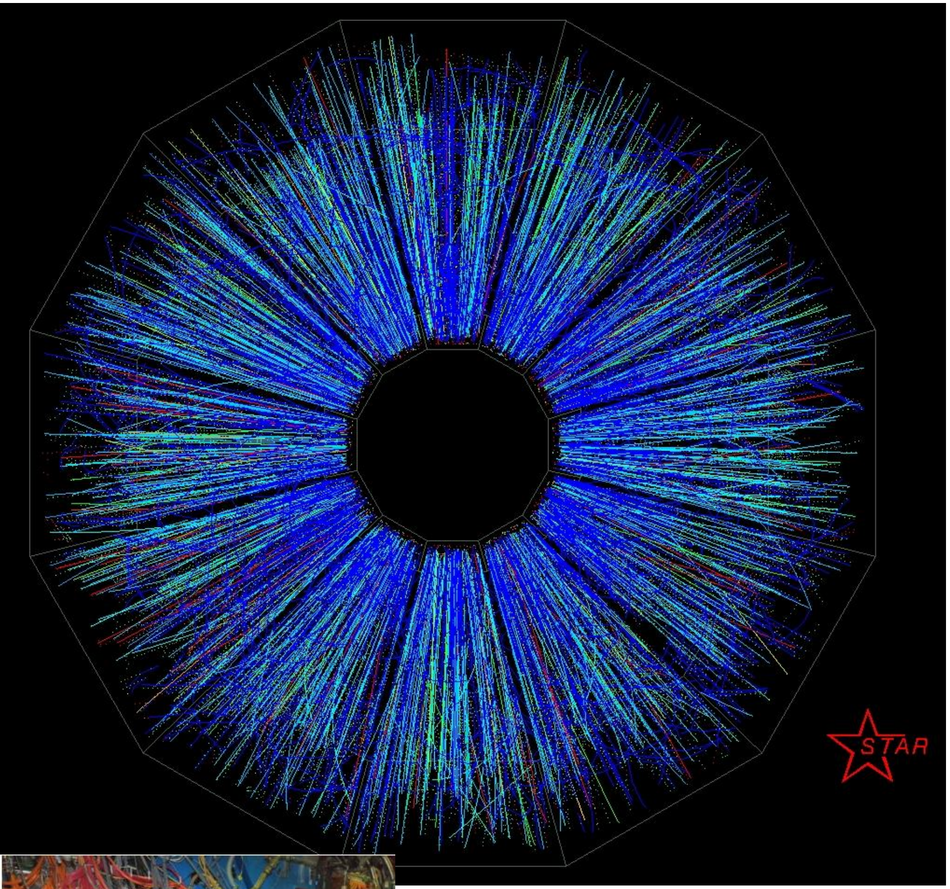
STAR Program Overview

Zhangbu Xu (BNL)



1. Heavy-Flavor Program (2014—2017)
2. Beam Energy Scan II (2019-2020)
3. High-Luminosity and high-rate (2020+)

NSAC LRP report:
"Reaching for the Horizon"
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NATURE | LETTER

Measurement of interaction between antiprotons

The STAR Collaboration

Affiliations | Contributions

Nature (2015) | doi:10.1038/nature15724

Received 25 July 2015 | Accepted 11 September 2015 | Published online 04 November 2015

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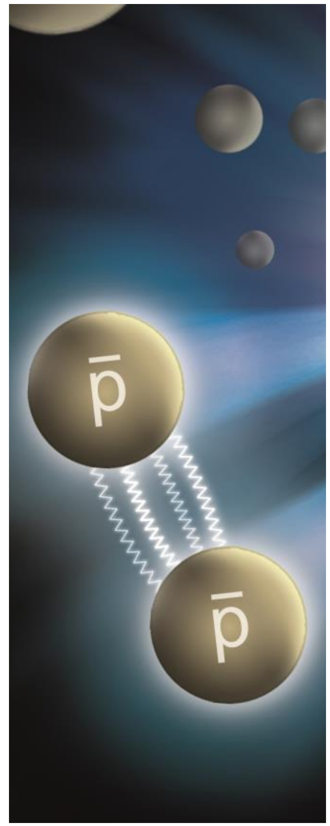
One of the primary goals of nuclear physics is to understand the force between nucleons, which is a necessary step for understanding the structure of nuclei and how nuclei interact with each other. Rutherford discovered the atomic nucleus in 1911, and the large body of knowledge about the nuclear force that has since been acquired was derived from studies made on nucleons or nuclei. Although antinuclei up to antihelium-4 have been discovered[1] and their masses measured, little is known directly about the nuclear force between antinucleons. Here, we study antiproton pair correlations among data collected by the STAR experiment[2] at the Relativistic Heavy Ion Collider (RHIC)[3], where gold ions are collided with a centre-of-mass energy of 200 gigaelectronvolts per nucleon pair. Antiprotons are abundantly produced in such collisions, thus making it feasible to study details of the antiproton–antiproton interaction. By applying a technique similar to Hanbury Brown and Twiss intensity interferometry[4], we show that the force between two antiprotons is attractive. In addition, we report two key parameters that characterize the corresponding strong interaction: the scattering length and the effective range of the interaction. Our measured parameters are consistent within errors with the corresponding values for proton–proton interactions. Our results provide direct information on the interaction between two antiprotons, one of the simplest systems of antinucleons, and so are fundamental to understanding the structure of more-complex antinuclei and their properties.



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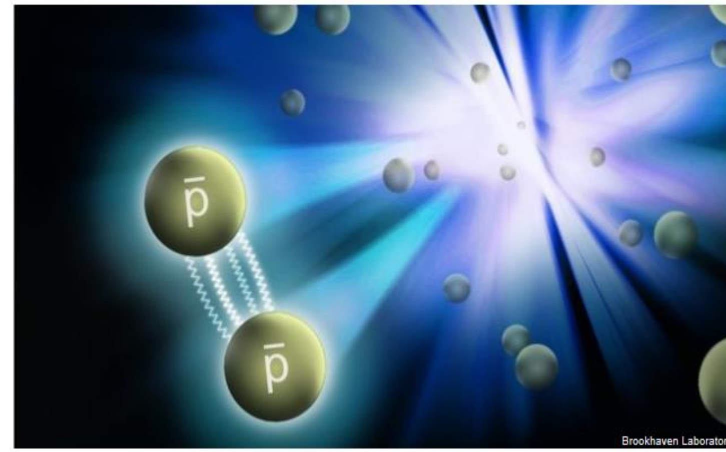
Science & Environment

Strong forces make antimatter stick

4 November 2015 | Science & Environment



Physicists have shed new light on one of the greatest mysteries in science: Why the Universe consists primarily of matter and not antimatter.

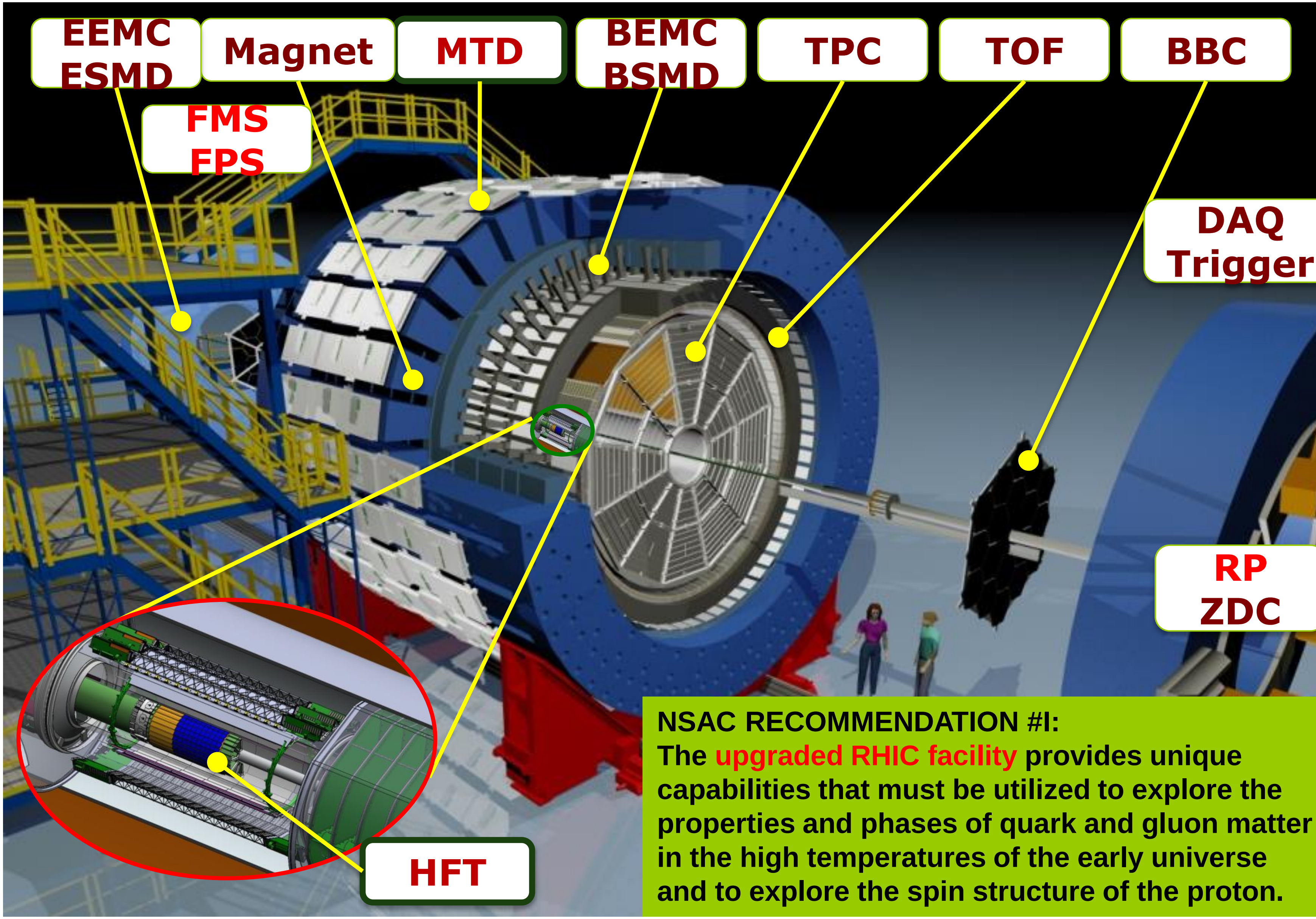
Antimatter is a shadowy mirror image of the ordinary matter we are familiar with.

For the first time, scientists have measured the forces that make certain antimatter particles stick together.

"There are many ways to test for matter/antimatter asymmetry, and there are more precise tests, but in addition to precision, it's important to test it in qualitatively different ways. This experiment was a qualitatively new test," said Richard Lednický,
a STAR scientist from the Joint Institute for Nuclear Research, Dubna,
and the Institute of Physics, Czech Academy of Sciences, Prague.

STAR Detector System

15 fully functioning detector systems



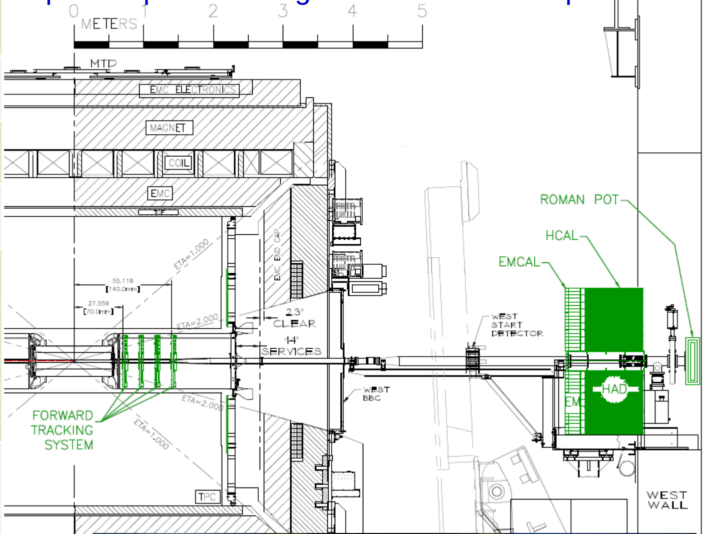
NSAC RECOMMENDATION #I:
The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.

