STAR Science for the Coming Decade

Carl Gagliardi
Texas A&M University

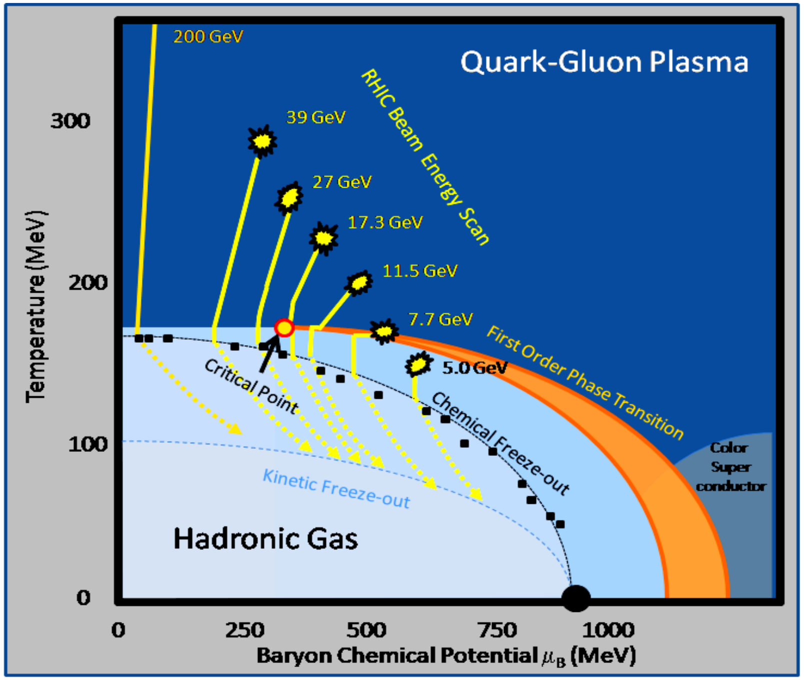
for the
***STAR* Collaboration**

Outline

- Eight key questions
- ***STAR*** now to mid-decade
- ***STAR*** in the second half of the decade
- ***eSTAR*** at eRHIC phase 1

RHIC: eight key unanswered questions

Hot QCD Matter



1: Properties of the sQGP

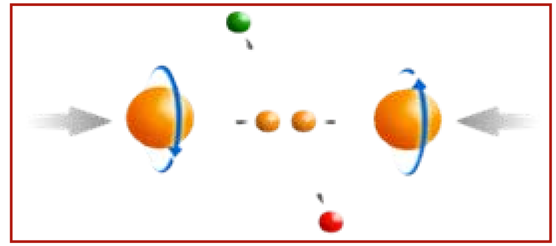
2: Mechanism of energy loss:
weak or strong coupling?

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

4: Novel symmetry properties

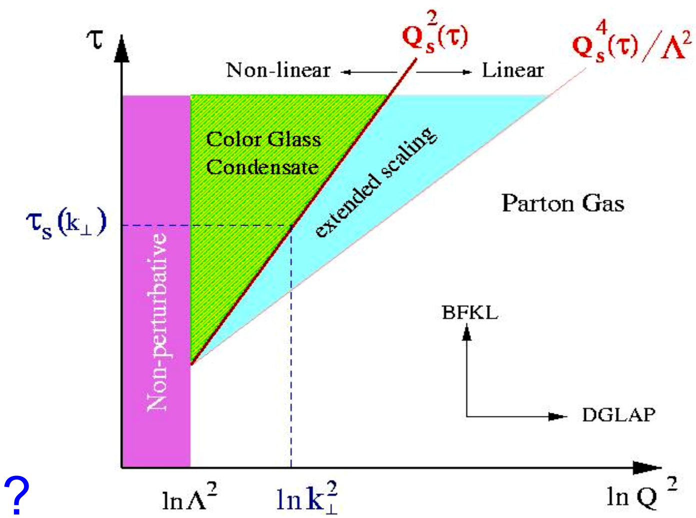
5: Exotic particles

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?

