Search for the doubly heavy baryon Ξ_{bc}^0 via decays to D^0pK^-

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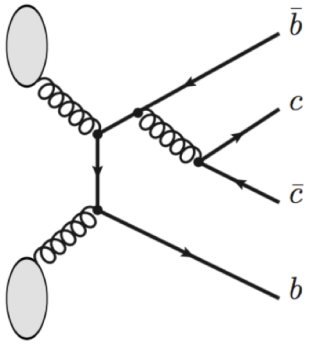
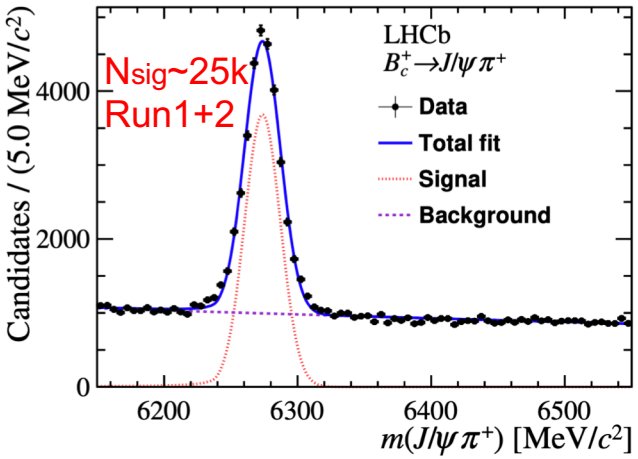
Outline

- Introduction
- Theoretical prediction
- LHCb detector and data-taking
- Event selection
- Control mode
- Results

Introduction

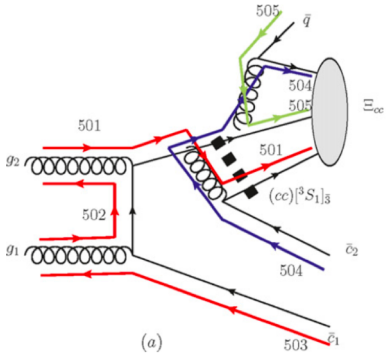
- Huge double-charm, B_c events @ LHCb

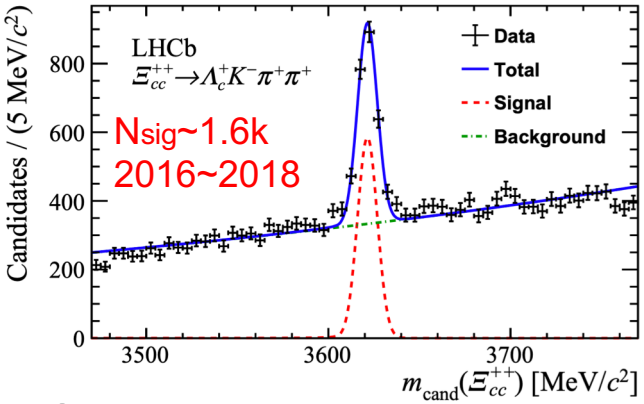




[JHEP 07 (2020) 123]

- Ξ_{cc}^{++} first observed @ LHCb, high signal yield





[JHEP 02 (2020) 049]

- Ξ_{bc} (bcq) also at horizon?

Prediction: mass & lifetime

- Predicted Ξ_{bc}^{0} mass ~6.9 GeV

Reference	Value (MeV)	Method
Present work	6914 ± 13	
[25]	6916 ± 139	QCD-motivated quark model
[28]	6938	QCD-motivated quark model
[44]	6930	Potential models
[46]	6990 ± 90	Feynman-Hellmann + semi-empirical formulas
[47]	7029	Mass sum rules
[48]	6950	Relativistic quasipotential quark model
[49]	6915	Three-body Faddeev equations.
[52]	6820 ± 50	Potential approach and QCD sum rules
[53]	6960	Nonperturbative string
[54]	6933	Relativistic quark-diquark
[55]	6800	Bag model
[58]	6919	Variational
[59]	7011	Quark model
[60]	6789	Coupled channel formalism
[61]	6840 ± 10	Instantaneous approx. + Bethe-Salpeter
[62]	6750 ± 50	QCD sum rules

Phys. Rev. D 90, 094007 (2014)

- Predicted Ξ_{bc}^{0} lifetime 100~500 fs

[fs]

(93, 118) Phys. Rev. D 99, 073006 (2019)

93 Phys. Rev. D 90, 094007 (2014)

260 arXiv:9912425

270±30 Eur. Phys. J. C 16, 461 (2000)

280±70 Phys. Usp. 45, 455 (2002)

510±9 (~B_c^+) Nucl. Phys. B 440, 251 (1995)

