Heavy Flavor Physics with Fast MAPS Detector at sPHENIX

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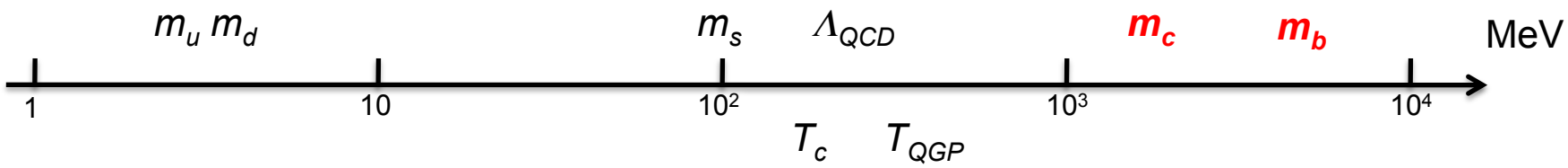
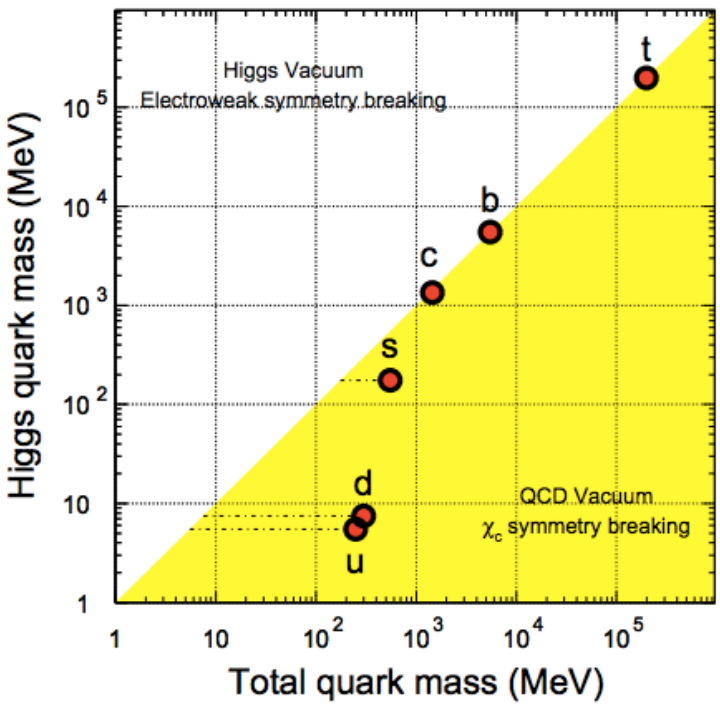
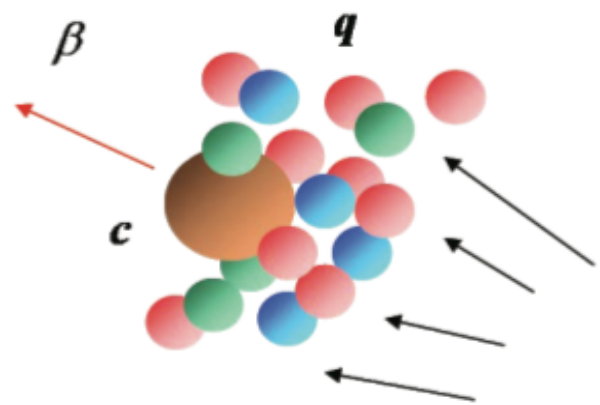
Uniqueness of Heavy Quarks in QCD





Zhu et al., PLB 647(2007)366



When $M_{HQ} >> T$, $M_{HQ} >> gT$

"Brownian" motion → Langevin simu.

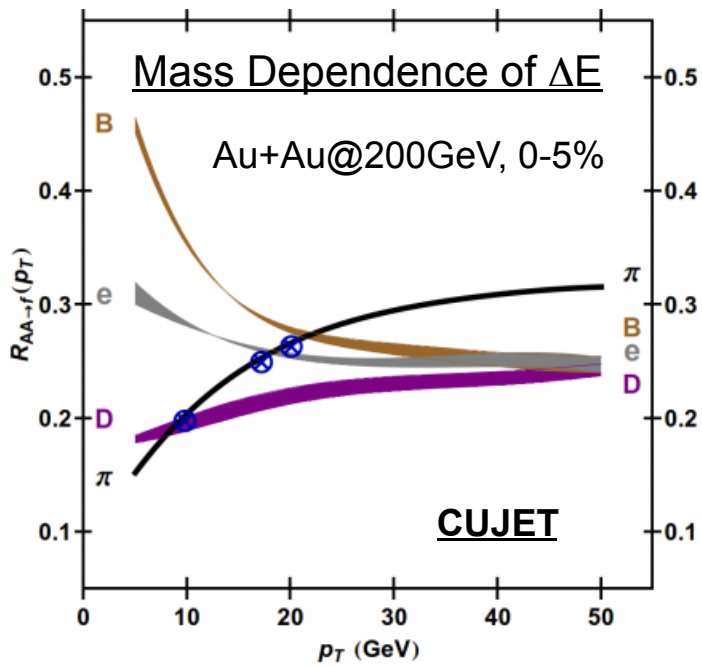
$$\frac{dp^i}{dt} = -\eta_D p^i + \xi^i(t)$$

drag → Diffusion coefficient D_{HQ}

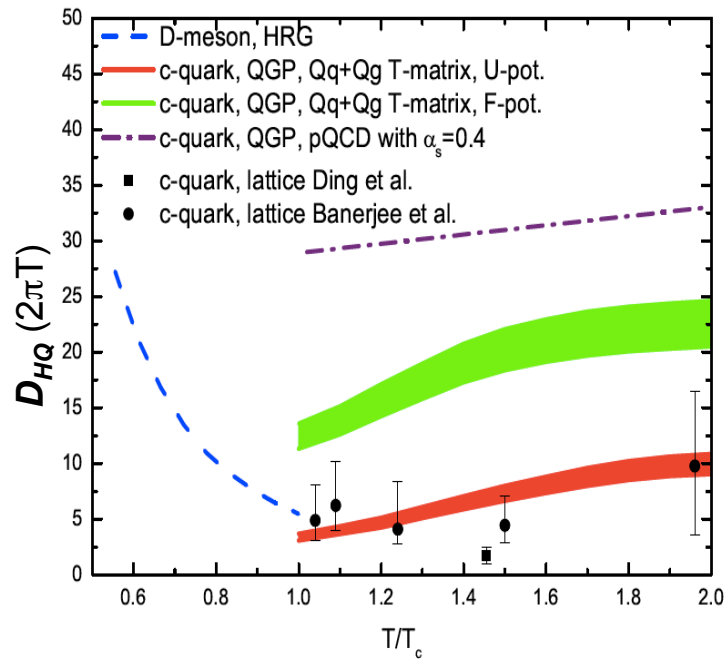
fluctuations → Diffusion coefficient D_{HQ}

Physics Goals of Heavy Flavor Measurements

- Mass/flavor dependence of parton energy loss
- Quantify the medium transport parameter – heavy quark diffusion coefficient, DHQ

