sPHENIX Heavy Flavor Overview

Jin Huang

For sPHENIX Collaboration

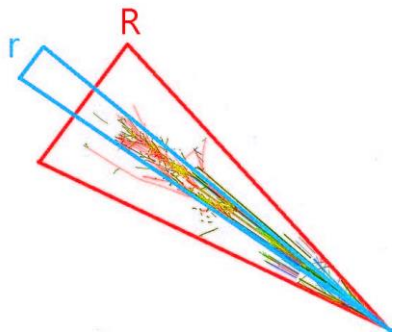
Brookhaven National Laboratory

Core physics programs

See also: Nov-7 D. Anderson, Nov-9 C. Hughes, J. Osborn

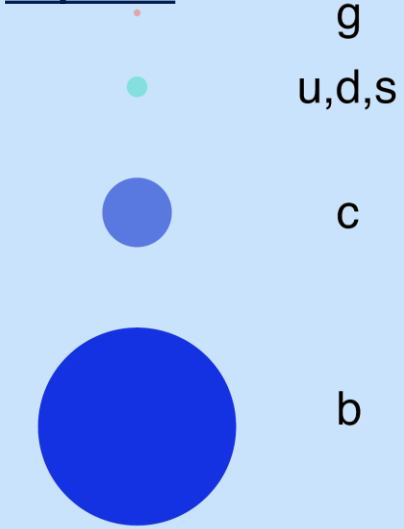
Jet cor. & substructure

Vary momentum/ angular size of probe



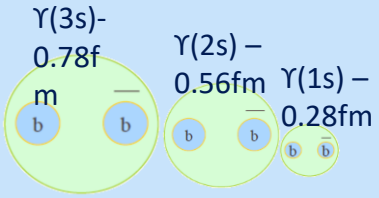
Parton energy loss

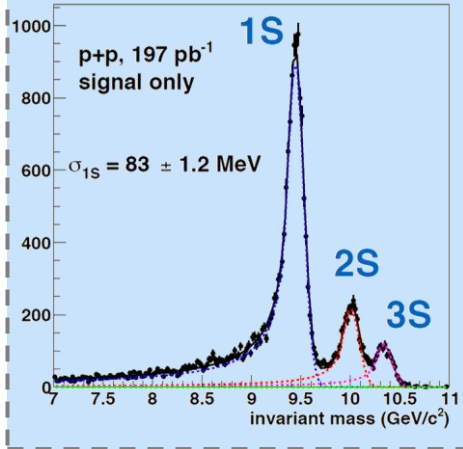
Vary mass/ momentum of probe



Upsilon spectroscopy

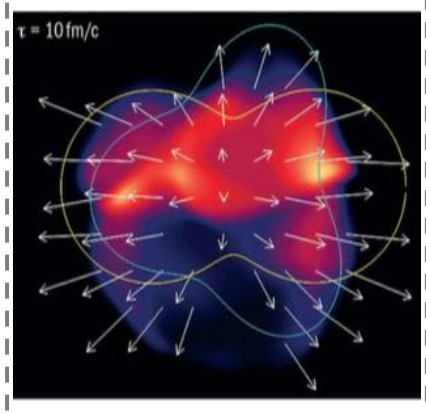
Vary size of the probe





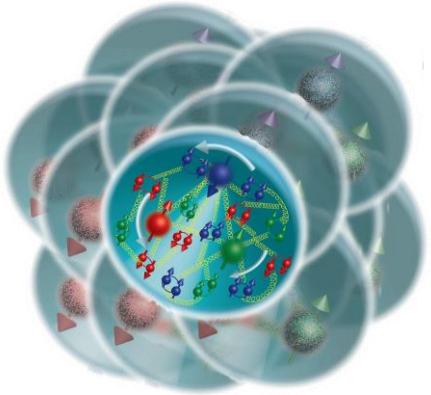
Bulk Medium

Global/local medium properties



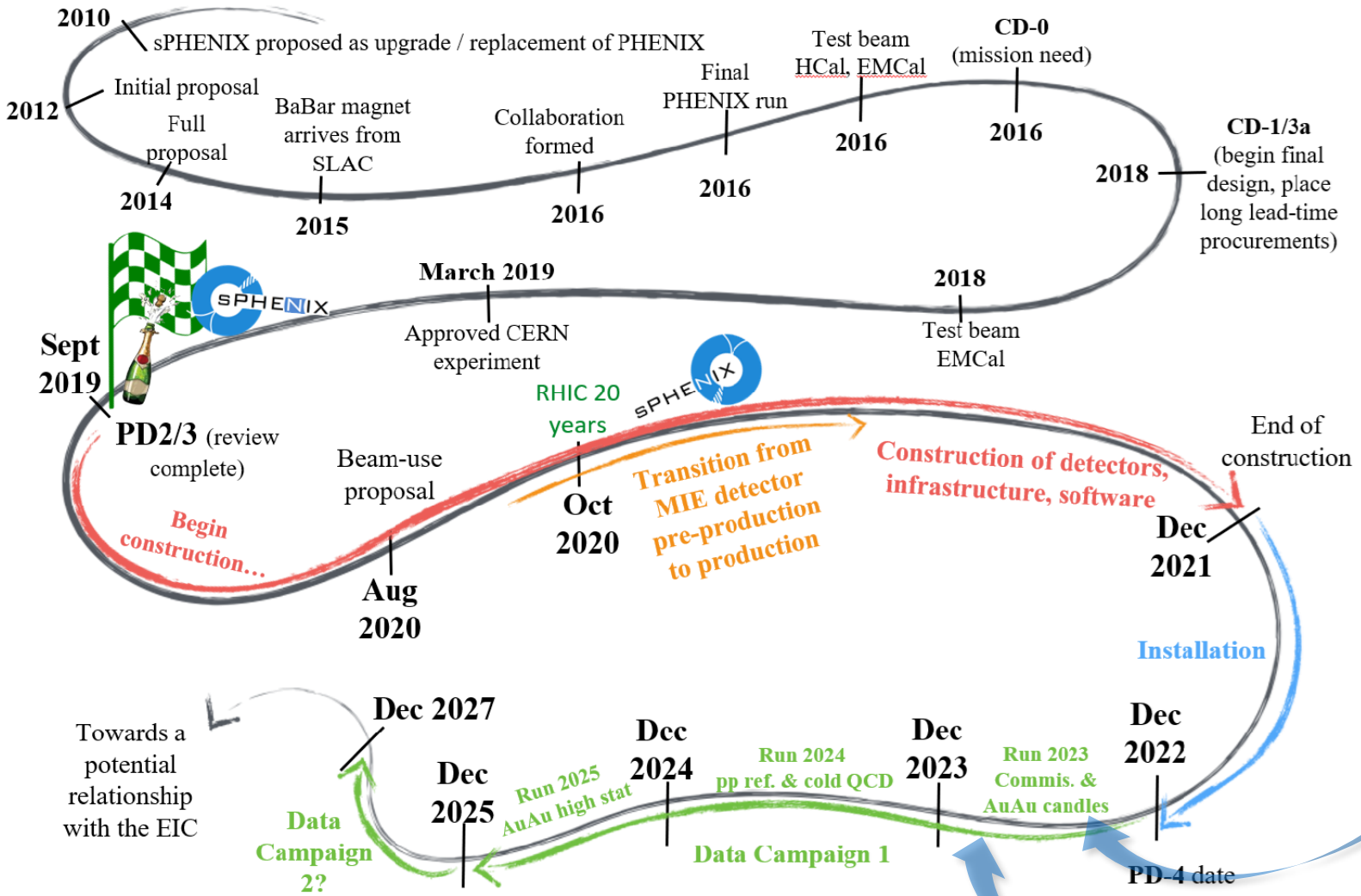
Cold QCD

Vary temperature of QCD matter



Focus of this talk

Also: HF as a unique probe for hot and cQCD systems

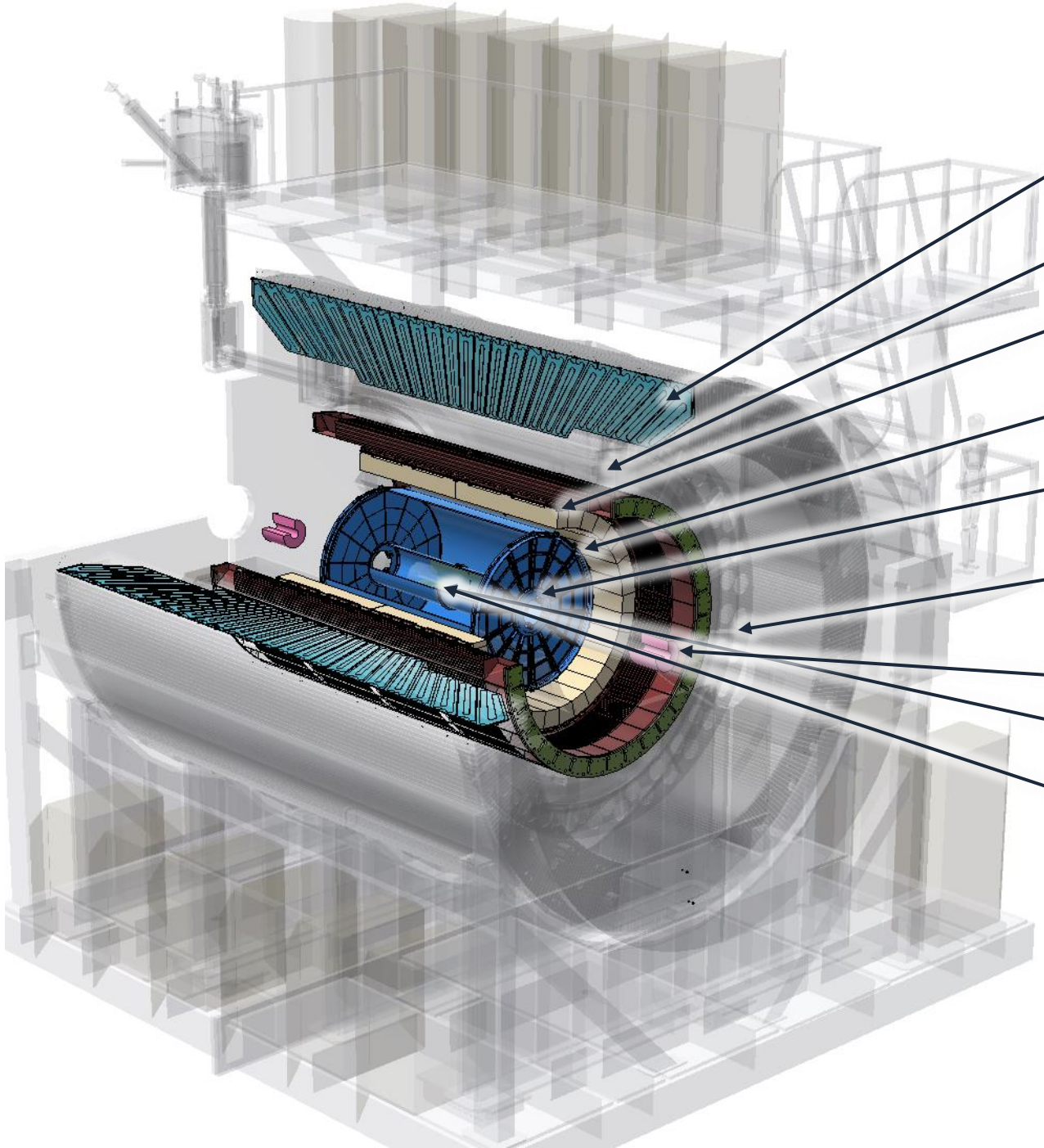


Center for Frontiers in Nuclear Science

2nd workshop on advancing the understanding of non-perturbative QCD using energy flow

Nov 6 – 9, 2023
Stony Brook University/Online
America/New_York timezone

Enter your search term



Hadronic Calorimeter(s)

1.4 T super conducting magnet

Electromagnetic Calorimeter

Micromegas Outer Tracker (TPOT)

Time Projection Chamber (TPC)

Event plane detector (EPD)

M.B. and Event Plane Detectors

Intermediate Tracker (INTT)

MicroVertex Detector (MVTX)

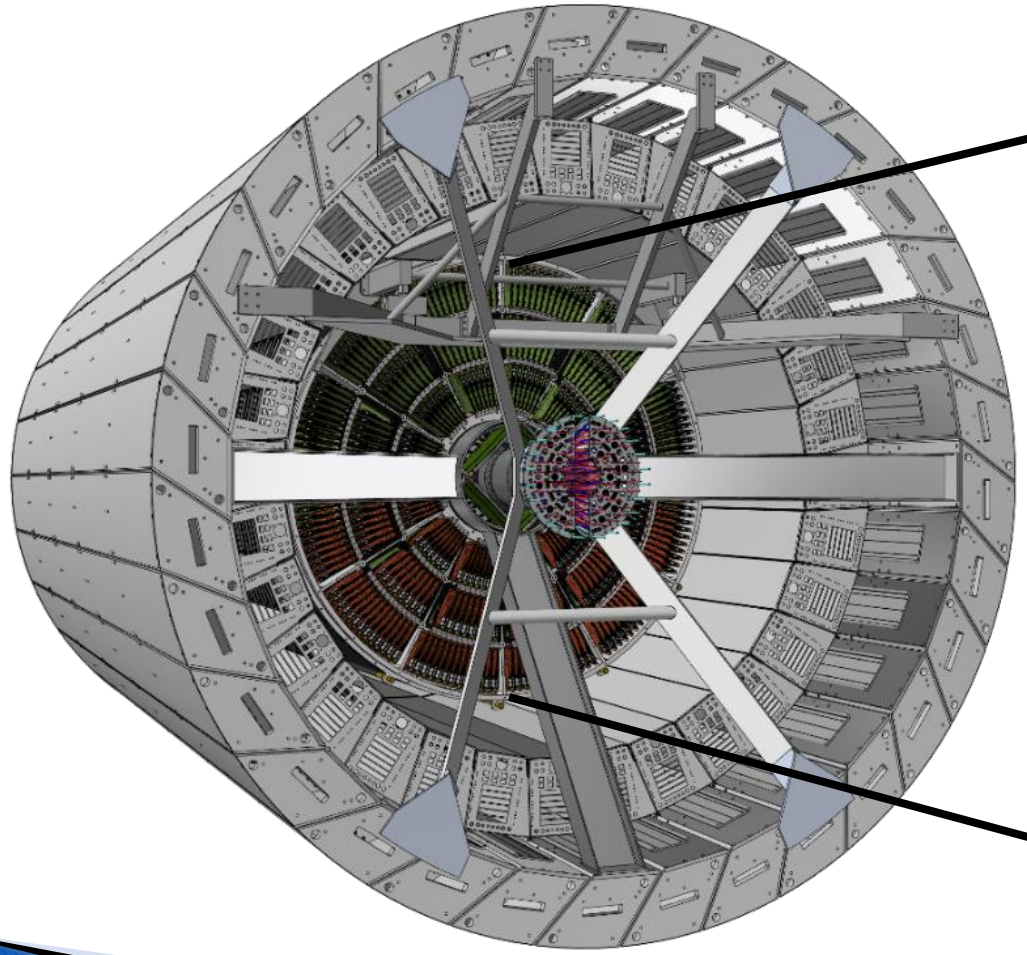
DAQ:

