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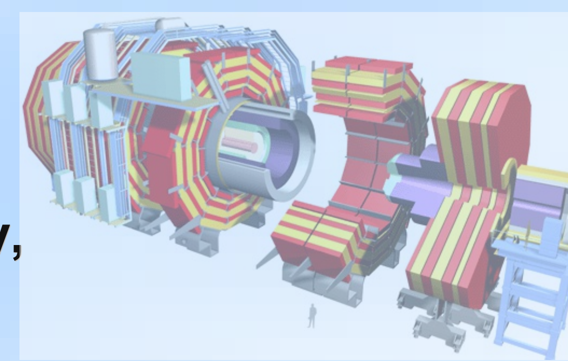
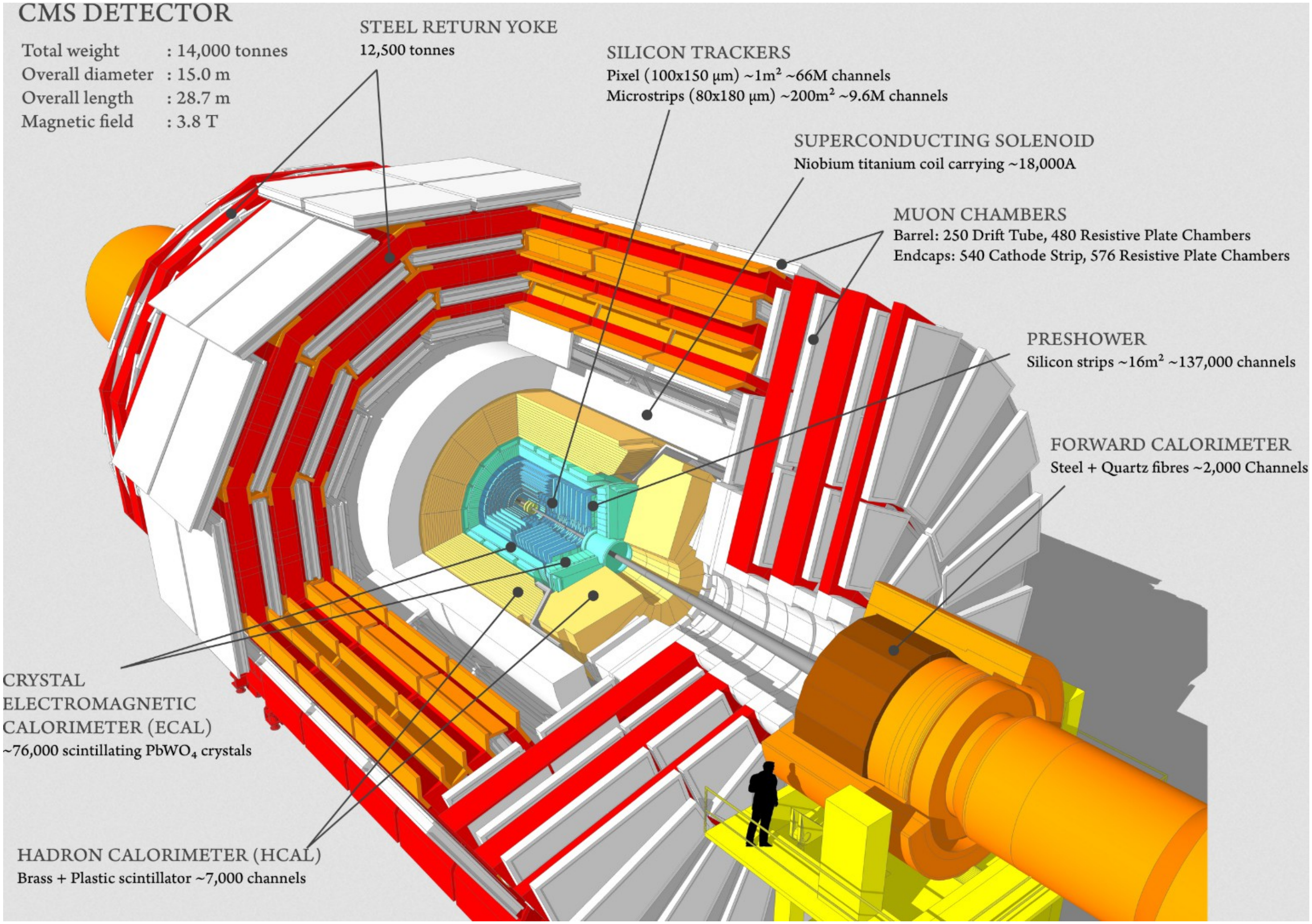
Latest results on heavy-ion physics with the CMS detector

21st Lomonosov Conference
on Elementary Particle Physics

Lomonosov Moscow State University,
Moscow, Russia
24 – 30 August 2023



CMS is a nice heavy-ion experiment

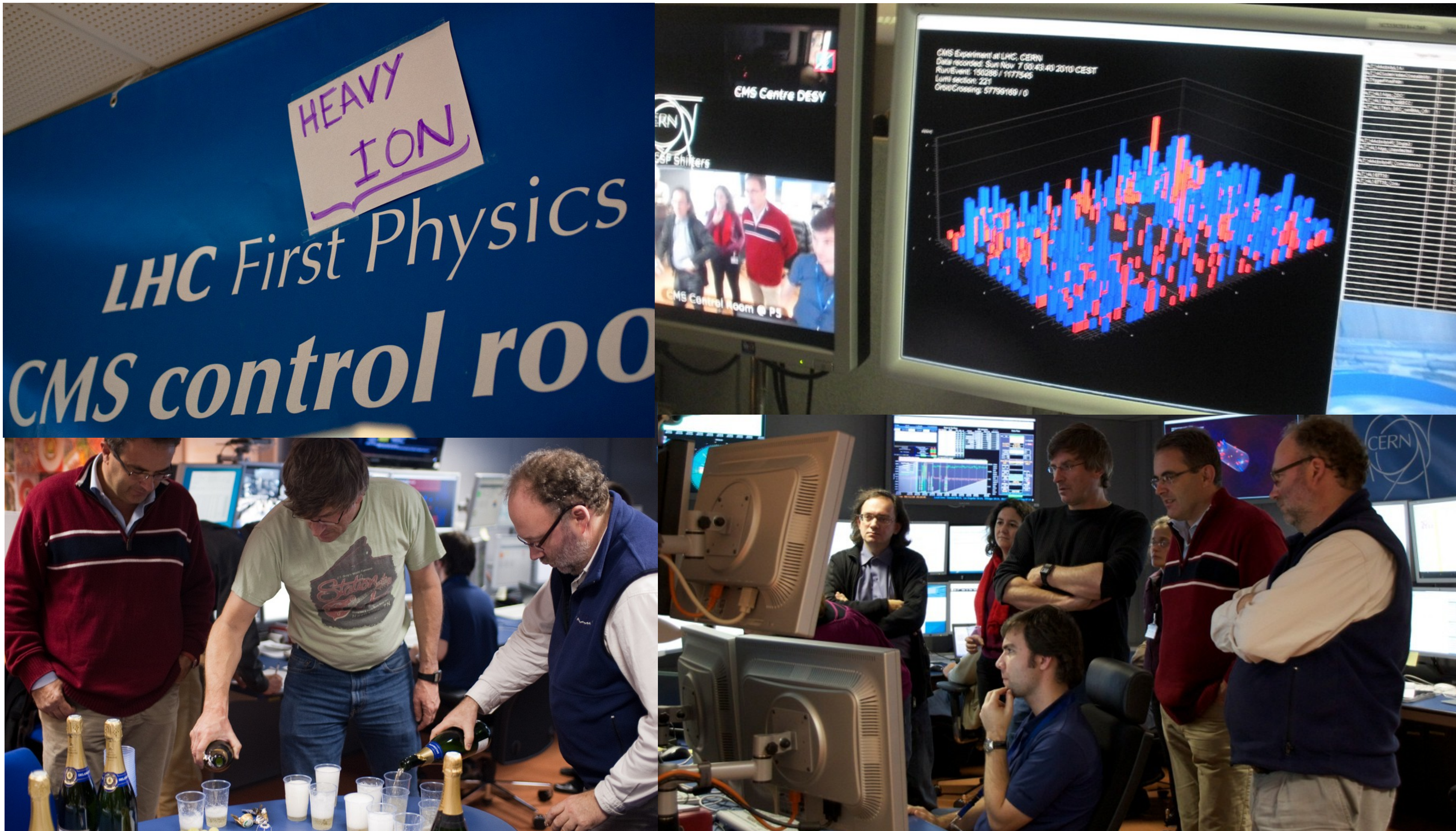


- **Silicon Tracker**
  $|\eta| < 2.4$
- **Electromagnetic Calorimeter**
  $|\eta| < 3.0$
- **Hadron Calorimeter**
  barrel and endcap
  $|\eta| < 3.0$
  with HF-calorimeter up to
  $|\eta| < 5.2$
- **Muon Chambers**
  $|\eta| < 2.4$

+ CASTOR detector
$-5.2 < \eta < -6.6$
+ Zero-degree calorimeter
+ TOTEM

Magnetic field: 3.8 Tesla

November 7, 2010 0:27. CMS Control Room



CMS heavy-ion physics results

129 published/submitted
Heavy-ion Physics CMS papers:

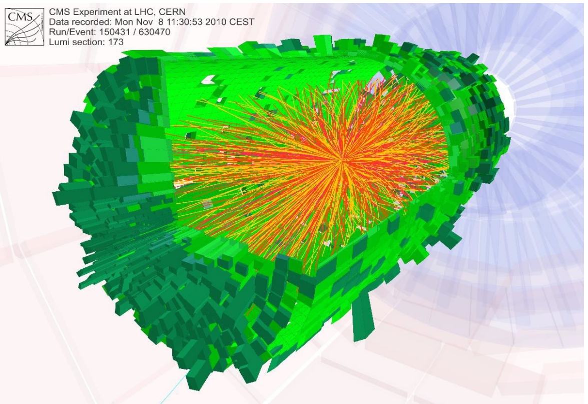
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN/index.html

…and also > 100
Heavy-ion Physics CMS preliminary results (PAS):

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIN/index.html

CMS heavy-ion physics results

- **Global picture of heavy-ion collisions**
  - multiplicity,
  - energy,
  - flow, ...



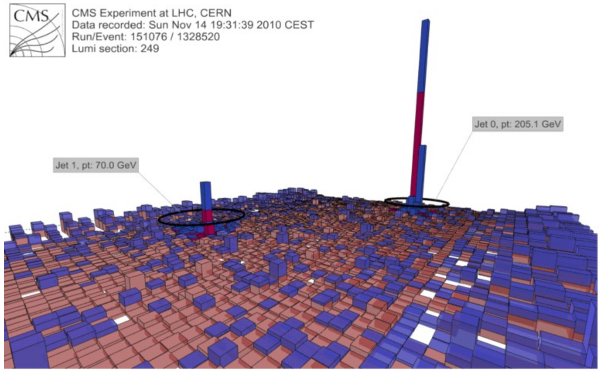
Pb+Pb collisions

2010-11: 2.76 TeV 0.16/nb

2015-18: 5.02 TeV 1.7/nb

2023- ? : 5.36 TeV ...

- **Hard probes**
  - jets
  - dimuons (quarkonia)
  - charged hadrons R_{AA}, ...

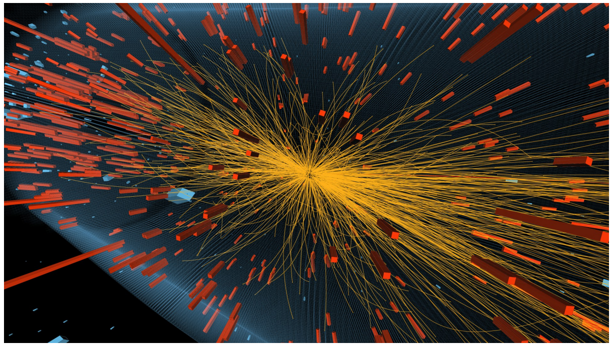


- **p+p, p+Pb, Xe+Xe**
  - correlations
  - flow,
  - jets, ...

p+p 2.76, 5.02, 7, 8, 13 TeV

p+Pb 5.02, 8.16 TeV

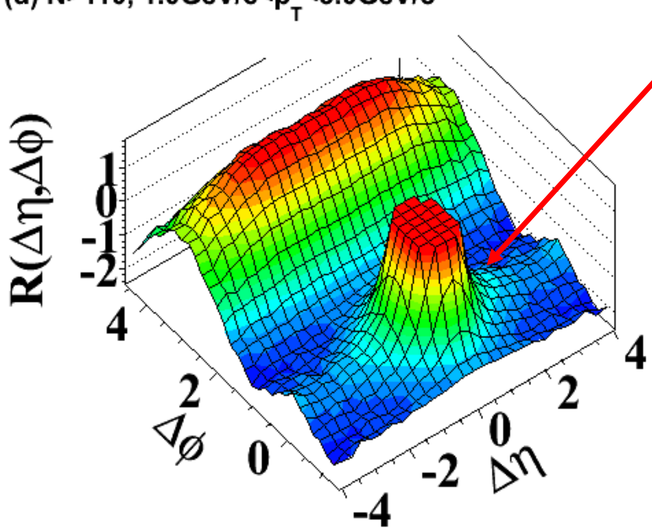
Xe+Xe 5.44 TeV



Correlations: “RIDGE” is everywhere...

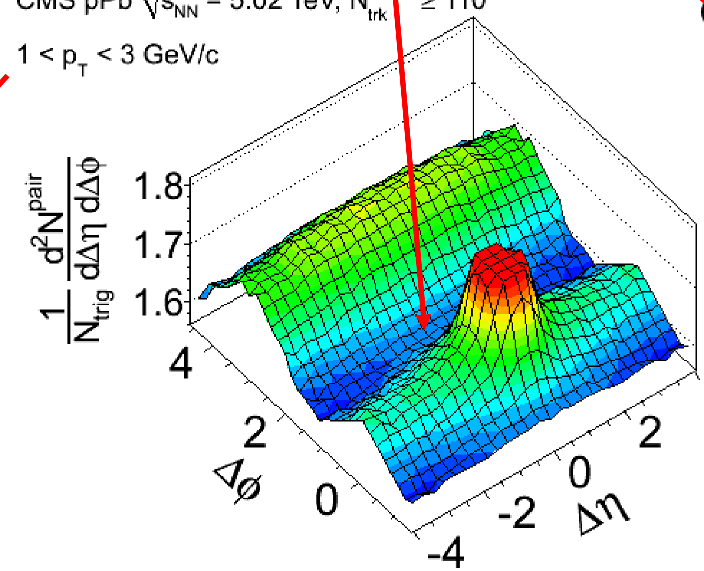
Long-range ($2 < |\Delta\eta| < 4$), near-side ($\Delta\phi \approx 0$) angular correlations were observed in high multiplicity p+p and p+Pb collisions (as well as in Pb+Pb)

