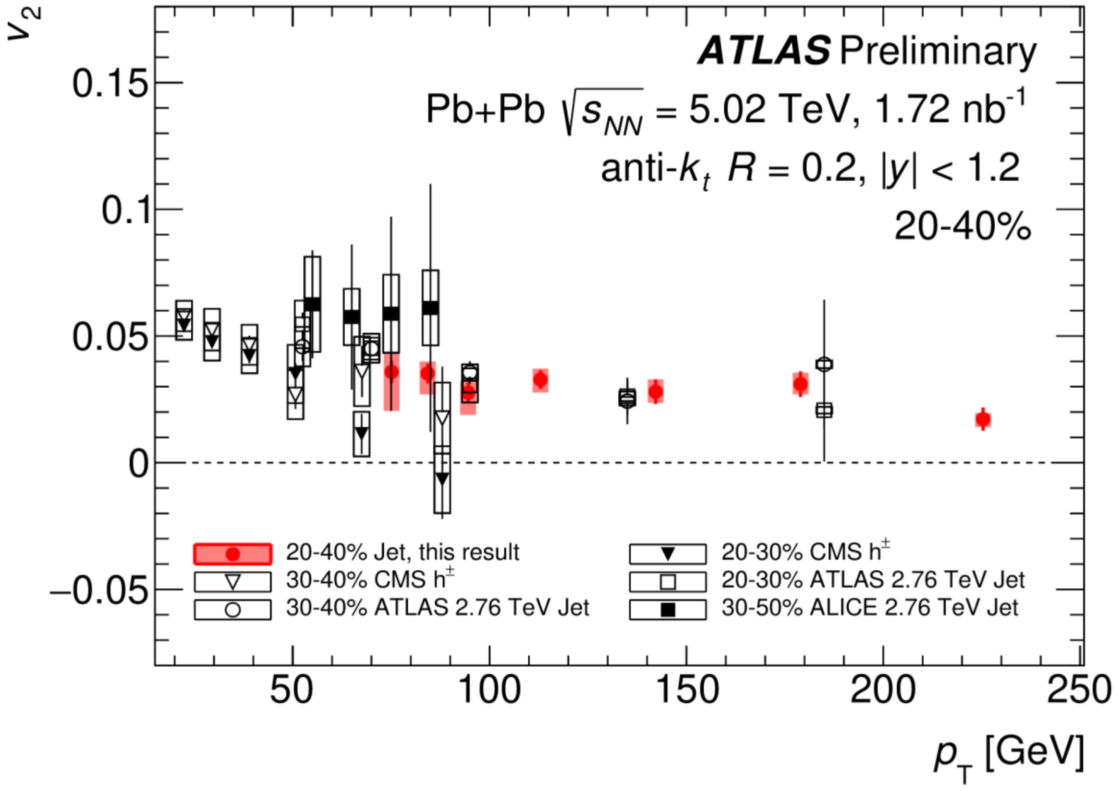
$$\frac{\mathrm{d}N}{\mathrm{d}\phi} \propto 1 + 2\sum_{n=1}^{n} v_n \cos\big(n(\phi - \Psi_n)\big)$$

In-plane: shorter path length in the medium less suppression

Out-of-plane: longer path length in the medium more suppression positive v2.

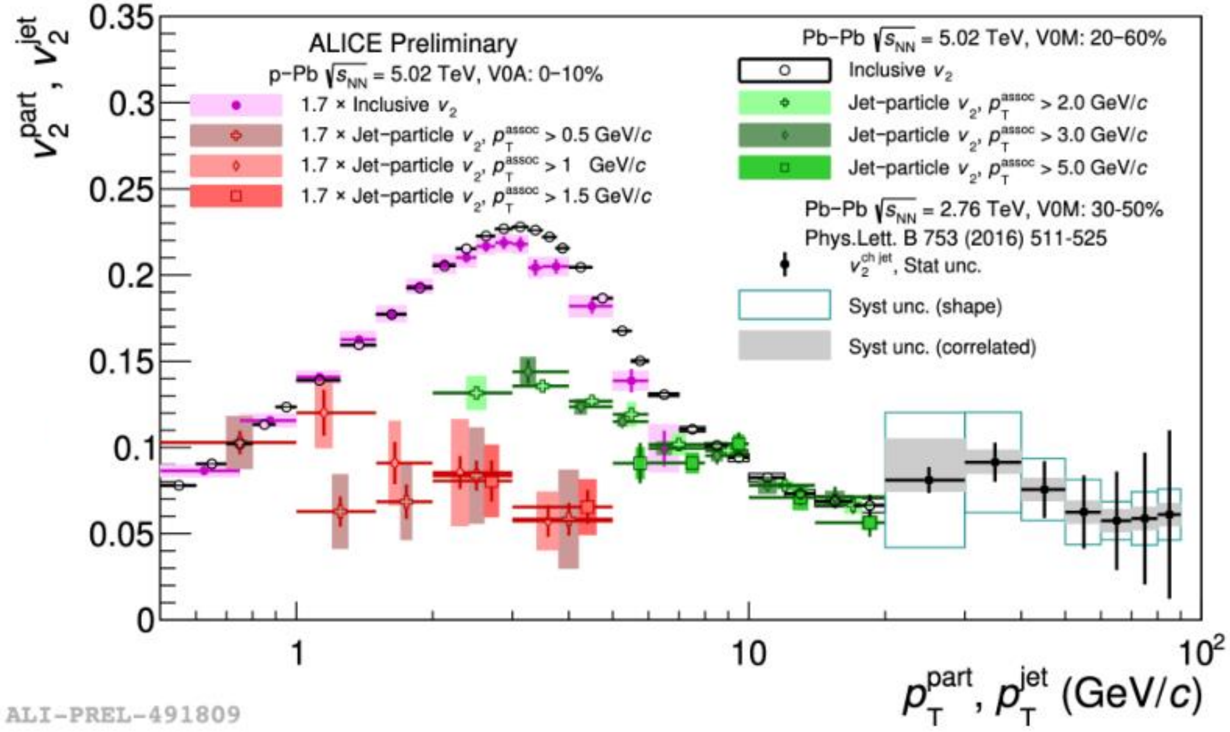
Jet anisotropies

ATLAS-CONF-2020-019



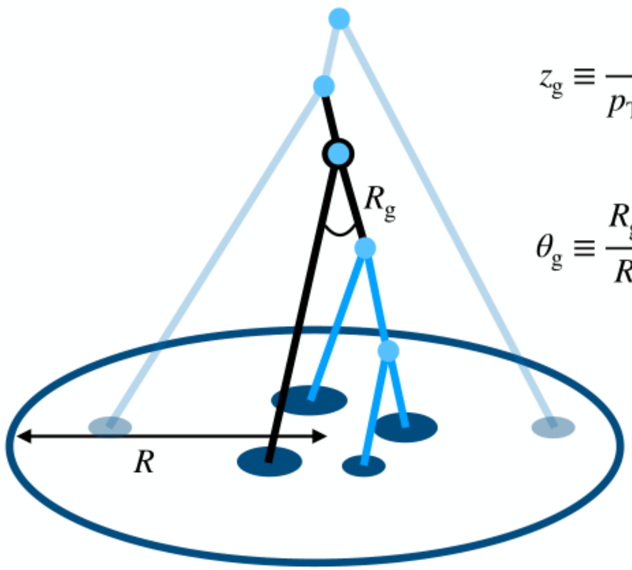
Consistent results from the LHC experiments

alice-figure.web.cern.ch



Lower pT reach in ALICE allowing a general picture of v2 measurement arXiv:2107.12984

Groomed jet substructure: How is the hard jet substructure modified in heavy-ion collisions?



$$z_g \equiv \frac{p_{\mathrm{T,subleading}}}{p_{\mathrm{T,leading}} + p_{\mathrm{T,subleading}}}$$

$$\theta_g \equiv \frac{R_g}{R} \equiv \frac{\sqrt{\Delta y^2 + \Delta\varphi^2}}{R}$$

Groomed jet substructure

arXiv:2107.12984

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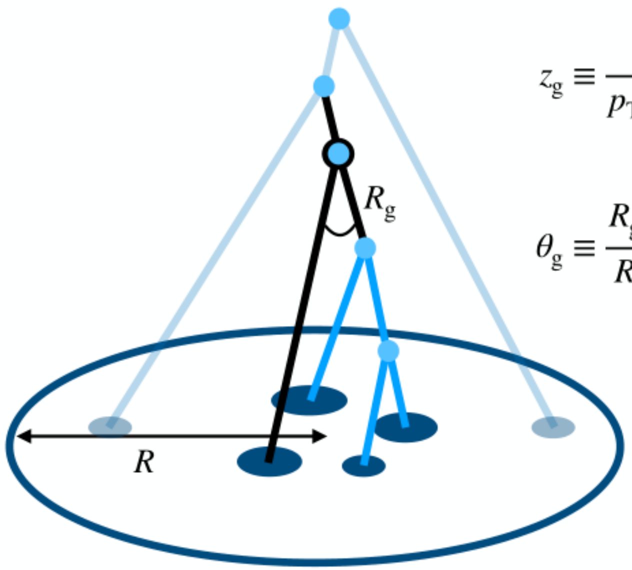

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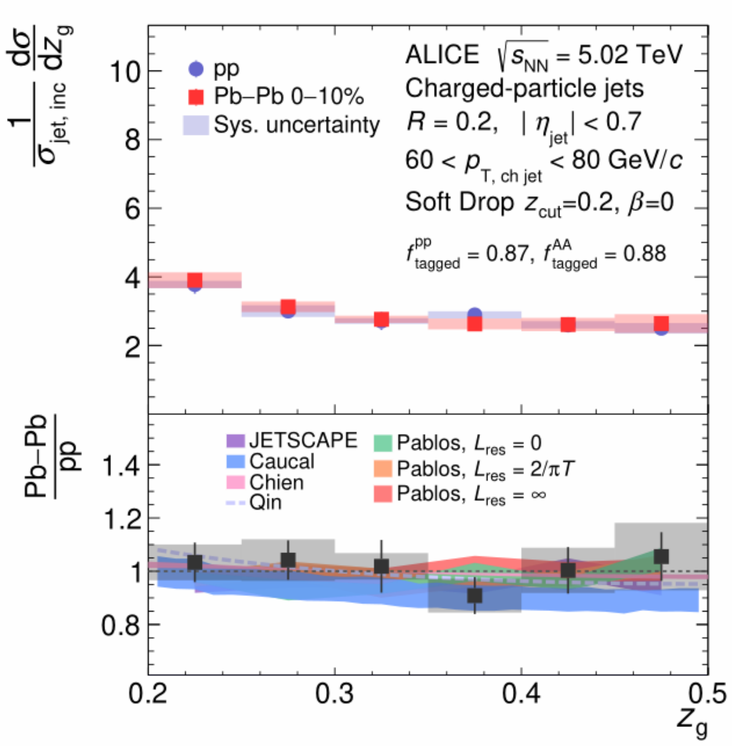