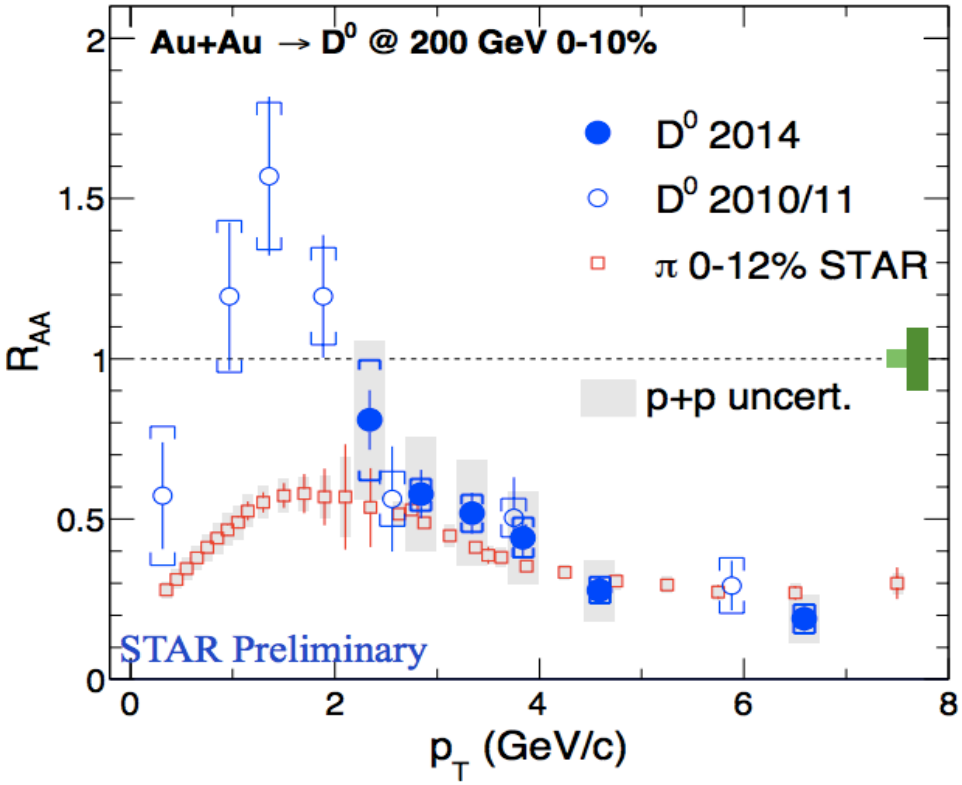


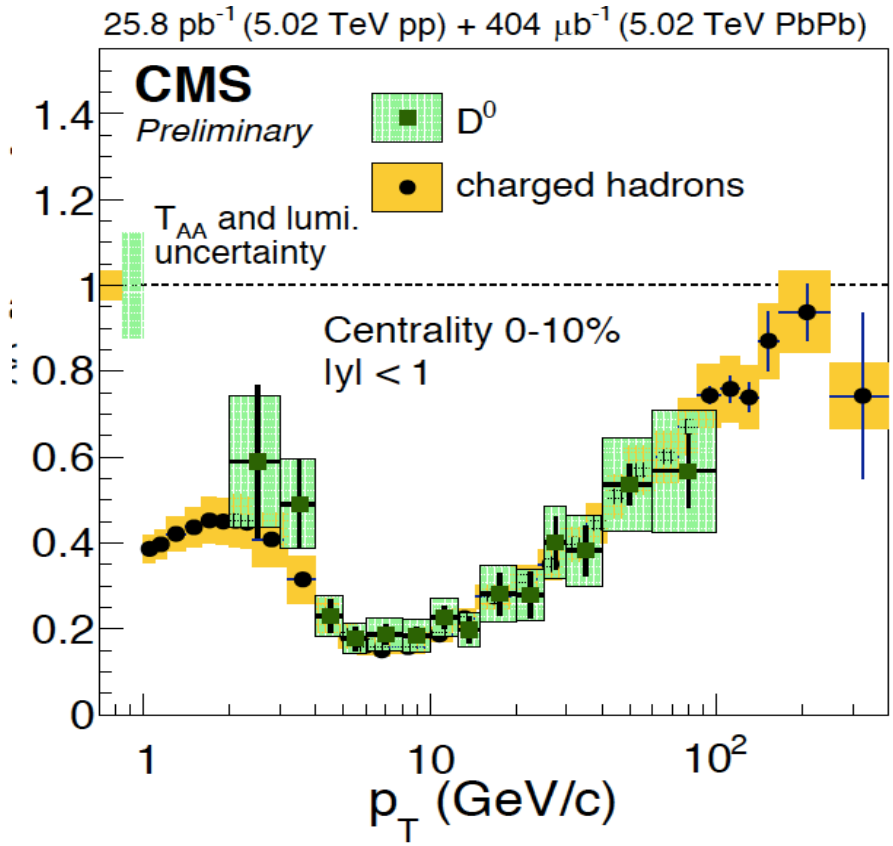
PRL 108 (2012) 022301



QCD white paper - arXiv: 1502.02730

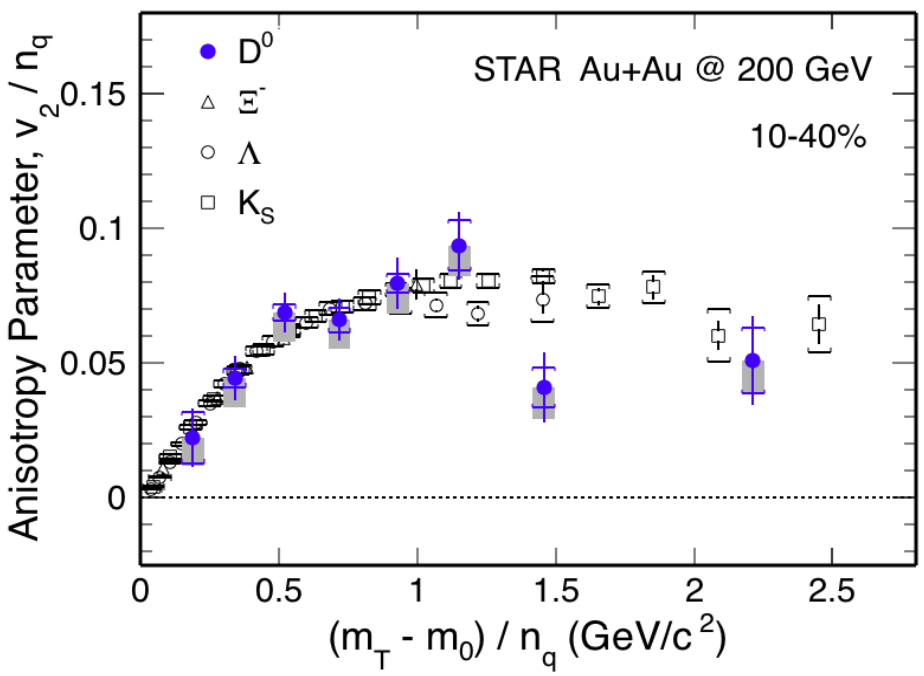
Achievements in Charm-Hadron R_{AA}

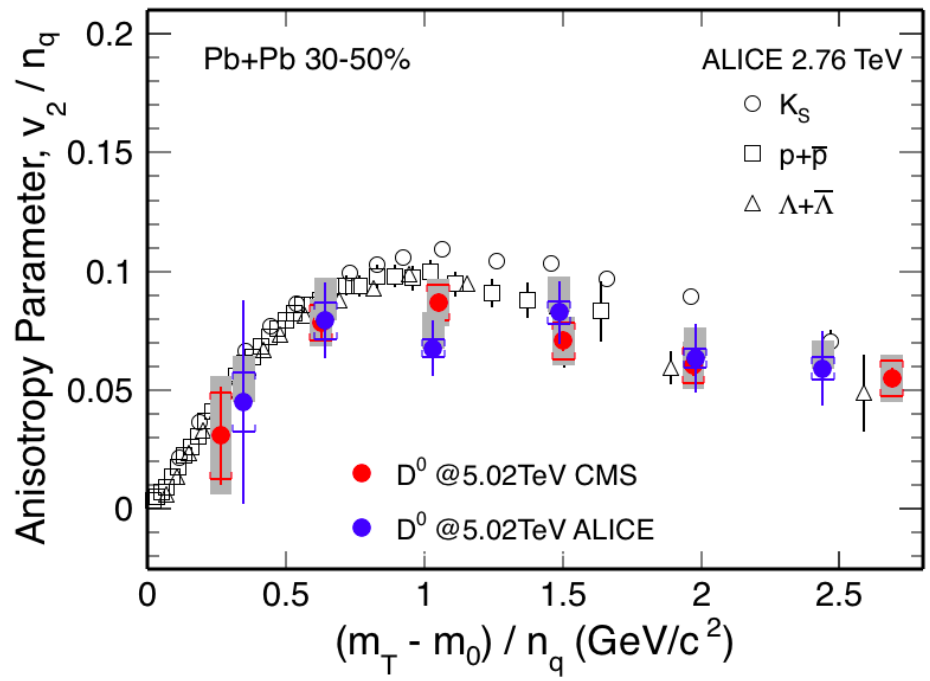




R_{AA} (D) ~ R_{AA} (h) at p_T > 4 GeV/c
- Significant suppression of charmed hadron R_{AA} in central A+A collisions
- strong charm-medium interactions

Achievements in Charm-Hadron v_2





- v_2 of D^0 follows the same trend as light hadrons
- Charm quarks flow the same as light quarks
- Indication of charm quark thermalization

Go Heavier - Open Bottom Production

Open bottom production over a wide range of momentum

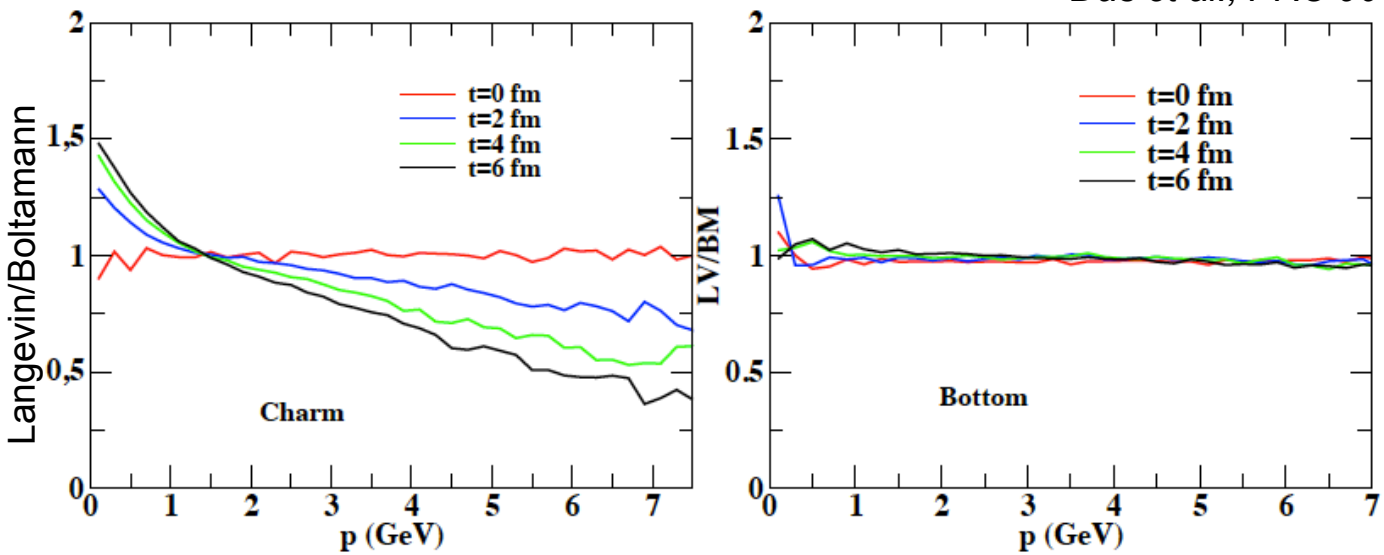
Mass/Flavor dependence of parton energy loss

Cleanest probe to quantify medium transport properties – e.g. D_{HQ}

Total bottom yield for precision interpretation of Upsilon suppression

- low p_T coverage is critical

Das et al., PRC 90 (2014) 044901



Is charm heavy enough?

