The Heavy Flavor Tracker (HFT)

The Silicon Vertex Upgrade of STAR @ RHIC

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Lake Louise Winter Institute
Feb 20-26th, 2011

Outline

- The Heavy Flavor physics opportunities in Heavy Ion Collisions
- The HFT concept and realization
- Physics performance (simulations)

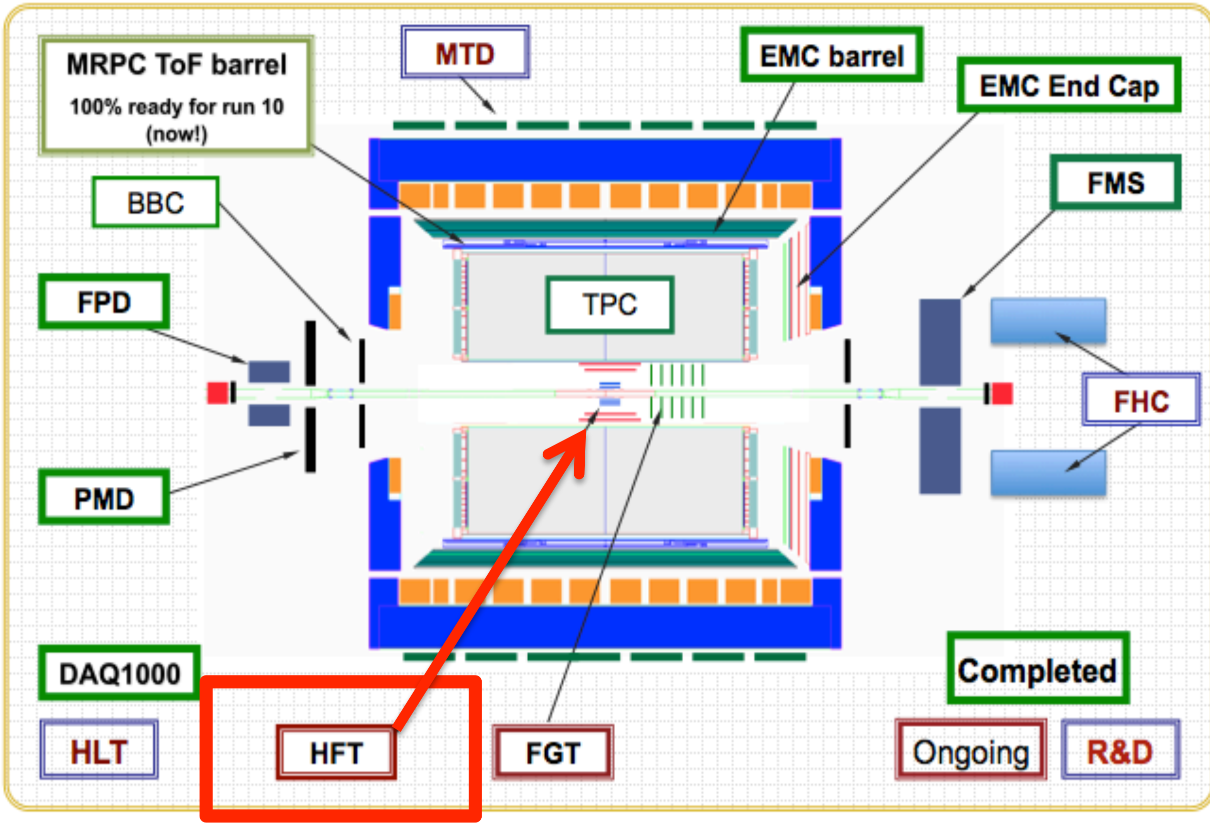
The Bottom Line

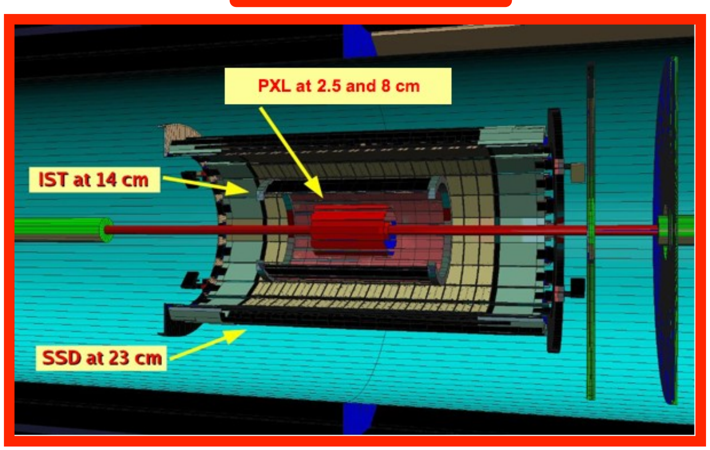
- Hot and dense (partonic) matter with strong collectivity has been formed in Au+Au collisions at RHIC. Study of the properties of the new form of matter requires more penetrating probes like **heavy** quarks.
    - Mechanism for parton energy loss.
    - Thermalization

- **New micro-vertex detector is needed for STAR experiment.**

- DOE milestone for 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."

STAR Detector



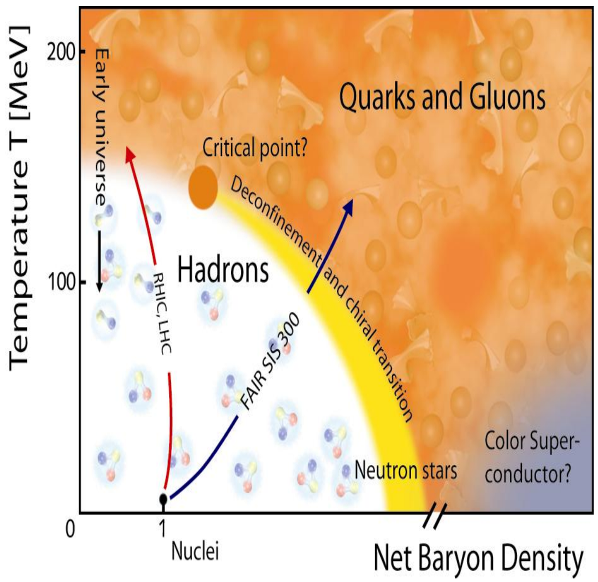


TPC & HFT

- Large acceptance at midrapidity, |η| <1

- Full azimuthal coverage, $0 < \phi < 2\pi$

STAR Physics Program

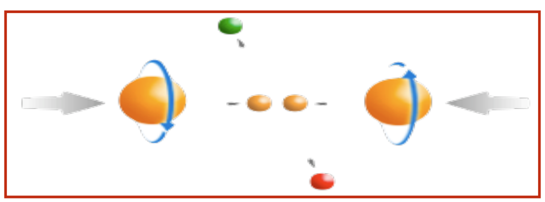


1) At 200 GeV top energy

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

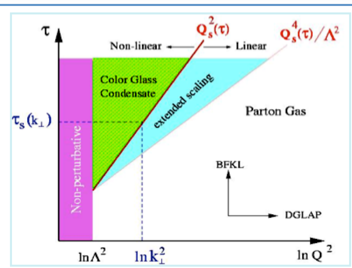
2) RHIC beam energy scan

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



Spin program

- Study ***proton intrinsic properties***

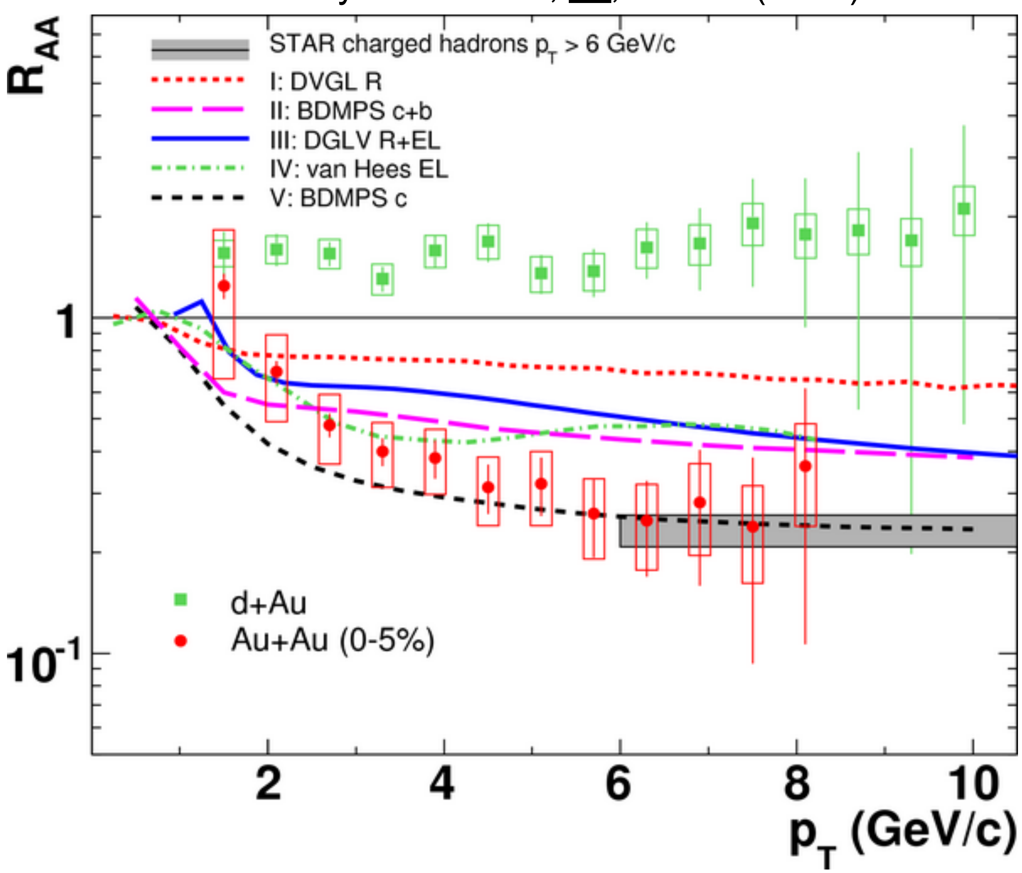


Forward program

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

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

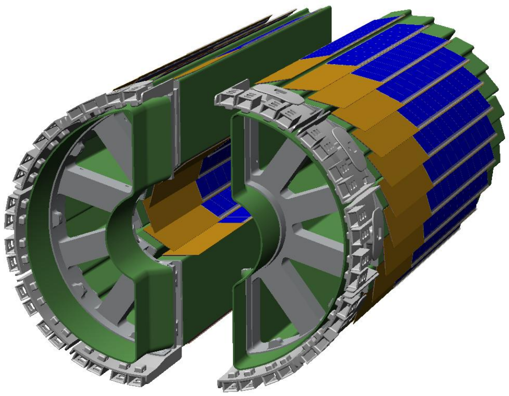
Contradicts naïve pQCD predictions

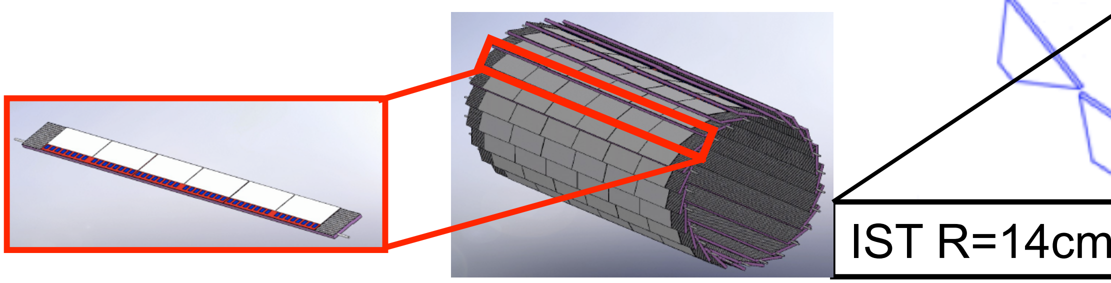
Surprising results -

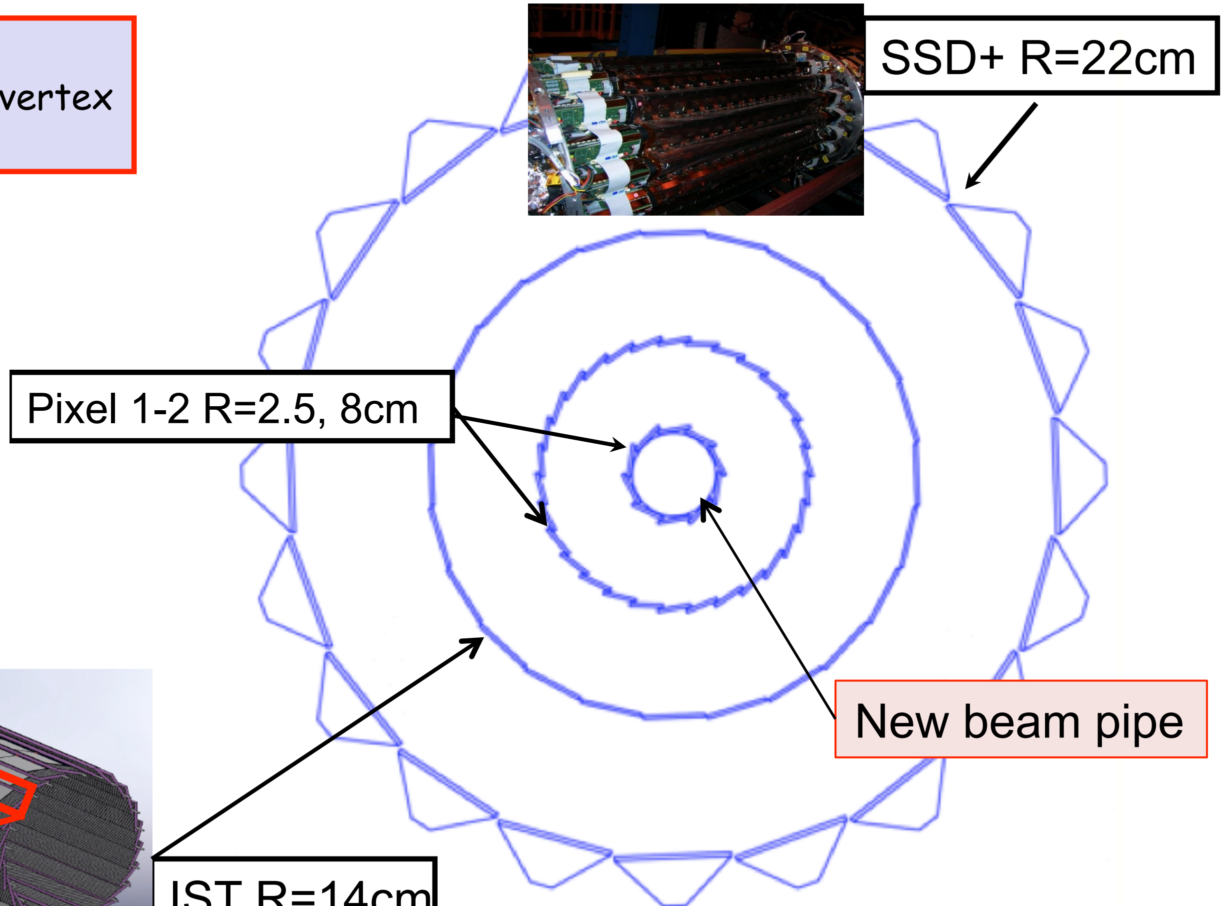
- challenge our understanding of the energy loss mechanism
- force us to RE-think about the elastic-collisions energy loss
- **Requires direct measurements of c- and b-hadrons.**

