Open Heavy Flavor Results at RHIC/STAR

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For the STAR collaboration

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Outline

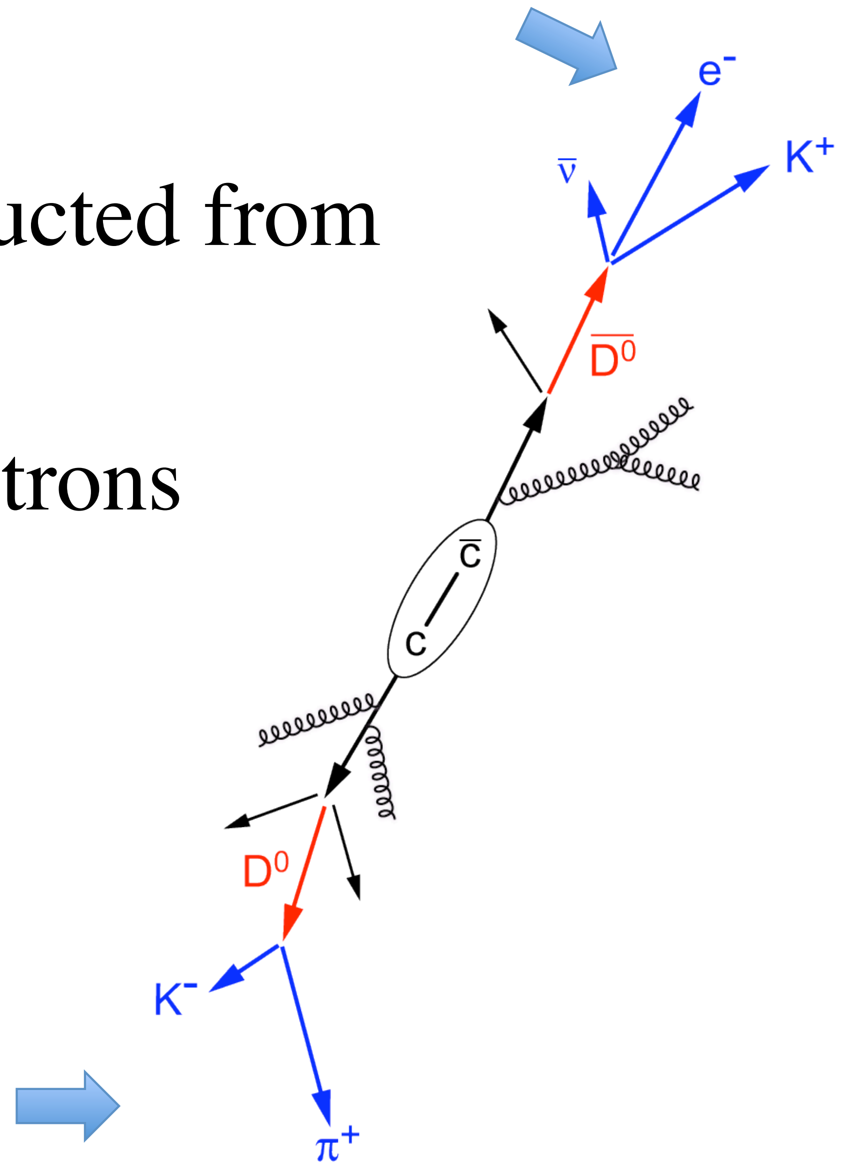
Heavy Flavor decay electrons

1: Introduction

2: Charm mesons reconstructed from hadronic decay daughters

3: Heavy flavor decay electrons

4: Related STAR upgrades

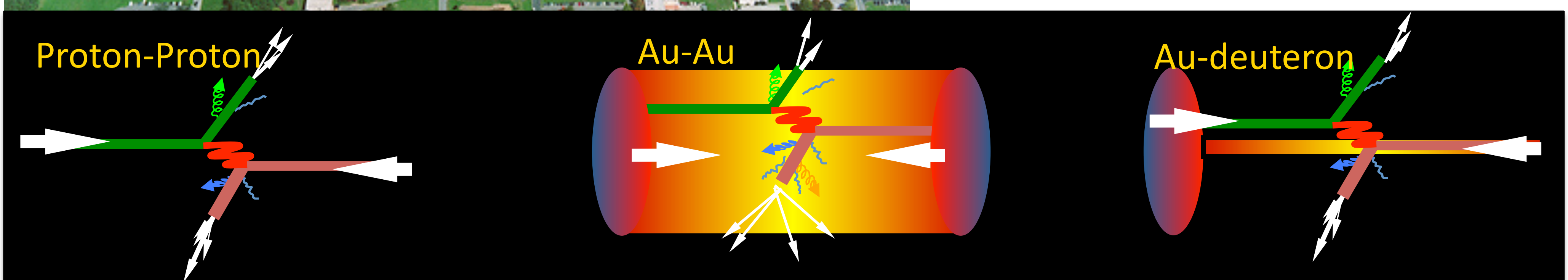


Charm meson reconstructed from hadronic decay daughters

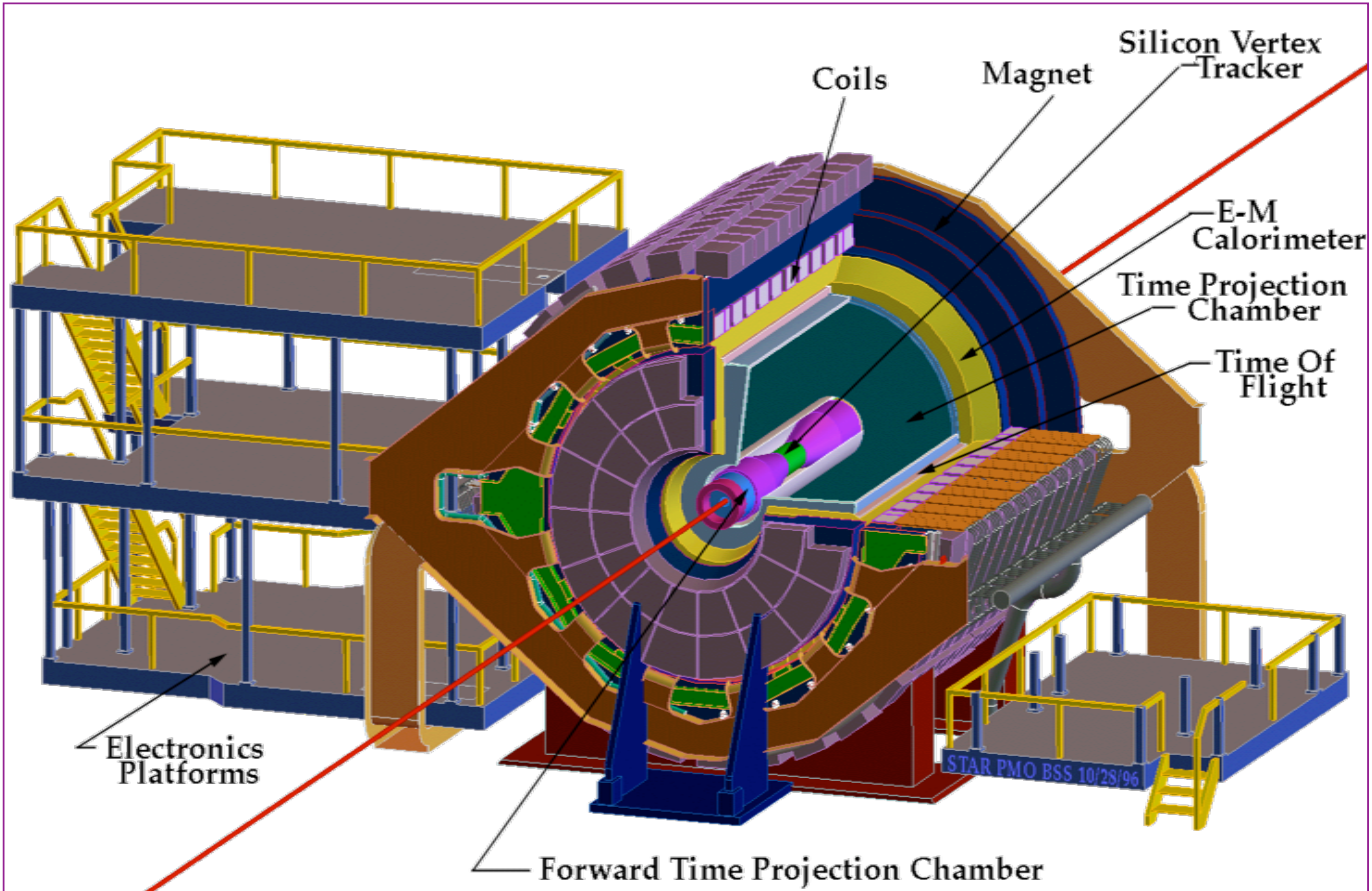
The Relativistic Heavy Ion Collider @ Brookhaven National Lab

We've created a strongly-coupled QCD matter at high temperature and energy density with partonic collectivity.

- Jet quenching
- Modification of high p_T particle correlations
- Quark number scaling

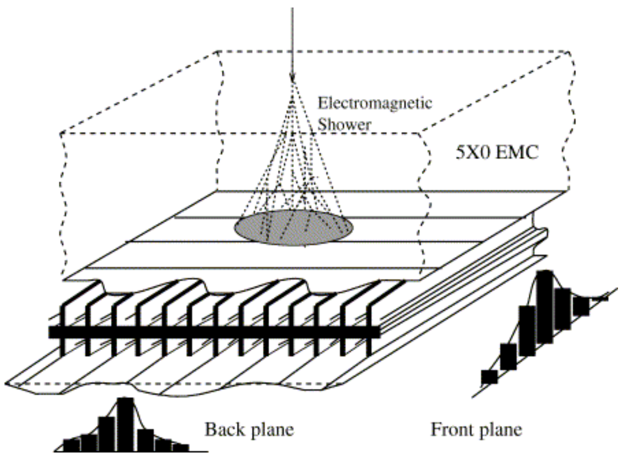


The Solenoidal Tracker At RHIC

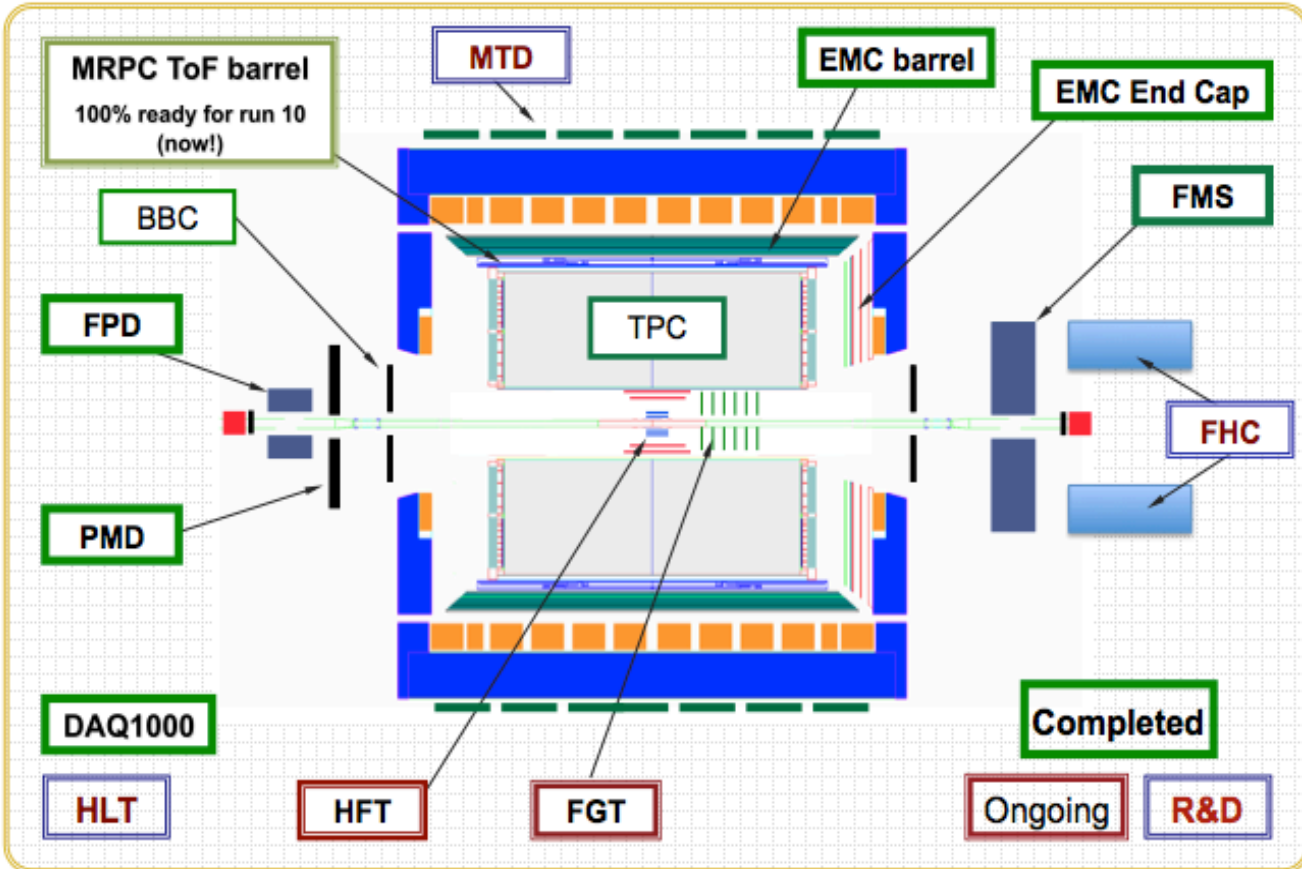


Detectors for open heavy flavor analysis

Large acceptance
$|\eta| < 1,\ 0 < \phi < 2\pi$

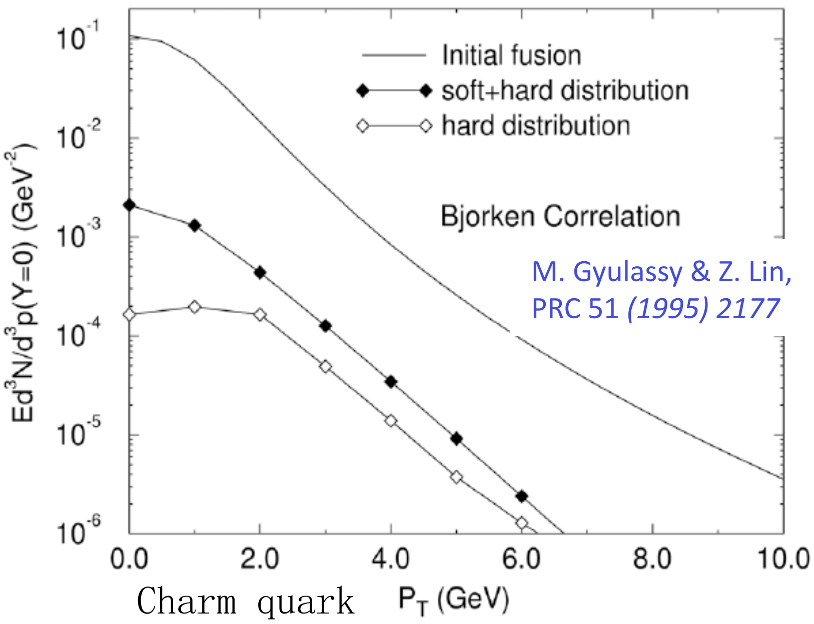


BSMD: embedded in BEMC



Time Projection Chamber(TPC): tracking, PID via ionization energy loss
Barrel Electromagnetic Calorimeter(BEMC): shower energy, triggering, electron PID via E/P
Barrel Shower Maximum Detector(BSMD): fine spatial resolution, electron PID via shower profile
Time of Flight detector (TOF): significantly improved PID for charged particles

