Highlights of the "QCD at High Temperature" Parallel Sessions

July 19-21, 2006

Saskia Mioduszewski, Rene Bellwied, Tony Frawley

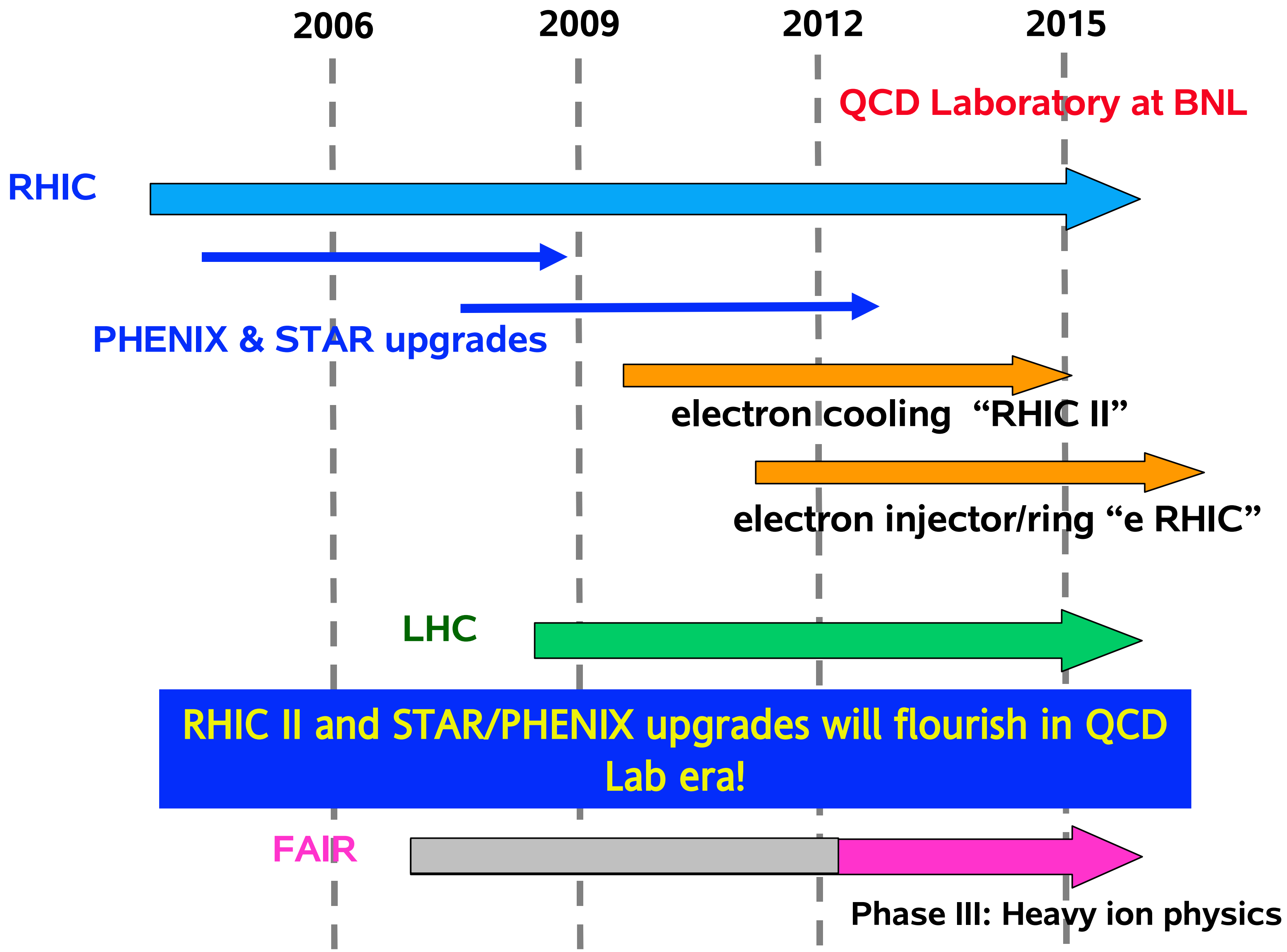
July 22, 2006

14 talks over three afternoons of parallel sessions.

Very lively discussions!

We have time here only for a few "take home" messages.

