

Spin and Cold QCD Physics at sPHENIX

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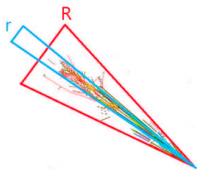
RHIC/AGS AUM 2022

June 8, 2022



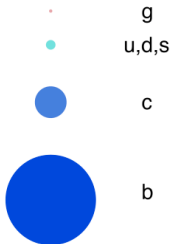
Jet correlation & substructure

Vary momentum/
angular
size of probe



Parton energy loss

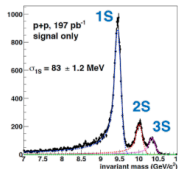
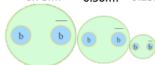
Vary mass/
momentum
of probe



Upsilon spectroscopy

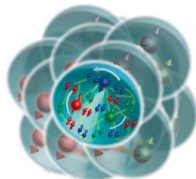
Vary size
of the probe

$\Upsilon(3s)$ - 0.78fm $\Upsilon(2s)$ - 0.56fm $\Upsilon(1s)$ - 0.28fm



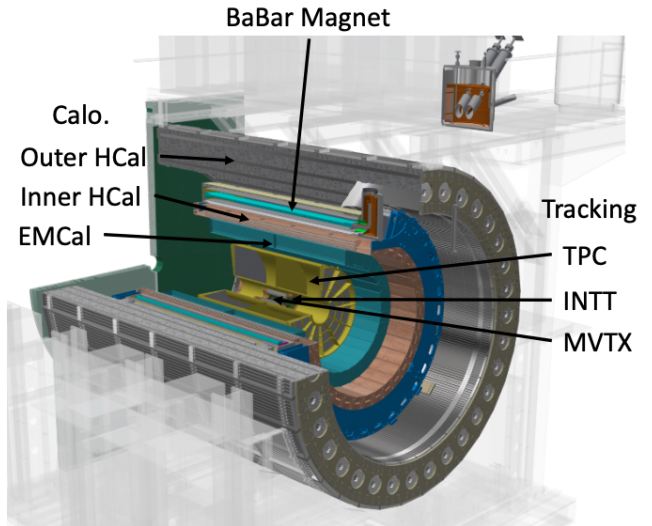
Cold QCD

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

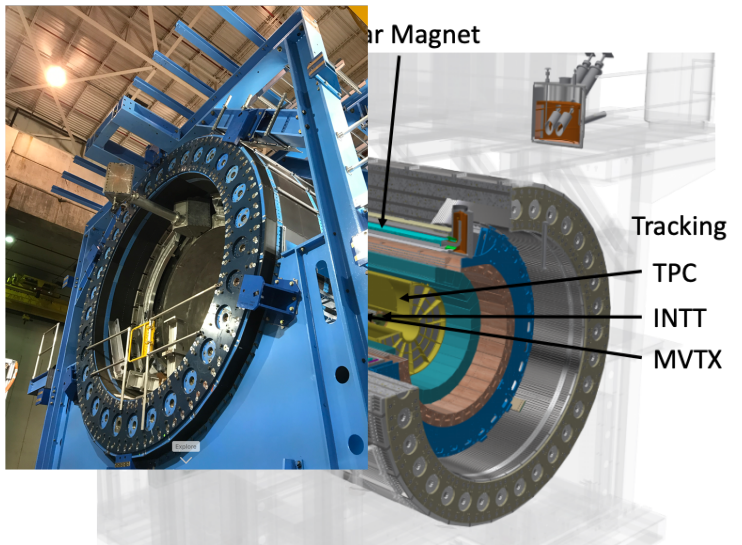
