STAR HFT Upgrade –– Heavy Quark Physics at RHIC

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(For STAR Collaboration)

Outline:

- Physics Motivation
- Hadronic reconstruction with HFT
- D&B $\rightarrow$ e simulation with HFT
- Summary

HQ Workshop

UCLA, 21-25 Jan, 2009

Motivation - Heavy quark masses

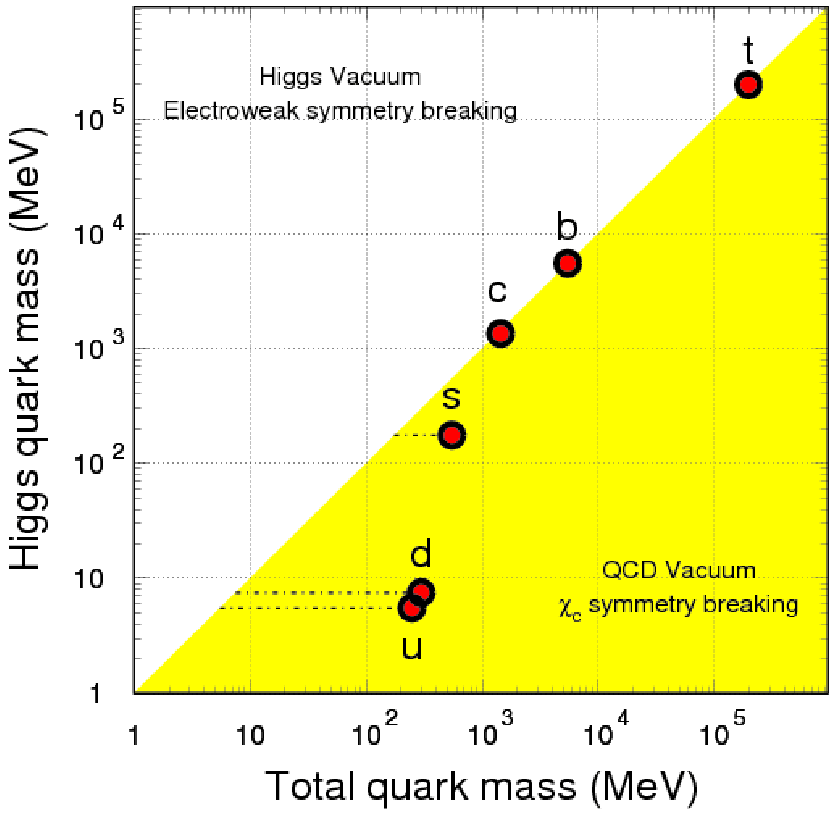
$M_b \approx 4.8$ GeV
$M_c \approx 1.5$ GeV
$\gg T_c, \Lambda_{QCD}, M_{uds}$

① Higgs mass: electro-weak symmetry breaking. (current quark mass)

② QCD mass: Chiral symmetry breaking. (constituent quark mass)

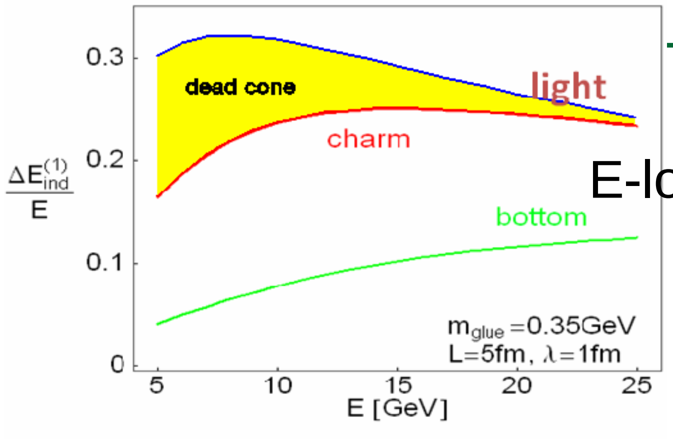
➢ Heavy quark masses are not modified by QCD vacuum. Strong interactions do not affect them.

➢ Important tool for studying properties of the hot-dense matter created at RHIC energy.



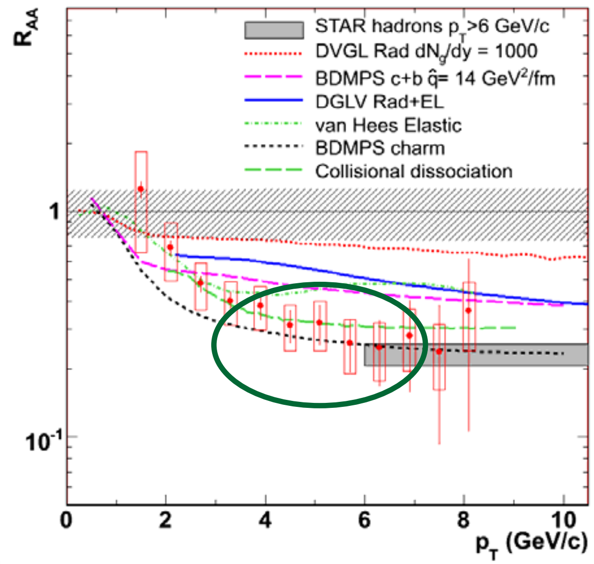
X.Zhu, *et al., PLB 647 (2007) 366*

Heavy quark e-loss and v_2



E-loss: b < c < q

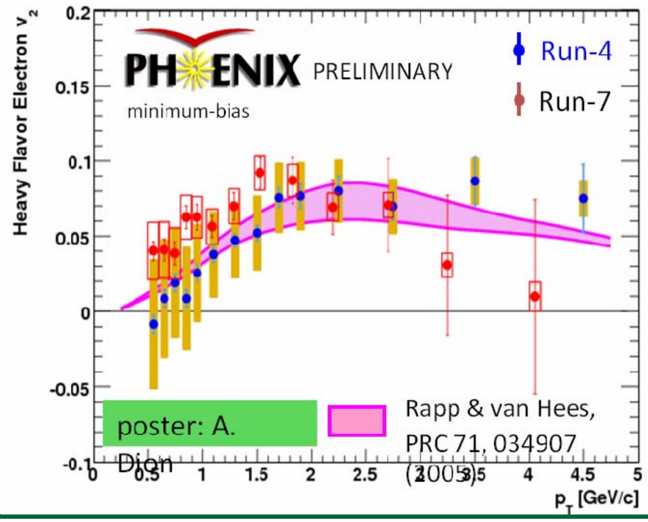
STAR PRL **98** (2007) 192301



The R_{AA} of single electron from heavy flavor decay has the similar suppression as that of light flavor hadrons.

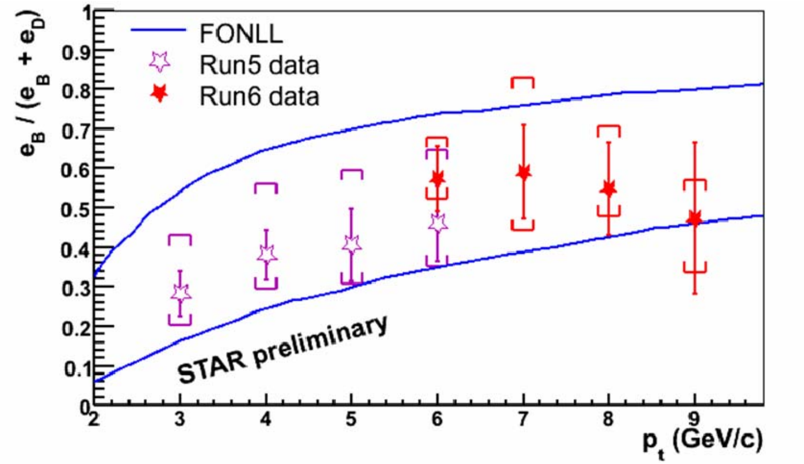
Spectra, $R_{AA}(D\rightarrow e)$ & $R_{AA}(B\rightarrow e)$? => heavy quark energy loss mechanism, heavy quark interaction with medium.

