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B_s Physics and Prospects at the Tevatron

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Both experiments CDF and D0 at the Tevatron collider have now the first samples of B_s where preliminary measurements are performed. The mass and lifetime determination is shown and the yield for the hadronic B_s decays, the first step towards the B_s production fraction and Branching Ratio, is discussed. This also sets the bases for a re-evaluation of mixing capabilities in Run II.

1 Introduction

The new data taking started March 2001 marked a new era for the B_s physics at the Tevatron collider. Both experiments, CDF and D0, have new strategies to select events with this meson among the huge $p\bar{p}$ production which rely on the triggers based on track impact parameter. Fully hadronic decays like $B_s \to D_s\pi$, considered fundamental to measure the mixing frequency, can be selected requiring at least two tracks displaced from primary vertex.
The combination of one displaced track and a lepton (muon or electron) allows to lower the threshold on the lepton trigger respect to the Run I data taking, increasing the number of events in the semileptonic sample. But also the "old" dilepton trigger has been improved thanks to the new tracking systems and the upgraded electronics increasing the number of events with a J/ψ in the final state. Besides the mixing frequency many other measurements can be done in the B_s system to test the Standard Model and to go beyond it. Here the mixing, the lifetime, the lifetime differences and the mass are discussed.

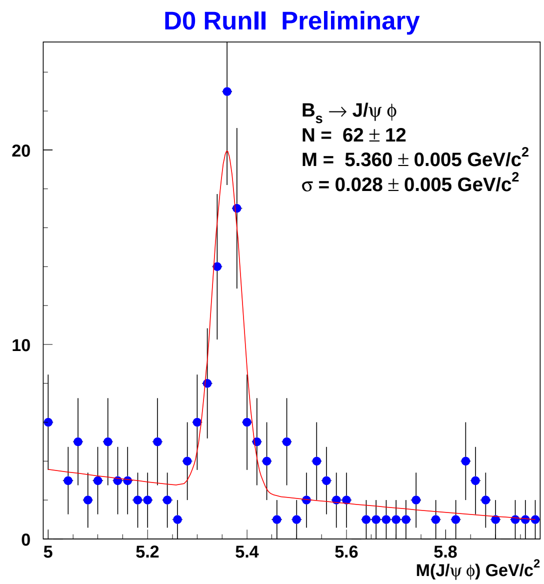

Figure 1. D0: invariant mass distribution of $J/\psi\varphi$ system.

2 B_s mass, lifetime and lifetime difference

The precise B_s mass determination is one of the measurements that both CDF and D0 can do with high precision to test the description given by the QCD of the fundamental mesons constituents. In this analysis the B_s is recostructed through the decay $B_s \to J/\psi\varphi$ with the $J/\psi \to \mu^+\mu^-$ and the $\varphi \to k^+k^-$. Starting from the dataset of $\sim$47 pb^{-1} collected with the dimuons trigger D0 has reconstructed a sample of 62 ± 12 events, shown in figure 1, with a very low background.

CDF reconstructs the same decay in a sample of $\sim$ 80 pb^{-1}. The 71 ± 8 events (see figure 2) are used to measure the B_s mass: M(B_s) = 5365.50±1.29(stat.)±0.94(syst.) MeV/c^2. This measurement improves both Run I [1] errors, the statistical and the systematic one and it is at the moment the world best measurement.

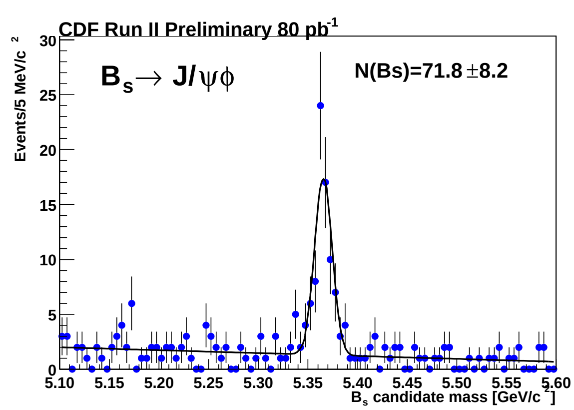

Figure 2. CDF: invariant mass distribution of $J/\psi\varphi$ system.

