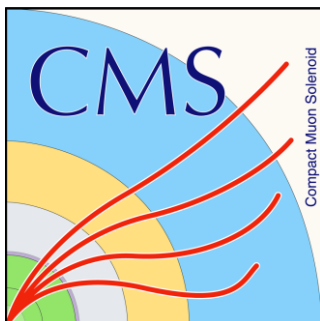


Physics Highlights from CMS

Yen-Jie Lee (MIT)

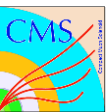
For the CMS collaboration



Quark Matter 2017

Chicago, USA

5-11 Feb, 2017

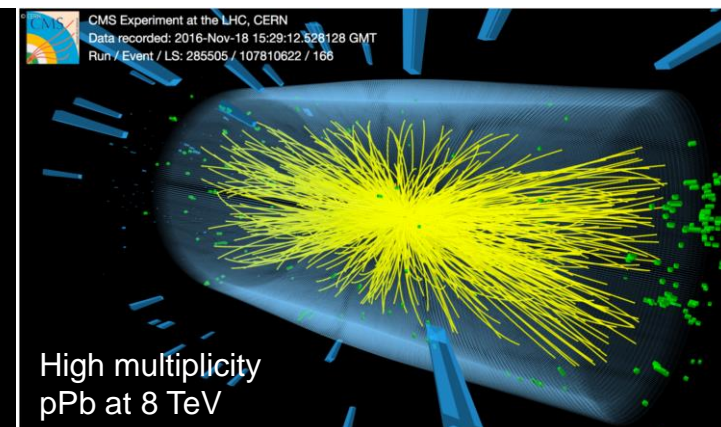
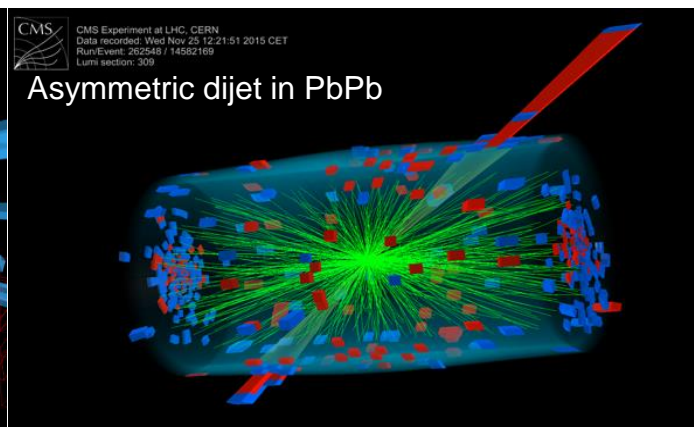
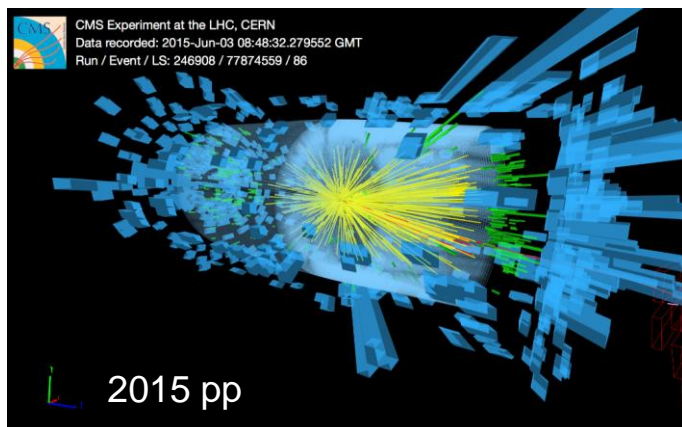


Physics Highlights from CMS

2015+2016 13 TeV pp

2015 5 TeV pp & PbPb

2016 5 & 8 TeV pPb



- Gluon parton distribution function in Pb
- Azimuthal anisotropy in pp, pPb and PbPb
- Charge separation signals from pPb and Chiral Magnetic Effects
- Parton flavor and shower dependence of energy loss
- Suppression of quarkonium states in a hotter and denser medium

All exciting new results with Run II data!

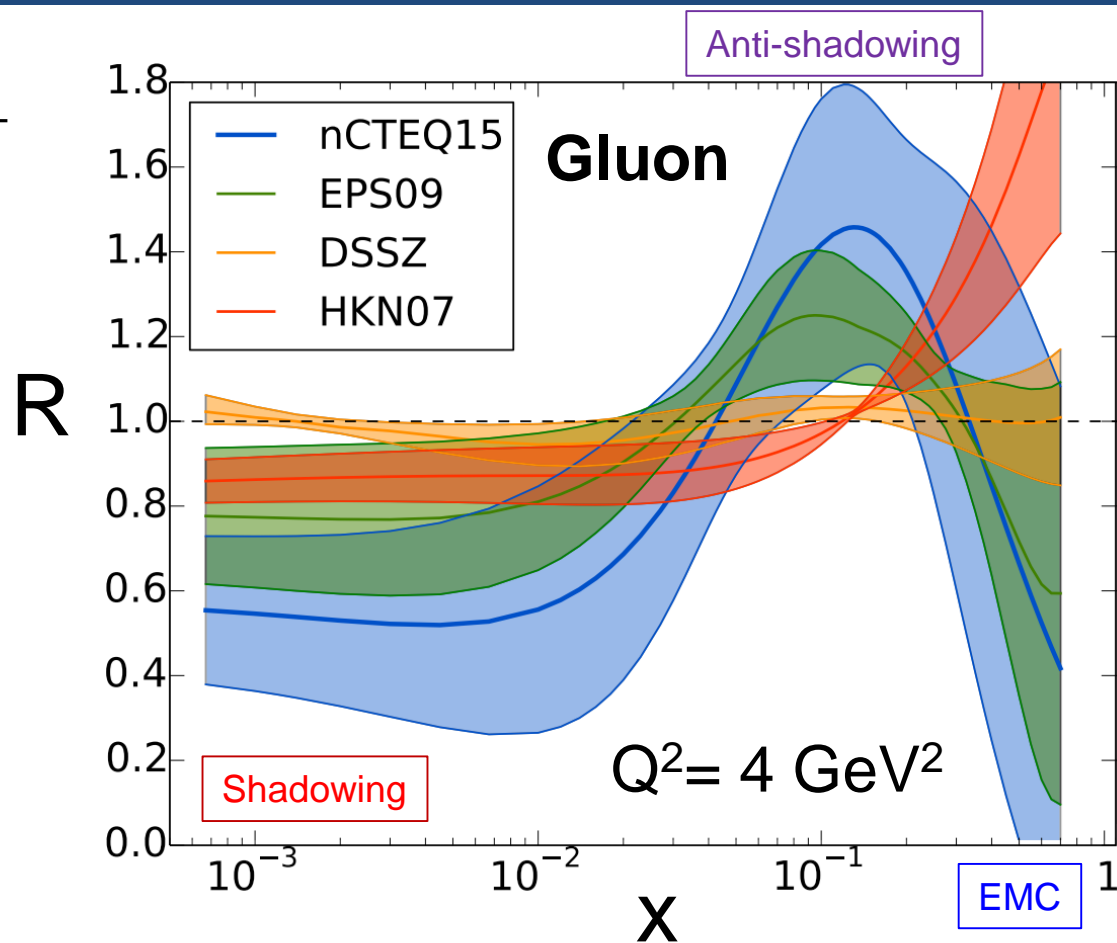
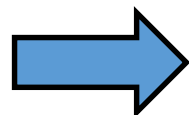
Nuclear Parton Distribution

Deep Inelastic Scattering Data

Drell-Yan Data

RHIC Pion Data in dAu

$$R = \frac{nPDF}{PDF}$$



Different Interpretation of d+Au Pion Data

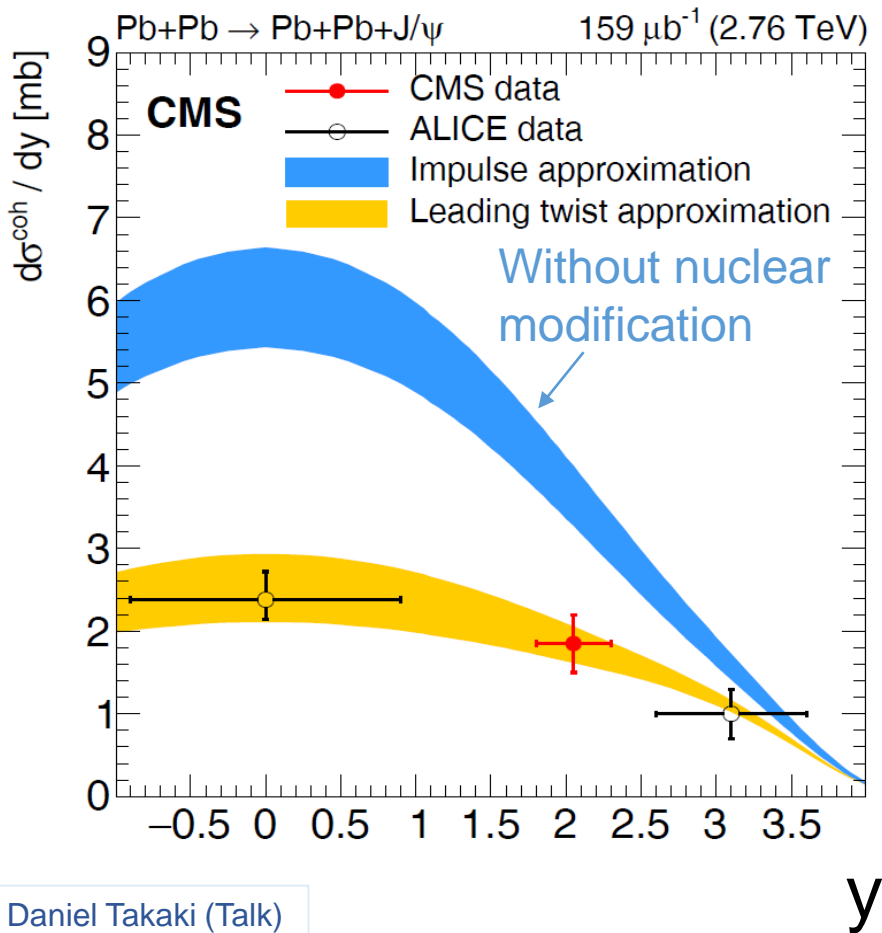
- **EPS09** & **nCTEQ15**: gluon (anti-)shadowing
- **DSSZ**: modified parton-to-pion fragmentation (gives nucleon-like gluon PDF)

- Limited knowledge in the $x > 0.3$ (EMC) region



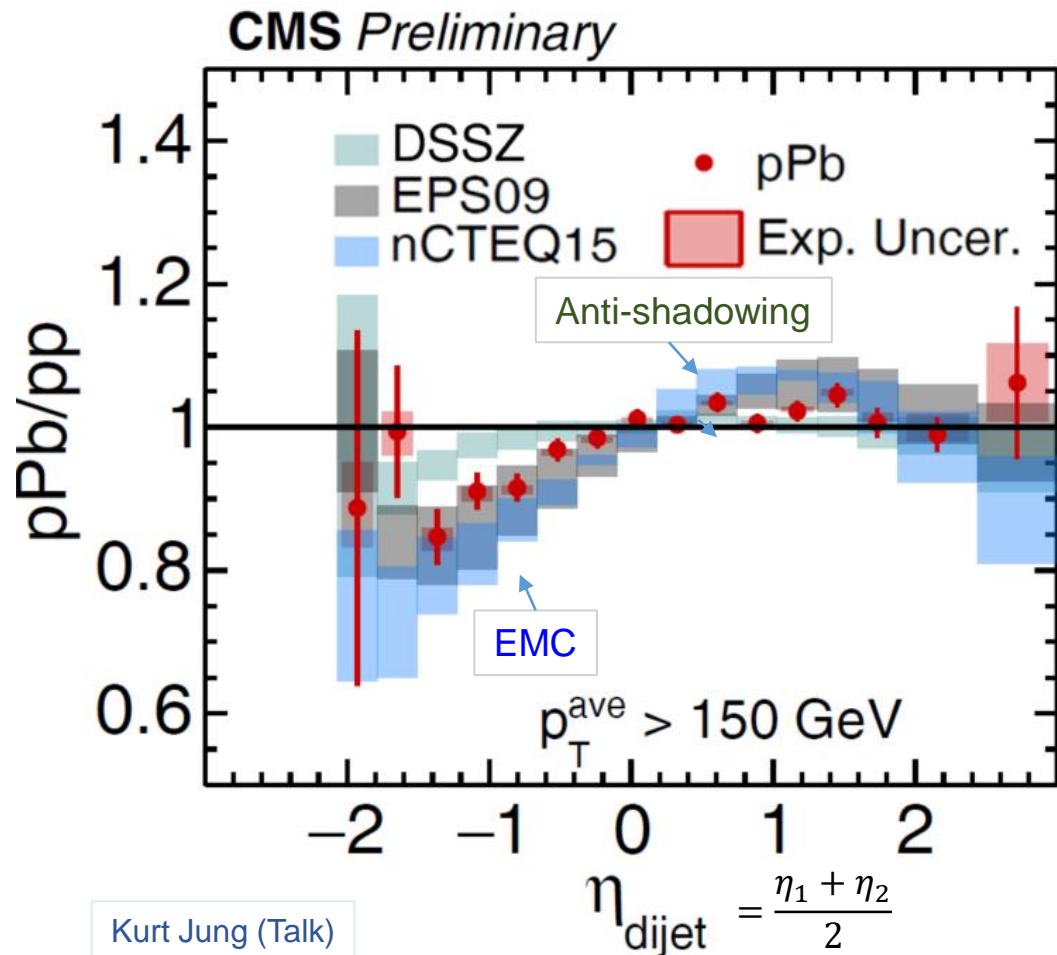
Modification of Gluon PDF in Pb Ion

UPC J/ψ $Q^2 \sim 2.4$



- Evidence of nuclear modification of gluon PDF at $x \sim 8 \times 10^{-3}$

Dijet average η $Q^2 \sim 20000$



- Inconsistent with DSSZ and nCTEQ15
- Evidence of gluon **anti-shadowing** and modification in the EMC region $x > 0.3$

arXiv: 1605.06966
Submitted to PLB

See also: the first inclusive c-jet spectra in Kurt Jung's talk

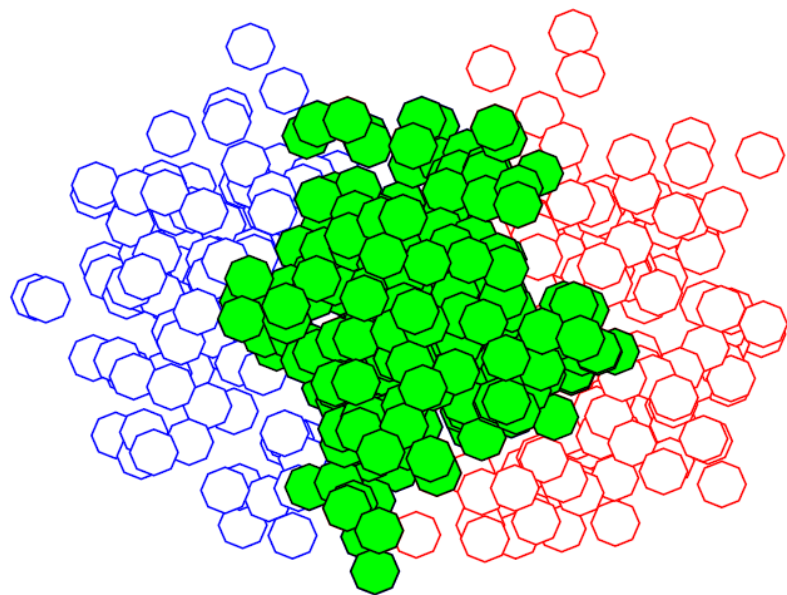
EPJC 74 (2014) 2951

CMS-PAS-HIN-16-003

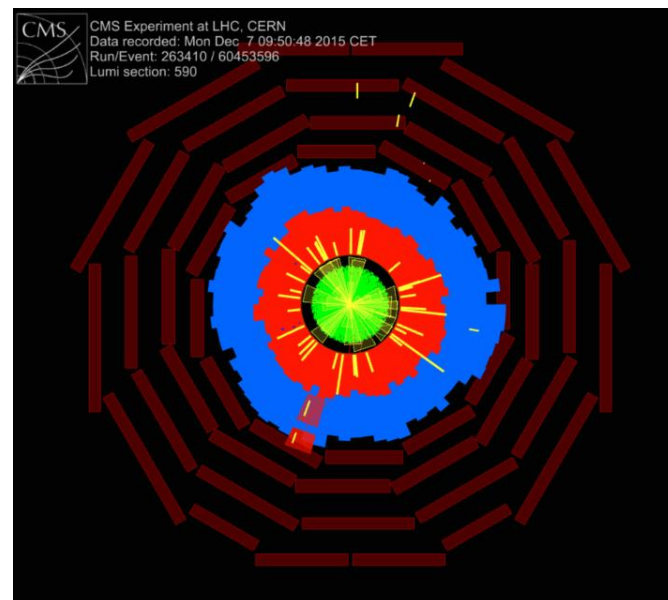
From Initial State to Final State Anisotropy

