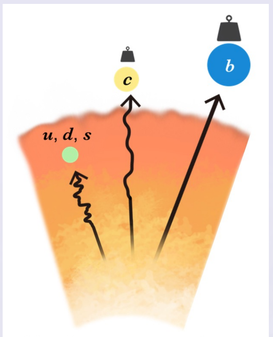
sPHENIX measurements of heavy flavor production in p+p collisions

Xudong Yu, Peking University, for the sPHENIX Collaboration

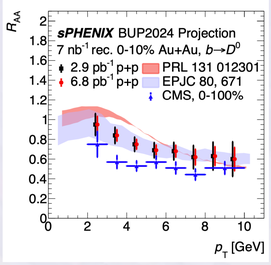
Abstract

sPHENIX is the first new collider detector experiment dedicated to heavy-ion physics since the LHC began collecting data. Successfully commissioned in 2023–2024, one of its standout features is a streaming-capable tracking system that enables the collection of large, unbiased p+p datasets—previously unattainable at the Relativistic Heavy Ion Collider (RHIC). Leveraging this capability, sPHENIX recorded over 100 billion unbiased p+p collisions at 200 GeV during Run-24. This unprecedented dataset unlocks a high-precision open heavy flavor physics program with extended low-pT reach, spanning both charm and beauty sectors. This poster presents progress in the analysis of open heavy flavor in the p+p dataset, where, from one hour of data and early-stage calibrations, we see observations of open-charm mesons and evidence of Λ_c^+ in p+p collisions for the first time at RHIC. These resonances will allow for novel physics measurements to be performed for the first time at RHIC.

Open heavy flavor physics program



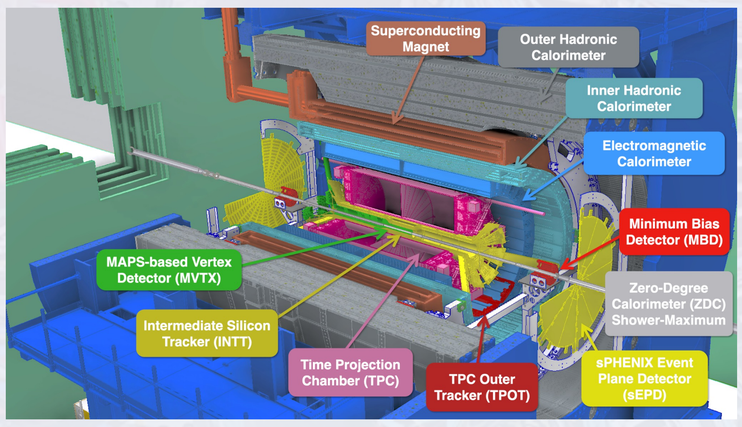
Parton energy loss



- One of the cornerstones of sPHENIX scientific program
- Heavy quarks (charm and bottom) are excellent probes for Quark Gluon Plasma (QGP)
  - $m_{b,c} \gg \Lambda_{QCD}$ → pQCD prediction of initial production
  - $m_{b,c} \gg T_{QCD}$ → No thermal production; conserved from the initial hard scatterings & experience full QGP evolution
- Explore the parton energy loss mechanism and study the collective behavior in medium by varying the mass/momentum of the probe
  - Two popular & crucial observables for QGP studies: Collective flow v_n & Nuclear Modification Factor R_{AA}
- Investigate hadronization mechanism via ratio of production yields between various hadron species, which is the initial physics program of sPHENIX
  - Baryon/meson ratio Λ_c^+/D^0
  - strangness enhancement D_s^+/D^0

sPHENIX detector

The sPHENIX detector consists of high precision tracking (**MVTX**, **INTT**, **TPOT**, **TPC**), large acceptance electromagnetic (**EMCAL**) and hadronic calorimeters (**iHCAL**, **oHCAL**), minimum bias detector (**MBD**) and event plane detector (**sEPD**)