Long Term Timeline of Heavy Ion Facilities



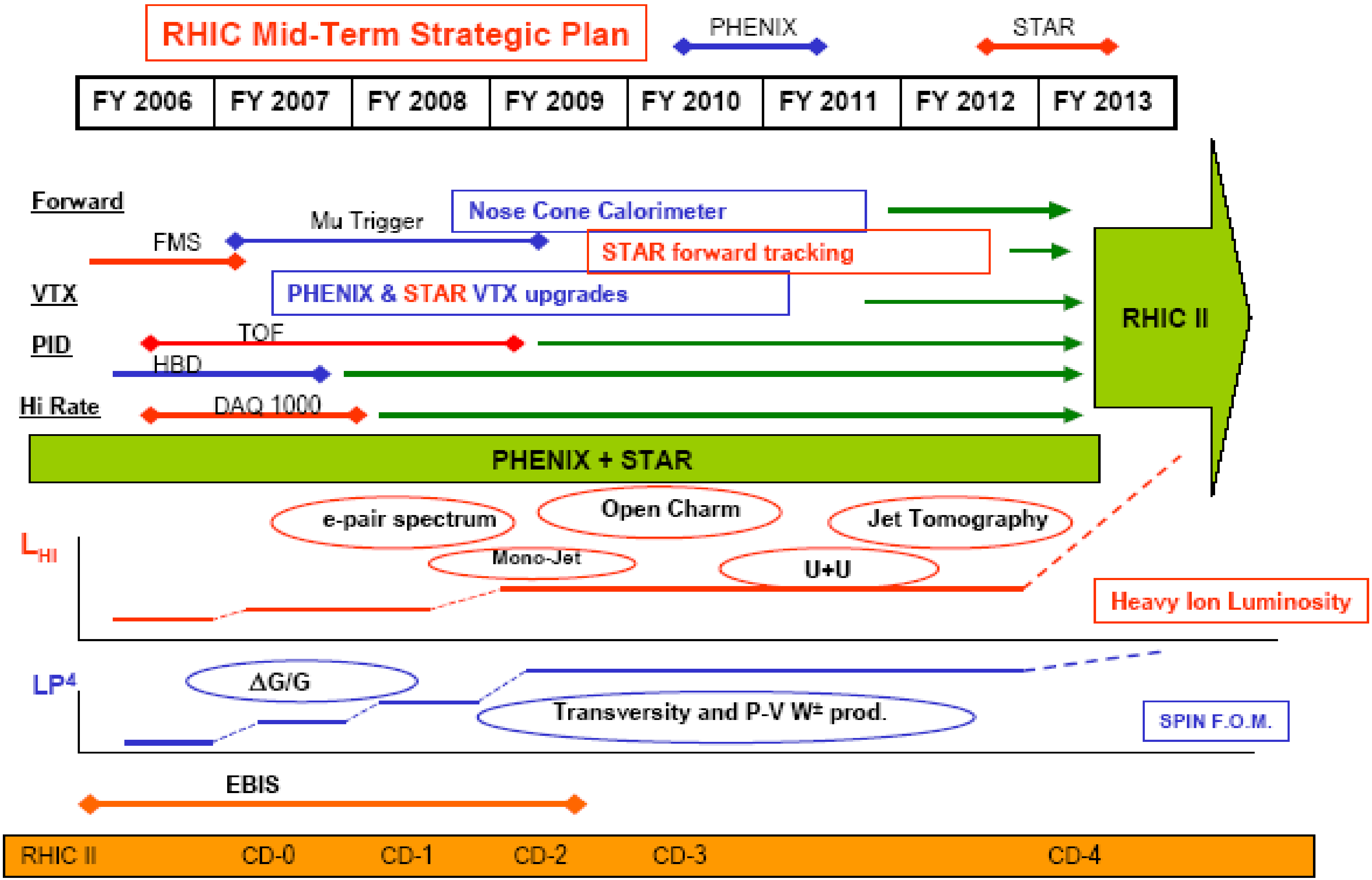


Figure 2
Graphic illustration of the Mid-Term Plan

QGP plasma properties known, so far

Barbara Jacak

Extract from models, constrained by data

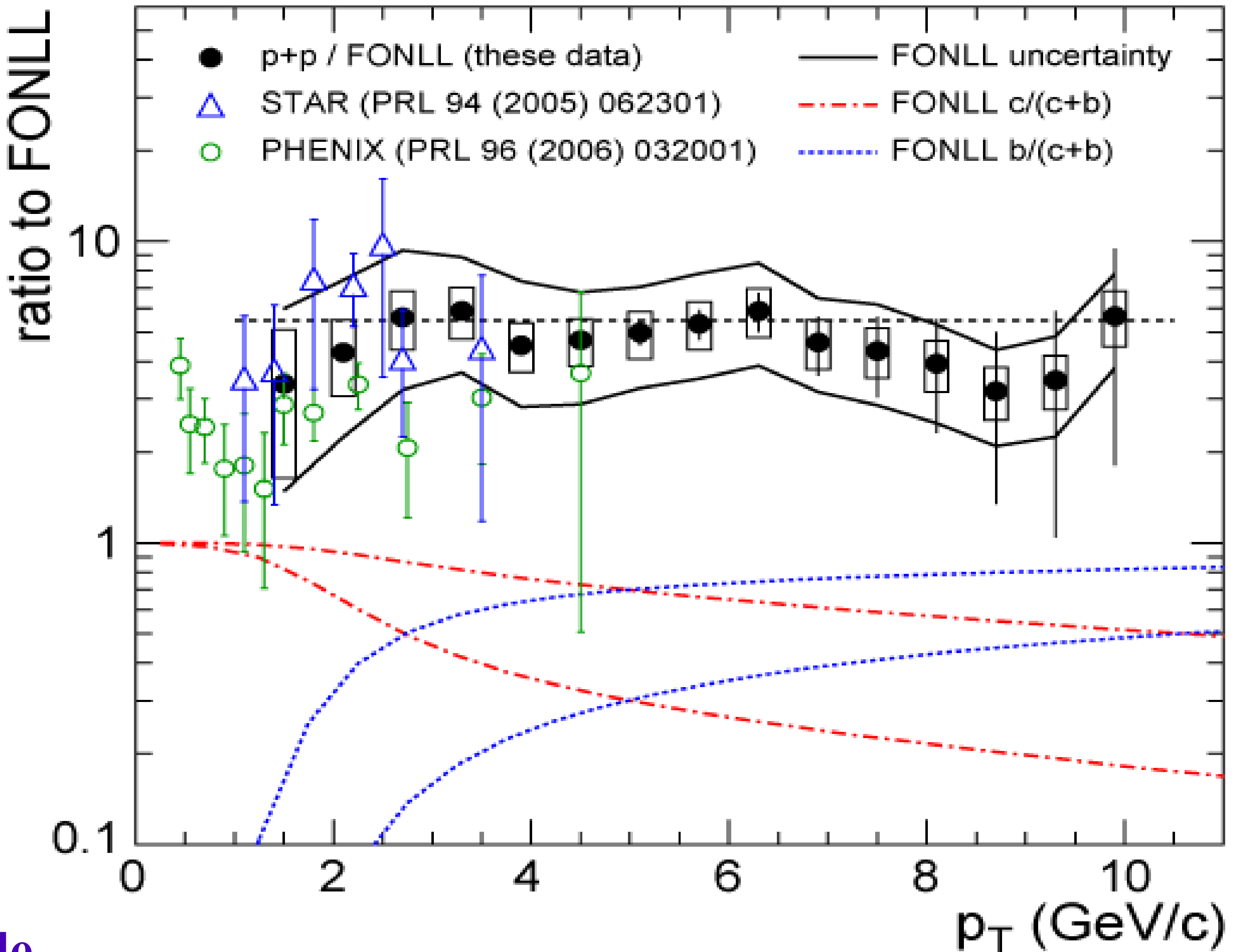
Energy loss <dE/dz> (GeV/fm)	7-10	0.5 in cold matter
Energy density (GeV/fm^3)	14-20	>5.5 from E_T data *above hadronic E density!*
dN(gluon)/dy	~1000	From energy loss, hydro *huge!*
T (MeV)	380-400	*Experimentally unknown as yet*
Equilibration time τ_0 (fm/c)	0.6	From hydro initial condition; cascade agrees *very fast!* *NB: plasma folks have same problem & use same technique*
Opacity (L/mean free path)	3.5	Based on energy loss theory
viscosity	~0	hydro constrained by flow

Plasma properties we will measure at RHIC II

property	measurement
T	γ, γ^* as fn. of ε, μ
equation of state	particle flows as fn. of ε, μ critical point location
screening length	onium spectroscopy
ρ (x,v)	jet tomography
diffusion	open C, B spectra & flow
viscosity	strange & charmed hadron flows used to constrain 3d hydro
energy transport	>2 particle correlations vs. T, p_T

Barbara Jacak

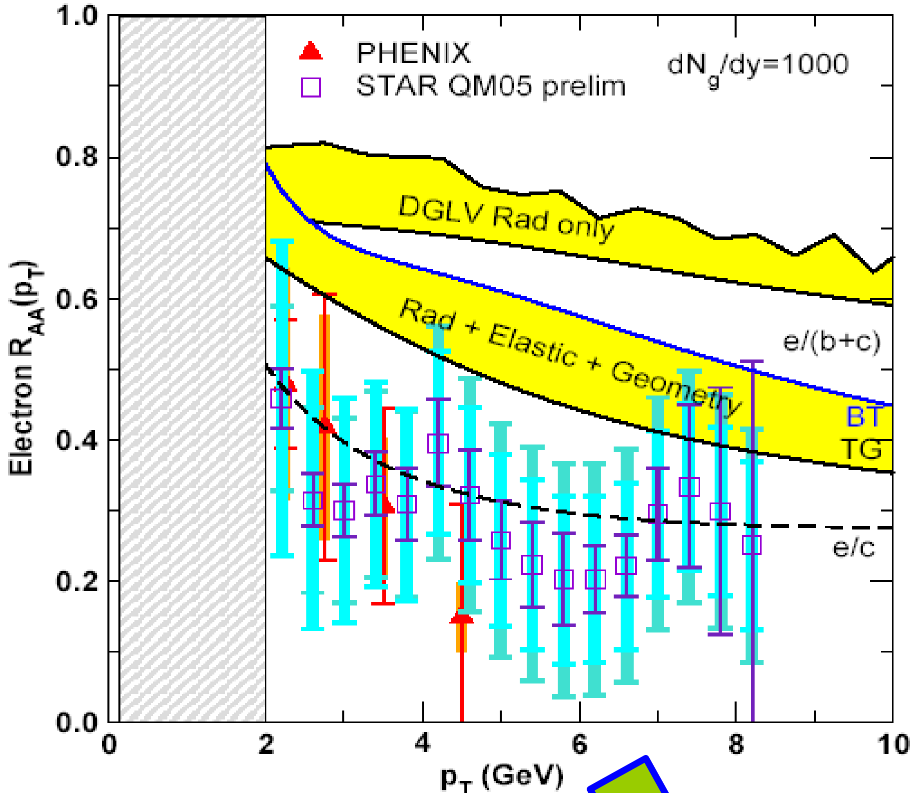
Charm Measurements at RHIC disagree with FONNL
(and, to a smaller extent, with each other!)

