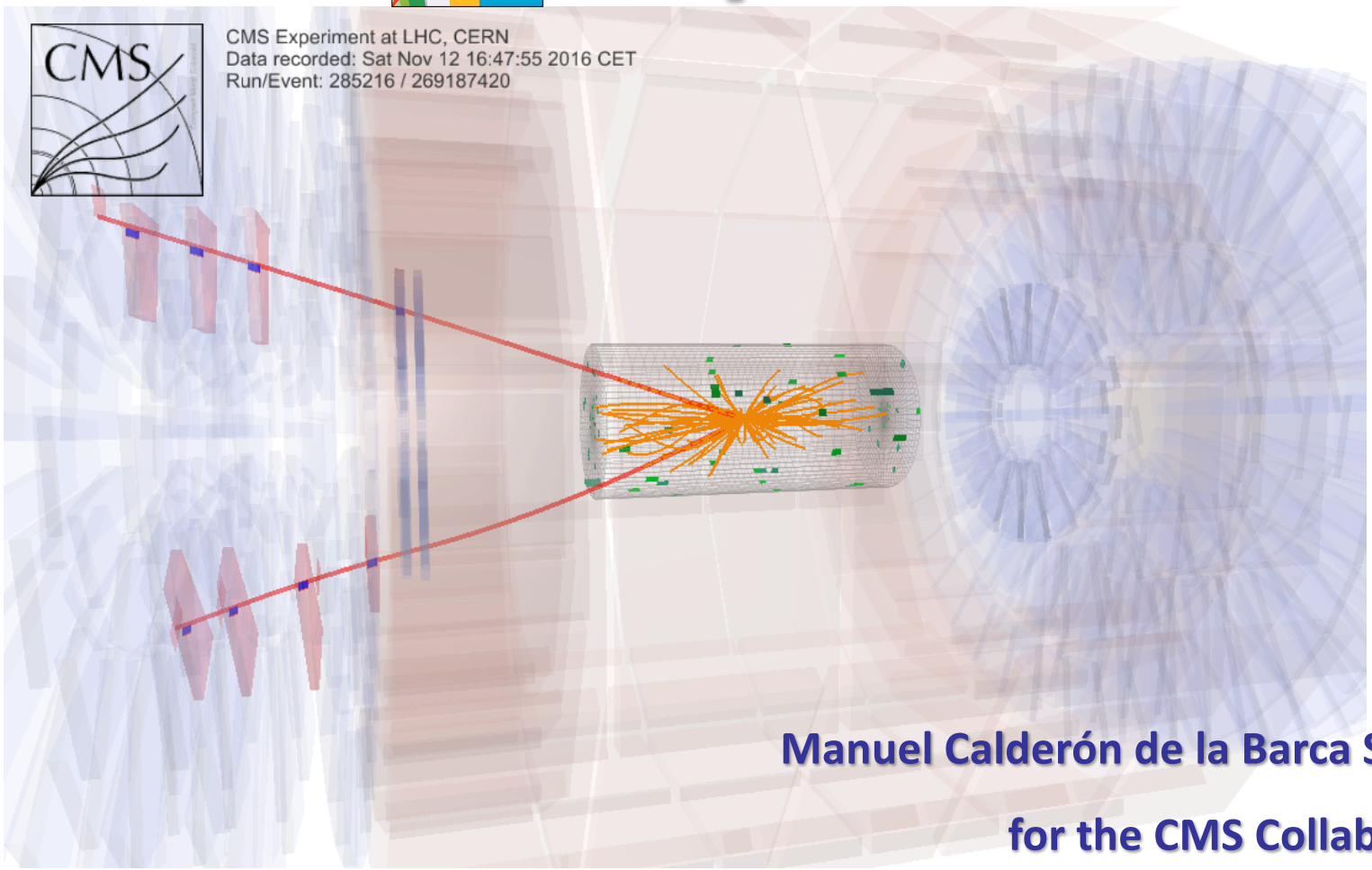
Heavy Ion Highlights from the CMS experiment



Manuel Calderón de la Barca Sánchez

for the CMS Collaboration

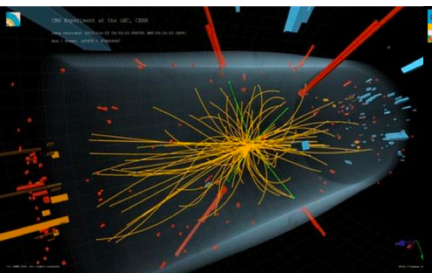
CIPANP
Palm Springs, May 2018

UC DAVIS

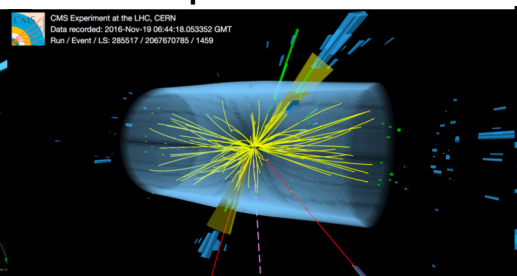
Physics Highlights from CMS Heavy Ions

- Onset of collective effects: from small systems to PbPb
  - Are QGP effects present even in pPb?
- System size dependence of QGP effects: XeXe vs. PbPb.
- Flavor dependence of parton shower modification: gluon vs quark vs Heavy Quark
- Quark distribution functions in Pb: W boson measurements
- Quarkonia in hot medium
- New physics observables:
  - Limits on chiral-magnetic effect
  - Observation of light-by-light scattering

