Heavy Ion Results From CMS Experiment

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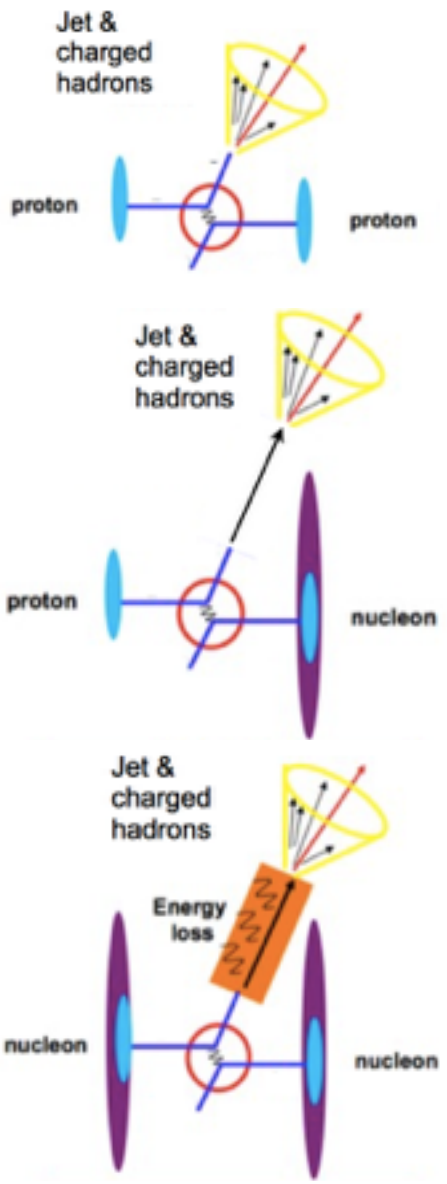
On Behalf of CMS Collaboration

SPRACE - UNESP

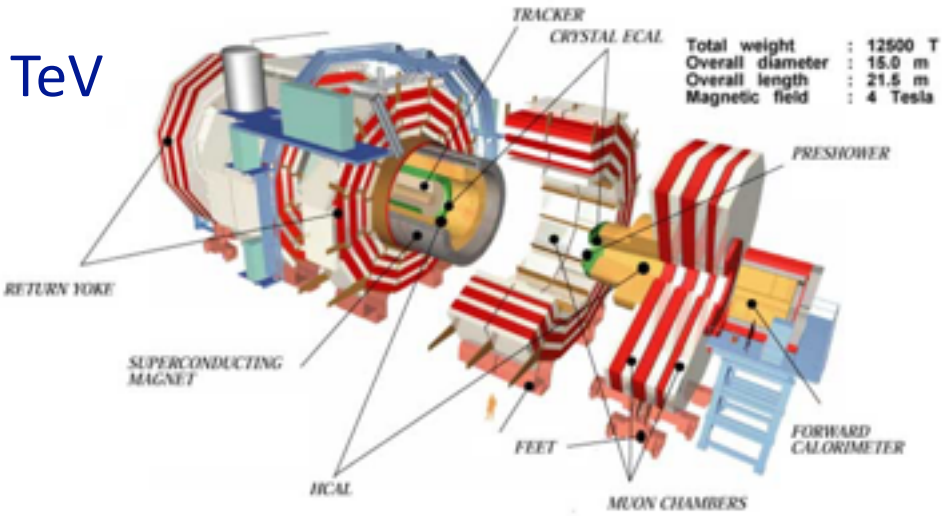
Outline

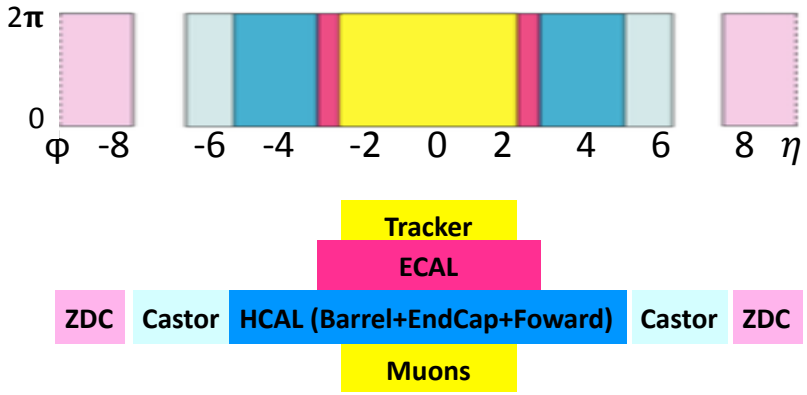
- Detector Capabilities and Data Samples
- Global Observables
  - Pseudorapidity distributions
- Bose-Einstein Correlations
  - pp, pPb, PbPb
- Azimuthal Anisotropy
  - Charged Particles
  - Identified Particles
- Hard Probes in Heavy Ion Collisions
  - Jet Modifications
    - Jets shapes and fragmentation
  - Quenched Energy Flow
- Quarkonia
  - J/Ψ, ϒ
- Electro-Weak
  - Z, W
- Summary and Future Prospect



CMS detector capabilities and dataset

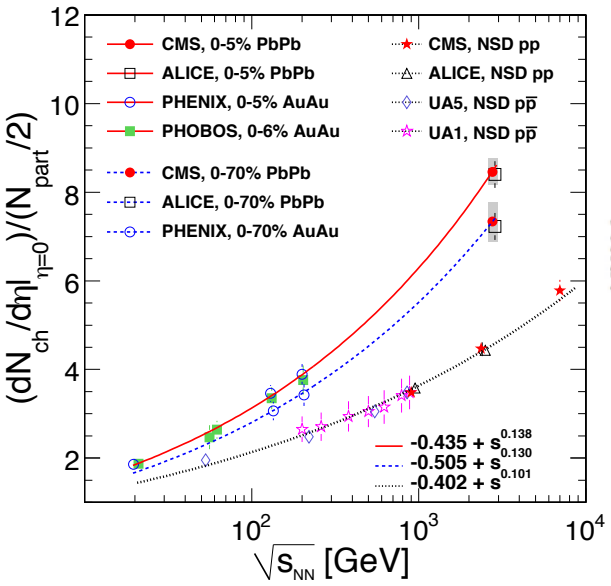
- Heavy Ion collisions
  - PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV
    - 1st Run – 2010 L_{int} =13 μb^{-1}
    - 2nd Run – 2011 L_{int} =150 μb^{-1}
  - pPb Collisions at $\sqrt{s_{NN}}$=5.02
    - Run 2012 – 2013 TeV L_{int} =35 nb^{-1}
- pp Collisions
  - 2013 $\sqrt{s_{NN}}$= 2.76 TeV L_{int} =5.3 pb^{-1}
  - 2015 $\sqrt{s_{NN}}$= 13 TeV Ongoing