Motivation for heavy flavor studies

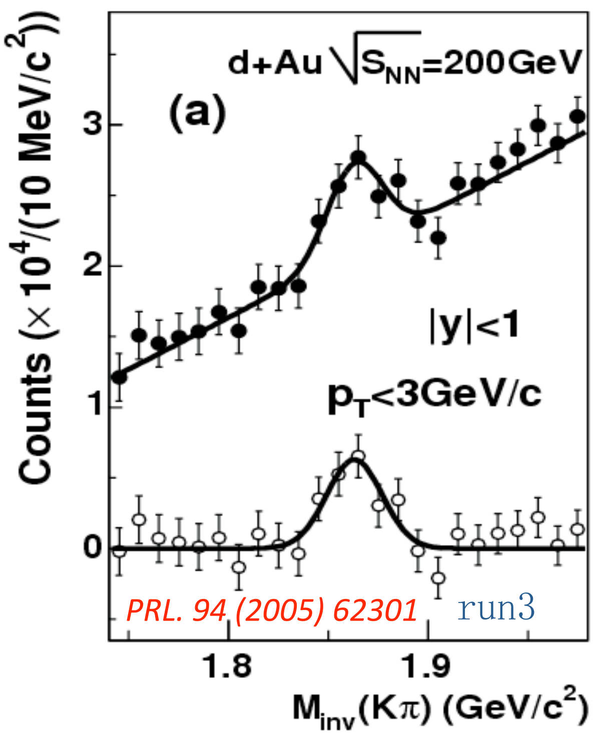


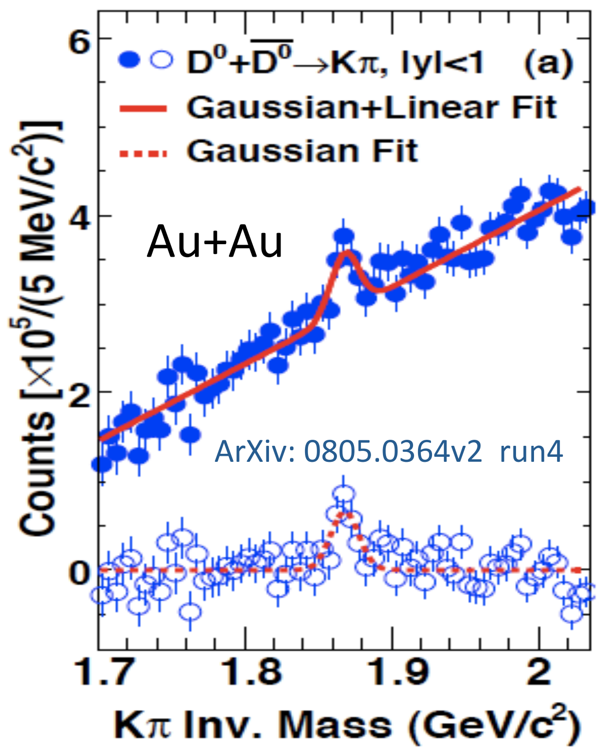
Good theoretical control:
Initial fusion (hard process) dominates heavy flavor production.
Large masses ensure an energy scale where perturbative QCD is applicable.

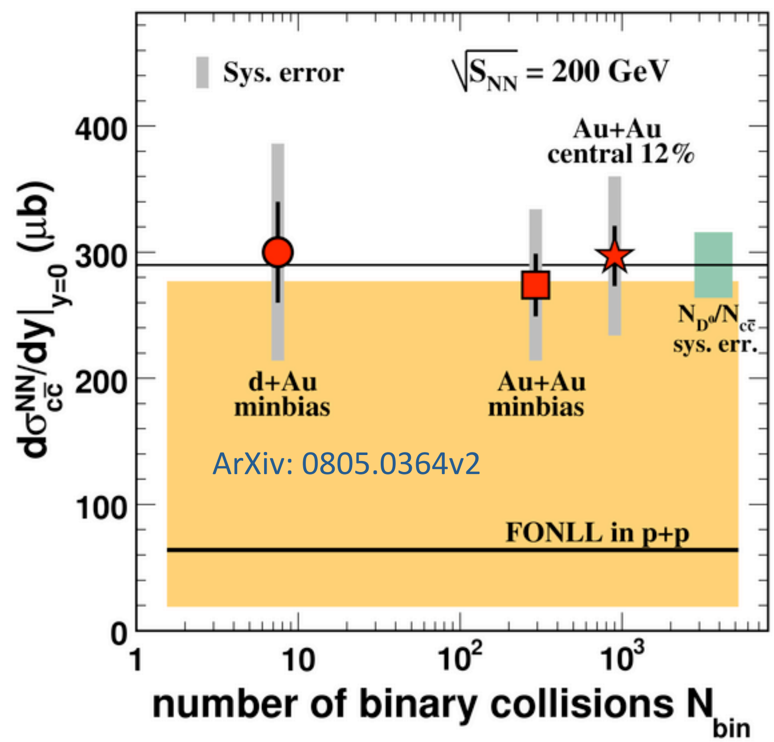
- Study charm and bottom cross-section
- Study the energy loss mechanism of heavy quarks inside the medium
- Study properties of the hot and dense medium at the early stage of heavy-ion collisions

Previous D^0 meson direct reconstructions

$$D^0(\overline{D^0}) \rightarrow K^{\mp} + \pi^{\pm} \qquad B.R. \sim 3.89\ \%$$







Identify and combine kaons with pions, without secondary vertex reconstructed.

Charm production is proportional to number of binary collisions

D^0 meson in Cu+Cu 200GeV

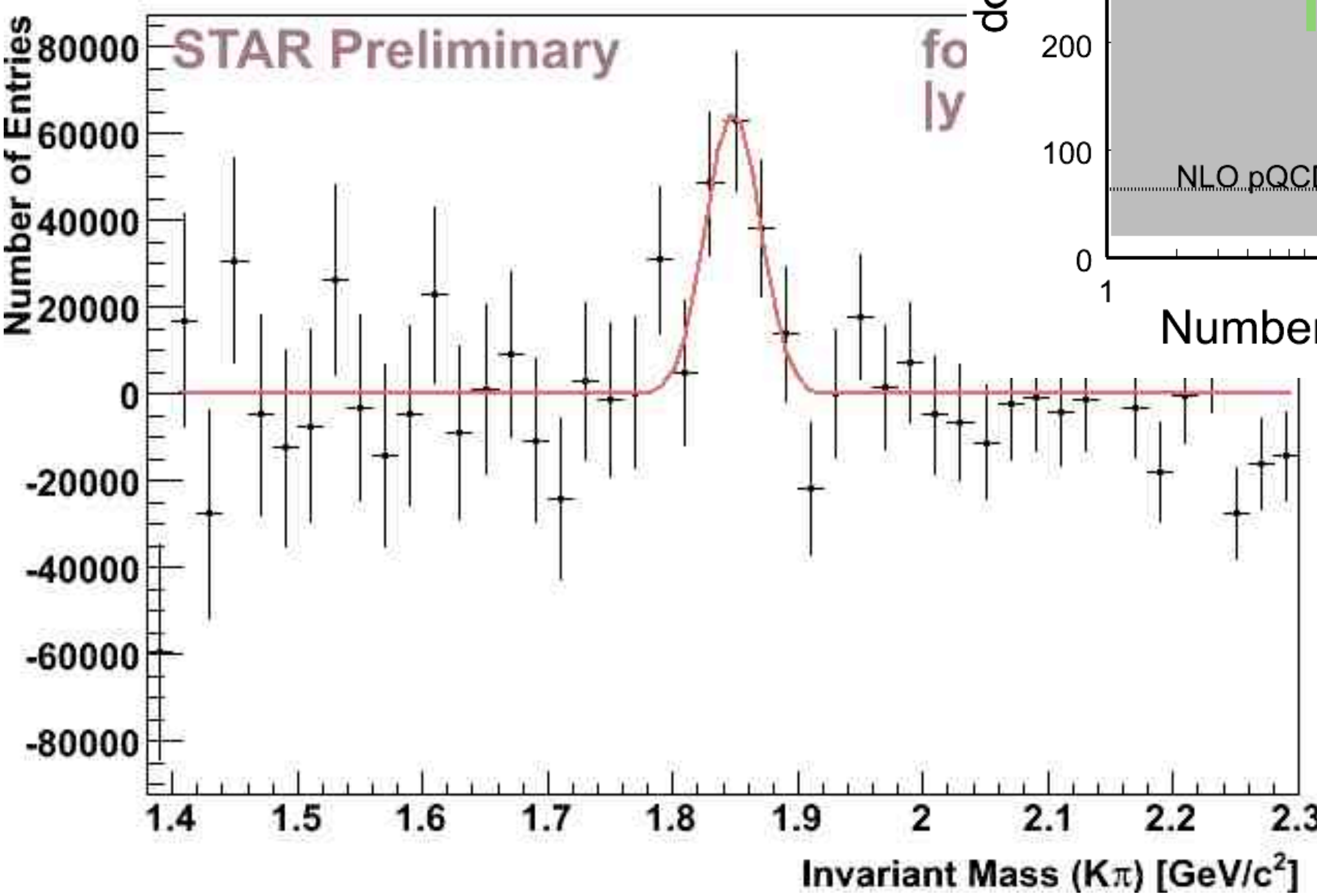
Significance = 4.3 σ

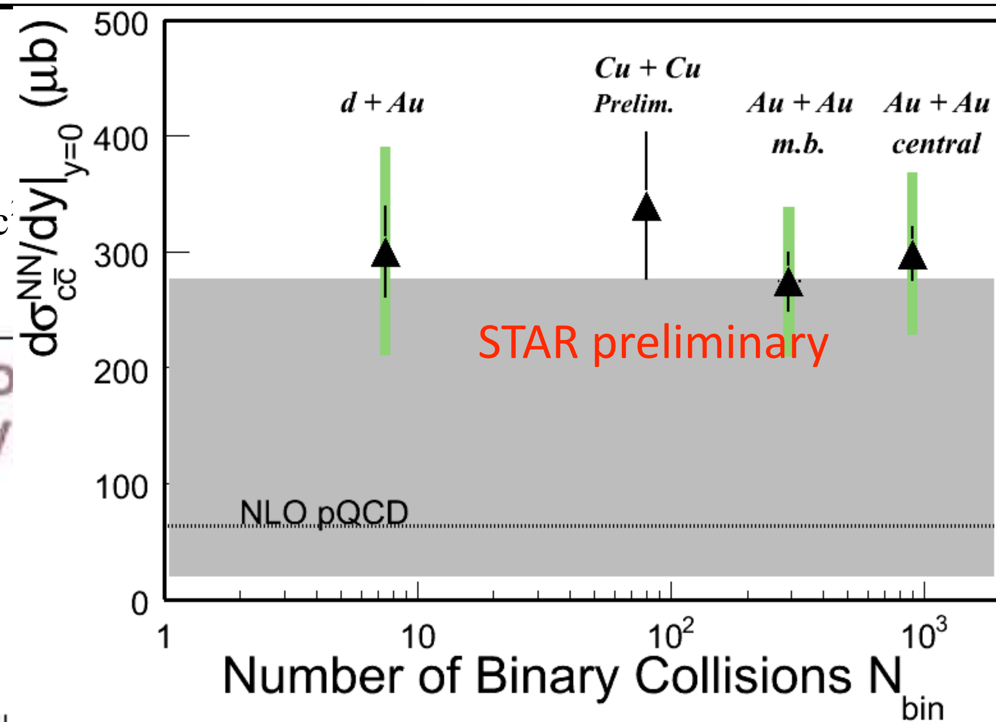
$$\sigma = \frac{S}{\sqrt{S + (1 + \frac{1}{n_{rot.}})B}}$$

