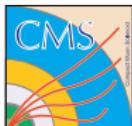


Overview of recent CMS results

Émilien Chapon

Laboratoire Leprince-Ringuet, École polytechnique, Palaiseau

Rencontre QGP France
Étretat, Oct 10-12, 2016



CMS HIN France: LLR

François Arleo	perm.
Raphaël Granier de Cassagnac	perm.
Matthew Nguyen	perm.
Abdulla Abdulsam	postdoc
Émilien Chapon	postdoc
Mihee Jo	postdoc
Javier Martin Blanco	postdoc
Yetkin Yilmaz	postdoc
Stanislas Lisniak	PhD student
André Ståhl	PhD student



CMS HIN France: LLR

François Arleo	perm.	theo, onia
Raphaël Granier de Cassagnac	perm.	onia
Matthew Nguyen	perm.	jets
Abdulla Abdulsam	postdoc	onia
Émilien Chapon	postdoc	onia
Mihee Jo	postdoc	onia
Javier Martin Blanco	postdoc	onia
Yetkin Yilmaz	postdoc	jets
Stanislas Lisniak	PhD student	jets
André Ståhl	PhD student	onia



CMS HIN France: LLR

François Arleo	perm.	theo, onia	
Raphaël Granier de Cassagnac	perm.	onia	
Matthew Nguyen	perm.	jets	
Abdulla Abdulsam	postdoc	onia	in
Émilien Chapon	postdoc	onia	out
Mihee Jo	postdoc	onia	
Javier Martin Blanco	postdoc	onia	in
Yetkin Yilmaz	postdoc	jets	out
Stanislas Lisniak	PhD student	jets	out
André Ståhl	PhD student	onia	



CMS HIN France: LLR

François Arleo	perm.	theo, onia		HP, Étretat
Raphaël Granier de Cassagnac	perm.	onia		Leiden
Matthew Nguyen	perm.	jets		HP, Leiden
Abdulla Abdulsam	postdoc	onia	in	Étretat
Émilien Chapon	postdoc	onia	out	HP, Étretat
Mihee Jo	postdoc	onia		HP, Leiden
Javier Martin Blanco	postdoc	onia	in	Étretat
Yetkin Yilmaz	postdoc	jets	out	Étretat
Stanislas Lisniak	PhD student	jets	out	
André Ståhl	PhD student	onia		Étretat



New CMS HIN papers since QGP France '15

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

Heavy-Ion Physics Publications			
50	HIN-14-005	Suppression and azimuthal anisotropy of prompt and nonprompt J/ ψ production in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV	Submitted to EPJC Run1 J/ ψ 3 October 2016
49	HIN-16-009	Observation of charge-dependent azimuthal correlations in pPb collisions and its implication for the search for the chiral magnetic effect	Submitted to PRL 1 October 2016
48	HIN-13-005	Measurement of inclusive jet cross sections in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV	Submitted to PRC 17 September 2016
47	HIN-15-011	Decomposing transverse momentum balance contributions for quenched jets in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV	Submitted to JHEP 8 September 2016
46	HIN-16-010	Evidence for collectivity in pp collisions at the LHC	Submitted to PLB 20 June 2016
45	HIN-12-009	Coherent J/ ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the CMS experiment	Submitted to PLB 23 May 2016
44	HIN-15-006	Multiplicity and rapidity dependence of strange hadron production in pp, pPb, and PbPb collisions at the LHC	Submitted to PLB 22 May 2016
43	HIN-14-009	Pseudorapidity dependence of long-range two-particle correlations in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	Submitted to PRC 18 April 2016
42	HIN-15-003	T(nS) polarizations versus particle multiplicity in pp collisions at $\sqrt{s} = 7$ TeV	PLB 761 (2016) 31 9 March 2016
41	HIN-14-001	Measurement of inclusive jet production and nuclear modifications in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	EPJC 76 (2016) 372 8 January 2016
40	HIN-14-016	Correlations between jets and charged particles in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV	JHEP 02 (2016) 156 1 January 2016
39	HIN-15-002	Study of Z boson production in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	PLB 759 (2016) 36 20 December 2015
38	HIN-14-007	Transverse momentum spectra of b jets in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	PLB 754 (2016) 59 12 October 2015
37	HIN-14-010	Measurement of transverse momentum relative to dijet systems in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV	JHEP 01 (2016) 008 30 September 2015

+ (in the next month): Run1 Υ R_{AA} (Nicolas F.'s thesis), Run2 ψ double ratios



New CMS HIN preliminary results since QGP France '15

Recent Heavy-Ion Physics Preliminary Results

CMS-PAS-HIN-16-008	Strong suppression of T excited states in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	September 2016
CMS-PAS-HIN-16-011	Study of B^+ meson production in pp and PbPb collisions at $\sqrt{s_{\text{cm}}} = 5.02$ TeV using exclusive hadronic decays	September 2016
CMS-PAS-HIN-16-024	Relative modification of prompt $\psi(2S)$ and J/ψ yields from pp to PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	September 2016
CMS-PAS-HIN-16-002	Study of isolated-photon+jet correlations in PbPb and pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV	September 2016
CMS-PAS-HIN-16-007	D^0 meson v_h harmonics in PbPb collisions at 5.02 TeV	September 2016
CMS-HIN-15-005	Measurement of inclusive jet cross sections in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV	Submitted to PRC
CMS-PAS-HIN-16-005	Transverse momentum balance of b-jet pairs in pp and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	17 September 2016
CMS-PAS-HIN-16-003	Dijet pseudorapidity in pp and pPb collisions at $\sqrt{s_{\text{cm}}} = 5.02$ TeV with the CMS detector	July 2016
CMS-PAS-HIN-16-006	Splitting function in pp and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	July 2016
CMS-PAS-HIN-15-001	D^0 meson nuclear modification factor in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	June 2016
CMS-PAS-HIN-15-014	High-pT track v_h harmonics in PbPb collisions at 5.02 TeV	May 2016
CMS-PAS-HIN-15-013	Study of Z+jet correlations in PbPb and pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV	May 2016
CMS-PAS-HIN-15-015	Measurement of the charged particle nuclear modification factor in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	May 2016
CMS-PAS-HIN-16-010	Observation of particle-species dependence and collectivity in azimuthal correlations of pp collisions at the LHC	Submitted to PLB
CMS-PAS-HIN-15-006	Multiplicity and rapidity dependence of strange hadron spectra in pp, pPb, and PbPb collisions at LHC energies	Submitted to PLB
CMS-PAS-HIN-15-009	Azimuthal anisotropy harmonics from long-range correlations in high multiplicity pp collisions at $\sqrt{s} = 7$ TeV	October 2015
CMS-PAS-HIN-14-014	Centrality and pseudorapidity dependence of transverse energy flow in pPb collisions at $\sqrt{s_{\text{cm}}} = 5.02$ TeV	September 2015
CMS-PAS-HIN-15-012	Charm-tagged jet production in pPb collisions at 5.02 TeV and pp collisions at 2.76 TeV	September 2015
CMS-PAS-HIN-15-011	Decomposing energy balance contributions for quenched jets in PbPb versus pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV	Submitted to JHEP
CMS-PAS-HIN-15-008	Differential flow harmonic v_h in pPb and PbPb collisions	September 2015
CMS-PAS-HIN-15-005	Nuclear modification factor of prompt D^0 in PbPb collisions at $\sqrt{s_{\text{cm}}} = 2.76$ TeV	September 2015
CMS-PAS-HIN-15-010	Principal component analysis of two-particle azimuthal correlations in PbPb and pPb collisions at CMS	September 2015