The B_s lifetime is expected [2] of the same order of the

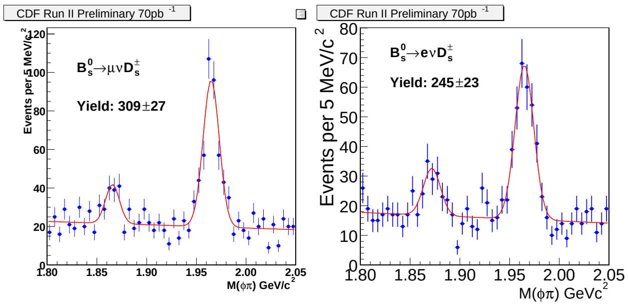

Figure 3. Inavriant mass of $\varphi\pi$ when they are close to a lepton (muon and electron) and the charge combination is that required by the decays.

$B_{d,u}$ lifetime and with the current data B^0 and B_s are equal within $\simeq$ 4% accuracy. The B_s measurements are statistical dominated and the Tevatron experiments are expected to improve it in a near future.
CDF can perfom this measurement in two different samples: the semileptonic decays and the fully reconstructed hadronic decays. The former has already been used at CDF in Run I [3] and based on this analysis CDF predicts that in 2 fb^{-1} CDF can reach a 2% precision on the lifetimes. Figure 3 displays the invariant mass when a $D_s \to \varphi\pi$ is reconstructed close to a muon(left) and an electron(right) and the charges of D_s and lepton match the requirement of the decay. The lifetime measurement is in progress. At the moment CDF has already $\sim$ 5 times the statistics of Run I with the signal to noise ratio even better than expected. This has been achived thanks to the trigger on the impact parameter since these candidates are recontructed on the lepton plus displaced track sample.

The Run II predictions for the lifetime measured with fully hadronic decays are based on the Monte Carlo simulation as discribed in [4]. The statistics is expected to be larger than the semileptonic sample and with the proper time resolution of about 45 fs an error of 0.5% with 2fb^{-1} of data is within the CDF reaches.

The $B_s \to J/\psi\varphi$ has two components: one with CP even (dominant) with a short lifetime and one at CP odd with a long lifetime. These events will be used to measure the lifetime difference, $\Delta\Gamma$, between the two eigenstates, the even and the odd. The best accuracy will obtained when the short component measured in this decay and the average lifetime obtained from the $B_s \to D_s\pi$ are combined. By using the result obtained in Run I [5] CDF evaulated its reach with 2fb^{-1} of data: $\Delta\Gamma/\Gamma \sim 0.06$.
At the moment the statistics is limited and CDF presents a measurement of the lifetime without no separation of the two components: $\tau(B_s^0) = 1.26 \pm 0.20(stat) \pm 0.02(sys)$.

This process is considered a “gold-plated” B_s decay because it is also sensitive to new physics beyond Standard Model. Within this model the CP asymmetry is expected to be very small and an observation of a deviation can only be attributed to sources of new physics.

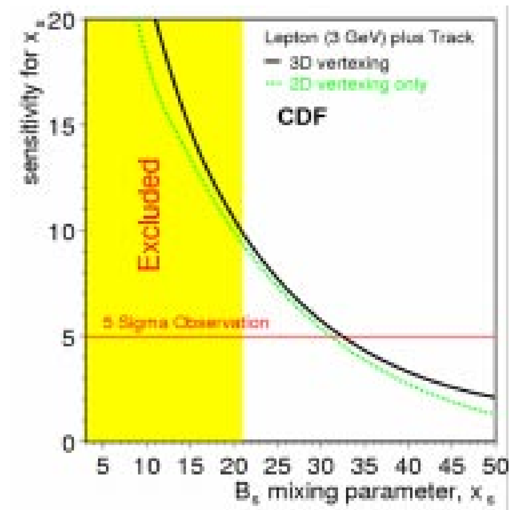

Figure 4. Sensitivity for x_s using only B_s semileptonic decays.

3 B_s mixing with semileptonic decays

The mixing frequency in the B_s system is one of most important measurement to verify the Standard Model. The current limit is $\Delta m_s > 14.4$ ps^{-1} which translates in $x_s = \Delta m_s \tau_{B_s} > 21$, that compared with B_d oscillation frequency $\Delta m_d = 0.502 \pm 0.006$ ps^{-1} gives an idea of how difficult will be to measure a so fast oscillation.
The sensitivity on x_s can be expressed:

$$sig(x_s) = \sqrt{\frac{N\epsilon D^2}{2}} exp(-(x_s\sigma_{c\tau}/\tau)^2/2)\sqrt{\frac{S}{S+1}}$$

where N is the total number of events before the flavor tagging, ϵ is the tagging efficiency, D the dilution, $\sigma_{c\tau}$ the proper time resolution and S the signal-to-noise ratio. The above formula drives the analysis: a statistically consistent sample of events with a reasonable signal-to-noise is needed, but also a good resolution in reconstructing the decay time is necessary as well as an efficient flavor tagging algorithm.