$D^0 \to K^-\pi^+, \overline{D}^0 \to K^+\pi^-,$

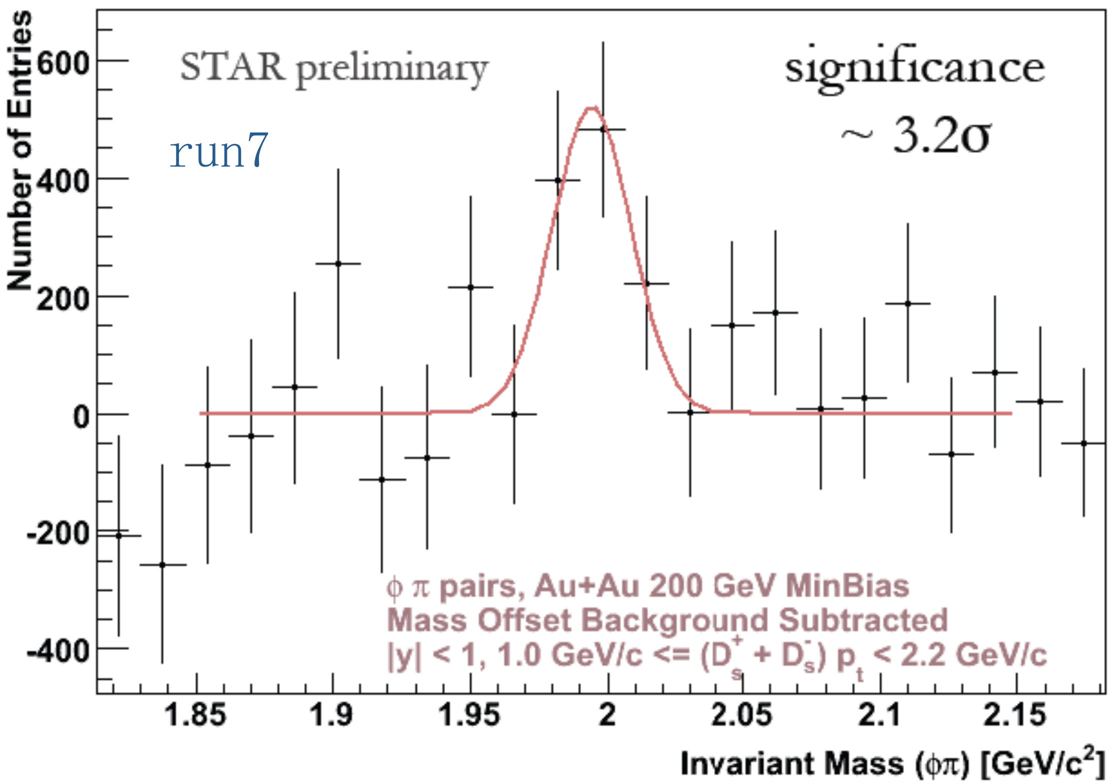
$B.R. = 3.80 \pm 0.07\%$

PDG mass = 1.8645 ± 0.0003 GeV/c²





$D_s^{\pm}$ meson in AuAu 200GeV

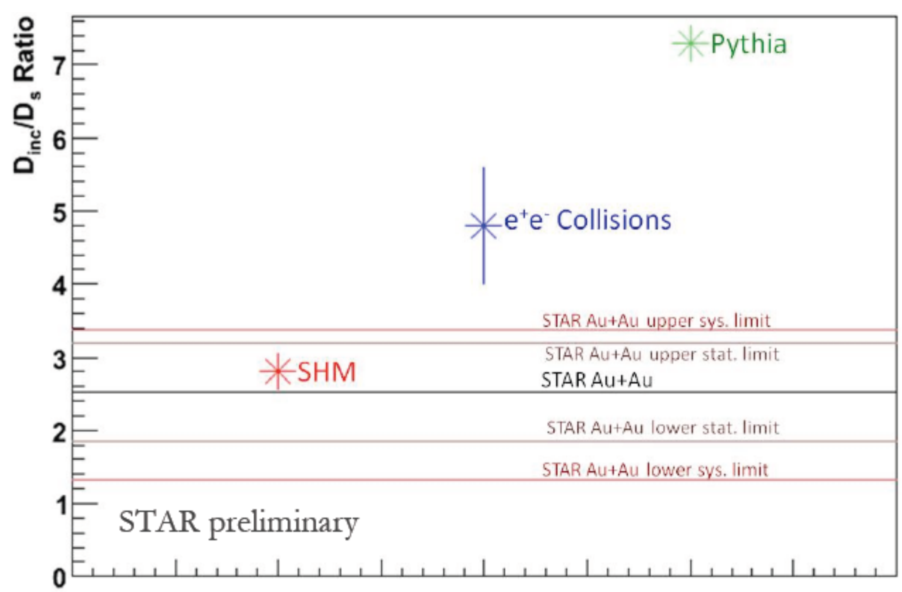


with the help of Silicon Vertex Tracker

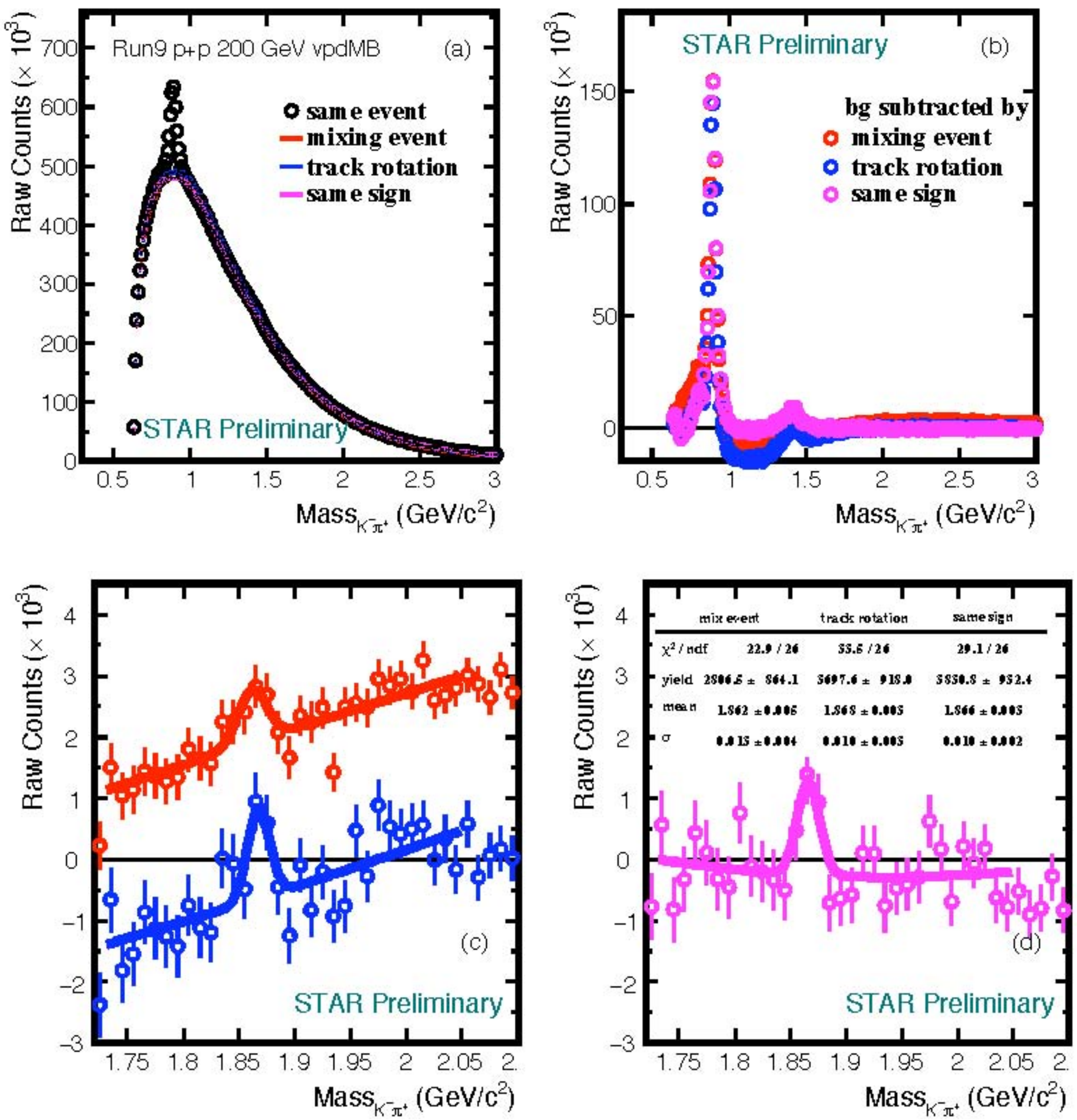
- Assume p_T spectrum shape similar to D^0: 47% yield covered.
- $D^{\pm}$ yields estimated from $D^{\pm}/D^0$ ratio from e+e− data.

$$D_s^{\pm} \to \phi + \pi^{\pm} \qquad B.R. \sim 4.5\%$$

Preliminary result is consistent with statistical hadronization.

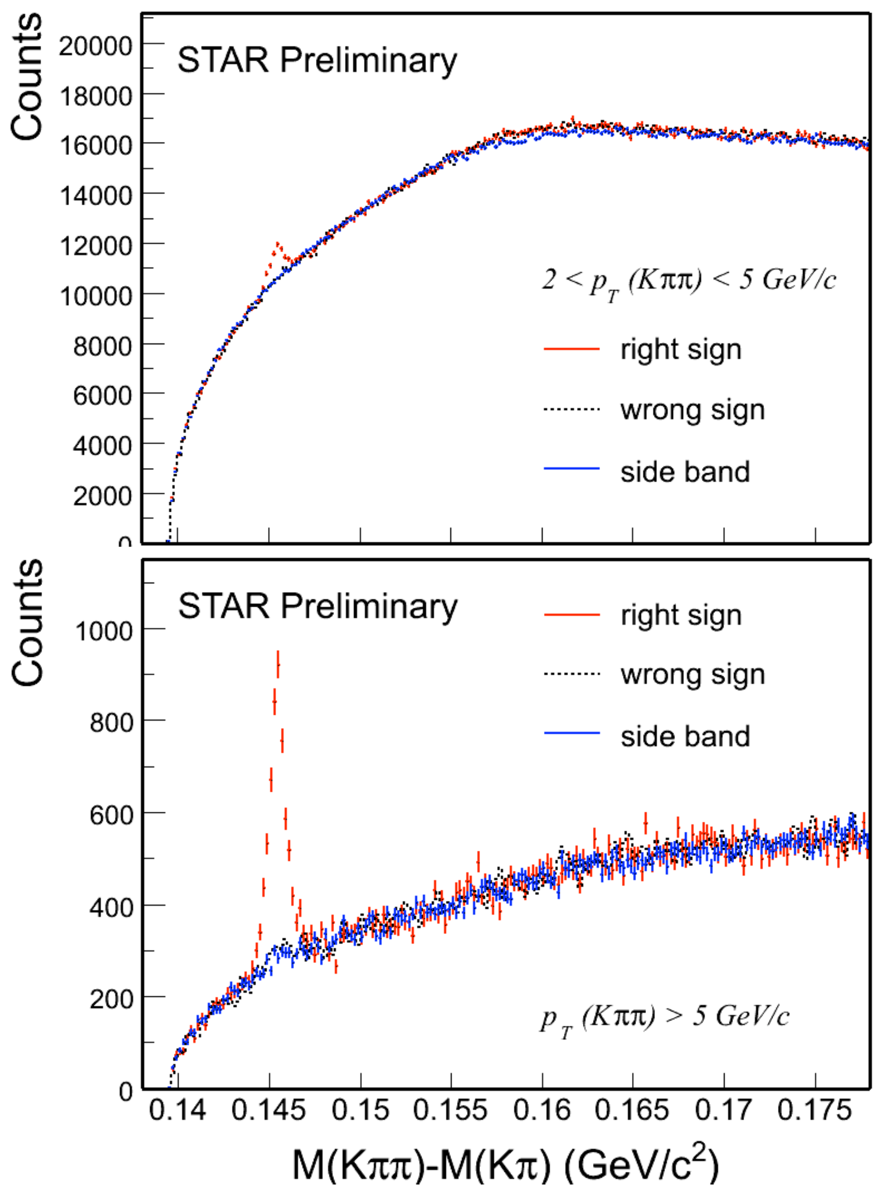


D^0 meson in p+p 200 GeV



- Year 2009 data.
- 72% TOF installed.
- various background reconstruction methods.
- consistent signal ~4sigma observed.

D^* meson in p+p 200GeV



- D^{*+} (D^{*-})→D^0(D^0bar) + $\pi_s^{\pm}$
- More than 4sigma signal at low p_T
- Very significant at high p_T - mostly from EMC-based high neutral energy triggers.
- Wrong sign and side-band method reproduce background well.

Summary of charm mesons

- STAR measurements in Cu+Cu, Au+Au and d+Au show N_{bin} scaling of charm cross-section

- STAR D_s measurement in Au+Au is consistent with the statistical hadronization model.

- Open charm hadrons are reconstructed from STAR run9 p+p 200 GeV data. Four sigma D^* signal at low p_T and more significant D^* signal at high p_T are observed.