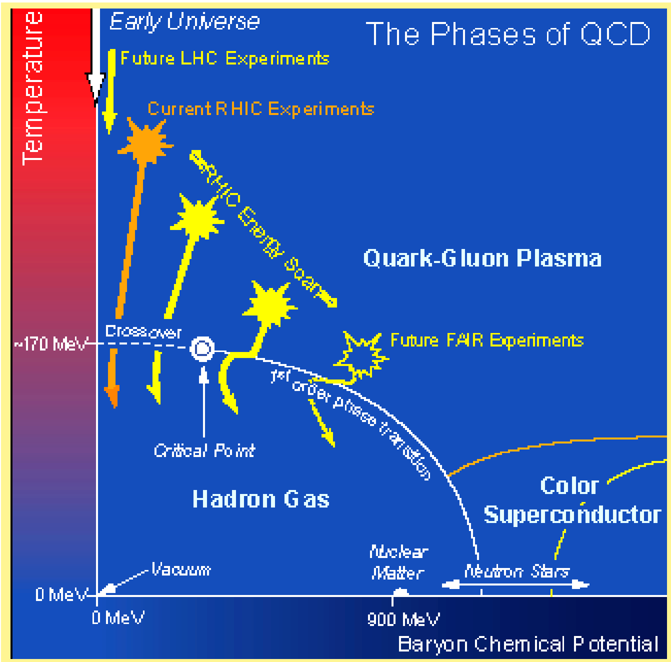
How to answer these questions

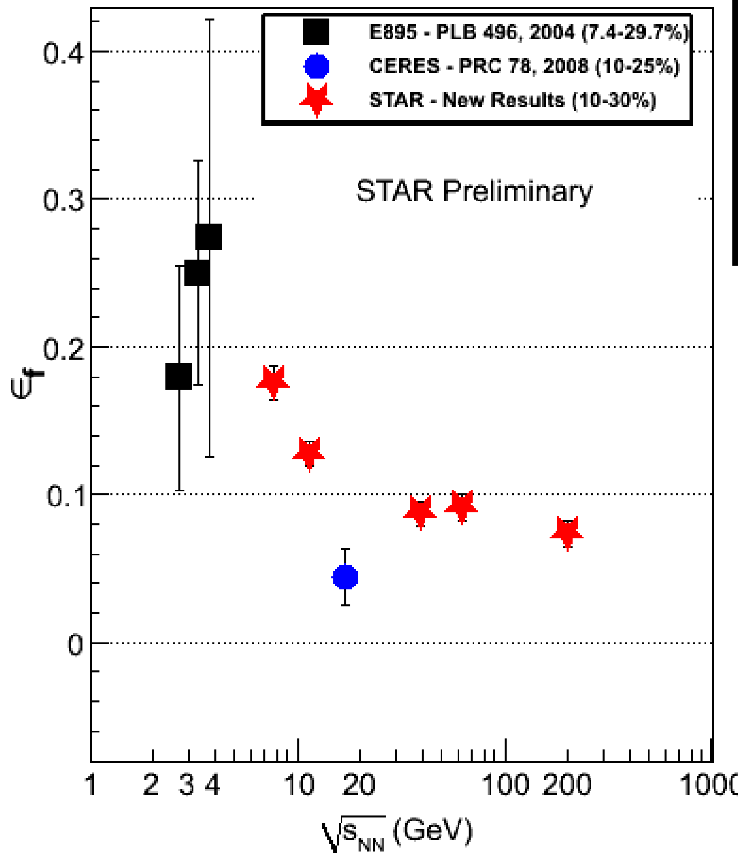
- Hot QCD matter: high luminosity RHIC II (fb^{-1} equivalent)
  - Heavy Flavor Tracker (HFT): precision charm and bottom
  - Muon Telescope Detector (MTD): e+μ and μ+μ at mid-rapidity
  - Trigger and DAQ upgrades to make full use of luminosity

- Phase structure of QCD matter: energy scan

- Cold QCD matter: high precision p+A, followed by e+A
  - Major upgrade of capabilities in forward direction
  - Devote the time to explore p+A, not d+A
  - Existing mid-rapidity detectors well suited for portions of the initial e+A program

Near future: where is the QCD critical point?





See talks by:

- A. Schmah, 5/23
- T. Tarnowsky, 5/23
- B. Mohanty, 5/26
- C. Anson, 5/27
- L. Kumar, 5/27

- A **landmark on the QCD phase diagram**
- Narrowing down the region of interest during Runs 11/12
- Future: **need detailed study of the key region**
  - Finer energy steps with higher statistics

Mid-rapidity ***STAR***: now to mid-decade

Tracking: TPC

Particle ID: TOF

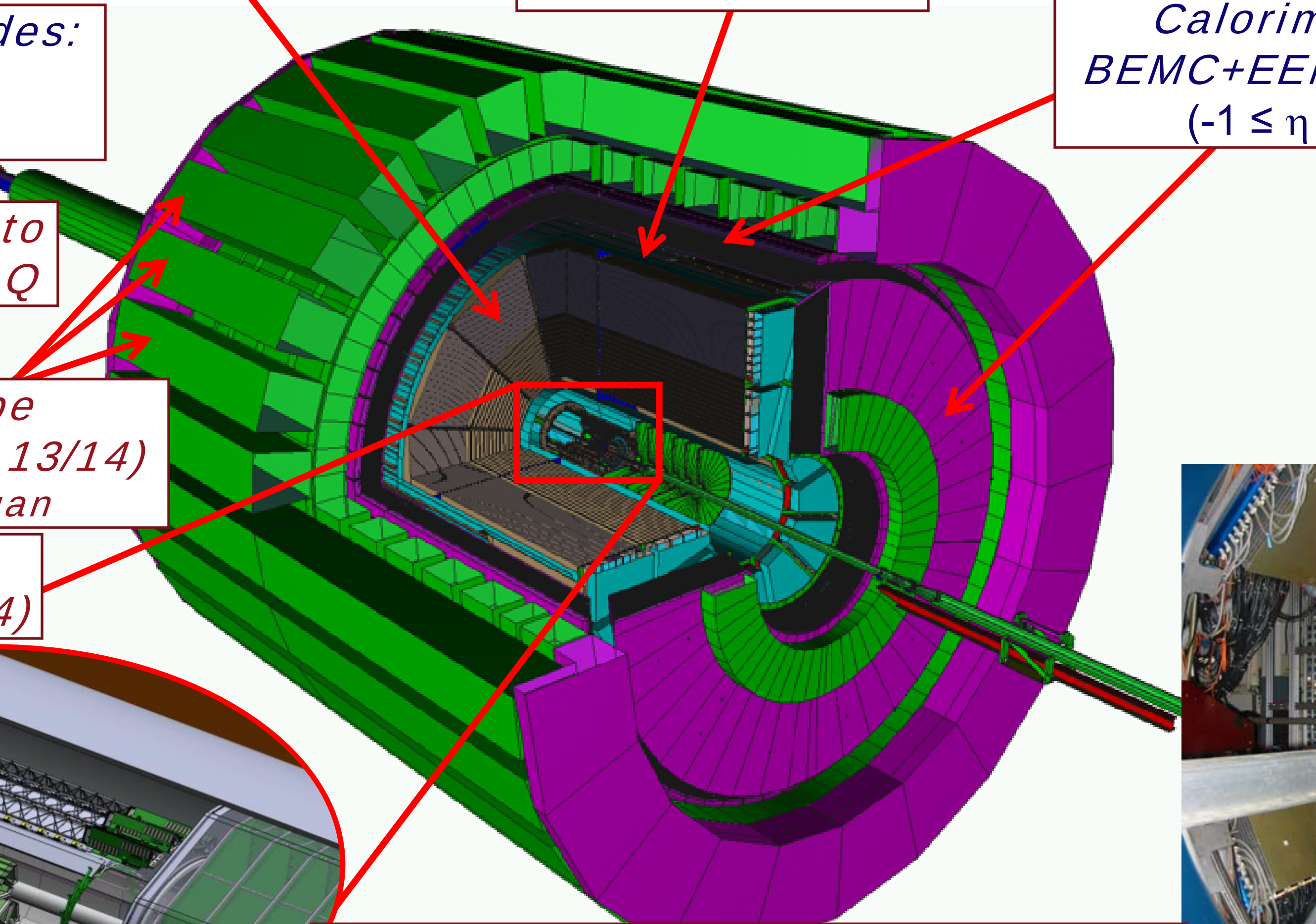
Electromagnetic Calorimetry: BEMC+EEMC+FMS (-1 ≤ η ≤ 4)