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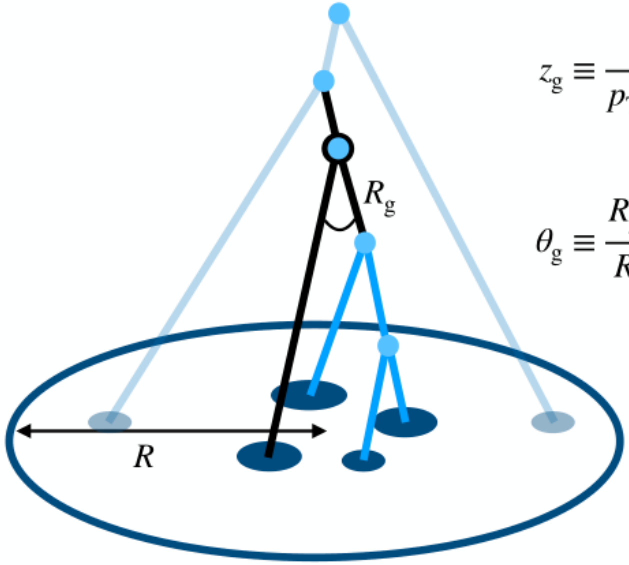

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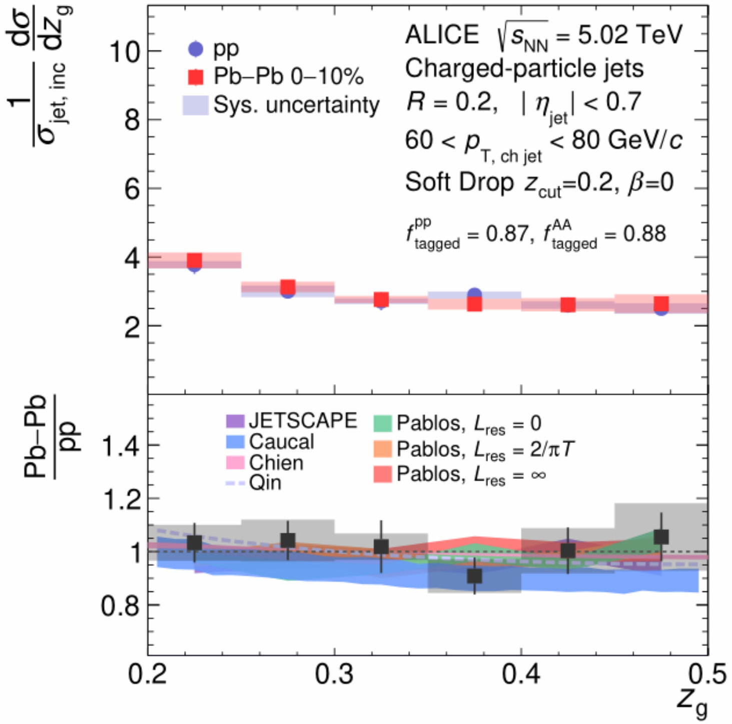
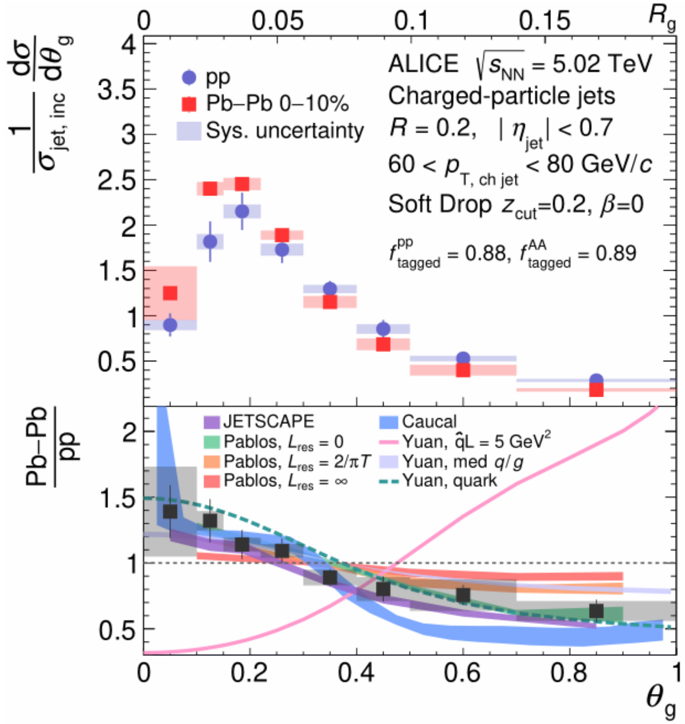




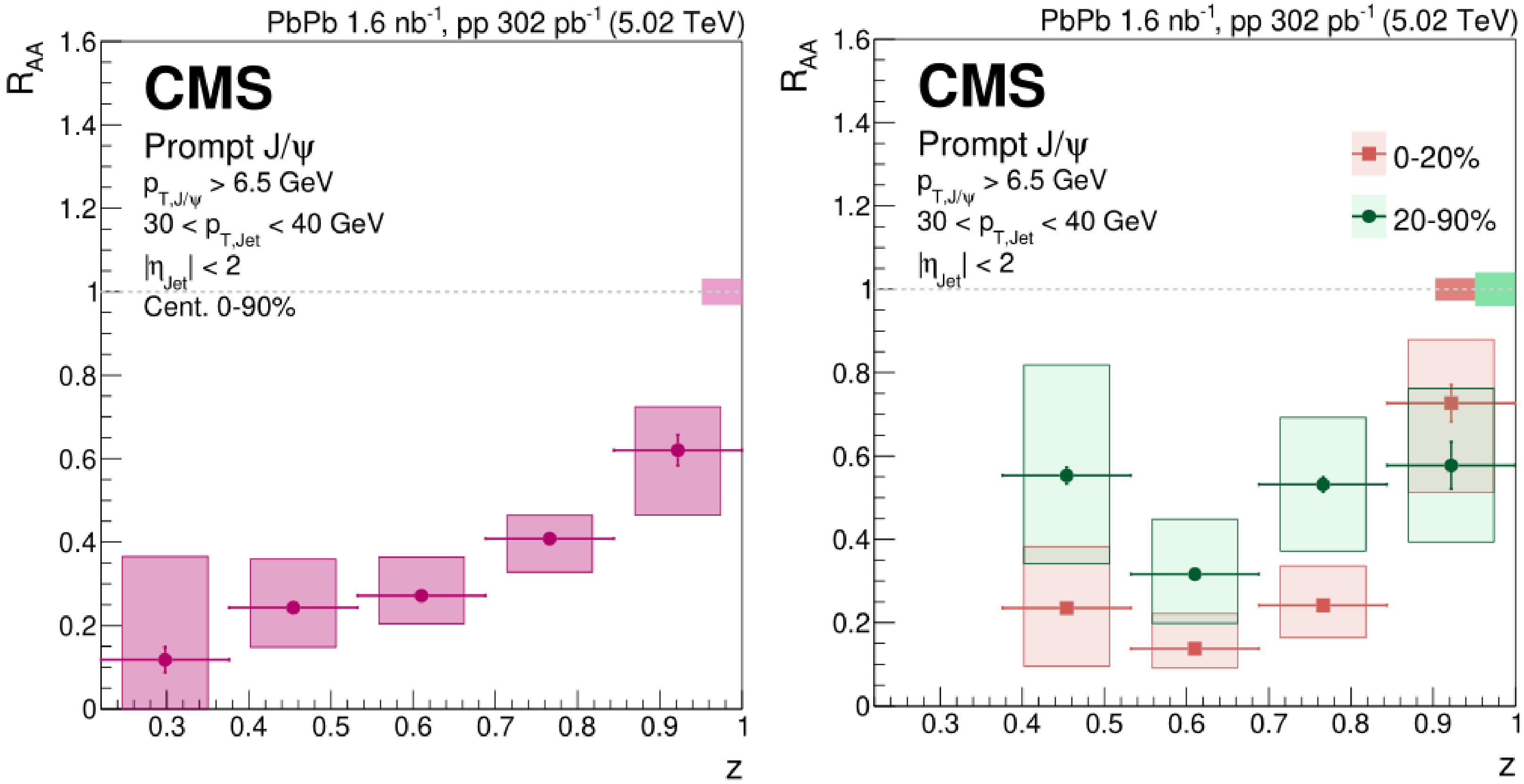
- Narrower θg distribution for Pb–Pb
- Sensitivity to the microscopic structure of the QGP
- Towards quantitative understanding of the properties of QGP

Jets containing a prompt J/ψ

$$R_{AA} = \frac{\text{Pb-Pb}}{\text{scaled}\otimes\text{pp}}$$

The J/ψ produced with a large degree of surrounding jet activity are more highly suppressed than those produced in association with fewer particles.

➔importance of incorporating the jet quenching mechanism in models of J/ψ suppression.



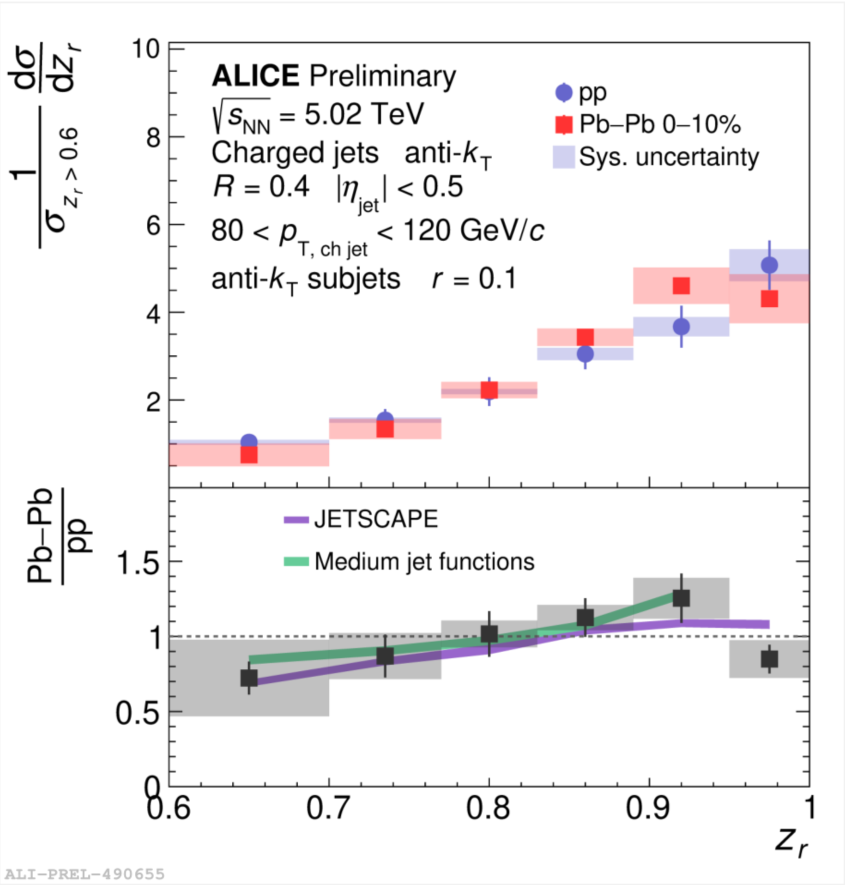
arXiv:2106.13235

Leading subjet fragmentation

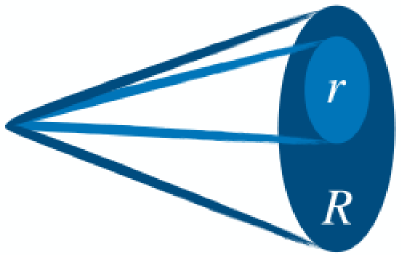
Alice-figure.web.cern.ch

Good description from theoretical predictions form :
JETSCAPE collaboration arXiv:1903.07706 and Medium Jet functions