- Working on efficiency for p_T spectra and cross-section and Run10 data

Non-photonic electrons (NPE)

NPE: semi-leptonic decays of open heavy quark hadrons

$$c \rightarrow e^{+} + anything(9.8\%) \qquad D^{0} \rightarrow K^{-} + e^{+} + \nu_{e}(3.5\%)$$

Advantage: EMC based high tower trigger, reaching high p_T
Disadvantage: Incomplete kinematics

Outline:

✧Background in the NPE analysis

✧High pT NPE yield, R_{AA}

✧High pT NPE-hadron correlation in p+p 200GeV, the near side: b/c seperation

✧High pT NPE-hadron correlation in Au+Au, Cu+Cu, d+Au 200GeV, the away side

✧NPE elliptic flow

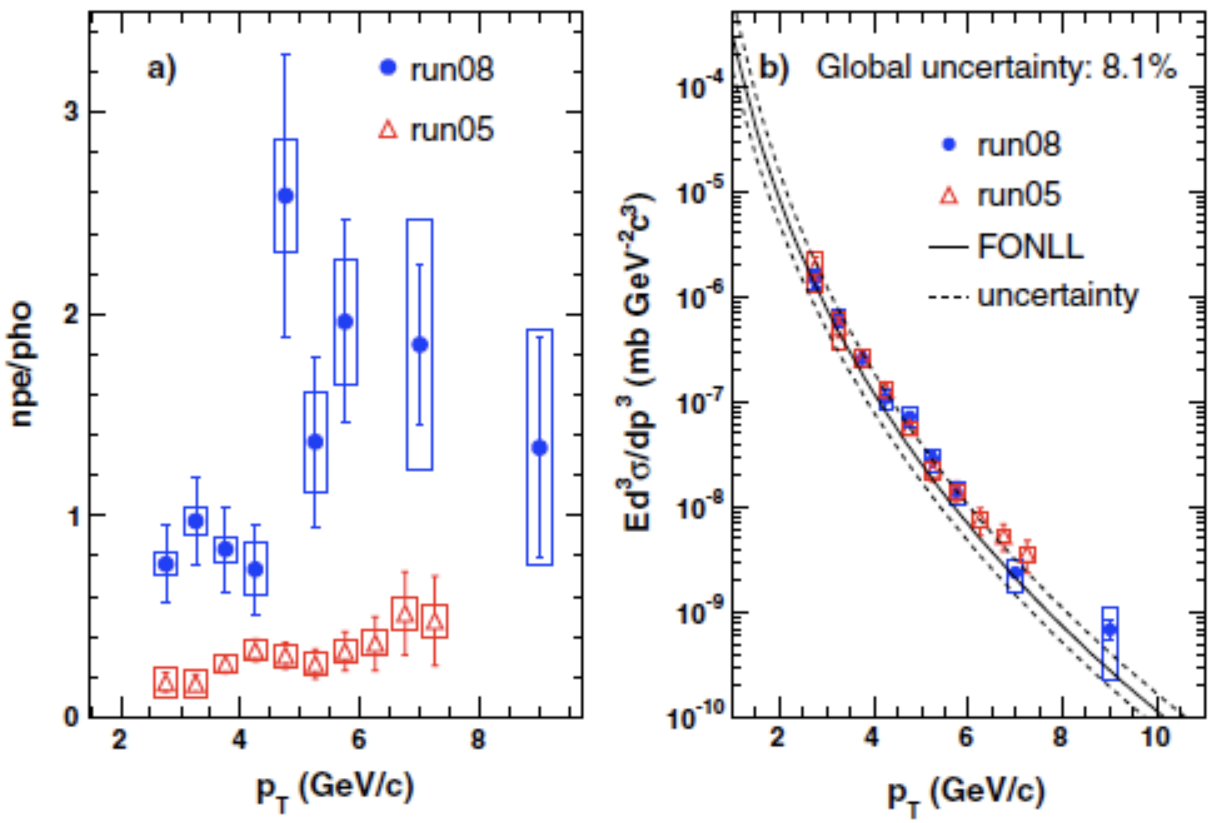
Background in NPE analysis

The main background is photonic electrons:

Photon conversions in material $\gamma \rightarrow e^{+} + e^{-}$

Dalitz decays of pseudoscalar mesons $\pi^{0}, \eta \rightarrow \gamma + e^{+} + e^{-}$

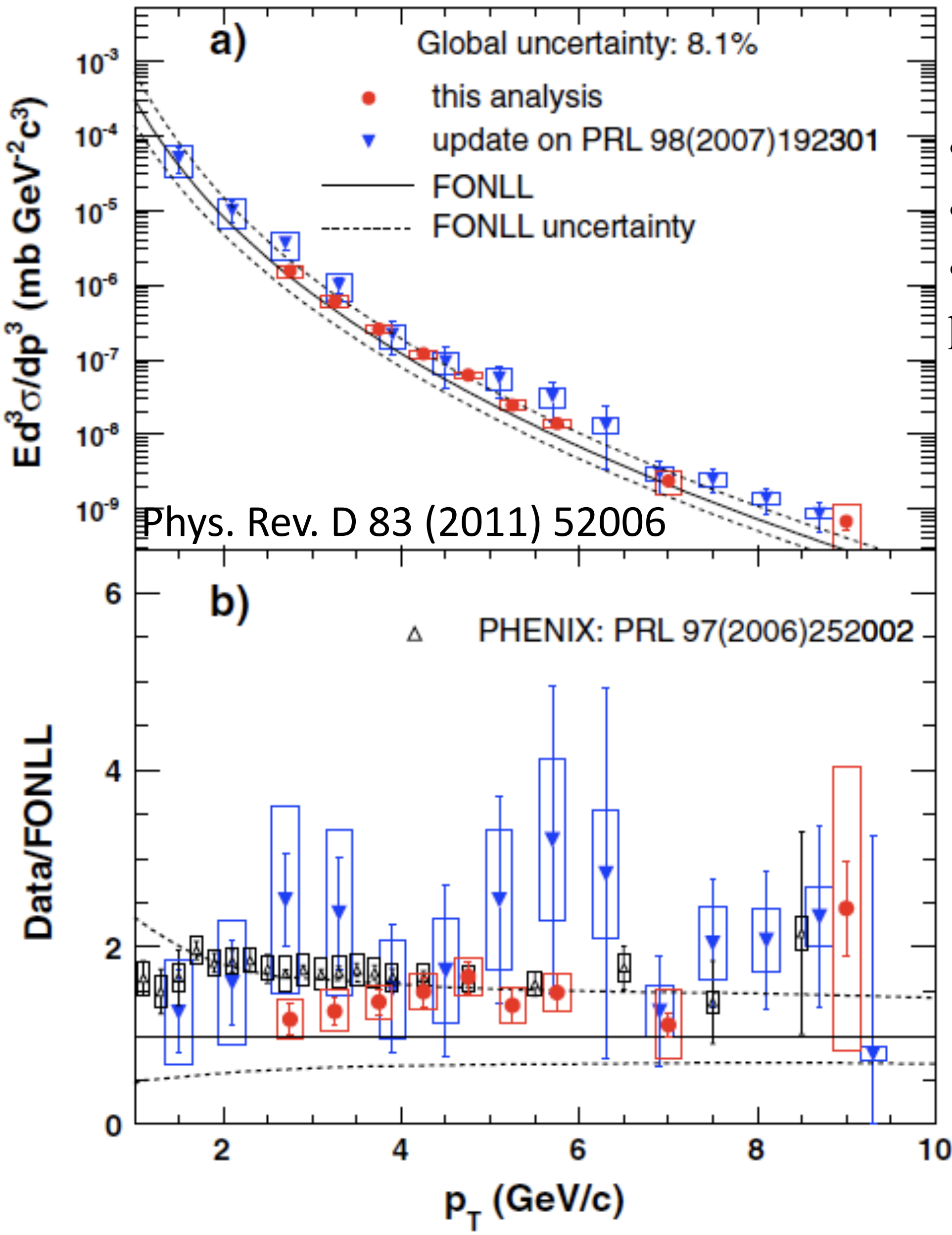
In Run08, inner detectors (SVT and SSD) were removed, significantly reduced this background



Phys. Rev. D **83** (2011) 52006

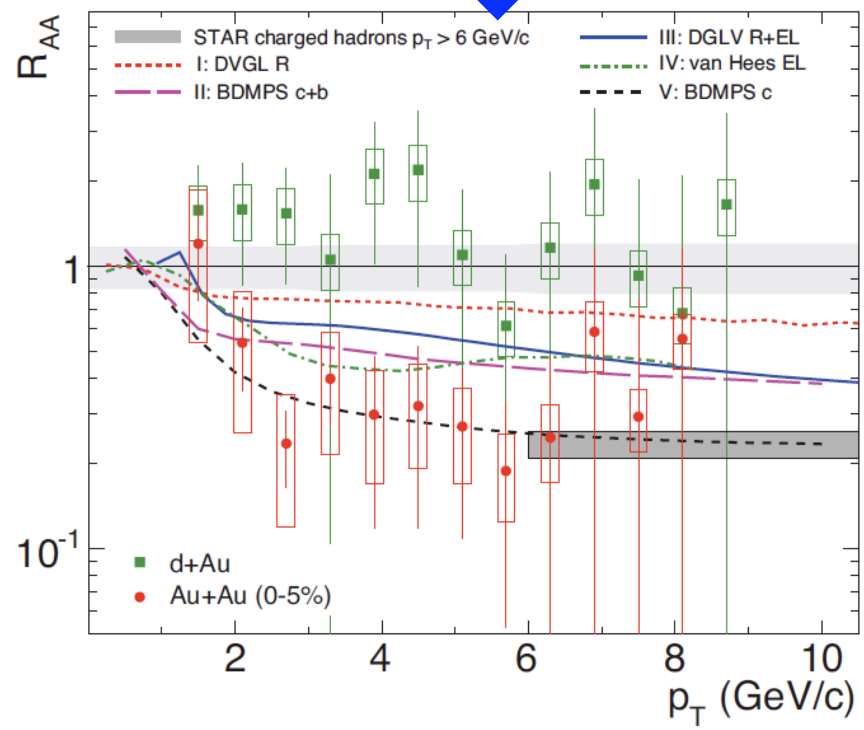
p_T>2.5GeV/c NPE measurement with dramatically different photonic electron background agree with each very well

High p_T NPE in 200GeV p+p



←Latest measurement with high precision in pp

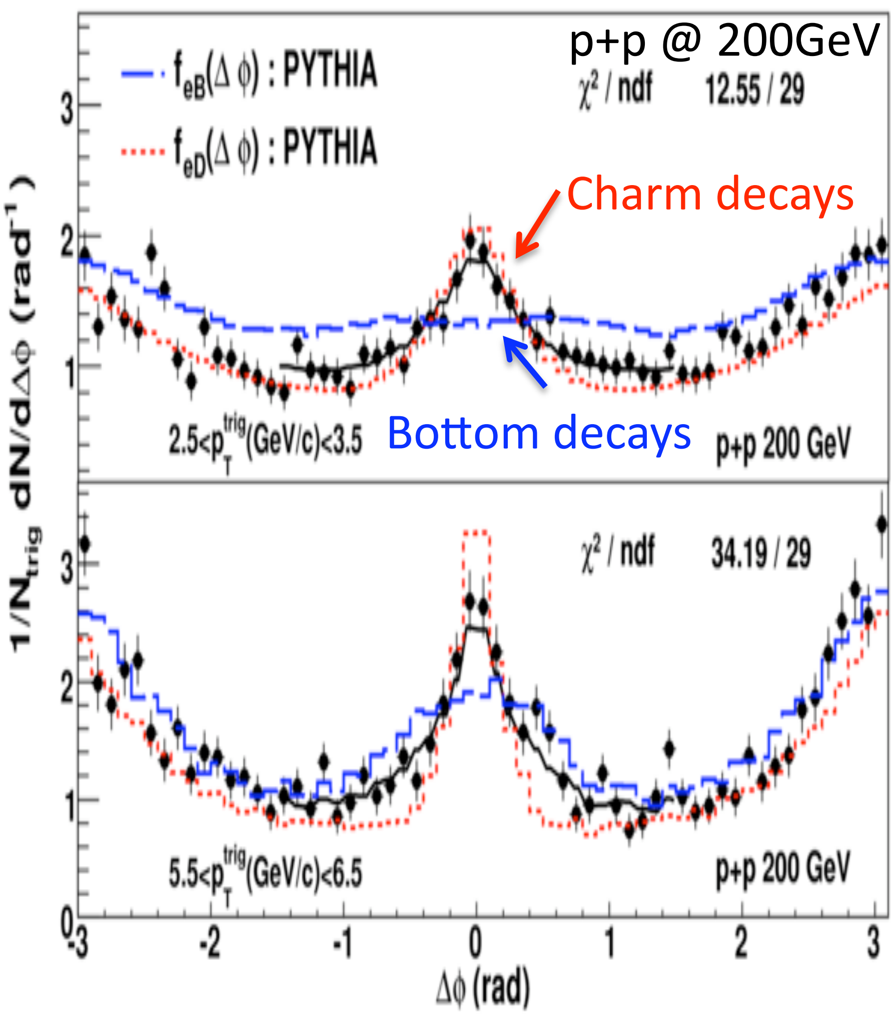
- Re-check the previous data, consistent now.
- Still strongly suppressed, with larger uncertainties.
- We are analyzing Run10 Au+Au data, will have high precision results.

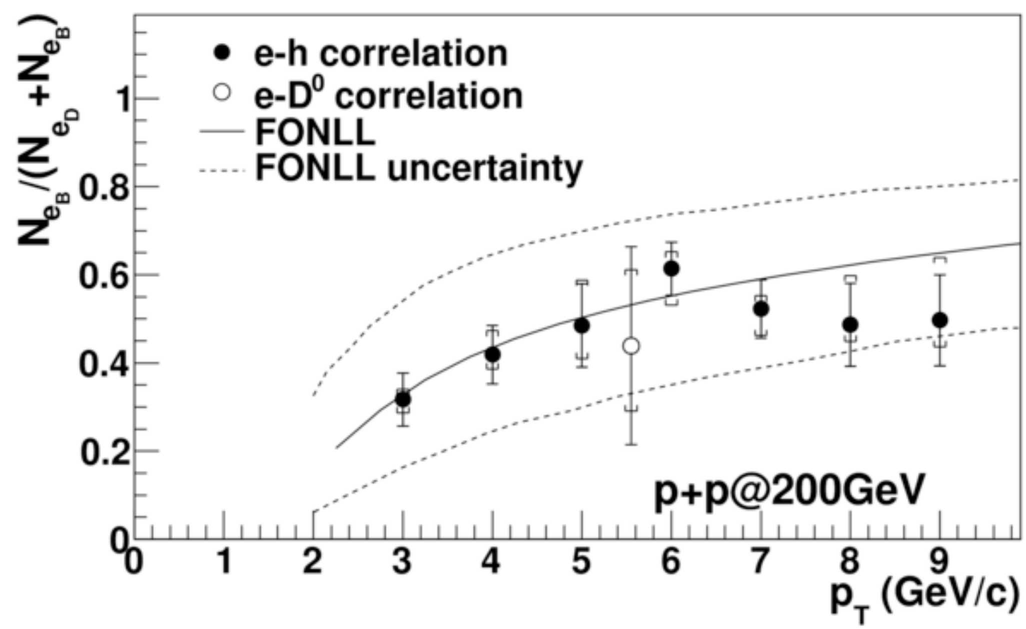


Erratum on PRL 98(2007) 192301

High p_T NPE-hadron correlations:near side

Different decay kinematics for charm and bottom hadrons
→Crucial for charm and bottom discrimination.





