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Statistical combination of $X^{\pm}(5568) \to B_s^0\pi^{\pm}$ searches

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A statistical combination of the search results for the $X^{\pm}(5568) \to B_s^0\pi^{\pm}$ decay is reported, based on published results from the ATLAS, CMS, CDF and LHCb Collaborations.
A narrow structure in the invariant mass distribution of $B_s^0\pi^{\pm}$ has been observed by the D0 Collaboration with a mass value of 5568 MeV and interpreted as the first observation of a possible tetra-quark state with four different flavours. The evidence of such a state was not confirmed by any of the latest searches from LHCb, CDF, ATLAS and CMS Collaborations. CDF and the LHC experiments have set limits on ρ_X, the relative production rate of the $X(5568)$ and B_s^0 rates times the branching ratio for the $X^{\pm}(5568) \to B_s^0\pi^{\pm}$ decay.
With a statistical combination of limits set by the three LHC experiments, we derive a limit, at 95% Confidence Level, of $\rho_X < 0.92\%$ for $p_T(B_s^0) > 10$ GeV, and $\rho_X < 0.91\%$ for $p_T(B_s^0) > 15$ GeV which represent the most stringent upper limits up to present.
The contribution reviews the experimental results from Tevatron and LHC, describes the combination procedure and the obtained results. The effect of including the results from Tevatron in the combination is also discussed.

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1. Introduction and review of experimental results

In 2016 the D0 Collaboration published the evidence of a charged state X decaying to $B_s^0\pi^{\pm}$ [1], with a mass peaking at 5568 MeV/c^2 and a width of 21.9 MeV/c^2, with a possible interpretation as a tetraquark state. Similar searches performed by the LHCb [3], CDF [4], CMS [5] and ATLAS [6] did not show any evidence of a signal. Finally, D0 increased the data set including the semileptonic decay channel for the B_s^0 [2] and confirmed the result with a clear indication of a signal.

The observation of D0 is based on 10.4 fb^{-1} at 1.96 TeV data. B_s^0 are reconstructed in the $J/\psi\phi \to \mu^+\mu^-K^+K^-$ channel (hadronic) or in the $D_s\mu^{\pm}Y \to \phi\pi^{\pm}\mu^{\pm}Y$, channel (semileptonic), with $\phi \to K^+K^-$ and Y=anything. LHCb searched for the $X^{\pm}(5568)$ signal in 3 fb^{-1} at 7 and 8 TeV data, with the same B_s^0 decay channels, and $p_T(B_s^0) > 5, 10, 15$ GeV. Similar analyses have been carried out by CDF (9.6 fb^{-1} at 1.96 TeV), CMS (19.7 fb^{-1} at 8 TeV) and ATLAS (4.9 fb^{-1} at 7 TeV and 19.5 fb^{-1} at 8 TeV), all looking at the $B_s^0 \to J/\psi\ \phi$ channel with $p_T(B_s^0) > 10$ GeV for CDF and > 10, 15 GeV for CMS and ATLAS.

In absence of a signal, the LHC experiments and CDF have set upper limits on the relative production rate of the $X^{\pm}$ and B_s^0 states, times the branching ratio for the decay $X^{\pm} \to B_s^0\pi^{\pm}$:

$$\rho_X = \frac{\sigma(pp \to X + \text{anything})}{\sigma(pp \to B_s^0 + \text{anything})} \times \mathcal{B}(X \to B_s^0\pi^{\pm}) = \frac{N(X)}{N(B_s^0)} \times \frac{1}{\epsilon_X} \tag{1}$$

where $N(B_s^0)$ and $N(X)$ is the number of reconstructed B_s^0 and $X^{\pm}$ candidates, respectively, and ϵ_X is the relative efficiency for the reconstruction of B_s^0 and X events. Figure 1 shows the measured values (D0) and the 95% C.L. limits (LHCb, CDF, CMS, ATLAS) of ρ_X.

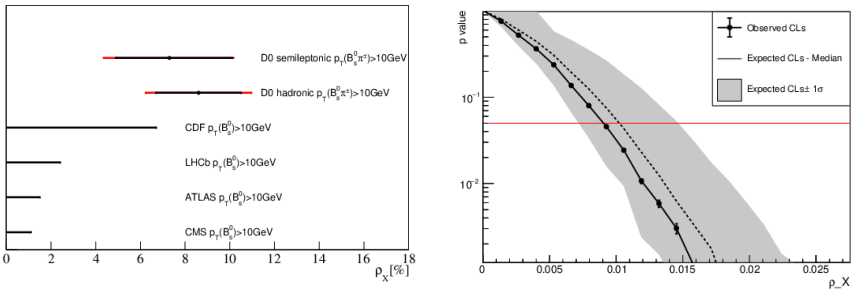

Figure 1: Left: experimental results on ρ_X. For D0, statistical errors are in black; red lines refer to statistical and systematic errors added in quadrature. Right: p-value as function of ρ_X for the combination of the LHC experiments for $p_T(B_s^0) > 15$ GeV. The observed limit at 95% confidence level corresponds to a p-value of 0.05 (red line). The expected median value (dashed line) and the $\pm 1\ \sigma$ band (gray area) are also shown.

