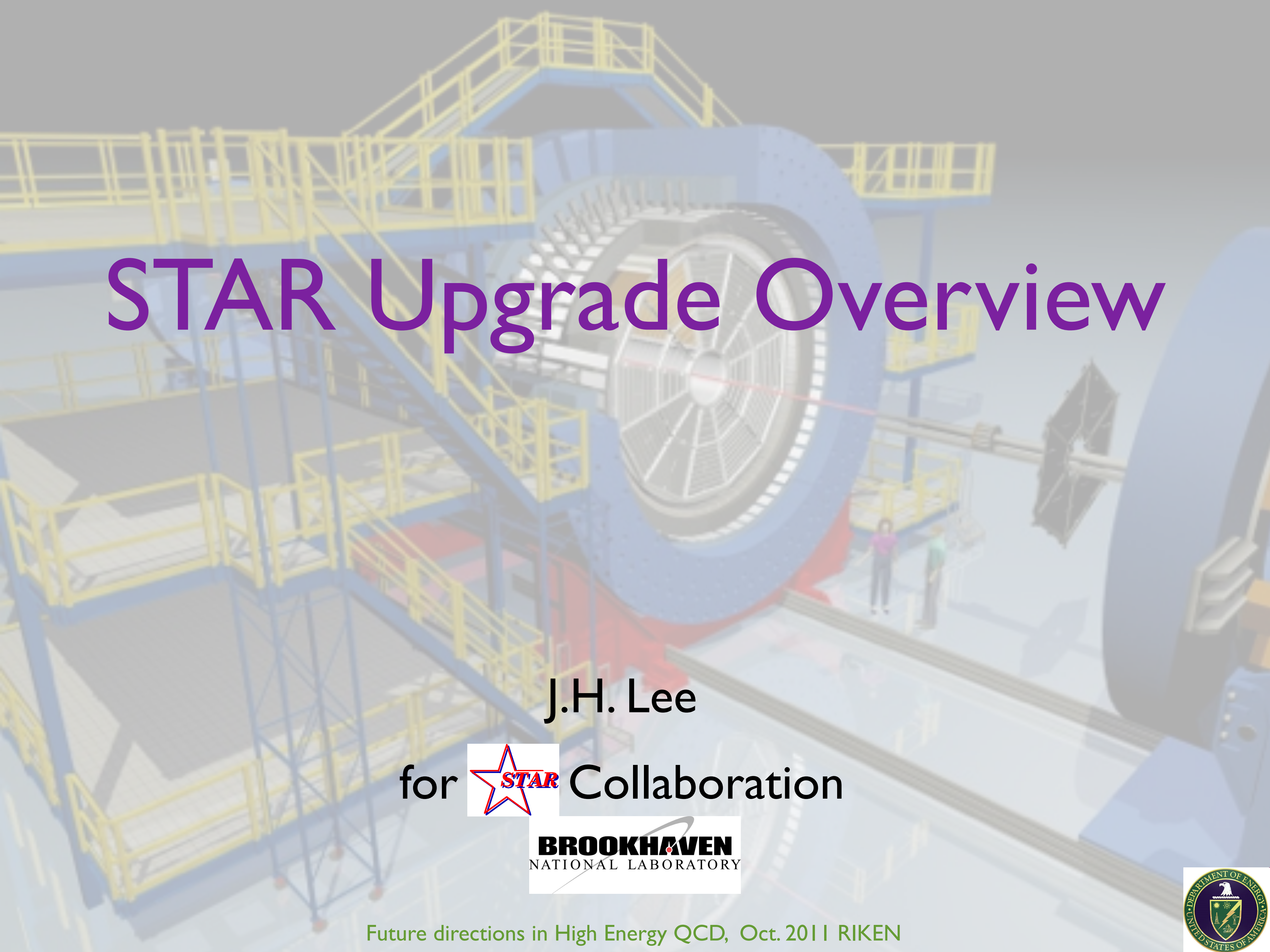
STAR Upgrade Overview



J.H. Lee

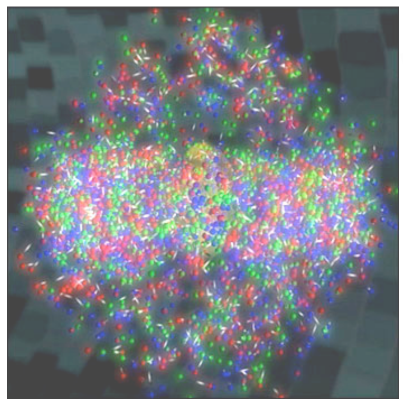
for STAR Collaboration

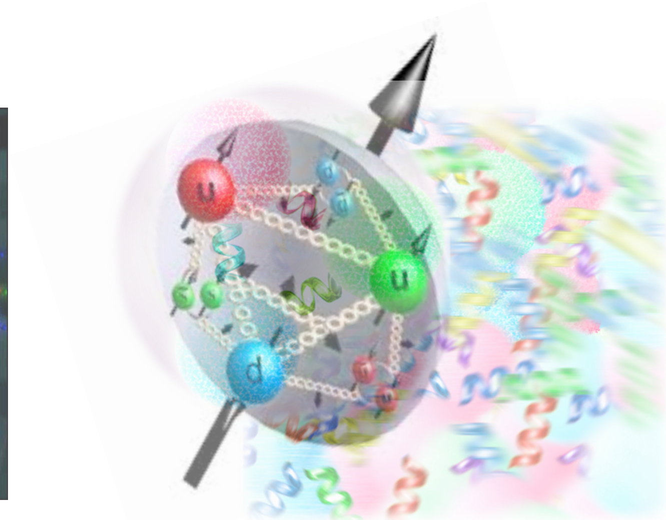
BROOKHAVEN
NATIONAL LABORATORY

Outline

- Unanswered/open questions at RHIC:
  - STAR plans and strategies on how to address them in the context of upgrades in the next decade
- Extending Physics reach with new lepton probe: eSTAR at eRHIC

Main physics themes at RHIC/STAR for the first decade and continuing...



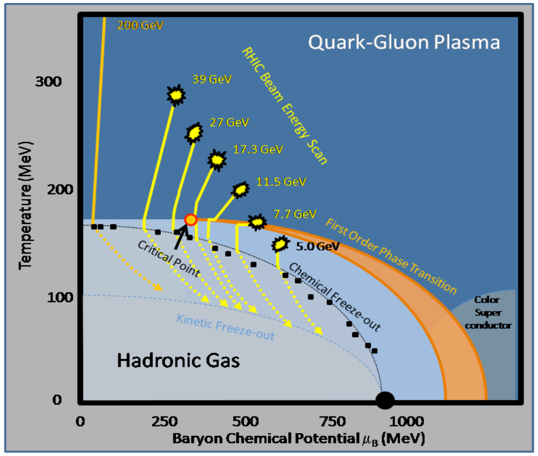


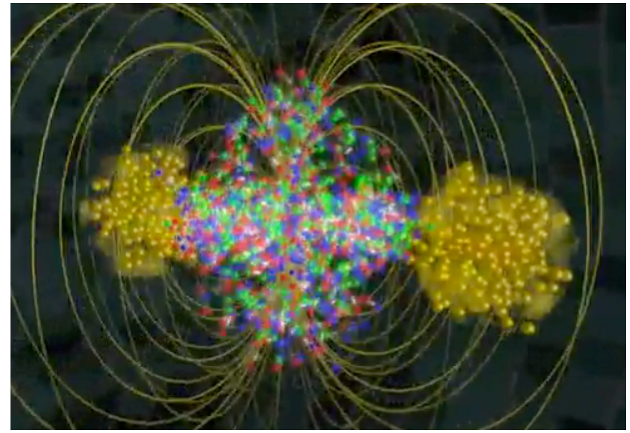
- Phases of QCD matter: properties of sQGP
- Spin structure of nucleon
- Properties of cold nuclear matter

Great discoveries and new understandings, yet with remained and newly opened questions...

Key unanswered questions I

What is the nature of QCD matter at the extremes

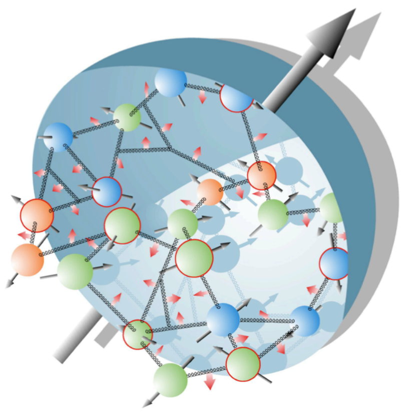


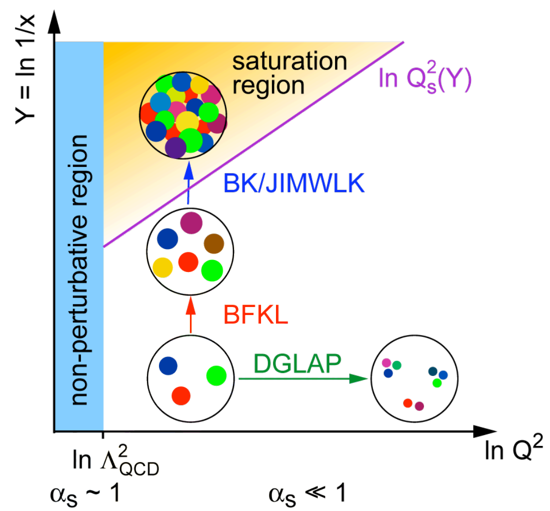


- What are the properties of the strongly-coupled system produced at RHIC, and how does it thermalize?
- Where is the QCD critical point and the associated first-order phase transition line?
- Are the interactions of energetic partons with QCD matter characterized by weak or strong coupling? What is the detailed mechanism for partonic energy loss?
- Can we strengthen current evidence for novel symmetries in QCD matter and open new avenues?
- What other exotic particles are produced at RHIC?

Key unanswered questions II

What is the partonic structure of nucleons and nuclei?





- What is the partonic spin structure of the proton?
- What are the dynamical origins of spin-dependent interactions in hadronic collisions?
- What is the nature of the initial state in nuclear collisions? Nuclear structure at high-energy (small-x)?

STAR strategies to answer these questions I

- Hot QCD matter: high luminosity RHIC II (fb^{-1} equivalent)
  - Heavy Flavor Tracker: precision charm and beauty
  - Muon Telescope Detector: e+μ and μ+μ at mid-rapidity
  - Trigger and DAQ upgrades to make full use of luminosity
  - Full use of the flexibility of RHIC (U+U,...)
- Phase structure of QCD matter: energy scan
  - Analysis of Phase I Completed in Runs 10,11 followed by targeted fine-scale energy scan
  - Electron cooling if lowest beam energies most promising

STAR strategies to answer these questions II

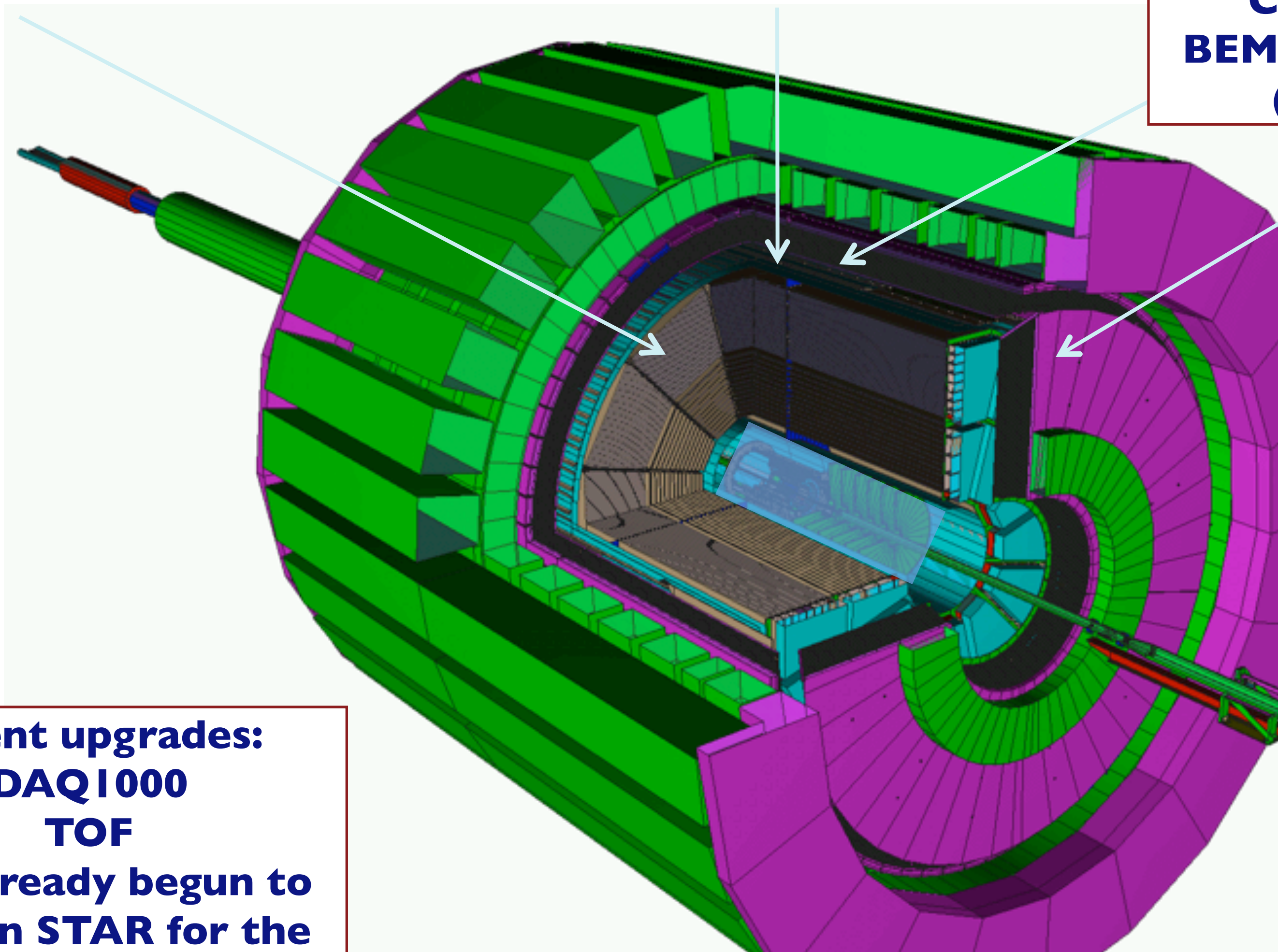
- Nucleon spin structure and diffraction
  - Forward GEM Tracker: flavor-separated anti-quark polarizations
  - Forward Hadron Calorimeter: strange quark polarization
  - Roman Pots (phase II): proton spectator tagging in polarized p $+^3He$, central exclusive diffraction $p+p \rightarrow p+M_X+p$
- Nucleon spin and cold QCD matter: high precision p+p and p +A, followed by e+p and e+A
  - Major upgrade of capabilities in forward/backward (electron) direction
  - Utilizing mid-rapidity detectors for the initial e+p and e+A program

