# Study of $B_c^+$ to $\psi(2S)\pi^+$ and $J/\psi\pi^+$ decays

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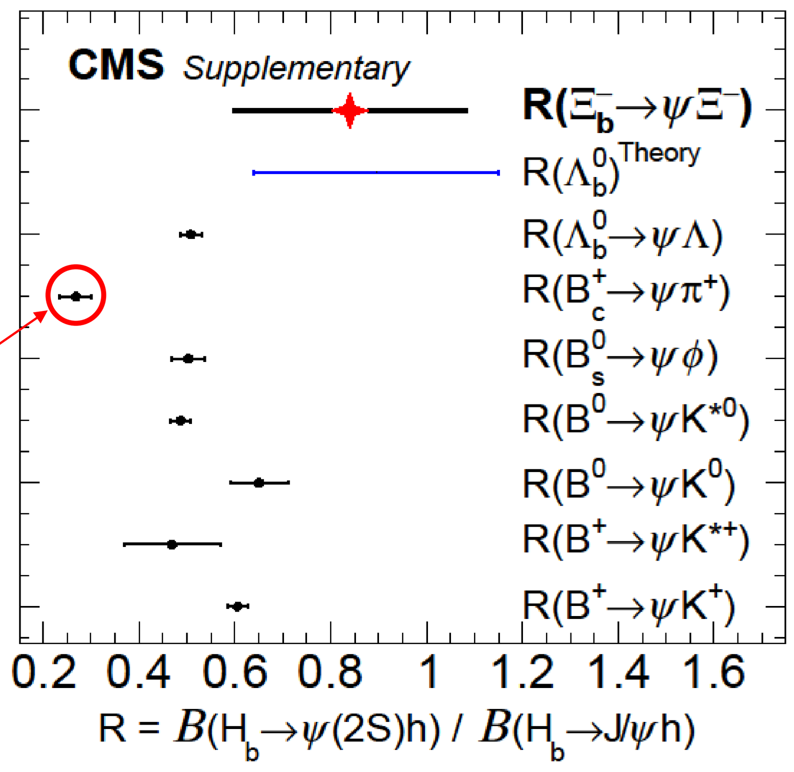
## MOTIVATION

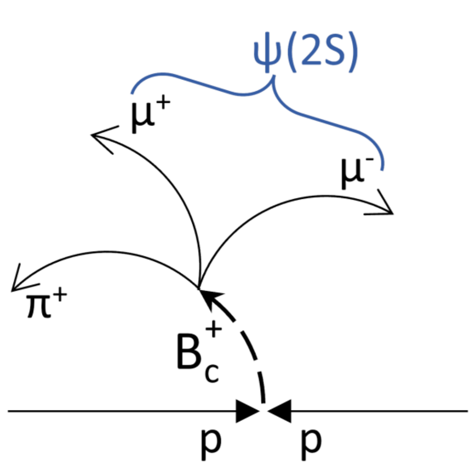
- Probability ratios of similar decays, such as the two-particle decays of ground states of b hadrons at the [ψ(2S) h] and [J/ψ h], where h is a light hadron, have been measured quite accurately.
- Comparing the ratios, we can see that for the $B_c$ meson the ratio R stands out from the general pattern. The reason is probably related to the internal dynamics of $B_c$ decay.
- The only $\mathcal{R}$ for $B_c$ meson is measured by the LHCb collaboration. The last LHCb measurement [1] is obtained using both RunI and RunII data (with total unc. ~7.4%).

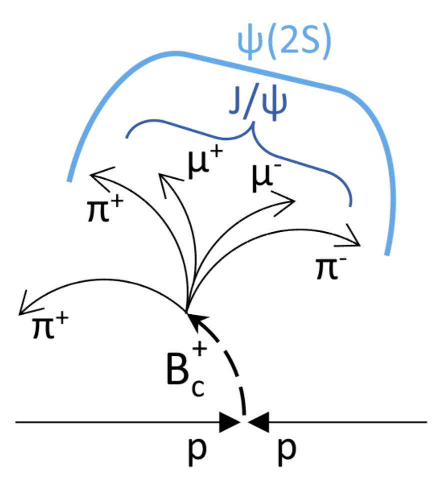


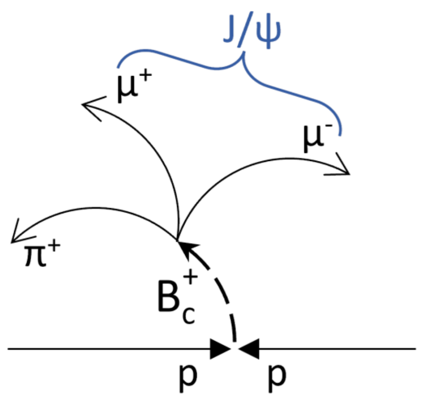

CMS-BPH-23-002, arXiv:2402.17738

## RECONSTRUCTION

- Used 2016-2018 datasets.
- ψ(2S) is reconstructed in 2 channels: $\mu^+\mu^-$ and $J/\psi\ \pi^+\pi^-$
- Trigger optimized to select $\mu\mu + track$ in final state.
- Ψ(2S) (or J/ψ) is result of μμ vertex fit with mass constraint




- The normalization channel $B_c^+ \to J/\psi\ \pi^+$ is chosen according to the similar decay topology to reduce the systematic uncertainties.

