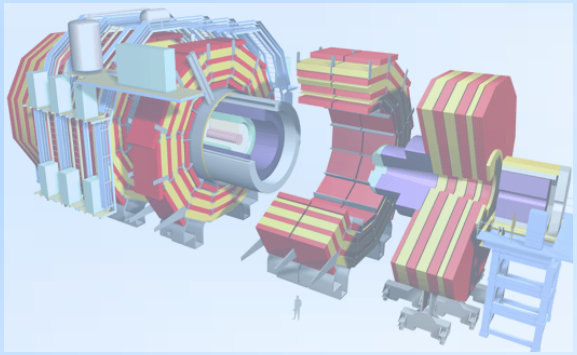
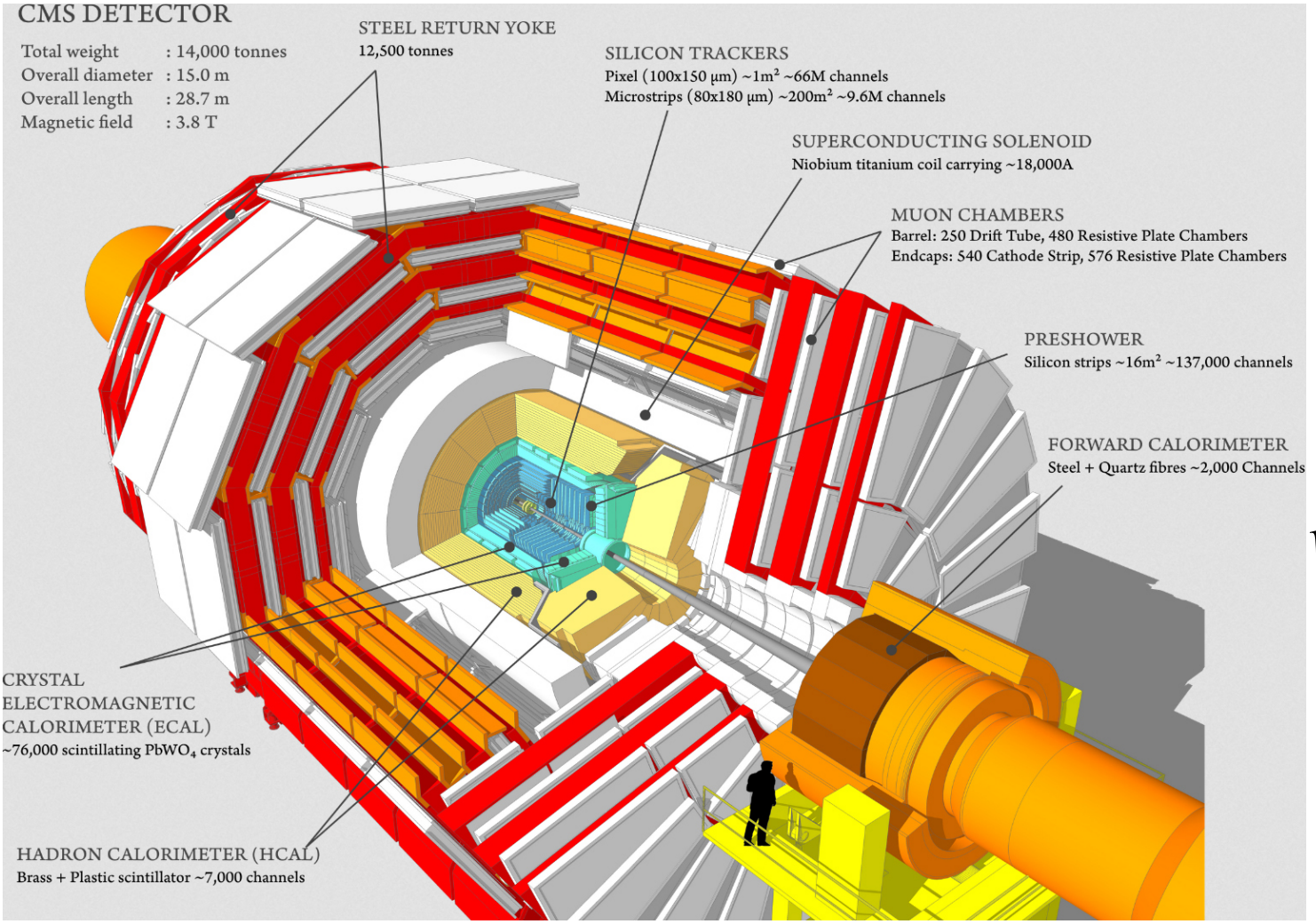
**Sergey Petrushanko**
**(for CMS Collaboration)**
**SINP Moscow State University**
**Russian Federation**

# Soft Probes in Heavy Ion Collisions with CMS


**40th International Conference on High Energy Physics**
***VIRTUAL in Prague***
***28 July - 6 August 2020***



# CMS is a nice heavy-ion experiment

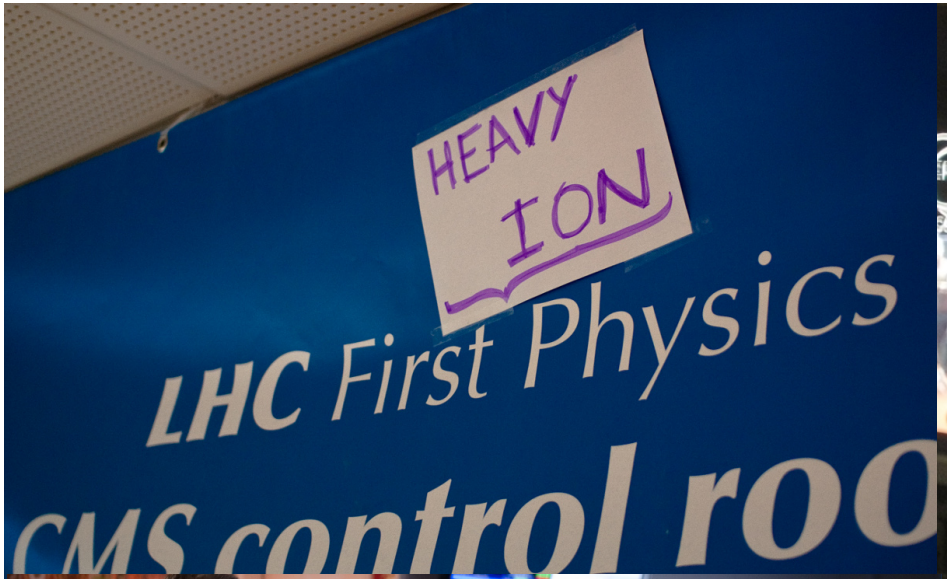


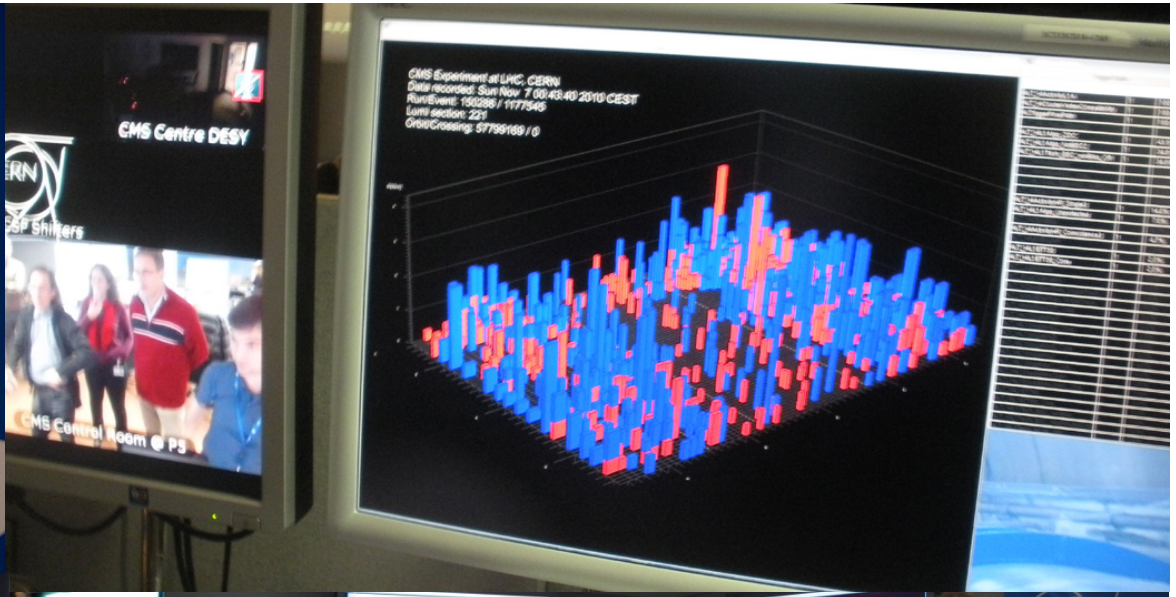

**Magnetic field: 3.8 Tesla**

- **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**

# November 7, 2010 0:27 CMS Control Room

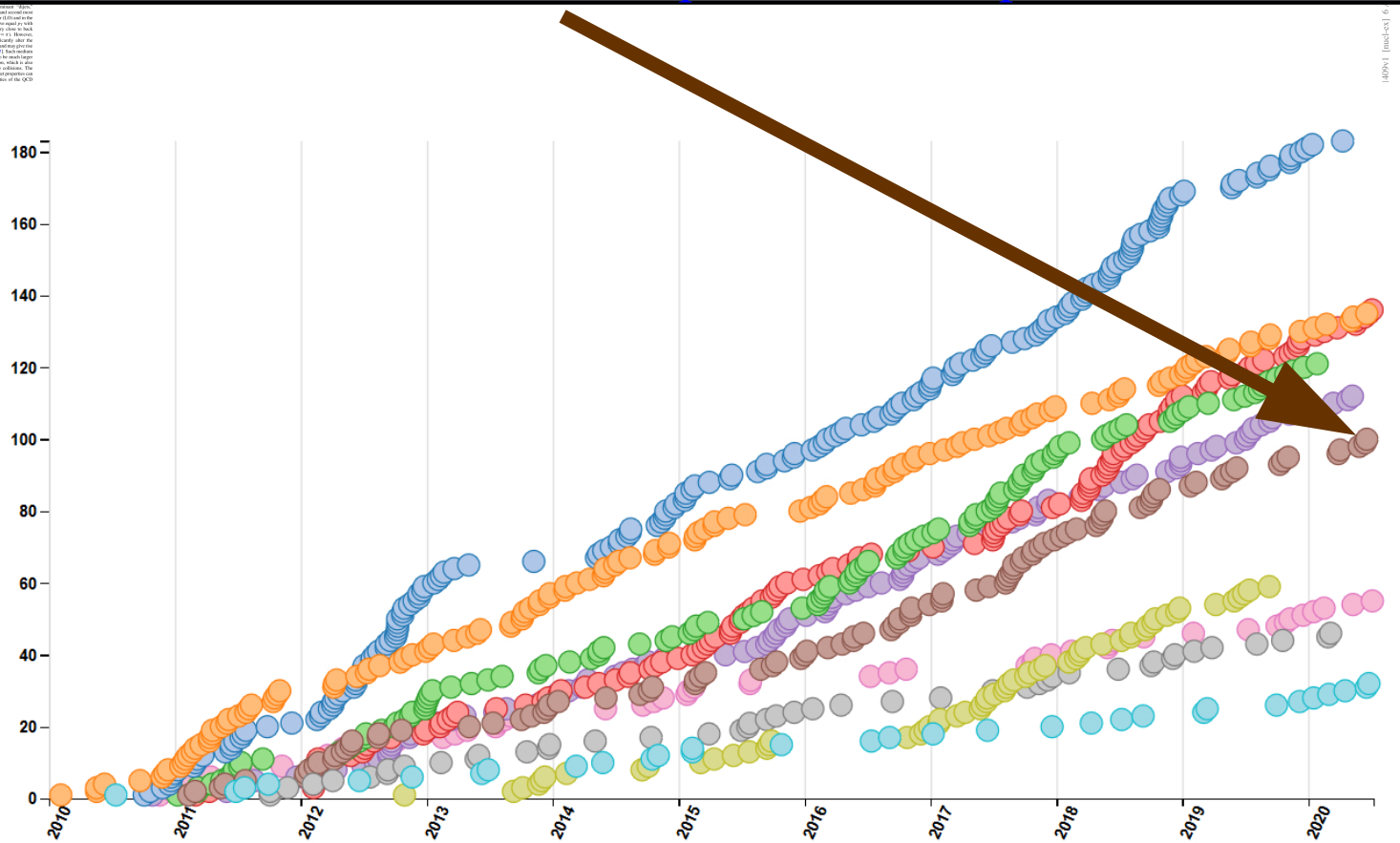



# CMS heavy-ion results

**100 (!) published/submitted Heavy-ion Physics CMS papers:**

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

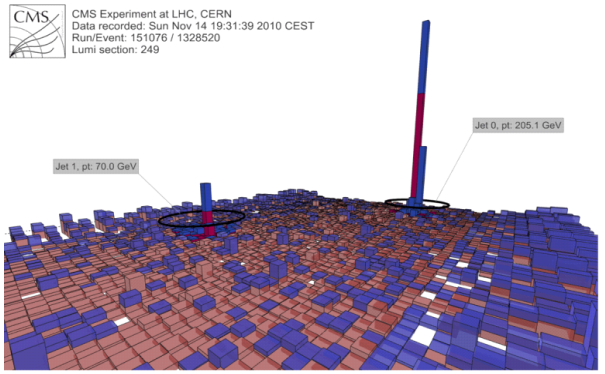



**… and also preliminary results:**

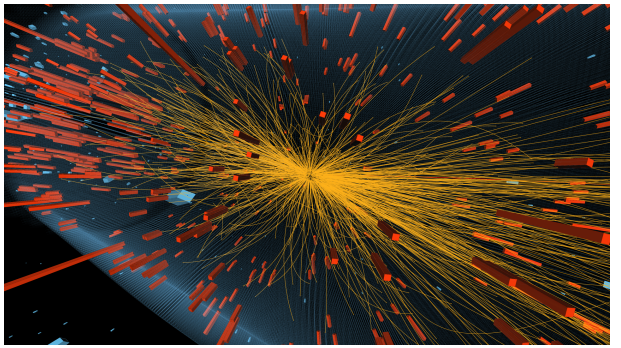
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIN/index.html

