RHIC Related Town Meetings

Relativistic Heavy Ion Town Meeting and RHIC and AGS Users' Group Open Forum Meeting

chaired by Paul Sorensen (BNL), Xin-Nian Wang (Lawrence Berkeley National Laboratory)

Thursday, October 25, 2012 from **08:00** to **22:15** (Europe/Zurich)
at **Hyatt Regency (Plaza III)**
Newport Beach, CA

Description This is one of four mini-town meetings being held at the 2012 Fall Meeting of the APS Division of Nuclear Physics: http://physics.ucr.edu/dnp2012/

Thursday, October 25, 2012

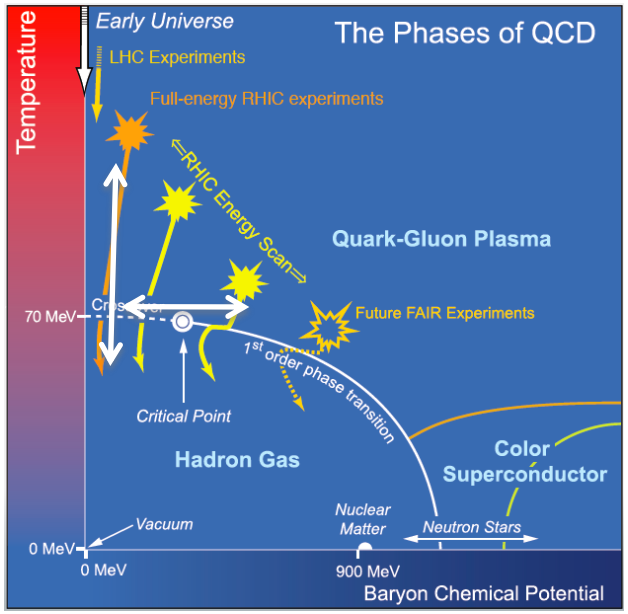
18:00 - 18:20	The Next Directions for the HI Program Envisioned in the White Paper *20'* Speaker: Prof. Steffen A. Bass (Duke University) Material: document
18:20 - 18:40	The Hard Probes Program at RHIC *20'* Speaker: Anne Sickles (Brookhaven)
18:40 - 19:00	Hard Probes and the Temperature Dependence of Transport Properties *20'* Speaker: Abhijit Majumder (Wayne state university)
19:00 - 19:15	The Beam Energy Scan II at RHIC *15'* Speaker: Prof. Daniel Cebra (U.C. Davis)
19:15 - 19:45	Community Input and Discussion *30'*
19:45 - 20:05	Break
20:05 - 20:25	RHIC and Visions for the Long-Term Future of QCD-Related Research *20'* Speaker: Steven Vigdor (Brookhaven National Laboratory)
20:25 - 20:40	The Spin Program at RHIC *15'* Speaker: Carl Gagliardi (Texas A&M University)
20:40 - 20:55	The p+A Program and Future Studies of Gluon Saturation at RHIC *15'* Speaker: John Lajoie (Iowa State University)
20:55 - 21:10	RHIC and the Road to an EIC *15'* Speaker: Matthew Lamont (BNL)

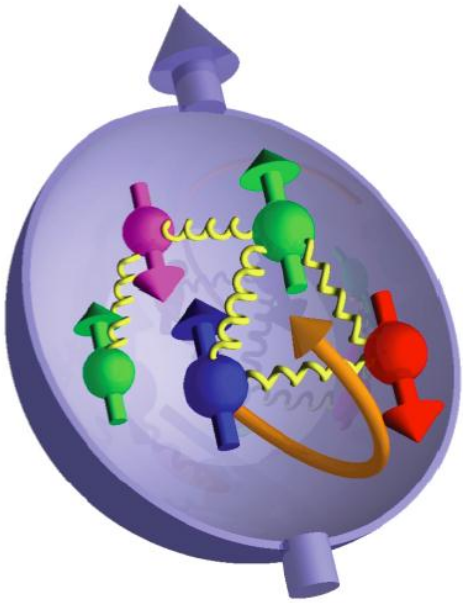
DC Town Meeting on Heavy Ions:
Held Saturday afternoon, after the conclusion of the Quark Matter Conference

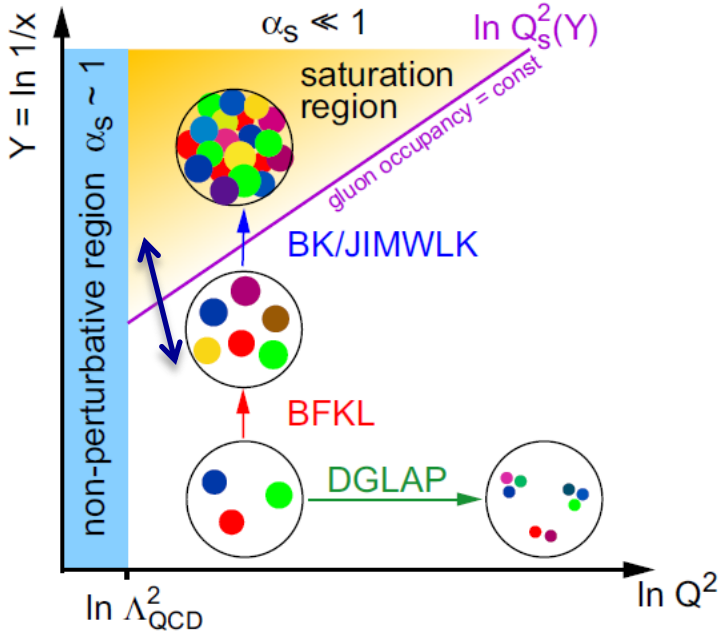
Presentations by
- Peter Jacobs – *Tribble subcommittee charge*
- Steve Vigdor – *The case for continuing RHIC operations*
- Peter Braun-Munzinger – *Report on European Town Meeting*
- Stephan Bass – *White-paper discussion*

Followed by public comments

The RHIC Physics Program







RHIC's versatility facilities the study many aspects of the strong force:

- condensed QCD matter and its phase structure
- transitions between degenerate vacuum states
- gluon saturation
- proton spin

"It's time to stop testing QCD and start understanding it"

Yuri Dokshitzer

Selected Scientific Highlights from RHIC

- **Quark Gluon Plasma created** at RHIC with a temperature several times T_C
*(setting a record in 2010 for **HOTTEST** man-made temperature ever measured)*
  - **equilibrates** very quickly $\lesssim$1 fm/c
  - has a **viscosity near a lower bound** *established from string theory*
  - **propagates quantum fluctuations** from the initial state through the perfect liquid phase into the final state
  - is **opaque** to fast moving partons
  - slows heavy quarks nearly as much as light quarks
  - **melts** quarkonium states

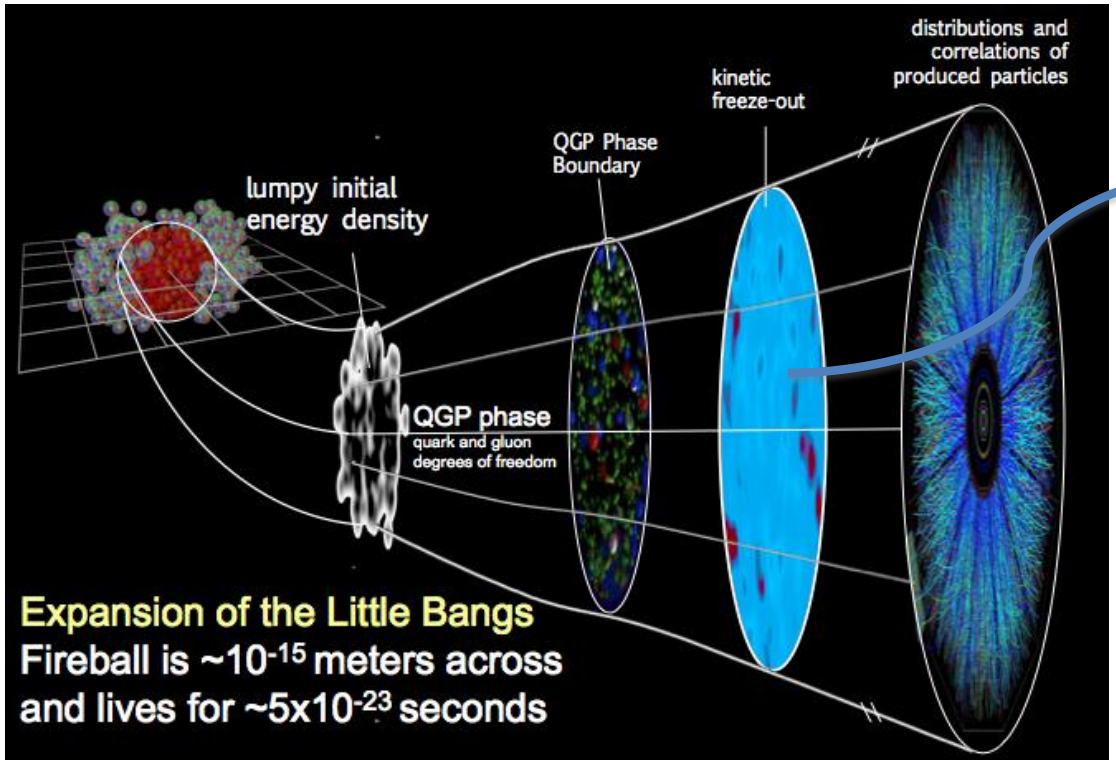
- Collisions at RHIC created the **HEAVIEST antimatter nucleus** ever measured and the **FIRST anti-hypernucleus** ever measured

