Exploring b-physics at sPHENIX

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RBRC Workshop: Predictions for sPHENIX
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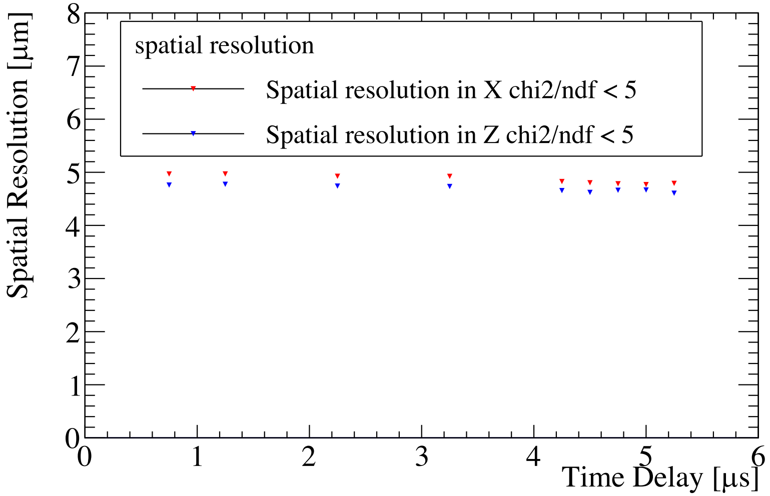
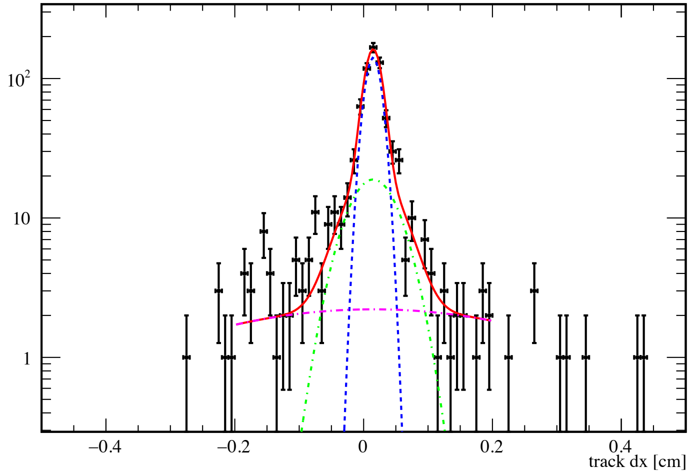
Overview

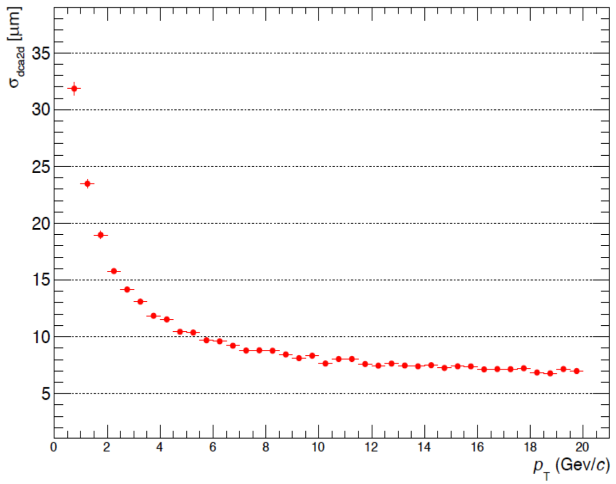
- One stated goal of sPHENIX is precision b-physics in heavy ion collisions
- Many great talks yesterday on experimental status and theory
- Heavy flavor program at sPHENIX is larger than just b-physics
  - This topic was my personal choice to stimulate discussion
- This talk:
  1. How do we measure 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