sPHENIX detector



July 28, 2020

sPHENIX at RHIC

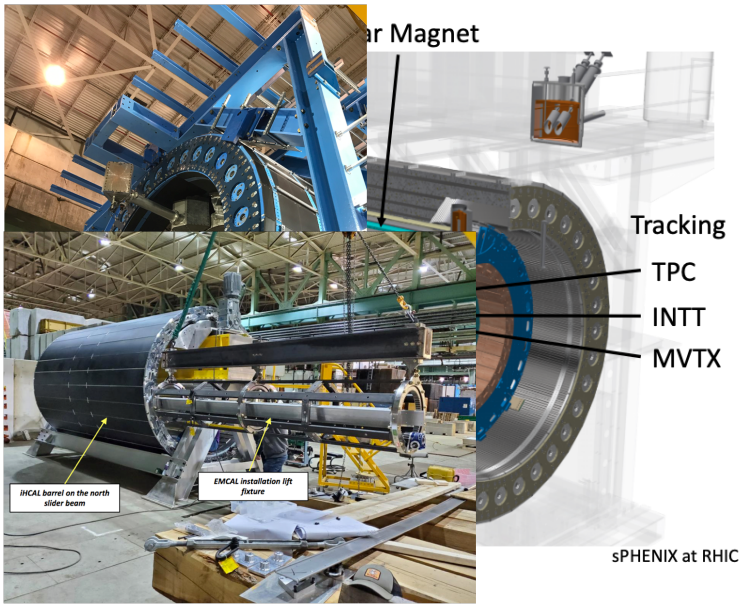
sPHENIX detector



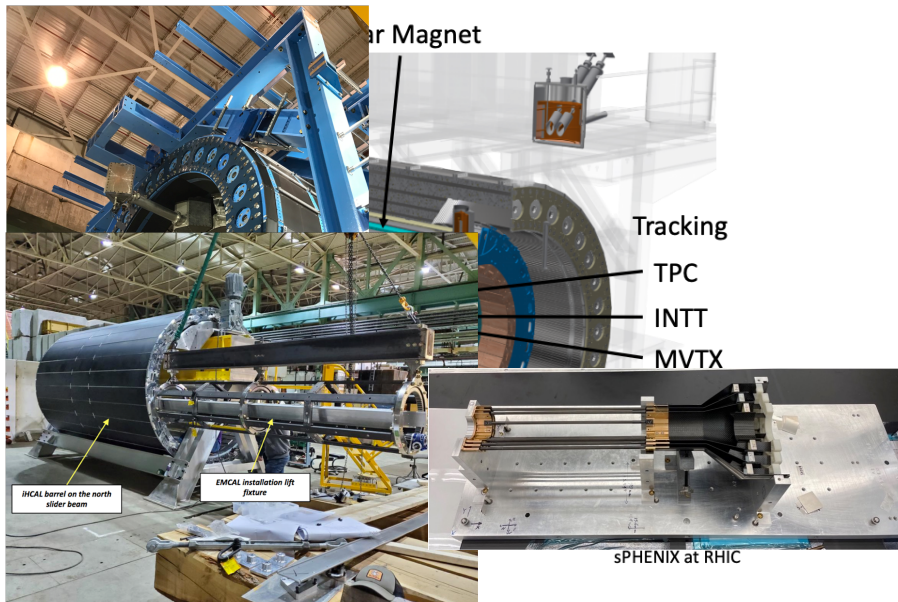
July 28, 2020

sPHENIX at RHIC

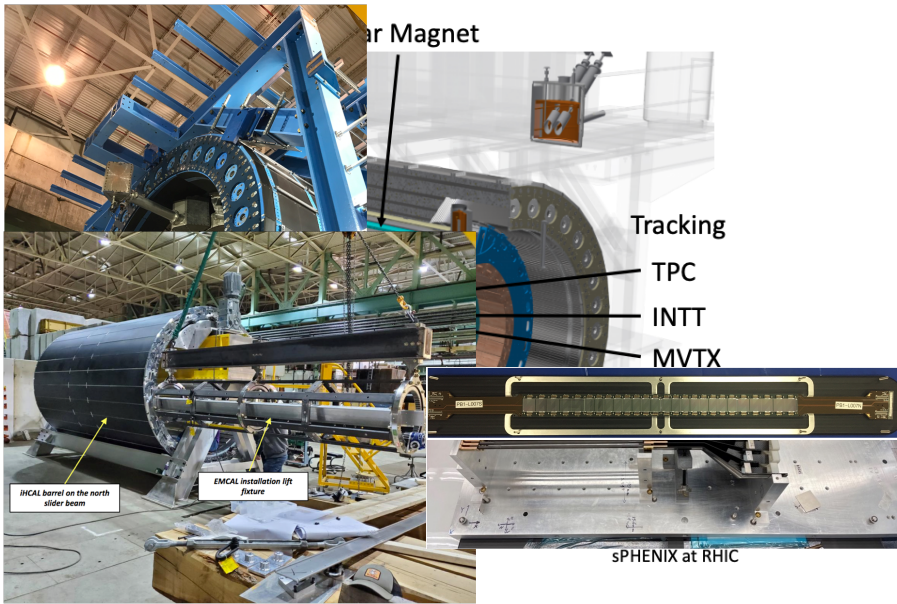
sPHENIX detector



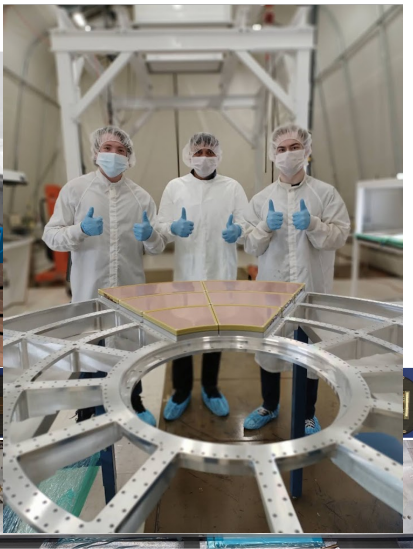
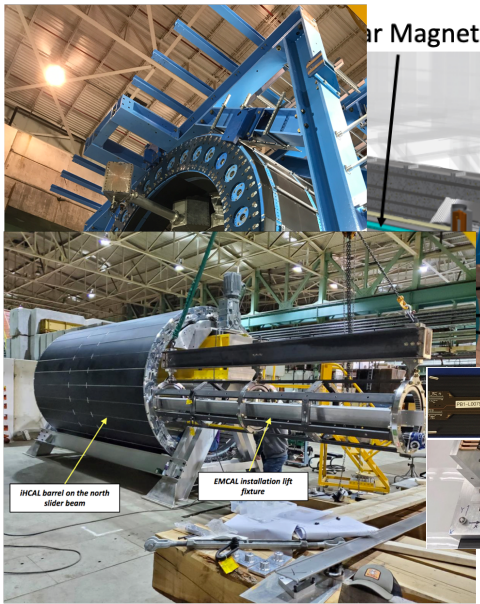
sPHENIX detector



