Physics of the Heavy Flavor Tracker at STAR

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The Bottom Line

① Hot and dense matter with strong collectivity has been formed in Au+Au collisions at RHIC. Study the properties of the new form of matter requires more penetrating probes like heavy quark. **New micro-vertex detector is needed for STAR experiment**

② PHENIX has a similar approach, but with a different philosophy

③ **DM12** (DOE milestone 2016): "Measure production rates, high pT spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}}$ = *200* GeV for identified hadrons with **heavy flavor** valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma."

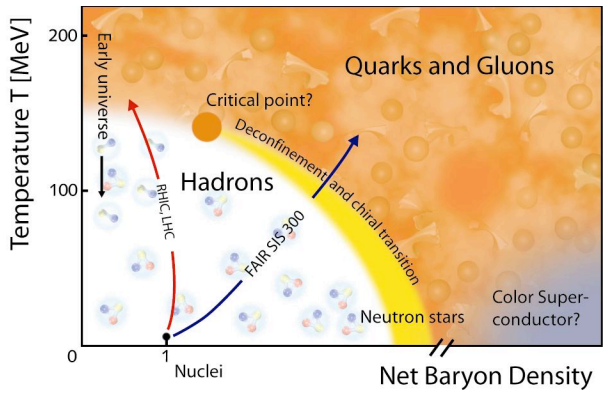
Outline

(1) Introduction

(2) Recent results from RHIC

(3) HFT and measurement plan

STAR Physics Focus

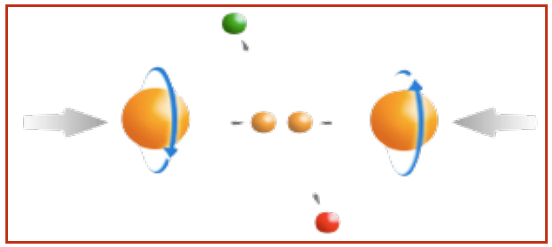


1) At 200 GeV top energy

- Study ***medium properties, EoS***
- pQCD in hot and dense medium

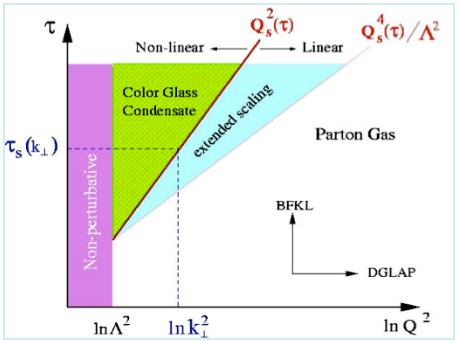
2) RHIC beam energy scan

- Search for the ***QCD critical point***
- Chiral symmetry restoration



Spin program

- Study ***proton intrinsic properties***

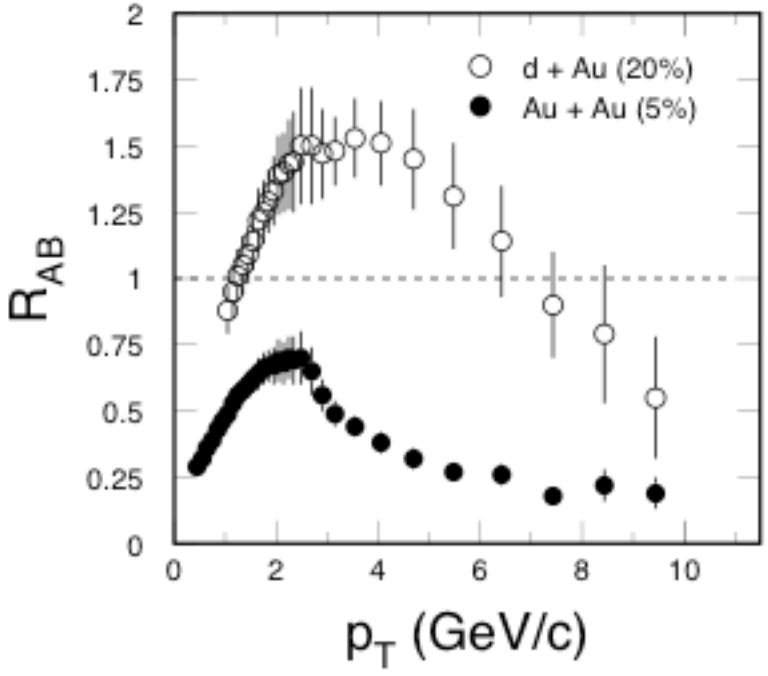


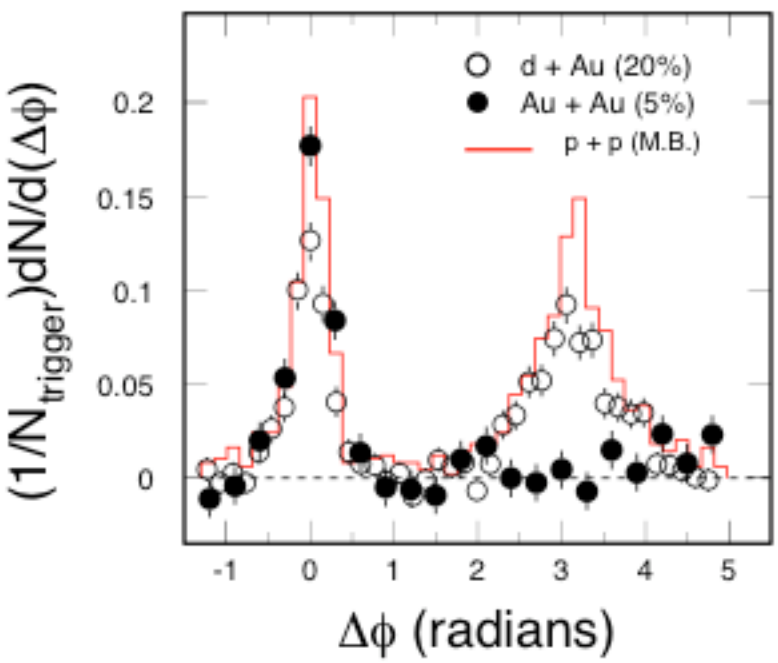
Forward program

- Study low-x properties, search for ***CGC***
- Study elastic (inelastic) processes (pp2pp)
- Investigate ***gluonic exchanges***

Partonic Energy Loss at RHIC

STAR: Nucl. Phys. ***A757***, 102(2005).





Central Au+Au collisions: light quark hadrons and the away-side jet in back-to-back 'jets' are suppressed. Different for p+p and d+Au collisions.

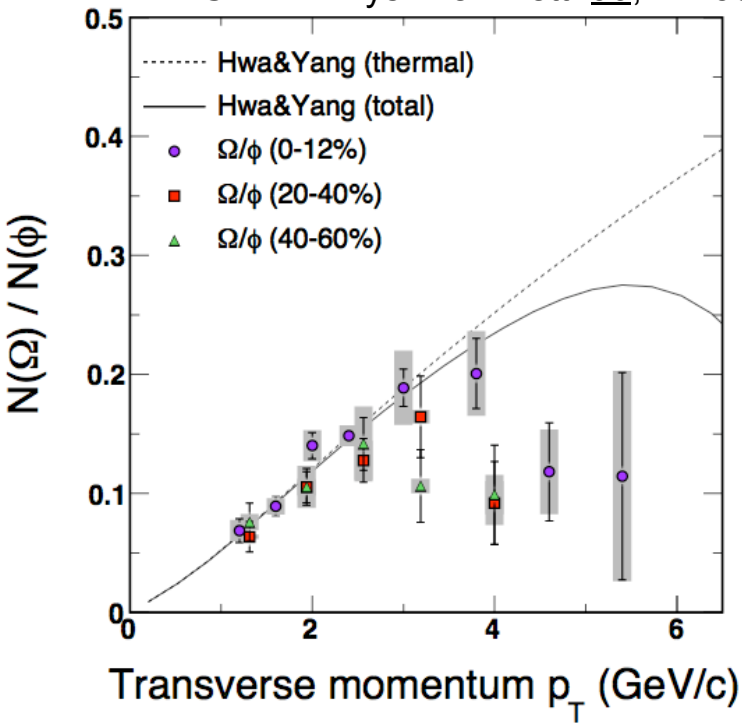
Energy density at RHIC: $\varepsilon > 5$ GeV/fm$^3 \sim 30\varepsilon_0$

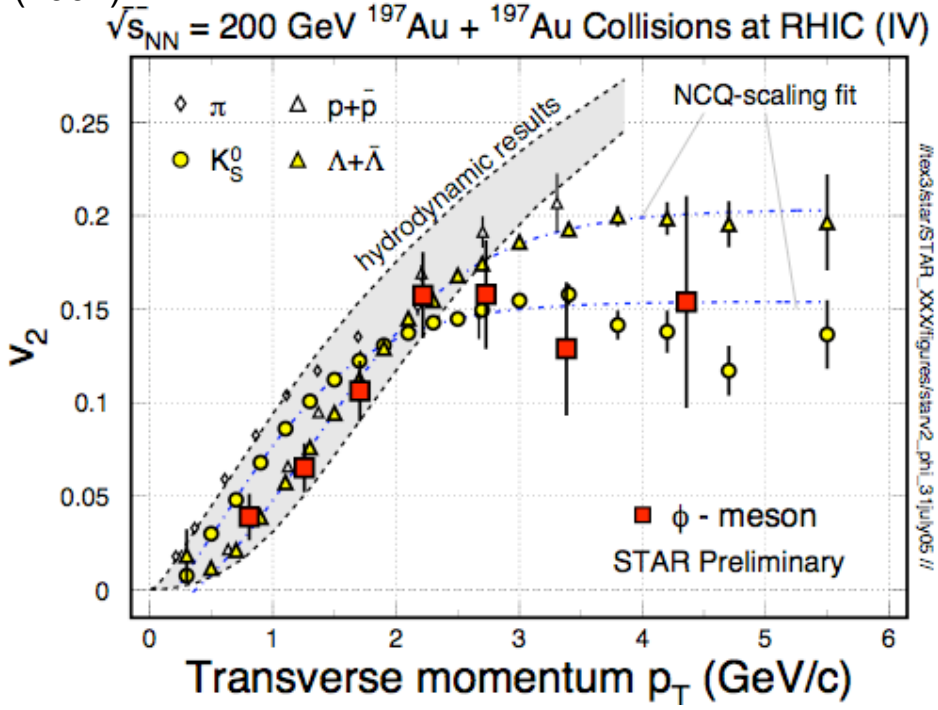
Explore pQCD in hot/dense medium: heavy, early production c,b

R_{AA}(c,b) measurements are needed!

ϕ -meson Flow: Partonic Flow

STAR: Phys. Rev. Lett. ***99***, 112301(2007).