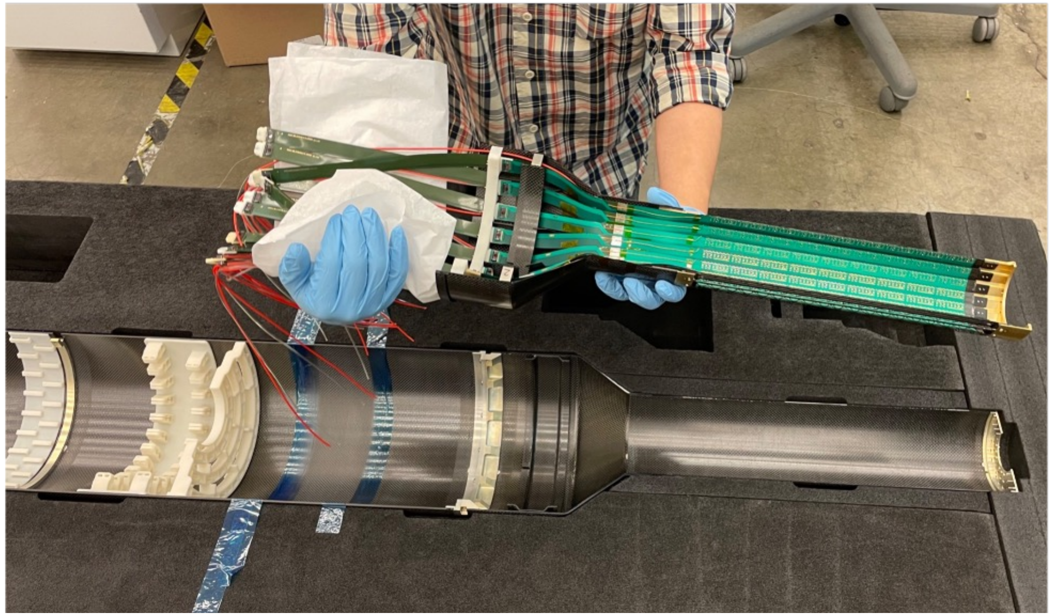
Left – MVTX spatial resolution as a function of trigger delay from test beam
Middle – MVTX track resolution from test beam
Right – sPHENIX DCA_{XY} resolution from simulation

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

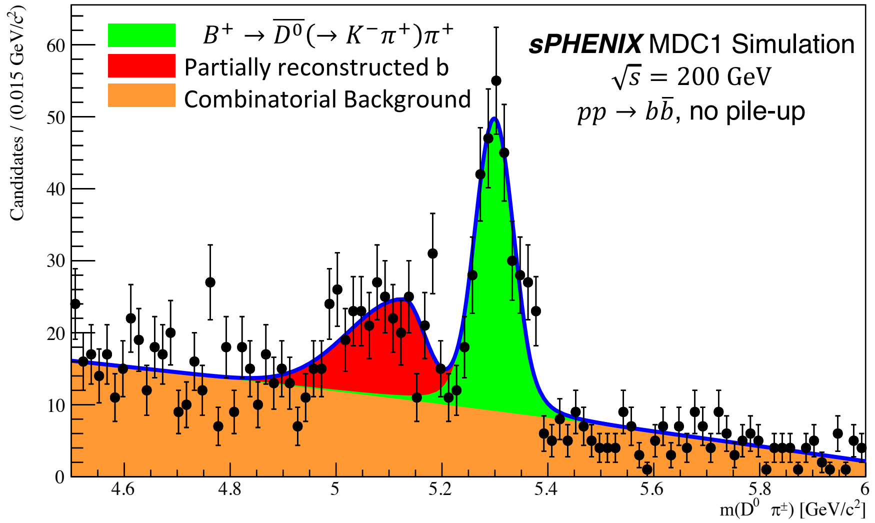
ALPIDE thickness [µm]	50
Pixel size [µm] / matrix	29 x 27 / 1024 x 512
Technology	180nm CMOS
Power Consumption [mW/cm^2]	40 (mean), 300 (peak)
Stave Material Budget	0.3% X_0
ToT	A few µs (tunable)
XZ spatial resolution [µm]	< 6