## OPTIMIZATION

- Serial scans on variables to find optimal value of cut by maximizing ***f*** value
- When ***f*** achieves the maximum value corresponding cut is fixed, and its value is used in next scans
- When next iteration shows the same result optimization is completed

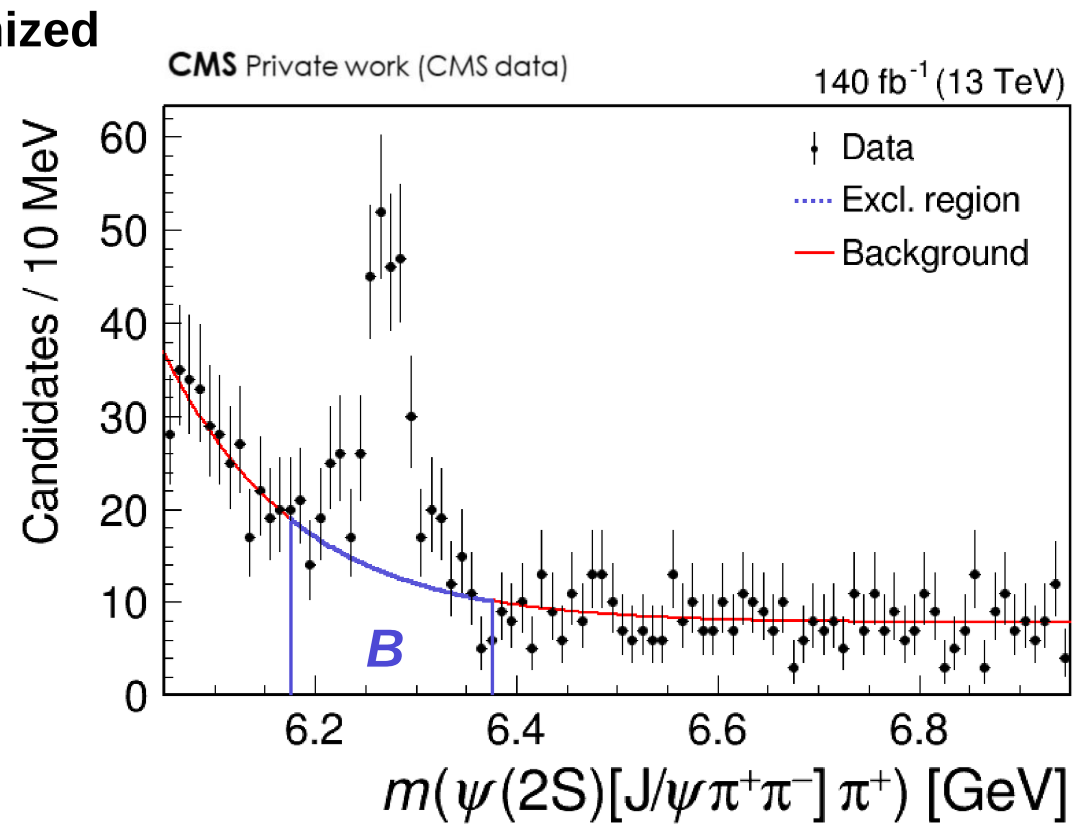
**Punzi** figure of merit is used:

$$f = S/\left(\frac{463}{13} + 4\sqrt{B} + 5\sqrt{25 + 8\sqrt{B} + 4B}\right)$$

- ***S*** is number of signal events from MC
- ***B*** is expected number of background events, extracted from experimental data fit with excluded region $m_{PDG}(\mathrm{Bc}) \pm 3\sigma_{eff}$ . The integral in the excluded region is ***B***.

