sPHENIX heavy flavour and quarkonium studies

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Los Alamos National Laboratory

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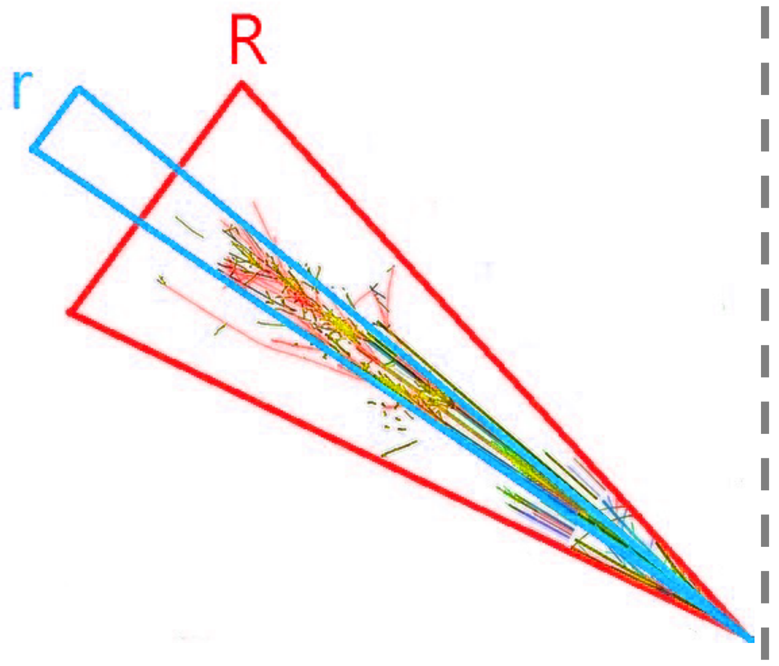
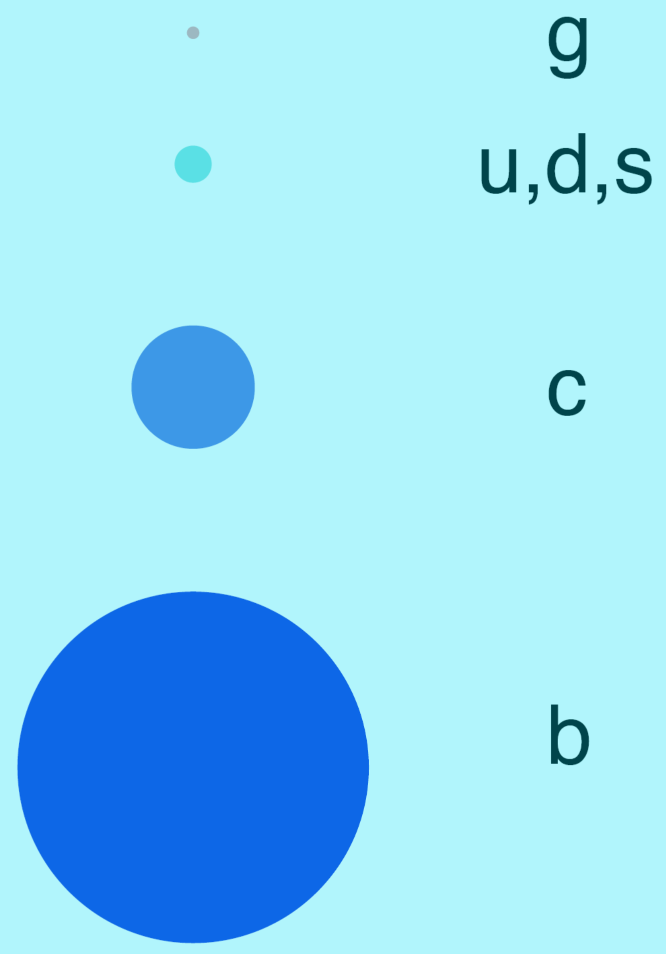
sPHENIX Core physics program

➢ Super PHENIX (sPHENIX) is a a hermetic detector designed to study heavy flavor and jet physics in heavy ion collisions at RHIC:

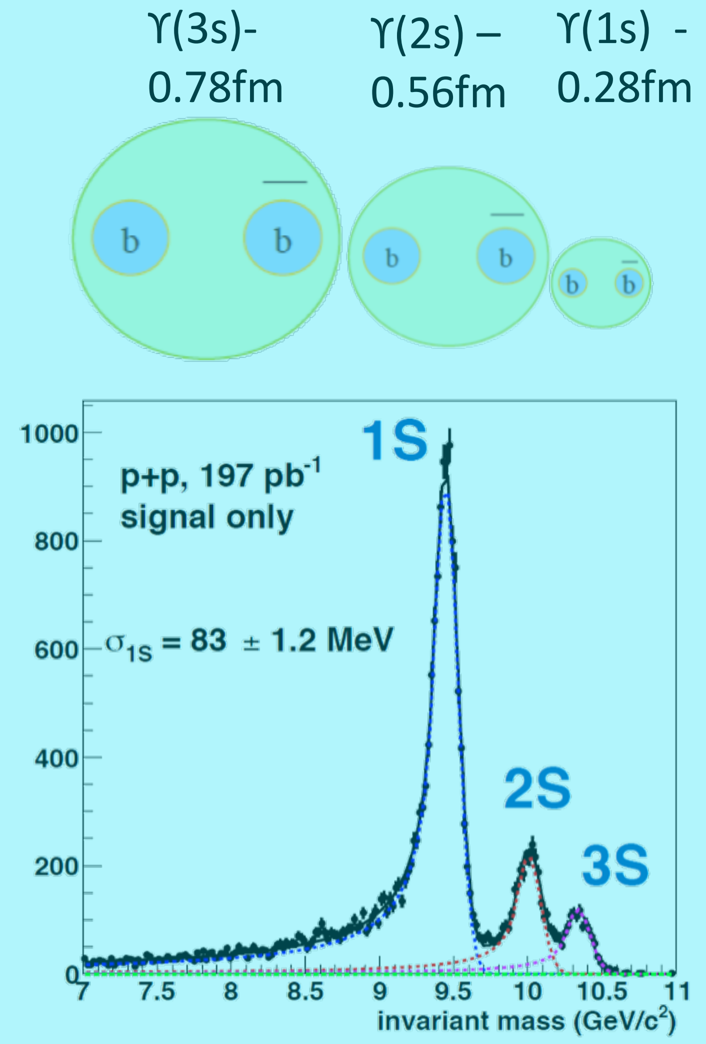
Jet correlation & substructure
Vary momentum/ angular size of probe



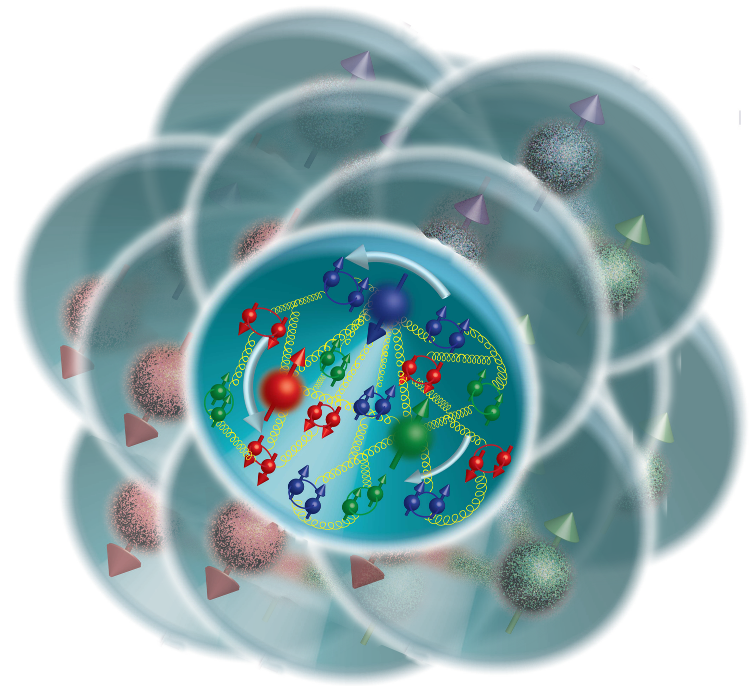
Parton energy loss
Vary mass/ momentum of probe



Upsilon spectroscopy
Vary size of the probe



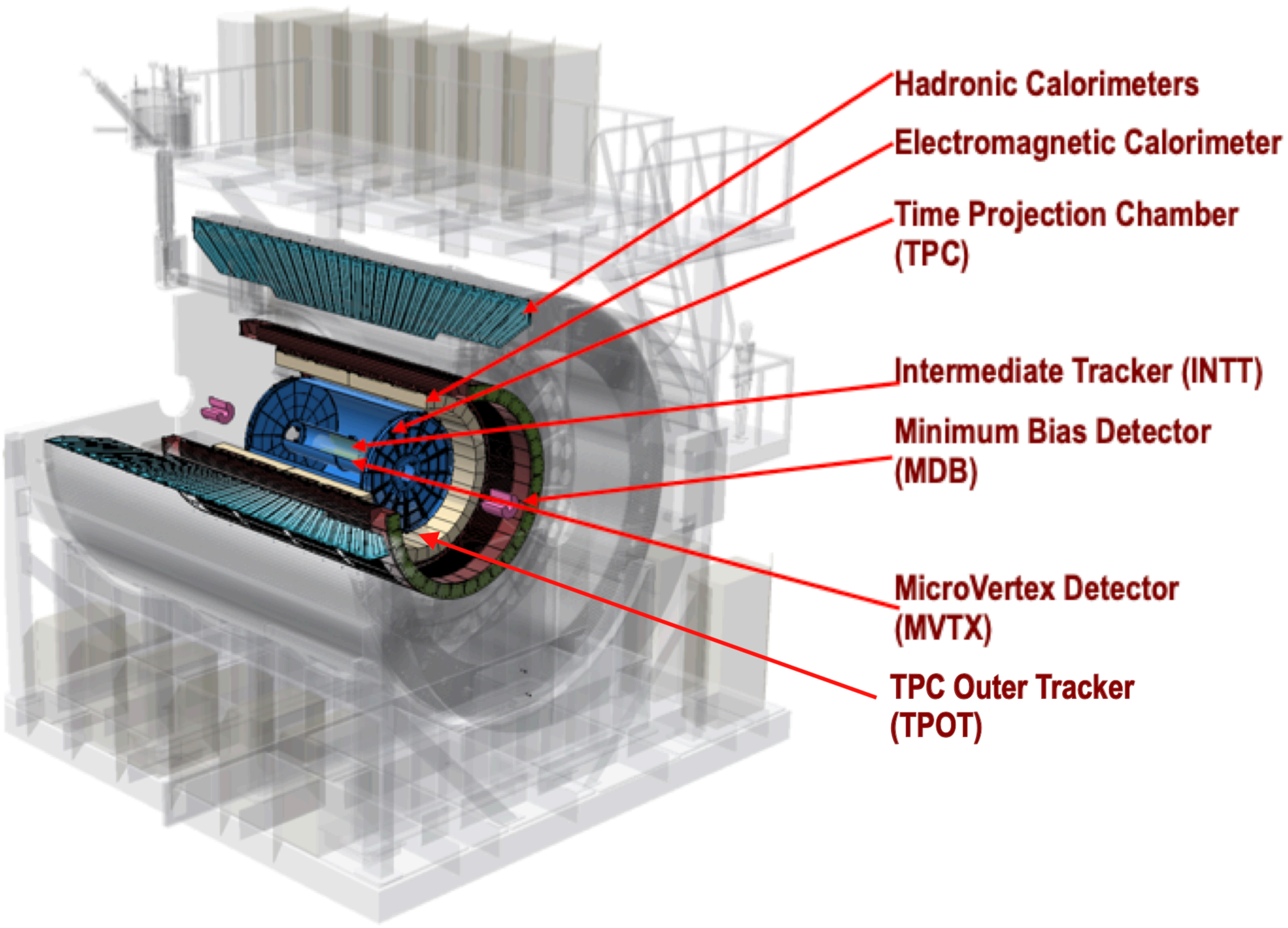
Cold QCD
Vary temperature of QCD matter



Significant overlap in kinematic reach between LHC and RHIC

The sPHENIX Detector

- Hermetic coverage: $|\eta| < 1.1$
- High data rate (AuAu): 15 kHz for all detectors
- Trigger capability combine also with streaming readout
- 1.4 T magnetic field (reuse of old BarBar solenoid)
- High precise vertexing capability with MVTX
- Large-acceptance EM+Had calorimeters