p+p 7 TeV



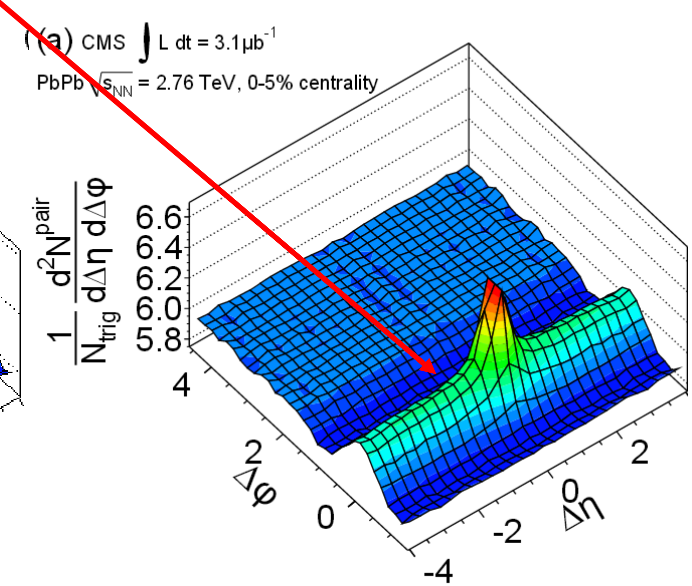
JHEP 09 (2010) 091

p+Pb 5.02 TeV



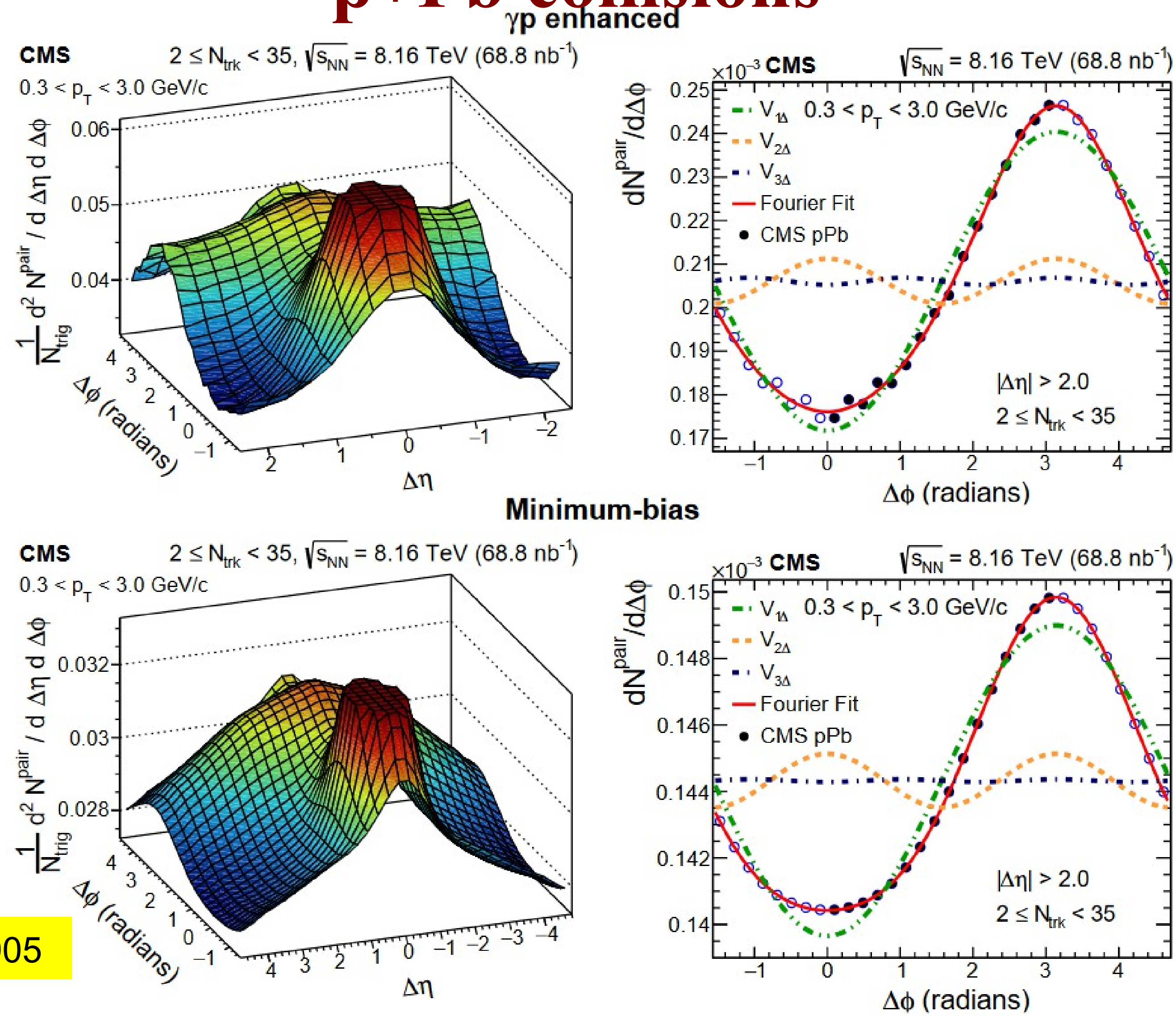
PLB 718 (2013) 795

Pb+Pb 2.76 A TeV, 0-5%



JHEP 07 (2011) 076

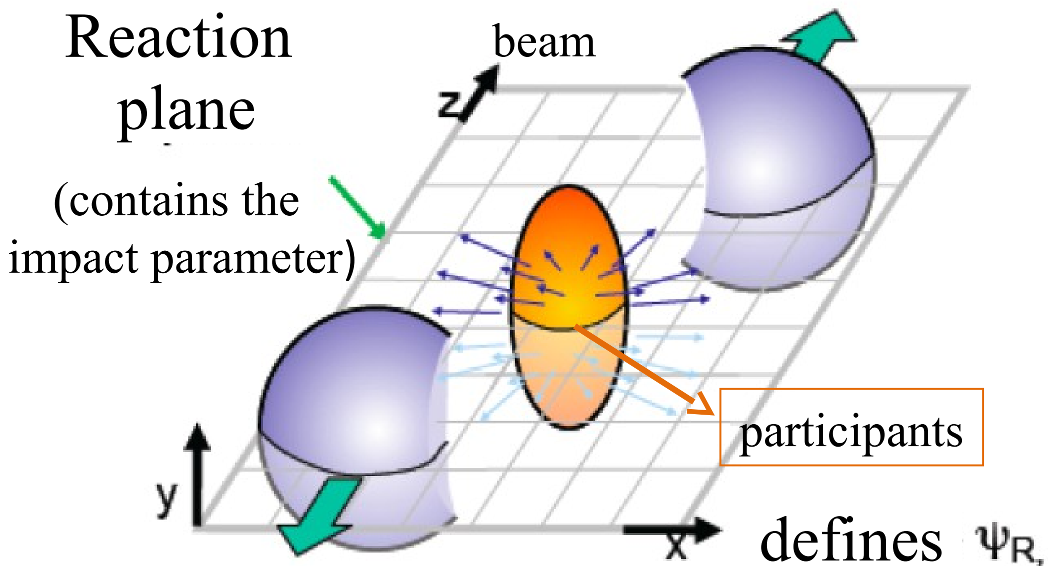
γp interactions within ultra-peripheral p+Pb collisions



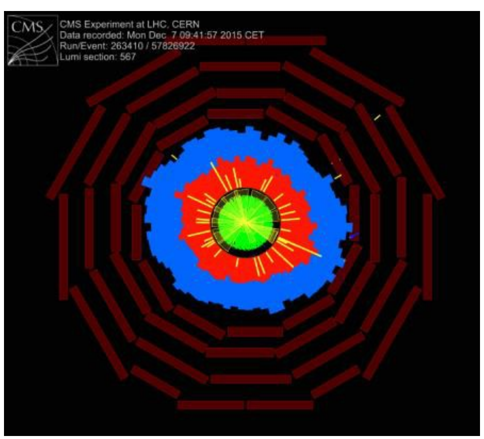
PLB 844 (2023) 137905

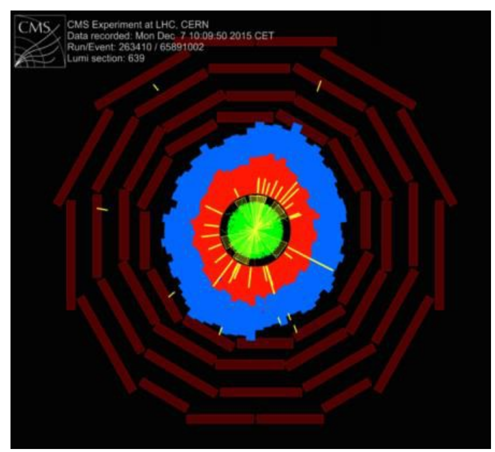
The single particle flow coefficient $v_2(p_T)$ is larger for γp-enhanced events than for minimum-bias collisions. But we don't see "ridge" here!

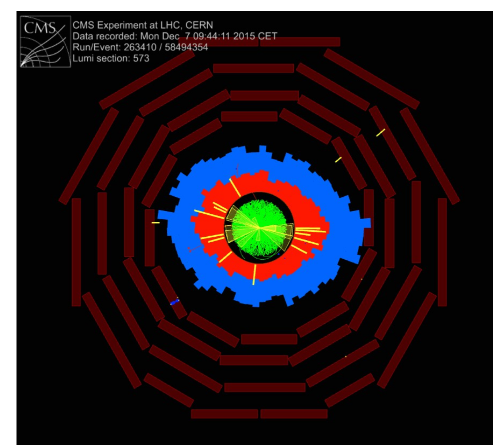
Flow



Non-central Pb+Pb “screen shots” from CMS Event Monitor:
Electromagnetic, **Hadronic** **Energy** and **charged particles tracks**

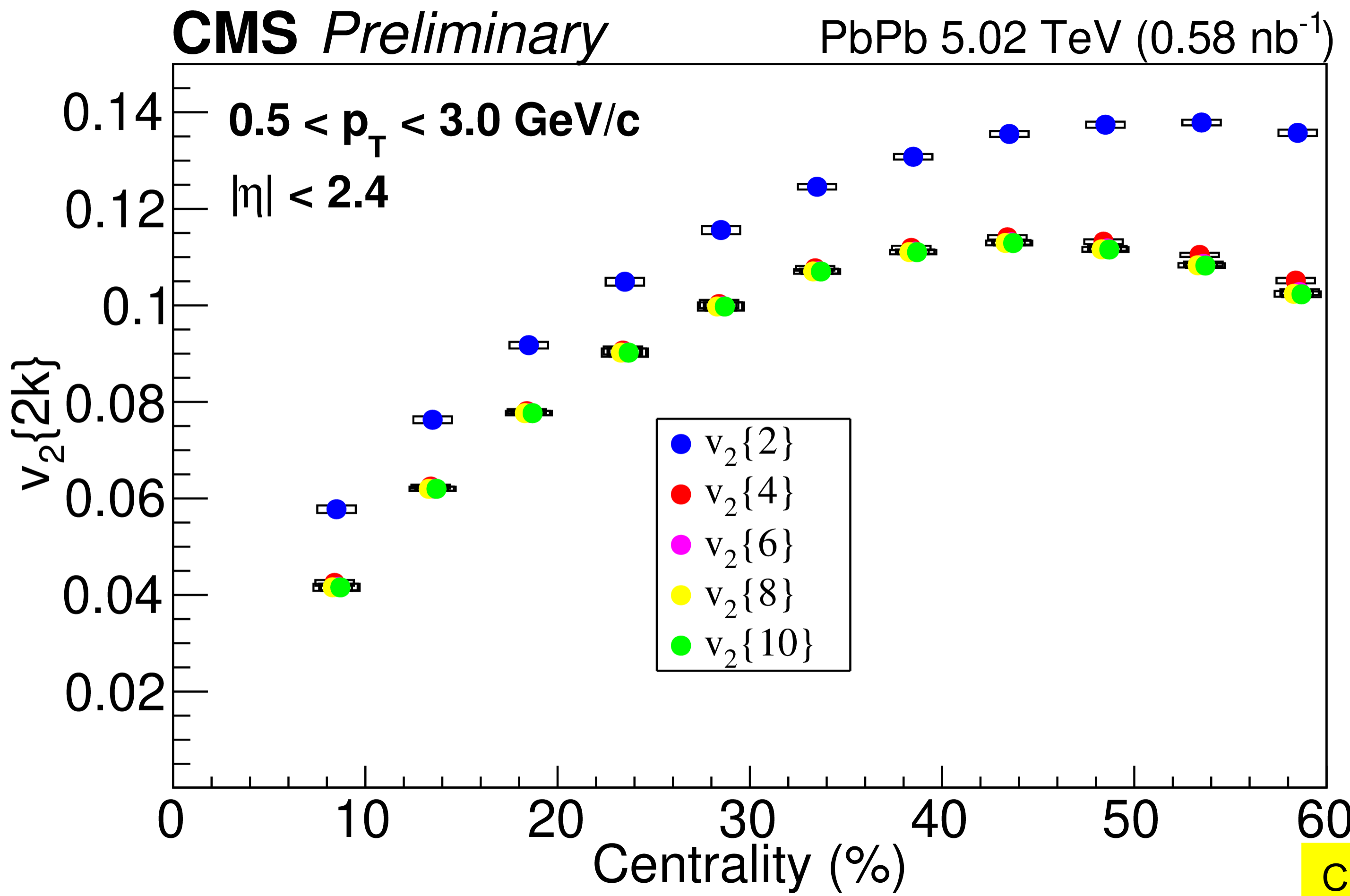






Collective motion is observed in the event azimuthal distributions

The cumulants of the elliptic flow $v_2\{2k\}$ in Pb+Pb collisions

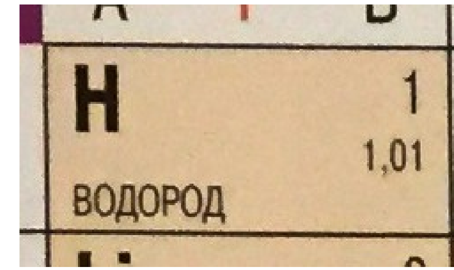


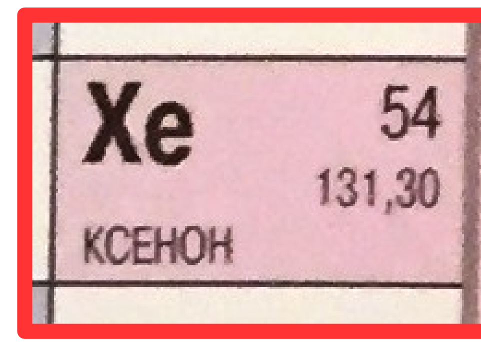
CMS-PAS-HIN-21-010

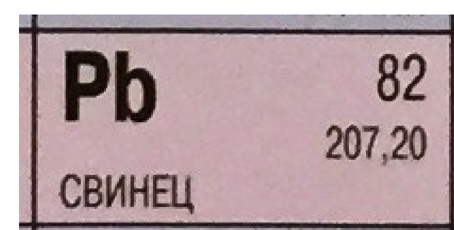
$v_2\{2\} > v_2\{4\} \gtrsim v_2\{6\} \gtrsim v_2\{8\} \gtrsim v_2\{10\}$ ($v_2\{10\}$ is the first time ever)

The subtle differences in the higher order harmonics allow for a precise determination of the underlying hydrodynamics and what condition prevail before the onset of hydrodynamics.

