Heavy Flavor & Quarkonia Measurements at sPHENIX

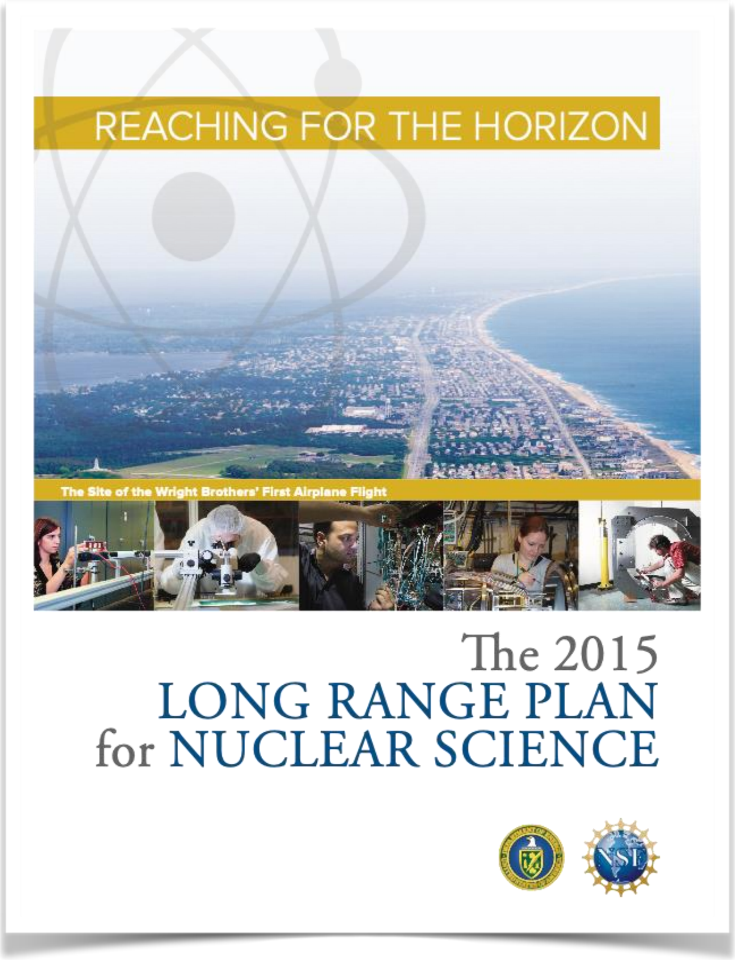
2020 RHIC/AGS Annual Users Meeting

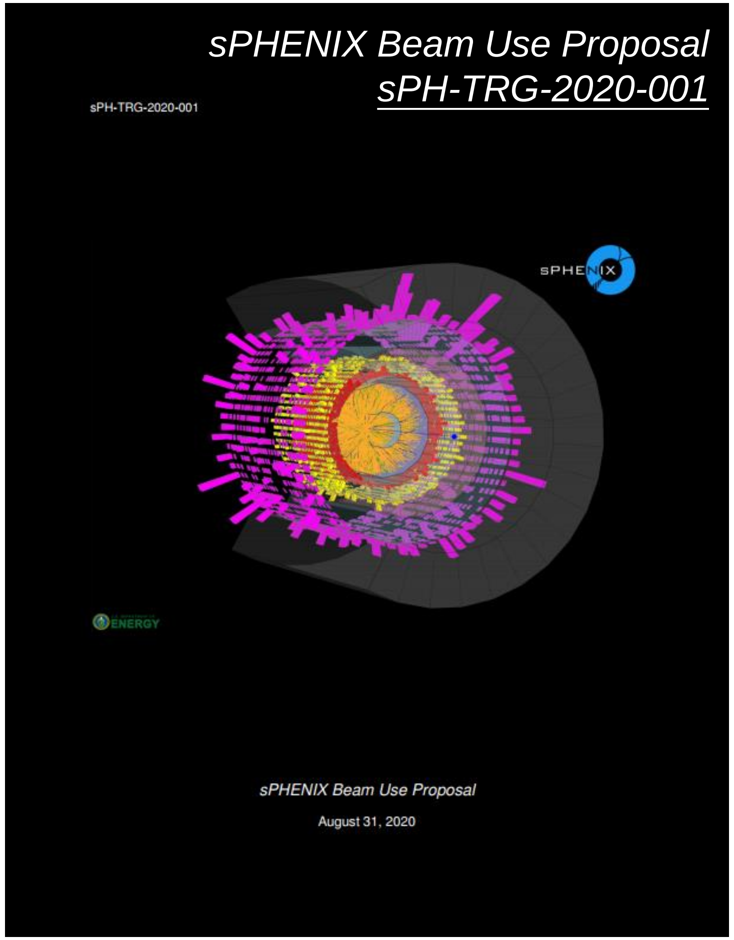
October 22-23, 2020

Hideki Okawa (Fudan University)

for sPHENIX Collaboration

sPHENIX Mission

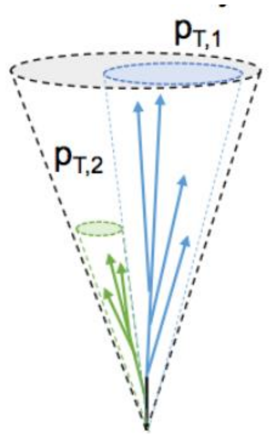




- A state-of-the-art jet detector; the first new detector at RHIC in >20 years.
- Completing the scientific mission of RHIC, as prioritized in DOE/NSF NSAC 2015 Nuclear Physics Long Range Plan.
- Complementarity in kinematics and medium property to LHC, also confirmed by ECFA WG5 (Heavy Ion group).
- Submitted Beam Use Proposal (BUP) on Aug. 31, 2020.
- sPHENIX as the highest priority for Runs 2023-2025 (PAC Report, Sep. 2020)

Core Physics Program

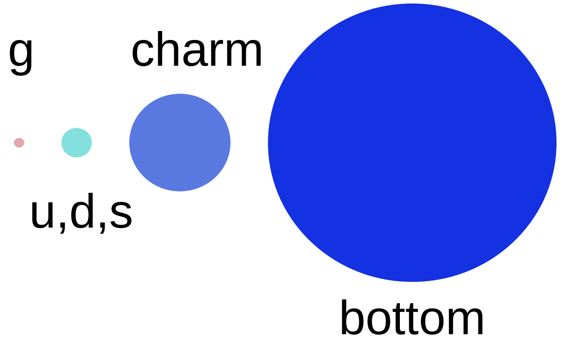
Jet Structure



Vary momentum & angular scale of probe

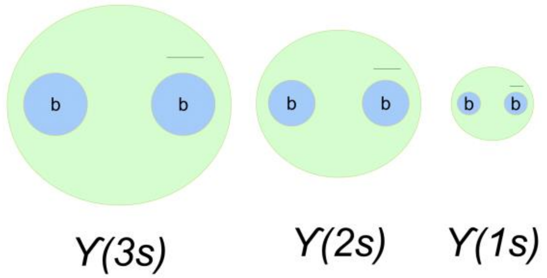
Talk by Christopher McGinn

Open Heavy Flavors



Vary mass & momentum of probe

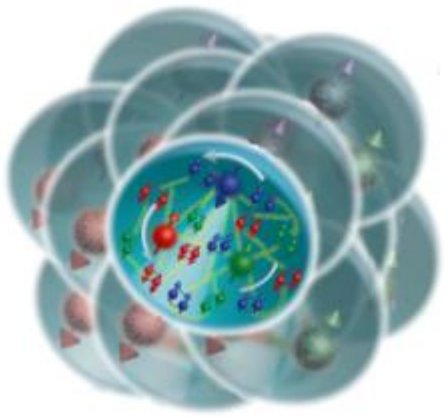
Upsilon Spetroscopy



Vary size of probe

This Talk

Cold QCD



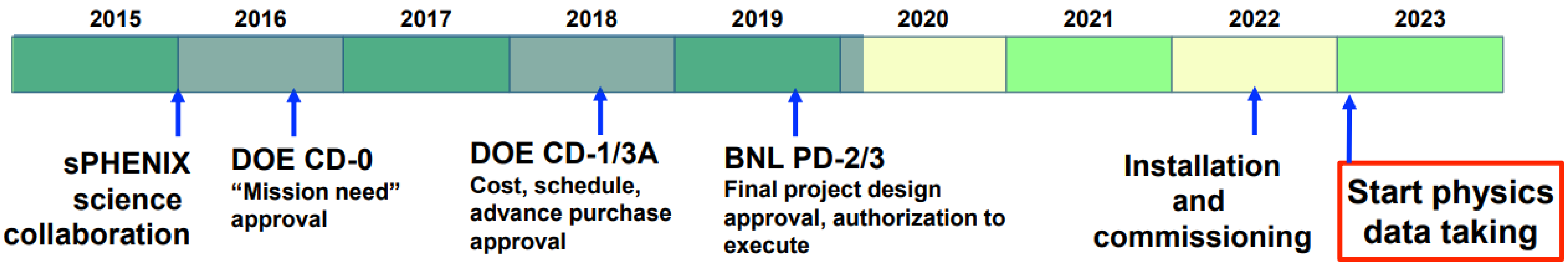
Vary temperature of QCD matter

Talk by Desmond Shangase

Plenary talk by Caroline Riedl

4 pillar physics topics, making use of very high statistics of jets & open/hidden heavy flavors over unprecedented kinematic range

Schedule



NEW!

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}
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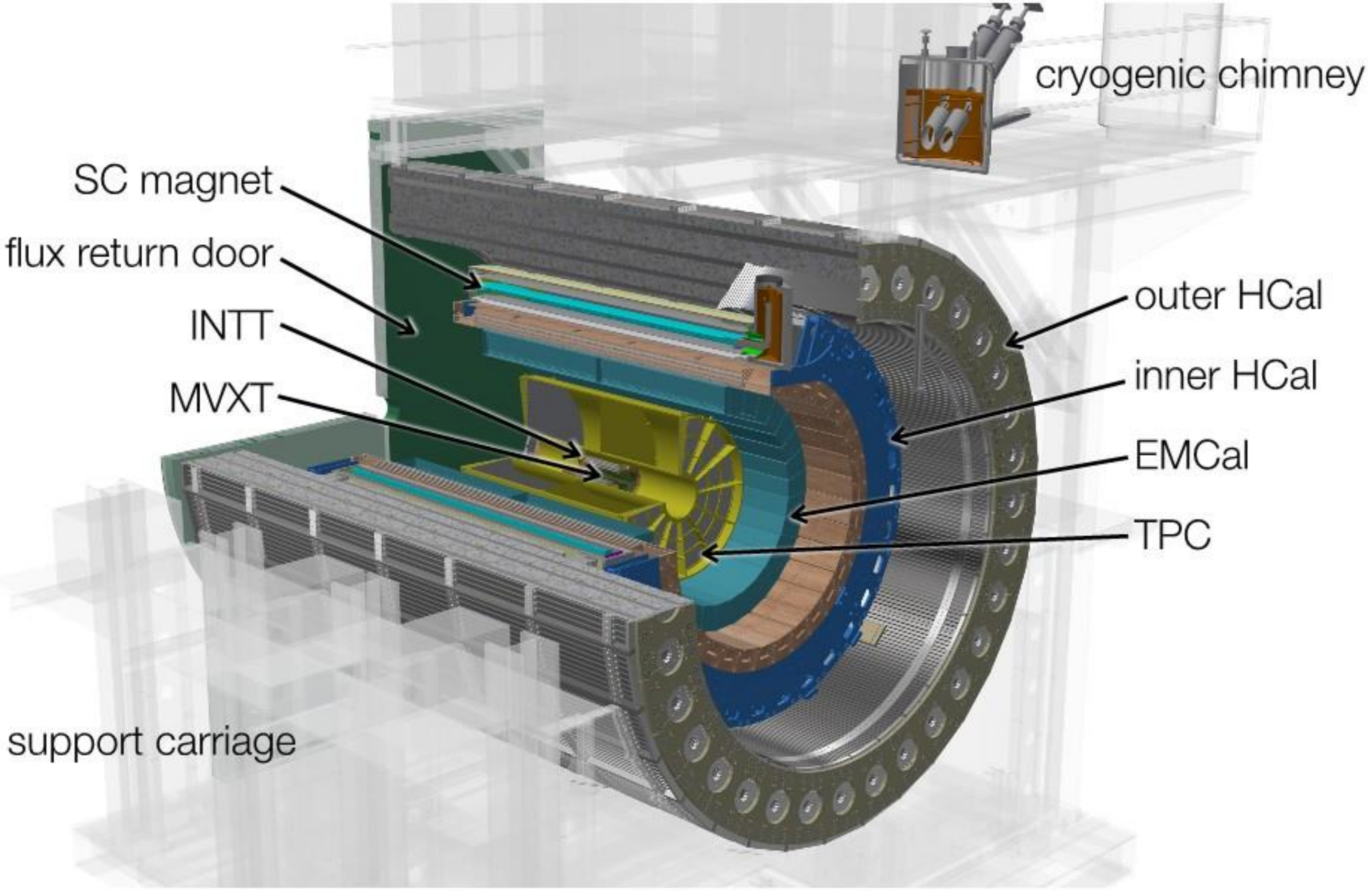
- Scientific mission of sPHENIX can be achieved with 3 years of running.
- Consistent with the currently envisioned EIC schedule.
- If opportunity arises, additional runs can fully utilize the potential of the detector.

Run plan updated in BUP 2020

sPHENIX Detector

- High data rates: 15 kHz for all subdetectors
- 1.4 T Solenoid from BaBar
- Hermetic coverage: $|\eta|<1.1$
- Trigger capability also for pp with streaming readout
- High resolution vertexing with MVTX
- Large acceptance hadronic calorimetry for jets
  → brings first b-jet tagging at RHIC w/ MVTX!!



