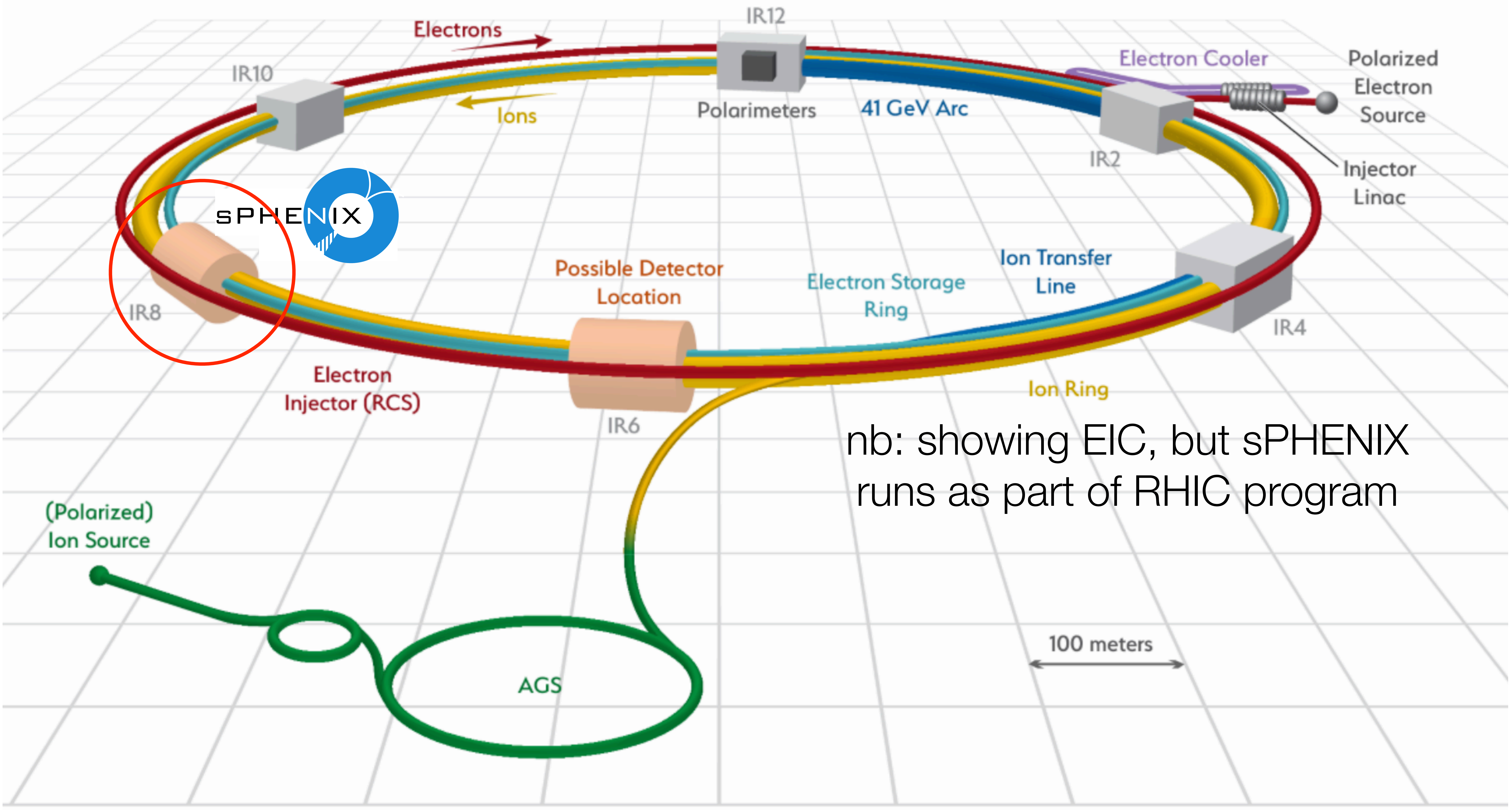
sPHENIX heavy flavor program and a path to the EIC

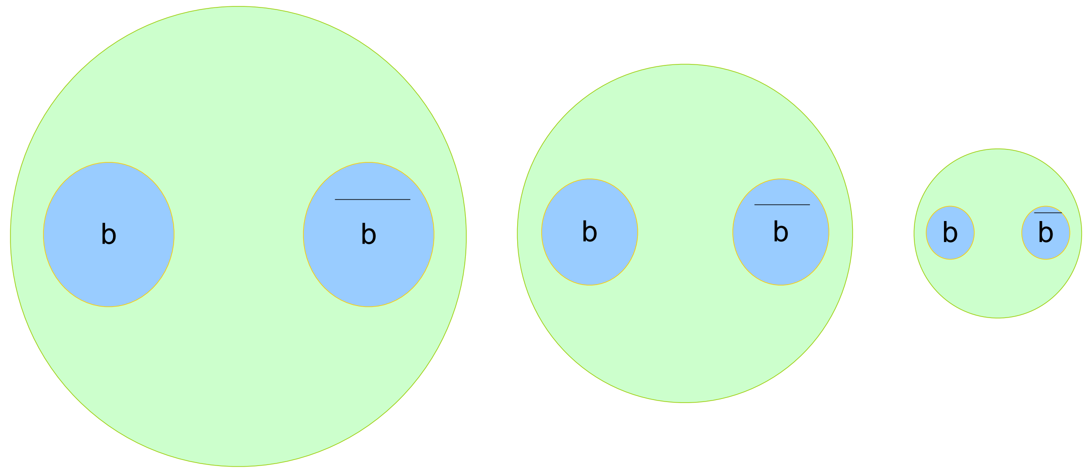
Dave Morrison (BNL), sPHENIX co-spokesperson
for the collaboration



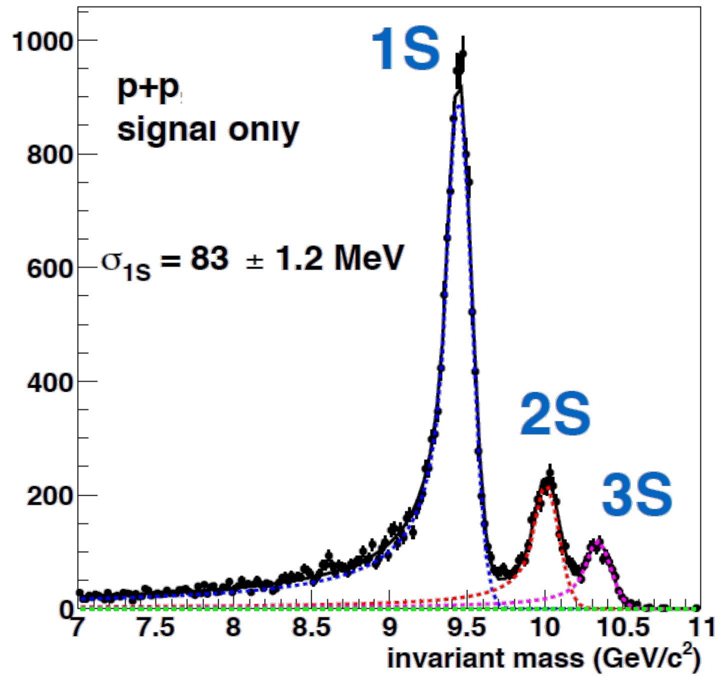
nb: showing EIC, but sPHENIX runs as part of RHIC program

Studying the QGP/QCD at multiple scales with sPHENIX

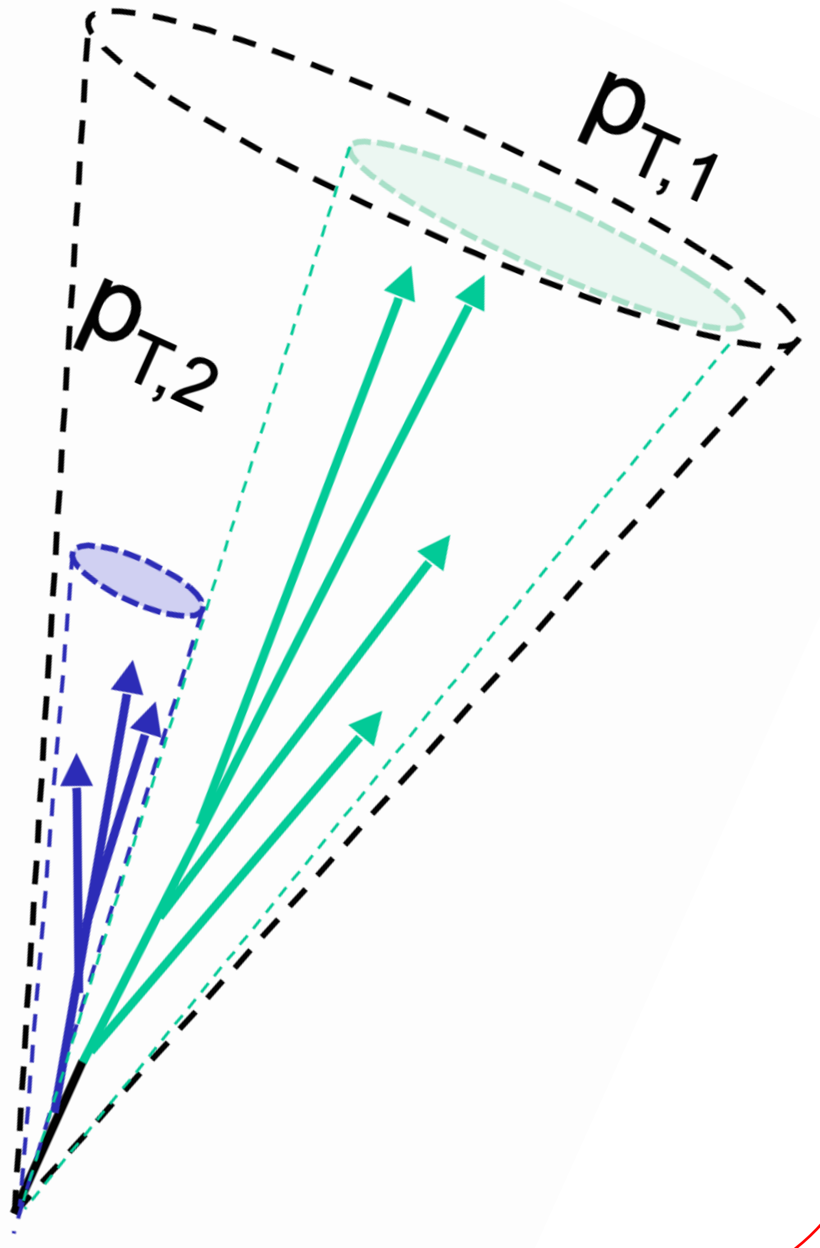
Quarkonium spectroscopy
vary size of probe



Υ(3s) Υ(2s) Υ(1s)



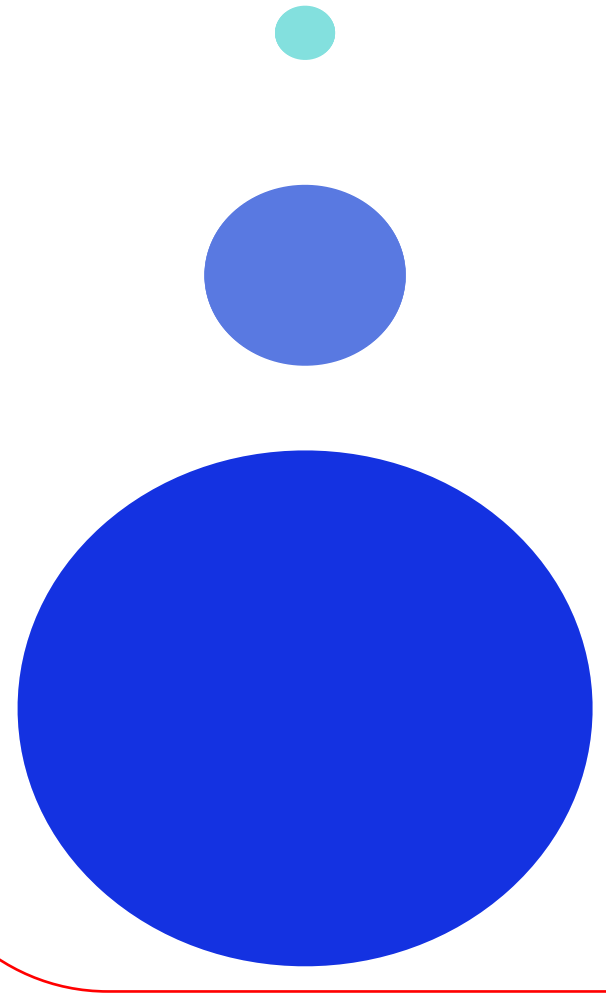
Jet structure
vary momentum/angular scale of probe



