The Future of Physics at RHIC

Timeline, Upgrades, and Selected Topics

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Mini-Symposium on the Future of Physics at RHIC
APS Division of Nuclear Physics Meeting
October 24, 2013

University of Colorado Boulder

APS physics™

Outline

RHIC to date

RHIC plan
Science, operations, and upgrades

Current and upcoming physics
Mainly small systems and heavy flavor

Intermediate-term physics
Beam energy scan phase II

Longer-term topics
sPHENIX, eRHIC

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And a few disclaimers

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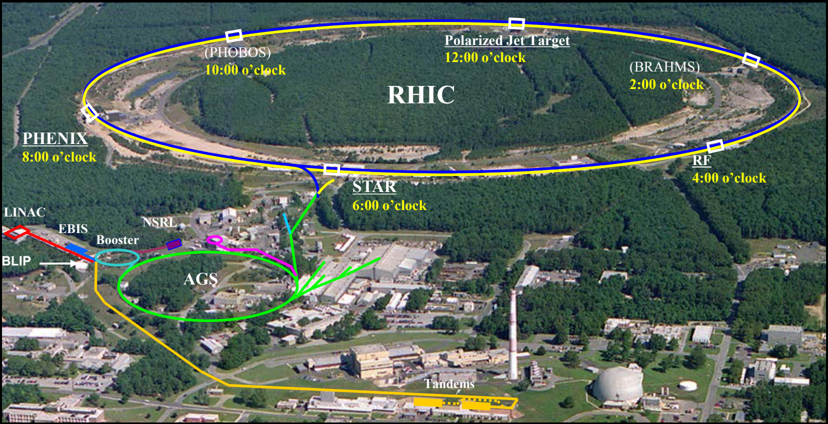
This talk will NOT be:

- Comprehensive (will select a few topics)
- Uniformly covering time periods (near-future emphasis)
- Balanced (a bit PHENIX-centric, no spin)

RHIC: 13 years of success

and counting

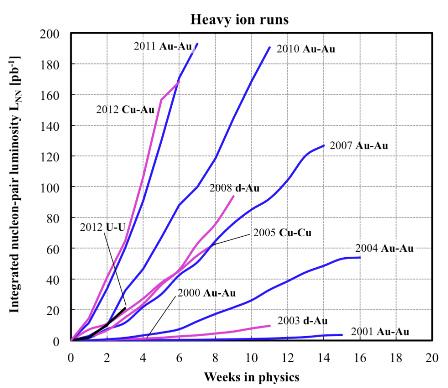


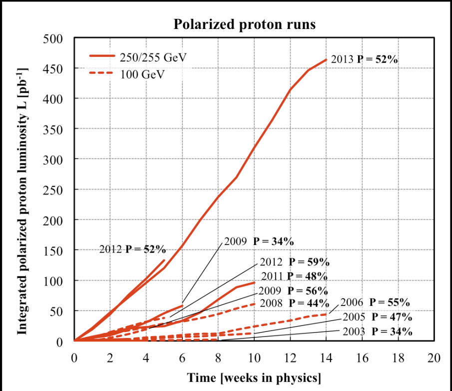
- $>$ 350 refereed papers
- $> 3 \times 10^4$ citations
- $>$ 300 PhDs
- Broad range of ion species
- Wide $\sqrt{s}$ range
- World's only polarized *pp* collider

RHIC performance history

Integrated luminosity since 2000

$A + A$ | Polarized $p + p$

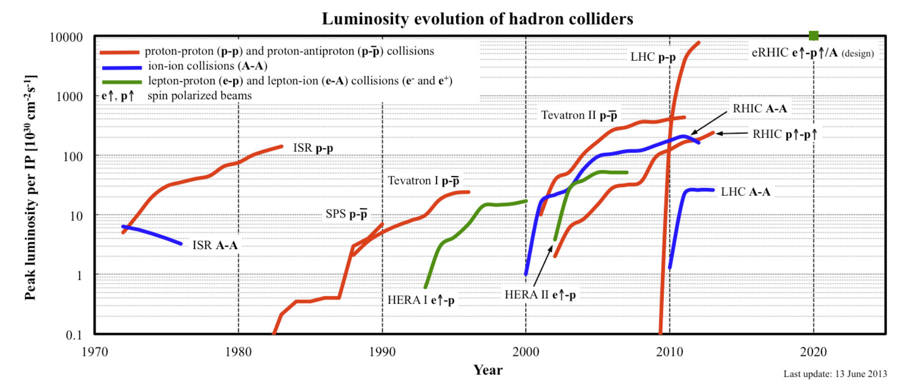




Huge rate improvements, thanks to hard work + incremental machine upgrades

RHIC among its peers

Currently unmatched A+A luminosity



RHIC remains a cutting-edge machine…and poised to remain competitive.