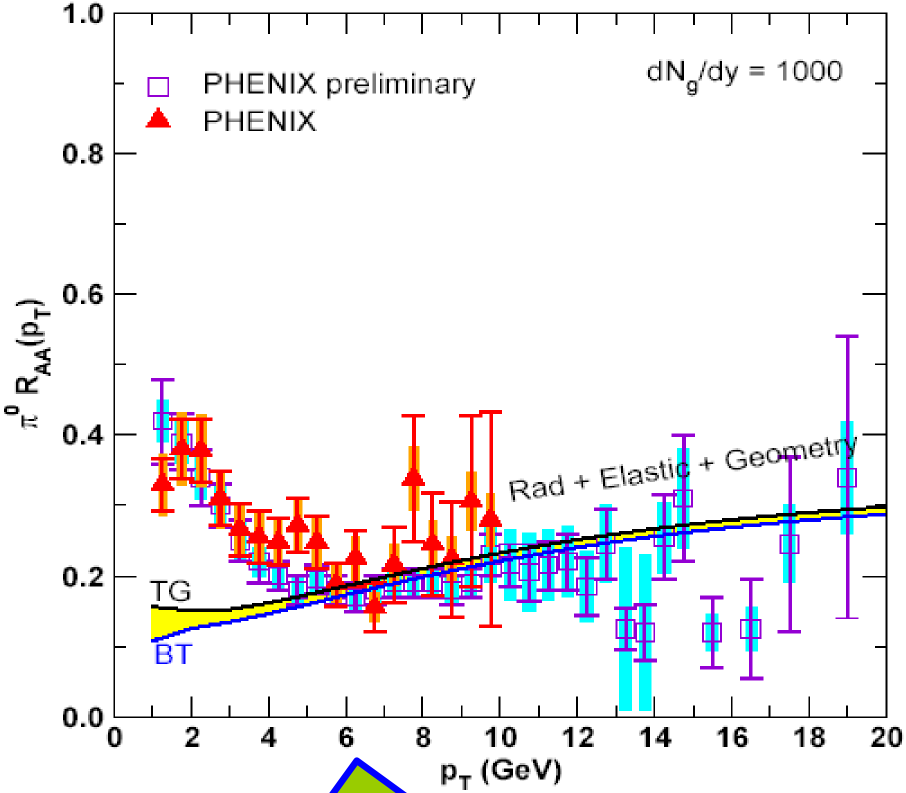


Alex Suiade

Most up to date pion and single electron predictions (collisional + radiative)

(S. Wicks, W. Horowitz, M.D. and M. Gyulassy, nucl-th/0512076)





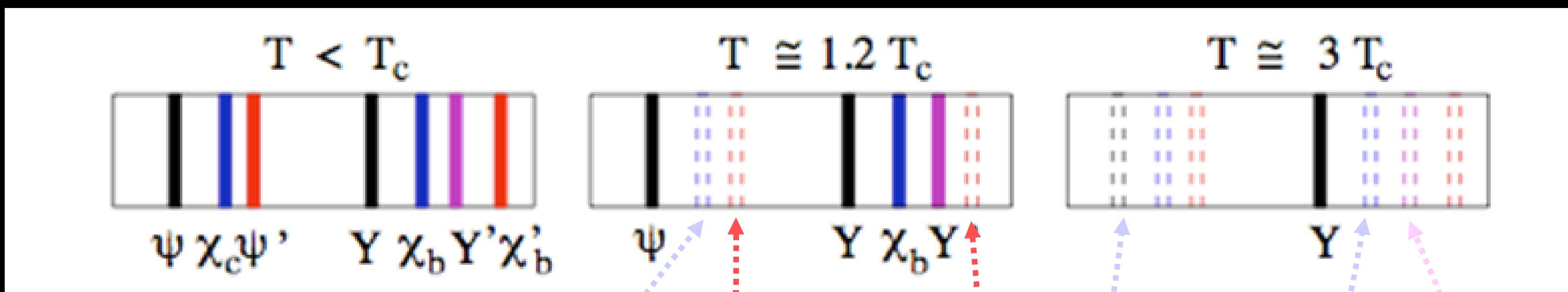
Inclusion of collisional energy loss leads to good agreement with pions and an improved agreement with single electron data at dN_g/dy=1000.

Magdalena Djordjevic

Need to separate charm and bottom. Is bottom thermalized? If so, how!

Quarkonium – Thermometer of Dense QCD

Satz, HP2006



$T_{RHIC} > T_{melt}(\chi_c)$, $T_{melt}(\Psi')$, $T_{melt}(\Upsilon(3S))$

$T_{LHC} > T_{melt}(J/\Psi)$, $T_{melt}(\chi_b)$, $T_{melt}(\Upsilon(2S))$

$T_{melt}(\Psi') < T_{melt}(\Upsilon(3S)) < T_{melt}(J/\Psi) \approx T_{melt}(\Upsilon(2S)) < T_{RHIC} < T_{melt}(\Upsilon(1S))$?

Quarkonium and Open Heavy Flavor

* large background
** states maybe not resolved
*** min. bias trigger
**** pt > 3 GeV

Will be statistics limited at RHIC and LHC!

Compiled by T.Frawley

Signal $\|\eta\|$ or η	PHENIX <0.35, 1.2-2.4	STAR <1	ALICE <0.9, 2.5-4	CMS <2.4	ATLAS <2.4
$J/\Psi \to \mu\mu$ or ee	440,000	220,000	390,000	40,000	8K-100K
$\Psi' \to \mu\mu$ or ee	8000	4000	7,000	700	140-1800
$\chi_c \to \mu\mu\gamma$ or $ee\gamma$	120,000 *	-	-	-	-
$\Upsilon \to \mu\mu$ or ee	1400	11000**	6000	8000	15,000
$B \to J/\Psi \to \mu\mu$ (ee)	8000	2500	12,900	-	-
$D \to K\pi$	8000****	30,000***	8,000	-	-

Potential improvements with dedicated experiment

4π acceptance	J/Ψ, Ψ'	10x
	Υ	2-10x
background rejection	χ_c	????

LHC relative to RHIC

Luminosity ~ 10%
Running time ~ 25%
Cross section ~ 10-50x

Note: for B, D increase by factor 10 extends p_T by ~3-4 GeV

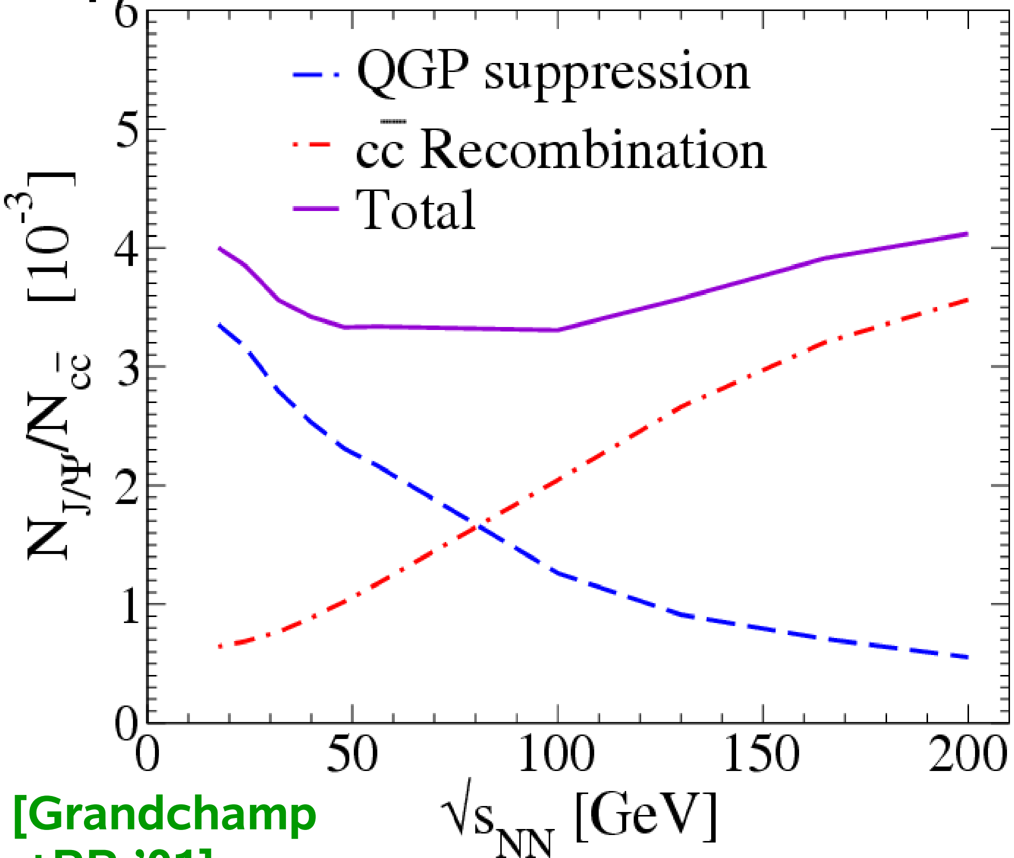
~ similar yields!

There is room for improvement if needed!

