Charm reconstruction with STAR's Silicon Vertex Detectors

Spiros Margetis,

For the STAR collaboration

1. Motivation
2. Heavy Flavor measurements in STAR
   - sorted by identification method
   - not a complete list
3. Summary and future measurements

Charmed mesons in Heavy Ion collisions

• Heavy flavor is produced dominantly at the earlier stages of the collision via gluon fusion :

- not affected by chiral symmetry restoration.
- production cross section are found to binary scale[1].

– **ideal to probe the medium created** in HI collision.

•Theoretical models predicted gluon radiative energy loss for heavy quarks to be **smaller** than of light quarks[2], which is **not** experimentally observed [3].

•Measuring collective motion (v_2) of charm mesons will also indicate whether thermalization in light quark sector is reached in the earlier steps of the collision.

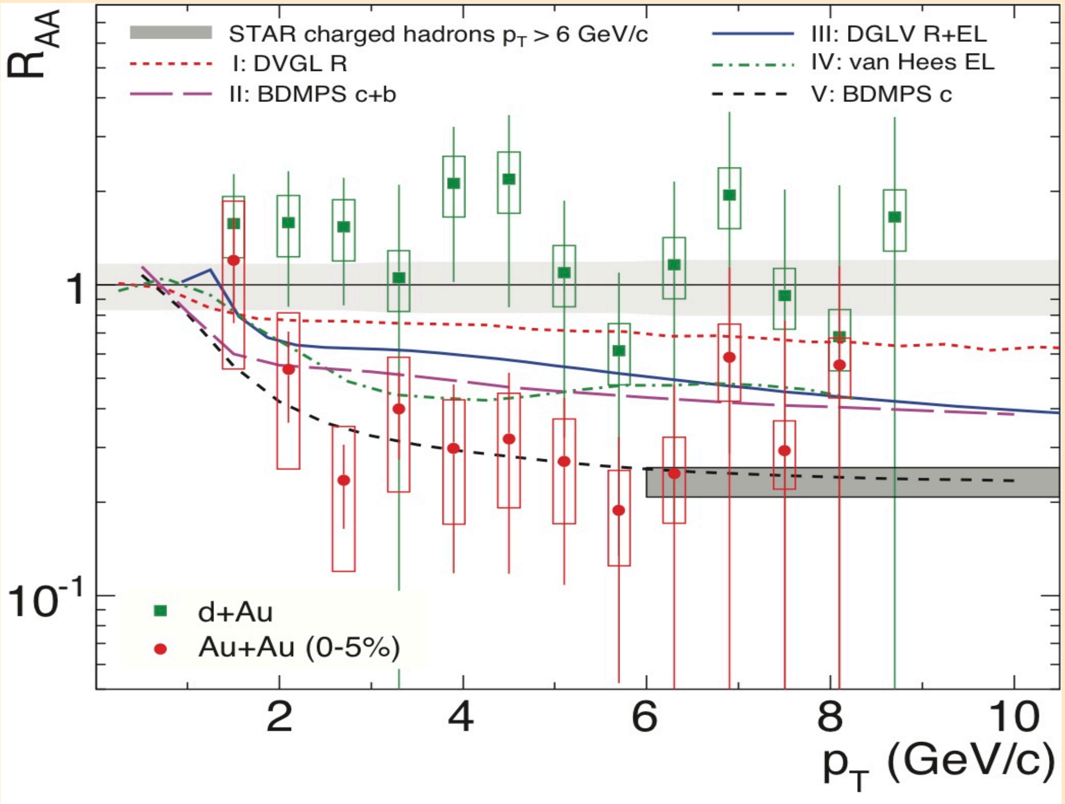
[1]Phys. Rev. Lett. ***94*** *(2005) 082301*
*[2]Phys. Lett. B**519** (2001) 199-206*
[3]Phys. Rev. Lett. ***98*** *(2007) 192301*

The Beginnings - Heavy Quark Energy Loss – NPE Method

STAR: Phys. Rew. Lett, **98**, 192301(2007)

nucl-ex/0607012v3

Still the main method at RHIC



1) Non-photonic electrons (NPE) decayed from - charm **and** beauty hadrons

2) At $p_T \geq 6$ GeV/c,

R_{AA}(NPE) ~ $R_{AA}(h^{\pm})$!!!

Contradicts naïve pQCD predictions

Surprising results -

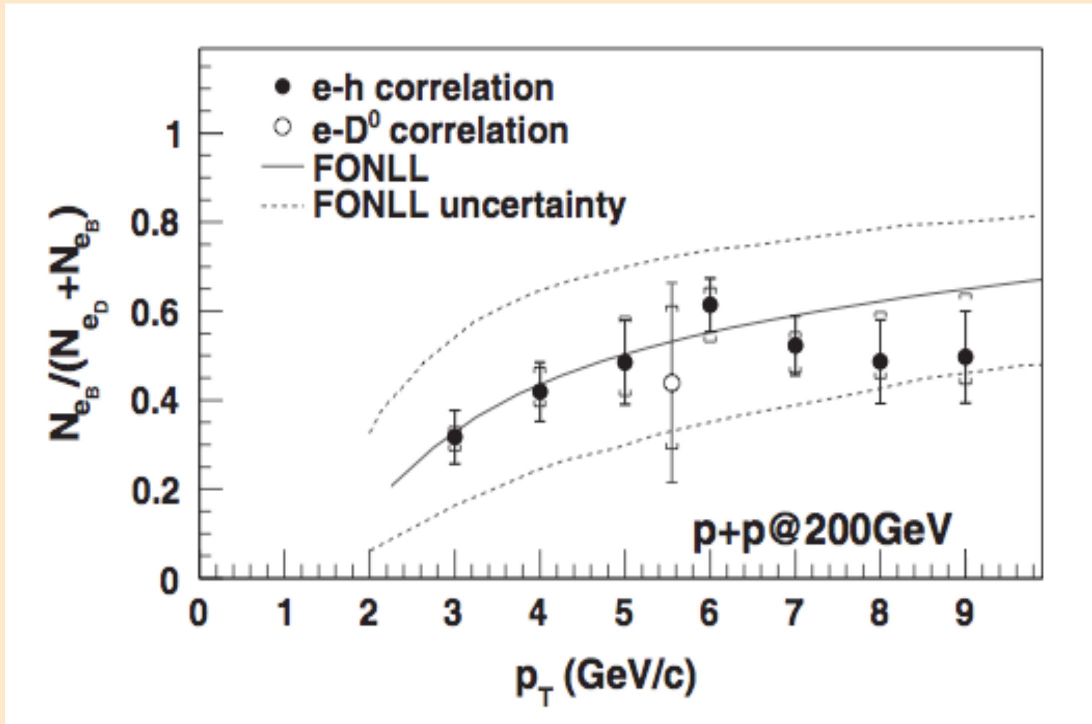
- challenge our understanding of the energy loss mechanism
- force us to RE-think about the elastic-collisions energy loss
- **Requires direct measurements of c- and b-hadrons.**

Next Step/Method in NPE: Charm/Bottom separation (next talk by W. Borowski)

- **Azimuthal correlations** of electrons with hadrons or open charm meson can help disentangle between the charm and bottom contribution[4].
- Data set is typically triggered on high p_T electrons.

*[4] Phys. Lett. B**671**(2008) 361 ;*
*Phys. Rev. Lett. **105** (2010) 202301*

For NPE results on elliptic flow see talk by S. Kabana

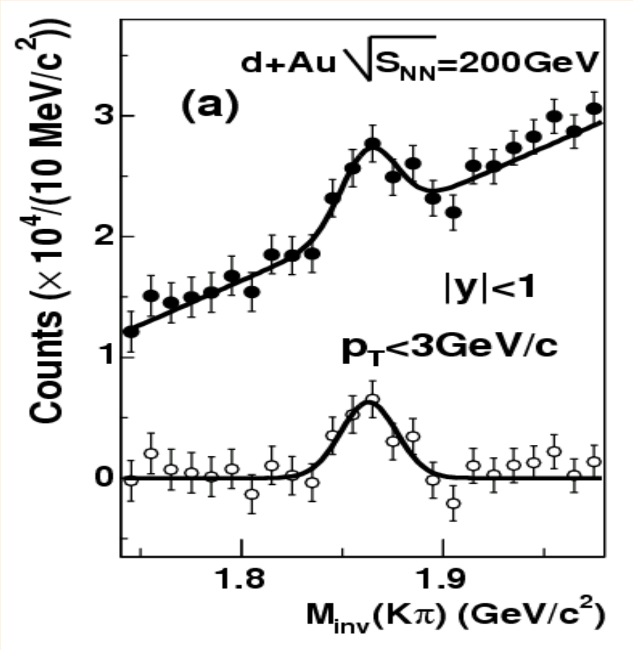


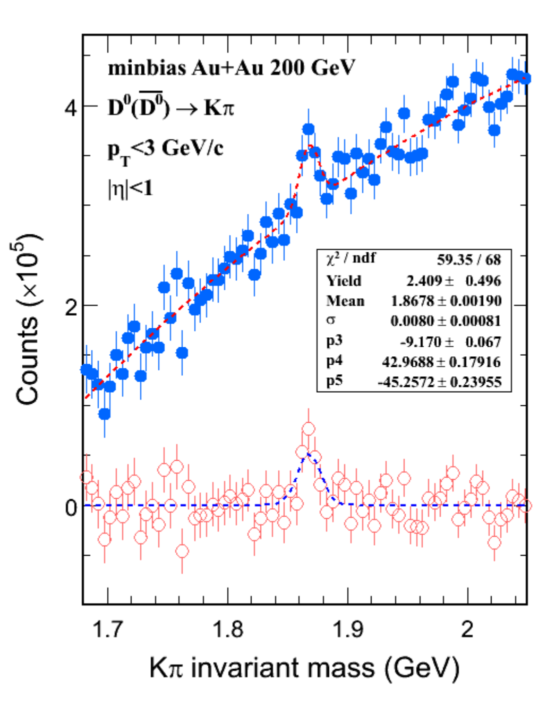
Any information from direct reconstruction of D and B-mesons would help

Next Method: Hadronic decays

d+Au and Au+Au @ 200 GeV/c

- **Combinatorial/Invariant Mass method**
  - Measurement of hadronic decay modes via invariant mass analysis.
    - D^0 (D^{0bar})$\rightarrow K^-\pi^+$($K^+\pi^-$) BR : 3.8 %
  - Obtained by pairing identified kaons and pions.
  - No triggers, no decay vertex reconstruction.
  - Typically limited to low momentum (p_T<3GeV/c).