15 kHz calo trigger + 10% streaming

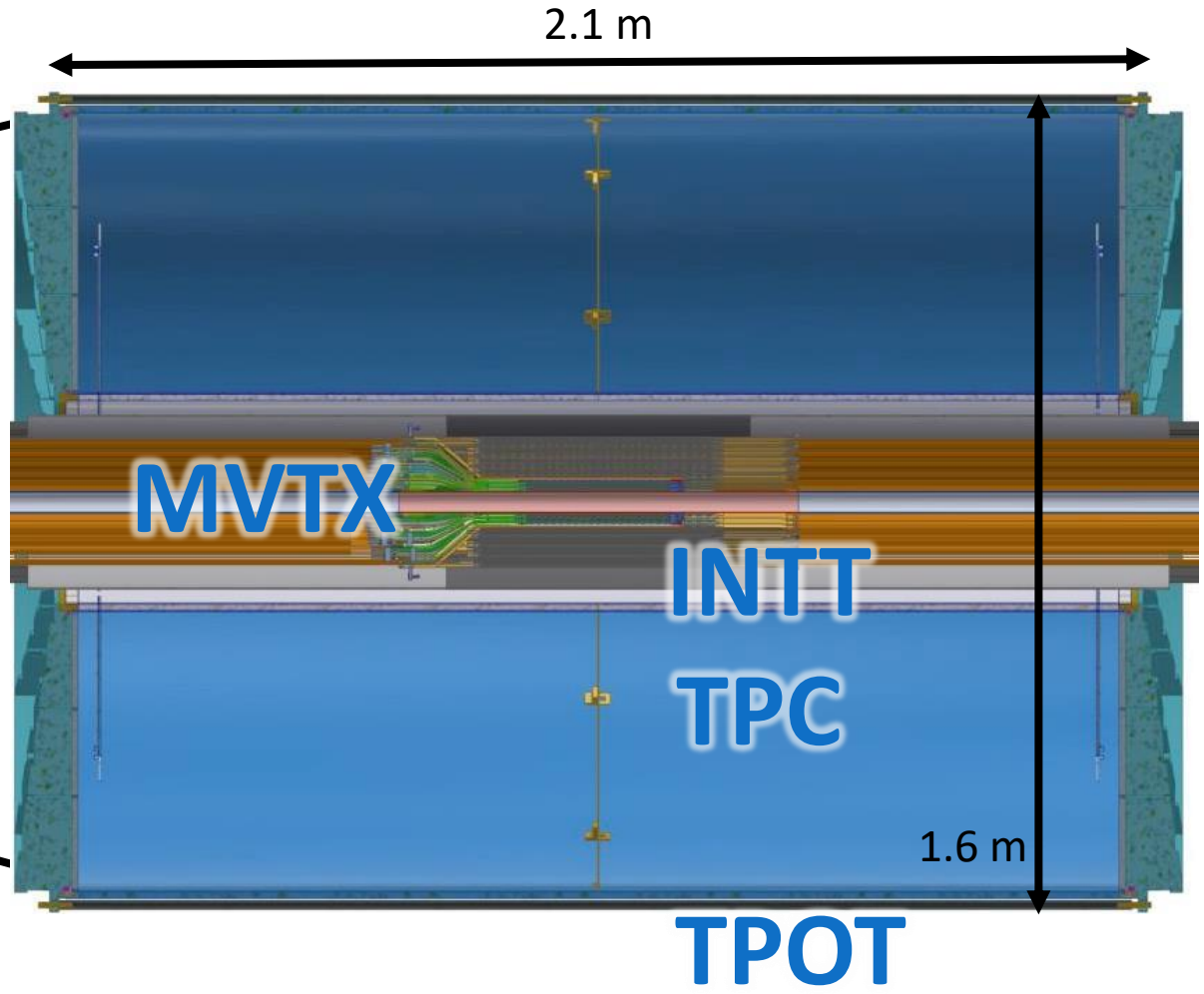
10 GB/s data logging

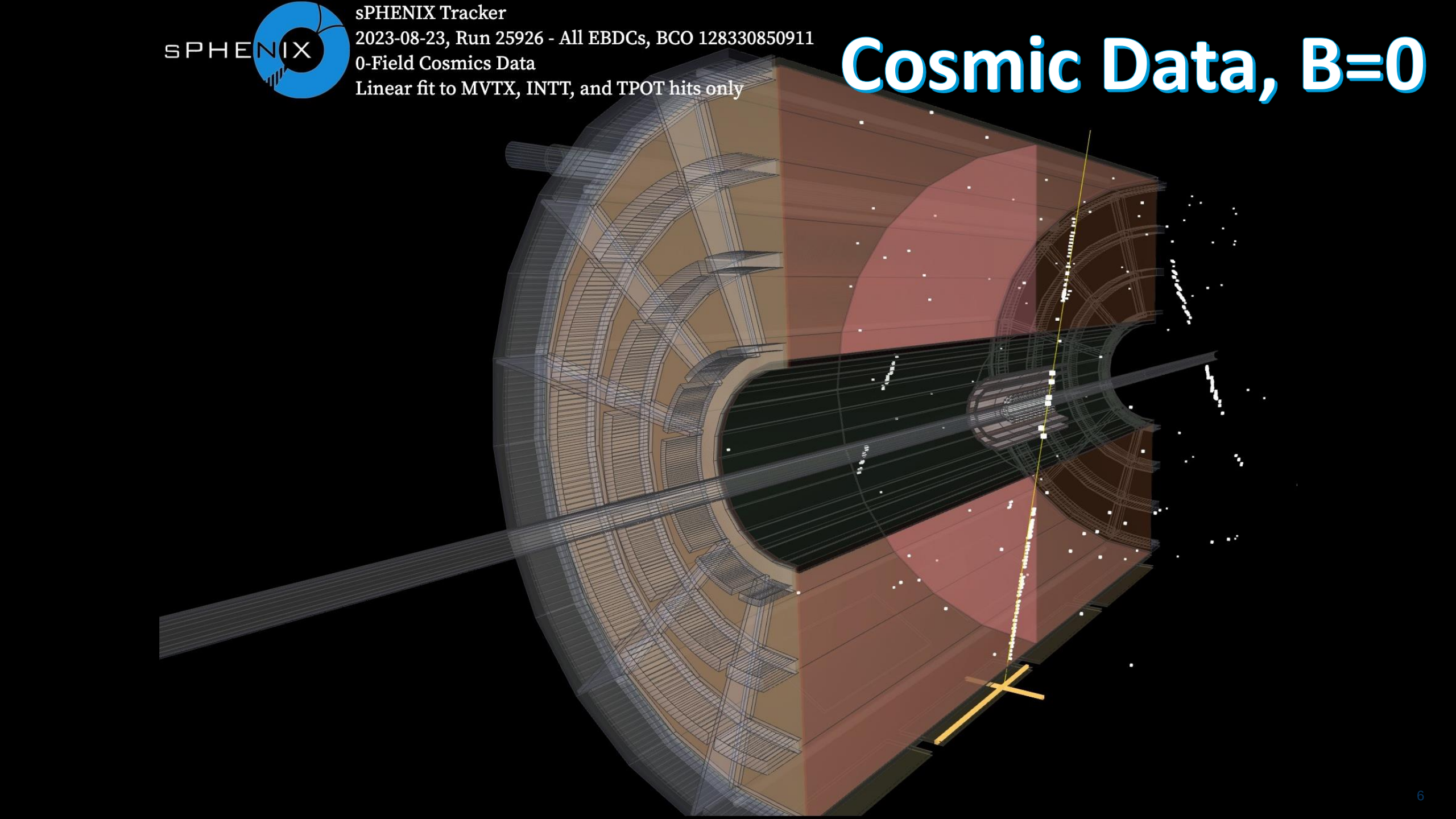
sPHENIX Tracking Detectors

See also: Nov-9 C. Hughes

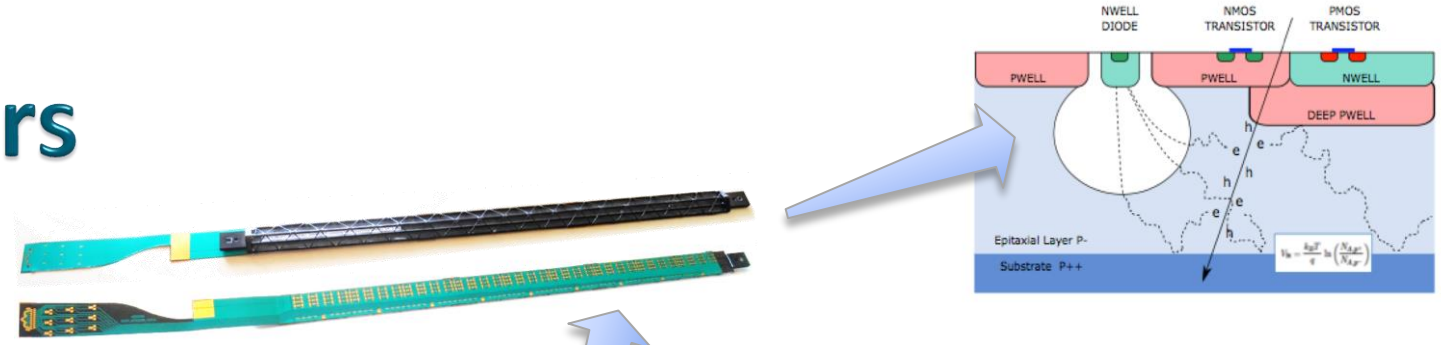


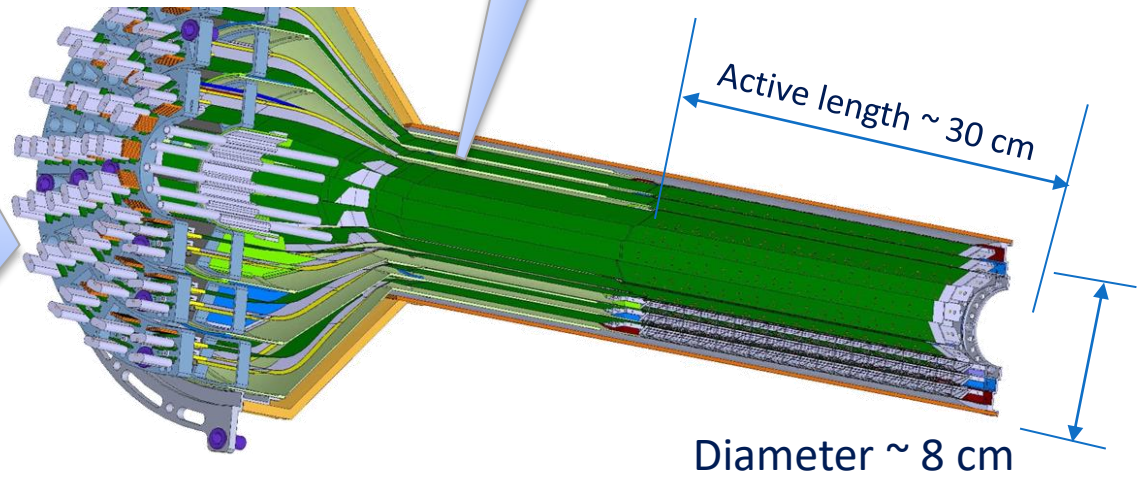
Detectors inside the magnet




sPHENIX Tracker
2023-08-23, Run 25926 - All EBDCs, BCO 128330850911
0-Field Cosmics Data
Linear fit to MVTX, INTT, and TPOT hits only
Cosmic Data, B=0

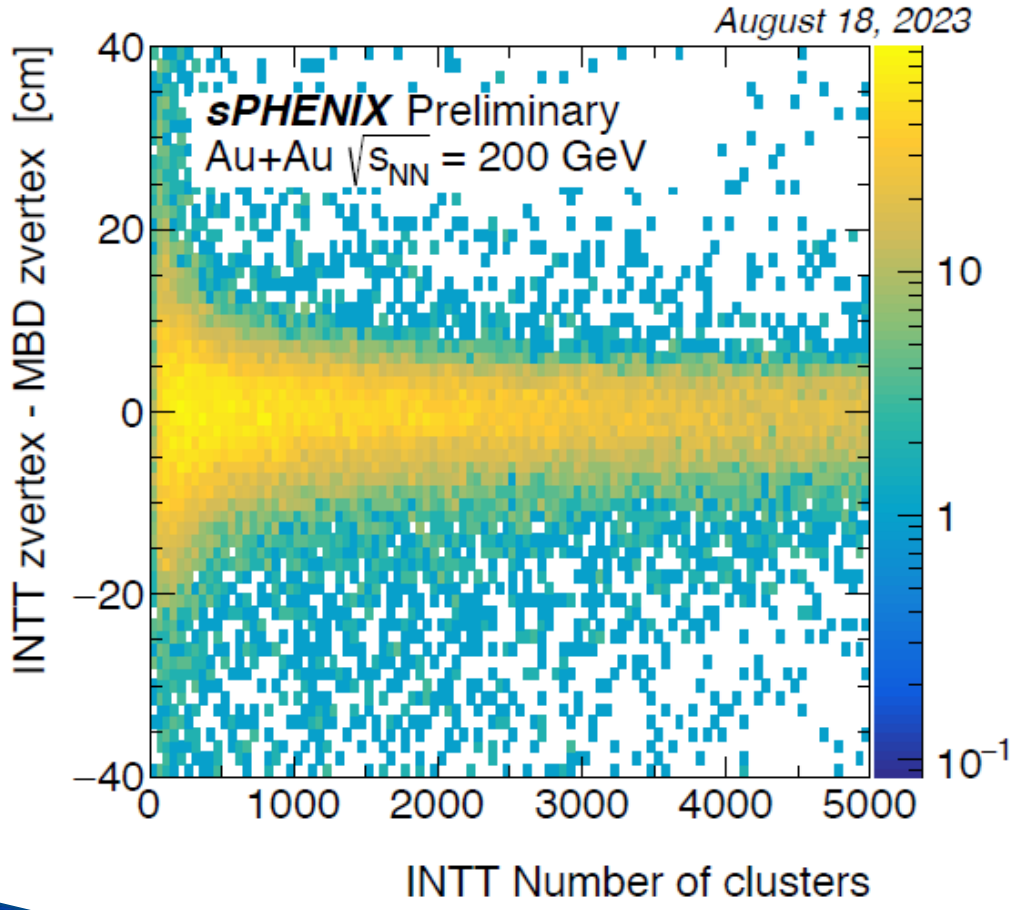
Precision vertex trackers

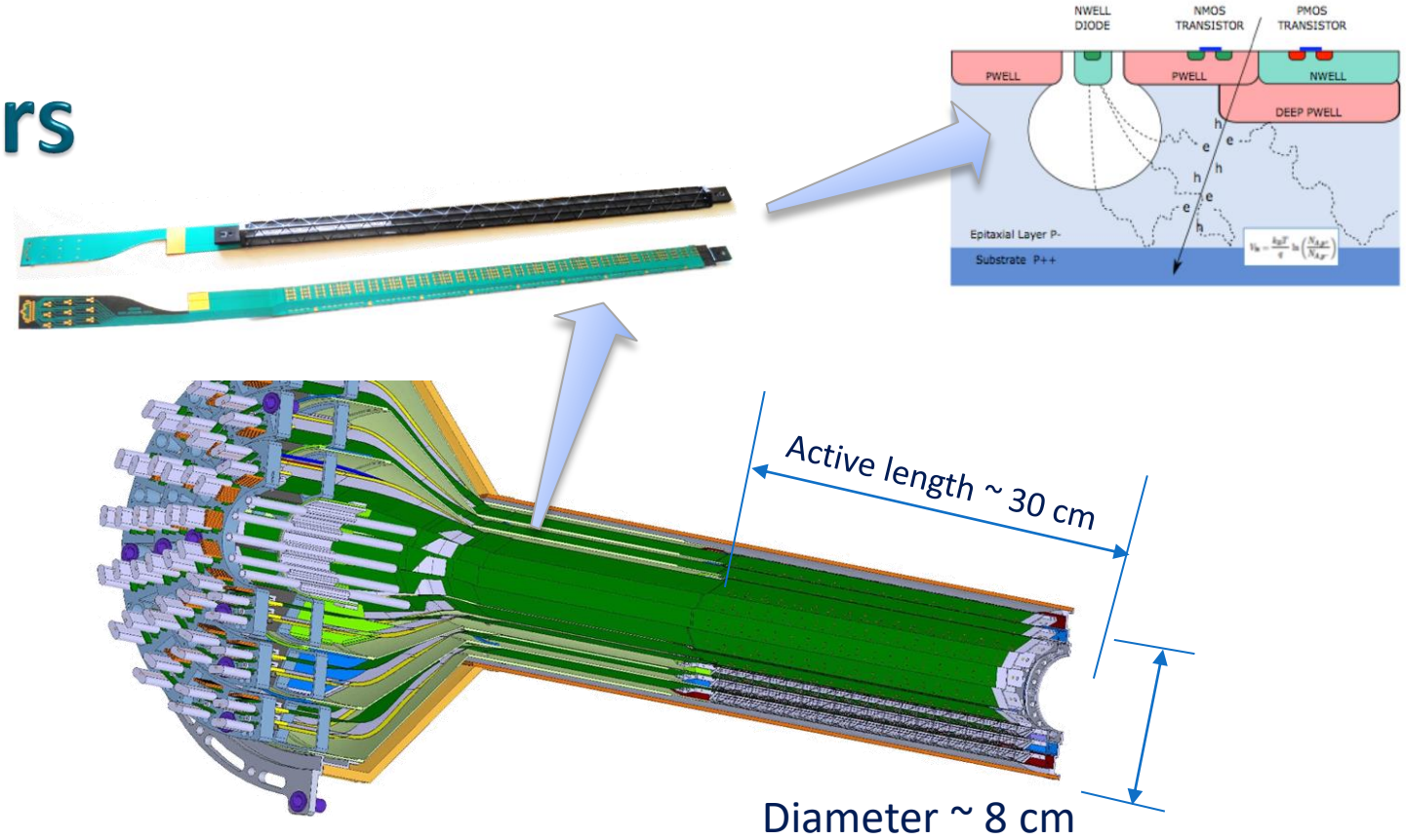




- **MVTX**: MAPS based vertex tracker, 3 layers
  - Using staves from ALICE ITS2 upgrade
  - ALPIDE chip, 30um pitch, Low mass (~0.3% X_0)
  - 5um position resolution, 5-10us integration time
- **INTT**: silicon strip tracker, 2 layers
  - 78 um pitch, provides timing tag resolving bunch crossing

Precision vertex trackers





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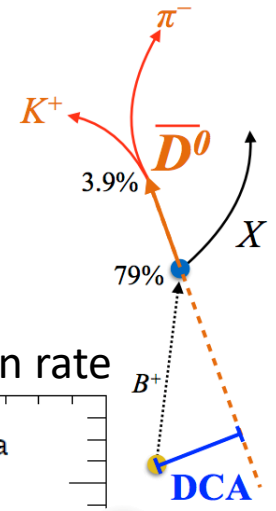
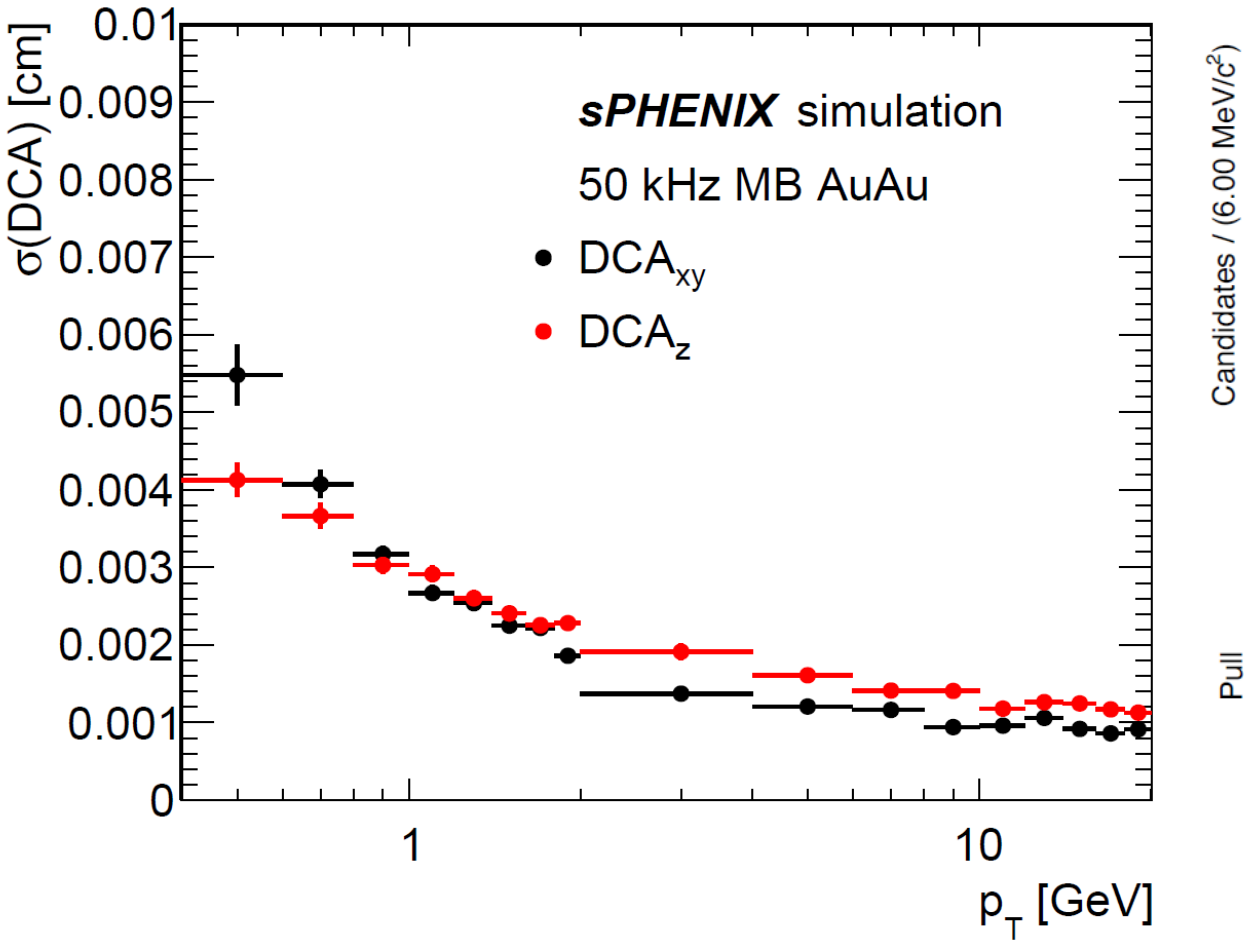
Cleanly separate open bottom meson via DCA

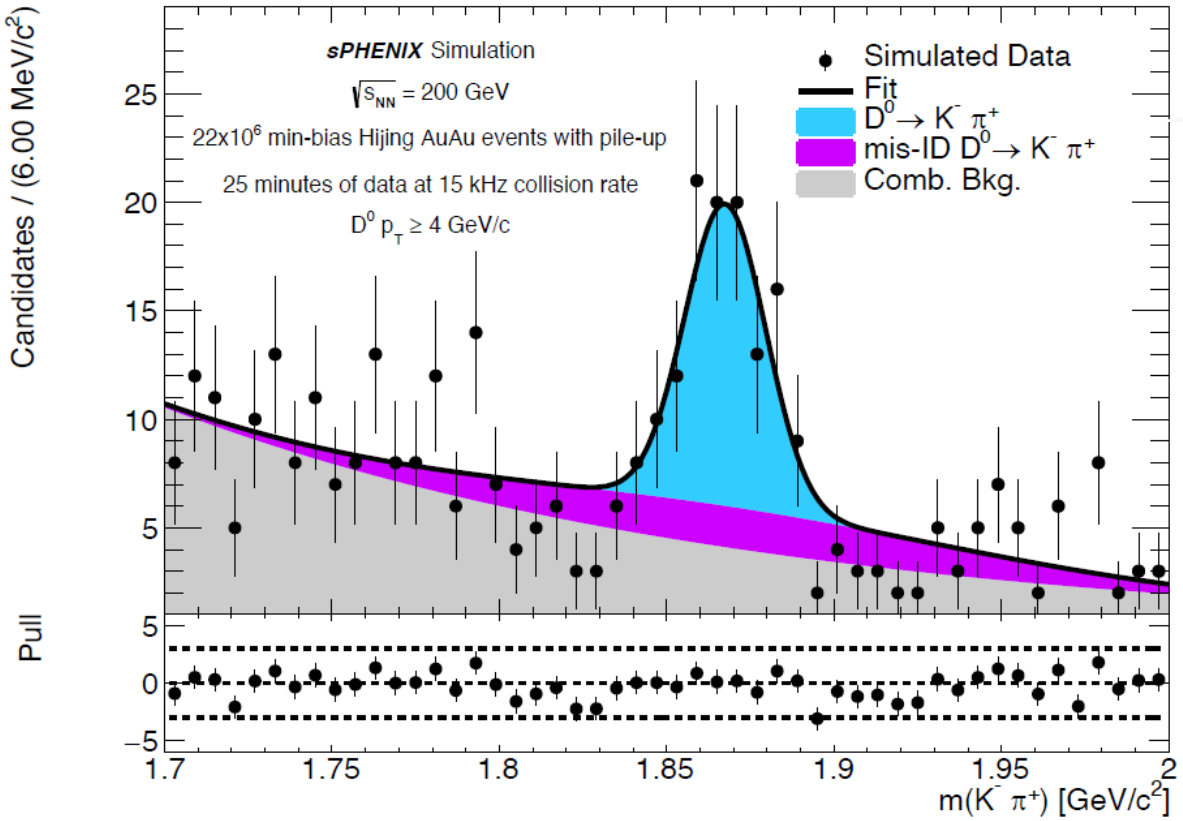


DCA resolution

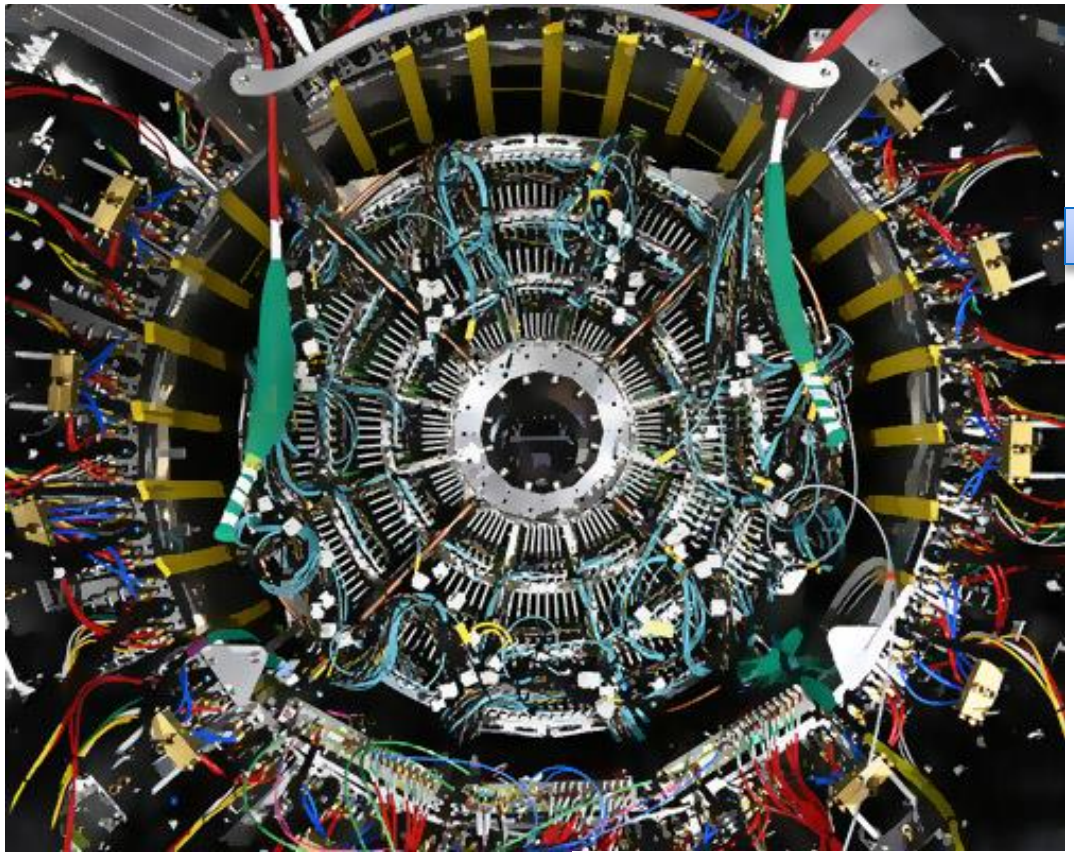


Precision vertex + fast DAQ → large HF sample

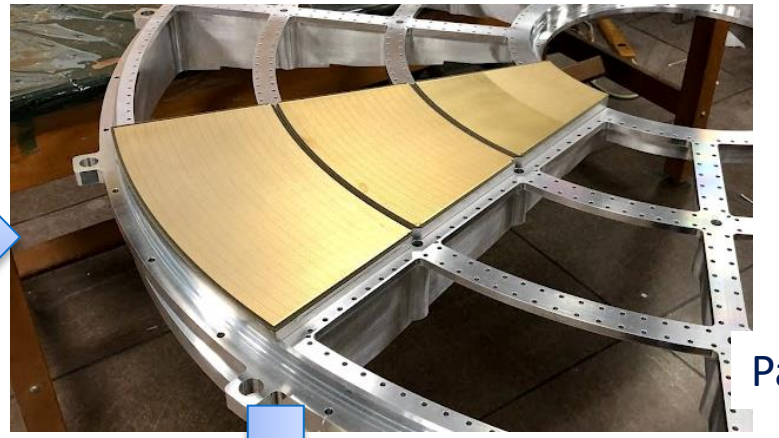
Simulation: 25 minutes of data at 15 kHz collision rate