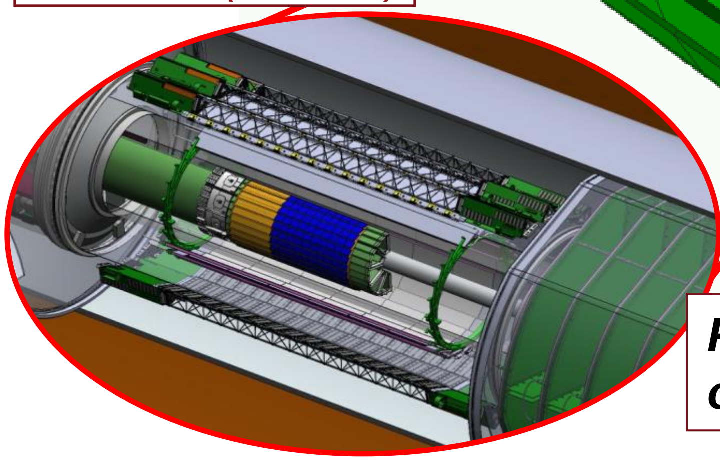
Recent upgrades: DAQ1000 TOF

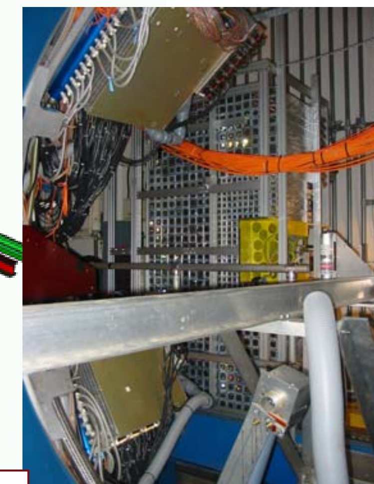
Plus upgrades to Trigger and DAQ

Muon Telescope Detector (runs 13/14)
See poster: L. Ruan

Heavy Flavor Tracker (run 14)



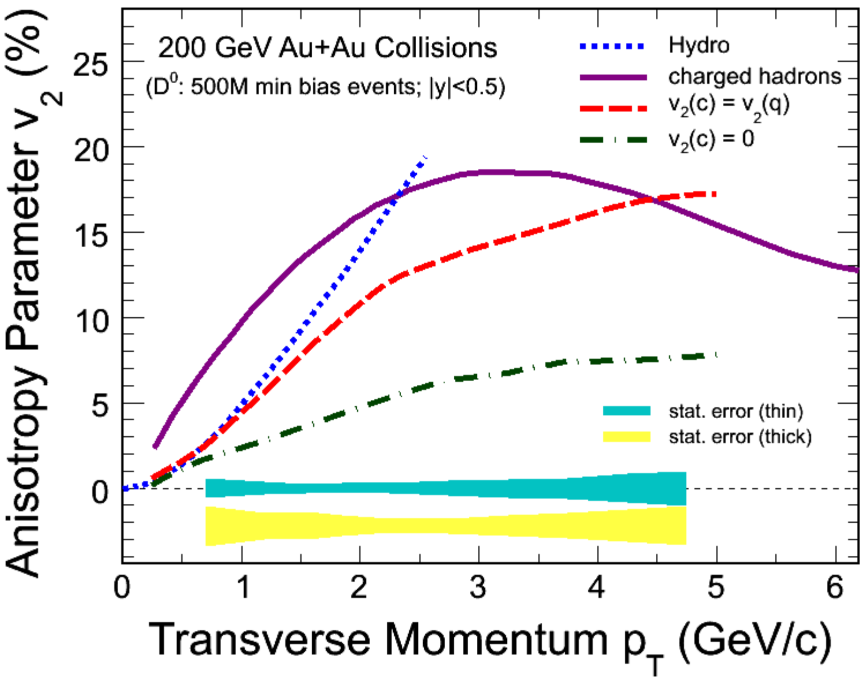


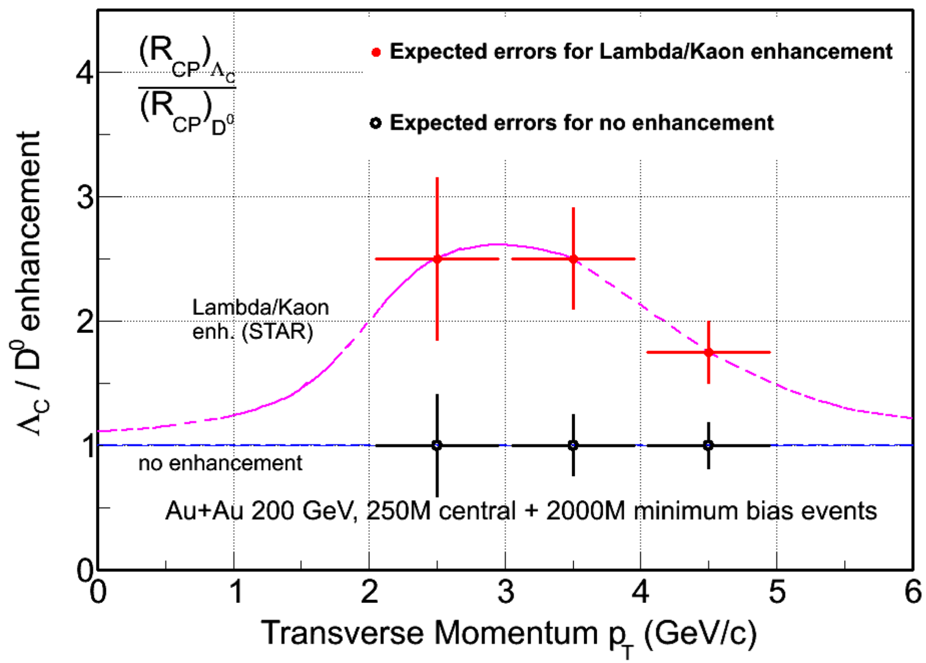


Full azimuthal particle identification over a broad range in pseudorapidity

A beautiful detector gets even better!

