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Charm reconstruction using a micro-vertexing technique with the STAR Silicon Vertex Detectors

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Due to their production at the early stages, heavy flavor particles are of interest to study the properties of the matter created in heavy ion collisions at RHIC. In particular the measurement of their elliptic flow, as well as their energy loss could give insights about the properties of the medium. Previous measurements of *D*– and *B*–mesons at RHIC using indirect methods such as non-photonic electron spectra show a suppression similar to that of light quarks, which is in contradiction with theoretical models including gluon radiative energy loss mechanism. However, this method involves large incertainties to disentangle between the *b* and *c* quarks contributions. A direct topological reconstruction is then needed to obtain a precise measurement of charm meson decays. In this talk we will present a micro-vertexing technique used in the reconstruction of D^0 decay vertex ($D^0 \rightarrow K^- \pi^+$) and its charge conjugate.
The STAR experiment has recorded data from Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV (year 2007) with its inner tracker, consisting of a 3-layer Silicon Drift detector (SVT) and an one-layer Silicon Strip detector. We report here preliminary results of this analysis.

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1. Introduction

Due to their large masses, heavy flavor (*c* and *b*) quarks are produced in the early stages of heavy ion collisions [1] by perturbative QCD processes such as gluon-gluon fusion and $q\bar{q}$ annihilation. Therefore heavy flavor measurement may provide useful insights of the initial matter created during heavy ion collisions. Theoretical models predicted that the principal energy loss mechanism of heavy quark, gluon Bremsstrahlung, to be less significant than the gluon radiation of light quarks because of the dead cone effect [2]. This mechanism states a suppression of the energy loss at small angles θ<m_{q}/E , where m_{q} and E are respectively the heavy quark mass and its energy. Energy loss is experimentally studied through the nuclear modification factor (R_{AA}), defined as the ratio of hadron yield in heavy ion collisions over the hadron yield in $p+p$ collisions, geometrically scaled by the number of collisions. A surprising result from the Relativistic Heavy Ion Collider (RHIC) was a R_{AA} of non-photonic electrons at high transverse momentum p_{T} similar to the one observed for light hadrons [4] for p_{T}>5 GeV/c and is then in contradiction with models. RHIC measurements of heavy quark energy loss [4, 5] involving non-photonic electrons from semi-leptonic decays, include the contributions of both *D* and *B* mesons. From ref. [4], models with only radiative components predict less suppression than observed, and even so when adding collisional component. As mentioned in ref. [6], there is an uncertainty between the contributions of *B* and *D* mesons to non-photonic electrons at intermediate p_{T} around 3-4 GeV/c.
It is essential to determine experimentally their relative contribution to understand the observed suppression of heavy flavor at high p_{T} in Au+Au collisions.

One new analysis technique proposed to separate charm and bottom quarks was to look for azimuthal correlations of electrons with open charm mesons [8]. It has been shown from ref. [7] that the shape of the azimuthal correlation distribution ($\Delta\phi$) in the transverse plan to the colliding beams, due to different kinematics, allows the measurement of the ratio of electrons from *B* decays and *D* decays. This method uses the fact that charm quarks preferentially hadronize directly to D^0 (c$\rightarrow$D^0+X, BR = 56.5%) whereas bottom quarks indirectly with a production of a *B* meson ($b\rightarrow B^-/\overline{B^0}/\overline{B^0_s}\rightarrow D^0$+X, BR = 59.6%) [9] and with a charge correlation between the electron and the kaon coming from the D^0 decay (see left panel of figure 1).

