Overview of CMS and ATLAS results

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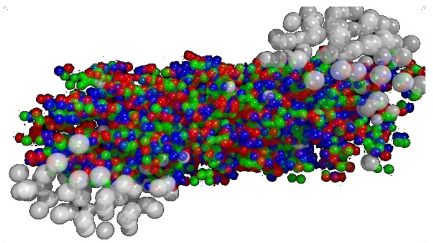
Second LHCb Heavy Ion Workshop
September 4–6, 2019

Heavy ion collisions

Different collision systems, different information

- PbPb: hot medium effects (quark-gluon plasma)
- pPb: cold nuclear effects (initial state, nuclear absorption, energy loss)
- pp: reference ("nucleons in vacuum") at the same $\sqrt{s}$

Year	System	$\sqrt{s_{NN}}$ [TeV]	Luminosity (CMS)	Lumi. $\times A^{(2)}$
2011	PbPb	2.76	$150\,\mu b^{-1}$	$6.5\,pb^{-1}$
2013	pPb	5.02	$30\,nb^{-1}$	$6.2\,pb^{-1}$
2013	pp	2.76	$5\,pb^{-1}$	$5\,pb^{-1}$
2015	pp	5.02	$30\,pb^{-1}$	$30\,pb^{-1}$
2015	PbPb	5.02	$400\,\mu b^{-1}$	$17\,pb^{-1}$
2016	pPb	8.16	$170\,nb^{-1}$	$35\,pb^{-1}$
2017	XeXe	5.44	$3.4\,\mu b^{-1}$	$0.058\,pb^{-1}$
2017	pp	5.02	$320\,pb^{-1}$	$320\,pb^{-1}$
2018	PbPb	5.02	$1.8\,nb^{-1}$	$78\,pb^{-1}$

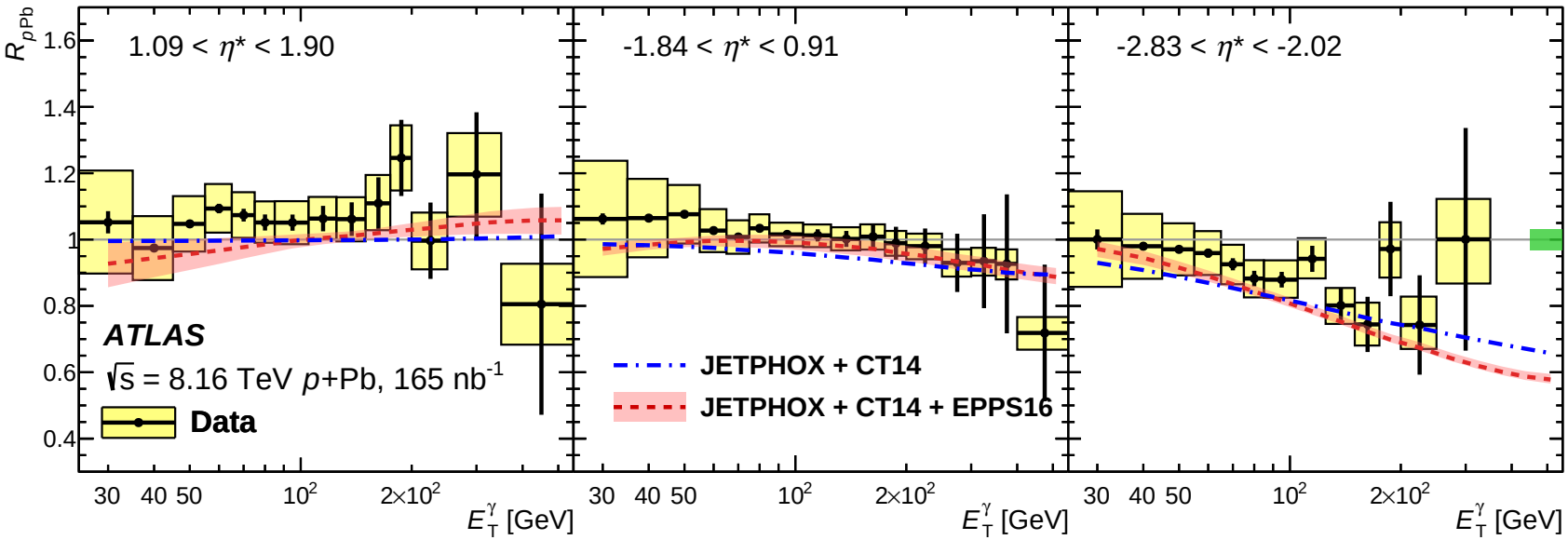


Run2: higher $\sqrt{s_{NN}}$, larger datasets

Isolated photons in pPb

arXiv:1903.02209

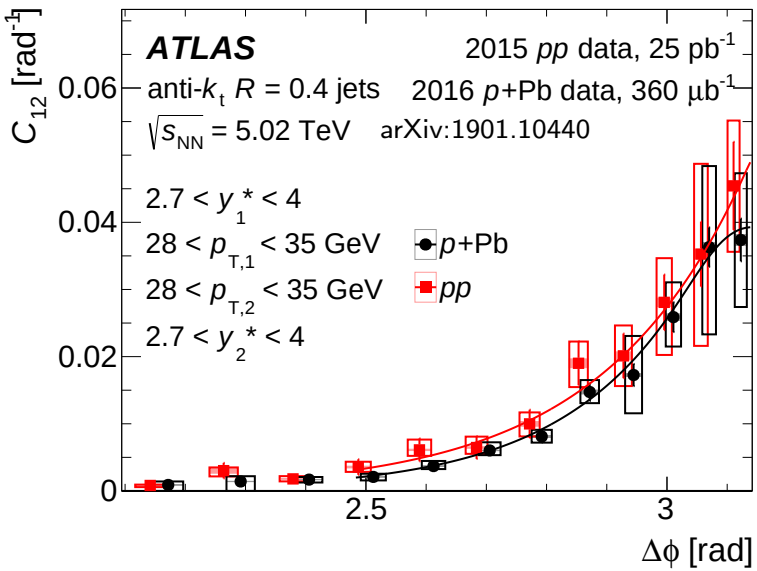
- Nuclear modification factor of photons
- Sensitive to nuclear PDFs and initial state energy loss
  - Also modification because of different quark content (up / down) in the nucleus



- The data disfavour a large amount of energy loss
- Constraints on nPDFs

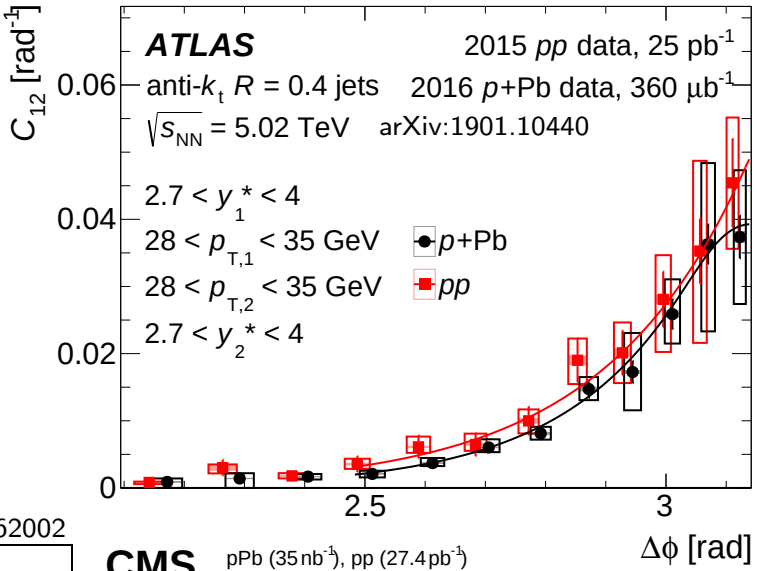
Dijets in pPb

- Saturation at low x_{Pb} (10^{-4}–10^{-3})?
  - No broadening of azimuthal angular correlations for dijets in pPb

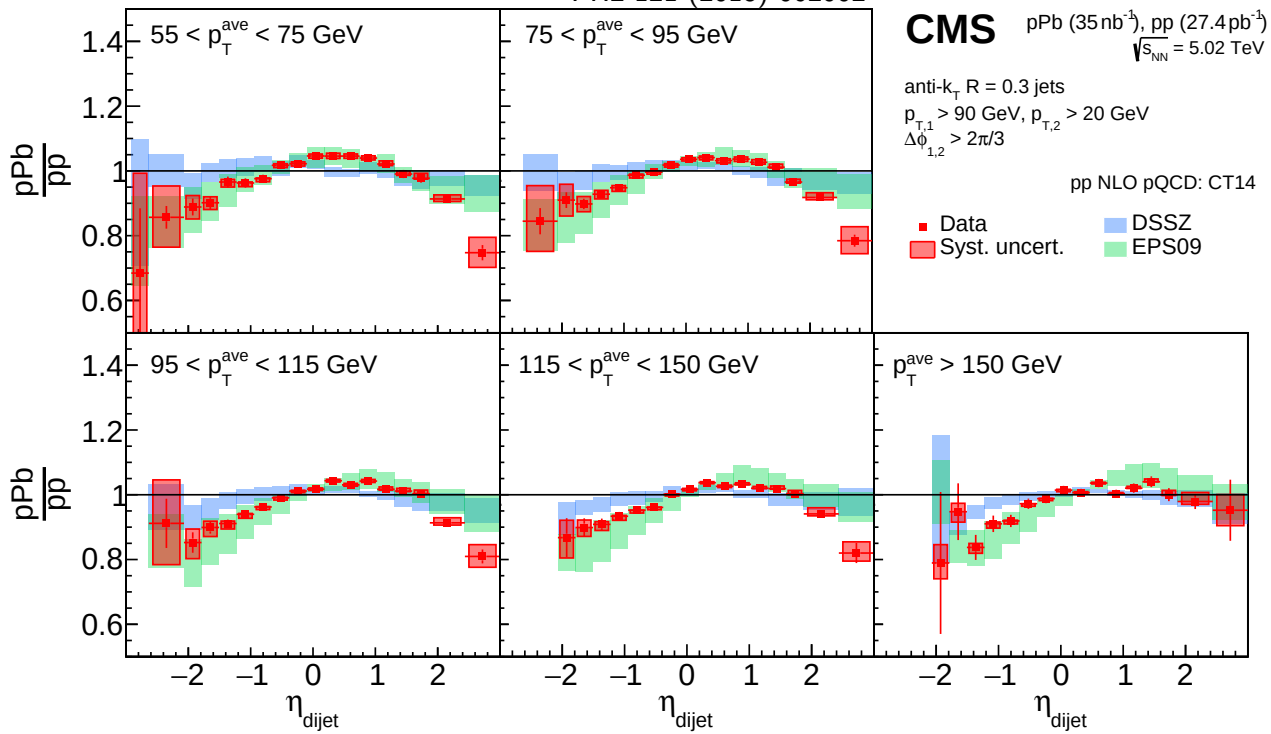


Dijets in pPb

- Saturation at low x_{Pb} (10^{-4}–10^{-3})?
  - No broadening of azimuthal angular correlations for dijets in pPb
- Strong constraints on gluon nPDFs: shadowing, anti-shadowing, EMC
  - dijet $\eta \leftrightarrow x_{Pb}$
  - $p_T \leftrightarrow$ scale Q^2
  - imperfect modelling in pp $\rightarrow$ data-driven pp reference



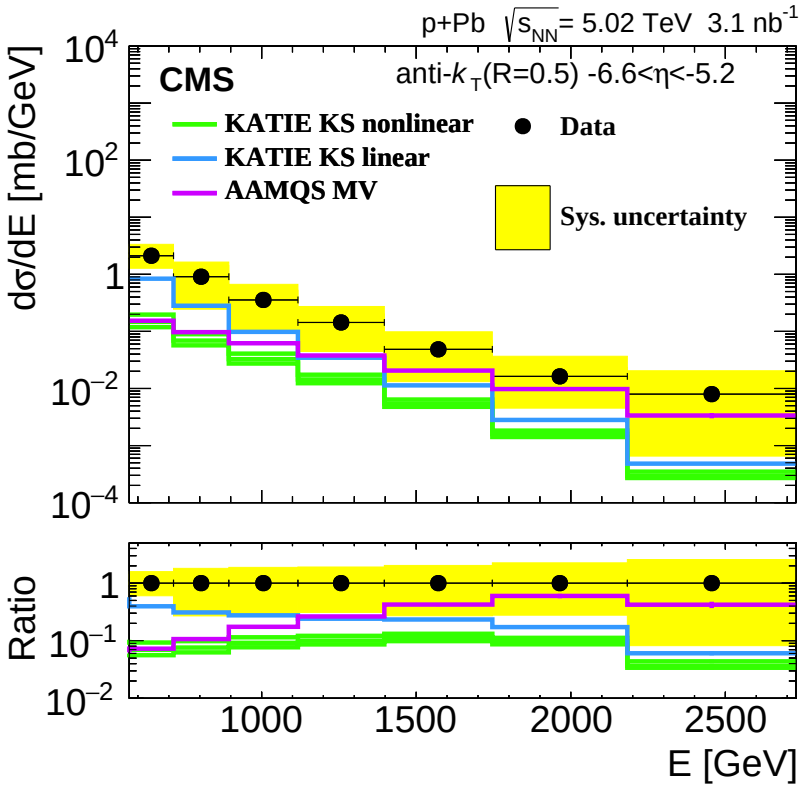
PRL 121 (2018) 062002



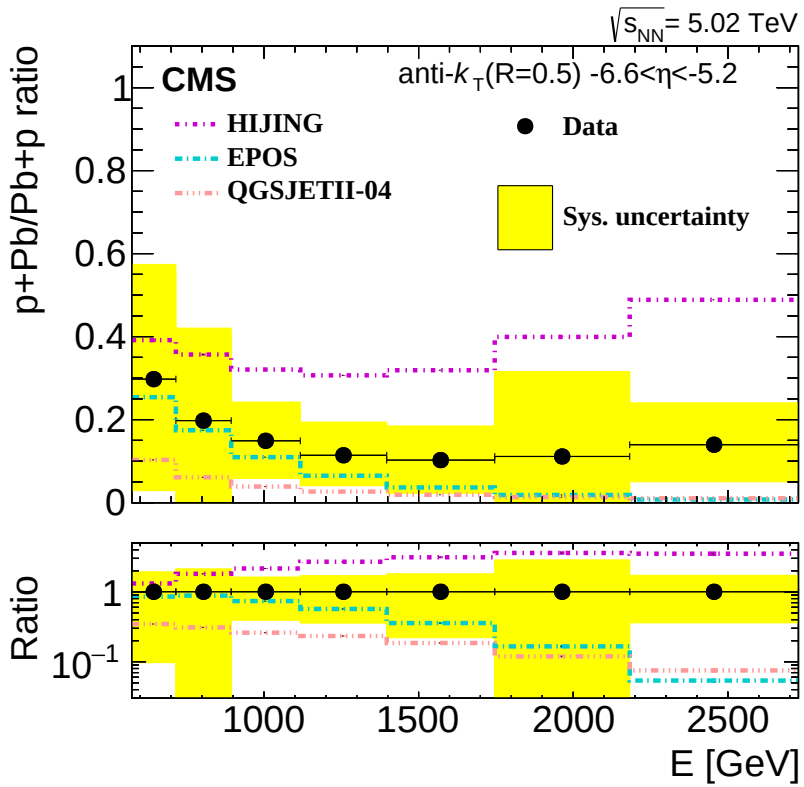
Forward jets in pPb

JHEP 05 (2019) 043

Forward: $-6.6 < \eta < -5.2$: $x_{\mathrm{Pb}} \approx 10^{-6}$



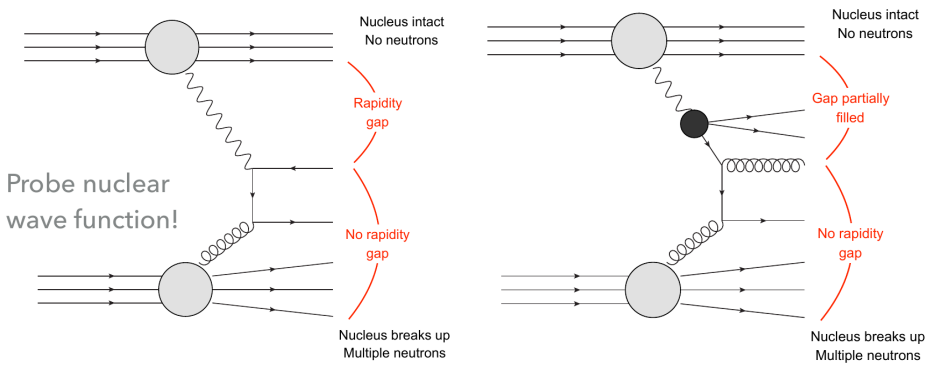
Saturation models do not describe the data