Prediction: cross-section

- $\sigma(bc) = 39$ nb @ 14 TeV in LHCb PRD 83 (2011) 034026

[nb]	$p_{T\text{cut}}/y_{\text{cut}}$ or η_{cut}	NO-cut	LHC (CMS, ATLAS) $\lvert y\rvert < 1.5$	LHC (CMS, ATLAS) $\lvert y\rvert < 2.5$	LHCb $1.9 < \lvert\eta\rvert < 4.9$
$(bc)_{\bar{3}}[^3S_1]$	0 GeV	47.24	21.70	33.43	25.85
	2.5 GeV	36.55	16.92	26.04	19.17
	4.0 GeV	24.92	11.70	17.95	12.34
$(bc)_6[^1S_0]$	0 GeV	11.55	5.259	8.112	6.250
	2.5 GeV	9.255	4.243	6.537	4.822
	4.0 GeV	6.607	3.067	4.713	3.269
$(bc)_6[^3S_1]$	0 GeV	70.67	31.80	49.19	38.89
	2.5 GeV	54.29	24.65	38.07	28.74
	4.0 GeV	36.59	16.85	25.97	18.36
$(bc)_{\bar{3}}[^1S_0]$	0 GeV	12.46	5.794	8.909	6.788
	2.5 GeV	9.802	4.591	7.049	5.111
	4.0 GeV	6.855	3.248	4.975	3.377

- σ_{total} for $p_{\text{T}} > 4$ GeV & $|y| < 1.5$, $\sigma(\Xi_{bc}) : \sigma(\Xi_{cc}) \sim 1 : 2.5$

[nb]	Ξ_{cc} $\sqrt{S} = 7.0$ TeV	Ξ_{cc} $\sqrt{S} = 14.0$ TeV	Ξ_{bc} $\sqrt{S} = 7.0$ TeV	Ξ_{bc} $\sqrt{S} = 14.0$ TeV	Ξ_{bb} $\sqrt{S} = 7.0$ TeV	Ξ_{bb} $\sqrt{S} = 14.0$ TeV
$[^3S_1]$	38.11	69.40	16.7	28.55	0.503	1.137
$[^1S_0]$	9.362	17.05	3.72	6.315	0.100	0.226
Total	47.47	86.45	20.42	34.87	0.603	1.363

- Fragmentation fraction, $u : d : s \sim 1 : 1 : 0.3$

$\sigma(\Xi_{bc}^+) = \sigma(\Xi_{bc}^0) \sim 17$ nb, $\sigma(\Omega_{bc}^0) \sim 5$ nb

Prediction: branching fraction

- Semi-leptonic decay Eur. Phys. J. C 80, 568 (2020) , Eur. Phys. J. C 80, 320 (2020)

  e.g. $\Xi_{bc}^0 \to \Xi_b^- l^+ \upsilon_l$, $\mathcal{B}\sim 10^{-2}$; $\Xi_{bc}^0 \to \Xi_{cc}^+ l^- \bar{\upsilon}_l$, $\mathcal{B}\sim 10^{-2}$

- Weak scattering Phys. Lett. B 767, 232 (2017), Phys. Usp. 45, 455 (2002)

  e.g. $\Xi_{bc}^0 \to pK^-$, $\mathcal{B}\sim 10^{-7\sim-8}$; $\Xi_{bc}^0 \to D^0 pK^-$, $\mathcal{B}\sim 10^{-3}$

- Charged current by c Eur. Phys. J. C 77, 781 (2017)

  e.g. $\Xi_{bc}^0 \to \Xi_b^- \rho^+$, $\mathcal{B}\sim 10^{-1}$; $\Xi_{bc}^0 \to \Xi_b^- \pi^+$, $\mathcal{B}\sim 10^{-2}$

- Charged current by b Phys. Rev. D 62, 054021 (2000)

  e.g. $\Xi_{bc}^0 \to \Xi_{cc}^+ \rho^-$, $\mathcal{B}\sim 10^{-2}$; $\Xi_{bc}^0 \to \Xi_{cc}^+ \pi^-$, $\mathcal{B}\sim 10^{-2}$

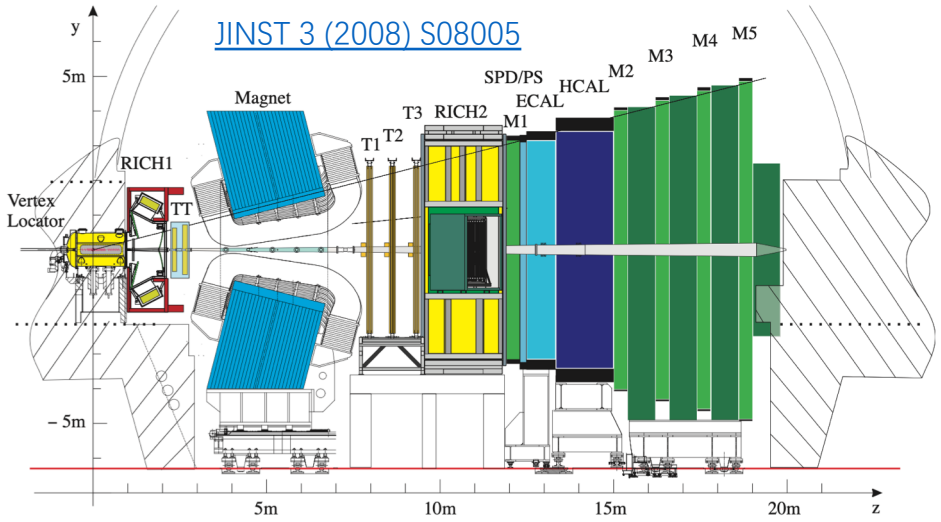
- FCNC Phys. Rev. D 98, 056002 (2018)