sPHENIX detector



sPHENIX detector

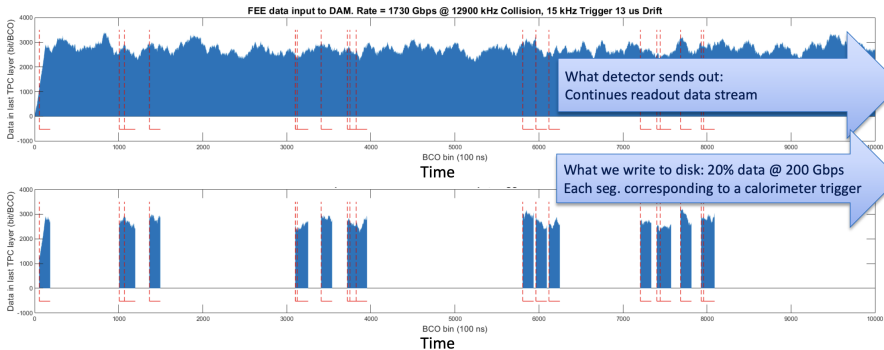


Proposed run schedule

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

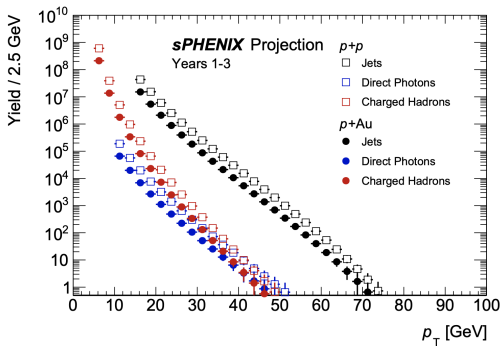
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $ z < 10$ cm	Samp. Lum. $ z < 10$ cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb ⁻¹	4.5 (6.9) nb ⁻¹
2024	$p^\uparrow p^\uparrow$	200	24 (28)	12 (16)	0.3 (0.4) pb ⁻¹ [5 kHz] 4.5 (6.2) pb ⁻¹ [10%-str]	45 (62) pb ⁻¹
2024	p^\uparrow +Au	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)

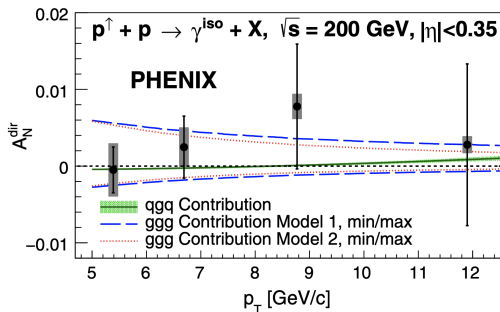
cQCD kinematic reach



- 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

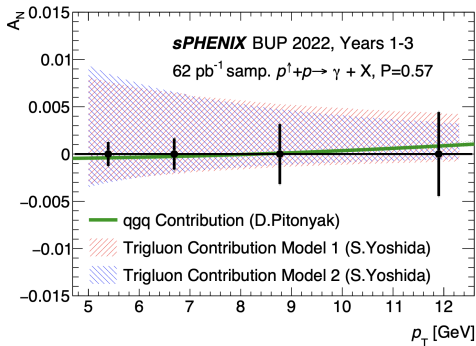
- PHENIX recently published first direct γ A_N from RHIC



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

Trigluon correlator with direct γ

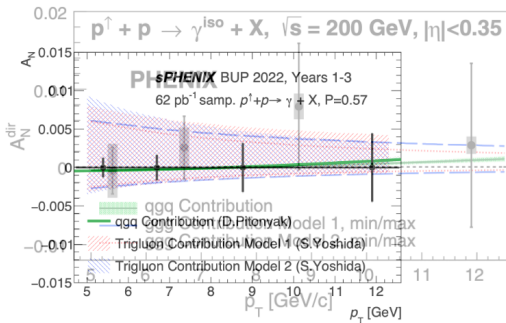
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- sPHENIX will be able to improve upon this first measurement!
- Goal to have 2-3 bins which will help constrain trigluon contribution



sPHENIX BUP 2022

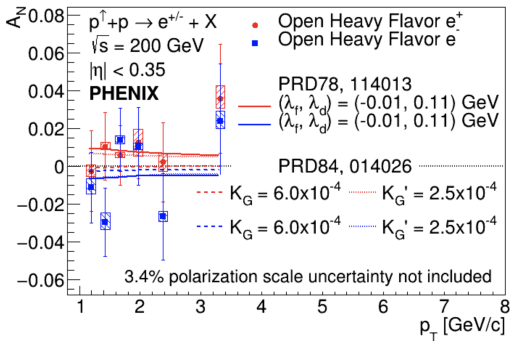
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Trigluon correlator with open heavy flavor

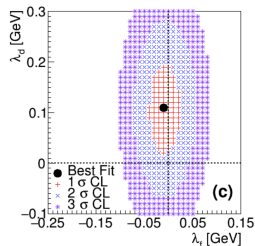
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arXiv:2204.12899

Trigluon correlator with open heavy flavor

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- Constraints on gluon correlators extracted for charge separated measurements