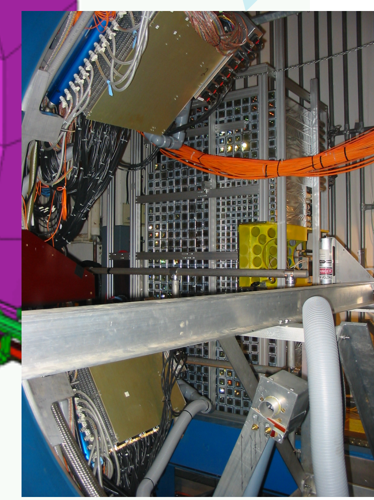
STAR: today

Tracking: TPC

Particle ID: TOF

Electromagnetic Calorimetry: BEMC+EEMC+FMS
($-1 \leq \eta \leq 4$)





Recent upgrades:
DAQ1000
TOF
have already begun to position STAR for the coming decade

Full azimuthal particle identification over a broad range in pseudorapidity

Evolution of STAR

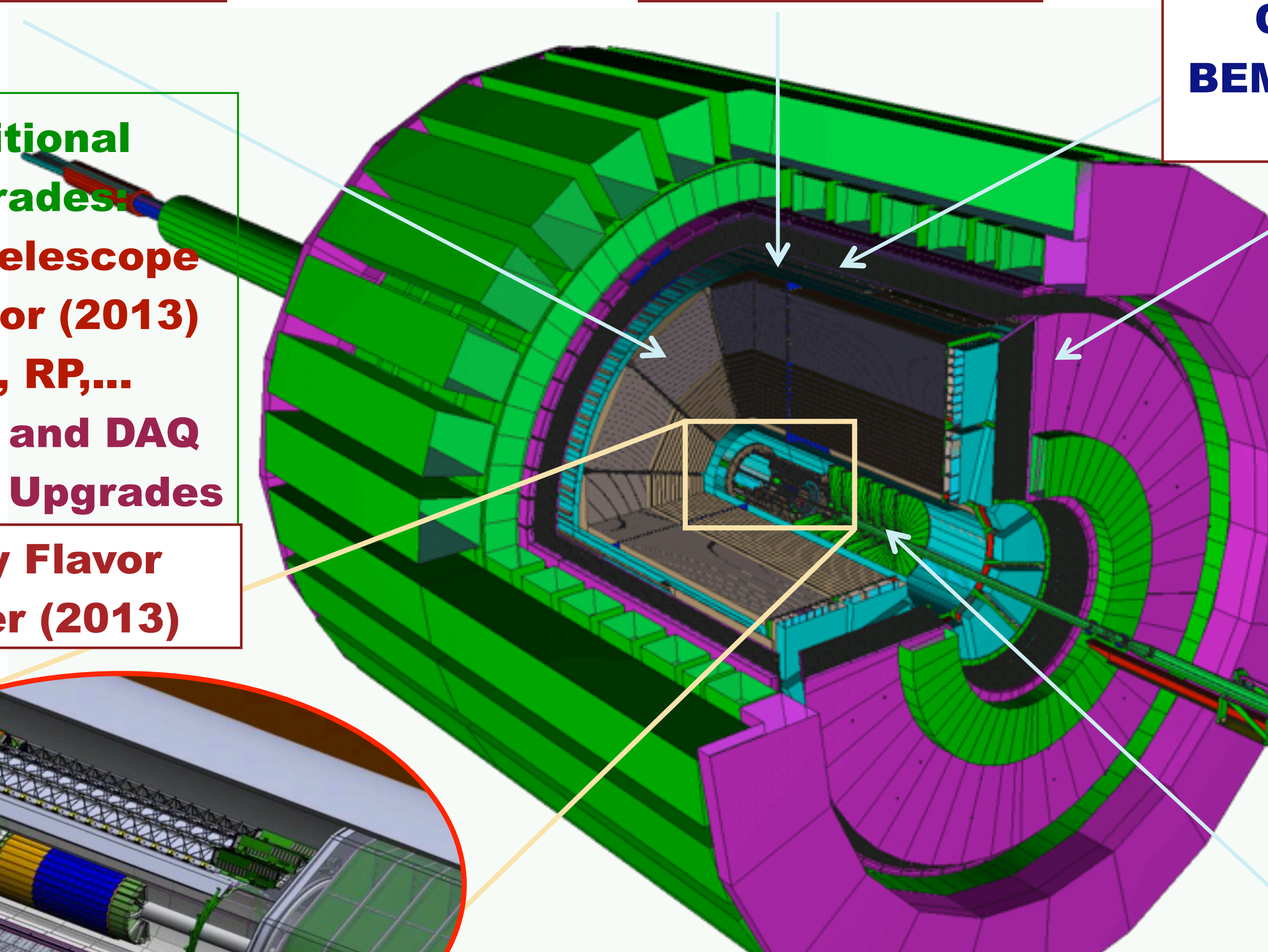
Tracking: TPC

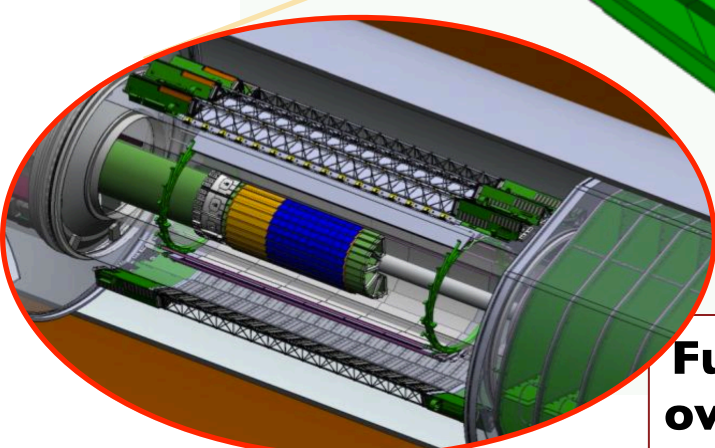
Particle ID: TOF

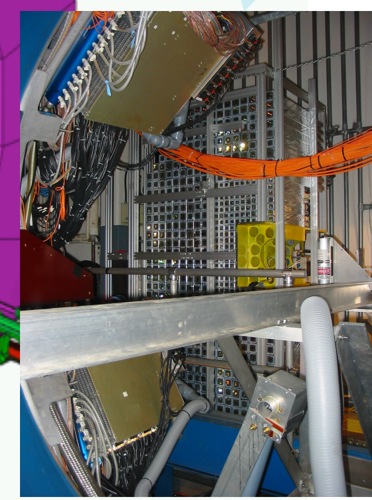
Electromagnetic Calorimetry: BEMC+EEMC+FMS
$(-1 \leq \eta \leq 4)$

Additional upgrades:
Muon Telescope Detector (2013)
FHC, RP,...
Trigger and DAQ
Forward Upgrades

Heavy Flavor Tracker (2013)







Forward GEM Tracker (2011)

Full azimuthal particle identification over a broad range in pseudorapidity

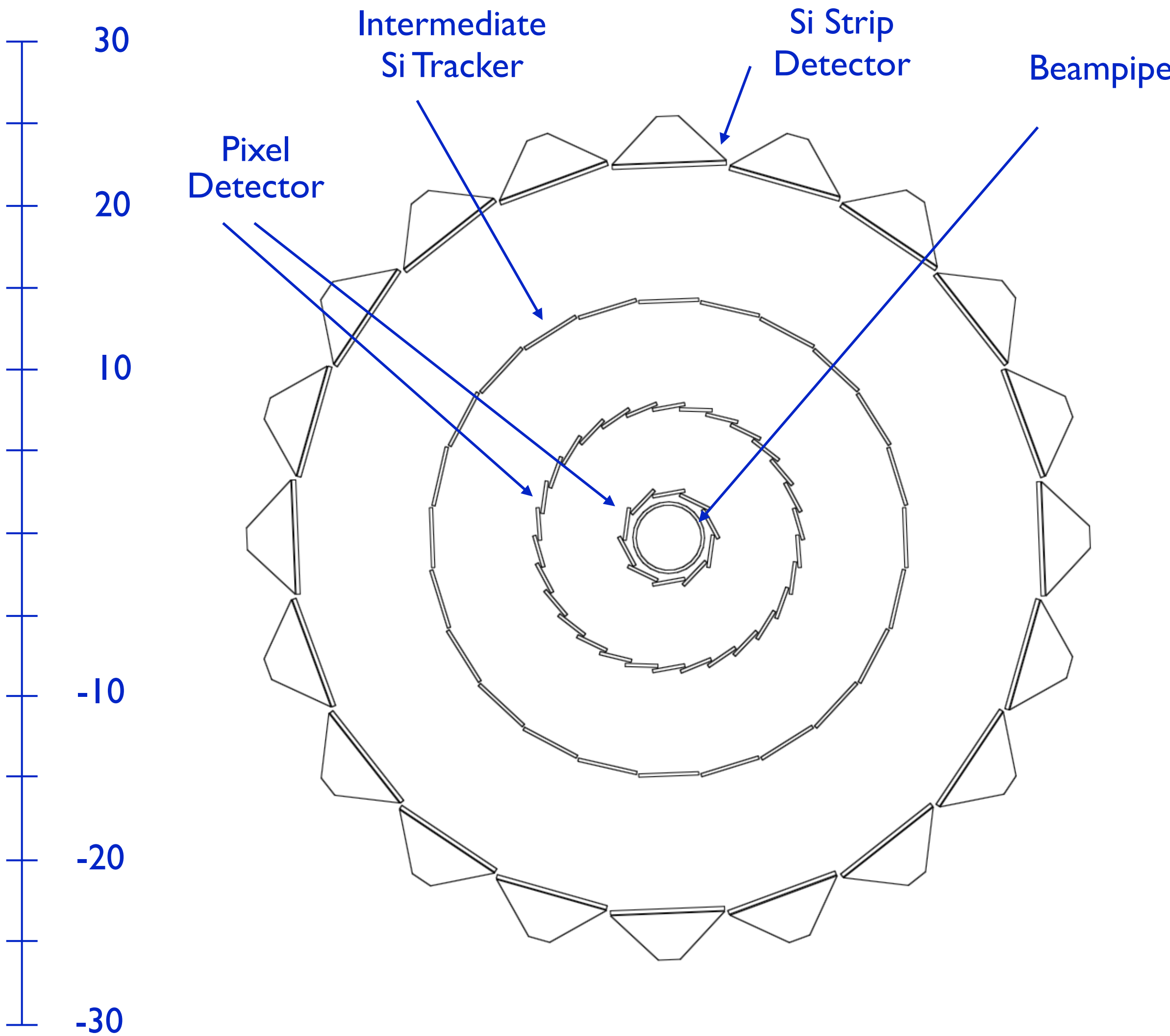
STAR Upgrades and physics: sQGP, QCD phases

year	near term (11-13)	mid-decade (14-16)	long term (17-19)
Colliding system	p+p, A+A	p+p, A+A	p+p, p+A, A+A
Upgrade	FGT, FHC, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Detectors, Trigger
Properties of sQGP	Υ, J/Ψ→ee, m_{ee}, v_2	Υ, J/Ψ→μμ, Charm v_2, R_{CP}, corr, Λ_c/D, μ-atoms	p+A comparison
Mechanism of energy loss	Jets, γ-jets, NPE	Charm, Bottom	Jets in CNM
QCD critical point	Fluctuations, Correlations, Ratios	Focused study of critical point region	
Novel symmetries	Azimuthal correlations	e-μ, μ-μ	
Exotic particles	Heavy antimatter		

