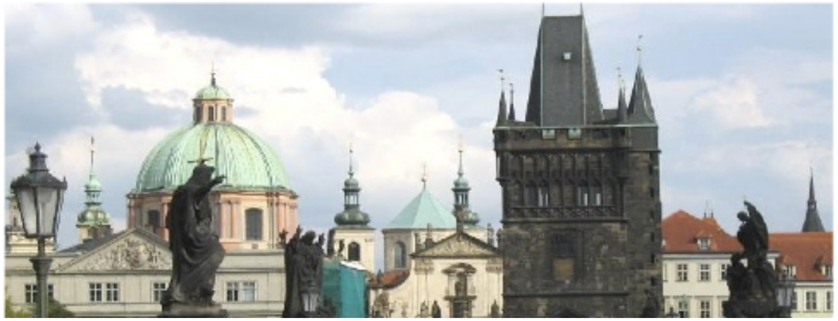
Charm meson production in 200 GeV p+p and Au+Au collisions at STAR

6th HADES School + 23rd Indian-Summer School of Physics

PHYSICS @ FAIR



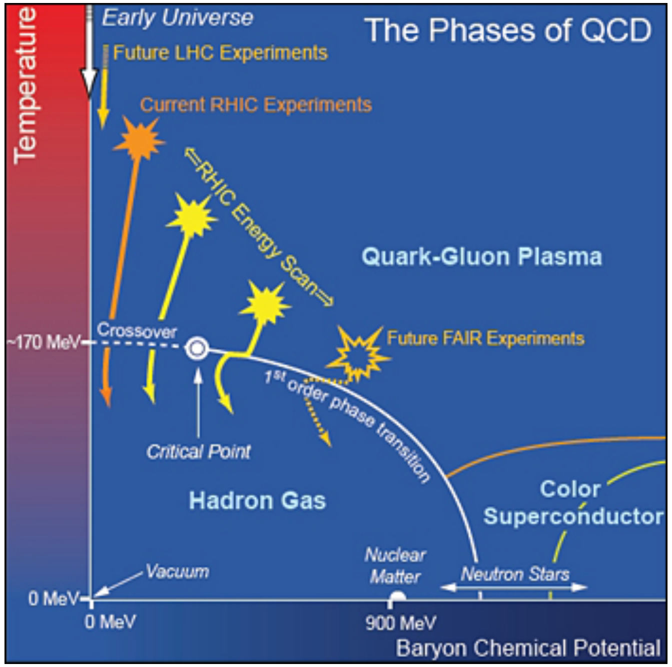
David Tlusty

NPI ASCR, CTU Prague

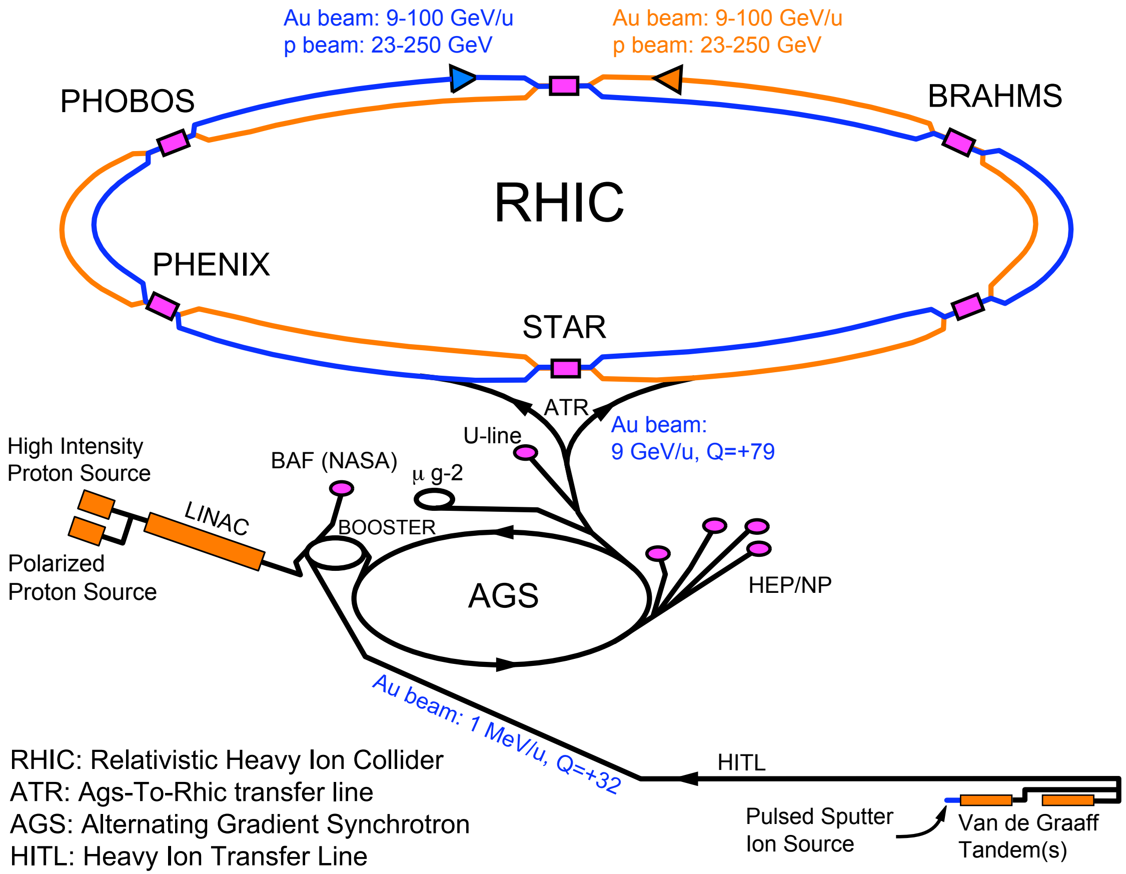
for STAR collaboration

QCD phase diagram and RHIC

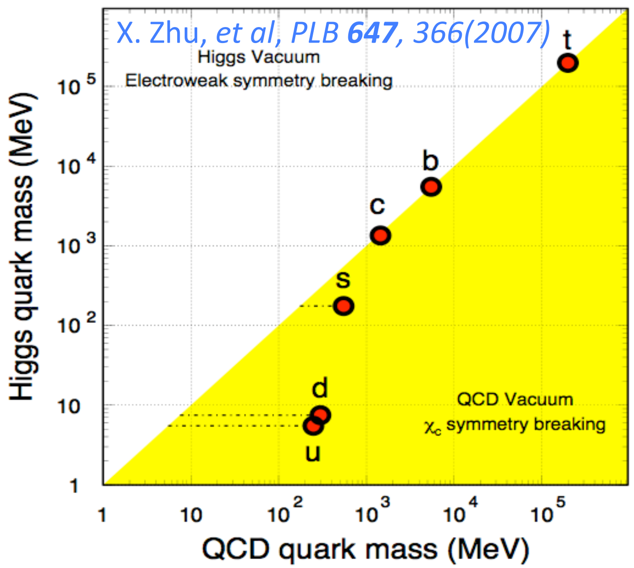
- How was the Universe created
- What are properties of strong interaction
- Search for and characterize the new state of matter – Quark Gluon Plasma

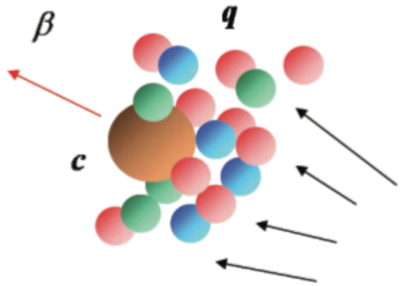


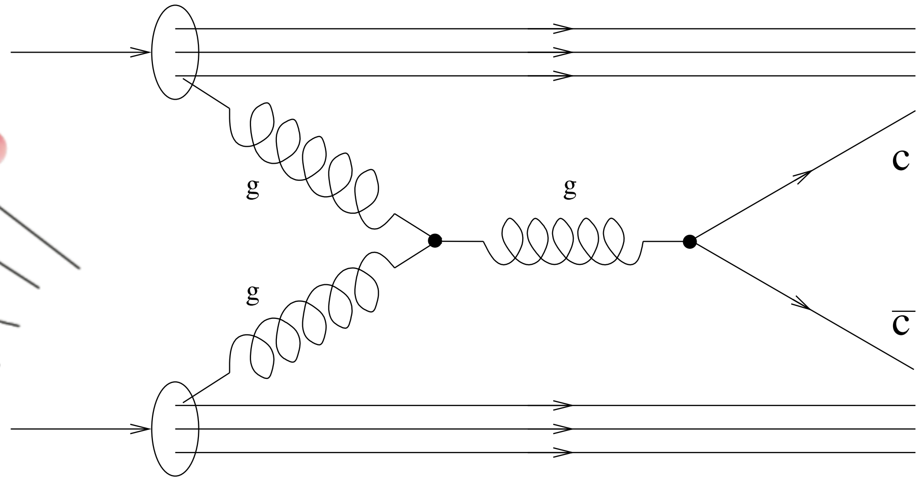
RHIC is an intersecting storage ring and particle accelerator
Two independent rings each 3.834 km circumference
Can collide any nuclear species on any other.
Max Energy: $\sqrt{s_{NN}} \approx (Z/A)\cdot 500\ \mathrm{GeV}$