$v_2(D\rightarrow e)$ & $v_2(B\rightarrow e)$? => light flavor thermalization, drag constants.



Directly measure D is not a problem with HFT

Measure B & Λ_c



Important for understanding the bottom contribution in current NPE measurements.

Large systematic errors for both theory (FONLL) and data (STAR e-h correlation).

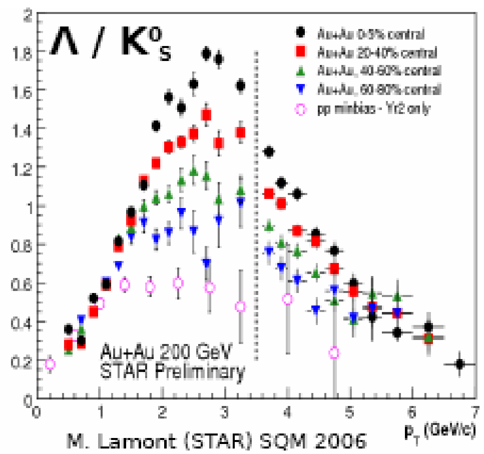
Need improve the measurement accuracy.

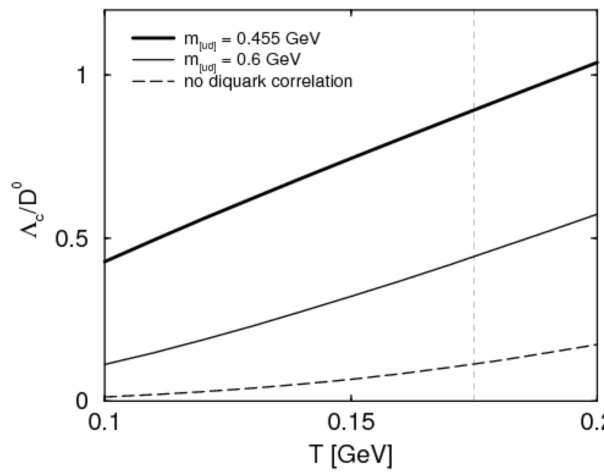
Measure this ratio directly from spectra.

- No B meson spectra measured.
- Separately measure $B \to e$ spectrum will indirectly measure B meson spectrum from its decay kinematics.
- $B \to e$ = NPE – $D \to e$

STAR HFT has the capability to measure D^0 decay vertex topologically via hadronic decay channel. Measured D^0 spectrum constrain $D \to e$.

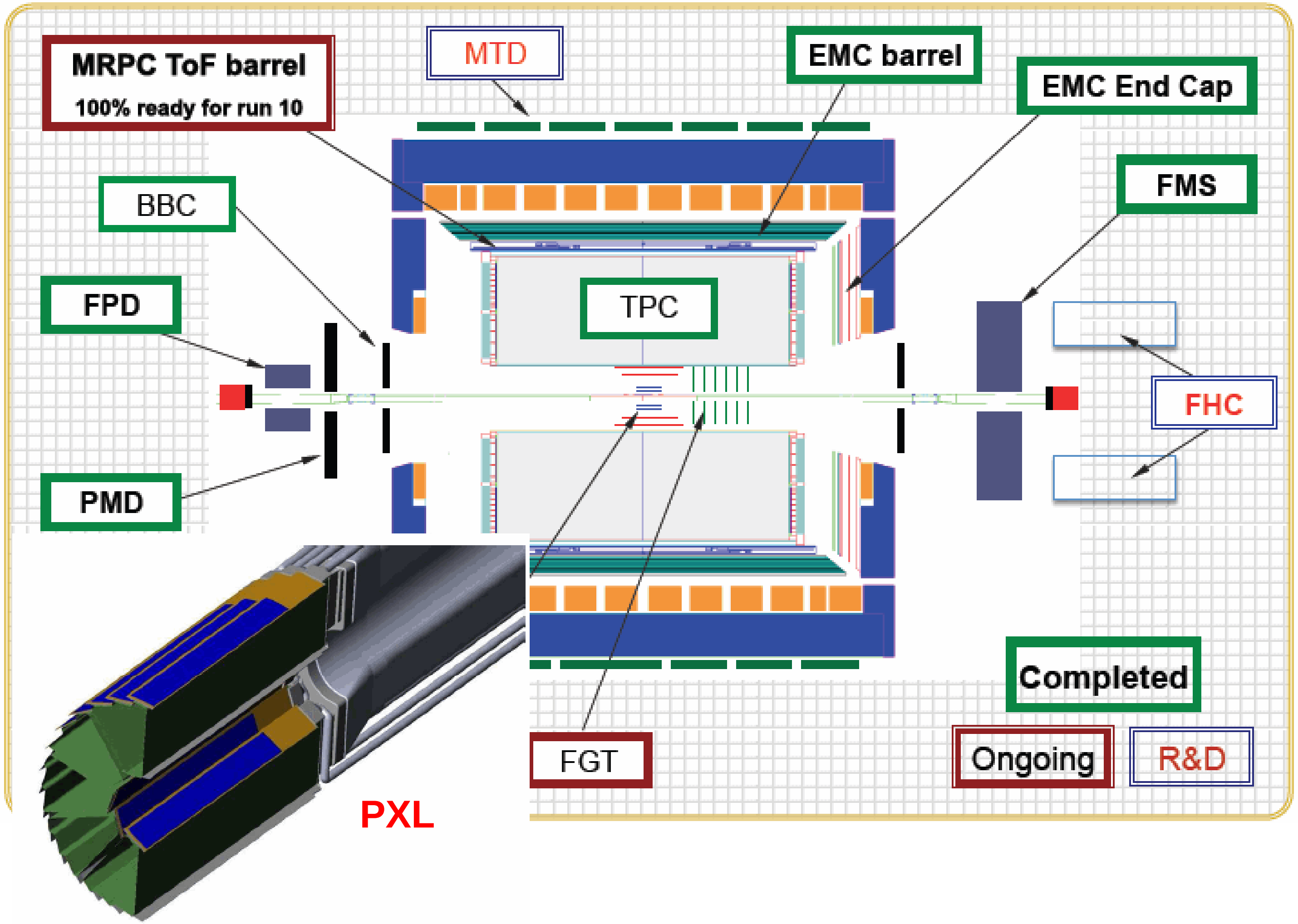
- Λ_c yield, Λ_c / D^0 enhancement, di-quark?





