#### **Heavy lons at CMS**





#### Gábor Veres for the CMS collaboration

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MTA-ELTE Lendület CMS Particle and Nuclear Physics Group

# Heavy Ion highlights from CMS

#### 2015+16: 13 TeV p+p 2015: 5 TeV pp & Pb+Pb 2016: 5 & 8 TeV p+Pb



- Gluon distribution function in Pb
- Azimuthal **anisotropy** in p+p, p+Pb and Pb+Pb
- Charge separation signals from p+Pb 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 LHC Run II data!





## **Nuclear Parton Distribution Function**



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## Gluon PDF in the Pb nucleus



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

EPJC 74 (2014) 2951

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of gluon PDF at x~8x10<sup>-3</sup>

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arXiv: 1605.06966 Submitted to PLB

CMS-PAS-HIN-16-003



# Initial → final state anisotropy

#### Initial State Anisotropy ( $\epsilon_n$ )



Hydrodynamics

#### Final State Anisotropy (v<sub>n</sub>)



How does the initial state anisotropy fluctuate?

How does that translate to final state anisotropy?

(1)  $v_2$  event-by-event fluctuation

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(2) Linear (mainly from  $\epsilon_n$ ) and **non-linear contribution** (from lower

order) in v<sub>n</sub>: *mixing* coming from initial state geometry or at freeze-out

(3) Correlation strength between  $v_n$  from small to large systems?



#### Results: 5 TeV Pb+Pb



## Correlation between $v_2$ , $v_3$ and $v_4$



- Positive correlation between  $v_2$  and  $v_4$ Normalized correlation of  $v_2$  and  $v_3$ : similar in **p+Pb** and **Pb+Pb** → common origin of the
  - Ordering observed: **pp** > **pPb** > **PbPb**
  - → different transport properties?



observed anisotropy? CMS, CERN

CMS-PAS-HIN-16-022

# Chiral magnetic eff.: charge separation



We expect much smaller Charge Separation signal in p+Pb

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



$$\gamma = \frac{\left<\cos(\varphi_{\alpha} + \varphi_{\beta} - 2\varphi_{c})\right>}{v_{2,c}}$$



# Charge separation in p+Pb and Pb+Pb



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# Charged particle $R_{pA}$ and $R_{AA}$ at 5 TeV

#### With high statistics **p+p data** at **5 TeV**



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

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ALICE 2.76 TeV

ATLAS 2.76 TeV

and 2.76 TeV Almost no suppression at very high  $p_{\tau}$ 



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Submitted to JHEP

CMS

## Flavour dependence of energy loss



## Flavour dependence of energy loss



### Heavy quark "flow"



- Low  $p_T$ :  $D^0 v_2$  and  $v_3$  is significantly lower than that of charged particles
- High p<sub>T</sub>: D<sup>0</sup> V<sub>2</sub> ≈ charged particle V<sub>2</sub>

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## Boson-jet momentum ratio in Pb+Pb



# Tracing the 'lost' energy







- Jet shapes and fragmentation functions in p+p and Pb+Pb collisions at 5 TeV
- Sensitive to the possible medium response to hard probes and induced radiation





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#### Jet sub-structure

Does the jet suppression correlate with the shower shape? It does, in the following scenarios:



When the prongs are 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

#### Let's measure the fluctuation of jet substructure!





#### Sub-jets: momentum sharing



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#### Quarkonium suppression



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





#### Inclusive Y suppression

Pb+Pb at 5 TeV

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## Inclusive Y suppression



- Indication of **larger** suppression at 5 TeV
- Consistent with predictions from a hotter and denser medium
- Highest precision measurement
- Y sequential suppression at 5 TeV
- Still no sign of Y(3S) with high statistics data







#### Summary

- Successful low pileup p+p & Pb+Pb run in 2015 & p+Pb 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 p+Pb challenges pure CME and CMW interpretations of the Pb+Pb data
  - Precision measurement of absolute energy loss with boson-jet
  - Parton flavor and shower dependence of energy loss
  - Sequential suppression of Quarkonia

For all the details and links to papers, presenatations, please see:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN http://qm2017.phy.uic.edu/ (e.g. plenary by Y-J. Lee – these slides)



#### BACKUP





#### The CMS experiment



## The CMS Experiment







## Heavy Ion runs in CMS

- 2010: **Pb+Pb** at 2.76 TeV/nuleon pair, 7.3/ub
- 2011: **Pb+Pb** at 2.76 TeV
- 2013: p+p and p+Pb at 5 TeV
- 2015: **p+p** and **Pb+Pb** at 5 TeV
- 2016: p+Pb at 5 and 8 TeV

165/ub 35/nb 464/ub 185/nb