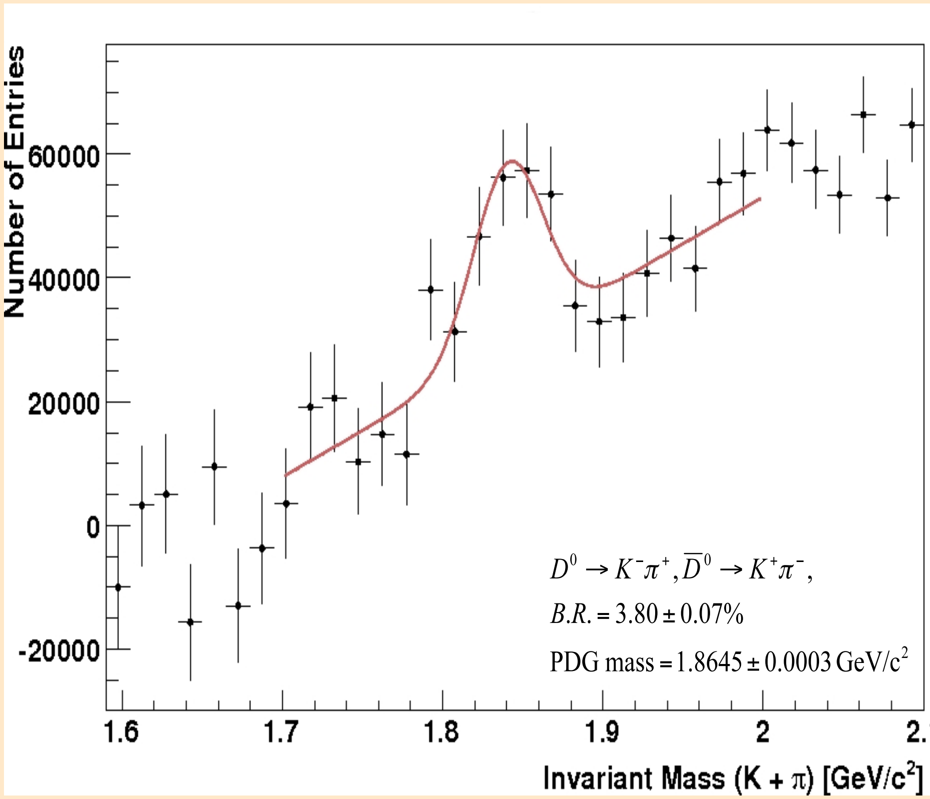


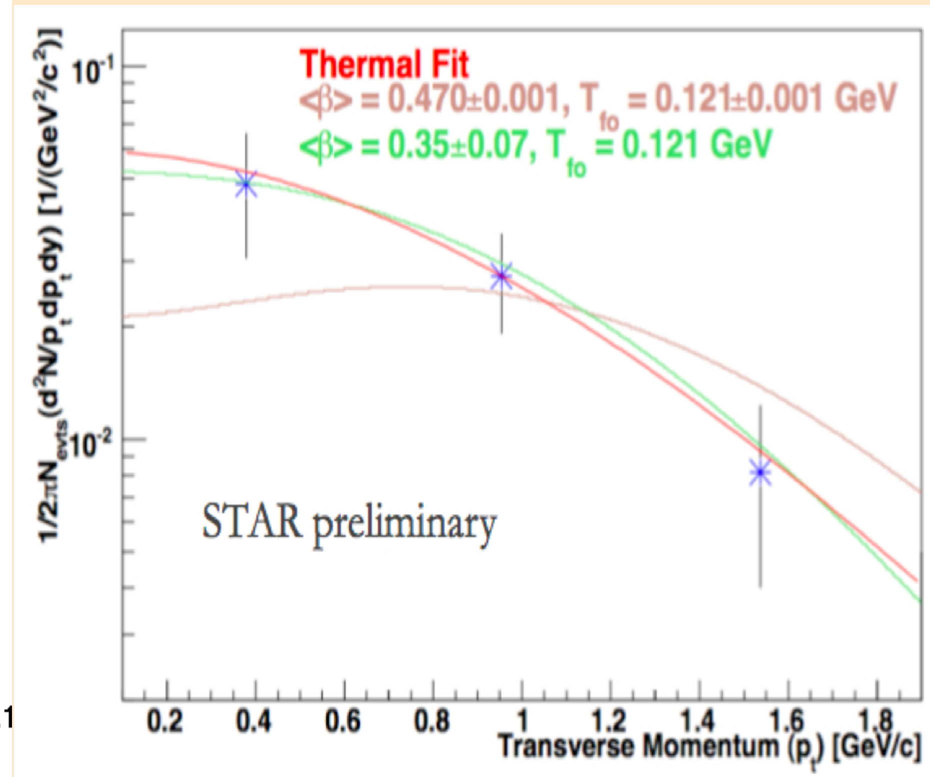


*[7]dAu : Phys. Rev. Lett. **94** (2005) 62301*
[8]AuAu : arXiv:0805.0364

Cu+Cu @ 200 GeV/c (0-60% central)

D^0 + D^0-bar

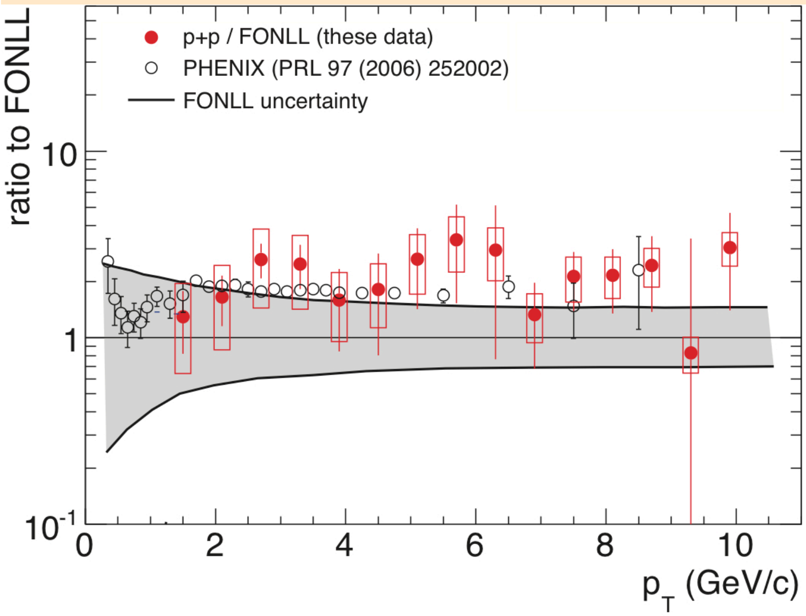


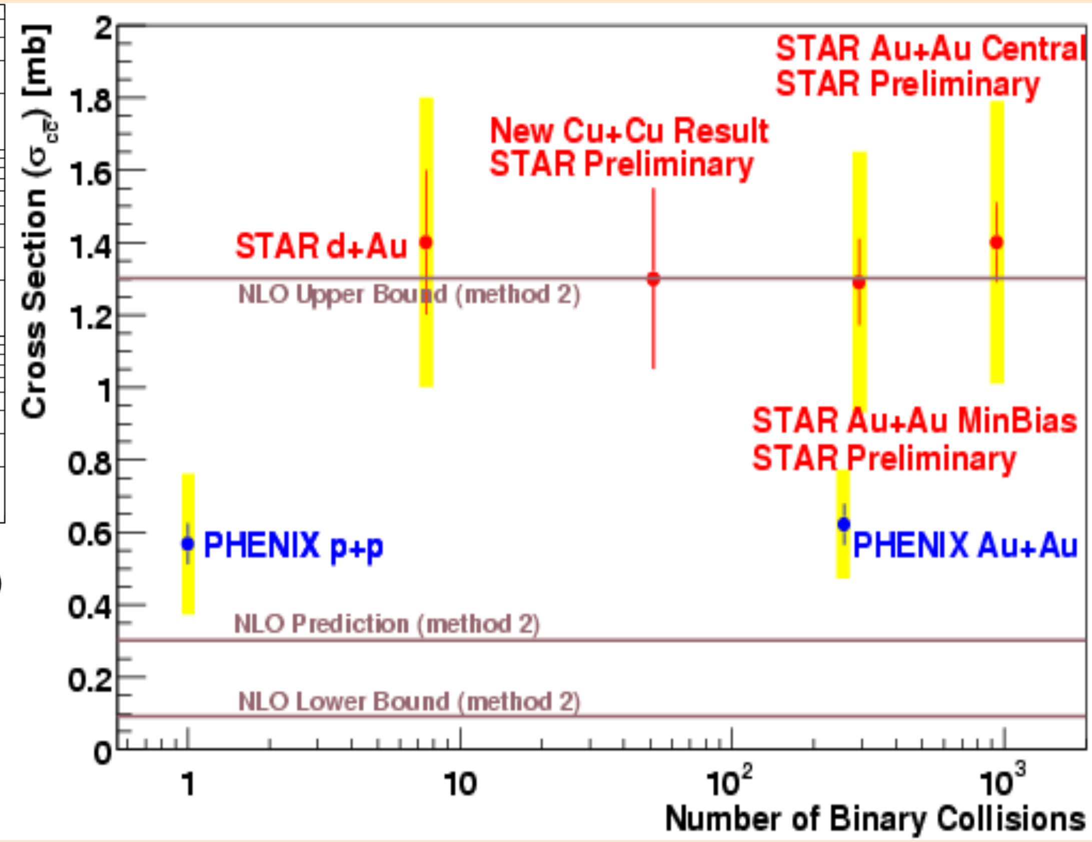


S. Baumgart: PhD Thesis, Yale Univ. and arXiv:nucl-ex/0709.4223

Result-1: It appears that the transverse-flow velocity of charm doesn't follow the light hadrons.
Result-2: x-section estimate -> next slide

Charm Cross-Section Comparison at 200 GeV





Newer STAR data/reanalysis resolved high p_T discrepancies with PHENIX but non-total x-section (see talk by S. Kabana)

NLO Ref: R. Vogt, arXiv: 0709.2531v1 [hep-ph]

PHENIX:
S. Adler, et al. Phys. Rev. Lett. 94 082301 (2005)
S. Adler, et al. Phys. Rev. Lett. 97 252002 (2005)

STAR:
C. Adler, et al. Phys. Rev. Lett. 91 172302 (2003)
S. Baumgart, arXiv:nucl-ex/0709.4223
Y. Zhang, arXiv:nucl-ex/0607011