Xe+Xe as a “bridge” between p and Pb

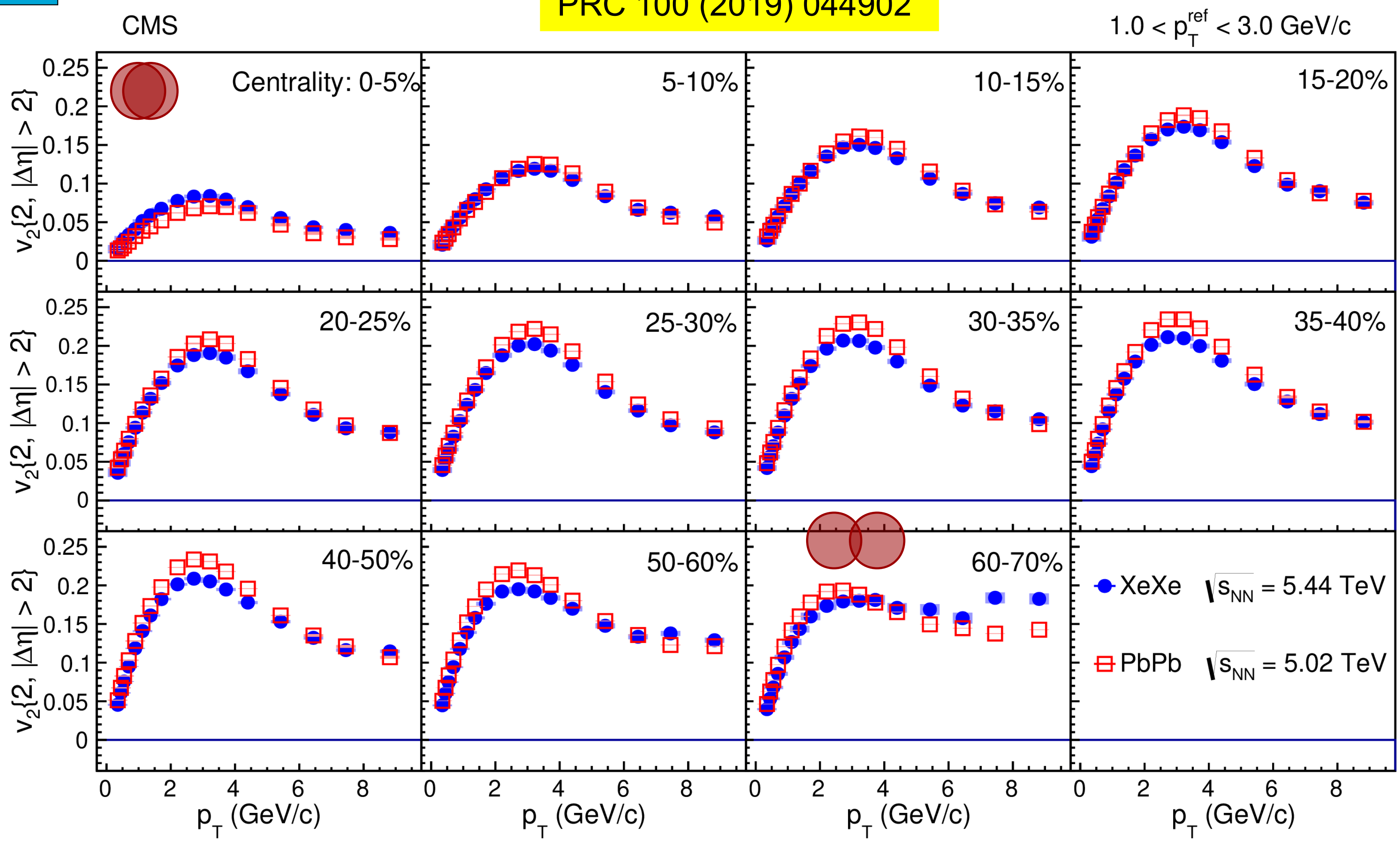


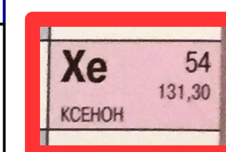




v_2 Xe+Xe vs. Pb+Pb

PRC 100 (2019) 044902

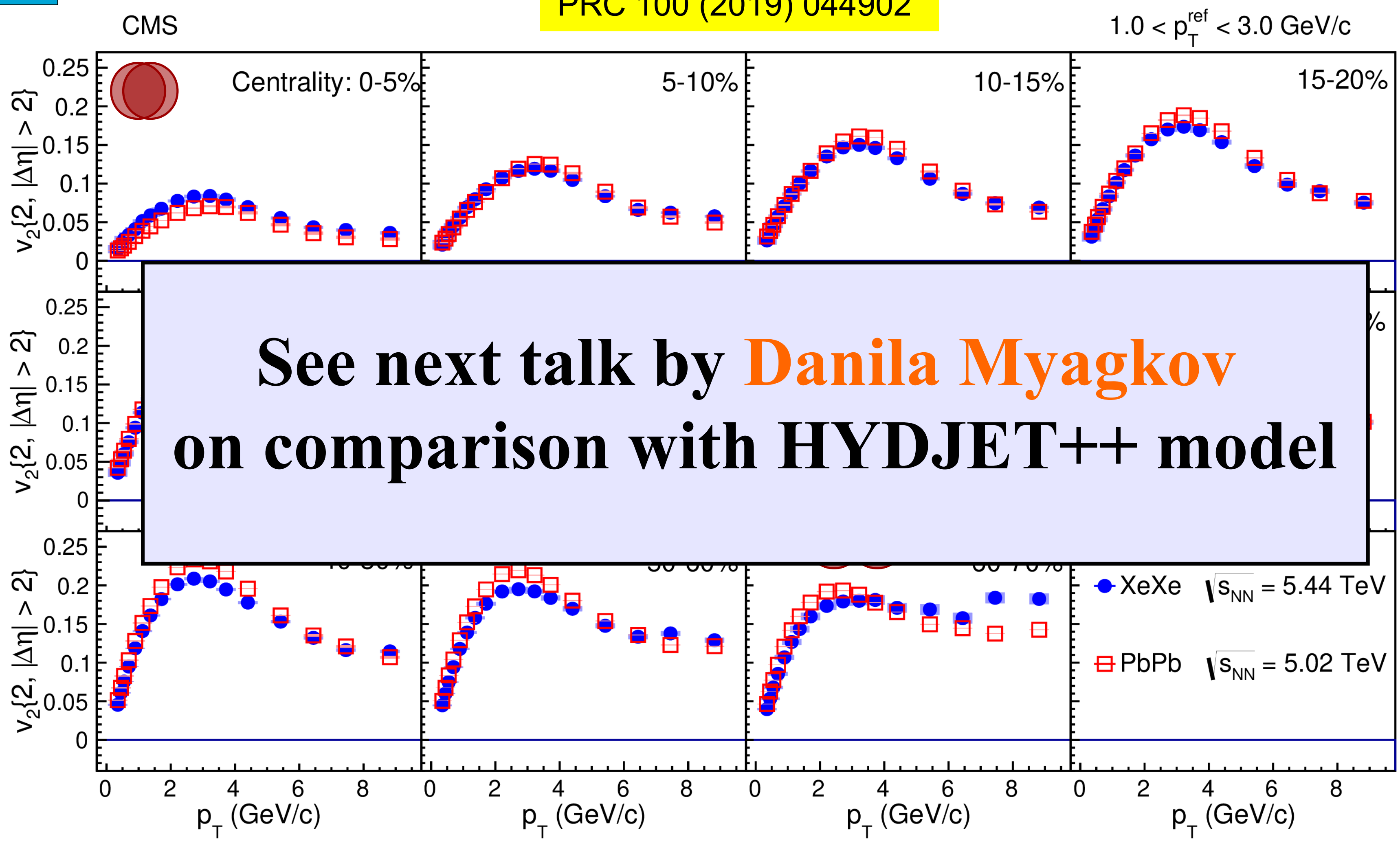


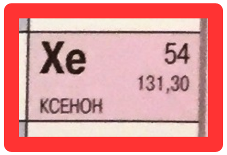


The magnitude of the v_2 coefficients for Xe+Xe collisions are larger than those found in Pb+Pb collisions for the most central collisions. This is attributed to a larger fluctuation component in the lighter colliding system.

v_2 Xe+Xe vs. Pb+Pb

PRC 100 (2019) 044902



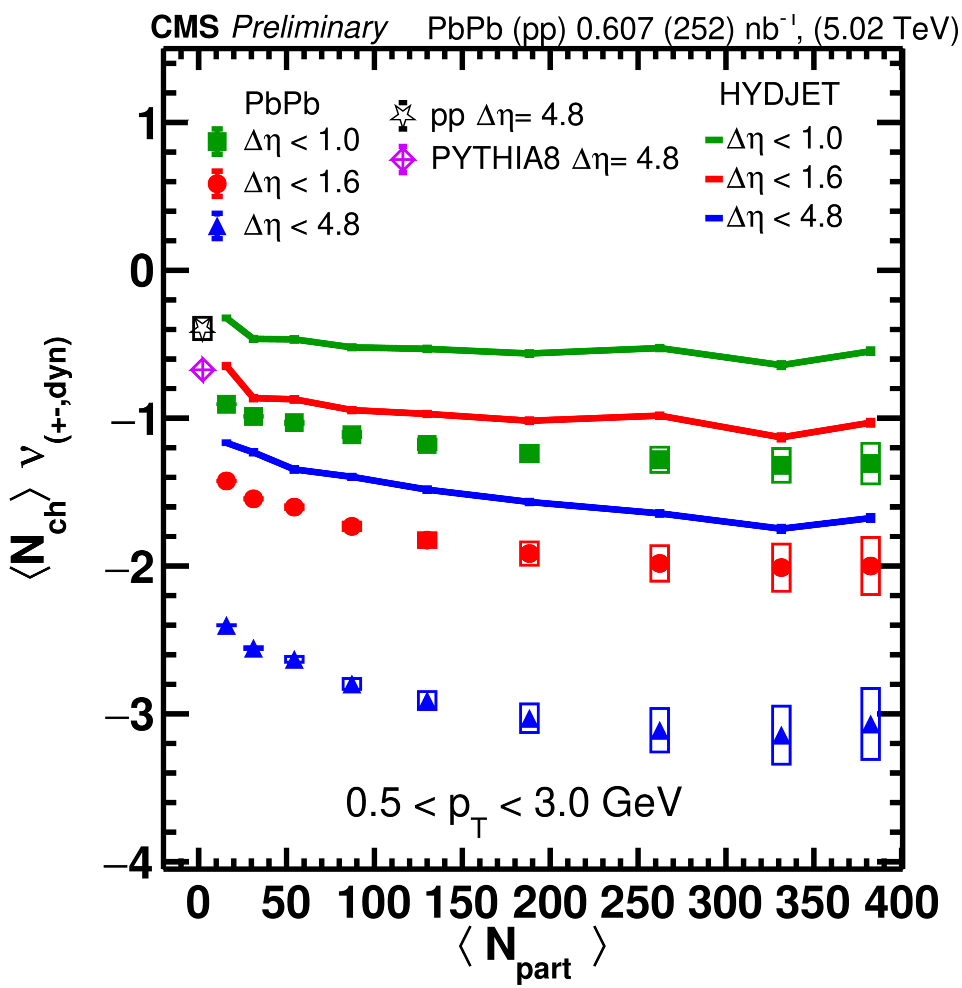


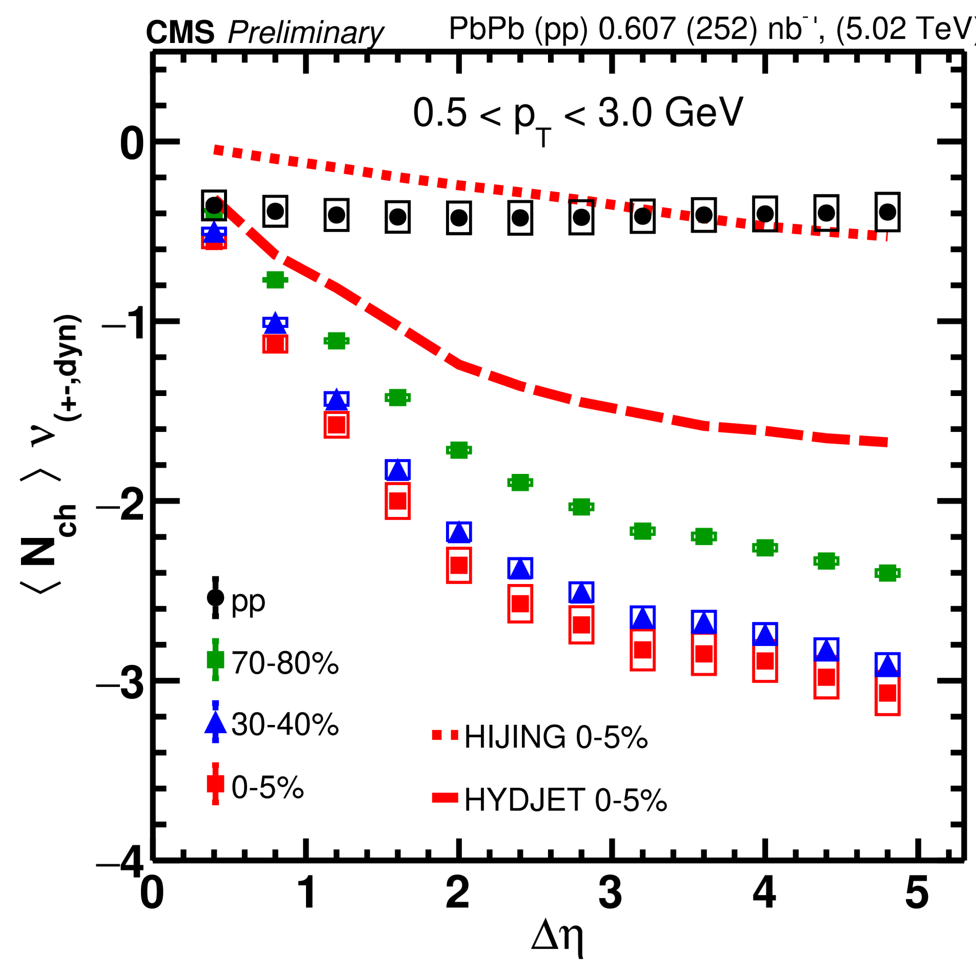
See next talk by Danila Myagkov on comparison with HYDJET++ model

The magnitude of the v_2 coefficients for Xe+Xe collisions are larger than those found in Pb+Pb collisions for the most central collisions. This is attributed to a larger fluctuation component in the lighter colliding system.

