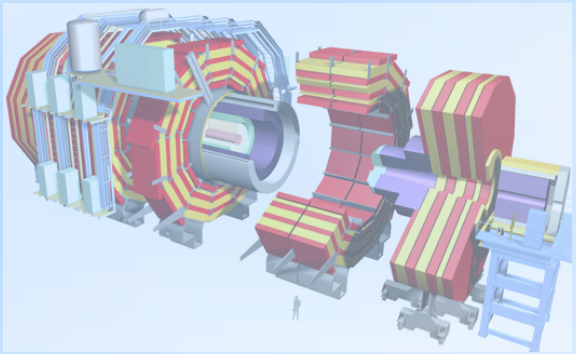
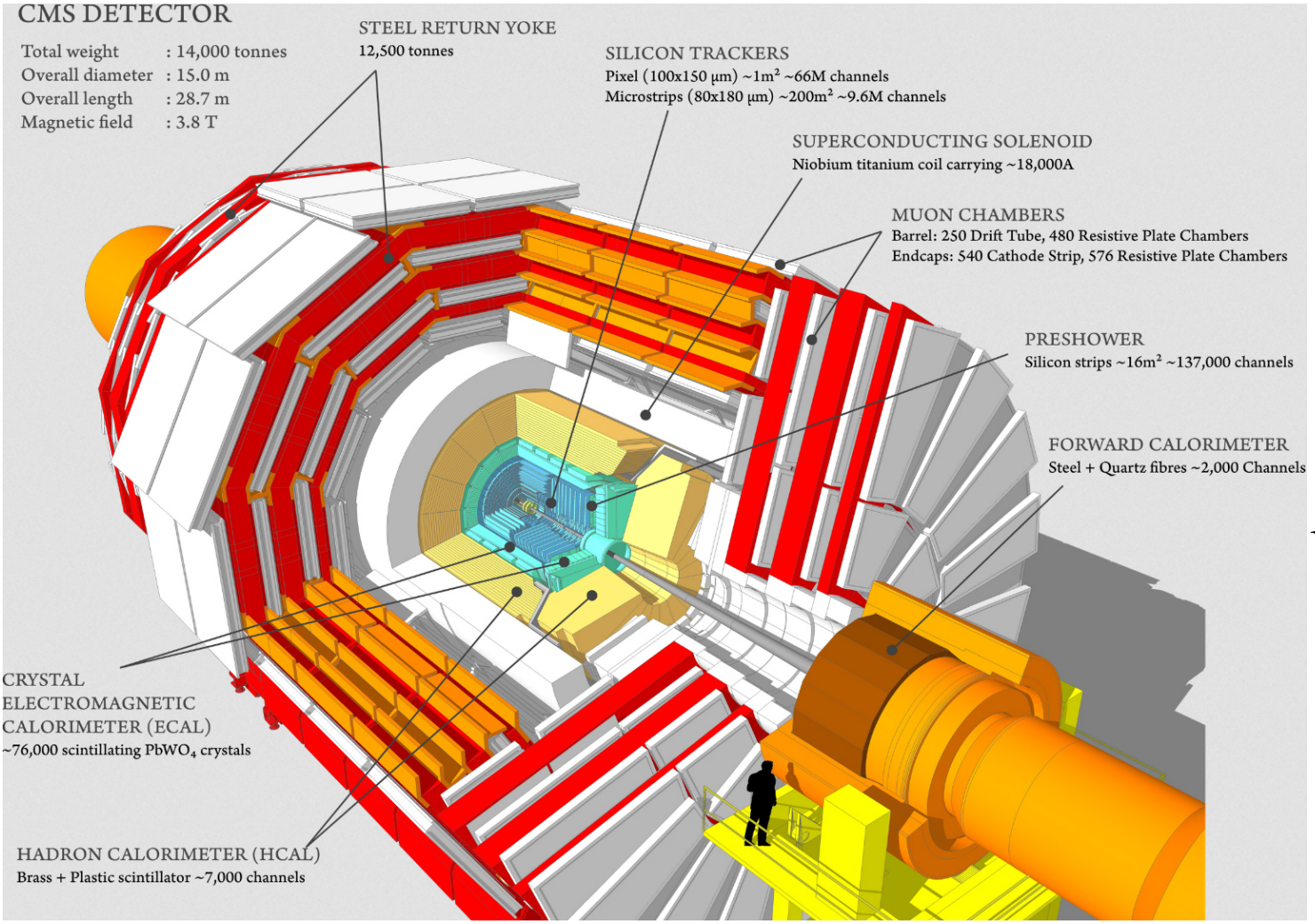
Sergey Petrushanko
(for CMS Collaboration)
SINP MSU Russia

Heavy-ion physics with the CMS detector at the LHC

Сессия-конференция
СЯФ ОФН РАН
Новосибирск, РФ
10-12 марта 2020 года



CMS is a nice heavy-ion experiment

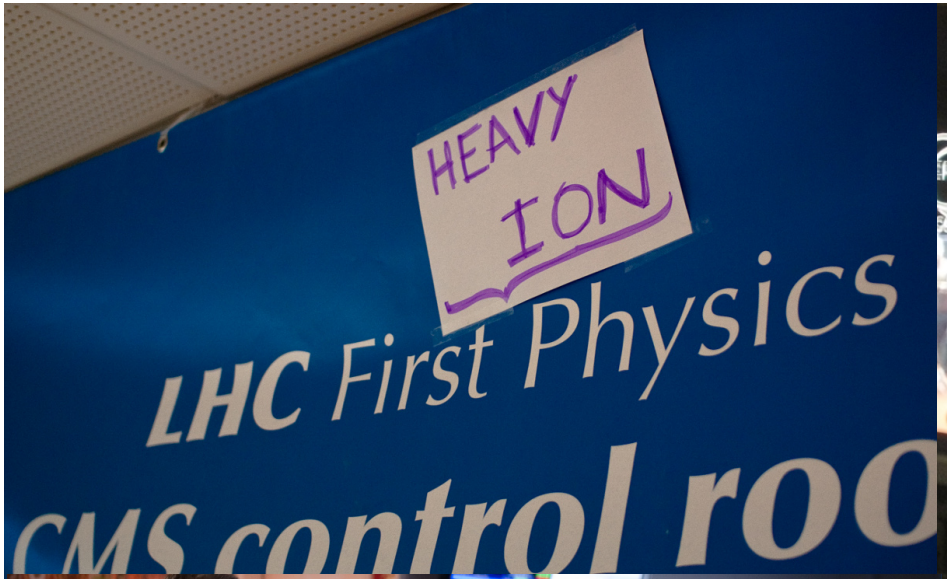


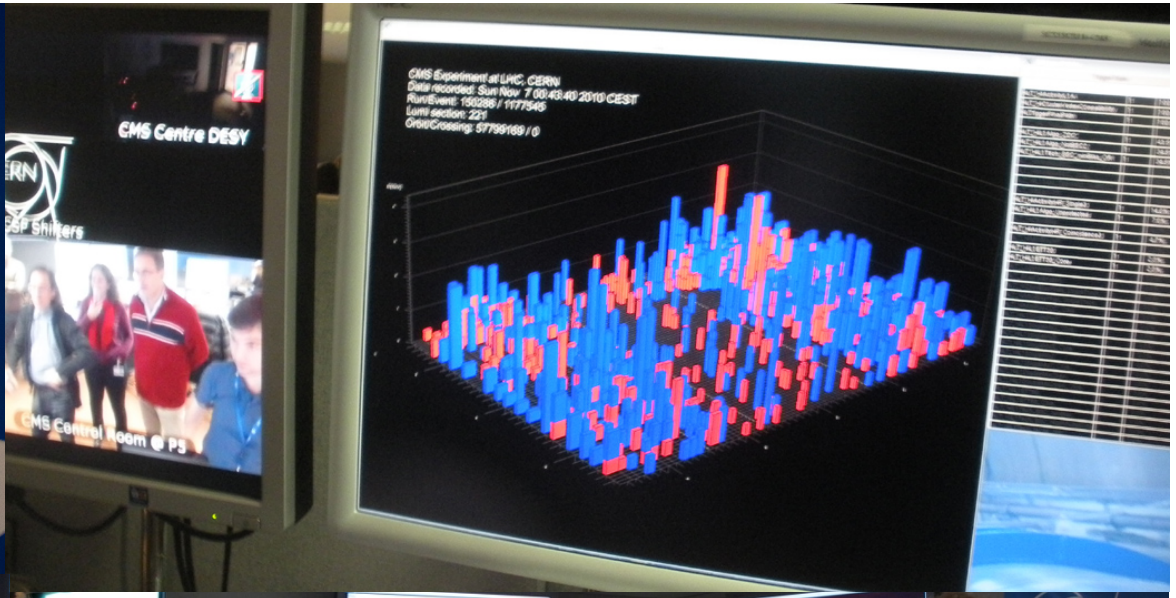
- **Silicon Tracker**
  $|\eta| < 2.4$
- **Electromagnetic Calorimeter**
  $|\eta| < 3.0$
- **Hadron Calorimeter**
  barrel and endcap
  $|\eta| < 3.0$
  with HF-calorimeter up to
  $|\eta| < 5.2$
- **Muon Chambers**
  $|\eta| < 2.4$

