Spin and Cold QCD Physics at sPHENIX

Joe Osborn

Oak Ridge National Laboratory and Brookhaven National Laboratory

RHIC/AGS AUM 2022
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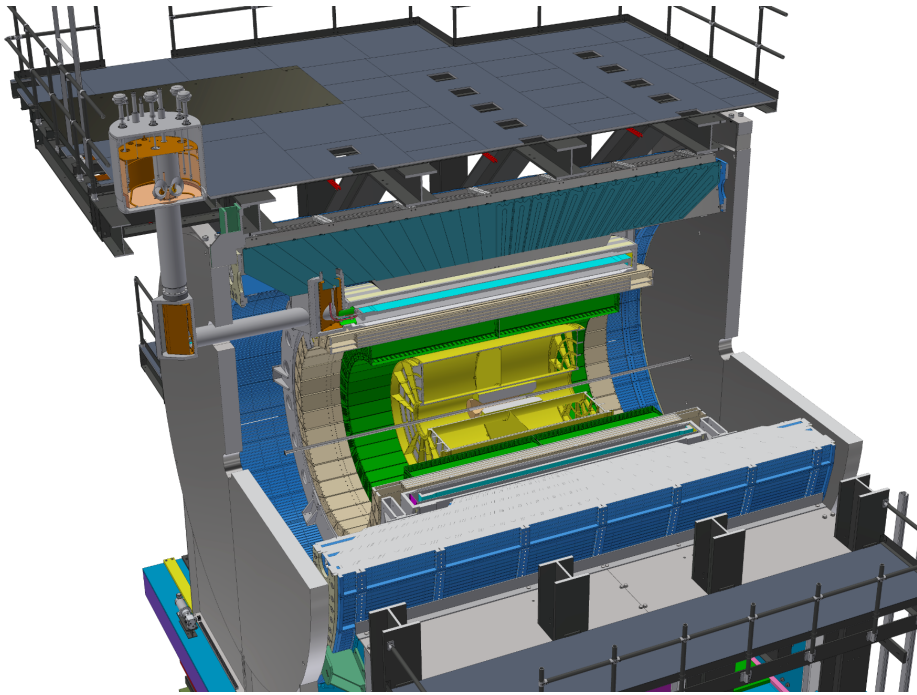
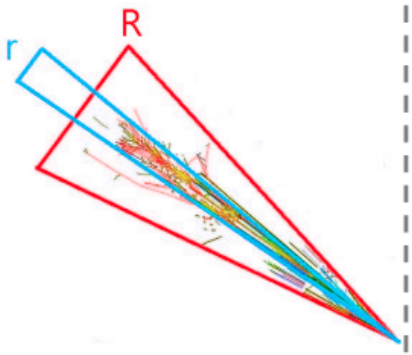
sPHENIX

- sPHENIX is a new detector being commissioned this year at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory
- Jet and heavy flavor probes for precision hot and cold QCD measurement comparisons to LHC
- Reuse Babar 1.4T solenoid and introduce hadronic calorimetery for the first time at RHIC for full jet measurements

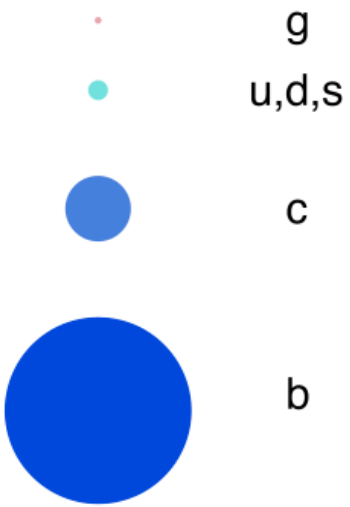


sPHENIX

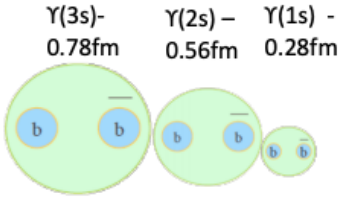
Jet correlation & substructure
Vary momentum/ angular size of probe

