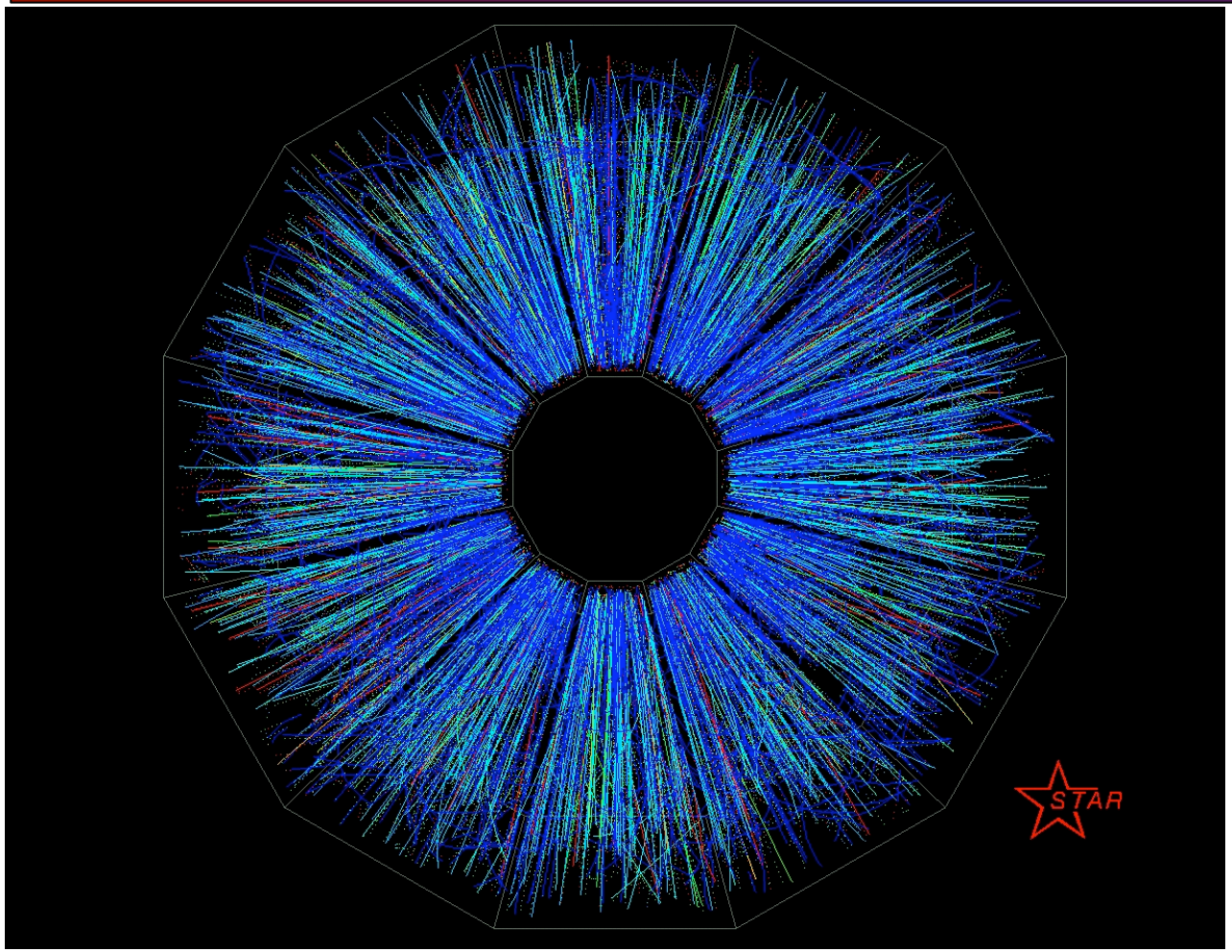
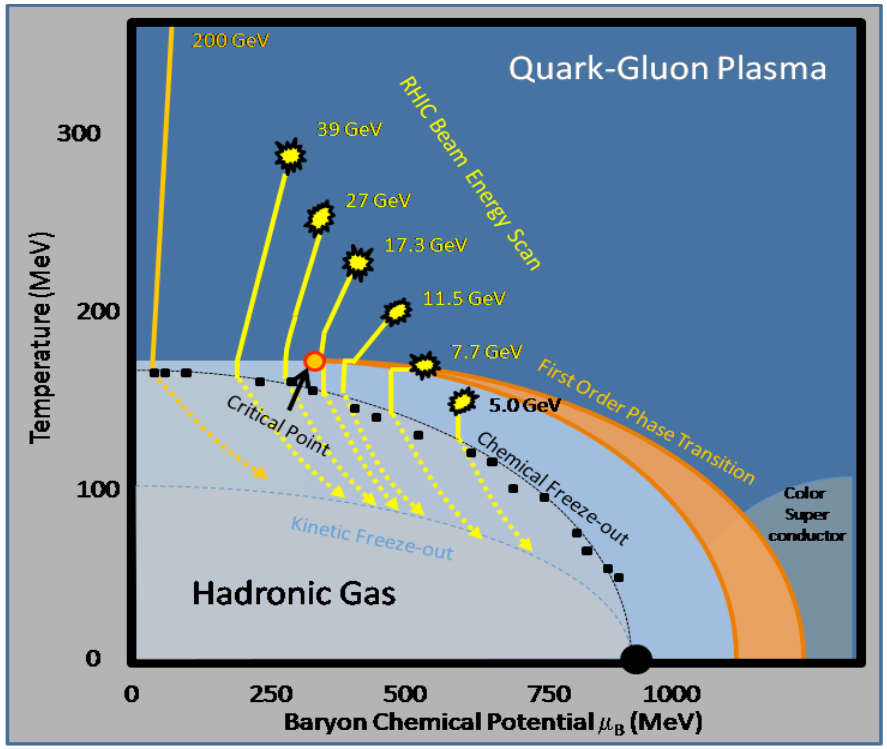
The next decade of physics with STAR



James Dunlop for the STAR Collaboration

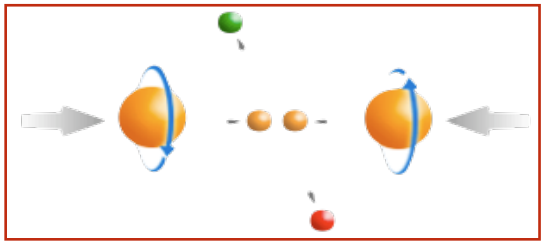
RHIC: Exploring QCD in detail

Hot QCD Matter

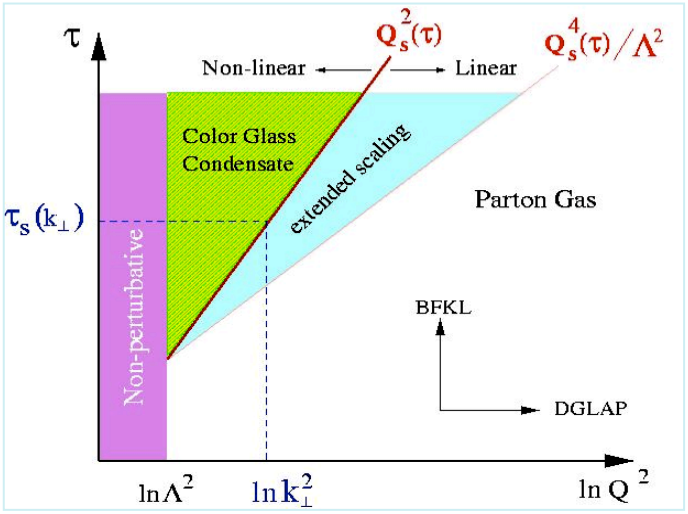


Properties of the sQGP in detail
Mechanism of Energy Loss:
weak or strong coupling?
Is there a critical point, and if so, where?
Novel symmetry properties
Exotic particles

Partonic structure



Spin structure of the nucleon
How to go beyond leading twist and colinear factorization?



What are the properties of cold nuclear matter?

STAR: A Correlation Machine

Tracking: TPC

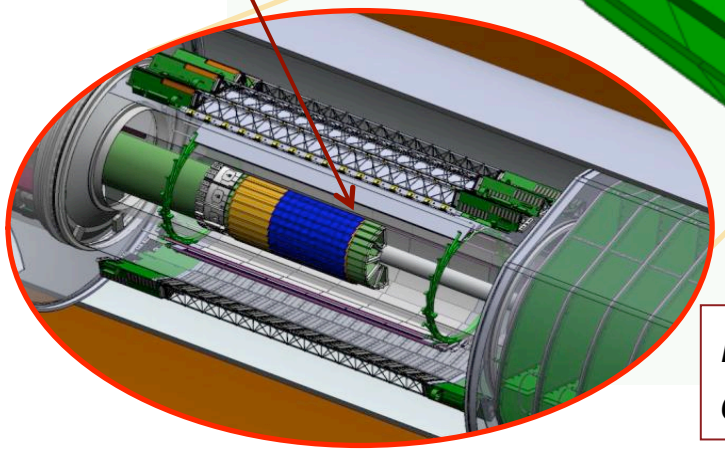
Particle ID: TOF

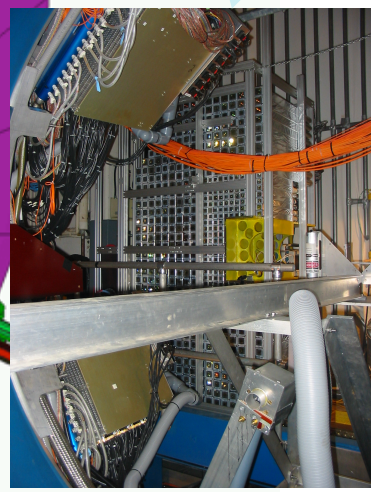
Electromagnetic Calorimetry: BEMC+EEMC+FMS
$(-1 \leq \eta \leq 4)$

Muon Telescope Detector (2014)

Further Upgrades:
Roman Pots Phase 2
Inner TPC Upgrade
Forward Upgrade

Heavy Flavor Tracker (2014)





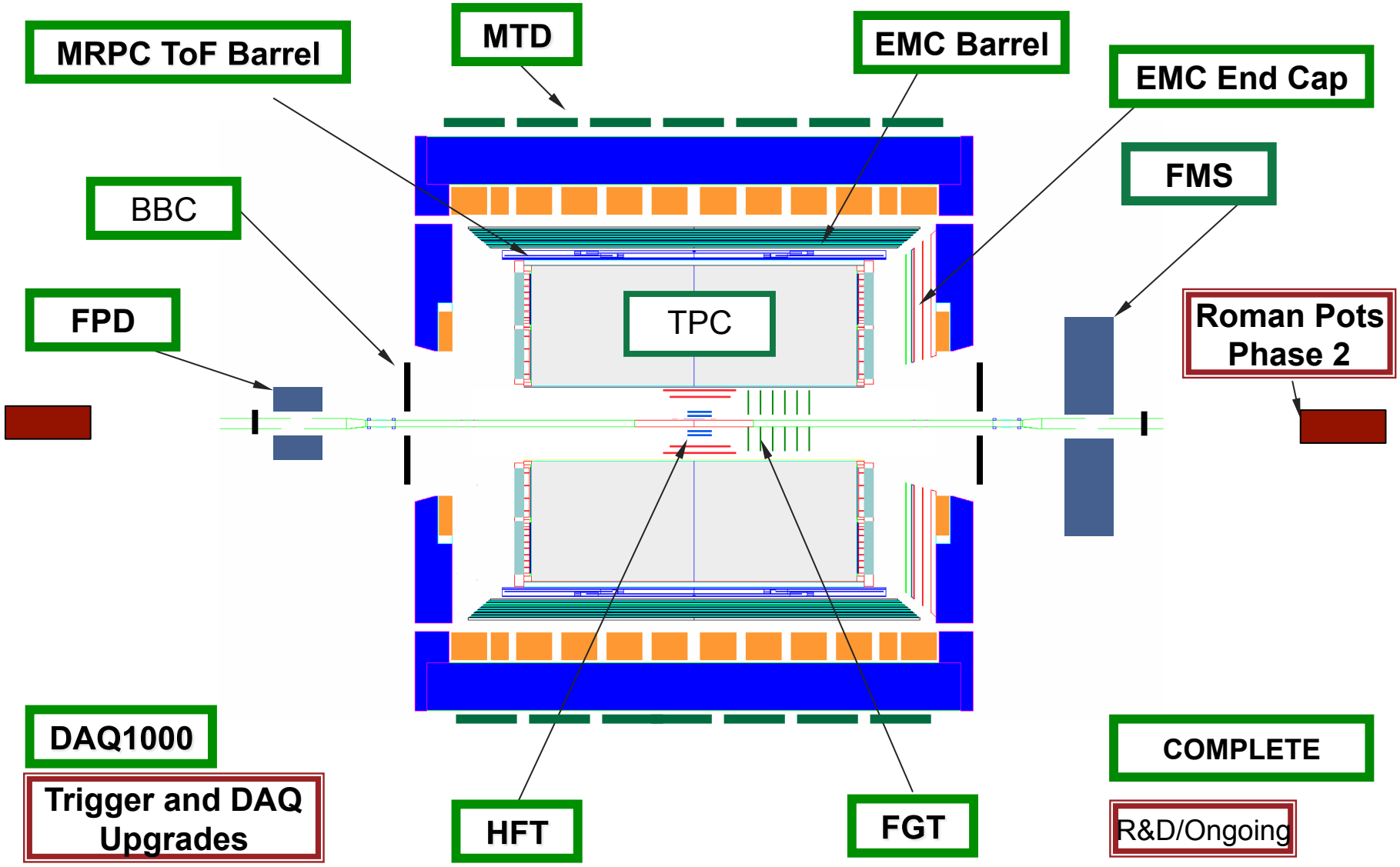
Full azimuthal particle identification over a broad range in pseudorapidity