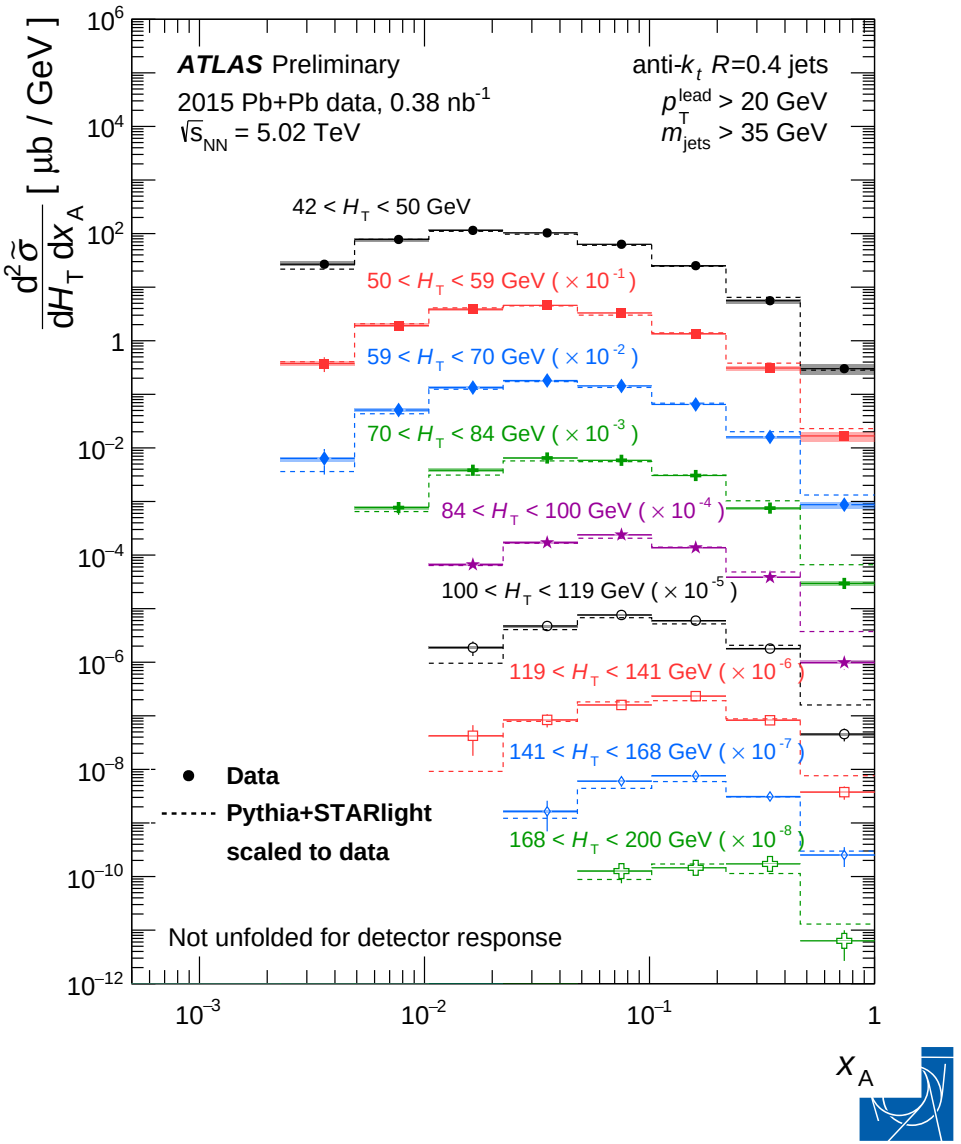
None of the models describe pPb / Pbp well

Photonuclear jets in pPb

ATLAS-CONF-2017-011

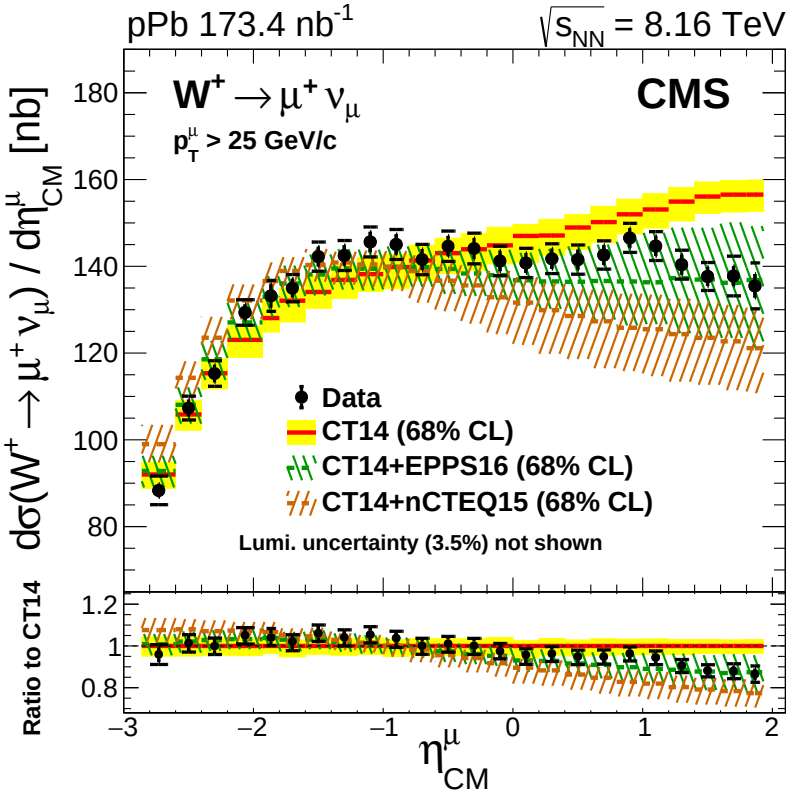


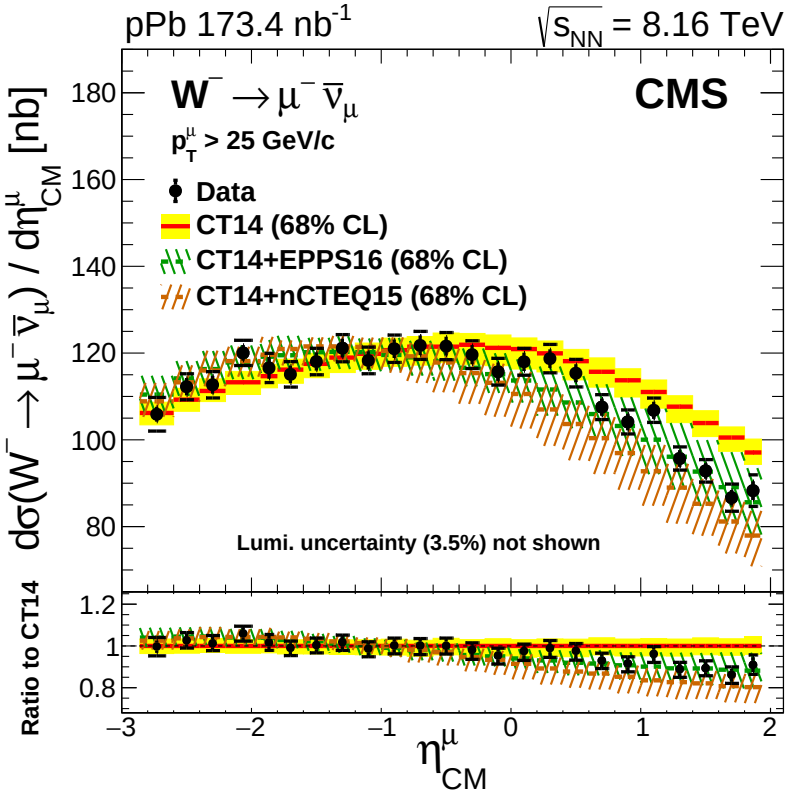
- Selecting γPb interactions using ZDC + rapidity gaps
- Comparison with PYTHIA (γ spectrum reweighted to STARLIGHT)
- Sensitivity to nPDF



Electroweak bosons in pPb

arXiv:1905.01486

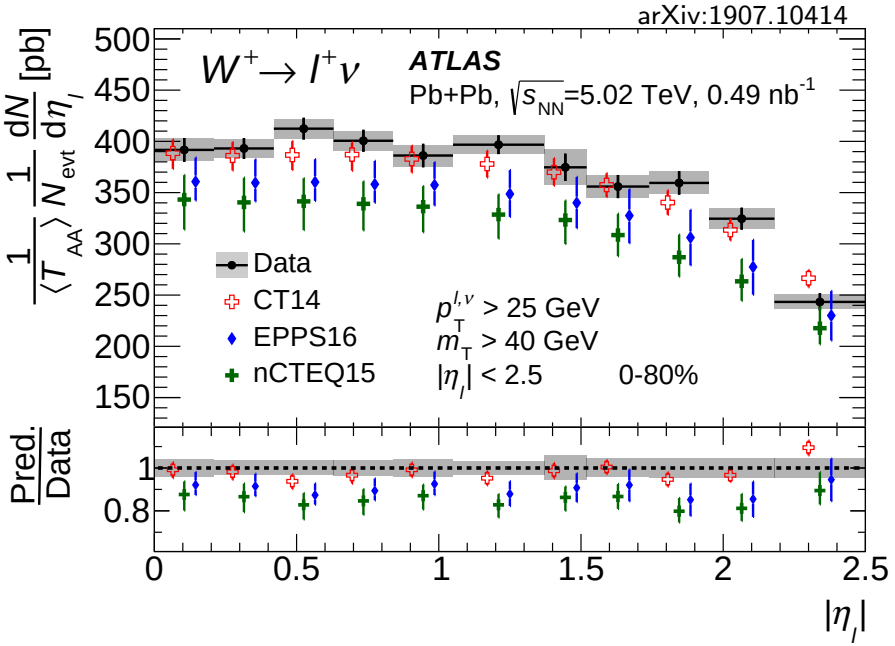




- W bosons are sensitive to isospin effects (up vs down quarks)
- $\eta_{CM} < 0$ (Pb-going, large x_{Pb}): data agrees with both PDF and nPDF
  - slight anti-shadowing at $x_{Pb} \approx 10^{-1}$
- $\eta_{CM} > 0$ (p-going, small x_{Pb}): data favors nPDF
  - significant shadowing at $x_{Pb} \approx 10^{-3}$
  - consistent with EPPS16, exclude CT14 (free nucleon PDF)

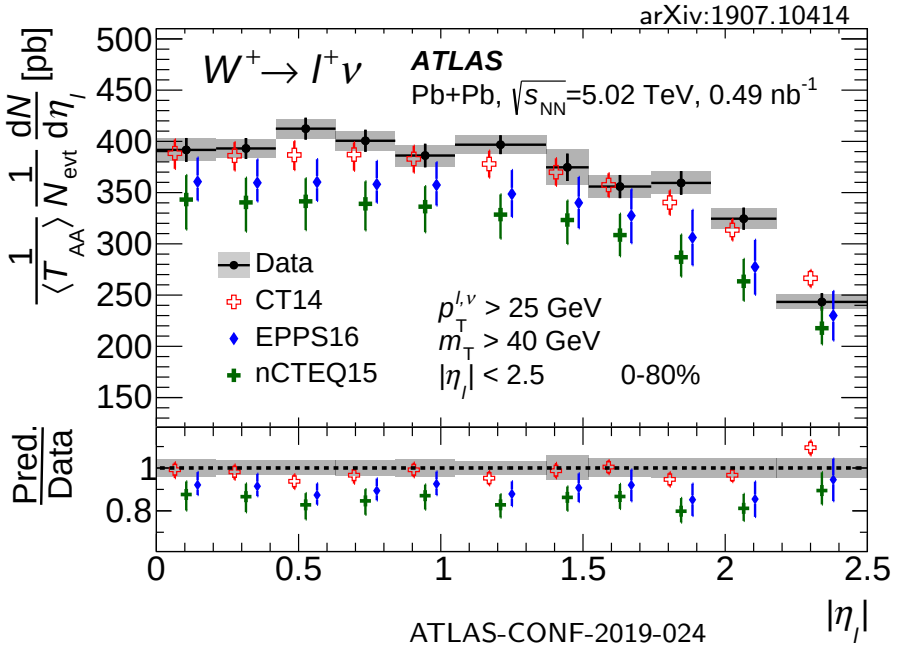
Electroweak bosons in PbPb

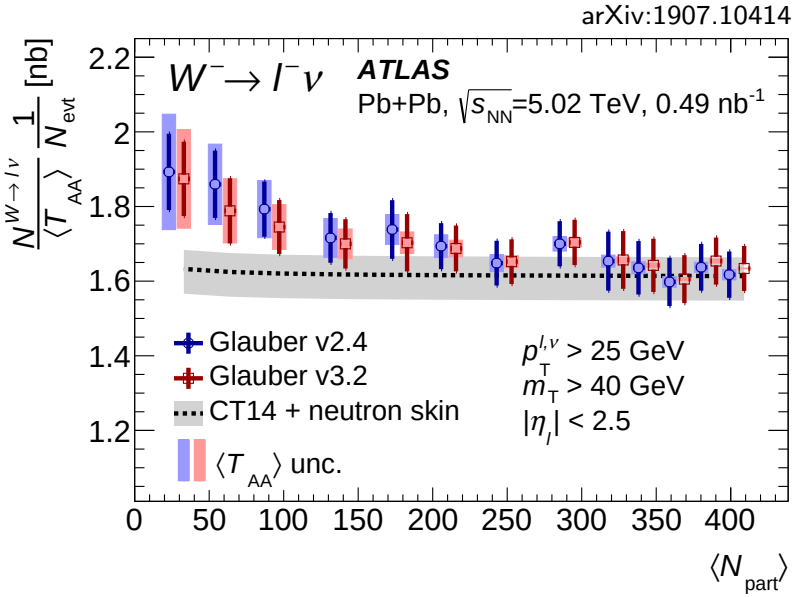
- Data systematically higher than nPDF models
- Peripheral data: smaller experimental uncertainties than Glauber

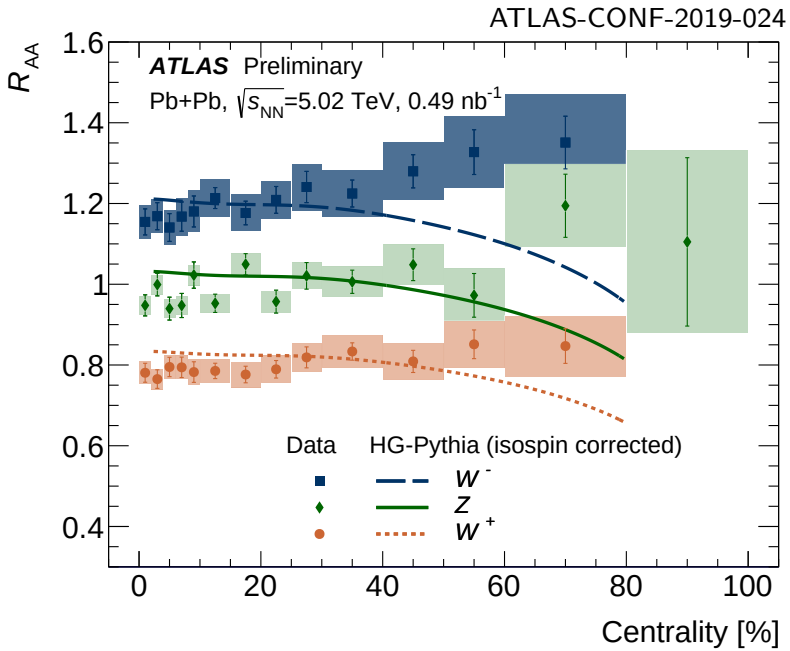


Electroweak bosons in PbPb

- Data systematically higher than nPDF models
- Peripheral data: smaller experimental uncertainties than Glauber
- Non-flat centrality dependence
  - Not captured by different Glauber parameters
  - Not captured by neutron skin model
  - Opposite trend compared to HG-Pythia (selection bias, reproduces hadron R_{AA})
  - Then... what??