Why to study heavy quarks







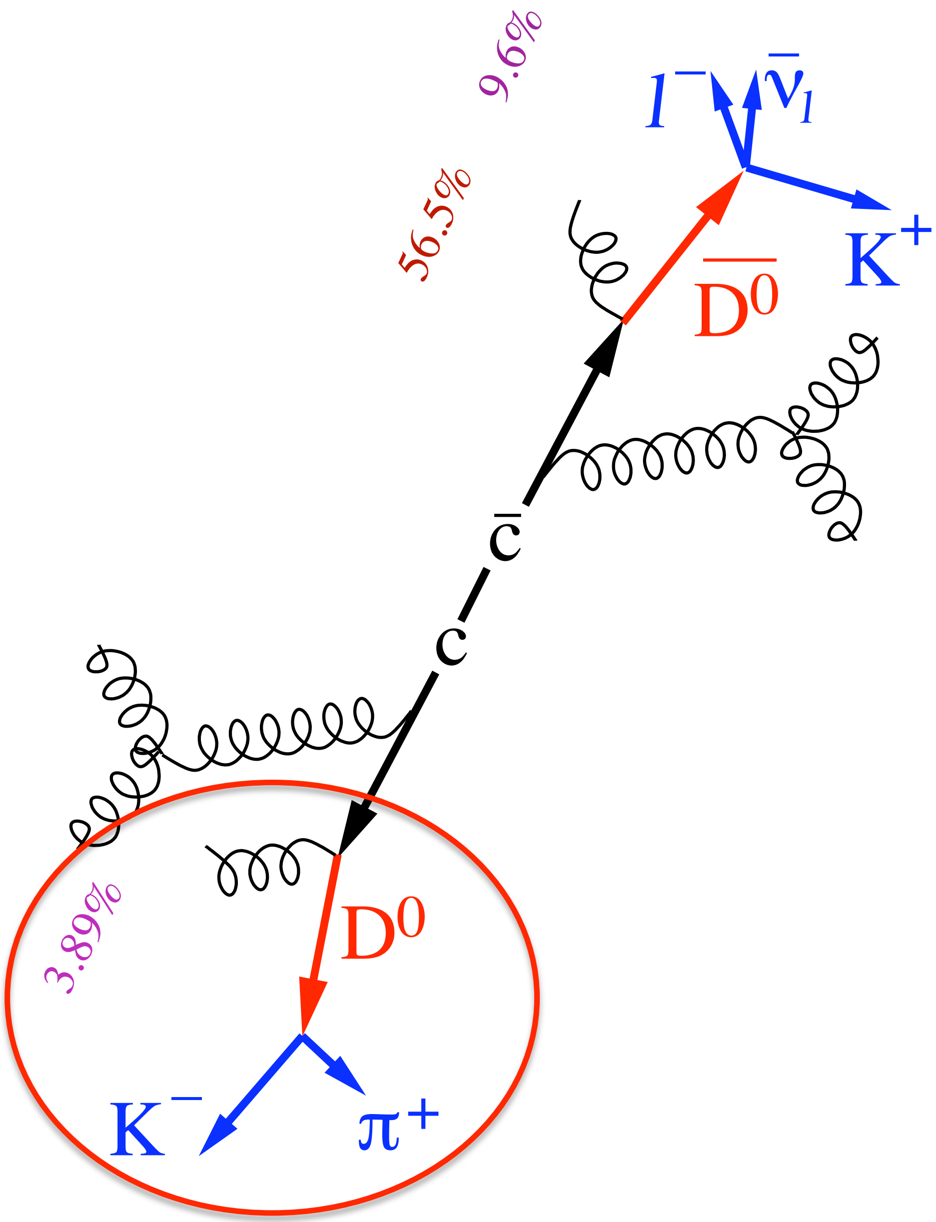
knowledge on total charm production cross sections from p+p to central heavy ion collisions is critical to understand both open charm and charmonium production mechanisms in the QGP medium at RHIC

- large heavy quark mass is not easily modified by the QCD medium
- heavy quarks expected to be created from the initial hard scatterings
- Study properties of the hot and dense medium at the early stage of heavy-ion collisions.
- Charm collectivity => Light flavor thermalization.
- Test pQCD at RHIC.

How to measure charm quarks

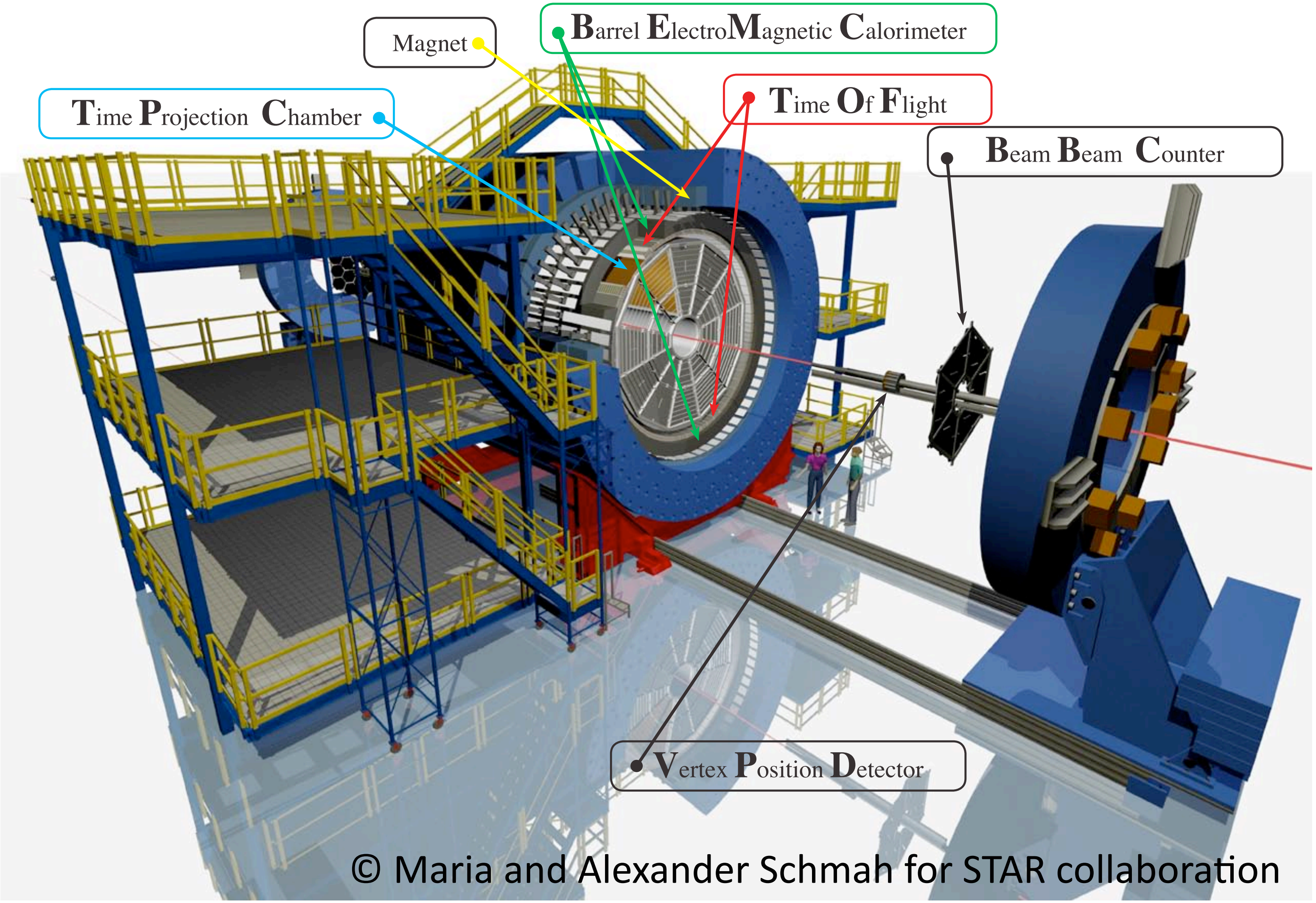
- direct clean identification (invariant mass peak)
  - At RHIC only STAR can provide this
- large combinatorial background
- need handle on decay vertex