Forward Gem Tracker (2012)

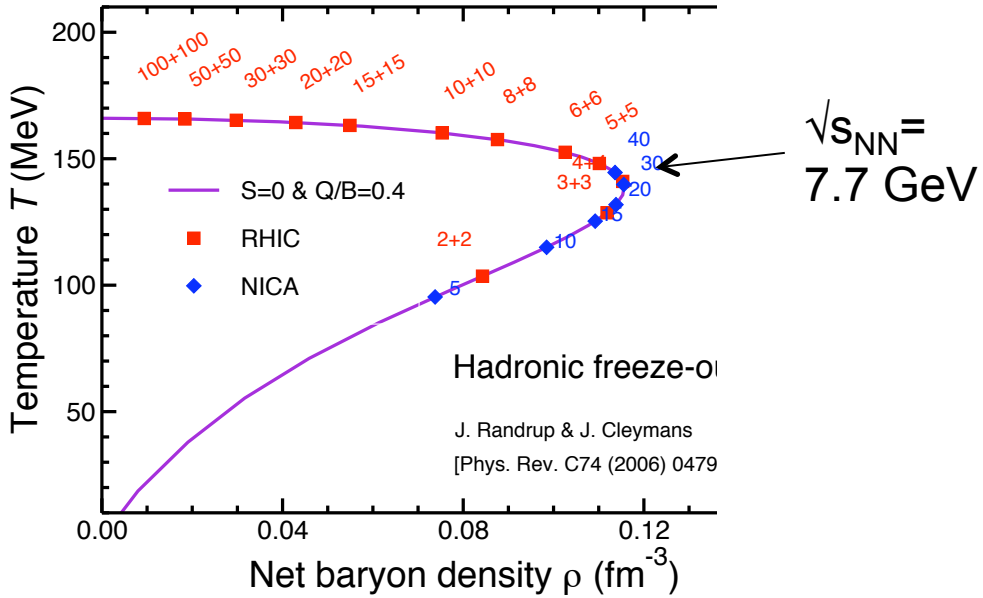
How to explore QCD: from hot to cold

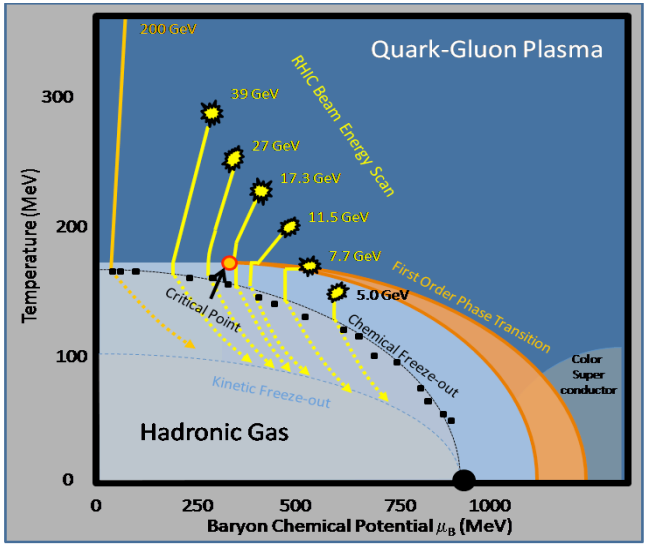
- Hot QCD matter: high luminosity RHIC II (fb^{-1} equivalent)
  - Heavy Flavor Tracker: precision charm and beauty
  - Muon Telescope Detector: e+μ and μ+μ at mid-rapidity
  - Trigger and DAQ upgrades to make full use of luminosity
  - Tools: jets combined with precision particle identification
- Phase structure of QCD matter: Energy Scan Phase II
  - Fixed Target to access lowest energy at high luminosity
  - Low energy electron cooling to boost luminosity for $\sqrt{s_{NN}}$<20 GeV
- Cold QCD matter: high precision p+A, followed by e+A
  - Major upgrade of capabilities in forward direction
  - Existing mid-rapidity detectors well suited for portions of e+A program

STAR Experiment as of 2014



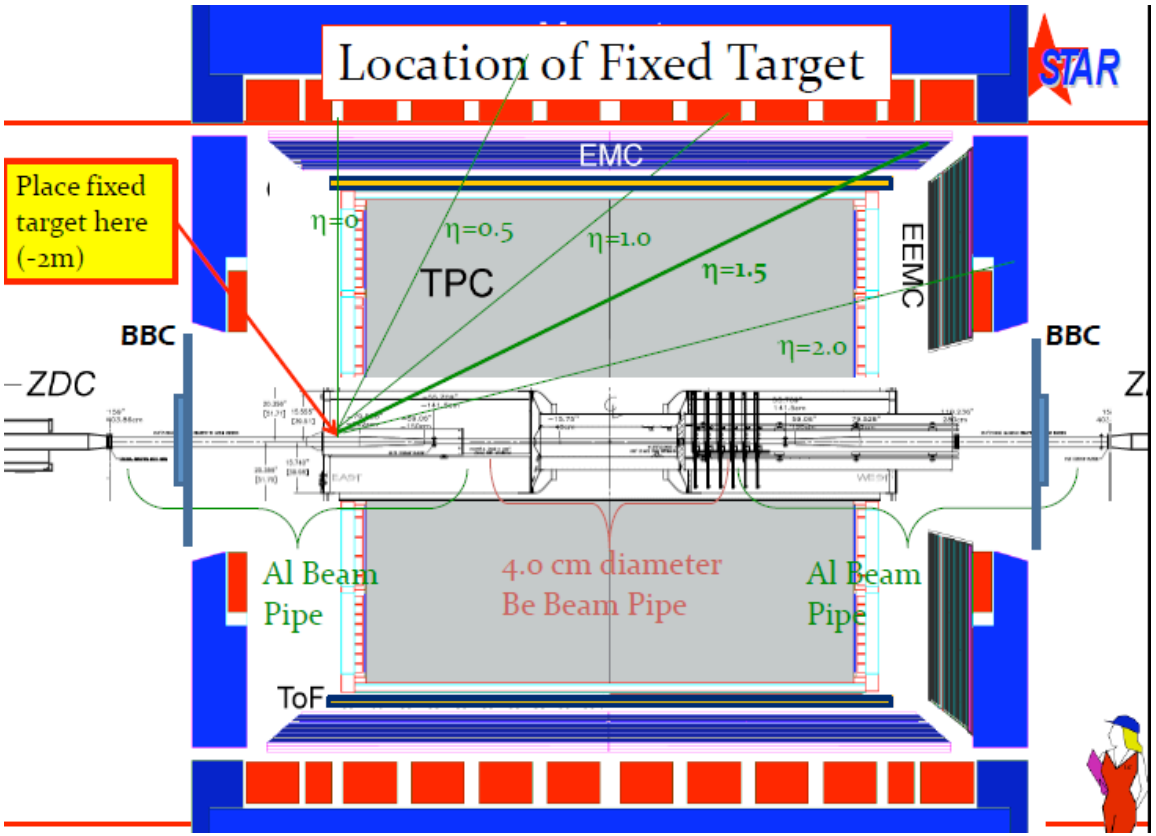
Beam Energy Scan Phase II





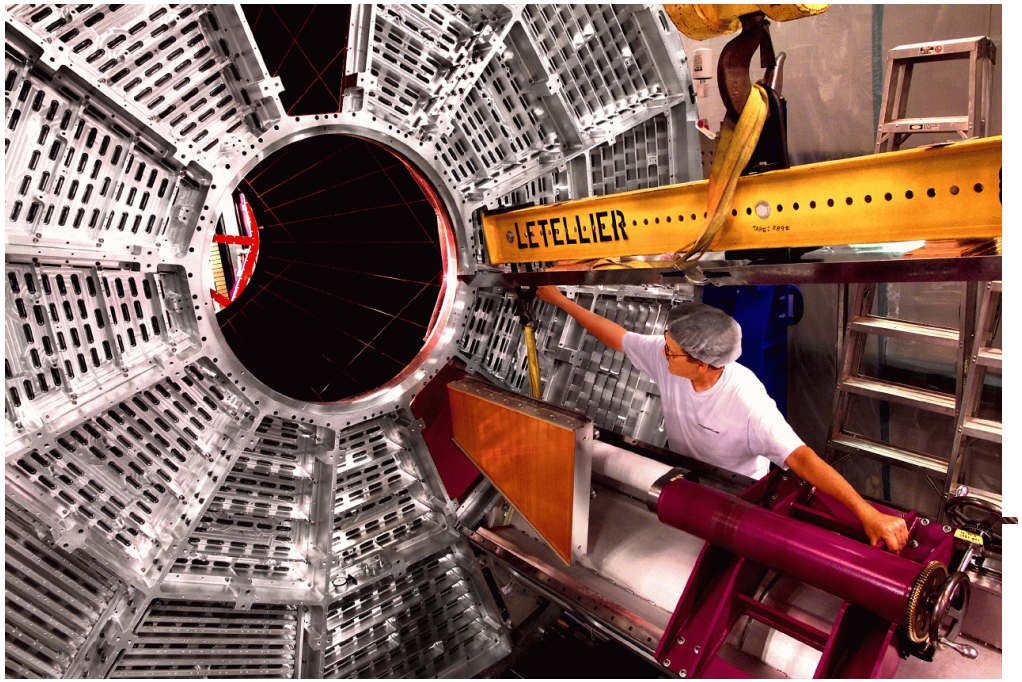
- From Phase I: Indications for changes for $\sqrt{s_{NN}}$ <~20 GeV
  - Breakdown of naïve constituent quark scaling of v_2
  - Disappearance of Local Parity Violation signal
  - Fluctuations: potentially interesting behavior, wait for QM2012 …
- Two pronged approach on timescale 2016+
  - Electron cooling: detailed scan from 7.7 – 20 GeV
  - Fixed target: approach peak in net baryon density from lower $\sqrt{s_{NN}}$
  - Upgrades: inner TPC: improve η coverage, dE/dx