STAR Upgrades and physics: Nucleon spin and Cold nuclear matter

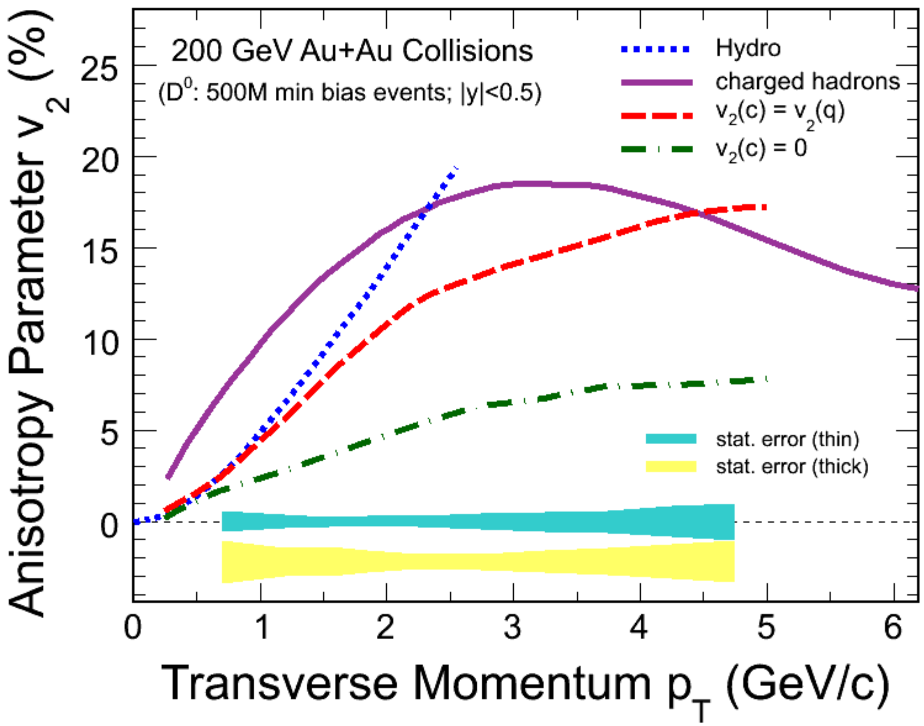
year	near term (11-13)	mid-decade (14-16)	long term (17-19)
Colliding system	p+p	p+p, p+^{3}He	p+p, p+A
Upgrade	FGT,FHC,DAQ10K, Trigger	HFT,MTD,Trigger, RP phase II	Forward Detectors,Trigger
Nucleon spin structure	W A_L jet and di-jet A_{LL}, intra-jet correlation, Λ D_{LL}/D_{TT}	W A_L with polarized ^{3}He	A_N in p+p, p+A
QCD beyond collinear factorization	Forward A_N	Forward A_N with ^{3}He (Flavor separation)	Drell-Yan, Forward-Forward corr.
Exotic particles		exotic mesons,baryons	exotic mesons,baryons
Properties of initial states			Charm corr. Drell-Yan J/Ψ. F-Fcorr. ,Λ

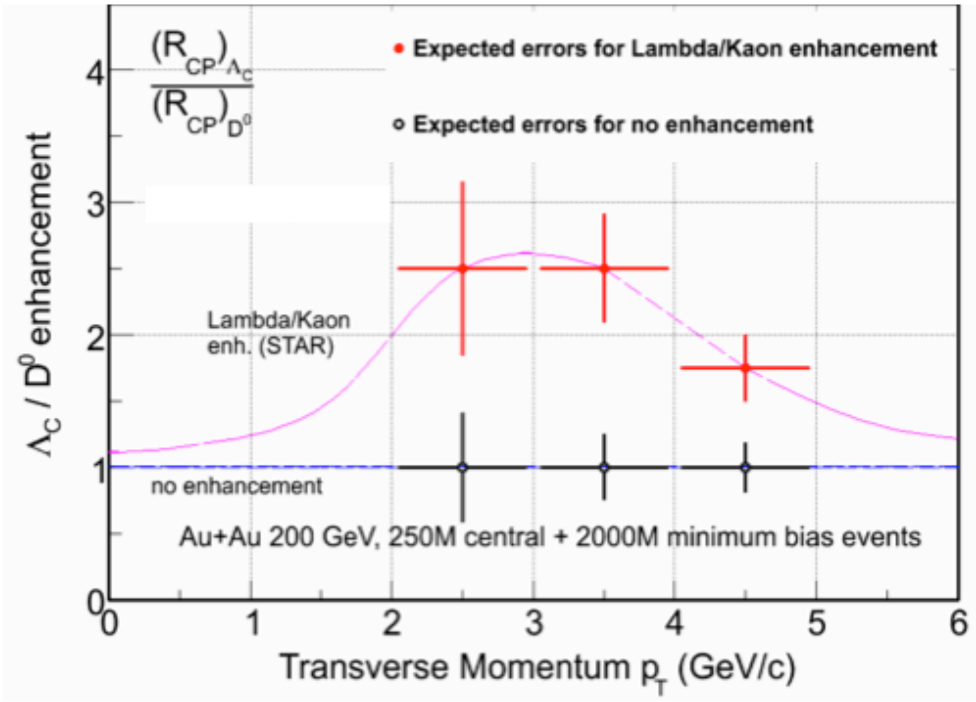
Heavy Flavor Tracker (HFT)



- The HFT puts 4 layers of Silicon around the vertex
- Provides ~20 μm space point resolution on tracks
- Uniquely thin pixels (< 0.6% X_0/layer, targeting 0.32% X_0)
- Topological reconstruction of open charm at low p_T
- DAQ1000-level rate capabilities
- Will be ready for the 2014 run

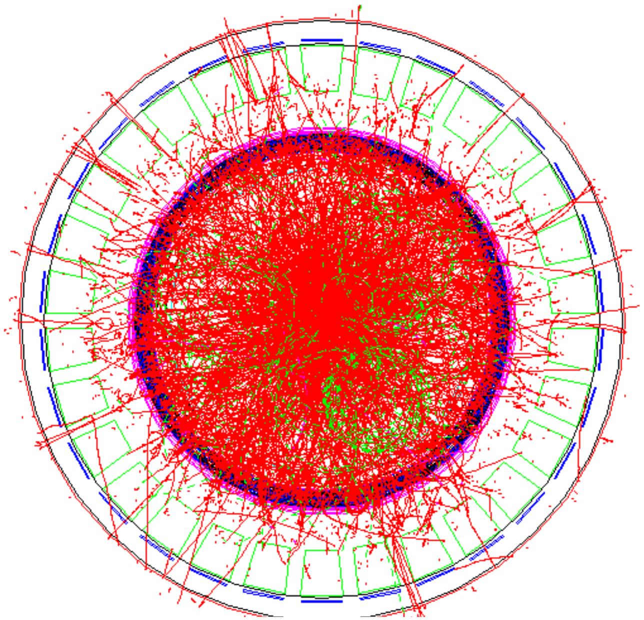
HFT Physics: Properties of sQGP with Open Charm

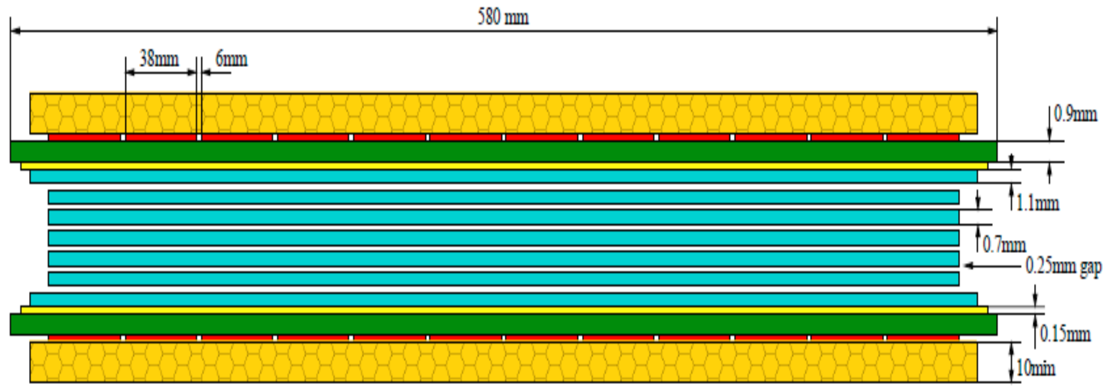




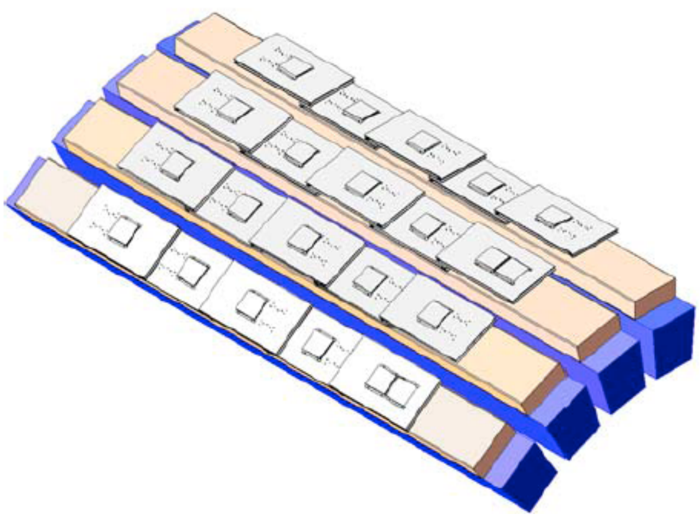
- Does charm flow **hydrodynamically**?
  - Heavy Flavor Tracker: unique access to low-p_T fully reconstructed charmed meson (D)
- Are charmed hadrons produced via **coalescence**?
  - Heavy Flavor Tracker: unique access to charm baryons (Λ_C)
  - Would force a **significant reinterpretation** of non-photonic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

Muon Telescope Detector (MTD)



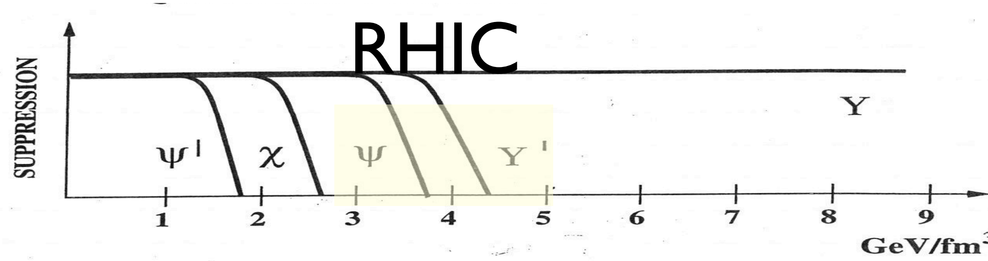


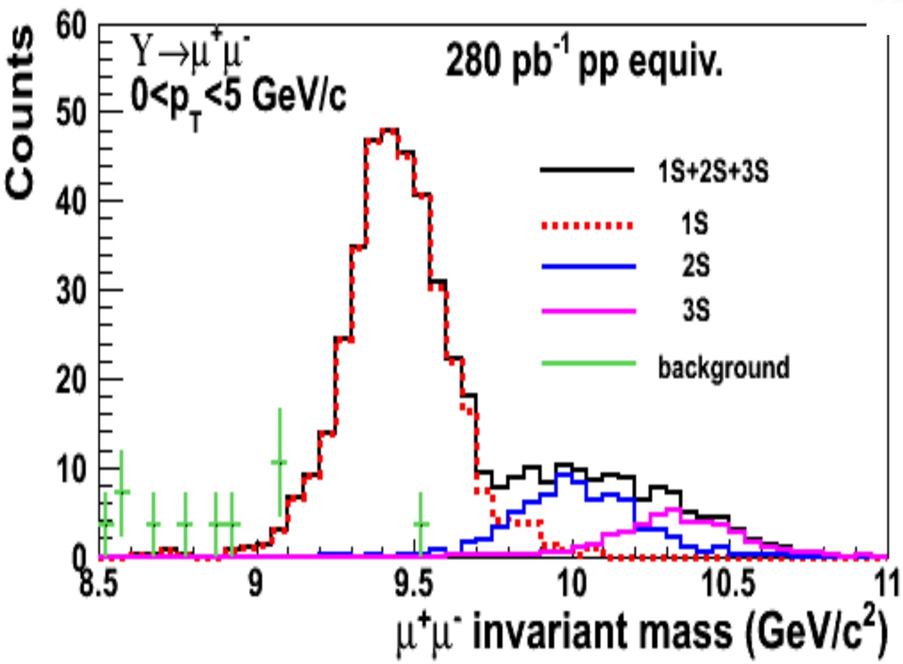
- Muon Tagger: use the magnet steel as absorber, TPC for tracking
- Acceptance: 45% for $|\eta|<0.5$
- 118 modules, 1416 readout strips, 2832 readout channels
- Long-MRPC detector technology, HPTDC electronics (same as STAR-TOF)
- Unique capability to identify muons at mid-rapidity at RHIC
- Ready in 2014

