The 37th Winter Workshop on Nuclear Dynamics

February 27, 2022 to March 5, 2022
Marriott Puerto Vallarta Resort & Spa

HEAVY FLAVOR AND QUARKONIA PHYSICS AT SPHENIX

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For the sPHENIX Collaboration

Overview

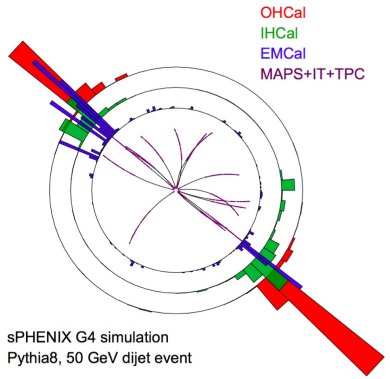
- sPHENIX Physics Program and Detectors
- Tracking Reconstruction Progress
- Heavy Flavor (HF) and Quarkonia Physics Motivation and Projections
- Recent Studies and Results
- Assembly and Installation Progress
- Summary

sPHENIX Physics Program

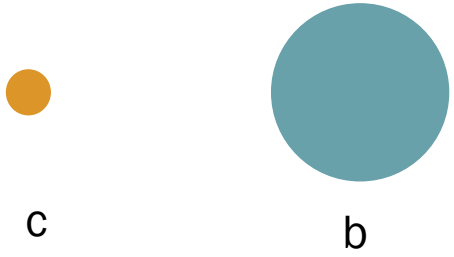
- Next generation of RHIC detectors
- Detailed study of:
  - Quark-Gluon Plasma produced at RHIC
  - Parton energy loss and structure
  - Mass dependent energy loss
- p+p, p+Au, Au+Au collisions

Jets and Photons

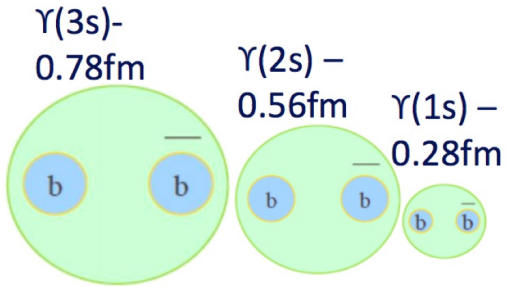
Virginia's talk earlier in the week



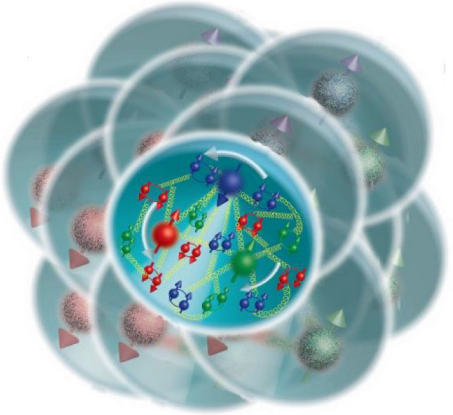
Open Heavy Flavor



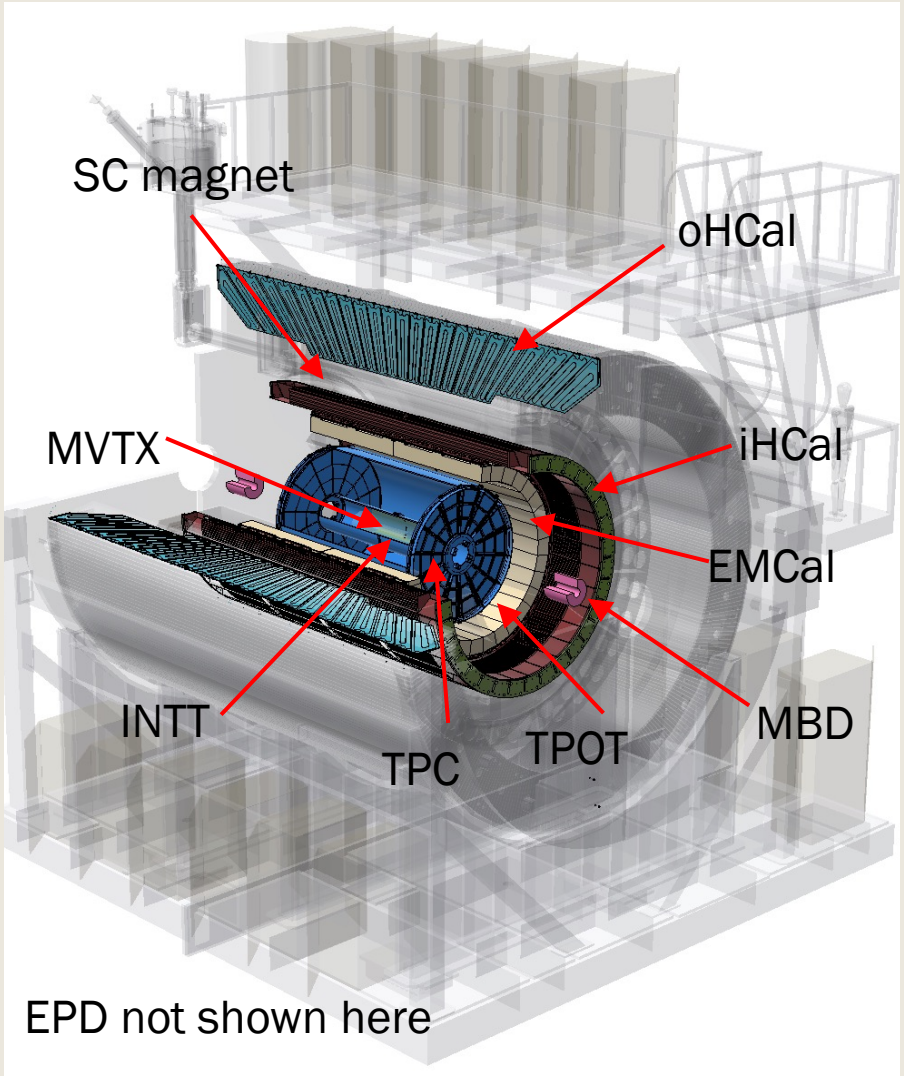
Upsilons



Cold QCD



sPHENIX Detector



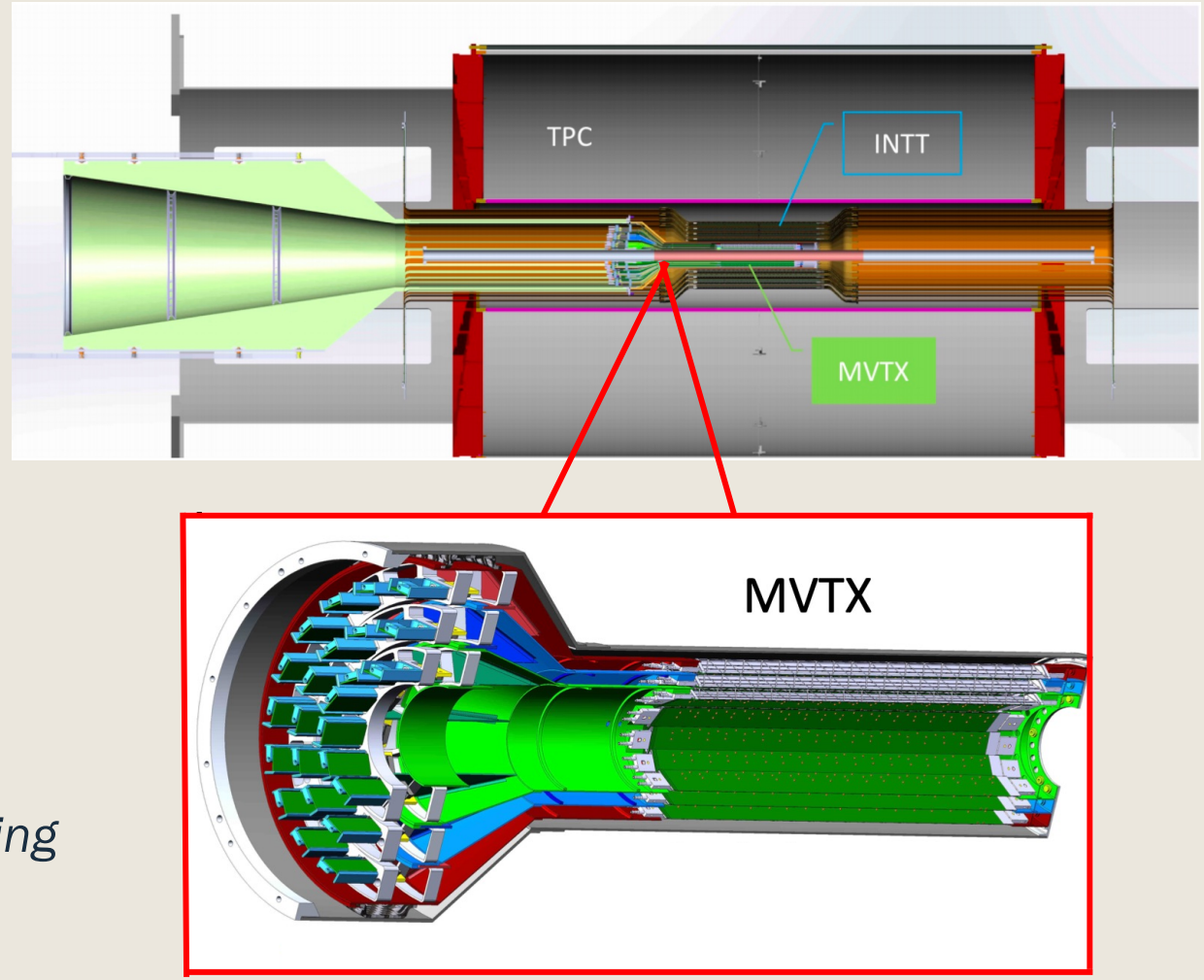
- 1.4 T solenoidal B field
- 15 kHz Trigger plus streaming readout events
- $|\eta| \leq 1.1$
- Full 2π azimuthal coverage
- *"sPHENIX construction, installation and operation to accomplish its science goals is now the overarching priority for RHIC for the next 4-5 years"* - PAC Report, June 2021

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

sPHENIX Beam Use Proposal,2021.

Tracking Detectors

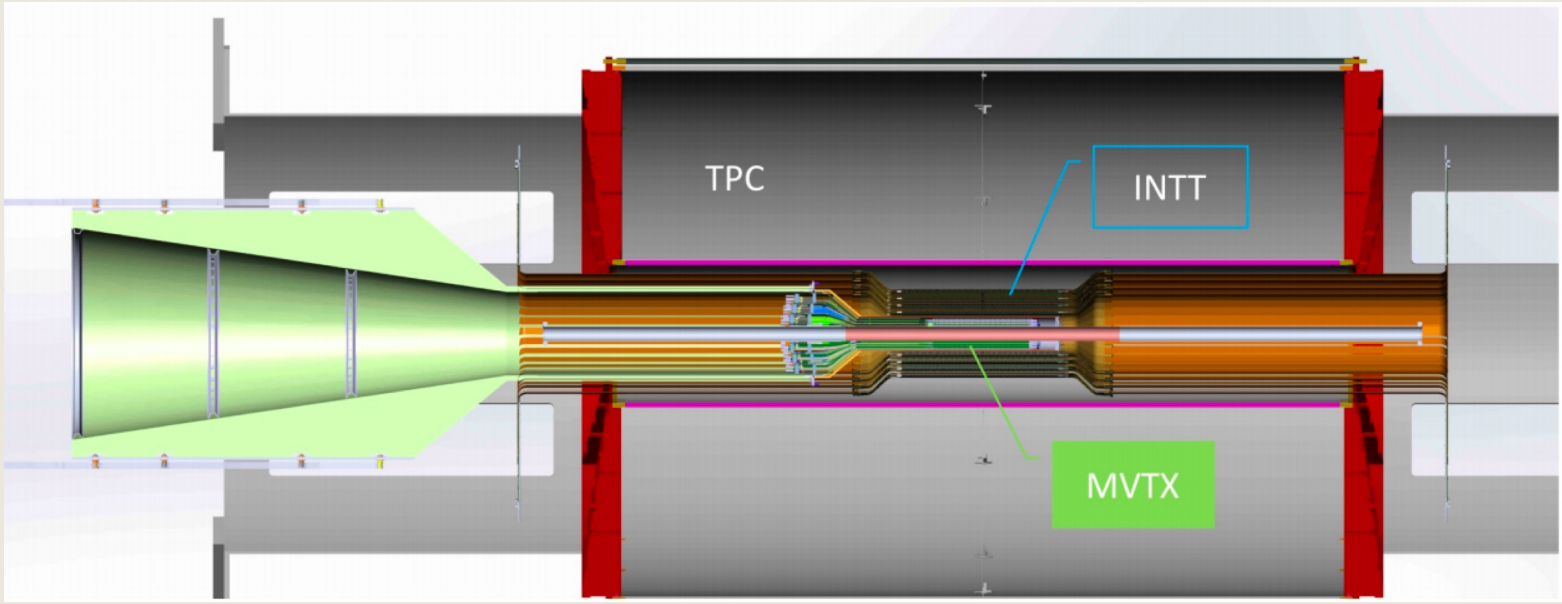
- MAPS-based micro-VerTeX detector (MVTX):
  - *30 μm pitch MAPS pixels*
  - *3 layers, 2.3 cm < r < 3.9 cm*
  - *~ 5 μm space point precision each*
  - *5-10 μs integration time*
- INTermediate silicon strip Tracker (INTT):
  - *4 layers, 6 < r < 12 cm*
  - *Pitch 78 μm*
  - *Fast enough to resolve one beam crossing*



Dean, Cameron. Heavy Flavor at sPHENIX. Jun. 9, 2021.
Frawley, Anthony. Quarkonium Detection and Physics with sPHENIX. Oct. 25-27, 2021.