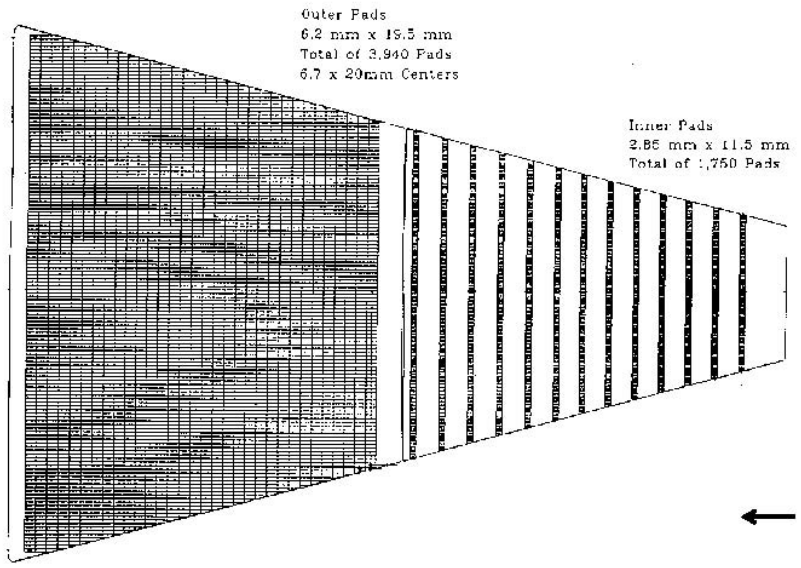
Fixed target

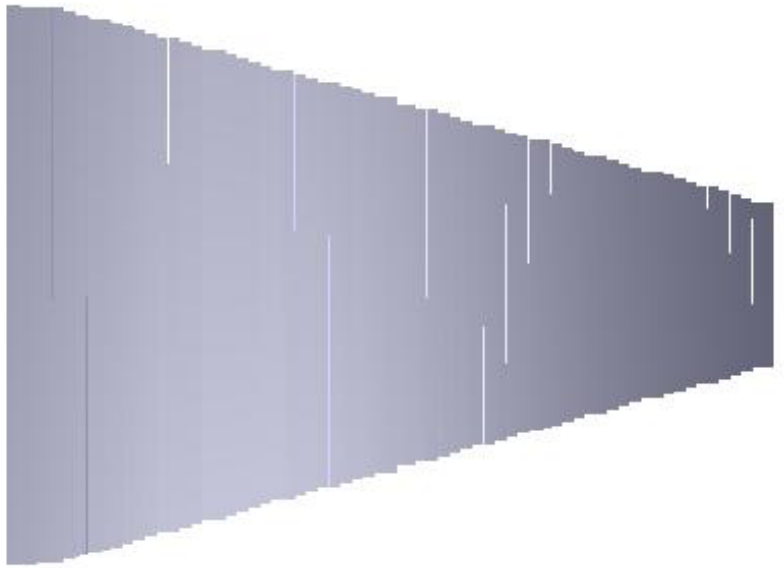


- Fixed target annulus of Au inside beampipe on east side
- Running parasitic with colliding program
  - Proven capability to reconstruct Au+Al in Runs 10+11
- Allows for access to $\sqrt{s_{NN}}$ ~ 3-4.5 GeV with high luminosity

Inner TPC Upgrade: iTPC



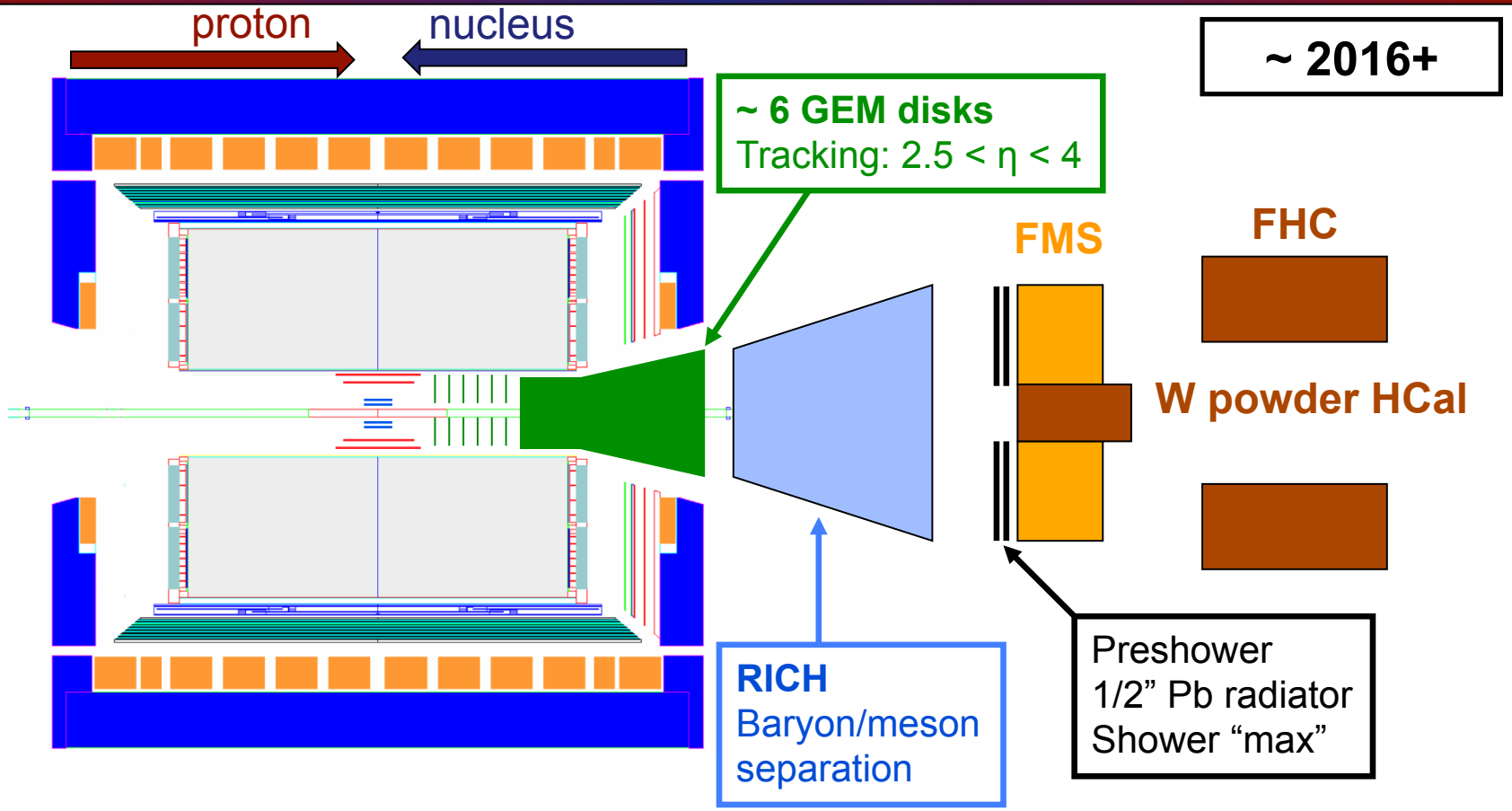




Better tracking and dE/dx PID capability
broad physics impact on
- **spin W boson measurement**
- **hyperon and exotic particle searches**
- **high p_T identified particles**
- **BES Phase II+**

Timescale: 2016+; $ Scale: CEP

STAR Forward Upgrade (West)



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

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*
    - 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
  - Baryon production at large x_F
- What more might we learn by scattering ***polarized* protons off nuclei**?

- **Forward-forward correlations, Drell-Yan, and Λs** are also very powerful tools to unravel the **dynamics of forward transverse spin asymmetries – Collins vs Sivers effects, TMDs or Twist-3, …**

Targeting eSTAR: Forward Upgrade East

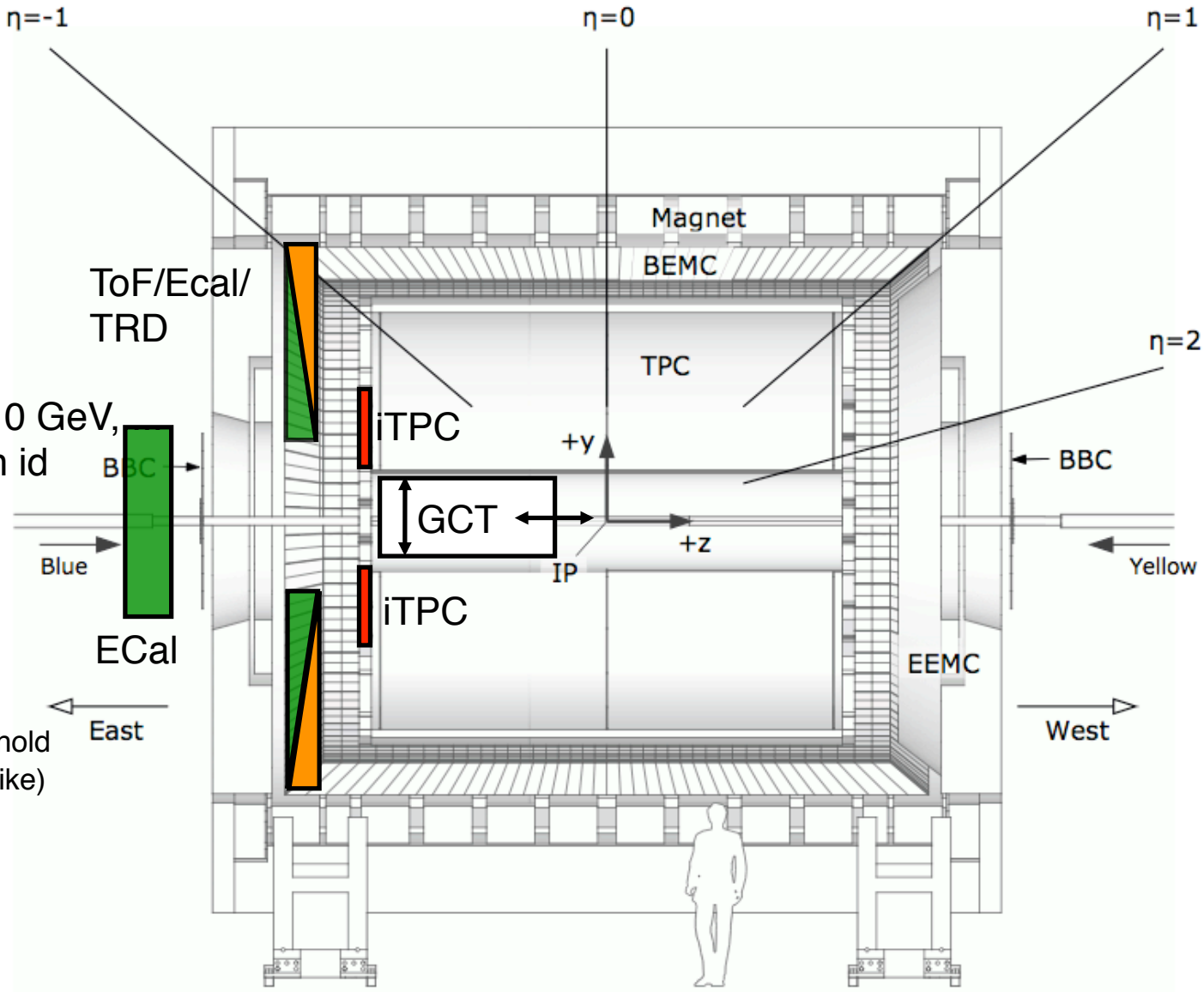
ToF: π, K identification, t_0, electron

ToF/Ecal/TRD: 5 GeV, 10 GeV, extended electron id

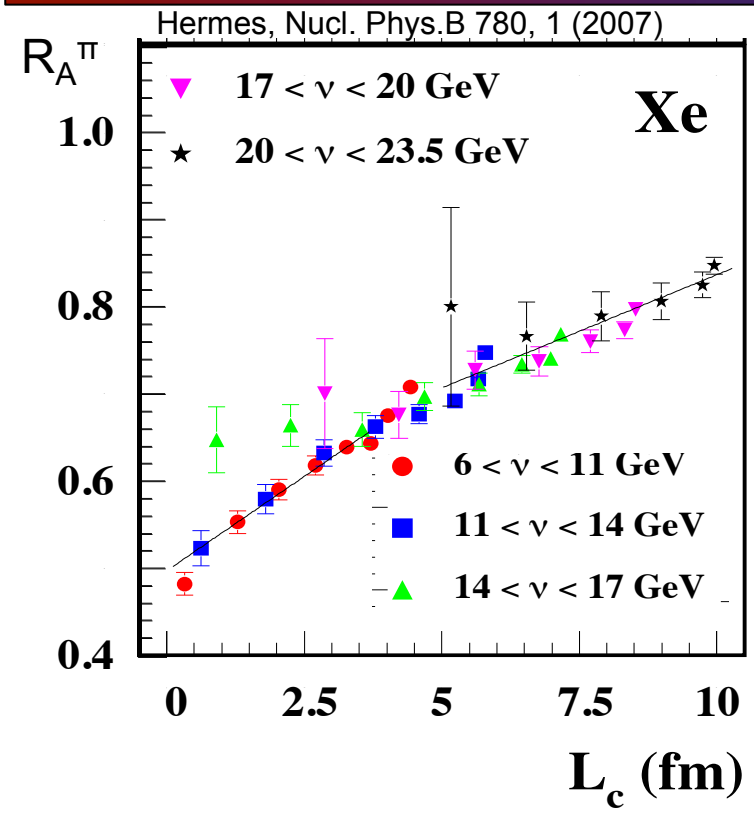
GCT: a compact tracker with enhanced electron capability;

