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 in the earlier stage of the collision dominantly via gluon fusion:

- • not affected by chiral symmetry restoration.
- • production cross section are found to follow binary scaling[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.

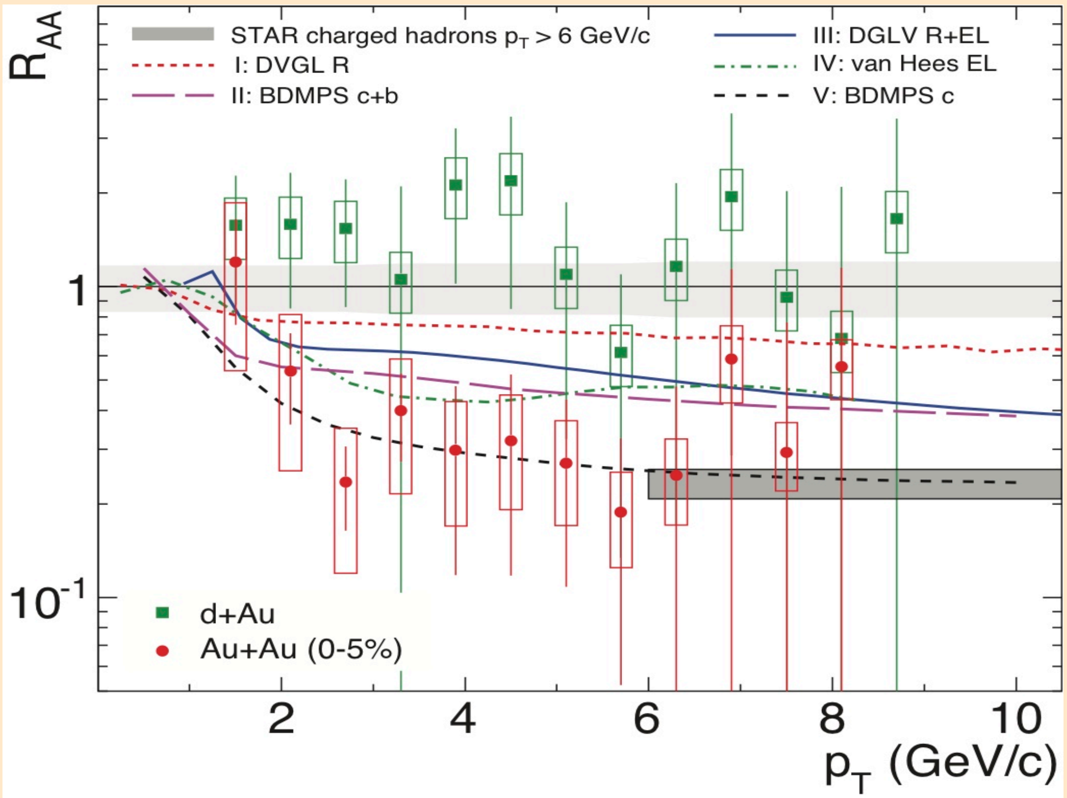
*[1]Phys. Rev. Lett. **94** (2005) 082301*
*[2]Phys. Lett. B**519** (2001) 199-206*
*[3]Phys. Rev. Lett. **98** (2007) 192301*

The Beginnings - Heavy Quark Energy Loss – NPE Method

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

and 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 -

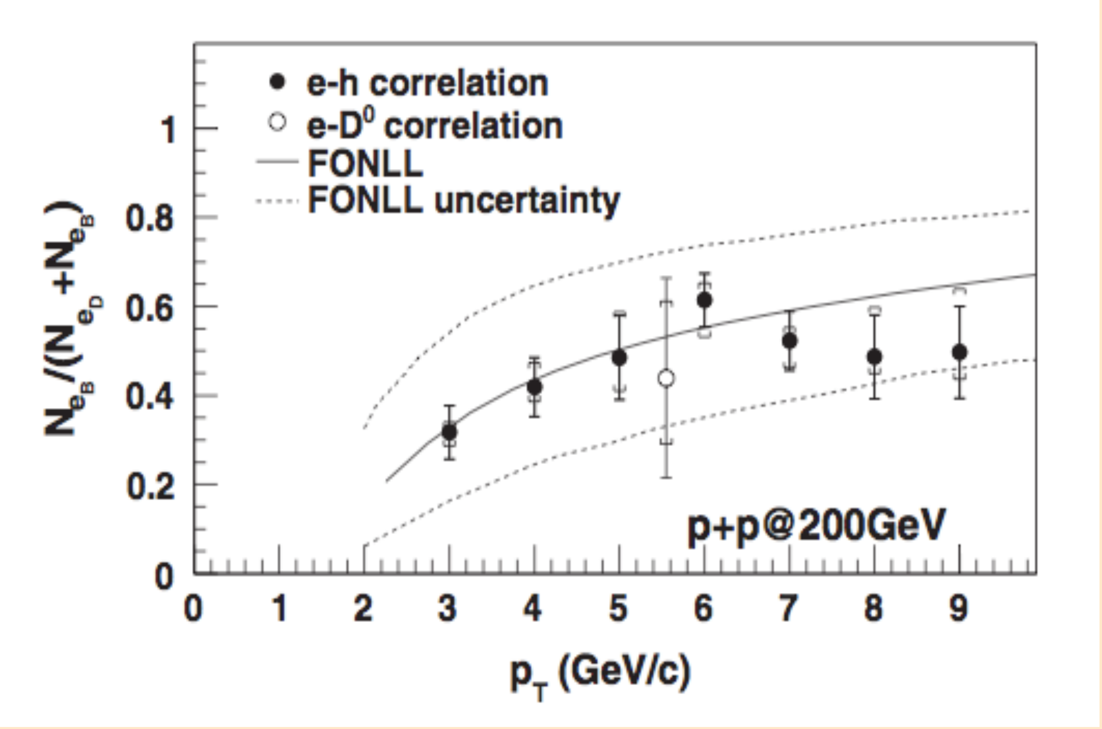
- challenge our understanding of the energy loss mechanism
- force us to RE-think about the elastic-collisions energy loss
- **Requires direct measurements of c- and b-hadrons.**

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

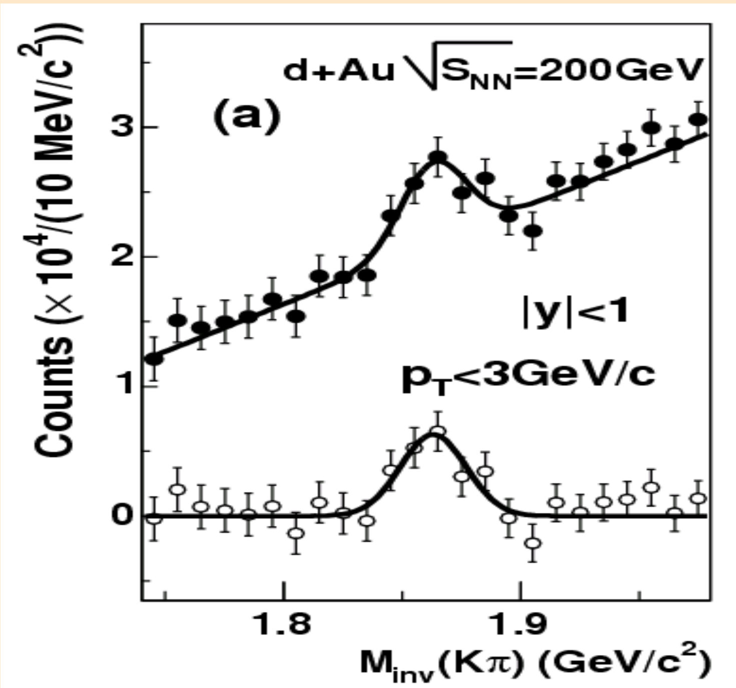


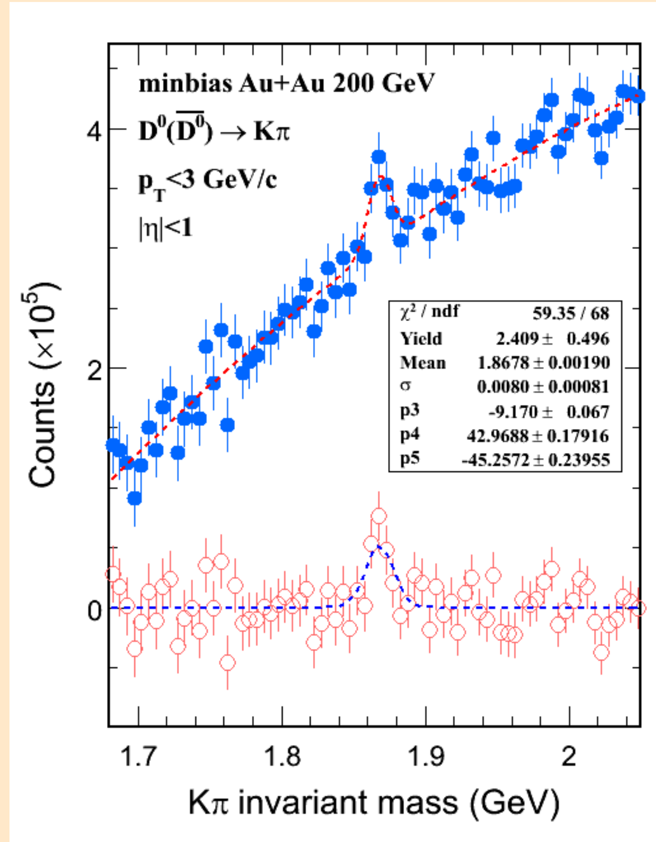
Any information from direct reconstruction of D and B-mesons would help

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).