Run2 $\psi(2S)$

Run2 di-bjets



MR

Heavy-ion datasets

Year	System	$\sqrt{s_{NN}}$ [TeV]	Luminosity (CMS)	$\text{Lumi.} \times A^{(2)}$
2010	PbPb	2.76	$7 \mu\text{b}^{-1}$	303 nb^{-1}
2011	pp	2.76	230 nb^{-1}	230 nb^{-1}
2011	PbPb	2.76	$150 \mu\text{b}^{-1}$	6.5 pb^{-1}
2013	pPb	5.02	30 nb^{-1}	6.2 pb^{-1}
2013	pp	2.76	5 pb^{-1}	5 pb^{-1}
2015	pp	5.02	28 pb^{-1}	28 pb^{-1}
2015	PbPb	5.02	$550 \mu\text{b}^{-1}$	24 pb^{-1}
2016	pPb	5.02	≈ 0	≈ 0
2016	pPb	8	$\sim 100 \text{ nb}^{-1}?$	$\sim 20 \text{ pb}^{-1}?$

- Equivalent yield of N_{coll} scaled hard probes between PbPb and corresponding pp reference.
- $20 \times$ more PbPb data in 2011 than 2010.
- $\sim (3 - 5) \times$ more data in 2015.



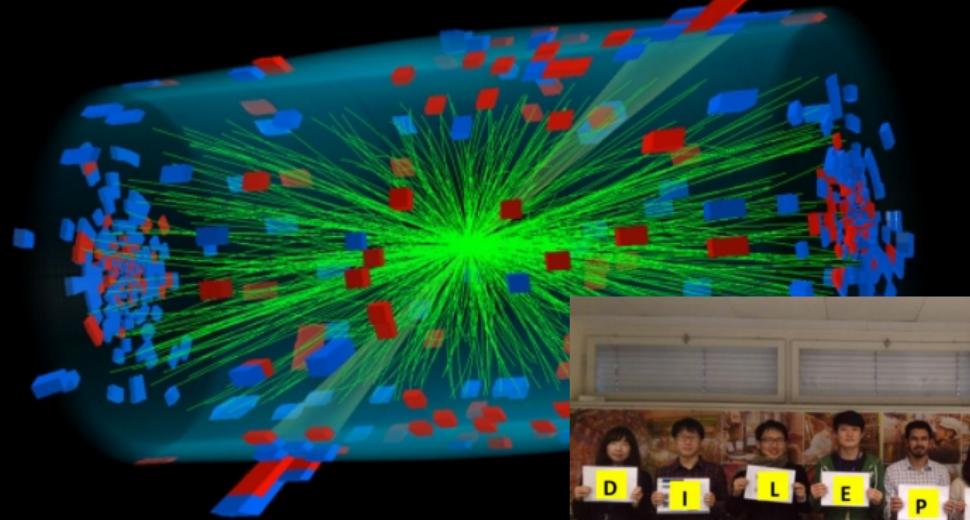
LLR



Very successful heavy ion run at 5 TeV

Recorded luminosity

$\text{pp } 28 \text{ pb}^{-1}$
 $\text{PbPb } 550 \mu\text{b}^{-1}$





Very successful heavy ion run at 5 TeV

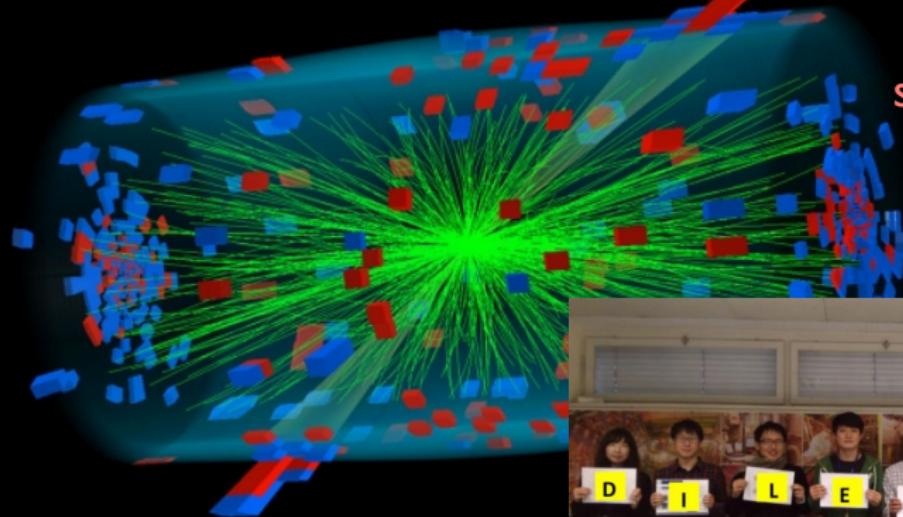
Recorded luminosity

$\text{pp } 28 \text{ pb}^{-1}$

Larger luminosity

$\text{PbPb } 550 \mu\text{b}^{-1}$

Cross section for hard probes is larger



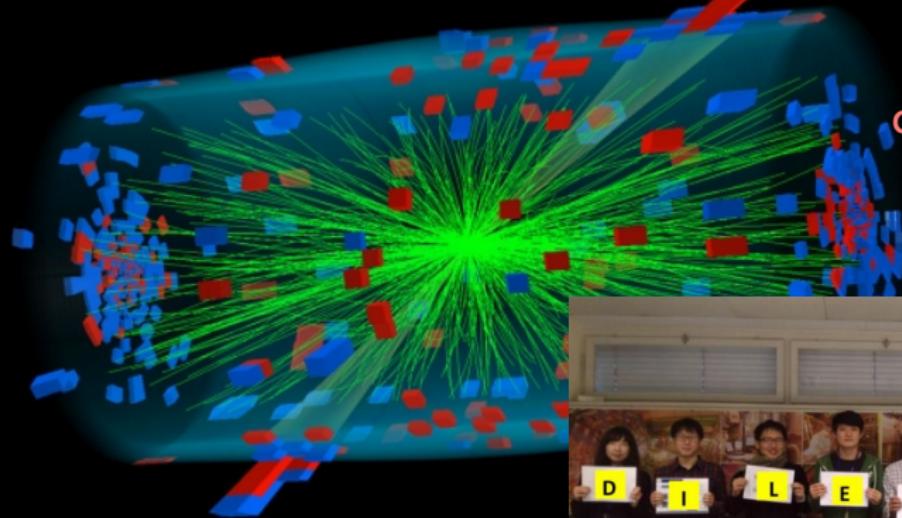
Increased statistics to study rare probes