Some key goals and questions

for the next decade

QCD and the sQGP

- How can strong coupling and asymptotic freedom be reconciled?

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Nuclear phase transitions

- Location and sharpness of phase boundaries
- sQGP near $T_c \rightarrow$ weak coupling at asymptotically high T
- Critical point

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Parton distributions and interactions

- Distribution of sea quarks and gluons, and their spins, in space and momentum inside the nucleon
- Where does the saturation of gluon densities set in?
- Effect of nuclear environment on parton interactions

The ten-year plan

Year	Beam Species, $\sqrt{s}$	Science Goals	New Systems
2014	15 GeV *Au* + *Au* 200 GeV *Au*+*Au*	Heavy flavor flow, energy loss, Thermalization Quarkonium studies QCD Critical pt. search	Electron lenses 56 MHz SRF Full STAR HFT STAR MTD
2015-2016	*pp* at 200 GeV *p*+*Au*, *d*+*Au*, ^{3}*He*+*Au* at 200 GeV High statistics *Au*+*Au*	Extract $\eta/s(T)$ & constrain initial quantum fluctuations Further HF studies Transverse spin physics	PHENIX MPC-EX Coherent *e*-cooling test

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2023-2024	No Runs	-	Transition to eRHIC

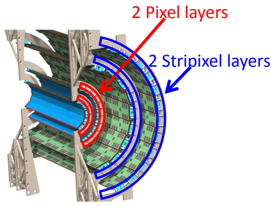
1. Current & near-term physics

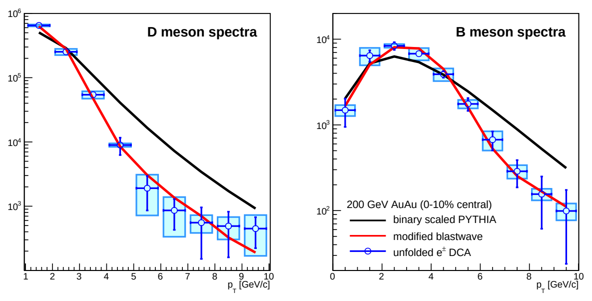
(A few selected topics)

Heavy flavor physics with PHENIX VTX

charm-bottom separation is within reach

- VTX detector installed 2011, analyses underway
- High vertex resolution $\rightarrow$ heavy flavor $e^{\pm}$ ID
- Stay tuned for QM 2014!



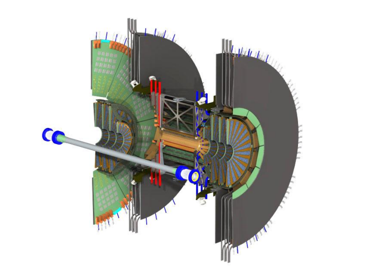


c/b Proof of concept in simulation: Unfold PYTHIA electron vertices $\rightarrow$ D,B p_T distributions

Separate modification of *c* and *b* quarks!

PHENIX silicon detector upgrades

Forward vertex tracker

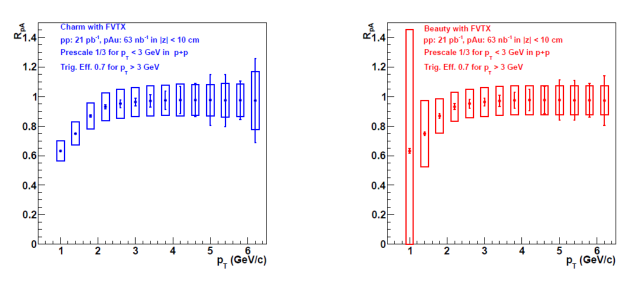


PHENIX F-VTX Installed 2012

4 tracking planes with full azimuthal coverage over $1.2 < |\eta| < 2.4$

- Precise muon DCA measurements
  Distinguish c, b from π, K
- **Open heavy flavor**
  Charm and beauty in *d+A* / *p+A*