Main tracker: Time projection chamber (TPC)



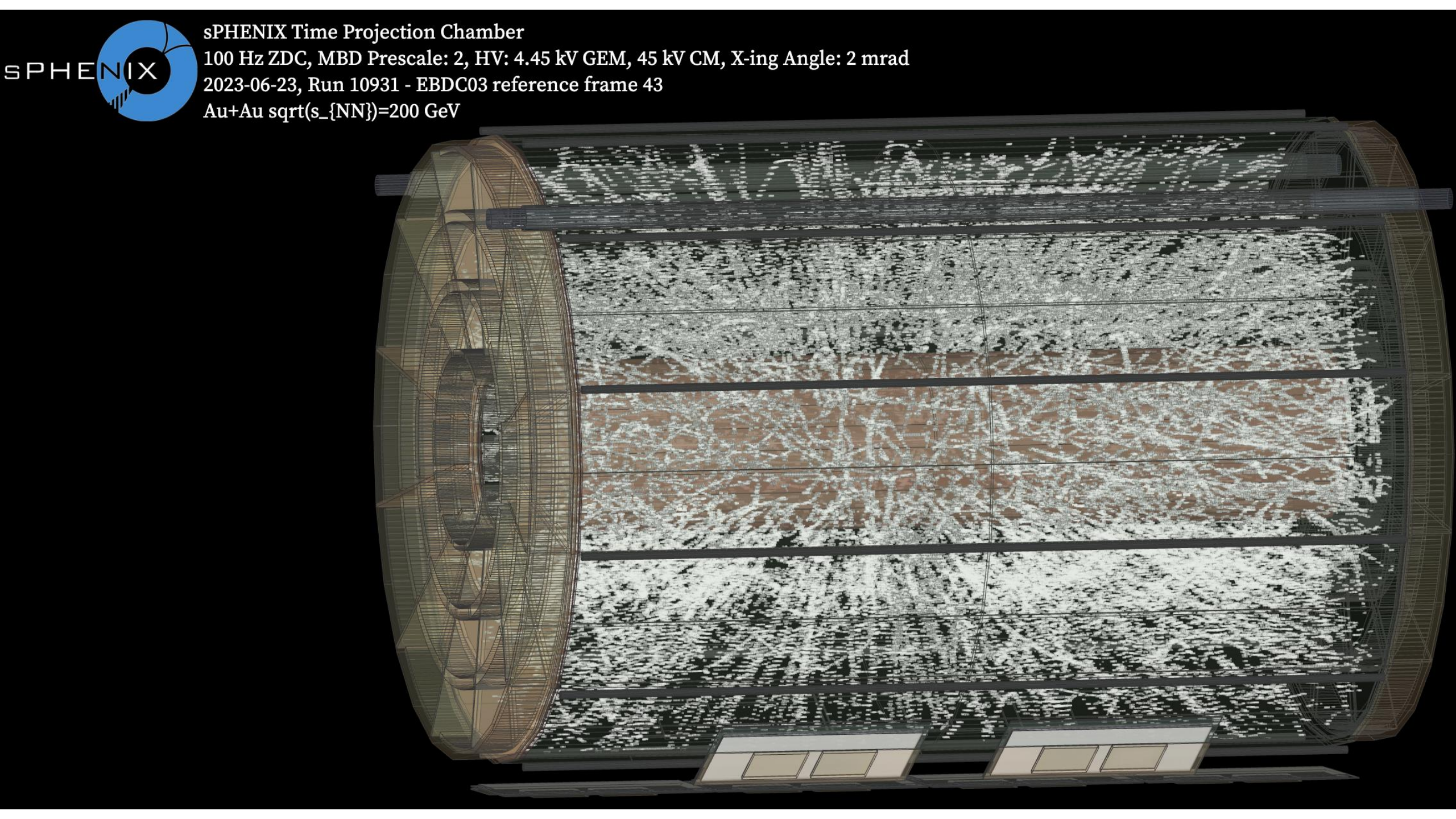
Installed TPC in sPHENIX



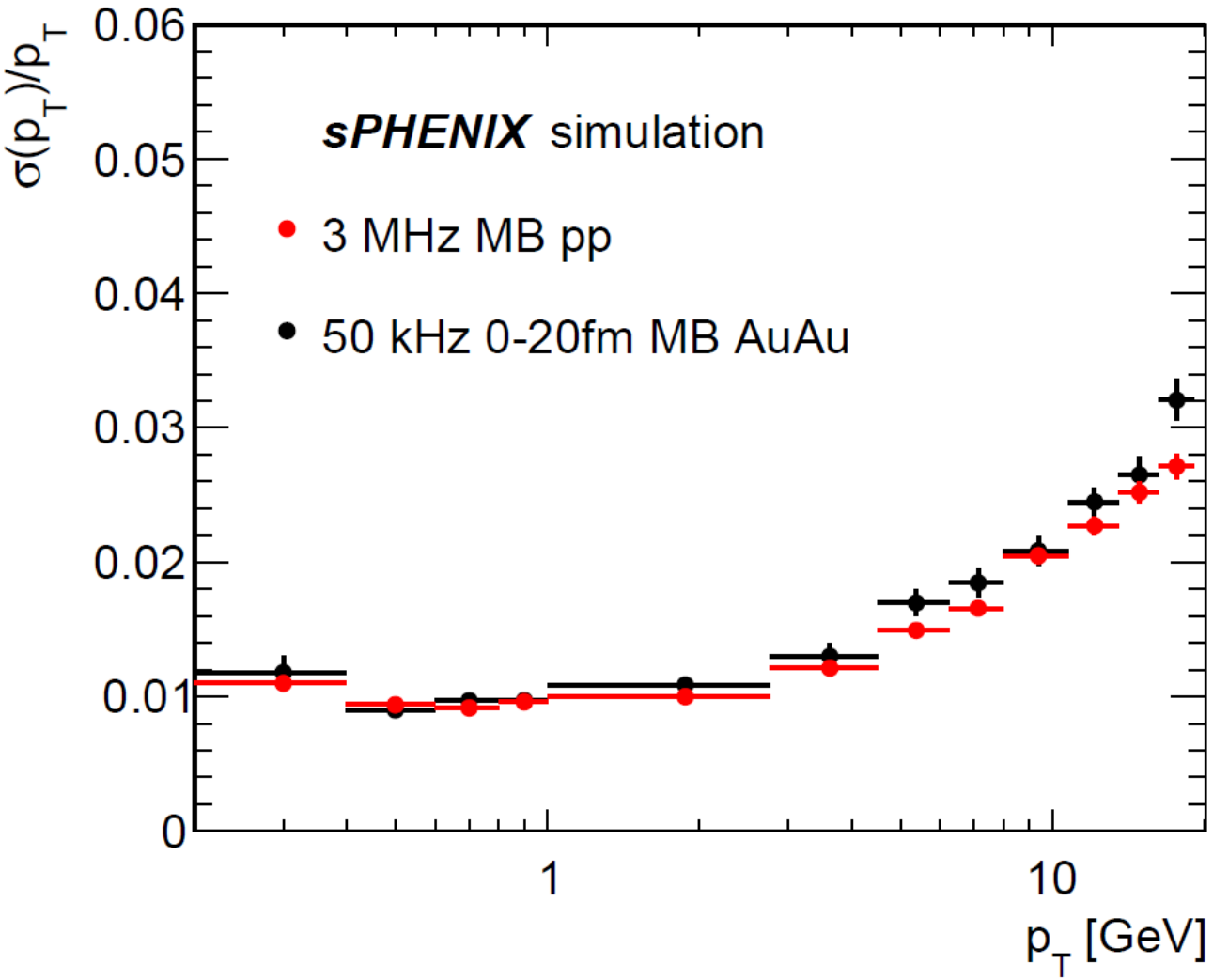
Pad Planes

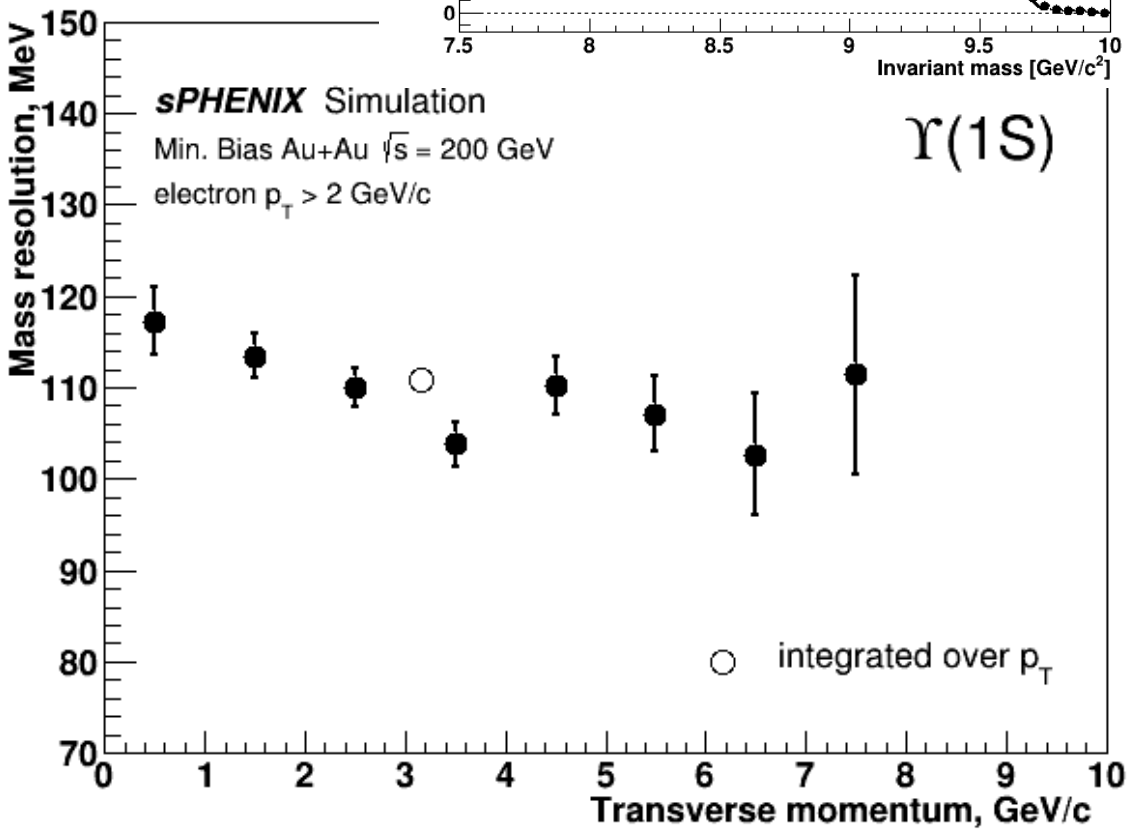
TPC FEE

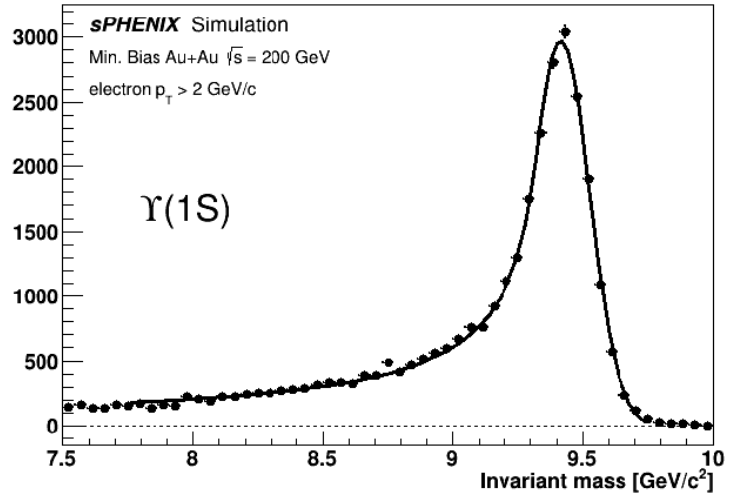
FELIX Readout card


sPHENIX
sPHENIX Time Projection Chamber
100 Hz ZDC, MBD Prescale: 2, HV: 4.45 kV GEM, 45 kV CM, X-ing Angle: 2 mrad
2023-06-23, Run 10931 - EBDC03 reference frame 43
Au+Au sqrt(s_{NN})=200 GeV

Tracking performance

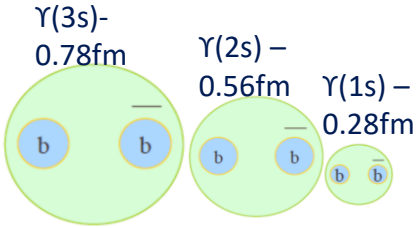




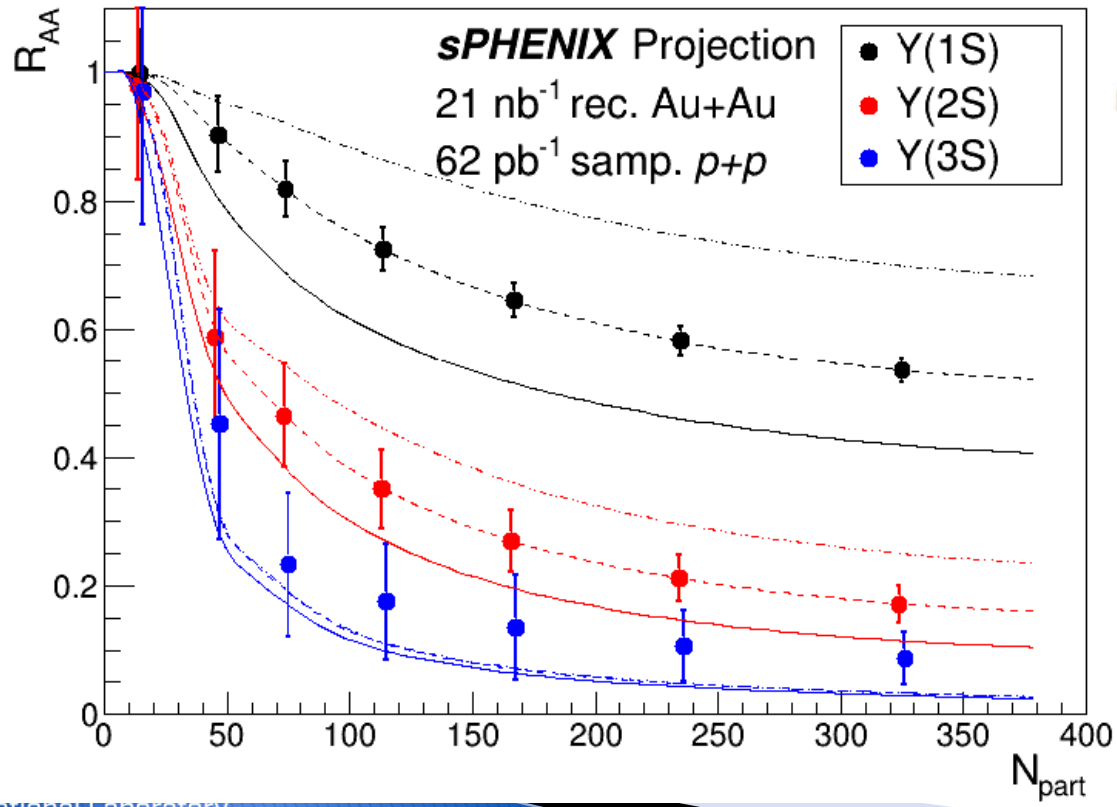


sPHENIX hidden heavy flavor

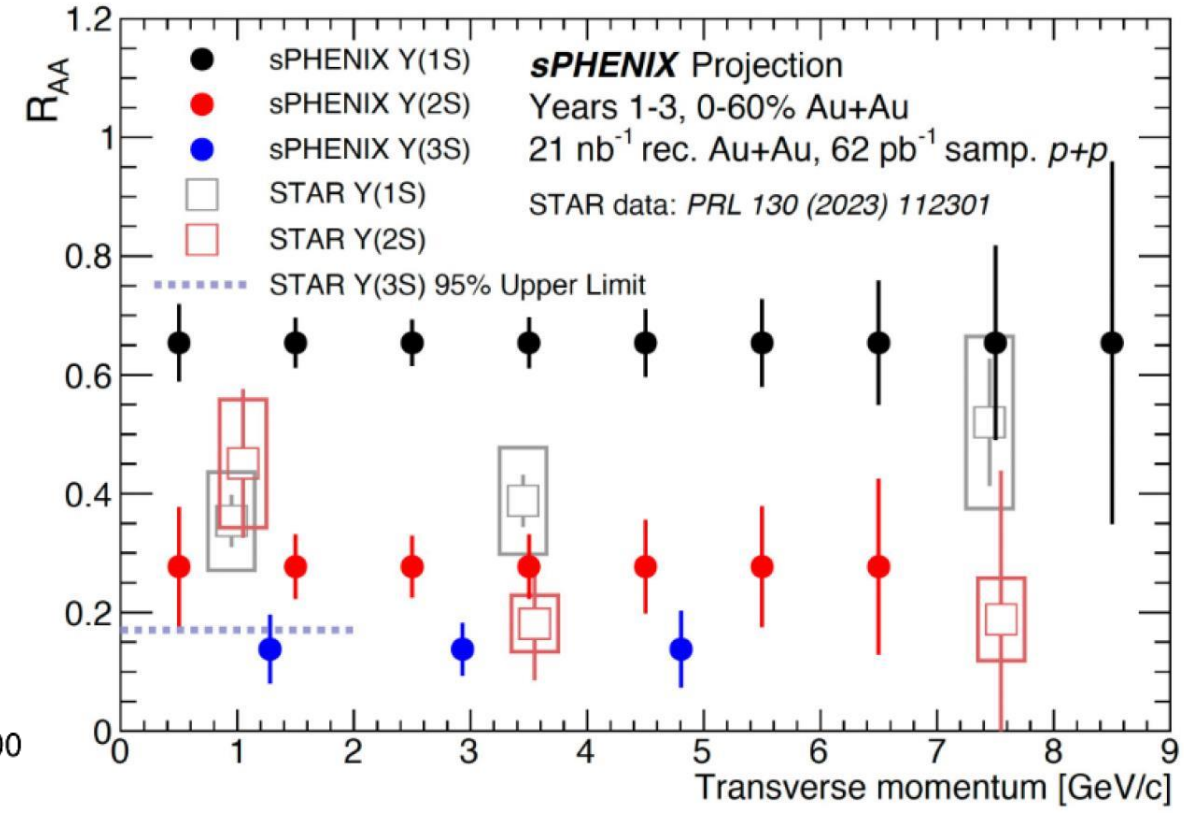
- Suppression with clear distinction of three Upsilon states
- Color dipoles probing the QGP at three length scales