Lee, et. al, PRL 100 (2008) 222301

STAR Detector



TPC & HFT

Large acceptance

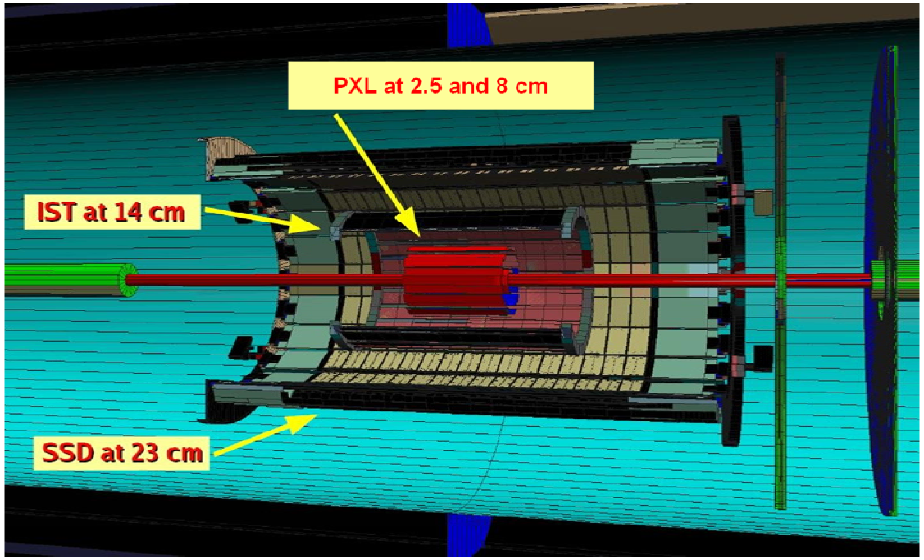
Mid-rapidity

$|\eta| < 1$

Full barrel coverage

$0 < \varphi < 2\pi$

Inner Tracking Detectors



Graded Resolution from the Outside – In	Resolution(σ)
TPC pointing at the SSD (23 cm radius)	~ 1 mm
SSD pointing at IST (14 cm radius)	~ 400 μm
IST pointing at Pixel-2 (8 cm radius)	~ 400 μm
Pixel-2 pointing at Pixel-1 (2.5 cm radius)	~ 70 μm
pixel-1 pointing at the vertex	~ 40 μm

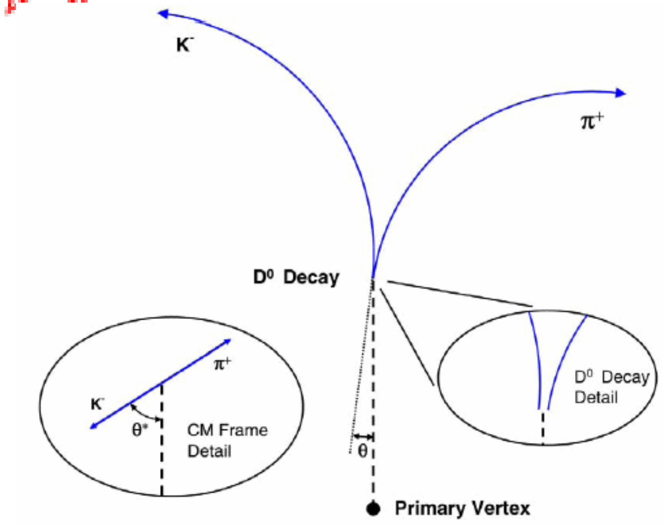
- **SSD** (r = 23 cm), existing detector, double side trips, 1% X_0
- **IST** (r = 14 cm), 500 μm x 1cm strips along beam direction, 1.2% X_0

  Improve hit finding between SSD and outer PIXEL layer.
- **PIXEL** (r = 2.5, 8 cm), 18 μm pixel pitch, 2 cm x 20 cm each ladder.

  deliver ultimate pointing resolution

  hit density for 1st layer ~ 60 cm^{-2}

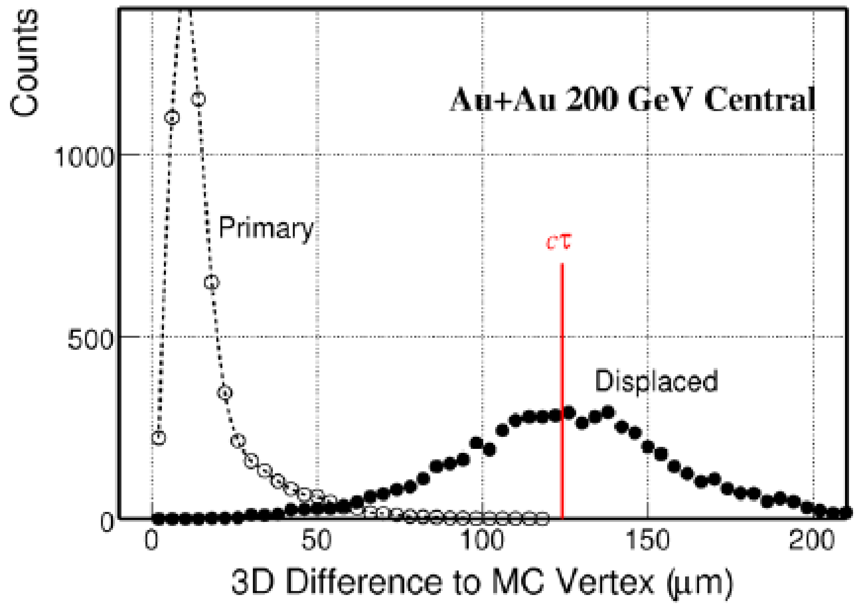
Hadronic channels

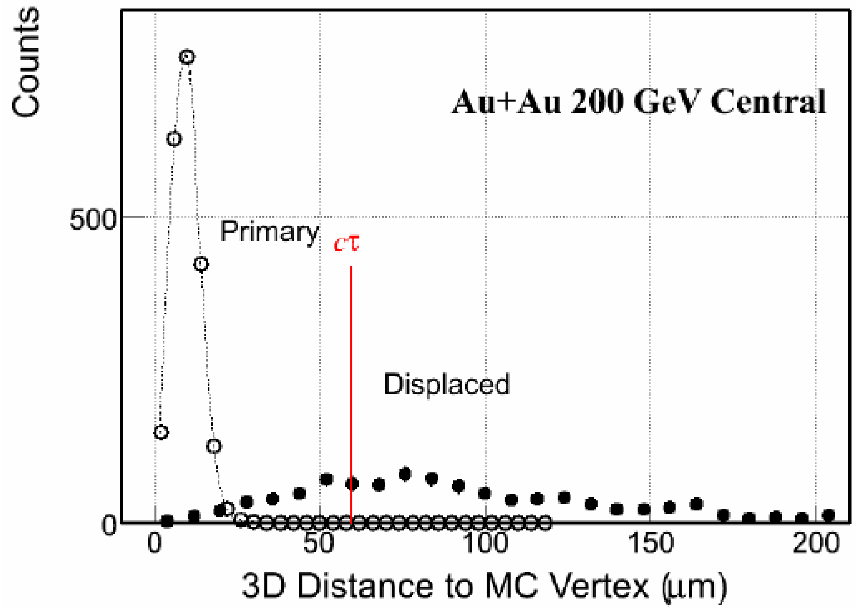


STAR HFT also has the capability to reconstruct the displaced vertex of

$D^0 \rightarrow K\pi$ (B.R.=3.8%) and

$\Lambda_c \rightarrow \pi Kp$ (B.R.=5.0%, Λ_c $c\tau$=59.9 μm)