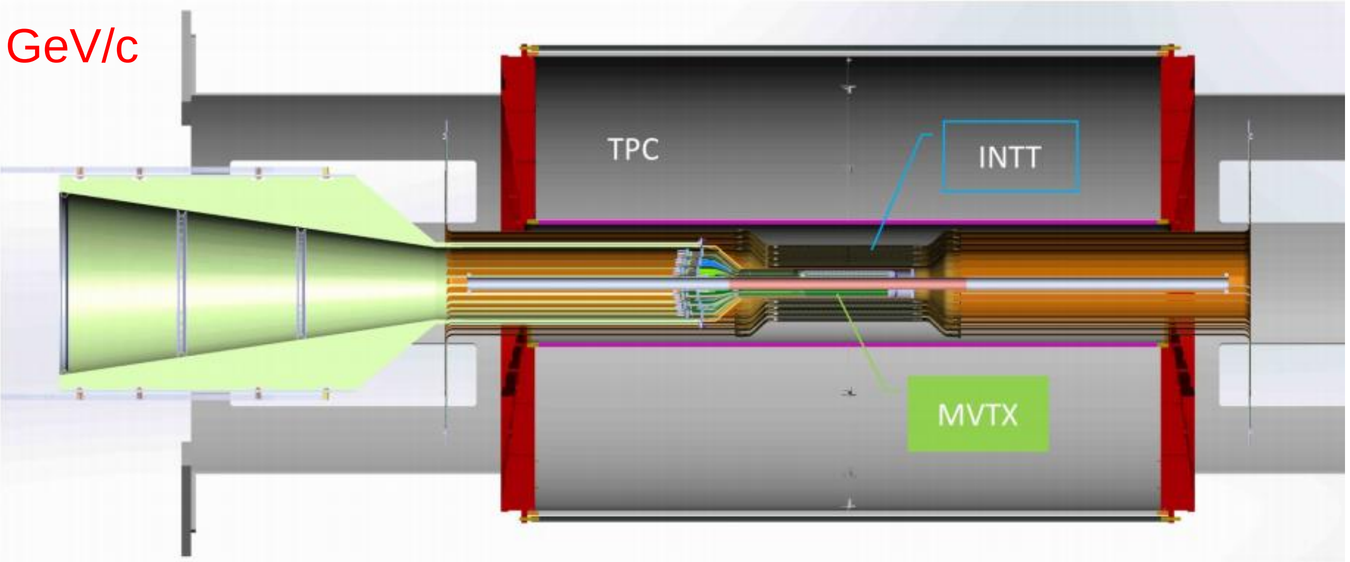
sPHENIX Tracking Detectors

<u>Inner tracker:</u>

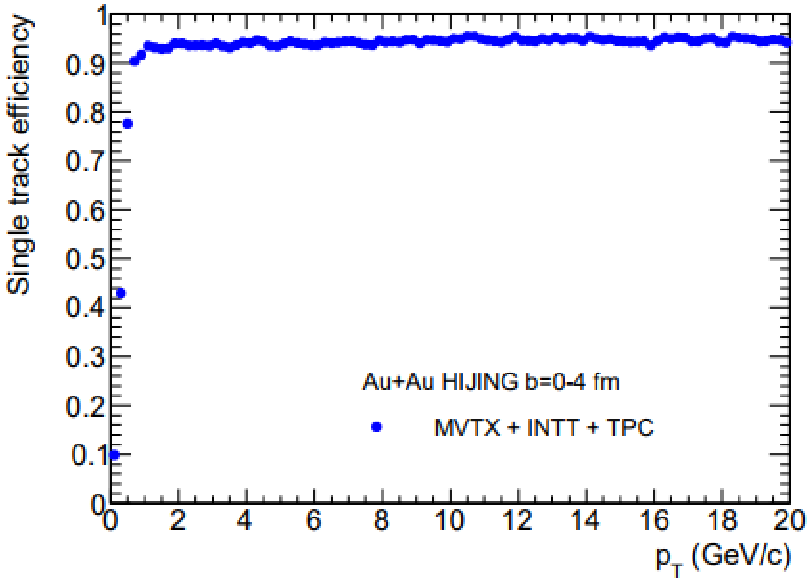
- **MVTX**: Monolithic Active Pixel Sensors (3 layers)
  - Procurement copies of ALICE ITS IB staves integrated into sPHENIX
  - Precision vertexing
- **INTT**: strip pattern recognition, timing silicon sensors (2 layers)
- DCA(rϕ or z) resolution < 50μm for p_T>1 GeV/c

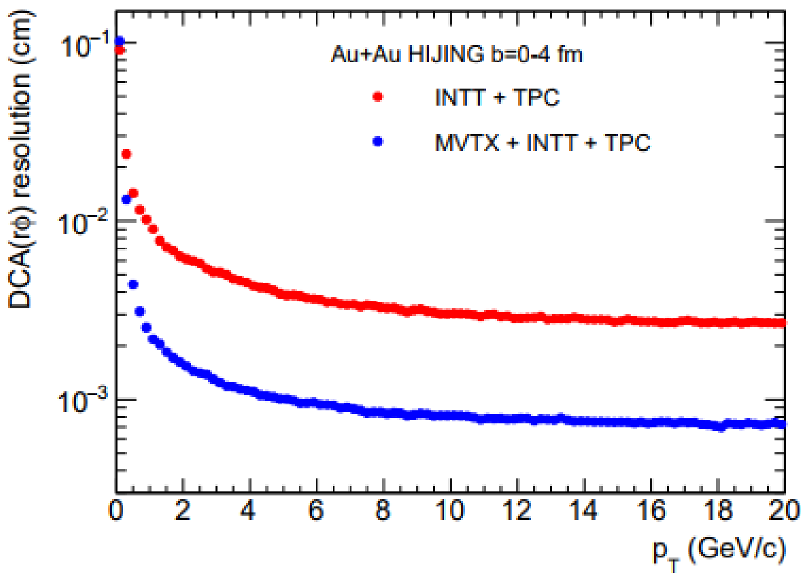
<u>Outer tracker:</u>

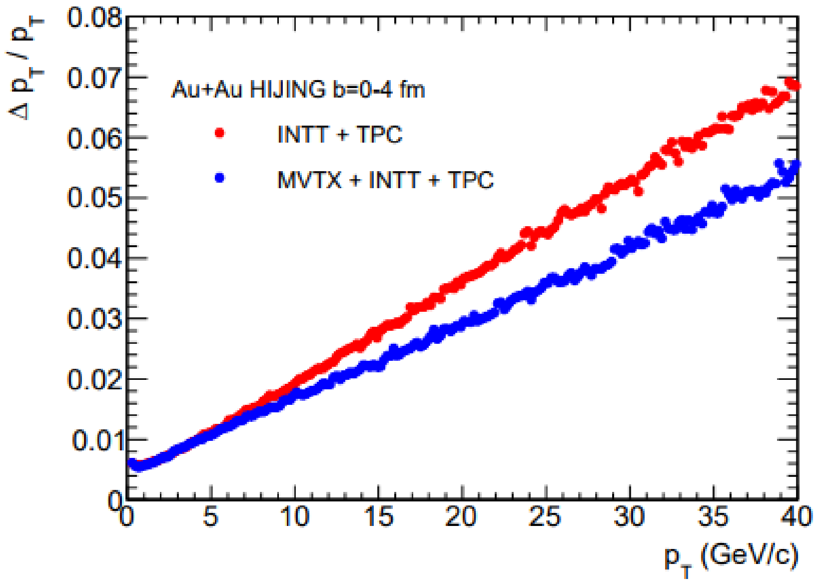
- **TPC**: 48 layers with gateless and continuous readout
  - Main tracking device; provide momentum measurement
- $\delta p/p$ < 2% for p_T<10 GeV/c



Impact of MVTX on Tracking

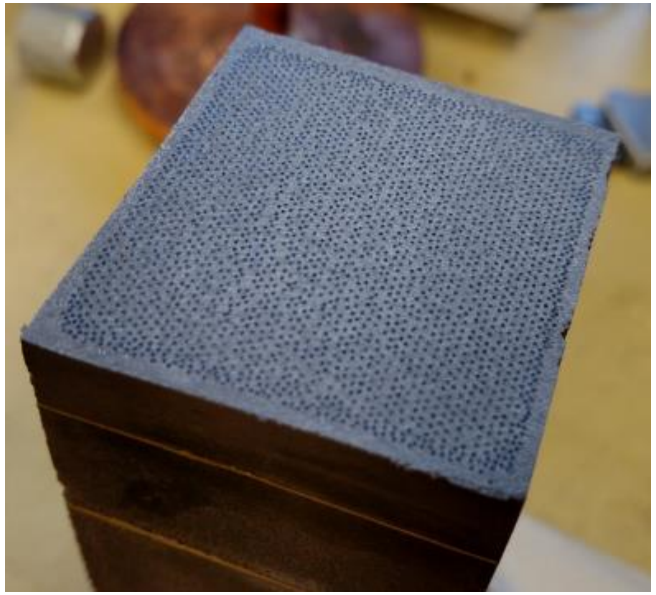


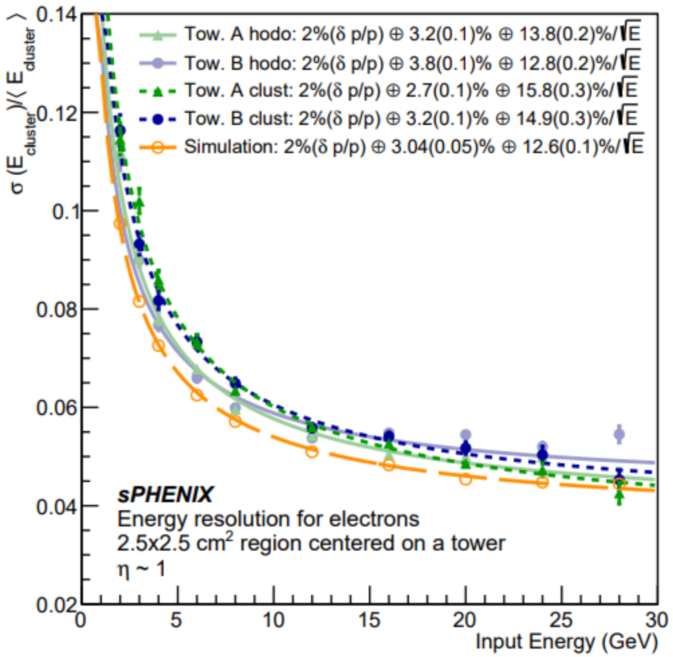


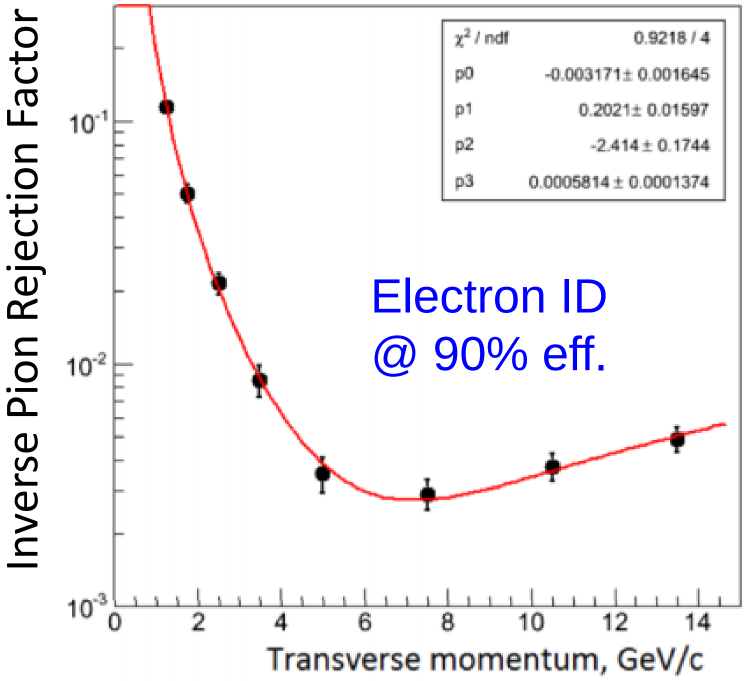


- Tracking efficiency above 90% at p_T>1 GeV/c. → promising to measure rare processes such as Υ(nS) production.
- DCA pointing resolutions in rϕ & z ~ 40μm at p_T=0.5-1 GeV/c. → crucial for open heavy-flavor programs.
- Momentum resolution < 2% for p_T < 10 GeV/c. → Important for Υ(nS) separation; δM < 125 MeV required.

