LHCb results from heavy quark spectroscopy, exotic states and QCD

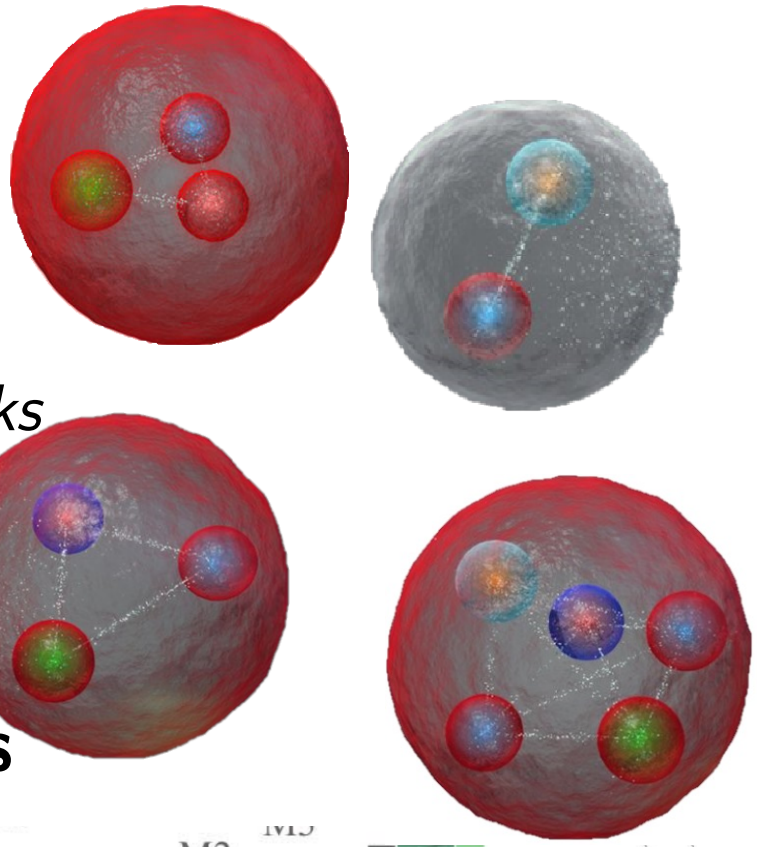
Vladimir Macko
on behalf of the LHCb Collaboration

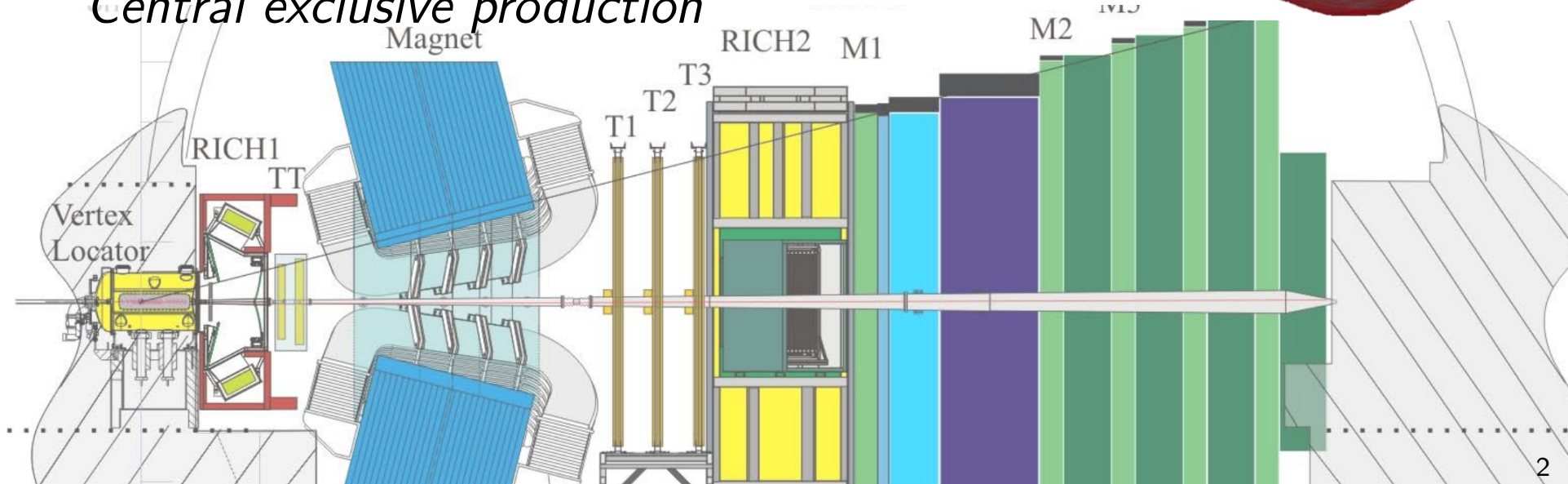
Lake Louise Winter Institute
Canada Lake Louise
2019/02/10

Introduction

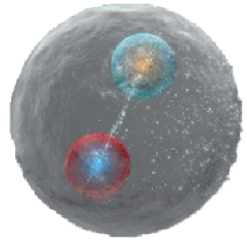
Personal selection of the latest LHCb results from:

- **Heavy quark spectroscopy**
  States with two or three heavy quarks
- **Exotic states**
  States with four or five quarks
- **Quantum chromodynamics**
  Central exclusive production





