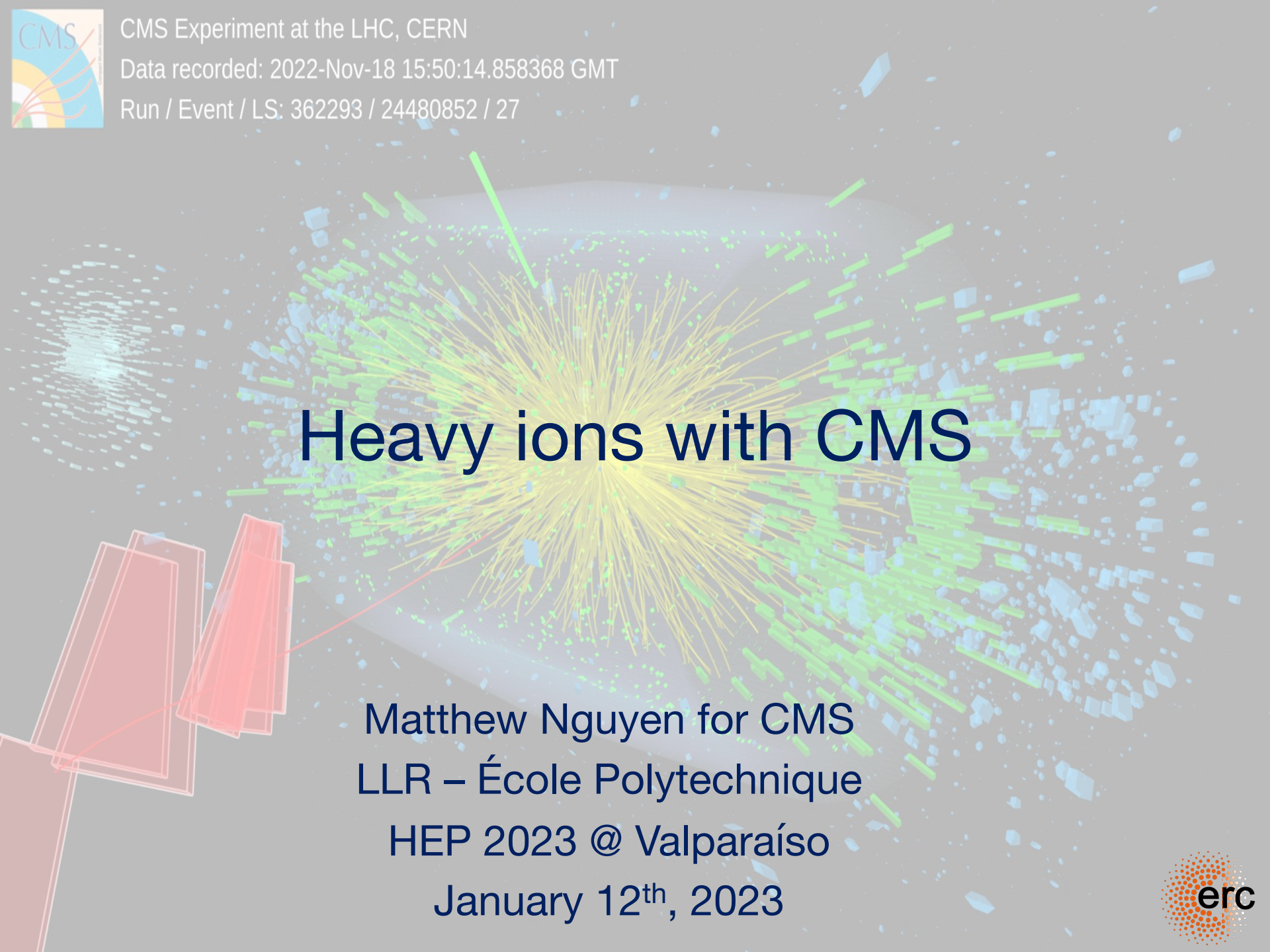


Heavy ions with CMS

Matthew Nguyen for CMS
LLR – École Polytechnique

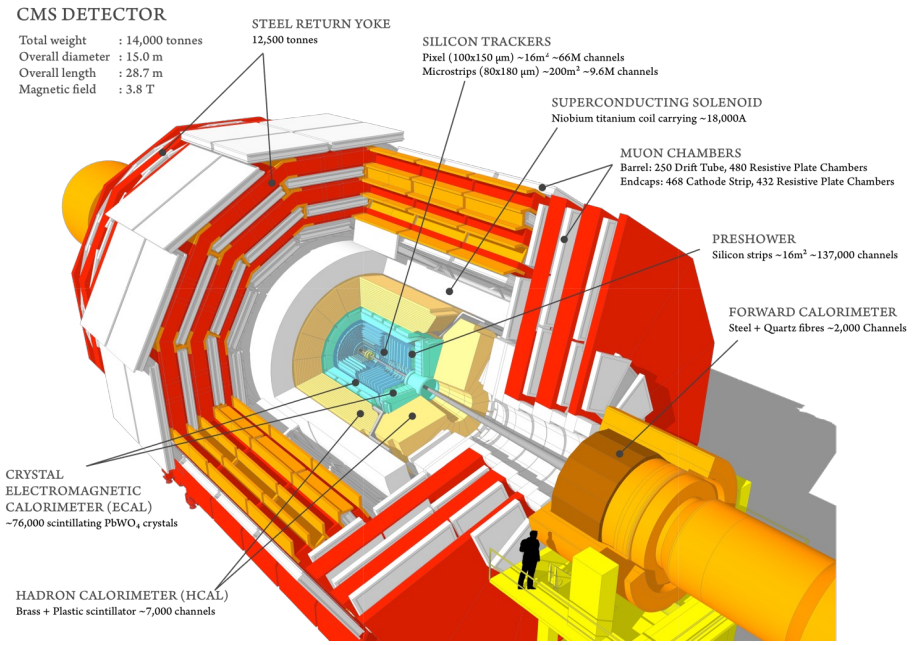
HEP 2023 @ Valparaíso

January 12th, 2023

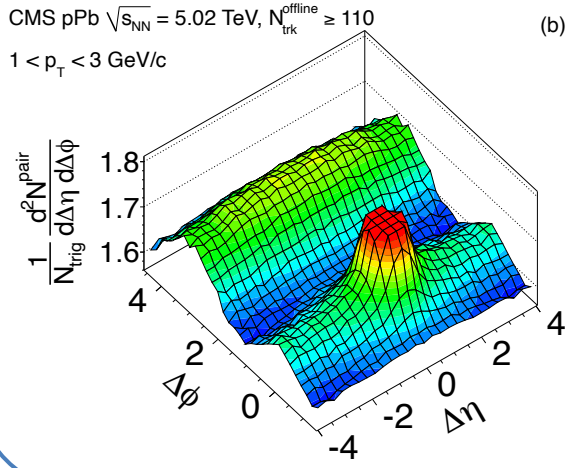
CMS as a heavy-ion detector

Distinguishing features

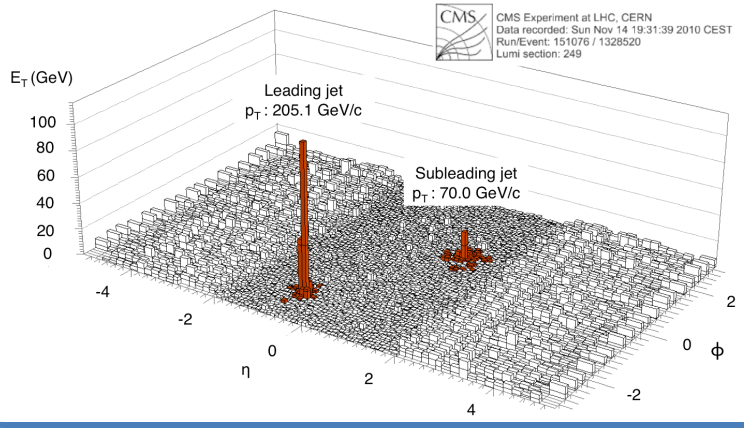
- High rate capabilities
- Precise tracking in 4T B field
- Large acceptance
- Excellent muon identification



Program comprises particle correlations to study "bulk observables"