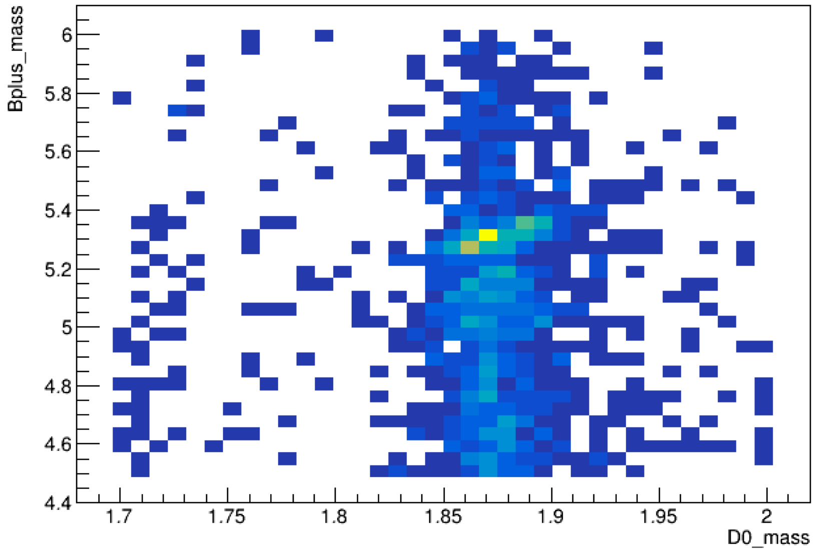


MVTX under construction at LBNL, 07/12/22

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





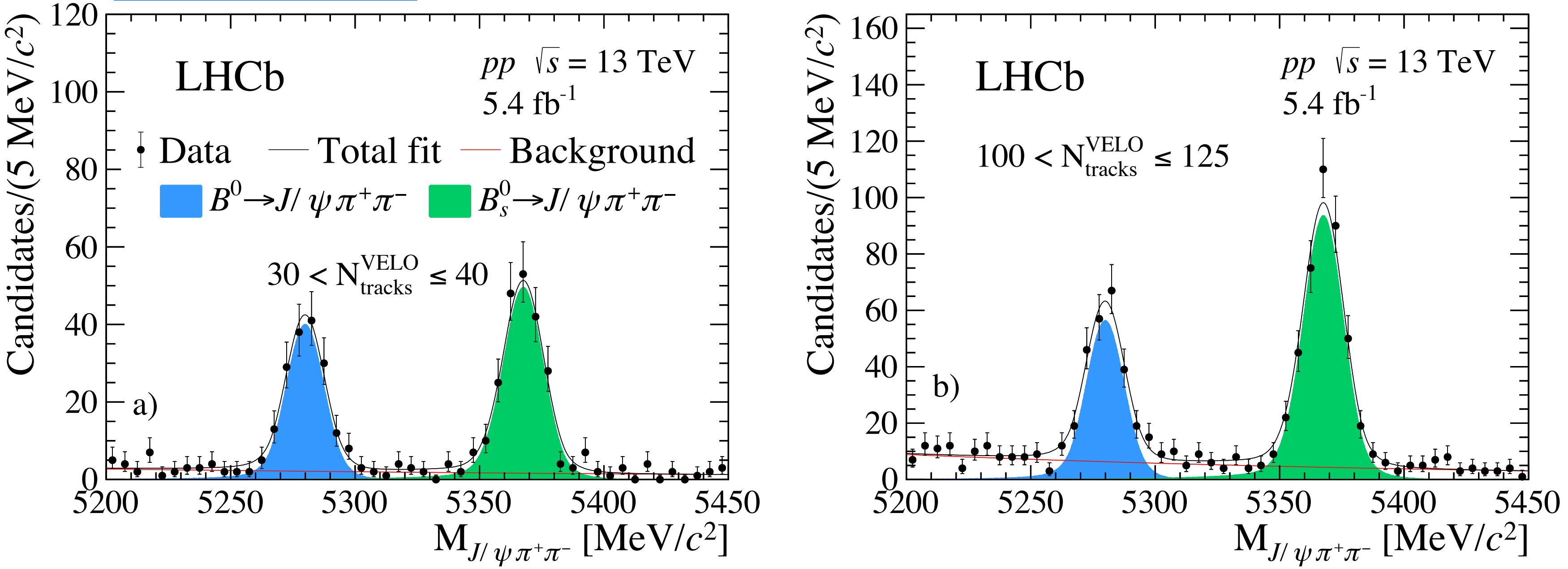
b-hadron overview

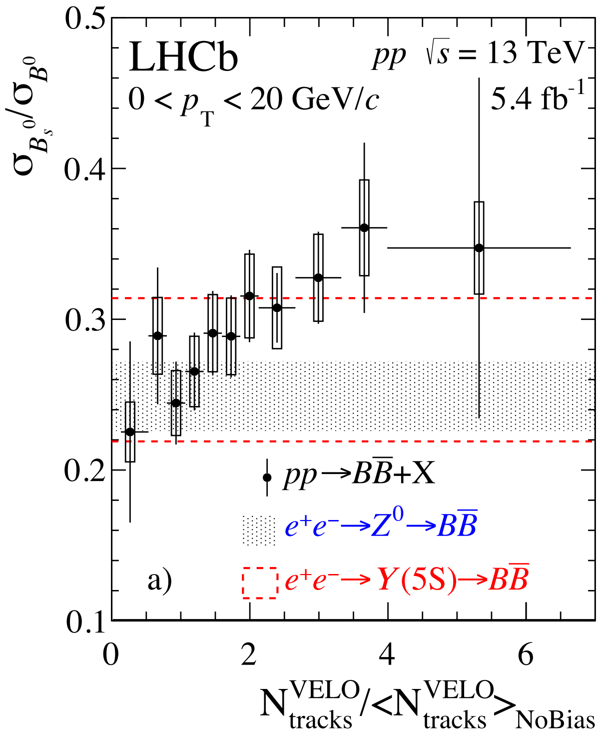
Particle	Mass [MeV]	Decay Time [ps]	Main Inclusive Decay	Easiest* Exclusive Decay	Comments
B^0	5279.66 ± 0.12	1.519 ± 0.004	$\bar{D}^0 X$ $(47 \pm 3)\%$ $D^- X$ $(37 \pm 3)\%$	$D^-\pi^+$ $(0.25 \pm 0.01)\%$	Oscillates between B^0 and $\bar{B}^0$ every 12 ps Can often access B_s^0 in the same spectrum
$B^\pm$	5279.34 ± 0.12	1.638 ± 0.004	$D^0 X$ $(79 \pm 4)\%$	$D^0\pi^+$ $(0.47 \pm 0.01)\%$	Can sometimes access $B_c^\pm$ in the same spectrum
B_s^0	5366.92 ± 0.10	1.527 ± 0.011	$D_s^- X$ $(62 \pm 6)\%$	$D_s^-\pi^+$ $(0.30 \pm 0.01)\%$	Oscillates between B_s^0 and $\bar{B}_s^0$ every 350 fs Can often access B^0 in the same spectrum
$B_c^\pm$	6274.47 ± 0.32	0.510 ± 0.009	$J/\psi \ell^+ \nu_\ell X$	$J/\psi \pi^+$	Can sometimes access $B^\pm$ in the same spectrum
Λ_b^0	5619.60 ± 0.17	1.464 ± 0.011	$\Lambda_c^+ \ell^- \bar{\nu}_\ell X$ $(11 \pm 2)\%$	$\Lambda_c^+ \pi^-$ $(0.49 \pm 0.04)\%$	