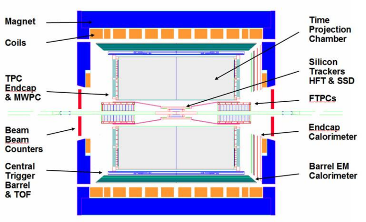
Projected R_{pA} for open charm and beauty



STAR detector upgrades

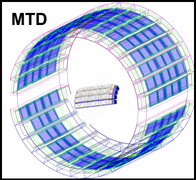
HFT, MTD, and FGT

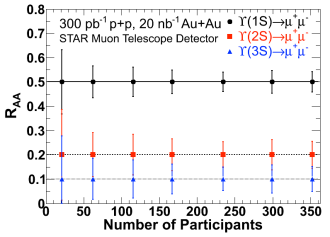
Heavy Flavor Tracker



- 2014: v_2 and R_{cp} from D^0 and HFE
- Later: Λ_c, D^0 R_{AA}
- 3 HFT talks this session

Muon Telescope Detector





- MRPCs for muon ID and triggering
- High mass resolution for J/ψ & separate Υ states from dimuons
- Single muons and e-μ correlations

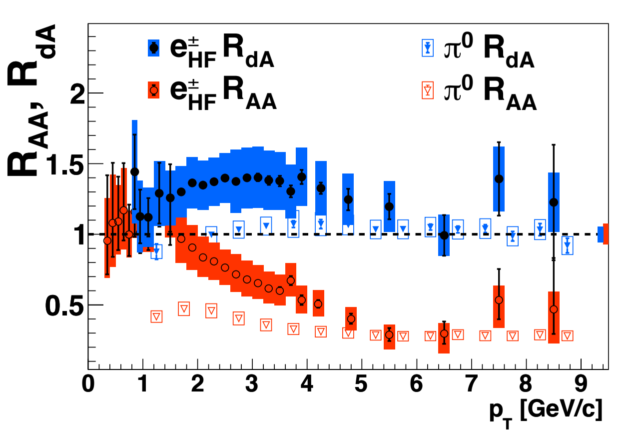
Both ready for physics 2014

Also: **Forward GEM Tracker** installed 2013

Heavy-flavor electron R_{dAu}

PHENIX, 1208.1293v1

Strong electron suppression in *Au+Au*, but $e^{\pm}_{HF}$ $R_{dAu} > 1$.



CNM effects are the "Traditional" explanation for enhancement…
Perhaps other explanations are appropriate as well.

Low-p_T heavy flavor measurements

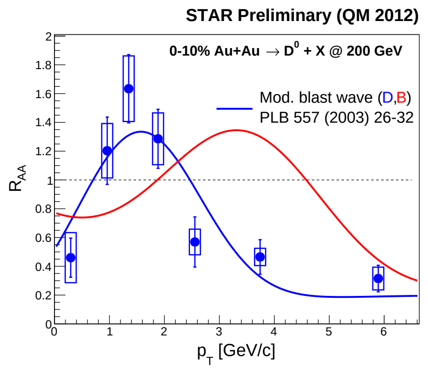
A new paradigm

Traditional focus: heavy quark energy loss

- Theory: simpler at high p_T; dominant effect
- Experiment: accessible at high p_T

Emerging focus: collective effects

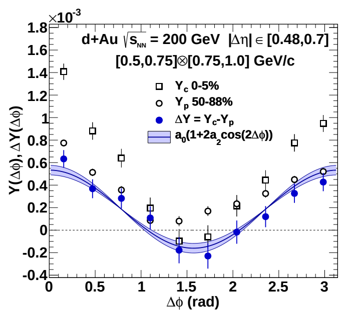
- Recent measurements show fascinating features at low p_T
- Significant constraint on hydro, transport, hadronization models
- System size dependence highly informative



For the first time, precision heavy-flavor anisotropy is within reach, and Si upgrades are improving low p_T accessibility…stay tuned!

d+Au correlations: Flow in small systems?