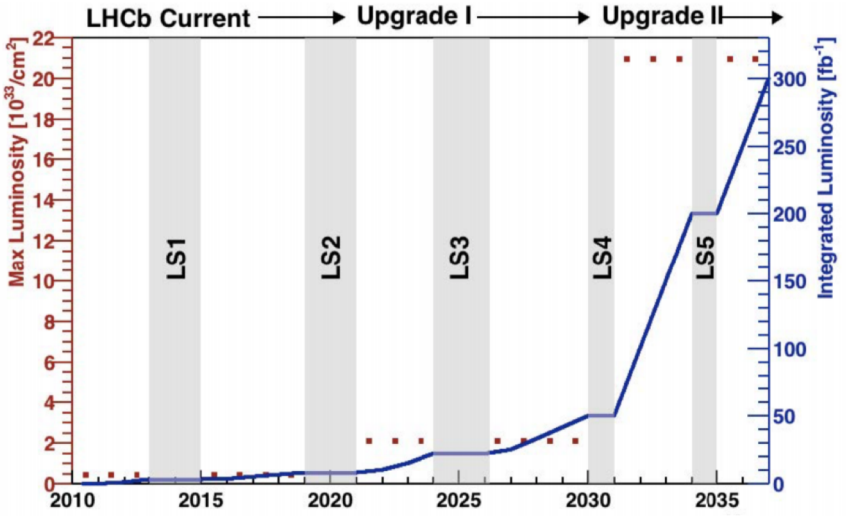
  e.g. $\Xi_{bc}^0 \to \Xi_c^0 l^+ l^-$, $\mathcal{B}\sim 10^{-8}$; $\Xi_{bc}^0 \to \Sigma_c^0 l^+ l^-$, $\mathcal{B}\sim 10^{-9}$

☆ Search for $\Xi_{bc}^0 \to (D^0 \to K^-\pi^+)pK^-$, $\mathcal{B}_{\text{total}}\sim 10^{-5} - 10^{-4}$

LHCb detector and data-taking

- Acceptance $2 < \eta < 5$, with excellent vertexing, tracking, PID





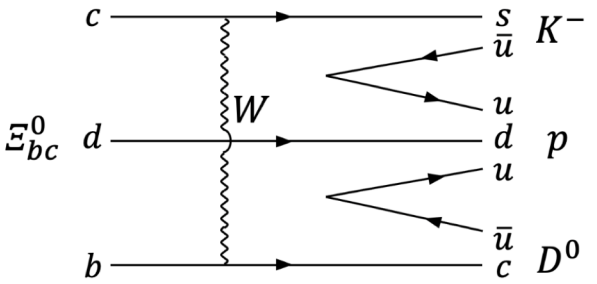
- Run1 (2011-2012):

$$1\ \mathrm{fb}^{-1}\ @\sqrt{s} = 7\ \mathrm{TeV},\ \ 2\ \mathrm{fb}^{-1}\ @\sqrt{s} = 8\ \mathrm{TeV}$$

- Run2 (2011-2012):

$$5.9\ \mathrm{fb}^{-1}\ @\sqrt{s} = 13\ \mathrm{TeV}$$

Searching for $\Xi_{bc}^0 \longrightarrow D^0 p K^-$



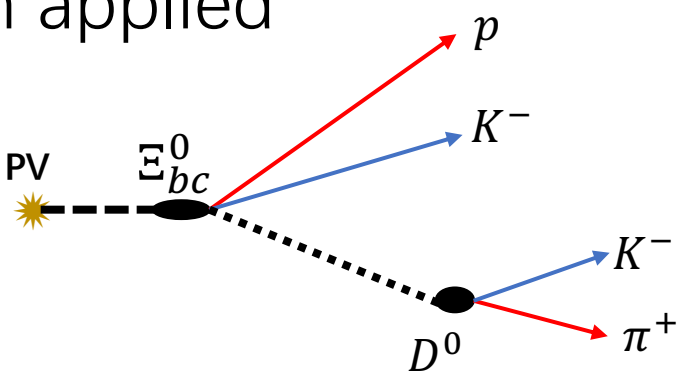
- Analysis blind in $6.7\sim7.2\ \mathrm{GeV}/c^2$
- Observation
  - measure mass
- No observation
  - setting upper limit of production ratio with 2016, 2017 and 2018 data