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

Magnetic field: 3.8 Tesla

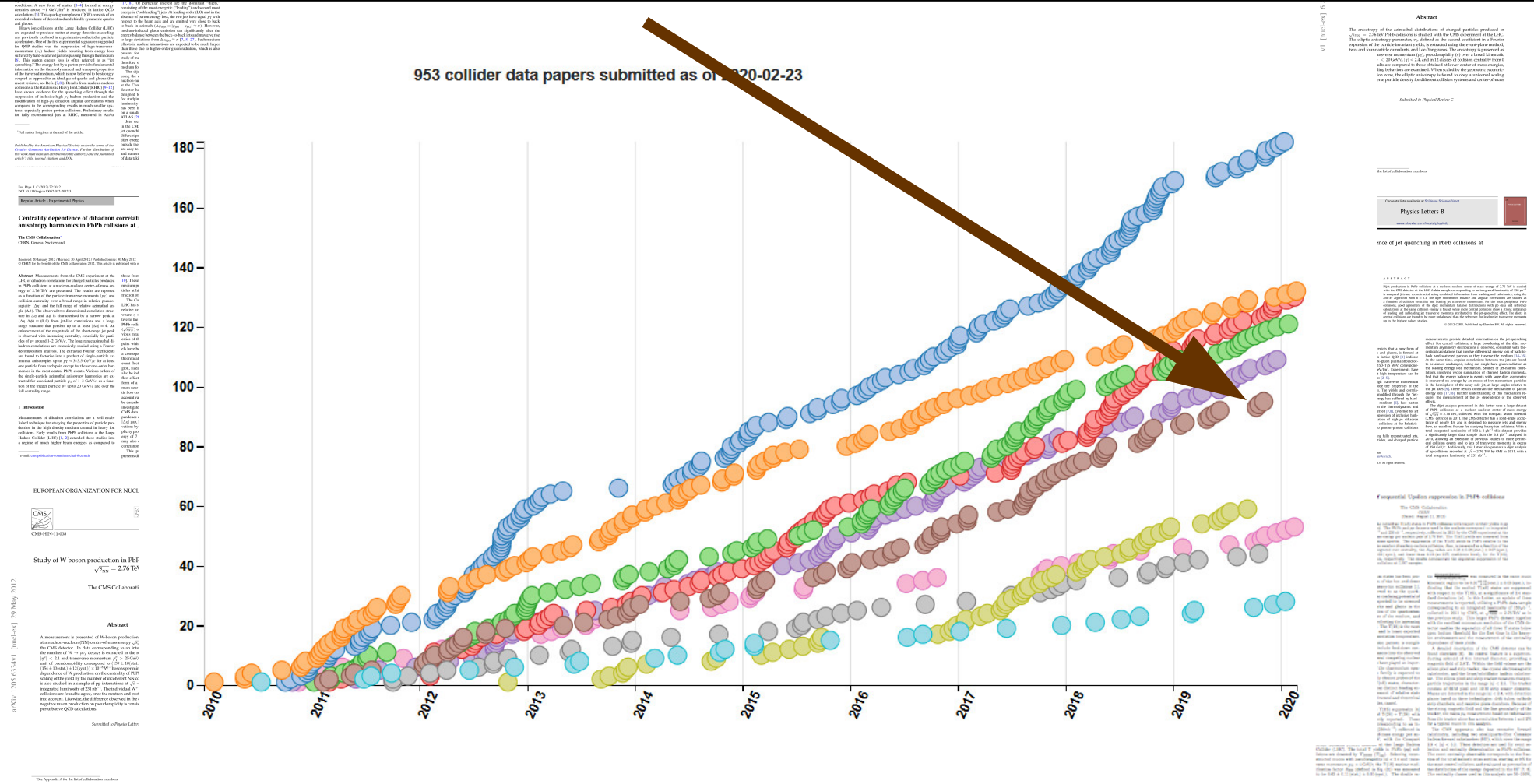
November 7, 2010 0:27 CMS Control Room





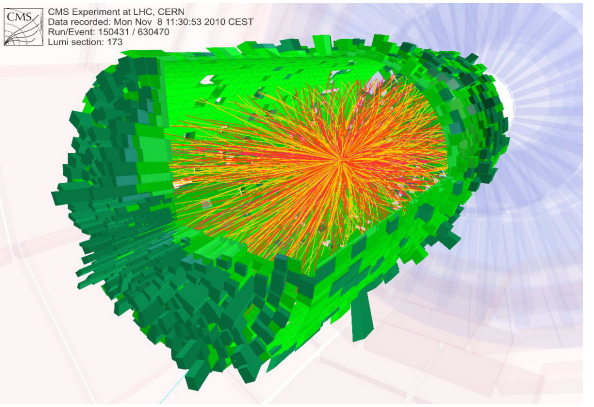
CMS heavy-ion results

95 published/submitted Heavy-ion Physics CMS papers:
http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN/index.html



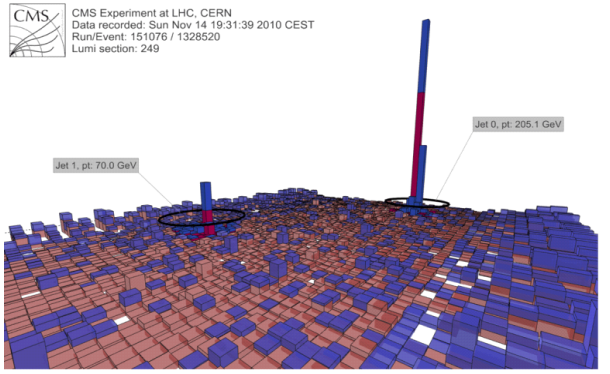
CMS heavy-ion results

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



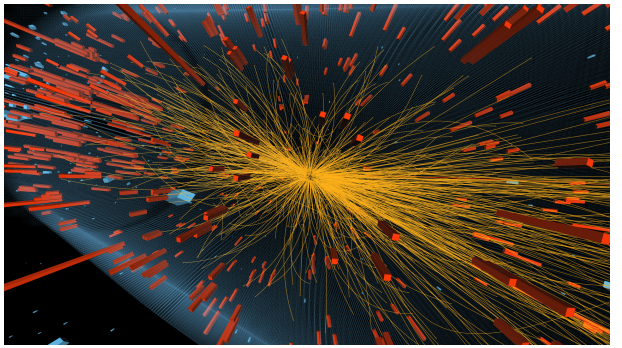
Pb+Pb collisions
2010-11: 2.76 TeV 0.16/nb
2015-18: 5.02 TeV 1.7/nb

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

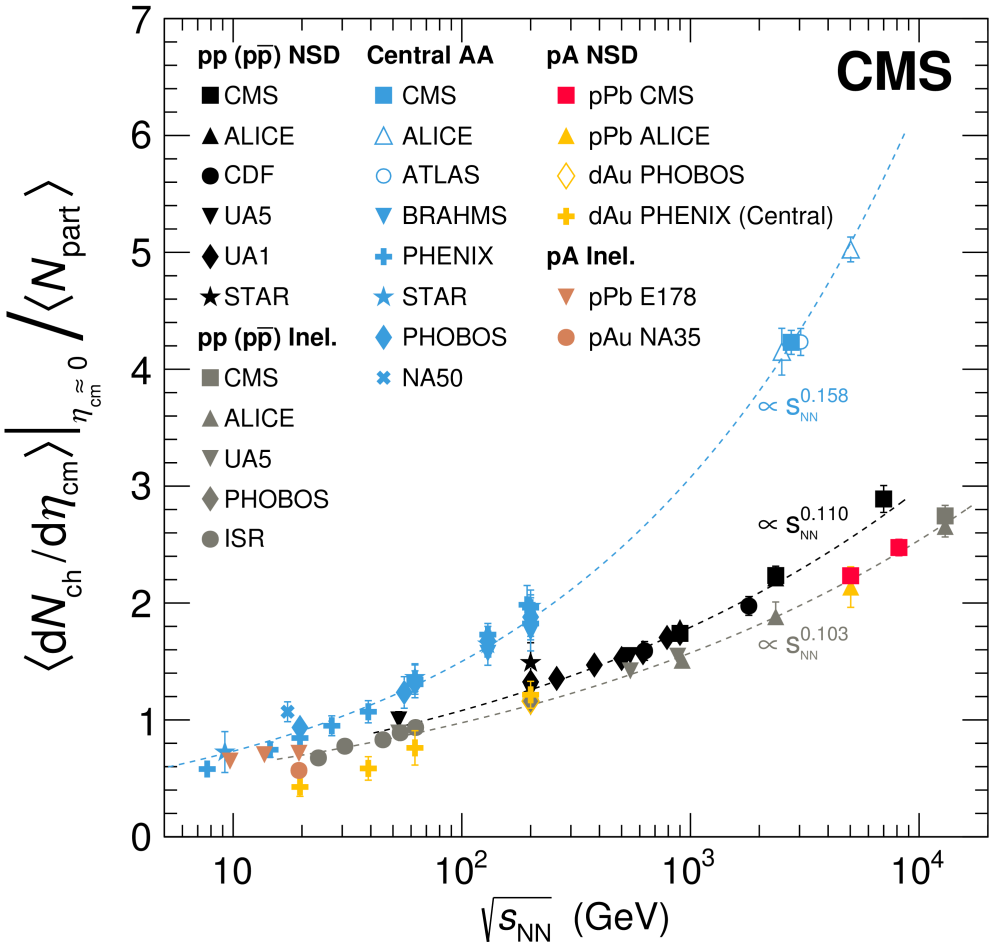


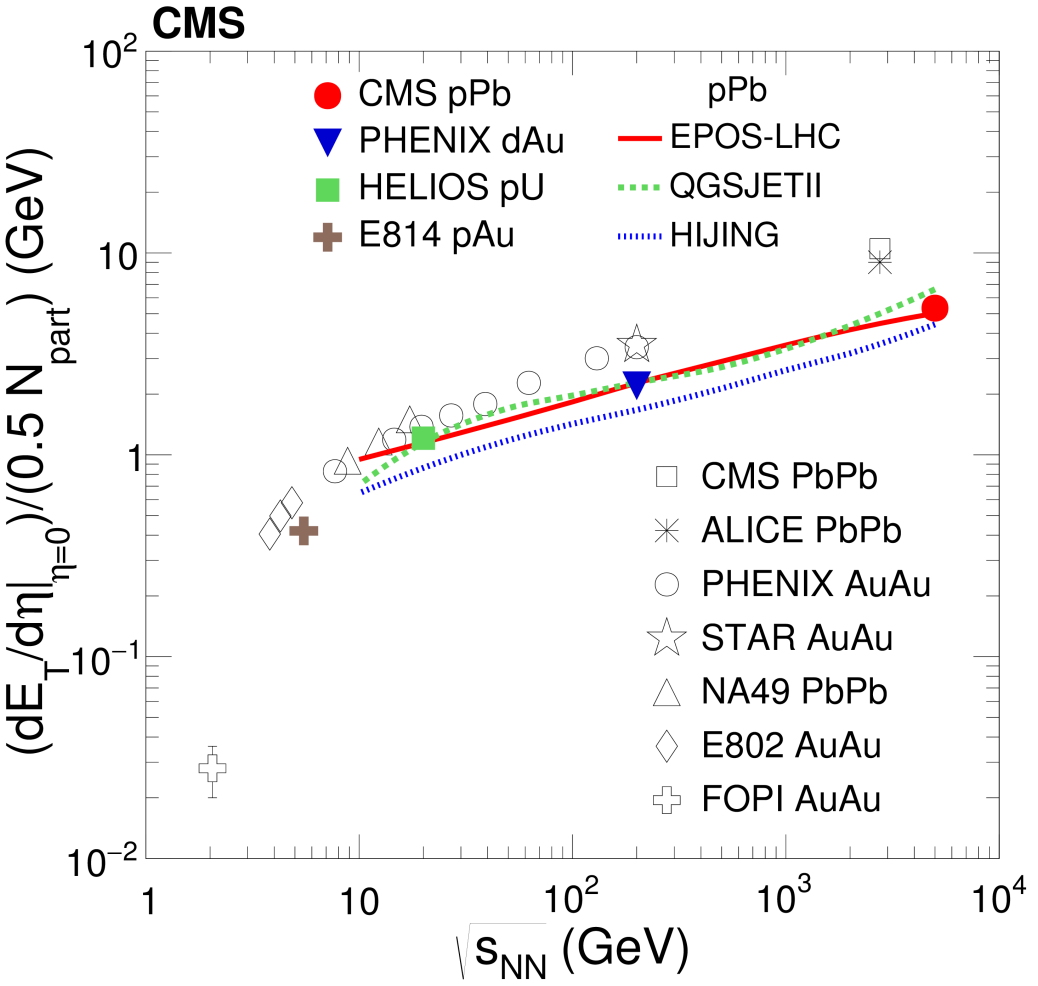
- **p+p, p+Pb, Xe+Xe**
  - correlations
  - flow,
  - jets, ...