Axel Drees

3.3.2 Observables II: Excitation Function + Rapidity

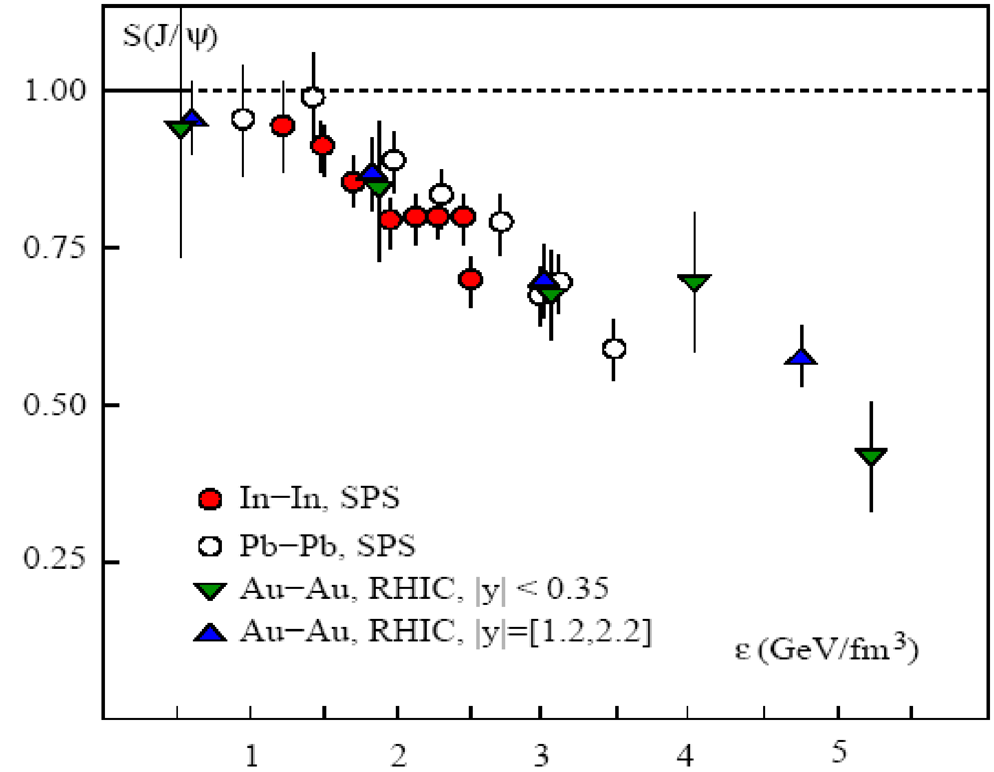
J/ψ Suppression vs. Regeneration



[Grandchamp +RR '01]

- nontrivial "flat" dependence
- similar interplay in rapidity!? (need accurate dN_c/dy)

Sequential Ψ'+ χ_c Suppression



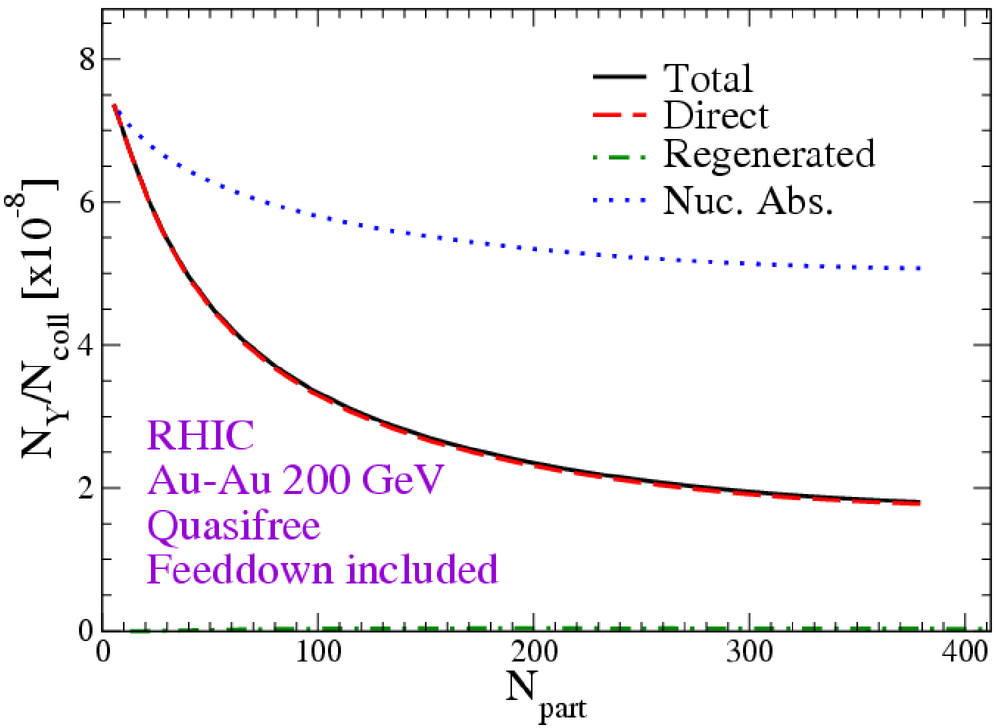
[Karsch,Kharzeev+Satz '06]

- direct J/ψ essentially survive (even at RHIC)

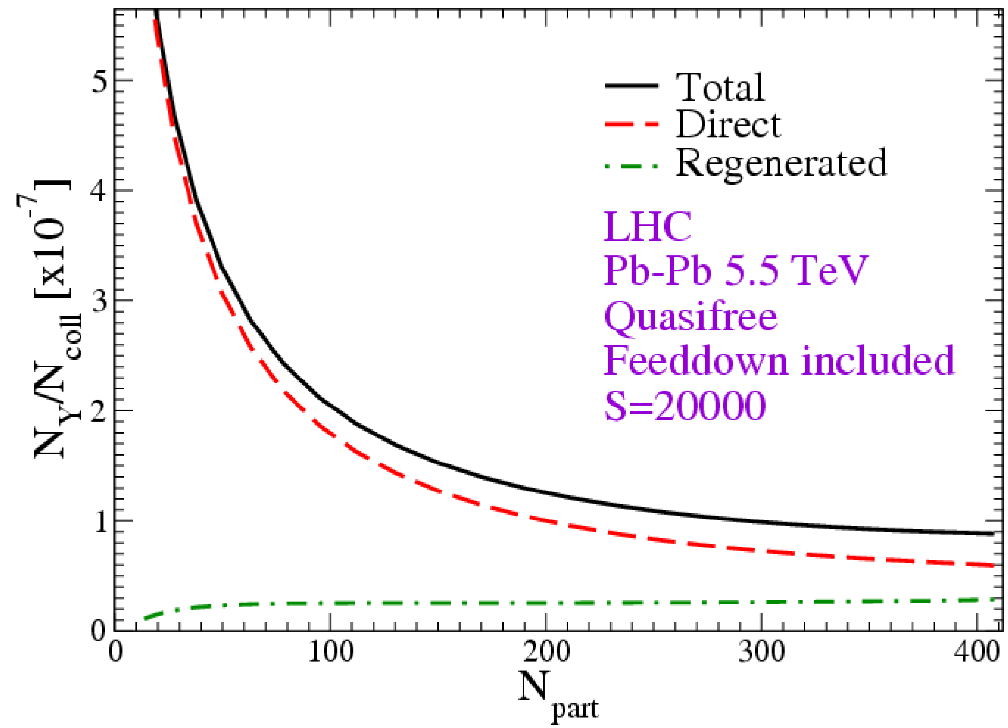
Ralf Rapp

3.3.3 Bottomonium at RHIC and LHC

RHIC



LHC



- **50% feeddown from Υ’, χ_b**
- importance of **color-screening!**
- **bottomonium suppression as unique QGP signature ?!**

[Grandchamp etal ’05]

Ralf Rapp

Quarkonia – Goals and Requirements

Physics Motivation	Probes	Studies	Requirements
Baseline	J/ψ, ψ', ϒ(1S), ϒ(2S), ϒ(3S) through μμ and ee decay channels	Rapidity $y(x_F)$ and p_T spectra in AA, pA, pp as a function of A, $\sqrt{s}$	High luminosity and acceptance. High resolution to resolve ϒ states
Deconfinement & Initial Temperature	J/ψ, ψ', ϒ(1S), ϒ(2S), ϒ(3S)	Melting patterns of quarkonia states	Extract suppression mechanism taking into account: feed down, nuclear absorption, and recombination
Properties of the medium	High-p_T J/ψ	R_{AA}: Dissociation ↔ Quenching	High luminosity
Thermalization &Transport properties of the Medium	J/ψ	J/ψ flow (v_2) as a function of A, $\sqrt{s}$ Recombination: y and $\langle p_T^2 \rangle$	High luminosity to obtain good statistics in short time (A, $\sqrt{s}$ scans)