# CMS heavy-ion results in ICHEP 2020

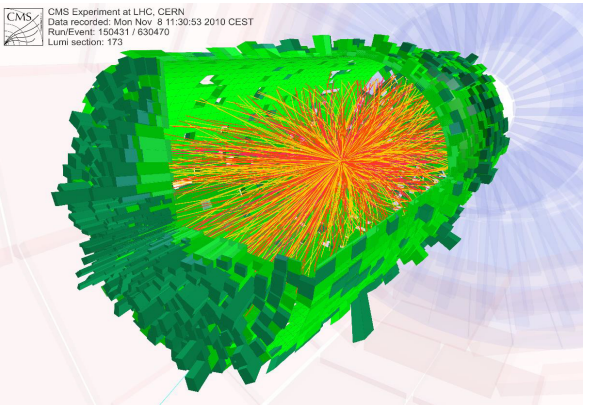
- **Hard probes in heavy ion collisions with CMS**
  **28 July 2020**
  Xiao Wang (Univ. of Illinois at Chicago)



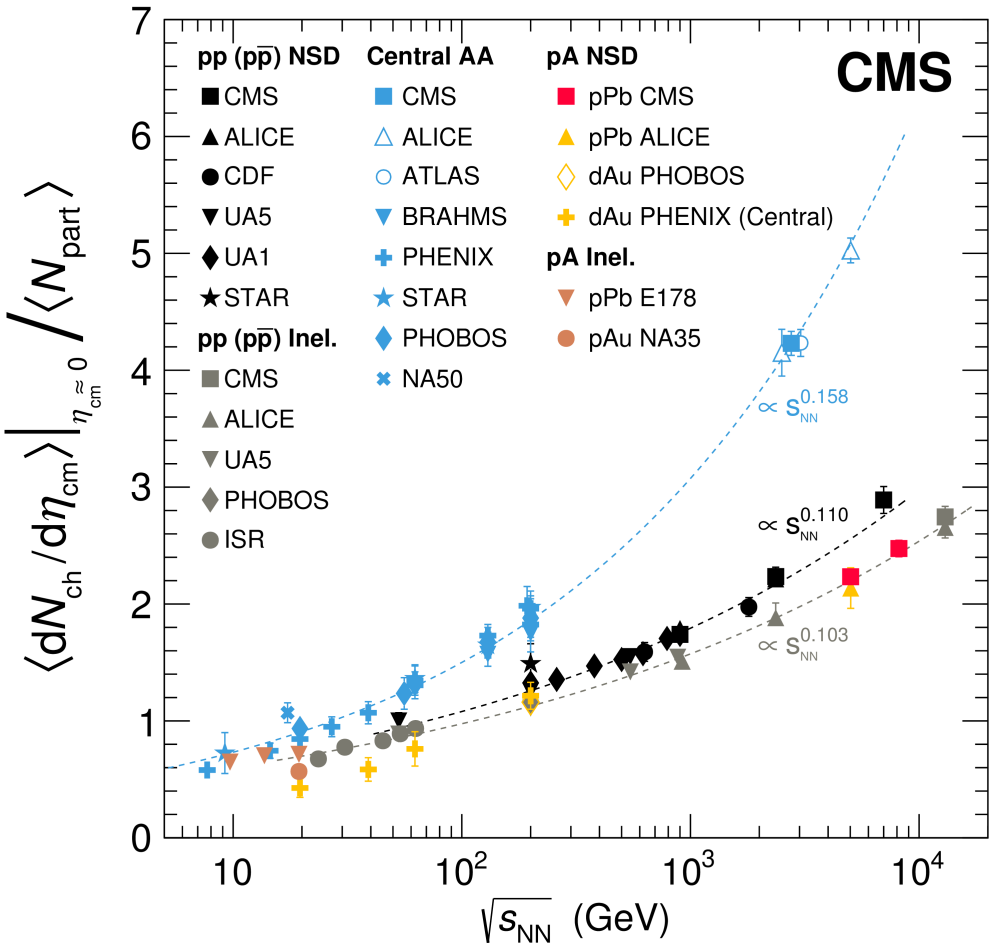

- **Diffractive and exclusive processes in heavy ion collisions with CMS**
  **29 July 2020**
  Aleksandr Bylinkin (The Univ. of Kansas)



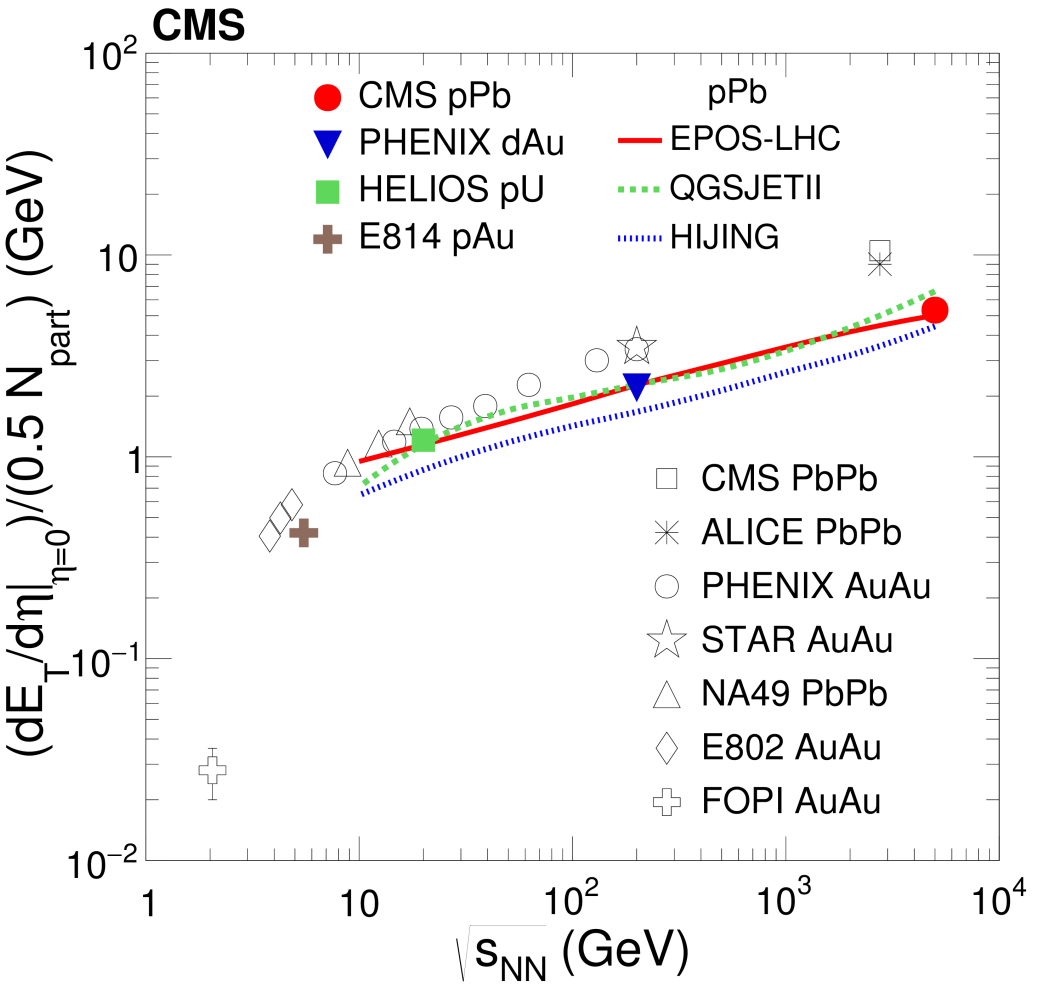
- **Soft probes in heavy ion collisions with CMS**
  *(including heavy flavours and quarkonia)*
  **30 July 2020**
  Sergey Petrushanko (Moscow State Univ.)



# Charged particle multiplicity
# Transverse energy density



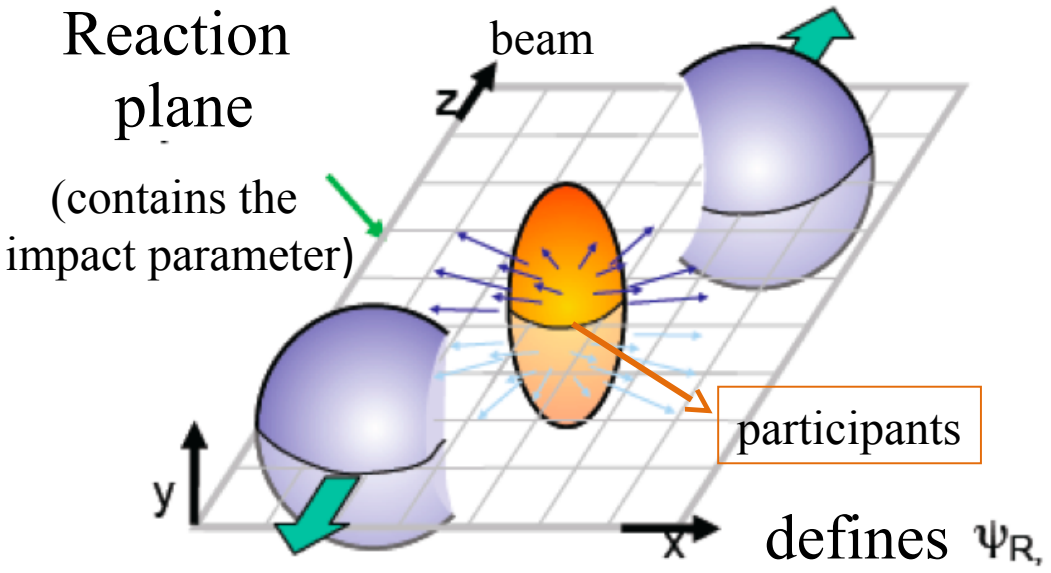

JHEP 01 (2018) 045



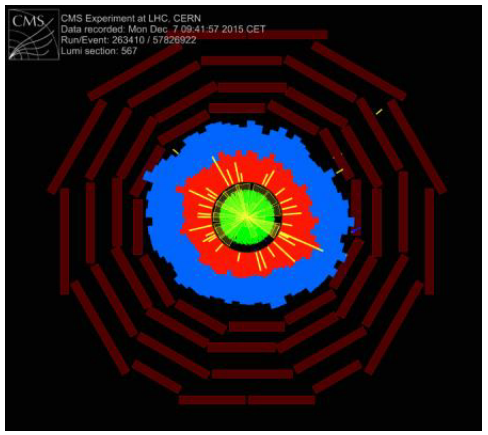

PRC 100 (2019) 024902

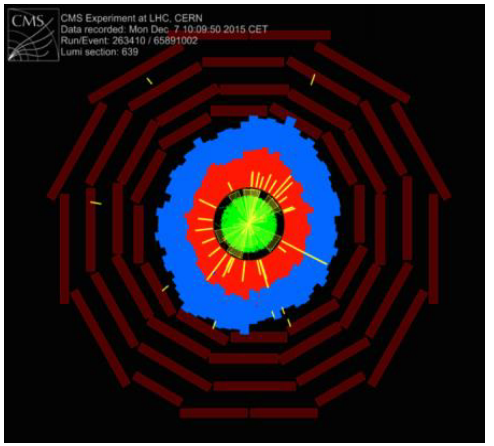
√s dependence
- pp, pPb, PbPb follow power law

