

Displaced B_c^- mesons as an inclusive signature of weakly decaying double beauty hadrons

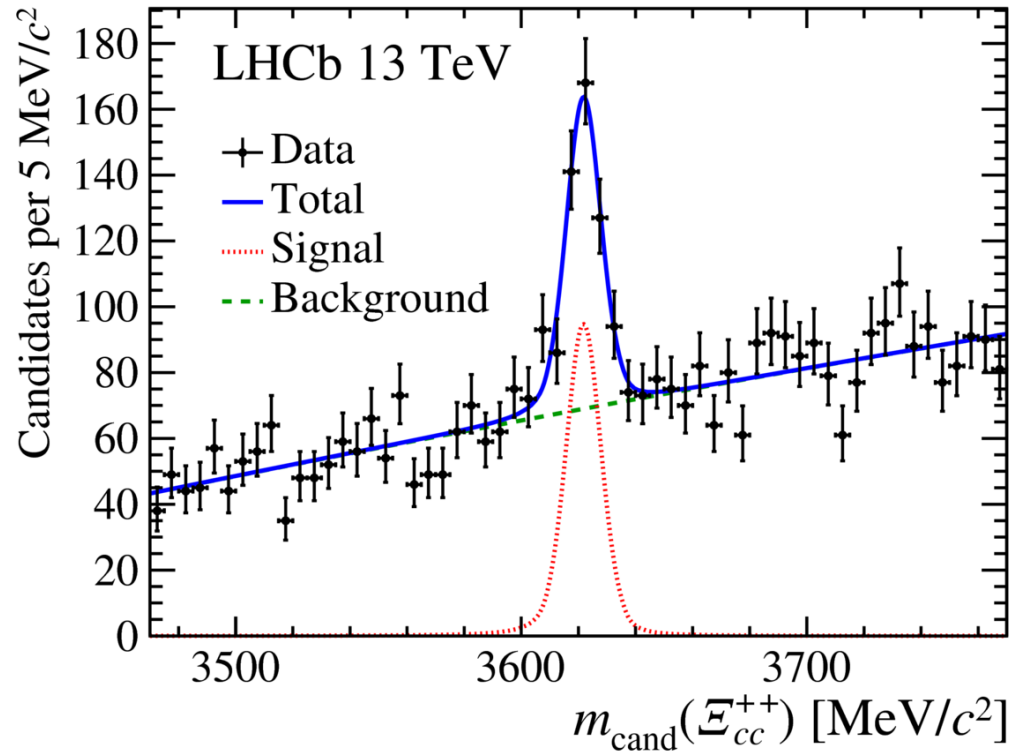
Tim Gershon & Anton Poluektov

Implications of LHCb measurements
and future prospects

18 October 2018

arXiv:1810.06657

Ξ_{cc}^{++} discovered



How about other double heavies?

- Searches ongoing for Ξ_{cc}^{+} , Ω_{cc}^{+}
- Lots of work for Ξ_{bc} states
- Prospects for Ξ_{bb} in exclusive decay modes less promising
 - Curse of product BFs: 2 x (b → c) x (c → s) x efficiency ... low yields

Proposed double beauty tetraquarks

Heavy-Quark Symmetry Implies Stable Heavy Tetraquark Mesons $Q_i Q_j \bar{q}_k \bar{q}_l$

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(Dated: November 29, 2017)

Discovery of doubly-charmed Ξ_{cc} baryon implies
a stable $bb\bar{u}\bar{d}$ tetraquark

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For very heavy quarks Q , relations derived from heavy-quark symmetry predict the existence of novel narrow doubly heavy tetraquark states of the form $Q_i Q_j \bar{q}_k \bar{q}_l$ (subscripts label flavors), where q designates a light quark. By evaluating finite-mass corrections, we predict that double-beauty states composed of $bb\bar{u}\bar{d}$, $bb\bar{u}\bar{s}$, and $bb\bar{s}\bar{s}$ will be stable against strong decays, whereas the double-charm states $cc\bar{q}_k\bar{q}_l$, mixed beauty+charm states $bc\bar{q}_k\bar{q}_l$, and heavier $bb\bar{q}_k\bar{q}_l$ states will dissociate into pairs of heavy-light mesons. Observation of a new double-beauty state through its weak decays would establish the existence of tetraquarks and illuminate the role of heavy color-antitriplet diquarks as hadron constituents.

