Statistical combination of searches for the $X^{\pm}(5568)$ state decaying into $B^0_s\pi^{\pm}$

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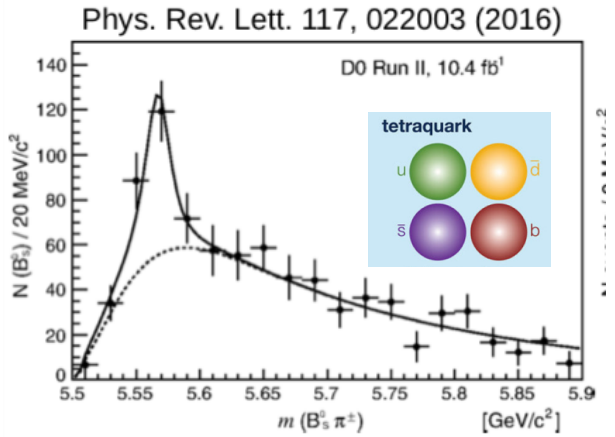
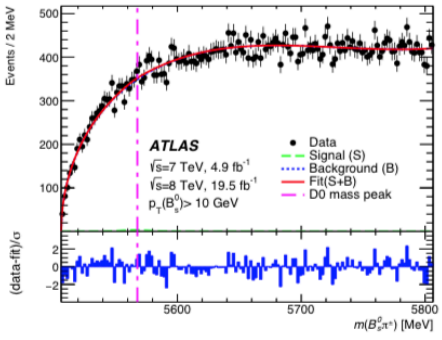
Introduction

- In 2016 D0 published evidence of a state $X^{\pm}(5568)$ in the $B_s\pi^{\pm}$ spectrum via $B_s^0 \rightarrow J/\psi\,\phi$, $J/\psi \rightarrow \mu^+\mu^-$, $\phi \rightarrow K^+K^-$ [1]
- Interpreted as a possible tetraquark *usbd* state
- Also seen in semi-leptonic decays[2]: $X^{\pm}(5568) \rightarrow B^0_s\pi^{\pm}$ where $B^0_s \rightarrow \mu^{\pm}D^{\pm}_sX$, $D^{\pm}_s \rightarrow \phi\pi^{\pm}$
- Subsequent searched from LHCb[3], CDF[4], ATLAS[5] and CMS[6] did not confirm the D0 observation



Phys. Rev. Lett. **120 (2018)**, 202007



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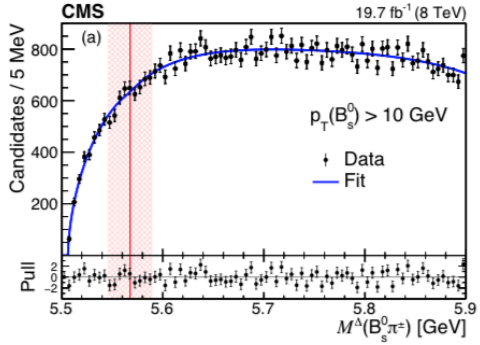


[1] V.M. Abazov *et. al* (D0 Collaboration) Phys. Rev. Lett. **117**, 022003

[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

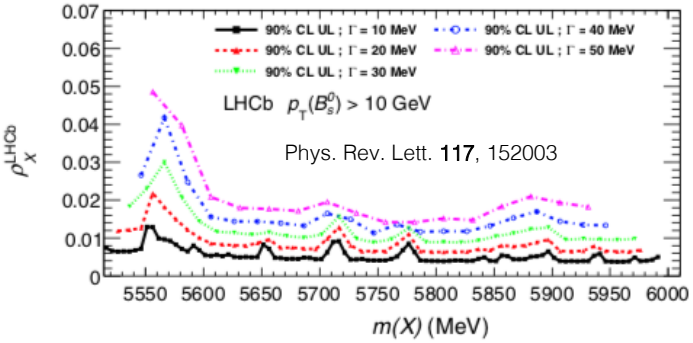
[5] G. Aad *et. al* (ATLAS Collaboration) Phys. Rev. Lett. **120** (2018), 202007