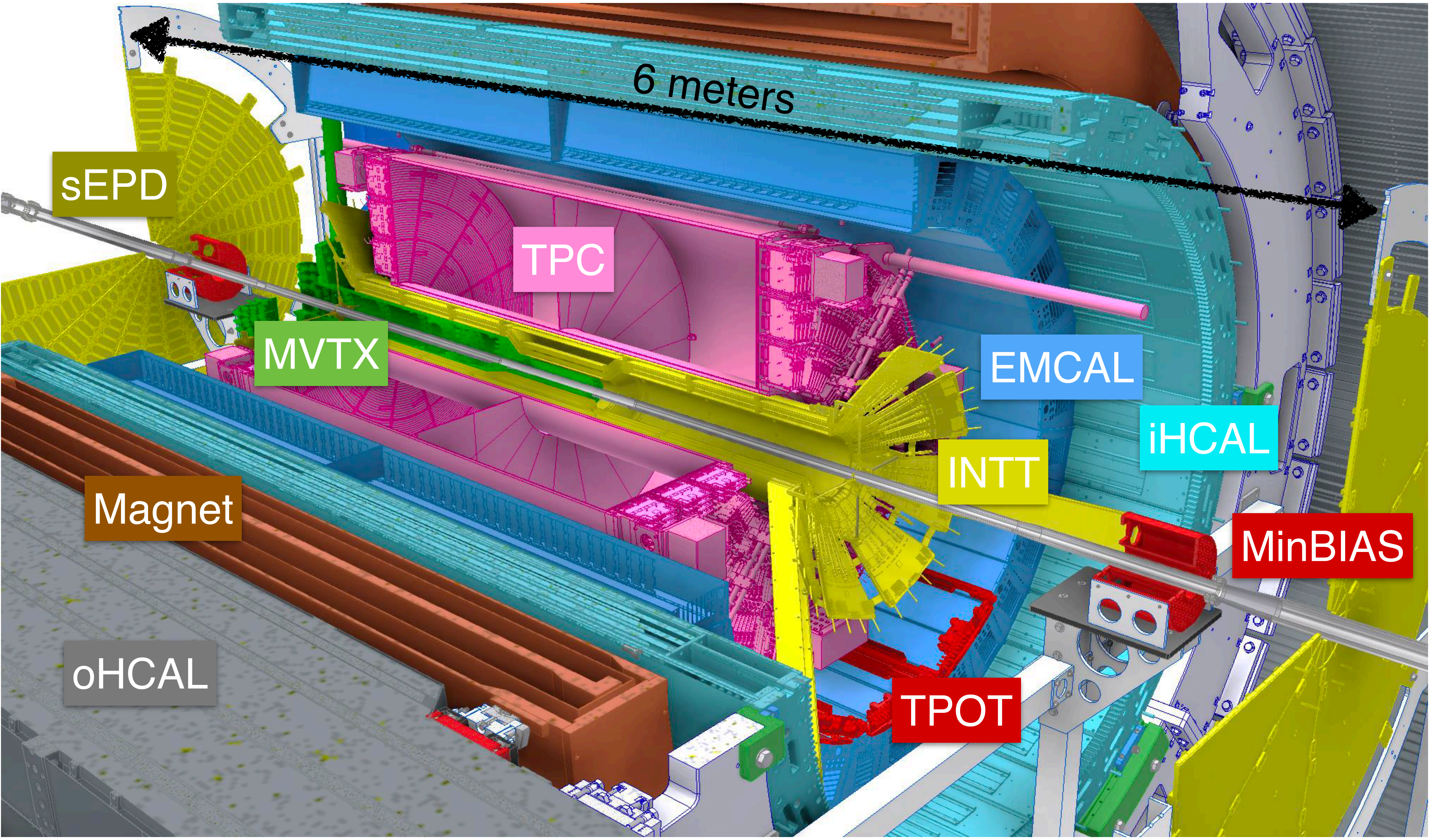


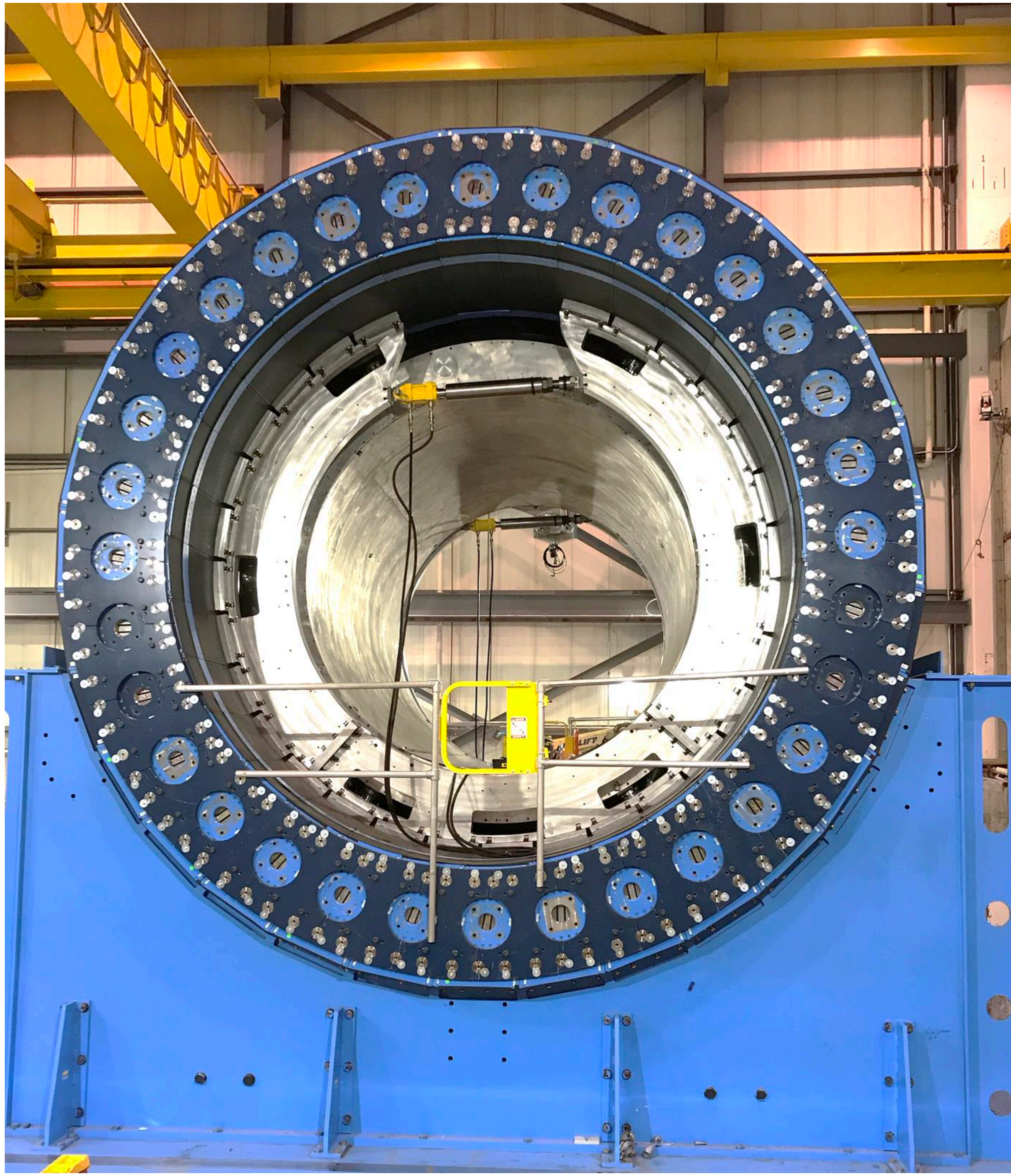
sPHENIX Tracking Detectors

- Tracking currently consists of 3 sub-detectors:
  - MVTX: Monolithic Active Pixel Sensors (3 layers)
  - INTT: Intermediate Silicon Tracker
  - TPC: Time Projection Chamber

first full jet reconstruction & b-jet tagging at RHIC!!

