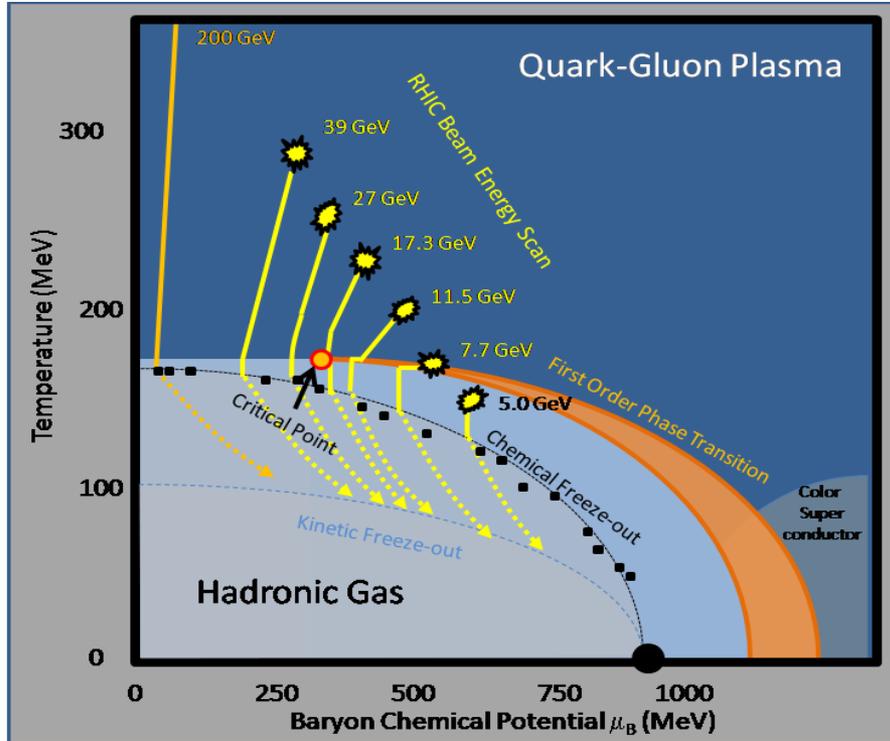


1<sup>st</sup> Collision  
June 12, 2000

James Dunlop for the STAR Collaboration

## Hot QCD Matter



Properties of the sQGP in detail

Mechanism of Energy Loss:

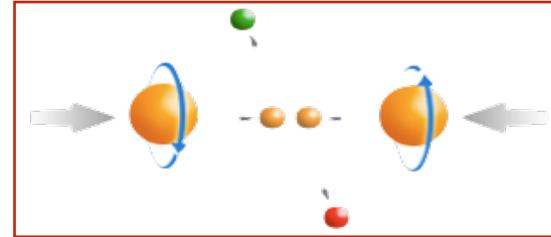
weak or strong coupling?

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

Novel symmetry properties

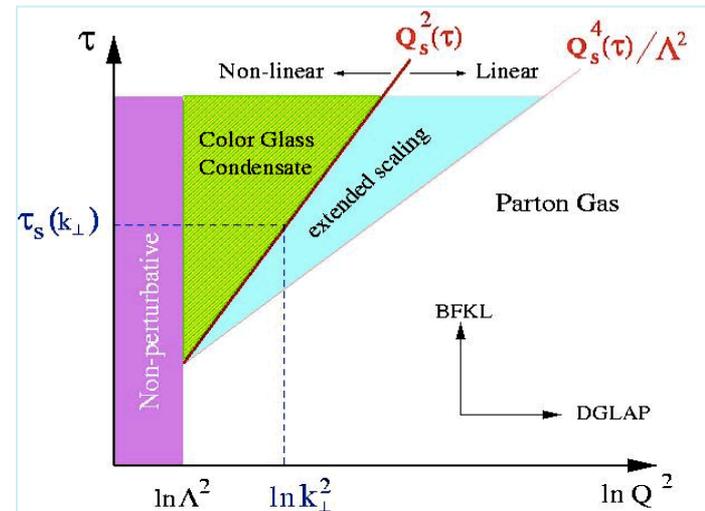
Exotic particles

## Partonic structure

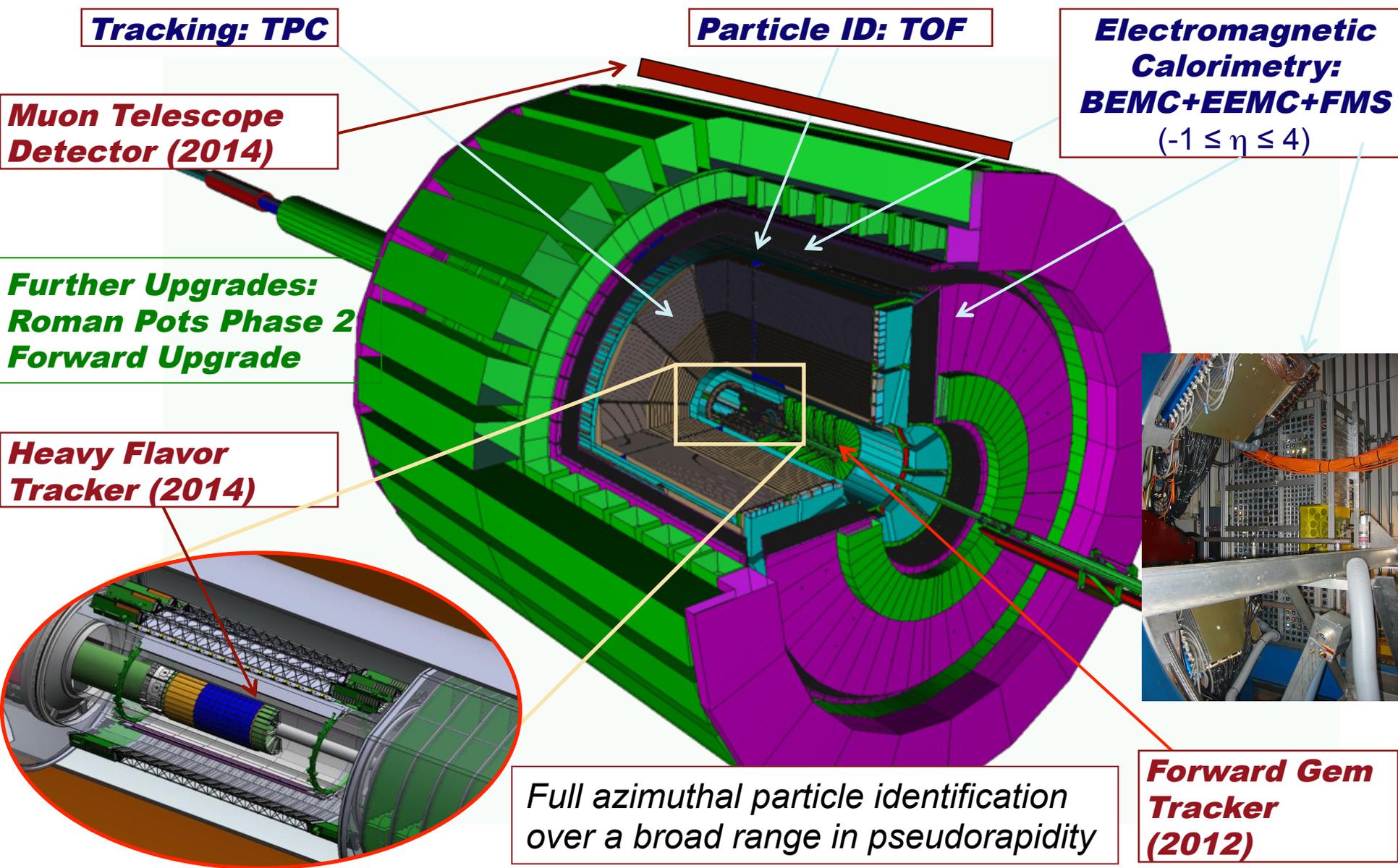


Spin structure of the nucleon

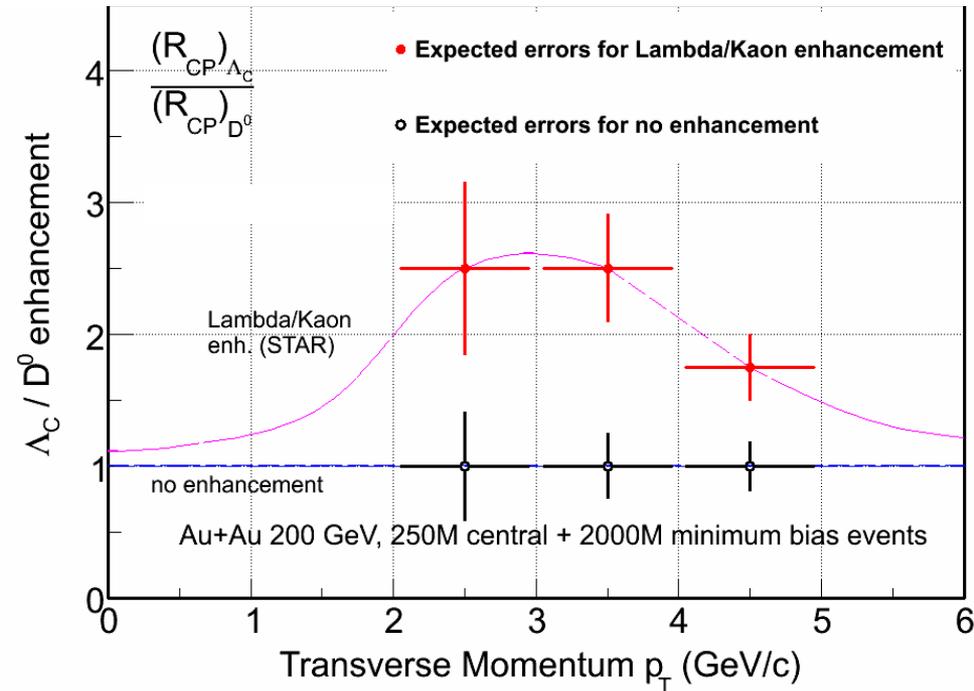
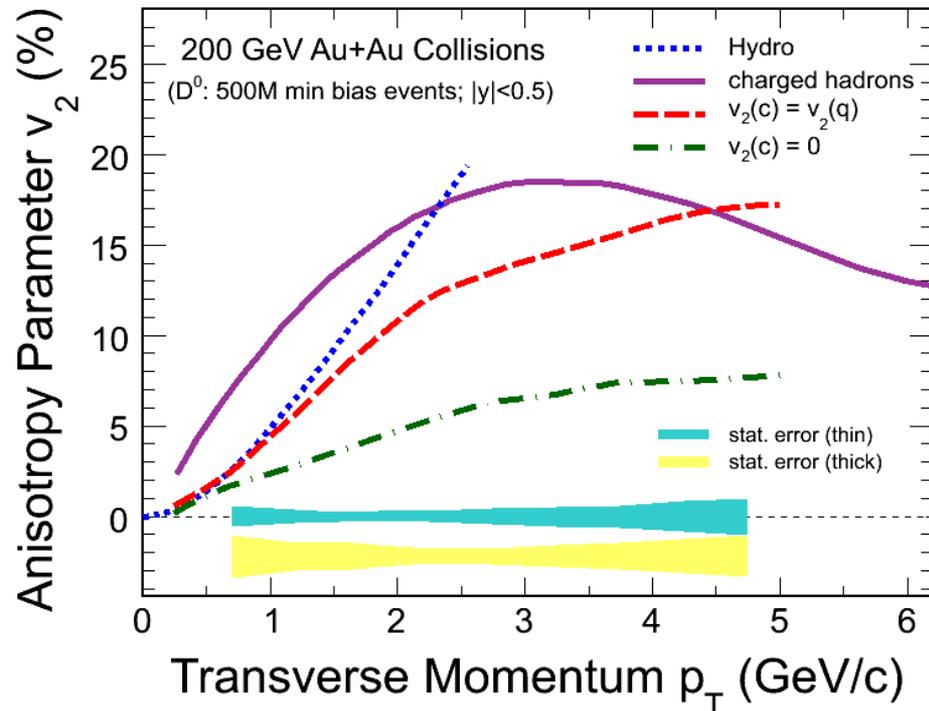
How to go beyond leading twist and colinear factorization?