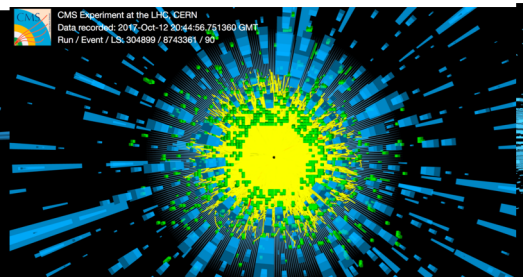
p+p



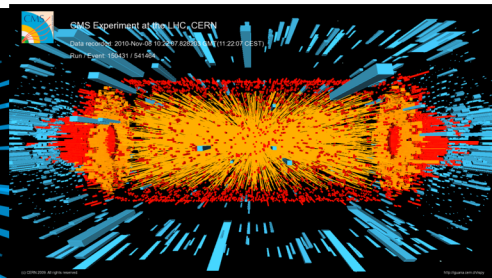
p+Pb



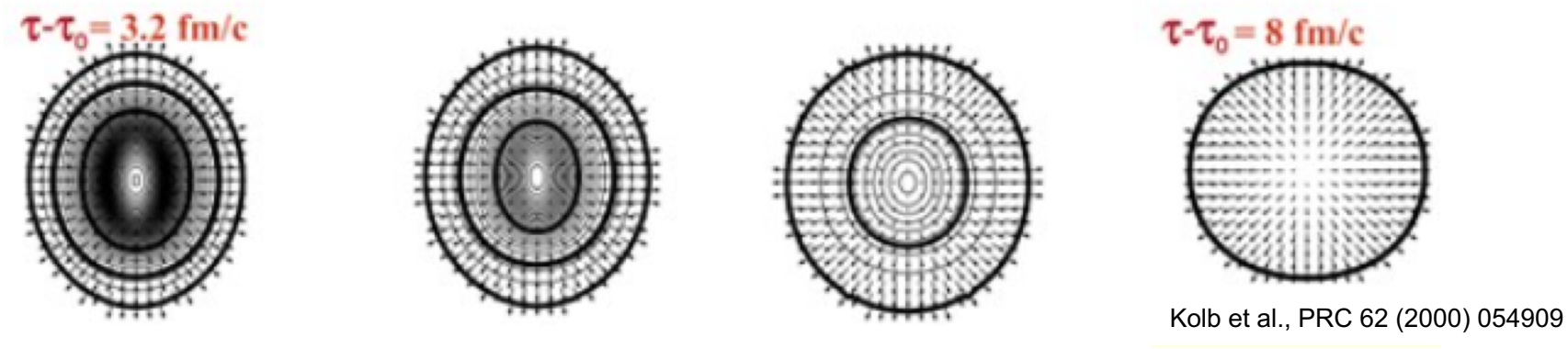
Xe+Xe



Pb+Pb



COLLECTIVE EFFECTS: AZIMUTHAL CORRELATIONS

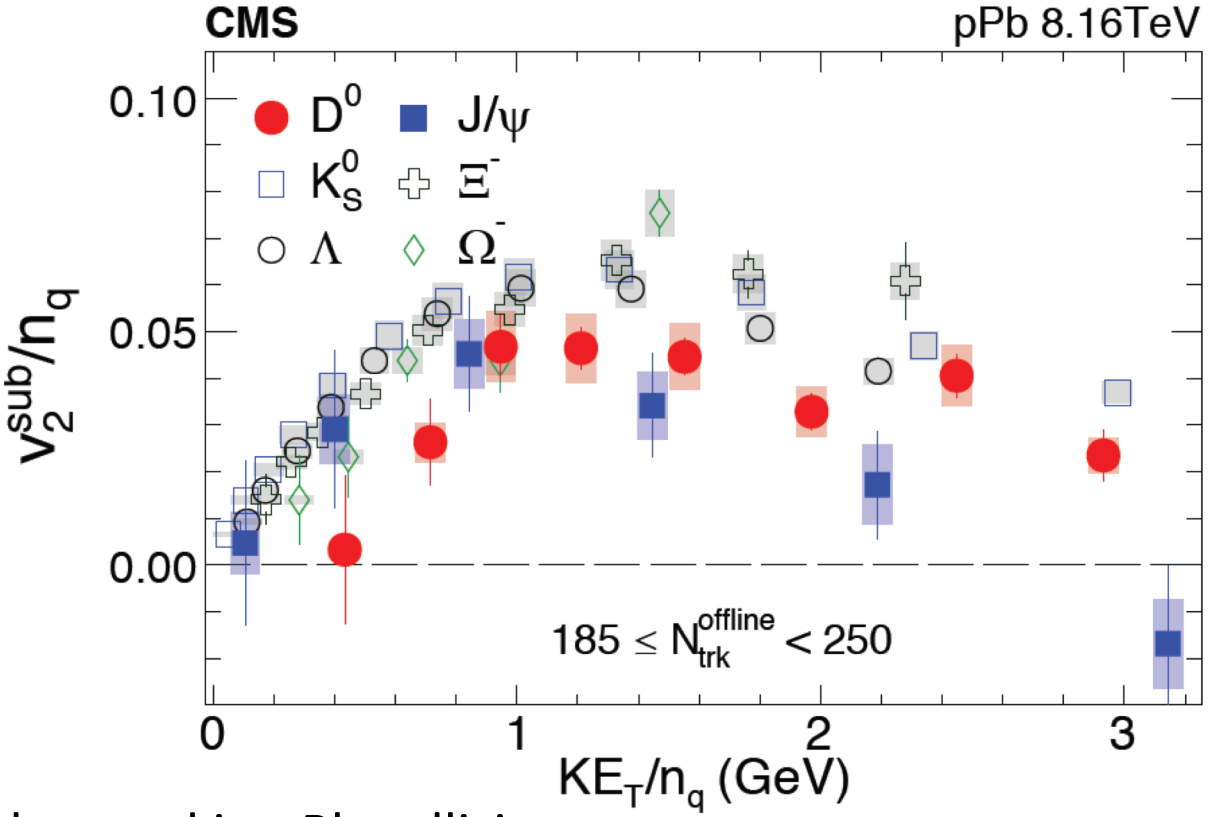


Kolb et al., PRC 62 (2000) 054909

Strange and charm v_2 in pPb

arXiv:1804.09767, CMS PAS HIN-18-010

- Charm (D^0, J/ψ) and strange quark flow in pPb



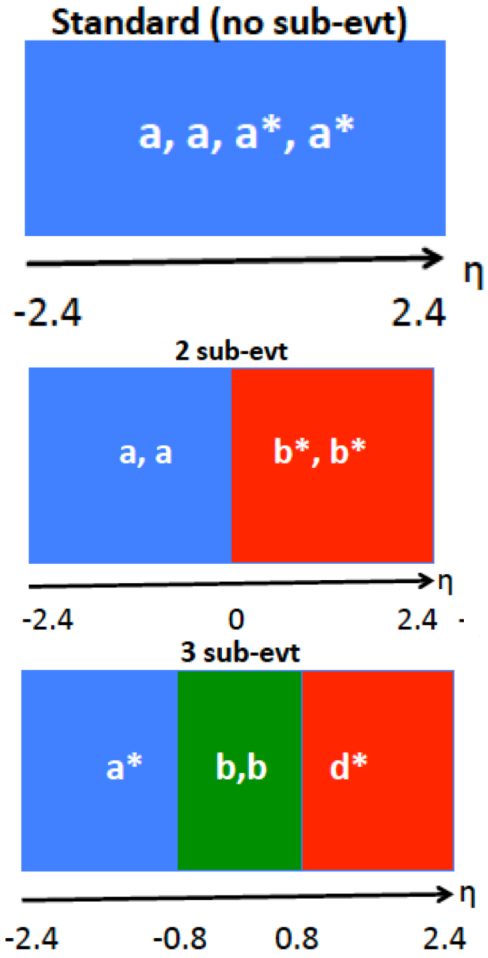
Z. Chen, Parallel Talk

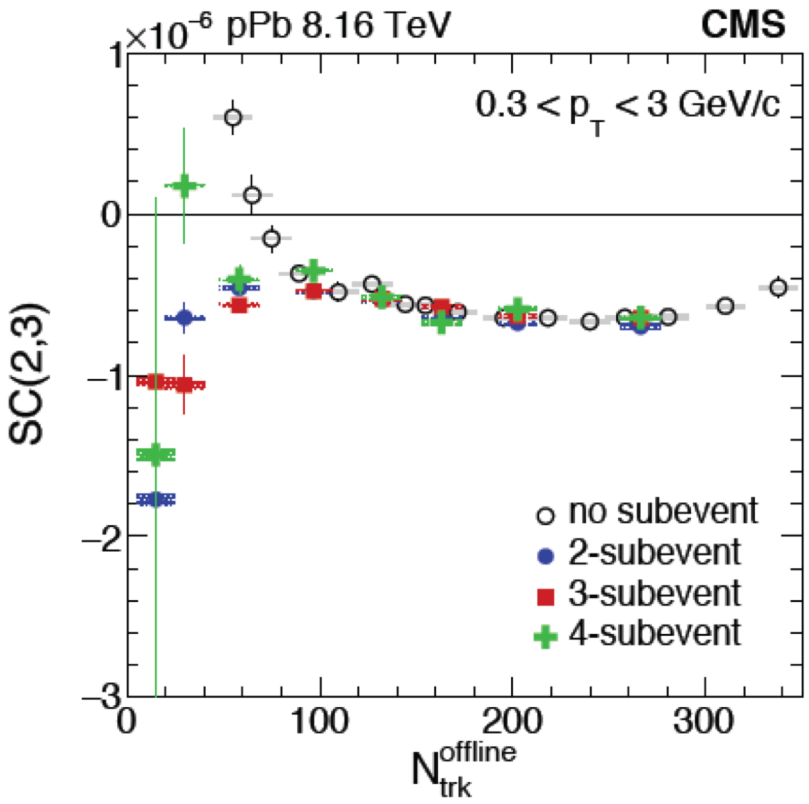
- Charm v_2 observed in pPb collisions.
  - Weaker than flow for light quarks for $KE_T/n_q > 1$ GeV.
  - Less collectivity for charm quarks in pPb?

Collectivity in small systems

- Suppressing contamination (jets, resonances) in low multiplicity events using η subevents
- Goal: understand onset of collective behavior

CMS PAS HIN-18-015





N_{trk} > 80: All methods consistent.
⇒ negligible contamination

N_{trk} < 80: Contamination suppressed via subevents.

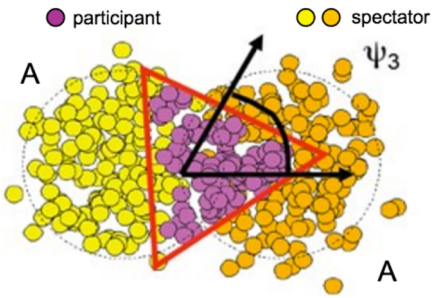
⇒ Observe v_2,v_3 anti-correlation in pPb collisions for N_{trk} ~ 50.

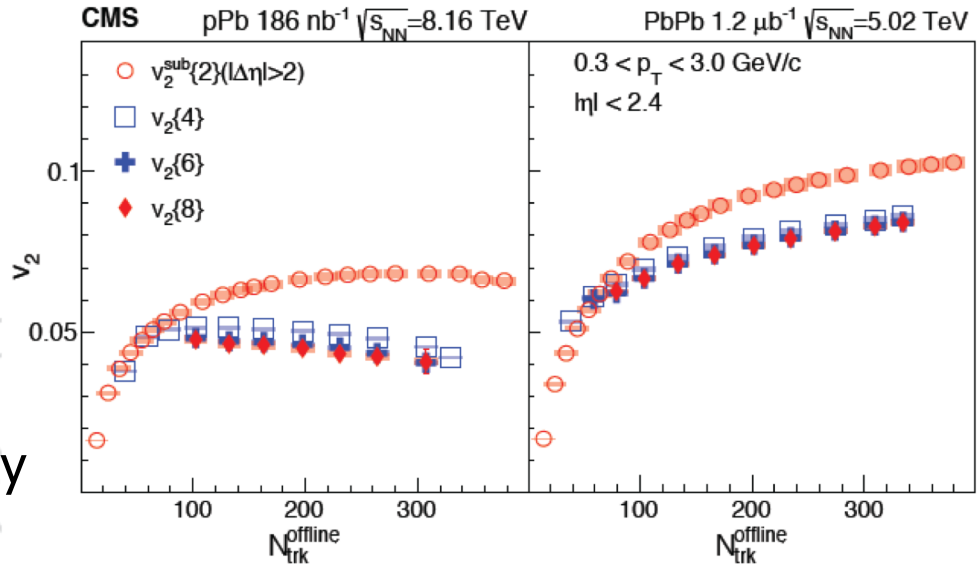
⇒ Similar to PbPb: attributed to hydrodynamic flow.

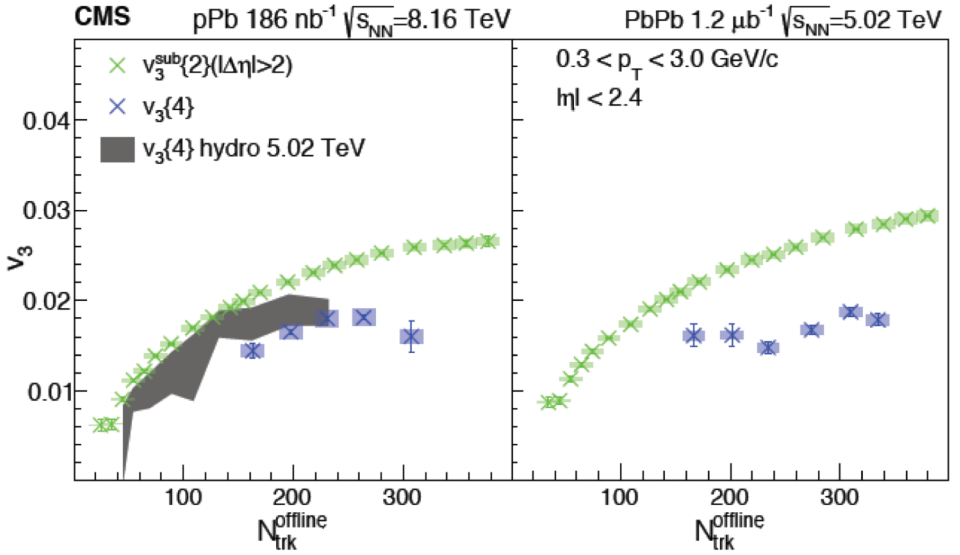
Higher harmonics: PbPb and pPb

CMS PAS HIN-17-004

- v_2, pPb vs PbPb:
  - Multiparticle $v_2 > 0$ in both pPb and PbPb:
    - Collective behavior.
  - Different trend with multiplicity
    - Fluctuation-driven eccentricity decreases in pPb?
- v_3, pPb vs PbPb
  - Comparable
    - Dominated by initial state geometry fluctuation
    - pPb: consistent with magnitude from hydro