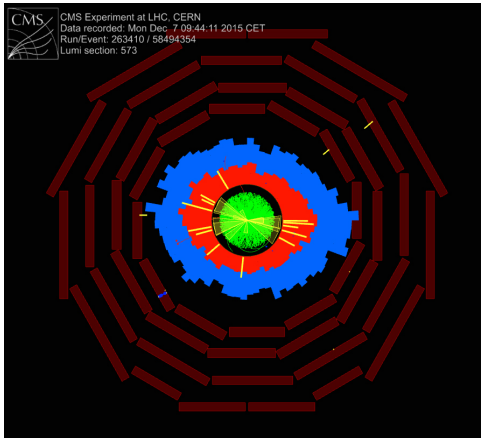
# Flow




Non-central Pb+Pb "screenshots" from CMS Event Monitor:
**Electromagnetic**, **Hadronic** **Energy** and **charged particles tracks**



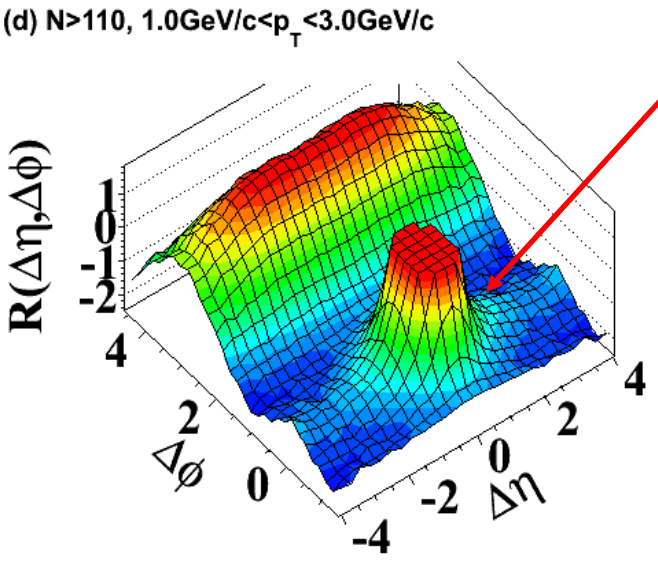




**Collective motion is observed in the event azimuthal distributions**

# Correlations: "RIDGE" everywhere...

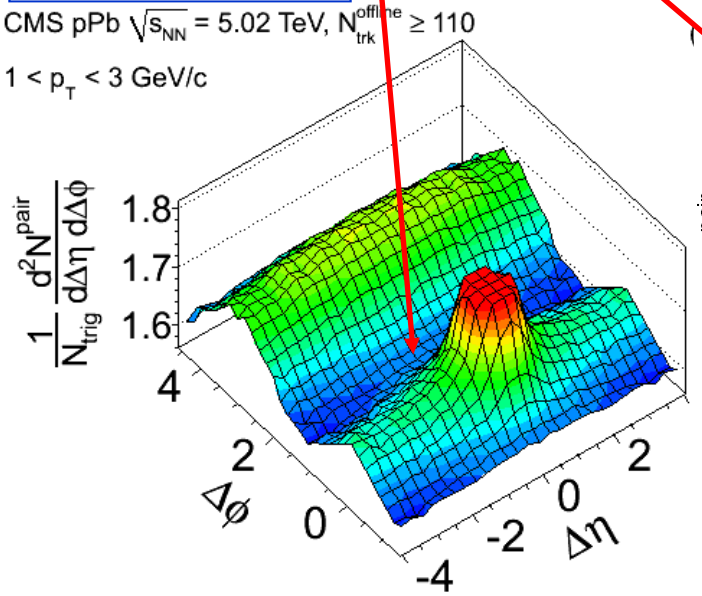
**Long-range ($2 < |\Delta\eta| < 4$), near-side ($\Delta\phi \approx 0$)**
angular correlations were observed in high multiplicity pp and pPb collisions (as well as in PbPb)

pp 7 TeV



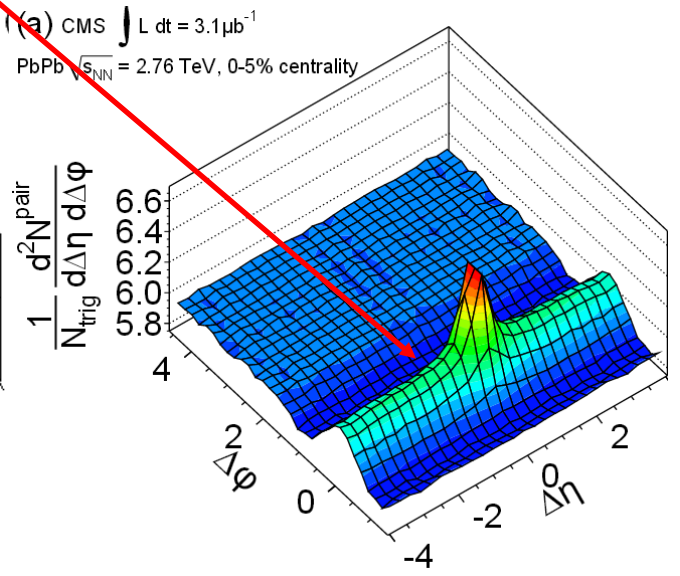

JHEP 09 (2010) 091

pPb 5.02 TeV




PLB 718 (2013) 795

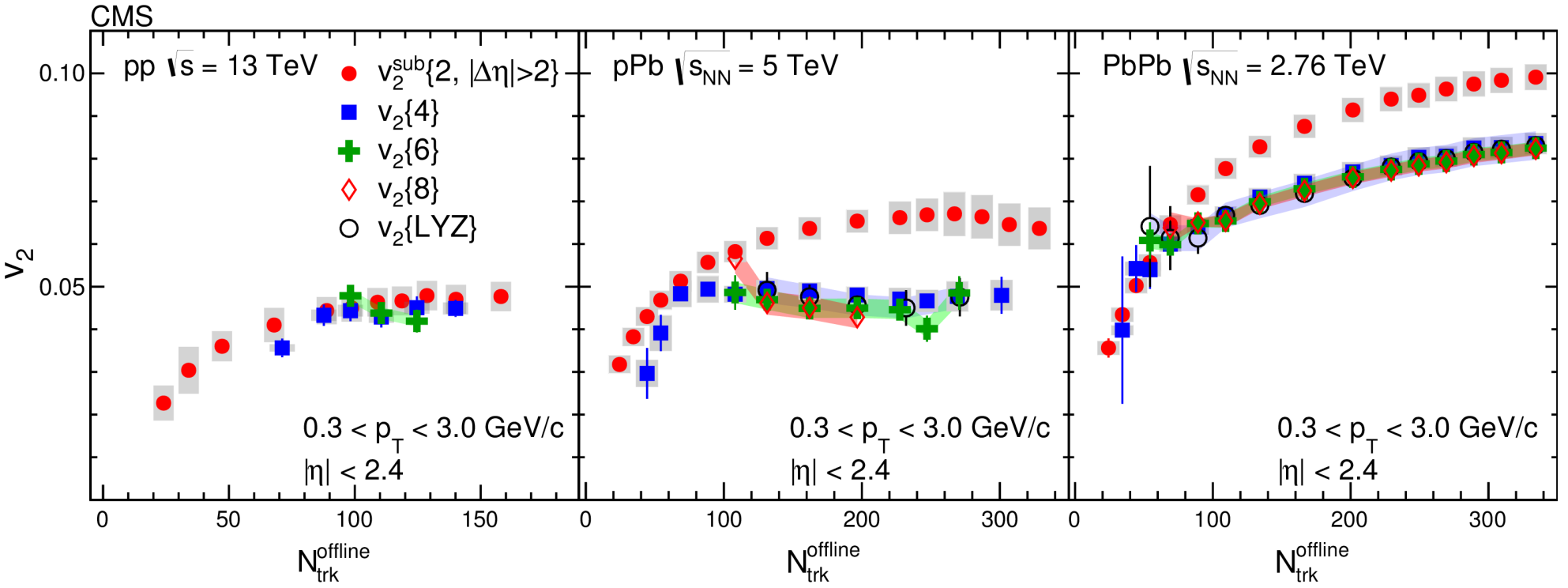
PbPb 2.76 A TeV, 0-5%




JHEP 07 (2011) 076

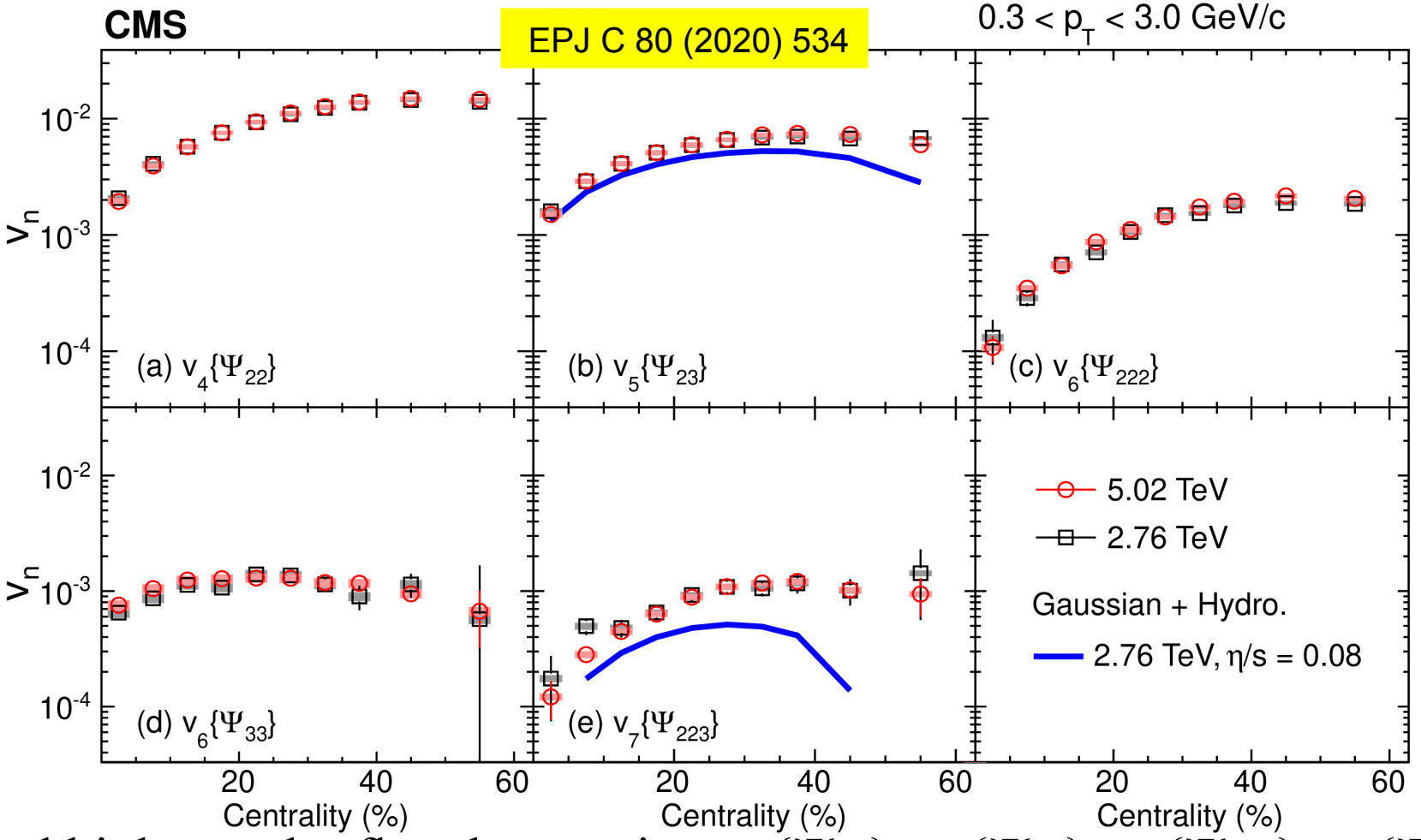
# Collectivity in pp, pPb, PbPb

PLB 765 (2017) 193




Elliptic flow extracted from long-range two-particle correlations was similar for pp and pPb
(collective origin for the observed long-range correlations in high-multiplicity pp collisions?)