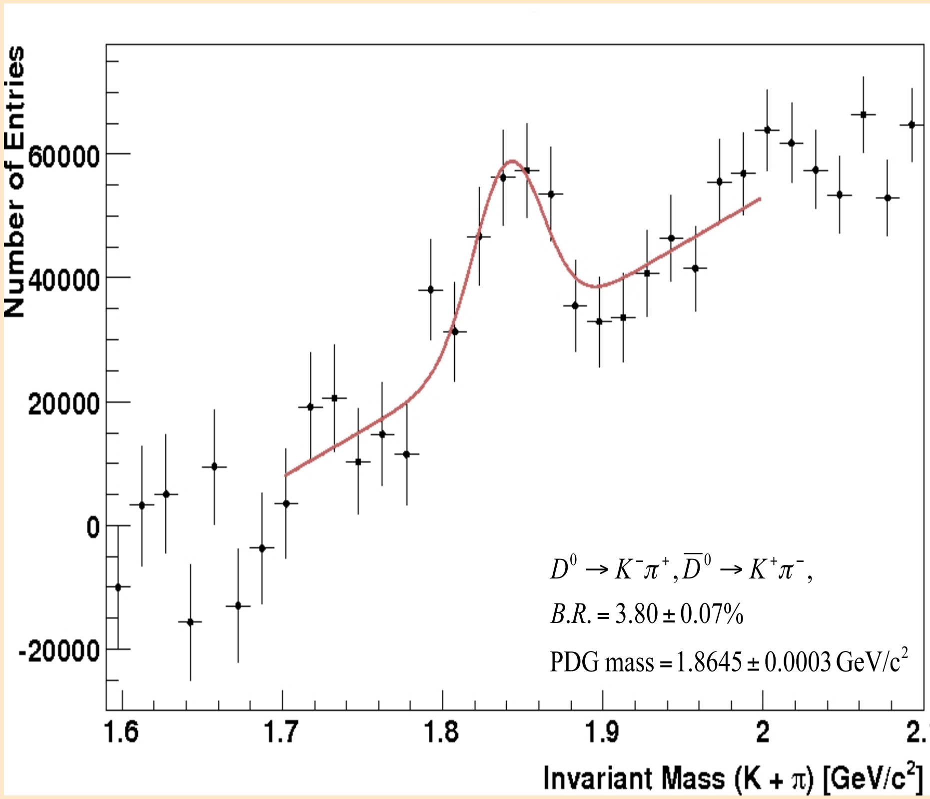


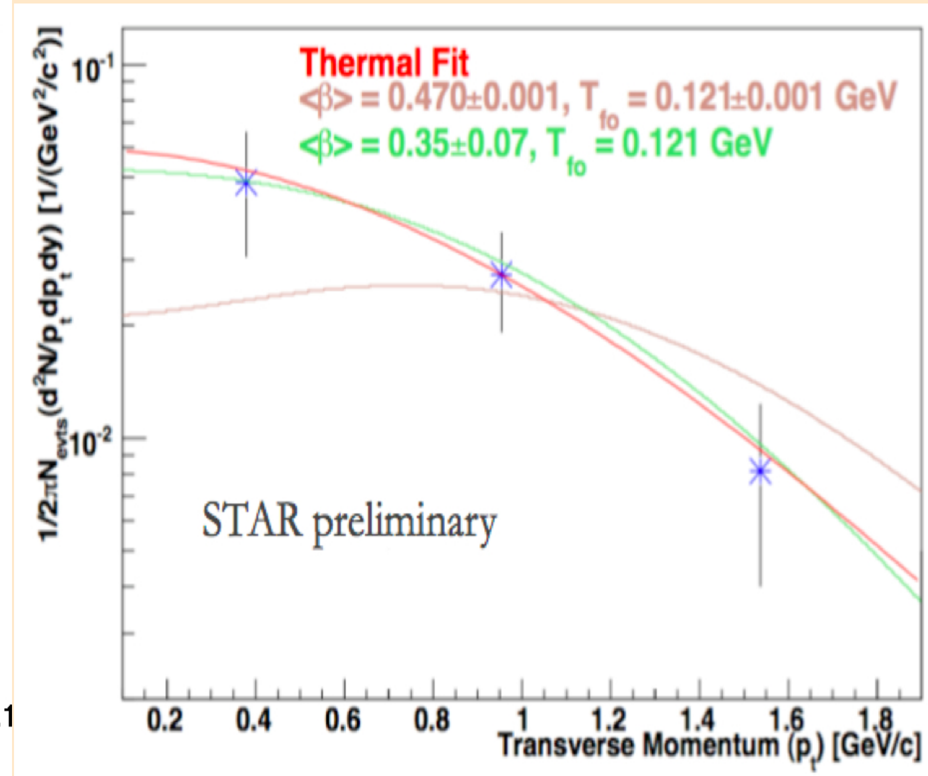


*[7]dAu : Phys. Rev. Lett. **94** (2005) 62301*
[8]AuAu : arXiv:0805.0364

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

D^0 + D^0-bar

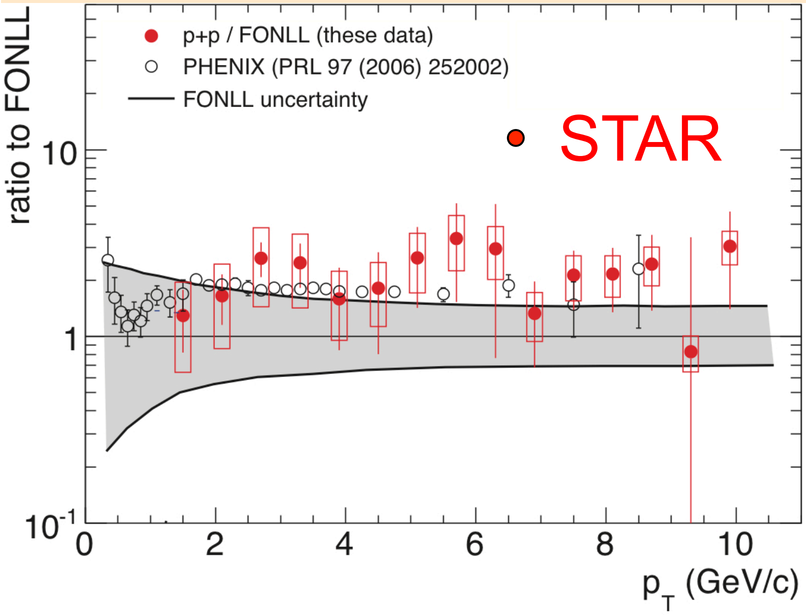


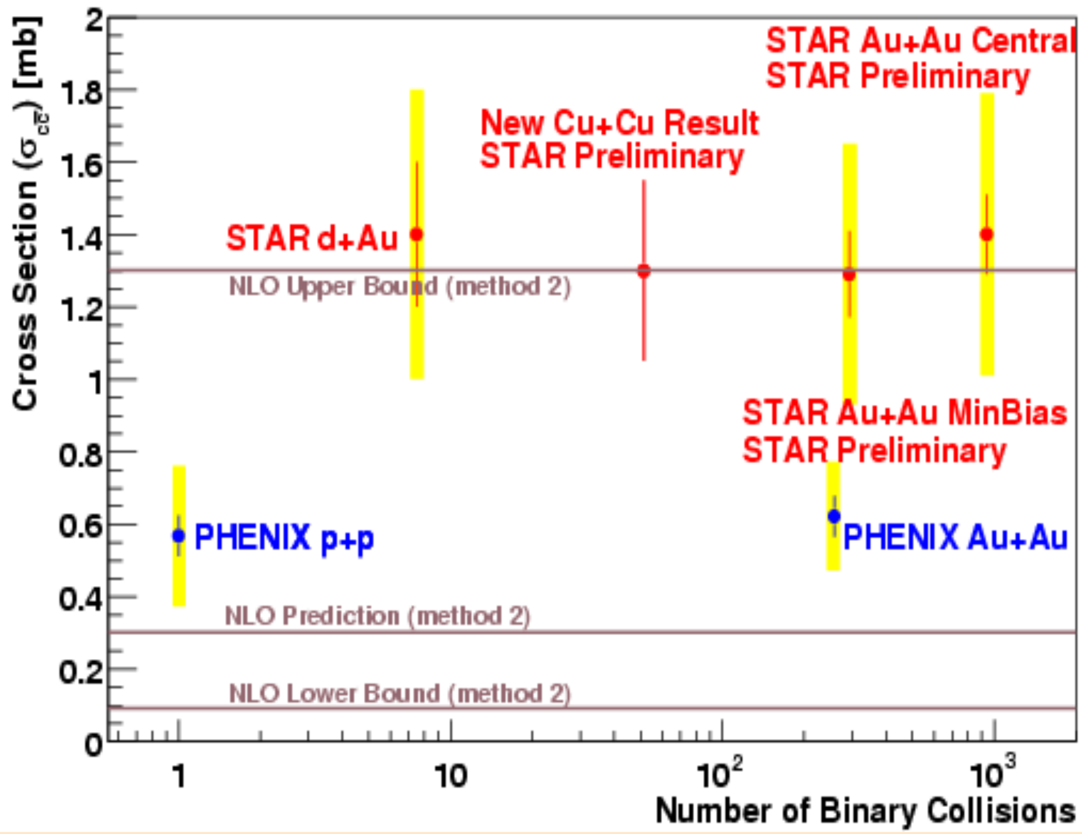


S. Baumgart: PhD Thesis, Yale Univ. and arXiv:nucl-ex/0709.4223

Result-1: It appears that the transverse-flow velocity of charm doesn't follow the light hadrons (slower).
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