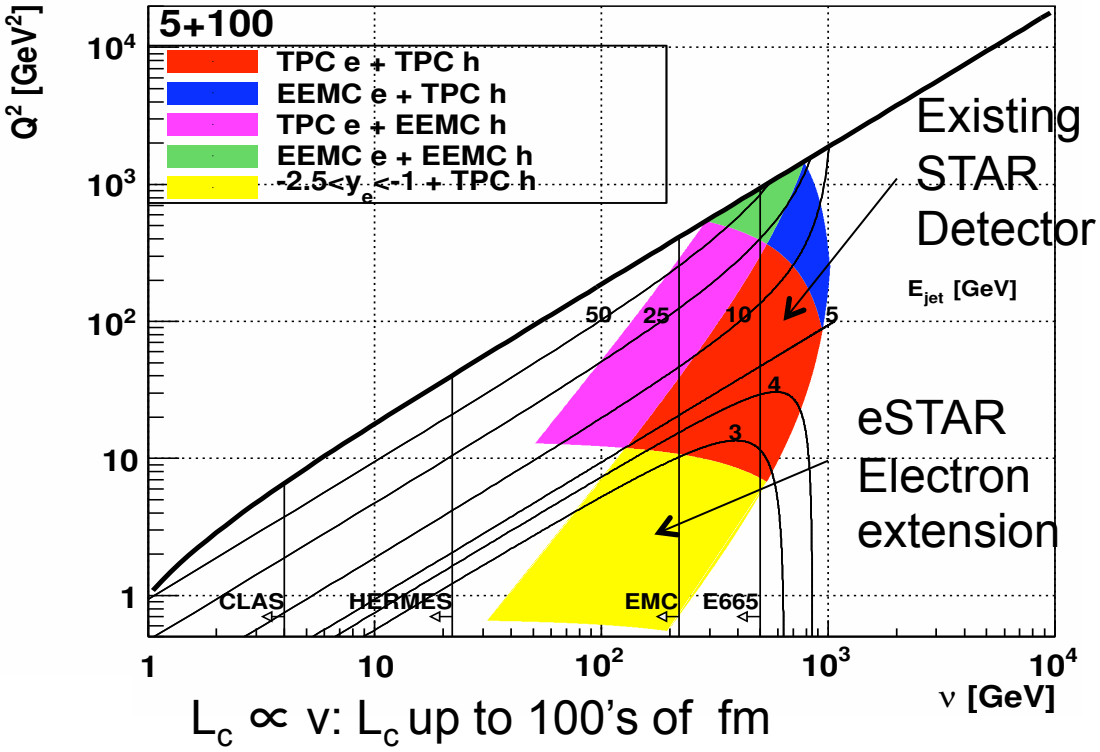
- seeks to combine high-threshold (gas) Cherenkov with TPC(-like) tracking

eSTAR task force for



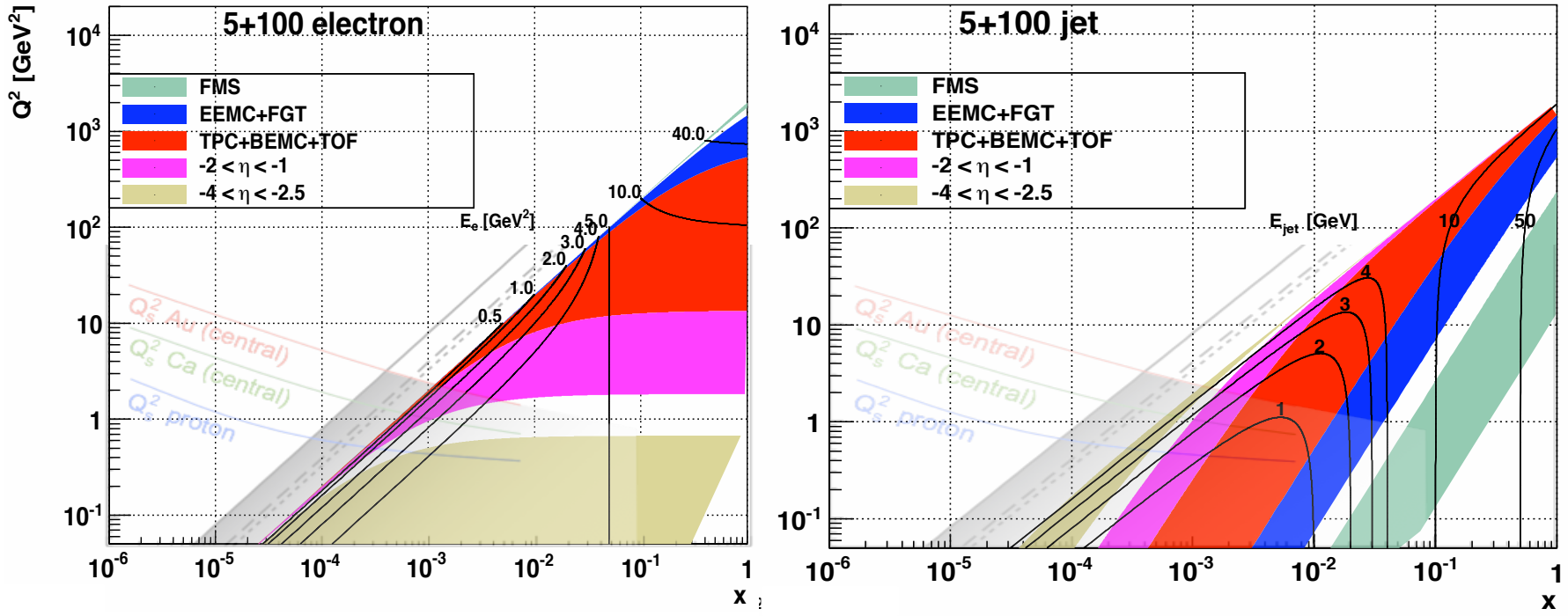
Energy loss in cold QCD matter





- Complementary probe of mechanism of energy loss
- HERMES: mixture of hadronic absorption and partonic loss
  - Hadrons can form partially inside the medium
- eRHIC: light quarks form far outside medium
- Heavy quarks: unexplored to date. Low β: short formation time

STAR and eRHIC Phase 1



- Current detector matches quite well to kinematics of eRHIC
  - Particle ID, sufficent 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 ***K* and Λ** to investigate **strange quark distributions and their polarization**

Summary: exploring QCD from Hot to Cold

Near-term: → 2016-2017

- Finish and exploit current upgrades
  - Forward Gem Tracker (FGT): W A_N
  - Heavy Flavor Tracker (HFT): Charm and Beauty
  - Muon Telescope Detector (MTD): Quarkonia and dilepton continuum
- Beams: p+p at 200, 500 GeV; A+A at 200 GeV
  - Fixed target for parasitic running at low √s

Intermediate term: 2016→~2020

- Beam Energy Scan Phase II
  - Inner TPC Upgrade (iTPC)
  - RHIC: low energy electron cooling
- Cold QCD matter with p+A, transverse spin phenomena
  - Forward Upgrade West + iTPC

Long term: 2020+→ evolve to eSTAR

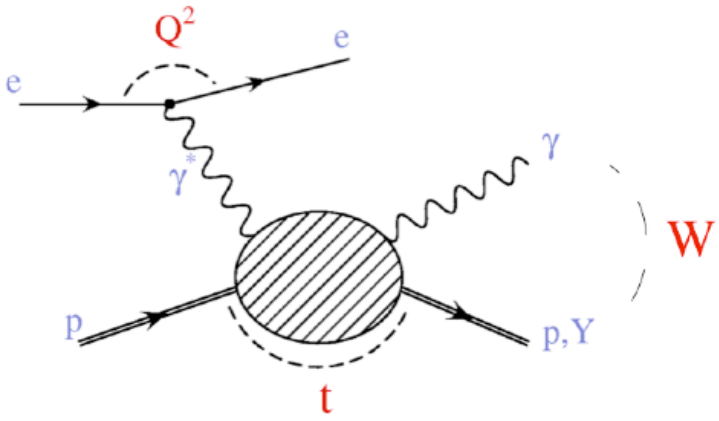
- Precision study of cold QCD matter with e+A and polarized p
  - Forward Upgrade East

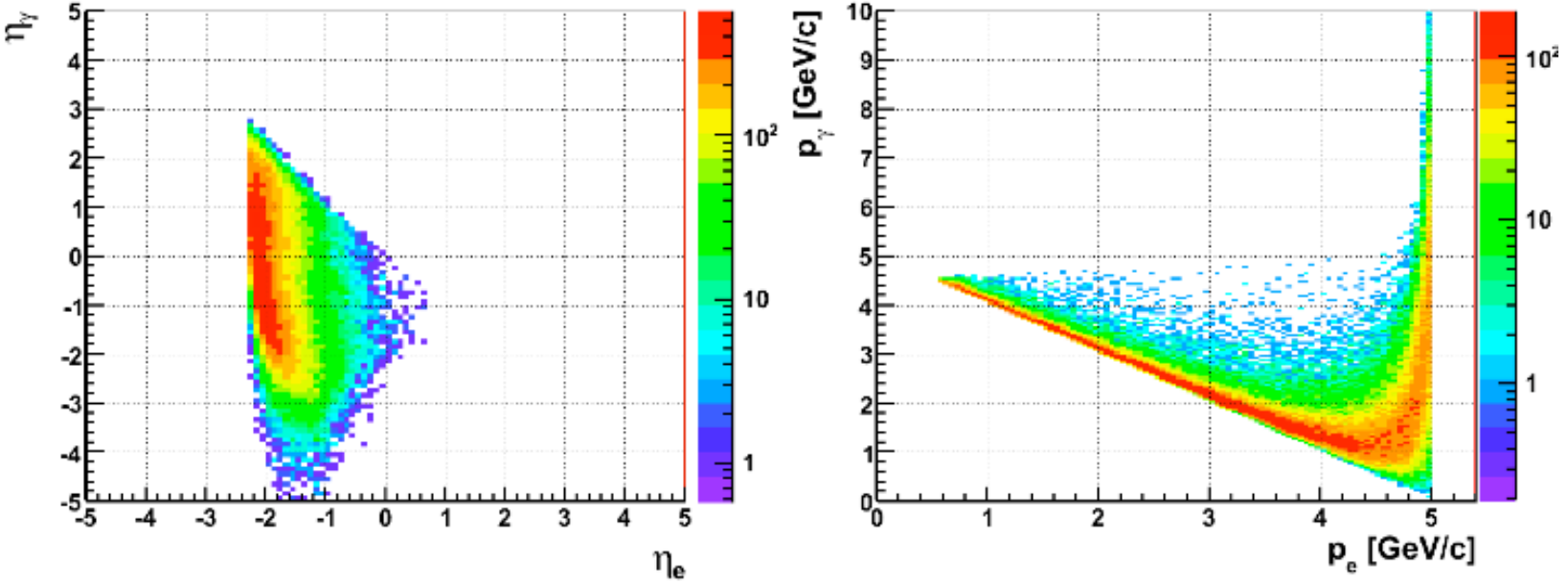
Backup

Beyond DIS: DVCS

Investigate Deeply Virtual Compton Scattering
- Requires measurement of electron, proton, and photon,