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

- In absence of a signal the LHC experiments and CDF have set limits on the production cross-section x branching ratio of the resonance, normalised to the production cross-section of the B^0_s:

$$\rho_X \equiv \frac{\sigma(pp \rightarrow X + \text{anything})\,\mathcal{B}(X \rightarrow B^0_s\pi^{\pm})}{\sigma(pp \rightarrow B^0_s + \text{anything})} = \frac{N_X}{\epsilon_{\text{rel}} N_{B^0_s}}$$

- Asymptotic CLs frequentist method with PDF models for signal and background

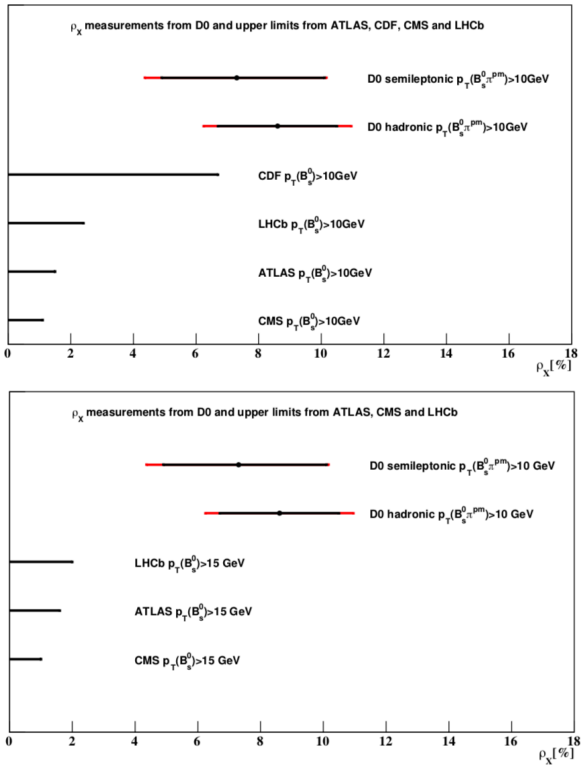


Statistical combination

- $X^{\pm}(5568)$ searches have been performed in hadronic/ semileptonic decay channels and different $p_T(B^0_s)$ cut ($p_T(B^0_s\pi^{\pm})$ for D0)

Experiment	B^0_s decay channel	p_T cut	$N(B^0_s)/10^3$	$N(X)$
D0	$B^0_s \to D^-_s\pi^+$	10 GeV	6222 ± 141	121^{+51}_{-34}
D0	$B^0_s \to J/\psi\phi$	10 GeV	5582 ± 100	133 ± 31
LHCb	$B^0_s \to D^-_s\pi^+$	5 GeV	62.2 ± 0.3	3 ± 64
LHCb	$B^0_s \to D^-_s\pi^+$	10 GeV	28.4 ± 0.2	75 ± 52
LHCb	$B^0_s \to D^-_s\pi^+$	15 GeV	8.8 ± 0.1	14 ± 31
LHCb	$B^0_s \to J/\psi\phi$	5 GeV	46.3 ± 0.2	-33 ± 43
LHCb	$B^0_s \to J/\psi\phi$	10 GeV	13.2 ± 0.1	12 ± 33
LHCb	$B^0_s \to J/\psi\phi$	15 GeV	3.7 ± 0.1	-10 ± 17
CDF	$B^0_s \to J/\psi\phi$	10 GeV	3.552 ± 0.065	36.0 ± 33
CMS	$B^0_s \to J/\psi\phi$	10 GeV	49.277 ± 0.278	-85 ± 160
CMS	$B^0_s \to J/\psi\phi$	15 GeV	40.292 ± 0.246	-103.0 ± 230
ATLAS	$B^0_s \to J/\psi\phi$	10 GeV	52.75 ± 0.28	60 ± 140
ATLAS	$B^0_s \to J/\psi\phi$	15 GeV	43.46 ± 0.24	-30 ± 150

- Summary of the experimental results on ρ_X



- We have performed a statistical combination of the upper limits on ρ_X based on the CLs method
- Combined PDF:

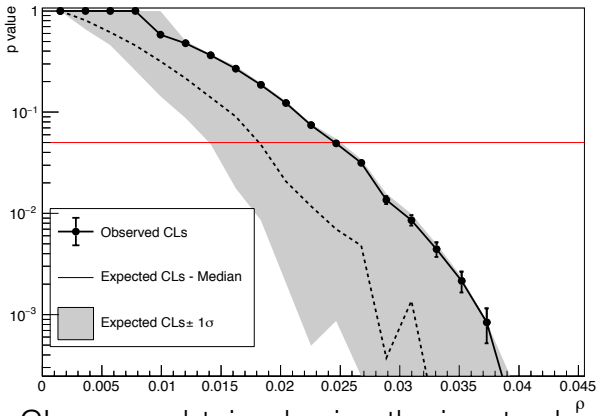
$$\mathcal{L} = \Pi_i\Pi_j\, \mathcal{G}[N^{obs}_{ij}(B^0_s)|N^{exp}_{ij}(B^0_s), \sigma(N_{ij}(B^0_s))] \times \mathcal{G}[\epsilon^{obs}_{ij}(X)|\epsilon^{exp}_{ij}(X), \sigma(\epsilon_{ij}(X))] \times \mathcal{G}[N^{obs}_{ij}(X)|N^{exp}_{ij}(B^0_s)\cdot\rho_X\cdot\epsilon_{ij}(X), \sigma_{ij}(N_X)]$$

- N^{obs}_{ij}= Number of observed (B^0_s or X) candidate events
- N^{exp}_{ij}= Number of expected (B^0_s or X) candidate events
- $\sigma_{ij}(N)$ = uncertainty on N
- ε_{ij} = relative reconstruction efficiency
- i = {ATLAS, CDF, CMS, LHCb}
- j = {hadronic, semileptonic}

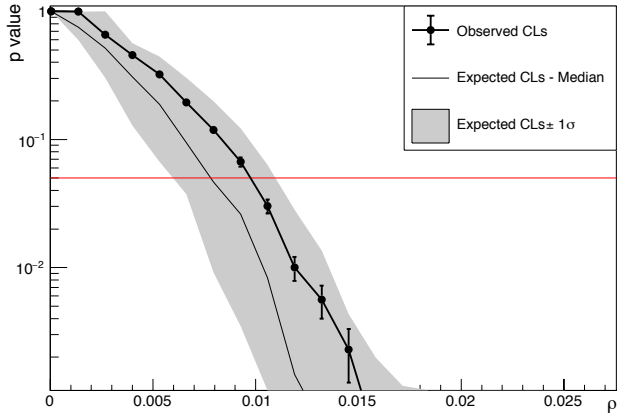
Results & Conclusions

- Consistency check: reproduction of upper limit results of the single experiments

Experiment	p_T cut	Measured upper limit on $\rho_X(\%)$	Upper limit on $\rho_X(\%)$ obtained in this work
ATLAS	10 GeV	1.5	1.48 ± 0.04
ATLAS	15 GeV	1.6	1.70 ± 0.07
CDF	10 GeV	6.7	6.69 ± 0.12
CMS	10 GeV	1.1	1.15 ± 0.04
CMS	15 GeV	1.0	1.04 ± 0.05
LHCb	10 GeV	2.4	2.45 ± 0.04
LHCb	15 GeV	2.0	2.19 ± 0.05



CLs vs ρ_X obtained using the input values of LHCb for the $p_T(B^0_s)$> 10 GeV bin



CLs vs ρ_X obtained using the input values of ATLAS, CDF, CMS and LHCb for the $p_T(B^0_s)$> 10 GeV bin

Inputs for combination	$p_T(B^0_s)$> 10	$p_T(B^0_s)$> 15
ATLAS, CMS, LHCb	ρ_X < 0.915%	ρ_X < 0.909%
ATLAS, CDF, CMS, LHCb	ρ_X < 0.961%	--

Upper limit on ρ_X at 95% CL obtained from the inputs of the three LHC experiments and, separately, with the inclusion of CDF for the two analysis bins $p_T(B^0_s)$> 10 and 15 GeV

- The statistical combination on the exclusion of the $X^{\pm}(5568)$ from the LHC experiments brings for the fist time the upper limit at 95% CL on ρ_X below 1% in both analysis bins:

$\rho_X(p_T(B^0_s)>10\ \text{GeV}) < 0.915\%$; $\rho_X(p_T(B^0_s)>15\ \text{GeV}) < 0.909\%$