Evidence for the existence of $ud\bar{b}\bar{b}$ and the non-existence of $ss\bar{b}\bar{b}$ and $cc\bar{b}\bar{b}$ tetraquarks from lattice QCD

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We combine lattice QCD results for the potential of two static antiquarks in the presence of two quarks qq of finite mass and quark model techniques to study possibly existing $qq\bar{b}\bar{b}$ tetraquarks. While there is strong indication for a bound four-quark state for $qq = (ud - du)/\sqrt{2}$, i.e. isospin $I = 0$, we find clear evidence against the existence of corresponding tetraquarks with $qq \in \{uu, (ud + du)/\sqrt{2}, dd\}$, i.e. isospin $I = 1$, $qq = ss$ and $qq = cc$.

Lattice Prediction for Deeply Bound Doubly Heavy Tetraquarks

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(Dated: May 10, 2017)

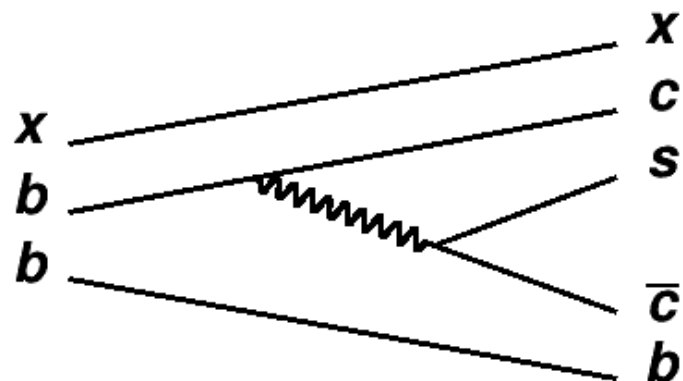
We investigate the possibility of $qq\bar{b}\bar{b}$ tetraquark bound states using $n_f = 2 + 1$ lattice QCD ensembles with pion masses $\simeq 164, 299$, and 415 MeV. Motivated by observations from heavy baryon phenomenology, we consider two lattice interpolating operators both of which are expected to couple efficiently to tetraquark states: one with diquark-antidiquark and one with a meson-meson structure. Using nonrelativistic QCD to simulate the bottom quarks, we study the $ud\bar{b}\bar{b}$, $\ell s\bar{b}\bar{b}$ channels with $\ell = u, d$, and find unambiguous signals for strong-interaction-stable $J^P = 1^+$ tetraquarks. These states are found to lie 189(10) and 98(7) MeV below the corresponding free two-meson thresholds.

Many new theory papers prompted by
 Ξ_{cc}^{++} discovery; also older literature

See other talks in this meeting

How to search for double beauty?

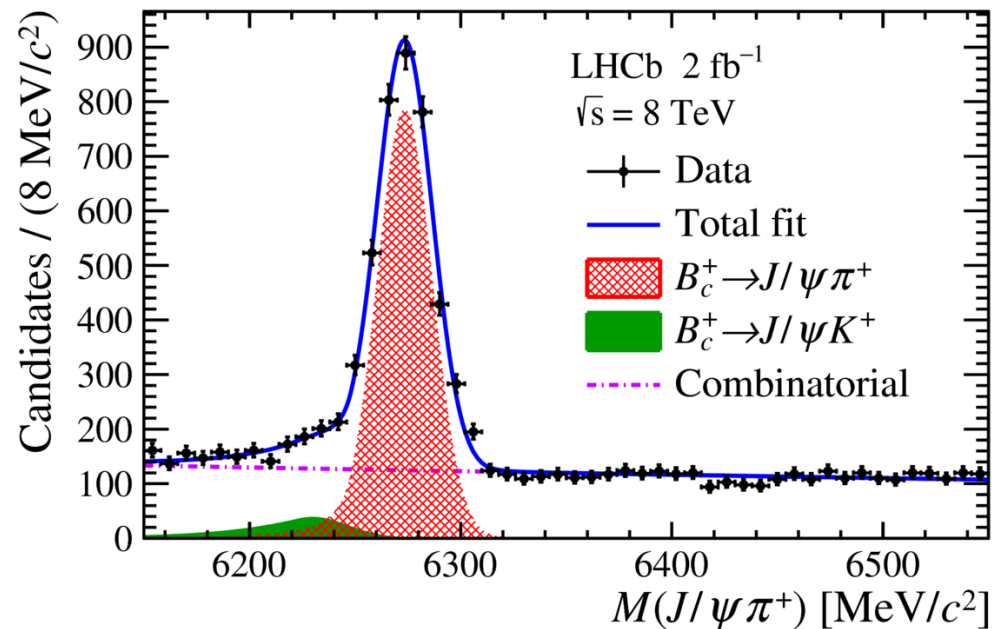
- Exclusive approaches appear unattractive
 - therefore go inclusive
 - see also Ali et al. PL B785 (2018) 605, arXiv:1806.09288 proposing search for double beauty jets
- Key observation:
 - Weakly decaying double beauty hadrons are the only(*) possible source of displaced B_c^- mesons
 - requires $b \rightarrow \bar{c}$ transition, e.g.