Parton energy loss
vary mass/momentum of probe

photon

gluon

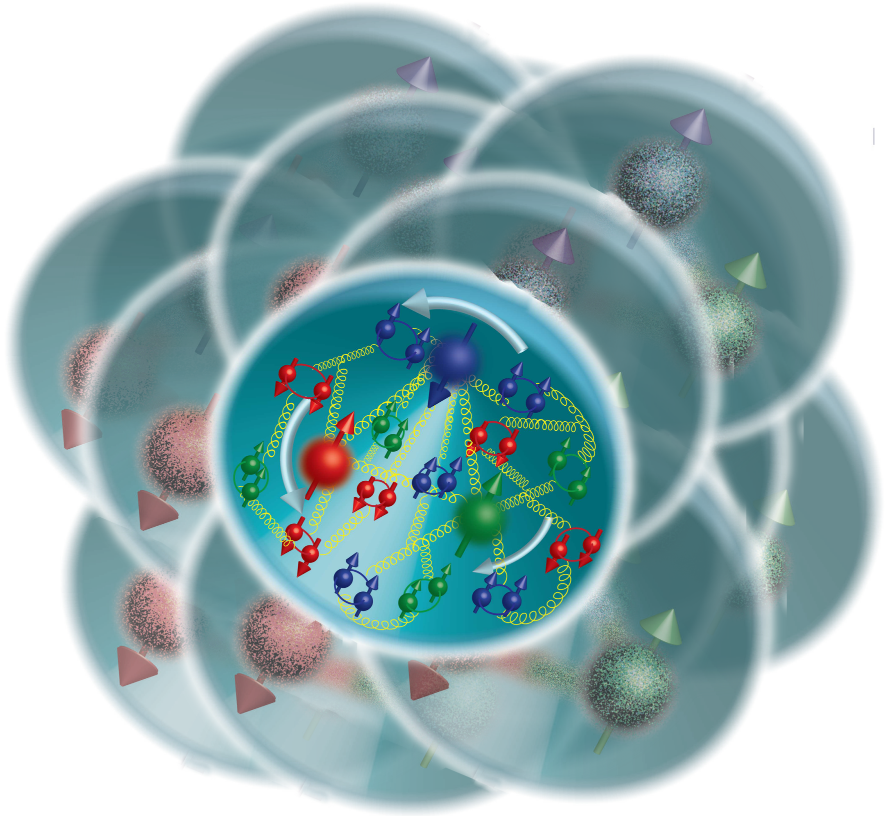


u,d,s

c

b

Cold QCD
vary temperature of QCD matter



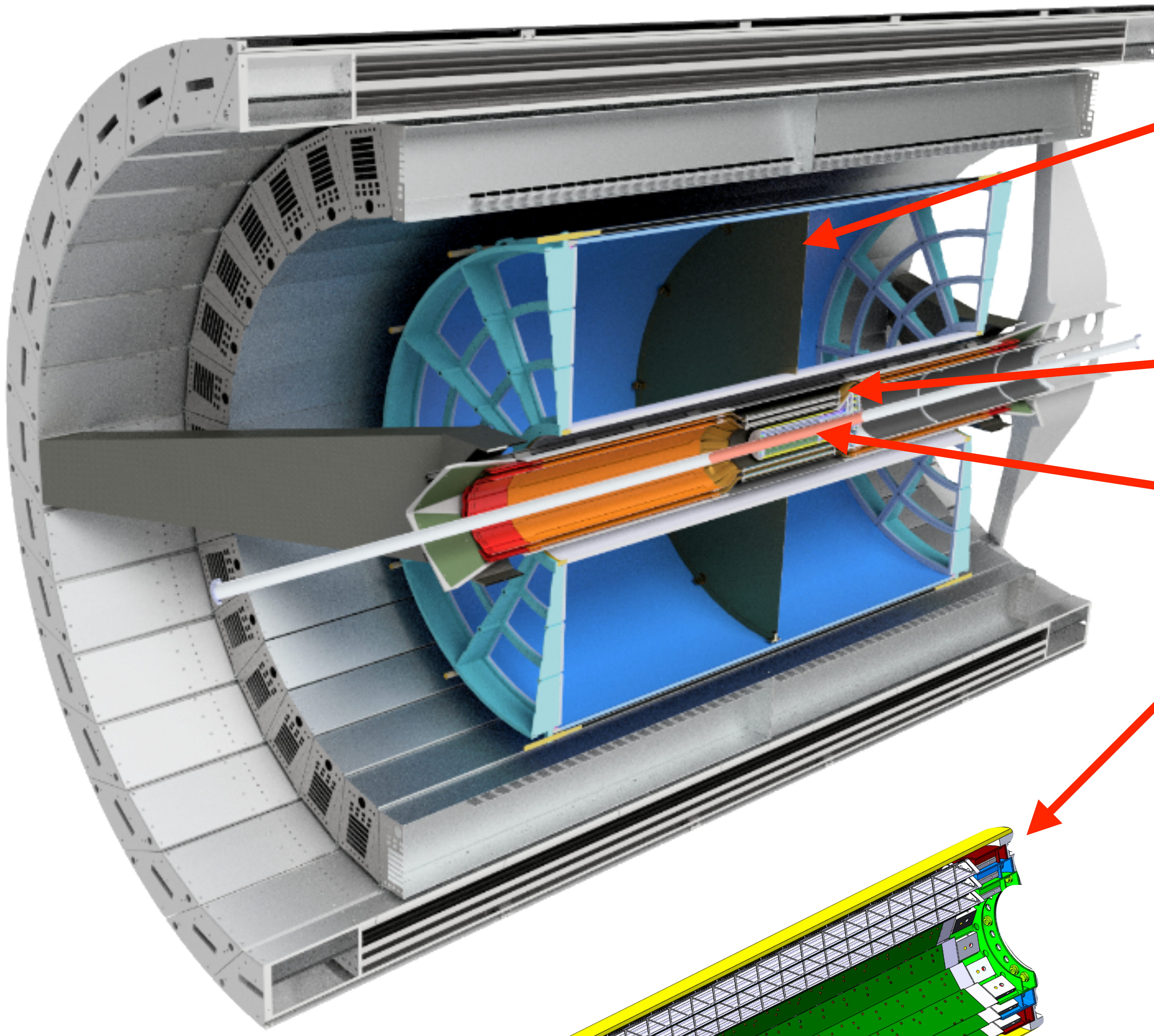
Heavy flavor (open or hidden) is a major part of the sPHENIX program


BaBar superconducting solenoid
outer HCAL
inner HCAL
EMCAL

BaBar high field test at BNL

nostalgia for Stephen Sekula :-)

sPHENIX Tracking detectors



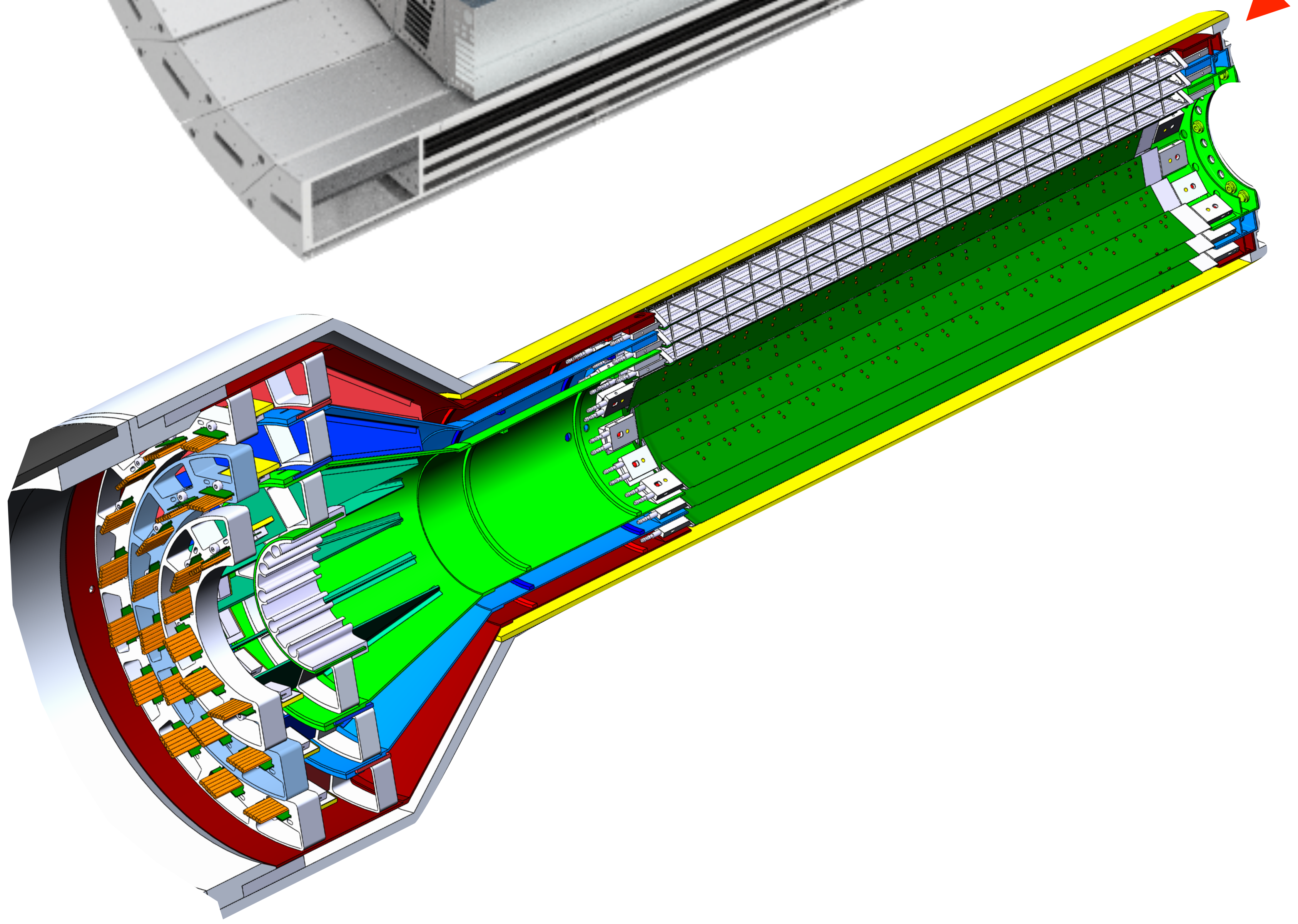
Continuous readout TPC (R = 20-78cm)

- shares many concepts with ALICE TPC upgrade
- compact – 1/30 of ALICE TPC volume

Si strip intermediate tracker (R = 6-12cm)

3-layer precision vertex tracker (R = 2.3, 3.1, 3.9cm)

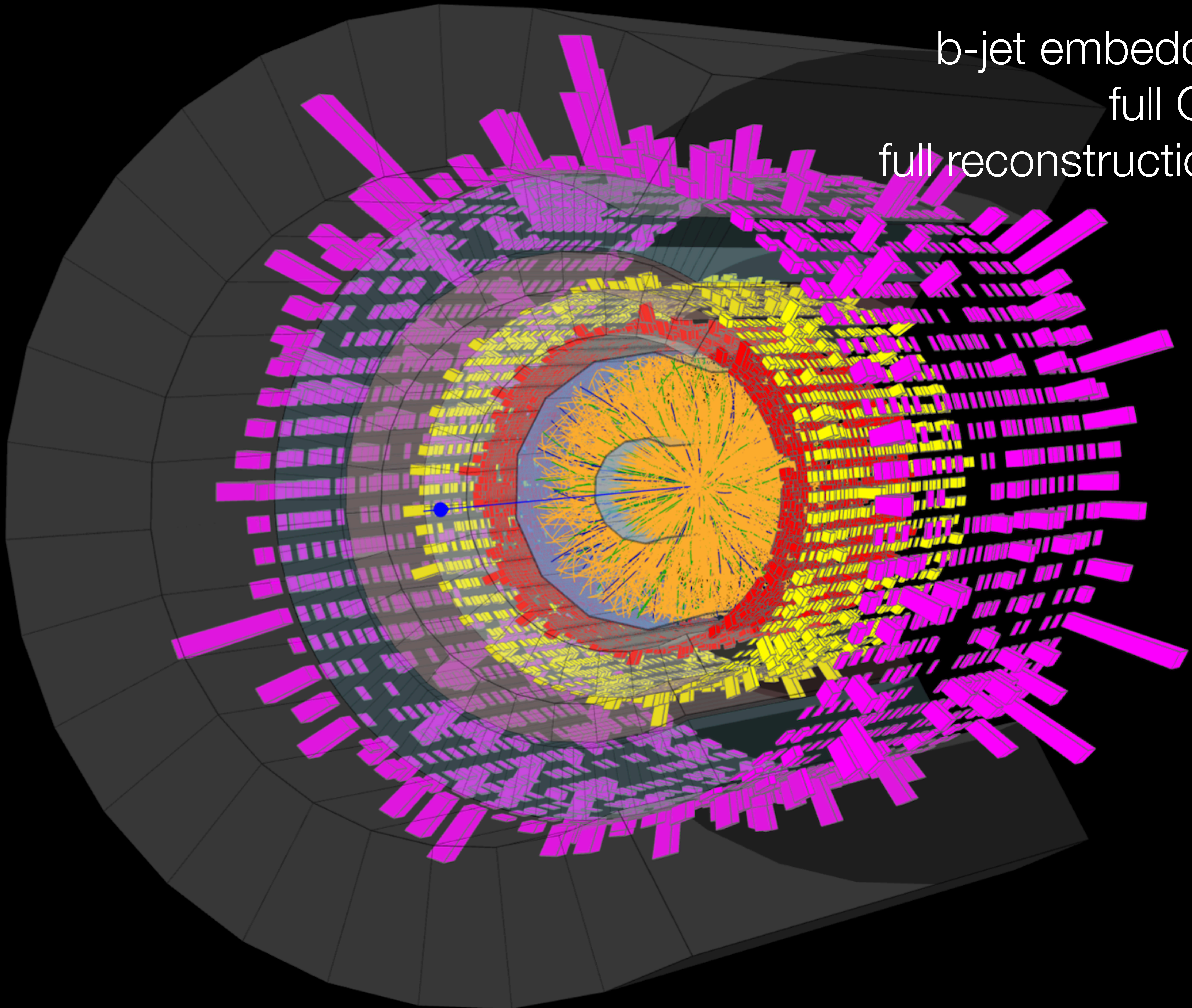
- near-copy of ALICE ITS IB detector



b-jet embedded in 200 GeV Au+Au event

full GEANT4 detector description

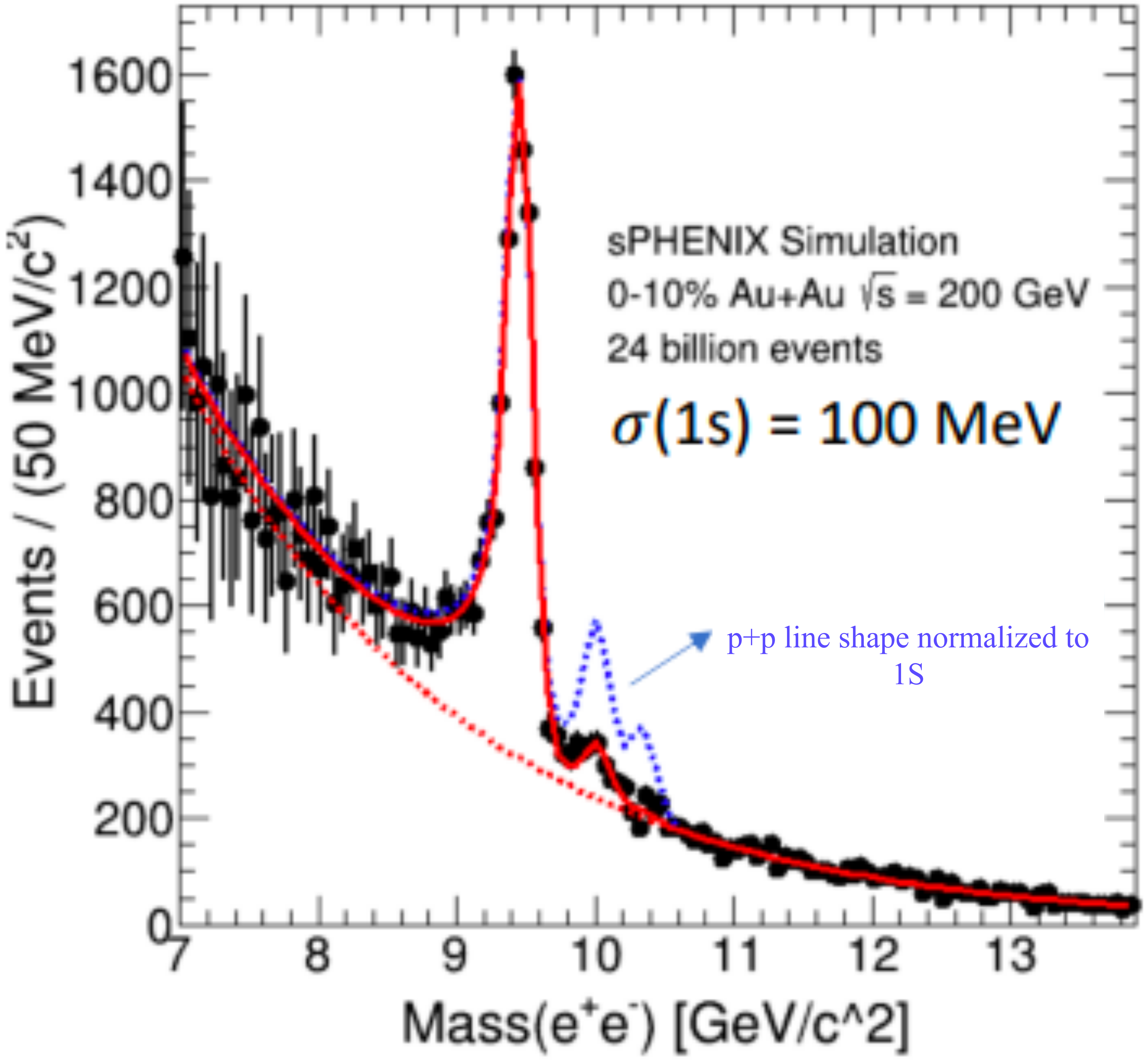
full reconstruction of tracks and calorimeters