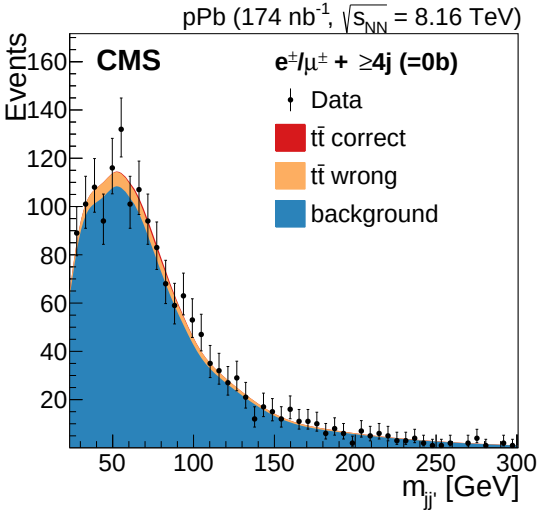


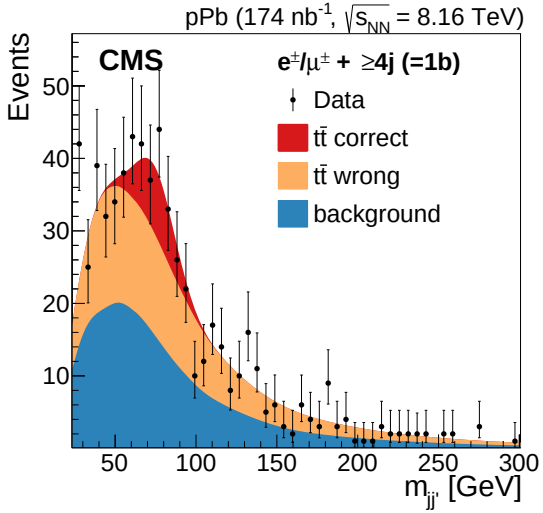


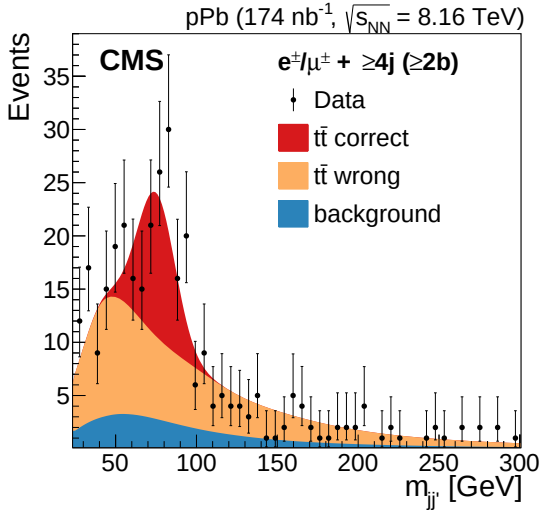
Top quarks in pPb

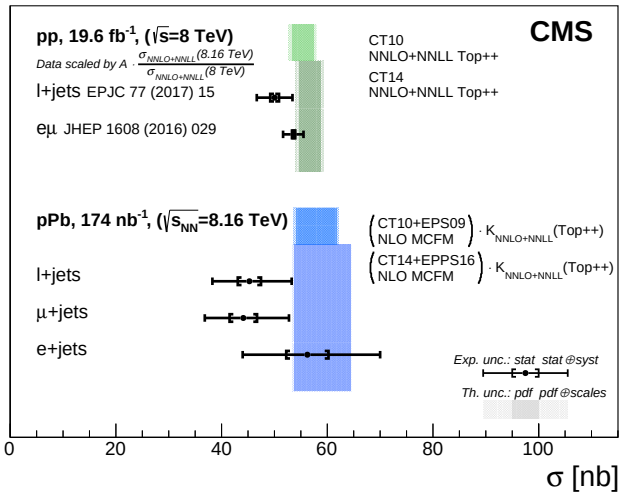
PRL 119 (2017) 242001

First top quark observation in heavy ion collisions!









- ℓ + jets channel (electron and muon)
- Fitting the W→jj mass in the different b-jet and lepton flavour categories
- Measurement in agreement with pQCD + nPDF expectations

Quarkonia in pPb

pPb: nPDF, energy loss, final state interactions? (excited states vs ground states)

- p_T and y dependent suppression of all 5 S-wave quarkonium states
- Excited states are more suppressed than the ground state
- Event activity dependence?

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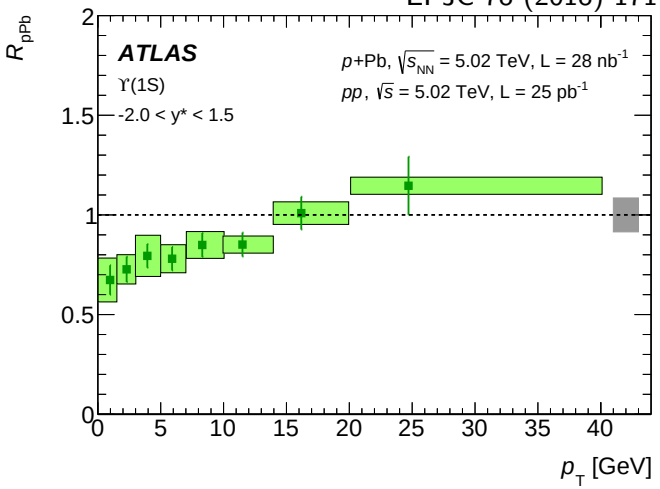
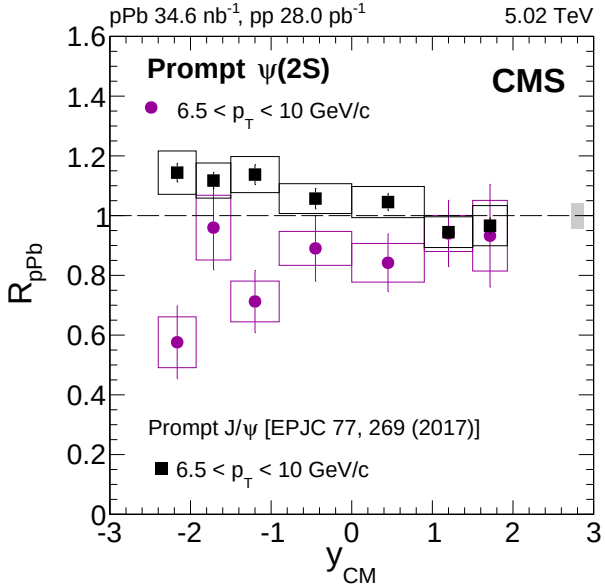


PLB 790 (2019) 509



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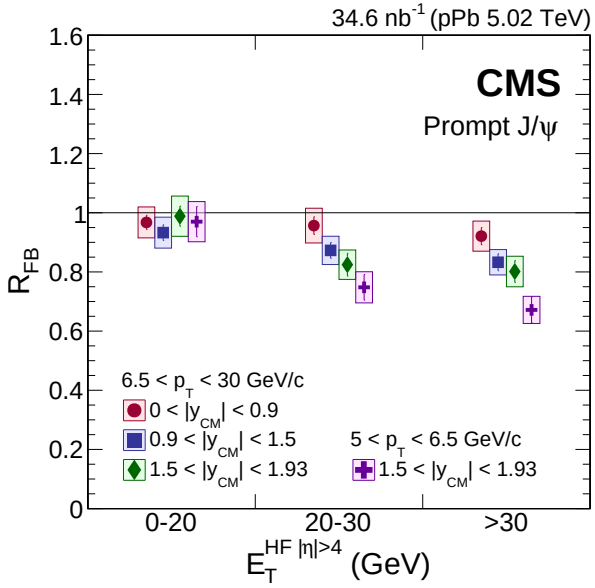

Quarkonia: puzzles in small systems

- Prompt J/ψ fragmentation not well modeled in PYTHIA

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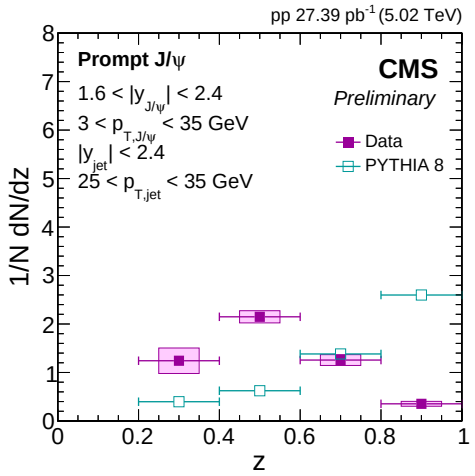

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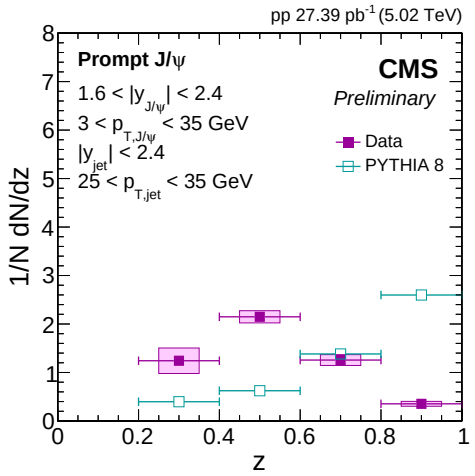

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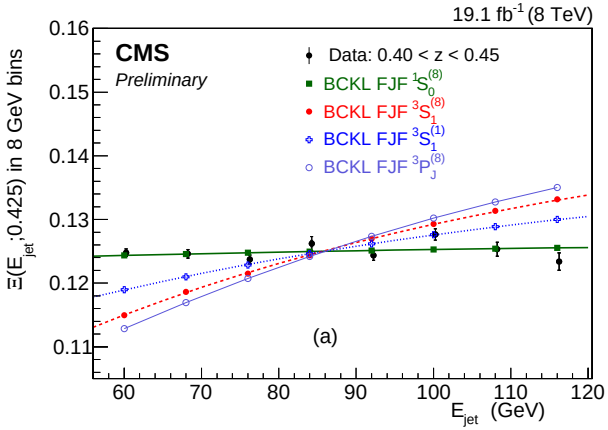

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  - Similar trend in pp, pPb, PbPb

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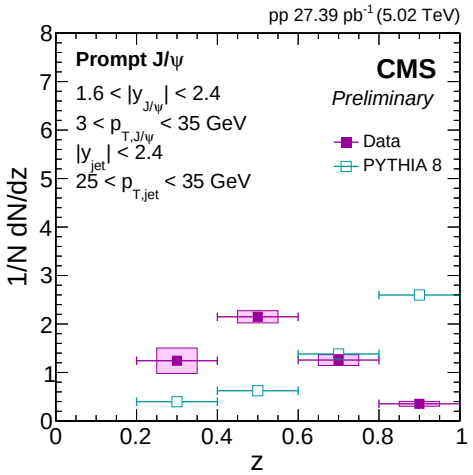

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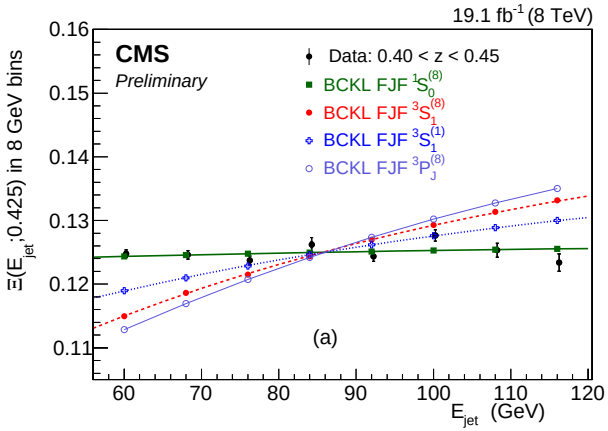

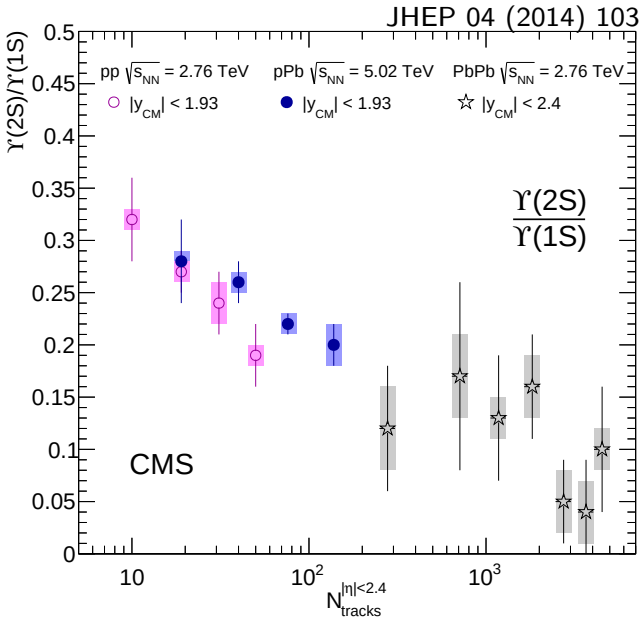

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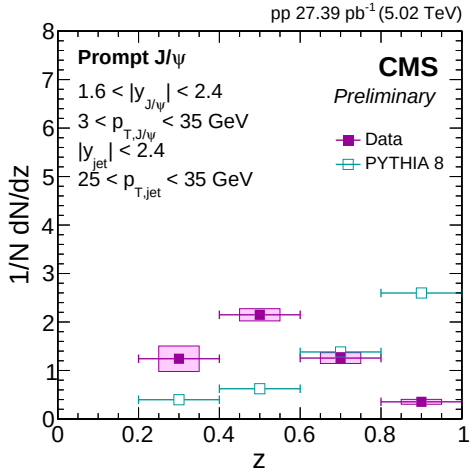

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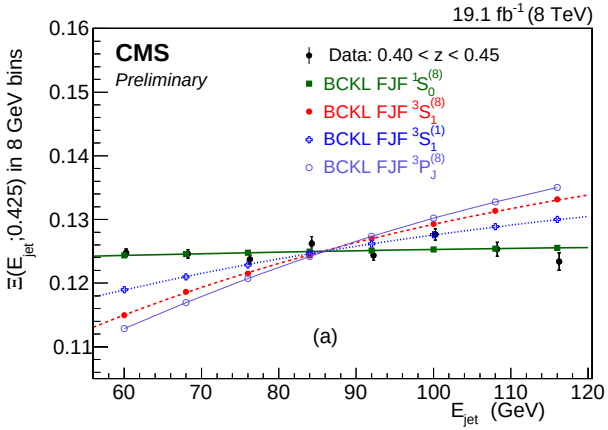

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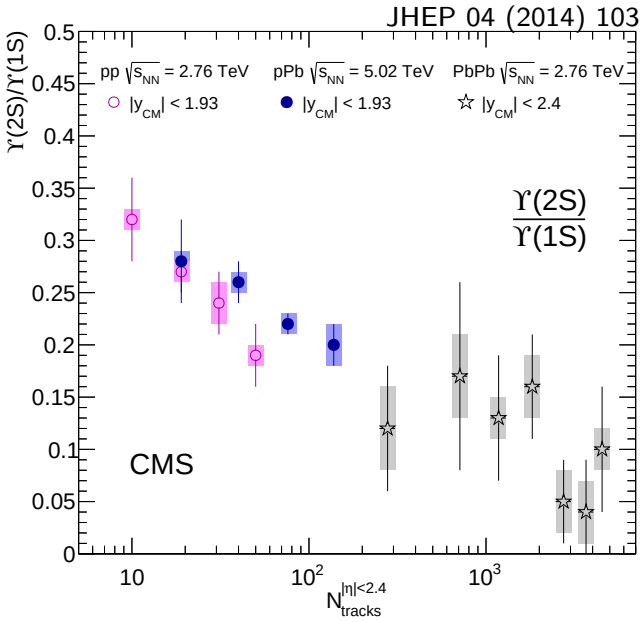

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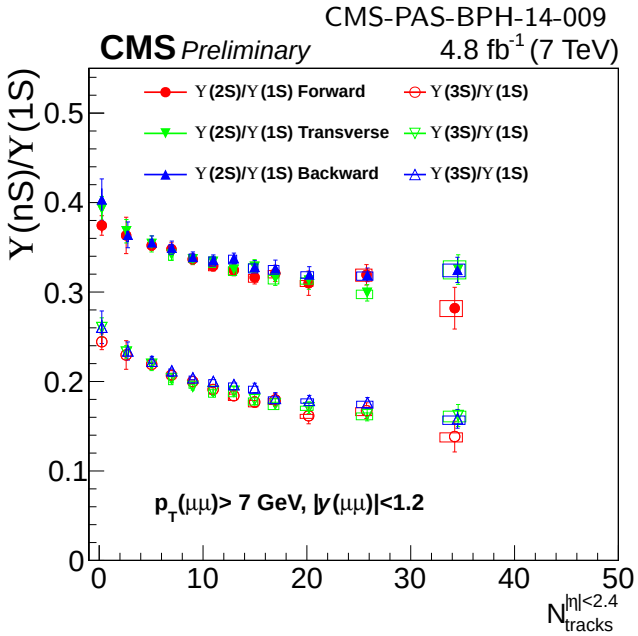

