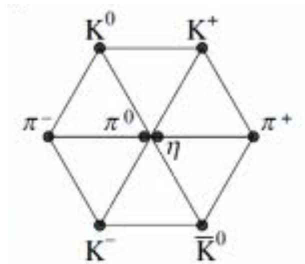
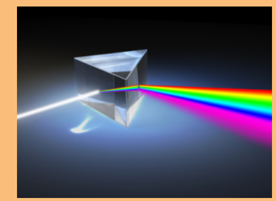


Meson spectroscopy at LHCb



Outline

- LHCb Experiment
- Excited B states
- Charmed spectroscopy
- Search for Ξ_{cc} baryon
- Summary

On behalf of the LHCb Collaboration

Tomasz Szumlak AGH-UST, **Michal Kreps** University of Warwick

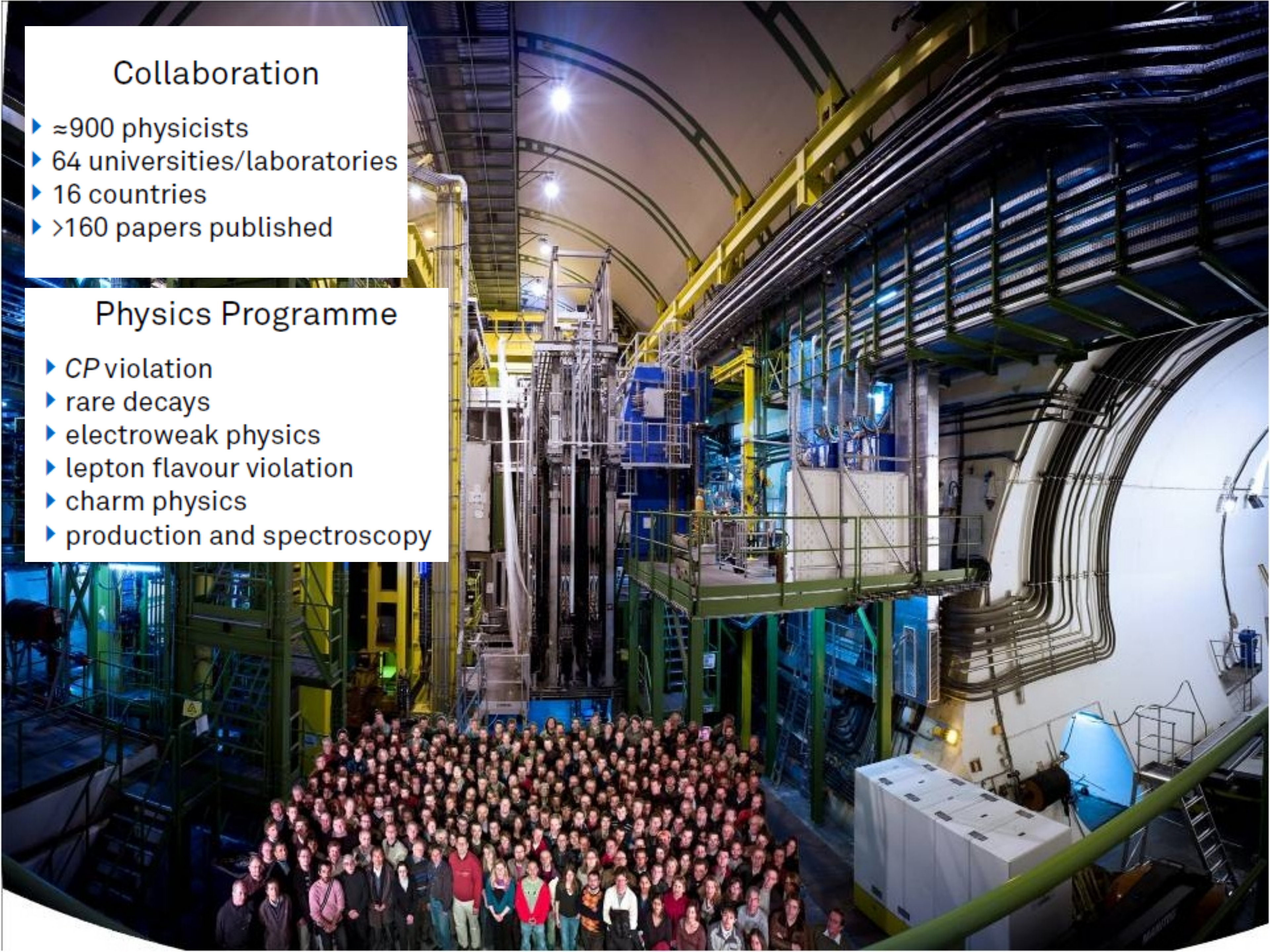
13th Workshop on Meson Production, Properties and Interactions
29/05 – 03/06/2014, Krakow, POLAND