Initial State Anisotropy (ϵ_n)

Final State Anisotropy (v_n)



Hydrodynamics



How does the initial state anisotropy fluctuate?

How do they translate to final state anisotropy?

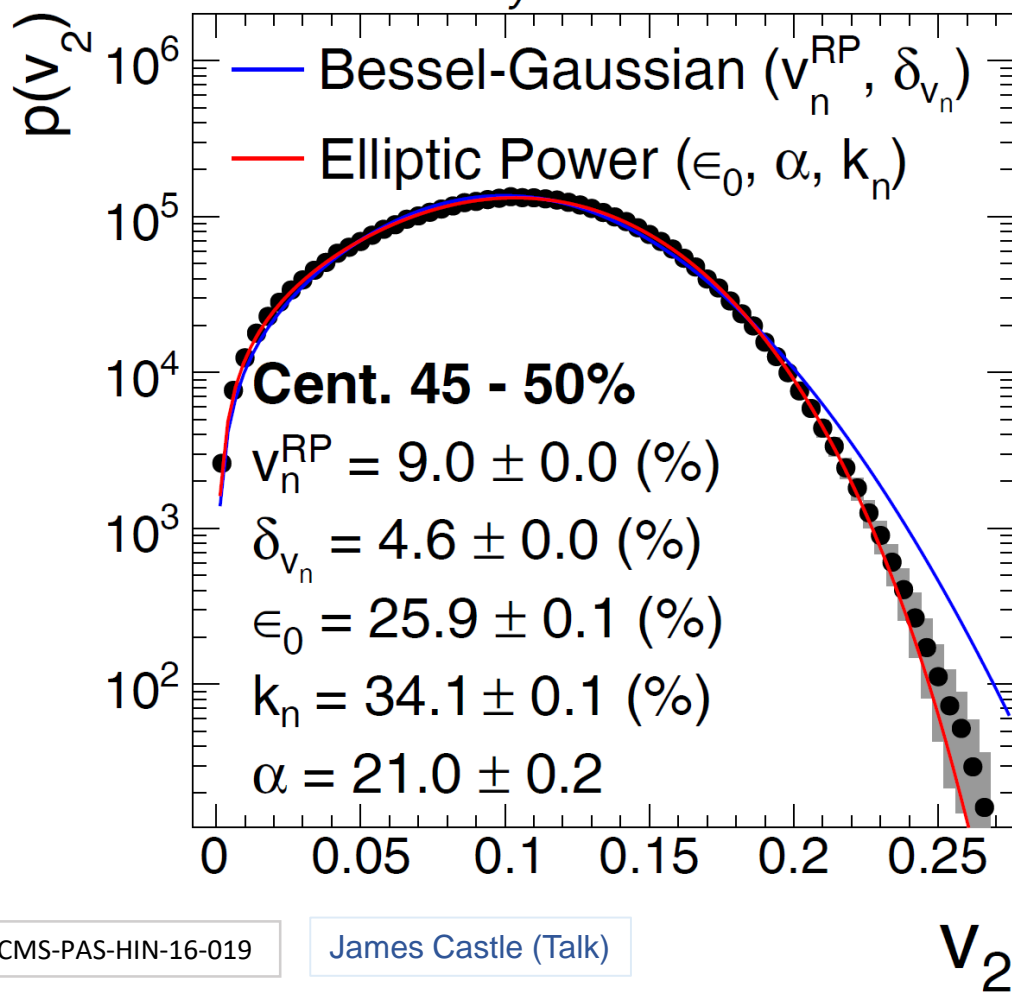


- (1) v_2 event-by-event fluctuation
- (2) Linear (mainly from ϵ_n) and **non-linear contribution** (from lower order) in v_n : ***mixing*** coming from **initial state geometry** or at **freeze-out**
- (3) Correlation strength between v_n from small to large systems

Results from 5.02 TeV PbPb

(1) Elliptic flow fluctuation

CMS Preliminary PbPb 5.02 TeV



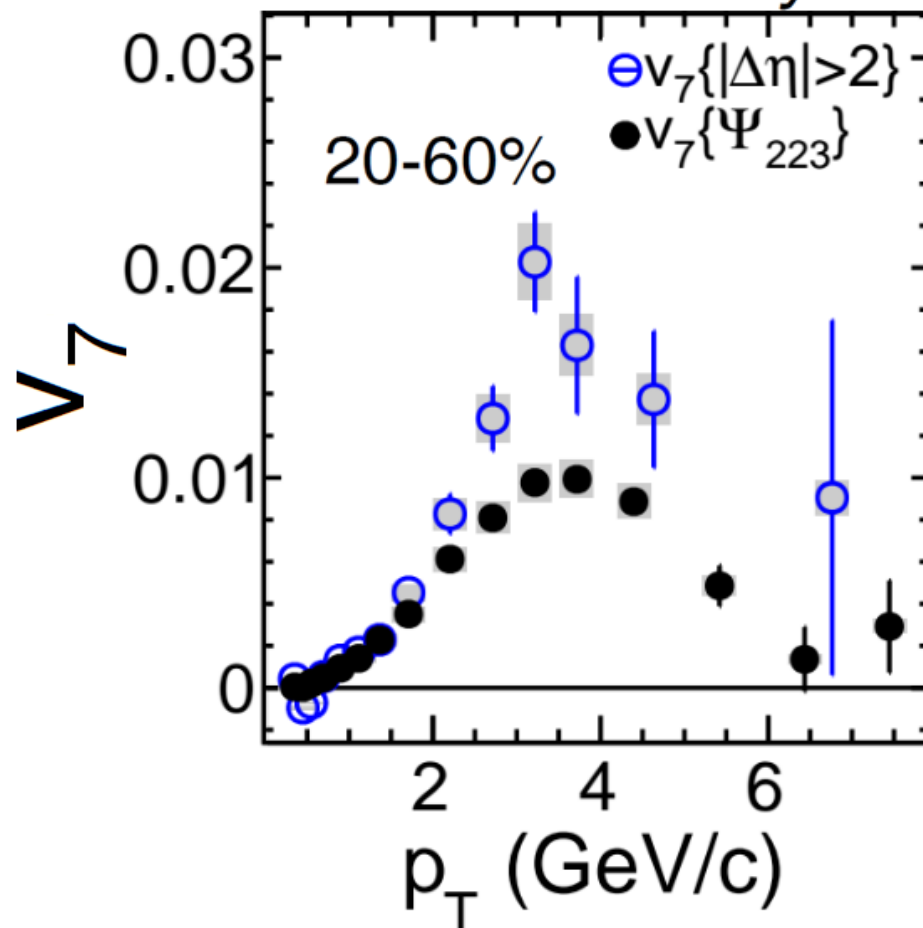
CMS-PAS-HIN-16-019

James Castle (Talk)

- **Elliptic power:** describe the data very well
- Allow extraction of initial anisotropy and response coefficient

(2) Decompose v_n

CMS Preliminary



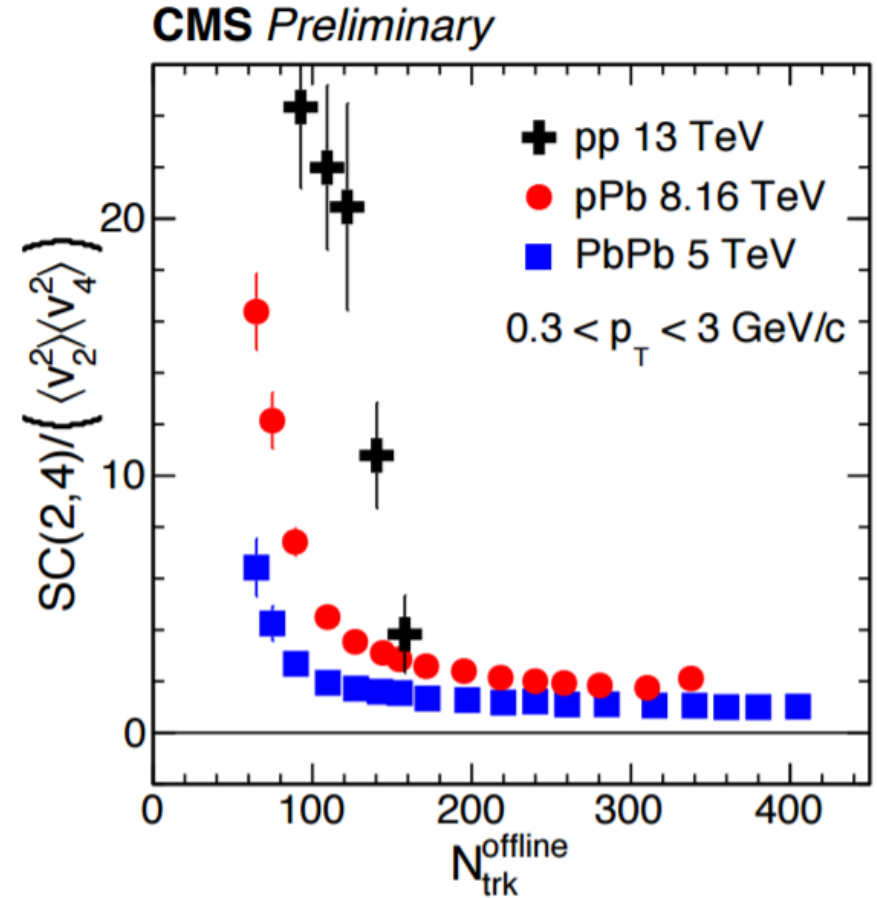
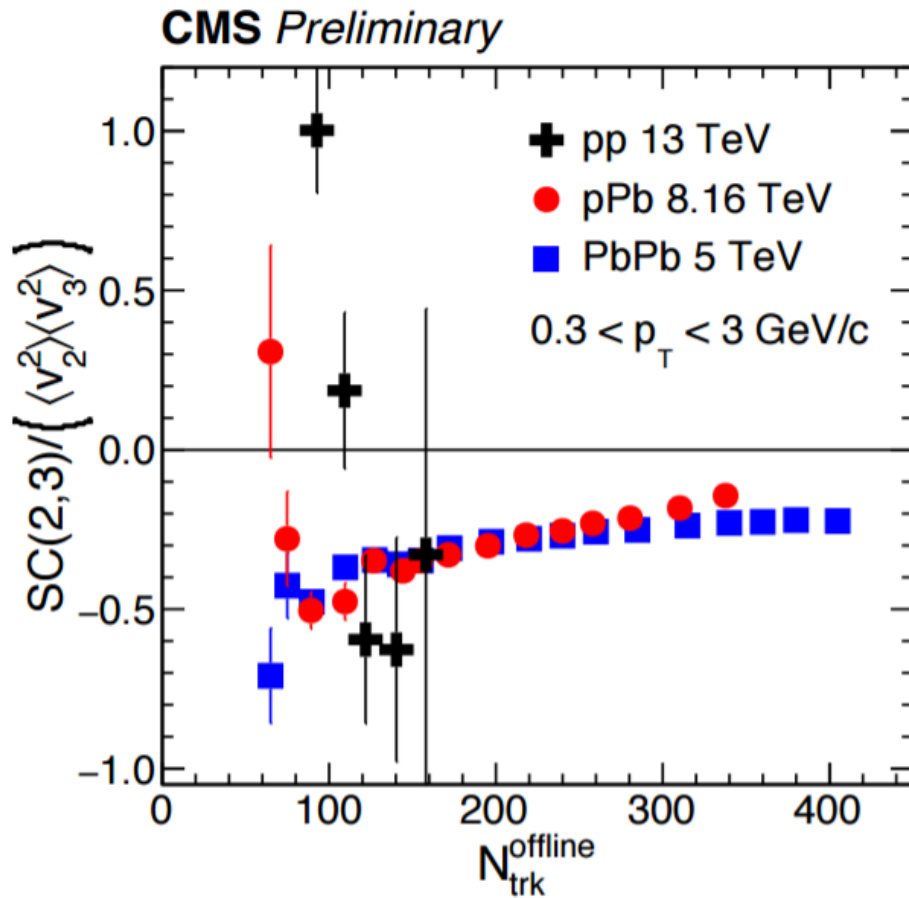
- Significant fraction of v_7 is **non-linear contributions** from lower order harmonics

Shengquan Tuo (Talk)

CMS-PAS-HIN-16-018

(3) Correlation between v_2 , v_3 and v_4

Symmetric Cumulants $SC(n, m) = \langle v_n^2 v_m^2 \rangle - \langle v_n^2 \rangle \langle v_m^2 \rangle$