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

$$\sqrt{s} = 200 \text{ GeV}$$

$$|\eta| < 0.35$$

PHENIX

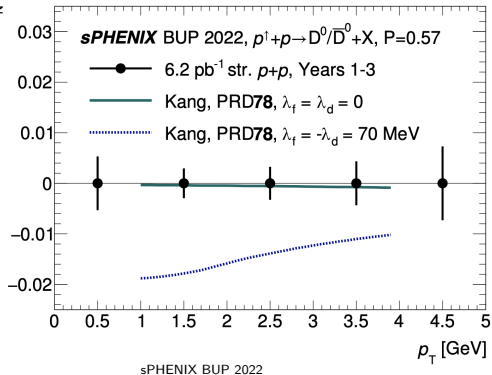
Theory: PRD78, 114013

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

arXiv:2204.12899

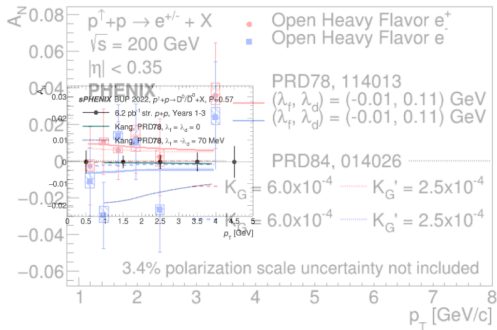
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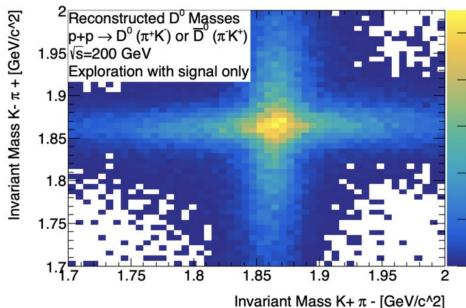
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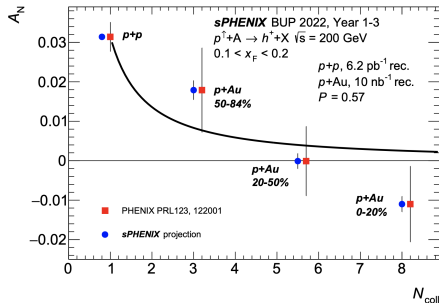
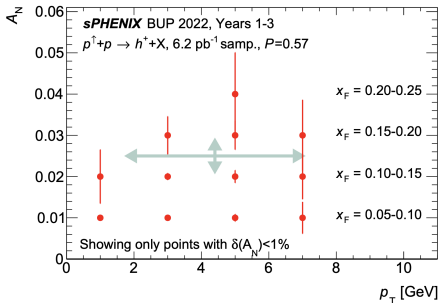
sPHENIX BUP 2022

Trigluon correlator with open heavy flavor

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- sPHENIX to improve upon first measurement with D^0
- Ongoing initial studies to use ML to separate D^0 and \bar{D}^0 signal

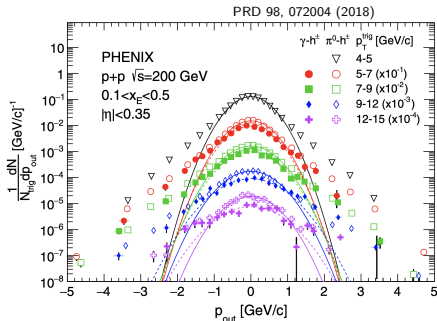
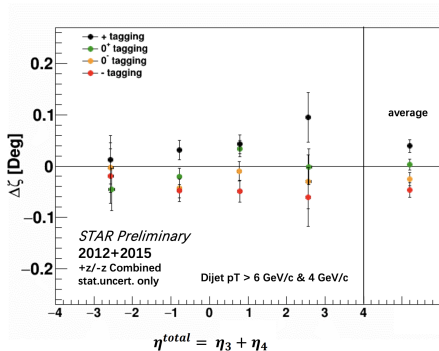