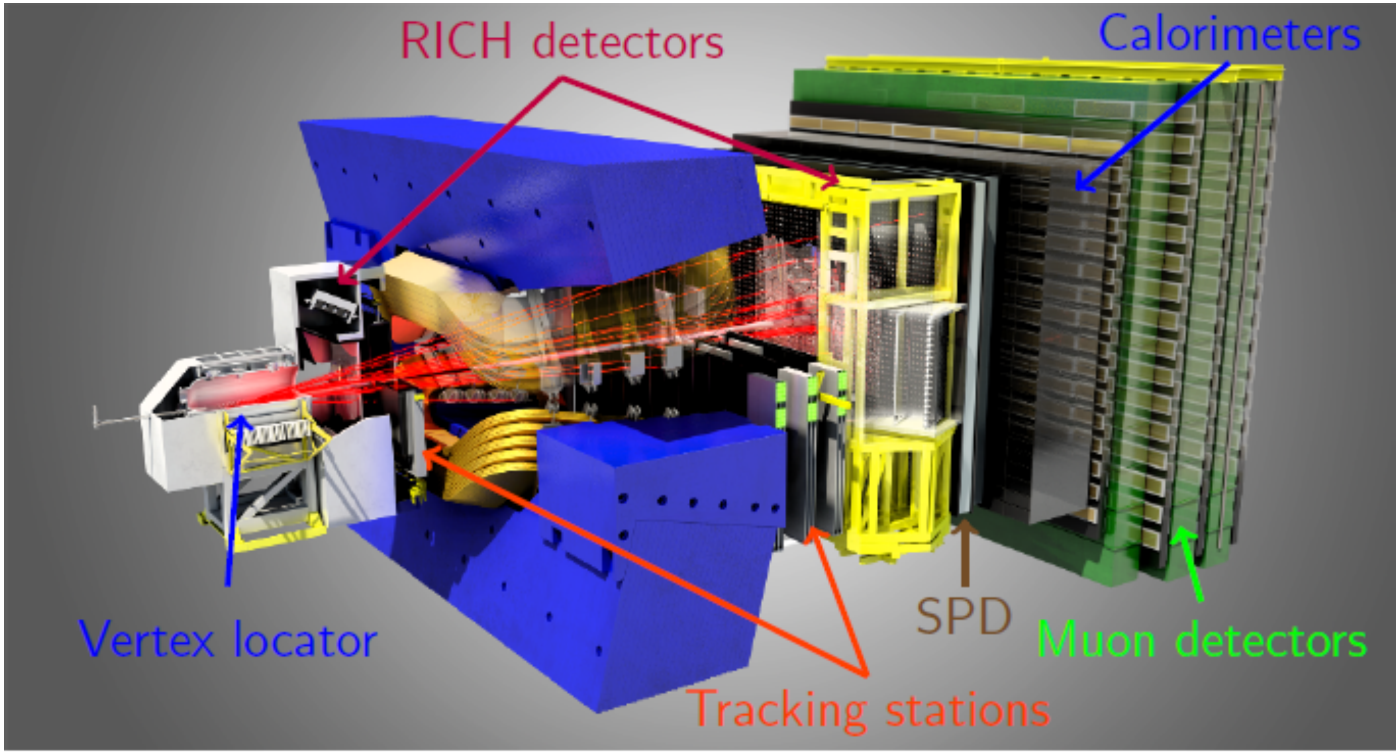
Collaboration

- ≈900 physicists
- 64 universities/laboratories
- 16 countries
- >160 papers published