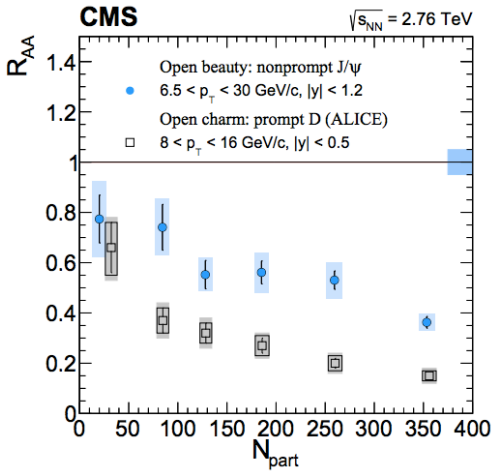
Sizable correction to the Langevin approach for charm

- may limit the precision in determining D_{HQ}

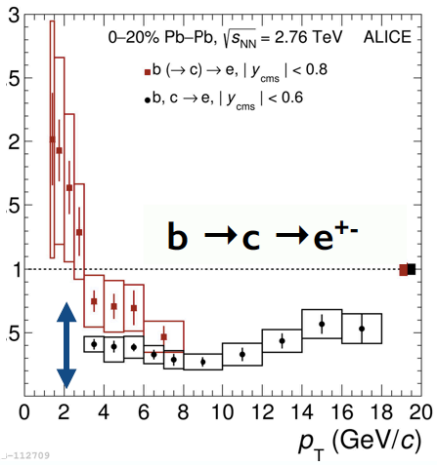
Recent Achievements on Bottom

LHC 2.76 TeV | **RHIC 200 GeV**

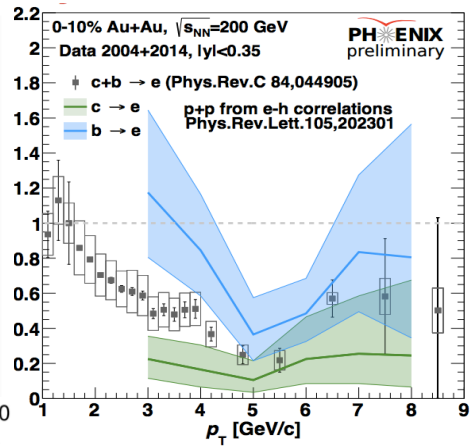
$R_{AA}(J/\psi_B) > R_{AA}(D)$

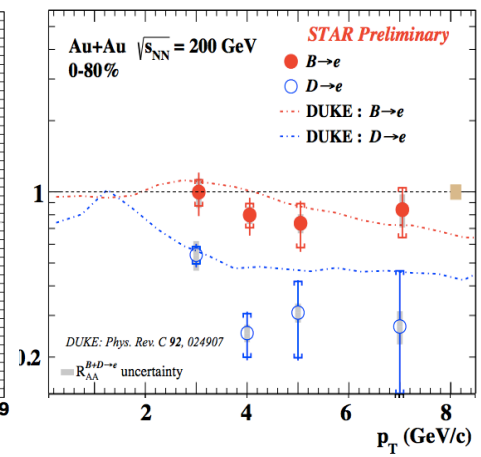


$R_{AA}(e_B) > R_{AA}(e_{D+B})$



$R_{AA}(e_B) > R_{AA}(e_D)$



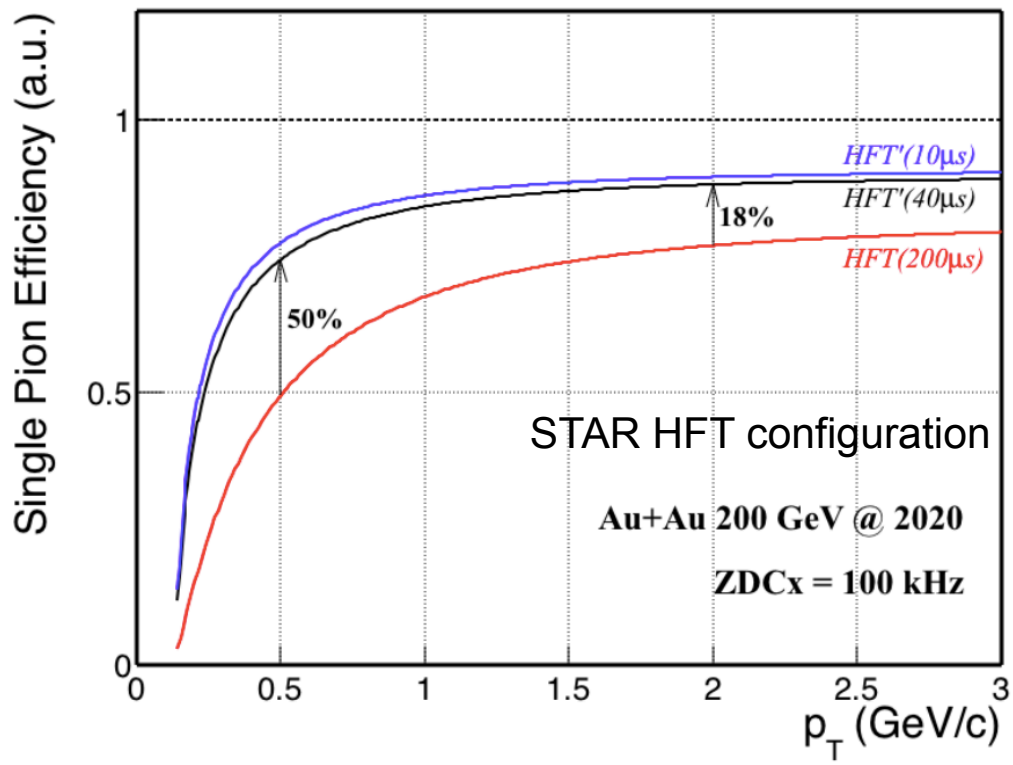


- R_{AA} of B-meson, b-jet, non-prompt J/ψ's are consistent with light hadrons/jets at p_T > 10 GeV/c
- Less R_{AA} suppression for B-decay daughters (J/ψ's, e) compared to D-mesons at low p_T

Evidence of less energy loss of bottom in the QGP

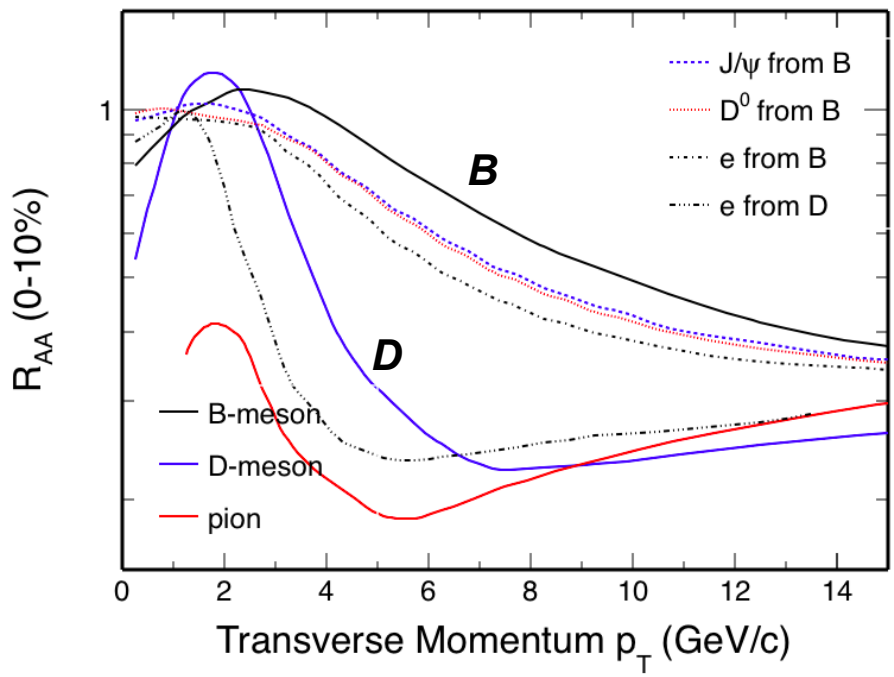
Requirements for Precision Open Bottom Production at RHIC

- High luminosity runs and large datasets (triggered and untriggered)
  B->J/ψ, B->D, B->e, B->Dπ and b-jet etc.
  -> Fast DAQ rate
- Fast silicon detector with ultimate pointing resolution
  Next generation MAPS sensors with much shorter integration time < 20 μs (vs. 186 μs)
  - high efficiency at high RHIC luminosity, particularly at low p_T



Physics Channels

Hadron	Abundance	cτ (μm)
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435



Theory curves on B/D-mesons from TAMU/DUKE/CUJET

$B \rightarrow J/\psi + X$ 1.2%

$B \rightarrow \overline{D}^0 + X$ 60%

$B \rightarrow e + X$ 11%

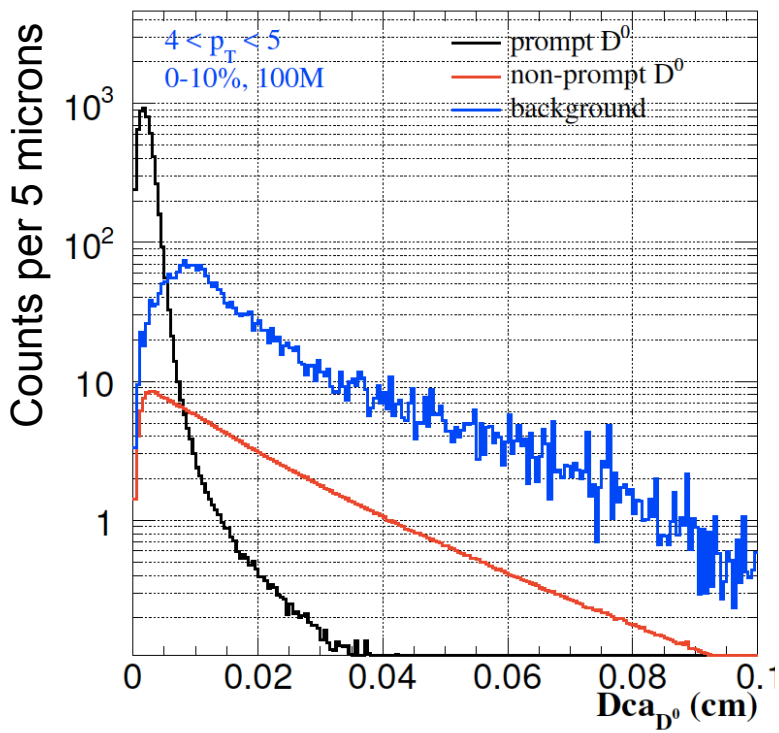
$B^+ \rightarrow \overline{D}^0 \pi^+$ 0.5%