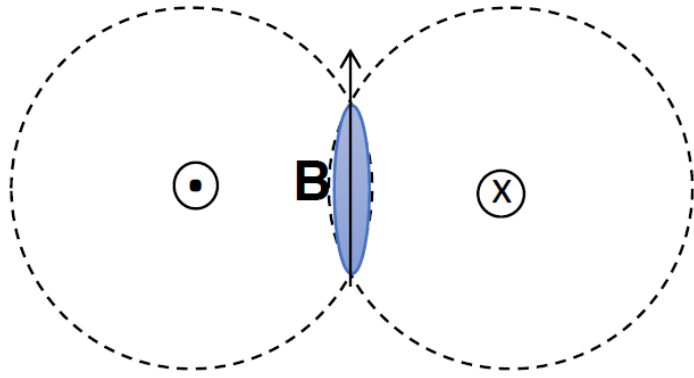


- Negative correlation between v_2 and v_3
- Normalized correlation of v_2 and v_3 in **pPb** and **PbPb** are similar; points to **common origin of the observed anisotropy**

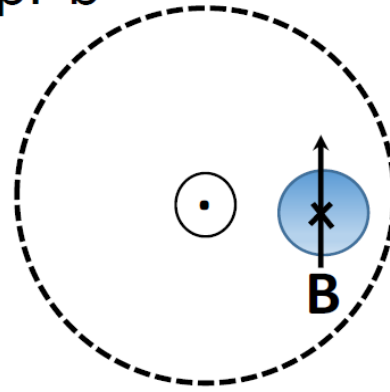
- Positive correlation between v_2 and v_4
- Ordering observed:
pp > pPb > PbPb
- The result may point to different transport properties

CME through Charge Separation Signal

PbPb



pPb

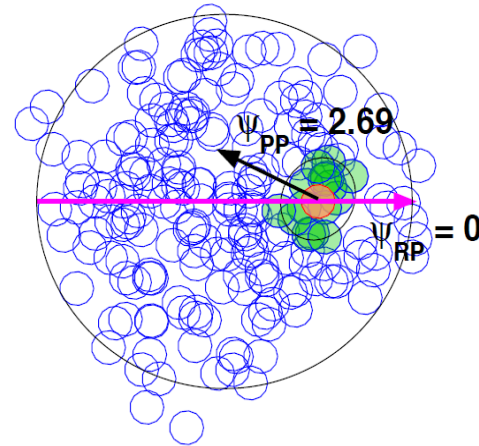
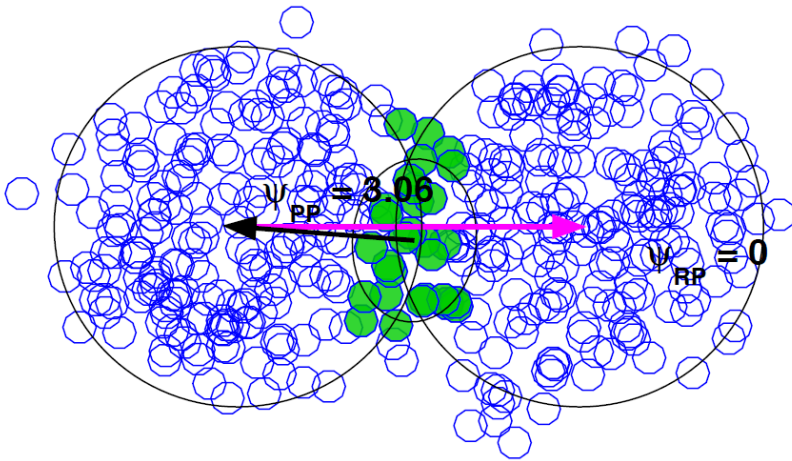


For the same multiplicity

Magnetic field
from all the charges

$$B_{pPb} < B_{PbPb}$$

arXiv: 1610.00263



Almost no correlation
between **event plane** and
the **direction of \vec{B}** in pPb.
Strong correlation in PbPb

Expect much smaller Charge Separation Signal in pPb

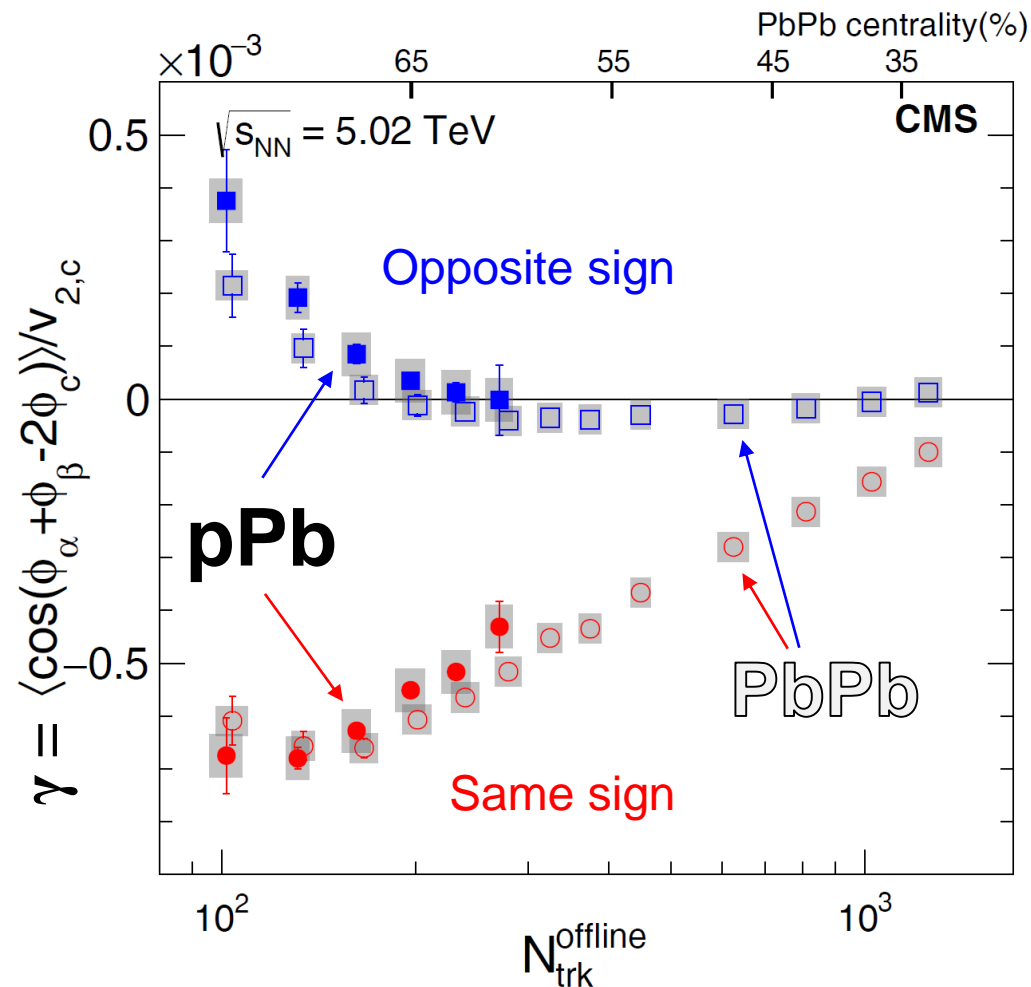
$$\Delta\gamma \sim B^2 \left\langle \cos\left(2\Psi_B - 2\Psi_{EP}\right) \right\rangle$$

$$\gamma = \frac{\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_c) \rangle}{v_{2,c}}$$

Charge Separation Signal in pPb and PbPb

arXiv: 1610.00263
Submitted to PRL

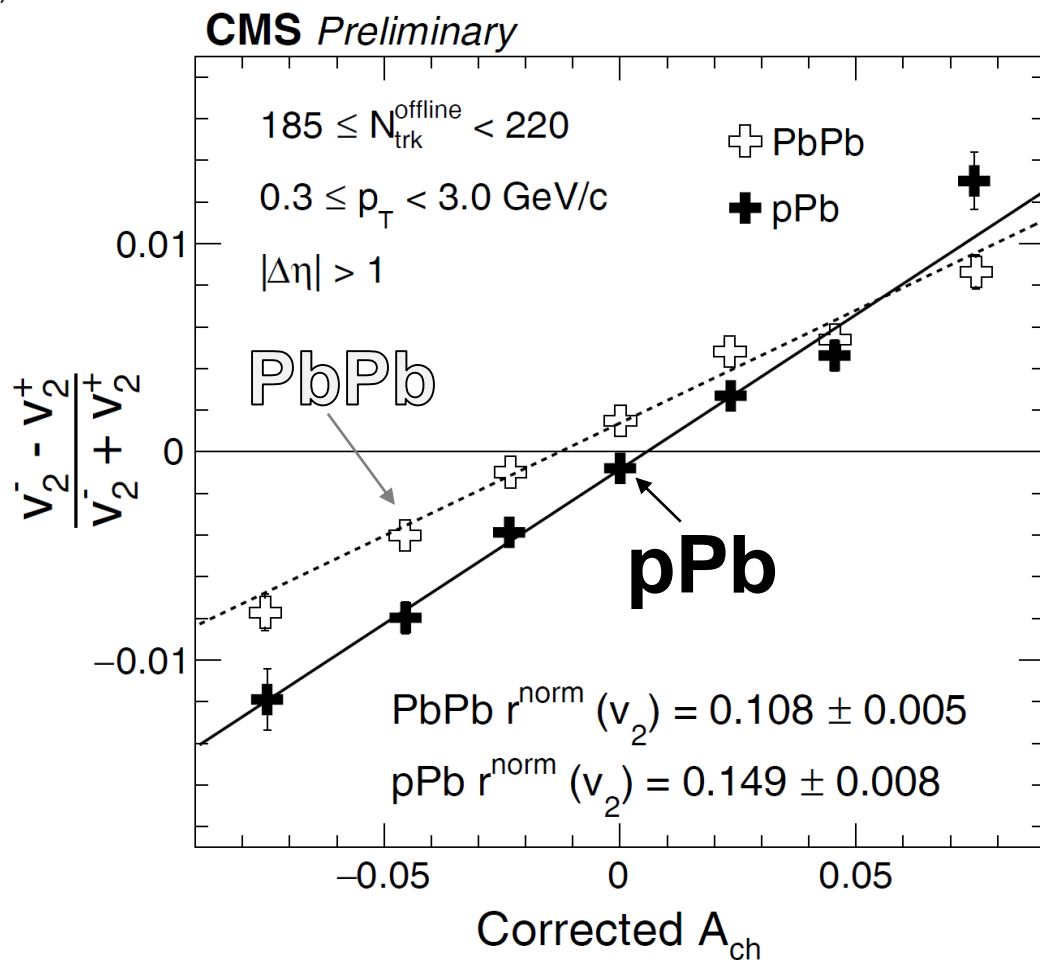
Charge Separation Signal γ



PbPb and pPb with the same event multiplicity are **similar...!**

Challenge to CME interpretation!

Normalized v_2 difference vs. charge asymmetry A_{ch}



Significant slope observed in pPb!

Challenge to CMW interpretation!

Zhoudunming Tu (Talk)

Sang Park (Talk)

CMS-PAS-HIN-16-017

Yen-Jie Lee (MIT)

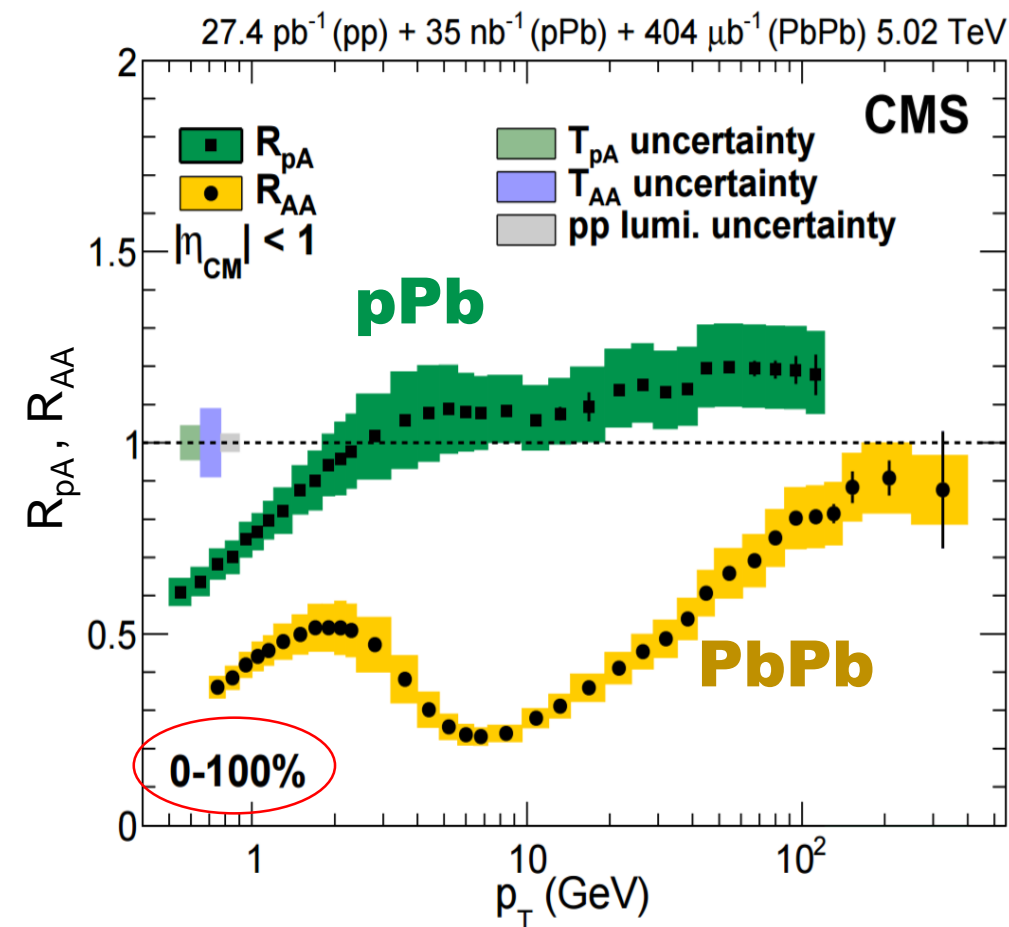
Highlights from CMS

9

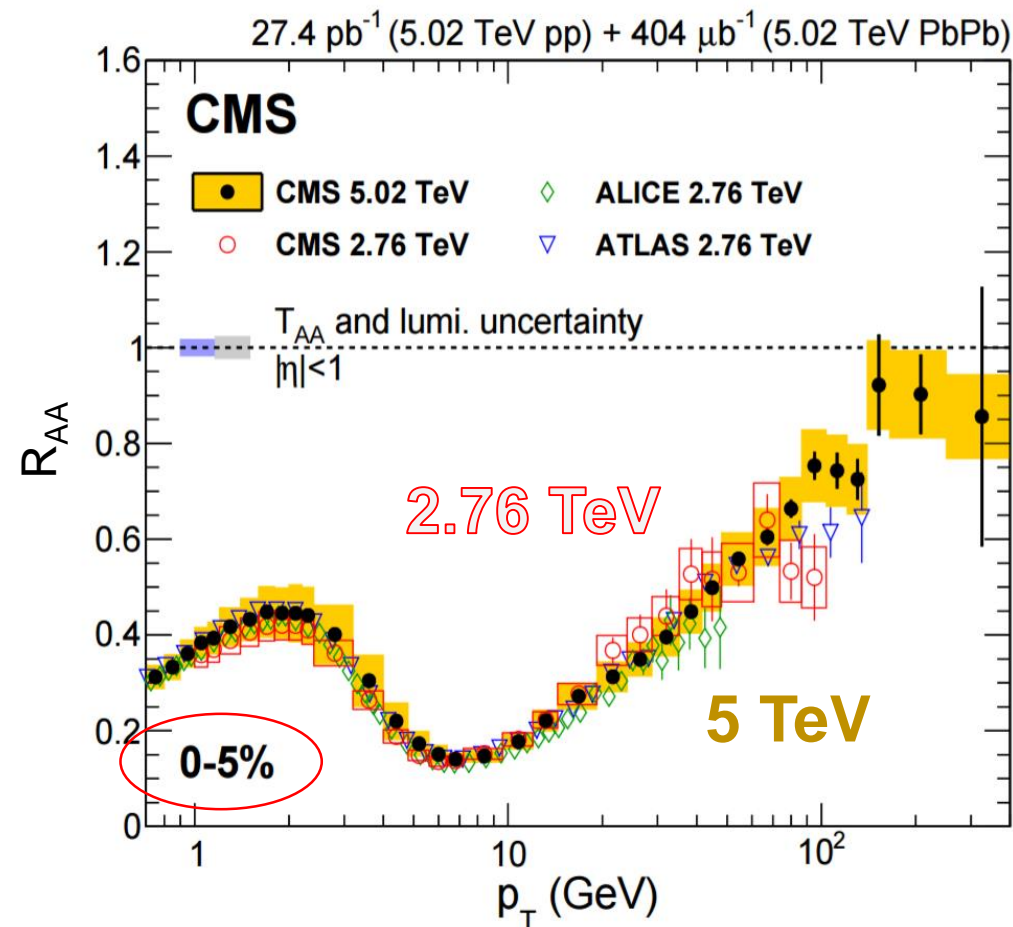


Charged Particle R_{pA} and R_{AA} at 5 TeV

With high statistics **pp data at 5 TeV**



- **Charged particle R_{pPb}** , possible anti-shadowing and hadronization effects
- R_{AA} measured up to $p_T = 400$ GeV for the first time!