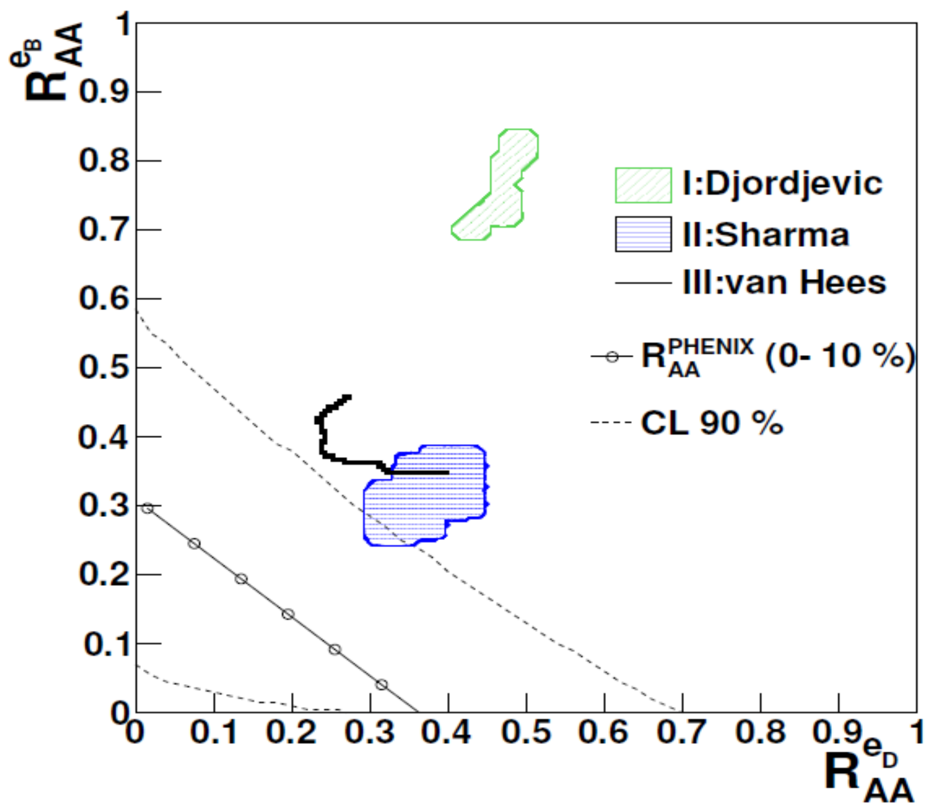
Bottom quark contributes significantly in interested p_T ranges!

STAR: PRL 105, 202301 (2010)

Bottom electron is suppressed

Combine the obtained b/c separation with NPE R_{AA} (PHENIX:arXiv:1005.1627)

$$R_{AA}^{NPE} = (1 - r_B) R_{AA}^{e_D} + r_B R_{AA}^{e_B}$$

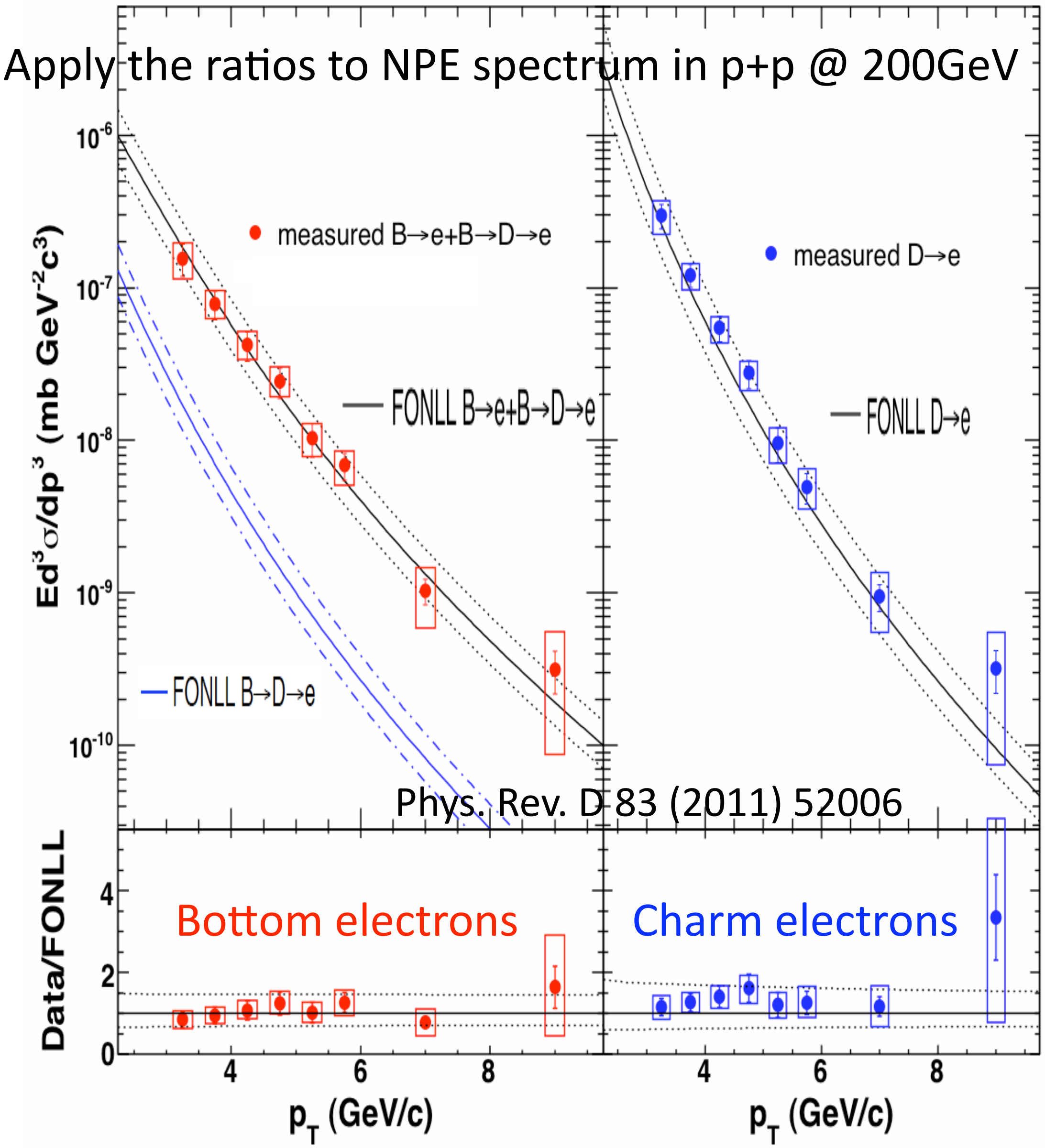


p_T > 5 GeV/c, Bottom electron R_{AA}<1

STAR: PRL 105, 202301 (2010)

Separated Bottom electron and Charm electron

Apply the ratios to NPE spectrum in p+p @ 200GeV



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With spectrum shapes from model calculations, one can extrapolate the total production cross sections of bottom quark:

In p+p collisions at $\sqrt{s} = 200$ GeV, extrapolated based on STAR NPE measurements at high p_T,

$\sigma_{b\bar{b}} = 1.34\mu b$ with PYTHIA, MSEL=1 Mode.

$\sigma_{b\bar{b}} = 1.83\mu b$ with PYTHIA, MSEL=5 Mode.

PYTHIA results bear12.5% (stat.) and 27.5% (sys.) experimental uncertainties.

FONLL[1] calculation: $\sigma_{b\bar{b}} = 1.87^{+0.99}_{-0.67}\,\mu b$

Wenqin, LLWI 2011

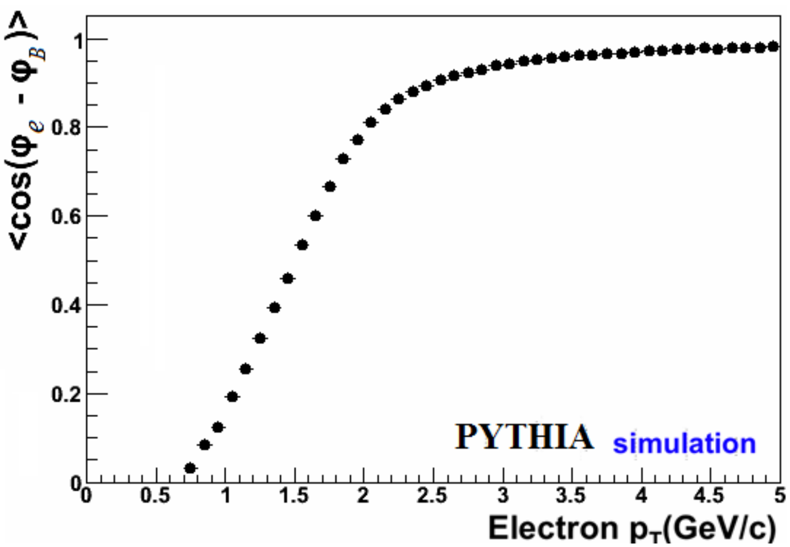
FONLL[1] is consistent with data in the bottom case; slightly lower for charm

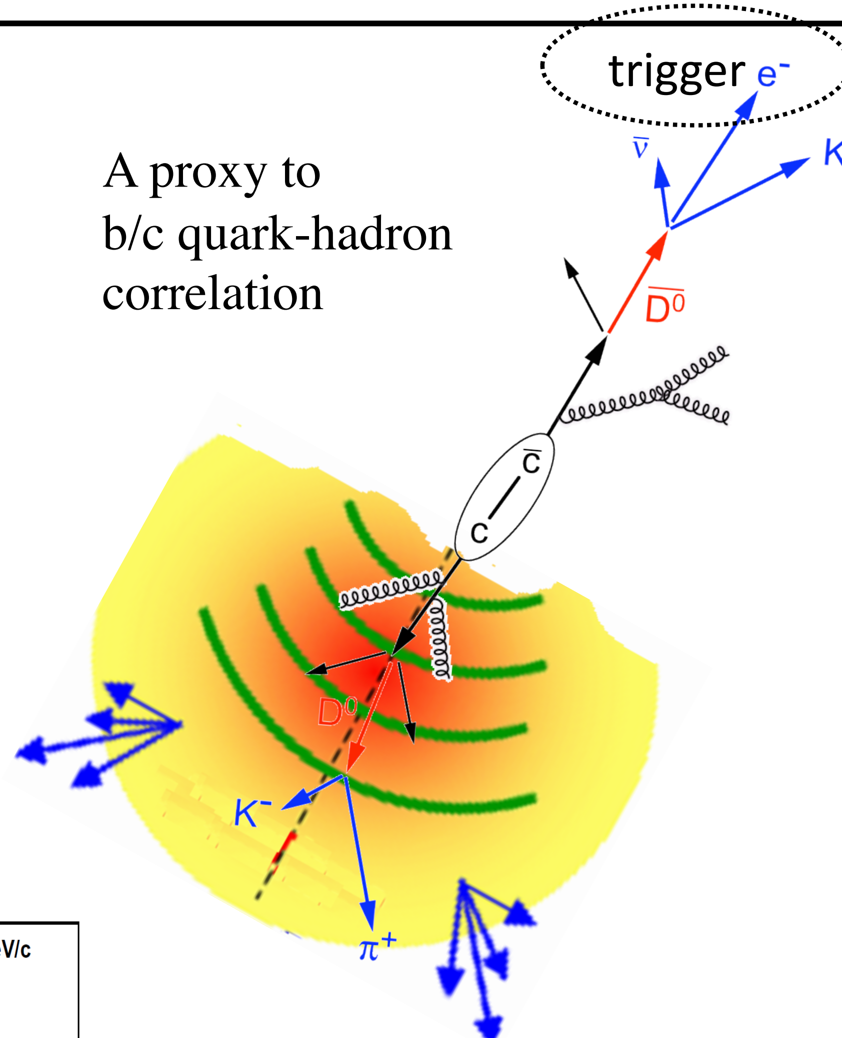
[1] FONLL: M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. **95, 20 122001 (2005);**
M. Cacciari, R. Vogt, private communications.

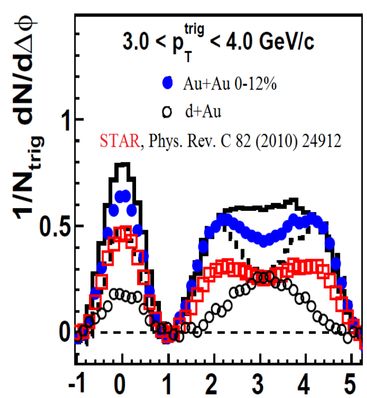
High p_T NPE-hadron correlations: away side

Heavy flavor daughter electrons represent parent momentum direction well, when p^e_T>1.5 GeV/c for D case, and when p^e_T > 3 GeV/c for B case.