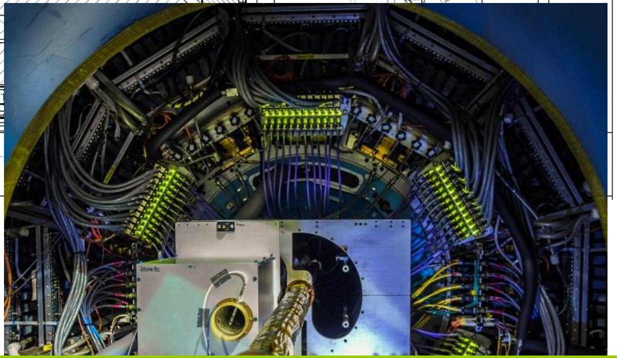
X10^3 increases in DAQ rate since 2000, most precise Silicon Detector (HFT)

STAR Physics Opportunities in the Coming Decade

Period	Physics	Upgrades
2008	Generic	Trigger QT
2009	Generic	TPC/DAQ1000
2010-2011	BES I, PID	TOF
2013--2015	Heavy-Flavor	HFT, MTD
2015--2017	Heavy-Flavor, jets Spin Sign Change Diffractive	FMS, FPS, FPS+, Roman Pots
2019--2020	BES II	iTPC, EPD, CBMTOF
2021-2022	High-statistics Unbiased Jets, Open Beauty, PID FF Drell-Yan, Longitudinal correl	Forward West, HFT+ TPC Streaming

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0592
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0640



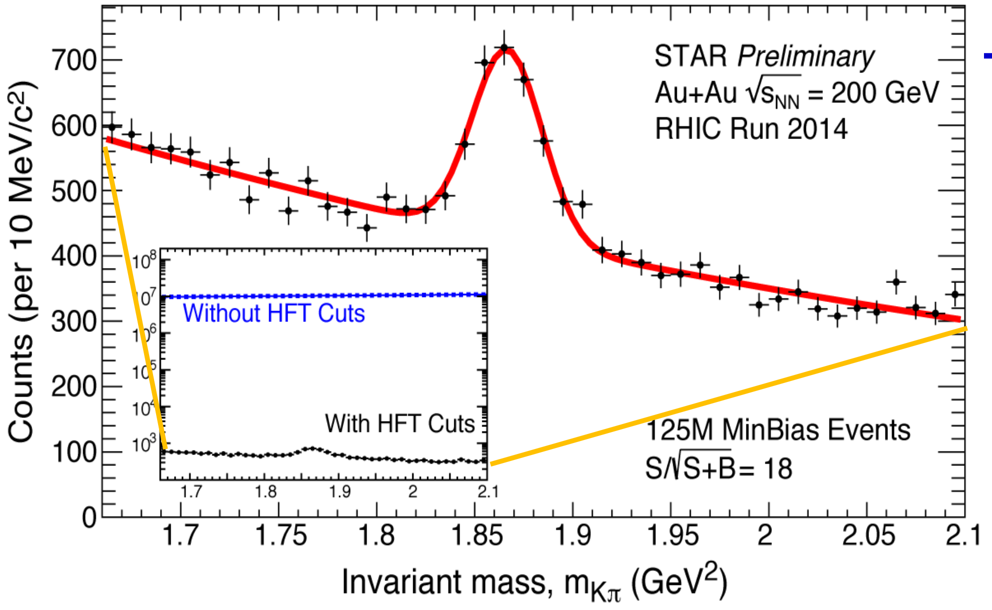


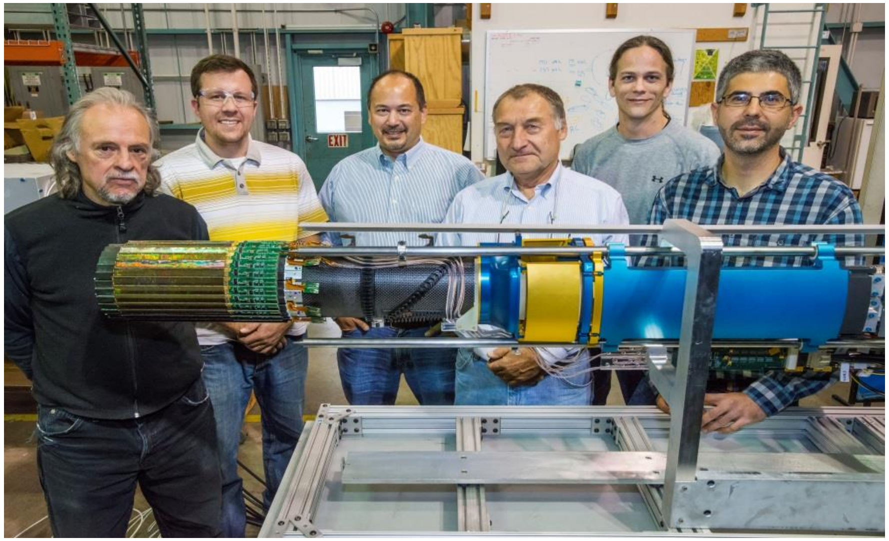
Capitalize/strengthen on tens M$ Multi-Purpose Upgrade Investments

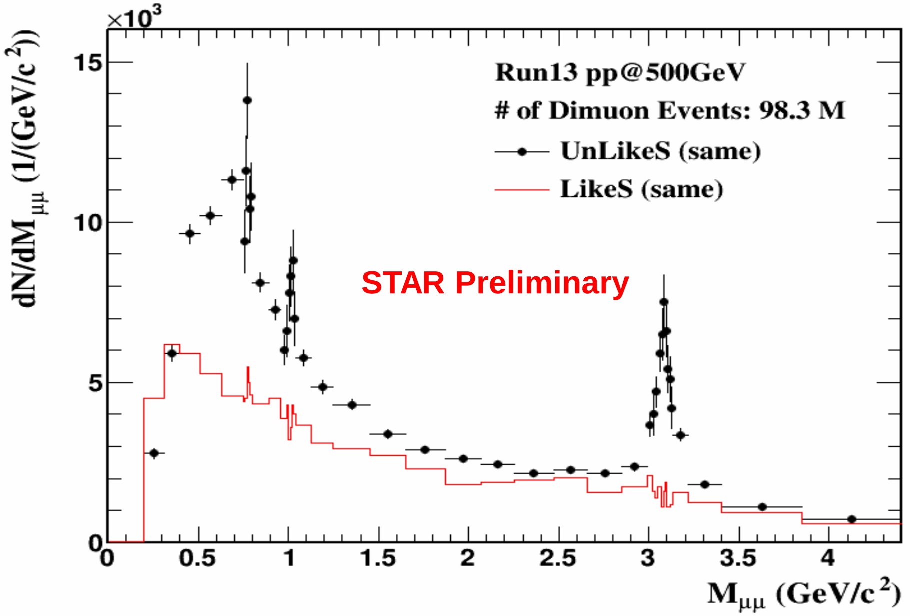
Complementarity and risk mitigation with two IRs
Collaboration is committed to the program (53 Institutions)

NSAC RECOMMENDATION #IV
We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

Heavy-Flavor Program (2014-2017)

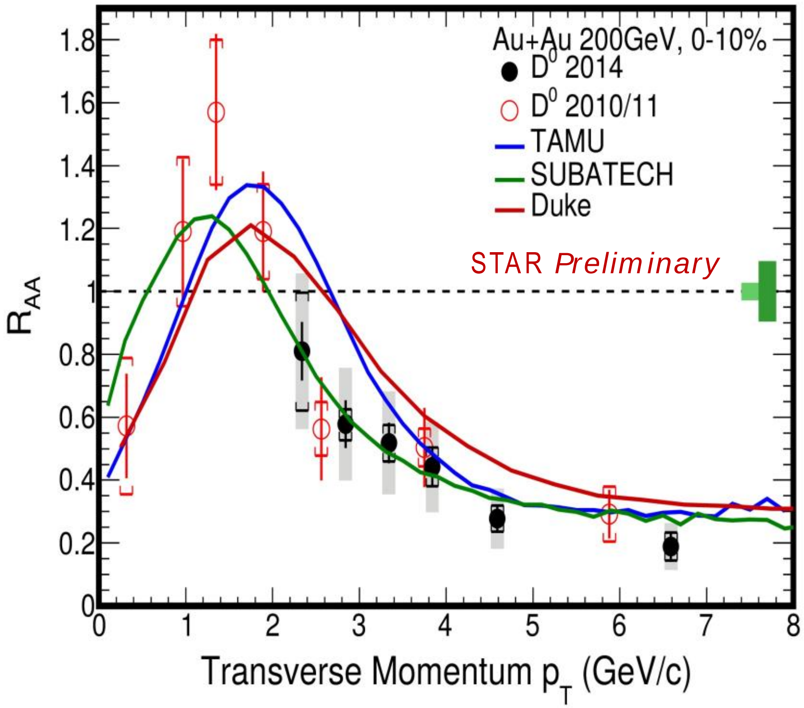


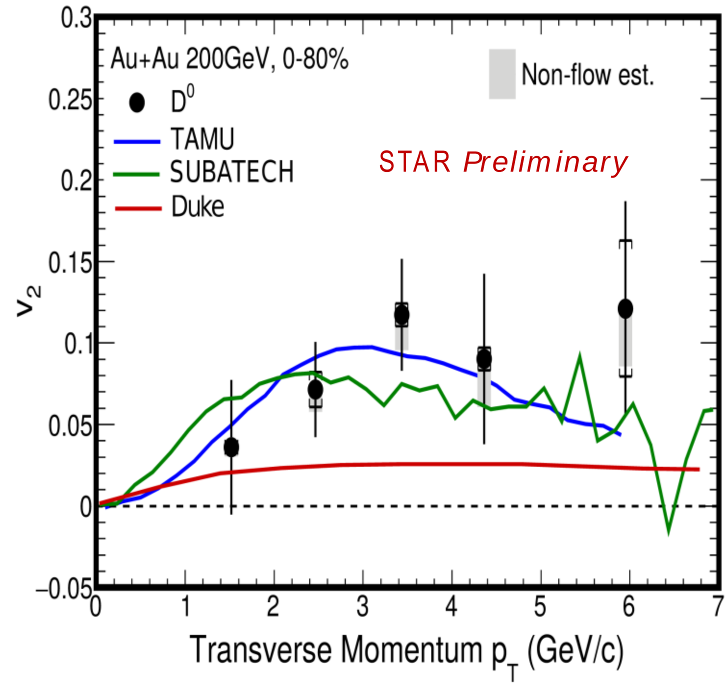




Heavy Quark probes QGP Properties

Mustafa Mustafa - QM15 - Kobe, Japan





Data favors models with charm diffusion

➔charm exhibits collectivity with the medium

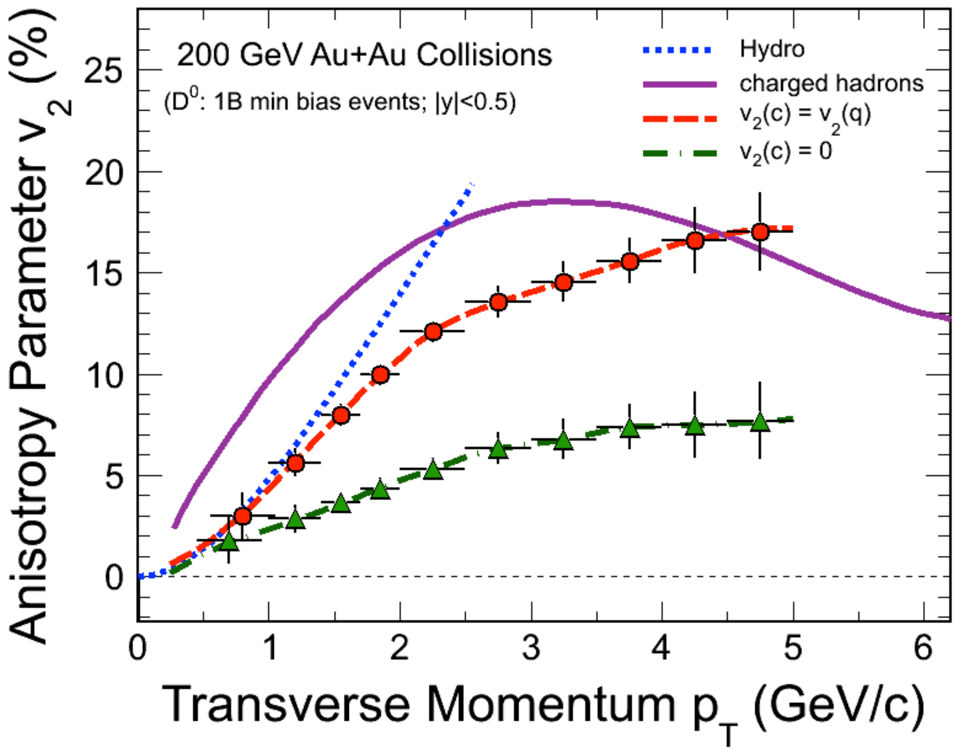
➔ However, it is not completely thermalized