HFT
Technology

- Low mass
- Near the event vertex
- Active pixels





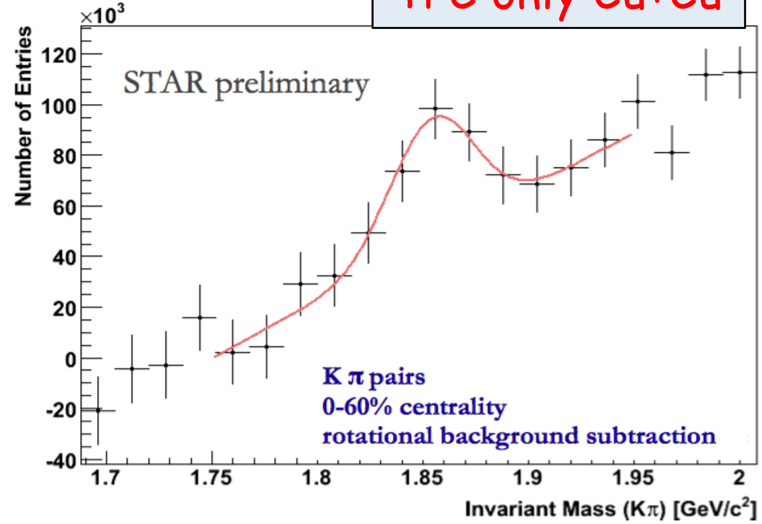


	Technology	Hit resolution R-ϕ (μm - μm)	Radiation Length
SSD+	double sided strips	30 - 857	1% X_0
IST	Silicon Strip Pad sensors	170 -1700	1.2% X_0
PIXEL	Active Pixels	8.6 - 8.6	0.3% X_0

Pointing resolution ~25 μm@1 GeV/c to resolve average decay length ~80 μm

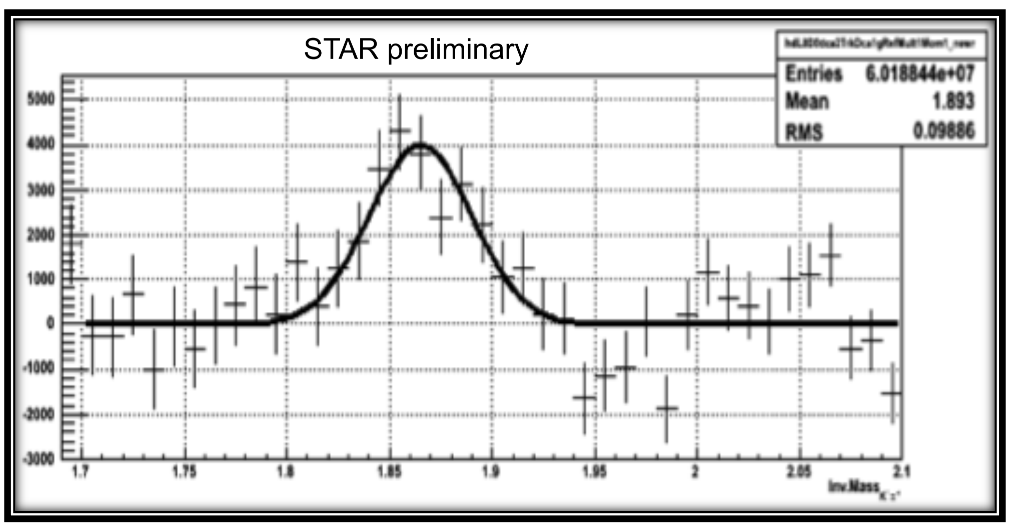
200 GeV DATA with old Silicon

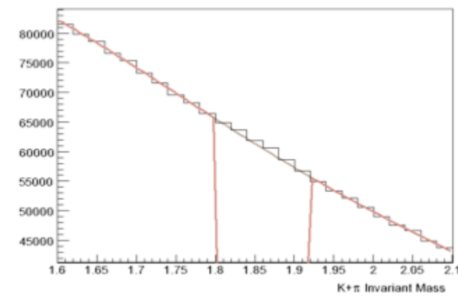
TPC only Cu+Cu

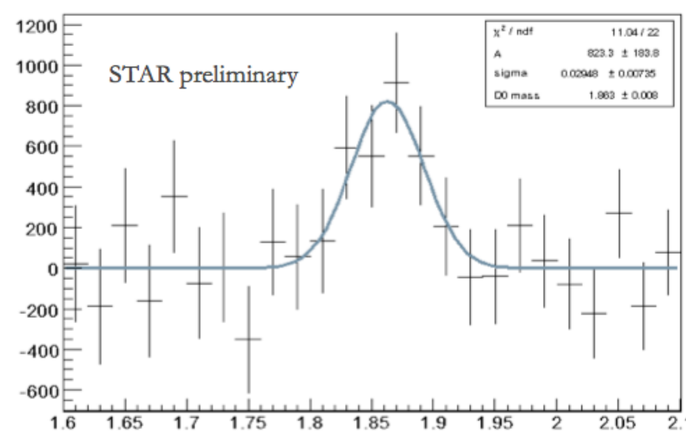


- (Relatively) low significance peaks have already been observed in the DATA but of limited physics reach

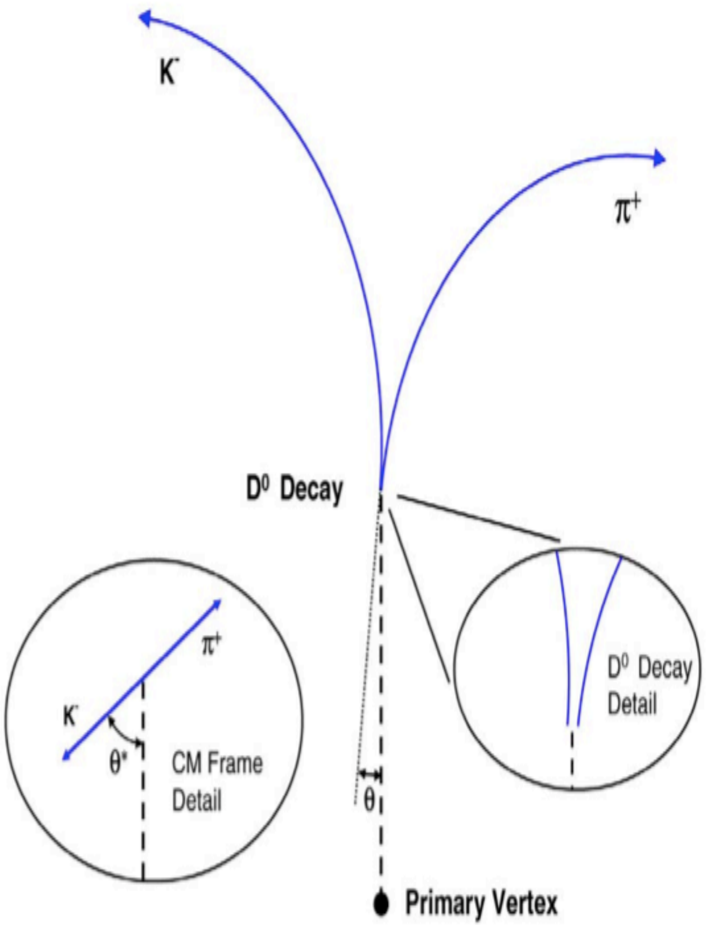
TPC+SVT+SSD Au+Au





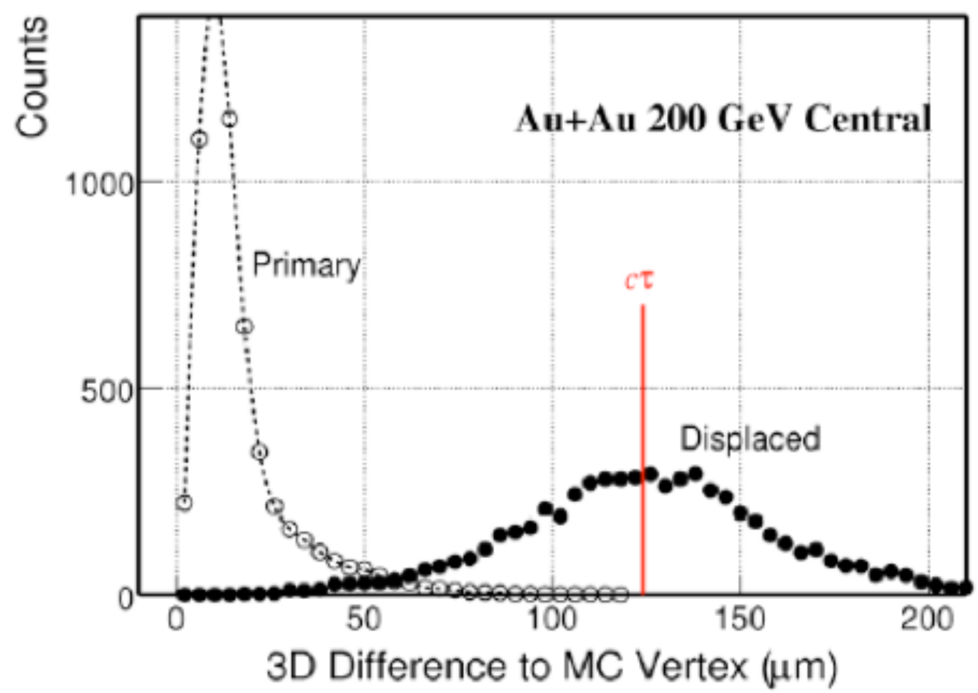


Hadronic reconstruction with HFT



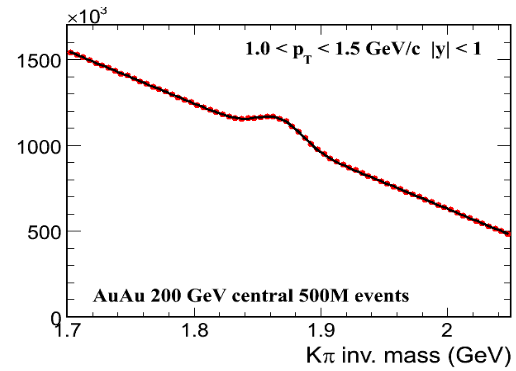
STAR HFT has the capacity to reconstruct the displaced vertex of

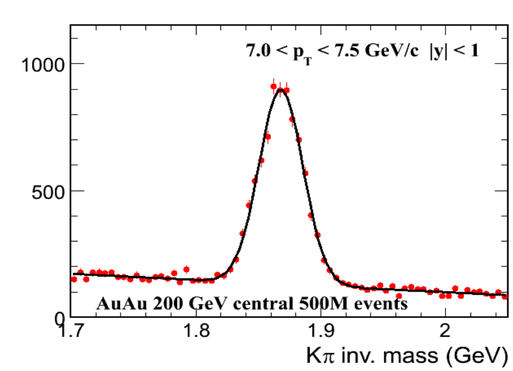
$D^0 \rightarrow K\pi$ (B.R 3.8%, $c\tau$ = 123μm)
$\Lambda_c \rightarrow \pi K p$ (B. R. 5.0%, $c\tau$ = 59.9μm)

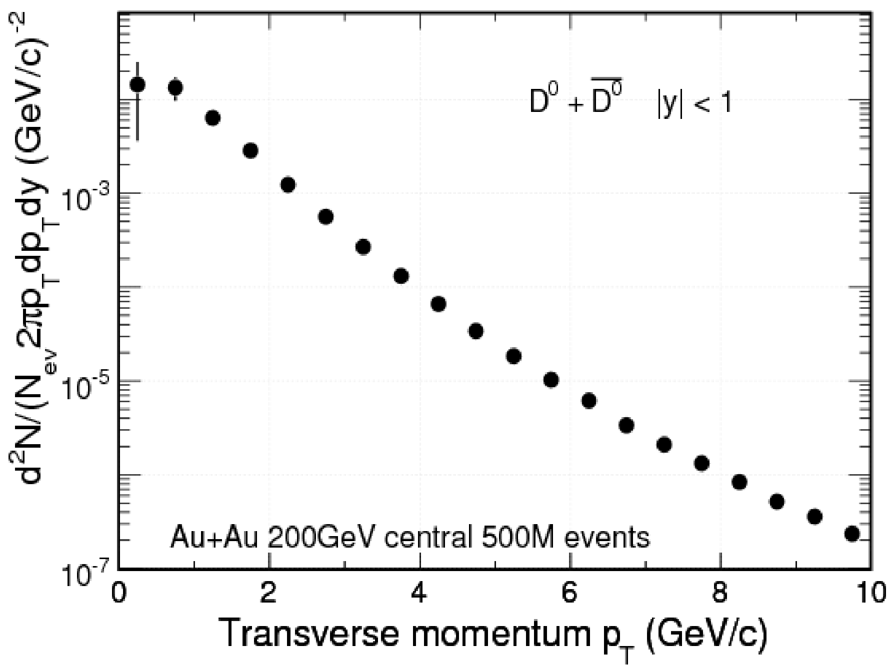


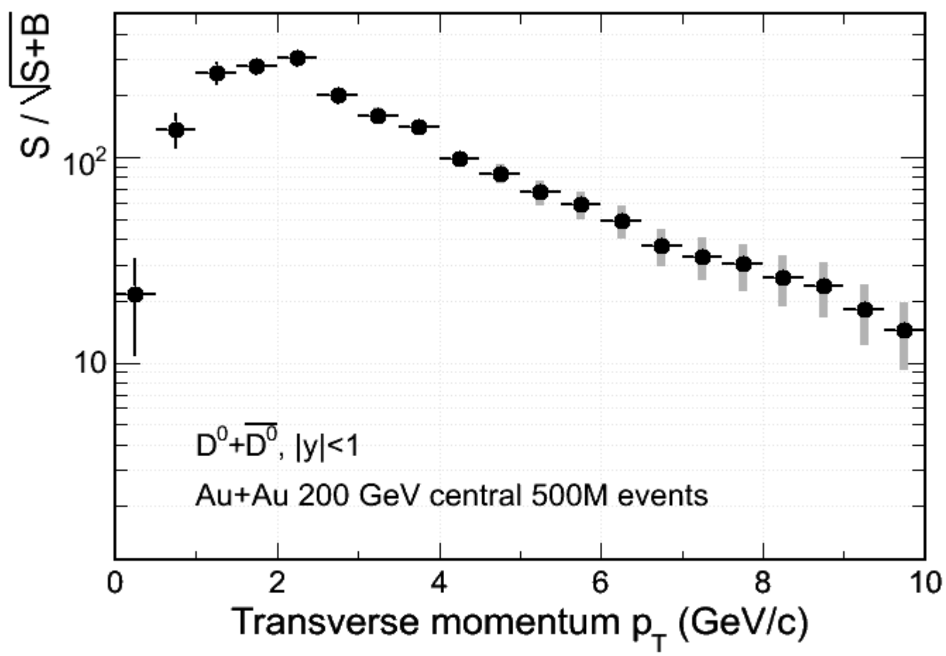
HFT Performance example on the $D^0 \rightarrow K\pi$ reconstruction