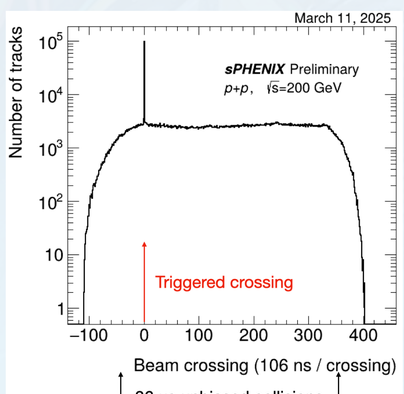
Tracking detectors for heavy flavor reconstruction

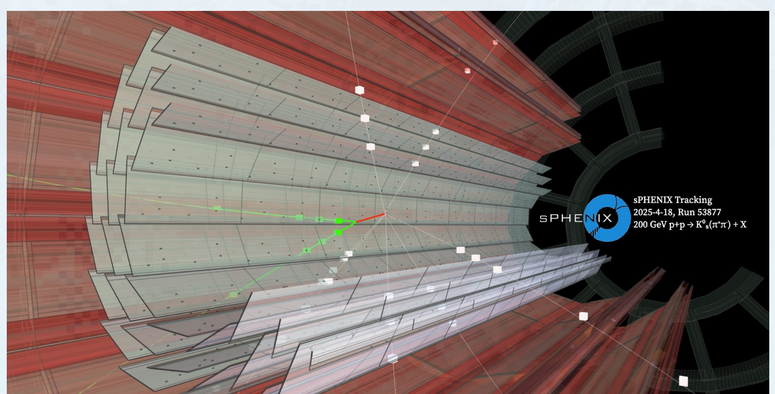
- MVTX:
  - Three layers silicon pixel detector
  - 5 um position resolution
  - Allows vertex reconstruction for HF
- INTT:
  - Two layers silicon strip detector
  - Short integration time allows single bunch identification to mitigate pile-up
- TPC:
  - 48 layers GEM continuous readout
  - ~1% momentum resolution @ 1 GeV
  - dE/dx information for particle ID
- TPOT:
  - Micromegas based detector with partial coverage
  - Facilitates calibration for TPC distortions

Streaming DAQ system and tracking reconstruction

In pp collisions, with streaming DAQ capability, we record data for 14 us (TPC drift time) + 36 us (extended readout). In the normal data-taking mode of Run24, a 20% streaming rate can increase the minimum bias (MB) sampling rate to 200 kHz, which is 20 to 50 times higher compared to the pure MB trigger mode. Over the entire Run24, sPHENIX collected 100 billion streaming events that can be used for open heavy flavor physics analysis.

sPHENIX tracking software uses 4D detector information for track reconstruction. A Common Tracking Software (ACTS) is implemented. Full reconstruction workflow split into 4 steps: clustering hits, full track seeding, final track fitting and vertexing