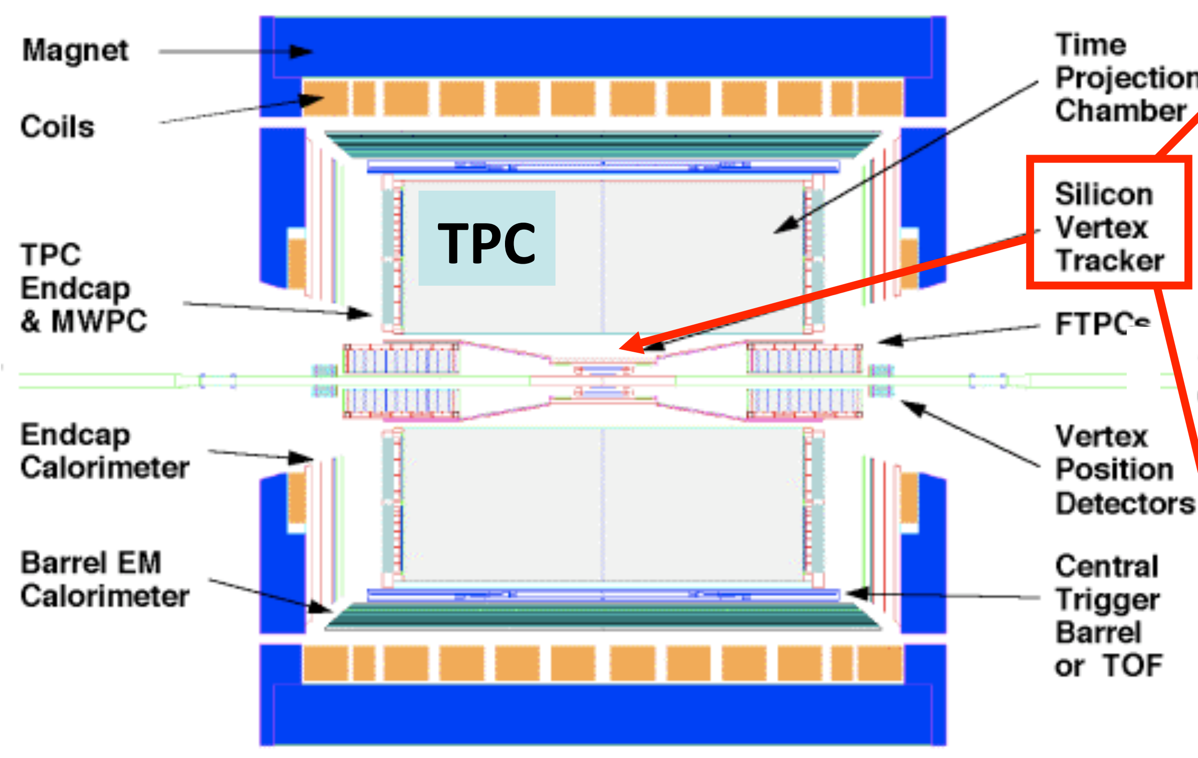
Next Method: Use the Silicon Vertex Detectors

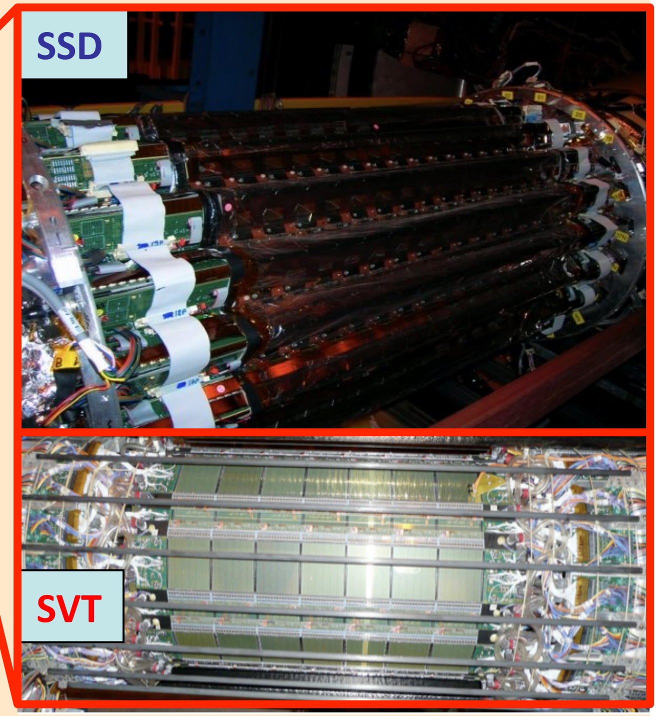
- STAR used 1990 silicon technology (drift/2d strips):
  - Designed for multi-strange particles **not** charm
  - In Full operation in 2005 and 2007

- LHC used 1995-2000 technology (pixels[“long”, thick]):

- Silicon upgrades (under construction) in STAR use today’s++ technologies (active square/thin pixels)
  - Scheduled for operation in 2013-14 Run
  - Technology can be developed for LHC (ILC) upgrades

STAR detector (in 2007)





The tracking system consisted of :

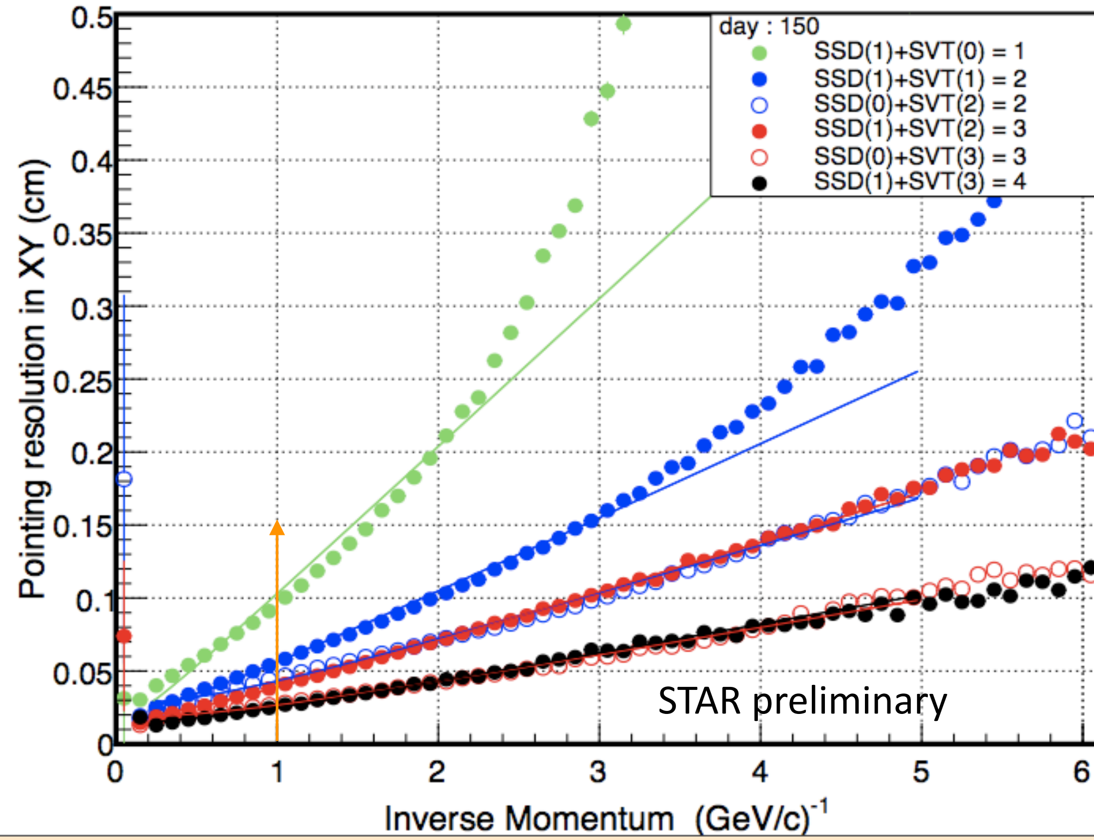
- **TPC :** provides momentum, particle identification.
- **2 silicon detectors** :
  - 1 layer of silicon strip detectors (**SSD**) and 3 layers of silicon drift detectors (**SVT**).
  - **high spatial resolution** : pointing resolution of ~250μm in transverse direction was achieved with Cu+Cu data in run 5 (y2005)[9].

[9] Fisyak Y V et al. 2008 J. Phys. Conf. Ser. 119 032017

Silicon system resolution

- run 7 Au+Au@200GeV (MinBias trigger) .
- DCA resolution as a function of inverse momentum.
- Reflect the (detector +alignment) resolution and Multiple Coulomb Scattering (MCS).

Fisyak Y V et al. 2008 J. Phys. Conf. Ser. 119 032017

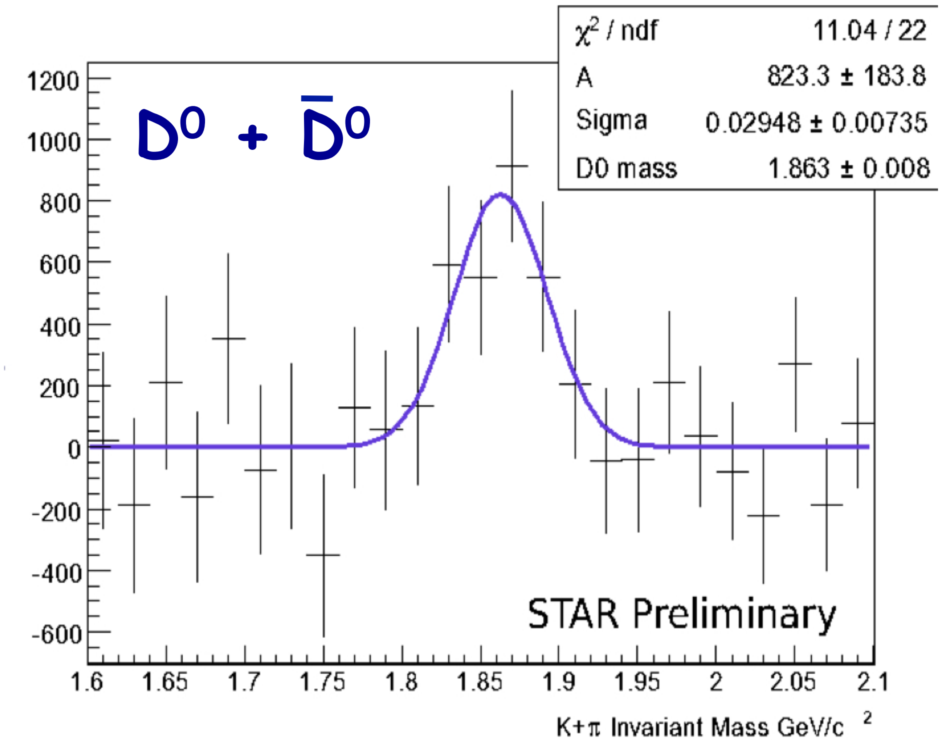


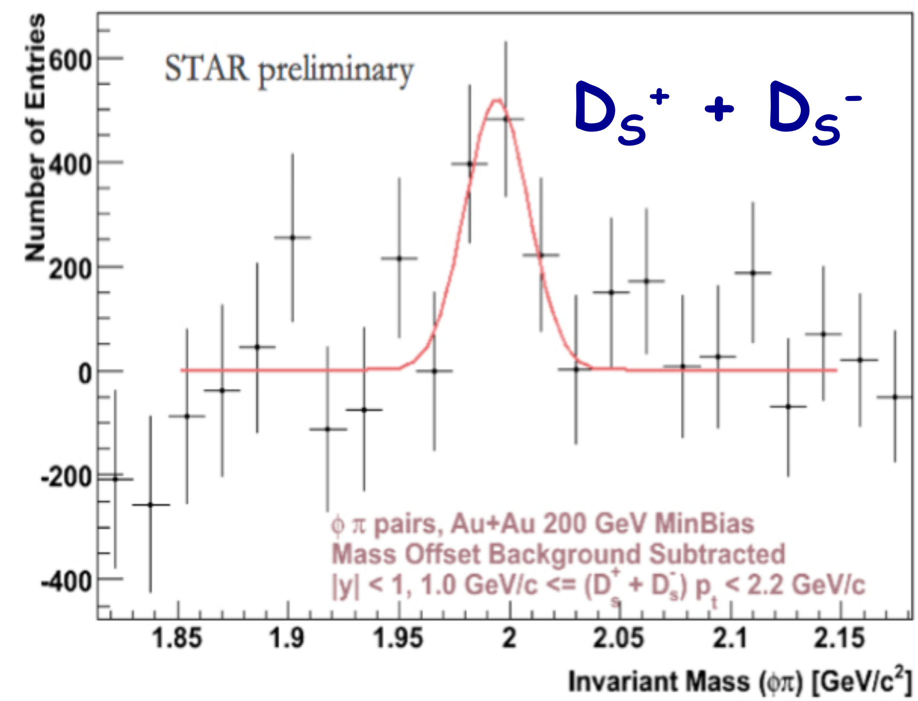
➔Including the silicon detectors in the tracking improves the pointing resolution.

