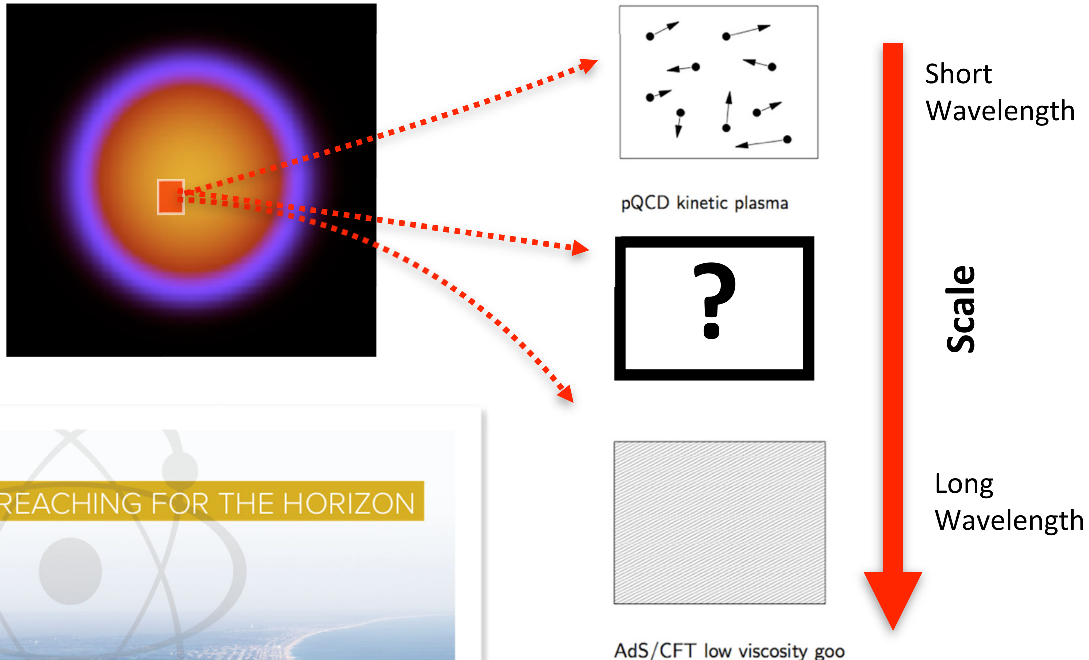
From sPHENIX to the EIC

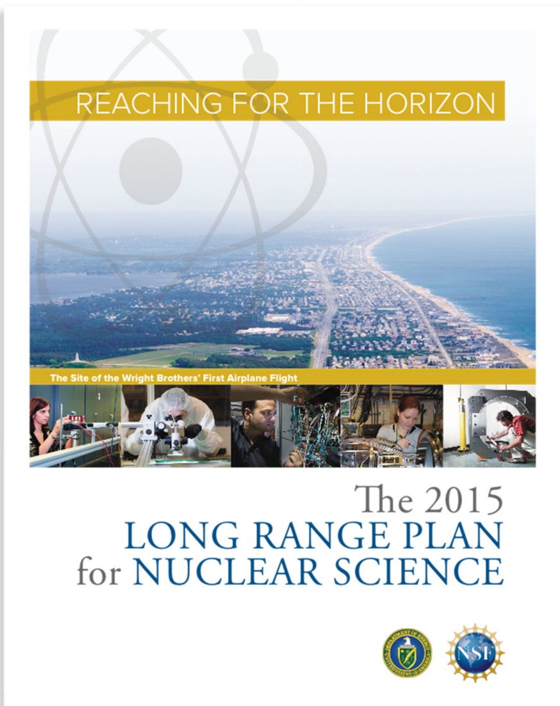
John Lajoie

Iowa State University

for the sPHENIX Collaboration

sPHENIX Science Mission

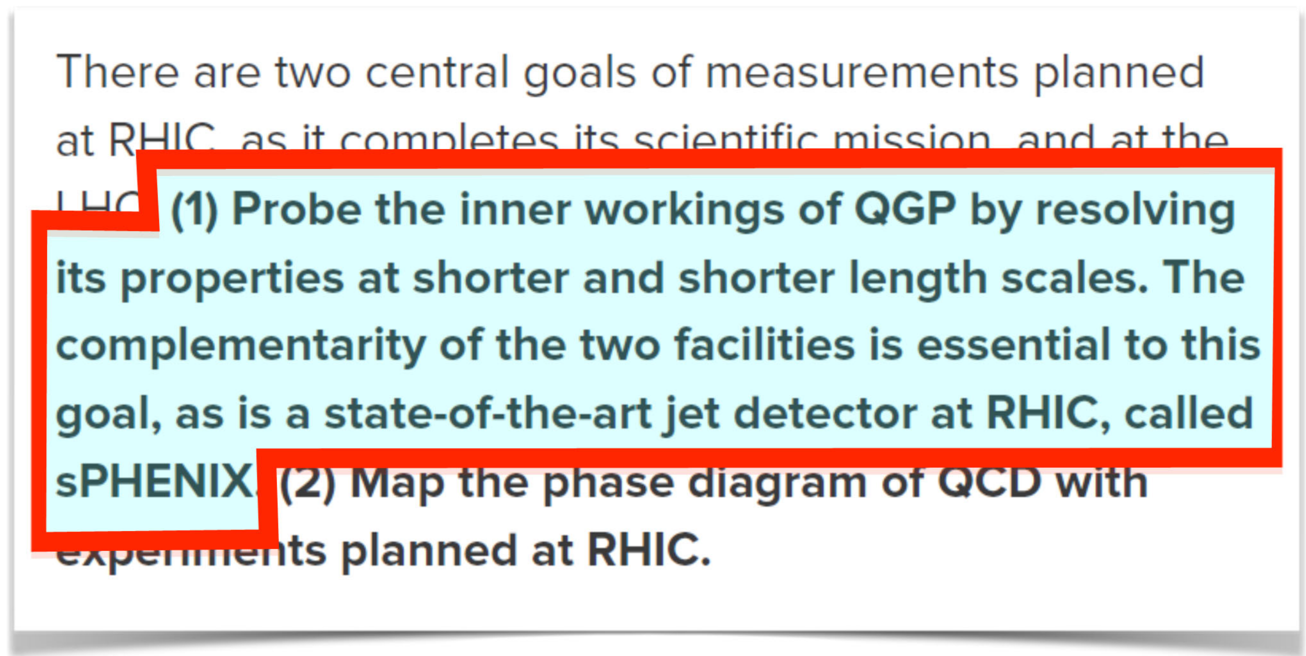




How does QGP work?

What is its microscopic structure?

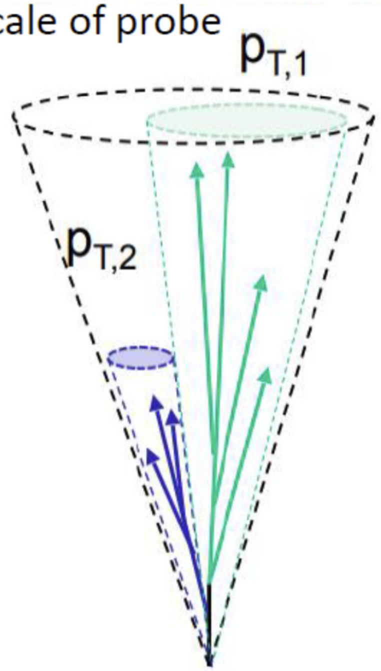
Section 2.2, page 22


There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: (1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.

sPHENIX Science Program

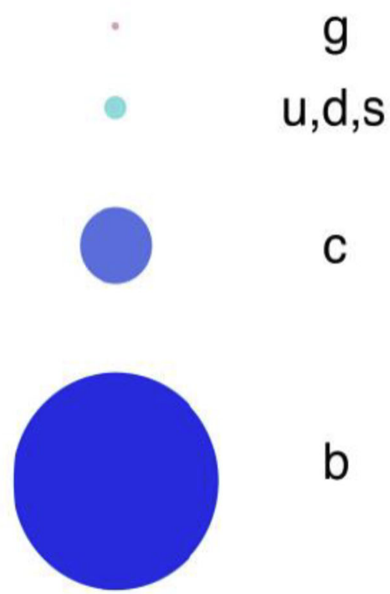
Jet cor. & substructure

Vary momentum/angular scale of probe



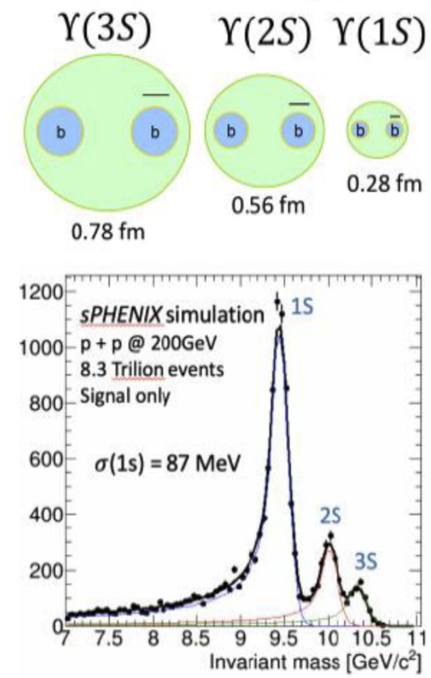
Open heavy flavors

Vary mass/momentum of probe



Upsilon spectroscopy

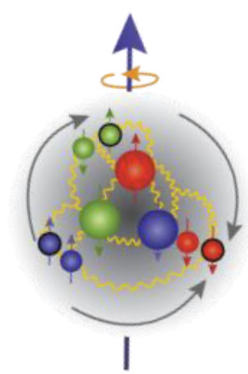
Vary size of the probe



Cold QCD

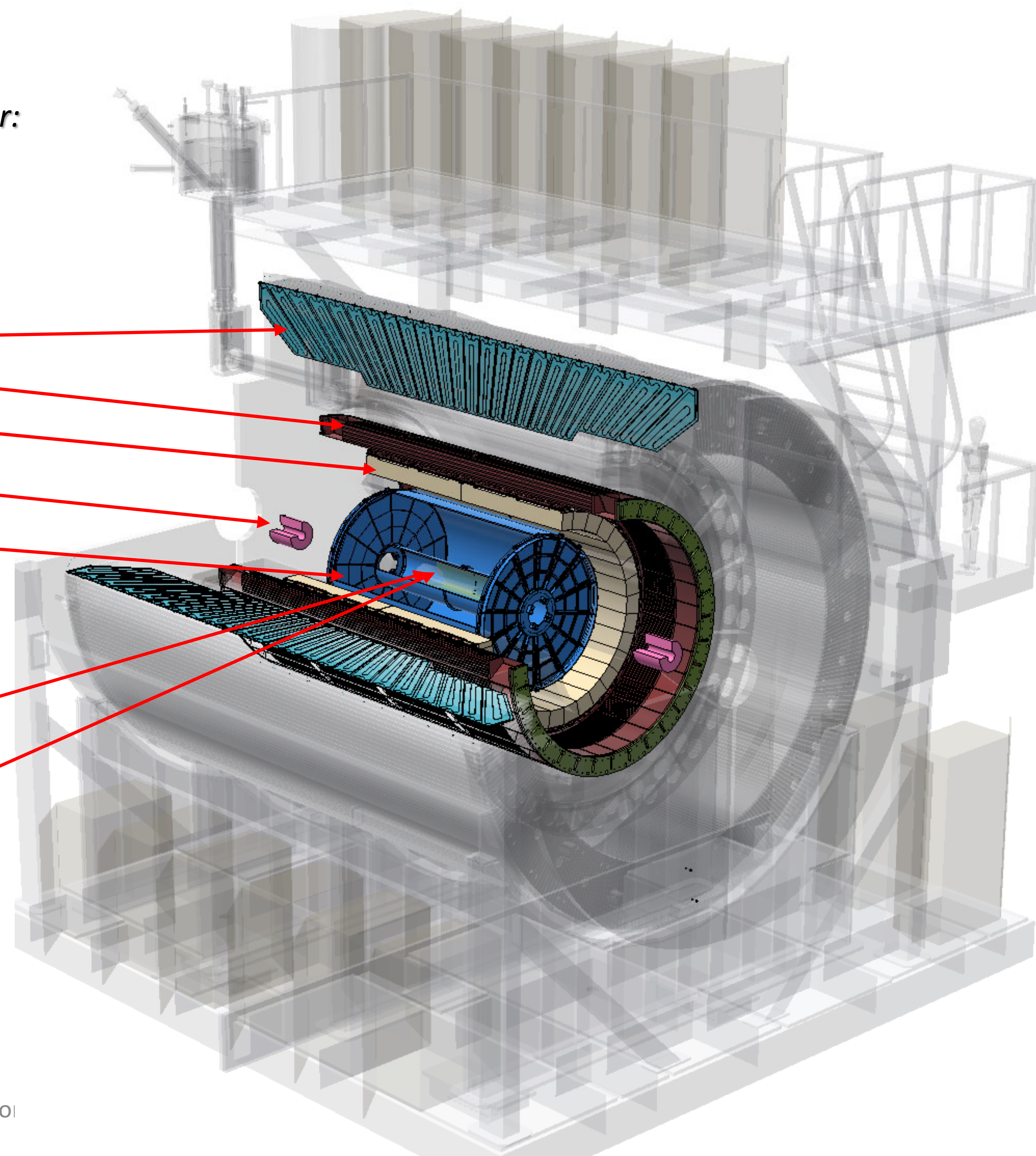
Spin-orbit correlations in transversely polarized nucleons