* Easiest decay is personal choice; high branching fraction, low number of final state particles, no neutrinos or photons

b-physics at LHCb

[arXiv 2204.13042](https://arxiv.org/abs/2204.13042)



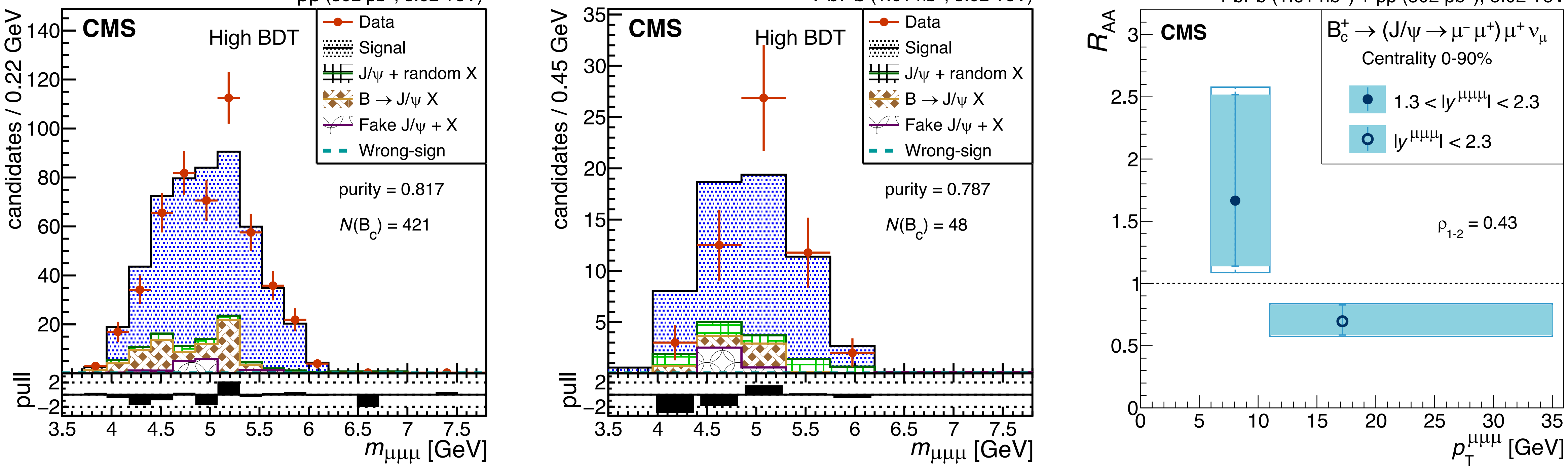


- Same final state was used for B^0 and B_s^0
  - Lots of systematics cancel
- Strangeness enhancement is visible by eye
- $\sigma_{B_s^0}/\sigma_{B^0}$ did not change with track number in opposite direction to b-hadron flight