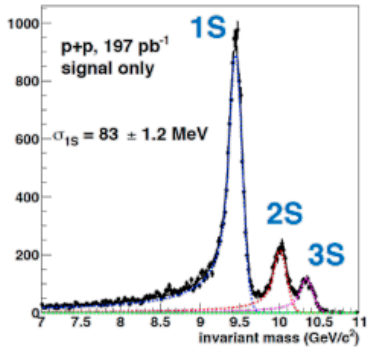


Parton energy loss
Vary mass/ momentum of probe

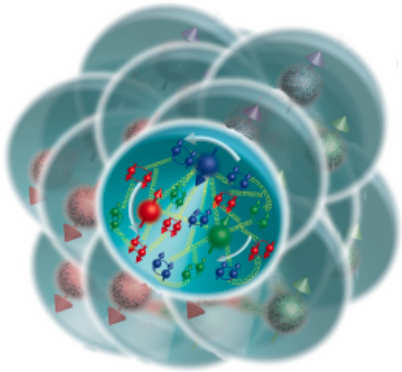


Upsilon spectroscopy
Vary size of the probe



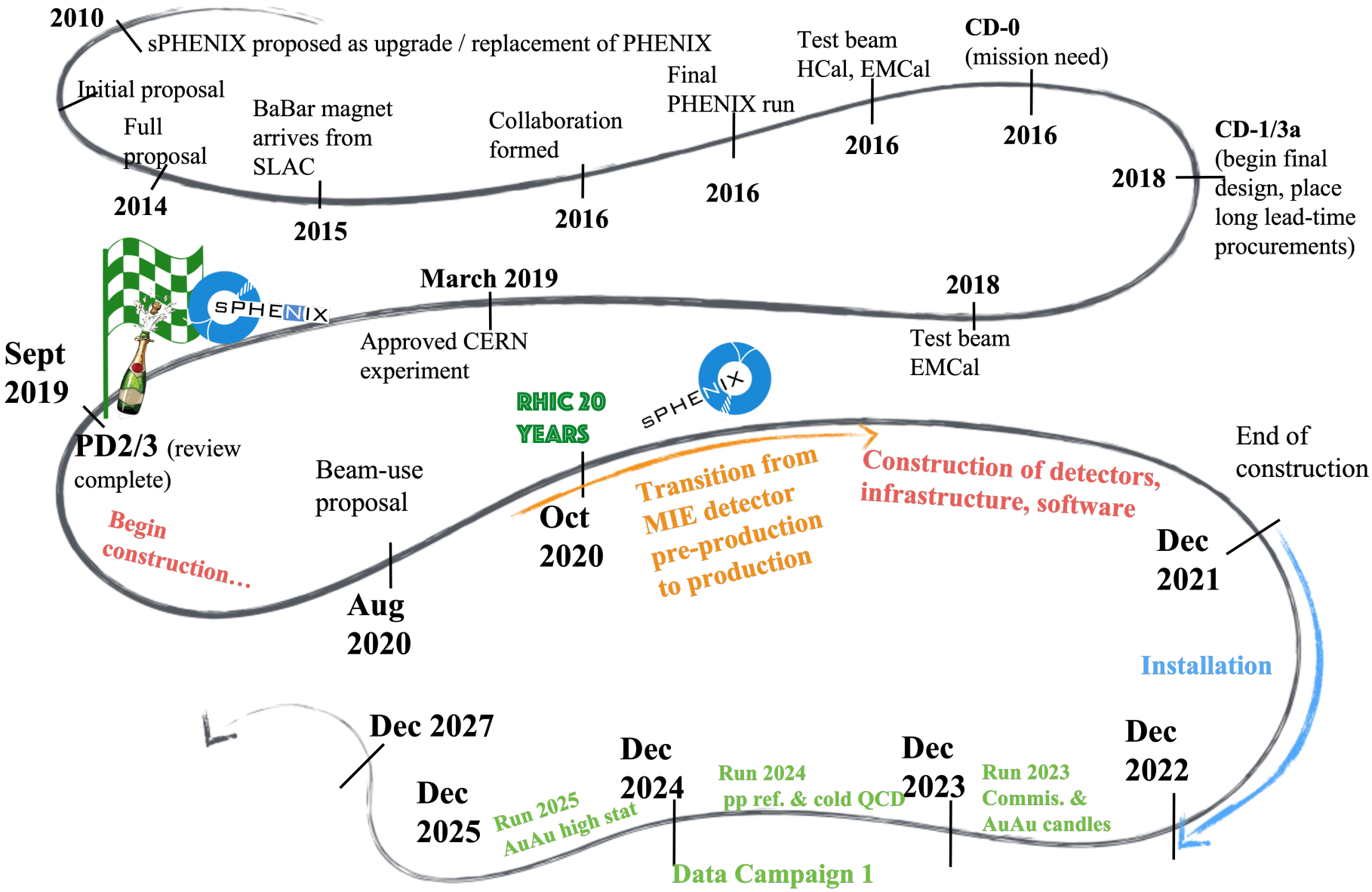


Cold QCD
Vary temperature of QCD matter

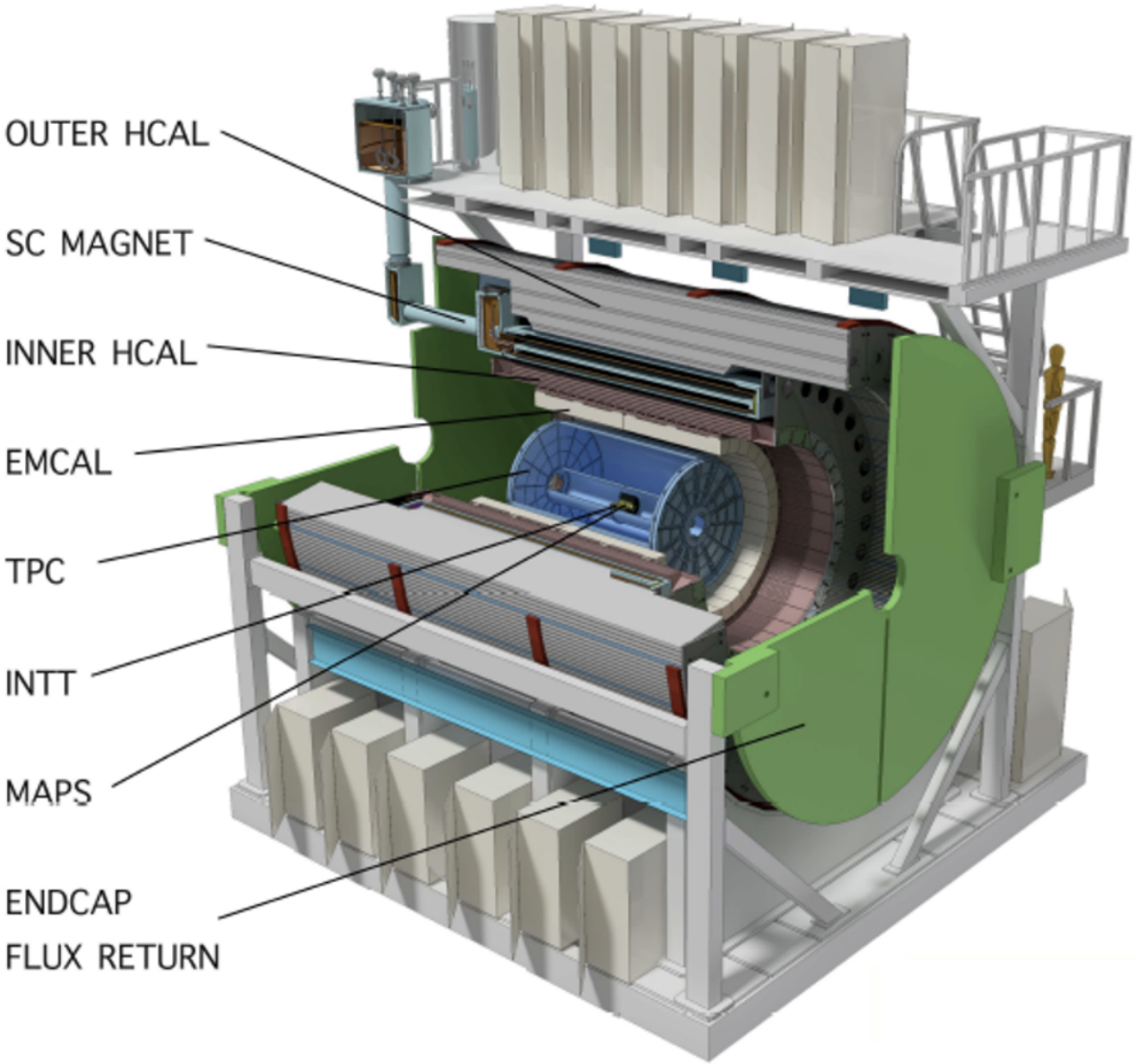


- Study QCD matter at varying temperatures for direct comparisons to LHC with rare probes
- Study partonic structure of protons and nuclei

sPHENIX timeline



sPHENIX detector



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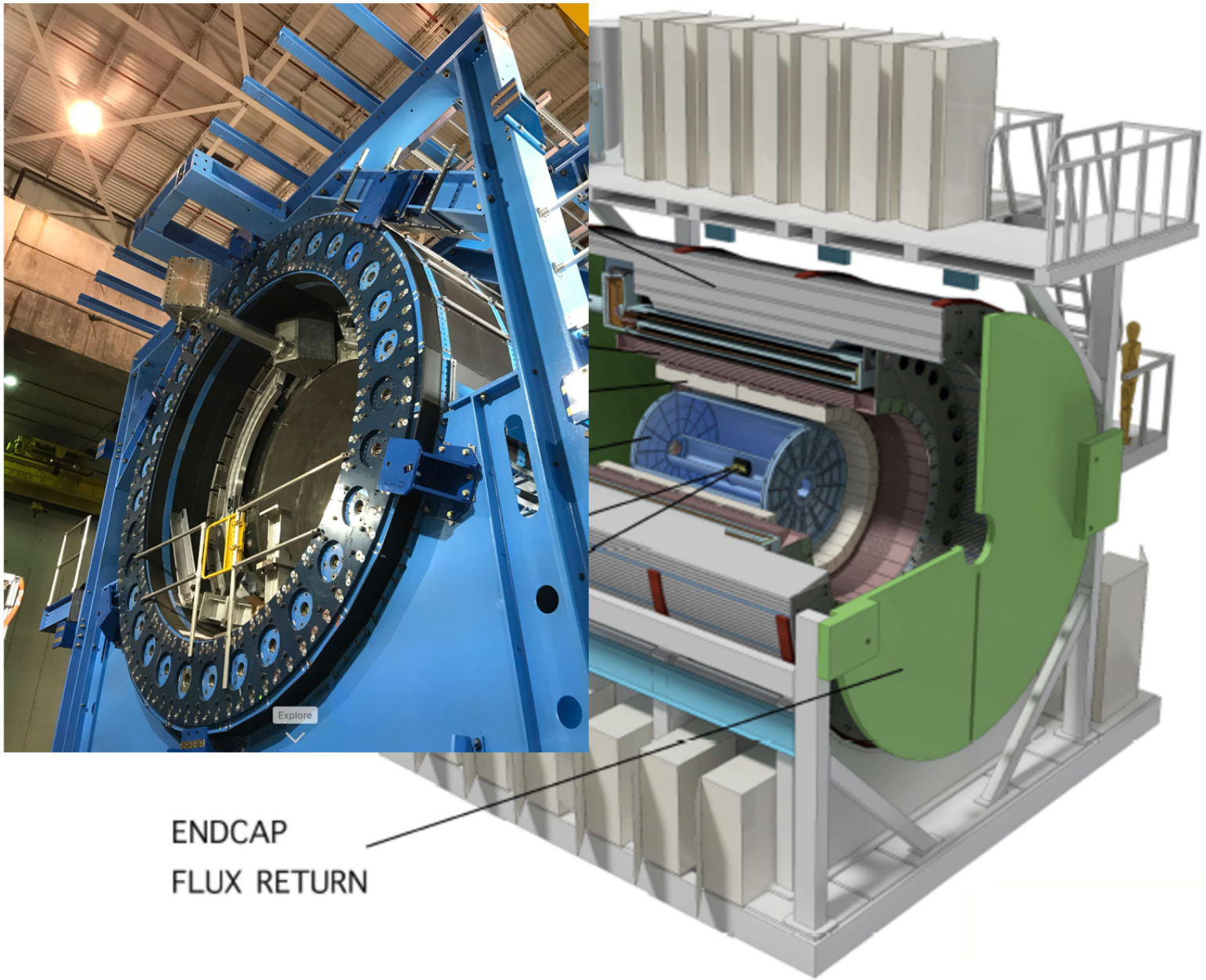

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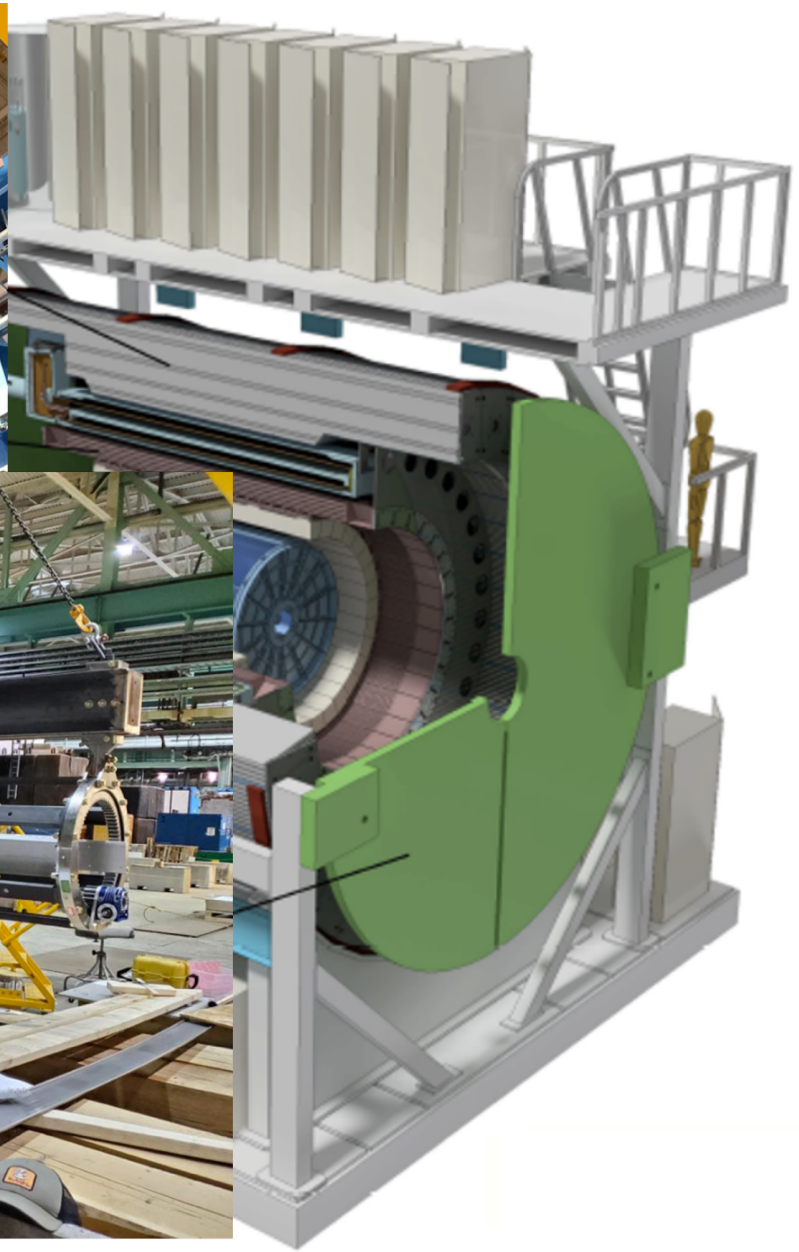