Alex Suiade

Handles of Jet tomography

- Single particle spectra
  - PID spectra out to high pT ($\pi^{0\pm}$, η, k, p,Λ) *
  - Direct photon. *
  - Heavy flavor to high pT (NP-electron, D→kπ) * *
- Jets
  - 2-particle correlation in $\Delta\phi$ and $\Delta\eta$ *
  - γ – h correlation. *
  - Identified – identified correlation *
  - Heavy flavor – hadron correlation (e-h, D-h). *
  - Multi-particle correlation *
  - Full jet reconstruction (γ-jet, HQ-jet) *

* Precision measurement

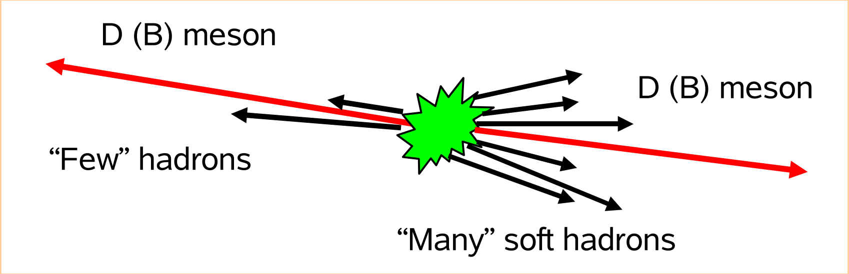
* Exploratory measurement

- Variables to explore
  - pT, centrality and η dependence.
  - Reaction Plane dependence (or v2 in single particle case)
  - Species dependence (Cu+Cu, Au+Au, U+U, A+B).
  - Energy dependence (sps energy → 200 GeV)
- Reference p+p, p+A

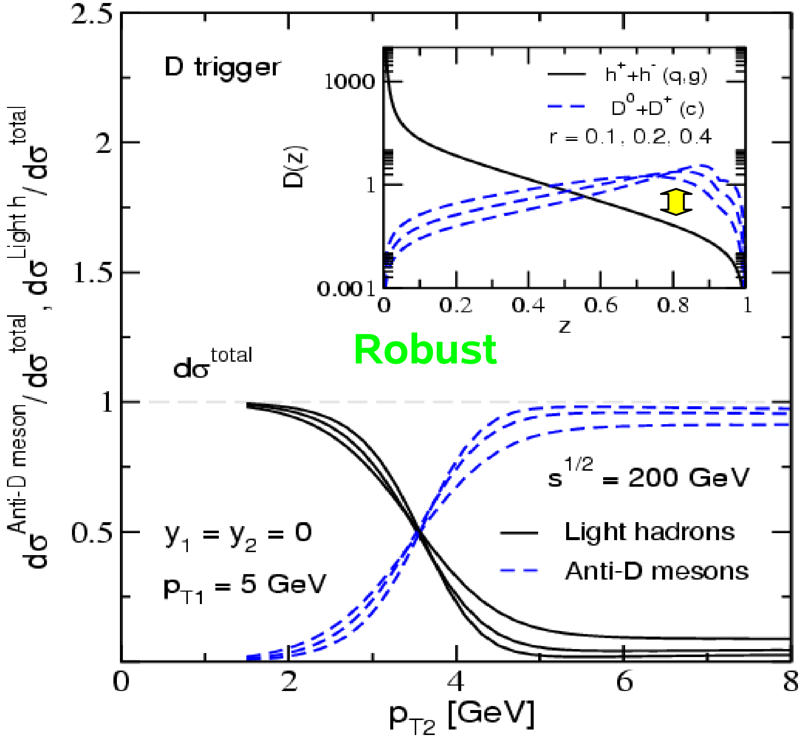
Jiangyong Jia

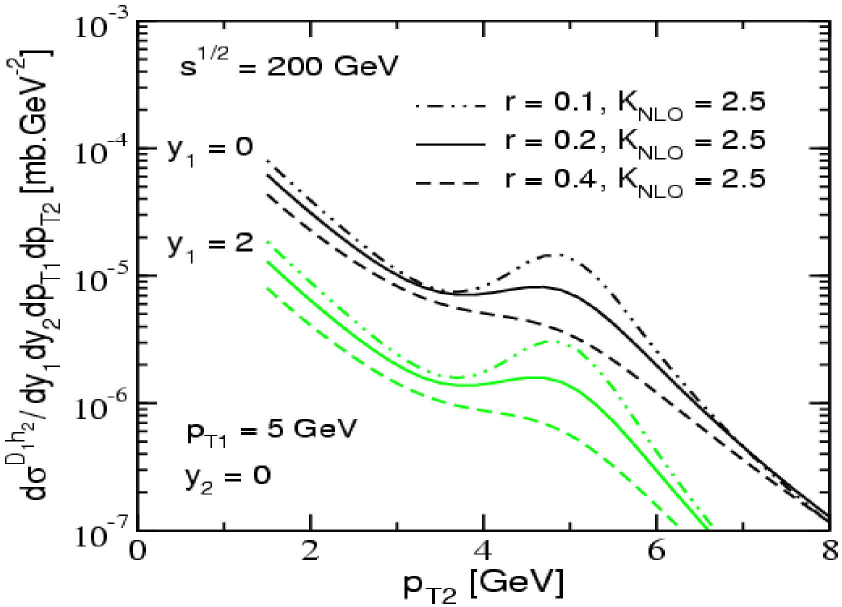
Hadron Composition of C (B) Triggered Jets

Possibility for new measurements of heavy flavor production at RHIC



- Can clarify the underlying hard scattering processes and open charm production mechanisms
- Can constrain the hardness of D and B meson fragmentation





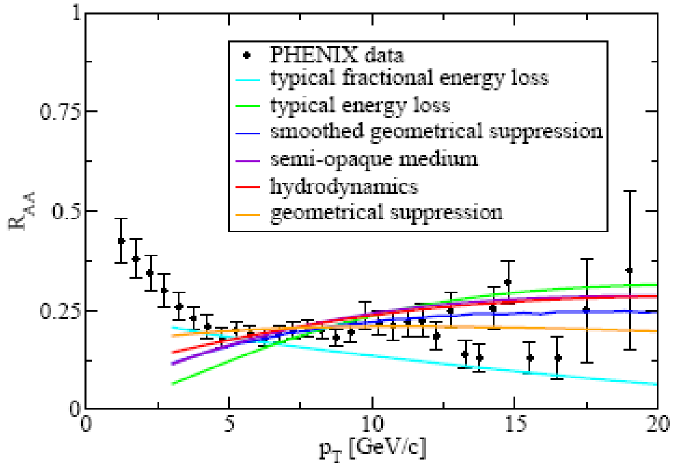
Ivan Vitev

Photon tagged jets

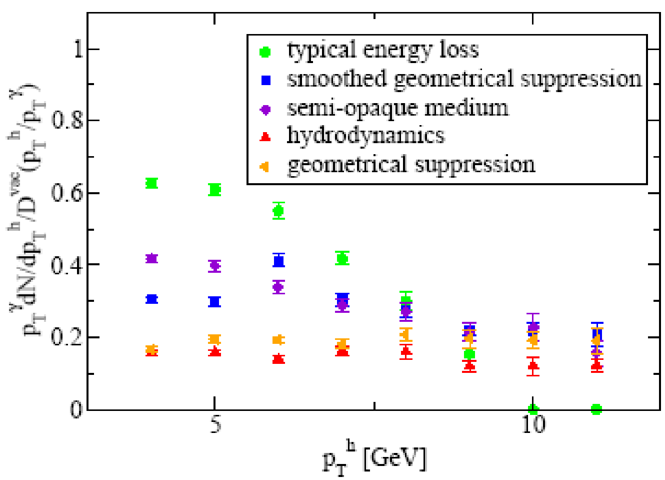
- "Golden" channel: $q + g \rightarrow q + \gamma$.
- Photon tags p_T (and flavor - *u*/*d* quark!) of scattered parton.
- Can be used to perform *jet tomography* (R_{AA} does not work)
- Important baseline and calibration for (opposite side) di-hadron tomography.