Very successful heavy ion run at 5 TeV

Reference for
2013 pPb data at same sNN → *Recorded luminosity*
 $\bar{pp} \text{ } 28 \text{ } pb^{-1}$
 $\text{PbPb } 550 \text{ } \mu b^{-1}$



Verify the conclusions from pPb



Triggering in PbPb

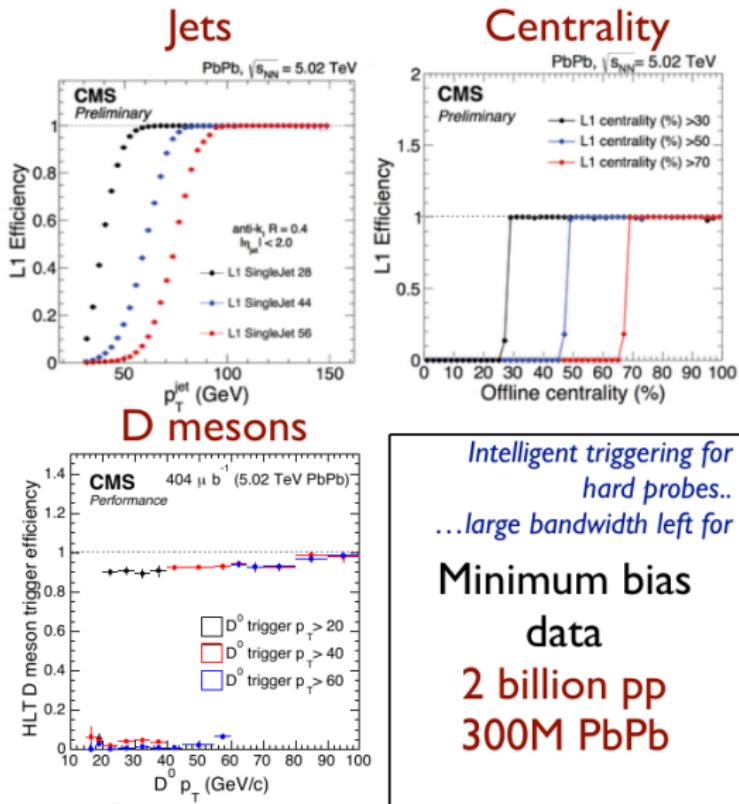
Level 1

Heavy ion specific

- **Jets with UE subtraction:** large statistics of low p_T jets but reasonable bandwidth
- **Centrality:** comparable statistics for peripheral and central events

HLT

- Global track reconstruction
- Online reconstruction of rare probes
 - b-jets, high p_T tracks, D mesons...



Intelligent triggering for
hard probes..
...large bandwidth left for

Minimum bias
data

2 billion pp
300M PbPb

Outline

- ① nPDF
- ② Light flavour
- ③ Hidden heavy flavour: quarkonia
- ④ Heavy flavour



nPDF

nPDF



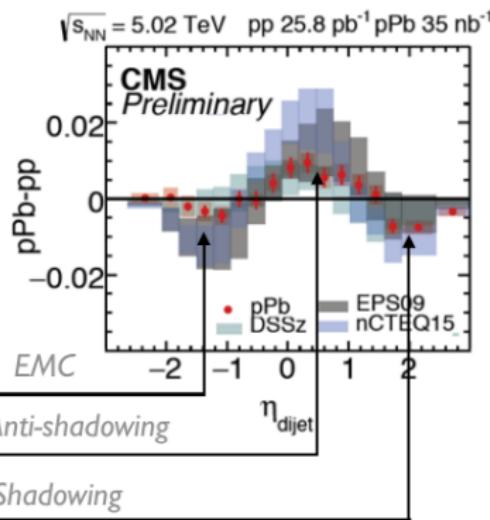
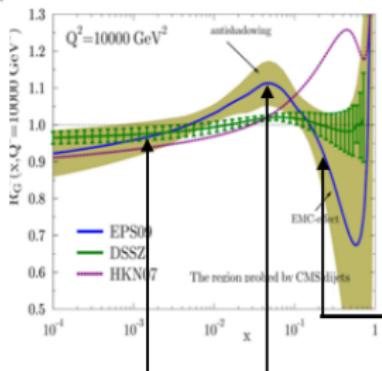
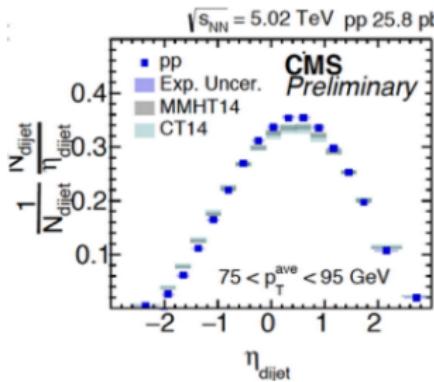
LLR

Dijets and EWK bosons in pPb



$$\eta_{\text{dijet}} = (\eta_1 + \eta_2)/2 \approx 0.5 \log(x_1/x_2)$$

CMS-PAS-HIN-16-003



Dijets in pPb (NEW)

Update using the 5 TeV pp reference

- Disagreement between pp ref. and NLO
- Sensitivity to shadowing, anti-shadowing and EMC regions

W and Z bosons

- Quark nPDFs
- Asymmetries (forward-backward, lepton charge)



Light flavour

Light flavour

Higher and higher p_T

- Do quenching effects sustain at very high p_T ?
- Suppression, path length dependence and inner structure modifications

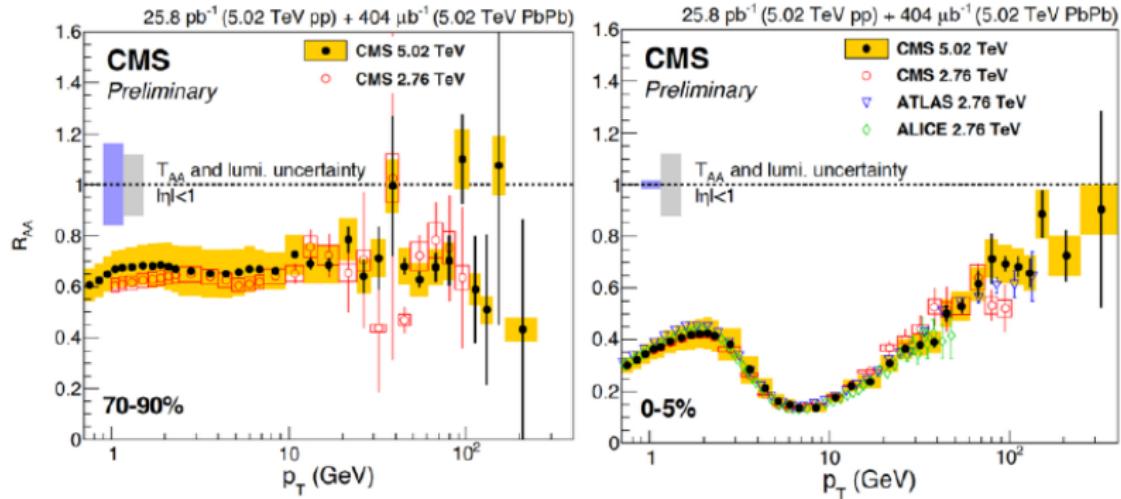
Boson-jet studies

- What is the absolute E_{loss} and how does it occur?
- What are the characteristics of the medium?