A proxy to b/c quark-hadron correlation







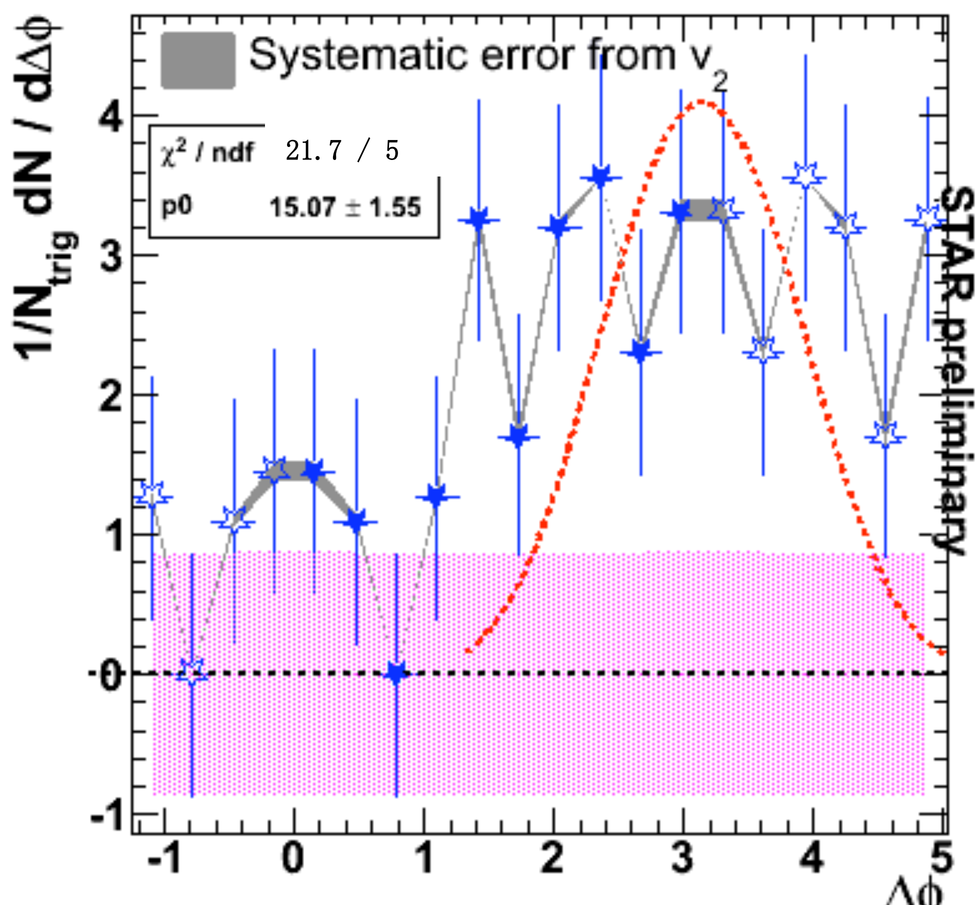
Away Side in medium:

How does B/D lose energy?

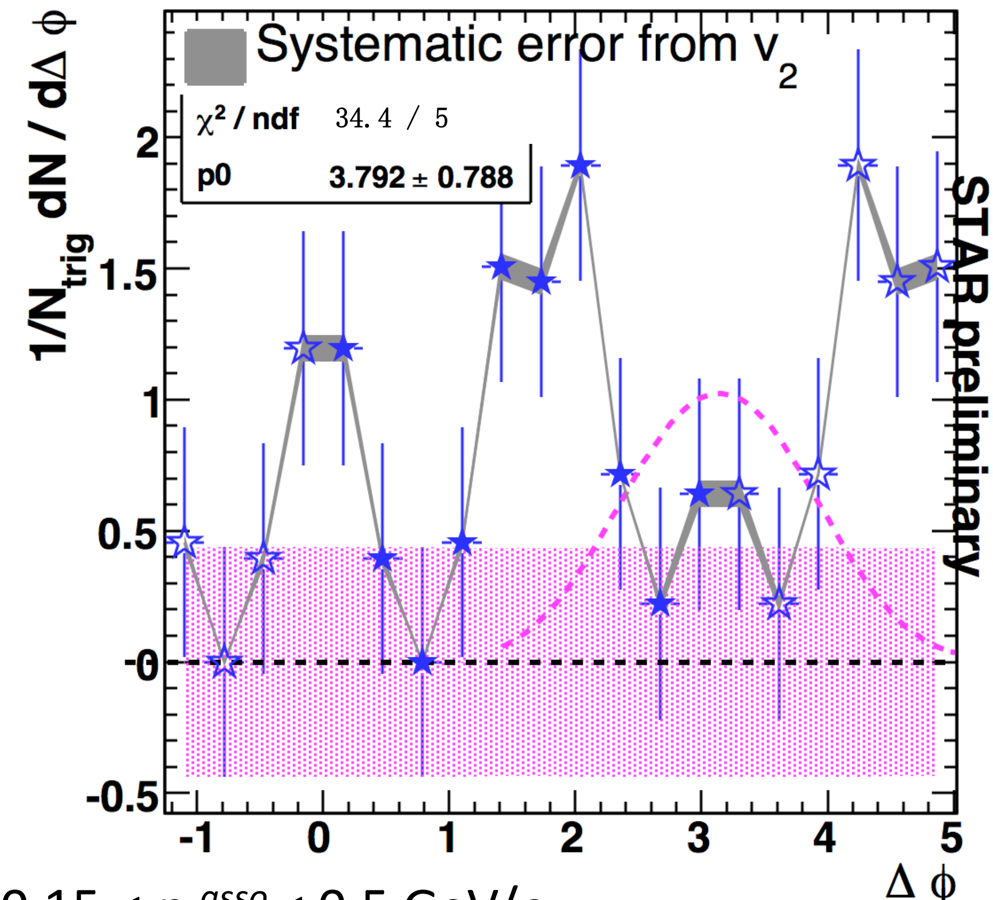
Any pattern like what seen in di-hadron?

High p_T NPE-hadron correlations away side Broadened in Au+Au, Cu+Cu

AuAu



CuCu



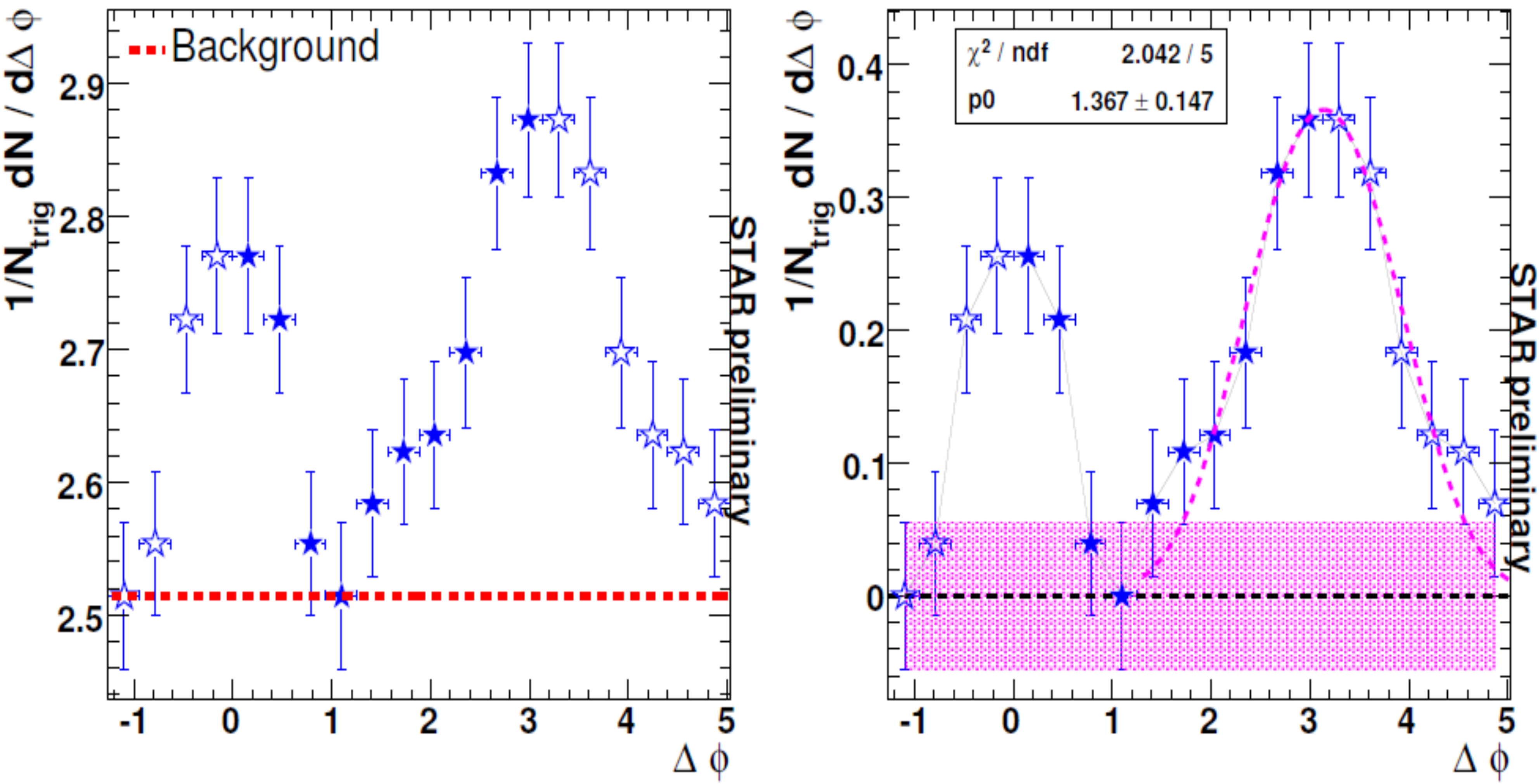
0 – 20%: $3 < p_T^{trig} < 6$ GeV/c & $0.15 < p_T^{asso} < 0.5$ GeV/c

Away side broadened, beyond PYHTIA fit, in both Au+Au and Cu+Cu

The new result from Run10 data could have the uncertainty reduced by ~4 in certain centralities.

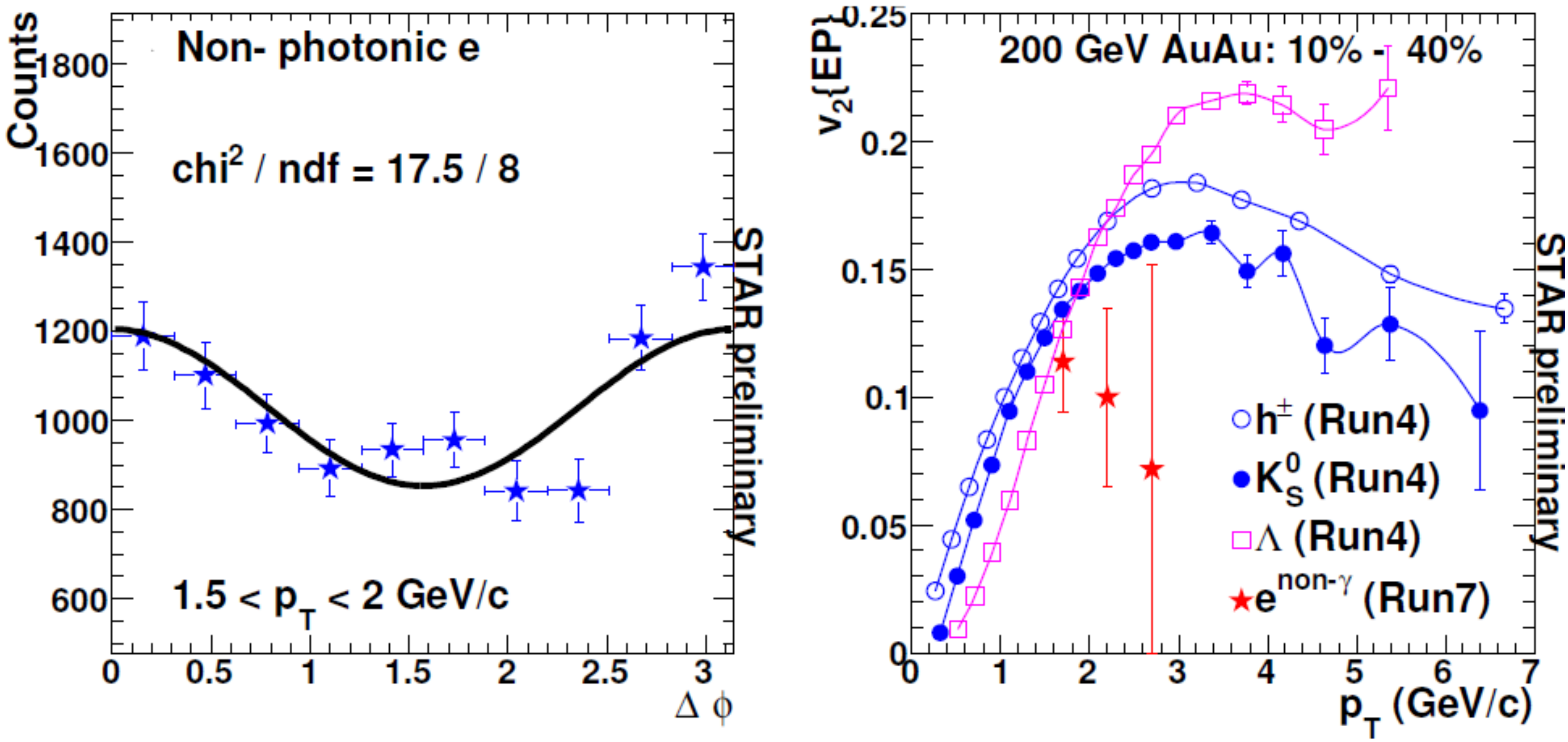
High p_T NPE-hadron correlations away side NOT broadened in d+Au

$3 < p_T^{trig} < 6$ GeV/c & $0.15 < p_T^{asso} < 0.5$ GeV/c



The away-side correlation can be well described by PYTHIA calculations for p+p. No medium effects seen here.

How much do heavy flavor quarks flow?