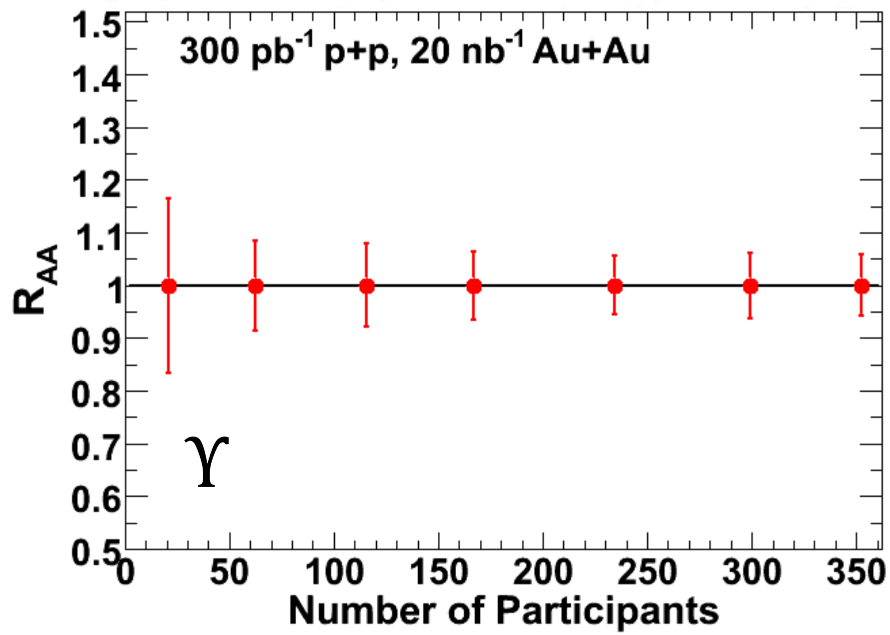


MTD physics: Properties of sQGP with Upsilon

- What quarkonia states dissociate at RHIC energy densities?
- What is the energy density?

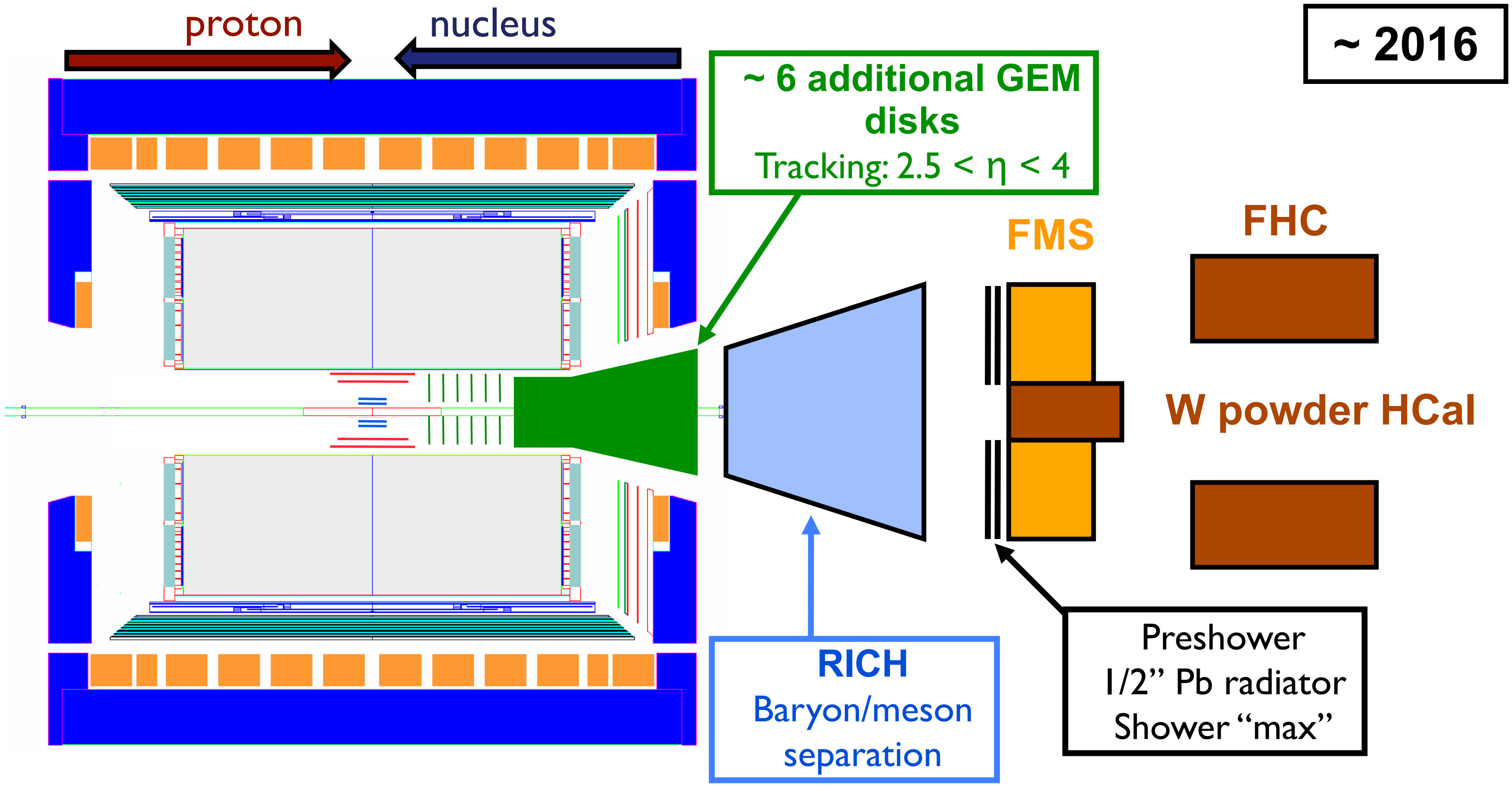






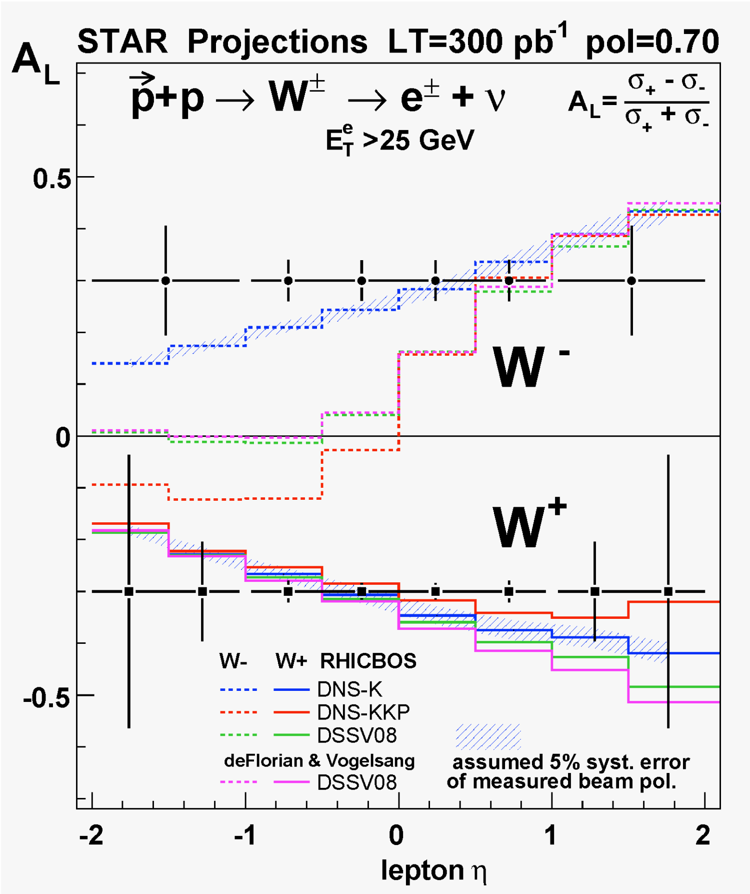
- Muon Telescope Detector: dissociation of ϒ, separated by state
  - At RHIC: small contribution from coalescence, so interpretation clean
  - No contribution of Bremsstrahlung tails, unlike electron channel

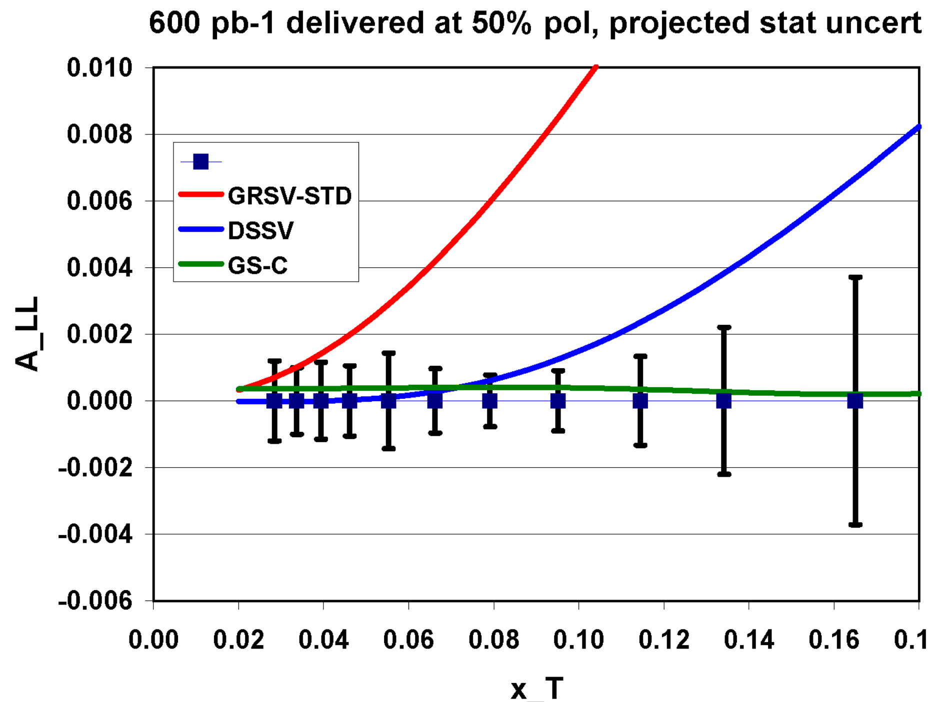
STAR moving forward: instrumentation upgrade



- Forward instrumentation optimized for **p+A** and **transverse spin** physics
  - Charged-particle tracking
  - e/h and γ/π^0 discrimination
  - Baryon/meson separation
- The upgrade can be utilized for forward (hadronic side) in e+p, e+A

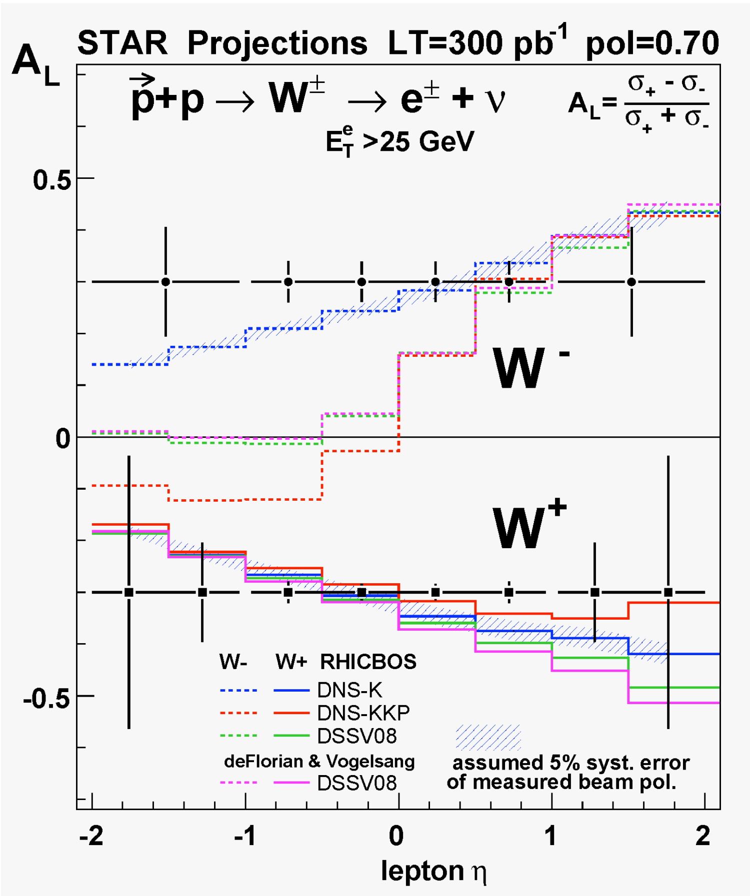
Anti-quark and gluon polarization with 500 GeV p+p