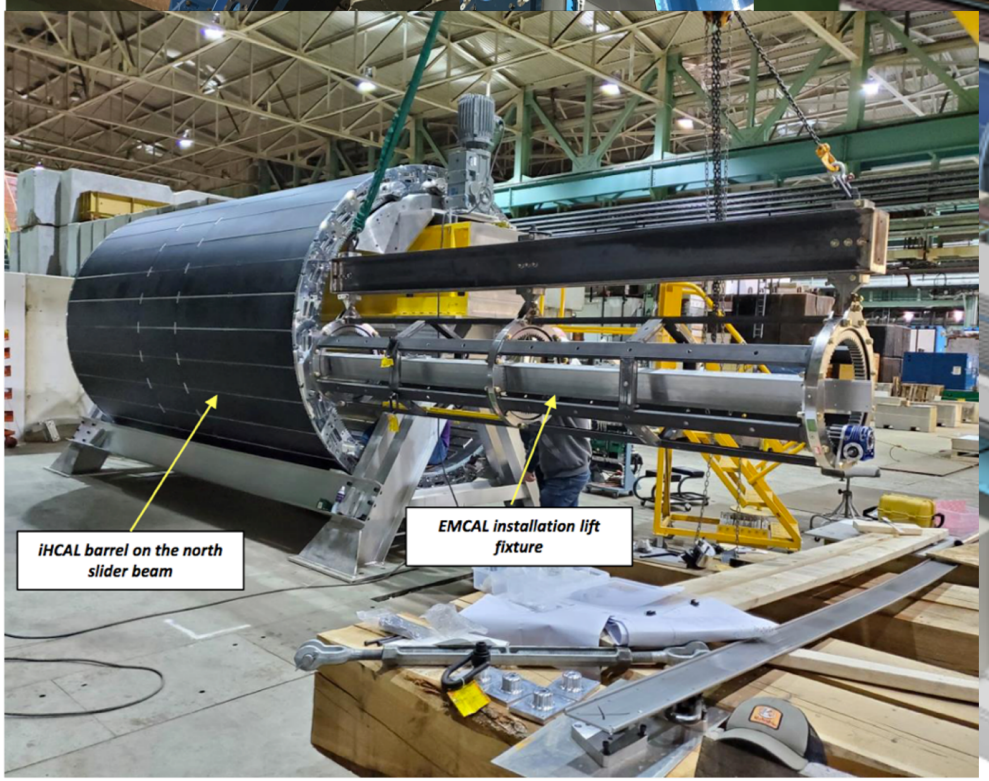

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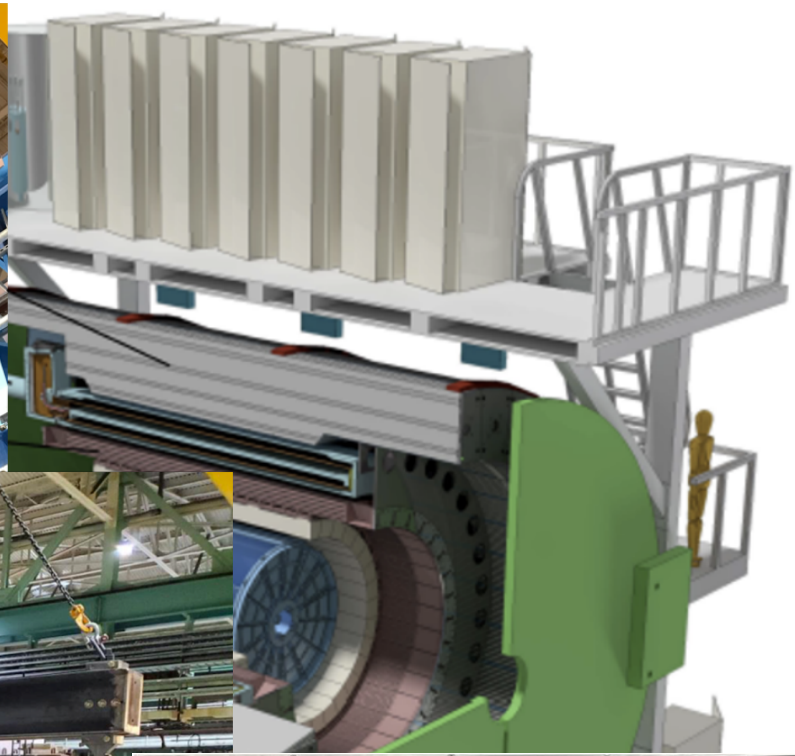

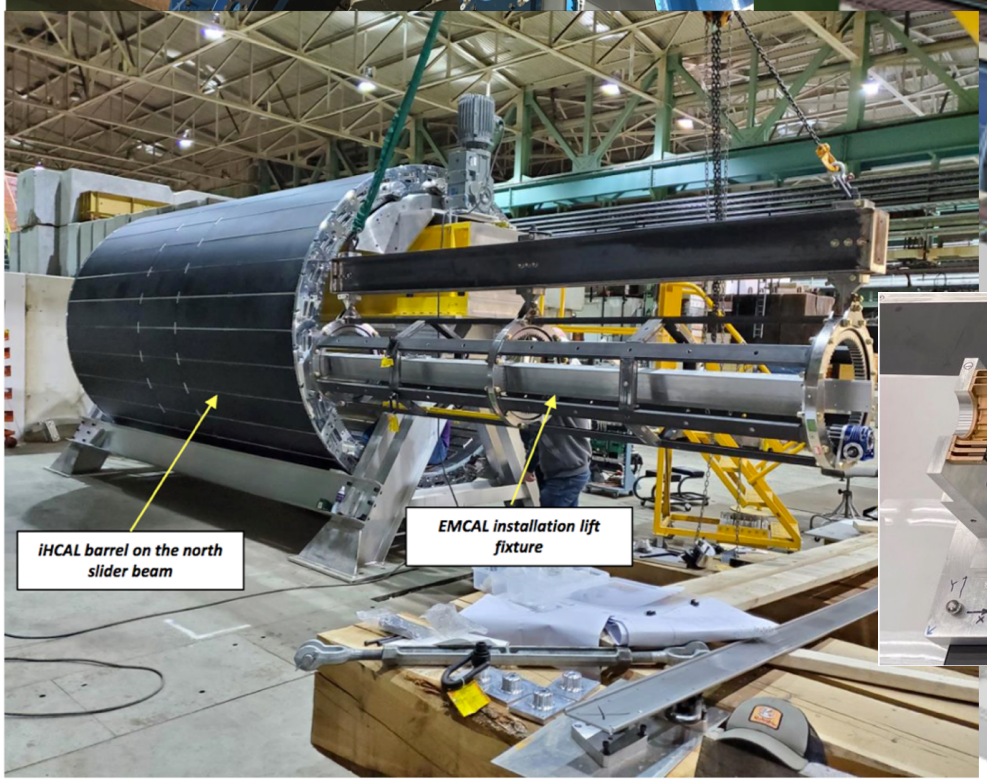

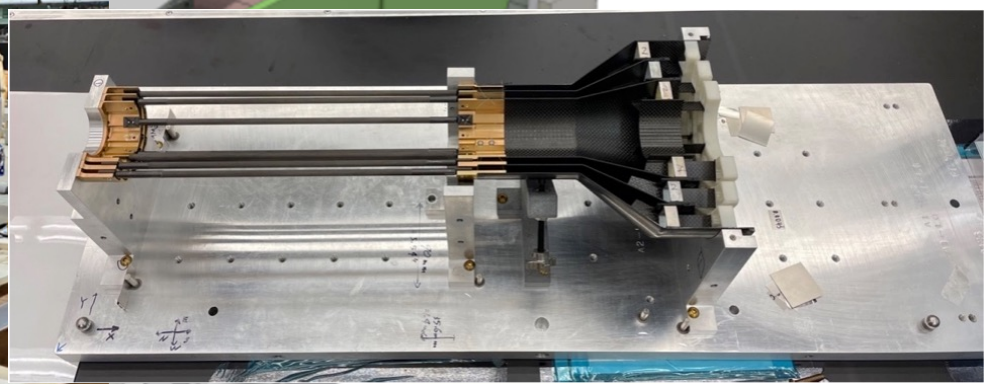

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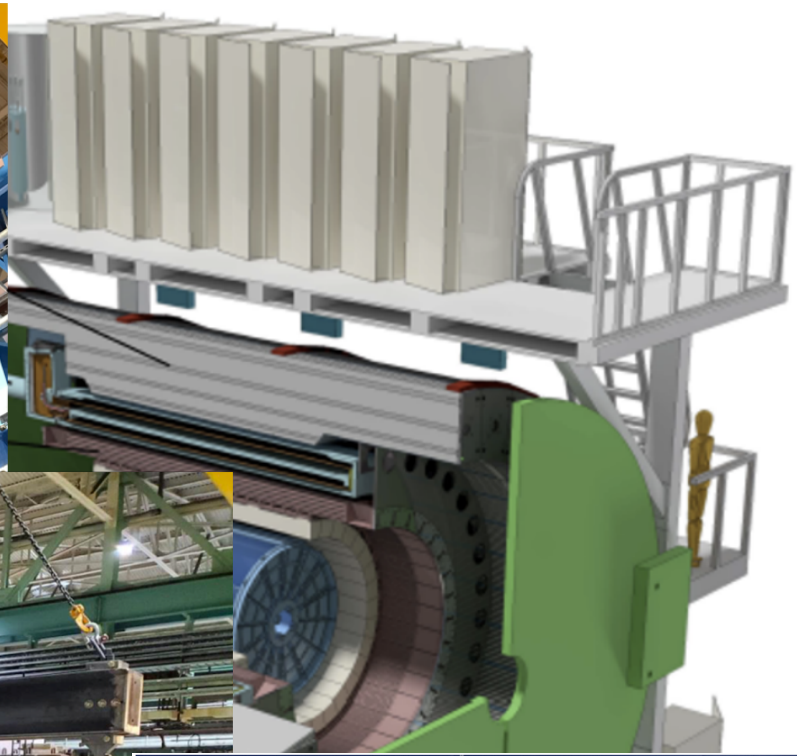
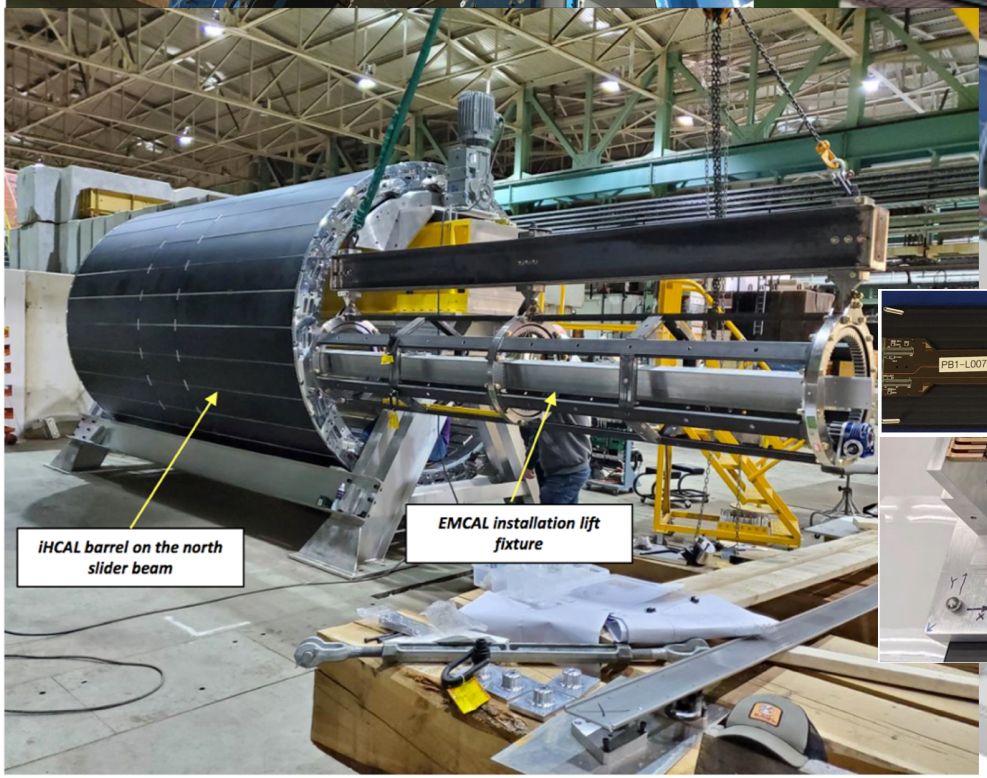
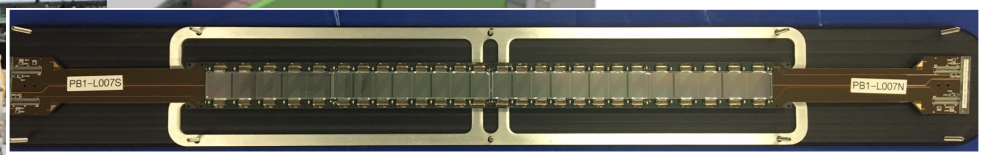
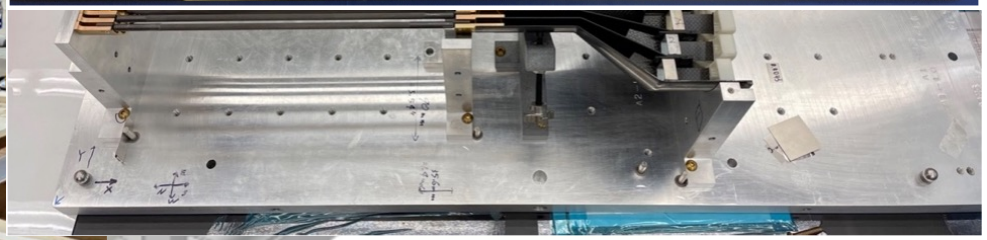