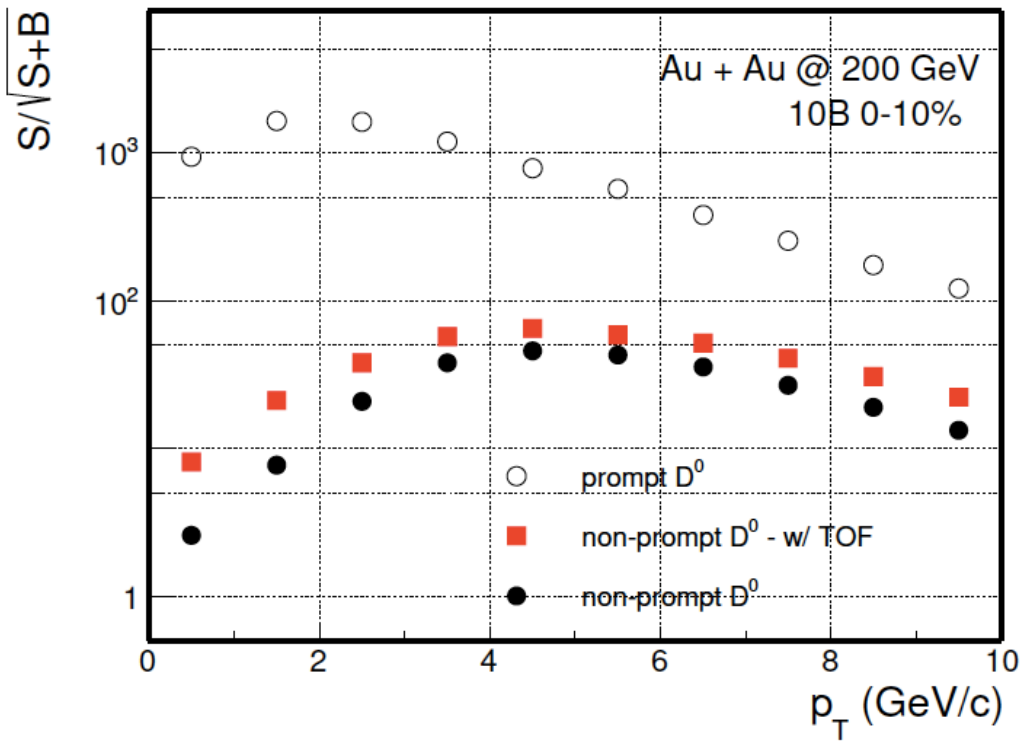
Needed for p_T<10 GeV

b-tagged jet

Estimation for Non-Prompt D^0

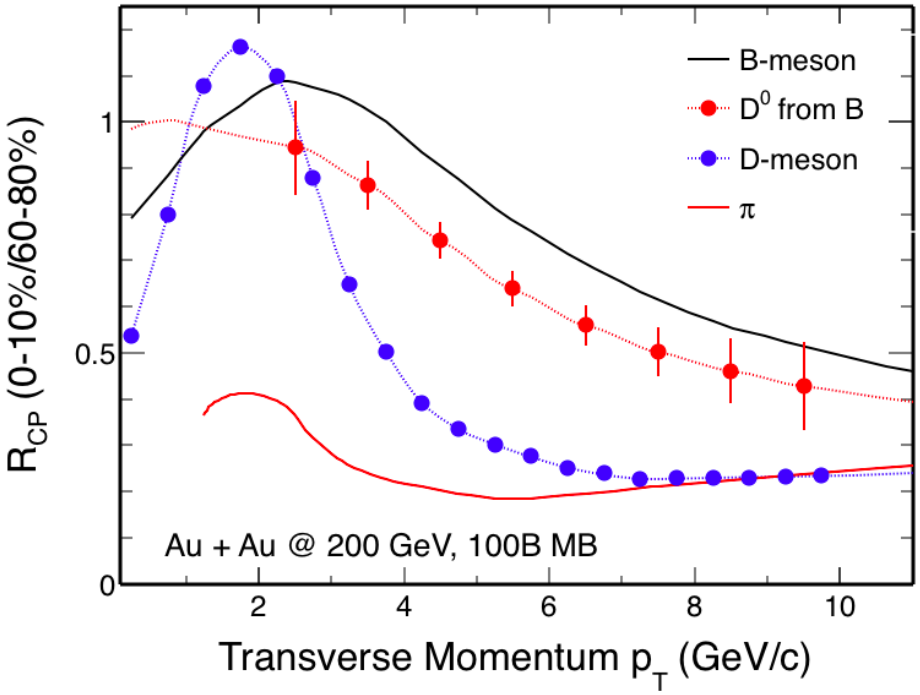
- Single track efficiency, DCA distributions taken from full Hijing + GEANT simulations
- These fed into a fast Monte Carlo package to generate the distributions for signals (prompt and non-prompt D^0) as well as combinatorial background

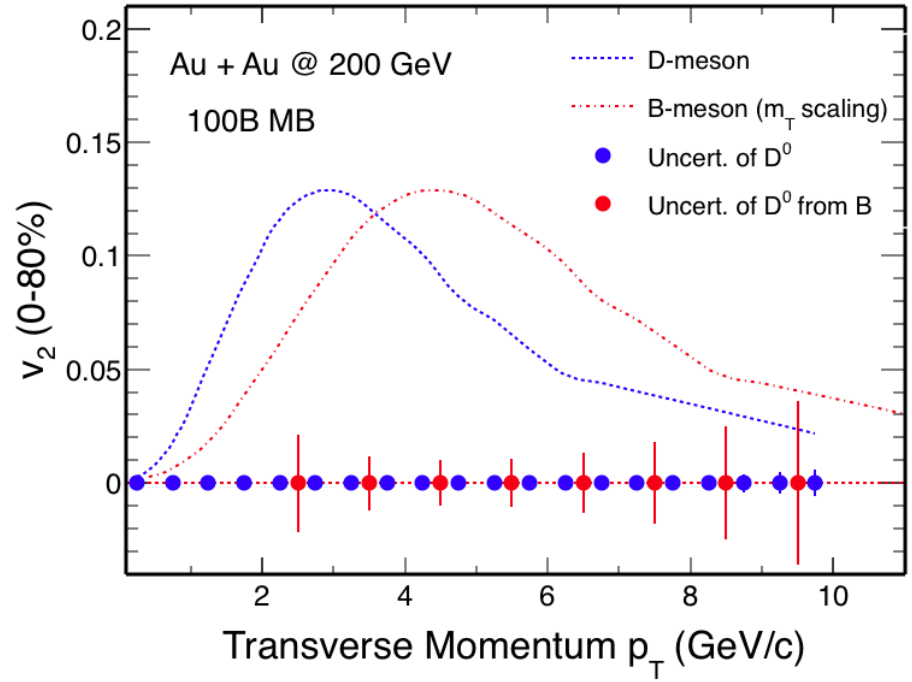




Physics Performance via Non-Prompt D^0

100B MB Au+Au collisions at 200 GeV





Assuming signal scales with N_{bin}, background scales with $Npart^2$

To-do list:
- Realistic estimation on the pileup MB/UPC hit density at MAPS sensors.
- Decay channels B->D, B->J/ψ, B->e and B->Dπ etc.
- Tracking improvement

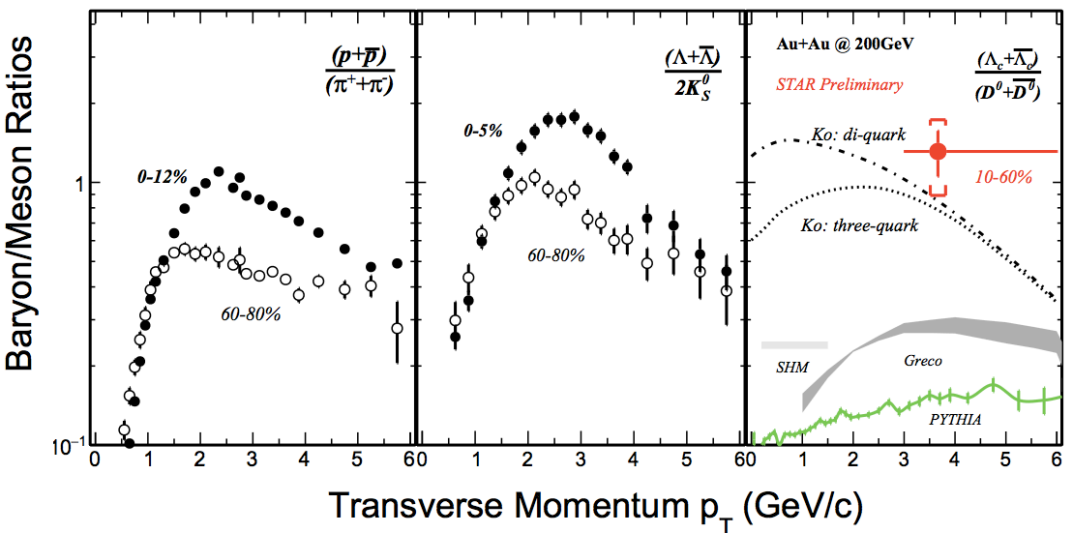
Λ_c and HQ Correlations

High statistics Λ_c measurements

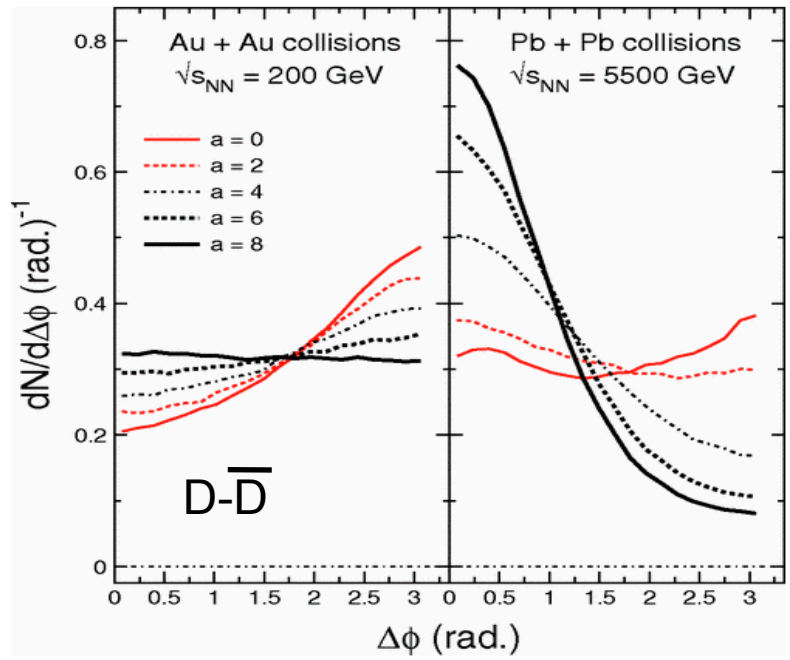
Λ_c/D^0 enhancement sensitive to
- charm quark hadronization, thermalization, domains in sQGP etc.