CDF set a limit $\Delta m_s > 5.8$ ps^{-1} at 95% C.L. using Run I B_s semileptonic decays [6]. In Run II the statistics and the signal to noise ratio will be improved as already discussed in 2 but the CDF sensitivity for x_s in this decay channel remain limited due to the partially reconstructed decay. The proper time $ct = \frac{L_{xy}M(B_s)}{P_t(B_s)} = \frac{L_{xy}M(B_s)}{P_t(l+D_s)} \cdot K$ is given by the decay length divided by $\beta\gamma$, which has to be corrected for the missing neutrino(K factor). This correction, calculated using the Monte Carlo, intoduces an additional resolution factor, $\sigma_t = 60\text{fs} \oplus t \cdot \sigma K/K$ with $\sigma K/K \sim 14\%$. The CDF predictions, shown in figure 4, are calculated assuming the above time resolution in a sample of $\sim 40,000$ events (in 2 fb^{-1}) including $B_s \to D_s l$ and $B_s \to D_s^* l$, with

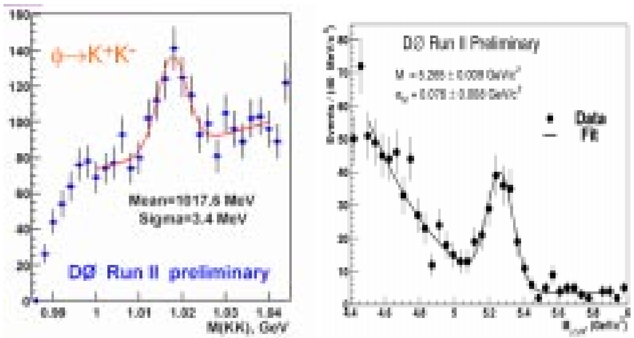

Figure 5. D0: Invariant mass of two kaons.

$D_s \to \varphi\pi, K^{*0}K^{\pm}$ and $\pi^-\pi^+\pi^{\pm}$. The tagging figure of merit, ϵD^2 is assumed 11.3%. The conclusion is that this sample will be useful to measure x_s up to ~ 30.

The same exercise has been done by D0. The number of events assumed in 2 fb^{-1} is 40,000 collected by triggering on two leptons, one from the reconstructed B_s and the other from the other B of the event. D0 reach, $x_s \leq 30$, is similar to the CDF one.

4 B_s mixing with hadronic decays

Both experiments CDF and D0 in this new data taking optimized their triggers to collect samples of hadronic B_s decays where there is no missing neutrino in particular for the B_s oscillation observation.

D0 is planning to collect hadronic B_s triggering on the lepton from the other B of the events and by using a track trigger not implemented yet. D0 expects to reconstruct $\sim 1,000$ of $B_s \to D_s^{\mp}\pi^{\pm}$ and $B_s \to D_s^{\mp}\pi^-\pi^+\pi^{\pm}$ with $D_s^{\mp} \to \varphi\pi^{\mp}, K^{*0}K^{\mp}, K^{*\mp}K^0$. A first incouraging φ resonance has been reconstructed, as shown in figure 5(left) in 40 pb^{-1} of data. The flavor tagging, which includes different algorithims, is being optimized in a sample of $B^{\pm} \to J/\psi K^{\pm}$(see figure 5 right) and compared with the predictions [4]. Table 1 summarizes the preliminary results regarding the efficiency, the dilution and the figure of merit, ϵD^2.

	Muons	Jet Charge
ϵ(%)	8.2 ± 2.2	55.1 ± 4.1
D(%)	63.9 ± 30.1	21.1 ± 10.6
ϵD^2	3.3 ± 1.8 (3.1 pred.)	2.4 ± 1.7(4.7 pred.)

Table 1. Summary of flavor tagging study

Exploiting its good dilepton trigger D0 can collect betwen 400 and 1,000 events of $B_s \to J/\psi K^*$, $K^* \to K^{\pm}\pi^{\mp}$ which can be combined with the hadronic sample to increase the statistics. Under the assumption that the proper time resolution is 0.40 ps D0 draws its sensitivity curve as function of x_s, shown in figure 6, from where D0 can say to measure x_s up to 30.