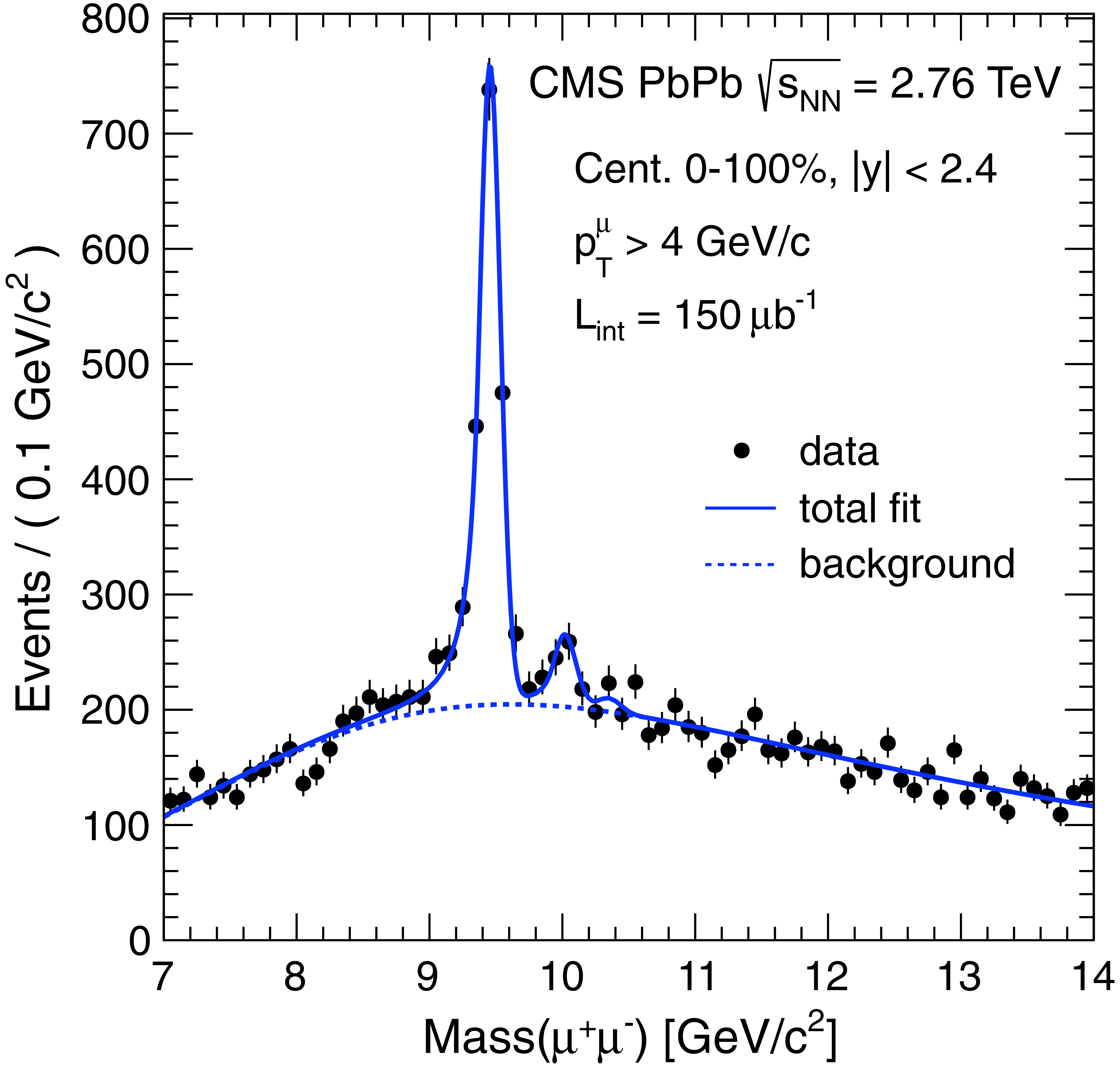
Upsilon spectroscopy

sPHENIX

Sufficient mass resolution to enable clear separation of Y mass states for the first time at RHIC ($\sigma_p/p = 0.2\% \times p \Longrightarrow \sigma_M|_{Y(1S)} = 100\ \text{MeV}/c^2$)

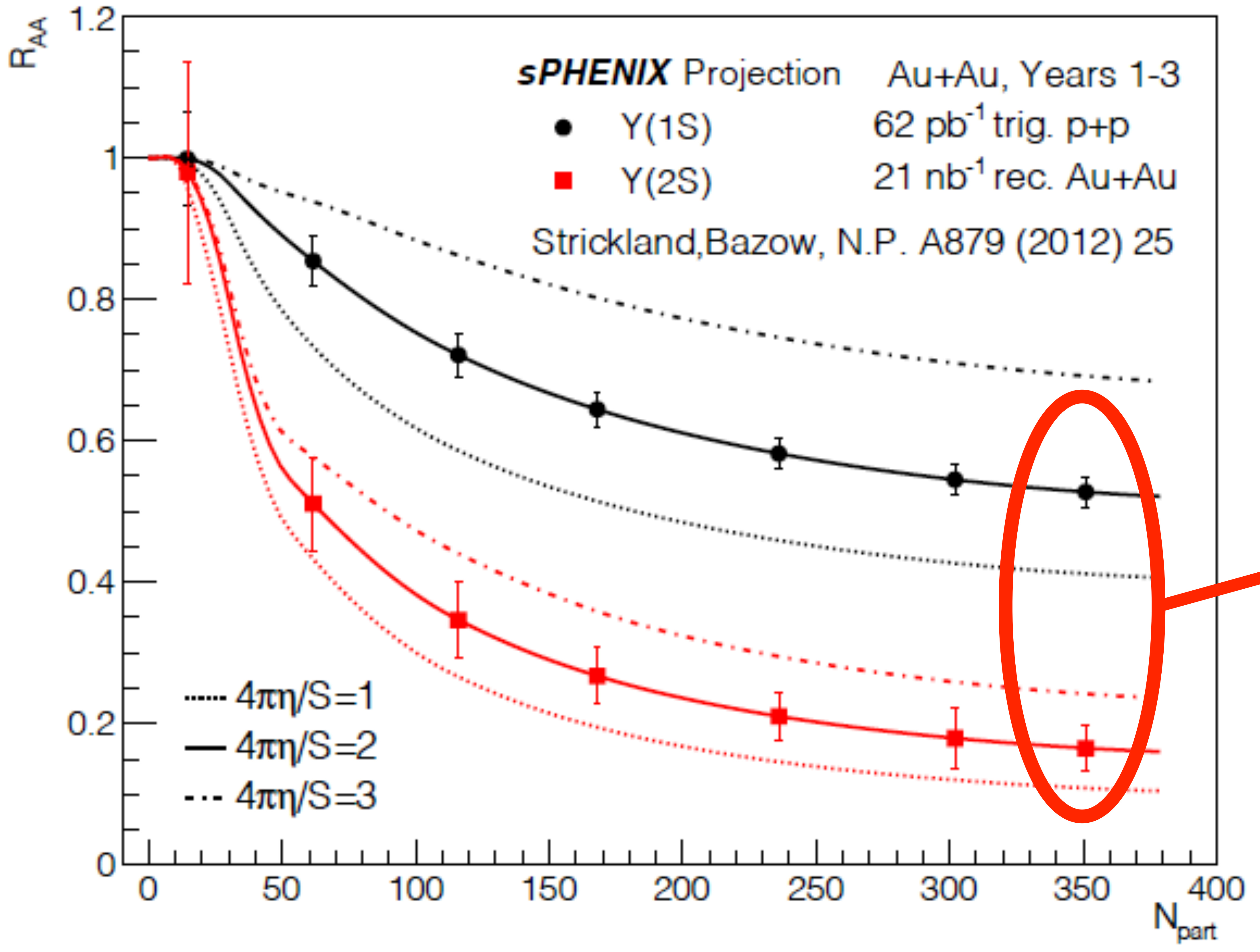


PRL 109, 222301 (2012)