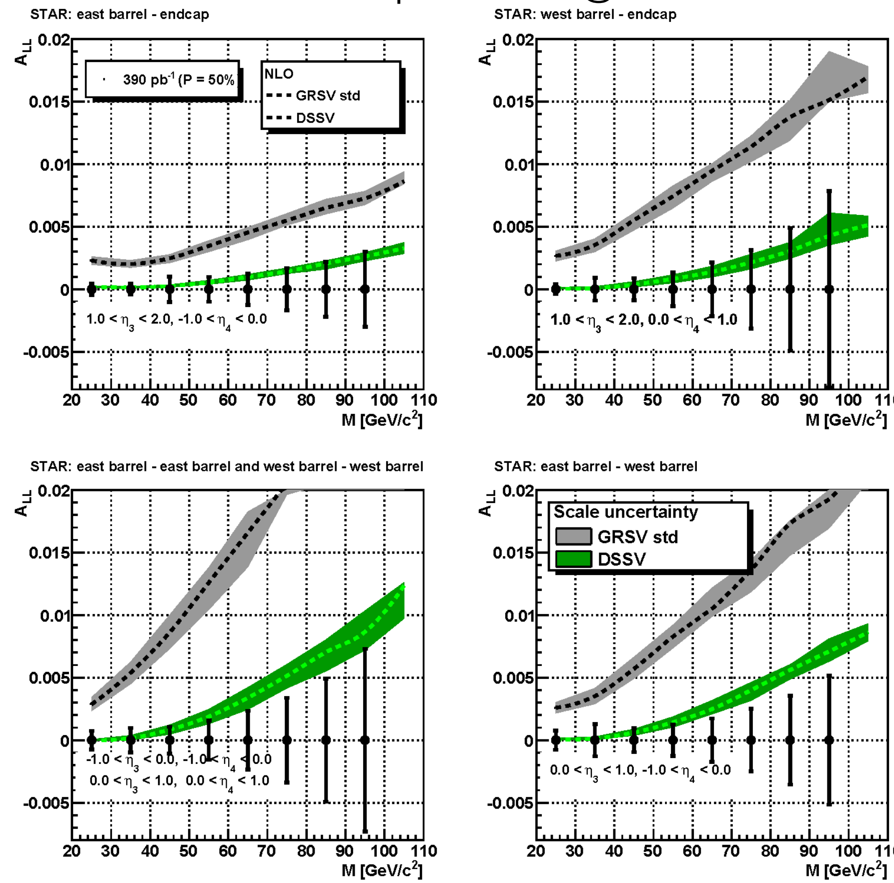


- W measurement will significantly reduce uncertainties on anti-quark polarizations
  - FGT essential for the forward W's
- Inclusive jet and di-jet A_{LL} will extend our knowledge of gluon polarization to smaller-x

Anti-quark and gluon polarization with 500 GeV p+p



Assumes 600 pb^{-1} delivered @ P = 50%



- W measurement will significantly reduce uncertainties on anti-quark polarizations
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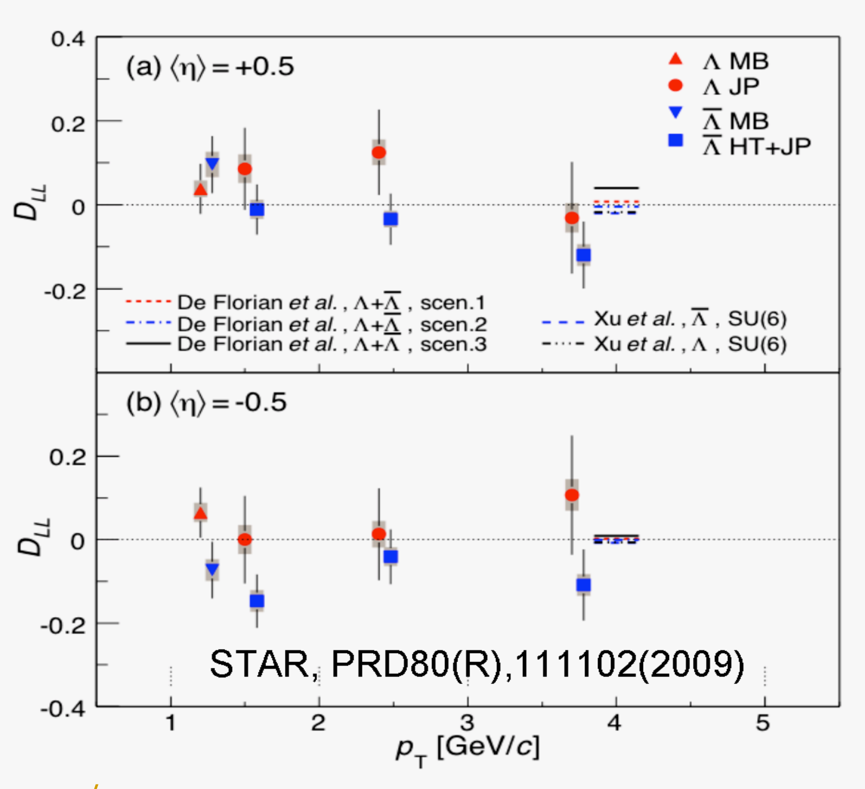
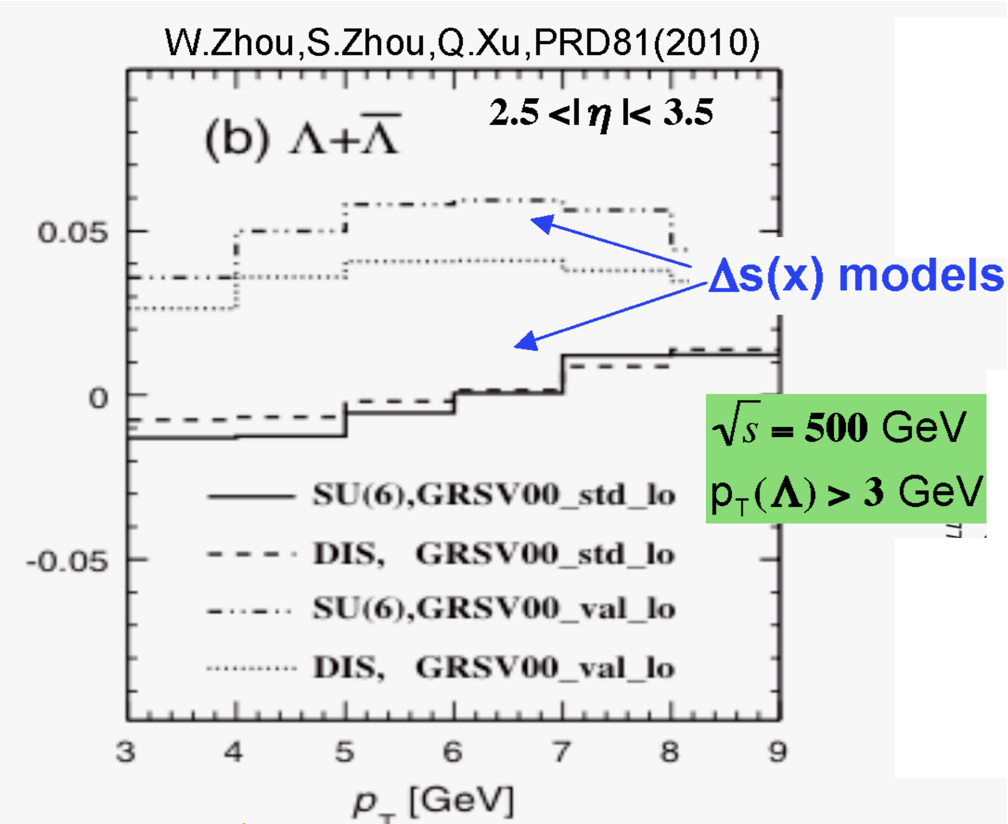
Accessing strange polarization with Λ



√s = 200 GeV, run-5 data, mid rapidity



√s = 500 GeV, forward rapidity

- **STAR** has performed initial Λ D_{LL} measurements at mid-rapidity
  - Provides access to strange quark polarization
  - Most interesting with quite high p_T Λ (trigger and statistics limited)
- Similar measurements at forward rapidity are **very promising**
  - Requires the Forward Hadron Calorimeter

Some planned p+A measurements

- Nuclear modifications of the gluon PDF
  - Access from charm production
- Gluon saturation
  - Forward-forward correlations (extension of existing π^0-π^0)
    - *h*-*h*
    - π^0-π^0

    } Easier to measure
    - γ-*h*
    - γ-π^0

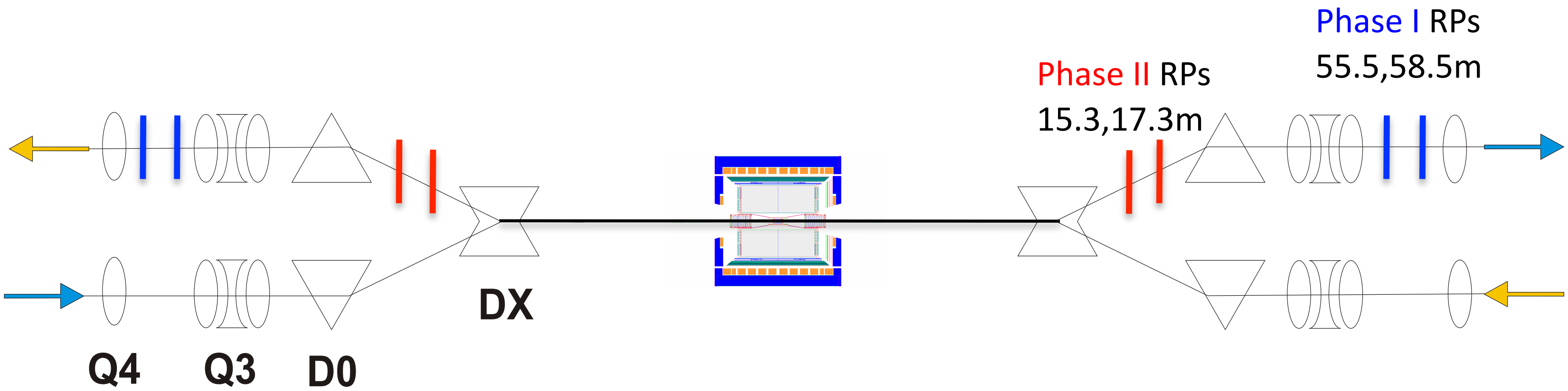
    } Easier to interpret
  - Drell-Yan
    - Able to reconstruct x_1, x_2, Q^2 event-by-event
    - Can be compared directly to nuclear DIS
    - True 2 → 1 provides model-independent access to $x_2 < 0.001$
  - Λ polarization at high-x_F (polarization sensitive to saturation scale)

- polarized proton + A: Probing the saturation scale in the nucleus with asymmetries? (Z. Kang, F. Yuan PRD84 (2011))

More Forward: Roman Pots (Phase II)