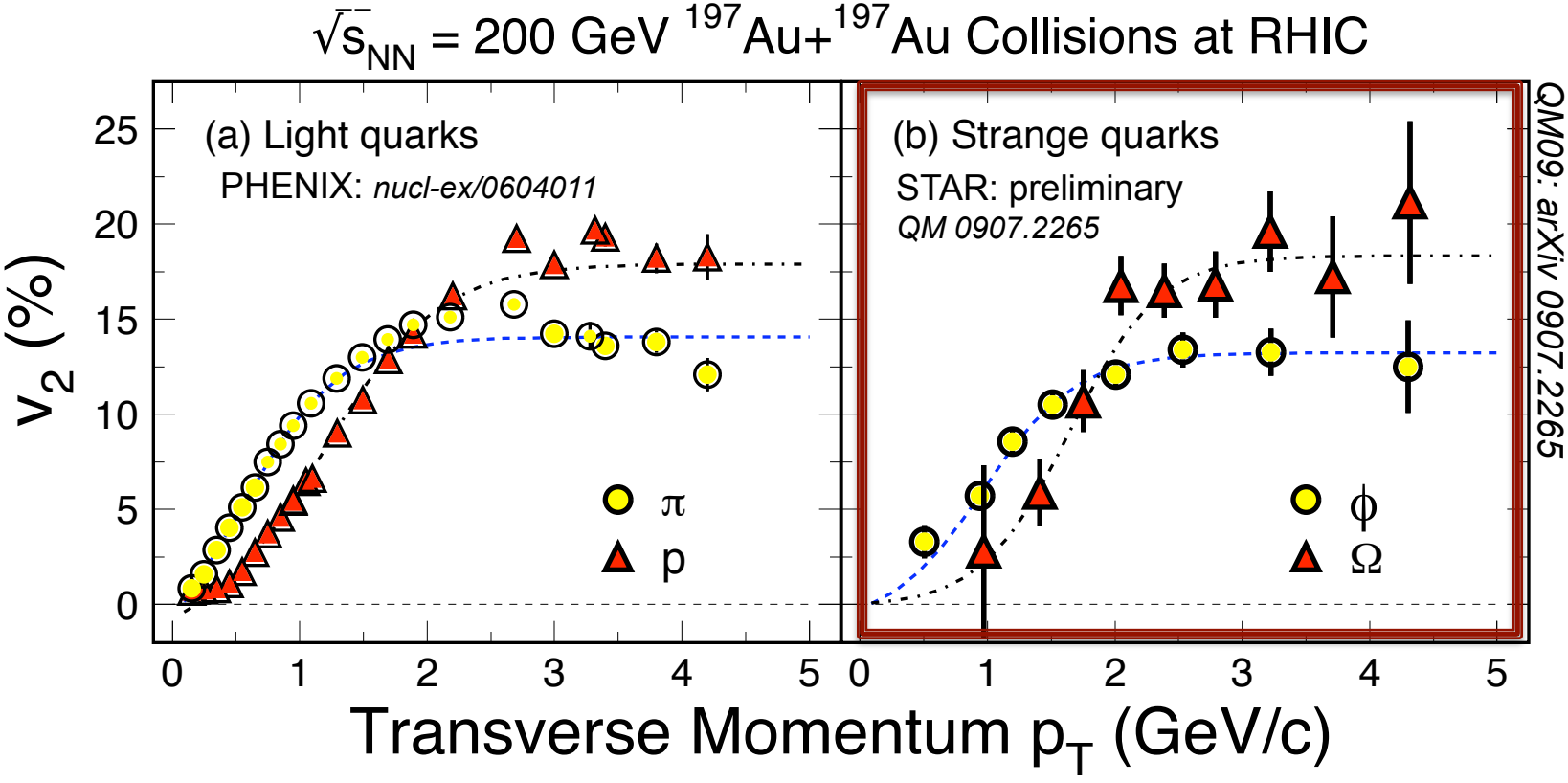




"ϕ-mesons (and other hadrons) are **produced via coalescence of seemingly thermalized quarks in central Au+Au collisions. This observation implies *hot and dense matter with partonic collectivity* has been formed at RHIC"**

In order to test early thermalization: $v_2(p_T)$ of c- and b-hadrons data are needed!

Partonic Collectivity at RHIC

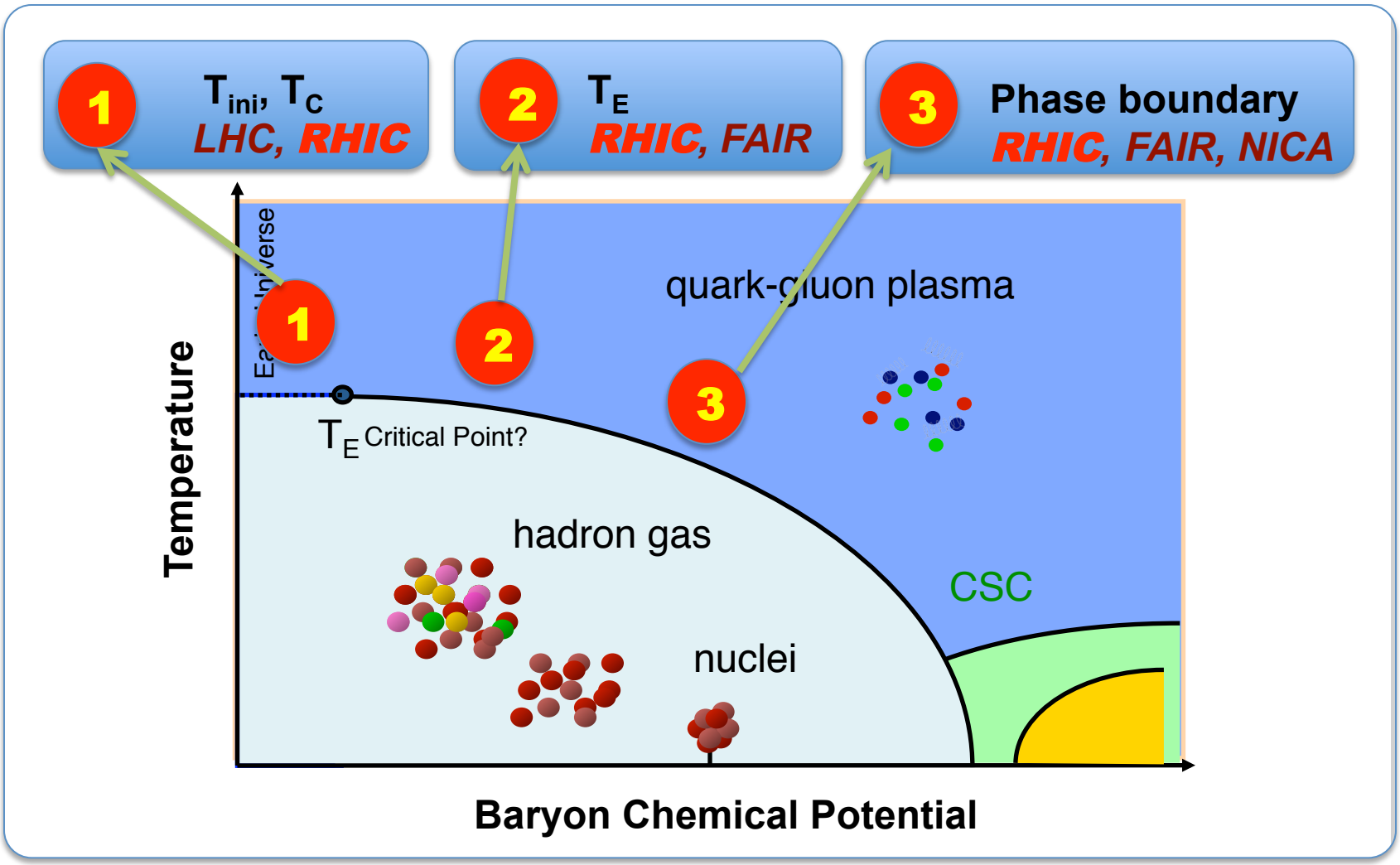


Low p_T (≤ 2 GeV/c): hydrodynamic mass ordering
High p_T (> 2 GeV/c): ***number of quarks ordering***

=> Collectivity developed at partonic stage!

=> De-confinement in Au+Au collisions at RHIC!

The QCD Phase Diagram and High-Energy Nuclear Collisions



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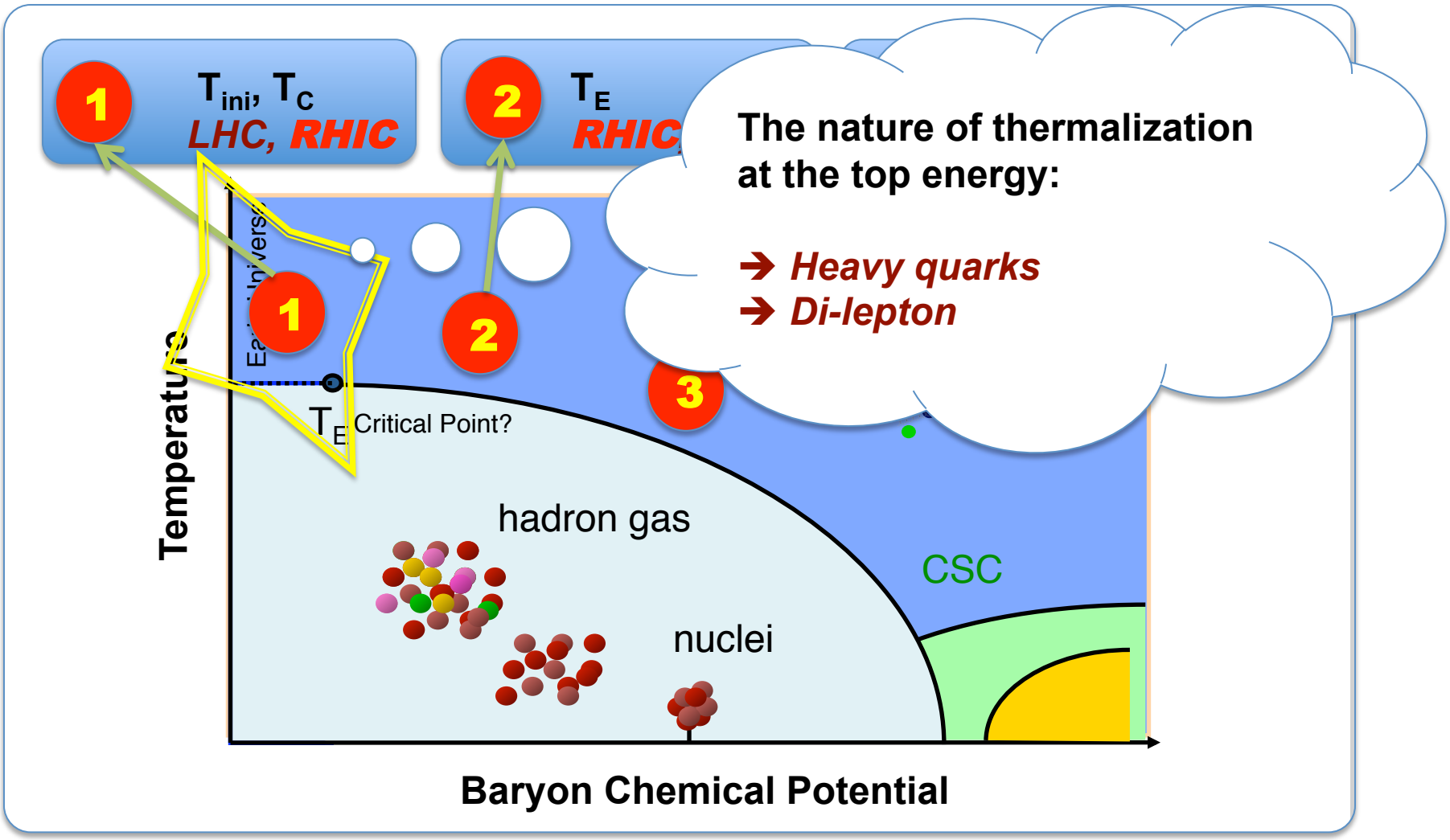
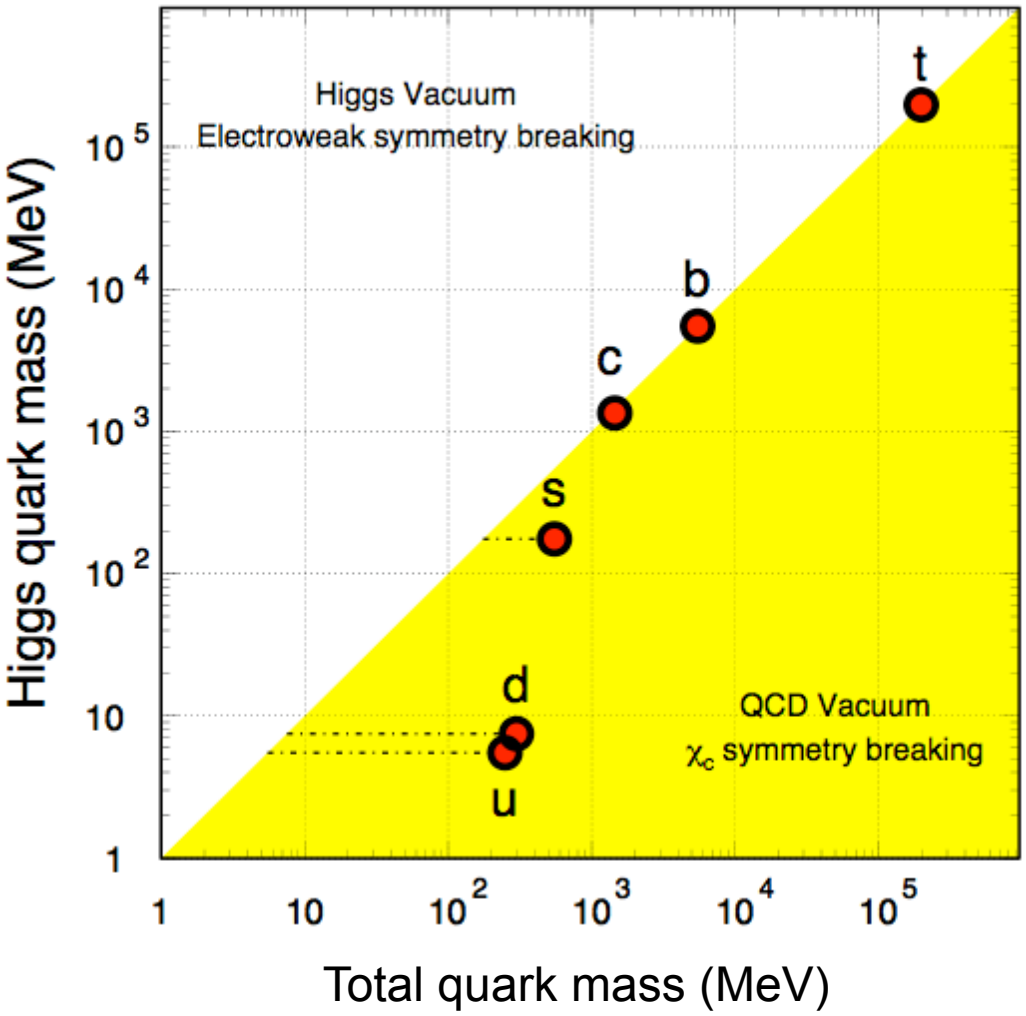