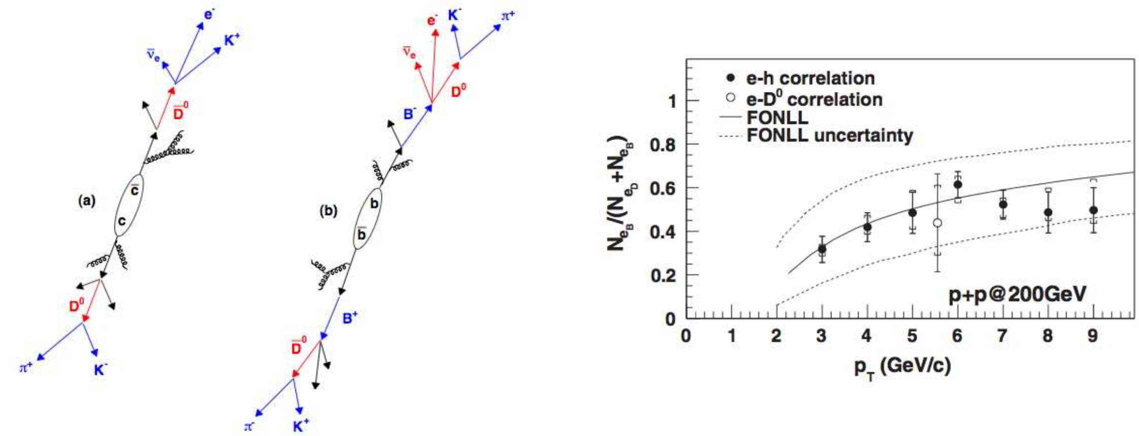

Figure 1: Left : schematic view of the fragmentation of a $c\bar{c}$ and $b\bar{b}$ pair; right : Relative contribution from B mesons (r_{B}) to the non-photonic electrons yield as a function of the transverse momentum p_{T} of electrons [7].

Results from ref. [7] indicate the relative contribution of *B* decays to the non-photonic electron production increases with p_T and comparable to the *D* meson decay contribution at $p_{\mathrm{T}} > 5$ GeV/c (right panel of figure 1). These measurements are consistent with Fixed Order Next to Leading Log (FNOLL) calculations [6] and suggest that the contribution of non-photonic electron from *B* meson decay should be as well be considered in theoretical models.
Another method to disentangle between the *B* and *D* meson decay would be a direct measurement of charm through the *D* meson hadronic decay ($D^0 \rightarrow \mathrm{K}\pi$, BR = 3.89%, $D^+ \rightarrow K^-\pi^+\pi^+$ and its charge conjugate, BR = 9.22% [9]). Indeed as semi-leptonic measurements do not provide the full kinematic of the heavy flavor, a direct measurement could provide this.
STAR experiment has measured this channel through several colliding systems : d+Au [10], Au+Au [11], Cu+Cu [12]. These measurements used an invariant mass technique to identify *D* mesons. The combinatorial background, inherent to this technique, is then subtracted by using either a rotational or mixed events technique.
The direct measurements of *D* mesons mentioned here had been done using identified tracks only. This can be improved by using precise detectors allowing a secondary vertex reconstruction method, thus to reduce combinatorial background.

2. STAR detector and analysis method

2.1 Tracking apparatus

STAR is a multi purpose detector [14] at RHIC. The subsystems used in this analysis are the tracking detectors in the central region. They are composed of a cylindrical Time Projection Chamber [15] (TPC) surrounded by a solenoid magnet. The TPC measures the momentum of charged particles and allows their identification through the energy loss (*dE/dx*) inside a gas mixture of argon and methane. Pion and proton bands are separated up to $p_{\mathrm{T}} \sim 1.2$ GeV/c.
Close to the colliding beams axis are located the Silicon Vertex Tracker detectors, composed by the

Silicon Vertex Tracker (SVT) [17] and the Silicon Strips Detector (SSD) [16].
The SVT used silicon drift sensors and the SSD used double sided micro-strips sensors. Their positions, thicknesses and spatial resolutions are listed in Table 1.

Table 1: Characteristics of each silicon layer of the STAR silicon Vertex Tracker.

Detector	Number of layers (radius) [cm]	Technology	Hit resolution (design) ($R-\phi[\mu$m] -Z[μm])	Thickness radiation lengths (X_0)
SSD	1 (23)	double sided strips	20- 700	1%
SVT	3 (6.8 ; 10.8 ; 14.8)	Silicon drift	20 -20	1.5% per layer

The figure of merit of a vertex tracking system is the pointing resolution of reconstructed tracks (σ_{DCA}), Distance of Closest Approach (DCA), to the primary collision vertex. Single track DCA is a crucial part of the charm decay reconstruction because some geometrical cuts are often based on the distance of tracks to the primary or distance between the primary and secondary vertexes. The pointing resolution then mostly depends on the characteristics of the inner detector layers.