⇒requires high resolution silicon vertex detectors



The STAR detector

Solenoidal Tracker At RHIC : $-1 < \eta < 1$, $0 < \phi < 2\pi$



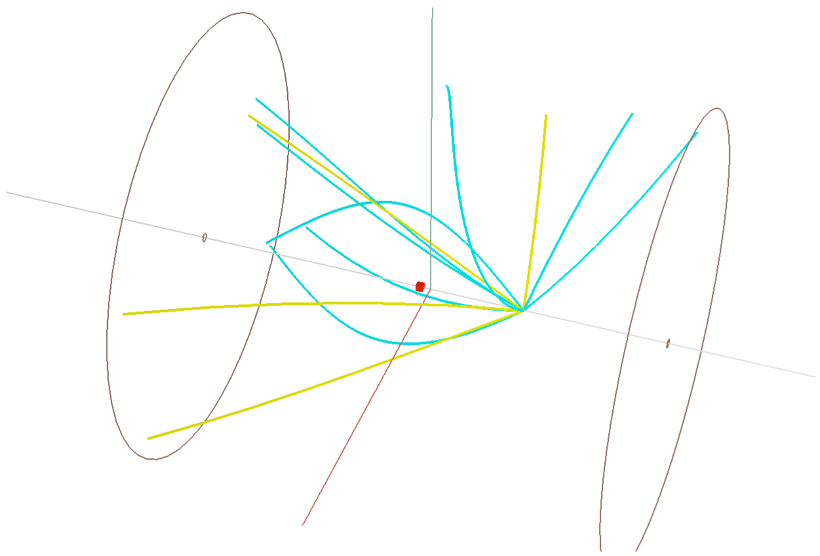
- VPD EW coincidence: minimum bias trigger, TOF start time
- TPC : PID, tracking
- TOF : PID (β, time resolution = 110 ps)
- BEMC : remove pile-up tracks, E_T triggers

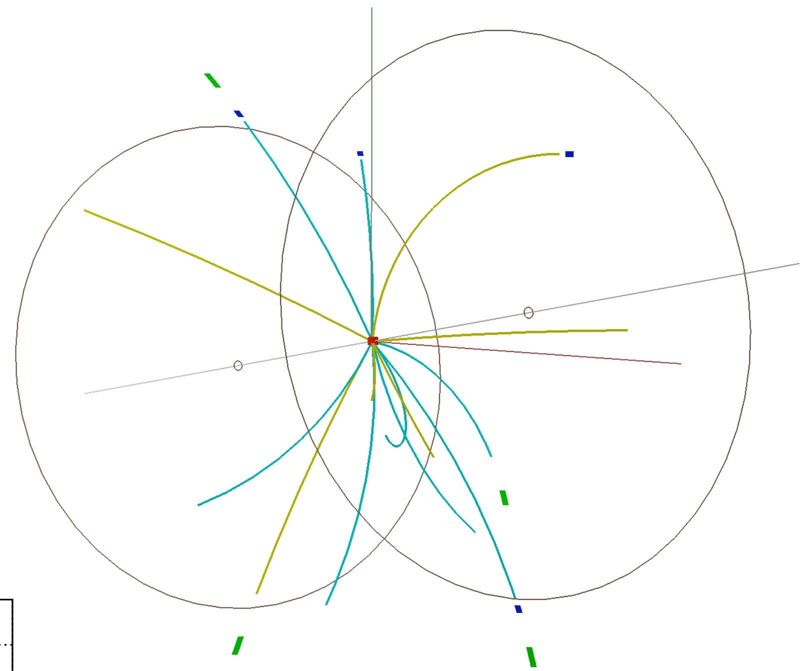
- TPC dE/dx vs p : pions PID
- TOF 1/β vs p : kaons PID

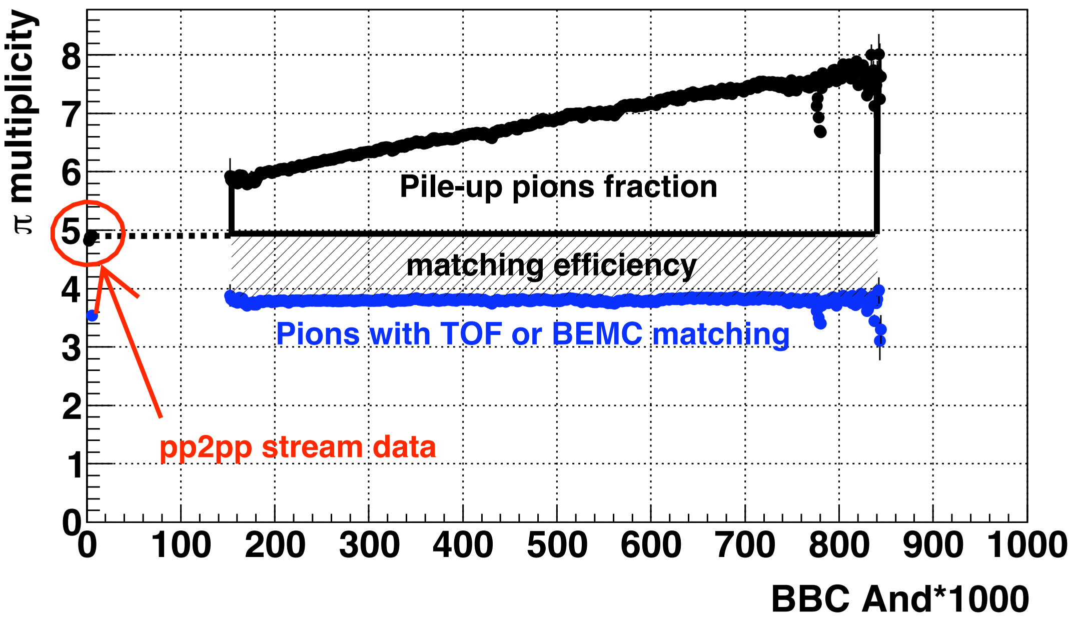
Year 2009 72% of full TOF

Year 2010 100% of full TOF

Pile-up removal







- pp collisions peak luminosity

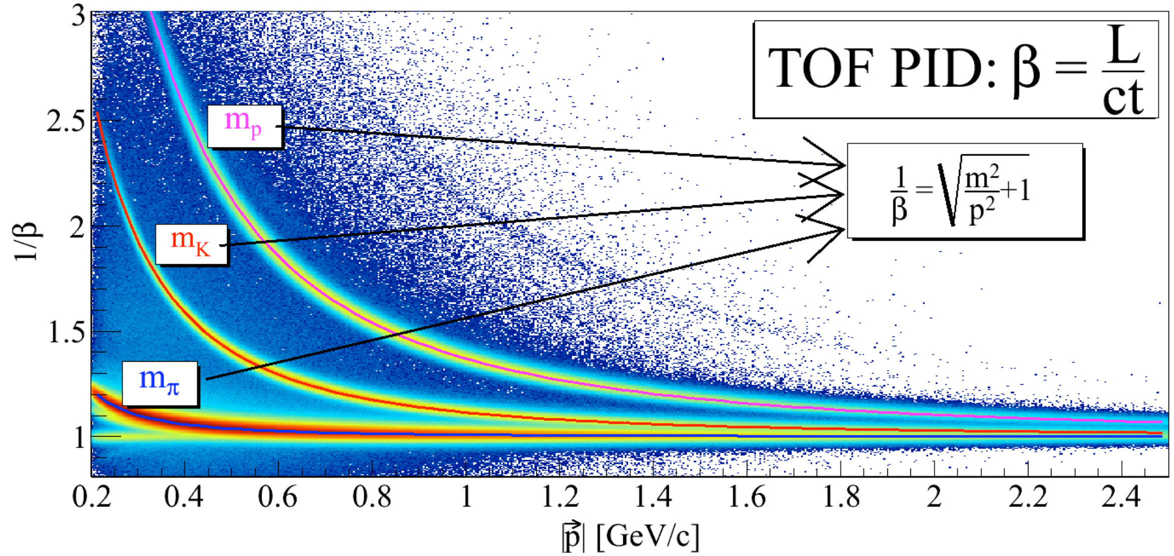
$L_{peak} = 5*10^{31}\ cm^{-2}s^{-1}$ in year 2009.