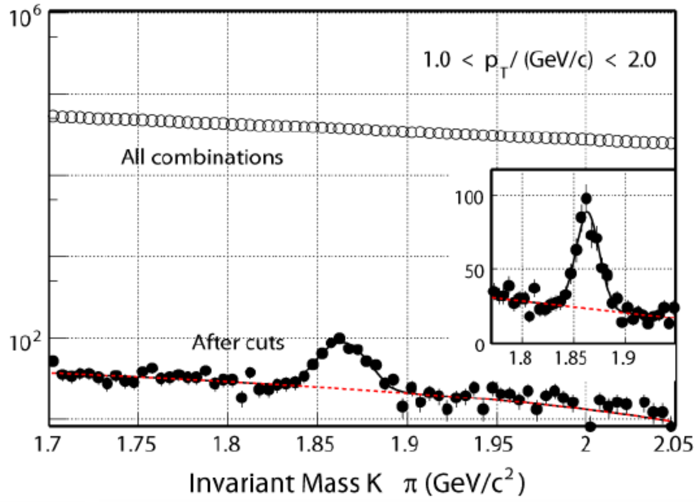


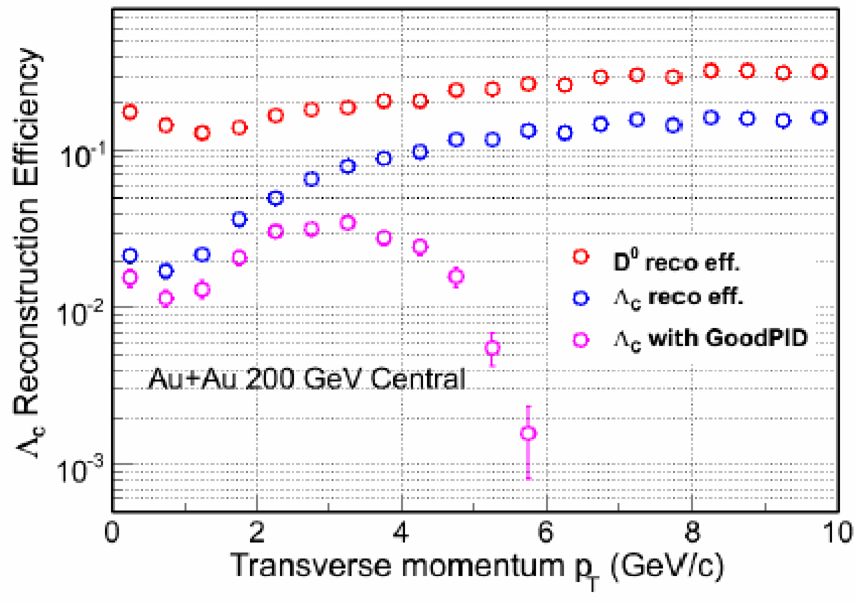


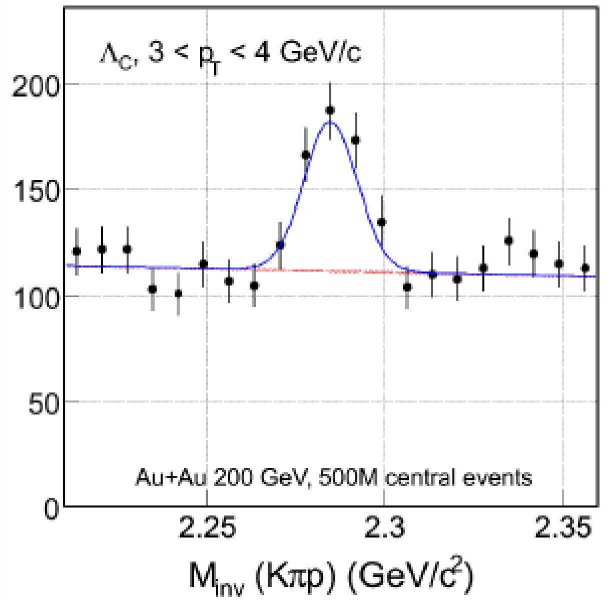
D^0, Λ_c efficiencies

Greatly suppress the combinatorial background!

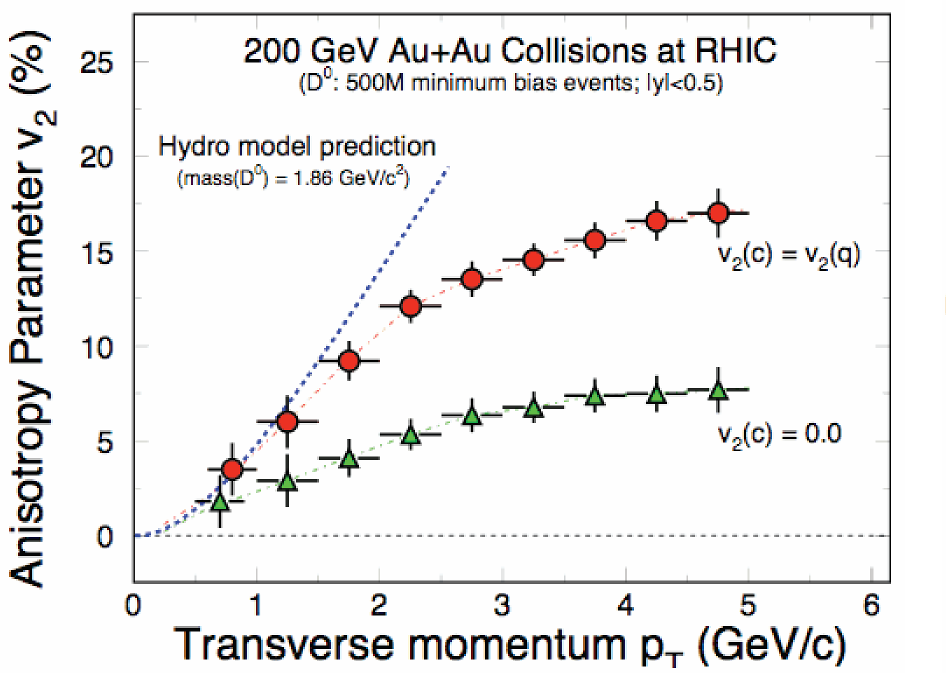
Measure Λ_c yield is important for the charmed baryon and meson ratio.

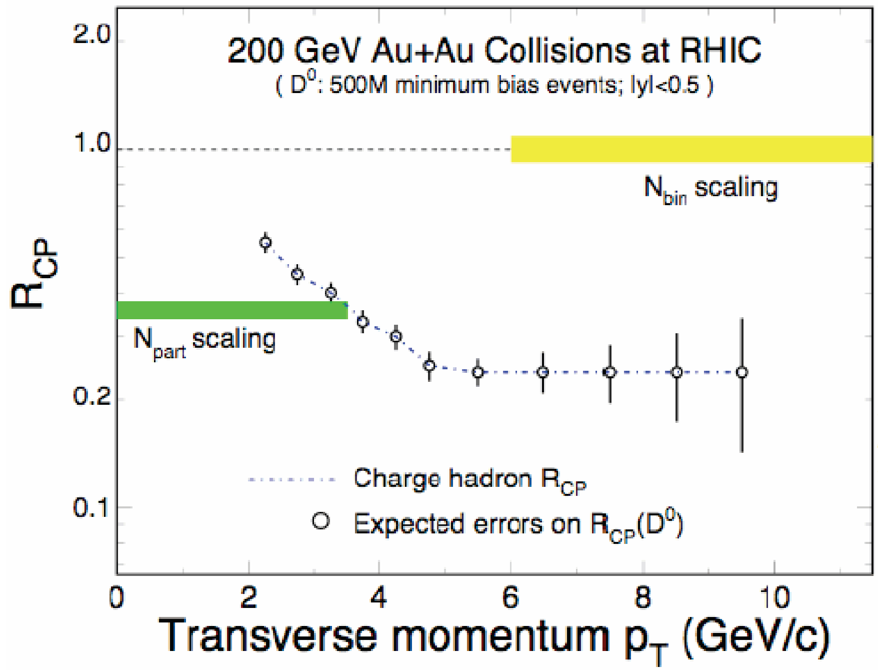






Error estimate of D^0 v_2 and R_{cp}





Assuming D^0 v_2 distribution from quark coalescence.

500M Au+Au m.b. events at 200 GeV.