b-physics at CMS

sPHENIX

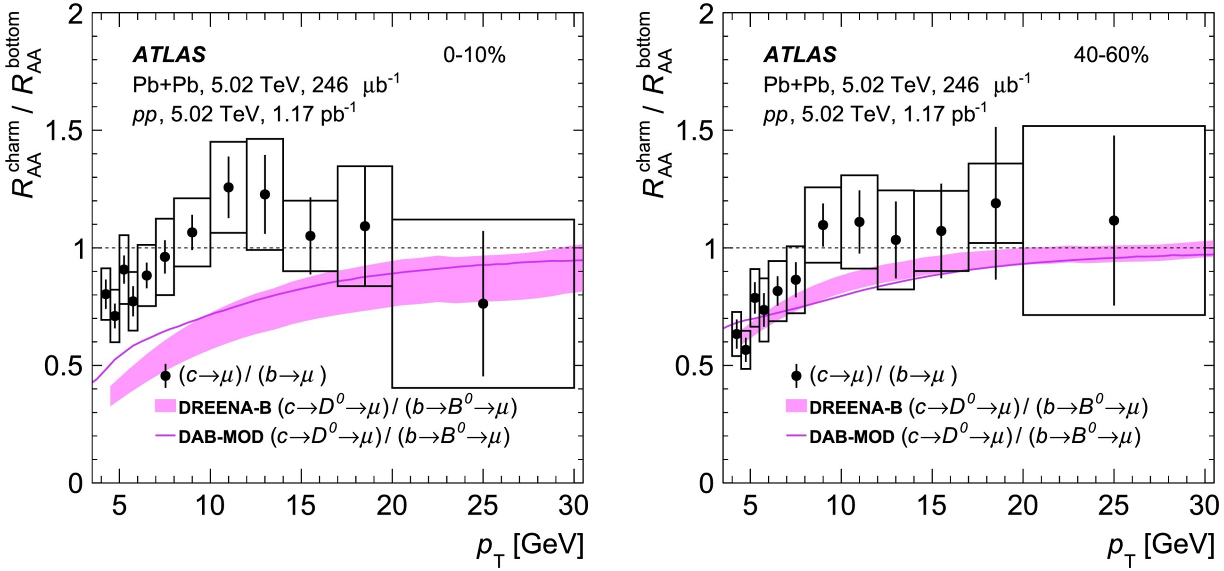
PRL 128, 252301



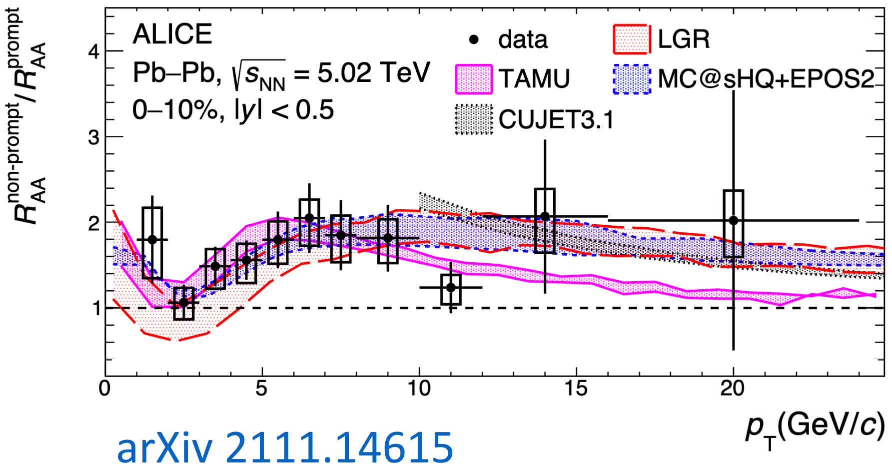
- $B_c^{\pm}$ was measured in PbPb collisions
  - Challenging, cross-section is small compared to $B^{\pm}$
- Took advantage of ML techniques and good simulations