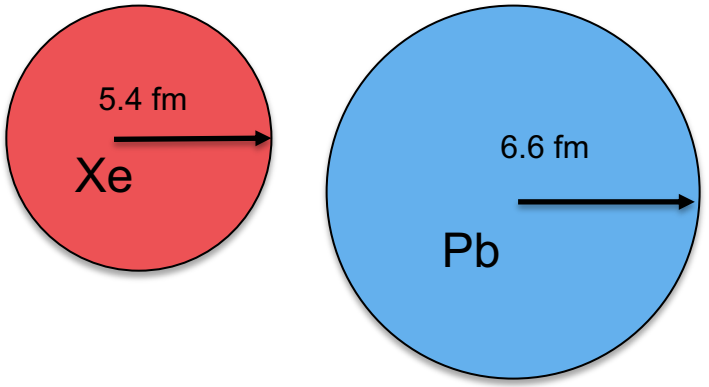


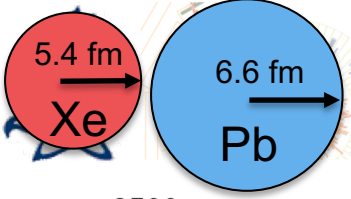




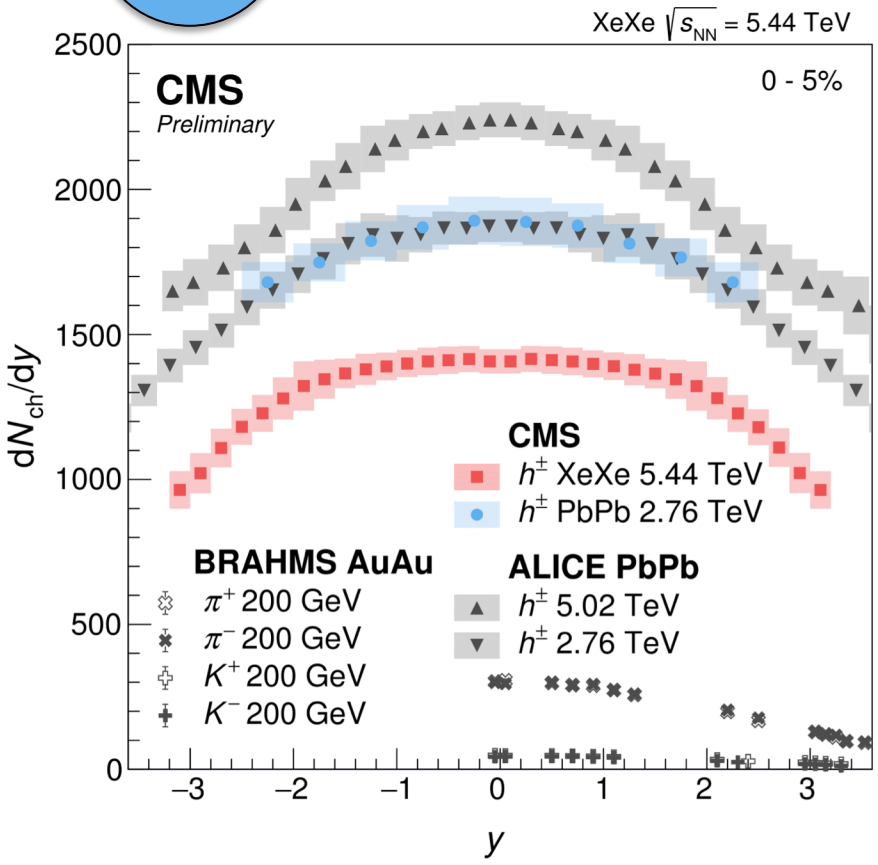
SYSTEM SIZE DEPENDENCE

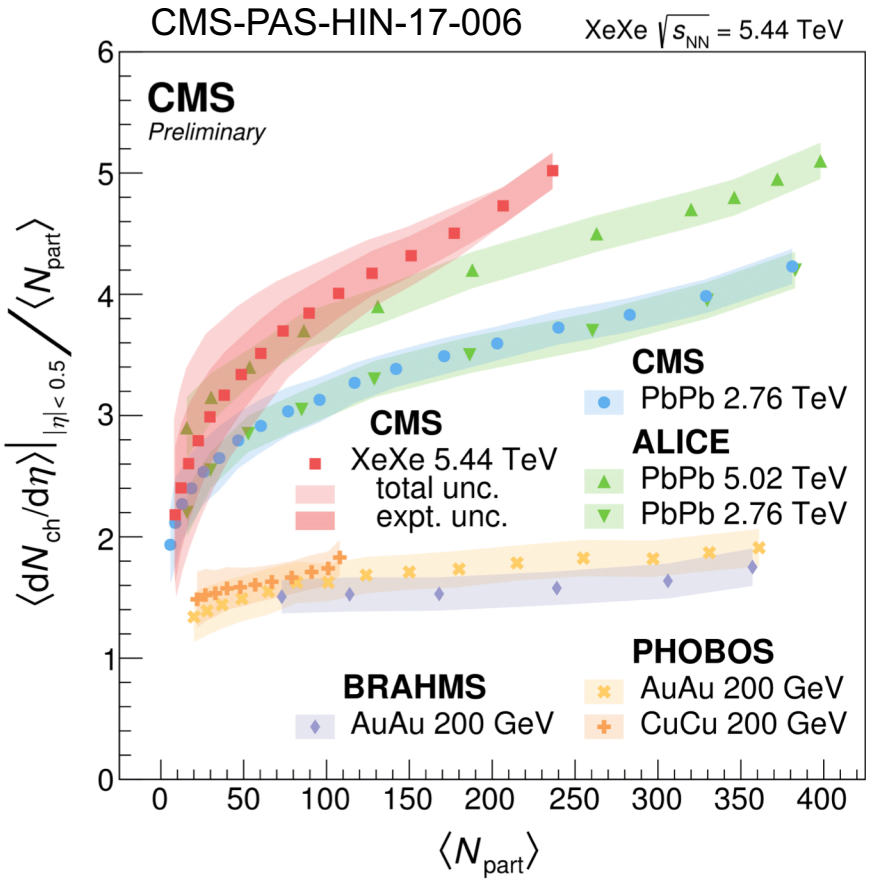
XeXe measurements





XeXe: Particle production

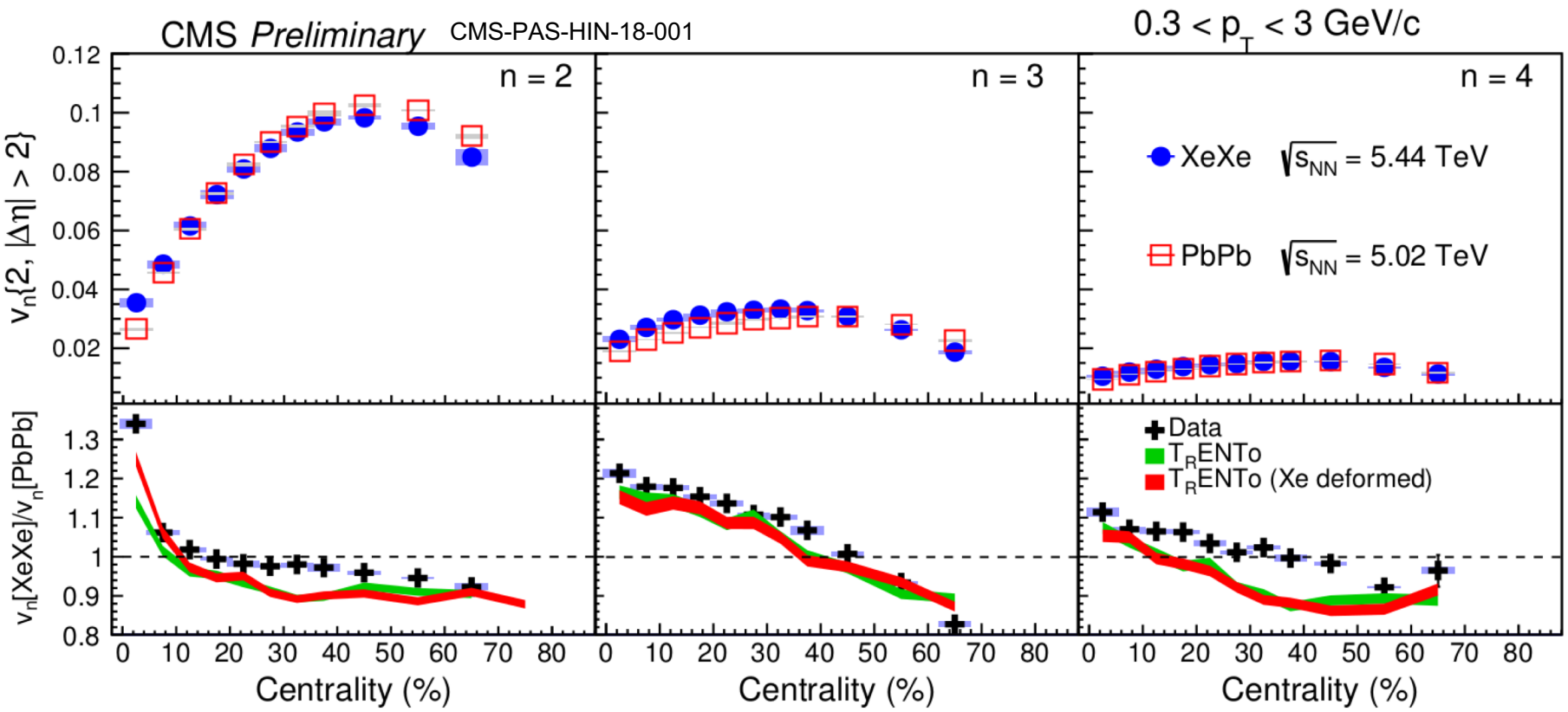




- XeXe ~1.4 less multiplicity than PbPb.

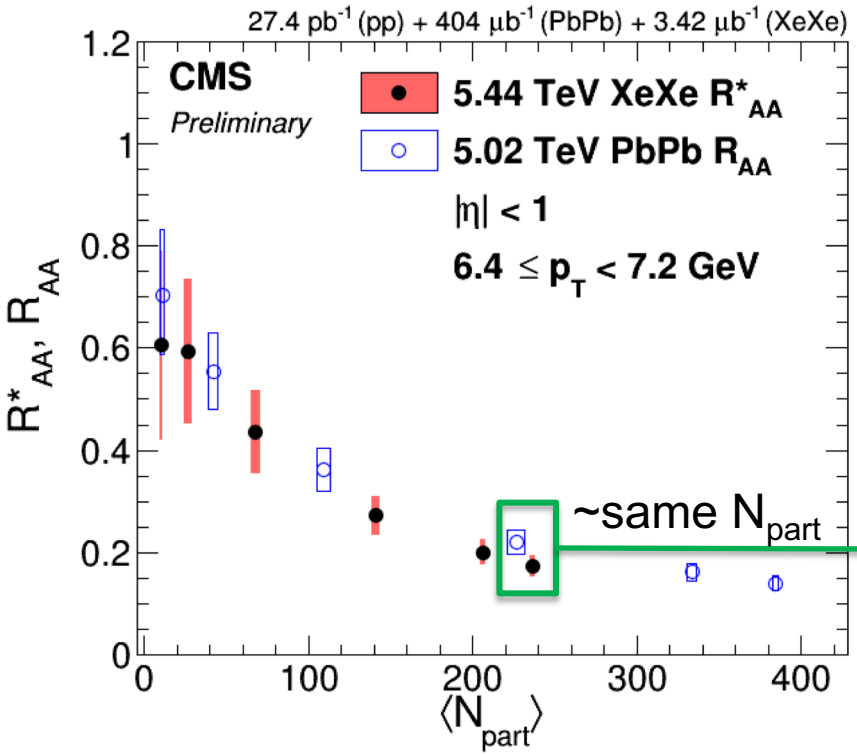
- For N_{part}~200, Xe produces more particles per participant than Pb.
- No system size scaling

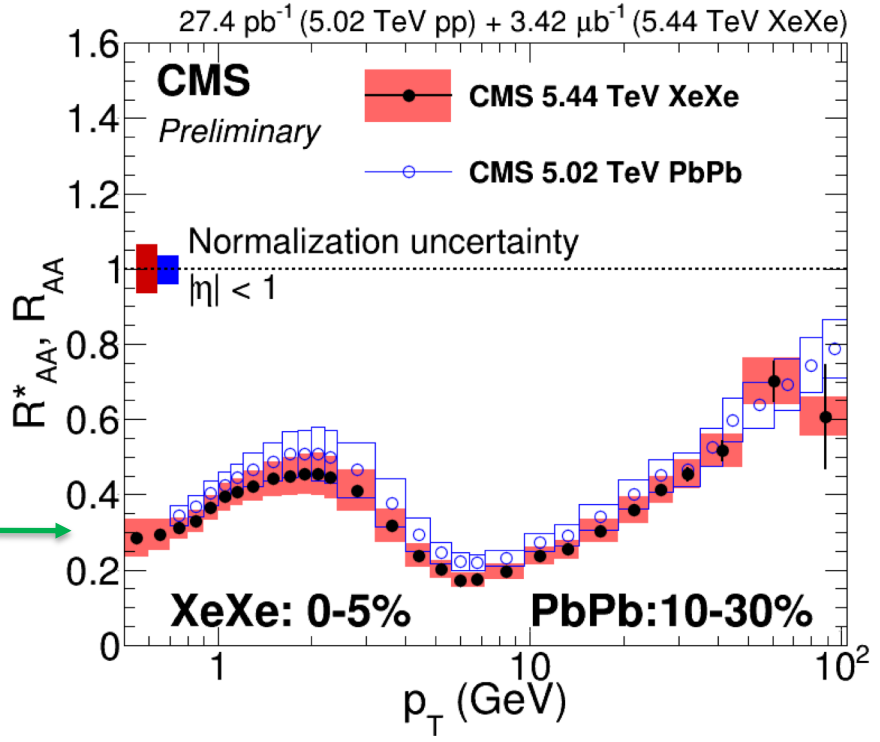
Flow in XeXe



- Xe v_2 higher than Pb in central, lower in peripheral
  - Most-central events: Xe quadrupole deformation matters.
- v_3 behavior as expected, but not v_4?

XeXe: high-p_T hadron suppression



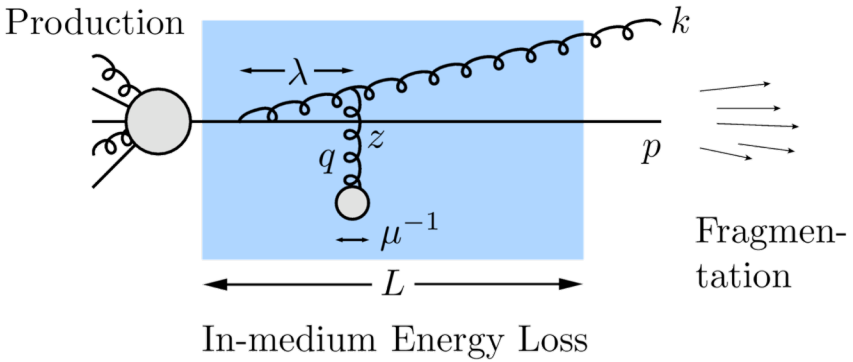


- R_{AA}:
  - Similar scaling with N_{part} in Xe and Pb.
  - At same N_{part}, $R_{AA}(p_T)$ consistent within uncertainties between Xe and Pb

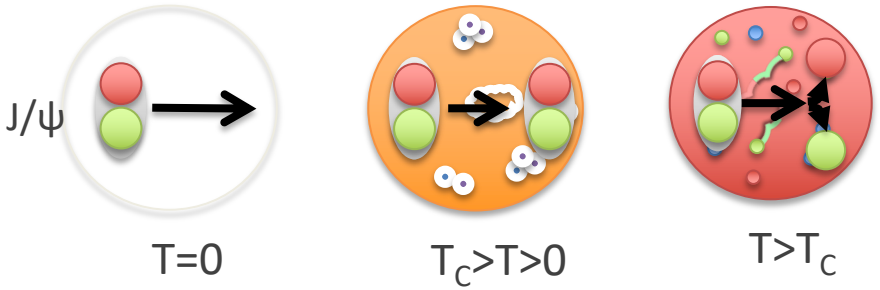
Studying the QGP density and Temperature via