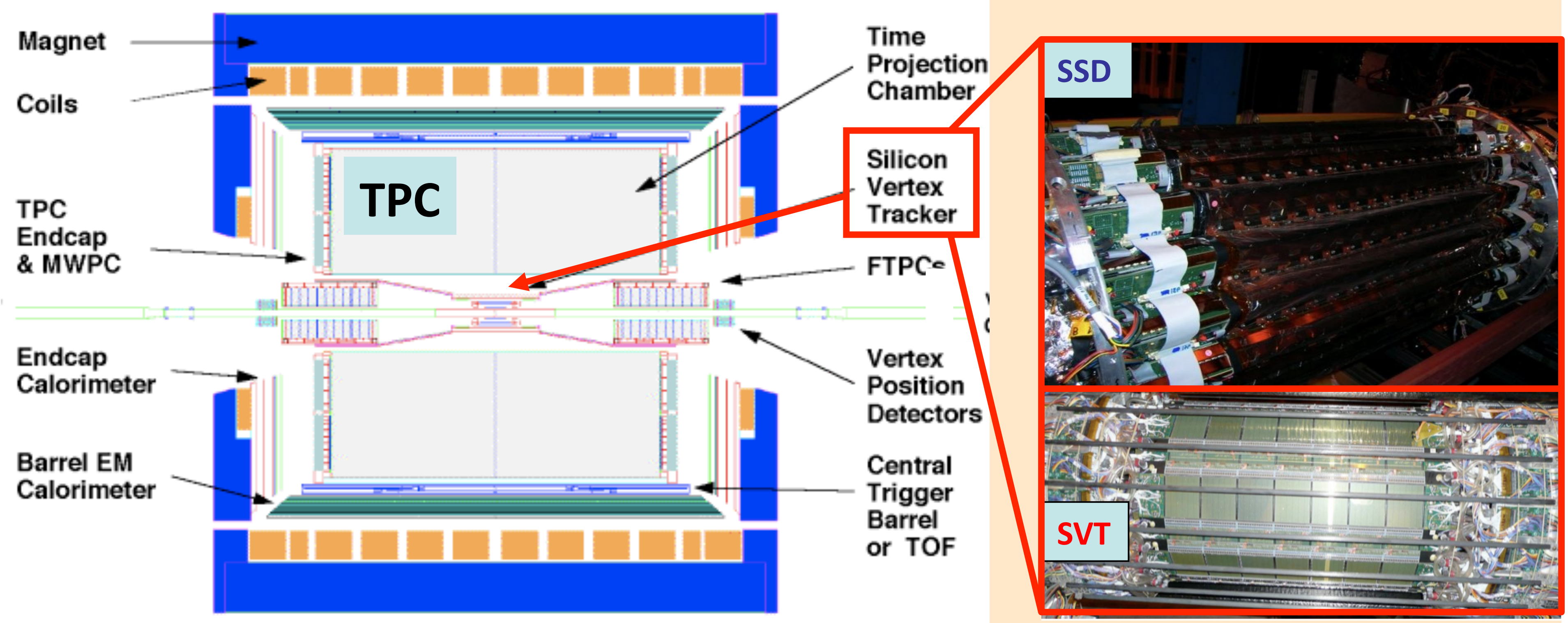
Next Method: Use the Silicon Vertex Detectors

- 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 :

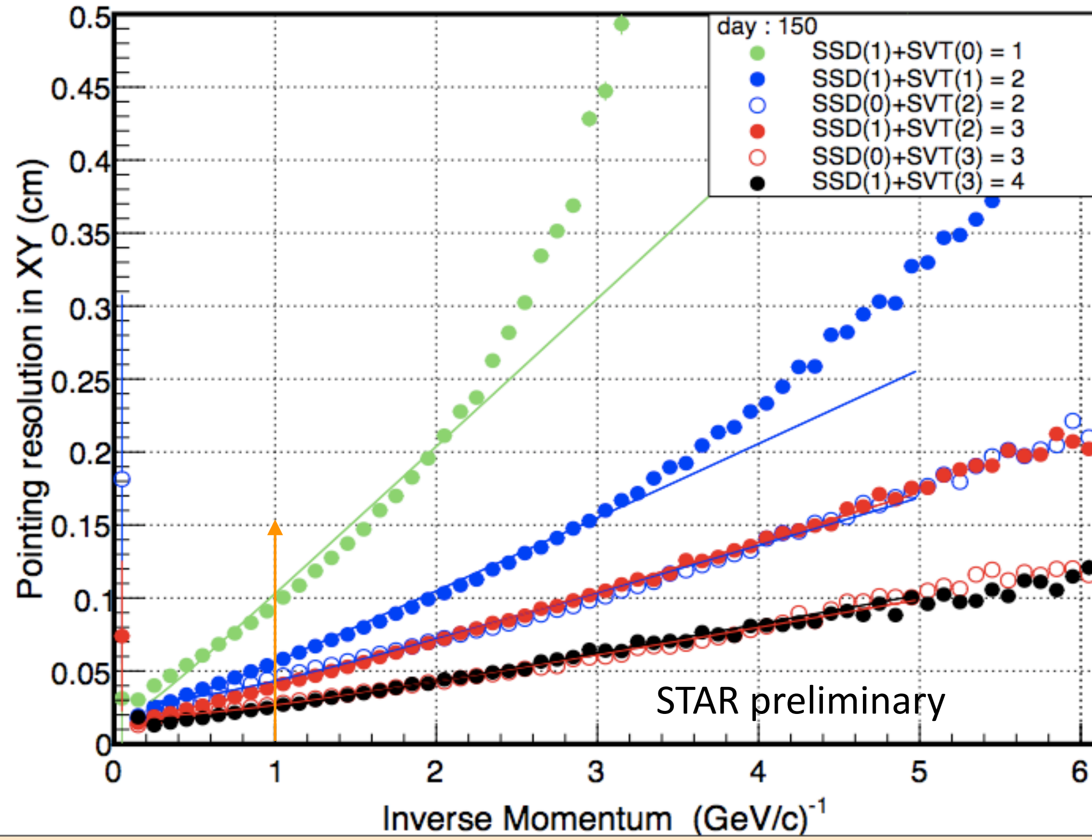
- **TPC :** provides momentum, particle identification.
- **2 silicon detectors** :
  - 1 layer of silicon strip detectors (**SSD**) and 3 layers of silicon drift detectors (**SVT**).
  - **high spatial resolution** : pointing resolution of ~250µm in transverse direction was achieved with Cu+Cu data in run 5 (y2005)[9]. This is more than 10 times the TPC pointing resolution.

[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).

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

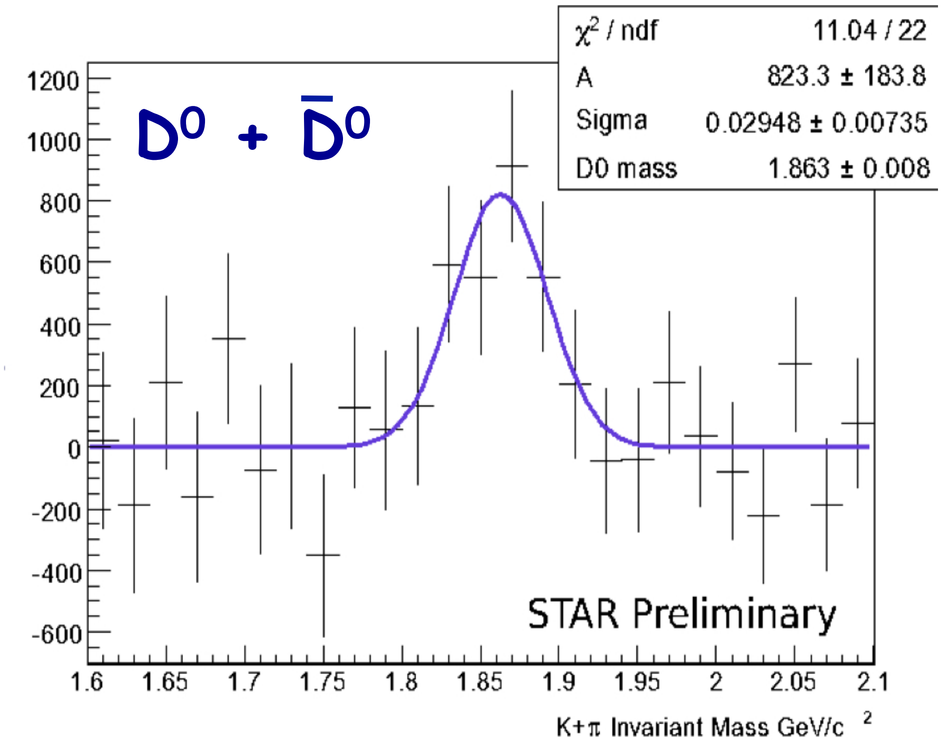


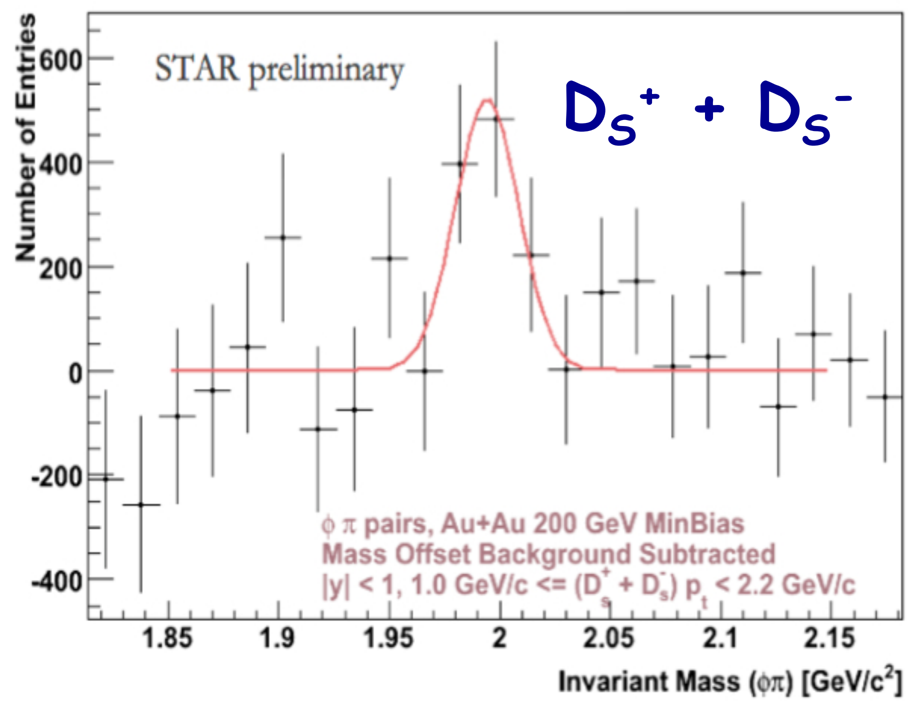
➔Including the silicon detectors in the tracking improves the pointing resolution.