Simulation



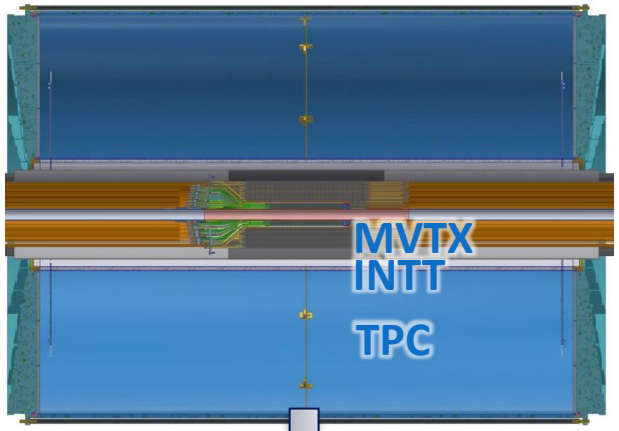
Simulation

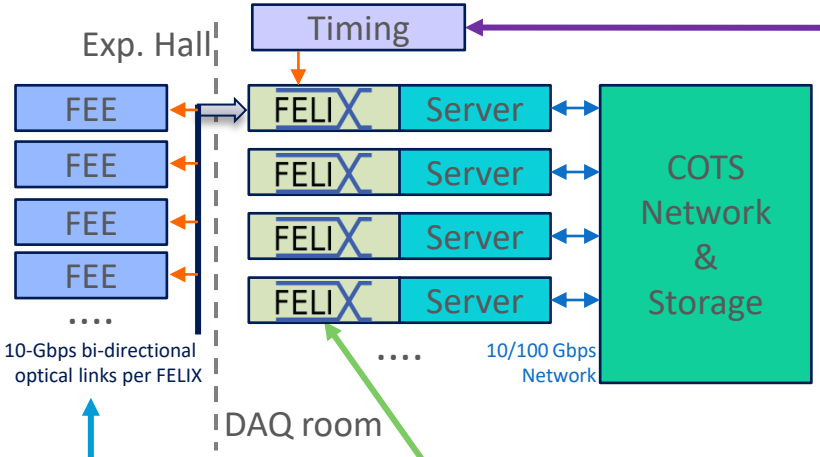


Streaming readout electronics

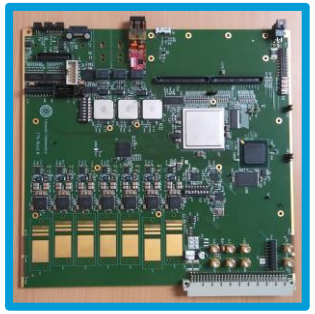
Plan to recording 10% p+p collisions in hybrid streaming DAQ
→ 2-3 orders of magnitude increase in soft-HF statistics

sPHENIX streaming DAQ for tracker





Global Timing Module
(NSLS II/sPHENIX)
Receiving from RHIC RF low glitter clock source

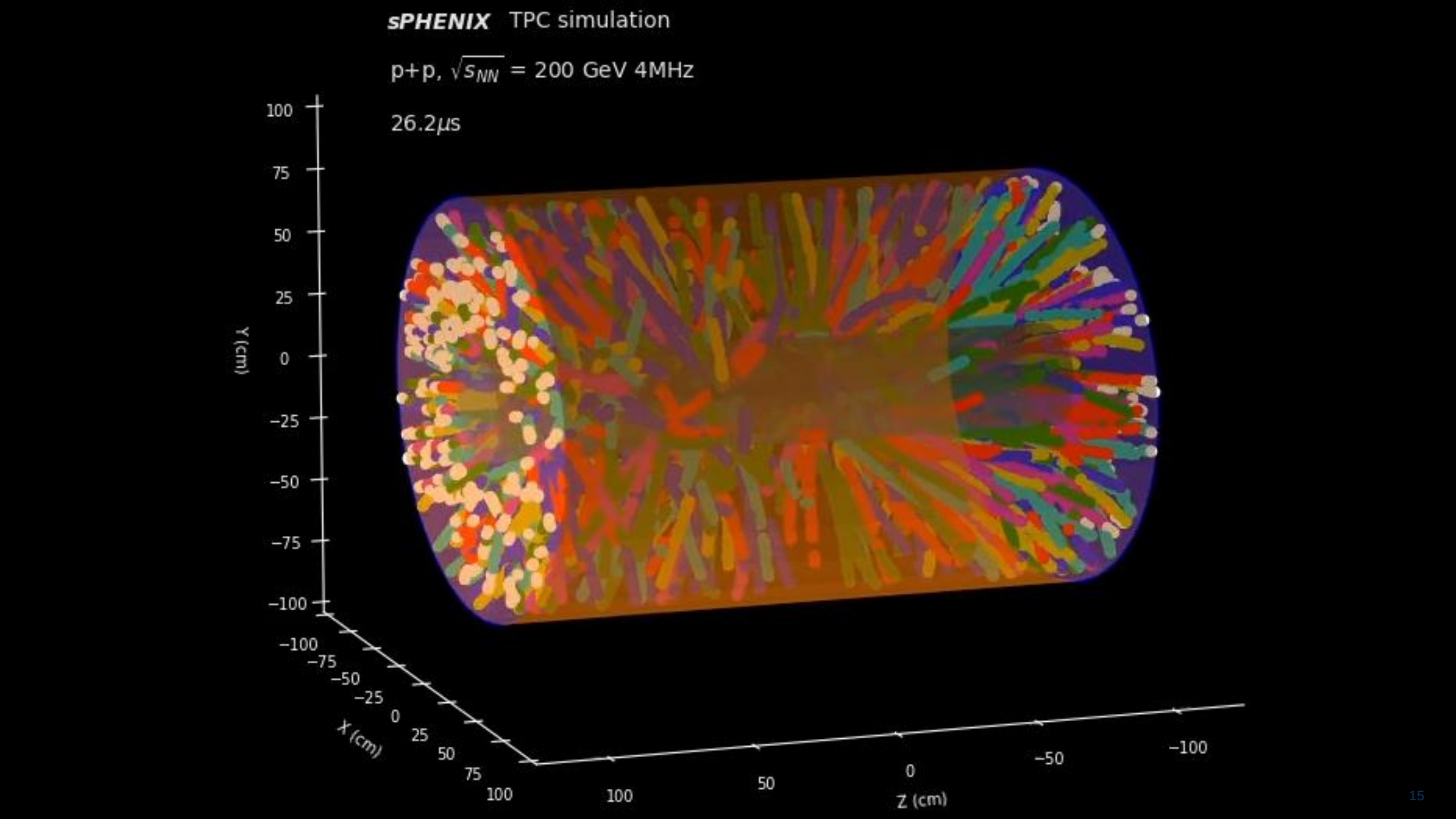


MVTX RU, 200M ch
ALPIDE (ALICE/sPHENIX), FPHX (PHENIX)

INTT ROC, 400k ch

TPC FEE, 160k ch
SAMPAv5 (ALICE/sPHENIX)

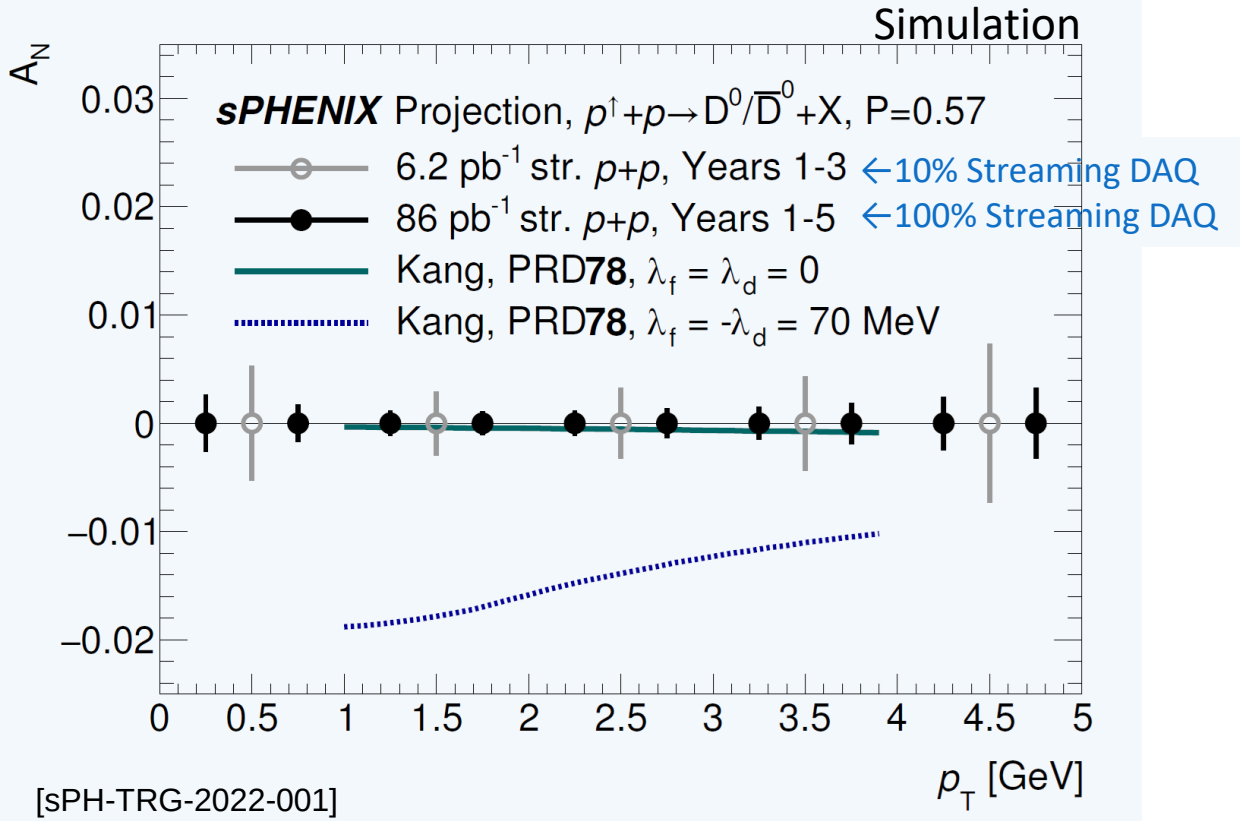
BNL-712 / FELIX v2 x38 (ATLAS/sPHENIX)
FELIX Ref: 10.1109/tim.2019.2947972


sPHENIX TPC simulation
p+p, $\sqrt{s_{NN}}$ = 200 GeV 4MHz
26.2μs
Y (cm)
X (cm)
Z (cm)

Streaming-DAQ enabled scientific connection: e.g. gluon dynamics via heavy flavor transverse spin asym.

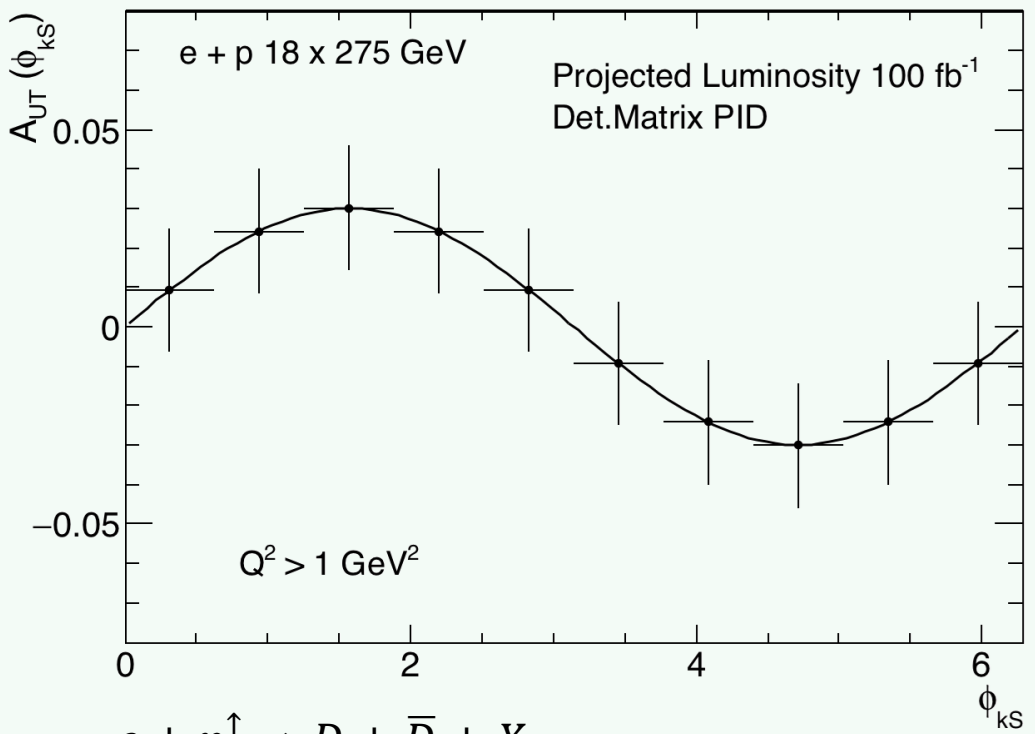
Universality test on gluon Sievers

sPHENIX D^0 trans. spin asymmetry, A_N → Gluon Sievers via tri-g cor.



[sPH-TRG-2022-001]
Model: 10.1103/PhysRevD.78.114013

EIC SIDIS D^0 transverse spin asymmetry → Gluon Sievers

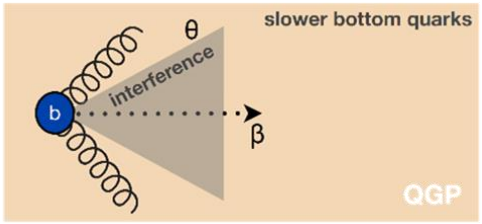


$e + p^{\uparrow} \to D + \bar{D} + X$

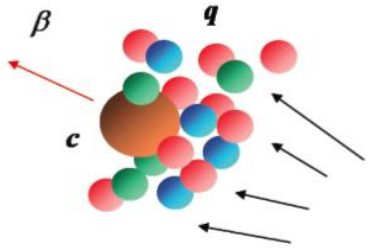
[CNFS HF@EIC workshop, Nov 4-6, 2020]

Access b-quark suppression/v2 via non-prompt D

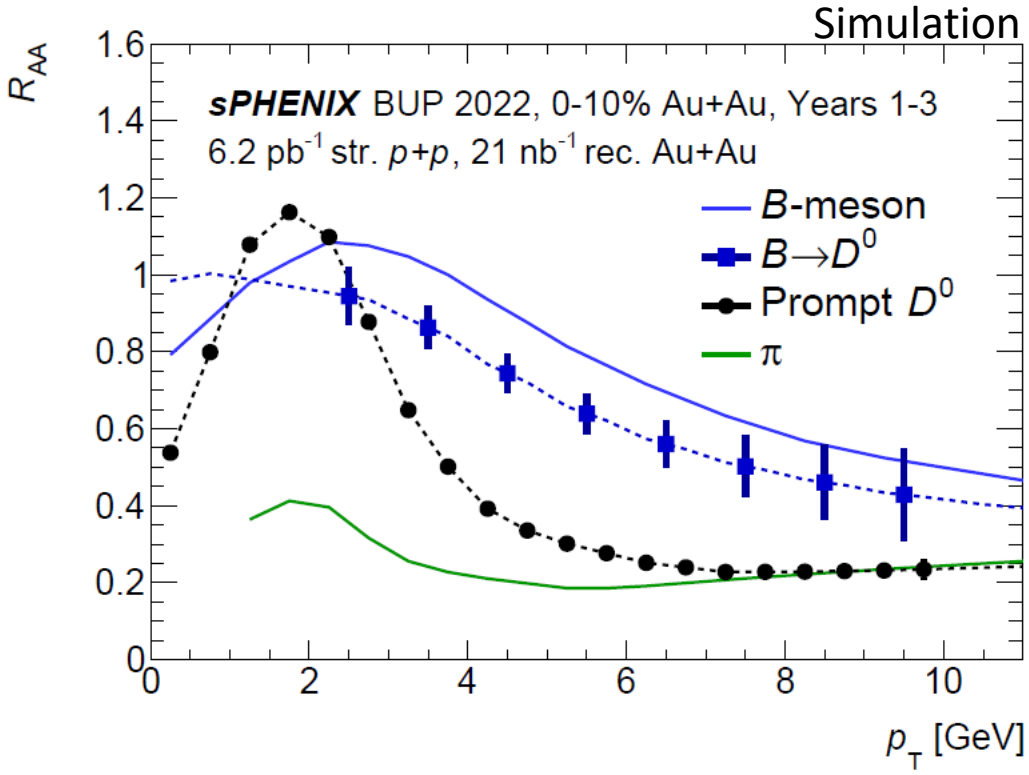
- Bringing high precision non-prompt-*D* suppression and flow to RHIC

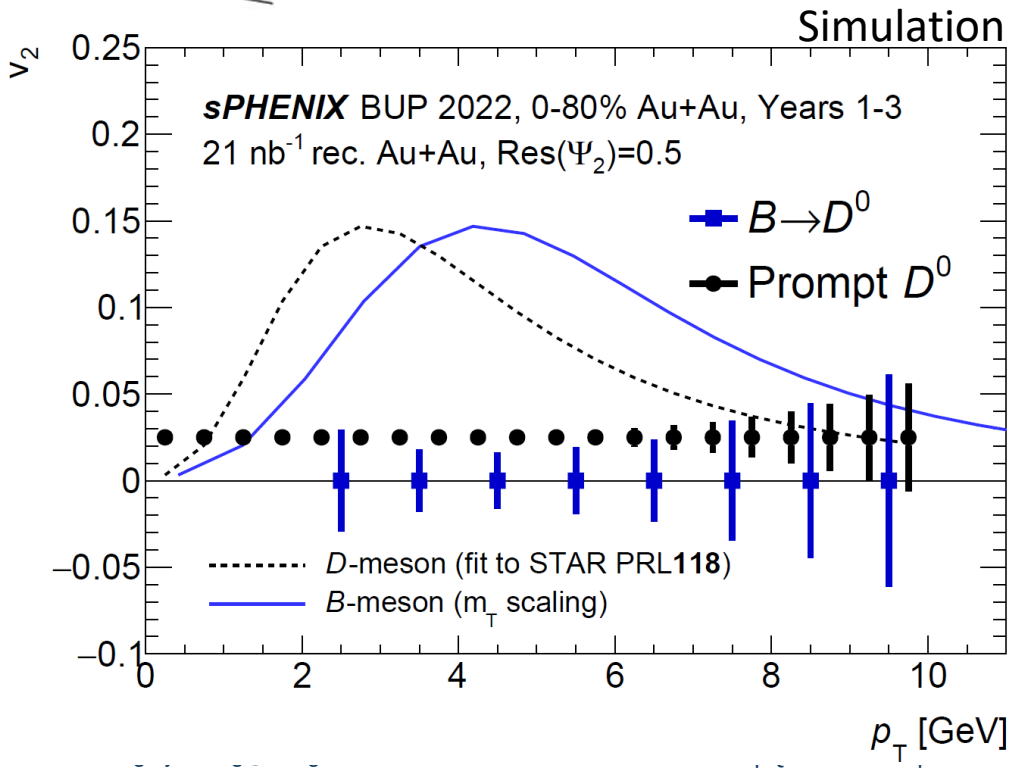


- Probe the mass dependence of quark energy loss in QGP, light → c → b
- Sensitive to pick up collision energy loss



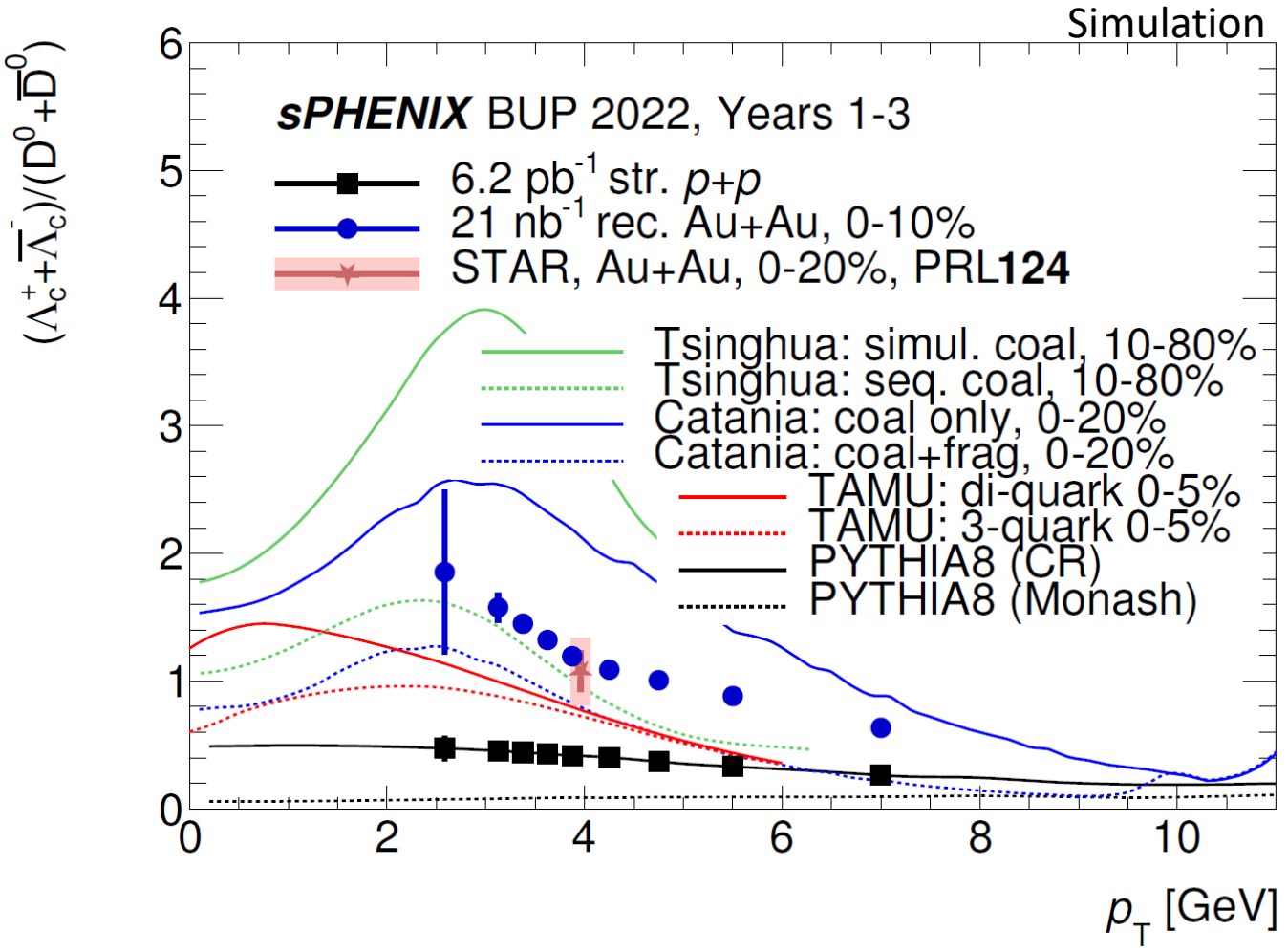
- Determine the bottom quark collectivity
- → clean access to D_{HQ} at RHIC energy