Tracking Detectors

- Time Projection Chamber (TPC):
  - *90:10 Ne-CF4 gas*
  - *8 cm/μs electron drift velocity*
  - *48 layers, 30 < r < 78 cm*
  - *Δp/p ~ 1% at 5 GeV/c*



Dean, Cameron. Heavy Flavor at sPHENIX. Jun. 9, 2021.
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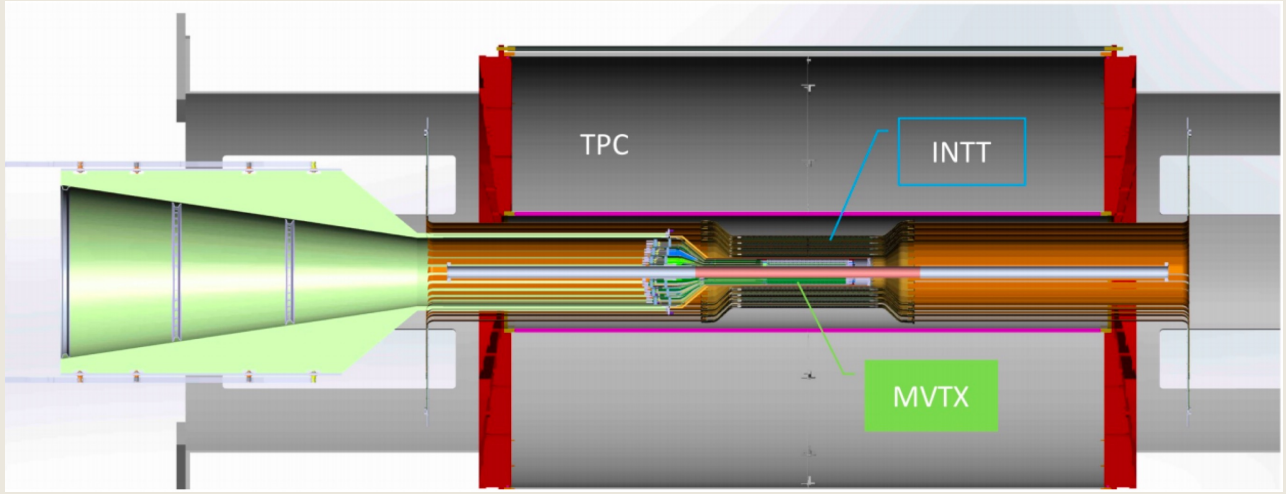
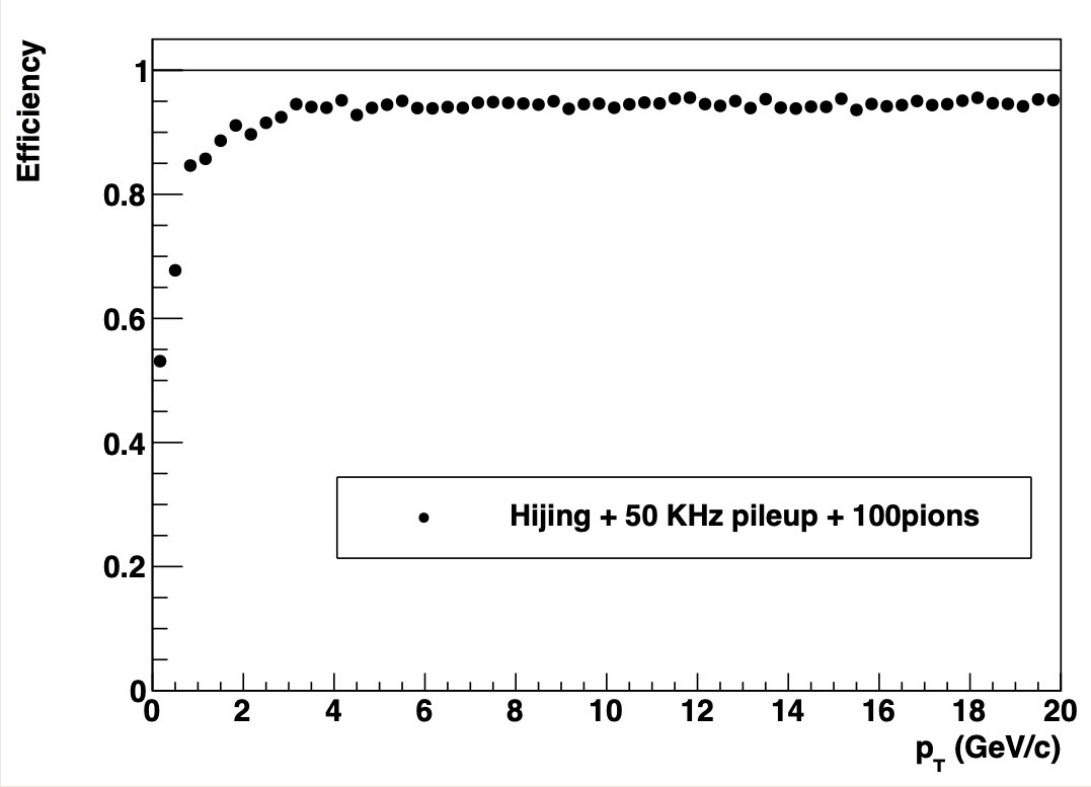
Recent Progress in Tracking Performance

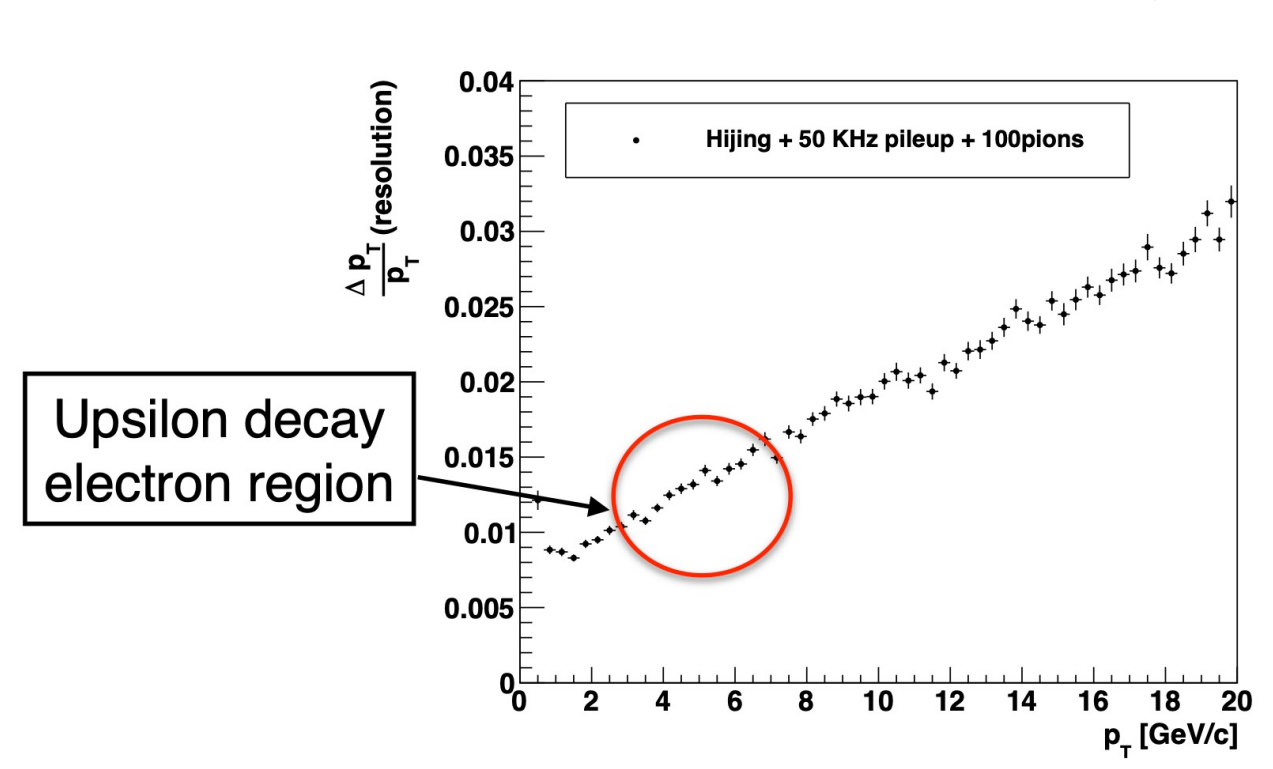


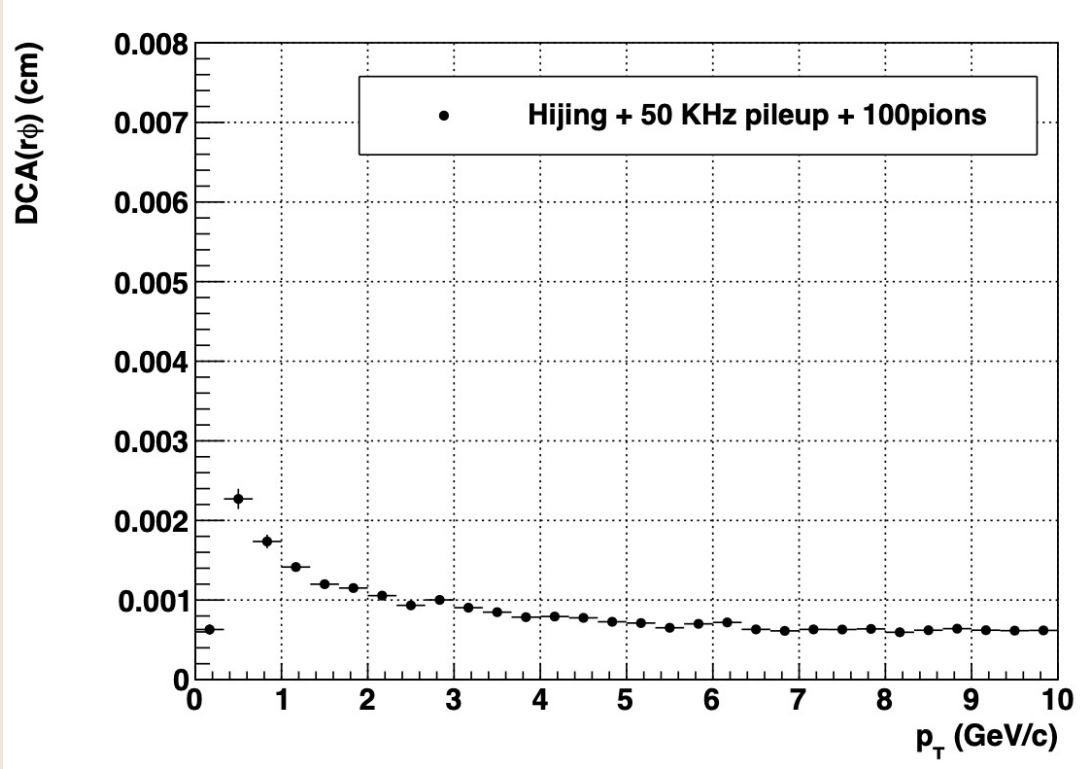


- Requiring MVTX hits for HF analysis drops the efficiency by ~5-10%

Frawley, Anthony. Quarkonium Detection and Physics with sPHENIX. Oct. 25-27, 2021.