Net-charge fluctuation in Pb-Pb collisions

CMS-PAS-HIN-22-005

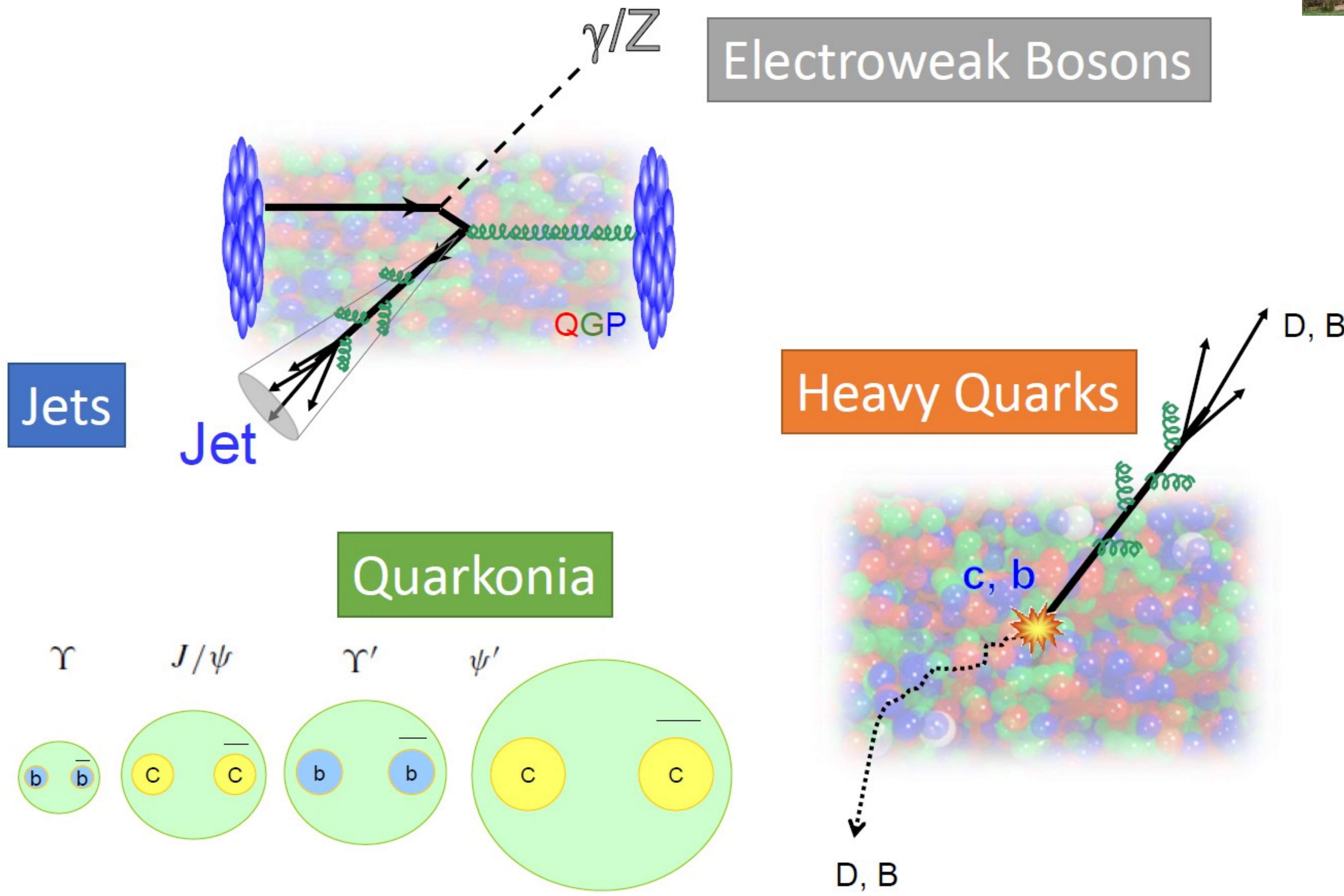




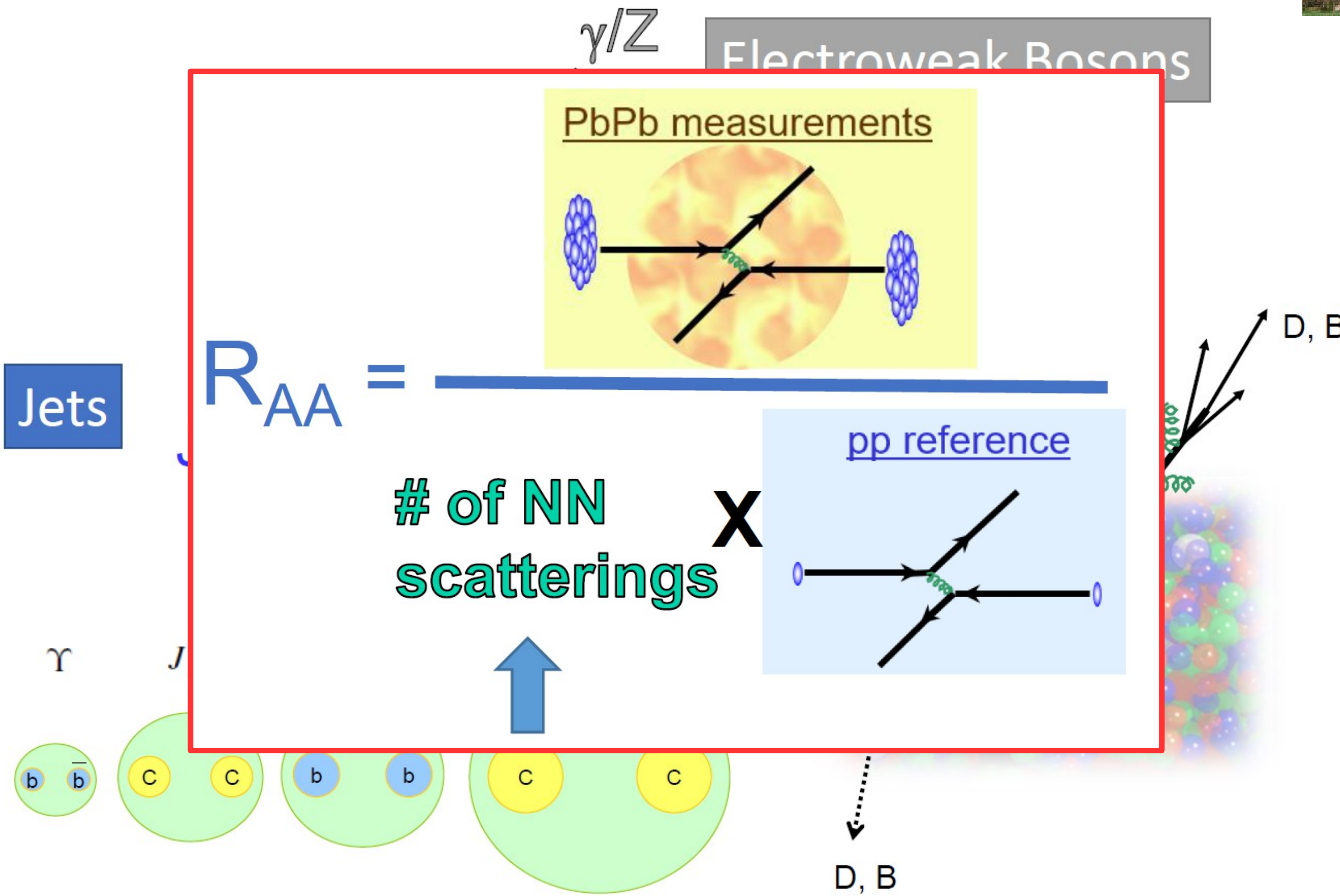
Net-charge fluctuations differ between QGP and hadron gas phase

We see the signature of QGP

Hard Probes for Quark-Gluon Plasma

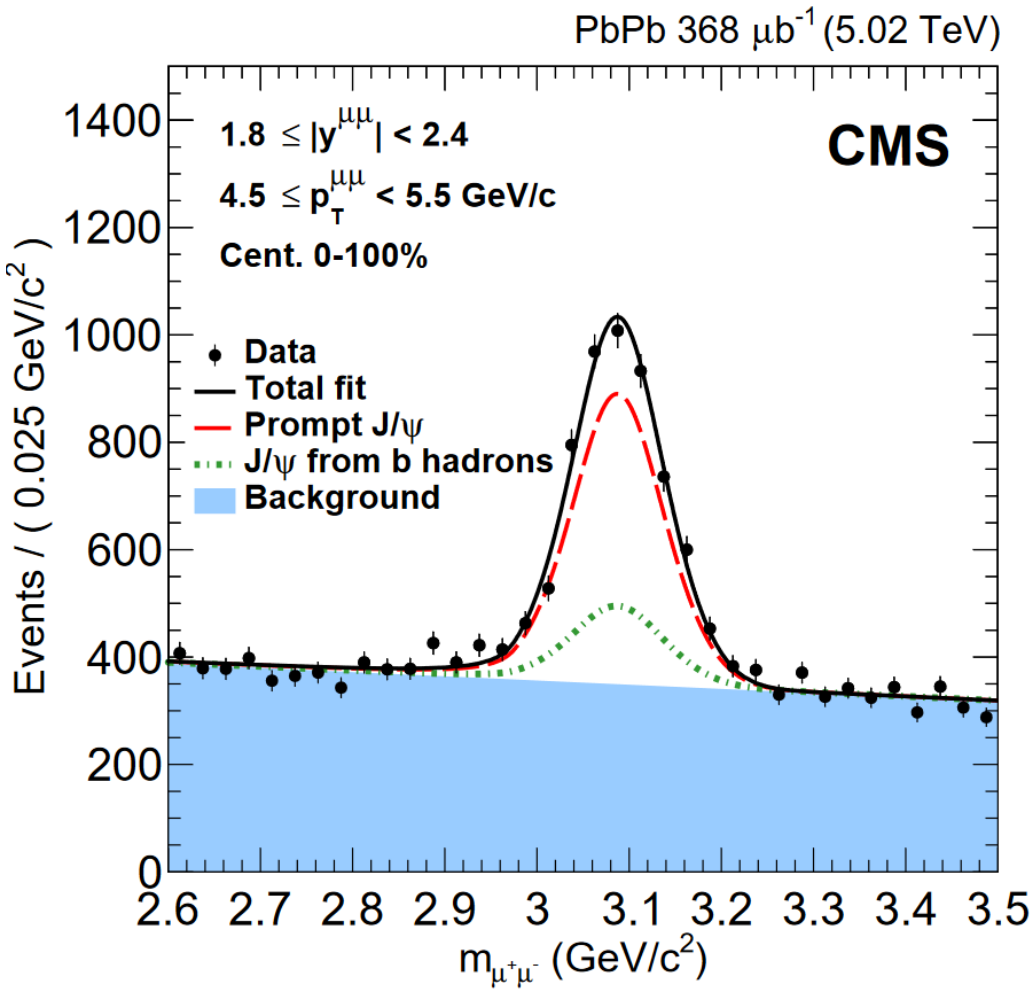


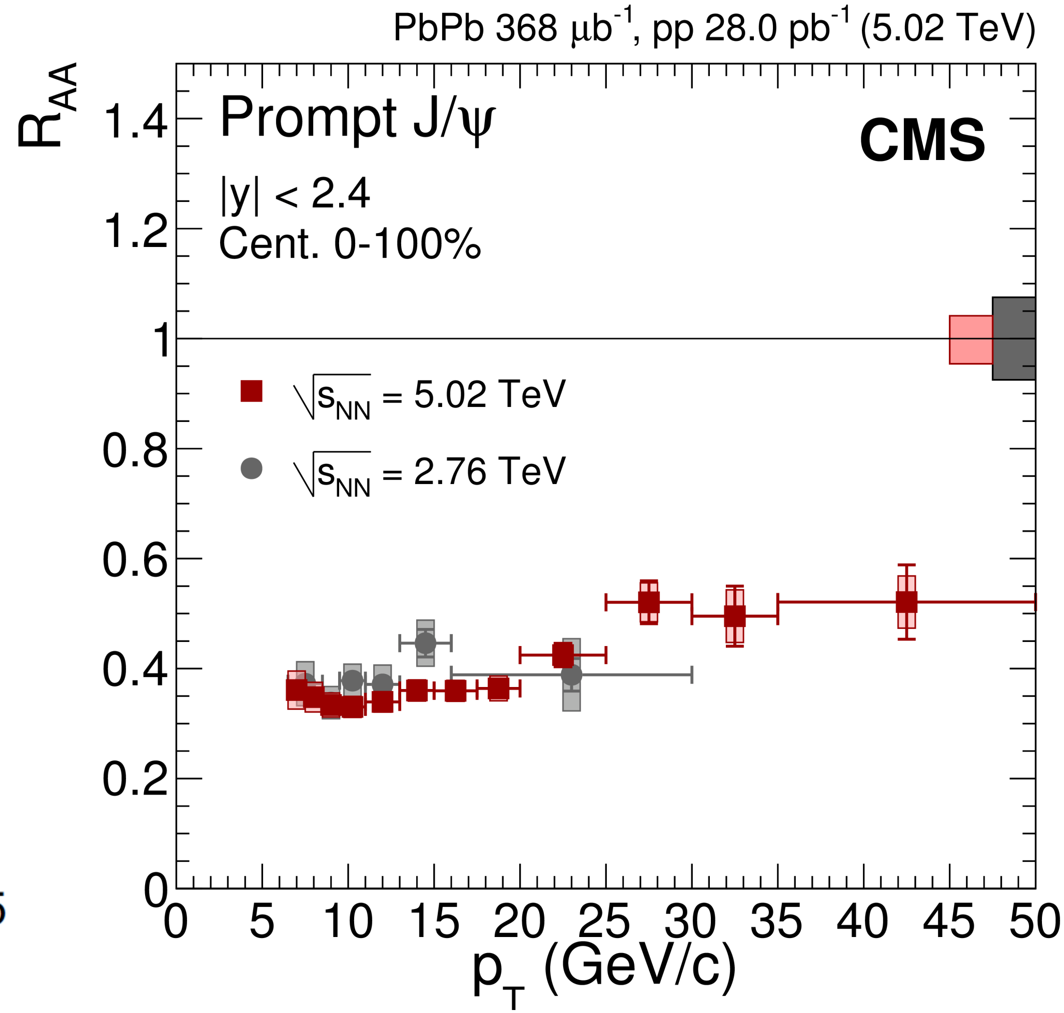
Hard Probes for Quark-Gluon Plasma



J/ψ suppression in Pb+Pb

EPJ C 78 (2018) 509

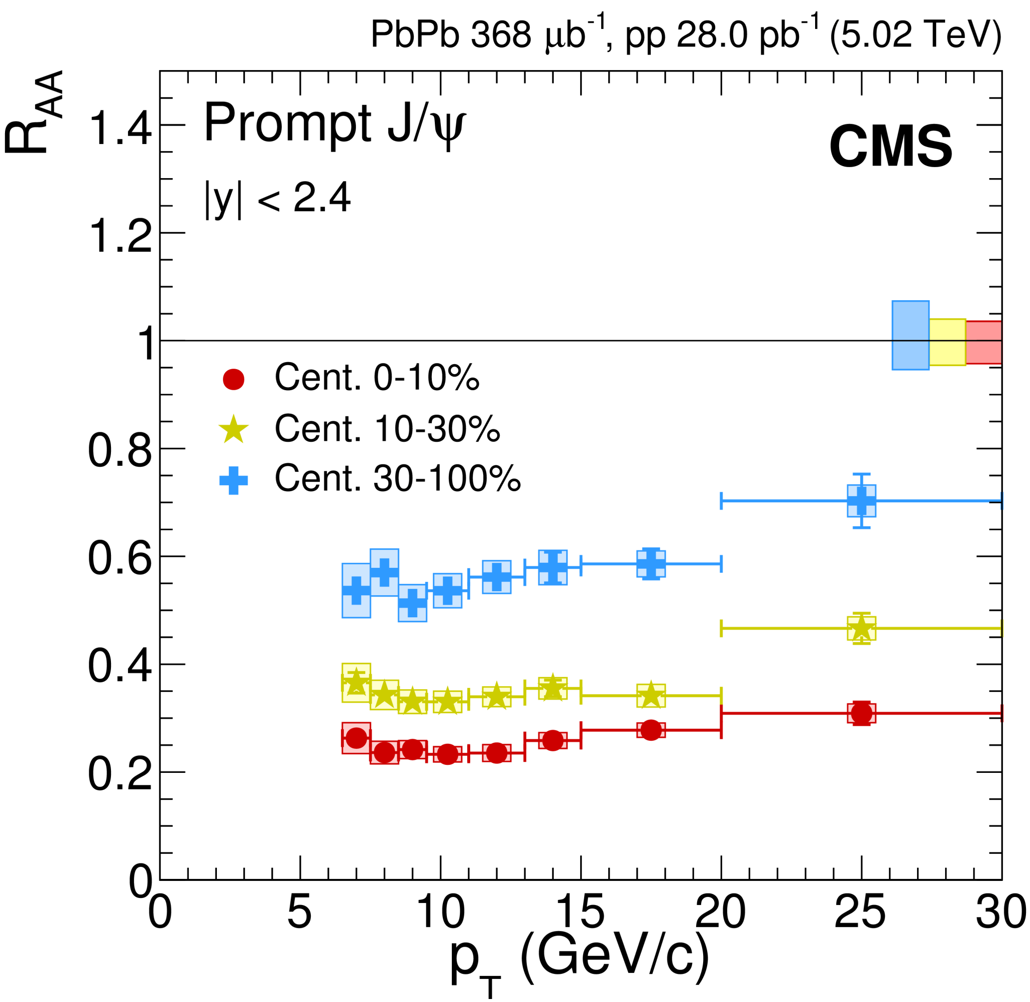


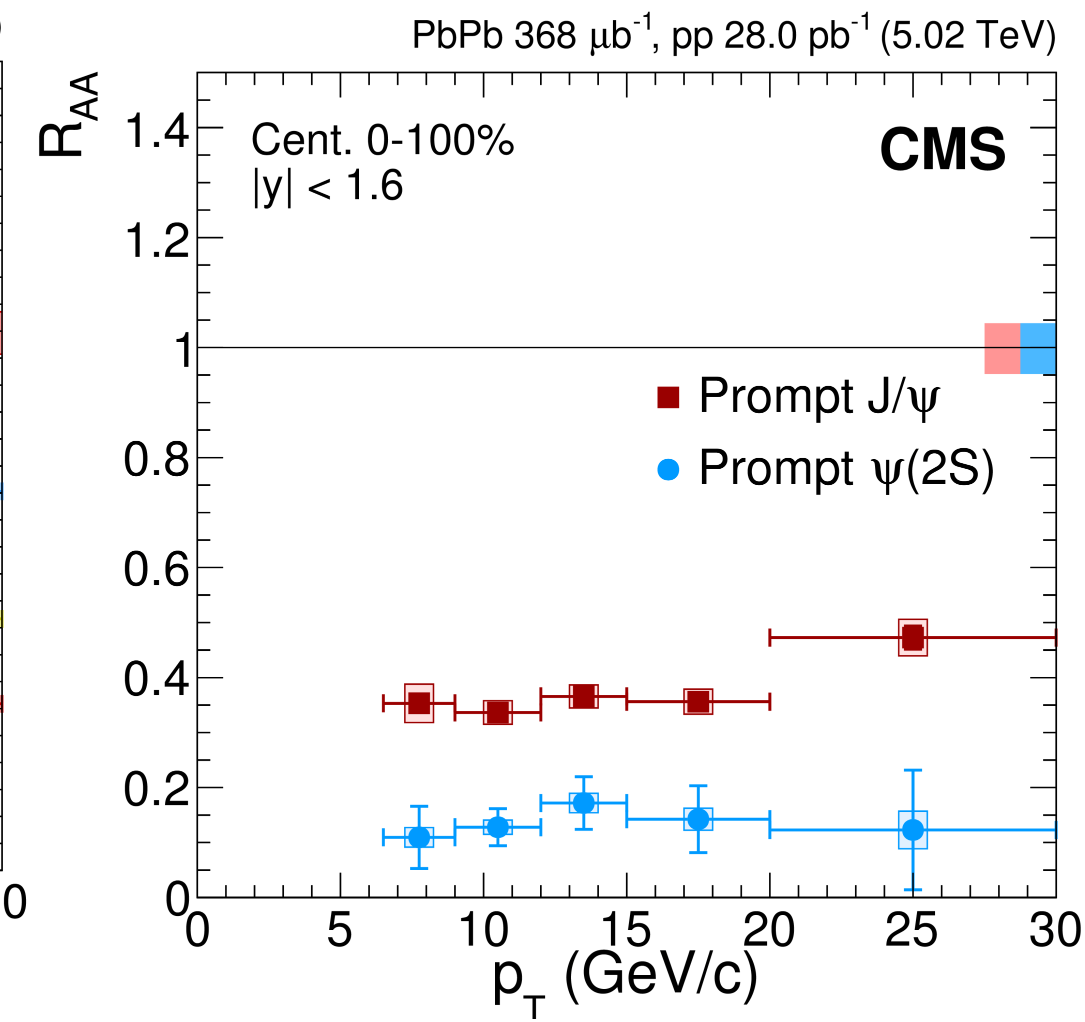


J/ψ mesons are observed to be suppressed (similarly in 2.76 and 5.02 TeV)