(*) loophole for $bq\bar{c}\bar{c}$ tetraquark, if stable, but negligible impact

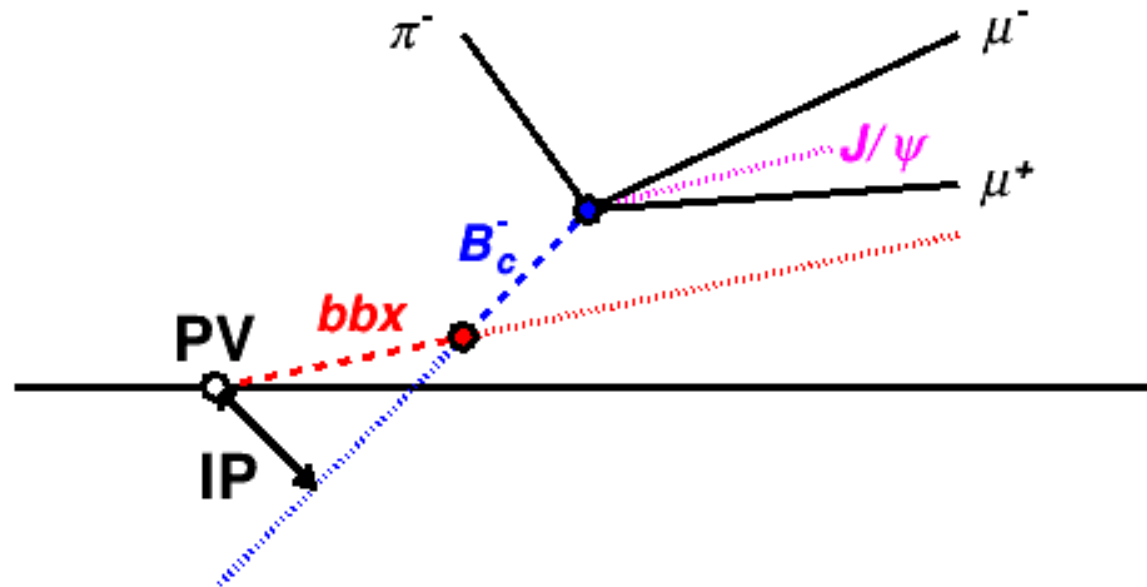
Displaced B_c^- mesons @ LHCb

- Inclusive signature of displaced B_c^- mesons is well suited for LHCb
 - use $B_c^- \rightarrow J/\psi \pi^-$, with $J/\psi \rightarrow \mu^+ \mu^-$
 - largest yields as only 3 tracks to reconstruct
 - 3325 ± 73 signal in LHCb-PAPER-2017-042 ($B_c(2S)$ search)
 - $B_c^- \rightarrow J/\psi \pi^- \pi^+ \pi^-$ may also be worth including eventually



