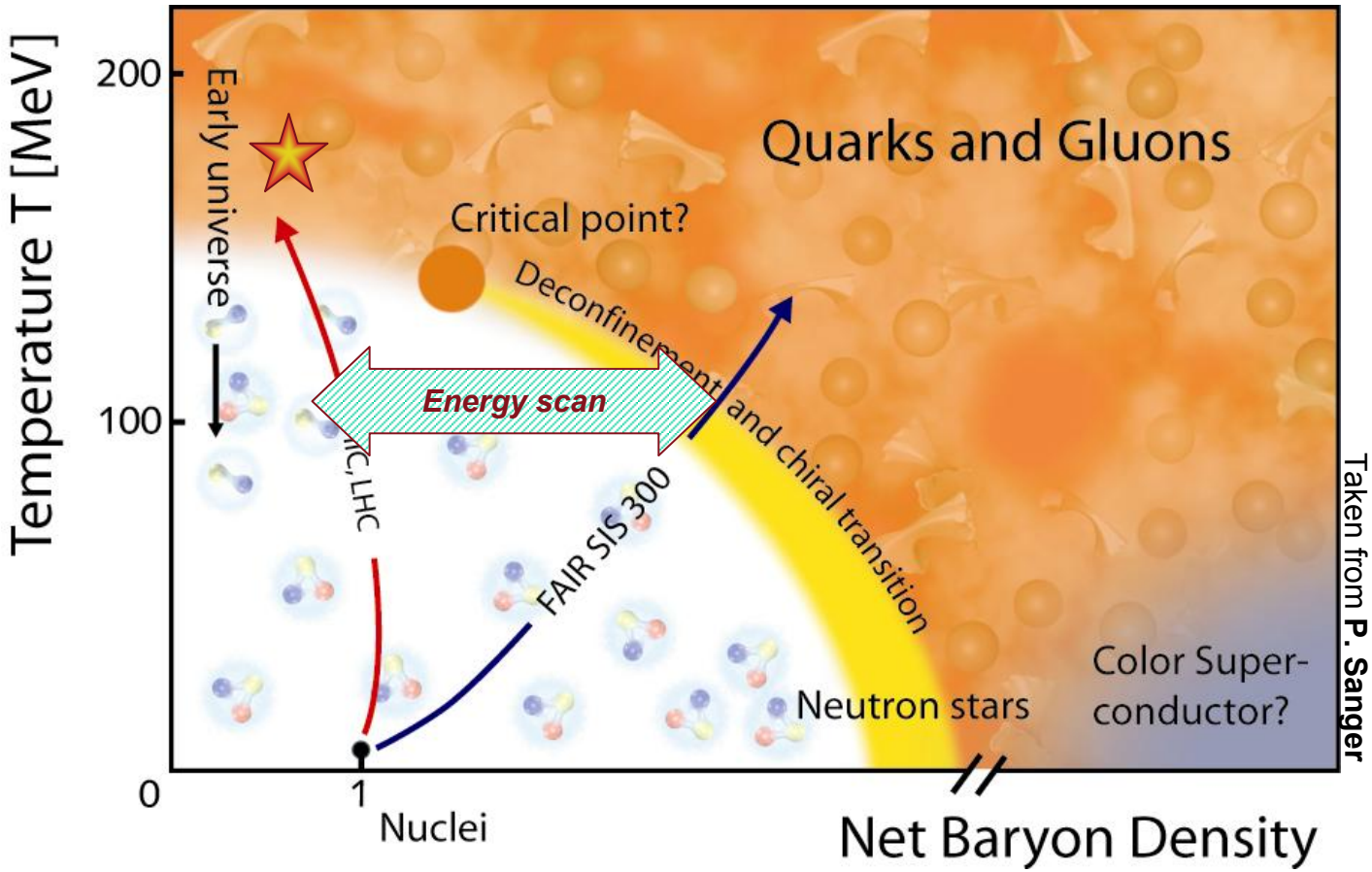
Charm with STAR

Kai Schweda, University of Heidelberg

A. Dainese, X. Dong, J. Faivre, Y. Lu, H.G. Ritter, L. Ruan,
A. Shabetai, P. Sorensen, N. Xu, H. Zhang, Y. Zhang.



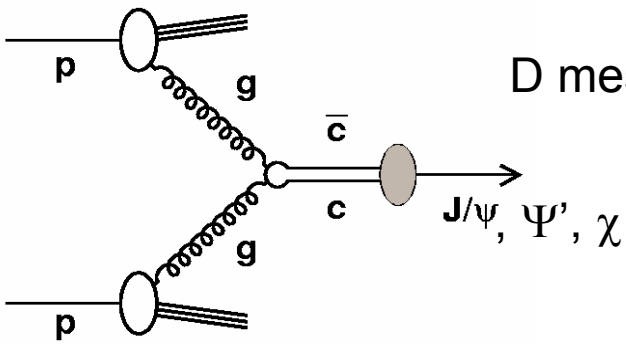
1) RHIC heavy-flavor program / LHC:
   - Study ***medium properties*** at RHIC
   - pQCD in hot and dense environment

2) RHIC energy scan / GSI program:
   - Search for the possible ***phase boundary***.
   - Chiral symmetry restoration

Outline

1) Introduction
2) Charm production in STAR
3) Heavy – quark collectivity
4) Summary

Heavy flavor in pQCD



D mesons

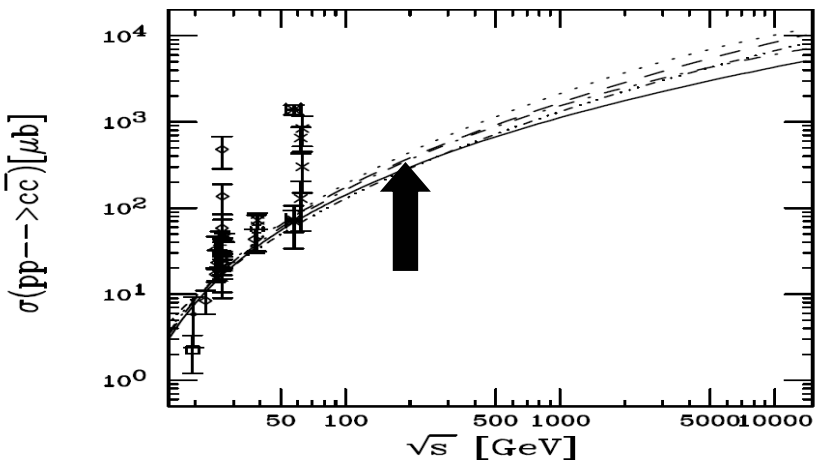
Large Q value needed (>≈3GeV)

➔ powerful test for pQCD calculation

R. Vogt *Int. J. Mod. Phys. E 12(2003)211*

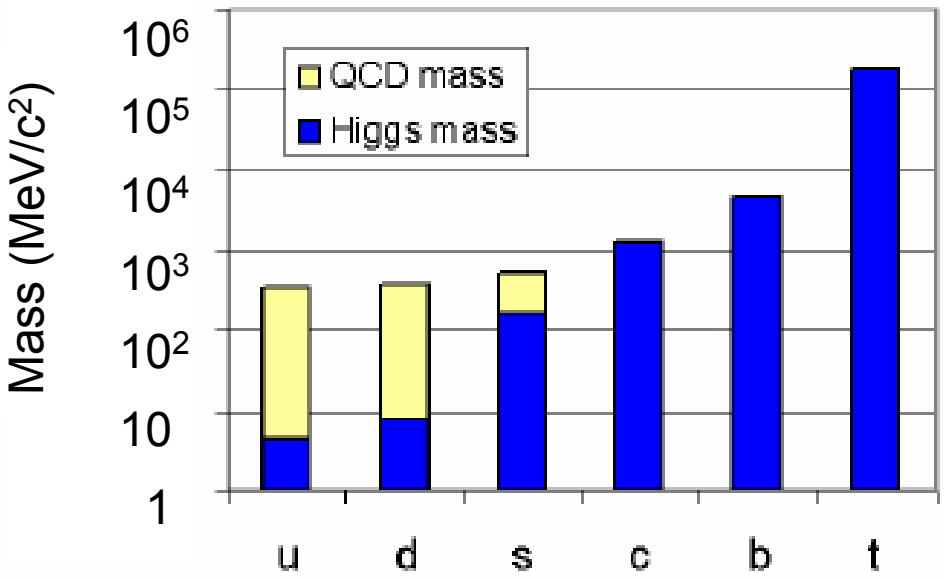
$$\sigma_{pp}(s, m_Q^2) = \sum \int_{4m_Q^2}^{1} \frac{d\tau}{\tau} \delta(x_i x_j - \tau) f_{i/p}(x_i, \mu^2) f_{j/p}(x_j, \mu^2) \hat{\sigma}_{ij}(\tau, m_Q^2, \mu^2)$$