p+p 2.76, 5.02, 7, 8, 13 TeV
p+Pb 5.02, 8.16 TeV
Xe+Xe 5.44 TeV



Charged particle multiplicity
Transverse energy density



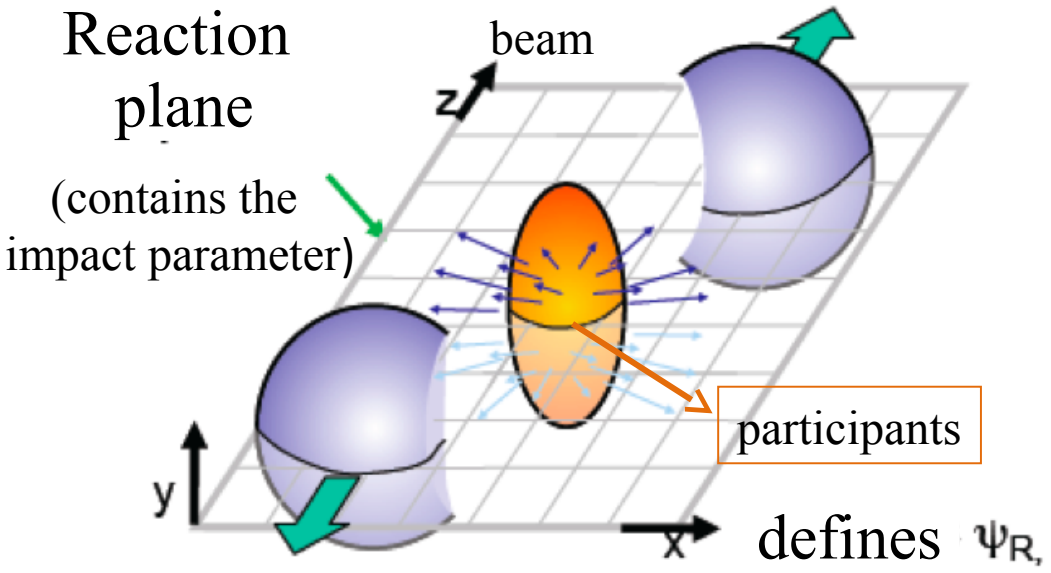


JHEP 01 (2018) 045

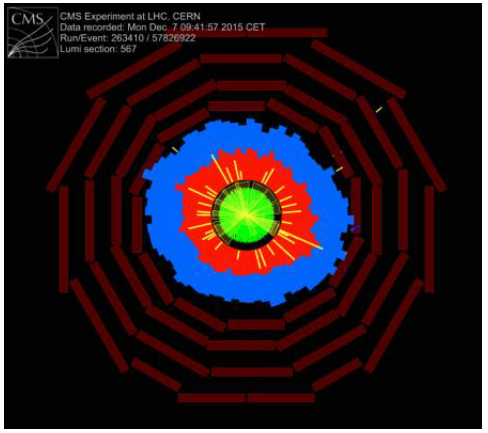
PRC 100 (2019) 024902

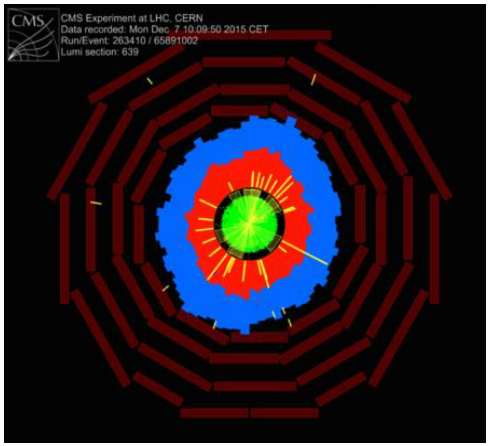
- √s dependence:
  - p+p, p+Pb, Pb+Pb follow power law

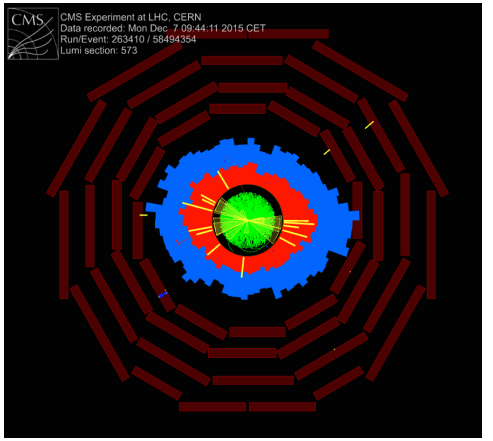
Flow



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





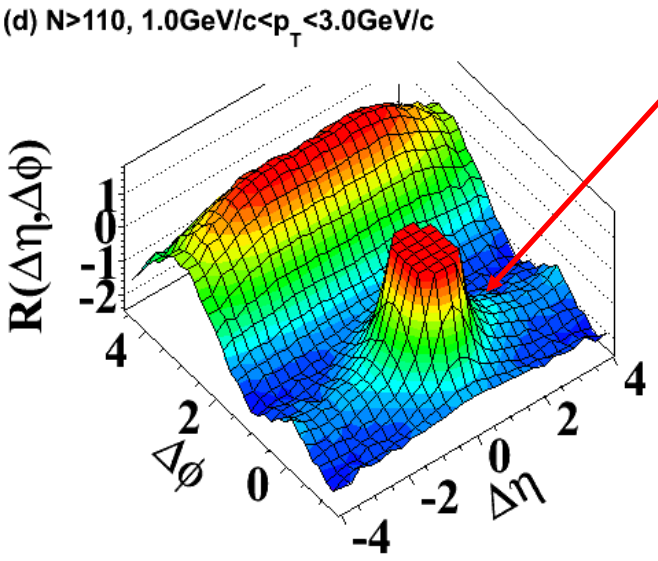


Collective motion is observed in the event azimuthal distributions

Correlations: “RIDGE” everywhere...

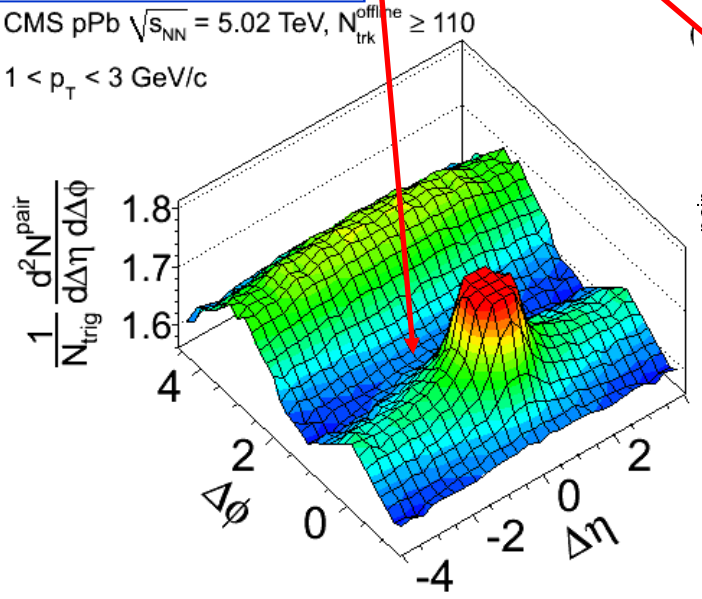
Long-range ($2 < |\Delta\eta| < 4$), near-side ($\Delta\phi \approx 0$)
angular correlations were observed in high multiplicity p+p and p+Pb collisions (as well as in Pb+Pb)