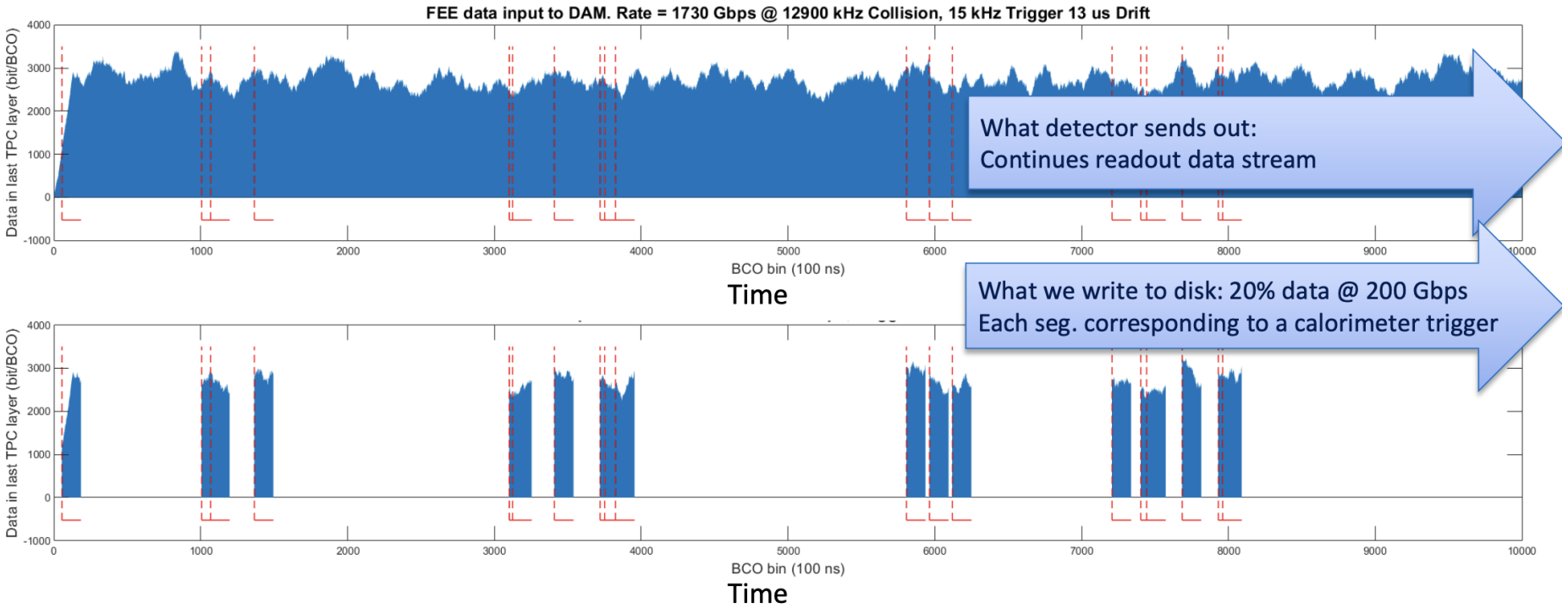
sPHENIX detector

Proposed run schedule

sPHENIX BUP 2022 [sPH-TRG-2022-001] 24 (28) cryo week scenarios

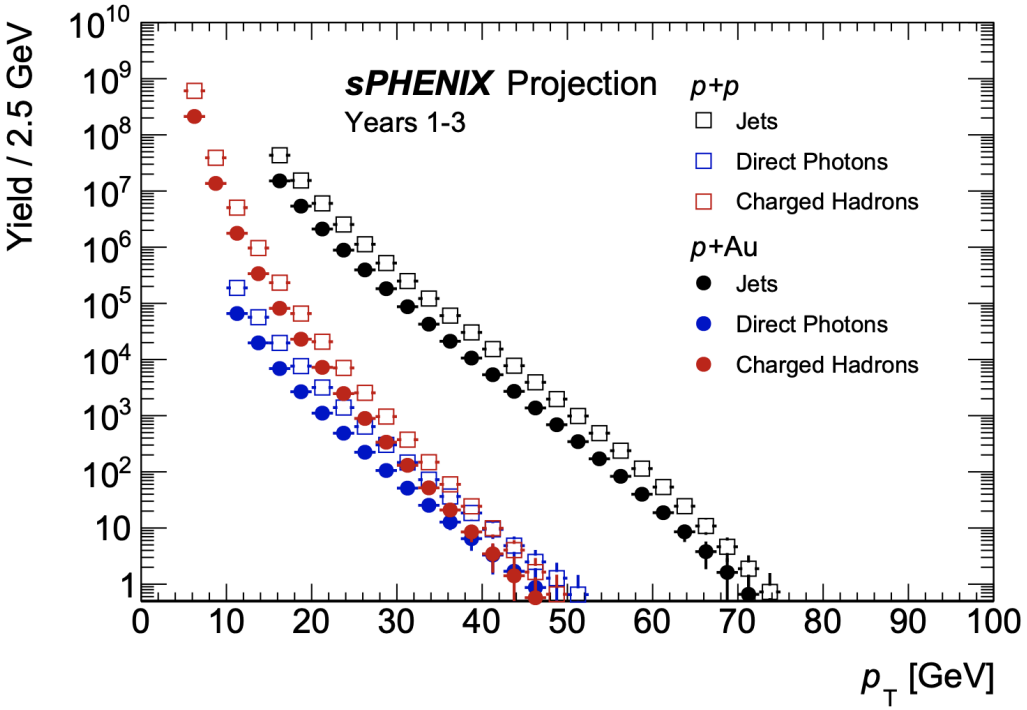
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	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}

Streaming readout in 2024



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

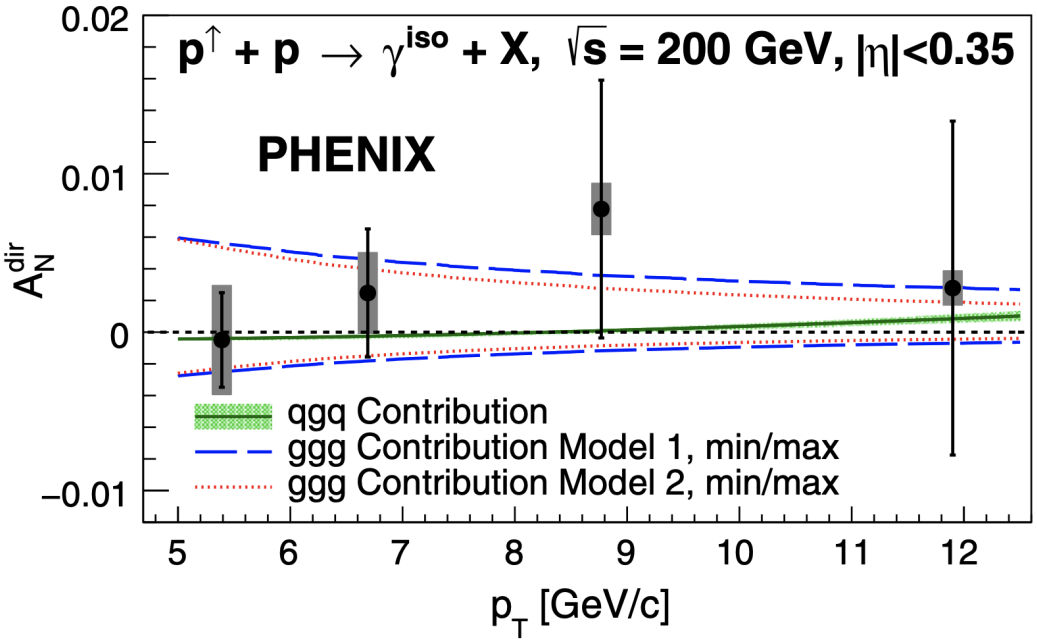
cQCD kinematic reach



- Transversely polarized observables
  - Trigluon correlation functions: direct γ, OHF
  - Hadron A_N, pp vs. pA
  - Sivers effect : dijet and γ-jet
  - Transversity via Collins FF & IFF : h-in-jet, dihadrons
- Unpolarized observables
  - Quarkonia polarization and hadronization: J/ψ, Υ
  - (n)PDFs: inclusive jets, dijets, γ-jet
  - (n)FFs and hadronization: hadrons, h-in-jet

Trigluon correlator with direct γ

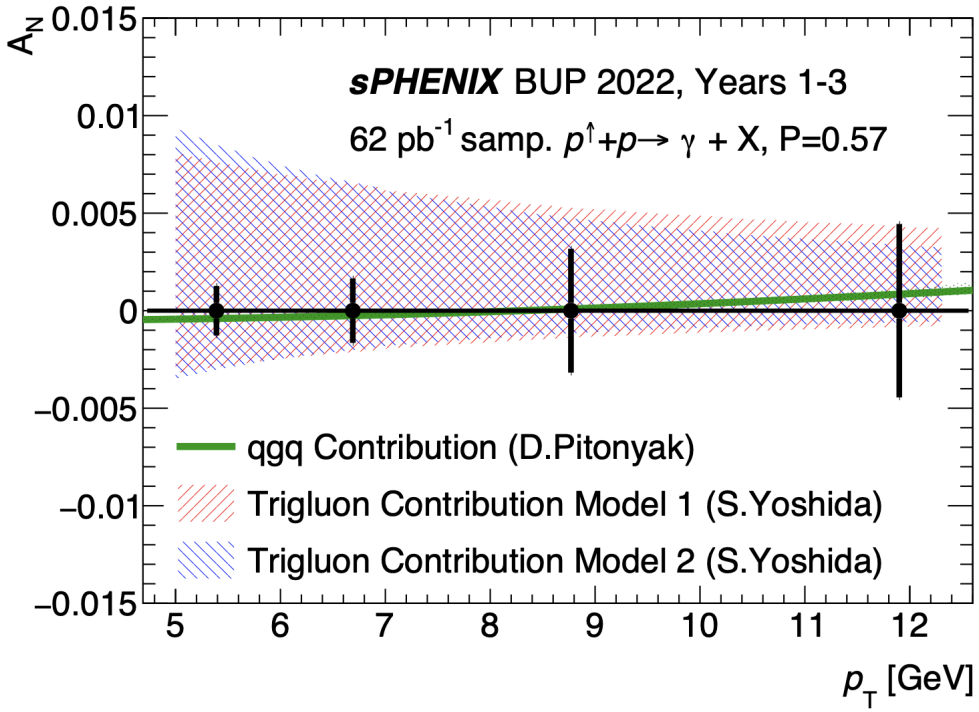
- PHENIX recently published first direct γ A_N from RHIC