HARD PROBES

Jet Energy Loss/Tomography



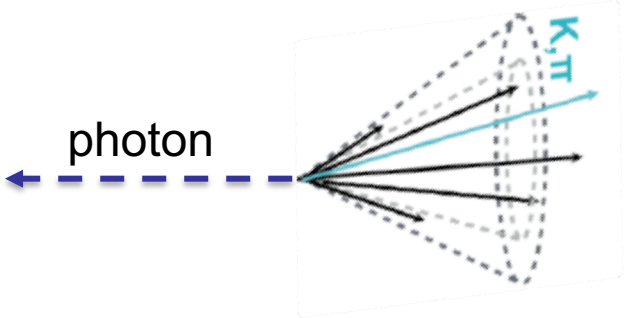
Quarkonium Melting

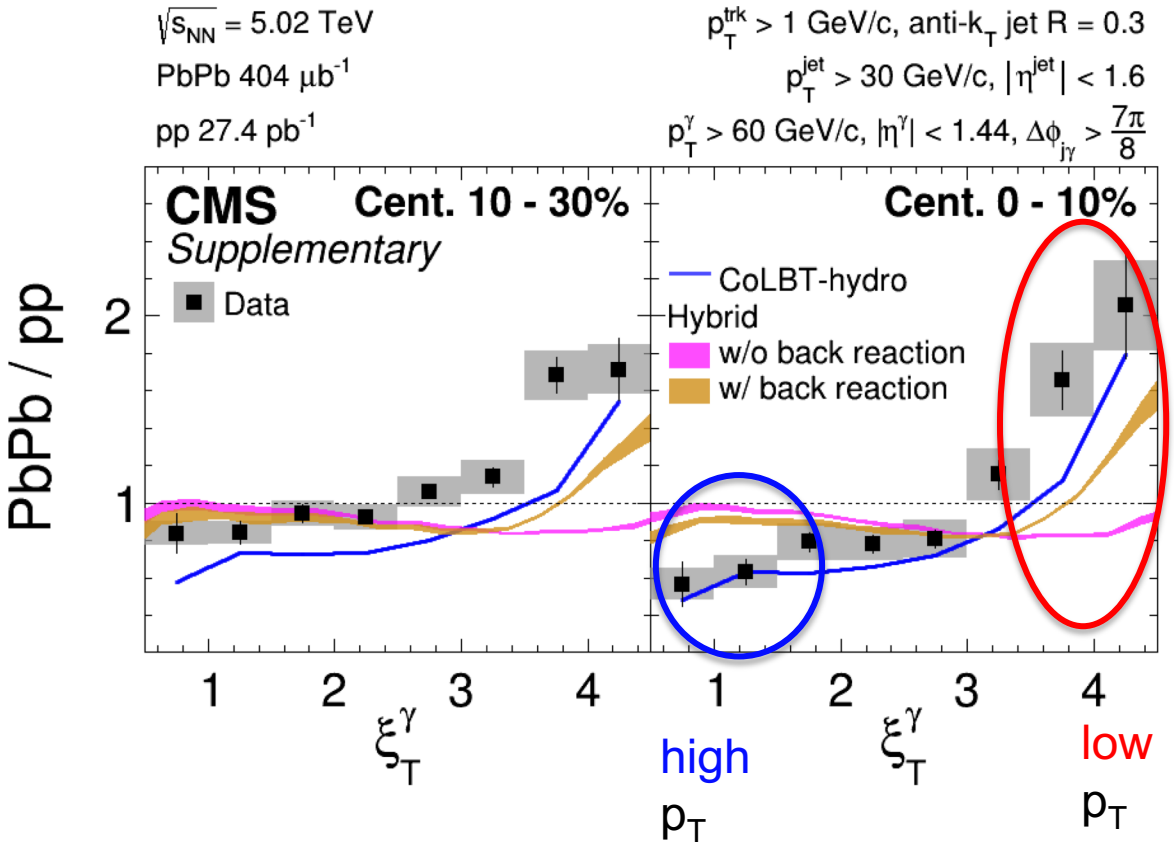


Photon-tagged jet fragmentation

arXiv:1801.04895

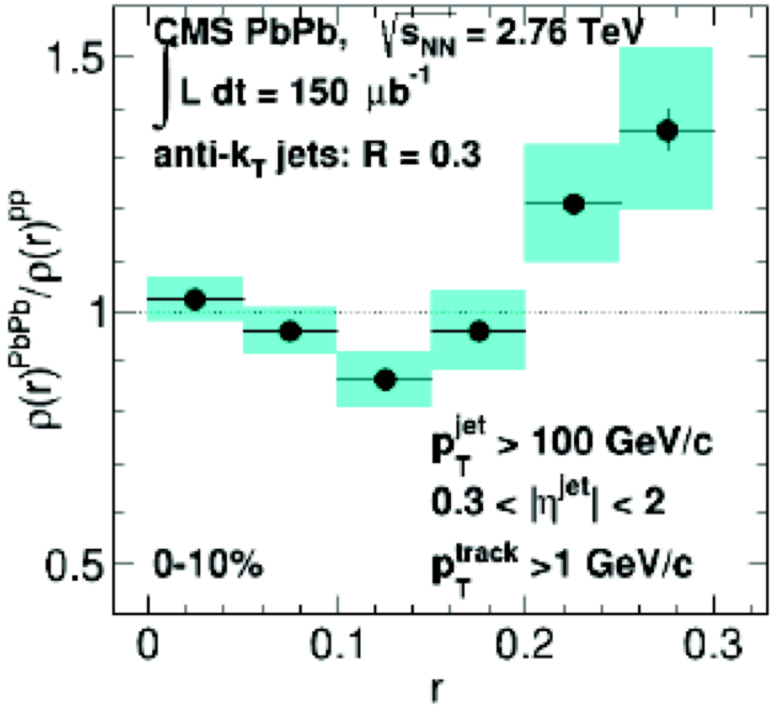
- Final state: γ-quark
- photon p_T constrains parton energy.
- Quark enriched sample:
  - flavor dependence of jet quenching.
- Most central collisions:
  - Depletion of high momentum particles
    - Sensitive to hard parton shower
  - Enhancement of particles carrying small fraction of jet momentum
    - Recoil

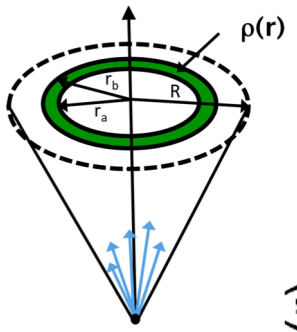




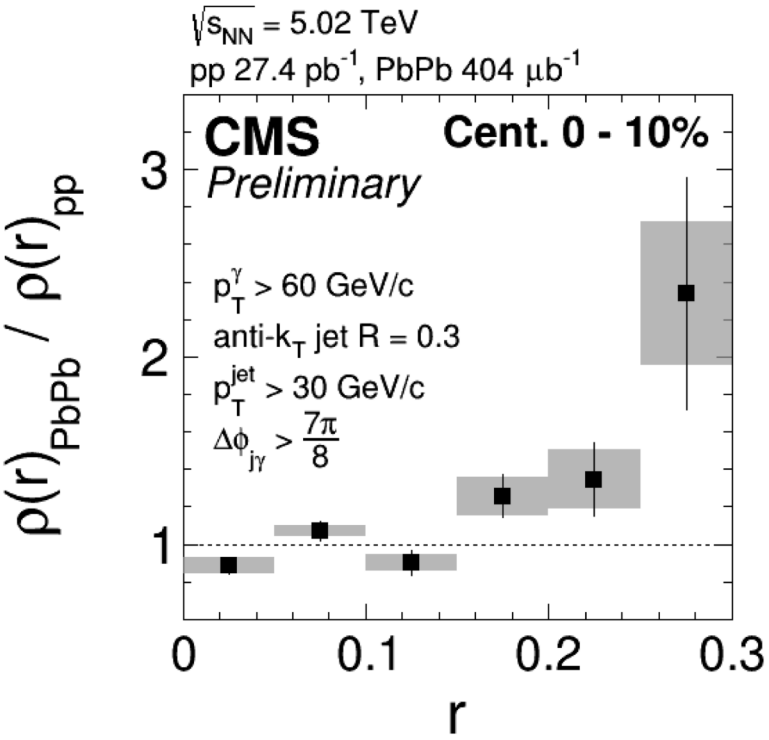
Jet Shapes: gluon vs quarks

Inclusive: Gluon/quark mixture





γ-jet: quark dominated

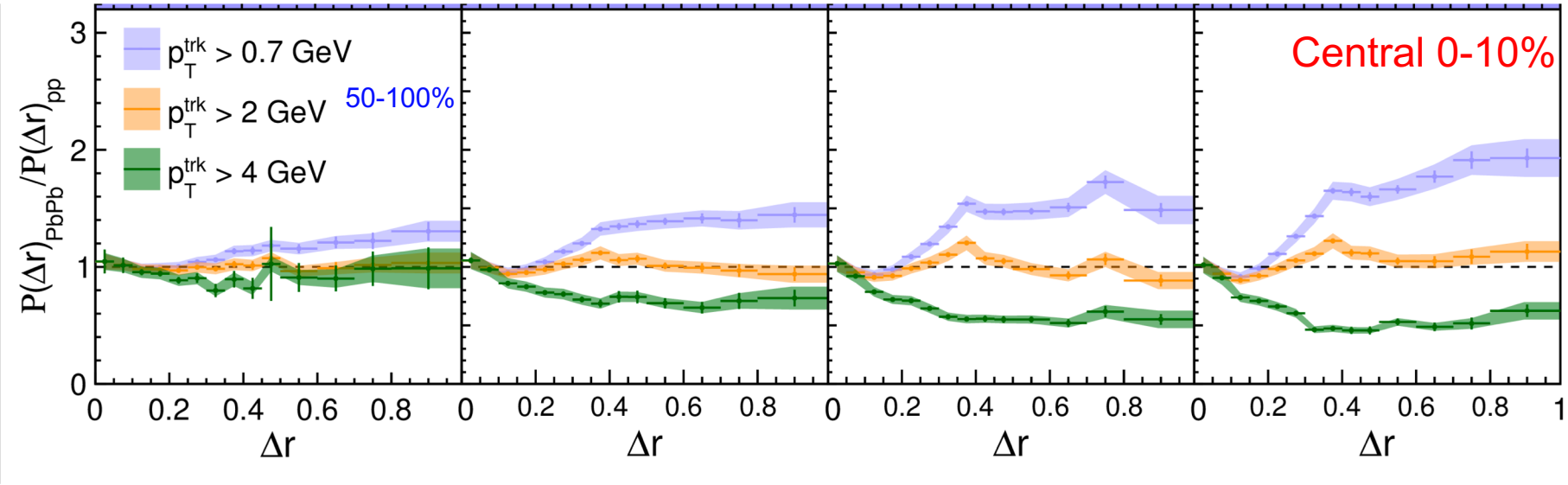


- Observe Jet-shape modification in PbPb compared to pp
- r~0.1: Depletion for inclusive jets, no depletion for photon-tagged jets.
  - Due to changing q/g fraction for inclusive sample?
- r>0.15: Redistribution of energy to large angle for both light quark and gluon jets

Jet shapes vs track p_T.

- How does the jet-shape modification depend on p_T?