sPHENIX EMCAL & Electron ID

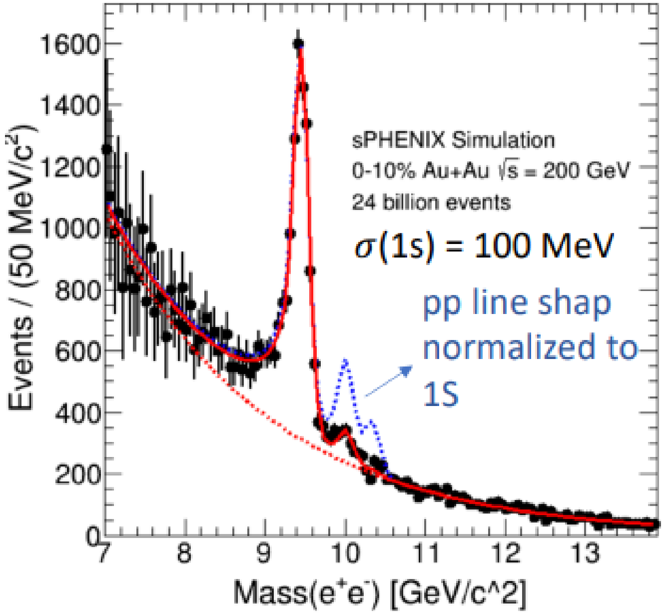


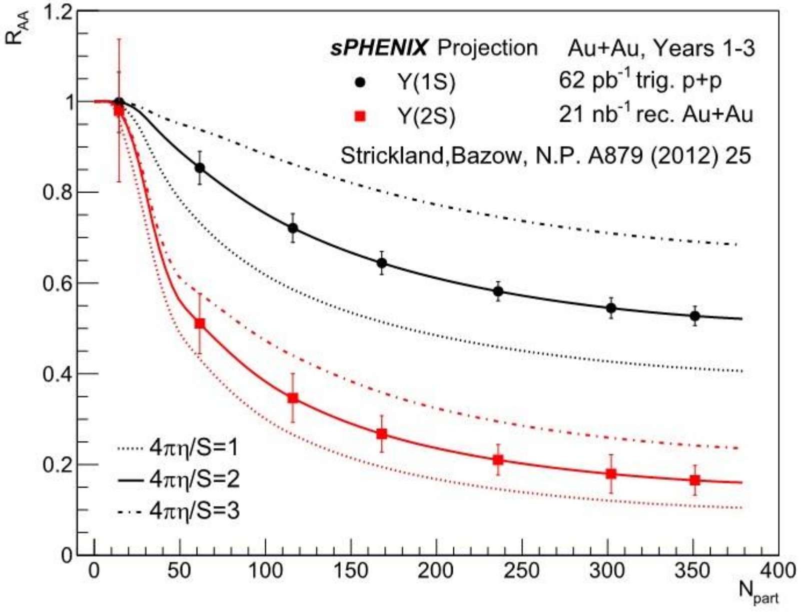


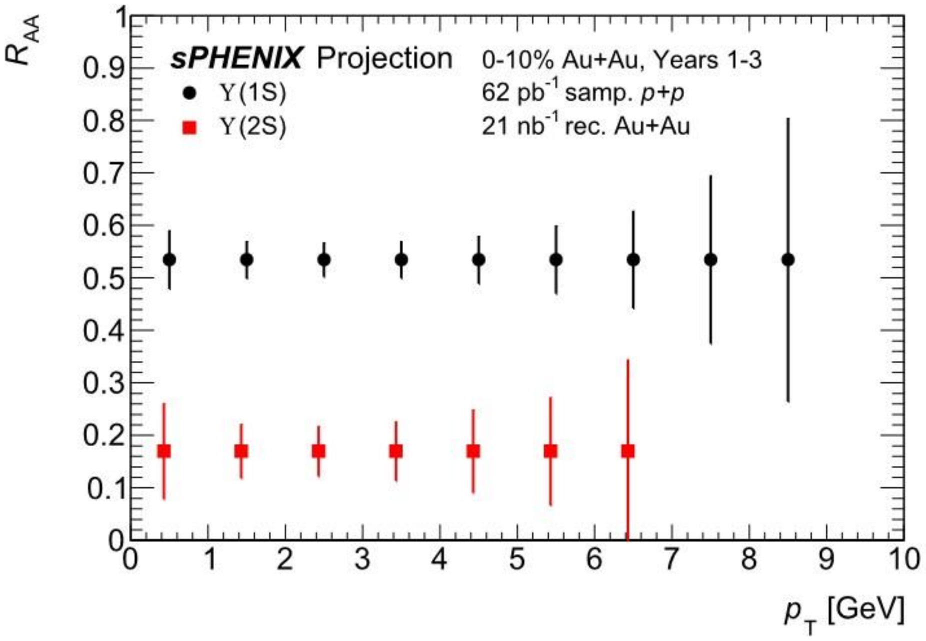


- Tungsten/scintillating-fiber SPACAL. Radiation length~7mm. Fits inside solenoid.
- Tower size Δη x Δϕ=0.025x0.025. Resolution ~ 16%/√E ⊕5%.
- Promising hadron (K/π/p) rejection factor with E/p requirement.

Upsilon R_{AA}

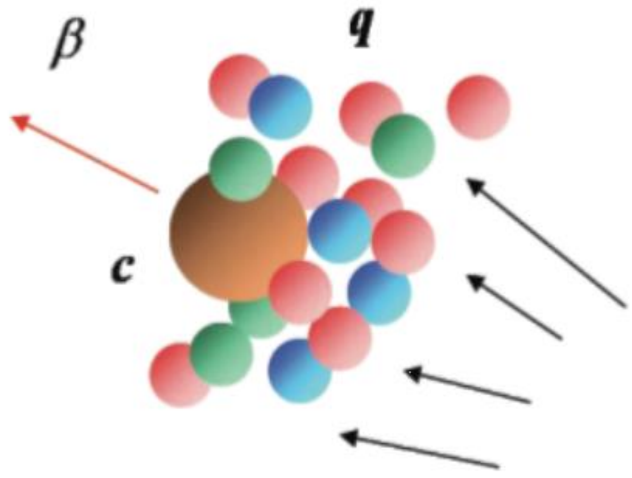


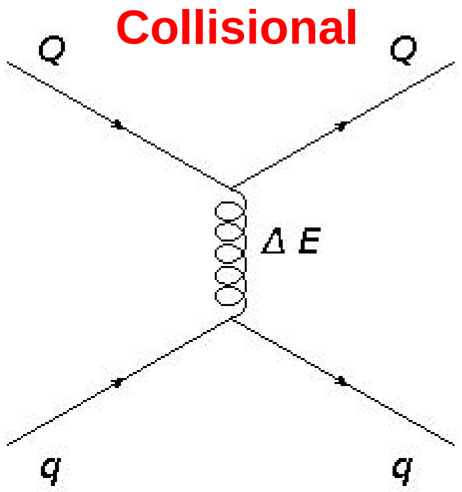


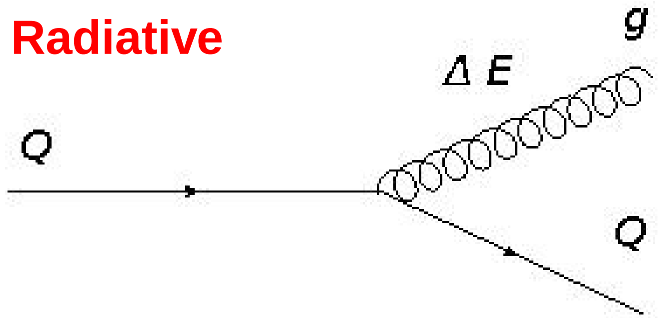


- sPHENIX can reconstruct Upsilons with excellent mass resolution.
- Measuring centrality & p_T dependence of R_{AA} is critical to compare with LHC.
- Measuring Υ(3S) modification will be challenging due to the large suppression. Feasibility checks ongoing for Υ(3S) modification.

QGP with Open Heavy-Flavor Quarks







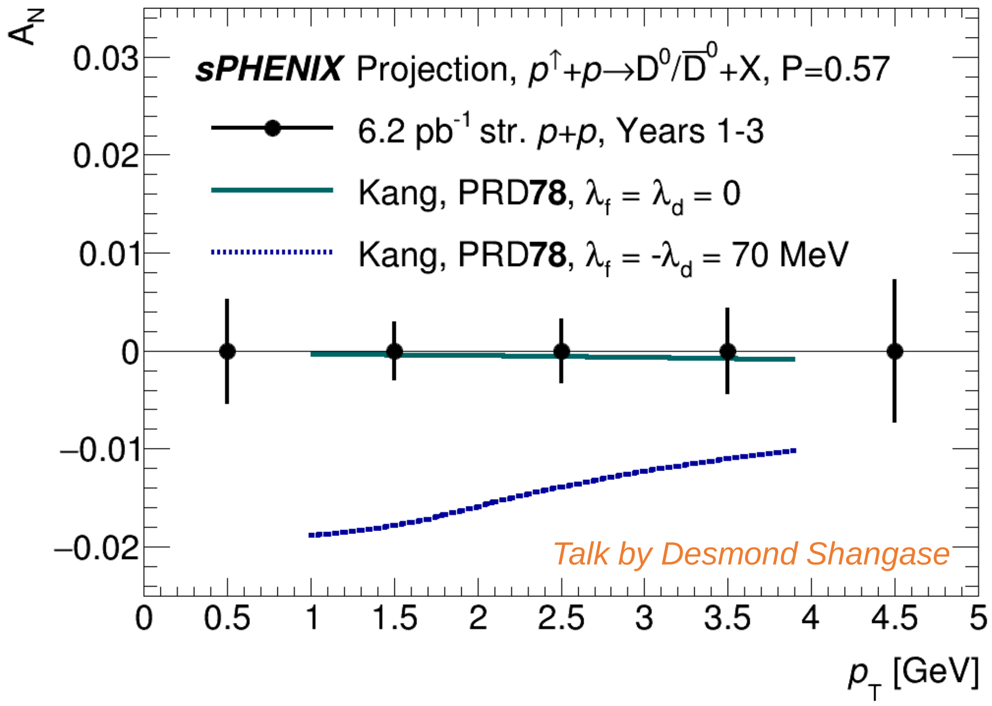
- Comprehensive coverage in p_T range:
  - **$p_T \lesssim m_b$:** diffusion of HQ (diffusion coeff. D_s)
  - **$m_b \lesssim p_T \lesssim$ 10 GeV:** differential sensitivity to collisional energy loss, good probe for hadronization.
  - **$p_T \gtrsim$10 GeV:** transition from collisional to radiative energy loss.
- **sPHENIX brings precision measurements of b-quark sector to RHIC!**

Streaming Readout & pp Program

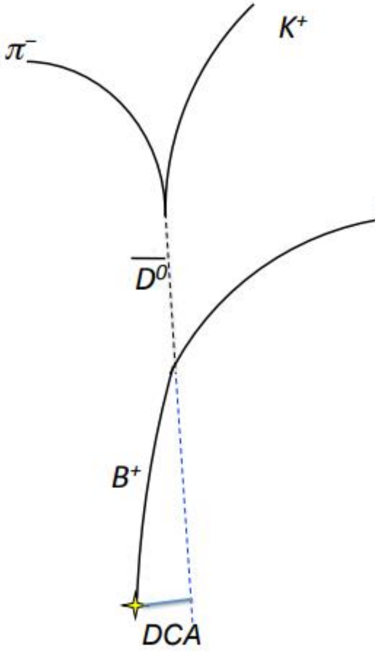
- **Streaming readout:** triggerless configuration recording 10% of collisions.
  → increases amount of Run-24 data by orders of magnitude
  - Commended by PAC 2020 for this effort.

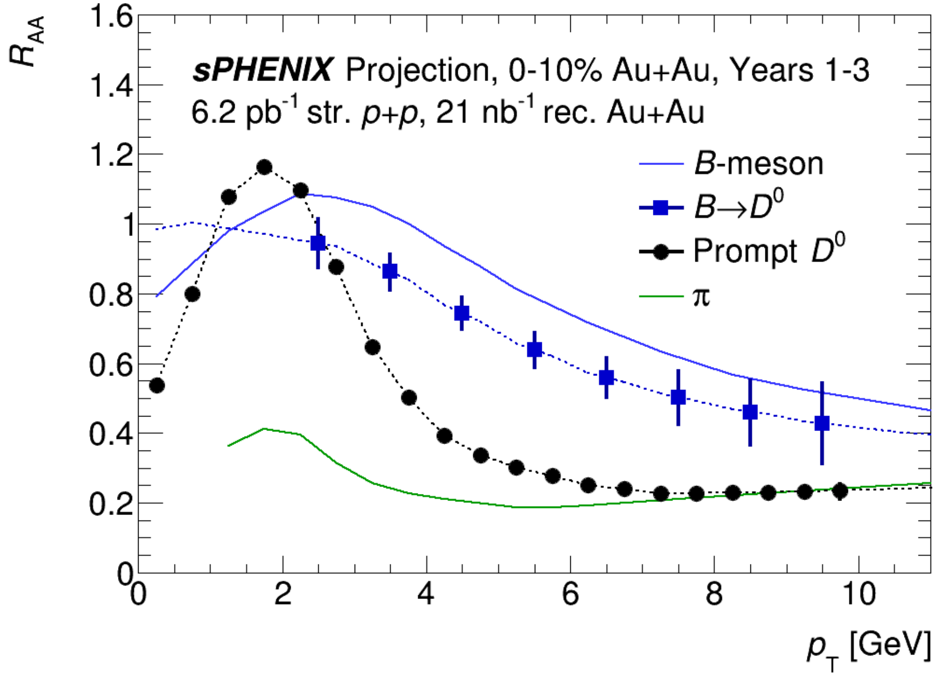
- Crucial for open heavy ion programs: i.e. **enables to measure HF meson R_{AA} instead of R_{CP} as well as other qualitatively novel measurements**

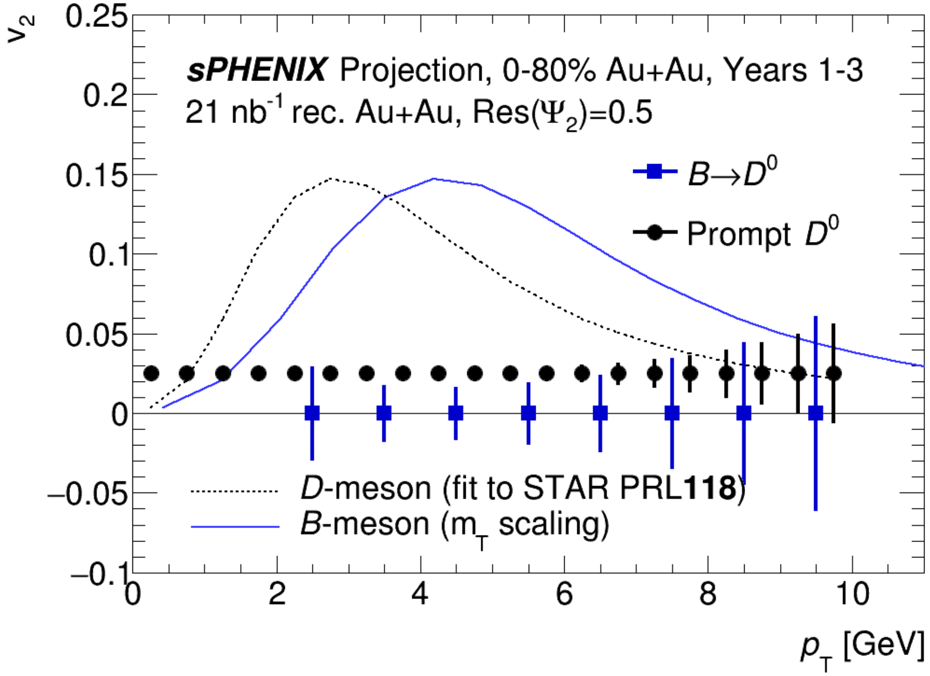
- Also **brings other exciting opportunities for spin-dependent QCD**; e.g. D^0 single spin asymmetry