Recent Progress in Tracking Performance

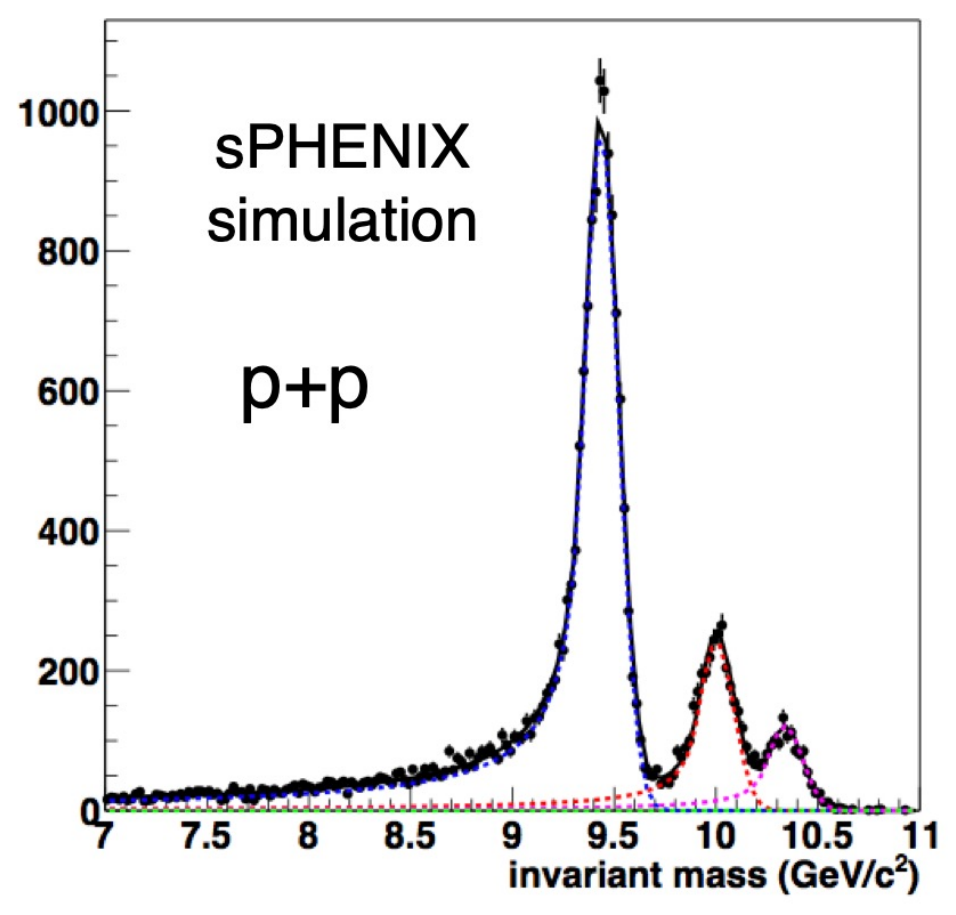




Implementation of TPC clustering designed to handle overlaps should further improve efficiency and pT resolution

Frawley, Anthony. Quarkonium Detection and Physics with sPHENIX. Oct. 25-27, 2021.

Upsilon Mass Reconstruction



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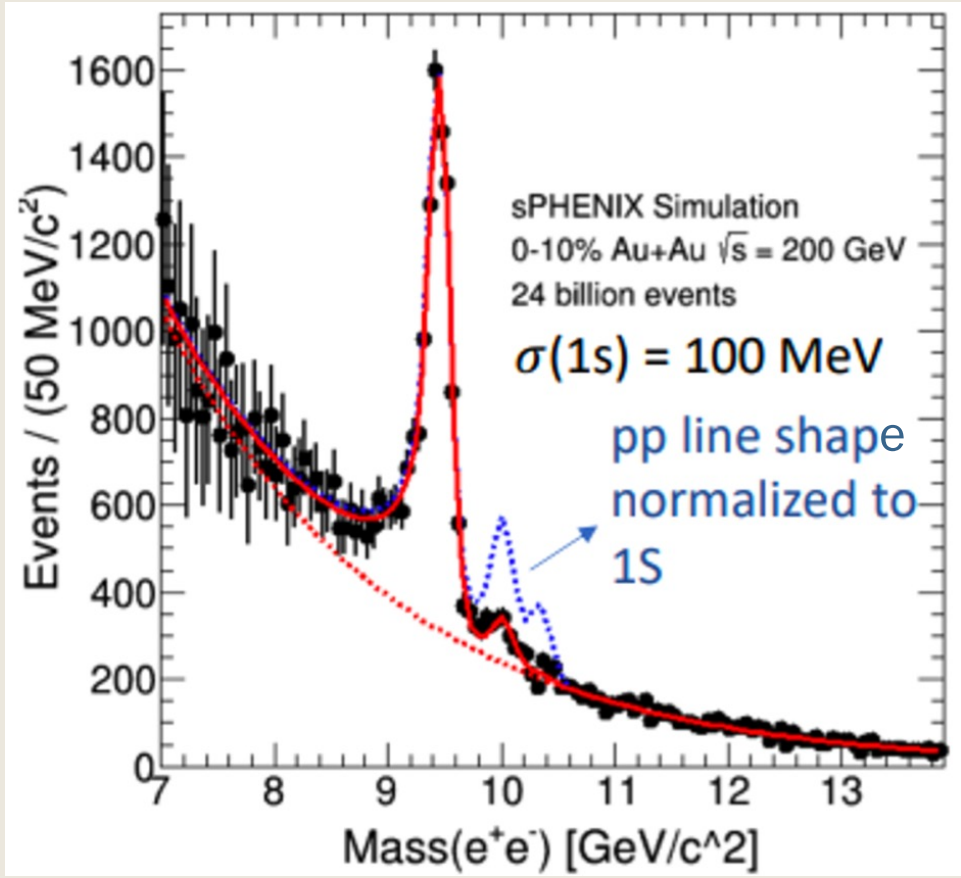
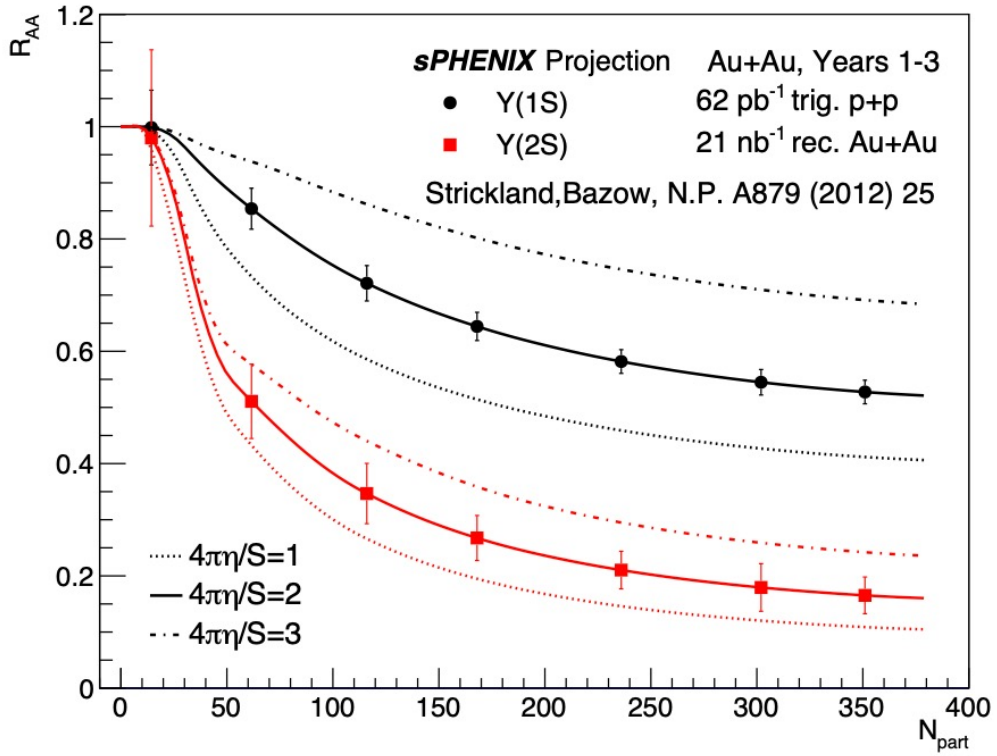
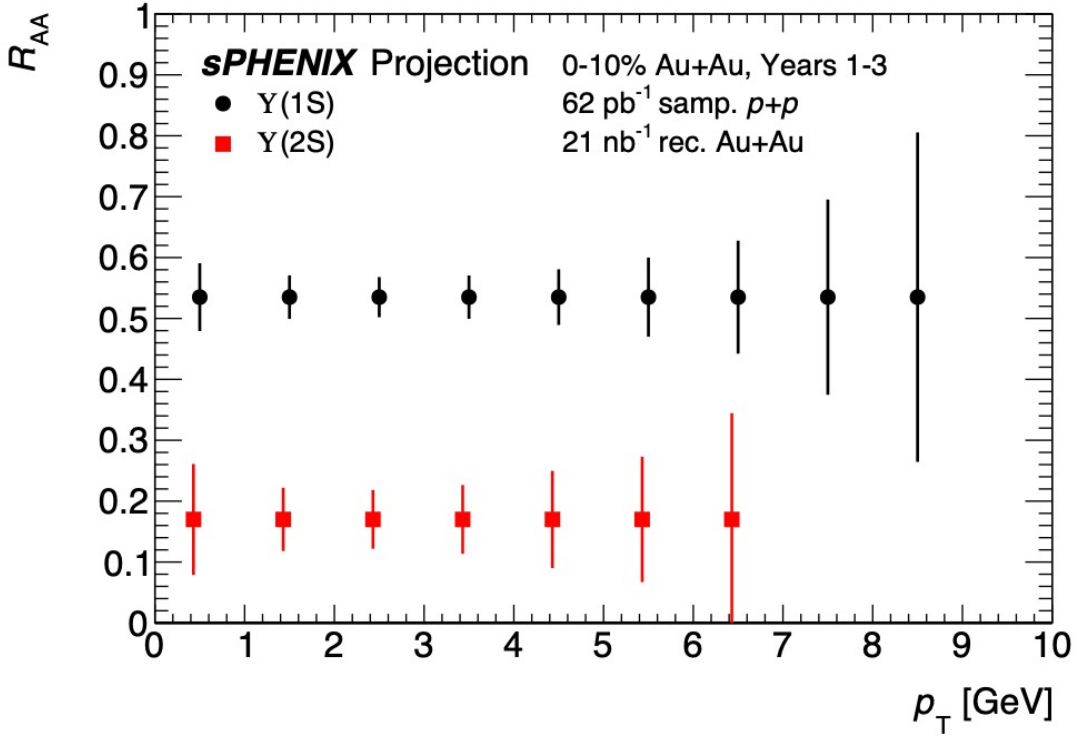