PDF pQCD



			40 GeV	200 GeV	5.5 TeV
		$c\bar{c}$			
PDF	m_c (GeV)	μ/m_c	σ (μb)	σ (μb)	σ (mb)
MRST HO	1.4	1	37.8	298	3.18
MRST HO	1.2	2	43.0	382	5.83
CTEQ 5M	1.4	1	40.3	366	4.52
CTEQ 5M	1.2	2	44.5	445	7.39
GRV 98 HO	1.3	1	34.9	289	4.59

Heavy-Flavor Quarks



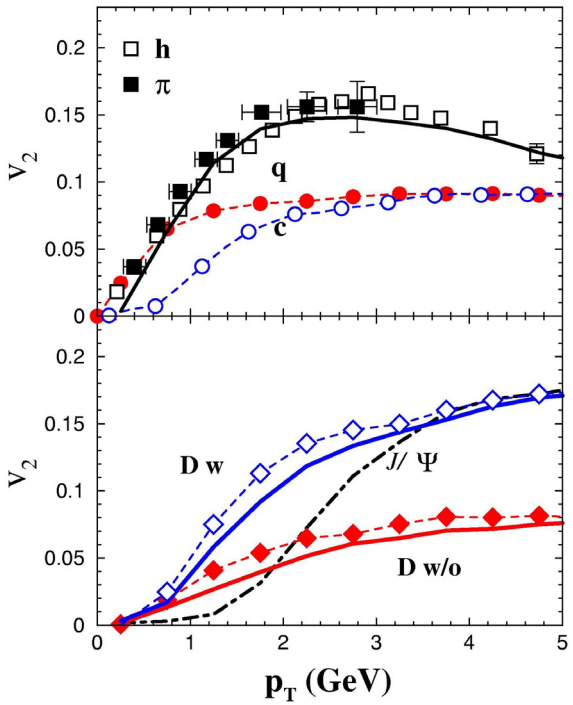
Plot: B. Mueller

- Symmetry is broken:
  → QCD dynamical mass
  → EW Higgs mass
- Even in a QGP, charm and beauty quark-mass heavy !
- ***If heavy quarks flow:***
  → frequent interactions among all quarks
  → light quarks (u,d,s) likely to be thermalized

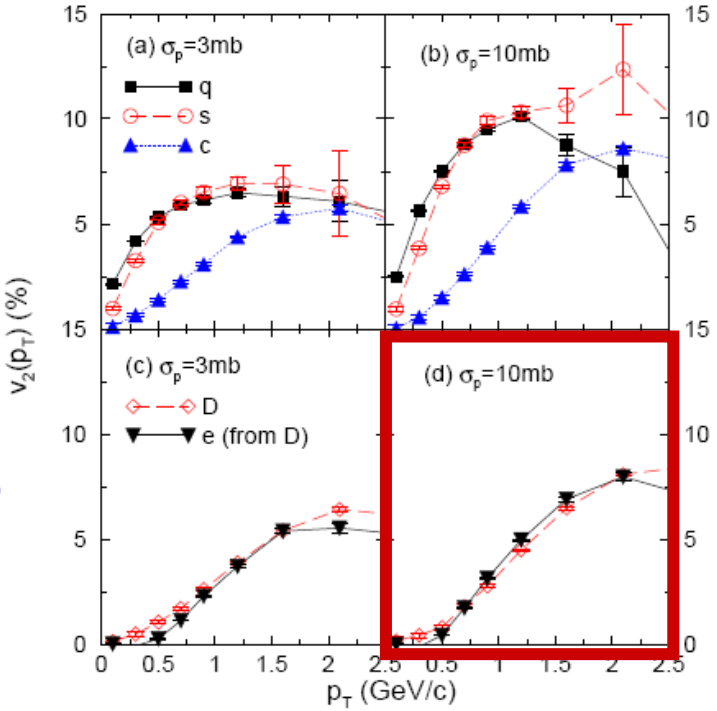
Charm-quark Elliptic Flow

✓ Coalescence approach
V. Greco et al., PLB 595(2004)202.

✓ AMPT transport model
B. Zhang et al.,PRC 72(2005) 024906.



$D = (c\bar{u})$

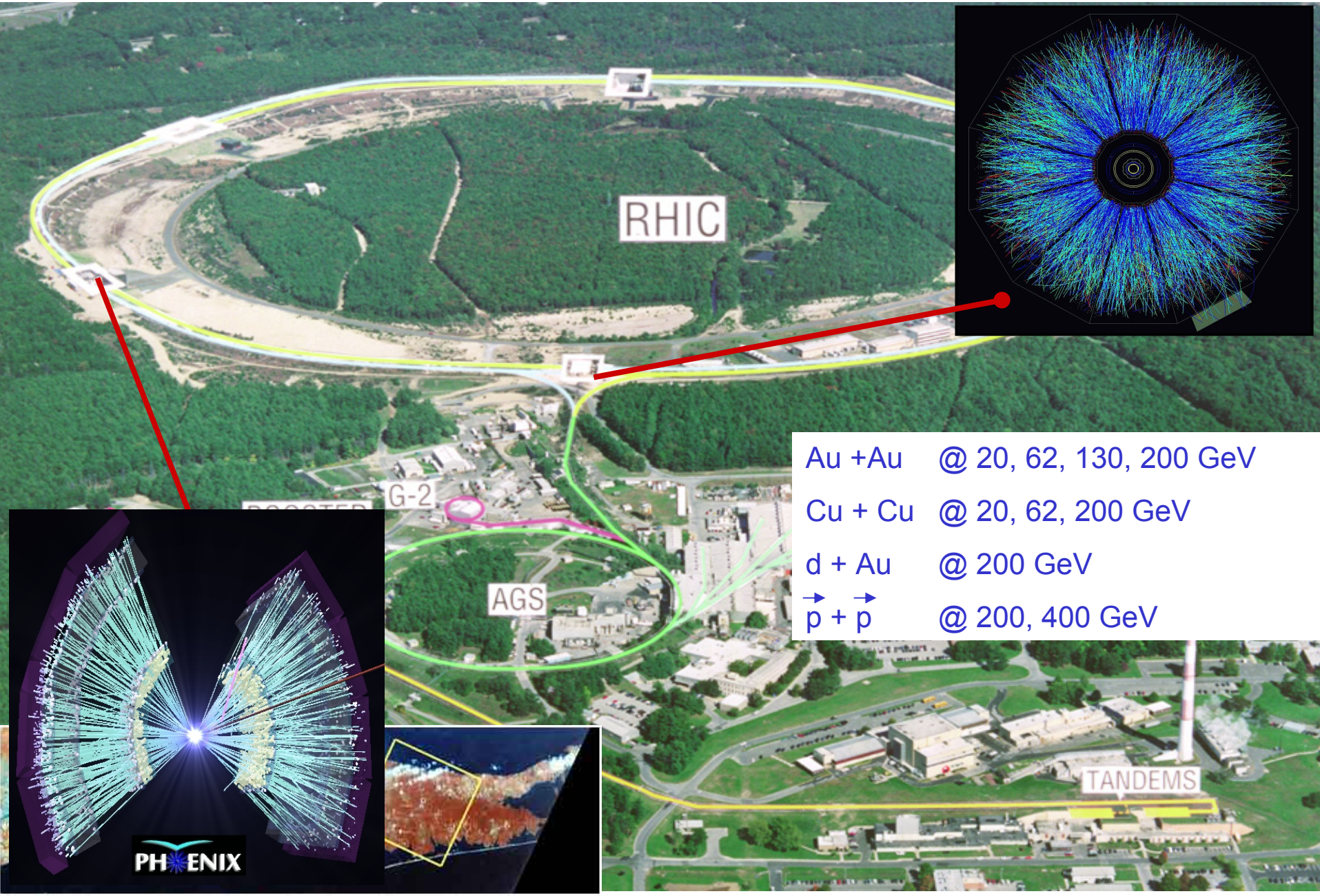


- *Heavy-quark collective flow observable in D-meson v_2*
- *Large partonic cross sections needed → Frequent interactions*
- *Challenge to theory ?*