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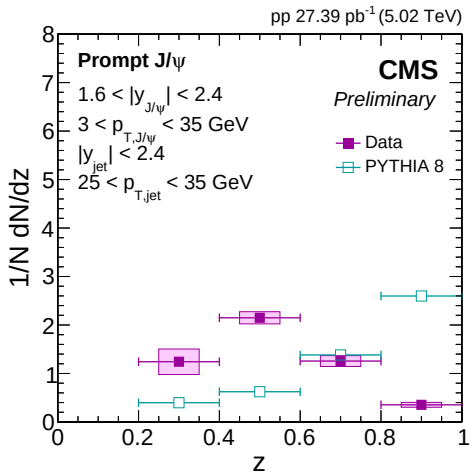
- Sensitivity to LDMEs
- Υ(nS) vs multiplicity: several studies
  - Similar trend in pp, pPb, PbPb
  - Not related to local track multiplicity
  - No dependence of polarisation

CMS-PAS-HIN-18-012



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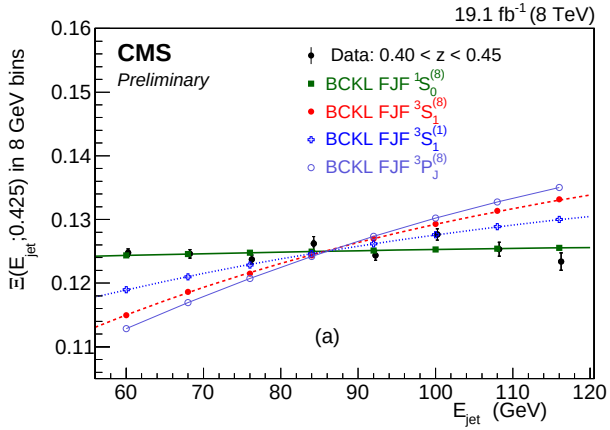

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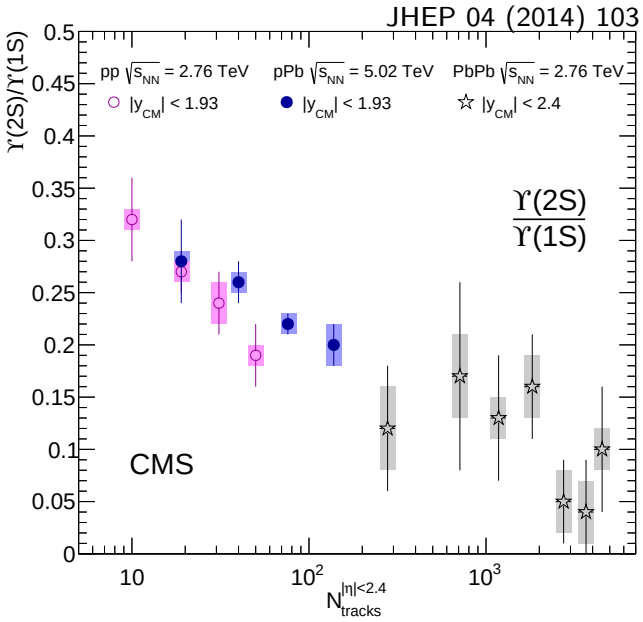

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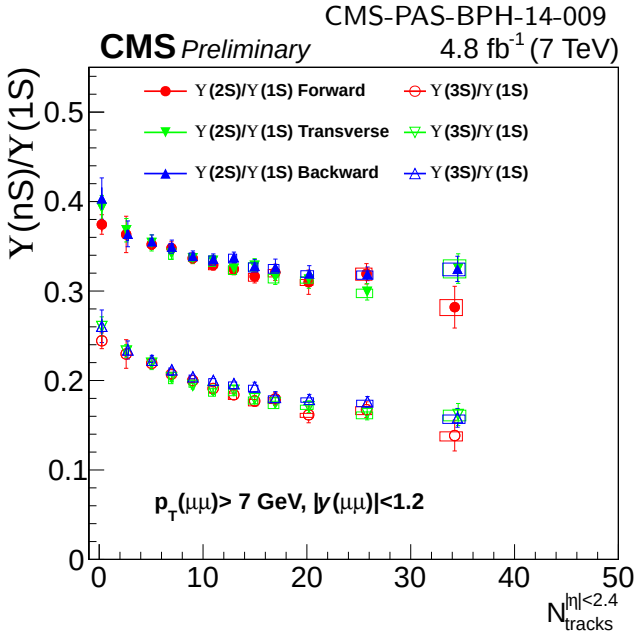

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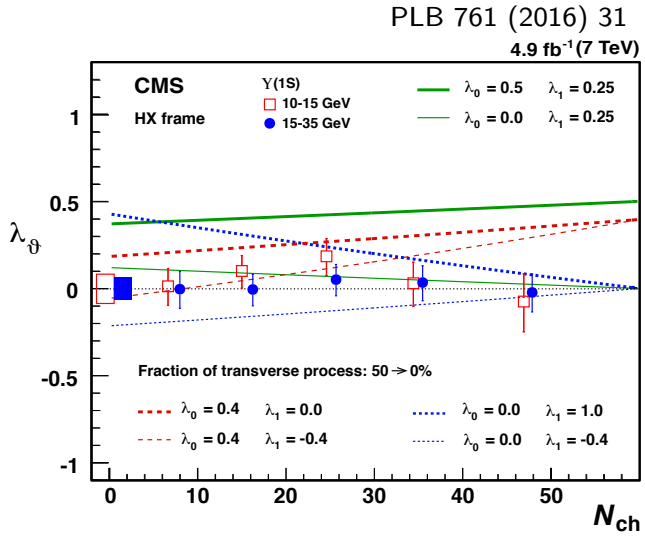
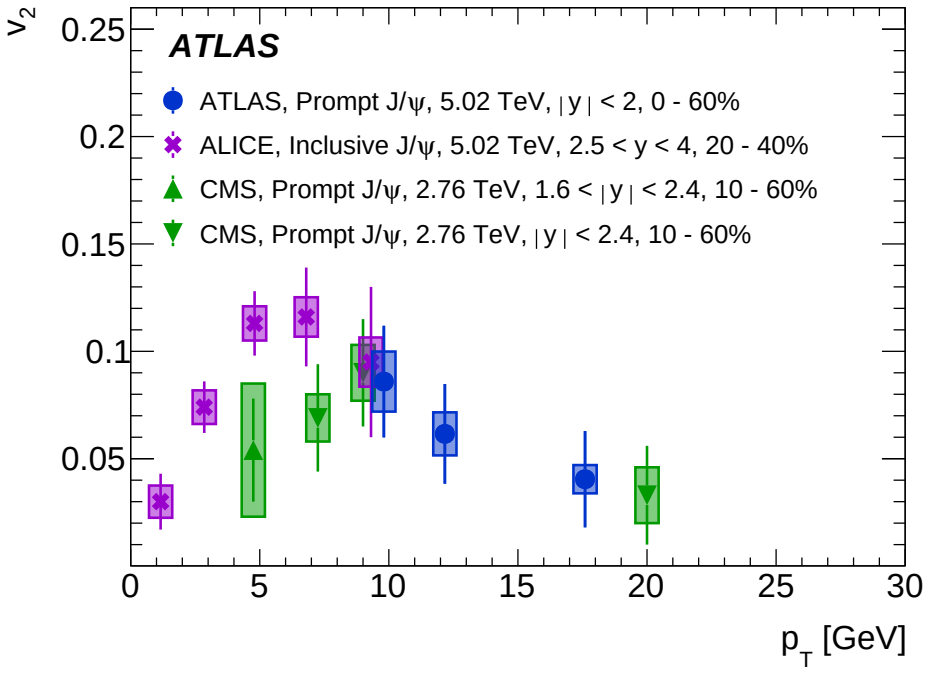


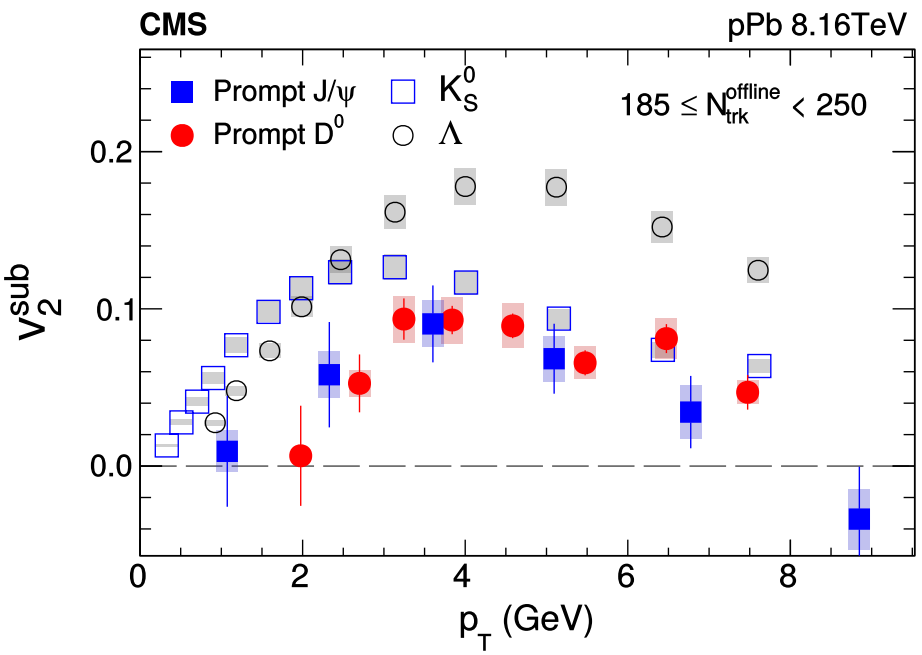
Quarkonia flow in pPb and PbPb

Non-zero v_2 in PbPb... but also in pPb!

EPJC 78 (2018) 784

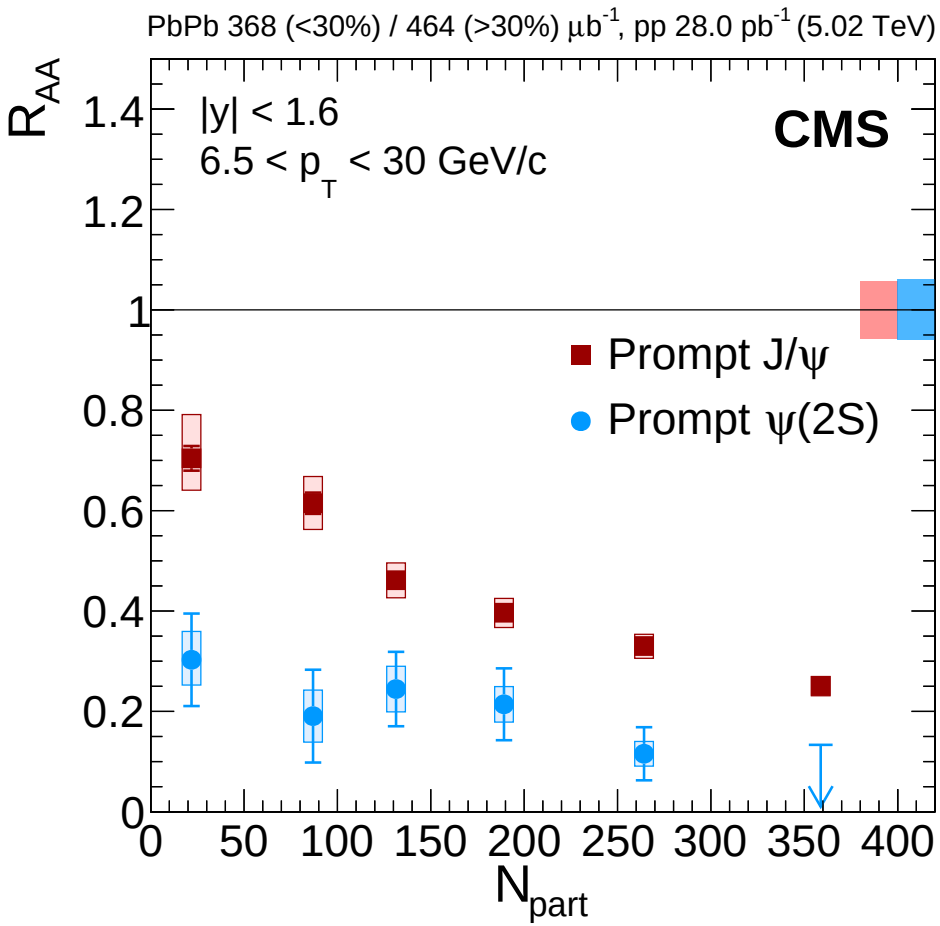


PLB 791 (2019) 172

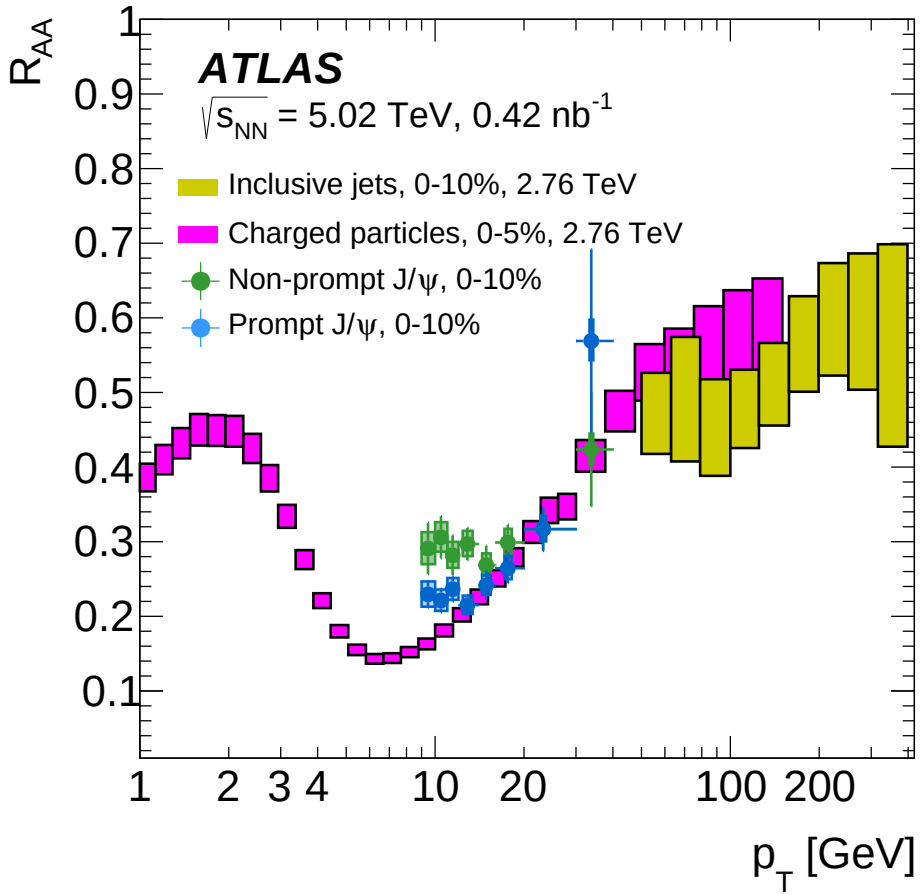


PbPb: sequential melting (color screening) in the QGP, regeneration at low p_T, jet quenching at high p_T?