Heavy quark spectroscopy



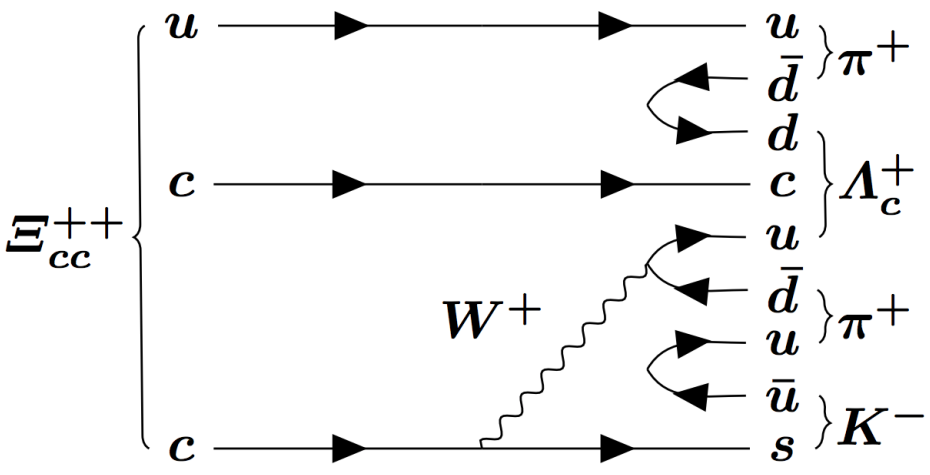
Doubly charmed baryon Ξ_{cc}^{++}

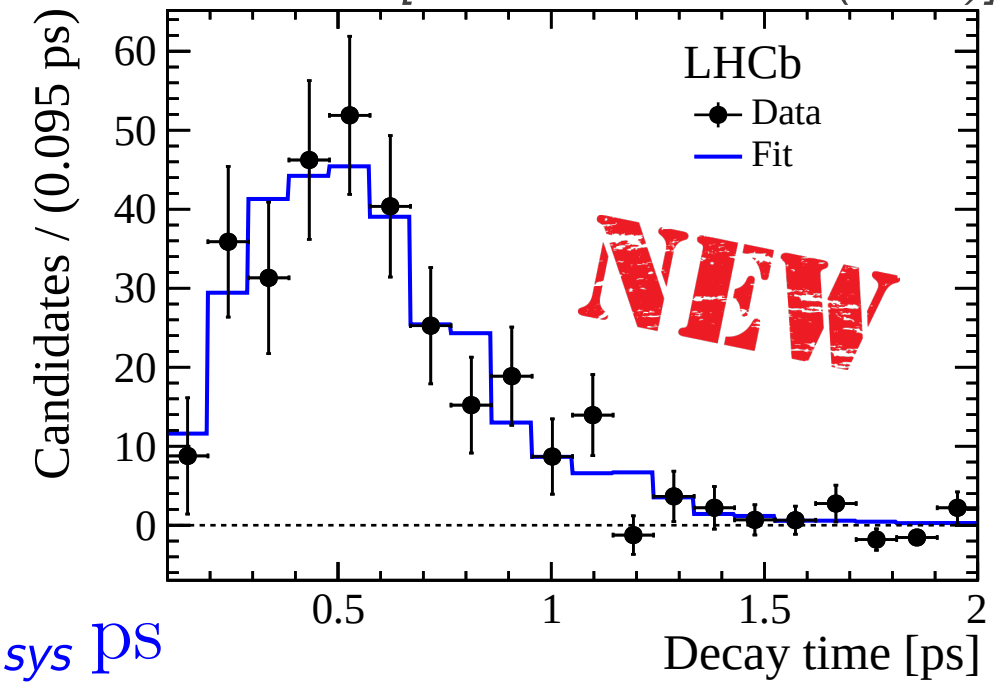
Predicted by Quark Model, unique for QCD tests

- LHCb: observation of Ξ_{cc}^{++} *[PRL 119, 112001 (2017)]*

  $m_{\Xi_{cc}^{++}} = 3621.40 \pm 0.72_{stat} \pm 0.27_{syst} \pm 0.14_{\Lambda_c}$ MeV *[PRL 89, 112001 (2002)]*
- 103 MeV SELEX discrepancy, SELEX remains unconfirmed
- LHCb: Ξ_{cc}^{++} lifetime from $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ using MVA selector, background subtraction with *sPlot*

[PRL 121, 052002 (2018)]



