Charm reconstruction with STAR’s Silicon Vertex Detectors

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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.

The Beginnings - Heavy Quark Energy Loss – NPE Method

and nucl-ex/0607012v3

Still the main method at RHIC

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.

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

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

$$R_{AA\text{(NPE)}} \sim R_{AA\text{(h\pm)}}$$

Contradicts naïve pQCD predictions
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.


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.
    - $D^0 (D^0 \bar{\text{bar}}) \rightarrow K^- \pi^+ (K^+ \pi^-)$ 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).

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)


PHENIX:

STAR:
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
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.

• 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).

ër Including the silicon detectors in the tracking improves the pointing resolution.
ër with 4 silicon hits, the pointing resolution to the interaction point $\sim 250\mu m$ at $P = 1\text{GeV/c}$.

|$\text{Note : the Silicon Vertex detectors were not designed (thickness, geometry) for charm measurement.}$
Silicon + Decay vertex reconstruction (no fit)

\[
\begin{align*}
\chi^2 / \text{ndf} & = 11.04 / 22 \\
A & = 823.3 \pm 183.8 \\
\text{Sigma} & = 0.02948 \pm 0.00735 \\
D_0 \text{ mass} & = 1.863 \pm 0.008
\end{align*}
\]
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
- 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

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 $\sigma_L$.

- 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 $D^0$bar combined

Secondary vertex fit gives a factor of ~two gain in significance
Invariant mass of $D^0$ and $D^0\bar{b}$ separately

Uncorrected raw yield $Au+Au$ at $\sqrt{s}=200GeV$

Ratio of $D^0\bar{b}/D^0 = 1.05 +/- .19(stat.)$

Compatible with vanishing $\mu_B$ (consistency check)
Future measurements at STAR

- future upgrade in STAR: **Heavy Flavor Tracker**[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.

Key measurements of the HFT

Measurements:

1) $v_2$ and $R_{cp}$ of $D^0$
2) Charm baryon $\Lambda_c$
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 \textbf{x-section} (confirm recent results, smaller errors).
  – First estimate of D^0\textbf{}s v_2 (to compare with NPE).

• Silicon upgrades (HFT, under construction) in STAR will perform detailed exclusive charm and bottom studies.
End
• There is **no systematic shift** in reconstructed quantities.
• The **standard deviation** of the distribution is flat at \( \sim 250 \, \mu m \), which is of the order of the resolution of (SSD+SVT).
Conversion from $dN/dy$ to Cross-Section

$$\sigma_{cc}^{NN} = \frac{dN_{Cu+Cu}^{D_0}}{dy} \times \sigma_{inel}^{pp} / N_{bin}^{Cu+Cu} \times f / R$$

$dN_{D_0} / dy = 0.184 \pm 0.035$ (stat.)

number of binary collisions

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

p+p inelastic cross section

$$\sigma_{inel}^{pp} = 42 \text{ mb}$$

conversion to full rapidity

$$f = 4.7 \pm 0.7$$

(using PYTHIA simulation, ver. 6.152)

ratio from $e^+e^-$ collider data

$$R = \frac{N_{D_0}}{N_{cc}} = 0.54 \pm 0.05$$

$$\Rightarrow \sigma_{cc}^{NN} = 1.30 \pm 0.25 \text{ (stat.) mb}$$

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

*Systematic error evaluation for $dN/dy$ in progress.*
STAR detector

**Time Projection Chamber**:
- provides momentum, particle identification.
- separation of electrons from pions for $p > 1.5 \text{GeV/c}$.

**Barrel Electro-Magnetic Calorimeter**:
- provides electron energy measurement $E$.
- expect $p/E \sim 1$ for electrons.

**Barrel Shower Maximum Detector**
- provides shower position.
- electron shower has broader distribution (# of strips) than hadron shower.
## Inner tracker system

<table>
<thead>
<tr>
<th></th>
<th>Number of layer (radius)</th>
<th>technology</th>
<th>Sensor size (mm$^2$)</th>
<th>Intrinsic resolution (design)</th>
<th>Radiation length</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD</td>
<td>1 (23 cm)</td>
<td>Double sided silicon strips</td>
<td>42 x 73</td>
<td>r/φ $\sim$ 20 µm, Z $\sim$ 700 µm</td>
<td>$\sim$1% $X_0$</td>
</tr>
<tr>
<td>SVT</td>
<td>3 (6.8 cm ; 10.8 cm ; 14.8 cm)</td>
<td>Silicon drift</td>
<td>60 x 60</td>
<td>r/φ $\sim$ 20 µm, Z $\sim$ 20 µm</td>
<td>$\sim$1.5% $X_0$ per layer</td>
</tr>
</tbody>
</table>
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 $D^0 + D^0\bar{\text{bar}}$ 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 $p_T^{\text{electron}} \sim 5\text{GeV}[12]$.

• 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 $(c\tau (D^0) \sim 123 \mu\text{m})$. 

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: $n\sigma_K < 2$, $n\sigma_\pi < 2$ (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%
    - \( D^{+/0} \rightarrow e^{+/0} + X \) BR: 17.2%
  - Measurement includes 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].

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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


$D_{inc}/D_s$

PYTHIA: 7.3

$e^+e^-$ data: $4.8 \pm 0.79$

It may affect our estimation of total charm cross section

Sarah LaPointe 26th Winter Workshop on Nuclear Dynamics, Ocho Rios, Jamaica