- Proton requires Roman Pot, intimately tied to I.R. design
  - Aperture needs mostly driven by proton energy
- Electron requirements appear similar to DIS, 5x50GeV:
  - Especially important to measure over -2<η<-1
  - Acceptance needs mostly driven by electron energy





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

Key unanswered questions

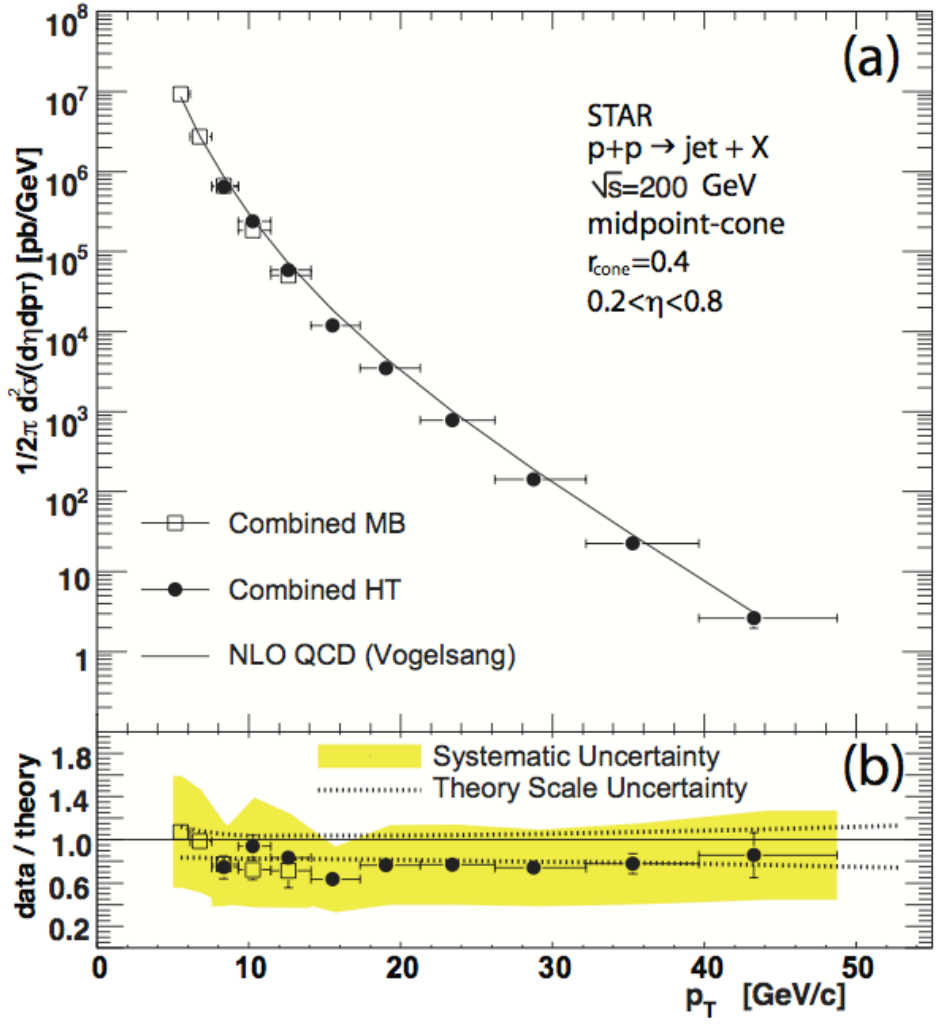
- What is the nature of QCD matter at the extremes?
  - What are the properties of the strongly-coupled system produced at RHIC, and how does it thermalize?
  - Are the interactions of energetic partons with QCD matter characterized by weak or strong coupling? What is the detailed mechanism for partonic 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 Measurement Plan

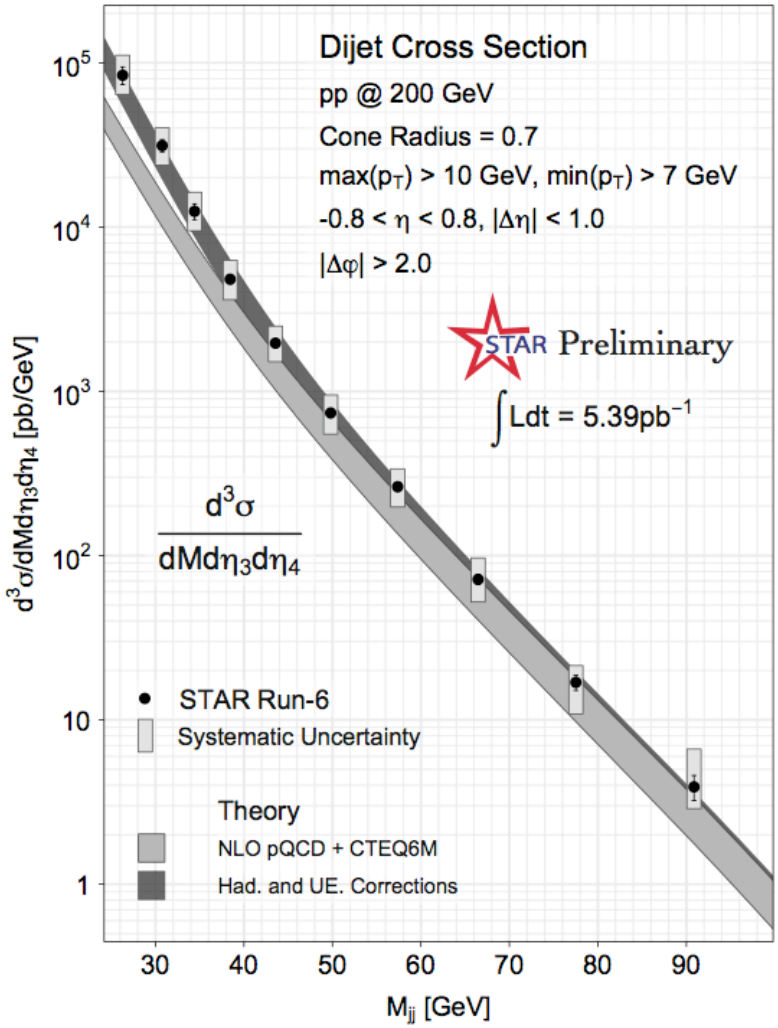
	Near term (Runs 11–13)	Mid-decade (Runs 14–16)	Long term (Runs 17–)
Colliding systems	p+p, A+A	p+p, A+A	p+p, p+A, A+A, e+p, e+A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \to ee$, m_{ee}, v_2	Υ, $J/\psi \to \mu\mu$, Charm 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

Jets: Proven Capabilities in p+p

B.I. Abelev et al. (STAR Coll.), Phys.Rev.Lett. 97, 252001, 2006



SPIN-2010: Matt Walker/Tai Sakuma, *for the collaboration*

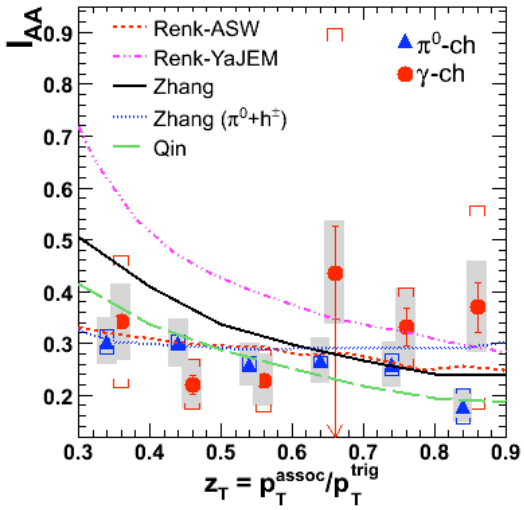


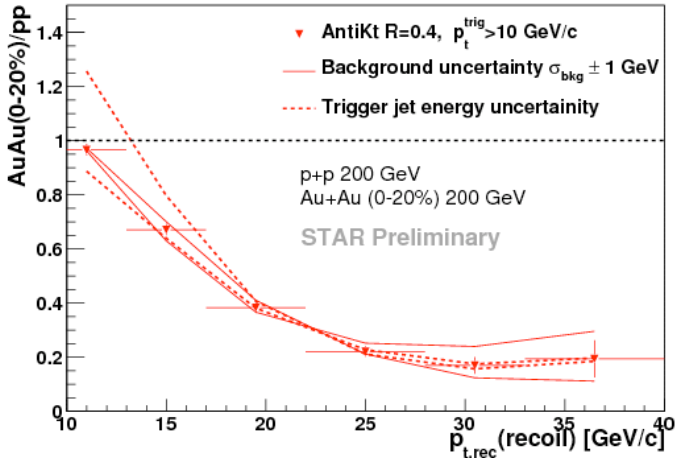
Jets well understood in STAR, experimentally and theoretically