PHENIX, 1303.1794v1 (accepted by PRL last week)



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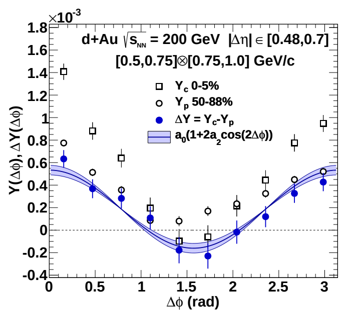
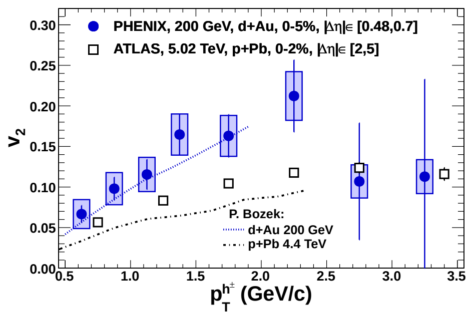
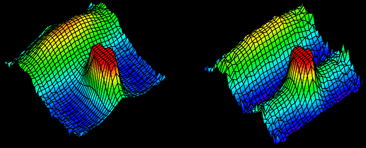






ATLAS *p+Pb*: peripheral (left) & central (right)

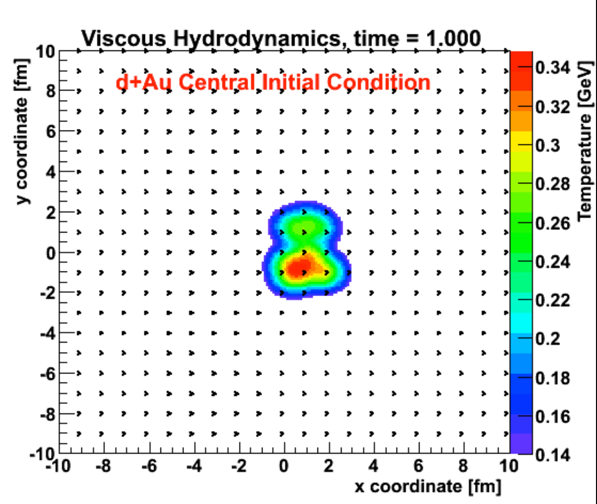
v_2 in *p+Pb* rises with multiplicity at LHC.

But large v_2 in *d+Au* at RHIC even at low multiplicity!

Large v_2 in *d+Au* from initial geometry?

Hydro + Langevin simulation in *d+Au*

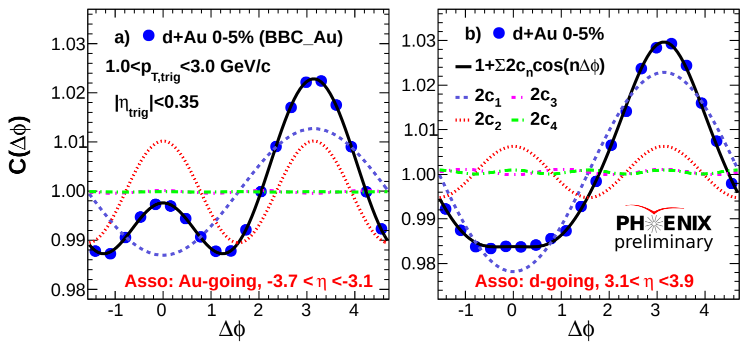
Initial $\varepsilon \to$ final p anisotropy



Are small systems exhibiting hydrodynamic behavior like this?

Long-range correlations at RHIC

d+Au correlations



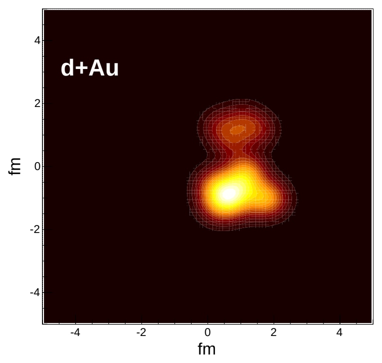
- Ridge observed in Au-going, but not d-going direction
- Long-range near-side anisotropy not easily explained by jets