- Similar or slightly larger suppression in PbPb at **5 TeV** compared to **2.76 TeV**
- **Almost no suppression at very high p_T** compared to **pp reference**

Austin Baty (Poster)

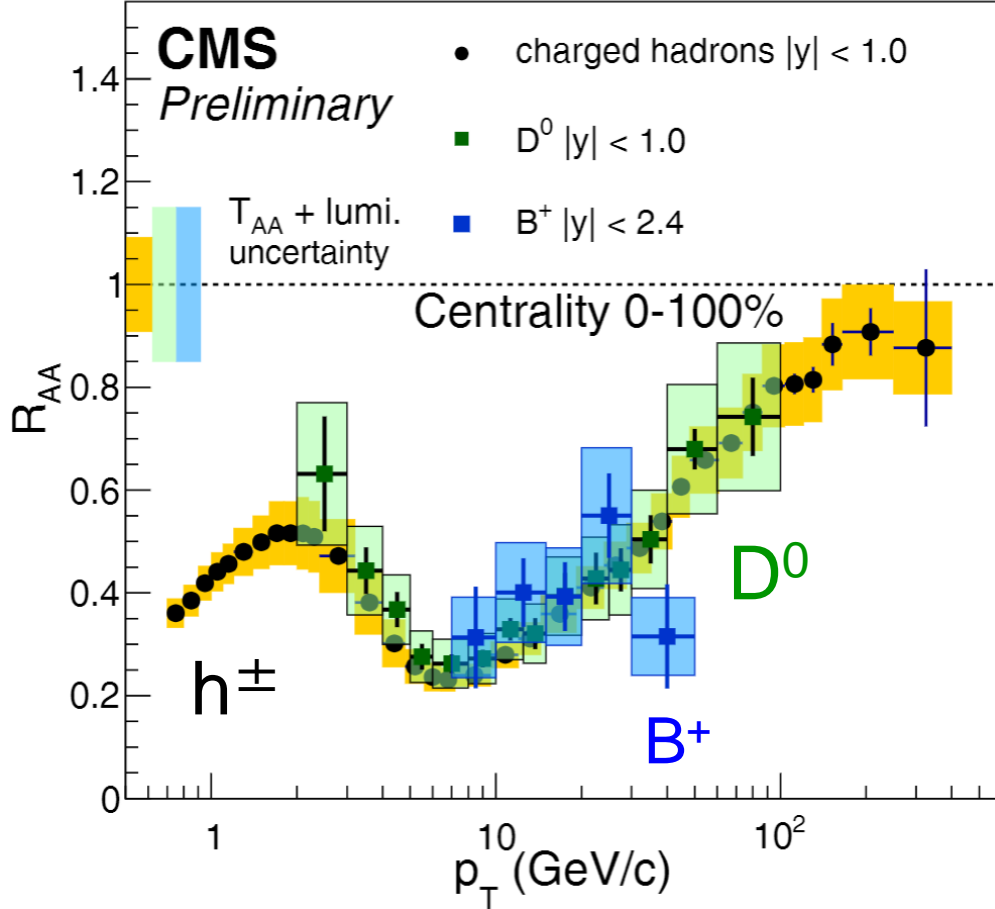
arXiv: 1611.01664
Submitted to JHEP



Flavor Dependence of Parton Energy Loss

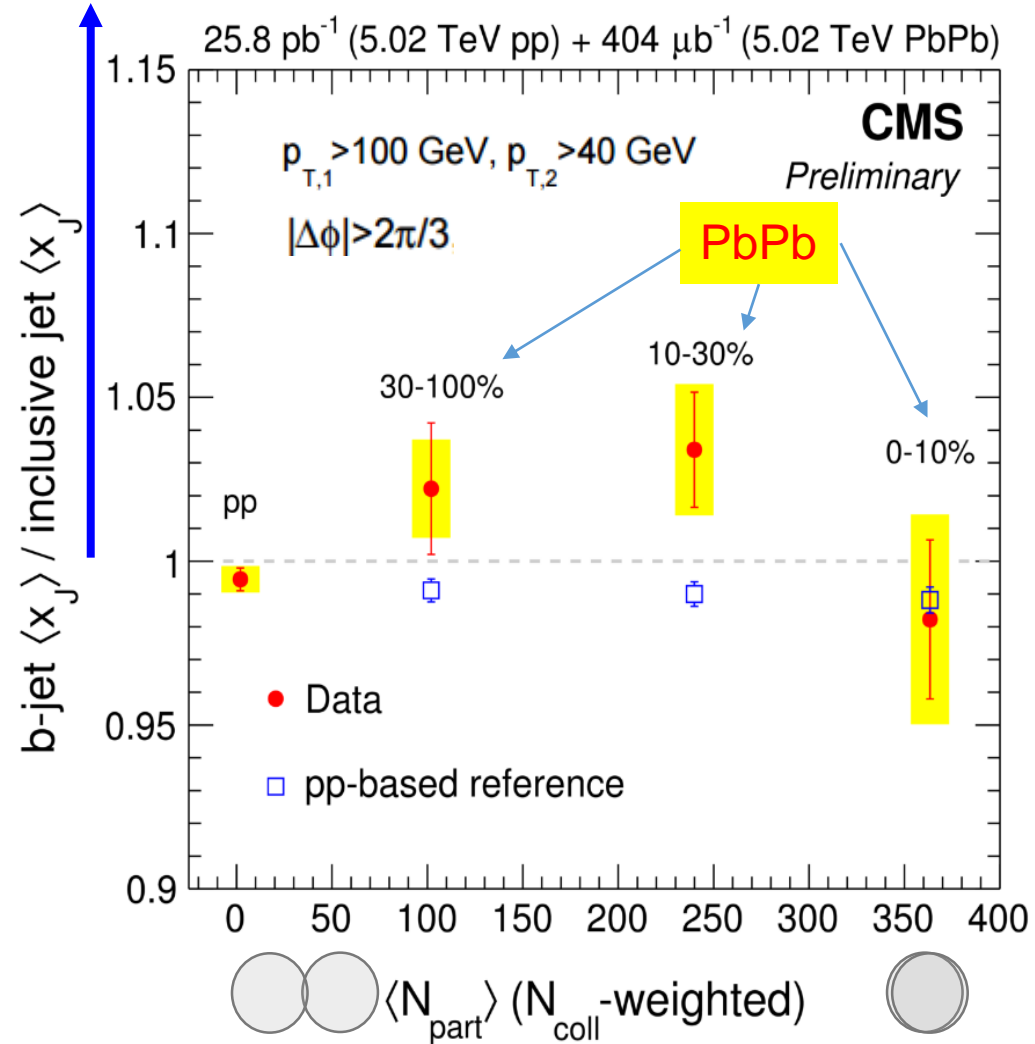
PbPb 5.02 TeV

350.68 μb^{-1} (5.02 TeV PbPb)



No flavor dependence seen

b dijet and inclusive dijet balance $x_J = p_{T,2} / p_{T,1}$
 Large double ratio if b jets are less quenched



- b dijet are not more symmetric than dijet
- **Similar b jet and inclusive jet**

D^0 CMS-PAS-HIN-16-001
 Charged hadrons
 arXiv: 1611.01664
 Submitted to JHEP

B^+ CMS-PAS-HIN-16-011

Ta-Wei Wang (Talk)
 Jing Wang (Poster)

Gian Michele Innocenti (Poster)

Kurt Jung (Talk)

B dijet CMS-PAS-HIN-16-005

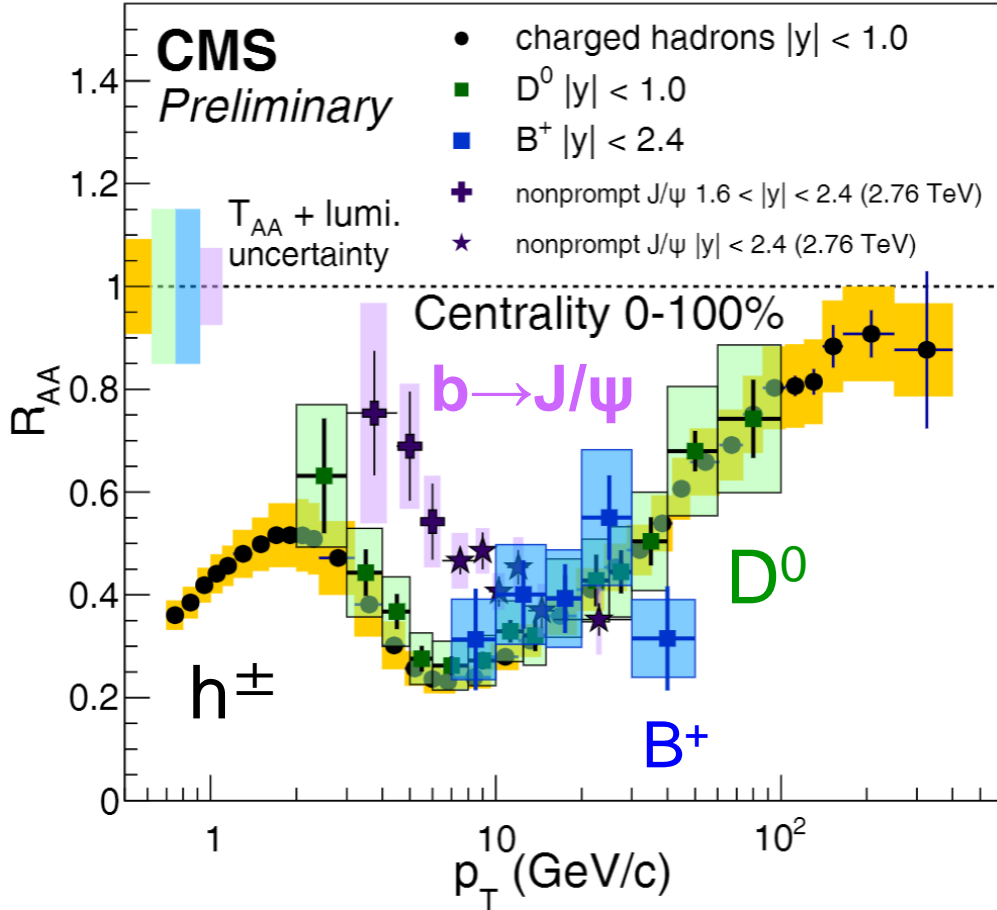
Flavor Dependence of Parton Energy Loss

PbPb 2.76, 5.02 TeV

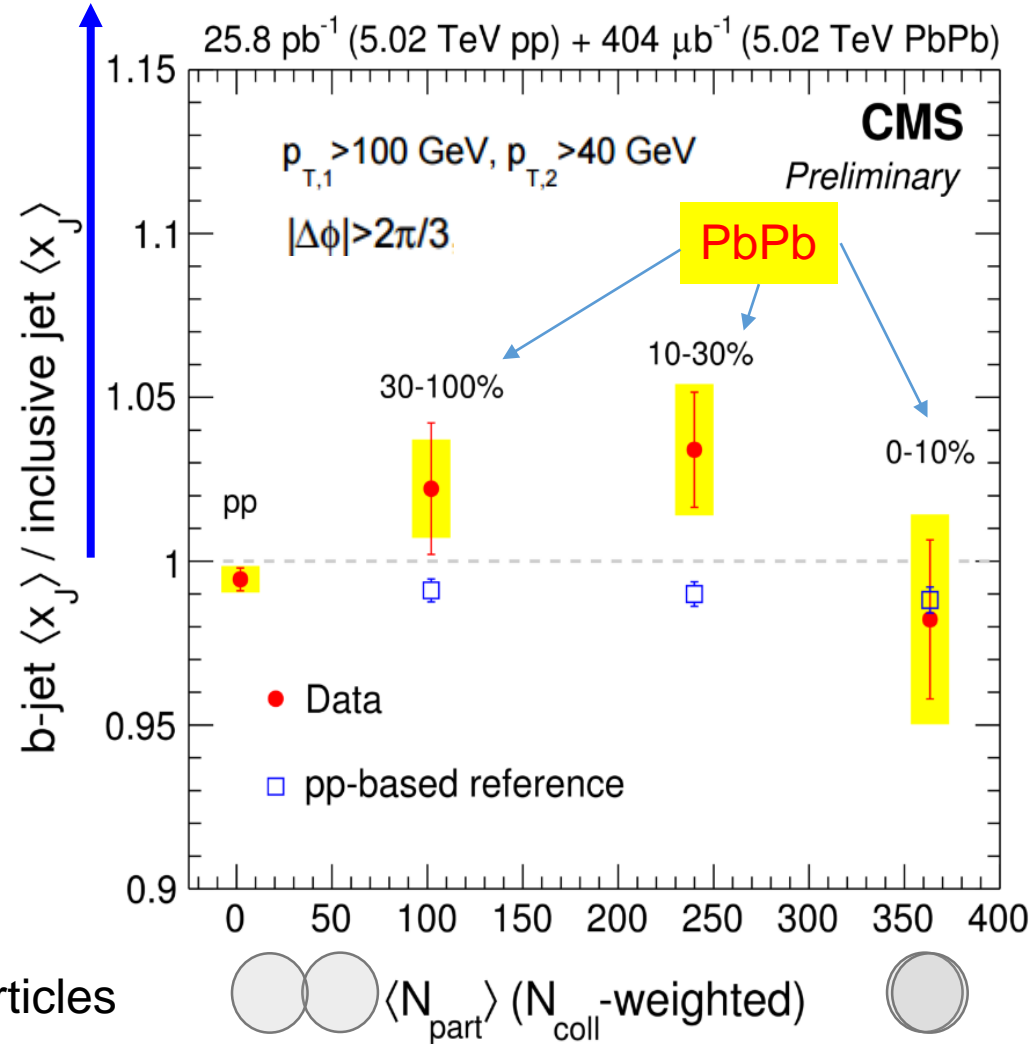
b dijet and inclusive dijet balance $x_J = p_{T,2} / p_{T,1}$