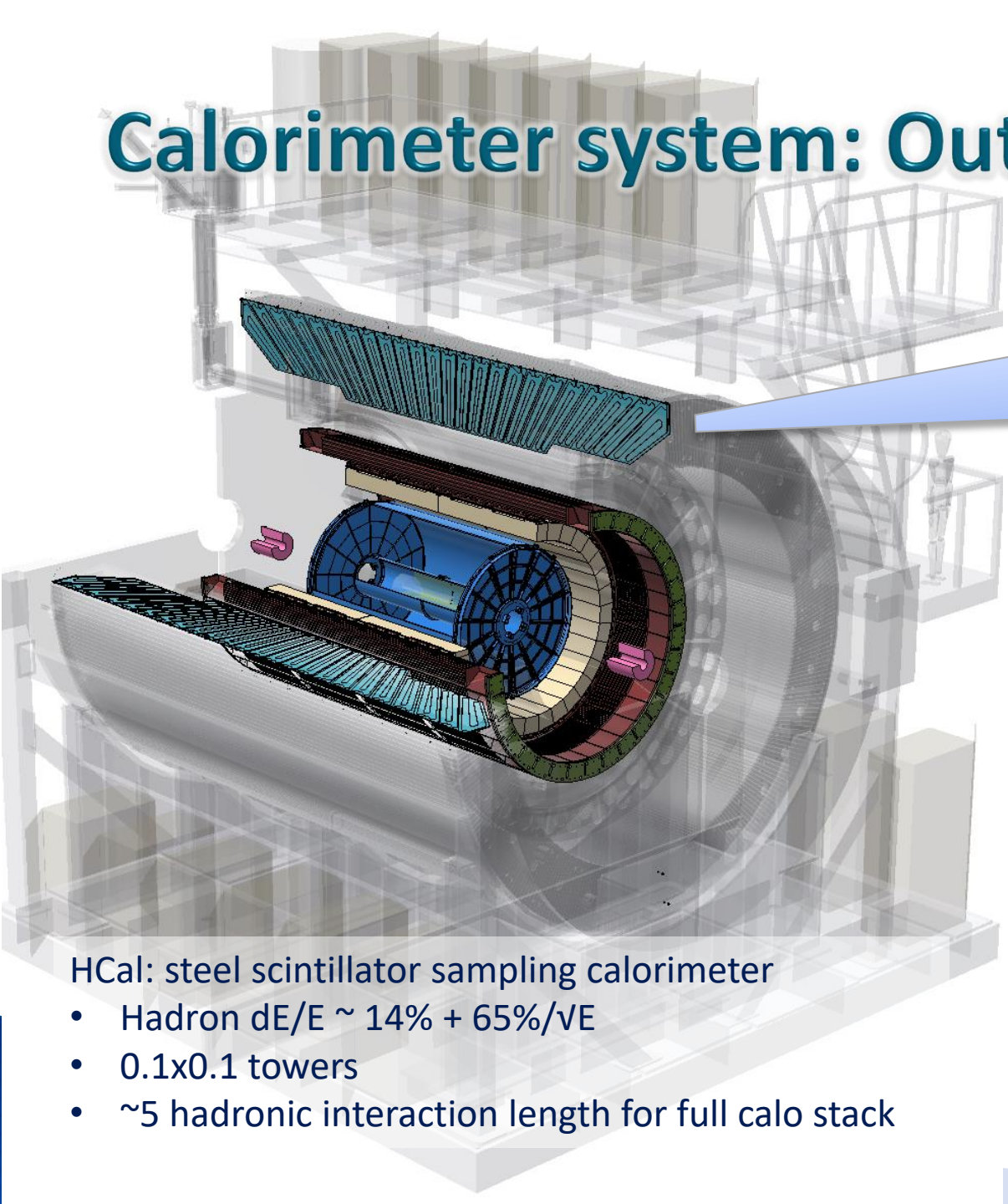


News from beam use proposal 2020 – hadronization

- 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



Calorimeter system: Outer HCal



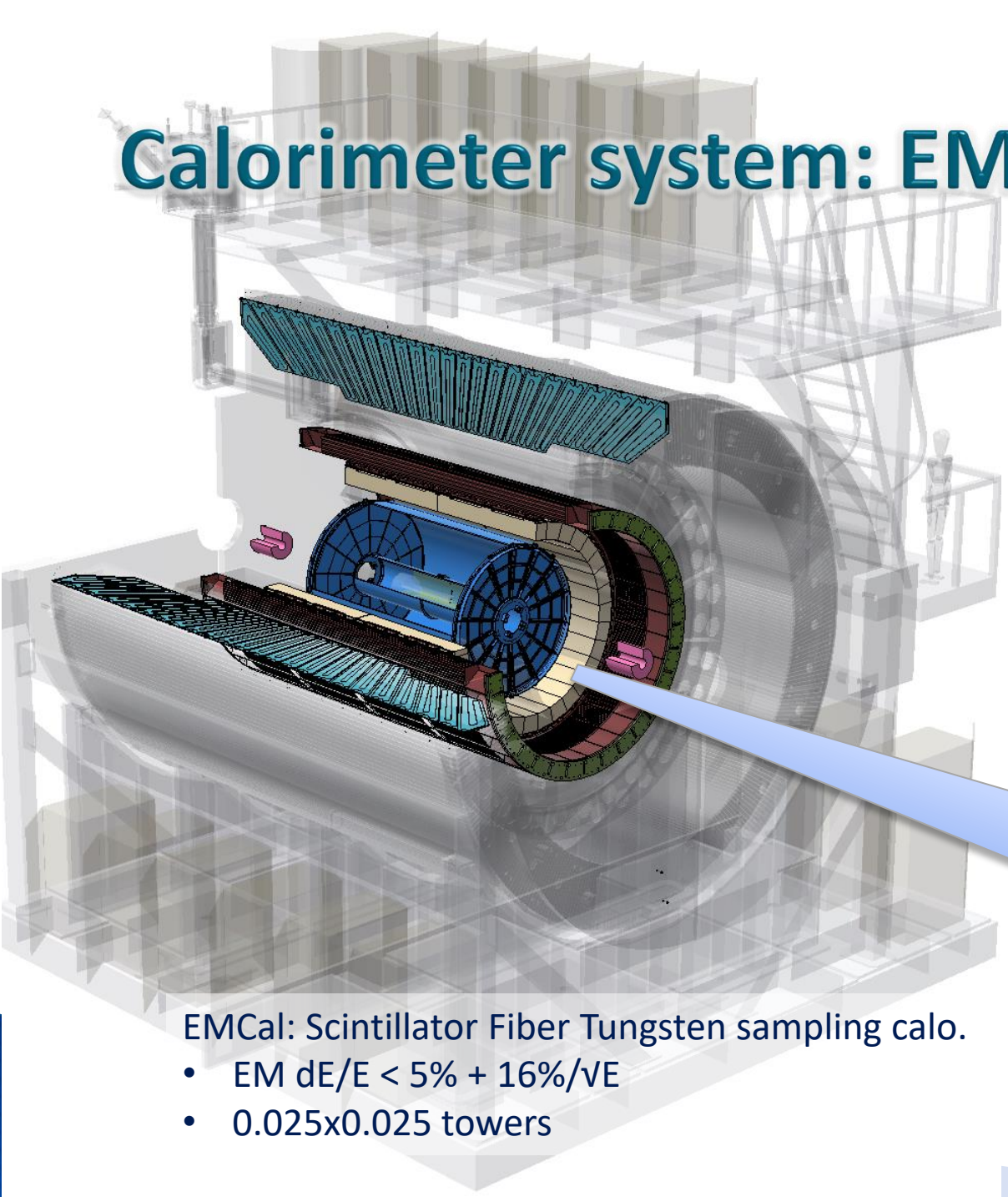
HCal: steel scintillator sampling calorimeter

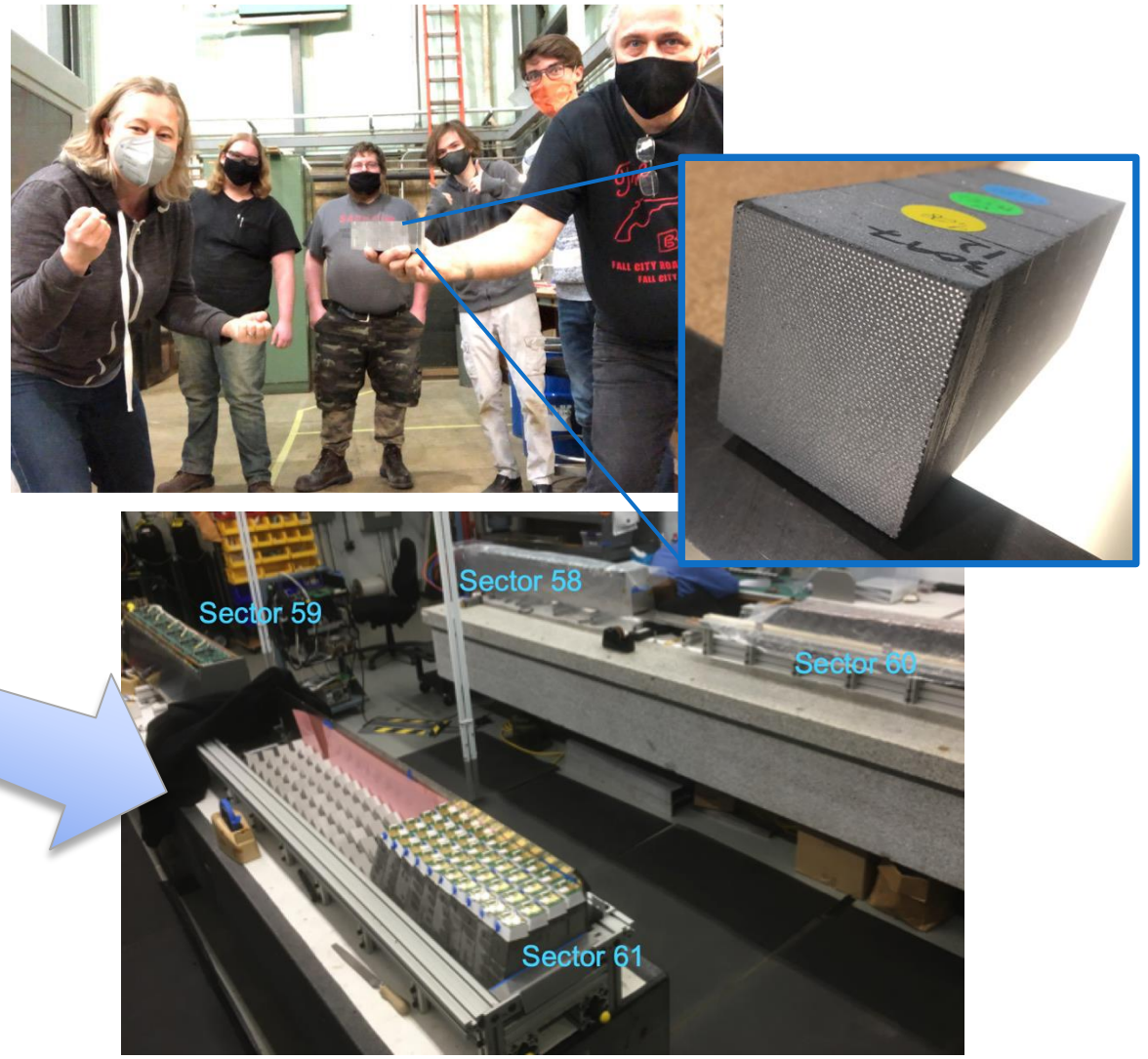
- Hadron dE/E ~ 14% + 65%/√E
- 0.1x0.1 towers
- ~5 hadronic interaction length for full calo stack

Calorimeter system: Inner HCal

Inner HCal: Al-scintillation tile sampling calorimeter
Mechanical support for EMCal + EM-shower tail catcher
+ constraint longitudinal position of hadronic shower

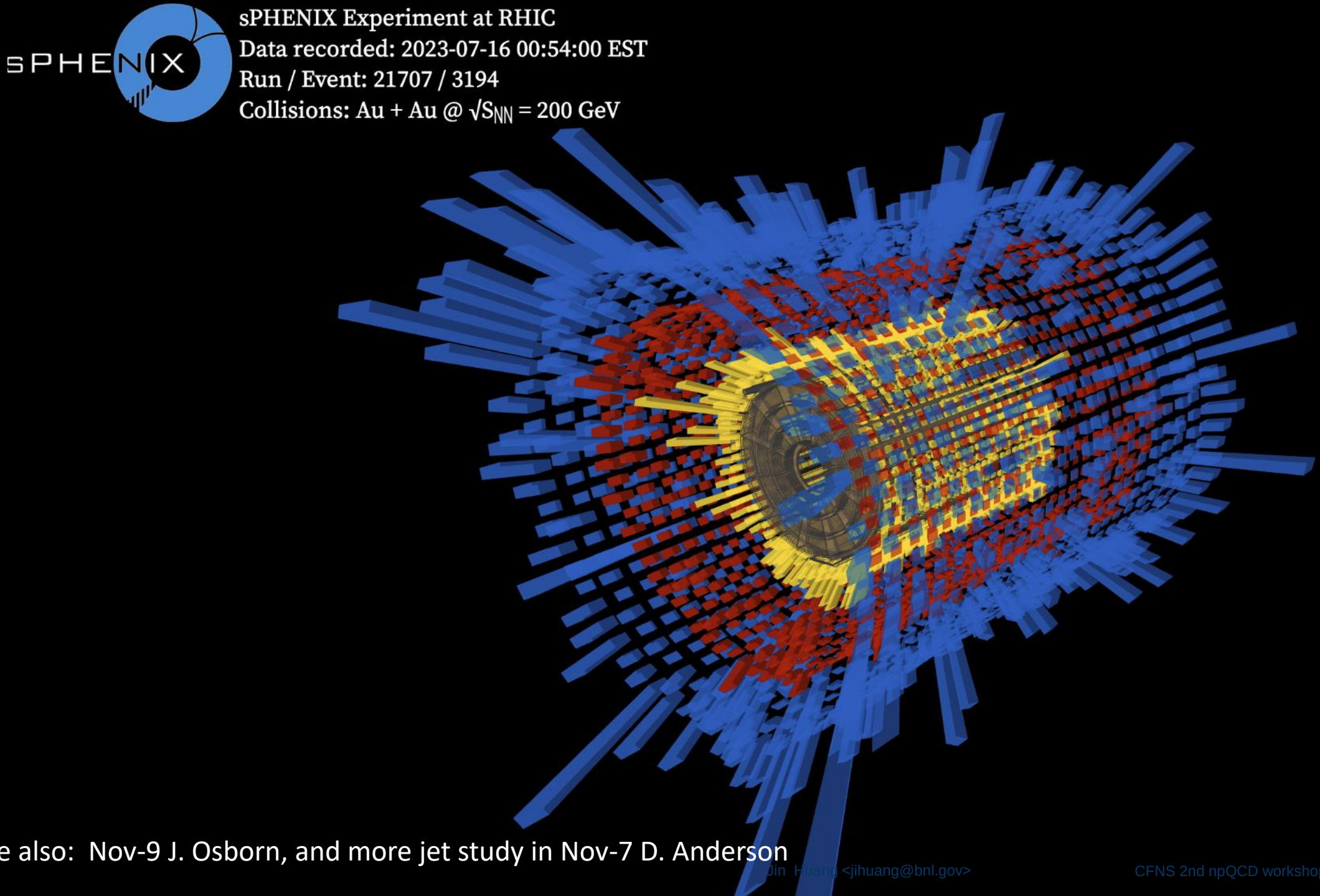
Calorimeter system: EMCal





EMCal: Scintillator Fiber Tungsten sampling calo.

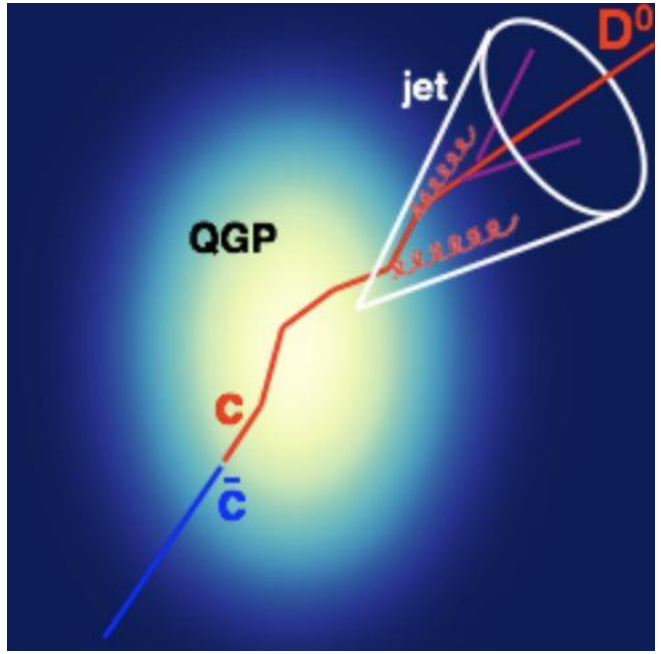
- EM dE/E < 5% + 16%/√E
- 0.025x0.025 towers

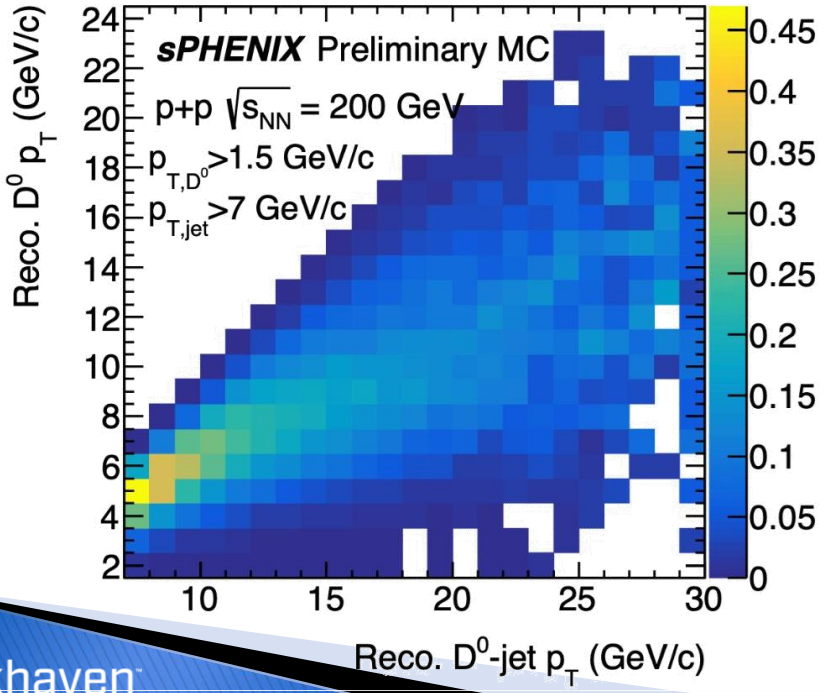


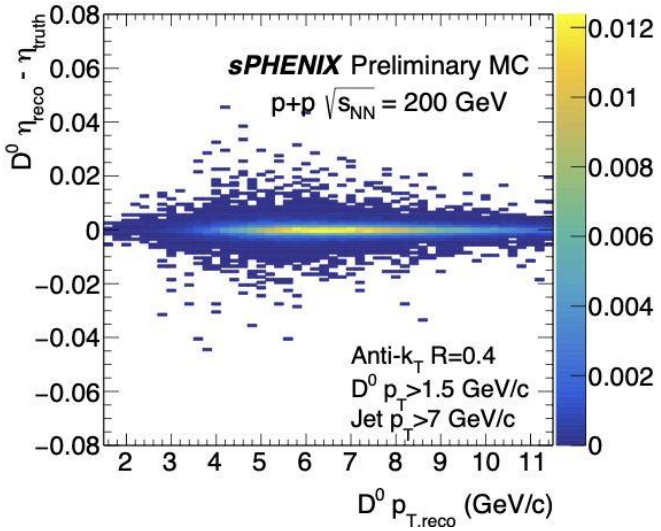
See also: Nov-9 J. Osborn, and more jet study in Nov-7 D. Anderson

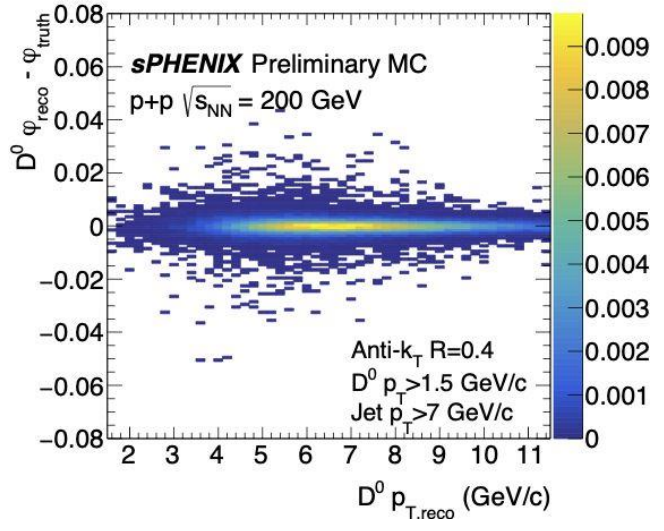
D-tagged jets

- Access charm jet and easy background rejection
- Study of heavy-quark initiated jet structure and parton shower
- Enabled by abundant D0 statistics + jet capability

