◇ Monograph Excerpt ◇

Matter Antimatter Fluctuations

search, discovery and analysis of Bs flavor oscillations

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Chapter 13

Epilogue

The development, technique, and results of the oscillation analysis yielding the precise measurement and world's first observation of the time-dependent flavor oscillations in the $B_s - \bar{B}_s$ system performed at the CDF experiment have been presented.

The construction of the experimental technique, of its multiple components and ingredients, was explained in a progressive fashion in the preceding chapters. Including the selection and reconstruction of the B_s mesons, and also the higher-yield B^0 and B^+, in their multiple exclusive and inclusive decay modes, the composition of the data samples, their characterization in the mass and proper decay time spaces, the development of the flavor tagging algorithms, the measurement of the B mesons lifetimes and B^0 mixing parameters, the establishment of the corresponding likelihood model and fitting framework, and overall input calibration and thorough method validation.

In Chapter 8 the B_s 'box was open' for the first time. That is, the mixing analysis was apllied to the samples of reconstructed and flavor-tagged B_s decays. Employing a dataset of $355\,\mathrm{pb}^{-1}$ and the opposite-side tagging algorithms alone, a Δm_s sensitivity (which is estimated in advance, from the blinded samples) up to $13\,\mathrm{ps}^{-1}$ was attained. Under the assumption of $\Delta m_s < 25\,\mathrm{ps}^{-1}$ and after combination with the world average amplitude measurements performed in that range, the interval of frequencies not excluded at 95% C.L. $\Delta m_s \in (16.6, 20.8)\,\mathrm{ps}^{-1}$ was inferred.

In Chapter 9 a novel same-side (kaon) tagging algorithm was developed, which brings about a substancial increase in tagging power – its addition may be translated as the trebling of the effective sample statistics. From the application of the additional tagger to solely the fully reconstructed $B_s \to D_s\pi(\pi\pi)$ decays on the same $355\,\mathrm{pb}^{-1}$ dataset, we have first observed the emergence of the B_s oscillation signal, within the sensitivity of about $18\,\mathrm{ps}^{-1}$, and with a significance $\mathcal{A}/\sigma_{\mathcal{A}} \sim 3$. The frequency range not excluded at 95% C.L. became $\Delta m_s \in (16.6, 18.2)\,\mathrm{ps}^{-1}$.

In the next stage the full accumulated dataset amounting to 1 fb^{-1} was explored, as shown in Chapter 10. The tagging information from opposite-side and same-side tagging methods was combined, assuming to be uncorrelated, and applied to the samples of partially and fully reconstructed decay modes. This yields the world's first direct measurement: $\Delta m_s = 17.31^{+0.33}_{-0.18}(\text{stat.}) \pm 0.07(\text{syst.})\,\text{ps}^{-1}$, achieved well within the sensitivity of $25.8\,\text{ps}^{-1}$. The amplitude significance at $\Delta m_s = 17.3\,\text{ps}^{-1}$ is measured to be $\mathcal{A}/\sigma_{\mathcal{A}} = 3.7$. The probability that random fluctuations could produce a comparable signal is found to be 0.2%, corresponding to a 3σ signal significance.

Finally, the definitive observation of B_s oscillations is achieved. Various relatively small but determining improvements are made which lead to the increase in signal yield and flavor tagging performance. These comprise the addition of B_s decay modes, an extended exploitation of kaon identification, and the use of multivariate implementations to optimize selection and combination of flavor tagging information. These together result in an increase by a factor of 2.5 in the effective statistical size of the data sample. The Δm_s sensitivity attained is $31.3\,\text{ps}^{-1}$. The statistical significance of the amplitude measurement at $\Delta m_s = 27.75\,\text{ps}^{-1}$ is $\mathcal{A}/\sigma_{\mathcal{A}} = 6$. The probability that random fluctuations could produce a signal comparable to that observed is estimated to be $8 \cdot 10^{-8}$, corresponding to a significance in excess of $5\,\sigma$.

The B_s oscillation frequency is measured to an exquisite precision:

$$\Delta m_s = 17.77 \pm 0.10(\text{stat.}) \pm 0.07(\text{syst.})\,\text{ps}^{-1}.$$

The ratio of oscillation frequencies in the B^0 and B_s systems yields the following ratio of CKM matrix elements:

$$|V_{td}/V_{ts}| = 0.2060 \pm 0.0007(\text{exp.})^{+0.0081}_{-0.0060}(\text{theor.})\,.$$

The measurement provides an important demonstration of the standard model of flavor interactions while also imposing strict constraints on the phase-space available for new physics contributions to the flavor sector, and concludes a two decade long search.