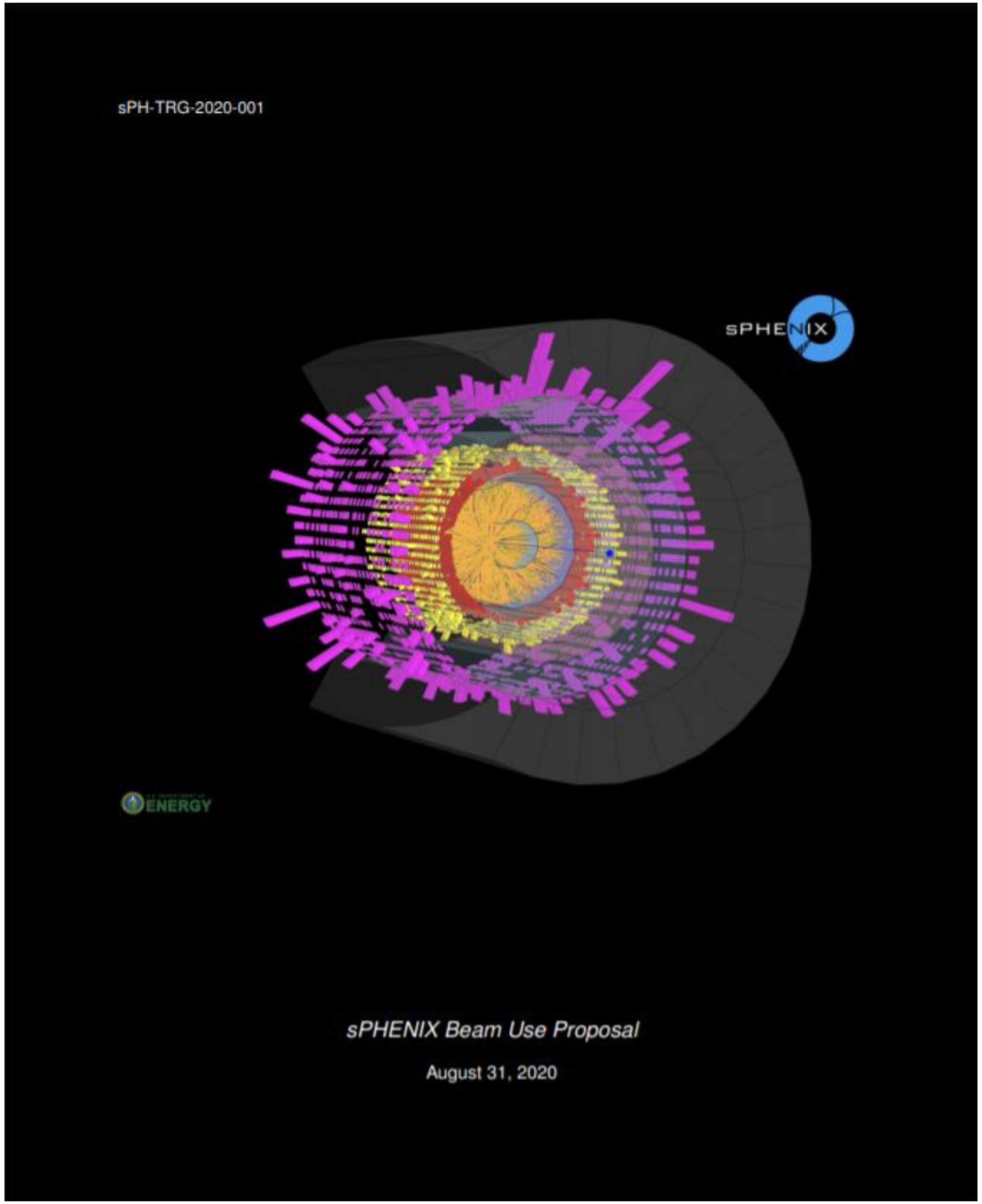
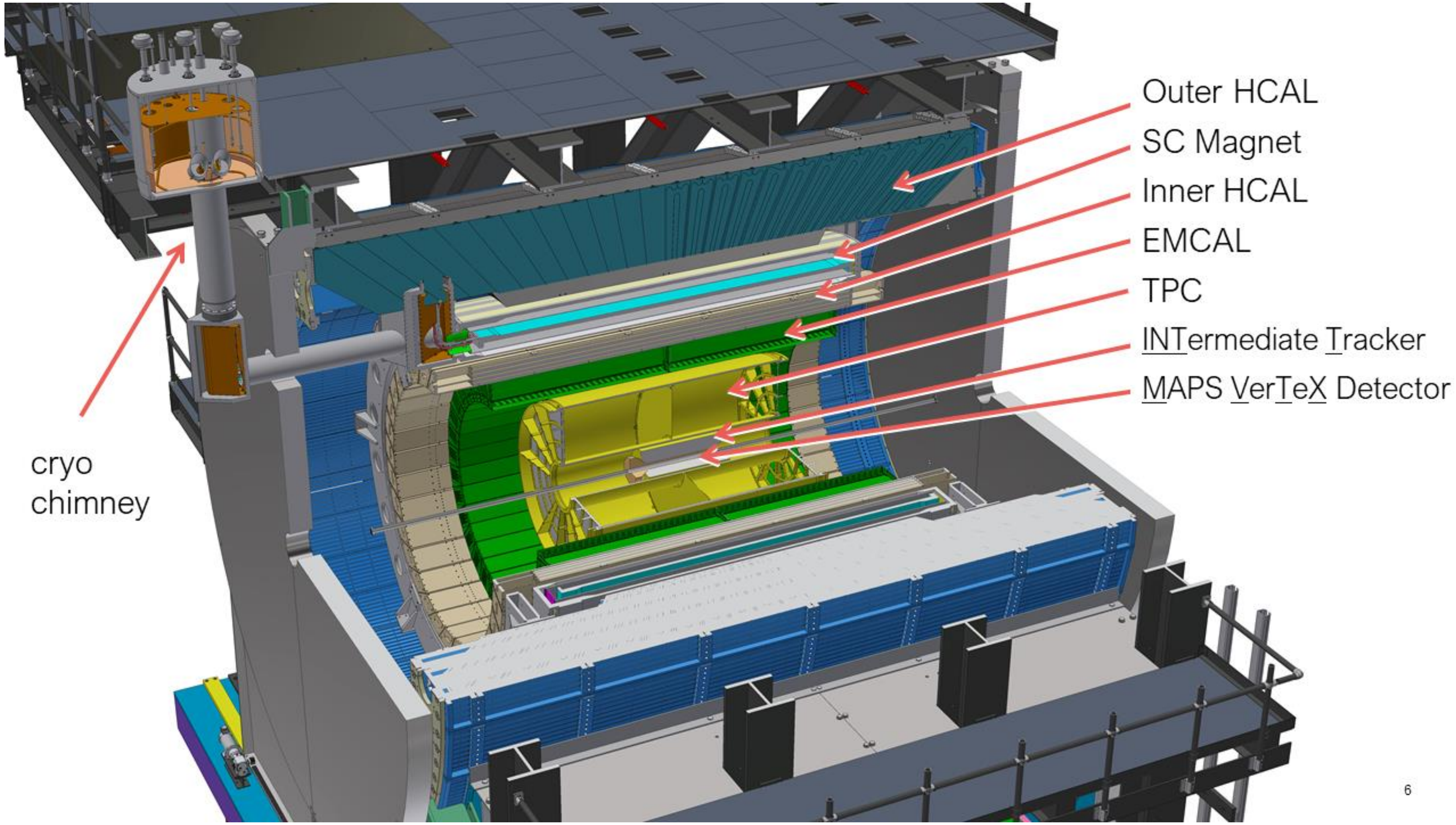
The future Cold QCD program with the sPHENIX detector

Desmond Shangase (University of Michigan) on behalf of the sPHENIX Collaboration
RHIC/AGS Annual Users Meeting - October 22nd 2020

Contents

- sPHENIX Detector Design + Run
- Cold QCD Measurements
  - Transverse Spin Measurements
  - Unpolarized Measurements





sPHENIX Detector

- Full azimuthal detector (Central Barrel)
- Data collection expected to begin 2023
- Cold QCD Physics Program
  - Parton Dynamics (TMD PDFs)
  - Proton/Nuclear Structure (PDFs)
  - Hadronization (FFs, $\hat{q}$, etc.)