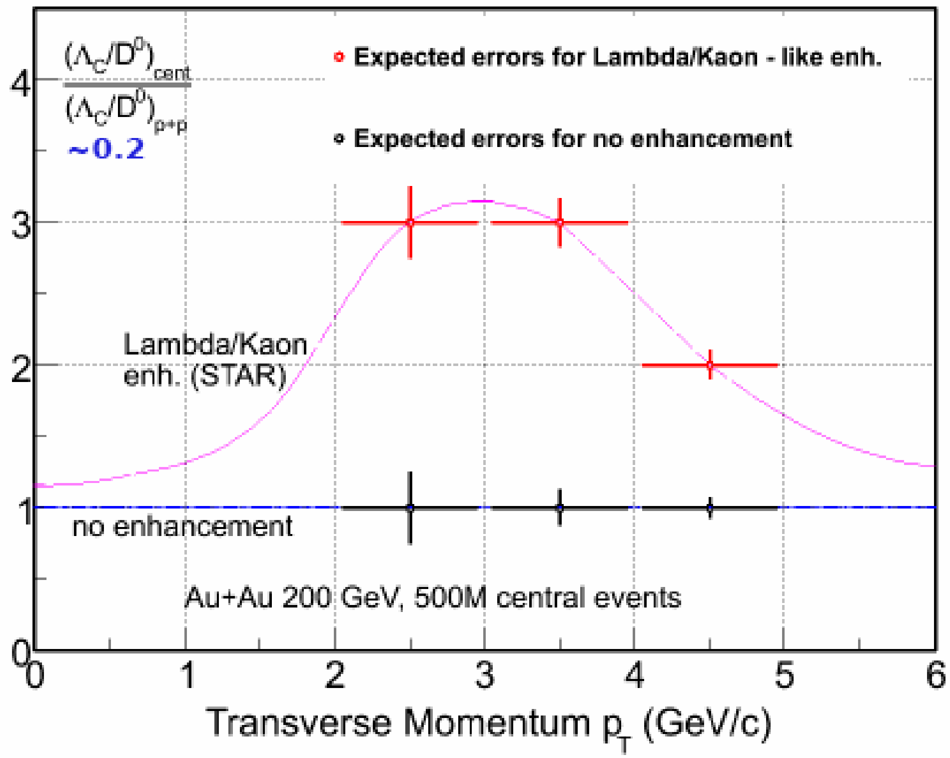
Charm collectivity => Medium properties, light flavor thermalization.

Assuming D^0 R_{cp} distribution as charged hadron.

500M Au+Au m.b. events at 200 GeV.

Charm energy loss => Energy loss mechanisms, QCD in dense medium.

Error estimate of Λ_c/D^0 ratio



Good measurement for D^0 p_T distribution in Au+Au central events.

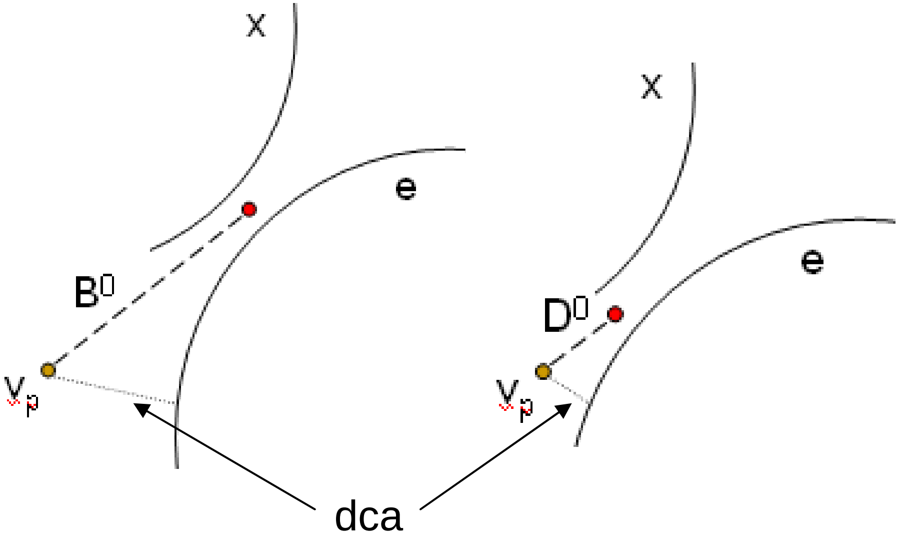
Measure Λ_c yields.

Λ_c / D^0 ratio => Charmed baryon / meson ratio, enhancement?

Additional Capability -- Semi-leptonic Channels

particle	$c\tau$ (μm)	Mass (GeV)	$q_{c,b} \to x$ (F.R.)	$x \to e$ (B.R.)
D^0	123	1.865	0.54	0.0671
$D^{\pm}$	312	1.869	0.21	0.172
B^0	459	5.279	0.40	0.104
$B^{\pm}$	491	5.279	0.40	0.109

B.R. = Branching Ratio
F.R. = Fragmentation Ratio



The distance of closest approach to primary vertex (dca):

Due to larger **$c\tau$,** $B \to e$ has broader distribution than $D \to e$

Dca of $D^+ \to e$ is more close to that of $B \to e$

Simulation on electron channel

- Signal + background events produced.

  Only semileptonic decay to electron channel.

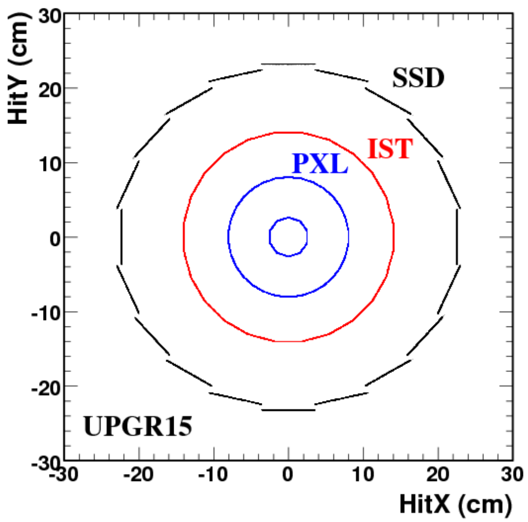
  Flat in $0 < p_T < 20$ GeV/c, p_T weighted using STAR measured D^0 spectrum power-law distribution for D mesons and FONLL calculation for B meson.

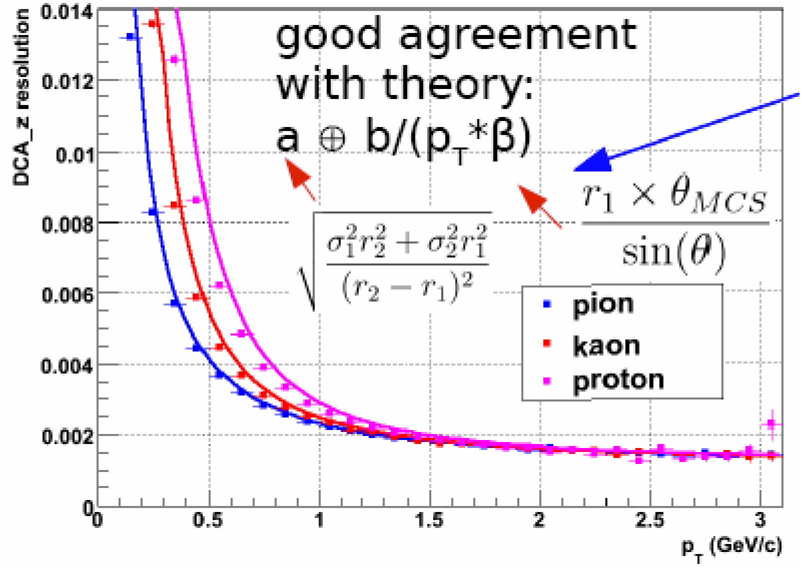
  Flat in $-1 < \eta < 1$ and flat in $0 < \varphi < 2\pi$

  Normalized by the F.R. and B.R., and total electron yield was normalized to STAR measured NPE spectrum. $(B \rightarrow e)$ / NPE ratio was normalized to fit STAR measured data (from e-h correlation).