- Simulation of Au+Au@200GeV Hijing events with STAR tracking software including pixel pileup (RHIC-II luminosity) extrapolated to 500 M events (~one RHIC run).
- Identification done via topological cuts and PID using Time Of Flight

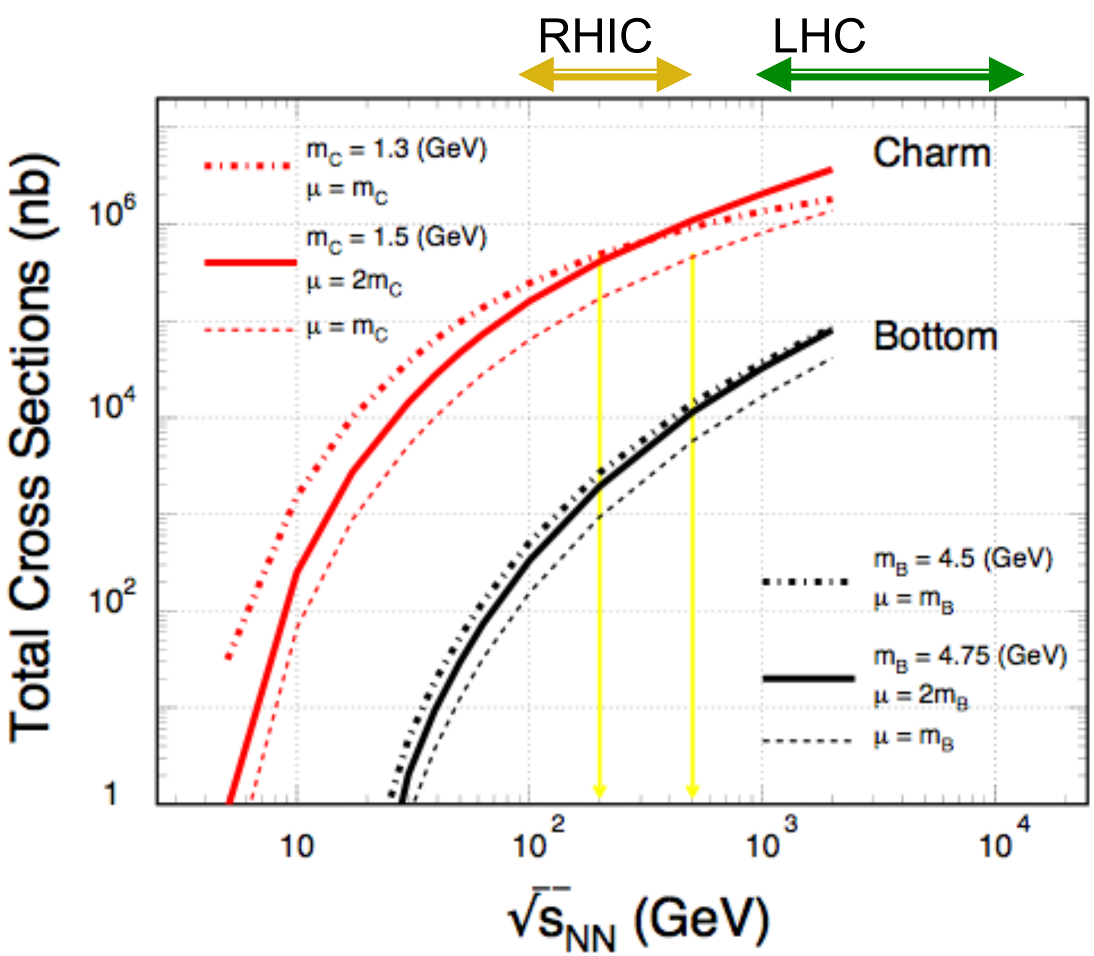








Heavy Quark Production



R. Vogt http://www-rnc.lbl.gov/ISMD/talks/Aug9/1400_Vogt.pdf

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.

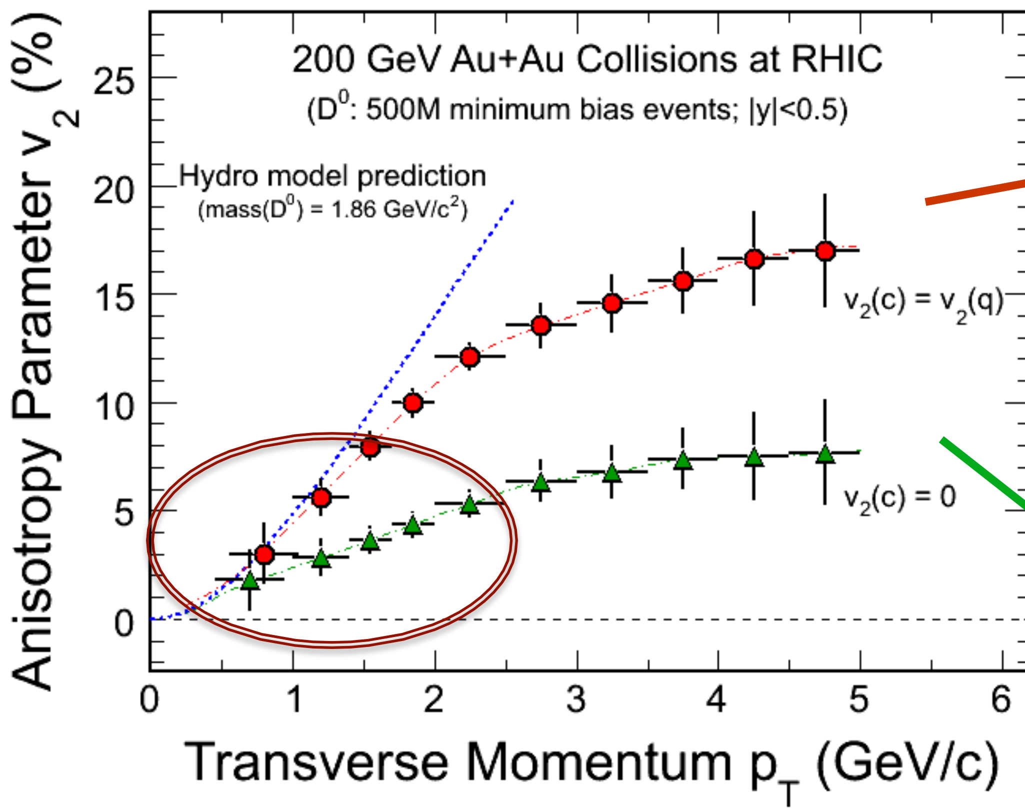
RHIC: 200, 500 GeV
LHC: 900, 14000 GeV

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

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

Estimated error bars of measurement comparable to line thickness!

HFT - Charm Hadron v_2



Charm-quark flow
➠ Thermalization of light-quarks!

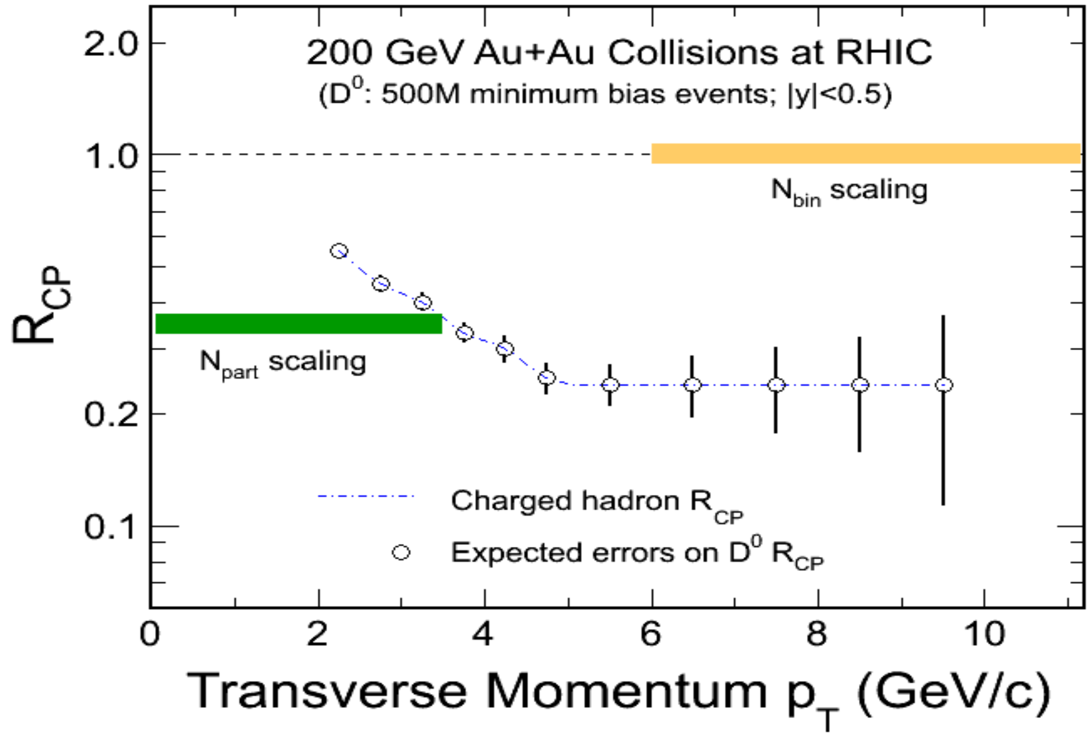
Charm-quark does not flow
➠ Drag coefficients

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

STAR ONLY can perform precision low p_T flow measurements for D^0

HFT - Charm Hadron R_{CP}

Simulation – D^0 p_T, **NOT** decay electron



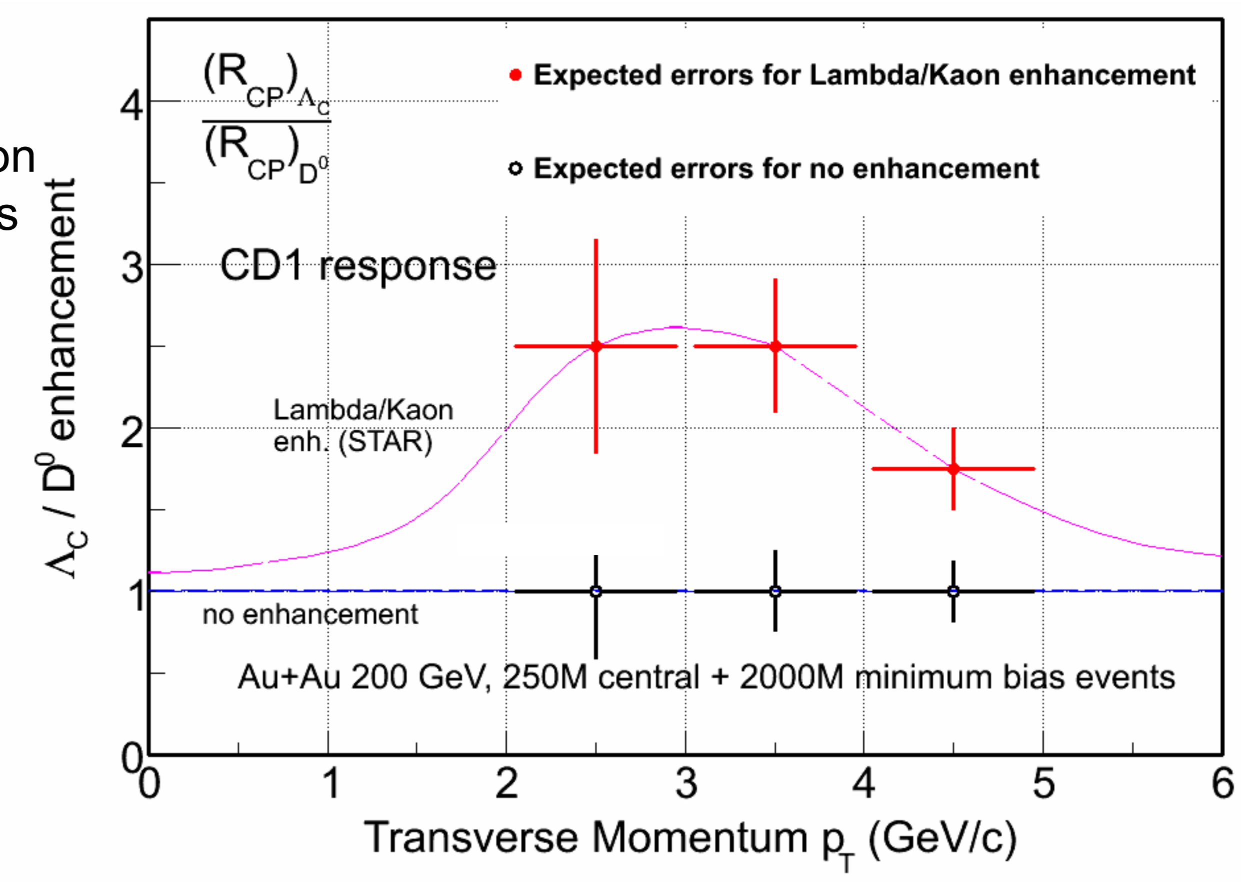
$$R_{CP} = \frac{dN/dp_T^{10\%}}{< N_{bin}^{10/(60-80)} > dN/dp_T^{(60-80)\%}}$$

- 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!***

Λ_c Measurements

Λ_c (➔ p + K + π):

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

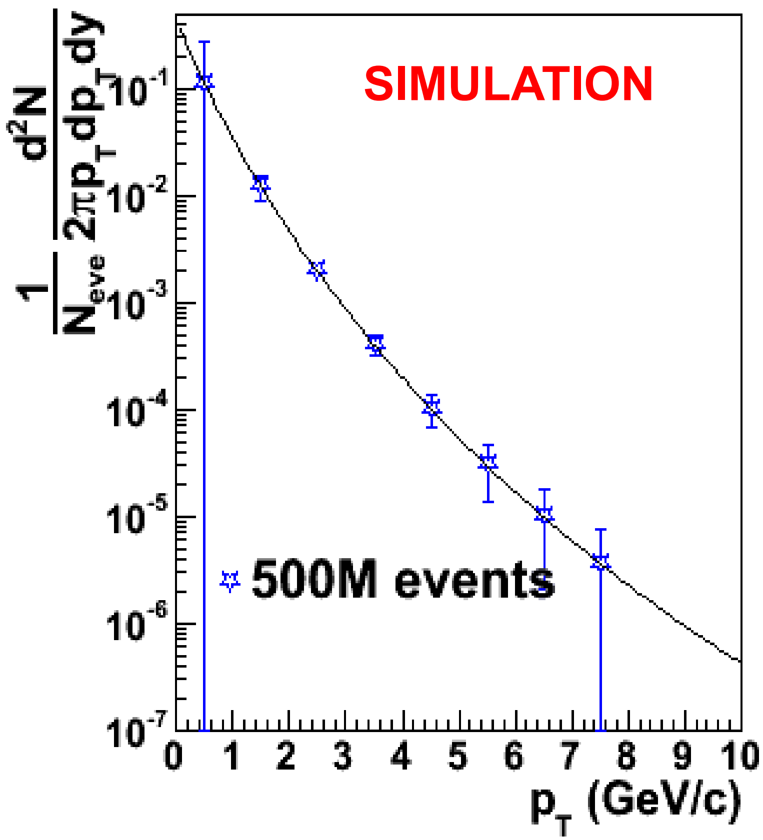


Λ_c/D^0 enhancement?