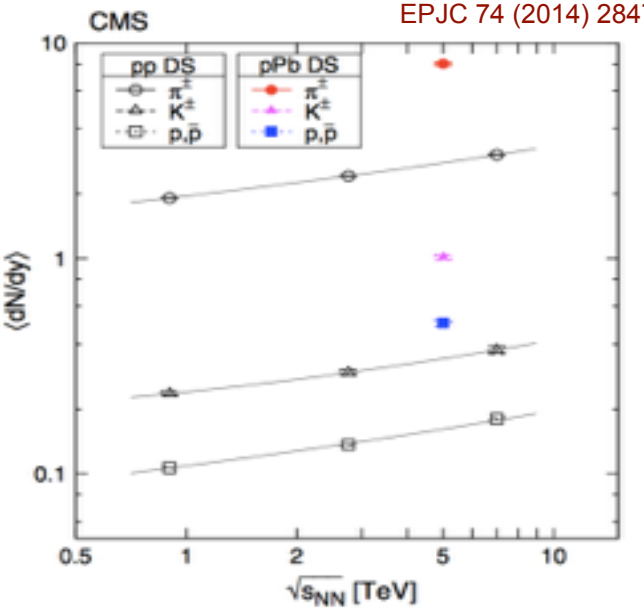


dn/dη of charged hadrons

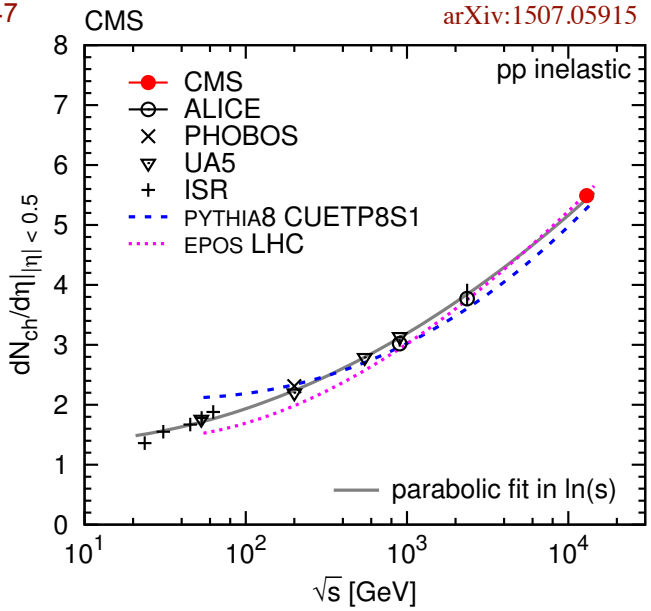
JHEP 08 (2011) 141



EPJC 74 (2014) 2847



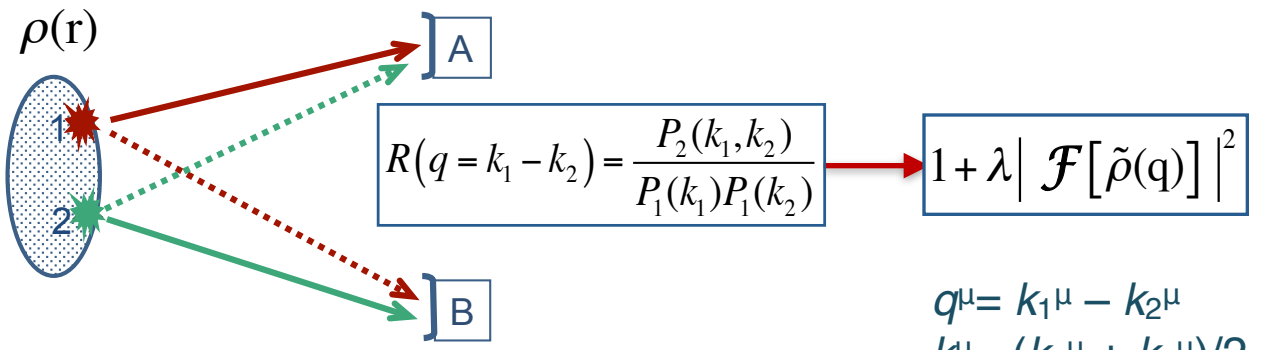
arXiv:1507.05915

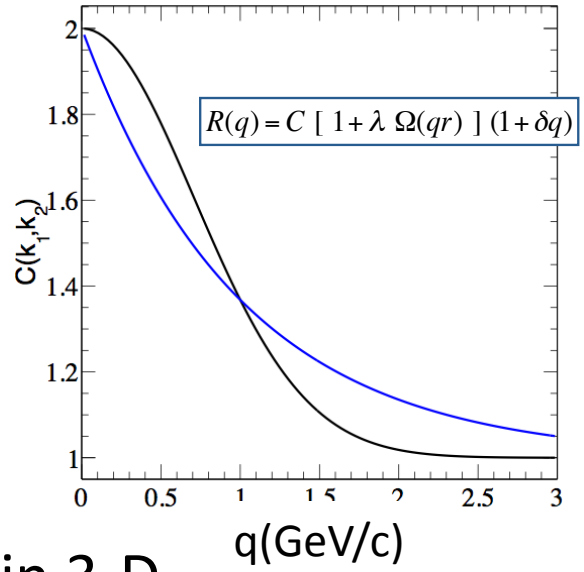


- Average rapidity densities ⟨dN/dy⟩ as a function of center-of-mass energy for pp, pPb and PbPb collisions
- Averaged dN/dη result for *inelastic* events from pp collisions at 13TeV Central value: 5.49±0.01(stat)±0.17(syst)

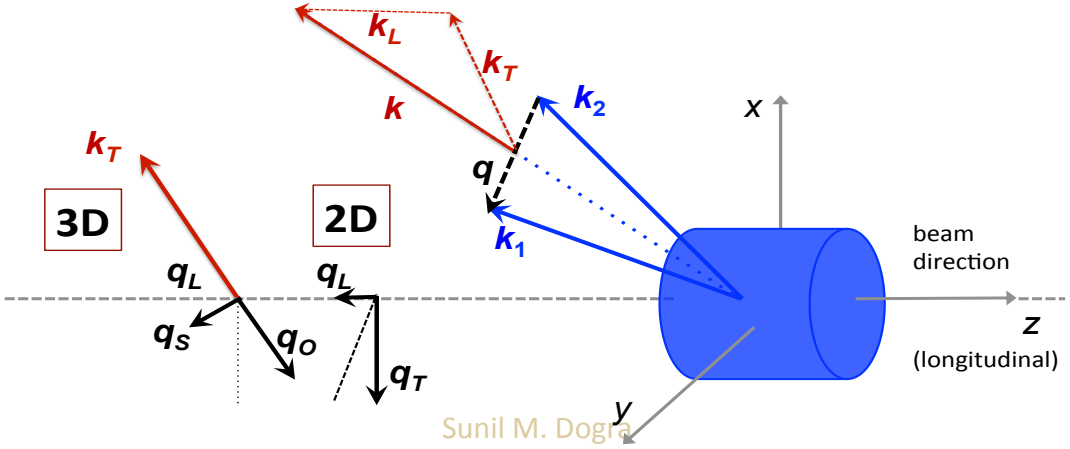
Bose - Einstein Correlations

- Identical boson-boson correlations can be used to determine the effective size of the emission source

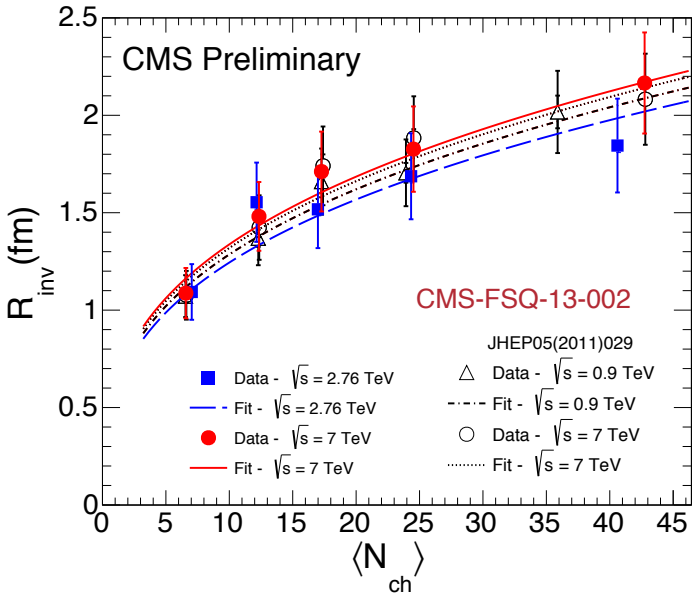


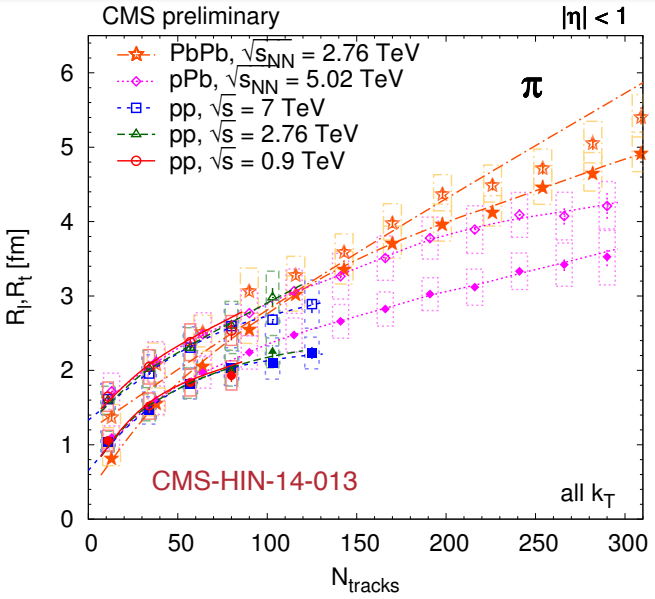


- Decomposition: (q_L, q_T) in 2-D and (q_L, q_O, q_S) in 3-D

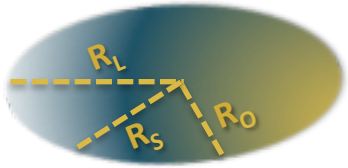


Bose - Einstein Correlations from CMS

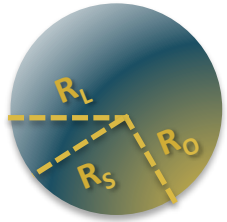


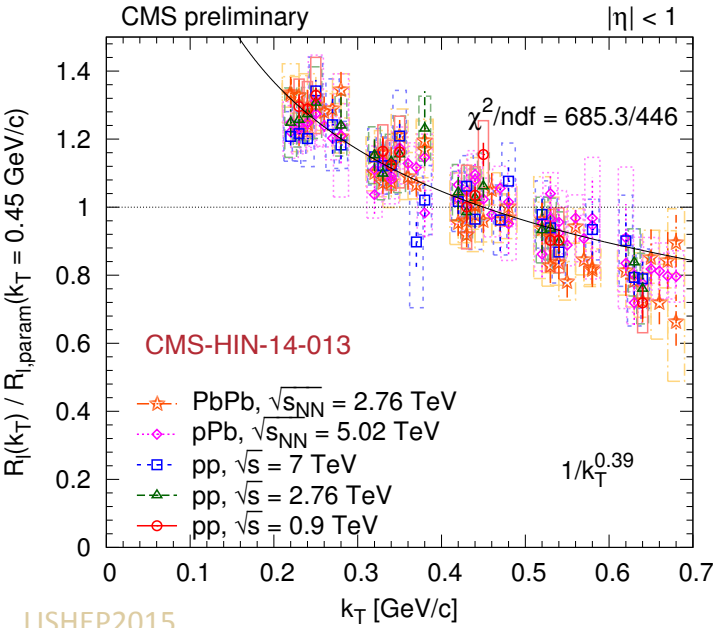


pp & pPb



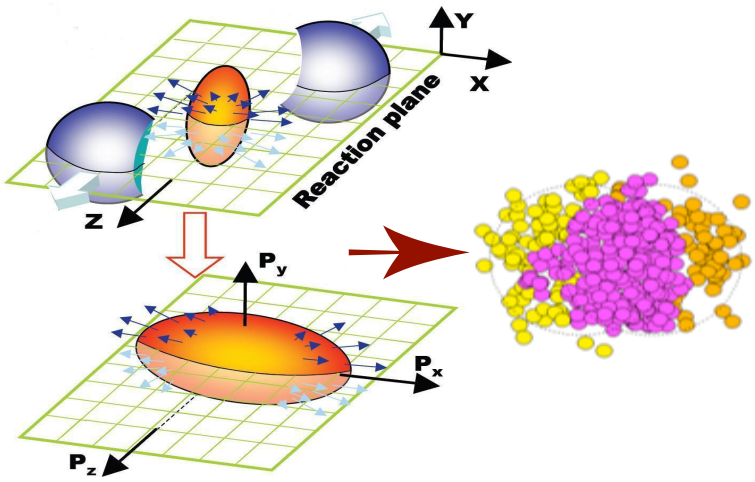
PbPb



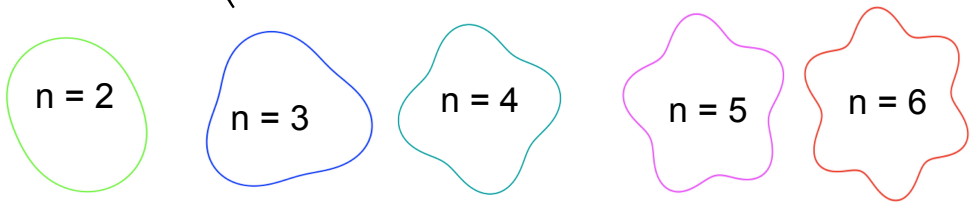


- Identified particles, multi-dimensional analysis
- Scaling and similarity between pp, pPb, PbPb vs N_{ch}