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

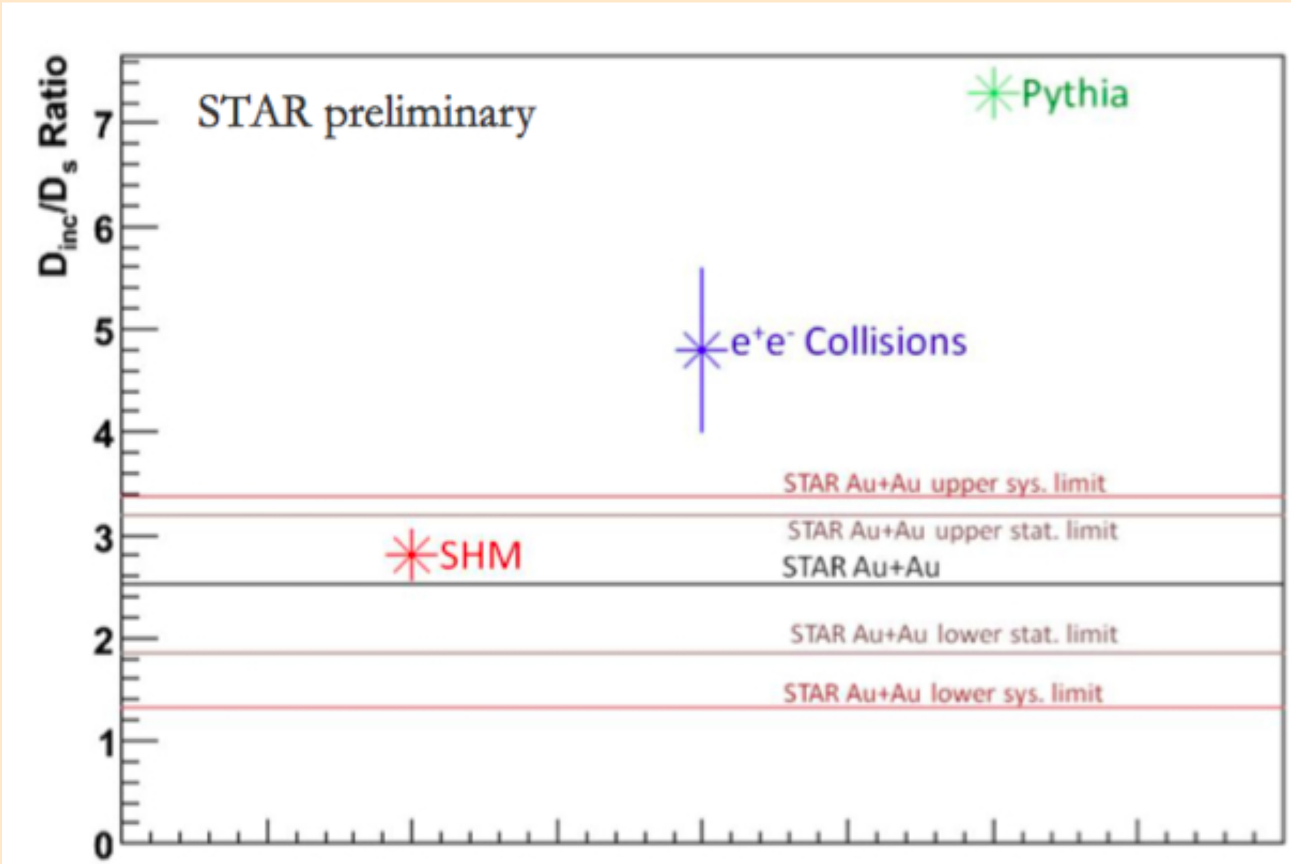
☒ Note : the Silicon Vertex detectors were not designed (thickness, geometry) for charm measurement.

Silicon + Decay vertex reconstruction (no fit)





S. LaPointe WWND2010 proceedings



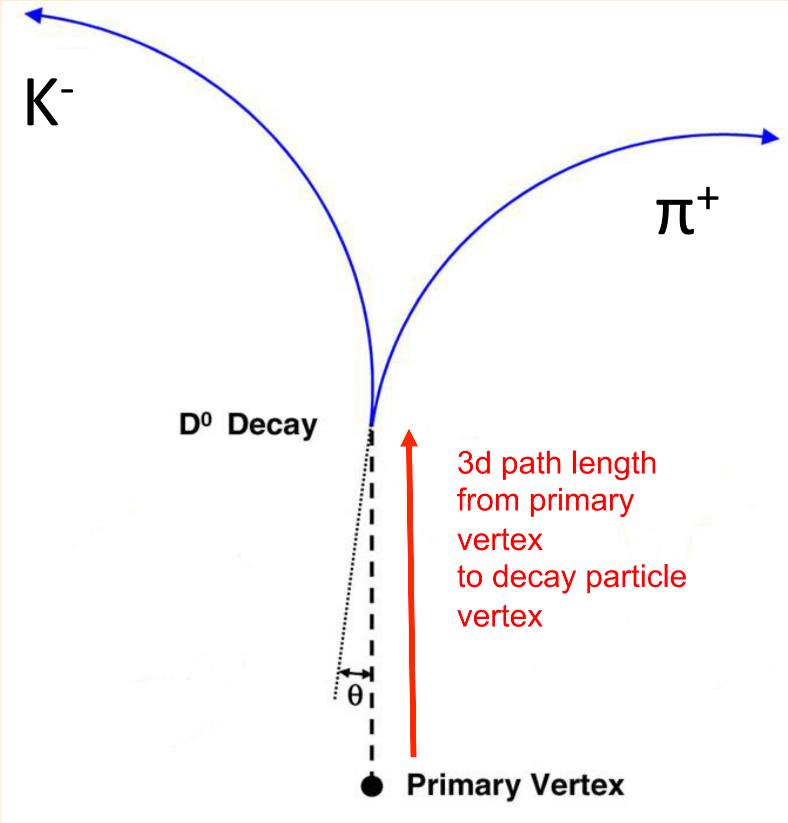
SHM = Statistical Hadronization Model
I. Kuznetsova and J. Rafelski, Eur. Phys. J. C 51 113 (2007)

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

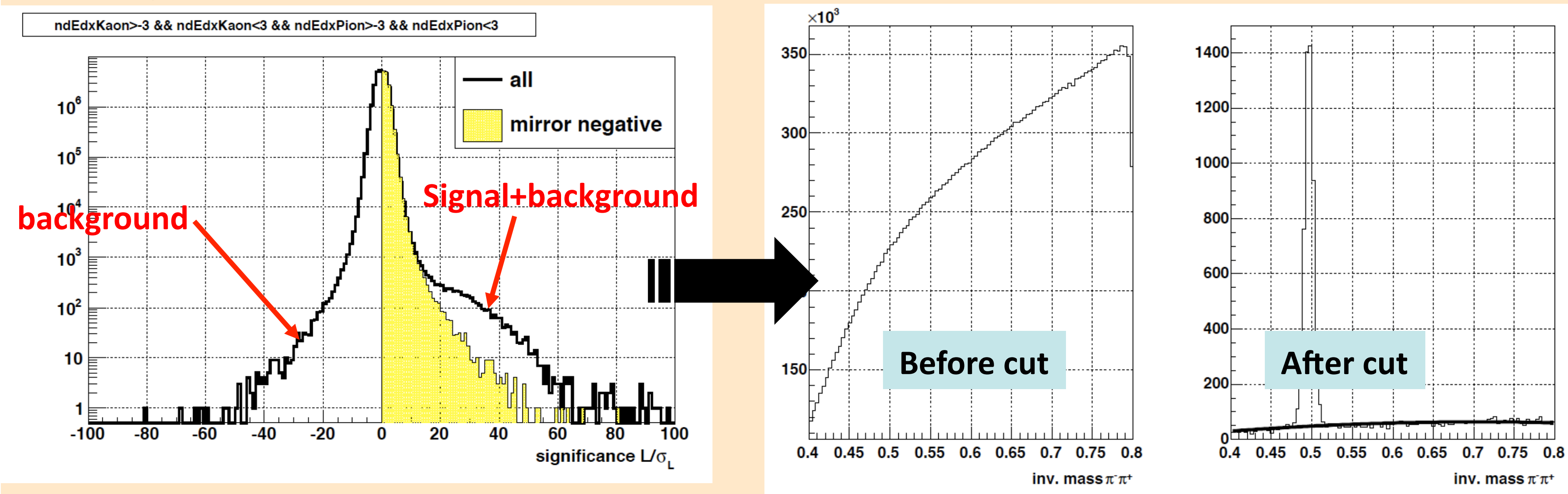
[10] Decay Chain Fitting with a Kalman Filter, W. D. Hulsbergen (arxiv:physics,0503191)

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 .

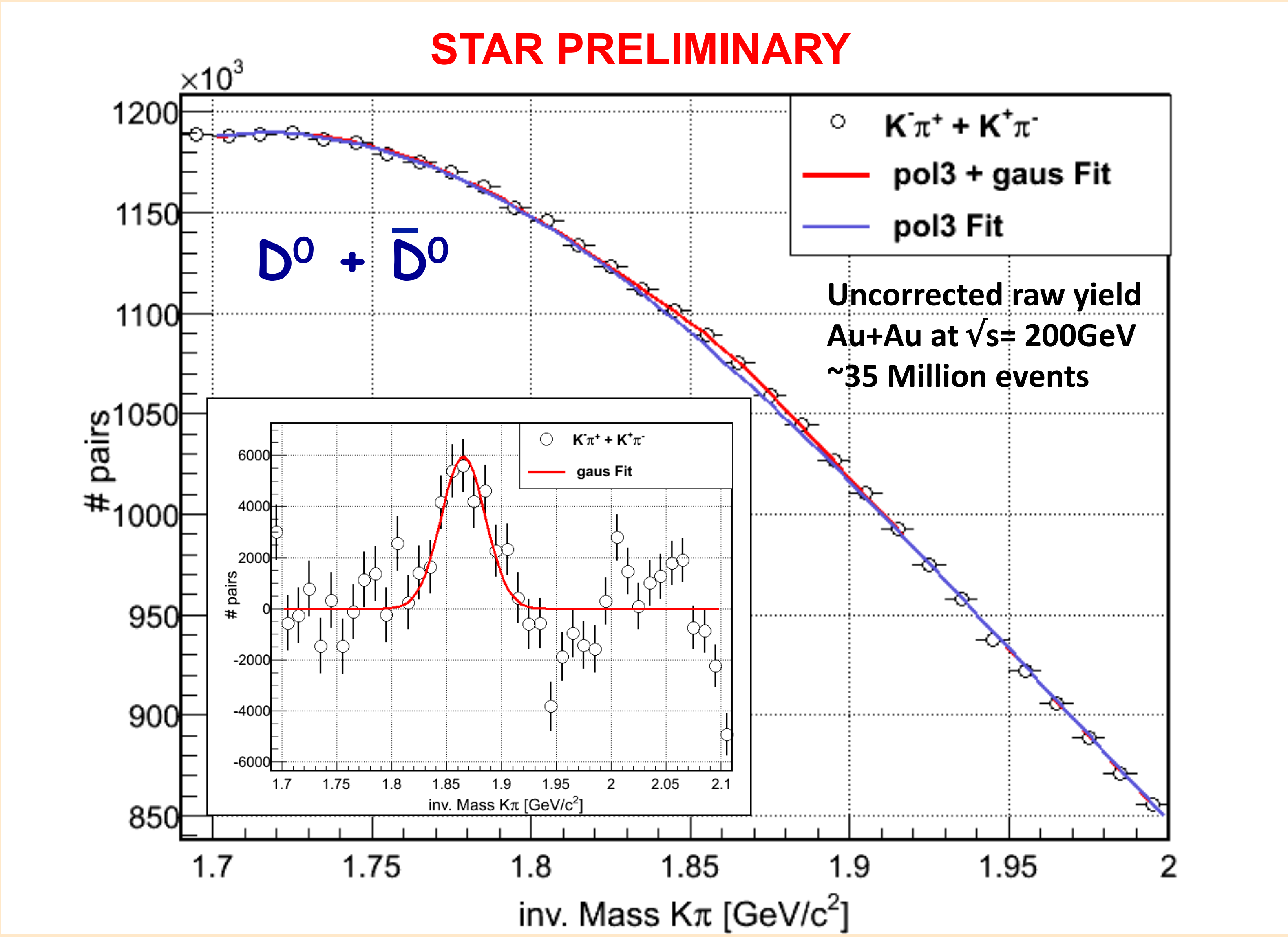
- Test with K^0_s decay reconstruction :