Measuring Λ_c yield is important for charmed baryon/meson ratio.

D_s Reconstruction

200 GeV Au+Au Collisions at RHIC

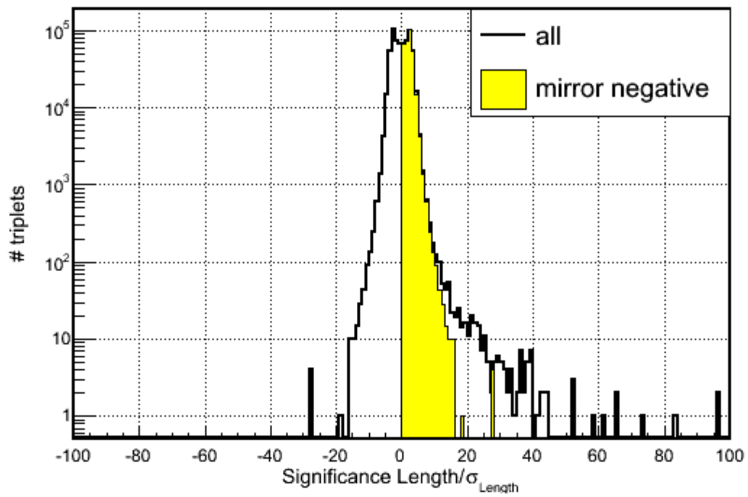


- $D_s \to K^+K^-\pi$ (BR 5.5%)
- $D_s \to \varphi\pi \to K^+K^-\pi$ (BR 2.2%)
- mass = 1968.49 ± 0.34 MeV
- **decay length** ~ 150 μm

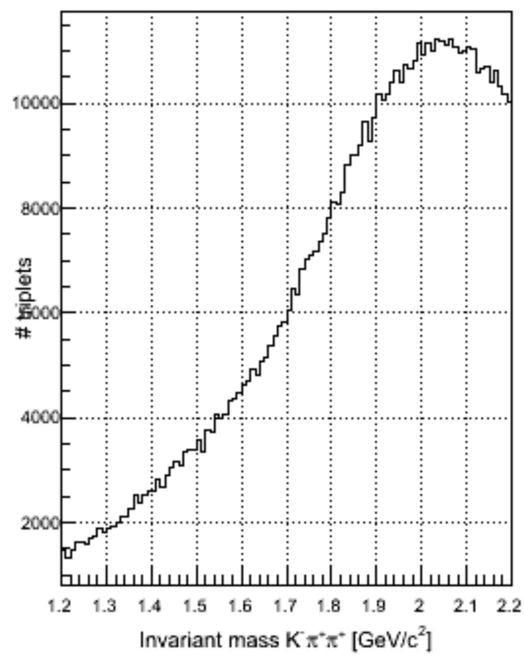
- **Work in progress …**
- 200 GeV central Au+Au
- Ideal PID
- Power-law spectrum with: $n = 11$, $\langle p_T \rangle = 1$ GeV/c

0.5B events will work!

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



No cuts



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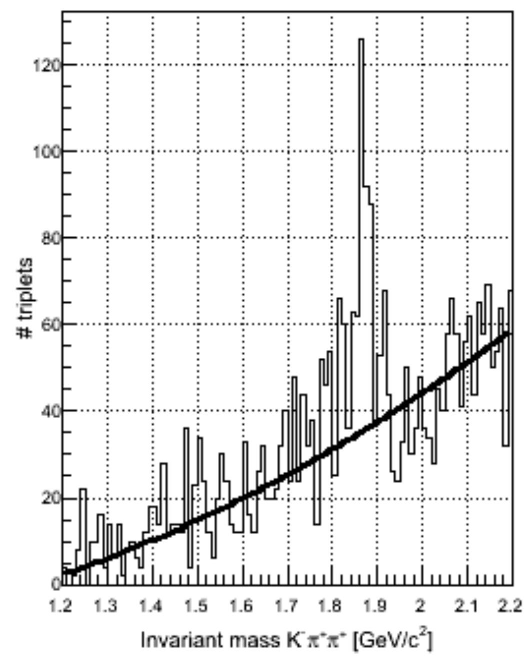


- Another charmed meson reconstructed using a full secondary vertex (Kalman) fit

The HFT is going to reconstruct ALL major charm-carrying particles

D^0, D_S, D^{+-}, D*

- This is important for 'bottom' contribution using the 'subtraction' method (next slide)

Strategies for Bottom Measurement

(1) All Charm states
($D^{0,\pm}$, D_s, Λ_C)

⇩

(2) Charm decay electrons
(Charm)

Some Bottom states
(Statistics limited at RHIC)

(1.a) Displaced vertex
electrons (TOF+HFT)
+MTD trigger?

⇩

⇨ (1.a) - (2)

⇩

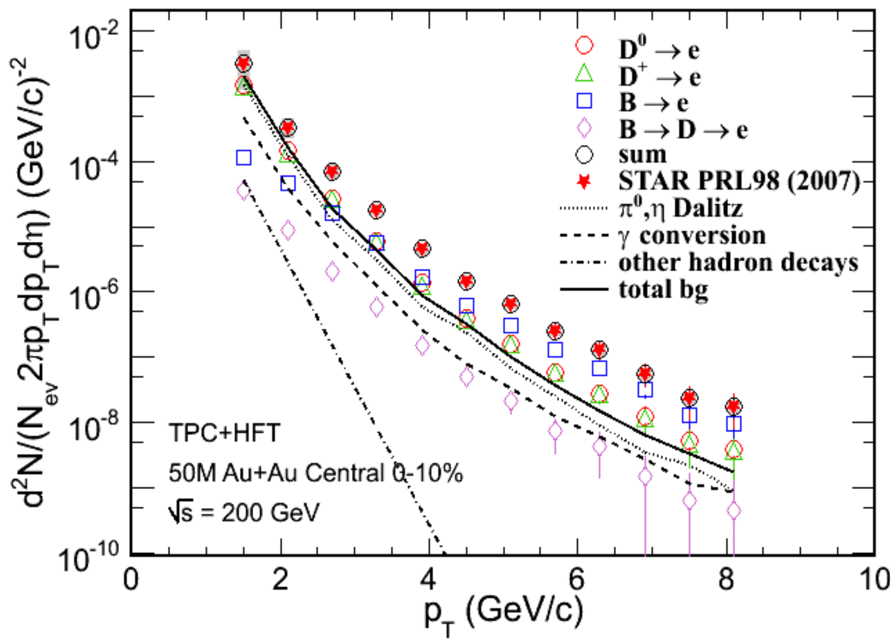
Bottom decay electrons

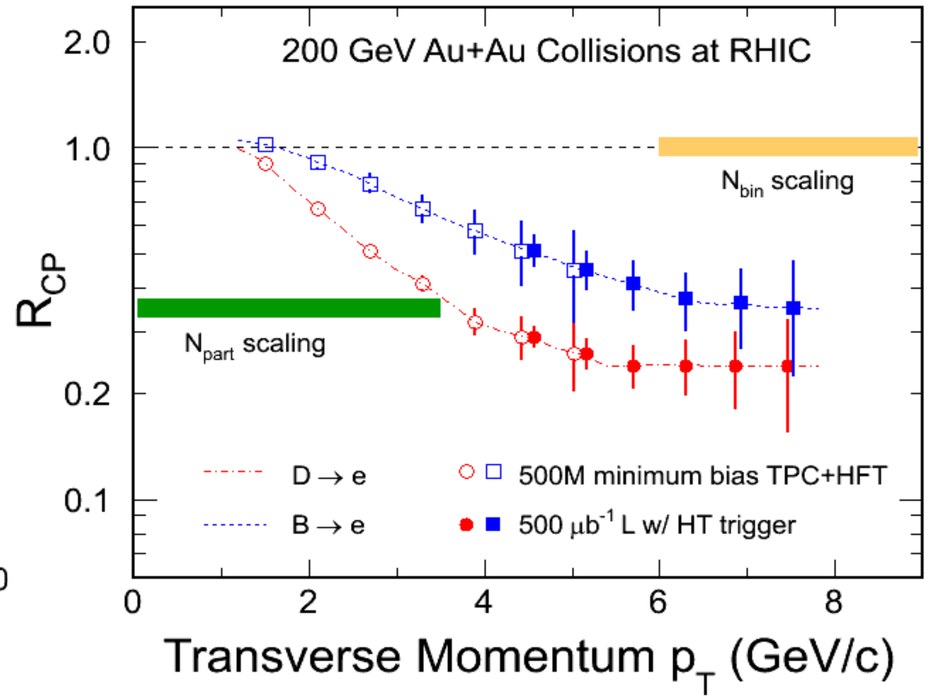
Measure **Charm** and **Bottom** hadron:

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)





$$R_{CP} = \frac{dN/dp_T^{10\%}}{< N_{bin}^{10/(60-80)} > dN/dp_T^{(60-80)\%}}$$

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

Summary

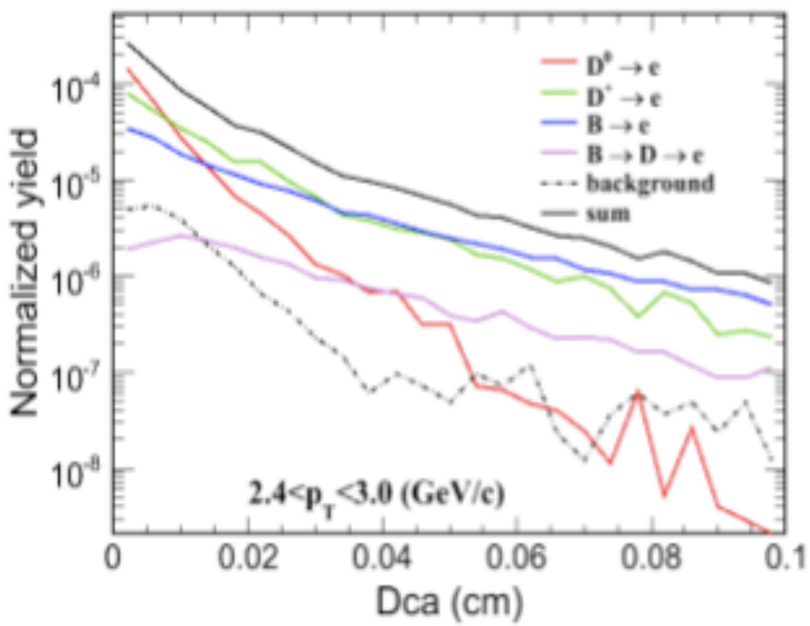
- Detailed spectra of heavy flavor (c, b) is an invaluable piece of information in solving the heavy flavor RHIC puzzle.

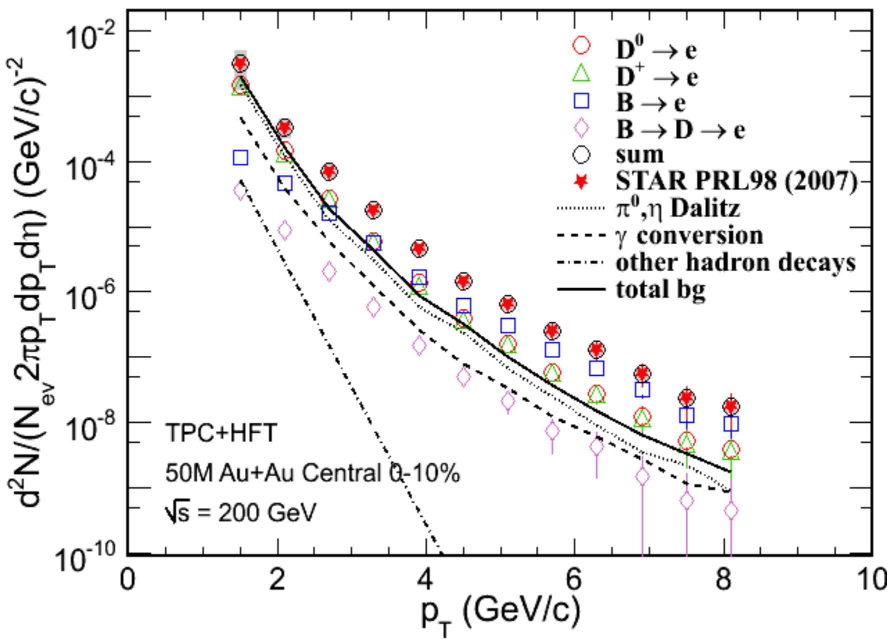
- First generation of detectors needs smart replacements

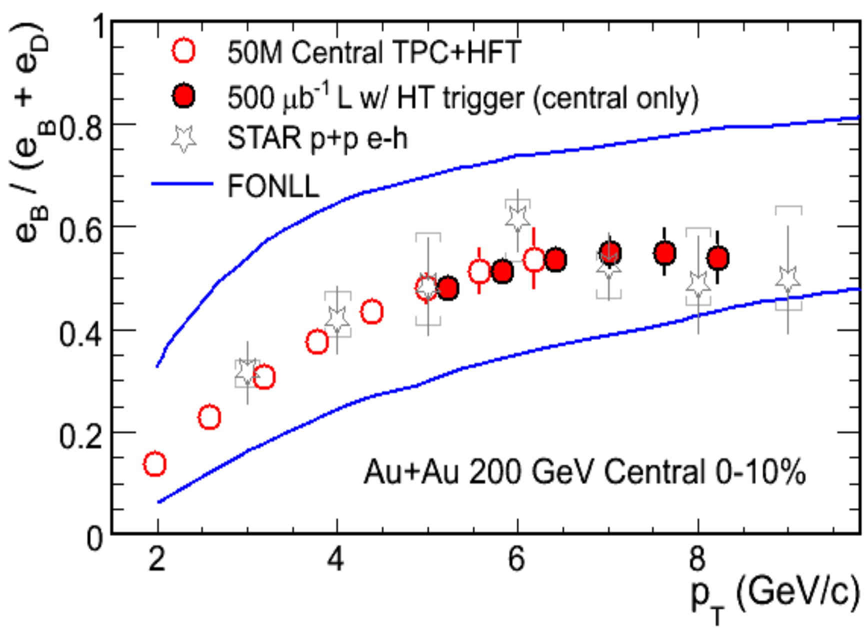
- The **Heavy Flavor Tracker** in STAR is the most advanced answer to this need