Heavy quark correlations

- More sensitivity to HQ-medium interaction, thus better determination of ΔE mechanisms and D_{HQ}
- LHC vs. RHIC – different initial pair correlation/medium dynamics



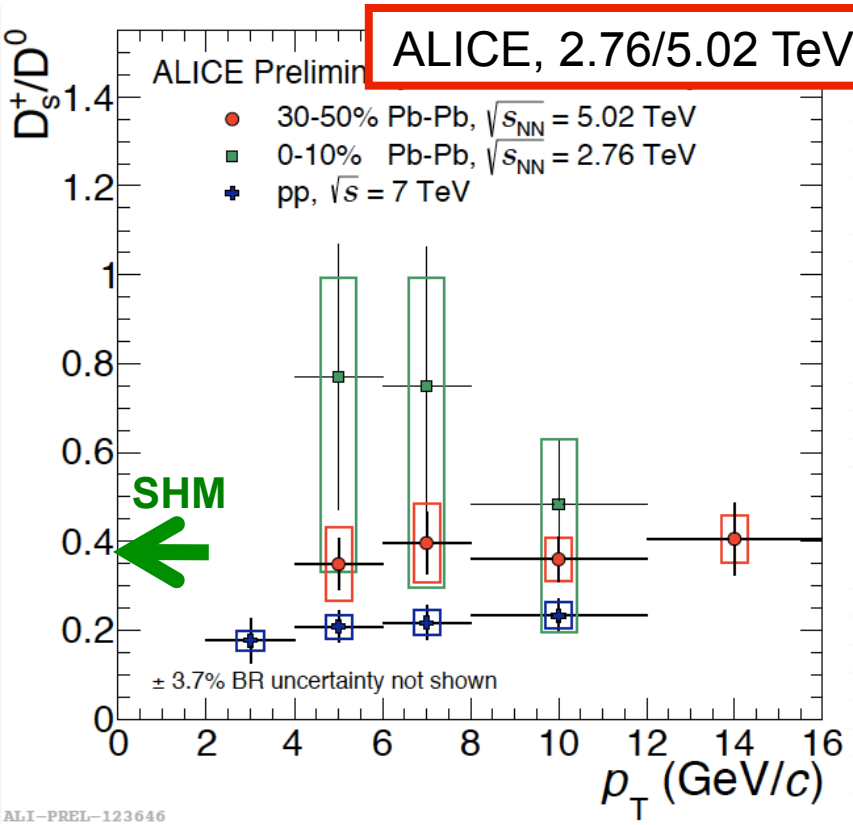
Lee et al, PRL 100 (2008) 222301
Ghosh et al, PRD 90 (2014) 054018
STAR, QM17

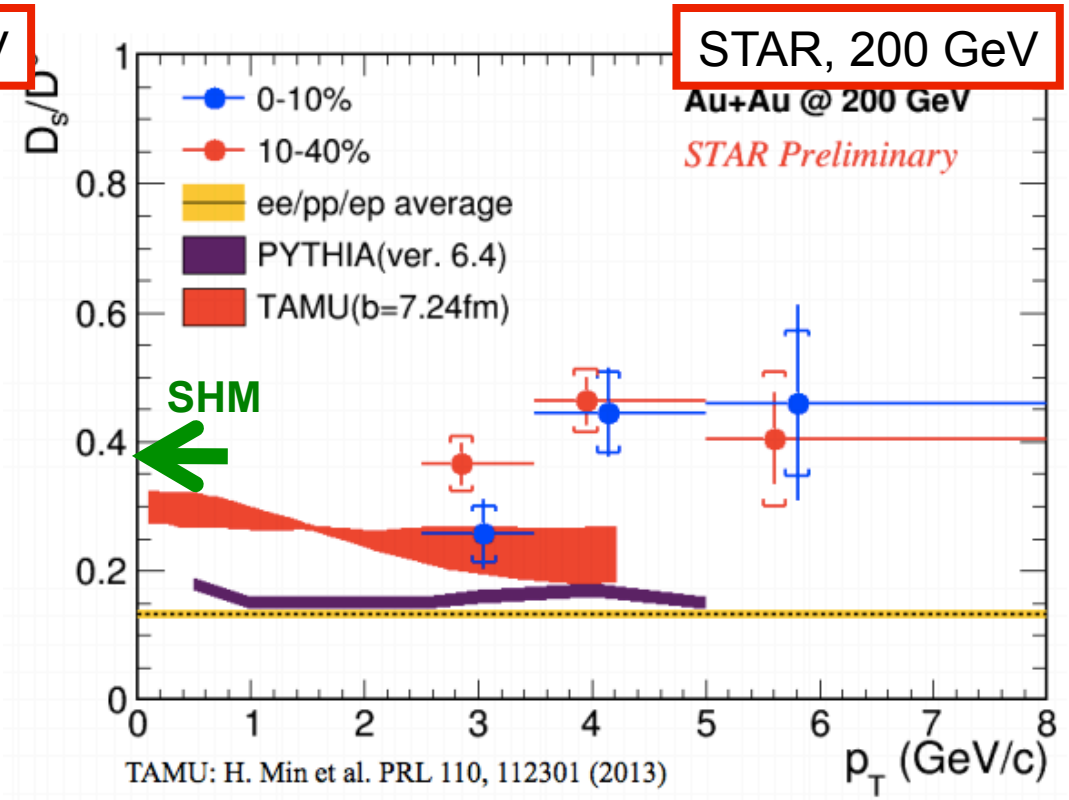


Zhu et al, PRL 100 (2008) 152301

Backups

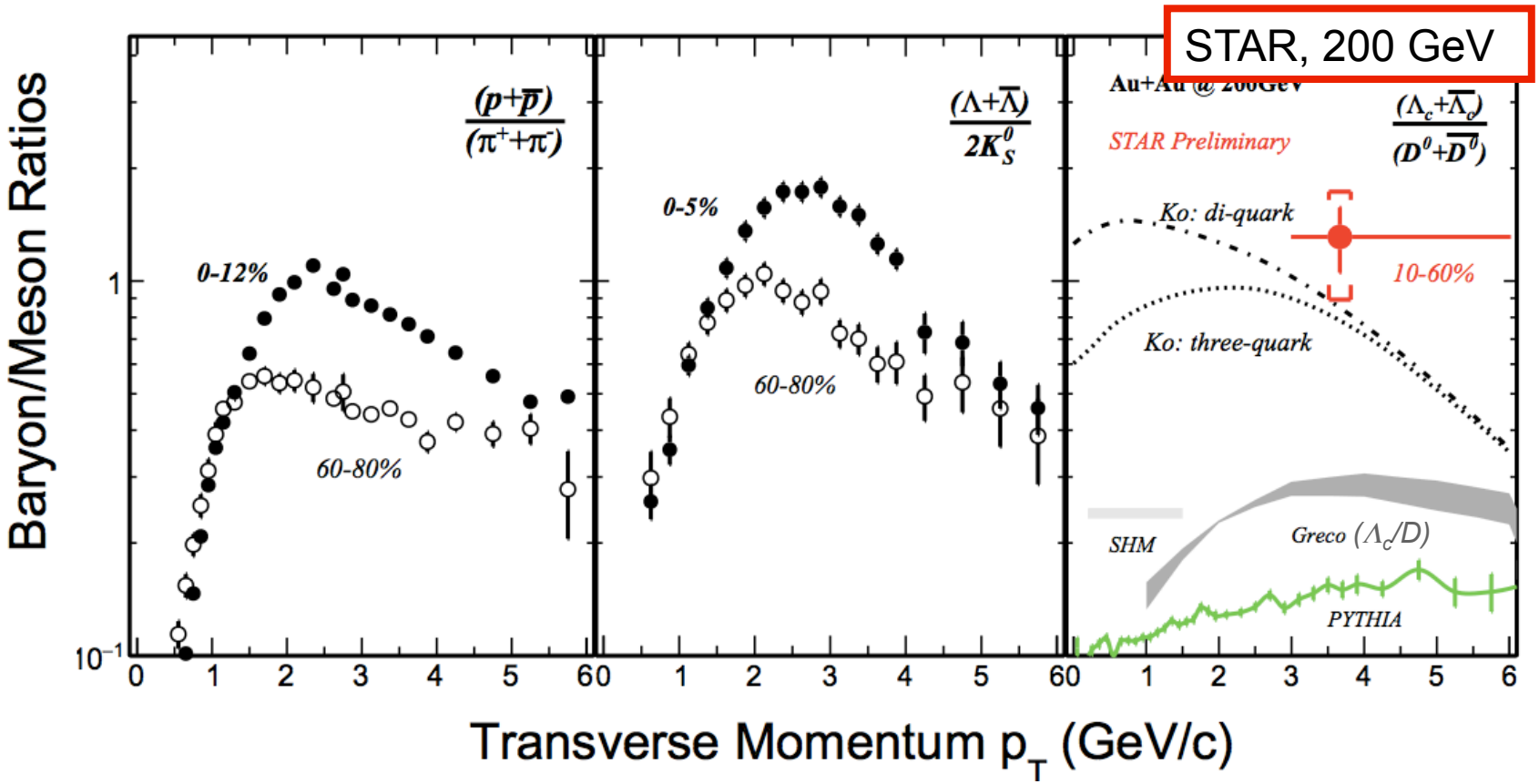
D_s Enhancement in Heavy Ion Collisions





- Significant D_s/D^0 enhancement in mid-central Au+Au and Pb+Pb collisions w.r.t fragmentation baseline or p+p measurement
  - Coalescence hadronization
  - SHM predicts D_s/D^0 ratio ~ 0.35-0.40 (central) *A. Andronic et al., PLB 571 (2003) 36*
  - relation to charm quark thermalization in QGP?