T. Renk, hep-ph/0607166

R_{AA} does not discriminate ?



γ-jet discriminates models



Berndt Mueller

Summary

Jets are *rich and discriminative probes* of the medium:

- Strong energy loss agrees semi-quantitatively with theory;
- Probes of a well defined transport coefficient: q-hat;
- Quantitative determination of q-hat requires sophisticated and realistic description of medium evolution (transport);
- Rigorous, nonperturbative calculation of q-hat in QCD ?
- Relative weight of radiative and collisional energy loss ?
- Dependence on primary parton flavor ?
- Interaction of radiated energy with medium probes dissipation mechanisms and collective QGP modes.

Jet studies at the LHC will complement and greatly extend the RHIC measurements, but a lot remains to be explored at RHIC (heavy quarks, photon-jet correl's, di- and multi-hadron correl's with particle ID, etc.)

If ϕ and Ω are produced mainly by the recombination of thermal s quarks, then no jets are involved.

Select events with ϕ or Ω in the $3<p_T<5$ region, and treat them as trigger particles. Look for associated particles in the $1<p_T<3$ region.

Predict: no associated particles giving rise to peaks in $\Delta\phi$, near-side or away-side.

Suggested future measurement

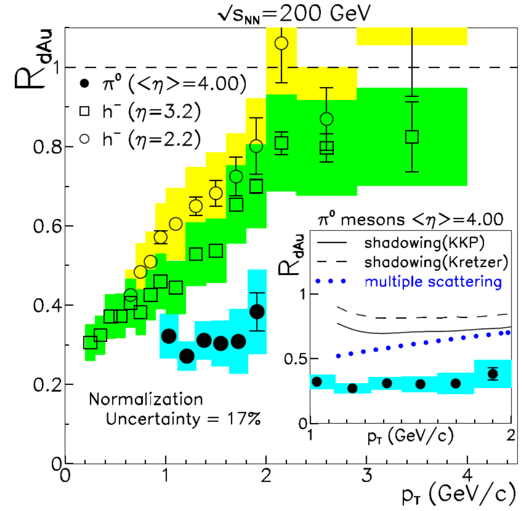
Verify or falsify that prediction

Rudy Hwa

Forward Physics and Gluon Saturation in the RHIC-II Era

Mike Leitch – LANL (leitch@lanl.gov)

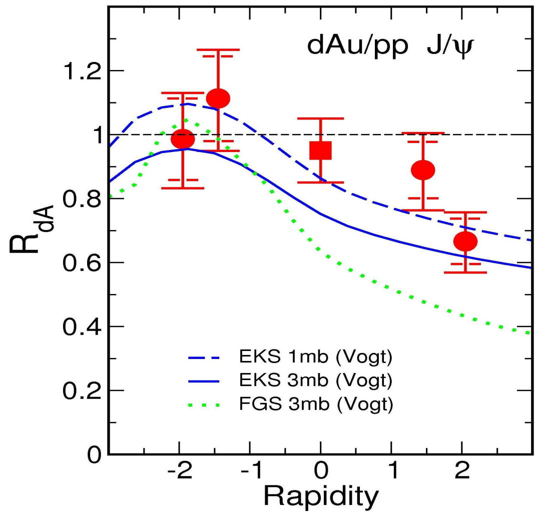
Future Prospects in QCD at High Energy, 17-22 July 2006, BNL



Physics at large rapidity & small-x:

cold nuclear matter (CNM) effects & gluon saturation

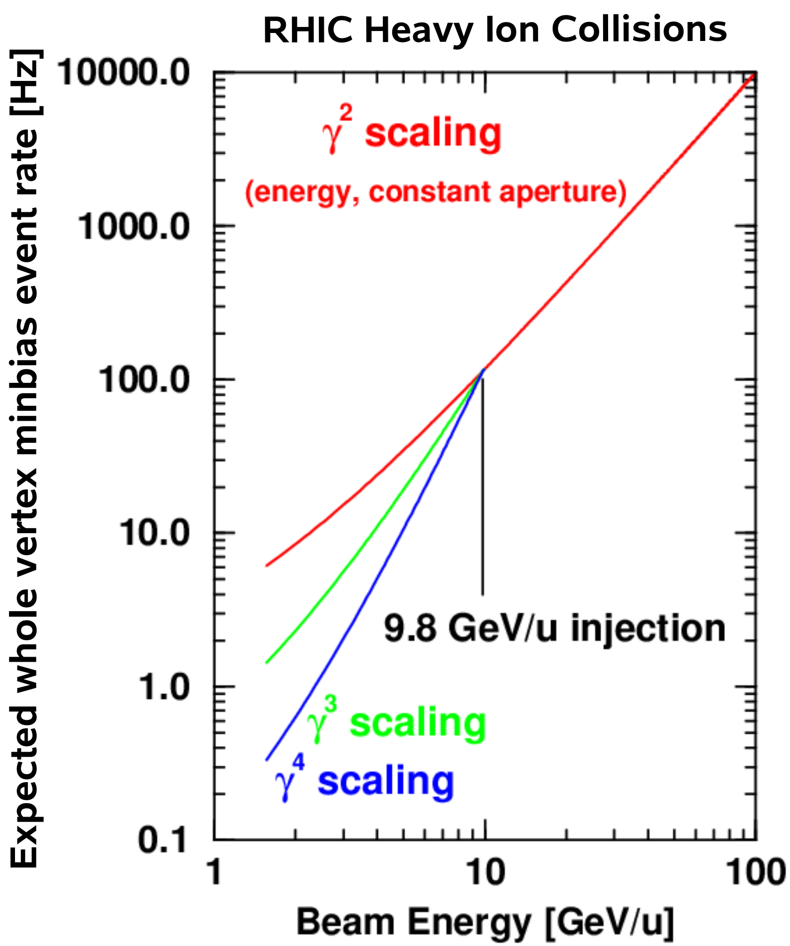
- quarkonia
- forward hadrons
- correlations & mono-jets
- open heavy quarks
- UPC's



These are essential **control measurements** for hot dense QCD studies.

RIKEN Workshop Accelerator Summary (April 2006)

- No apparent show-stoppers for RHIC collisions at E_{cm} = 5-50 GeV/n
  - Only equal energies
  - Unequal species possible only if minimum rigidity > 200 T-m
  - Without cooling → long vertex distribution
- Small set of specific energies (and species?) should be a workshop deliverable for planning
  - 2.5,3.2,3.8,4.4… GeV/n total beam energy
- Studies that should be done soon:
  - A ~1 day study period at low total beam energy to identify power supply, lifetime, tuning issues/limitations
  - Low-current superconducting magnet measurements
- Pre-cooling in AGS → 10+x luminosity ?
- RHIC electron beam cooling would make this a fantastic facility: ~100x luminosity, small vertex distribution, long stores.



T. Roser, T. Satogata

Summary

- There is substantial and growing interest in RHIC operations at low energies ($\sqrt{s_{NN}}$= 5-50 AGeV)
  - Discovery of the QCD critical point would be another major discovery at RHIC
- There are no show-stoppers to a low-energy program
  - Low-energy ($B\rho$=37.4 T-m) test run occurred June 5-6 2006
  - Addressable issues: sextupoles, instabilities, lumi monitoring
  - BUT RF challenges presently indicate <1Hz interaction rates
- Future planning
  - ~1 week at low energy in 2007 with Au is natural next step
  - Recommended energies: $\sqrt{s_{NN}}$=7.6 GeV/u, test at $\sqrt{s_{NN}}$=5 GeV/u
  - Low-energy electron cooling in both AGS and RHIC look very beneficial in multi-year timescale, but require program support

Todd Satogata

Conclusions

- There is much interest in a RHIC low energy scan program.
- PHENIX is capable of producing high quality measurements now and in the future on the wide variety of observables that could be needed to isolate the QCD critical point.
- PHENIX would benefit from a centrality detector designed specifically for low energy running.
- However, to cover all the bases, it would be nice to complete the program with:
  - Enough energy steps with sufficient statistics to map out any inflections about the critical point.
  - More than one species in order to investigate universal behavior and critical exponents near the critical point.
  - Companion p+p and/or d+Au data at each energy in order to reduce any systematic errors in measuring baseline distributions – very important for R_{AA} measurements.
- Estimated time for a 3σ correlation function critical exponent measurement (η): 18 days at 20 GeV