cf. CMS PbPb measurement using μ+ μ-

Quarkonia Physics at sPHENIX

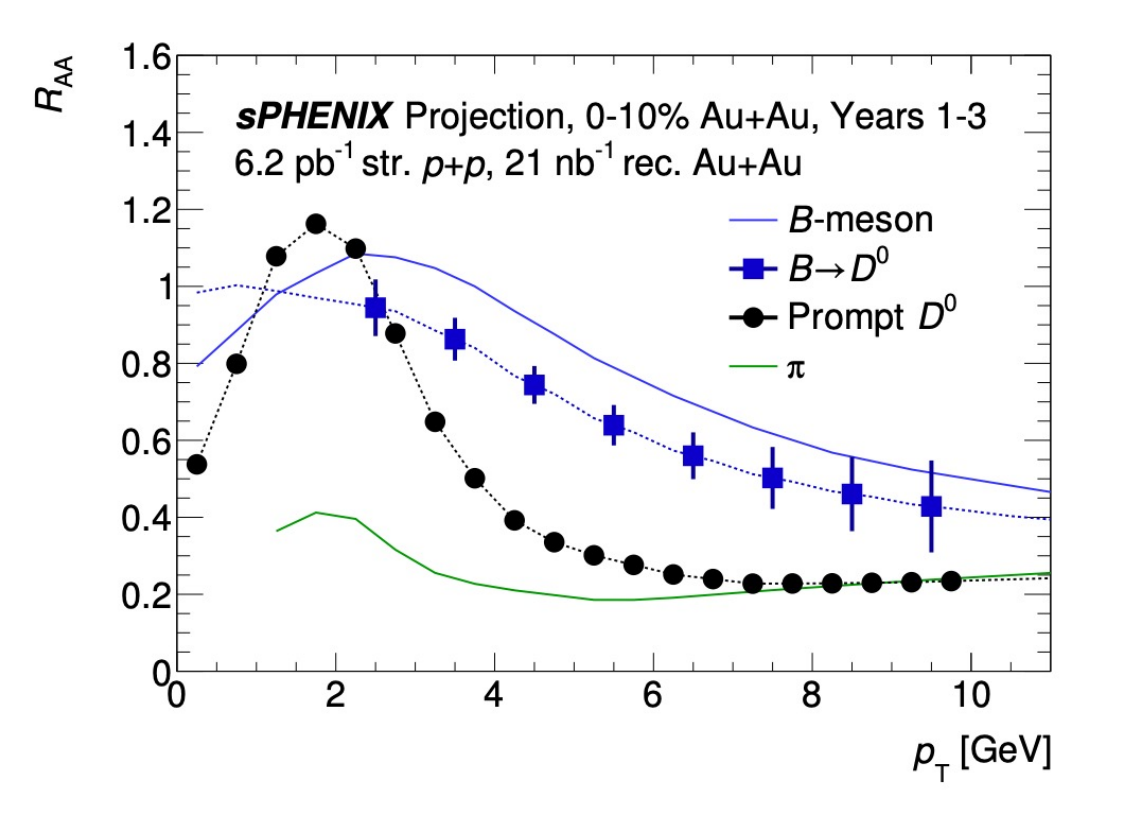


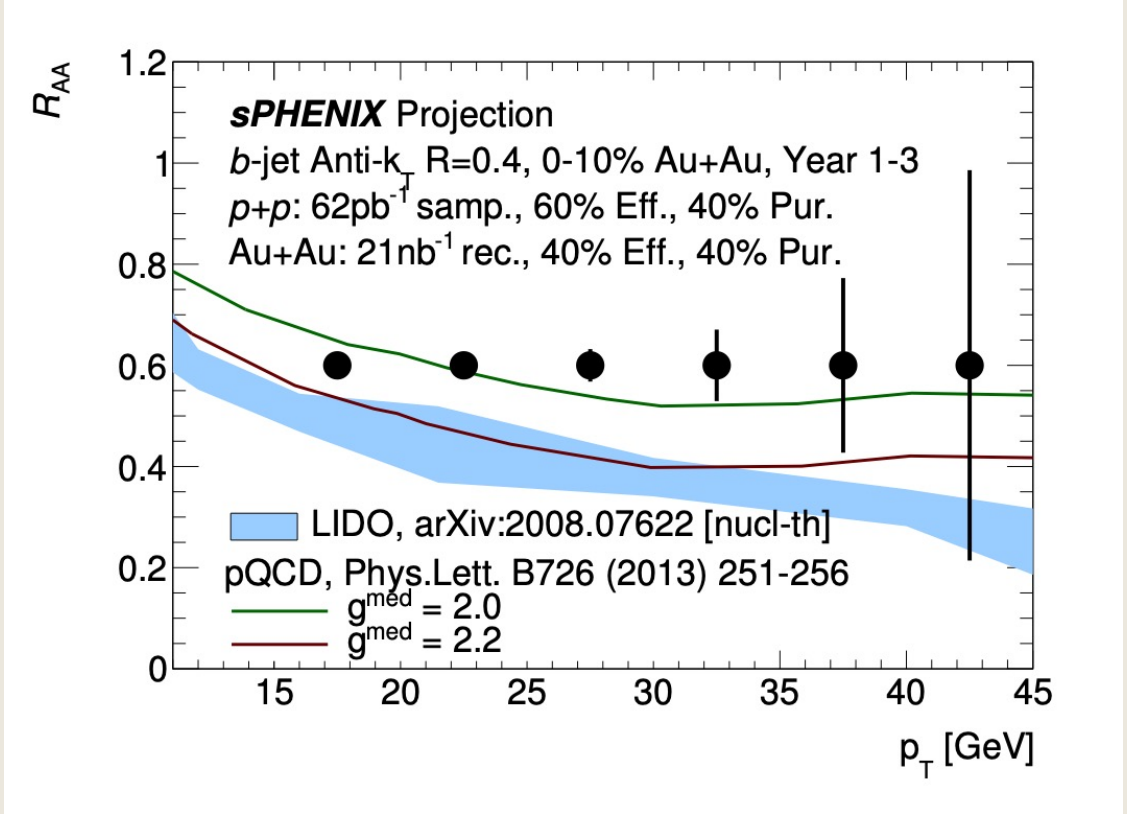


- Y(3s) state heavily suppressed
- Uses expected luminosity from 2024 p+p run and 2025 Au+Au run

sPHENIX Beam Use Proposal,2021.

Open Heavy Flavor Physics at sPHENIX

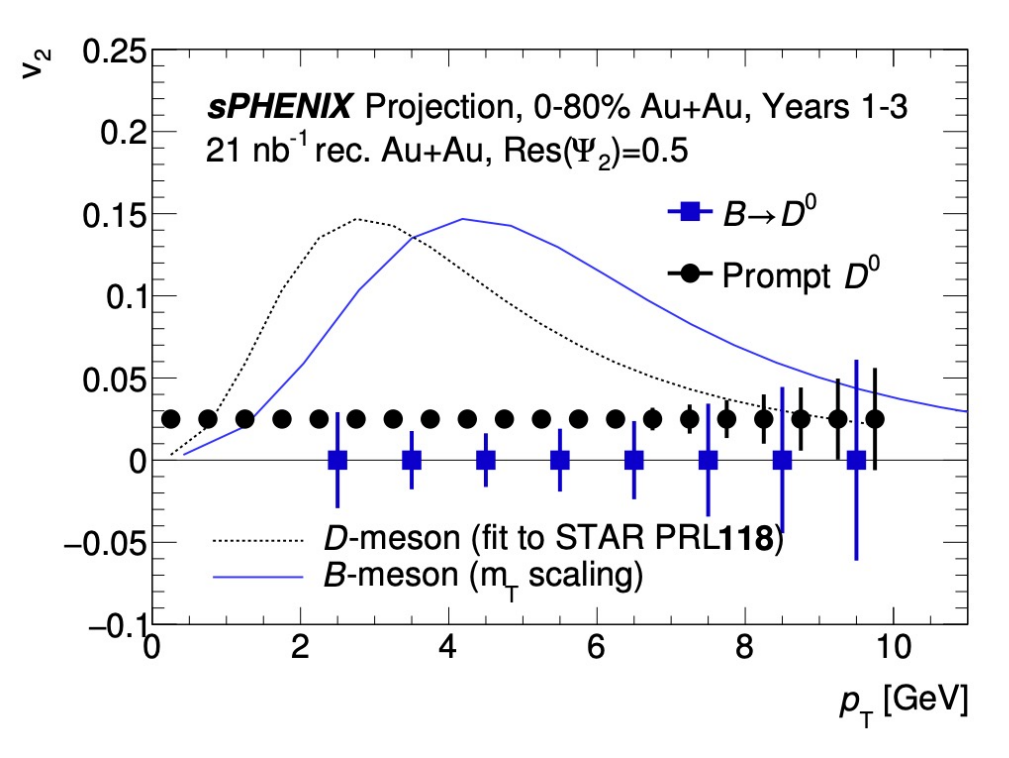


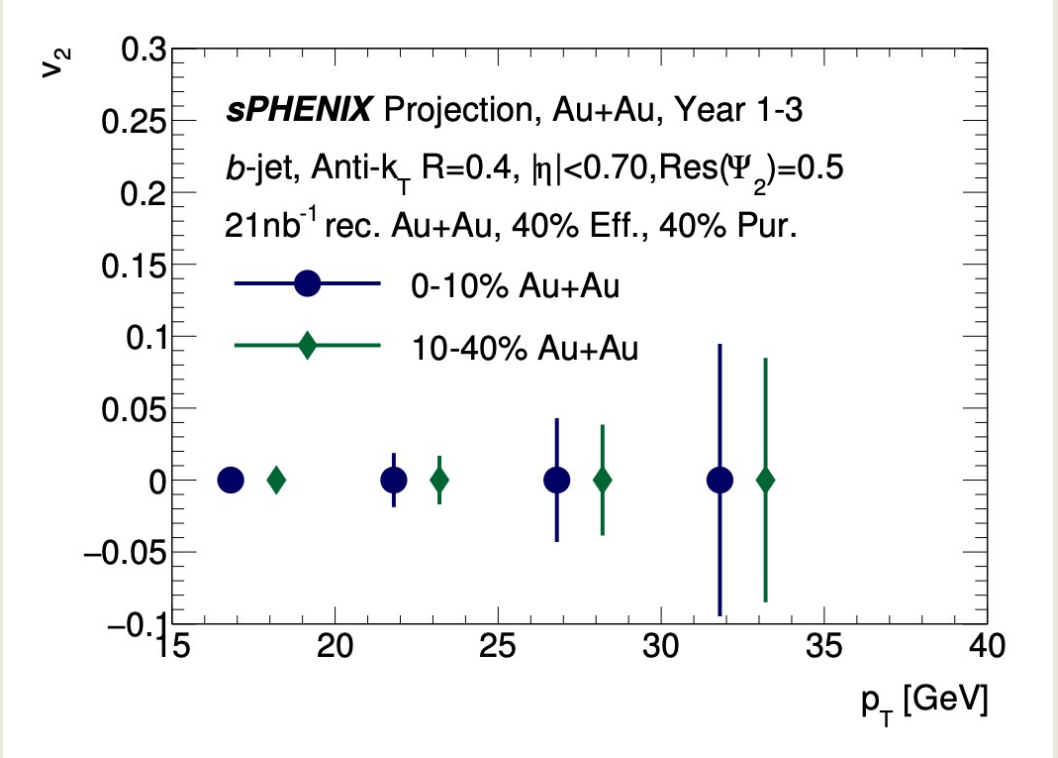


- R_{AA} for bottom quarks and light quarks expected to be different for $p_T \lesssim 15$ GeV
- Less significant for b-jets at higher p_T

sPHENIX Beam Use Proposal,2021.

Open Heavy Flavor Physics at sPHENIX



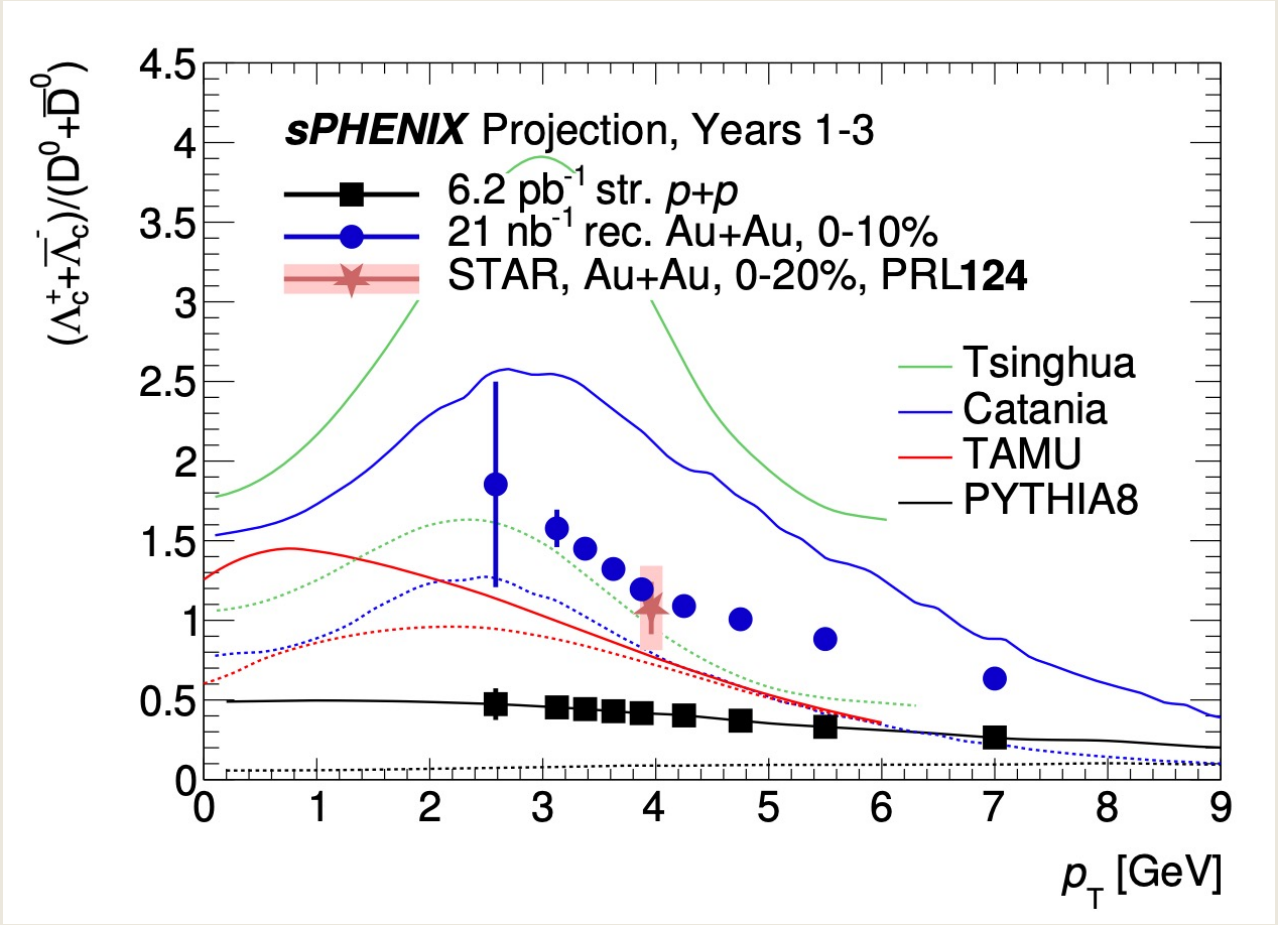


- Collective motion of particles sensitive to initial stages of collision (deconfined QGP phase)
- Precision bottom measurements allow better constraints on heavy quark diffusion transport parameter of QGP and its temperature dependence

sPHENIX Beam Use Proposal,2021.