Λ_c Enhancement in Heavy Ion Collisions

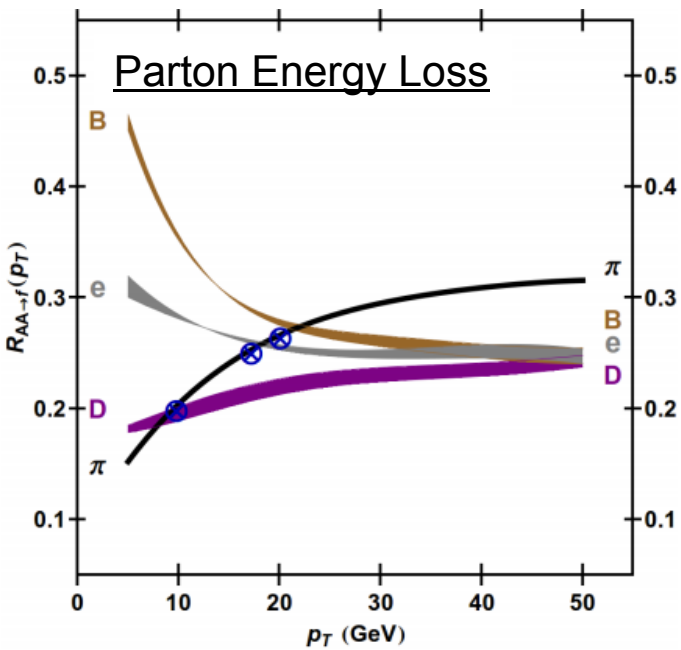


Ko model : Y. Oh, et.al. PRC 79 (2009) 044905; Greco model : S.Ghosh, et. al. PRD 90 (2014) 054018

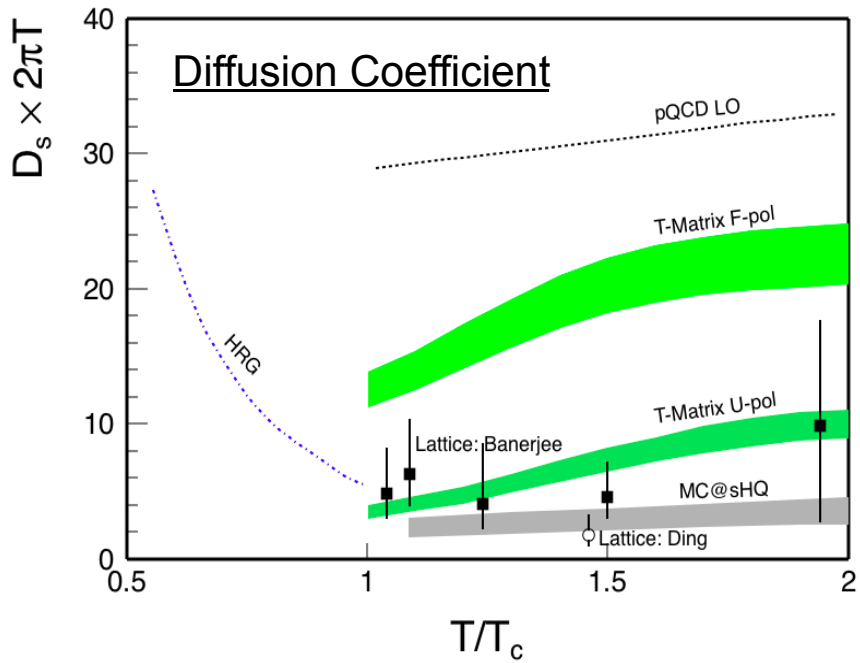
- Significant enhancement in Λ_c/D compared to PYTHIA/fragmentation baseline
- The Λ_c/D^0 ratio is compatible with light flavor baryon-to-meson ratios
- Consistent with coalescence + thermalized charm quarks

Summary

- Heavy-flavor phase-I program at RHIC (2014-2016)
  - Precision charmed hadron measurements from STAR-HFT/PHENIX-(F)VTX
- Heavy-flavor phase-II program at RHIC (2021+)
  - Open bottom / correlation measurements
  - Complementary to the HF program at LHC
- Fast MAPS silicon detector is necessary and will deliver the physics

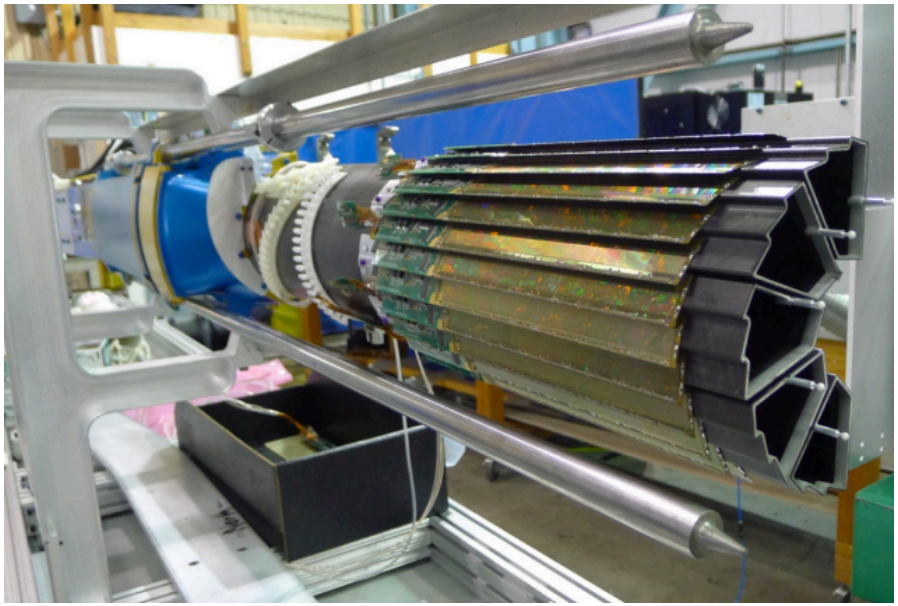


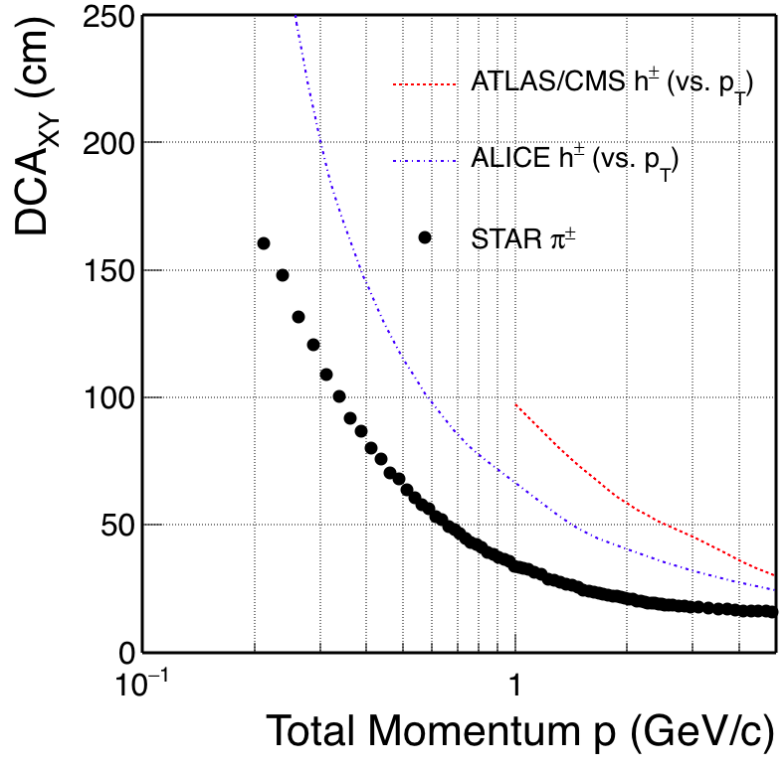
Buzzatti et al., PRL 108 (2012) 022301



arXiv: 1502.02730, 1506.03981

STAR Heavy Flavor Tracker





STAR HFT/PXL – first application of MAPS pixel detector at a collider

- Aim for precision measurements of charmed hadron production in HIC
- PXL detector designed, developed and constructed (including mechanics) at LBNL
- First layer thickness: 0.4%X_0 } critical for ultimate pointing resolution in wide p
- Pitch size 20.7x20.7μm
- Integration time: 186 μs (see next page)

Hit Density on STAR PXL at RHIC Environment

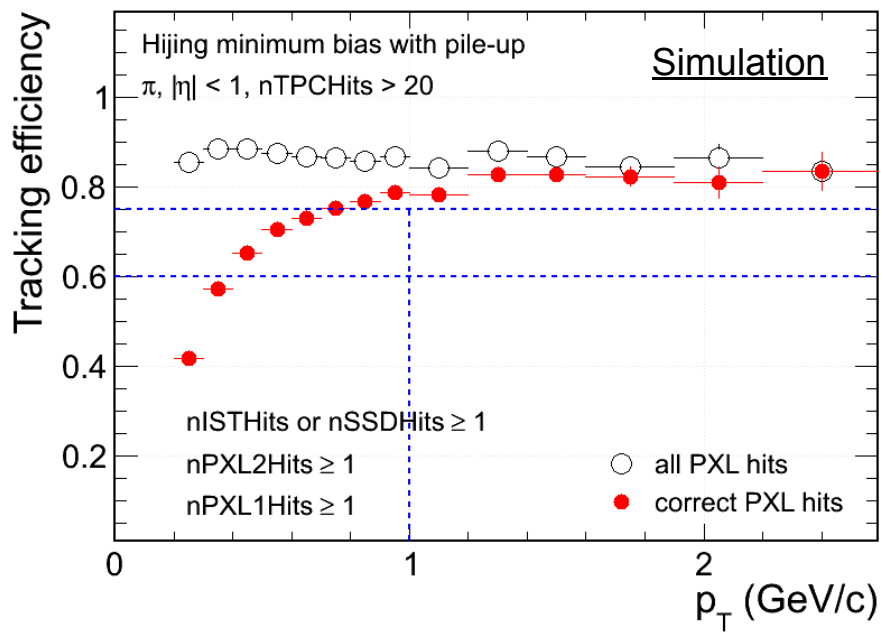
Simulation@50kHz

	PXL inner	PXL outer
Radius (cm)	2.8	8
MB pileup hits (cm^{-2})	13	~3
UPC electrons (cm^{-2})	33	~3
Total bkgd hits (cm^{-2})	46	~6
MB signal Au+Au (cm^{-2})	~8	~1
Au+Au MB real data (cm^{-2})	~50	~5