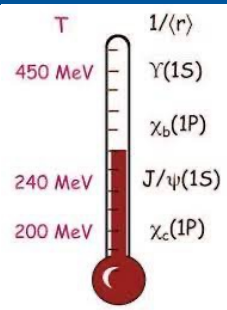


& "hard probes" of QGP, especially jets, quarkonia & open heavy flavor

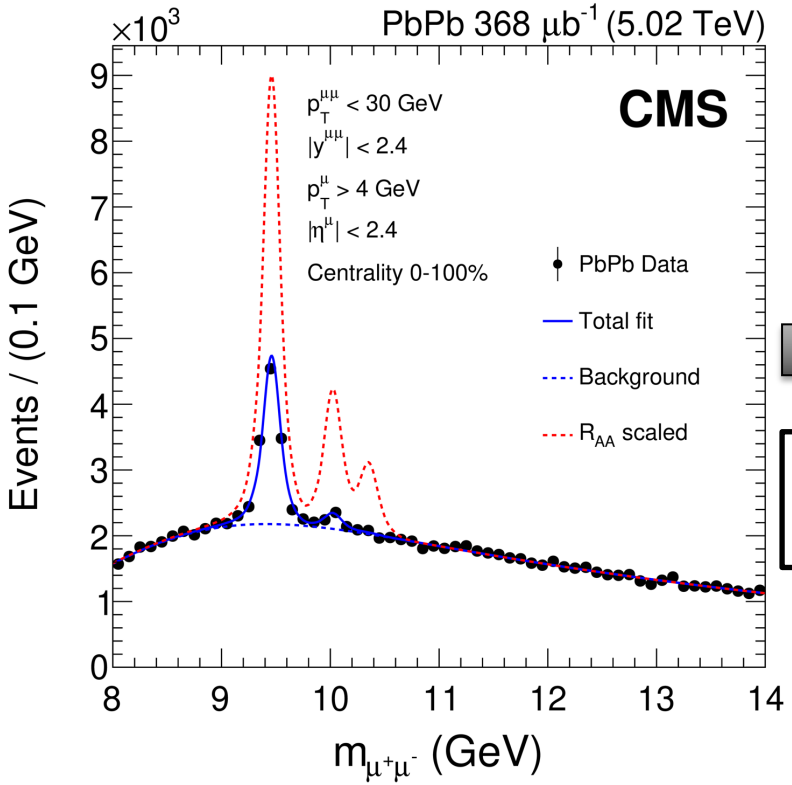


Upsilon family

Dissociation of quarkonia states probes the quark-gluon plasma temperature

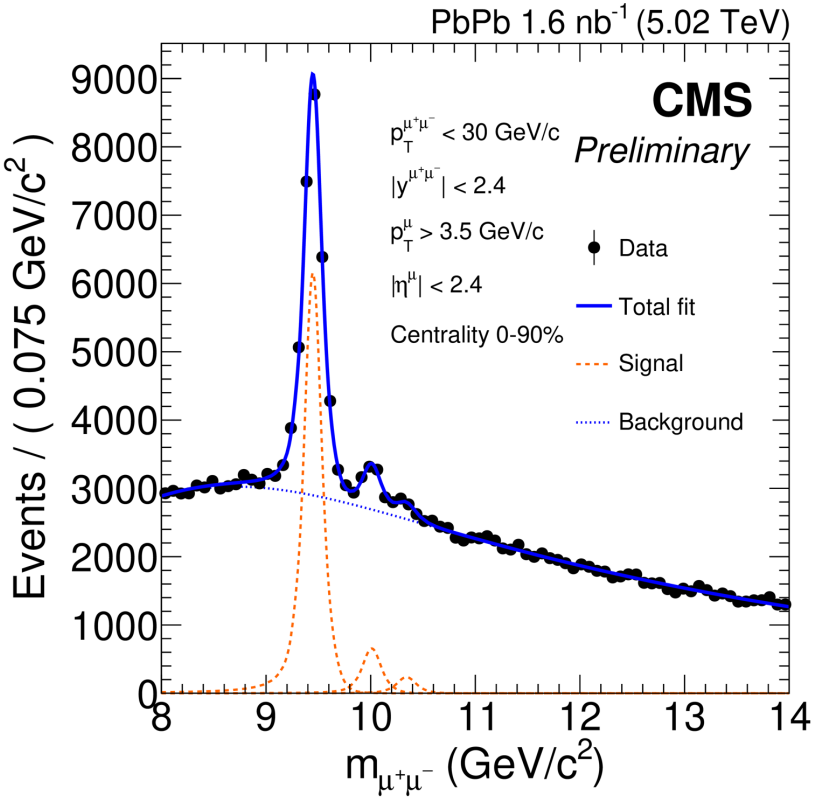


2015 PbPb data: PLB 790 (2019) 270



4x stats
+ BDT

2018 PbPb data: CMS-PAS-HIN-21-007



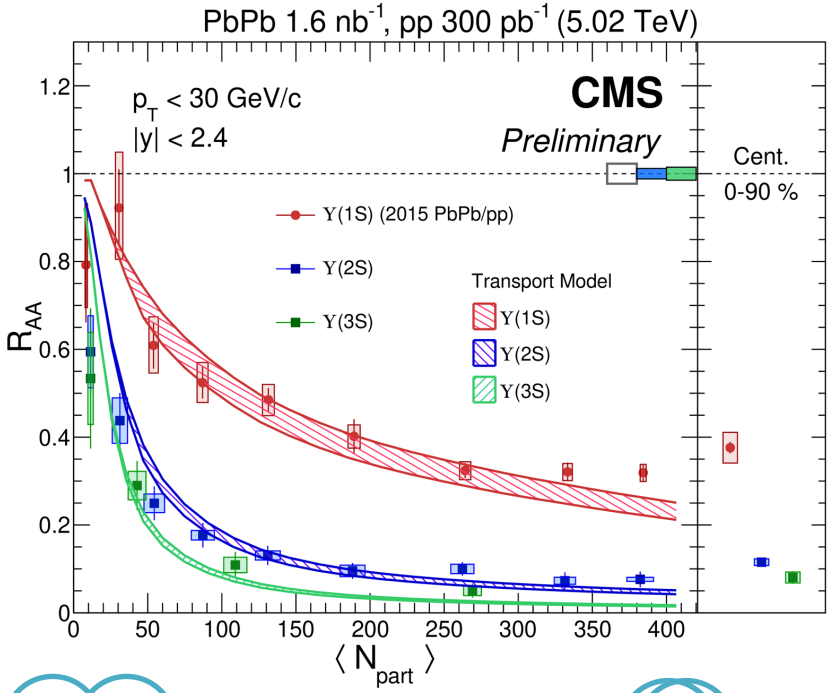
1st observation of the elusive Y(3s) in AA!