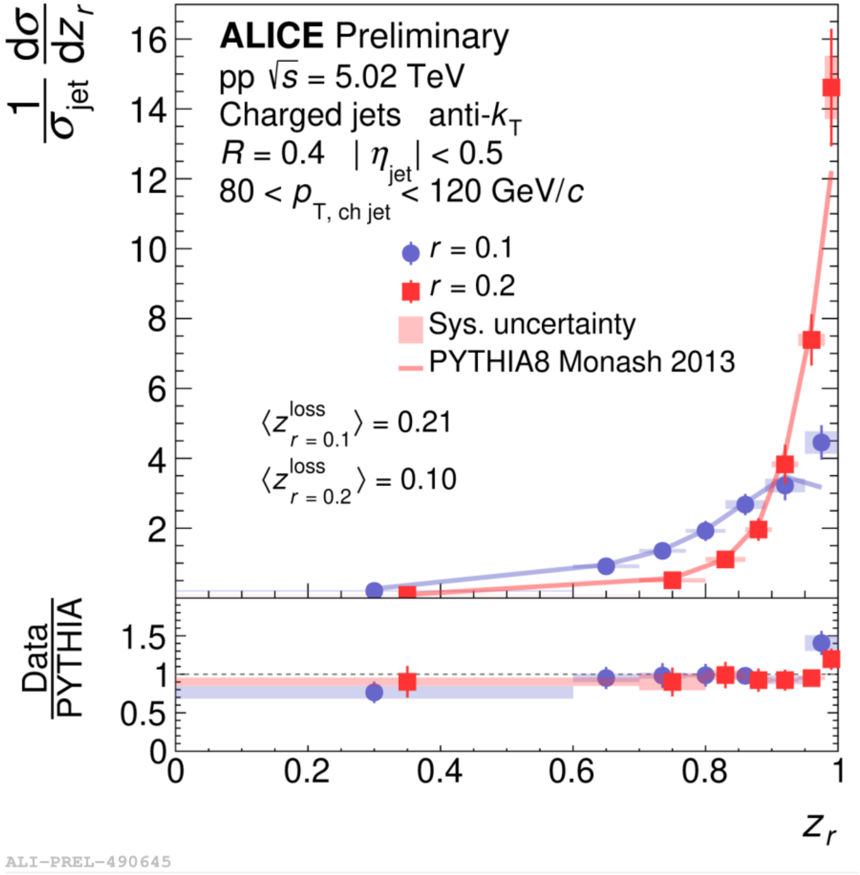
Pb-Pb



$$z_r = \frac{p_T^{\text{ch subjet}}}{p_T^{\text{ch jet}}}$$

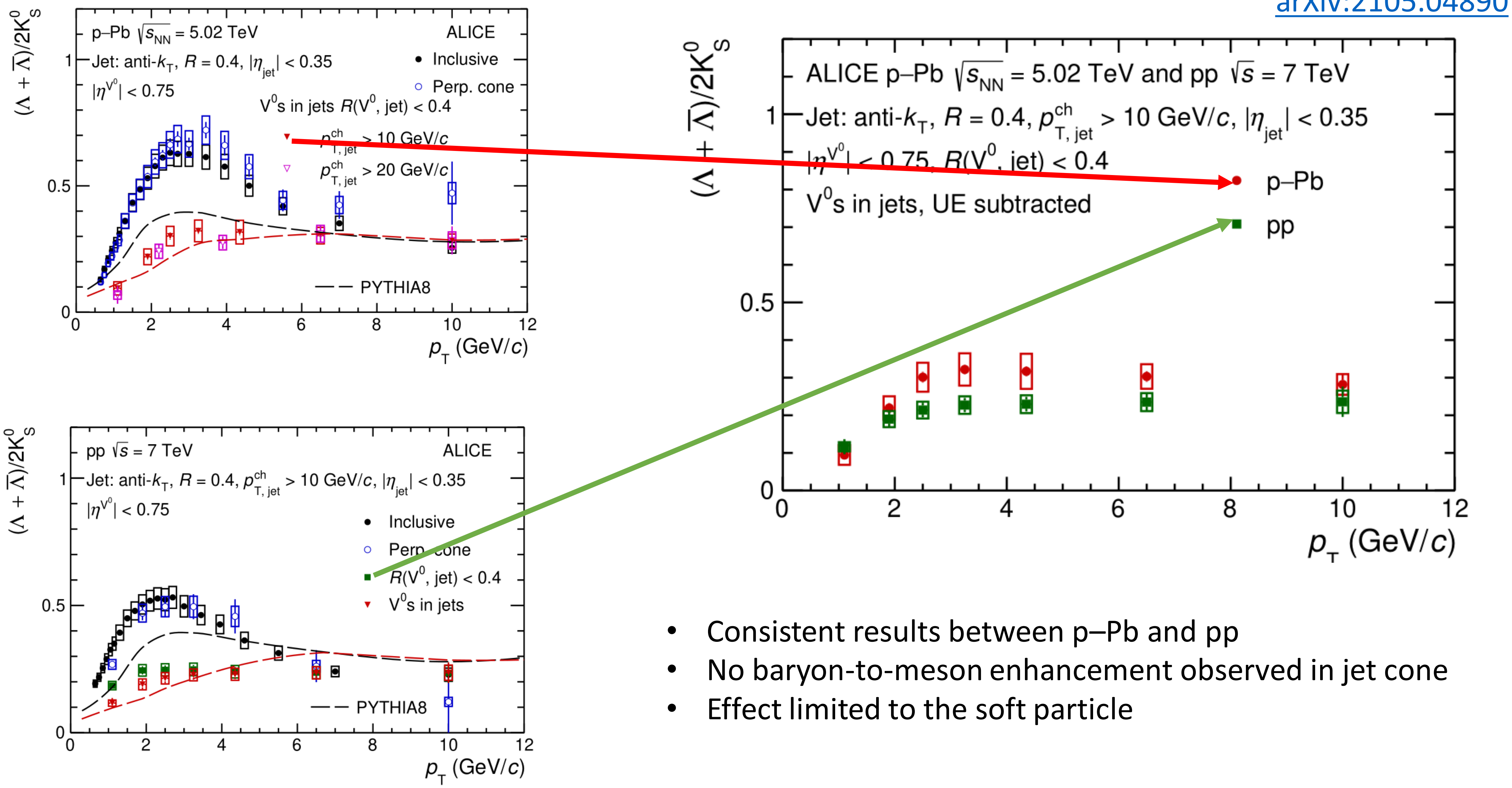


pp



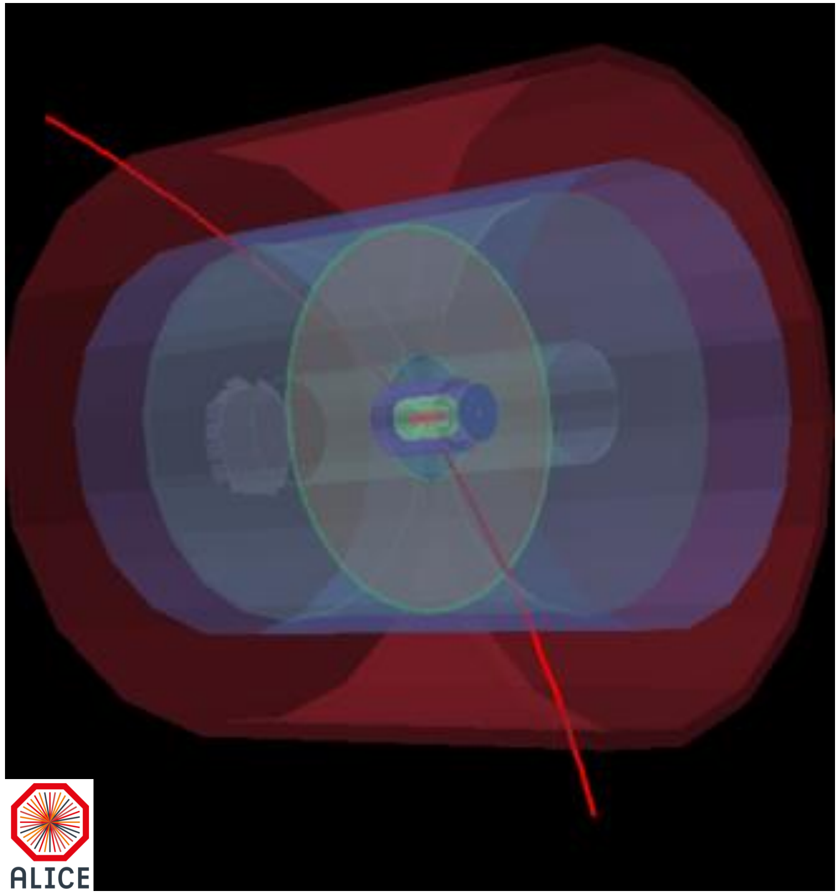
Λ and K^0_S in jets in p–Pb and pp collisions

arXiv:2105.04890

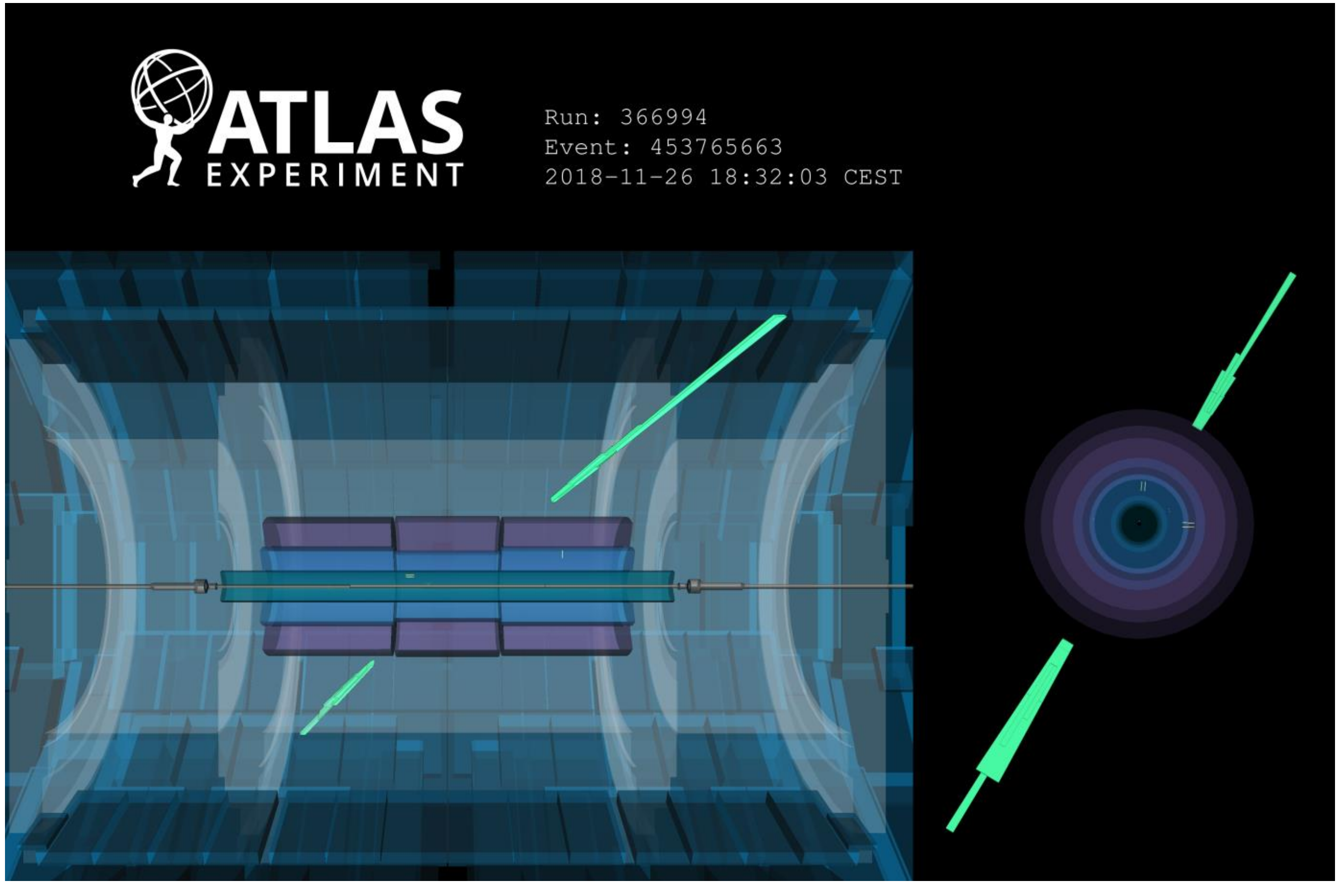


- Consistent results between p–Pb and pp
- No baryon-to-meson enhancement observed in jet cone
- Effect limited to the soft particle