Signal hits fraction in MB (Central) events:
~15% (~30%) at PXL inner

Increasing fake matches in low p_T

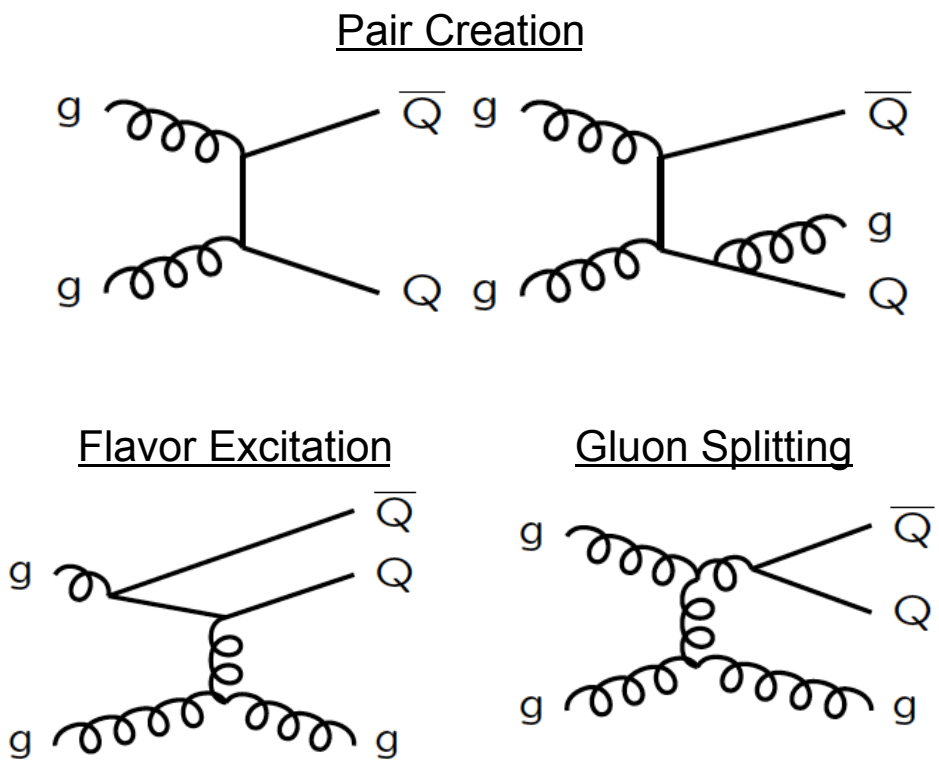
Technology chosen considering both physics and technology readiness

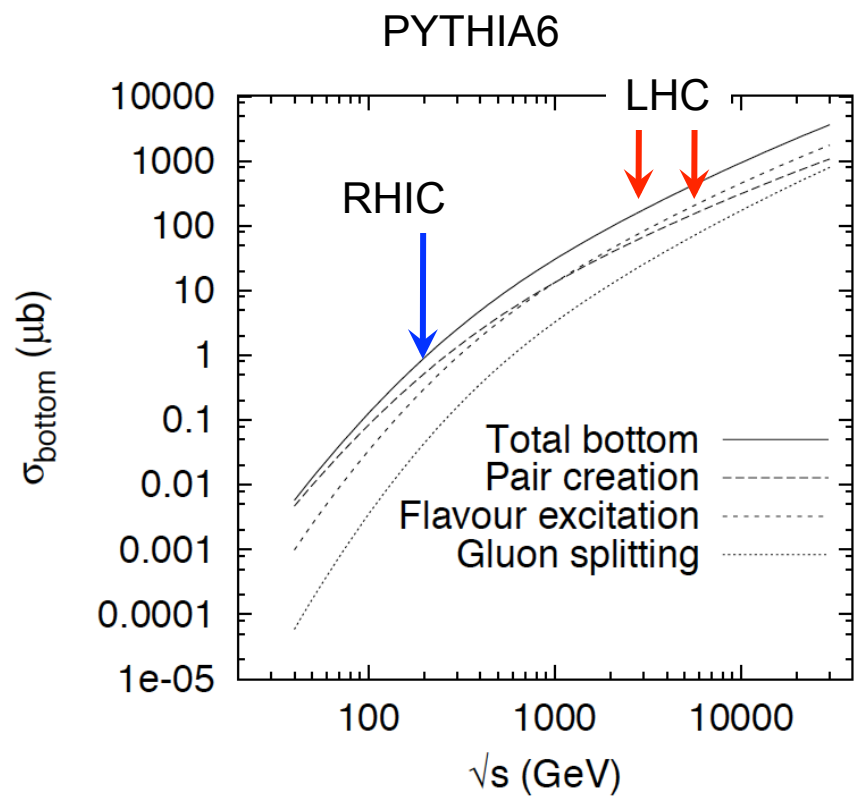


Uniqueness at RHIC

Uniqueness at RHIC

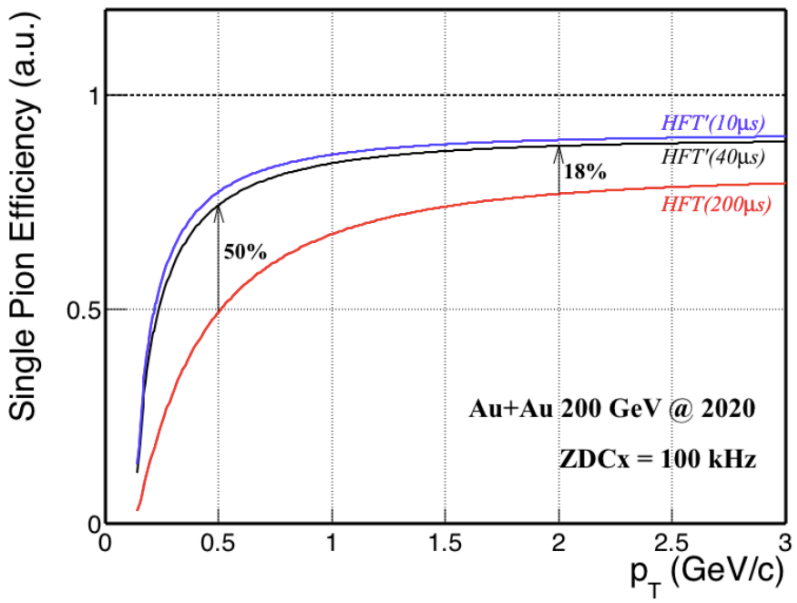
- dominated by pair creation, clean interpretation for experimental results