Physics Programme

- *CP* violation
- rare decays
- electroweak physics
- lepton flavour violation
- charm physics
- production and spectroscopy





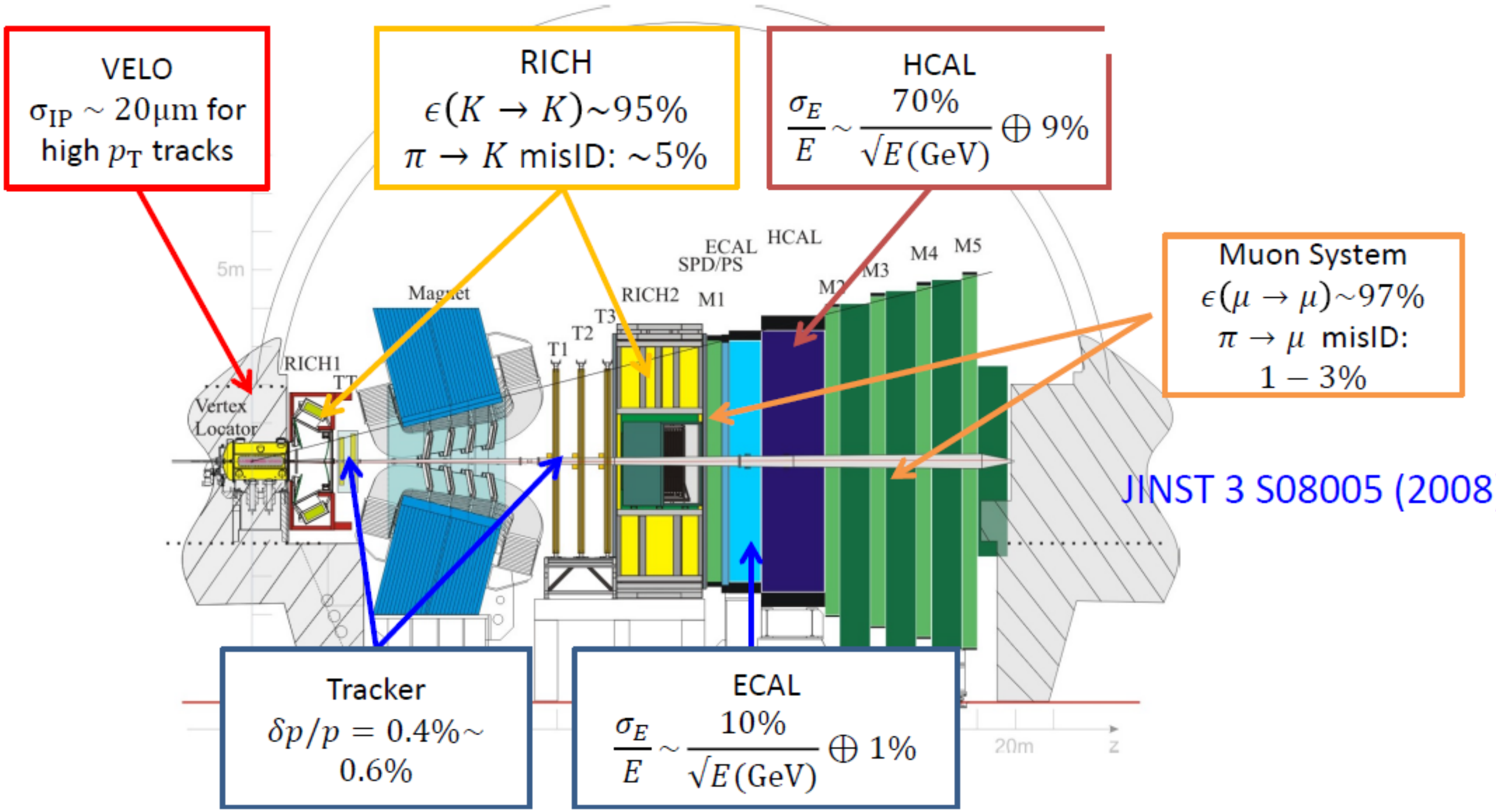
LHCb is a dedicated flavour experiment with the main focus on searches for New Physics (NP)