$J/\psi(2s) \rightarrow \mu^+\mu^-$



$\gamma\gamma \rightarrow \gamma\gamma$



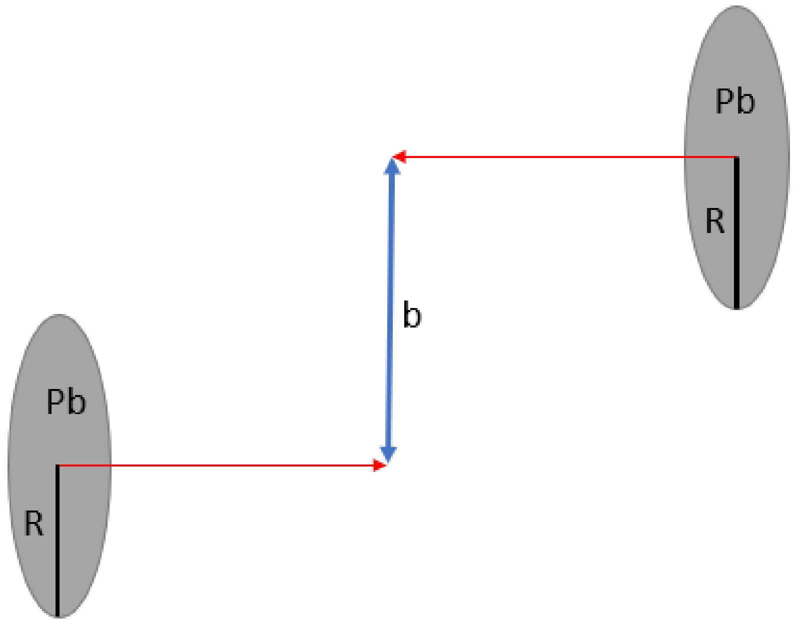
Giulia Manca's talk !

UPC @ LHC

Ultraperipheral Heavy ions collision induce a Huge EM fields which act as a source of high-energy, quasi real photons (Equivalent Photon Approximation)

The photons produce a wide variety of exclusive final states in lead-lead collisions

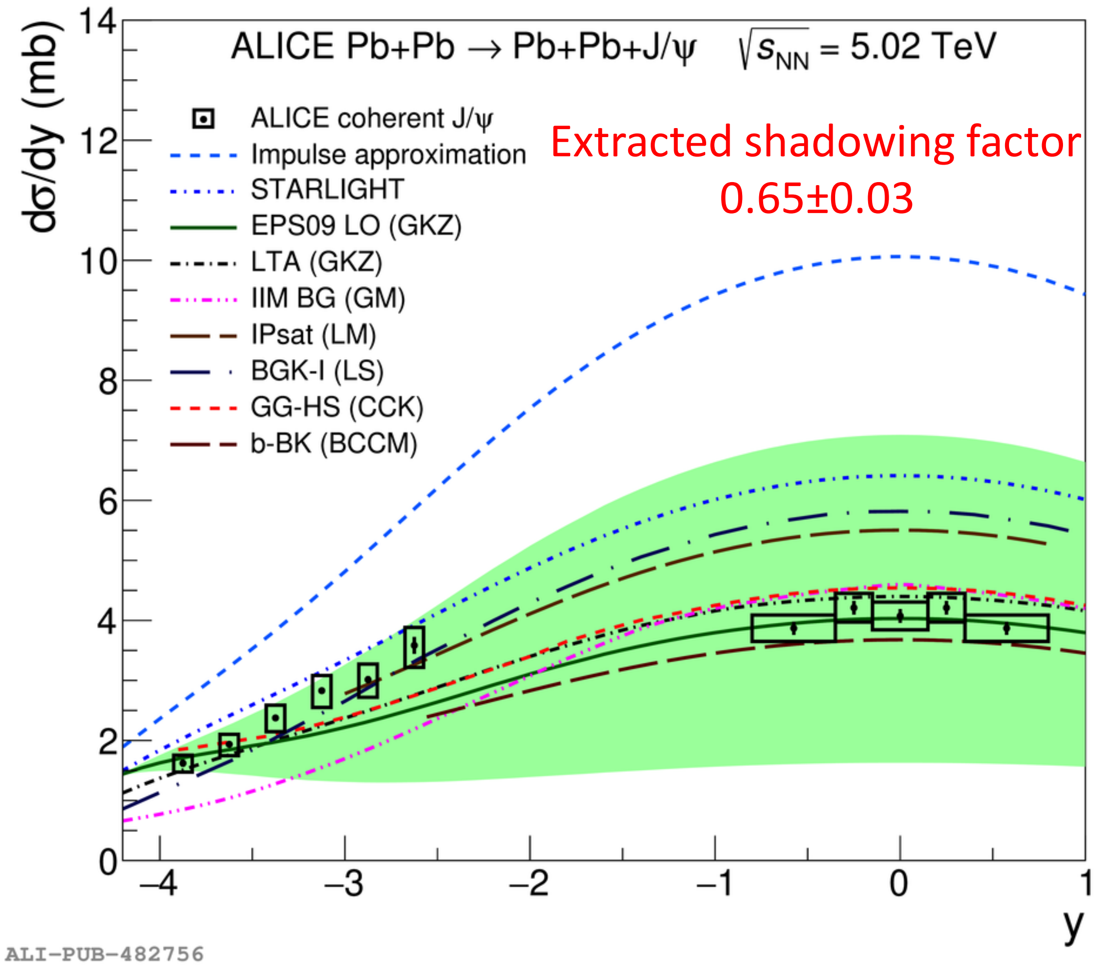
The photon may also interact with a parton in the nucleus (photonuclear interactions.)



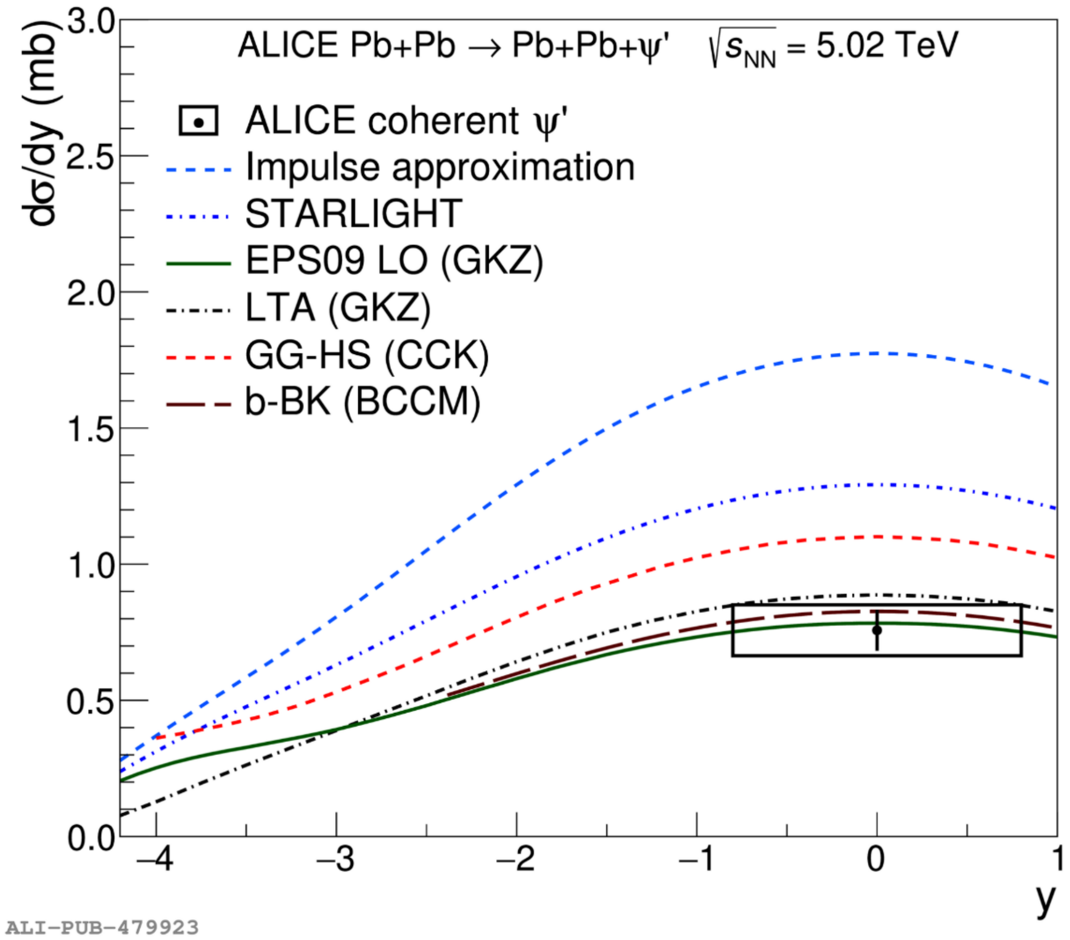
b ≈ 0	b≈2R	b>2R
Central	Peripheral	**Ultraperipheral**

UPC J/ψ and ψ′ @ midrapidity

Eur. Phys. J. C 81 (2021) 712



No models fully describe the whole rapidity dependence



Well described by models with moderate shadowing

Ratio ψ' to J/ψ

Eur. Phys. J. C 81 (2021) 712

$$\frac{\frac{\sigma^{coh}_{\psi'}}{dy}}{\frac{\sigma^{coh}_{J/\psi}}{dy}} = 0.18 \pm 0.0185(\text{stat.}) \pm 0.028(\text{syst.}) \pm 0.005(\text{BR}).$$