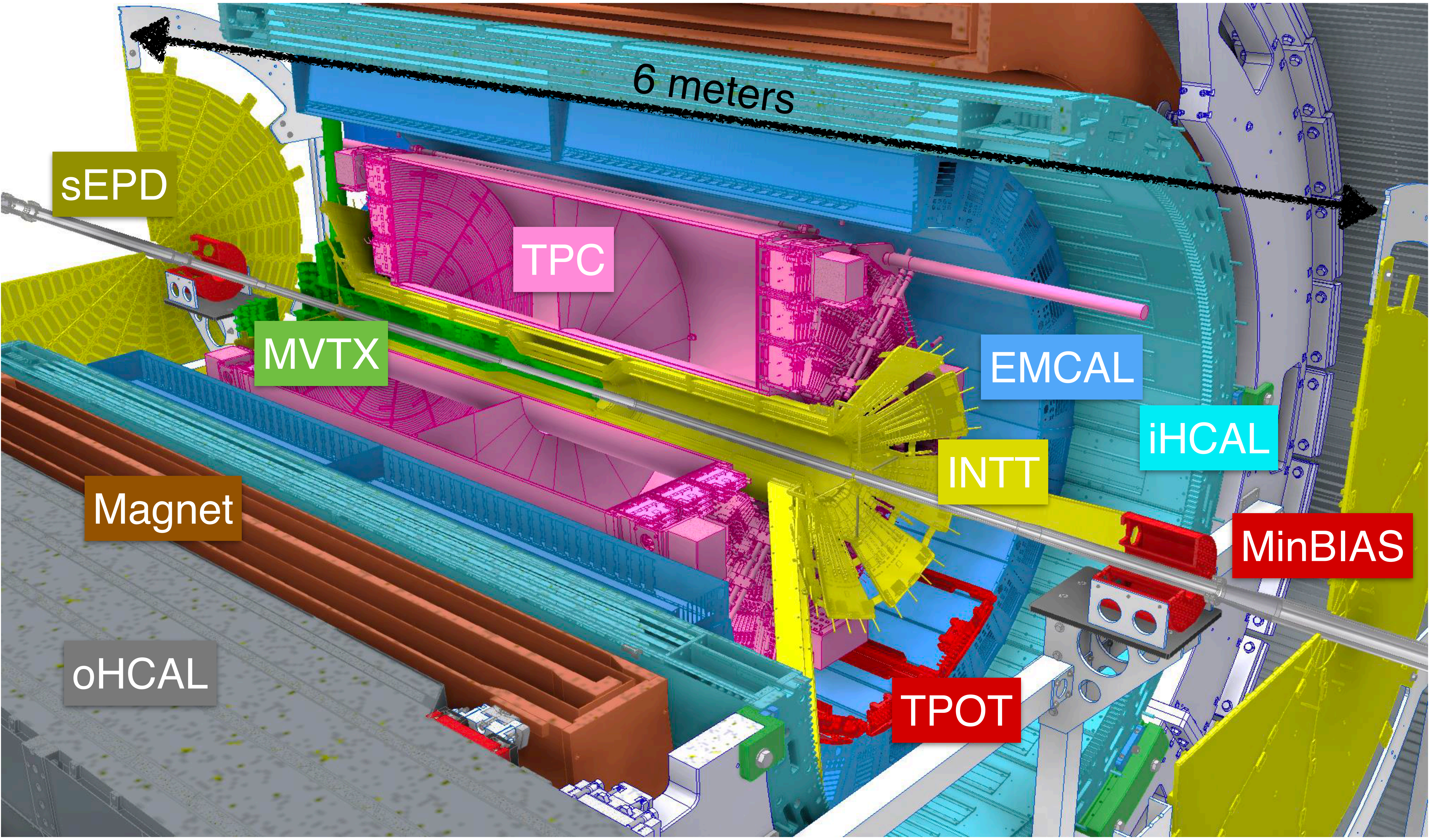
The sPHENIX Detector

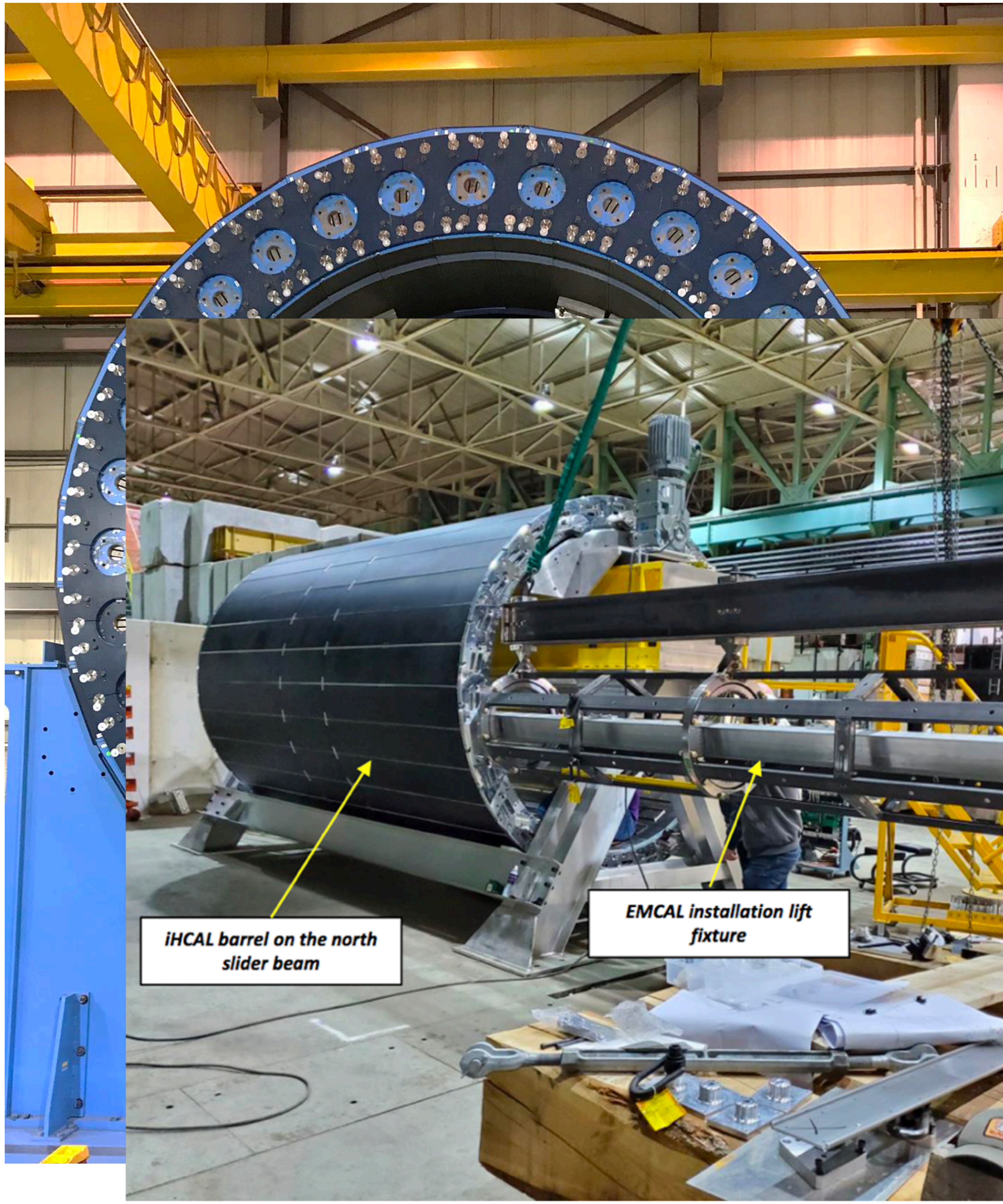




- ➢ First run year 2023

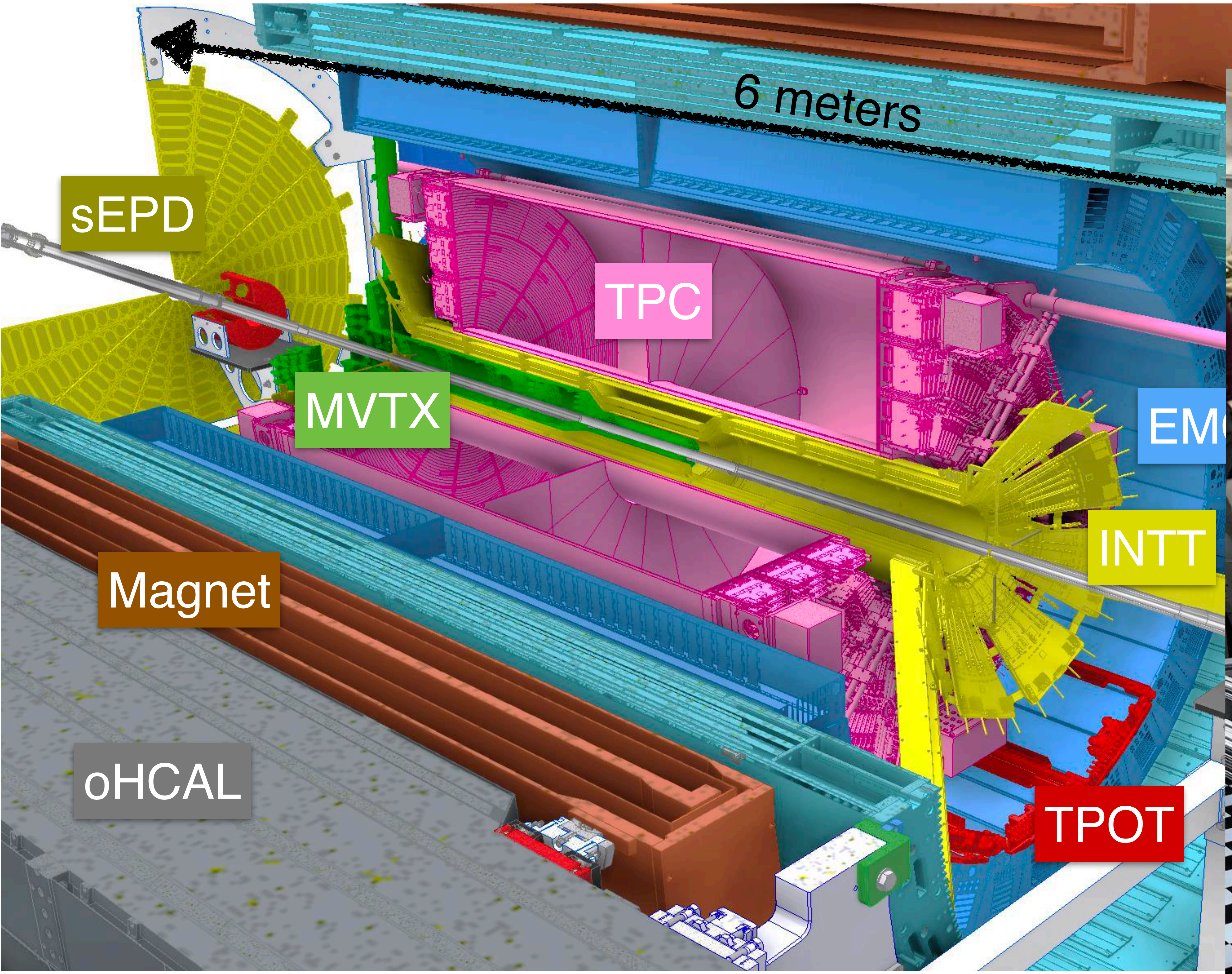
The sPHENIX Detector

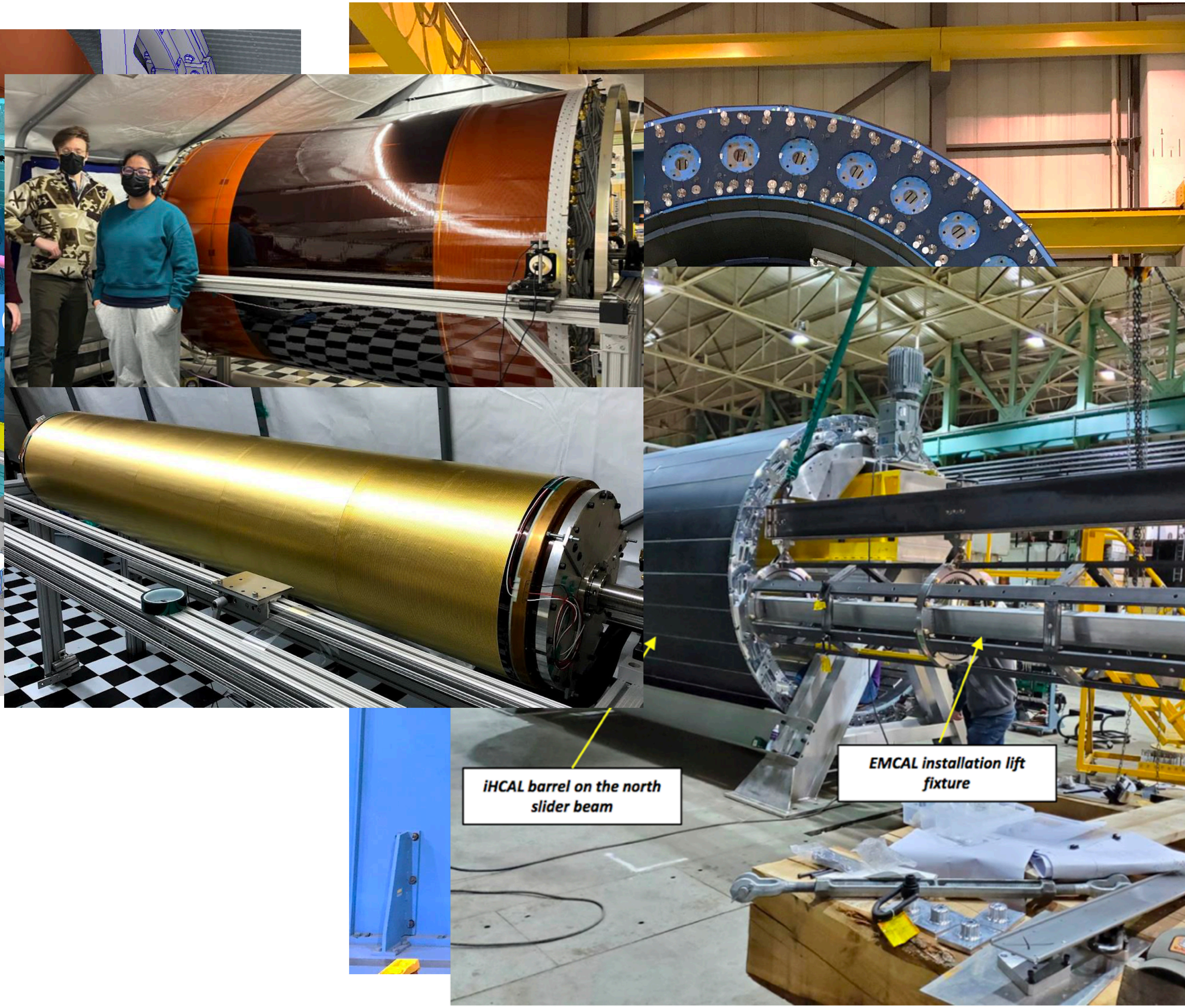




➢ First run year 2023

The sPHENIX Detector





- First run year 2023

The sPHENIX Detector

The sPHENIX Detector

Proposed run, year 1-3

- ➢ sPHENIX BUP 2022 [sPH-TRG-2022-001] 24 (28) cryo week scenarios
- ➢ Proposed run plan constraint by EIC construction

Year-1: commissioning, calibration, reco; Au+Au standard candle

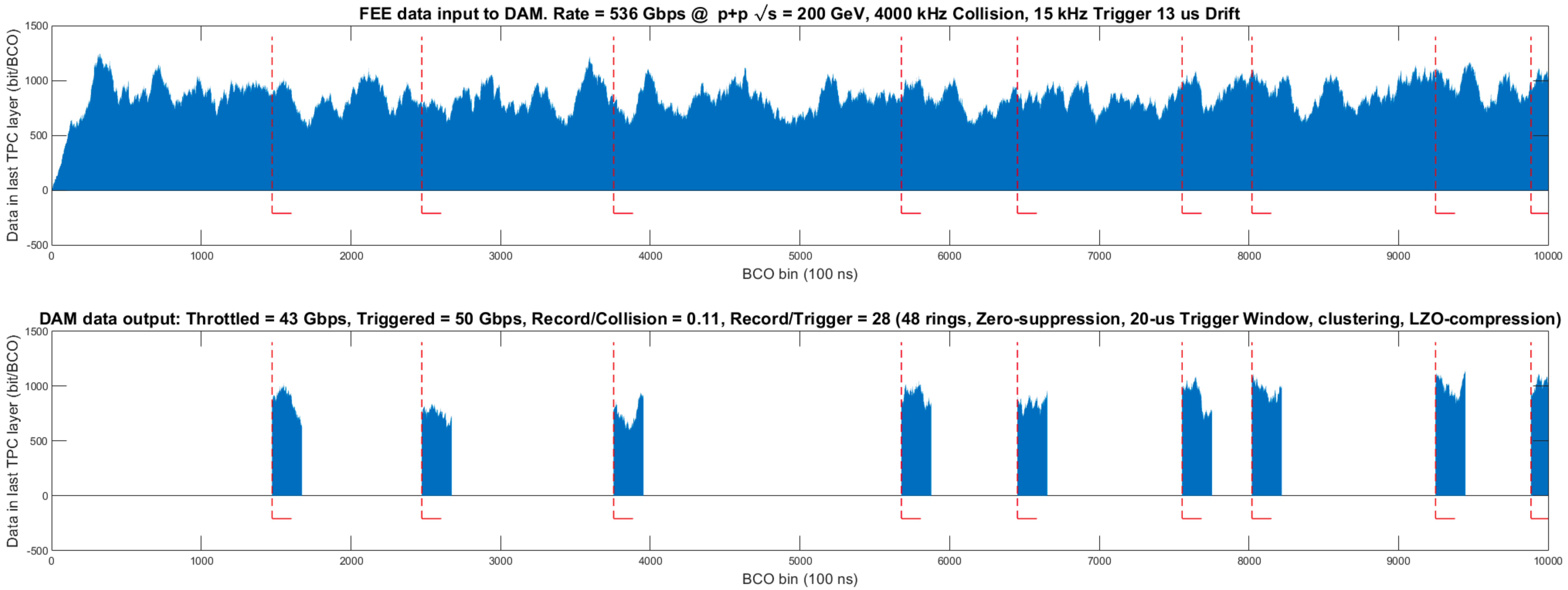
Year-2: p↑+p↑, p↑+Au: HI reference set & cold QCD

Year-3: very large Au+Au HI set

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}

Data taking in early 2023,
Just few months for first data

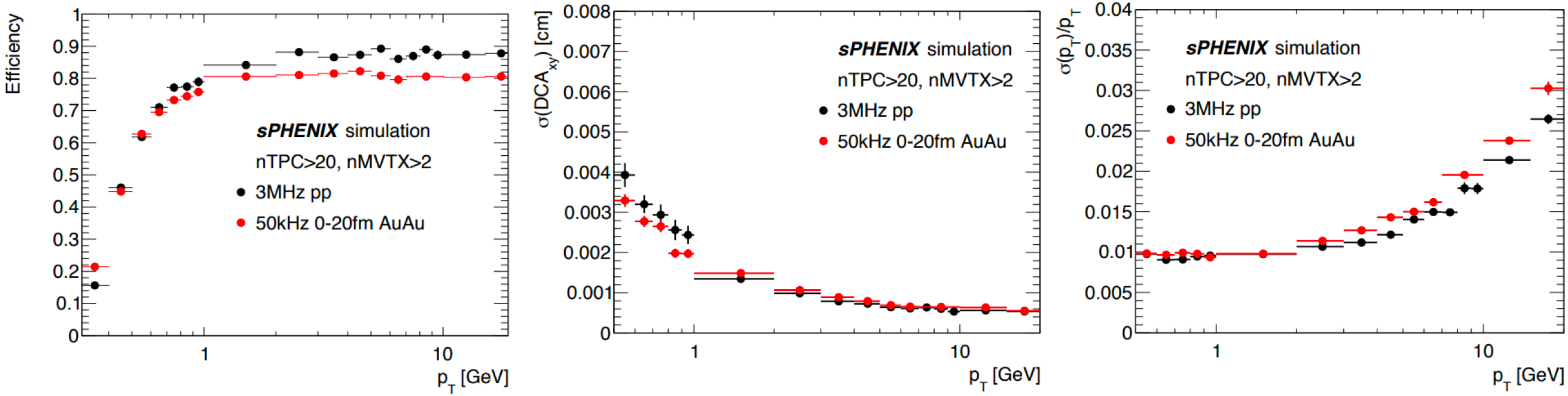
Streaming Readout in 2024



Write 10% of data @ 200 Gbps, each segment corresponding to a calorimeter trigger

- Tracking detectors capable of streaming data - Archive 10% of all pp collisions in hybrid mode
- Increases un-triggerable measurements by orders of magnitude, e.g. low p_T heavy flavor decays (similar to LHCb and ALICE)