Cold nuclear matter effects and hadronization



sPHENIX

State of the art detector for:
Jets
Upsilons
Open heavy flavor



Hadronic Calorimeter(s)

Electromagnetic Calorimeter

Minimum Bias Detector (MBD)

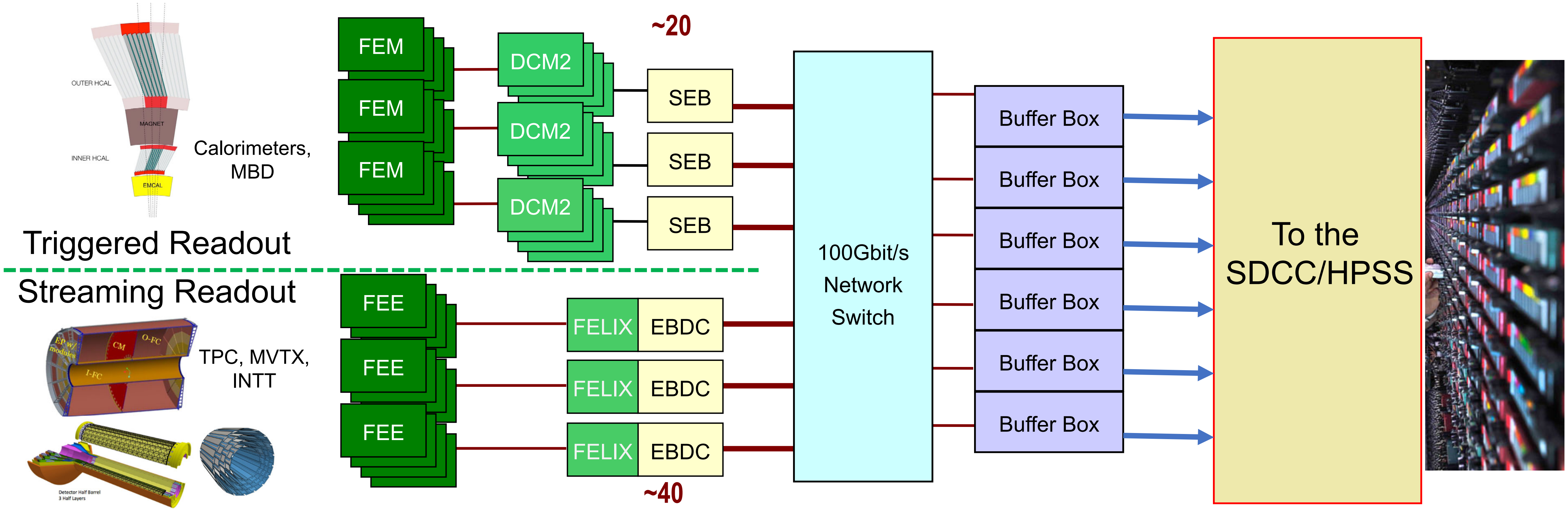
Time Projection Chamber (TPC)

Intermediate Tracker (INTT)

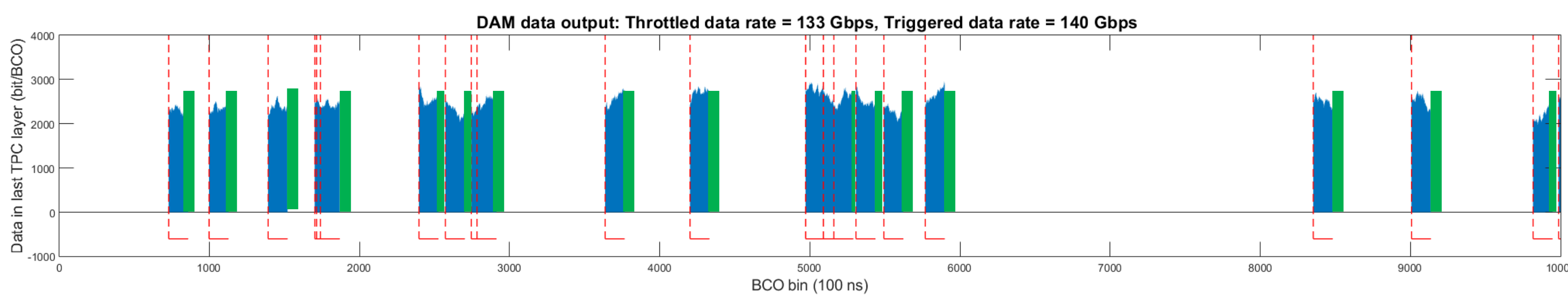
MicroVertex Detector (MVTX)


sPHENIX
UNDER
CONSTRUCTION
Outer Hadronic Calorimeter
32 modules, ~400 tons
- Assembly Complete!
iHCAL Sectors (32)
TPC Inner Field Cage
Electromagnetic Calorimeter
Sector (64 total)
1.4T “BaBar” Solenoid
Detector Support Cradle
TPC End Cap Support

sPHENIX Hybrid Streaming DAQ



Extending the stream time for the tracking detectors gains track-only MB events.



Run Plan 2023-2025

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}
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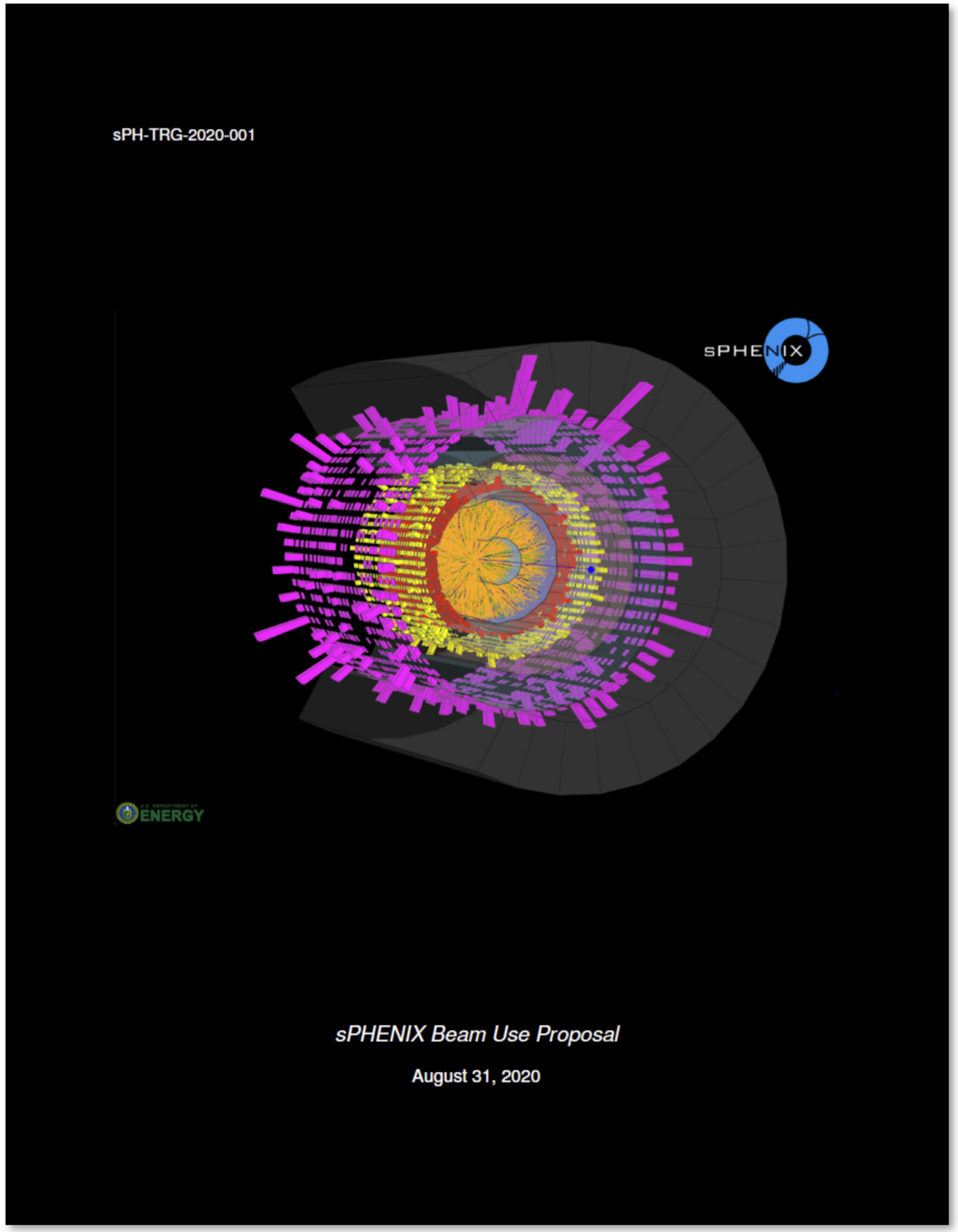
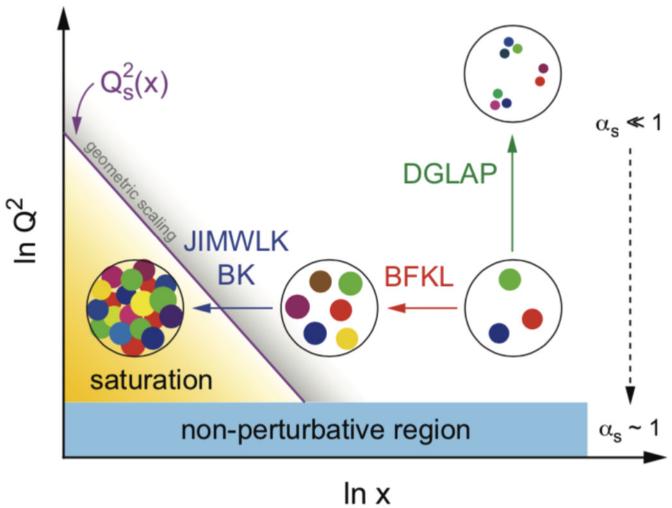
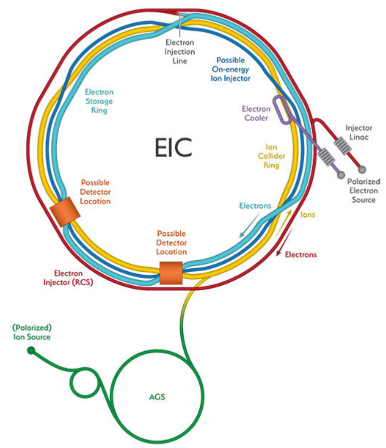
https://indico.bnl.gov/event/7881/attachments/30176/47160/sPH-TRG-2020-001.pdf



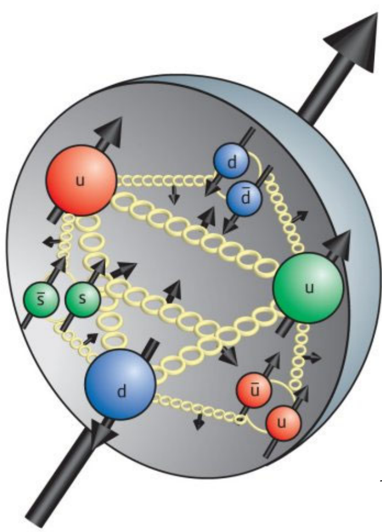
The Big Picture *from* RHIC to the EIC…

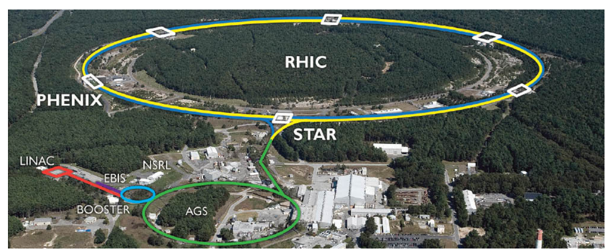
p+A Collisions



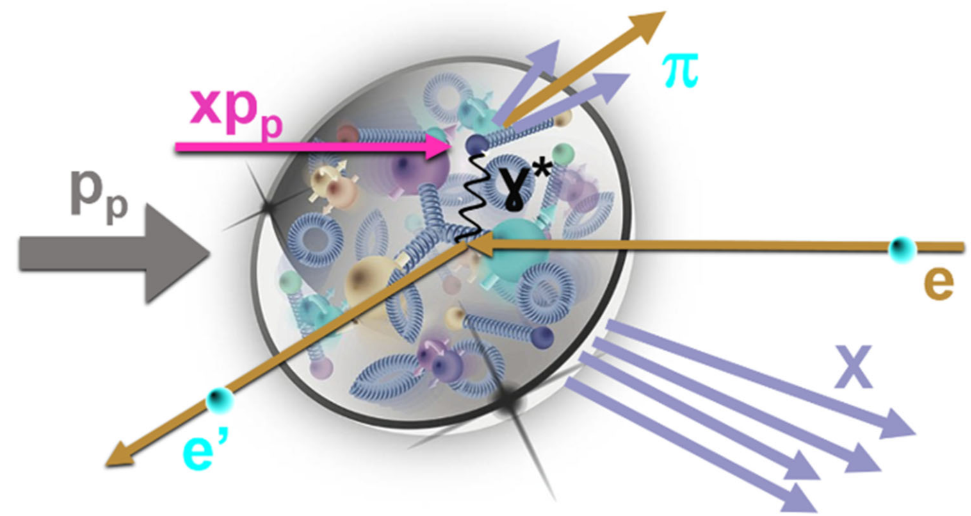


How do collective, many-body phenomena arise from first-principles QCD?