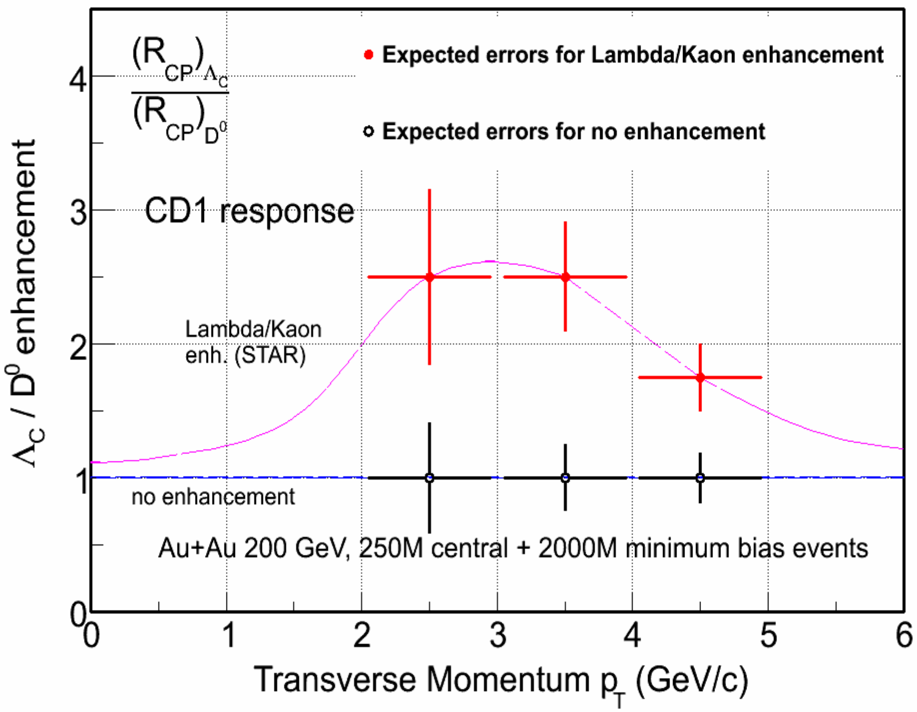
	$D \times 2\pi T$	Diff. Calculation
TAMU	2-11	T-Matrix
SUBATECH	2-4	pQCD+HTL
Duke	7	Free parameter

arXiv:1506.03981 (2015) & private comm.

Open charm flow and coalescence

HFT Projection for Au+Au **run14** + **run16**

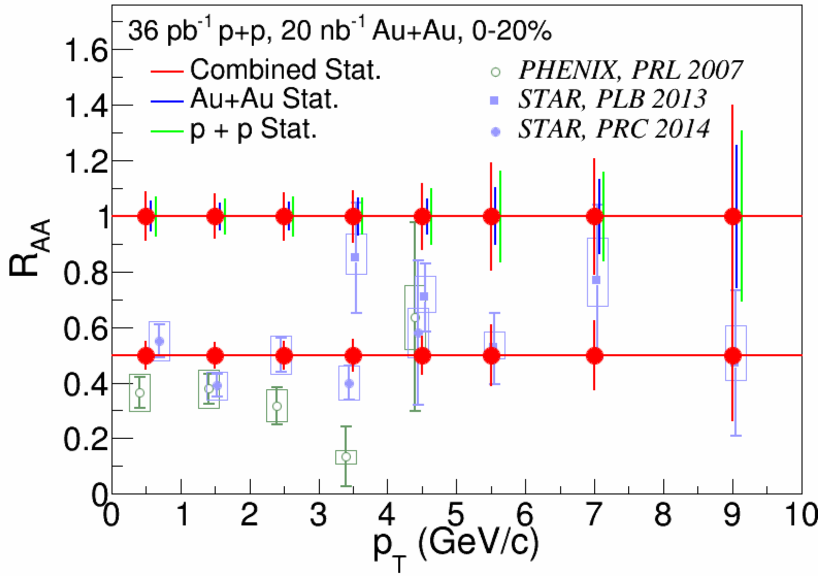


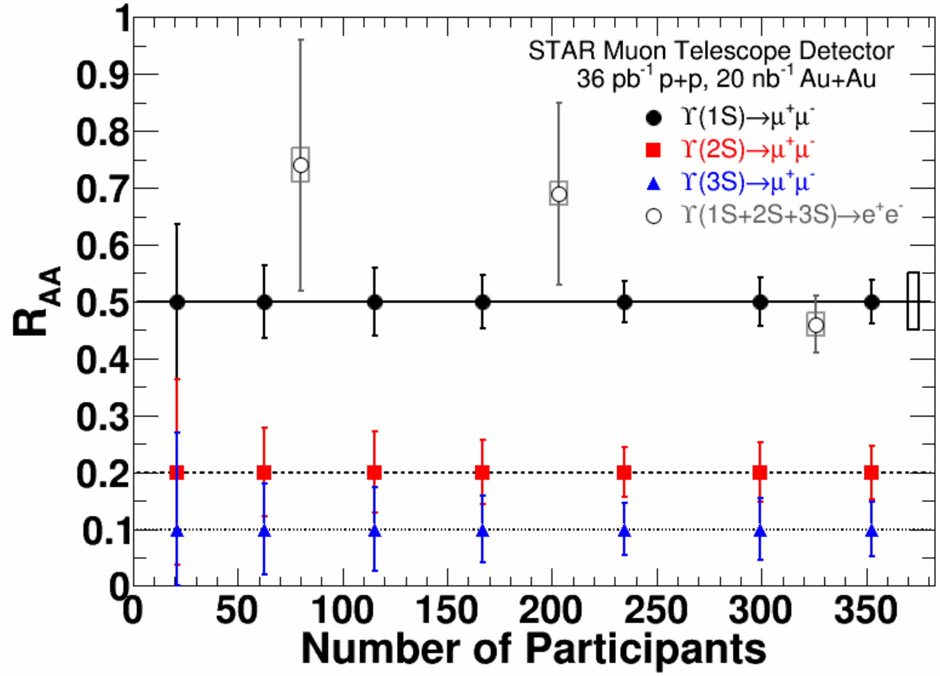


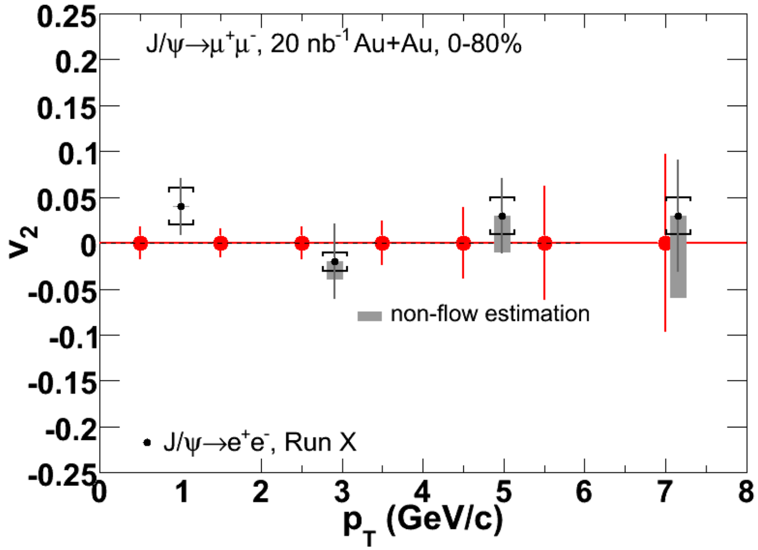
Quantify charm quark flow and coalescence:

1. Charmed baryon enhancement?
2. Centrality Dependent of charm v_2

Run14+16 Quarkonium Measurements





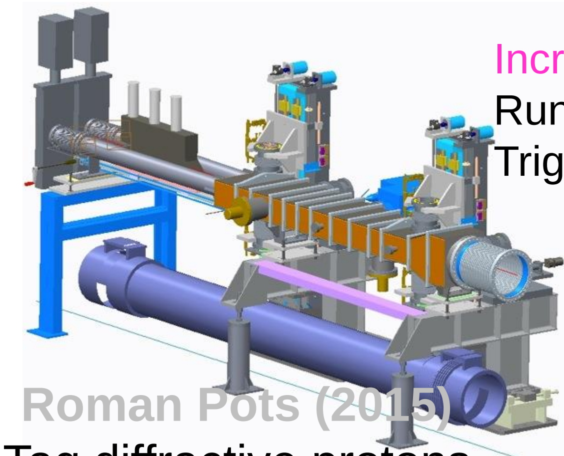


MTD: Improves statistical uncertainty

As well as systematic uncertainty

Separate Upsilon states

Detector Upgrades and Performance Improvements



Tag diffractive protons

Incremental upgrades/improvements, big impacts

Run15,16,17, 19, 20 (Year2015—2020)

Trigger/DAQ x2 throughput

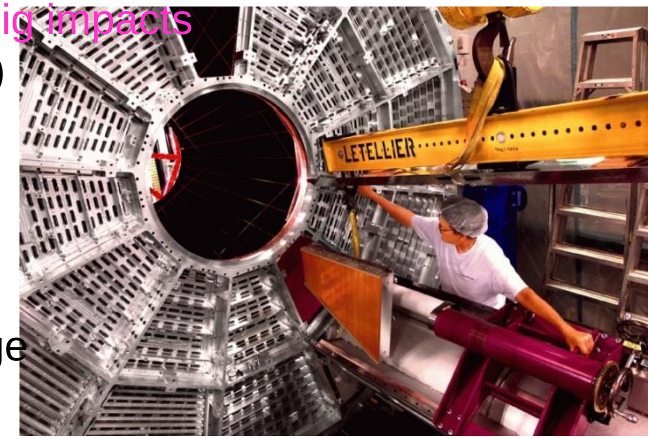
iTPC upgrade (2018)