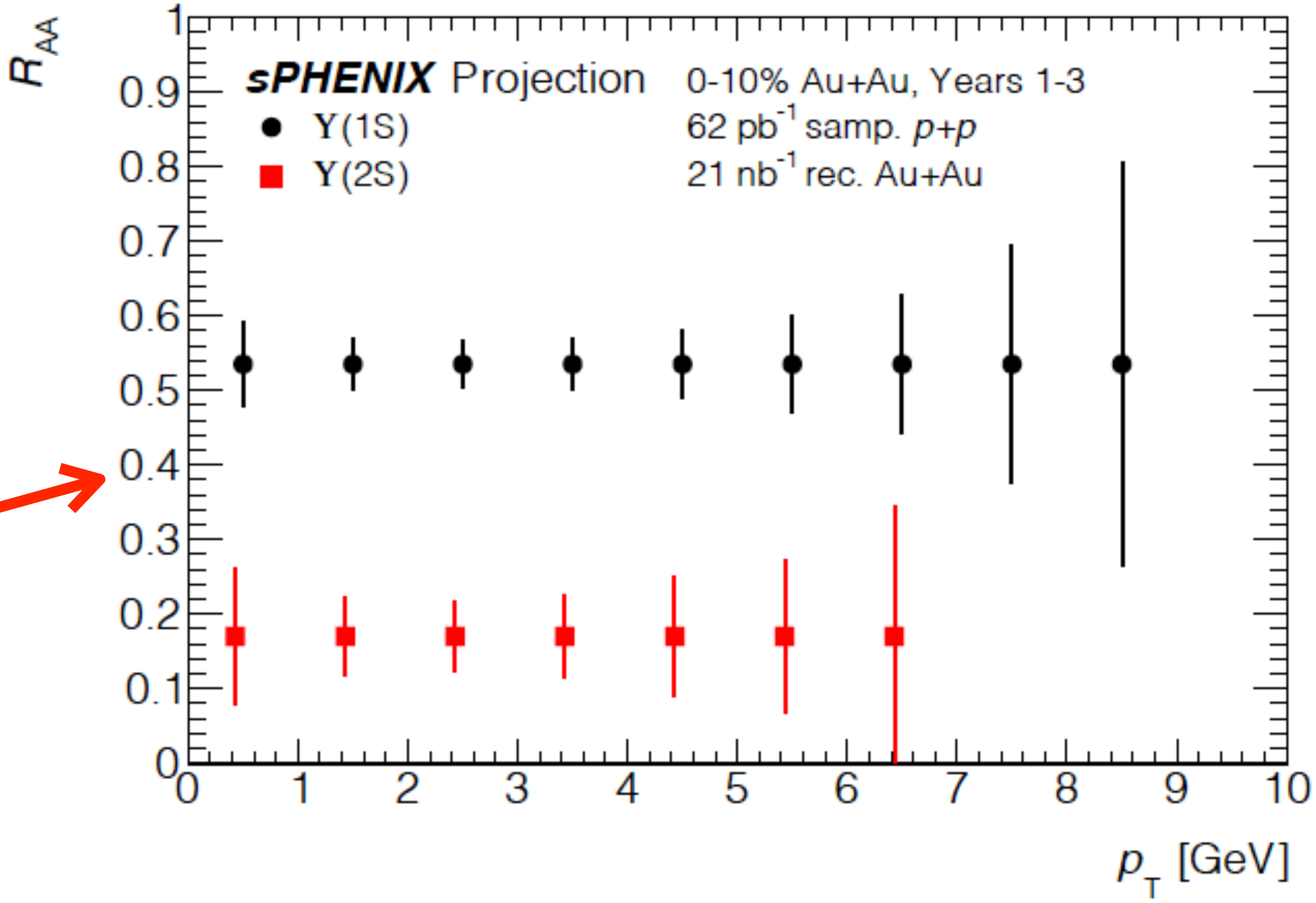


High rate DAQ + RHIC luminosity ⟹ multiply differential observables

suppression vs centrality



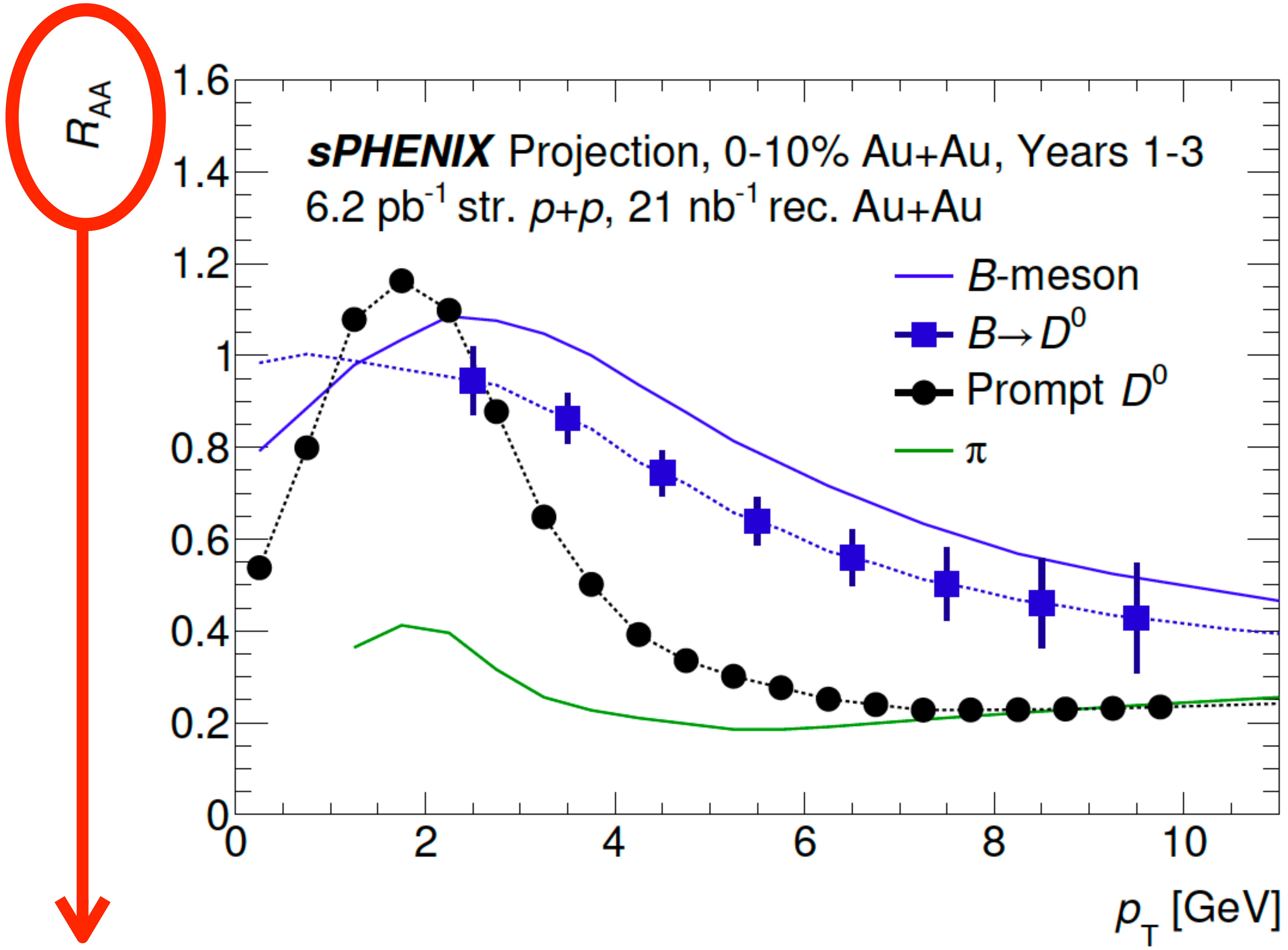
p_T-dependence for most-central collisions

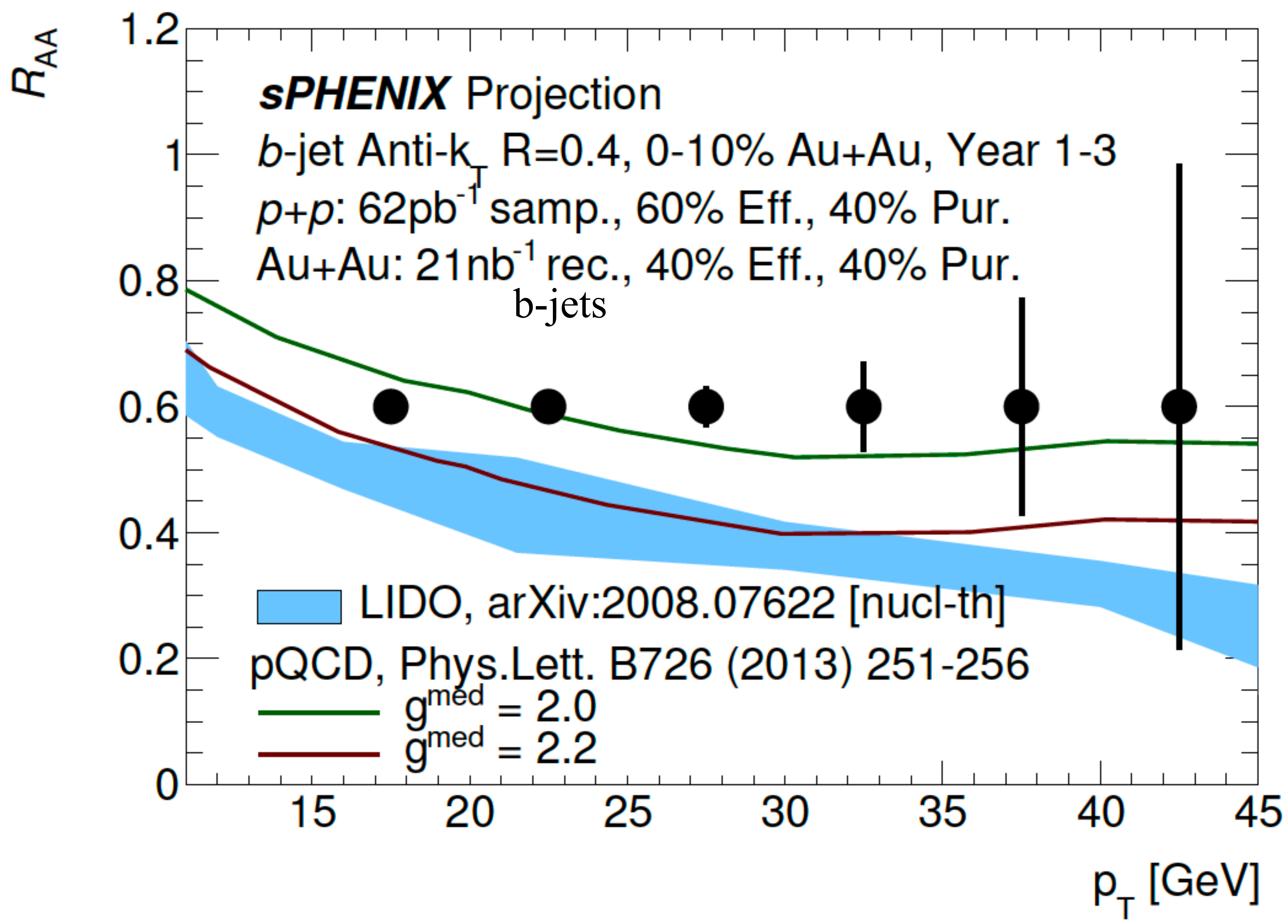


Open heavy flavor via single hadrons and via jets

sPHENIX will enable precision bottom measurements at RHIC over broad kinematic range

First b-jet tagging at RHIC

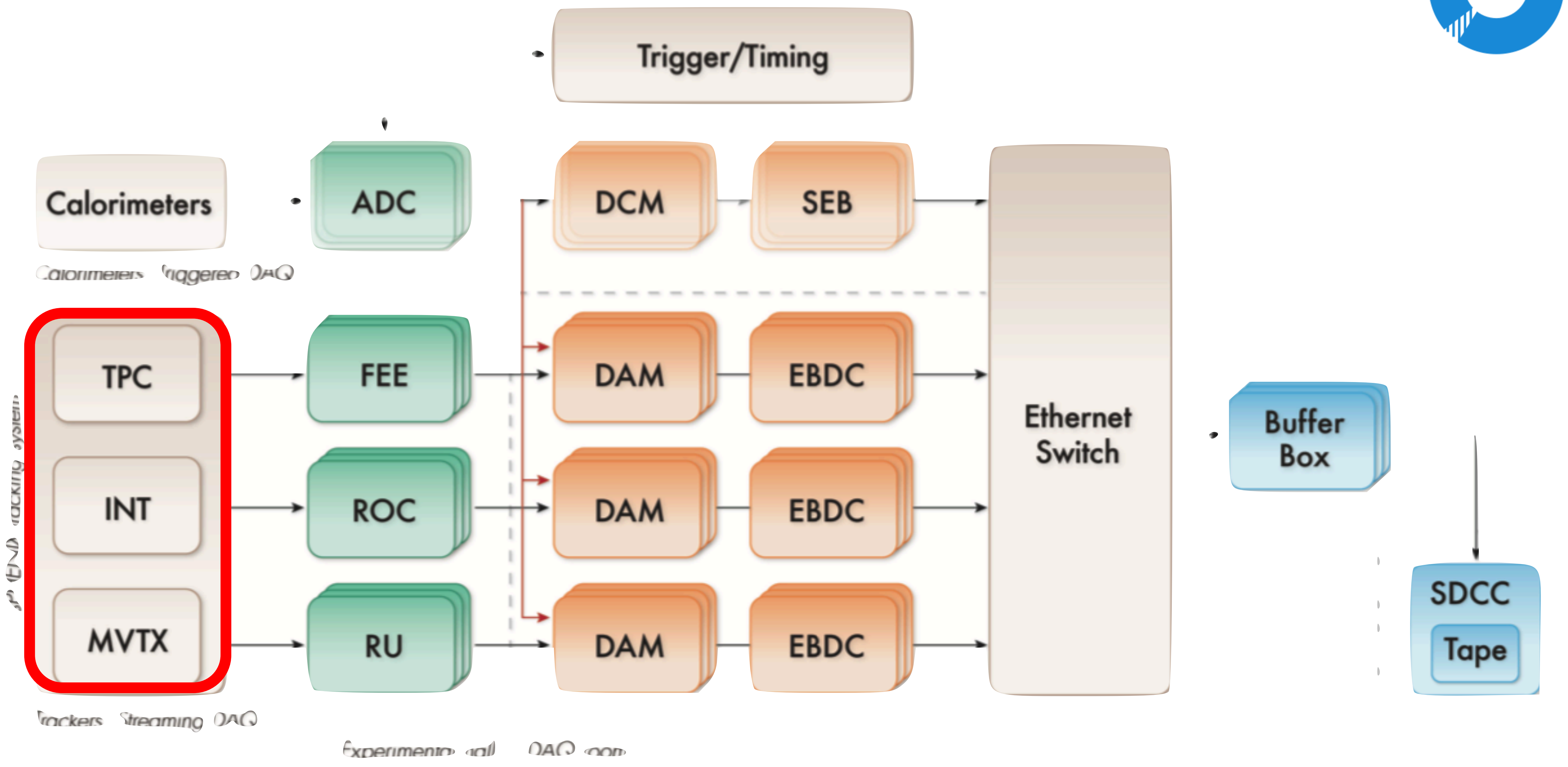




subtle point: low p_T HF isn't triggerable, challenge to get statistics in pp – sPHENIX uses streaming readout of tracking detectors to do this

Streaming readout means even better HF physics

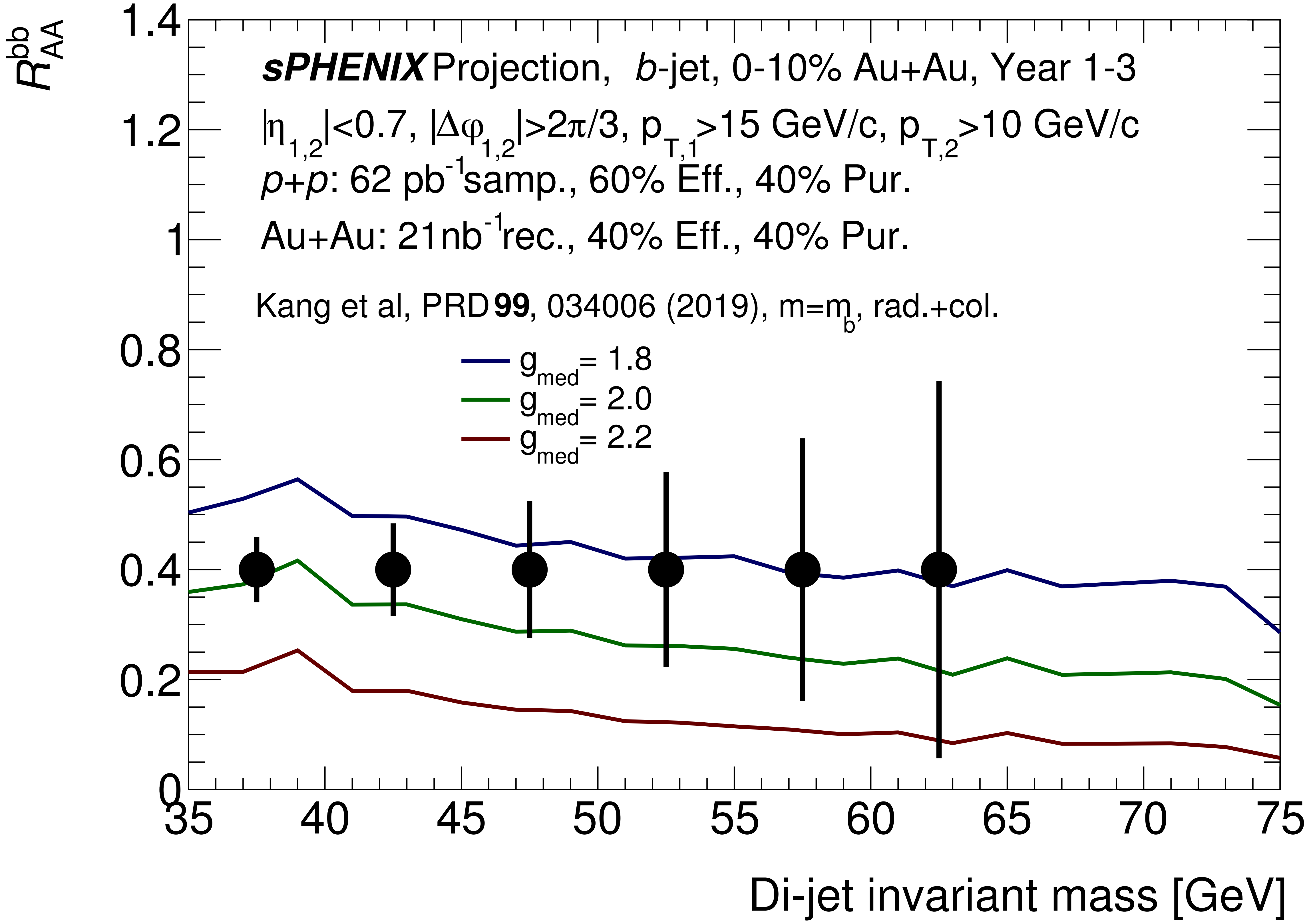
p+p collision statistics		Year-2024, triggered DAQ per-1kHz M.B. trigger	Year-2024, w/ str. tracker
M.B. p+p	Data Mode	Each 1k Hz M.B. trigger w/ 4×10^{-4} of M.B. coll. triggered	10% M.B. events str. recorded
	Stats	1 Billion M.B. evts $0.026\ \mathrm{pb}^{-1}$ recorded	250 Billion M.B. evts $6.2\ \mathrm{pb}^{-1}$ recorded
Physics Reach	$B \to D^0 \to \pi K$ R_{AA} ref.	620 evts	150k evts
	$D^0 \to \pi K$ pair Diffusion of $c + \bar{c}$	620 evts	150k evts
	$\Lambda_c \to \pi K p$ Charm hadronization	1.3k evts	310k evts
	Prompt $D^0 \to \pi K$ Tri-Gluon Corr. via TSSA	0.2M evts	50M evts

