X(5568) Studies Questions and Answers

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Q1 *Could the X(5568)→ $B_s\pi$ state seen by D0 be a statistical fluctuation?*

A1 Evidence for the X(5688) was found in both the hadronic ($B_s \rightarrow J/\psi\ \phi$) [1] and semileptonic ($B_s \rightarrow D_s^+ \mu^- X$) [2] channels. The joint significance of the signal in hadronic and semileptonic channels, including systematics and the look elsewhere effect, is over 6 standard deviations which indicates that probability of a statistical fluctuation is extremely low.

Q2 *D0 uses the so called "ΔR" cut on the angular separation between pion and B_s. Could this cut be the reason for the observed X(5568) excess of events?*

A2 "ΔR" cut is used by various experiments in particle physics to improve signal/background ratio. We analyzed our data using a range of ΔR cuts (see Ref.[3]) and found that the mass, width and signal yields, corrected for efficiency, were consistent. We performed the analyses without the ΔR cut in both hadronic and semileptonic B_s decay modes and confirmed the existence of X(5568).

Q3 *Could the significance of the D0 X(5568) observation be affected by the shape of the background function?*

A3 We studied various background shapes based on the Tevatron data and on simulation. The effects of event pileup were incorporated in the simulations. All of them give consistent results. The results using different background parameterizations are used to establish systematic uncertainties which were taken into account in the overall significance calculations [1,2].

Q4 *Could the excess observed by D0 +be due to pileup of events at high luminosities?*

A4 The D0 triggers used in its X(5568) analysis are typically prescaled, and thus correspond to lower average luminosity than in high p_T event selections. In our data sample, the average number of proton-antiproton collisions is two, with a typical distance between vertices along the beam of ~30 cm, so combinatoric background due to multiple interactions in the analyzed events is low.

Q5 *Have you verified that there are not multiple copies of the same events in the data sets?*

A5 We note that since we allow combination of the B_s with more than one pion candidate in an event, the number of combinations exceeds the number of events by a factor of about 1.5. We have checked that there is no duplication of combinations.

Q6 *How do the $B_s\pi$ mass distributions compare for positive and negative pions?*

A6 Mass distributions for positive and negative pions are consistent (see Fig. 1) and both demonstrate the X(5568) presence, albeit with lower significance due to lower statistics in each channel. Similar subdivisions of the sample according to the sign of the pion pseudorapidity or the sign of the vertical component of the pion p_T also show good consistency.

Q7 *There are quite different X(5568) signal efficiencies (by ~50%) between CDF [4] and D0. Why is this?*

A7 Most of this difference is due to the different cuts on transverse momentum of the pion (0.4 GeV for CDF and 0.5 GeV for D0).

Q8 *Could there be reasons for the differences between the CDF and D0 results?*

A8 There are differences between the selection cuts for the two analyses. These include the different requirements on the pion transverse momentum mentioned above, a cut on $p_T(B_s)$>10 GeV (CDF) compared with the cut $p_T(B_s\,\pi)$ > 10 GeV (D0), and differences in the selections of the detached B_s system and the prompt pion. Most importantly, the muon pseudorapidity cuts are different: ($|\eta_\mu|< 1$ for CDF and $|\eta_\mu|< 2$ for D0). When both muons in the D0 data are restricted to $|\eta_\mu|< 1$ (see Fig. 2), the signal is smaller than when at least one muon is forward.

Q9 *Is there evidence for a difference in the ratio of forward production relative to central production for other exotic mesons?*

A9 We can compare the rapidity distributions for the X(5568) and the well-established exotic state X(4140). D0 previously observed [5] X(4140) → $J/\psi\ \phi$ with similar kinematic selections for both prompt production (as is the case for X(5568) and through B meson decays. Two ratios are measured. The first is R1 = f/c where c (f) is the rapidity range $|\eta|<1$ ($1<|\eta|<2$) for the parent X particle. We find:

R1 = 1.5 ± 0.5 for X(5568) → B_s ($J/\psi\ \phi$) π
R1 = 1.25 ± 0.05 for inclusive B_s
R1 = 2.3 ± 0.9 for prompt X(4140)
R1 = 1.6 ± 0.5 for X(4140) from B decays.

The second ratio is R2 = (CF+FF)/CC, where C(F) is the rapidity range $|\eta|<1$ ($1<|\eta|<2$) for either of the muons from J/ψ decay, is taken from distributions like Fig. 2.

R2 = 2.6 ± 1.1 for X(5568) → Bs ($J/\psi\ \phi$) π
R2 = 1.63 ± 0.07 for inclusive B_s
R2 = 5.3 ± 2.8 for prompt X(4140)
R2 = 1.7 ±0.5 for X(4140) from B decays.