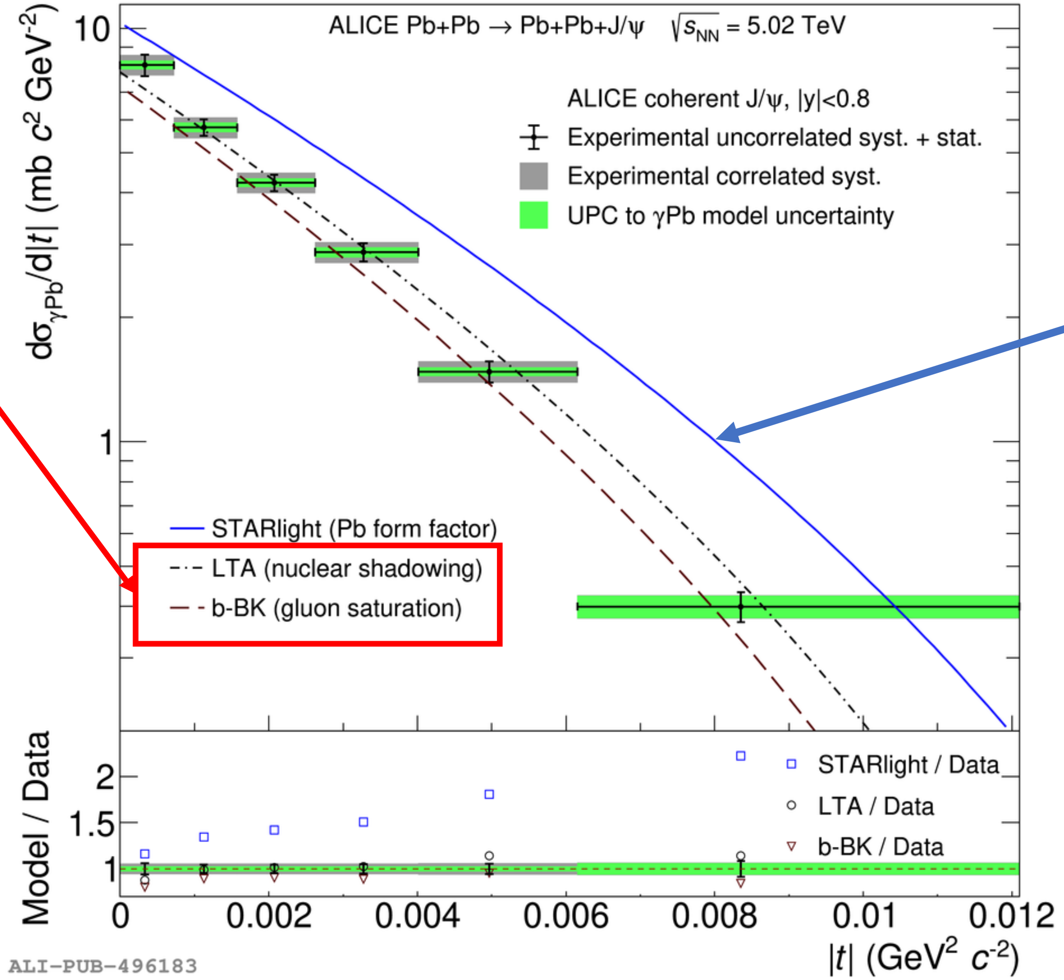
The measured ratio of the ψ’ to J/ψ cross section is compatible with the:

- Exclusive photoproduction cross section ratio measured by the H1 collaboration in ep collisions Phys. Lett. B 541 (2002) 251–264
- Ratio measured by the LHCb collaboration in pp collisions JHEP 10 (2018) 167
- Ratio predicted in the leading twist approximation Phys.Rev. C 93 no. 5, (2016) 055206,

|t|-dependence of to J/ψ cross-section

PLB 817 (2021) 136280

Good description of data from



STARlight overestimates the measured cross section and the shape of the distribution appears to be wider than that of the measured data.

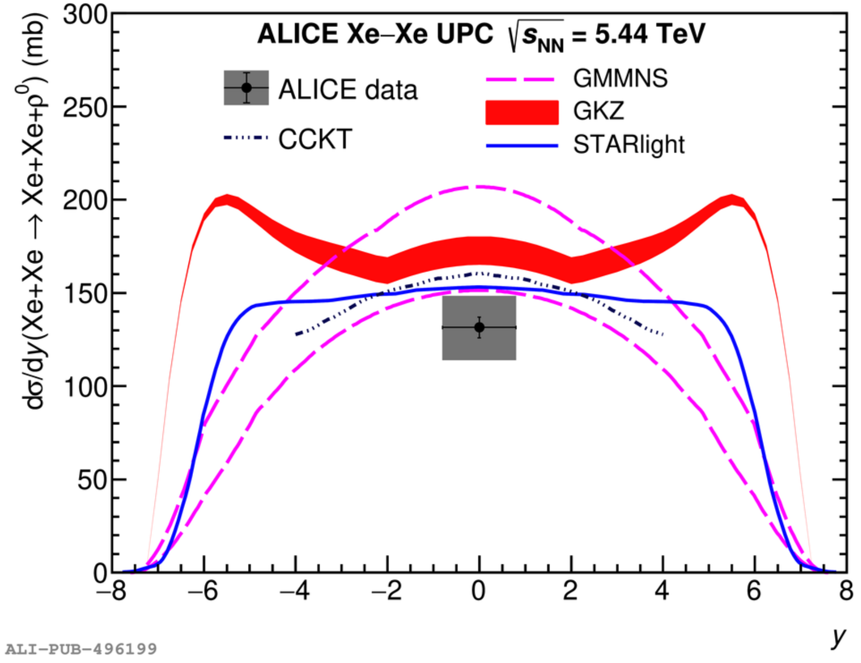
QCD dynamical effects not taken into account

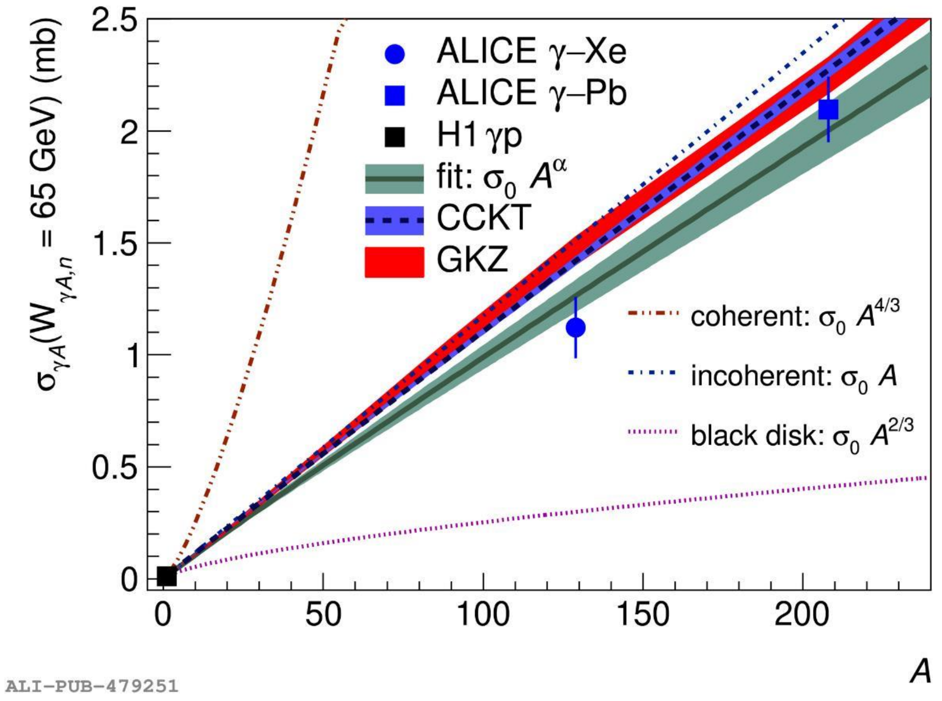
|t|: ≈ pT^2 the square of the momentum transferred between the incoming and outgoing target nucleus

Xe+Xe→ρ^0+Xe+Xe

Phys. Lett. B 820 (2021) 136481

$$d\sigma/dy = 131.5 \pm 5.6(\text{stat.})^{+17.5}_{-16.9}(\text{syst.})$$





First measurement with Xe nucleus -> first study of A dependence

- The theoretical predictions slightly overestimate the measurement
- Fair agreement between data and predictions

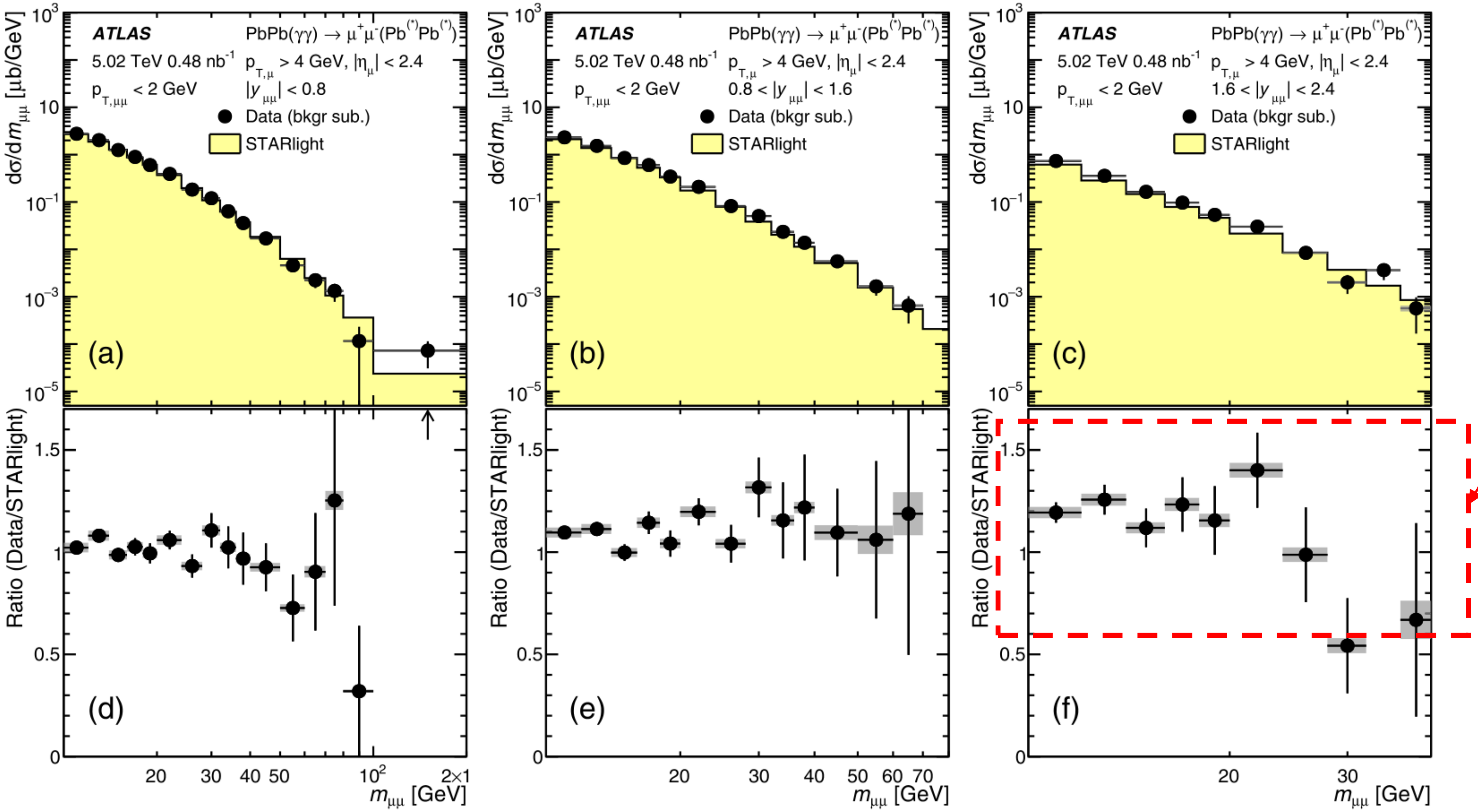
Fit parameter α= 0.96±0.02

Significantly bellow 4/3=> important shadowing effects
Close to unity => not incoherent behavior, just large shadowing suppression
Oxygen data in the future !