The key point is to determine

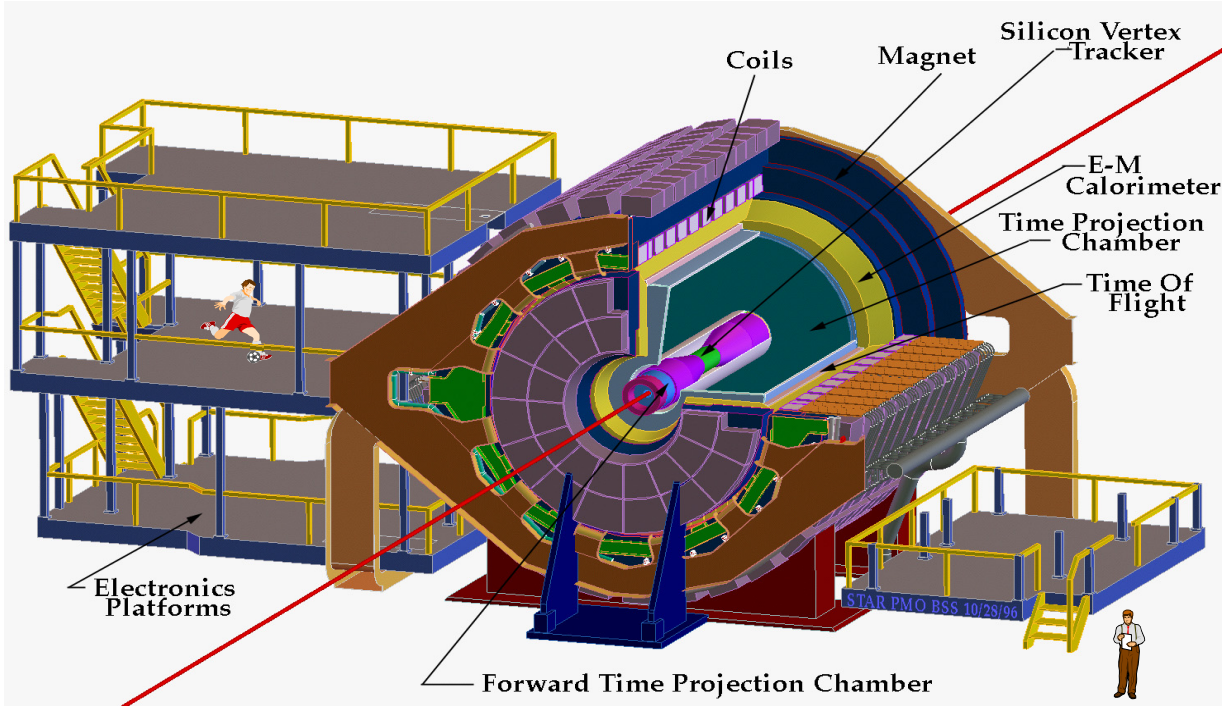
Heavy-Flavor Collectivity

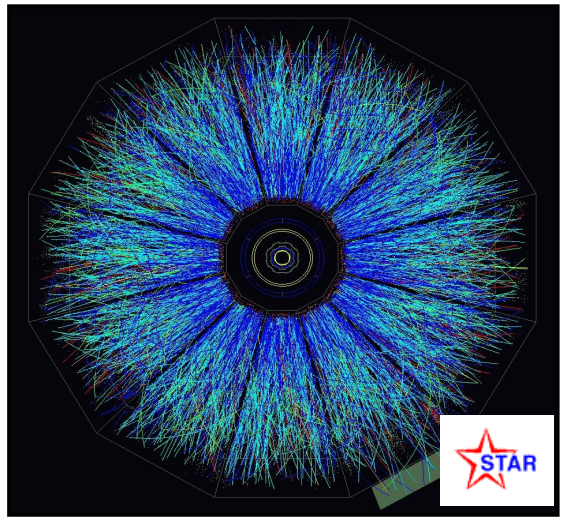
D^0, $D^{\pm}$, D^+_s, Λ^+_c, J/ψ, …



Au +Au	@ 20, 62, 130, 200 GeV
Cu + Cu	@ 20, 62, 200 GeV
d + Au	@ 200 GeV
$\vec{p} + \vec{p}$	@ 200, 400 GeV

The STAR Detector





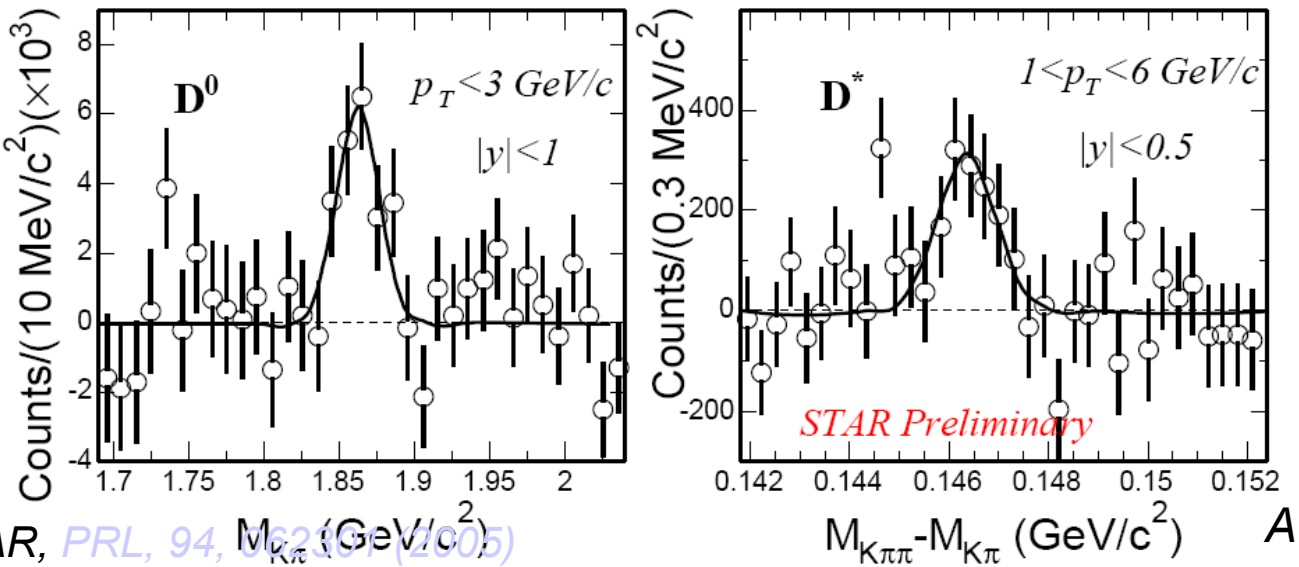
- D recon. from hadronic decay channels:
  TPC (+TOF)
- electrons:
  TPC, TPC+TOF, TPC+EMC
- Advantage: Direct D-meson reconstruction
  large acceptance, $|\phi| < 2p$, $|\eta| < 1.5$

Direct Open Charm Reco.

STAR:

Mixed-event technique benefiting from large acceptance of the TPC

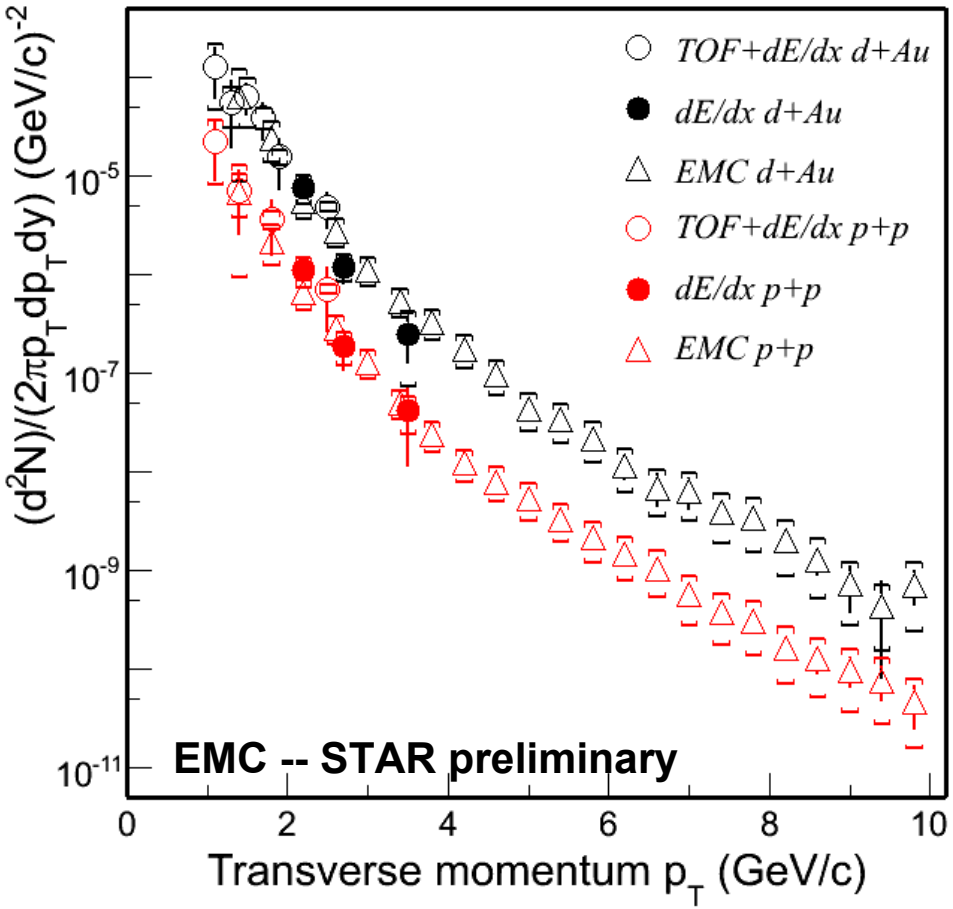
$$D^0 \to K^-\pi^+(3.8\%) \qquad D^{*\pm} \to D^0\pi_s(68\%), D^0 \to K\pi(3.8\%)$$