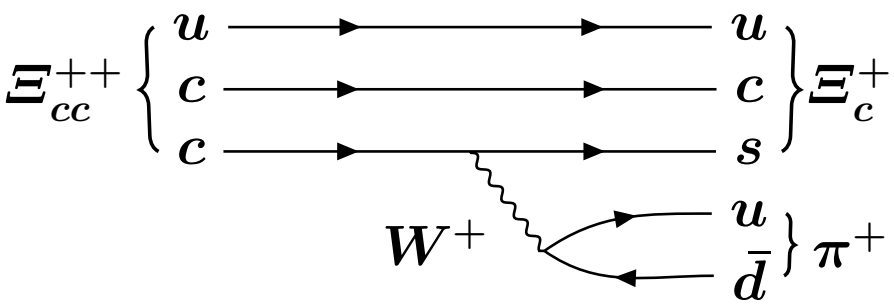


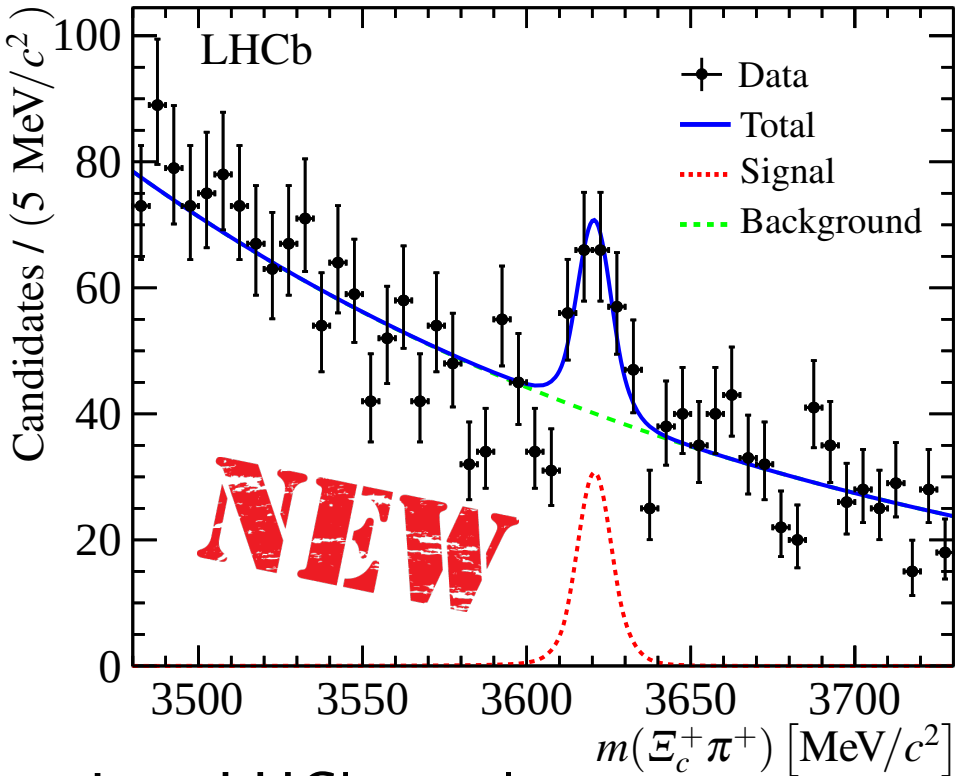
$\tau_{\Xi_{cc}^{++}} = 0.256^{+0.024}_{-0.022 stat} \pm 0.014_{sys}$ ps

Doubly charmed baryon Ξ_{cc}^{++}

Predicted by Quark Model, unique for QCD tests

[PRL 121, 162002 (2018)]





- LHCb: **First** observation of $\Xi_{cc}^{++} \to \Xi_c^+\pi^+$ using MVA selector

- Measured mass agrees with the previous LHCb result:
  $m_{\Xi_{cc}^{++}} = 3620.6 \pm 1.5_{stat} \pm 0.4_{sys} \pm 0.3_{\Xi_c^+}$ MeV

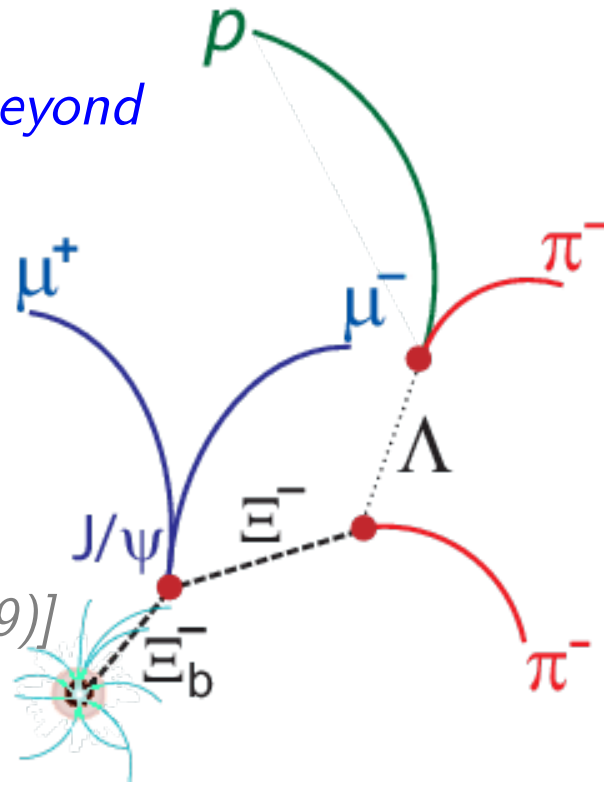
- The ratio of branching fractions measured:

NEW

$$\frac{\mathcal{B}_{\Xi_{cc}^{++}\to\Xi_c^+\pi^+}\times\mathcal{B}_{\Xi_c^+\to pK^-\pi^+}}{\mathcal{B}_{\Xi_{cc}^{++}\to\Lambda_c^+K^-\pi^+\pi^+}\times\mathcal{B}_{\Lambda_c^+\to pK^-\pi^+}} = 0.035 \pm 0.009_{stat} \pm 0.003_{sys}$$

[PRL 121, 162002 (2018)]

Ξ_b^- baryon *Sensitive probe of SM and beyond*



Fragmentation fractions f needed for absolute branching ratio measurements

LHCb: **First** measurement of Ξ_b^- production rate relative to that of Λ_b^0 baryon, $f_{\Xi_b^-}/f_{\Lambda_b^0}$, and of $m_{\Xi_b^-}$ using $\Xi_b^- \to J/\psi \Xi^-_{(\to \Lambda\pi^-)}$ and $\Lambda_b^0 \to J/\psi\Lambda$ with $J/\psi \to \mu^+\mu^-$ and $\Lambda \to p\pi^-$ *[arXiv:1901.07075 (2019)]*

- SU(3) flavour symmetry: $\frac{\Gamma_{\Xi_b^- \to J/\psi \Xi^-}}{\Gamma_{\Lambda_b^0 \to J/\psi\Lambda}} = 3/2$

$$\frac{N_{\Xi_b^- \to J/\psi\Xi^-}}{N_{\Lambda_b^0 \to J/\psi\Lambda}} \frac{\epsilon_{\Lambda_b^0}}{\epsilon_{\Xi_b^-}} = R \equiv \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\mathcal{B}_{\Xi_b^- \to J/\psi\Xi^-}}{\mathcal{B}_{\Lambda_b^0 \to J/\psi\Lambda}} = \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\Gamma_{\Xi_b^- \to J/\psi\Xi^-}}{\Gamma_{\Lambda_b \to J/\psi\Lambda}} \frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}} = \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{3}{2} \frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}}$$

- $\sqrt{s}$=7,8 TeV and 13 TeV samples analysed separately with requirements on decay kinematics and decay products
- Samples split based on $\pi^-_{(\Xi^-)}$ decay point into *long* and *downstream*
- Simultaneous fit of all samples performed to measure $m_{\Xi_b^-}$

Ξ_b^- baryon

[arXiv:1901.07075 (2019)]