Phys. Rev. Lett. 127, 162001 (2021)

Trigluon correlator with direct γ

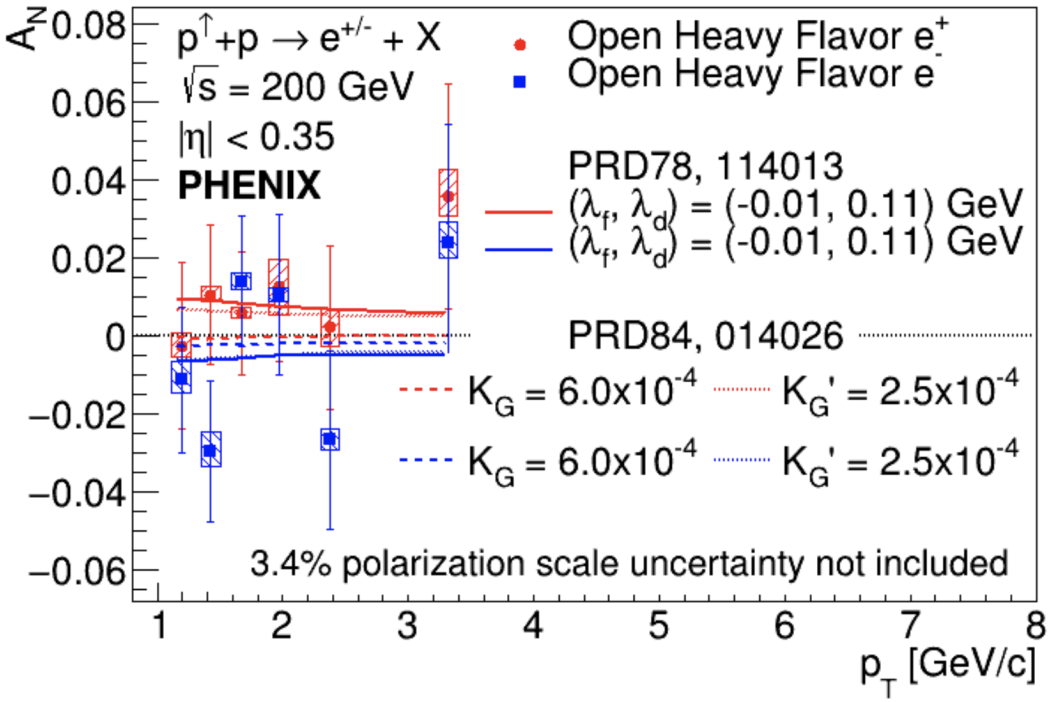
- PHENIX recently published first direct γ A_N from RHIC
- sPHENIX will be able to improve upon this first measurement!
- Goal to have 2-3 bins which will help constrain trigluon contribution



sPHENIX BUP 2022

Trigluon correlator with open heavy flavor

- PHENIX recently submitted open heavy flavor decay electron A_N measurement!



arXiv:2204.12899

Trigluon correlator with open heavy flavor

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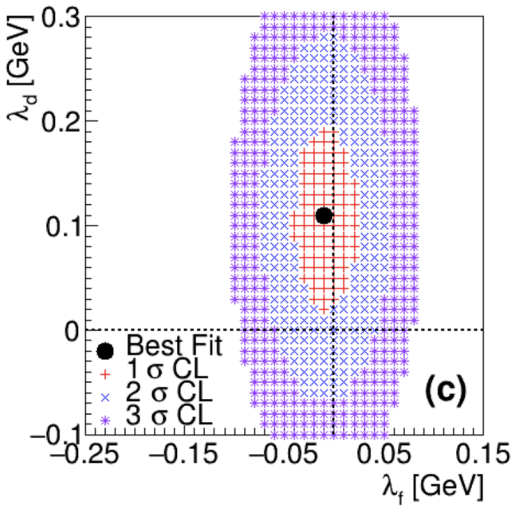
- Constraints on gluon correlators extracted for charge separated measurements



$A_N(p^{\uparrow}+p \rightarrow HF(e^{+/-}) + X)$

$\sqrt{s} = 200$ GeV

$|\eta| < 0.35$

PHENIX

Theory: PRD78, 114013

$A_N^{D^0/\bar{D}^0 \rightarrow e^{+/-}}(\lambda_f,\lambda_d)$

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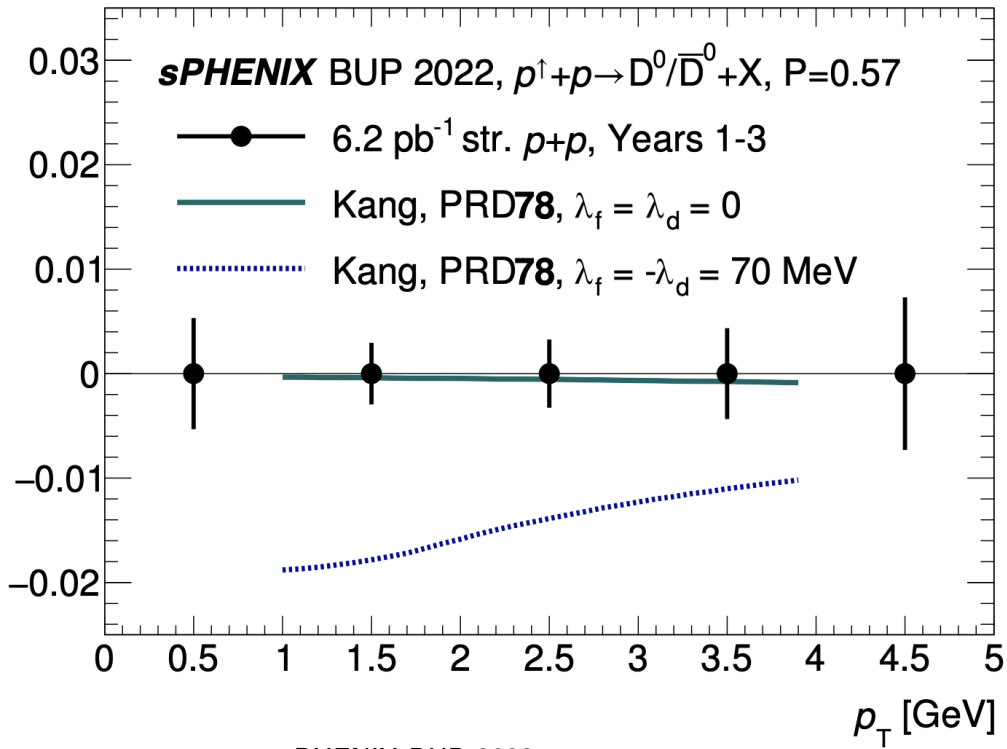
- sPHENIX to improve upon first measurement with D^0



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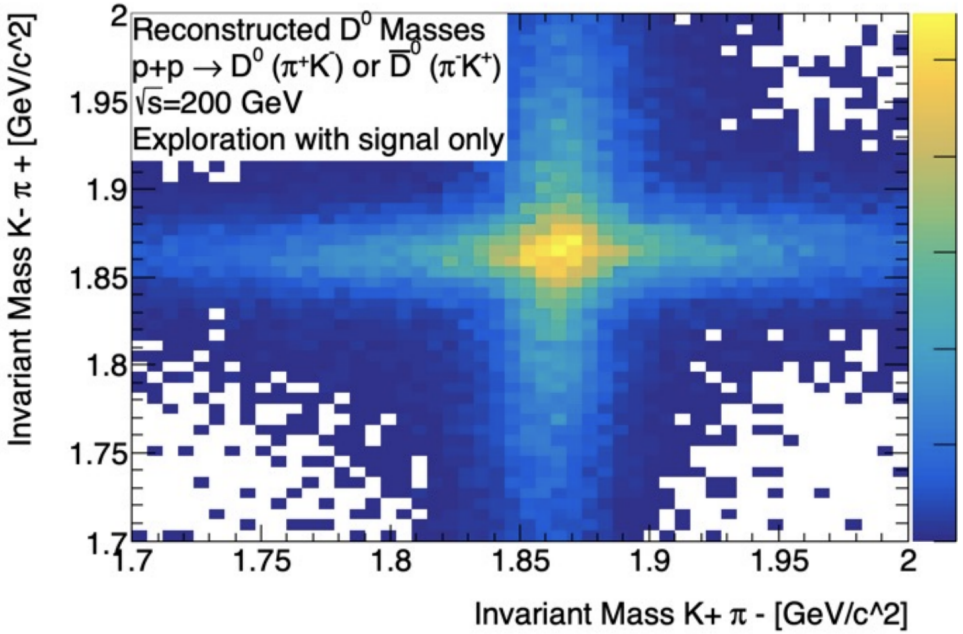
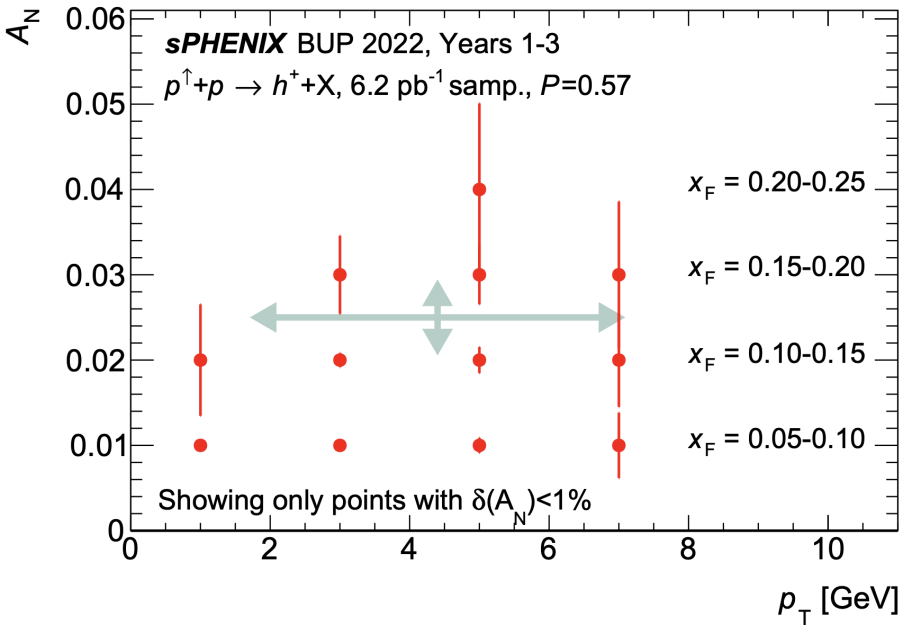
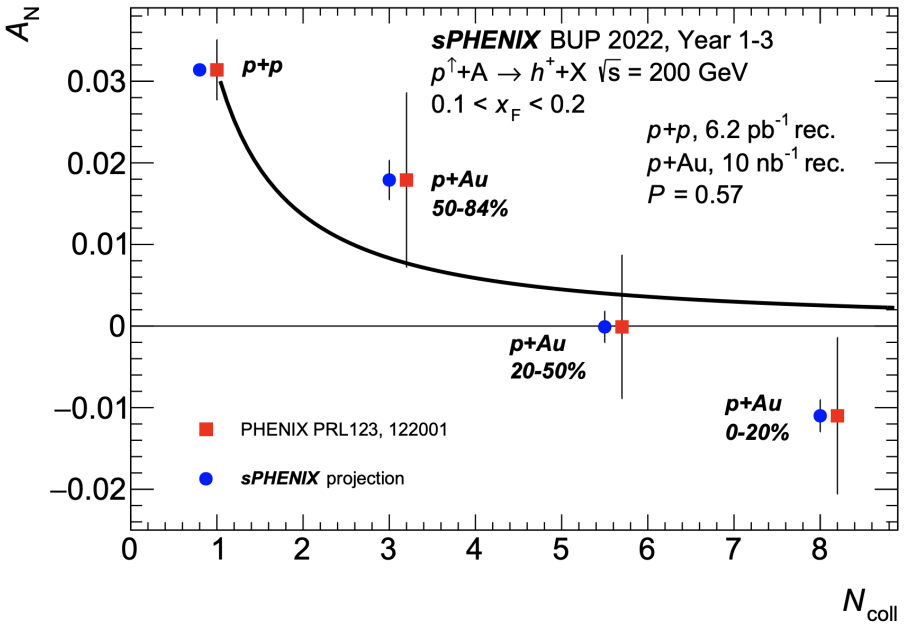
- Ongoing initial studies to use ML to separate D^0 and $\bar{D}^0$ signal