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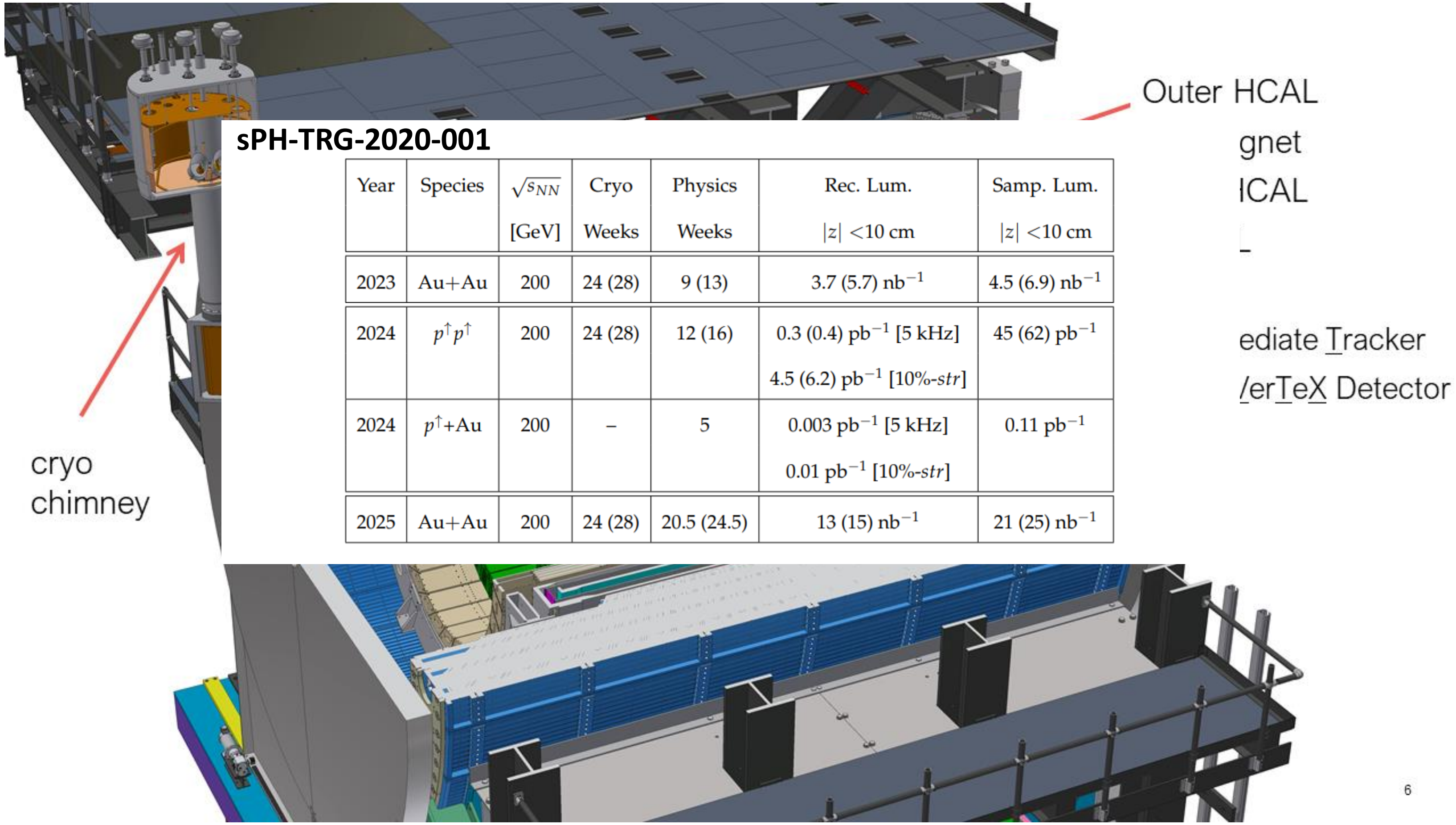
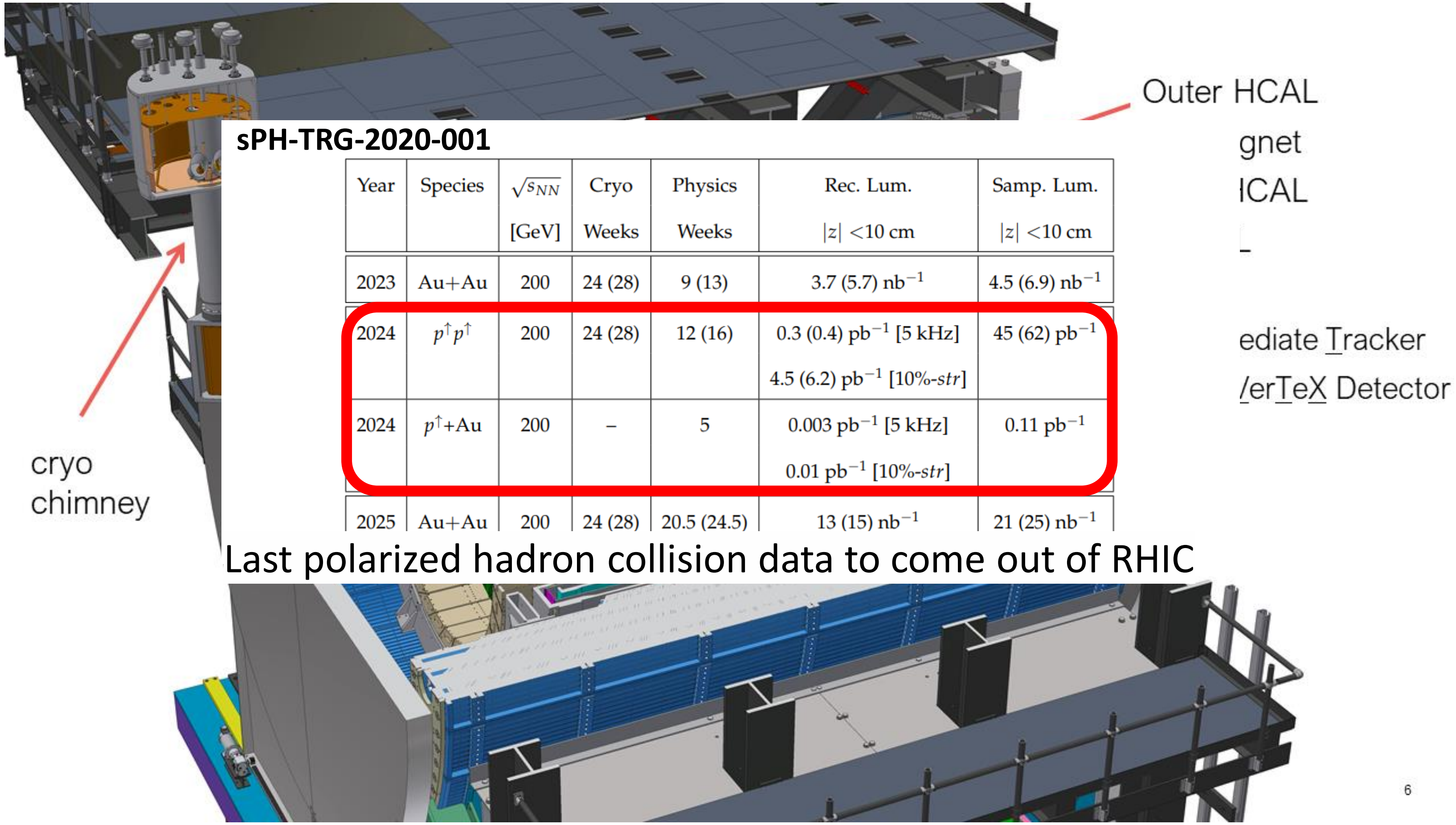


sPH-TRG-2020-001

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}

sPHENIX Detector



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Last polarized hadron collision data to come out of RHIC