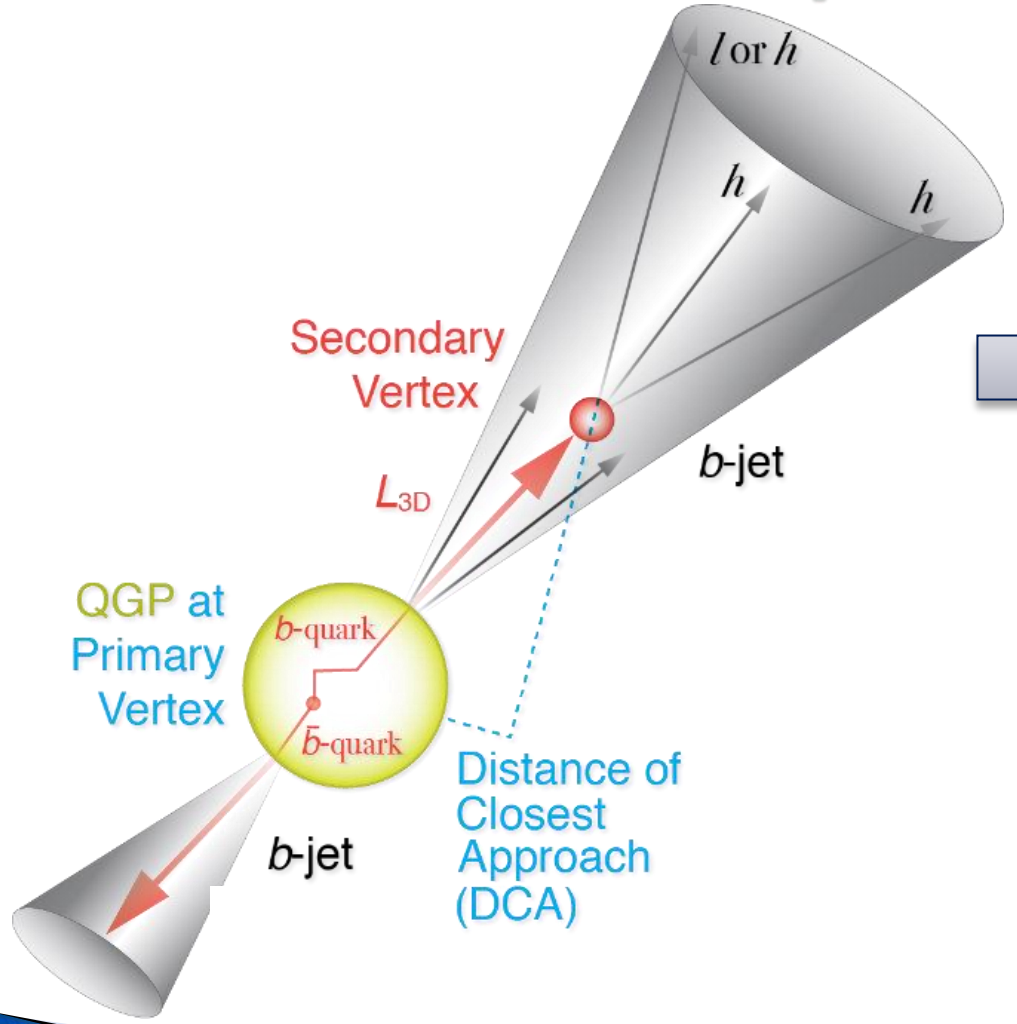


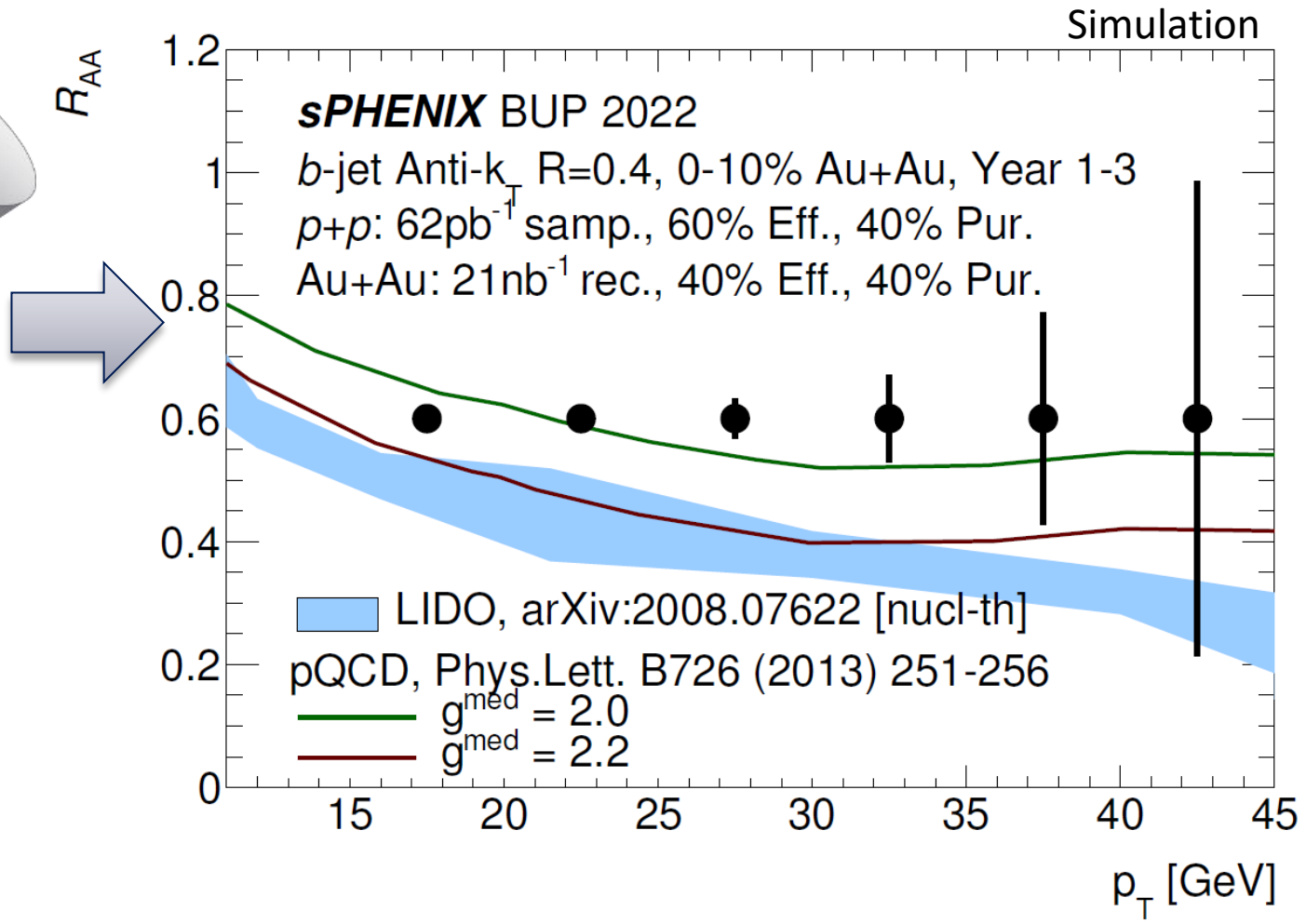




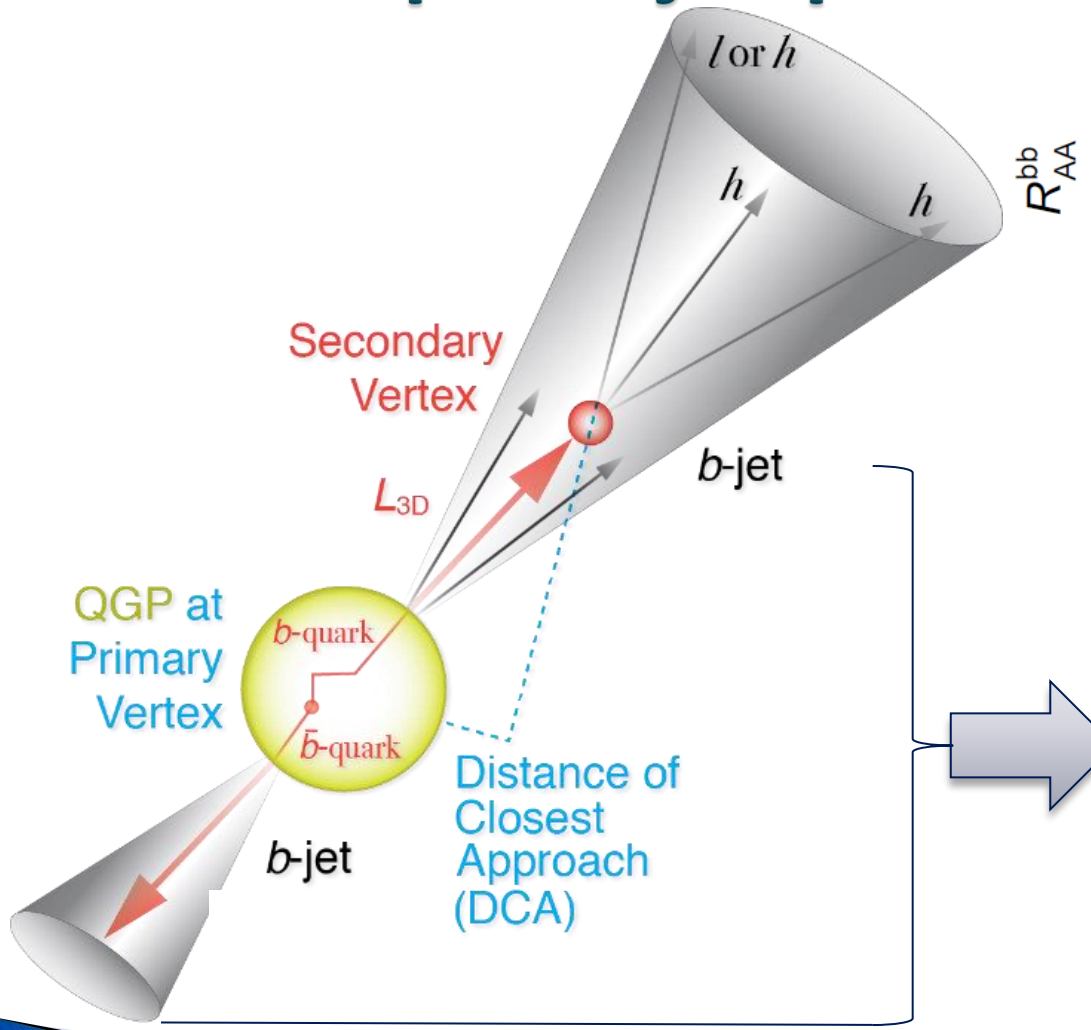


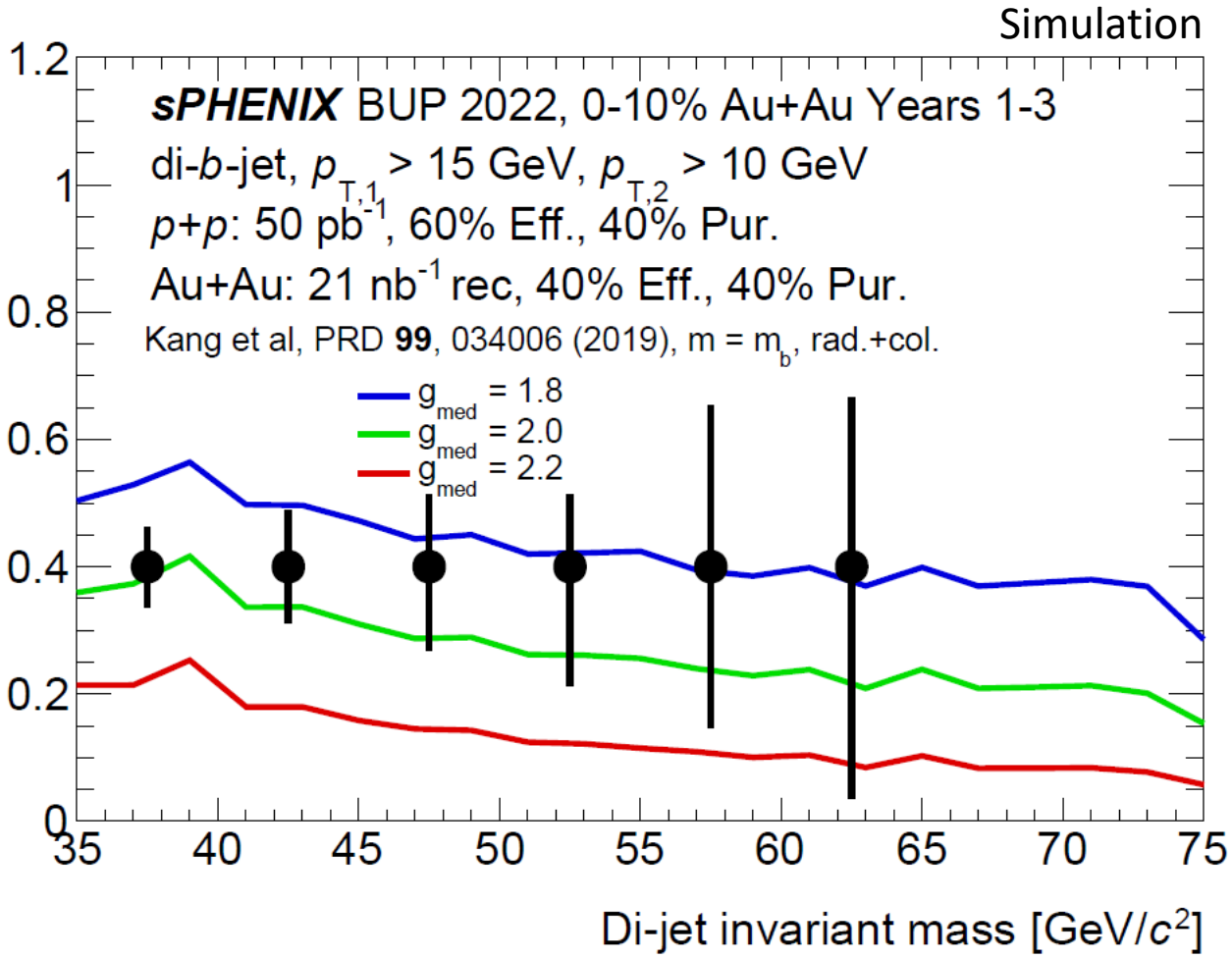
sPHENIX bottom quark jet





Bottom quark jet pairs → Enhanced sensitivity





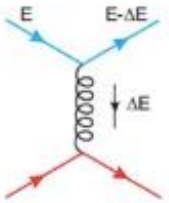
b-jet vs light jet → differentiating energy loss mech.

b/light ratio on RAA
Partial exp. systematic uncert. cancelation

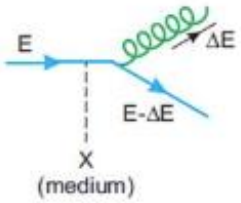
1-8 times mass effect!
x2 effect vs 10% variation on g_{med}!

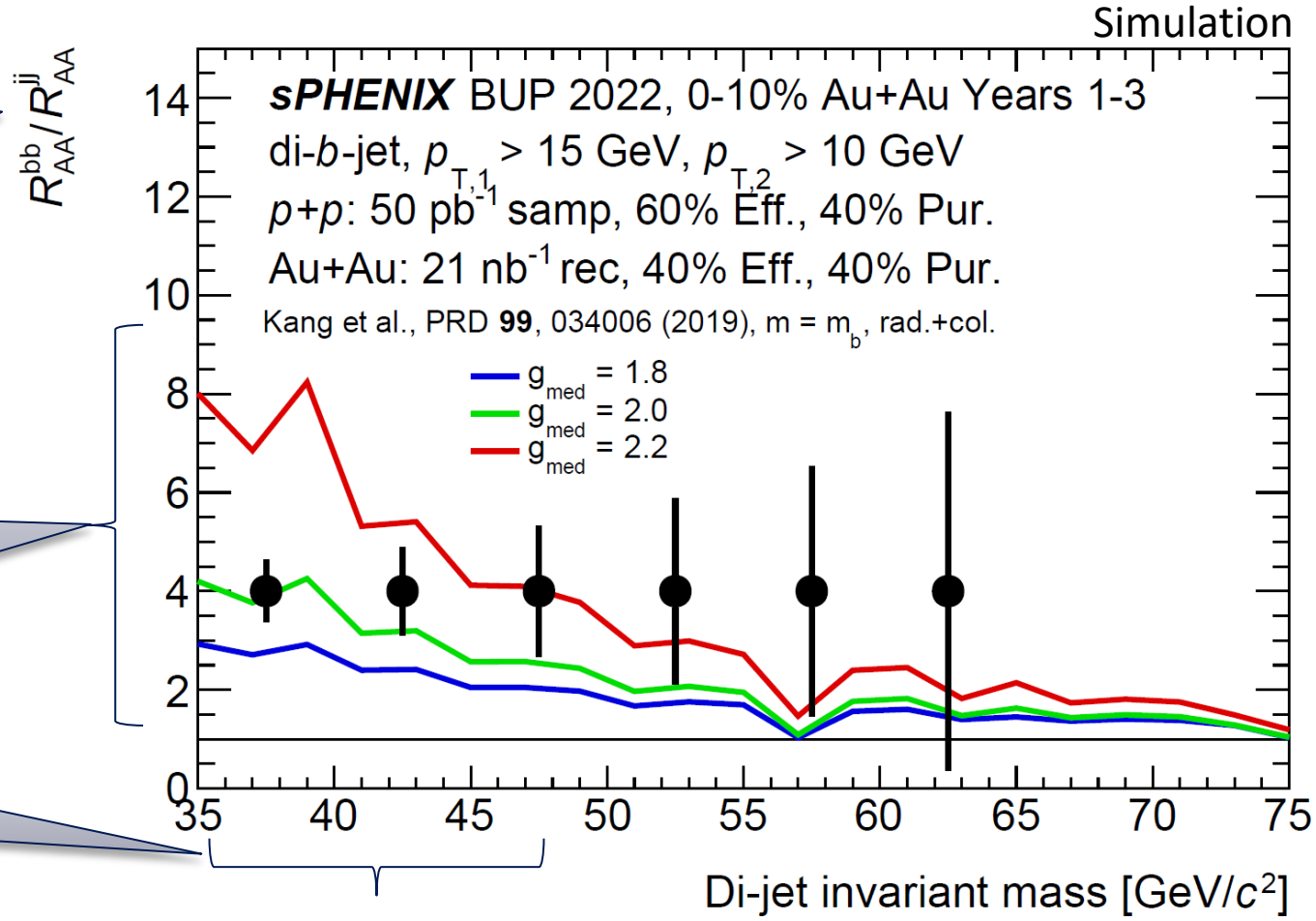
Unique region in the RHIC kine.
@ max sensitivity to mass eff.

