Exploring b-physics at sPHENIX

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RBRC Workshop: Predictions for sPHENIX
07/21/2022
Overview

• One stated goal of sPHENIX is precision b-physics in heavy ion collisions

• Many great talks yesterday on experimental status and theory

• Heavy flavor program at sPHENIX is larger than just b-physics
  • This topic was my personal choice to stimulate discussion

• This talk:
  1. How do we measure HF at sPHENIX?
  2. What is the status of the field?
  3. What yields can we expect at sPHENIX?
  4. How do we get the best physics with this?
Unlocking HF at sPHENIX

- What is needed to reconstruct heavy flavor decays?
  - Minimum: tracks and vertices
  - Extras: calorimeters, jet algorithms, PID
- sPHENIX uses KFParticle for HF reconstruction, wrapped in sPHENIX code for IO

Left – MVTX spatial resolution as a function of trigger delay from test beam
Middle – MVTX track resolution from test beam
Right – sPHENIX DCA$_{XY}$ resolution from simulation
Unlocking HF at sPHENIX

The Maps VerTeX detector

- Comprises of 3 layers of monolithic active pixel sensors using the ALICE ALPIDE
- The front-end readout uses the ALICE Readout Unit
- The back-end uses the ATLAS FELIX

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>ALPIDE thickness [µm]</td>
<td>50</td>
</tr>
<tr>
<td>Pixel size [µm] / matrix</td>
<td>29 x 27 / 1024 x 512</td>
</tr>
<tr>
<td>Technology</td>
<td>180nm CMOS</td>
</tr>
<tr>
<td>Power Consumption [mW/cm²]</td>
<td>40 (mean), 300 (peak)</td>
</tr>
<tr>
<td>Stave Material Budget</td>
<td>0.3% X₀</td>
</tr>
<tr>
<td>ToT</td>
<td>A few µs (tunable)</td>
</tr>
<tr>
<td>XZ spatial resolution [µm]</td>
<td>&lt; 6</td>
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</table>

MVTX under construction at LBNL, 07/12/22
b-hadron overview

- A major aim of sPHENIX is precision b-physics in HI collisions
- Major differences between beauty and charm decays:
  1. \( m_b \gg m_c \), smaller relative momentum transfer in media!
  2. \( c\tau_B > c\tau_D \), more displacement from PV
  3. \( \sigma_{b\bar{b}} \ll \sigma_{c\bar{c}} \), b-hadrons are much rarer than charm hadrons
- Many beauty decays go through a resonance, you can reconstruct charm hadrons to reduce background
# b-hadron overview

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>$B^0$</td>
<td>$5279.66 \pm 0.12$</td>
<td>$1.519 \pm 0.004$</td>
<td>$D^0X$ (47 ± 3)%</td>
<td>$D^-\pi^+$ (0.25 ± 0.01)%</td>
<td>Oscillates between $B^0$ and $\bar{B}^0$ every 12 ps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$D^-X$ (37 ± 3)%</td>
<td></td>
<td>Can often access $B_s^0$ in the same spectrum</td>
</tr>
<tr>
<td>$B^\pm$</td>
<td>$5279.34 \pm 0.12$</td>
<td>$1.638 \pm 0.004$</td>
<td>$D^0X$ (79 ± 4)%</td>
<td>$D^0\pi^+$ (0.47 ± 0.01)%</td>
<td>Can sometimes access $B_c^\pm$ in the same spectrum</td>
</tr>
<tr>
<td>$B_s^0$</td>
<td>$5366.92 \pm 0.10$</td>
<td>$1.527 \pm 0.011$</td>
<td>$D_s^-X$ (62 ± 6)%</td>
<td>$D_s^-\pi^+$ (0.30 ± 0.01)%</td>
<td>Oscillates between $B_s^0$ and $\bar{B}_s^0$ every 350 fs</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Can often access $B^0$ in the same spectrum</td>
</tr>
<tr>
<td>$B_c^\pm$</td>
<td>$6274.47 \pm 0.32$</td>
<td>$0.510 \pm 0.009$</td>
<td>$J/\psi\ell^+\nu_\ell X$</td>
<td>$J/\psi\pi^+$</td>
<td>Can sometimes access $B^\pm$ in the same spectrum</td>
</tr>
<tr>
<td>$\Lambda_b^0$</td>
<td>$5619.60 \pm 0.17$</td>
<td>$1.464 \pm 0.011$</td>
<td>$\Lambda_c^+\ell^-\nu_\ell X$ (11 ± 2)%</td>
<td>$\Lambda_c^+\pi^-$ (0.49 ± 0.04)%</td>
<td></td>
</tr>
</tbody>
</table>
b-physics at LHCb

- Same final state was used for $B^0$ and $B_S^0$
  - Lots of systematics cancel
- Strangeness enhancement is visible by eye
- $\sigma_{B^0_S}/\sigma_{B^0}$ did not change with track number in opposite direction to b-hadron flight
b-physics at CMS

\[ B_C^\pm \] was measured in PbPb collisions
  • Challenging, cross-section is small compared to \( B^\pm \)
  • Took advantage of ML techniques and good simulations

\[ B_C^\pm \rightarrow (J/\psi \rightarrow \mu^- \mu^+) \mu^+ \nu_\mu \]