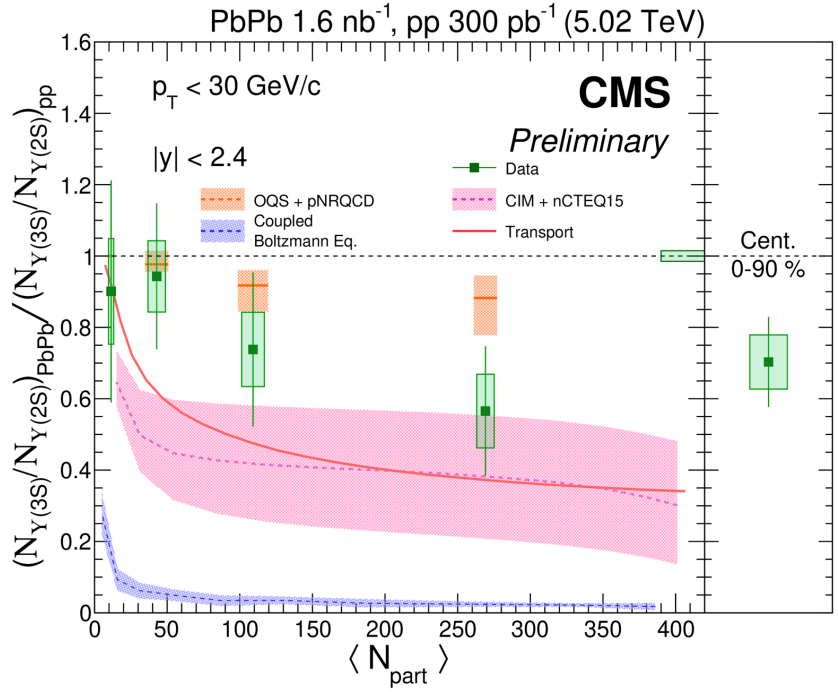
CERN courier article

Upsilon model comparisons

CMS-PAS-HIN-21-007

Y(2s) / Y(3s) $R_{AA} \approx 2$

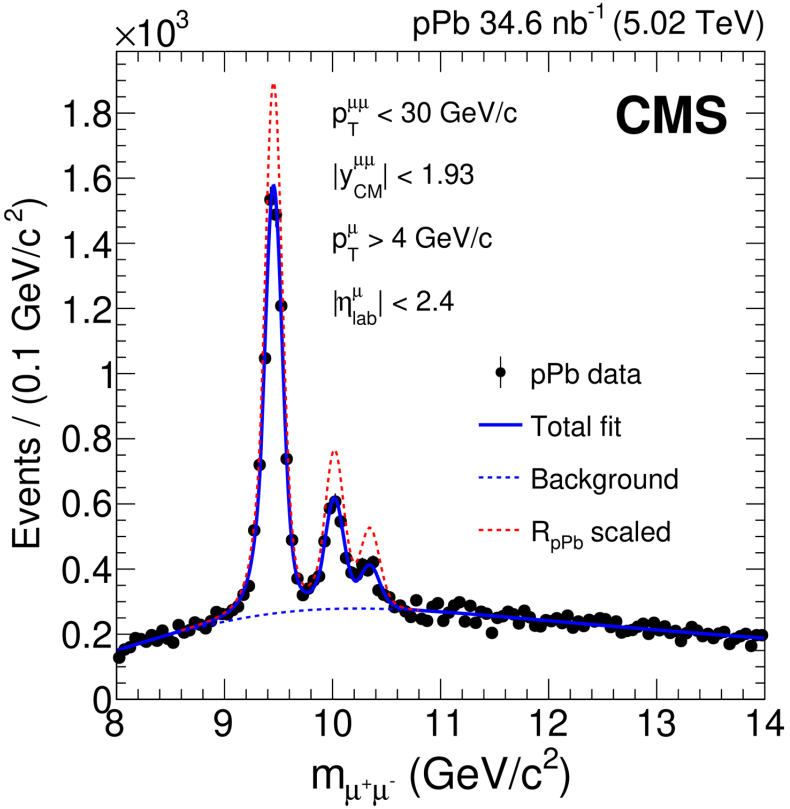


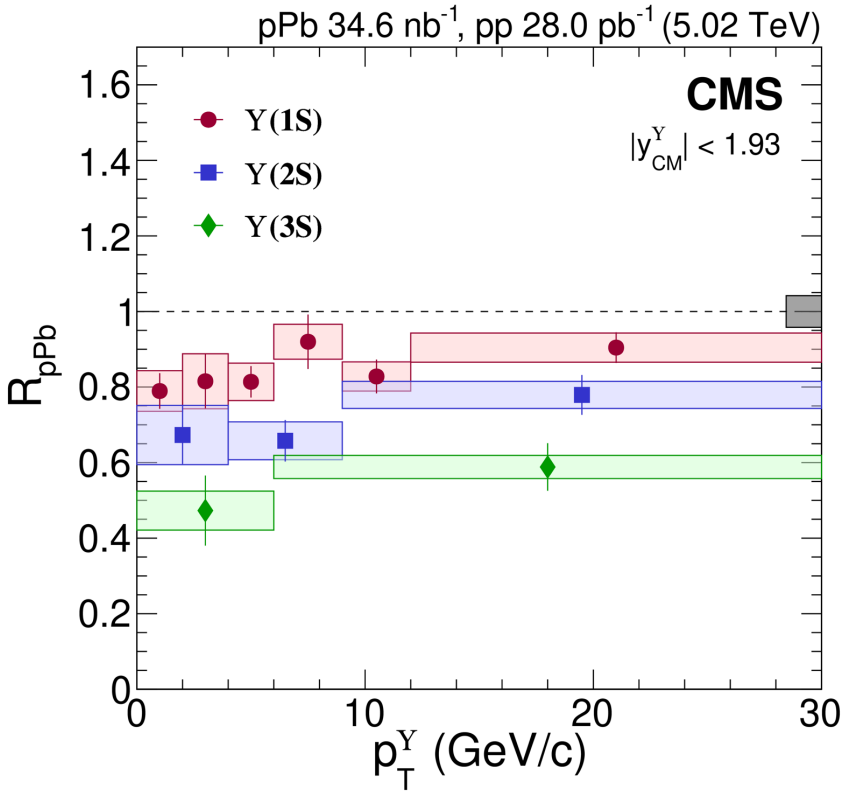


Strong model discrimination from double ratio

Upsilon in pA

PLB (2022) 137397





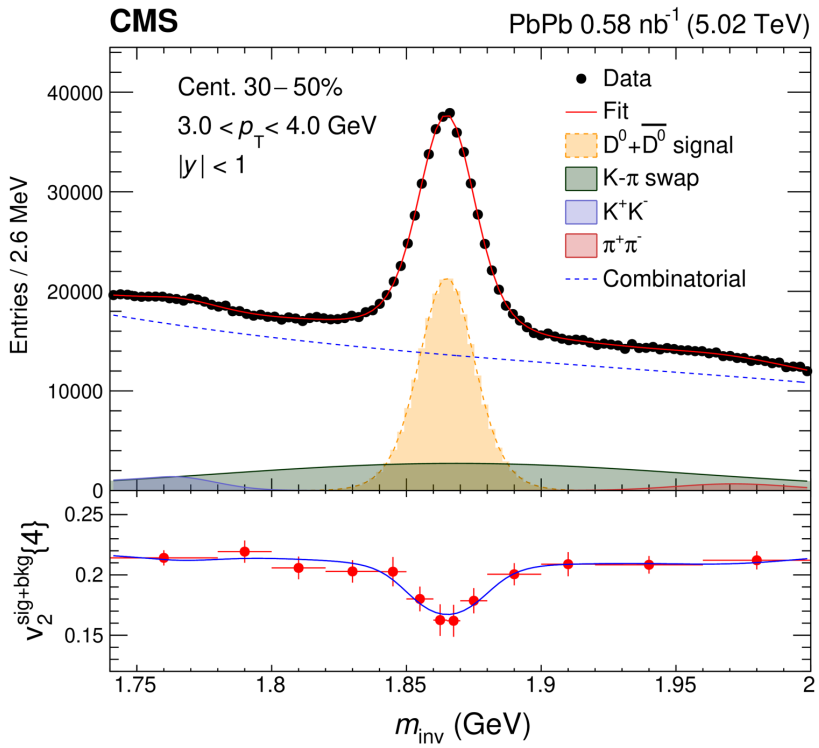
”Sequential suppression” is also observed in pPb

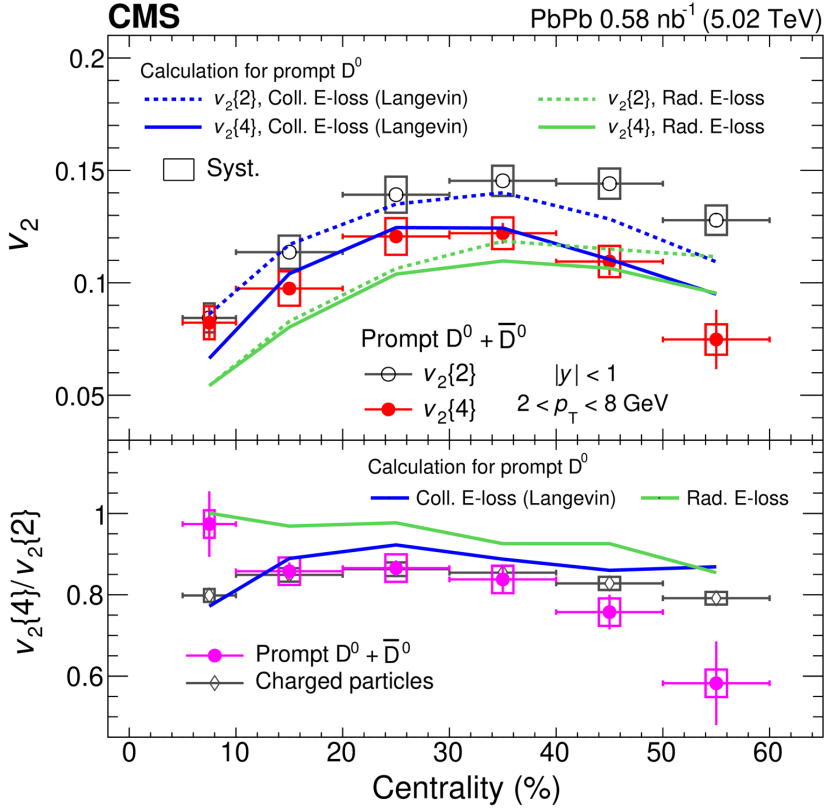
Suggests that final state effects are already important in pA

(initial state effects would affect all 3 states equally)

Charm elliptic flow in AA

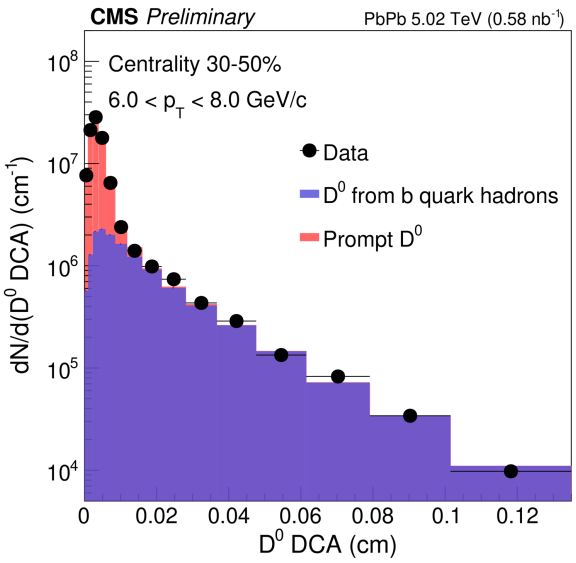
PRL 129 (2022) 022001





- Prompt D_0 v_2 measured with 2 and 4 particle cumulants
- Similar v2{4} / v2{2} to charged particles, pointing to similar origin (event-by-event fluctuations)