Collisional energy loss

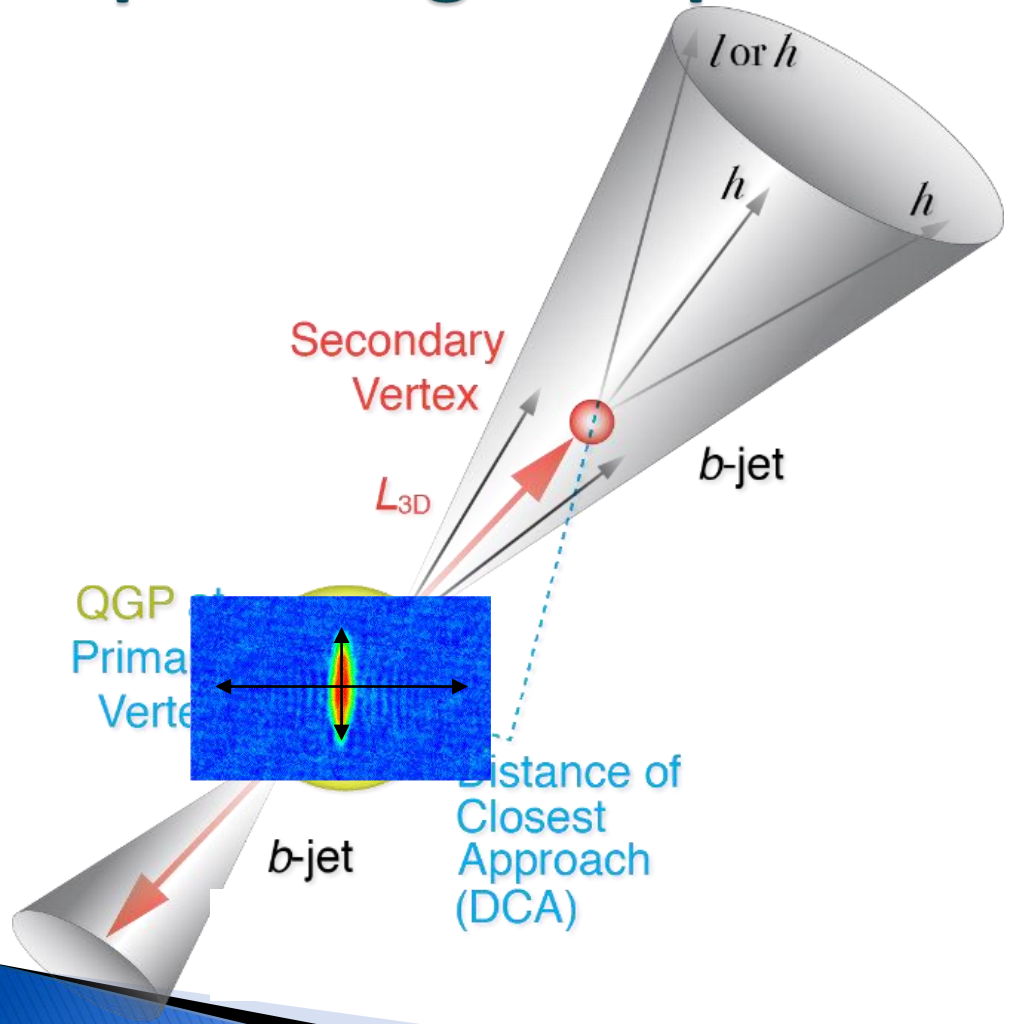


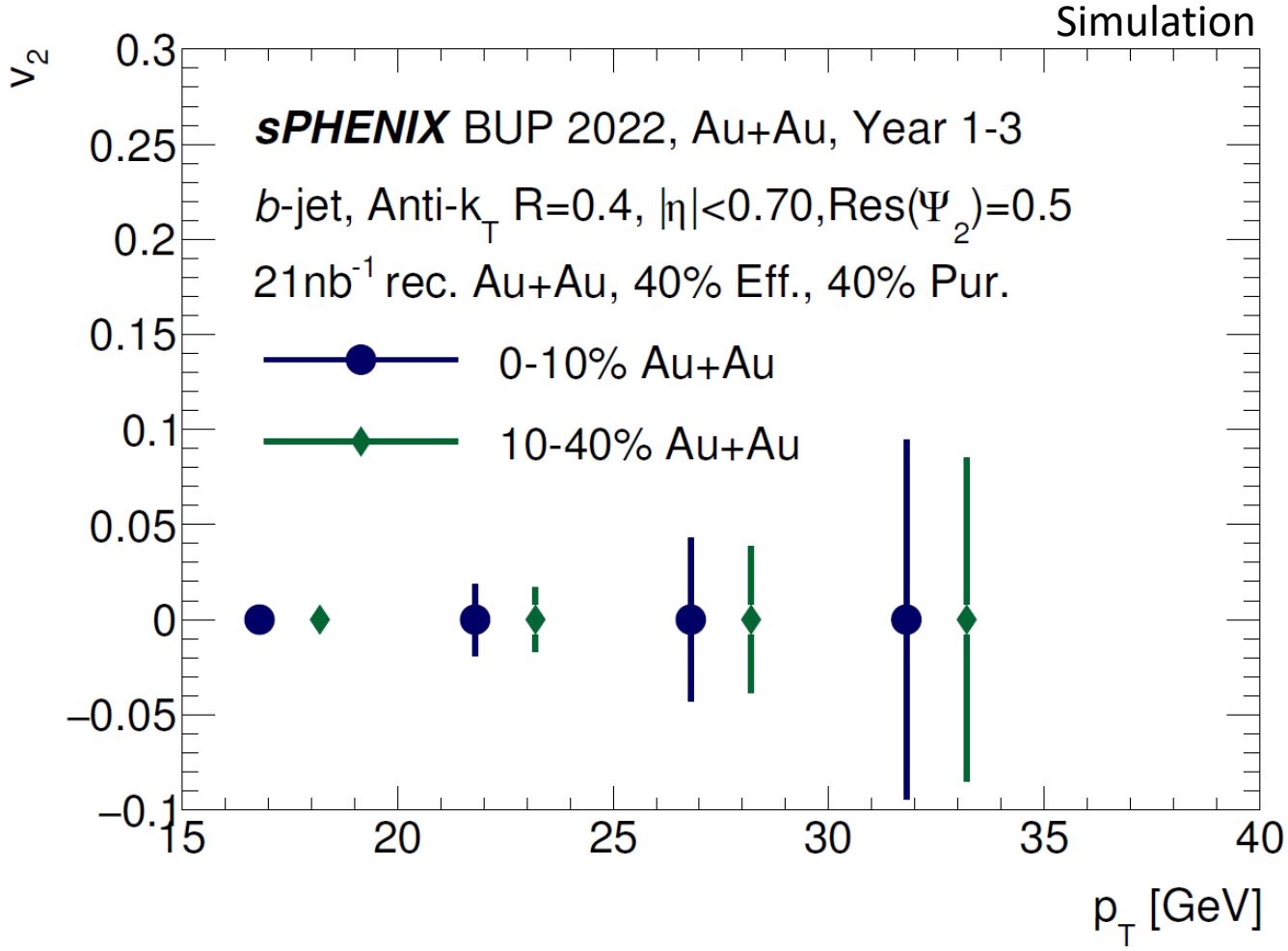
Radiative energy loss





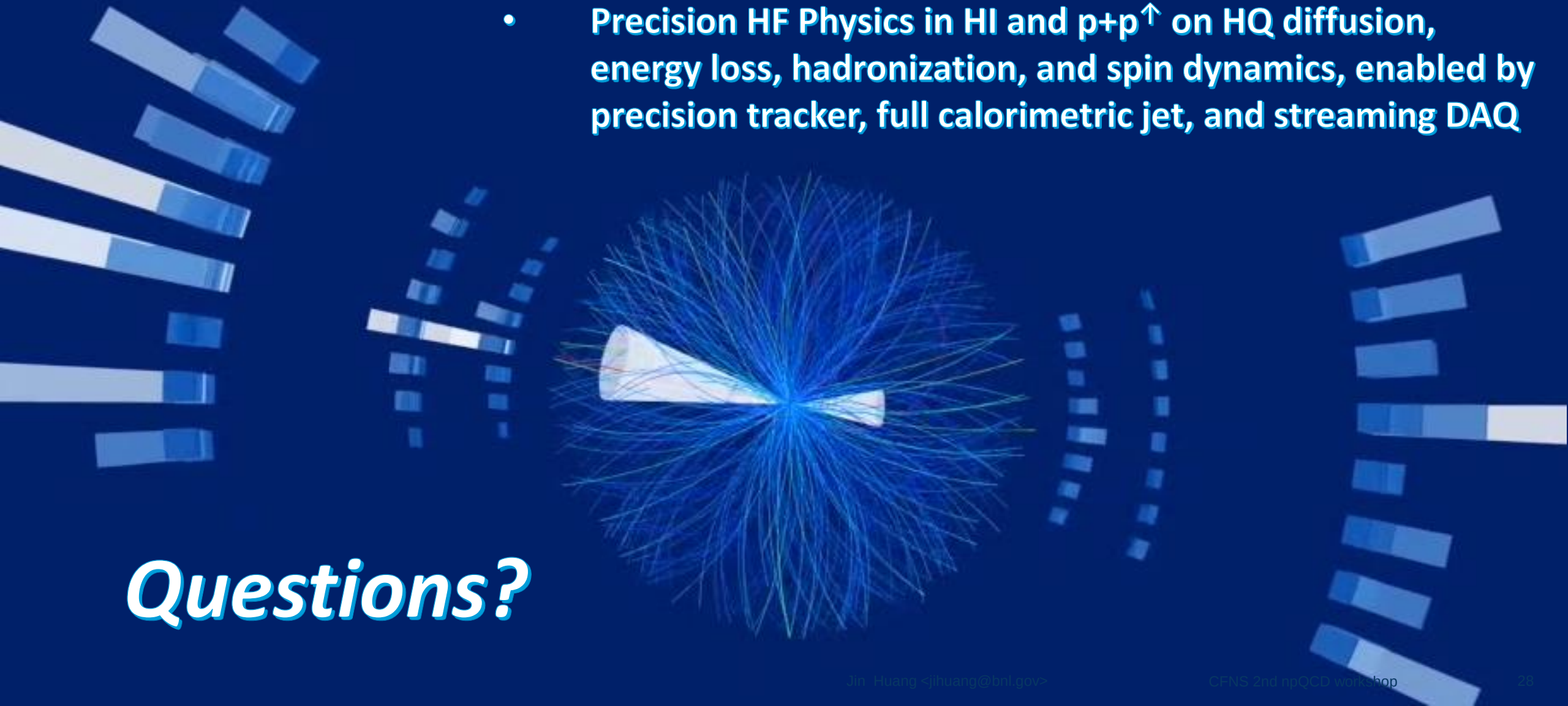
b-jet Flow signature
→ pathlength dependence energy loss





Summary

- Beam commissioning for all subsystems in 2023, despite early termination of the RHIC run
- p+p$^{\uparrow}$ run starts soon in early 2024
- Precision HF Physics in HI and p+p$^{\uparrow}$ on HQ diffusion, energy loss, hadronization, and spin dynamics, enabled by precision tracker, full calorimetric jet, and streaming DAQ



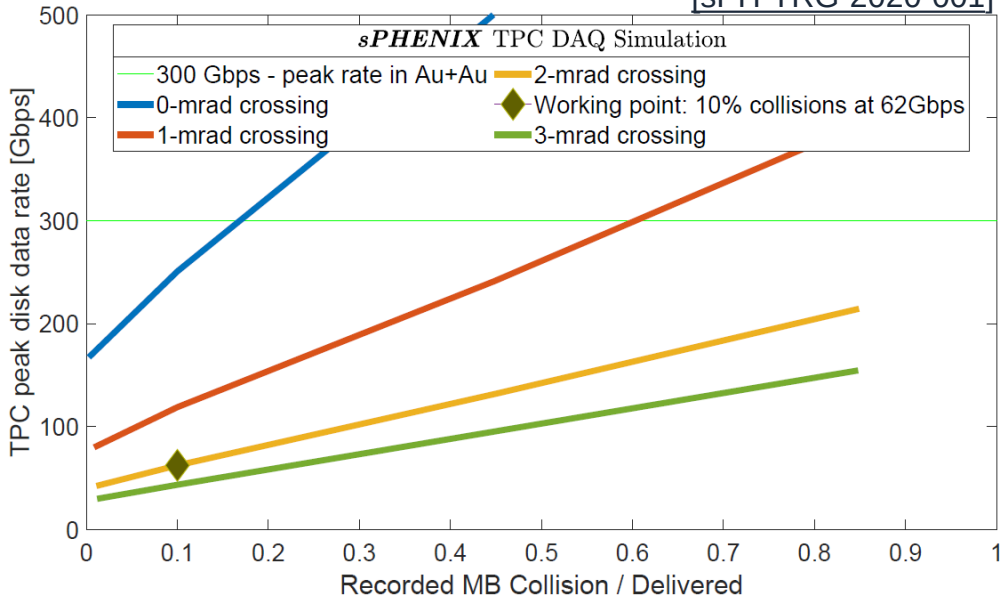
Questions?

Extra Information

Streaming readout status at sPHENIX

- All three sPHENIX tracking detector uses streaming readout
- Developed plan to take 10% streaming data for heavy flavor physics program commended by RHIC PAC.

[sPH-TRG-2020-001]

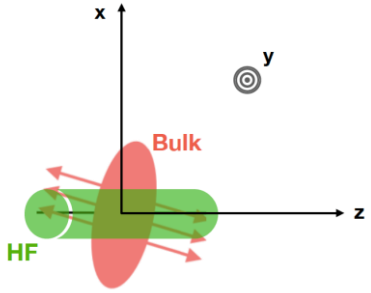


RHIC PAC 2020 report

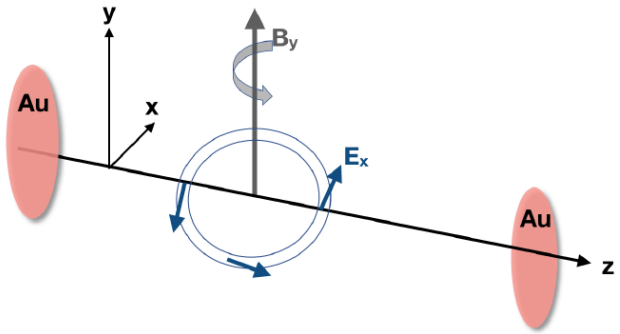
We commend sPHENIX for developing the continuous streaming readout option for the detector, which increases the amount of data that can be collected in Run-24 by orders of magnitude. In particular in the sector of open heavy flavor, this technique will give access to a set of qualitatively novel measurements that would otherwise not be accessible. Given the tight timeline for completing the RHIC physics program before construction of the EIC begins, this is a tremendous and highly welcome achievement.

Charm v_1 (via prompt D_0)→ initial geom. & *B*-field

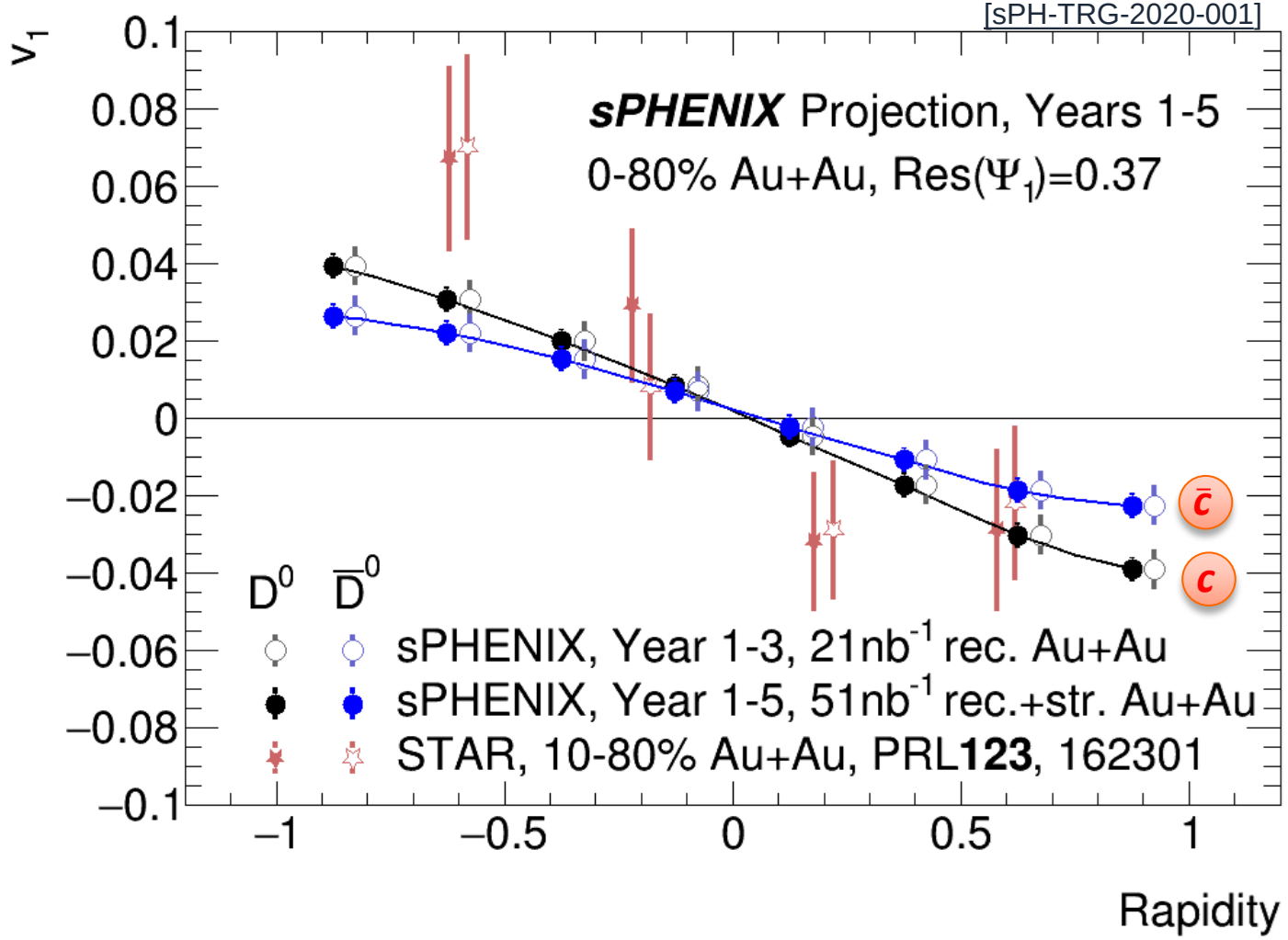
- v_1: Geometry tilt of QGP source



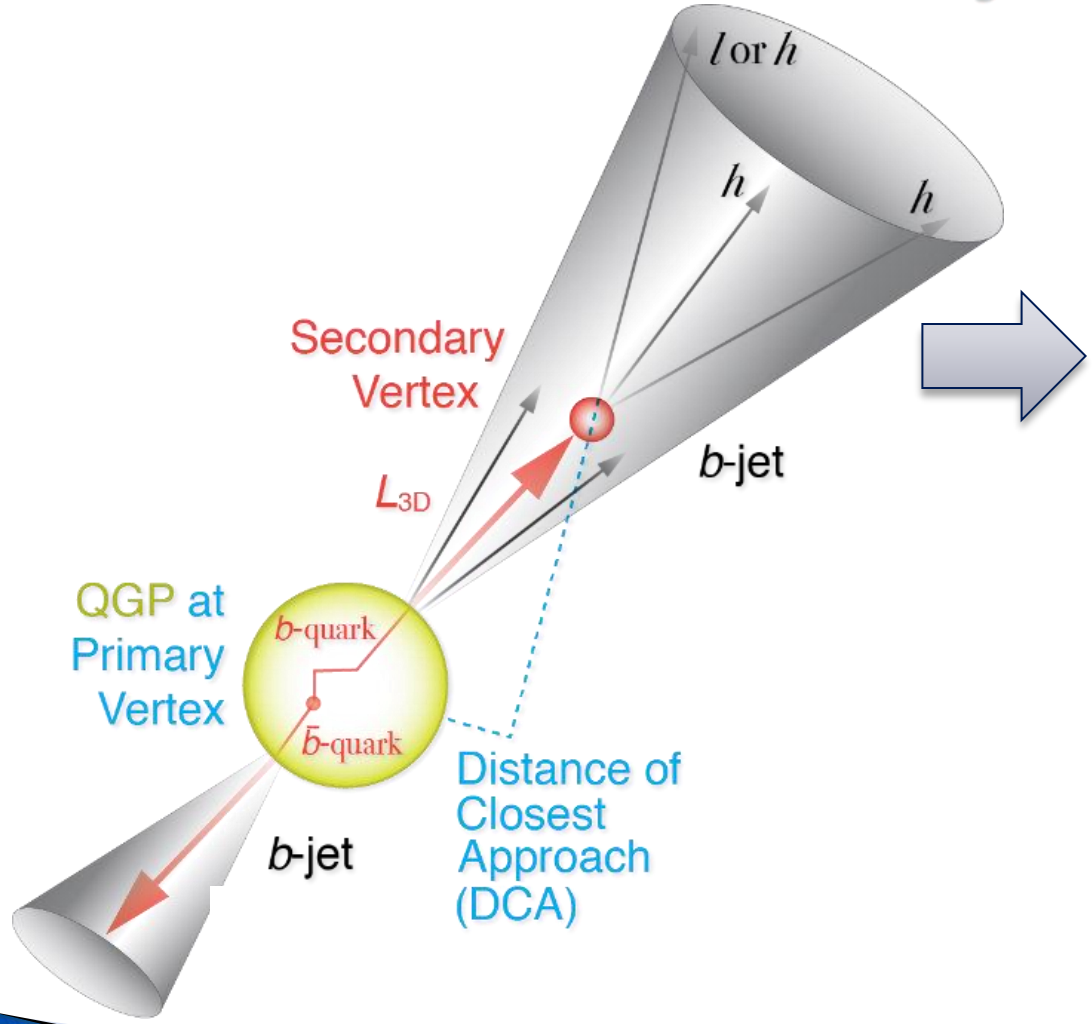
- Δv_1: Initial magnetic field

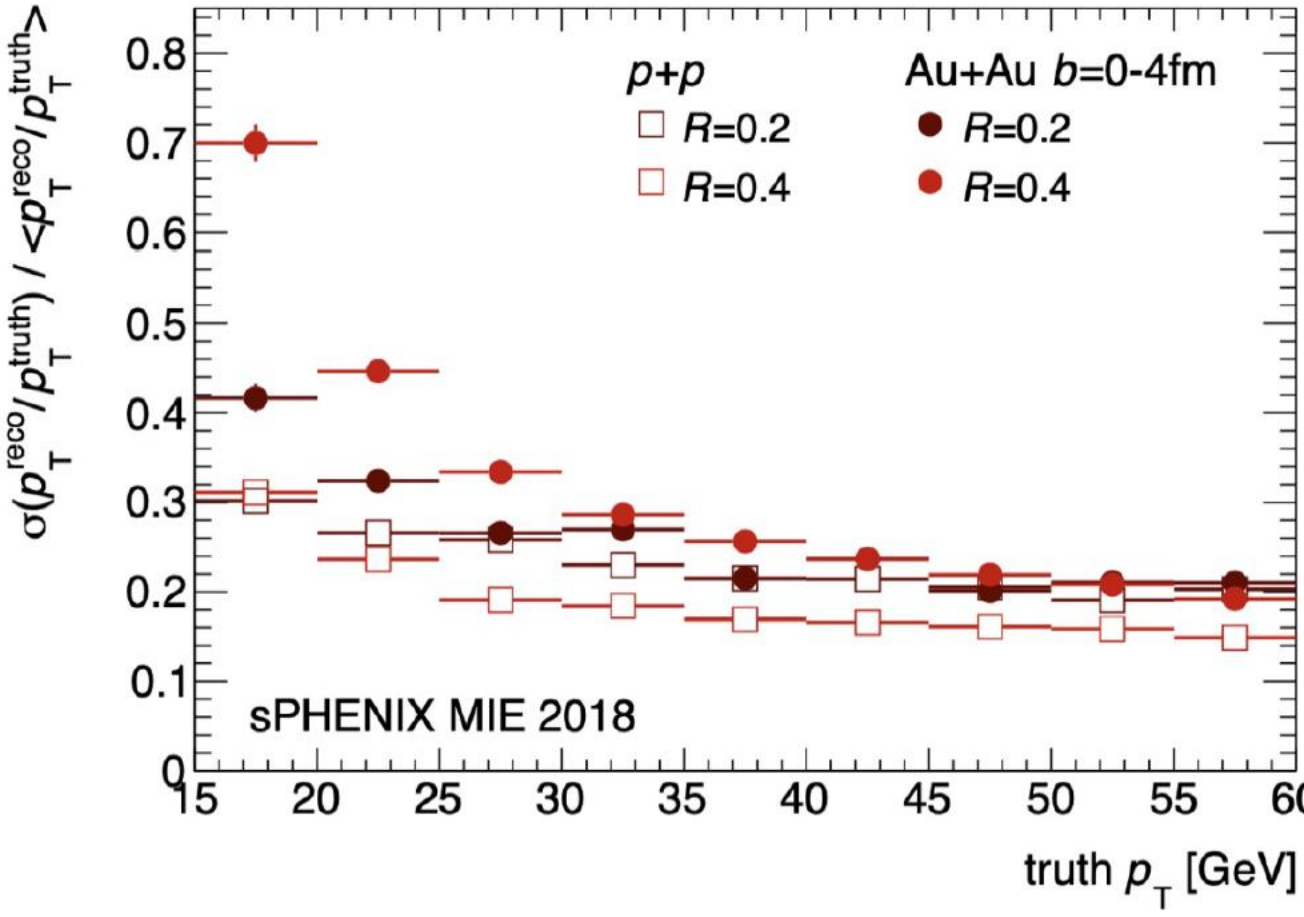


[sPH-TRG-2020-001]