b-physics at STAR, ALICE and ATLAS

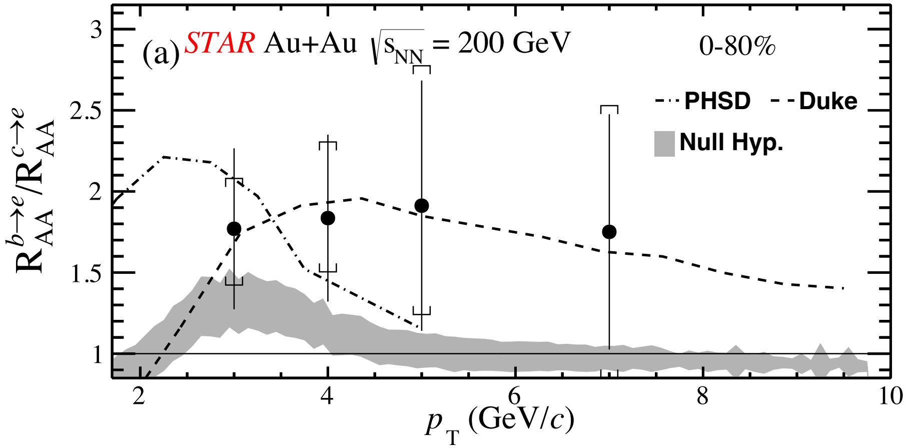
PLB 2022 137077



arXiv 2202.00815



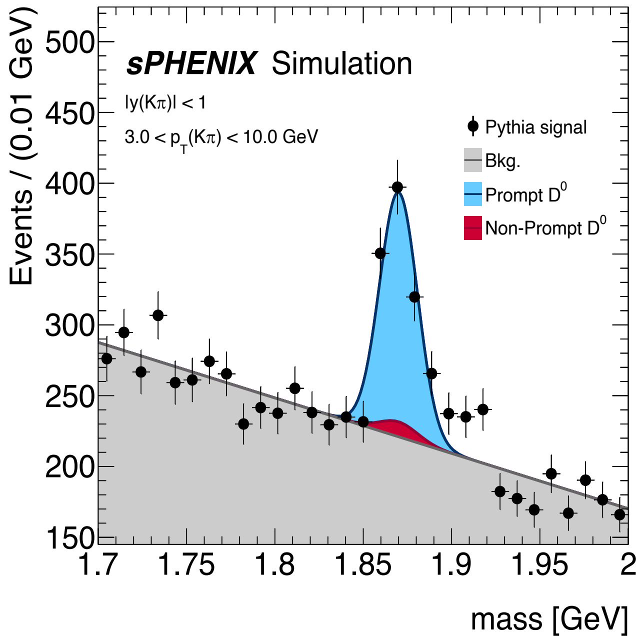
arXiv 2111.14615

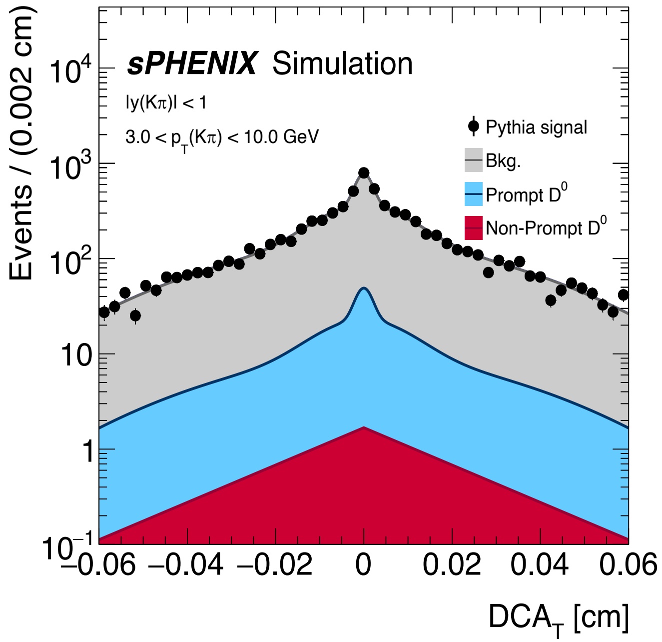


- $m_b \gg m_c$, would expect less suppression
  - Especially at low p_T
- Evidence from many collaborations
  - More statistics at low p_T would help us

