Future of hadron spectroscopy at LHCb

Matthew Rudolph

Syracuse University

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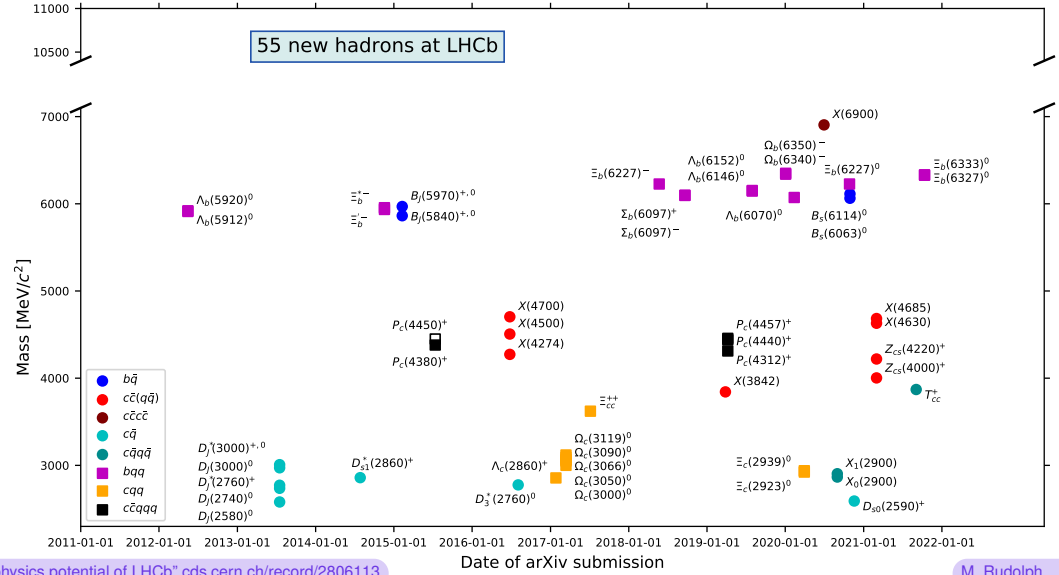
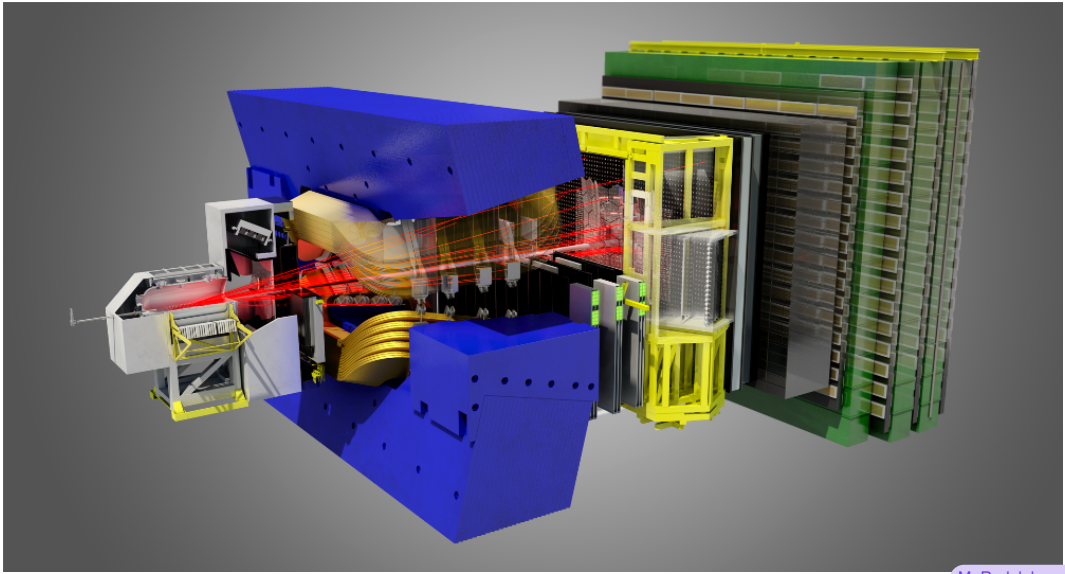
Spectroscopy at LHCb