350.68 μb^{-1} (5.02 TeV PbPb)

Large double ratio if b jets are less quenched



- Appearance of the **flavor dependence** at $p_T < 10$ GeV between $b \rightarrow J/\psi$ and other particles



- b dijet are not more symmetric than dijet
- **Similar b jet quenching and inclusive jet**

Ta-Wei Wang (Talk)

Kurt Jung (Talk)

D^0 CMS-PAS-HIN-16-001

Charged hadrons
arXiv: 1611.01664
Submitted to JHEP

J/ψ arXiv: 1610.00613
Submitted to EPJC

Jing Wang (Poster)

Gian Michele Innocenti (Poster)

B dijet CMS-PAS-HIN-16-005

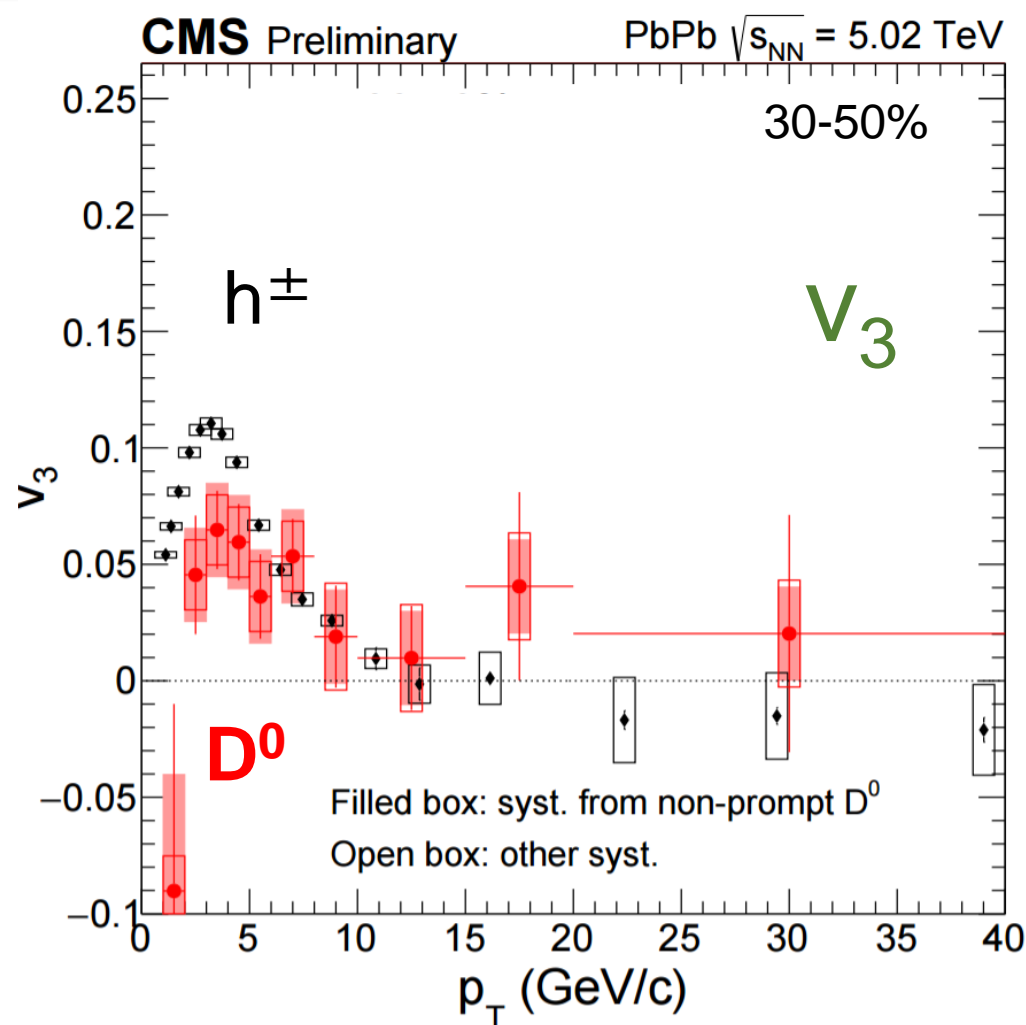
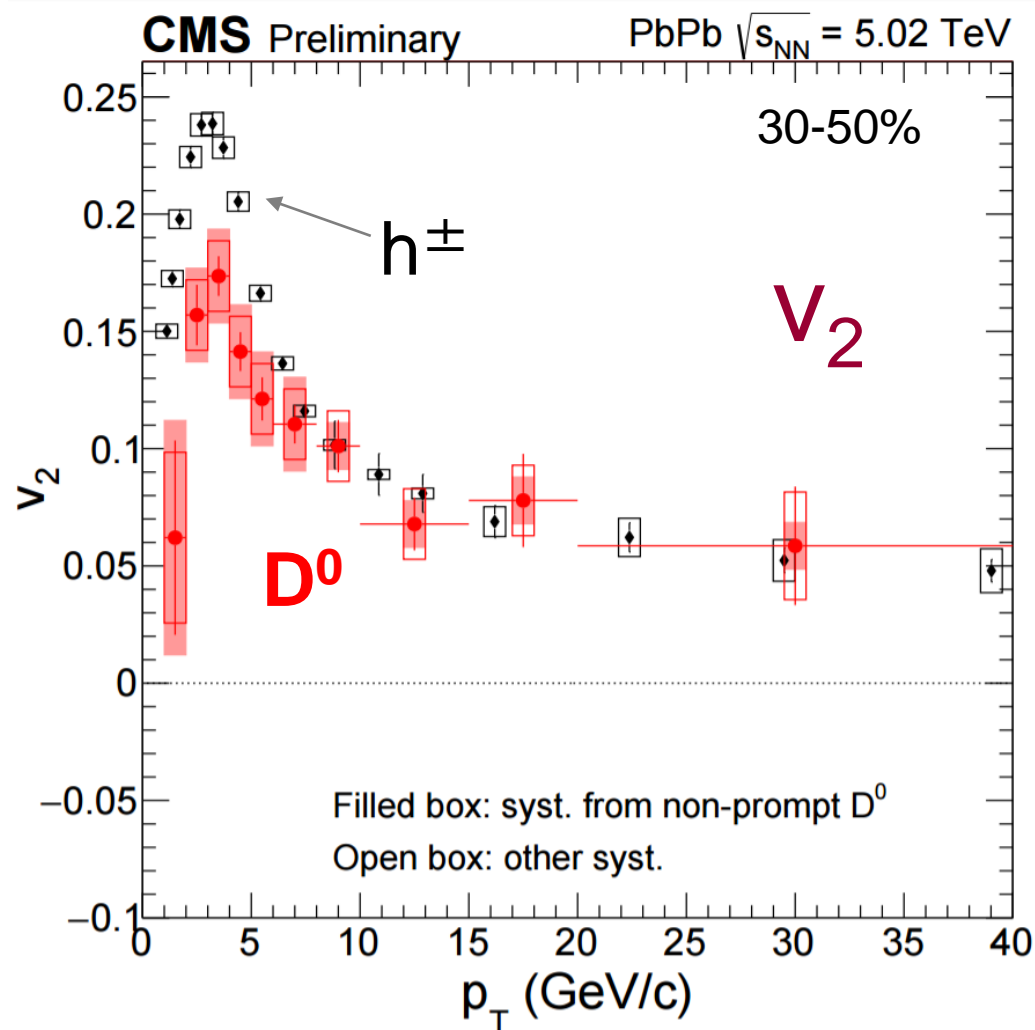
Yen-Jie Lee (MIT)

Highlights from CMS

12



The Life of Heavy Quark in the Soup



- At low p_T : $D^0 v_2$ signal is significantly lower than that of charged particles
 - At high p_T : $D^0 v_2 \approx$ **charged particle v_2** , v_3 signal consistent with 0
- Same parton energy loss picture from high $p_T D^0 R_{AA}$ and v_2 measurements

Jian Sun (Talk)

Quan Wang (Talk)

Hao Qiu (Poster)

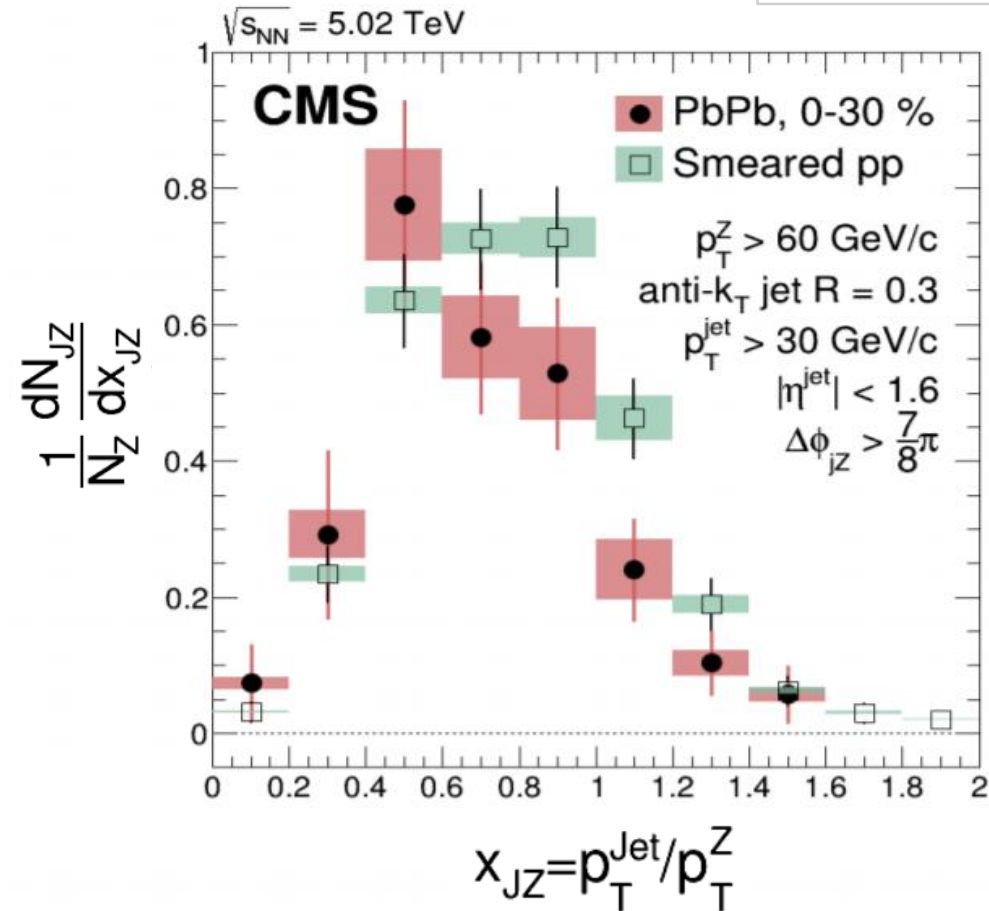
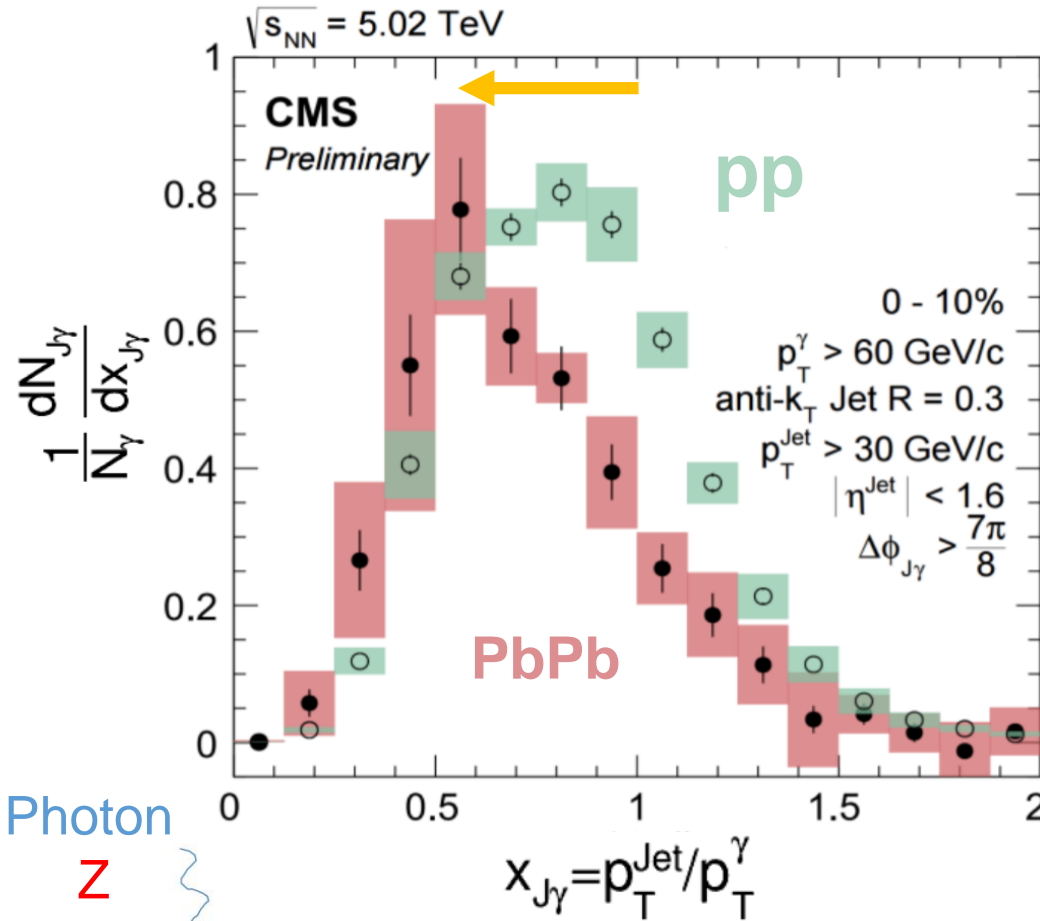
CMS-PAS-HIN-16-007

