## Heavy flavor in small systems

Experimental overview

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Heavy Flavor in different colliding systems

**p+p** pQCD Vacuum Reference

**p+A** Cold Nuclear Matter Effect A+A Hot Medium Effects + CNM

Heavy Flavor in different colliding systems



Heavy Flavor in p+A crucial for initial state

- nPDFs, CGC ...
- Interplay with other CNM effect

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### **Selected HF production results in p+A**

Heavy Flavor in different colliding systems



Heavy Flavor in p+A crucial for initial state

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### Selected HF production results in p+A HF flow in small system – hot medium effect?

## **Open Charm: D meson**



Suppressed at forward, no suppression at backward Consistent with nPDF and CGC Potential to constrain nPDF models with precise data

Schmidt, Mon. 11:45

## **Open Charm: D meson**

arXiv: 1906.03425



Similar results for D<sup>+</sup>, D<sup>0</sup>, D<sup>\*</sup>, even  $D_s^+$ 

## **Open Charm: D meson**



Faggin, Tue. 15:20

**Open Charm:**  $\Lambda_{c}$ 



#### Forward-backward ratio described by nPDF models

Schmidt, Mon. 11:45

## **Open Charm:** $\Lambda_{c}$



Forward-backward ratio described by nPDF models  $\Lambda_c^+/D^0$  ratio at mid-rapidity similar to pp, higher than MC

Schmidt, Mon. 11:45 Faggin, Tue. 15:20



CNM effects mainly affect production at forward rapidity Described by various models



#### Limited CNM effects in p+AlBig change at low $p_T$ with target size



### Limited CNM effects in p+Al Big change at low $p_T$ with target size Little/no change with projectile size



### Limited CNM effects in p+Al Big change at low p<sub>T</sub> with target size Little/no change with projectile size Evolution of CNM effects with system size

Lim, Mon. 14:30

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### Bottomonium: Y



#### Suppression stronger at forward y and low $p_T$

### Bottomonium: Y



### Suppression stronger at forward y and low $p_T$ Hint of over-estimation of backward $R_{pA}$

### Bottomonium: Y



### Suppression stronger at forward y and low p<sub>T</sub> Hint of over-estimation of backward R<sub>pA</sub> **Possible final state effect?**

## Bottomonium: excited $\Upsilon$



#### **CNM** effects cancel out

## Bottomonium: excited $\Upsilon$



### CNM effects cancel out Y excited states more suppressed than pp Indication of final state effects from (cold) co-mover

## Bottomonium: excited $\Upsilon$



### CNM effects cancel out Y excited states more suppressed than pp Indication of final state effects from (cold) co-mover Could there be hot medium effect?

## Collectivity in small systems



### Strong evidences of medium effects in light flavor sector How about Heavy Flavor?

Xu, Wed. 16:50

## Heavy flavor lepton $v_2$ in pPb



### Non-zero v<sub>2</sub> for heavy flavor leptons Smaller than charged hadrons

## Heavy flavor lepton $v_2$ in pPb



Non-zero v<sub>2</sub> for heavy flavor leptons Smaller than charged hadrons Indication of extension to low multiplicity

## $D^0 v_2$ in pPb



## $D^0 v_2$ in pPb

PRL 121.082301 (2018)



### Significant D<sup>0</sup> v<sub>2</sub> Smaller than light flavors with NCQ scaling

## $D^0 v_2$ in pPb



### Significant D<sup>0</sup> v<sub>2</sub> Smaller than light flavors with NCQ scaling Less medium interaction than in PbPb?

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# Strong evidence of HF transport in QGP in A+A when combine $v_2$ and $R_{AA}$ results



Strong evidence of HF transport in QGP in A+A when combine v<sub>2</sub> and R<sub>AA</sub> results Same in p+A?

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# Transport models assuming QGP disfavored by $\rm R_{pA}$ No large medium modification observed



Transport models assuming QGP disfavored by R<sub>pA</sub> No large medium modification observed Flow purely from coalescence? Check J/ψ!!