- **precise measurement of CP-violation**
- **rare decays of b- and c-mesons**

Performs indirect searches using quantum loops

- **complementary to energy frontier experiments ATLAS & CMS**

Must provide: excellent position, vertex and momentum resolution & PID

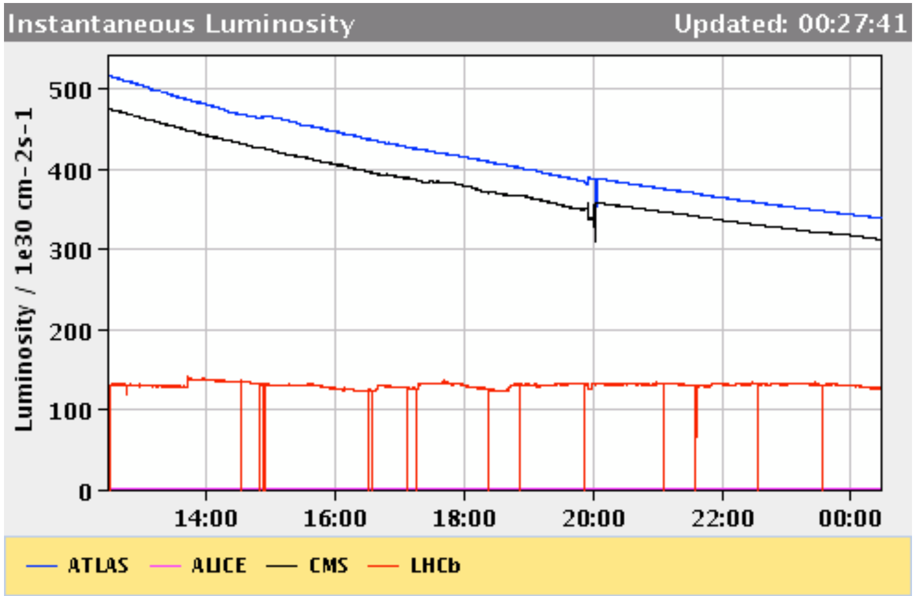


- **Single arm spectrometer geometry**
- **Fully instrumented in rapidity range 2 < η <5**
- **Capable of reconstructing backward tracks (-4 < η < -1.5)**

The LHCb detector at LHC **(JINST 3 2008 S08005)**

Operation conditions of the LHCb in 2011

- ❑ recorded luminosity L ≈ **1,2** [fb^{-1}] at beam energy 3.5 [TeV]
- ❑ LHCb stably operated at L_{inst} = **4.0 x 10^{32}** [$cm^{-2}s^{-1}$] (nominal **2.0 x 10^{32}**)
- ❑ Average number of visible interactions per x-ing μ = **1.4** (nominal **0.4**)
- ❑ Data taking efficiency ~**90 %** with **99 %** of operational channels
- ❑ HLT (High Level Trigger) input ~ **0.85 MHz**, output ~ **3 kHz**
- ❑ Ageing of the sub-detectors monitored – according to expectations