Anisotropic Flow in Heavy ion Collisions



$$\frac{dN}{d\varphi} \propto \left(1 + 2\sum_{n=1}^{+\infty} v_n \cos\left[n(\varphi - \psi_n)\right]\right)$$



Elliptic flow Triangular flow

- Anisotropy in position space (initial) ➛Anisotropy in momentum space (final)
- v_3 and higher harmonics (v_n) are sensitive to initial-state fluctuations and hydrodynamic evolution and they probe smaller length scale than v_2

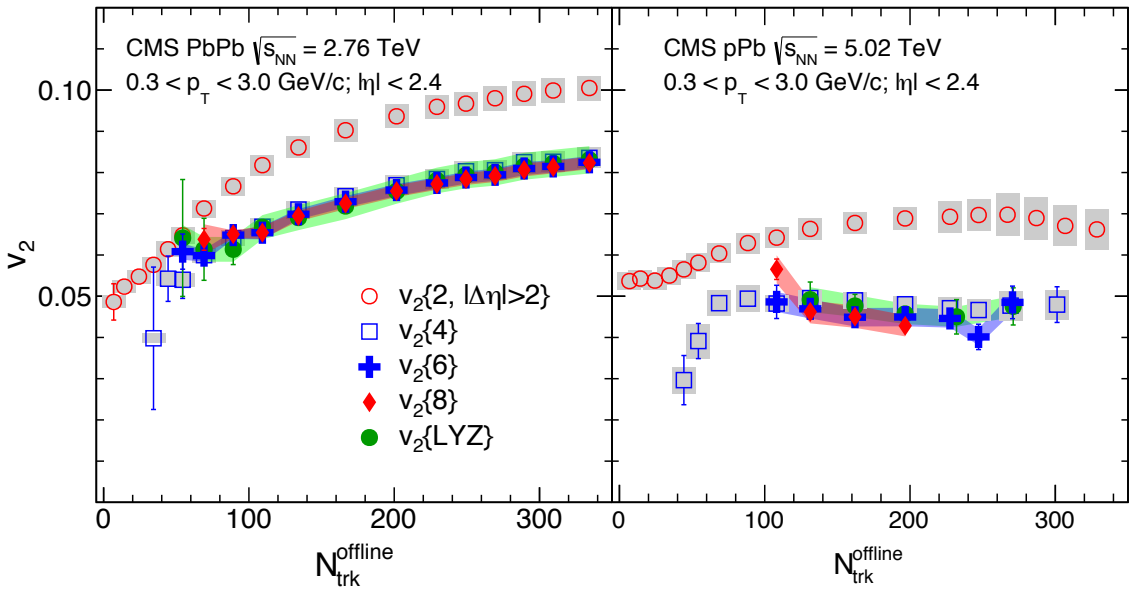
Methods:

- ❖ Event Plane
- ❖ Two Particle Correlations
- ❖ Multi Particle Cumulant Method
- ❖ Lee- Yang Zero : All Particle Correlations

Z. Phys. C 70, 665 (1996),
Nucl. Phys. A590, 561c (1995),
Phys. Rev. C 58, 1671 (1998)

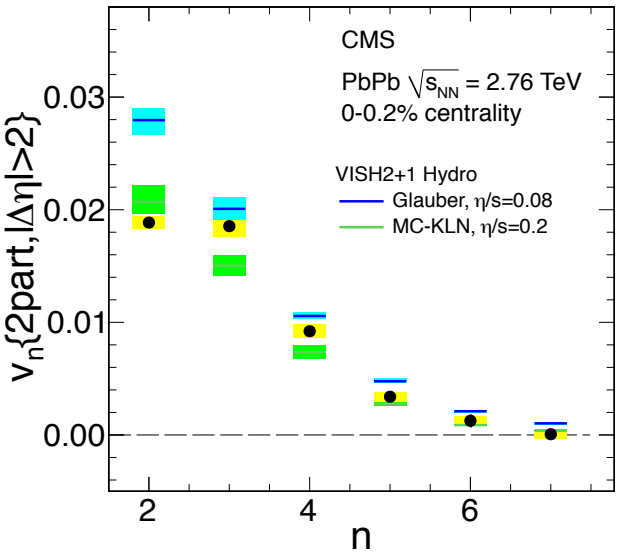
Azimuthal Anisotropy from CMS

PRL 115, 012301 (2015)



PRL 115, 012301 (2015)

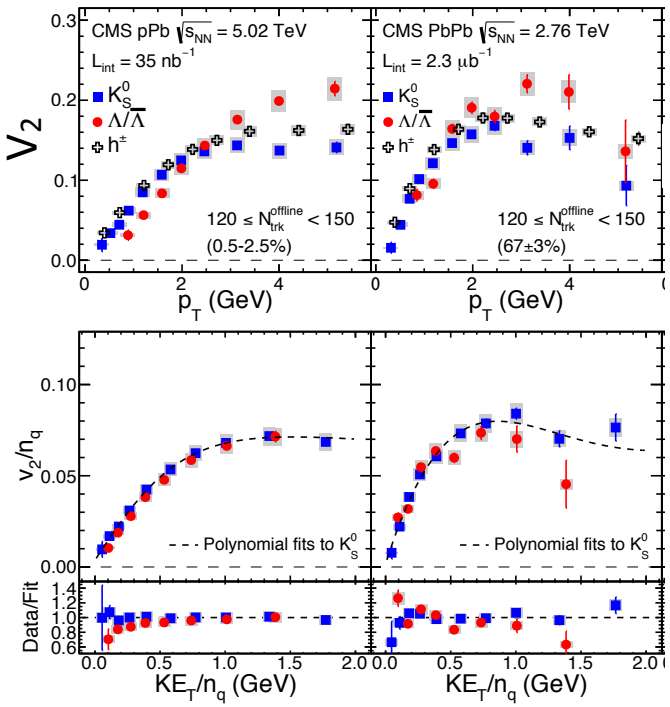
JHEP 02 (2014) 088



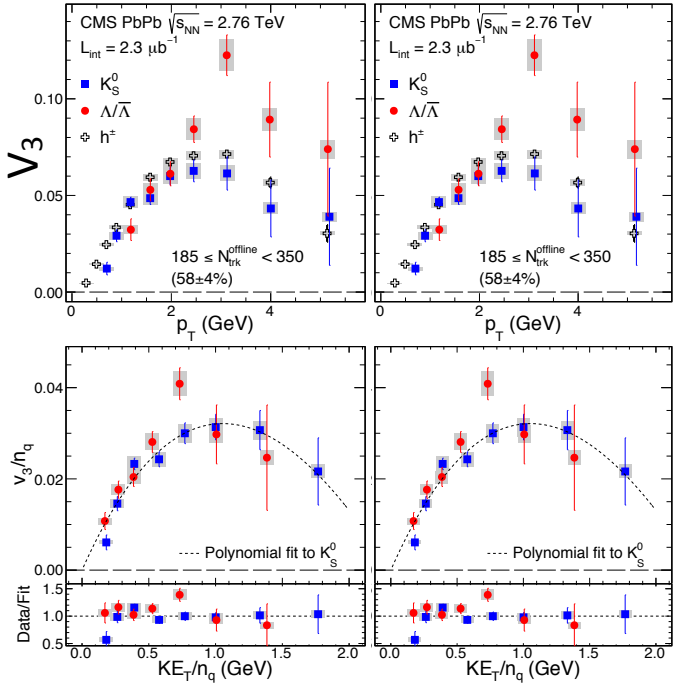
- Multiple methods give a handle on non-flow and fluctuations
- Multi-particle azimuthal correlations 2,4,6,8 and all particles measured in pPb and PbPb
- v_2 from 4, 6, 8 particle correlations are consistent within 2% for PbPb, and within 10% for p-Pb
- v_n measured for for PbPb ultra central collisions

Azimuthal Anisotropy: Identified Particles

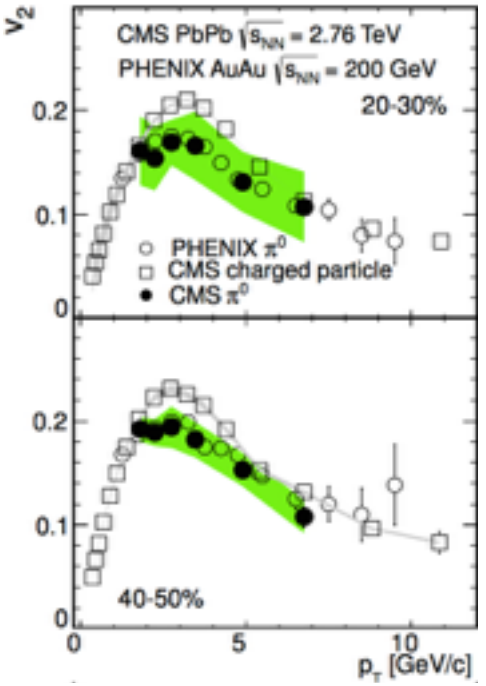
PLB 742 (2015) 200



PLB 742 (2015) 200



PRL 110 (2013) 042301



- Measured Azimuthal anisotropy using identified particles
- Smaller v_2 for heavier particles at low p_T → Consistent with hydrodynamics
- Scaling holds better than 10% over most of the KE_T/n_q range.
- In PbPb stronger violation of constituent quark number scaling than what is observed in pPb.
- v2 for neutral pion is smaller to charged particles

Hard Probes from CMS (Run1)

- Study properties of hot and dense medium produced in HI collisions (AA) and compare to proton-proton (pp) collisions.
- Compare in the same AA sample the yields of particles that are modified by QGP (jets, onia, etc) to those of unmodified reference particles (photons, Z, etc)
- Many quantities in inclusive measurements