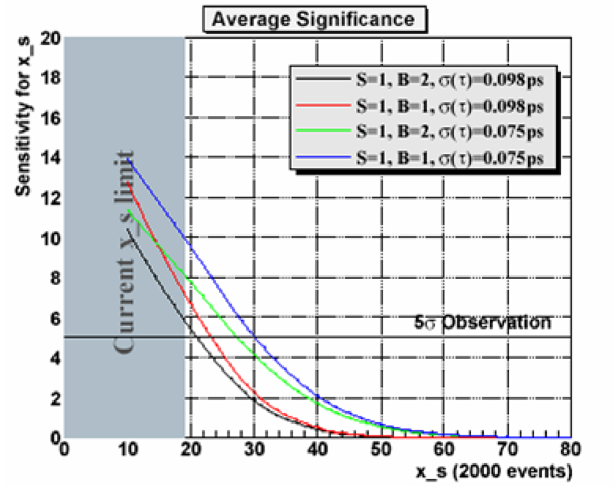

Figure 6. D0: x_s sensitivity in the hadronic sample

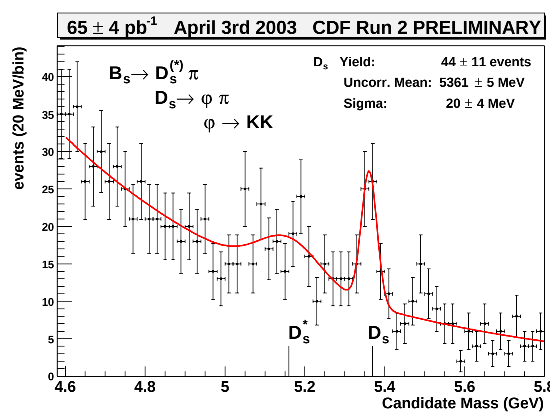

Figure 7. CDF: invariant mass of $D_s\pi$ reconstructed in the hadronic triggered sample

CDF has reconstructed for the first time the decay $B_s \to D_s^{\mp}\pi^{\pm}, D_s^{\mp} \to \varphi\pi^{\mp}$. In 65 pb^{-1} of data collected triggering on displaced tracks 44 ± 11 events are identified, see figure 7 where the $D_s\pi$ invariant mass is shown. This is the first step to check the prediction on the x_s sensitivity. While other parameter like the proper time resolution and the flavor tagging can be tested on other samples, the yield, namely the B_s cross section times the branching fraction, is unknown and it is the first thing to measure. The direct measurement of N_{B_s} goes through the knowledge of the b cross section and the B_s fraction, $N_{B_s} = \sigma(b) f_s Br(B_s \to D_s^{\mp}\pi^{\pm}) Br(D_s^{\mp} \to \varphi\pi^{\mp} Br(\varphi \to K^+K^-)$. Both quantities, $\sigma(b)$ and f_s are not well known. The former has a 2 sigma discrepancy between data and theory while in the second one the LEP determination differs from the Tevatron mea-

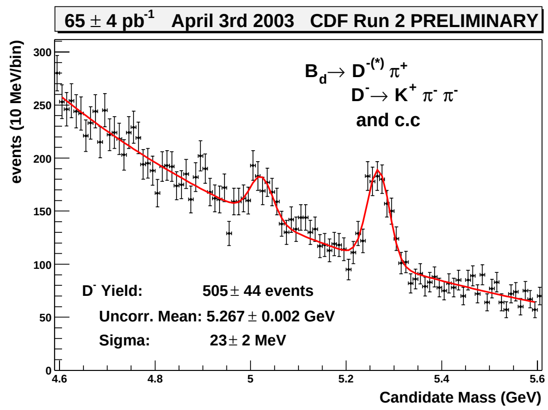

Figure 8. CDF: invariant mass of $D^{\mp}\pi^{\pm}$.

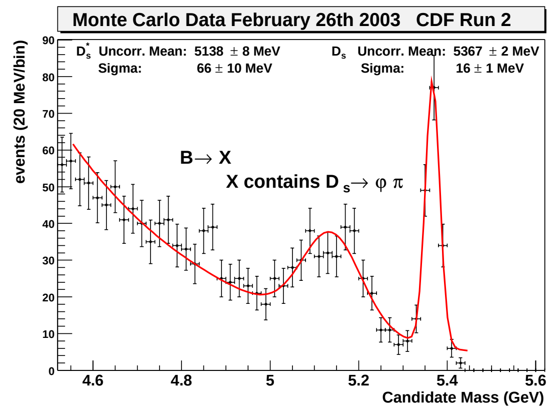

Figure 9. CDF: invariant mass of $D_s\pi$ reconstructed in Monte Carlo data after the trigger and detector simulation