B-meson Projections

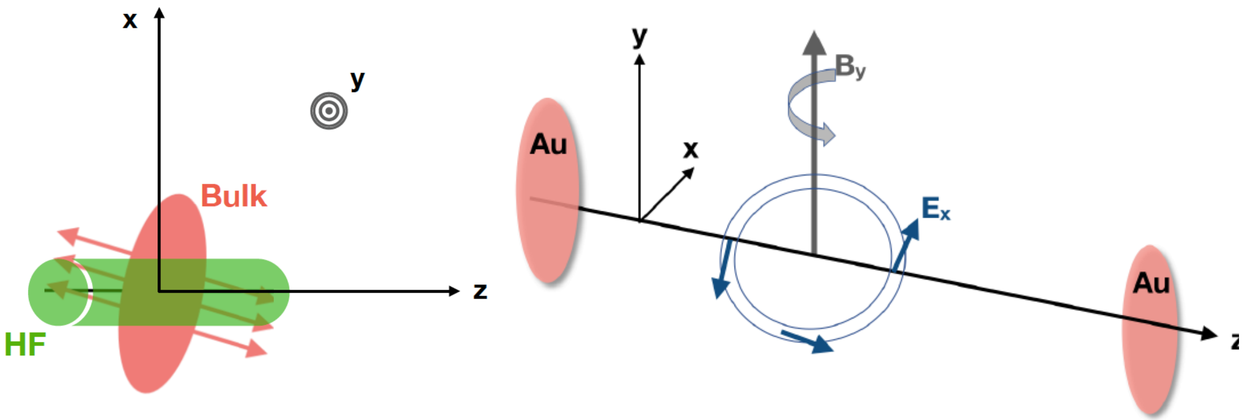


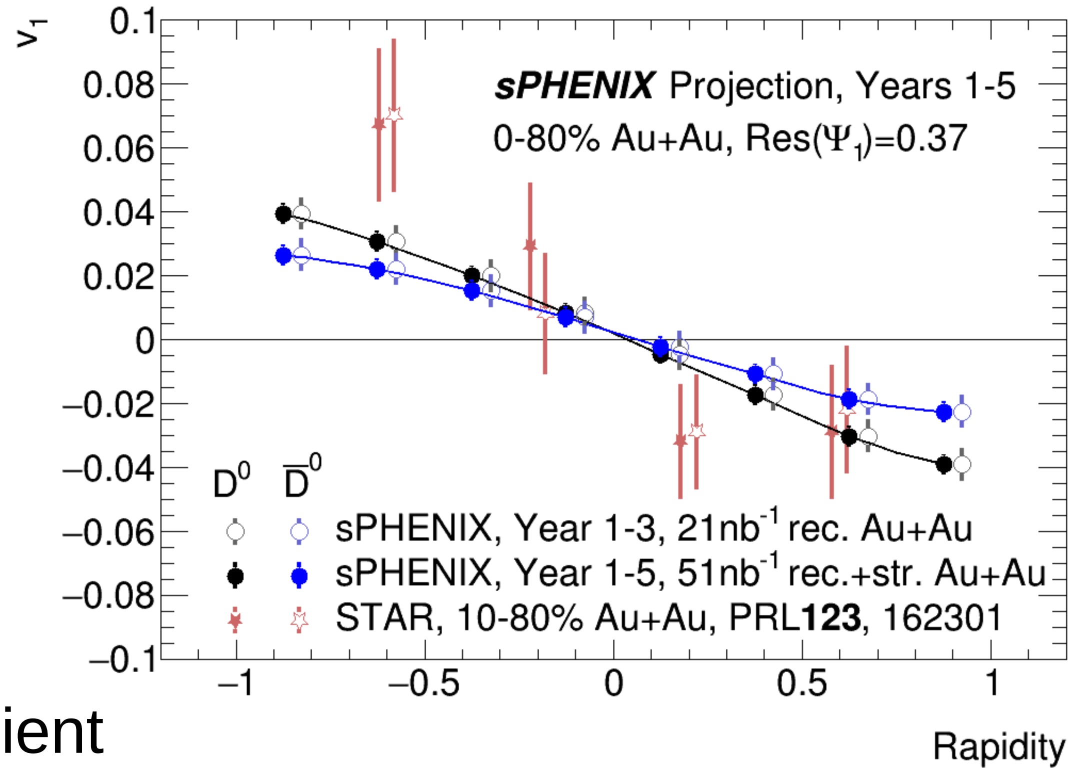




- B mesons can be studied through their decay daughters (i.e. non-prompt D^0).
- Non-prompt D^0 suppression → collisional energy loss
- Determine b-quark flow → clean access to diffusion at RHIC

D^0 v_1 measurement





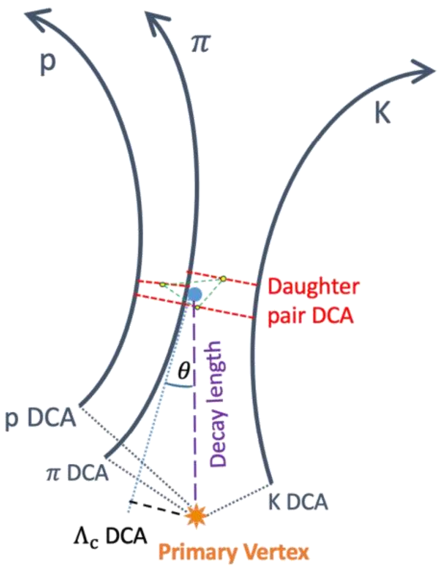
D^0 meson v_1 is sensitive to:

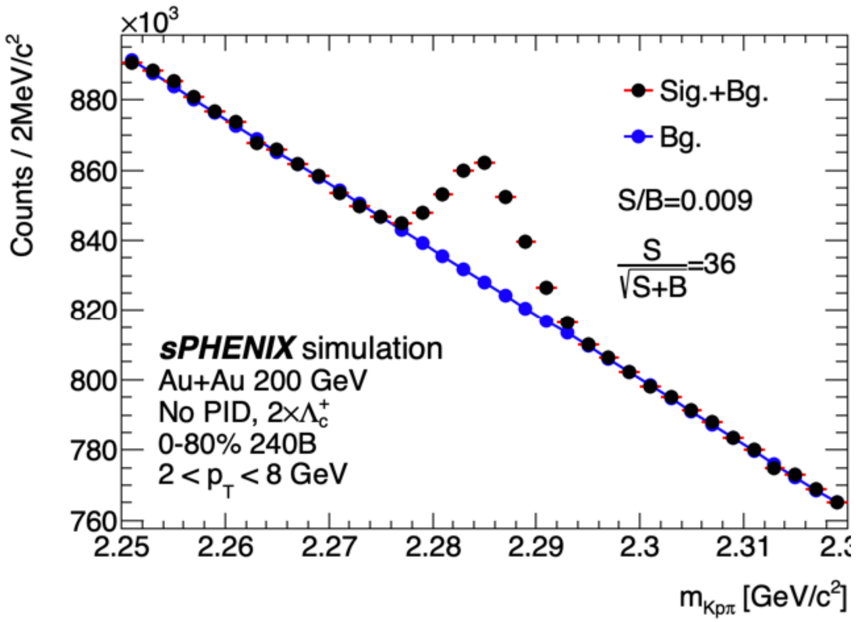
1. T-dependence of HQ diffusion coefficient
2. Geometrical tilt of QGP source
3. Initial magnetic field (from $D^0/\overline{D}^0$ v_1 difference)

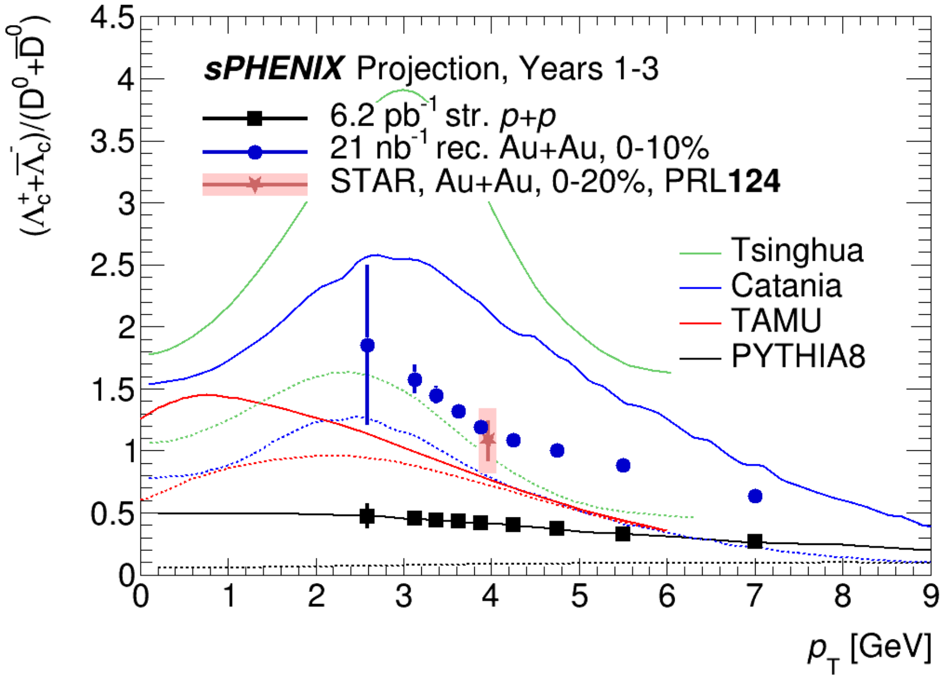
1st observation of D^0 v_1 by STAR

sPHENIX will provide high precision measurements

Λ_c Hadronization

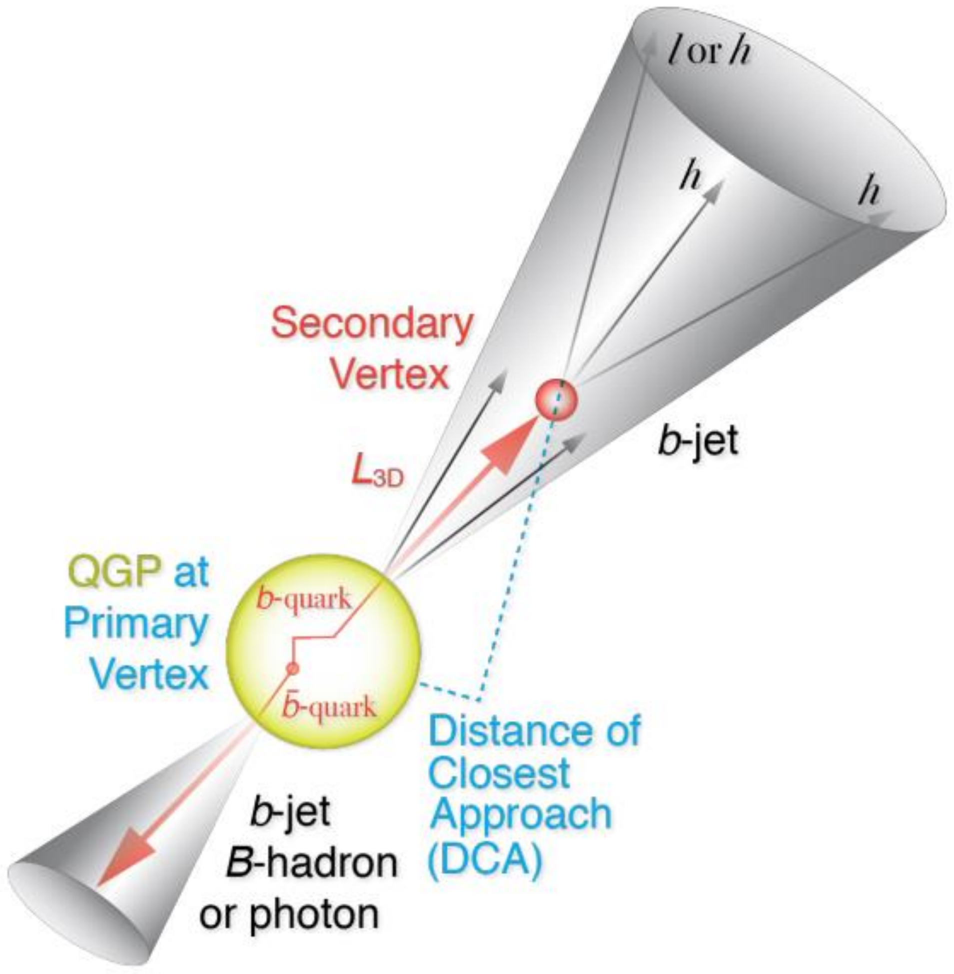






- Λ_C/D^0 significantly larger than the baseline Pythia calculation in pp, pA, AA. Important probe to understand the hadronization (coalescence model?).
- Charm baryons & charm-strange mesons give sizable contributions to the total charm xsec.
- sPHENIX will provide precision measurement at p_T~3-8 GeV.

b-jet Identification

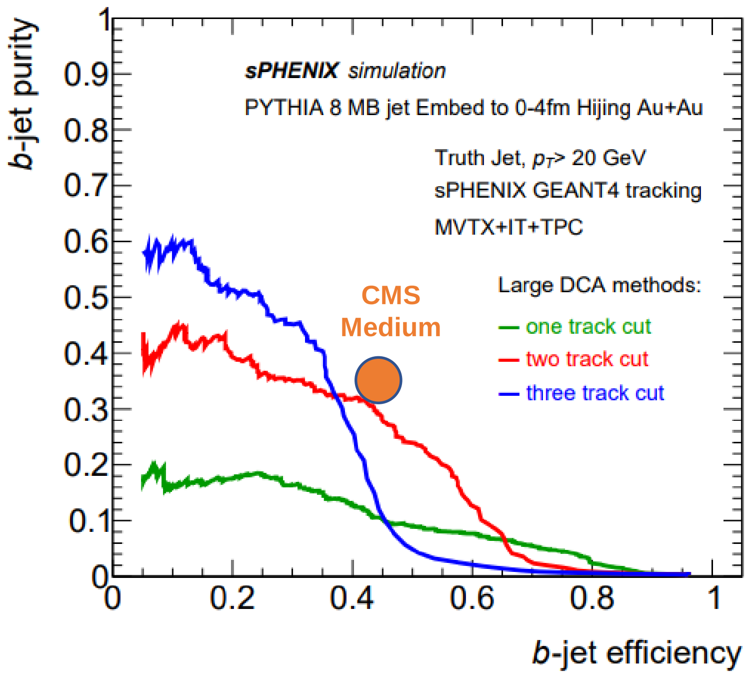


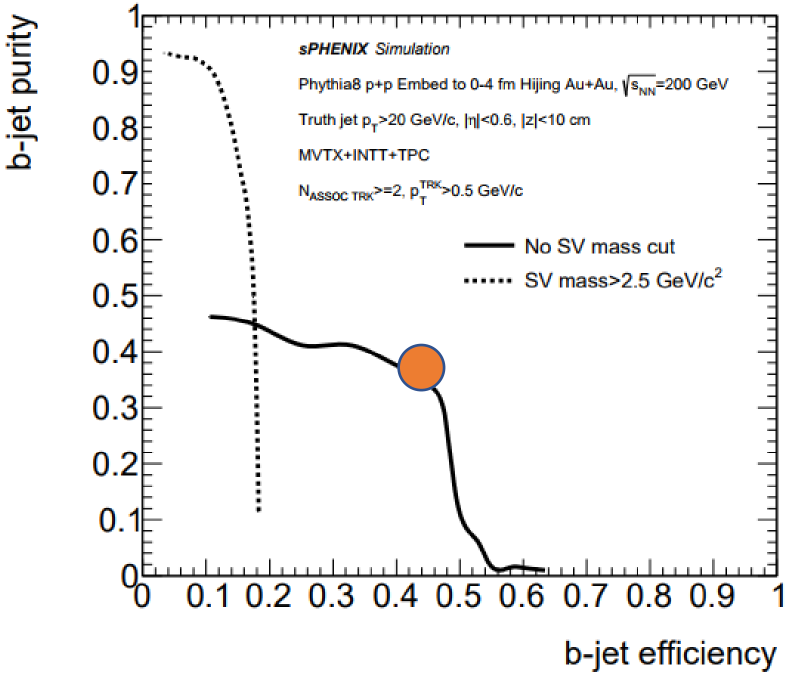
- The high-p_T probe.
- RHIC has an advantage over LHC for having much less b-jets from gluon splitting ($g \rightarrow b\bar{b}$).
- Heavy flavor jets have distinct signatures with:
  - Tracks with large DCA
  - Presence of secondary vertex
  - Presence of displaced lepton
- Taggers making use of the first two features are investigated so far.