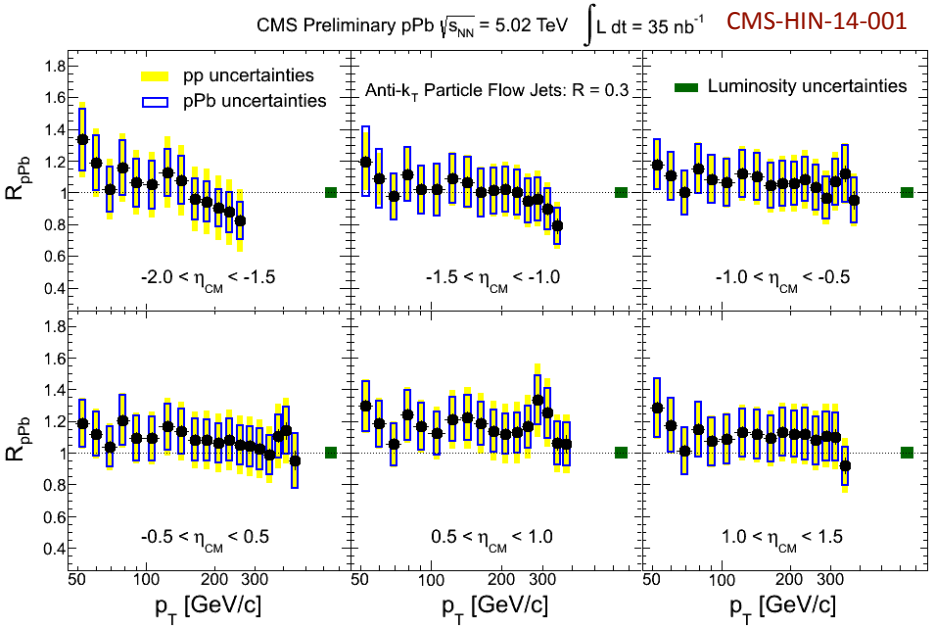
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{AA}/dp_T}{dN^{pp}/dp_T} \quad (1)$$

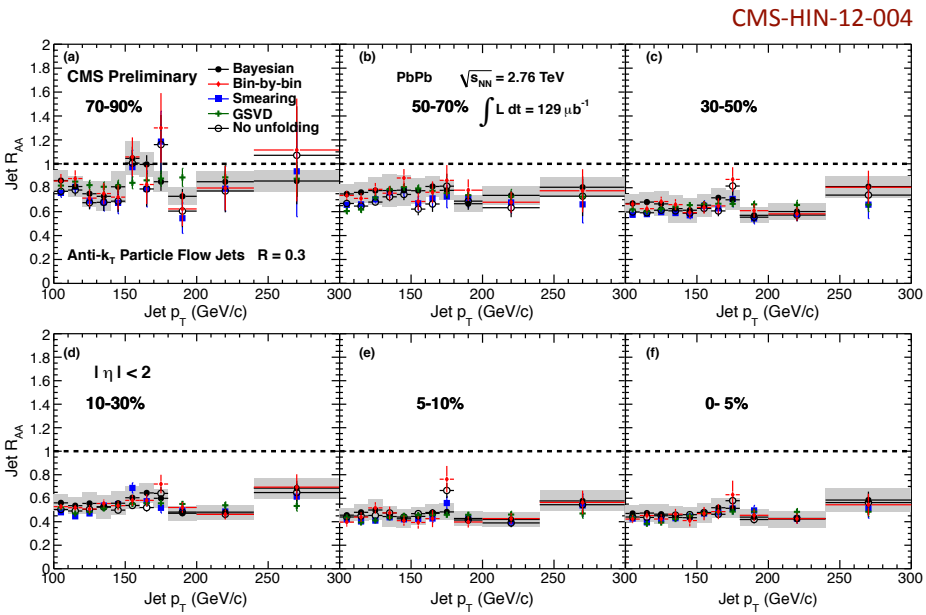
or

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN^{AA}/dp_T}{d\sigma^{pp}/dp_T} \quad (2)$$

  - $\langle N_{Coll} \rangle$ describes how many nucleons the proton is expected to encounter if it goes through Pb
  - $\langle T_{AA} \rangle$ average "thickness function", the integrated luminosity from going through one nucleus

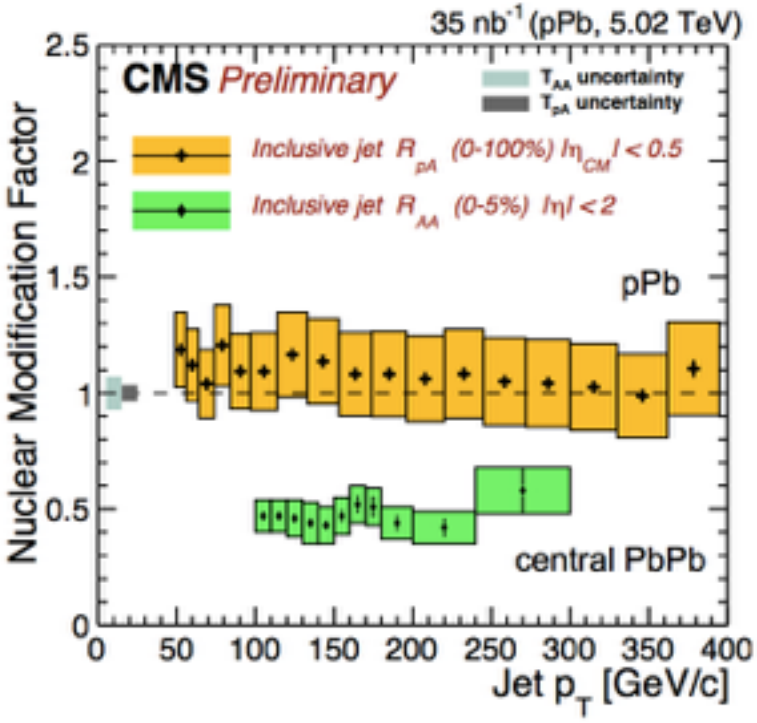
Inclusive Jets in pPb and PbPb



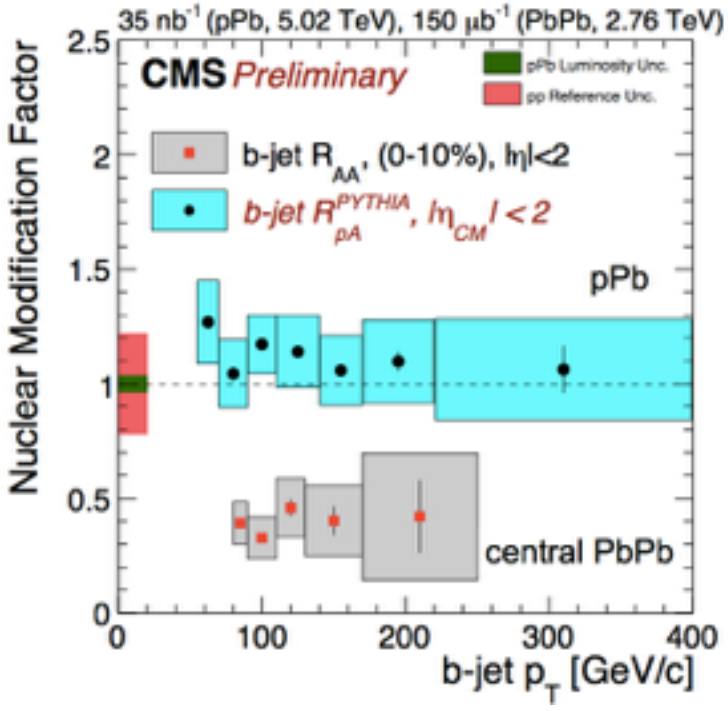


- Inclusive jets are produced at a comparable rate as in pp (superposition) in pPb
- PbPb jets are suppressed by a factor of 0.4–0.6
- No strong p_T dependence visible

b-jet in pPb and PbPb



CMS-HIN-14-001 CMS-HIN-12-004

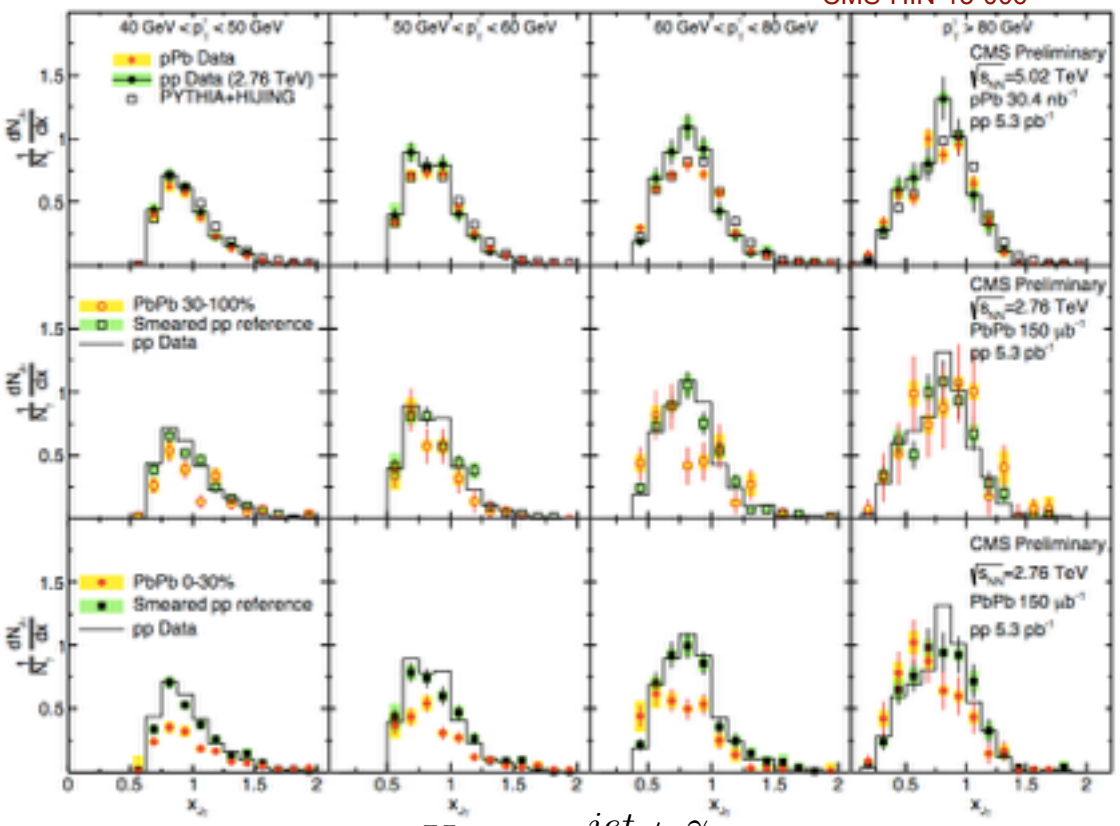


CMS-HIN-14-007 PRL 113 (2014) 132301

- In *central* PbPb: inclusive and b-jets show similar suppression in PbPb ($R_{AA} \approx 0.5$)
- In pPb (*no centrality selection*), inclusive and b-jets RpPb ~1
- No heavy flavor dependence observed