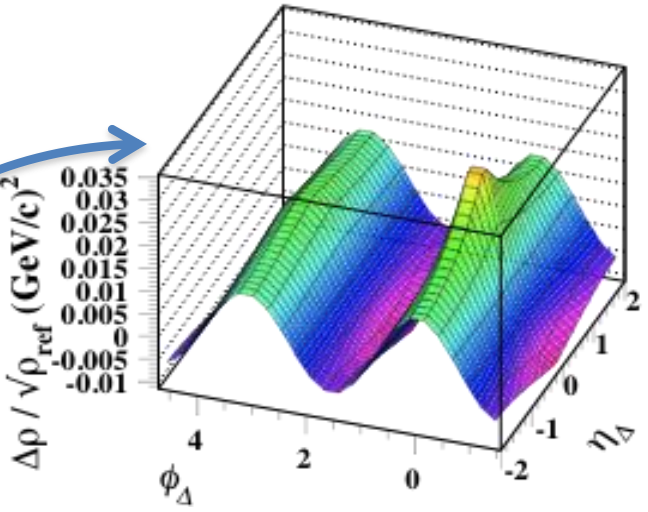
- Hadrons and di-hadrons are suppressed in the low-x coherent regime: providing **indications of gluon recombination** (A Color Glass Condensate)

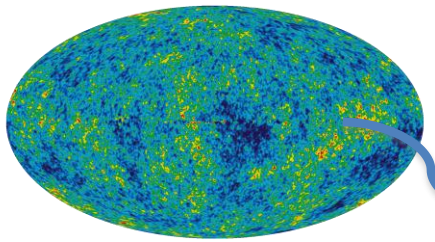
- First experimental evidence of **non-zero gluon polarization**
(RHIC is the worlds only polarized proton collider)

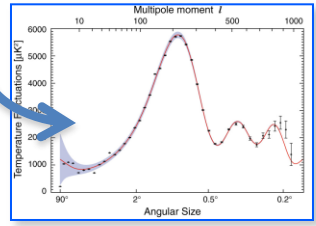
High impact in scientific publications and in the popular press

Our Standard Model



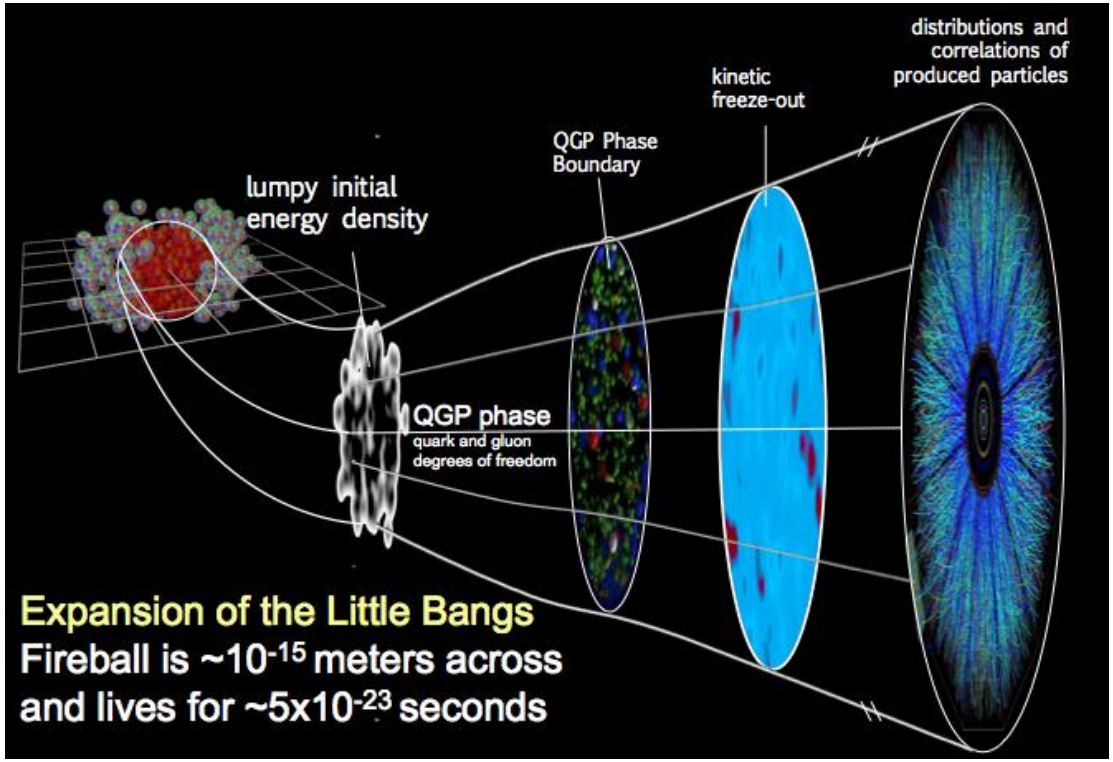




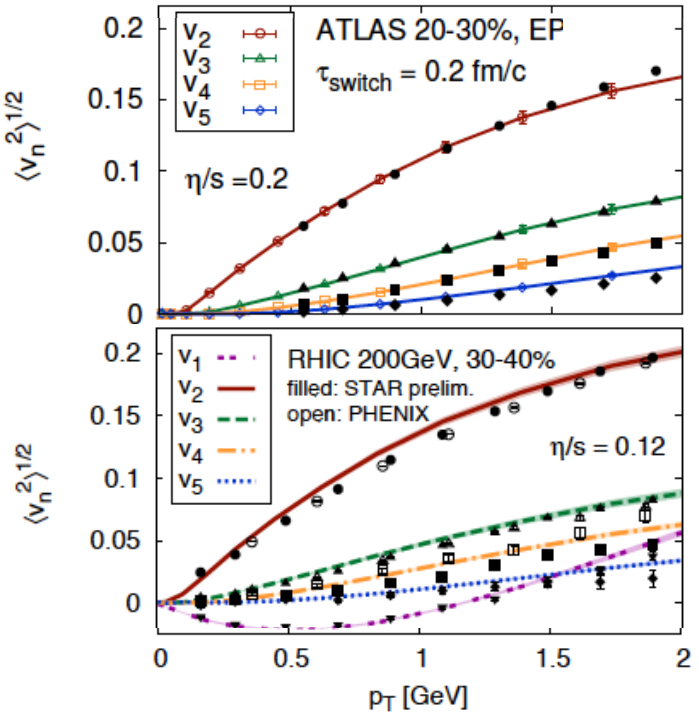


QCD theory+modeling ***with constant experimental guidance from RHIC*** now gives us a detailed picture of the evolution of heavy ion collisions