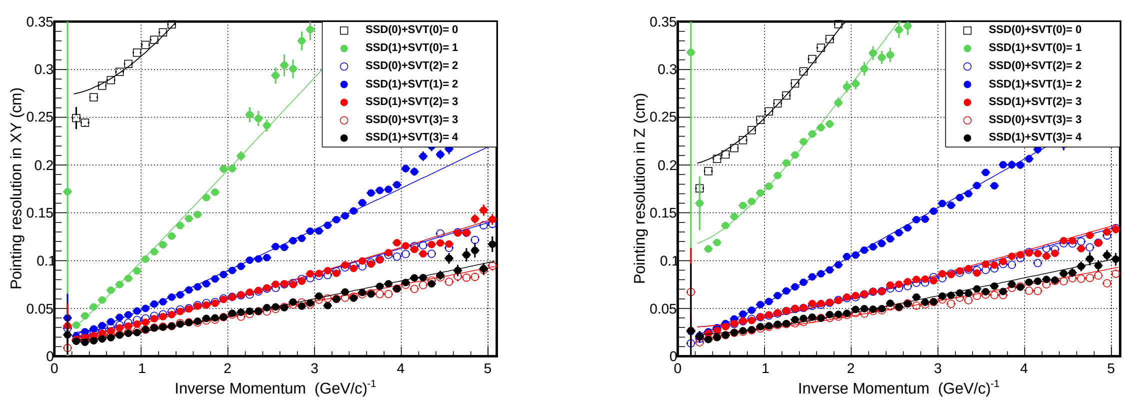

Figure 2: Pointing resolution (DCA) in $R-\phi$ (left) and Z (right) as a function of inverse momentum for tracks with 0 to the maximum (4) of silicon hits.

Figure 2 show the pointing resolution, expressed as the standard deviation of the global DCA as a function of the inverse momentum *1/P*, for different combinations of silicon hits included in tracking. The lines modelize the pointing resolution vs. *1/P* using the function $\sqrt{A^2+(B/p)^2}$. This function aims to describe the different tracking components of the DCA (primary vertex resolution, track pointing resolution and alignment of detectors, Multiple Coulomb Scattering (MCS)[13]). We can see that :

- the pointing resolution increases at low momentum because of MCS effect.
- for a given momentum, the resolution is significantly improved from tracks using no silicon hits (open squares, tracks with only TPC hits) to tracks using all silicon hits (filled circles).

We can see that tracks with 2 or more silicon hits have 10 times better σ_{DCA} than tracks with only hits from the TPC.

The pointing resolution in transverse direction ($\sigma^{R-\phi}_{\mathrm{DCA}}$) and along the beam axis ($\sigma^{Z}_{\mathrm{DCA}}$) at $p = 1$ GeV/c, obtained from the form function, are reported in Table 2 for all silicon hits combinations.

Table 2: Pointing resolution [μm] vs. number of silicon hits for 1 GeV/c track momentum obtained from the form function.

number of hit in SSD	0	1	1	0	1	0	1
number of hits(s) in SVT	0	0	1	2	2	3	3
$\sigma^{R-\phi}_{\mathrm{DCA}}$	3140	990	483	365	341	260	252
$\sigma^{Z}_{\mathrm{DCA}}$	2490	1730	550	397	400	284	295

Pointing resolutions are different in $R-\phi$ and Z for tracks without any SVT hits due to the asymmetric hit resolution of the SSD (worst in the Z direction). We also note that adding the SSD hit to tracks with already 2 or more SVT hits does not change much the pointing resolution. The reason is because the pointing resolution is mainly driven by the inner layers of the SVT.

The achieved error at momentum $p = 1$ GeV/c is compatible to that of the charmed mesons decay (for e.g. $c\tau(\mathrm{D}^0)$= 122.9μm), making a first attempt to measure charmed particle through displaced vertex technique. Indeed even the characteristics of the inner tracker, in terms of geometry and material thickness, are not *optimized* for direct charm reconstruction, the pointing resolution obtained with the single track may be sufficient to considerably suppress the combinatorial background by few orders of magitude.