What are the properties of cold nuclear matter?

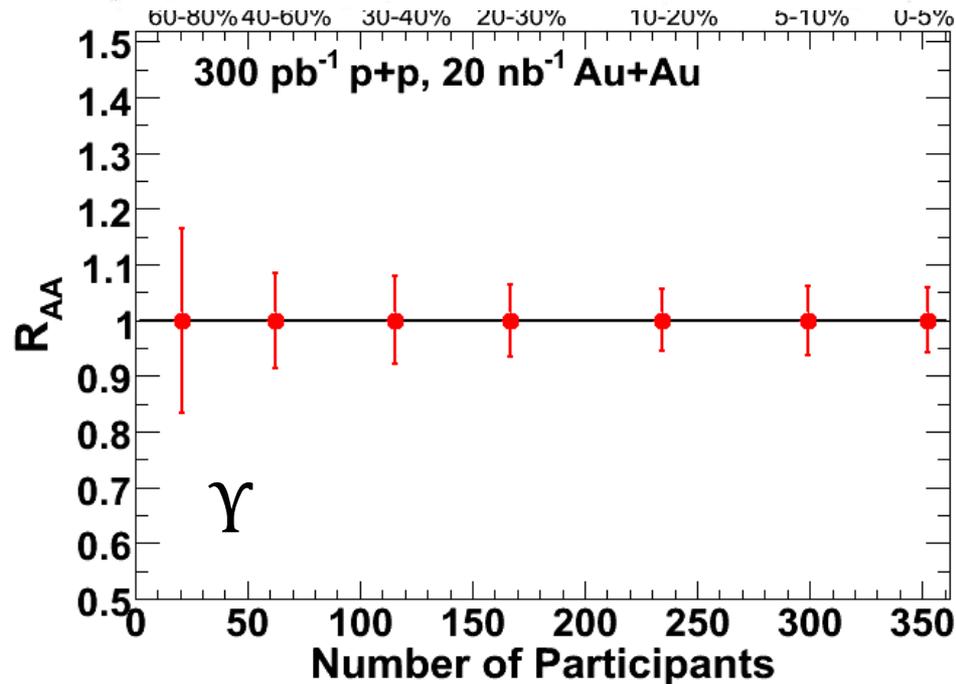
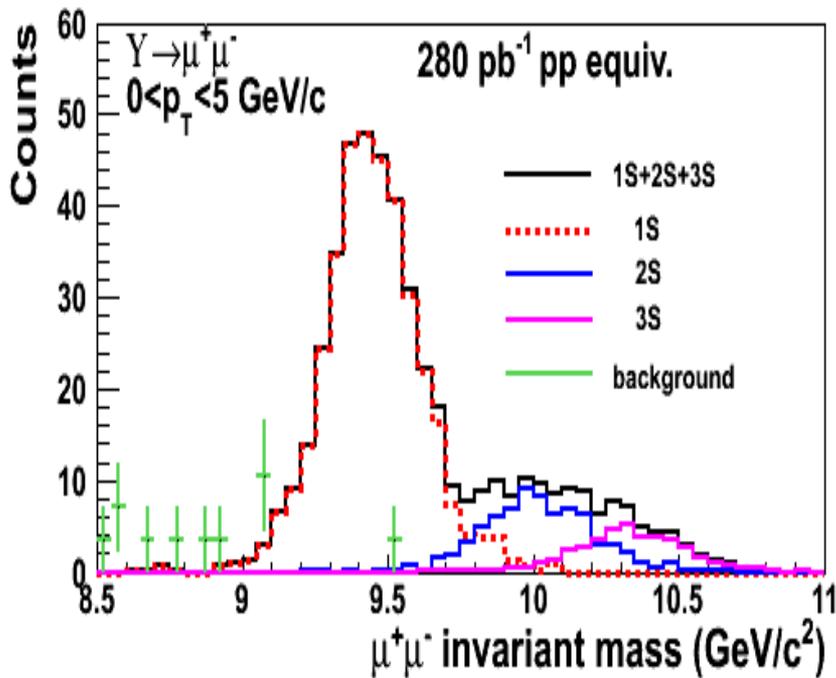
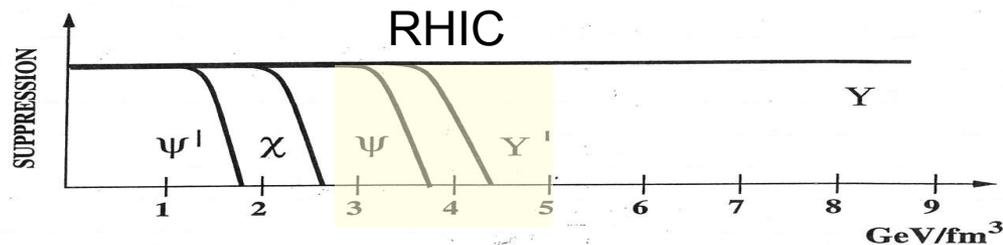


- Hot QCD matter: high luminosity RHIC II ( $\text{fb}^{-1}$  equivalent)
    - Heavy Flavor Tracker: precision charm and beauty
    - Muon Telescope Detector:  $e+\mu$  and  $\mu+\mu$  at mid-rapidity
    - Trigger and DAQ upgrades to make full use of luminosity
    - Tools: jets combined with precision particle identification
  - Phase structure of QCD matter: energy scan
- 
- 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
  - Is there a universal form of cold QCD matter, and what are its properties?



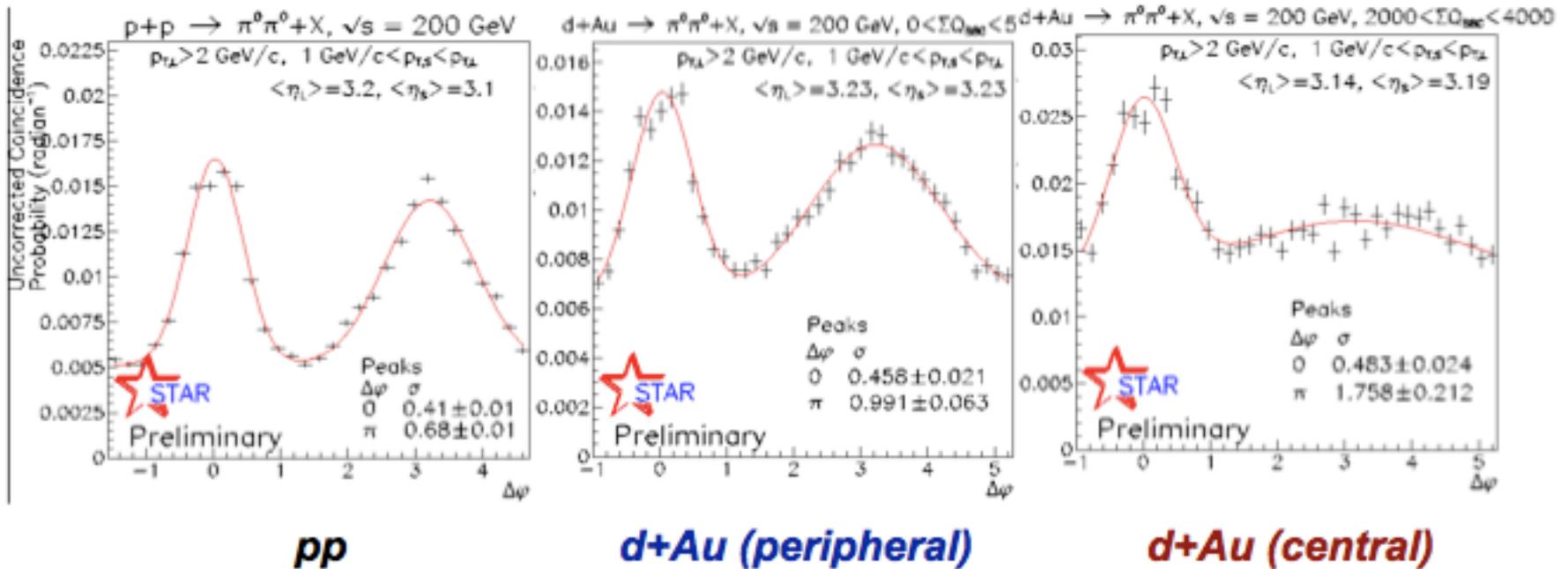
- Does charm flow **hydrodynamically**?
  - Heavy Flavor Tracker: Unique access to fully reconstructed charm at low  $p_T$
- Are charmed hadrons produced via coalescence?
  - Heavy Flavor Tracker: unique access to charm baryons (may affect NPE)
  - Muon Telescope Detector: does  $J/\Psi$  flow?