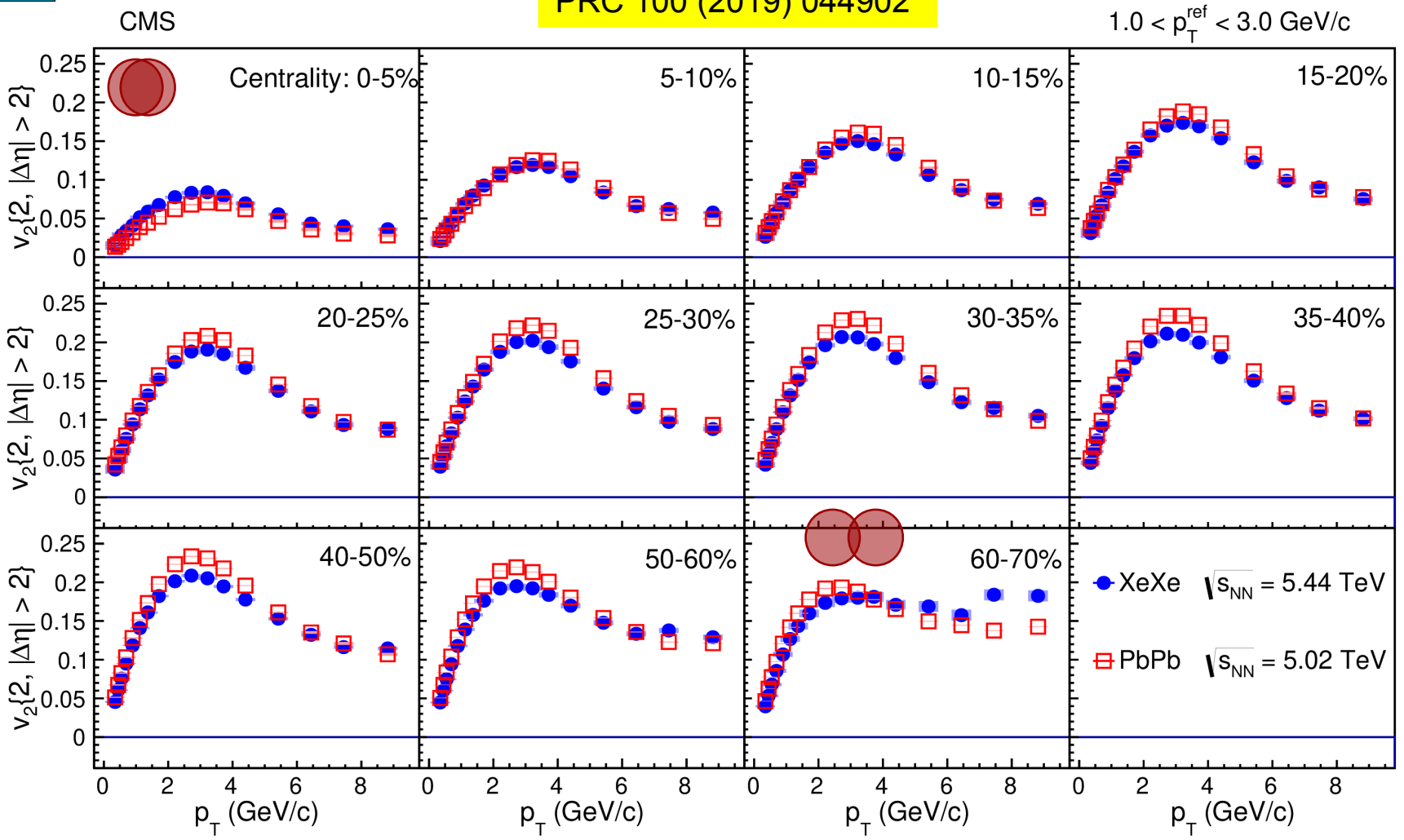
# Mixed higher-order anisotropic flow in PbPb




The mixed higher-order flow harmonics, $v_4\{\Psi_{22}\}$, $v_5\{\Psi_{23}\}$, $v_6\{\Psi_{222}\}$, $v_6\{\Psi_{33}\}$, and $v_7\{\Psi_{223}\}$ all have a qualitatively similar $p_T$ dependence. Viscous hydrodynamic calculation with Glauber initial conditions and shear viscosity doesn't provide a simultaneous description.

# $v_2$ XeXe vs. PbPb

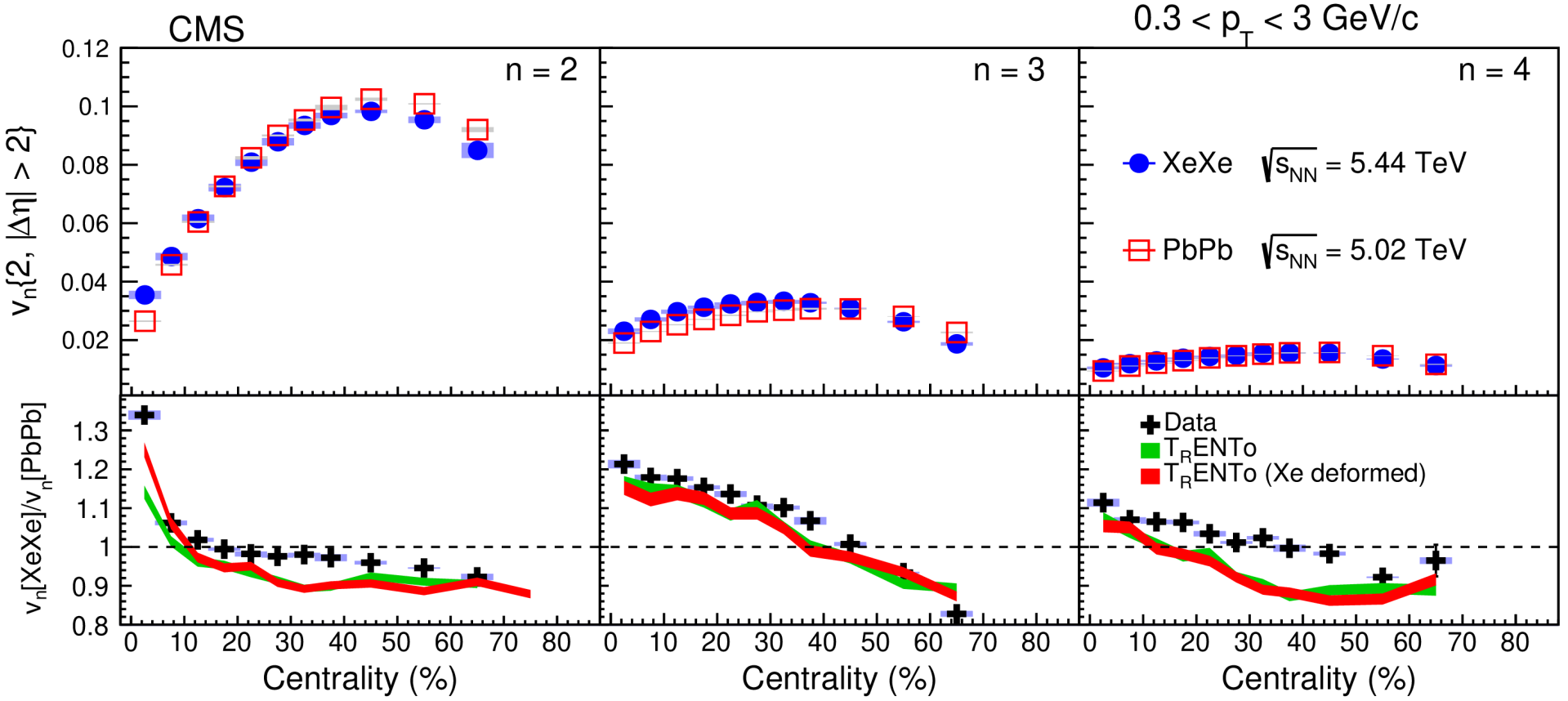
PRC 100 (2019) 044902




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

# $v_{2,3,4}$ XeXe vs. PbPb

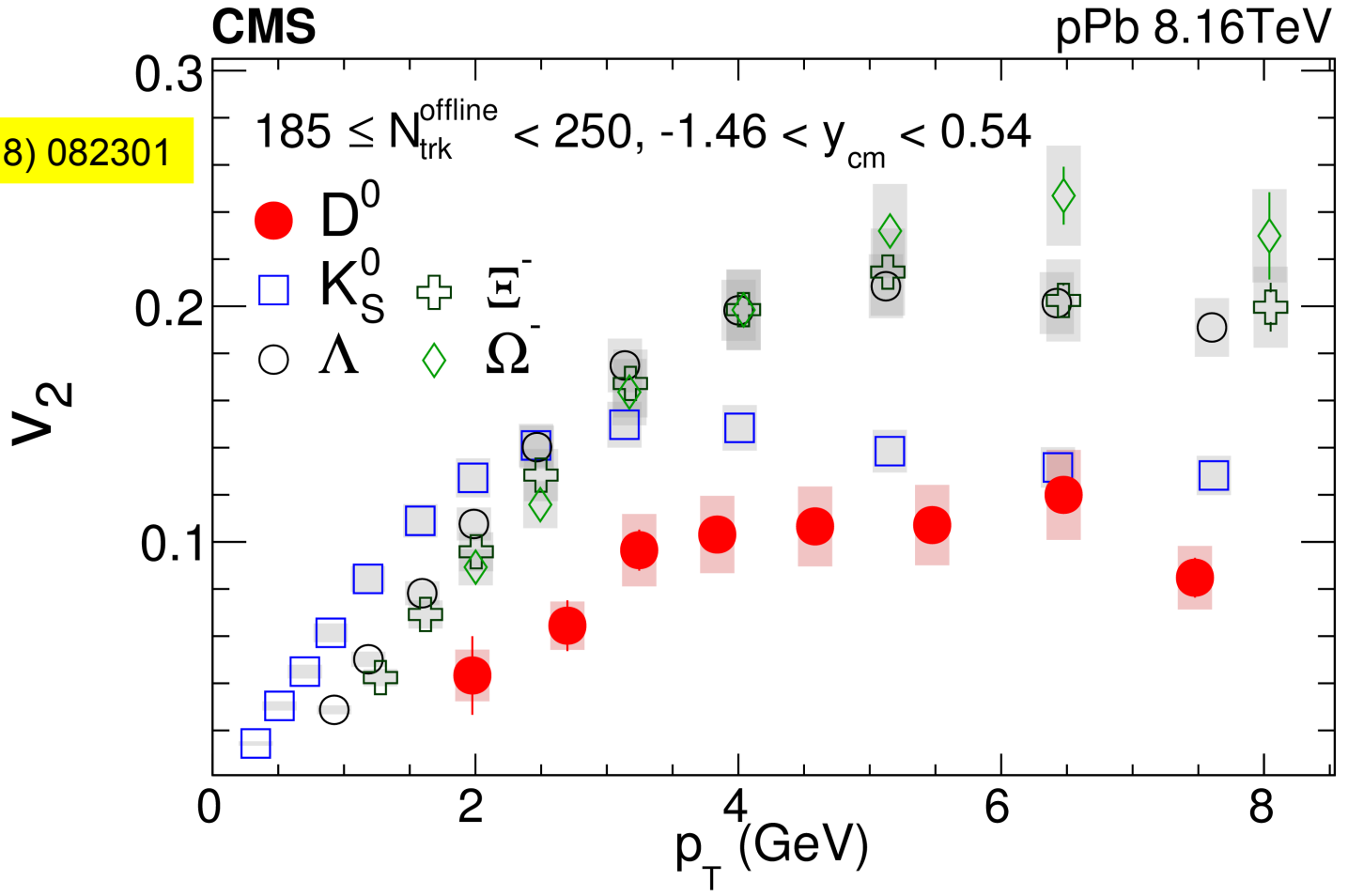
PRC 100 (2019) 044902




Hydrodynamic models that consider the Xe nuclear deformation are able to better describe the $v_2$[XeXe]/$v_2$[PbPb] ratio in central collisions than those assuming a spherical Xe shape.

# Heavy quark collectivity in small systems

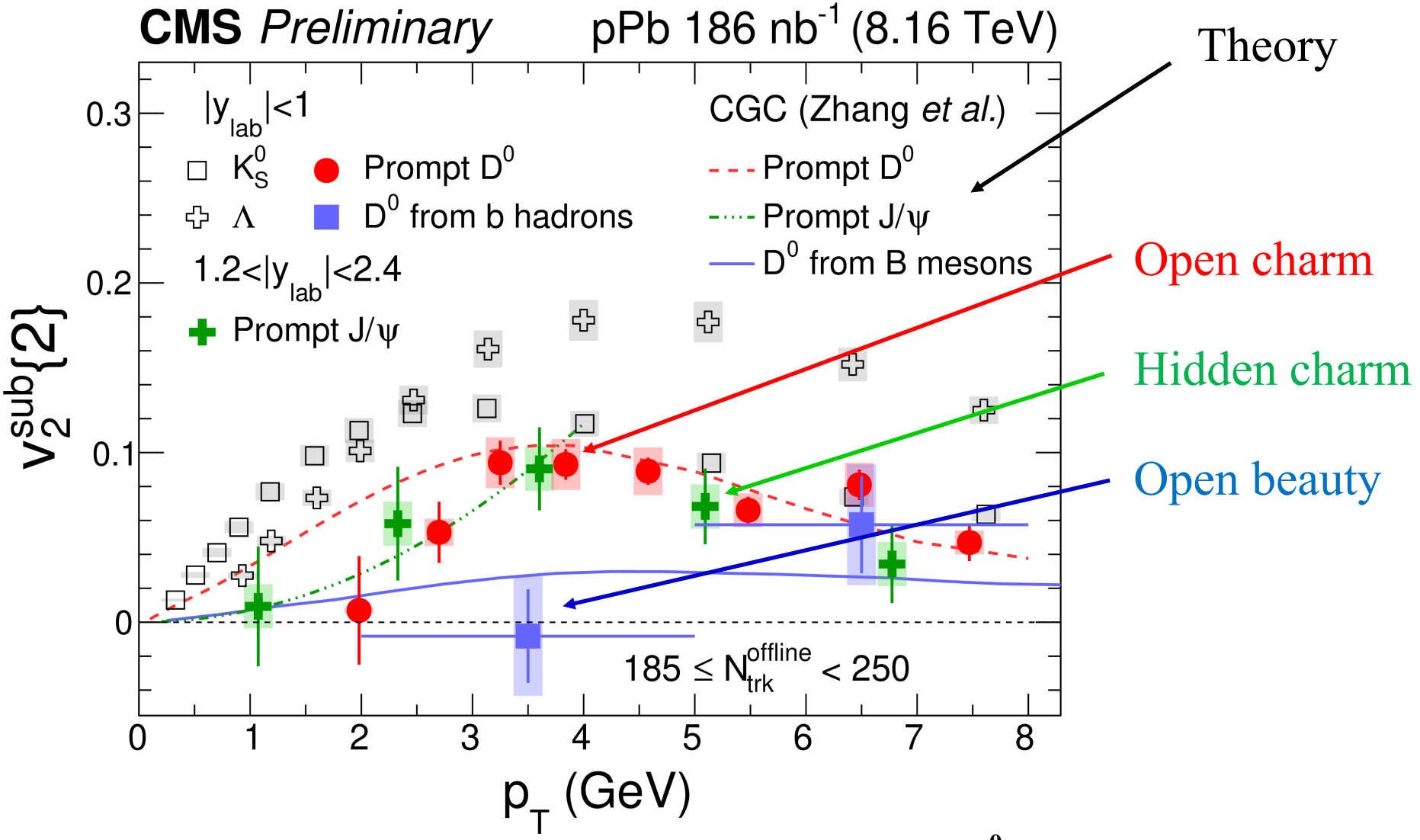
PRL 121 (2018) 082301




- Significant positive $v_2$ values are observed for $D^0$ mesons with $p_T > 2$ GeV/*c*.
- The collective behavior of charm quarks in high-multiplicity pPb collisions is weaker than that of the light-flavor quarks.