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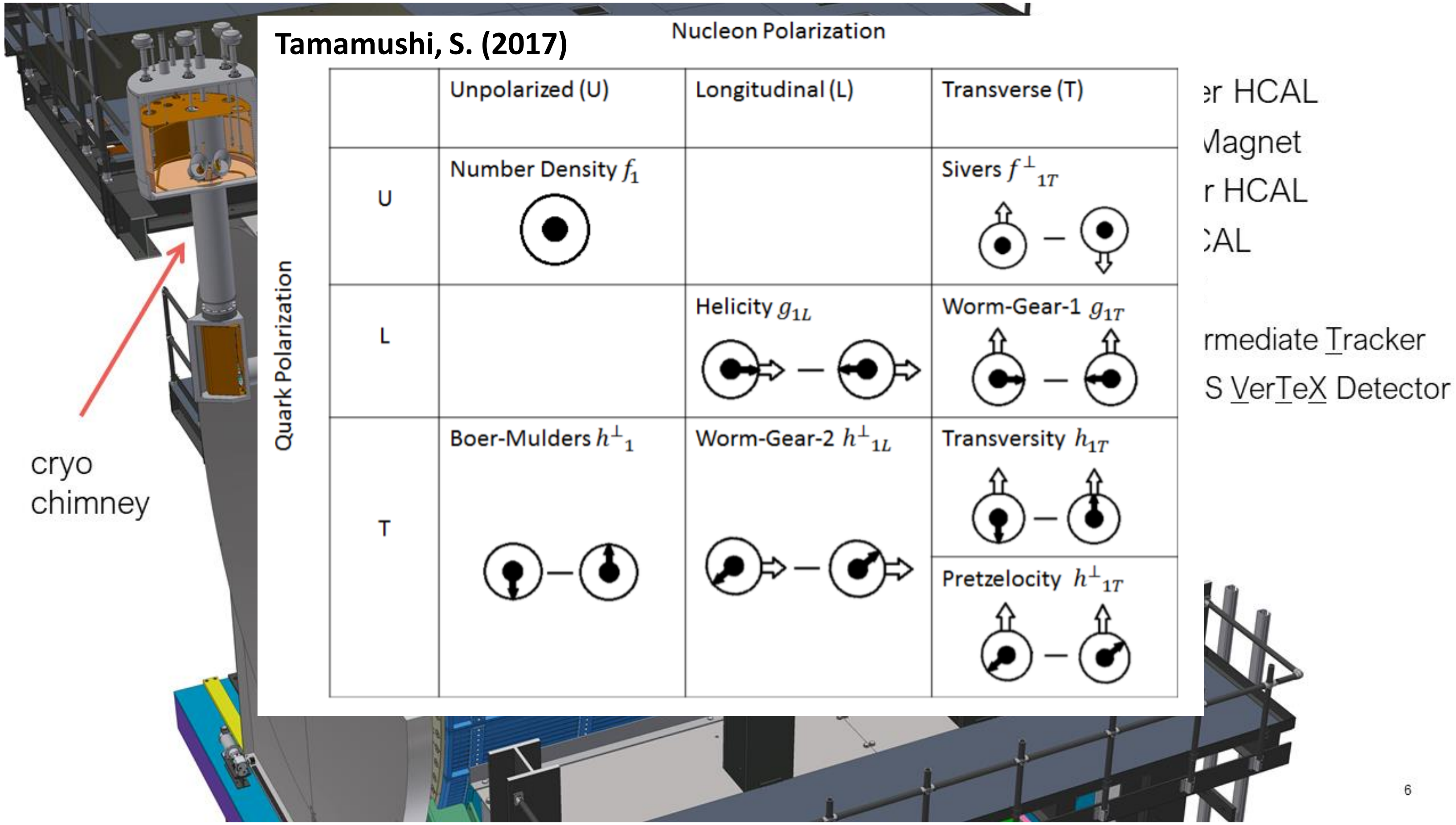

	Unpolarized (U)	Longitudinal (L)	Transverse (T)
U	Number Density f_1		Sivers $f^{\perp}_{1T}$
L		Helicity g_{1L}	Worm-Gear-1 g_{1T}
T	Boer-Mulders $h^{\perp}_1$	Worm-Gear-2 $h^{\perp}_{1L}$	Transversity h_{1T} Pretzelocity $h^{\perp}_{1T}$

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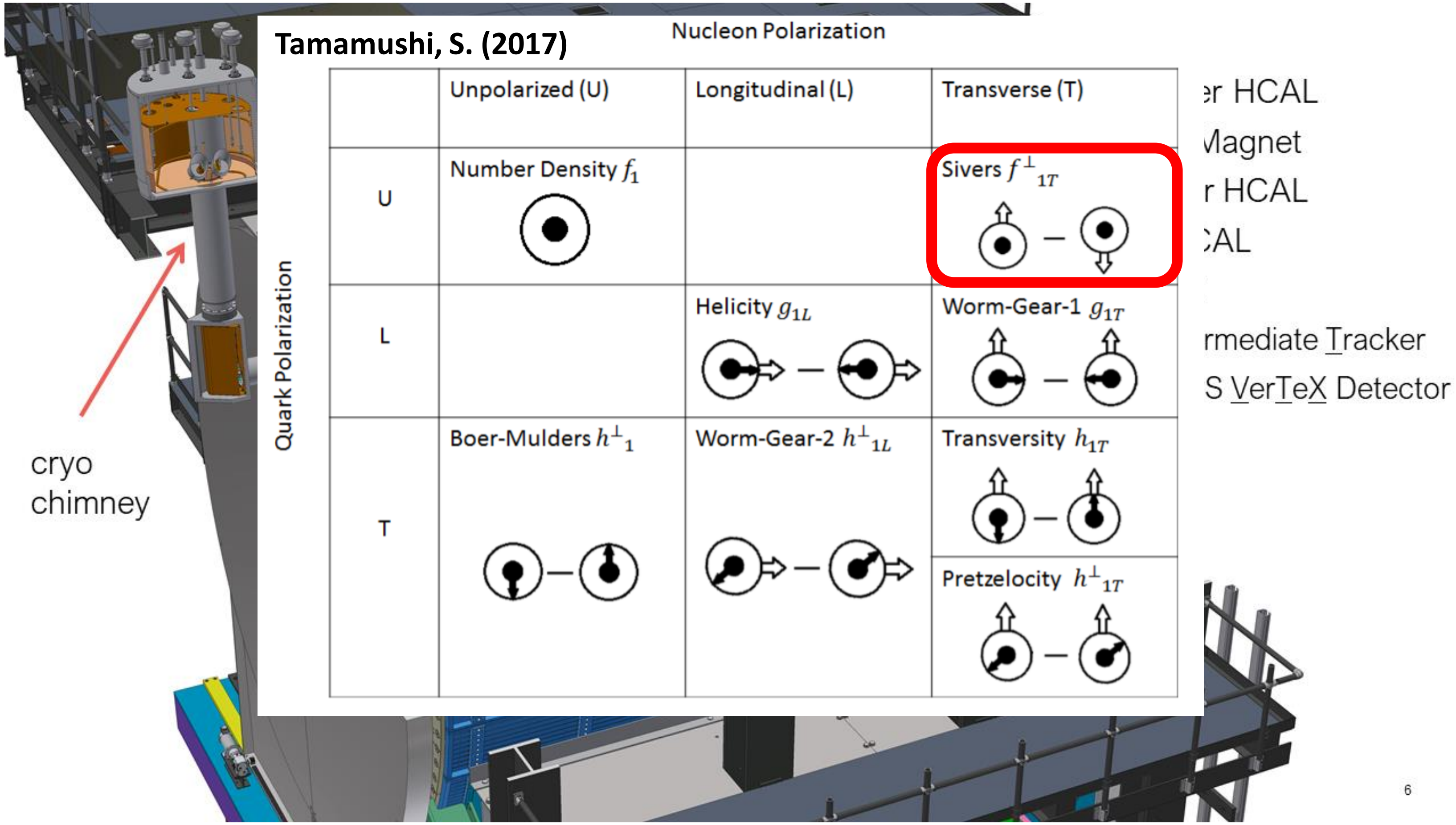