$$R \equiv \frac{\sigma(\Xi_{bc}^0) B[\Xi_{bc}^0 \longrightarrow D^0 p K^-]}{\sigma(\Lambda_b^0)\, B[\Lambda_b^0 \longrightarrow D^0 p K^-]} = \frac{N_{\mathrm{sig}}/\varepsilon_{\mathrm{sig}}}{N_{\mathrm{con}}/\varepsilon_{\mathrm{con}}}$$

  - fiducial range: $5 < p_{\mathrm{T}} < 25\ \mathrm{GeV}/c$, $2.0 < y < 4.5$
  - quote R on Ξ_{bc}^0 lifetime $\tau = 100, 200, 300, 400, 500$ fs
- In simulation: $m\sim6.9\ \mathrm{GeV}/c^2$, $\tau\sim400$ fs

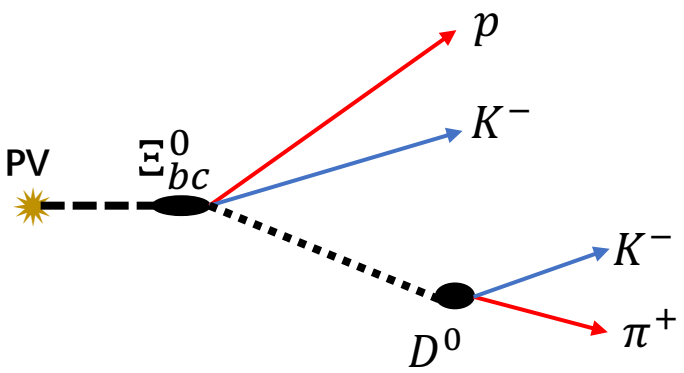
Candidate selection

- Expecting large hadronic backgrounds, a MVA-based "online" pre-selection applied
- All final states
  - large p_{T}
  - tight PID required
- D^0
  - large p_{T}
  - good end vertex quality
  - has fly distance
  - Δm from PDG < 25 $\mathbf{MeV}$
- Ξ_{bc}^0
  - good end vertex quality

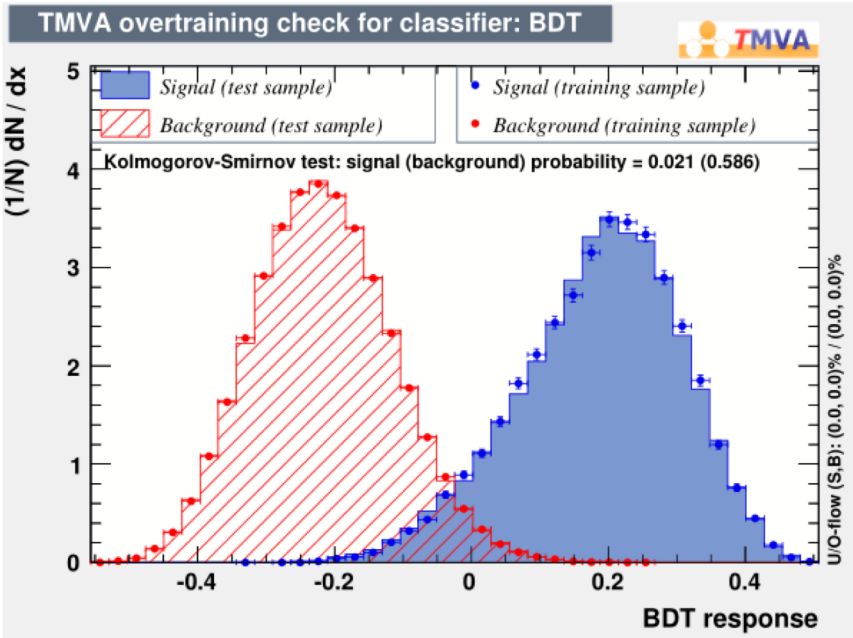


The machine learning

- Multivariate selector further explores
  - decay fit quality
  - kinematics & PID of final states
  - Ξ_{bc}^0 vertex separation from PV