Quark Masses



X. Zhu, *et al*, Phys. Lett. **B647**, 366(2007).

- Higgs mass: electro-weak symmetry breaking (current quark mass).
- QCD mass: Chiral symmetry breaking (constituent quark mass).

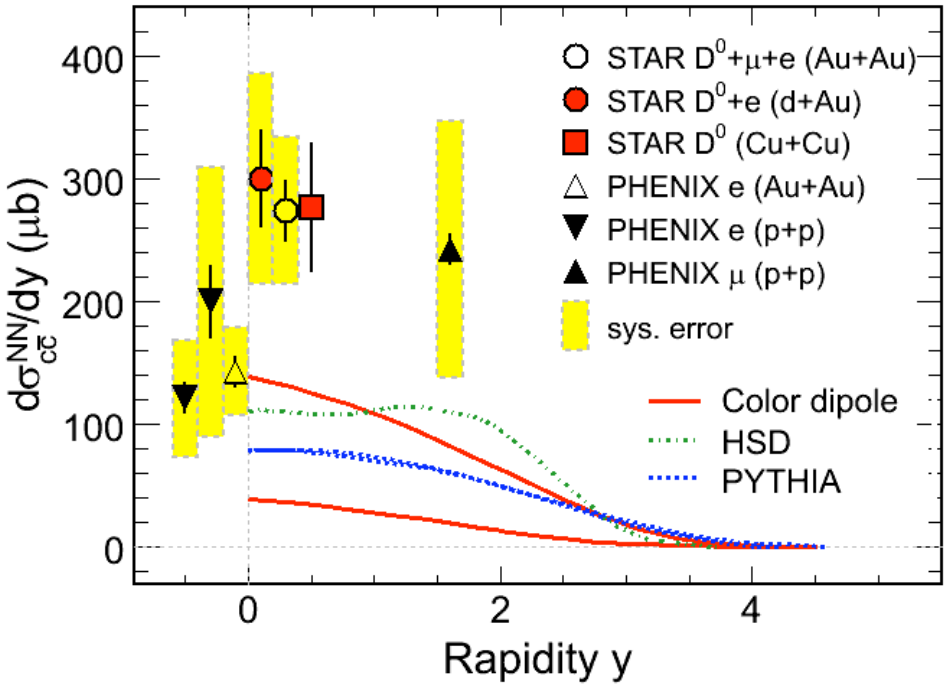
⇨ Strong interactions do not affect heavy-quark mass.

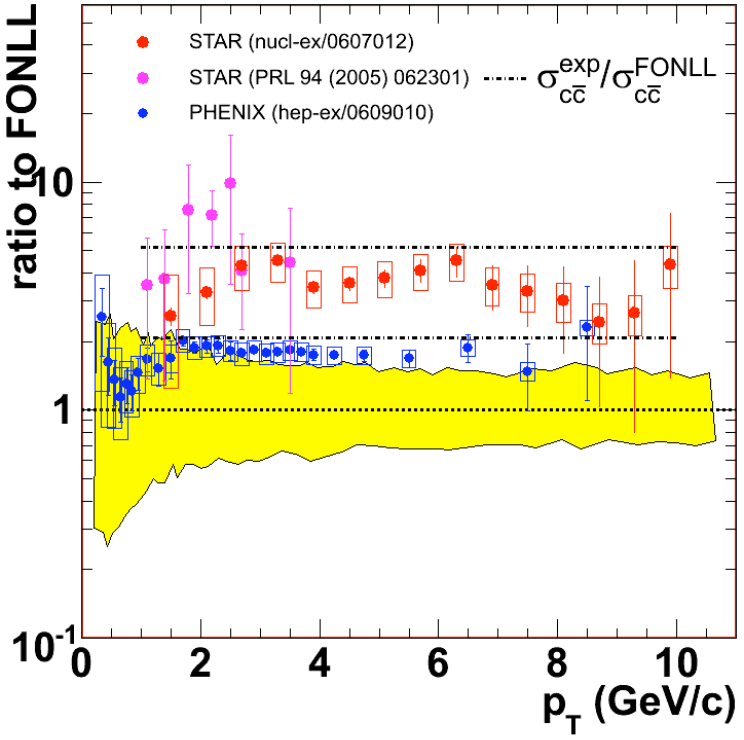
⇨ New scale compare to the excitation of the system.

⇨ Study properties of the hot and dense medium at the ***foremost early stage*** of heavy-ion collisions.

⇨ Explore pQCD at RHIC.

Charm Cross Sections at RHIC

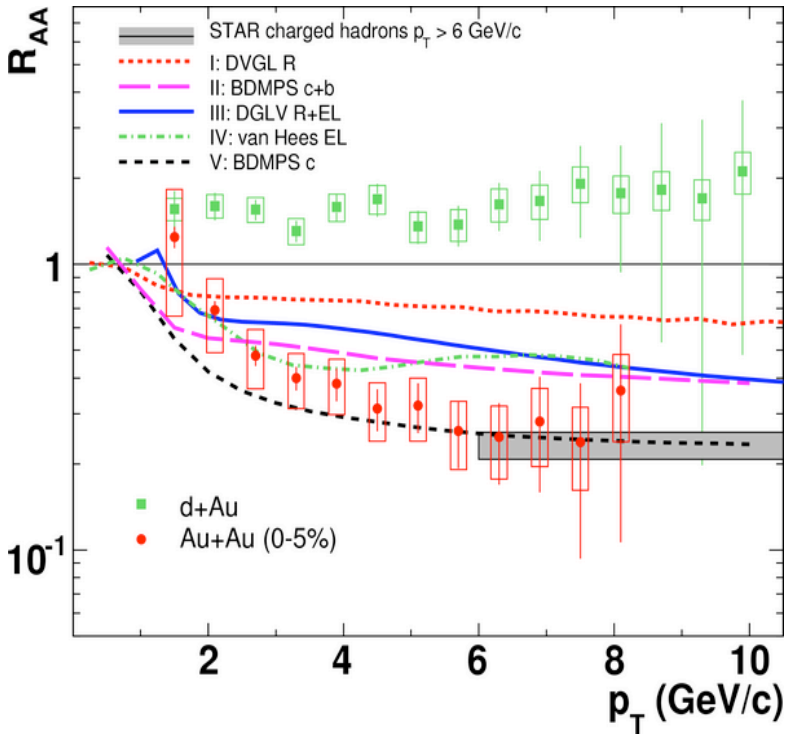




1) Large systematic uncertainties in the measurements
2) New displaced, topologically reconstructed measurements for c- and b-hadrons are needed ⇨ ***Upgrade***

Heavy Quark Energy Loss

STAR: Phys. Rew. Lett, **98**, 192301(2007).



1) Non-photonic electrons decayed from - charm and beauty hadrons

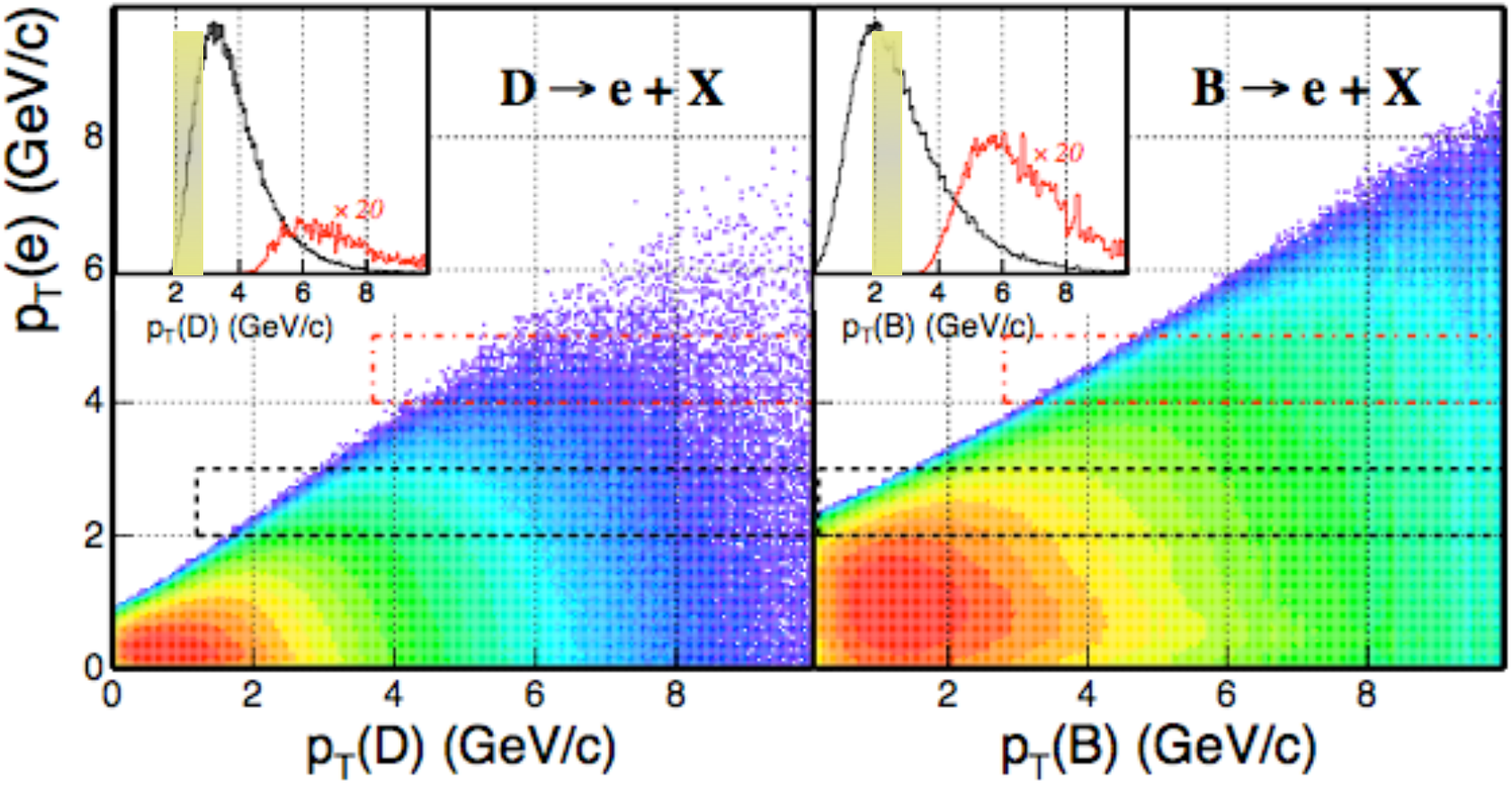
2) At $p_T \geq 6$ GeV/c,

R_{AA}(n.p.e.) ~ $R_{AA}(h^{\pm})$!