p+p 7 TeV



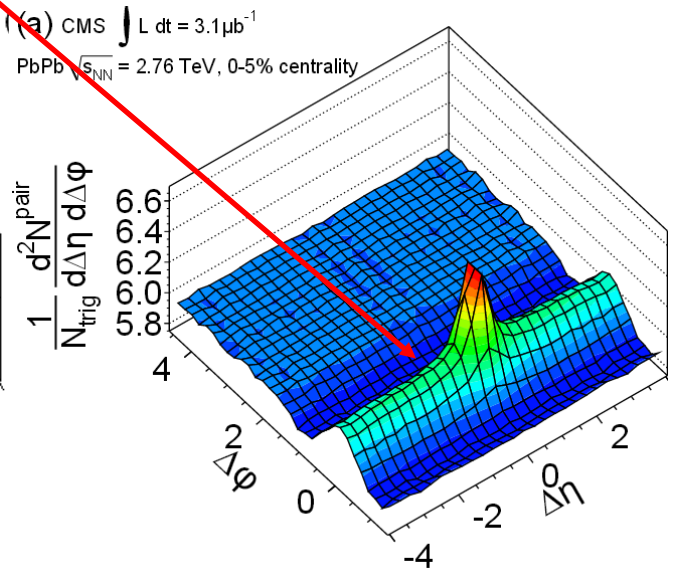
JHEP 09 (2010) 091

p+Pb 5.02 TeV



PLB 718 (2013) 795

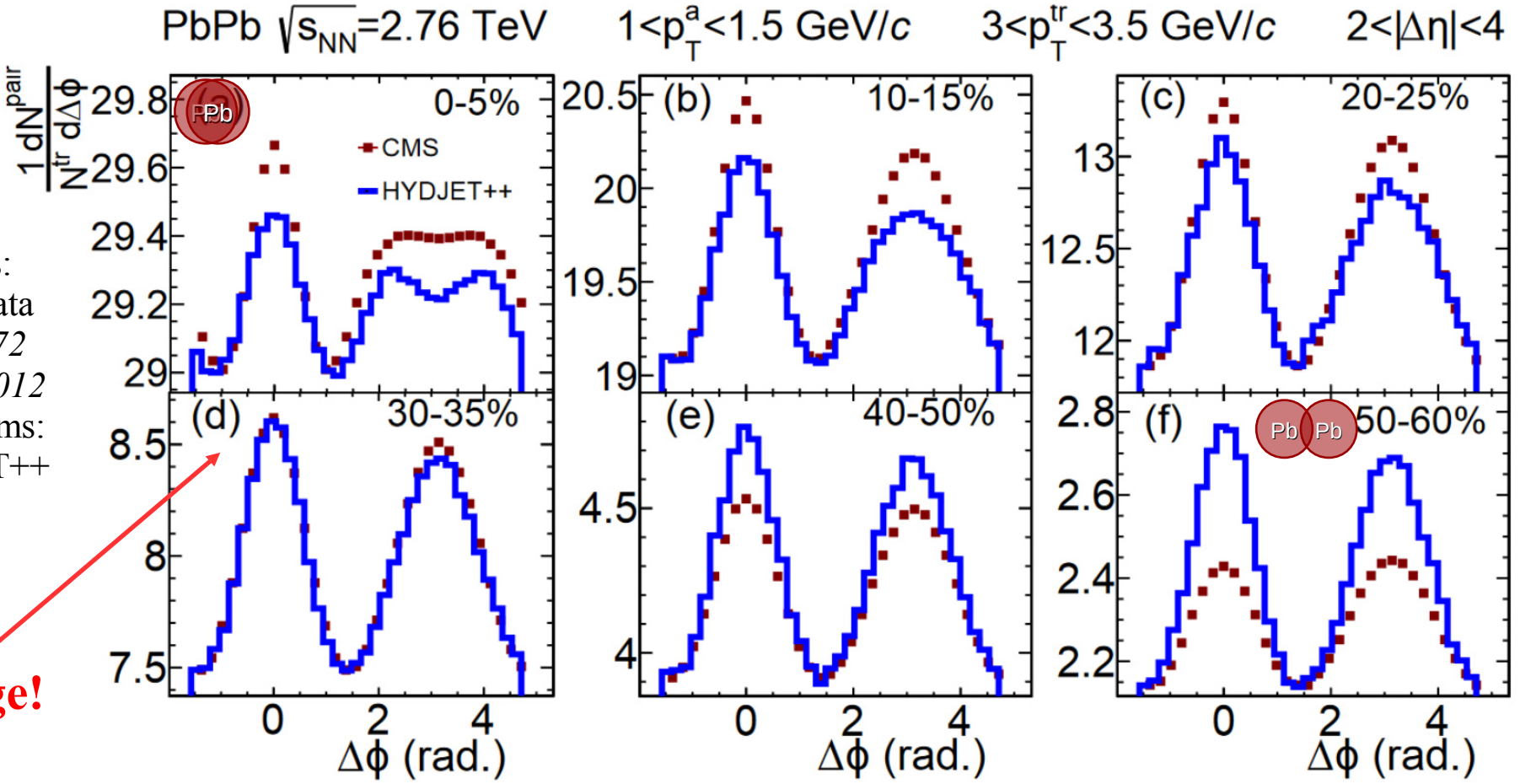
Pb+Pb 2.76 A TeV, 0-5%



JHEP 07 (2011) 076

One of the possible interpretation in Pb+Pb: hydrodynamical model HYDJET++

I.Lokhtin, L.Malinina, S.Petrushanko, A.Snigirev, I.Arsene, K.Tywoniuk, Comp.Phys.Comm. 180 (2009) 779



Points: CMS data *EPJC 72 (2012)2012*
histograms: HYDJET++

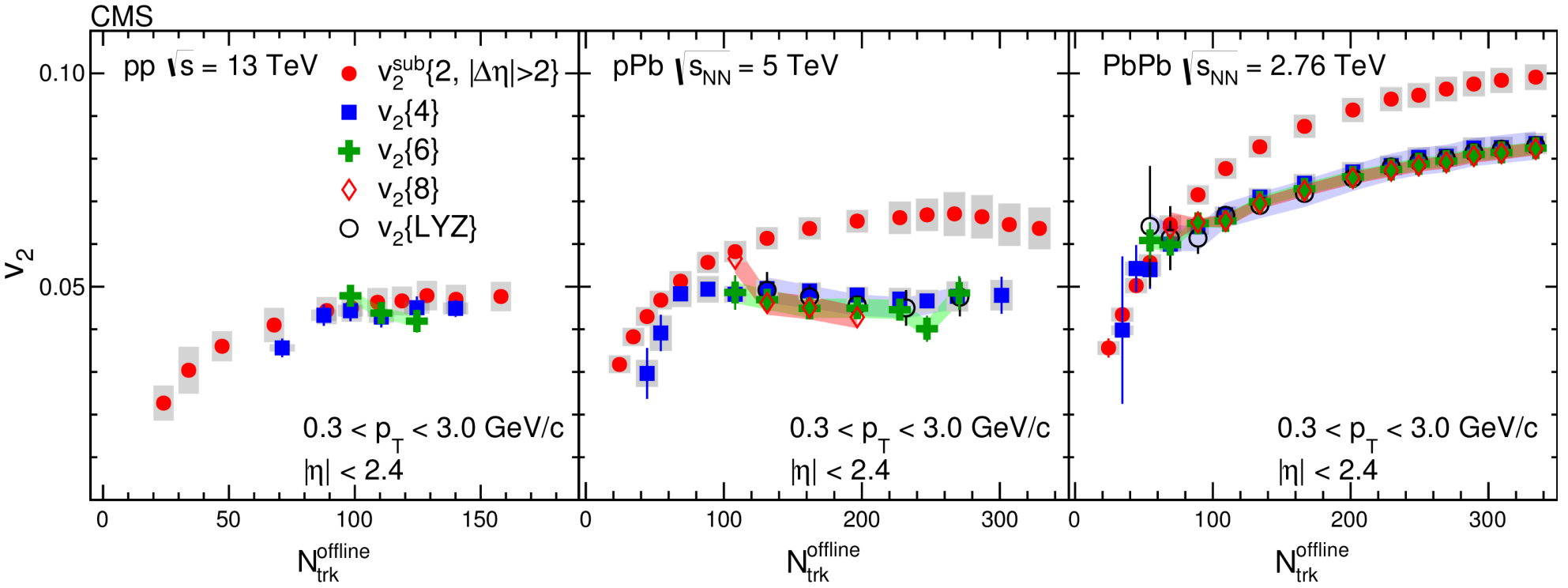
ridge!

Interplay of elliptic and triangular flows in HYDJET++

G. Eyyubova, V. L. Korotkikh, I. P. Lokhtin, S. V. Petrushanko, A. M. Snigirev, L. Bravina, E. E. Zabrodin, Phys. Rev. C 91 (2015), 064907

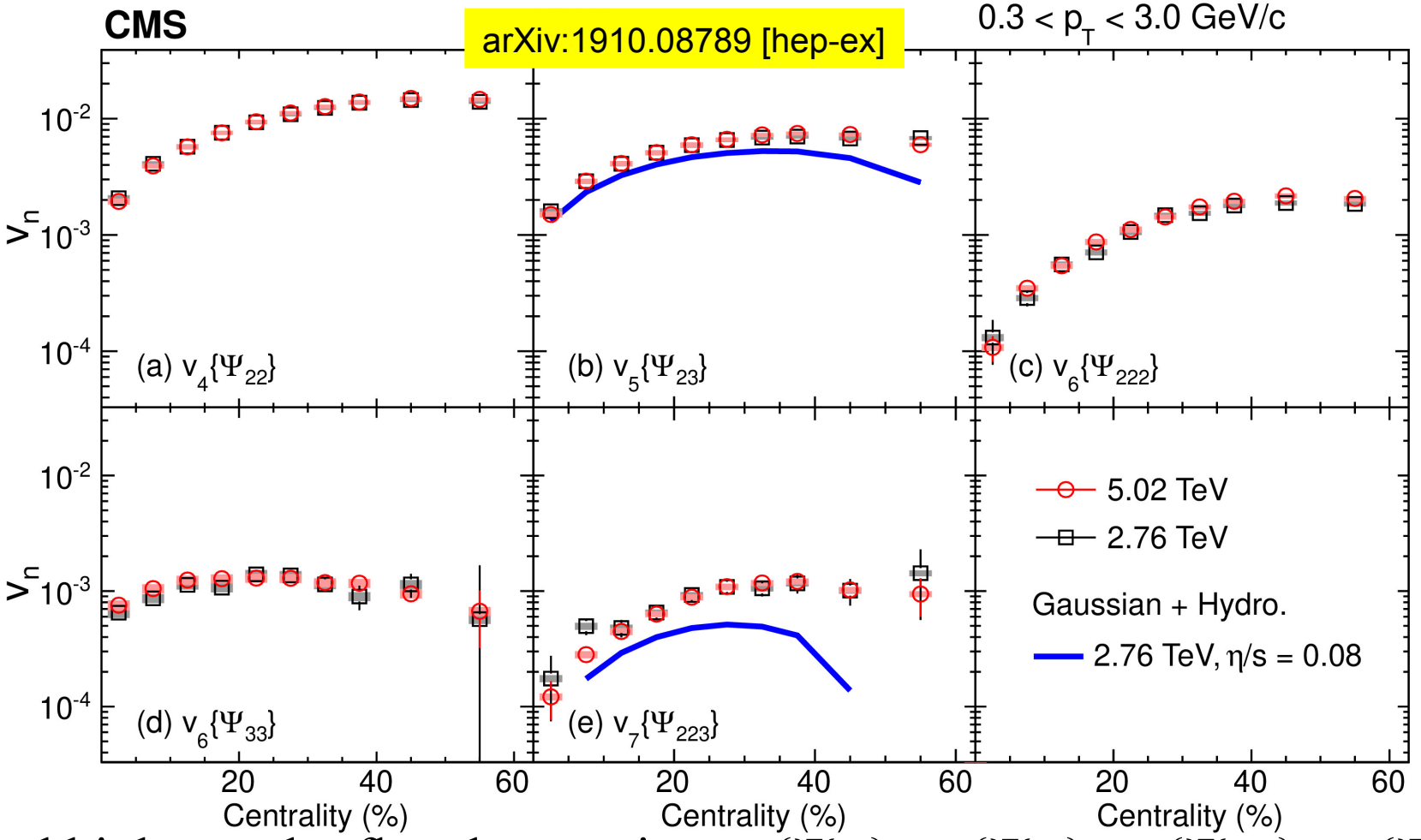
Collectivity in p+p, p+Pb, Pb+Pb

PLB 765 (2017) 193



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

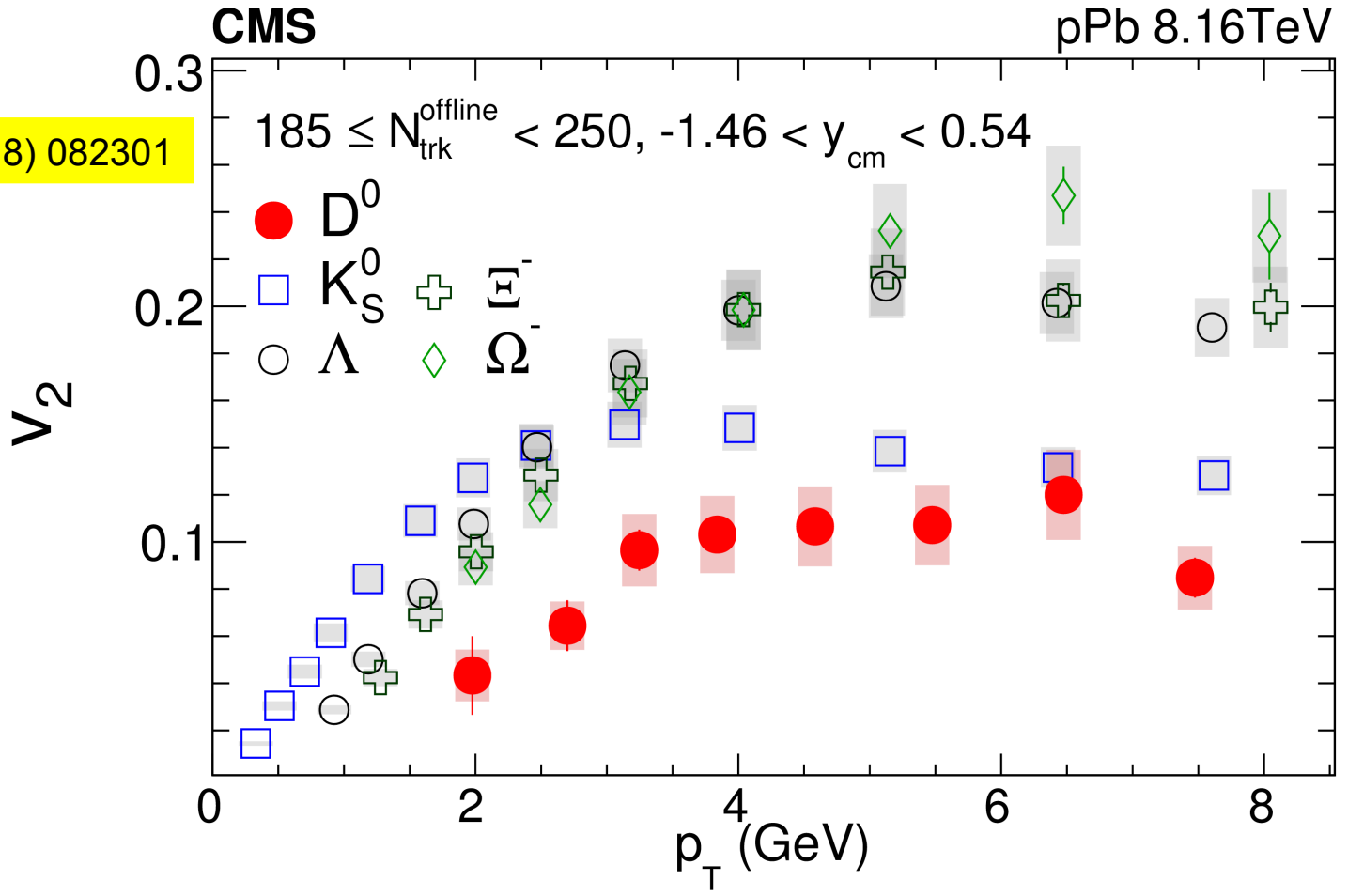
Mixed higher-order anisotropic flow in Pb+Pb