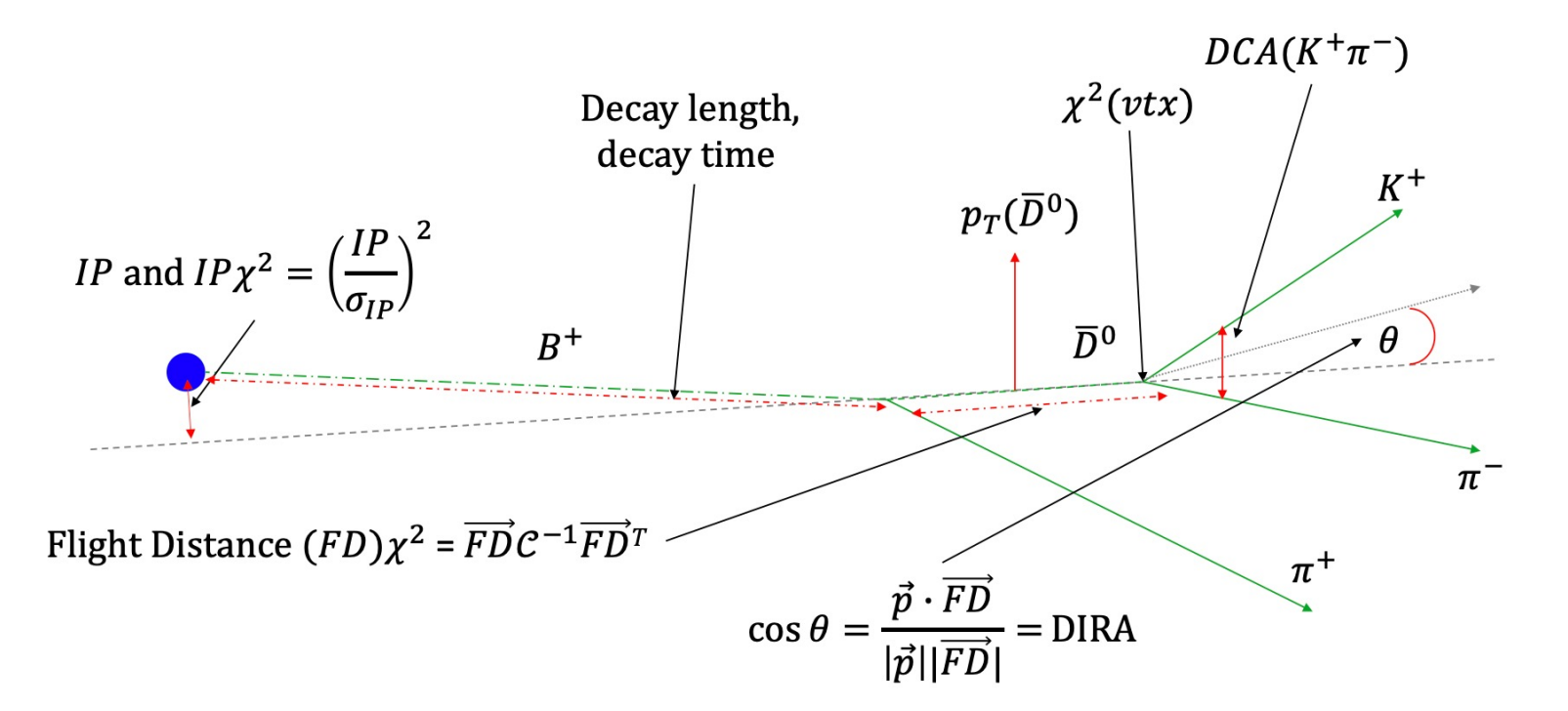
Open Heavy Flavor Physics at sPHENIX

- RHIC and LHC data suggest significant enhancement of Λ_c baryon to D^0 meson production ratio in p+p, p+A, and A+A collisions
- sPHENIX enables first p+p Λ_c/D^0 measurement at RHIC



sPHENIX Beam Use Proposal,2021.

KFParticle Package

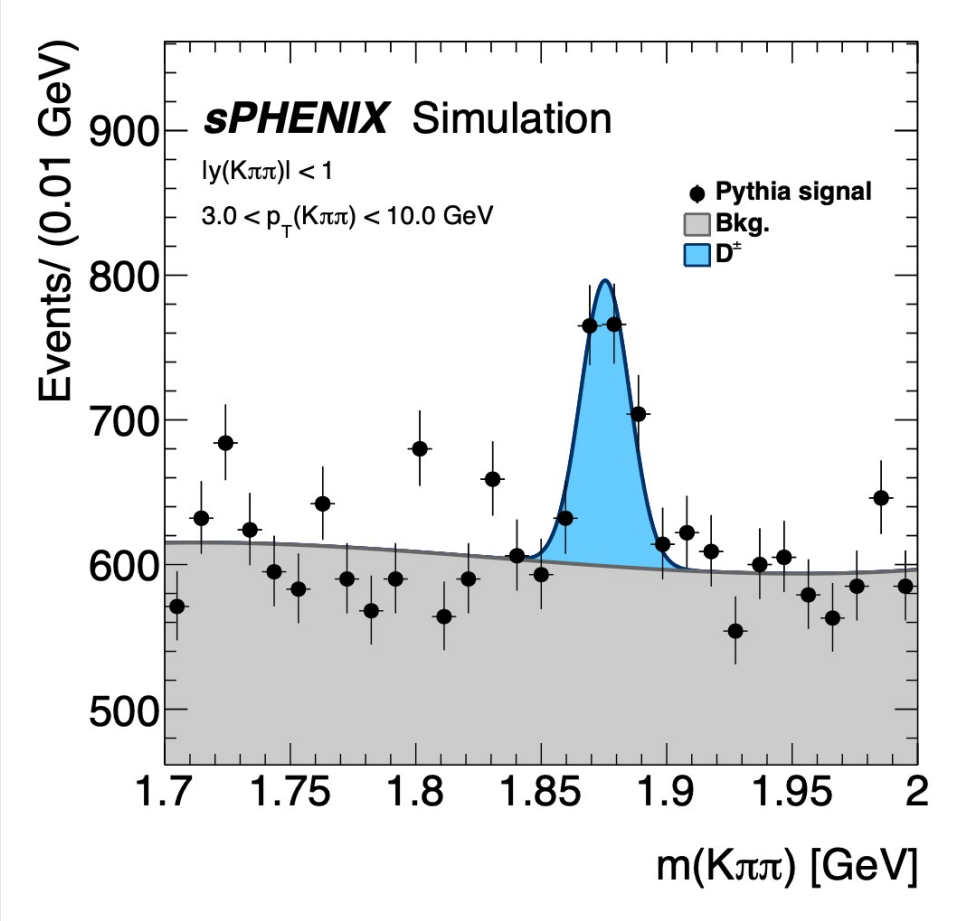


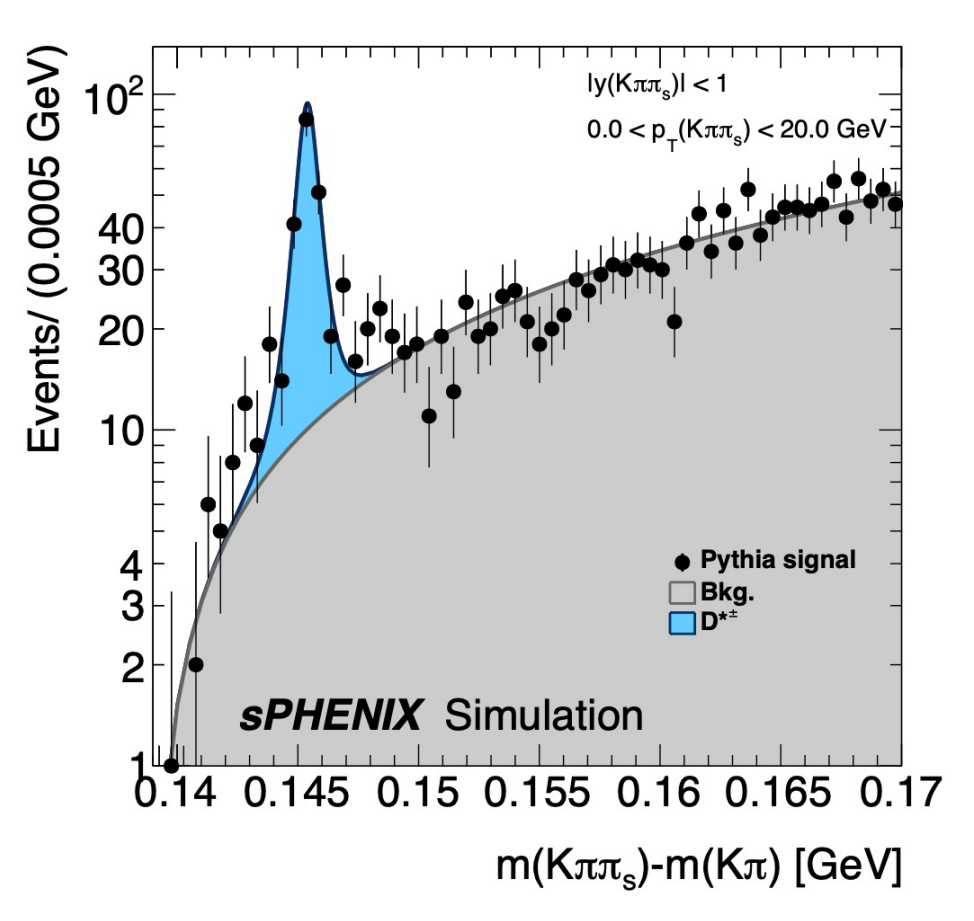
Topological cuts used to create unique PID assignments during heavy flavor reconstruction

Sacha Gorbunov and Ivan Kisel. Reconstruction of Decayed Particles Based on the Kalman Filter. May 2007.
Sebastian Tapia Araya, Cameron Dean, Jin Huang, Hideki Okawa, and Zhaozhong Shi. First MDC1 Results from Heavy Flavor Topical Group. April 2021

$D^+ \to K^-\pi^+\pi^+$
$D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$ Channels

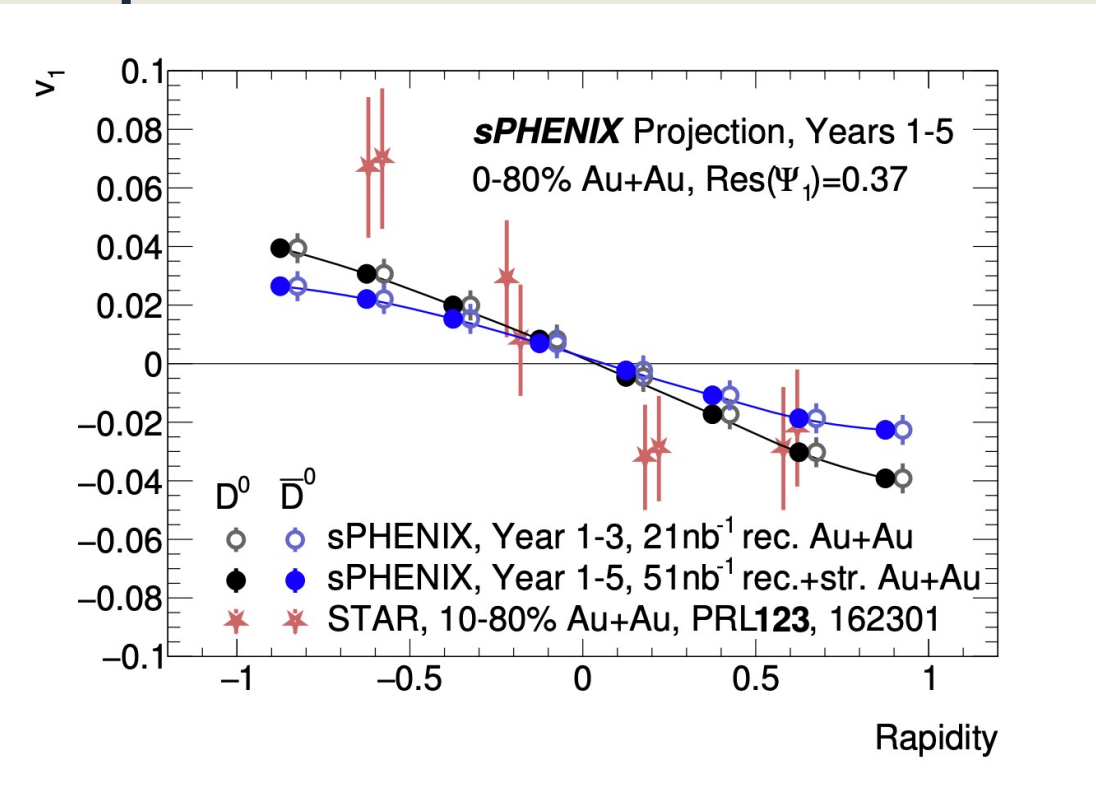
50 million $c\bar{c}$ sample, p+p $\sqrt{s} = 200$ GeV, no pileup