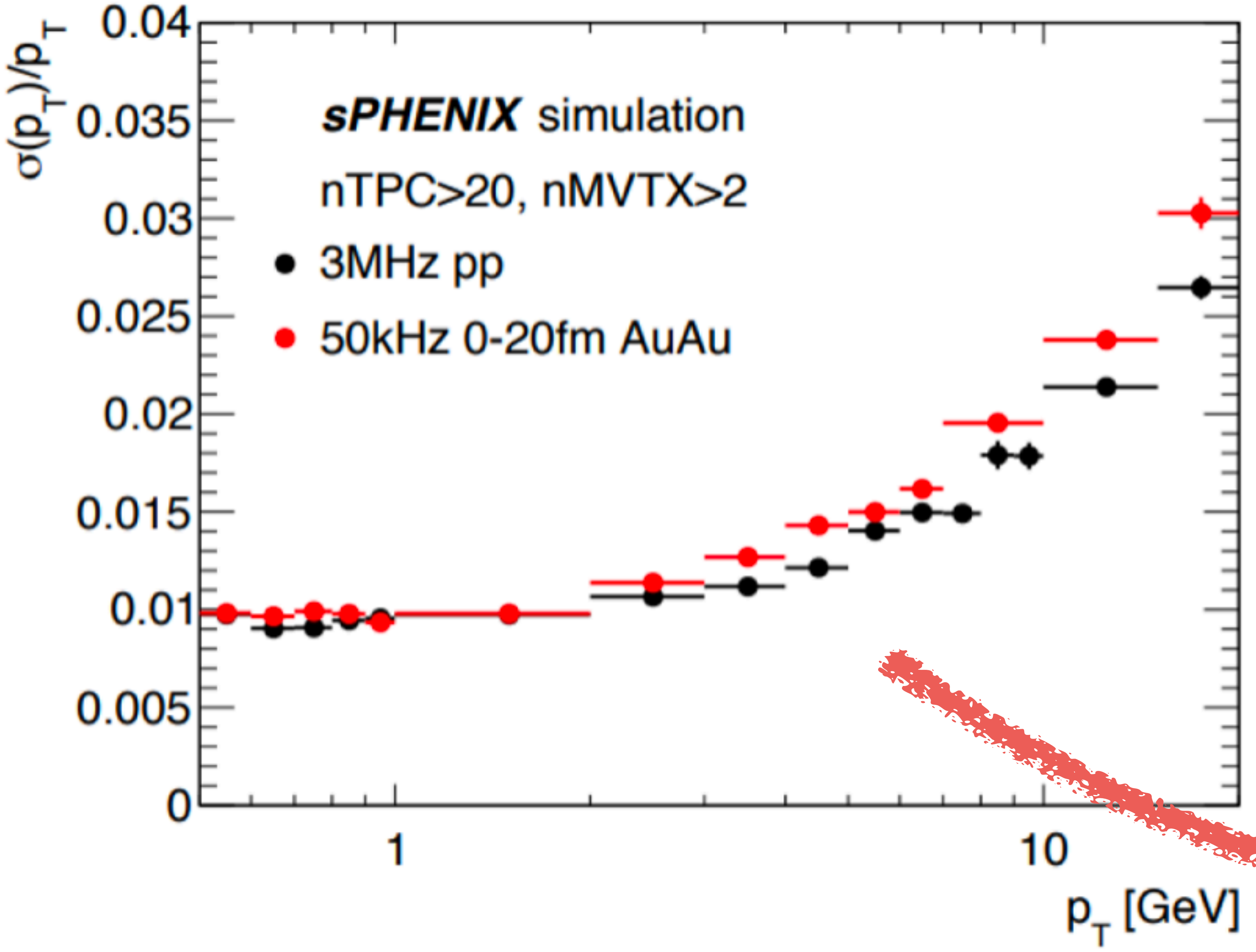
Tracking performance

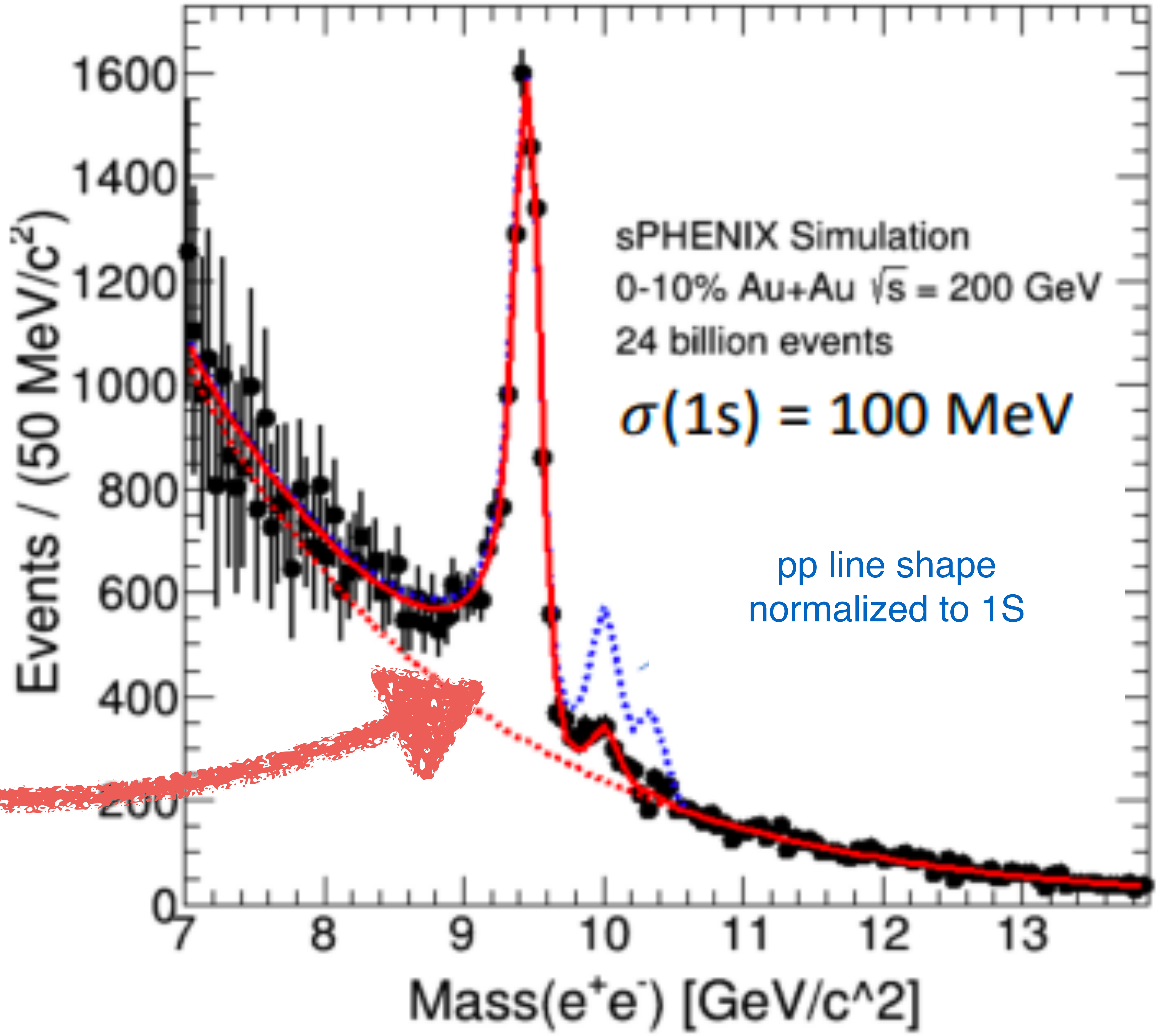


- ➢ Eff. ~90% for pp at p_T >1 GeV. -> promising to measure rare processes: e.g. Υ(nS)
- ➢ DCA resolutions in rϕ, z < 40μm at p_T >0.5 GeV. -> crucial for open heavy-flavor
- ➢ p_T resolution < 2% for p_T < 10 GeV. -> meets δM/M < 125 MeV for Υ(nS) separation

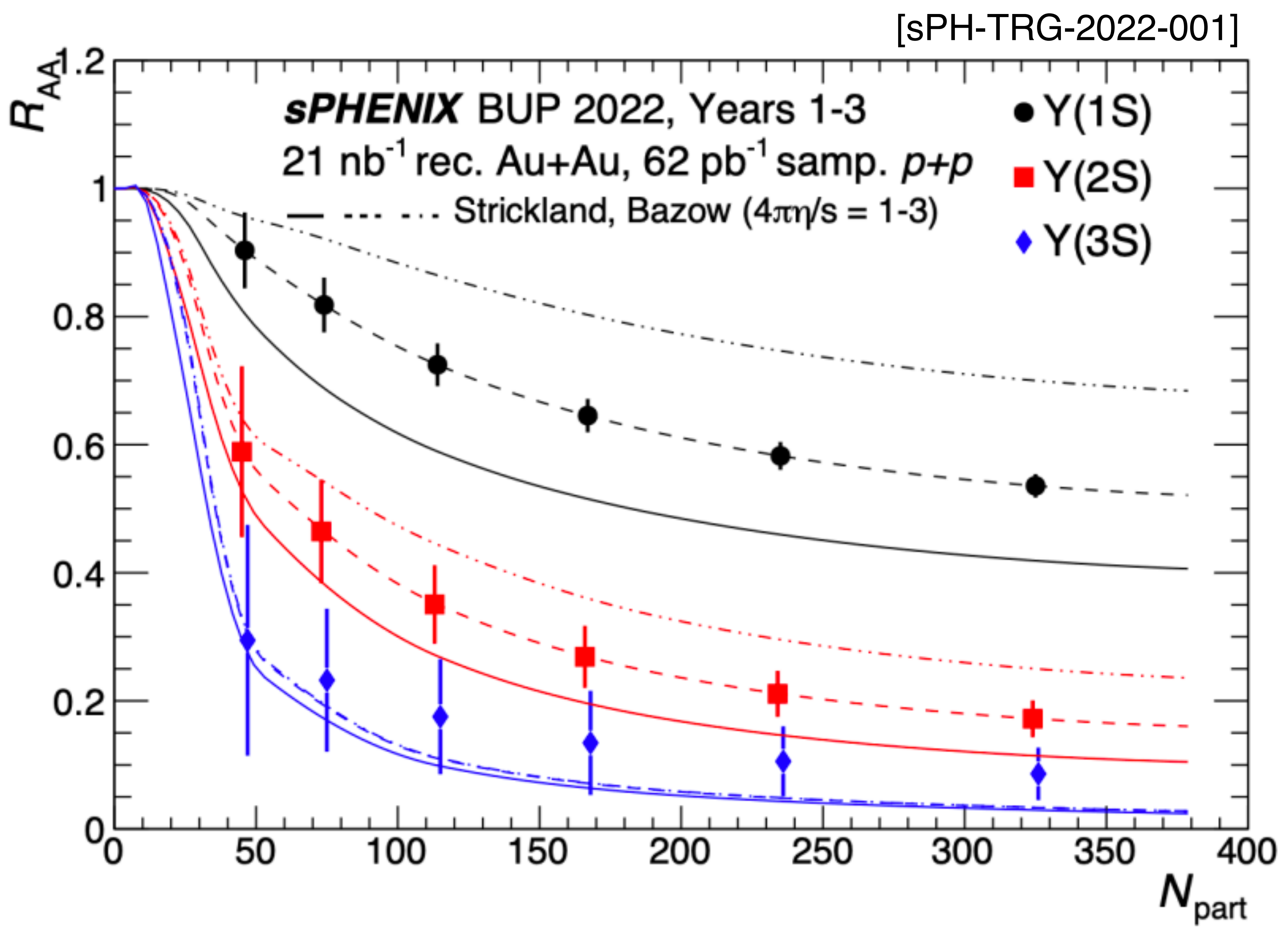
Quarkonium studies at sPHENIX

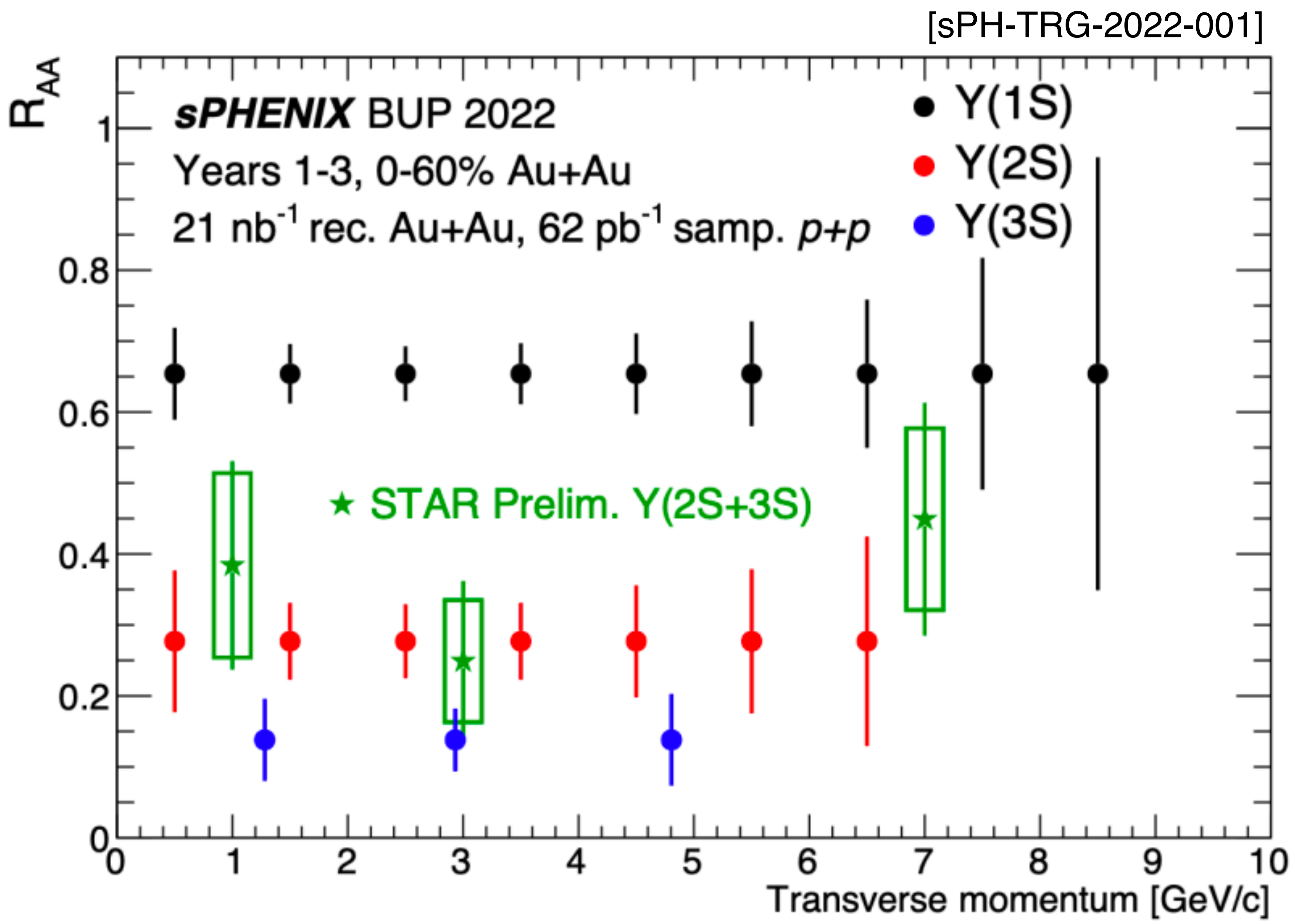
- ➢ Mass resolution of precision tracking -> **First separation of three Y states @ RHIC!**