# Charm and beauty long-range correlations in pPb collisions

CMS-PAS-HIN-19-009




Theory

Open charm

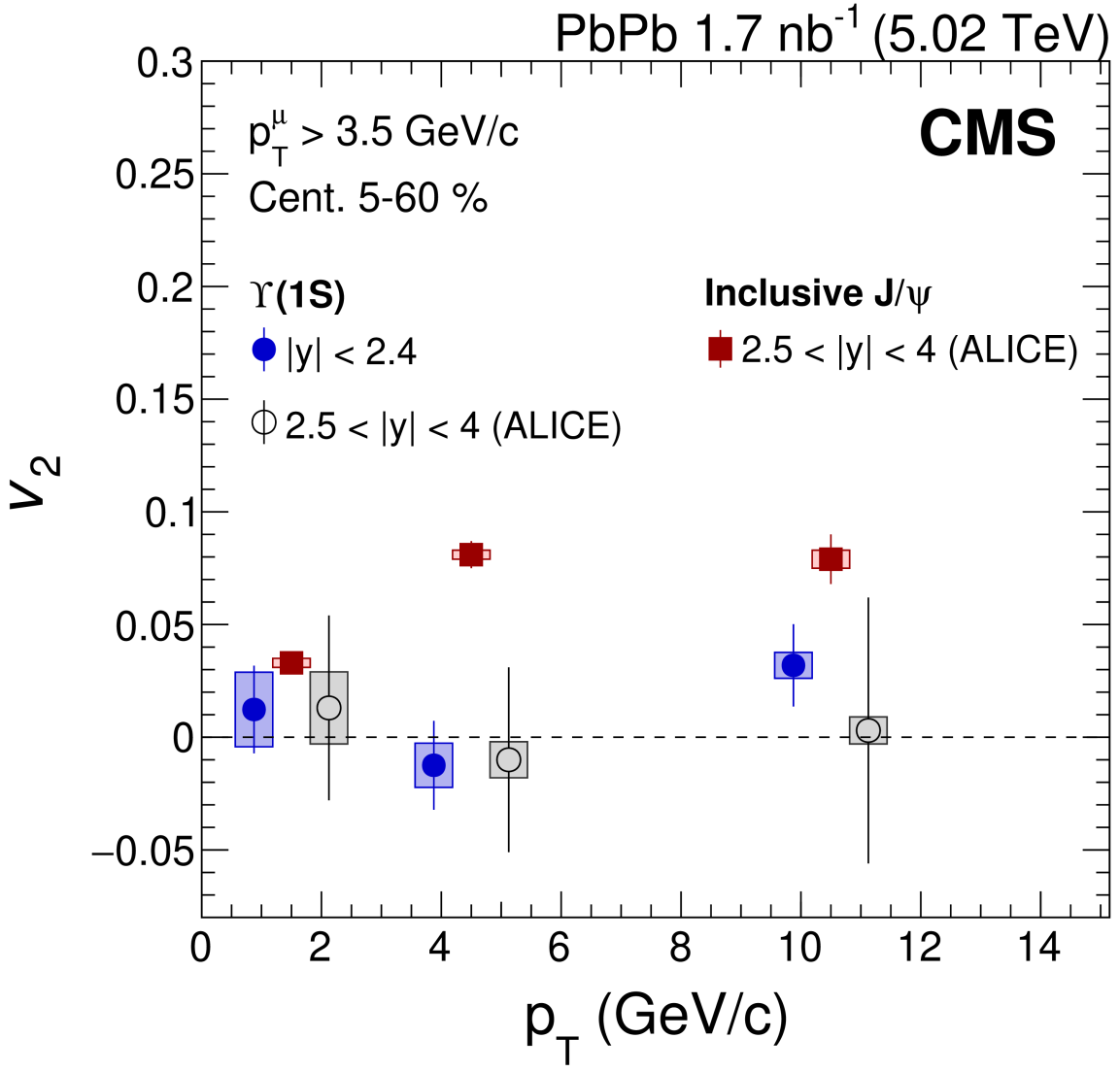
Hidden charm

Open beauty

**No significant flow for nonprompt $D^0$**

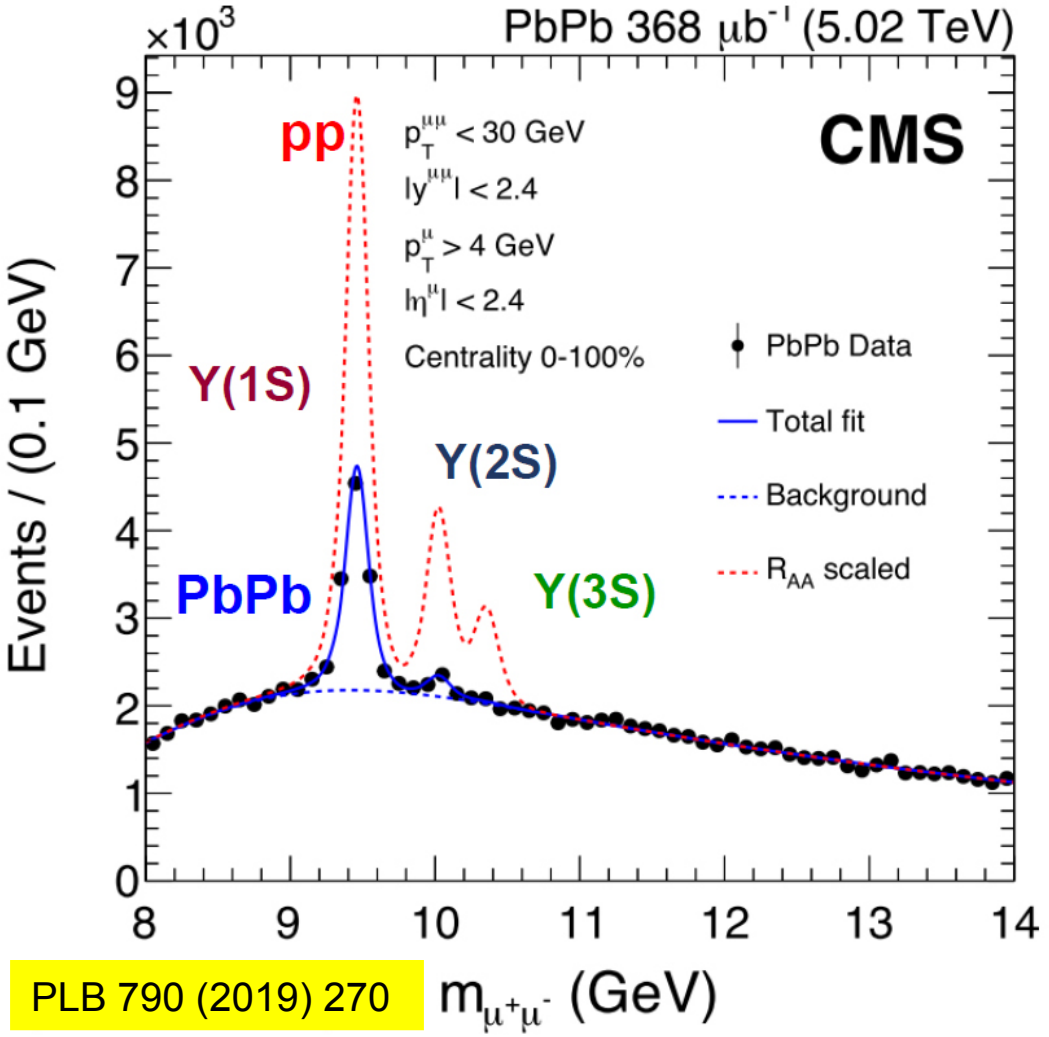
# Measurement of $v_2$ of Υ in PbPb collisions