STAR, PRL, 94, 062301 (2005) *A. Tai,* QM04

d+Au 200 GeV

Charm(Bottom) → e – Spectrum



- Three independent analyses using different sub-detectors
- σ_{cc} = 1.4 ± 0.2 ± 0.4 mb

PHENIX, Au+Au:

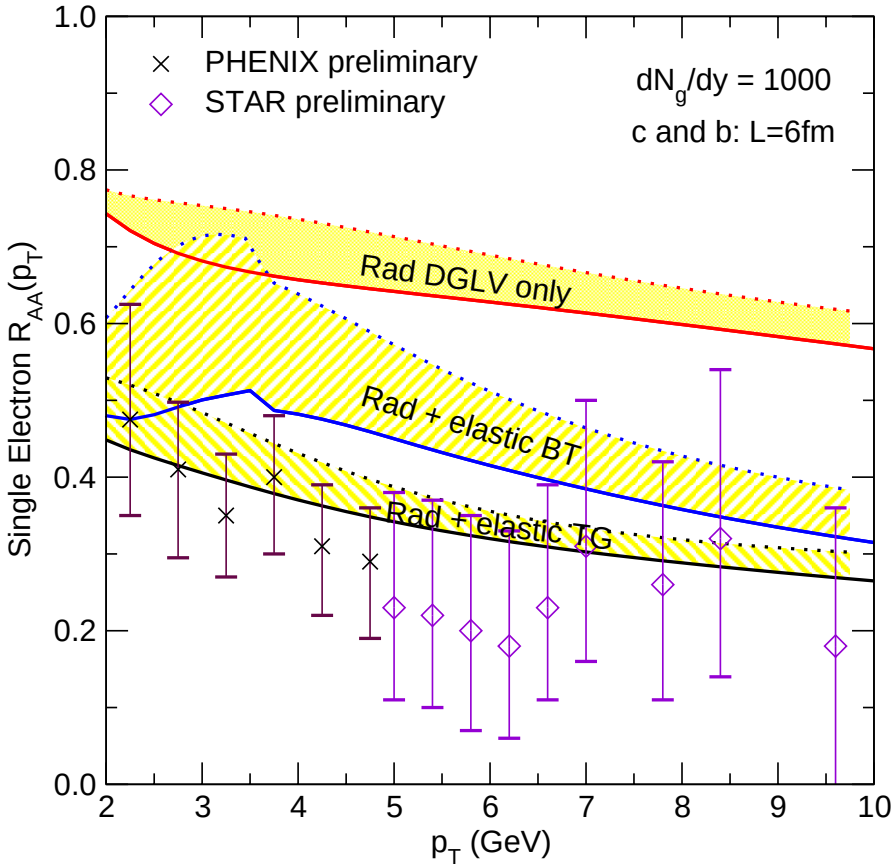
σ_{cc} = 0.62 ± 0.06 ± 0.16 mb

→ **Need direct open charm reconstruction !**

($D^0 \rightarrow K + \pi$)

STAR: PRL 94, 062301 (2005);
PHENIX: PRL 94, 082301 (2005).

Heavy-flavor Energy Loss



Heavy-flavor decay electrons:

Probe interaction with medium

← Induced gluon radiation only

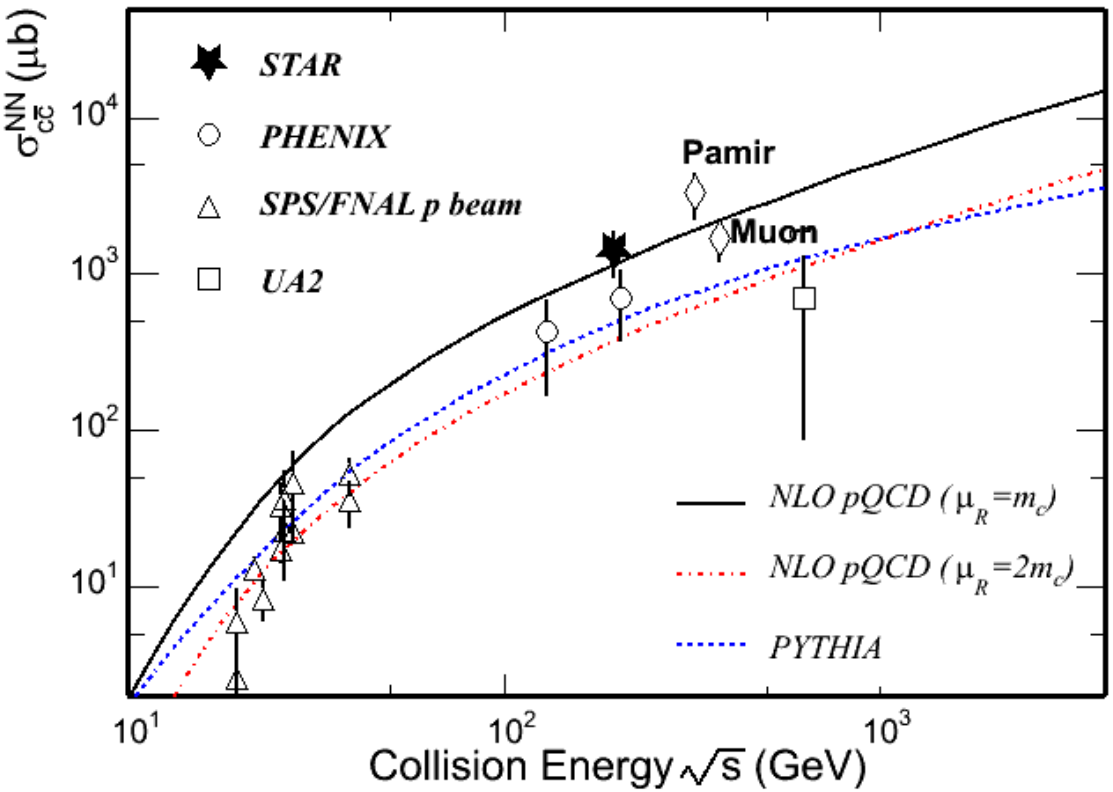
← Plus elastic collisions

→Collisional Energy loss important, also for light quarks* !

→Gluon radiation is NOT dominant mechanism for energy loss !

Calculations: M. Djordjevic et al., nucl-th/0507019;
*J. Alam et al., hep-ph/0604131.