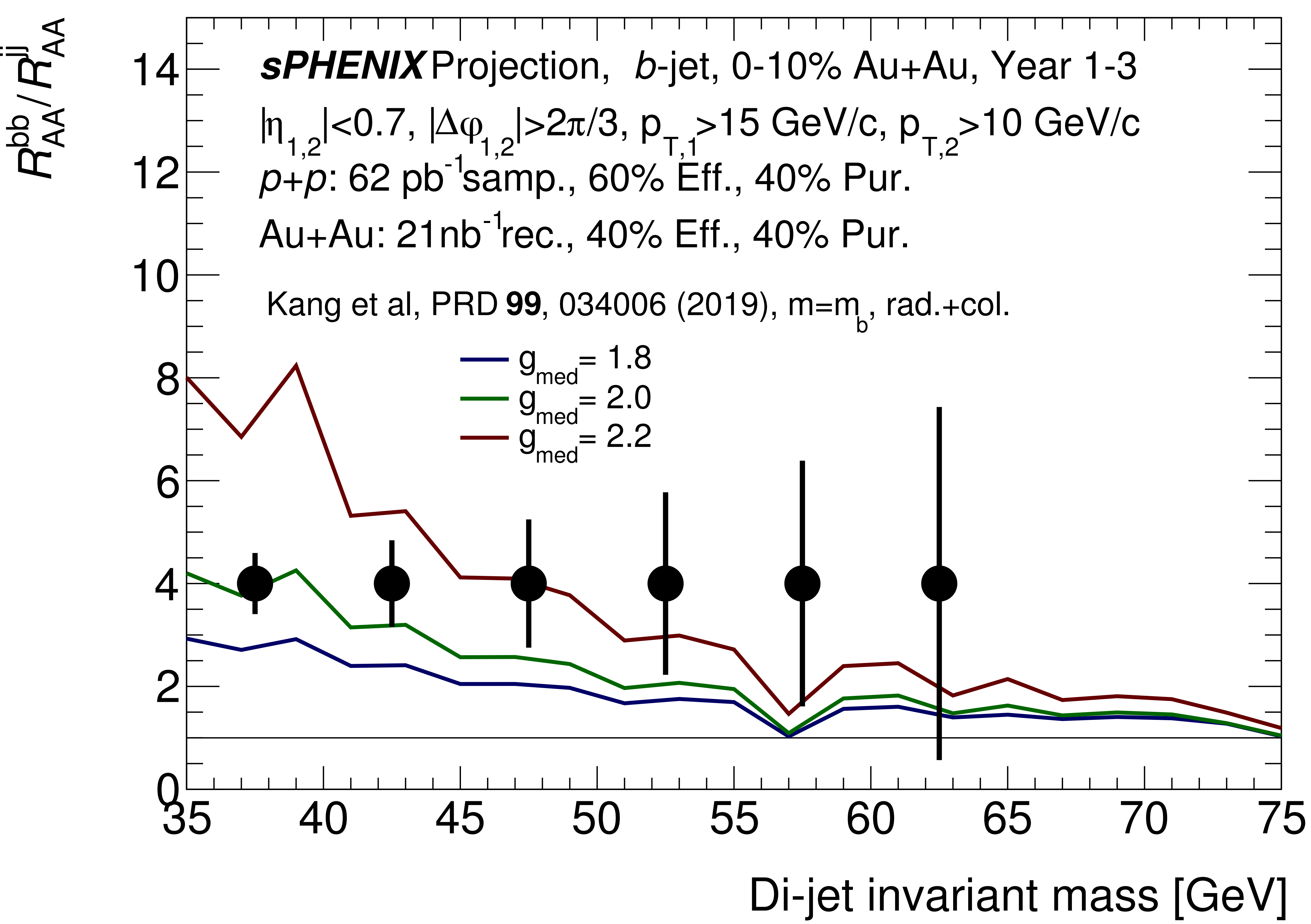


(co-host Jin Huang is the expert on this!)

Di-b-jet increases sensitivity to physics

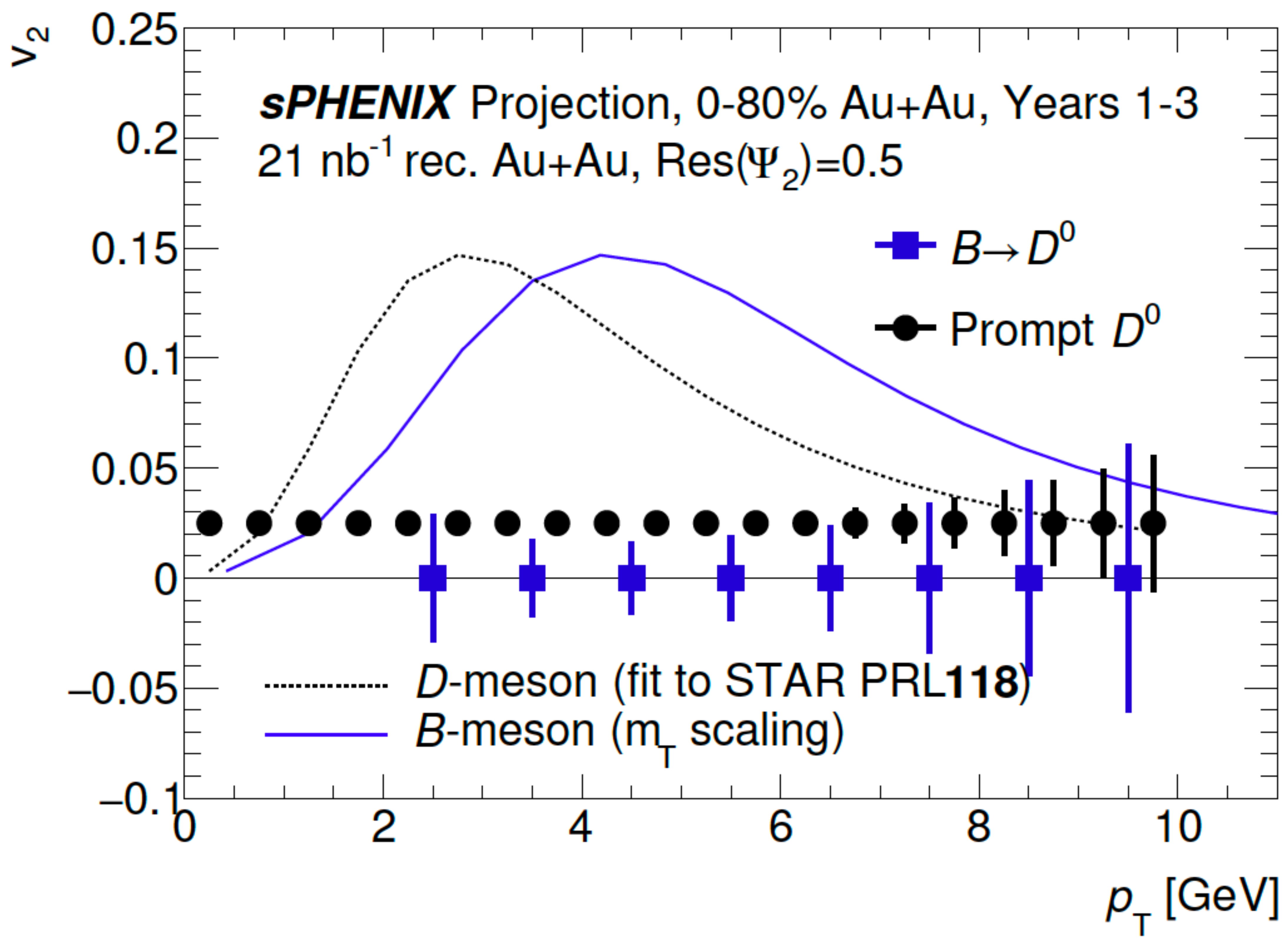
Another observable enabled by sPHENIX high rate DAQ + RHIC luminosity

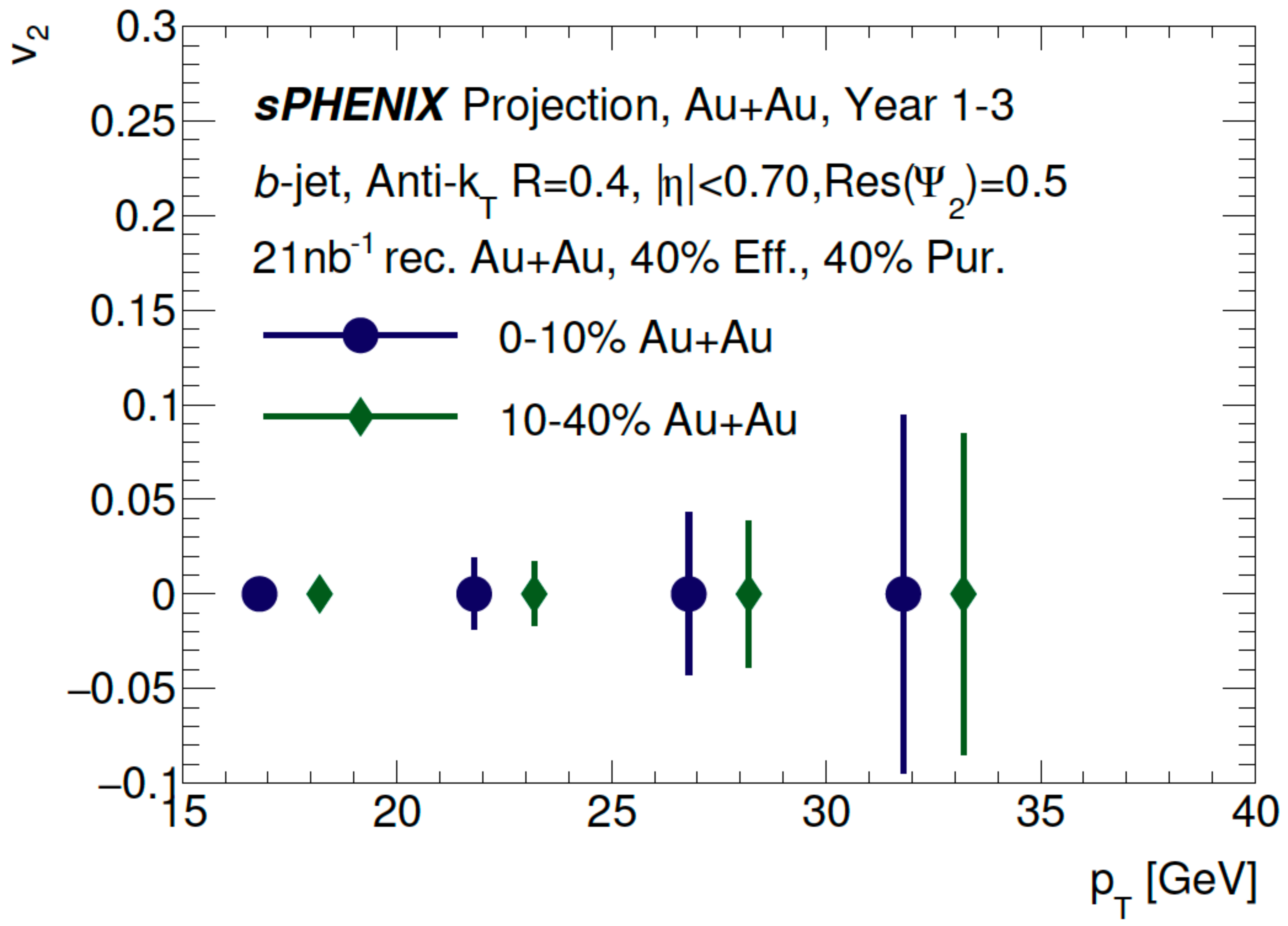




Zhong-Bo Kang, Jared Reiten, Ivan Vitev, and Boram Yoon. *Phys. Rev. D*, 99(3):034006, 2019