Heavy flavor azimuthal anisotropy

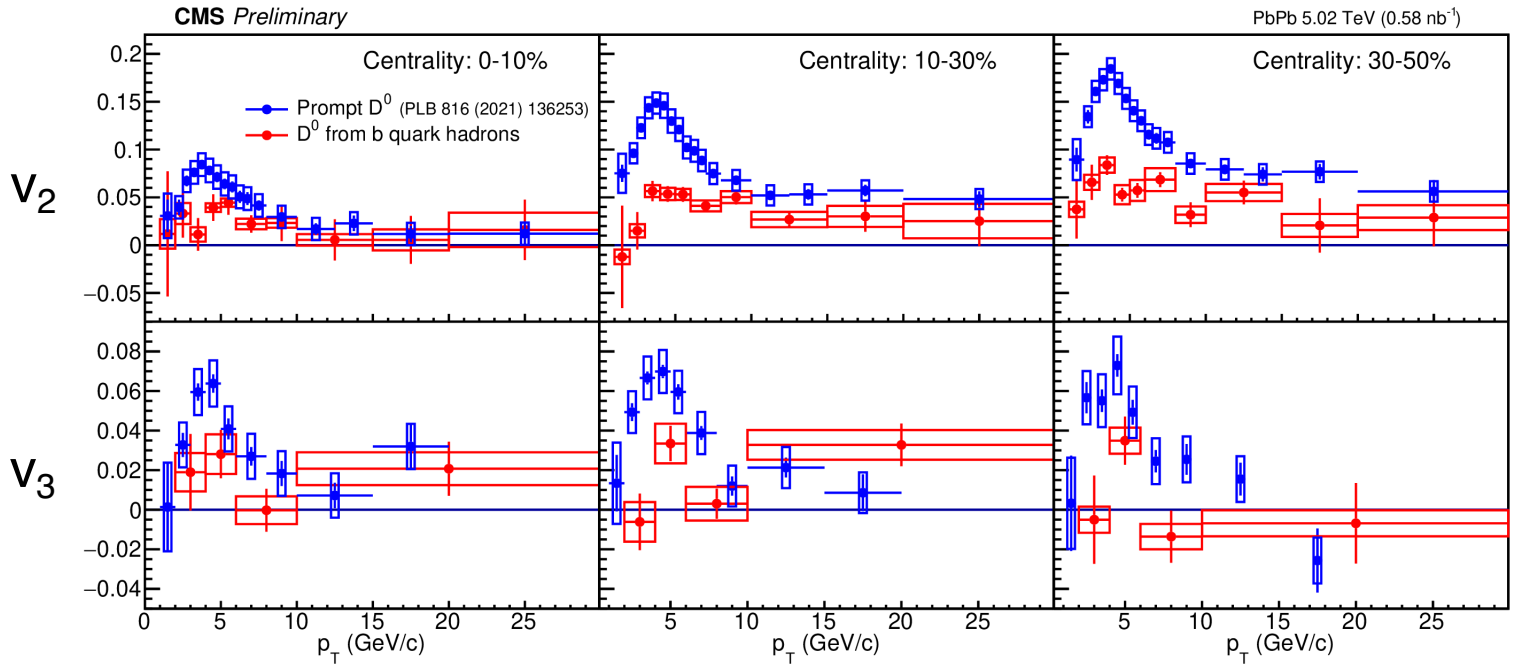


arXiv:2212.01636

Prompt / nonprompt D^0 separated based on DCA

- Charm v_2 & v_3 show characteristics of flow + energy loss
- Bottom more resistant to collective effects, but still shows influence of path-length dependent energy loss

Charm
Bottom

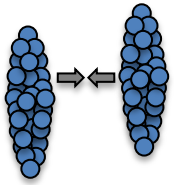


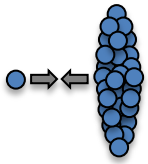
Azimuthal anisotropy of quarkonia

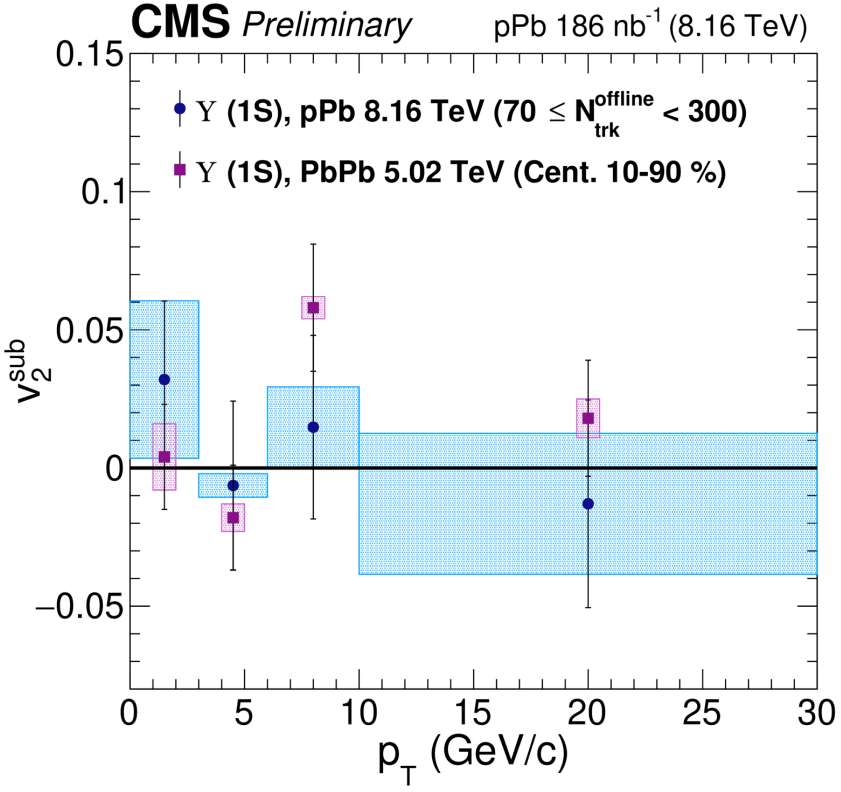
No sign of v_2 for Υ(1s) in high multiplicity pPb or PbPb

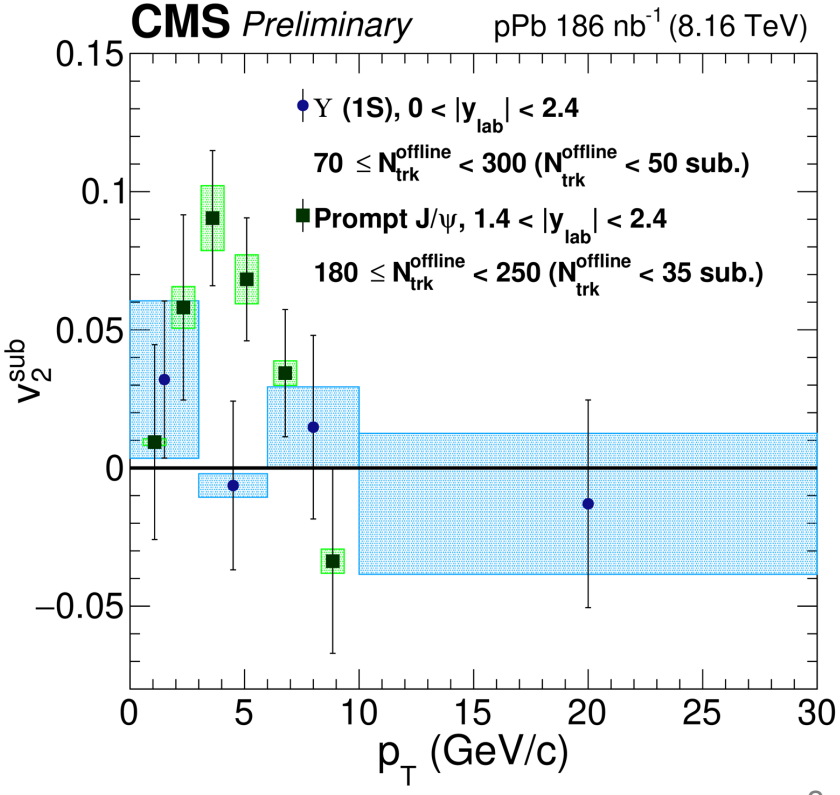
Significantly smaller than J/ψ v_2 in high multiplicity pPb

CMS-PAS-HIN-21-001

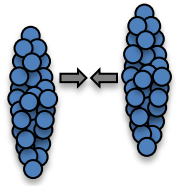


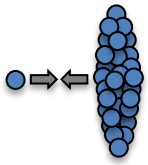


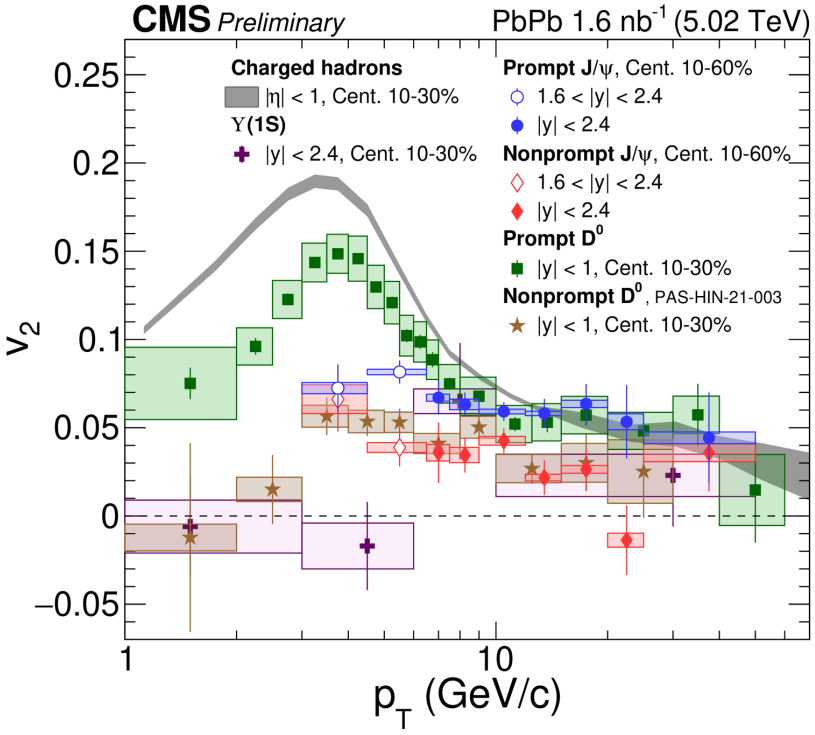


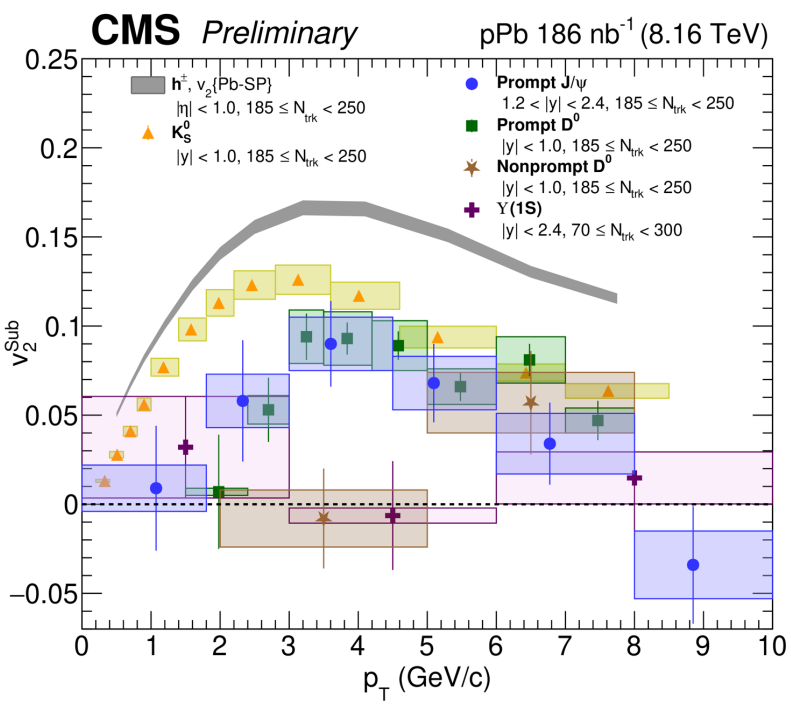


Heavy flavor v_2 hierarchy









h$^{\pm}$
D^0
J/ψ
b→D^0
b→J/ψ
Υ(1s)