Displaced B_c^- mesons @ LHCb

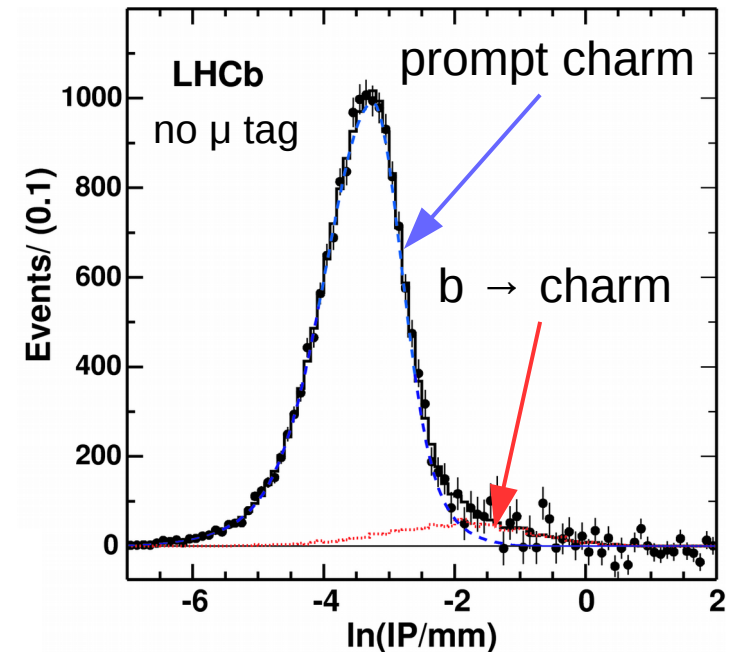
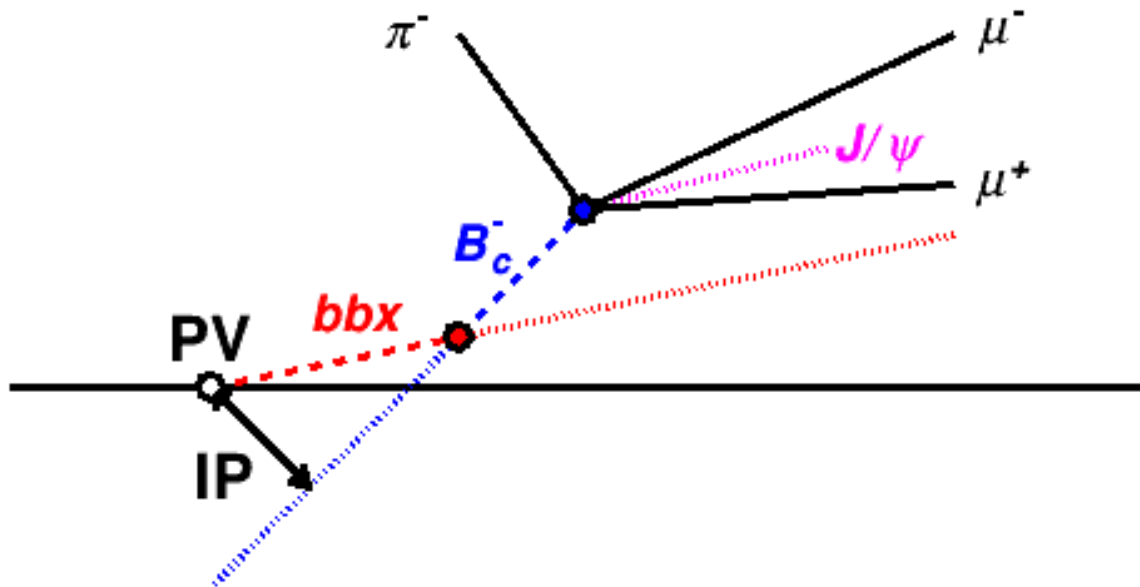
- Inclusive signature of displaced B_c^- mesons is well suited for LHCb
 - benefit from excellent vertex & hence IP resolution
 - Already good now, and expect better in Run 3 (VELOPIX)



Working example: Displaced charm

Signature of displaced charm used to measure inclusive $pp \rightarrow b\bar{b}X$ production cross-section
LHCb-PAPER-2010-002

Muon tag from semileptonic decay helps to suppress background from prompt charm
→ not possible for displaced B_c analysis
→ $(b \rightarrow \bar{c})$ instead of $(b \rightarrow c)$



signal:background $\sim 1:20$
still able to distinguish
displaced charm with 2.9 nb^{-1}
IP resolution since improved

Is it feasible?

- How large are the potential yields?
 - Product of the following (with estimated/known values)
 - integrated luminosity
 - bbx hadron production cross-section (1 nb; arXiv:1806.09288)
 - branching fractions for inclusive $bbx \rightarrow B_c^- X$ (10%) ...
 - ... and for $B_c^- \rightarrow J/\psi \pi^-$ (2%) and $J/\psi \rightarrow \mu^+ \mu^-$ (6%) transitions
 - detection efficiency (10%)
 - Leads to around 10 displaced B_c^- mesons per fb^{-1}
 - around 1% of prompt B_c^- yield

Prospects of observing Stable Tetraquarks at the LHC

[AA, Qin Qin, Wei Wang, Phys. Lett. B785, 605 (2018).]