Inclusive: Quark/Gluon Mixture



- Peripheral collisions: radial distribution similar to pp
- Central collisions: enhancement of low p_T tracks, depletion for p_T> 4 GeV

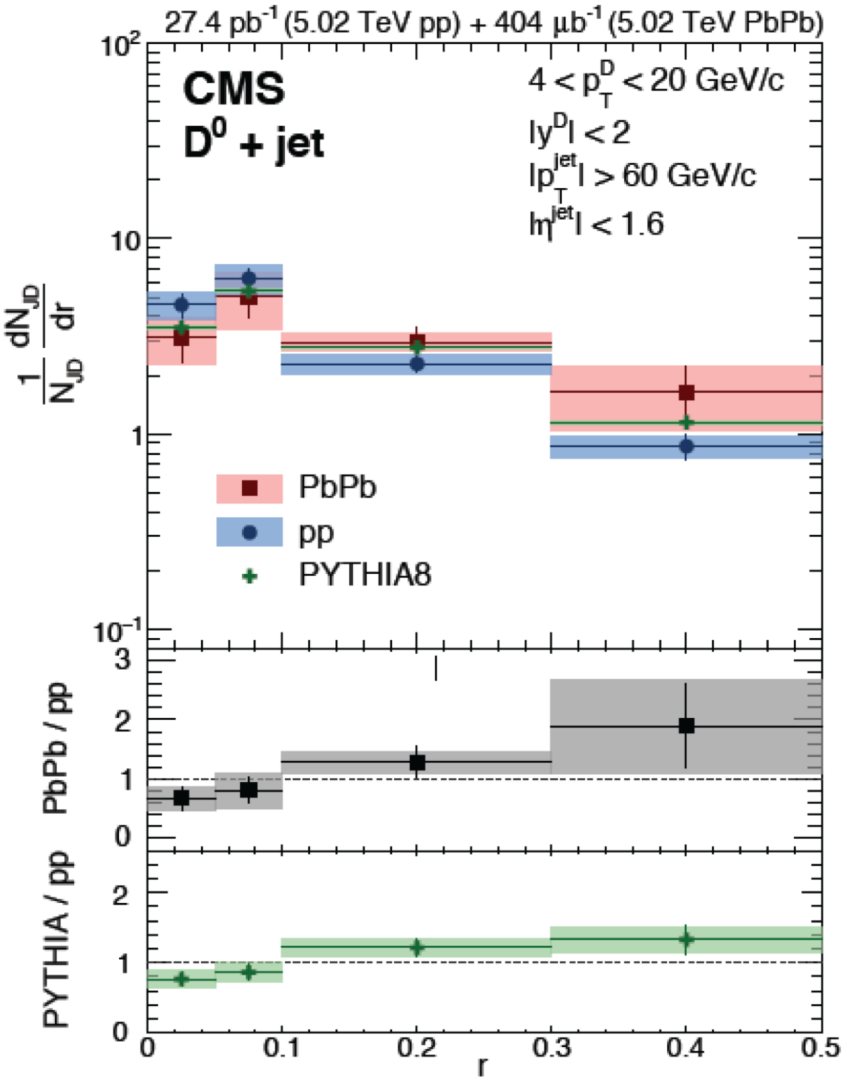
arXiv:1803.00042
CMS-PAS-HIN-18-006

Jet shapes: charm quarks

CMS PAS HIN-18-007

- Radial distributions of D0's in pp and PbPb

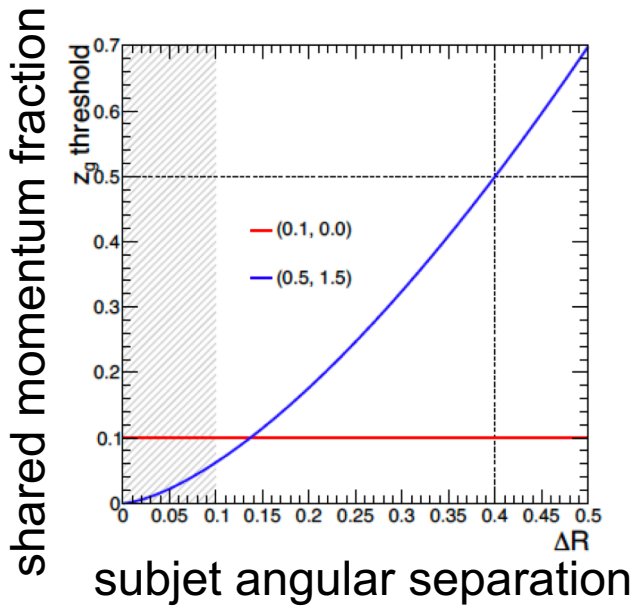
- Indication that D mesons are further away from jet axis in PbPb.



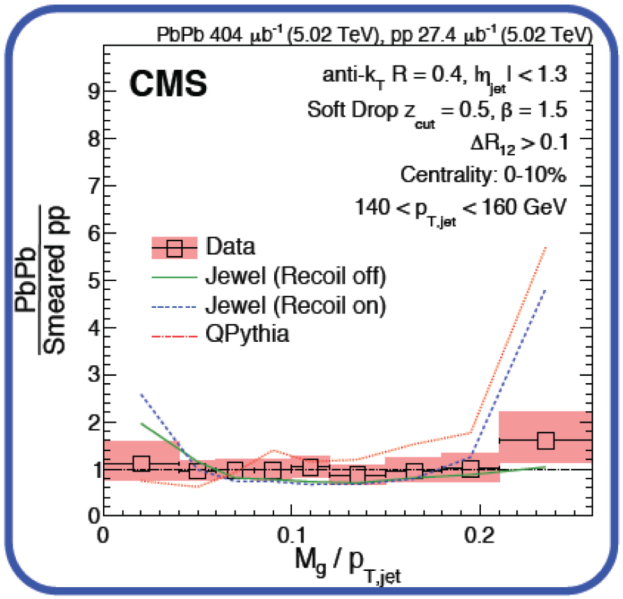
Jet substructure via groomed jet mass

Jet grooming: sequentially prune soft constituents of jet until pair of hard subjets is found
⇒ information about hard splitting in medium

Flat : insensitive to multiple emissions
Large angle: Focus on jet core

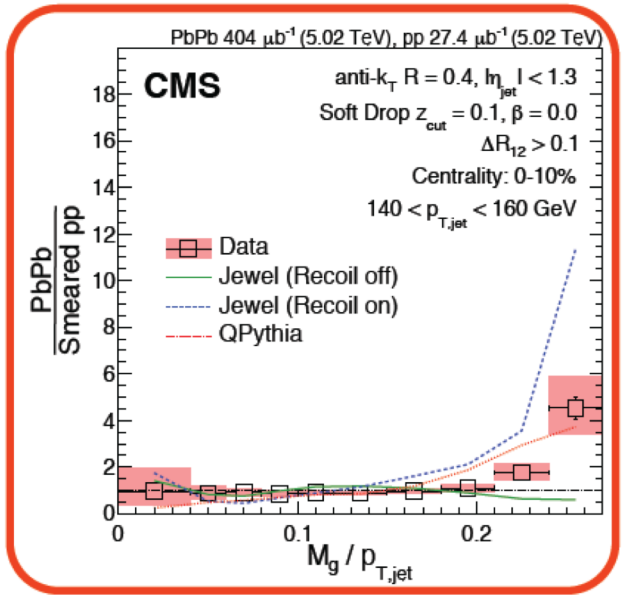


Large angle grooming



- Jet core unaffected by medium

Flat grooming



- Possible high mass enhancement

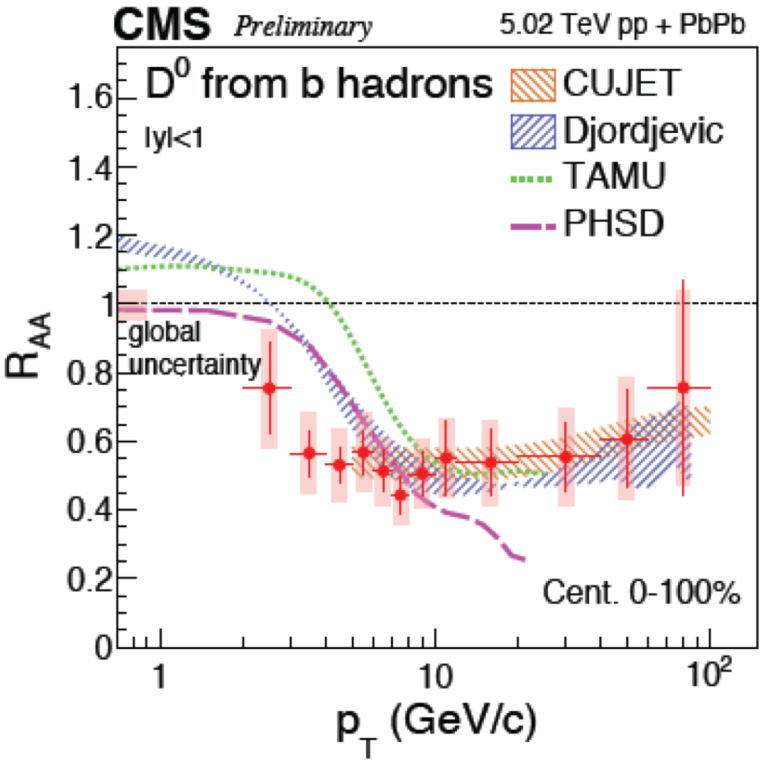
- Jet quenching models do not describe large mass data for both large angle and flat grooming

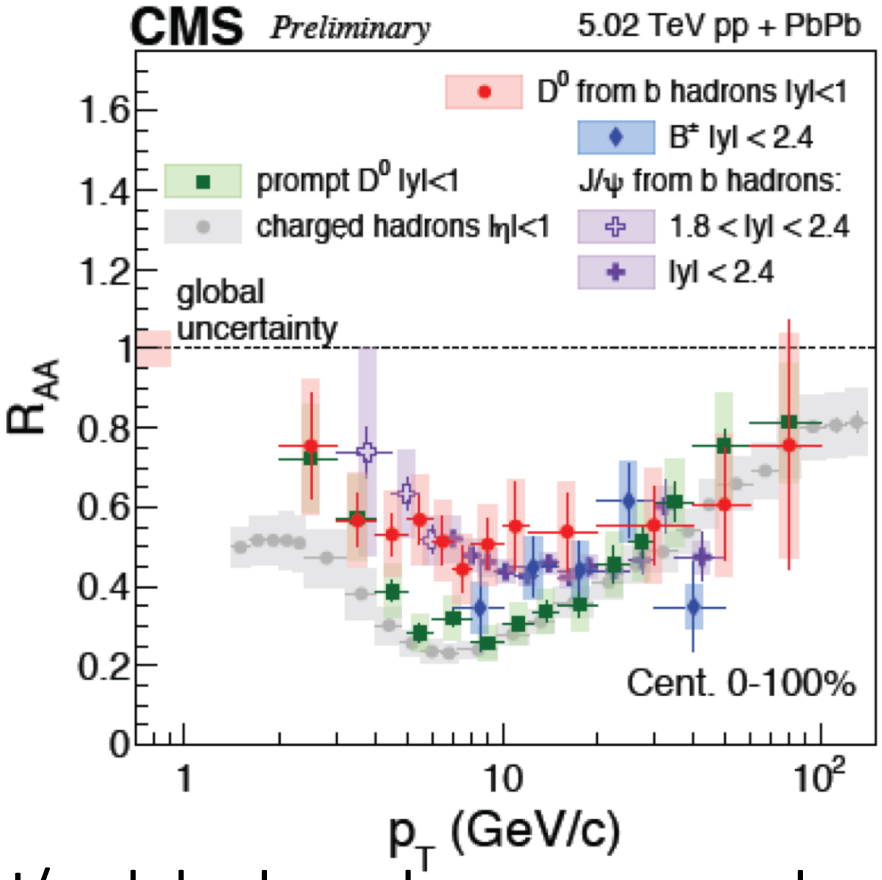
PRL 120 (2018) 142302
arXiv:1805.05145

Non-prompt D: Beauty suppression

- First measurement of non-prompt D^0 R_{AA}.

