Measurements of charm meson production in p+p and Au+Au collisions by the STAR experiment

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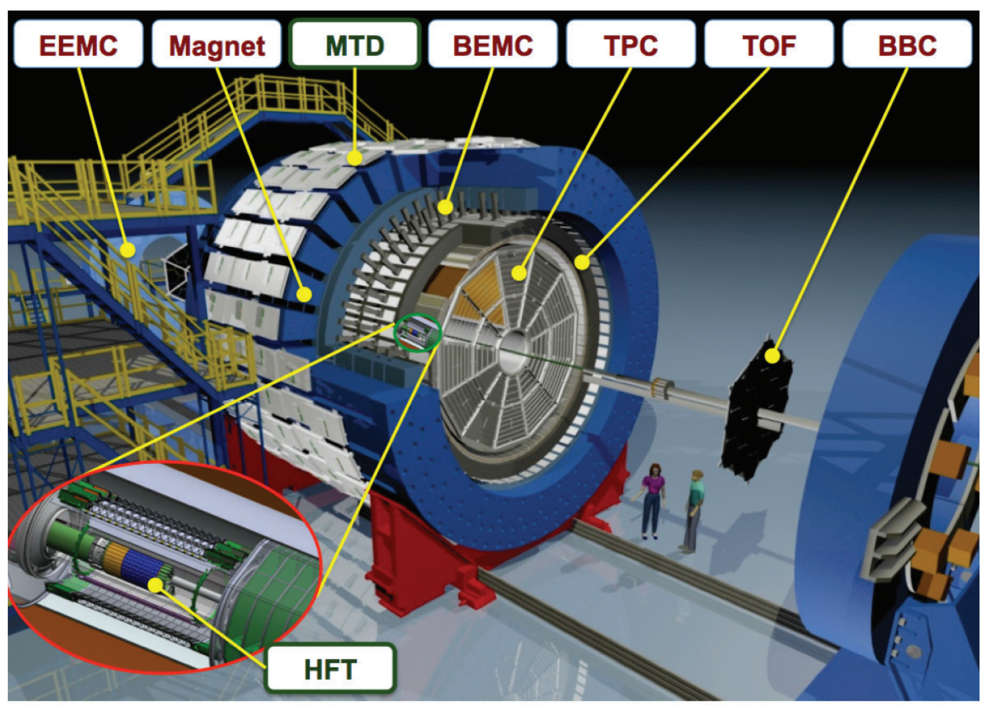
Motivation

- In central heavy-ion collisions at Relativistic Heavy Ion Collider (RHIC), a hot and dense nuclear matter, called the quark-gluon plasma (QGP), is created.
- Charm quarks possess large masses, and thus are produced primarily at the initial stages of heavy-ion collisions. Therefore, they are considered excellent probes to QGP properties.
- Charm quarks are expected to lose energy while traversing the medium. In particular, a mass ordering of the parton energy loss in the hot medium is predicted, i.e. heavy-flavour quarks are expected to lose less energy than light-flavour quarks.
- The possible collective behavior of charm quarks reflects the degree of thermalization of charm quarks in the medium, and is related to the bulk properties of the QGP.

STAR detector

- The Solenoidal Tracker at RHIC (STAR) was designed to study the strongly interacting matter by detecting particles emerging from heavy-ion collisions.
- STAR excels in tracking and identification of charged particles at mid-rapidity ($|\eta| < 1$) with full azimuthal coverage.
- Most of the subsystems are immersed in 0.5 T solenoidal magnetic field.