Although uncertainties are large, the prompt X(4140) and X(5568) have forward to central ratios that tend to be larger than those for final states arising from B meson decays.

Q10 *Are CDF and D0 results compatible, even if one experiment observes X(5568) and another does not?*

A10 The ratios of the production of X(5568) → $B_s\pi$ to inclusive B_s for two experiments are compatible at the 2σ level.

Q11 *Could an excess of events for X(5568) be due to reflections?*

A11 We performed tests by replacing the pion mass assigned to the slow charged track with a kaon or proton mass and saw no bumps [3].

Q12 *Are there any known channels with similar decay kinematics which can be used as calibration/verification of the D0 analysis?*

A12 When a B_d is selected instead of a B_s and combined with a pion as in the B_s analysis, there is no $B_d\,\pi$ enhancement just above threshold, but the known B_1 meson is clearly observed (see Fig. 3).

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References

1. V. M. Abazov et al., "Evidence for a $B_s^0\pi^\pm$ state ", Phys. Rev. Lett. 117, 022003 (2016).

2. V. M. Abazov et al., "Study of the $X^\pm$(5568) state with semileptonic decays of the B^0_s meson", submitted to Phys. Rev. D, arXiv 1712.10176 (2017).

3. V. M. Abazov et al., supplemental material published with Ref. [1], https://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B16A/

4. T. Aaltonen et al., "A search for the exotic meson X(5568) with the Collider Detector at Fermilab, arXiv:1712.09620 (2017)

5. V. M. Abazov et al., "Inclusive production of the X(4140) state in pp collisions at D0", Phys. Rev. Lett. 115, 232001 (2015).

Figures

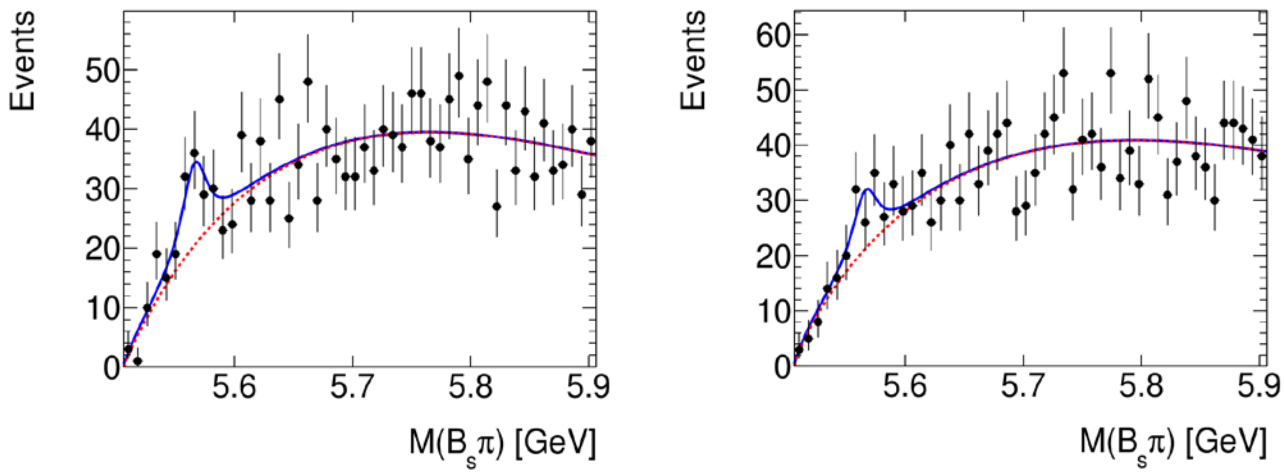

Fig. 1. $B_s\pi$ mass distribution with fits for the signal and background for (left) positively and (right) negatively charged pion for the analysis of Ref. [1].