contradicts to naïve pQCD predictions

Surprising results -
- challenge our understanding of the energy loss mechanism
- force us to RE-think about the collisional energy loss
- **Requires direct measurements of c- and b-hadrons.**

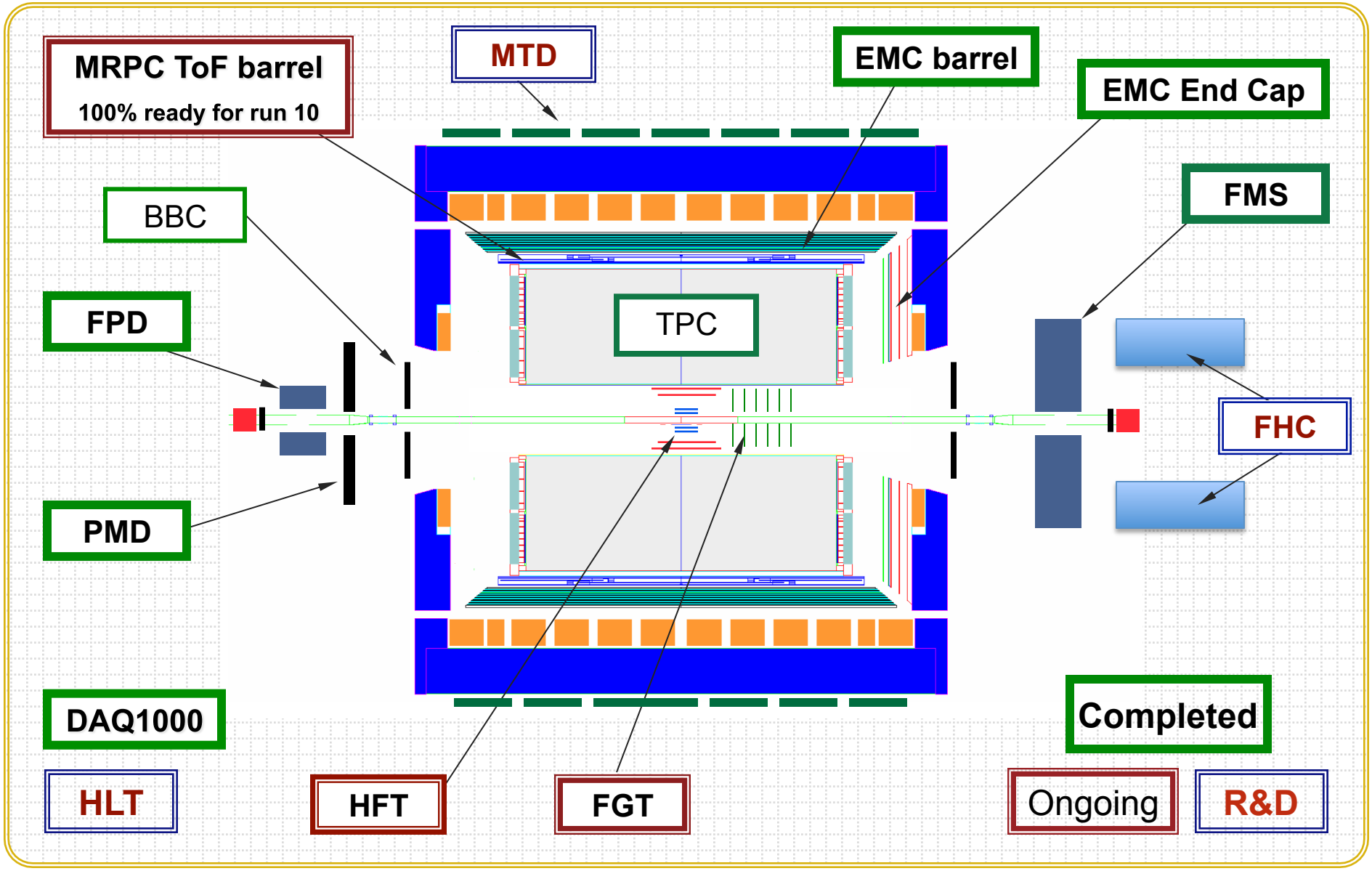
Decay ***e*** p_T vs. B- and C-hadron p_T



Key: ***Directly reconstructed heavy quark hadrons!***

Pythia calculation Xin Dong, USTC October 2005

STAR Detector

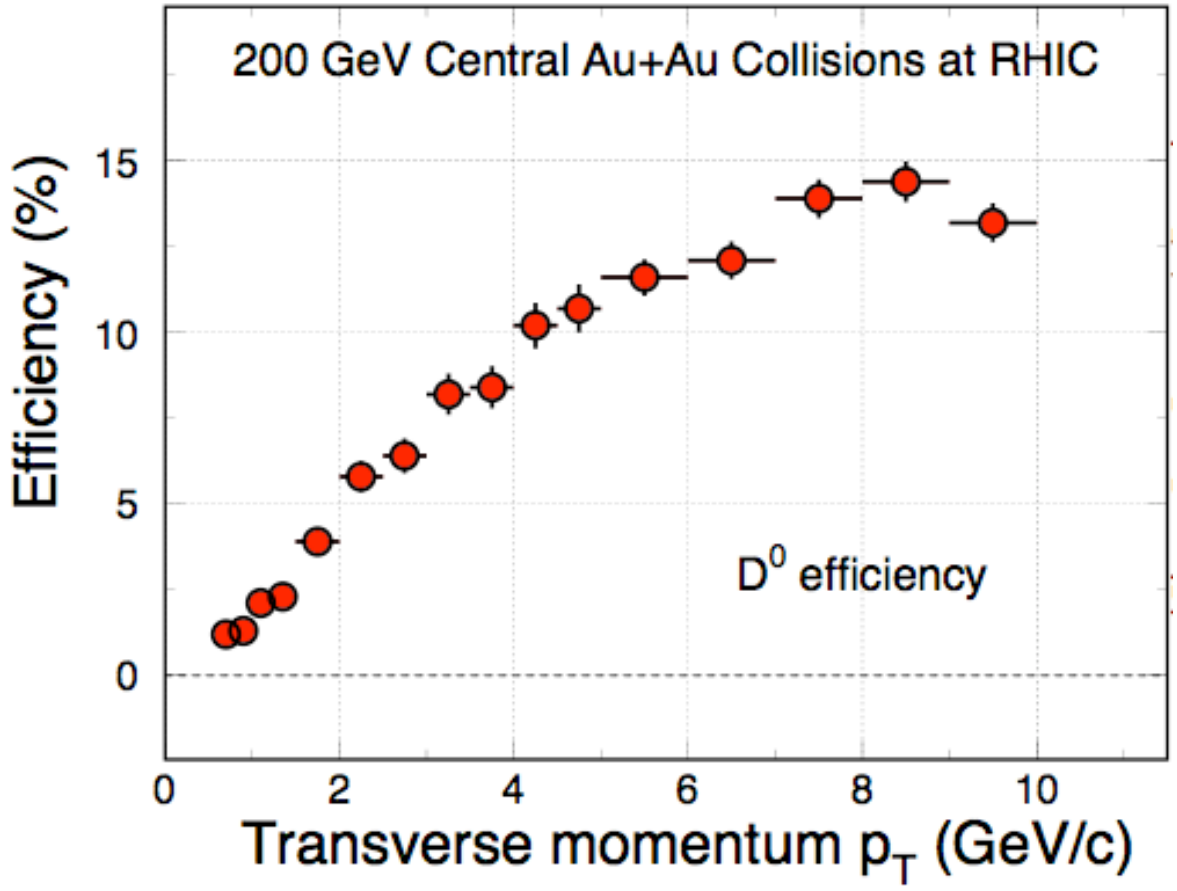


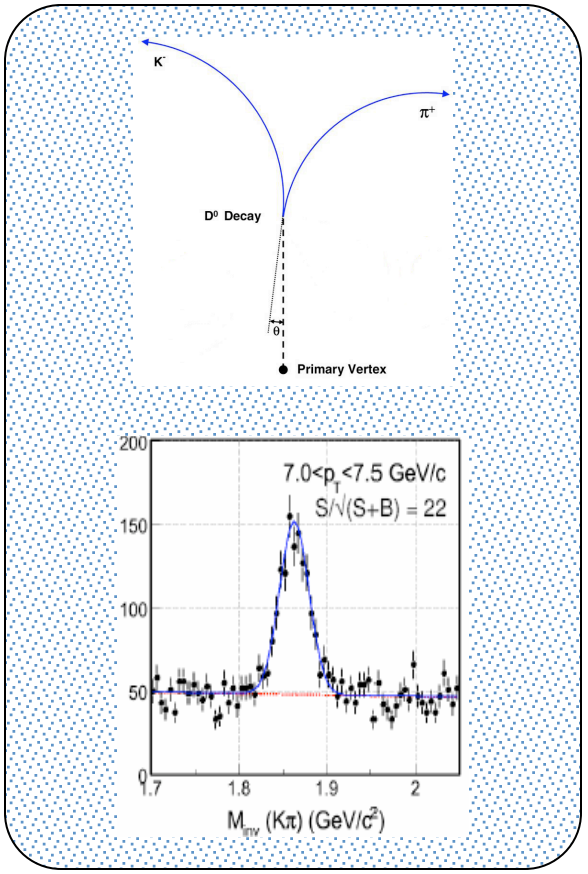
Requirement for the HFT

	Measurements	Requirements
Heavy Ion	heavy-quark hadron v_2 - the heavy-quark collectivity	- Low material budget for high reconstruction efficiency - p_T coverage ≥ 0.5 GeV/c - mid-rapidity - High counting rate
	heavy-quark hadron R_{AA} - the heavy-quark energy loss	- High p_T coverage ~ 10 GeV/c
p+p	energy and spin dependence of the heavy-quark production	- p_T coverage ≥ 0.5 GeV/c
	gluon distribution with heavy quarks	- wide rapidity and p_T coverage