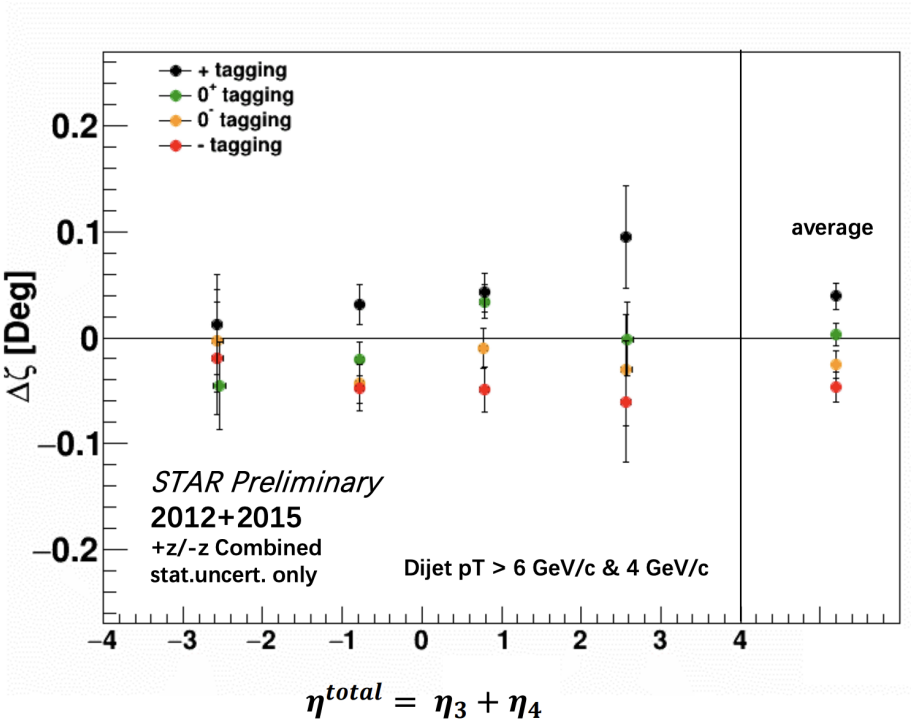
Hadron A_N in p+A

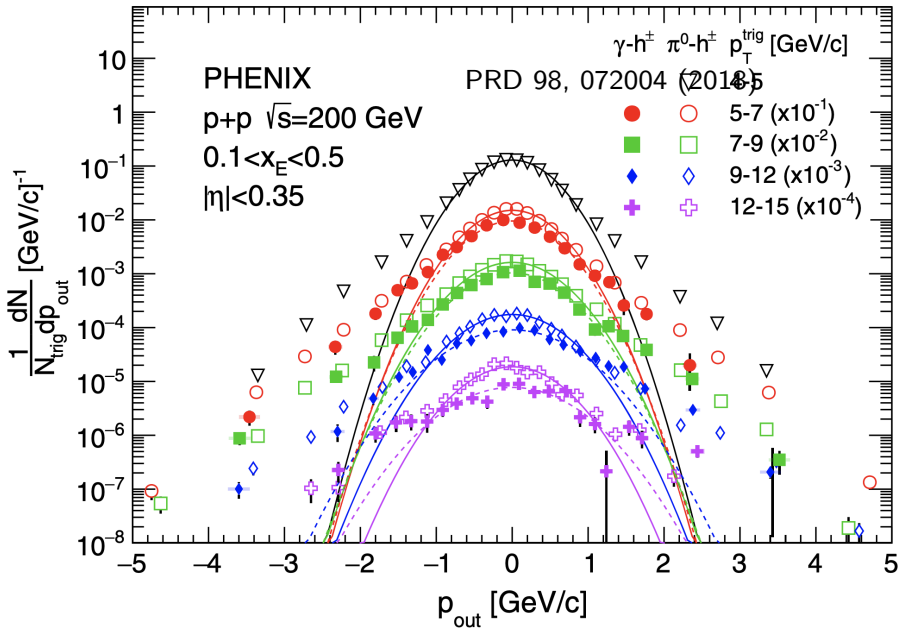




- Measured A dependence of moderately forward charged hadron A_N by PHENIX
  - STAR measured little to no suppression of forward π^0
- sPHENIX could further reduce uncertainties with certain z_{vtx} selections enabled by streaming recorded data

Sivers effects via γ-jet and dijet





- STAR and PHENIX use γ/di-hadron and dijet for various observables sensitive to TMDs
- sPHENIX, as a dedicated jet detector, will be able to make additional precise measurements of e.g. spin sorted p_{out}

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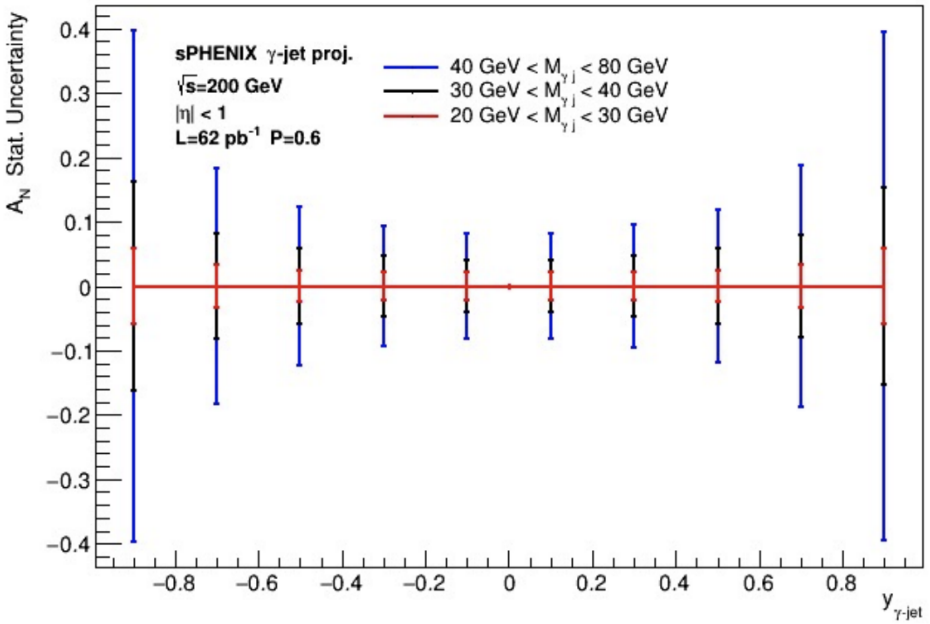