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

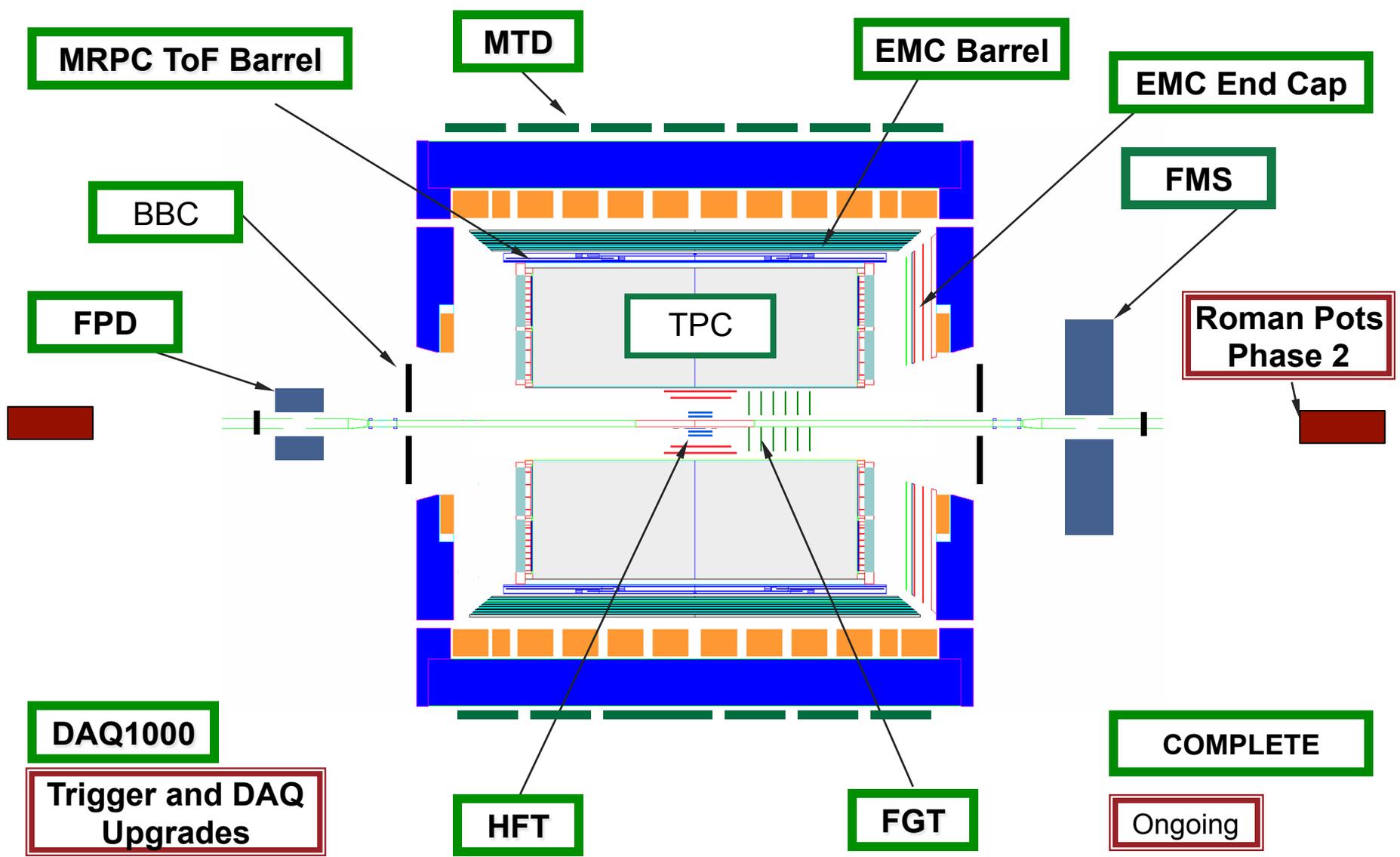


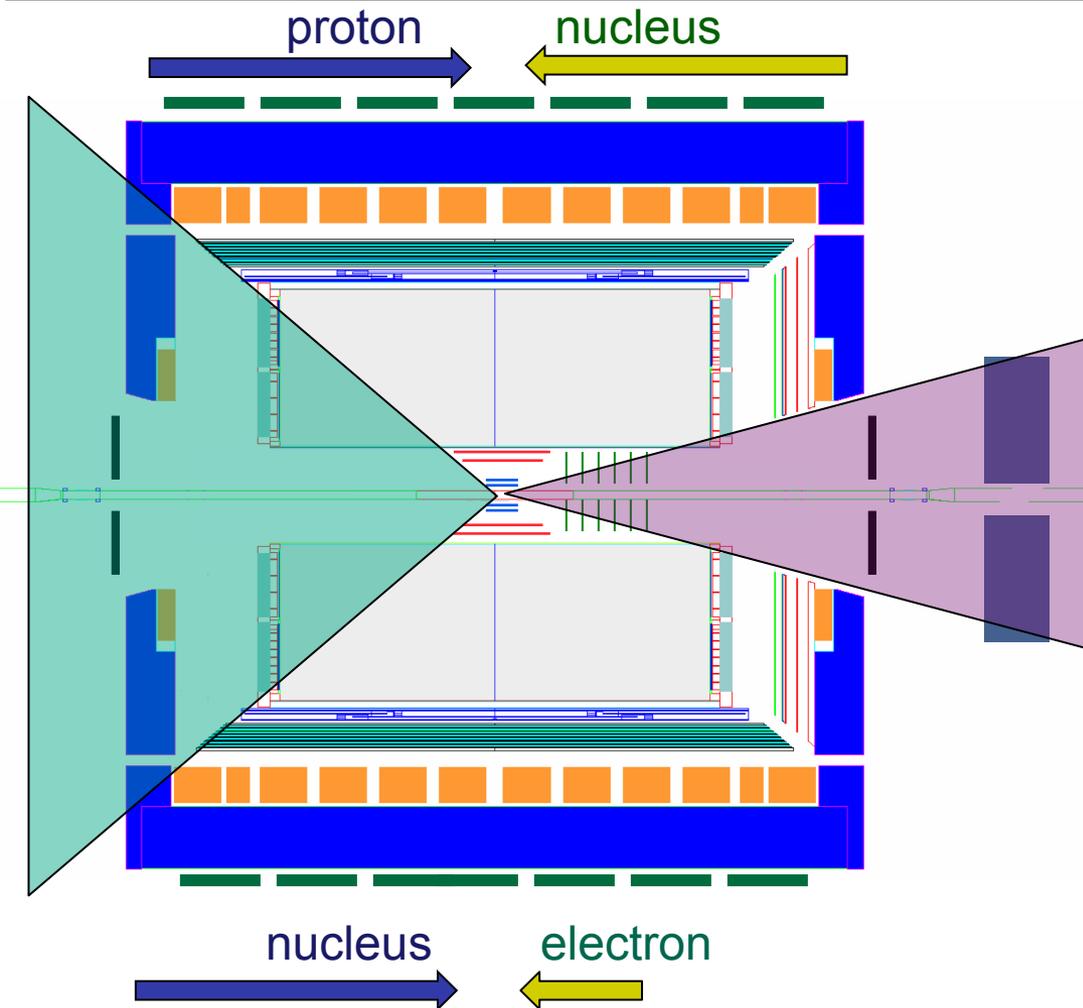
- Muon Telescope Detector: Dissociation of  $\Upsilon$ , separated by state
  - At RHIC: small contribution from coalescence, so interpretation clean
  - No contribution of Bremsstrahlung tails, unlike electron channel