CMS-PAS-HIN-16-016
arXiv:1712.08959

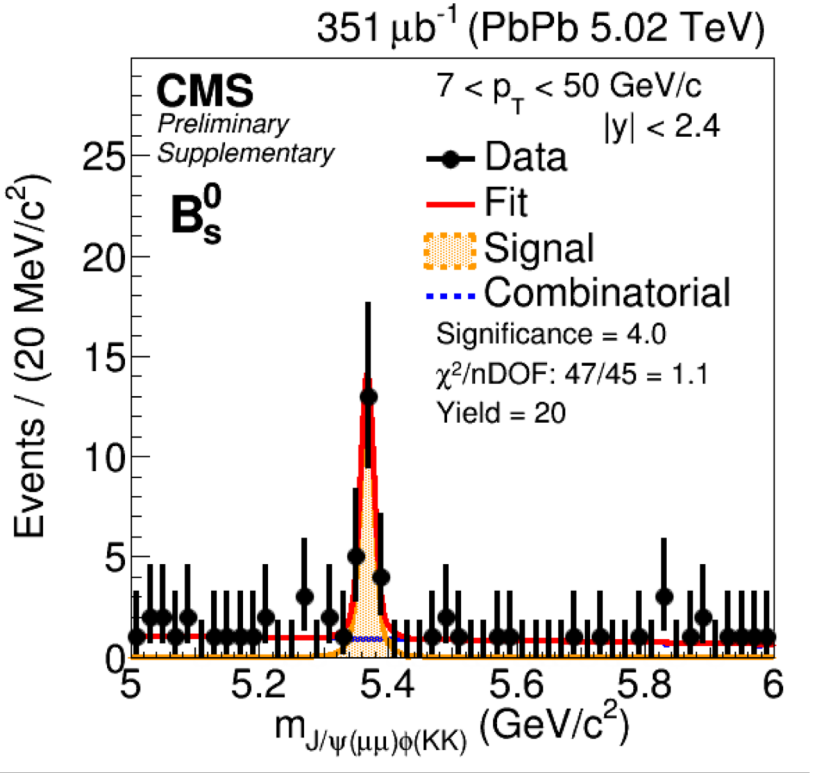


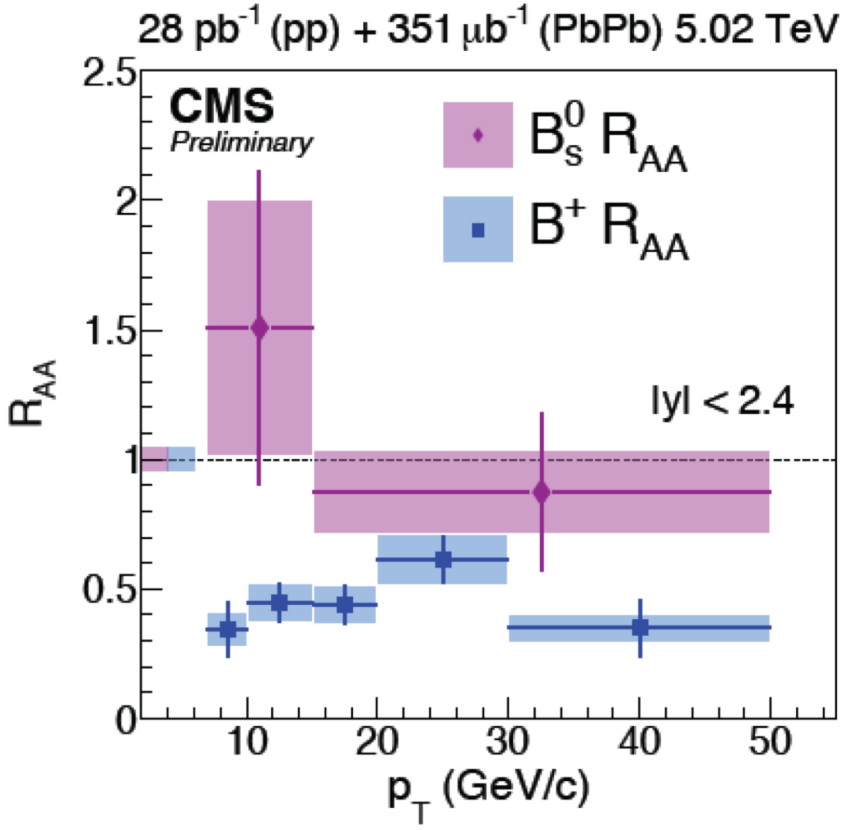


- Non-prompt D^0 and non-prompt J/ψ: b hadrons less suppressed than prompt D^0 and light hadrons for p_T<10 GeV/c
  - Consistent with dead-cone effect for heavy quarks.

Strange B mesons

- First probe of recombination between beauty and strange quarks.



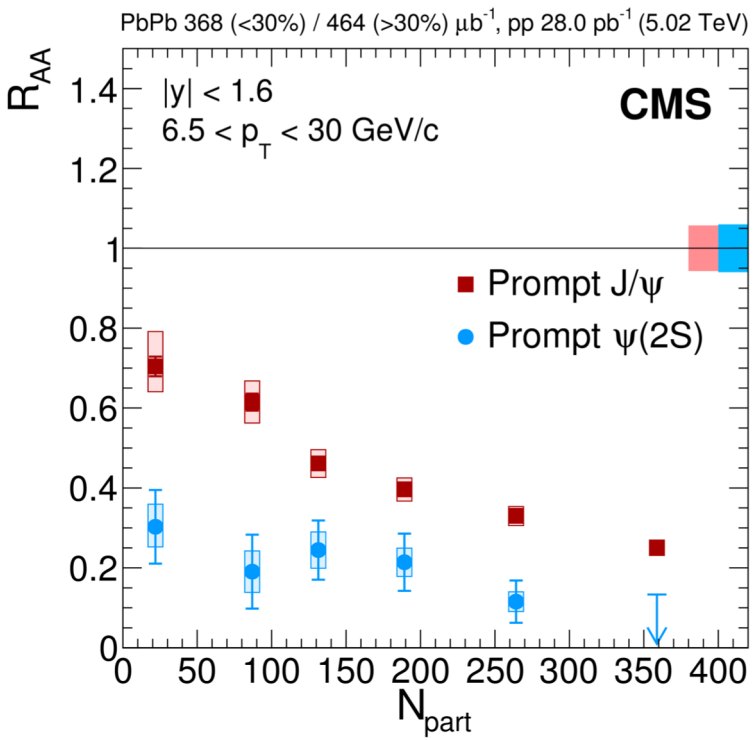


CMS-PAS-HIN-17-008

- Hint of enhancement of B_s with respect to B^+.
  - Recombination with abundantly produced s quarks in QGP?

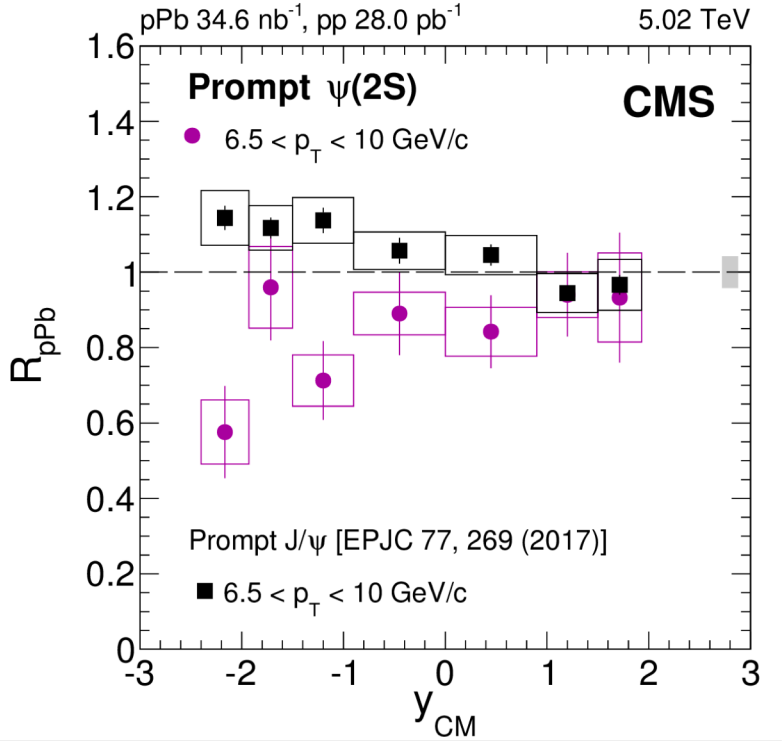
Charmonia: J/ψ and ψ(2S)

PbPb



pPb

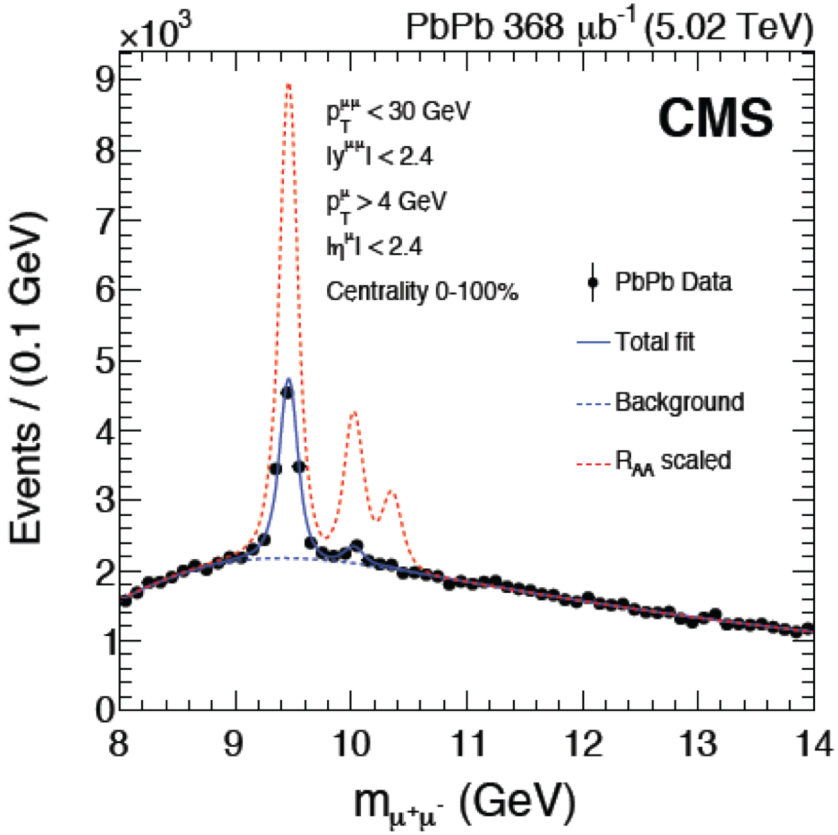
arXiv:1712.08959
iv:1805.02248

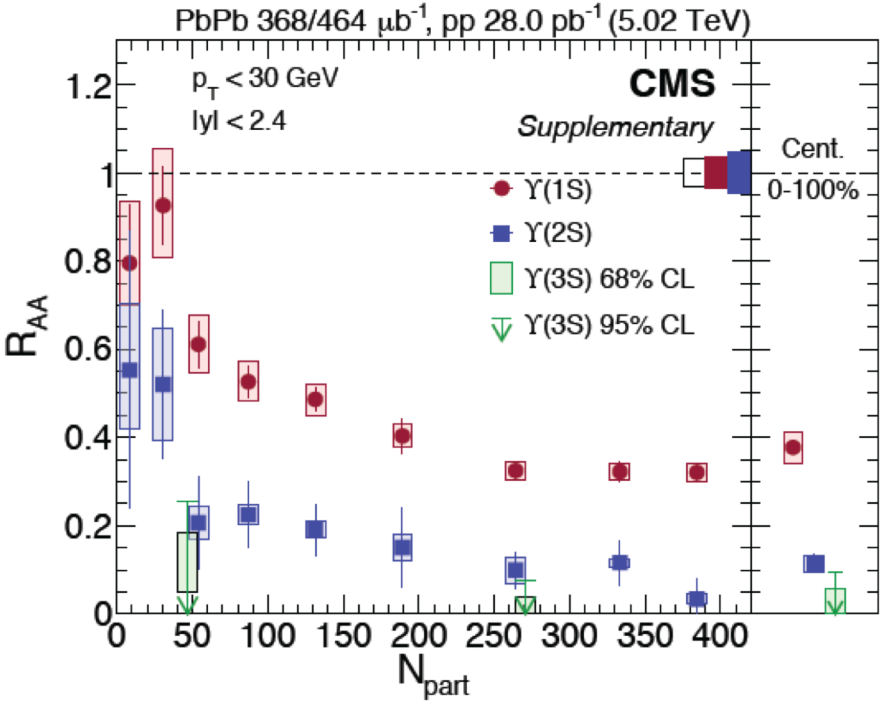


- ψ(2S) R_{AA} < J/ψ R_{AA}
  - Observed in both PbPb and pPb
- Effects beyond shadowing and energy loss in pPb
- Quantitative comparison in PbPb and pPb: towards disentangling cold vs. hot nuclear matter effects