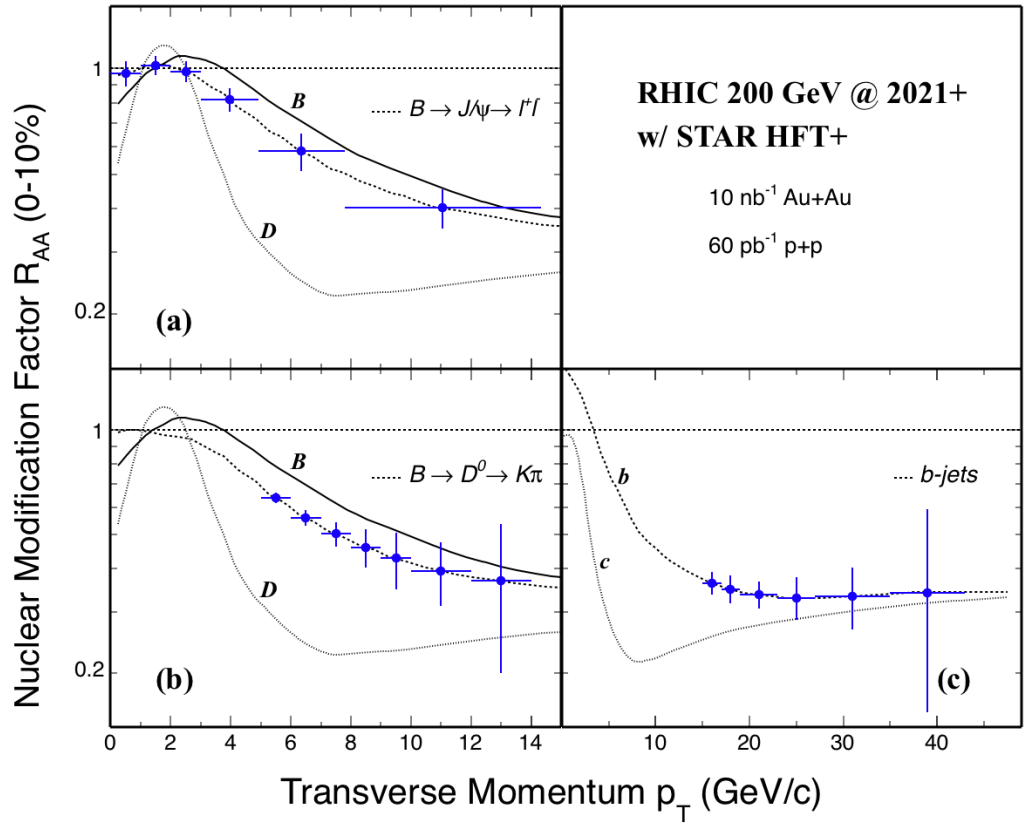




T. Sjostrand, EPJC17 (2000) 137

Fast MAPS Detectors at RHIC – STAR HFT+

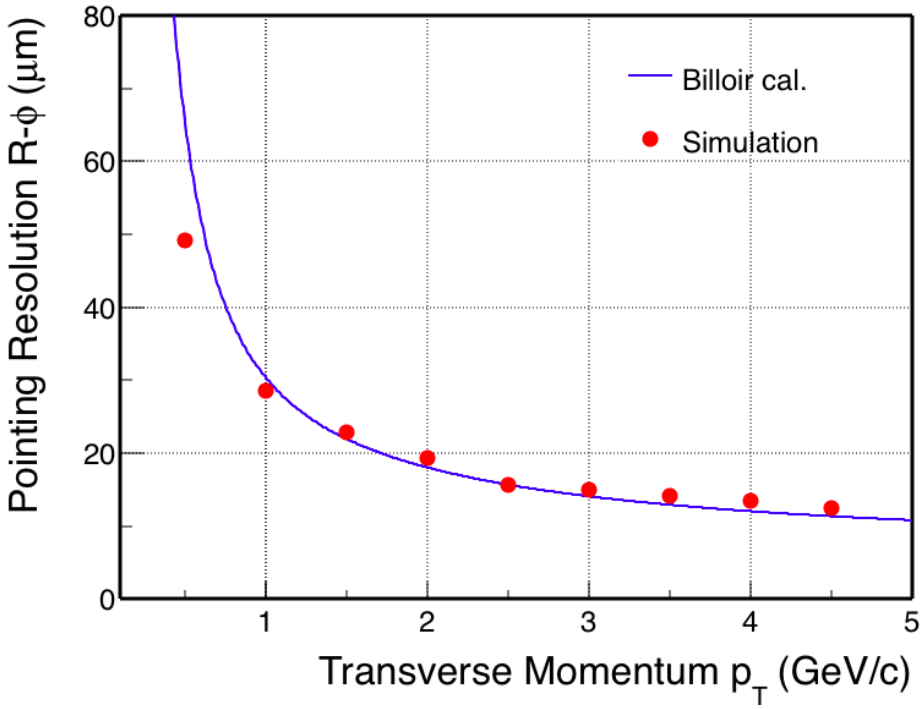


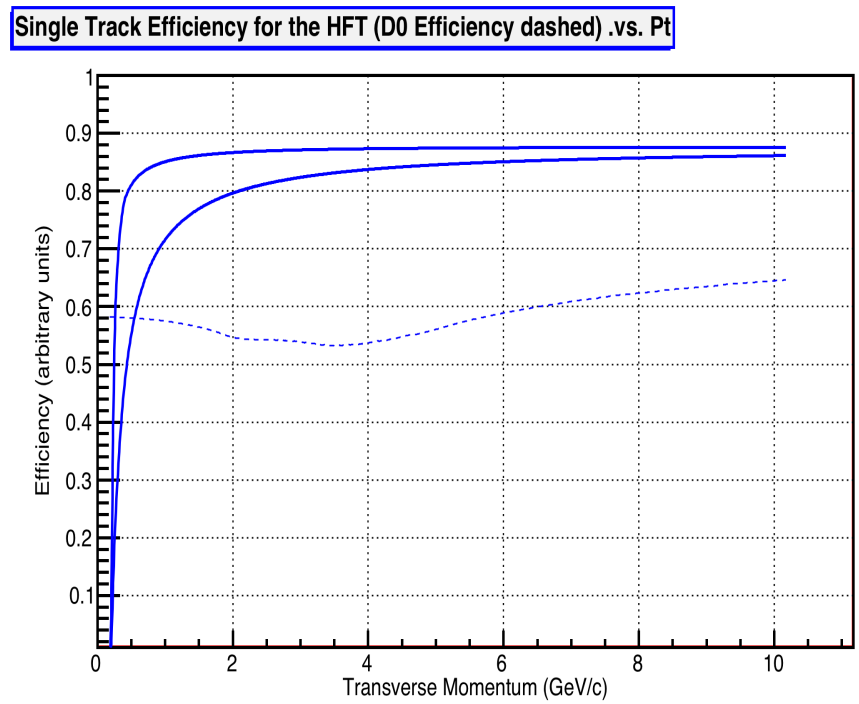


STAR HFT+ upgrade / sPHENIX pixel detector:
- Faster (<20μs) MAPS sensors – benefiting from ALICE ITS upgrade
- Aim for precision bottom measurements in 2021+ at RHIC

Complementary to LHC heavy flavor program

Pointing Resolution and Efficiency





80×10^{26} RHIC luminosity, central Au+Au 200 GeV collisions

MAPS: 20 us integration time

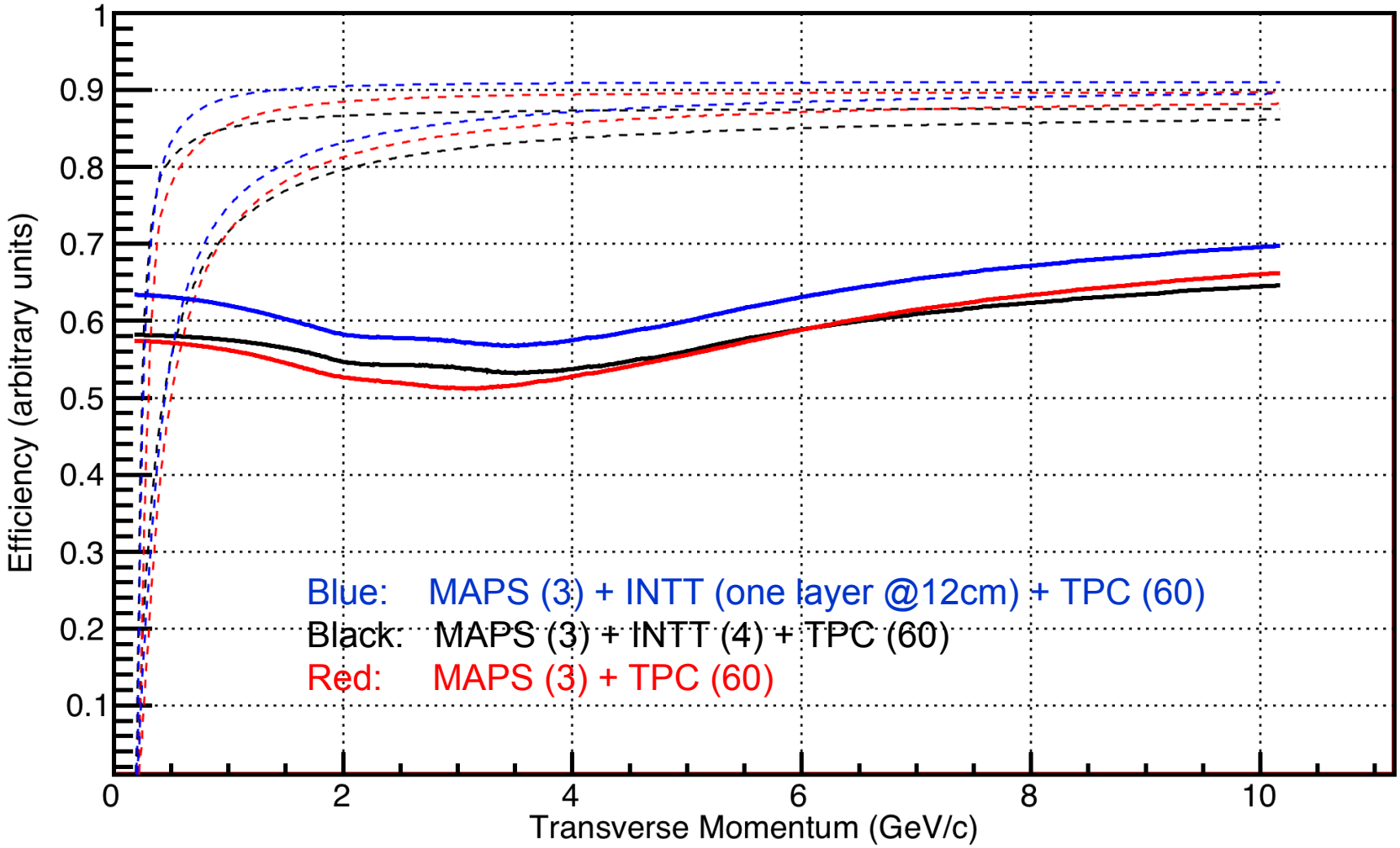
MB pileup events and UPC hits included (small contribution)

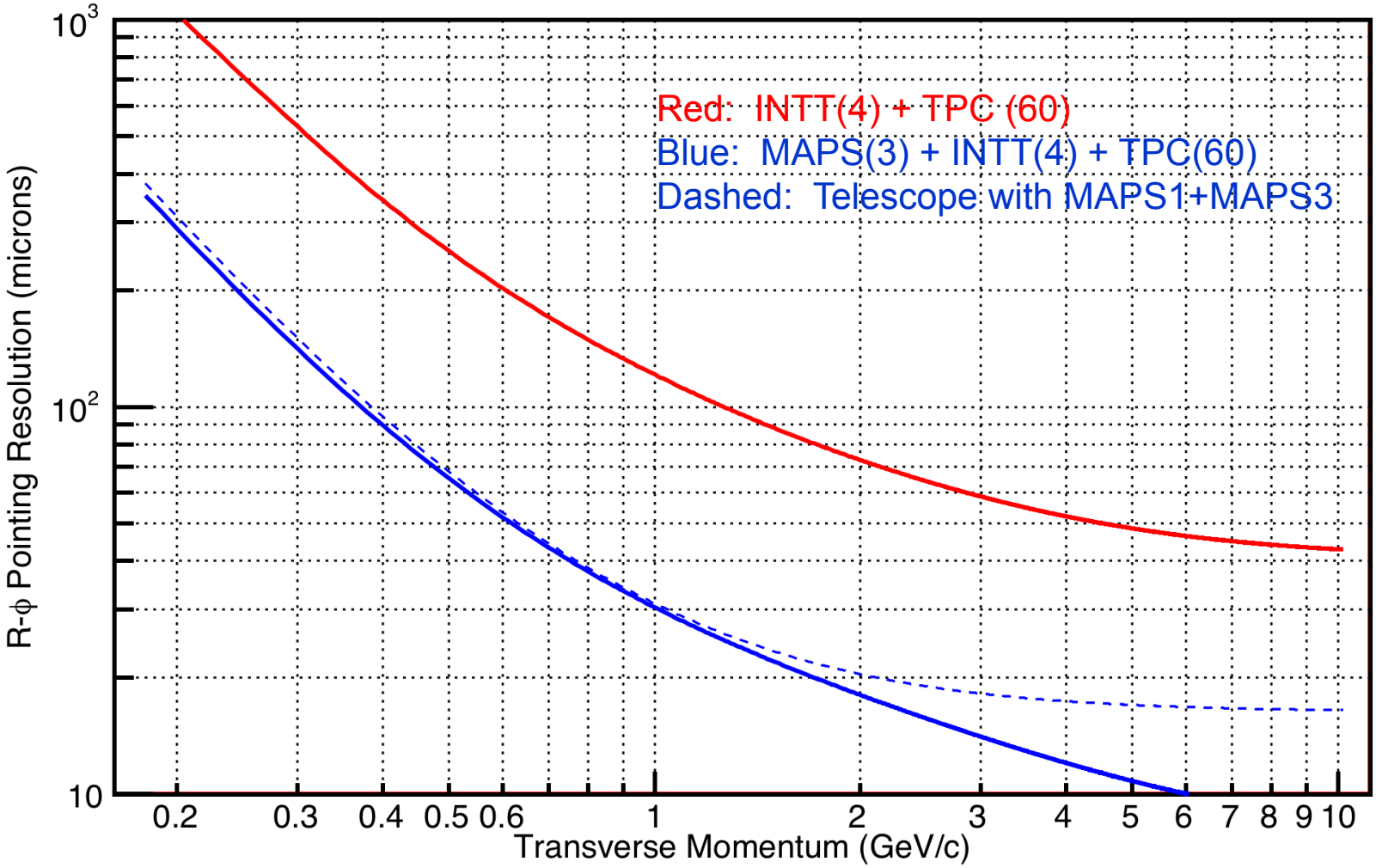
Efficiency or good hit probability: inefficiency due to mis-association

Efficiency/Good Hit Probability = $\dfrac{1}{1 + 2\pi R_{r\phi} R_z \rho}$

$$R = \sqrt{R_{proj}^2 + R_{\det}^2}$$

Tracking Configuration Study



Tracking Configuration Study

R-ϕ Pointing Resolution .vs. Pt