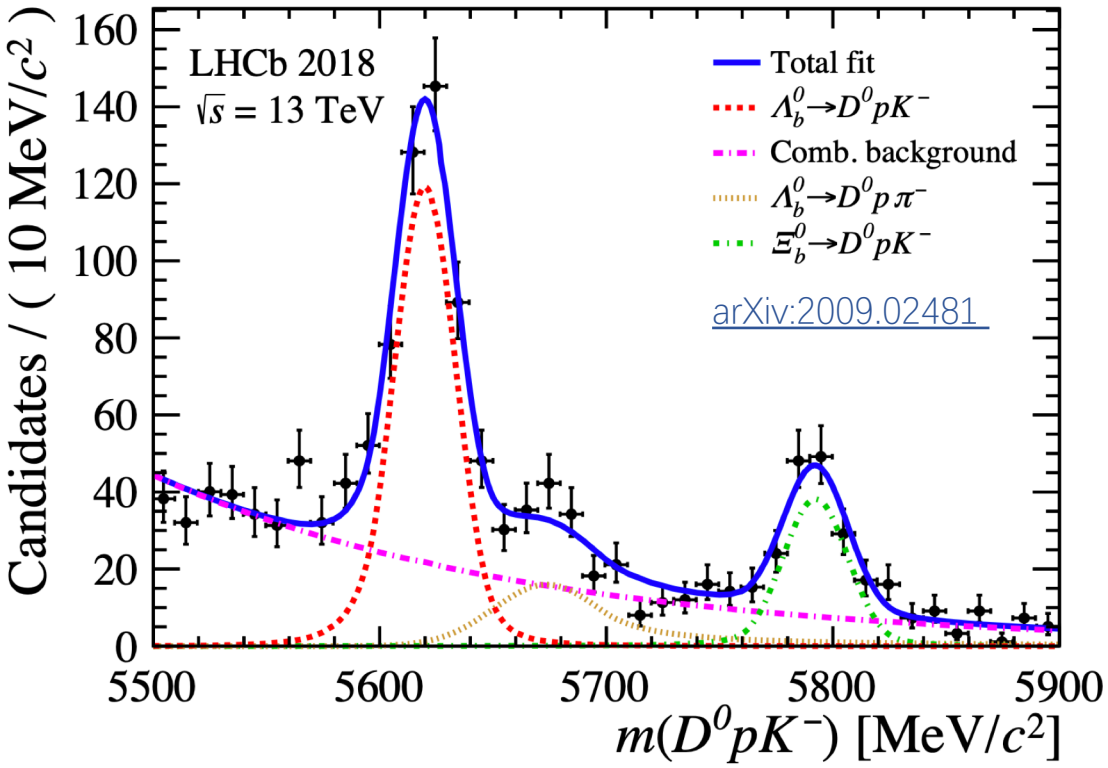
- Selector optimized using simulated decays for signal and backgrounds from far upper sideband
  - good performance
  - no obvious overtraining



Control mode $\Lambda_b^0 \longrightarrow D^0 p K^-$

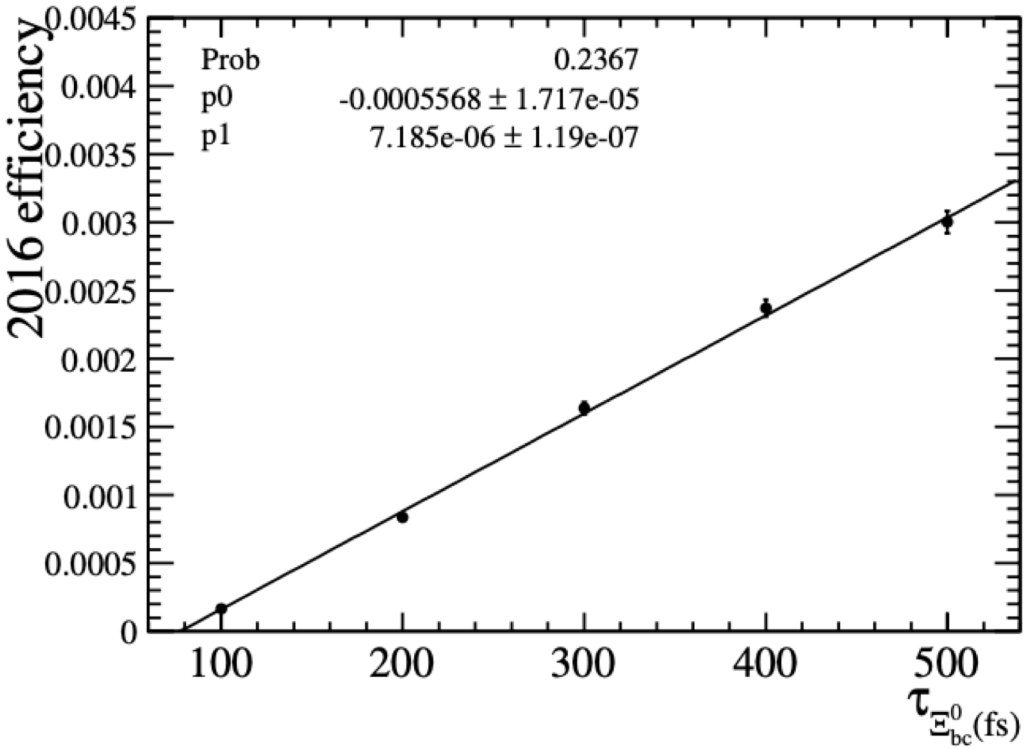
- Same selection with signal mode
- Tighter PID for $K(\Lambda_b^0)$ to suppress CF $\Lambda_b^0 \longrightarrow D^0 p \pi^-$
- Obtained about 400 Λ_b^0 candidates for each year