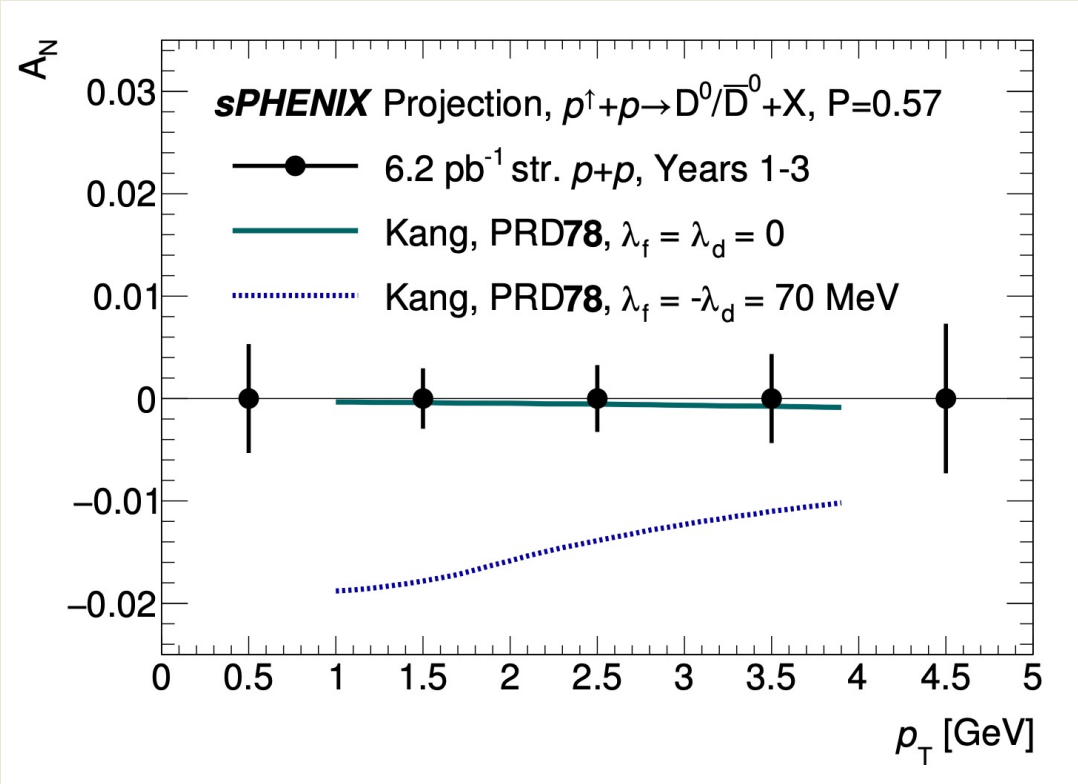




Sebastian Tapia Araya, Cameron Dean, Jin Huang, Hideki Okawa, and Zhaozhong Shi. First MDC1 Results from Heavy Flavor Topical Group. April 2021

Measurements Requiring D^0 / $\overline{D^0}$ Separation

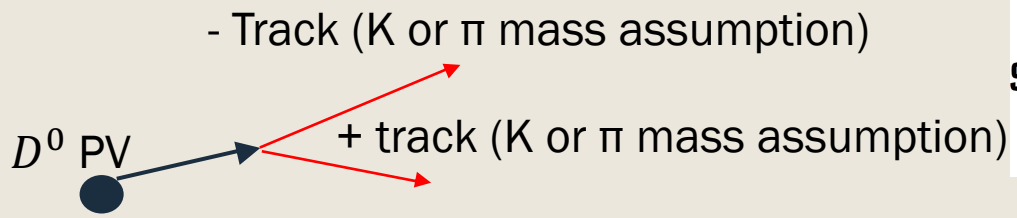




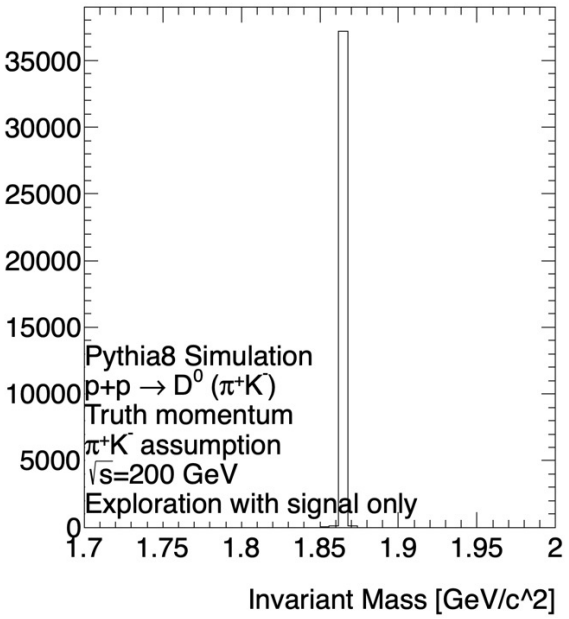
- Clean separation of v1 allows for quantitative access to initial B field in heavy ion collisions
- Transverse single spin asymmetry (TSSA) measurements able to be separated instead of averaged over D^0 / $\overline{D^0}$ together

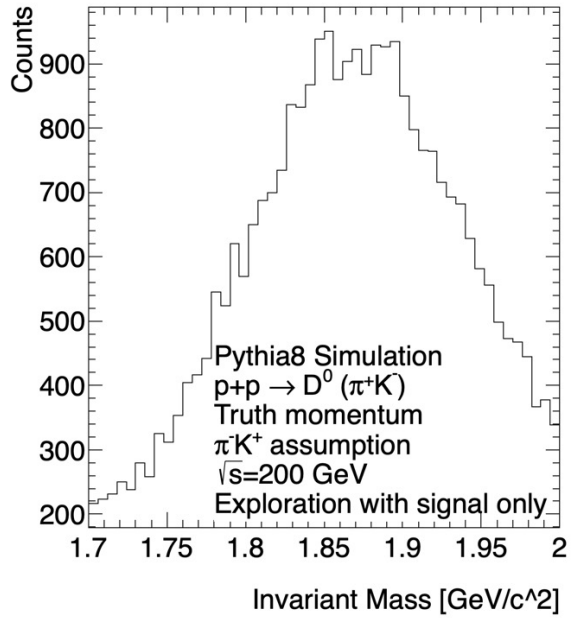
sPHENIX Beam Use Proposal,2021.

D^0 / $\overline{D^0}$ Separation

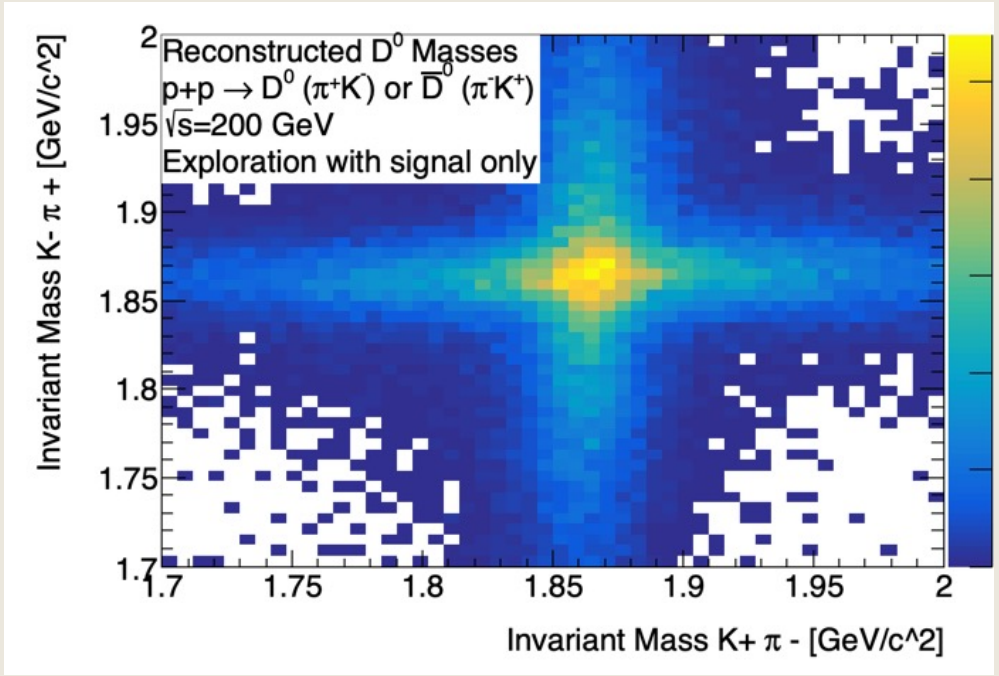


Truth D^0 Momentum



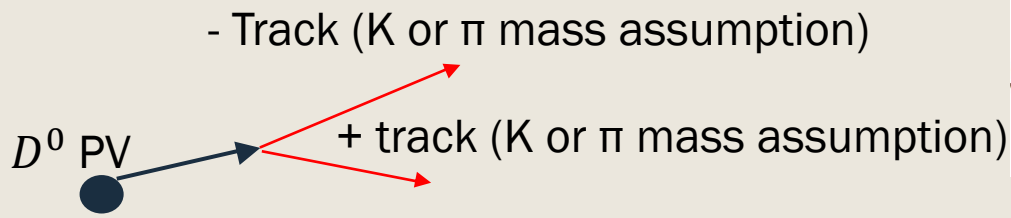


Reconstructed D^0 / $\overline{D^0}$ Momentum

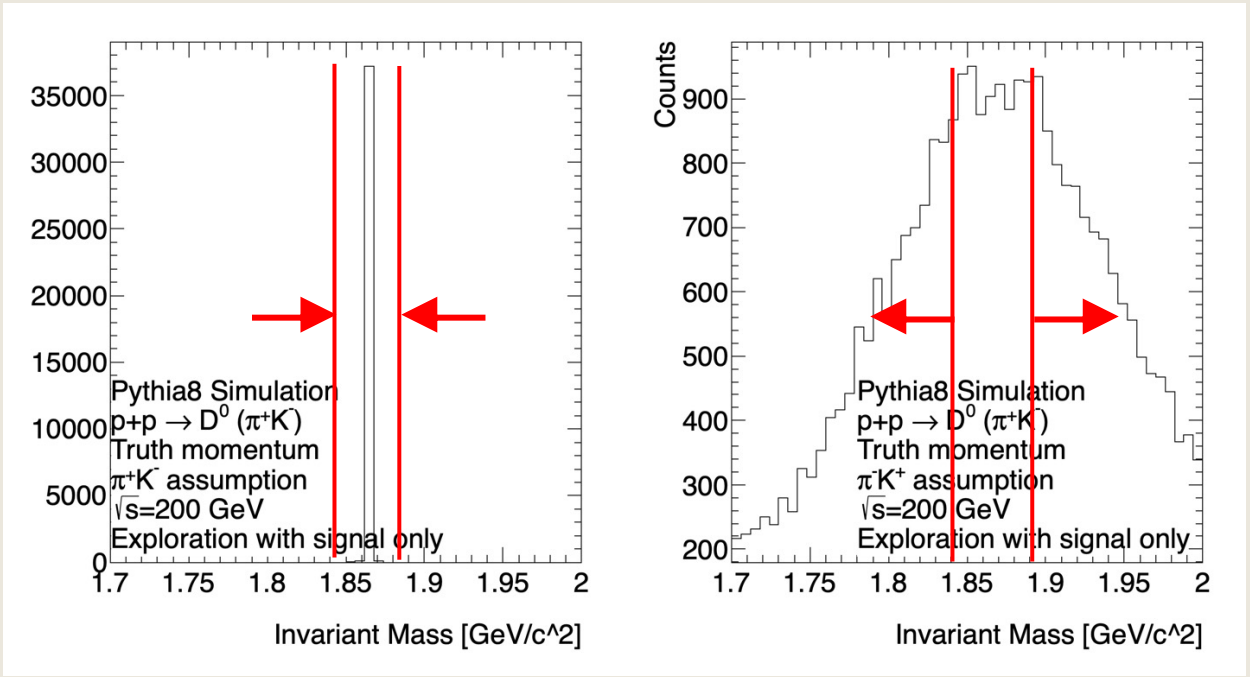


- 3 MHz p+p pileup simulation data
- Even without PID detectors, D^0 / $\overline{D^0}$ can be separated based on reconstructed invariant mass through sPHENIX's precision tracking
- Multivariate analysis ongoing, early results show clean separation at 80% signal efficiency