**Variables to have been optimized**

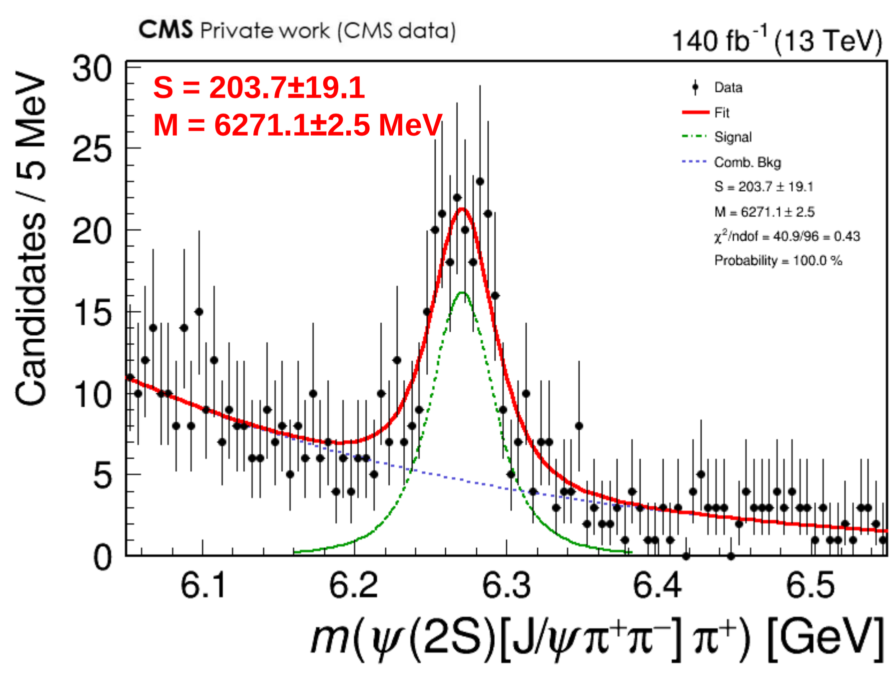
- Transversal momentum
  - $p_T(B_c)$
  - $p_T(\psi(2S))$ and/or $p_T(J/\psi)$
  - $p_T(\pi^\pm)$ from $B_c$
- Detach significance
  - $L_{XY}/\sigma_{L_{XY}}(B_c, PV)$
- Vertex fit probability
  - $P_{vtx}(B_c)$
- Impact parameter significance
  - $IPS(\pi^\pm, PV)$
- Angle
  - $\cos(\overrightarrow{L_{XY}}, \overrightarrow{p_T})\ (B_c)$
- for $B_c^+ \to \psi(2S)\ [\psi(2S) \to J/\psi\ \pi^+\pi^-]\ \pi^+$
  - $m(\pi^+\pi^-)$ from ψ(2S)
  - $m(\psi(2S))$