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.

Heavy quark collectivity in small systems

PRL 121 (2018) 082301



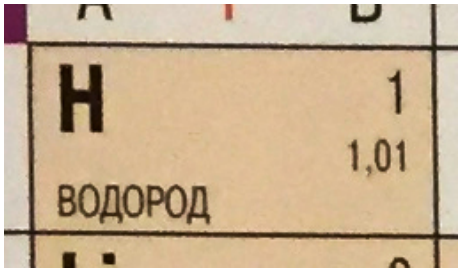
- Significant positive v_2 values are observed for D^0 mesons with $p_T > 2$ GeV/*c*.
- The collective behavior of charm quarks in high-multiplicity p+Pb collisions is weaker than that of the light-flavor quarks.

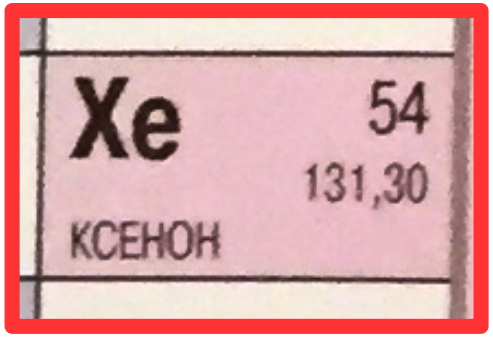
Xe+Xe as a “bridge” between p and Pb

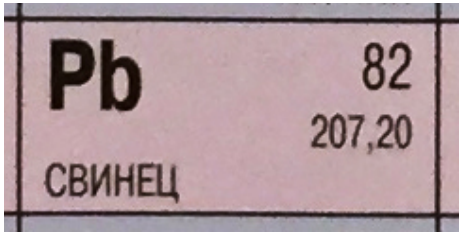
United Nations Educational, Scientific and Cultural Organization

2019 IYPT International Year of the Periodic Table of Chemical Elements

Dmitri Mendeleev

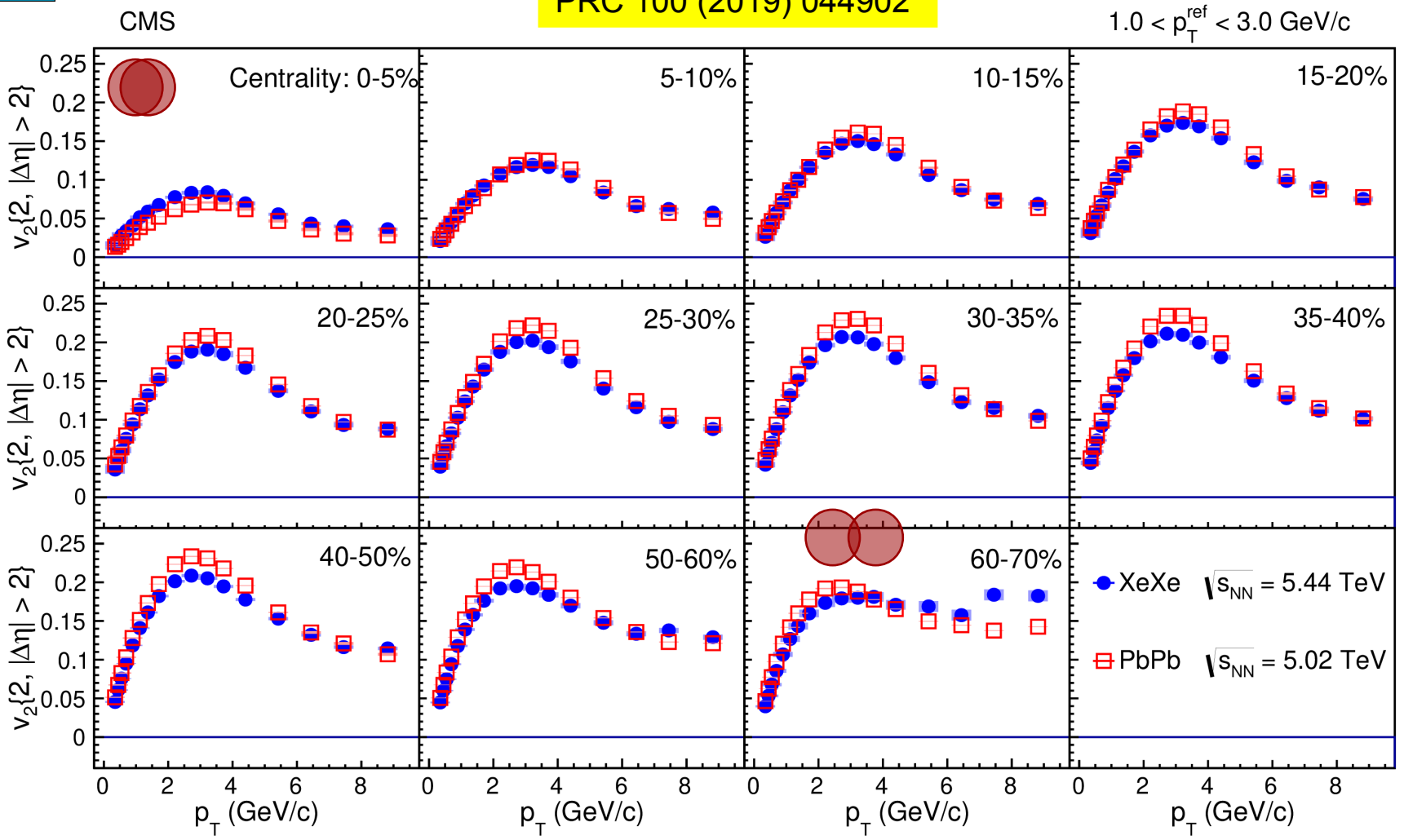






v_2 Xe+Xe vs. Pb+Pb

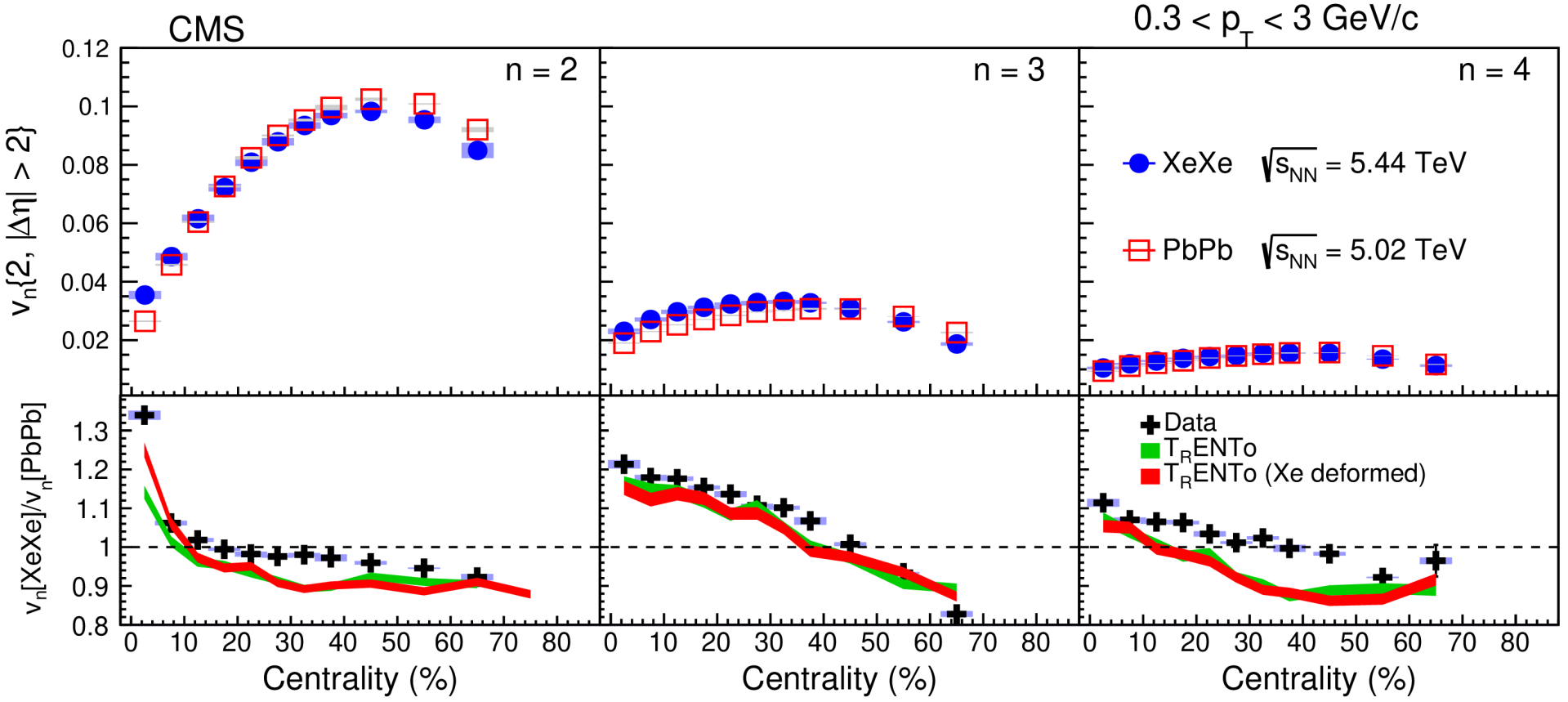
PRC 100 (2019) 044902



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.