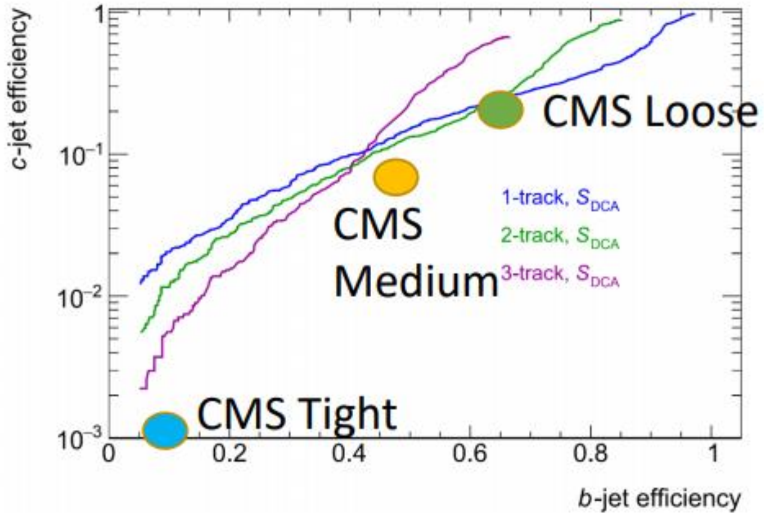
b-jet Identification

sPH-HF-2018-001 - MVTX Proposal

sPH-HF-2017-001



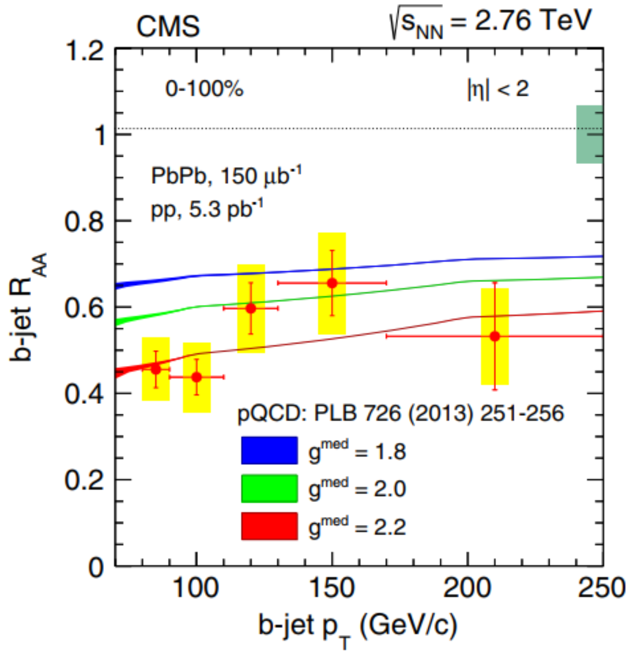




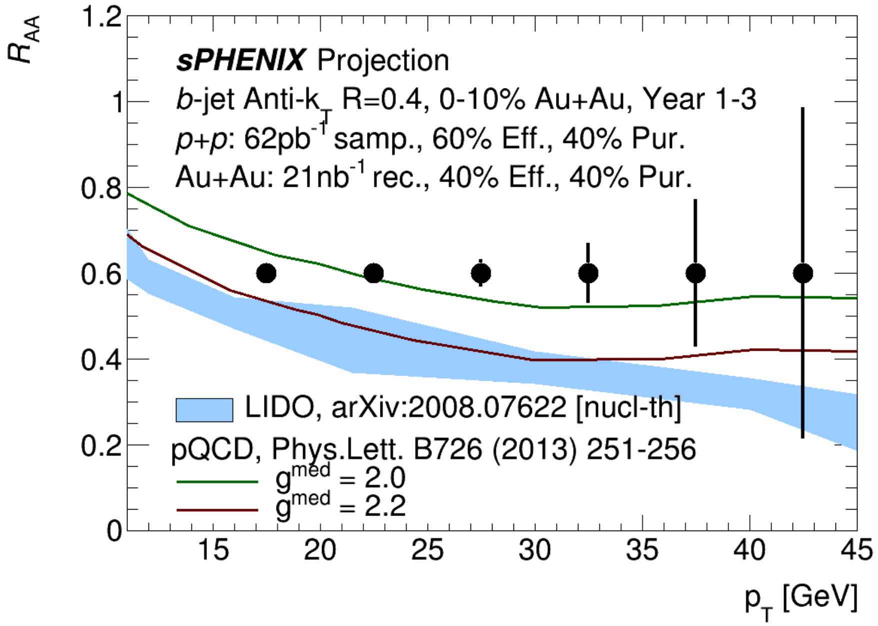
CMS working point, Phys. Rev. Lett. 113, 132301 (2014)

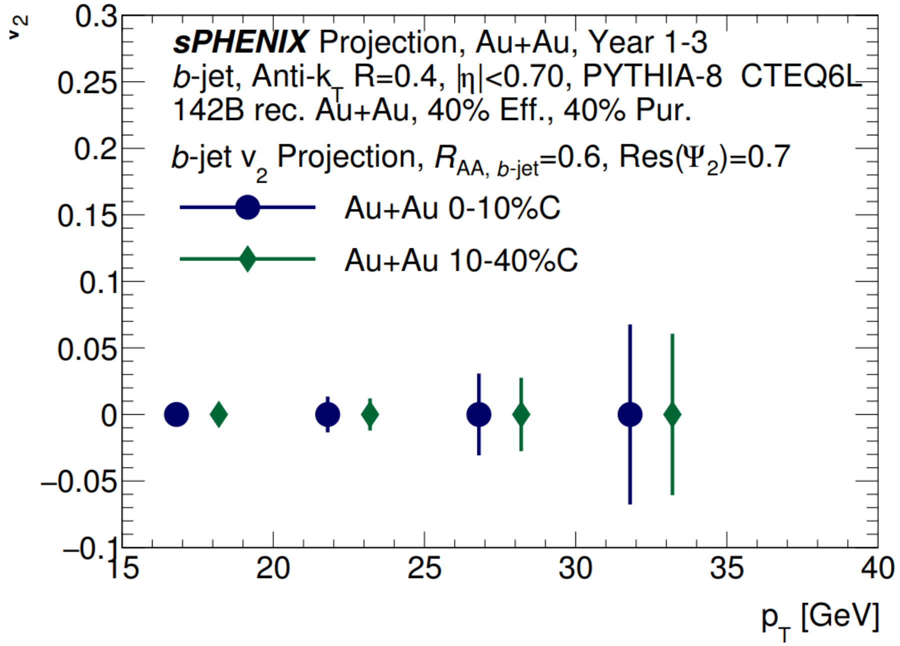
- Already compatible as CMS benchmark performance in Heavy Ion.
- Further studies ongoing to combine the two tagging schemes as well as making use of displaced leptons.

b-jet R_{AA} & v_2 Projection



CMS, Phys. Rev. Lett. 115, 029903 (2015)



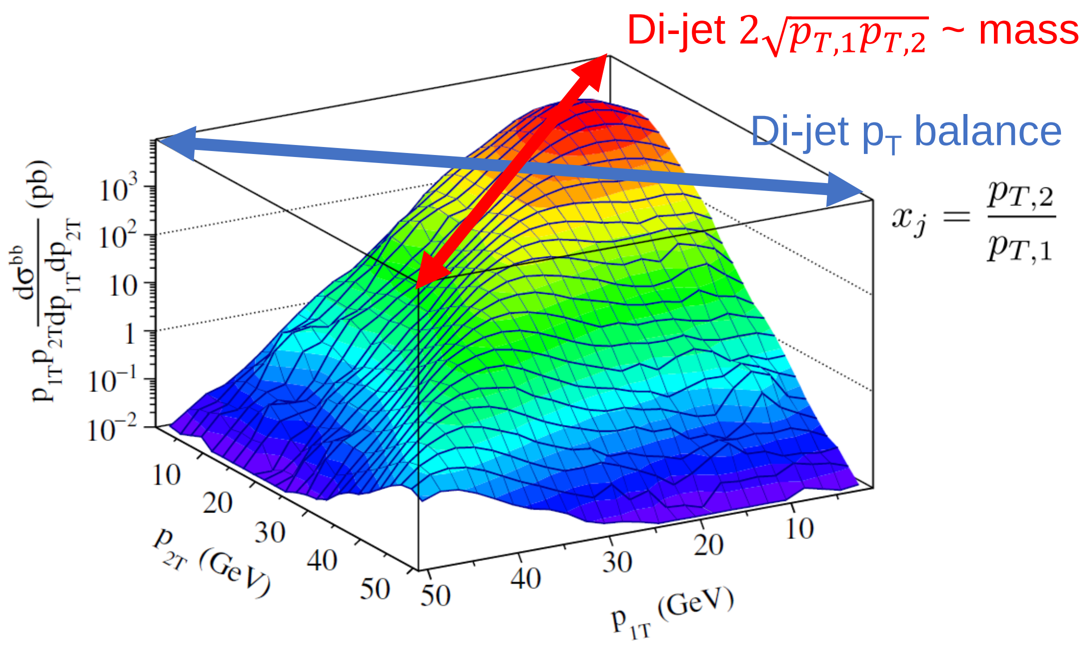


- sPHENIX brings precise inclusive b-jet R_{AA} & v_2 measurements to RHIC.
- Strong constraints on the energy loss model.

b-jet Pairs

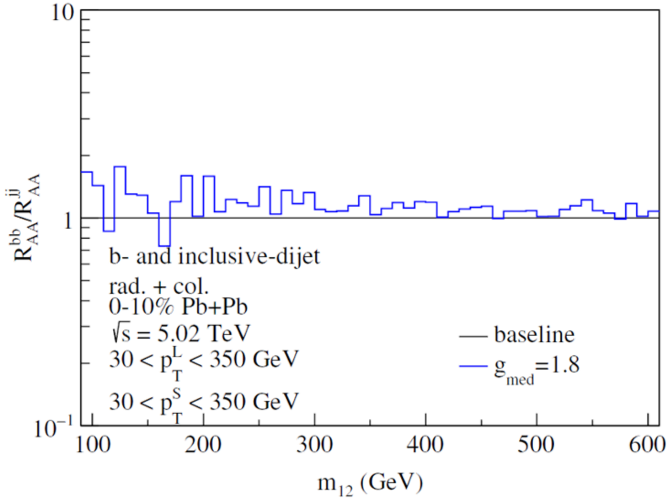
Kang, Reiten, Vitev, Yoon, Phys. Rev. D **99**, 034006.