➔with 4 silicon hits, the pointing resolution to the interaction point ~ 250μm at P = 1GeV/c.

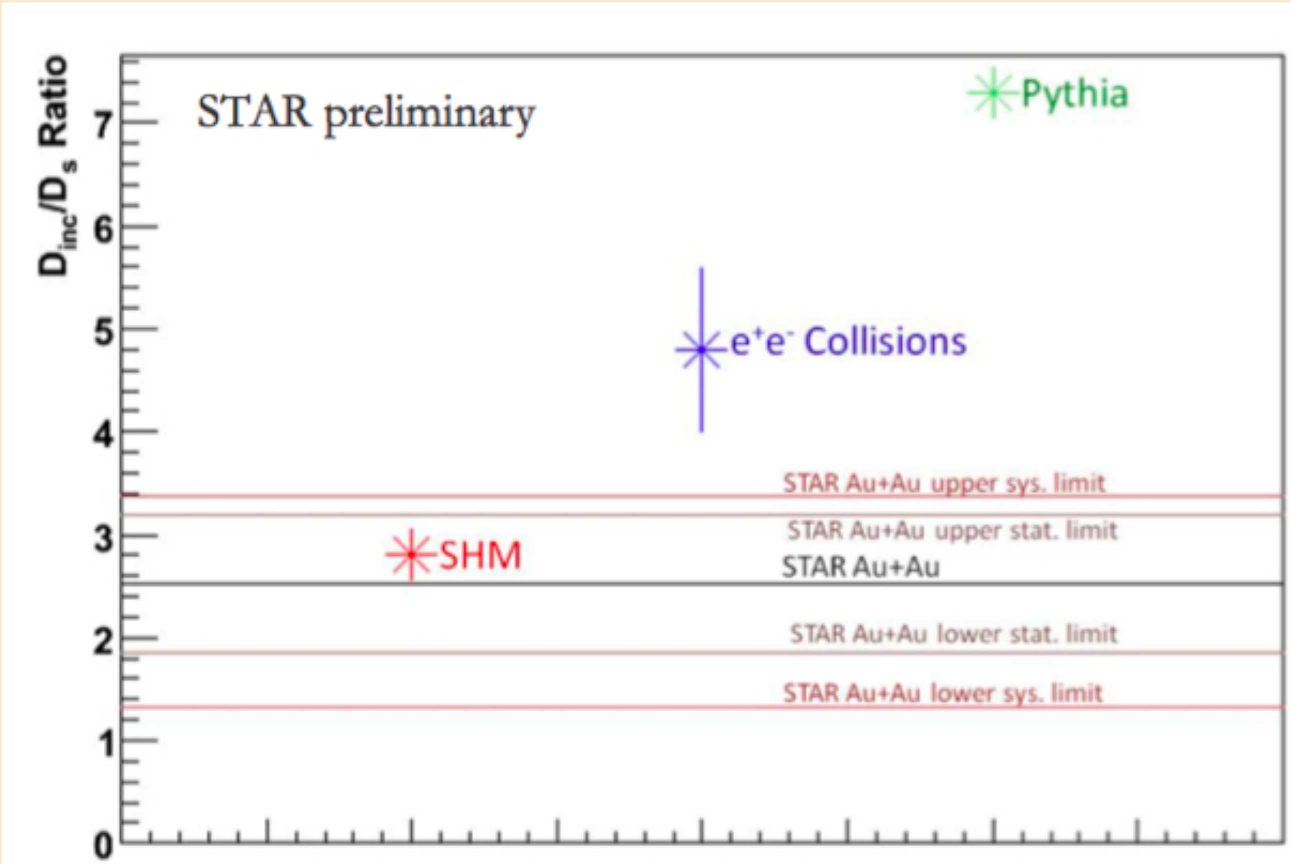
☒ Note : the Silicon Vertex detectors were not designed (thickness, geometry) for charm measurement.

Silicon + Decay vertex reconstruction (no fit)





S. LaPointe WWND2010 proceedings



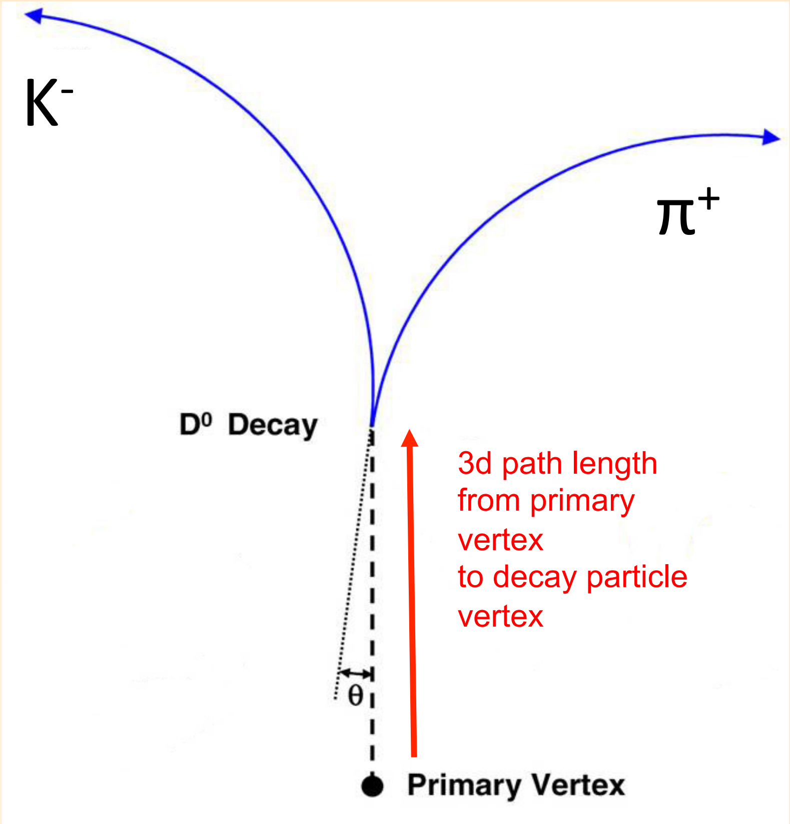
SHM = Statistical Hadronization Model
I. Kuznetsova and J. Rafelski, Eur. Phys. J. C 51 113 (2007)

Result compatible with SHM and an enhanced strangeness production

S. LaPointe WWND2010 proceedings

Next Step: + decay vertex fitting

- Full reconstruction/fit of the decay vertex [10] .
- Introduction/Use of full track error matrix for best error estimates.
- Optimization of cuts based on MC studies.



An estimated factor of two was gained in sec. vertex resolution

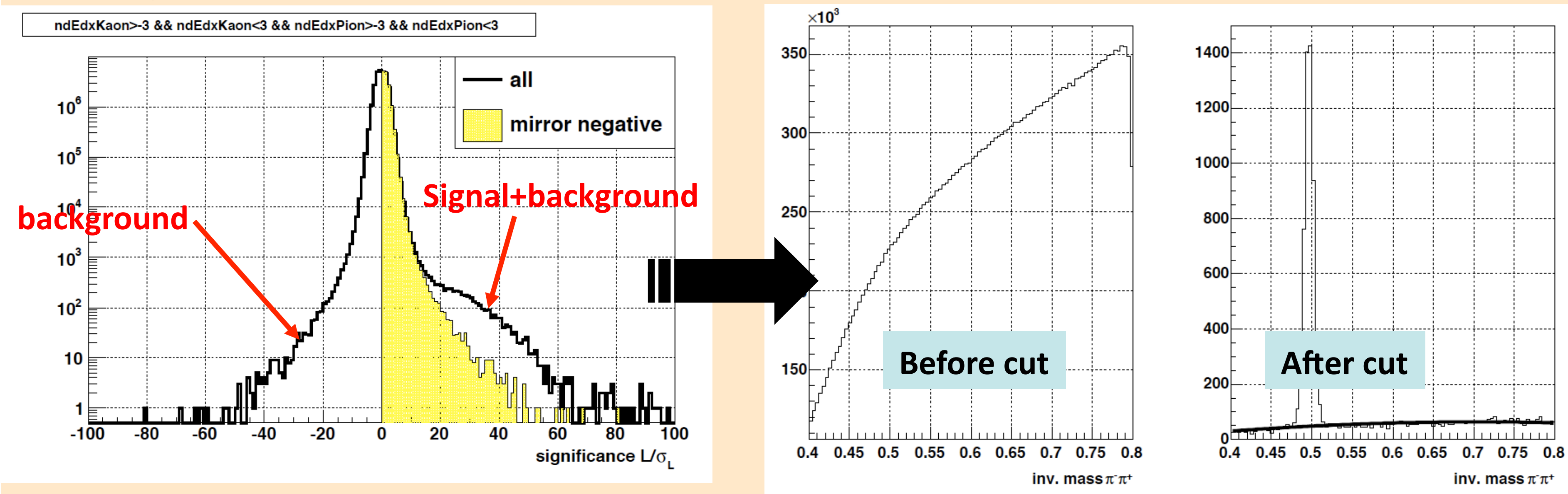
[10] Decay Chain Fitting with a Kalman Filter, W. D. Hulsbergen (arxiv:physics,0503191)

Proof of principle with K^0_s

- Signed decay length :
  - an excess can be observed on the positive side of the decay length distribution, indicating the presence of long-lived decays.
  - use the decay length significance $S_L = L/\sigma_L$ to improve the signal.
  - more appropriate because of the momentum dependence L and σ_L .