Boson-Jet Momentum Ratio in PbPb at 5 TeV

arXiv: 1702.01060
Submitted to PRL

Photon-Jet

Z-Jet

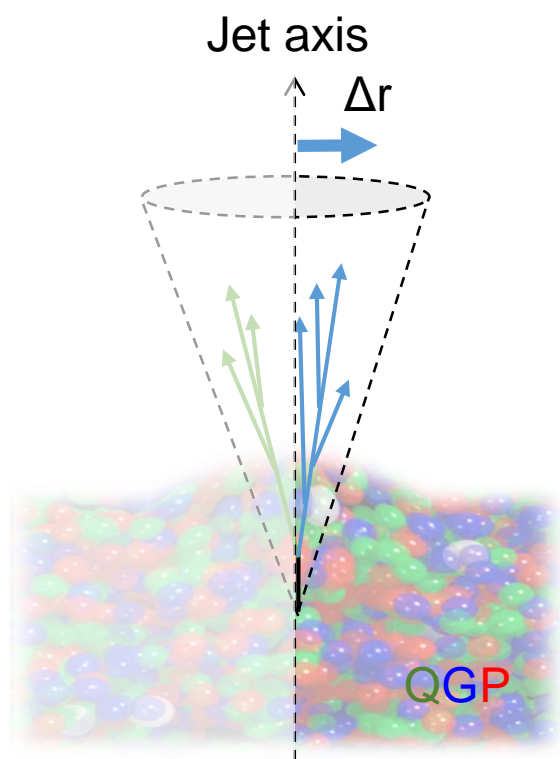


- Measured “**absolute energy loss**” (out of the jet cone) by comparing photon/Z and jet transverse momentum
- First evidence of Z-Jet momentum imbalance, consistent with results from photon-jet

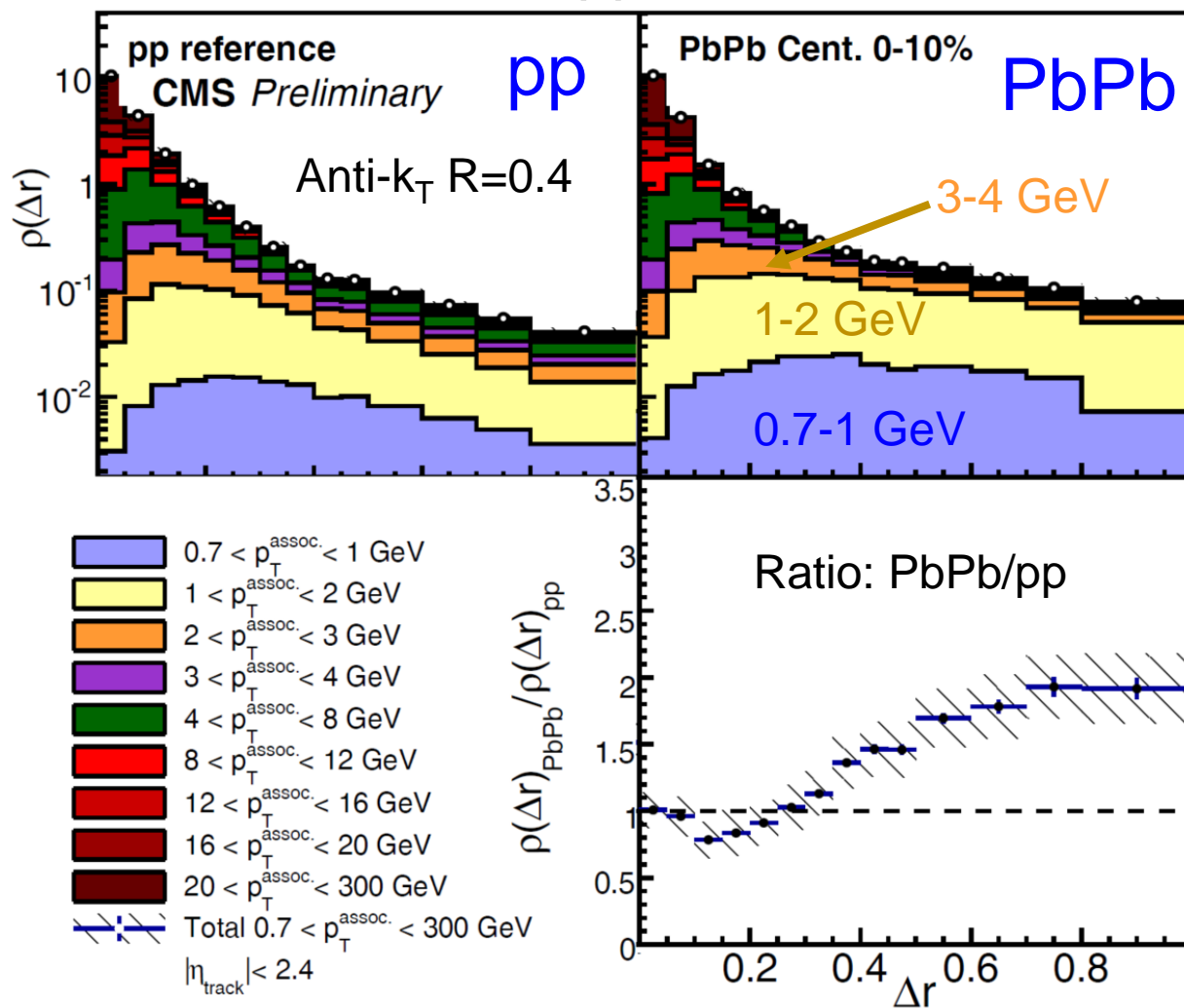
Ran Bi (Talk)

CMS-PAS-HIN-16-002

Trace the Lost Energy



Jet-Hadron Correlation in pp and PbPb at 5.02 TeV

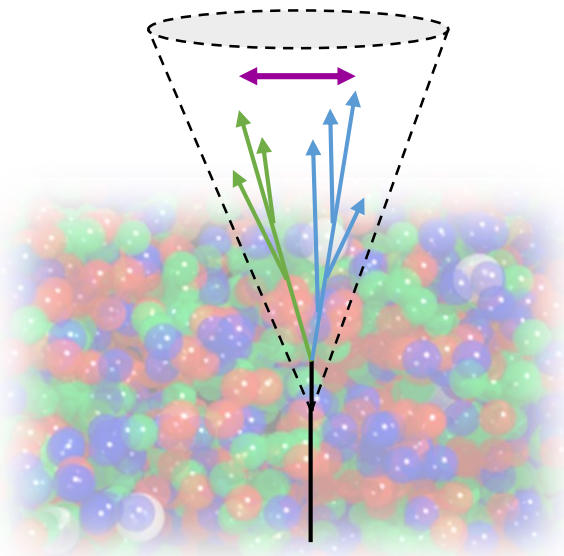


- Jet shapes and fragmentation functions in pp and PbPb collisions at 5 TeV
- Sensitive to the possible **medium response** to hard probes and **induced radiation**

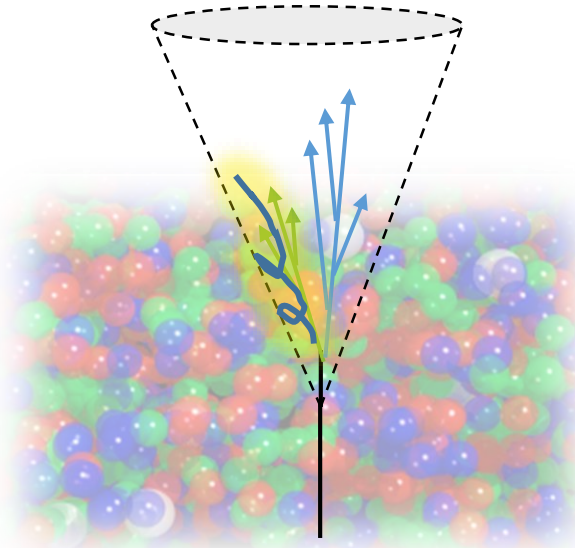
Let's Look into the Jet Substructure

Does the jet suppression depend on the shower shape?

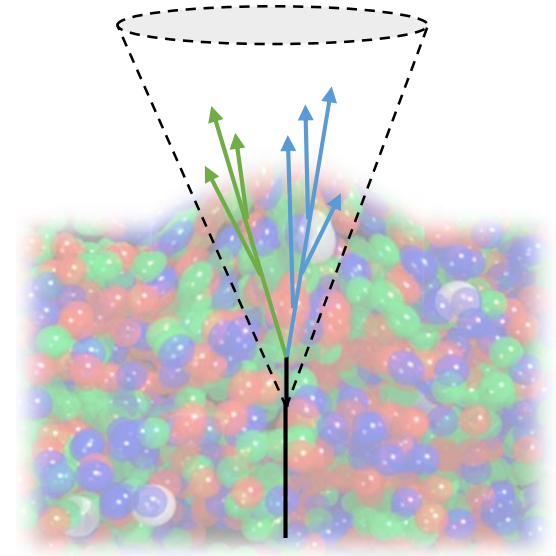
It does in the follow scenarios:



When the prongs **separated enough** so that they are seen by the QGP



Presence of **extra emission** and/or modification of parton branching in the QGP



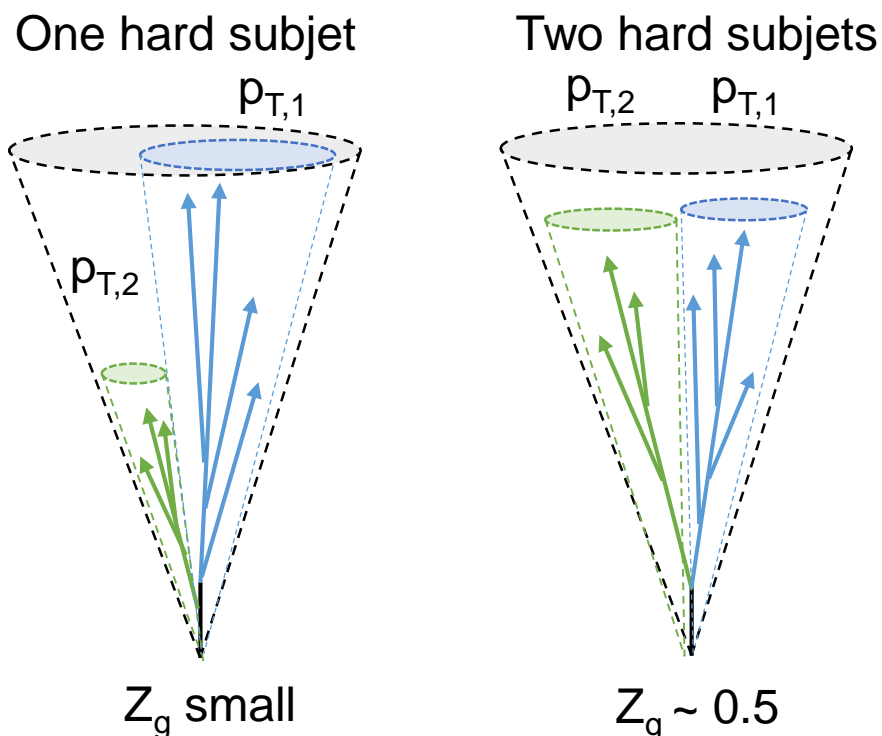
If there are **correlated background particles** with the shower in the QGP



Measure the fluctuation of jet substructure

Momentum Sharing of Subjets

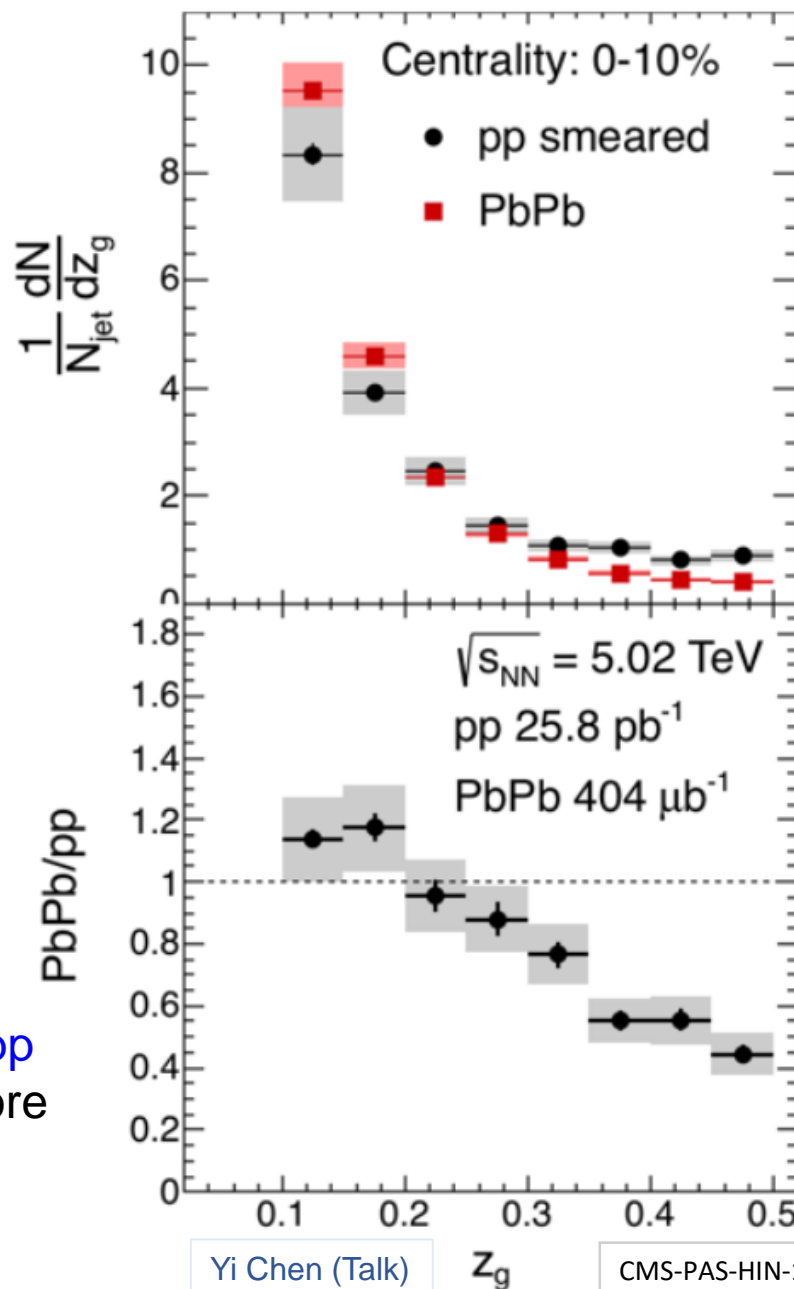
CMS-PAS-HIN-16-006



$$Z_g = \frac{p_{T,2}}{p_{T,1} + p_{T,2}}$$

- Quark and gluon Z_g distributions are very similar in pp
- Jets with two hard subjets (large Z_g) “**relatively**” more suppressed than jets with a single core (small Z_g)