Our Standard Model



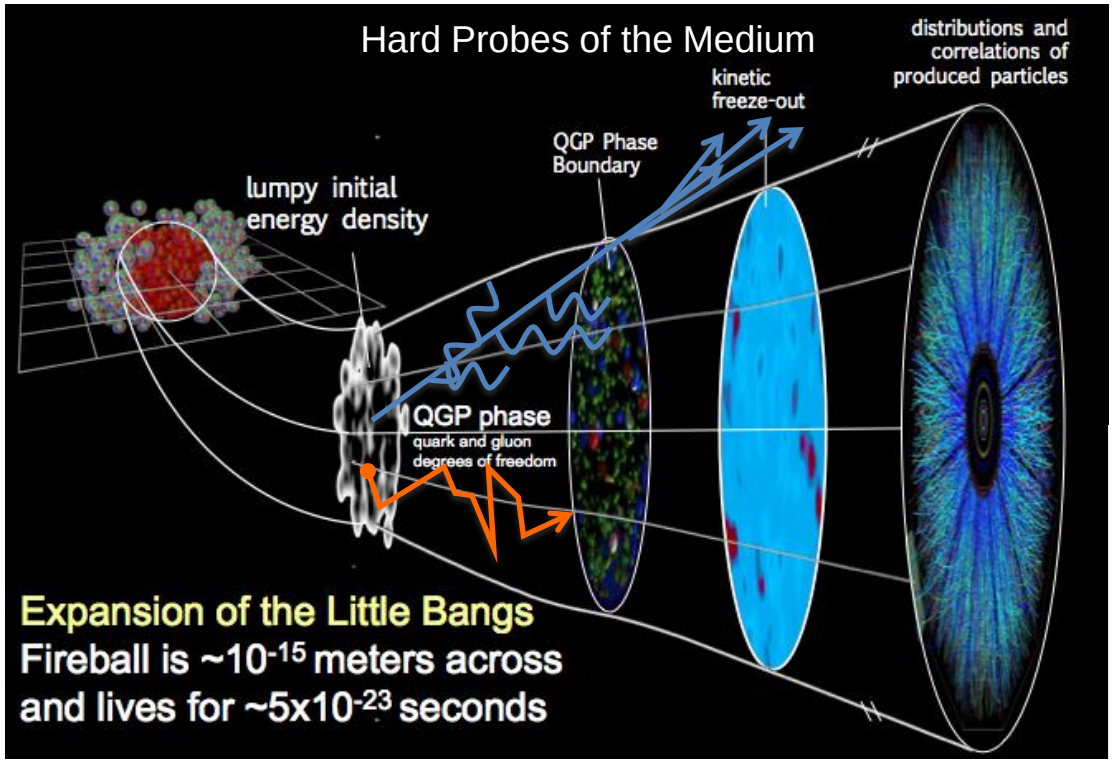
Similar to power-spectrum analysis of the cosmic microwave background

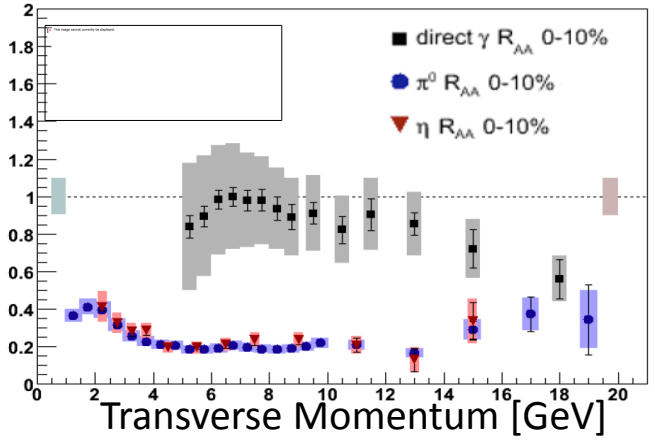


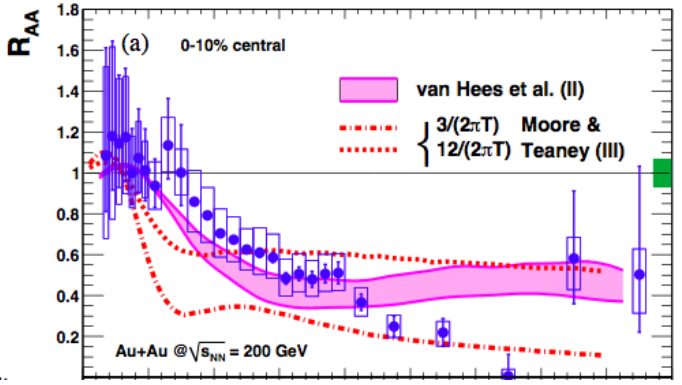
At high √s, excellent agreement between data and model in the soft sector

steady increase of accuracy in quantities like the transport properties of the quark gluon plasma: ***Textbook Ready Physics***

Our Standard Model



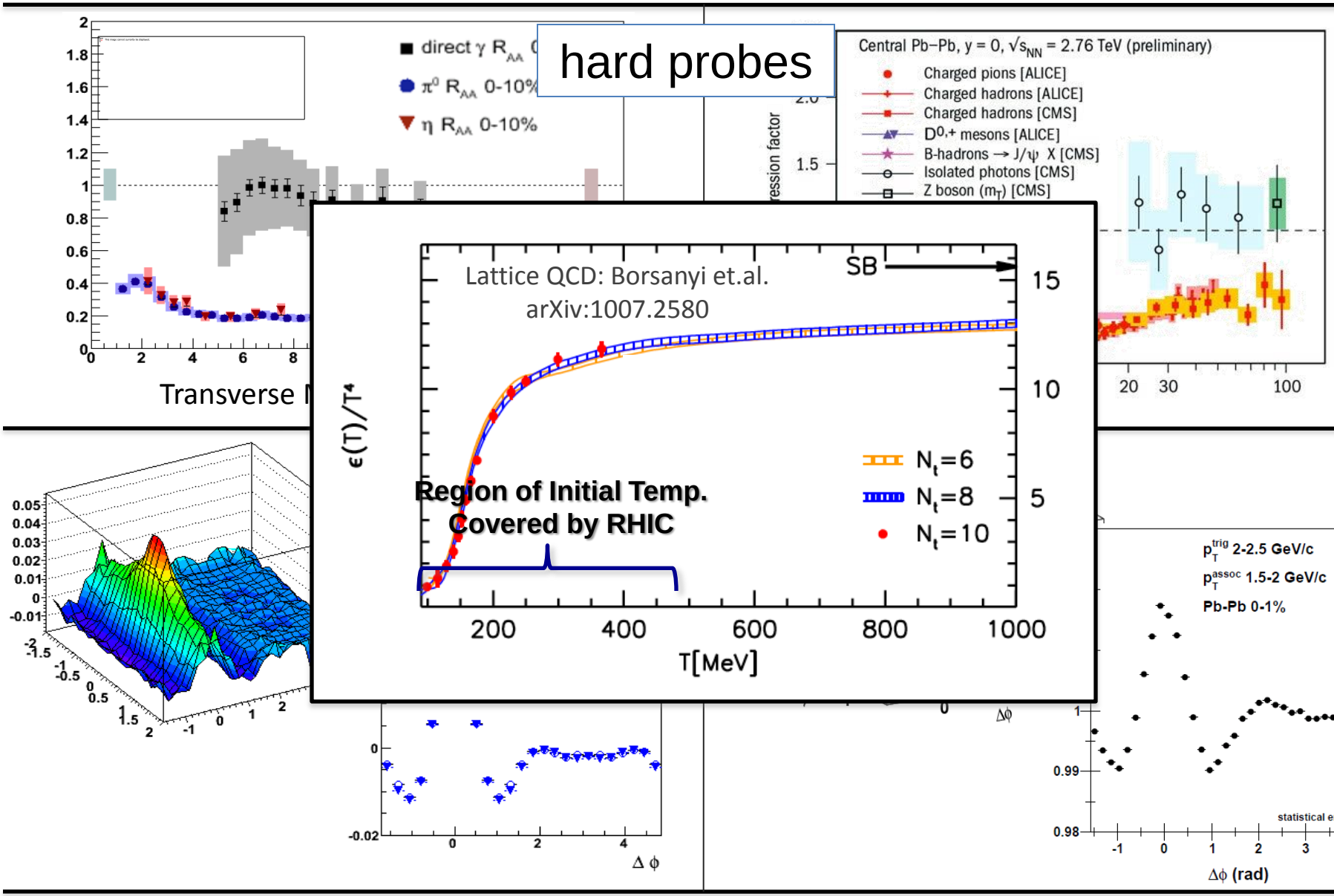




Hard probes (heavy quark diffusion, jet-quenching, Quarkonium screening) allow us to look deep inside the plasma and study it at different scales