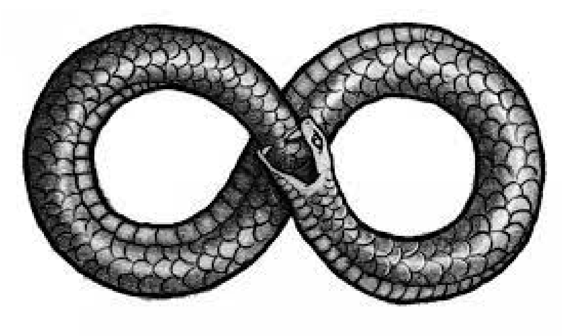


$p\uparrow + p\uparrow$ Collisions



EIC Connections…

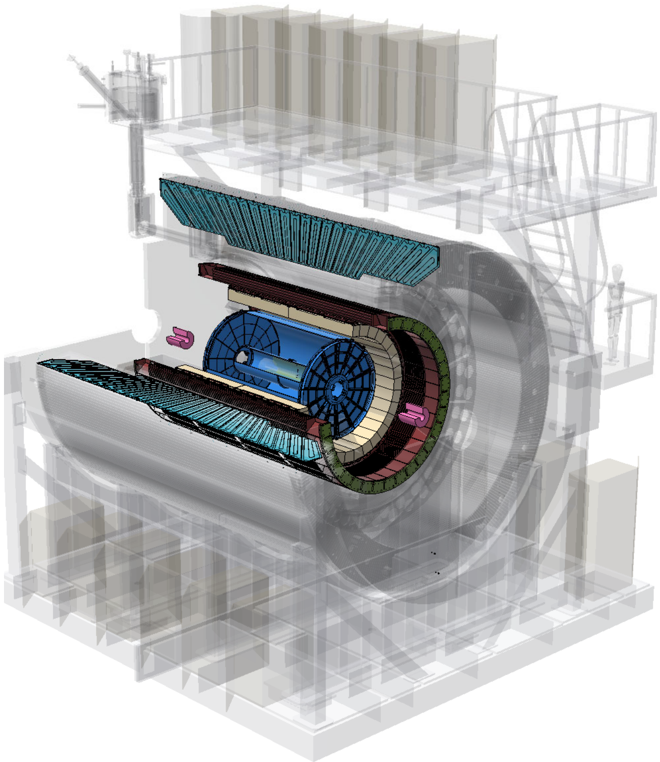
EIC Yellow Report, page 17



Measurements at the EIC are also expected to deliver important input for several areas of astroparticle physics. Fields such as cosmic-ray air showers and neutrino astrophysics will benefit from better constrained models of hadronic interactions. Deeply inelastic scattering and photo-nuclear processes have natural ties with the physics of hadronic collisions. These relate to the issue of small-x gluons and factorization in e+p and e+A versus p+p and p+A, and to the implications of the determination of parton distributions for p+A collision for an improved understanding of the initial conditions in heavy-ion collisions. Similar, the accurate characterization of parton distributions in nuclei provided by the EIC can directly benefit the neutrino physics program. In return, neutrino scattering can help better understand the parton structure of nucleons and nuclei, where the nucleon strangeness content is one example.

The sPHENIX Cold QCD Program

Many unpolarized and polarized measurements in *p+p* and *p+A* are possible utilizing the jet, heavy flavor and direct photon strengths of the sPHENIX barrel:



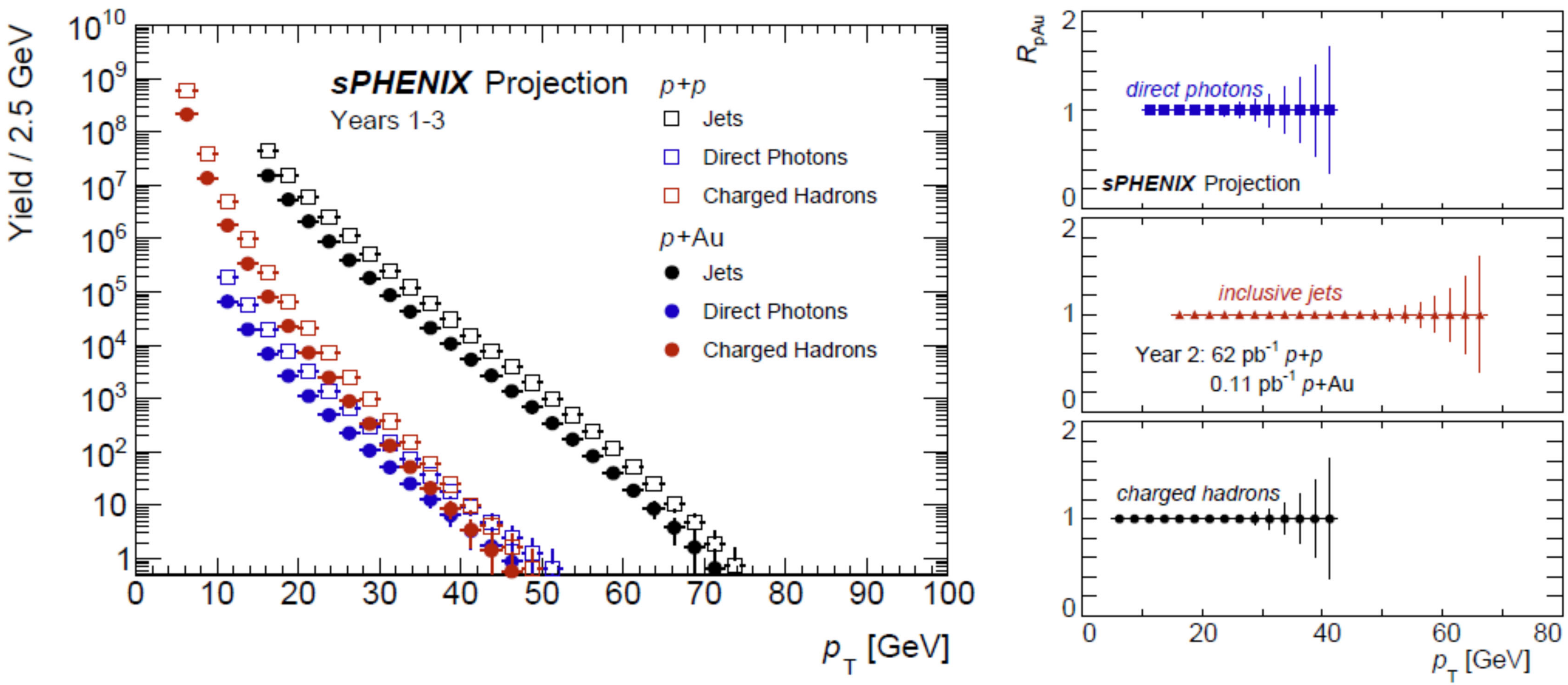
Unpolarized

Quarkonia Polarization :	J/Ψ, Υ
Nuclear PDF :	*h, jet, di-jet,* γ*-jet, DY*
Hadronization in Nuclear Env. :	*h in jet, di-jet,* γ*-jet*

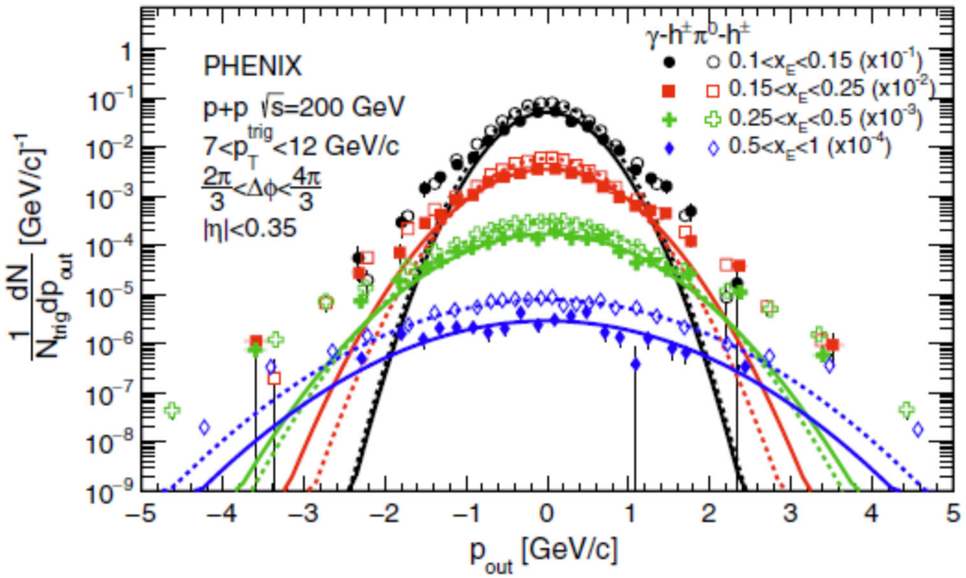
Polarized

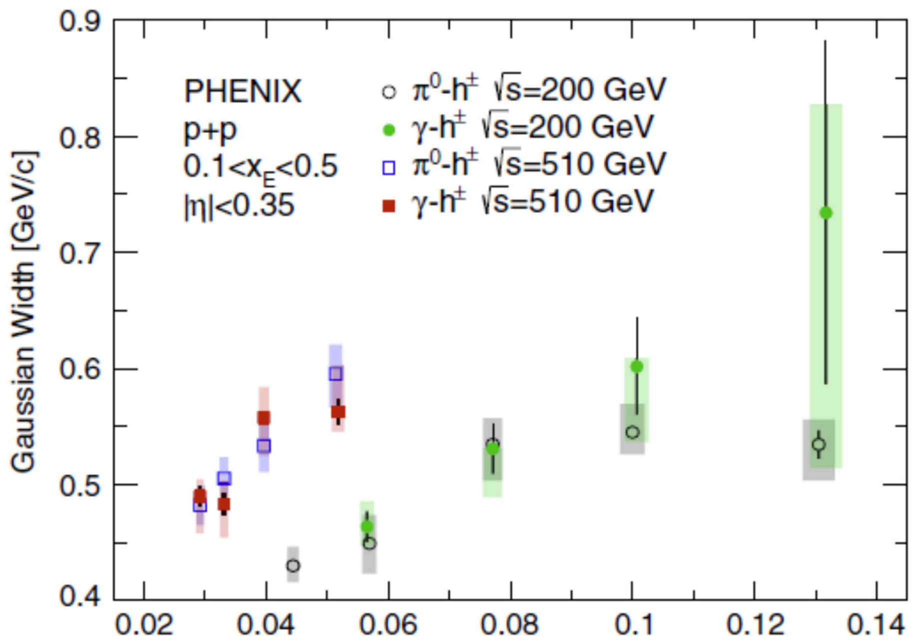
Hadron A_N, *p+p* vs. *p+A* :	*h*
Transversity x Collins FF :	*h in jet*
Transversity x Interference FF:	*di-h*
Sivers asymmetry :	γ*-jet, jet-jet*
Gluon Dynamics (Twist-3) :	γ, *HF* (D^0, *etc.*)

Unpolarized Photon, Hadron, Jet Yields

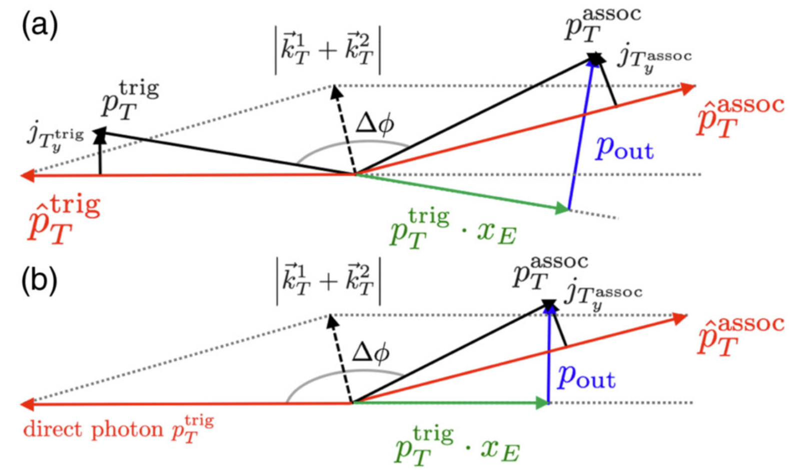


TMD Factorization Breaking





PHYS. REV. D 98, 072004 (2018)



Di-hadron and photon-hadron correlations studied in PHENIX. Predicted to violate TMD factorization due to quantum-correlated partons between colliding hadrons due to color flow.