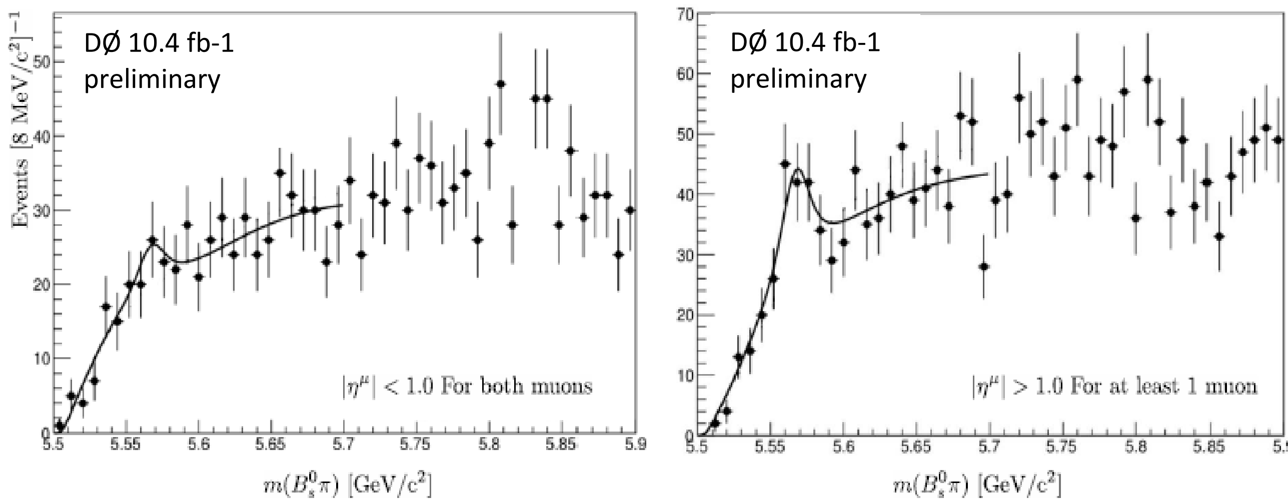

Fig. 2: Mass distributions for $B_s\ \pi$ with $B_s \rightarrow J/\psi\ \phi$, $J/\psi \rightarrow \mu^+\ \mu^-$, for both muons in the central region (CC), one central and one forward (CF) or both forward (FF). The central (forward) region is defined by $|\eta|<1$ ($1 < |\eta|<2$).

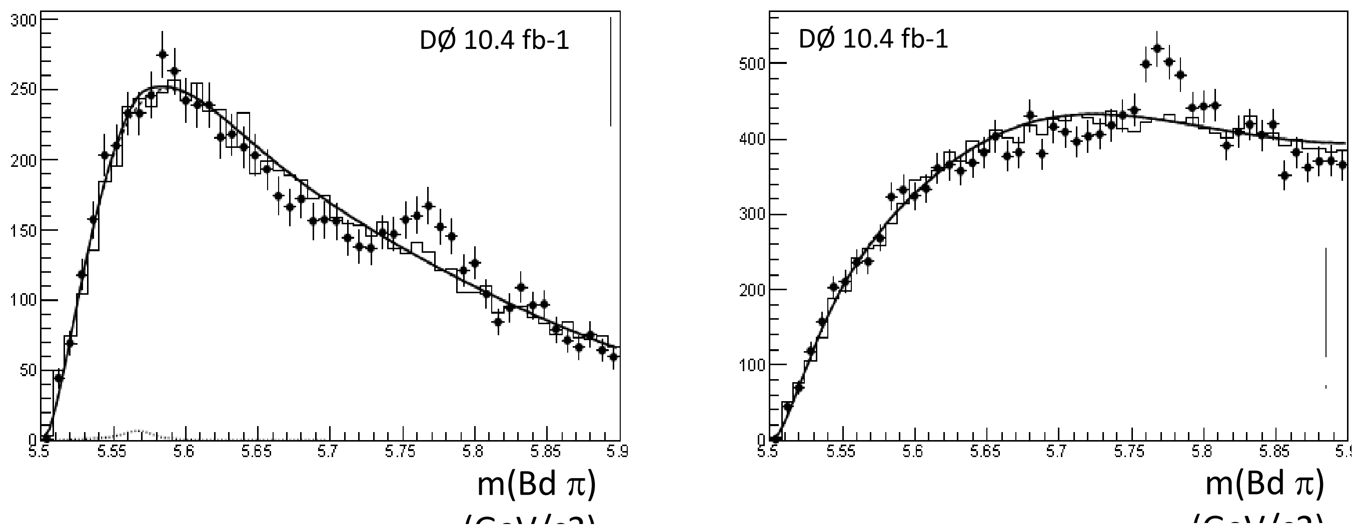

Fig. 3 m(B_d^0 $\pi^{\pm}$) distribution for the $B_d^0 \rightarrow J/\psi\ K^{*0}$, $K^{*0} \rightarrow K^+ \pi^-$ mode, with the ΔR cut (left) and without (right). To have the same mass definition as in the $B_s\pi$ analysis, the plotted mass is defined as m($B_d\pi$) – m(B_d) +5.3667 GeV. No evidence of an enhancement in the 5568 GeV region is seen but the known B_1 state is evident at about 5.76 GeV.