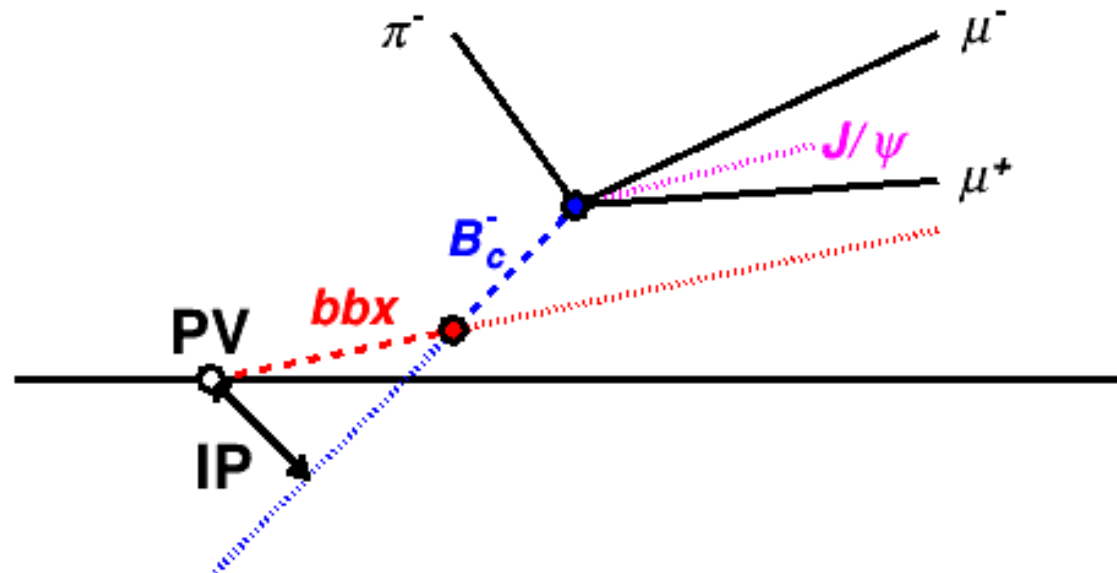
- bbx hadron production cross-section (1 nb; arXiv:1806.09288)

$$\sigma(pp \rightarrow H_{\{bb\}} + X) = (14.8^{+5.4}_{-3.7}) \text{ nb}$$

- around 1% of prompt B_c^- yield (still)

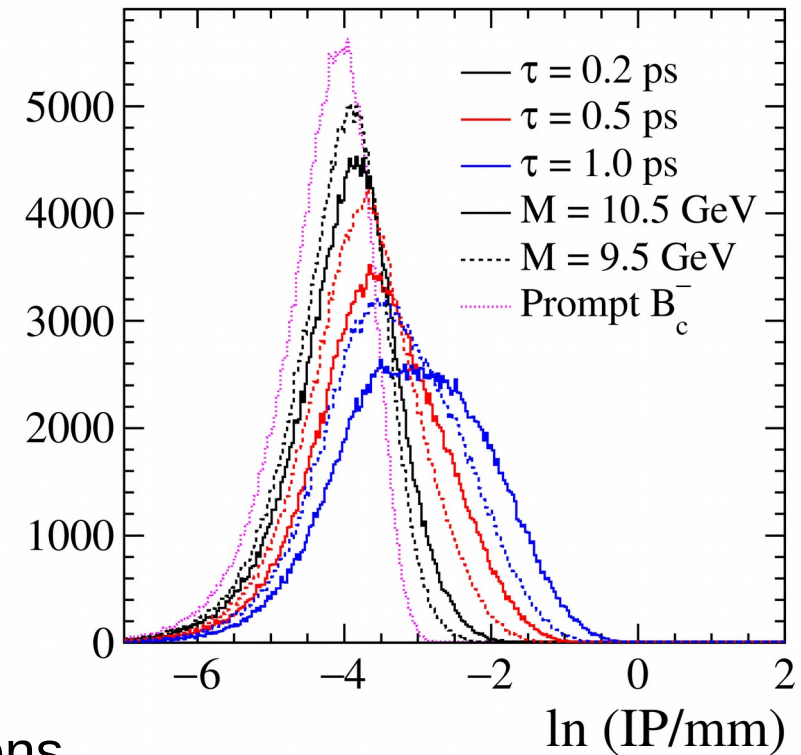
Is it feasible?