$\gamma\gamma \to \mu^+\mu^-$

Differential cross section as function of invariant mass
In bins of absolute rapidity

Phys. Rev. C 104 (2021) 024906



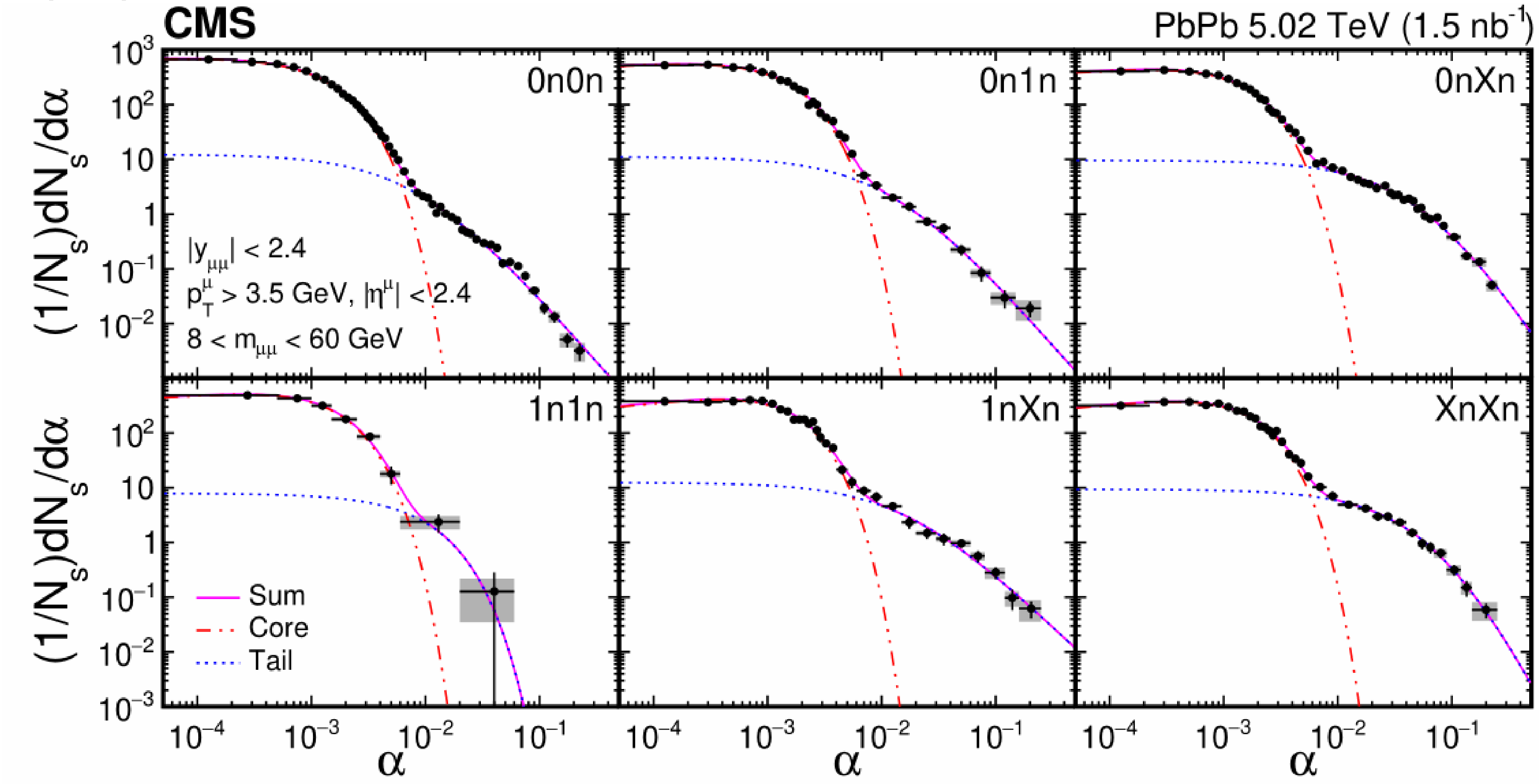
XS 10–20% larger in data than in the calculations, suggesting the presence of larger fluxes of photons in the initial state.

Good description from starlight prediction after background subtraction

Forward neutron multiplicity dependence

$\gamma\gamma \rightarrow \mu^+\mu^-$

PhysRevLett.127.122001



$$\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}$$

Broader acoplanarity for events with a larger number of emitted neutrons from each nucleus
Impact parameter dependence of initial states photon

Two-particle azimuthal correlations

Phys. Rev. C. 104 014903

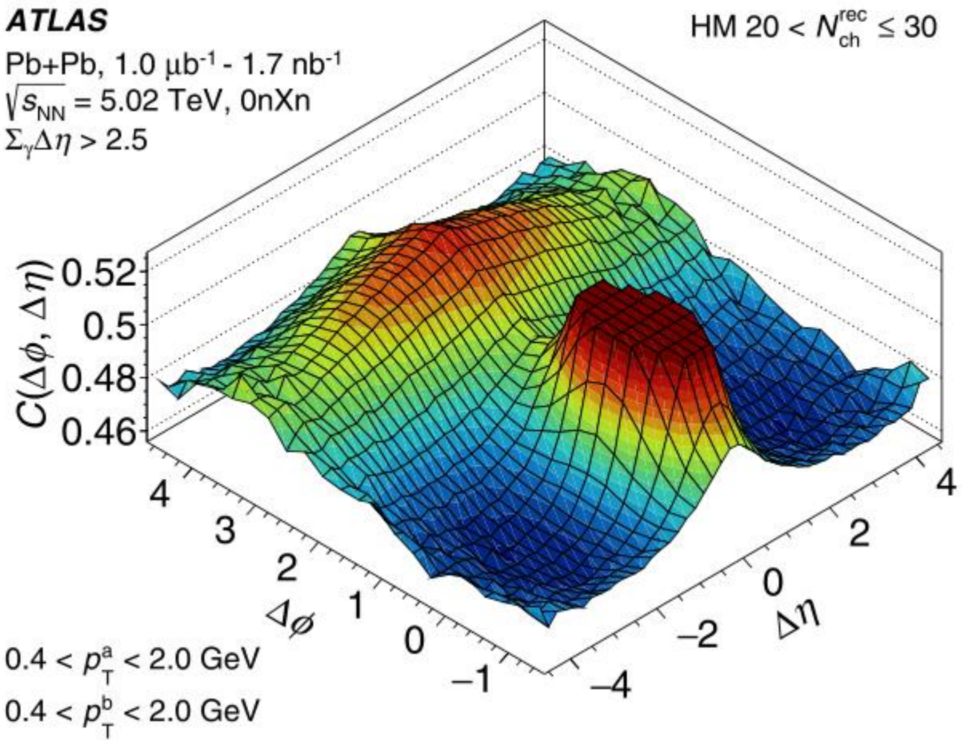
Measurement done using photonuclear UPC events

$$C(\Delta\phi, \Delta\eta) = \frac{1}{N_a} \frac{d^2 N_{\text{pair}}}{d\Delta\phi\, d\Delta\eta} \bigg/ \frac{1}{N_{\text{pair}}^{\text{mixed}}} \frac{d^2 N_{\text{mixed}}}{d\Delta\phi\, d\Delta\eta},$$

correlation function in LM events

$$Y^{\text{HM}}(\Delta\phi) = FY^{\text{LM}}(\Delta\phi) + G\left\{1 + 2\sum_{n=2}^{4} v_{n,n}\cos(n\Delta\phi)\right\}$$
$$= FY^{\text{LM}}(\Delta\phi) + Y^{\text{ridge}}(\Delta\phi). \quad (1)$$