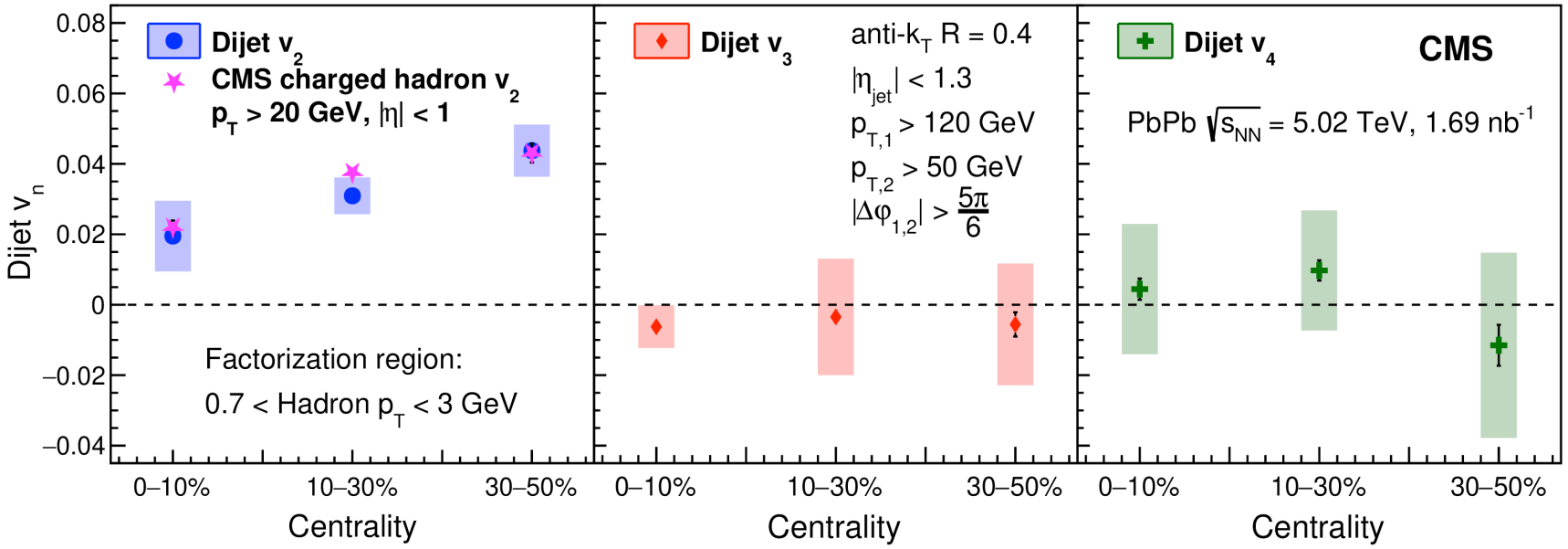
Hierarchy of heavy flavor azimuthal asymmetry starting to become clear

Should be further clarified with Run 3 data

CMS heavy-ion preliminary results

Dijet azimuthal anisotropy

arXiv:2210.08325

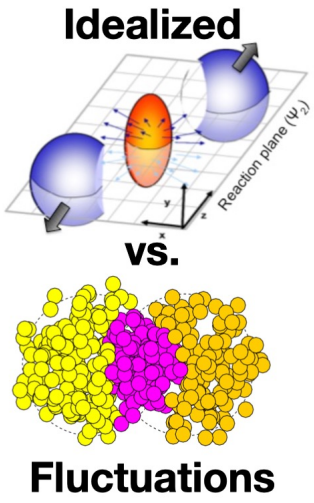


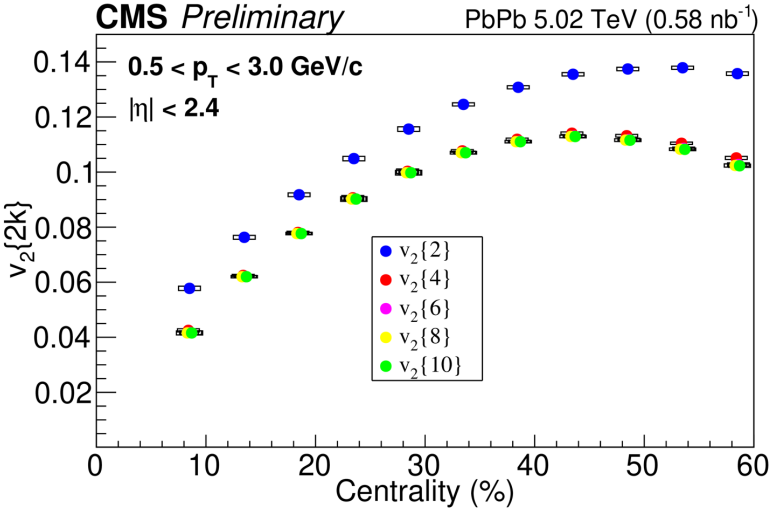
Strong v_2 arises from path-length dependence of jet quenching

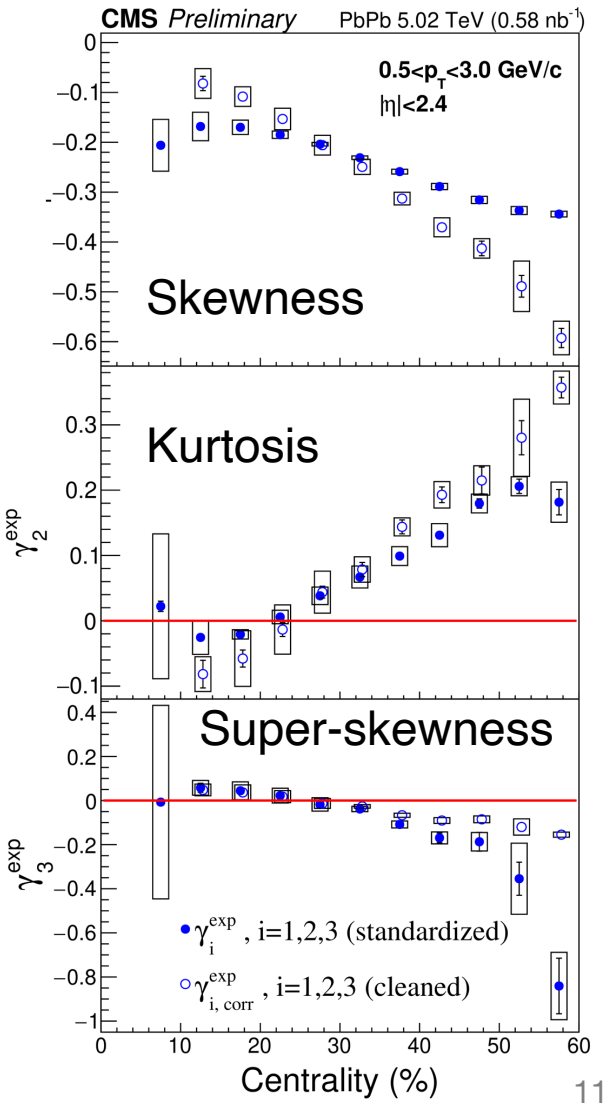
Higher order v_n consistent w/ zero → fluctuations don't play a role