- EventRate = $L_{peak}*\sigma^{NSD}$(30 mb) = 1.5 MHz
- TPC readout ~ 80 μs => TPC sees tracks

from 120 collisions. Pile-ups are removed by

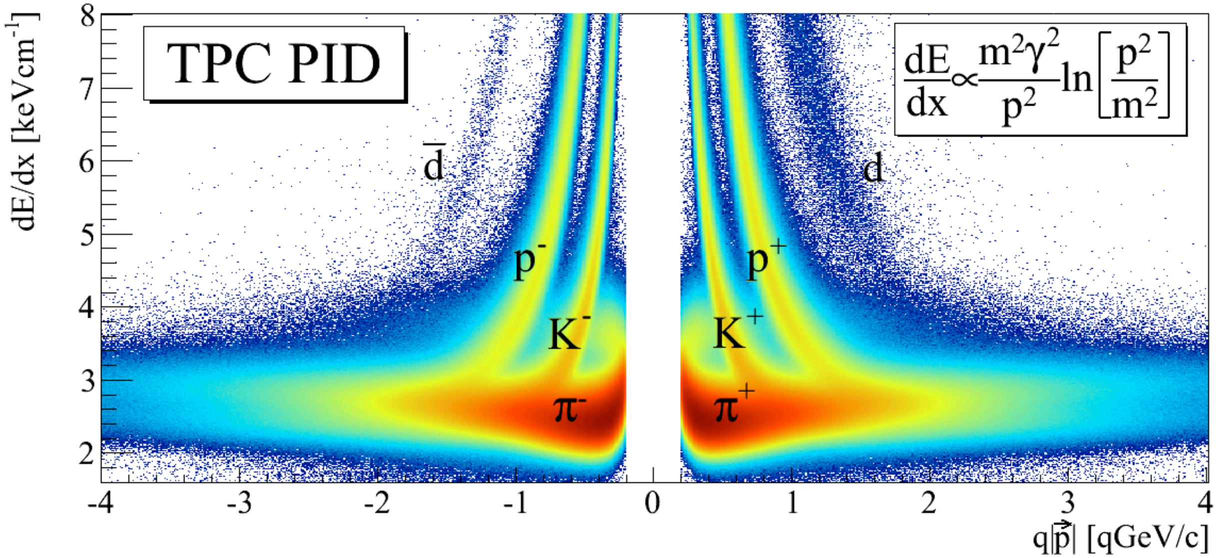
  - |VpdVz - TpcVz| < 6cm cut
  - TPC PPV reconstruction algorithm

Particle Identification

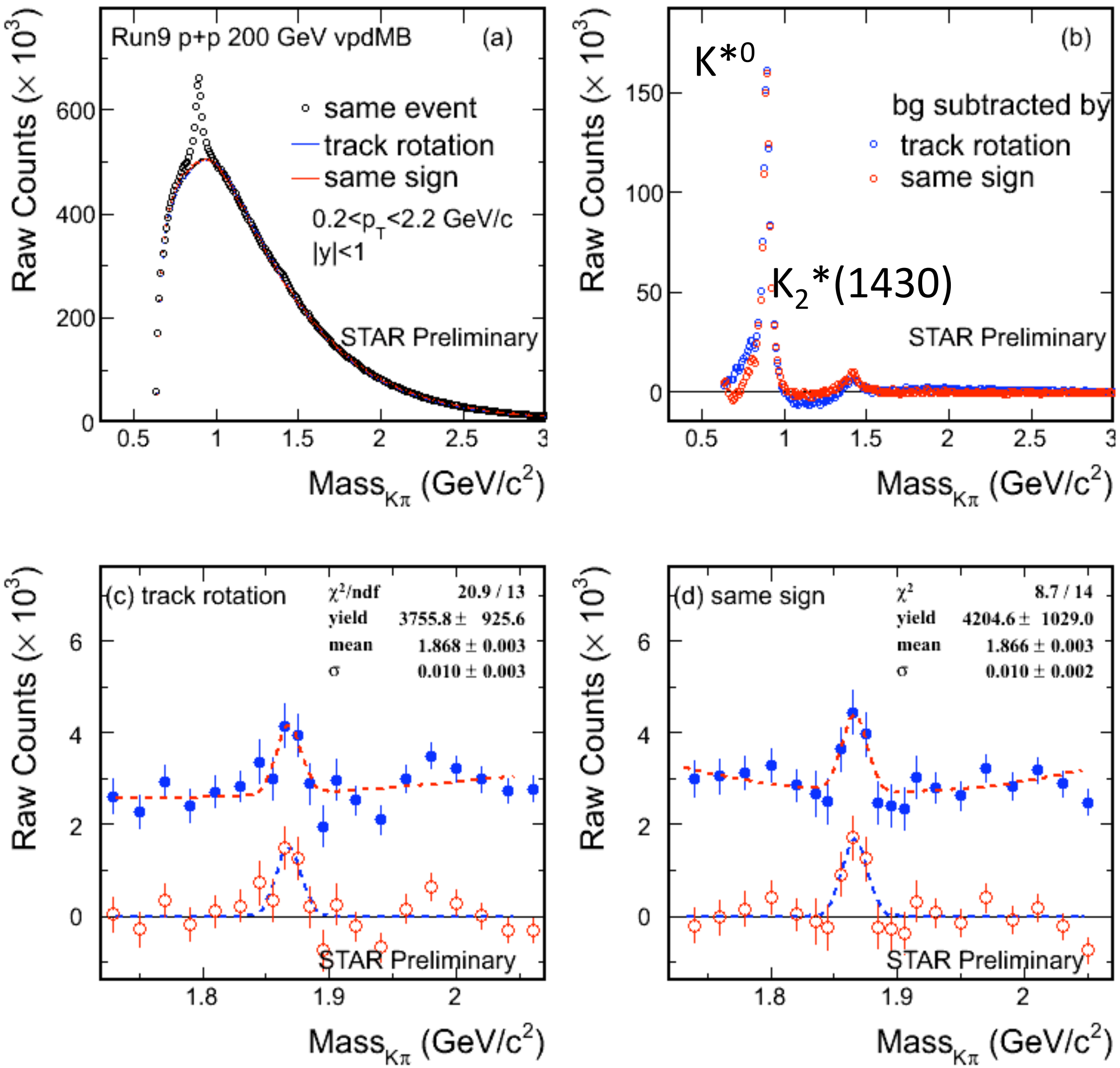


From $|\vec{p}| = m\gamma\beta,\ \beta = L/ct$ one can calculate mass from

$$m^2_{track} = p^2\left(\frac{t^2c^2}{L^2} - 1\right) \qquad m[GeV/c^2], p[GeV/c]$$



D0 signal in p+p 200 GeV



$D^0(\overline{D}^0) \rightarrow K^{\mp}\pi^{\pm}$

B.R. = 3.89%

p+p minimum bias 105 M

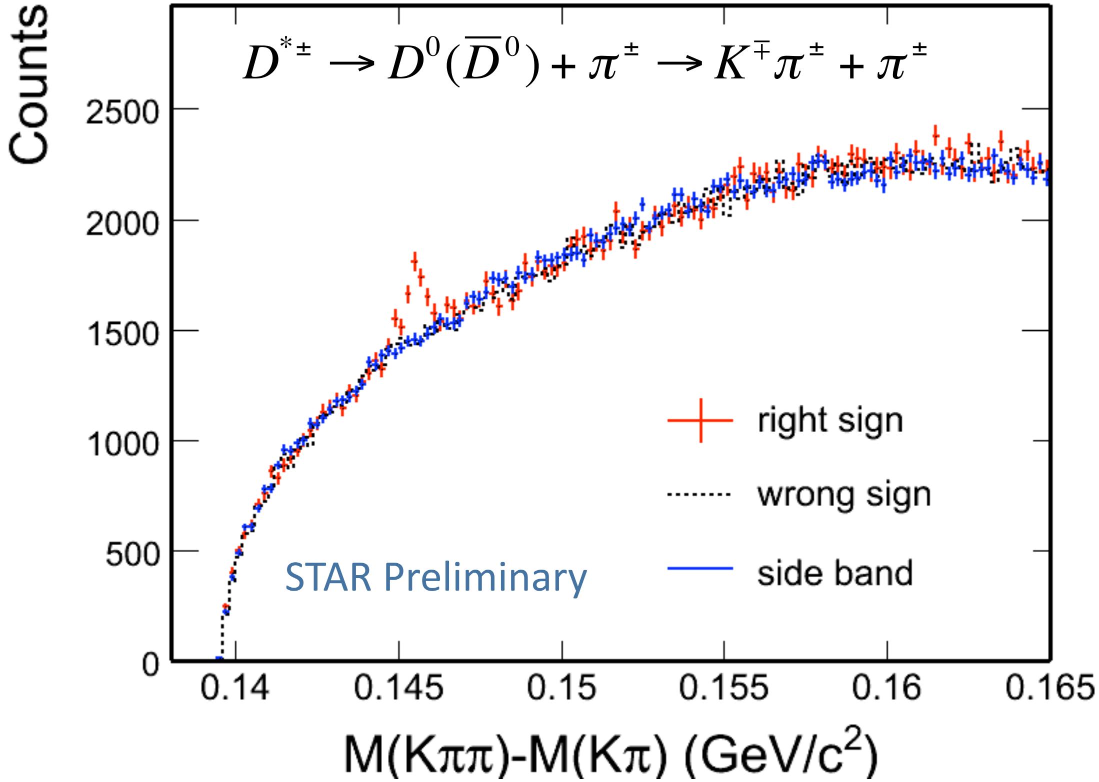
4-σ signal observed.