## $J/\psi v_2$ in pPb

CMS pPb 8.16TeV  $\Box K_s^0$ Prompt J/ψ  $185 \le N_{trk}^{offline} < 250$ Prompt D<sup>0</sup>  $\circ \Lambda$ 0.2  $\bigcirc$ 0  $\bigcirc$  $\bigcirc$ Θ  $\bigcirc$ v<sup>sub</sup> 2 0.1 0.0 0 2 6 8 4  $p_{_{T}}$  (GeV)

#### Surprisingly large v<sub>2</sub>, compatible with D<sup>0</sup> Charm quark flow confirmed

## $J/\psi v_2$ in pPb

PLB 791 (2019) 172



Surprisingly large v<sub>2</sub>, compatible with D<sup>0</sup> Charm quark flow confirmed Hint of un-expected NCQ scaling at low KE<sub>T</sub>/n<sub>q</sub> Where does the flow come from?!

 $J/\psi v_2$  in PbPb



#### Transport model assuming QGP describe R<sub>AA</sub> Large regeneration in A+A

## $J/\psi v_2$ in PbPb



Transport model assuming QGP describe R<sub>AA</sub> Large regeneration in A+A Collective flow from regenerated J/ψ High p<sub>T</sub> v<sub>2</sub> not well understood

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 $J/\psi v_2$  in pPb

JHEP 03 (2019) 015



### Same model describe $R_{pA}$

 $J/\psi v_2$  in pPb

JHEP 03 (2019) 015



### Same model describe R<sub>pA</sub> Small regeneration - small hot medium effect

 $J/\psi v_2$  in pPb



### Same model describe R<sub>pA</sub> Small regeneration - small hot medium effect Disfavored by v<sub>2</sub> in p+A

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Alternative CGC model describe  $R_{pA}$  and  $v_2$ Predicting Upsilon  $v_2$  same as  $J/\psi$ Interesting to see open Heavy Flavor hadron results

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## $c/b \rightarrow \mu v_2 \text{ in } pp$



#### Open a new gate for b flow in small system Indicate ~0 v<sub>2</sub> for b quark

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## $c/b \rightarrow \mu v_2 \text{ in } pp$



Open a new gate for b flow in small system Indicate ~0 v<sub>2</sub> for b quark CGC: not applicable at this p<sub>T</sub> range Hydro: early formation time & small system size? Detail study of b hadron v<sub>2</sub> needed (esp. low p<sub>T</sub>)

## $c/b \rightarrow \mu v_2$ in pp



#### How to understand the large flow of $c \rightarrow \mu$ in pp?

## Summary & Outlook

Heavy Flavor production in small systems

- CNM effects describe major results
- Indication of final state effect for excited Quarkonium

Flow of Heavy Flavor quarks

- Transport in QGP model dis-favored
- Color Glass Condensate model favored
- Constraints and puzzles from pp c/b $\rightarrow \mu$  v<sub>2</sub>





## Summary & Outlook

Huge amount of small system data expected-detailed R<sub>pA</sub>, flow for c & b

• LHC: Run 3&4 with detector upgrades



RHIC small system scan proposals – CNM & hot medium effect evolution

- Symmetric collisions arXiv.1904.10415 (O+O proposed in STAR BUR)
- Asymmetric collisions PRC 99 (2019) 044904

## Thank you!!



Why showing my cats in physics conference?! Simply because they are too cute!!



### Charmonium



Model with only shadowing effects touch upper limit Additional nuclear absorption favored

### CMS Lambda\_c ratio



### HF flow in AA & pA



## **Open Beauty: B<sup>+</sup>**



Good agreement with non-prompt J/psi and nPDF models

### Survival of initial state flow

#### See also: PRC 92, 054906 (2015)



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## **Fireball parameters**



## CGC v2 vs Qs