Heavy flavor as a probe of collectivity, coupling in the medium

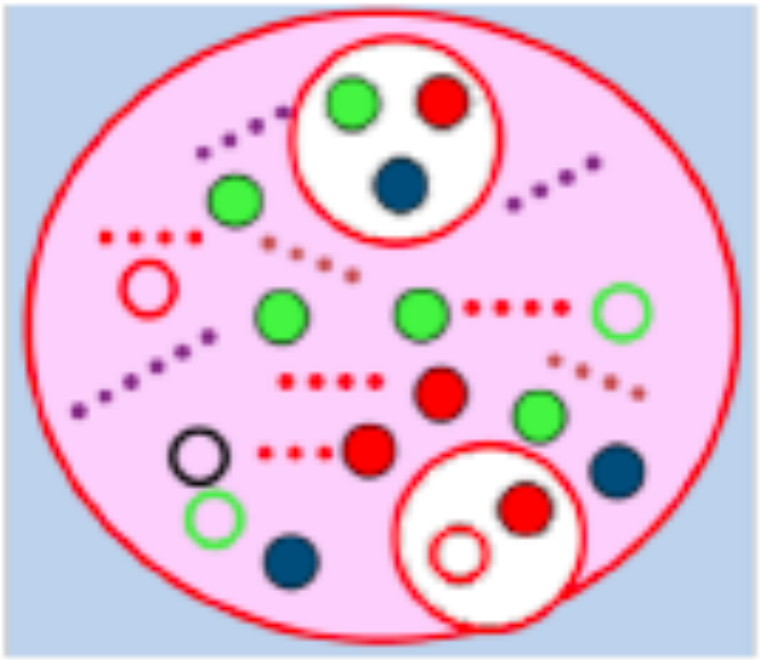


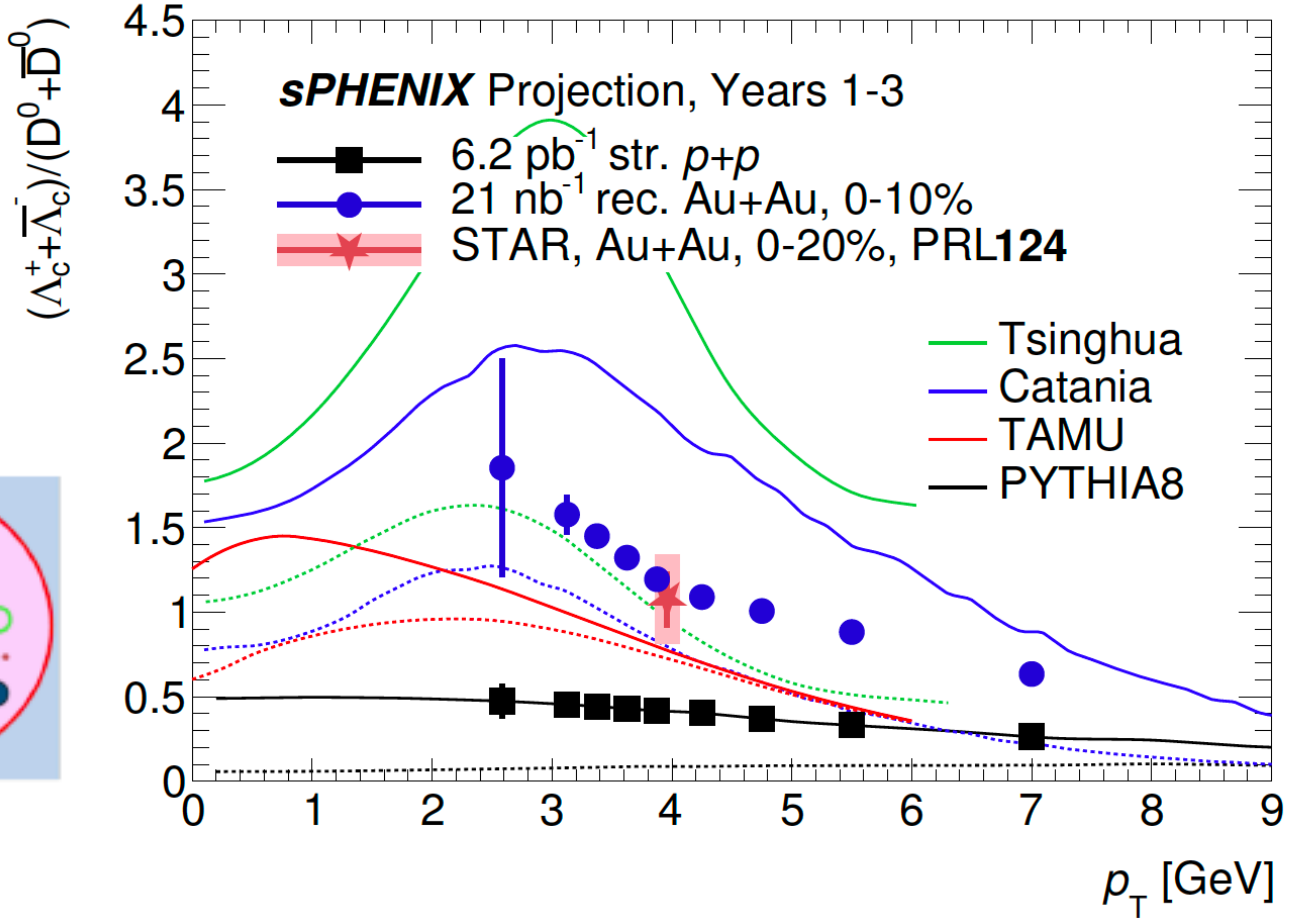


Probing the diffusion of the b-quark in the QGP

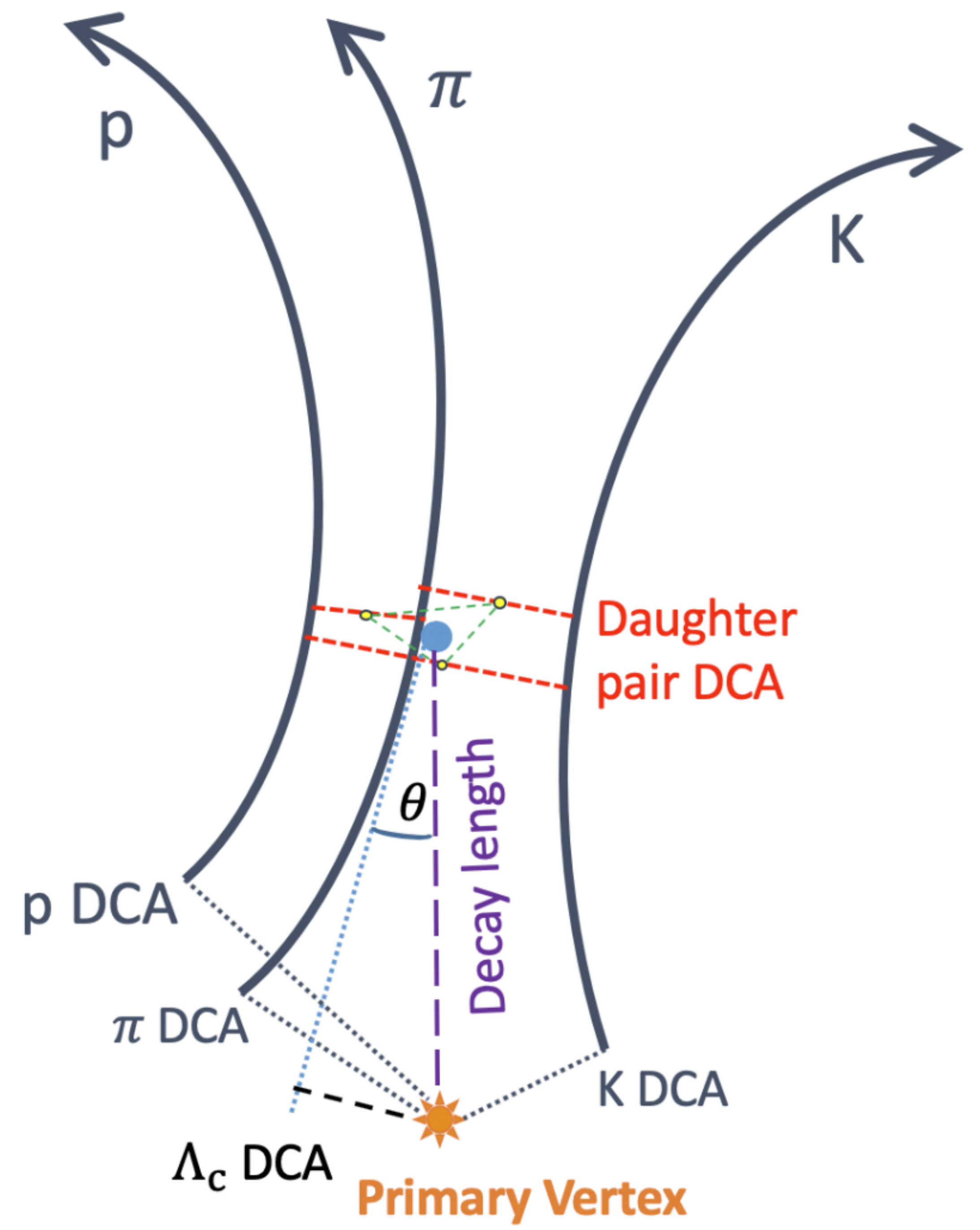
Probing the path-length differential energy loss of the b-quark

Charm hadronization in the deconfined medium





Uses sophisticated multi-variate analysis methodology to use available information optimally



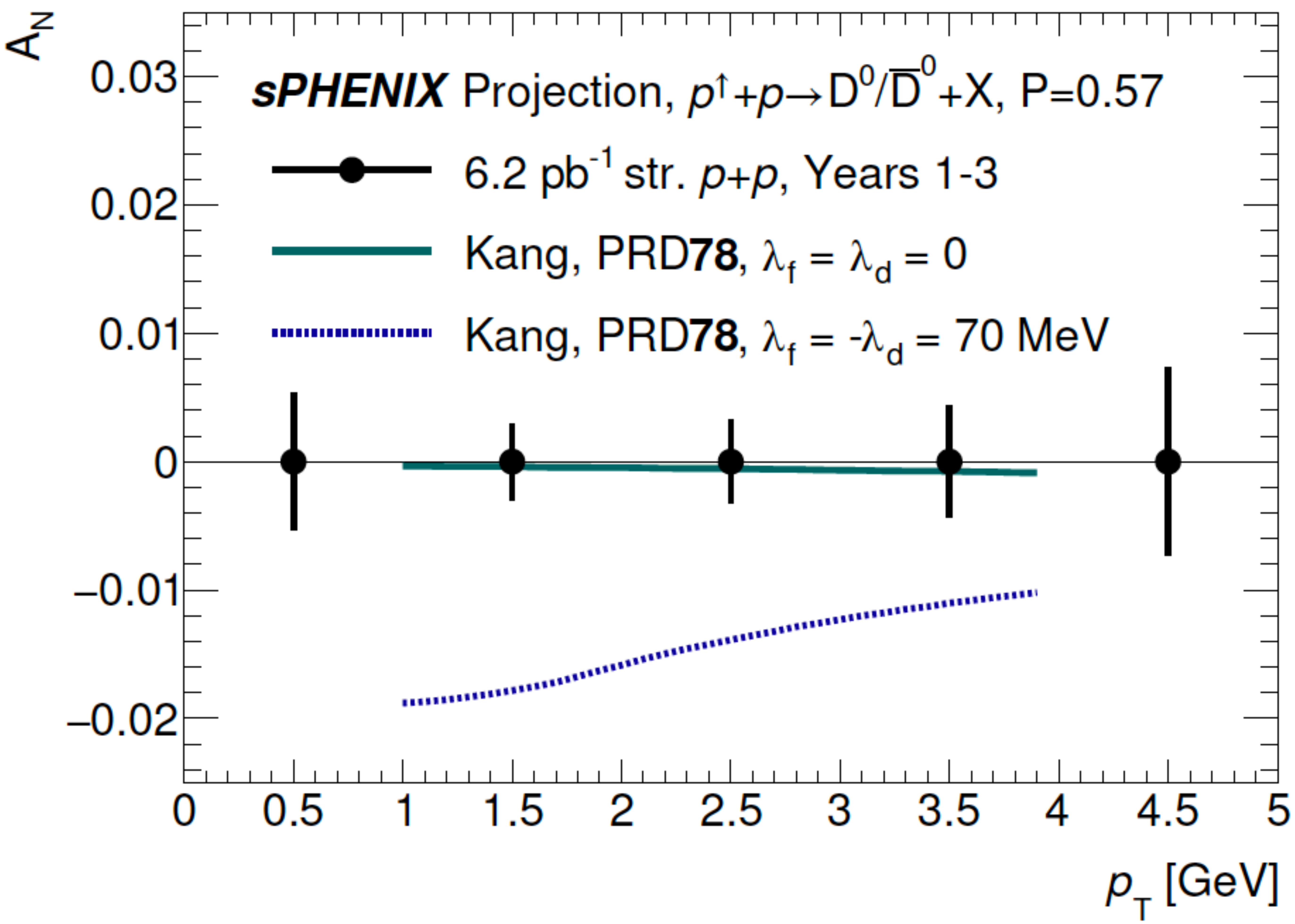
Min He, Ralf Rapp, *"Hadronization and Charm-Hadron Ratios in Heavy-Ion Collisions", Phys.Rev.Lett.* 124 (2020) 4, 042301

Jaroslav, Adam et al. First Measurement of Λ_C Baryon Production in Au+Au Collisions at $\sqrt{s_{NN}}$=200 GeV. *Phys. Rev. Lett.*, 124(17):172301, 2020.

HF in cold QCD with sPHENIX

Gluon Sivers TMD

TSSA in direct-γ and heavy-flavor production



Zhong-Bo Kang, Jian-Wei Qiu, Werner Vogelsang, and Feng Yuan. "Accessing tri-gluon correlations in the nucleon via the single spin asymmetry in open charm production." *Phys. Rev. D*, 78:114013, 2008

sPHENIX run plan 2023 – 2025

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}

Key transverse polarized $p^{\uparrow}p^{\uparrow}$, $p^{\uparrow}$Au data sets

141 billion Au+Au events with |z| < 10 cm recorded

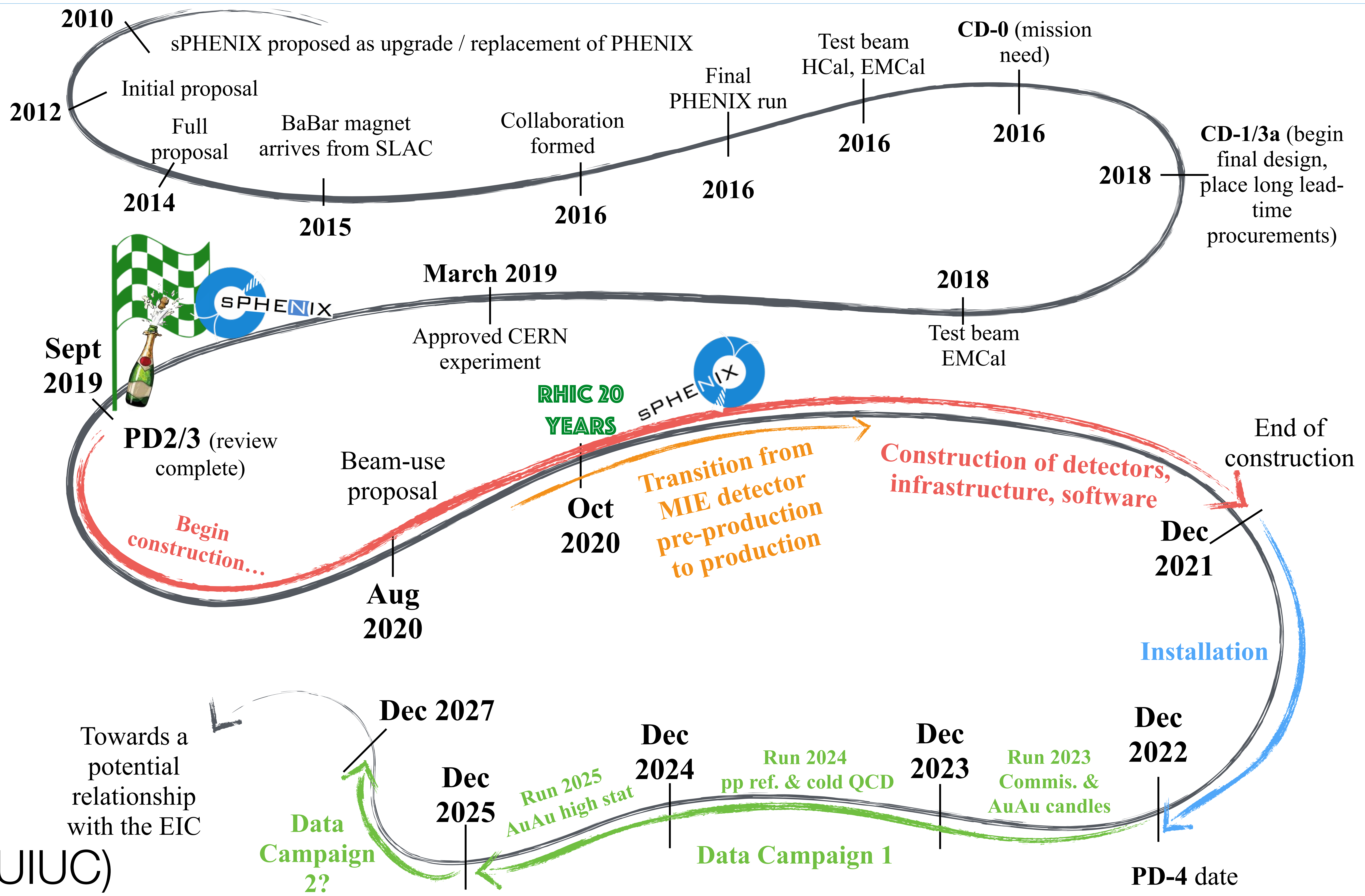
sPHENIX as a path to EIC? A number of possible answers.