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



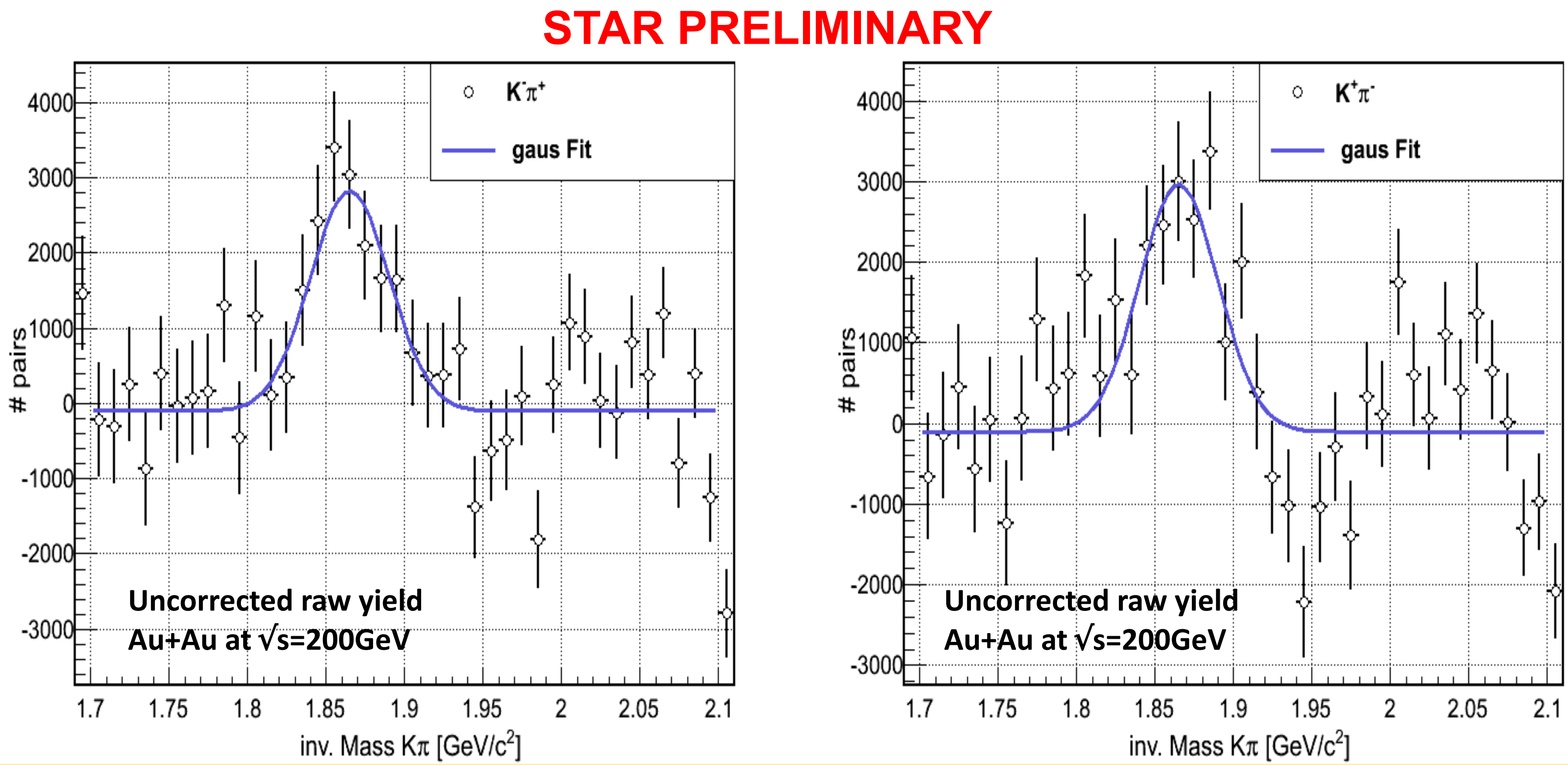
✔ After using a cut $S_L > 10$, a clear peak at the K^0_S mass is observed.

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



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

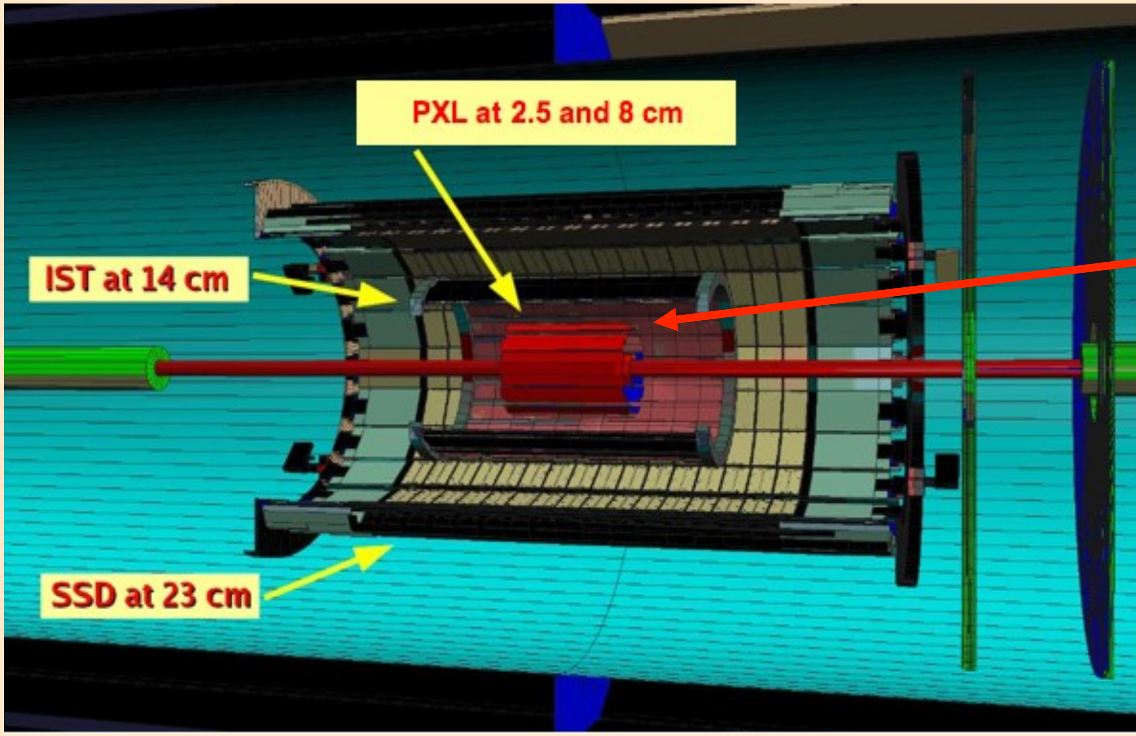
Invariant mass of D^0 and D^0bar separately

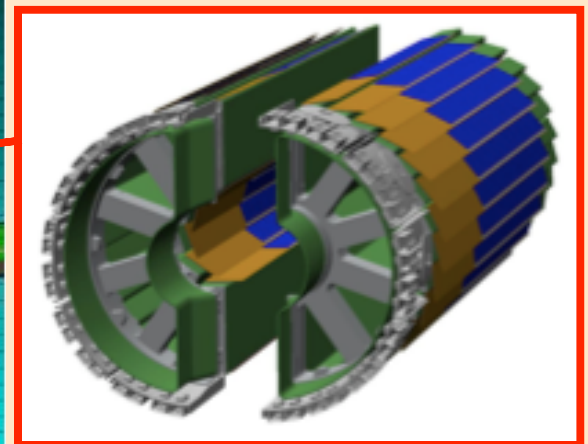


Ratio of D^0bar/D^0 = 1.05 +/- .19(stat.)