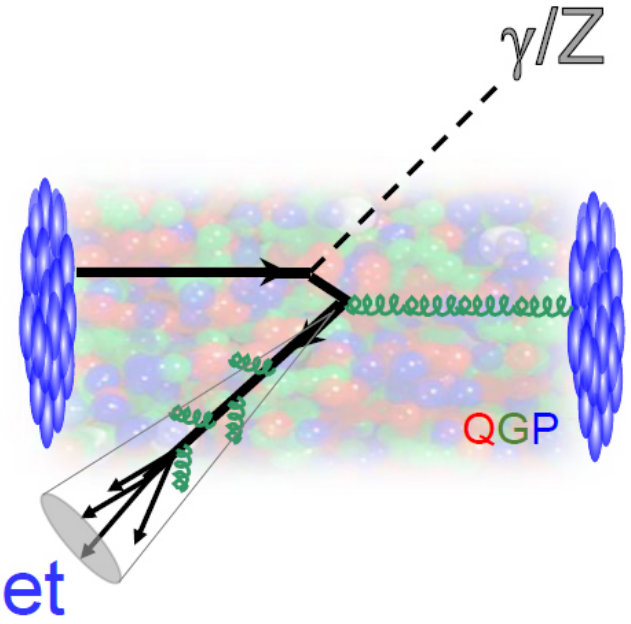
$v_{2,3,4}$ Xe+Xe vs. Pb+Pb

PRC 100 (2019) 044902



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

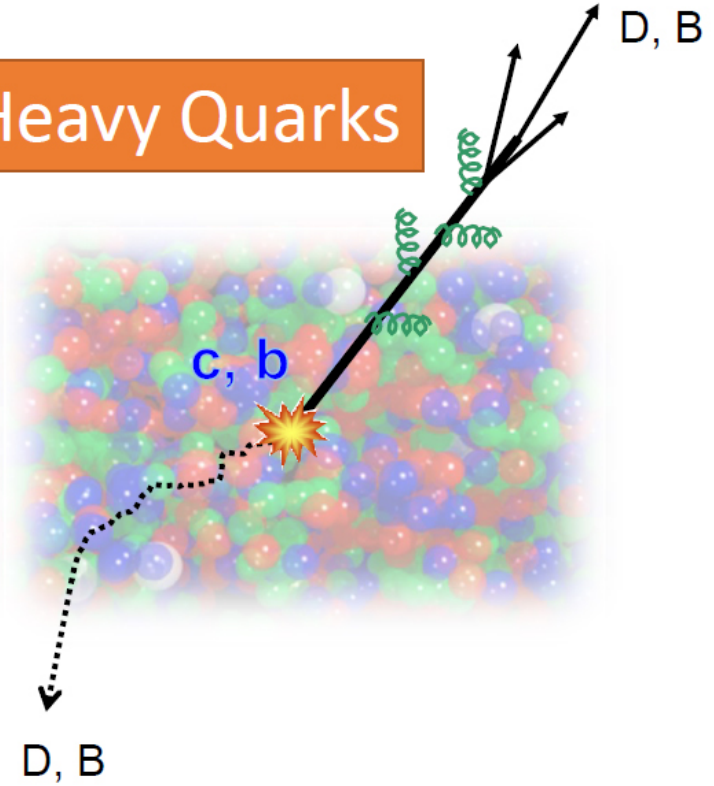
Hard Probes for Quark-Gluon Plasma



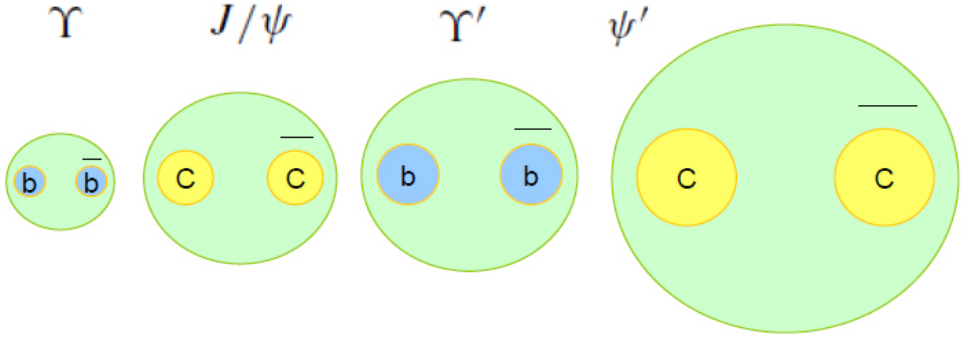
Electroweak Bosons

Jets

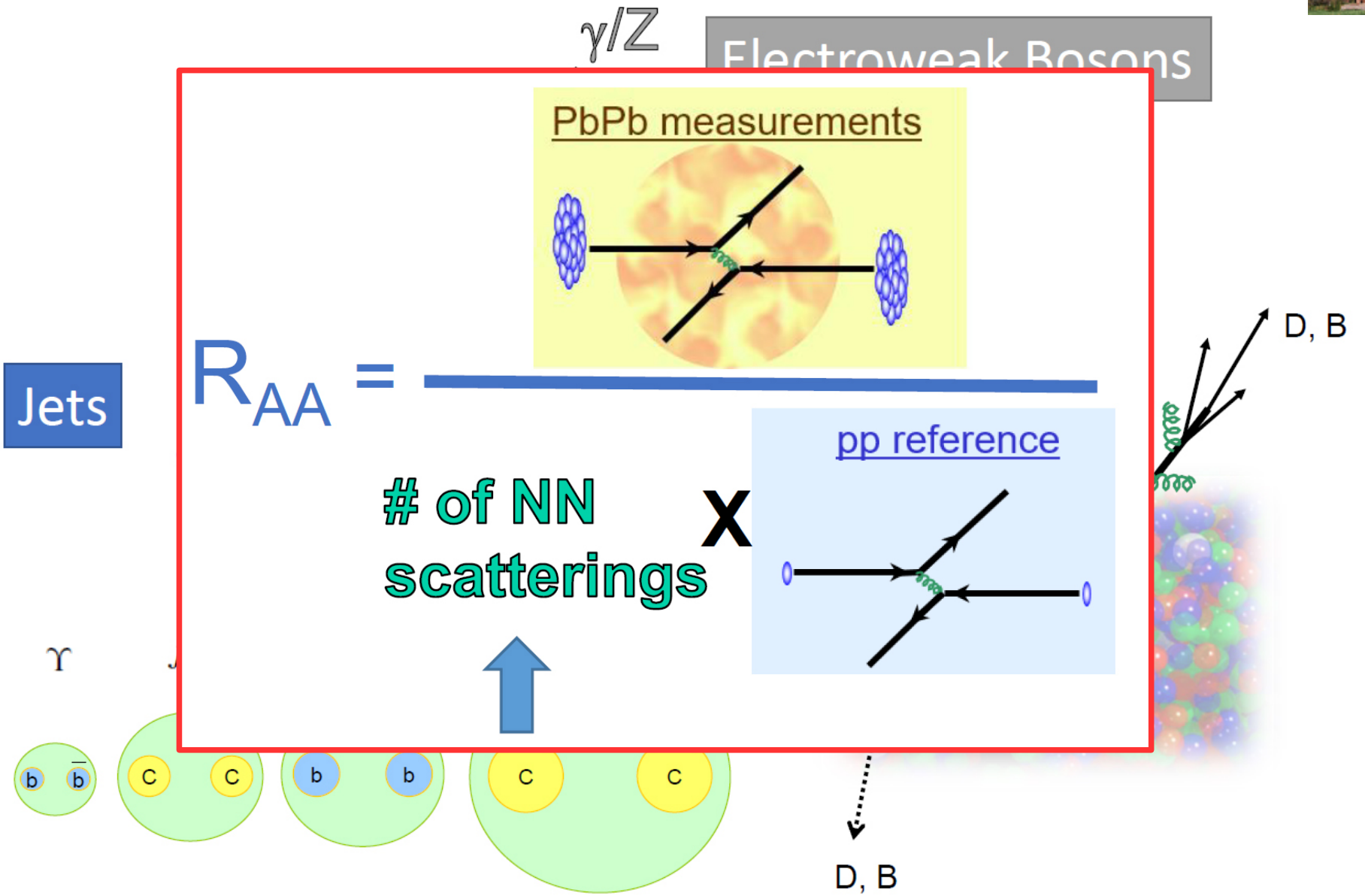
Heavy Quarks



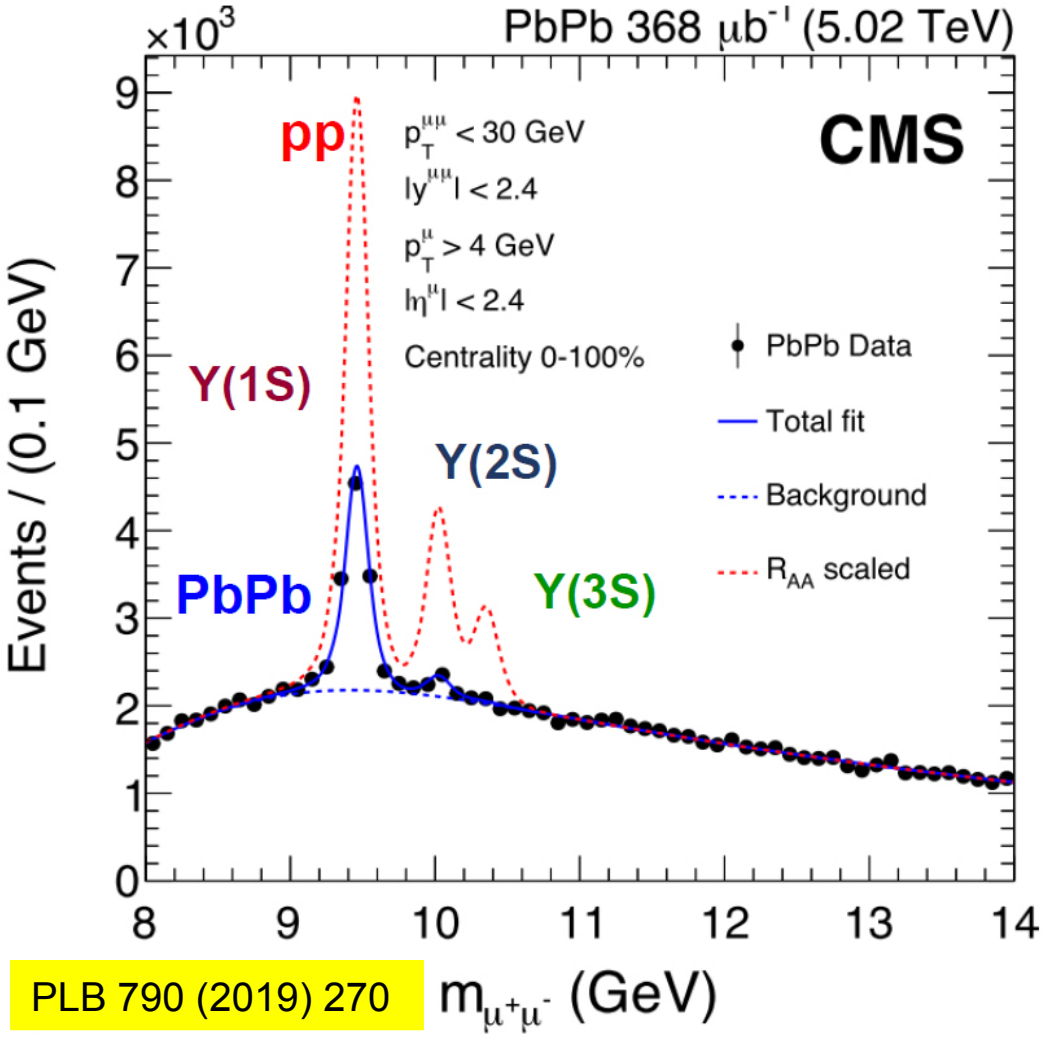
Quarkonia



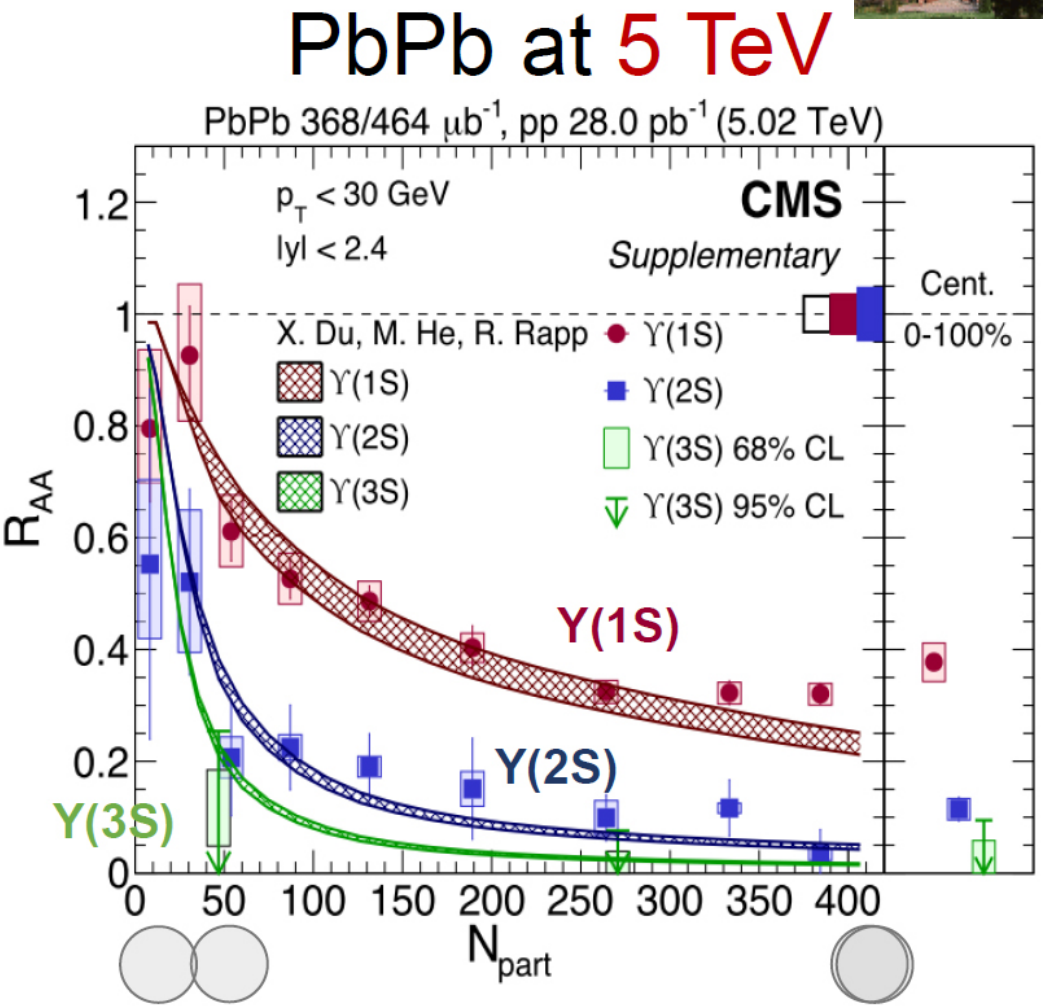
Hard Probes for Quark-Gluon Plasma