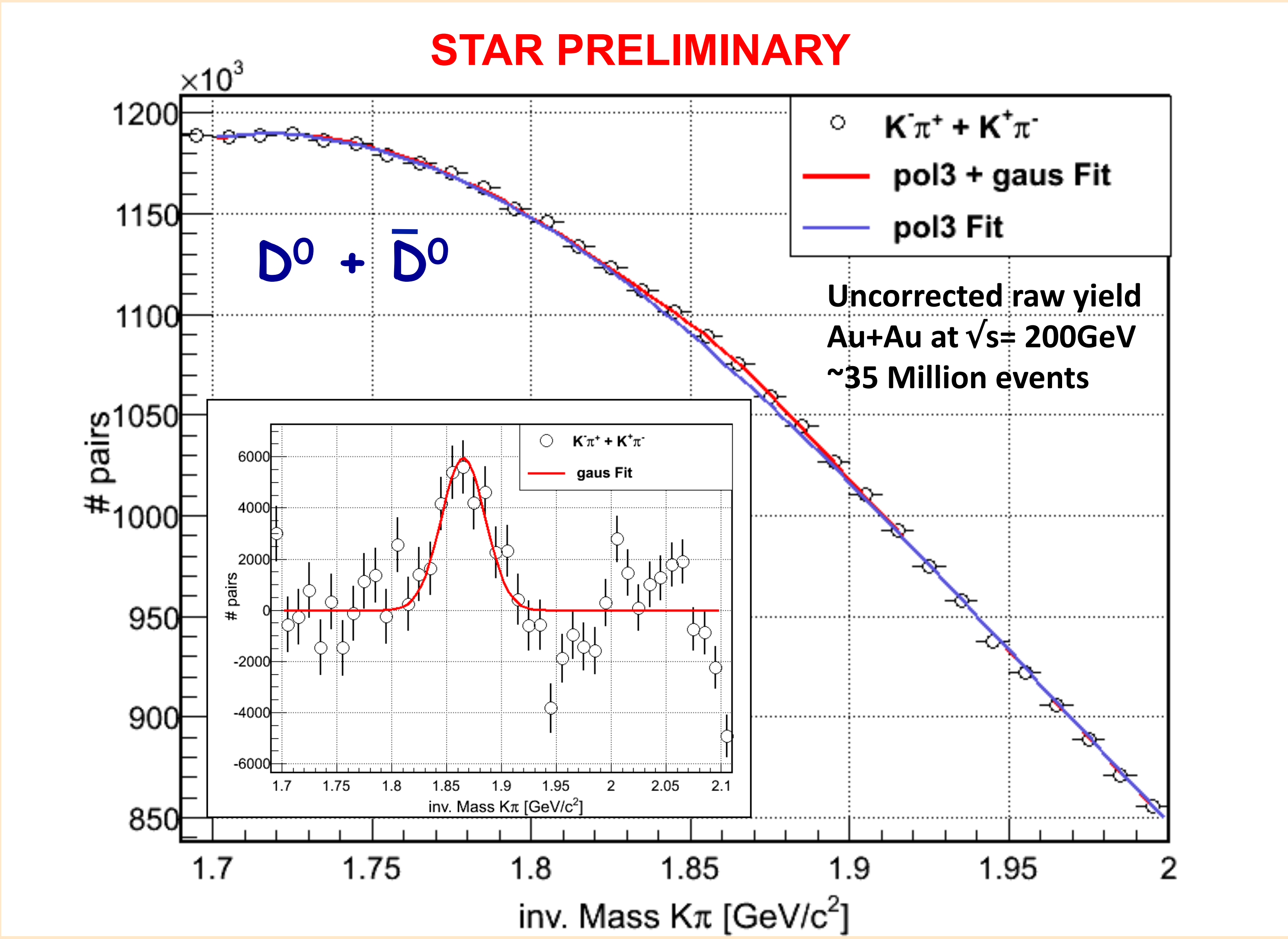
- Test with K^0_s decay reconstruction :

  $K^0_S \rightarrow \pi^+ \pi^-$ (BR = 69.2%) ; $c\tau$ = 2.68 cm ; Mass = 0.497 MeV/c^2



✔ After using a cut S_L > 10, a clear peak at the K^0_S mass is observed.

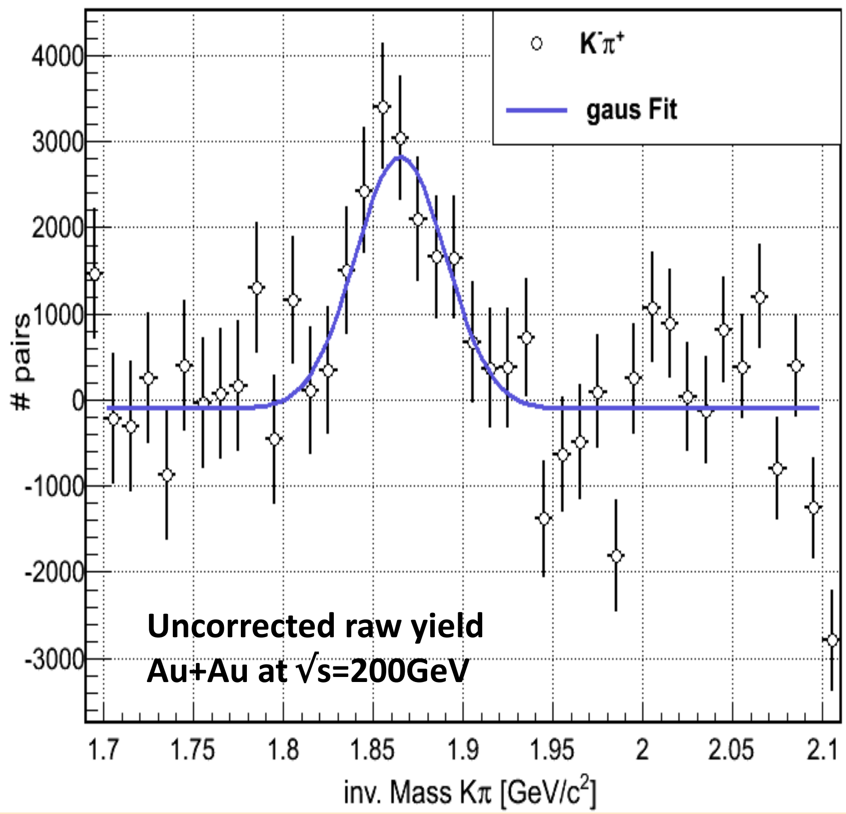
Invariant mass of D^0 and D^0bar combined

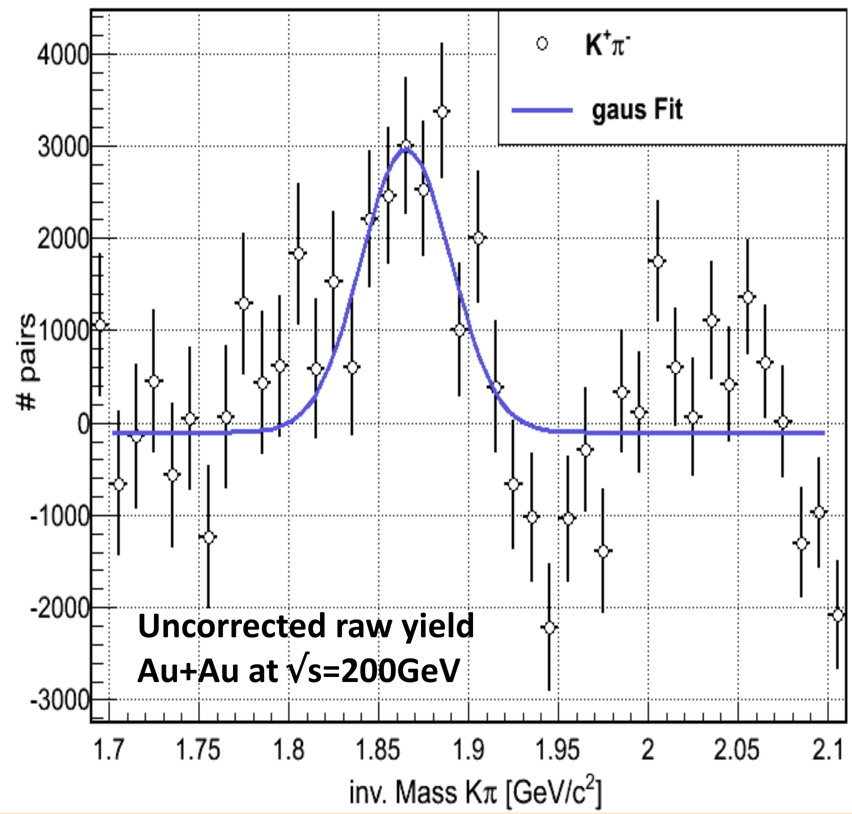


Secondary vertex fit gives a factor of ~two gain in significance

Invariant mass of D^0 and D^0bar separately

STAR PRELIMINARY

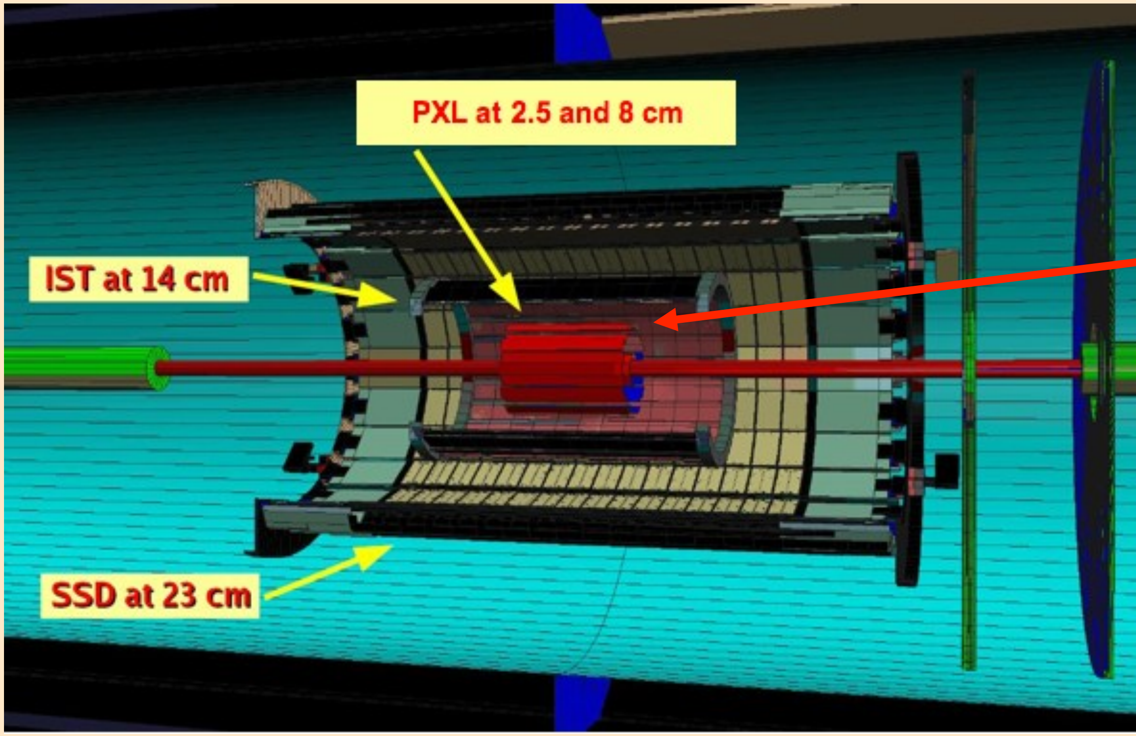


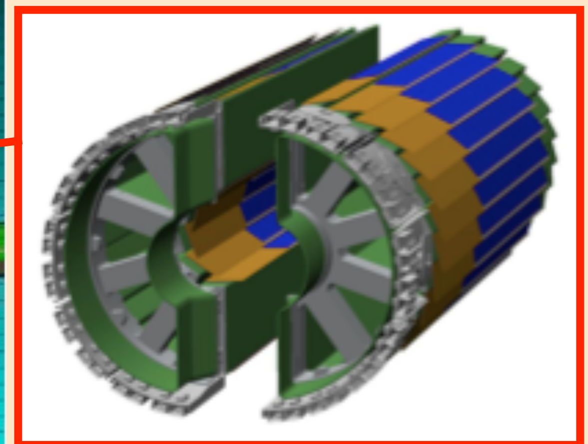


Ratio of D^0bar/D^0 = 1.05 +/- .19(stat.)