RHIC and the LHC

hard probes



LHC confirms the paradigms established at RHIC

Upgrade Program

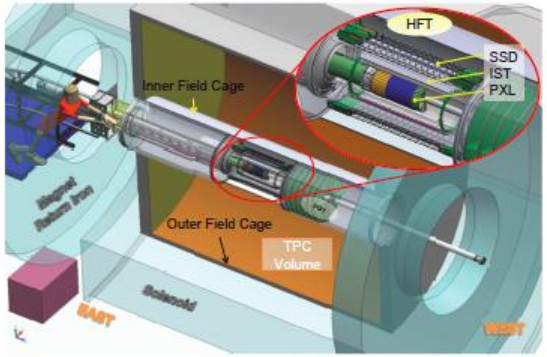
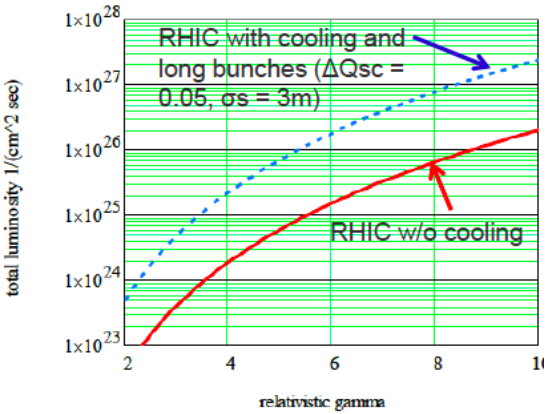


Figure 4.3: HFT detector within the STAR TPC.



FVTX (heavy flavor) and FGT (W+/W-) (in place)

Heavy Flavor Tracker & Muon Telescope *(2014)*

- Open heavy flavor hadrons for heavy quark interactions in the QGP: Diffusion, **better constrain QGP transport properties**
- Muon trigger for Quarkonium: **screening lengths in QGP**

Muon Piston Calorimeter Extension *(2015)*

Access to low-x gluons to **study saturation boundary**

Electron Cooling *(earliest possible 2017)*

Factor 10 luminosity boost for Beam Energy Scan II: **phases of QCD, Critical Point, and T dependence of transport**

Inner TPC Upgrade *(2017)*

Coverage at higher rapidity and lower p_T essential for studying glue (eRHIC) and long range correlations

STAR and PHENIX Forward Upgrades *(~2017)*

Very forward capabilities to study the **gluon dynamics of saturation**; leading to eRHIC

sPHENIX *(2018)*

Added jet capabilities to study **plasma coupling over a broad temperature range**

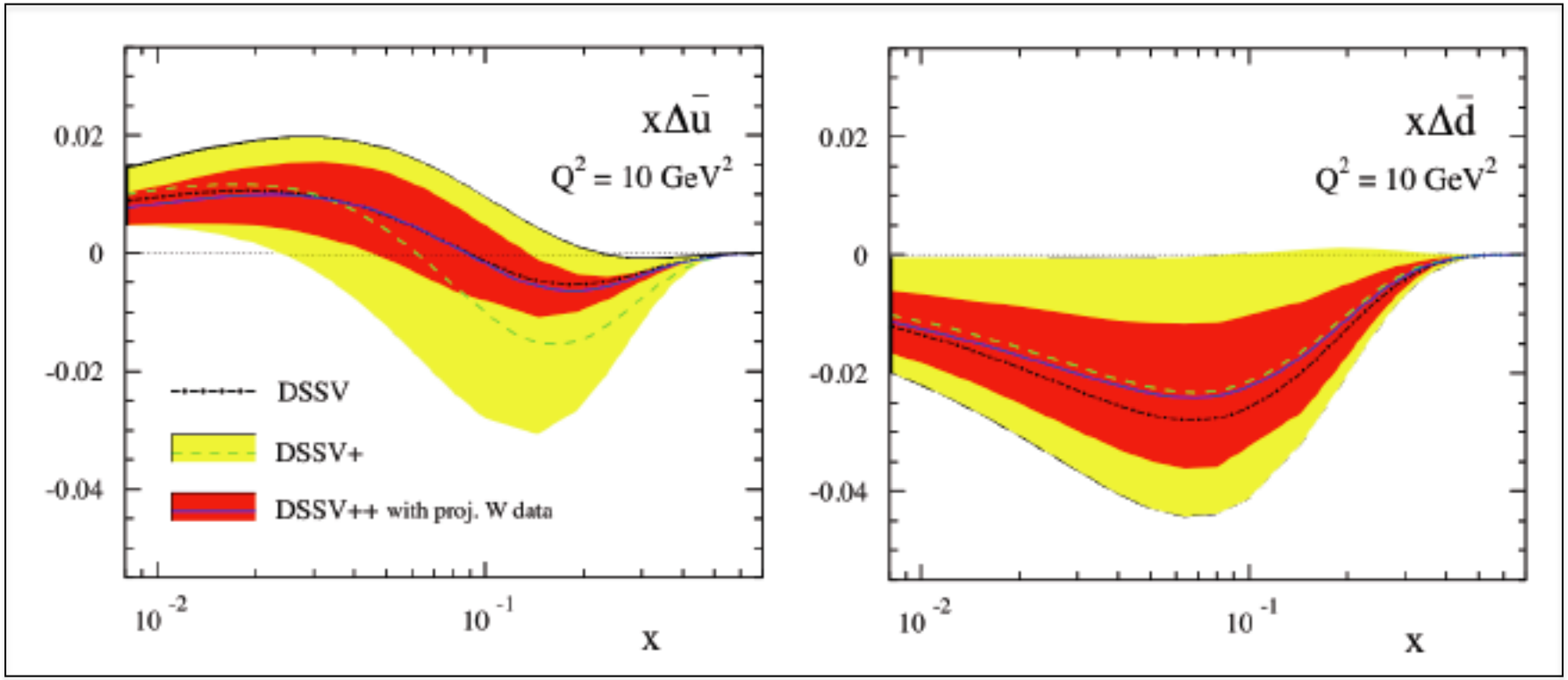
RHIC continues to attract significant international interest & funding

Timeline

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p}+\vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 GeV p+p (needed for new det. subsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Ex. (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p}+\vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p}+\vec{p}$ • 200 GeV $\vec{p}+A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different qq states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					