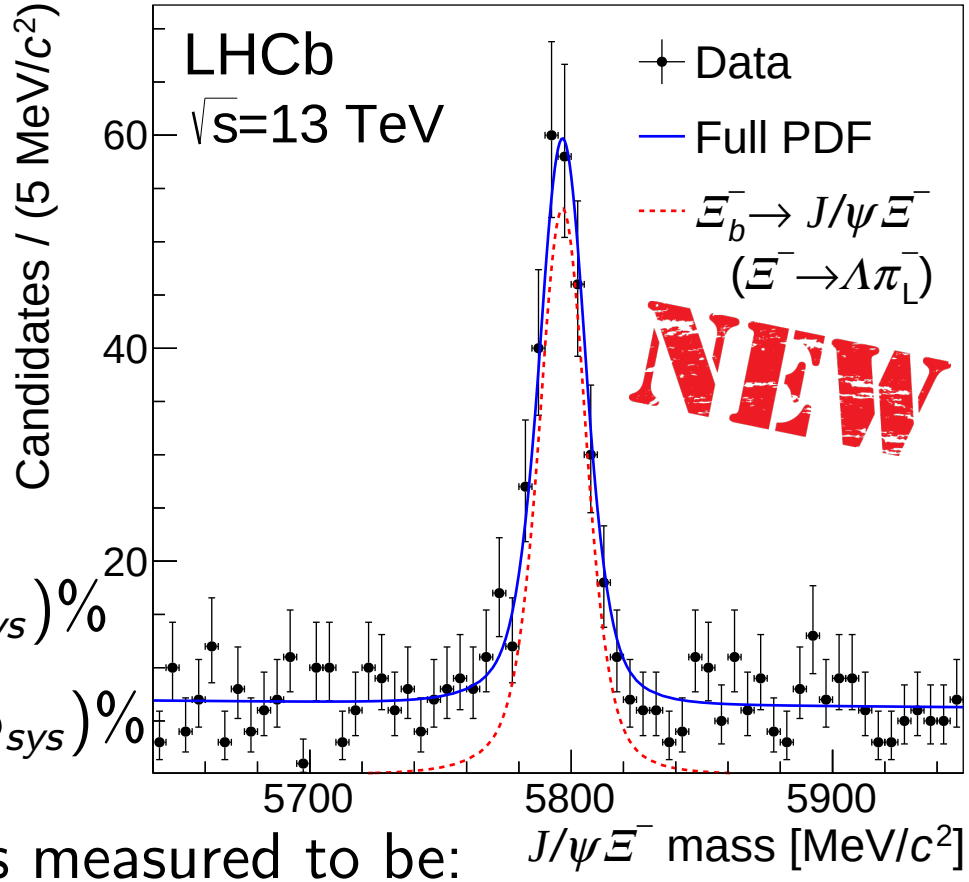
$$m_{\Xi_b^-} = 5796.70 \pm 0.39_{stat} \pm 0.15_{sys} \pm 0.15_{m_{\Lambda_b}}\ \text{MeV}$$

- **Most** precise $m_{\Xi_b^-}$ determination
- Background subtracted for measurement of fragmentation fraction ratio and for the first measurement of Ξ_b^- production asymmetry:

NEW

$$A_{\text{prod}}^{\Xi_b^-\ \sqrt{s}=7,8\,\text{TeV}} = (1.1 \pm 6.1_{stat} \pm 2.0_{sys})\%$$

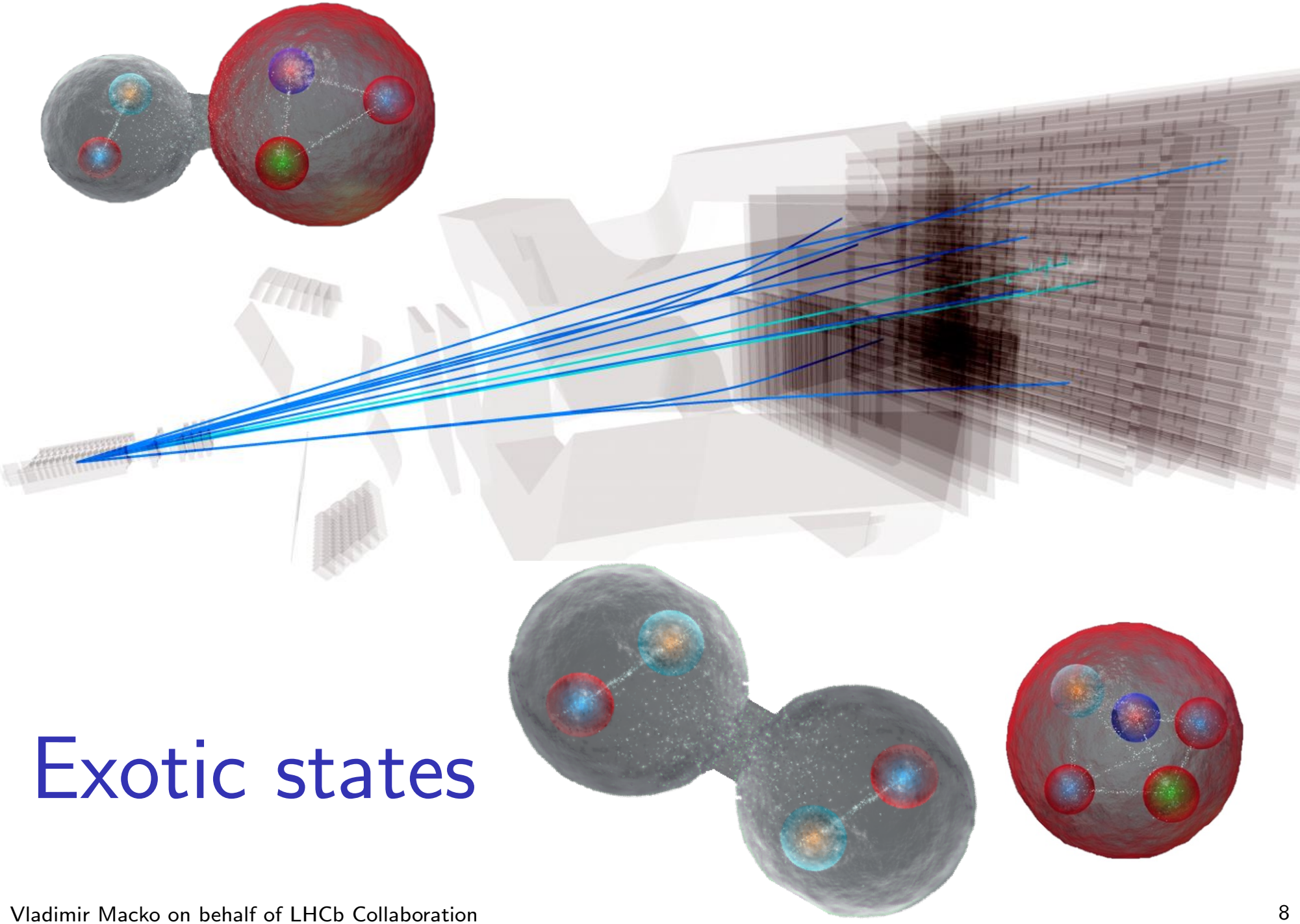
$$A_{\text{prod}}^{\Xi_b^-\ \sqrt{s}=13\,\text{TeV}} = (-3.9 \pm 5.6_{stat} \pm 2.5_{sys})\%$$