Introduction

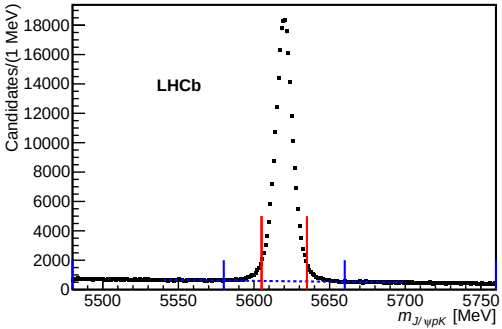
- LHCb is a hadron factory: production has only just begun
- Upgrade I and the proposed Upgrade II are opportunities to collect enormous data samples
  - More states to discover, including surprises
  - Full analyses to better understand properties of states only observed

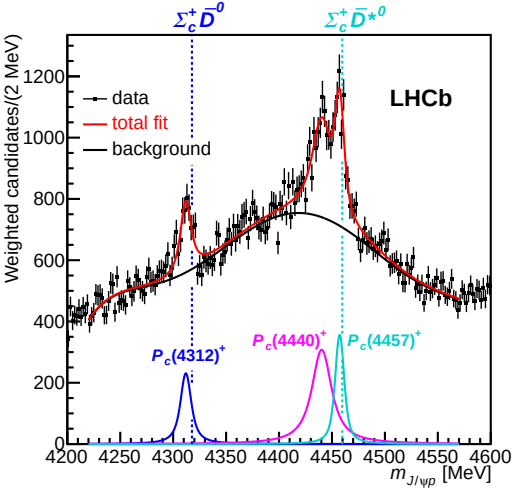
LHCb detector



Pentaquarks

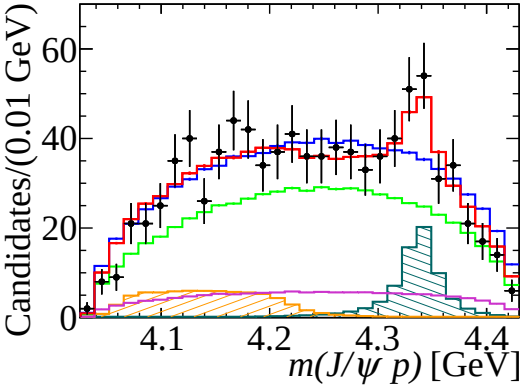
- Large, pure sample of Λ_b^0 is key
- Future data will allow more complete analysis and potential for related modes like $\eta_c p$



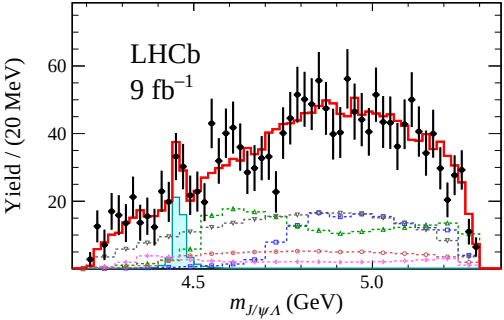


Pentaquarks

More data—more options



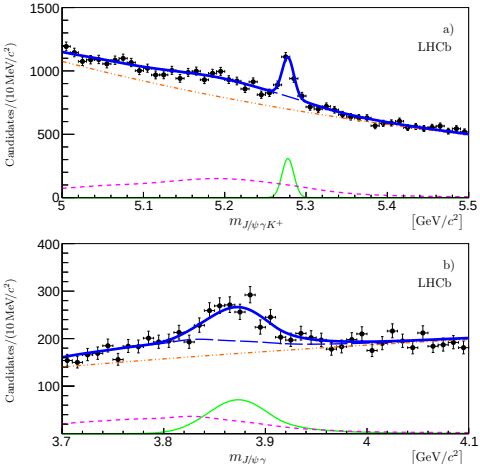
$J/\psi\, p$ in $B_s^0 \to J/\psi\, p\bar{p} \sim 3.1\sigma$



$J/\psi\,\Lambda$ in $\Xi_b^- \to J/\psi\,\Lambda K^- \sim 3\sigma$

Decays with neutrals

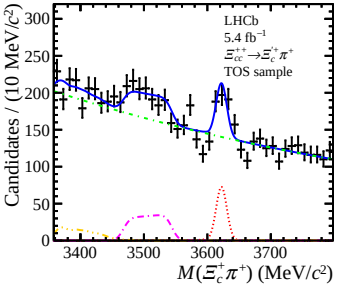
- LHCb can also analyze states with neutral particles
- Example of Run 1 analysis of X(3872) in $B^+ \to J/\psi\,\gamma K^+$

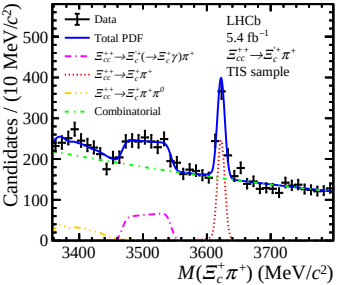


Doubly heavy

Baryons

- Ξ_{cc}^{++} baryons observed and continuing to be studied with more decay modes