surement [7,8] and in principle can be different. These two fact motivated CDF to measure a relative B_s yield. The best decay chanel to normalize to is $B_d \rightarrow D^{\mp}\pi^{\pm}$ with $D^{\mp} \rightarrow K^{\mp}\pi^{\mp}\pi^{\pm}$ also reconstructed in the hadronic trigger. By using this two decay CDF can measure:

$$\frac{N(B_s)}{N(B_d)} = \frac{f_s}{f_d}\frac{\epsilon(B_s)}{\epsilon(B_d)} \times \frac{Br(B_s \to D_s^{\mp}\pi^{\pm})Br(D_s^{\mp} \to \varphi\pi^{\mp})Br(\varphi \to K^+K^-)}{Br(B_d \to D^{\mp}\pi^{\pm})Br(D^{\mp} \to K^{\mp}\pi^{\mp}\pi^{\pm})}$$

The number of $B_d \rightarrow D^{\mp}\pi^{\pm}$ identified in the displaced tracks trigger is $N(B_d) = 505 \pm 44$. The invariant mass of the $D^{\mp}\pi^{\pm}$ is displayed in figure 8. The second peak around 5 GeV/c^2 is due to partially reconstructed $B_d \rightarrow D^{*\mp}\pi^{\pm}$ where a π^0 from $D^{*\mp} \rightarrow D^{\mp}\pi^0$ is not reconstructed.

From the numbers of reconstructed events: $\frac{N(B_s)}{N(B_d)} = 0.087 \pm 0.023$. A systematic error of $0.008 \oplus 0.008$ due to the fitting procedure have been assigned to the ratio for B_s and B_d.

The relative efficiencies, $\frac{\epsilon(B_s)}{\epsilon(B_d)}$ have been measured using Monte Carlo data. This ratio includes the relative trigger and reconstruction efficiencies. A very detailed Monte Carlo detector simulation have been developed and tuned on data to reproduce the different data taking configurations CDF had: the silicon coverage now is almost 100% but in two years varied a lot due to Tevatron incident and subsequent recovering. This is one of the most important element to take into account to properly evaluate the efficiencies. On the other hand the trigger on displaced tracks depends on the silicon coverage and its optimization in reconstructing tracks has changed to follow the detector behavior. In figure 9 the invariant mass of $D_s\pi$ on Monte Carlo data is shown after the trigger and the detector simulation have been performed demonstrating a good agreement with data.

The same procedure is used to evaluate the B_d efficiency from where $\frac{\epsilon(B_s)}{\epsilon(B_d)} = 1.08 \pm 0.02(stat)^{+0.06}_{-0.08}$ is obtained.
The major sources of systematic errors on this ratio are the B_s, B_d, D_s and $D^{\mp}$ lifetimes and the b quark momentum spectrum.

The ratio $\frac{Br(D_s^{\mp} \to \varphi\pi^{\mp})Br(\varphi \to K^+K^-)}{Br(D^{\mp} \to K^{\mp}\pi^{\mp}\pi^{\pm})} = 0.19 \pm 0.05$ is taken from PDG [7]. By combining all the numbers together CDF quotes:

$$\frac{f_s}{f_d}\frac{Br(B_s \to D_s^{\mp}\pi^{\pm})}{Br(B_d \to D^{\mp}\pi^{\pm})} = 0.42 \pm 0.11(stat) \pm 0.11(PDG) \pm 0.07(syst)$$

This the first measurement of the B_s branching ratio times the production fraction, dominated at present by the statistical error and the uncertanties on the D branching ratios.

5 Conclusions

CDF and D0 have reconstructed the first signals of B_s decays in data collected in the new data taking. Both collaborations are working in order to optimize the tools necessary to perform the various measurements accessible in this sector, in particular a big effort is going in the mass and lifetime determination and of course in the mixing frequency analysis. Both D0 and CDF, have nice samples of $B_s \rightarrow J/\psi\varphi$ where the mass has been measured by CDF. While the lifetime determination is in progress, CDF has shown for the first time the decay $B_s \rightarrow D_s\pi$ where the relative production fraction have been measured. Both experiments have to face the fact the the Tevatron is giving a lower luminosity than the expected and that the reaches quoted in [4] result to be somehow optimistic. The first thing is not so negative as can appear for B physics because the trigger threshold optimized for high rate can be lowered. This is currently under study in CDF, in particular for the trigger on displaced tracks. The other good thing is that other B_s decays not considered in [4] appeared more reconstructable than what have been tought increasing the B_s statistics in the fully reconstructed sample. Work is in progress to quantify all these factors and give a data based expectation for B_s mixing measurement.

References

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