Elliptic flow higher moments

CMS-PAS-HIN-21-010





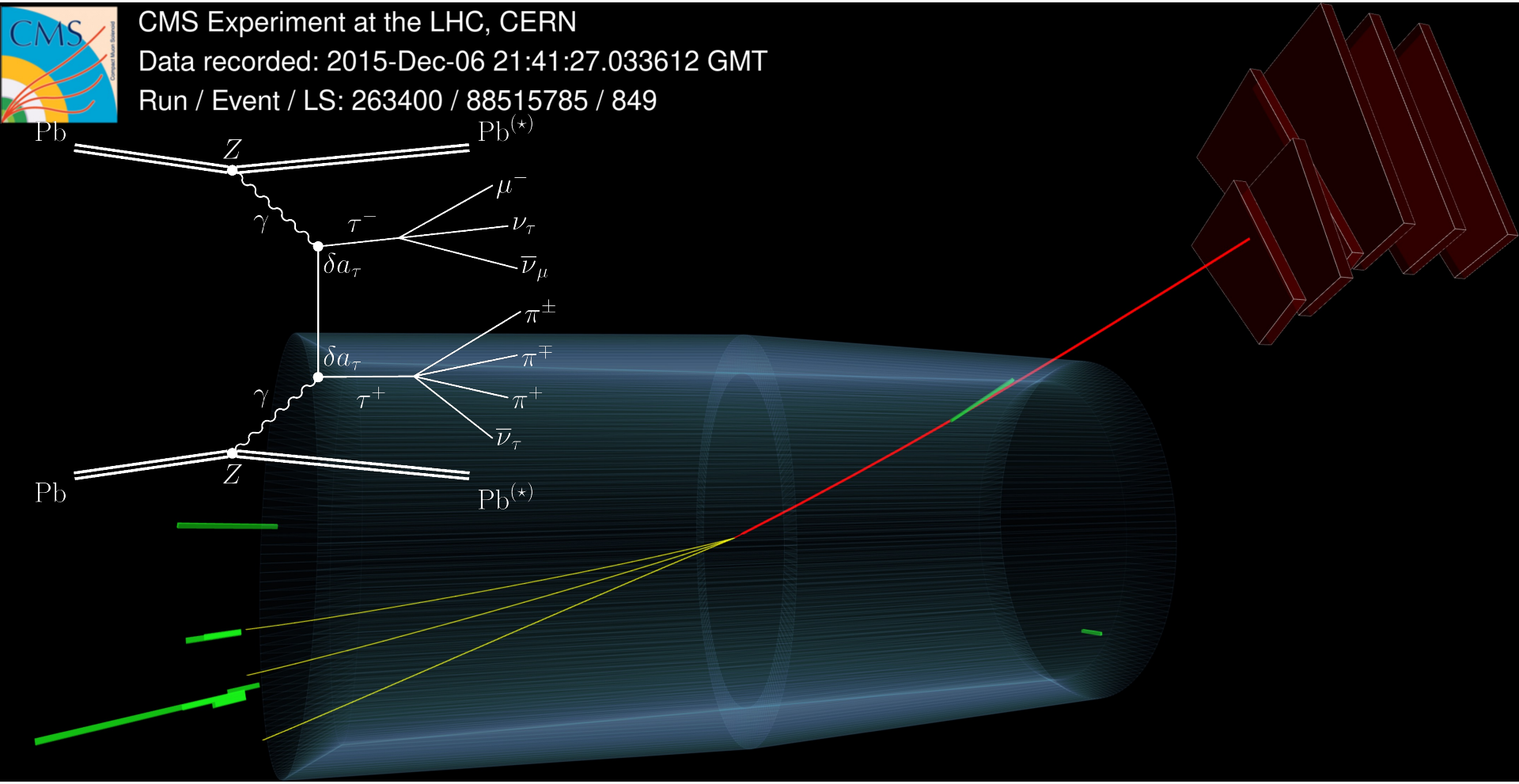


- Elliptic flow is sensitive to event-by-event fluctuations of the initial nucleon positions
- For Gaussian fluctuations: $v_2\{n\}$ independent of # of final state particles used to measure it (n), where n > 2
- Fine splitting of v_2 therefore maps out non-Gaussian fluctuations of the initial state
- Measured up to 5th central moment (n = 10)

Ultra-peripheral collisions

$\gamma\gamma \rightarrow \tau\tau$ event display

$\sigma \propto Z^4$, where Z(Pb) = 82



Observation of γγ → ττ

"Using light to make cousins of the electron"
CMS briefing

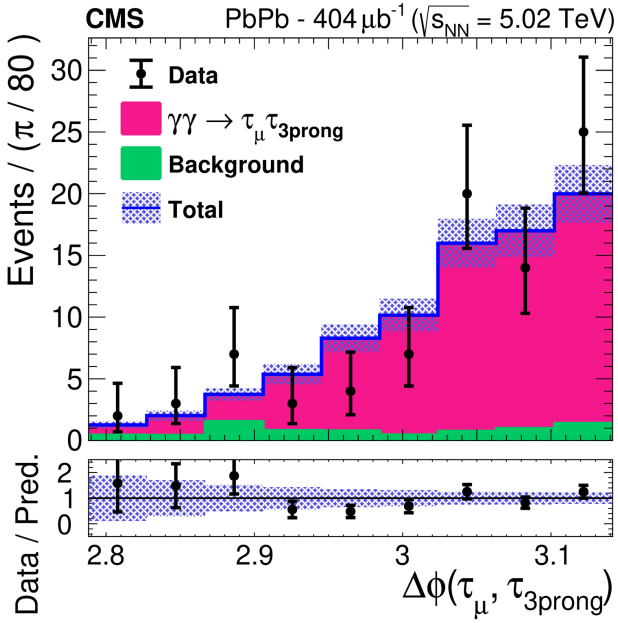
arXiv:2206.05192 (accepted by PRL)

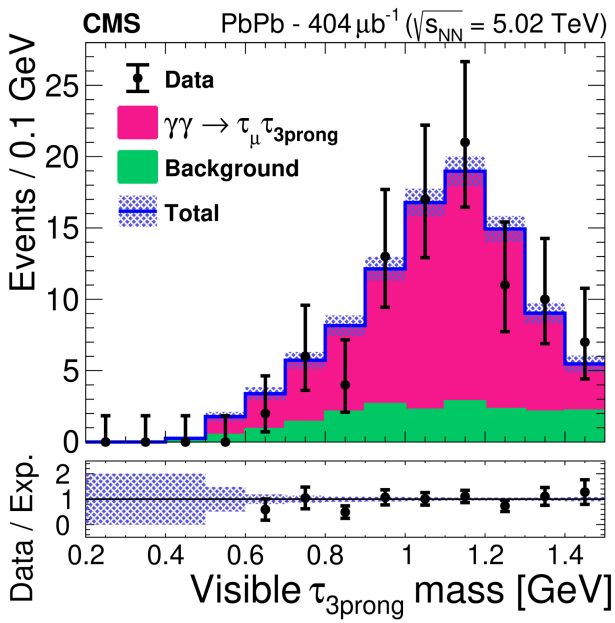
Anomalous magnetic moment a_τ sensitive to BSM