Compatible with vanishing μ_B (consistency check)

Future measurements at STAR

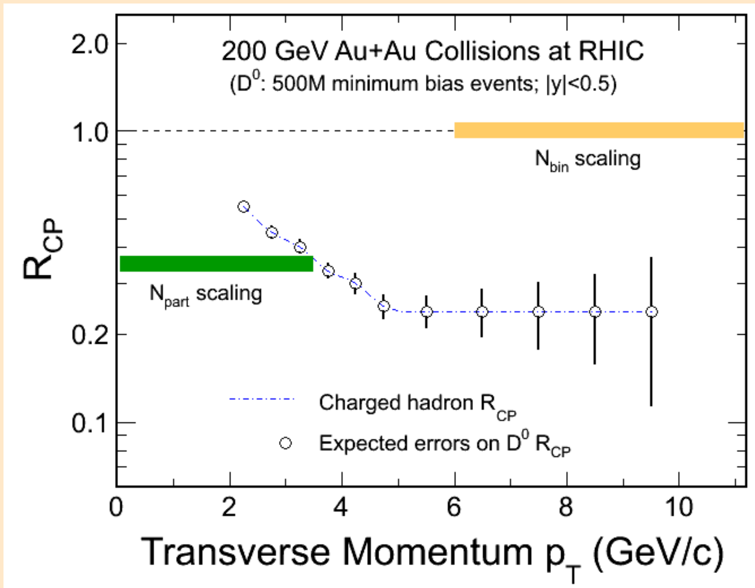


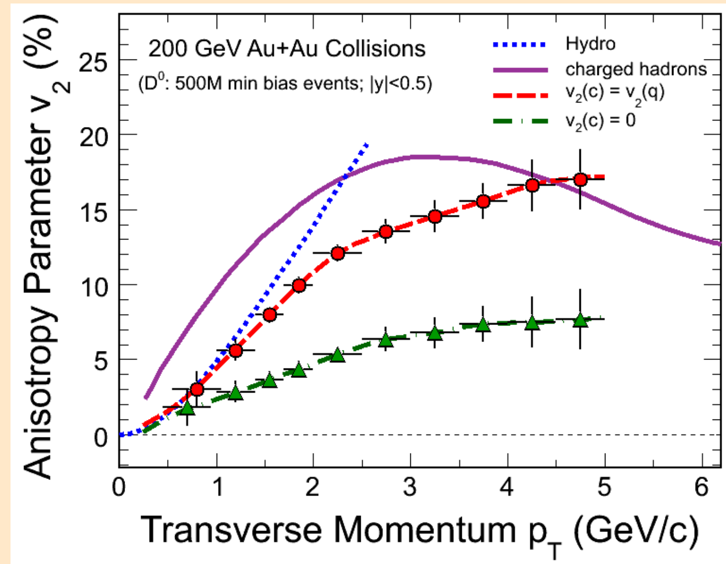


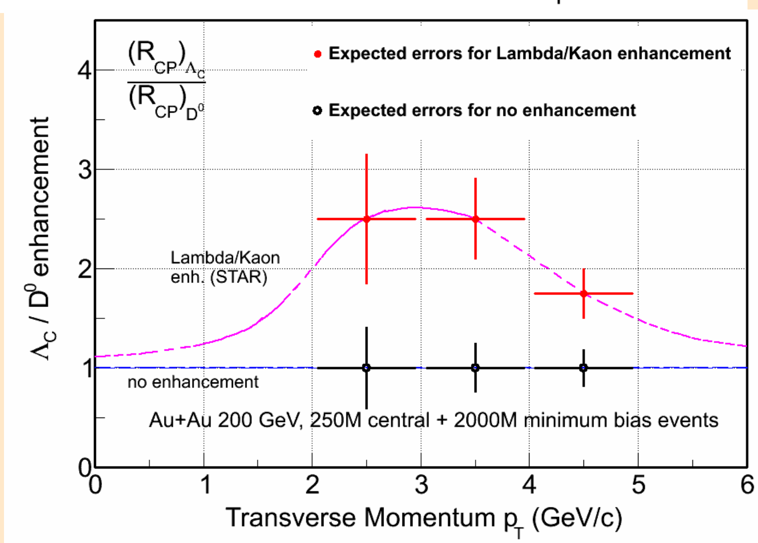
- future upgrade in STAR : **H**eavy **F**lavor **T**racker[11]
  - Low mass detector designed to identify mid-rapidity Charm and Beauty mesons and baryons through direct reconstruction and measurement of the displaced vertex with unprecedented pointing resolution.
  - CMOS sensors will provide single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

[11]: E. Anderssen et al., A Heavy Flavor Tracker for STAR, http://www.osti.gov/bridge/servlets/purl/939892-bel2Up/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

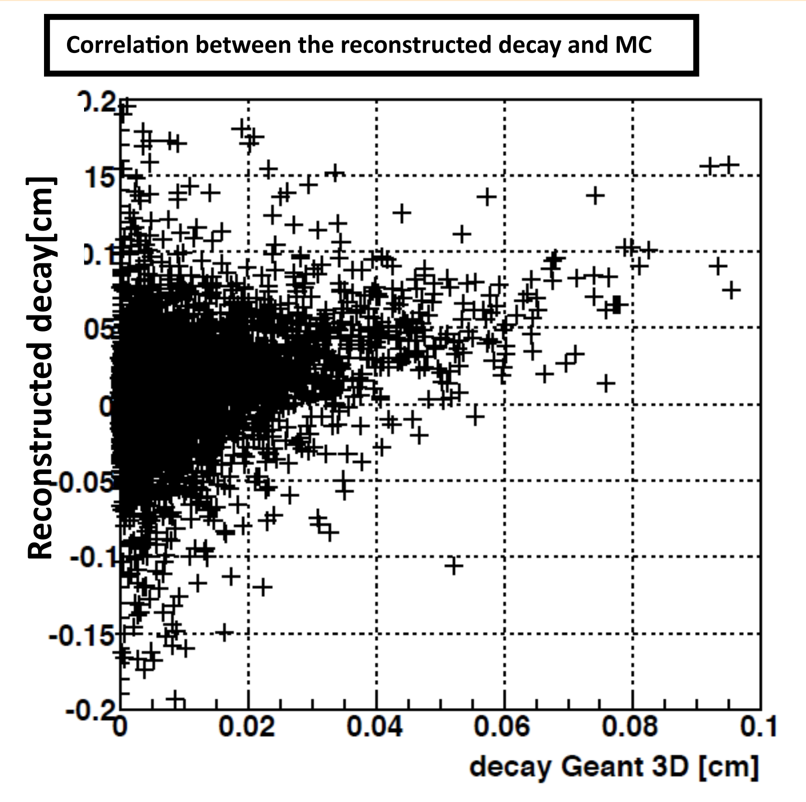
- We presented a method (not chronological) evolution of heavy flavor reconstruction

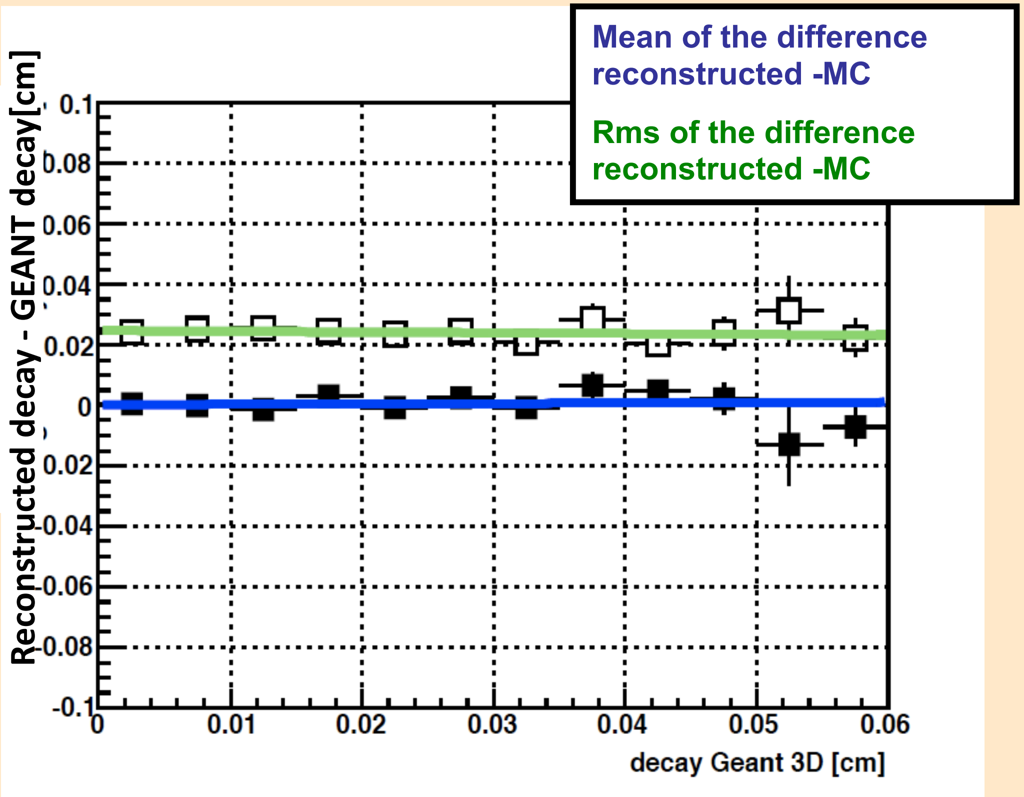
- Ongoing efforts and goals for QM2011:
  - Analyze full statistics.
  - Estimate total **x-section** (confirm recent results, smaller errors).
  - First estimate of D^0s $\mathbf{v_2}$ (to compare with NPE).

- 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 $N_{binary}^{Cu+Cu} = 51.5 + 1.0 - 2.9$