Hadron A_N in $p+A$



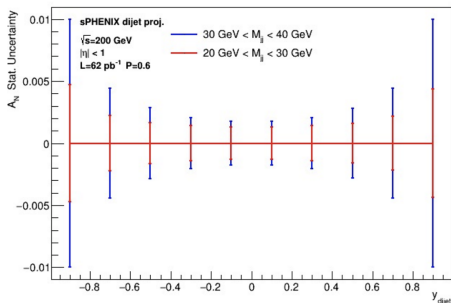
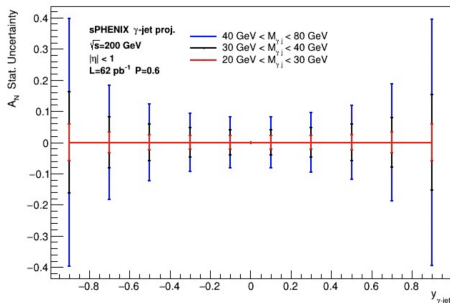
- Measured A dependence of moderately forward charged hadron A_N by PHENIX
 - STAR measured little to no suppression of forward π^0
- sPHENIX could further reduce uncertainties with certain Z_{vtx} selections enabled by streaming recorded data

Sivers effects via γ -jet and dijet



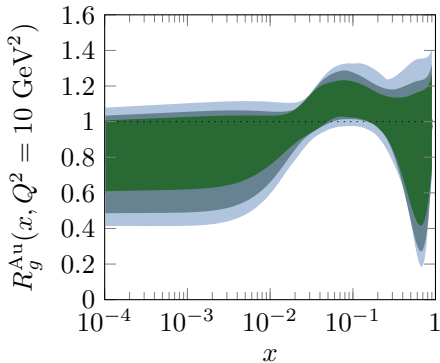
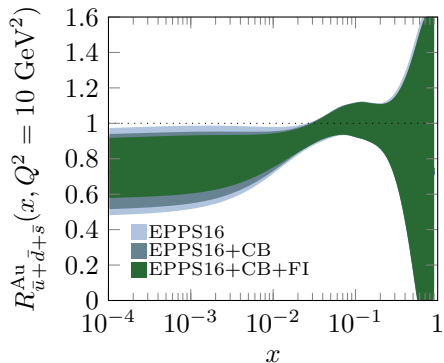
- STAR and PHENIX use γ /di-hadron and dijet for various observables sensitive to TMDs
- sPHENIX, as a dedicated jet detector, will be able to make additional precise measurements of e.g. spin sorted p_{out}

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nPDF Constraints with γ -jet and dijet

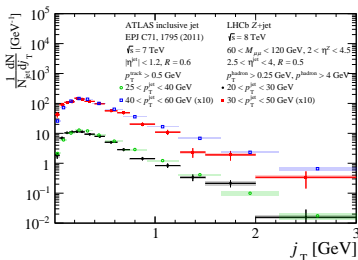


Helenius, Lajoie, JDO, Paakinen, Paukkunen PRD 100, 014004 (2019)

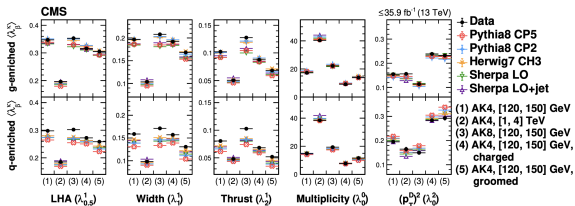
- Combined γ -jet and dijet measurements can be used to reduce impact of normalization uncertainties
- nPDF improvements at low Q^2

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

Nature 605, 440-446 (2022)

■ ALICE data - - - PYTHIA v.8 LQ/inclusive
 no dead-cone limit
— PYTHIA v.8
— SHERPA - - - SHERPA LQ/inclusive
 no dead-cone limit