- 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



- 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

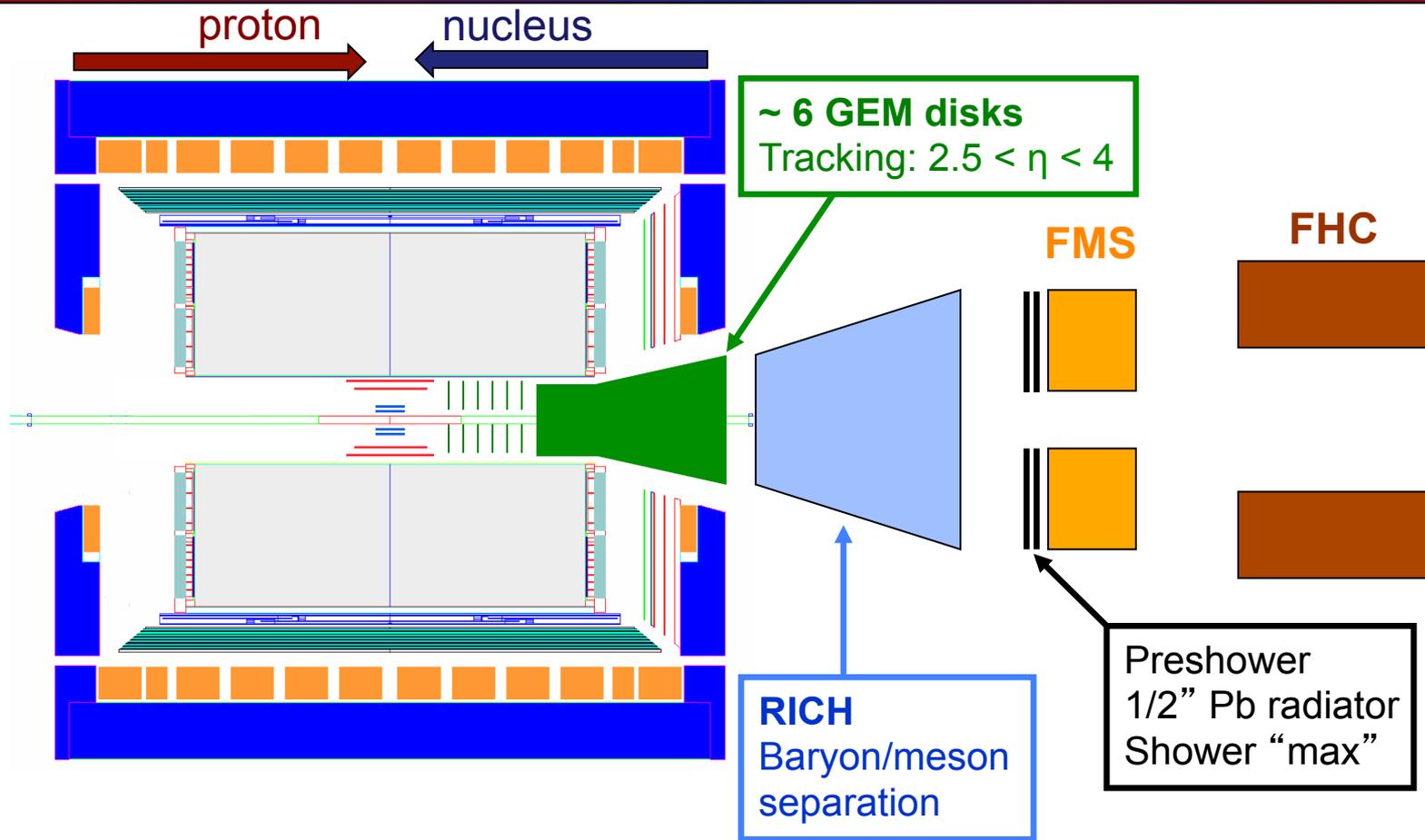




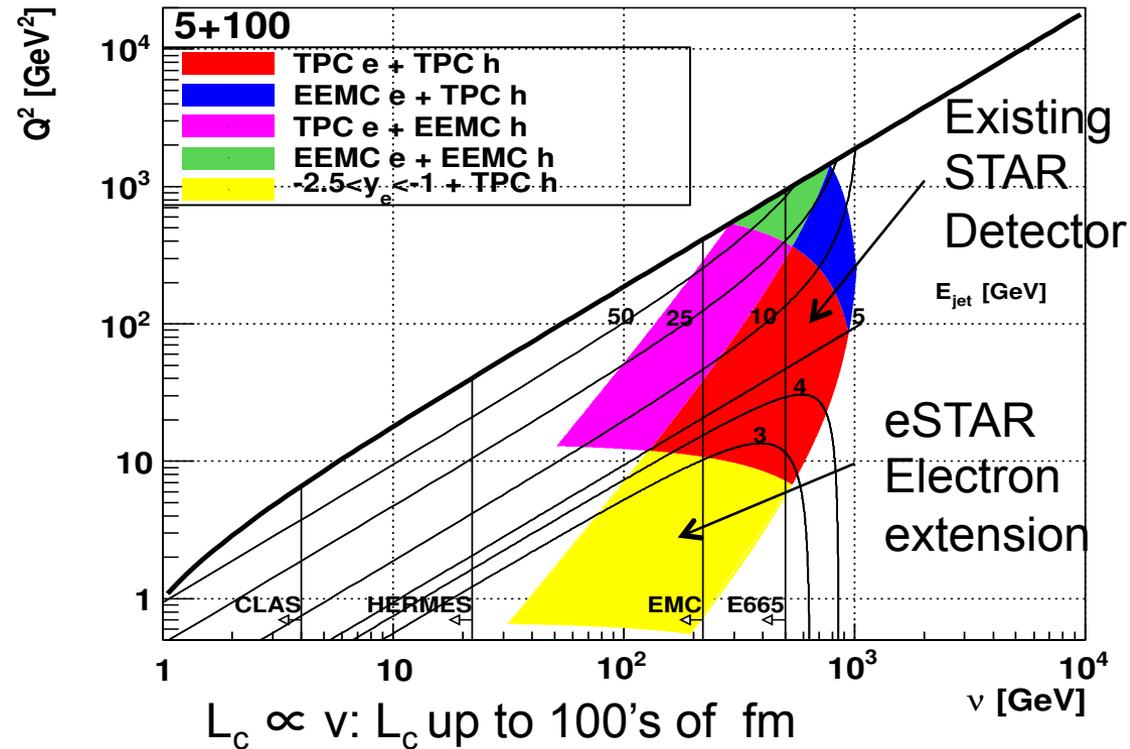
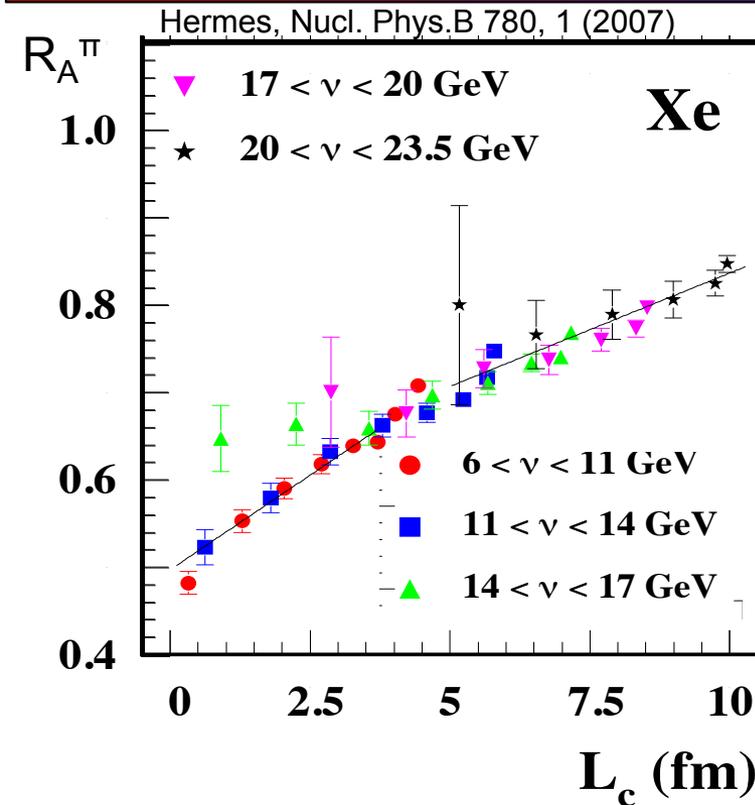
- Positive  $\eta$ : Drell Yan
  - High precision tracking and background rejection using calorimetry
  - Optimized for p+A and p+p
  - High momentum scale
- Negative  $\eta$ : eRHIC
  - Optimized for low energy electrons ( $\sim 1$  GeV)
  - Triggering, tracking, identification
  - R&D necessary for optimal technology choice

To fully investigate cold QCD matter, STAR will move forward

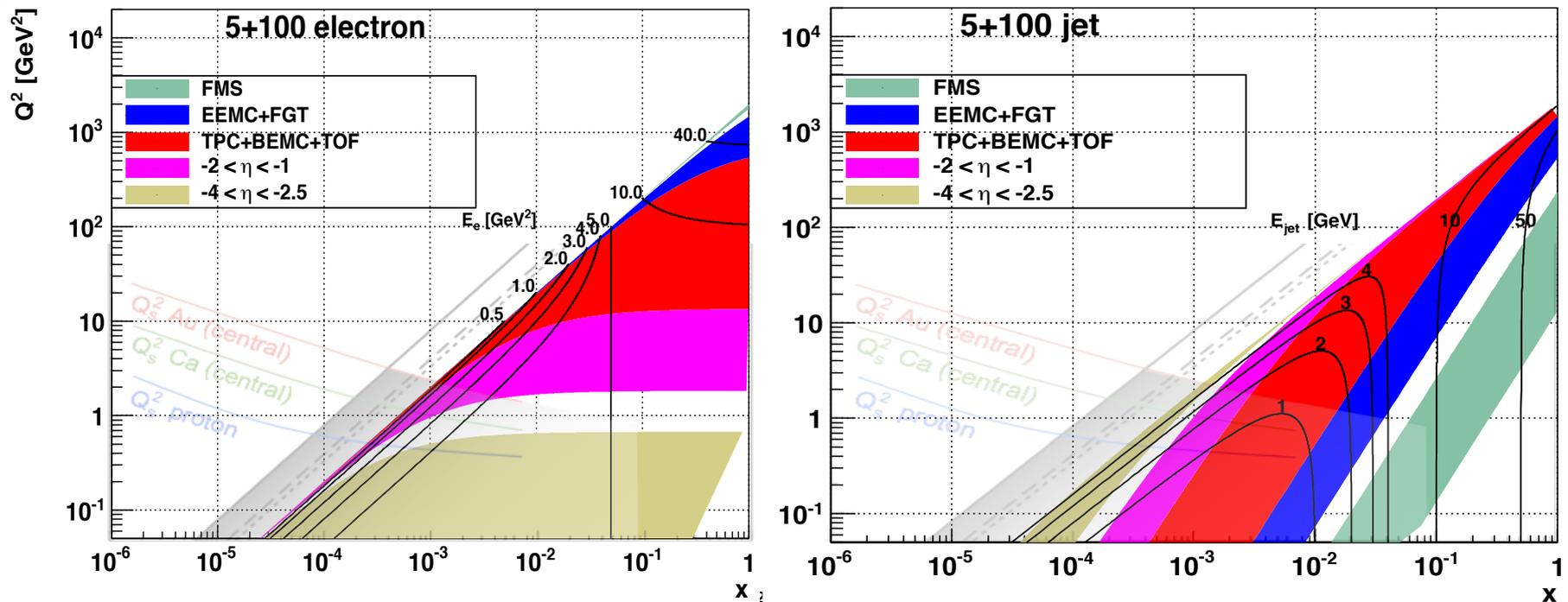
- Nuclear modifications of the gluon PDF
  - Correlated charm production
- Gluon saturation
  - Forward-forward correlations (extension of existing  $\pi^0$ - $\pi^0$ )
    - $h$ - $h$
    - $\pi^0$ - $\pi^0$  } Easier to measure
    - $\gamma$ - $h$
    - $\gamma$ - $\pi^0$  } Easier to interpret
  - Drell-Yan
    - Able to reconstruct  $x_1, x_2, Q^2$  event-by-event
    - Can be compared directly to nuclear DIS
    - True  $2 \rightarrow 1$  provides model-independent access to  $x_2 < 0.001$
  - $\Lambda$  polarization
  - Baryon production at large  $x_F$
- What more might we learn by scattering **polarized protons off nuclei?**
- **Forward-forward correlations, Drell-Yan, and  $\Lambda$ s are also very powerful tools to unravel the dynamics of forward transverse spin asymmetries – Collins vs Sivers effects, TMDs or Twist-3, ...**