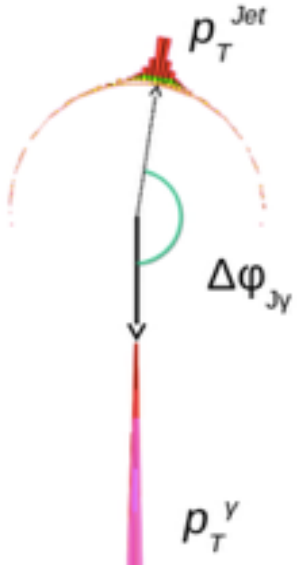
γ-jet in pPb and PbPb

CMS-HIN-13-006



$$X_{j\gamma} = p_T^{jet}/p_T^{\gamma}$$

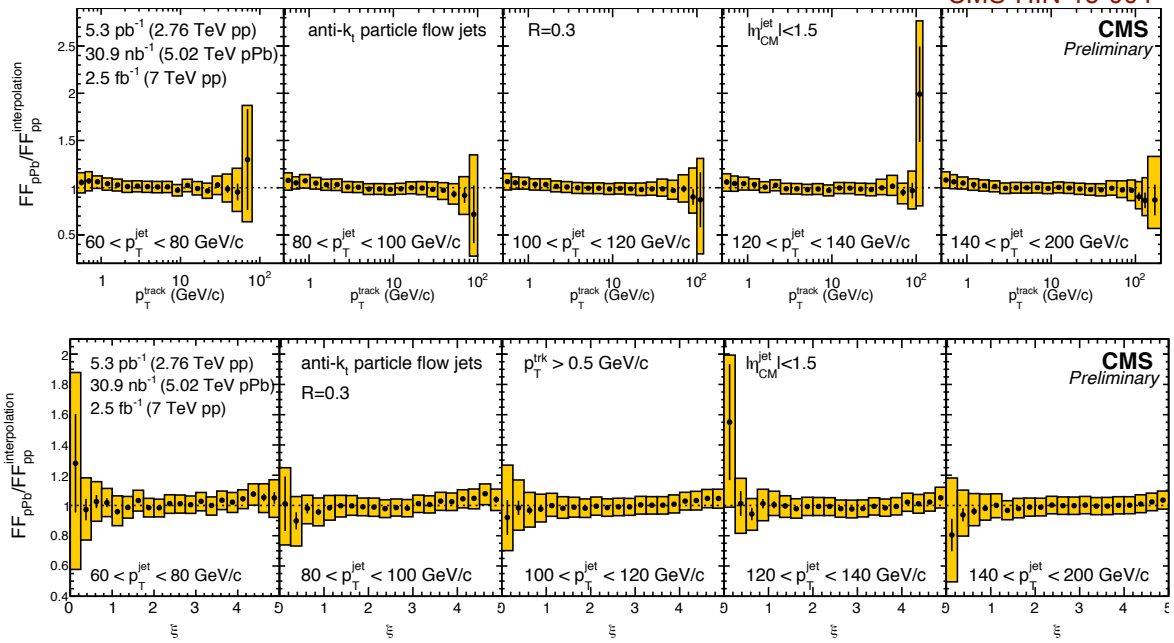
$|\eta^{\gamma}| < 1.44$, $|\eta^{jet}| < 1.6$,
$p_T^{jet} > 30$ GeV/c, $\Delta\phi > 7\pi/8$



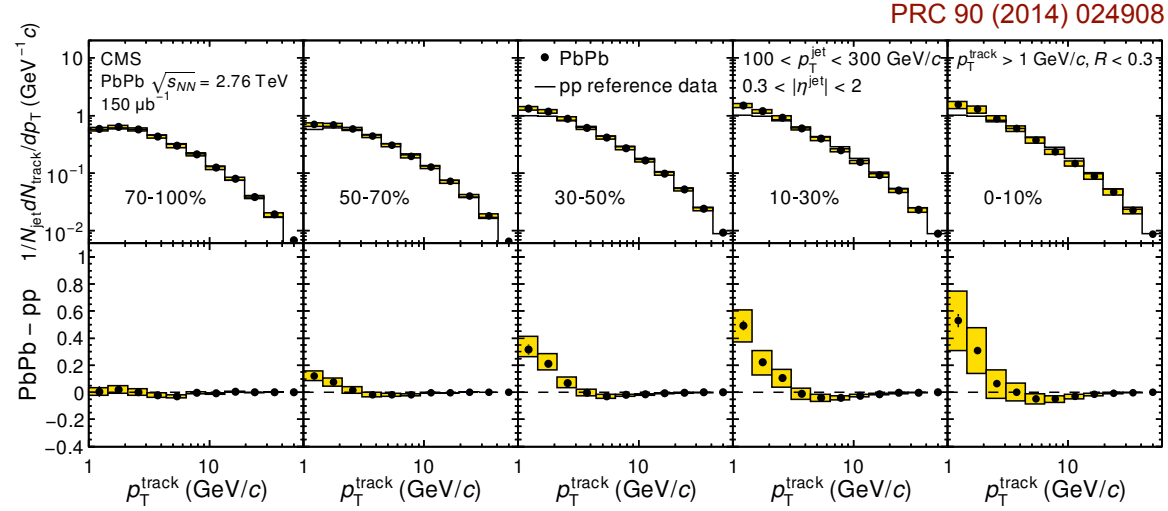
- Cut-off at low $X_{j\gamma}$ due to p_T^{jet} > 30 GeV/c cut
- Increased imbalance with PbPb vs. pPb, and increasing centrality

Jet Fragmentation in pPb and PbPb

CMS-HIN-15-004

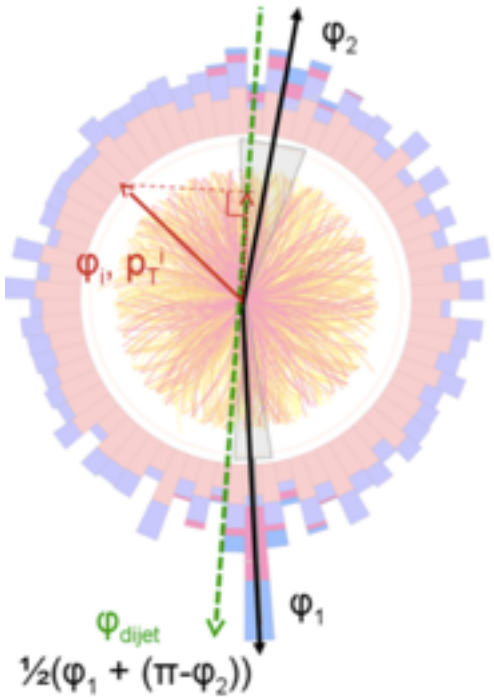


PRC 90 (2014) 024908

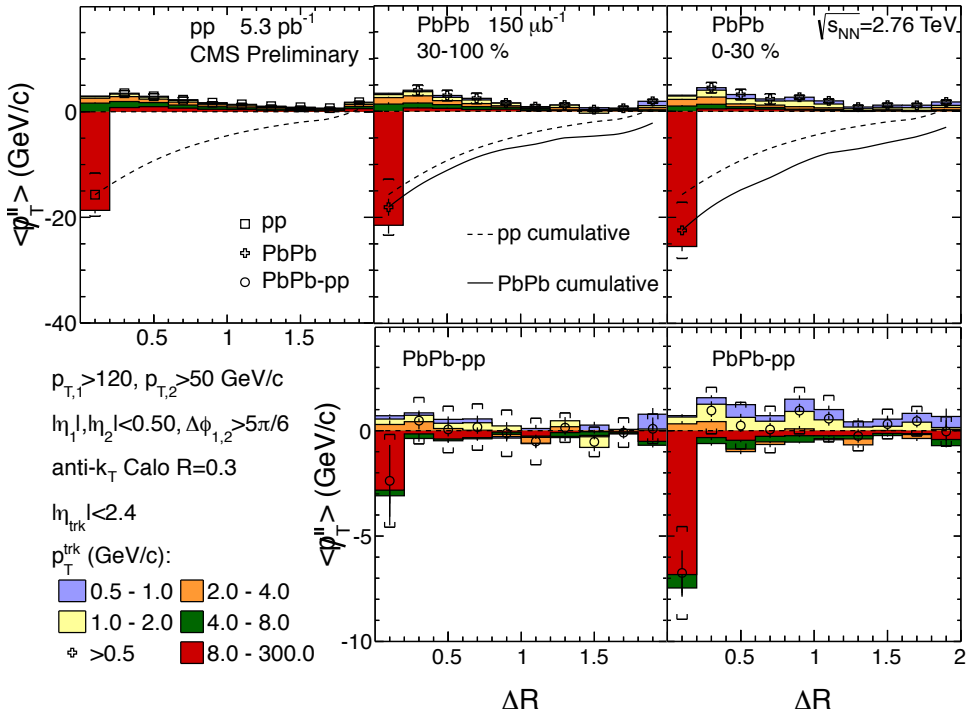


- Result is consistent with no modification across all points
- PbPb jets fragmentation function enhanced at low-pT , by approximately 1–2 additional particles on average
- High-pT largely unchanged