Behavior of non-perturbative component of p_{out} consistent with DY – no clear qualitative evidence for factorization breaking effects.

sPHENIX:

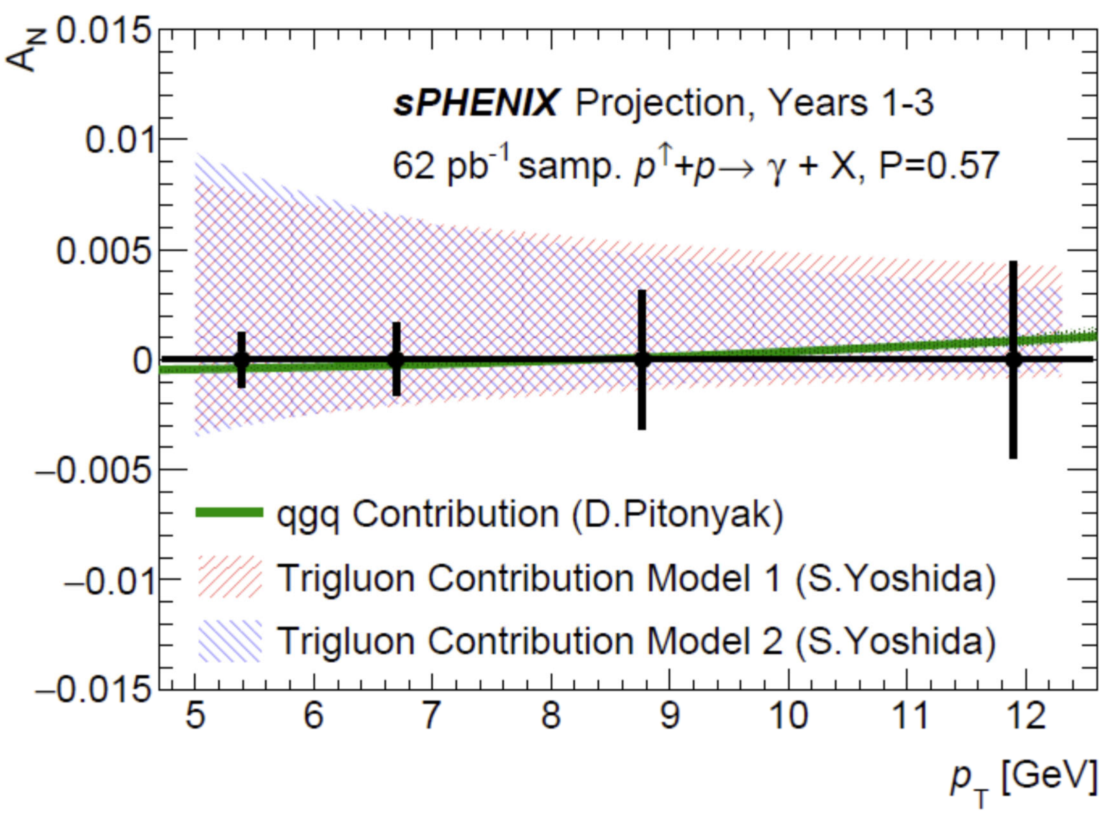
- Full jet reconstruction – access to better proxies for parton kinematics
- Spin asymmetries in photon+jet – breakdown of factorization can lead to additional spin asymmetries
- Spin asymmetries in *p↑+A* - nuclear dependence changes color exchanges

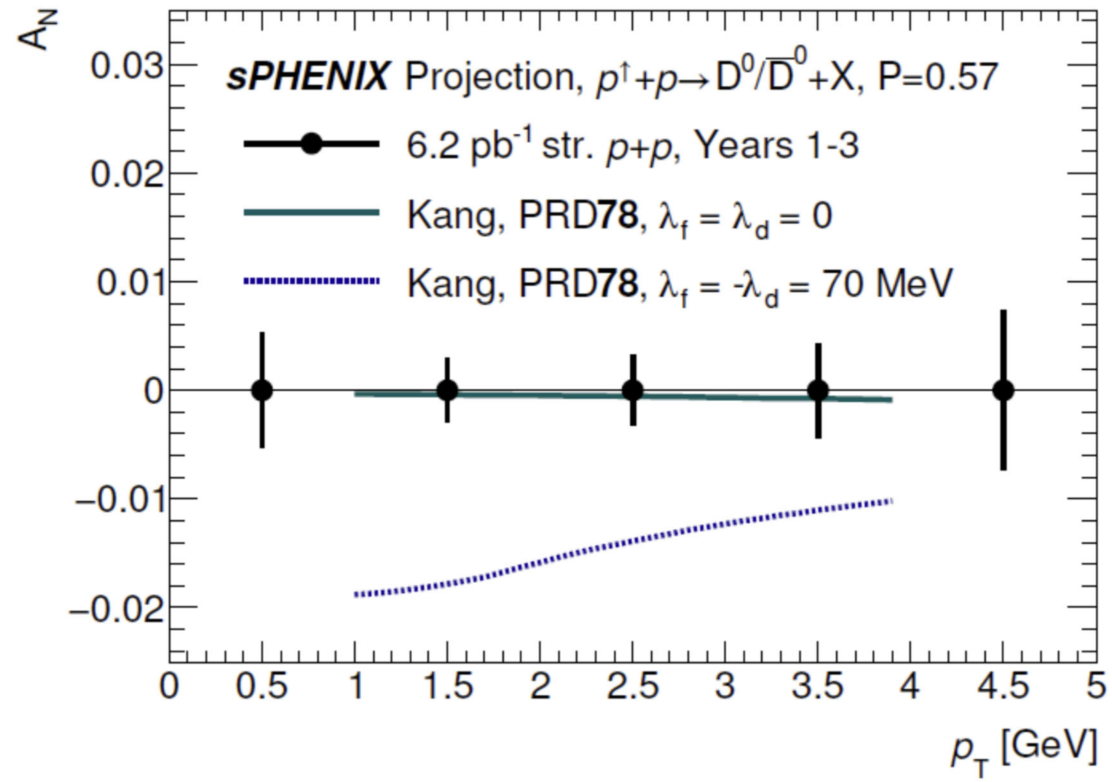
See talk by Zhongbo Kang

TSSA's sPHENIX - γ and HF

Prompt photons and HF probe gluon correlations in the nucleon

Prompt photons collected with EMCal-based trigger

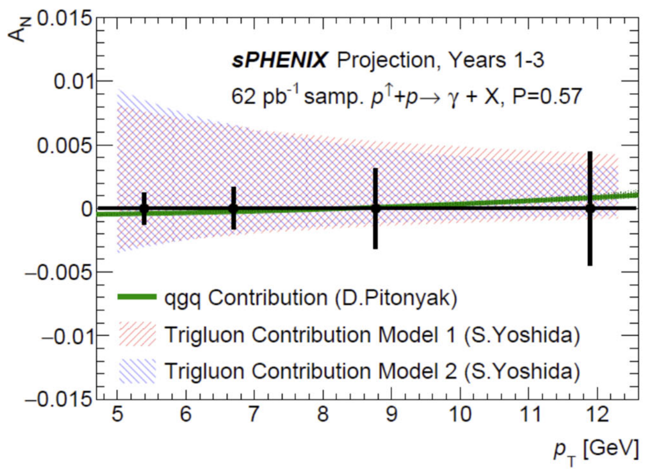


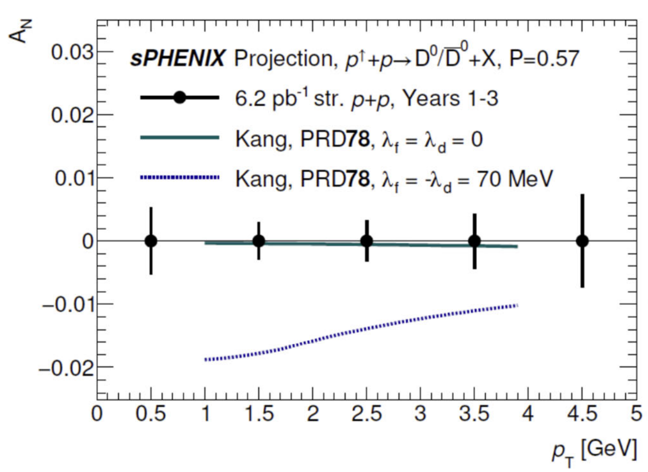


D^0 meson TSSA enabled by sPHENIX hybrid streaming DAQ

Parton Correlations sPHENIX -> EIC

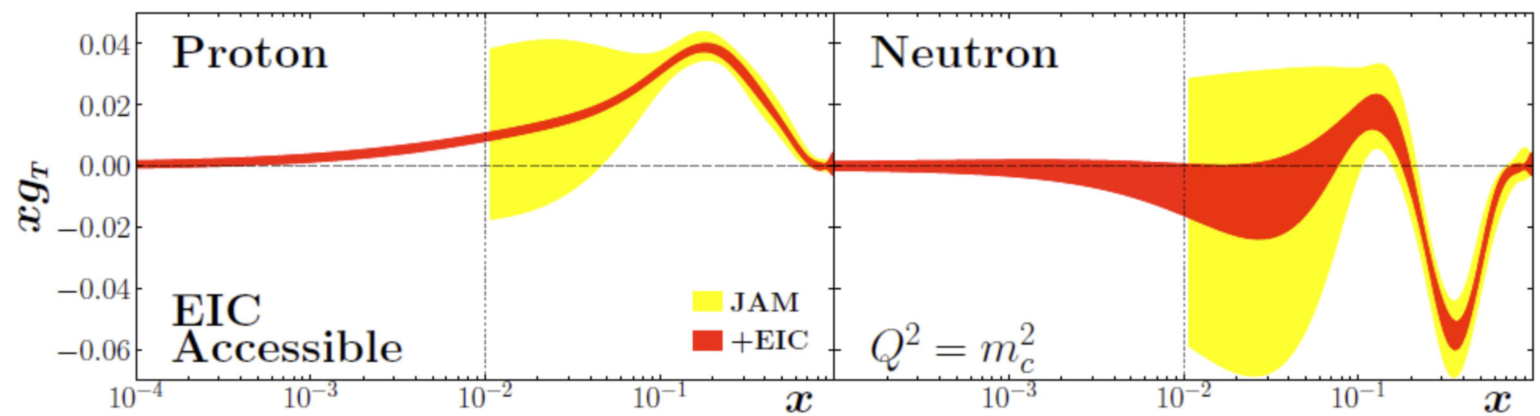
Direct access to the tri-gluon correlator unique to hadron collision data!





Other highly sensitive measurements of higher twist available at EIC

EIC Yellow Report Fig. 7.27



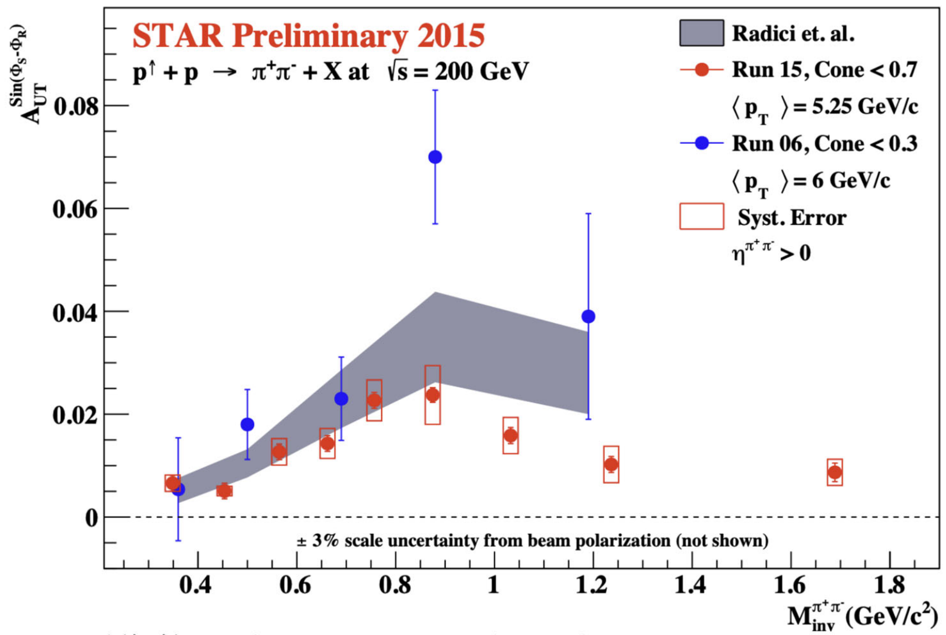
Twist-3 PDF $g_T^q(x)$ sensitive to quark-gluon-quark correlations!