Charged hadrons suppression

CMS-PAS-HIN-15-015



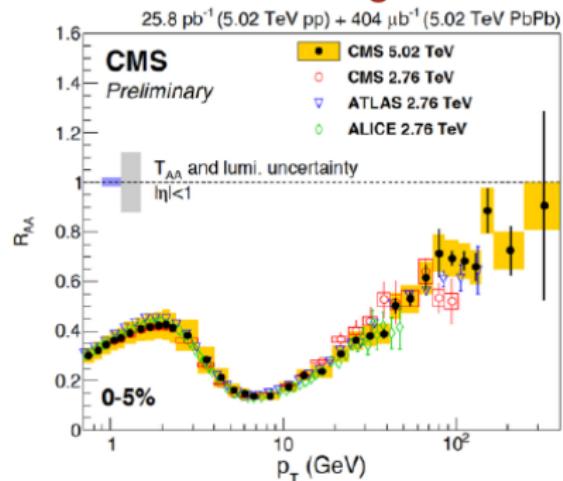
- Energy loss at high p_T
 - Rising trend as a function of p_T up to 400 GeV → approaching 1
- Center of mass energy dependence
 - Slightly larger E_{loss} → higher T and density



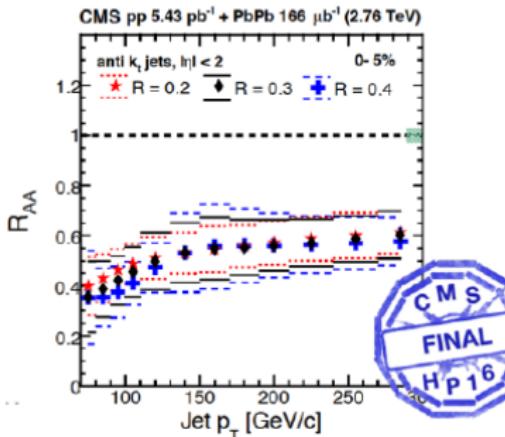
Charged hadrons vs jets at high p_T

CMS-PAS-HIN-15-015, arXiv:1609.05383

2.76 and 5 TeV charged hadrons



2.76 TeV jets



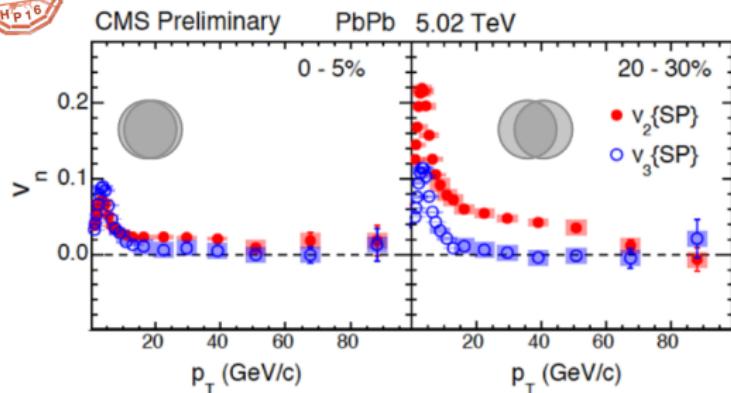
- Charged hadrons at high $p_T \rightarrow$ hard fragmenting high p_T jets
 - Center of mass energy is different but change is expected to be small
 - High p_T tracks are less suppressed than jets



LLR

Charged hadrons: flow coefficients

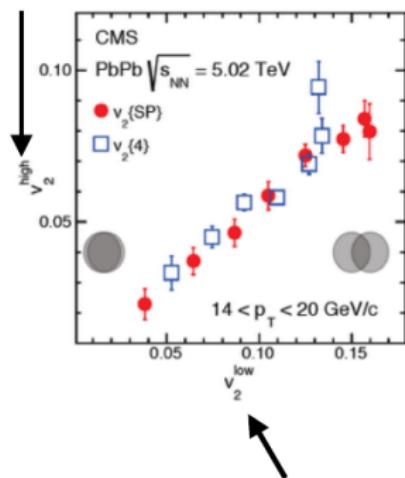
CMS-PAS-HIN-15-014



Together with R_{AA} provides additional constraints on models

- Low p_T
 - v_3 has little centrality dependence
- High p_T
 - non-zero v_2 up to 60 GeV → path length dependence of E_{loss}
 - $v_3 = 0 \rightarrow ?$

14-20 GeV



1-1.25 GeV

- Low and high p_T correlation
 - What is the origin of high p_T v_2 ?

LLR



Splitting function: inner jet structure

CMS-PAS-HIN-16-006

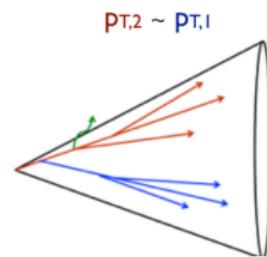
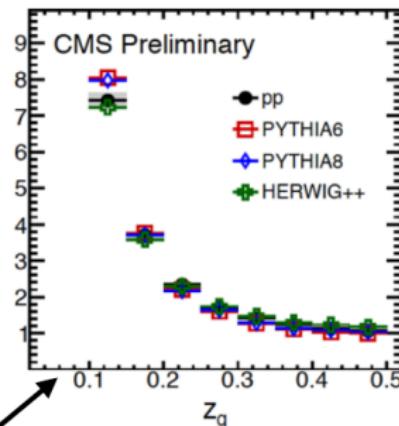
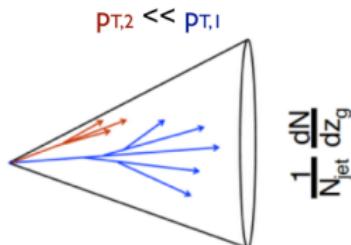


Fraction of energy carried by the low p_T subjet

- Jets with two subjets that are well separated in angle
- $\Delta R_{12} > 0.1 \rightarrow$ wide jets