- Ratio of fragmentation fraction is measured to be:

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}}(\sqrt{s} = 7,8\,\text{TeV}) = (6.7 \pm 0.5_{\text{stat}} \pm 0.5_{\text{sys}} \pm 2.0_{\text{SU(3)}}) \times 10^{-2}$$

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}}(\sqrt{s} = 13\,\text{TeV}) = (8.2 \pm 0.7_{\text{stat}} \pm 0.6_{\text{sys}} \pm 2.4_{\text{SU(3)}}) \times 10^{-2}$$



Exotic states

Exotics in $B^0 \to J/\psi K^+\pi^-$

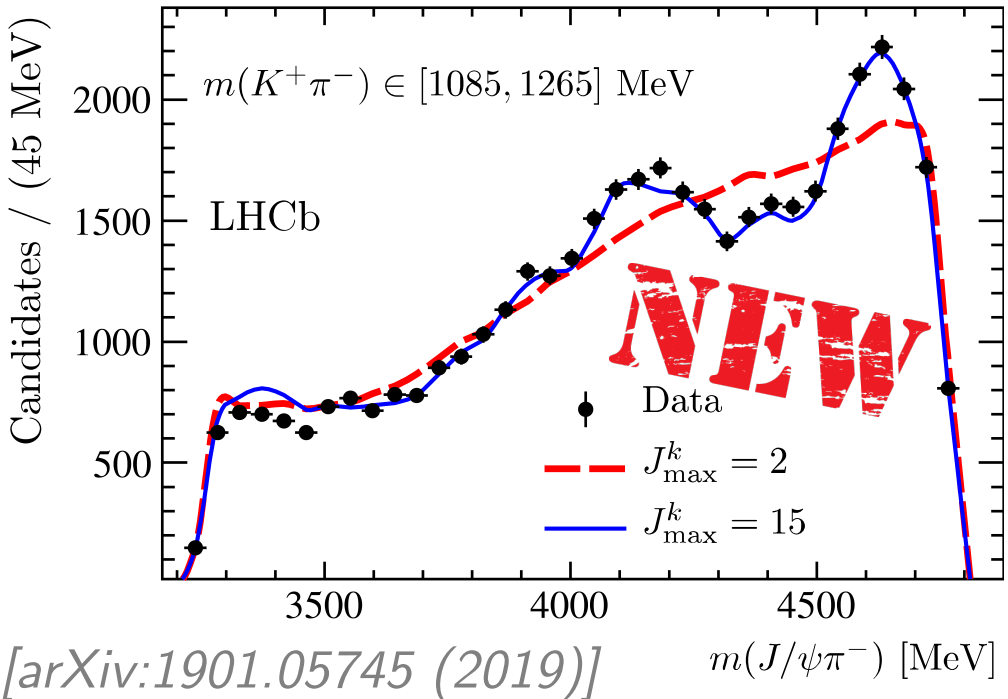
[PR D90 112009 (2014)] [PR D79 112001 (2009)]

Belle: New exotic $Z(4200)^-$, BaBar: No need for exotic contributions

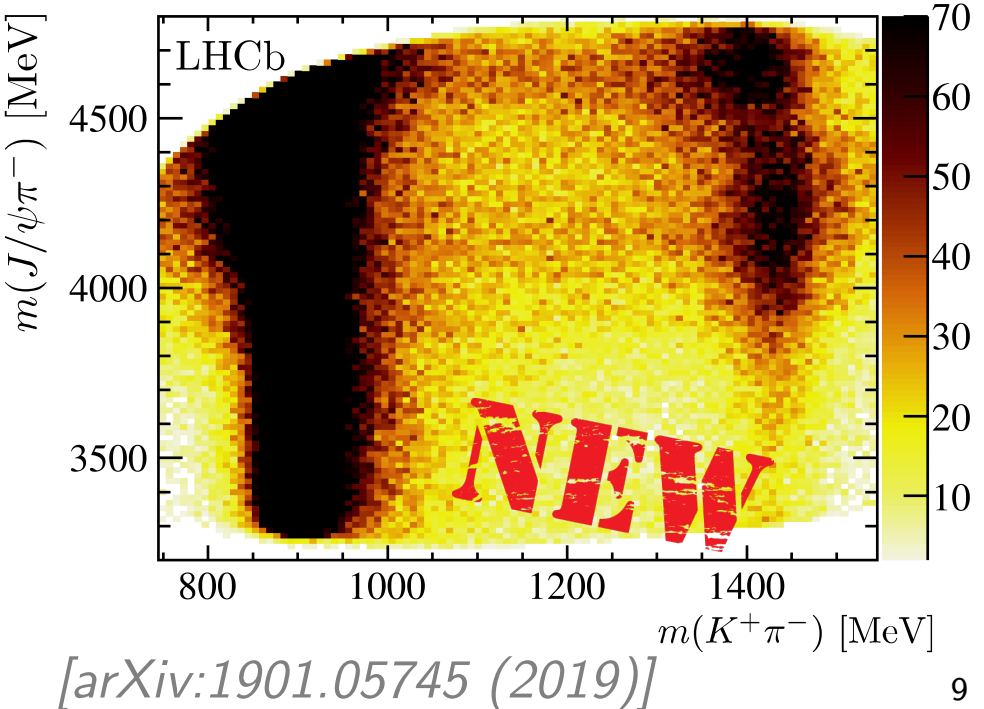
LHCb: Model independent 4-dimensional angular analysis in bins of $m(K^+\pi^-)$, hypothesis of non-exotic K_J^* spectrum description tested