Substantial Reduction in Uncertainties on Anti-quark Polarization from W+/W-

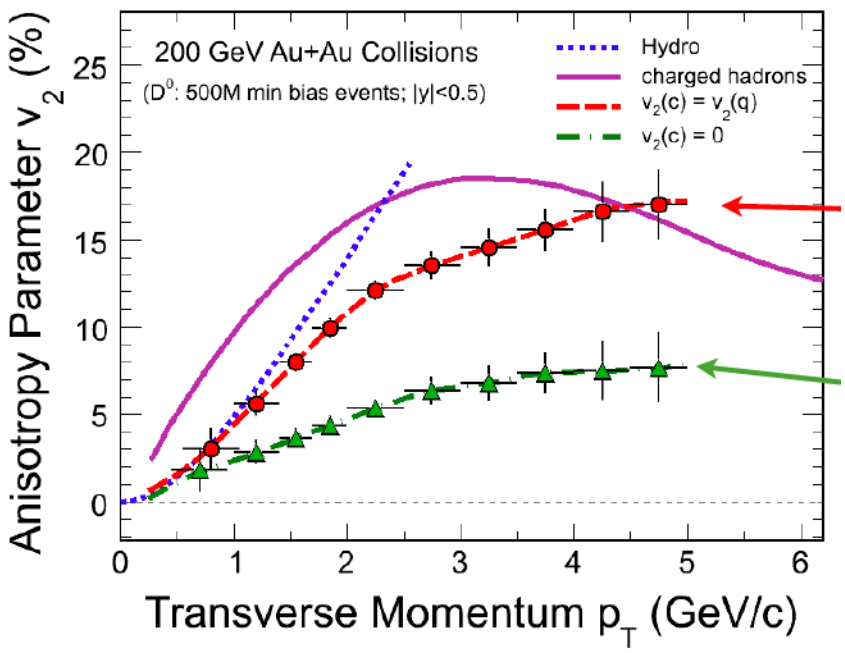


polarization of the u, u-bar, d, and d-bar quarks in the proton

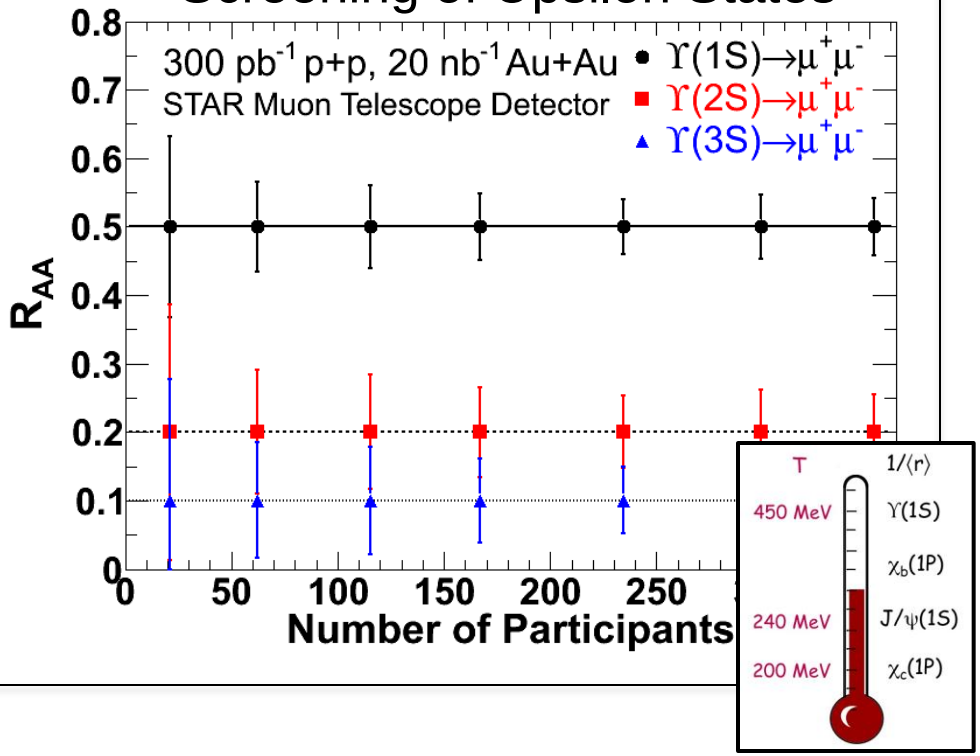
500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	Au+Au, U+U, Cu+Au at 1-2 energies 200 GeV p+A, 500 GeV p+p	BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au; 500 GeV p+p; 200 GeV (polarized) p+A

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					

Charm Flow



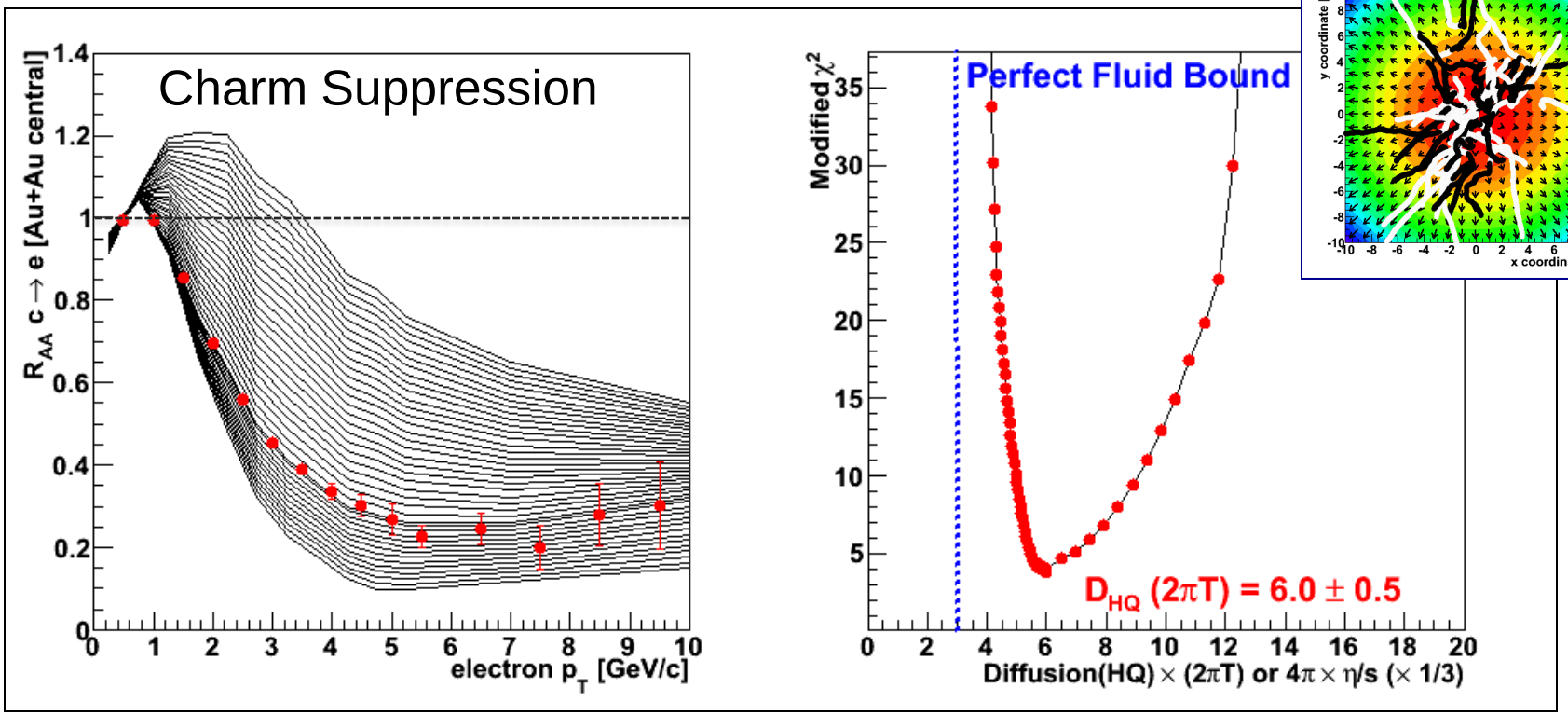
Screening of Upsilon States



charm quark diffusion, hadronization mechanism, screening lengths, and temperature of the plasma

500 GeV p+p 15 GeV A+A	**200 GeV A+A** **200 GeV p+p**	**Au+Au, U+U, Cu+Au at 1-2 energies** **200 GeV p+A**, 500 GeV p+p	BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au; 500 GeV p+p; 200 GeV (polarized) p+A

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					



Requires Reference Data: p+p; p+A

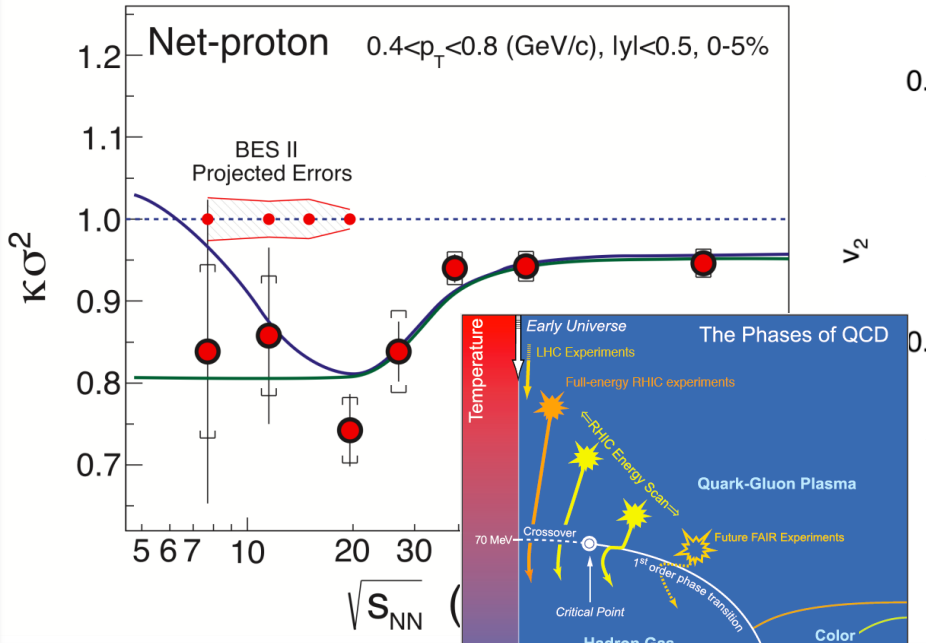
D_{HQ} 2πT = 3 (4π) η/s

charm quark diffusion; direct measure of coupling to the medium, complimentary to η/s from correlations data