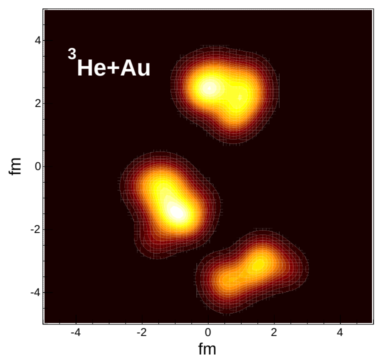
Understanding long-range correlations

Competing explanations:

- Initial-state fluctuations $\rightarrow$ long-range correlations
- Hydrodynamic effects
- CGC effects

Reality may require admixture of these. **Plan:** Vary initial geometry (p, d, ^{3}*He+Au*) and look for anisotropy. If hydro, signal should be strong! Initial geometry not just fluctuations.

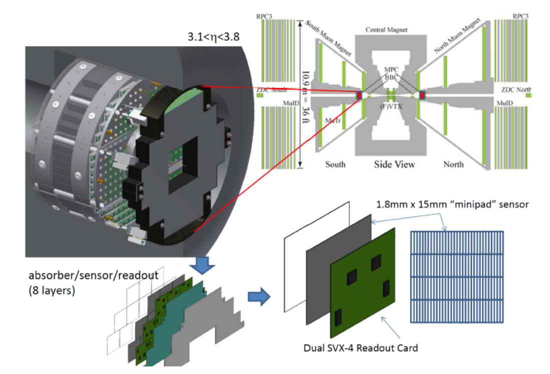




The PHENIX MPC-EX upgrade

Direct photons and neutral pions at forward rapidity

Silicon tracking / preshower addition to successful Muon Piston Calorimeter ($3.1 < |\eta| < 3.8$)



Proposal: 1301.1096v1

8-layer Si minipad / tungsten sandwich design

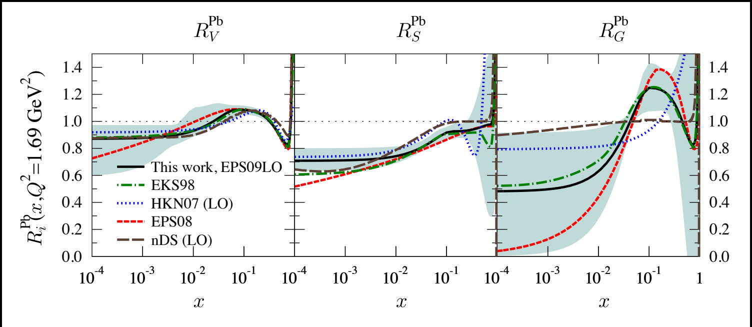
- Preshower improves MPC EM/hadronic shower discrimination
- $\pi^0 \to \gamma\gamma$ up to $p = 100$ GeV/c
- Prompt γ identification

Commissioning in 2014, ready for physics in 2015

Forward physics with PHENIX MPC-EX

Improving constraints on nuclear PDFs

EPS09: the state of the art in parton distributions
Valence and sea quarks well constrained.

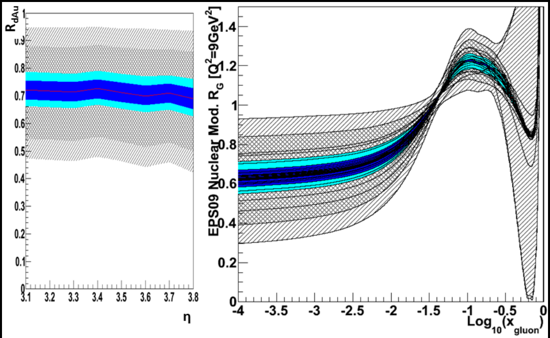


But LHC mid-y / RHIC forward-y gluon distribution models have large discrepancies.

Forward physics with PHENIX MPC-EX

Direct photons: the "golden channel"

Prompt photons are free from final-state effects…clean access to low-*x* shadowing / saturations effects.