- Inclusive b-jets at RHIC are expected to originate from b-quarks (i.e. not from gluon splitting), but considering the correlation between two b-jets will further suppress those from the gluon splitting.
- Two ways to produce 1D integral of 2D di-jet distribution
  - Di-b-jet p_T balance: sensitive to geometry fluctuation (our previous studies in the backup)
  - **Di-b-jet mass: enhance sensitivity to transport property**

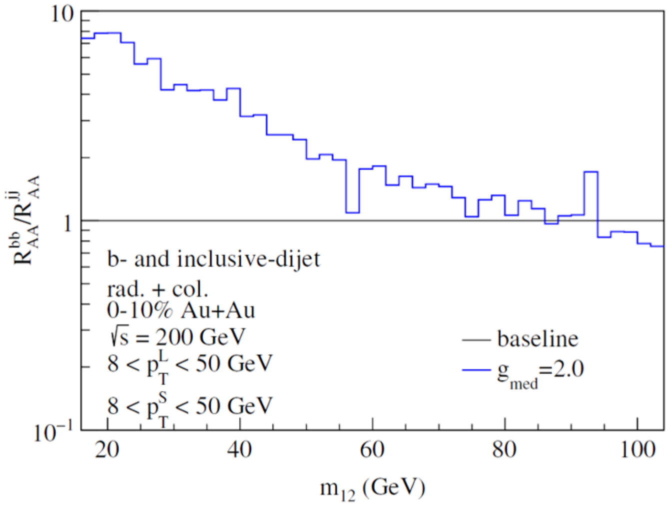


Sensitivity is enhanced at RHIC!

di-b/light-jet R_{AA} ratio: LHC

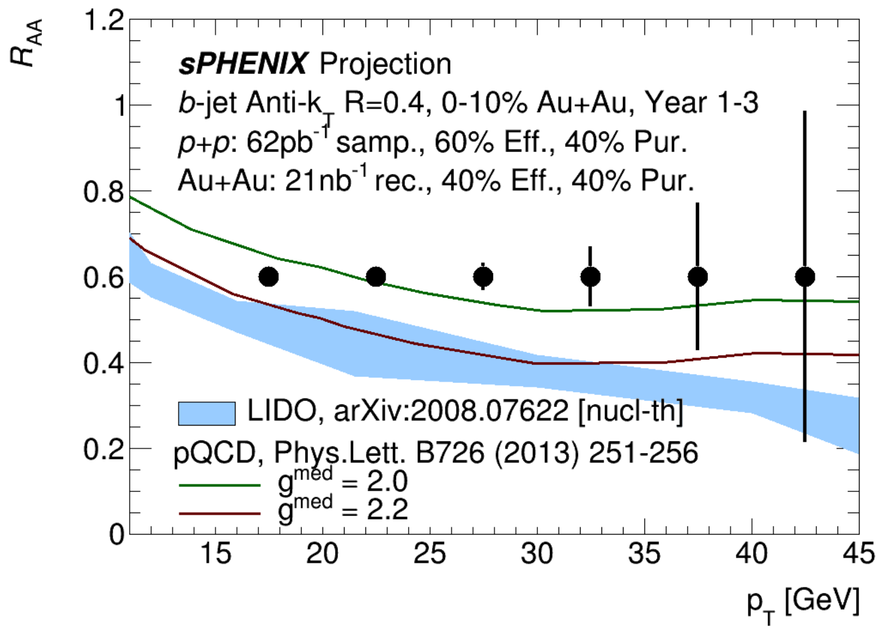


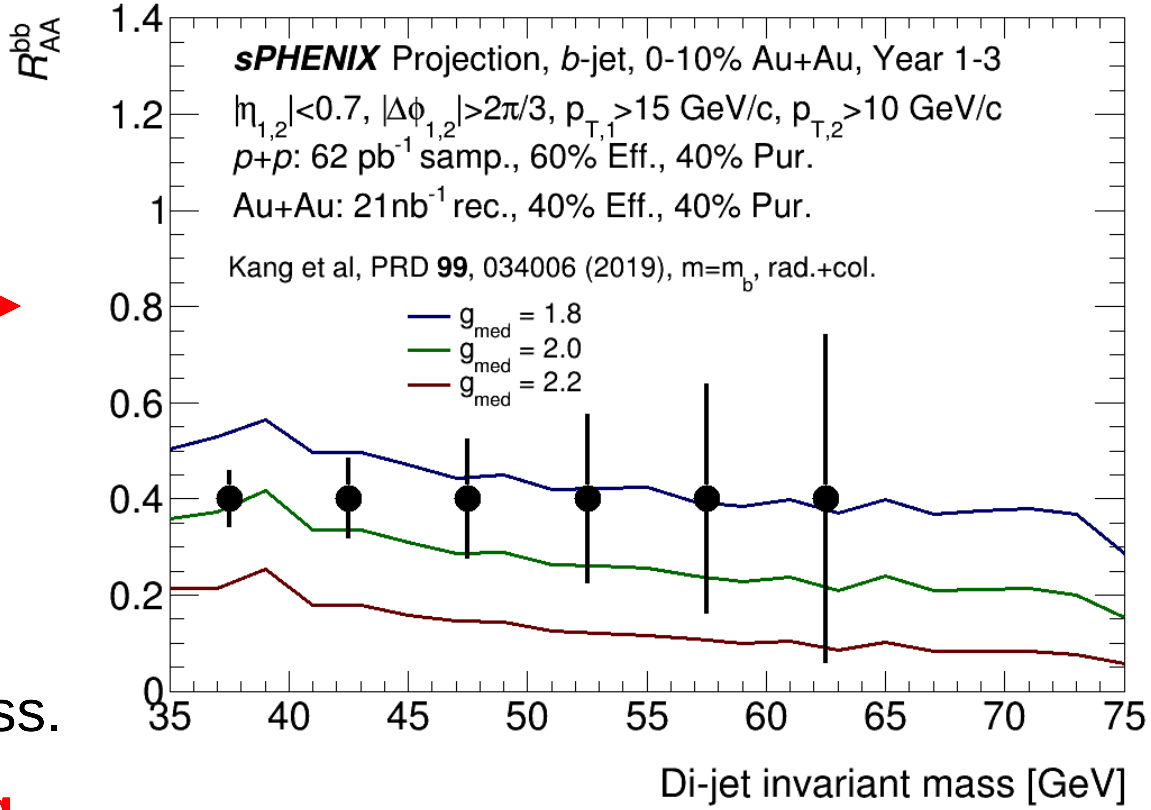
sPHENIX



b-jet Pair Mass

Inclusive b-jet



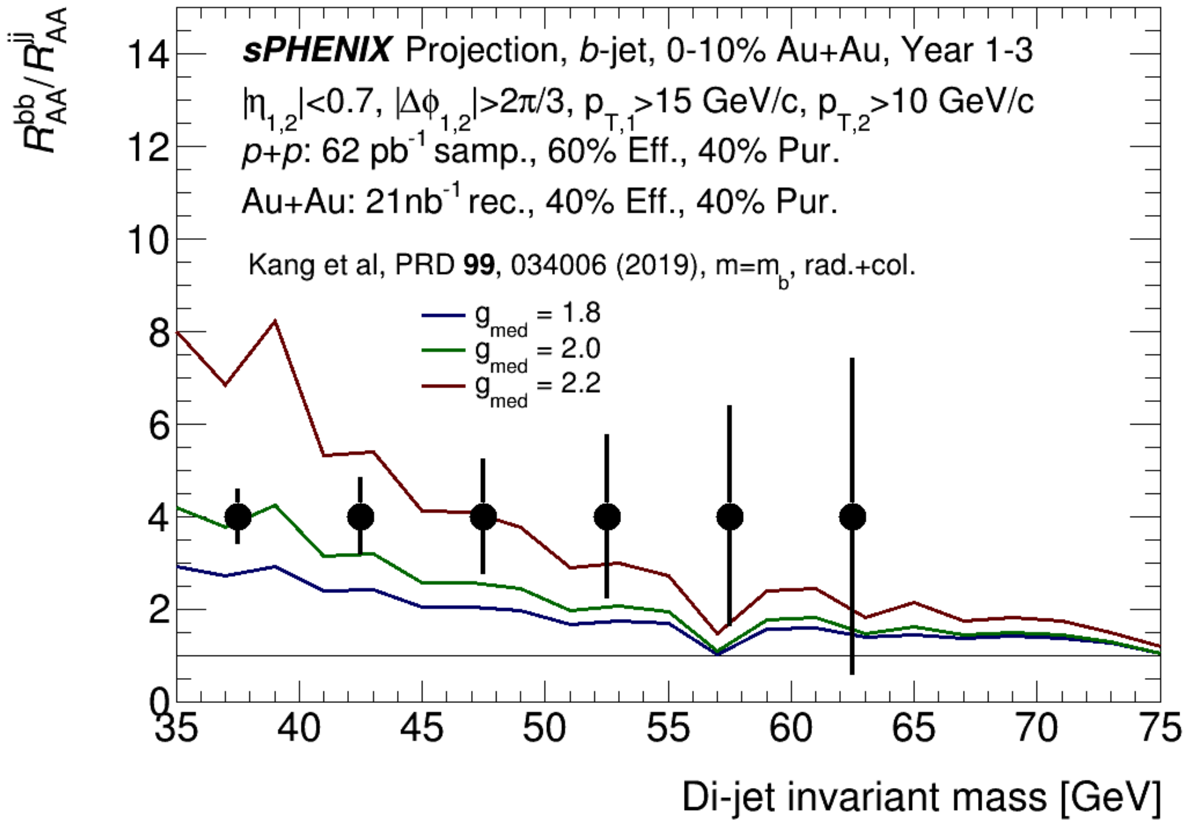


- Covers 35-70 GeV/c^2 in di-b-jet invariant mass.
- **Strong sensitivity to parton-QGP coupling.**
- **x2 effect against 10% variation on g_{med}!**

b-jet Pair vs Light-jet Pair

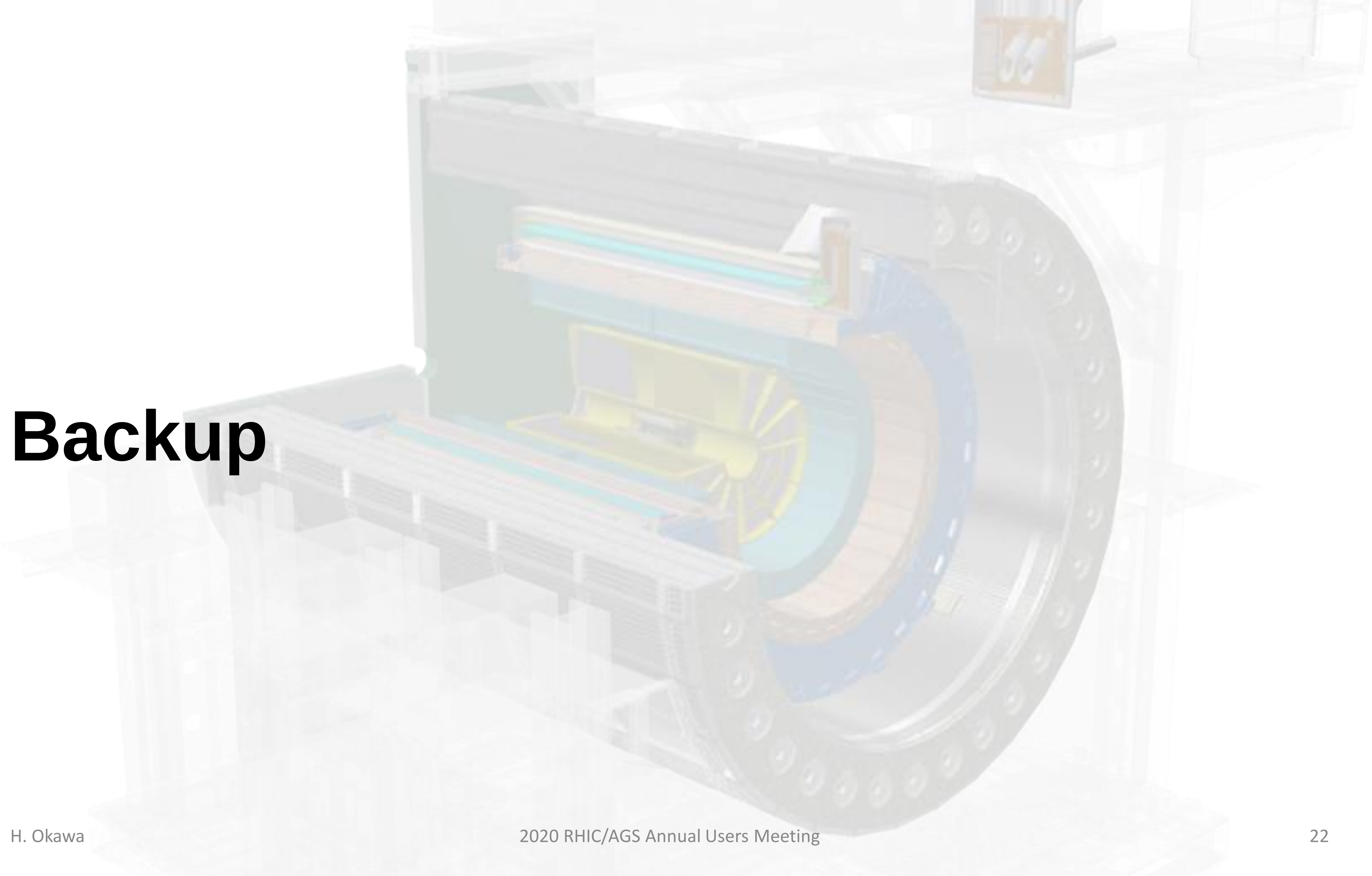
- b-jet vs light-jet pair mass ratio has **strong sensitivity to parton mass effect.**
- Partial cancellation of experimental systematic uncertainties.
- **1-8 times enhancement on the mass effect against g_{med} variations by taking this ratio.**
- Will continue to be in close contact w/ theory community & look for more observables/strategies.

b-jet vs light-jet



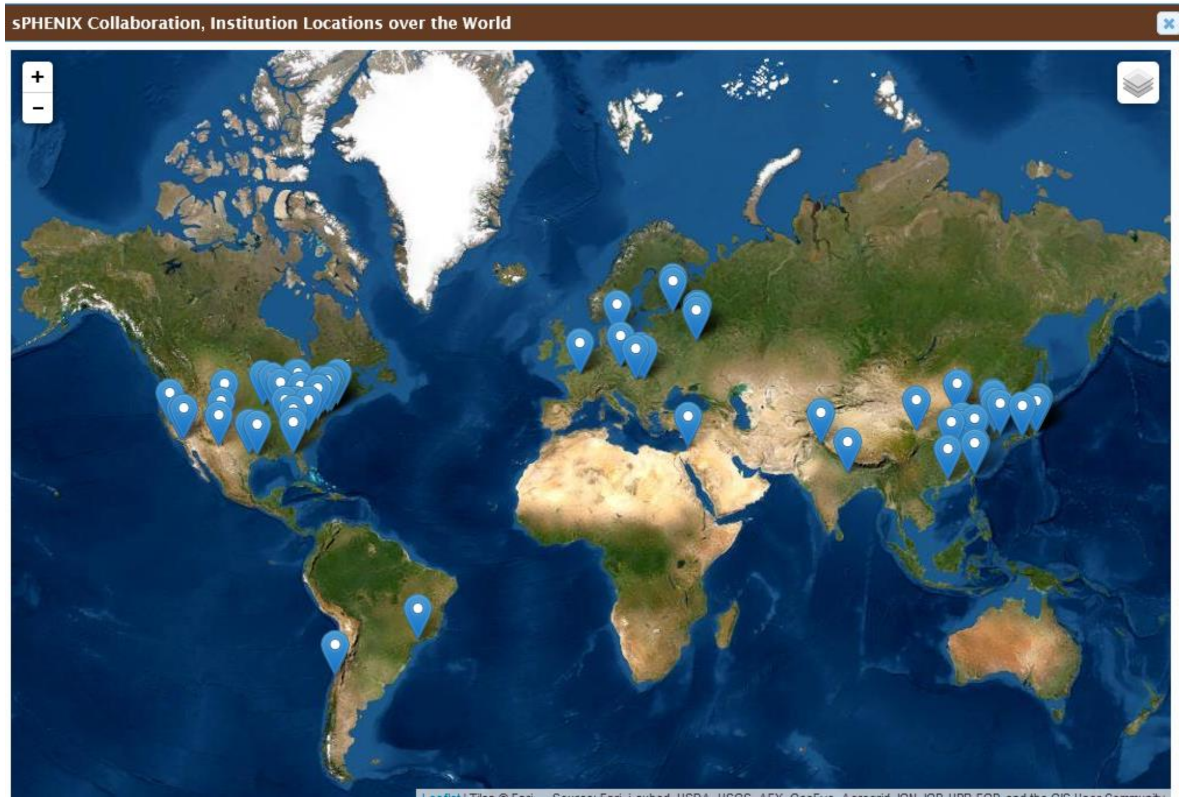
Summary

- sPHENIX brings precision measurements to b-quark sector at RHIC.
  - Upsilons to probe QGP with different size.
  - Comprehensively covers wide p_T range for open heavy flavor
    → diffusion properties, hadronization, parton energy loss (collisional vs radiative)
- Beam Use Proposal submitted with the updated run program.
- PAC lists sPHENIX as the highest priority for Runs 23-25.
- Despite the challenges from COVID-19, the construction is progressing, targeting the first data in 2023.