arXiv:2006.07707

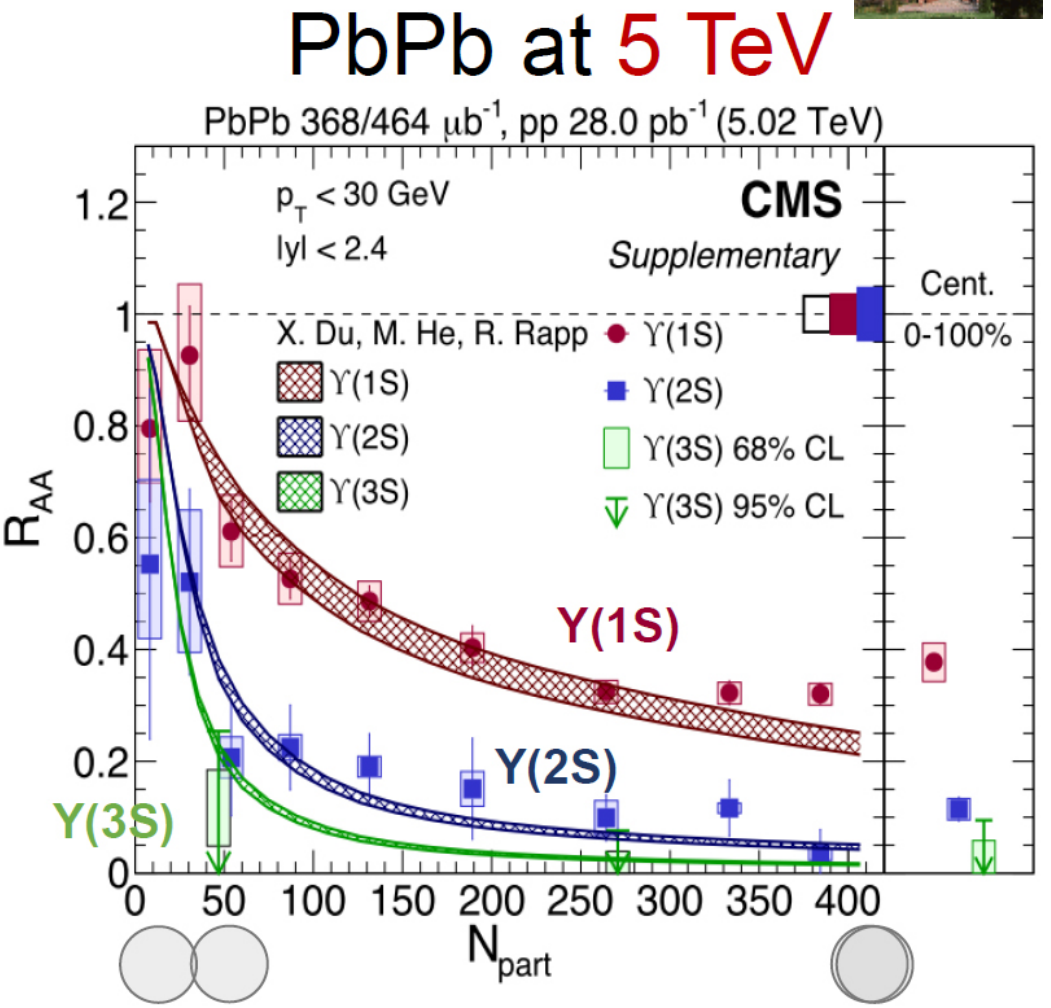



**In contrast to the J/ψ mesons,**
**no azimuthal anisotropy is observed for the Υ mesons.**

# Upsilon suppression in PbPb



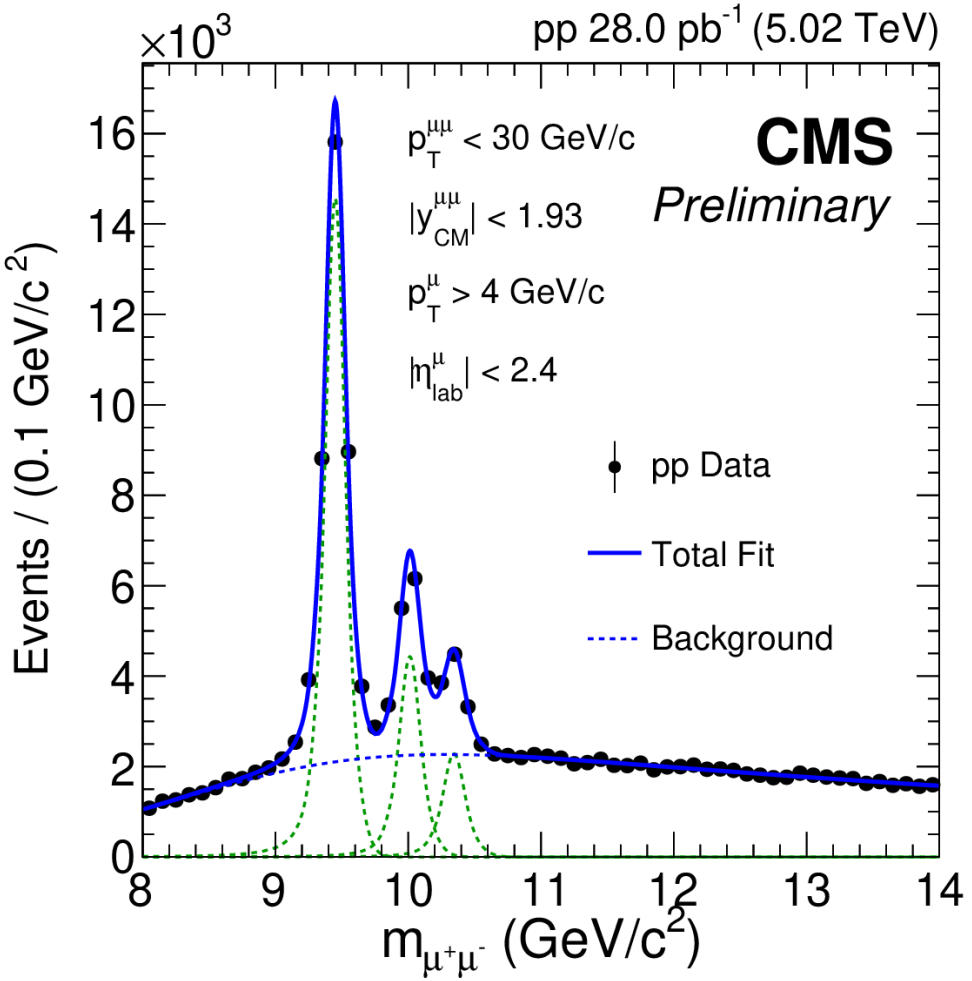

PLB 790 (2019) 270

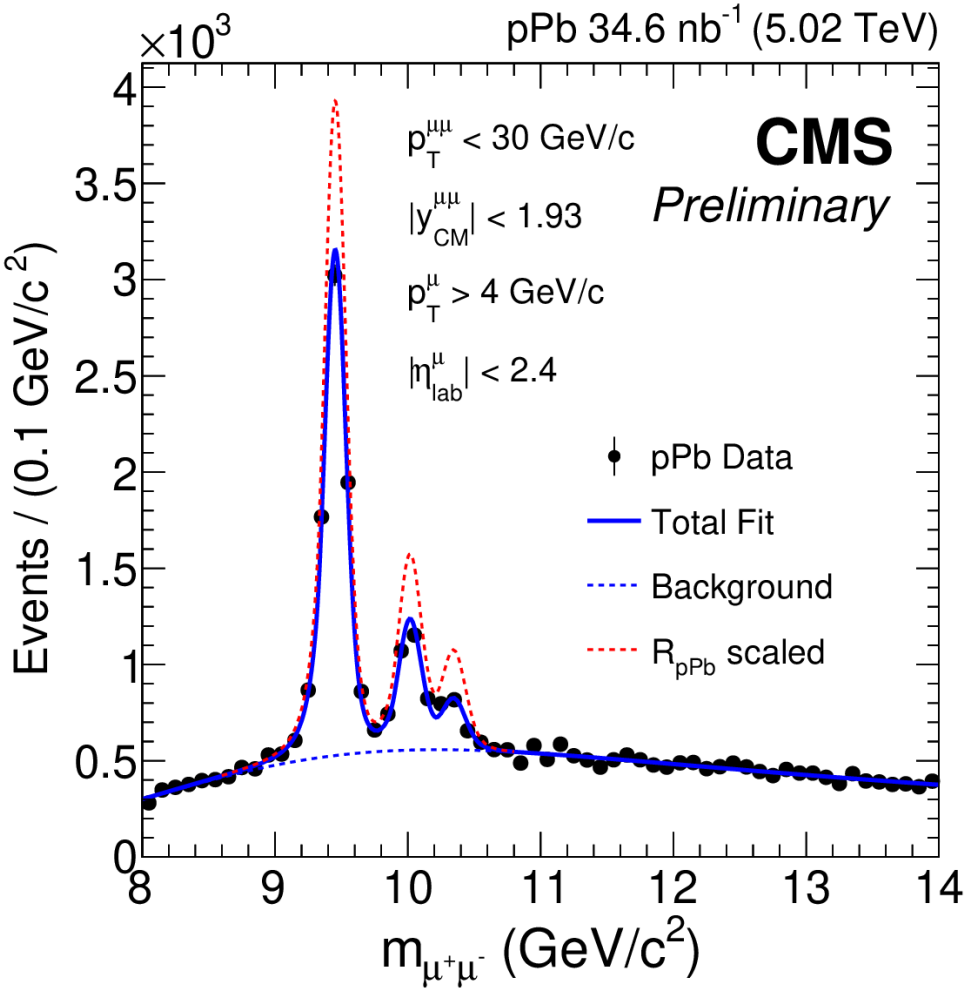



- Observation of sequential suppression of Υ family.
- No any sign of Υ(3S) in the high statistics 2015 data.

# Upsilon suppression in pPb

CMS-PAS-HIN-18-005

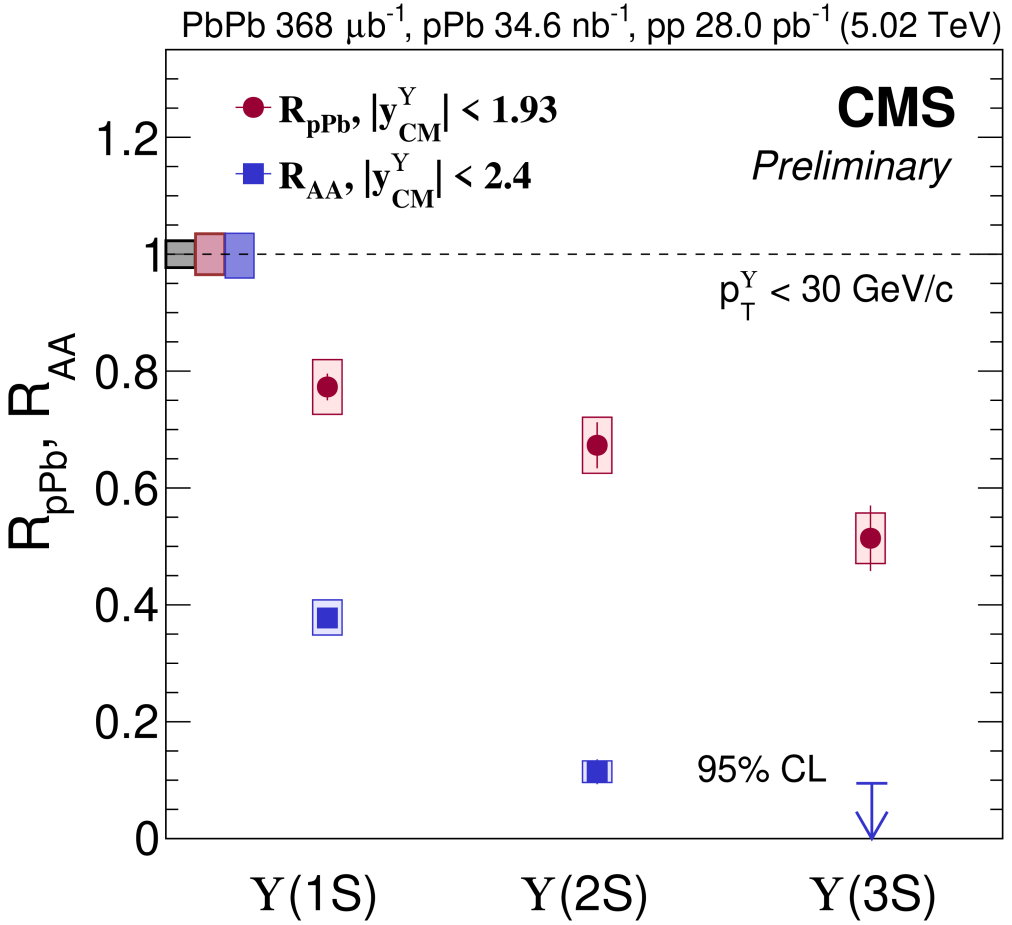



**All Y states are found to be suppressed in pPb collisions compared to pp collisions.**

# Upsilon suppression in pPb and PbPb

CMS-PAS-HIN-18-005




Ordered in binding energy

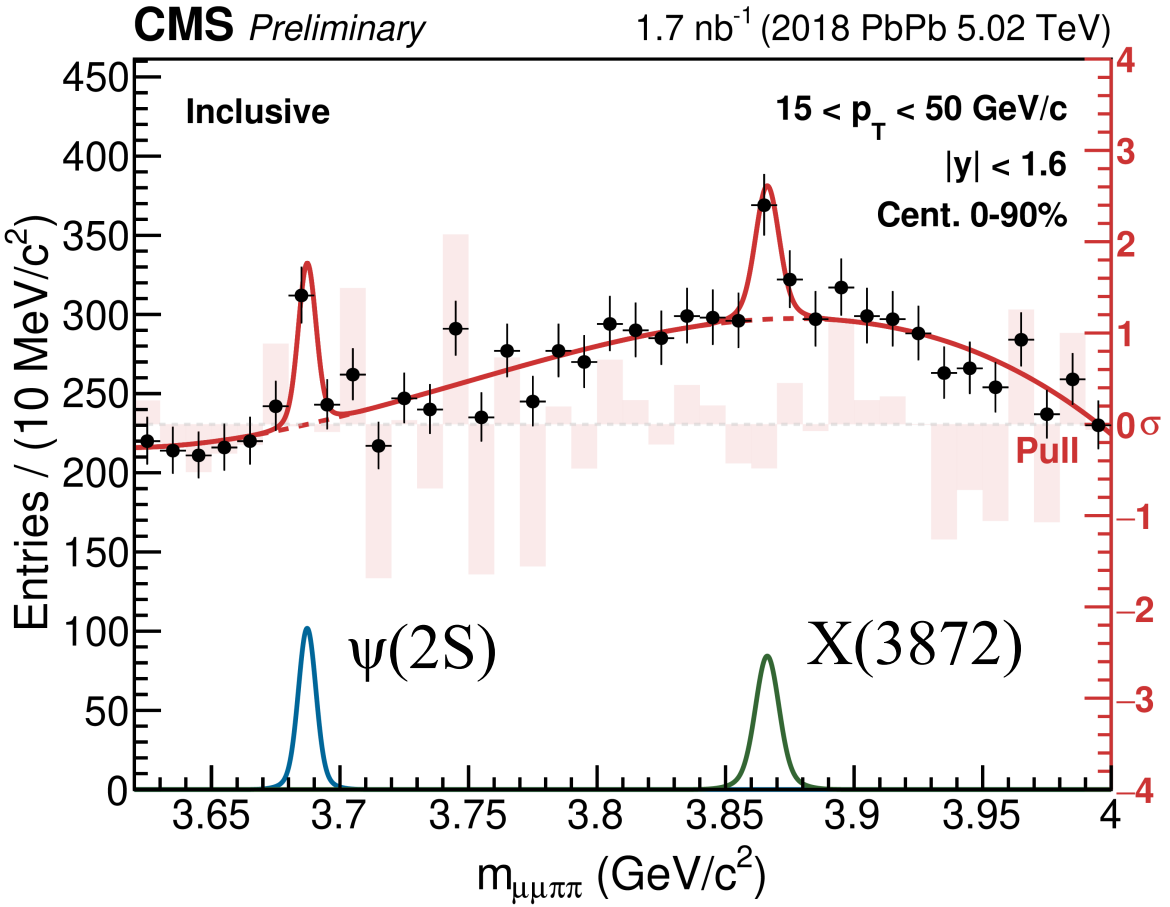
RpPb Υ(1S) > RpPb Υ(2S) > RpPb Υ(3S)