- $3\,\text{fb}^{-1}$ dataset, requirements on kinematics and products, bkg. subtraction
- For $m(K^+\pi^-) \in (1085, 1445)\,\text{MeV}$: higher spin states suppressed
- Non-K_J^* contributions observed at 10σ significance
- Structures visible at $m(J/\psi\pi^-) \approx 4200\,\text{MeV}$ and $\approx 4600\,\text{MeV}$

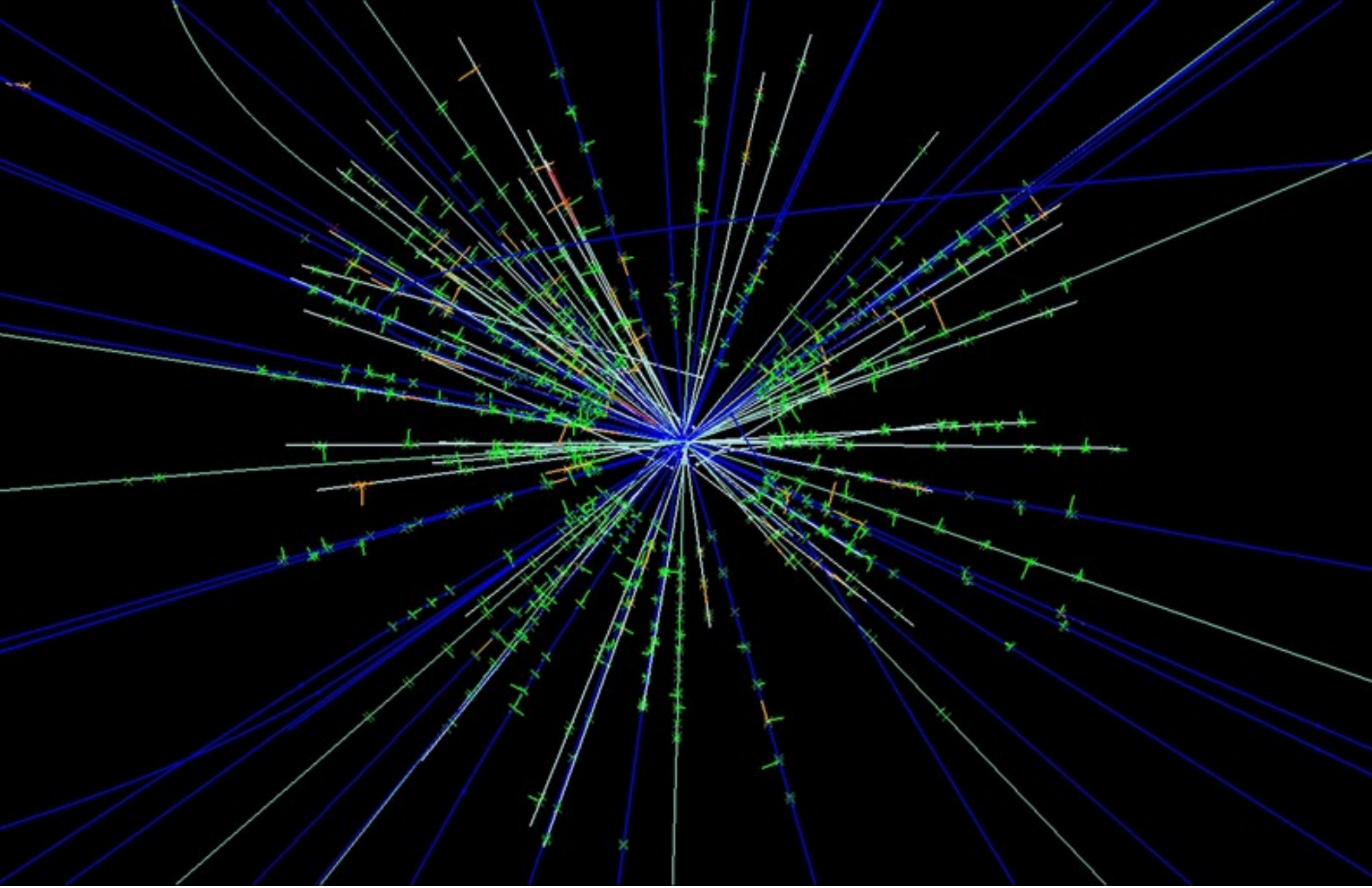
[arXiv:1901.05745 (2019)]



[arXiv:1901.05745 (2019)]



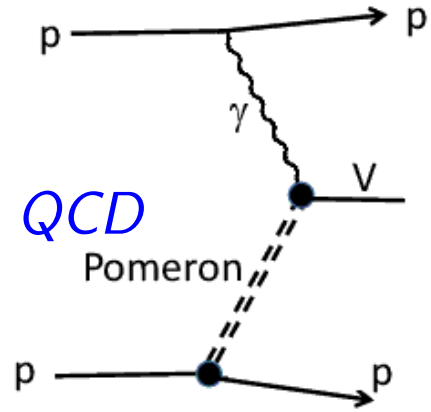
[arXiv:1901.05745 (2019)]