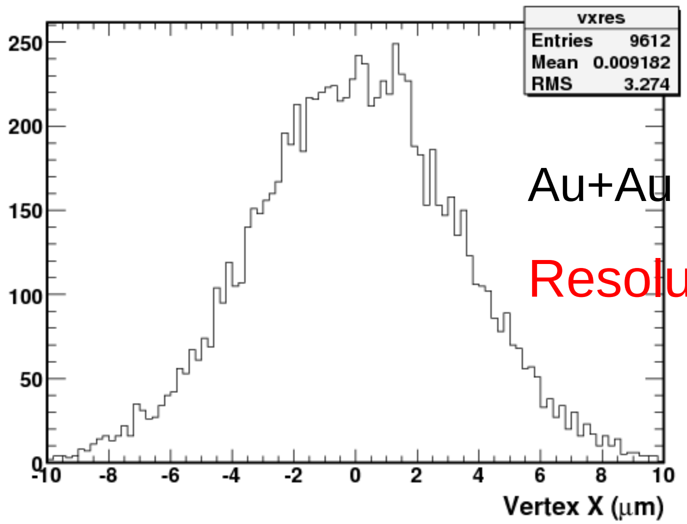
- Dca distributions and efficiency were obtained.
- Error estimation for spectra, $(B \rightarrow e)$ / NPE ratio and v_2.

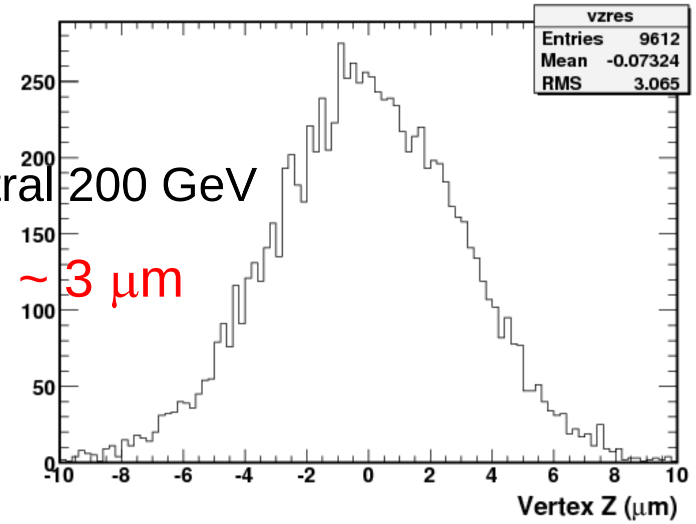
Vertex efficiency and resolution





Pointing resolution delivered by PXL detector

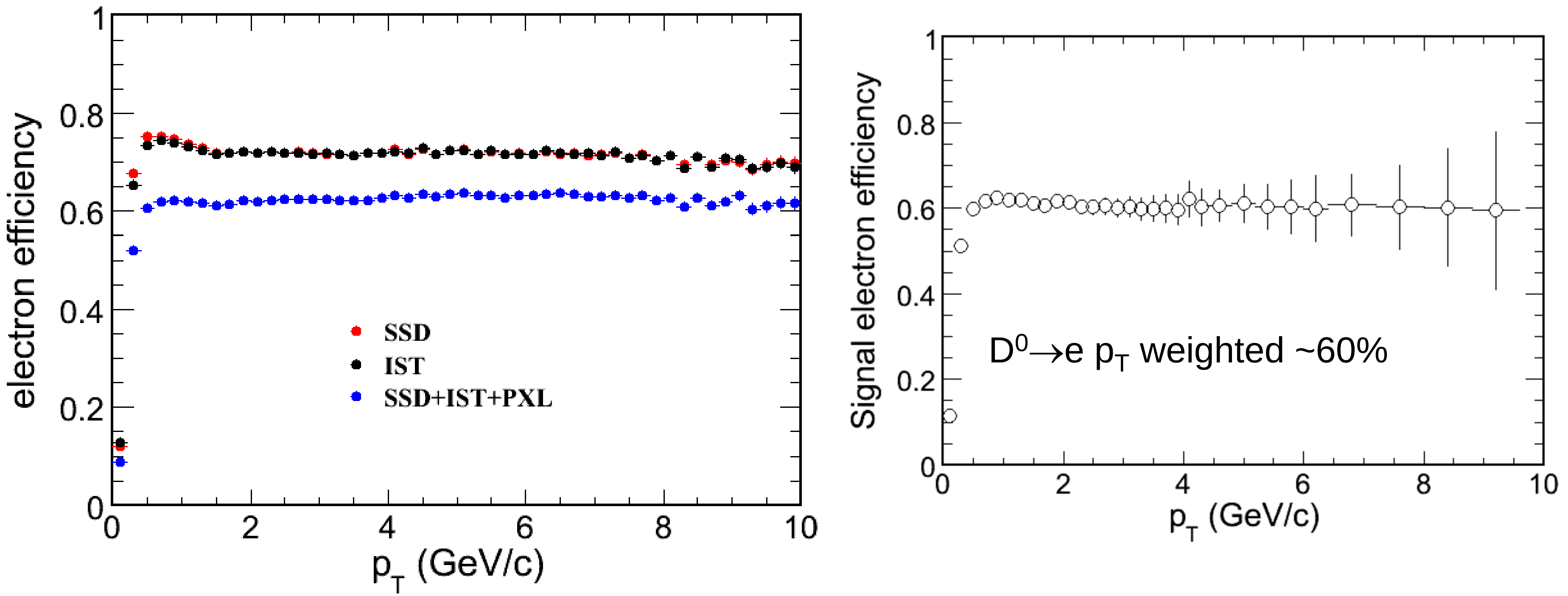




Au+Au central 200 GeV

Resolution ~ 3 μm

Electron efficiency



TPC tracking efficiency is included.

W/o PXL hits required, efficiency ~ 75%

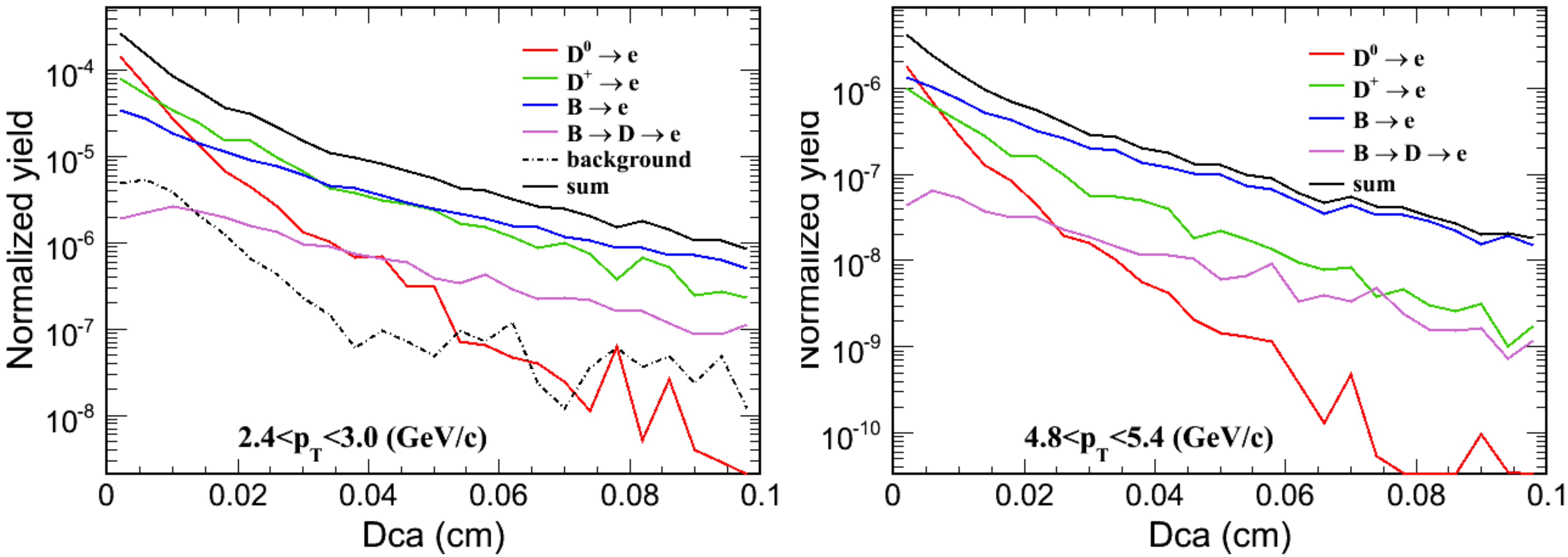
With PXL hits required, efficiency ~ 61%

Dca distributions

Electrons: nFitPts > 15, -1 < eta < 1, 2 PXL hits required, in several p_T bins.