Dijet missing pT: quenched energy flow

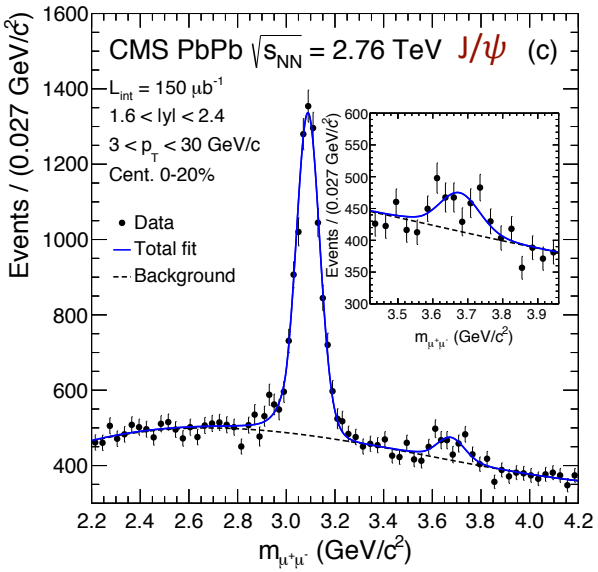


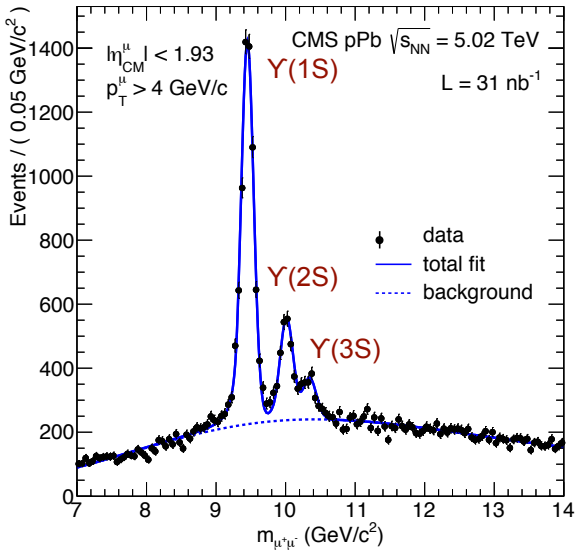
CMS-HIN-14-010



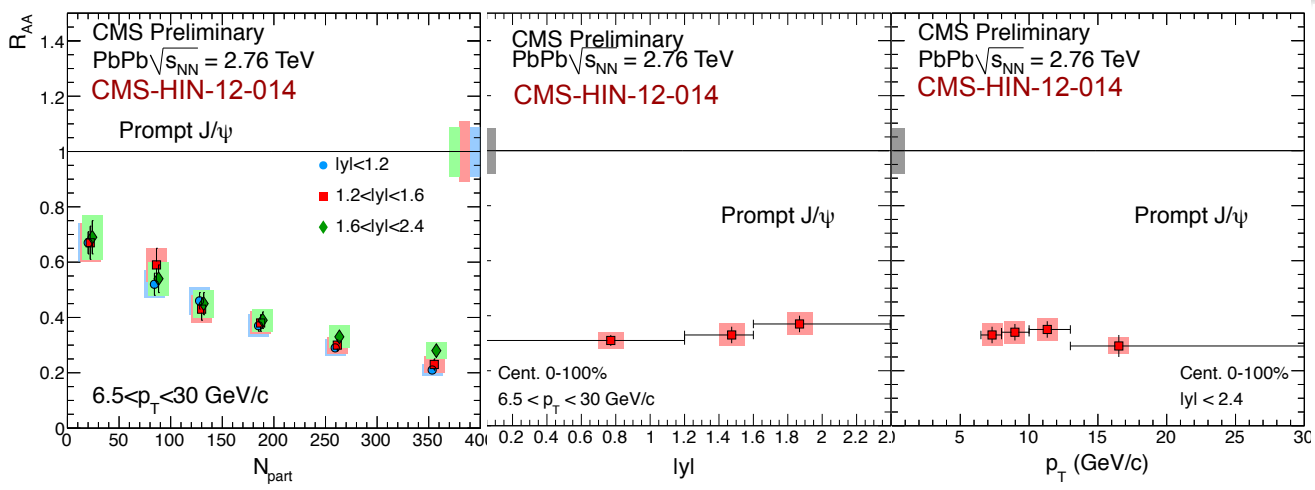
- The leading vs. subleading jet in pp is already imbalanced due to leading -vs -subleading selection and 3rd jet
- The PbPb is even more imbalanced, at the $\Delta R < 0.2$ core by 7 GeV/c
- This is offset by the soft particles produced at large angle
- Cumulatively the momentum is conserved

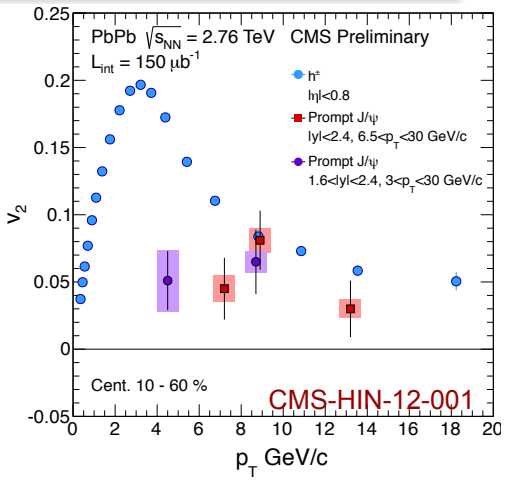
Quarkonia from CMS

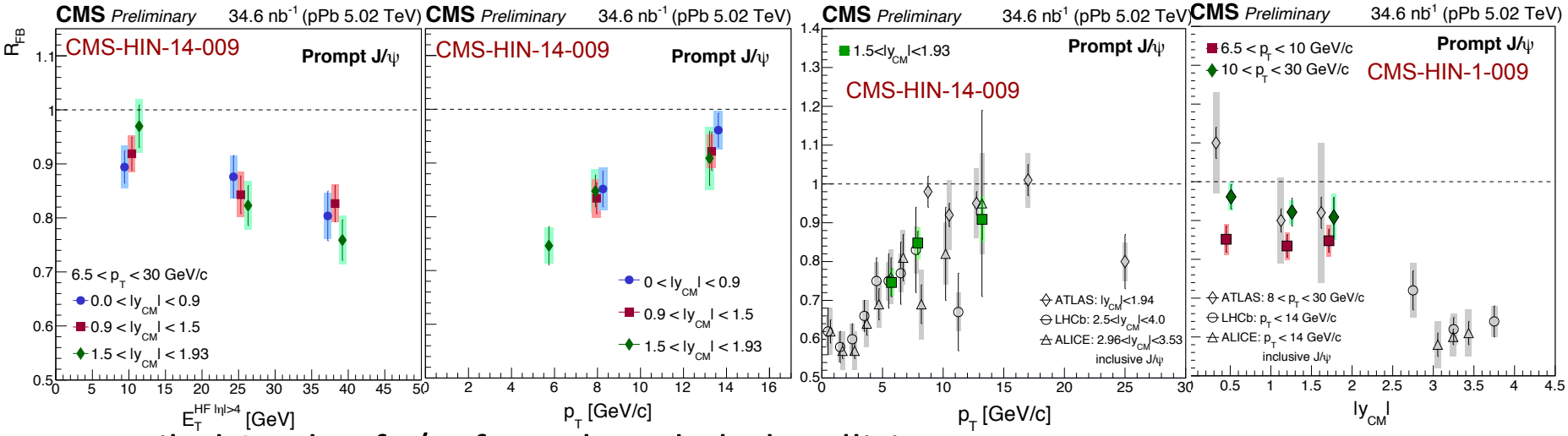




J/Ψ: R_{AA}, v2 and R_{FB} in pPb and PbPb

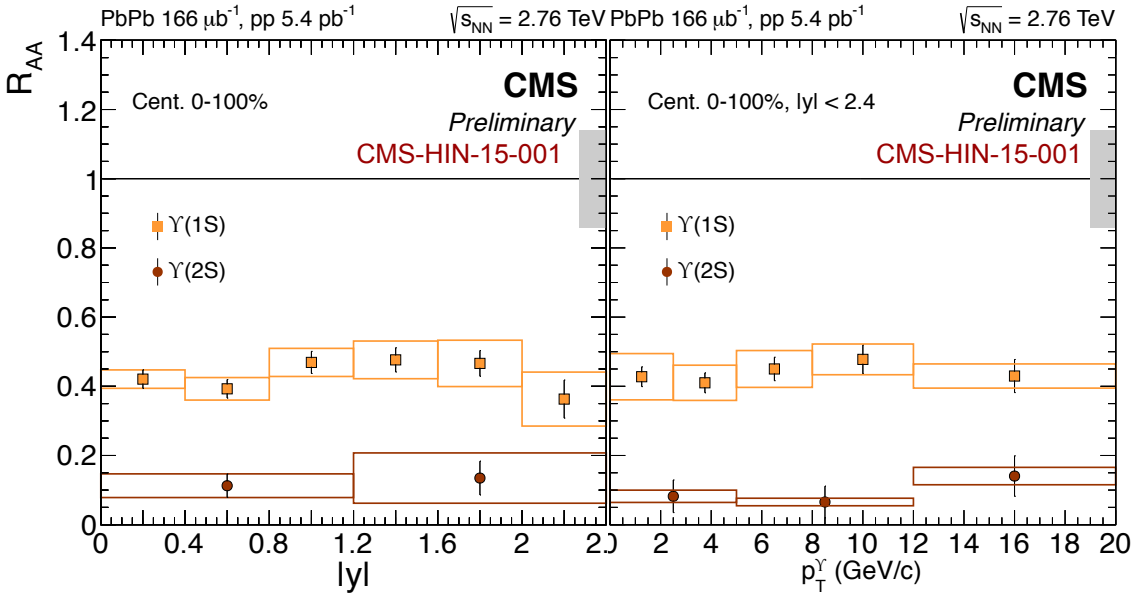


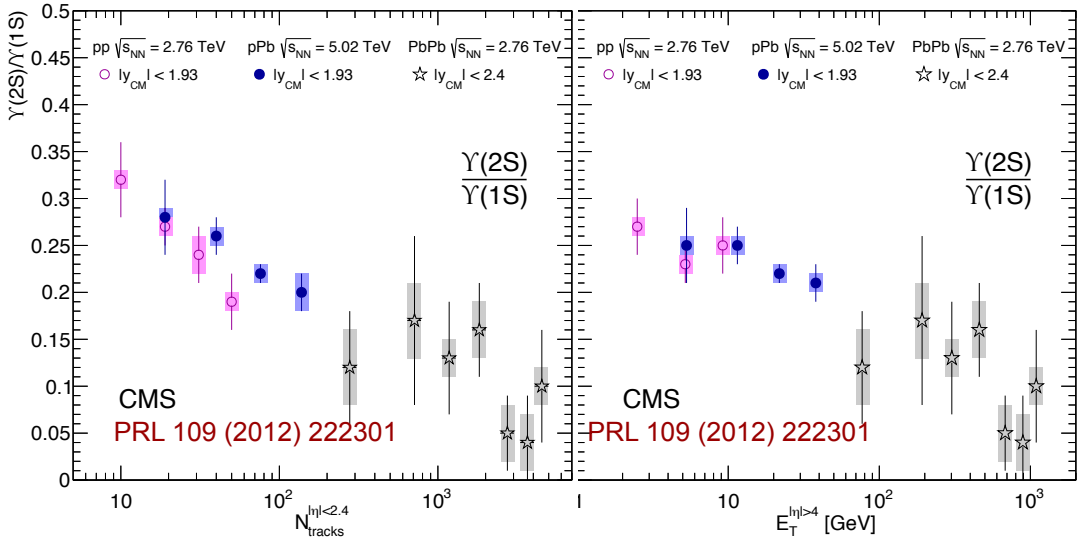




- Detailed Study of J/Ψ for pPb and PbPb collisions:
- No suppression dependence rapidity and p_T in PbPb and A non-zero v_2 measured in PbPb
- A good agreement between 4 LHC experiments for the R_{FB} vs. p_T and rapidity