Bottomonia Melting

CMS-HIN-16-023

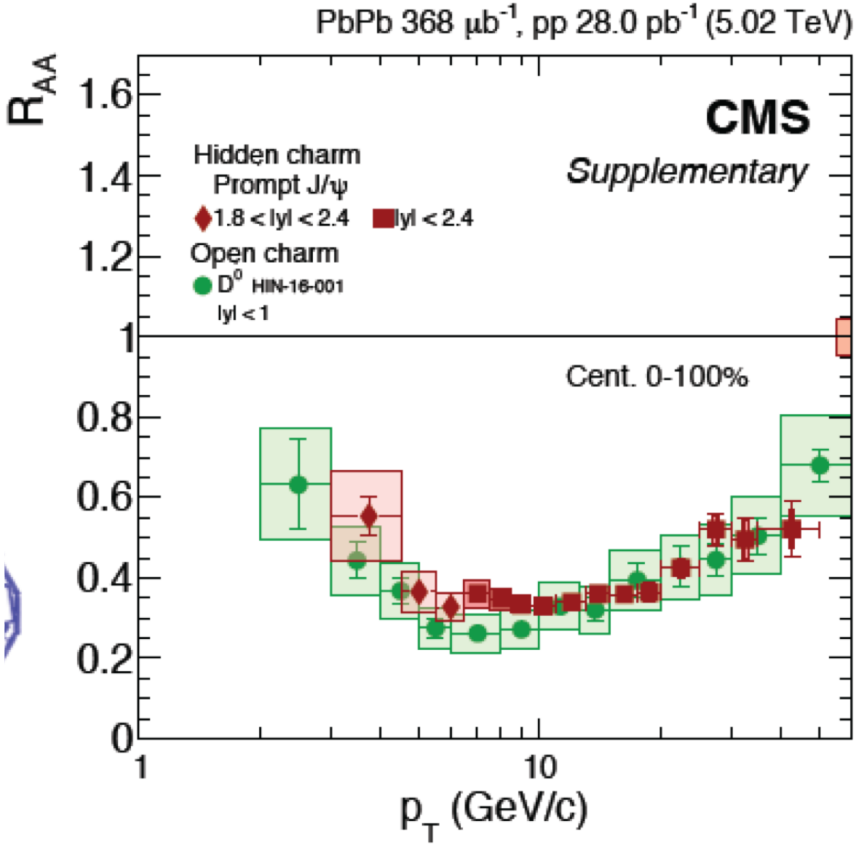


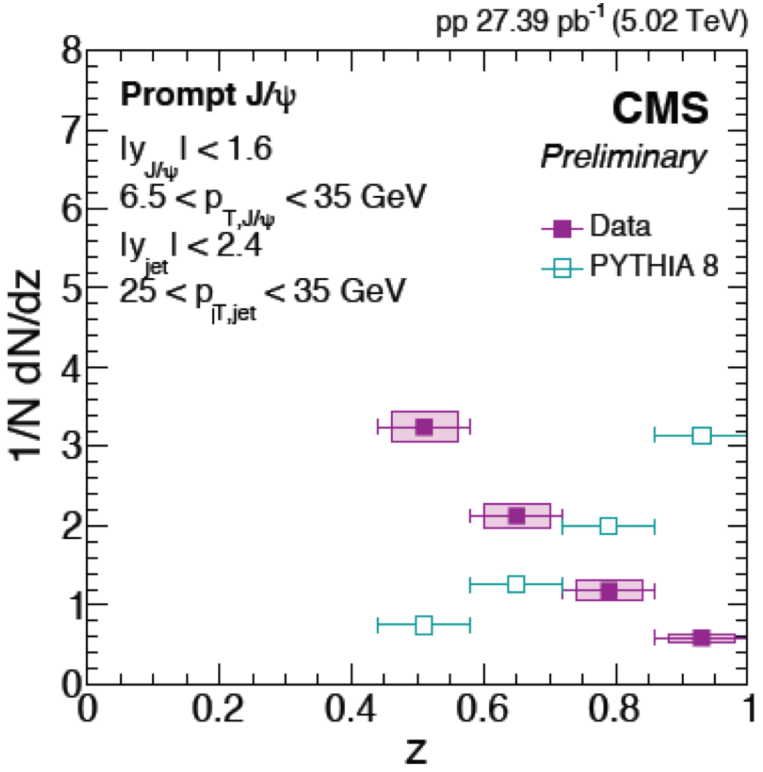


- Clear suppression of Upsilon family.
- Sequential suppression observed in all centralities
- Υ(3S): smallest R_{AA} observed for any hadron.

Prompt J/ψ: PbPb and pp

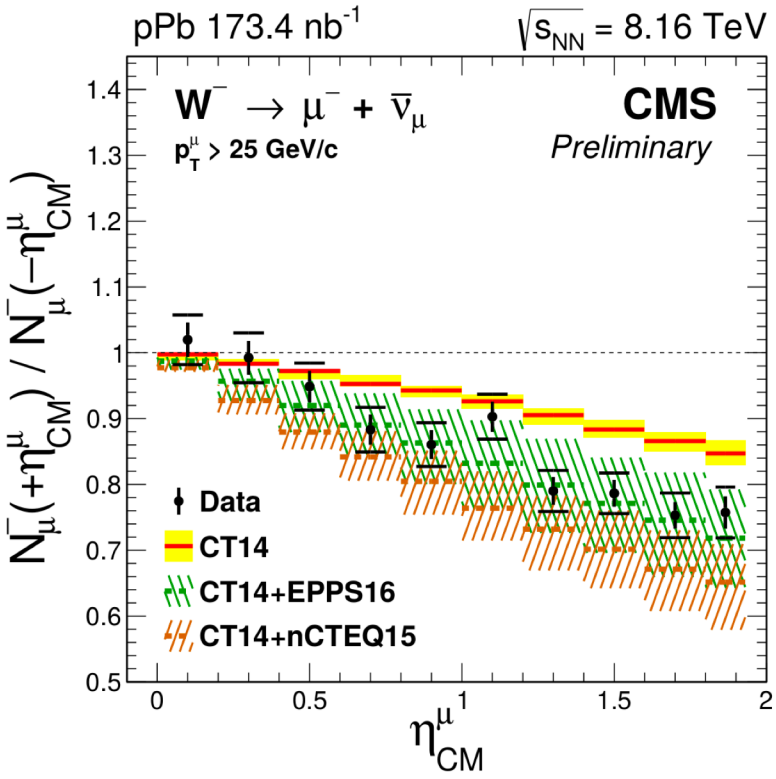
CMS-PAS-HIN-18-012

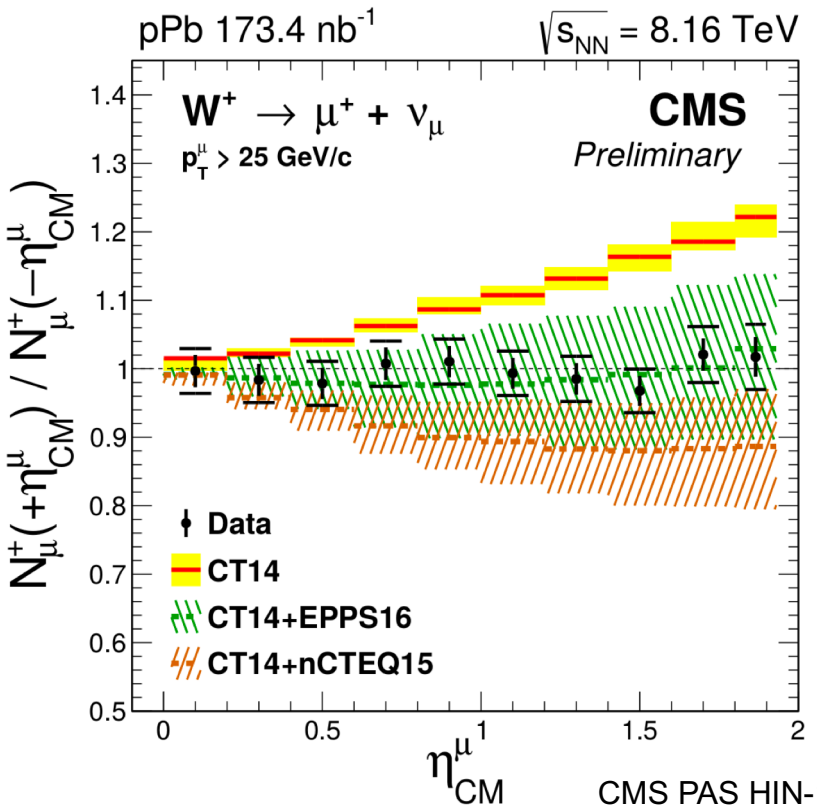




- PbPb: Suppression of charm
  - Similar R_{AA} for open and hidden charm for p_T>6.5 GeV/c.
- pp: production of J/y in jets
  - J/ψ carries only half of jet p_T.
  - Not well described by Pythia.

Quark PDFs with W boson

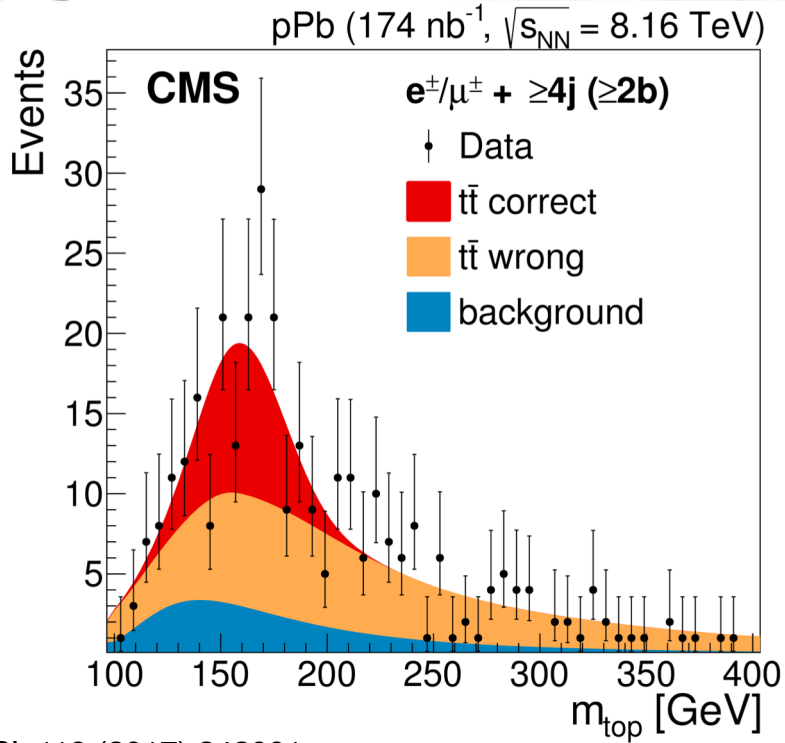




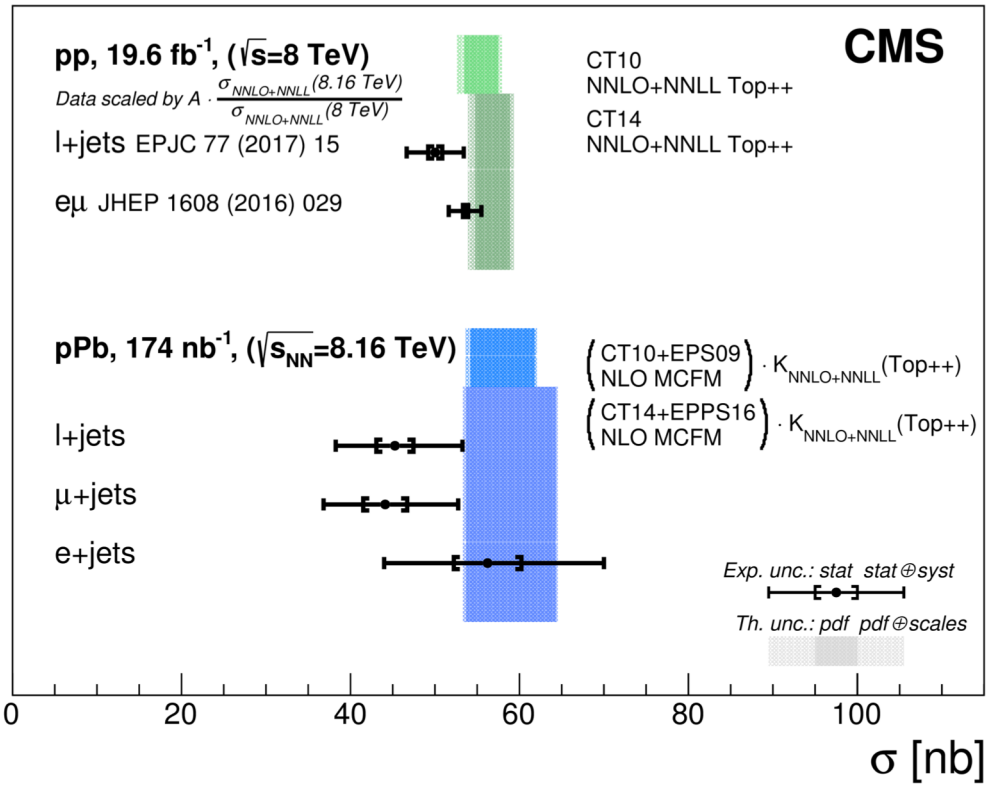
CMS PAS HIN-17-007

- Nuclear modification of quark PDF needed to describe our data.
  - Constrains q+antiquark PDF $10^{-3}<x<10^{-1}$.