Spares

B-meson capabilities (in progress)

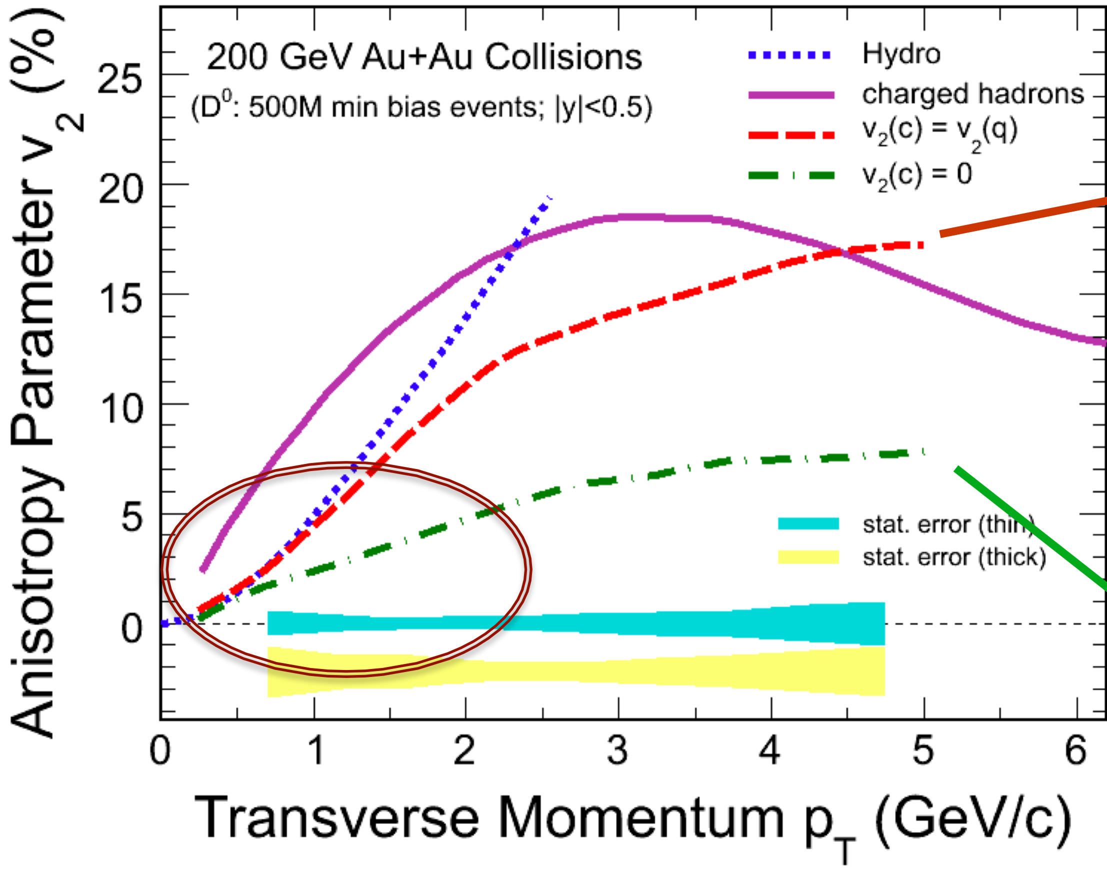






B->e+X approach
Rate limited, not resolution

HFT - Charm Hadron v_2



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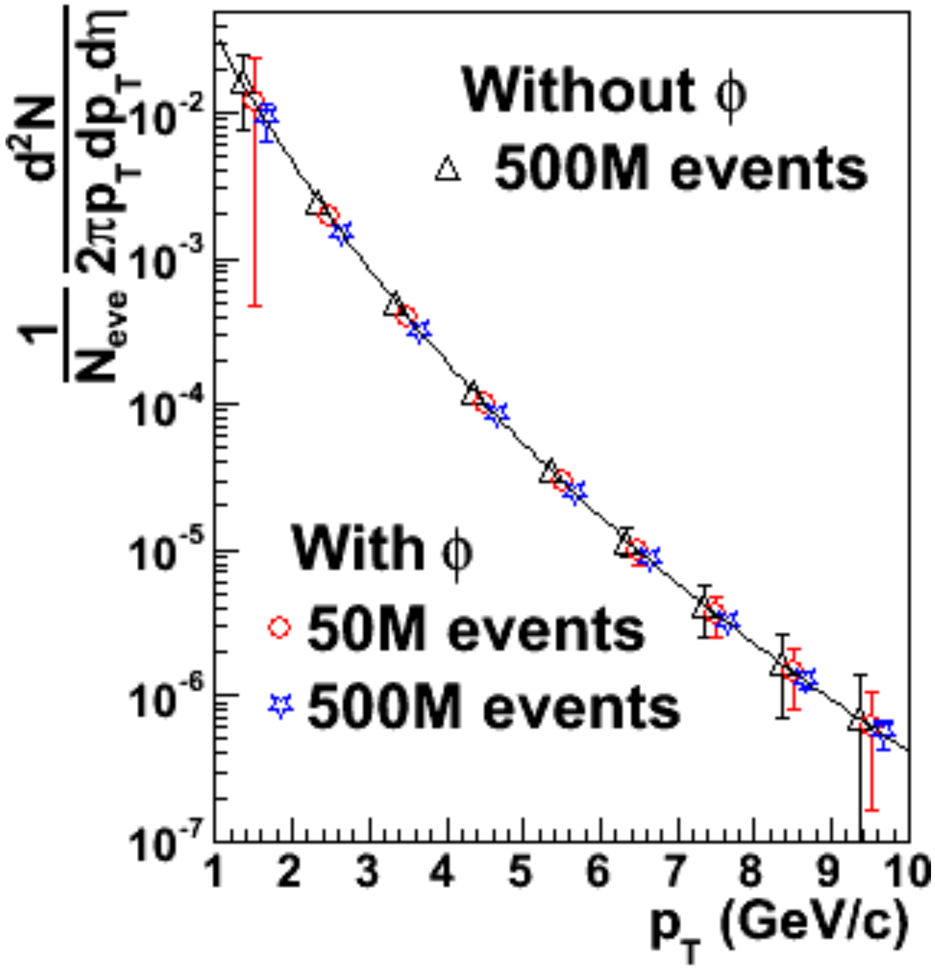

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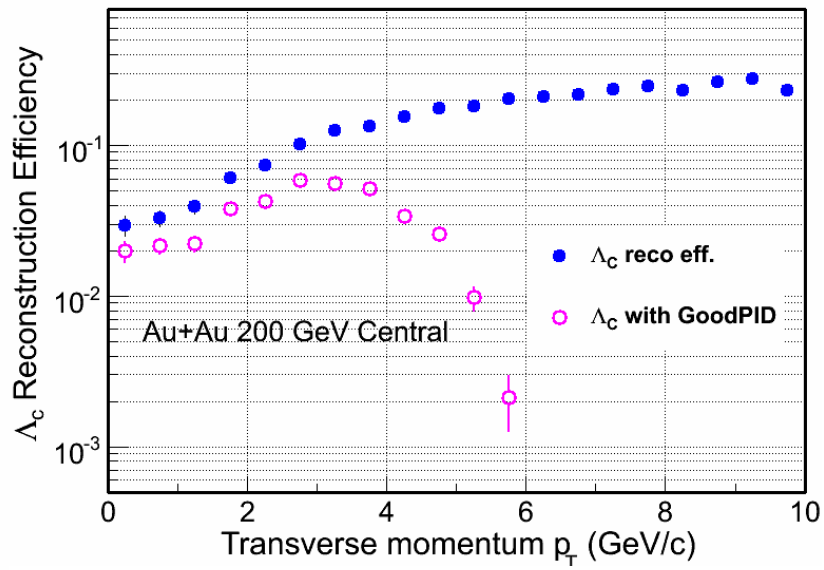
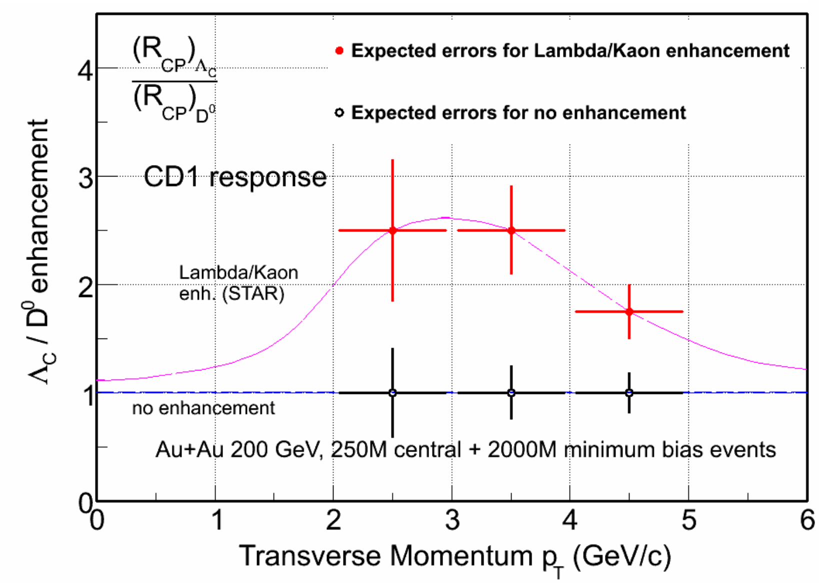
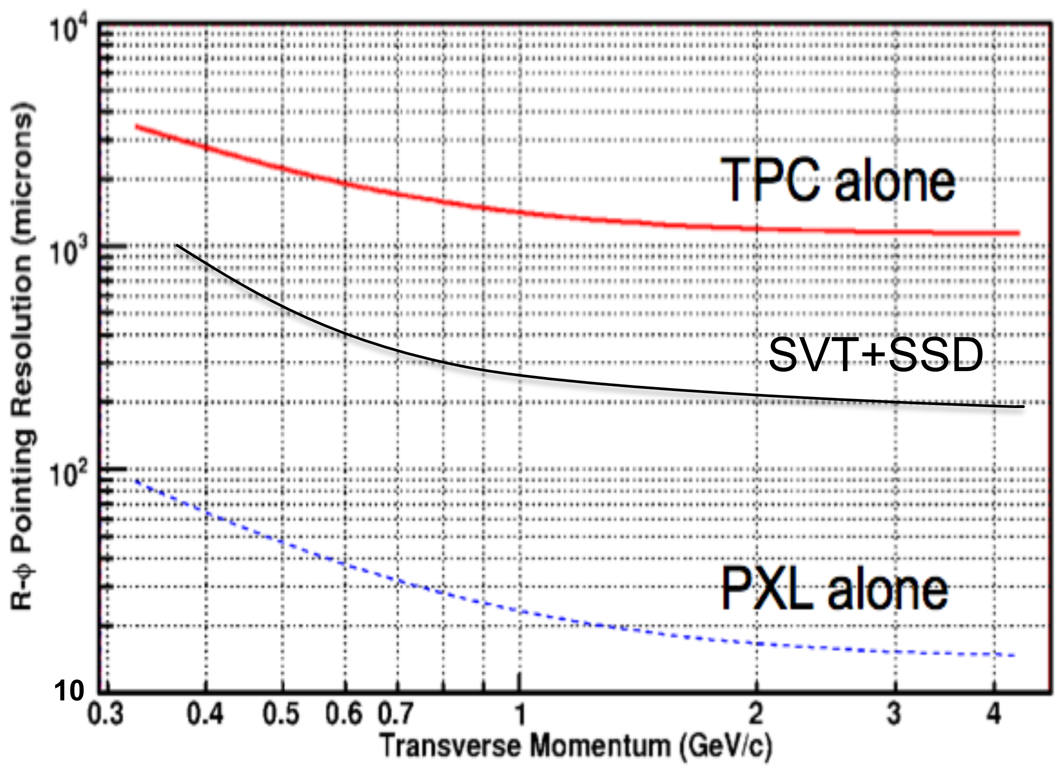


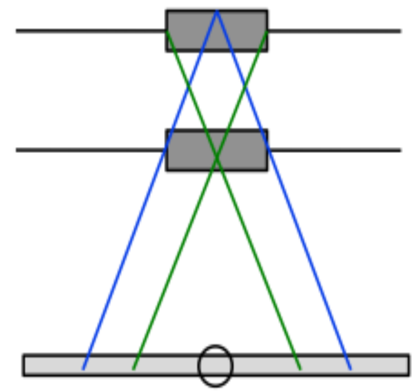


Λ_c/D^0 enhancement?

Measuring Λ_c yield is important for charmed baryon/ meson ratio.