1) **Low p_T coverage**
2) **Large solid angle coverage**

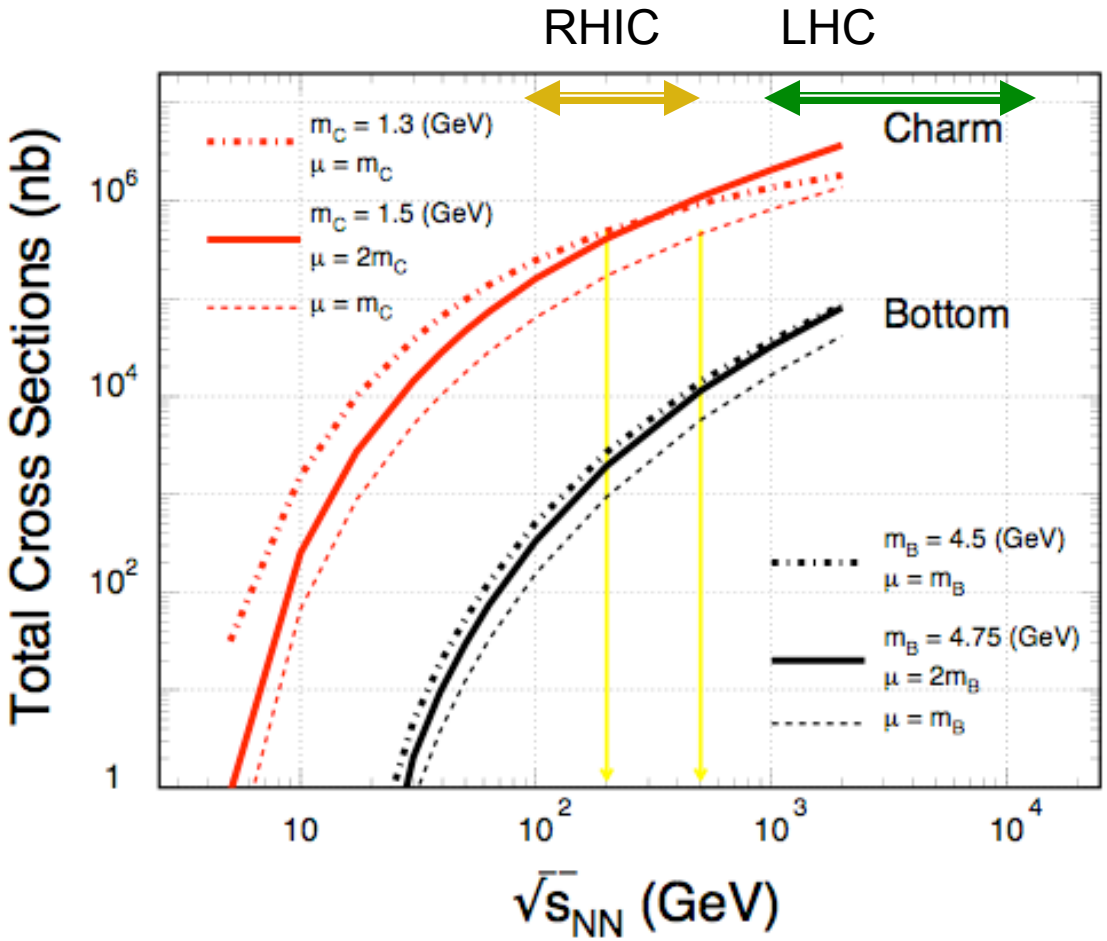
D^0 Reconstruction Efficiency





- Central Au+Au collisions: top 10% events.
- The thin detector allows measurements down to p_T ~ 0.5 GeV/c.
- Essential and unique!

Heavy Quark in p+p Collisions



Plan for p+p collisions:

200 GeV

500 GeV for σ, not in with full luminosity

NLO pQCD predictions of charm and bottom for the total p +p hadro-production cross sections.

Renormalization scale and factorization scale were chosen to be equal.

RHIC: 200, 500 GeV

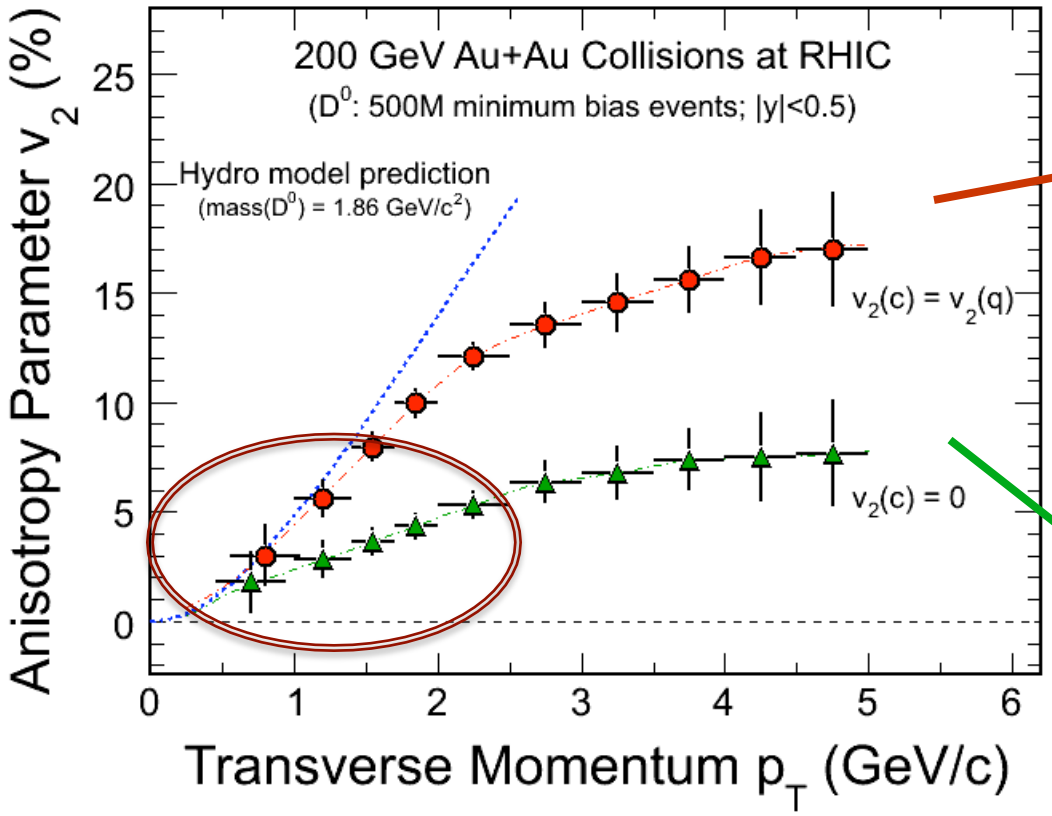
LHC: 900, 7000, 14000 GeV

Ideal energy range for studying pQCD predictions for heavy quark production.

Necessary reference for both, heavy ion and spin programs at RHIC.

Charm Hadron v_2

MC with HFT



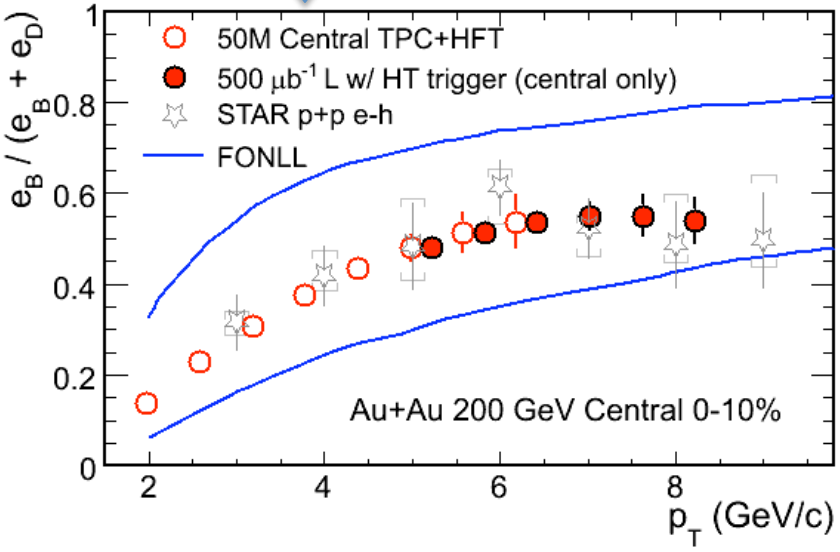
Charm-quark flow
➠ Thermalization of light-quarks!

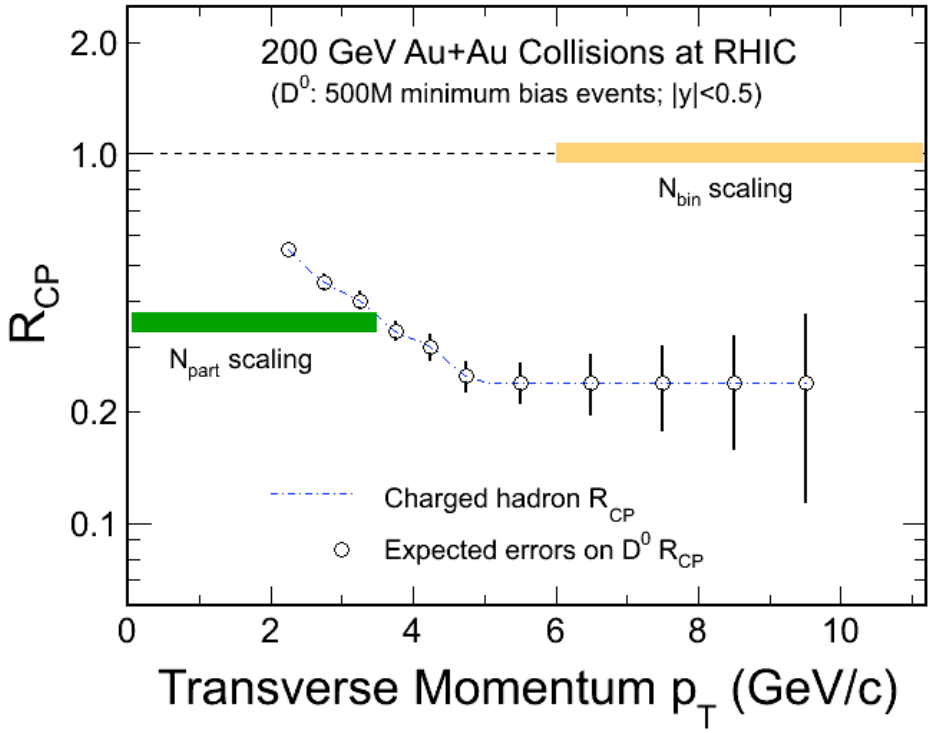
Charm-quark does not flow
➠ Drag coefficients

- 200 GeV Au+Au minimum bias collisions (500M events).
- Charm collectivity ⇨ drag/diffusion constants ⇨ ***medium properties!***