Quantum chromodynamics

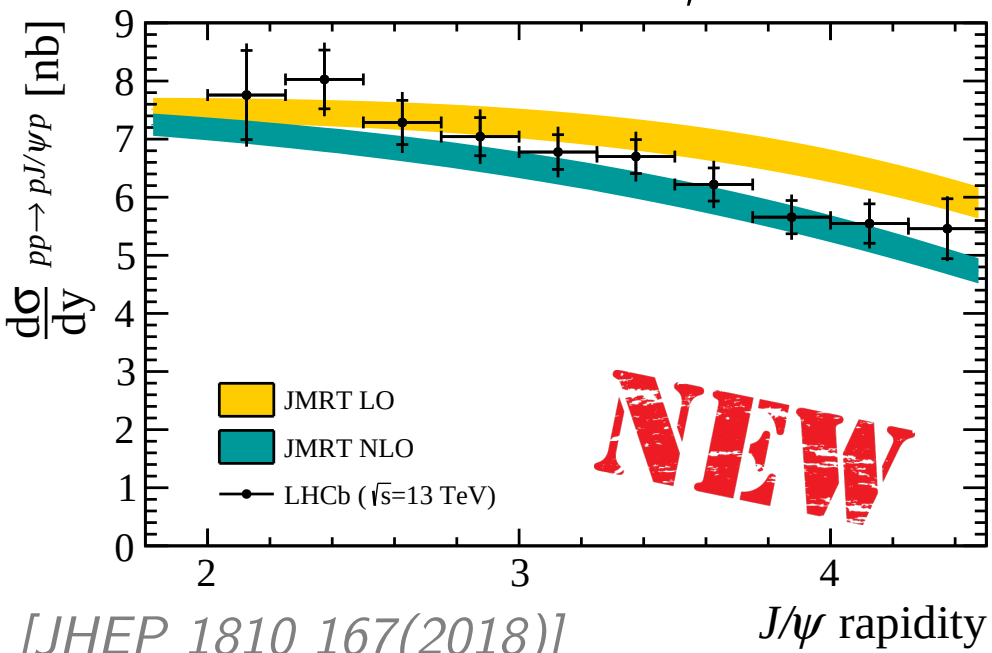
Central exclusive production of J/ψ and $\psi(2S)$

Test of perturbative QCD

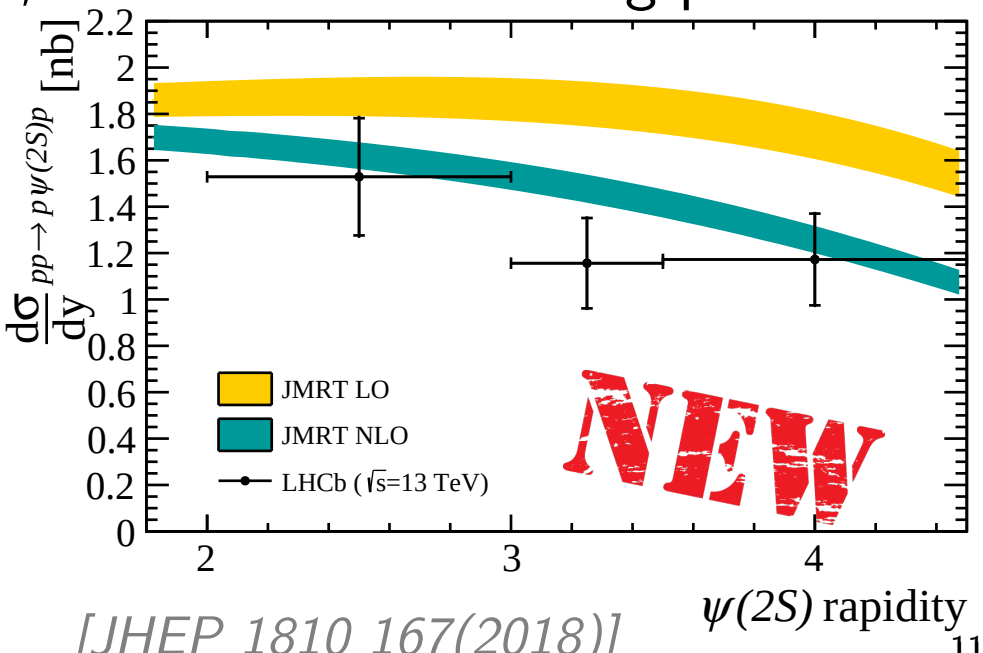


LHCb: Exclusive charmonium: pp ($\sqrt{s}$=13 TeV) interaction devoid of any activity, charmonium reconstructed from $\mu^+\mu^-$

- Selection based on kinematics, reconstructed mass and vetoes from VELO and HERSCHEL
- Background contributions estimated from the fit, considering non-resonant muons, feed-downs, undetected interacting protons

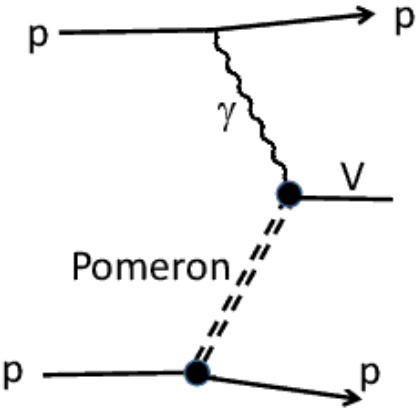


[JHEP 1810 167(2018)]