sPHENIX calorimetric jets and b-jet tagging

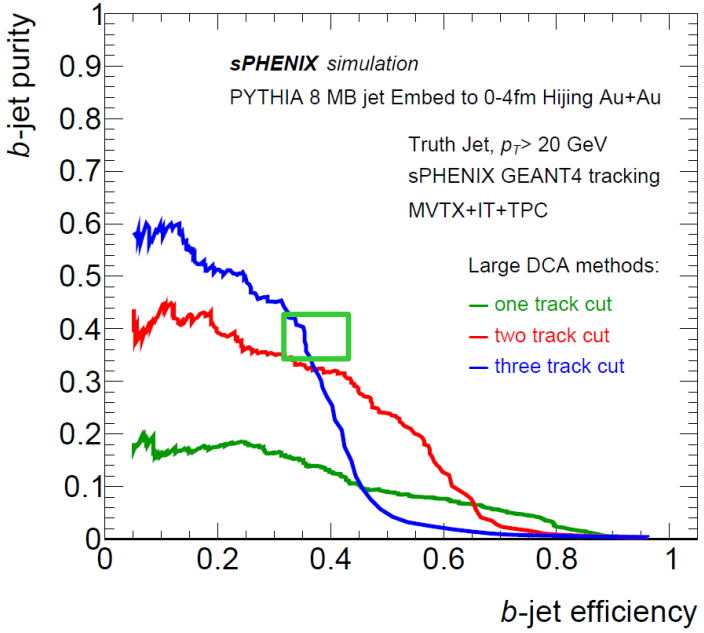




Combining calo.-jet and precision vertex: *b*-jet tagging

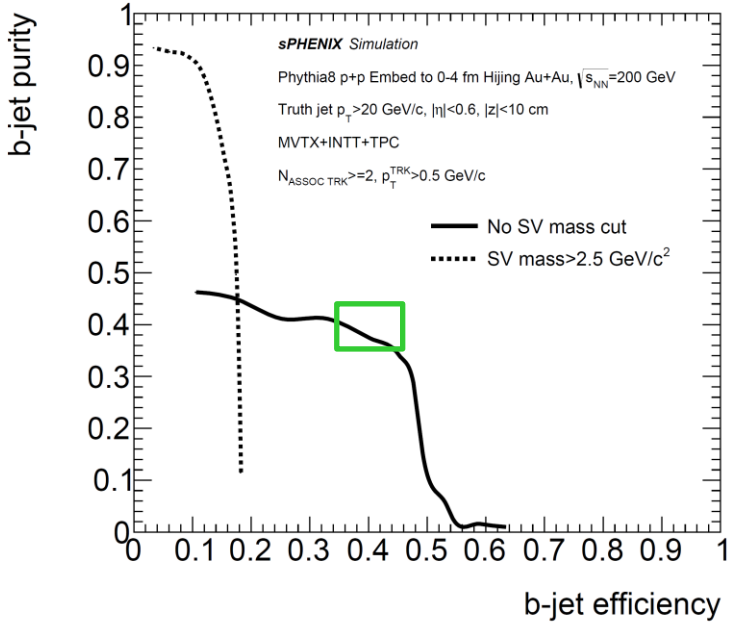
- Demonstrate b-jet capability: tagging algorithms evaluated using full detector HI simulation
- Reaching a promising working point in central Au+Au collisions

Track-counting tagger

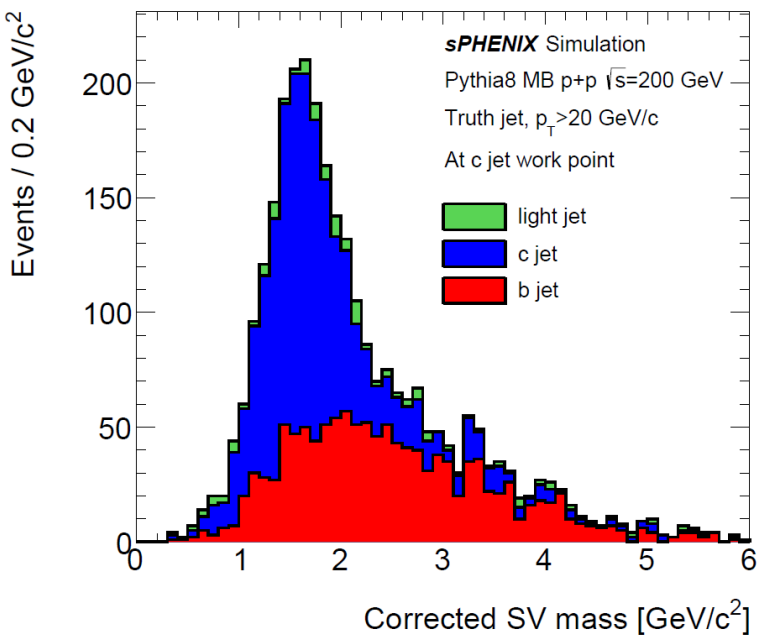


CMS work-point, Phys. Rev. Lett. 113, 132301 (2014)

Secondary-vertex tagger



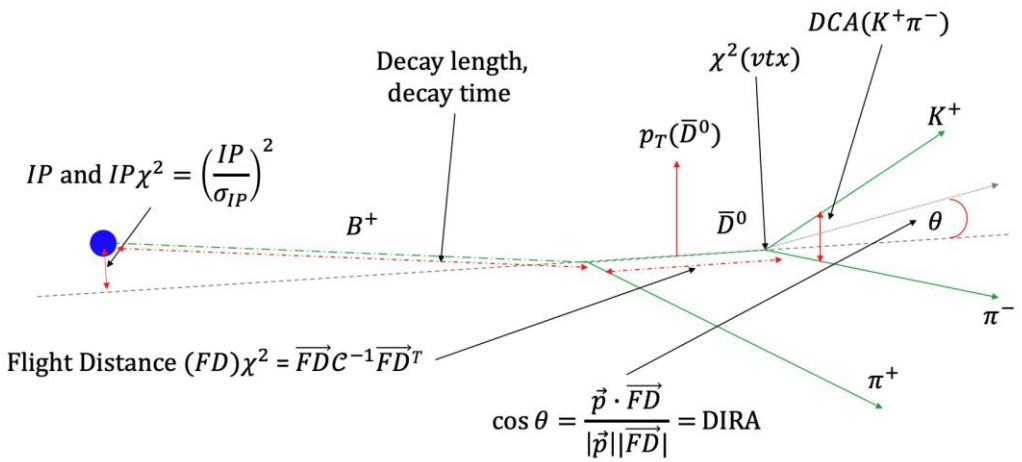
Secondary-vertex mass



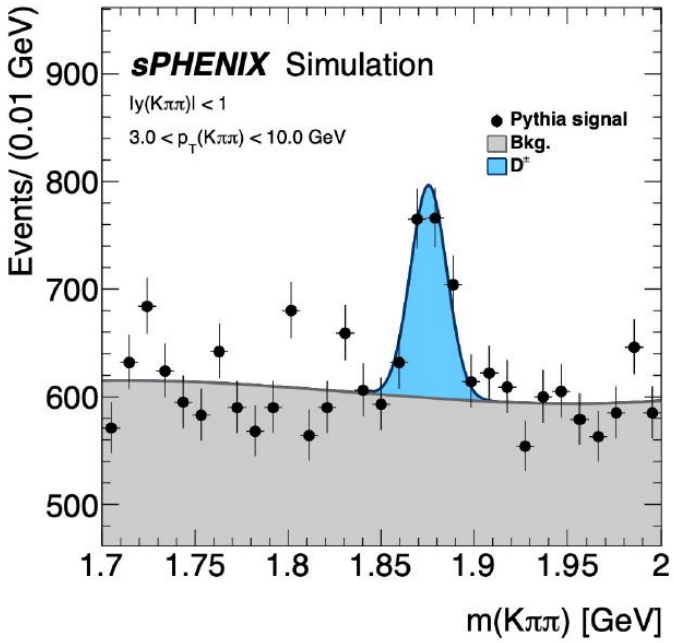
[sPH-HF-2018-001]

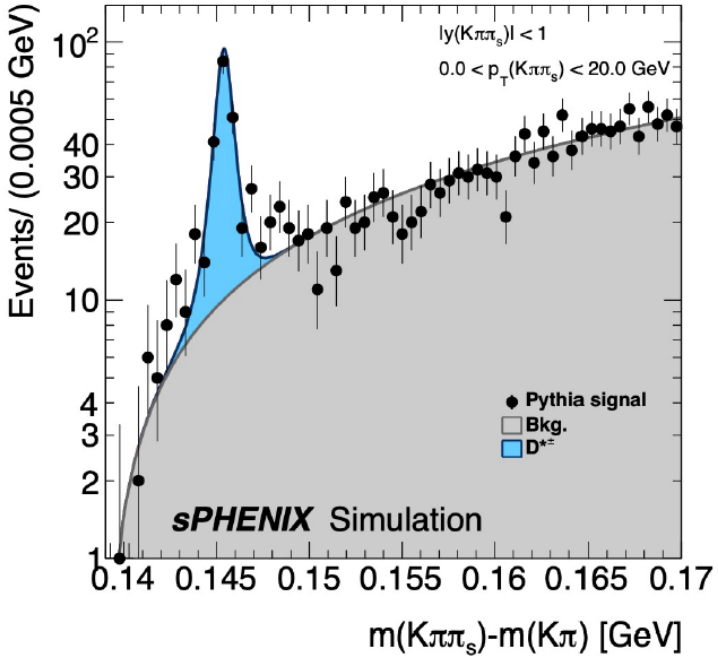
HF resonance reconstruction

- sPHENIX integration of KFParticle:
  - Generic resonance reco, also used in CBM, STAR , ALICE
- Used in mock data challenges → day-1 data

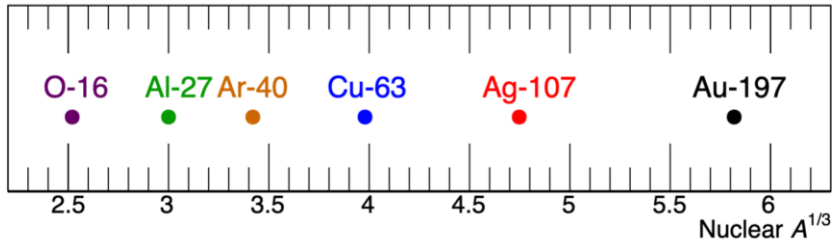


[sPH-HF-2021-001]

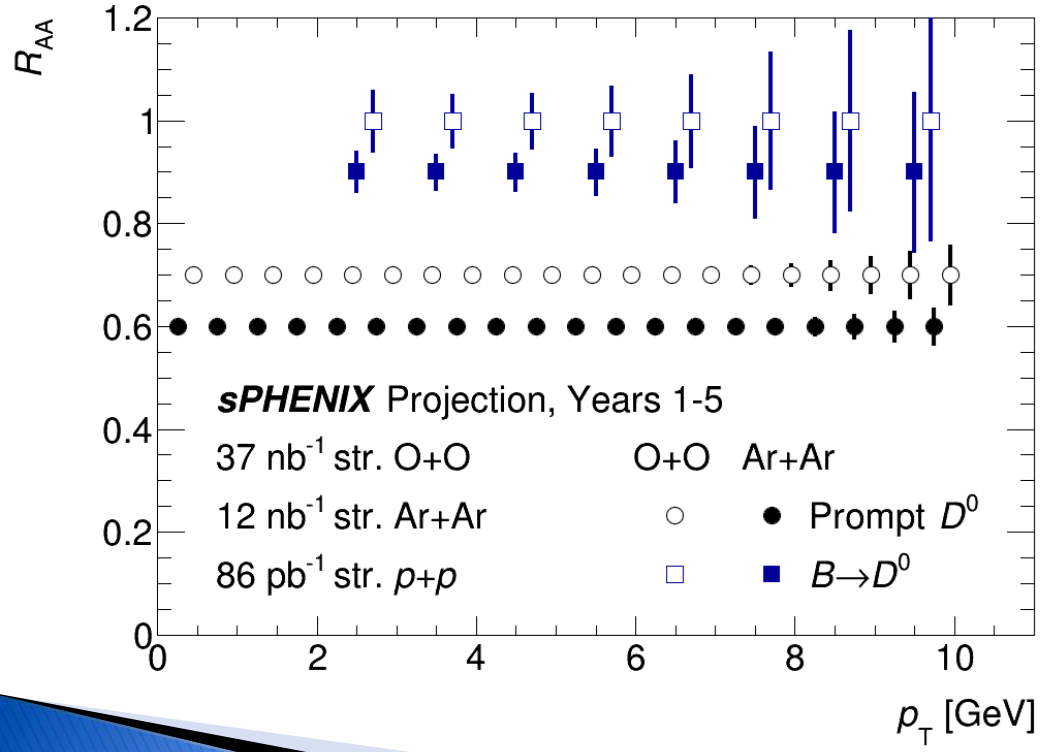




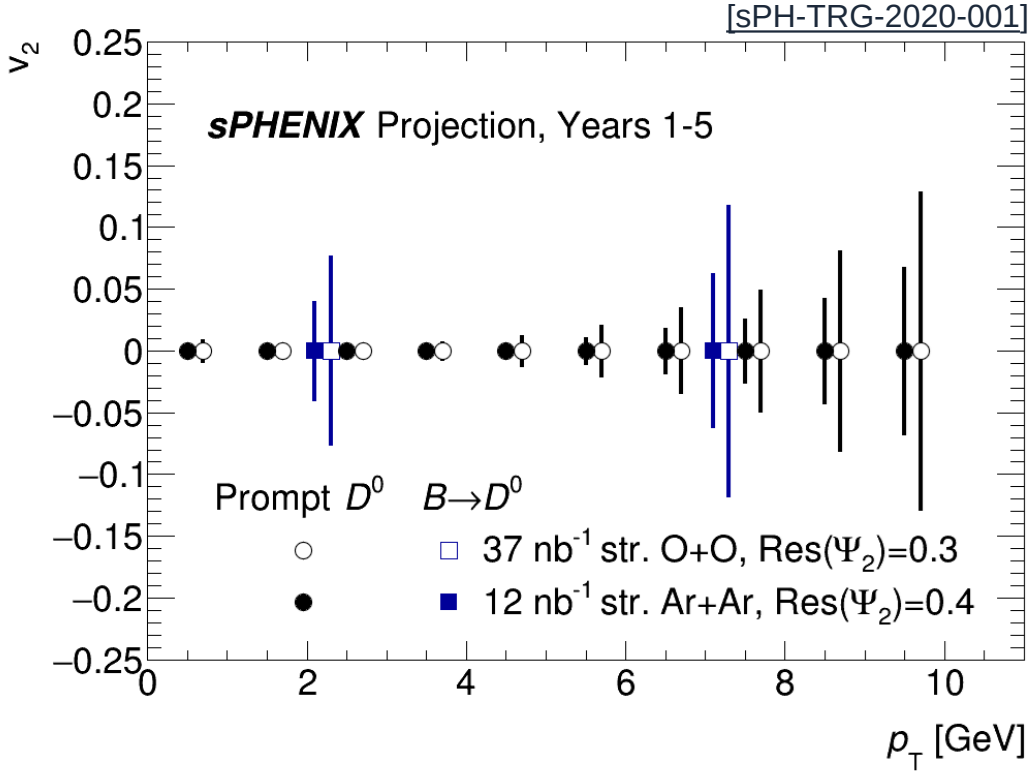
Possible runs beyond 2025 – Small collision system



- If opportunity arise in 2026-27, OO, ArAr runs
- pA: Mystery of non-zero HF v2 but lack of quenching. Small-A collision may bridge the gap from pA to large-AA



[sPH-TRG-2020-001]

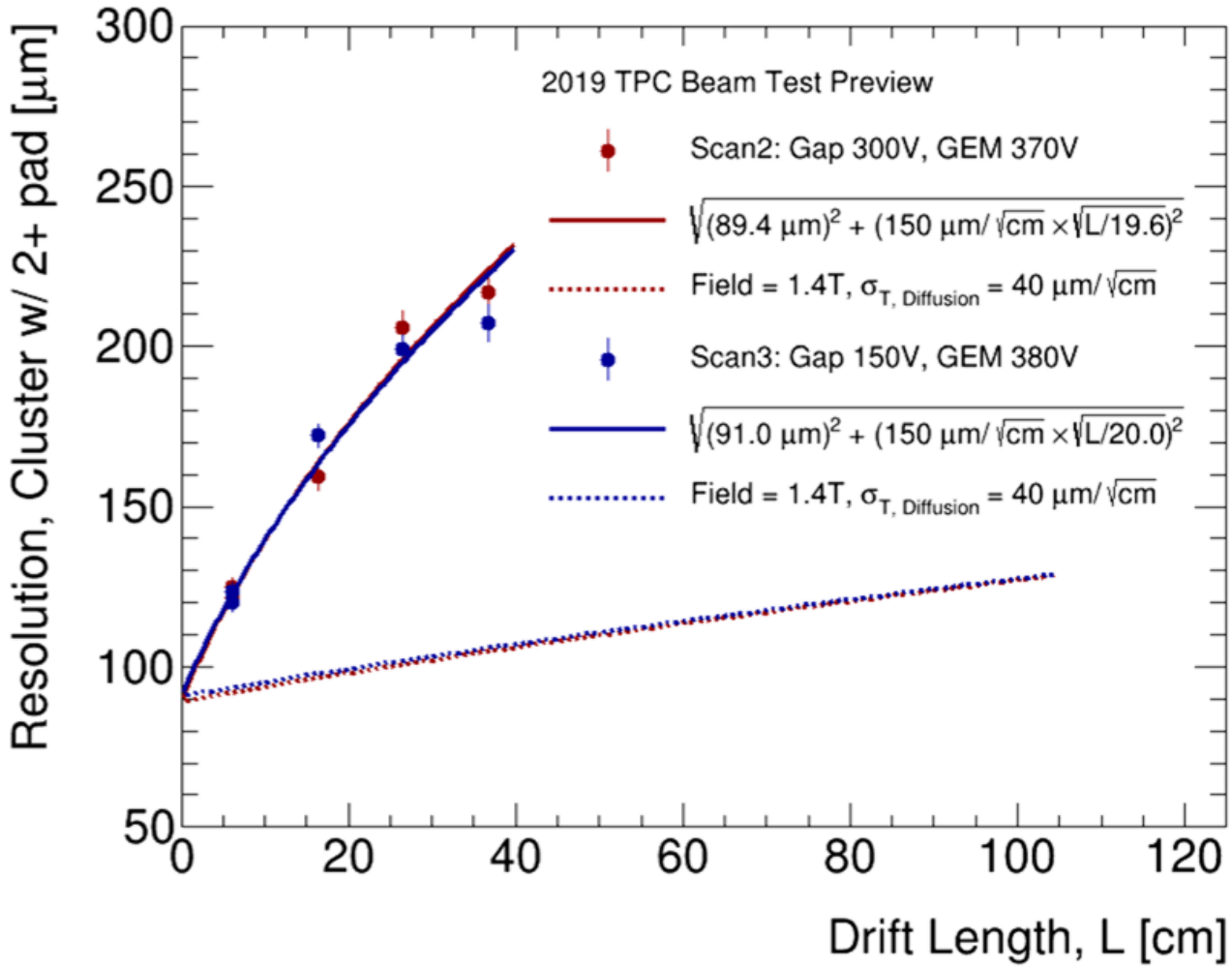


The tracking stack in the 2019 test beam

sPHENIX MVTX 2019 Beam Test
Using 180nm ITS2 ALPIDE MAPS sensor
MVTX Cluster hit Spatial Resolution < 5 um

Main tracker: Time projection chamber (TPC)

- Gateless and continues readout with GEM (similar to the ALICE TPC upgrade)
- Fast drift, low T diffusion, low ion backflow:
  50:50 Ne-CF4 gas, 13 us drift
- 48 layer of pad rows, zigzag pad
- SAMPA v5 ASIC with 80ns shaping time
- dp/p ~ 1% at 5GeV/c



Proposed run schedule, year 1-3

RHIC PAC-2021 Report:
"sPHENIX construction, installation and operation to accomplish its science goals is now the overarching priority for RHIC for the next 4 – 5 years."

sPHENIX BUP2021 [sPH-TRG-2021-001], 24 (& 28) cryo-week scenarios

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}