Properties of sQGP: charm





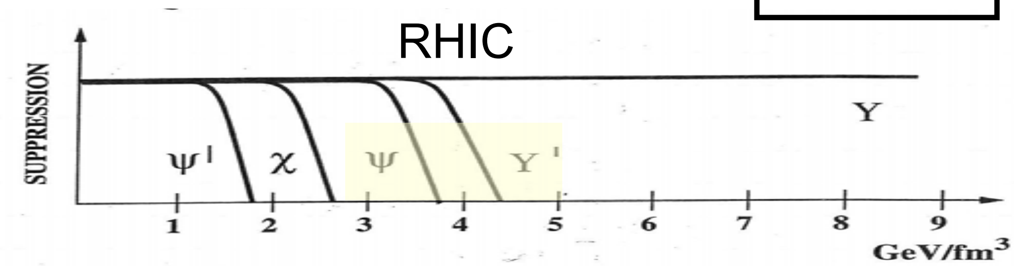
- Does charm flow **hydrodynamically**?
  - Heavy Flavor Tracker: unique access to low-p_T fully reconstructed charm
- Are charmed hadrons produced via **coalescence**?
  - Heavy Flavor Tracker: unique access to charm baryons
  - Would force a **significant reinterpretation** of non-photonic electron R_{AA}
- Muon Telescope Detector: precision measurements of J/ψ flow

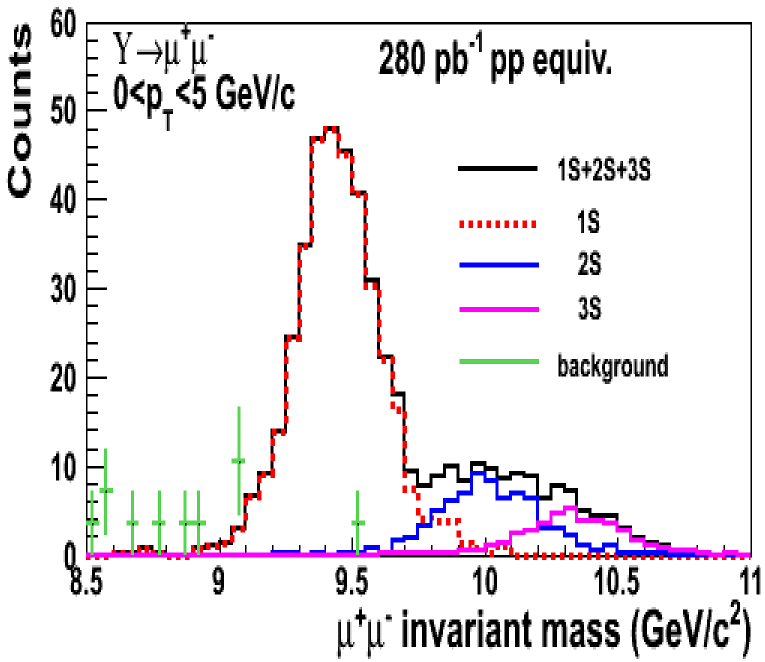
Properties of sQGP: Upsilon

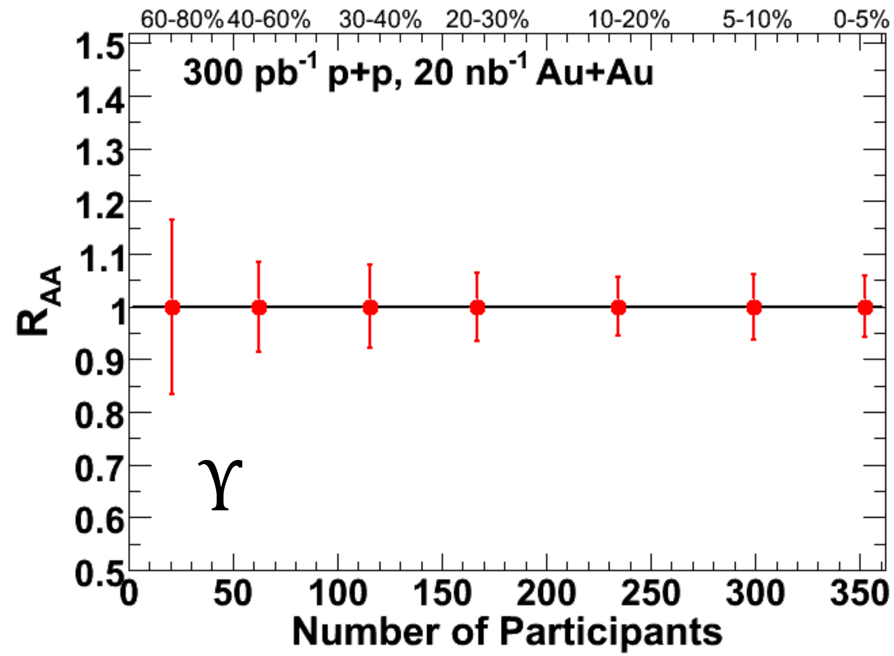
See poster R. Reed

What quarkonia states dissociate at RHIC energy densities?

What is the energy density?





