Signals consistent with the \( B^+_c(2S) \) and \( B^{+*}(2S) \) states are observed in proton-proton collisions at \( \sqrt{s} = 13 \) TeV, in an event sample corresponding to an integrated luminosity of 143 fb\(^{-1}\), collected by the CMS experiment during the 2015 - 2018 LHC running periods. These excited beauty states are observed in the \( B^+ \rightarrow \pi^+ \nu \) invariant mass spectrum, with the ground state \( B^+_c \) reconstructed through its decay to \( J/\psi \pi^+ \). The two states are reconstructed as two well-separated peaks, separated in mass by 28.3 \pm 1.5 (stat) \pm 0.7 (syst) MeV. The observation of two peaks, rather than one, is established with a significance exceeding five standard deviations. The mass of the \( B^{+*}(2S) \) meson is measured to be 6871.0 \pm 1.2 (stat) \pm 0.8 (syst) \pm 0.8 (B) MeV, where the last term corresponds to the uncertainty in the world-average \( B^+_c \) mass.

### Sources of systematic uncertainties

The systematic uncertainties come from:
- **B(2S) fit modeling**: J/\( K \) background, partially reconstructed decays and detector’s alignment:
  - Fit modeling:
    - Alternative functions for the signal and the backgrounds
    - Signal peaks: changed from two Gaussians to two Breit-Wigner functions
    - Background: changed from a polynomial to a threshold function
    - Observed differences in \( M \) and \( \Delta M \) are quoted as systematic uncertainties: 0.8 and 0.7 MeV, respectively
  - J/\( K \) background contamination:
    - Different fit results are modeled taking the shape from simulation.
  - Partially reconstructed \( B^+ \rightarrow J/\psi \pi^+ \) decays are modeled using an ARGUS function convolved with a Gaussian.

- **Unbinned ML fit**: the signal is modeled using a double Gaussian with common mean and the background as a polynomial.
- **Additional background contribution from \( B \rightarrow m \phi \) decays**: is modeled taking the shape from simulation.

### Results [Published on Physical Review Letters 122 (2019) 132001]

- The \( M(\pi^+\pi^-) - M(B^+_c) + m_\nu \) distribution is fitted with Gaussian functions for the peaks and a 3rd order polynomial for the background.
- Mass resolution agrees with MC expectations (-6 MeV) and is much lower than \( \Delta M \) thus allowing a two-peak structure to be observed ; \( B(2S) \) is assumed to be the right-most peak.
- Measured two peaks’ mass difference: \( \Delta M = [29.1 \pm 1.5 \text{ (stat)} \pm 0.7 \text{ (syst)}] \text{ MeV} \).

### Reconstruction of \( B^+_c \) in 2016, 2017, 2018 and events selection criteria

- \( J/\psi \) meson momentum required to be in plane of PV in xy plane.
- \( J/\psi \) meson momentum required to be in point of PV in yz plane.
- The PV is re-fitted excluding the three \( B \) decay tracks (two muons and one pion) \( \pi_2 \) and \( \pi_3 \) are tracks in that PV, e.g. they are pion tracks, which are going to be combined with \( \pi_1 \). Tracks and muons satisfy high-quality requirements.
- When multiple \( B^+_c \) candidates are found in the same event, keep only the one with the highest \( p_\text{vis} \) value.

### Extraction of \( B^+_c \) signal in full Run-II

- Wilson ML fit: the signal is modeled using a double Gaussian with common mean and the background as a polynomial.
- Additional background contribution from \( B \rightarrow m \phi \) decays: is modeled taking the shape from simulation.
- Partially reconstructed \( B^+ \rightarrow J/\psi \pi^+ \) decays are modeled using an ARGUS function convolved with a Gaussian.

---

### The 27th International Workshop on Weak Interactions and Neutrinos