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

pp



Most jets fall below
the 0.1 threshold



LLR

Splitting function: inner jet structure

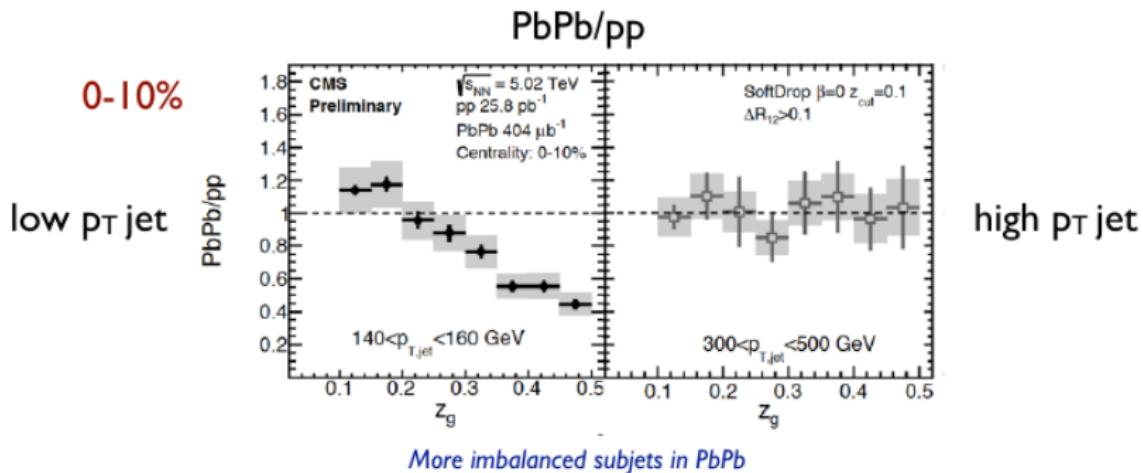
CMS-PAS-HIN-16-006



Fraction of energy carried by the low p_T subjet

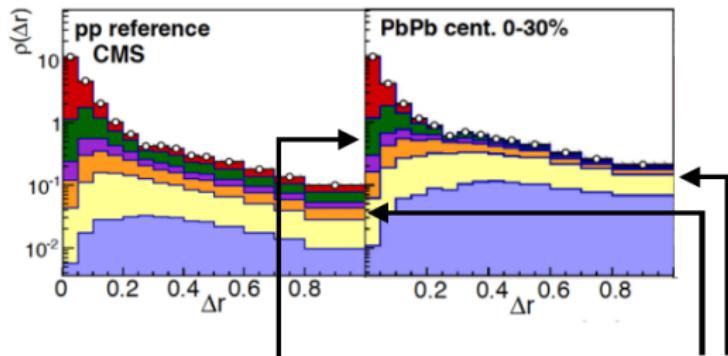
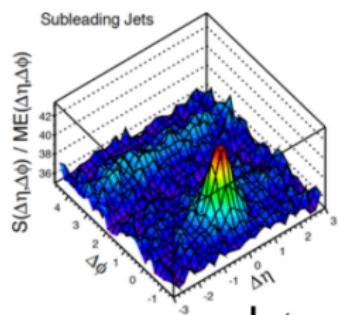
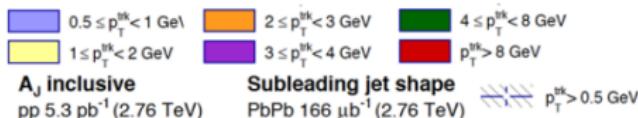
- Jets with two subjets that are well separated in angle
- $\Delta R_{12} > 0.1 \rightarrow$ wide jets