Year	$N(\Lambda_b^0 \longrightarrow D^0 p K^-)$
2016	376±26
2017	371±26
2018	425±28



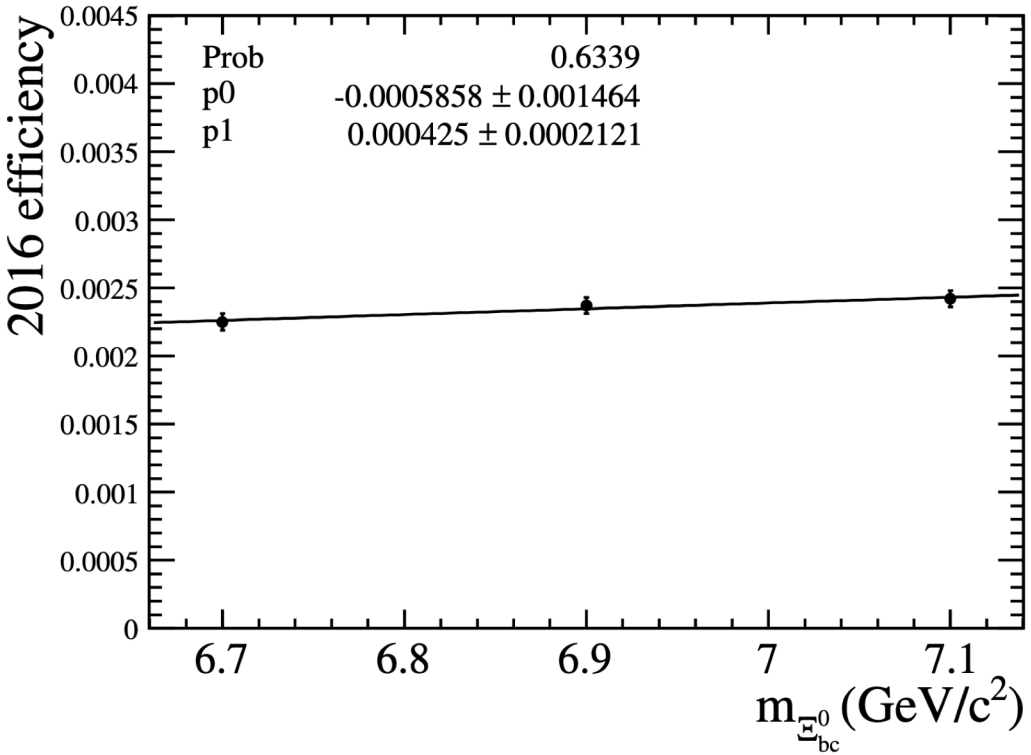
Efficiency on Ξ_{bc}^0 lifetime hypotheses

- To mimic different lifetime hypotheses t, per-event weight is assigned as $w(t) = \frac{\frac{1}{\tau}\exp(-\frac{t}{\tau})}{\frac{1}{\tau_0}\exp(-\frac{t}{\tau_0})}$, where $\tau_0 = 400$ fs
- Efficiency strongly depends on the lifetime $\tau(\Xi_{bc}^0)$