J/ψ and ψ(2S) suppression in Pb+Pb

EPJ C 78 (2018) 509

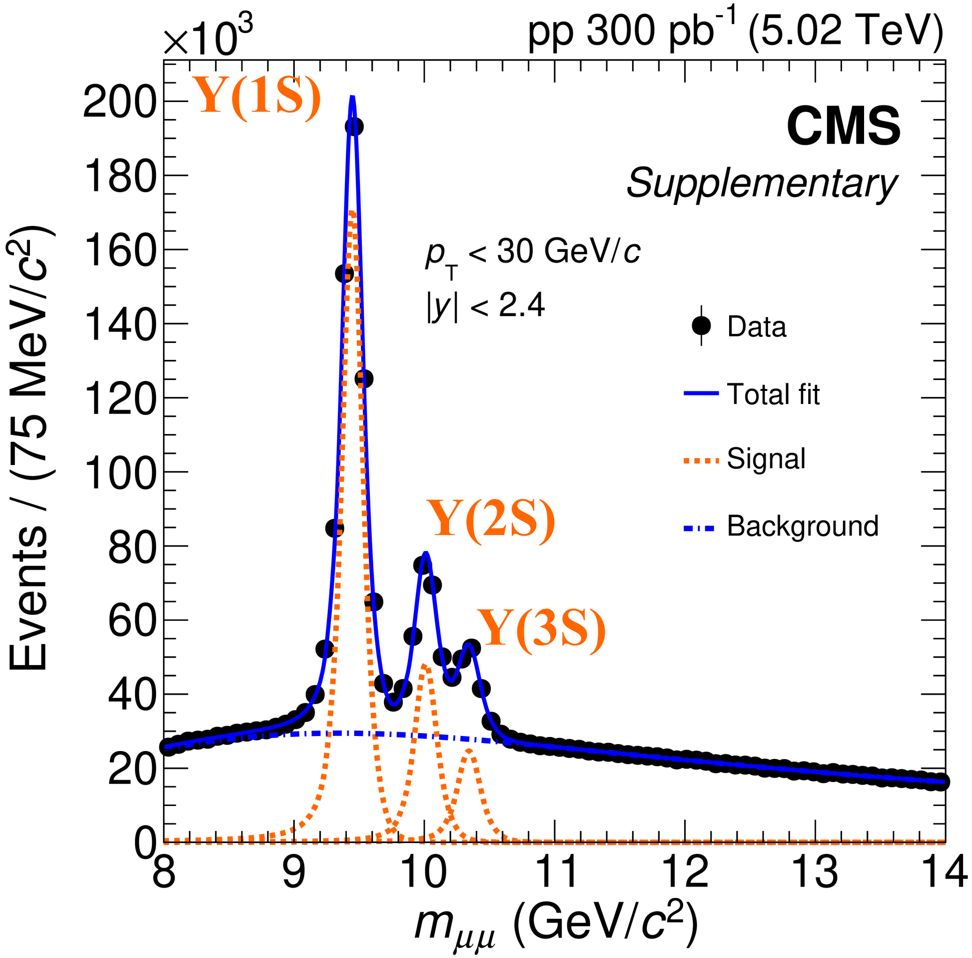


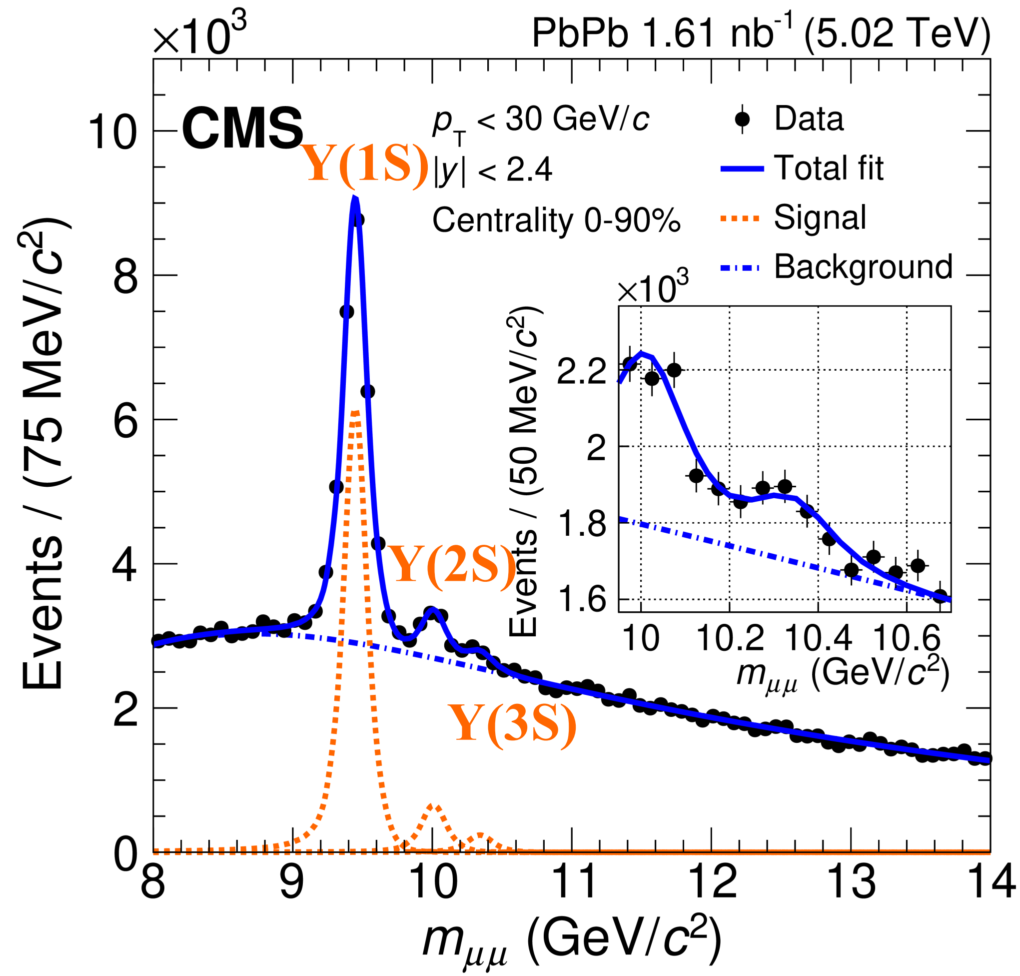


- **Increasing suppression for increasing centrality**
- **ψ(2S) is more suppressed than the J/ψ meson**

Upsilon suppression in Pb+Pb

arXiv:2303.17026

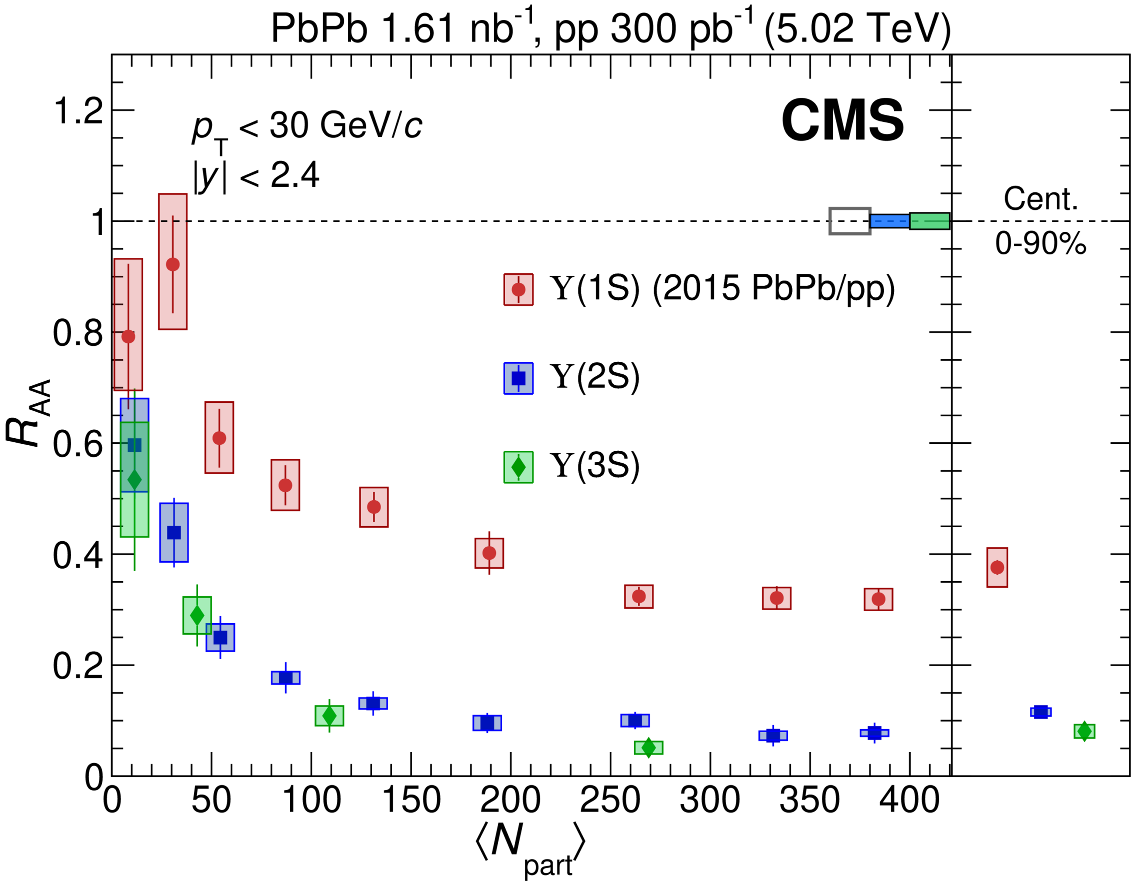


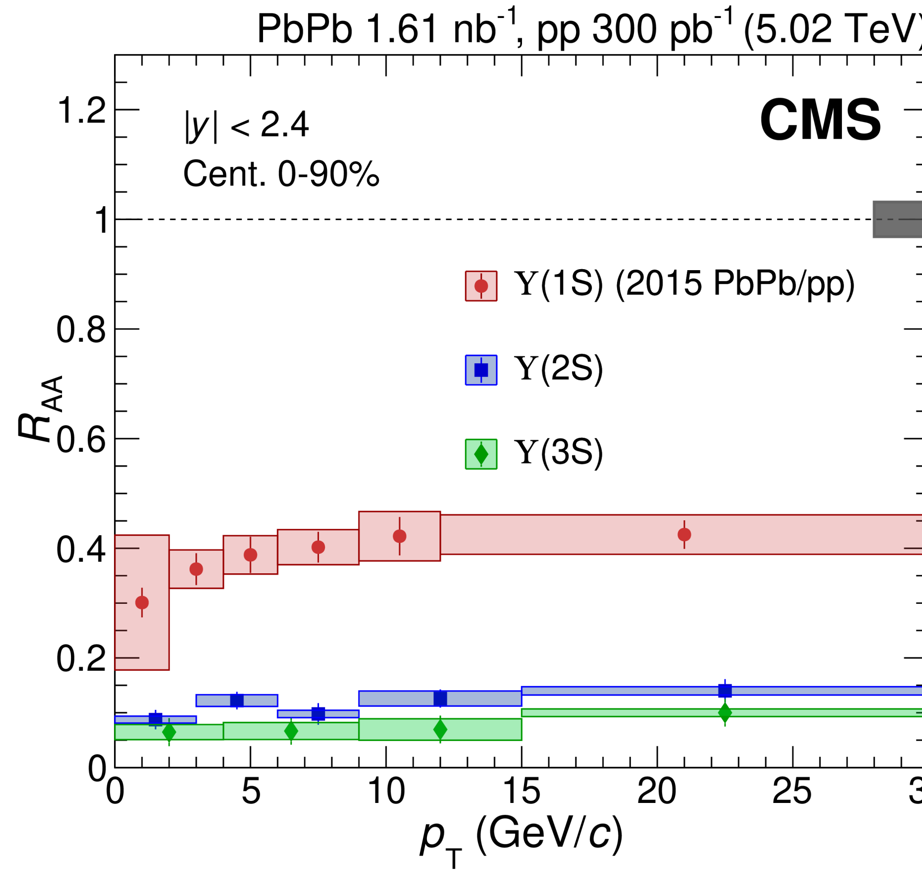


- **Observation of sequential suppression of Υ family in Pb+Pb.**
  - **First observation of Υ(3S) in heavy-ion collisions! (σ > 5)**