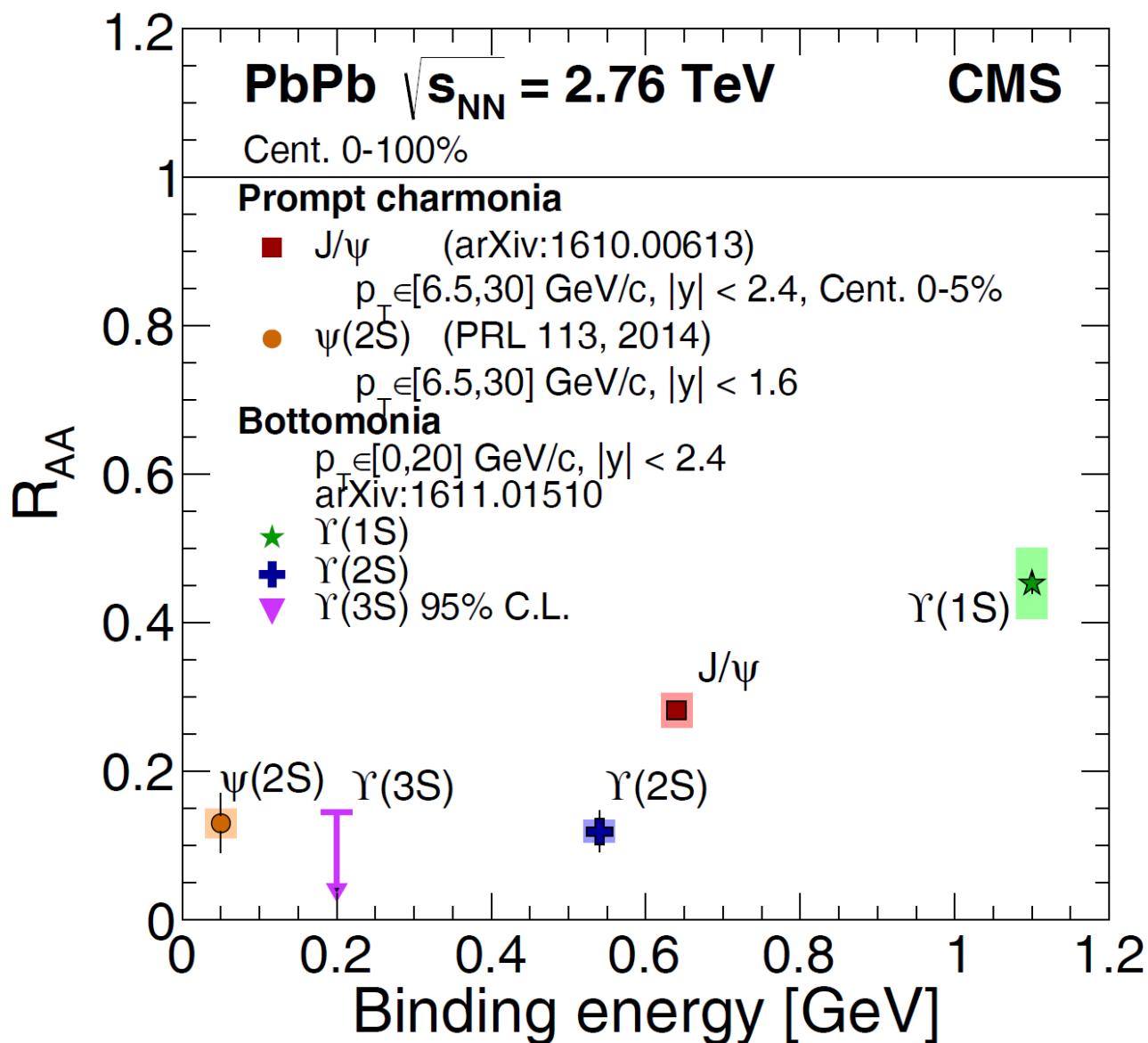
QGP “could see” the parton shower!



Yi Chen (Talk)

CMS-PAS-HIN-16-006

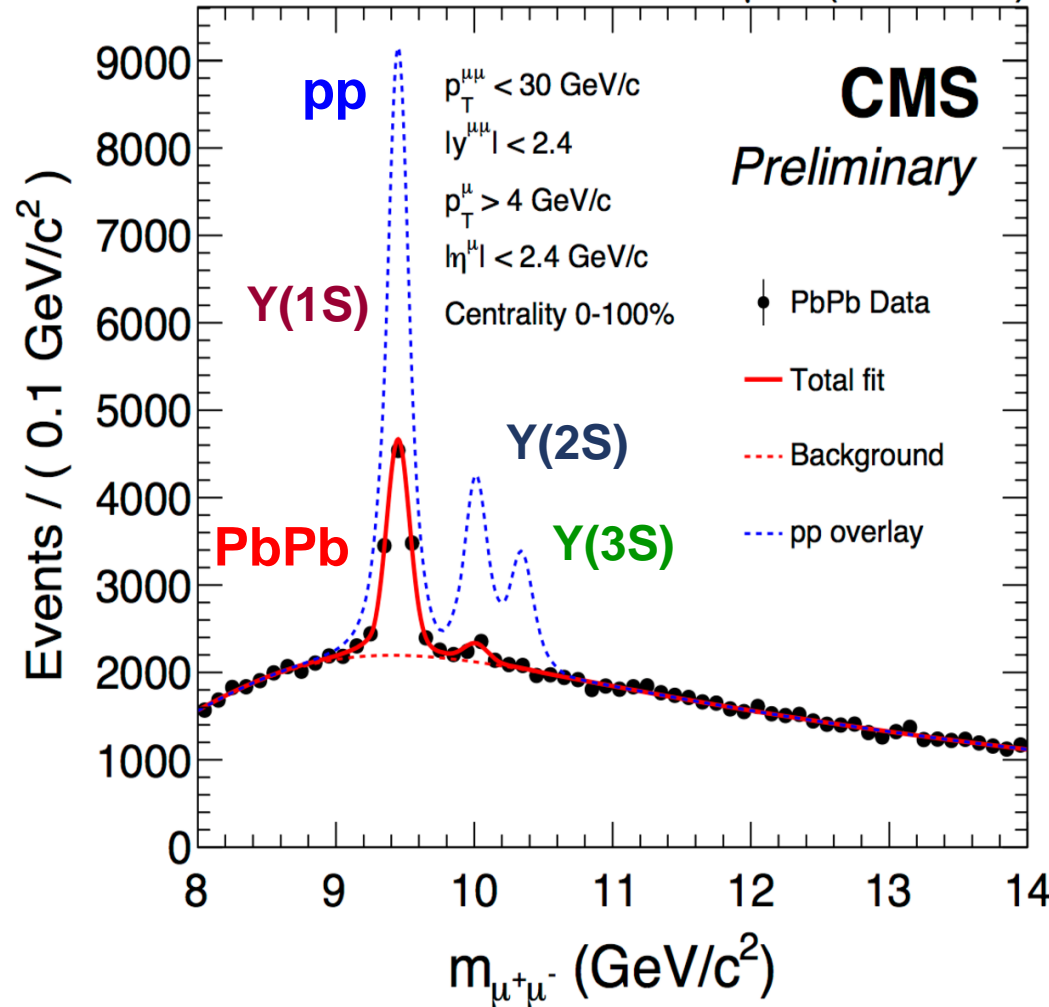
Sequential Suppression of Quarkonia



At 5 TeV: What will be the results from a **hotter** and **denser** QGP?

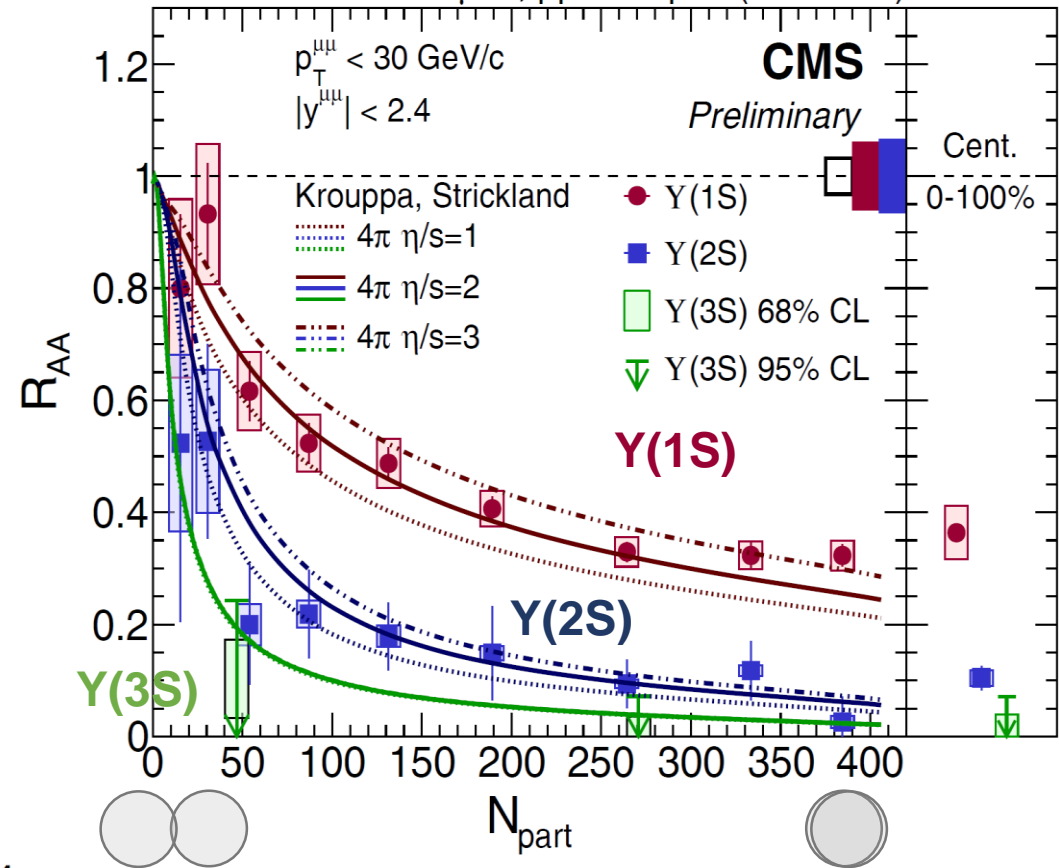
Inclusive Upsilon Sequential Suppression

PbPb 368 μb^{-1} (5.02 TeV)



PbPb at 5 TeV

PbPb 368/464 μb^{-1} , pp 28.0 pb^{-1} (5.02 TeV)



- Highest precision measurement
- Upsilon sequential suppression at 5 TeV
- Still no sign of Y(3S) with high statistics data

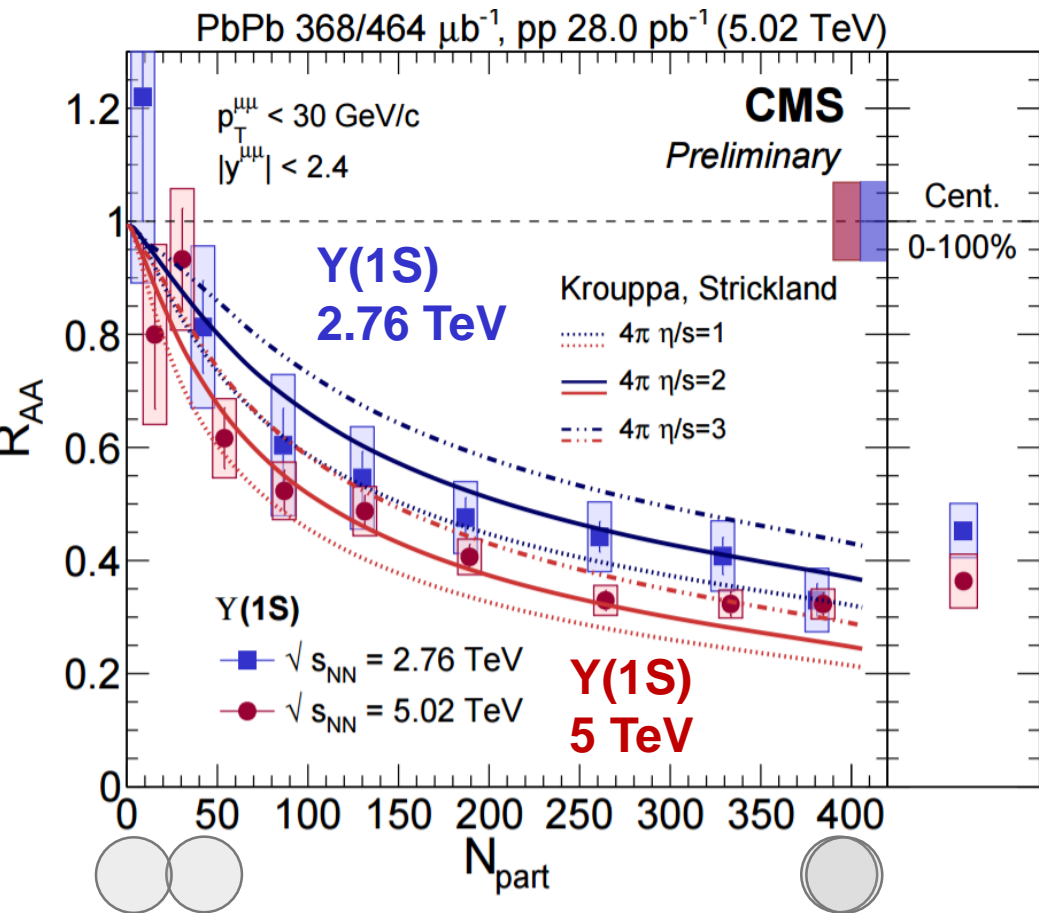
Jaebeom Park(Poster)

Chad Flores (Talk)

CMS-PAS-HIN-16-023

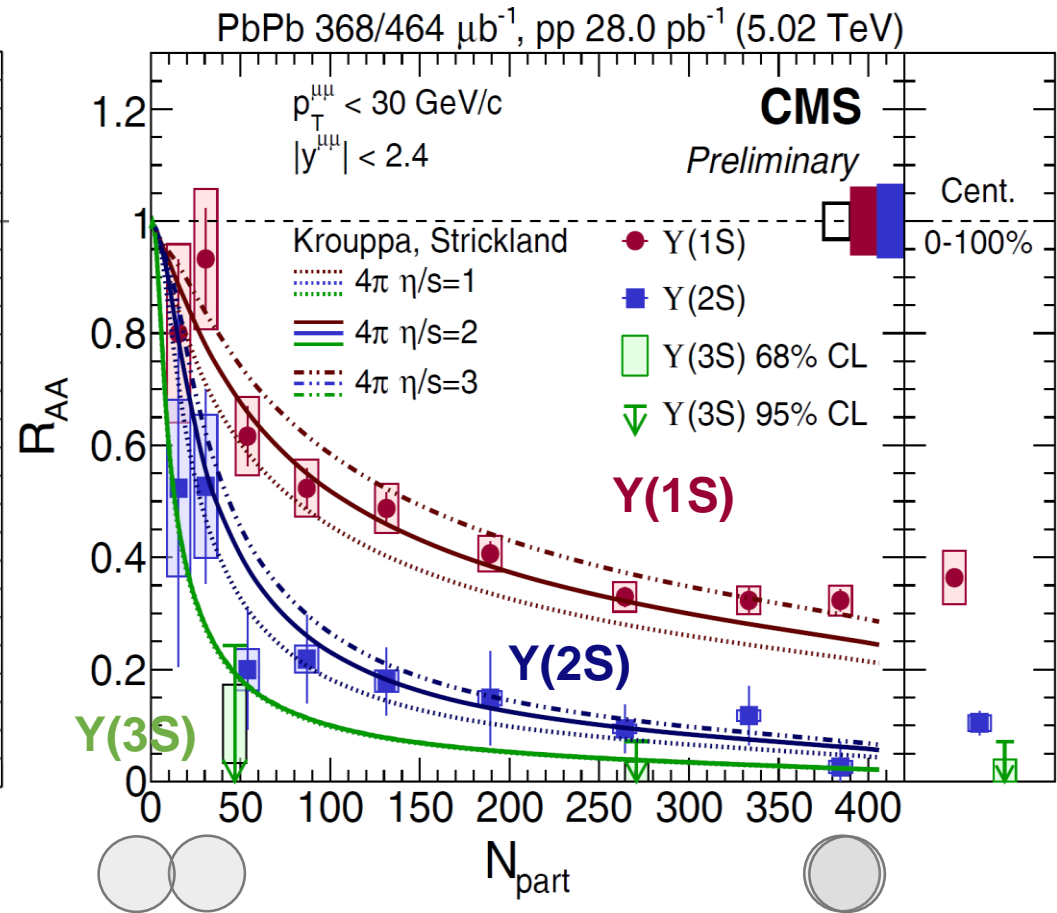
Upsilon Sequential Suppression

Y(1S) PbPb at 2.76 and 5 TeV



- Indication of larger suppression at 5 TeV
- Consistent with predictions from a **hotter** and **denser** medium