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

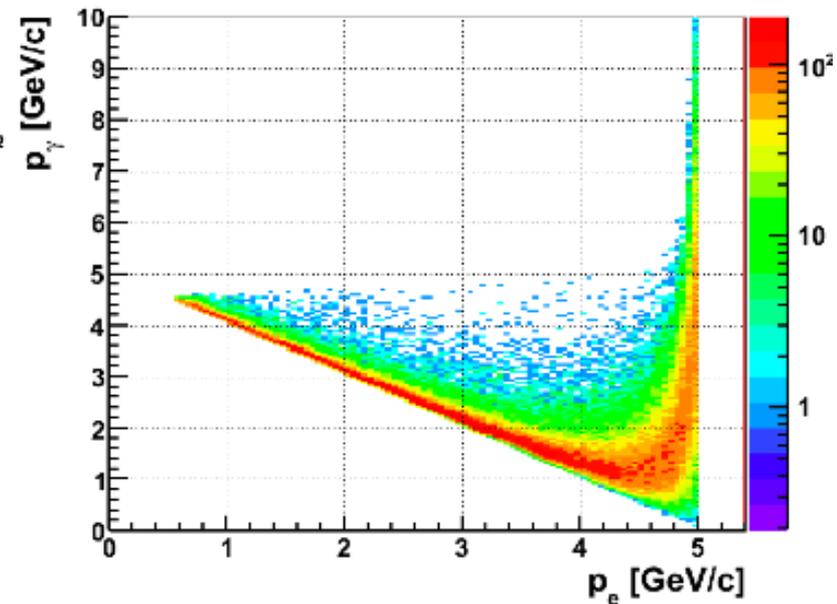
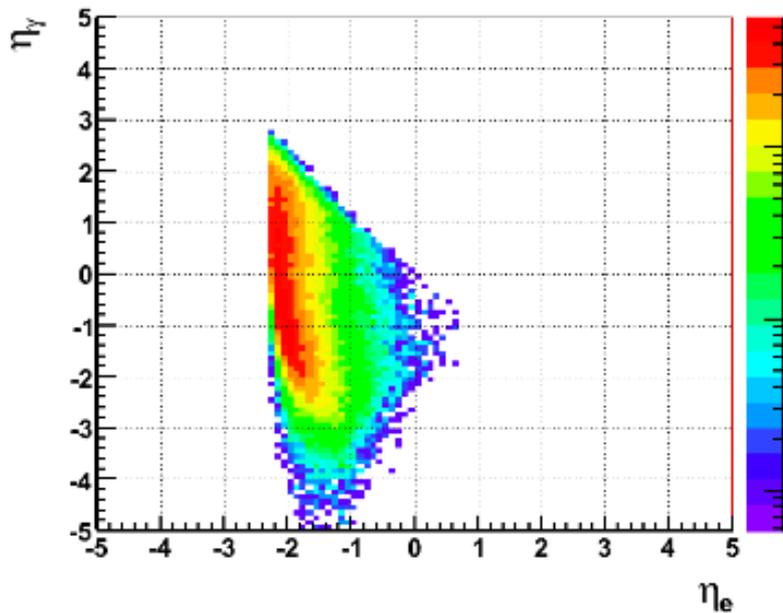
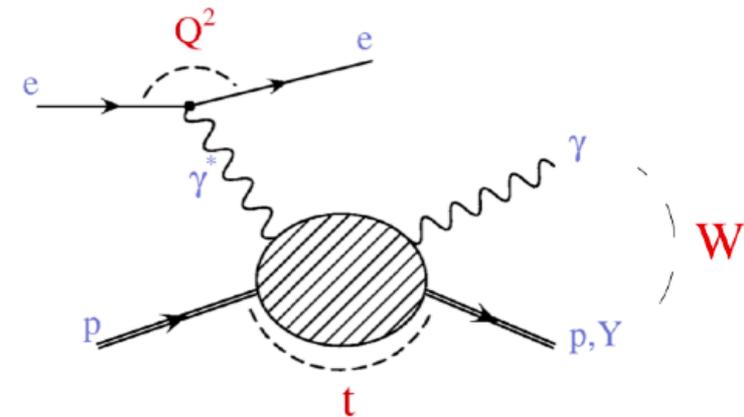


- Complementary probe of mechanism of energy loss
- HERMES: mixture of hadronic absorption and partonic loss
  - Hadrons can form partially inside the medium
- eRHIC: light quarks form far outside medium
- Heavy quarks: unexplored to date. Low  $\beta$ : short formation time



- Current detector matches quite well to kinematics of eRHIC
  - Particle ID, sufficient  $p_T$  resolution, etc. at mid-rapidity ( $Q^2 > 10 \text{ GeV}^2$ )
- Space to extend: focus on  $1 < Q^2 < 10 \text{ GeV}^2$  ( $-2 < \eta < -1$ )
- Some important phase 1 measurements:
  - $F_L$  in  $\mathbf{e+p}$  and  $\mathbf{e+A}$
  - $g_1$  in polarized  $\mathbf{e+p}$
  - **SIDIS** in  $\mathbf{e+p}$  and  $\mathbf{e+A}$  over broad  $(x, Q^2)$  range, including  $\mathbf{K}$  and  $\mathbf{\Lambda}$  to investigate **strange quark distributions and their polarization**

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  $-2 < \eta < -1$   
 Acceptance needs mostly driven by electron energy



Further possibilities under investigation: diffraction in  $J/\psi$ , ...

# Targeting eSTAR: Forward Upgrade East

ToF:  $\pi$ ,  $K$  identification,  
 $t_0$ , electron

ECal: 5 GeV, 10 GeV, ...  
electron beams

GCT: a compact  
tracker with enhanced  
electron capability;

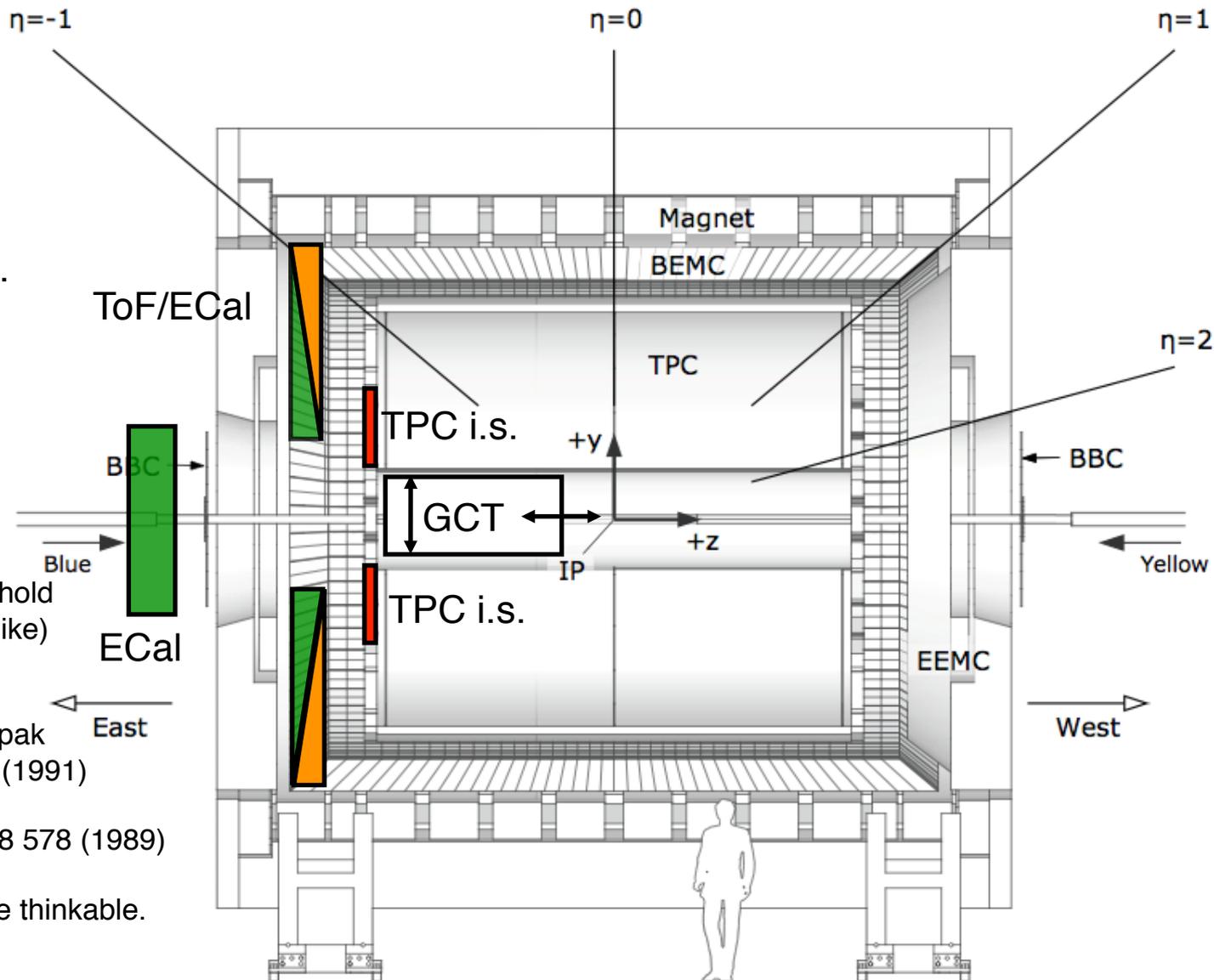
seeks to combine high-threshold  
(gas) Cherenkov with TPC(-like)  
tracking

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.

Simulations ahead:

eSTAR task force formed

12 April 2010



In the next decade, STAR will address:

Thermalization, properties, and phase structure of hot QCD matter

Mechanism of energy loss

Exotic particles and novel symmetries

Spin structure of the nucleon

with high luminosity beams and detector upgrades

By the end of the decade, STAR will move forward

to fully investigate cold QCD matter

in p+A collisions and at eRHIC

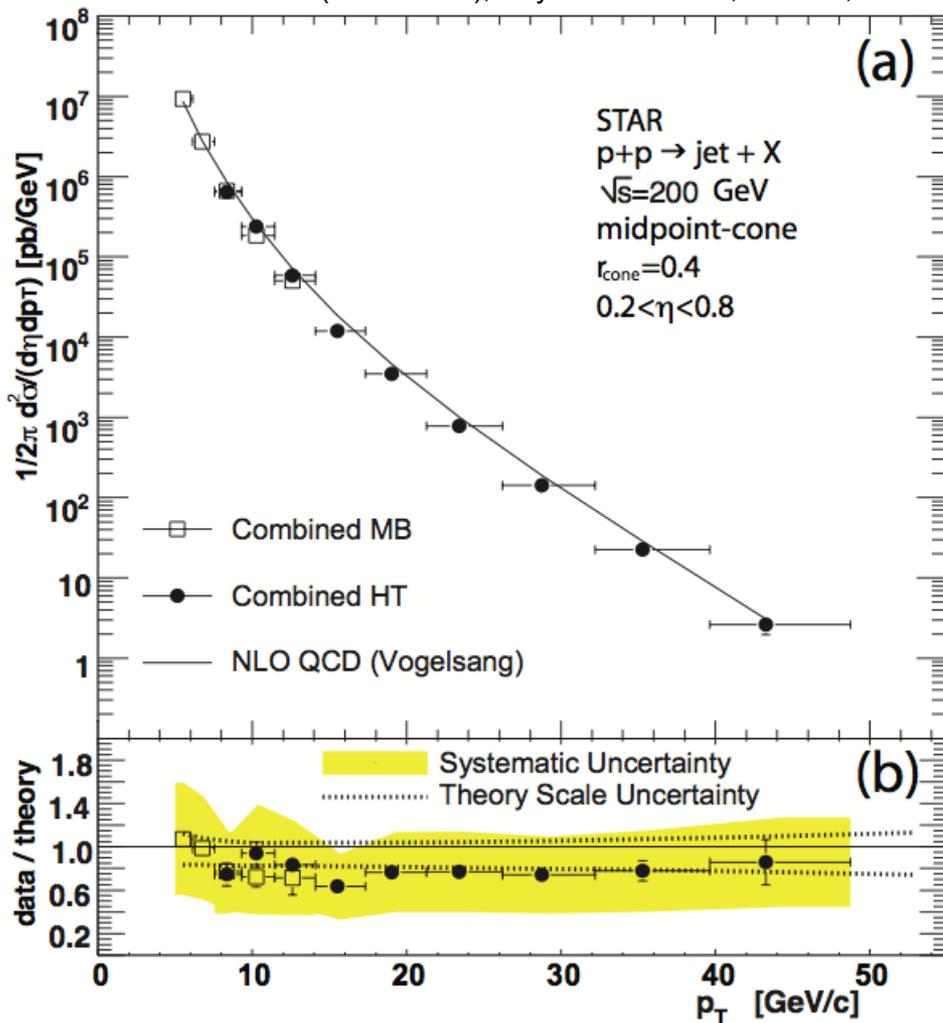
[http://www.bnl.gov/npp/docs/STAR\\_Decadal\\_Plan\\_Final%5B1%5D.pdf](http://www.bnl.gov/npp/docs/STAR_Decadal_Plan_Final%5B1%5D.pdf)