Total Charm X–section



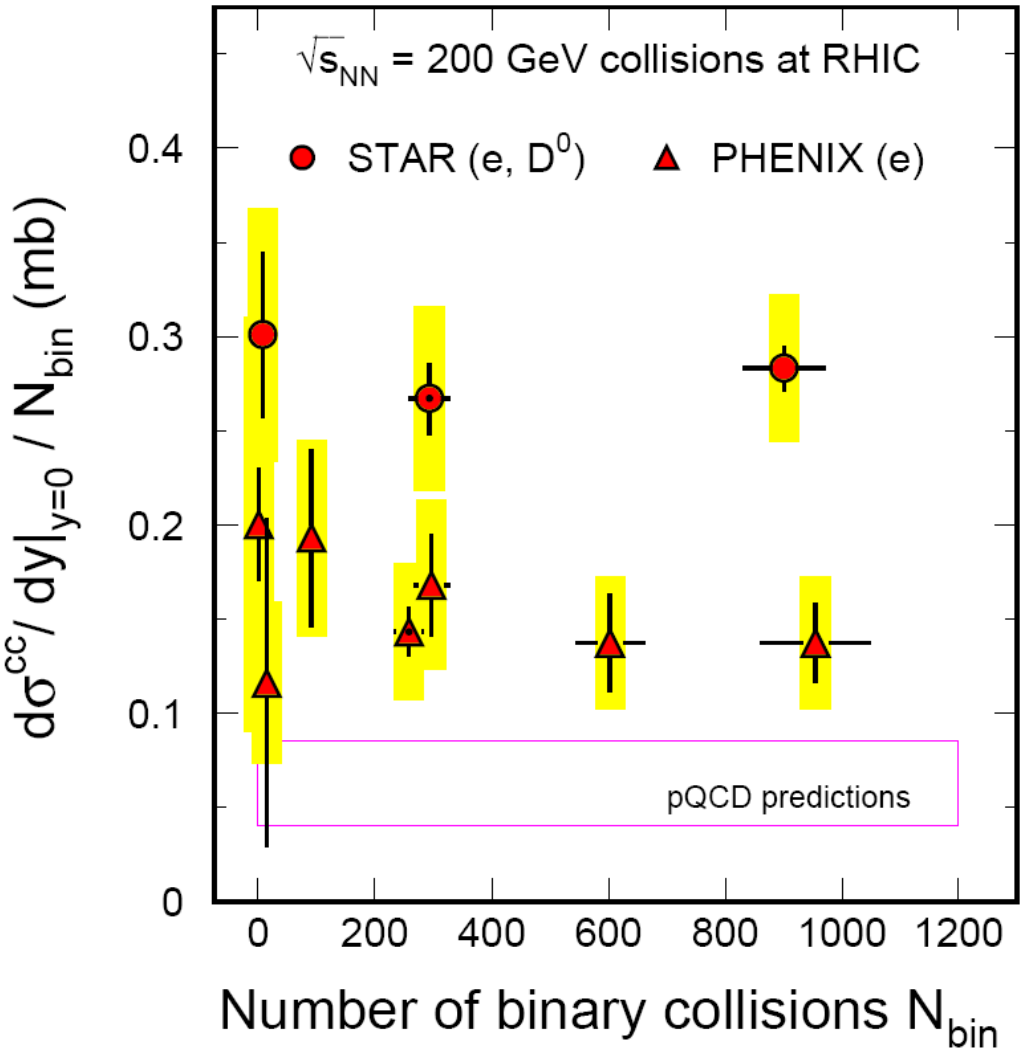
1) STAR > pQCD
   PHENIX >~ pQCD

2) Charm total cross section is a critical reference for J/ ψ suppression/enhancement determination.

3) Scales (μ_F and μ_R) may be energy dependent.

STAR, PRL, 94, 062301 (2005)
R. Vogt, private communication

Total Charm vs Centrality



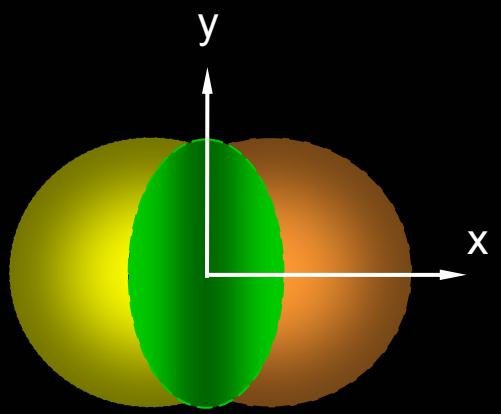
- Total cross section scales with binary collisions
- Disrepancy between experiments
- pQCD by factor 2–3 too low

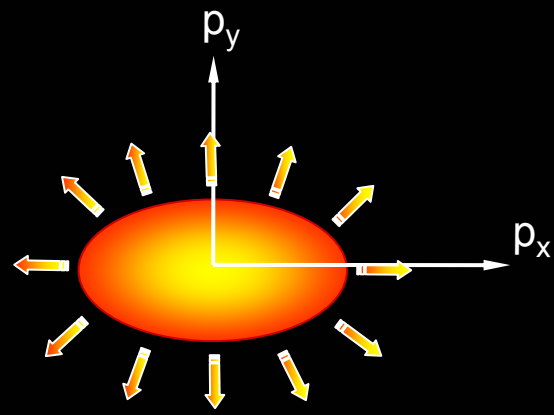
→ ***Charm is a good early stage probe !***