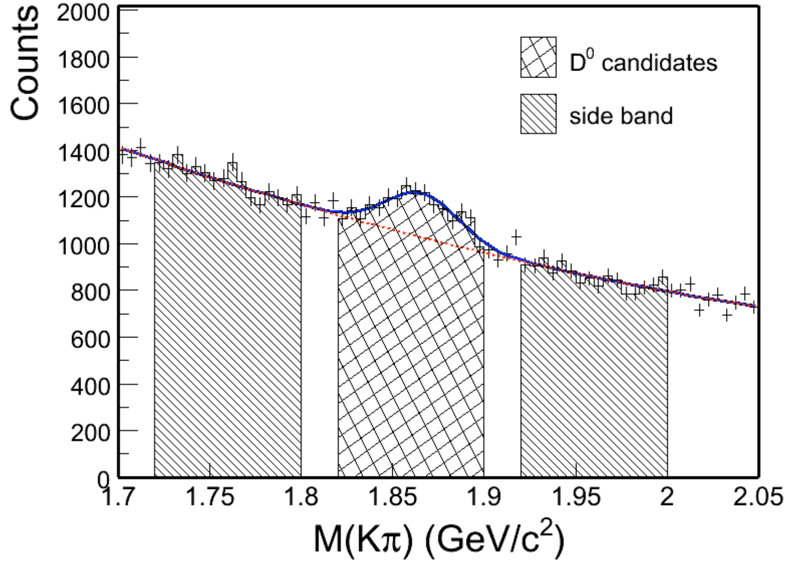
Different methods reproduce combinatorial background.

Consistent results from two background methods.

PDG mass = 1864.5 ± 0.4 MeV

D* signal in p+p 200 GeV





B.I.~Abelev, *et al., PRD 79 (2009) 112006.*

Minimum bias events in p+p 200 GeV collisions.

Two methods to reconstruct combinatorial background: wrong sign and side band.

8-σ signal observed.

<u>Background combinations:</u>

Wrong sign:

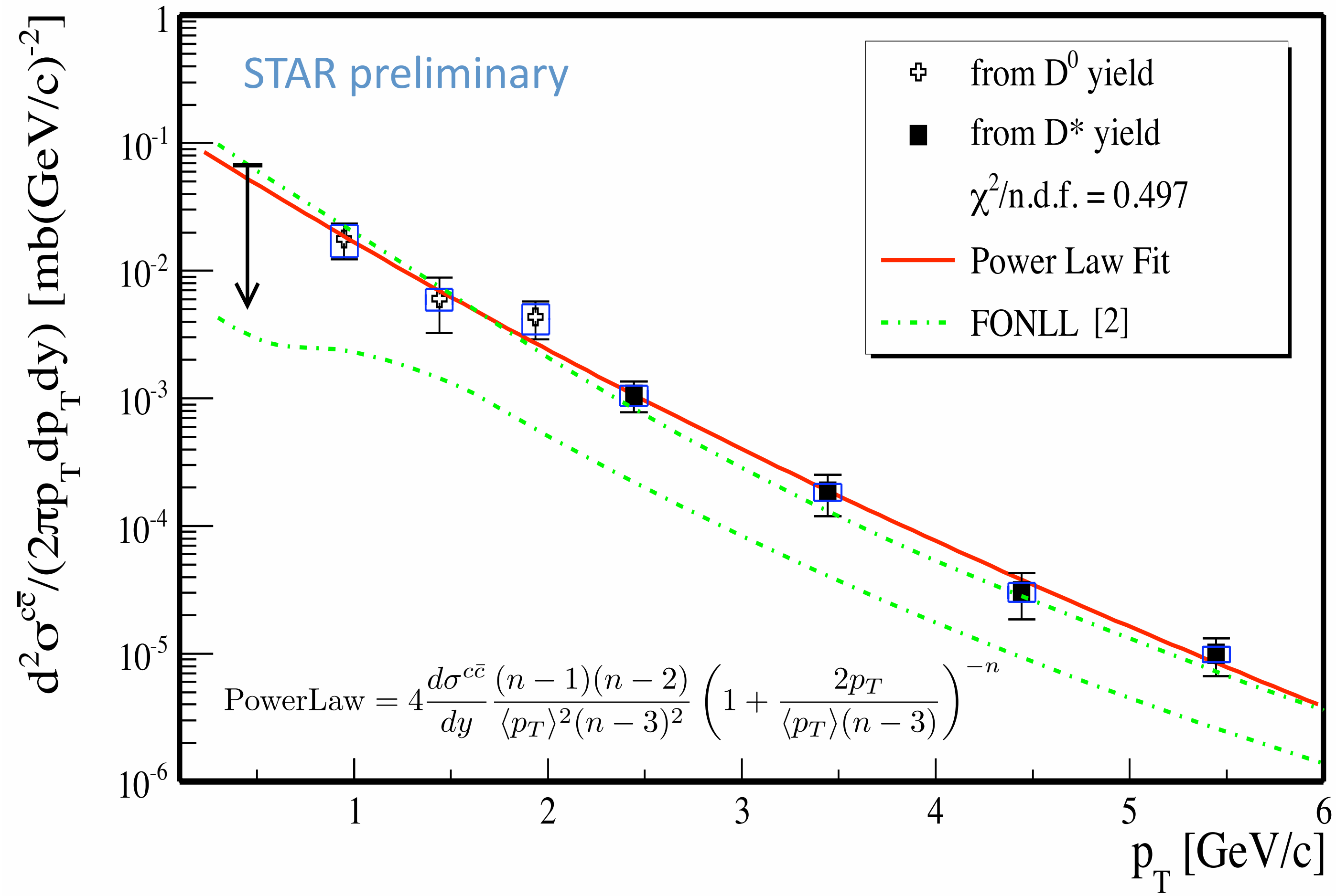
D^0 and π^-, $\overline{D}^0$ and π^+

Side band:

1.72< M(Kπ) < 1.80 or

1.92 < M(Kπ) < 2.0 GeV/c^2

D^0 and D^* p_T spectra in p+p 200 GeV



D^0 scaled by N_{D0}/N_{cc} = 0.56[1]

D^* scaled by N_{D*}/N_{cc} = 0.22[1]

Consistent with FONLL[2] upper limit.

Xsec = $dN/dy|^{cc}_{y=0} * F * \sigma_{pp}$

F = 4.7 ± 0.7 scale to full rapidity.

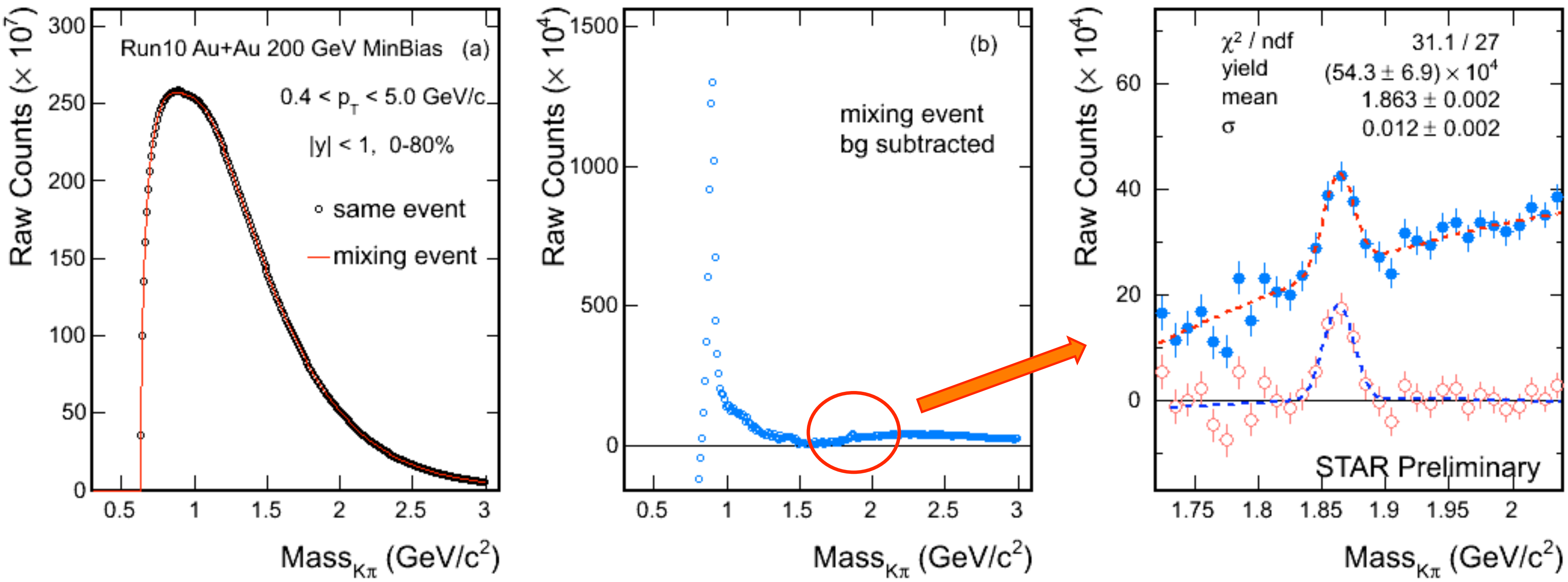
σ_{pp}(NSD) = 30 mb

The charm cross section at mid-rapidity is:
202 ± 56 (stat.) ± 40 (sys.) ± 20 (norm.) μb

The charm total cross section is extracted as:
949 ± 263 (stat.) ± 253 (sys.) μb

[1] C. Amsler et al. (Particle Data Group), PLB 667 (2008) 1.
[2] Fixed-Order Next-to-Leading Logarithm: M. Cacciari, PRL 95 (2005) 122001.