Largest suppression in PbPb

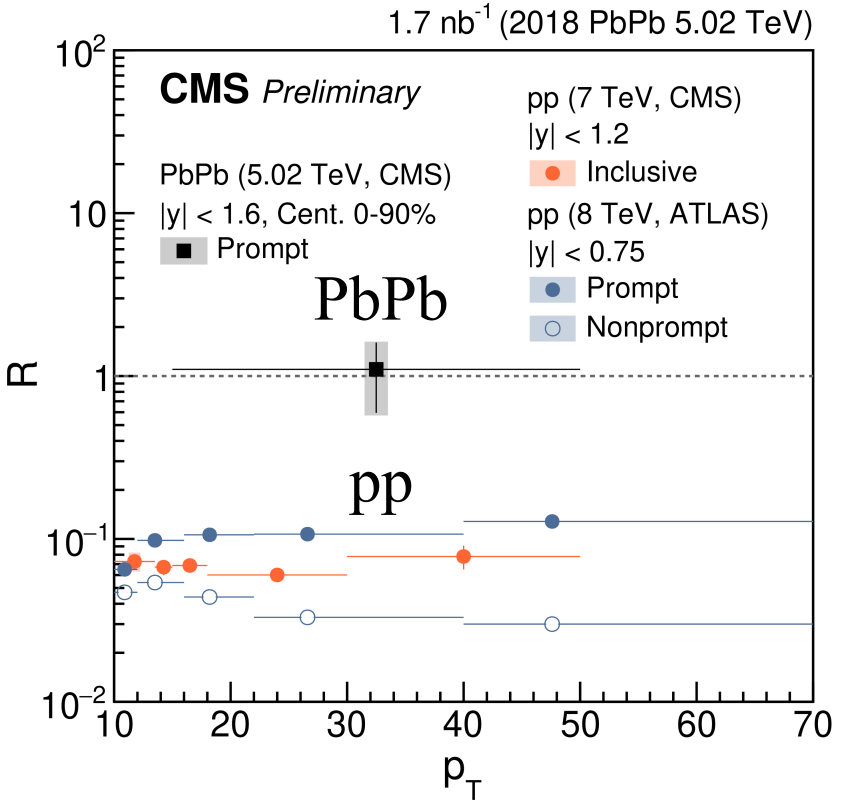
$R_{pPb} > R_{PbPb}$

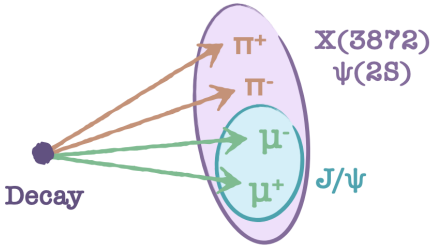
# First evidence of X(3872) in PbPb

CMS-PAS-HIN-19-005




## Comparison to ψ(2S)

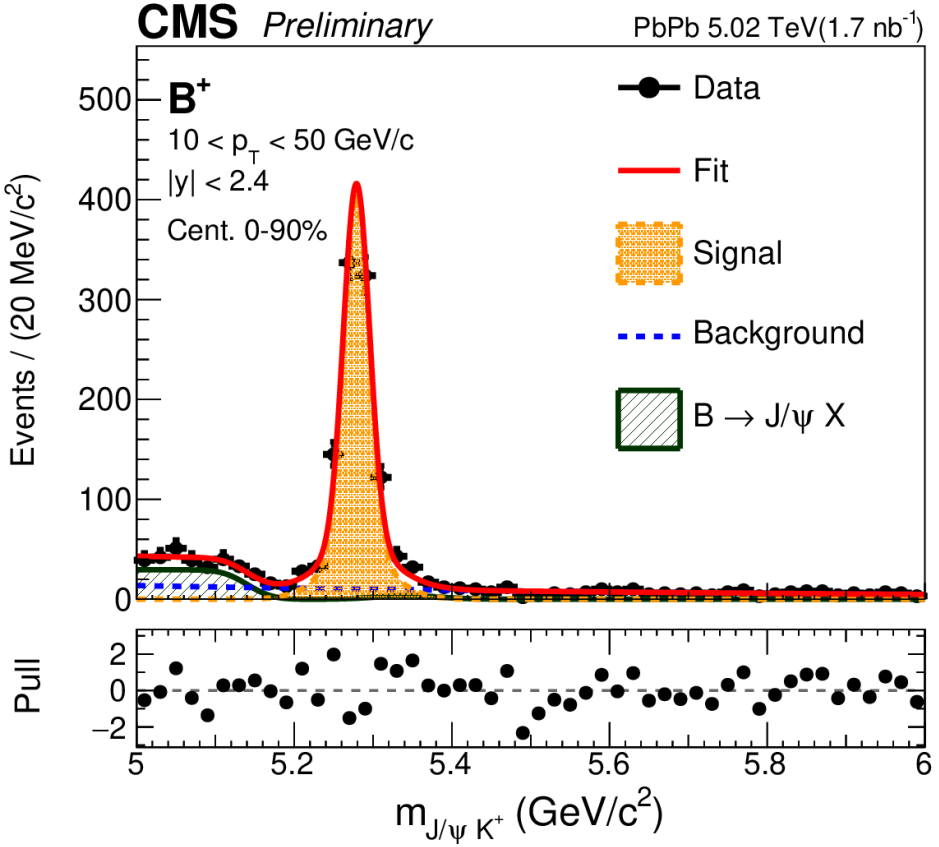


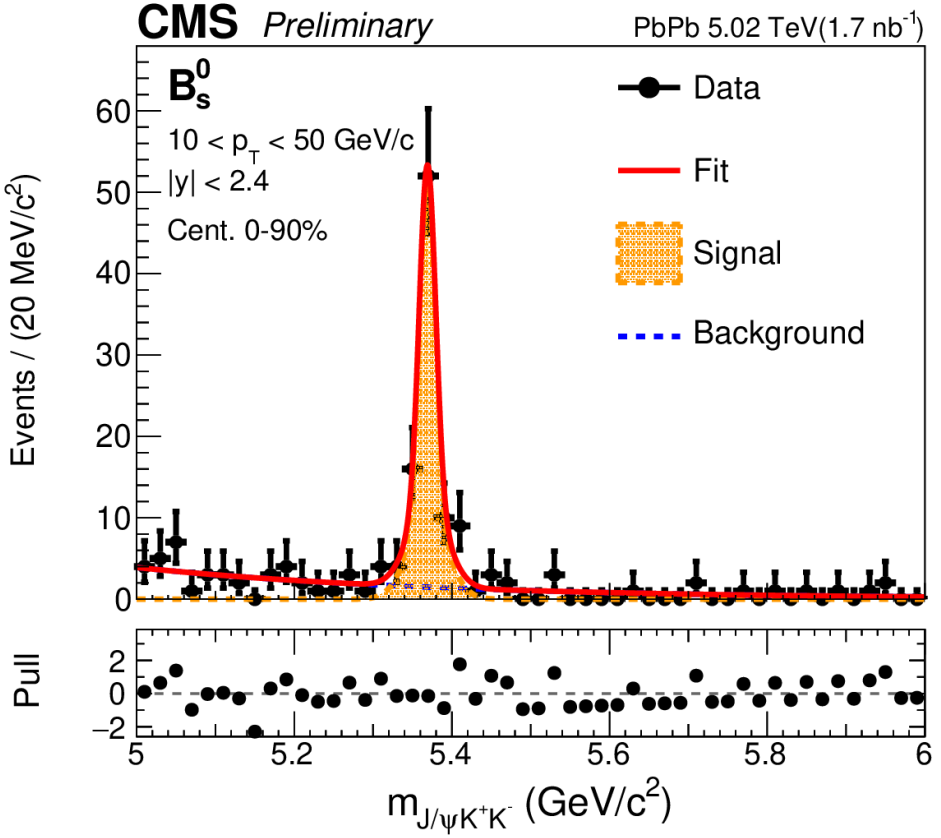




Result provides a unique experimental input to the theory, towards elucidating the production mechanism and the nature of the X(3872).

# Measurement of $B_s^0$ and $B^+$ meson in PbPb collisions

CMS-PAS-HIN-19-011

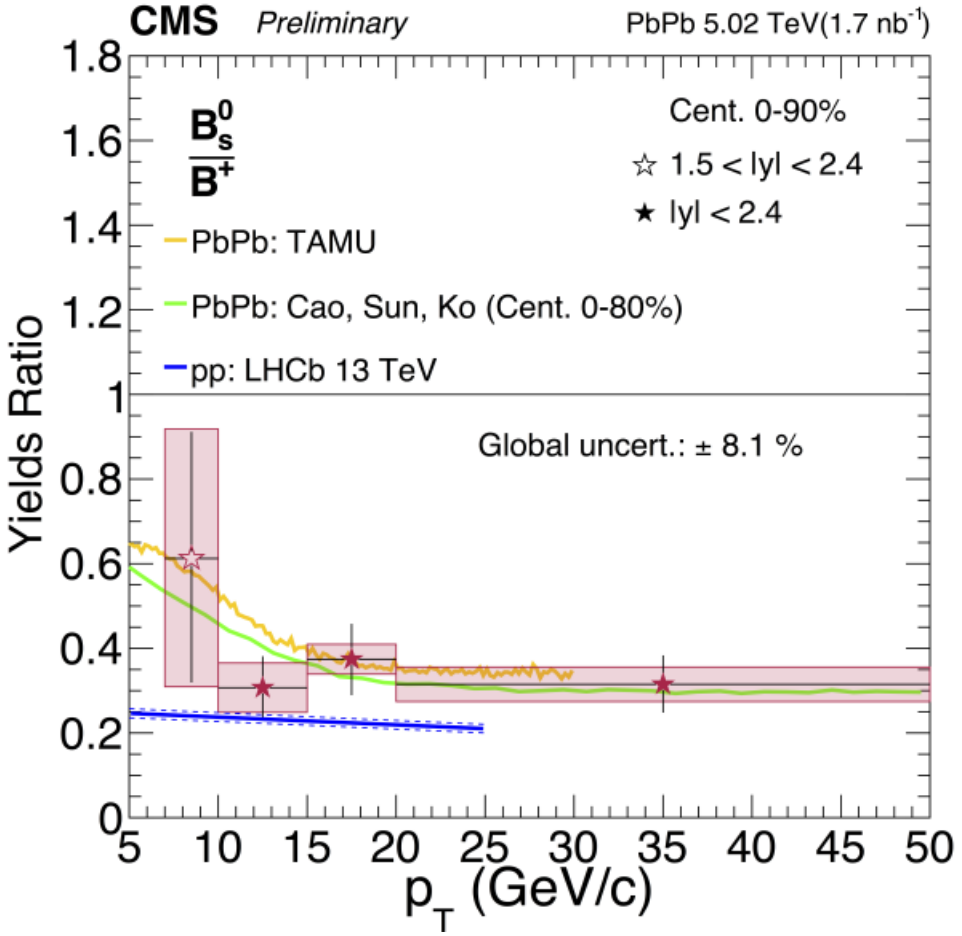


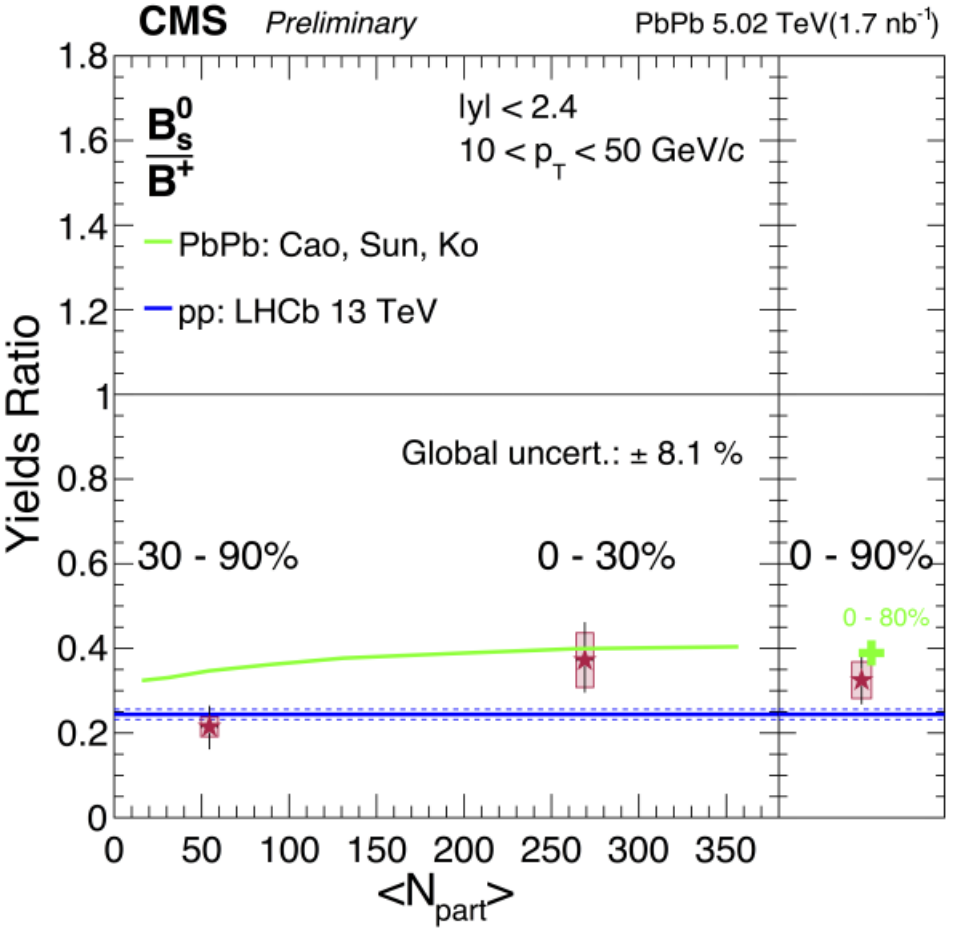




The $B_s^0$ meson is observed with a statistical significance in excess of 5 standard deviations for the first time in nucleus-nucleus collisions