Jeff Mitchell

Some Key Measurements

- yields and particle ratios
  $\rightarrow$ *T and μ_B*
- elliptic flow v_2
  $\rightarrow$ *collapse of proton flow?*
- k/π, p/π, $\langle p_T \rangle$ fluctuations
  $\rightarrow$ *the critical point signal*
- scale dependence of fluctuations
  $\rightarrow$ *source of the signal*
- v_2 fluctuations
  $\rightarrow$ *promising new frontier?*
- *Low mass dilepton measurements*
  $\rightarrow$ *Chiral symmetry restoration (?)*

Paul Sorensen

Heavy Ions in the QCD Lab – Fundamental QUESTIONS Requiring Real Answers

- Degrees of Freedom of the sQGP (when, how will we get this?)
- Properties of sQGP and characteristics of the phase transition

  (when can we describe these to others?)
  - Evolution of thermodynamic variables predicted from dynamical models
  - Fundamental properties predicted by fundamental theories - QCD, possibly AdS/CFT, others….
- Color Glass Condensate & evolution to QGP (requires all of above…)
- P and CP Violation near the QCD Phase Transition?
  - Large statistics data samples with reduced systematic errors
- Origin of Mass
  - Understanding hadronization from fragmentation into various flavors
- Chiral Symmetry Restoration
  - fragmentation into resonances in- and out-of-medium, chiral partners???

John Harris

Heavy Ions in the QCD Lab

- Real answers will require next generation RHI Experiment(s) at QCD Lab
  - This is an absolute necessity for this field to accomplish its goals!!
- One such experiment should include:
  - Large (nearly hermetic) acceptance
  - Identification of all hadrons track-by-track to large momenta
  - Flavor tagging capabilities track-by-track
  - Excellent resolution - track momenta and calorimetry (including γ's)
- Other experiments (small and/or large)?

Which Measurements are Unique at RHIC?

- General comparison to LHC
  - **LHC and RHIC (and FAIR) are complementary**
  - **They address different regimes (CGC vs sQGP vs hadronic matter)**
  - **Experimental issues: "Signals" at RHIC overwhelmed by "backgrounds" at LHC**
- Measurement specific (compared to LHC)
  - **Charm measurements: favorable at RHIC**

    Charm is a "light quark" at LHC, no longer a penetrating probe

    Abundant thermal production of charm

    Large contribution from jet fragmentation and bottom decay

    Bottom may assume role of charm at LHC
  - **Quarkonium spectroscopy: J/ψ, ψ' , χ_c easier to interpreter at RHIC**

    Large background from bottom decays and thermal production at LHC

    Upsilon spectroscopy can only be done at LHC
  - **Low mass dileptons: challenging at LHC**

    Huge irreducible background from charm production at LHC
  - **Jet tomography: measurements and capabilities complementary**

    RHIC: large calorimeter and tracking coverage with PID in few GeV range

    Extended p_T range at LHC

Axel Drees

Beyond PHENIX and STAR upgrades?

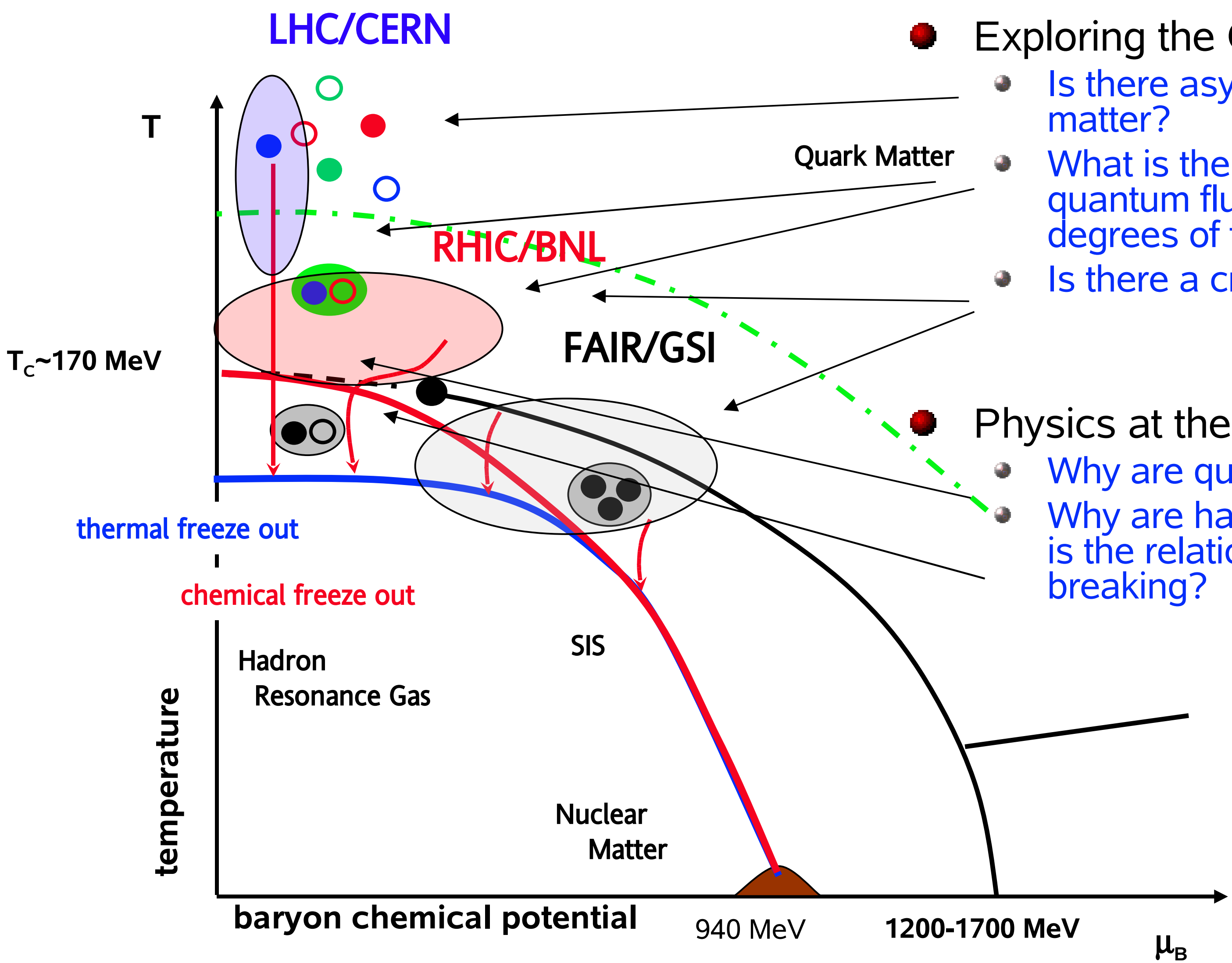
- Do we need (a) new heavy ion experiment(s) at RHIC?
  - **Likely, if it makes sense to continue program beyond 2020**
    - Aged mostly 25 year old detectors
    - Capabilities and room for upgrades most likely exhausted
    - Delivered luminosity leaves room for improvement
  - **Nature of new experiments unclear!**
    - Specialized experiments
    - 4π multipurpose detector …. "Die Eierlegendewollmilchsau"
- Key to future planning:
  - **First results from RHIC upgrades**
    - Detailed jet tomography, jet-jet and γ-jet
    - Heavy flavor (c- and b-production)
    - Quarkonium measurments (J/ψ, ψ', χ_c)
    - Electromagnetic radiation (e^+e^- pair continuum)
    - Status of low energy program
  - **Quantitative tests at LHC of models that describe RHIC data**
    - Validity of saturation picture
    - Does ideal hydrodynamics really work
    - Scaling of parton energy loss
    - Color screening and recombination

Axel Drees

New insights and short comings or failures of RHIC detectors will guide planning on time scale 2010-12