Current expectations

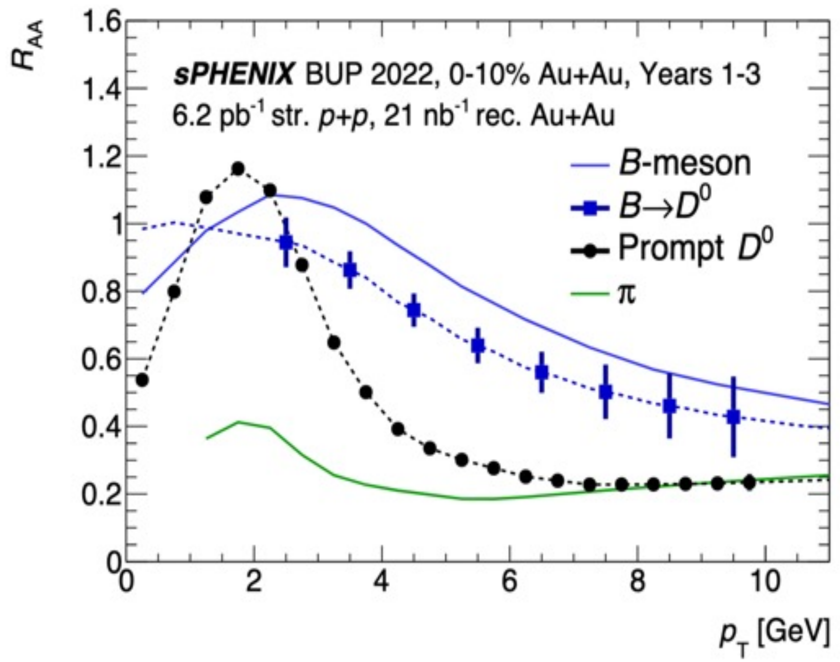
sPH-HF-2021-001



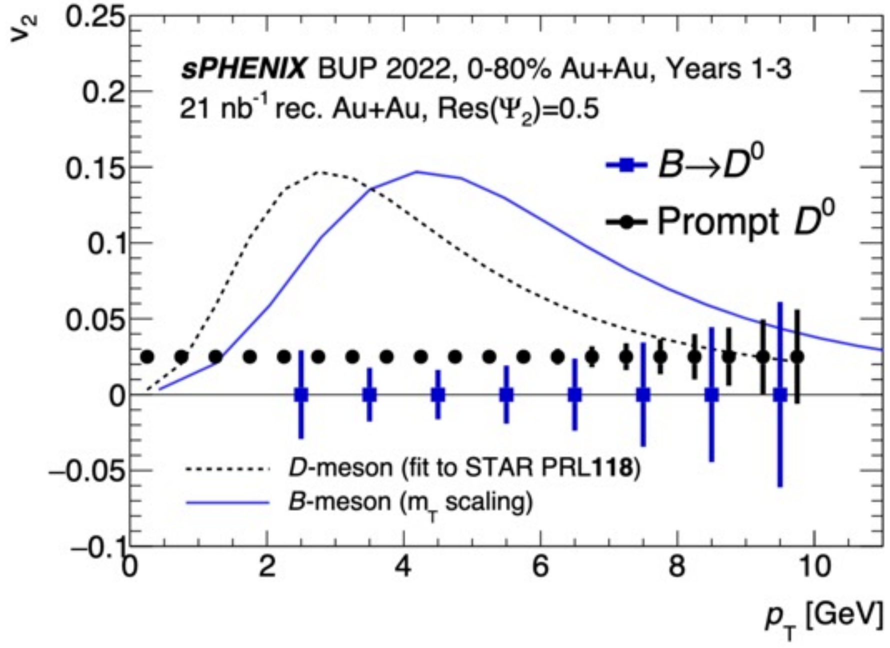


- Non-prompt charm meson decays require good DCA measurement
  - Can we handle separation in pile-up scenarios (by not mis-ID the primary vertex)
- Collaborations relied on external input on had. Fraction to separate B_s^0
  - Can a data-driven technique be developed for inclusive measurements?

Current expectations



PRL 118, 212301

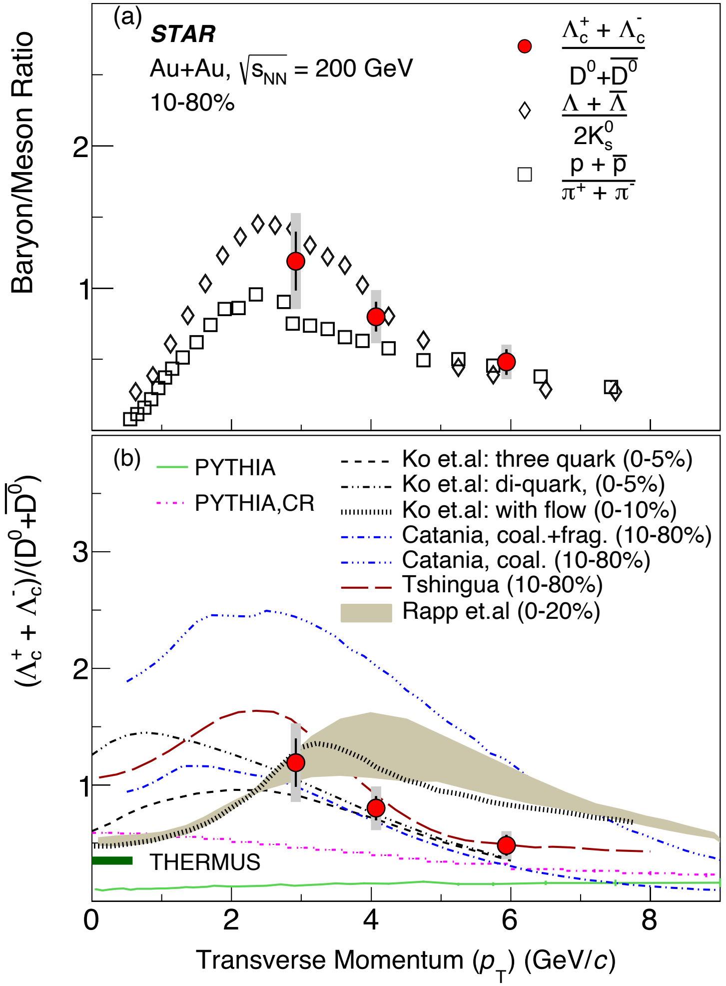


- Low pT heavy flavor region is interesting
  - More influence from the medium
- Can we also extract R_{AA} for Λ_b^0 for baryon/meson suppression

Personal musings

- Can we access Λ_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?