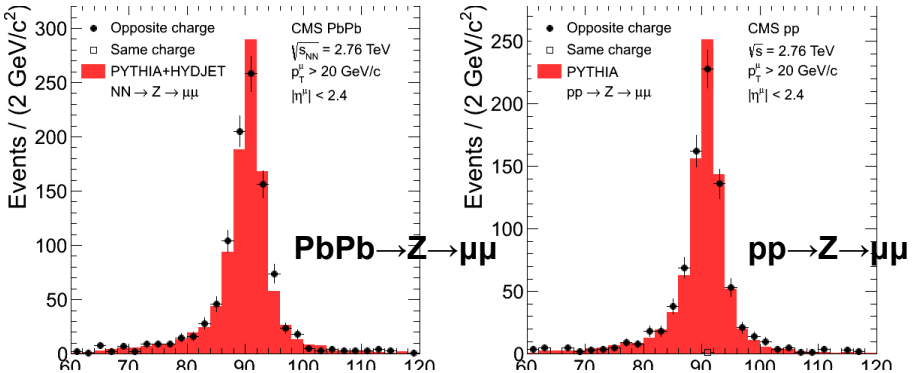
Υ : R_{AA} system dependence

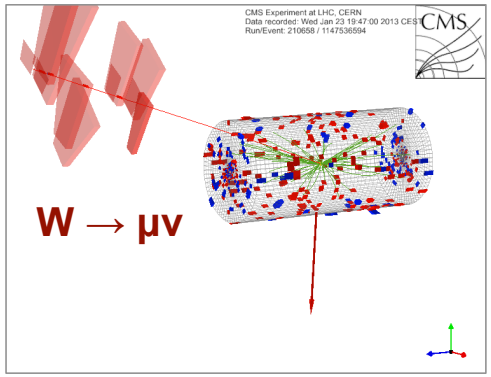


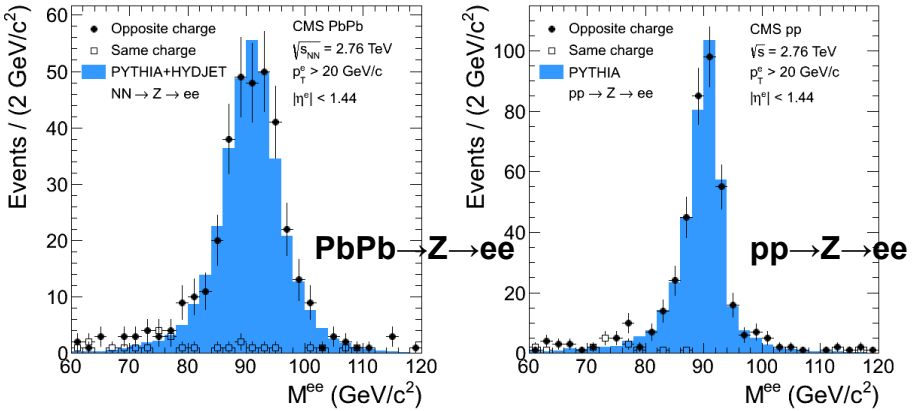


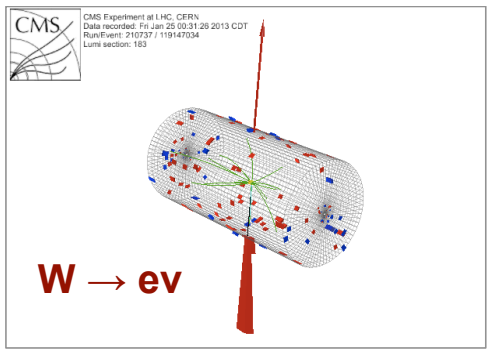
- The suppression is constant over the analysis range
- No significant dependence for PbPb results as function of N_{tracks} and $E_T(|\eta|>4)$, within large uncertainties

Electroweak Results from CMS (Run1)



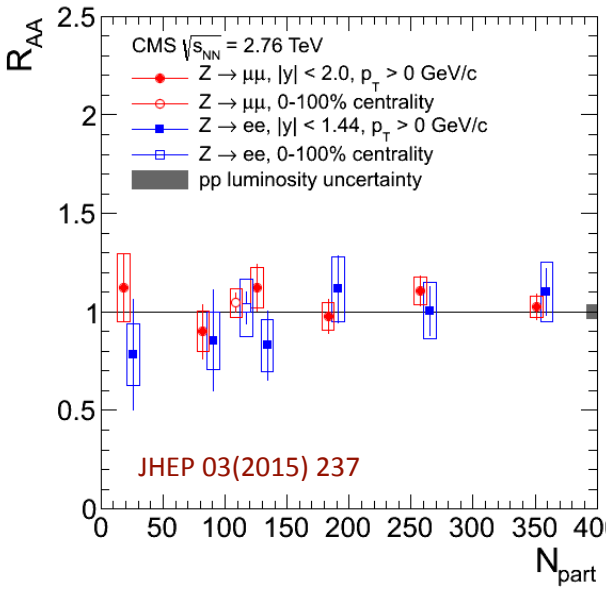


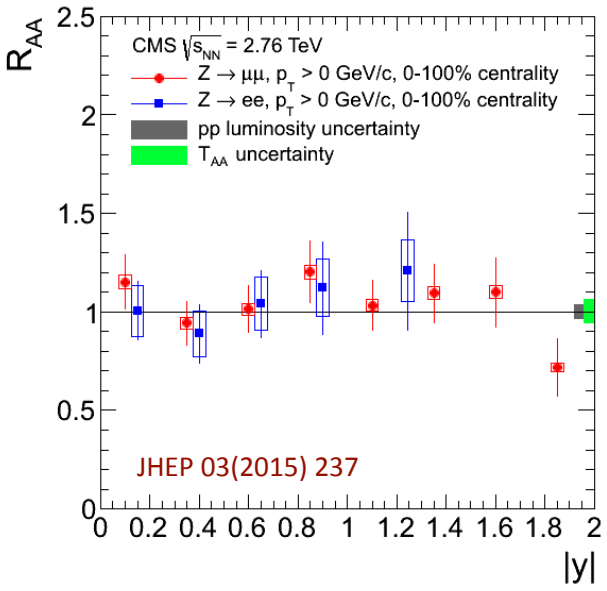


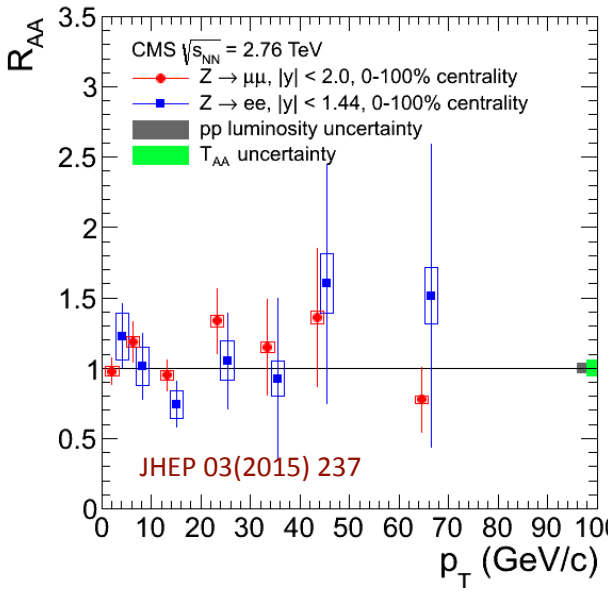


Type	PbPb & pp2.76 TeV	pPb5.02 TeV
Z	PRL 106 (2011) 212301 JHEP 03 (2015) 237 *	CMS-HIN-15-002 **
W	PLB 715 (2012) 66	arXiv:1503.05825 *
Isolated Photons	PLB 710 (2012) 256	***Finalized, ****New**