→ ***Need precise calibration !***

Anisotropy Parameter v_2

coordinate-space-anisotropy ⇔ momentum-space-anisotropy

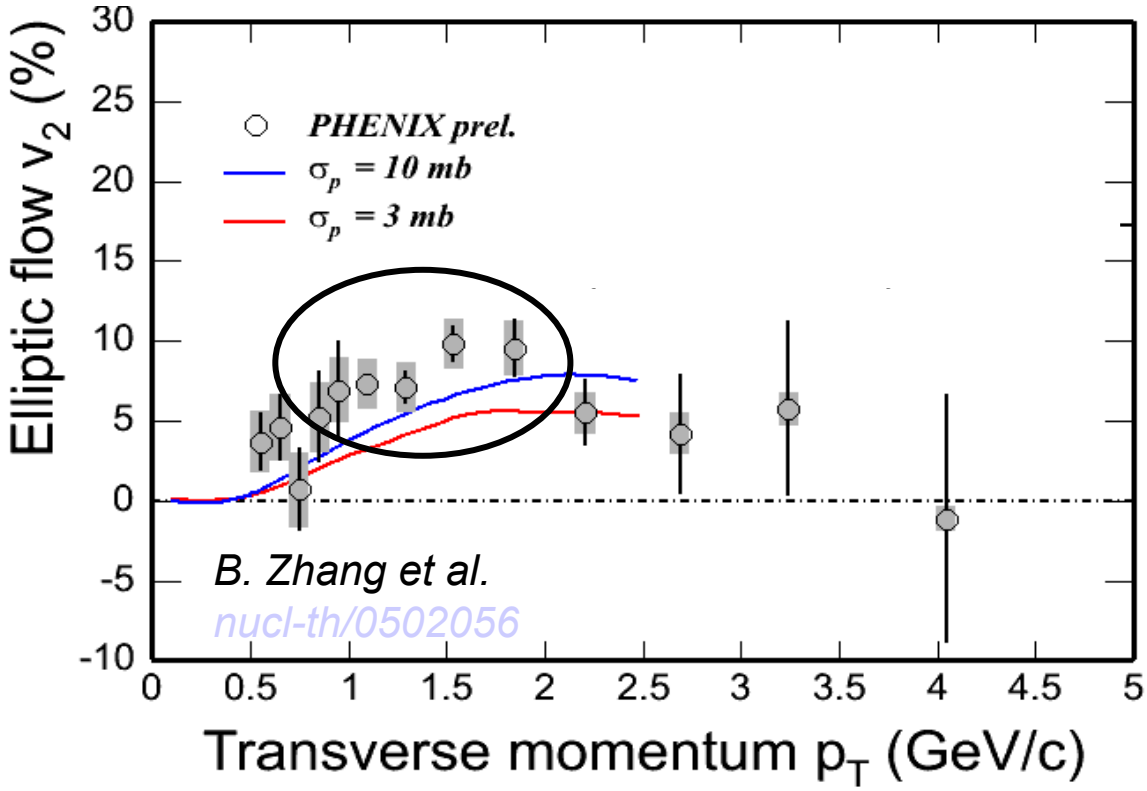




$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

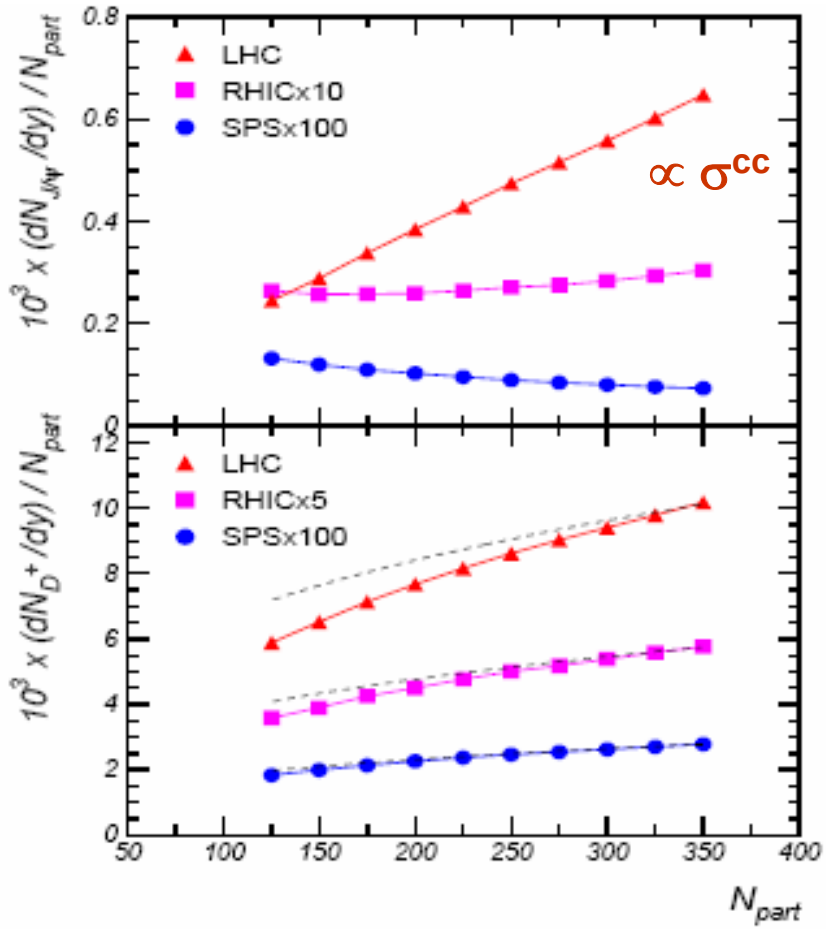
Non-photonic electron v_2



c (b) → e + X

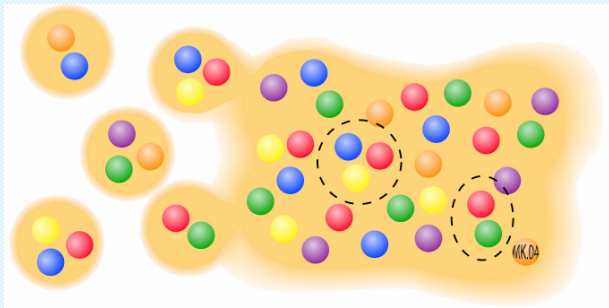
- ***Large syst. uncertainties due to large background***
- ***charm collective flow at p_t < 2GeV/c***
- ***v_2(e) favors non-zero v_2(c) at p_T(e)<2 GeV/c.***

J/ψ Enhancement at RHIC(LHC)



Calculations:P. Braun Munzinger, K. Redlich, and J. Stachel, nucl-th/0304013.

- Statistical hadronization



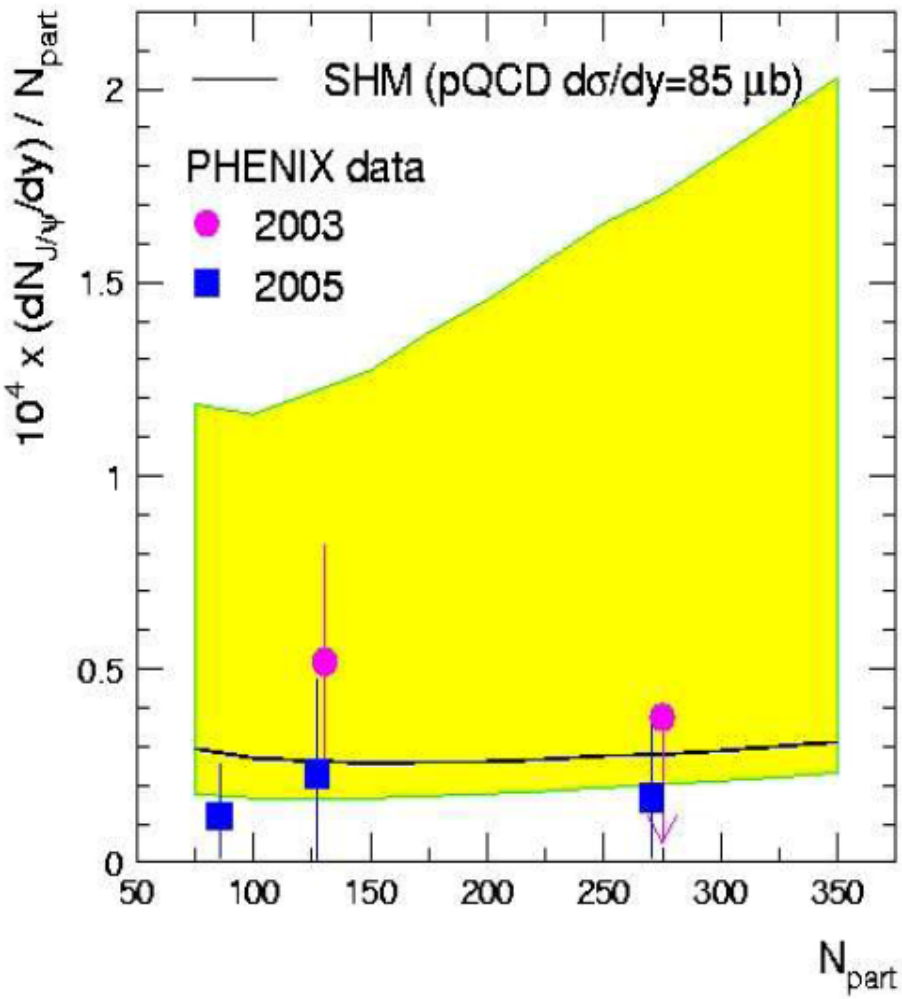
→ strong centrality dependence of J\ψ yield at LHC

- Need total charm yields !

→ ***Measure D^0, $D^{\pm}$, Λ_c***

→ ***Probe deconfinement and thermalization***

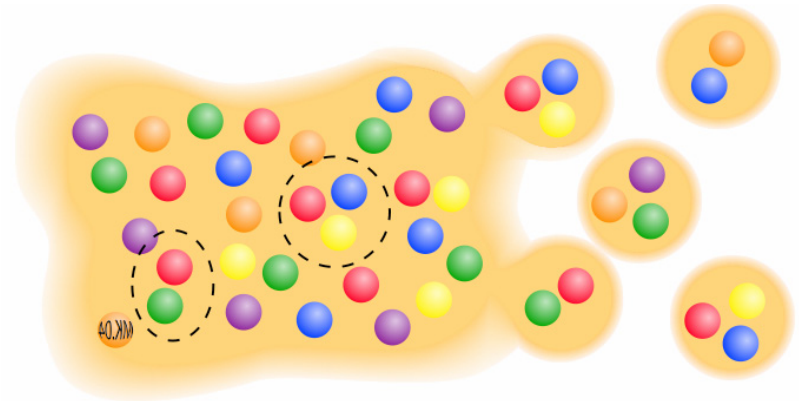
J/ψ at RHIC



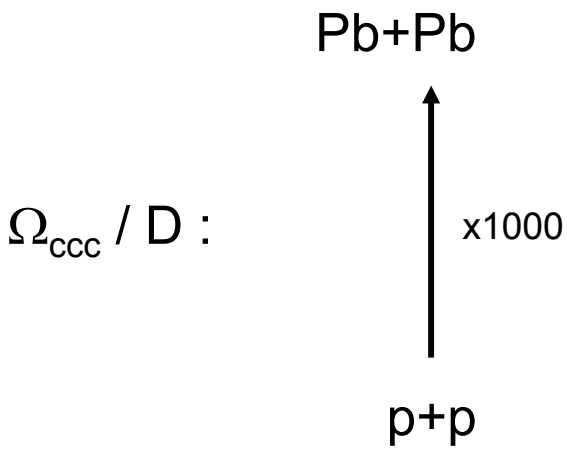
- Yellow band: allowed range by open charm from STAR and PHENIX
- Large uncertainty from open charm cross section !
- ***Statistical Charm-Hadronization might not dominate at RHIC***
- ***Check at LHC…***
- ***Need precise open charm reference !***