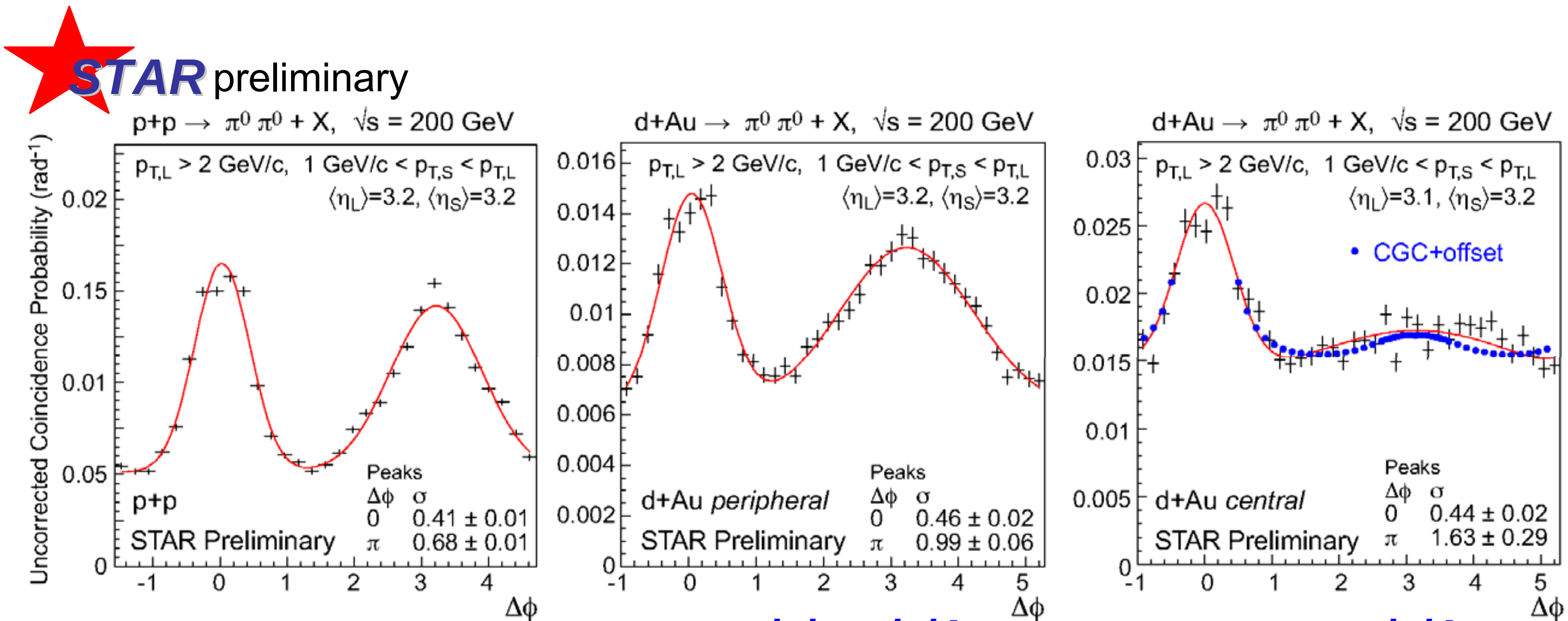


- Muon Telescope Detector: dissociation of ϒ, separated by state
  - At RHIC: small contribution from coalescence, so interpretation clean
  - No contribution of Bremsstrahlung tails, unlike electron channel

Mechanism of partonic energy loss

- Is the mechanism predominantly radiative or collisional?
  - Detailed, fully kinematically constrained measurements via gamma-hadron and full jet reconstruction
  - Pathlength dependence, especially with U+U
- Does the mechanism depend on the parton type?
  - Gluons: particle identification, especially baryons
  - Light quarks: gamma-hadron
  - Heavy quarks: Heavy Flavor Tracker and Muon Telescope Detector
- Does the energy loss depend on the parton energy and/or velocity?
  - High precision jet measurements up to 50 GeV
  - Vary velocity by comparing light quarks, charm, and bottom
- Example of **complementary to LHC**
  - RHIC: primarily light quarks for 30 to 50 GeV jets
  - LHC: gluons

Cold QCD matter – the initial state at RHIC



pp ***peripheral dAu*** ***central dAu***

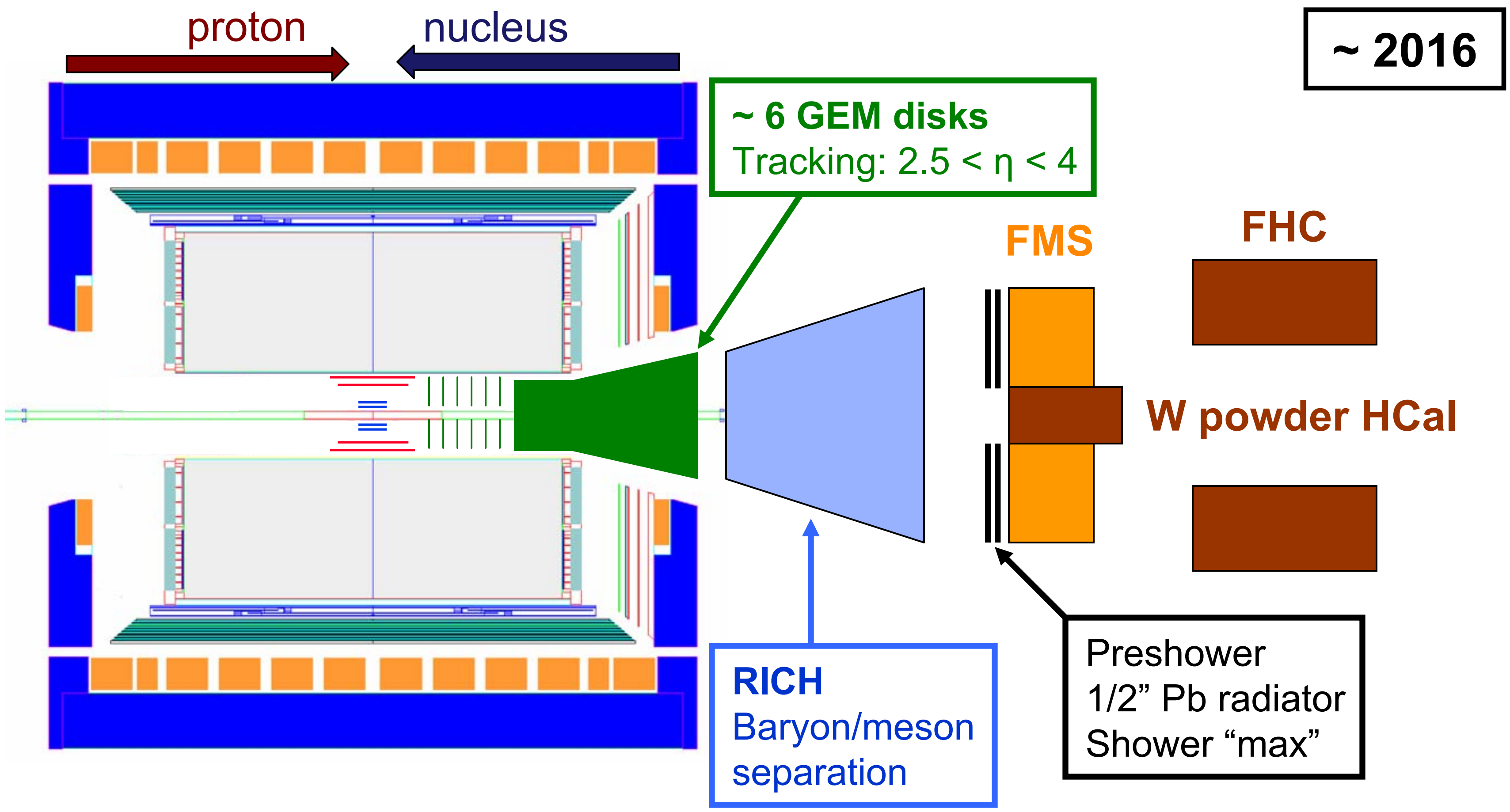
- RHIC may provide **unique access to the onset of saturation**
- Future questions for **p+A**
  - What is the gluon density in the (x,Q^2) range relevant at RHIC?
  - What role does saturation of gluon densities play at RHIC?
  - What is Q_s at RHIC, and how does it scale with A and x?
  - What is the impact parameter dependence of the gluon density?