Tamamushi, S. (2017)

Quark Polarization	Nucleon Polarization: Unpolarized (U)	Longitudinal (L)	Transverse (T)
U	Number Density f_1		Sivers $f^{\perp}_{1T}$
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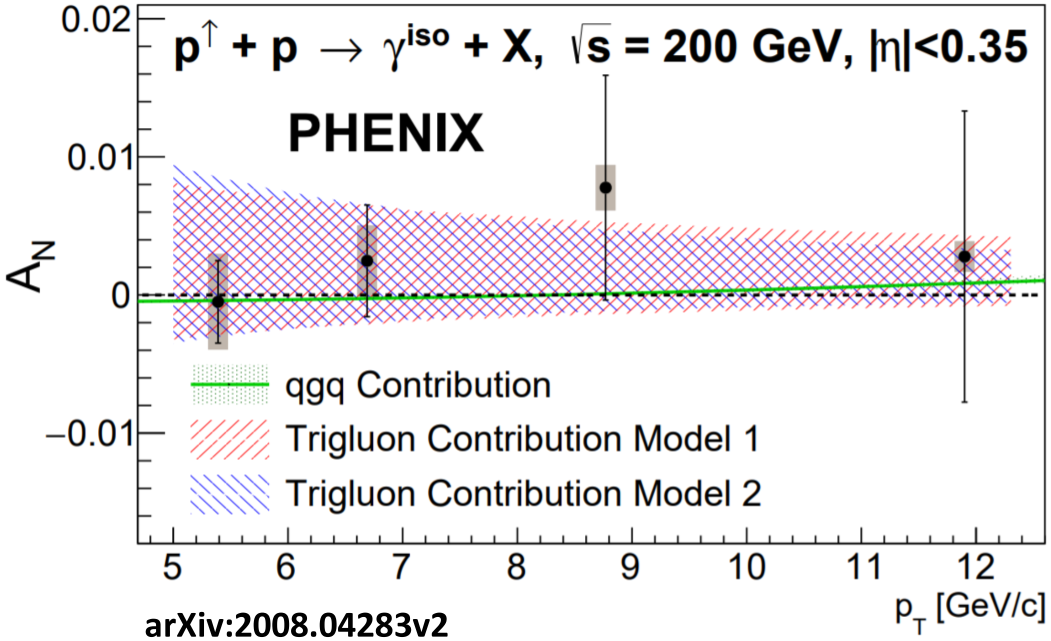
Transverse Spin Measurements in $p^{\uparrow}+p^{(\uparrow)}$ and $p^{\uparrow}+Au$

Gluon Dynamics via A_N

Direct Photon Asymmetry

- Will be used to constrain twist-3 framework w.r.t. gluon distributions
  - Coupled to $f_{1T}^{\perp}$ of gluons in the proton
- $A_N(\phi_q) = \frac{1}{P}\frac{Y^{\uparrow} - R \cdot Y^{\downarrow}}{Y^{\uparrow} + R \cdot Y^{\downarrow}} = \frac{1}{P}\frac{L(\sigma^{\uparrow}(\phi_q) - R \cdot \sigma^{\downarrow}(\phi_q))}{L(\sigma^{\uparrow}(\phi_q) + R \cdot \sigma^{\downarrow}(\phi_q))}$



arXiv:2008.04283v2

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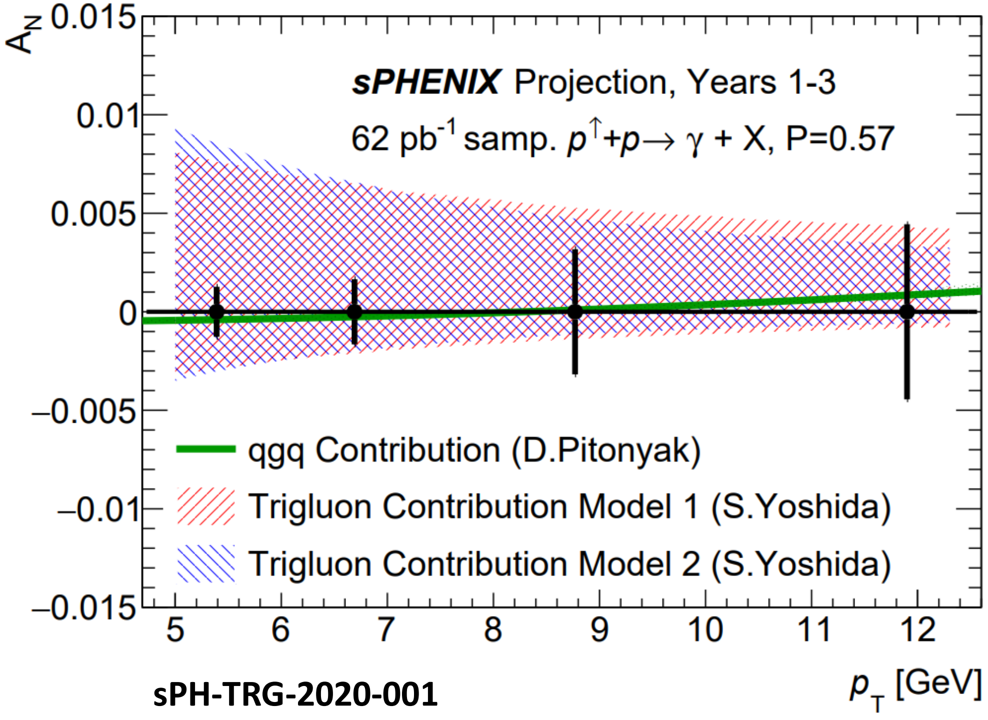

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Gluon Dynamics via A_N

Heavy Flavor Asymmetry

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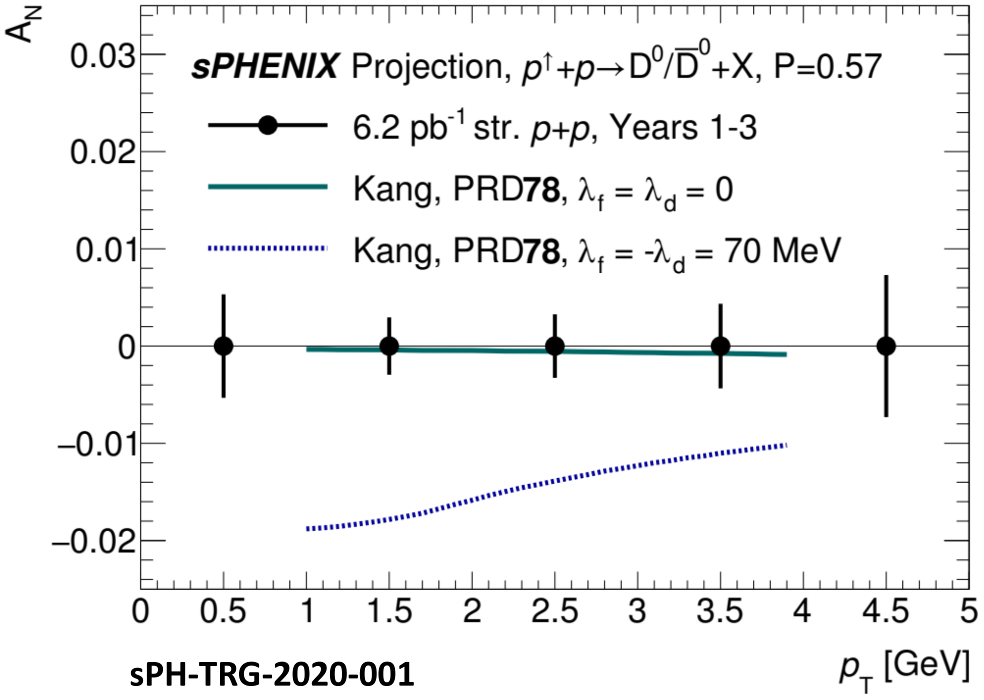
- $A_N(\phi_q) = \frac{1}{P}\frac{Y^{\uparrow} - R \cdot Y^{\downarrow}}{Y^{\uparrow} + R \cdot Y^{\downarrow}} = \frac{1}{P}\frac{L(\sigma^{\uparrow}(\phi_q) - R \cdot \sigma^{\downarrow}(\phi_q))}{L(\sigma^{\uparrow}(\phi_q) + R \cdot \sigma^{\downarrow}(\phi_q))}$
- Possible due to sPHENIX streaming DAQ
  - 10% of collisions will be recorded in this triggerless configuration