NPE v_2 is finite, and lower than hadron (or K^0s, Λ) v_2, with large uncertainties.

not apple to apple: the NPE p_T < heavy flavor parent hadron p_T,

Summary of NPE

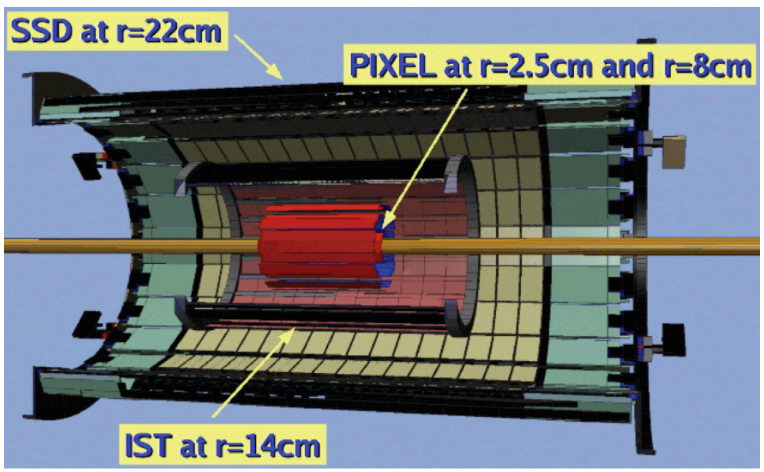
- NPE at high p_T is largely suppressed in central Au+Au collisions.
- NPE-h correlations in p+p collisions has been measured to separate *B* and *D* contributions
  - Bottom hadron yield in central Au+Au collisions is also suppressed.
  - Bottom electron at high p_T in p+p is consistent with FONLL, while charm electron is close
- The away side of NPE-h correlation is modified in central Cu+Cu and Au+Au collisions; not modified in d+Au collisions.
- NPE v_2 is finite, and lower than hadron (or K^0s, Λ) v_2, with large uncertainties

STAR upgrades for Heavy Flavor physics

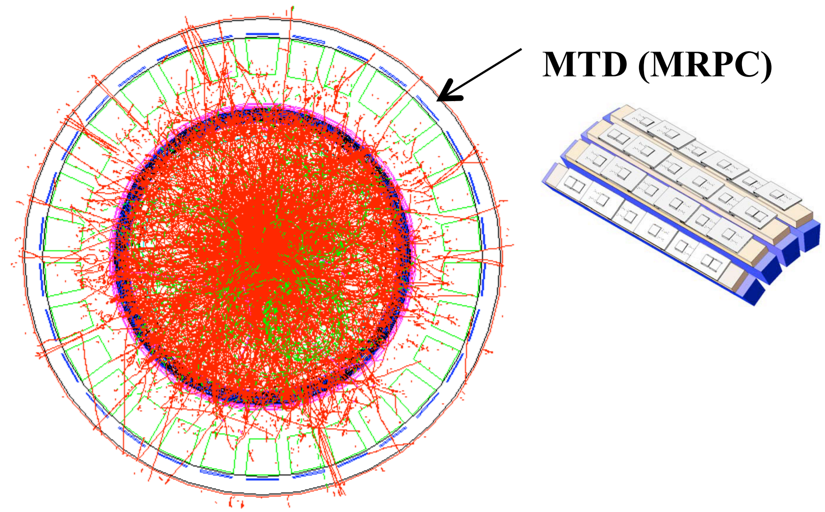
Heavy Flavor Tracker(HFT):

Direct topological reconstruction of open charmed hadrons in HI collisions

- No ambiguities in the charm hadron kinematics
- No ambiguities in the charm/bottom hadron mixture
- Significantly improved significance by secondary decay vertex reconstruction



HFT

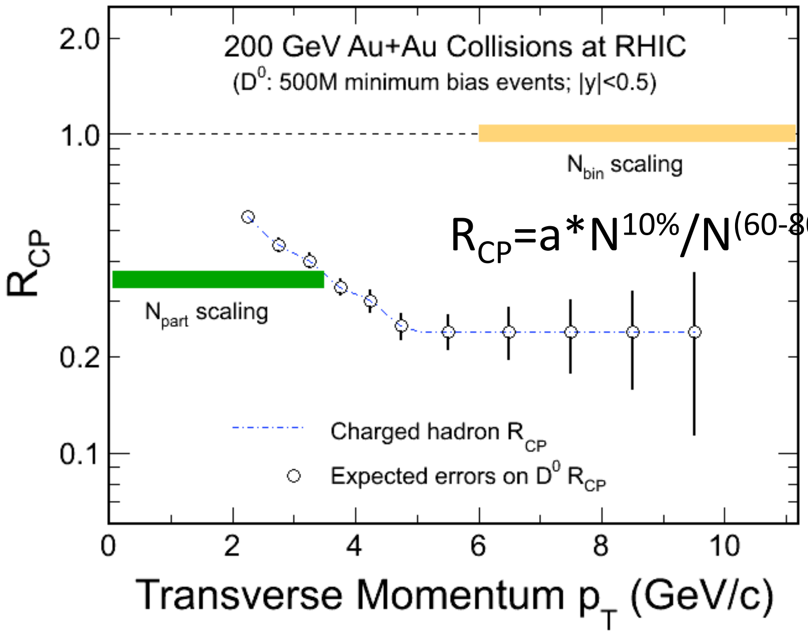


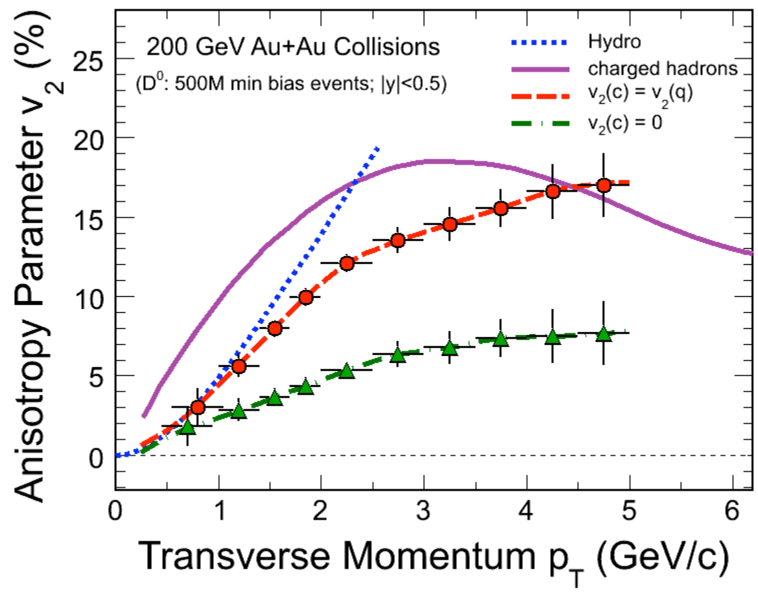
Muon Telescope Detector(MTD):

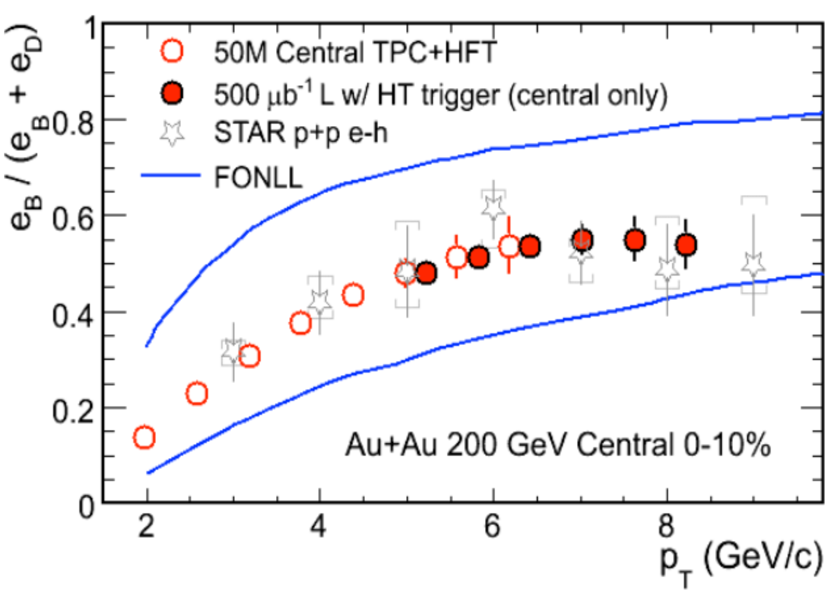
Advantages over electron channels:

- No γ conversion, much less Dalitz decay contribution, much less combinatorial background
- Less affected by radiative losses in the detector materials
- Also important for heavy quarkonia studies

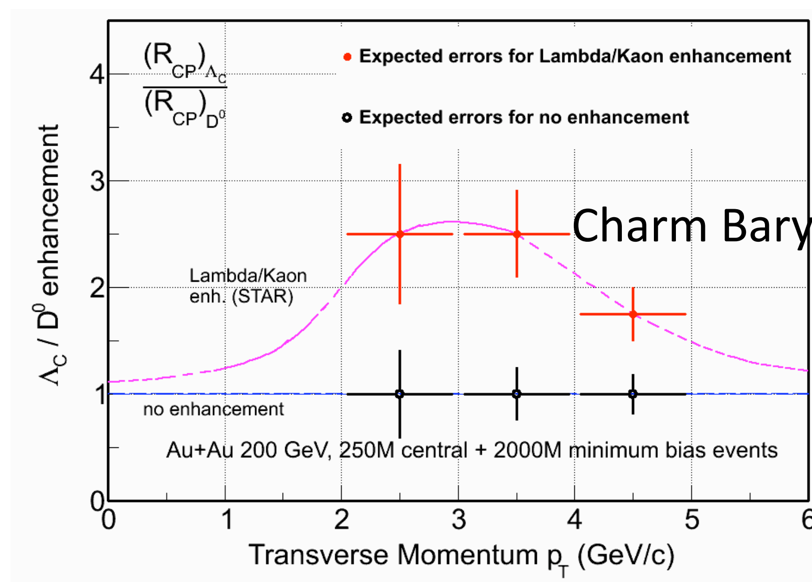
Physics Projections





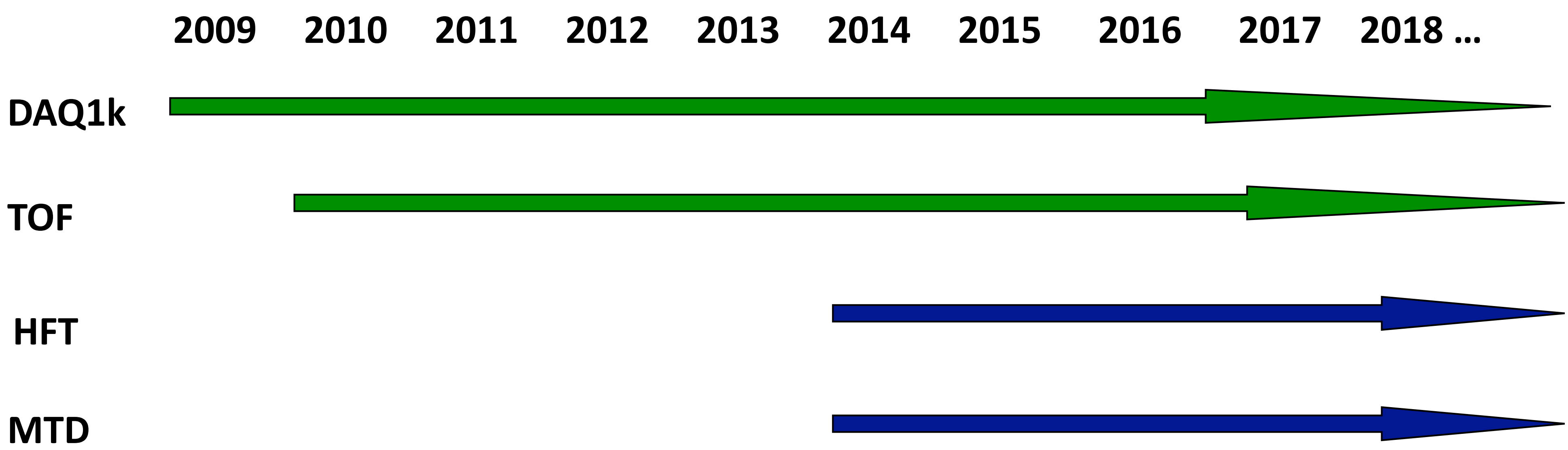


Charm Bottom separation



Charm Baryons

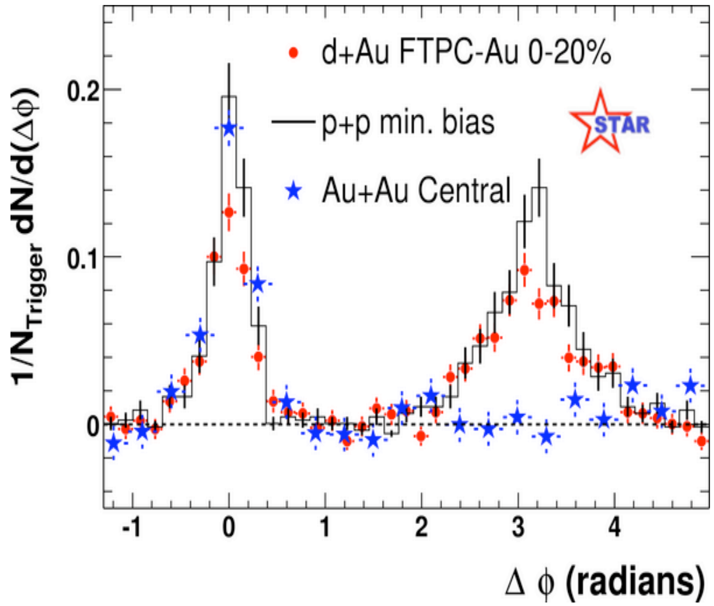
STAR Upgrade Schedule



STAR,
with the HFT and MTD upgrades,
remains the ideal place to carry out
Heavy Flavor studies