EPJC 78 (2018) 509

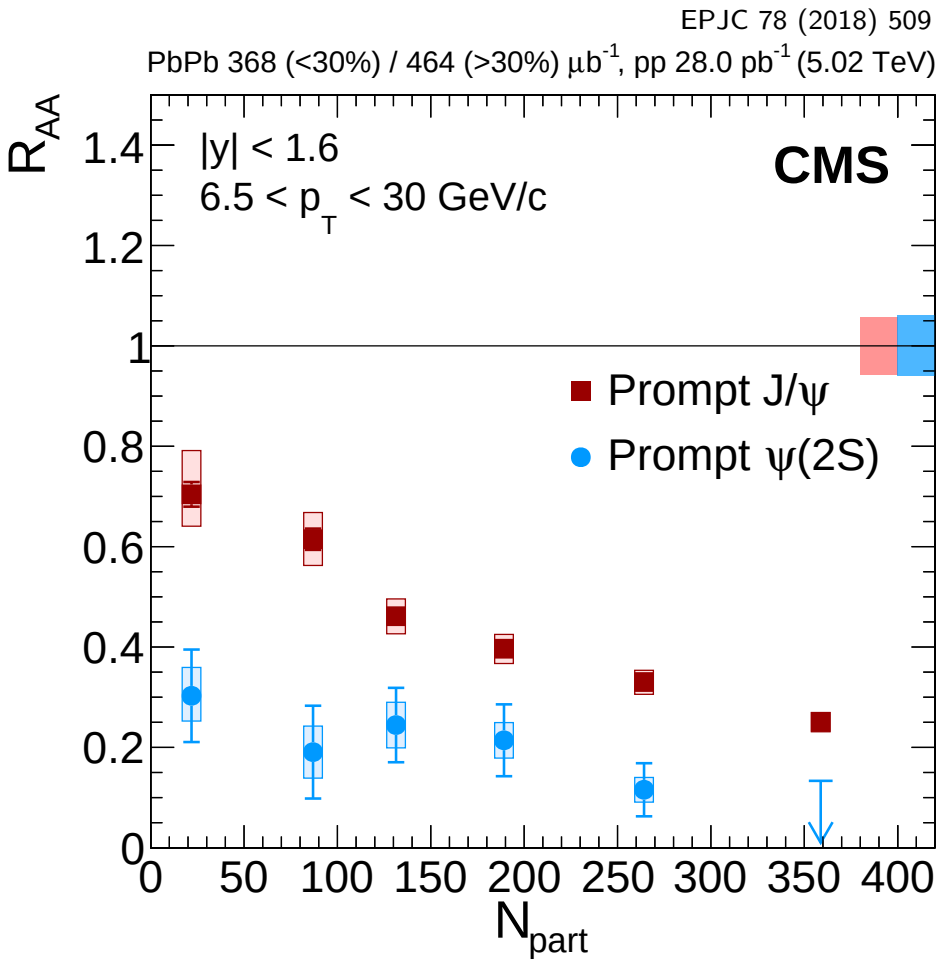


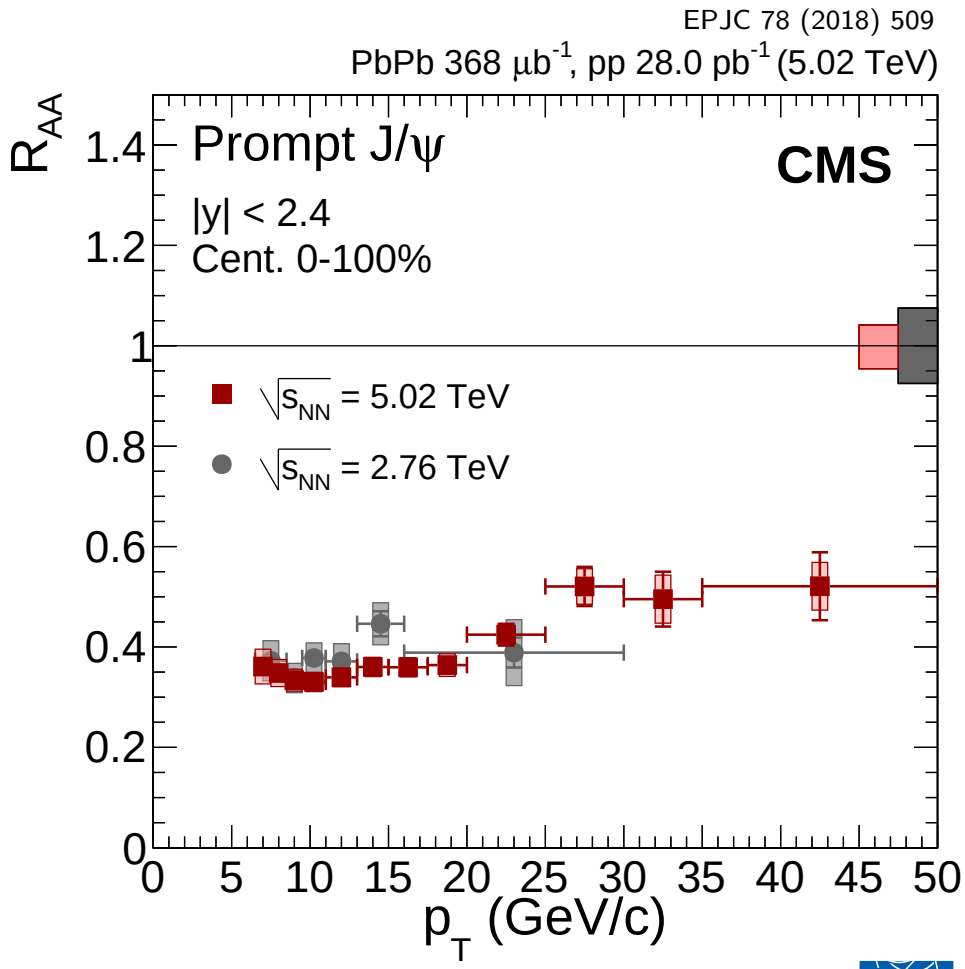
EPJC 78 (2018) 762



Charmonia in PbPb

PbPb: sequential melting (color screening) in the QGP, regeneration at low p_T, jet quenching at high p_T?

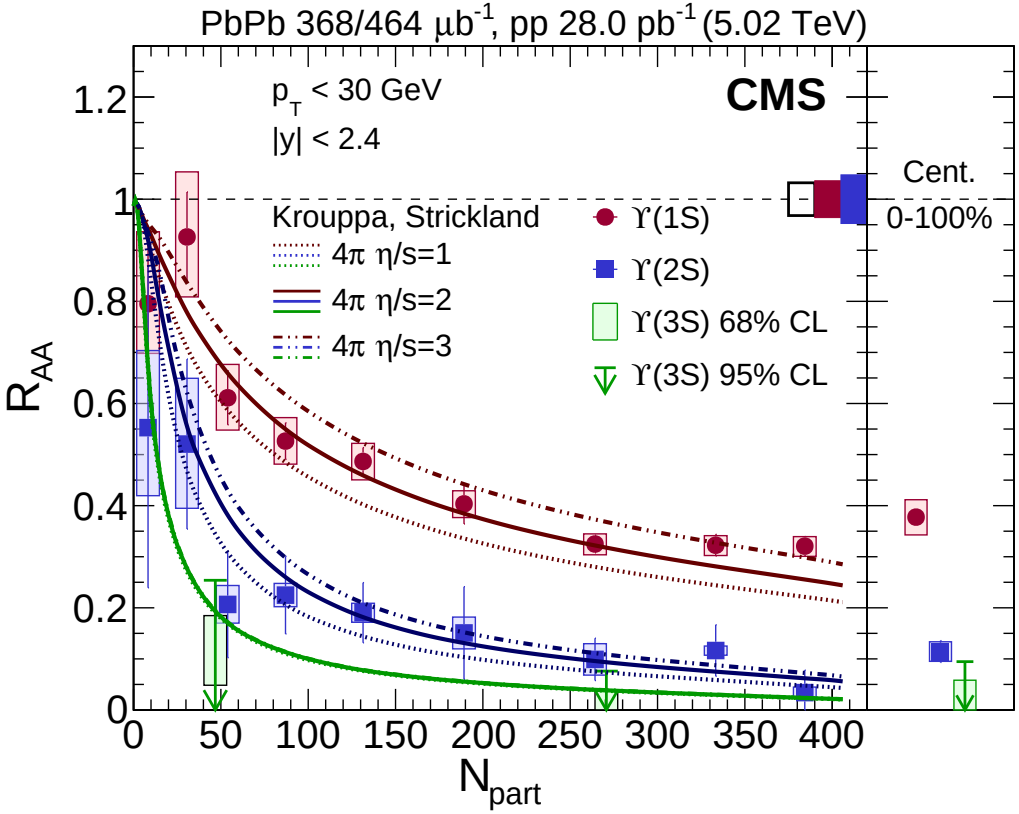


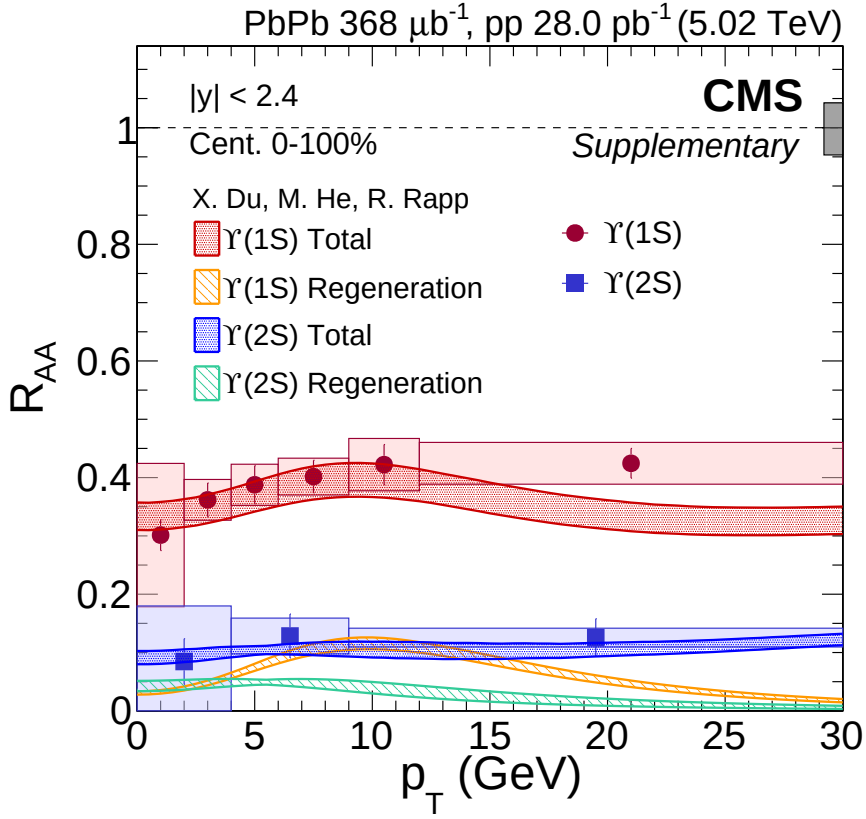


Bottomonia in PbPb

PLB 790 (2019) 270

- No sign of $\Upsilon(3S)$ in PbPb data (2015)
- Agree with models with melting + with or without Υ regenerations
- No rise at high p_T

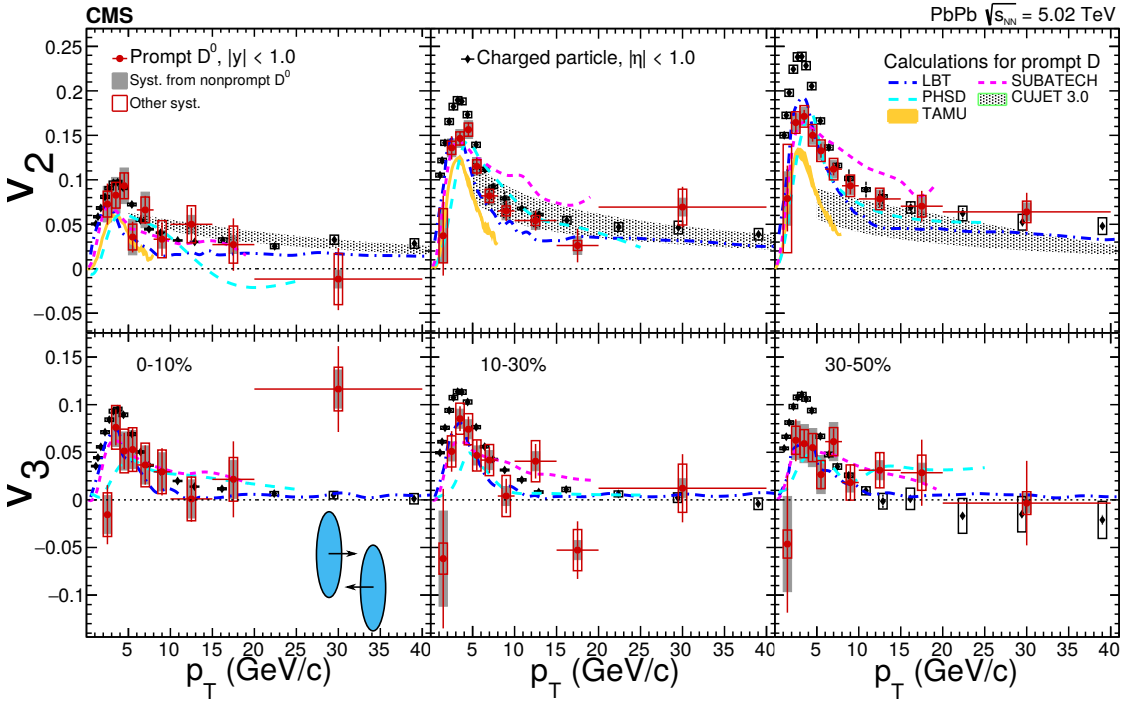




Open heavy flavour in pPb

- Charm (D^0, D^*)
- **PbPb**: flavour independence of energy loss at high p_T?
- **PbPb**: charm flows!
- **pPb**: no large D^0 or D^* forward/backward asymmetry

PRL 120 (2018) 202301



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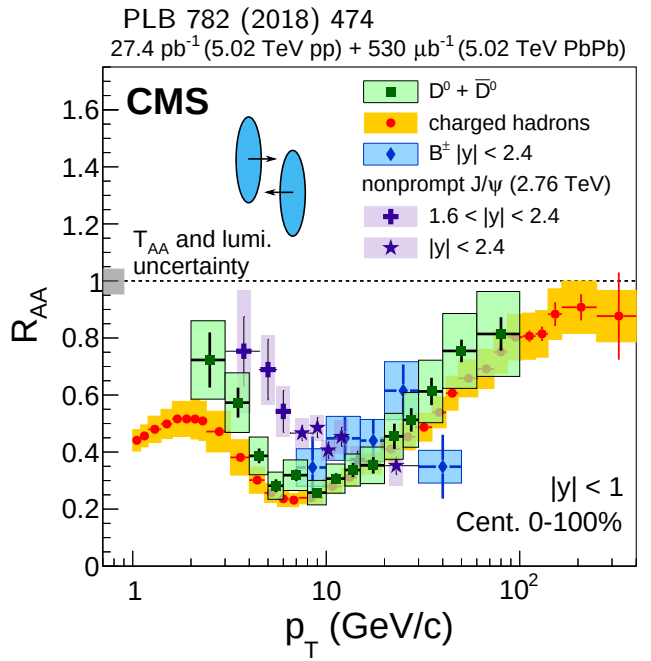

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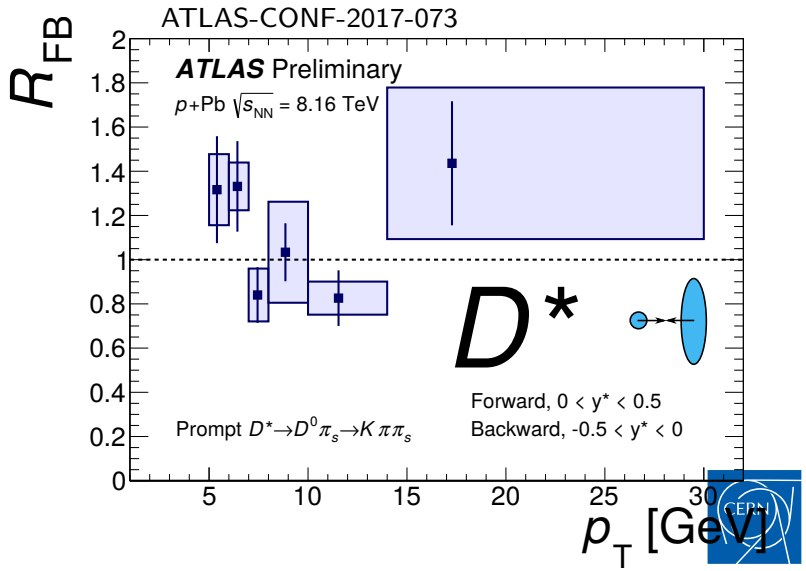
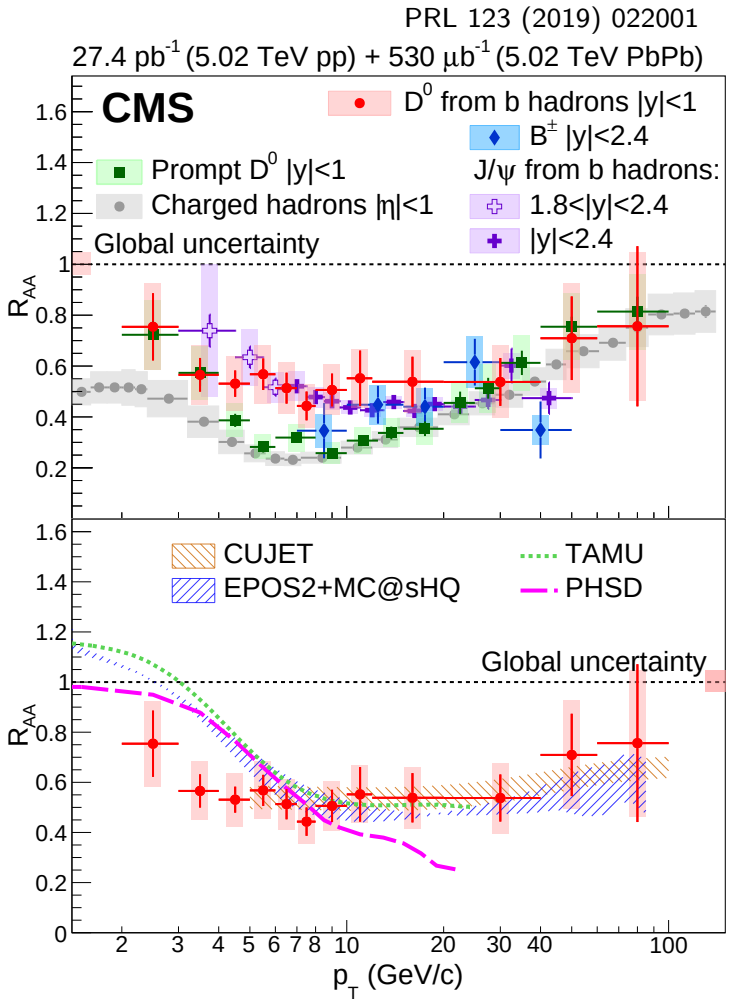