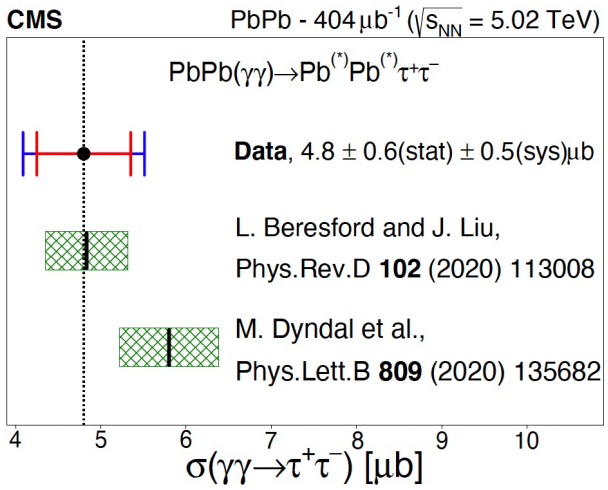
Observation by CMS:
77 ± 12 events

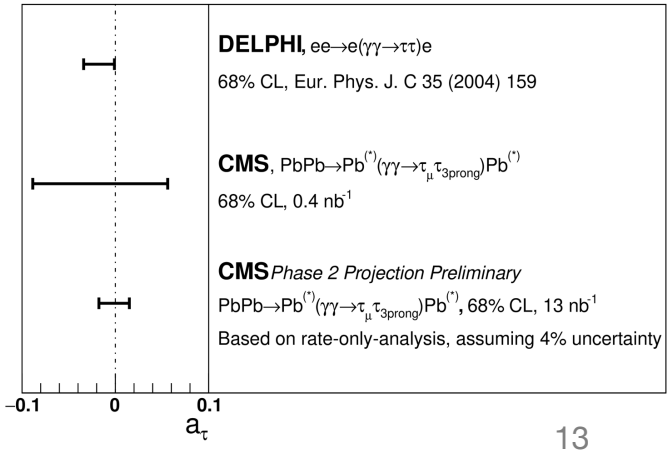
→ a_τ consistent w/ zero

Projected to be competitive w/ LEP in LHC Phase 2

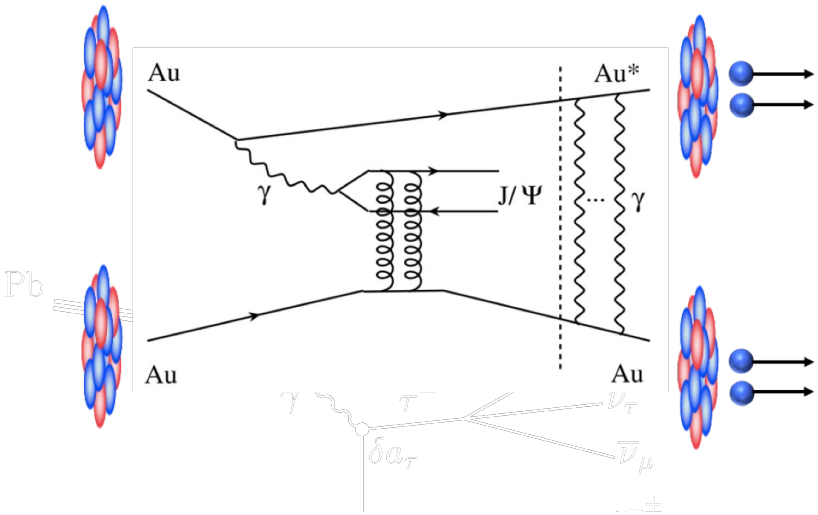


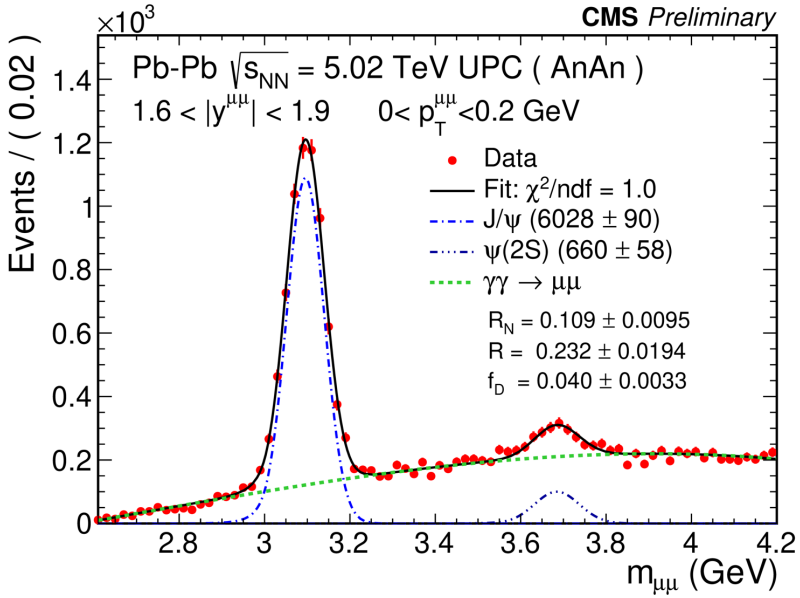




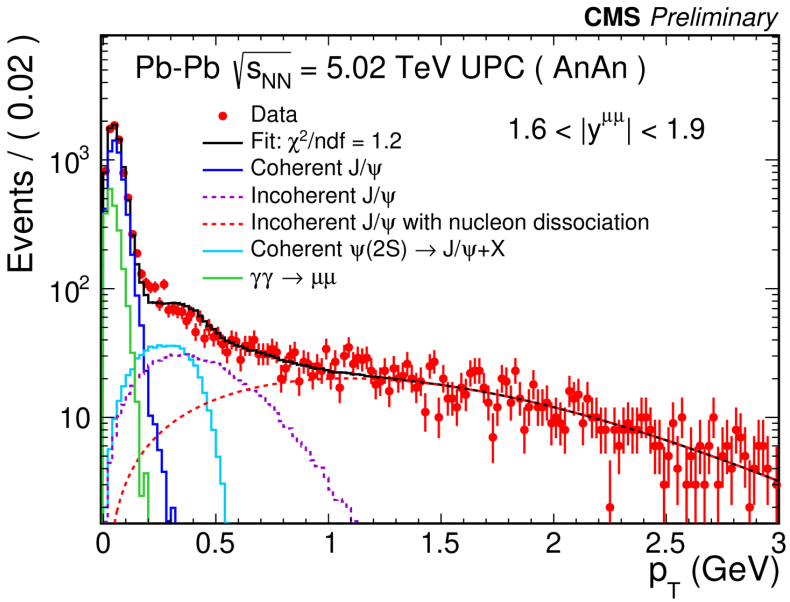


J/ψ from γ + A





[CMS-PAS-HIN-22-002]



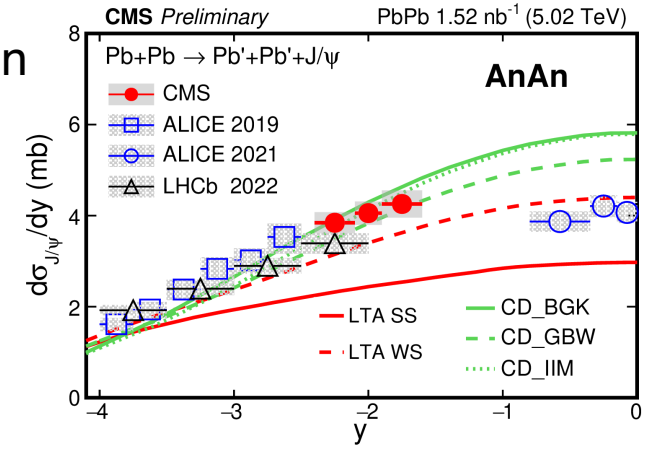
Interested in coherent component:
γ + A → J/ψ +A