To date: Jets and γ-hadron in A+A

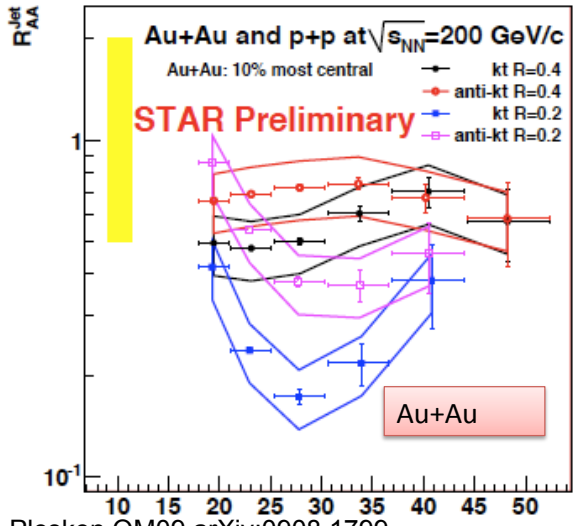
Phys. Rev. C 82, 034909

Triggered: ~0.3 nb^{-1}

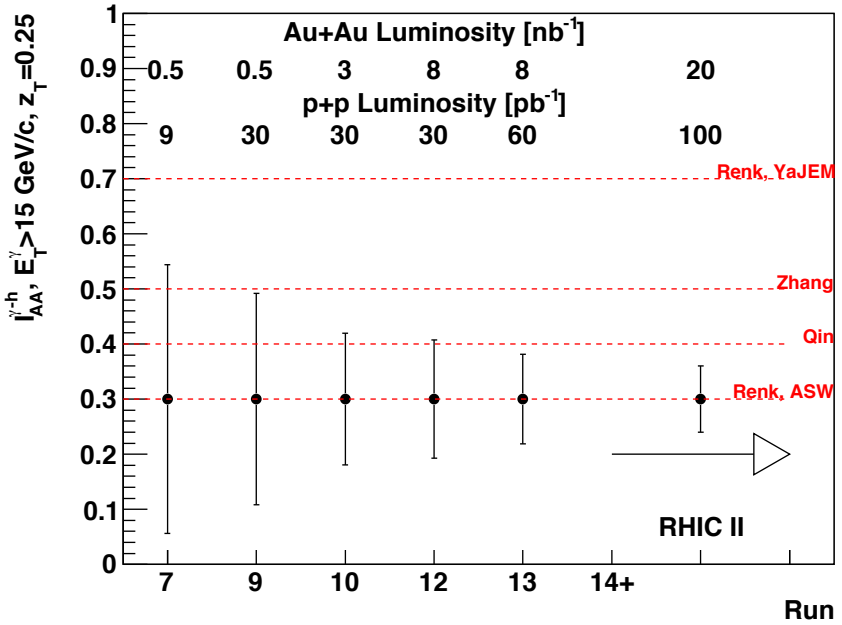




Untriggered: ~0.01 nb^{-1}



M. Ploskon QM09 arXiv:0908.1799



Beginning results from Run 7 indicative, but not final word

Huge increase in significance with trigger upgrades+luminosity

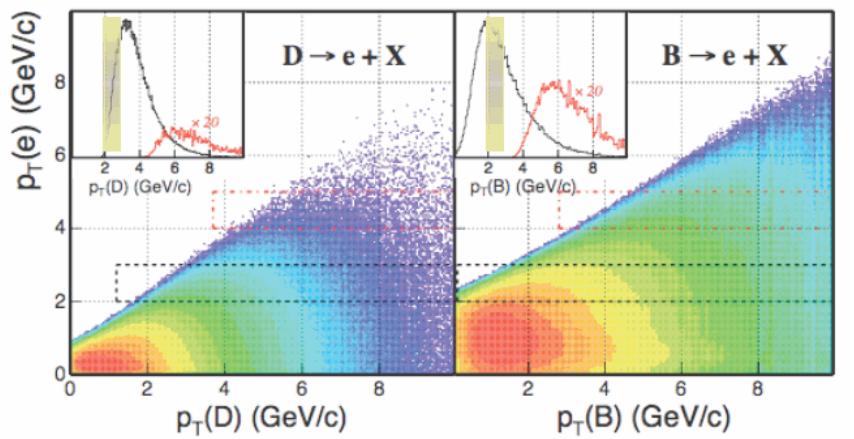
Complementary to LHC:

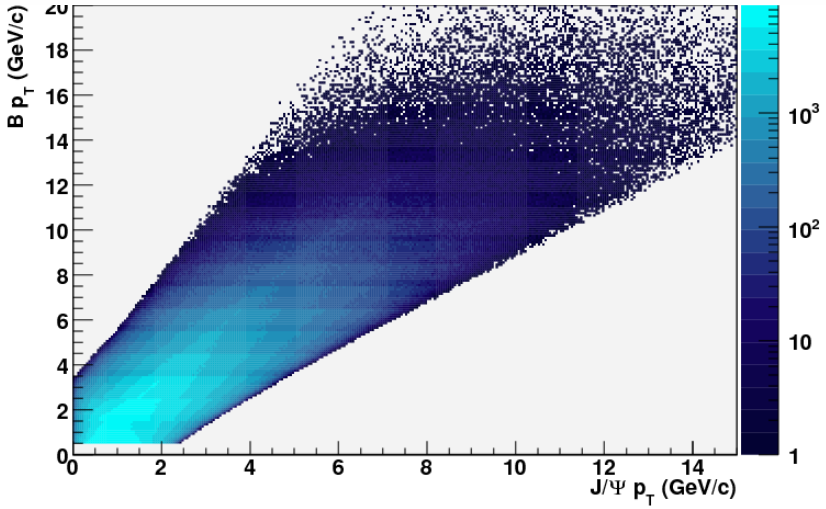
RHIC: quarks LHC: gluons

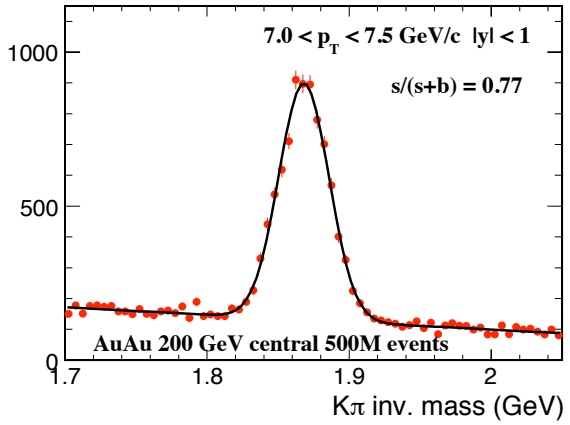
best place to do jets < ~50 GeV

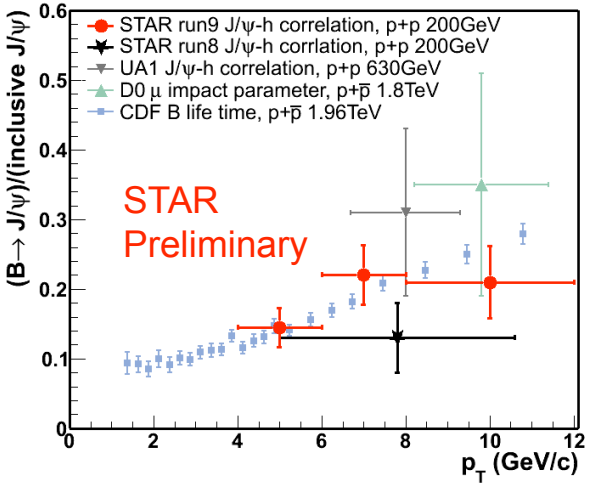
Mass dependence via Heavy Quarks

- What is the dependence of energy loss on parton mass?
  - Key tools: heavy quarks with precise kinematic reconstruction
  - Key technology: Heavy Flavor Tracker and Muon Telescope Detector