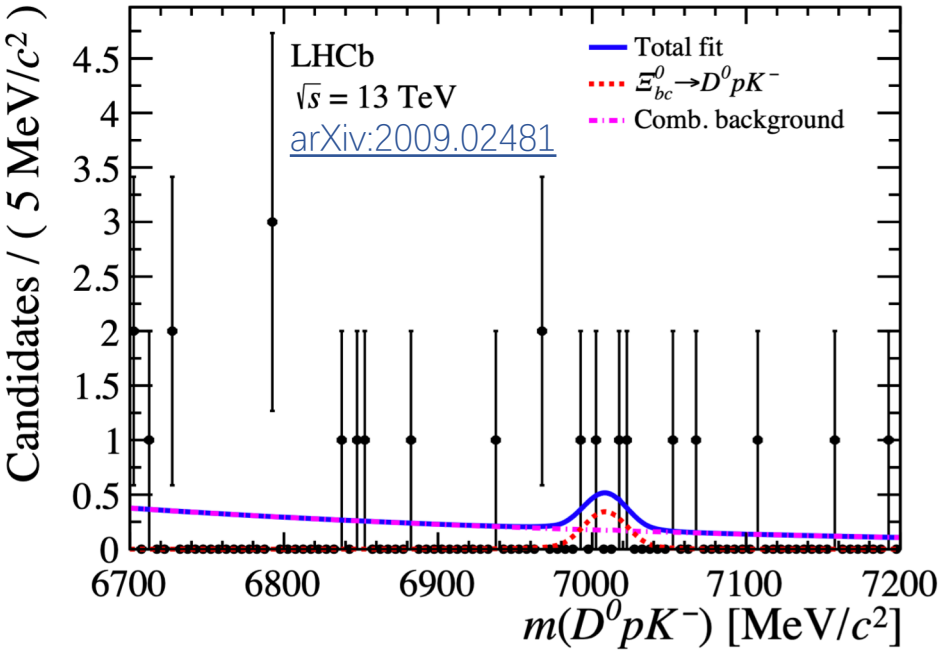
Efficiency on Ξ_{bc}^0 mass hypotheses

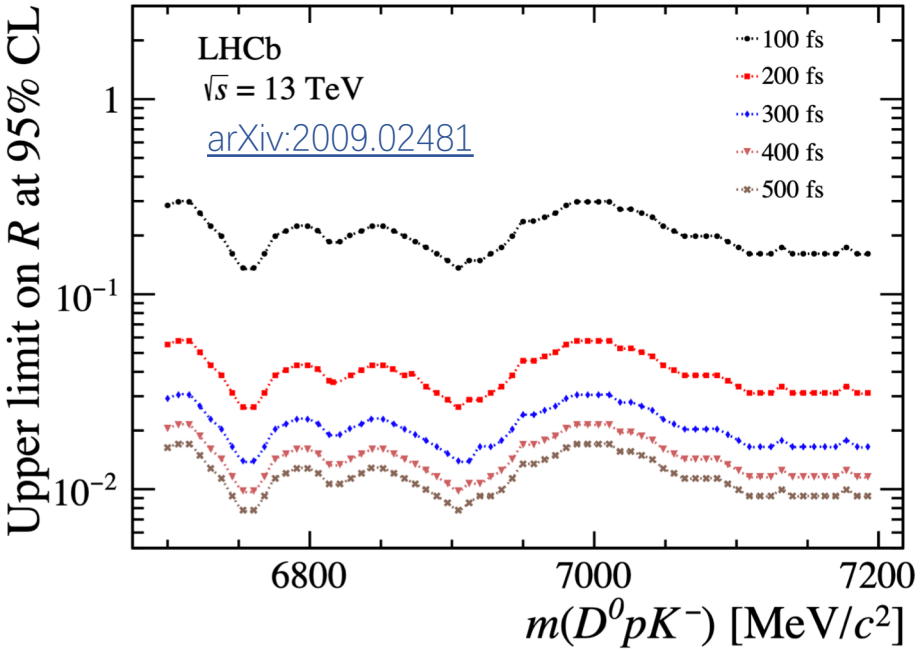
- Generator level MC with $6.7, 6.9, 7.1\ \mathrm{GeV}/c^2$ hypotheses
- Reweighting full simulated sample according generator level daughters' p_T differences with other mass hypotheses
- Efficiency depends weakly on $m(\Xi_{bc}^0)$



Results

- With 2016, 2017 and 2018 LHCb datasets
- Not observe significant Ξ_{bc}^0 signal, setting upper limit
- R varying from 3.0×10^{-1} to 1.7×10^{-2} @ $\tau(\Xi_{bc}^0) = 100\sim500$ fs