PbPb at 5 TeV



- Highest precision measurement
- Upsilon sequential suppression at 5 TeV
- Still no sign of Y(3S) with high statistics data

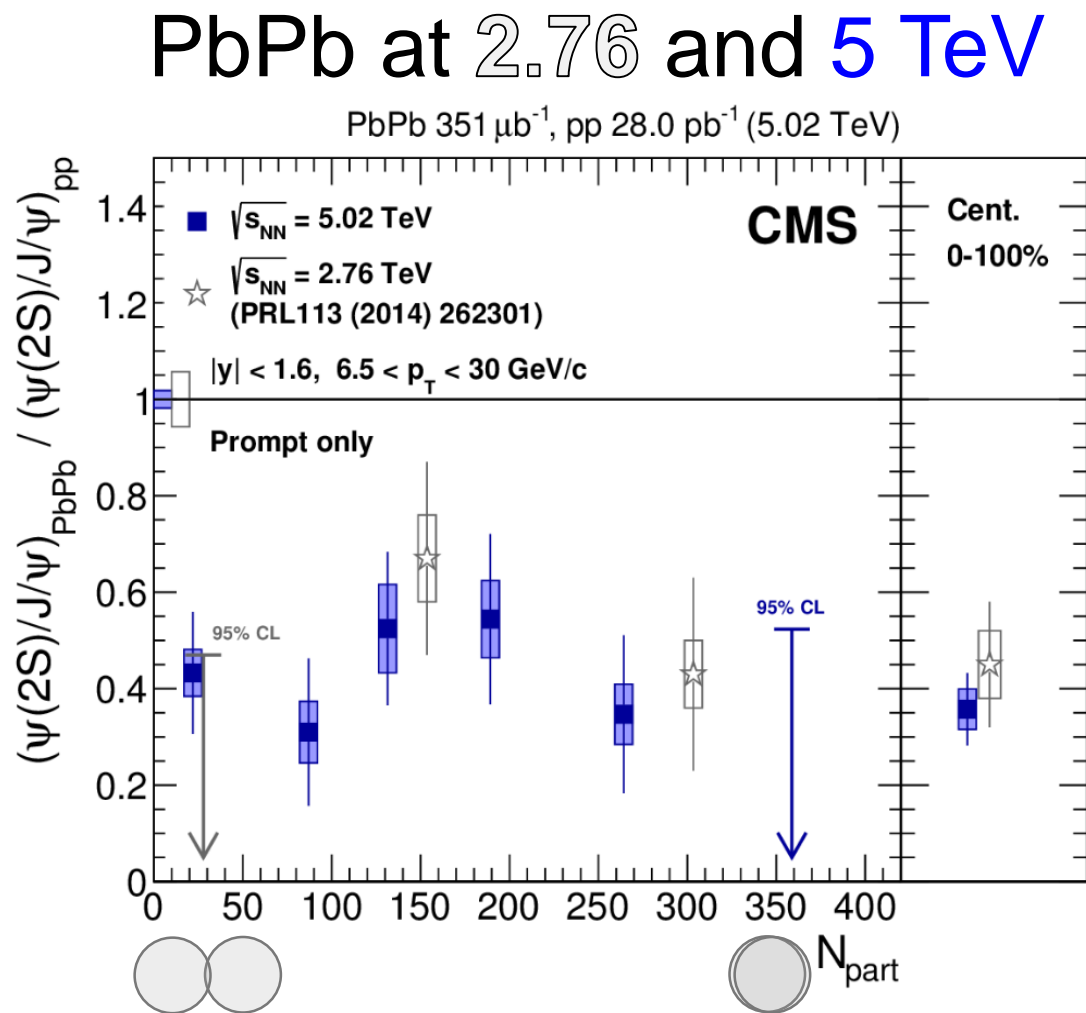
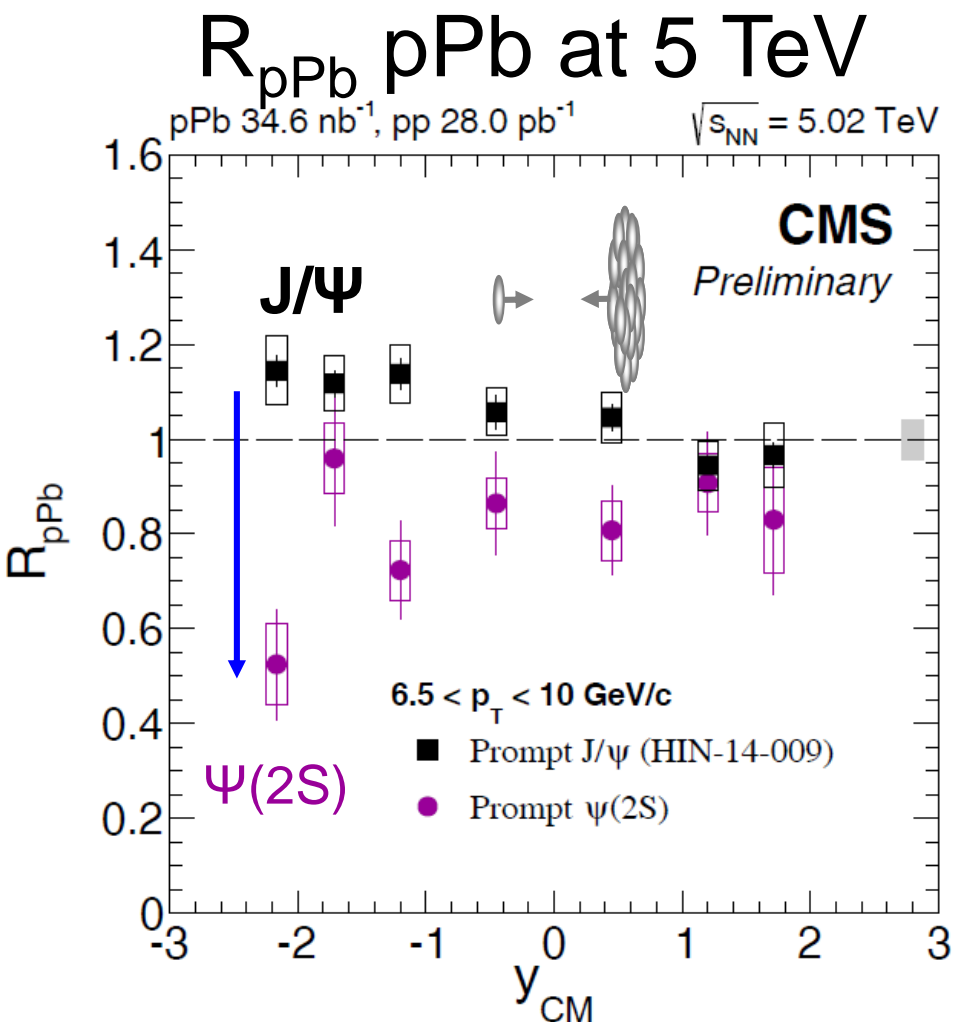
arXiv: 1611.01510
Submitted to PLB

Jaebeom Park(Poster)

Chad Flores (Talk)

CMS-PAS-HIN-16-023

Charmonia Production



- **J/ψ** and **ψ(2S)** difference increases as we move to backward (lead-going) direction (higher dN_{ch}/dy)
- Can not be explained by nPDF or coherence energy loss model
- Final state effects from comoving (local) medium?

- $R_{AA} \Psi(2S) / R_{AA} J/\Psi$**
- Prompt **ψ(2S)** is more suppressed than **J/ψ** from **5 TeV data**

Javier Blanco (Talk)

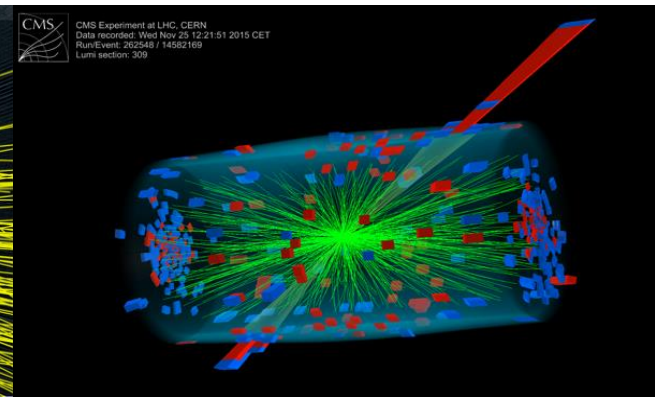
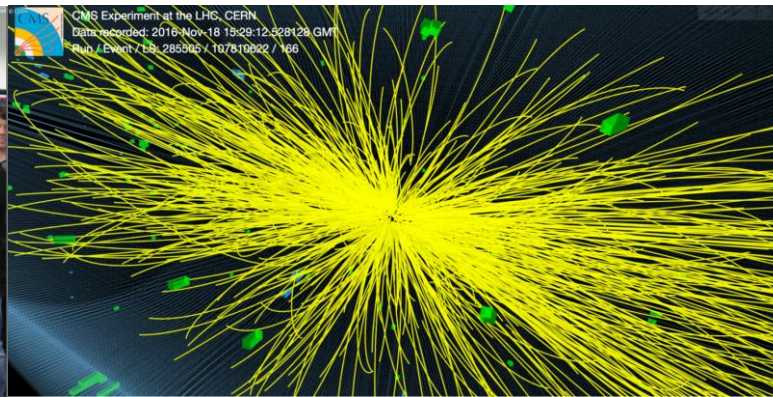
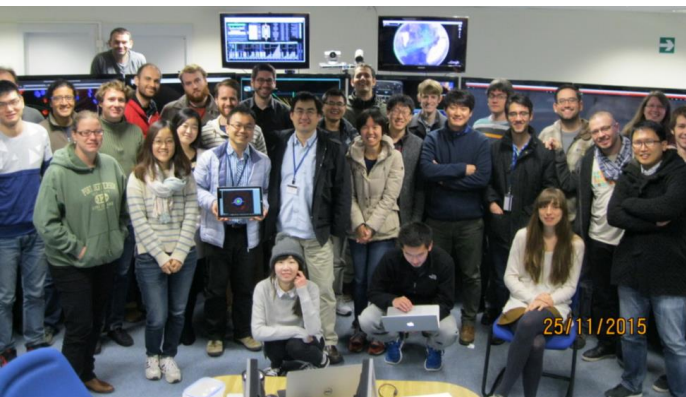
Songkyo Lee (Poster)

J/ψ R_{pA}
arXiv: 1702.01462
Submitted to EPJC

ψ(2S) R_{pA} CMS-PAS-HIN-16-015
ψ in PbPb CMS-PAS-HIN-16-004

Summary

- Very successful low pileup pp & PbPb run in 2015 / pPb run in 2016!
- Take home message from CMS:
 - Evidence of gluon (anti-)shadowing and EMC effects in Pb
 - Similarity of collective phenomena in small and large systems
 - Charge separation signal from pPb post big challenge to pure CME and CMW interpretation of the AA data
 - Precision measurement of absolute energy loss with boson-jet
 - Parton flavor and shower dependence of energy loss
 - Sequential suppression of Quarkonia and possible comover effect in $\psi(2S)$ data in pPb



Physics	QM 2017 Presentations	Talks / Posters
CME/CMW	Observation of charge-dependent azimuthal correlations in pPb and CME	Zhoudunming Tu
	Charge asymmetry dependence of elliptic and triangular flow in pPb and PbPb	Sang Park
Flow	Evidence for collective phenomena in pp	Zhenyu Chen
	Multi-particle azimuthal correlations via differential studies in high-multiplicity pPb	Maxime Guilbaud
	High pT v_n from 2- and multi-particle correlations in PbPb at 5.02 TeV	Quan Wang
	Higher-order flow harmonics and nonlinear response coefficients in PbPb	Shengquan Tuo
	Width and Skewness of Elliptic Flow Fluctuations in PbPb at 5.02 TeV	James Castle
UPC	Evidence of nuclear gluon effects in γ -Pb interactions	Daniel Takaki
	High momentum transfer of vector meson photo-production	Samuel Boren (Poster)
Heavy Flavor	D meson nuclear modification factor and v_n harmonics in PbPb at 5.02 TeV	Jian Sun
	Open beauty production and modifications in PbPb at 5.02 TeV	Ta-wei Wang
	D meson v_n harmonics in PbPb at 5.02 TeV	Hao Qiu (Poster)
	D meson nuclear modification factor in PbPb at 5.02 TeV	Jing Wang (Poster)
	B meson nuclear modification factor in PbPb at 5.02 TeV	Gian Michele Innocenti (Poster)
Jet	Jet Substructure through Splitting Functions And Mass in pp and PbPb at 5.02 TeV	Yi Chen
	Jet Structure Studies using Jet-Hadron Correlations in PbPb and pp at 5.02 TeV	Hallie Trauger
	Studies of Heavy Flavored Jets	Kurt Jung
	Jet energy loss in Boson-jet events in PbPb collisions at 5.02 TeV	Ran Bi
	Charged-particle nuclear modification factors in PbPb and pPb collisions at 5.02 TeV	Austin Baty (Poster)
Quarkonia	Bottomonia results from the LHC Run 1 and 2	Chad Flores
	$\Psi(2S)$ and J/ψ modification in pPb and PbPb collisions at 5.02 TeV	Javier Blanco
	$\Psi(2S)$ and J/ψ production in pPb collisions at 5.02 TeV	Songkyo Lee (Poster)
	Quarkonia production and polarization in pp	Charles Ferraioli (Poster)
	Statistical approach for the calculation for upper limit of $Y(3S)$ yield	Jaebeom Park (Poster)



Backup slides