Spectator proton tagging in p+^{3}He

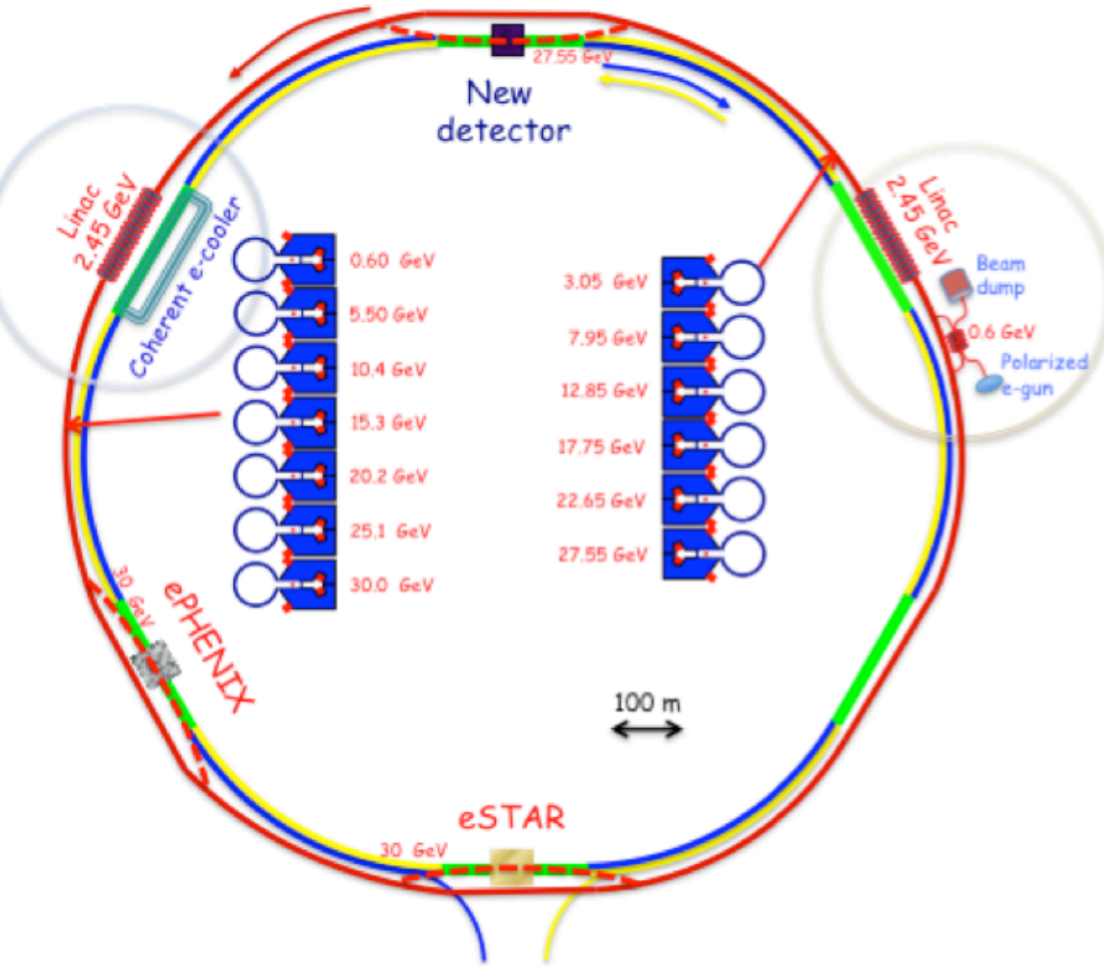
Diffraction in p+p



- Spectator tagging crucial for identifying target nucleon in p/e+^{3}He: polarized neutron target
- Deflected protons due to different rigidity can be detected in RPs
- A common detector system ("forward proton spectrometer") can be utilized for measuring diffractive protons and spectator protons in ^{3}He
- Detectors/technique can be utilized to measure p+p→p+M_X+p, and other large rapidity gap events

beyond the current decade

STAR to eSTAR



- Optimizing STAR for e+A and e+p collisions for eRHIC phase I (5 GeV energy energy)

STAR detector upgrade consideration for eRHIC phase I

- General consideration:
  - low multiplicity: $\langle N_{ch} \rangle \sim$ 4-6 for $\sqrt{s}$ = 40-65 GeV (from ep Hera measurements) $\langle N_{ch}(ep) \rangle \sim \langle N_{ch}(eA) \rangle$
  - Interaction rate: 300 - 600 kHz at 10^{34} cm^{-2} s^{-1}
- Inclusive measurements
  - Backward ($-2.5 < \eta < -1$) electron acceptance essential to span DIS regime
- Semi-inclusive physics
  - Need to investigate how well PID coverage is matched to SIDIS kinematics
  - Both backward and forward hadron coverage valuable for SIDIS
- Exclusive physics program
  - Need forward (~beam rapidity) proton and expanded photon detection (DVCS)
    - Roman Pots (also for spectator proton tagging in e+^{3}He)
  - EM calorimetry for $-4 < \eta < -1$
  - Rapidity gap acceptance for diffractive events

Golden Measurement in e+A

QCD matter in nuclei				
Deliverables	Observables	What we learn	Phase I	Phase II
integrated gluon distributions	$F_{2,L}$	nuclear wave function; saturation, Q_s	gluons at $10^{-3} \leq x \leq 1$	explore sat. regime
k_T-dep. gluons; gluon correlations	di-hadron correlations	non-linear QCD evolution/universality	onset of saturation; Q_s	RG evolution
transp. coefficients in cold matter	large-x SIDIS; jets	parton energy loss, shower evolution; energy loss mech.	light flavors, charm bottom; jets	precision rare probes; large-x gluons

The EIC Science case: a report
on the joint BNL/INT/JLab program (2011)

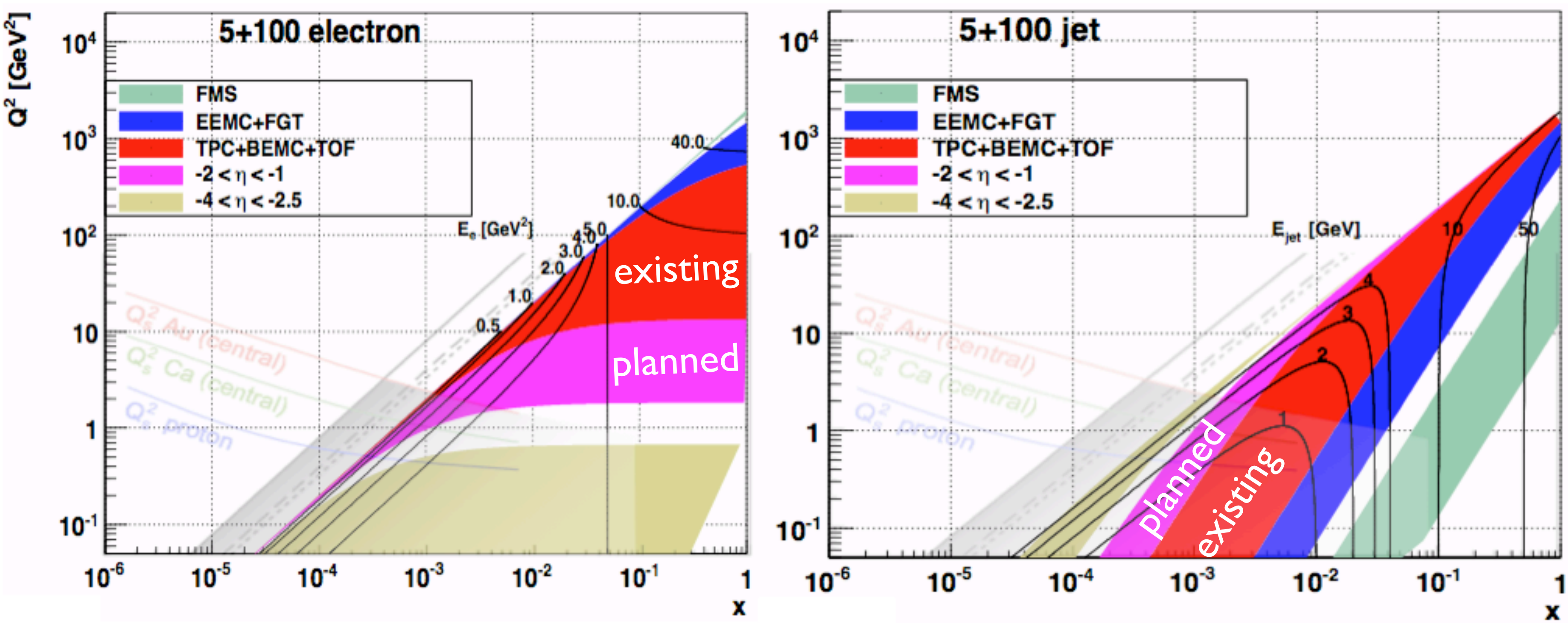
Golden Measurements in e+p

Spin and flavor structure of the nucleon			
Deliverables	Observables	What we learn	Requirements
polarized gluon distribution Δg	scaling violations in inclusive DIS	gluon contribution to proton spin	coverage down to $x \simeq 10^{-4}$; $\mathcal{L}$ of about 10 fb^{-1}
polarized quark and antiquark densities	semi-incl. DIS for pions and kaons	quark contr. to proton spin; asym. like $\Delta\bar{u} - \Delta\bar{d}$; Δs	similar to DIS; good particle ID
novel electroweak spin structure functions	inclusive DIS at high Q^2	flavor separation at medium x and large Q^2	$\sqrt{s} \geq 100$ GeV; $\mathcal{L} \geq 10\ \text{fb}^{-1}$ positrons; polarized ^{3}He beam

Three-dimensional structure of the nucleon and nuclei: transverse momentum dependence				
Deliverables	Observables	What we learn	Phase I	Phase II
Sivers and unpolarized TMDs for quarks and gluon	SIDIS with transv. polarization/ions; di-hadron (di-jet) heavy flavors	quantum interference multi-parton and spin-orbit correlations	valence+sea quarks, overlap with fixed target experiments	3D Imaging of quarks and gluon; Q^2 ($P_\perp$) range QCD dynamics

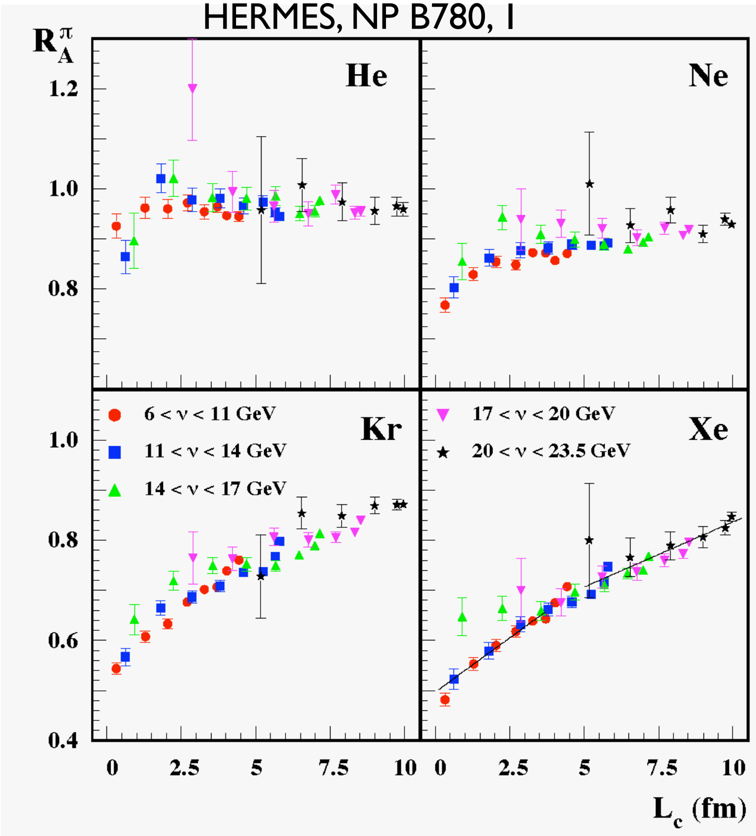
Three-dimensional structure of the nucleon and nuclei: spatial imaging			
Deliverables	Observables	What we learn	Requirements
sea quark and gluon GPDs	DVCS and $J/\psi, \rho, \phi$ production cross sect. and asymmetries	transverse images of sea quarks and gluons in nucleon and nuclei; total angular momentum; onset of saturation	$\mathcal{L} \geq 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$, Roman Pots wide range of x_B and Q^2 polarized e^- and p beams e^+ beam for DVCS

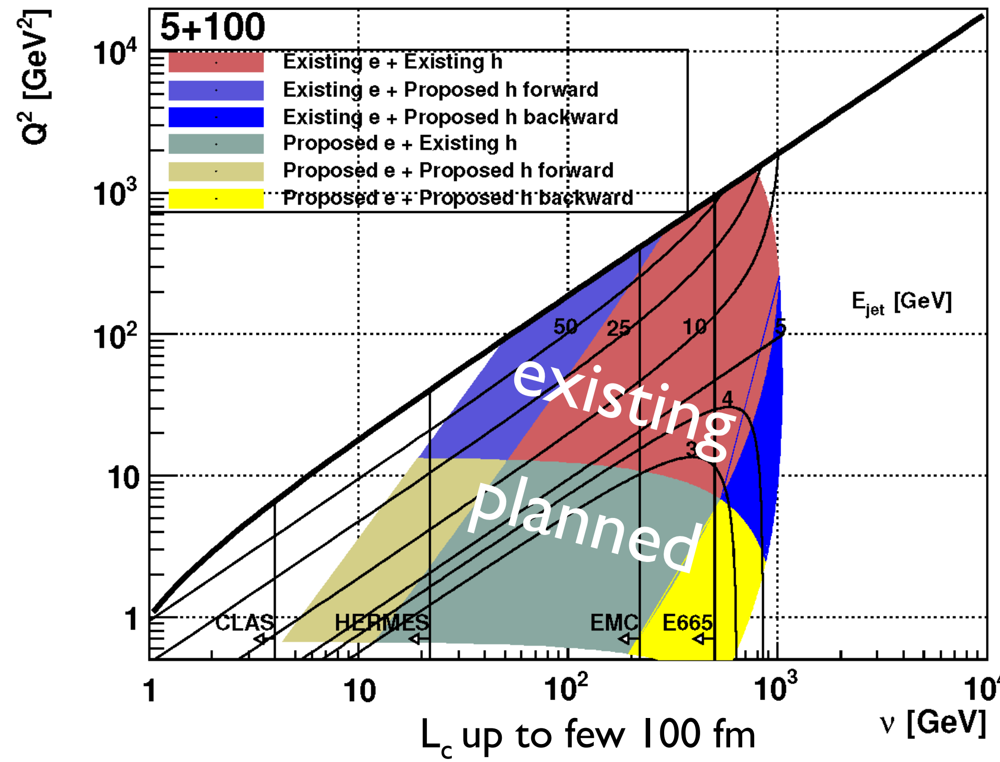
STAR at eRHIC - Phase 1



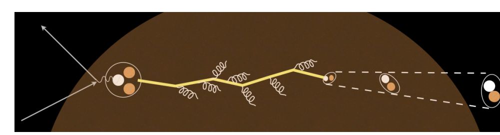
- Current detector matches quite well to kinematics of eRHIC
  - Particle ID, sufficient p_T resolution, etc. at mid-rapidity (Q^2>10 GeV^2)
- Space to extend: focus on 1<Q^2<10 GeV^2 (~-2 < η < -1)
- Some important phase 1 measurements:
  - F_L in e+p and e+A
  - g_1 in polarized e+p
  - SIDIS in e+p and e+A over broad (x,Q^2) range, including dihadron