Compatible with vanishing μ_B (consistency check)

Future measurements at STAR

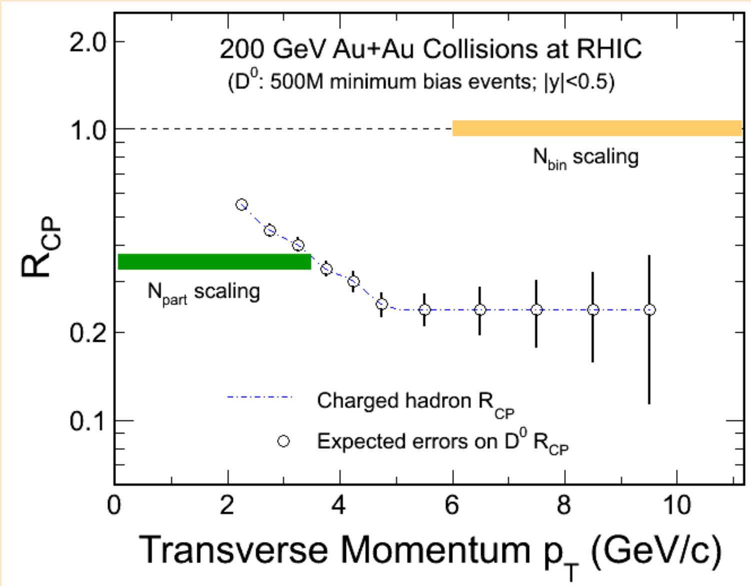


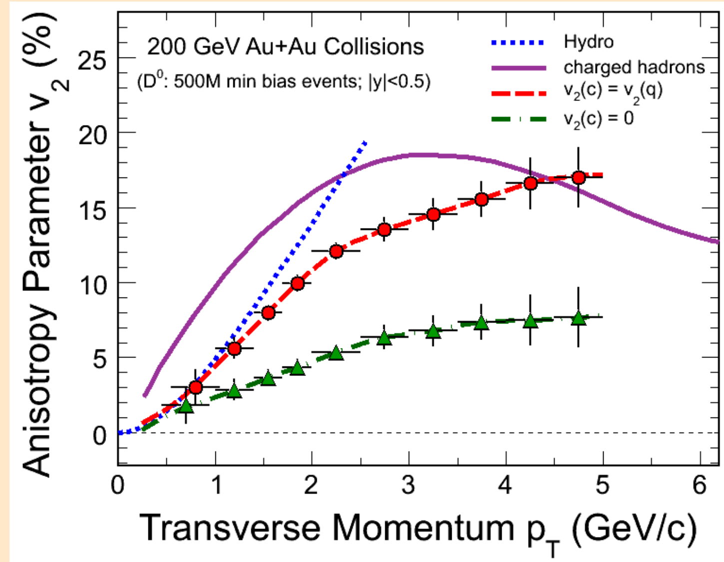


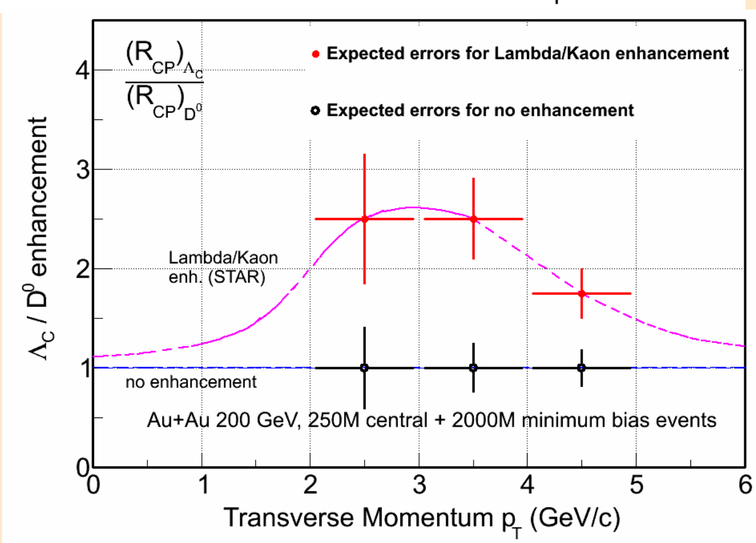
- future upgrade in STAR : **H**eavy **F**lavor **T**racker[11]
  - Low mass detector designed to identify mid-rapidity Charm and Beauty mesons and baryons through direct reconstruction and measurement of the displaced vertex with unprecedented pointing resolution.
  - CMOS sensors will provide single track resolution ~ 20-30 μm.

[11]: E. Anderssen et al., A Heavy Flavor Tracker for STAR, http://www.osti.gov/bridge/servlets/purl/939892-beI2Up/939892.pdf

Key measurements of the HFT







Measurements:

1) v_2 and R_{cp} of D^0
2) Charm baryon Λ_c
3) Bottom cross sections

Summary and perspectives

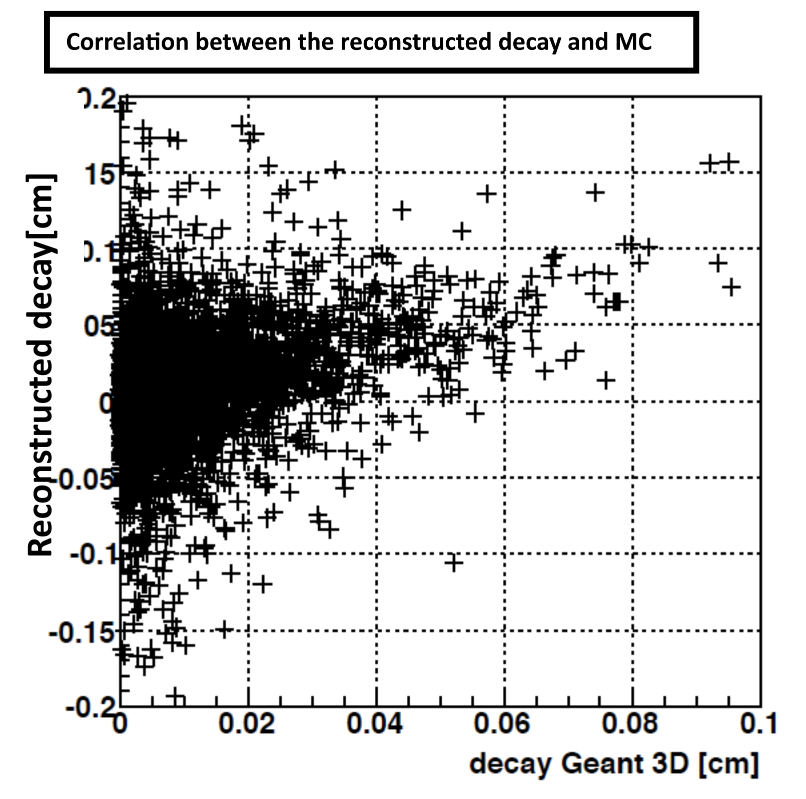
- We presented a method (not chronological) evolution of heavy flavor reconstruction

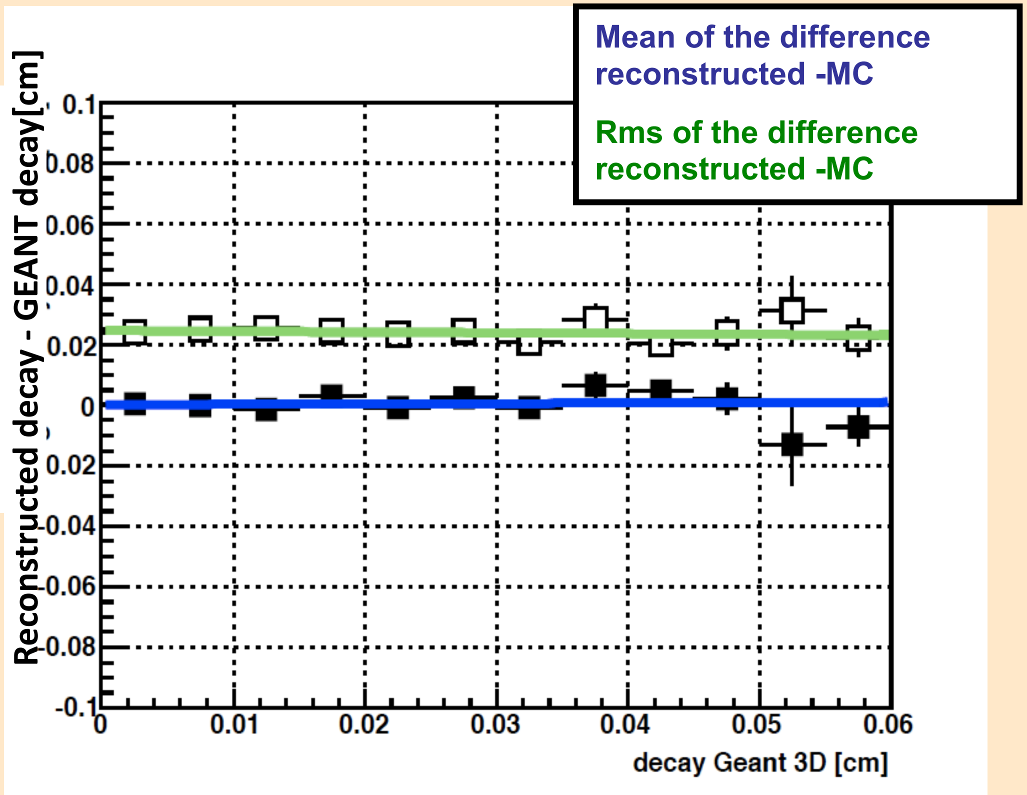
- Ongoing efforts and goals for QM2011:
  - Analyze full statistics.
  - Estimate total **x-section** (confirm recent results, smaller errors).
  - First estimate of D^0s $\mathbf{v_2}$ (to compare with NPE).

- Silicon upgrades (HFT, under construction) in STAR will perform detailed exclusive charm and bottom studies.

End

Secondary vertex fit (simulation studies)





•There is no systematic shift in reconstructed quantities.

•The standard deviation of the distribution is flat at ~ 250 μm , which is of the order of the resolution of (SSD+SVT).