P. Braun-Munzinger et al.

Multiply Heavy-flavored Hadrons



Quarks and gluons → hadrons



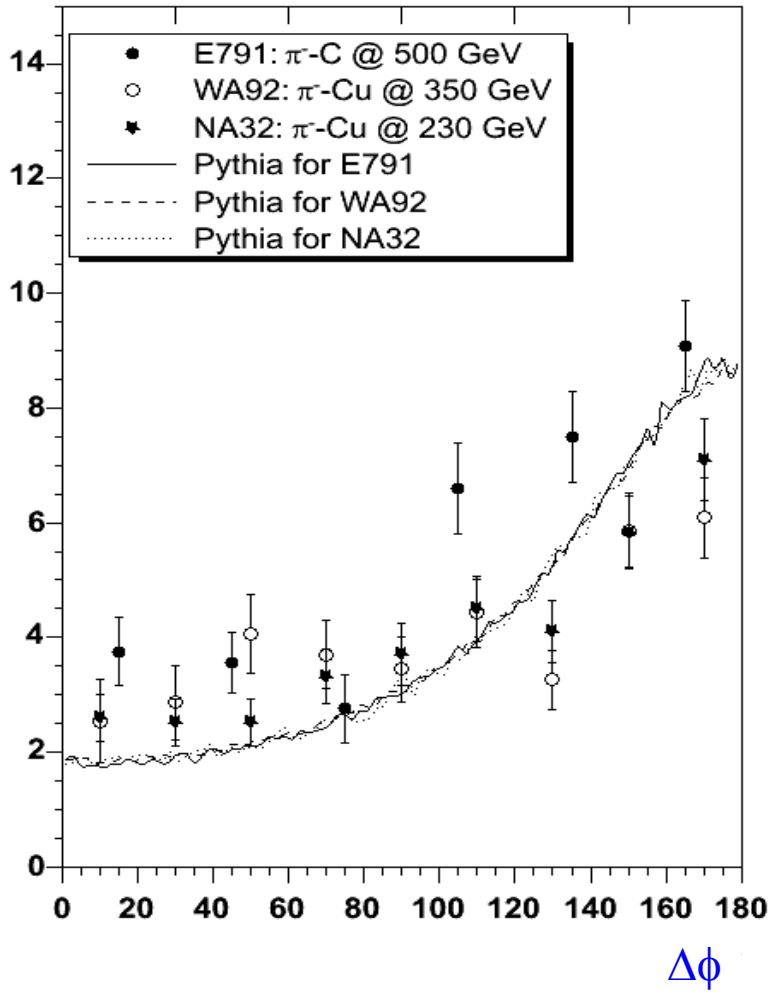
- ❑ Statistical hadronization
  - de-confined heavy-quarks
  - equilibrated heavy-quarks
  - → Enhancement up to x1000 !
- ❑ Measure Ξ_{cc}, Ω_{cc}, B_c, (Ω_{ccc})
- ❑ Need total charm yields

→ ***Probe deconfinement and thermalization at LHC***

→ ***QGP !***

F. Becattini, Phys. Rev. Lett. 95, 022301 (2005);
P. Braun Munzinger, K. Redlich, and J. Stachel, nucl-th/0304013.

D – Meson Pair Correlations

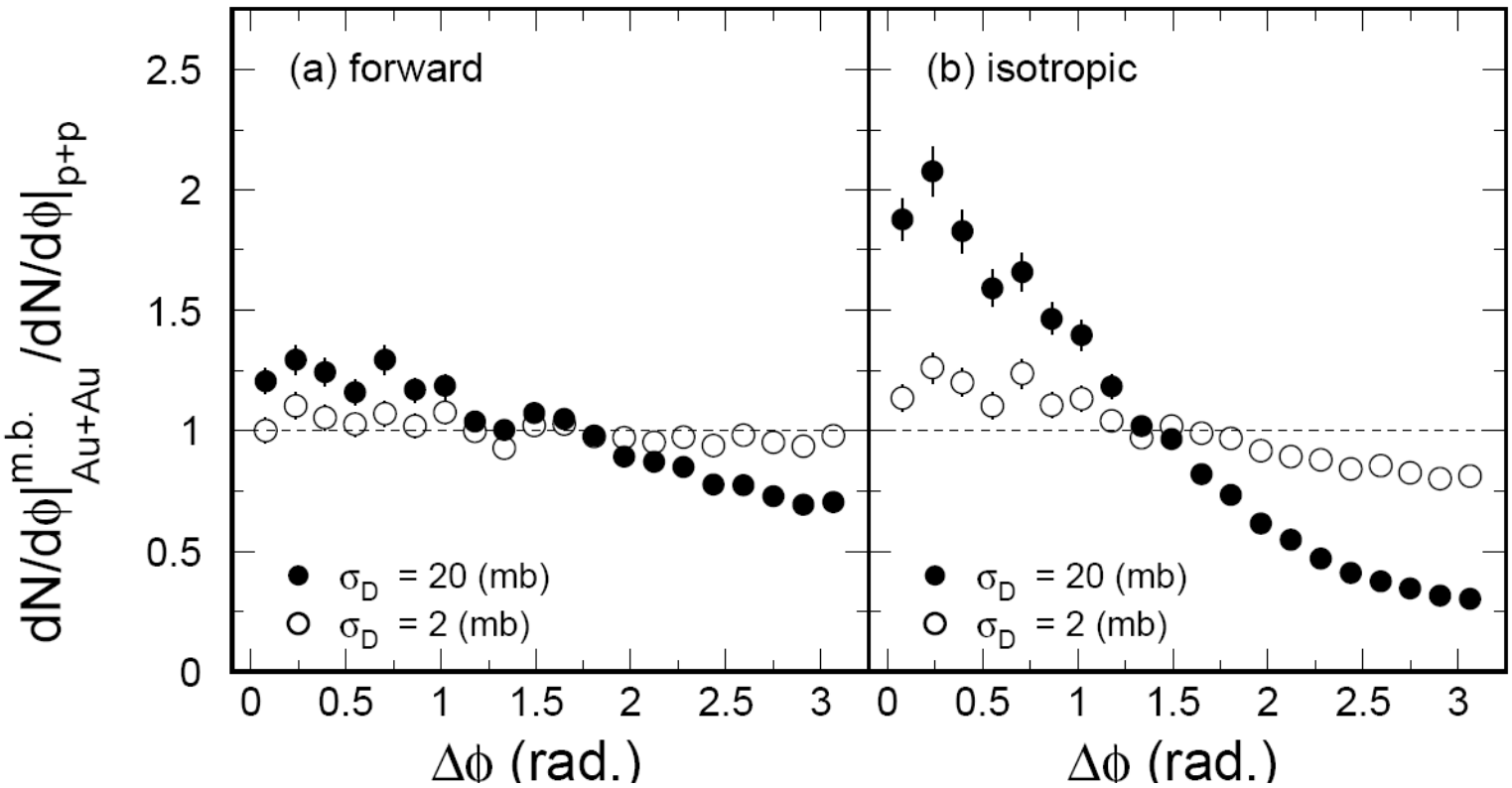


- ccbar pair production: DDbar pairs are correlated !
- Here: $\Delta\phi$ correlation
- ***If charm equilibrates → correlations vanish !***
- ***Influence of hadronic scattering (small) ?***

Pythia Calcs.: H. Woehri, priv. comm.

Hadronic Transport Model:
E.L. Bratkovskaya et al., PRC 71 (2005) 044901.

Hadronic Re-scattering



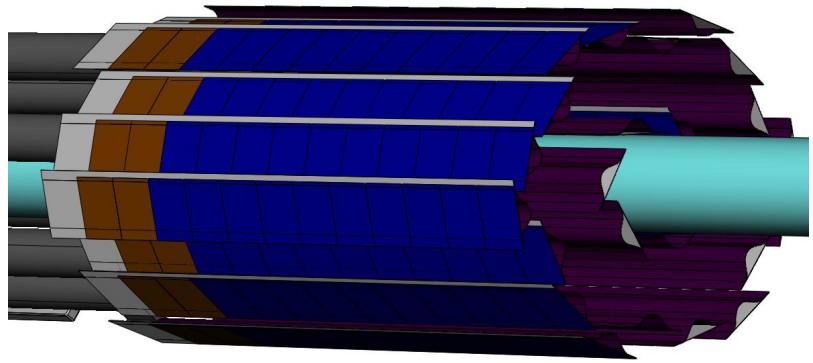
- Hadronic re-scattering can not completely wash out DD-correlations
- Frequent partonic re-scattering needed → ***light quark thermalization !***

M. Bleicher at al., subm. to Phys. Rev. Lett.

STAR Detector Upgrade

Full Barrel MRPC - TOF

Heavy Flavor Tracker



- $D^0 \rightarrow K + \pi$, $c\tau = 123\mu m$
- Measure decay vertex, $\sigma \leq 50\mu m$
- enhance S/B by factor 100

→ precise heavy-flavor measurements !

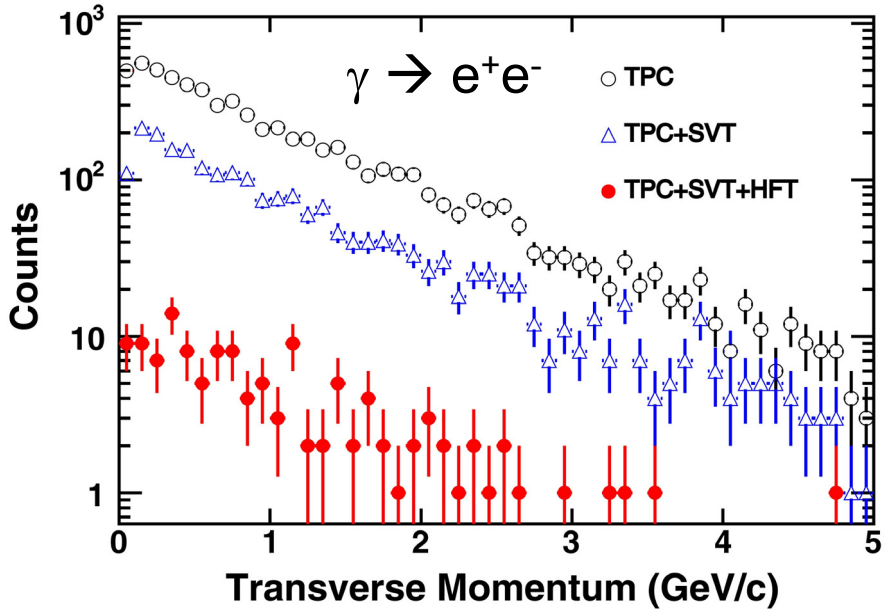
At μ-RHIC: measure Ω elliptic flow!