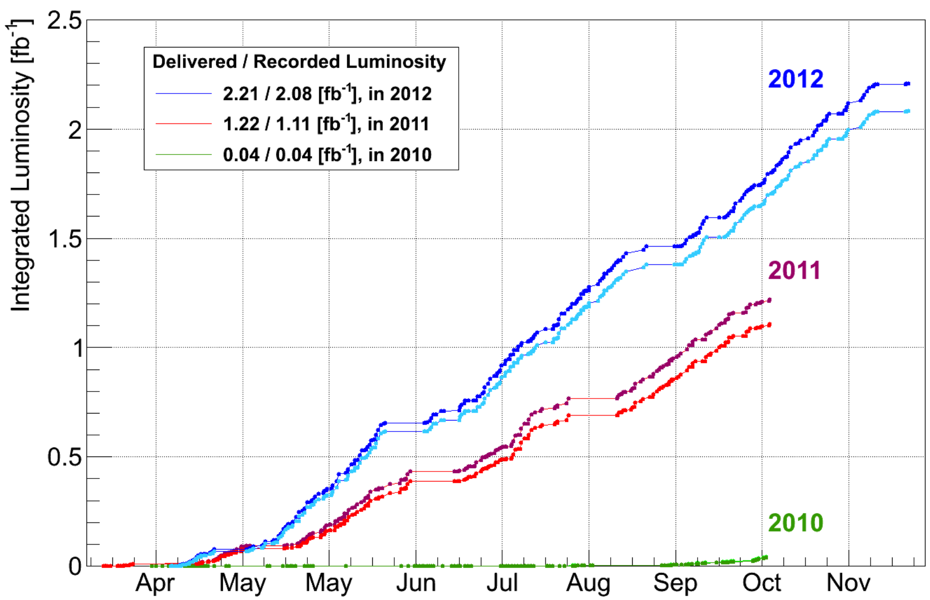


Luminosity leveling

❑ Use displaced p-p beams
❑ Lower inst. Luminosity
❑ Stable conditions during the run
❑ Lower pile-up

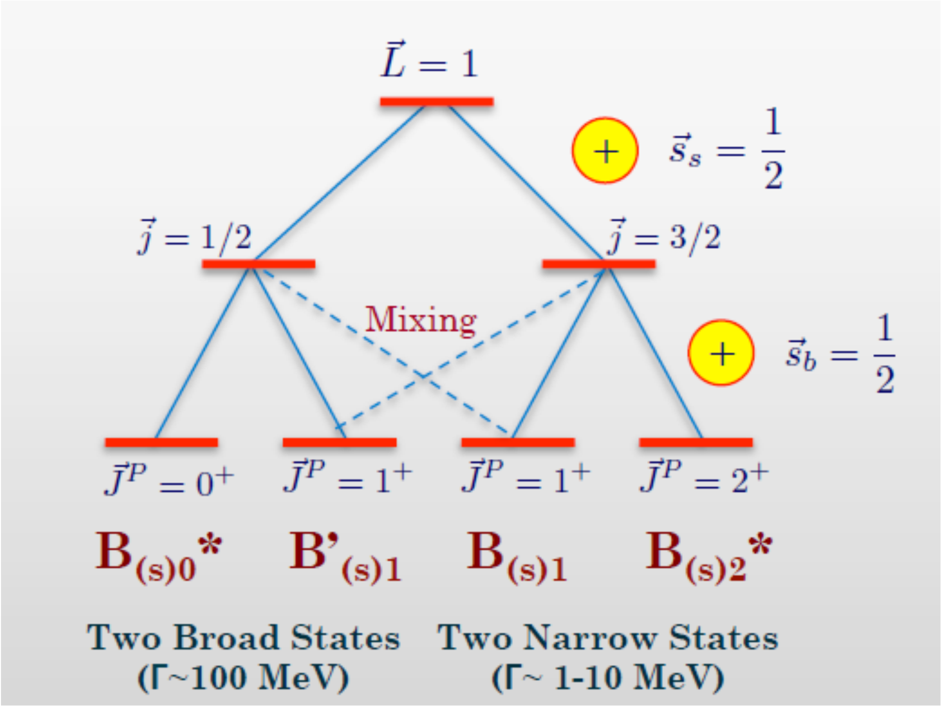
Operation conditions of the LHCb in 2012