Photonic background can be removed from its small invariant mass character combining a pair of electrons. Other background is small. Due to background statistics, assuming its p_T decreasing exponentially, at high p_T, background will be neglected.

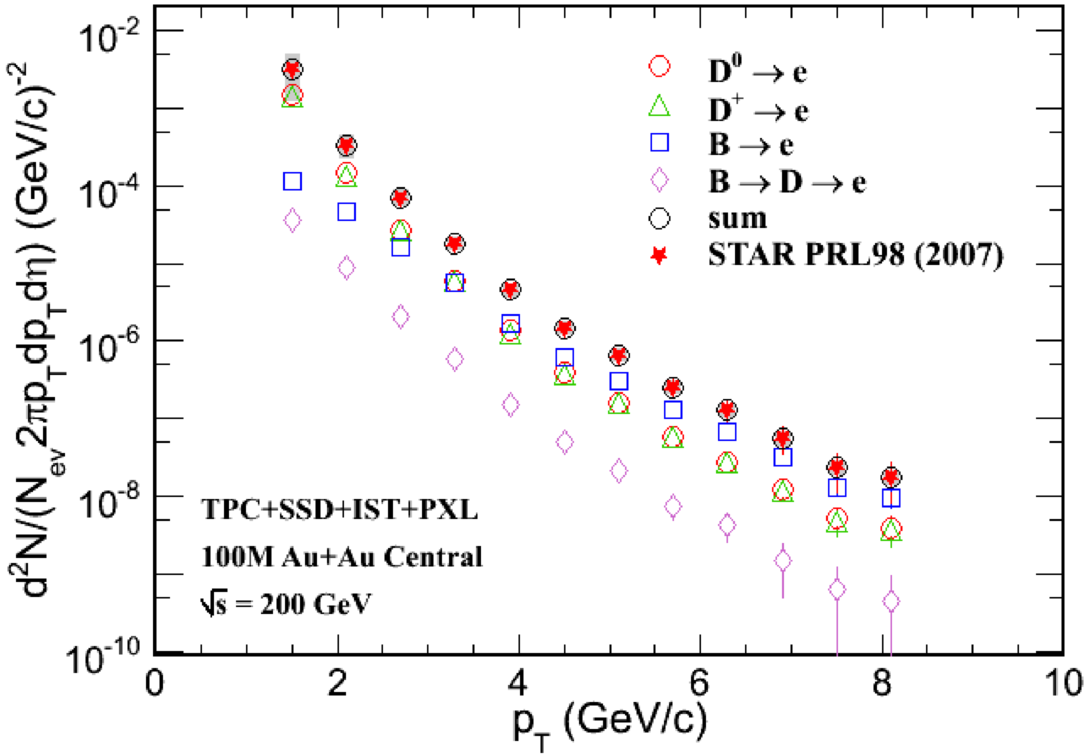
Normalized by the F.R. and B.R., and total electron yield was normalized to STAR measured NPE spectrum. (B→e) / NPE ratio was normalized to fit STAR measured data (from e-h correlation).



Errors estimate of spectra

In real experimental data, we can use the different dca distributions to fit the total dca distribution to extract the raw yield of each source of electrons.

From the dca distributions and the efficiency, the D→e, B→e and B→ D→e spectra can be obtained, and the statistical errors were estimated for 100M Au+Au central 200 GeV events (non-special trigger).



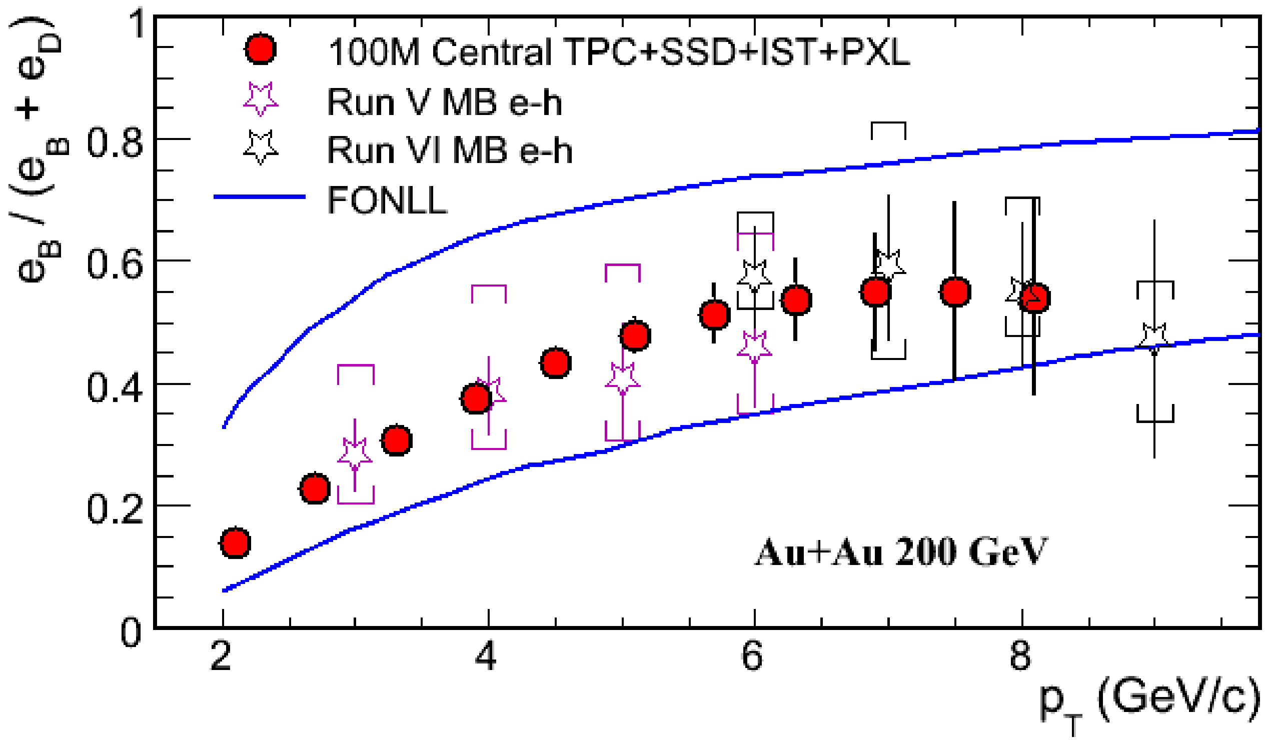
R_{AA} can be measured directly from the spectra with D→e, B→e separated.

Understanding the heavy quark energy loss mechanisms.

Errors estimate of (B→e)/NPE

(B→e)/NPE ratio can be directly measured from spectra. The statistical errors are estimated for 100M Au+Au central 200 GeV events.