Z-boson in PbPb

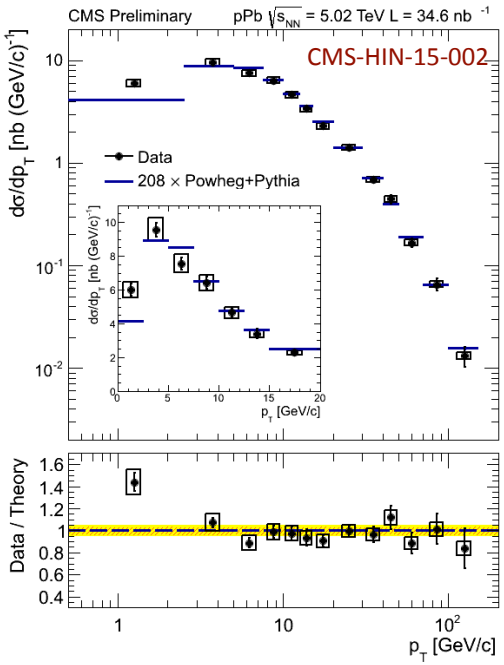


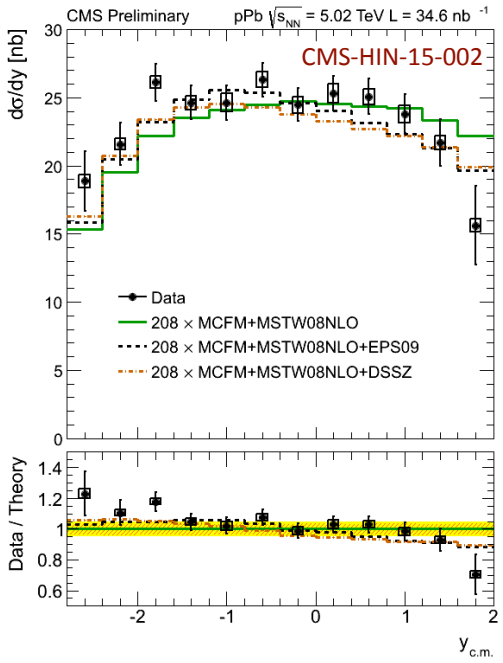


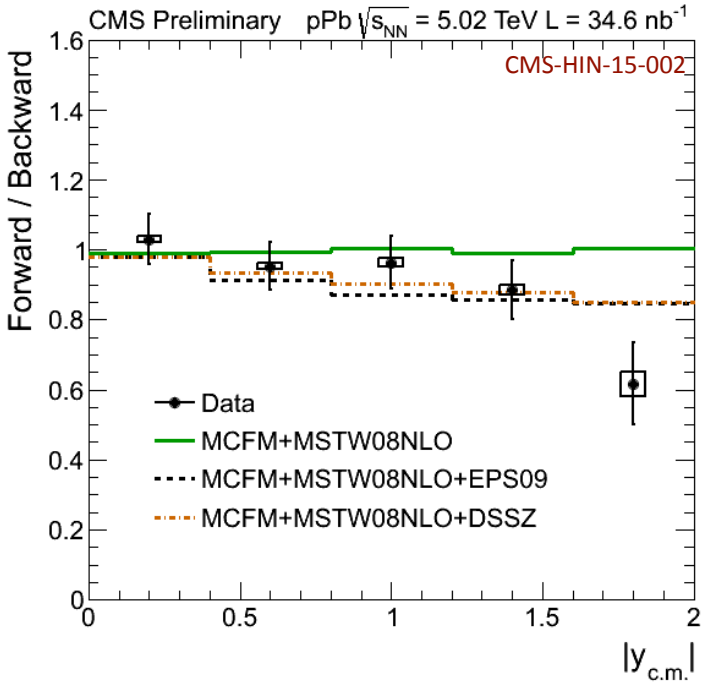


- Muon and electron results agree within statistics
- R_{AA} comparing PbPb with pp cross section→ results consistent with unity
- Binary collision scaling confirmed
- Possible nuclear effects on the pT or y spectrum are within the uncertainties of the measurement

Z-boson in pPb

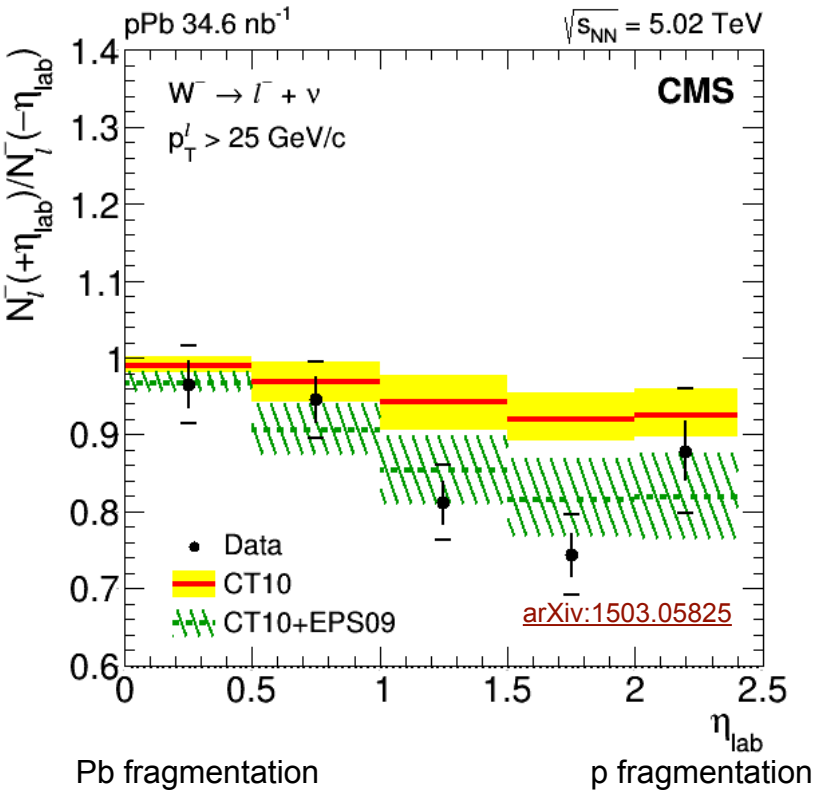




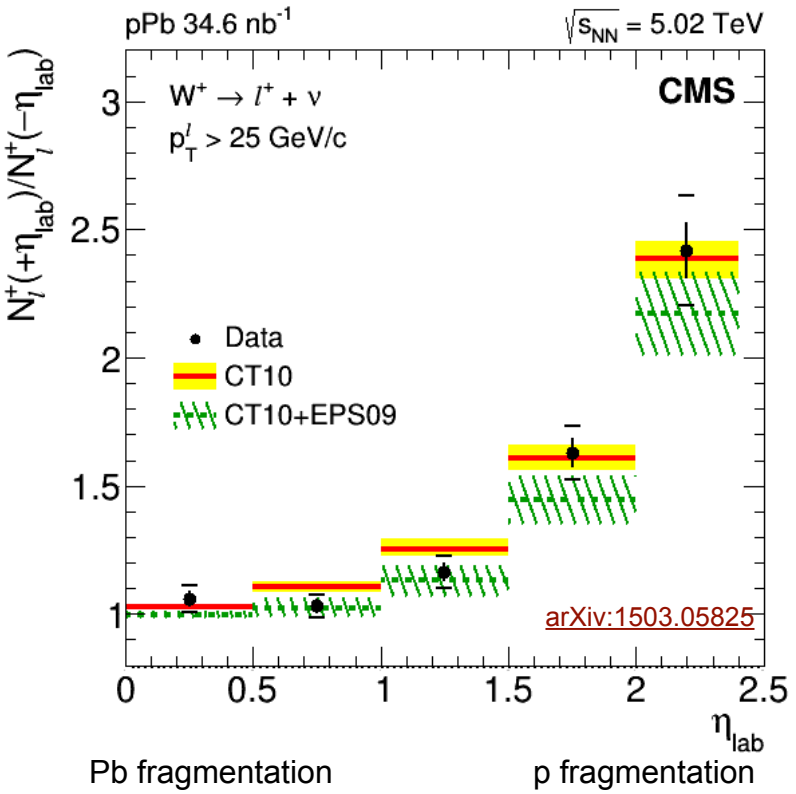


- p_T differential cross section - wide range 0-150 GeV/c
- Total inclusive cross section= 138.1 ± 2.4 (stats.) ± 8.6(sys.) ± 4.8 (Lumi) nb
- Forward-backward ratio compared to NLO-> hint of nuclear effects visible
- Expected nuclear effects are small

W-Boson in pPb



Pb fragmentation p fragmentation

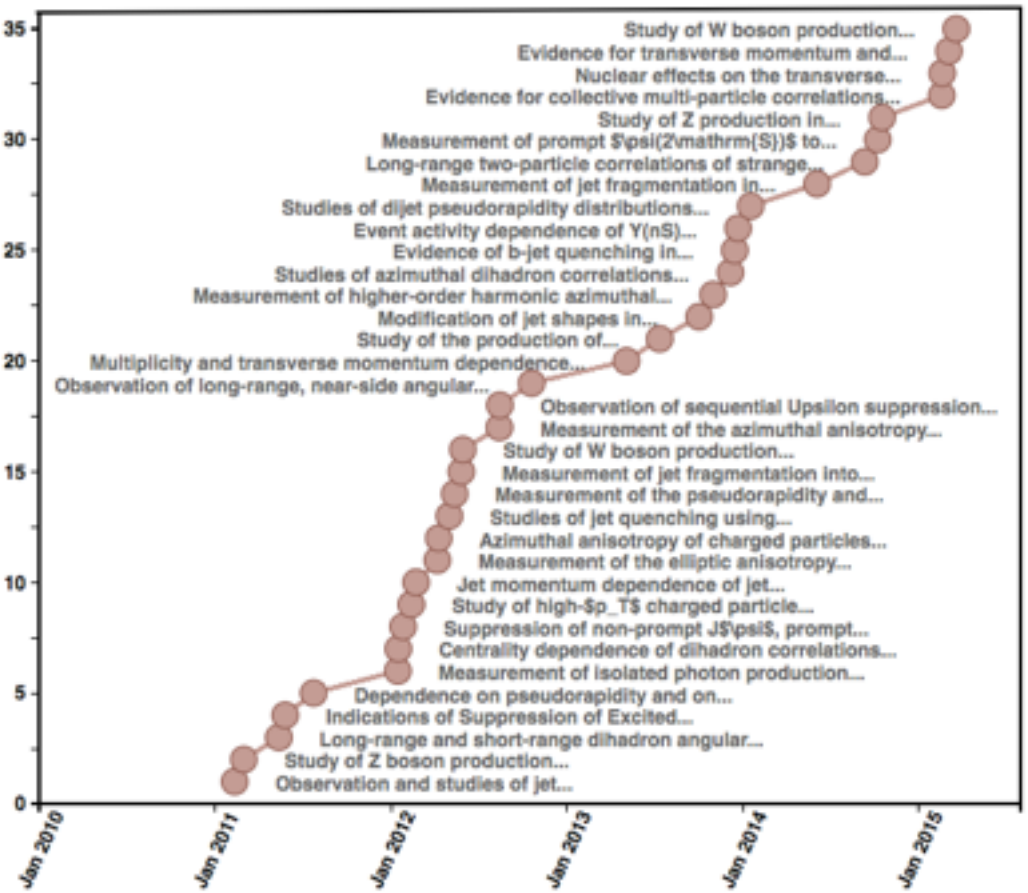


Pb fragmentation p fragmentation

- Forward-backward asymmetry
- More sensitive to nuclear modifications
- Different behavior of different charges→ hint for different u vs d quark modification?

Summary and Future Prospect

- Extensive measurements in
  - Bulk properties
  - Hard Probes
  - Quarkonia
  - Electroweak
- New run approaching
  - Higher energy
  - Luminosity
- New probes



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Thank you