Time Projection Chamber (TPC)

- main tracking device; momentum determination
- particle identification via specific energy loss dE/dx

Time Of Flight (TOF)

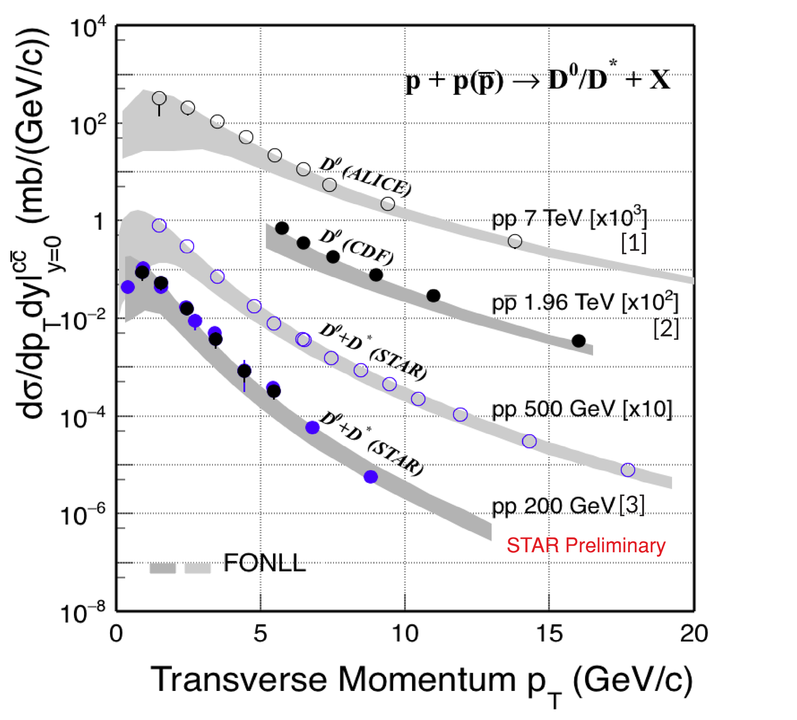
- particle identification at low transverse momentum p_T via velocity β

Heavy Flavor Tracker (HFT):

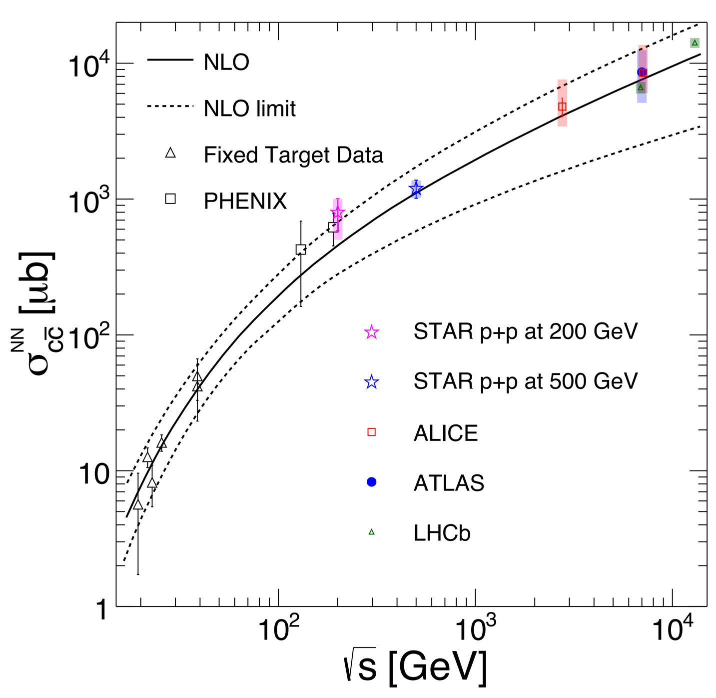
- inner tracking system composed of three silicon detectors – the PIXEL made of two Monolithic Active Pixel Sensor layers, Intermediate Silicon Tracker and Silicon Strip Detector
- excellent **DCA$_{xy}$ resolution: 30 μm** at $p_T = 1.5$ GeV/c

Charm quark production in p+p collisions

The D meson production cross section in p+p collisions from $\sqrt{s}$ = 200 GeV to $\sqrt{s}$ = 7 TeV, compared with QCD based theoretical predictions