Nuclear PDFs with top quark



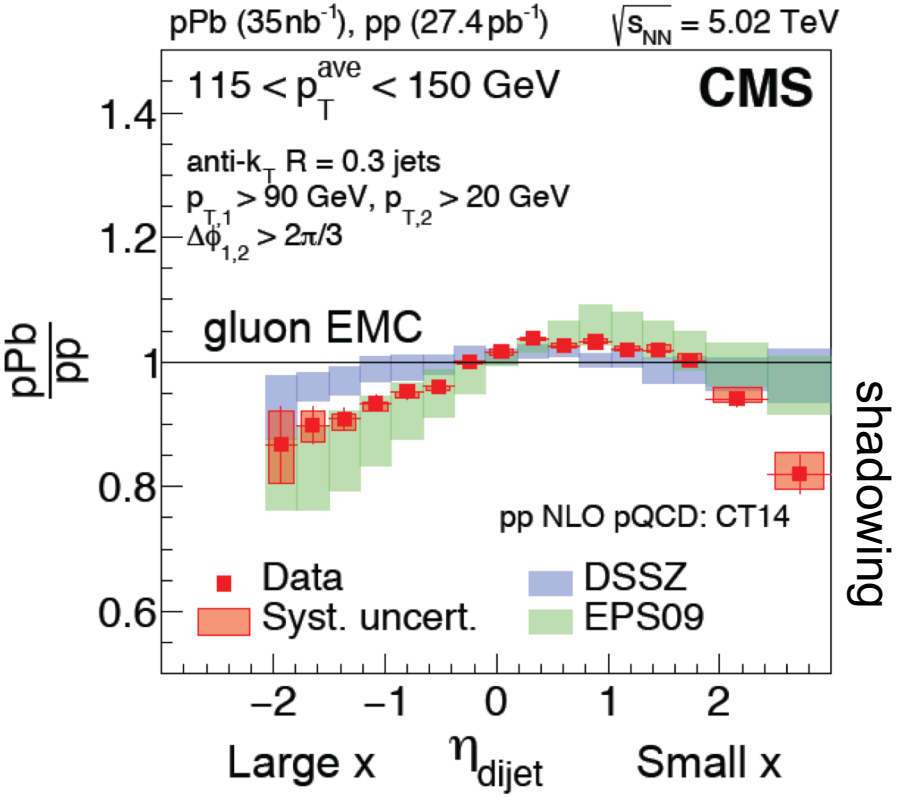
PRL 119 (2017) 242001

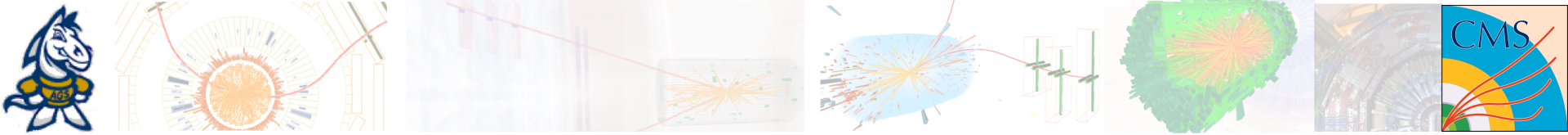


- First experimental observation of the top quark in nuclear collisions (>5σ)
- top cross section: Compatible with nPDF expectation.

Nuclear PDFs with dijets

- Large x (>0.3) in lead ions:
  - Clearly suppressed wrt unbound nucleons
    - Inconsistent with DSSZ
    - Evidence of strong gluon EMC effect
- Small x:
  - Stronger shadowing effect than models
    - Data more precise than nPDF uncertainties
    - Improve description of gluon nPDF

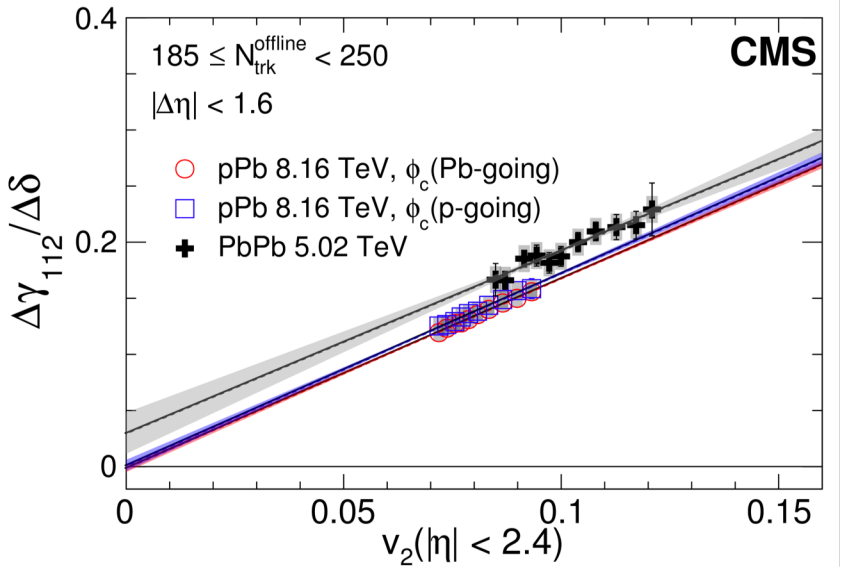




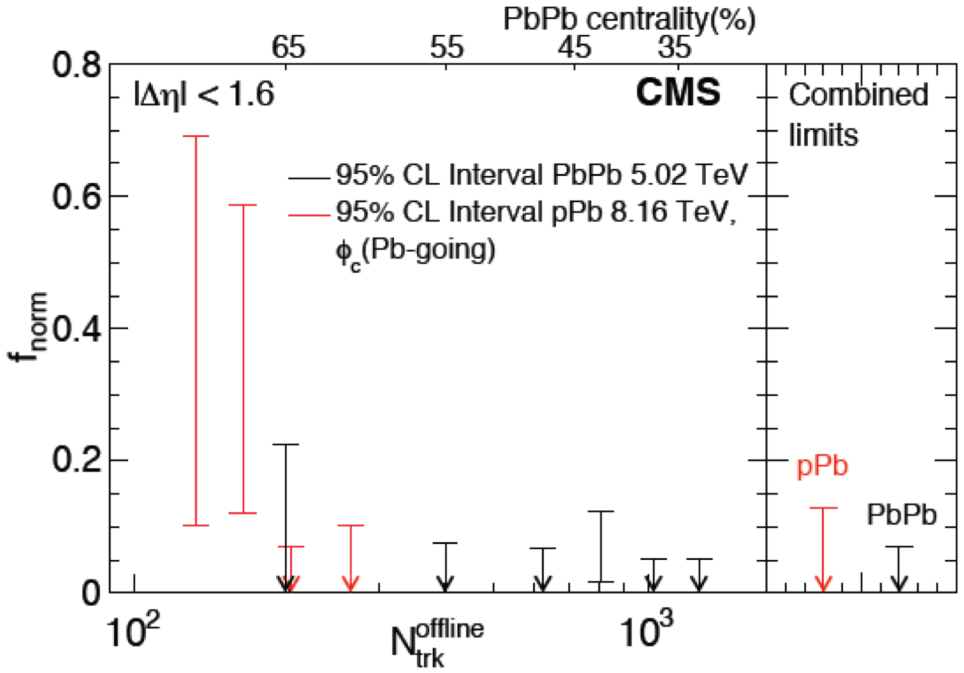
NEW OBSERVABLES

Chiral magnetic effect: null result

W. Li, Plenary Talk Phys. Rev. C, 97, 044912



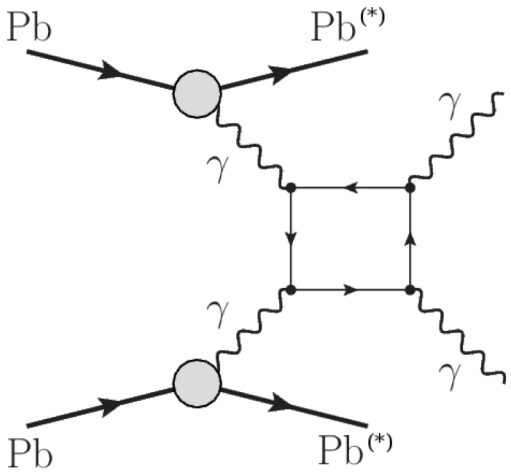
$$\frac{\Delta\gamma}{\Delta\delta} = \kappa \cdot v_2 + \frac{\Delta\gamma^{\mathrm{CME}}}{\Delta\delta}$$

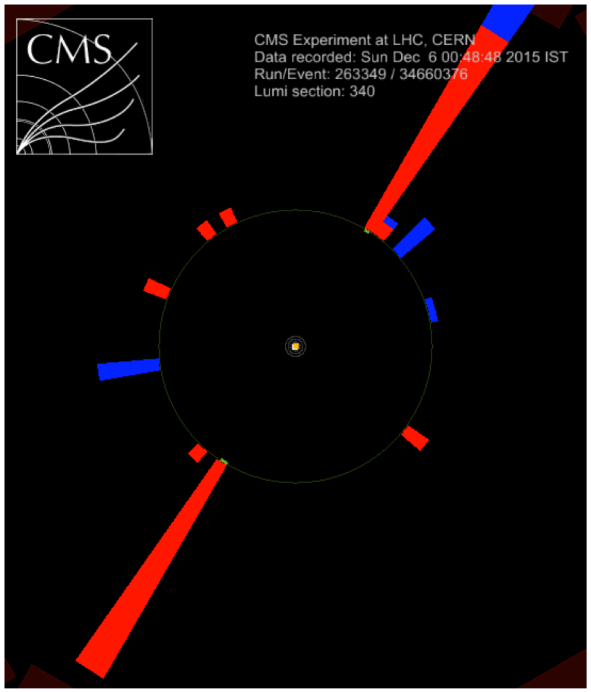


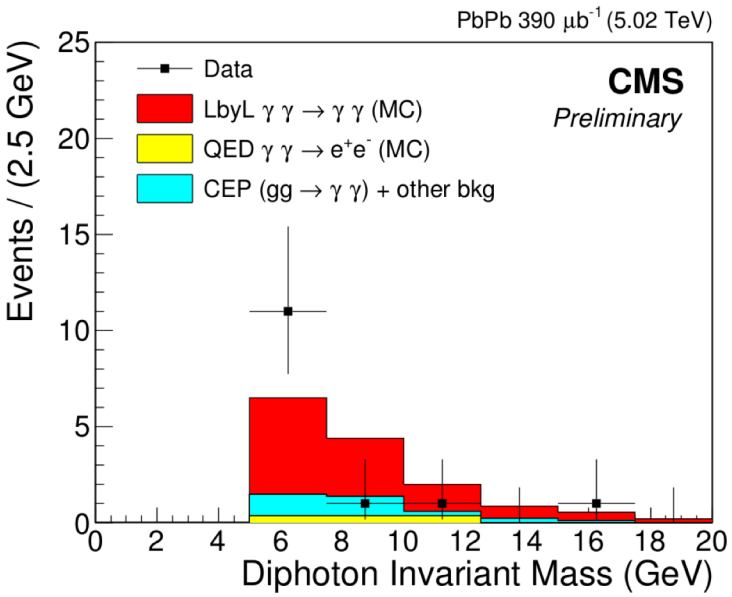
- CME signal: consistent with 0.
- Possible CME signal in PbPb at LHC energies < 7% @ 95% CL

Light-by-light scattering in QED

CMS PAS FSQ-16-012







- Significance of signal: 4.1σ observed (4.4σ expected)
- Measured fiducial cross section:
  - σ_{fid} = 122 ± 46 (stat) ± 29 (syst) ± 4 (th) nb
- Consistent with Standard Model:
  - $\sigma_{fid,SM}$ = 138 ± 14 nb

Summary

- Redistribution of light and charm quarks within a jet
- Core of jet not modified
- Bottomonium melting. Υ(3S) smallest R_{AA} observed
- Hint for beauty recombination with strange
- XeXe similar to PbPb
- Evidence of guon EMC effect and quark modification in Pb
- First observation of top quark in nuclear collisions
- Collectivity in pPb down to Ntrk=50
- CME effect not observable at LHC energies
- Observation of light-by-light scattering