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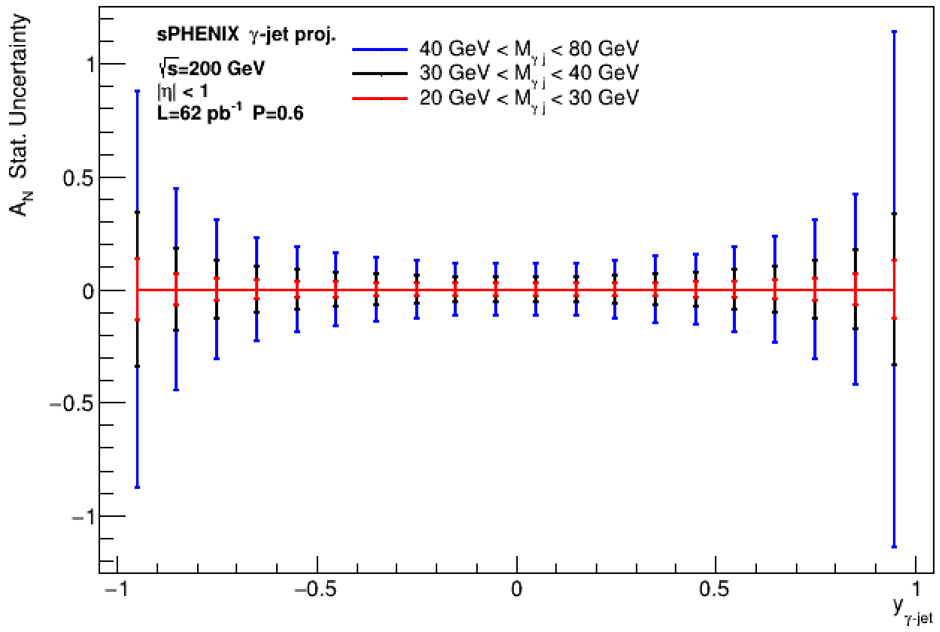
Gluon Dynamics via A_N

Gamma-jet Asymmetry

- Gluon-induced Compton scattering
  - Constrain gluon spin distribution in polarized proton
  - sPHENIX is designed to be a jet detector to the relevance of this and similar channels to heavy-ion physics



Parton Dynamics via A_N

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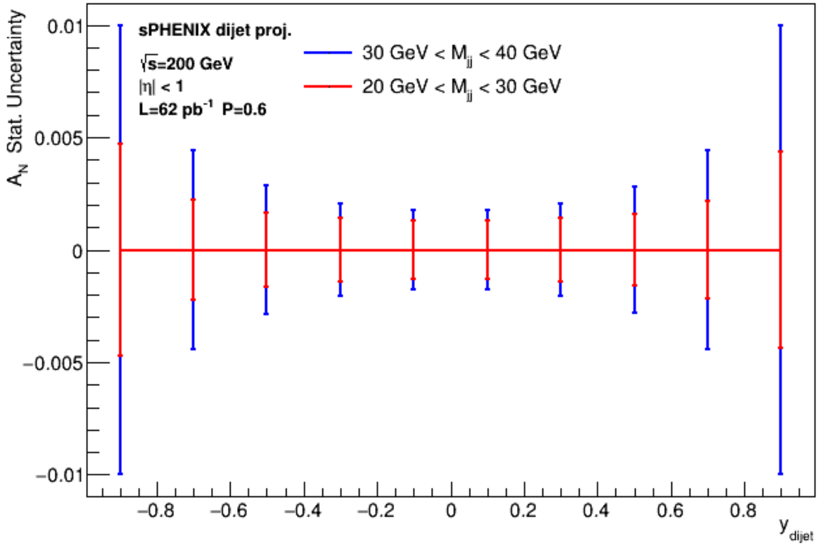
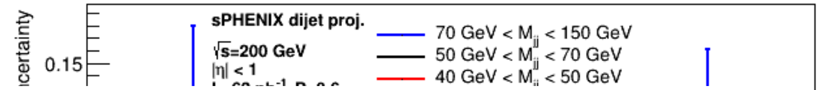
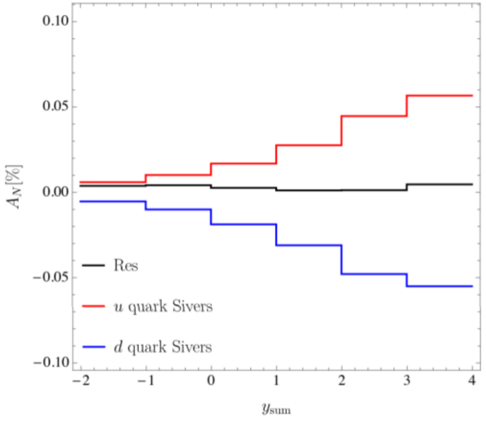
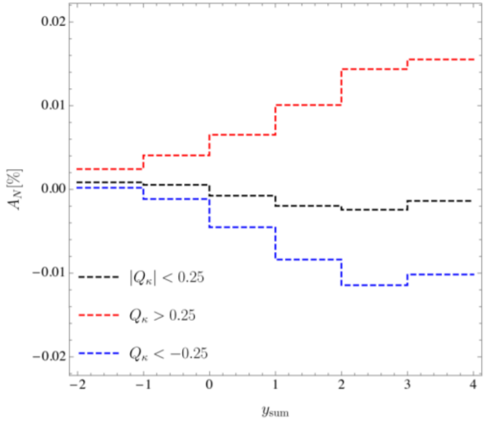
Dijet Asymmetry