# Measurement of $B^0_s$ and $B^+$ meson in PbPb collisions

CMS-PAS-HIN-19-011

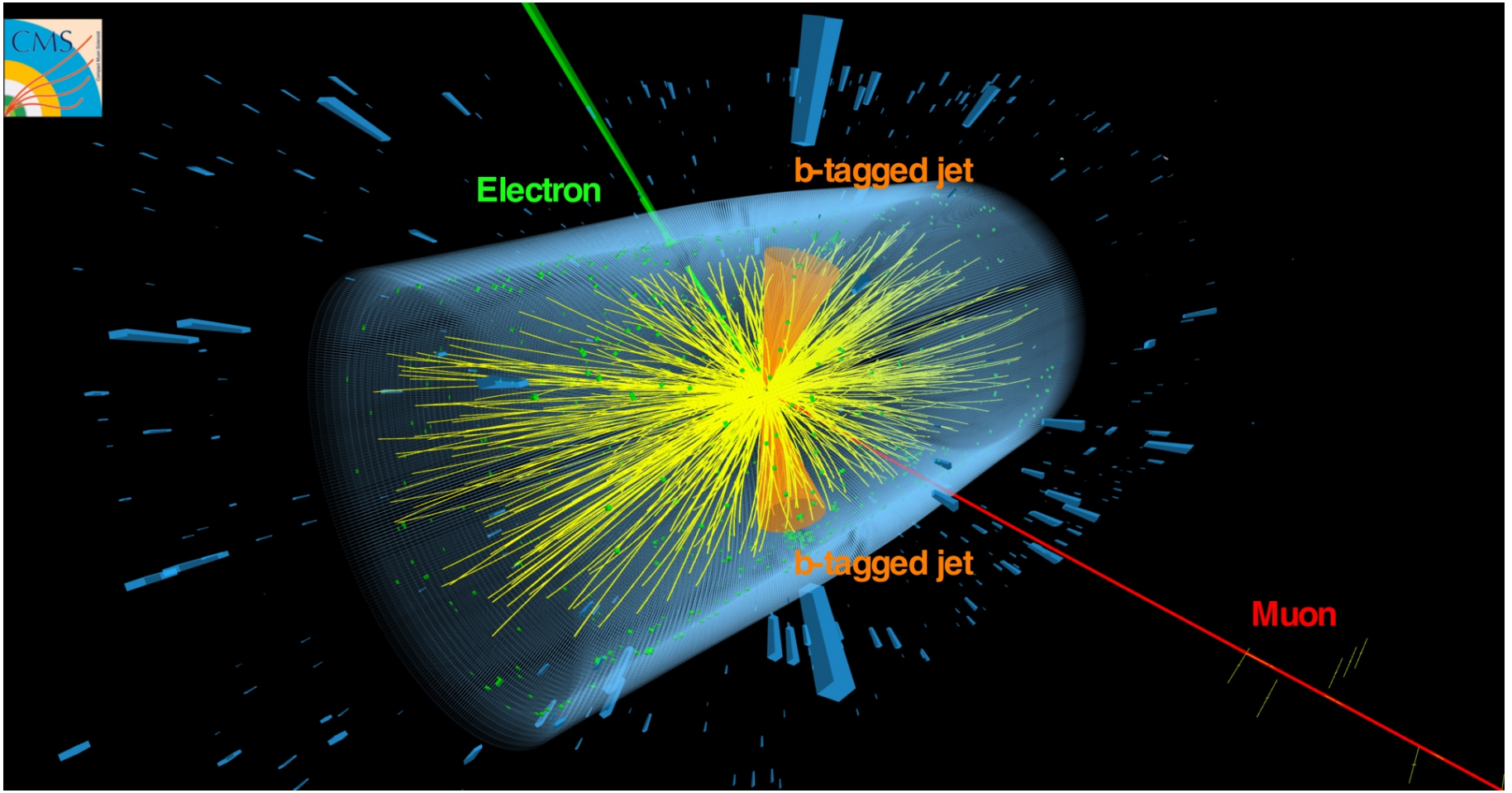



- No significant $p_T$-dependence of $B^0_s$ / $B^+$ ratio
  - Model predictions in reasonably well agreement with data
- $B^0_s$ / $B^+$ ratio in PbPb compatible with measurements in pp

# The first search for top using PbPb collisions

arXiv:2006.11110




**Using either charged leptons only or charged leptons + b jets.**
**The measured cross sections are compatible with expectations from scaled proton-proton data and QCD predictions.**

$$\sigma_{t\bar{t}} = 2.54^{+0.84}_{-0.74} \text{ and } 2.03^{+0.71}_{-0.64}\ \mu\text{b}$$

# The first search for top using PbPb collisions

arXiv:2006.11110

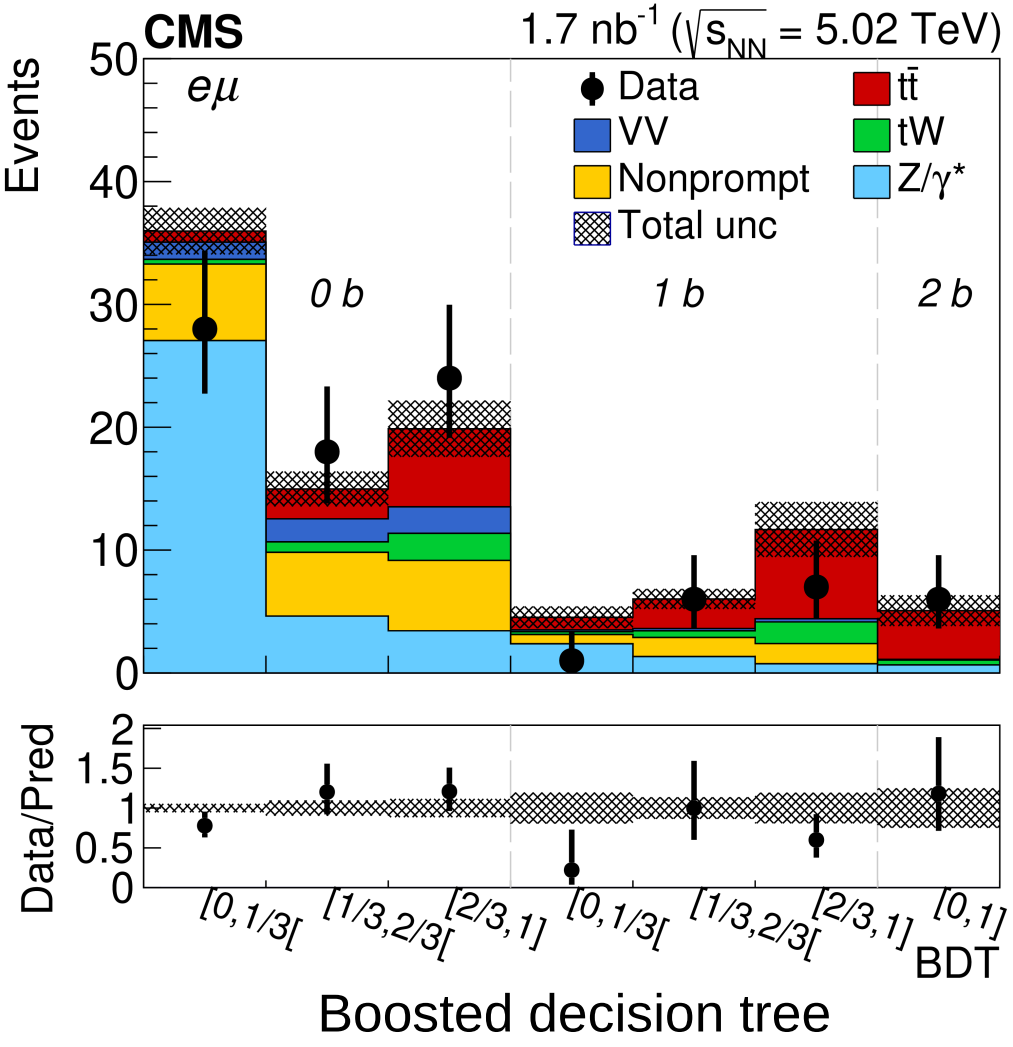
**4.0 σ significance**

Consistent with pQCD

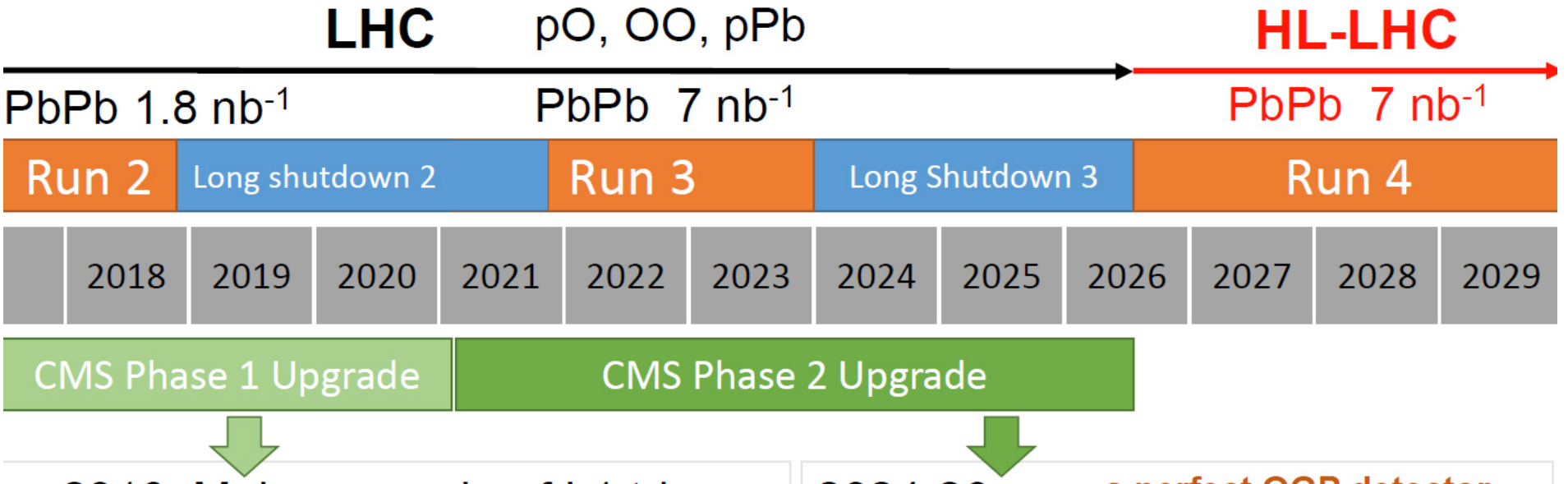
- **Top quarks can probe both the initial and final state**
- **Probing the QGP formation?**

Both dilepton multivariate & b-jet counting analyses

**The observed significance of the top signal against the background-only hypothesis amounts to 3.8 and 4.0 standard deviations in the two methods.**



# LHC Timeline and CMS Upgrade




- 2016: Major upgrade of L1 trigger
- 2017: 4-Layer Pixel Detector
- 2018 Performance:
  - pp L1 100kHz
  - PbPb L1 **30kHz** (3x of 2015)
  - DAQ: 6 GB/s
    - Up to **6.5 kHz** MinBias events to tape (20x of 2015)

2024-26 **a perfect QGP detector**

- Tracker **|η|<4**
- Muon ID up to **|η|<3**
- High Granularity Calo **1.6<|η|<3.0**
- **MIP timing detector**
  - 4D vertexing
  - **Possible p/K/π PID !!!**
- pp L1: 750 kHz
- DAQ: 60 GB/s

# CMS Summary for Heavy-Ions Soft Probes

- **Many interesting heavy-ion physics results with the CMS detector in pp, pPb, PbPb and XeXe...**

- **Future heavy-ion program at the LHC (Run 3 and 4) with the upgraded CMS detector will provide more exciting opportunities!**

# THANK YOU!

고마워!

СПАСИБО!

# THANK YOU!

고마워!


СПАСИБО!

**Děkuji mnohokrát !**