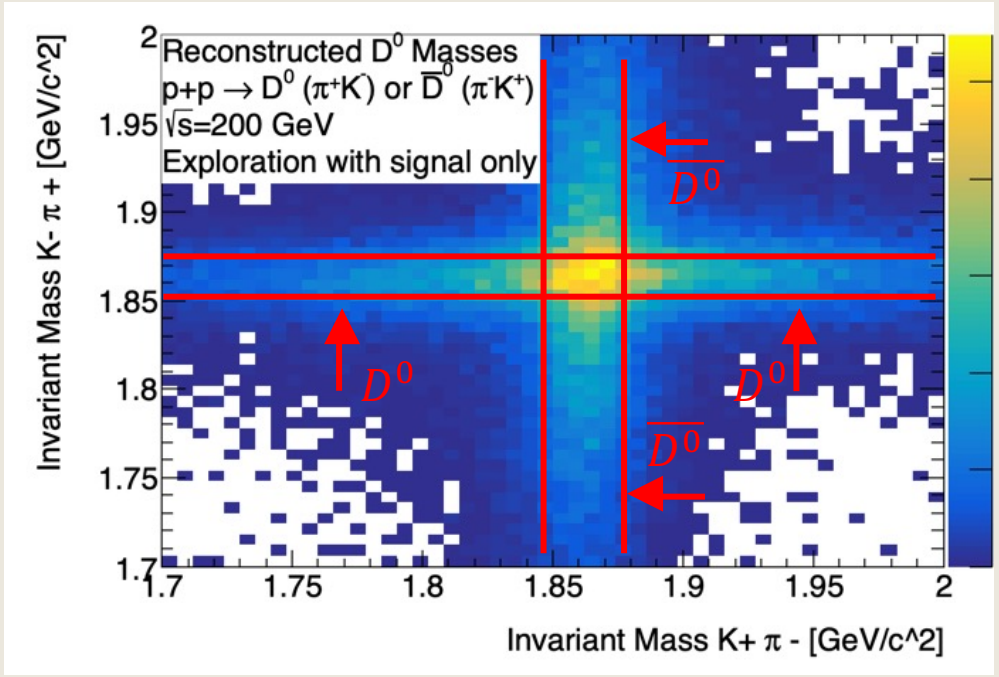
D^0 / $\overline{D^0}$ Separation



Truth D^0 Momentum



Reconstructed D^0 / $\overline{D^0}$ Momentum



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Data Taking Timeline

- oHCal and solenoid magnet completely installed
- iHCal sectors being installed in support structure to be moved and installed in assembly hall
- EMCal, TPC, INTT, and MVTX assembly all going well, installation coming soon
- Busy year ahead for the collaboration!

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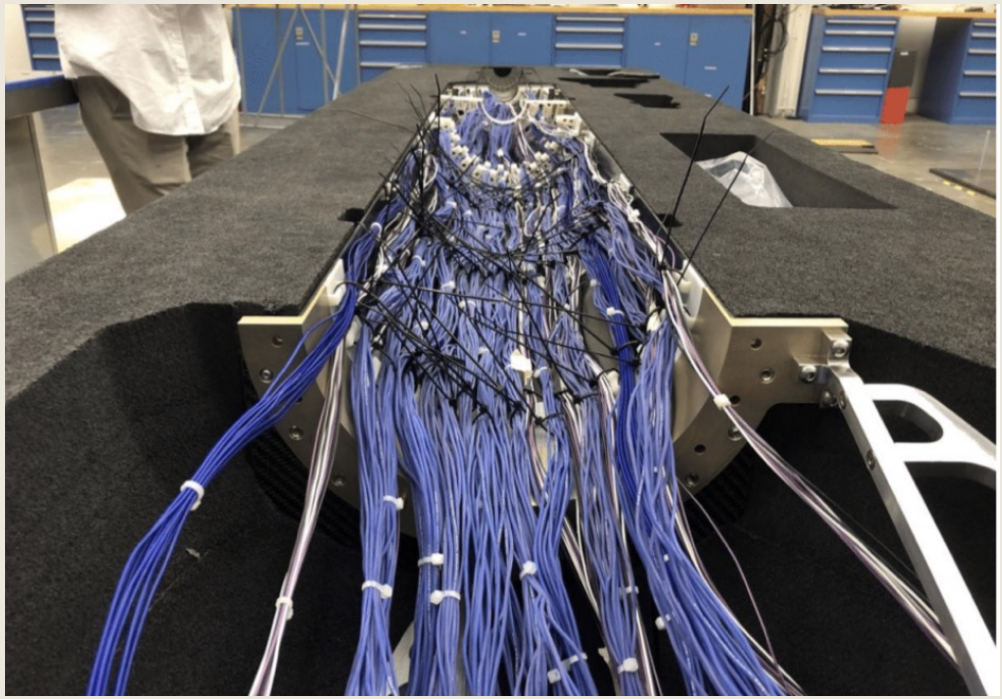
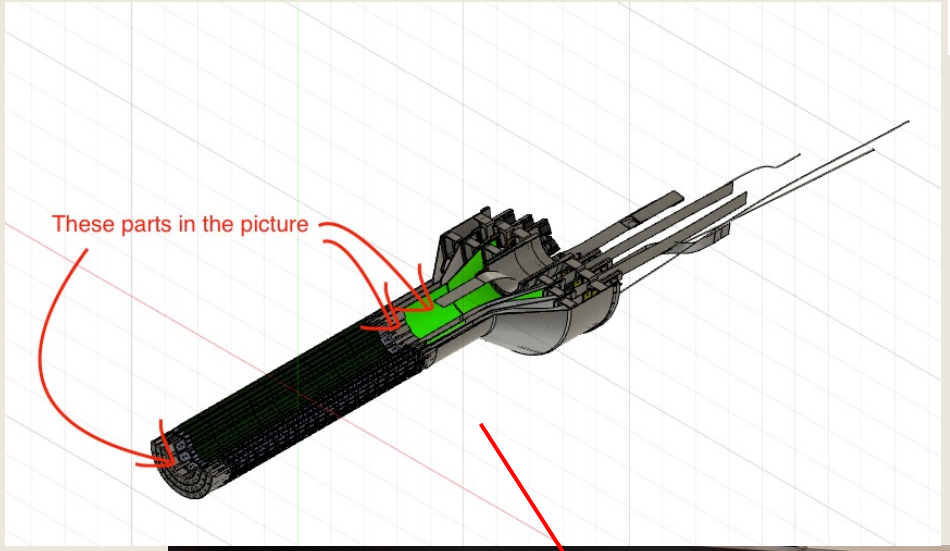
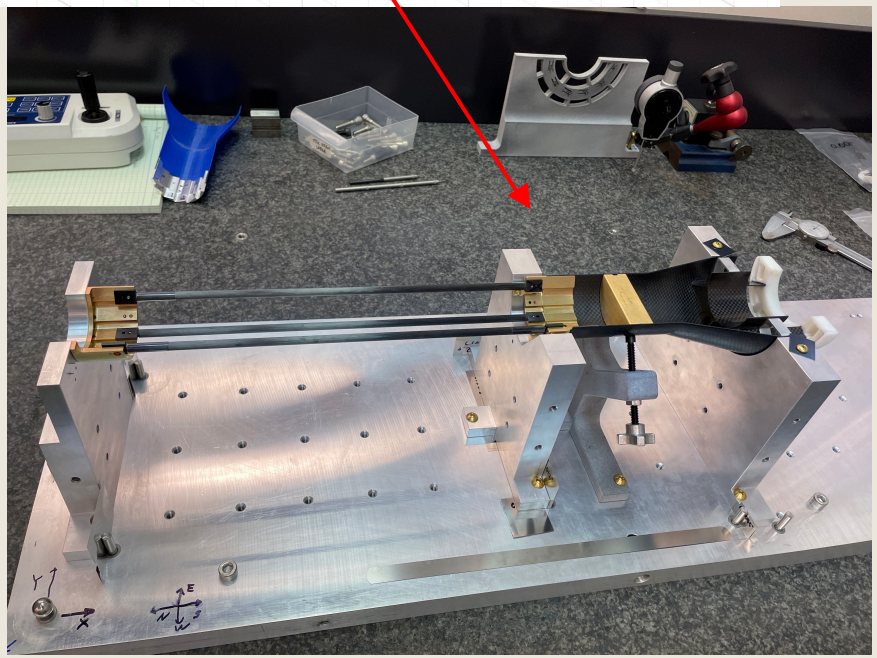
MVTX Progress

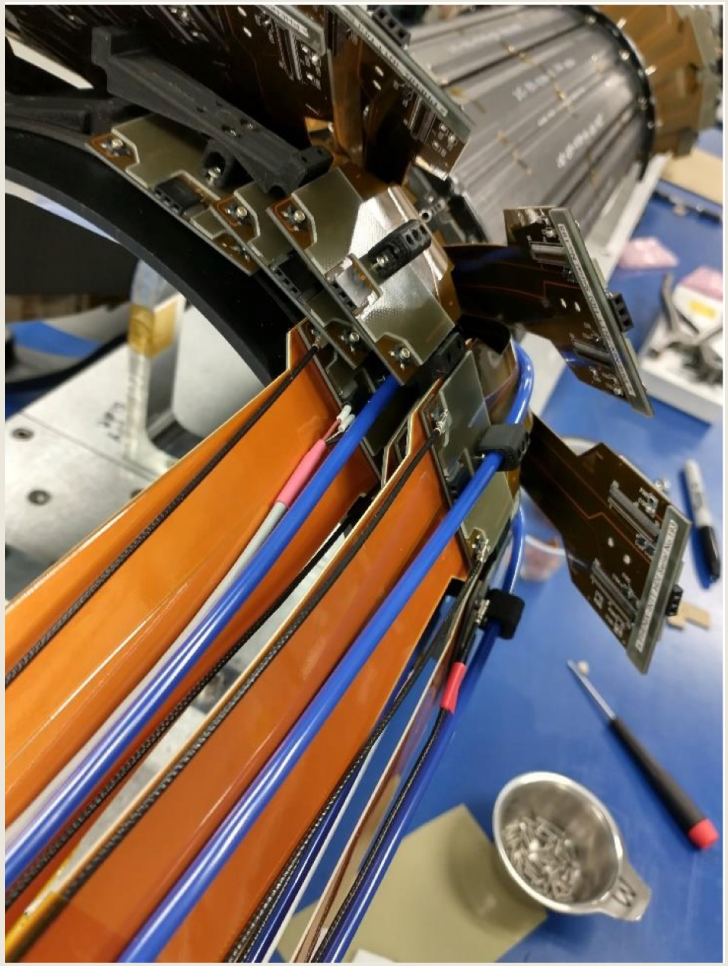






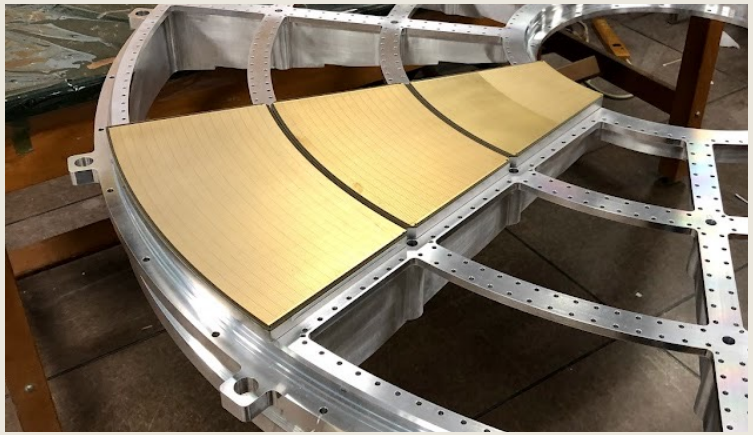
Thanks to Ho-San Ko and Cameron Dean for the pictures!