Projection error is a strong function of first-layer distance and thickness



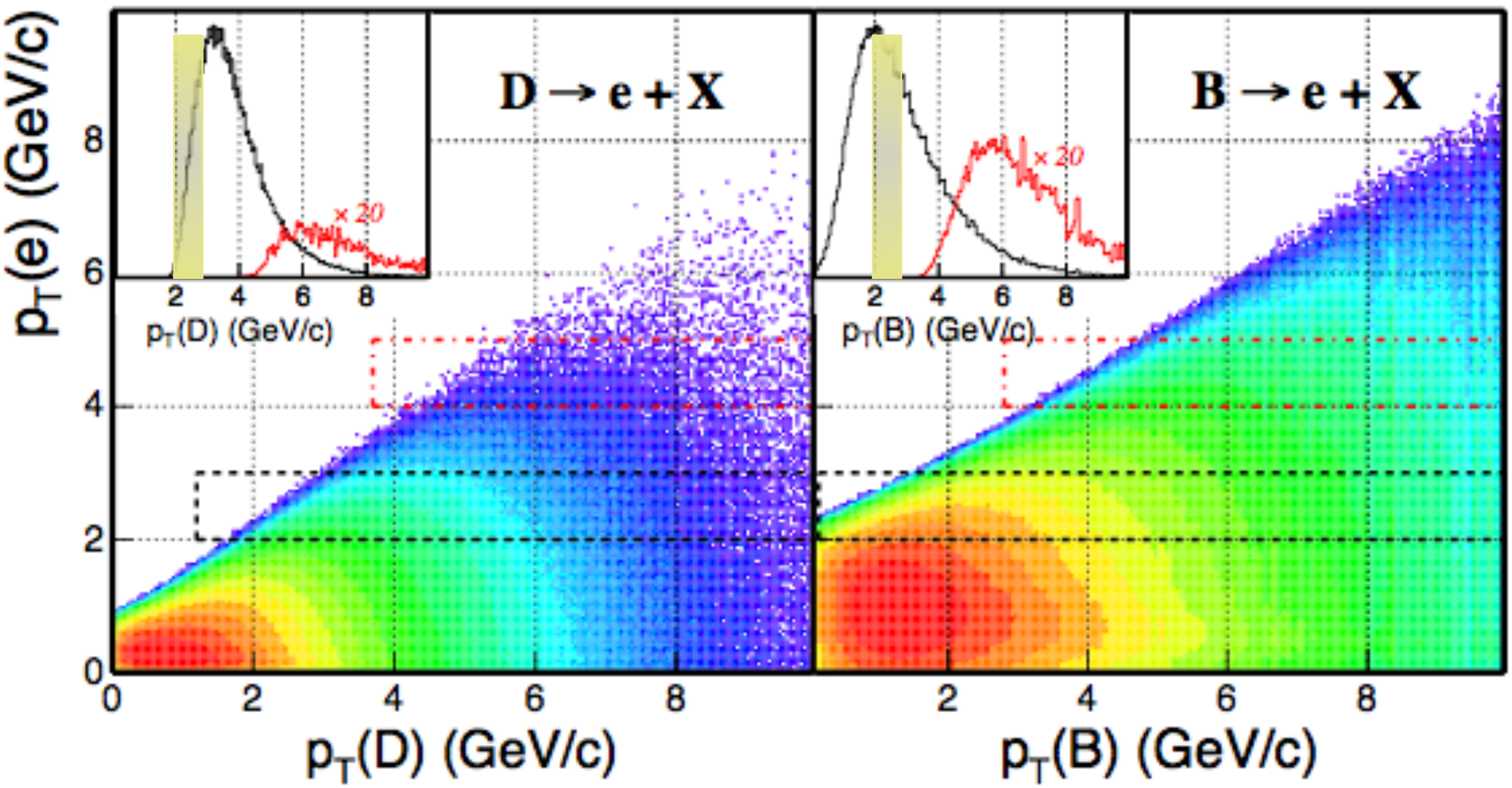


$$\sigma^2 = \frac{\sigma_1^2 r_2^2 + \sigma_2^2 r_1^2}{(r_2 - r_1)^2} + \frac{\theta_{mcs}^2 r_1^2}{\sin^2(\theta)}$$

$$\theta_{mcs} = \frac{13.6\,(MeV/c)}{\beta\ p}\sqrt{\frac{x}{X_0}}$$

- **In the critical region for Kaons from D^0 decay, 750 MeV to 1 GeV, the PXL single track pointing resolution is predicted to be 20-30 μm … which is sufficient to pick out a D^0 with $c\tau$ = 125 μm**
- **The system (and especially the PXL detector) is operating at the MCS limit**

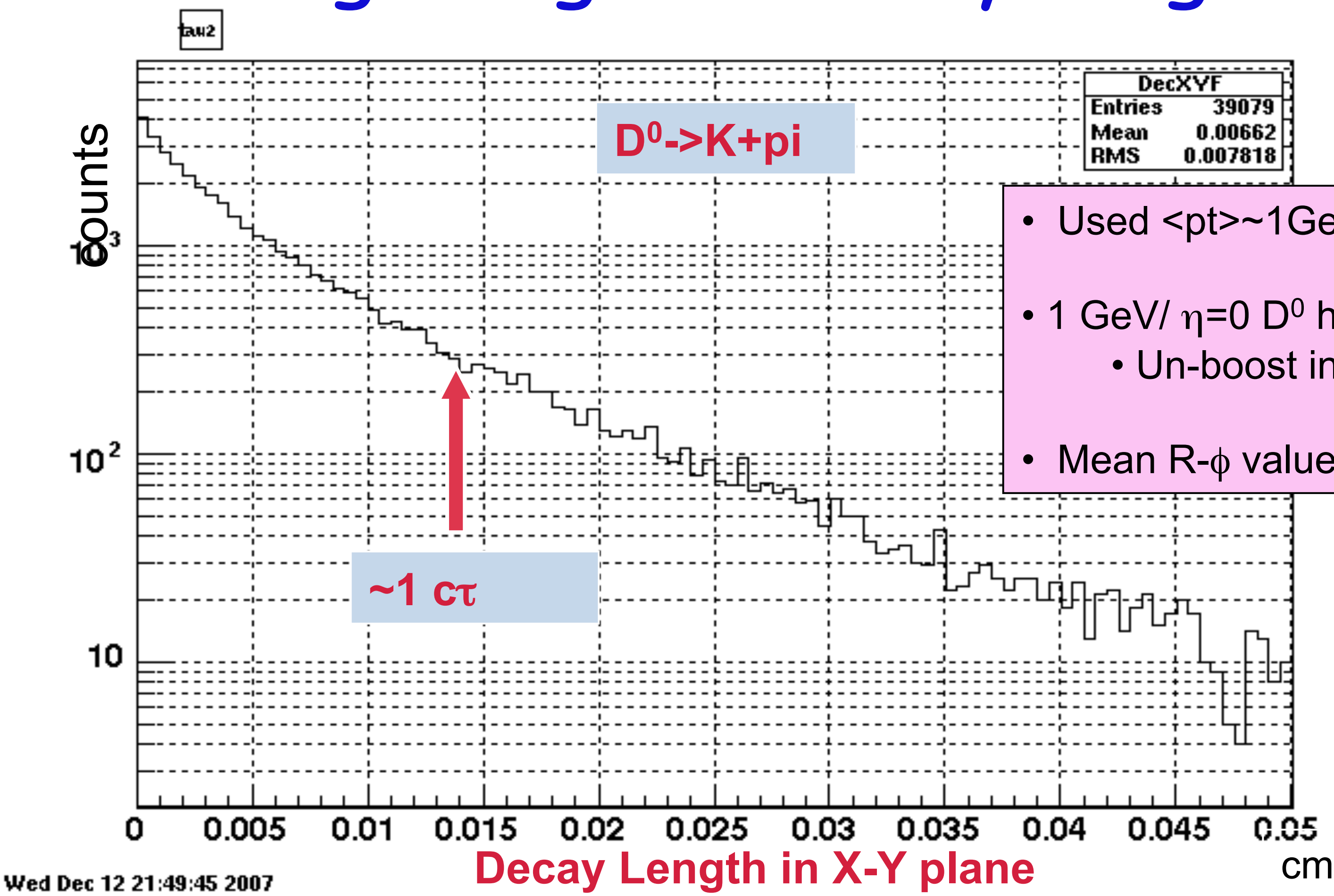
Decay **e** p_T vs. B- and C-hadron p_T



The correlations between the decayed electrons and heavy flavor hadrons is weak.

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

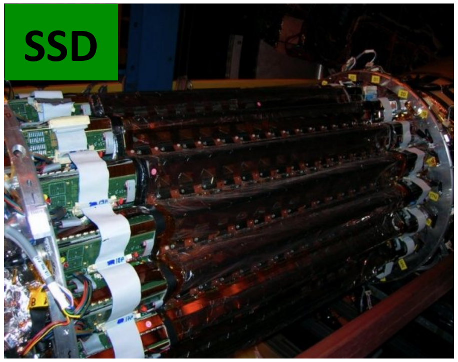
Challenge: e.g. D^0 decay length



- Used <pt>~1GeV
- 1 GeV/ η=0 D^0 has $\beta\gamma$~0.5
  - Un-boost in Collider !
- Mean R-ϕ value ~ 80 μm

For a realistic D^0 distribution, at midrapidity and $\langle p_T \rangle$ ~ 1GeV/c, the average decay length is ~80µm

OLD (SVT)



23cm

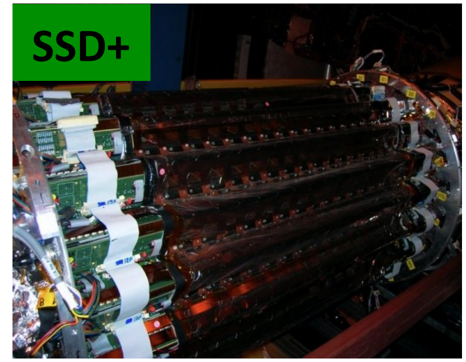
15cm

11cm

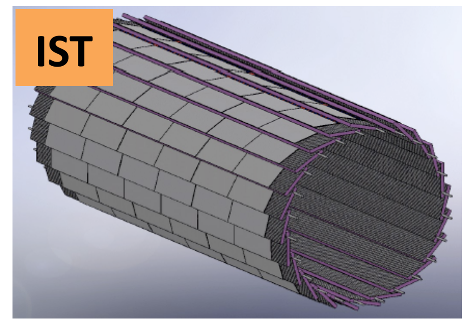
~6.5cm

SVT:~1.5%X0/layer

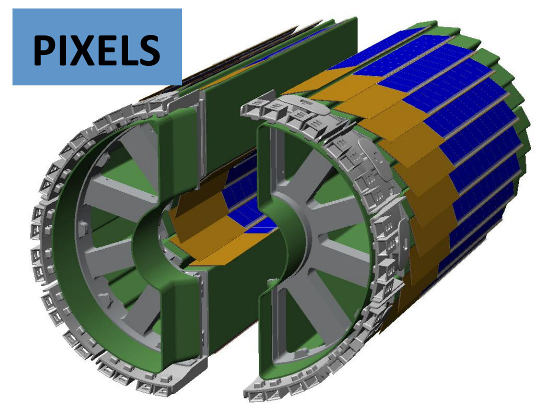
NEW (HFT)



22cm



14cm



8cm

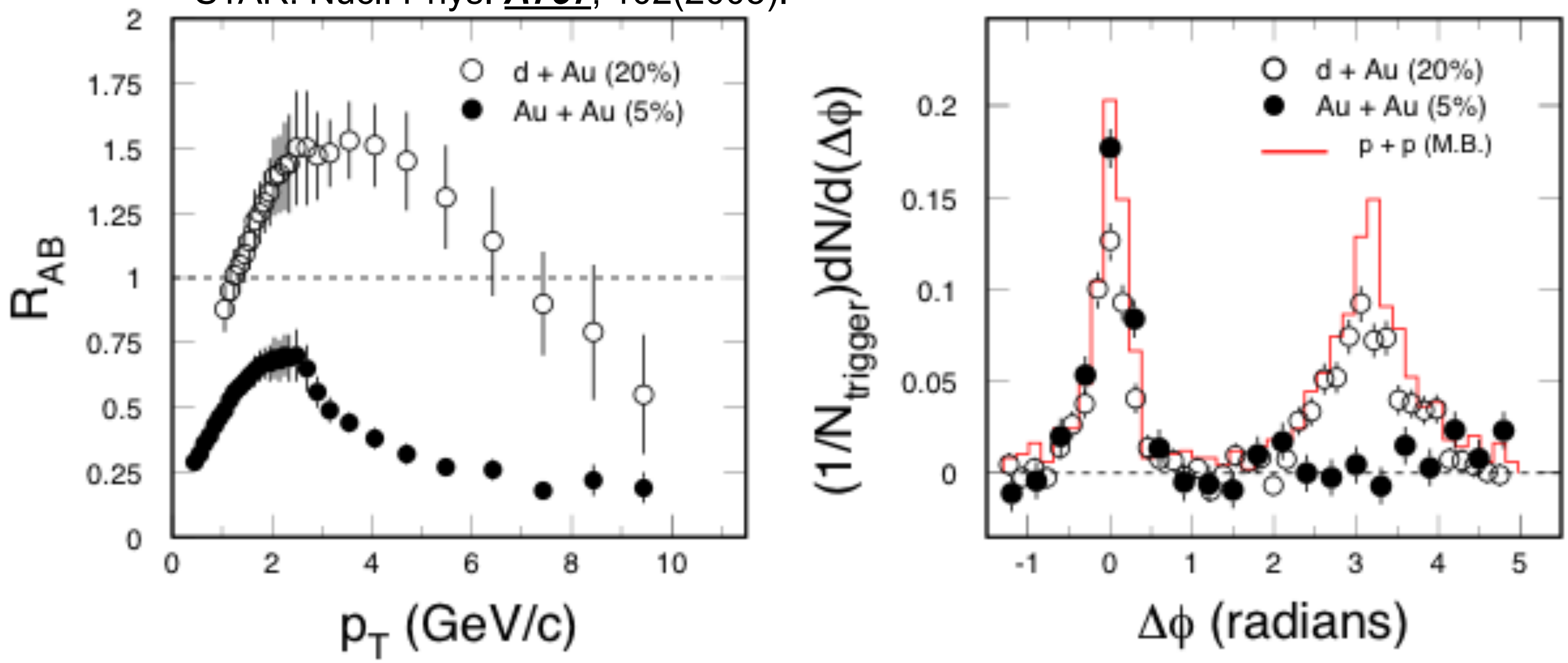
2.5cm

PXL:0.3-0.5%X0/layer

Detector resolutions differ by a factor of two but pointing by a factor of ten.