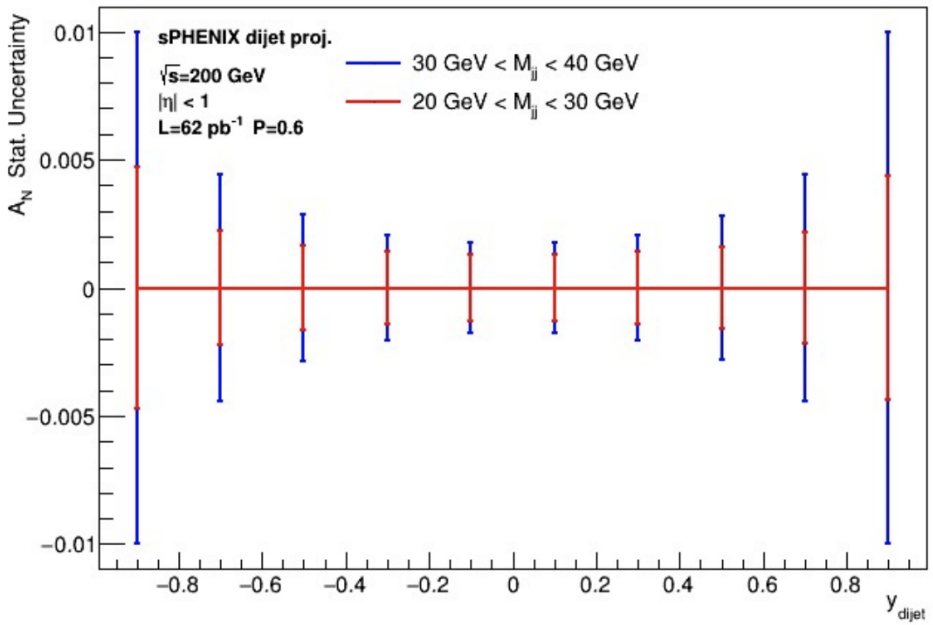

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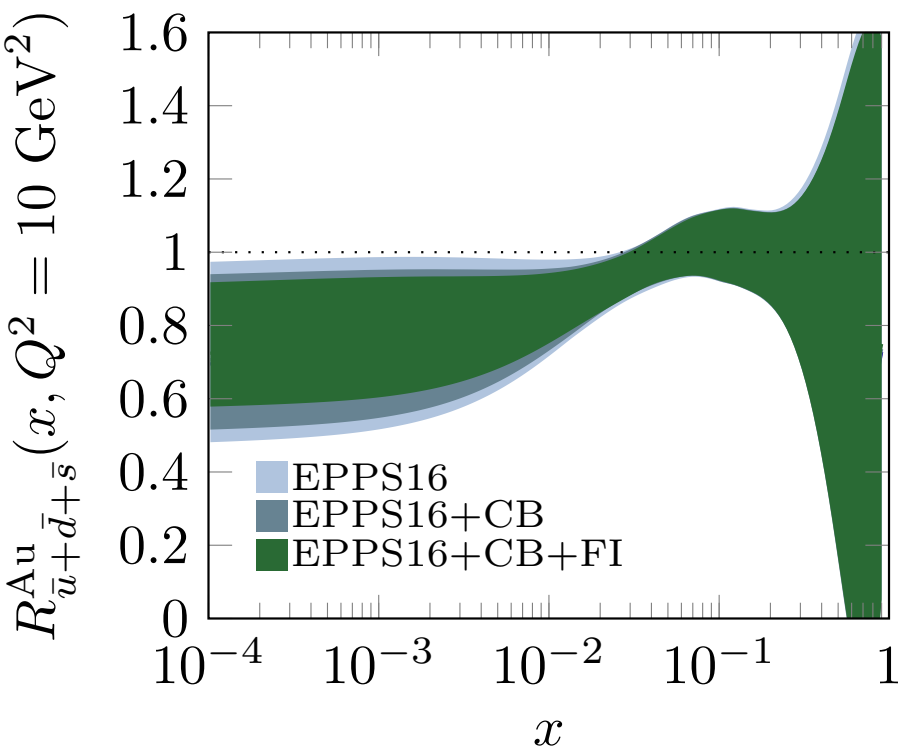
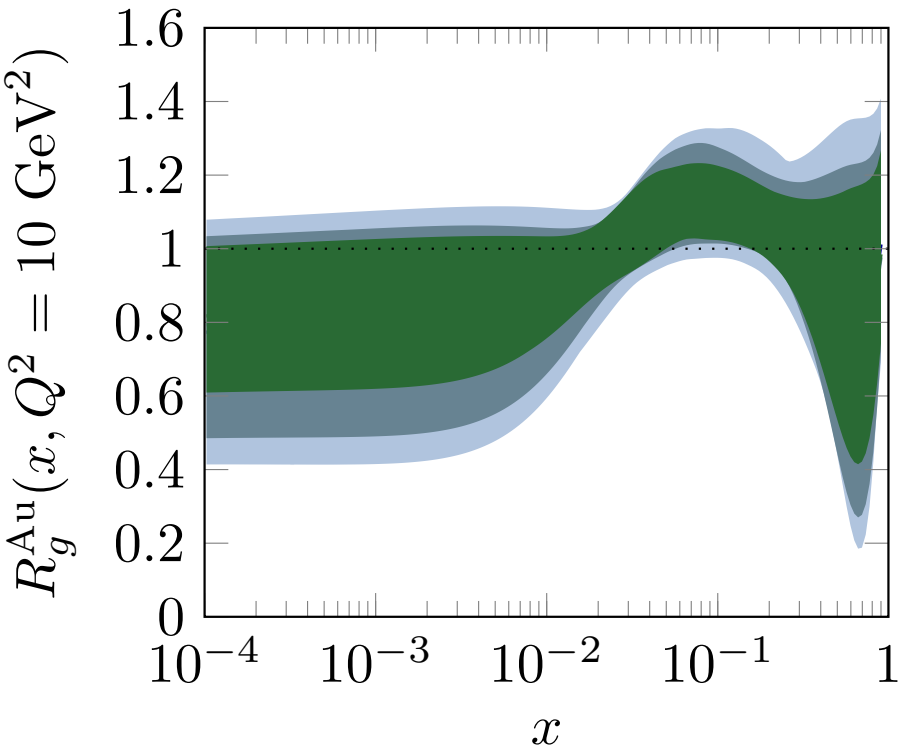
nPDF Constraints with γ-jet and dijet



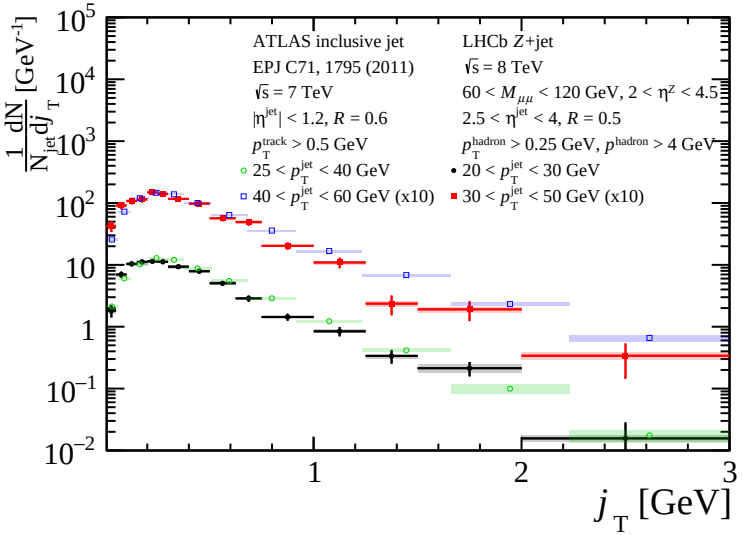


Helenius, Lajoie, JDO, Paakkinen, Paukkunen PRD 100, 014004 (2019)

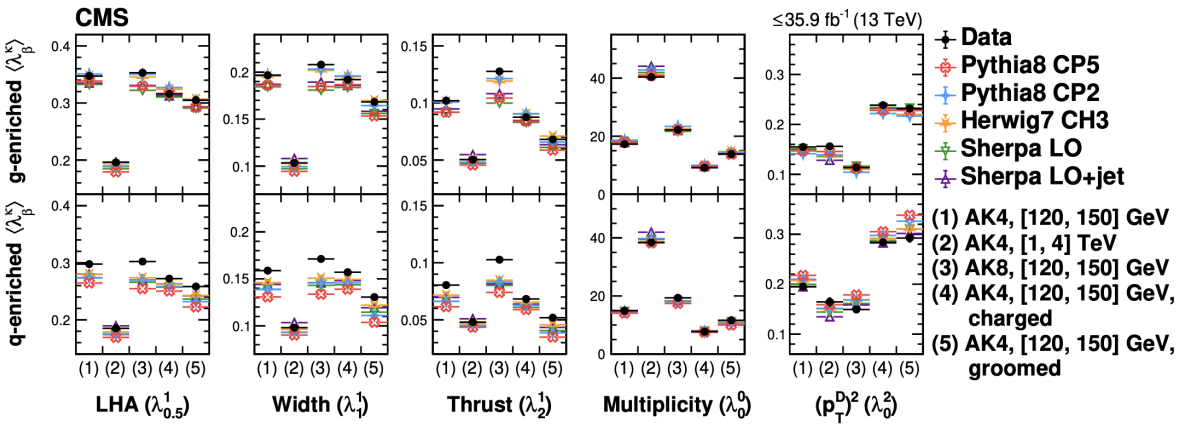
- Combined γ-jet and dijet measurements can be used to reduce impact of normalization uncertainties
- nPDF improvements at low Q^2

Hadronization and fragmentation

PRL 123, 232001 (2019)

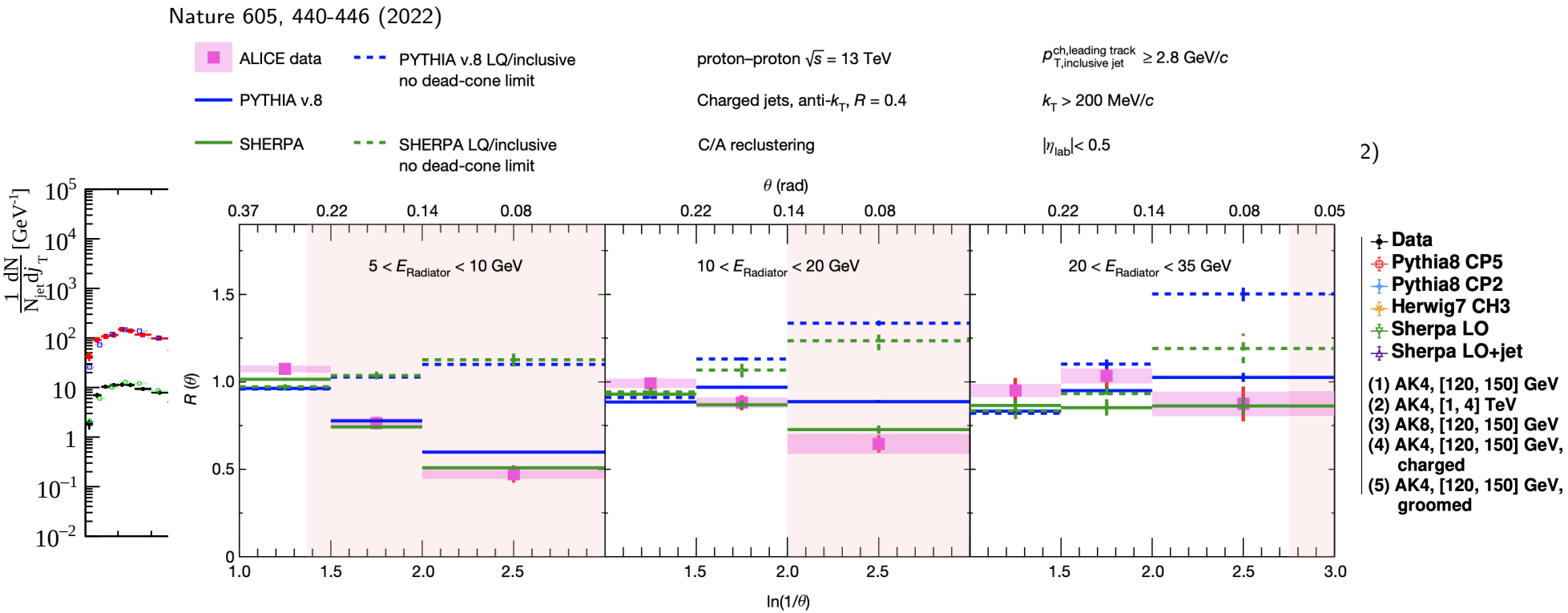


JHEP 01, 188 (2022)



- LHC experiments exploring hadronization and fragmentation with stronger parton→hadron relationships