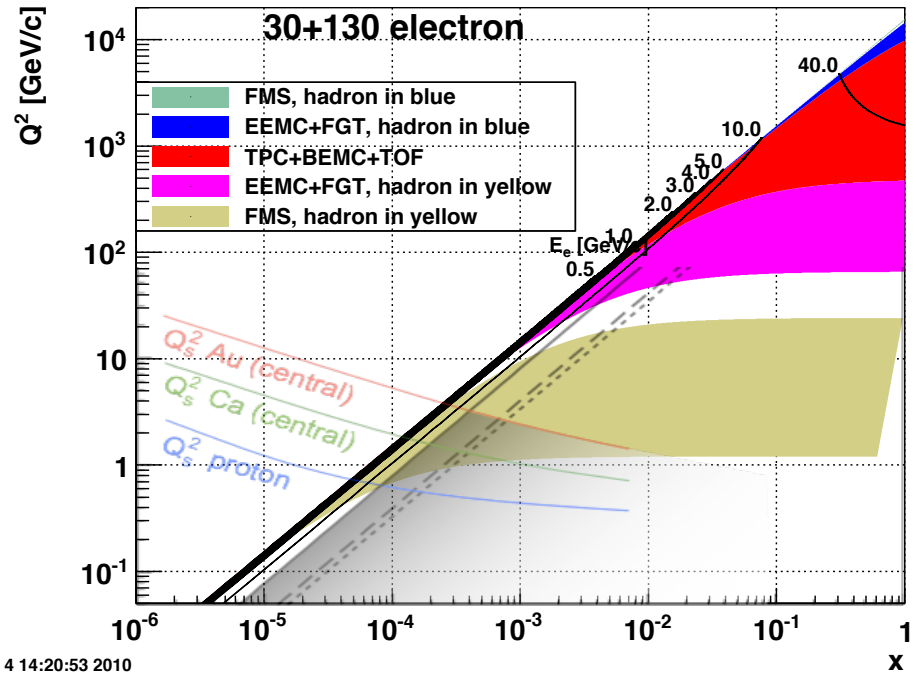


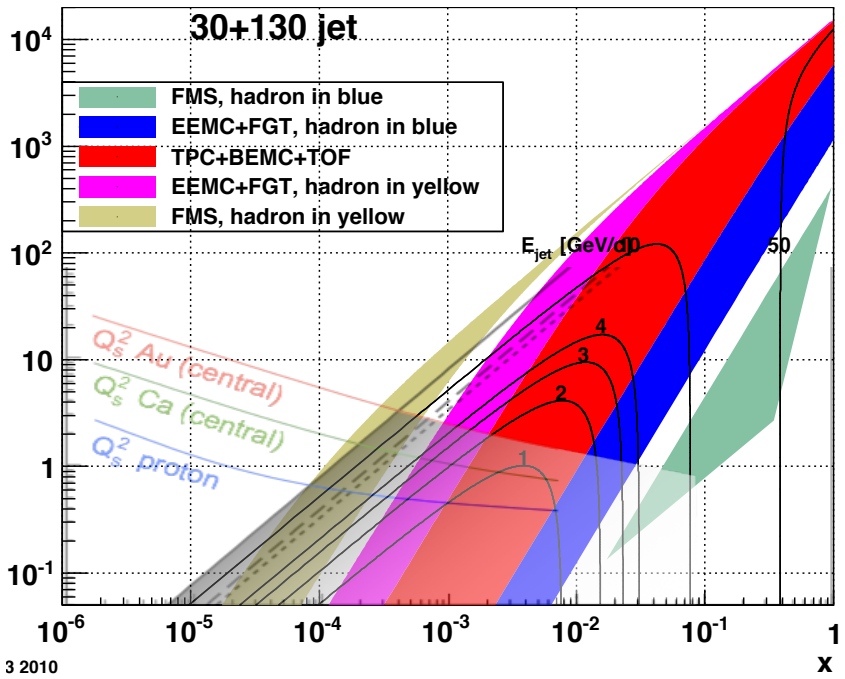






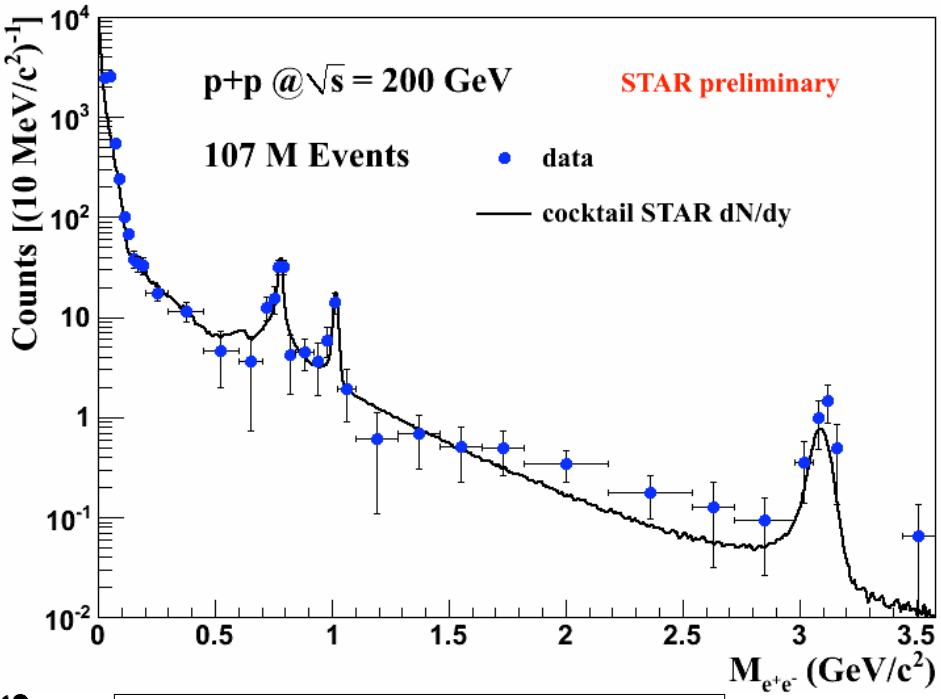
Longer term: STAR and eRHIC

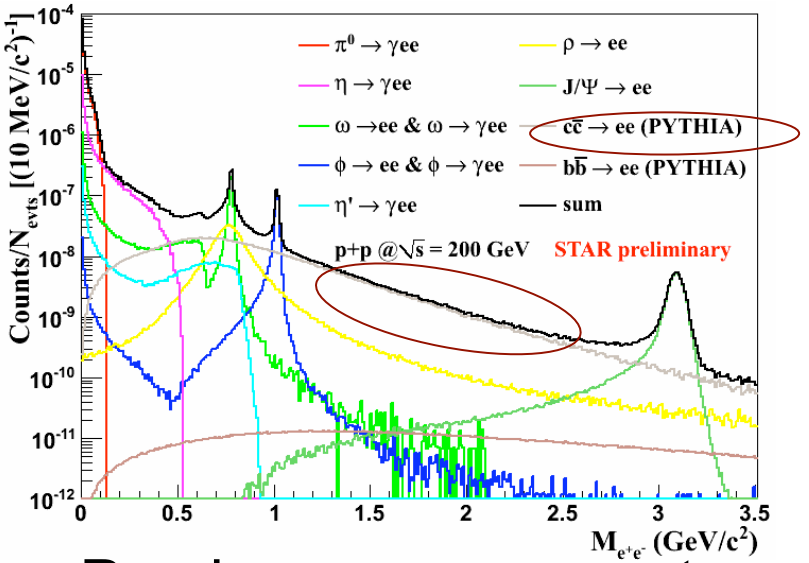


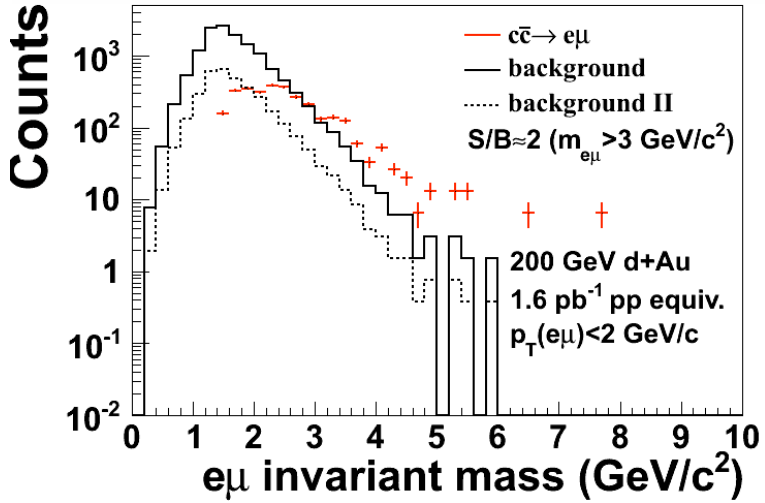


- Forward region critical for higher energy options
- Major upgrades in forward direction would be needed

Properties of sQGP: Dileptons



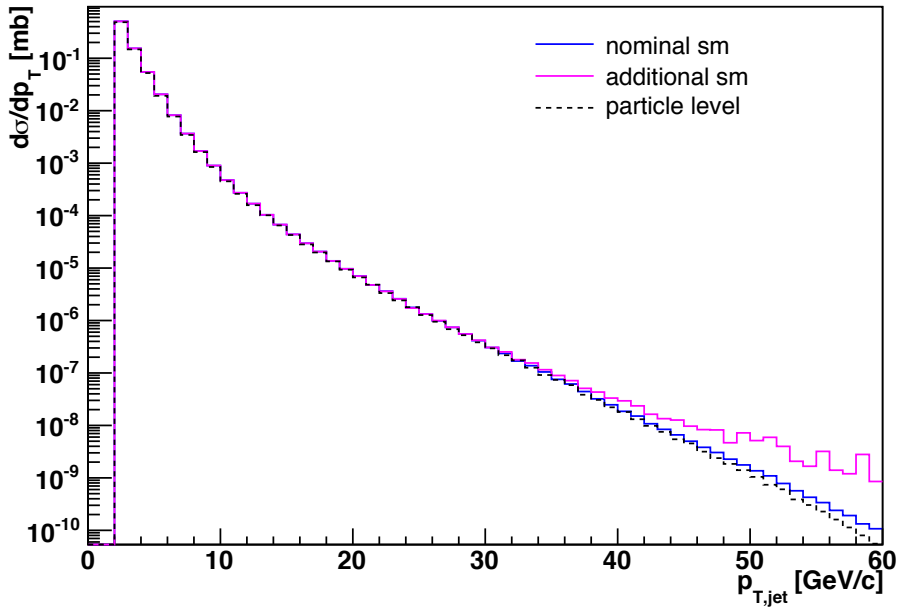


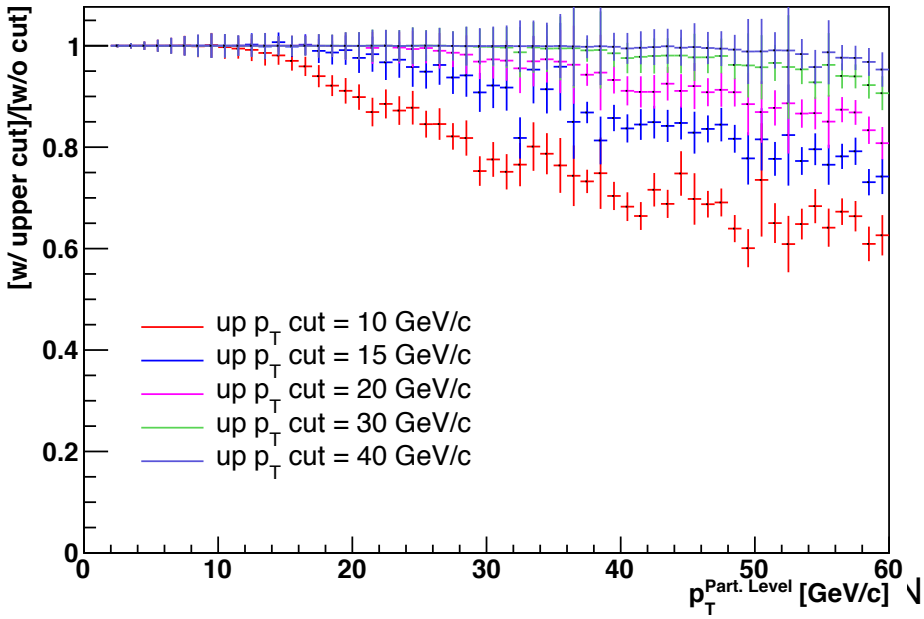


- Precise measurements with TOF, DAQ upgrade
- Correlated charm in A+A
  - Decorrelation? Order of magnitude uncertainty
- Address with:
  - HFT: D^0, displacement
  - MTD: e-μ correlations

See L. Ruan, Parallel 1C

Jet Capabilities in A+A

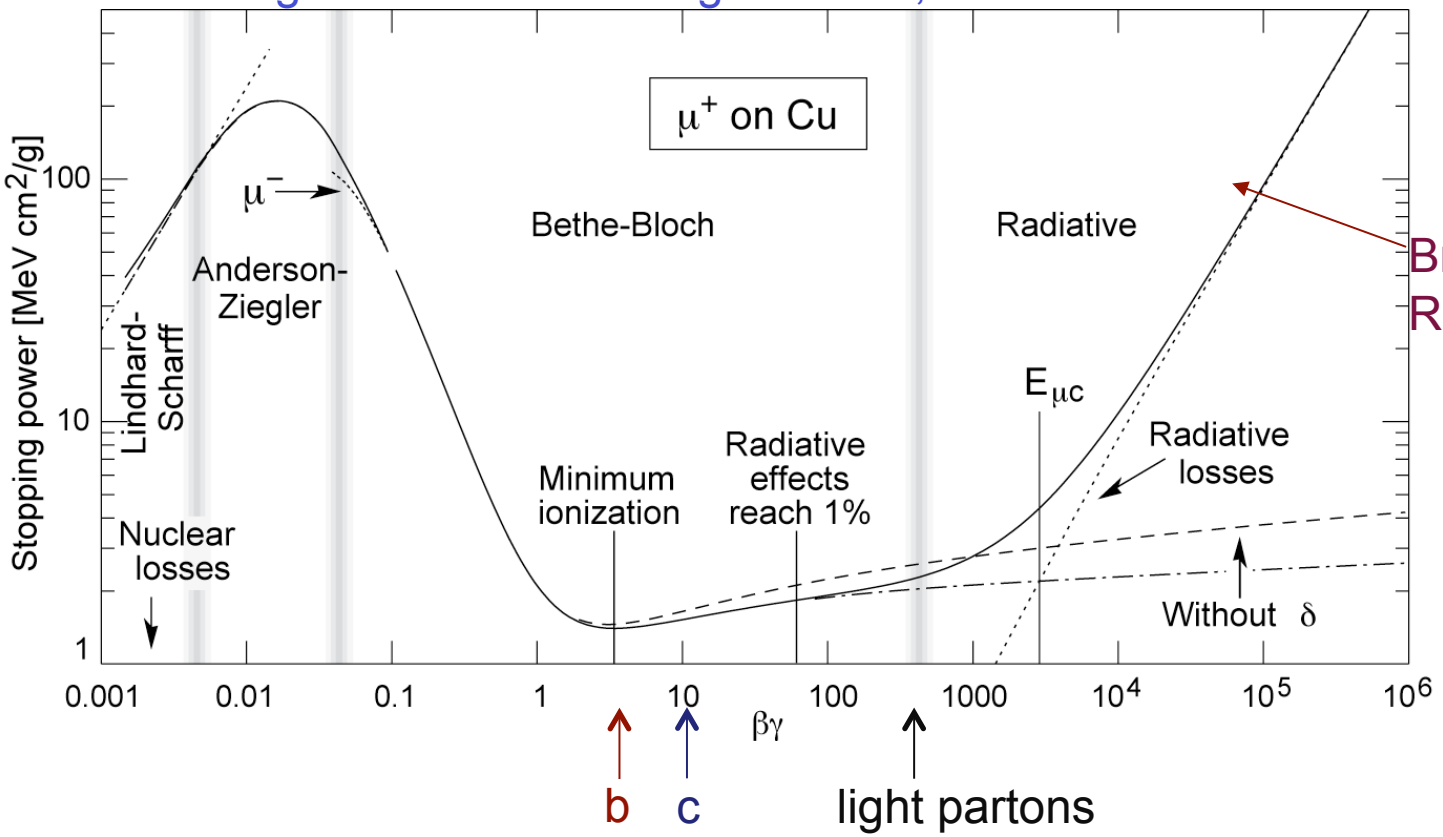




- Sufficient statistical reach out to ~50 GeV for precision measurements
  - Large unbiased datasets
  - Trigger upgrades to lessen bias with walking jet patches
- Smearing of high momentum charged hadrons under control
  - Corrections: need to calibrate level of smearing
  - Hard cutoff in hadrons: small loss of jets that fragment hard
- Dominant uncertainty fluctuations in the underlying event