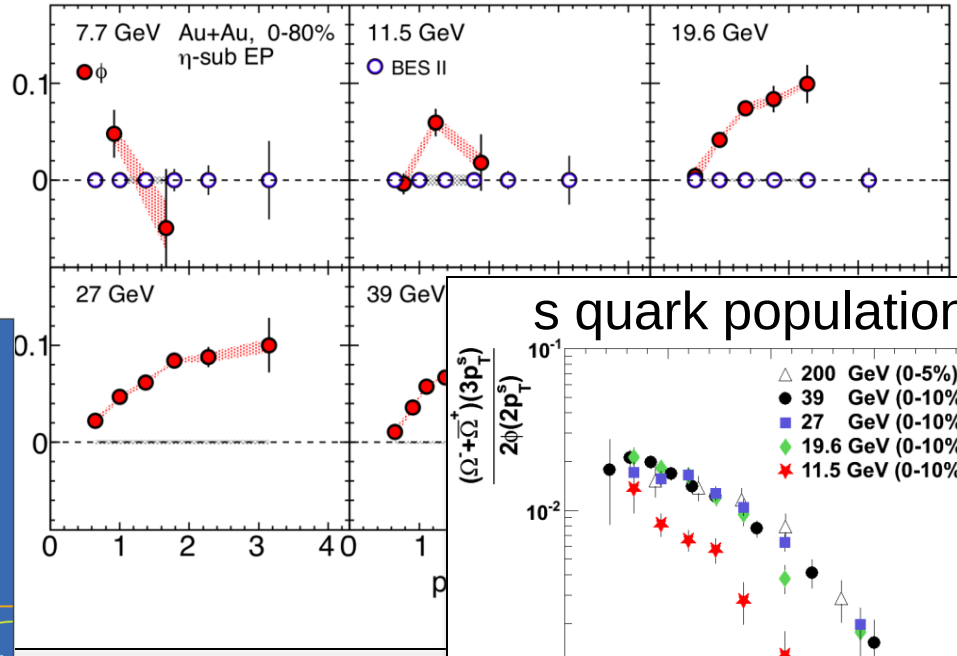
500 GeV p+p 15 GeV A+A	**200 GeV A+A** **200 GeV p+p**	**Au+Au, U+U, Cu+Au at 1-2 energies** **200 GeV p+A**, 500 GeV p+p	BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au; 500 GeV p+p; 200 GeV (polarized) p+A

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			**RHIC e-cooling** & STAR Inner TPC Upgrade					

Critical Fluctuations



Coupling of s Quarks to a QGP



s quark population

Mapping the phase diagram: critical point search, turning off the QGP, probing the transition region

500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	Au+Au, U+U, Cu+Au at 1-2 energies 200 GeV p+A, 500 GeV p+p	**BESII 5-20 GeV Au+Au**; 200 and 100 GeV Au+Au; 500 GeV p+p; 200 GeV (polarized) p+A

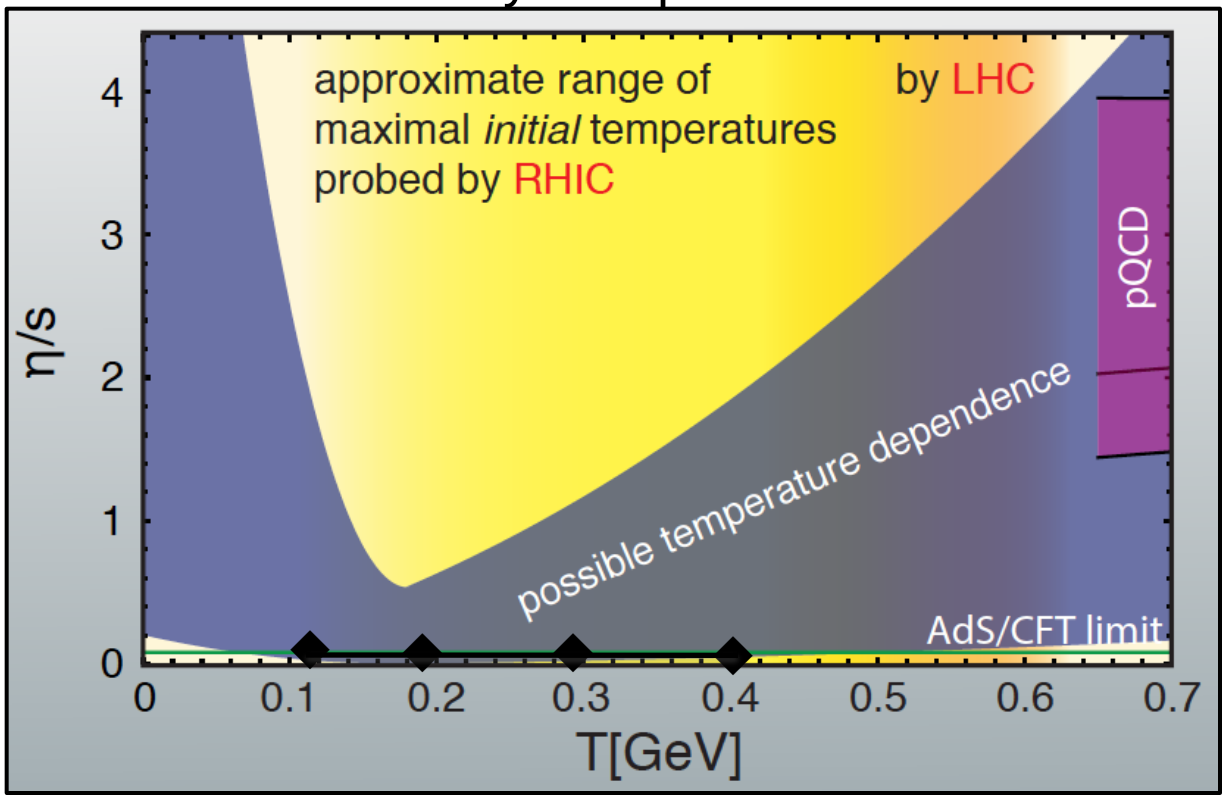
2013	2014	2015	2016	2017	2018	2019	2020	2021	2022

(F)VTX → Heavy Flavor Tracker & Muon Telescope Det. → sPHENIX & STAR/PHENIX Forward Detectors → eRHIC Constr.

FGT → Muon Piston Cal. Ext.