Open beauty in PbPb

- High p_T: similar suppression for beauty as charm and light
- Medium p_T: smaller suppression



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- High p_T: similar suppression for beauty as charm and light
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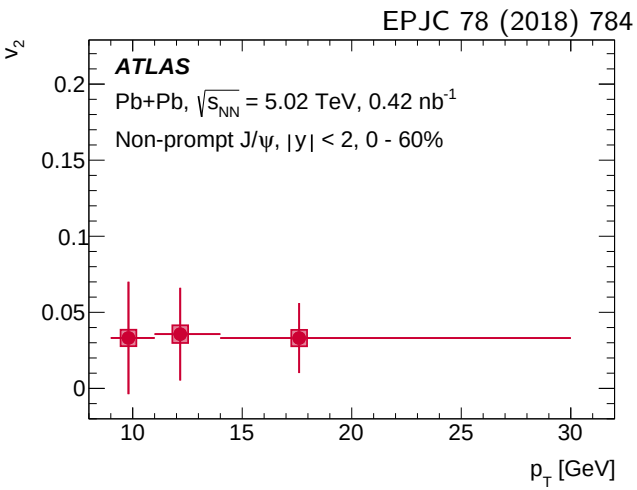
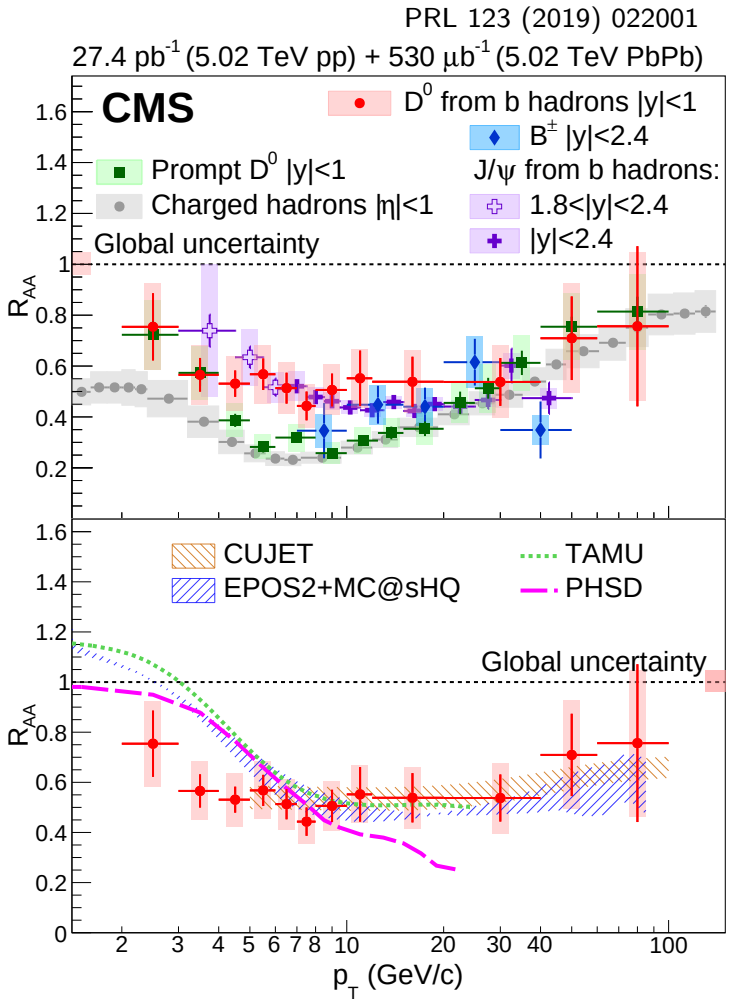
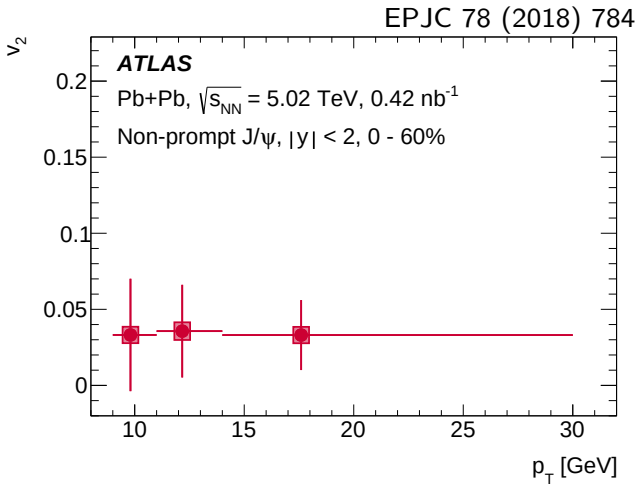
- Hint for nonzero v_2 for nonprompt J/ψ

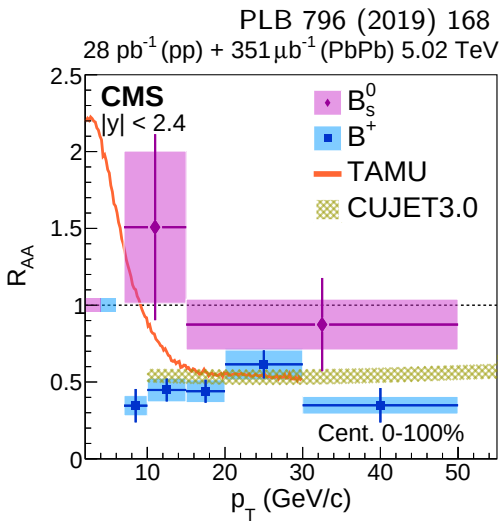


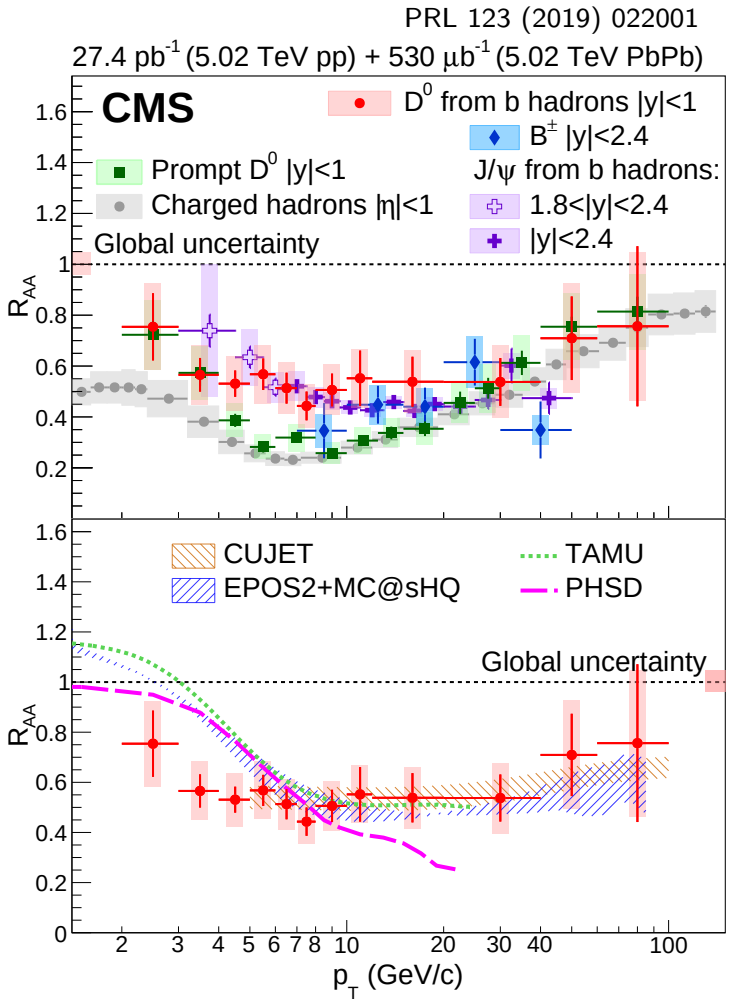


Open beauty in PbPb

- High p_T: similar suppression for beauty as charm and light
- Medium p_T: smaller suppression
- Hint for nonzero v_2 for nonprompt J/ψ
- B_s vs B^+: hint for strangeness enhancement?





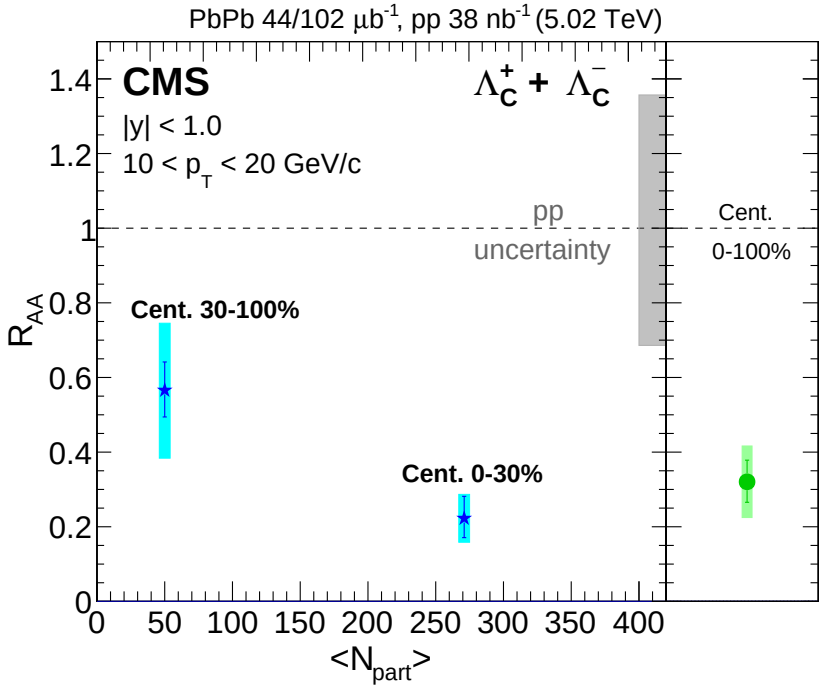


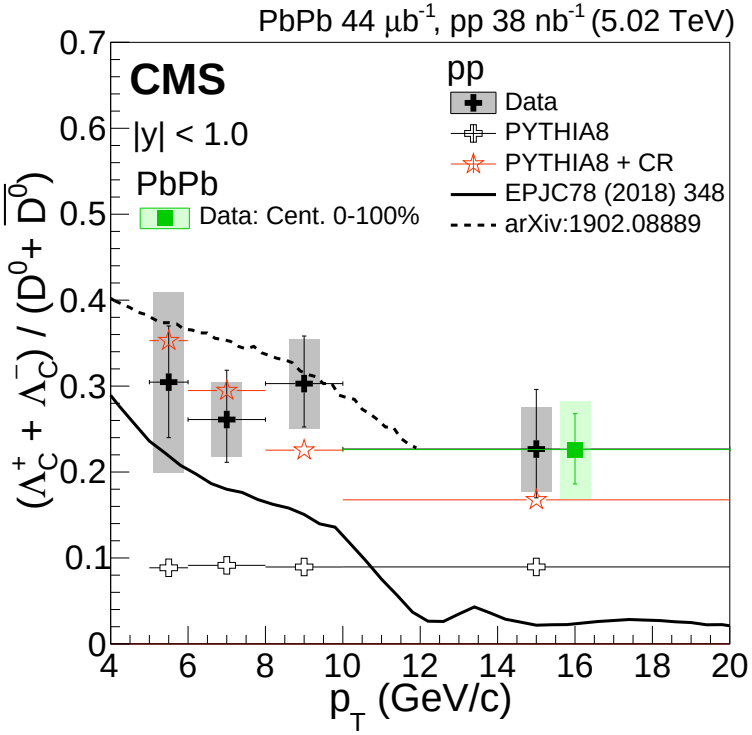
Λ_c in PbPb

arXiv:1906.03322

Charm quark hadronisation in the QGP

- indication of suppression in PbPb for $p_T > 10$GeV
- Higher suppression in central events
- Similar Λ_c/D^0 ratio in pp and PbPb: no significant contribution from coalescence for $p_T > 10$GeV

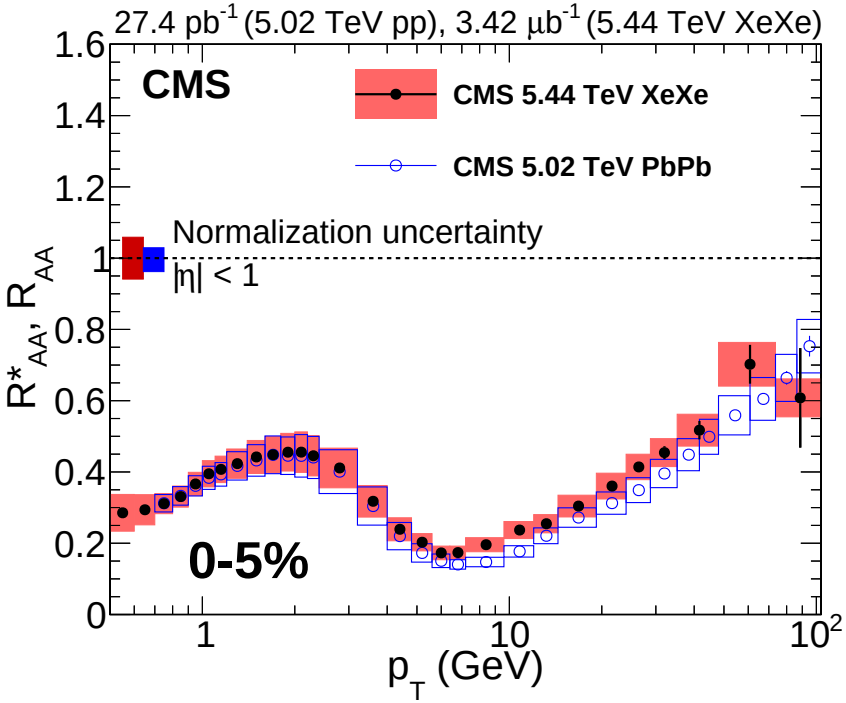




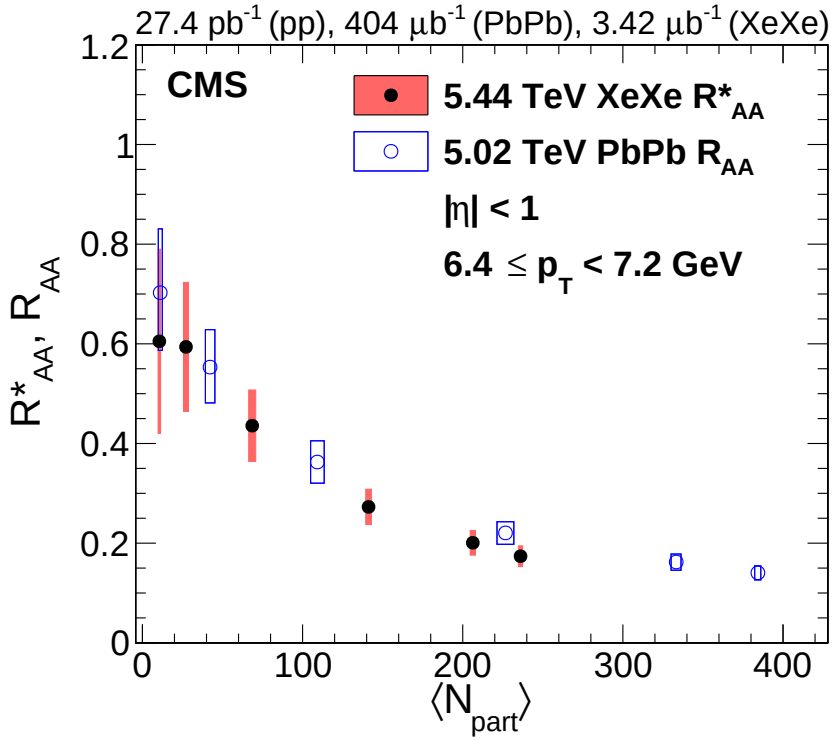
Smaller ions: suppression and energy loss