Upsilon suppression Pb+Pb

arXiv:2303.17026

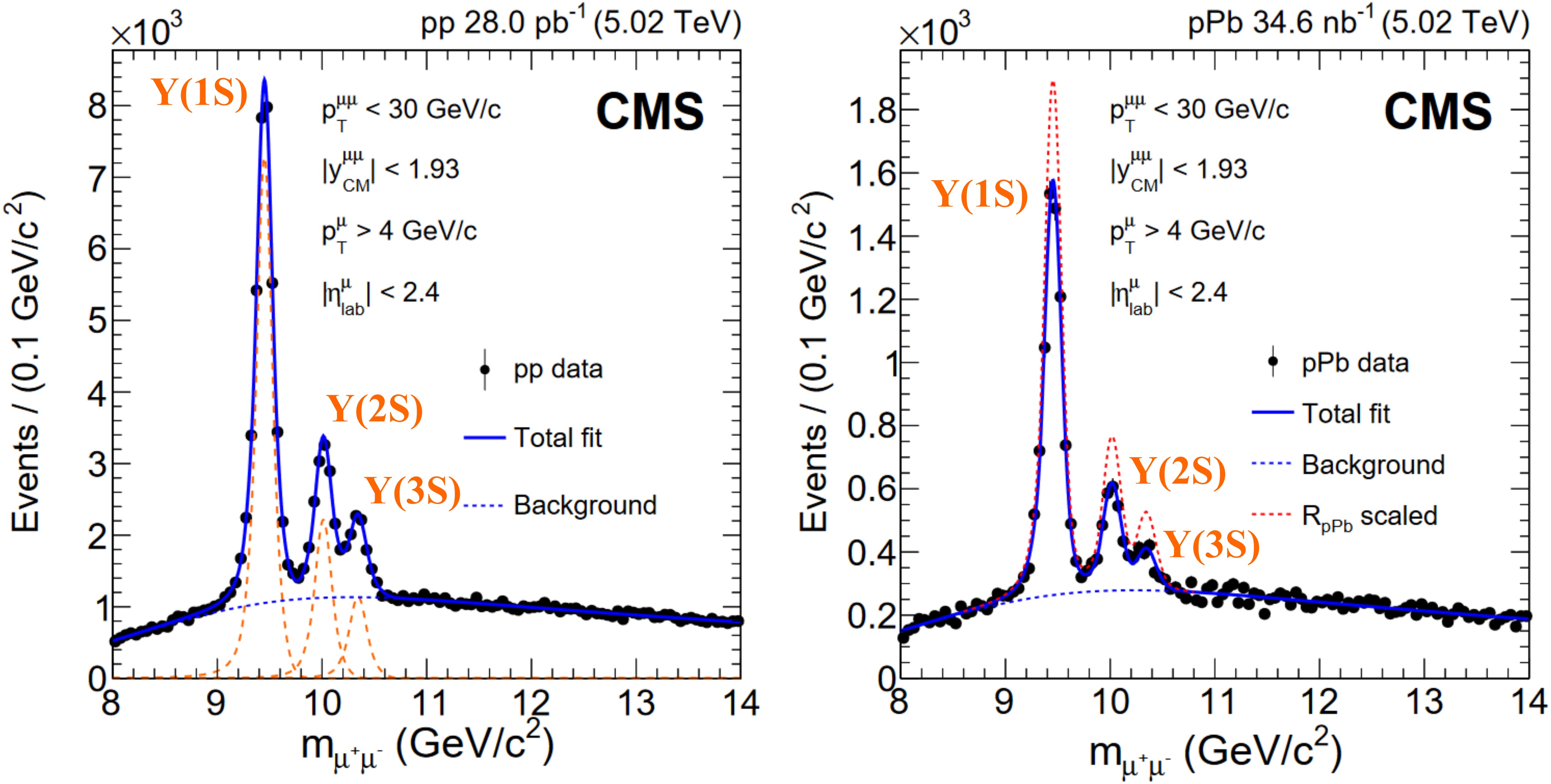




- **R_{AA} is decreasing with numbers of participants of Pb+Pb collision.**
- **Slightly increasing with p_T ?**

Upsilon suppression in p+Pb

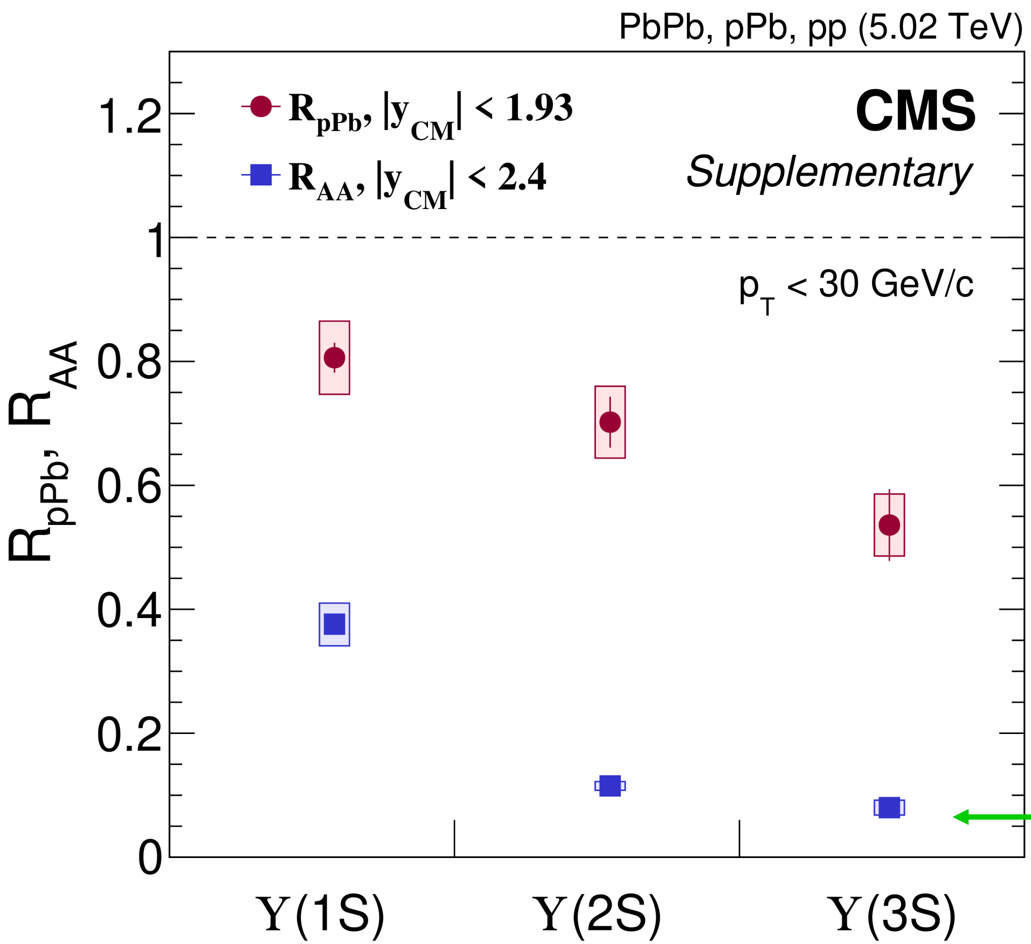
PLB 835 (2022) 137397



All Υ states are found to be suppressed in p+Pb collisions compared to p+p collisions.

Upsilon suppression in p+Pb and Pb+Pb

arXiv:2303.17026



Ordered in binding energy

RpPb Υ(1S) > RpPb Υ(2S) > RpPb Υ(3S)

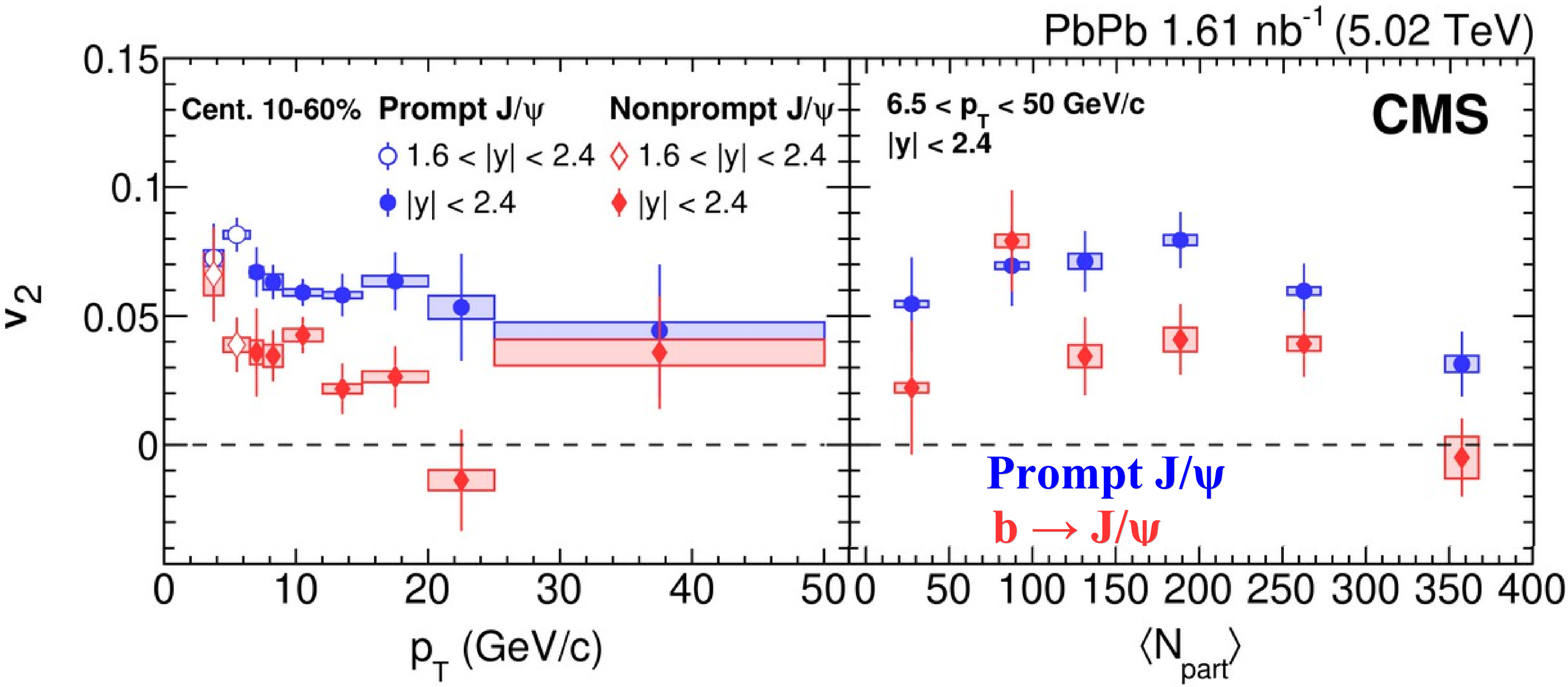
Largest suppression is in Pb+Pb

$R_{pPb} > R_{PbPb}$

New result for Υ(3S)

v_2 of J/ψ in Pb+Pb collisions

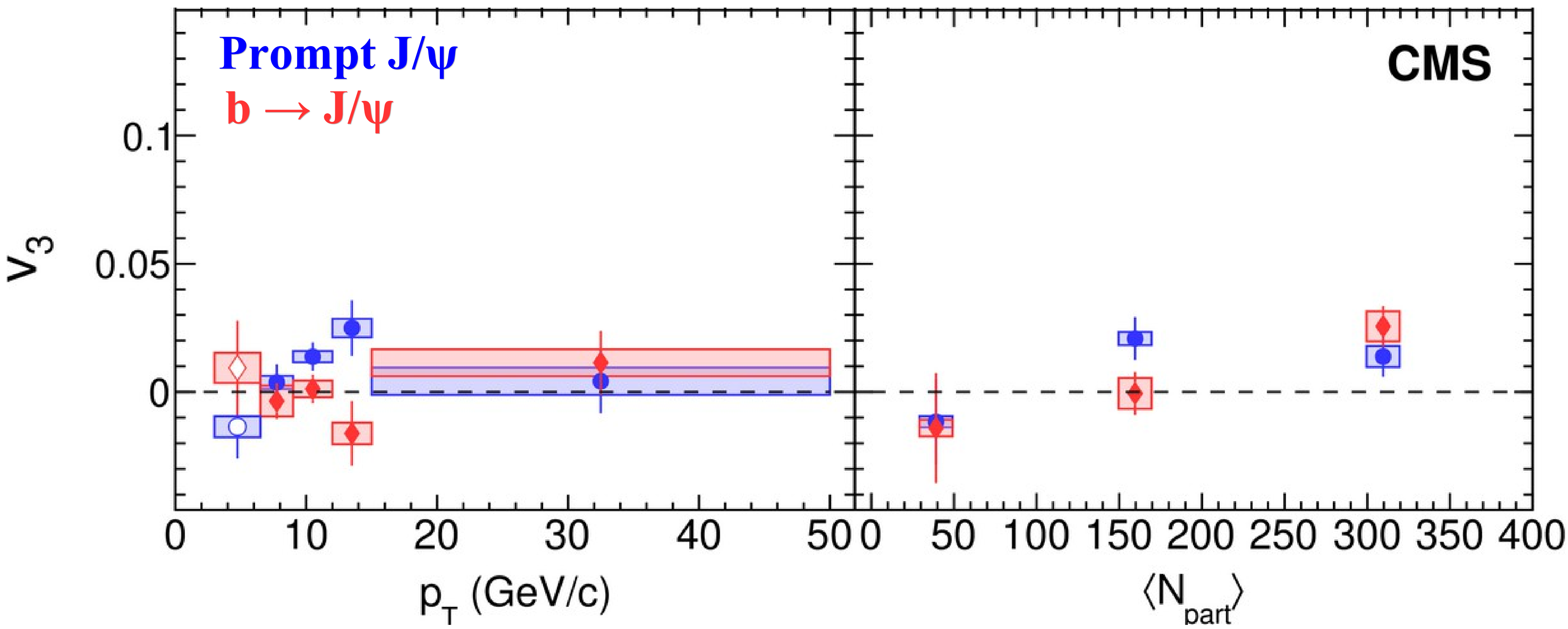
arXiv:2305.16928



- Large v_2 of J/ψ up to p_T= 50 GeV/*c*
  - v_2 (b → J/ψ) < v_2(prompt J/ψ)

v_3 of J/ψ in Pb+Pb collisions

arXiv:2305.16928

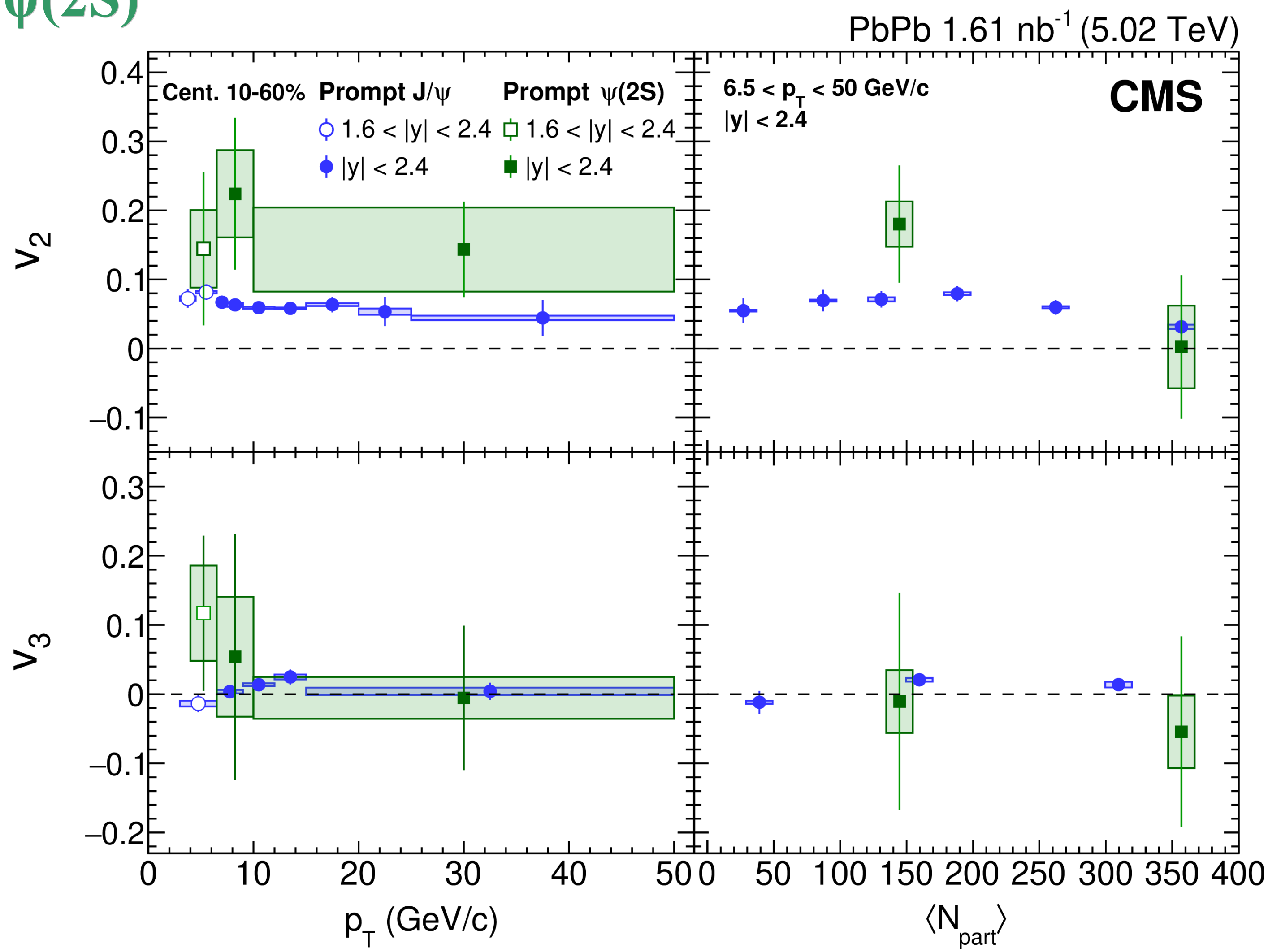


- **First measurement of v_3 for prompt and non-prompt J/ψ separately**
- **no significant non-zero v_3 (J/ψ)**