- Physics connections – e.g., measurements in spin polarized pp and pA, can seed interactions with theory community prior to EIC; validation of saturation picture of initial state in AA in EIC can inform RHIC analyses
- Equipment and infrastructure – e.g., BaBar solenoid, flux return, carriage, cryogenic connection to RHIC, gas mixing and handling facilities, electronics (e.g., ATLAS FELIX), select detectors
- Data acquisition – streaming readout infrastructure capable of handling EIC needs
- Software – battle-tested framework, simulations with full GEANT and highly performant track reconstruction (based on ATLAS ACTS code), increasing number of EIC specific detectors, KFParticle for state-of-the-art topological decay reconstruction, sophisticated jet structure analysis, b/c-jet tagging
- Collaboration – many sPHENIX institutions identify EIC as key reason for joining

An EIC detector project will be more complex than sPHENIX

- EIC detector: many more sub-detectors than sPHENIX (x3?), more hermetic, more tightly integrated with accelerator
- In comparison, sPHENIX has had it easy! Still …
  - PHENIX “removal and repurposing”: summer 2016 to summer 2019 (with interruptions): three years
  - BaBar solenoid acceptance: early 2015 to early 2018: three years
  - cryogenic hookup to RHIC: three years of design, procurement, installation
  - beam tests in support of directed R&D: three years
  - optimization of silicon pixel and silicon strip detector configuration: summer 2018 to summer 2019: one year

sPHENIX: a short history & plan



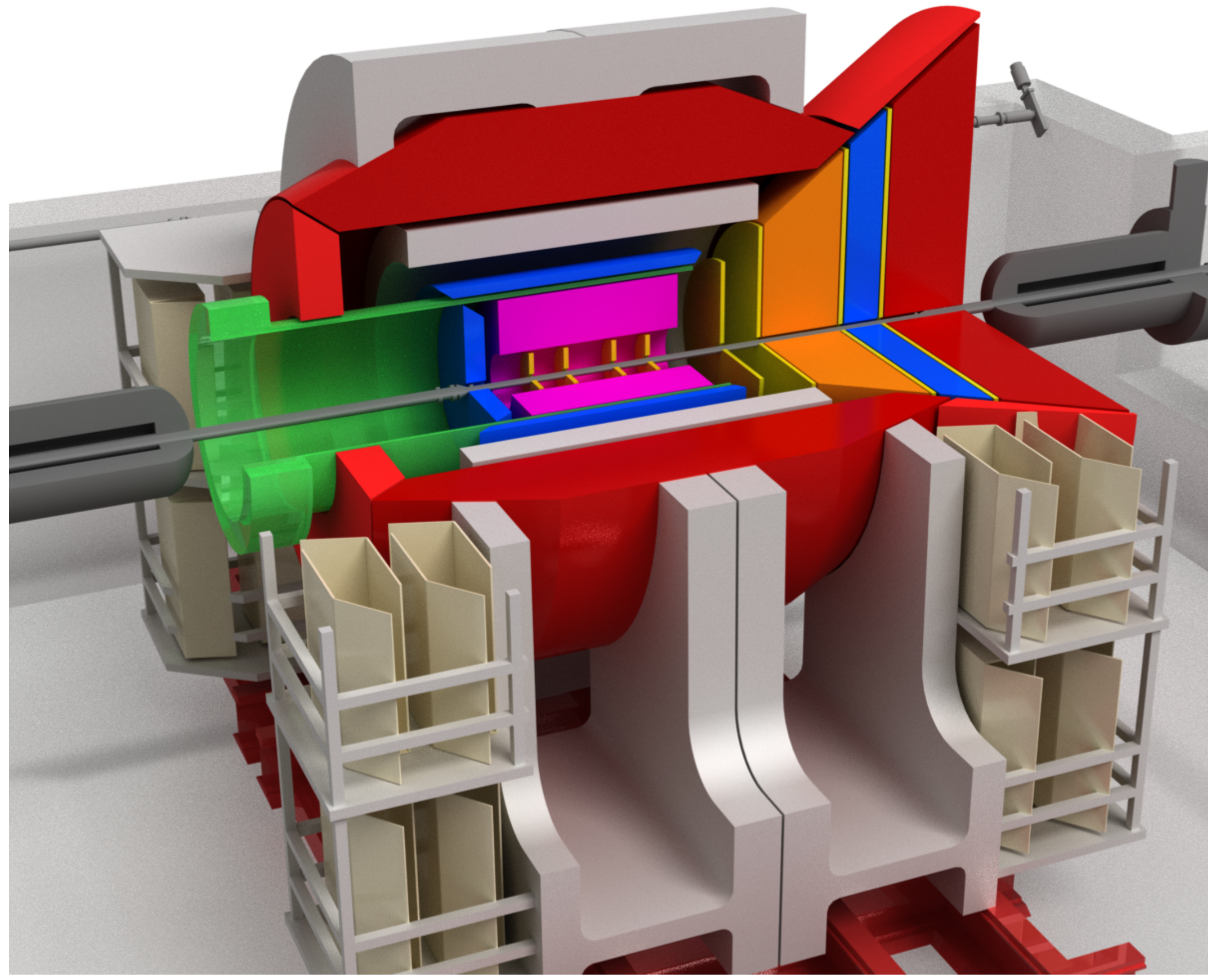
C. Riedl (UIUC)

Have there been studies?

sPHENIX

Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid

arXiv:1402.1209v1 [nucl-ex] 5 Feb 2014



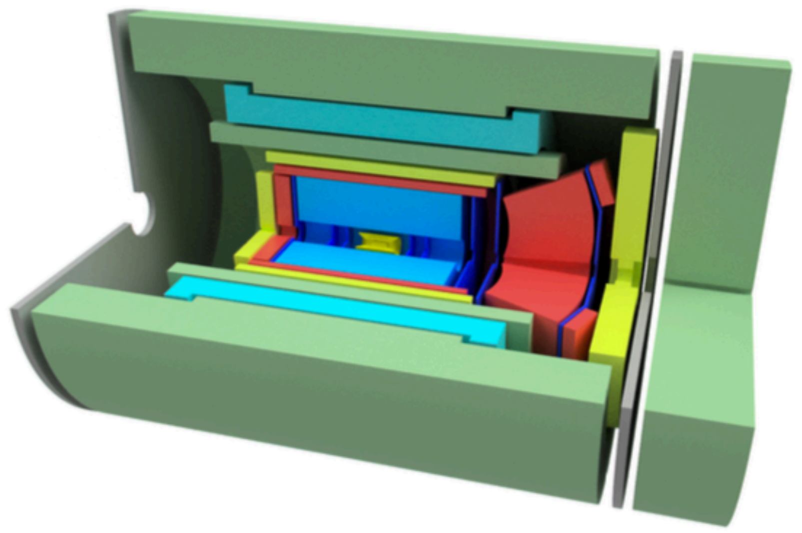
The PHENIX Collaboration
February 3, 2014

2014

sPHENIX-note sPH-cQCD-2018-001

An EIC Detector Built Around The sPHENIX Solenoid

A Detector Design Study



Christine Aidala, Alexander Bazilevsky, Giorgian Borca-Tasciuc, Nils Feege, Enrique Gamez, Yuji Goto, Xiaochun He, Jin Huang, Athira K V, John Lajoie, Gregory Matousek, Kara Mattioli, Pawel Nadel-Turonski, Cynthia Nunez, Joseph Osborn, Carlos Perez, Ralf Seidl, Desmond Shangase, Paul Stankus, Xu Sun, Jinlong Zhang

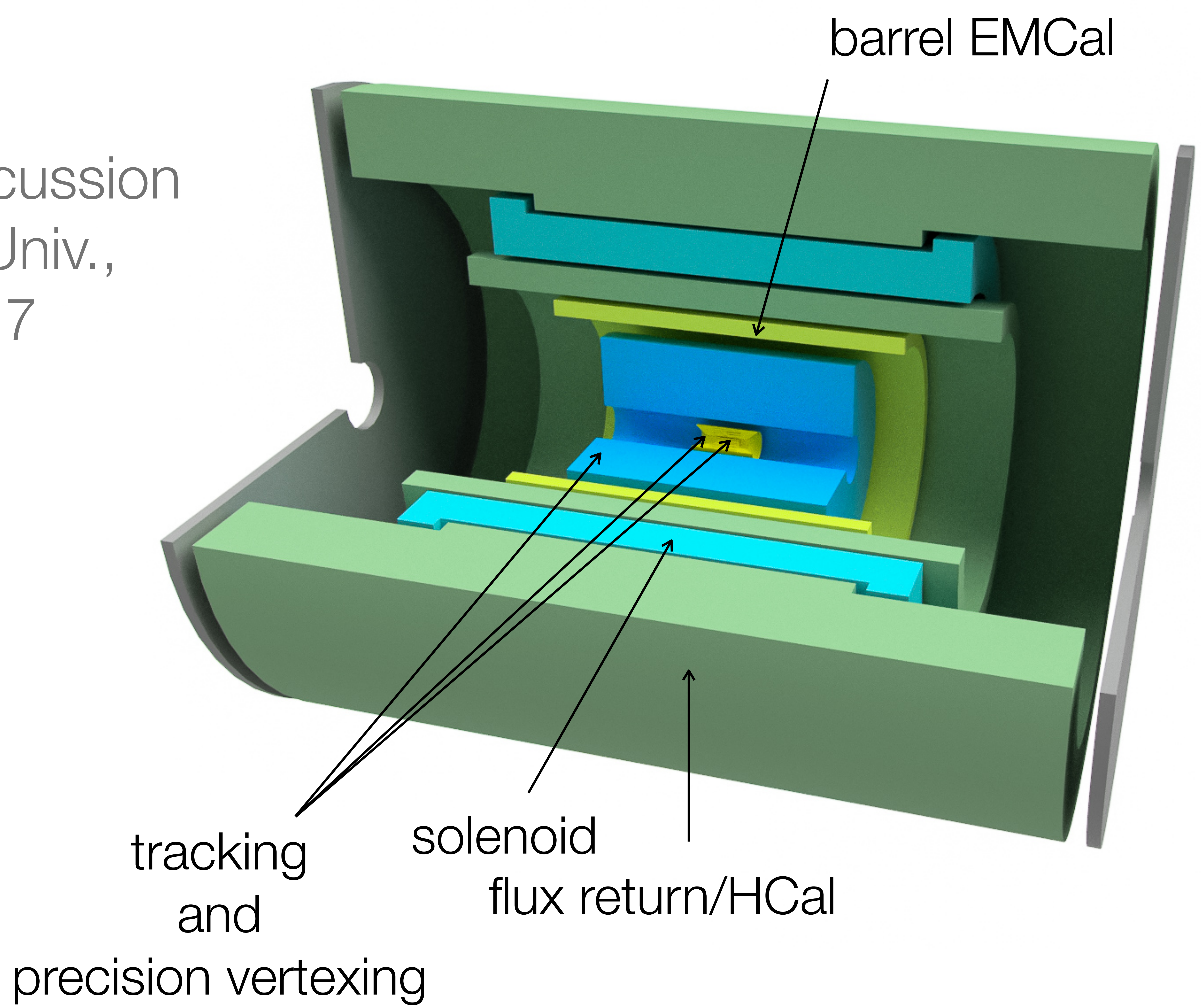
For the EIC Detector Study Group and the sPHENIX Collaboration