Some planned p+A measurements

- Nuclear modifications of the gluon PDF
  - Correlated charm production
- Gluon saturation
  - Forward-forward correlations (extension of existing π^0-π^0)
    - *h*-*h* } Easier to measure
    - π^0-π^0
    - γ-*h* } Easier to interpret
    - γ-π^0
  - Drell-Yan
    - Able to reconstruct x_1, x_2, Q^2 event-by-event
    - Can be compared directly to nuclear DIS
    - True 2 → 1 provides model-independent access to $x_2 < 0.001$
  - Λ polarization
  - Baryon production at large x_F
- What more might we learn by scattering ***polarized* protons off nuclei**?

- Must **look forward** to perform these measurements

STAR forward instrumentation upgrade



- Forward instrumentation optimized for **p+A** and **transverse spin** physics
  - Charged-particle tracking
  - *e*/*h* and γ/π^0 discrimination
  - Baryon/meson separation

STAR → ***eSTAR***

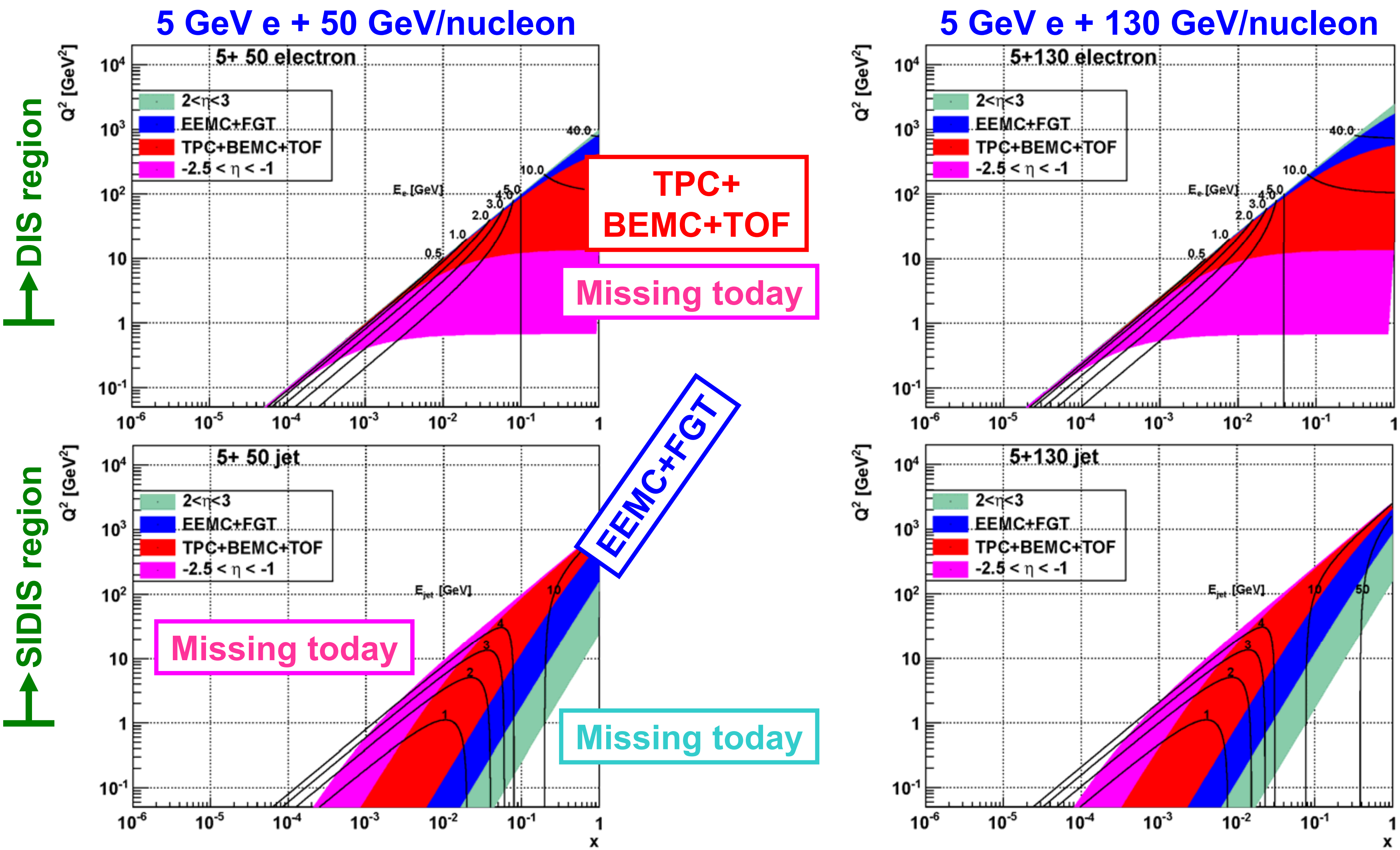
Optimizing ***STAR*** for e+A collisions from 5+50 to 5+130 GeV

- Inclusive scattering over the entire deep-inelastic region
  - Key measurements
    - F_L in e+A – direct measurement of nuclear gluon densities
    - F_2^A/F_2^d – parton distributions in nuclei (including gluons via Q^2 evolution)