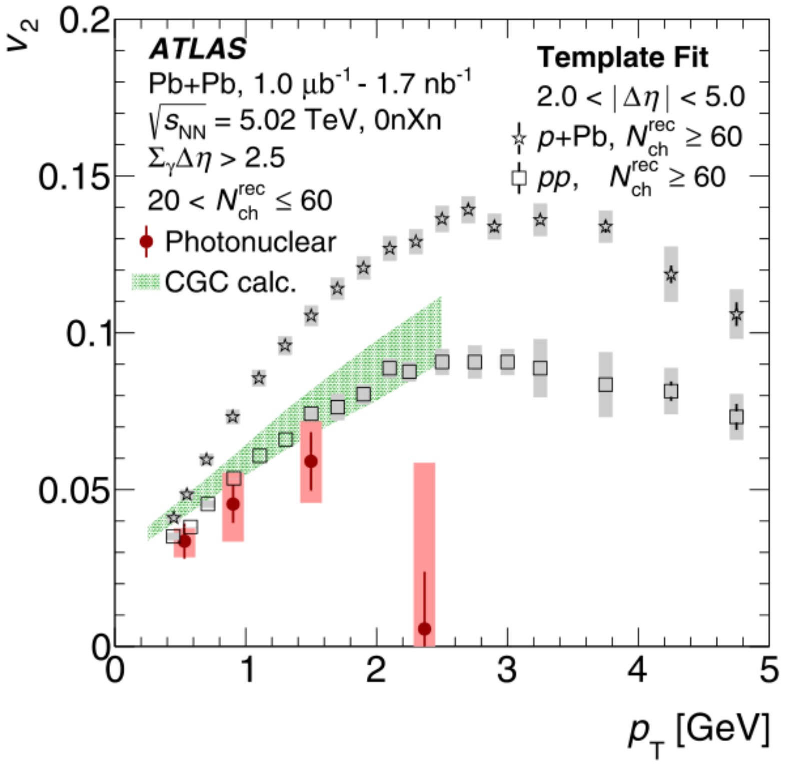
flow coefficients



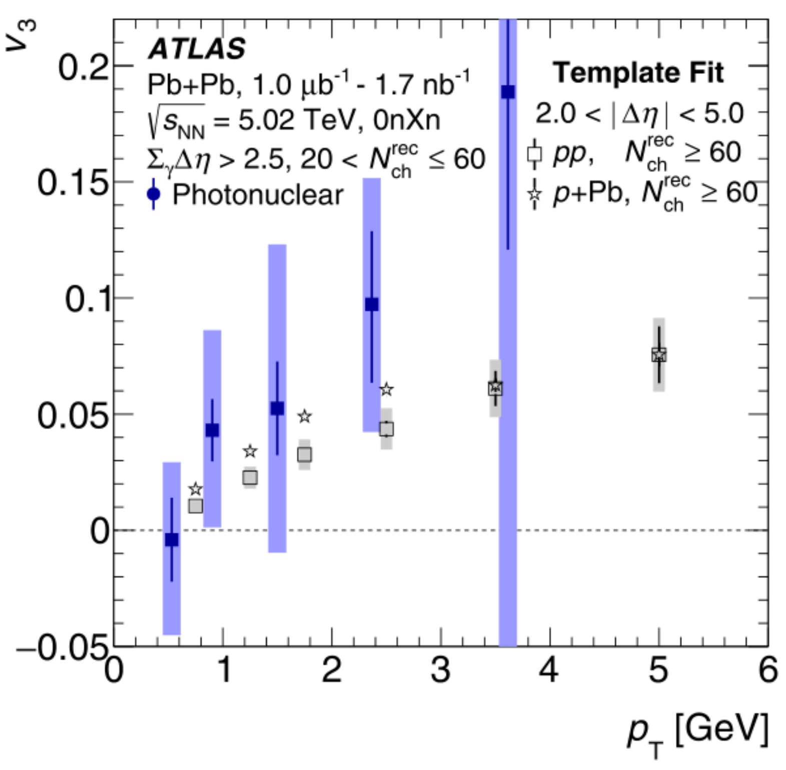
Two-particle azimuthal correlations

Phys. Rev. C. 104 014903

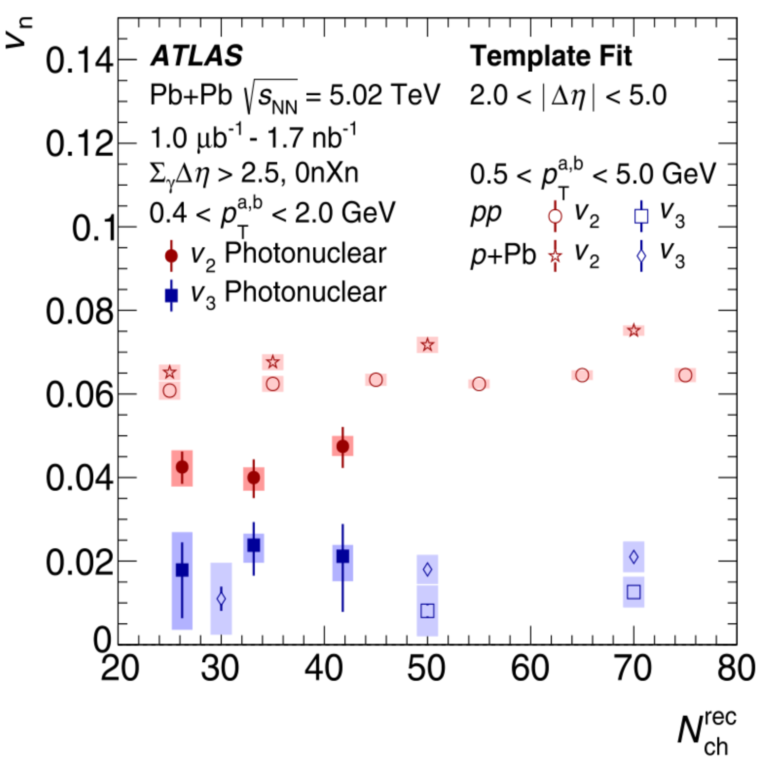
Comparison with in pp and p + Pb collisions : The v2 values are smaller at similar particle multiplicities



Flow coefficients v2 as a function of particle p_T



Flow coefficients v3 as a function of particle p_T

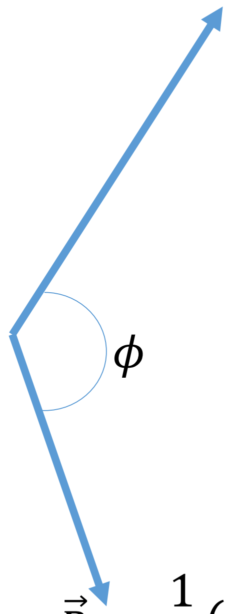


Flow coefficients vn as a function of Charged particles multiplicity

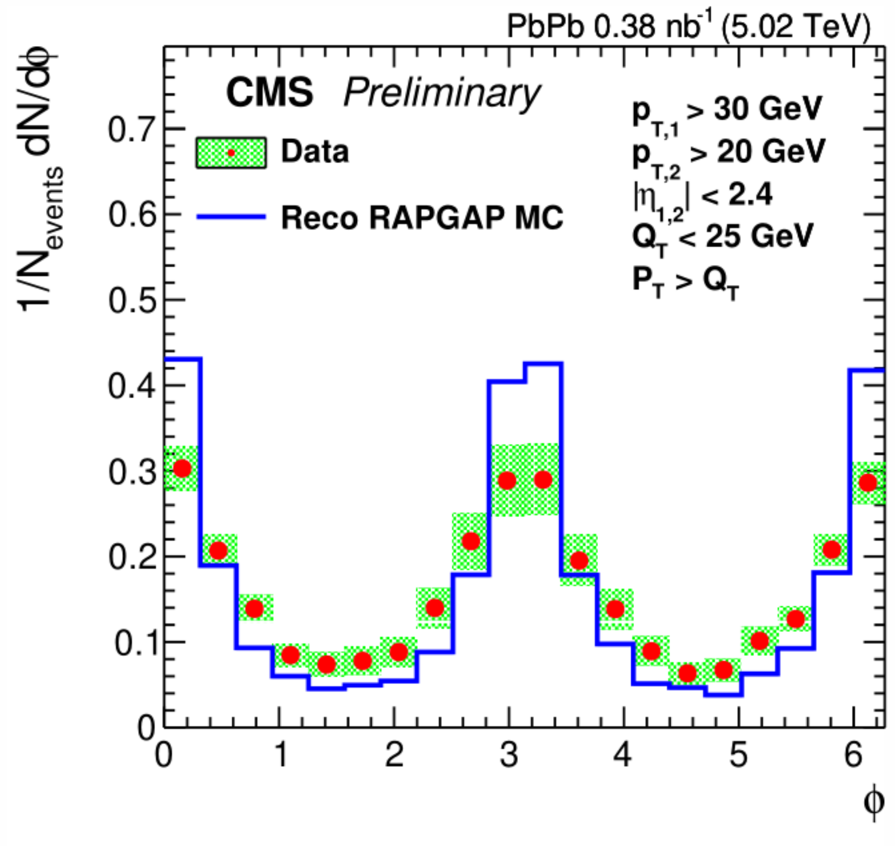
Exclusive dijet photoproduction

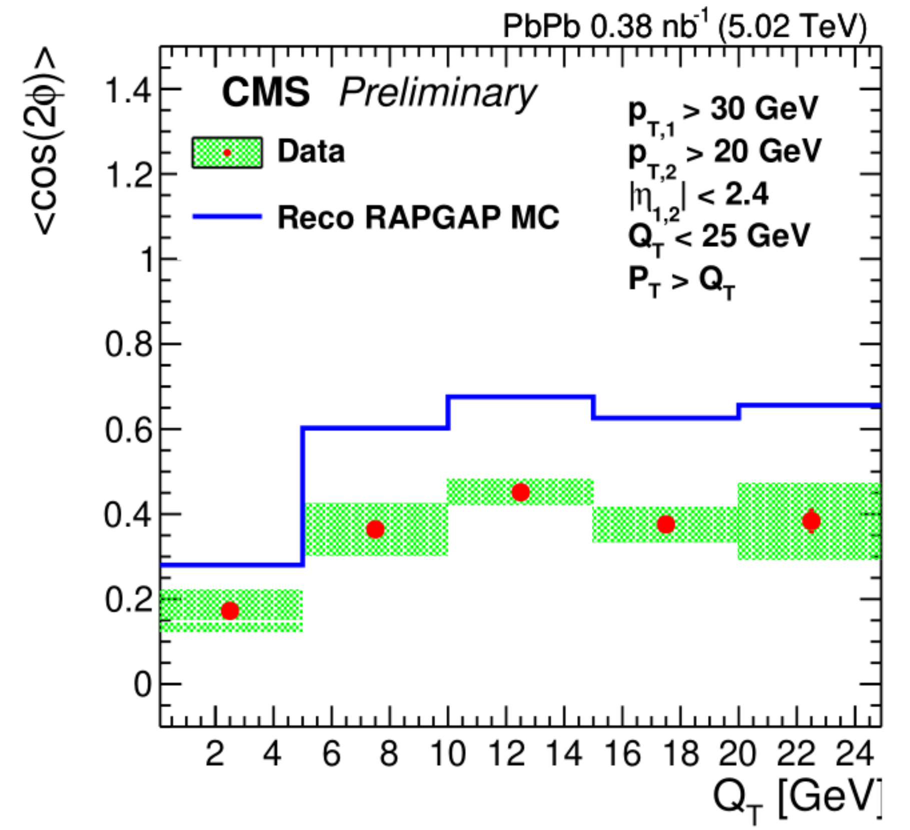
CMS-PAS-HIN-18-011

$$\vec{Q}_{\mathrm{T}} = \vec{p}_{\mathrm{T},1} + \vec{p}_{\mathrm{T},2}$$



$$\vec{P}_{\mathrm{T}} = \frac{1}{2}\left(\vec{p}_{\mathrm{T},1} - \vec{p}_{\mathrm{T},2}\right)$$



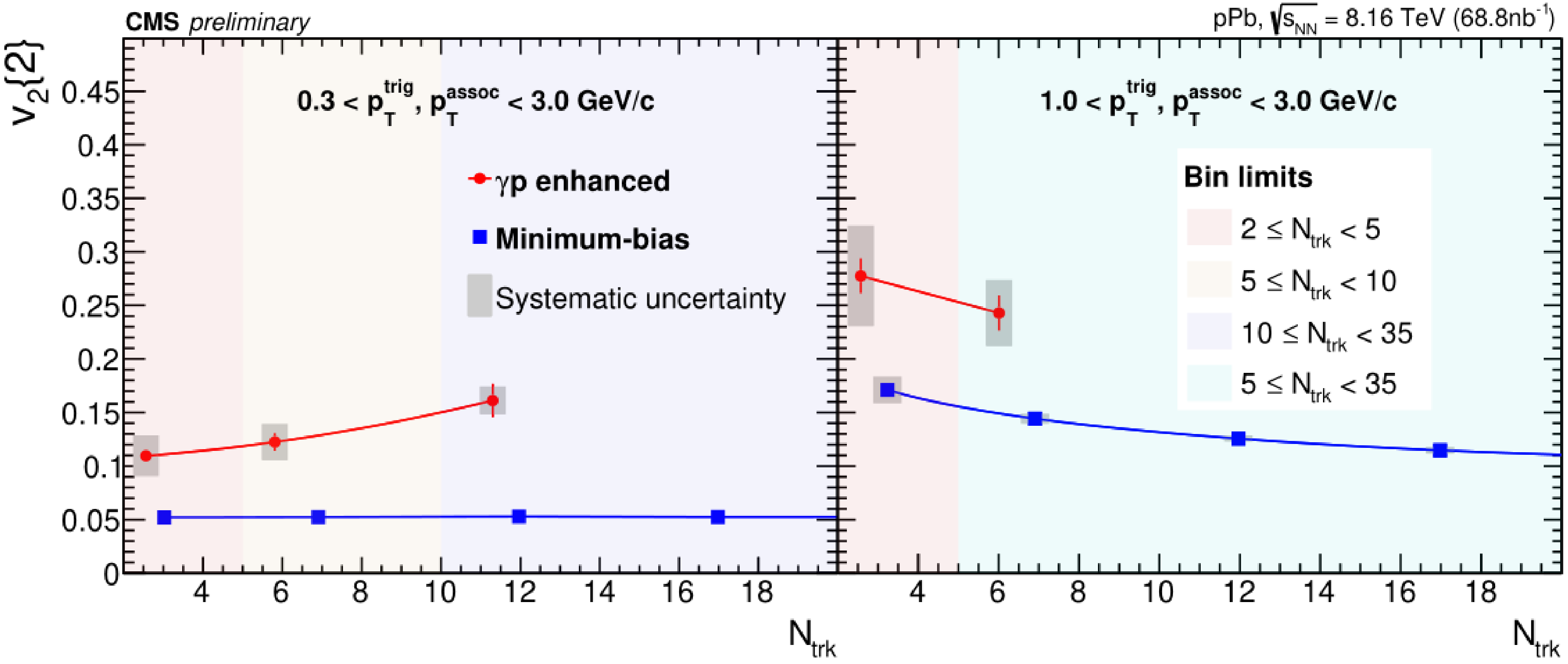


- MC prediction consistently above data in QT dependence
- Call for theoretical effort for a better description of QT dependence
- Towards the extraction of the Wigner or Husimi gluon distributions