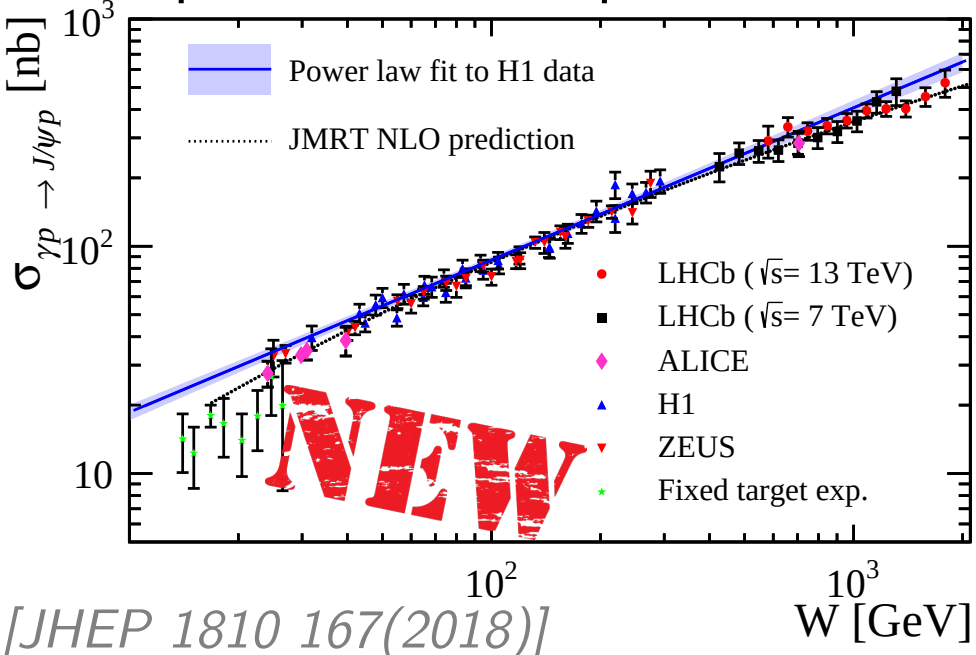
[JHEP 1810 167(2018)]

Central exclusive production of J/ψ and $\psi(2S)$

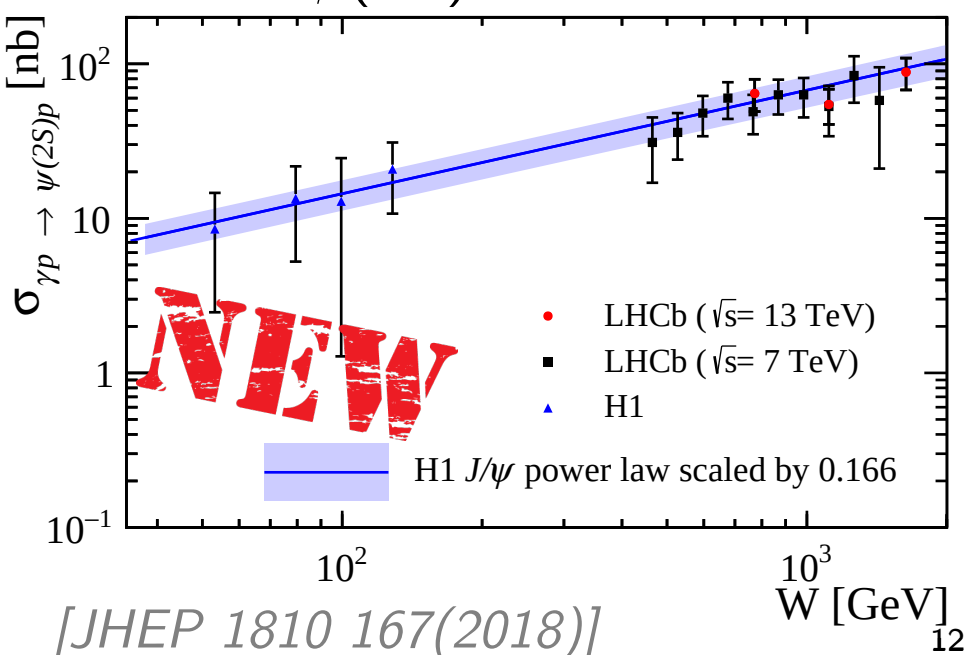


LHCb: Exclusive charmonium: pp ($\sqrt{s}$=13 TeV) interaction devoid of any activity, charmonium reconstructed from $\mu^+\mu^-$

- Measured cross-sections for the J/ψ and $\psi(2S)$ mesons compared to theory in better agreement with JMRT NLO rather than LO
- Derived cross-section for J/ψ photoproduction deviates from a power-law extrapolation of H1 data while $\psi(2S)$ does not



[JHEP 1810 167(2018)]



[JHEP 1810 167(2018)]

Summary

- LHCb measured the lifetime of doubly charmed baryon Ξ_{cc}^{++} in channel $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$
- Ξ_{cc}^{++} observed first time in channel $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$, measured mass is consistent with values previously reported.
- LHCb reported the most precise mass determination of $m_{\Xi_b^-}$ baryon and ratio of fragmentation fractions $\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}}$
- LHCb observed exotic contributions in $B^0 \to J/\psi K^+ \pi^-$ decays
- LHCb reported measurements of central exclusive production of J/ψ and $\psi(2S)$, derived cross-section for J/ψ photoproduction deviates from a power-law extrapolation of H1 data

Results beyond:

- Observation of $B^0_{(s)} \to J/\psi p\bar{p}$ decays and precision measurements of the $B^0_{(s)}$ masses [comming soon...]
- Observation of two resonances in the $\Lambda^0_b\pi^\pm$ systems and precise measurement of $\sigma^\pm_b$ and $\sigma^{*\pm}_b$ properties *[PRL 122(2019)012001]*
- Evidence for an $\eta_c(1S)\pi^-$ resonance in $B^0 \to \eta_c(1S)K^+\pi^-$ decays *[EPJ C78 (2018)1019]*
- Search for beautiful tetraquarks in the $\Upsilon(1S)\mu^+\mu^-$ invariant-mass spectrum [JHEP 10 (2018)086]

Thank you for your attention!

Backup

HERSCHEL

- The HERSCHEL detector: high-rapidity shower counters for LHCb