Charm Hadron R_{CP}

NEW





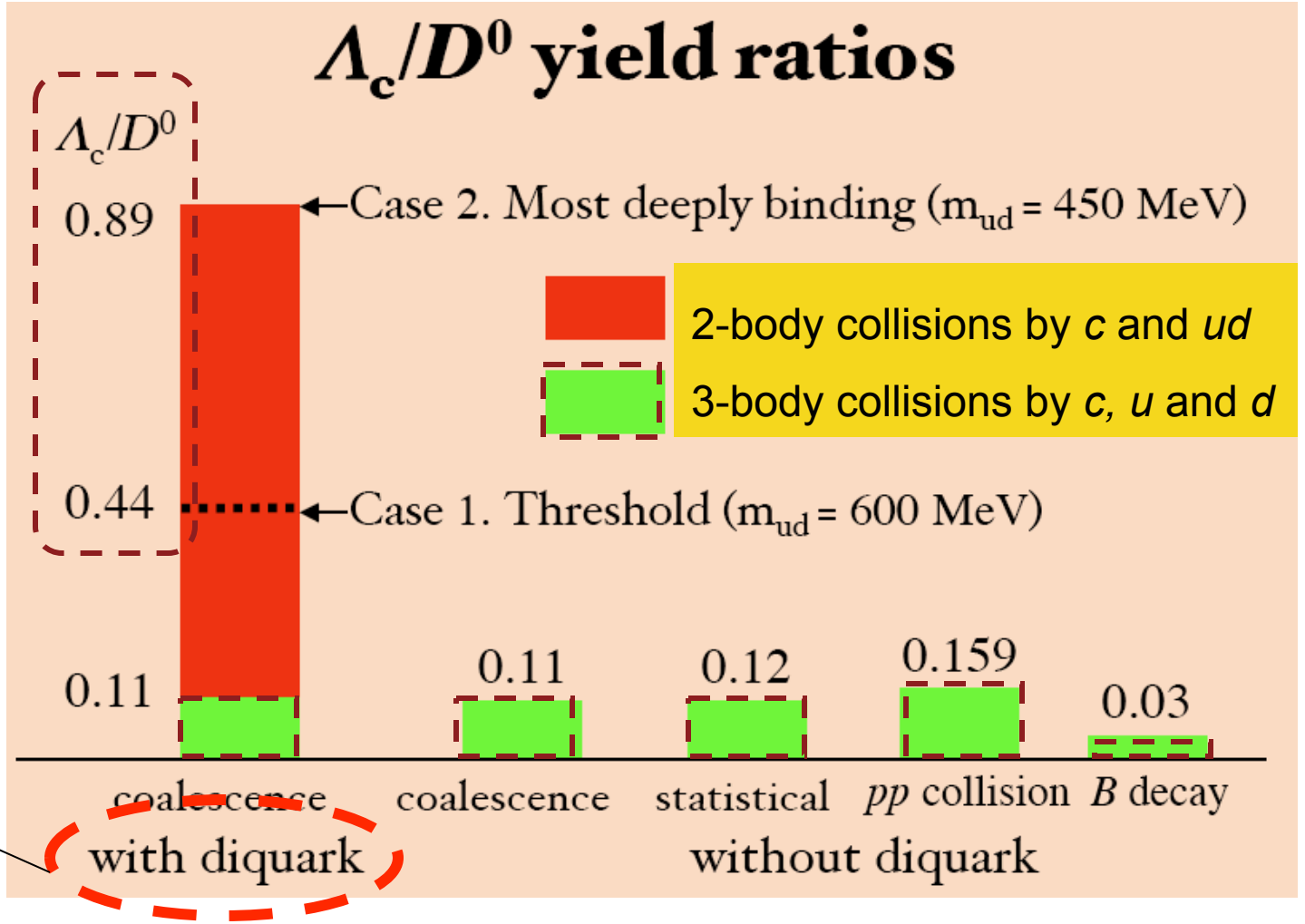
$R_{CP}=a*N^{10\%}/N^{(60-80)\%}$

- Significant Bottom contributions in HQ decay electrons.
- 200 GeV Au+Au minimum bias collisions (|y|<0.5 500M events).
- Charm R_{AA} ⇨ ***energy loss mechanism!***

Charm Baryon/Meson Ratios

$\Lambda_c \rightarrow pK^-\pi^+$

$D^0 \rightarrow K^-\pi^+$



QGP medium

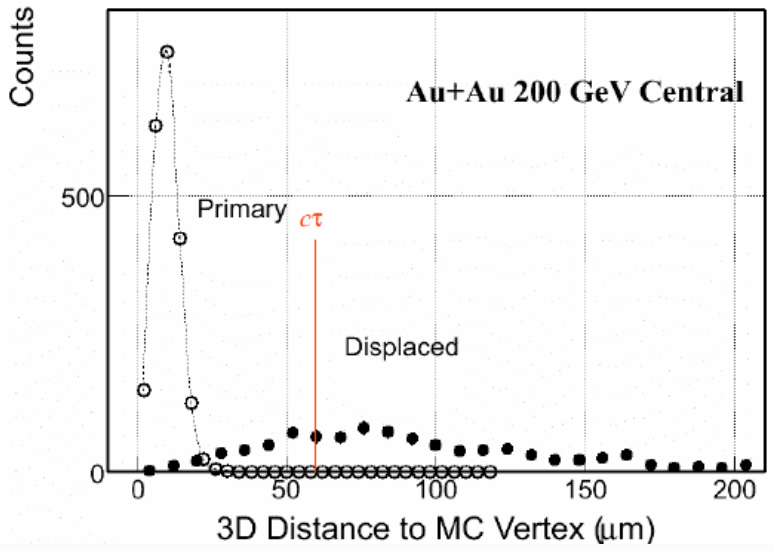
Y. Oh, C.M. Ko, S.H. Lee, S. Yasui, Phys. Rev. **C79**, 044905(2009).
S.H. Lee, K.Ohnishi, S. Yasui, I-K.Yoo, C.M. Ko, Phys. Rev. Lett. **100**, 222301(2008).

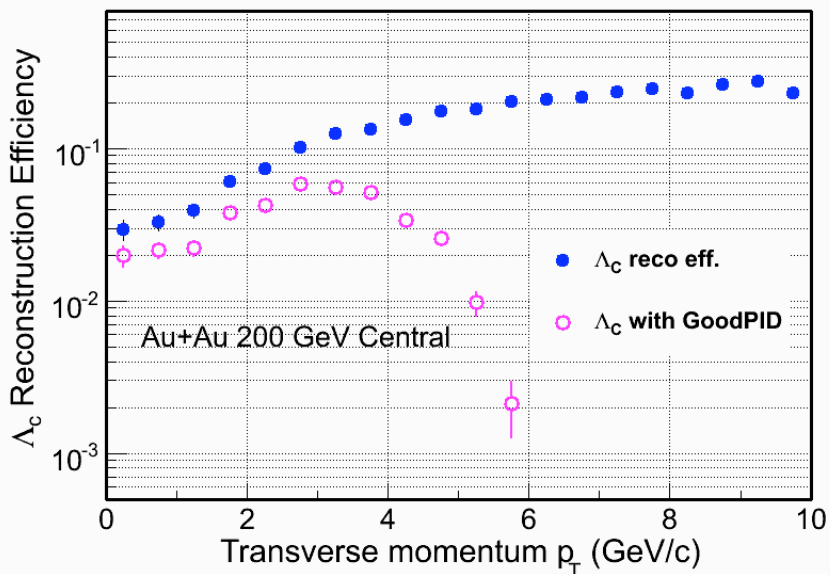
Λ_c Measurements

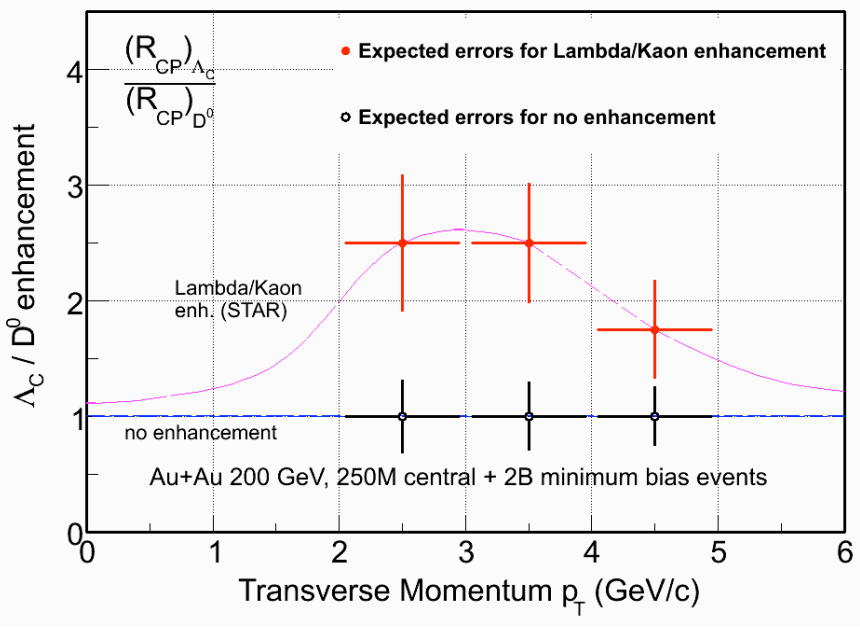
NEW

Λ_c (➔ p + K + π):

1) Lowest mass charm baryon
2) Total yield and Λ_c/D^0 ratios can be measured.