2. Statistical combination and results

The experimental results from LHC and Tevatron experiments have been combined to extract an upper limits on ρ_X. The combination uses the asymptotic frequentist CL_s method [8]. Details of the analysis can be found here [9]. The upper limit at 95% C.L. has been extracted for each experiment separately to test the consistency of the method, always finding good agreement with the results published by the four Collaborations. Inputs values for systematic uncertainties are

taken by the respective papers, except for CMS where we referred to [7]. Systematic and statistical uncertainties are added in quadrature. The limit for the combination is extracted, separately for $p_T(B_s^0) > 10$ and 15 GeV[1]. Figure 1 right shows the CLs extraction for the combination of the LHCb, CMS and ATLAS results for $p_T(B_s^0) > 15$ GeV. The results at 95% C.L. are:

$$\rho_X^{\text{ATLAS+CMS+LHCb}}(p_T(B_s^0) > 10 \text{ GeV}) < 0.92\%$$
$$\rho_X^{\text{ATLAS+CMS+LHCb}}(p_T(B_s^0) > 15 \text{ GeV}) < 0.91\%$$

The combination of the LHC results improves the upper limits on ρ_X bringing both of them below the 1% level. This result has to be compared with the D0 measurement of $(8.6 \pm 1.9(\text{stat}) \pm 1.4(\text{syst}))\%$ ($(7.3^{+2.8}_{-2.4}(\text{stat})^{+0.6}_{-1.7}(\text{syst})\%$) for the hadronic (semileptonic) channel.

The inclusion of the CDF result gives a looser limit ($\rho_X^{\text{LHC+CDF}}(p_T(B_s^0) > 10 \text{ GeV}) < 0.96\%$) as CDF measures a number of $X^{\pm}$ candidate events that is compatible with a $\sim 1\sigma$ signal: 36 ± 33. The result from D0 is not included in the combination as D0 made a measurement of ρ_X and did not set an upper limit. Moreover, some selection cuts in the D0 analysis are different from the other analyses. The statistical procedure can be, however, applied to the D0 result alone. The combination of the hadronic and semileptonic channels gives an upper limit on ρ_X of 12% at 95% CL.

In conclusion, we have performed a statistical combination of the results from the ATLAS, CDF, CMS and LHCb experiments of the searches for the $X^{\pm}(5568)$ state decaying into a $B_s^0\pi^{\pm}$ pair. The combination allows to set upper limits on the relative production rate of the $X^{\pm}(5568)$ and B_s^0 states, times the branching ratio for the decay $X^{\pm}(5568) \to B_s^0\pi^{\pm}$, ρ_X, for the first time below 1% at 95% CL. The most stringent limits are obtained when combining the results from the three LHC experiments: $\rho_X^{\text{LHC}} < 0.92\%$ and $< 0.91\%$ at 95% CL for $p_T(B_s^0) > 10$ and 15 GeV, respectively.

References

[1] V.M. Abazov *et al.* (D0 Collaboration) Phys. Rev. Lett. **117**, 022003; Publisher's Note **118**, 109904(A) (2017)

[2] V.M. Abazov *et al.* (D0 Collaboration) Phys. Rev. D **97**, 092004

[3] R. Aaij *et al.* (LHCb Collaboration) Phys. Rev. Lett. **117**, 152003

[4] T. Aaltonen *et al.* (CDF Collaboration) Phys. Rev. Lett. **120**, 202006

[5] A.M. Sirunyan *et al.* (CMS Collaboration) Phys. Rev. Lett. **120** (2018), 202005

[6] G. Aad *et al.* (ATLAS Collaboration) Phys. Rev. Lett. **120** (2018), 202007

[7] R.G. Mateo, CERN-THESIS-2018-375

[8] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Eur. Phys. J. C**71** (2011), 1554
Erratum: Eur. Phys. J. C**73** (2013), 2501; A. L. Read J. Phys. G. **28** (2002), 2963

[9] P. Iengo, arXiv:2010.00676 [hep-ex]

[1] as LHCb is the only experiment having done the analysis for $p_T > 5$ GeV, no combination is performed in this case.