RHIC e-cooling & STAR Inner TPC Upgrade

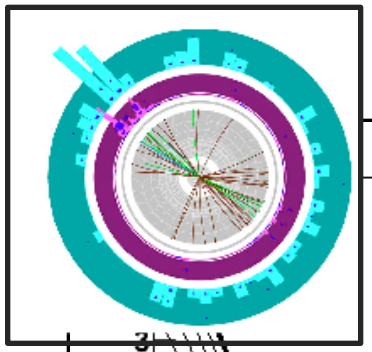
Constrained by Multiple Measurements

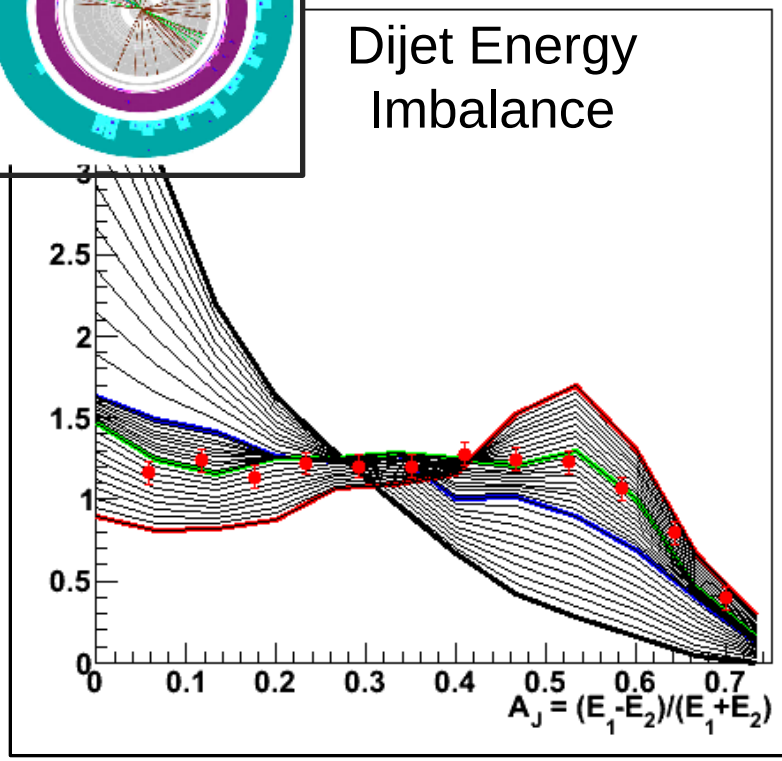


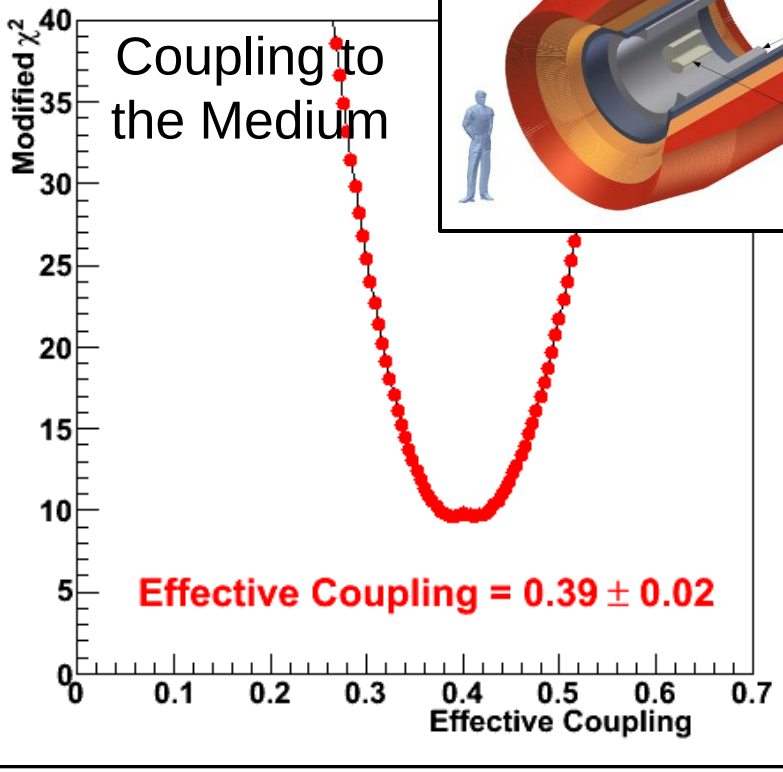
Large energy range of RHIC to map temperature dependence of η/s, strong coupling, comparison to string theory lower bound

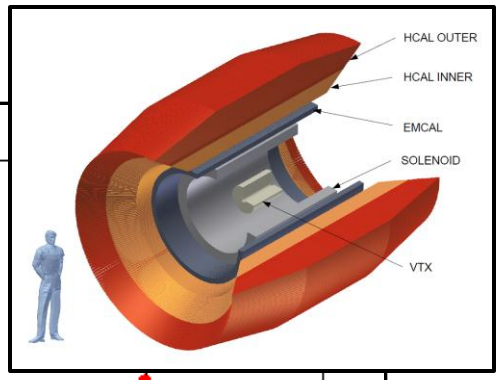
500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	**Au+Au, U+U, Cu+Au at 1-2 energies** 200 GeV p+A, 500 GeV p+p	**BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au;** 500 GeV p+p; 200 GeV (polarized) p+A

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					





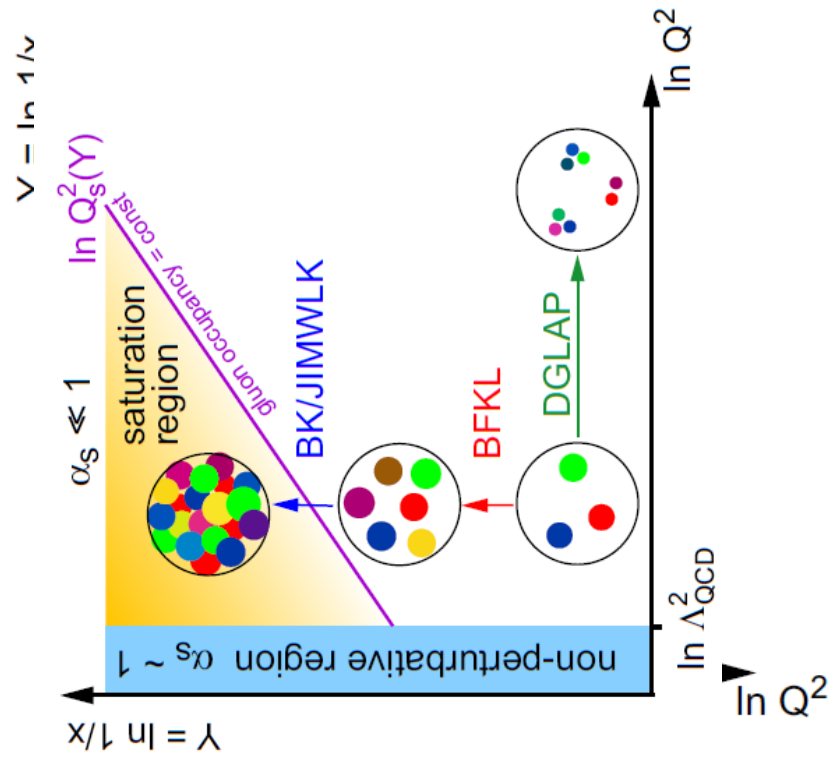


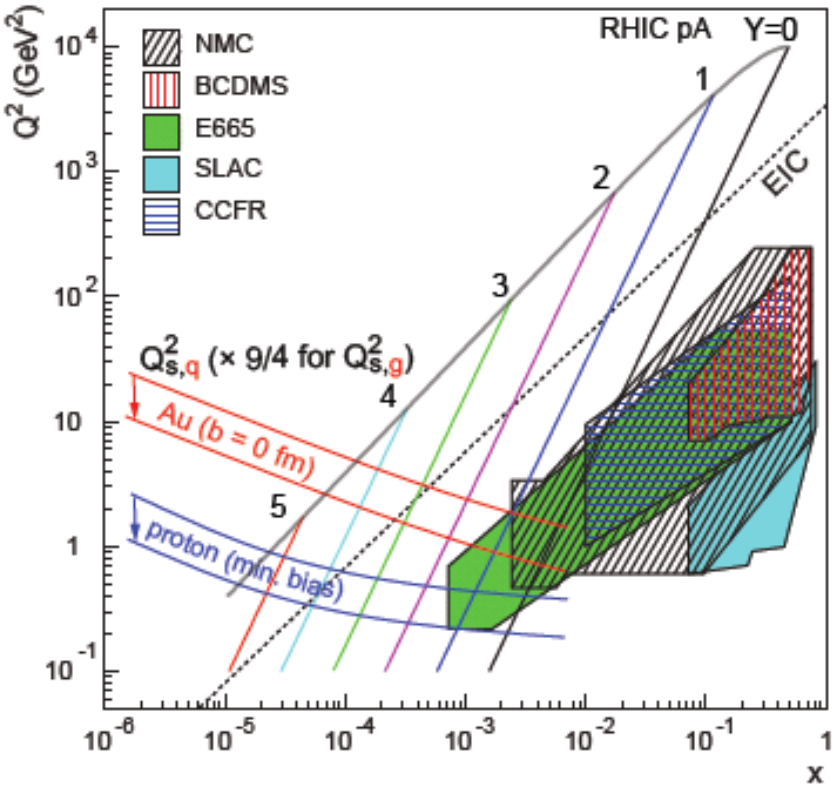


Jet measurements: effective coupling in QGP, temperature dependence of transport properties

500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	Au+Au, U+U, Cu+Au at 1-2 energies 200 GeV p+A, 500 GeV p+p	BESII 5-20 GeV Au+Au; **200 and 100 GeV Au+Au;** 500 GeV p+p; 200 GeV (polarized) p+A