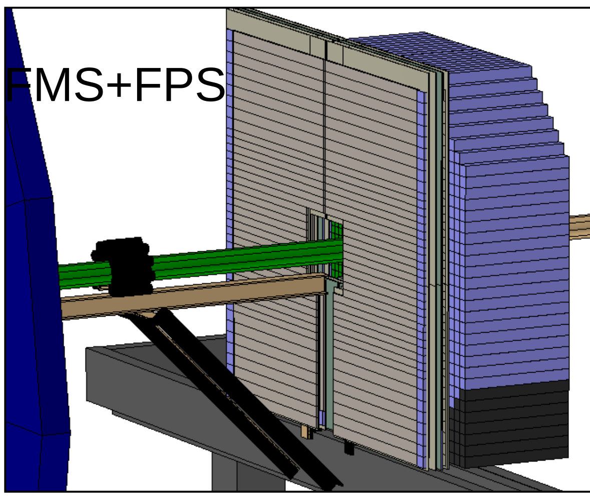
replace inner TPC Sectors

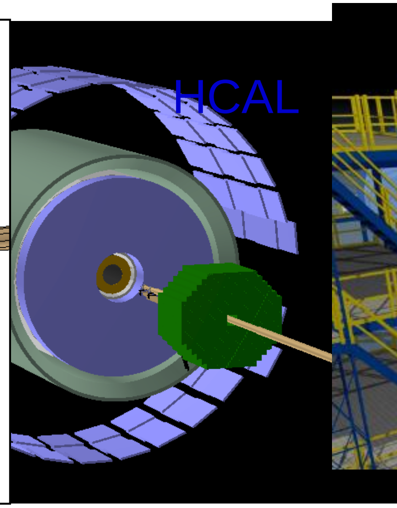
Extend rapidity coverage

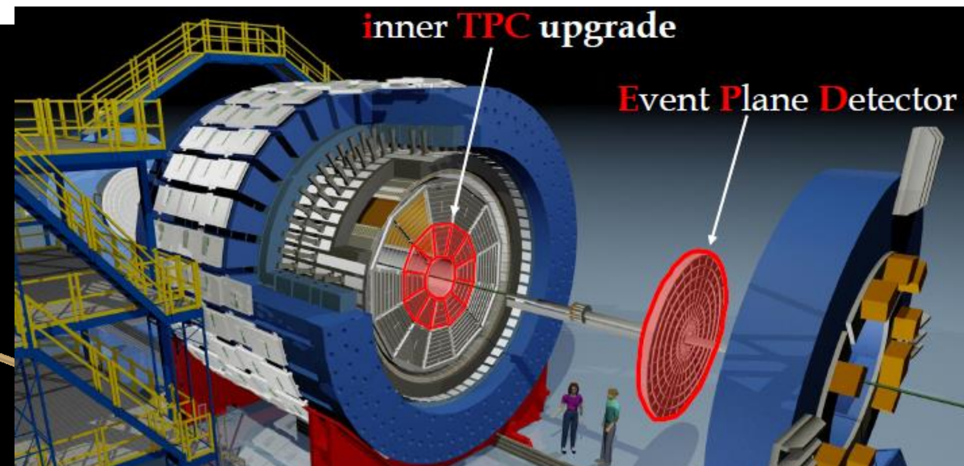
Better particle ID; Low p_T coverage

Proposal: public STAR Note 0619









Forward calorimeter instrumentation (2015—2020)

FMS + pre-shower (2015), +post-shower (2017)

A_N photon, jets, Drell-Yan; ridge, fluctuation, spectators

refurbished HCAL (--2020, forward spectator)

Event Plane Detector (2018):

Greatly improved Event Plane Info

Centrality definition

Better trigger

Background rejection

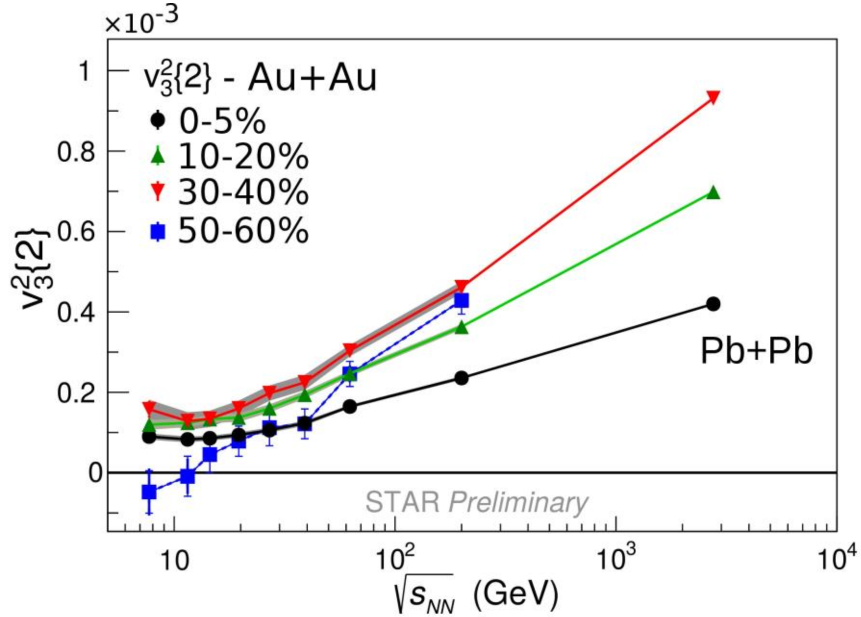
Overview and Priority (BES-II)

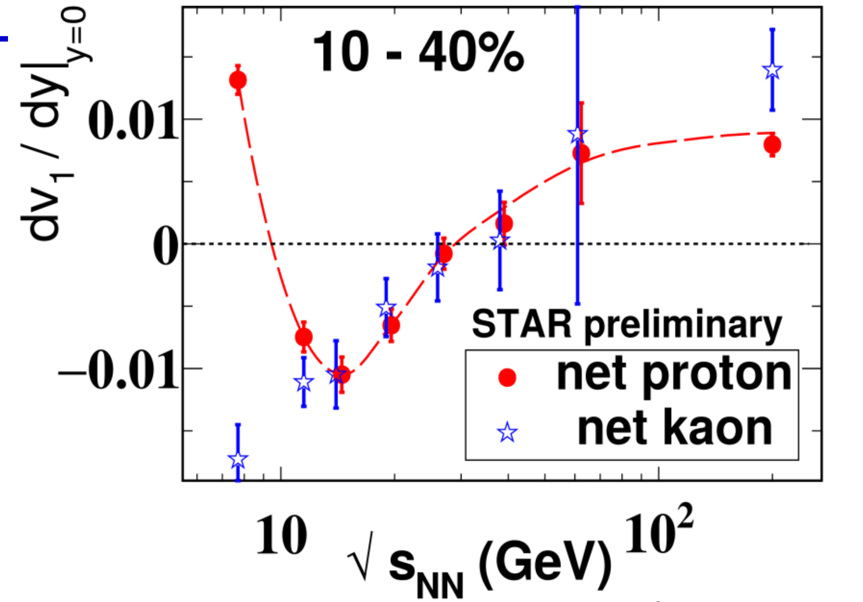
1. Net-proton Kurtosis (Δy=1.6) (iTPC)
   Beam energy, centrality and rapidity dependence with high statistics
2. Proton v_1 slope (iTPC+EPD)
   beam energy and centrality dependence
3. Charge separation on Chiral effect (EPD)
   beam energy and centrality dependence
4. Low-mass di-electron spectra (iTPC+eTOF)
   beam energy, centrality an
5. PID v_2 (ϕ) (iTPC+EPD+eTO
6. Lower collision energy with
   (iTPC+eTOF)

NSAC, p26:
The trends and features in BES-I data provide compelling motivation for a strong and concerted theoretical response, as well as for the experimental measurements with higher statistical precision from BES-II. The goal of BES-II is to turn trends and features into definitive conclusions and new understanding. This theoretical research program will require a quantitative framework for modeling the salient features of these lower energy heavy-ion collisions and will require knitting together components from different groups with experience in varied techniques, including lattice QCD, hydrodynamic modeling of doped QGP, incorporating critical fluctuations in a dynamically evolving medium, and more.

Priority: iTPC, EPD, eTOF

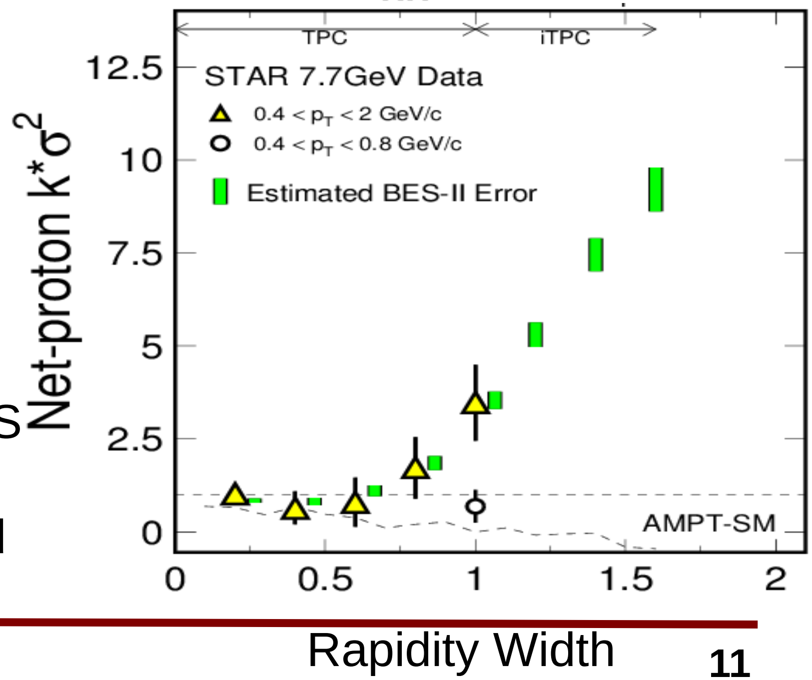
(STAR) Map QCD Phase Diagram



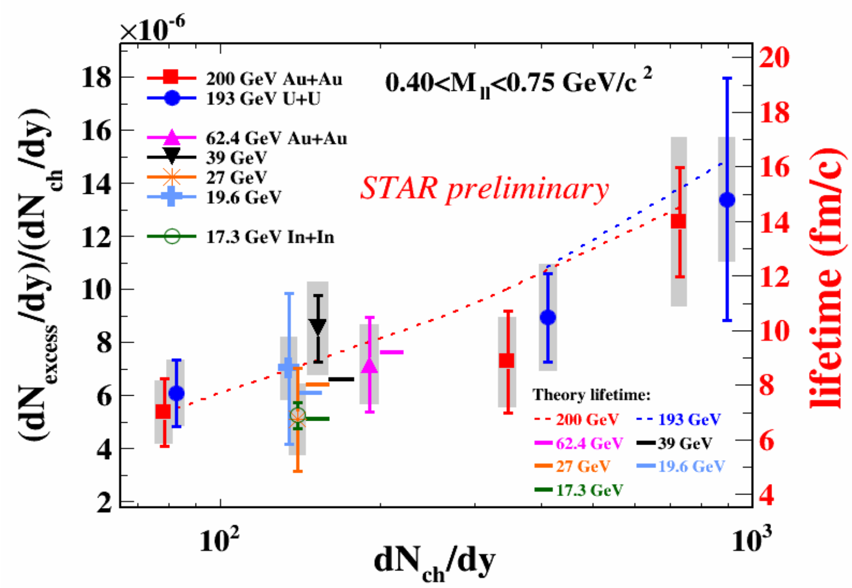


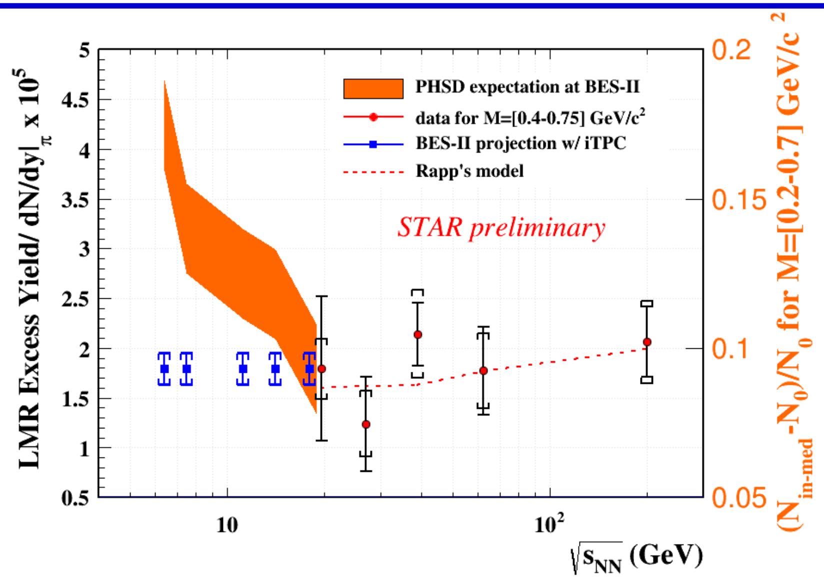
Beam Energy Scan Program:

- Turn off QGP Signatures
  triangle flow (v_3) in peripheral at low energy consistent with zero
- Search for first-order phase transition
  minimum net-proton v1 slope from interplay between baryon stopping and soft EOS
- Search for critical point
  net-proton Kurtosis possibly not Poissonian and grow with accepted rapidity window