- Charge-tagging can allow for flavor-dependent Sivers asymmetry measurement







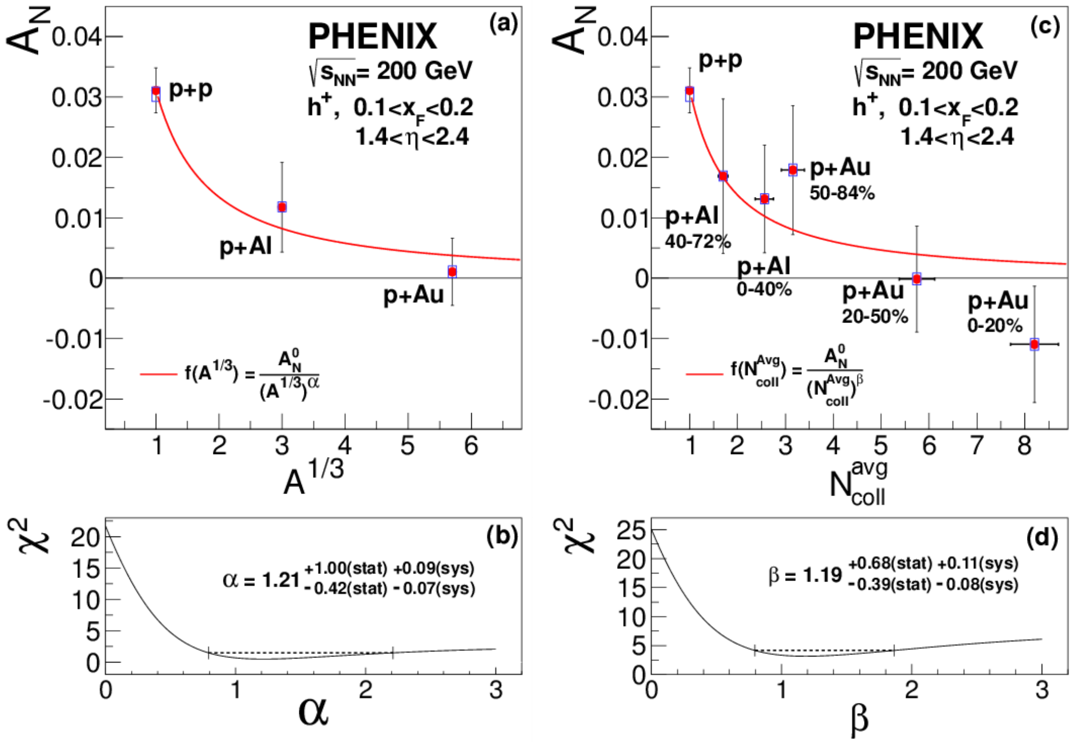


arXiv:2008.05470v2 [hep-ph]

Nuclear Effects in A_N

Charged hadron Asymmetry

- Noticeable decrease in A_N amplitude in differing collision systems
  - At forward pseudorapidity and intermediate x_F
  - Currently no consensus on this behavior

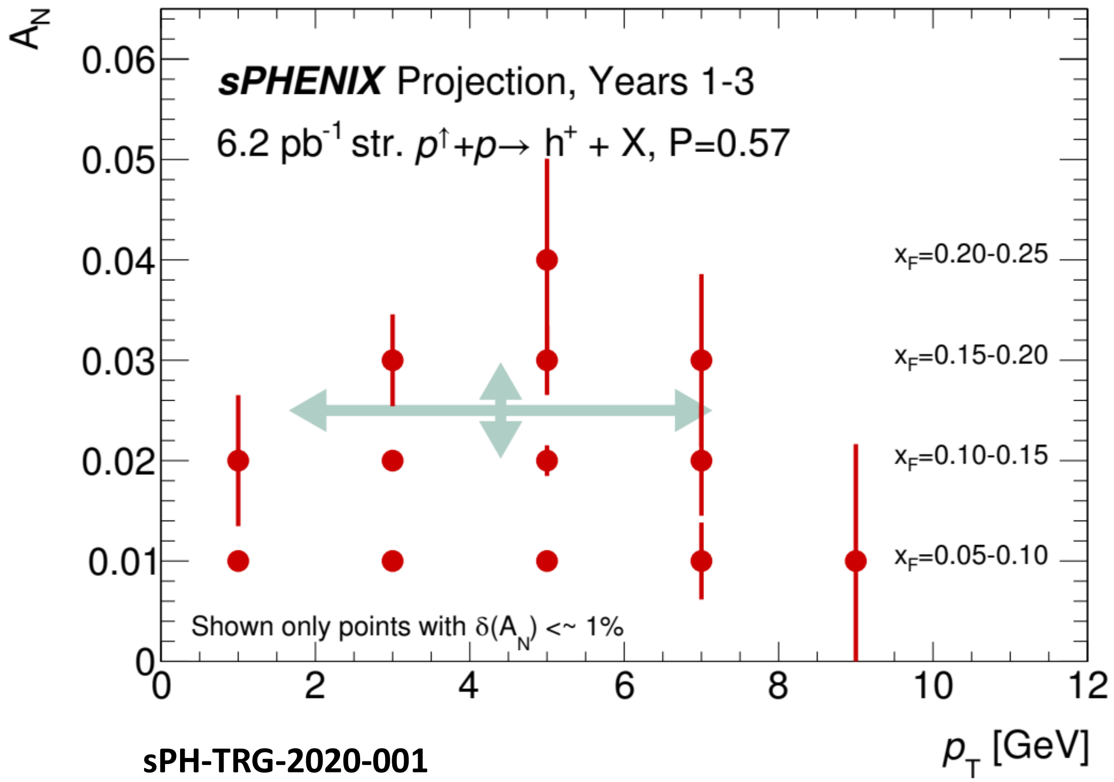


Phys. Rev. Lett. 123 (2019) 12, 122001

Nuclear Effects in A_N

Charged hadron Asymmetry

- Noticeable decrease in A_N amplitude in differing collision systems
  - At forward pseudorapidity and intermediate x_F
  - Currently no consensus on this behavior
- sPHENIX to improve statistics in this region of x_F
  - Specifically for $p^{\uparrow}+p^{\uparrow}$ and $p^{\uparrow}$+Au data points
  - Finer binning is expected



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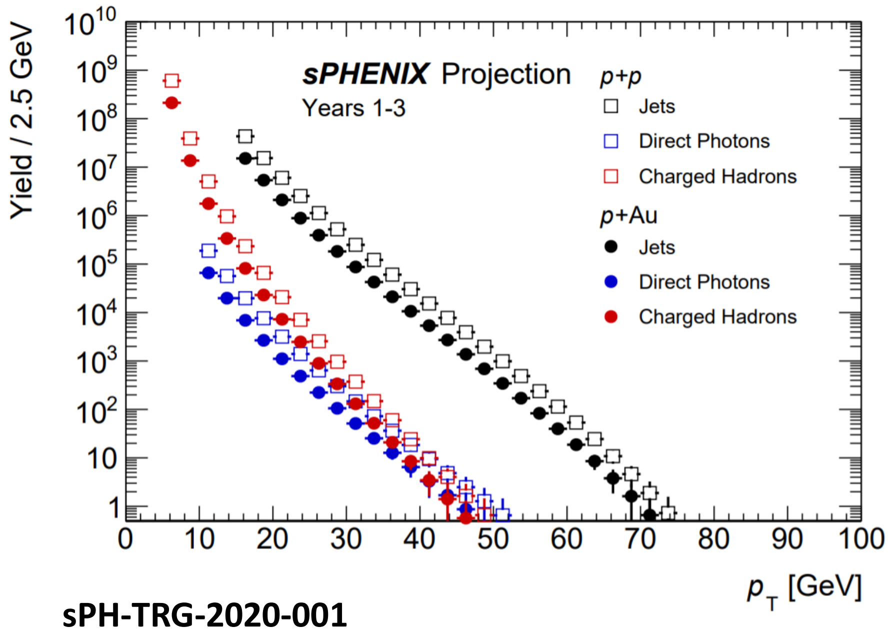
Unpolarized Measurements in p+p and p+Au