Conversion from dN/dy to Cross-Section

$$\sigma_{c\bar{c}}^{NN} = dN_{D^0}^{Cu+Cu} / dy \times \sigma_{inel}^{pp} / N_{bin}^{Cu+Cu} \times f / R$$

$$dN_{D^0} / dy = 0.184 \pm 0.035\,(\text{stat.})$$

number of binary collisions $\quad N_{binary}^{Cu+Cu} = 51.5 + 1.0 - 2.9$

p+p inelastic cross section $\quad \sigma_{inel}^{pp} = 42\, mb$

conversion to full rapidity
(using PYTHIA simulation, ver. 6.152) $\quad f = 4.7 \pm 0.7$

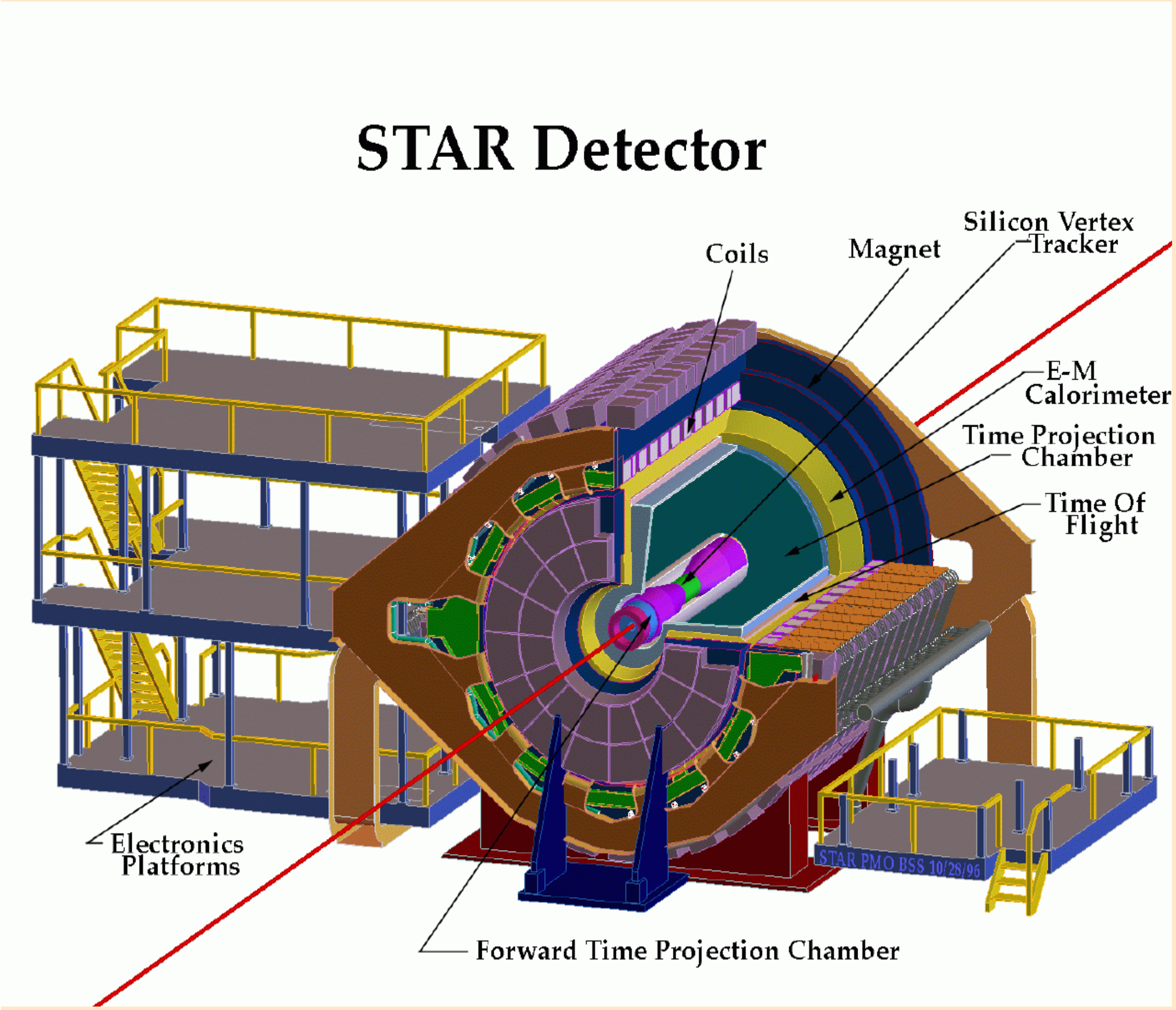
ratio from e^+e^- collider data $\quad R = N_{D^0} / N_{c\bar{c}} = 0.54 \pm 0.05$

$$\boxed{\Rightarrow \sigma_{c\bar{c}}^{NN} = 1.30 \pm 0.25\,(stat.)\, mb}$$

$$\text{sys. error from dN/dy to } \sigma \text{ conversion} = +0.17 - 0.18\, mb$$

*Systematic error evaluation for dN/dy in progress.

STAR detector



Time **P**rojection **C**hamber :

- provides momentum, particle identification.
- separation of electrons from pions for p>1.5GeV/c.

Barrel **E**lectro-**M**agnetic **C**alorimeter :

- provides electron energy measurement E.
- expect **p**/E ~ 1for electrons.

Barrel **S**hower **M**aximum **D**etector

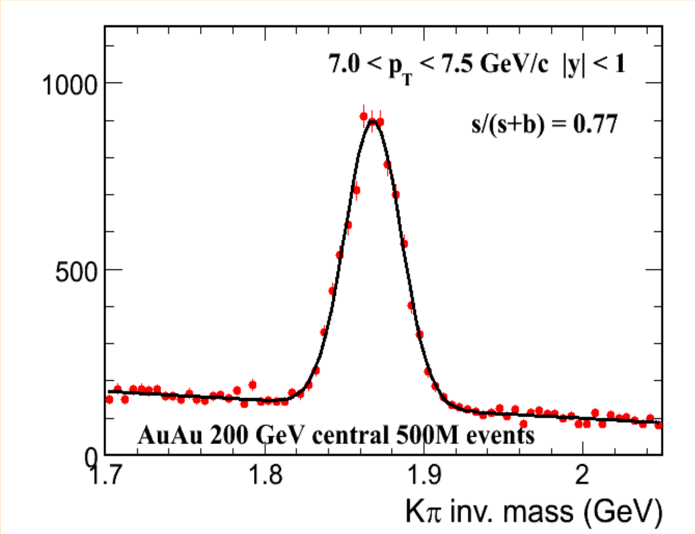
- provides shower position.
- electron shower has broader distribution (# of strips) than hadron shower.

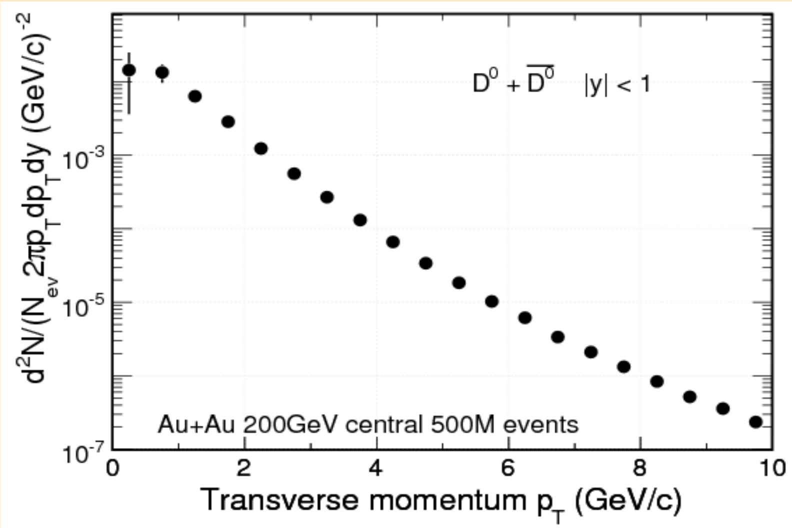
Inner tracker system

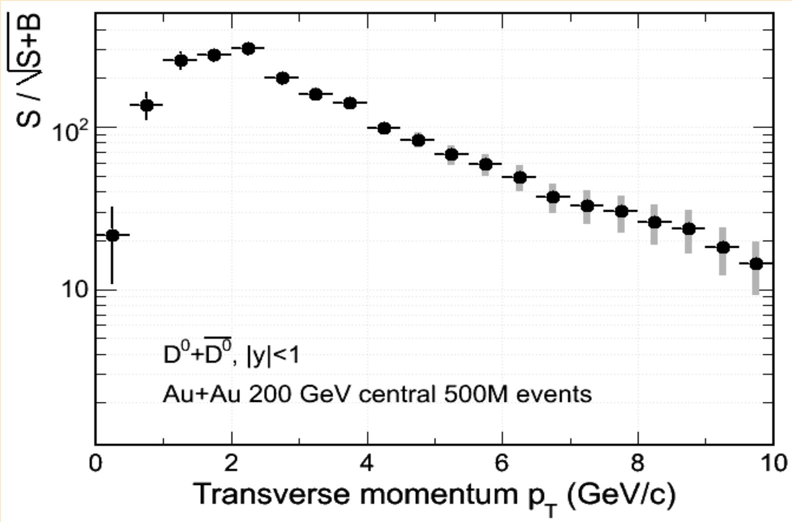
	Number of layer (radius)	technology	Sensor size (mm^2)	Intrinsic resolution (design)	Radiation length
SSD	1 (23 cm)	Double sided silicon strips	42 x 73	r/φ ~ 20 μm Z ~ 700 μm	~1% X_0
SVT	3 (6.8 cm ; 10.8 cm ; 14.8 cm)	Silicon drift	60 x 60	r/φ ~ 20 μm Z ~ 20 μm	~1.5% X_0 per layer

Performance example on the $D^0 \to K\pi$ reconstruction (HFT)

- Simulation of Au+Au@200GeV Hijing events with STAR tracking software including pixel pileup (RHIC-II luminosity) extrapolated to 500 M events.
- Identification done via topological cuts and PID using Time Of Flight

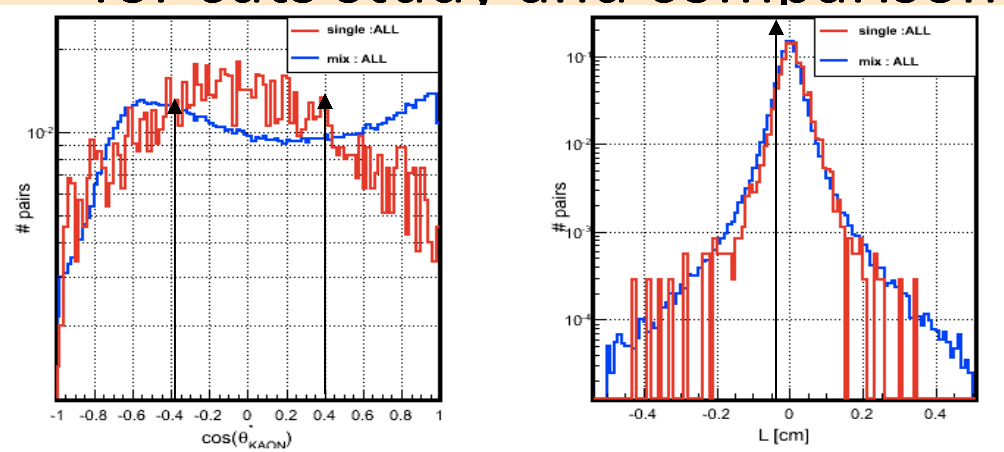






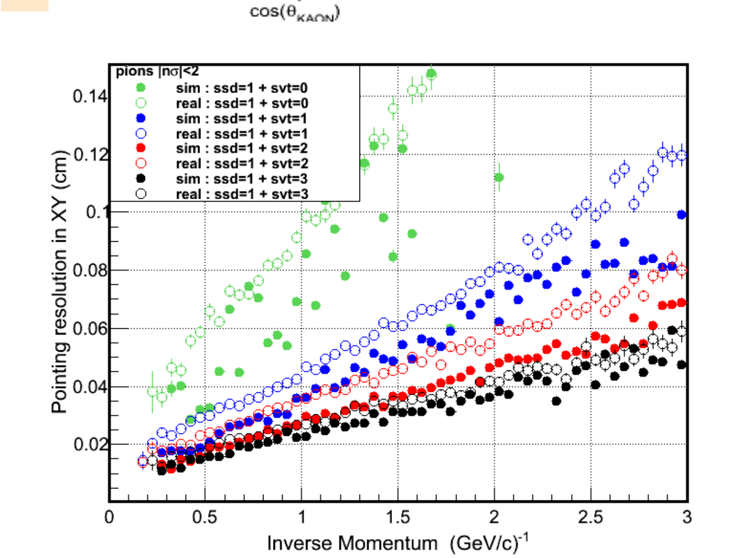
Simulation

- Use of single D^0+D^0bar mixing in Hijing Au+Au events for cuts study and comparison of simulation with real.