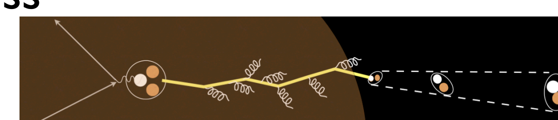
Parton energy loss in cold QCD matter





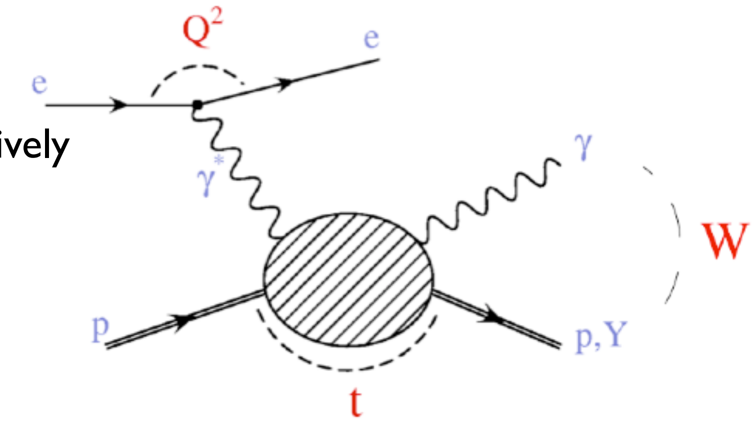
- Complementary tool to investigate partonic energy loss
- HERMES: hadrons can form partially inside the medium
  - Mixture of hadronic absorption and partonic energy loss
- eRHIC: light quark hadrons form well outside the medium
- Heavy quarks: unexplored to date. Low β → short formation time



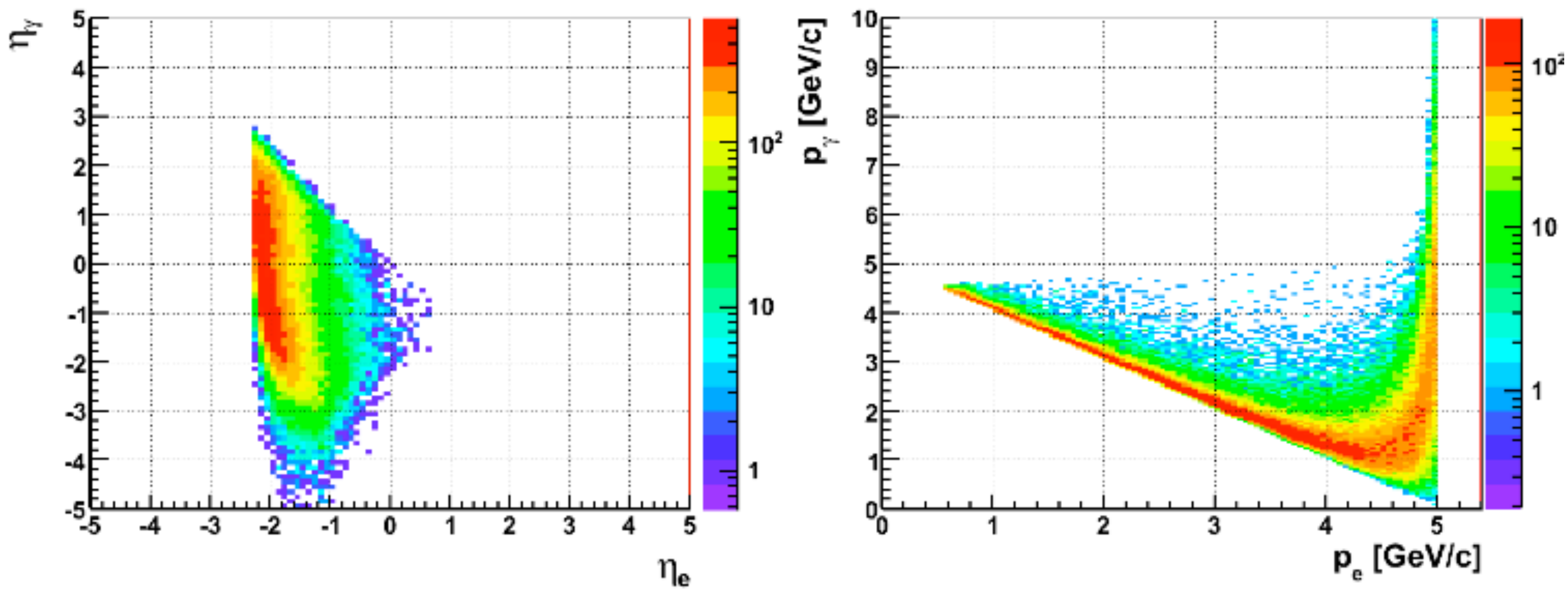


Beyond inclusive DIS: DVCS

Deeply Virtual Compton Scattering



- Requires measurement of electron, proton, and photon exclusively
- Proton requires Roman Pot, intimately tied to I.R. design
  - Aperture needs mostly driven by proton energy
  - Common device (Roman Pots) can be used for spectator tagging in ^{3}He
- Electron acceptance overlaps with inclusive DIS: $-2<\eta<-1$



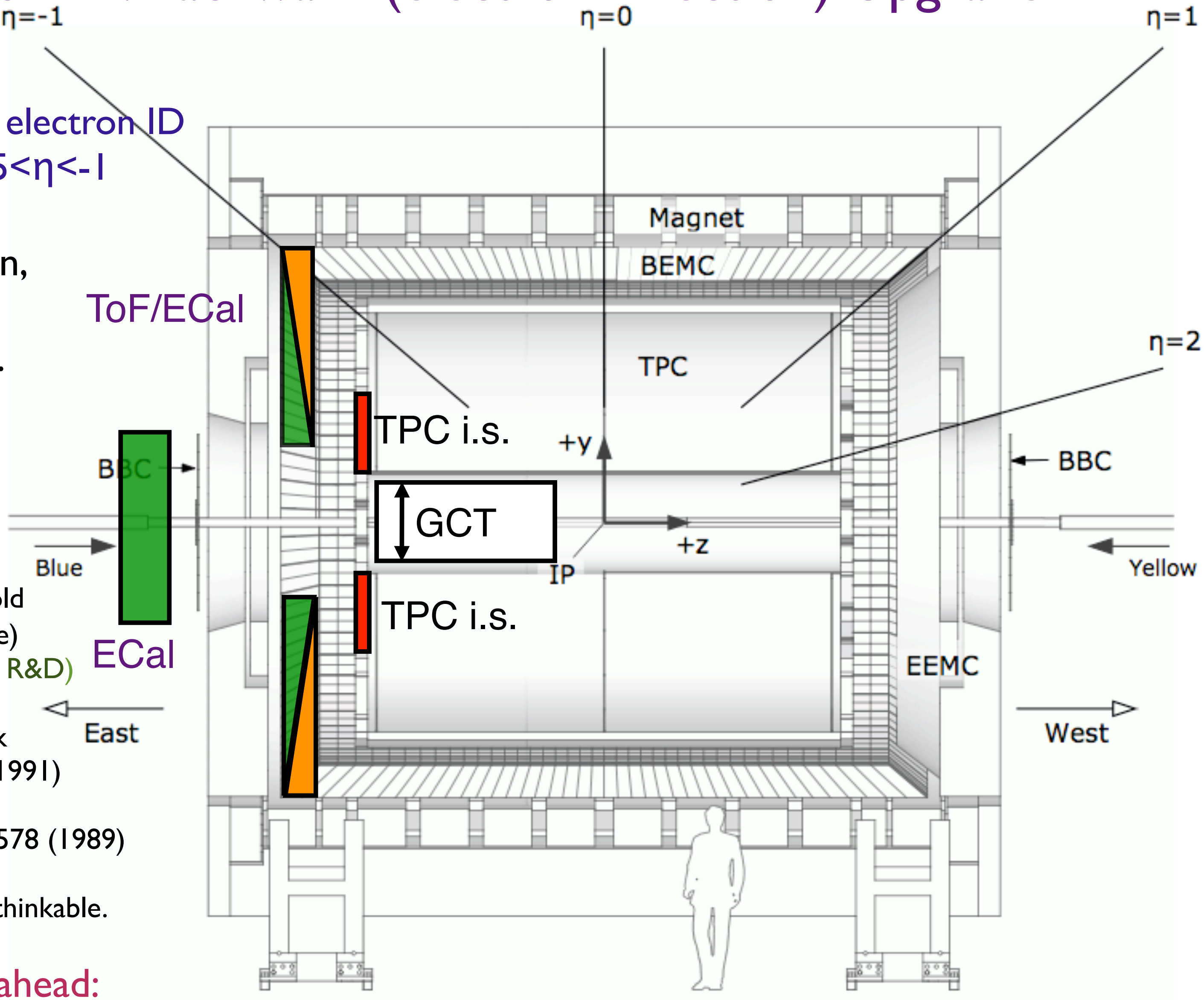
Further possibilities under investigation: diffraction in J/ψ, …

Targeting eSTAR: Backward (electron direction) Upgrade

Main upgrade: Additional electron ID and reconstruction in -2.5<η<-1

- ToF: π , *K* identification, t_0, electron
- ECal: 5 GeV, 10 GeV, ... electron beams
- GCT: a compact tracker with enhanced electron capability;

seeks to combine high-threshold (gas) Cherenkov with TPC(-like) tracking (EIC generic detector R&D)
Indeed, similarities with
Y. Giomataris and G. Charpak NIM A310 (1991) 589-595 (1991)
PHENIX HBD
P. Nemethy et al. NIM A328 578 (1989)
will certainly involve R&D.
Conventional alternatives are thinkable.



Design and Simulations ahead:
eSTAR Task Force at STAR formed

Summary

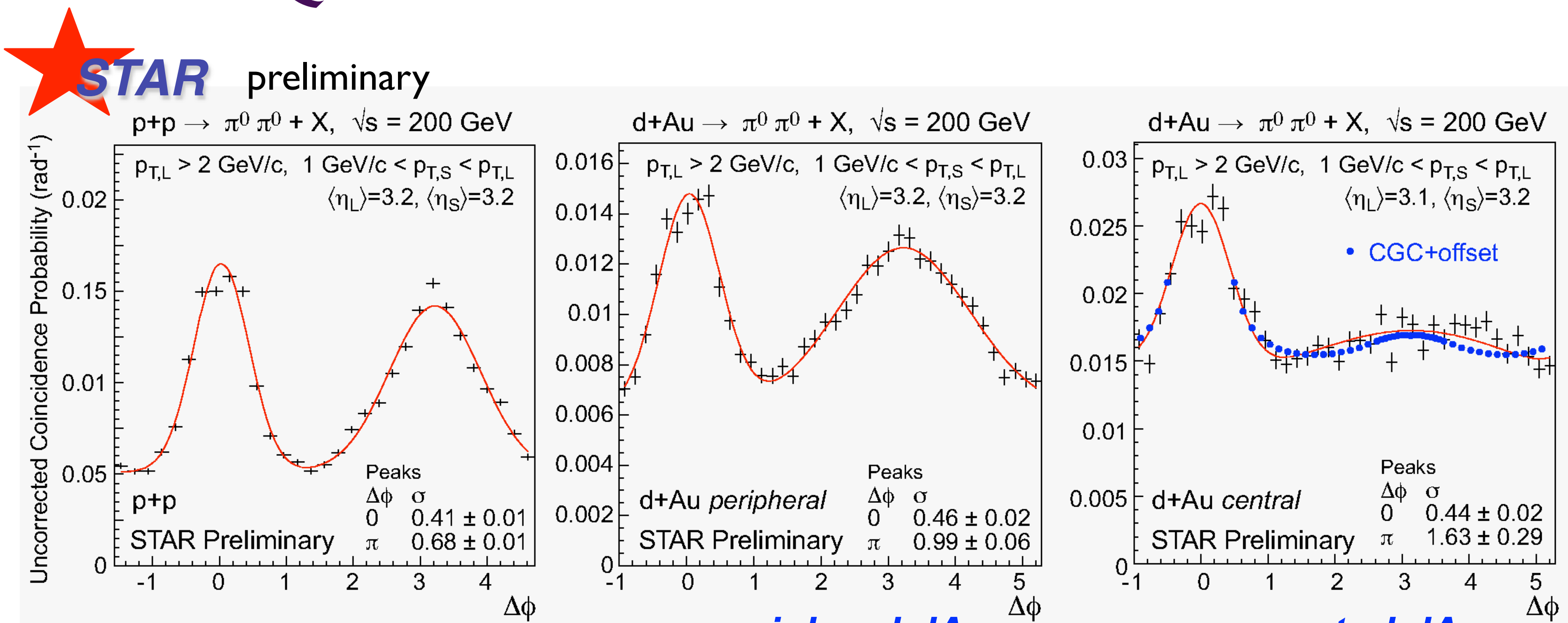
★ STAR upgrade to continue addressing the key open questions in hot/cold nuclear matter at extreme conditions and spin structures of nucleon