(STAR) Fundamental Symmetries



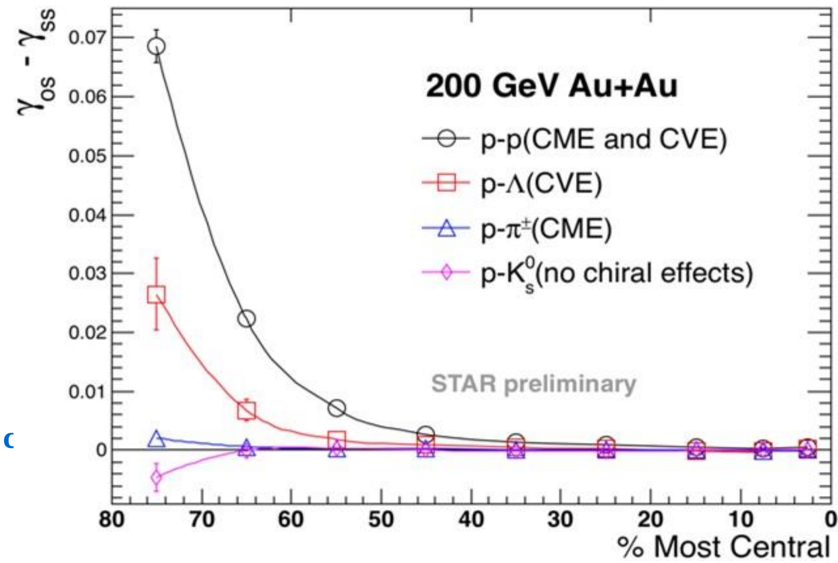


Low-mass di-electron production

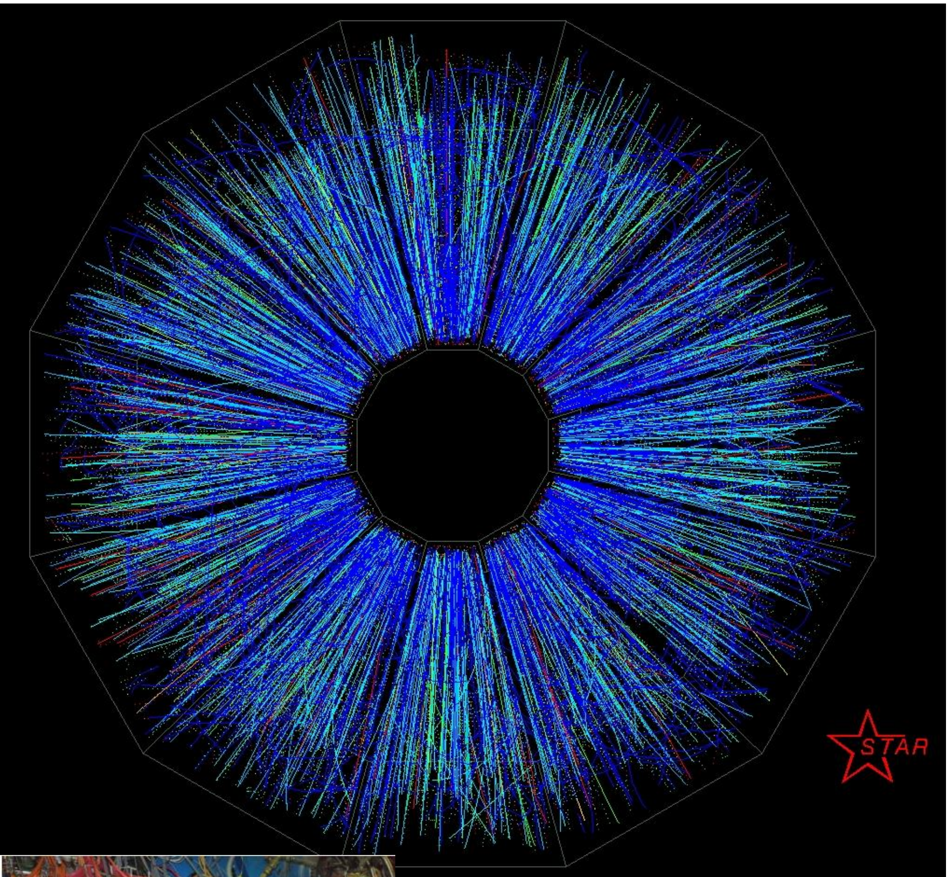
- **measured in many systems (Au+Au, U+U, p+p) and different energies (19.6, 27, 39, 62, 200 GeV)**
- **Quantifying how vector mesons are modified in medium**
- **The yields probe timescale of collisions**

Chiral and Magnetic hydrodynamics:

- **Chiral Magnetic Effect (CME):** local chirality imbalance + magnetic field →electric charge separation
- **Chiral Vortical Effect (CVE):** local chirality imbalance + fluid voriticity →baryonic charge separation
- **Chiral Magnetic Wave: CME+CSE**



STAR Physics Opportunities beyond BES-II



1. 1st look at nuclear parton distribution and fragmentation functions via Drell-Yan measurements and particles in jets
2. Constrain 3+1D hydrodynamic and temperature dependence of QGP properties via longitudinal event-by-event correlation
3. Bottom flow via low p_T measurements of $B \rightarrow J/\psi$ and $B \rightarrow D^0 \rightarrow \pi K$, and bottom tagged jets
4. Use spin to probe the nature of the pomeron and potentially odderon. Extend gluon polarization down to low-x using forward dijet reconstruction
5. Continue promising studies to increase STAR's minbias trigger rate to 5-10 kHz

NSAC LRP report:
"Reaching for the Horizon"
Page 117

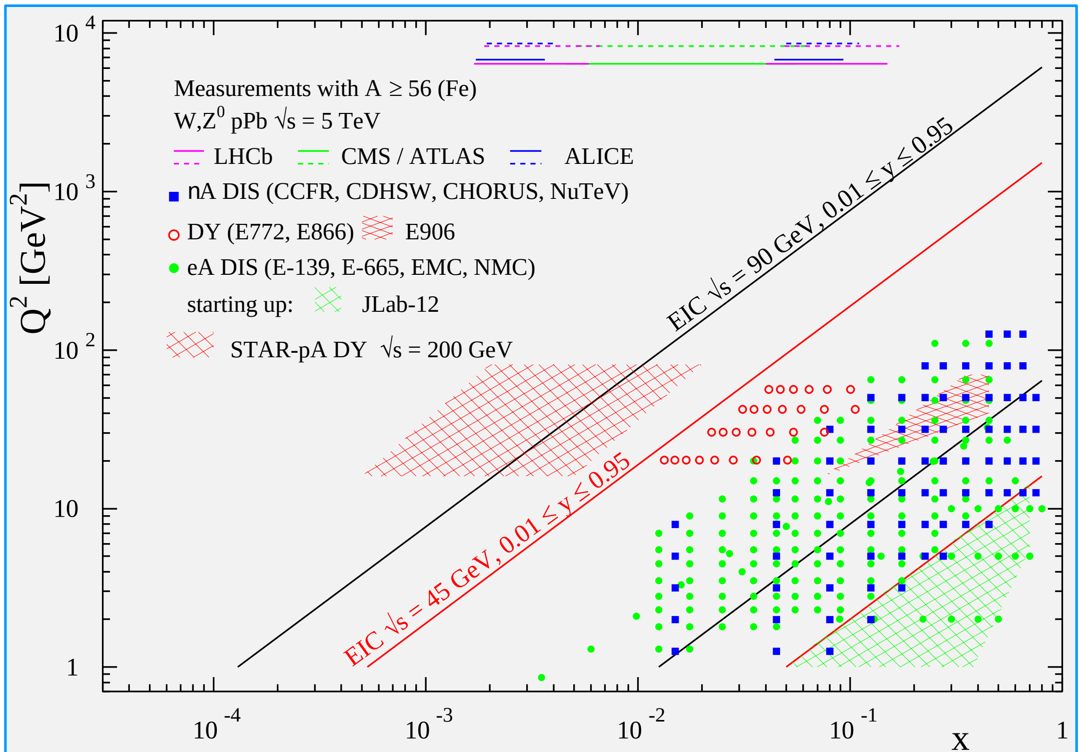
http://www.star.bnl.gov/

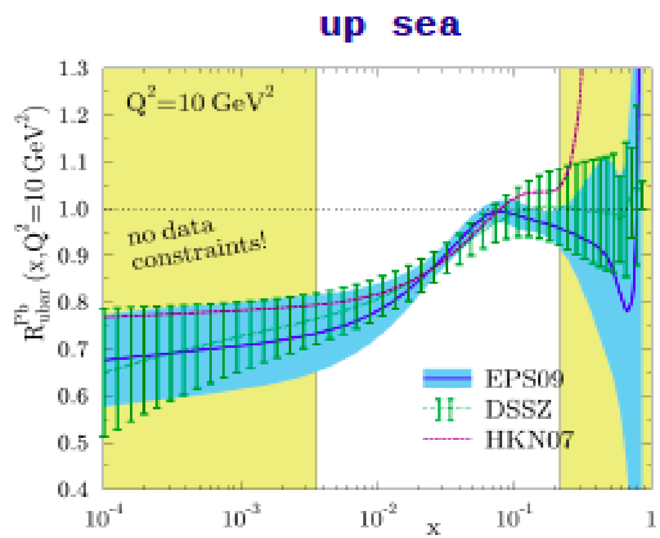
Summary and Priority (after BES-II)

- Provide 1st look at nuclear parton distribution and fragmentation functions via Drell-Yan measurements and particles in jets (DY: forward capabilities FF: midrapidity jet + π,K,P PID)

Cold QCD Physics: Nuclear PDFs and FF

- No low x data for quark and gluon nuclear PDFs! **Complementary to EIC**
- Drell-Yan observables are sensitive to initial state only, while particles in jets probe nuclear modifications in fragmentation.





RHIC is the only facility in the world able to perform a p + A scan in this unique kinematic space in x and Q^2

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0605

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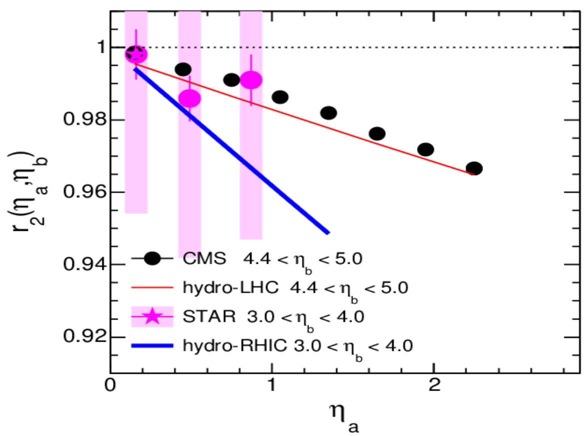
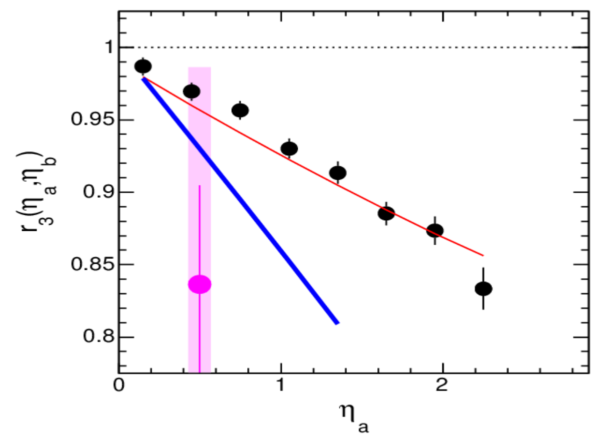
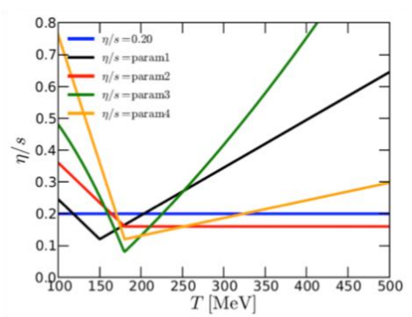
- Constrain 3+1D hydrodynamic and temperature dependence of QGP properties via longitudinal event-by-event correlation (Forward + EPD + iTPC)

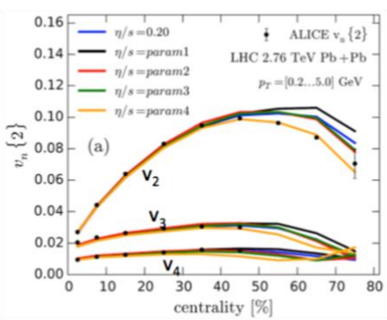
η/s 3+1D hydrodynamics for hard probes

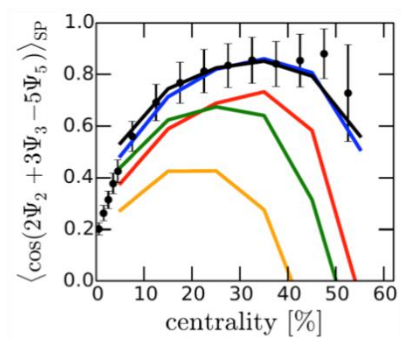
Uncertainties in the correct physics of the initial state are still problematic:
gluon saturation or Glauber?