PRL 124, 172301



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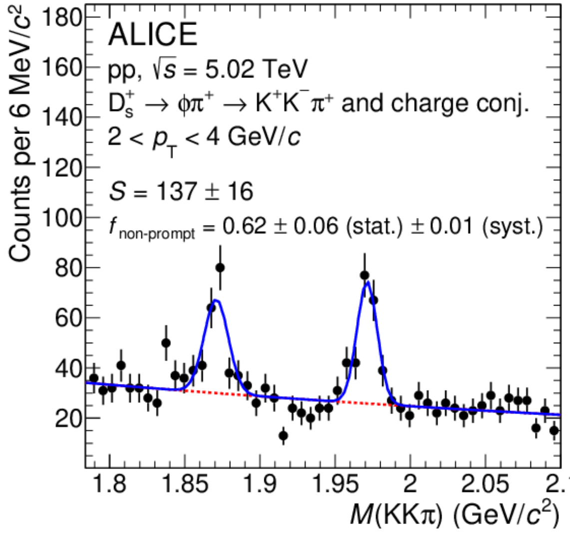
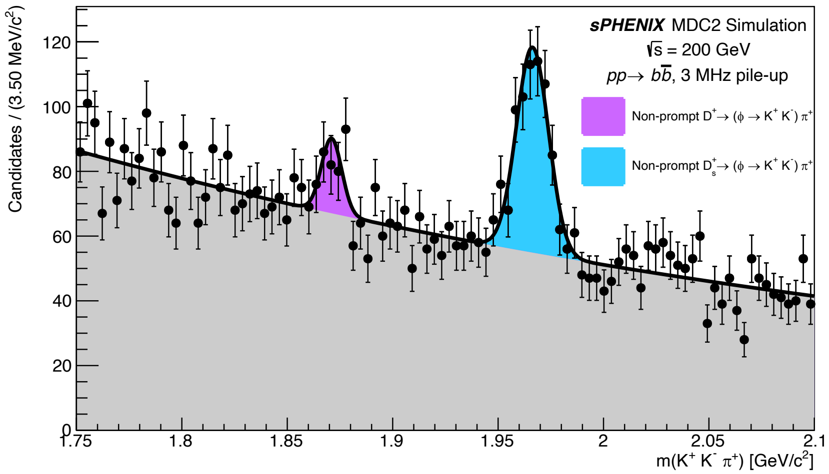
JHEP 2105 (2021) 220



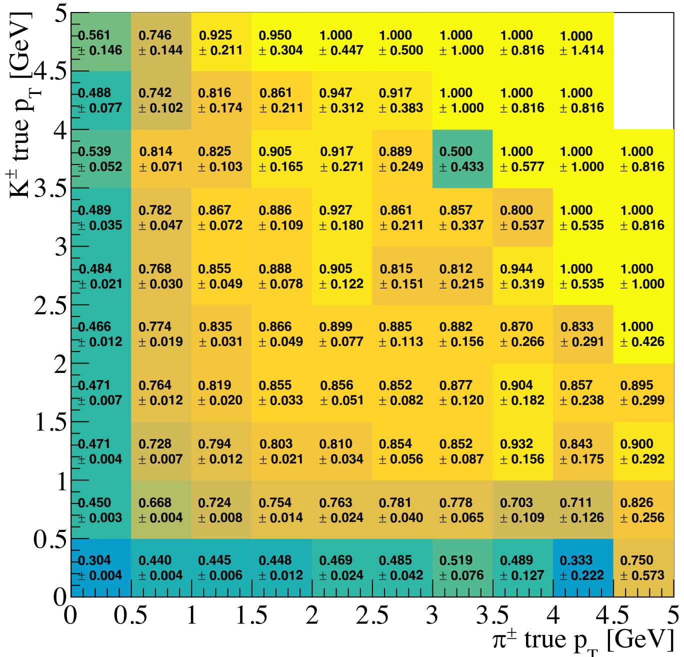


Expected yields at sPHENIX

Assumptions

1. Data samples:
   - *pp*: 2.4x10[11] min-bias events
   - *p*Au: 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, 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)



Heavy flavor tracking efficiency as a function of true track p_T for D^0.

n.b. The values are the products of both track efficiencies

Expected yields at sPHENIX

Channel	pp	pAu
$b \to D^0(\to K^-\pi^+)X$	1.1M	400k
$b \to D^+(\to K^-\pi^+\pi^+)X$	500k	180k
$b \to D_s^+(\to K^+K^-\pi^+)X$	250k	90k
$b \to \Lambda_c^+(\to pK^-\pi^+)X$	40k	15k
$B^+ \to D^0(\to K^-\pi^+)\pi^+$	2000	700
$B^0 \to D^+(\to K^-\pi^+\pi^+)\pi^+$	1000	350
$B_s^0 \to D_s^+(\to K^+K^-\pi^+)\pi^+$	250	100
$\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^+$	650	250

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)