1301.1096v1

Simulation using full statistical / systematic constraint method on EPS09 nPDFs

Projected measurement at 1σ and 2σ level

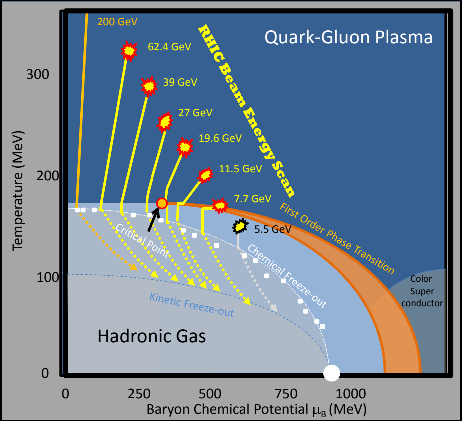
2. Intermediate-term physics

Beam energy scan II (2018-2019)

Beam Energy Scan Phase II

Searching for critical boundaries

Plan: Cover BES I energies with longer runs & upgraded detectors. Range may be extended to include $\sqrt{s} < 7$ GeV runs (fixed-target).



Focus on correlation and fluctuation observables:

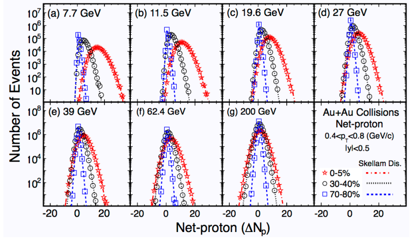
- **1st-order transition?**
  Azimuthal HBT and v_1
- **Partonic or hadronic matter?**
  v_2/NCQ scaling
- **Critical point?**
  Correlation length, fluctuation measurements

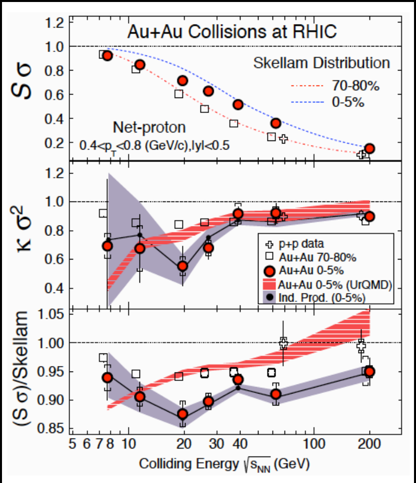
RHIC is our best bet for investigating these key questions.

Intriguing hints from BES I

STAR, 1309.5681v1

- Net-proton ($N_p - N_{\bar{p}}$) distributions over $\sqrt{s_{NN}} = 7.7$-200 GeV
- Baseline expectation: $p, \bar{p}$ multiplicities are Poisson-distributed (Skellam dist.)





Cumulant ratios show $\sqrt{s_{NN}}$ dependence

Not predicted by transport models (UrQMD does not model a critical point)

BES II Schedule

Planned for 2018-2019

Factor of 10 - 20 increase in statistics over BES 1 (with added step in μ_B), with several major detector upgrades in place.

$\sqrt{s}$ (GeV)	62.4	39	27	19.6	14.6	11.5	7.7	4.5	3.9	3.5	3.0
μ_B (MeV)	70	115	155	205	250	315	420	585	630	670	720
BES I (M Evts)	67	130	70	36	-	11.7	4.3				
BES II (M Evts)				400	100	120	80	5	5	5	5
Rate (M Evts/day)	20	20	9	3.6	1.6	1.1	0.5				
e Cooling				8	6	4.5	3				
Weeks				2	1.5	3.5	7.5				

3. The next generation at RHIC

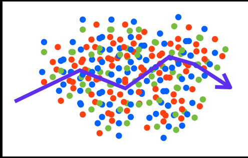
sPHENIX (2020-2022)

Probing the medium in sPHENIX

Collisional energy loss infers medium composition

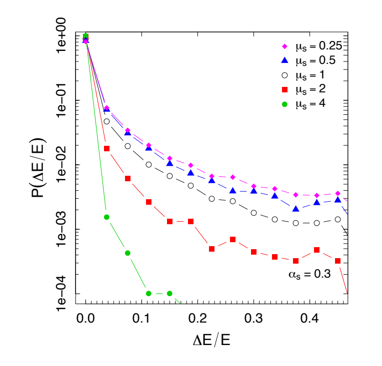
Why is energy loss at RHIC interesting?