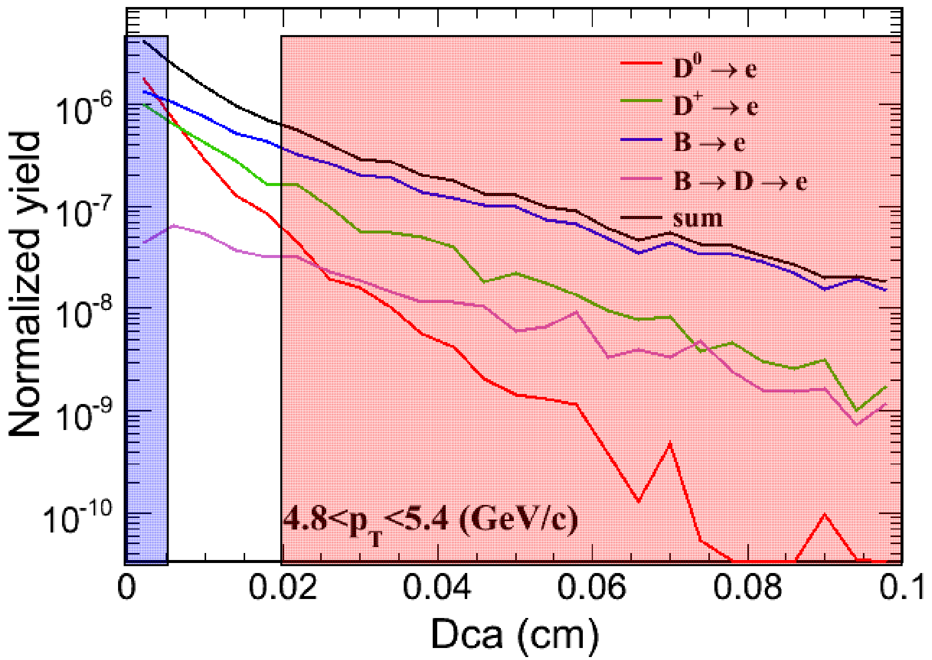
We will have high p_T electron trigger (EMC HT) in the future, high p_T statistics will not be a problem.



Measure v_2 from dca

$B \rightarrow e\ v_2$ and $D \rightarrow e\ v_2$ can be measured from different dca cuts. For example:

Case	Cut (cm)	e(D) eff. (%)	e(B) eff. (%)	r = e(B)/NPE
I	< 0.005	45.5	22.3	0.325
II	> 0.02	15.3	39.6	0.718



$r * v_2(B) + (1-r) * v_2(D) = v_2(NPE)$

$v_2(B)$ is $B \rightarrow e\ v_2$

$v_2(D)$ is $D \rightarrow e\ v_2$

$v_2(NPE)$ is the total non-photonic electron v_2 after dca selection.

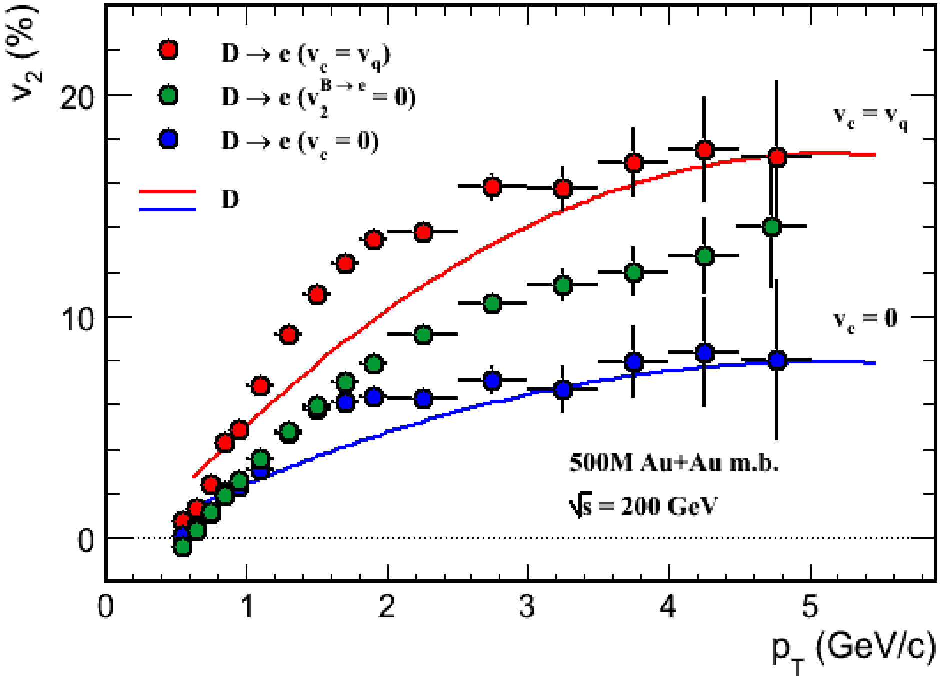
Error estimate for v_2

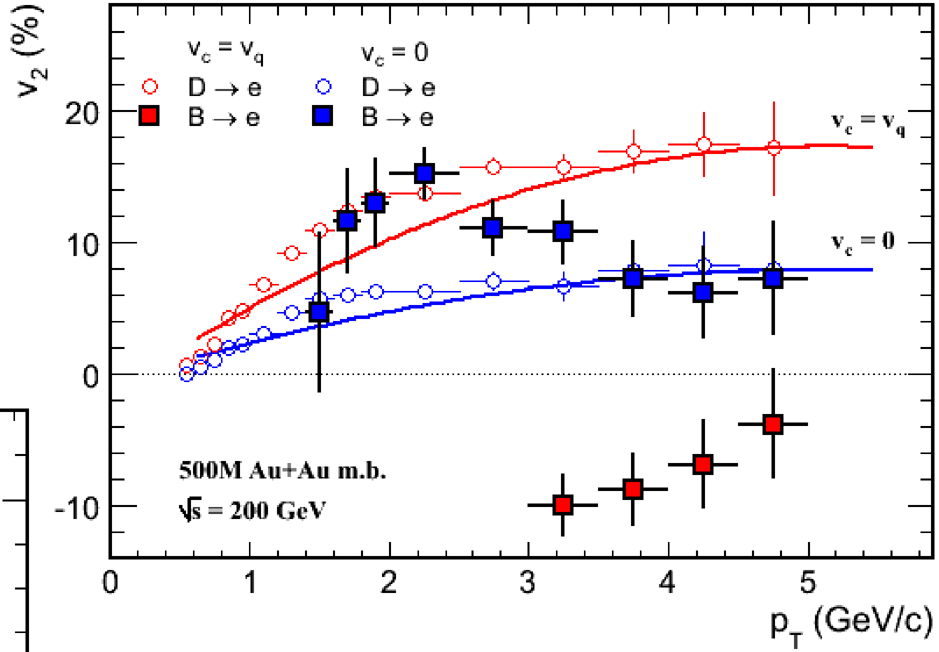
Assuming D meson v_2, using decay form factor to generate D → e v_2 distributions.

$r * v_2(B) + (1-r) * v_2(D) = v_2(NPE)$

$v_2(D)$ is D → e v_2

$v_2(B)$ is B → e v_2





Heavy quark collectivity

Study charm and bottom separately to understand the mass effect of such heavy quarks.

Probe medium properties.

Summary

- Tracking and reconstruction are very successful in STAR HFT simulation.
  Good vertex resolution, pointing resolution and tracking efficiency are obtained.

- STAR HFT has a great performance to:
  Measure charmed hadrons: $D^0 \rightarrow K\pi$, $D \rightarrow e$ and $\Lambda_{c.}$
  Measure bottomed mesons: $B \rightarrow e$.

- Topologically measure D^0 is important to measure charm collectivity and energy loss directly via hadronic channel reconstruction, and to provide a good reference for B measurement from electron channel.

- Topologically measure Λ_c yield will provide us the information on charmed baryon / meson ratio.

- Measure $D \rightarrow e$ and $B \rightarrow e$ is important for understanding heavy quark physics with charm and bottom separately at RHIC.

- Analysis method for the real data measurement is on development.