2.2 Secondary Vertex Fit

The secondary vertex technique consists in a least square fit of the daughters tracks, requiring that they are originating from a common point. The errors of individual daughter track (through their covariance matrix) have also been used for a better estimation of the fit parameters[1]. This method has been tested with Monte Carlo simulation (MC), using single D^0 particles generated by HIJING and propagated through the STAR software reconstruction.

The left-hand side plot of figure 3 shows the correlation between the reconstructed decay length (L_{reco}) of the D^0 and the MC decay length (L_{MC}). L_{reco} is signed : it is positive for decays for which the momentum vector and the decay length vector $\overrightarrow{L}$ [2] are pointing in the same direction and negative for decays with anti-parallel momentum and decay vectors. Fits with only confidence level more than 0.01 [18] have been used here. L_{reco} is clearly correlated with L_{MC} and shows no shift with respect with the simulated ones (plain symbols of right-hand side plot of figure 3), with a standard deviation of the order of the resolution achieved with the inner tracking system (open symbols).

[1]3D signed decay length (L) and its error σ_L, χ^2 and confidence level of the fit [18].

[2]$\overrightarrow{L}$ = $\overrightarrow{s_v}$ - $\overrightarrow{p_v}$, difference between the secondary and primary vertex.

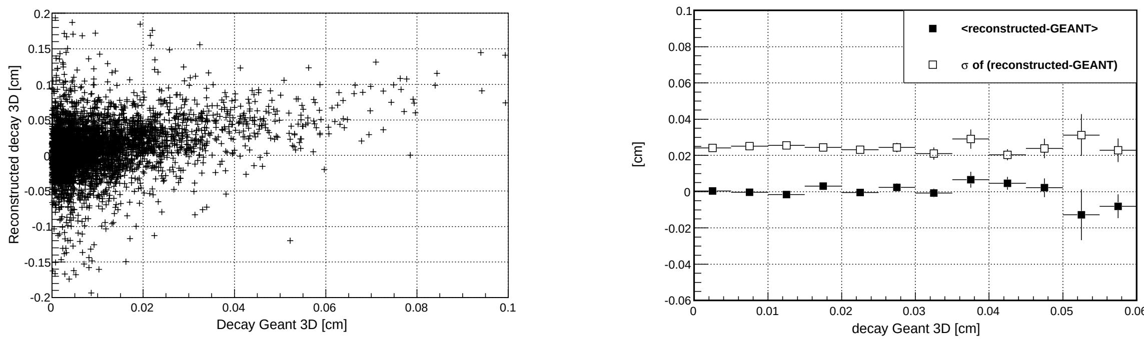

Figure 3: Left : correlation between L_{reco} and L_{MC} ; right : difference L_{reco}-L_{MC} as a function of p_{T} of the MC D^0.

3. Preliminary results

About 35 Million events have been analyzed from Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV from RHIC Run-7 [3]. The D^0 ($\overline{D^0}$) have been reconstructed through their hadronic decays D^0 ($\overline{D^0}$)$\rightarrow K^-\pi^+$ ($K^+\pi^-$) by pairing tracks identified as kaon and pion and calculating the invariant mass. Once the pairs have been formed, the secondary vertex fit then computes the signed decay length, as well as its error associated. Several quality cuts at each level (event, single track and pair association) have been used, in order to reduce the combinatorial background, such as (list is not exhaustive) :

- events for which the primary vertex position along the beam axis V_z is located in [-10;10 cm] and a resolution σ_{vz} < 200 μm.
- number of silicon hits : from figure 2 (left panel), we have chosen to keep only tracks with 3 or 4 silicon hits.
- global DCA of tracks to the primary vertex collision to be less than 1 mm.
- tracks with a measured *dE/dx* in the TPC between -2 and 2 for standard deviations from the expected mean *dE/dx* for pion and kaon.
- error of the signed decay length σ_L< 1mm.
- confidence level of the fit > 0.1

Left panel of figure 4 shows the preliminary uncorrected raw yield [4] of unlike sign $K\pi$ pairs before subtraction by a third order polynomial fit, represented by the red line : a small excess can be seen in the mass range around the D^0 mass (M_{D^0} = 1.864 GeV/c^2). The right panel of 4 shows the same uncorrected yield subtracted by a third order polynomial fit.
The total yield (Y) corresponding to the signal (S) + background (B) has also been been fitted by a gaussian function combined with a third order polynomial fit (red curve of left panel 4). The

[3] the silicon detectors were only used for run V and run VII.

