Heavy flavor in small systems
Experimental overview

Zhenyu Chen (陈震宇)
Stony Brook University & BNL
Initial Stages 2019
Probing initial state with heavy flavor

Heavy Flavor in different colliding systems

- $p+p$
  - pQCD
  - Vacuum Reference

- $p+A$
  - Cold Nuclear Matter Effect

- $A+A$
  - Hot Medium Effects
  - + CNM

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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 $p+A$

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Heavy Flavor in different colliding systems

- **p+p**
  - pQCD
  - Vacuum Reference

- **p+A**
  - Cold Nuclear Matter Effect + Hot Medium Effects?

- **A+A**
  - Hot Medium Effects + CNM

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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

Similar results for $D^+$, $D^0$, $D^*$, even $D_s^+$
Open Charm: D meson

Similar results for $D^+$, $D^0$, $D^*$, even $D_s^+$

Combined results compatible with various models

arXiv: 1906.03425
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
Charmonium: $J/\psi$

CNM effects mainly affect production at forward rapidity
Described by various models
Charmonium: J/ψ

Limited CNM effects in p+Al
Big change at low $p_T$ with target size
Charmonium: $J/\psi$

Limited CNM effects in p+Al
Big change at low $p_T$ with target size
Little/no change with projectile size
Charmonium: $J/\psi$

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

Evolution of CNM effects with system size

Lim, Mon. 14:30
Suppression stronger at forward $y$ and low $p_T$
Bottomonium: $\Upsilon$

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

Hint of over-estimation of backward $R_{pA}$

Hayashi, Tue. 15:00
Suppression stronger at forward $y$ and low $p_T$

Hint of over-estimation of backward $R_{pA}$

Possible final state effect?
Bottomonium: excited $\Upsilon$

CNM effects cancel out
Bottomonium: excited $\Upsilon$

CNM effects cancel out

$\Upsilon$ excited states more suppressed than pp

Indication of **final state effects** from (cold) co-mover
Bottomonium: excited γ

CNM effects cancel out

γ excited states more suppressed than pp

Indication of final state effects from (cold) co-mover

Could there be hot medium effect?

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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 $v_2$ for heavy flavor leptons
Smaller than charged hadrons
Heavy flavor lepton $v_2$ in $pPb$

Non-zero $v_2$ for heavy flavor leptons
Smaller than charged hadrons
Indication of extension to low multiplicity
$D^0 v_2$ in pPb

Preliminary CMS pPb 8.16TeV

Significant $D^0 v_2$

CMS

PRL 121.082301 (2018)

PbPb 5.02TeV

Centrality 30-50%

185 $\leq N_{\text{trk}}^{\text{offline}} < 250$

$|y| < 1$

Polynomial fits to $K$ (GeV/c)

$T_{p}$

$0 2 4 6 8$

$p_T$ (GeV/c)

$0.0 0.1 0.2$

$V_{2\text{sub}}$

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D⁰ v₂ in pPb

Significant D⁰ v₂
Smaller than light flavors with NCQ scaling
D$^0$ $v_2$ in pPb

Significant D$^0$ $v_2$
Smaller than light flavors with NCQ scaling
Less medium interaction than in PbPb?
Strong evidence of HF transport in QGP in A+A when combine $v_2$ and $R_{AA}$ results
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Same in p+A?
Transport models assuming QGP disfavored by $R_{pA}$
No large medium modification observed
Transport models assuming QGP disfavored by $R_{pA}$
No large medium modification observed
Flow purely from coalescence? Check $J/\psi$!!
Surprisingly large $v_2$, compatible with $D^0$ Charm quark flow confirmed
**J/ψ v$_2$ in pPb**

Surprisingly large v$_2$, compatible with D$^0$

Charm quark flow confirmed

Hint of unexpected NCQ scaling at low KE$_T$/n$_q$

Where does the flow come from?!
Transport model assuming QGP describe $R_{AA}$
Large regeneration in A+A
\( J/\psi \, v_2 \) in PbPb

Transport model assuming QGP describe \( R_{AA} \)

Large regeneration in A+A

Collective flow from regenerated \( J/\psi \)

High \( p_T \) \( v_2 \) not well understood
J/ψ \( v_2 \) in pPb

Same model describe \( R_{pA} \)
J/ψ v_2 in pPb

Same model describe R_{pA}
Small regeneration - small hot medium effect
J/\Psi \, \nu_2 \, \text{in pPb}

Same model describe $R_{pA}$
Small regeneration - small hot medium effect
Disfavored by $\nu_2$ in p+A
J/\psi \ \nu_2 \ in \ pPb

Alternative CGC model describe $R_{pA}$ and $\nu_2$

Predicting Upsilon $\nu_2$ same as J/\psi

Interesting to see open Heavy Flavor hadron results

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c/b → μ ν₂ in pp

Open a new gate for b flow in small system
Indicate ~0 ν₂ for b quark
c/b → $\mu$ $v_2$ in pp

Open a new gate for b flow in small system
Indicate $\sim 0$ $v_2$ for b quark
CGC: not applicable at this $p_T$ range
Hydro: early formation time & small system size?

Hill, Wed. 14:20
Open a new gate for b flow in small system
Indicate $\sim 0$ $v_2$ for b quark
CGC: not applicable at this $p_T$ range
Hydro: early formation time & small system size?
Detail study of b hadron $v_2$ needed (esp. low $p_T$)

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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→μ v₂
Summary & Outlook

Huge amount of small system data expected—detailed $R_{pA}$, flow for c & b

- LHC: Run 3&4 with detector upgrades
- RHIC: sPHENIX + upgraded STAR

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!!
Back up
Charmonium

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

PbPb 44 µb⁻¹, pp 38 nb⁻¹ (5.02 TeV)

CMS

|y| < 1.0

PbPb

Data: Cent. 0-100%

pp

Data

PYTHIA8

PYTHIA8 + CR

EPJC78 (2018) 348

arXiv:1902.08889

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HF flow in AA & pA

ALICE Preliminary
30–50% Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV
- Prompt $D^0$, $D^+$, $D^{*+}$ average, $|y|<0.8$
- $v_2 \{SP, |\Delta \eta|>0.9\}$
- $J/\psi$, $2.5<y<4$
- $v_2 \{SP, |\Delta \eta|>1\}$ JHEP 02 (2019) 012
- $\pi^+$, $|y|<0.5$
- $v_2 \{SP, |\Delta \eta|>2\}$ JHEP 1809 (2018) 006
- charged particles, $|\eta|<0.8$
- $v_2 \{SP, |\Delta \eta|>2\}$ JHEP 07 (2018) 103

CMS

185 $\leq N_{\text{trk}}^{\text{offline}} < 250$

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Open Beauty: $B^+$

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

PRD 99 052011 (2019)
Survival of initial state flow

See also:
PRC 92, 054906 (2015)

arXiv.1906.01422

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Fireball parameters

- **pPb @ 8.16 TeV -4.46<y<-2.96**

  - T[GeV] vs. time[fm/c]
  - Lines denote different collision percentages:
    - 2 - 10%
    - 10 - 20%
    - 20 - 40%
    - 40 - 60%
    - 60 - 80%
    - 80 - 100%

- **Fireball Radius**

  - Radius y (elliptic fireball)
  - Radius x (elliptic fireball)
  - Radius r (round fireball)

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CGC v2 vs Qs

$B_p = 6 \text{ GeV}^{-2}$

$\Delta = 0.5 \text{ GeV}$