Quarkonia studies at sPHENIX

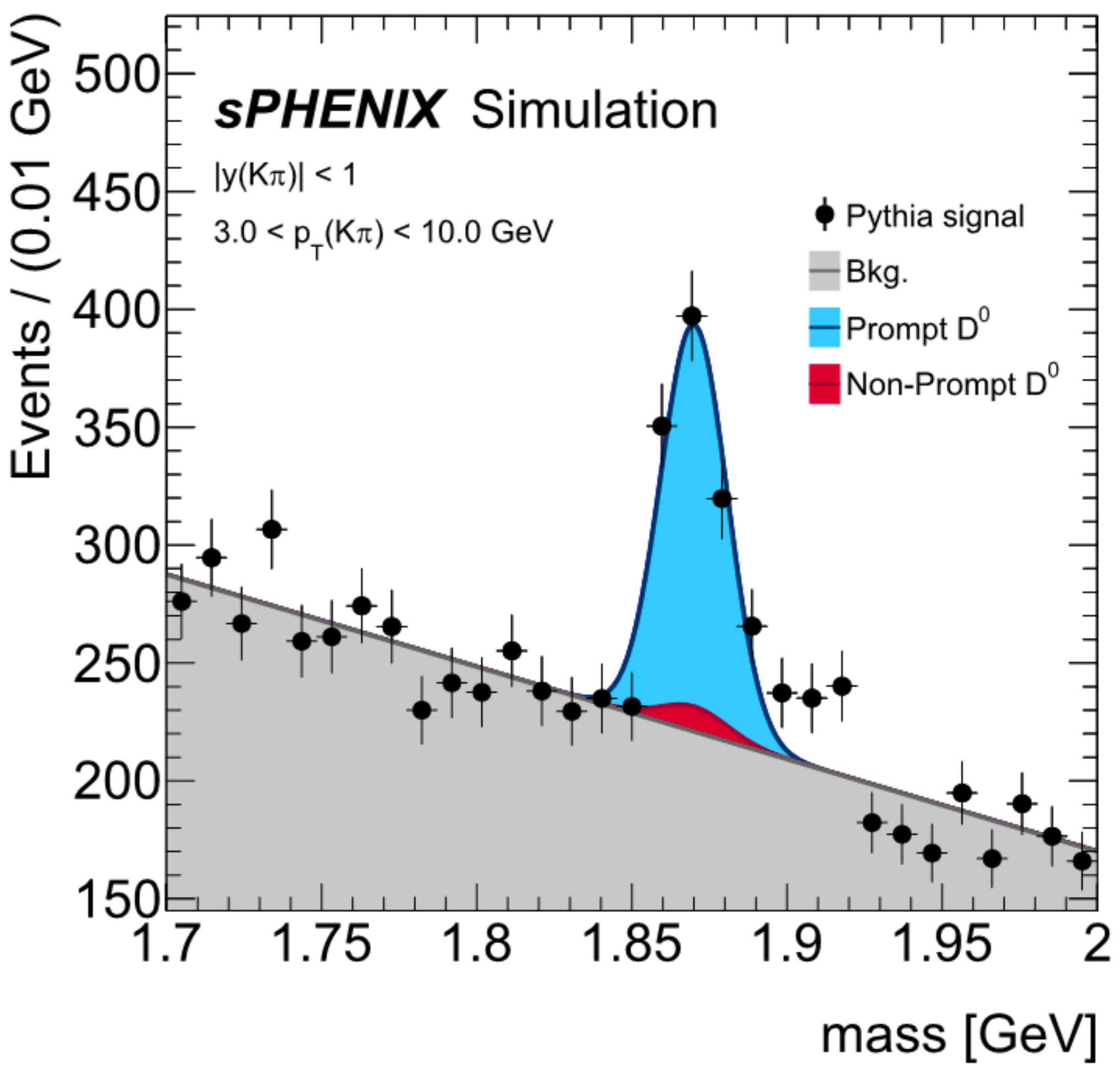


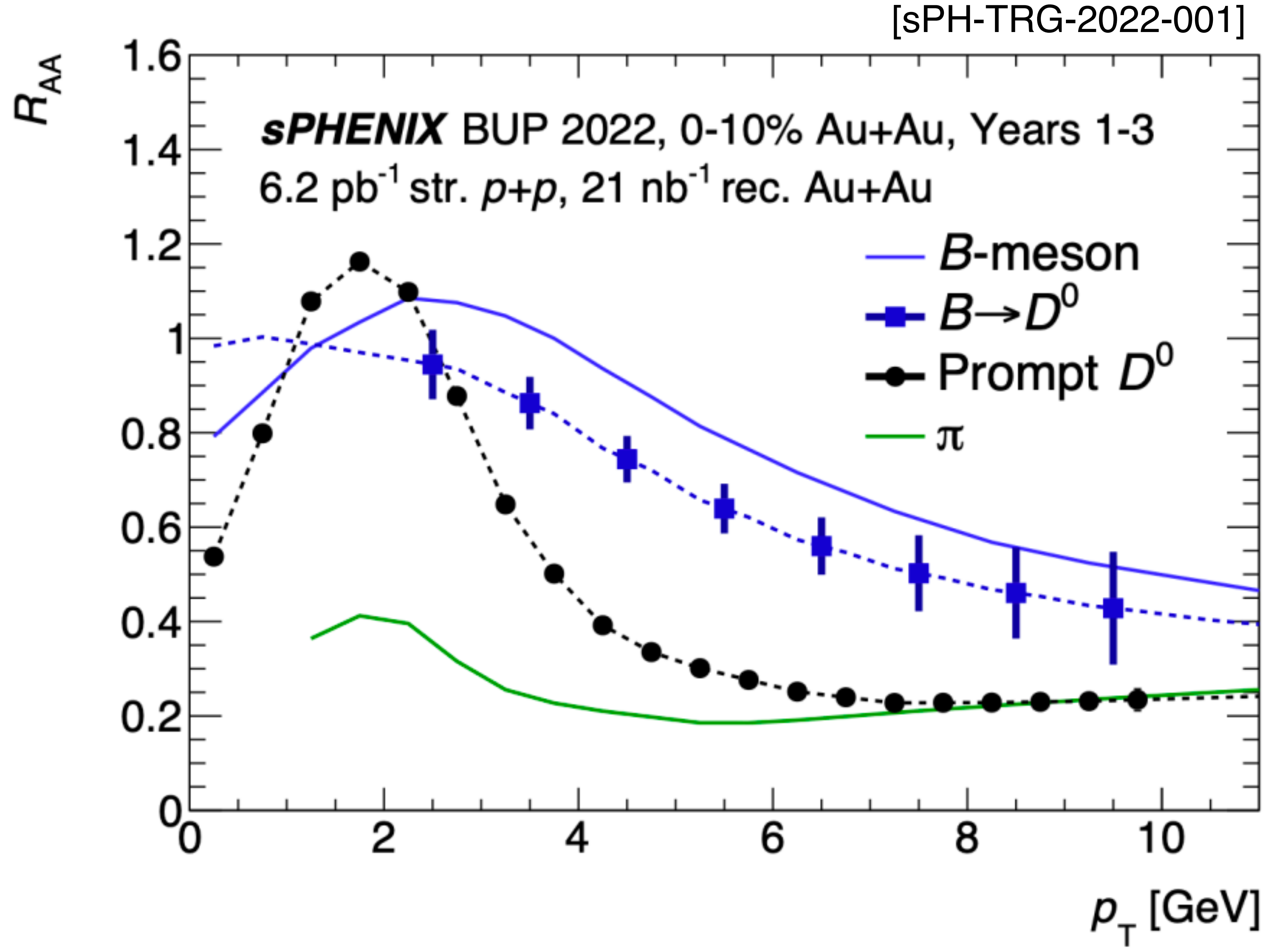


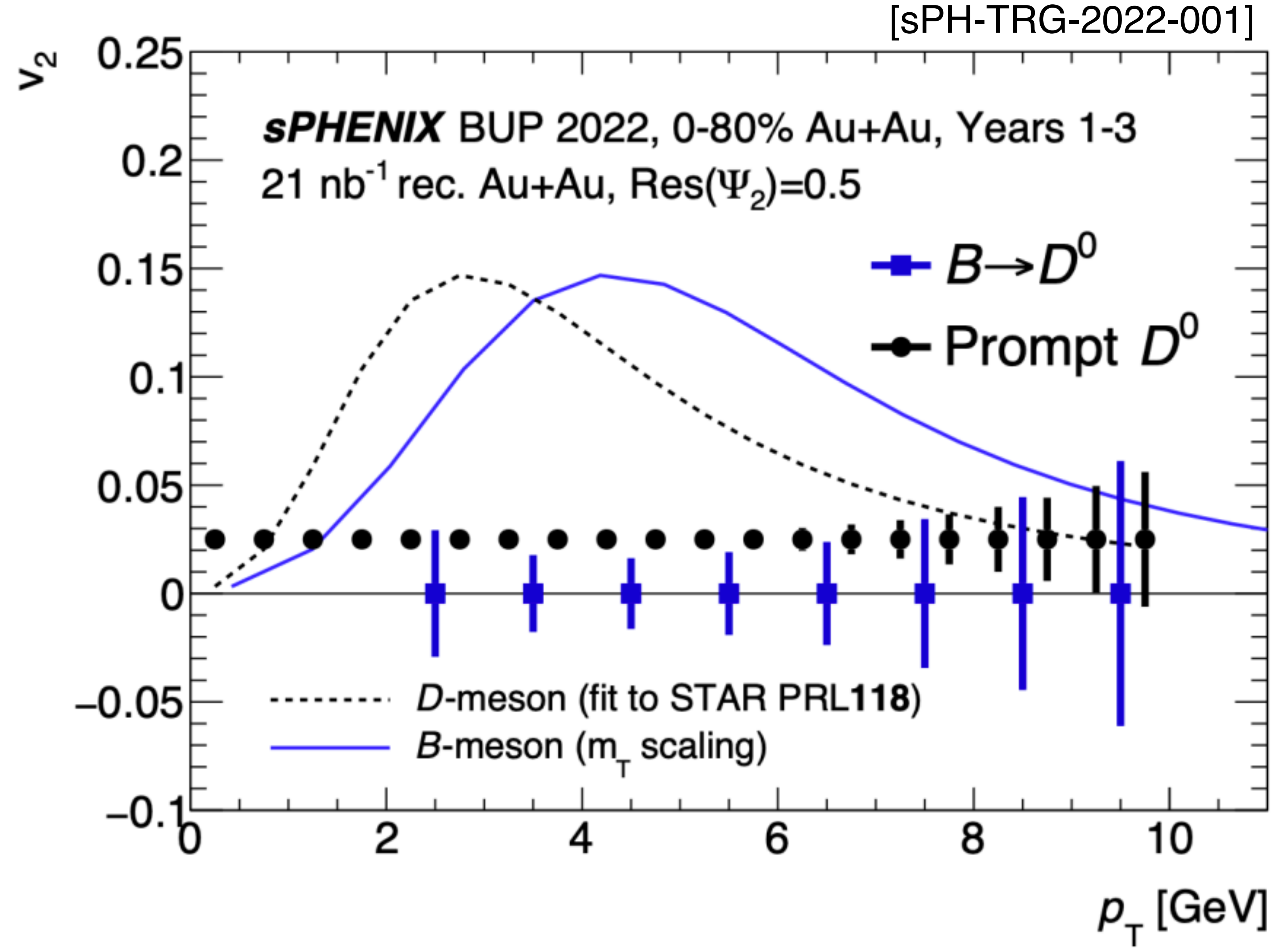
- ➢ Centrality & p_T dependent R_{AA} measurement -> crucial to compare with LHC.
- ➢ Υ(3S) projected, given the observation of R_{AA}(3S)/R_{AA}(2S)~0.5 at the LHC.
- ➢ sPHENIX has the unique opportunity to measure the Υ(3S) suppression at RHIC.

Heavy Flavor R_{AA} & Flow

Precision tracking and vertexting will enable extensive heavy flavor measurements in sPHENIX



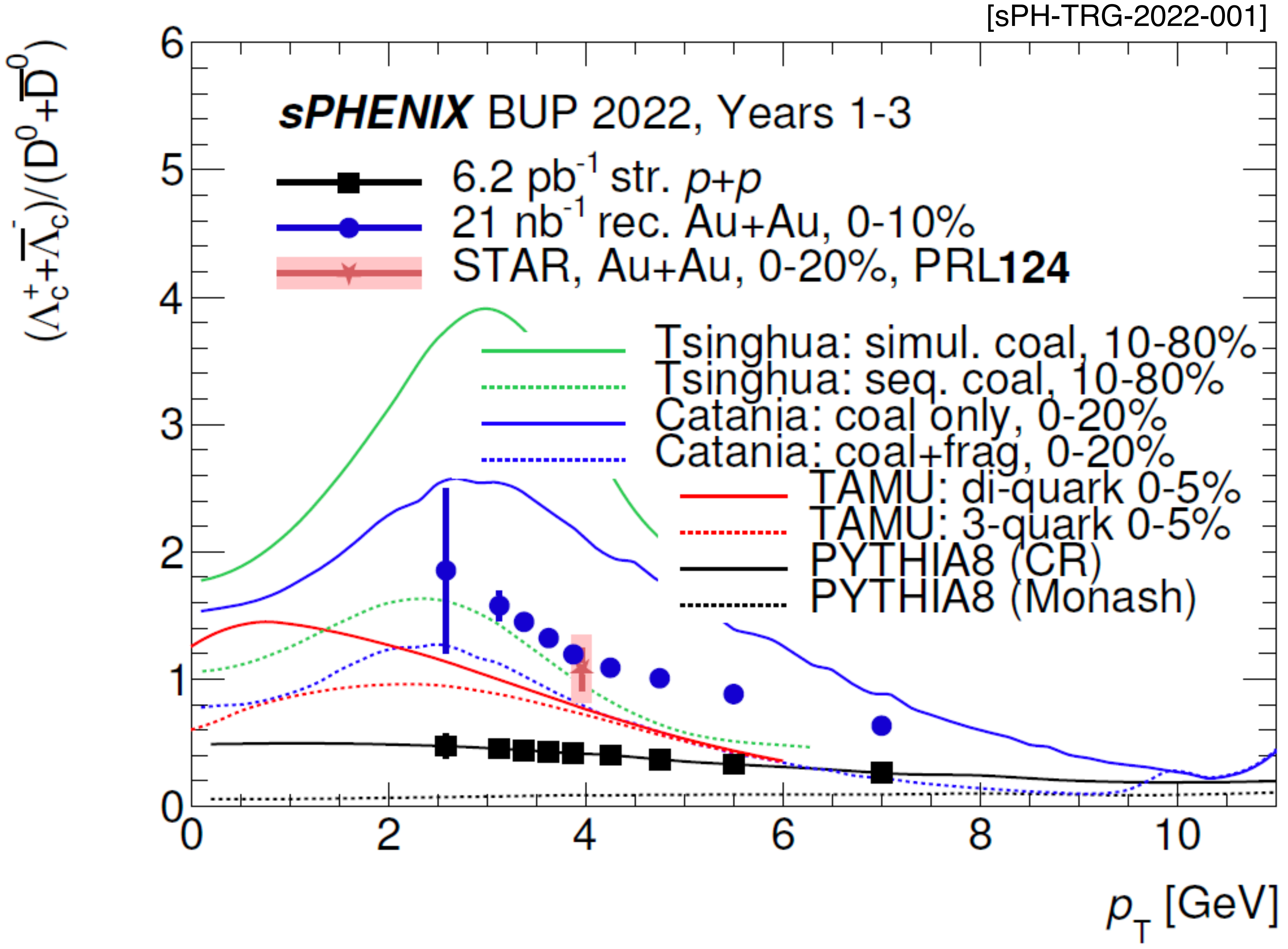




- ➢ non-prompt D^0 meson proxy for B meson measurements
- ➢ Precise measurements provide discrimination between transport models
- ➢ Study interplay between collisional and radiative energy loss
- ➢ Bottom quark collectivity -> clean access to D_{HQ} at RHIC energy