[4] of detector acceptance

estimated signal significance $S/\sqrt{S+B}$ is 10.

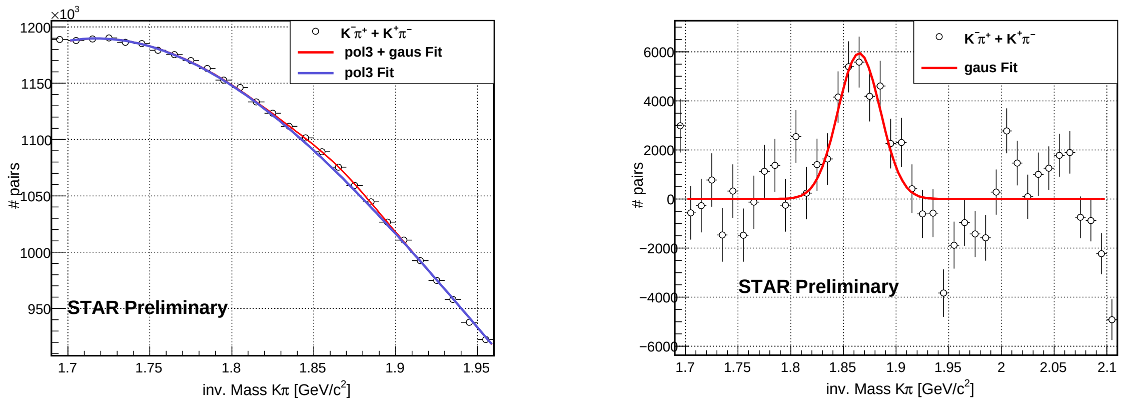

Figure 4: Invariant mass of $D^0 + \overline{D^0}$ before (left) and after (right) background subtraction.

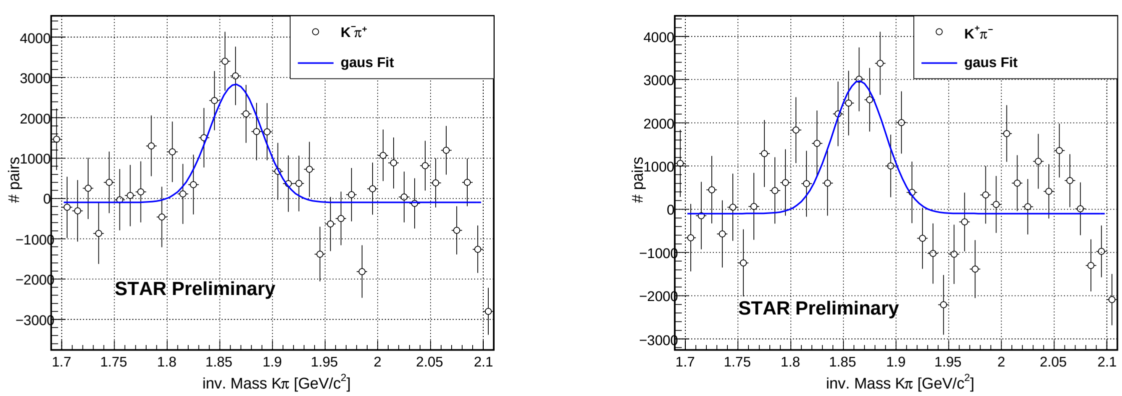

Figure 5: left : invariant mass of D^0 ; right : invariant mass of $\overline{D^0}$.

The preliminary invariant mass of D^0 and $\overline{D^0}$ separately has also been estimated within the same cuts (see figure 5 for subtracted yields with the same fit function as for the yield $D^0 + \overline{D^0}$). The ratio $\overline{D^0}/D^0$ is estimated to be 1.05 ± 0.19 where the quoted error is statistical only. This ratio is expected to be close to unity for collisions at RHIC energies due to a vanishing baryo-chemical potential. An independent combinatorial background reconstruction is needed to further understand the systematics of D^0 signals.