Partonic Energy Loss at RHIC

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



$$R_{AA} = \frac{dN/dp_T^{AA}}{< N_{bin}^{AA} > dN/dp_T^{pp}}$$

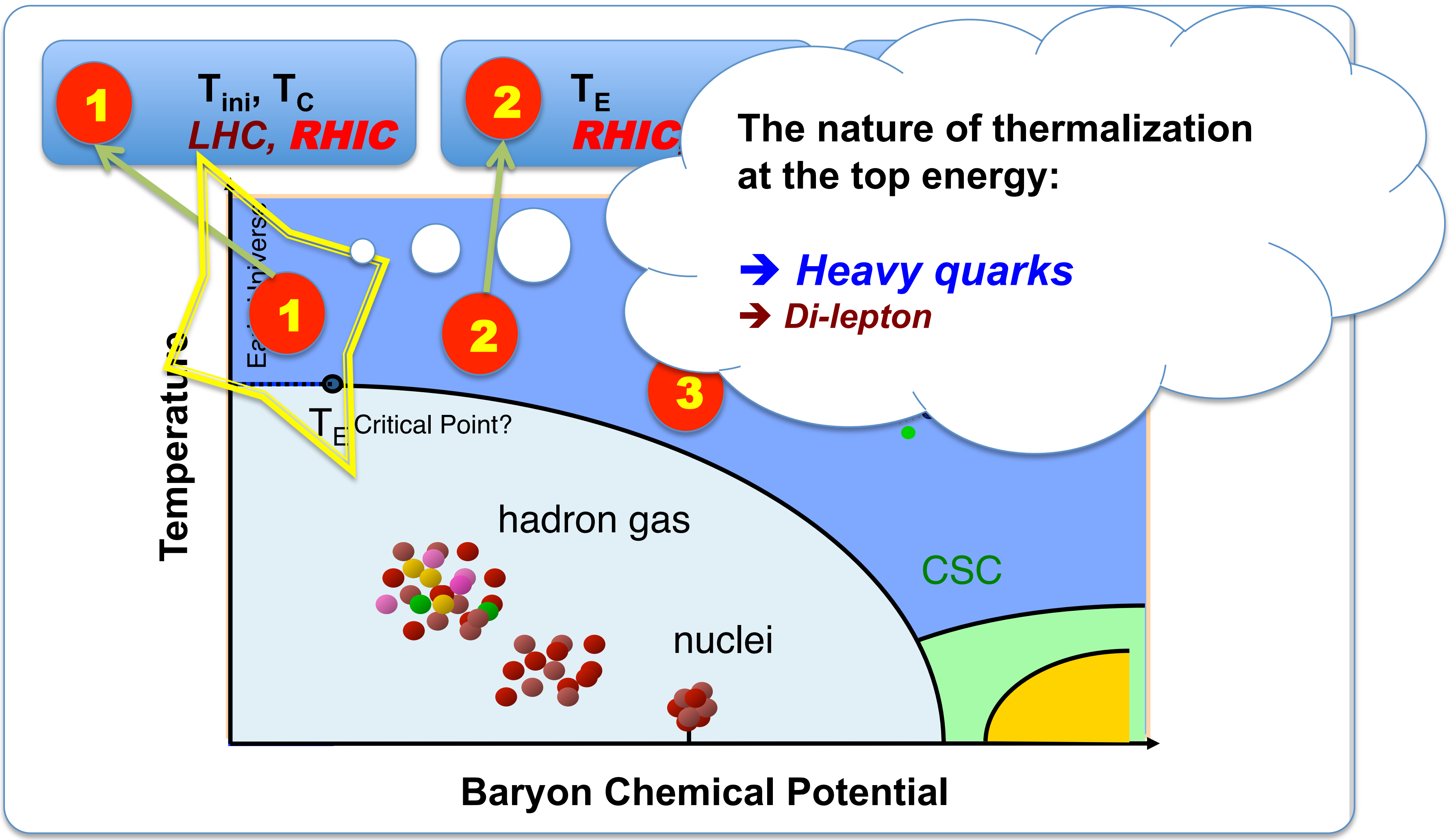
Central Au+Au collisions: light quark hadrons and the away-side jet in back-to-back 'jets' are suppressed. Different for p+p and d+Au collisions.

Energy density at RHIC: $\boldsymbol{\varepsilon} > 5$ GeV/fm^3 ~ $30\boldsymbol{\varepsilon_0}$

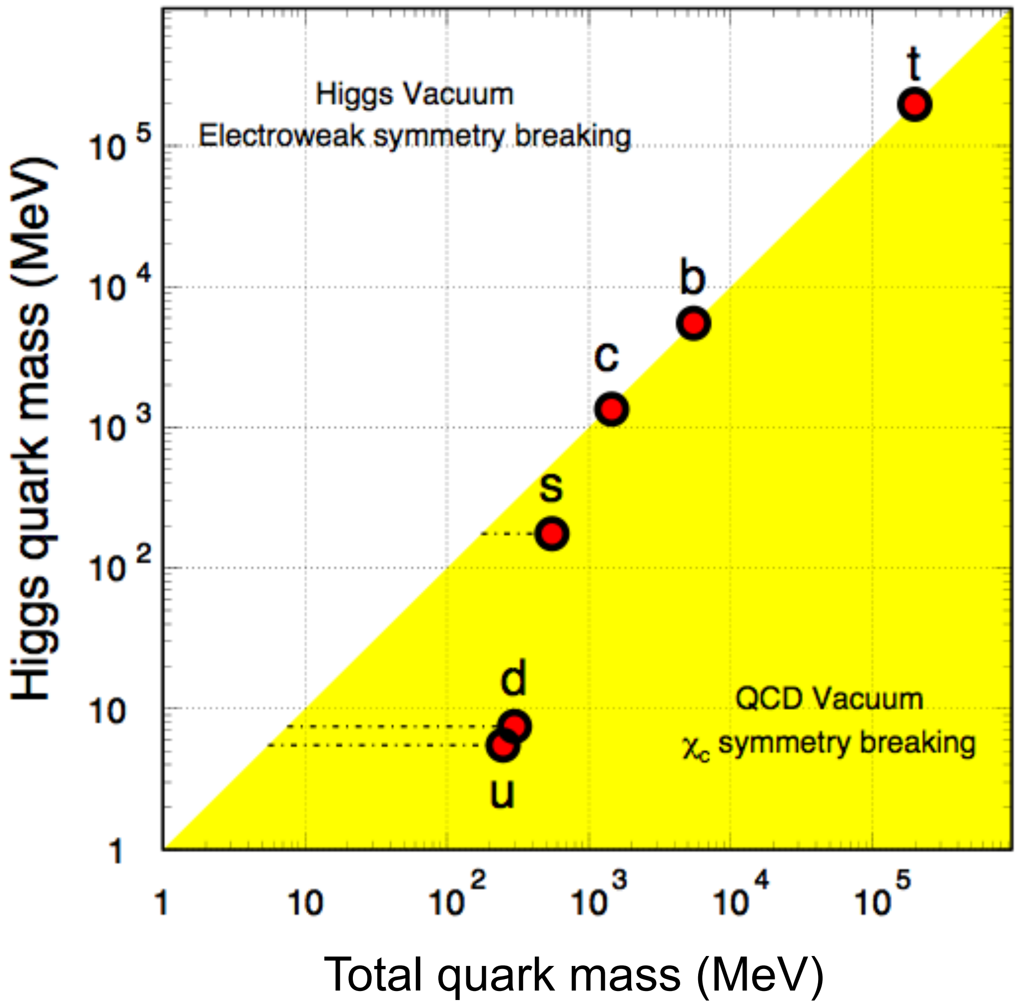
Explore pQCD in hot/dense medium

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

The QCD Phase Diagram and High-Energy Nuclear Collisions



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.

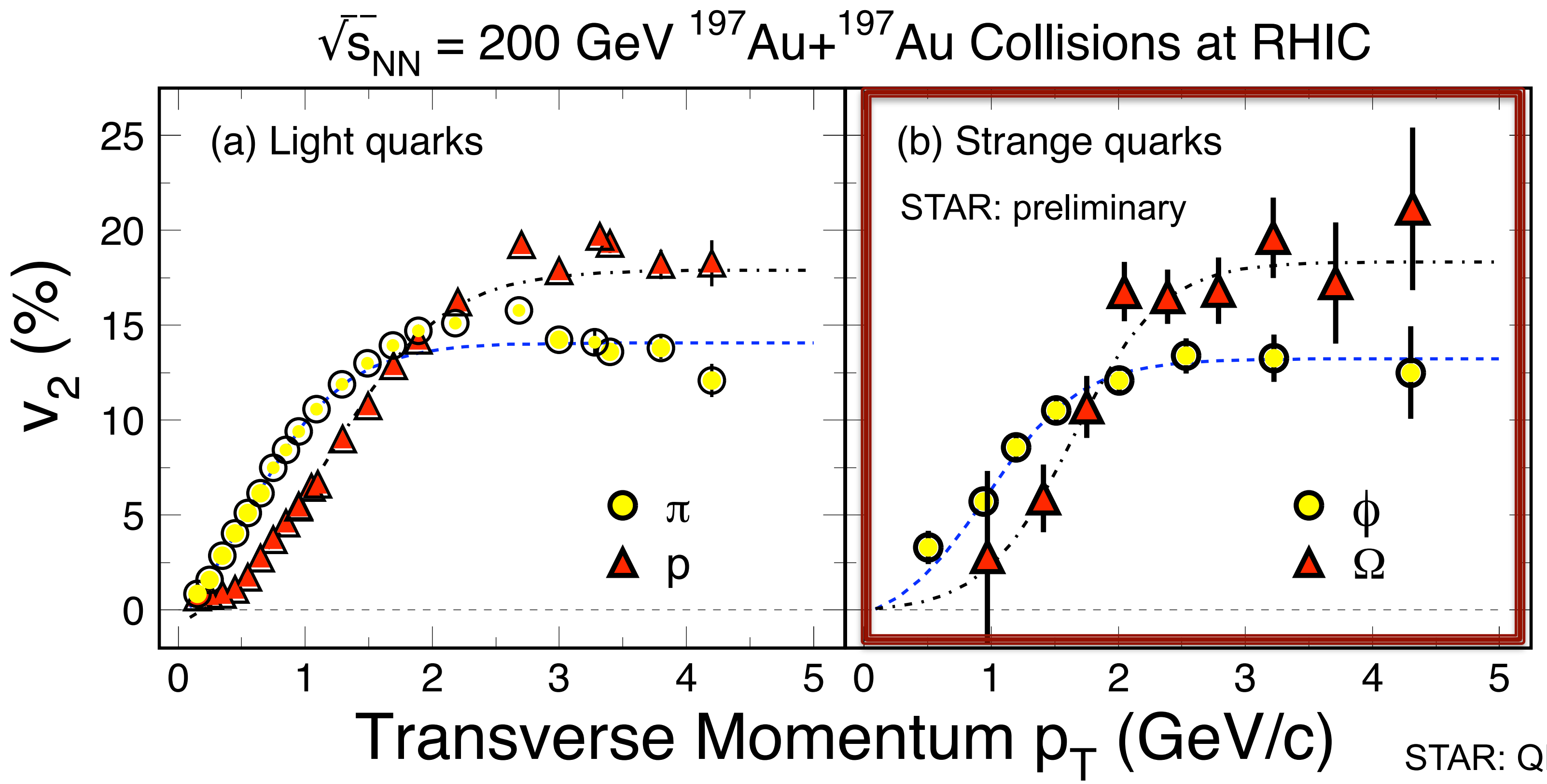
⇨ Study properties of the hot and dense medium at the ***foremost early stage*** of heavy-ion collisions.

⇨ Explore pQCD at RHIC.

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

Partonic Collectivity at RHIC



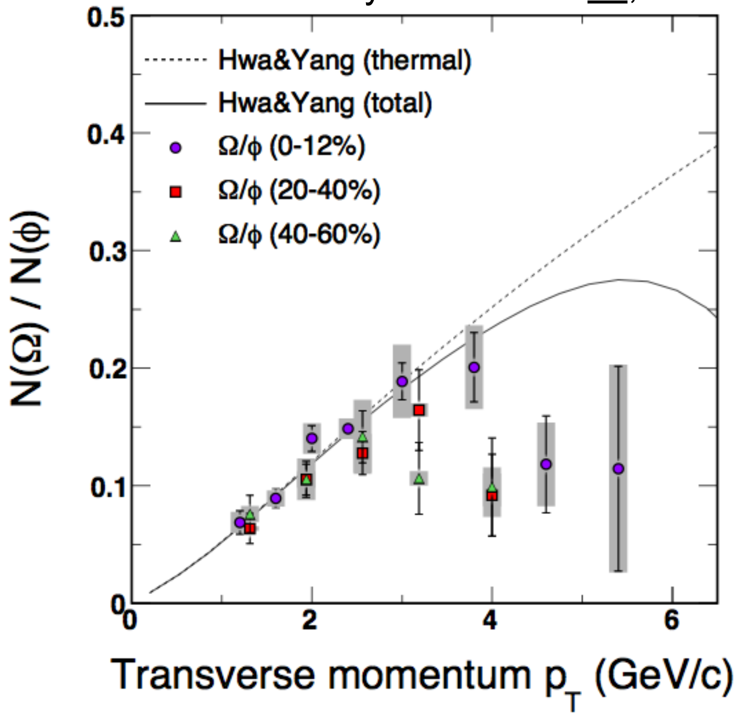
STAR: QM2009

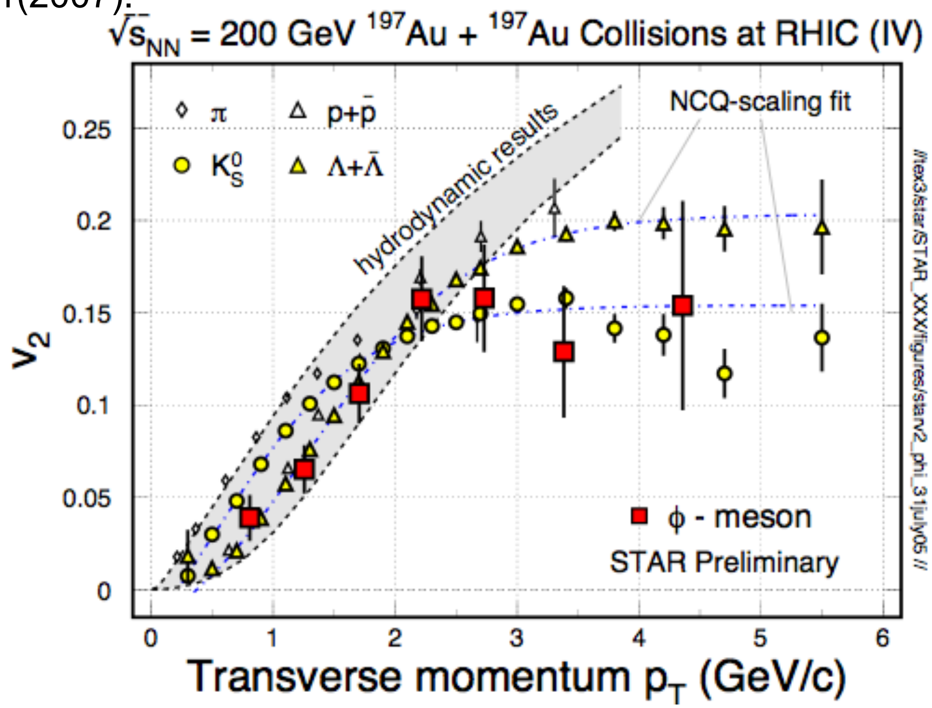
Low p_T (≤ 2 GeV/c): hydrodynamic mass ordering
High p_T (> 2 GeV/c): number of quarks ordering
s-quark hadron: smaller interaction strength in hadronic medium
light- and s-quark hadrons: similar v_2 pattern

=> Collectivity developed at partonic stage!