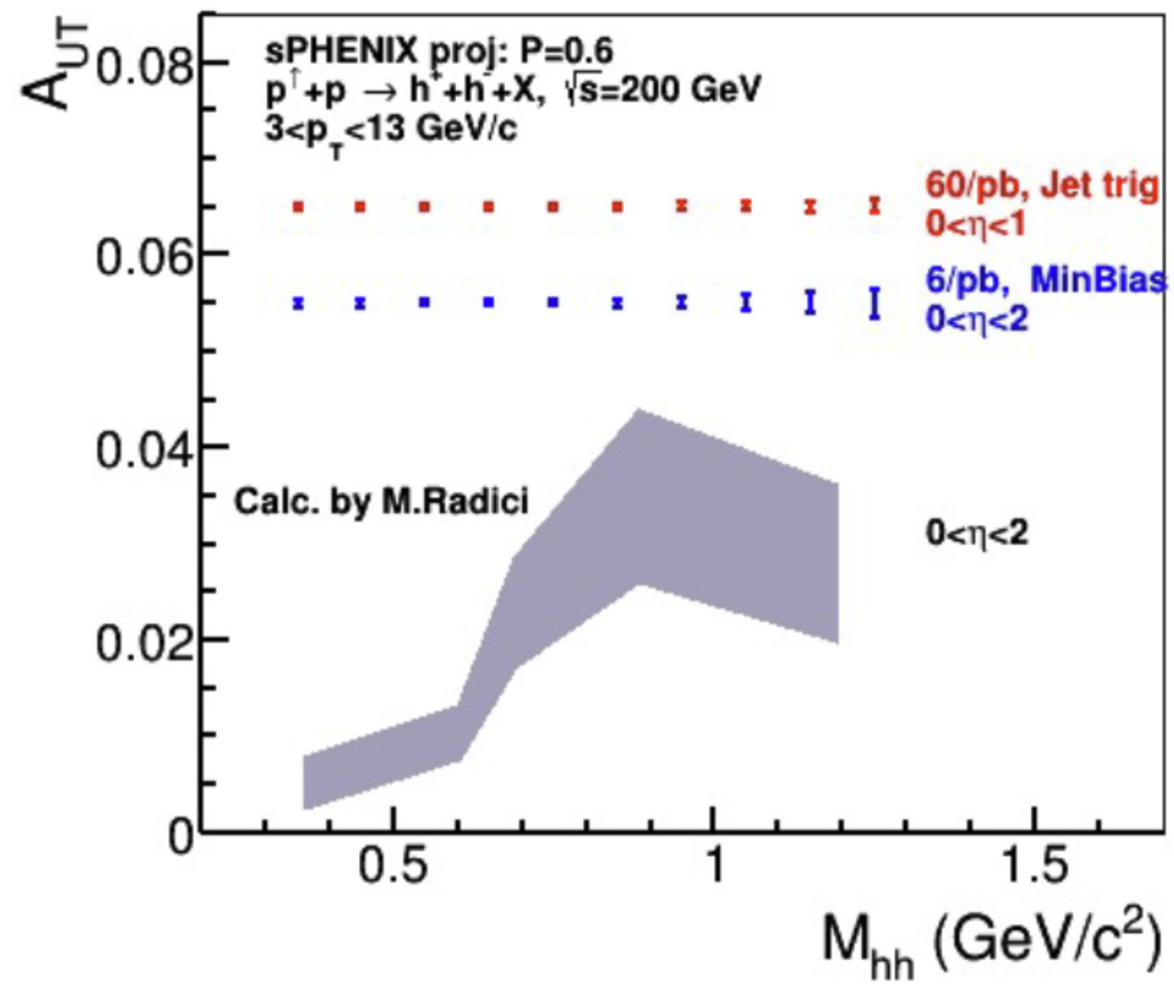
Derived from A_{LT} : $\vec{e} + p^{\uparrow} \rightarrow e' + X$

Transversity x IFF in sPHENIX

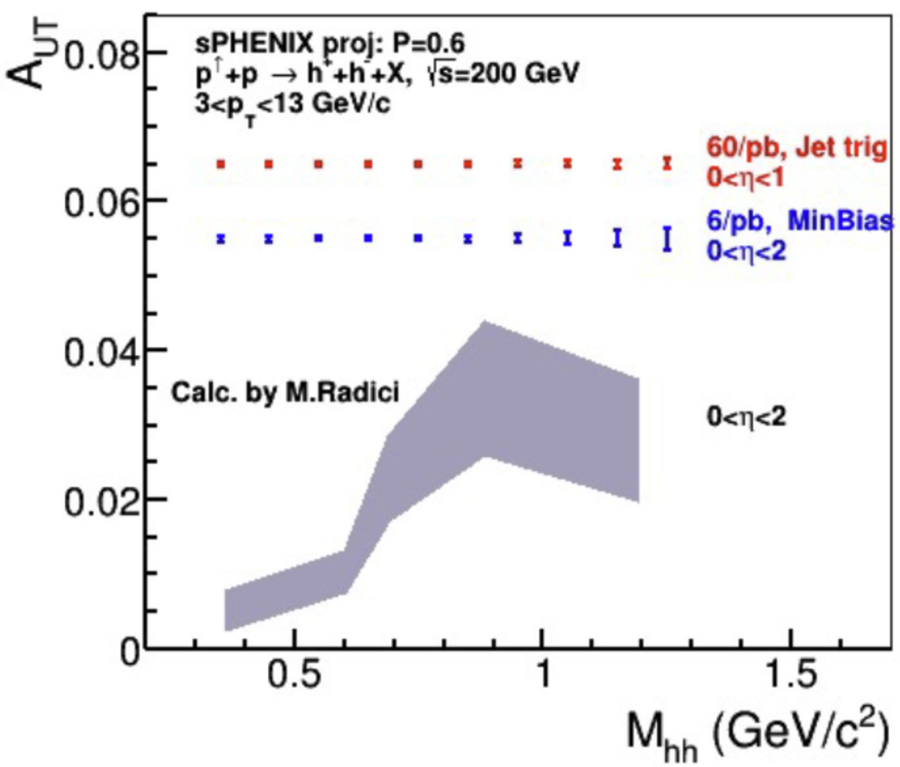
Enormous constraining power from high-statistics, high acceptance sPHENIX measurements.

First measurements from STAR were invaluable!



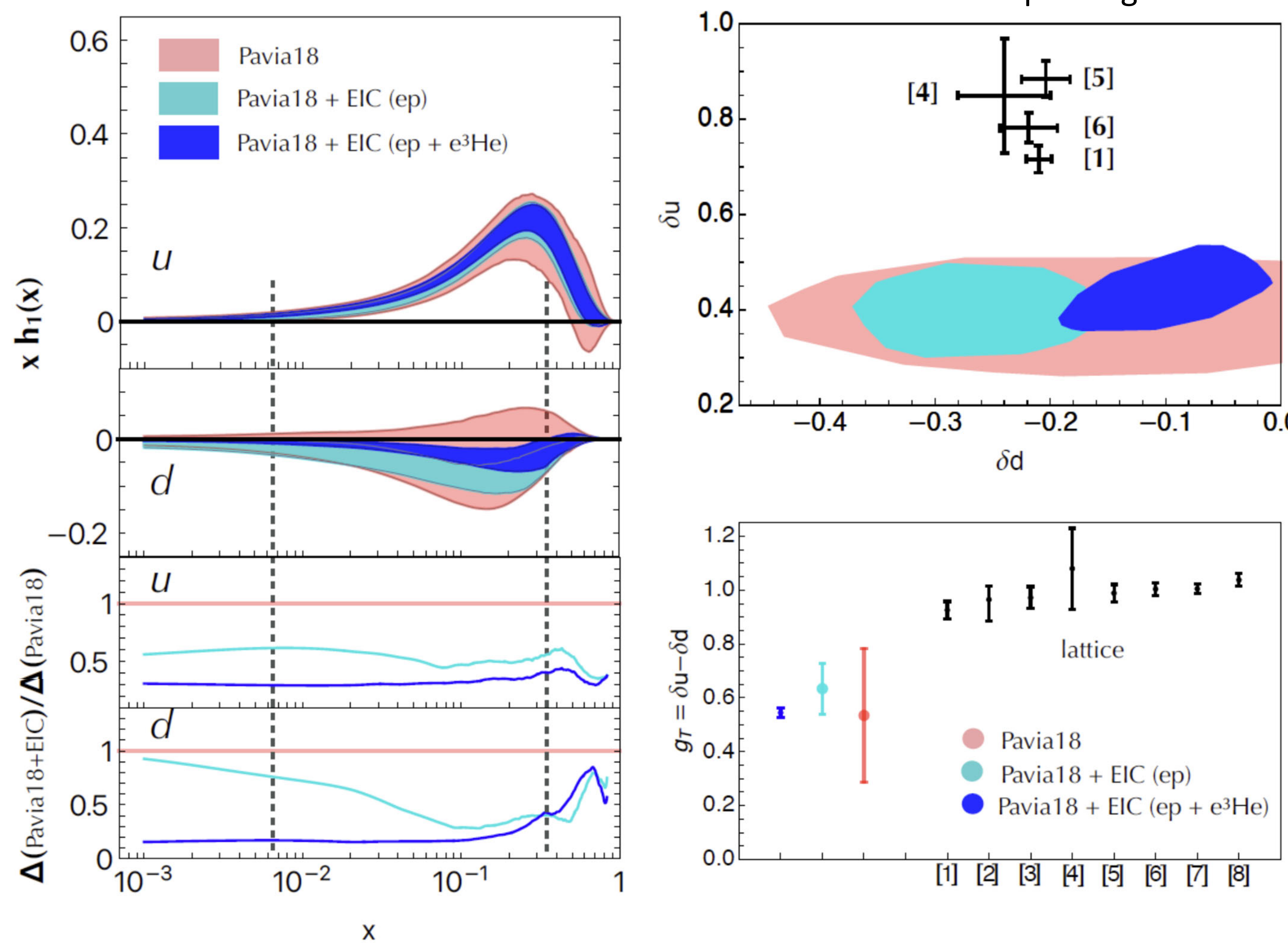


Transversity x IFF sPHENIX -> EIC



sPHENIX measurements help start the process of constraining transversity and tensor charge.

EIC Yellow Report Fig. 7.56



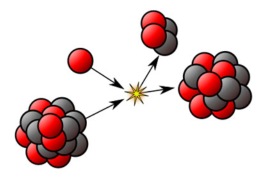
The EIC finishes the job…

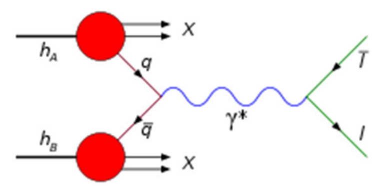
Process Dependence: *p+A* to *e+A*

Complicated initial state!

p+A: Hadrons, jets, heavy flavor, Drell-Yan ..

Multiple scattering/eloss of incident parton, saturation, color fluctuations, ...





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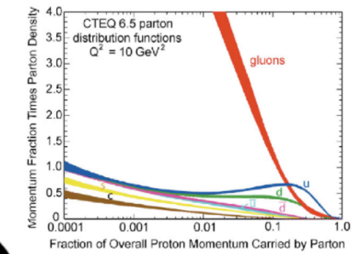

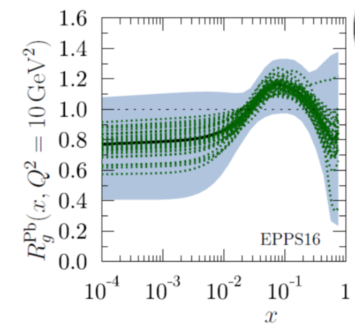

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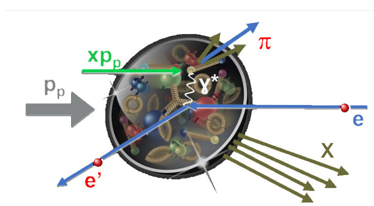
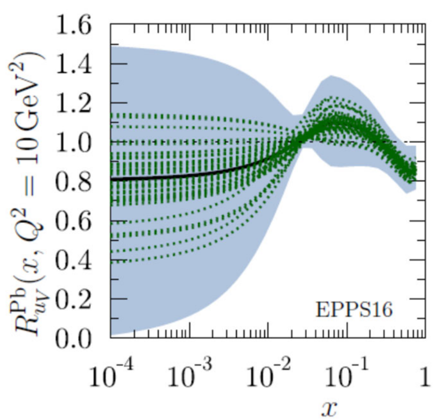
CNM energy loss, multiple scattering, ...