Hadronization and fragmentation



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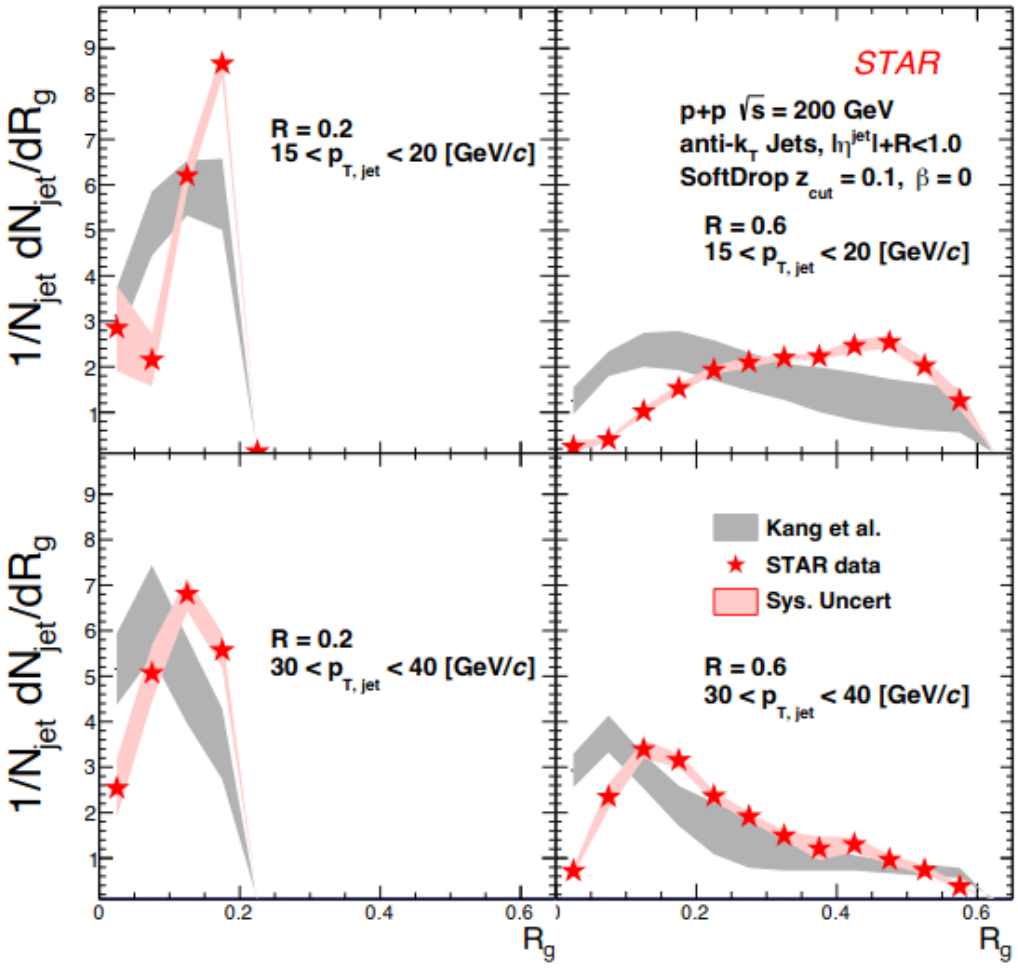
Hadronization and fragmentation

- Modern substructure techniques coming to RHIC



PLB 811, 135846 (2020)

Hadronization and fragmentation

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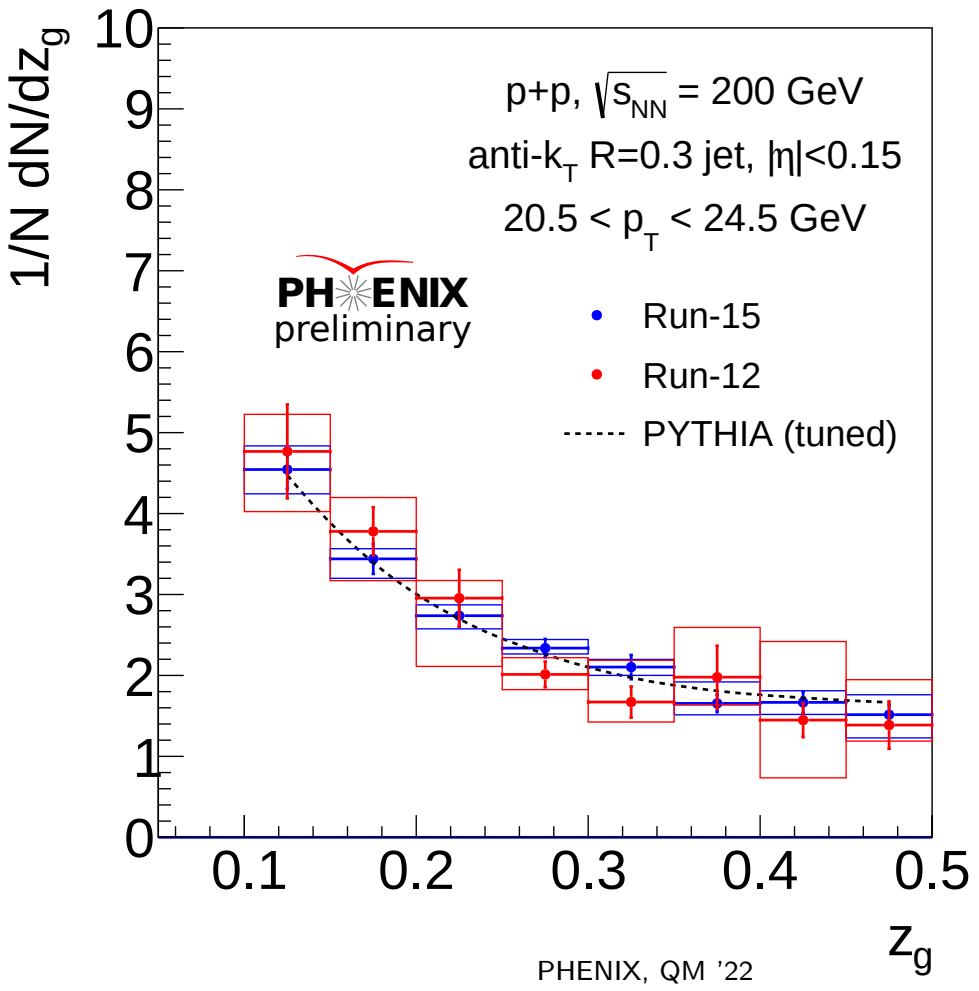
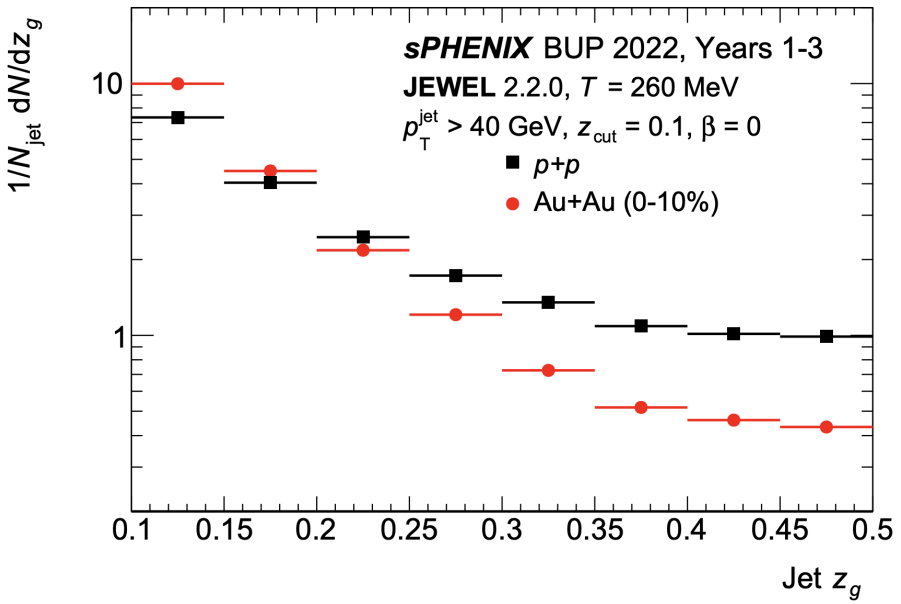
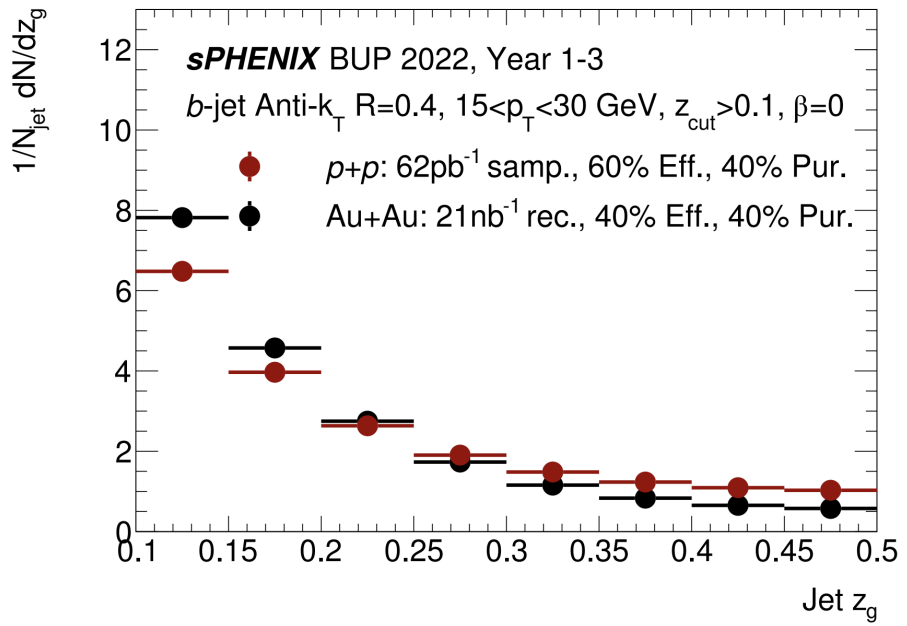


Hadronization and fragmentation

- Modern substructure techniques coming to RHIC
- Future measurements at sPHENIX will open up new research directions at RHIC, e.g. with comparisons of fragmentation patterns in light vs. heavy flavor jets





Conclusions

- sPHENIX is a detector designed for precision jet, high p_T charged hadron, and heavy flavor measurements
- Rich data set of transversely polarized $p + p$ and p+A collisions in Run 24
- High statistics observables enabled by high rates and unique streaming capabilities
- Opens up new opportunities at RHIC to further spin and cold QCD measurements sensitive to
  - Trigluon correlator
  - Sivers and Sivers-like effects
  - Hadronization and fragmentation
  - Many others, e.g. Collins and IFFs, Transversity$\rightarrow$ tensor charge, and more...

Extras