- left panel : cosine of kaon daughter in the D^0 frame for single D^0 and D^0 + hijing

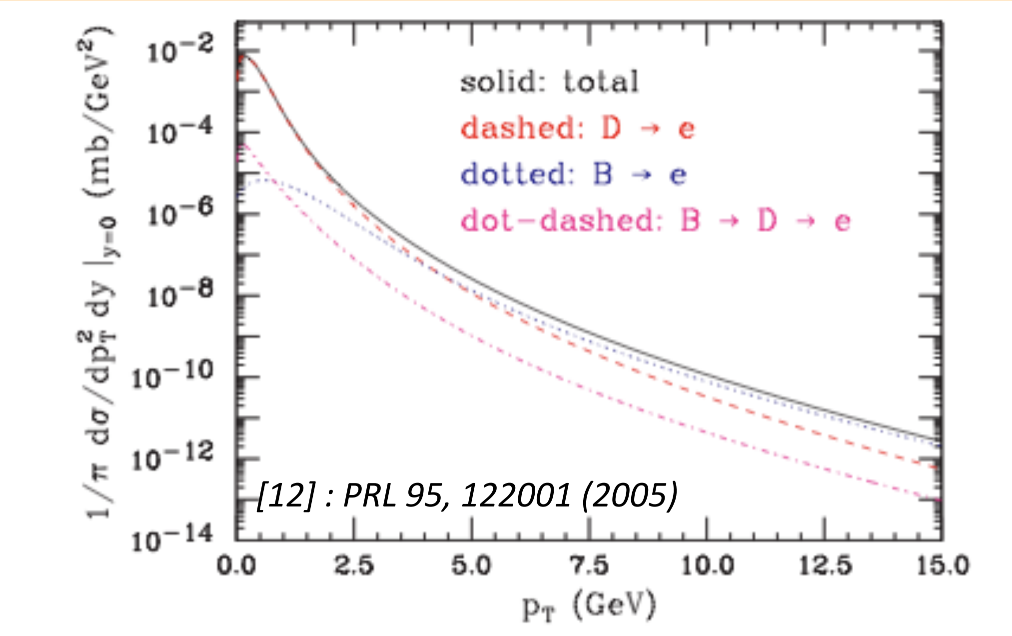
- Right panel : signed decay length for single D^0 and D^0 + hijing



- Comparison of DCA of daughters to PV (open =real data, filled = simulation)

Why using a secondary vertex fit

- Limitations of semi leptonic channel measurement:
  1. uncertainty of difference charm and bottom hadron contributions.
  2. incomplete kinematics measurement.
  3. pQCD predicts bottom contribution to be similar to charm production around $p_T^{electron} \sim 5$GeV[12].



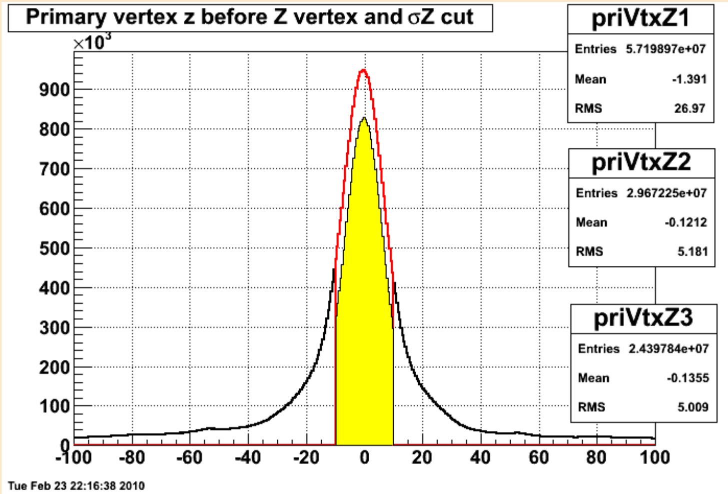
•To achieve precision measurement on the heavy quark production, a full topological reconstruction of the decaying particle is needed.

➔Challenging for charmed particles due to the small decay length ($c\tau$ (D^0) ~ 123 μm).

Strategy of reconstruction/ Datasets

➔Apply cuts to reduce the combinatorial background and select good quality tracks and pairs.

1. EVENTS level :
   - Primary vertex position and its error (ensured by trigger detectors).

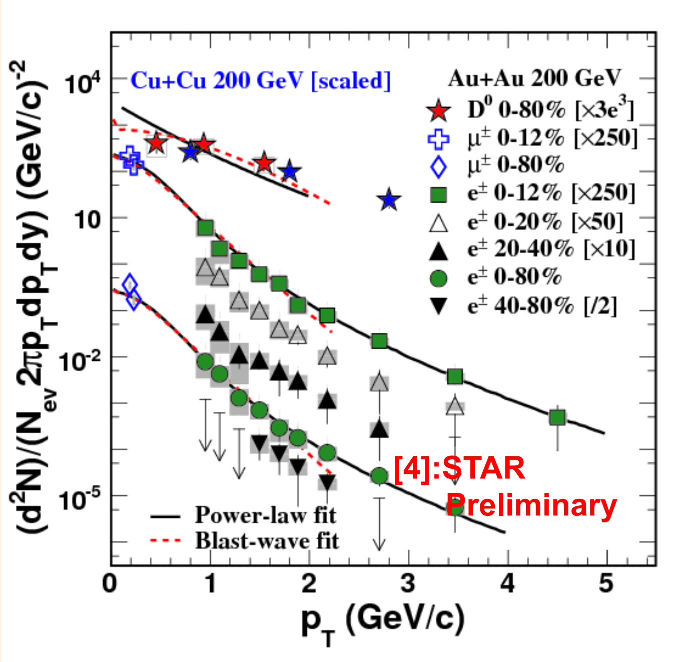


2. TRACKS level
   - Number of hits in the vertex detectors : **Silicon Hits > 2** (tracks with sufficient DCA resolution).
   - Number of fitted **TPC hits > 20** (avoid splitting tracks).
   - Particle identification : ndEdx : $|n\sigma_K|<2$, $|n\sigma_\pi|<2$ (select kaon and pion candidates).
   - Pseudo-rapidity : $|\eta|<1$ (Silicon detector acceptance).
   - DCA to Primary vertex (transverse) **DCA_{xy}< .1 cm** (remove tracks compatibles with strange particles decays).
3. PAIRS level
   - Momentum of pairs
   - results given by the secondary vertex fit

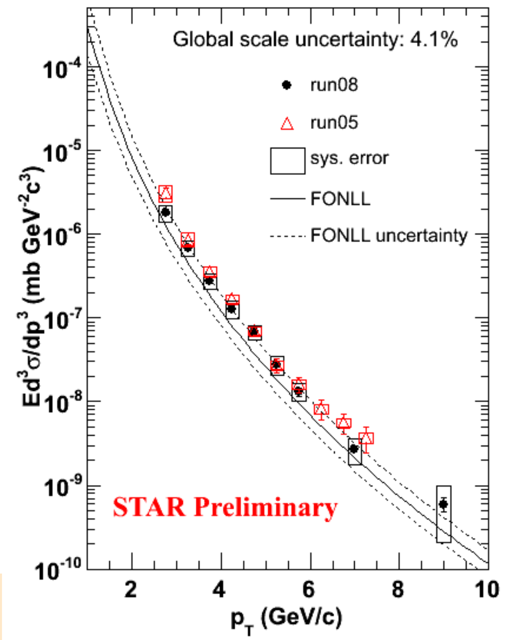
Measurement via semi leptonic decays

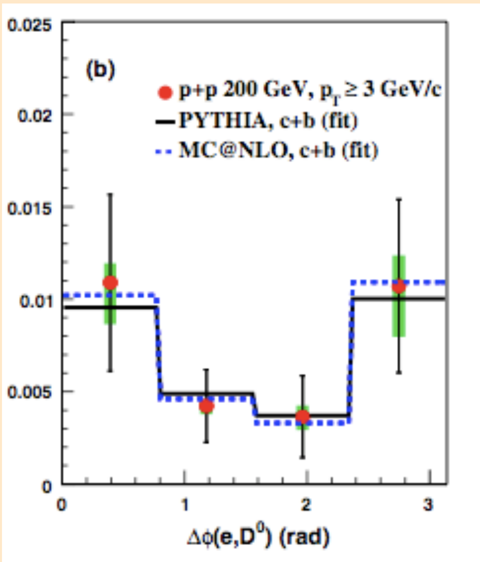
- **indirect method**
  - Electrons from semi-leptonic decays of B,D mesons .
    - $D^0 \rightarrow e^+ + X$ BR:6.9 %
    - $D^{+/-} \rightarrow e^{+/-} + X$ BR:17.2%
  - Measurement include electrons from B and D decays.
  - Use of specific triggers.
  - Large p_T range.

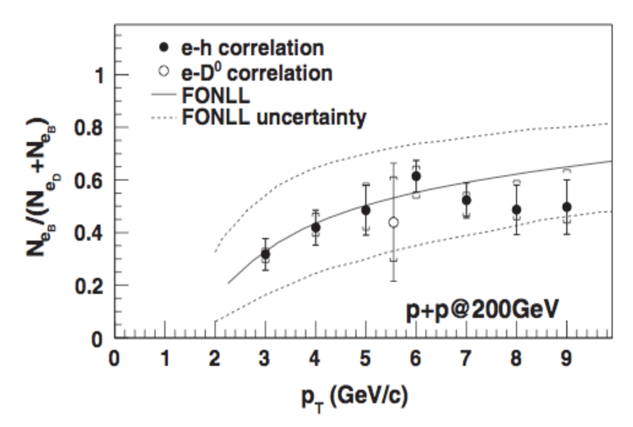
  - Azimuthal correlation of electrons with open charm meson would disentangle between the charm and bottom contribution[6].



STAR recent high p_T NPE measurements in 200 GeV p+p collisions[5]







[4]nucl-ex/0805.0364; Y Zhang QM2008
[5]W. Xie, DIS2010
*[6]Phys. Lett. B**671**(2008) 361 ;*
*Phys. Rev. Lett. **105** (2010) 202301*