- How good is signal/background separation?
 - IP distribution depends on properties of signal
 - flight distance (hence momentum & lifetime)
 - Q value of $bbx \rightarrow B_c^- X$ decay (hence mass)



Simple toy study

- Assume bbx kinematics same as B mesons
 - ~flat in η , ~exponential in p_T with mean 5 GeV
- Obtain approximate B_c^- IP
 - weighted mean of IP of 3 final state tracks
 - full vertex fit not possible
 - **likely to underestimate tails**
- Assume track IP resolution measured in 2012
 - $\sigma_{IP} [\mu\text{m}] = 11.6 + 23.4/p_T [\text{GeV}]$
- Reasonable separation from prompt B_c^- mesons
 - expect $M \sim 10.5 \text{ GeV}$, $\tau \sim 0.4 - 0.8 \text{ ps}$
- **Control of tails will be essential**
 - \bar{B}_s^{**} tagged $B^- \rightarrow J/\psi K^-$ control sample will help



Tails will be much trickier in real analysis

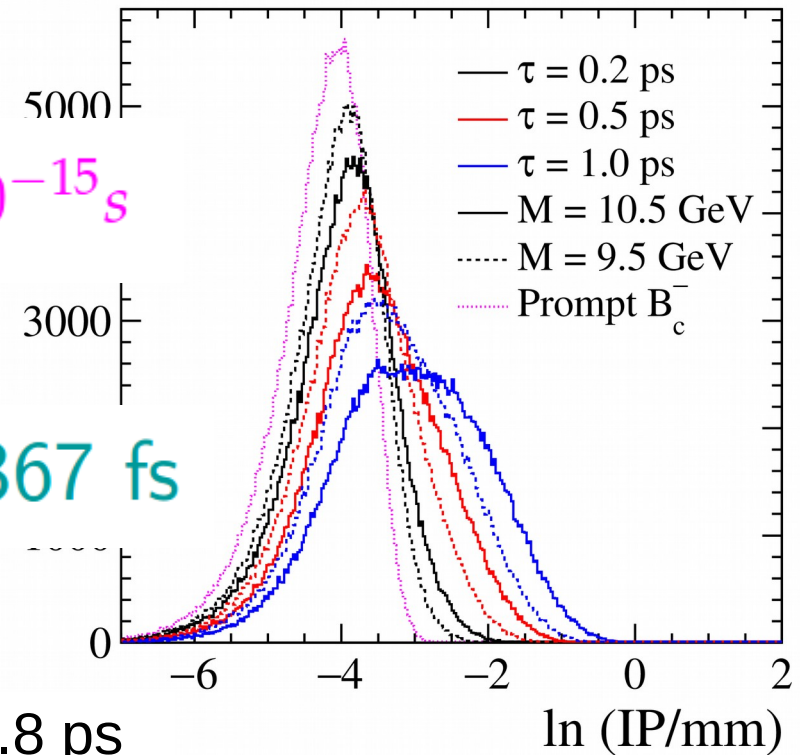
Simple toy study

Ali
Rosner

$$\tau(T_{[\bar{q}\bar{q}']}^{\{bb\}}) \sim \frac{1}{2} \times 1.6 \times 10^{-12} \text{s} = 800 \times 10^{-15} \text{s}$$

Estimated lifetime of $bb\bar{u}\bar{d}$ state: 367 fs

predictions for bb baryons also typically 0.4-0.8 ps



Tails will be much trickier in real analysis

What could be measured?

- Optimistically assume that a significant yield can be obtained, and its shape measured
 - **Yield** is related to
 - Production cross-section times $B(\text{bbx} \rightarrow B_c - X)$
 - Summed over all weakly decaying bbx hadrons
 - With improved theory predictions, **could indicate whether only bb baryons or also bb tetraquarks are being produced**
 - **Shape** is related to
 - Mass and lifetime
 - Averaged over all weakly decaying bbx hadrons
 - **With prediction for mass could infer average bbx lifetime (or vice versa)**
- Observation could also provide insight into future strategies for exclusive measurements

Summary

- Have presented an inclusive strategy to search for double beauty hadron production at the LHC through the signature of displaced B_c^- mesons
 - Well suited for search at LHCb
 - **Still highly challenging**, but seems to have better potential than exclusive searches
- **More detailed study needed to understand LHCb sensitivity**
 - Depends on bbx production cross-sections, inclusive branching fractions to final states containing B_c^- mesons, masses and lifetimes
 - More theory work on these would be welcome

arXiv:1810.06657