Total charm quark production cross section as a function of $\sqrt{s}$, compared with QCD calculations at NLO

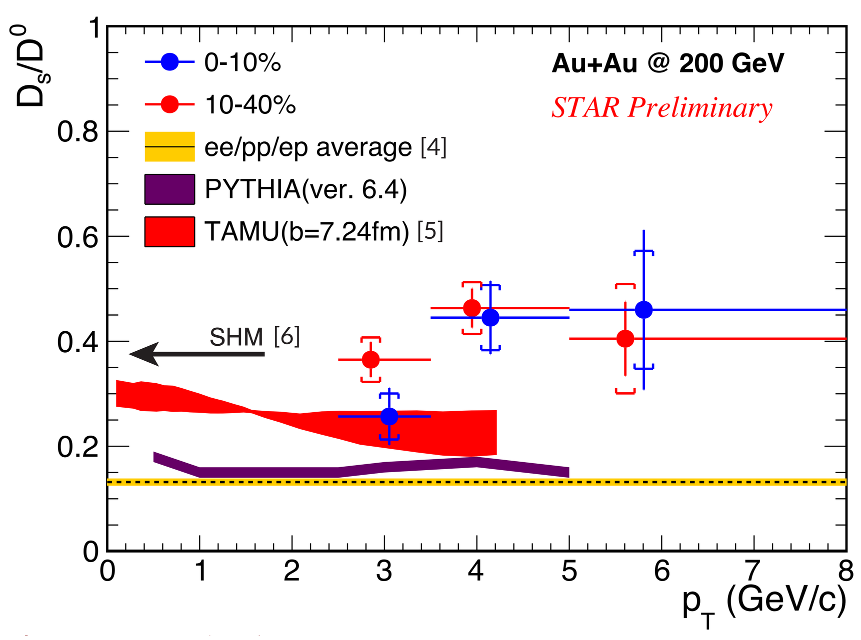


- Differential and total charm quark production cross sections are well described by QCD calculations in elementary p+p collisions at $\sqrt{s}$ = 200 GeV to 7 TeV.

Strangeness enhancement

The yield ratio of D_s to D^0 in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, compared to fragmentation baseline

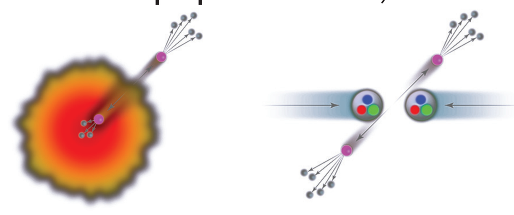
- D_s is more sensitive to properties of the QGP, due to earlier freeze-out compared to D^0 meson.
- D_s/D^0 ratio is significantly larger than the fragmentation baseline (p+p). It is also higher than the TAMU model calculation, but seems to be consistent with statistical hadronization model (SHM) prediction (0.35-0.4).
- Enhancement of strange-charm meson (D_s) in Au+Au collisions suggests that charm quarks also participate in coalescence hadronization in the QGP.



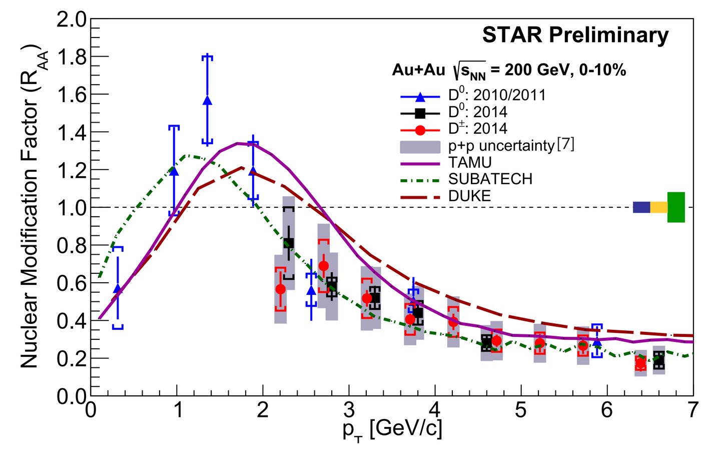
Energy loss in Au+Au

- **Nuclear modification factor** - ratio of particle production in A+A and p+p collisions, scaled by nuclear overlap function, is usually used to study parton energy loss:

$$R_{AA} = \frac{dN_{AA} / dp_T}{\langle T_{AA} \rangle d\sigma_{pp} / dp_T}$$

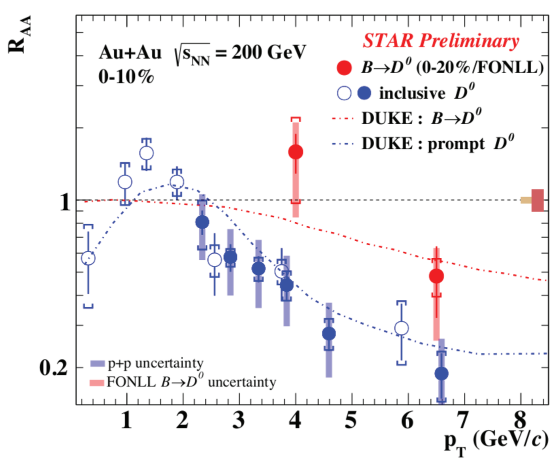


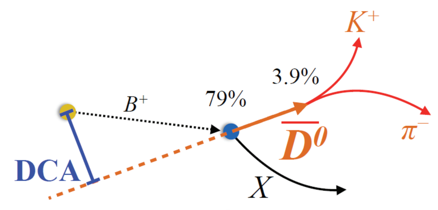
The $D^{\pm}$ and D^0 R_{AA} in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, compared to theoretical models



- The nuclear modification factor exhibits strong suppression at high p_T, indicating substantial energy loss of charm quarks in the medium.
- The D meson R_{AA} is consistent with model calculations including strong charm-medium interactions and coalescence hadronization at intermediate p_T.

The nuclear modification factors of prompt and non-prompt D^0 mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, compared to model calculations



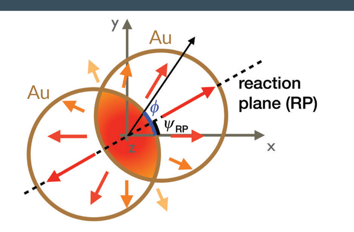


- Strong suppression observed for non-prompt D^0 mesons from B-hadron decays above 5 GeV/c.
- Hint of **less suppression for non-prompt** D^0 than prompt ones.

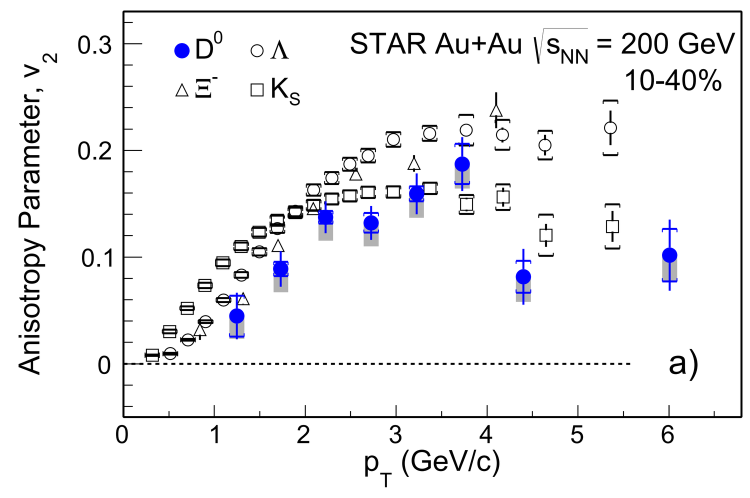
Elliptic and triangular anisotropy

- Fourier expansion of the particle yield with respect to the reaction plane:

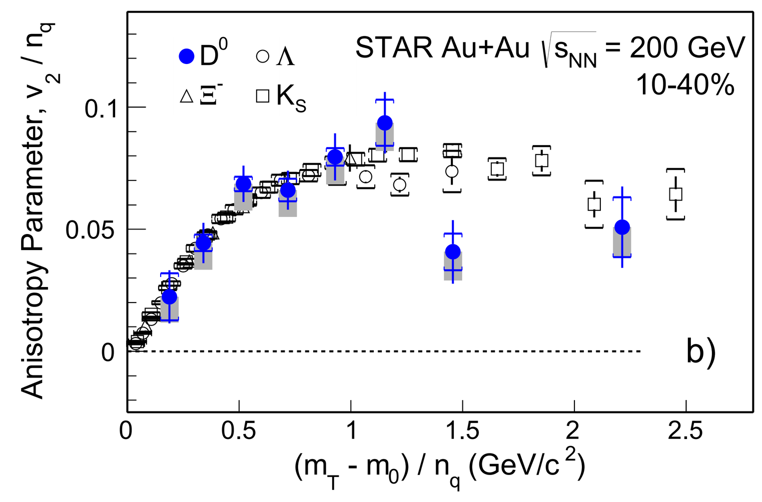
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos\left[n(\phi-\psi_{RP})\right]\right)$$



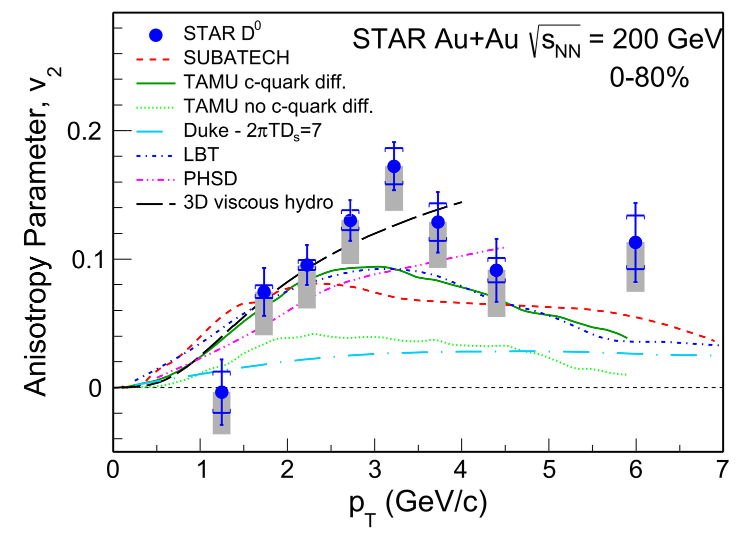
The elliptic anisotropy v_2 for D^0 mesons and light mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV



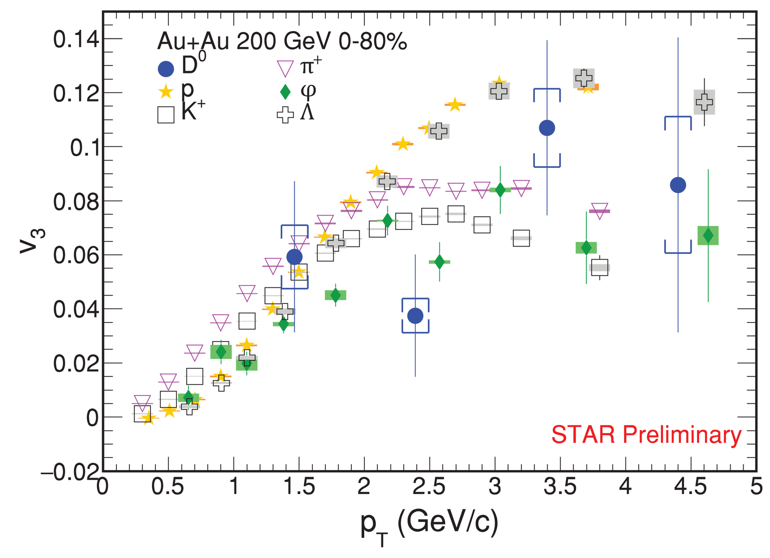
The elliptic anisotropy v_2 per constituent quark for D^0 mesons and light mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV