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



Jet-track correlations: p_T differential jet shapes

arXiv:1609.02466



Intermediate p_T jet shapes is
Sensitive to broadening

Large angle excess
of soft particles

Derived from 2D correlations functions in $\Delta\eta$ $\Delta\phi$

- Simultaneous info of fragmentation functions and jet shapes



LLR

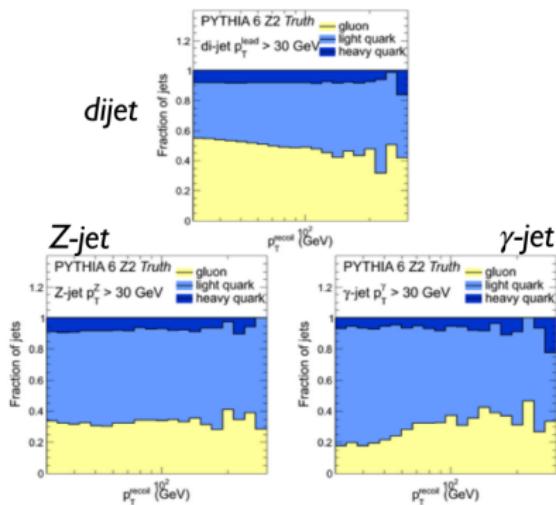
Boson-jet: absolute E_{loss} and more

Absolute E_{loss}

- Parton p_T and ϕ before quenching

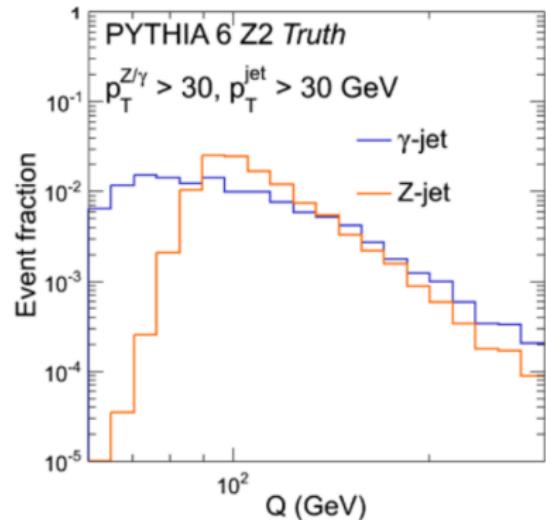
Parton flavour

- More quark jets



Varying virtuality

- Z mass makes virtuality higher



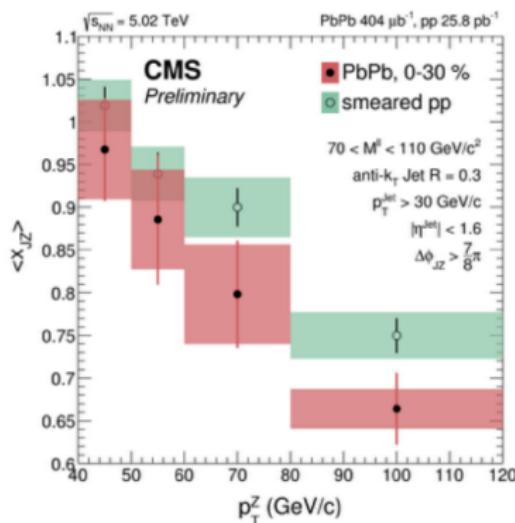
LLR

Boson-jet: transverse momentum imbalance

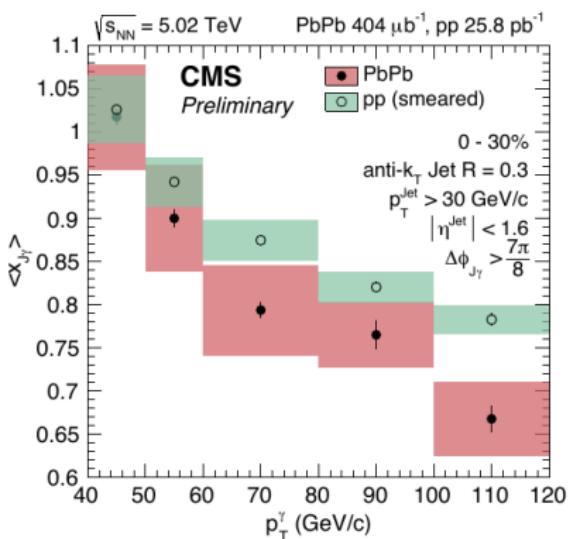


CMS-PAS-HIN-15-013, CMS-PAS-HIN-16-002

Z-jet



photon-jet

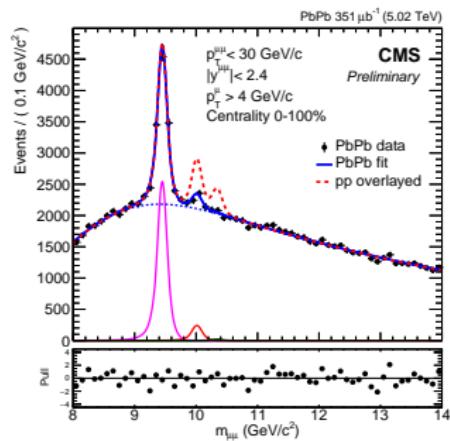
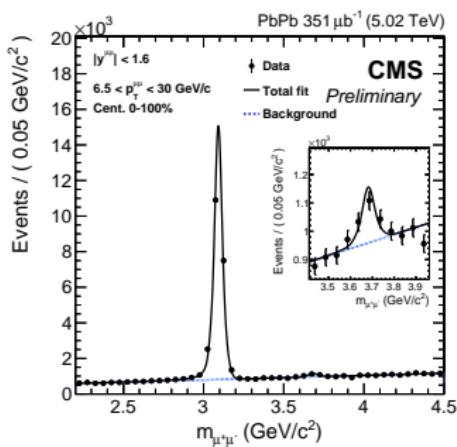


$$\chi_{JV} = \frac{p_T^{\text{jet}}}{p_T^V}$$

- Similar energy loss by jet recoiling against Zs and photons
- Also measured: azimuthal correlations

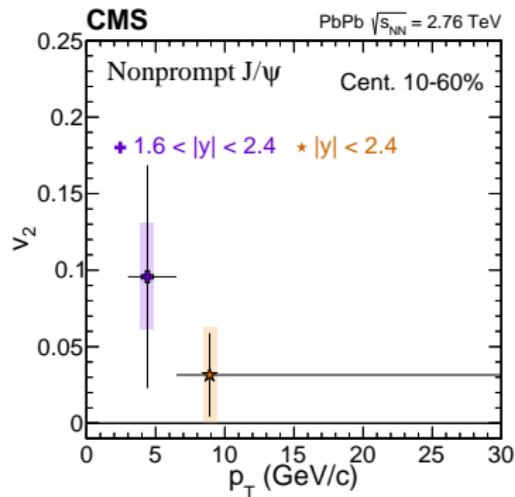
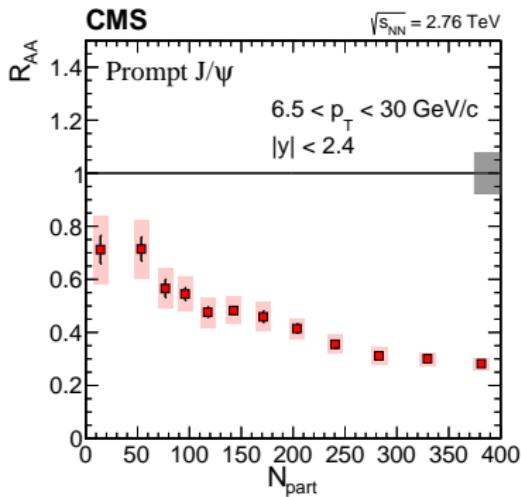
Quarkonia

Quarkonia



LLR

J/ψ at 2.76 TeV: R_{AA} and v_2



- Final J/ψ results from Run1
- R_{AA} of prompt and nonprompt J/ψ
- v_2 of prompt and nonprompt J/ψ (**first time!**)

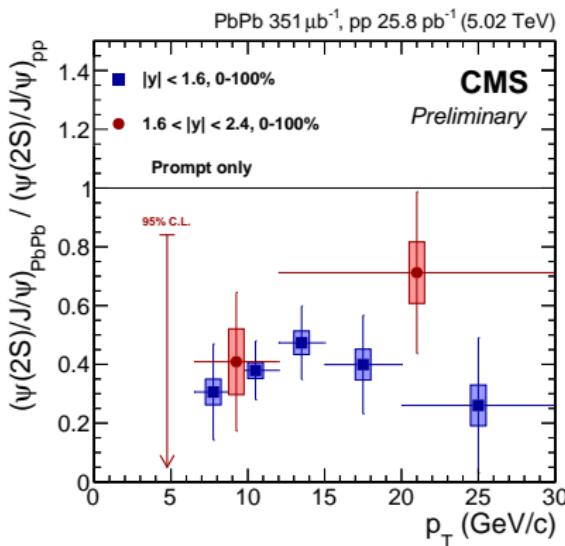


See Javier's talk

IR

Charmonia at 5.02 TeV

CMS-PAS-HIN-16-004



$$\frac{\left[\frac{\psi(2S)}{J/\psi} \right]_{\text{PbPb}}}{\left[\frac{\psi(2S)}{J/\psi} \right]_{\text{pp}}} = \frac{R_{\text{AA}}(\psi(2S))}{R_{\text{AA}}(J/\psi)}$$

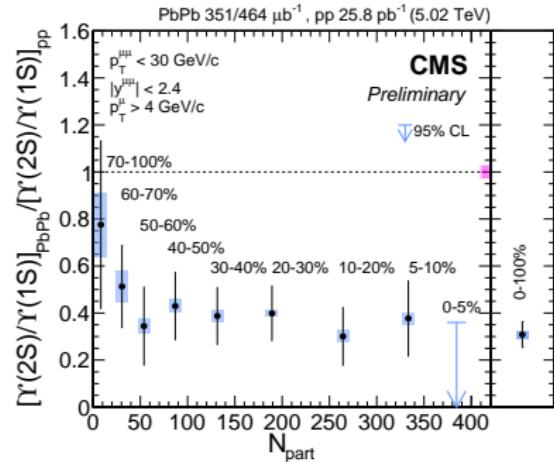
- Double ratio < 1 in all bins: $\psi(2S)$ more suppressed than J/ψ
 - 95% C.L. upper limits when no significant $\psi(2S)$ in PbPb
- No significant p_T dependence

See André's talk

Bottomonia at 5.02 TeV



CMS-PAS-HIN-16-008



- Excited state more suppressed than the ground state
- Stronger difference in central events

See Abdulla's talk



LLR

Heavy flavour

Heavy flavour

Can we see the dead cone effect?

- As p_T gets larger, effect gets smaller
- At low p_T , contribution from other effects, e.g. radial flow

Coalescence

- Is D meson v_2 enhanced?