JHEP 10 (2018) 138

Suppression of charged particles in ^{129}Xe data at 5.44 TeV (2017): R_{AA}



XeXe: smaller suppression than PbPb at the same centrality

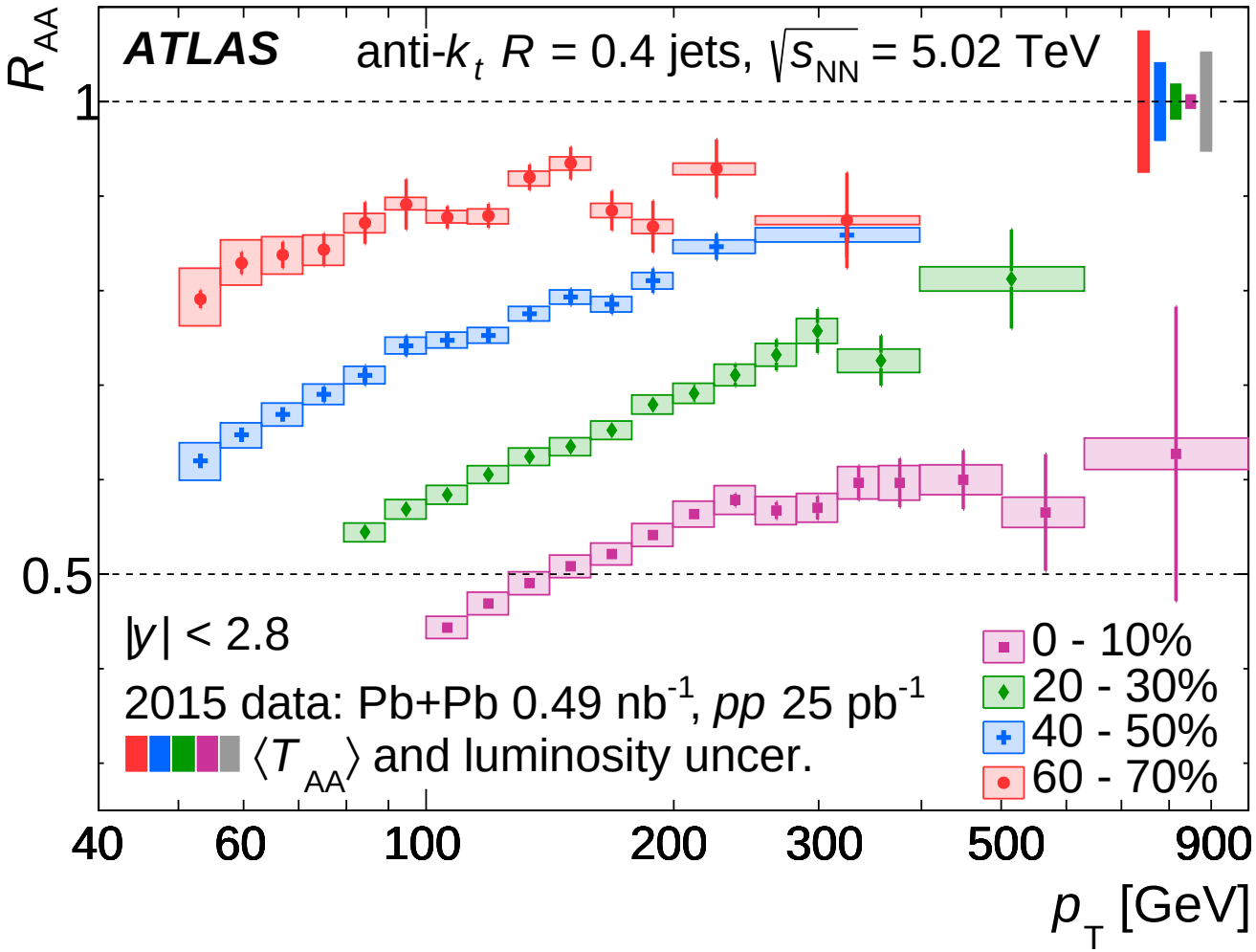


Slightly greater suppression in XeXe at the same N_{part}

Suppression of jets in PbPb collisions

PLB 790 (2019) 108

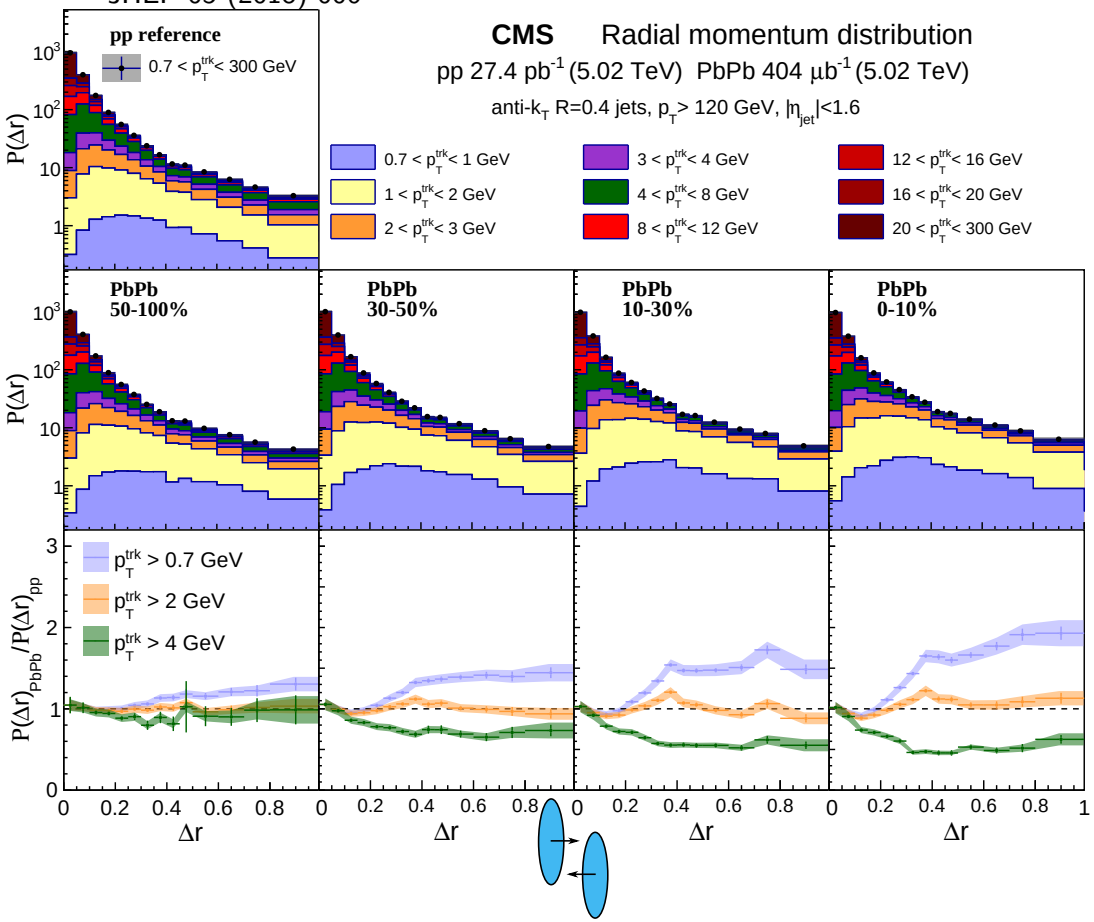
Nuclear modification factor: increases to high p_T and from central to peripheral



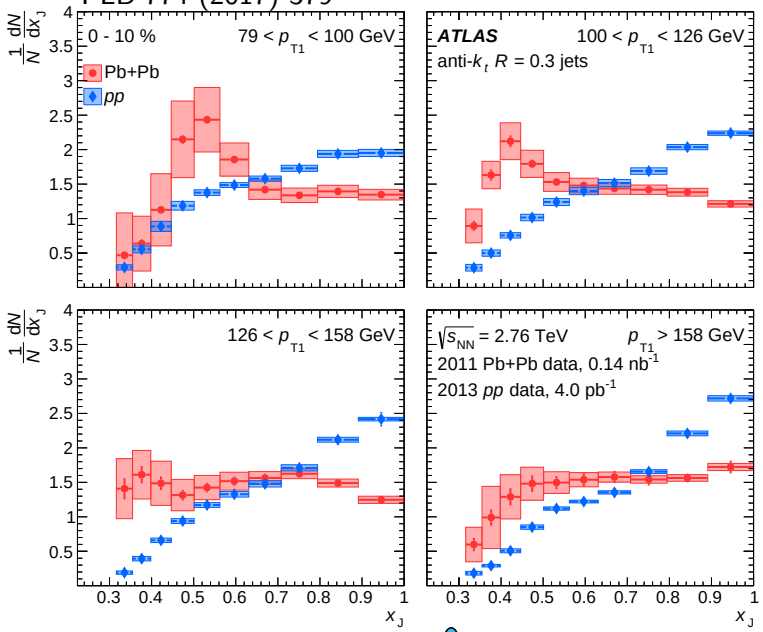
Further understanding of jet quenching

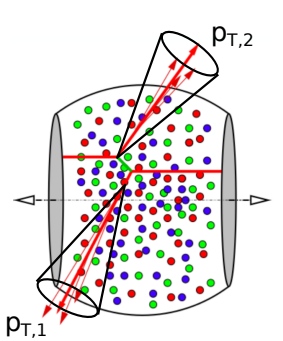
- Jet-hadron correlations in PbPb: fewer high p_T and more low p_T hadrons at large angles
- Enhanced dijet asymmetry in PbPb compared to pp

JHEP 05 (2018) 006



PLB 774 (2017) 379



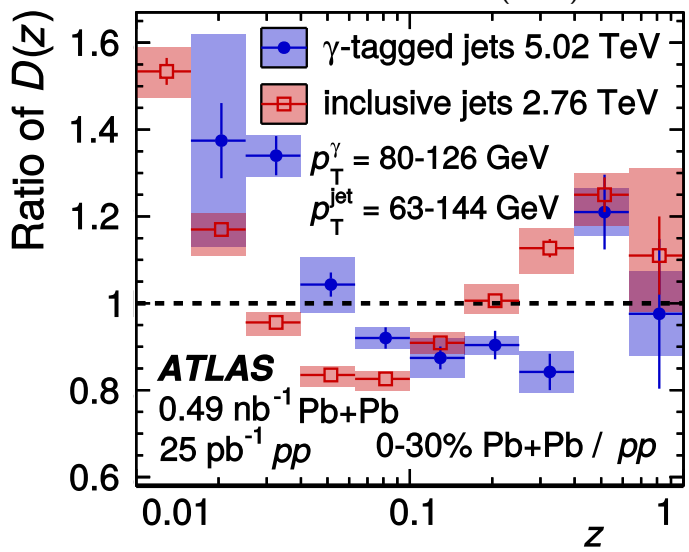


$$x_J = \frac{p_{T,2}}{p_{T,1}}$$

Flavour dependence of jet modification in PbPb

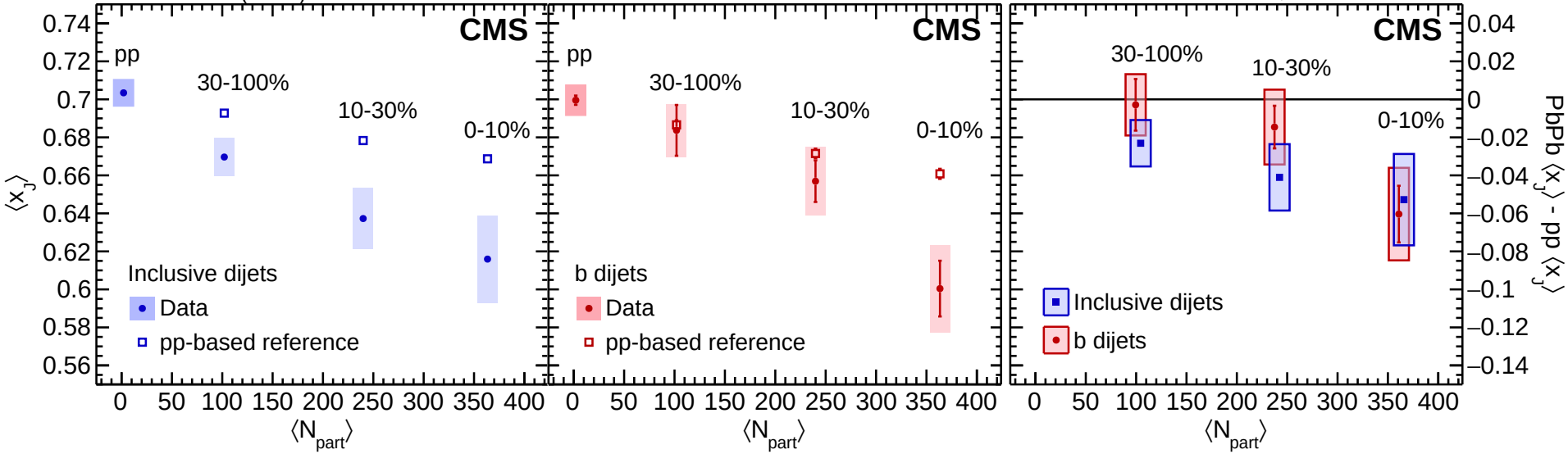
- Photon-tagged jets:
  - different modification in central events (enhanced quark jet fraction)
  - impact of the different p_T spectrum?
- b-jet pairs:
  - enhanced contribution of primary b quarks
  - compatible behaviour of light and b jets

PRL 123 (2019) 042001



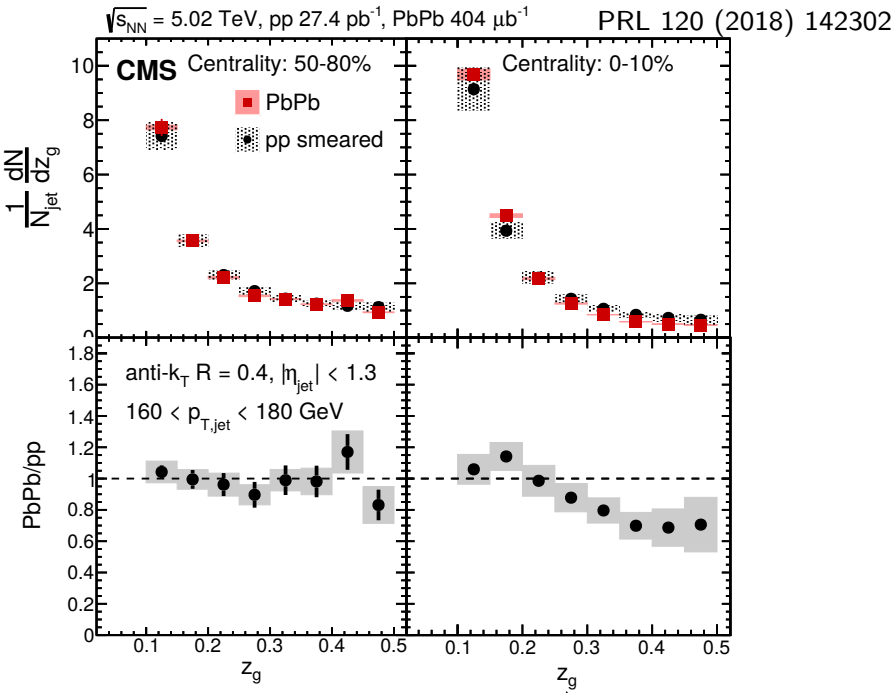
JHEP 03 (2018) 181

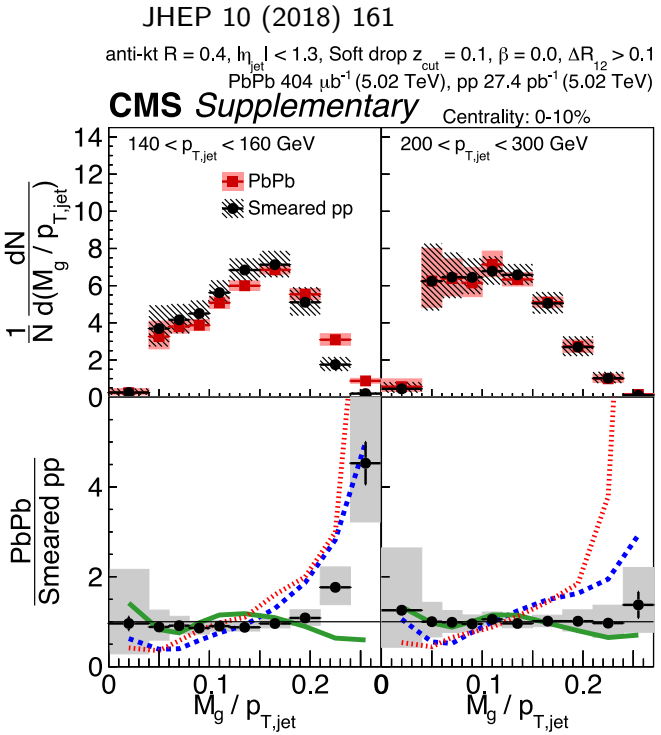
25.8 pb^{-1} (5.02 TeV pp) + 404 μb^{-1} (5.02 TeV PbPb)