Velocity dependence

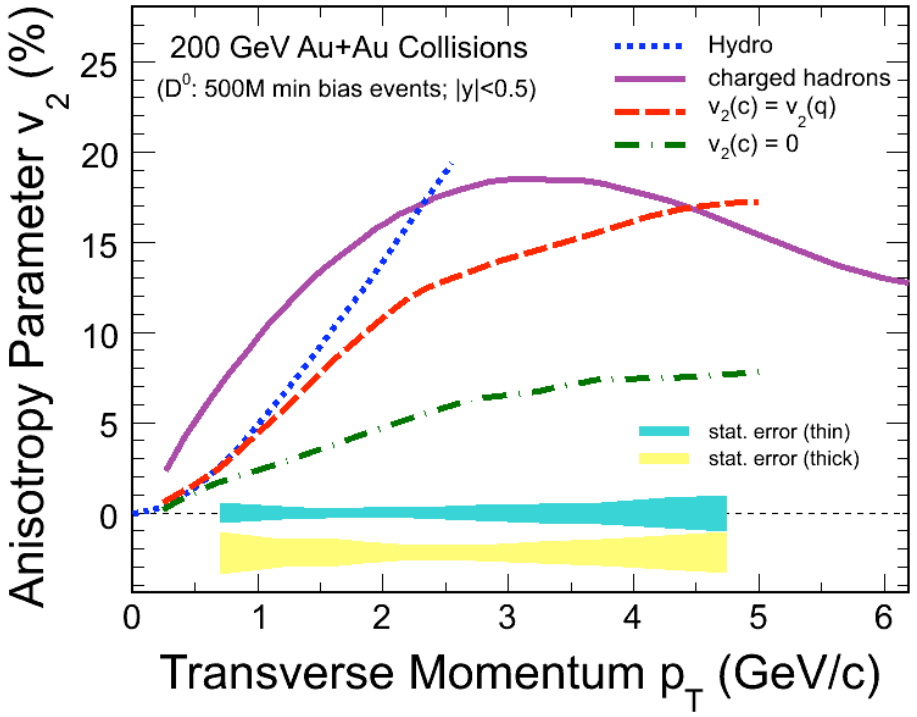
"Passage of Particles through Matter", Particle Data Book

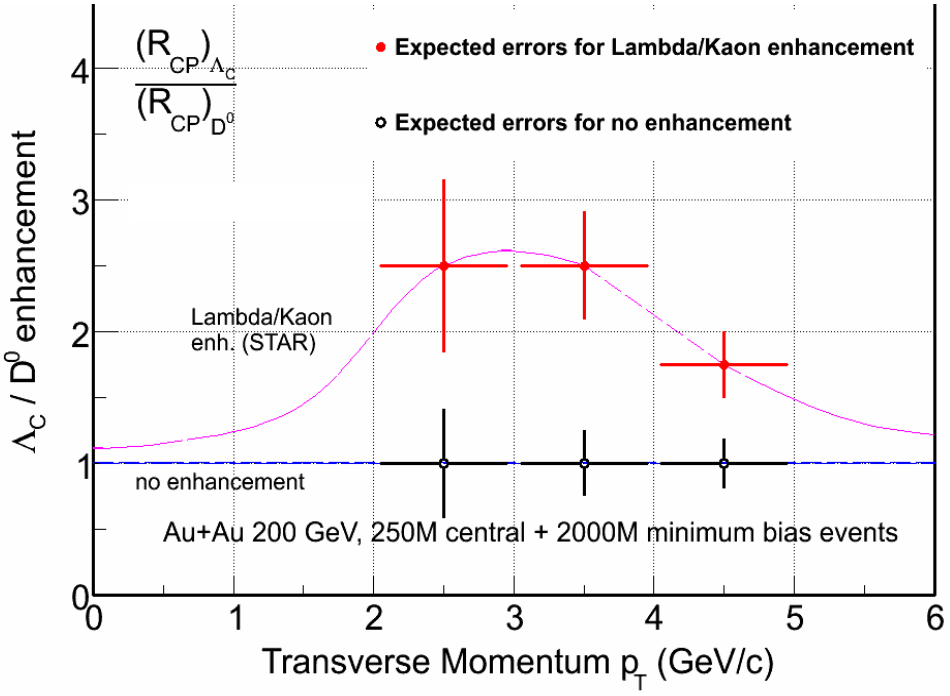


Bremsstrahlung
Radiative dE/dx

- QED: different momenta, different mechanisms
- Just beginning the exploration of this space in QCD

Properties of sQGP: Charm

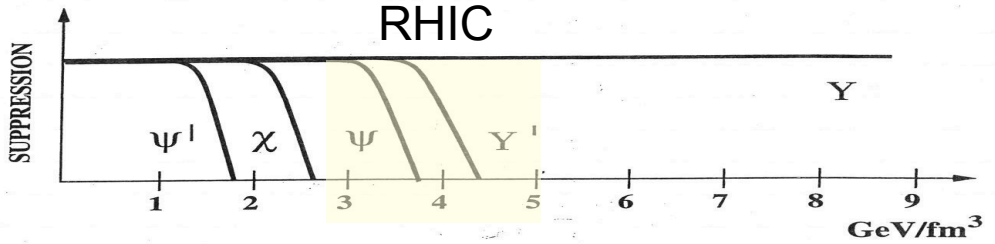


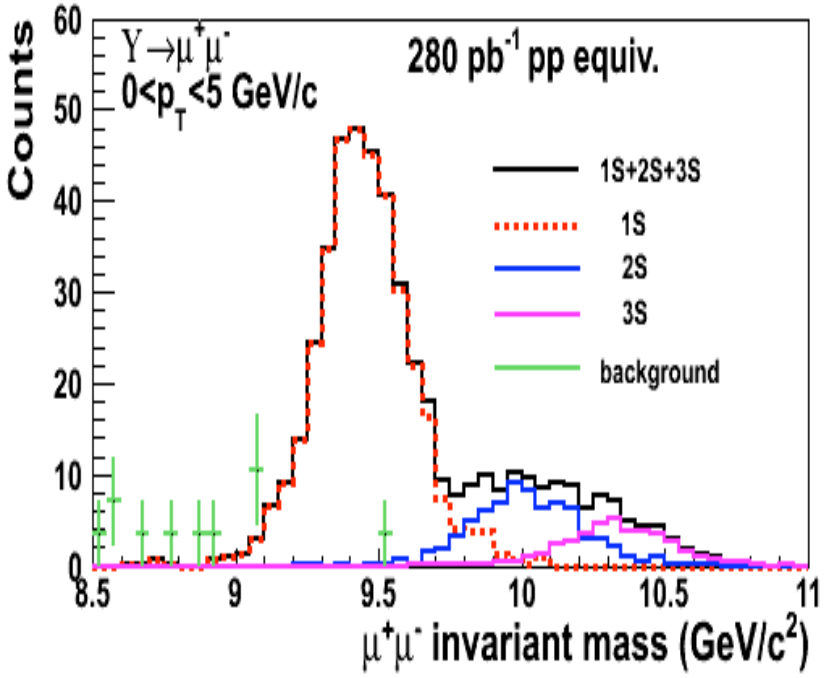


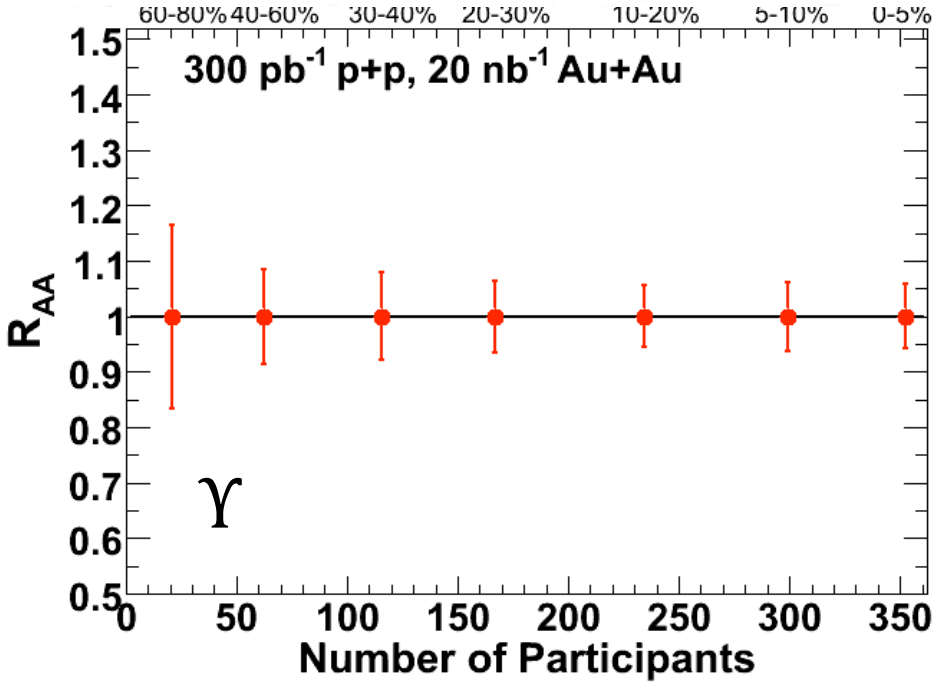
- Does charm flow hydrodynamically?
  - Heavy Flavor Tracker: Unique access to fully reconstructed charm at low p_T
- Are charmed hadrons produced via coalescence?
  - Heavy Flavor Tracker: unique access to charm baryons (may affect NPE)
  - Muon Telescope Detector: does J/Ψ flow?

Properties of sQGP: Upsilon

What states of quarkonia is the energy density of matter at RHIC sufficient to dissociate?
What is the energy density?





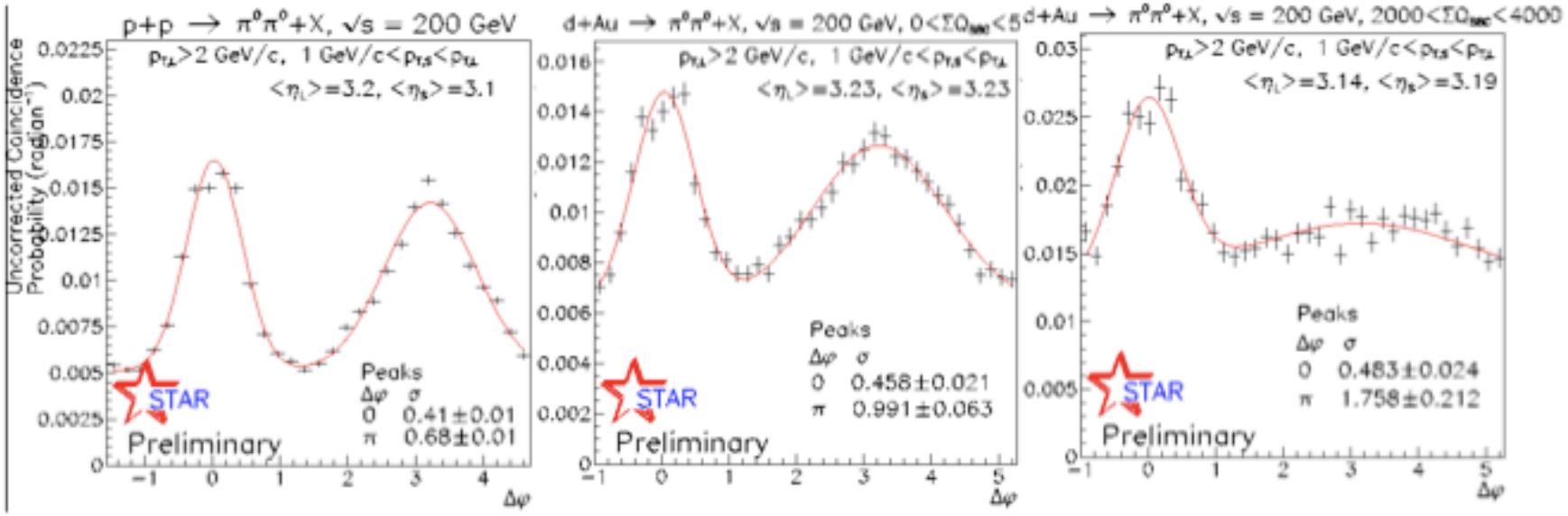


- Muon Telescope Detector: Dissociation of Υ, separated by state
  - At RHIC: small contribution from coalescence, so interpretation clean
  - No contribution of Bremsstrahlung tails, unlike electron channel

Mechanism of partonic energy loss

- Is the mechanism predominantly collisional or radiational?
  - 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 beauty

Cold QCD Matter



pp ***d+Au (peripheral)*** ***d+Au (central)***

- Hint that RHIC provides unique access to onset of saturation
- Compelling and necessary further measurements in future
  - Kinematic constraints: photons, Drell-Yan in p+A
  - Beyond p+A: the Electron Ion Collider

See C. Perkins