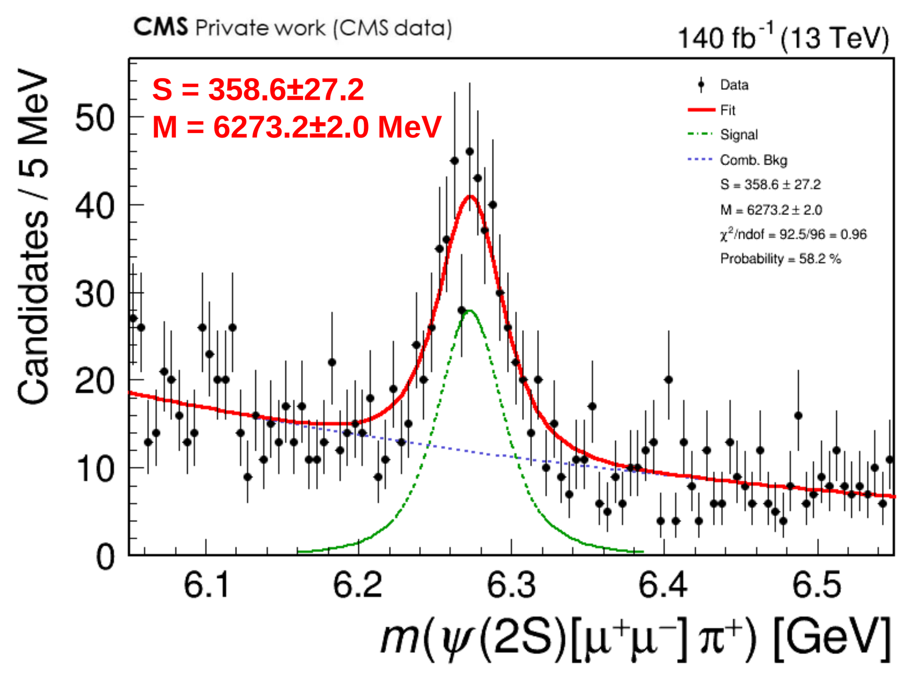

Fit example for FOM evaluation

## SIGNAL $B_c^+ \to \psi(2S)\pi^+$

### ψ(2S) → J/ψ π⁺π⁻




### ψ(2S) → μ⁺μ⁻



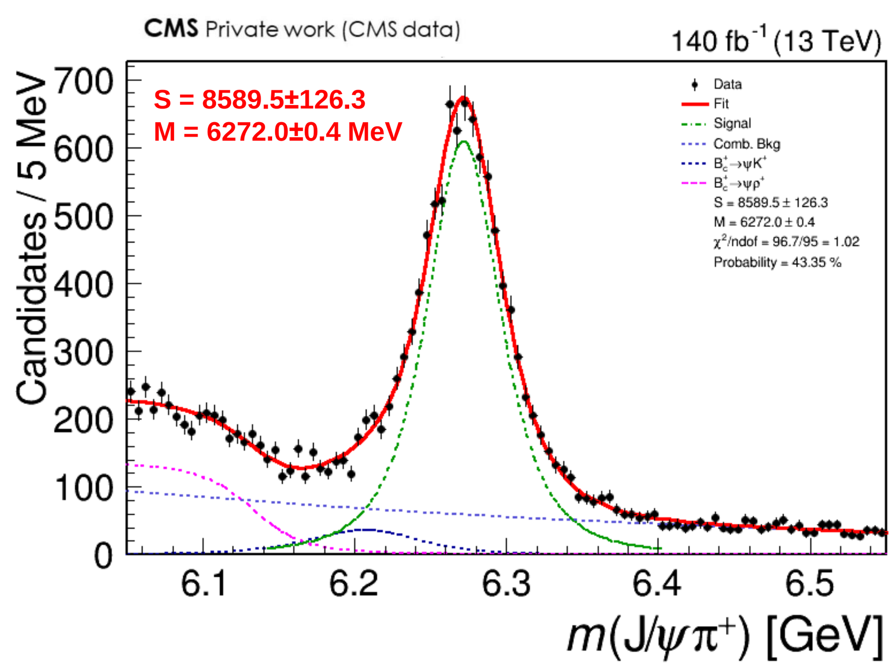

- Signal model: **Student T** with parameters fixed to MC except mean
- Background model: **exponent**

## NORMALIZATION CHANNEL

Signal model: **Student T** with parameters fixed to MC except mean

Background model:

- *combinatorial background* (**exponent**)
- *reflection from $B_c^+ \to J/\psi\ K^+$ decay* (**Student T** with shape fixed to MC and normalization fixed to branching fractions ratio)
- *partially reconstructed decay from $B_c^+ \to J/\psi\ \rho^+[\rho^+ \to \pi^+\pi^0]$ with lost $\pi^0$* (**Johnson** with shape fixed to MC)




## $\mathcal{R}$ MEASUREMENT STRATEGY

### ψ(2S) → J/ψ π⁺π⁻

$$\mathcal{R} \equiv \frac{N_{signal}}{N_{signal}^{norm}} \cdot \frac{\epsilon_{total}^{norm}}{\epsilon_{total}} \cdot \frac{1}{\mathcal{B}(\Psi(2S) \to J/\Psi\pi\pi)}$$

### ψ(2S) → μ⁺μ⁻

$$\mathcal{R} \equiv \frac{N_{signal}}{N_{signal}^{norm}} \cdot \frac{\epsilon_{total}^{norm}}{\epsilon_{total}} \cdot \frac{\mathcal{B}(J/\Psi \to \mu\mu)}{\mathcal{B}(\Psi(2S) \to \mu\mu)}$$

## EFFICIENCIES

$$\epsilon = \epsilon_{gen} \times \epsilon_{reco\&sel} = \frac{N_{gen,filtered}}{N_{gen,unfiltered}} \times \frac{N_{reco}}{N_{gen-DAS}}$$

- **Generator filter efficiency** is an efficiency of soft requirements applied at the generator level
- **Reconstruction and selection efficiency** is the ratio of the number of reconstructed in MC events to the number of generated events.

## SUMMARY

### DONE

- Processing full RunII data (and corresponding MC)
- Cuts optimization using Punzi FOM
- Signal and background shapes study
- Efficiencies evaluation

### PLANS

- Signal channels background study
- Systematic uncertainties
- Adding RunIII data
- Results for branching fractions ratios
- Average values for branching fractions ratio

## References:

[1] Aaij, Roel, et al. "Search for $ B_c^+\to\pi^+\mu^+\mu^-$ decays and measurement of the branching fraction ratio ${\cal B}(B_c^+\to\psi(2S)\pi^+)/{\cal B}(B_c^+\to J/\psi\pi^+) $." *arXiv preprint arXiv:2312.12228* (2023).

[2] Punzi, Giovanni. "Sensitivity of searches for new signals and its optimization." arXiv preprint physics/0308063 (2003).

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