- Semi-inclusive deep-inelastic scattering over a broad (x,Q^2) domain
  - Key measurements
    - Flavor-separated parton distributions in nuclei, including strangeness
    - Parton energy loss in cold nuclear matter

- **What's needed?**

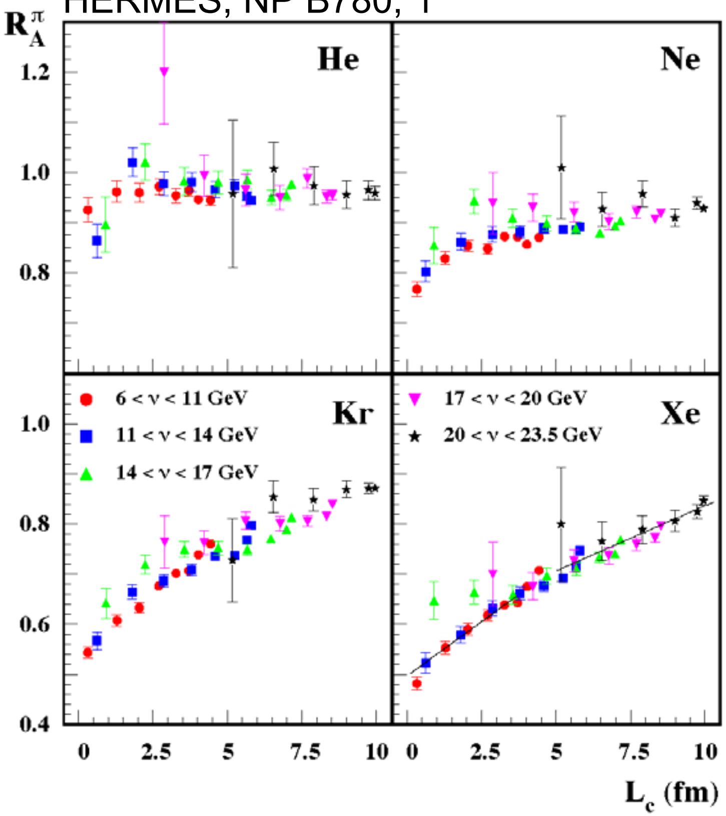
eRHIC phase 1: e+A kinematic range

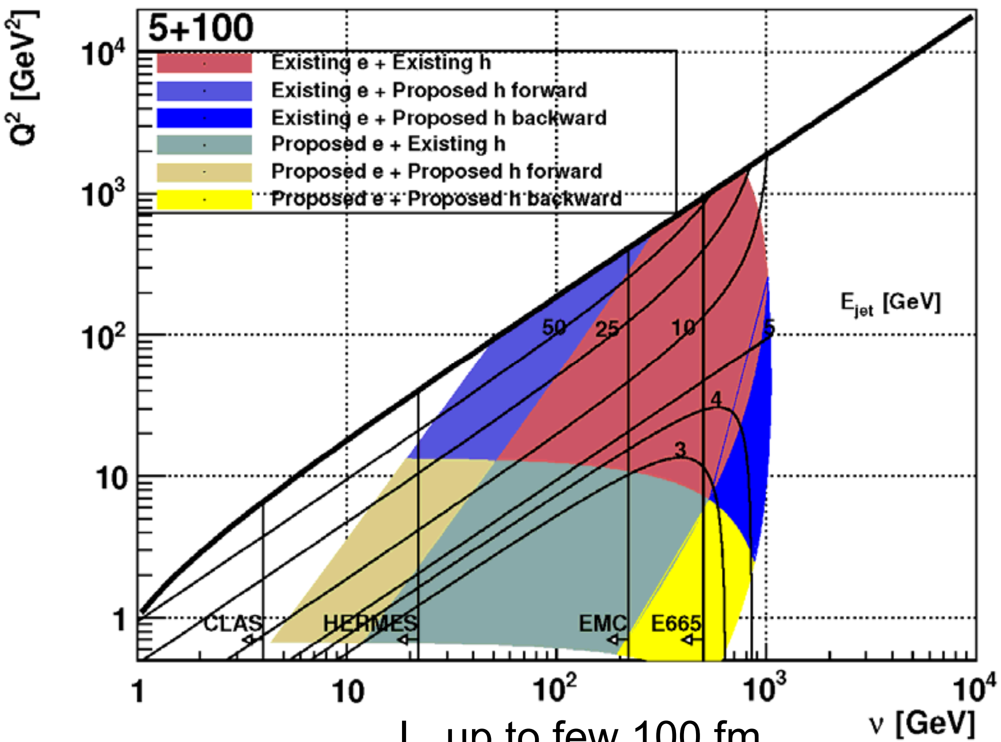


- "Forward" (-2.5 <~ η < -1) **electron acceptance essential** to span deep-inelastic (DIS) regime
- Both **backward** and **forward** **hadron coverage valuable** for semi-inclusive deep-inelastic (SIDIS) scattering

Parton energy loss in cold QCD matter

HERMES, NP B780, 1





L_c up to few 100 fm

- Complementary tool to investigate partonic energy loss
- HERMES: hadrons can form partially inside the medium
  – Mixture of hadronic absorption and partonic energy loss
- eRHIC: light quark hadrons form well outside the medium
- Heavy quarks: unexplored to date. Low β → short formation time

STAR → eSTAR

Optimizing ***STAR*** for e+A collisions from 5+50 to 5+130 GeV

- Inclusive scattering over the entire deep-inelastic region
  - Key measurements
    - F_L in e+A – direct measurement of nuclear gluon densities
    - F_2^A/F_2^d – parton distributions in nuclei (including gluons via Q^2 evolution)
  - Need electron detection, ID, and triggering over -2.5 <~ η < -1
    - Combined mini-TPC/threshold gas Cherekov detector

- Semi-inclusive deep-inelastic scattering over a broad (x,Q^2) domain
  - Key measurements
    - Flavor-separated parton distributions in nuclei, including strangeness
    - Parton energy loss in cold nuclear matter
  - Need hadron detection and identification beyond the TPC/EEMC
    - Extend TOF to cover -2 < η < -1
    - GEM disks (from forward instrumentation upgrade) plus hadronic calorimetry in the region 2 < η < 3