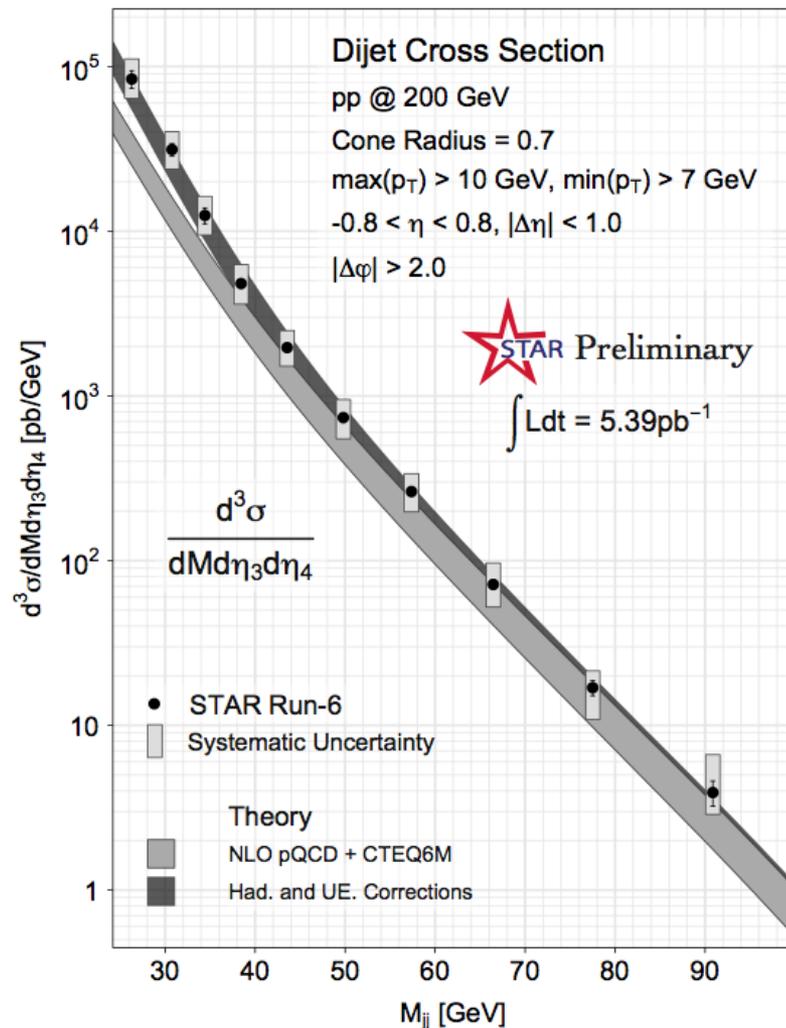
- What is the nature of QCD matter at the extremes?
  - What are the properties of the strongly-coupled system produced at RHIC, and how does it thermalize?
  - Are the interactions of energetic partons with QCD matter characterized by weak or strong coupling? What is the detailed mechanism for partonic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

	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	$\Upsilon$ , $J/\psi \rightarrow ee$ , $m_{ee}$ , $v_2$	$\Upsilon$ , $J/\psi \rightarrow \mu\mu$ , Charm $v_2$ , $R_{CP}$ , Charm corr, $\Lambda_c/D$ ratio, $\mu$ -atoms	$p+A$ comparison
(2) Mechanism of energy loss	Jets, $\gamma$ -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	$W_{AL}$ , jet and di-jet $A_{LL}$ , intra-jet corr, $(\Lambda + \bar{\Lambda}) D_{LL}/D_{TT}$		$\Lambda D_{LL}/D_{TT}$ , 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, $J/\psi$ , F-F corr, $\Lambda$ , DIS, SIDIS

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



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

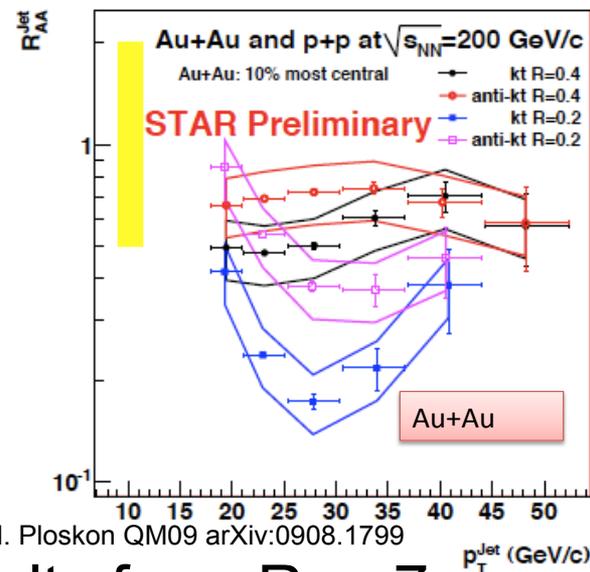
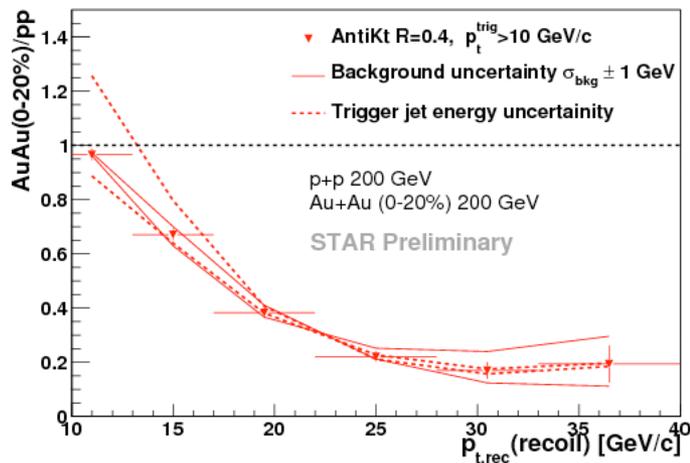
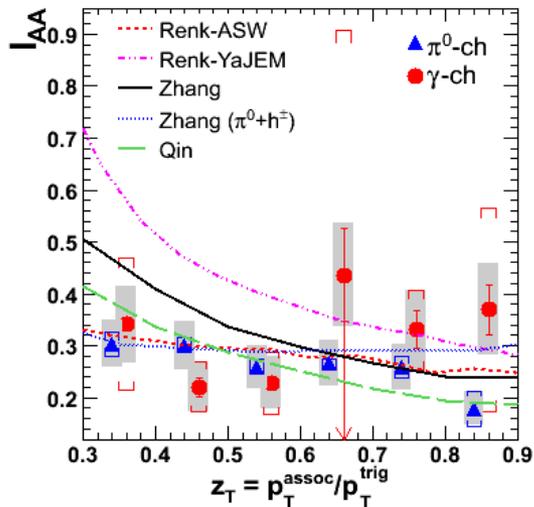