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

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

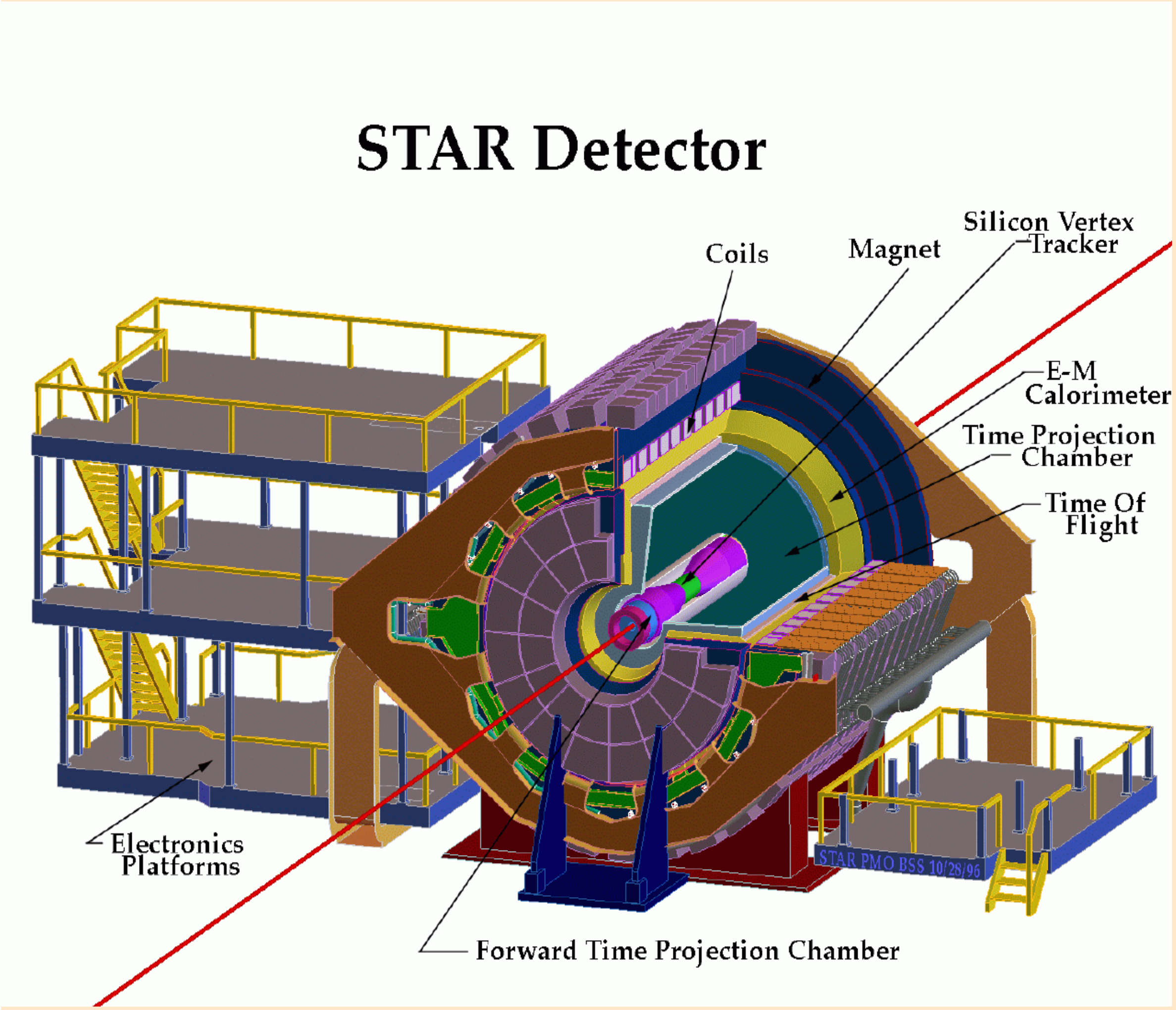
ratio from e+e- collider data $R = N_{D^0} / N_{c\bar{c}} = 0.54 \pm 0.05$

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

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

*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

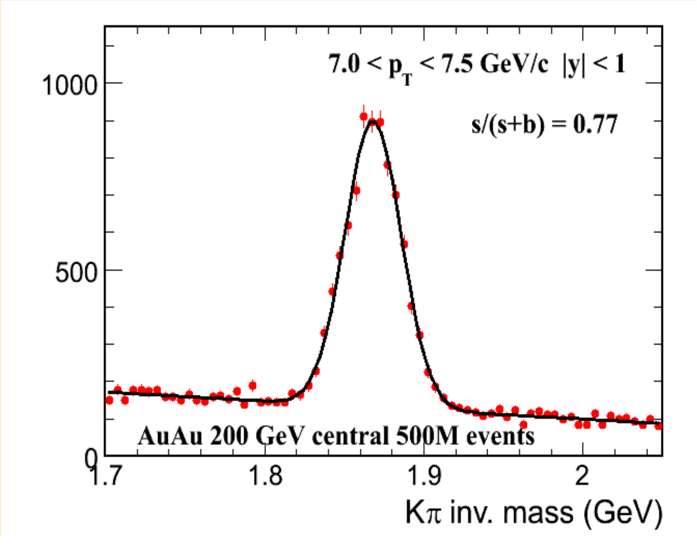
- provides shower position.
- electron shower has broader distribution (# of strips) than hadron shower.

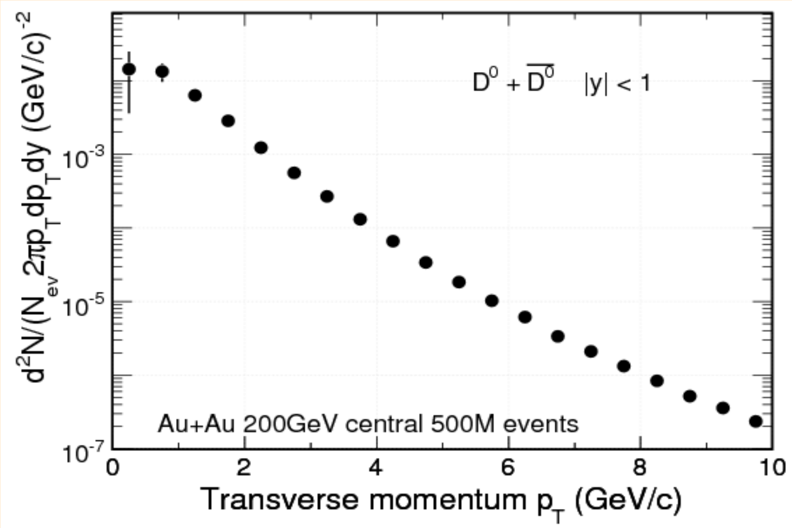
Inner tracker system

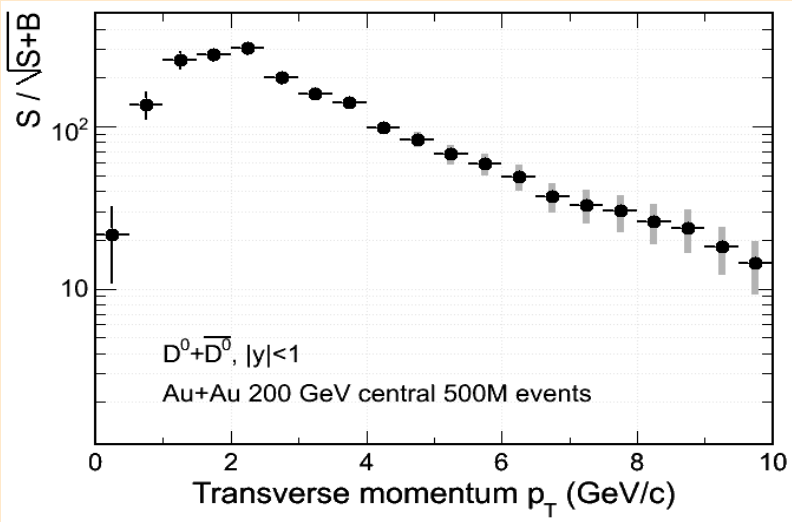
	Number of layer (radius)	technology	Sensor size (mm^2)	Intrinsic resolution (design)	Radiation length
SSD	1 (23 cm)	Double sided silicon strips	42 x 73	r/φ ~ 20 μm Z ~ 700 μm	~1% X_0
SVT	3 (6.8 cm ; 10.8 cm ; 14.8 cm)	Silicon drift	60 x 60	r/φ ~ 20 μm Z ~ 20 μm	~1.5% X_0 per layer

Performance example on the $D^0 \rightarrow K\pi$ 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

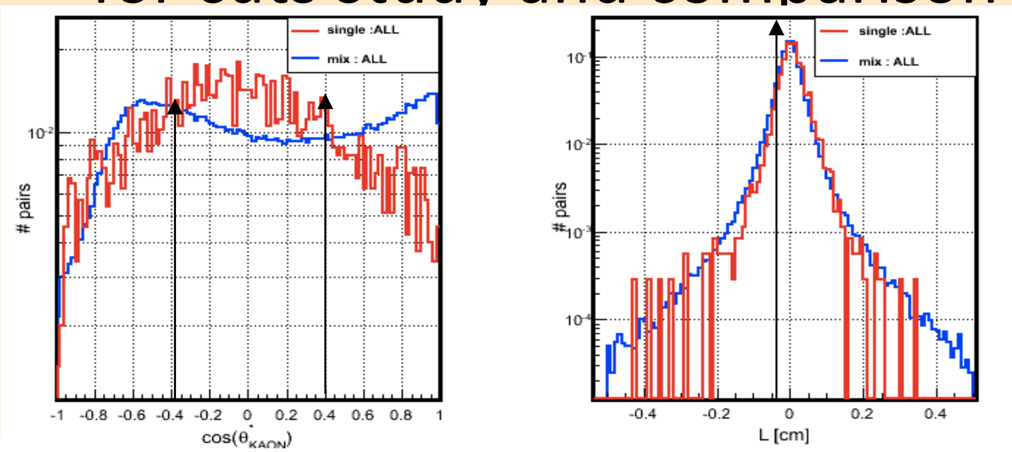






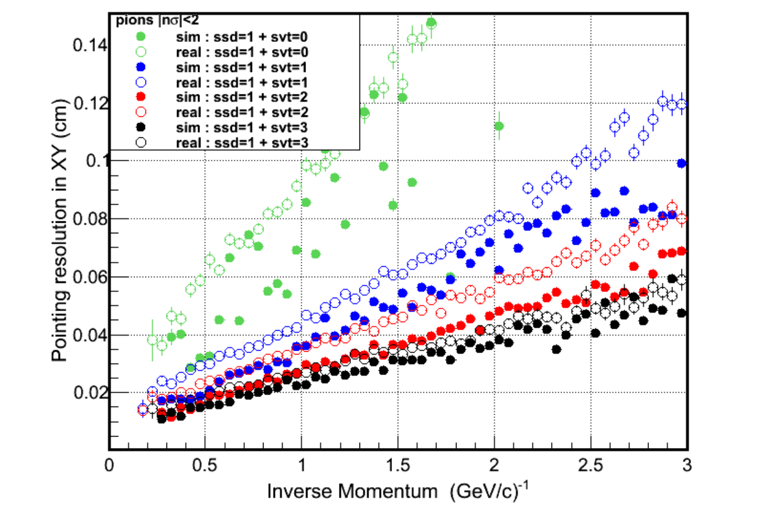
Simulation

- 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

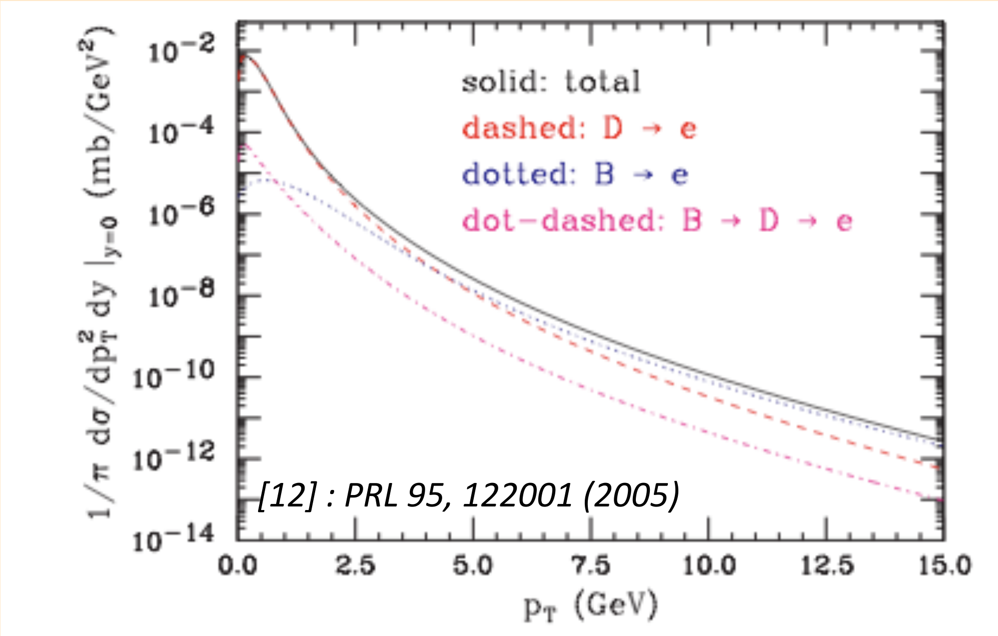
- Right panel : signed decay length for single D^0 and D^0 + hijing