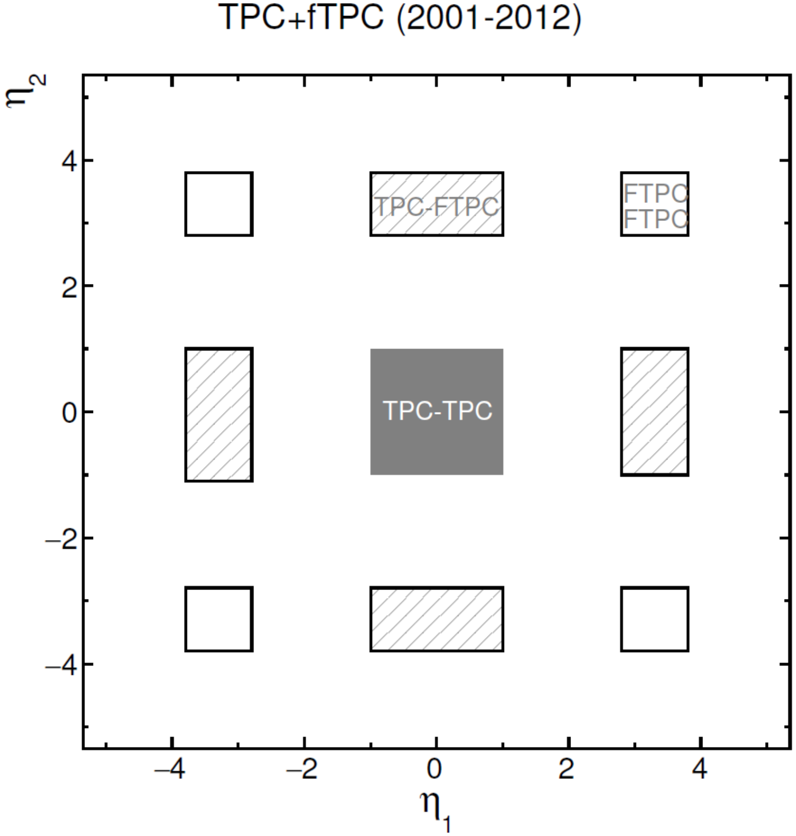




To what extent do thermal fluctuations during the expansion phase contribute to the correlations observed in the data?

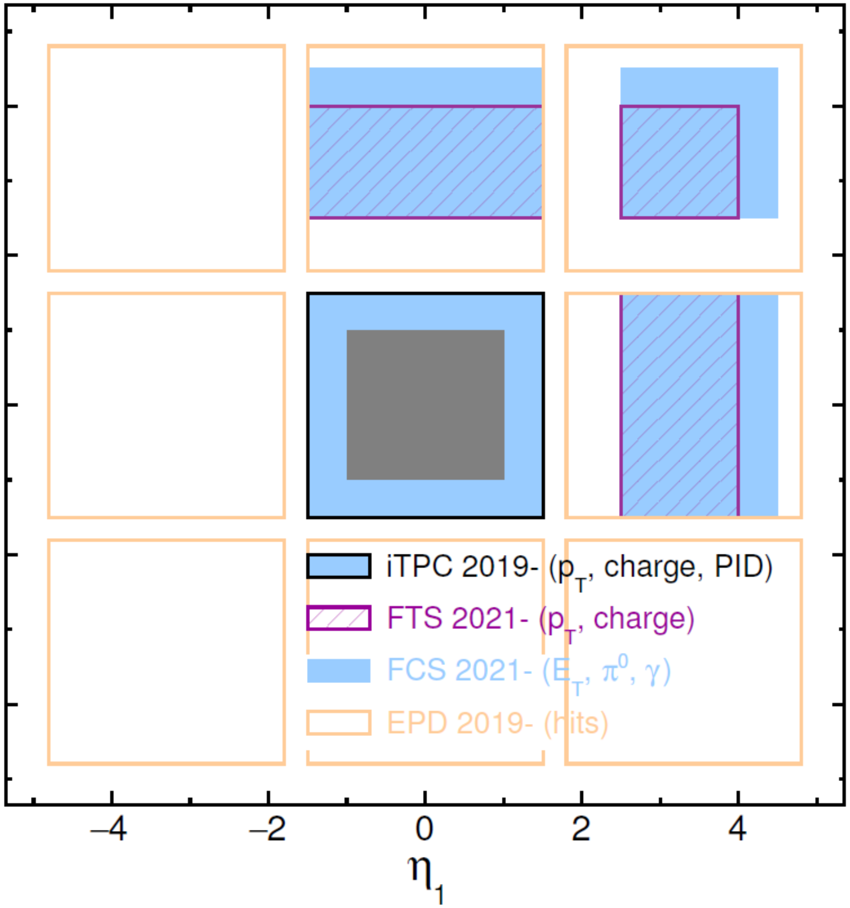
Both of these pressing uncertainties can be addressed by extending the longitudinal acceptance of the STAR detector.

STAR Rapidity Coverage



Limited coverage and low rate before 2012
No coverage for HI currently

Future Capabilities



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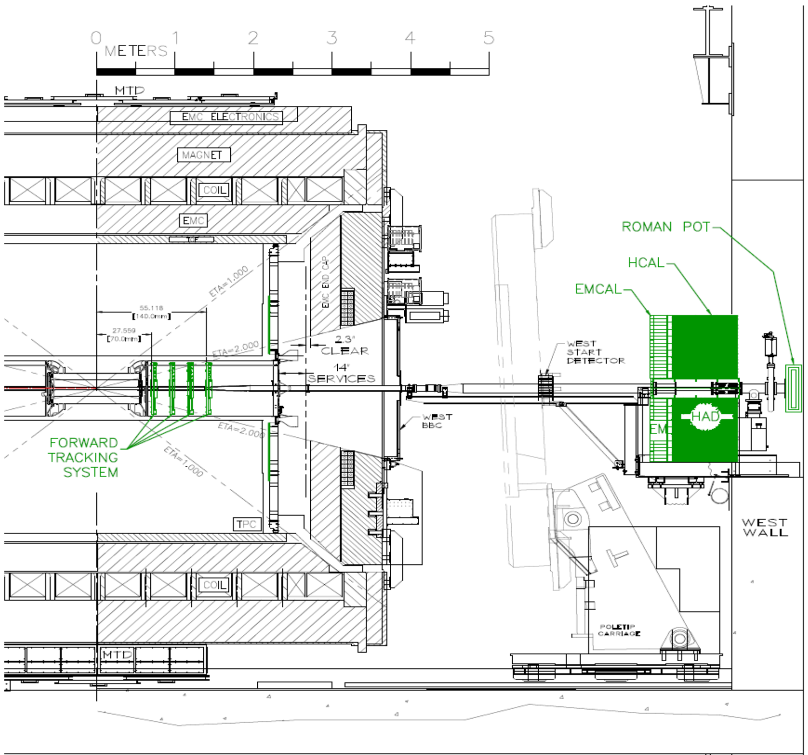
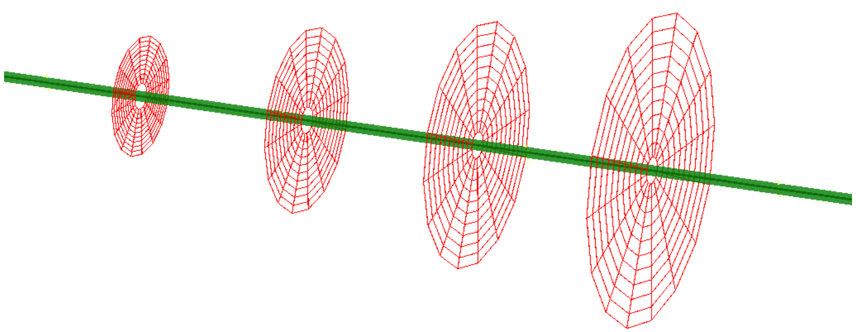
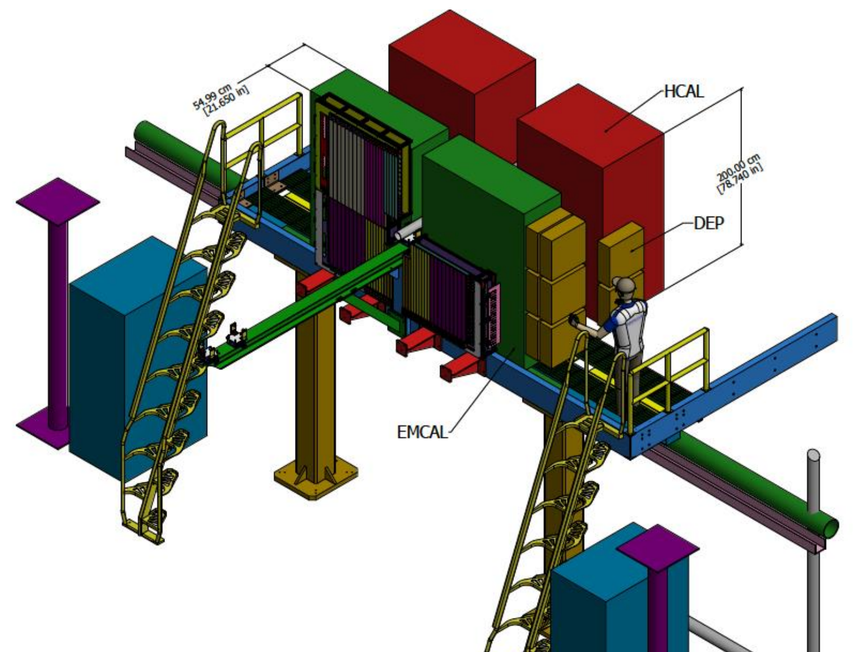
Forward Tracking and Calorimetry





- Forward Tracking System (FTS): four layers of Silicon Strips
- Event-Plane Detector: one Layer of Scintillator/fiber
- Electromagnetic+hadronic calorimeters



NSAC RECOMMENDATION #IV:
DOE-supported research and development (R&D) and Major Items of Equipment (MIE) at universities and national laboratories are vital to maximize the potential for discovery as opportunities emerge.