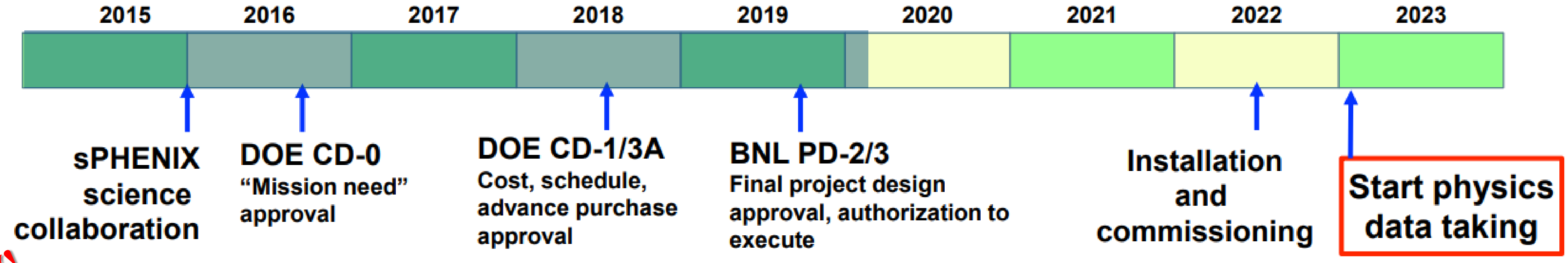
Backup

sPHENIX Collaboration



- More than 320 members from 80 institutions in 13 countries (as of early 2020)

Schedule



NEW!

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2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-str]	0.11 pb^{-1}
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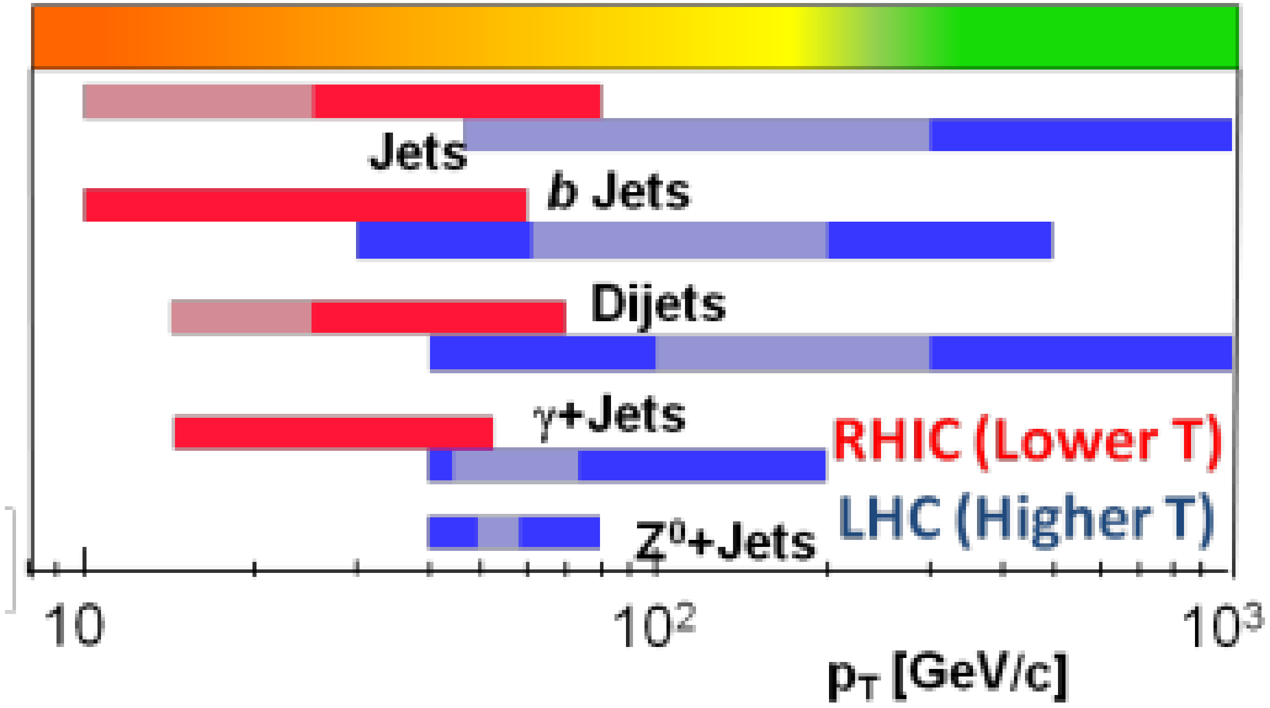
Run 2026-2027, if opportunity arises

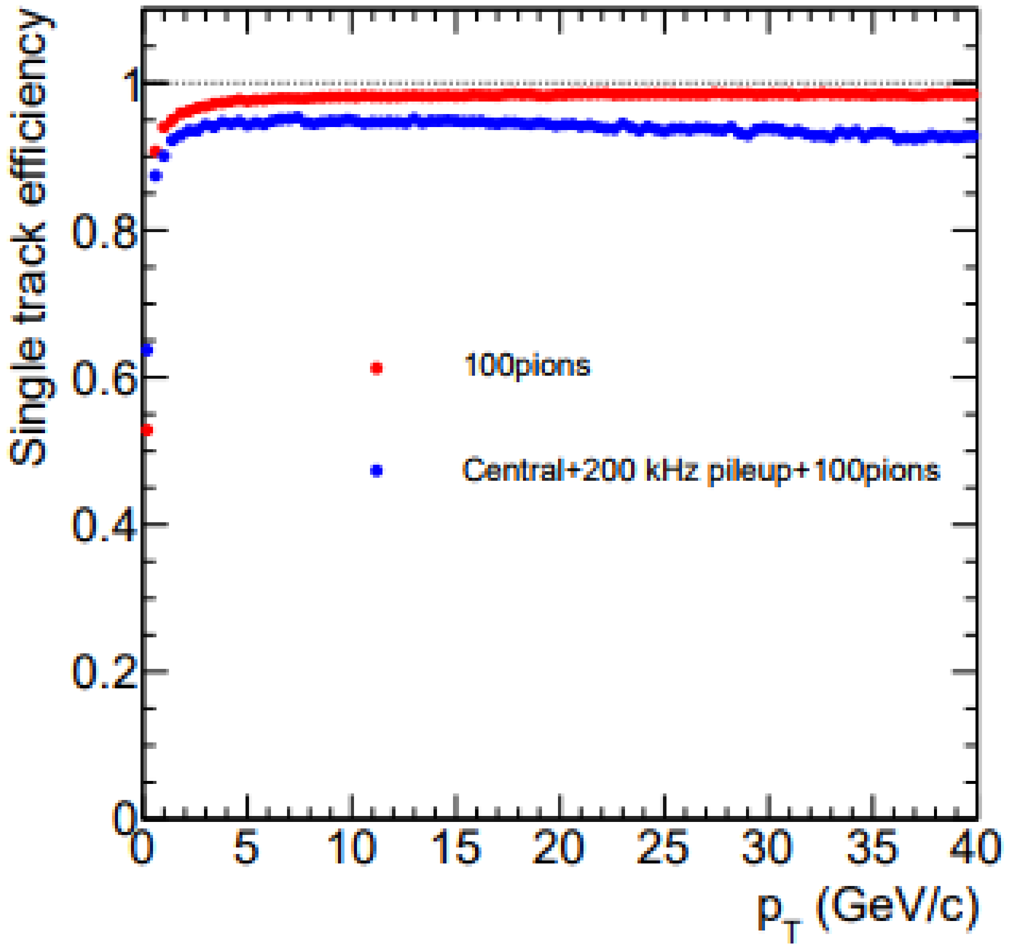
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\|z\| < 10$ cm	Samp. Lum. $\|z\| < 10$ cm
2026	$p^{\uparrow}p^{\uparrow}$	200	28	15.5	1.0 pb^{-1} [10 kHz] 80 pb^{-1} [100%-str]	80 pb^{-1}
–	O+O	200	–	2	18 nb^{-1} 37 nb^{-1} [100%-str]	37 nb^{-1}
–	Ar+Ar	200	–	2	6 nb^{-1} 12 nb^{-1} [100%-str]	12 nb^{-1}
2027	Au+Au	200	28	24.5	30 nb^{-1} [100%-str/DeMux]	30 nb^{-1}