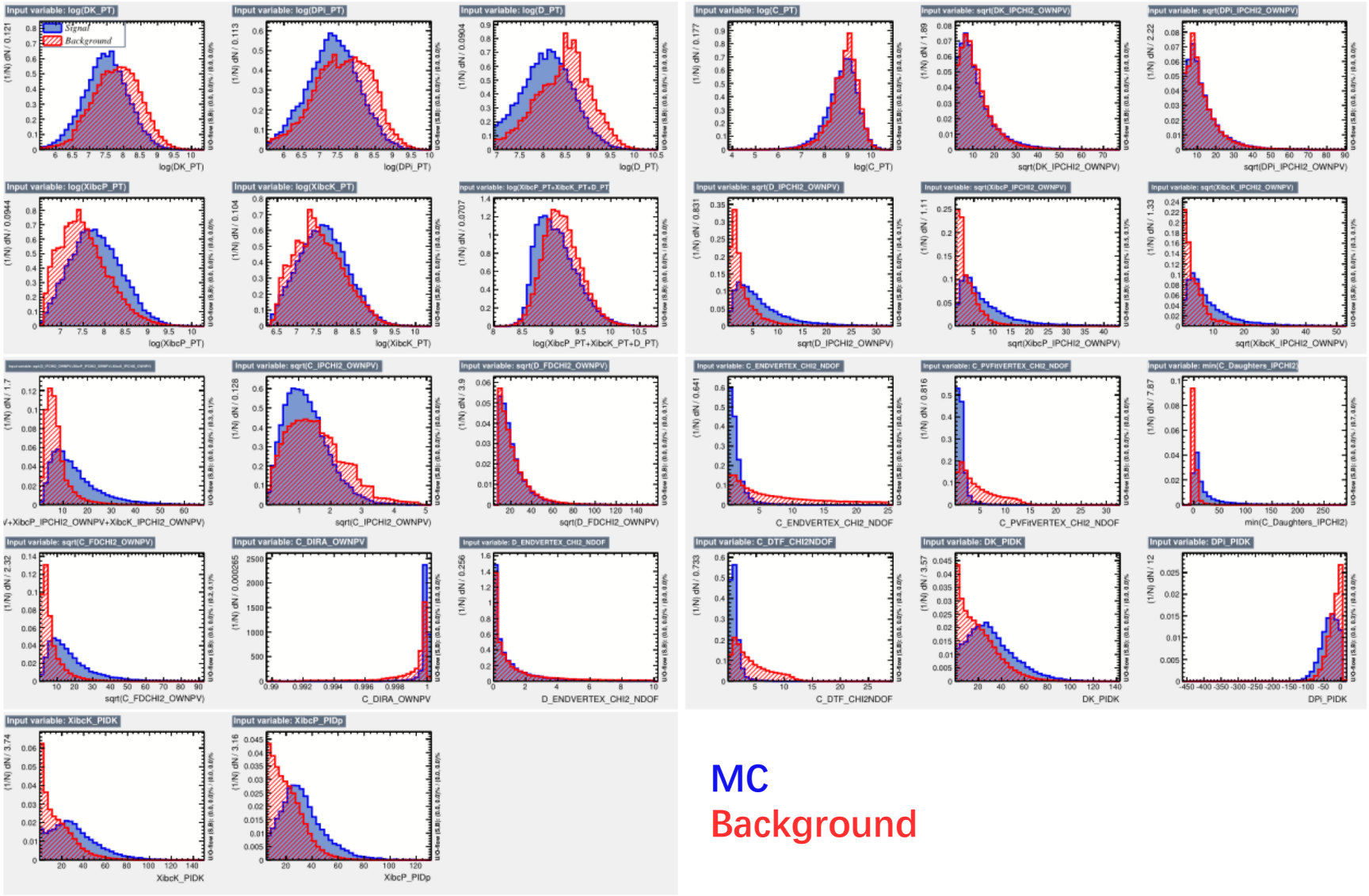
Summary

- First search for the Ξ_{bc}^0 baryon with $\Xi_{bc}^0 \longrightarrow D^0 p K^-$
- No significant signal is observed
- Upper limit on the ratio of production cross-section times branching fraction to Λ_b^0 is set
- Lots of efforts from LHCb-China group on the doubly heavy baryon studies

Thanks for your attention!

Backup

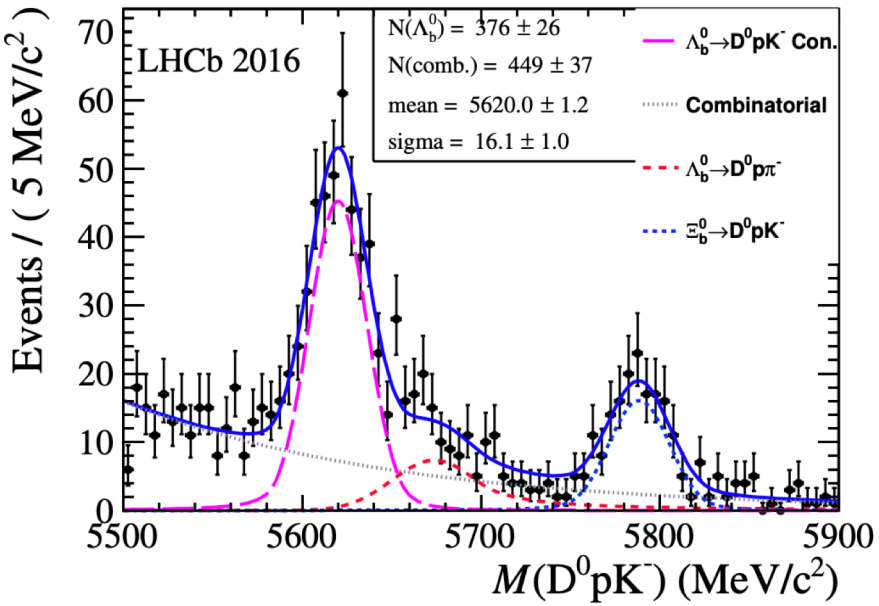
MVA input variables



MC

Background

Control mode $\Lambda_b^0 \longrightarrow D^0 p K^-$



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