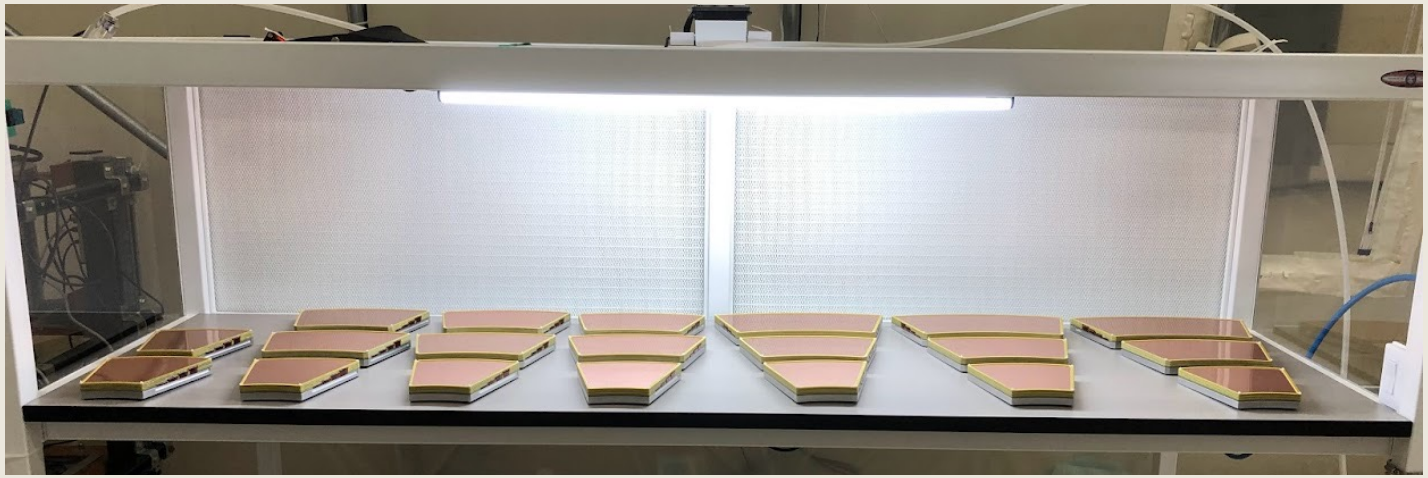
INTT Progress

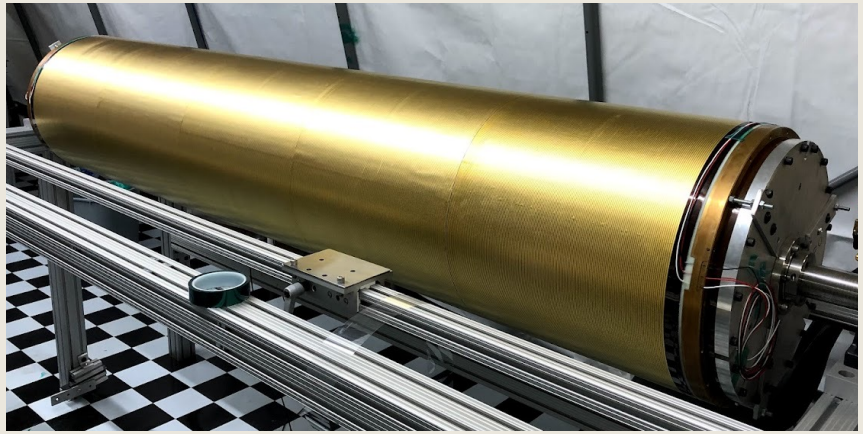


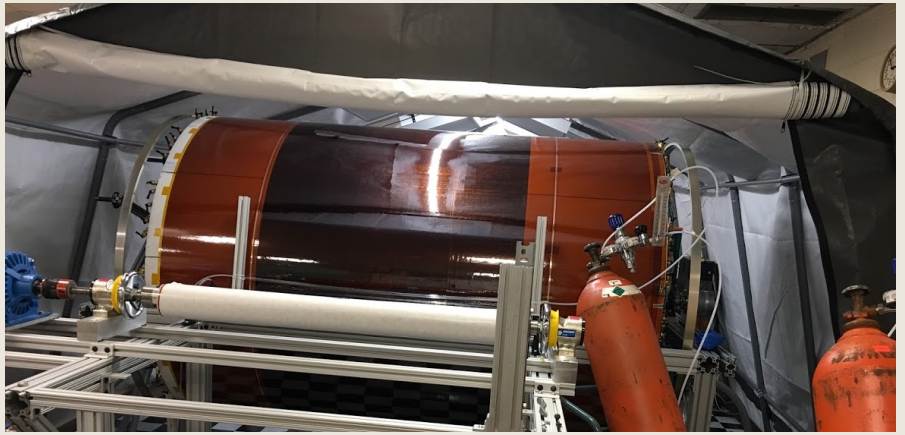
Itaru Nakagawa, Rachid Nouicer. INTT Status and Plans. Feb 2022.

TPC Progress









Hemmick, Thomas. TPC status and plans. Jan 2022.

EMCal Progress

Stoll, Sean. Status of Module Production and Sector Assembly. Feb 2022.

HCal Progress

iHCal

oHCal

Summary

- sPHENIX is poised to deliver on its physics goals and projections beginning with commissioning in early 2023
- Detector assembly and installation is underway
- Reconstruction and analysis software being tested with mock data challenges (MDC)
- D^0 / $\overline{D^0}$ separation study will allow us to probe initial B field and take separate TSSA measurements
- Excited for data-taking beginning next year!

Questions/Comments?

EXTRA: D^0 / $\overline{D^0}$ Separation

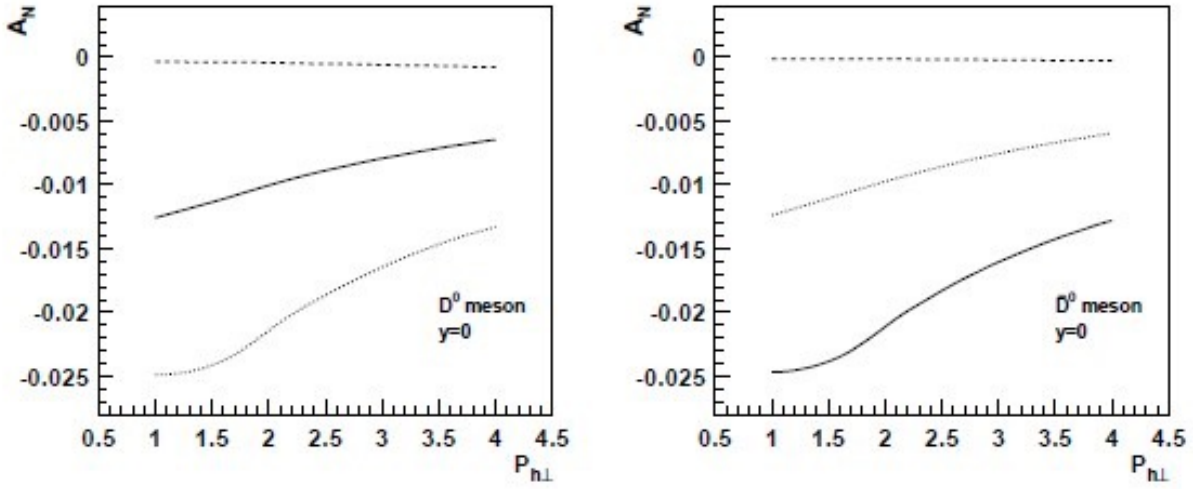
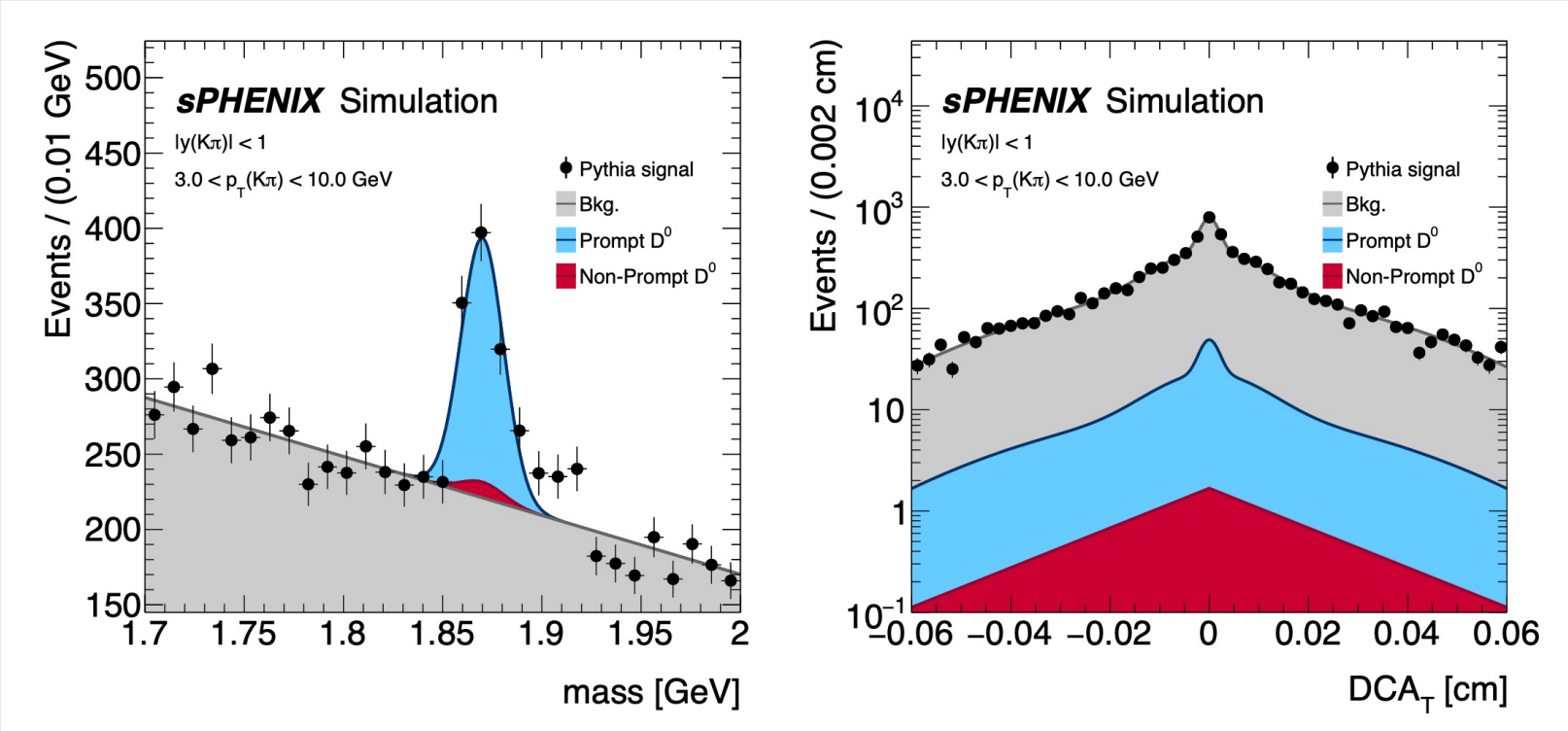


FIG. 6: The SSA as a function of $P_{h\perp}$ for D^0 (left) and $\bar{D}^0$ mesons (right) at mid-rapidity, $y = 0$, and $\sqrt{s} = 200$ GeV. The curves are: solid ($\lambda_f = \lambda_d = 0.07$ GeV), dashed ($\lambda_f = \lambda_d = 0$), dotted ($\lambda_f = -\lambda_d = 0.07$ GeV).

EXTRA: Recent Progress - Mock Data Challenge 1

- MDC1 - First use of complete Day-1 analysis chain
  - *Pythia 8.3 event generation, 200 GeV collisions*
  - *Simulation/digitization with full detector description*
  - *Reconstruction using A Common Tracking Software (ACTS) and **KFParticle***
  - *Analysis over inclusive HF signal samples*
  - *50 million $c\bar{c}$ events ~ 0.2 pb^{-1} or four-day data taking*
  - *50 million $b\bar{b}$ events ~ 30 pb^{-1} and 6xthe integrated luminosity of Min Bias p+p collision data in first three-year run plan*
  - *Single event multiplicity, no pile-up from collisions with different bunch crossings*
  - *Light flavor background still being produced, not included here*

EXTRA: $c, b \rightarrow D^0 \rightarrow K^{\mp}\pi^{\pm}$ Channel



EXTRA: $D_s^+ \to K^+K^-\pi^+$ $D_s^+ \to \phi\pi^+ \to K^+K^-\pi^+$ Channels