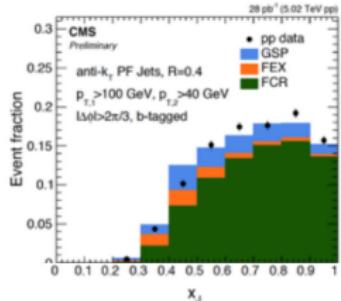
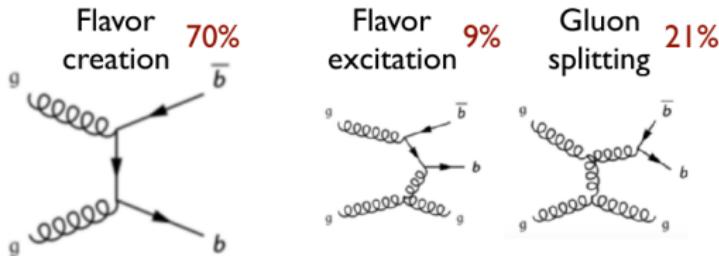


Di-b-jet vs inclusive flavour dijets



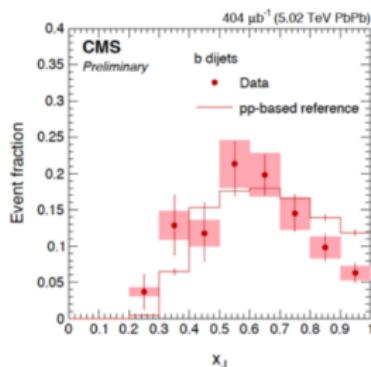
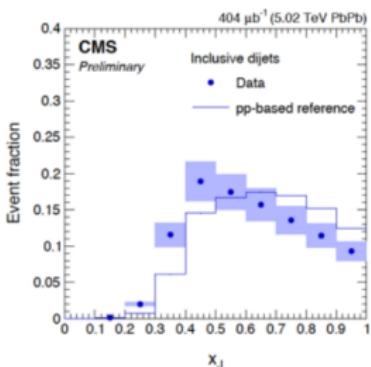
CMS-PAS-HIN-16-005

Contamination from gluon splitting processes is suppressed



PbPb
0-10%

inclusive
dijet



di-b-jet

→ no significant difference in the imbalance of dijets for heavy flavour and inclusive flavour

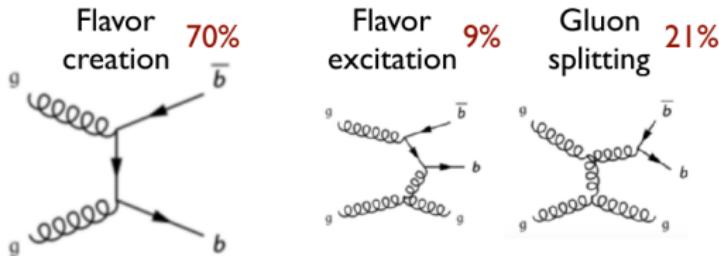
LHC

Di-b-jet vs inclusive flavour dijets



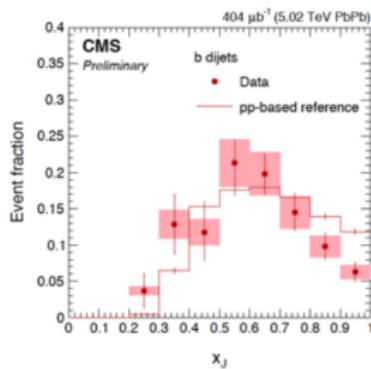
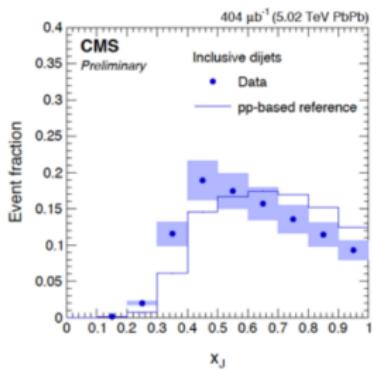
CMS-PAS-HIN-16-005

Contamination from gluon splitting processes is suppressed



PbPb
0-10%

inclusive
dijet

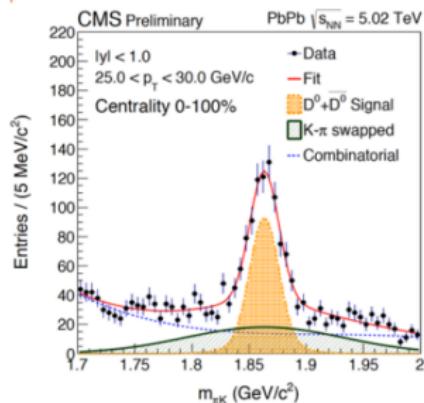
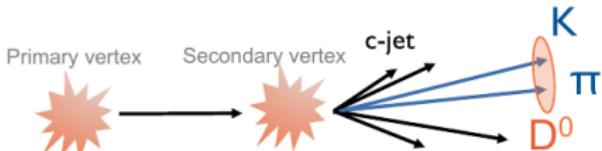
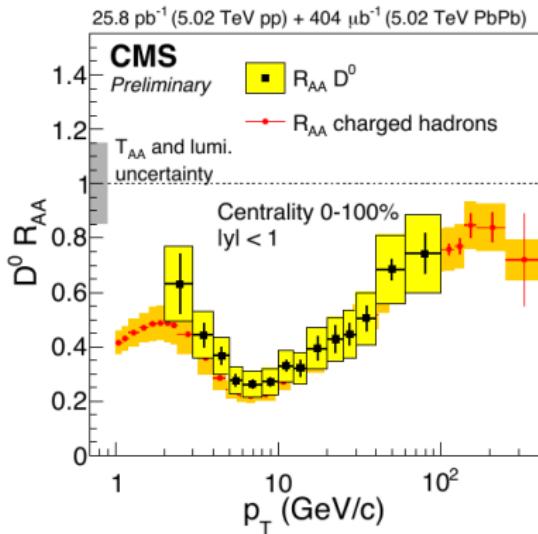


di-b-jet

See Yetkin's talk

D^0 meson suppression

CMS-PAS-HIN-16-001



D meson R_{AA} from 2 GeV (!!) to 100 GeV

- Same level of suppression as charged hadrons



LLR

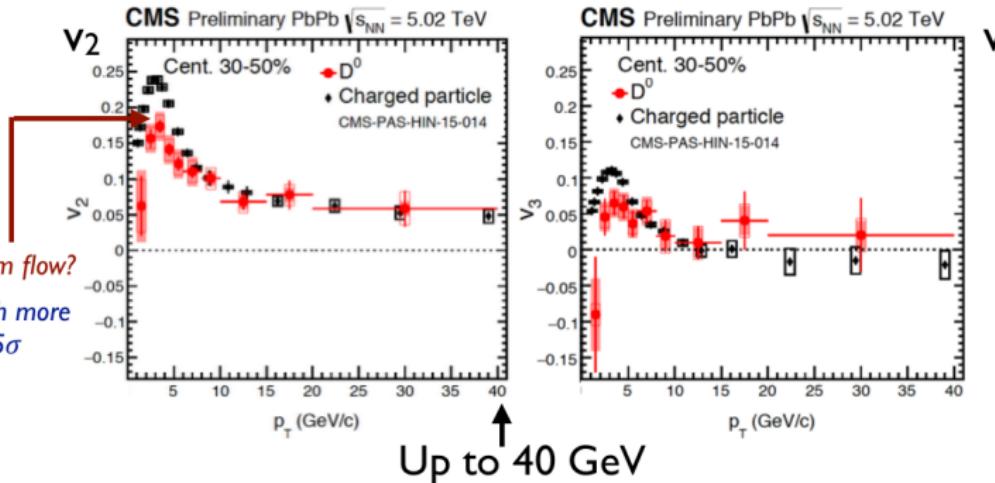
D^0 meson flow coefficients

CMS-PAS-HIN-16-007



Does charm flow?