D^0 signal in Au+Au 200 GeV



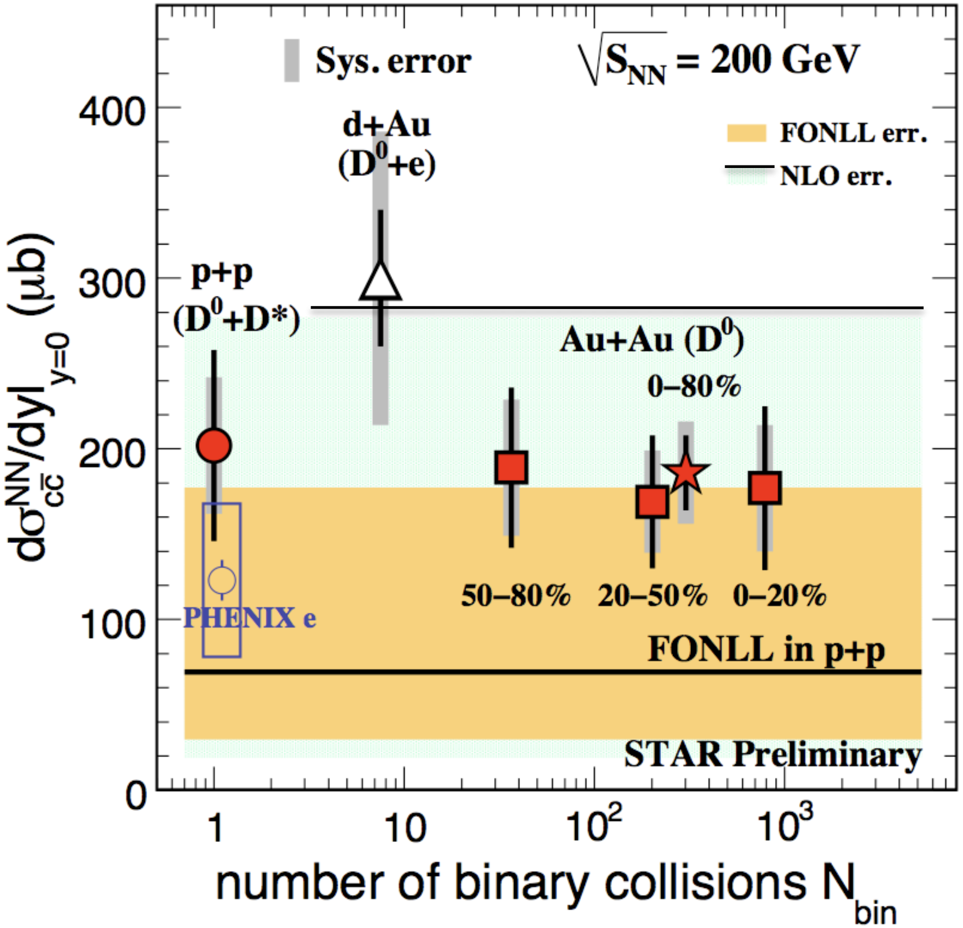
Minimum bias 0-80% 280M Au+Au 200 GeV events.

8-σ signal observed.

Mass = 1863 ± 2 MeV (PDG value is 1864.5 ± 0.4 MeV)

Width = 12 ± 2 MeV

Charm cross section vs N_{bin}



All of the measurements are consistent.

Year 2003 d+Au : D^0 + e

Year 2009 p+p : D^0 + D*

Year 2010 Au+Au: D^0

Charm cross section in Au+Au 200 GeV:

Mid-rapidity:

186 ± 22 (stat.) ± 30 (sys.) ± 18 (norm.) μb

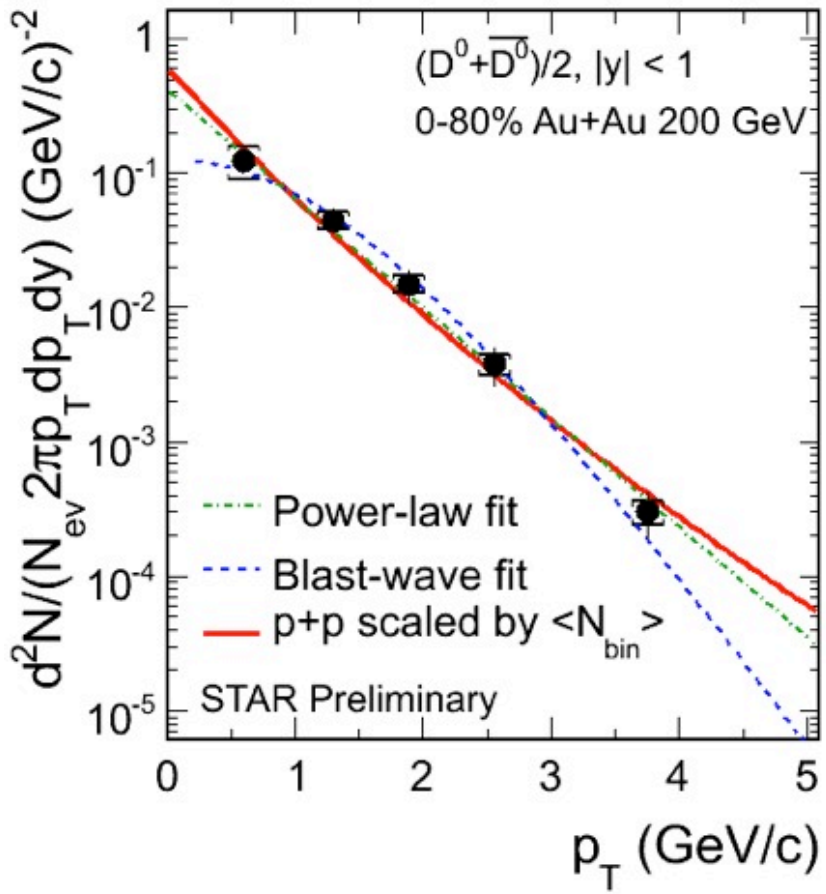
Total cross section:

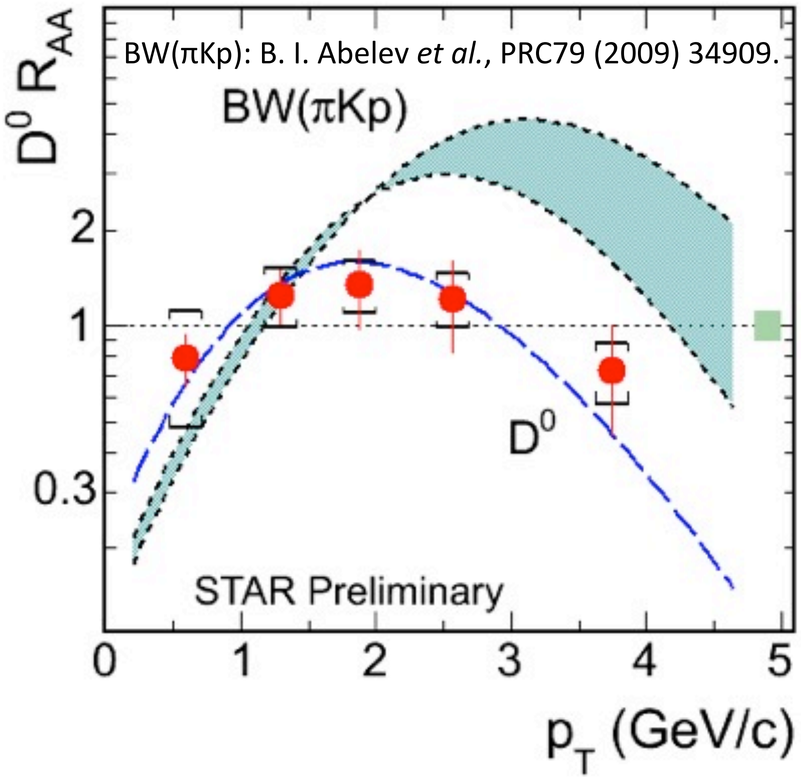
876 ± 103 (stat.) ± 211 (sys.) μb

[1] FONLL: M. Cacciari, PRL 95 (2005) 122001.
[2] NLO: R. Vogt, Eur.Phys.J.ST 155 (2008) 213
[3] PHENIX e: A. Adare, et al., PRL 97 (2006) 252002.

Charm cross section follows number of binary collisions scaling =>
Charm quark produced at early stage of collisions.

D^0 R_{AA} vs p_T





$$R_{AA}(p_T) = \frac{\frac{d\sigma_{c\bar{c}}^{Au+Au}}{dp_T dy}}{N_{\rm bin}^{Au+Au} \frac{d\sigma_{c\bar{c}}^{p+p}}{dp_T dy}}$$

Below 3 GeV/c, R_{AA} consistent with unity =>

Consistent with D^0 yield N_{bin} scaling behavior.