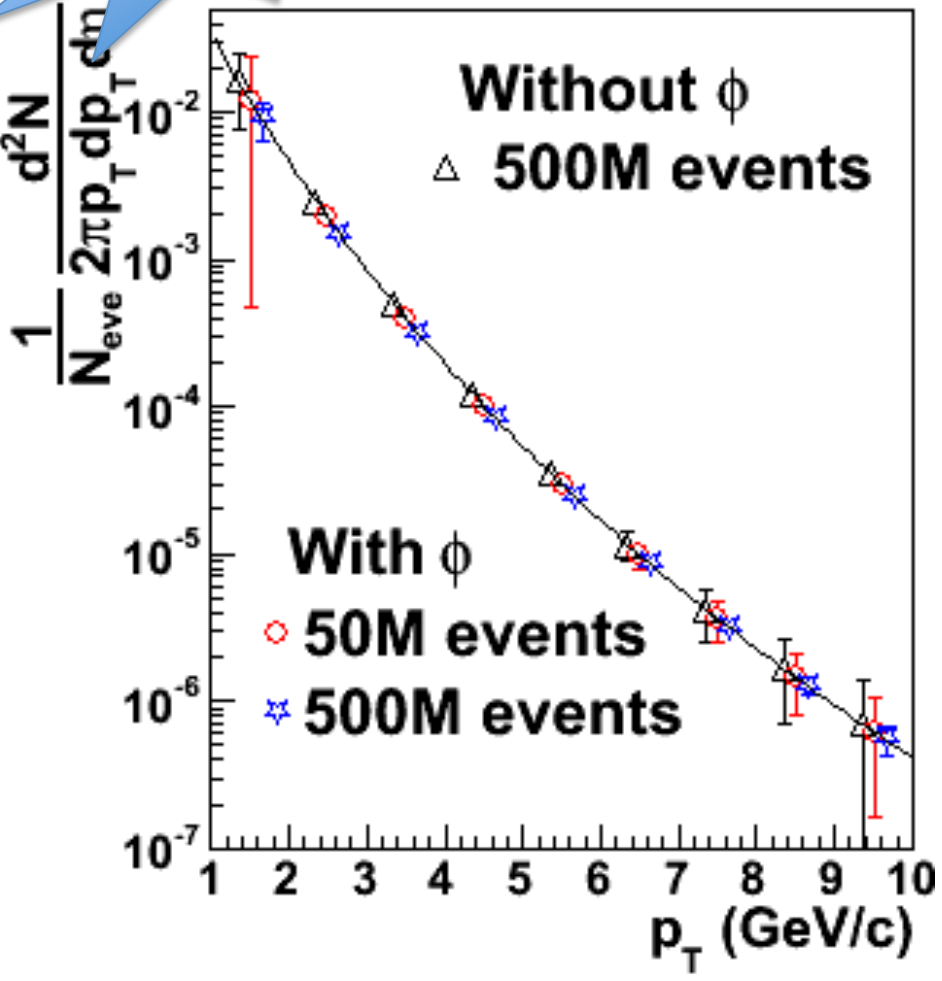




D_s Reconstruction

NEW

200 GeV Central Au+Au Collisions at RHIC

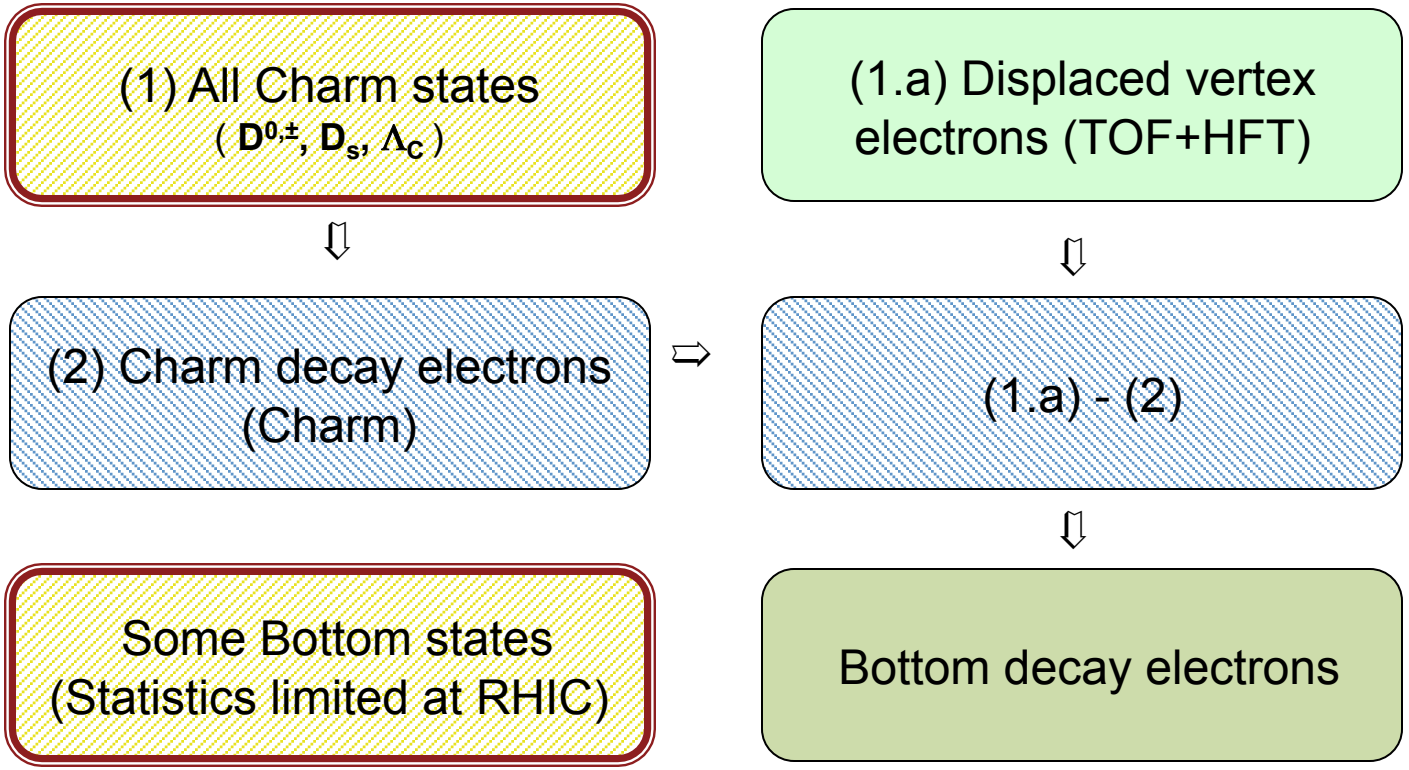


- $D_s \rightarrow K^+K^-\pi$ (BR 5.5%)
- $D_s \rightarrow \varphi\pi \rightarrow K^+K^-\pi$ (BR 2.2%)
- mass = 1968.49 ± 0.34 MeV
- **decay length** ~ 150 μm

- Work in progress …
- 200 GeV central Au+Au
- Ideal PID
- Power-law spectrum with:
  n = 11, $\langle p_T \rangle$ = 1 GeV/c

0.5B events will work!

Strategies for Bottom Measurement

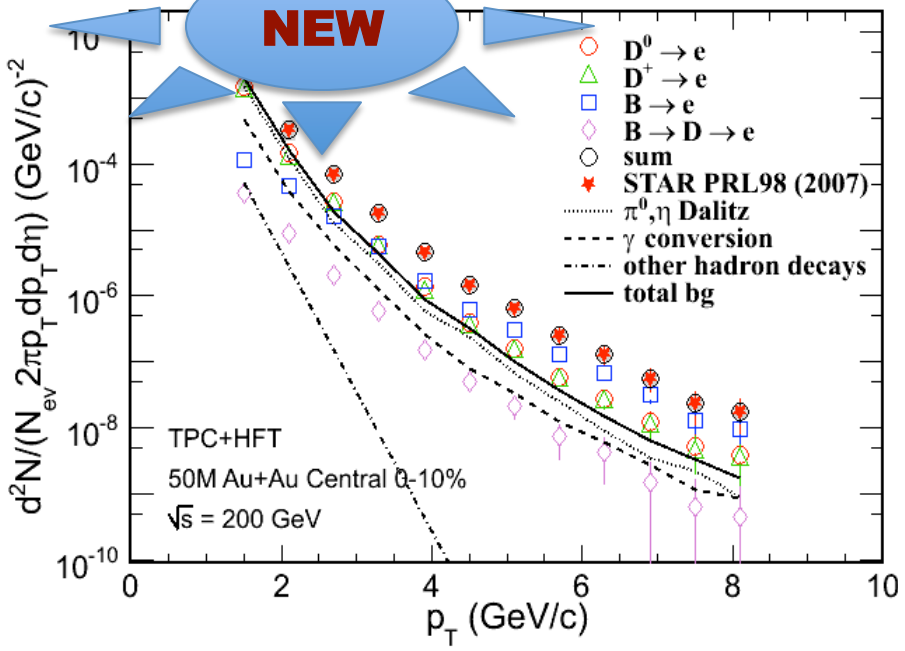


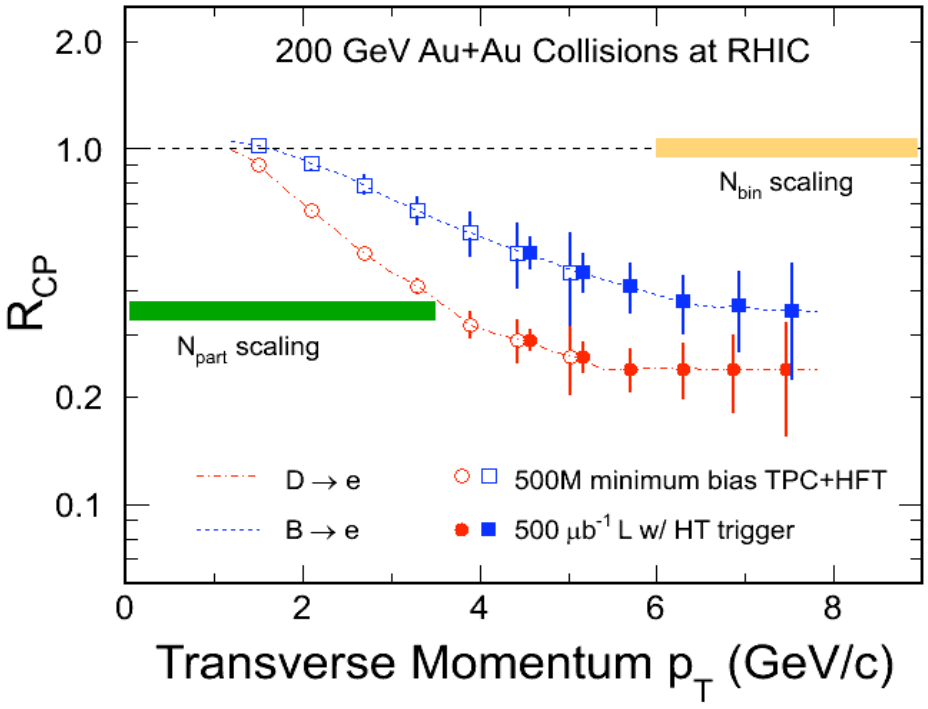
Measure **Charm** and **Bottom** hadron:

Cross sections, Spectra and v_2

c- and b-decay Electrons

H. van Hees *et al*. Eur. Phys. J. **C61**, 799(2009). (arXiv: 0808.3710)





$R_{CP}=a*N^{10\%}/N^{(60-80)\%}$

- DCA cuts ⇨ ***c- and b-decay electron distributions and R_{CP}***
- 200 GeV Au+Au minimum biased collisions (|y|<0.5 500M events)

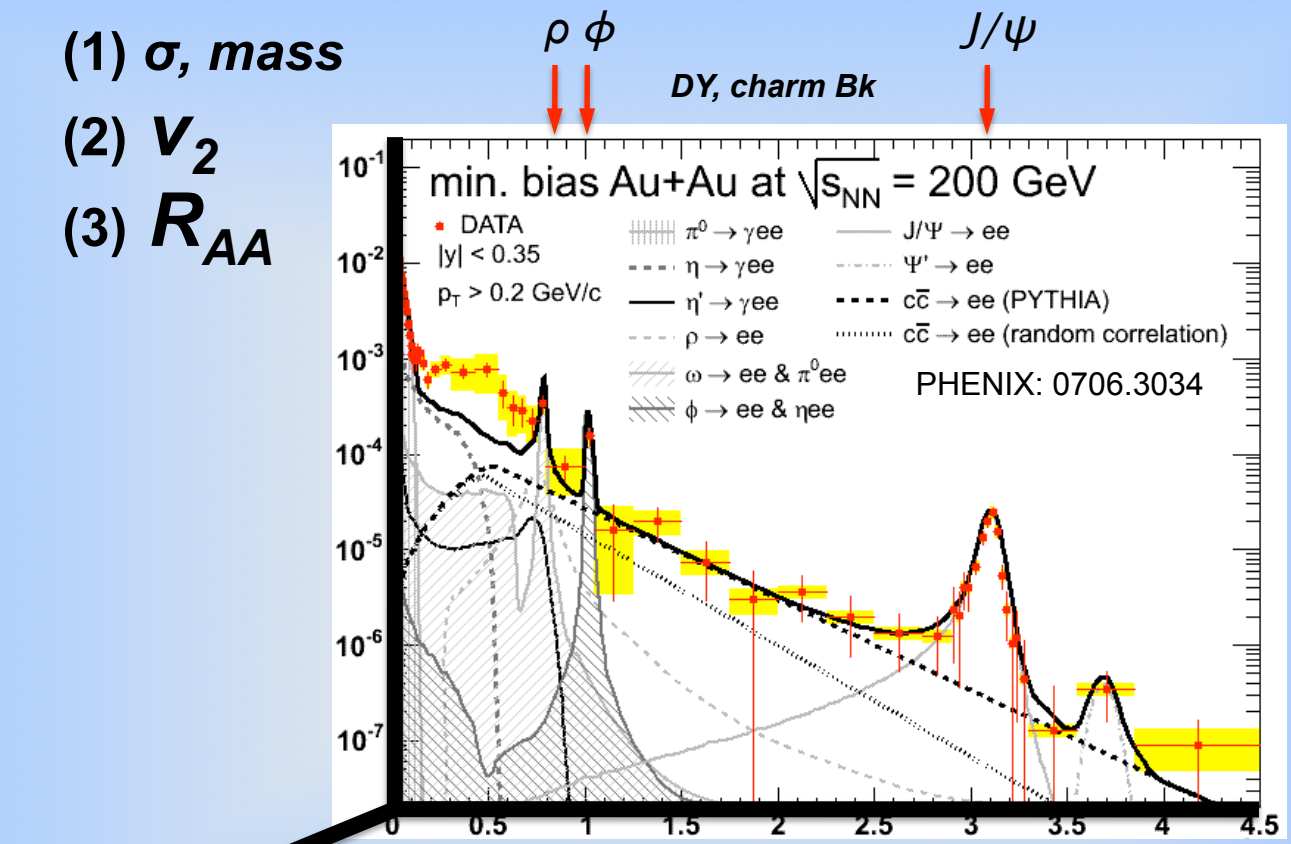
The di-Lepton Program at STAR

TOF + TPC + *HFT*

(1) *σ, mass*

(2) v_2

(3) R_{AA}



✓ **Direct radiation from the Hot/Dense Medium**

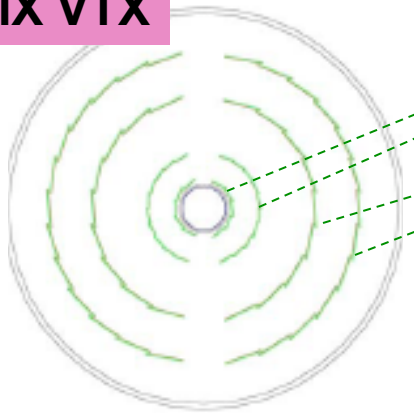
✓ **Chiral symmetry Restoration**

⇨ ***A robust di-lepton physics program extending STAR scientific reach***

HFT: removing irreducible correlated charm background!