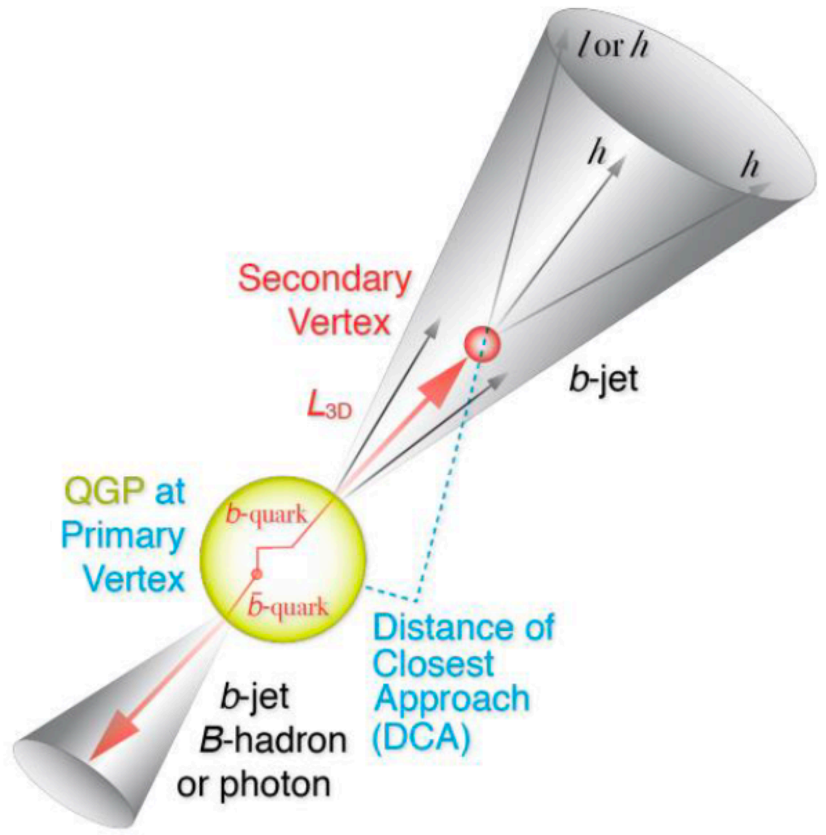
Heavy Flavor Hadronization

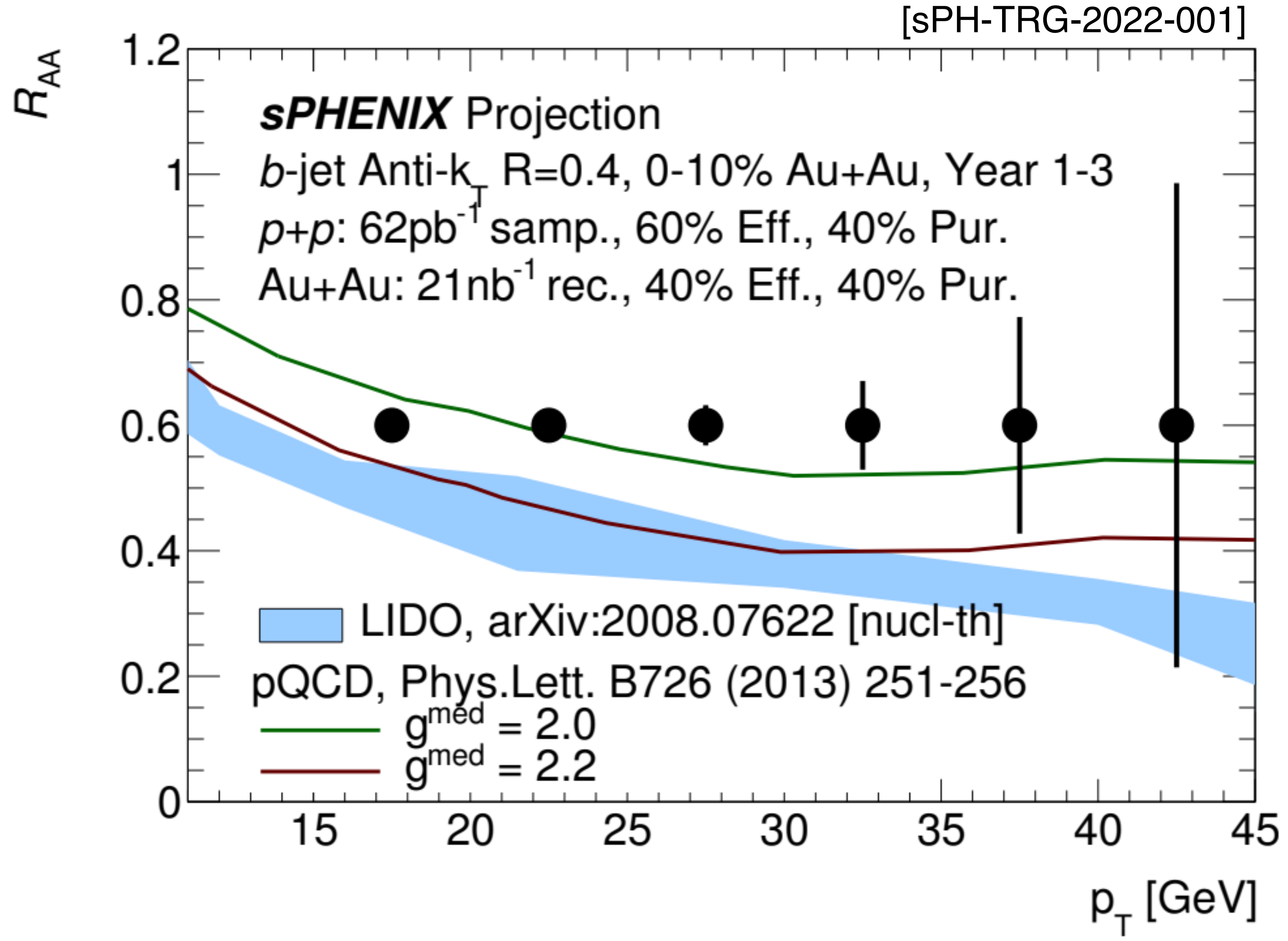
- ➢ STAR and ALICE collaboration reported enhanced charm baryon to meson ratio -> challenging hadronization models
- ➢ sPHENIX streaming readout will deliver first p+p measurement at RHIC
- ➢ sPHENIX will also map out the Λ_c/D ratio over momentum dependence

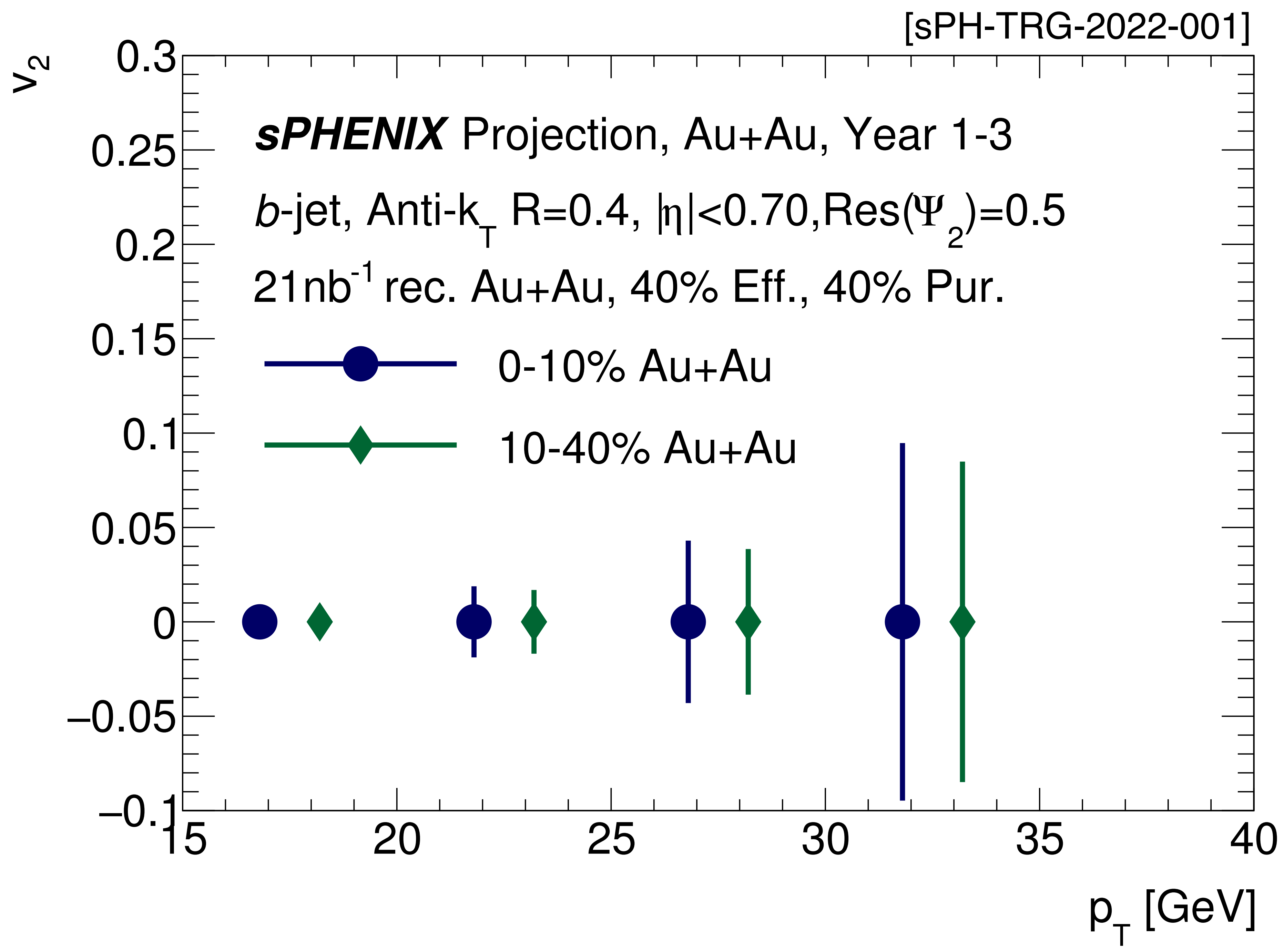


Higher p_T: Access bottom quark via b-jet

sPHENIX b-Jet tagging capabilities determined: strong measurements of both R_{AA} and v_2







First b-jet tagging at RHIC

2 b-jet finding methodologies:

- ➢ Track DCA based tagger
- ➢ Secondary vertices tagger

Complementary to single hadron measurements

Jets provide better access to parton-level quantities

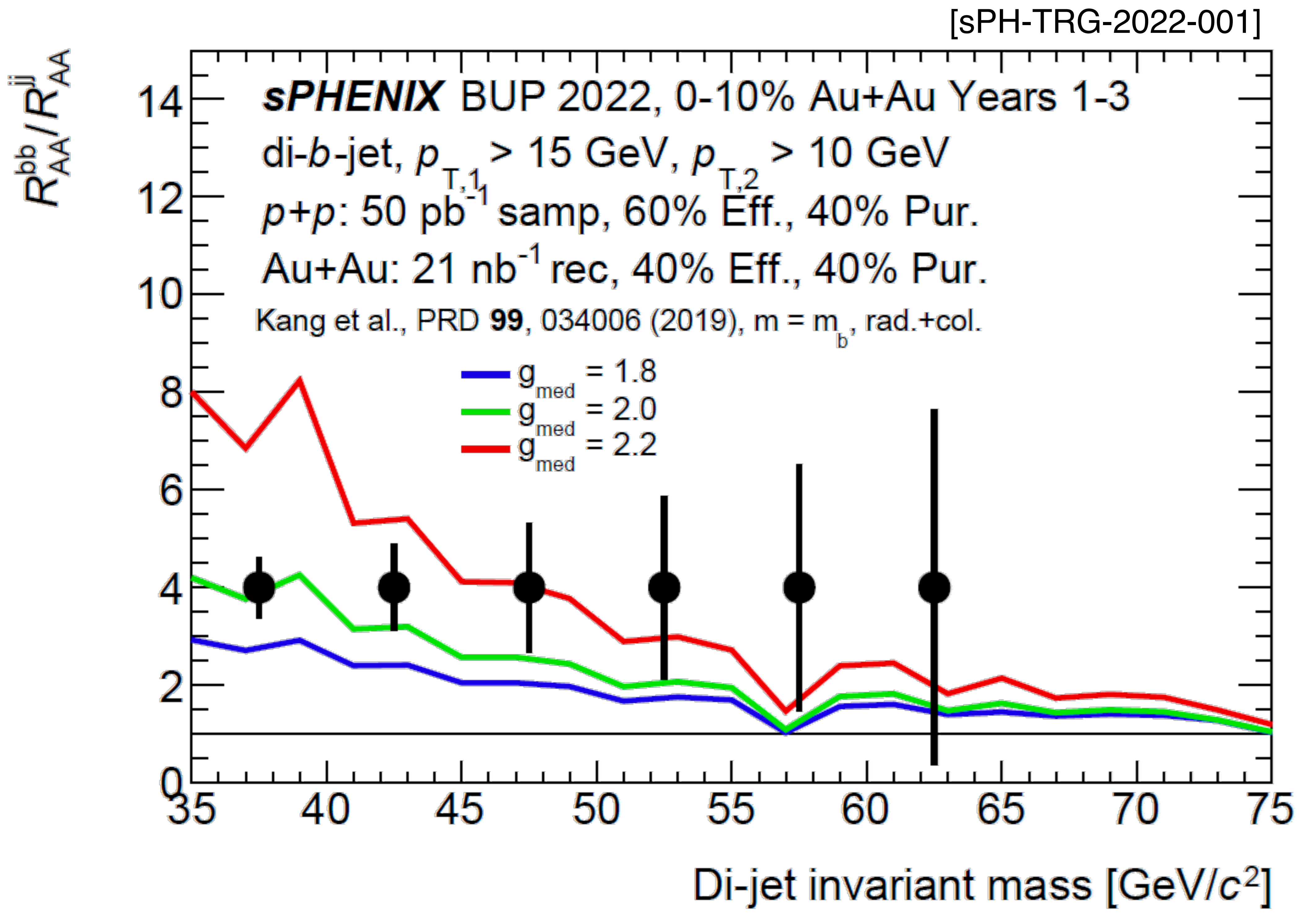
- ➢ Study heavy quark energy loss mechanisms in QGP