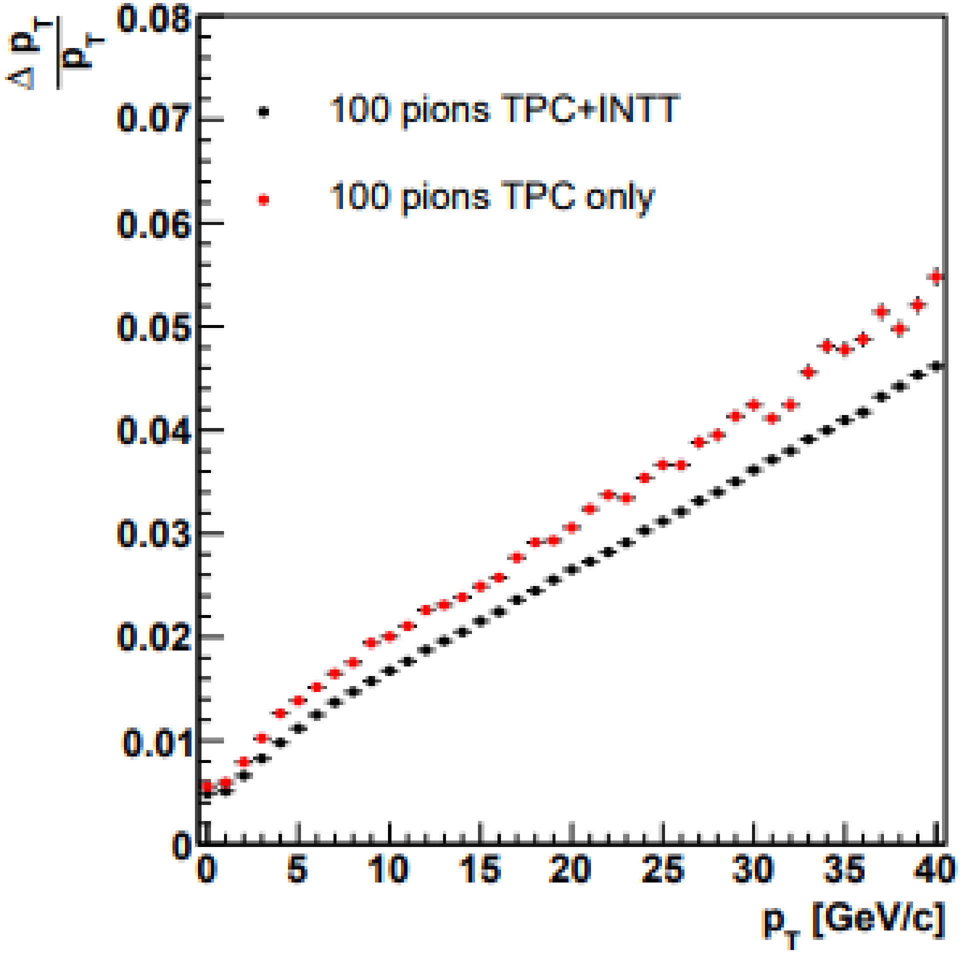
Run plan updated in BUP 2020

Complementarity of RHIC & LHC

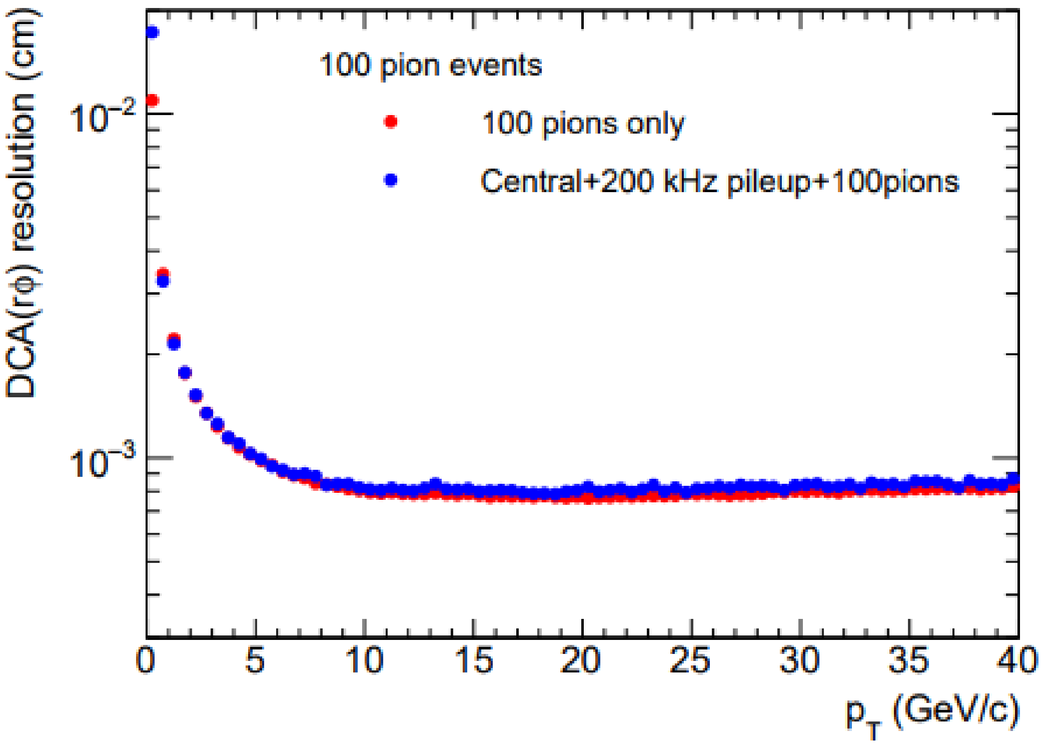


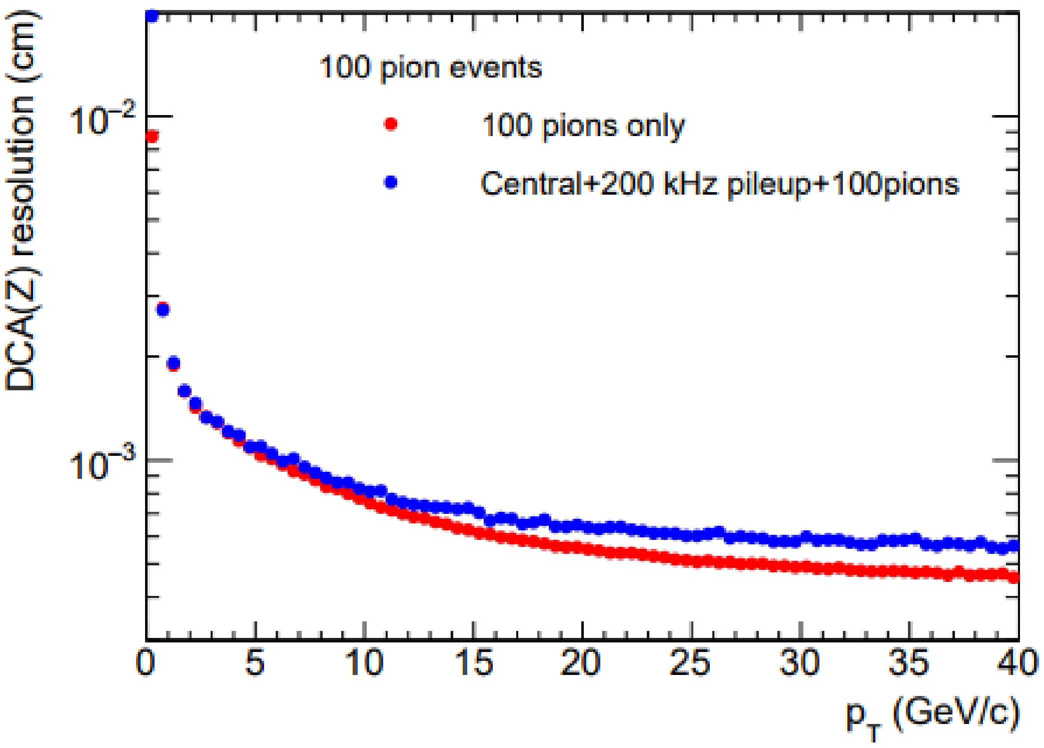
Tracking Performance



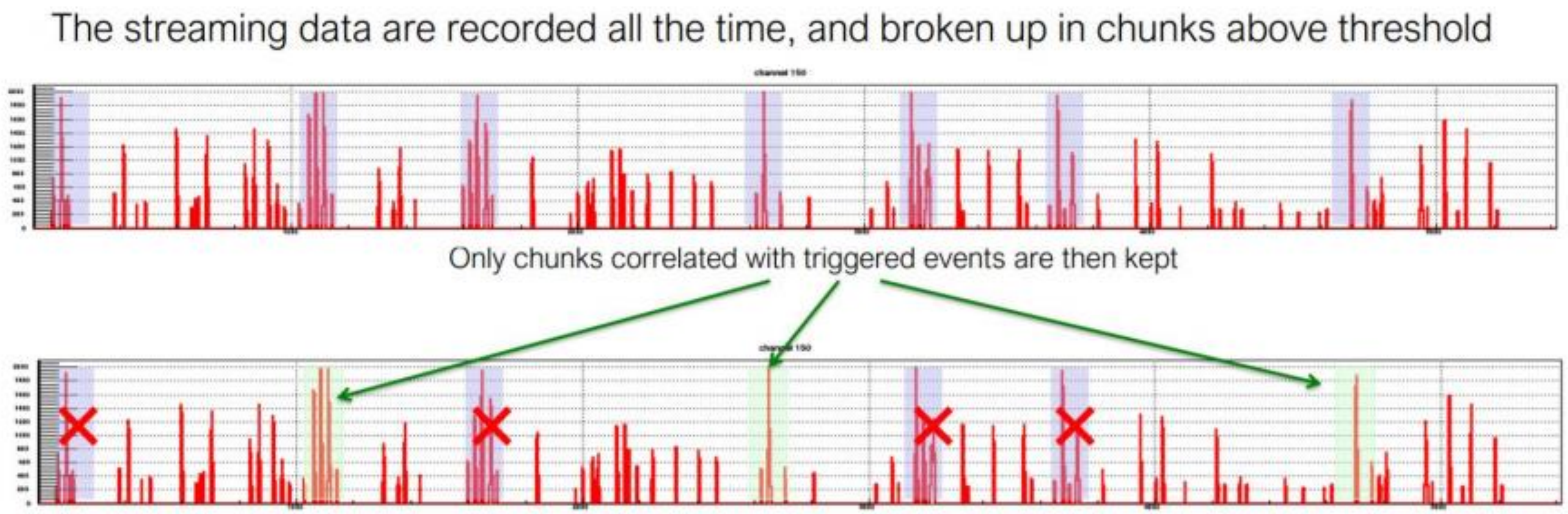


DCA Resolution





Streaming Readout



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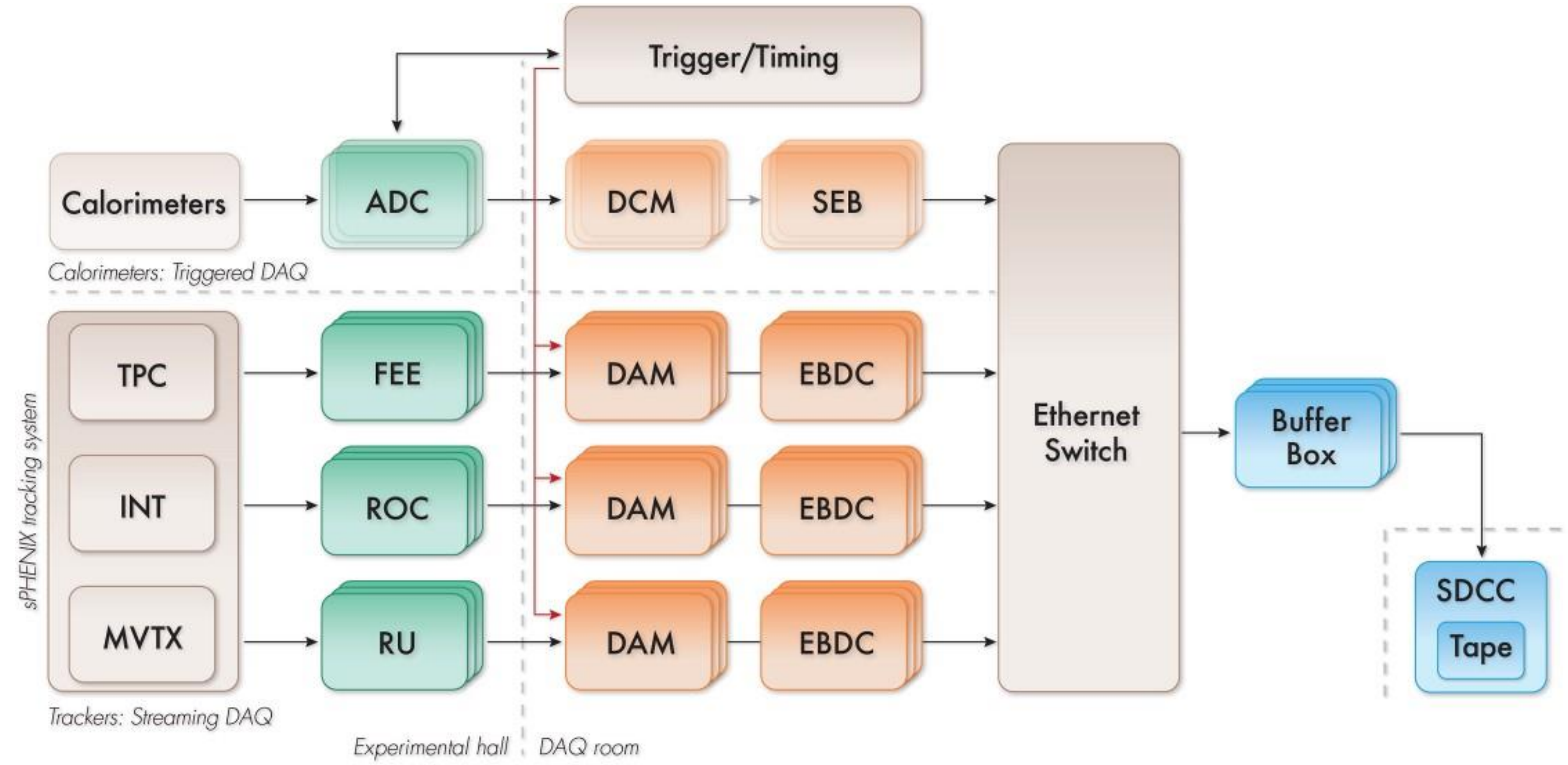
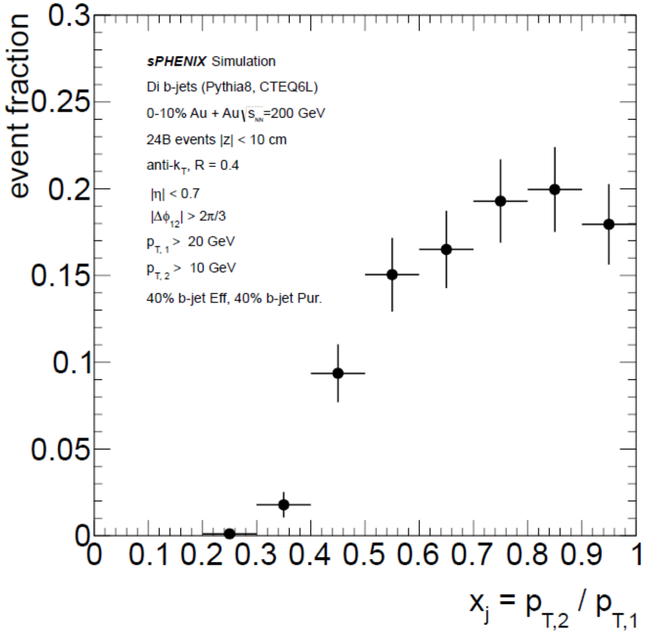


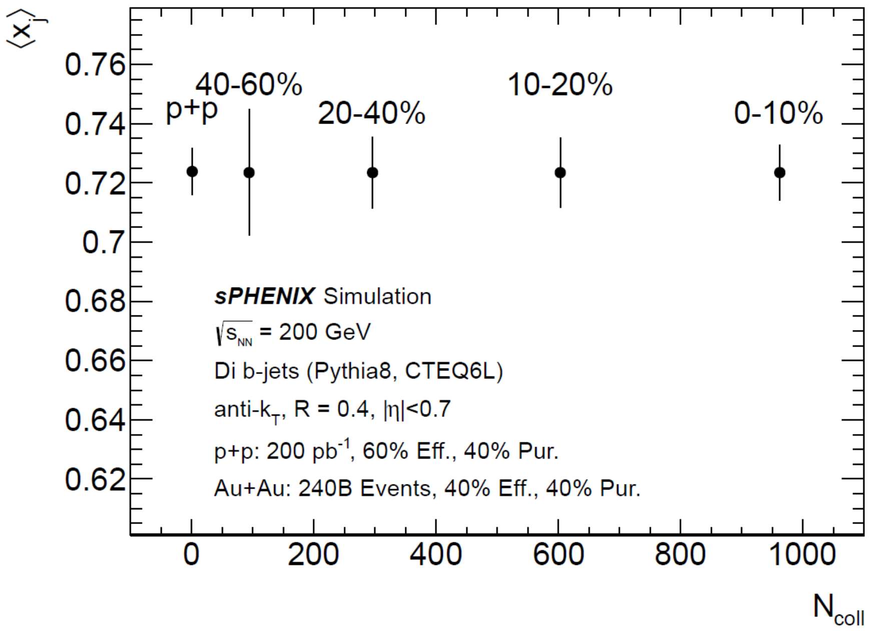
b-jet Correlation – Early Studies

sPH-HF-2018-001 - MVTX Proposal , sPH-HF-2017-001

Table 4.1: Analysis cut information for di-b-jet study.

	$p+p$	Au+Au
cuts	$\lvert\eta_{1,2}\rvert < 0.7$	
	$p_{T,1} > 20$ GeV/c	
	$p_{T,2} > 10$ GeV/c	
	$\lvert\Delta\phi_{12}\rvert > 2\pi/3$	
	$\lvert z\rvert < 10$ cm	
b-jet Eff	60%	40%
b-jet Purity	40%	40%
b-jet R_{AA}		0.6





- Inclusive b-jets at RHIC are expected to originate from b-quarks (i.e. not from gluon splitting), but considering the correlation between two b-jets will further suppress those from the gluon splitting.
- Previous studies with truth. Studies to be updated & expanded with full simulation.