Upsilon suppression in Pb+Pb



PLB 790 (2019) 270

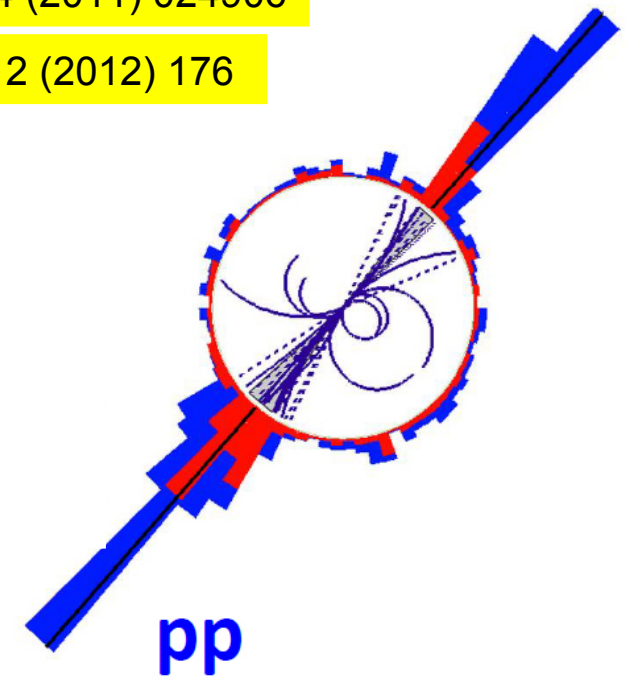


- Observation of sequential suppression of Y family.
- No any sign of Y(3S) in the high statistics 2015 data.

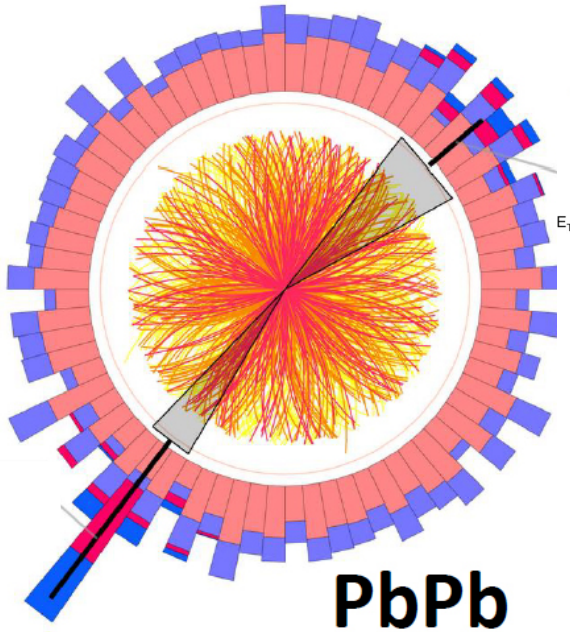
Jet quenching in Pb+Pb

PRC 84 (2011) 024906

PLB 712 (2012) 176



pp



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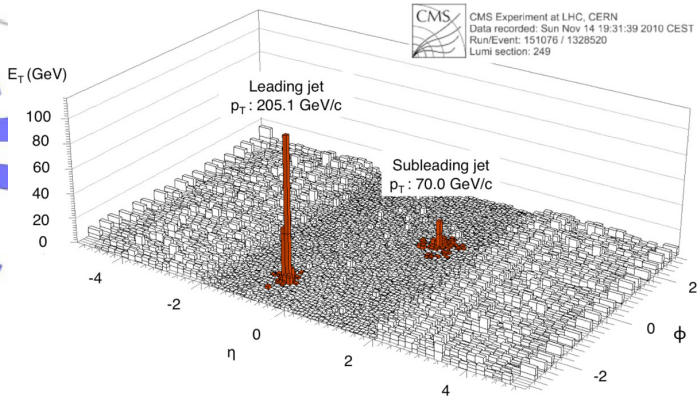
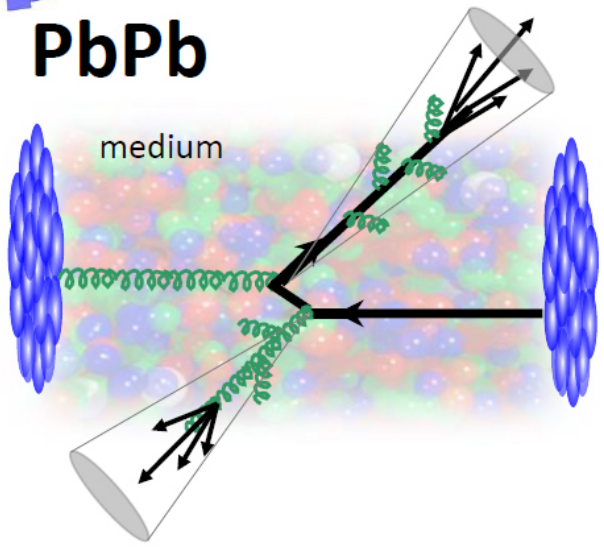