...and collective behavior...

Deep Inelastic Scattering, SIDIS, etc.





⊕

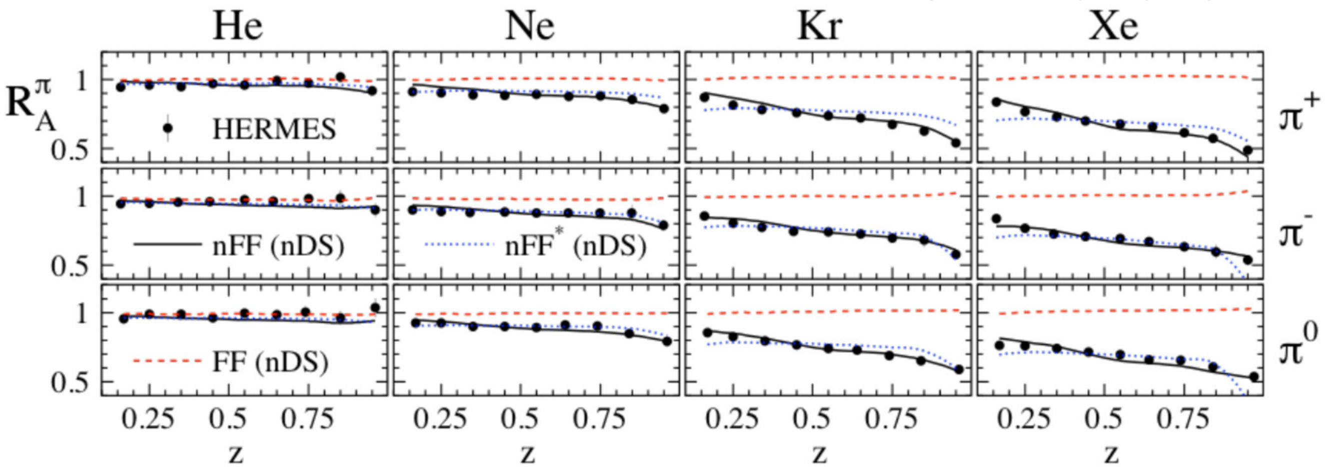
CNM energy loss, saturation, p_T broadening, ...

...and collective behavior...

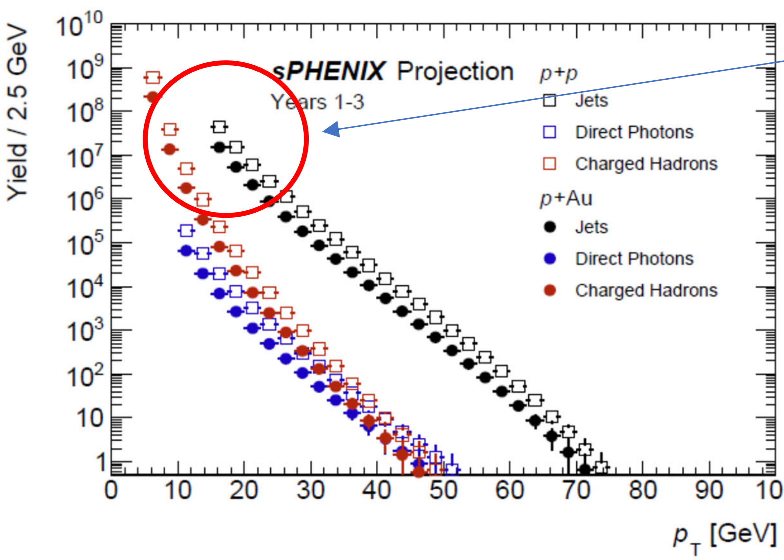
“Clean” measurement theoretically, sensitive to partons in nucleus and possibly final state effects

Hadronization in a Nuclear Environment

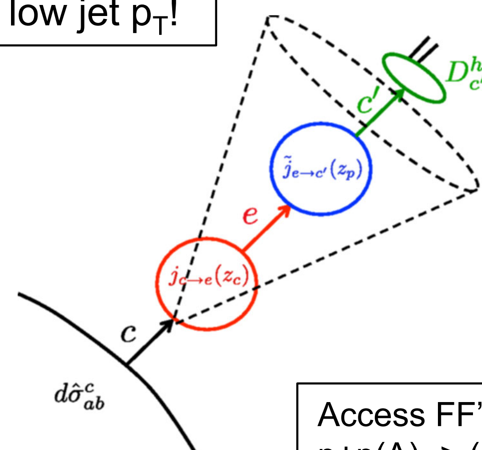
Phys. Lett. B577, 37 (2003)
Phys. Lett. B684, 114 (2010)



Hadron production in e+A suppressed compared to e+p – must be a fragmentation effect, but at low-Q^2….

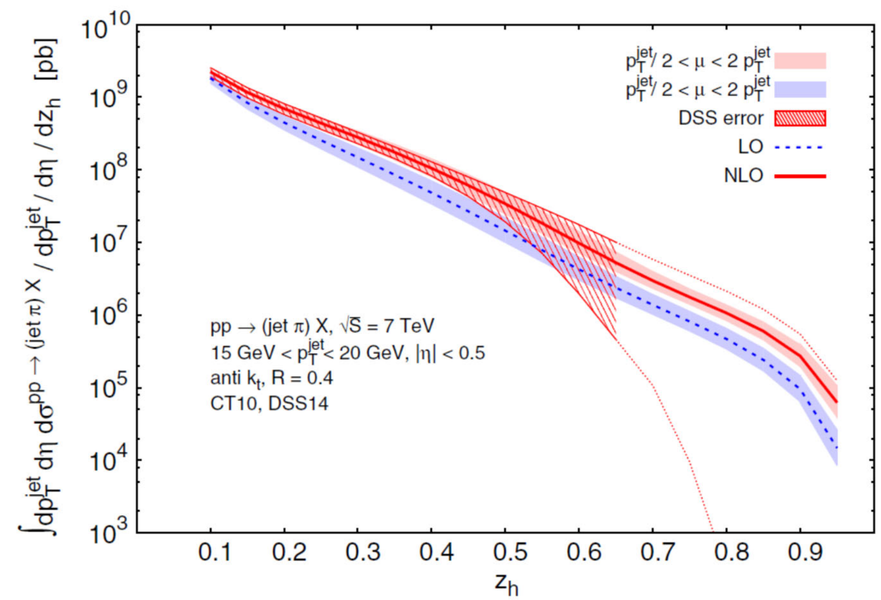


Enormous statistics available at low jet p_T!



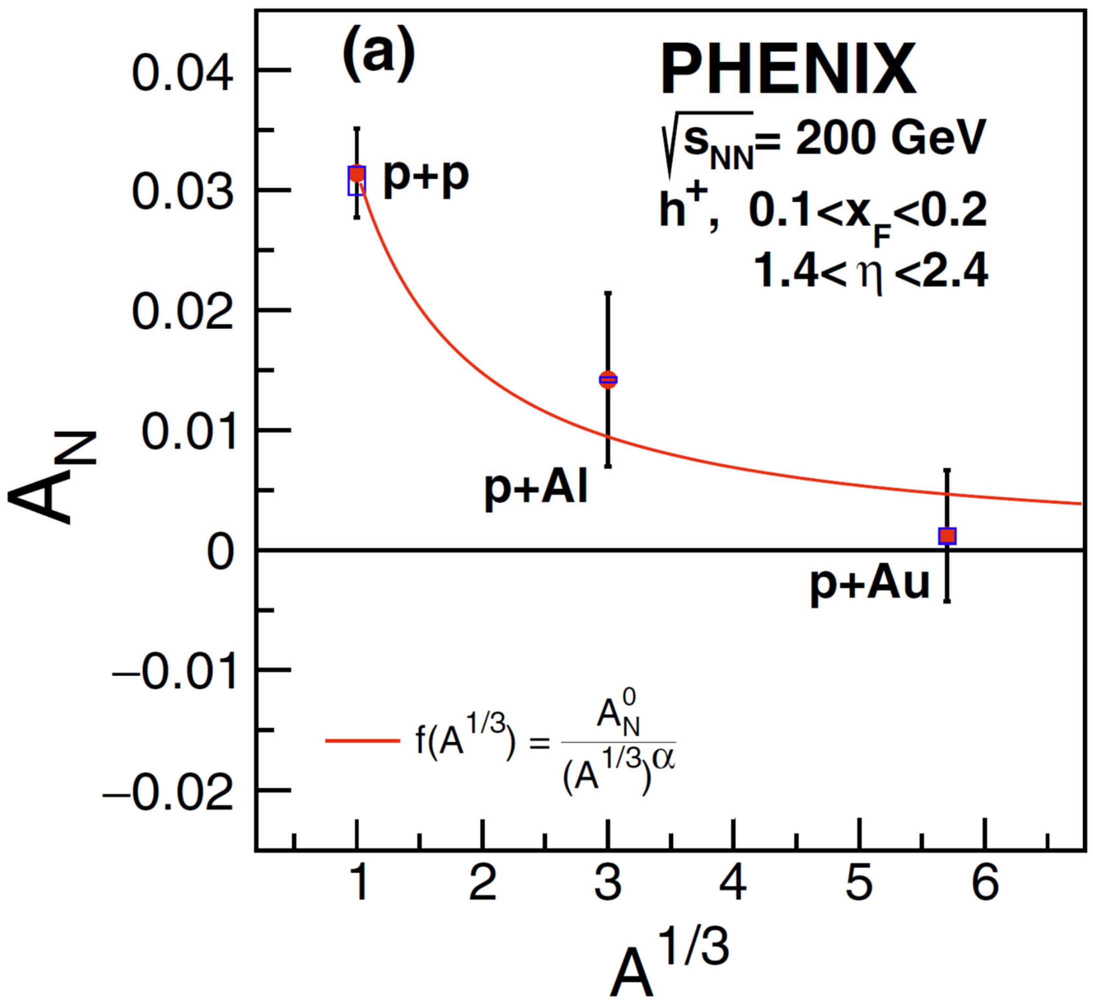
Access FF's through p+p(A) -> (jet *h*) X

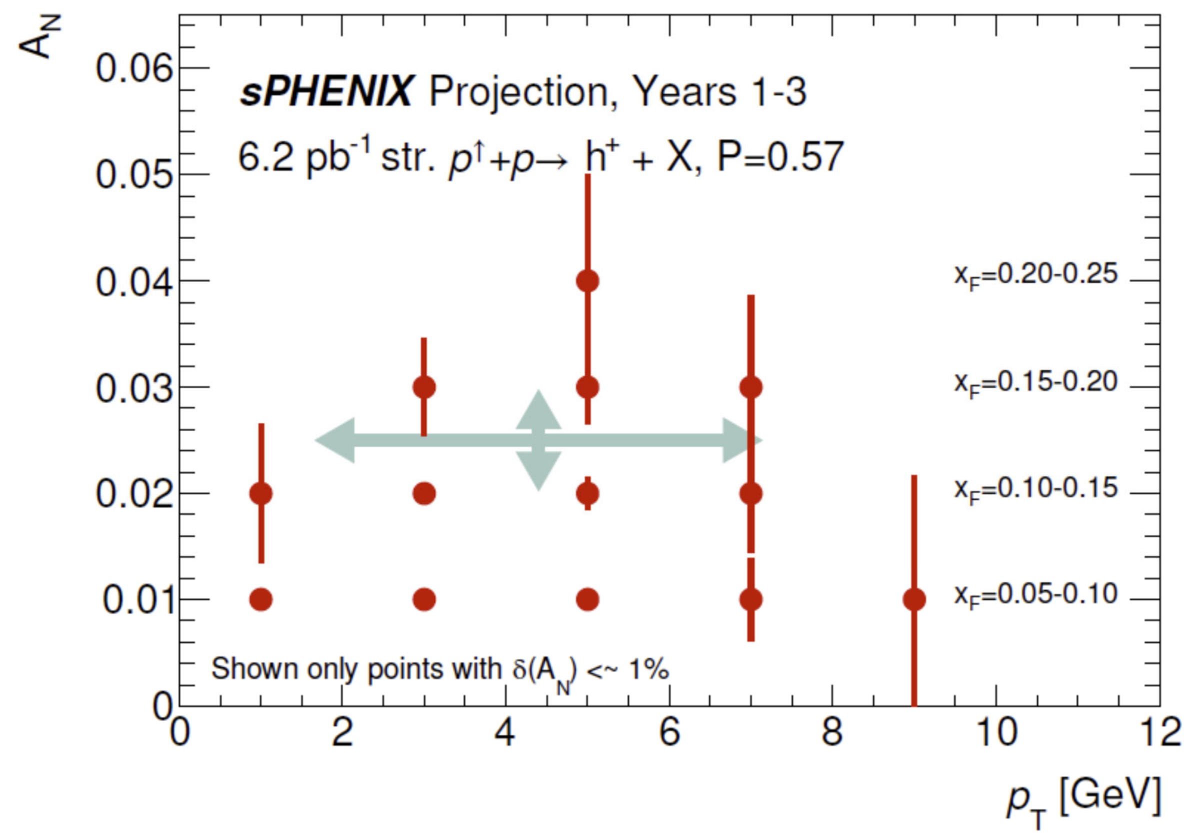
Kaufmann, Mukherjee and Vogelsang Phys.Rev.D 92 5, 054015



Hadron A_N in sPHENIX

Hadron A_N combines a variety of effects – but the *nuclear dependence* is a tool separate them!