4. Future in STAR

STAR experiment is actually upgrading its central tracking device in order to improve the measuring capabilities of heavy flavor. A new silicon vertex detector, the Heavy Flavor Tracker (HFT), using low mass CMOS sensors [20], will be able to directly reconstruct charm hadrons over a large momentum range and, thus, study flow and energy loss of heavy flavor particles [19]. The overall pointing capabilities of the HFT will be a factor of ten better than the current system.

Several physics capabilities such as baryon/meson ratio in the charm sector have been studied with full system simulations.

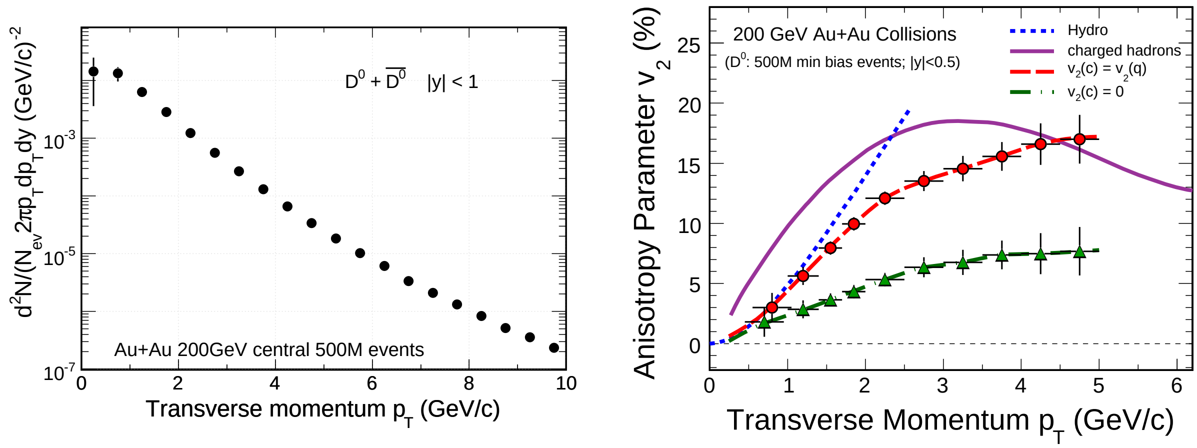

Figure 6: Expected D^0 p_T spectra and elliptic flow with the HFT.

Figure 6 illustrates the capabilities of the HFT : left panel shows the anticipated p_T of D^0_s for central Au+Au collisions. The measurement over a broad p_T range from almost 0 up to 10GeV/c will be possible. Right panel shows the elliptic flow of the D^0 for 2 scenarios where c quark flows with similar partonic flow of light quark (red symbols) and the limiting case where c have no elliptic flow ; the HFT will shed light between these 2 limits.

An enhancement of baryon/meson ratio has been observed in the light quark sector for intermediate p_T [22]. The HFT, by measuring the Λ_c/D^0 ratio, will also provide a measurement of the ratio baryon to meson, but in the heavy flavor regime (see figure 7).

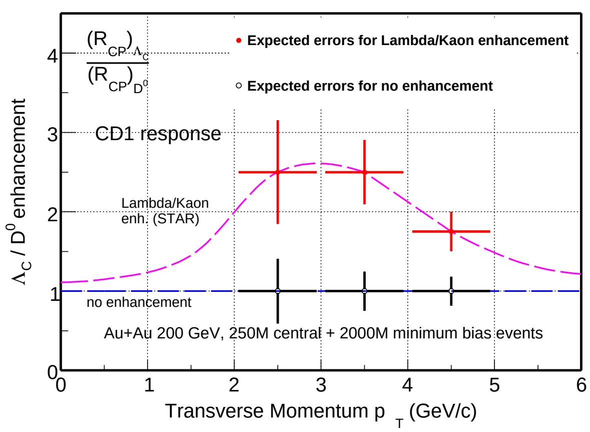

Figure 7: Estimated performance of HFT detector demonstrated at its ability to measure a possible Λ_C / D^0 enhancement.

5. Conclusion and perspectives

We have shown a method using full track information plus a secondary vertex fit using Silicon

Vertex information to obtain higher precision data. This method has been used for a better measurement of *D* meson hadronic decay channel from the Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV at RHIC. This method will be the baseline for future analysis involving the Silicon upgrades in STAR that will perform detailed exclusive charm and bottom studies.

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