- mid-decade - precision, extending to heavy flavor: HFT + MTD ...)
  - A+A, A+B, p+p, p+^{3}He
- later in the decade - exploring forward regime
  - polarized p+A, p+p, p+^{3}He
- end of decade - beginning of STAR with eRHIC: eSTAR

- STAR: The first successful decade, and continues with upgrades to deliver compelling physics in the coming decade and beyond

Backup Slides

Cold QCD matter – the initial state at RHIC

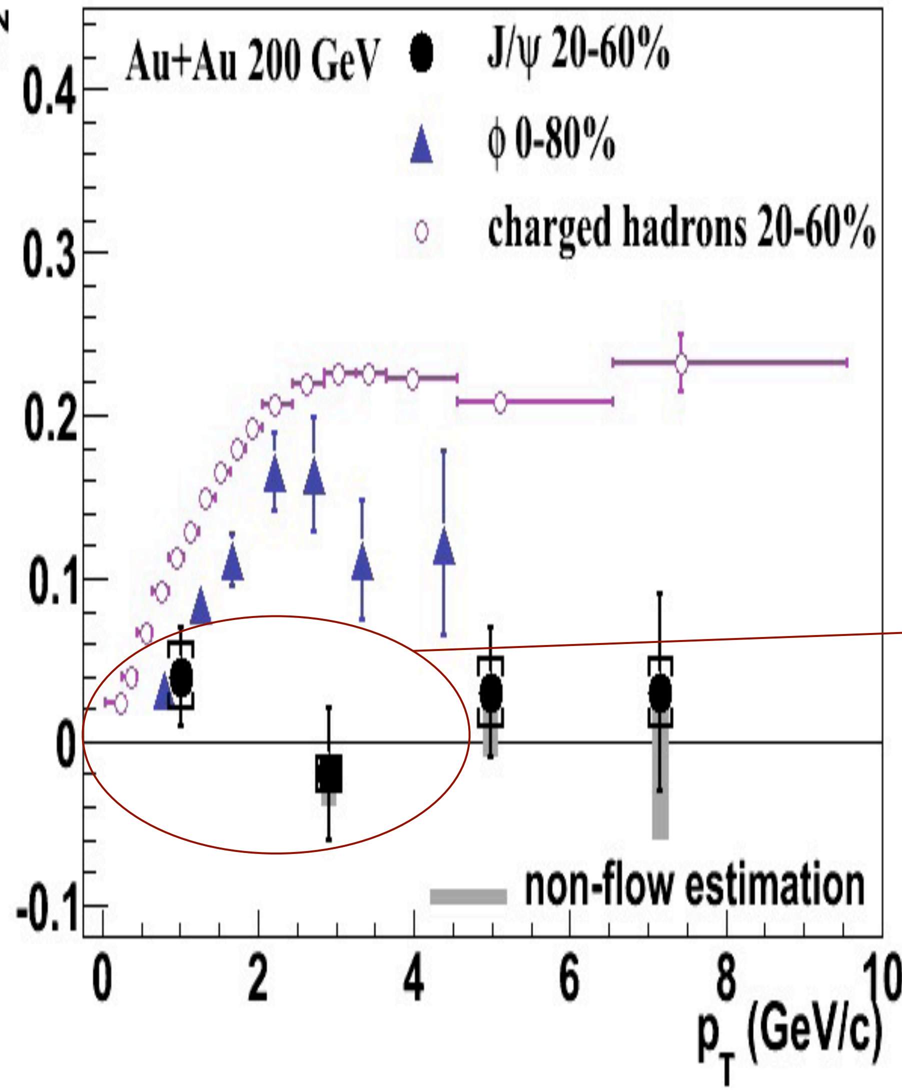


pp ***peripheral dAu*** ***central dAu***

- 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?
- Dihadron measurement in e+A with clean kinematic control at eRHIC

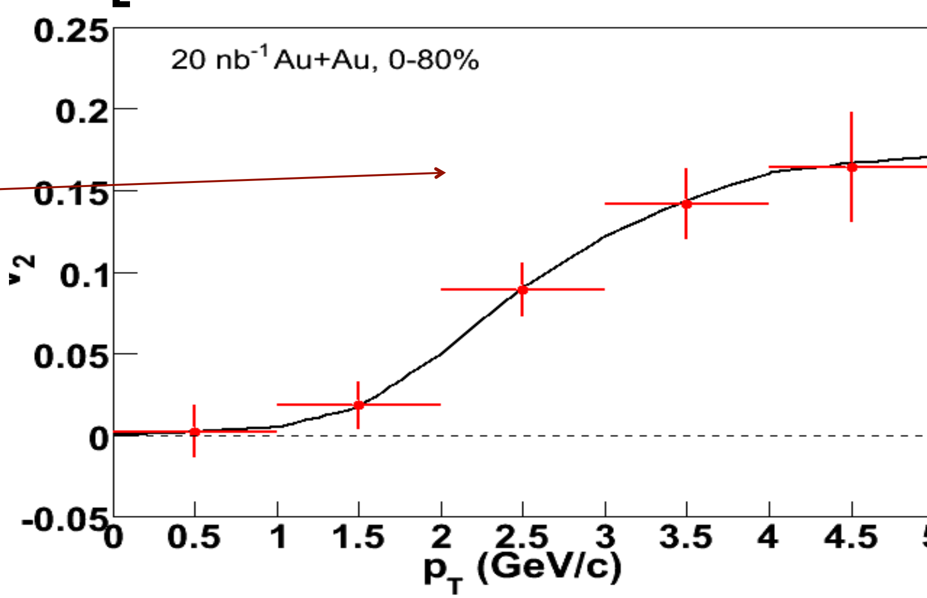
J/Ψ Flow: MTD projection

J/Ψ v_2 small



Either charm does not flow, or coalescence is not a dominant contributor to J/Ψ production, Or charm flows strongly for p_T where coalescence small, and vice versa.

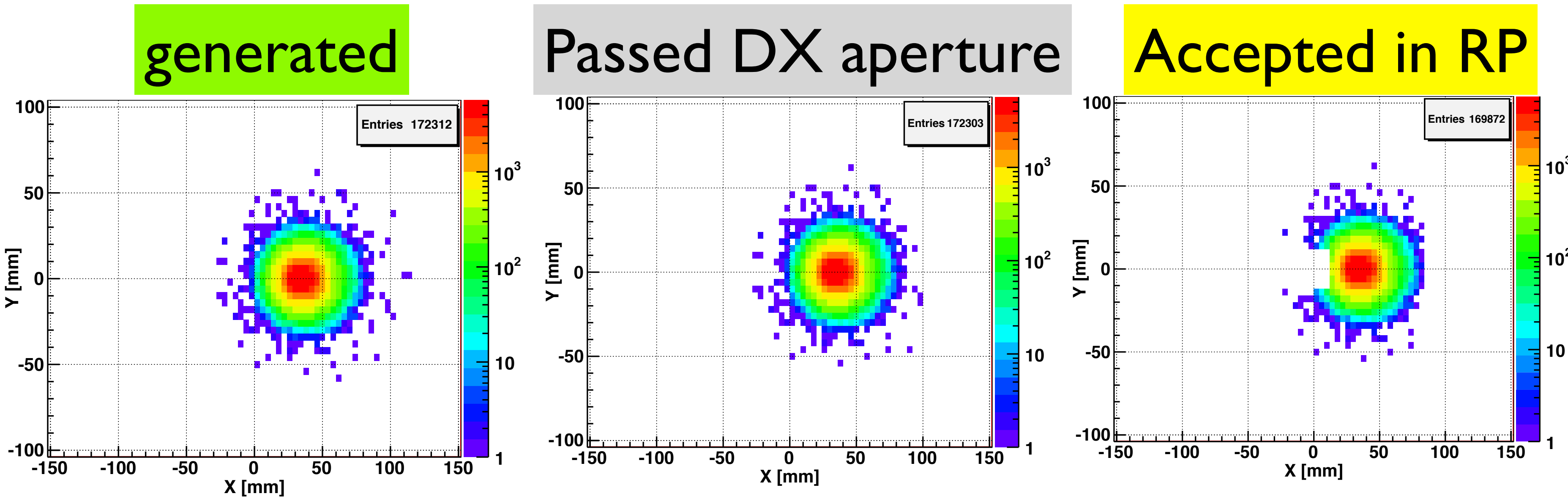
[X. Zhao and R. Rapp, Phys. Rev. C 82:064905 (2010)]



More subtle measurements needed

Dramatic improvement with RHIC II and MTD

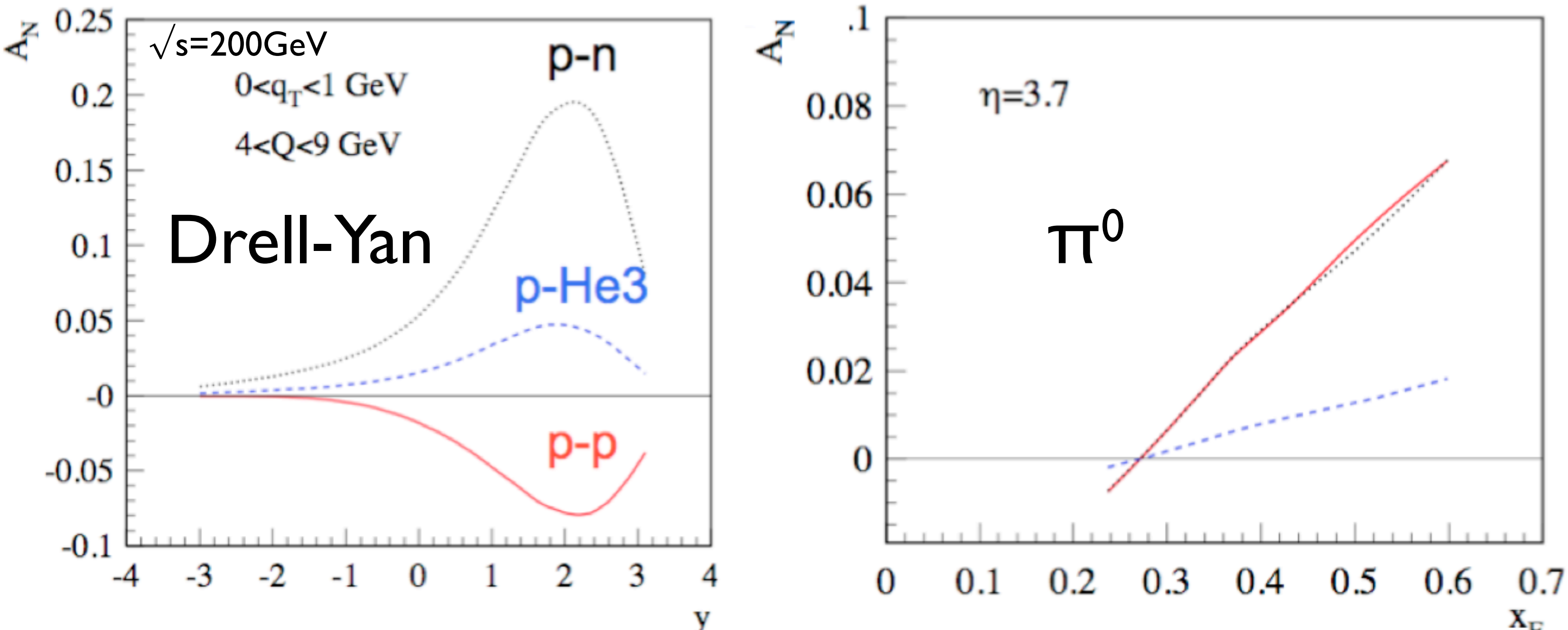
Spectator proton from ^{3}He with the current RHIC optics



DPMJETIII + Hector simulation

- The same RP configuration with the current RHIC optics (at z ~ 15m between DX and D0)
- High acceptance (~ 98%) of spectator proton can be achived

polarized n+p in ^{3}He+p



Z. Kang, Riken He3 Workshop (2011)

- Spin-dependent distribution, Sivers function has opposite sign for u- and d-quark flavor
- Polarized ^{3}He could be used to confirm and verify this opposite sign