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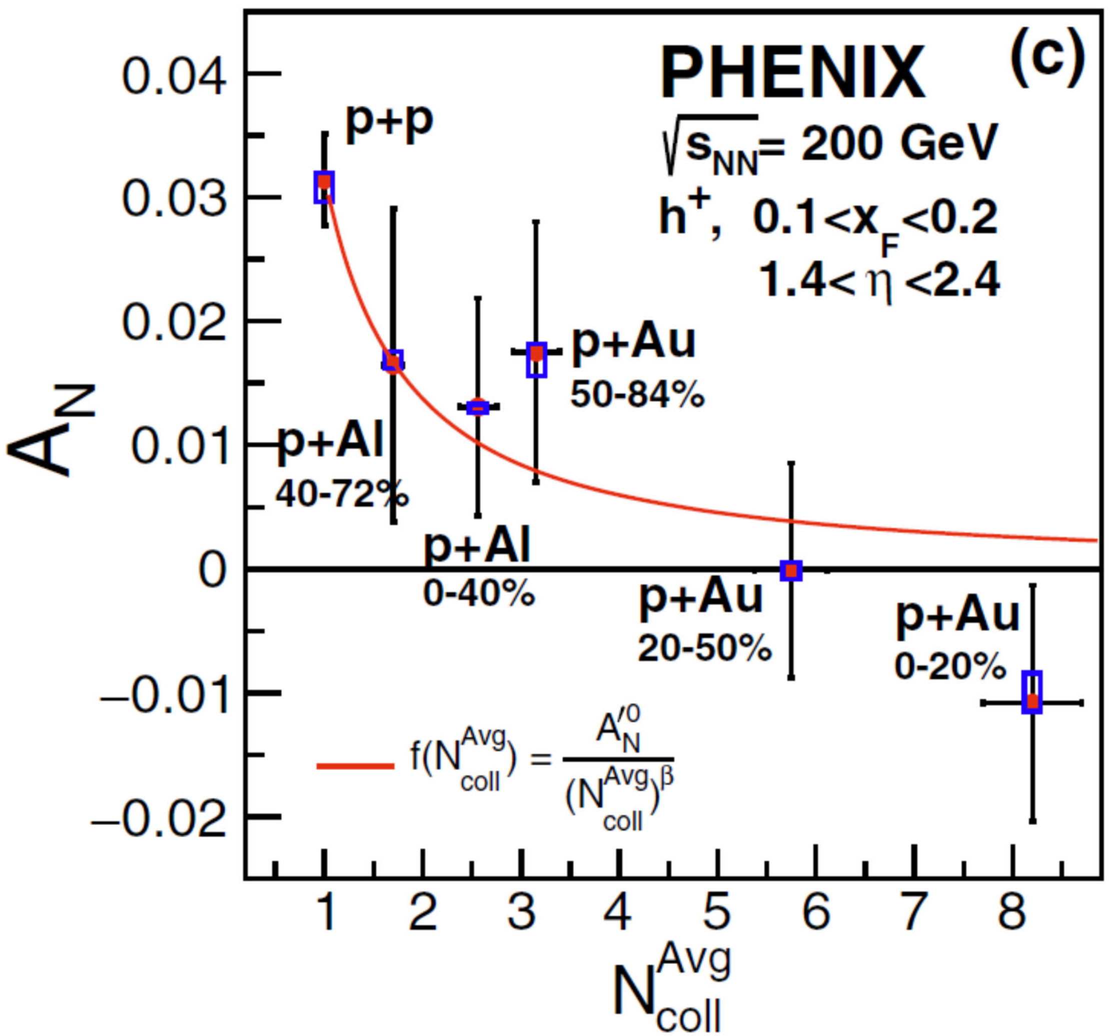
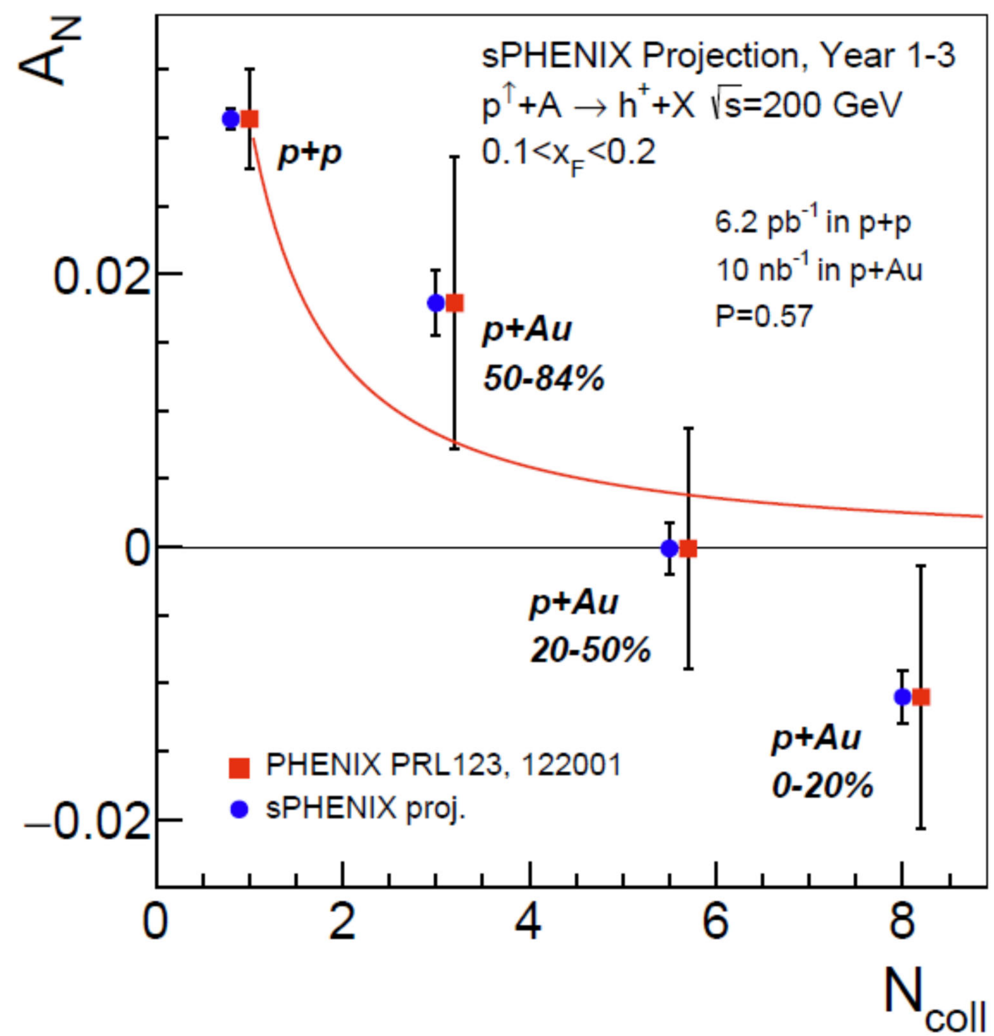
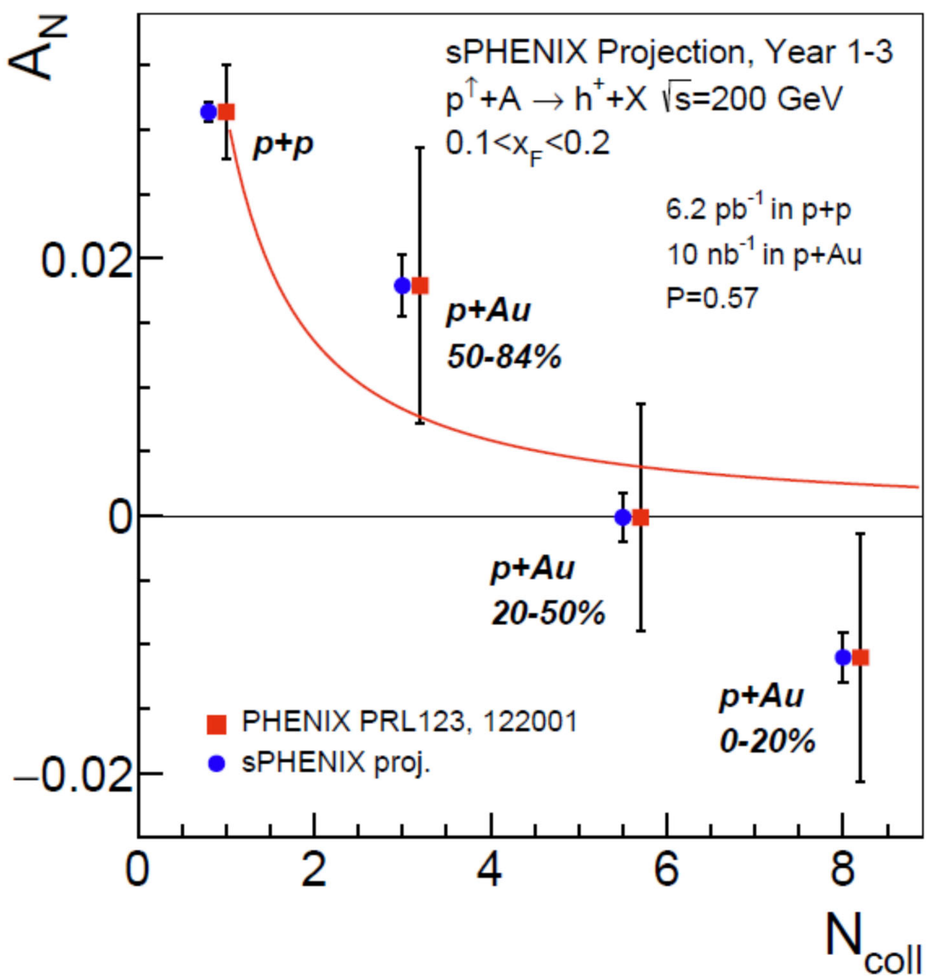