proton-proton $\sqrt{s} = 13$ TeV

Charged jets, anti- k_r , $R = 0.4$

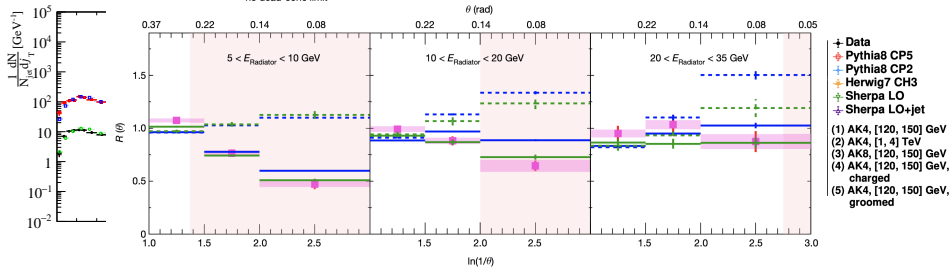
C/A reclustering

$p_{T, \text{inclusive jet}}^{\text{ch, leading track}} \geq 2.8$ GeV/c

$k_T > 200$ MeV/c

$|\eta_{\text{lab}}| < 0.5$

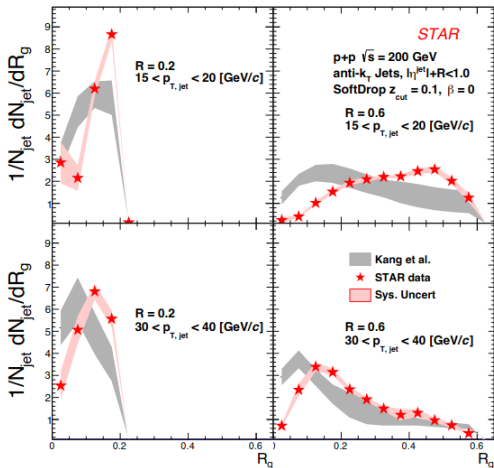
2)



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

Hadronization and fragmentation

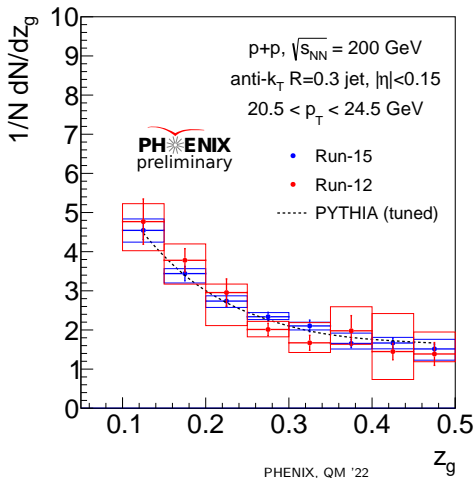
- Modern substructure techniques coming to RHIC



PLB 811, 135846 (2020)

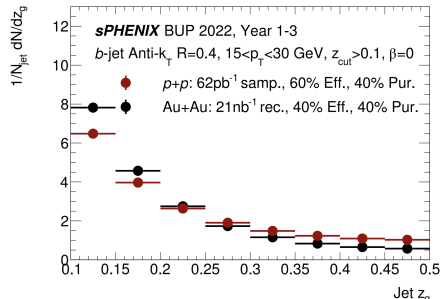
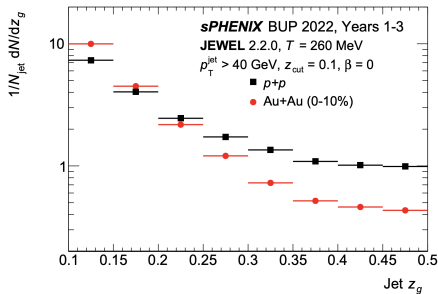
Hadronization and fragmentation

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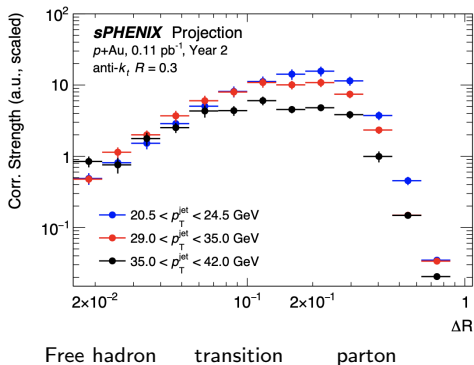


Hadronization and fragmentation

- 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



Hadronization and fragmentation



- New observables explored, e.g. energy-energy correlators
- EECs sensitive to wide range of fragmentation+hadronization process
- sPHENIX will have large jet and high p_T track statistics to study both $p + p$ and (if any) cold nuclear modification

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

sPHENIX timeline