- Not all radiative! Collisional energy loss is not negligible
- Collisional component depends on mass of scattering centers
- Also depends on length scale probed



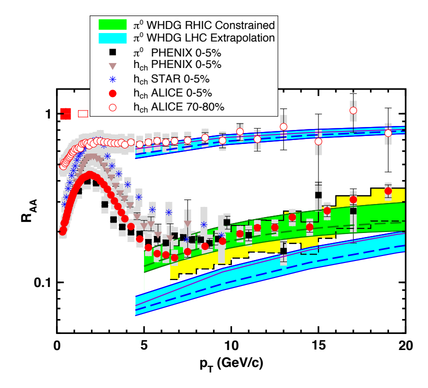
Collisional E loss decreases as mass scale μ_s increases

C. Coleman-Smith, B. Mueller (1209.3328v1)



E loss at different T, E_{parton}
→ info on medium (scattering centers)

sPHENIX



Horowitz & Gyulassy 1104.4958v1

Energy loss models require RHIC constraints

- WHDG fails to naturally match both RHIC and LHC R_{AA}
- RHIC R_{AA} provides important constraint
- Far more powerful energy loss observables available in sPHENIX

We need tools to study the medium at different length scales and temperatures: Jets, heavy quarks, and photons.

sPHENIX is optimized for these probes. LHC alone is insufficient!

See following talks by J. Haggerty, J. Huang, and D. Morrison.

4. The eRHIC era

2023 onward

Gluons

Central to QCD, yet still enigmatic

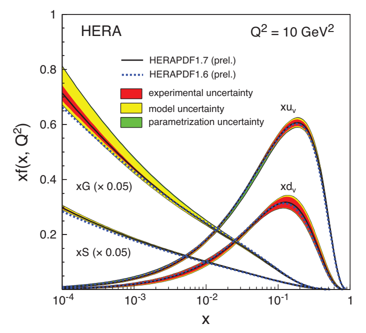
- Responsible for most of hadronic mass
- Self-interact, unlike photons
  $\rightarrow$ asymptotic freedom
- Gluons in nuclei dominate at small *x*

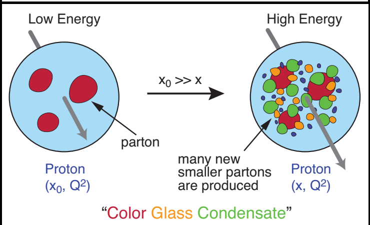
As nucleon moves faster,

- fluctuating gluons are longer-lived
- gluons crowd the hadron
- saturation momentum scale

$$Q_s^2(x) \propto A^{1/3} \left(\frac{1}{x}\right)^{0.2-0.3}$$

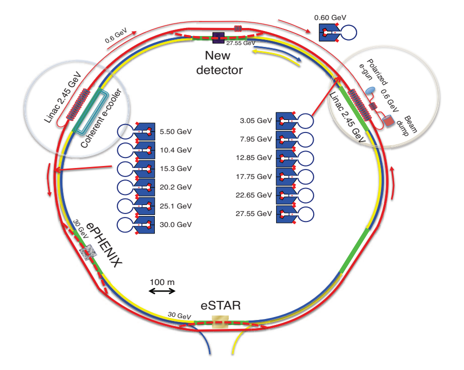
$\rightarrow$ Color glass condensate

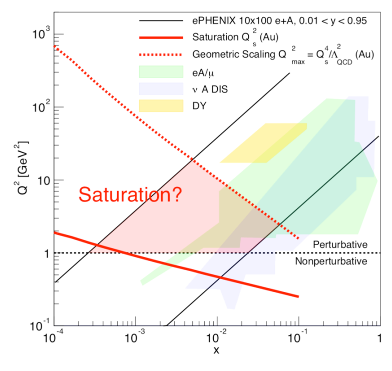




Where is the saturation scale?

eRHIC





$$Q_s^2(x) \propto A^{1/3}\left(\frac{1}{x}\right)^{0.2-0.3}$$

An $e + A$ collider is the ideal machine for physics at the saturation scale.
See Talks by B. Mueller, A. Deshpande, A. Bazilevsky, and others.

Summary

4 time periods with a few highlights

1. **Current and near future**
   Collective behavior in small systems
   New detectors $\rightarrow$ heavy flavor physics
2. **Beam energy scan phase II**
   Constraining phase boundaries and the critical point
3. **Adding T-dependence with sPHENIX**
   Energy loss and partonic interactions near T_c
4. **eRHIC era**
   Gluon nPDFs, saturation

Thank you