Jets well understood in STAR, experimentally and theoretically

Phys. Rev. C 82, 034909

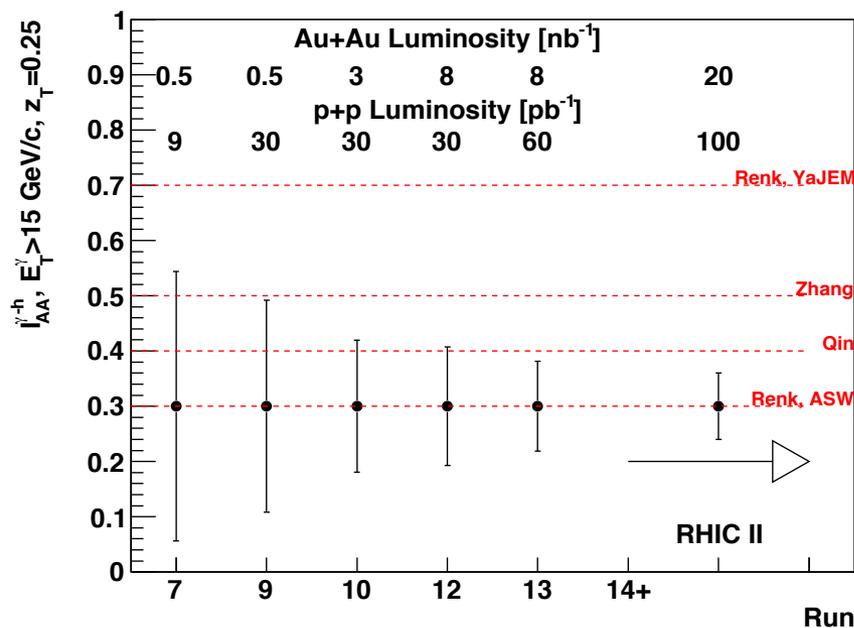
Triggered:  $\sim 0.3 \text{ nb}^{-1}$

Untriggered:  $\sim 0.01 \text{ nb}^{-1}$

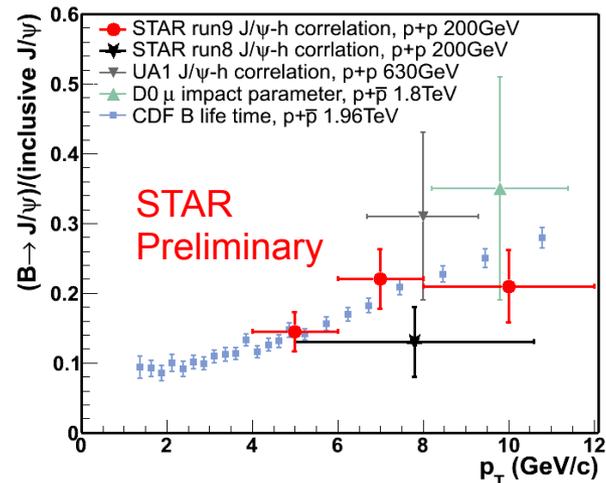
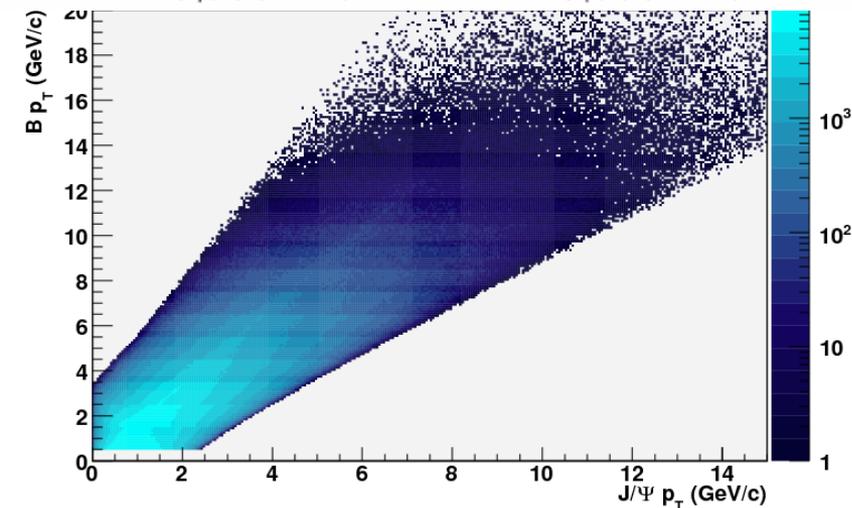
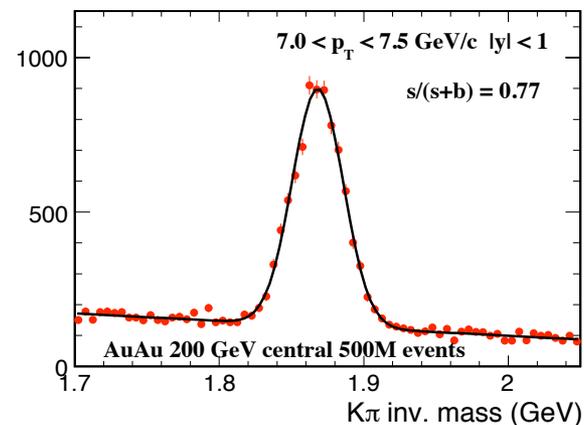
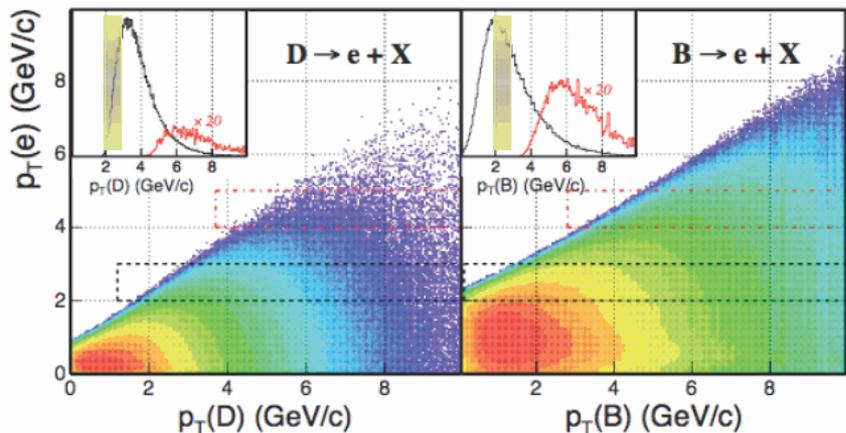


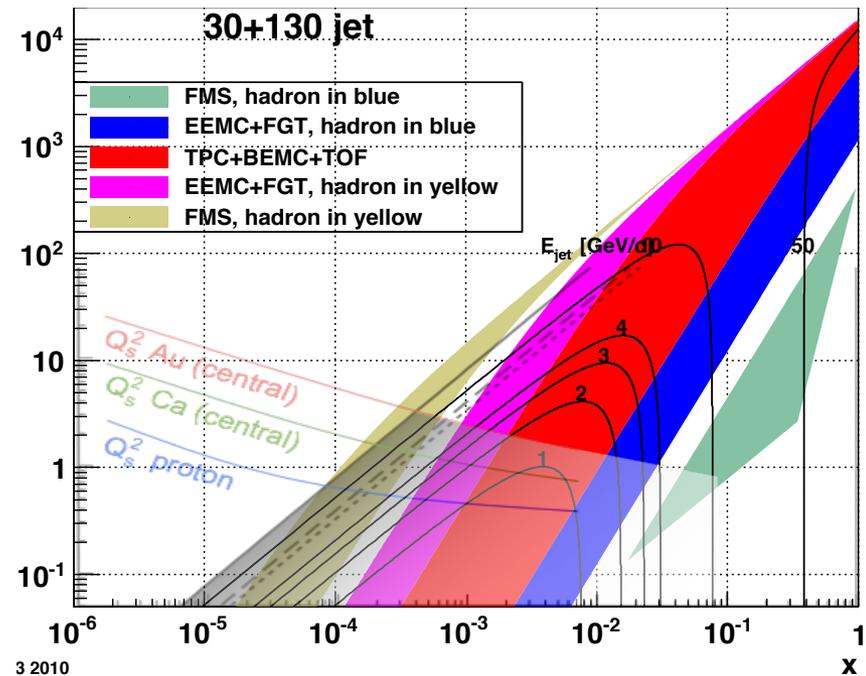
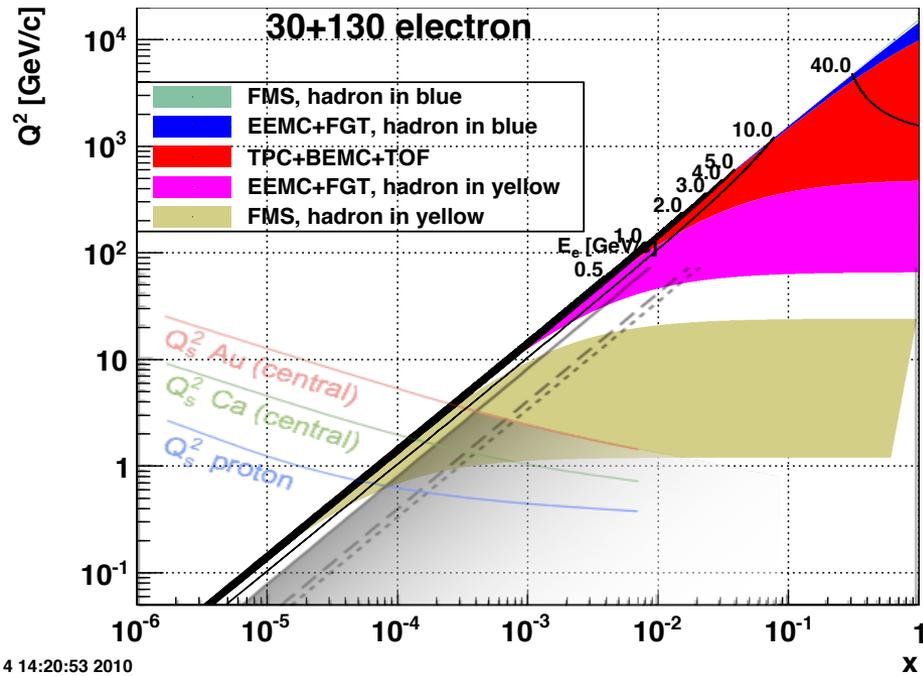
M. Ploskon QM09 arXiv:0908.1799

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  $< \sim 50 \text{ GeV}$

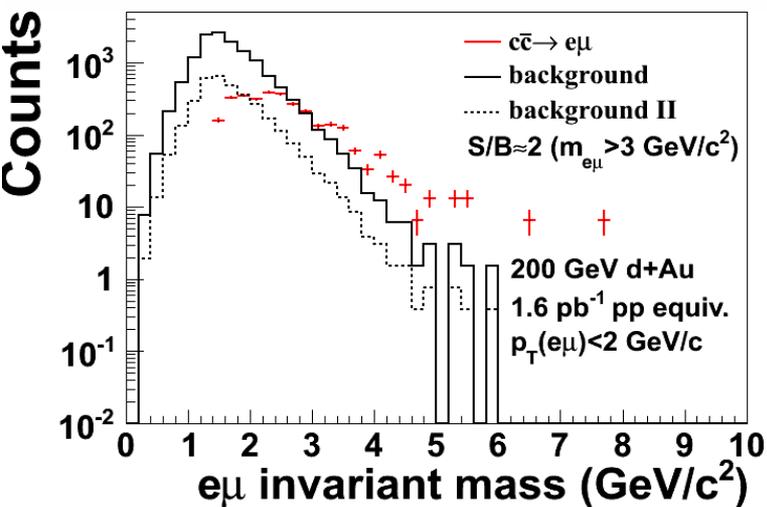
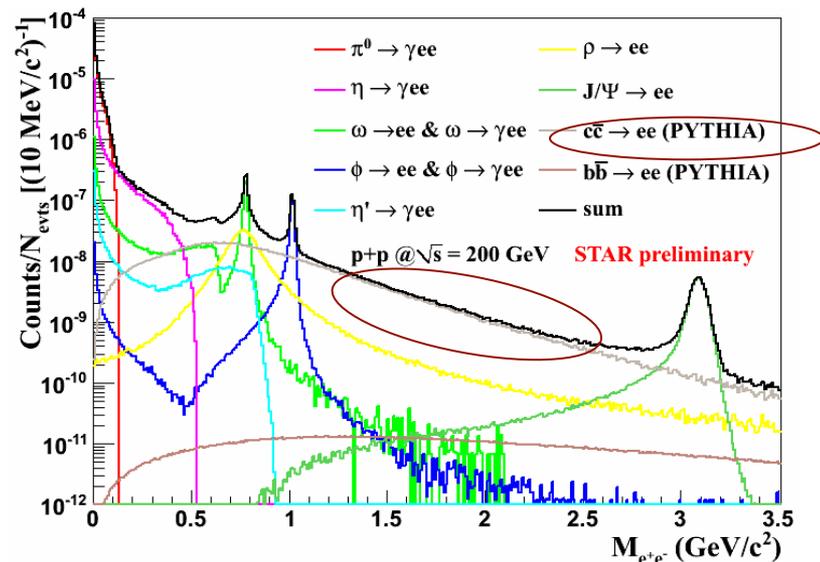
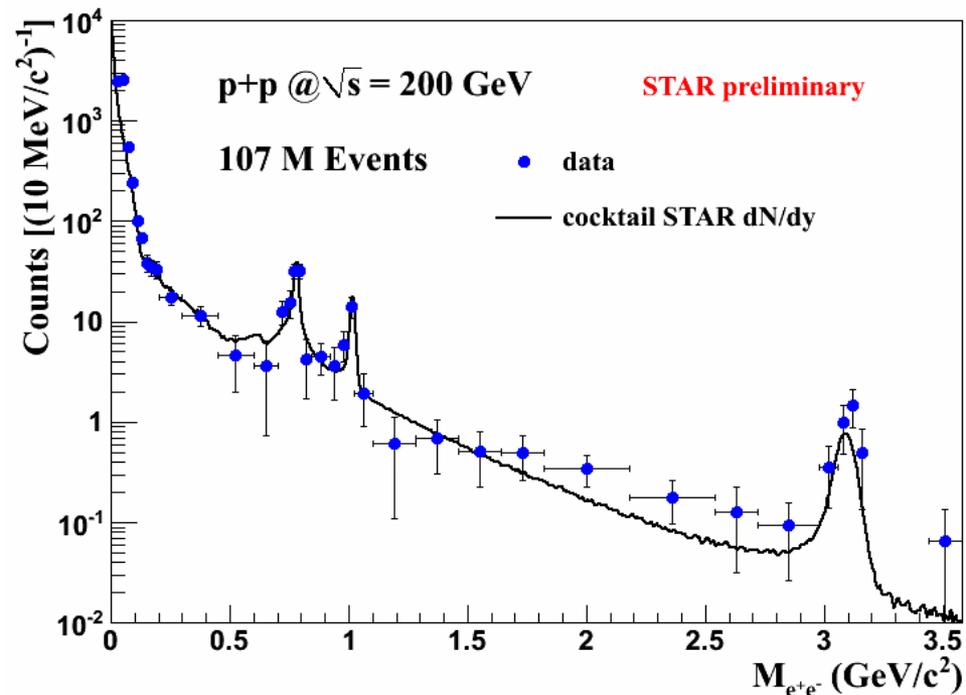