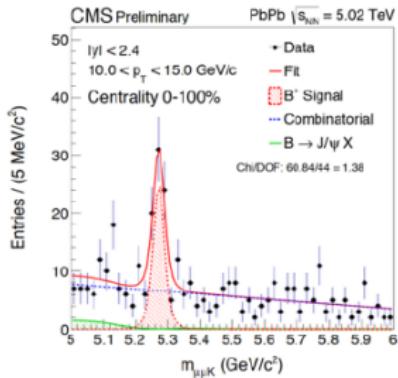
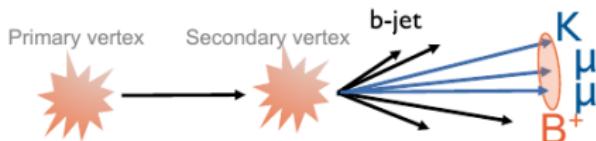
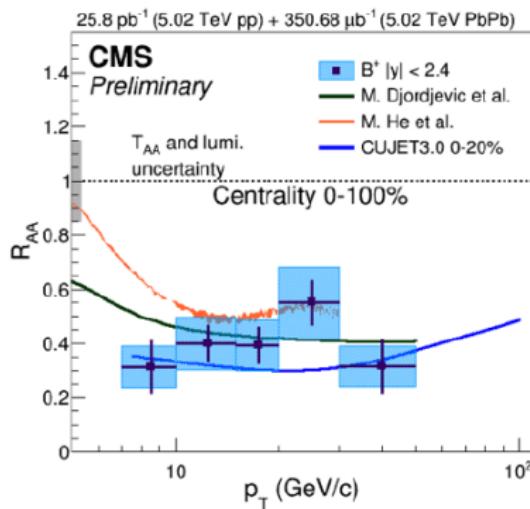
$v_2 > 0$ with more than 5σ



- Low p_T differences
 - Mass ordering
- Agreement at high p_T
 - No sign of difference in path length dependence of E_{loss} for inclusive flavour and charm

B^+ meson suppression ($B^+ \rightarrow J/\psi K^+$)

CMS-PAS-HIN-16-011



First ever measurement of fully reconstructed B meson in PbPb

- Strong suppression of 7-50 GeV B mesons

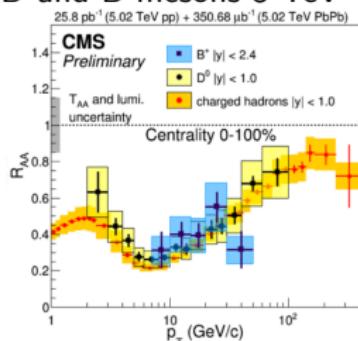


Comparison to inclusive flavour

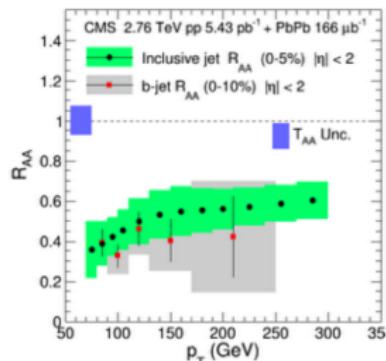
CMS-PAS-HIN-15-015, CMS-PAS-HIN-16-001, CMS-PAS-HIN-15-011,
PRL 113 (2014) 132301, arXiv:1609.05383, arXiv:1610.00613

High p_T

D and B mesons 5 TeV

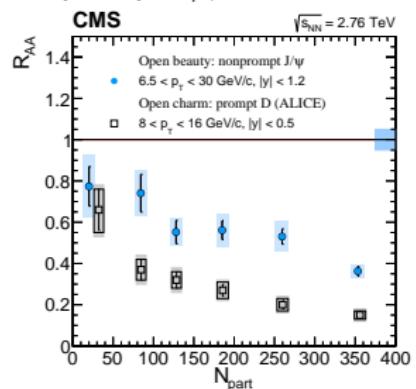


b jets 2.76 TeV



Low p_T

nonprompt J/ ψ 2.76 TeV



No significant separation within systematic uncertainties

- B mesons are sensitive to lower p_T b quarks than b jets
- What is the effect of gluon splitting?

Separation at low p_T ?

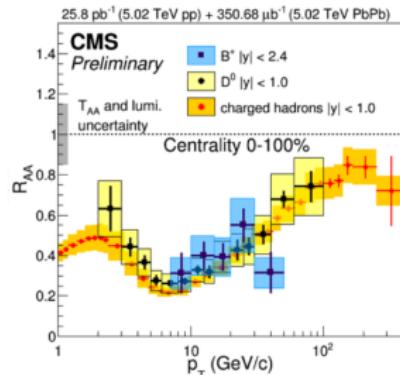
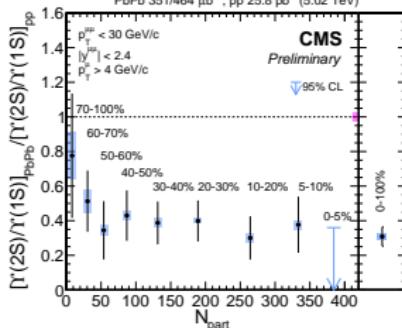
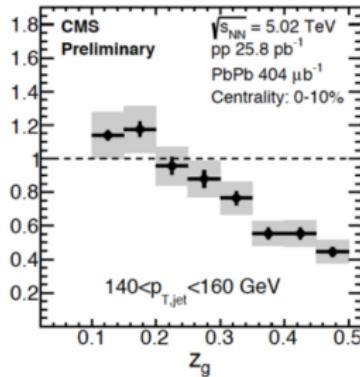
- $B \rightarrow J/\psi$
- Not clear which effects are dominating

LLR



Summary

PbPb/pp



- nPDF
 - Update pPb dijets with the 5 TeV pp reference
- Light flavour
 - Observables calculable from first principles
 - Quenching of “special” jets (V-jets, jets with two subjets)
- Heavy flavour
 - No significant sign of flavour dependence at high p_T
- Quarkonia
 - Sequential suppression of bottomonia and high p_T charmonia as usual?