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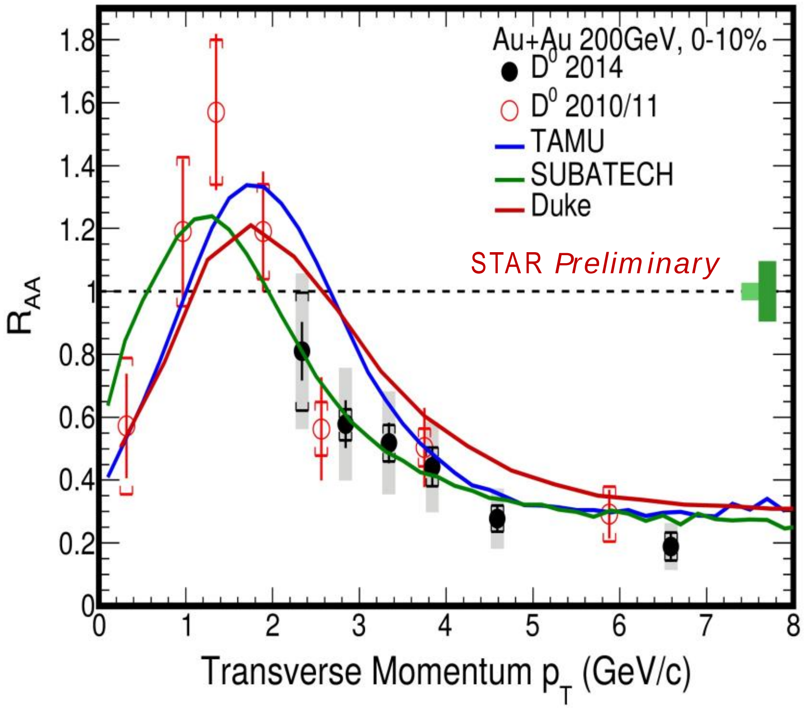
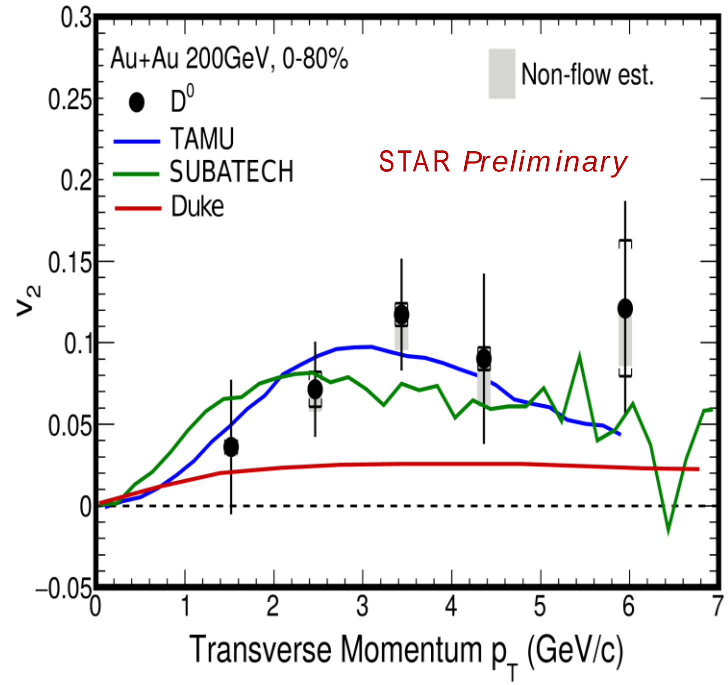
Heavy Quark probes QGP Properties

Mustafa Mustafa - QM15 - Kobe, Japan





Data favors models with charm diffusion

➔ charm exhibits collectivity with the medium

➔ However, it is not completely thermalized

Perfect condition for a perfect

Next step: how bottom quarks behave?

	$D \times 2\pi T$	Diff. Calculation
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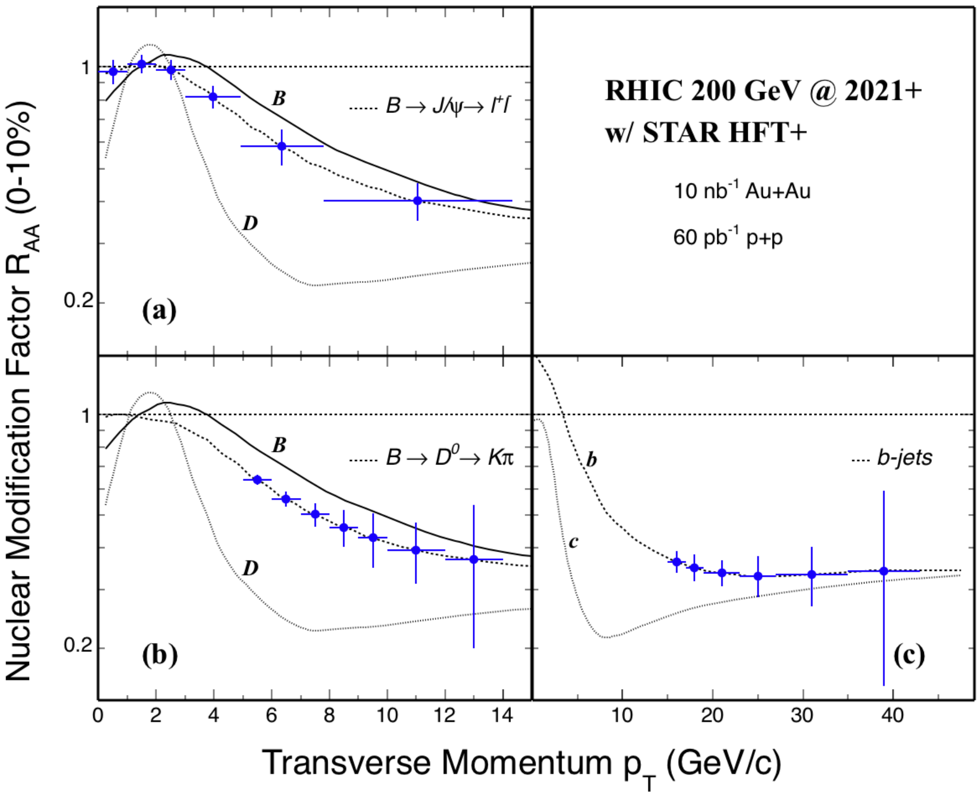
arXiv:1506.03981 (2015) & private comm.

HI Physics II in 2020+: Open Bottom

- Current HFT >180μs
- High-Speed HFT+:
  an integration time of <30 μs, possibly as low as 10 μs,
  TPC readout 40μs
- Improve TPC+HFT readout speed
  Reduce HFT hits from event pile-up
- Measurements of D^0 v_2 (constraint on diffusion constant, flow between 0 and light quarks)
- Bottom-quark Tagged jets
- Complementary and risk mitigation with two IRs



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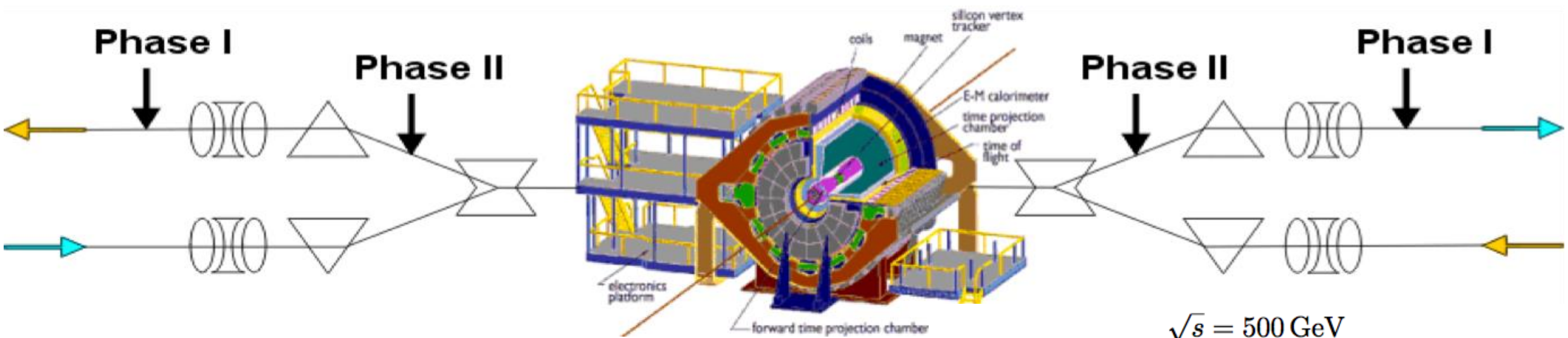
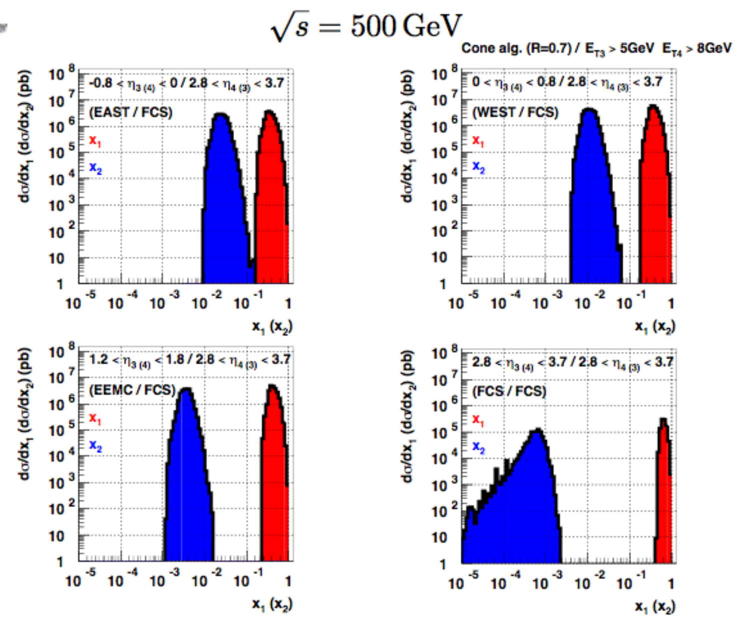
- Use spin as a vehicle to probe the nature of the pomeron and potentially discover odderon. Extend gluon polarization down to low-*x* using forward dijet reconstruction (Roman Pots, forward)

Exotic spin effects only accessible at RHIC

Guided by outcomes from the 2015 run, Phase II Roman Pot upgrade will drive new frontiers in diffraction, forward A_N, and the combined momentum-spatial gluon structure in the proton with cost-effective forward instrumentation.



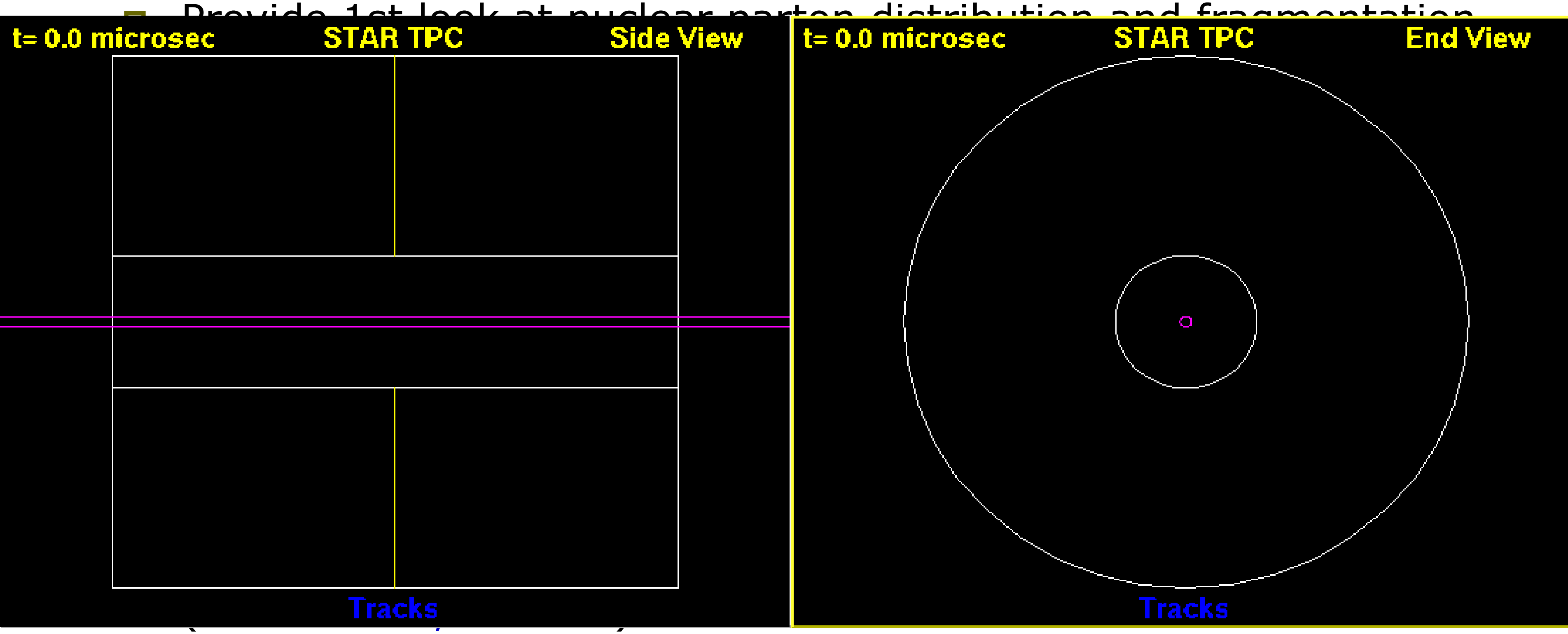
STAR's unique forward capabilities offer compelling target opportunities if external schedules were to slip, for example, low-x gluon helicity with forward (di-)jet measurements at 500 GeV