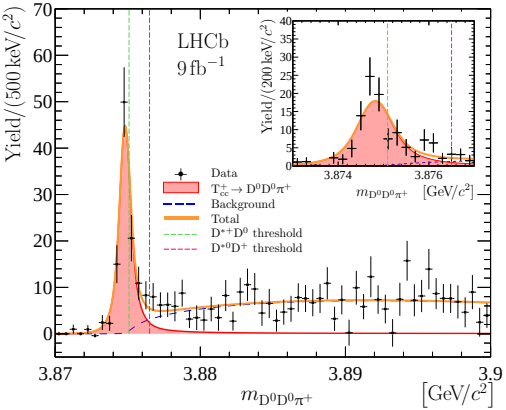




Doubly heavy

Tetraquarks

- Recently observed T_{cc}^{+} ($cc\bar{u}\bar{d}$) just above DD^{*} threshold
- Exciting hint of things to come

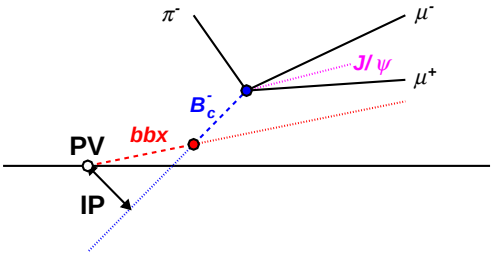


Doubly heavy

T_{bc} and T_{bb}

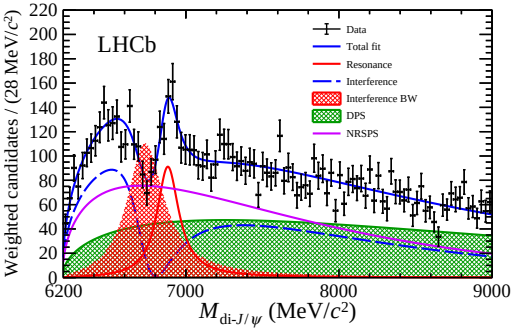
- Heavier versions may even be stable against strong decay
- T_{bc} may be observable with strong or weak decay in Upgrade I
- T_{bb} likely stable under strong force, harder to find exclusive weak decays: find in inclusive B_c^+ decays at Upgrade II?

arXiv:1810.06657



Quadruply heavy

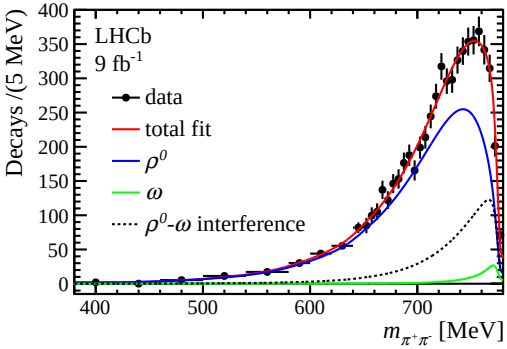
- Structures seen in $J/\psi\, J/\psi$ production
- Needs more study to unravel!



X3872

properties

- Quantum numbers[1]
- Lineshape [2]
- Decays[3]
- 276,600 expected in $B^+ \to (X(3872) \to J/\psi\,\pi^+\pi^-)K^+$ from Upgrade II

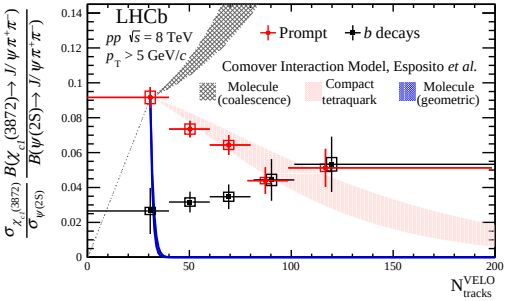


[1]:arXiv:1302.6269, 1504.06339; [2]: 2005.13429; [3]: 2204.12597

X3872

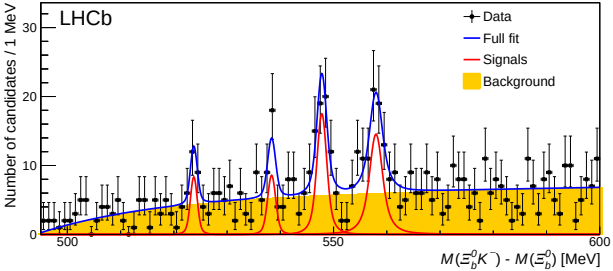
multiplicity

- Studying production also helps distinguish nature
- Can be extended to ion collisions