v_2 and v_3 of ψ(2S) in Pb+Pb collisions

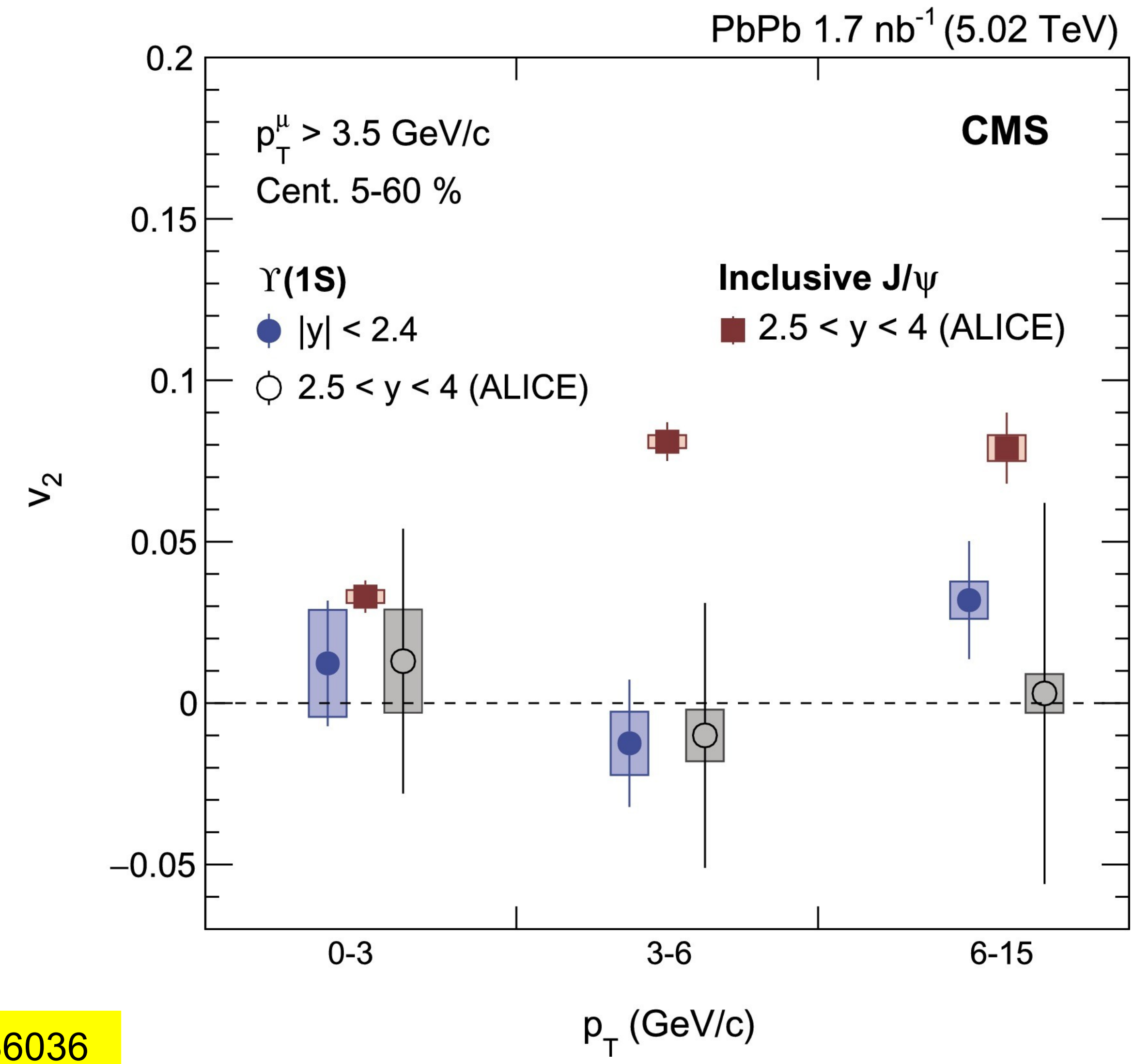
arXiv:2305.16928

Prompt ψ(2S)



- First measurements for prompt ψ(2S) !
- v_2 is non-zero in p_T = 4 – 50 GeV/c, v_3 is close to zero

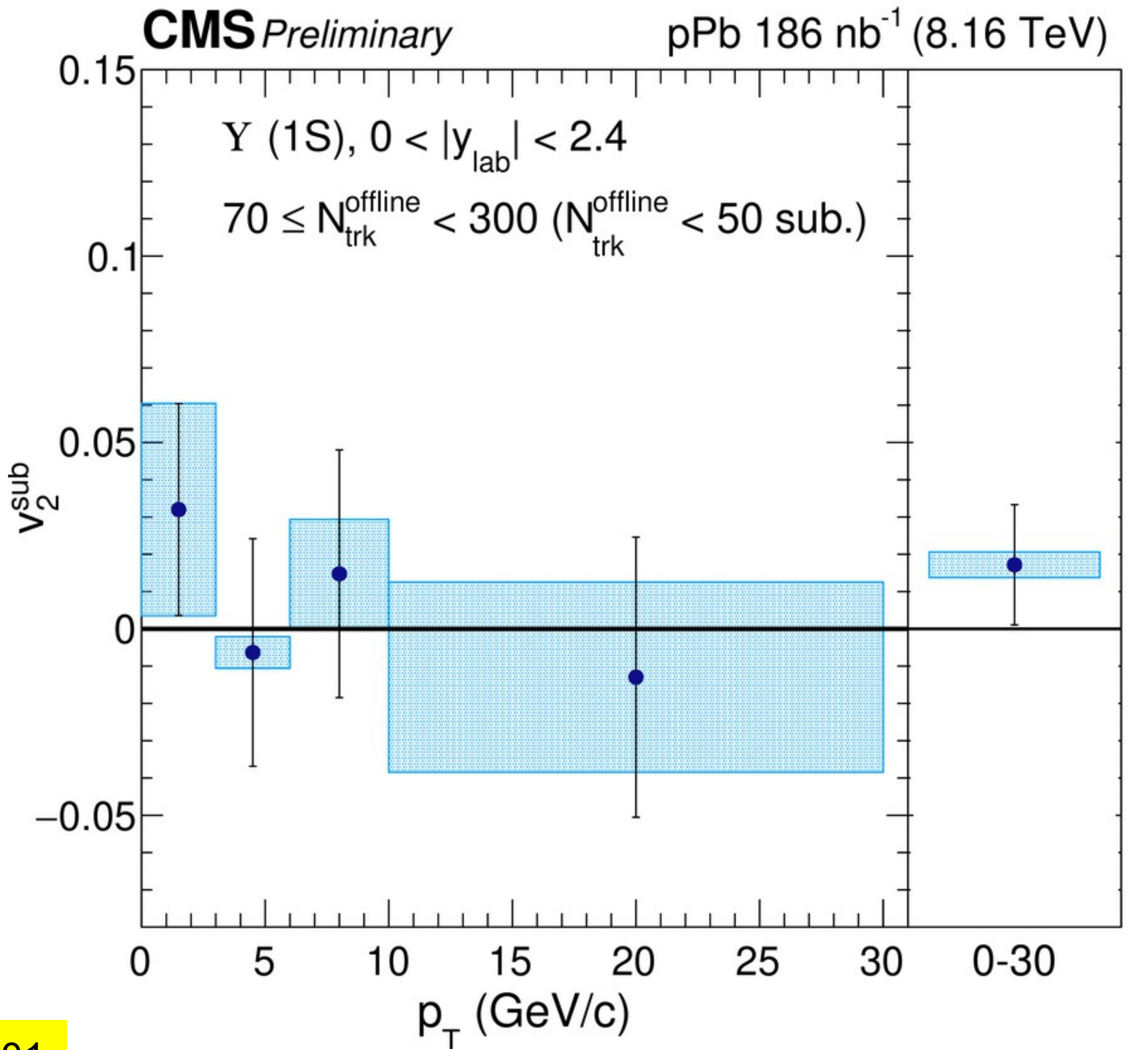
v_2 of Υ(1S) in Pb+Pb collisions



PLB 813 (2021) 136036

In contrast to the J/ψ mesons,
no azimuthal anisotropy is observed for the Υ(1S) in Pb+Pb...

v_2 of Υ(1S) in p+Pb collisions

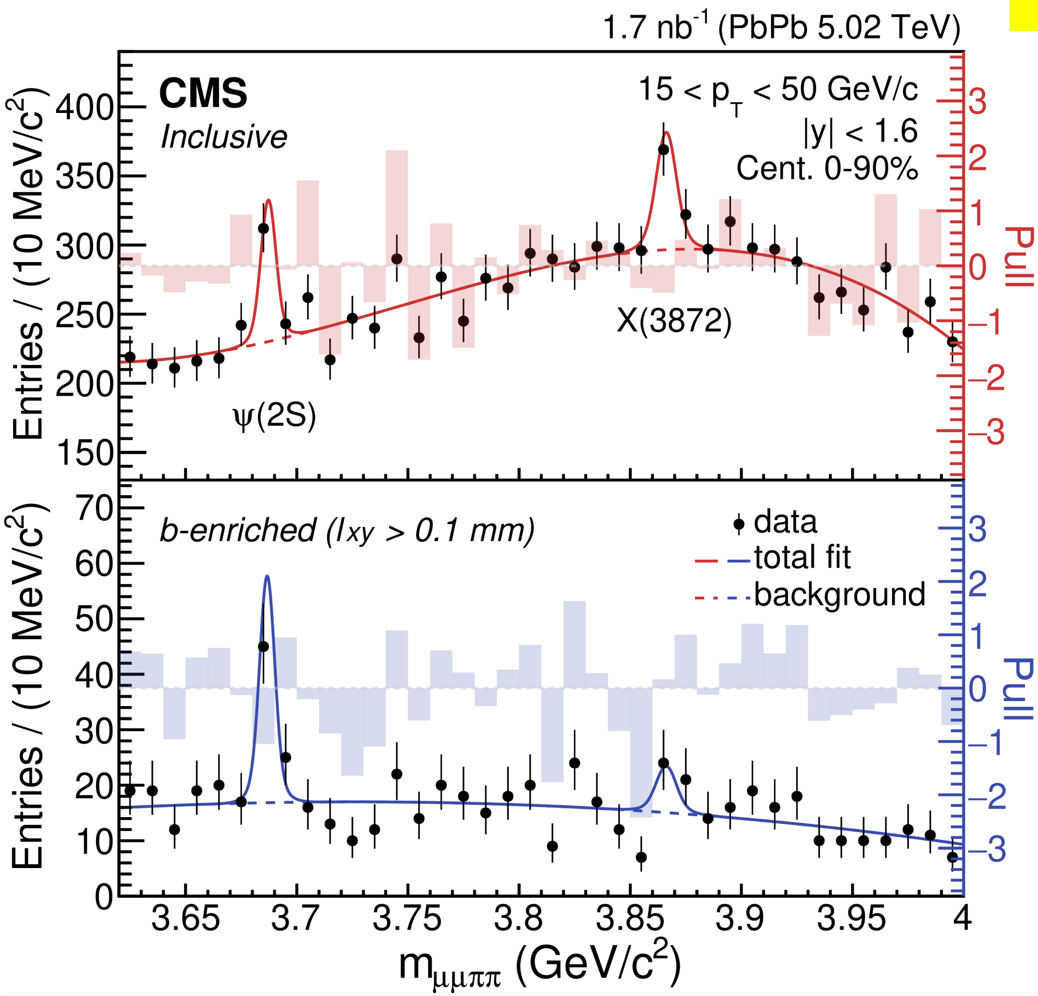


CMS-PAS-HIN-21-001

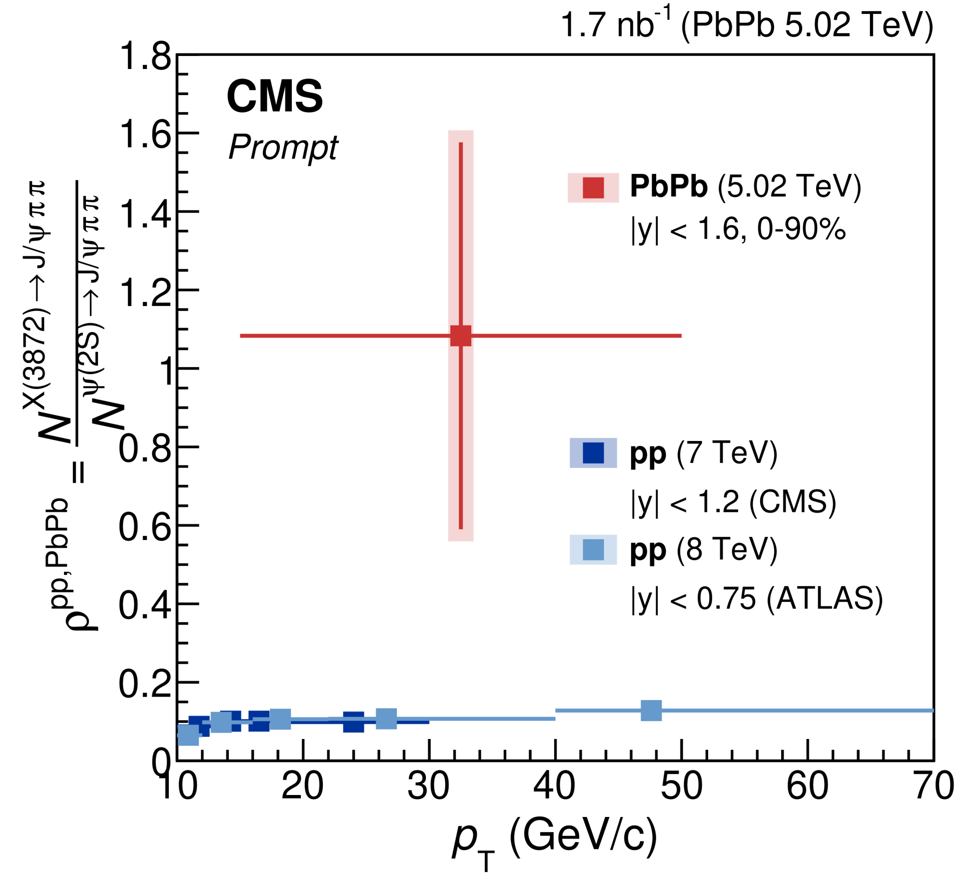
… and also no azimuthal anisotropy for the Υ(1S) in p+Pb !