Blast-wave describes data with

$\langle\beta_T\rangle = 0.21 \pm 0.20$ (small, not sensitive).

T = 287 ± 106 MeV

T > T_h ~ 100 MeV, larger than light hadrons

Summary

- D^0 and D* are measured in p+p 200 GeV up to 6 GeV/c – the first measurement at STAR

- D^0 are measured in Au+Au 200 GeV up to 5 GeV/c.

- 1) Charm cross sections at mid-rapidity follow number of binary collisions scaling

  2) R_{AA} is consistent with unity.

  Indicate charm is produced at early stage of the collisions.

- The charm cross section in mid-rapidity is measured to be

  p+p: 202 ± 56 (stat.) ± 40 (sys.) ± 20 (norm.) μb

  Au+Au: 186 ± 22 (stat.) ± 30 (sys.) ± 18 (norm.) μb

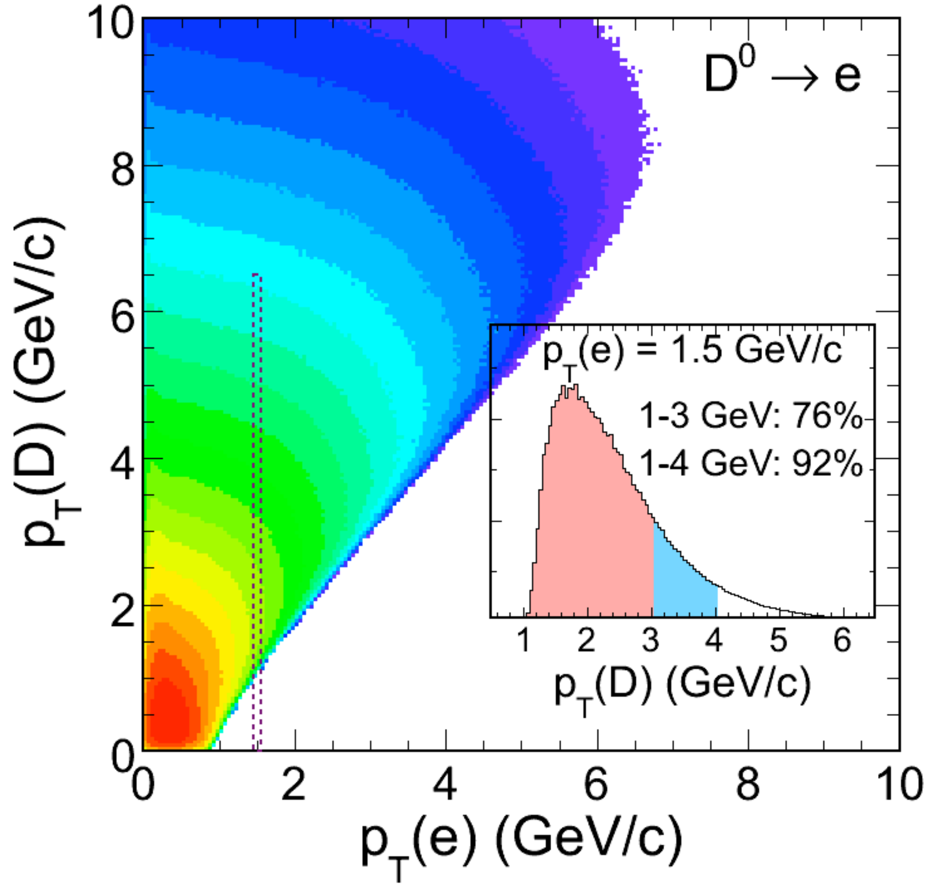
- Blast-wave fit favors larger temperature and smaller velocity compared to light hadrons, which could indicate that D^0 decoupled earlier from the medium than light hadrons.

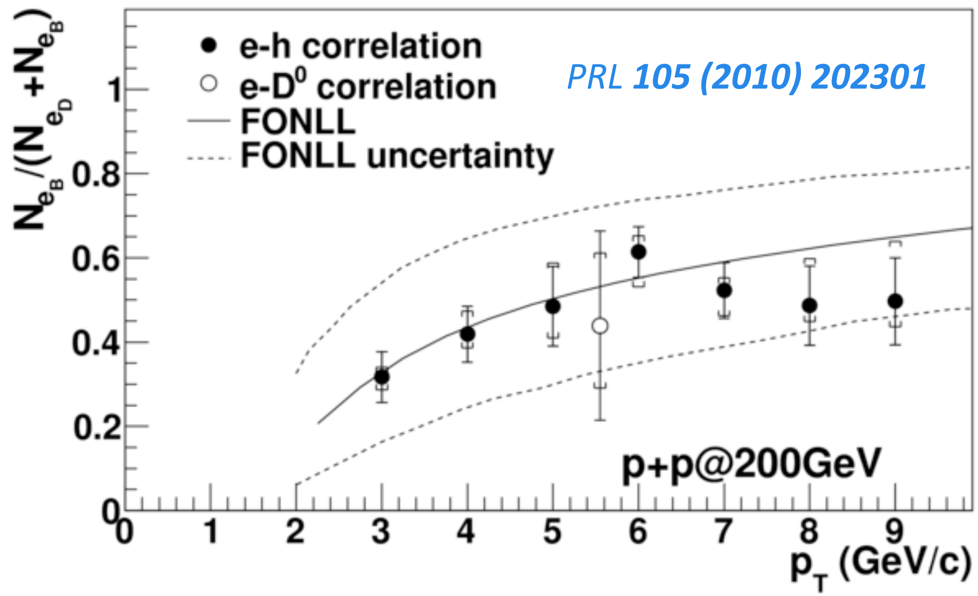
Why to measure D mesons?

Known limitations in semi-leptonic channel.

1) Kinematics smearing due to decay.

2) Suffering from charm and bottom contribution.

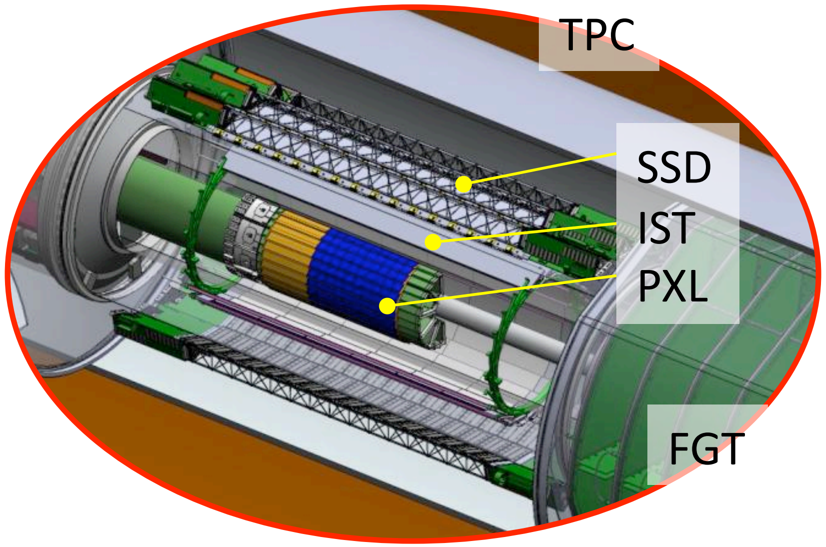


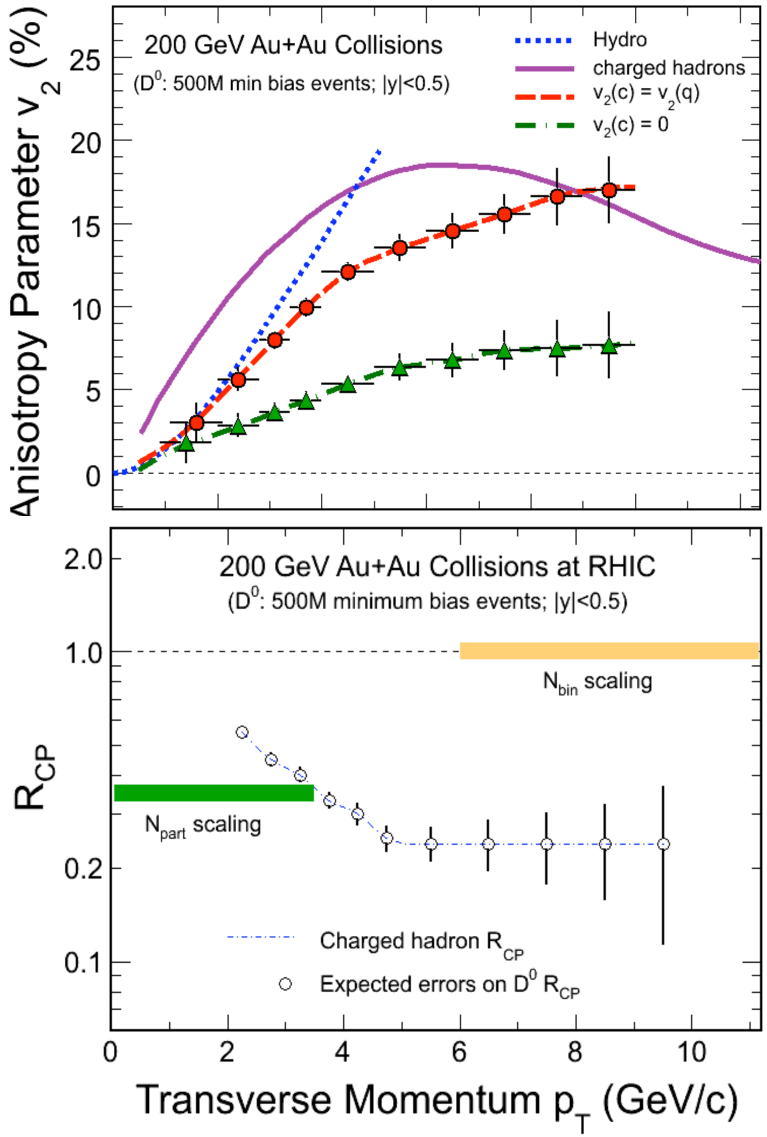


Both FONLL calculation and experimental data from electron channel are with large uncertainties.