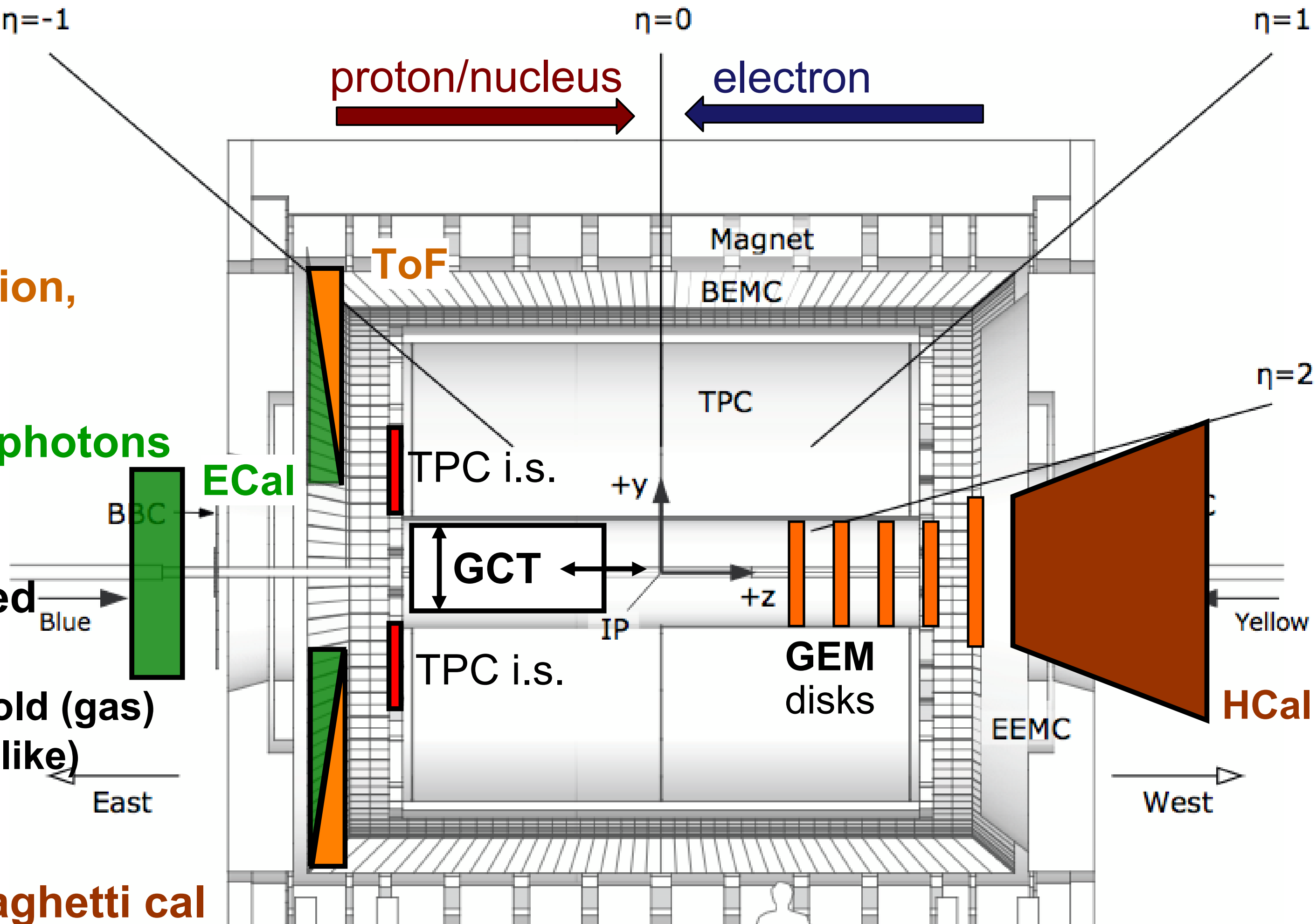
Evolving from ***STAR*** into ***eSTAR***

ToF: π , *K* identification, t_0, electron

ECal: electrons and photons

GCT: a compact tracker with enhanced electron capability
Combine high-threshold (gas) Cherenkov with TPC(-like) tracking

HCal: W powder, spaghetti cal



Simulations ahead:
eSTAR task force formed

GCT: LOI toward multi-institution R&D effort
HCal: R&D proposal

Presented to EIC Generic Detector R&D Panel

Conclusions

- The ***STAR*** Collaboration has identified **compelling physics opportunities** for the coming decade
  - Eight key questions
- The ***STAR*** Collaboration has identified the **detector upgrades** required to address these opportunities
- The path forward:
  - Early in the decade: physics with low mass in the central region
  - Mid decade: physics of the HFT and MTD
  - Later in the decade: physics in the forward region
  - End of the decade: early phase of eRHIC
- ***STAR*** has a vision for the future that will produce **important new results well into the eRHIC era**

Key unanswered questions

- What is the nature of QCD matter at the extremes?
  - What are the properties of the strongly-coupled system produced at RHIC, and how does it thermalize?
  - Are the interactions of energetic partons with QCD matter characterized by weak or strong coupling? What is the detailed mechanism for partonic energy loss?
  - Where is the QCD critical point and the associated first-order phase transition line?
  - Can we strengthen current evidence for novel symmetries in QCD matter and open new avenues?
  - What other exotic particles are produced at RHIC?
- What is the partonic structure of nucleons and nuclei?
  - What is the partonic spin structure of the proton?
  - How do we go beyond leading twist and collinear factorization in perturbative QCD?
  - What is the nature of the initial state in nuclear collisions?

Summary of the plan

	Near term (Runs 11–13)	Mid-decade (Runs 14–16)	Long term (Runs 17–)
Colliding systems	$p+p$, A+A	$p+p$, A+A	$p+p$, $p+$A, A+A, $e+p$, $e+$A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \to ee$, m_{ee}, v_2	Υ, $J/\psi \to \mu\mu$, Charm v_2, R_{CP}, Charm corr, Λ_c/D ratio, μ-atoms	$p+$A comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, c/b in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	$e-\mu$ corr, $\mu-\mu$ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS, polarized SIDIS
(7) QCD beyond collinear factorization	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

Measurements listed when they first become possible

Many will continue in future periods