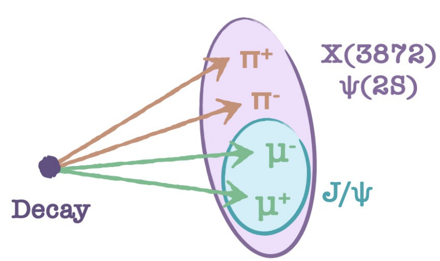
First evidence of X(3872) in Pb+Pb

PRL 128 (2022) 032001



Comparison to ψ(2S)



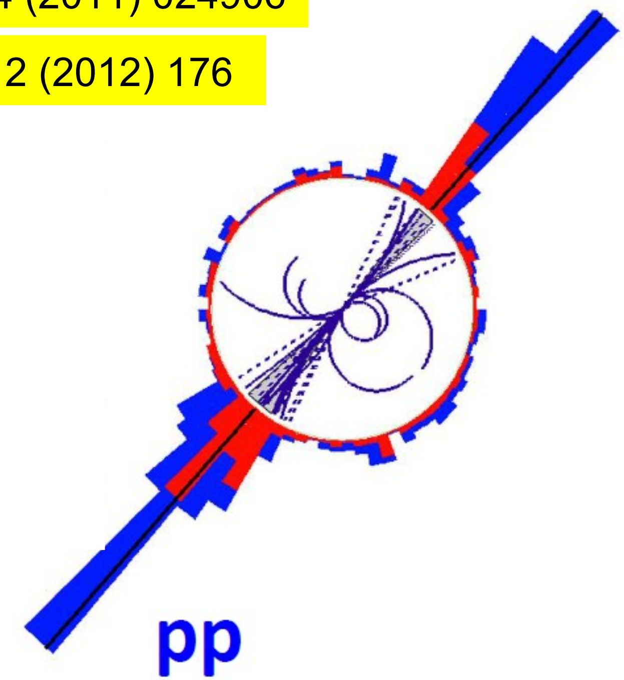


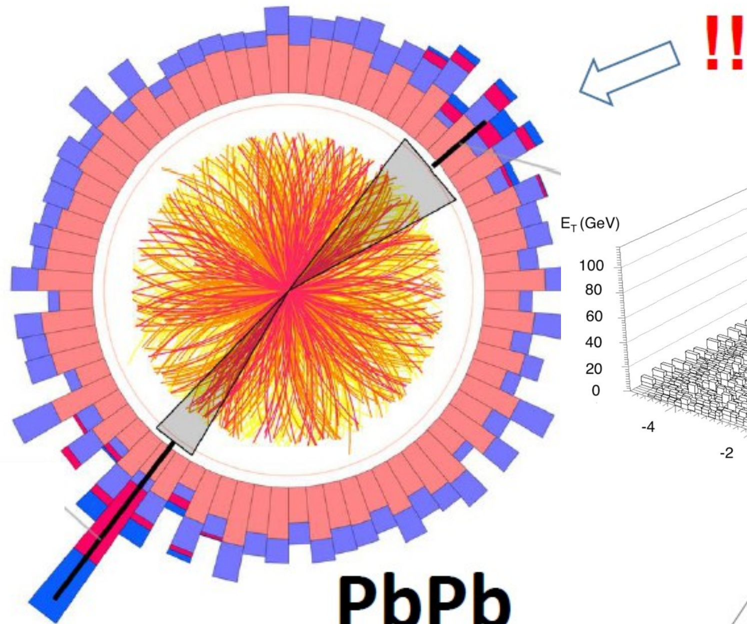
Result provides a unique experimental input to the theory, towards elucidating the production mechanism and the nature of the X(3872).

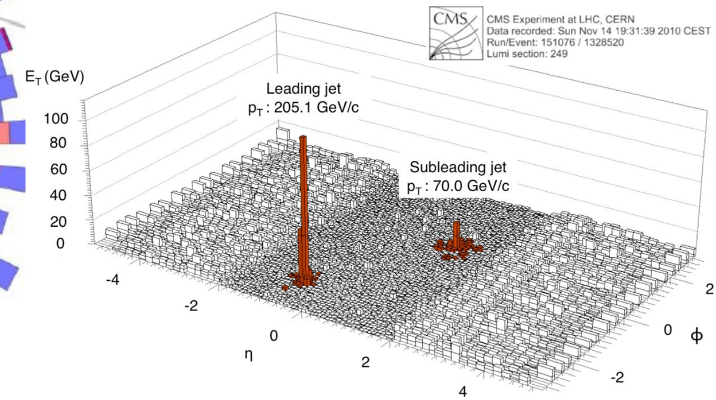
Jet quenching in Pb+Pb

PRC 84 (2011) 024906

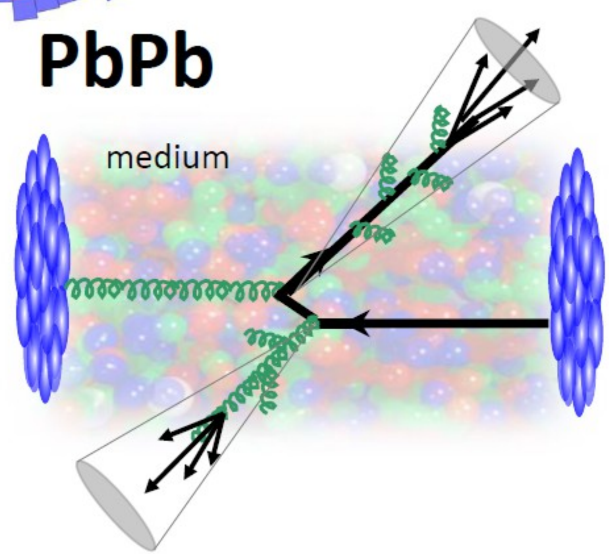
PLB 712 (2012) 176





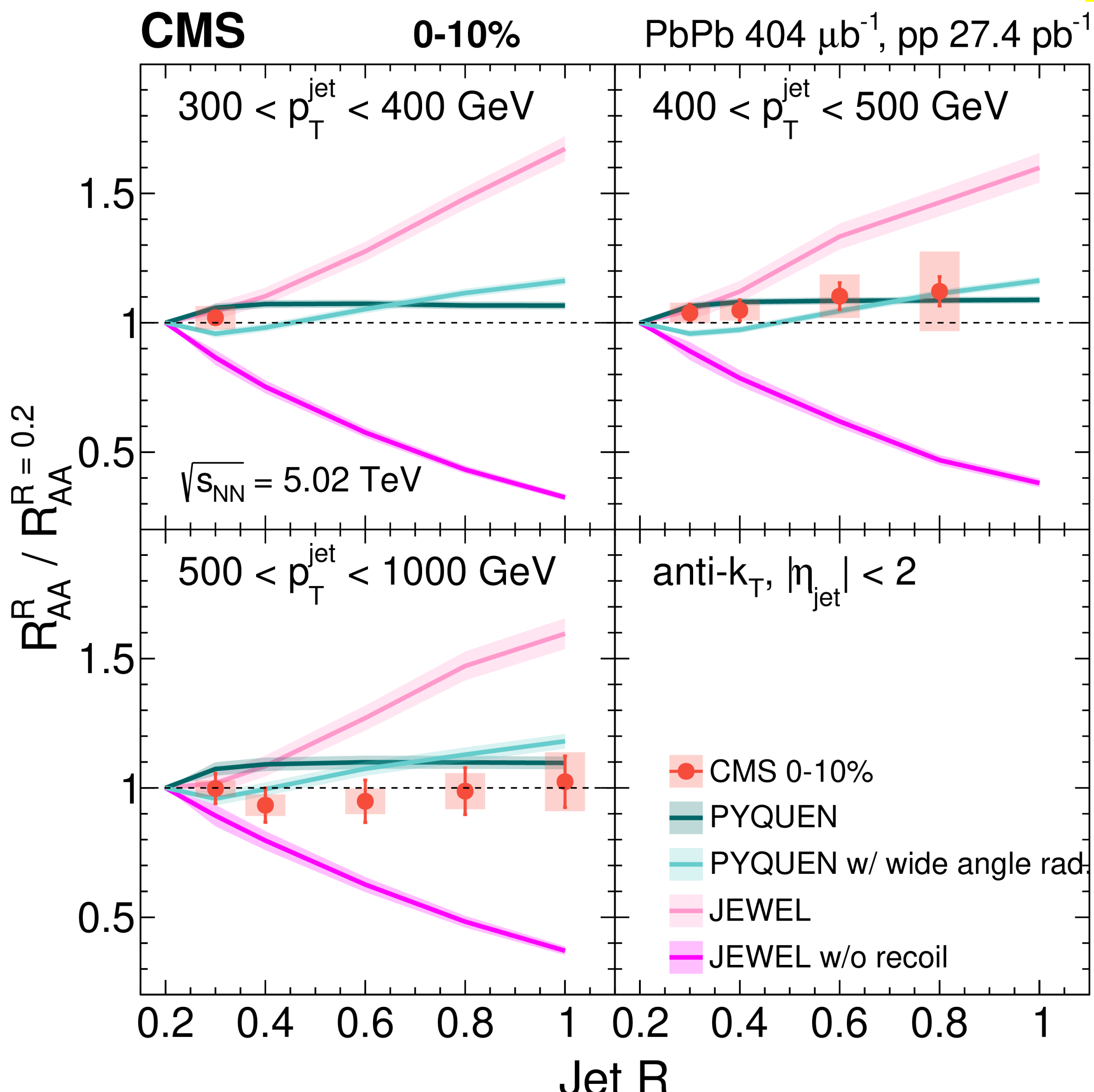


- Asymmetric dijets observed more frequently in PbPb collisions
- The stopping power (dE/dx) of the Quark Soup is **Incredibly Strong**



Jet radius scan

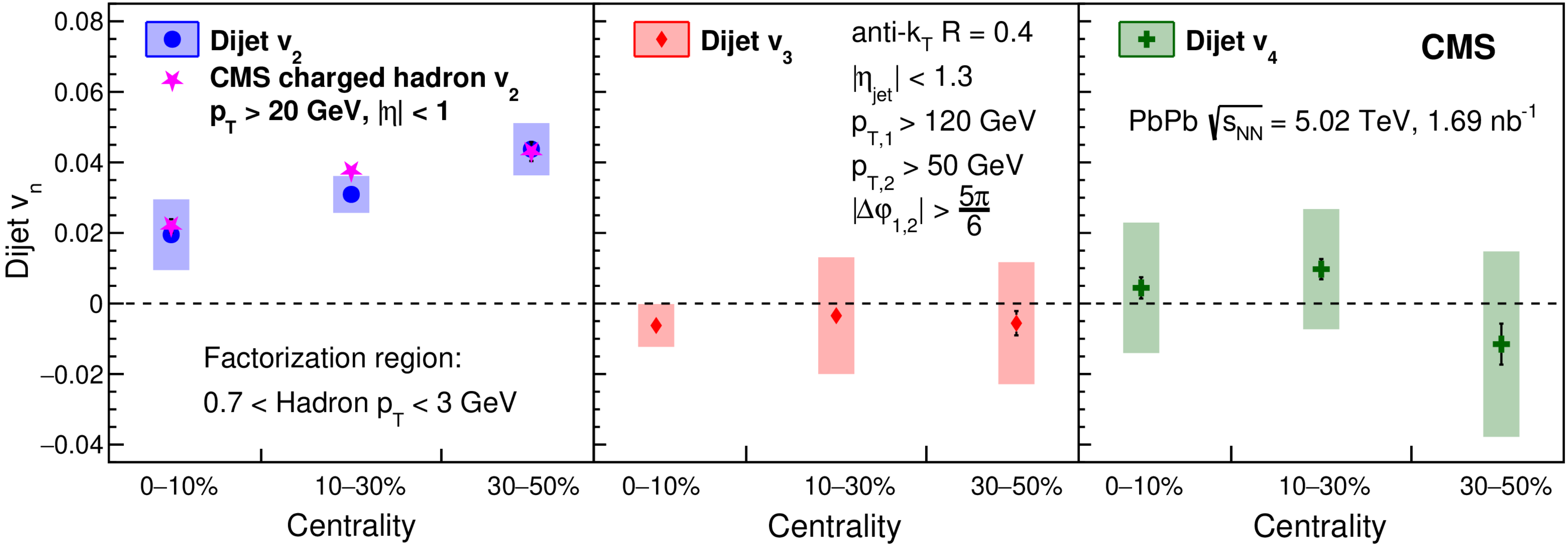
JHEP 05 (2021) 284



- Sensitive to balance between increasing radiative sources and recovering re-distributed energy
- Enables simultaneous comparisons of model calculations across jet radii
- First time at CMS: no radius dependence of jet energy loss in central Pb+Pb collisions for 400 GeV < p_T jet. (Also for 400 < p_T jet < 500 GeV)

Azimuthal anisotropy of di-jets in Pb+Pb

JHEP 07 (2023) 139

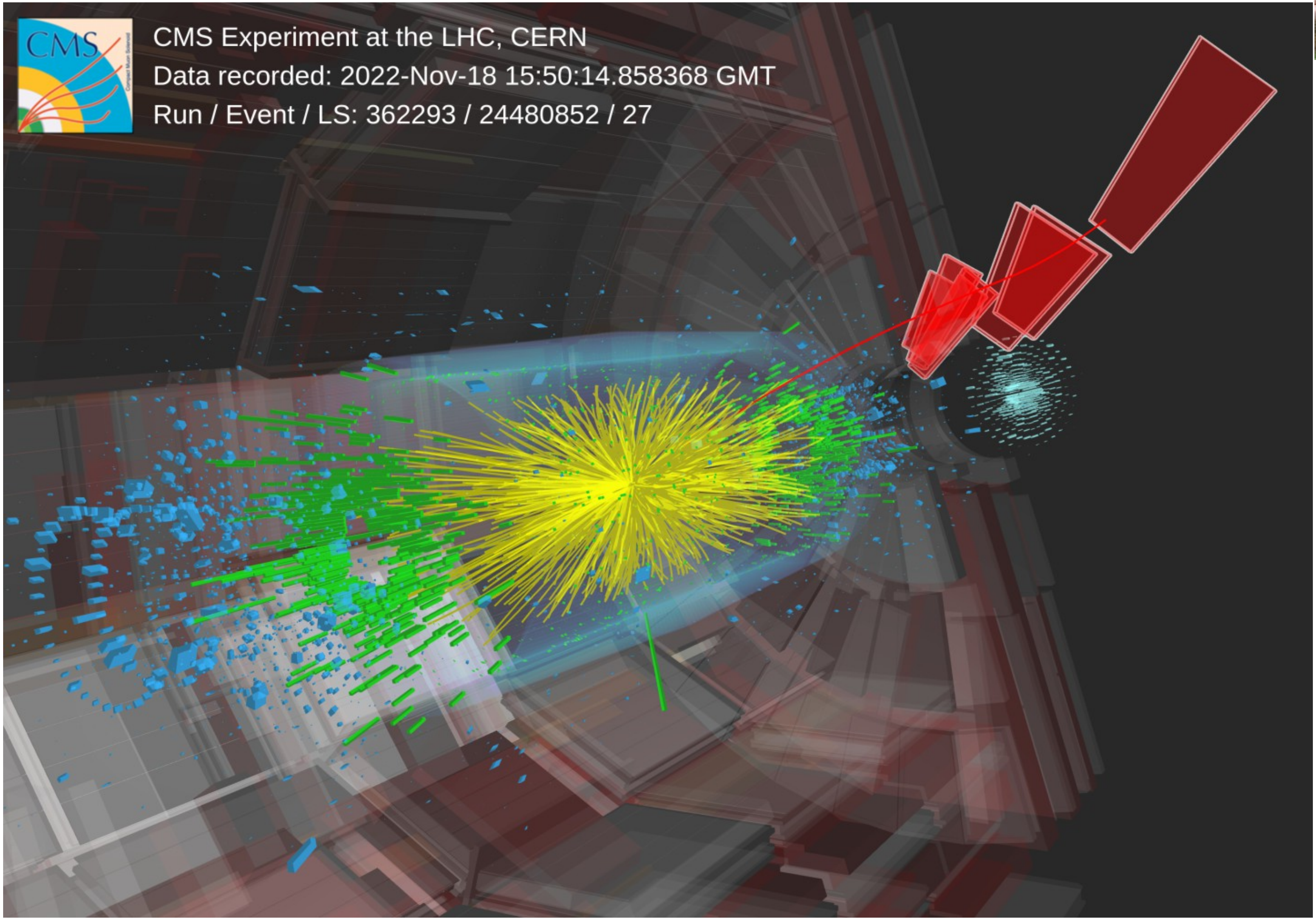


- v_2, v_3 and v_4 of the di-jets in Pb+Pb were measured for the first time
- Di-jets v_2 is compatible with v_2 of high p_T hadrons
- Di-jets v_3 and v_4 are consistent with zero

CMS Summary for Heavy-Ions

- **Many interesting heavy-ion physics results with the CMS detector in p+p, p+Pb, Pb+Pb and Xe+Xe...**
- **Future heavy-ion program at the LHC (Run 3 and 4) with the upgraded CMS detector will provide more exciting opportunities! Stay tuned!**

Run 3 was started in July 2022



One of the first Pb-Pb collisions during Run 3 in CMS detector.
Lead beams traveled for 3 days (17-19 November 2022) in the LHC !