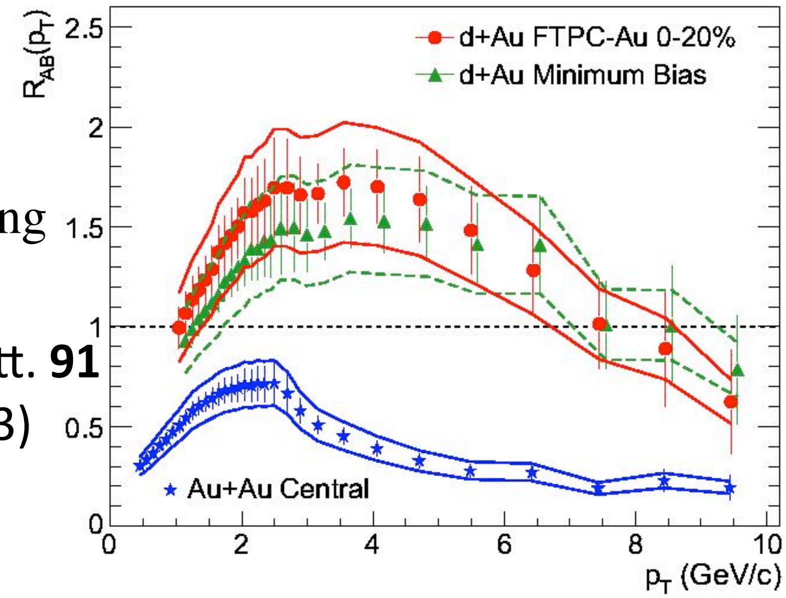
Backup

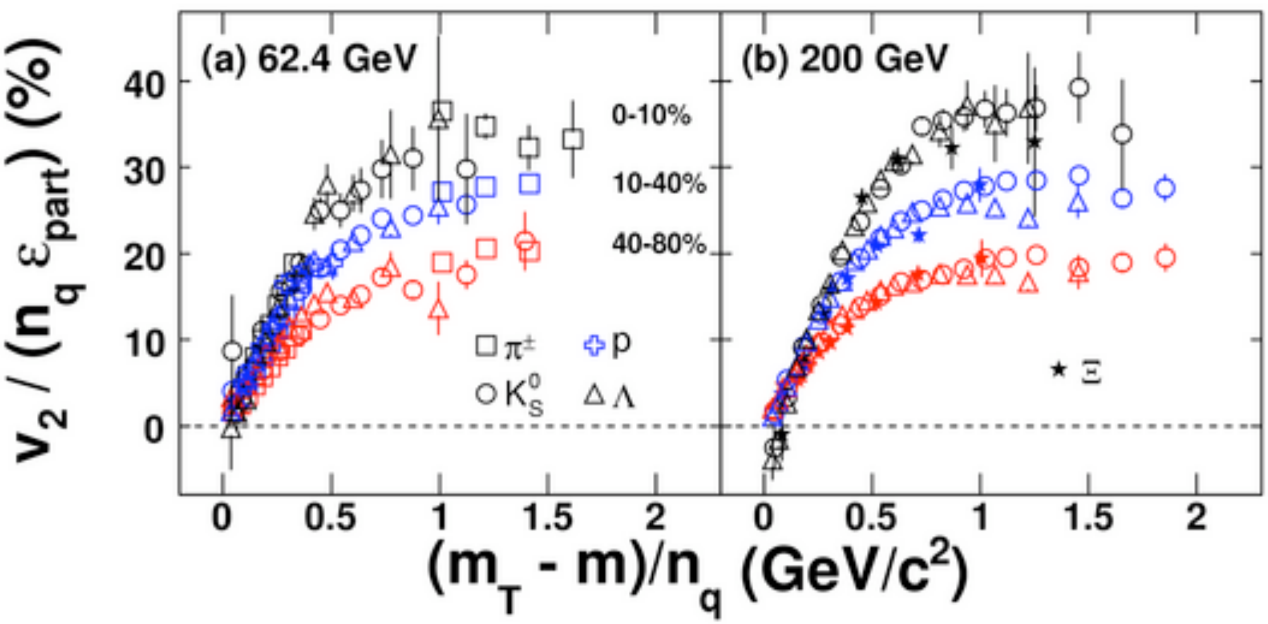
What we've learned in heavy ion collisions



High p_T:
Jet quenching

Phys. Rev. Lett. **91** 072304 (2003)





Low and intermediate p_T:
Strong partonic collectivity

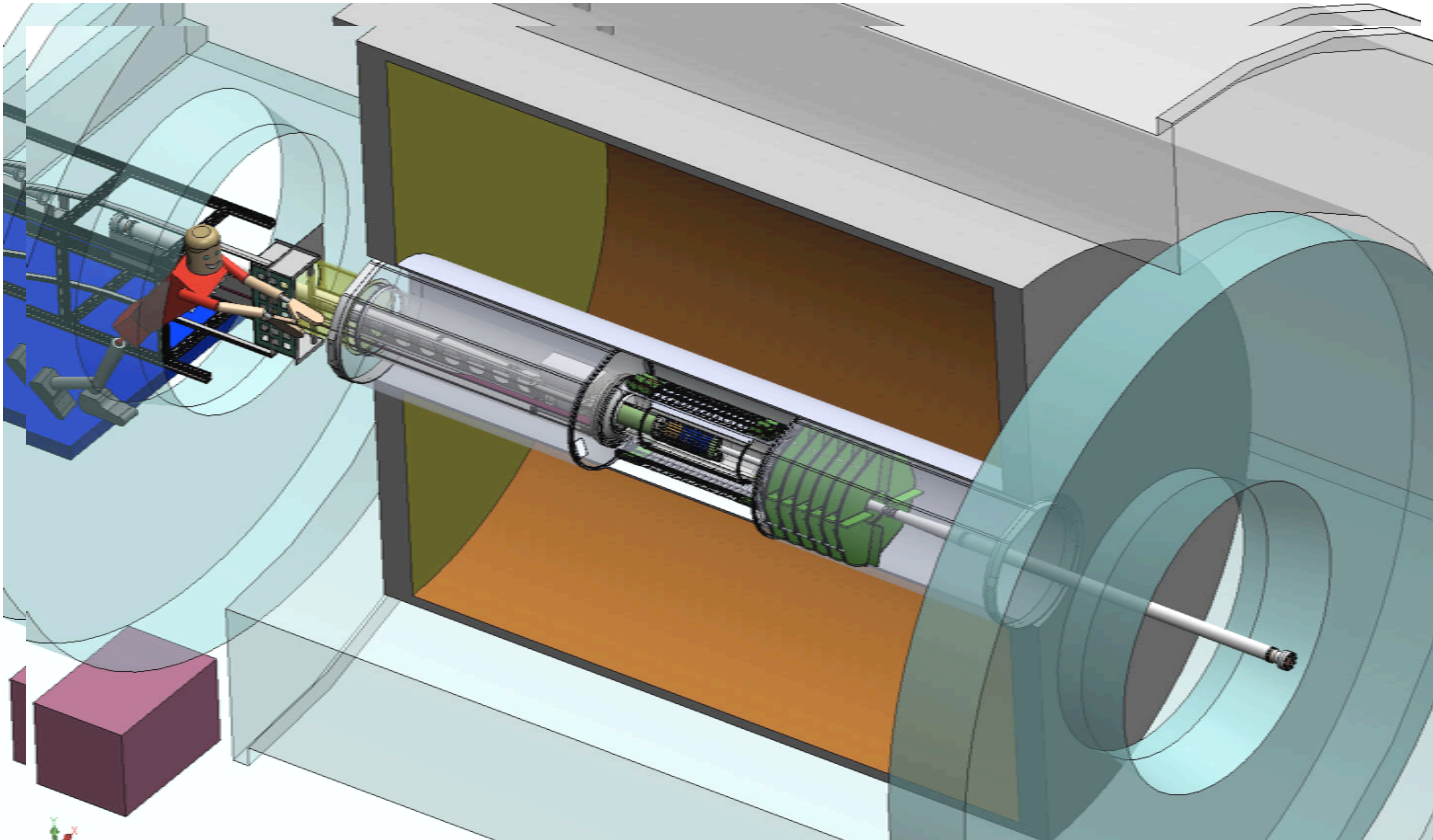
Phys. Rev. C.**77** 054901 (2008)

Summary of the talk:

Heavy Flavor is an important probe to the medium, with the potential of quantitatively understand the properties of the medium.

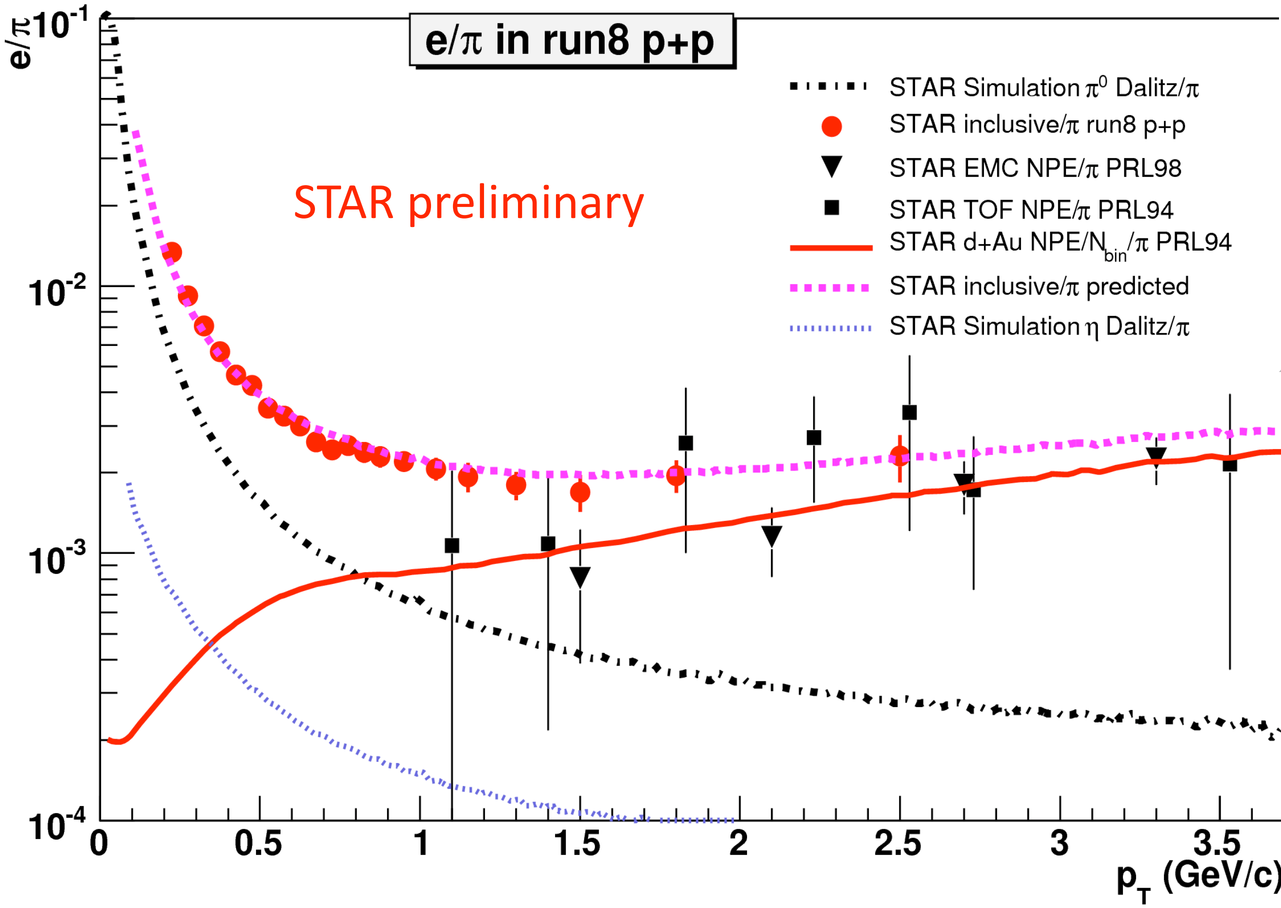
STAR studies open heavy flavor via direct construction and NPE.

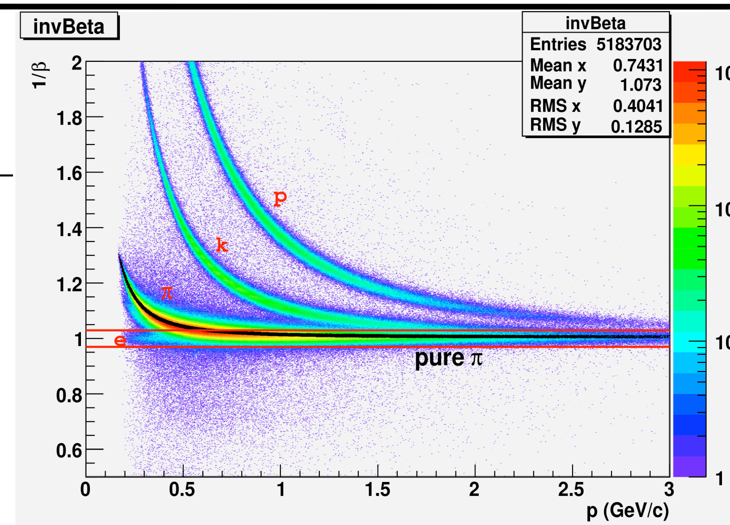
STAR, with the HFT and MTD upgrades, remains the ideal place to carry out these studies.



Lower p_T NPE in 200GeV p+p

Expressed as e/π ratio





Excellent e and π Identification by TOF

- Non-photonic electron signal is higher than photonic background at p_T>1.2 GeV/c
- The measured e/pion ratio from run8 supports our previous low p_T NPE measurements published
- Statistics are much higher than what we had before