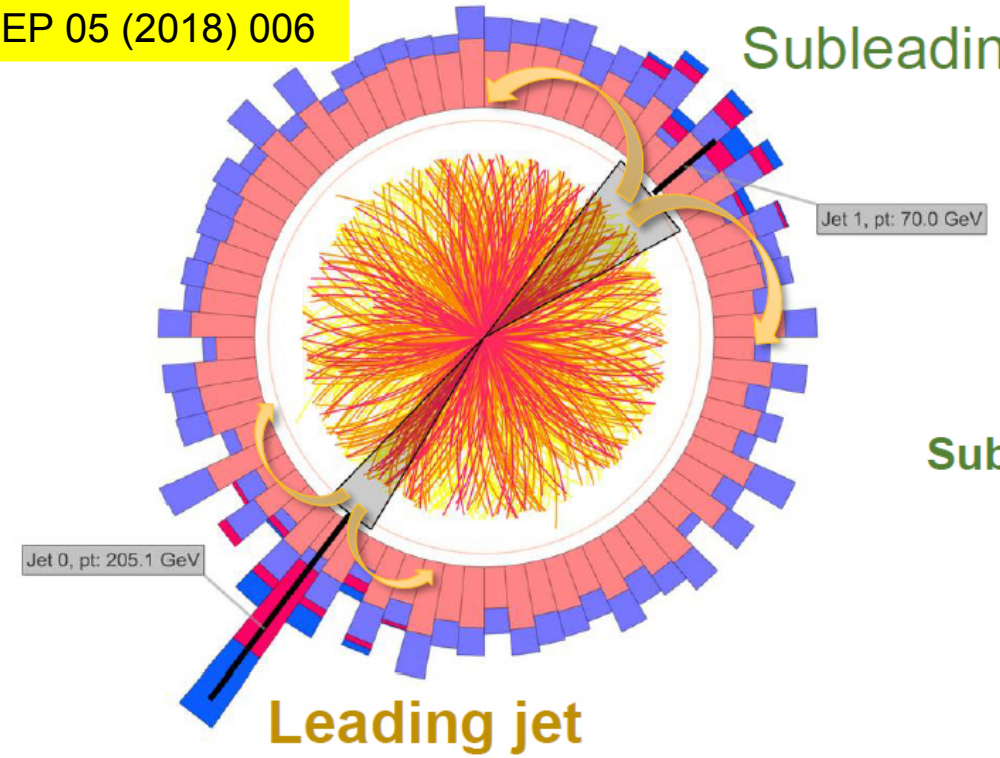
PbPb

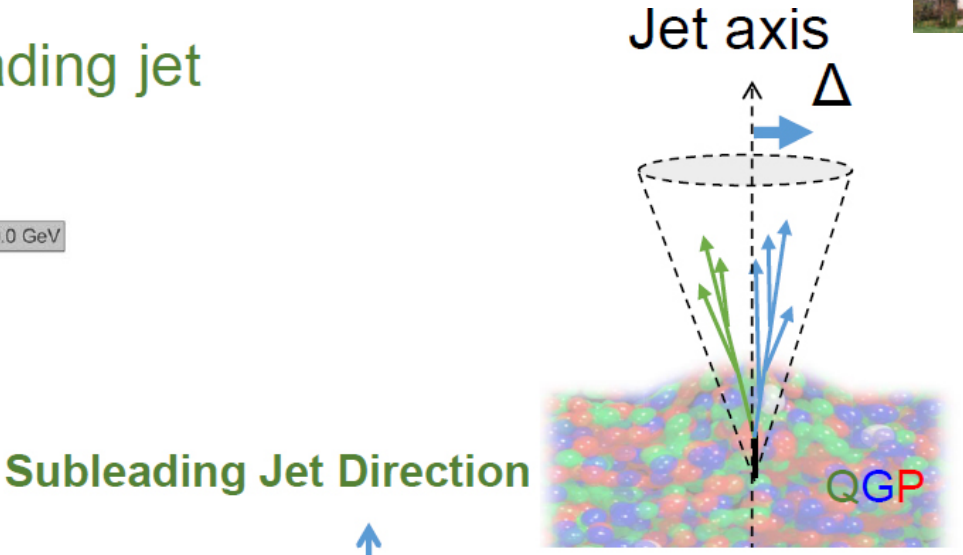
- Asymmetric dijets observed more frequently in PbPb collisions
- The stopping power (dE/dx) of the Quark Soup is **Incredibly Strong**

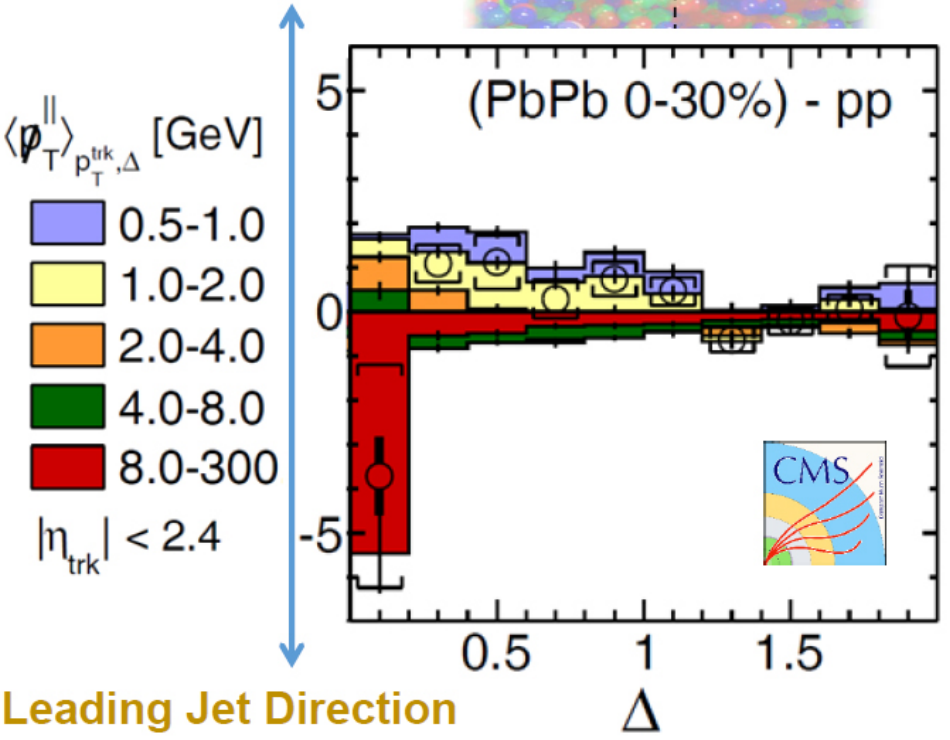


Where does the Quenched Energy Go?

JHEP 05 (2018) 006

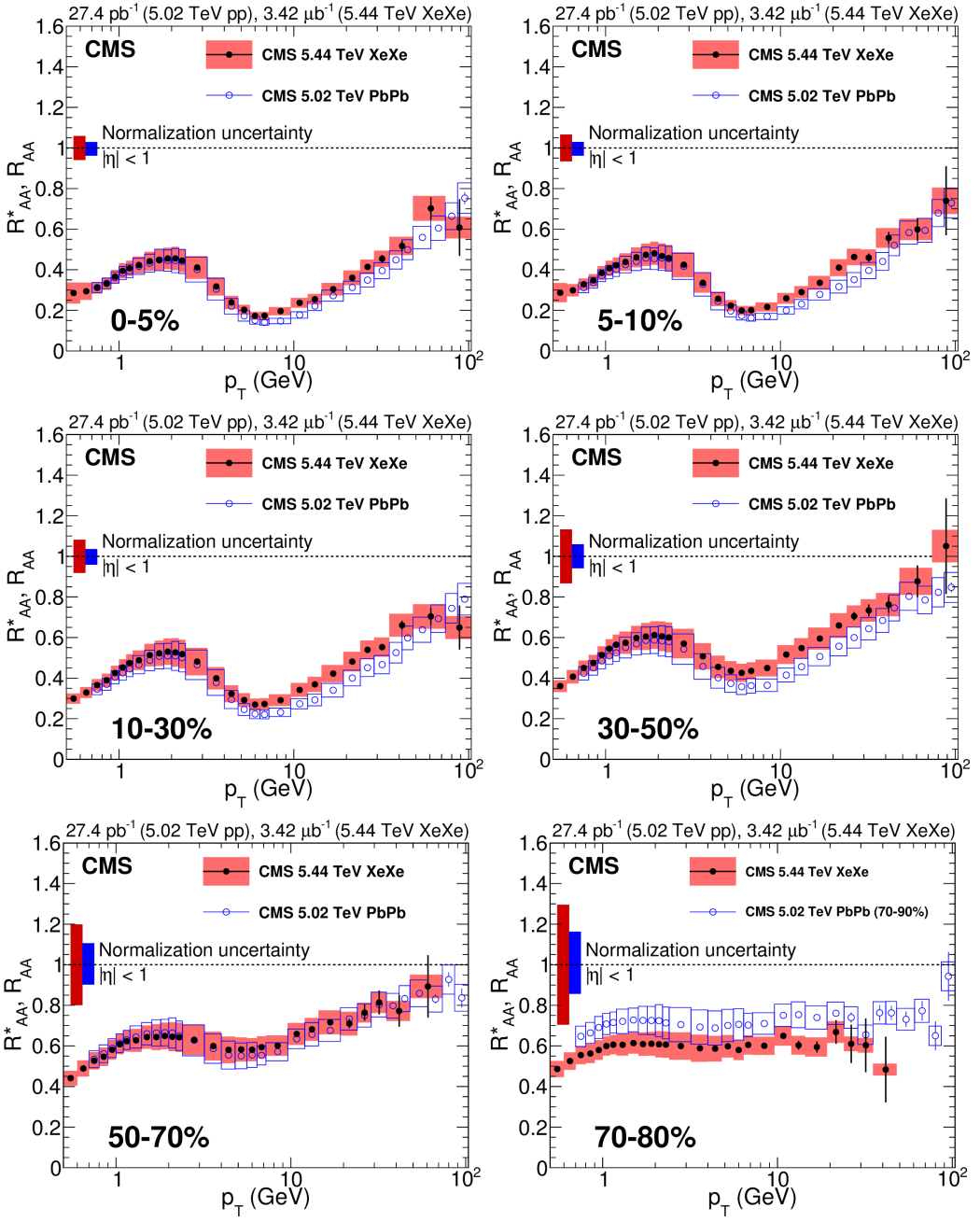






- No significant missing momentum if summed over all particles in the event
- Quenched energy carried by **low momentum particles!**

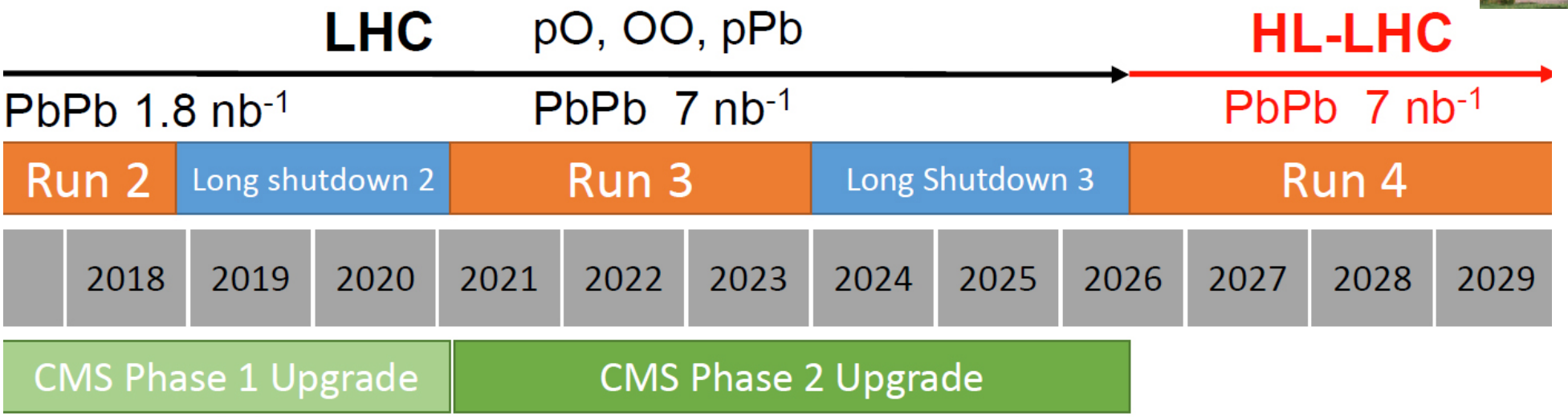
Charged-particle R_{AA}: Xe+Xe vs. Pb+Pb



For $p_T > 6$ GeV/c the Xe+Xe data show a notably smaller suppression than previous results for Pb+Pb collisions when compared at the same centrality.

JHEP 10 (2018) 138

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

- **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!**