Nuclear Effects in Hadronization



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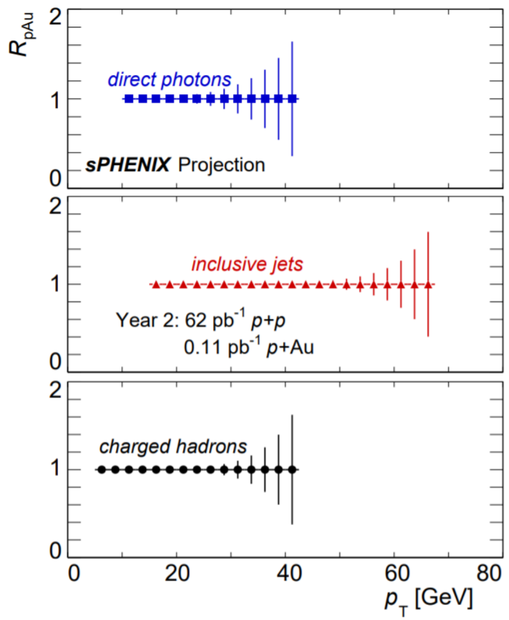
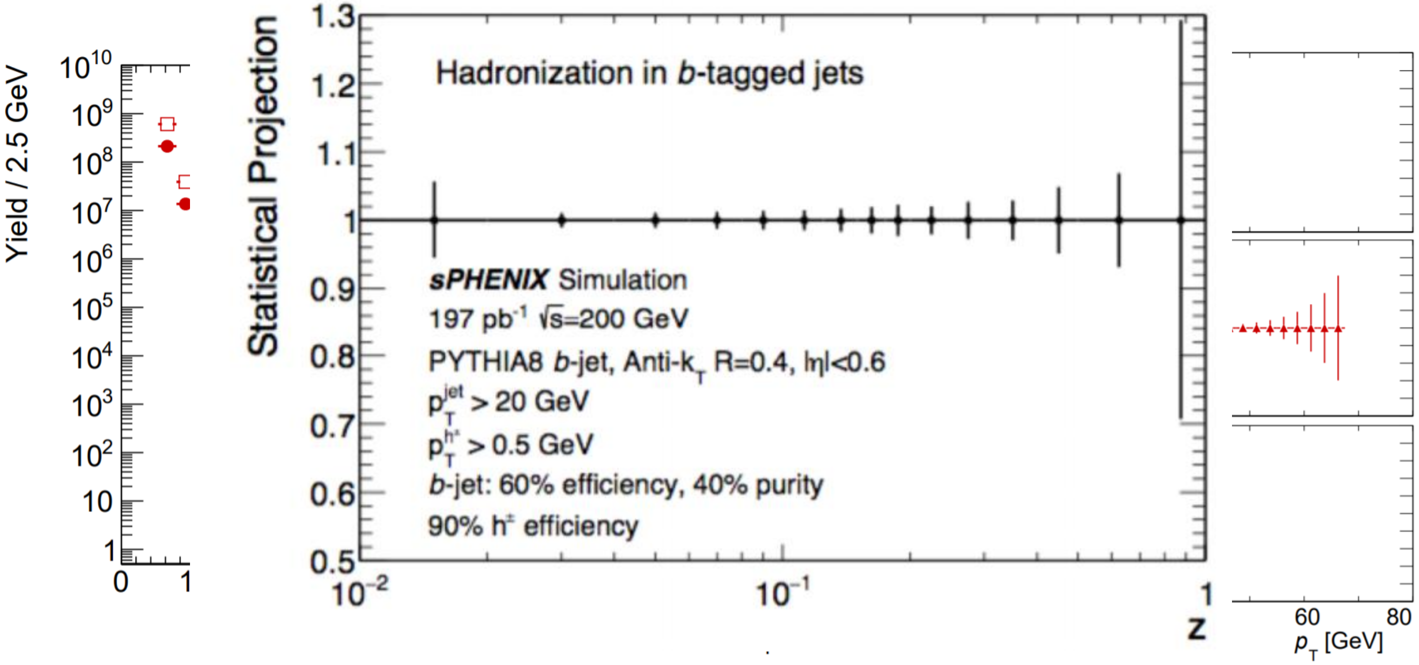


- Due to sPHENIX Central Barrel and Vertex Detector
  - Direct photons and charged hadrons up to ~45 GeV
  - Jets up to ~70 GeV
- Nuclear modification of hadron-in-jet distributions possible

Nuclear Effects in Hadronization



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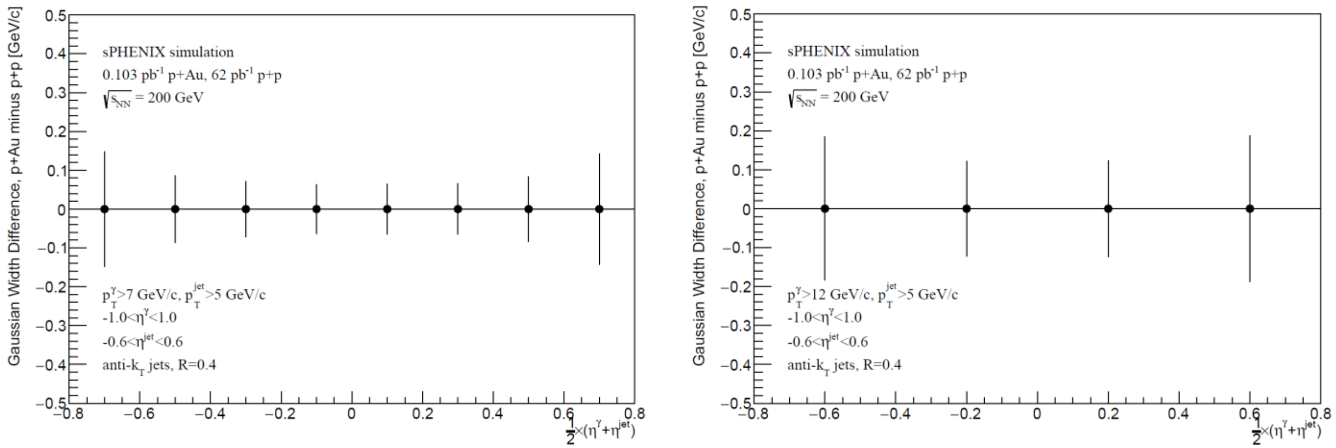

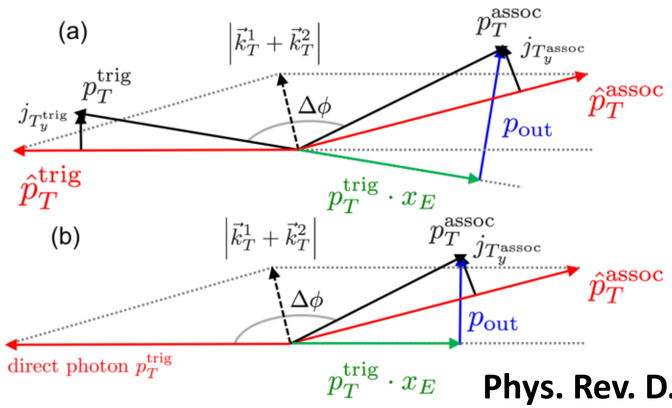

Phys. Rev. D. 98 (2018) 7, 072004

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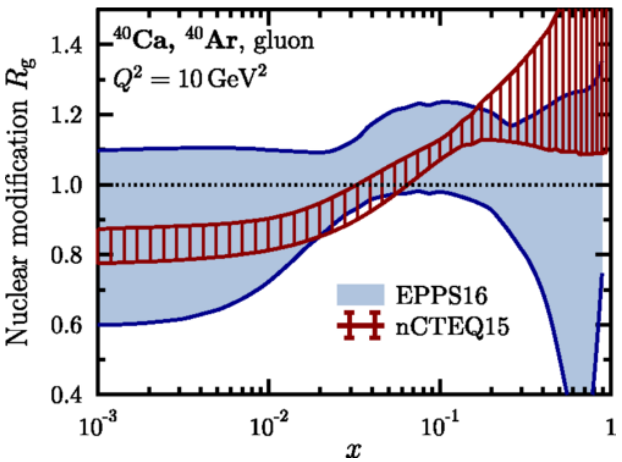
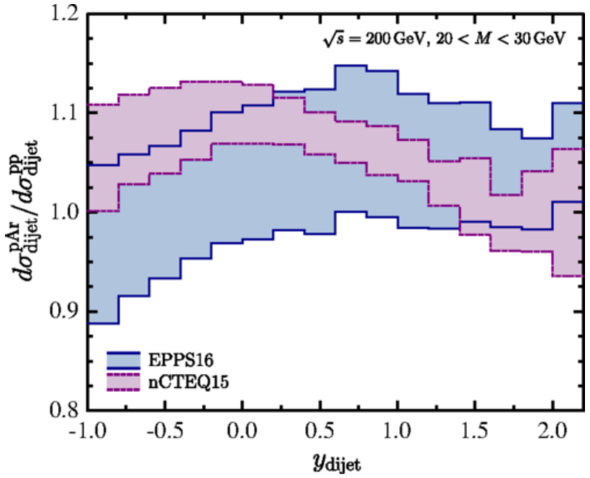
- Nuclear modification of hadron-in-jet distributions possible
  - w.r.t. z, j_T, r, etc.
- Similarly, can measure transport coefficient for gamma-jet systems
  - $\langle \hat{q}L\rangle/2 \cong \langle p_{out}^2\rangle_{pA} - \langle p_{out}^2\rangle_{pp}$