Centrality 0-90%

\[ 1.3 < |y_{\mu\mu}| < 2.3 \]

\[ |y_{\mu\mu}| < 2.3 \]

\[ \rho_{1,2} = 0.43 \]

\[ \rho_T^{\mu\mu} \]
• $m_b \gg m_c$, would expect less suppression
  • Especially at low $p_T$
• Evidence from many collaborations
  • More statistics at low $p_T$ would help us
Current expectations

- Non-prompt charm meson decays require good DCA measurement
  - Can we handle separation in pile-up scenarios (by not mis-ID the primary vertex)

- Collaborations relied on external input on had. Fraction to separate $B^0_S$
  - Can a data-driven technique be developed for inclusive measurements?
Current expectations

- Low $p_T$ heavy flavor region is interesting
  - More influence from the medium
- Can we also extract $R_{AA}$ for $\Lambda_b^0$ for baryon/meson suppression

PRL 118, 212301
Personal musings

• Can we access $\Lambda_b^0$ via non-prompt $\Lambda_c^{\pm}$?
  • $\Lambda_c^{\pm}$ can be fully reconstructed via $pK^-\pi^+$
  • $\Lambda_c^{\pm}$ will be several mm from collision

• In a similar vain, can be separate $B^0$ and $B_s^0$ via $D^\pm$ and $D_s^\pm$?
  • This will have more statistics than LHCb measurement to $J/\psi\pi^+\pi^-$ final state
  • $K^+K^-\pi^+$ spectra holds both $D^\pm$ and $D_s^\pm$
    • Could be cleaner measurement if we can separate $B^0$ and $B_s^0$

• Can $B_c^{\pm}$ be obtained through non-prompt b-hadron decays?
Personal musings

• Can we access $\Lambda^0_b$ via non-prompt $\Lambda^\pm_c$?
  • $\Lambda^\pm_c$ can be fully reconstructed via $pK^-\pi^+$
  • $\Lambda^\pm_c$ will be several mm from collision

• In a similar vain, can be separate $B^0$ and $B^0_S$ via $D^\pm$ and $D^\pm_S$?
  • This will have more statistics than LHCb measurement to $J/\psi\pi^+\pi^-$ final state
  • $K^+K^-\pi^+$ spectra holds both $D^\pm$ and $D^\pm_S$
    • Could be cleaner measurement if we can separate $B^0$ and $B^0_S$

• Can $B^\pm_c$ be obtained through non-prompt $b$-hadron decays?
Expected yields at sPHENIX

Assumptions

1. Data samples:
   - \( pp \): 2.4x10^{11} \) min-bias events
   - \( pAu \): 0.9x10^{11} \) effective \( pp \) min-bias events
   - \( AuAu \): 350x10^{11} \) effective \( pp \) min-bias events (~28% of total in 2023)

2. Cross-section, \( \sigma_{b\bar{b}} \approx \sigma_{MB}/1000 \)

3. Hadronisation fractions, \textit{arXiv 1909.12524 v3}
   - \( f_{B^0} = f_{B^\pm} = 0.344 \pm 0.021 \)
   - \( f_{B_s^0} = 0.115 \pm 0.013 \)
   - \( f_{\Lambda_b^0} = 0.165 \pm 0.015 \)

   • Branching fractions are taken from pdgLive as of 07/20/22
   • Acceptance efficiency is 50% per particle
   • Single track efficiency is 80%
   • No assumptions on selection efficiency (but 10% is reasonable)
# Expected yields at sPHENIX

<table>
<thead>
<tr>
<th>Channel</th>
<th>pp</th>
<th>pAu</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \rightarrow D^0(\rightarrow K^-\pi^+)X$</td>
<td>1.1M</td>
<td>400k</td>
</tr>
<tr>
<td>$b \rightarrow D^+(\rightarrow K^-\pi^+\pi^+)X$</td>
<td>500k</td>
<td>180k</td>
</tr>
<tr>
<td>$b \rightarrow D_s^+(\rightarrow K^+K^-\pi^+)X$</td>
<td>250k</td>
<td>90k</td>
</tr>
<tr>
<td>$b \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+)X$</td>
<td>40k</td>
<td>15k</td>
</tr>
<tr>
<td>$B^+ \rightarrow D^0(\rightarrow K^-\pi^+)\pi^+$</td>
<td>2000</td>
<td>700</td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+(\rightarrow K^-\pi^+\pi^+)\pi^+$</td>
<td>1000</td>
<td>350</td>
</tr>
<tr>
<td>$B_s^0 \rightarrow D_s^+(\rightarrow K^+K^-\pi^+)\pi^+$</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>$\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+)\pi^+$</td>
<td>650</td>
<td>250</td>
</tr>
</tbody>
</table>
Conclusions

• sPHENIX will collect a large data sample over 3 years
  • The lower CoM energy means better access to lower $p_T$ region

• Many experiments are now making b-physics measurements
  • Can sPHENIX improve on these measurements or study new regions?
  • We will have large inclusive data set and, with efficient selections, could access exclusive channels as well

• Please find me during breaks to discuss more (if we don’t finish discussions now)