- What is the dependence of energy loss on parton mass?
  - Key tools: heavy quarks with precise kinematic reconstruction
  - Key technology: Heavy Flavor Tracker and Muon Telescope Detector

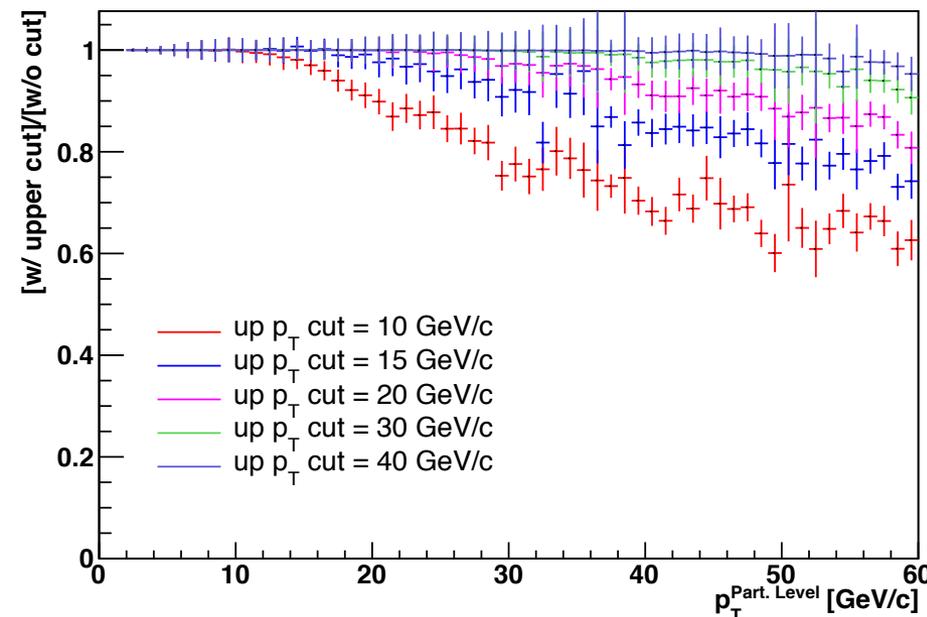
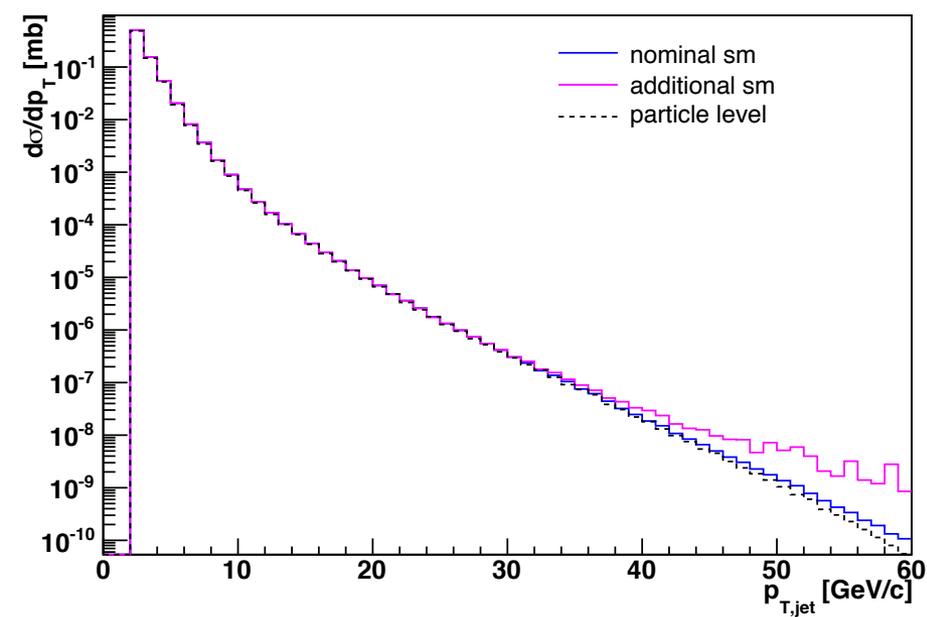




- Forward region critical for higher energy options
- Major upgrades in forward direction would be needed

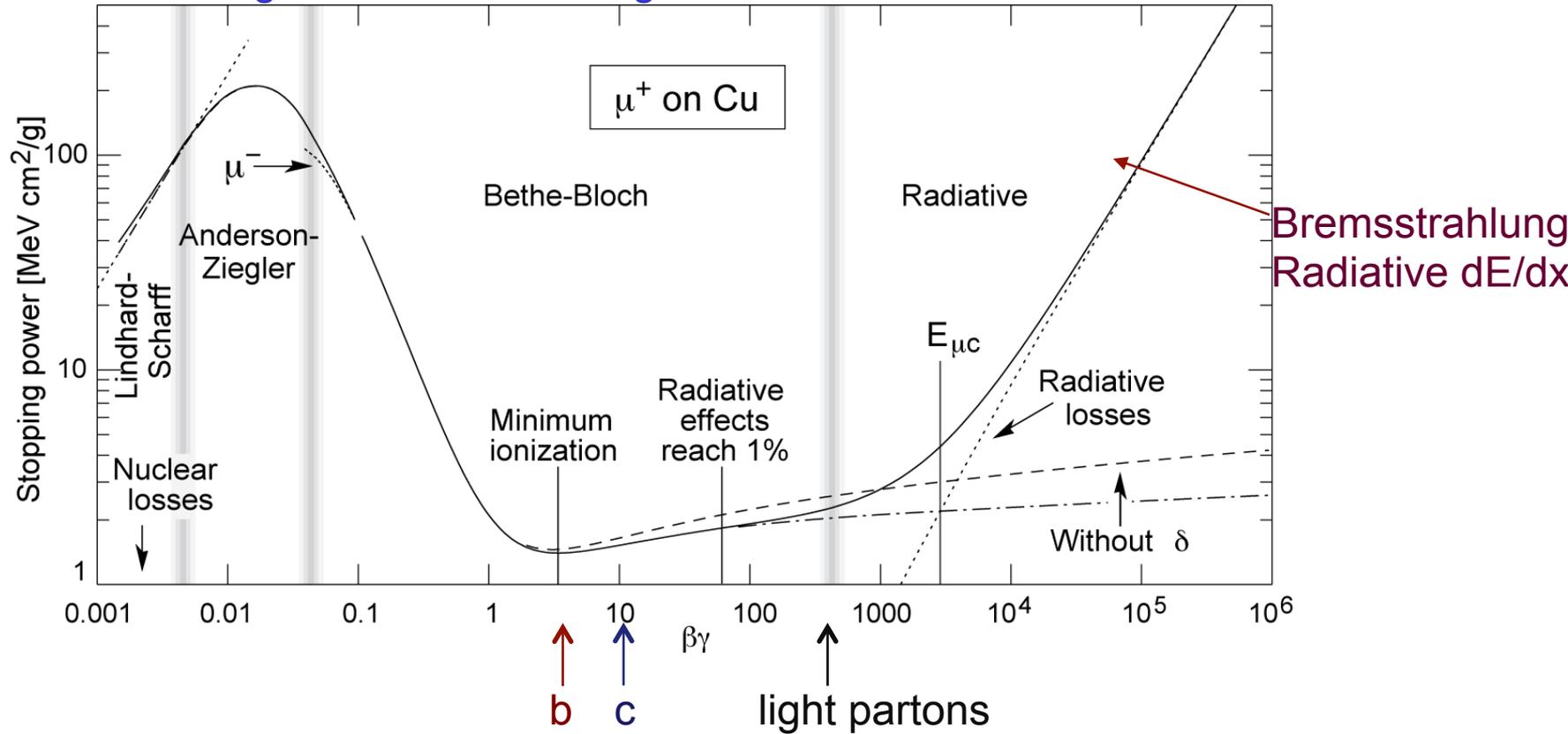


- Precise measurements with TOF, DAQ upgrade
- Correlated charm in A+A
  - Decorrelation? Order of magnitude uncertainty
- Address with:
  - HFT:  $D^0$ , displacement
  - MTD: e- $\mu$  correlations



- Sufficient statistical reach out to  $\sim 50$  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**

“Passage of Particles through Matter”, Particle Data Book



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