Direct measurement of D meson provides clean information of charm quark.

Outlook





STAR Heavy Flavor Tracker Project.

✓ Reconstruct secondary vertex.

✓ Dramatically improve the precision of measurements.

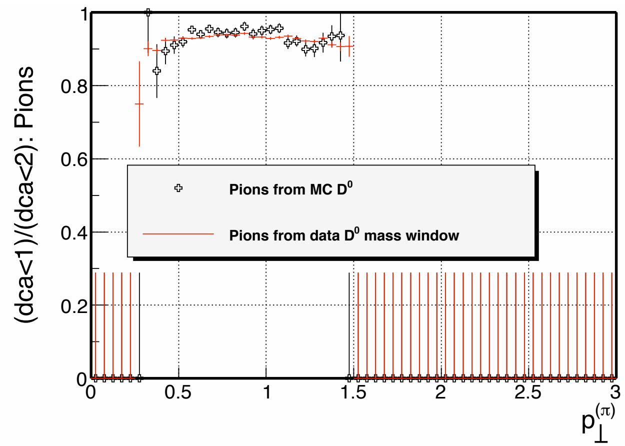
✓ Address physics related to heavy flavor.

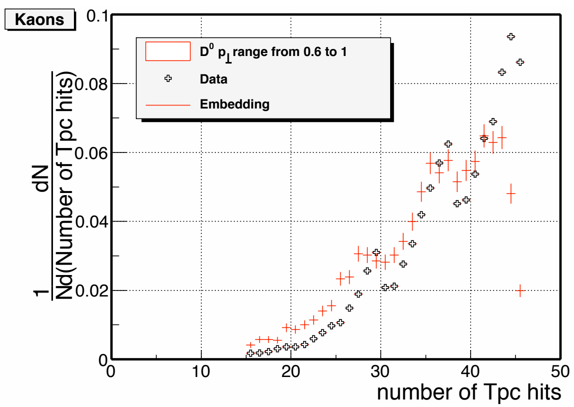
v_2 : thermalization

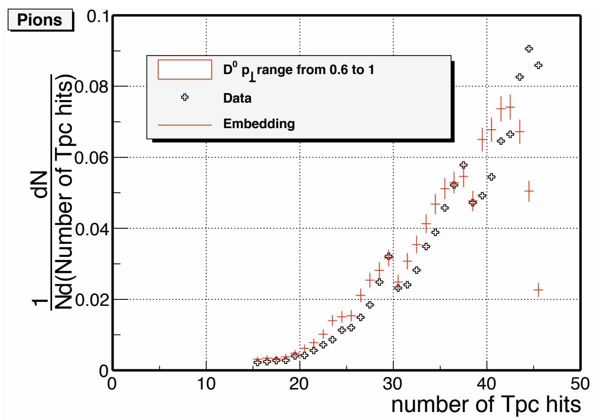
R_{CP}: charm quark energy loss mechanism.

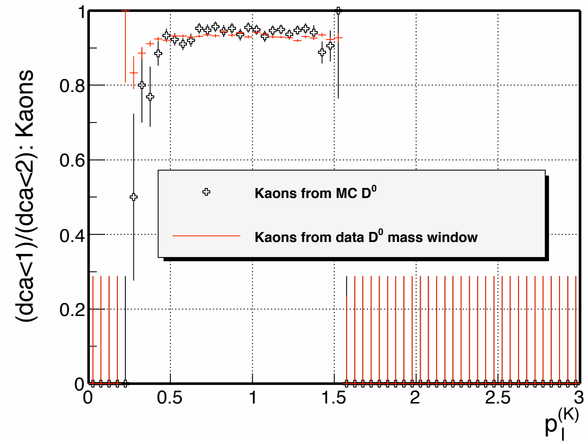
Systematic error study

1) Raw Counts – Difference between methods
2) nFitPoints - difference between MC(nFitPts>25)/MC(nFitPts>15) and Data(nFitPts>25)/Data(nFitPts>15)
3) DCA - difference between MC(dca<1)/MC(dca<2) and Data(dca<1)/Data(dca<2)

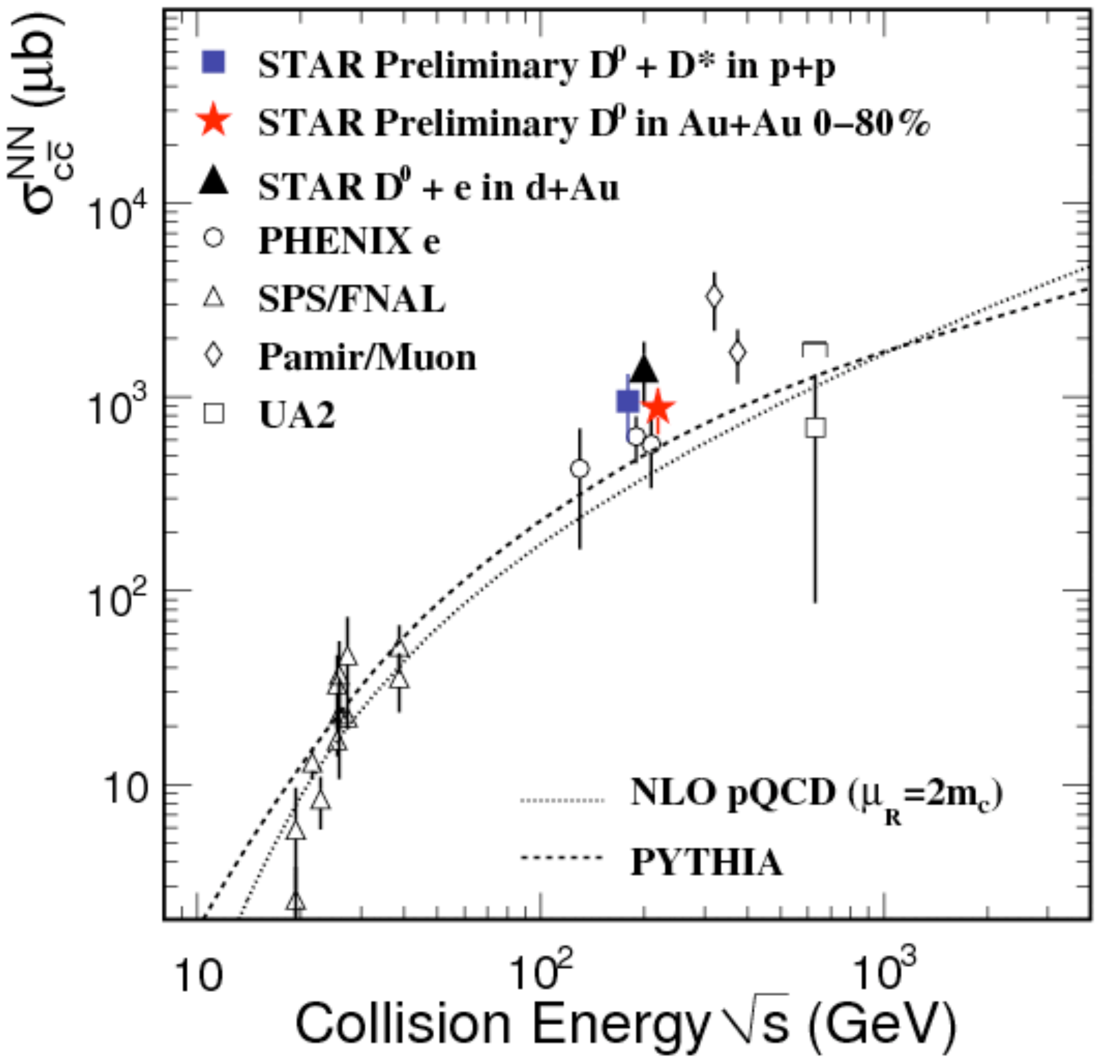








Charm cross section vs $\sqrt{s_{NN}}$



Most precise measurement so far, provide constraint for theories.