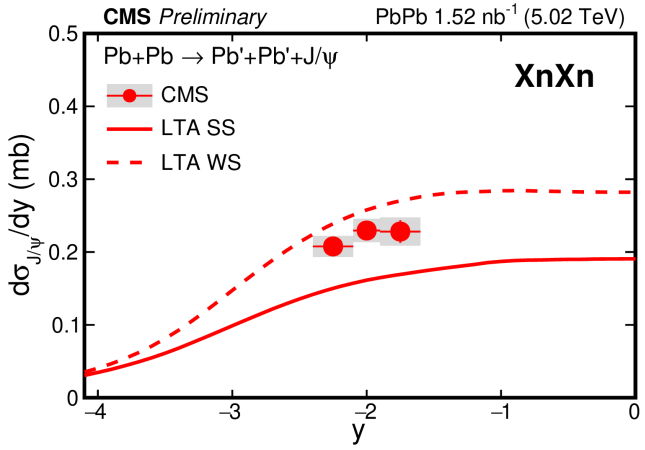
Extracted via template fit

Determining the photon kinematics

J/ψ x-section samples mix of low and high E γ-A c.o.m. contributions

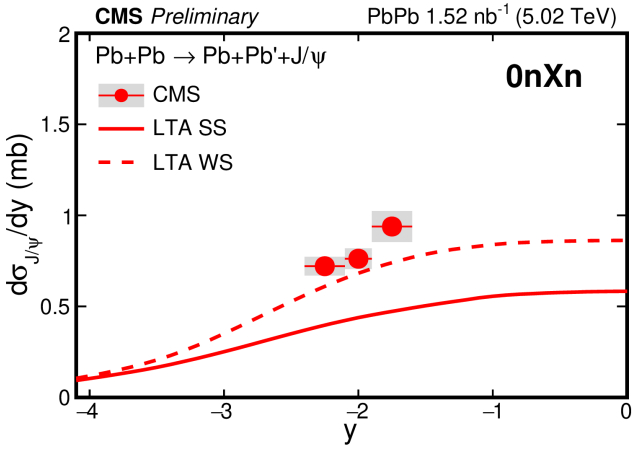
Any neutron multiplicity

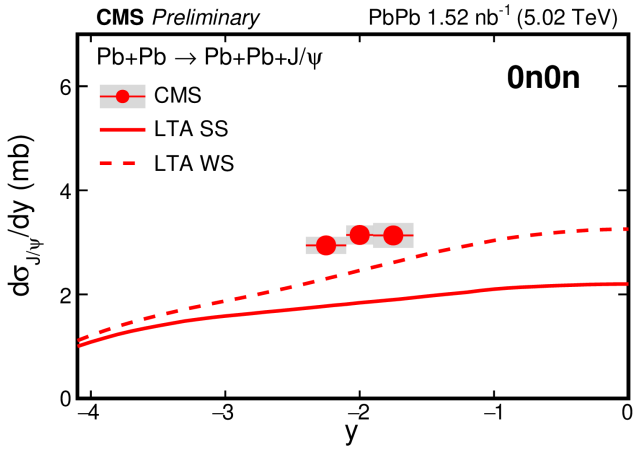




> 1n on both sides

> 1n on one side





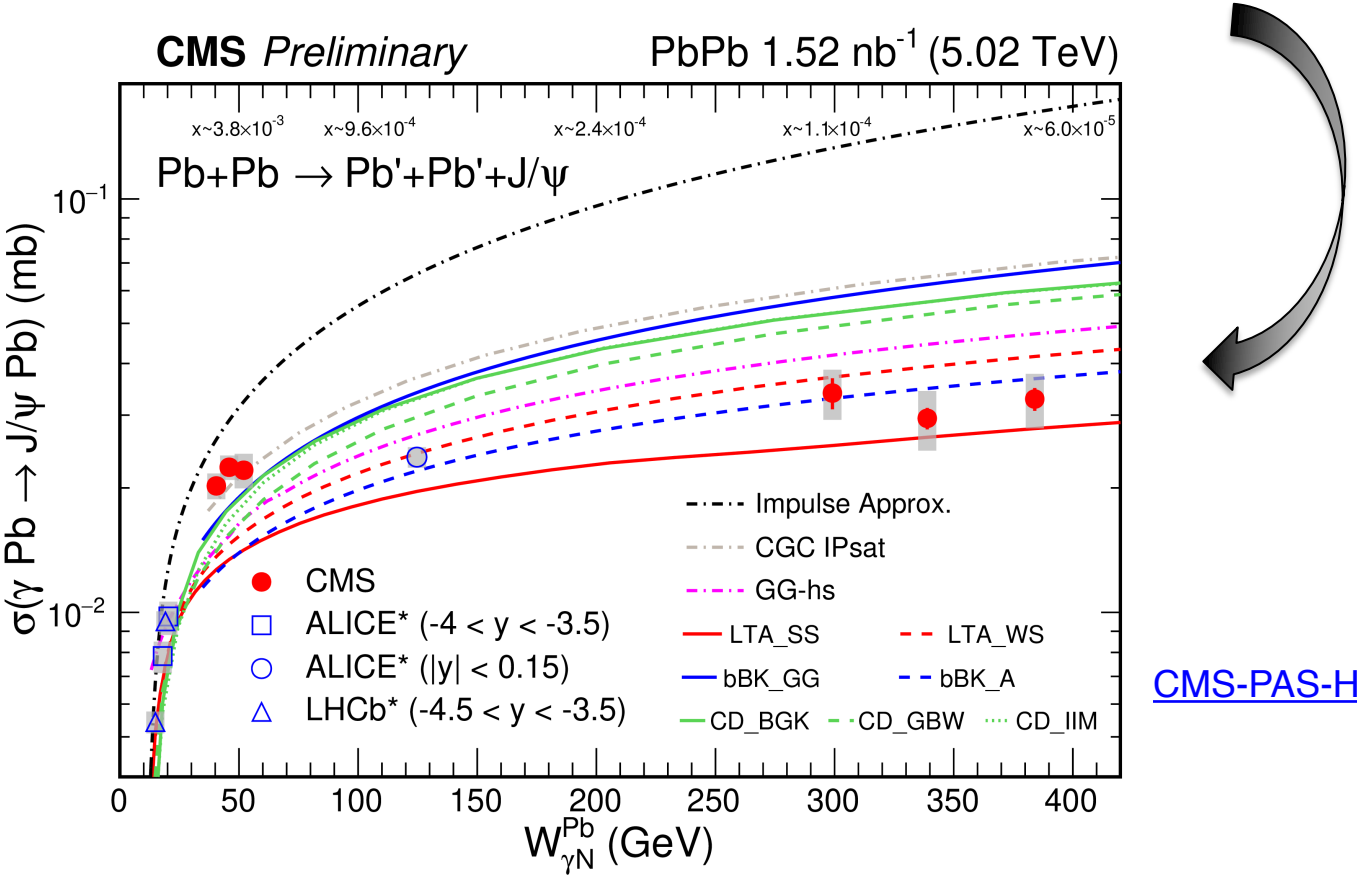
0n on both sides

Novel approach: Control UPC impact parameter by separating contributions from based on forward neutron multiplicity

[CMS-PAS-HIN-22-002]

Coherent J/ψ x-section vs COM energy

Control of kinematics allows the 1st measurement to large energy / small Bjorken x



CMS-PAS-HIN-22-002

Rapid rise of J/ψ x-section, which ”saturates” at high γ-A c.o.m. energy / low x

Could be an indication of gluon saturation and/or approach to black disk limit

1st NLO calculation show a large contribution from quark-initiated processes

→ important for physics interpretation

Eskola et al, arxiv:2203.11613

CMS Upgrades

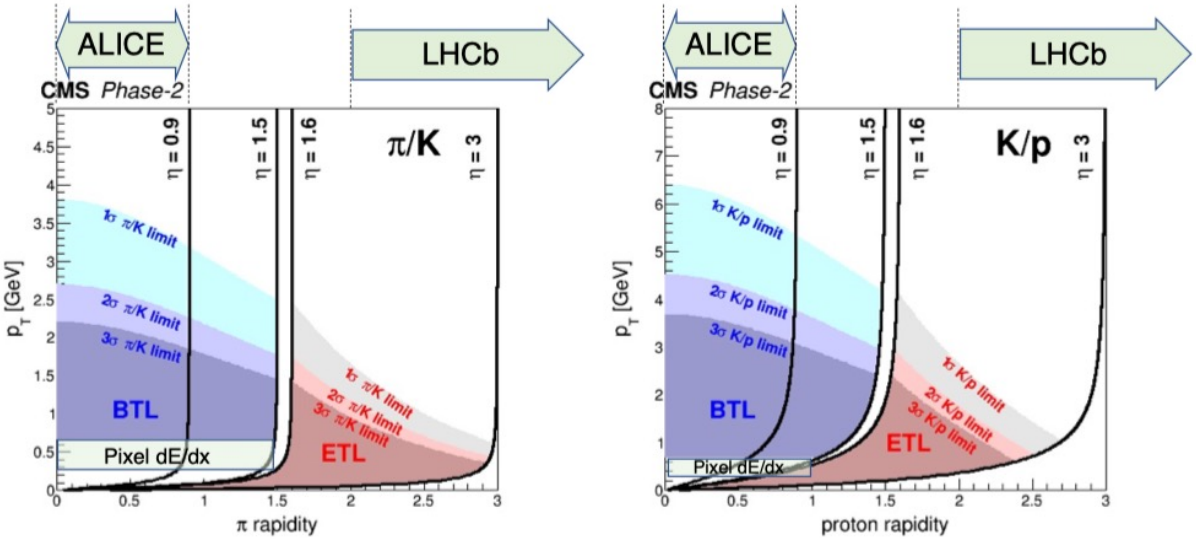
Phase 2 upgrades will prepare CMS for occupancies in pp that approach heavy ions

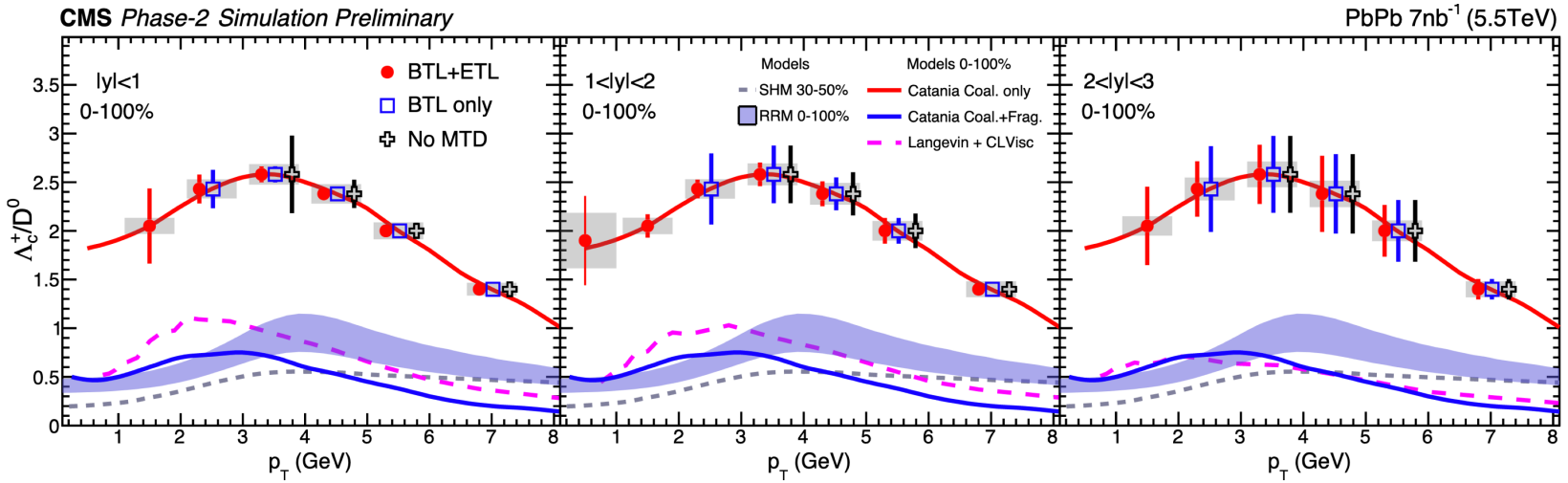
- Capabilities for heavy ions will improve across the board

CERN-LHCC-2019-003
CMS-DP-2021-037

MIP Timing Detector will bring time-of-flight based PID to CMS

Charm hadronization studies down to $p_T \approx 0$

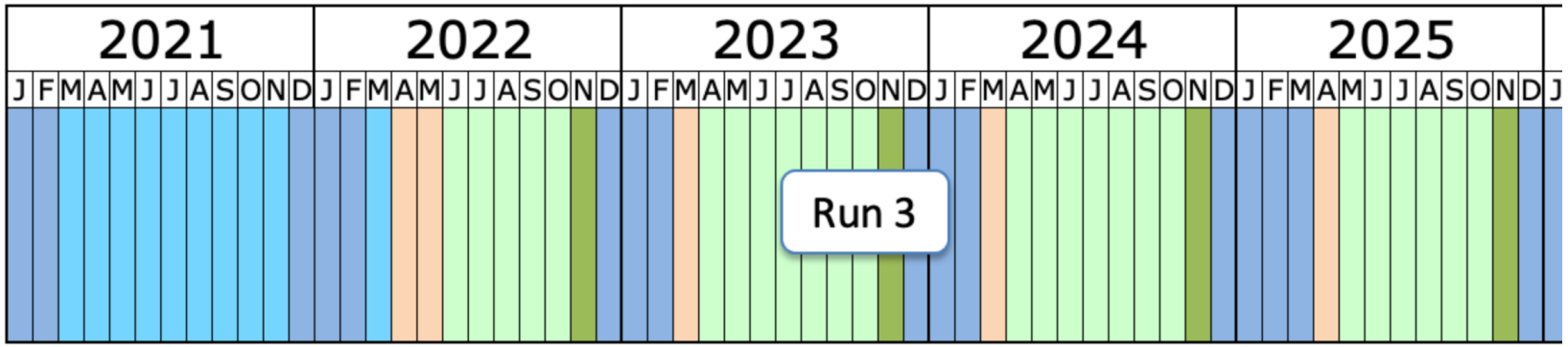




Conclusions

- CMS has plenty of recent heavy-ion results on
  - Quarkonia dissociation
  - Open heavy flavor
  - Flow fluctuations
  - Jet quenching
  - Ultraperipheral collisions

CMS heavy ion results



Although this year's run was postponed, still looking forward to many new & interesting results with the large Run 3 dataset & beyond!