https://drupal.star.bnl.gov/STAR/starnotes/public/sn0605

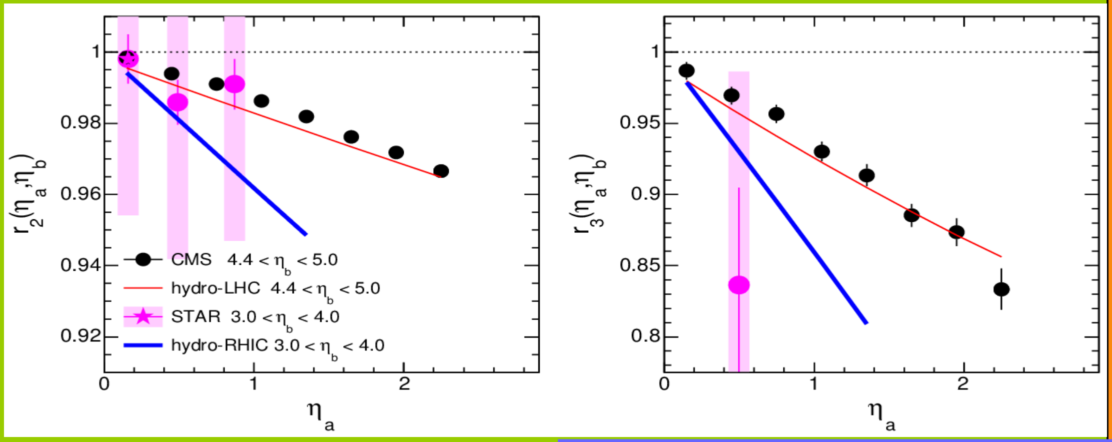
Summary and Priority (after BES-II)

- Provide 1st look at nuclear parton distribution and fragmentation

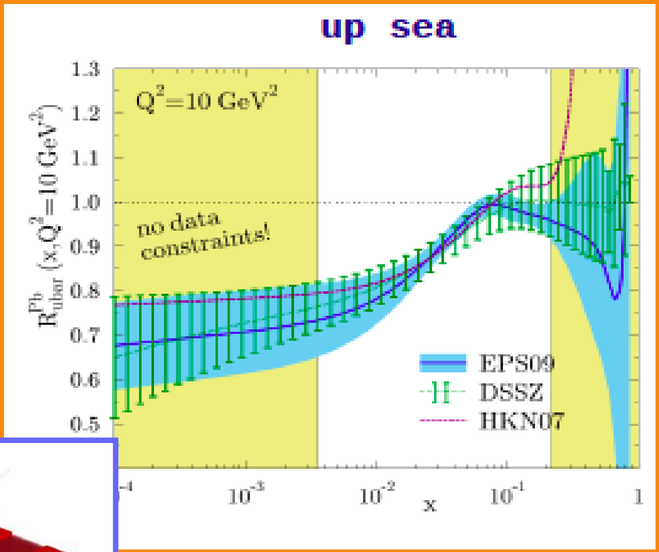


- Continue promising studies to increase STAR's minbias trigger rate to 5-10 kHz
  (High-rate EMC/Trigger electronics)

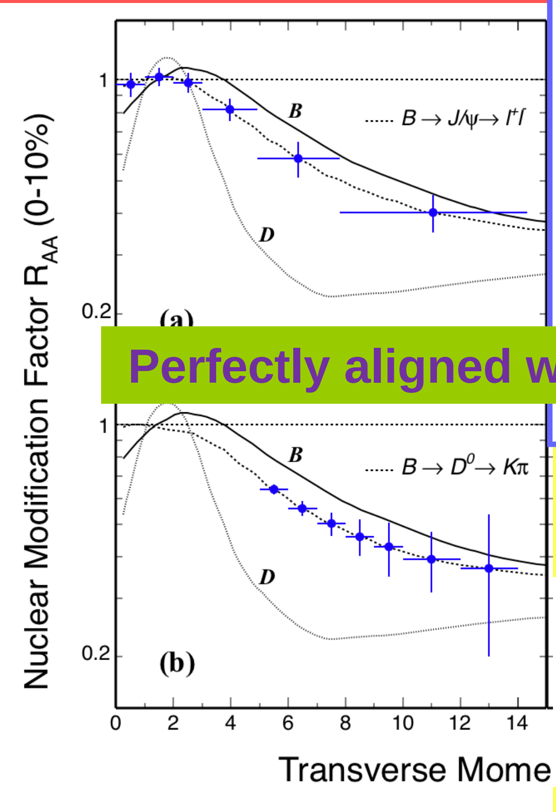
Longitudinal Correlations

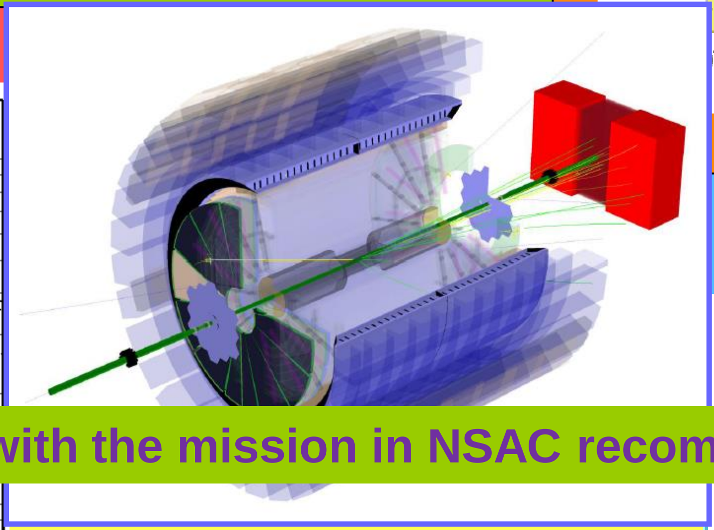


Low x Nuclear PDFs & FF



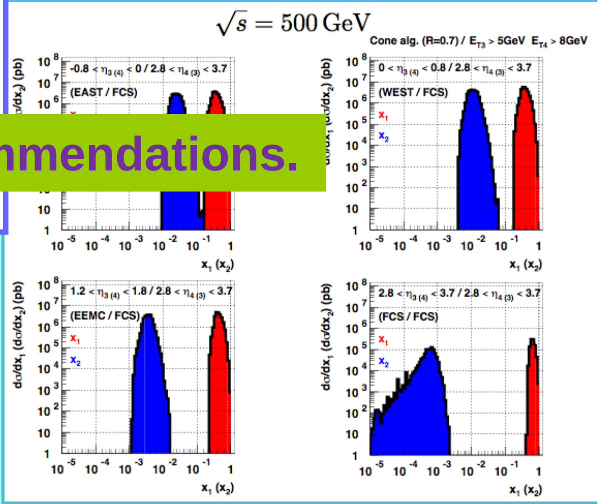
Bottom Flow



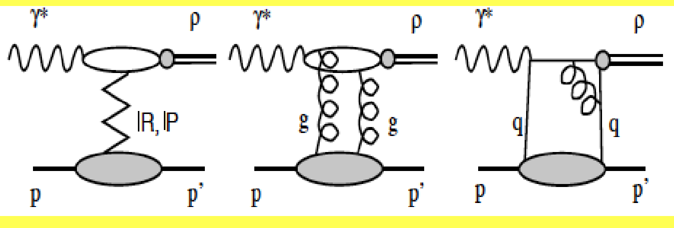


Perfectly aligned with the mission in NSAC recommendations.

Low x ΔG



Polarized Diffraction



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- SN0625-May. 19, 2015, ***RHIC Beam Use Request for runs 16 and 17***
- SN0619-Feb. 18, 2015, ***A Proposal for STAR Inner TPC Sector Upgrade (iTPC)***
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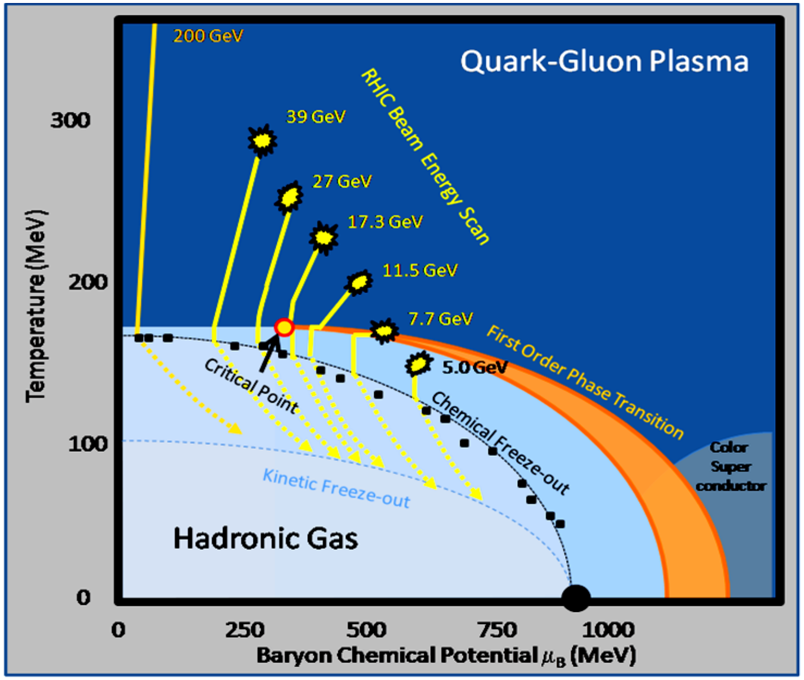
STAR addressing pressing issues in the field

Hot QCD Matter



1: Properties of the sQGP

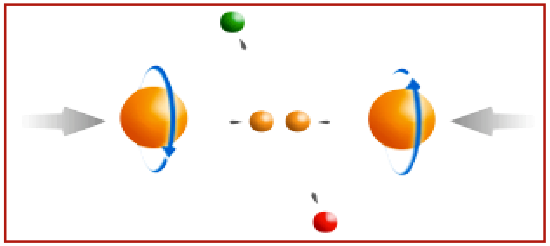
2: Mechanism of energy loss: weak or strong coupling?

3: Is there a critical point, and if so, where?

4: Novel symmetry properties

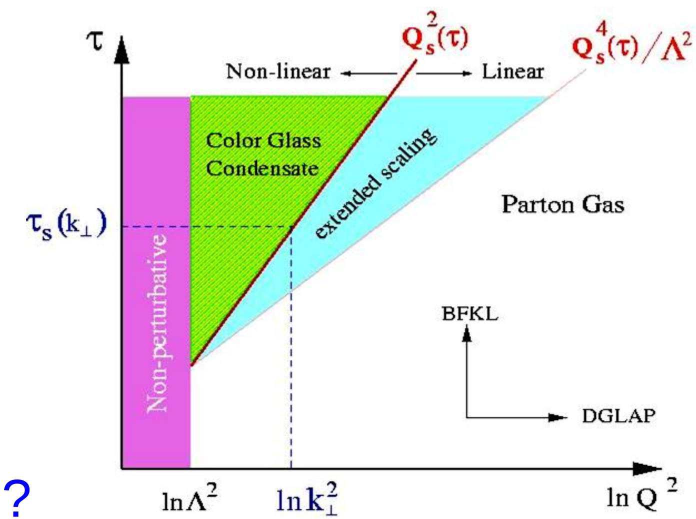
5: Exotic particles

Partonic structure



6: Spin structure of the nucleon

7: How to go beyond leading twist and collinear factorization?



8: What are the properties of cold nuclear matter?