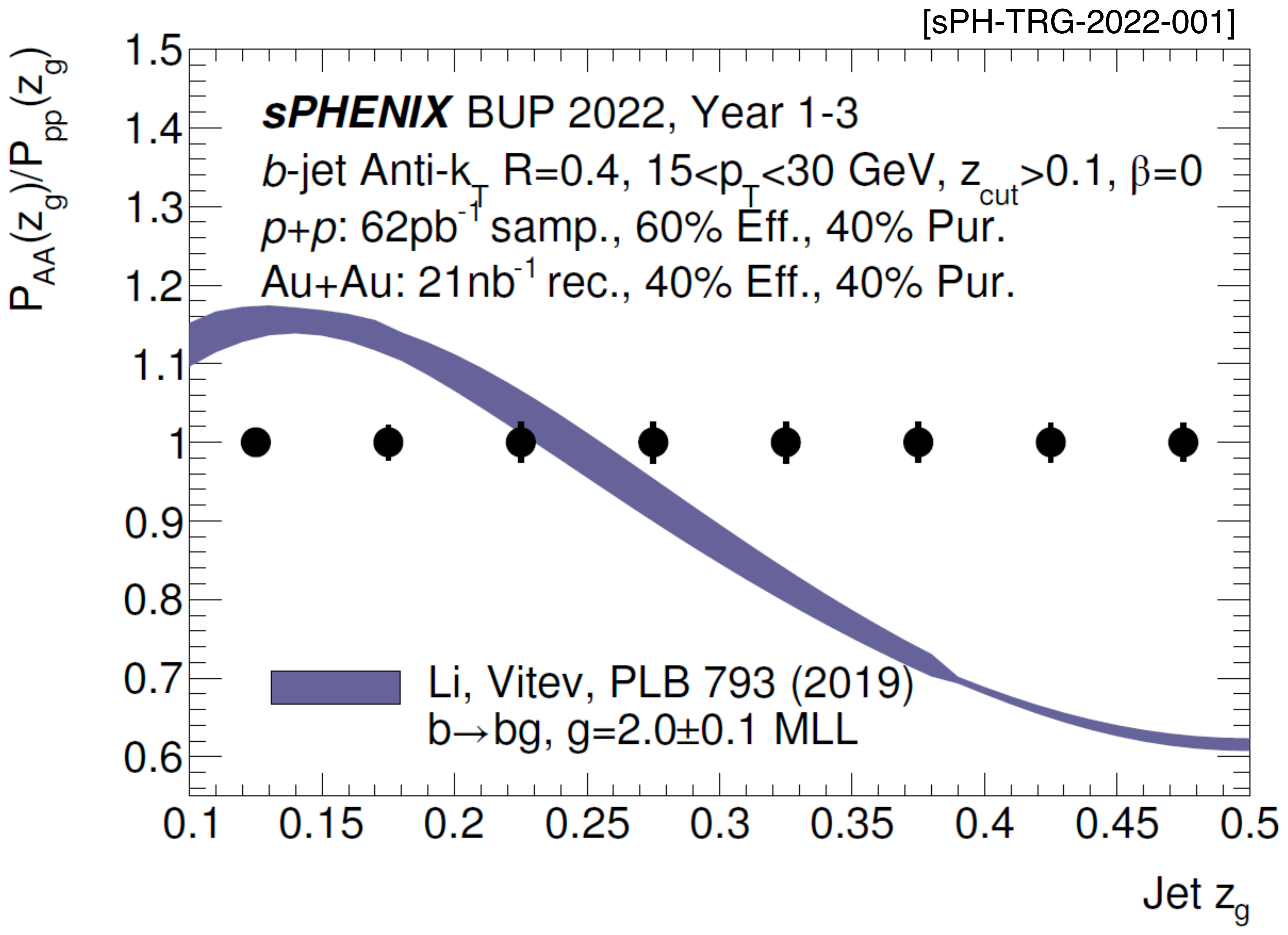
sPHENIX relevant p_T range: 15-45 GeV/c

Strong constraints on transport models

Higher p_T: Access bottom quark via b-jet

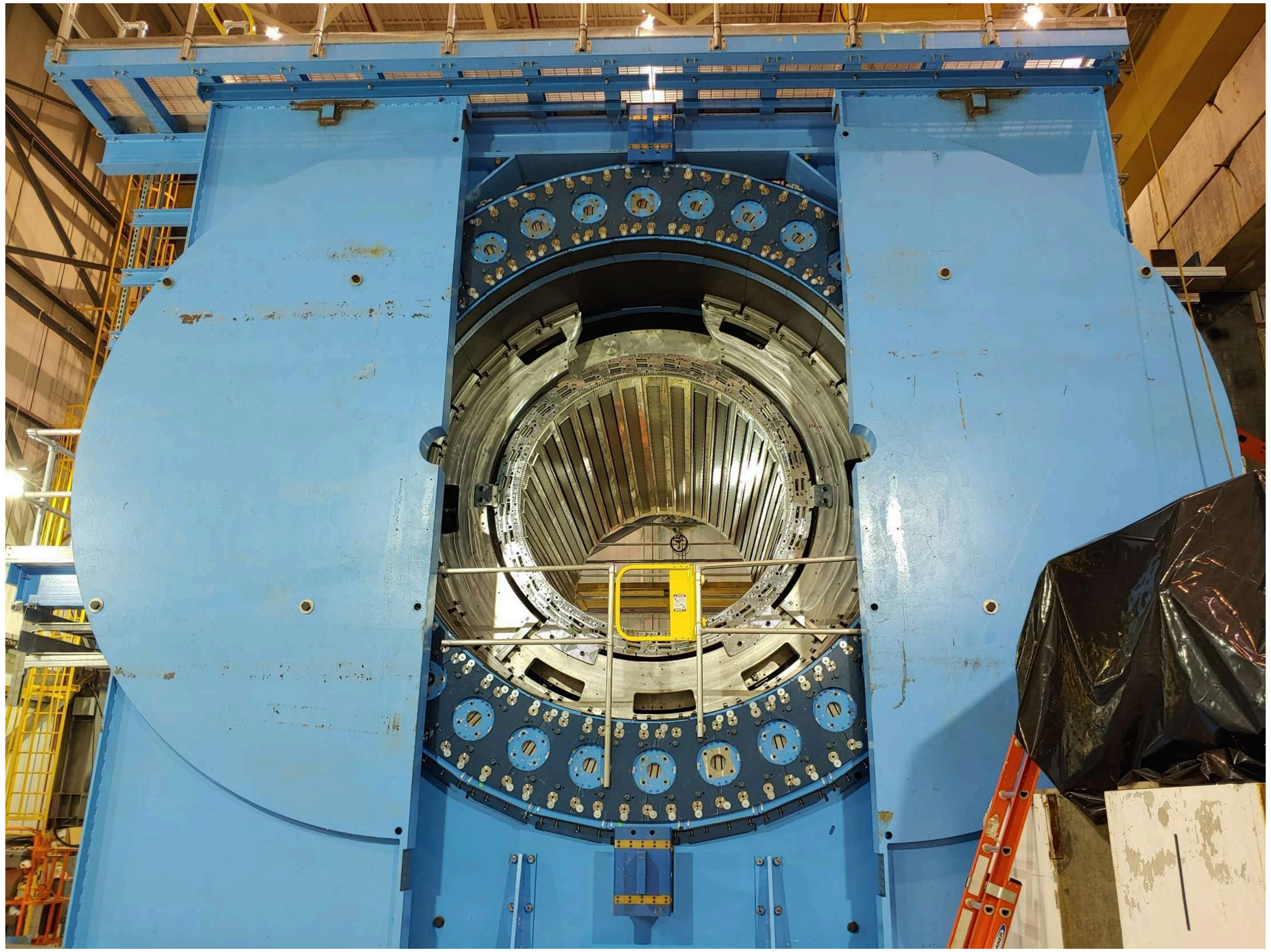
- **Large b-jet statistics -> further differential studies**
  - e.g: di-b-jet pair mass and b-jet substructure
  - Expect significant mass effect at the b-jet kinematics region at sPHENIX





Summary

- sPHENIX is a new detector at RHIC in more than 20 years.
- Thanks to high precise tracking, full calorimetric jet and streaming DAQ:
- sPHENIX offers unique capabilities to probe QGP at distinct length and mass scales at RHIC
  - Υ(3S) measurement at RHIC
  - Precision open HF physics, in particular via b-quark
- First collision in 7 months!

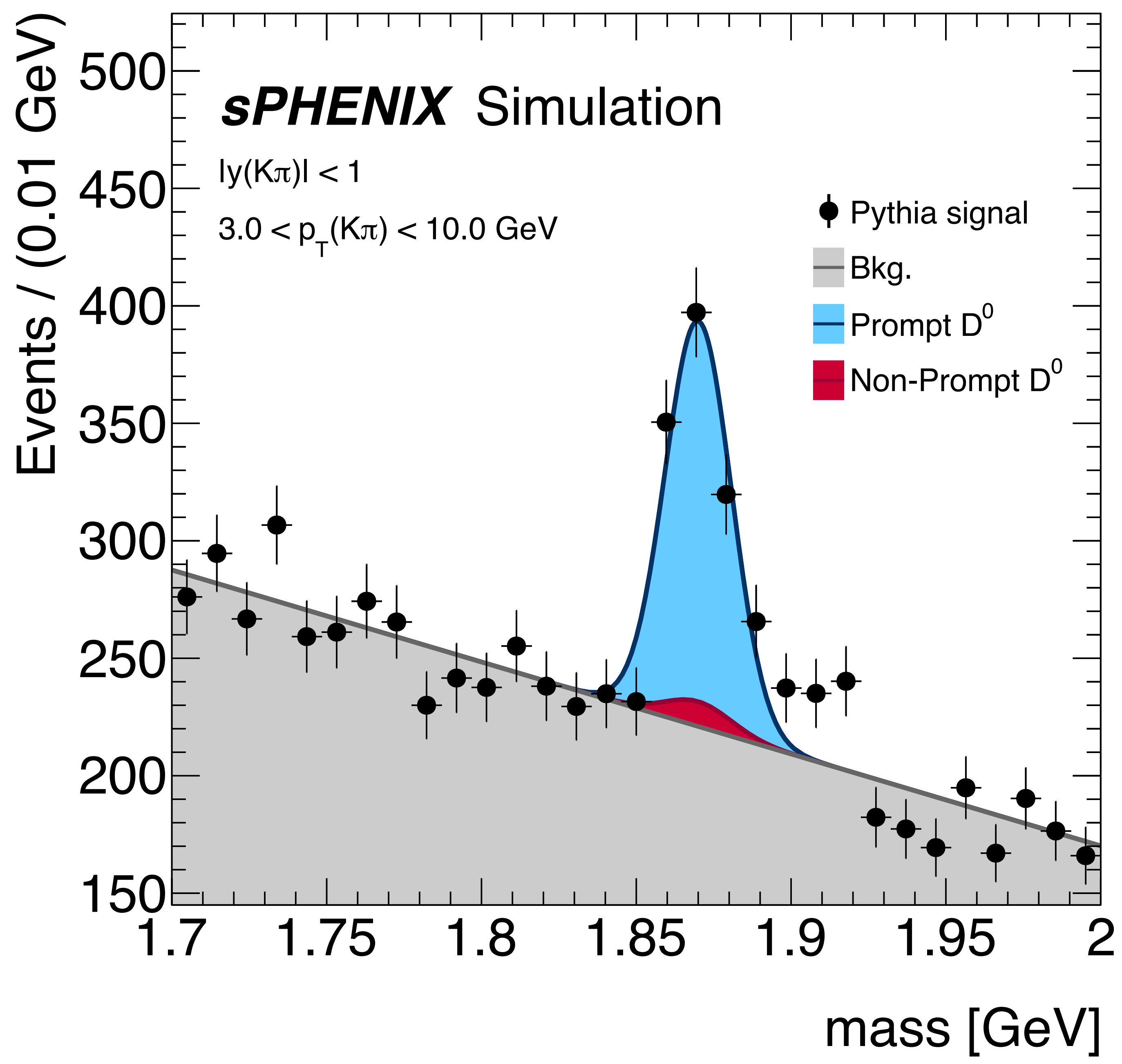


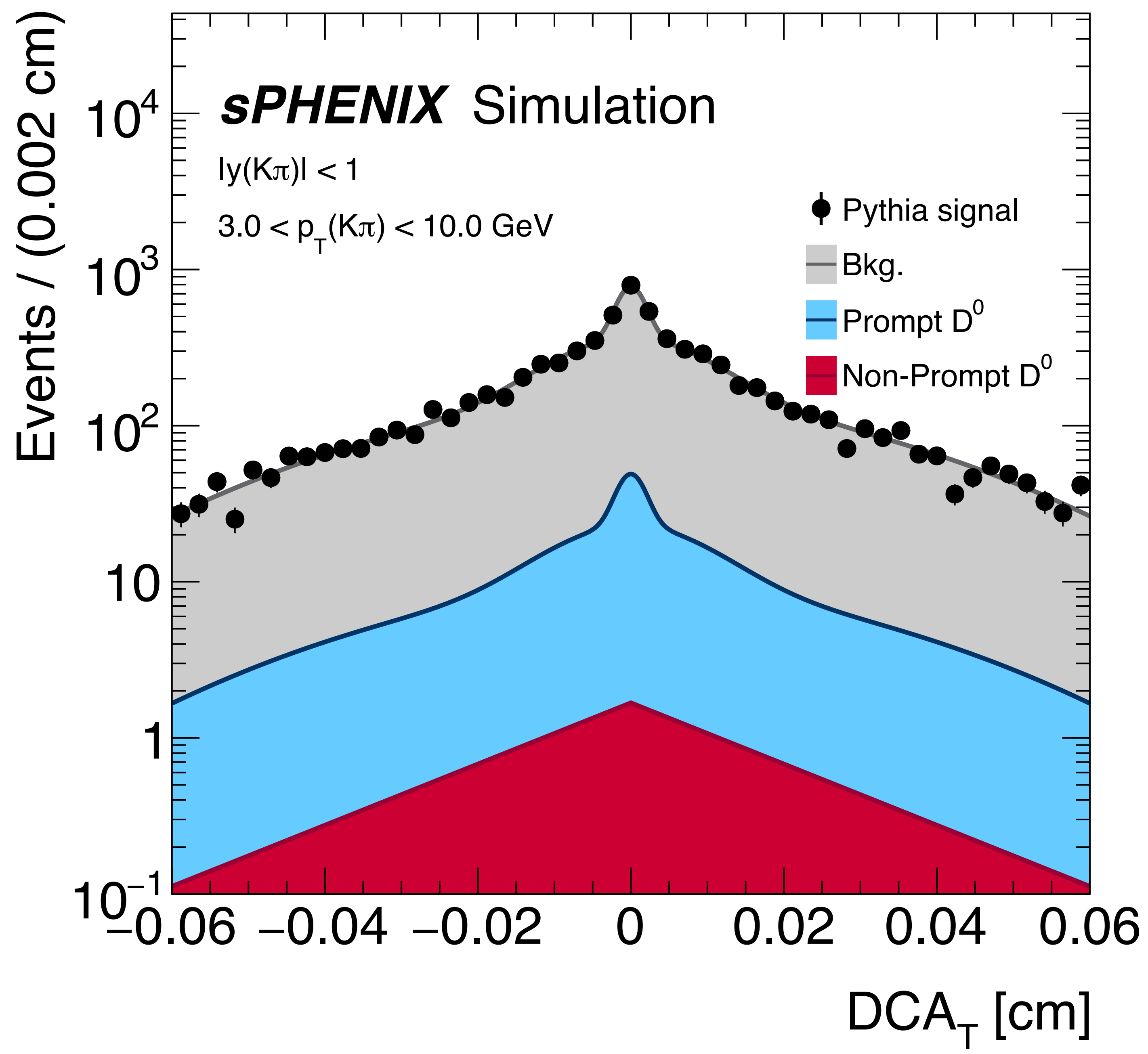
sPHENIX July 15th, 2022

Thank you

Backup

invariant mass and transverse DCA of fully reconstructed D^0 in the KFParticle framework





PYTHIA 8.3 pp + ccbar, bbbar events

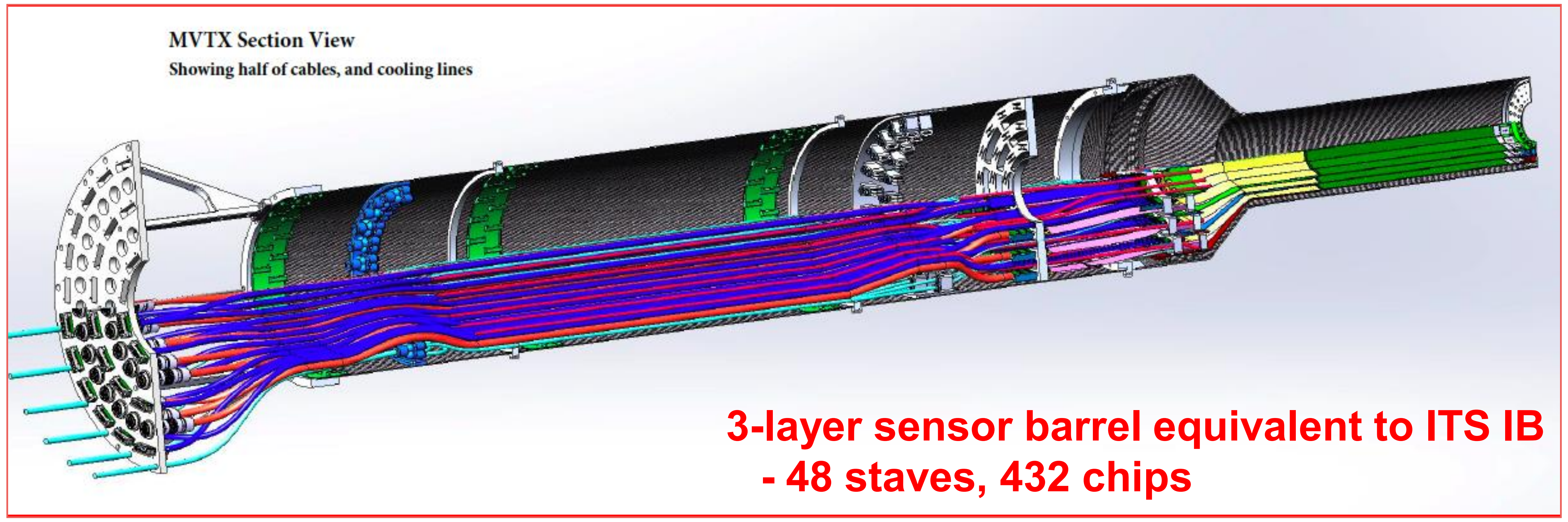
Statistic equivalent to 1 day of pp run data taking

No PID information.

- ➢ KFParticle originally developed for CBM and ACTS (A Common Tracking Software) **successfully implemented** in the sPHENIX simulation and reconstruction framework.
  - ◉ Both package used as default during the first Mock Data Challenge campaign.