The elliptic anisotropy v_2 for D^0 mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, compared to theoretical predictions

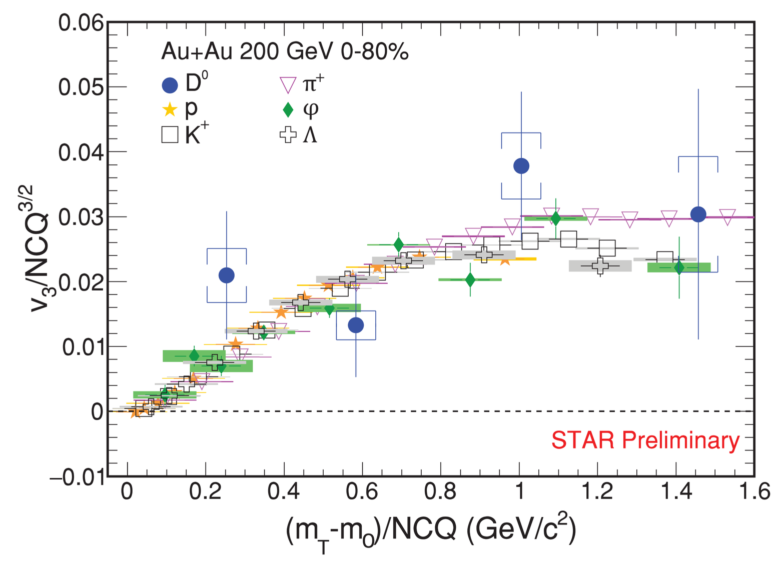


The triangular anisotropy v_3 for D^0 mesons and light hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV



- Clear mass ordering of v_2 for p_T < 2 GeV/c. D^0 v_2 follows other light hadrons for p_T > 2 GeV/c. [8]
- D^0 v_2 and v_3 follow NCQ scaling, suggesting that charm quarks flow with the QGP.
  - Light flavor v_2 and v_3 suggest hydrodynamic behavior of a strongly interacting matter.
- 3D viscous hydrodynamic model describes data below 4 GeV/c, suggesting charm quarks may have achieved local thermal equilibrium.
- First measurement of D^0 v_3 at RHIC - D^0 v_3 is non-zero.
- Models with charm quark diffusion coefficient of 2-12 can describe simultaneously D^0 R_{AA} and v_2 results. Lattice-QCD calculations of the diffusion coefficient are consistent with values inferred from data.

The triangular anisotropy v_3 per constituent quark for D^0 mesons and light mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV



Conclusion

- D mesons are reconstructed via their hadronic decay channels, as the daughter particles can be tracked and identified with excellent precision thanks to especially the Heavy Flavor Tracker at the STAR experiment.
- Charm quark production in p+p collisions is well described by QCD based calculations over a wide range of collision energies.
- Charm quarks participate in coalescence hadronization in the QGP as suggested by the enhanced D_s/D^0 ratio observed in Au+Au collisions.
- At high transverse momenta and in central Au+Au collisions, D meson production is strongly suppressed compared to that in p+p collisions, indicating strong charm-medium interactions.
- D^0 meson v_2 and v_3 follow NCQ scaling as light hadrons - suggests that charm quarks have gained significant flow through interactions with the QGP.
- D^0 meson v_2 for transverse momentum below 4 GeV/c is described by 3D viscous hydrodynamic model, suggesting charm quarks may have achieved local thermal equilibrium.

References

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