Constraining nPDFs

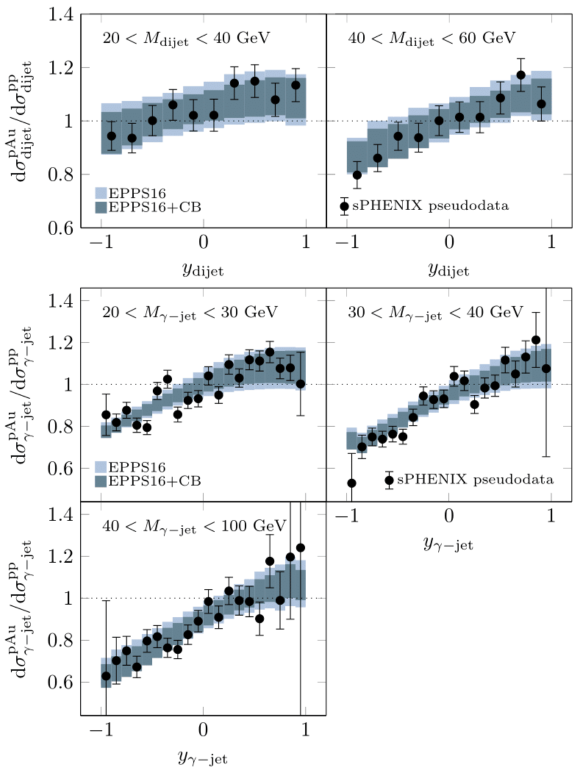


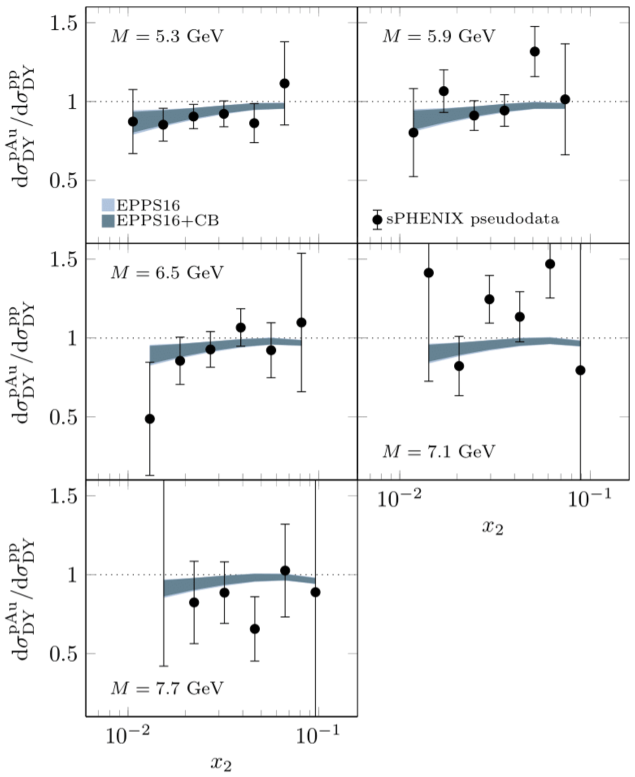


Phys. Rev. D 100, 014004

- Tension exists between nPDF models

Constraining nPDFs





Phys. Rev. D 100, 014004

- Tension exists between nPDF models
- Measurement of nuclear modifications can be used to constrain existing nPDFs
- Channels expected for simultaneous analysis
  - Drell-Yan
  - Dijet
  - Photon-jet

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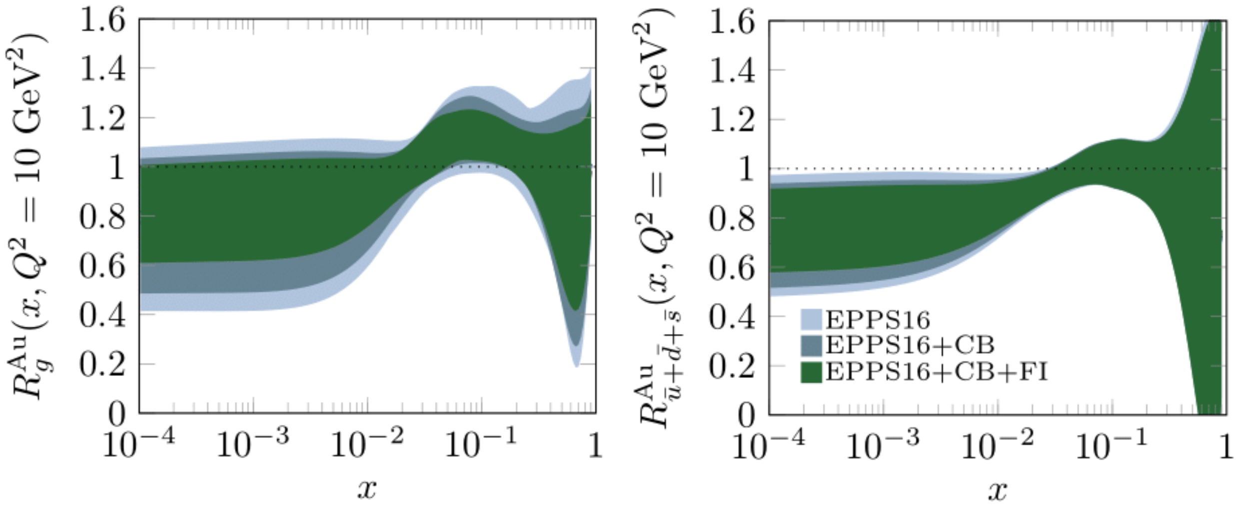

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- Expecting improved uncertainties in gluon and antiquark nPDFs with this method
  - Particularly in shadowing region

Further Prospectives

- Sivers via inclusive jet A_N
  - Yet to be measured at central rapidity
  - Uncertainty expected on the order of 10^{-4}
  - Complementary study to be done at EIC
- Collins Fragmentation Function
  - $H_1^{\perp}$ = distribution of in-jet hadron transverse momentum produced by a polarized quark
  - Provides us much needed access to transversity in protons
  - h_1 = parton transverse spin polarization in a transversely polarized proton
- Interference Fragmentation Function
  - Coupling between transversity and dihadron hadronization
  - Measured via dihedron angular distributions

Summary

- Parton dynamics and cold nuclear effects can be measured/constrained with the sPHENIX detector
- Transverse spin dependent observables grant us access to
  - Gluon dynamics via photon, photon-jet (new), heavy flavor, and dijet asymmetries
  - Quark dynamics via charge-tagging in dijet channel
  - A_N nuclear and pseudorapidity dependencies via inclusive hadron measurements
- Viable spin-independent measurements at sPHENIX will contribute to understanding of transport coefficients as well as the nuclear modification of
  - Direct photons, charged hadrons (new), and inclusive jet production
  - Heavy flavor distributions in jets
  - Gluon and antiquark PDFs via Drell-Yan, dijet, and photon-jet channels