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

Why using a secondary vertex fit

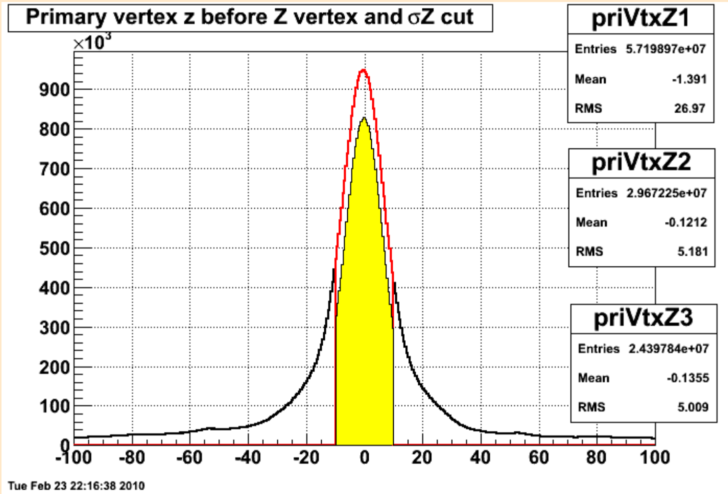
- Limitations of semi leptonic channel measurement:
  1. uncertainty of difference charm and bottom hadron contributions.
  2. incomplete kinematics measurement.
  3. pQCD predicts bottom contribution to be similar to charm production around $p_T^{electron}$ ~ 5GeV[12].



•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.

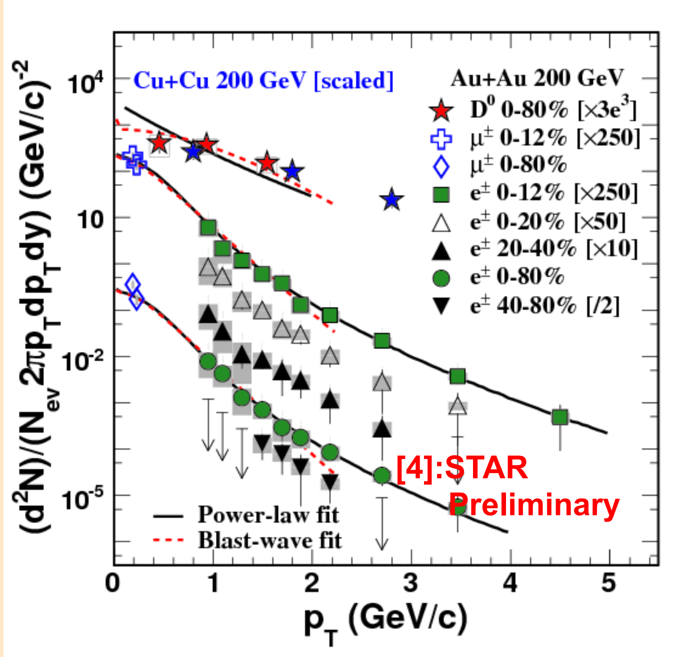
1. EVENTS level :
   - Primary vertex position and its error (ensured by trigger detectors).

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).

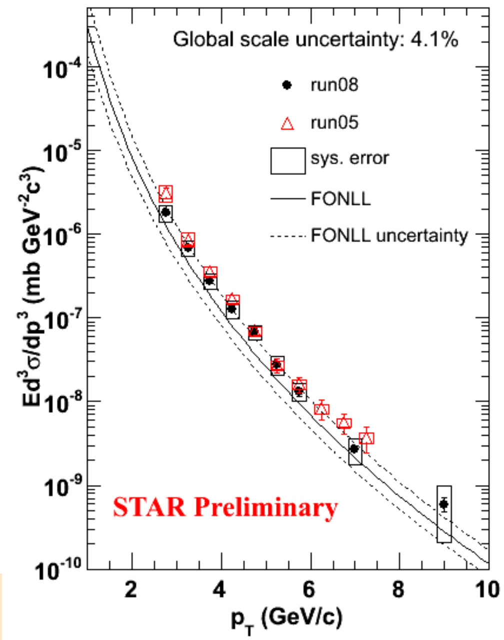
3. PAIRS level
   - Momentum of pairs
   - results given by the secondary vertex fit

Measurement via semi leptonic decays

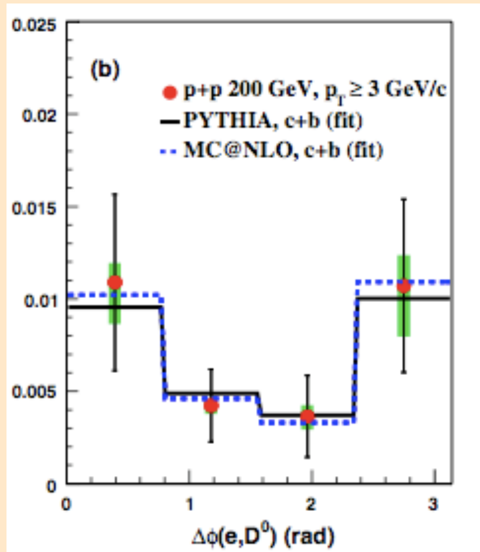
- **indirect method**
  - Electrons from semi-leptonic decays of B,D mesons .
    - $D^0 \rightarrow e^+ + X$ BR:6.9 %
    - $D^{+/-} \rightarrow e^{+/-} + X$ BR:17.2%
  - Measurement include electrons from B and D decays.
  - Use of specific triggers.
  - Large p_T range.

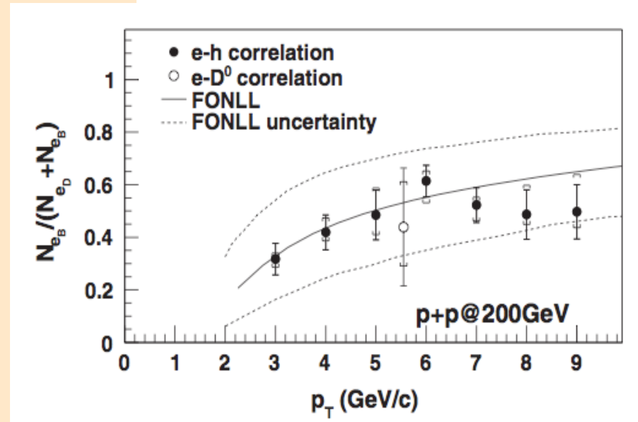


STAR recent high p_T NPE measurements in 200 GeV p+p collisions[5]



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





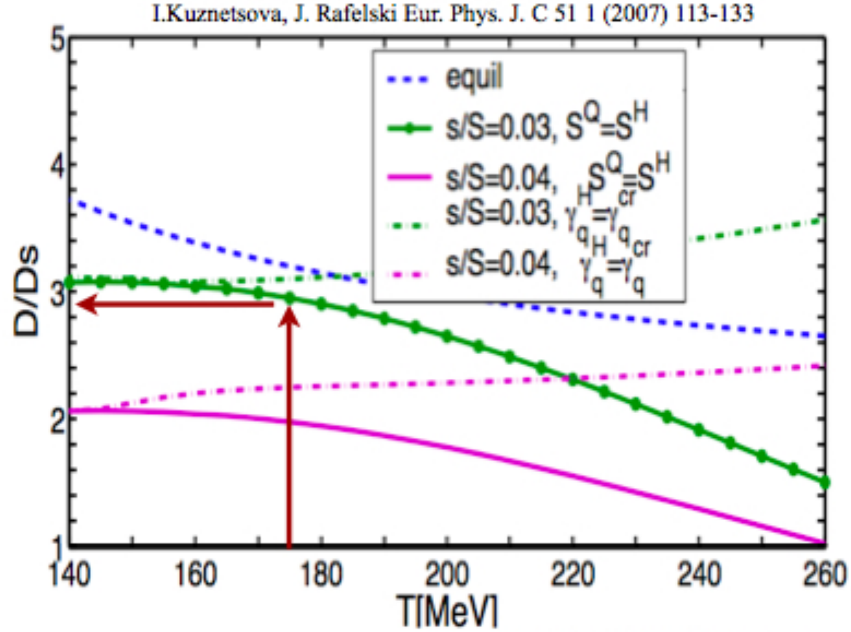
[4]nucl-ex/0805.0364; Y Zhang QM2008
[5]W. Xie, DIS2010
*[6]Phys. Lett. B**671**(2008) 361 ;*
*Phys. Rev. Lett. **105** (2010) 202301*

The Hadronization of Charm

Does charm hadronize from fragmentation or statistical → One check, look at the D_{inc}/D_s ratio

- Free charm in the sQGP = statistical hadronization
- Large s production should enhance D_s yield

I.Kuznetsova, J. Rafelski Eur. Phys. J. C 51 1 (2007) 113-133



D_{inc}/D_s

PYTHIA: 7.3

e^+e^- data: 4.8 ± 0.79

It may affect our estimation of total charm cross section