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					



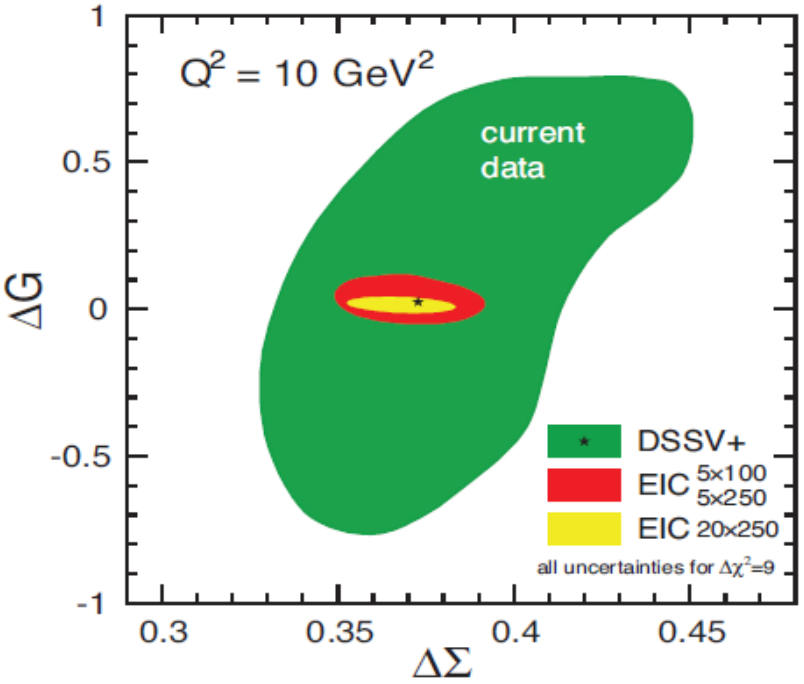


Gluon dynamics and probing the saturation boundary in the x-Q^2 QCD phase diagram

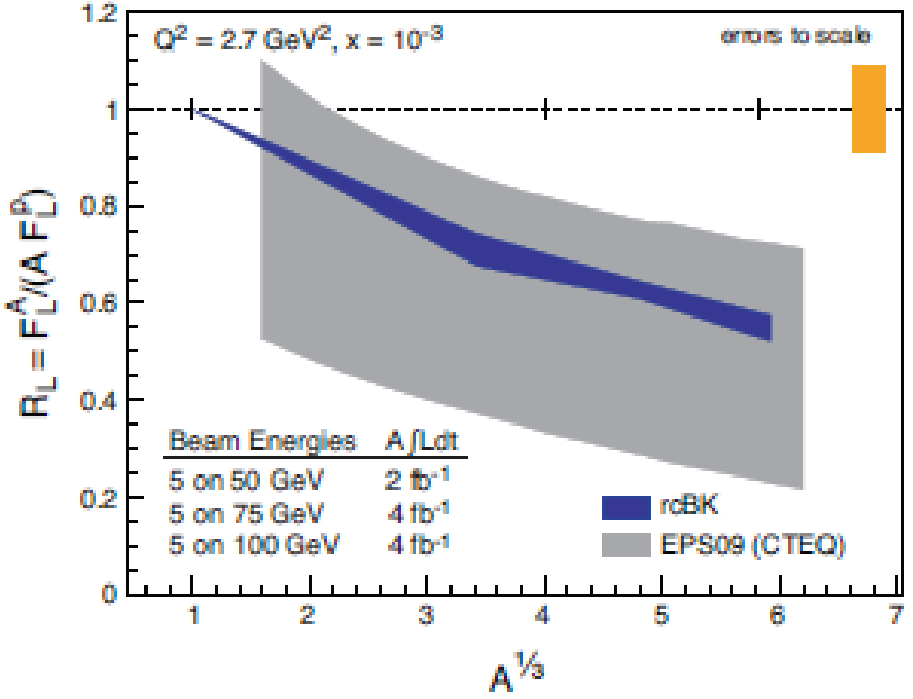
500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	Au+Au, U+U, Cu+Au at 1-2 energies 200 GeV p+A, 500 GeV p+p	BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au; 500 GeV p+p; **200 GeV (polarized) p+A**

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022↦
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					

q & g contributions to p spin



modifications of structure functions



spin physics, spatial distribution of quarks and gluons in nucleons and nuclei, non-linear regime of strong gluon fields

500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	Au+Au, U+U, Cu+Au at 1-2 energies 200 GeV p+A, 500 GeV p+p	BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au; 500 GeV p+p; 200 GeV (polarized) p+A	e+A ↦

Conclusion

RHIC creates conditions similar to the early universe

-Near perfect liquid-like QGP discovered: **un-anticipated result opens new possibility to study gluon fields at different scales**

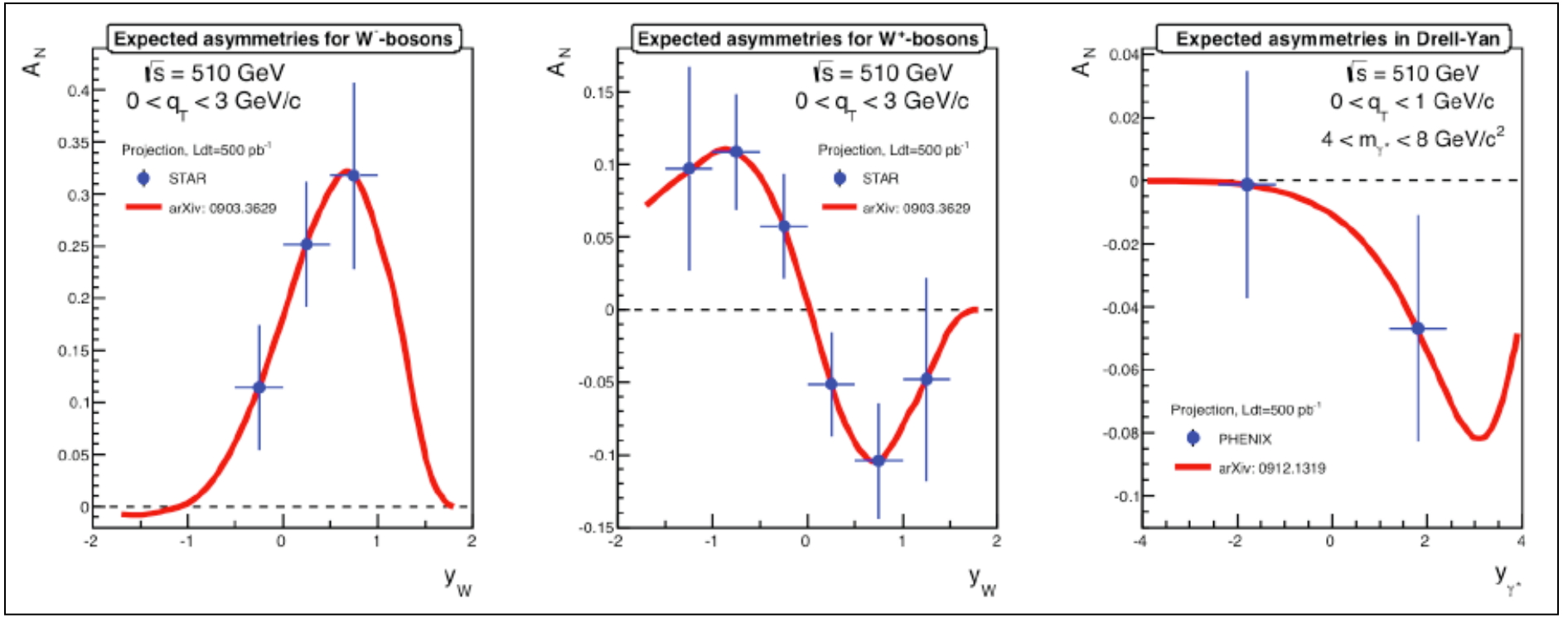
-Approaching a standard model leading to well constrained transport properties: *required many data sets Au+Au, Cu+Cu, d+Au, p+p*

-RHIC covers the region of most interest for QCD thermodynamics. This is not energy frontier physics

Data continues to guide theory breakthroughs: **flexibility and reach of RHIC is unique and extremely valuable for the next phase of measuring the properties of this QCD matter**

RHIC is in **mid-stride, very productive,** and has high **discovery potential** in a range of QCD related topics: *critical point, mechanism responsible for matter/anti-matter asymmetry at EW transition, gluon saturation*

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
(F)VTX	Heavy Flavor Tracker & Muon Telescope Det.				sPHENIX & STAR/PHENIX Forward Detectors				eRHIC Constr.
FGT	Muon Piston Cal. Ext.			RHIC e-cooling & STAR Inner TPC Upgrade					



Testing QCD prediction of sign change in the Sivers function

500 GeV p+p 15 GeV A+A	200 GeV A+A 200 GeV p+p	Au+Au, U+U, Cu+Au at 1-2 energies 200 GeV p+A, 500 GeV p+p	BESII 5-20 GeV Au+Au; 200 and 100 GeV Au+Au; **500 GeV p+p;** 200 GeV (polarized) p+A