Heavy Ion Collisions Provide the Laboratory

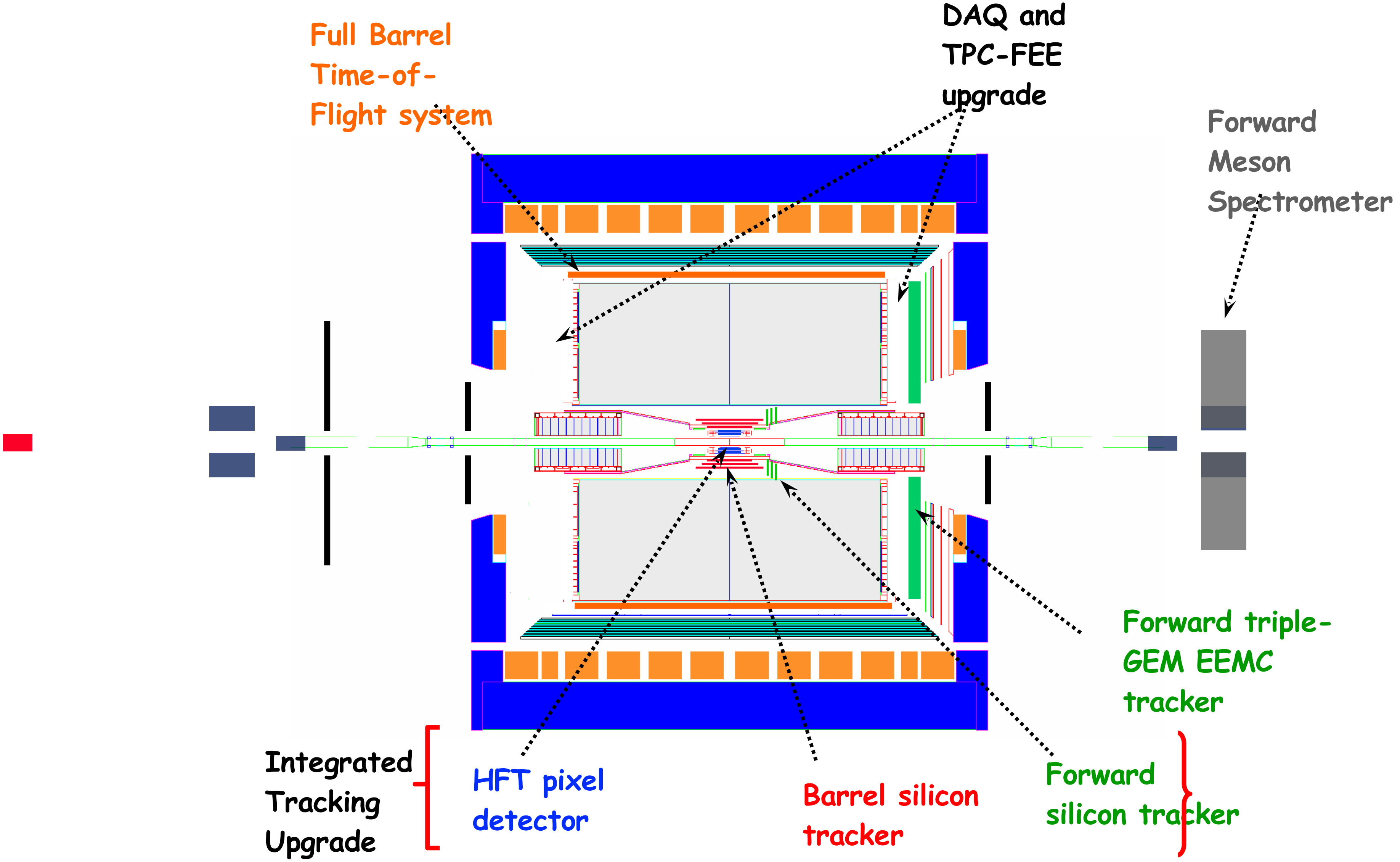
Different accelerators probe different regions of the phase diagram!



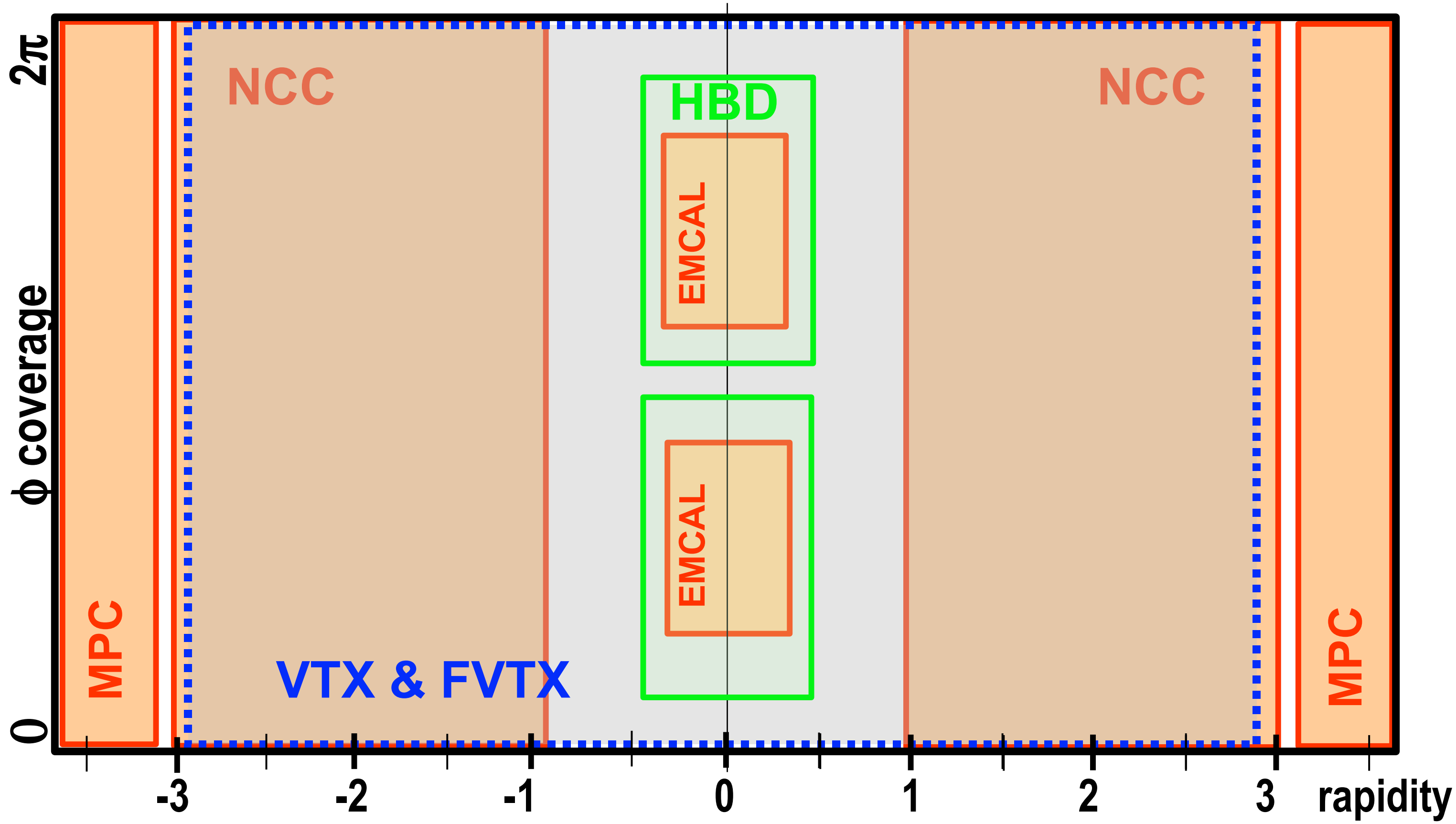
- Exploring the QCD phase diagram:
  - Is there asymptotically free quark matter?
  - What is the nature of a relativistic quantum fluid? What are the relevant degrees of freedom?
  - Is there a critical point?
- Physics at the phase transition:
  - Why are quarks confined in hadrons?
  - Why are hadrons massive and what is the relation to chiral symmetry breaking?

Backup

STAR Upgrades



Future PHENIX Acceptance for Hard Probes



(i) π^0 and direct γ with combination of all electromagnetic calorimeters

(ii) heavy flavor with precision vertex tracking with silicon detectors

combine (i)&(ii) for jet tomography with γ-jet

(iii) low mass dilepton measurments with HBD + PHENIX central arms