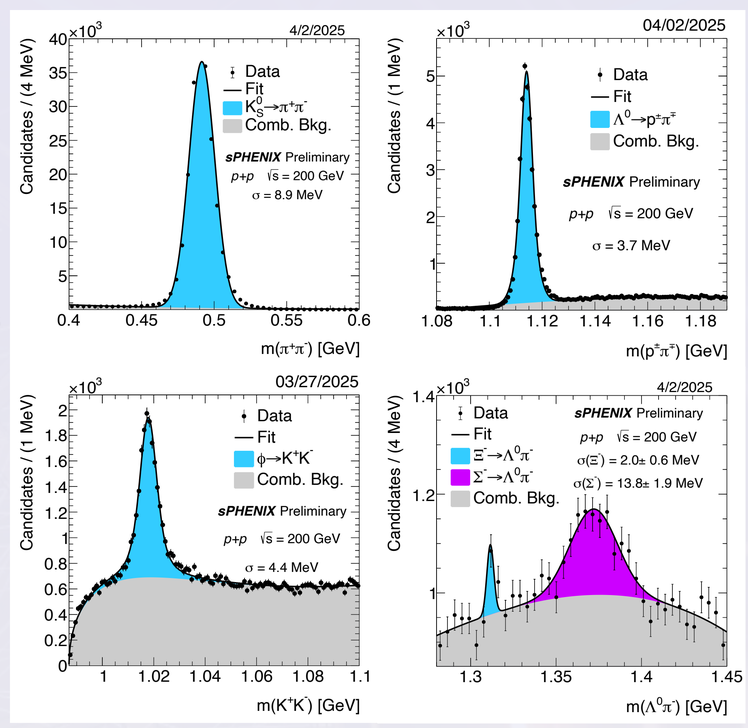




Reconstruction toolkit and light flavor reconstruction

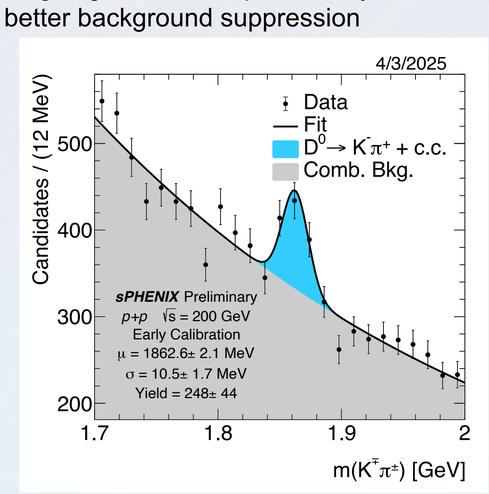
KFParticle is adapted to be used within the Fun4All framework for heavy flavor resonance reconstruction. Light flavor resonances are reconstructed from data to show the capability. The reconstruction process follows these steps:

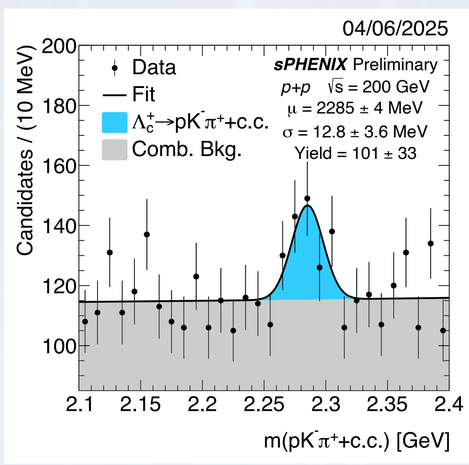
- Unpack reconstructed tracks and primary vertices from the sPHENIX tracking software
  - Tracks are selected by p_T, χ^2/nDoF, and impact parameter (IP) w.r.t. all primary vertices
- Reconstruct n-prongs vertices, calculate track-to-track distance-of-closest-approach (DCA) and vertex χ^2
- Assume PID to tracks combinations (If no PID information provided). If more than one PID combination for each decay vertex, choose the best PID combination:
  - For intermediates, choose the one with lowest invariant mass uncertainty of resonance
  - For mother candidates, choose the one with lowest IPχ^2 w.r.t. all primary vertices.
- Apply requirements of FDχ^2, DIRA, IP, IPχ^2 to mother candidates and intermediates.



Λ_c^+/D^0 reconstruction from real data

- First D^0 invariant mass peak at sPHENIX has been identified!
- First measurement of Λ_c^+ at ~3σ confidence level in p+p at RHIC!
- Statistically limited in ~1 hour of data – more to come
- Using early calibrations
  - MVTX alignment with field off data
  - TPC static distortion corrections from simulation and space charge distortion corrections only in ϕ direction using lamination fitting
- Suppress huge amouts of background by utilizing reconstructed secondary vertex and dE/dx at low momentum
  - D^0 proper decay length: 123 microns
  - Λ_c^+ proper decay length: 61 microns
- Ongoing efforts to improve early calibrations ⇒ Optimizing reconstruction efficiency, yields and better background suppression





Summary and outlook

- sPHENIX tracking detectors with streaming readout collected a large sample of unbiased p+p collisions in Run24, allowing for open charm meson measurements.
- Using the KFParticle package, we reconstruct the heavy flavor resonances Λ_c^+/D^0 in simulation data, and light flavor resonances (K_S^0, Λ, ϕ, Ξ^-, Σ^{*+}) in real data by leveraging track momentum information and primary vertex positions from the sPHENIX tracking software.
- Exciting open charm measurements from data are coming soon – Stay tuned!

U.S. DEPARTMENT of ENERGY | Office of Science
PEKING UNIVERSITY 北京大学
Brookhaven National Laboratory