ϕ -meson Flow: Partonic Flow

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

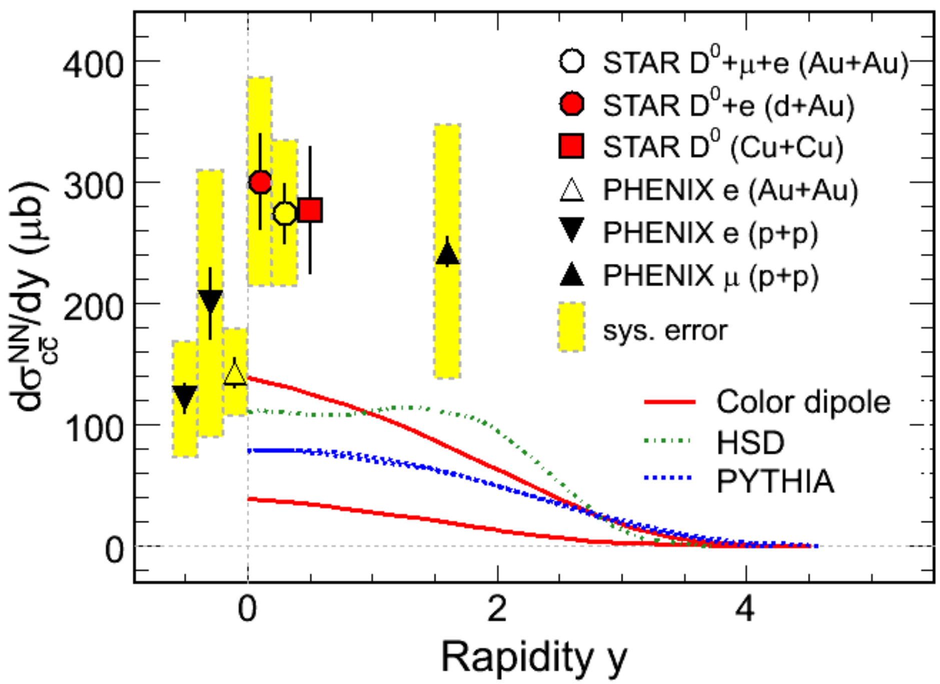


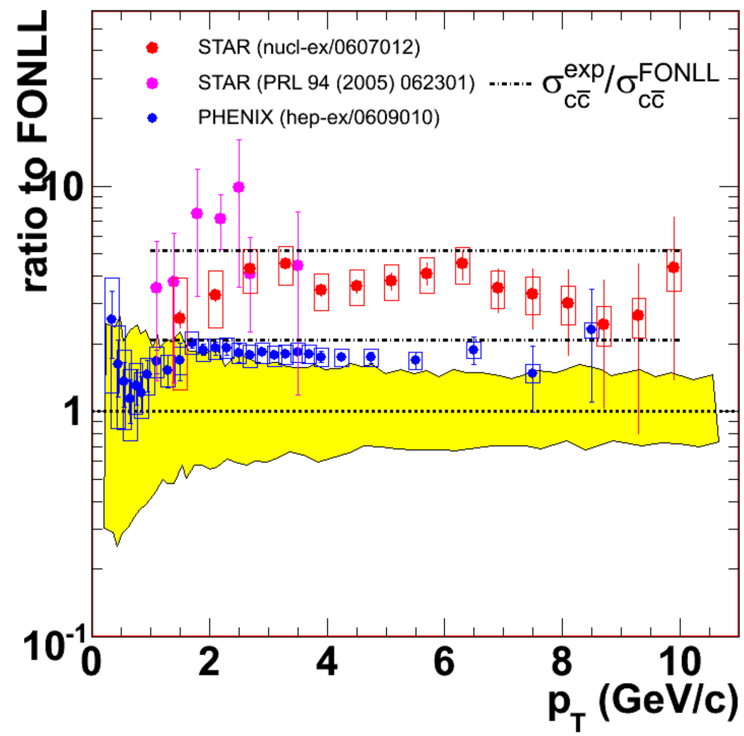


"φ-mesons (and other hadrons) are produced via coalescence of seemingly thermalized quarks in central Au+Au collisions. This observation implies *hot and dense matter with partonic collectivity* has been formed at RHIC"

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

Charm Cross Sections at RHIC

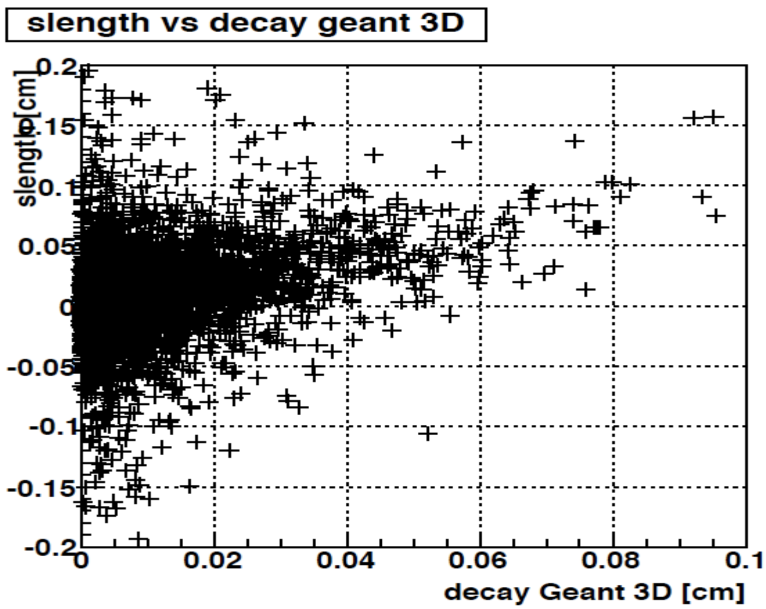




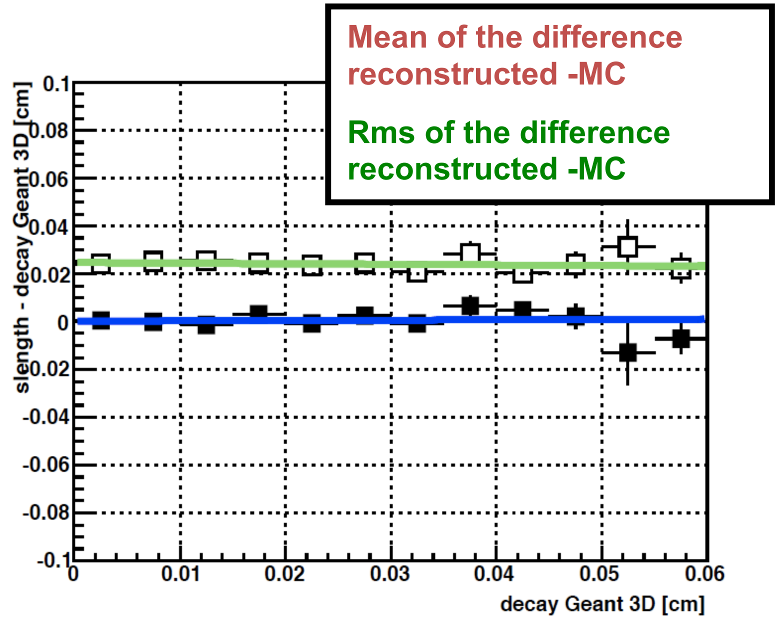
1) Large systematic uncertainties in the measurements
2) New displaced, topologically reconstructed measurements for c- and b-hadrons are needed ⇨ ***Upgrade***

SVT+SSD D0-vertex resolution (simulation)

Reco vs. MC [cm]



Reco - MC [cm]



MC [cm]

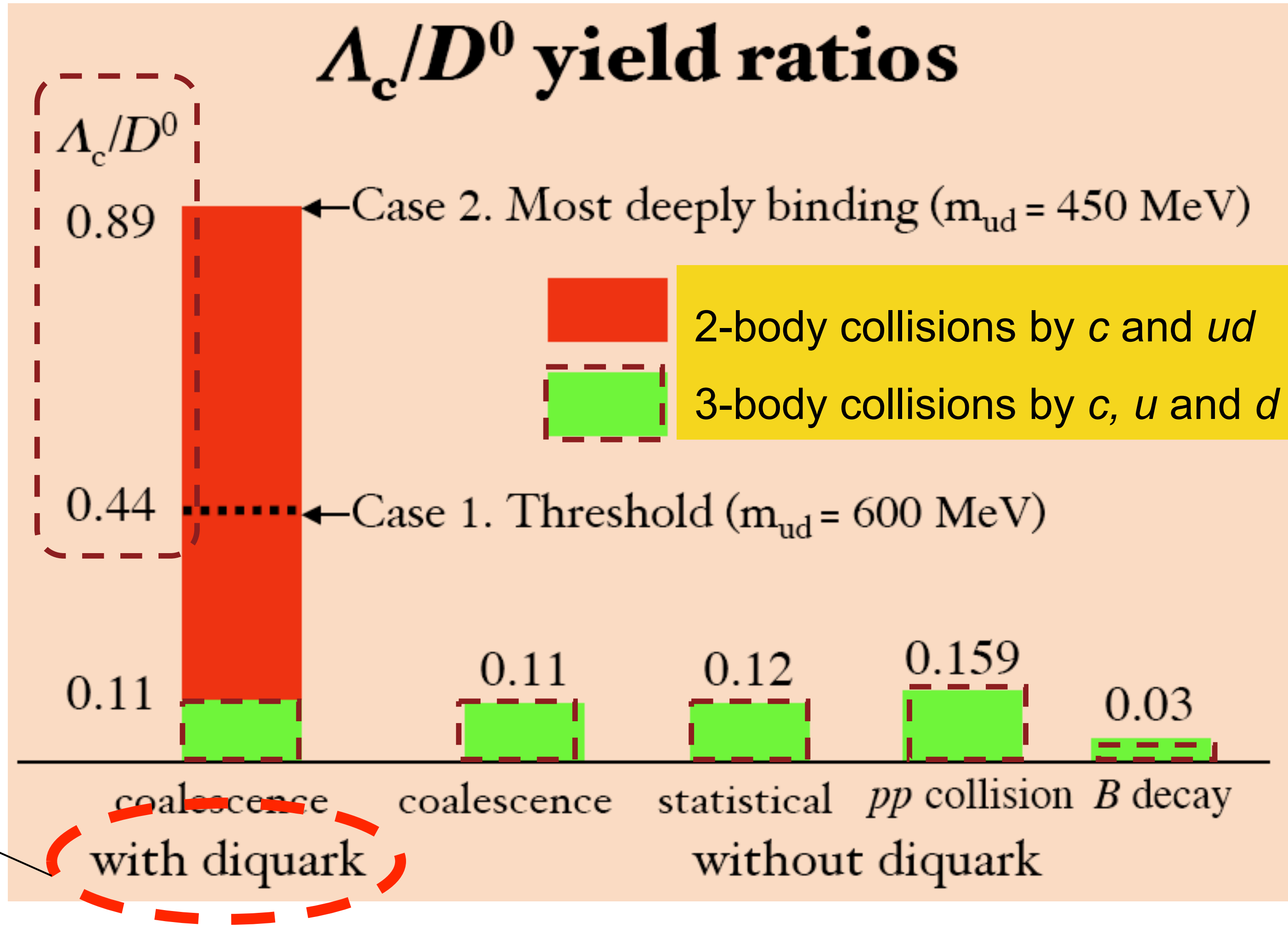
- Left : correlation between reconstructed path length and MC
- Right : Decay length resolution
  - There is no systematic shift in reconstructed quantities.
  - The standard deviation of the distribution is flat at ~ 250 μm , which is of the order of the resolution of (SSD+SVT).

Charm Baryon/Meson Ratios

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

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

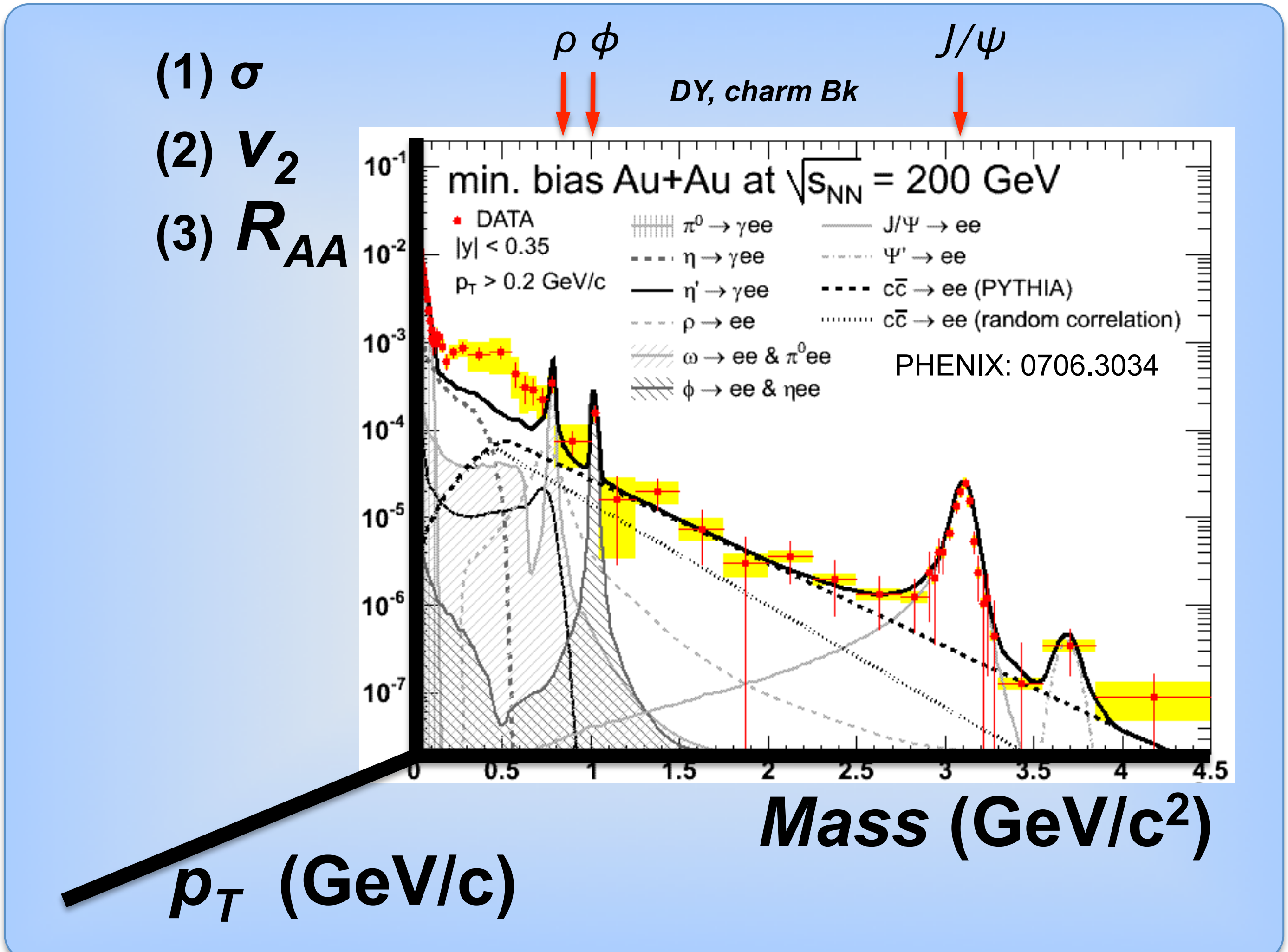
QGP medium



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).

The di-Lepton Program at STAR

TOF + TPC + *HFT*



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

✓ **Chiral symmetry Restoration**

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