Elliptic azimuthal anisotropies in γp interactions

[CMS-PAS-HIN-18-008]

Using pPb UPC : First correlation measurements for γp system



- V2 increase with pT for a given multiplicity range
- V2 higher in γp than Min-Bias events for the same multiplicity
- Possible different sets of initial state configurations between the 2 samples

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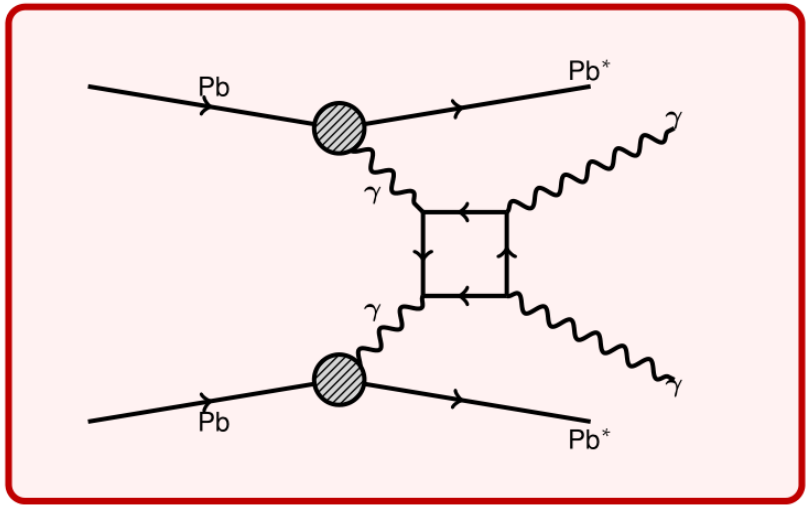
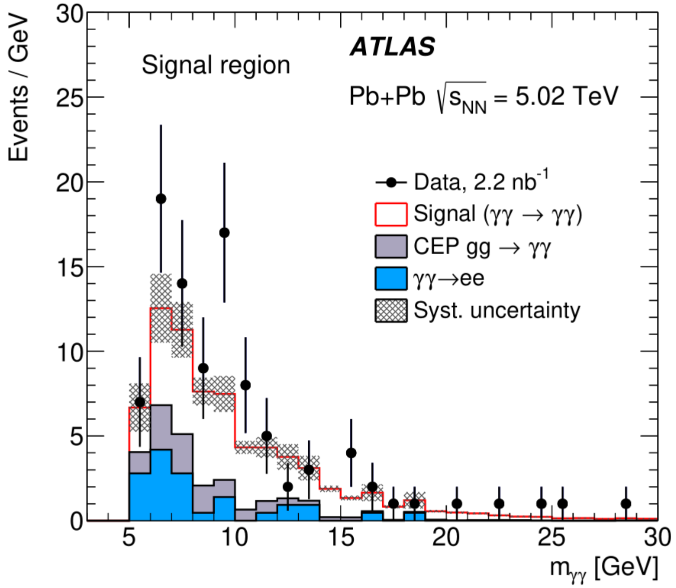
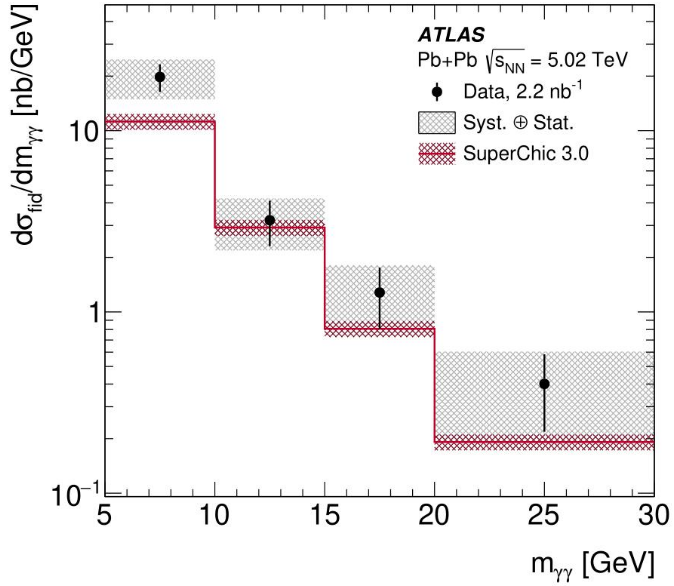




σ = 120 ± 17 (stat .) ± 13 (syst .) ± 4 (lumi .) nb

Comparable to predicted values of :

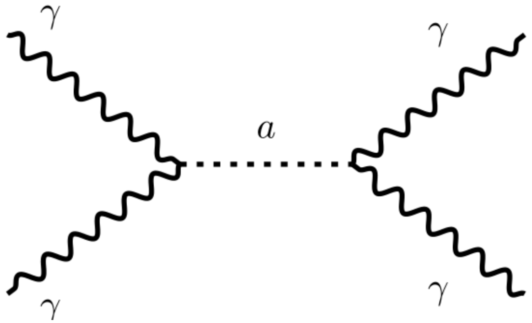


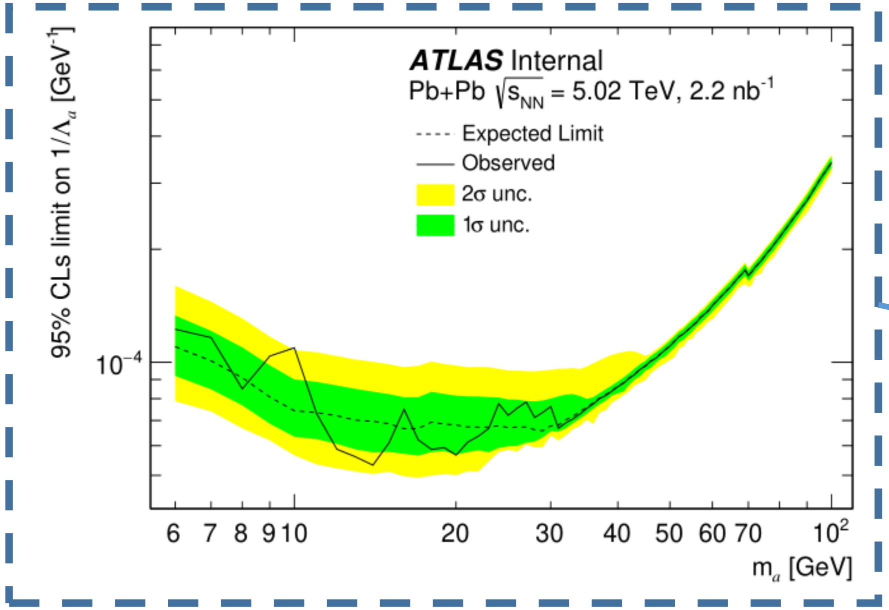
Predicted	Data/theory
80 ± 8 from Phys.Rev.C 93 (2016) 4, 044907	1.50 ± 0.32
78 ±8 from Eur.Phys.J.C 79 (2019) 1, 39	1.54 ± 0.32

Search for ALPs

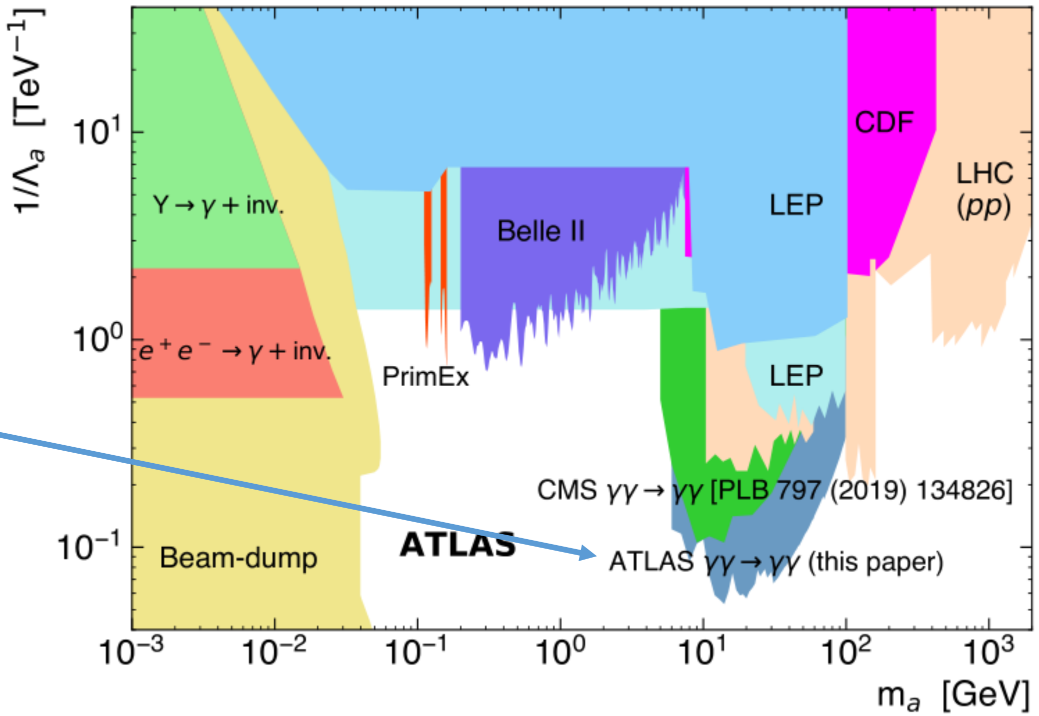
[JHEP 03 (2021) 243](#)

- The diphoton invariant mass distribution is used to set limits on the production of axion-like particles
- Assuming a 100% ALP decay branching fraction into photons
- Derived constraints on the ALP mass and its coupling to photons





Existing constraints from JHEP 12 (2017) 044



Summary

- JETS : colored probe for QGP
- Jet quenching measurements to learn about the QGP
- Quenching in small system ? medium response ?

- UPC heavy ion collisions allow to probe photon-induced interactions
- New testing ground for QED process.
- Clean way to search for particles that couples to photon such ALPs
- Stay tuned for more results from Run3 data taking @ LHC !

Thank you

Backup

Large R Jets in heavy-ion collisions

Inclusive jet suppression: large R=0.2 to 1.0!

➞ Possible recovery of the jet energy because of out-of-cone radiation

➞Possible difference in modification for larger vs smaller jets

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