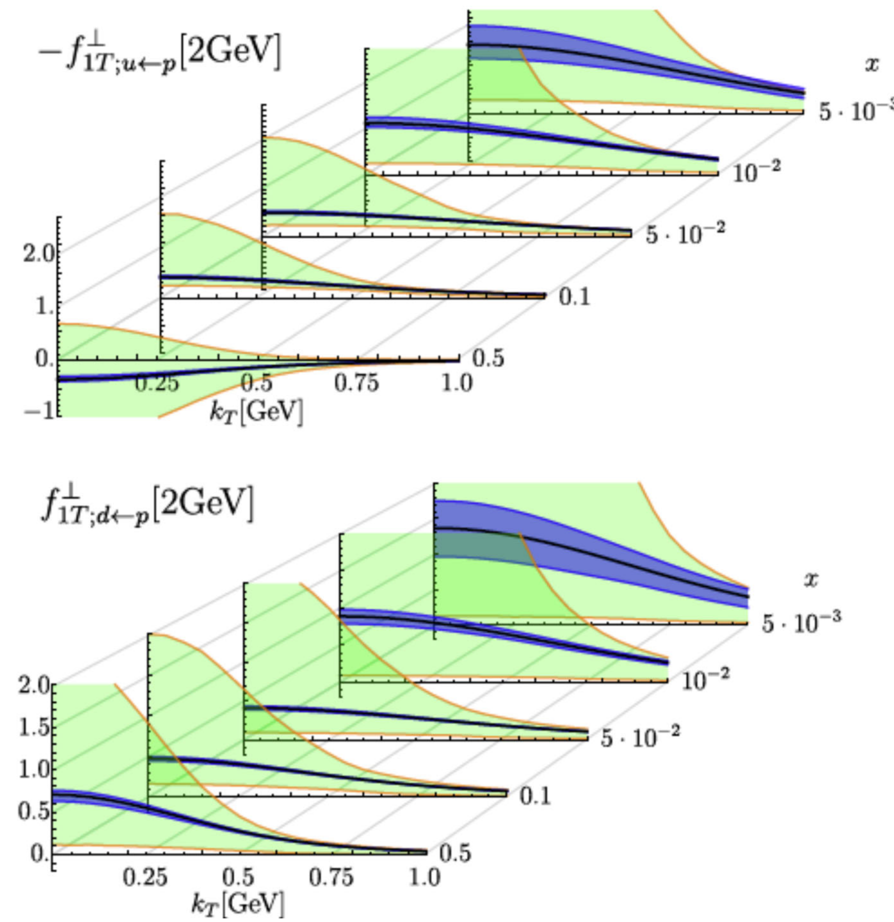
Hadron A_N in sPHENIX -> EIC

EIC Yellow Report Fig. 7.53



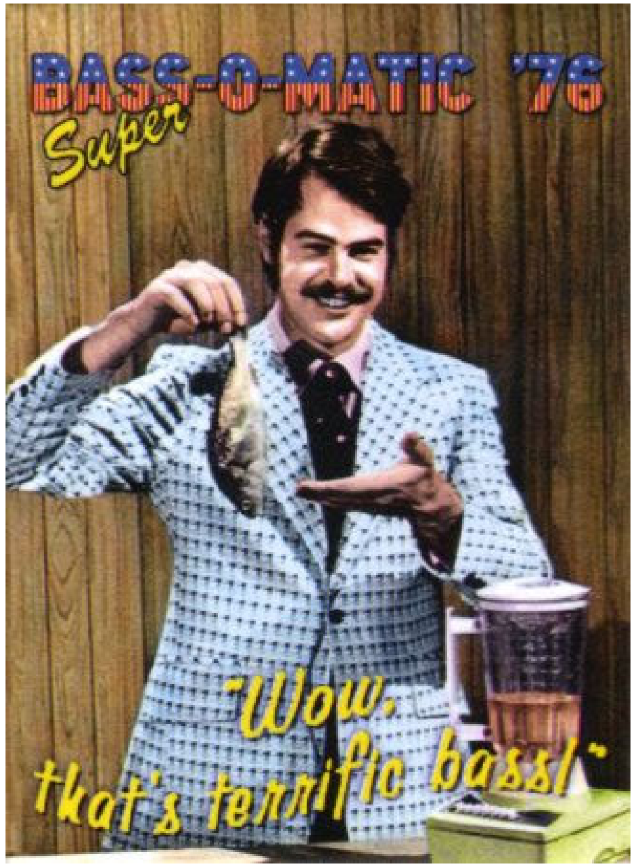
EIC impact on *u* and *d*-quark Sivers, as a function of *x* and k_T.

Imagine this also as a function of A…



But wait, there's more…

- Inclusive jet TSSA
  - sPHENIX can measure at level of 10^{-4}
- Dijet measurements
  - Sensitive to parton intrinsic k_T , TMDPDF's
- Charge-tagged jets
  - Tag jets with jet charge Q, separate u/d quarks
  - TMDFF from jet substructure
- Flow in small systems
  - See talk by Ron Belmont, Prithwish Tribedy



Challenges…

Unlike previous RHIC experiments, sPHENIX have a very definite timeframe in which to carry out its physics program:

- sPHENIX brings new capabilities, BUT quick and efficient commissioning will be essential
- Challenging to exploit these new capabilities in limited time
- Need cryo weeks, smooth operations

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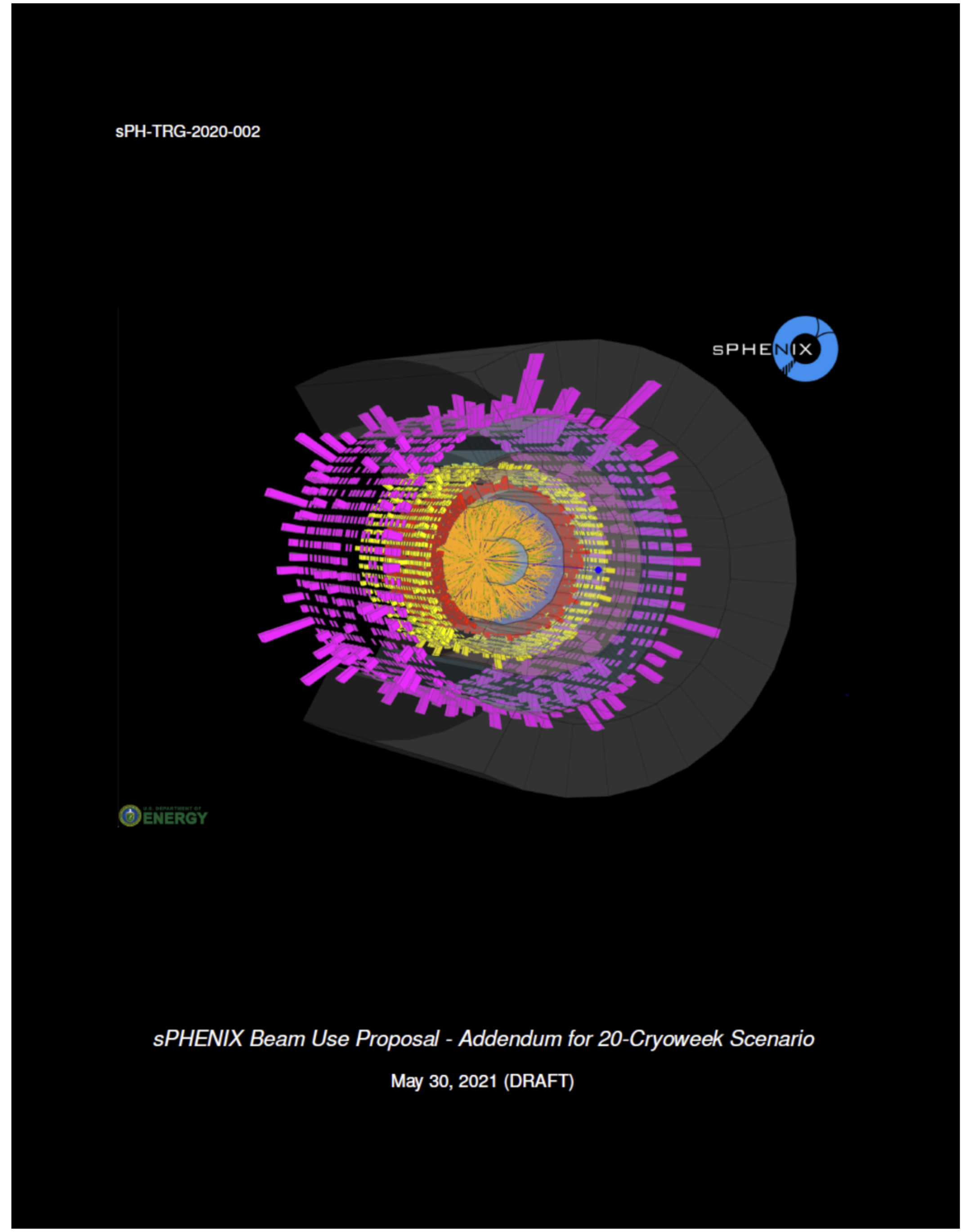
https://indico.bnl.gov/event/7881/attachments/30176/47160/sPH-TRG-2020-001.pdf



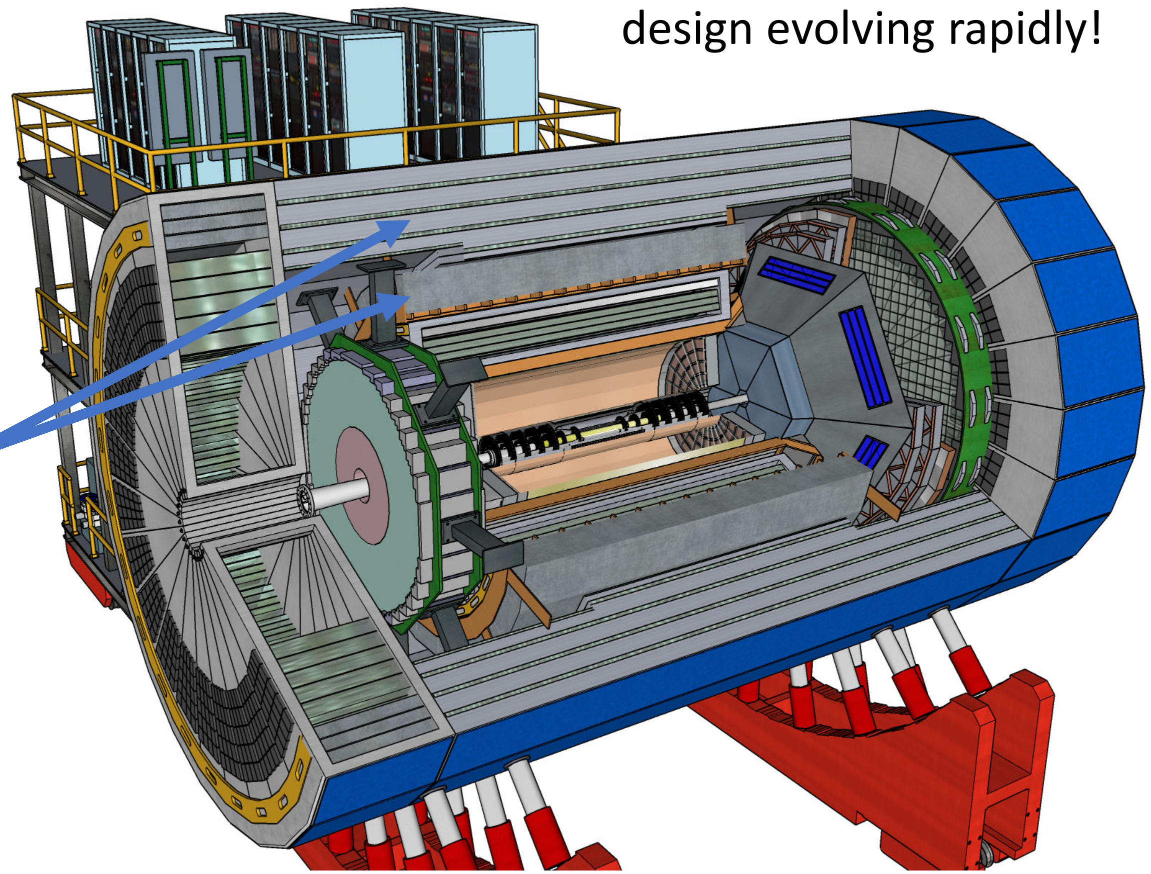
The ECCE Detector

Strategic re-use of 1.4T solenoid and flux return steel…

… AND …

the *intellectual curiosity of our HI collaborators* to gain a deeper understanding of emergent phenomena in QCD!

ECCE "strawman" design evolving rapidly!



https://www.ecce-eic.org

ECCE ELECTRON ENDCAP STRAWMAN

Tracking: MAPS, Micro Pattern Gaseous Detectors (MPGD)
Electron Detection: PWO&SciGlass
- Inner part: PWO crystals (reuse some)
- Outer part: SciGlass (backup PbGl)

h-PID: mRICH
- From yellow report

HCAL: Steel from magnet or PbSc or Fe/Sc
- Not instrumented and only serve as flux return?
- Instrumented \w reduced thickness (lower energies)

ECCE CENTRAL BARREL STRAWMAN

Tracking: Silicon barrel tracker (optional Si/GEM hybrid)
Electron PID: SciGlass (backup: W/Sc (Pb/Sc) shashlik)
- SciGlass remains to be demonstrated
- Several backup options – lower resolution though

h-PID: hpDIRC & AC-LGAD
- Compact
- AC-LGAD never been shown for barrel configuration
- AC-LGAD backup: dE/dx (needs more space)

HCAL: magnet steel (**reuse**) - **Fe/Sc**

ECCE HADRON ENDCAP STRAWMAN

Tracking: MAPS, Micro Pattern Gaseous Detectors (MPGD)
h-PID: dRICH&TOF
e/h separation: TOF & aerogel
- TRD to separate electrons from high momentum hadrons?

Electron PID: W/ScFi, Pb/Sc or W/Sc shashlik
HCAL: Fe/Sc
- Alternative for improved resolution: dual readout, high-granularity

Conclusions

- The sPHENIX physics program offers a number of key measurements in *p*+*p* and *p*+*A* that pave the way to the EIC.
  - Do NOT underestimate the value of early measurements to guide the more comprehensive program at the EIC!
- Complementarity is key!
  - Understanding the same fundamental physics in different reaction processes is essential.
- Challenging timescale and run plan
  - Capitalize on existing investment in sPHENIX