Active Pixel Sensors:
M. Winter et al., IReS/LEPSI, Strasbourg.

Measure Vector Mesons*

- $\phi \rightarrow e^+e^-$: leptons do not re-scatter → probe the medium at early stage
- Background: $\gamma \rightarrow e^+e^-$
- HFT discriminates background !
- Need low mass detector

Detectors	ω	ϕ
TPC+TOF	8 M	2 M
TPC+TOF+SVT+HFT	200K	100K



Summary

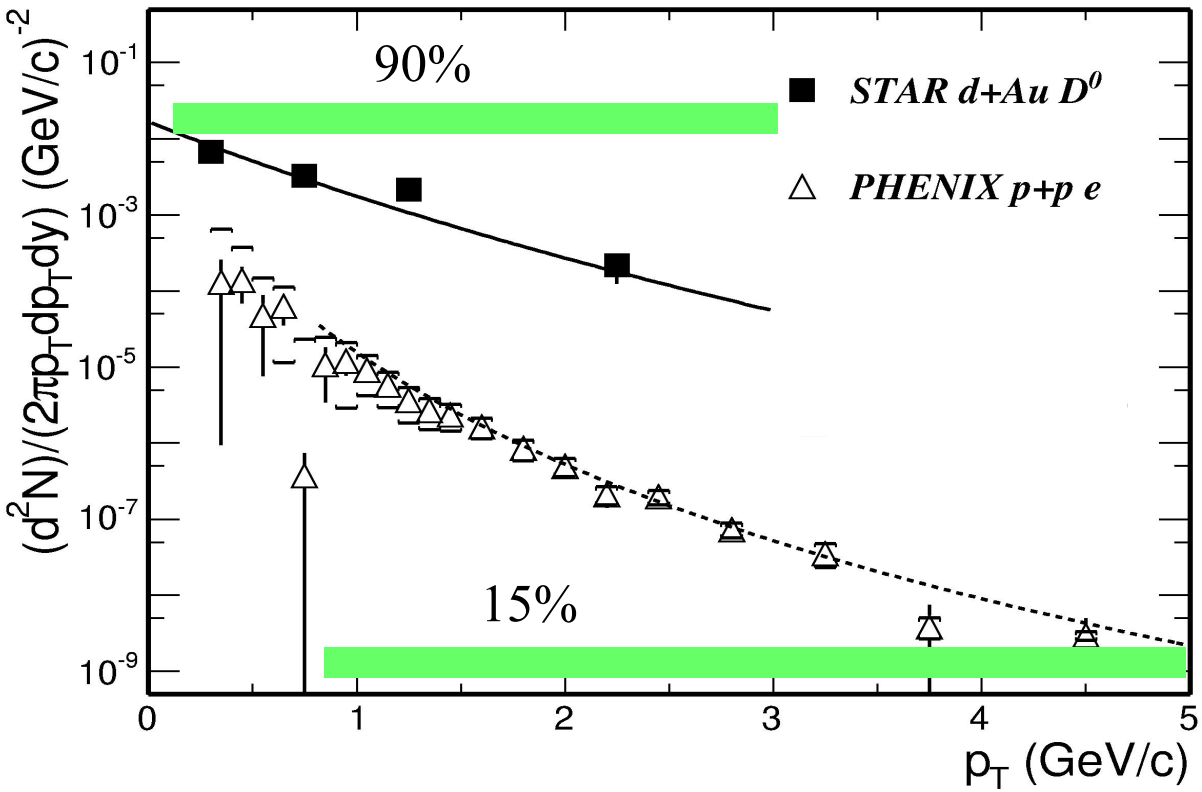
- Charm program at RHIC well established
- Need precision measurements on spectra, elliptic flow and yields of

D^0, $D^{\pm}$, D^+_s, **Λ^+_c**, **J/ψ**

→ Probe (u,d,s)-quark thermalization

- ***STAR: μVertex + full ToF (2008+)***

Spectrum coverage

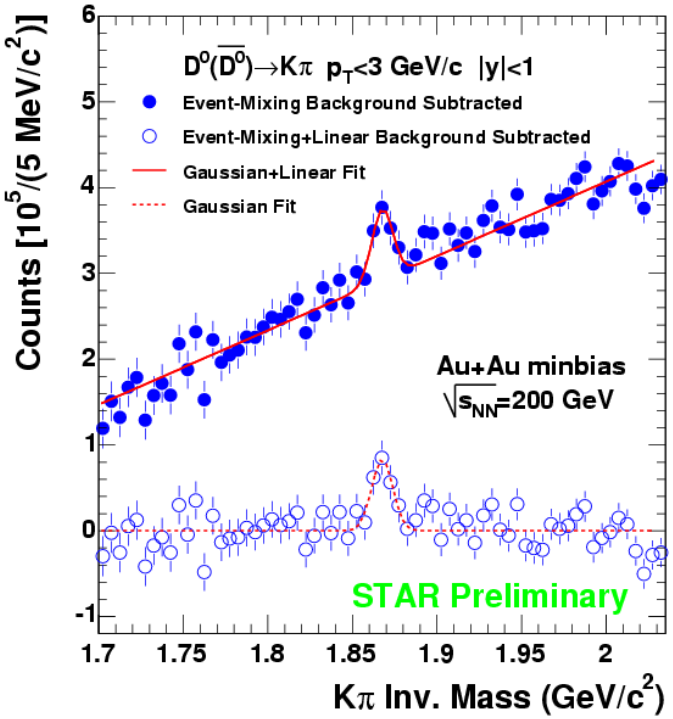


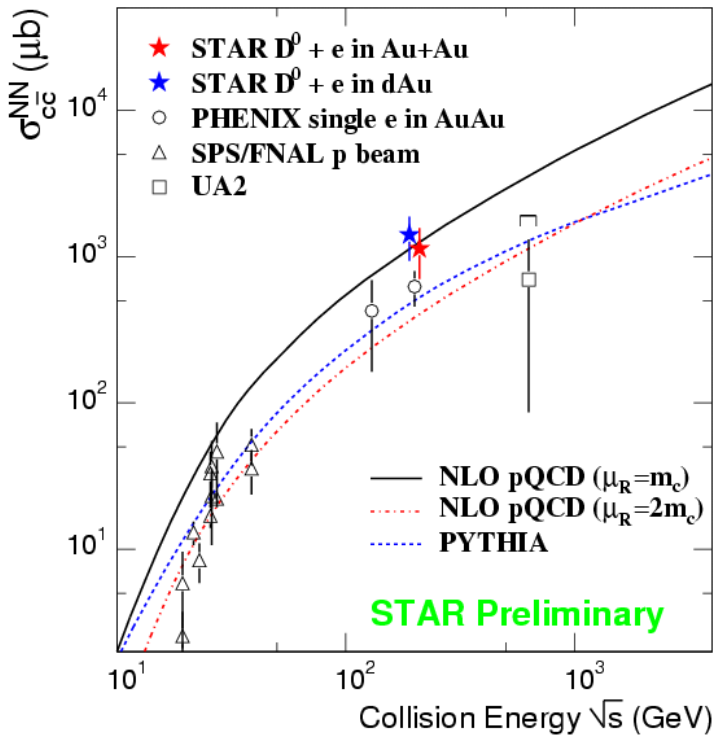
$\sigma_{cc} = 1.1 \pm 0.1 \pm 0.3$ mb $\langle p_T \rangle \sim 1.3$ GeV/c

The reconstructed D measurement has much smaller systematic uncertainties in determining the total cross section.

d + Au → Au + Au

STAR Highlight talk





1.13 ± 0.09 ± 0.42 mb in Au + Au

1.4 ± 0.2 ± 0.4 mb in d + Au

Approximately N_{bin} scaling from d+Au to Au+Au!

As expected ---

charm quarks are mostly created from initial NN interactions!