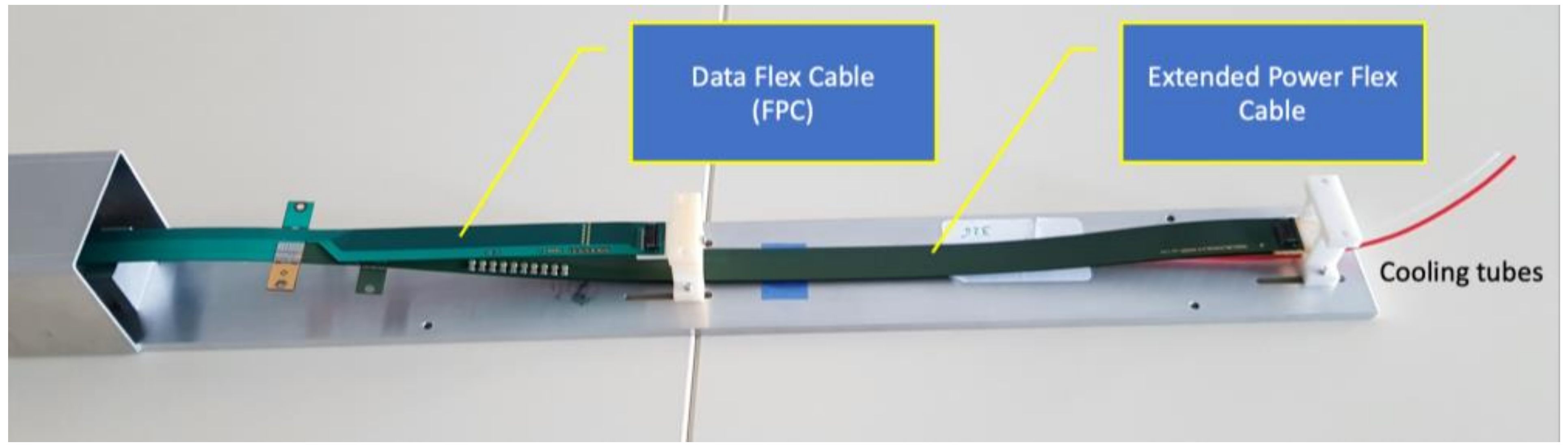
MVTX:

- 3 active layers (48 staves)
- 9 ALPIDE chips per stave
- Full azimuthal coverage: 2π
- $|\eta| < 1.1$
- Front-end readout uses ALICE Readout Unit
- The back-end uses the ATLAS FELIX



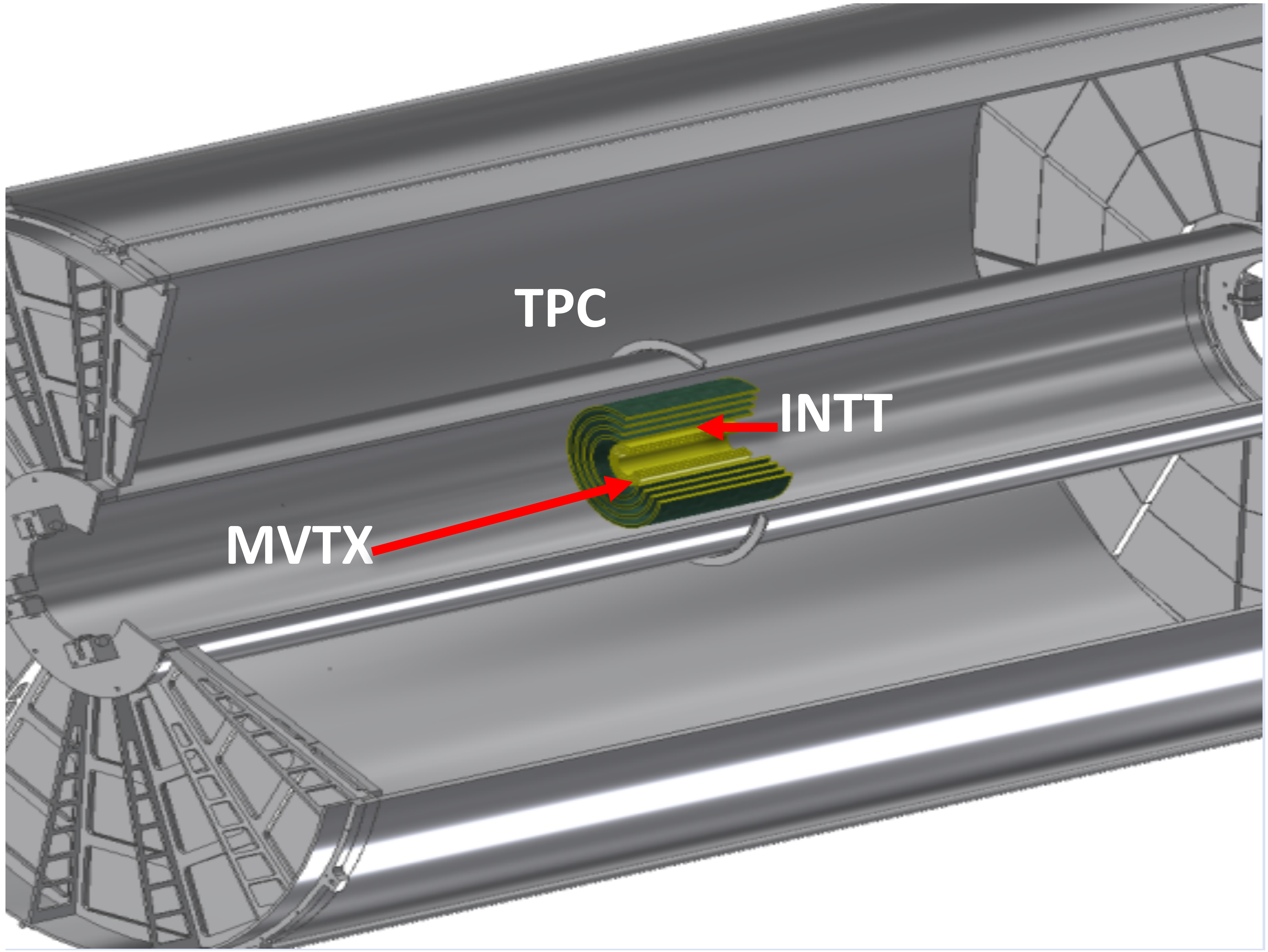
Basic unit: ALPIDE sensors

- Good spatial resolution
- Low power consumption
- High efficiency
- Low fake rate



Staves are identical to ALICE inner barrel staves, except for leads

Produced at CERN and shipped to LBNL for test and assembling



1/30th Volume
ALICE TPC

MVTX (based on ALICE ITS-II IB):

- 3-layers of Monolithic Active Pixel Sensors using ALICE ALPIDE
- Stave produced at CERN, following same procedure used for ALICE.
- Excellent 2-D DCA resolution, < 10 μm, $p_T > 2$ GeV/c
- high-performance vertexing to the integrated tracking program

INTT:

- 2-layers Si strip
- strip size (ϕ x z): $0.086 \times 20\ mm^2$
- very good integration time (< 100 ns)

TPC:

- very compact TPC
- 48 pad rows, continuous readout, $R = 20\text{-}78$ cm
- Momentum resolution $\sigma_{p_T}/p_T < 0.2\% \times p$ for $p_T = 0.2\text{-}40$ GeV/c

Full Electromagnetic and Hadronic calorimeter system!

- Large Acceptance: 1.1 < $|\eta|$ and full 2π azimuthal coverage
- SiPM used for light collection/readout

Electromagnetic Calorimeter (EMCal)

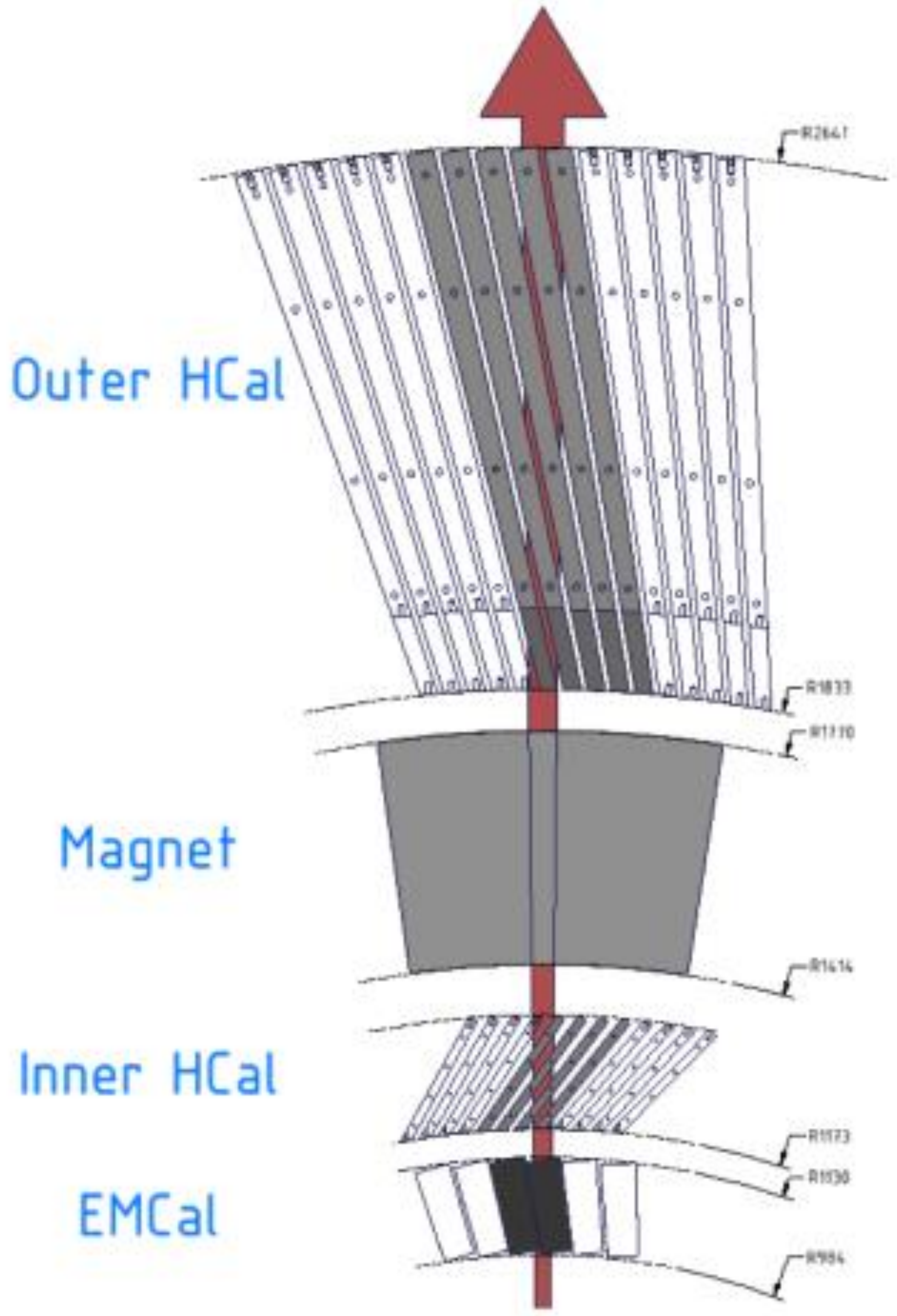
- Tungsten powder with embedded scintillating fiber matrix
- $\Delta\eta \times \Delta\phi \approx 0.024 \times 0.024$
- good energy resolution: ~ $15\%/\sqrt{E}$ (demonstrated with 3 beam-test)

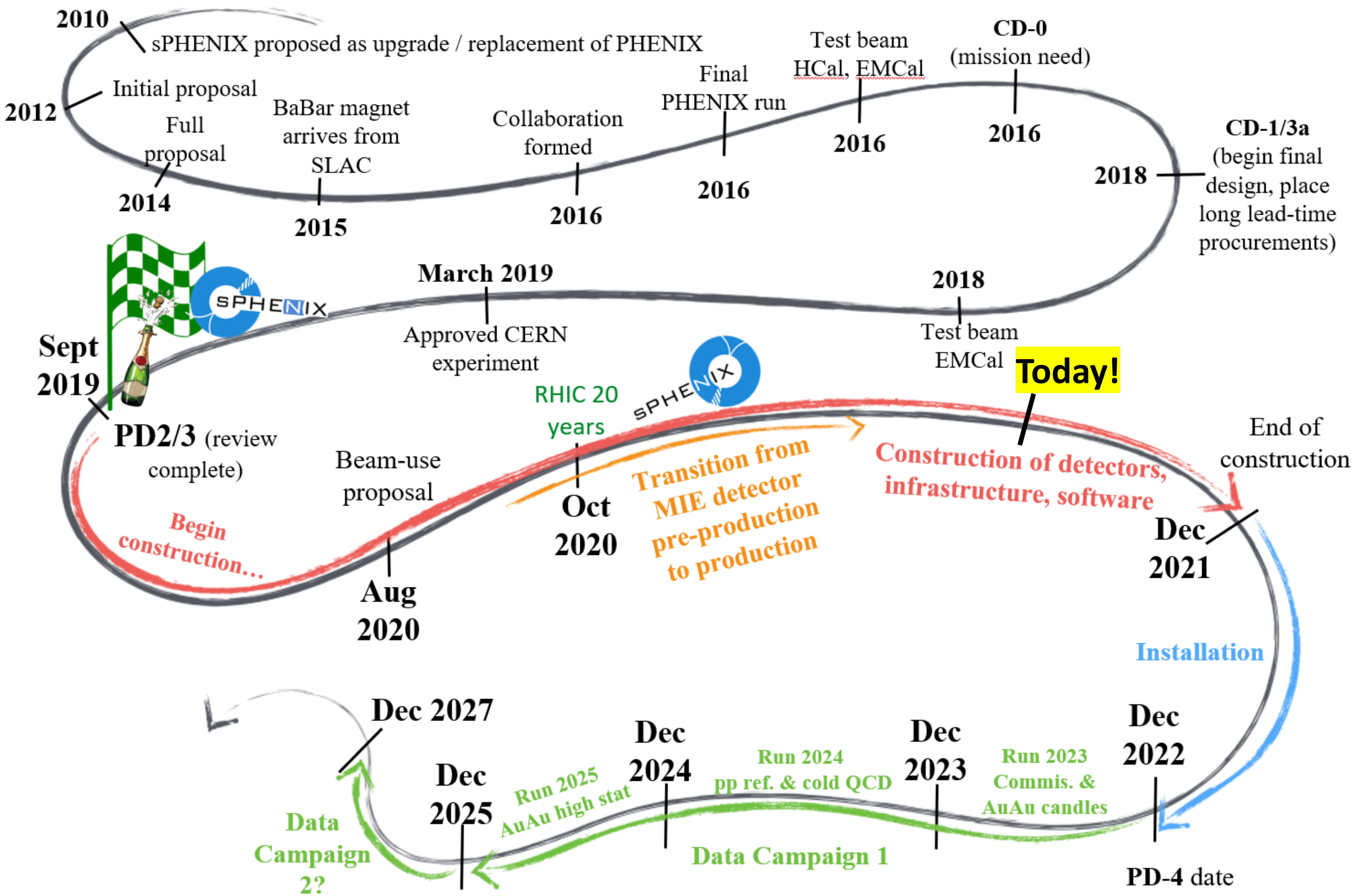
inner Hadronic Calorimeter (Inner HCal)

- Aluminum absorber plates and scintillating tiles with embedded WLS fibers

outer Hadronic Calorimeter (Outer HCal)

- Steel absorber plates and scintillating tiles with embedded WLS fibers




2010
sPHENIX proposed as upgrade / replacement of PHENIX
2012
Initial proposal
Full proposal
2014
BaBar magnet arrives from SLAC
2015
Collaboration formed
2016
Final PHENIX run
2016
Test beam HCal, EMCal
2016
CD-0 (mission need)
2016
2018
CD-1/3a (begin final design, place long lead-time procurements)
2018
Test beam EMCal
March 2019
Approved CERN experiment
Sept 2019
PD2/3 (review complete)
Begin construction…
Beam-use proposal
Aug 2020
RHIC 20 years
Oct 2020
Transition from MIE detector pre-production to production
Today!
Construction of detectors, infrastructure, software
End of construction
Dec 2021
Installation
Dec 2022
PD-4 date
Run 2023 Commis. & AuAu candles
Dec 2023
Run 2024 pp ref. & cold QCD
Dec 2024
Data Campaign 1
Run 2025 AuAu high stat
Dec 2025
Dec 2027
Data Campaign 2?