October 2018

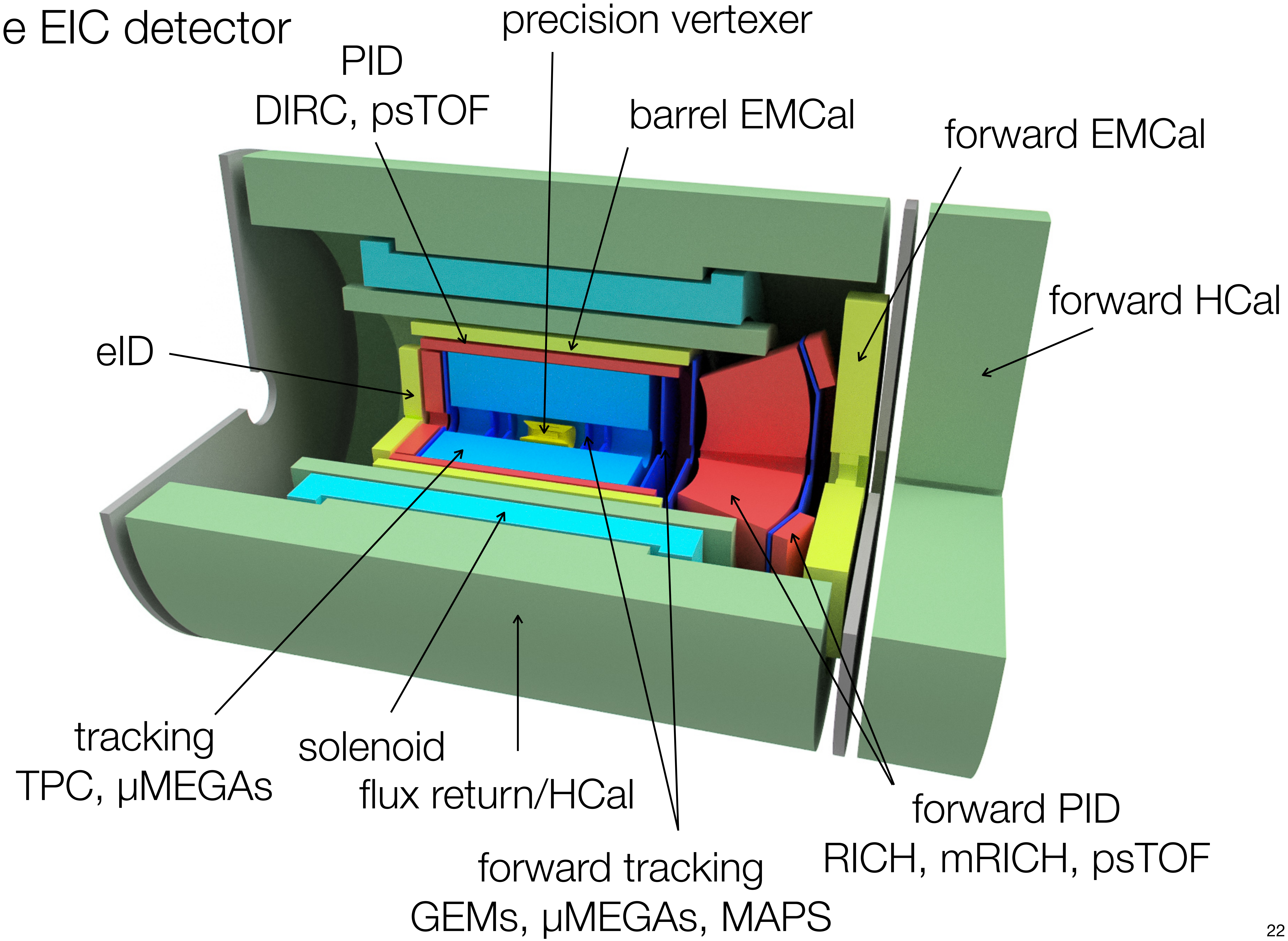
2018

sPHENIX detector

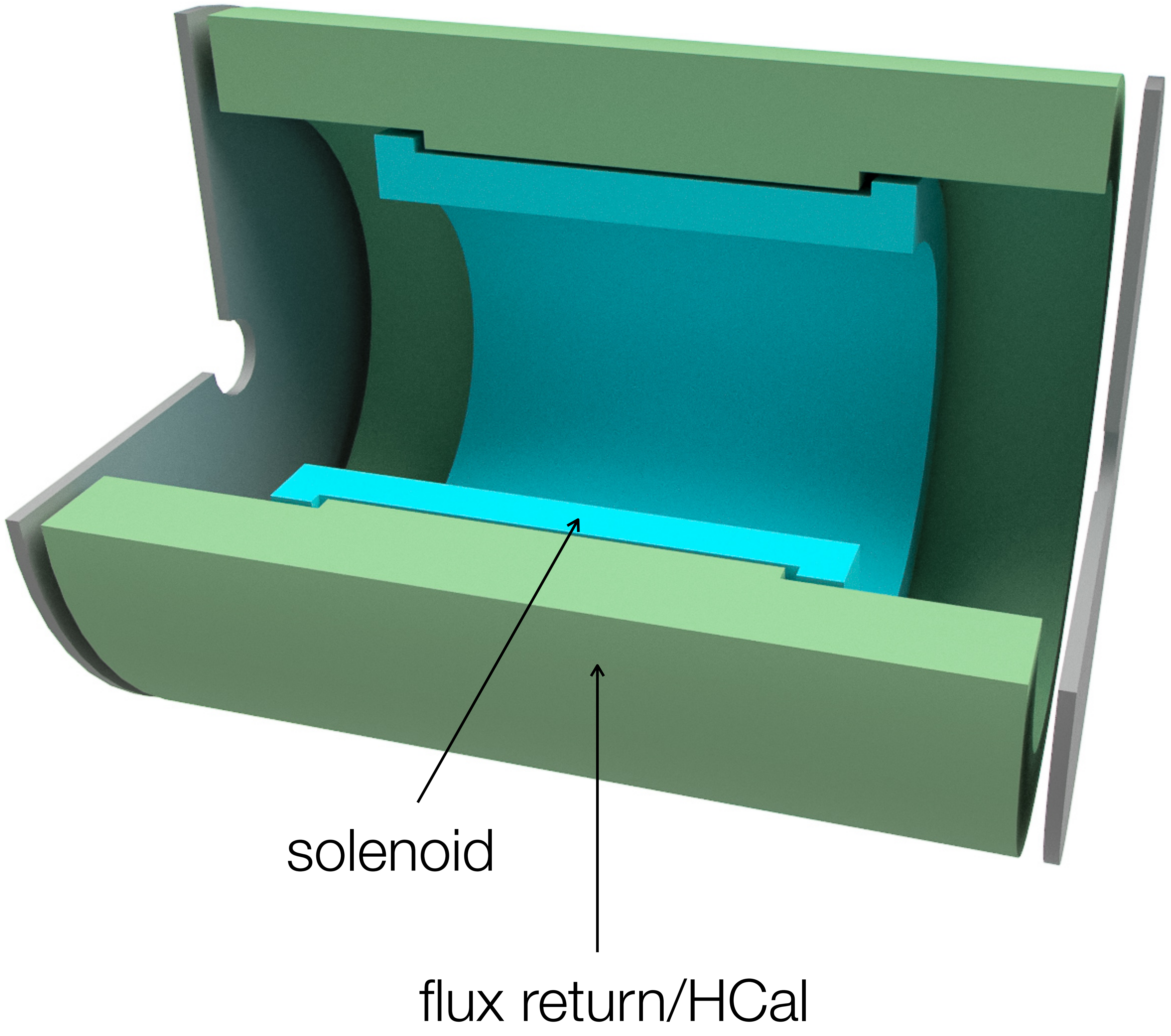
EICUG Detector Discussion Meeting, Temple Univ., November 2017



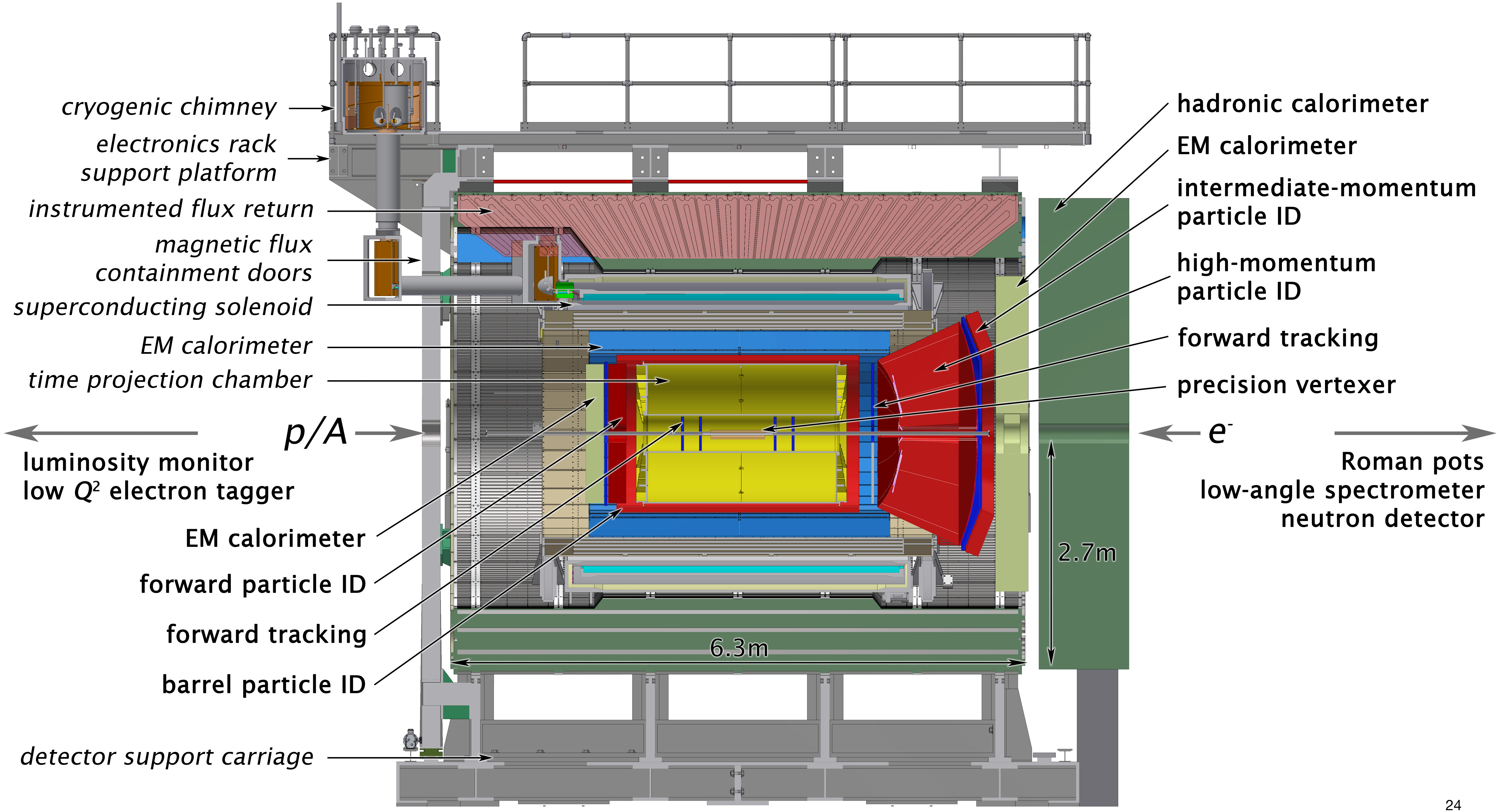
Evolved to a possible EIC detector



in extremis

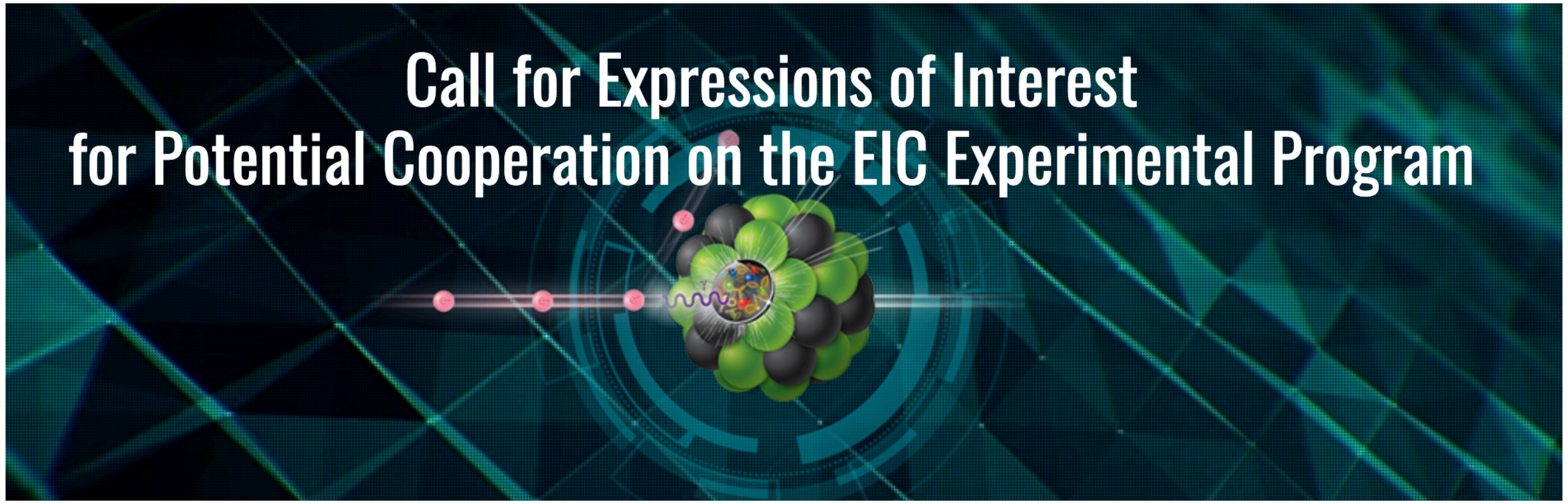


cf. later presentation by Xin Dong on silicon tracker


cryogenic chimney
electronics rack support platform
instrumented flux return
magnetic flux containment doors
superconducting solenoid
EM calorimeter
time projection chamber
p/A
luminosity monitor
low Q^2 electron tagger
EM calorimeter
forward particle ID
forward tracking
barrel particle ID
detector support carriage
hadronic calorimeter
EM calorimeter
intermediate-momentum particle ID
high-momentum particle ID
forward tracking
precision vertexer
e^-
Roman pots
low-angle spectrometer
neutron detector
2.7m
6.3m

ECCE

https://indico.bnl.gov/event/8552/contributions/43193/



Focus: selectively repurpose equipment and infrastructure at EIC IP8 to realize a fully capable EIC detector ready to deliver science when the accelerator delivers collisions

AANL/Armenia, Academia Sinica/Taiwan, BGU/Israel, BNL, CU Boulder, CUA, Charles U./Prague, Columbia, FIU, GWU, GSU, IJCLab-Orsay/France, ISU, JLab, Kentucky, LANL, LLNL, Lehigh, MIT, National Cheng Kung University/Taiwan, National Central University/Taiwan, National Taiwan University/Taiwan, National Tsing Hua University/Taiwan, ODU, Ohio University, ORNL, Rice, Rutgers, SBU, TAU/Israel, UConn, UIUC, UNH, UVA, Vanderbilt, Wayne State, and WI/Israel.

Summary

- Heavy flavor is a major component of the sPHENIX science program – not just in "hot" QCD but also in pp and pA
- Excellent magnet – still in its youth! – and detectors, many based on LHC developments provide capabilities for array of HF observables
- High luminosity from RHIC is matched by the high rate sPHENIX DAQ
- Heavy flavor simulations, analyses, and software can be used by the community
- sPHENIX and its extensive infrastructure potentially provide an advanced starting point for realizing an EIC detector