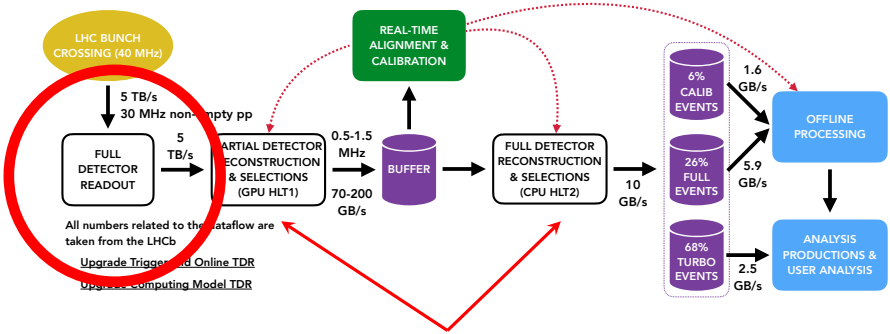


Conventional spectroscopy

- Many, many states that fit the conventional pattern have been and will be found!



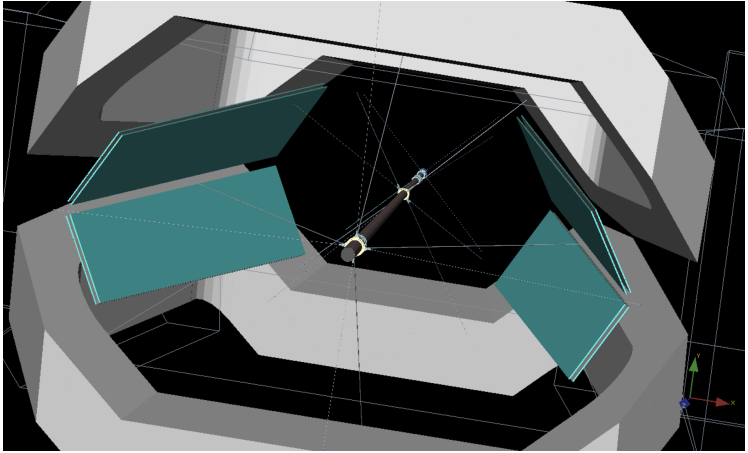
Upgrade I


LHC BUNCH CROSSING (40 MHz)
5 TB/s
30 MHz non-empty pp
FULL DETECTOR READOUT
5 TB/s
PARTIAL DETECTOR RECONSTRUCTION & SELECTIONS (GPU HLT1)
0.5-1.5 MHz
70-200 GB/s
BUFFER
REAL-TIME ALIGNMENT & CALIBRATION
FULL DETECTOR RECONSTRUCTION & SELECTIONS (CPU HLT2)
10 GB/s
6% CALIB EVENTS
26% FULL EVENTS
68% TURBO EVENTS
1.6 GB/s
5.9 GB/s
2.5 GB/s
OFFLINE PROCESSING
ANALYSIS PRODUCTIONS & USER ANALYSIS
All numbers related to the dataflow are taken from the LHCb
Upgrade Trigger and Online TDR
Upgrade Computing Model TDR
Software trigger

Upgrade Ib

between run 3 and 4

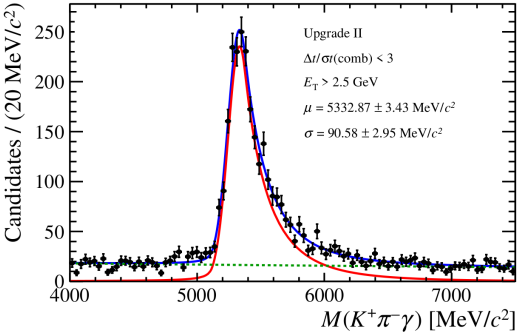
- Improve acceptance at lower momentum, *e.g.* $D^{*+} \to D^0 \pi^+$



Upgrade II

Run 5+

- Upgrade II promises to multiply Upgrade I data by 6
- Opportunity to improve performance in neutral channels if ECAL can be improved



Conclusions

- LHCb is a unique opportunity to collect enormous hadron samples for spectroscopy
- Upgrade I installing for LHC Runs 3 and 4
  - data $\times$ 5.5
  - Software trigger enhances efficiencies
  - need person power to exploit
- Upgrade II proposed for runs 5+
  - data $\times$ 6 ($>$ 30$\times$ now!)
  - Opportunity to extend capabilities, but hardware R&D needed