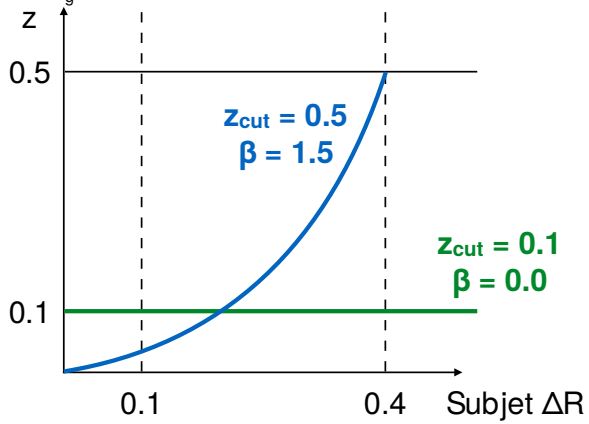


Jet substructure

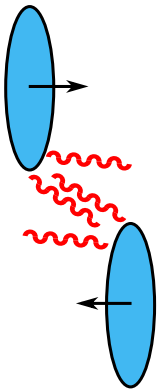
- Probing the jet substructure and the medium modification of the parton shower evolution: splitting functions, groomed jet mass







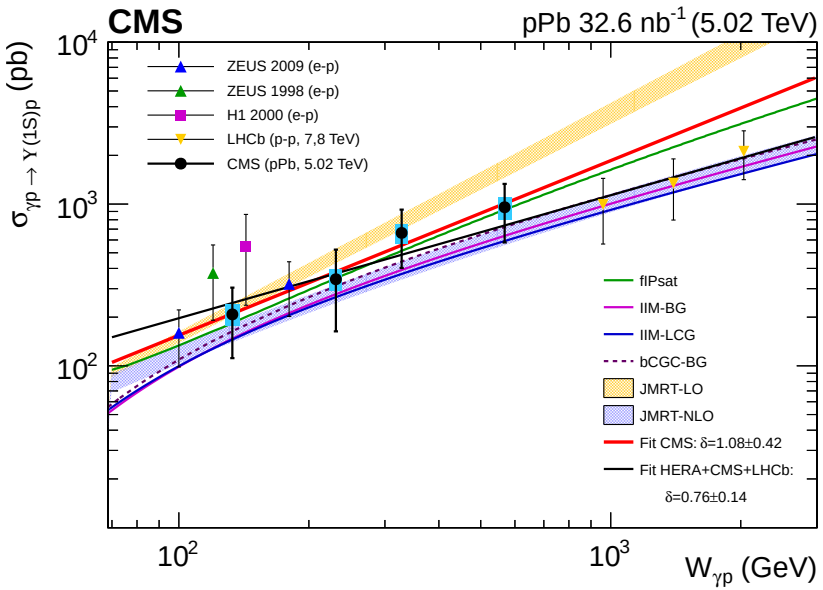
Ultra-peripheral collisions



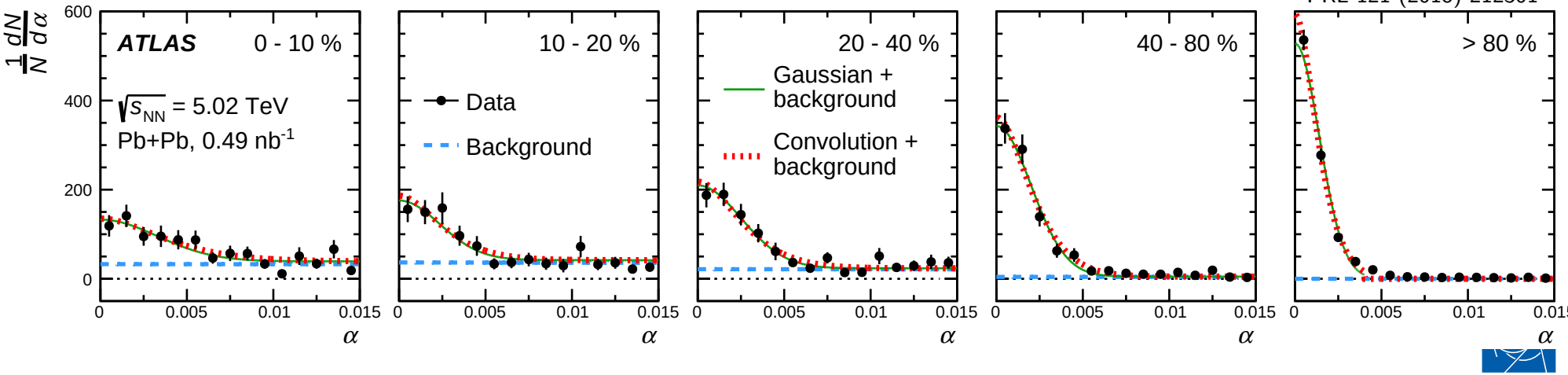
Very strong EM fields in PbPb collisions: $\gamma\gamma$ collider!

- $\Upsilon(1S)$ photoproduction in pPb collisions: bridging the gap in $W_{\gamma p}$ between HERA and LHCb
- Photon-induced processes also in non-UPC events

EPJC 79 (2019) 277

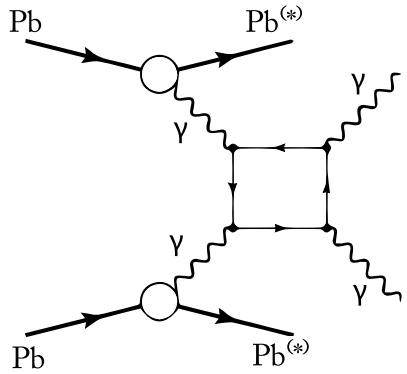


PRL 121 (2018) 212301

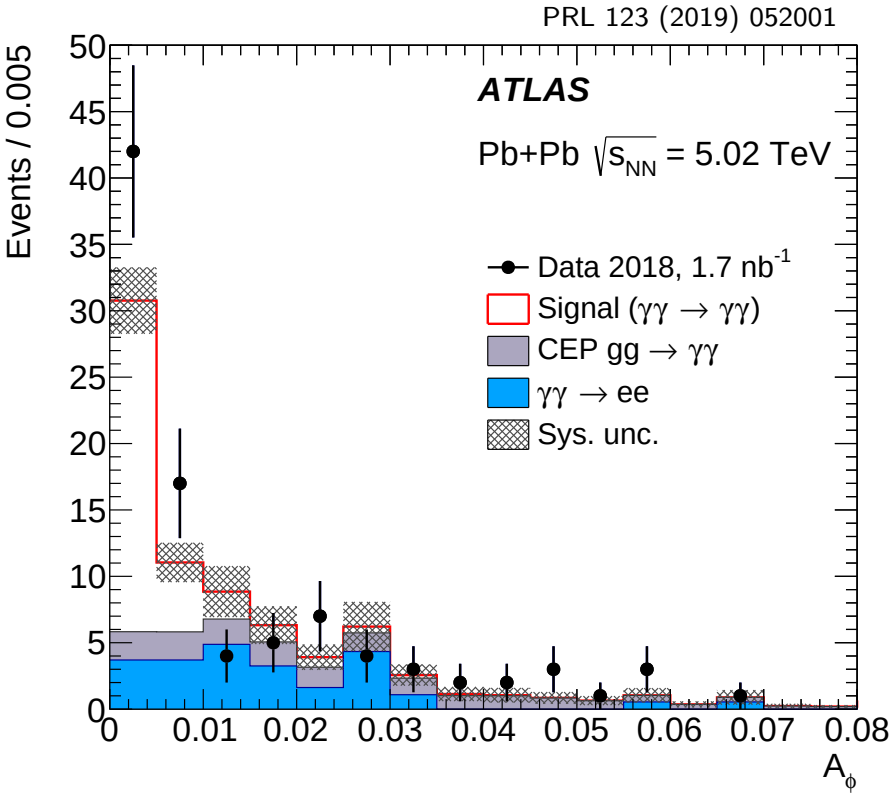


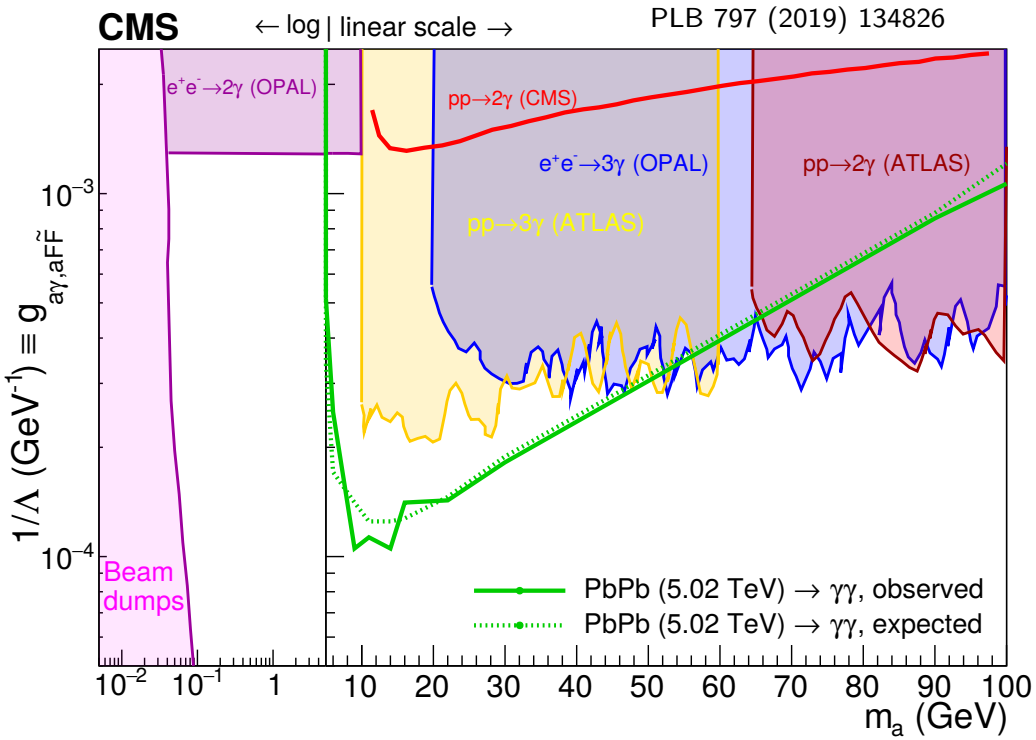
Light-by-light scattering

- Precise measurement with 2018 PbPb data
- Interpretation in terms of limits on axion-like particle models

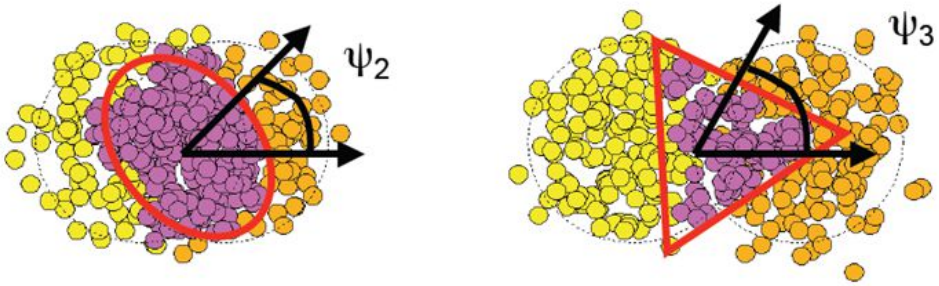


PRL 123 (2019) 052001

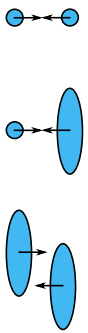


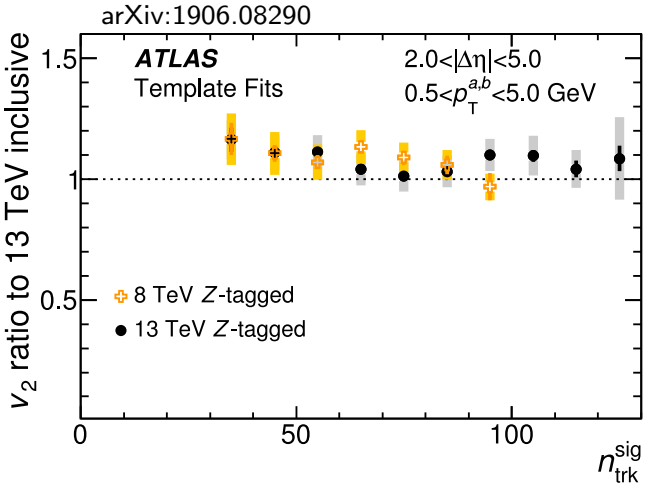


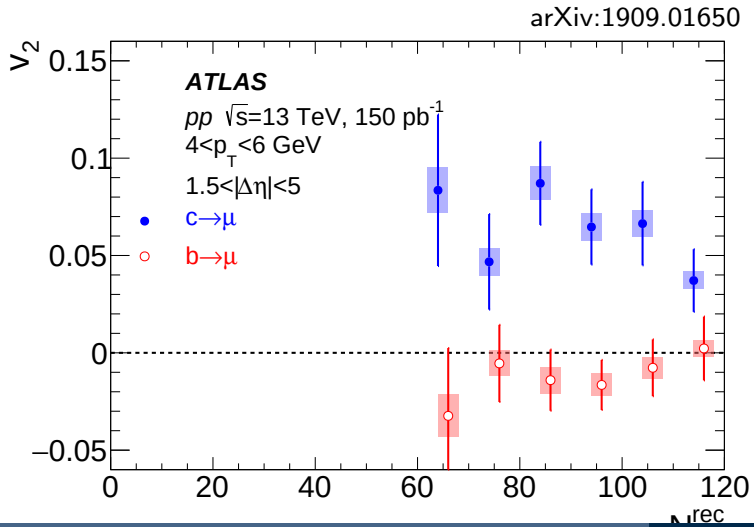
Collectivity

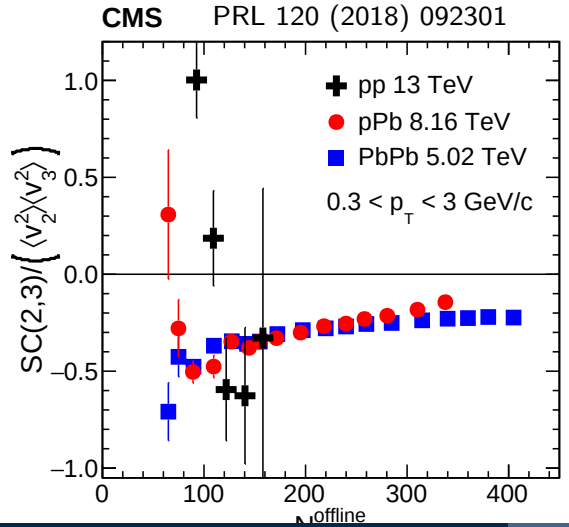


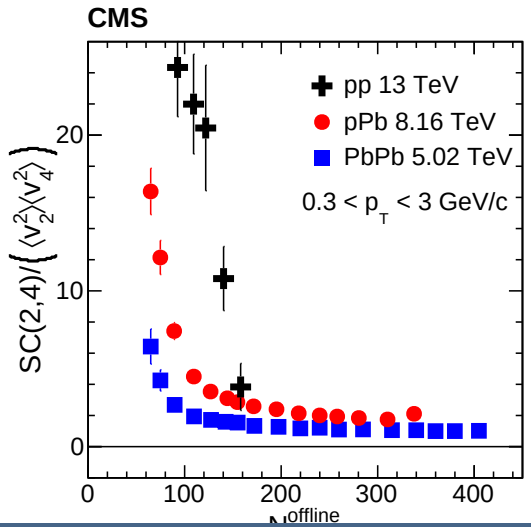
- Higher flow in Z-tagged events?
- Flow in small systems:
  - how to subtract non-flow?
  - HF μ v_2 in pp
  - event-by-event correlations in (v_n, v_m)











Summary

Completing the picture of QCD in a dense (and hot) medium

- Initial state, fluctuations, hydrodynamics, parton interactions, flavour dependence, time evolution...
- Access to new processes ($t\bar{t}$, $\gamma\gamma \to \gamma\gamma$, ...)
- Many results not shown
- Results starting to appear with the very large 2018 PbPb dataset ($1.7\,\mathrm{nb}^{-1}$)

More results

- ATLAS results
- CMS results: heavy ions (papers, preliminary), forward physics (papers, preliminary)