PHENIX and STAR Comparison

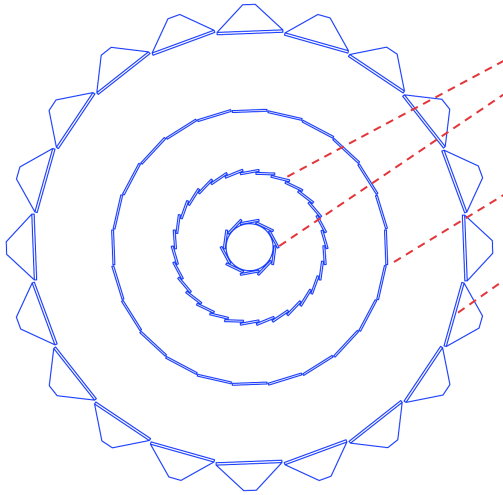
PHENIX VTX



- 2-layer Si hybrid pixels: $x/x_0 \sim 1.2\%$ per layer;
  2.5cm inner radius; fast readout
- 2-layer Si strips, $x/x_0 \sim 2\%$

$0.5 \le p_T \le 6$ GeV/c: $e^{\pm}$
$2 < p_T \le 6$ GeV/c: D-mesons…
$1 < p_T \le 6$ GeV/c: $B \rightarrow J/\psi$

STAR HFT



- 2-layer CMOS: $x/x_0 \sim 0.37\%$ per layer;
  2.5cm inner radius; 200μs integration
- 1-layer* Si strips
- SSD: $x/x_0 \sim 1\%$

e, $D^{0,\pm,s,*}$, Λ_c , B…

$0.5 < \boldsymbol{p_T} < 10$ GeV/c: v_2, R_{AA}

D-D correlation functions

Physics of the Heavy Flavor Tracker at STAR

1) The STAR HFT measurements (p+p and Au+Au)

(1) Heavy-quark cross sections: $D^{0,\pm,*}$, D_S, Λ_C , B…

(2) Both spectra ($R_{AA,}$ R_{CP}) and v_2 in a wide p_T region: 0.5 - 10 GeV/c

(3) Charm hadron correlation functions

(4) Full spectrum of the heavy quark hadron decay electrons

2) Physics

(1) Measure heavy-quark hadron v_2, heavy-quark collectivity, to study the medium properties ***e.g. light-quark thermalization***

(2) Measure heavy-quark energy loss to study pQCD in hot/dense medium ***e.g. energy loss mechanism***

(3) Measure di-leptions to study the ***direct radiation*** from the hot/dense medium

(4) Analyze ***hadro-chemistry including heavy flavors***

Physics of the Heavy Flavor Tracker at STAR

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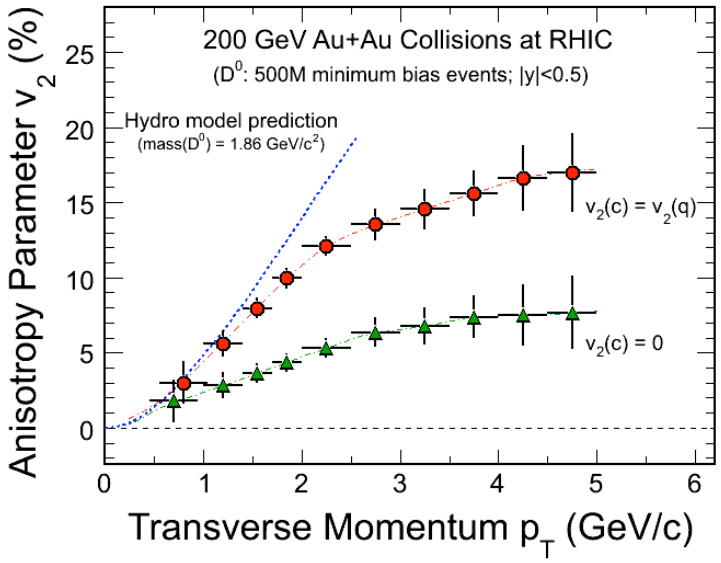
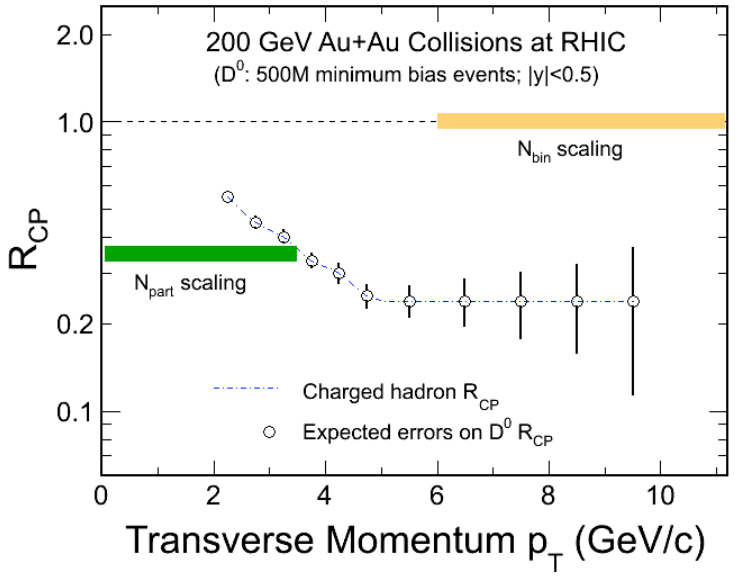




Projected Run Plan

1) First run with HFT: 200 GeV Au+Au

⇨ v_2 and R_{CP} with 500M M.B. collisions

2) Second run with HFT: 200 GeV p+p

⇨ R_{AA}

3) Third run with HFT: 200 GeV Au+Au

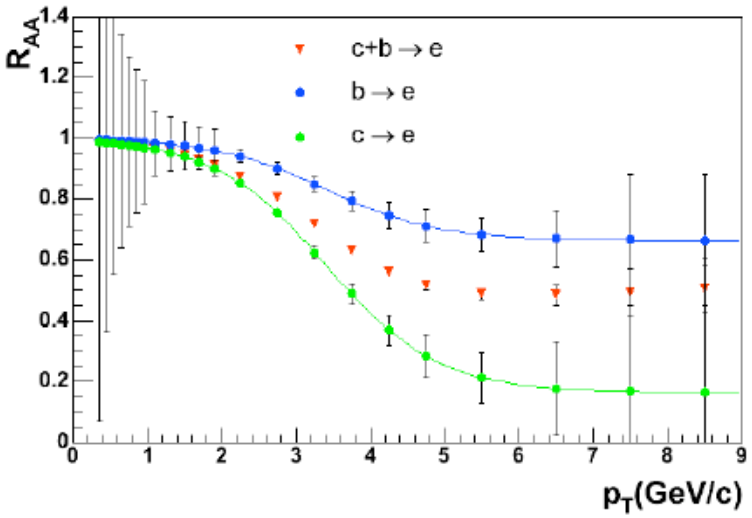
⇨ Centrality dependence of v_2 and R_{AA}

⇨ Charm background and first attempt for electron pair measurements

⇨ Λ_C baryon with sufficient statistics

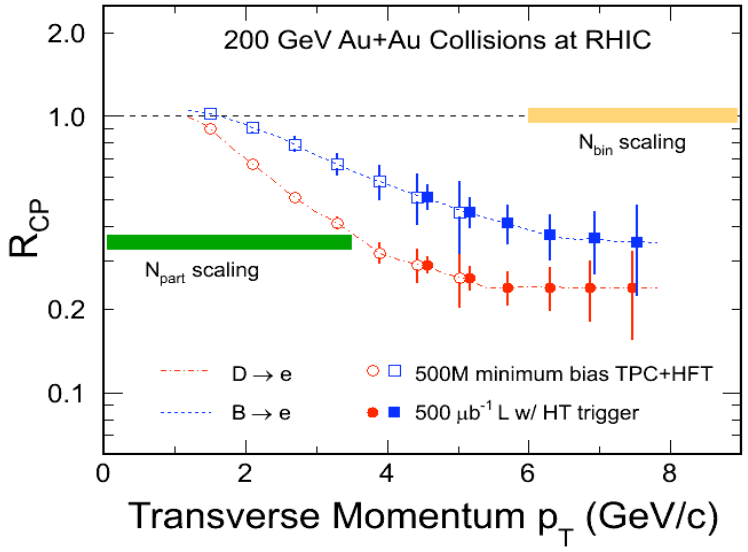
Auxiliary Slides (1)- R_{AA}

PHENIX VTX



Y. Akiba, PHENIX, 2008.

STAR HFT



Blue: Assumed c decay e

Red: Assumed b decay e

Open Symbols: M.B. events, not trigger

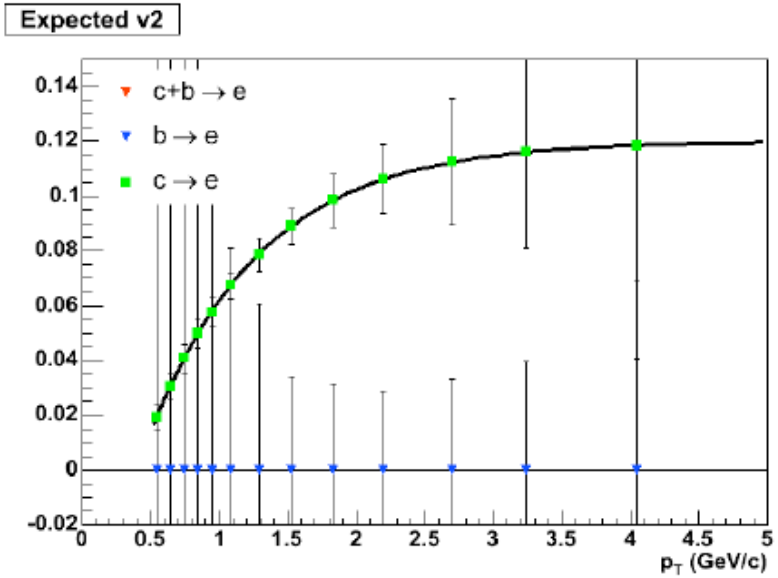
Filled Symbols: triggered with HT

Cuts: DCA on decay electrons

Events: 200 GeV 500 M.B. Au + Au events

Auxiliary Slides (2)- v_2

PHENIX VTX



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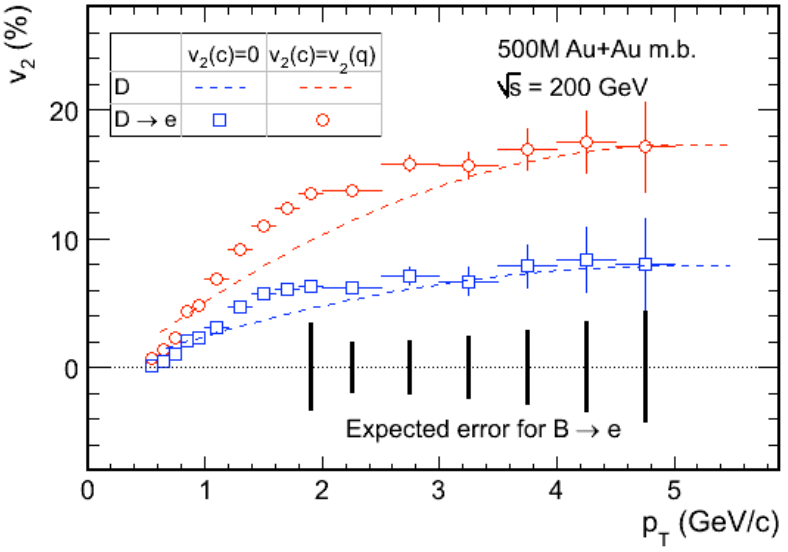
STAR HFT



Blue: c-quark flows *//* **Red:** c-quark does not

Dashed-curves: Assumed D^0-mesom $v_2(p_T)$

Symbols: *D decay e $v_2(p_T)$*

Vertical bars: errors for *b decay e $v_2(p_T)$* from 200 GeV 500M minimum bias Au + Au events

Cuts: DCA on decay electrons