- ❑ Beam energy **4.0** [TeV] (15 % increase of the b-barb x-section)
- ❑ Keep the luminosity at L_{inst} = **4.0 x 10^{32}** [$cm^{-2}s^{-1}$] for this year
- ❑ Average number of visible interactions per x-ing slightly higher μ = **1.6**
- ❑ Keep high data taking efficiency and quality
- ❑ HLT (High Level Trigger) input ~ **1.0 MHz**, output ~ **5 kHz** (upgraded HLT farm and revisited code)
- ❑ Collected ~ **2.1 fb^{-1}** of collision data



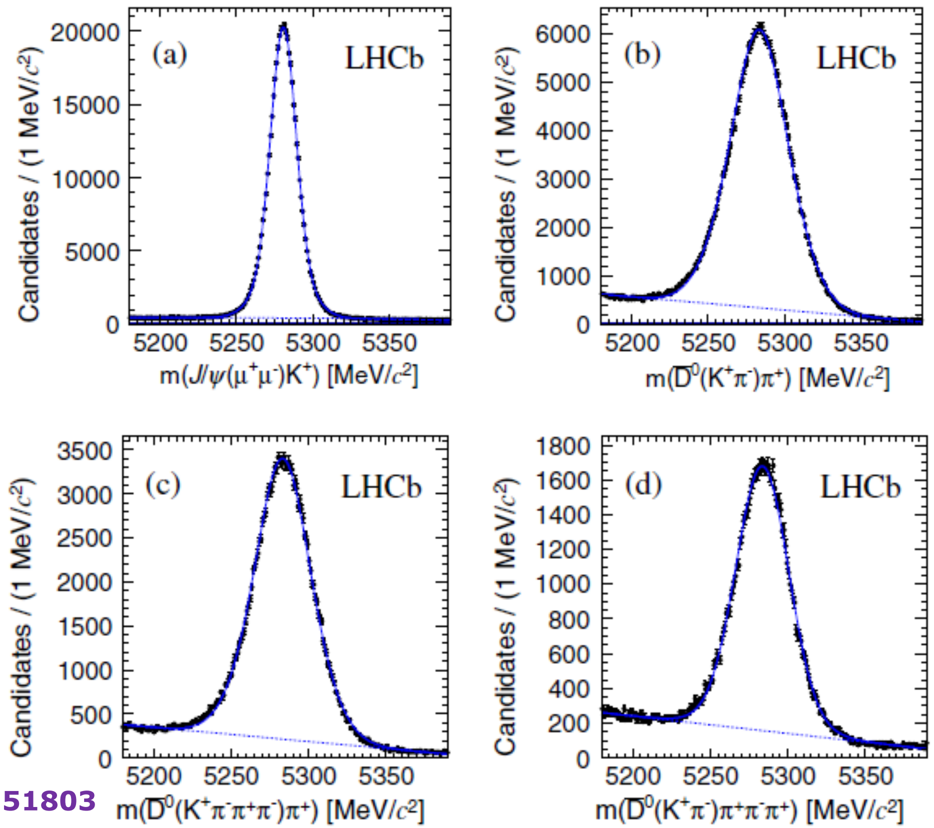
Orbitally excited (L=1) B states – Introduction

- The Heavy Quark Effective Theory (HQET) is an important tool for predicting masses of $\boldsymbol{B_{(s)}}$ mesons
    - Perturbative expansion in terms of Λ_{QCD}/m_b
- HQET can be validated by precise measurement of properties of the excited beauty mesons (both $\boldsymbol{B}$ and $\boldsymbol{B_s}$)



Study of the B_s^{**} states @ LHCb

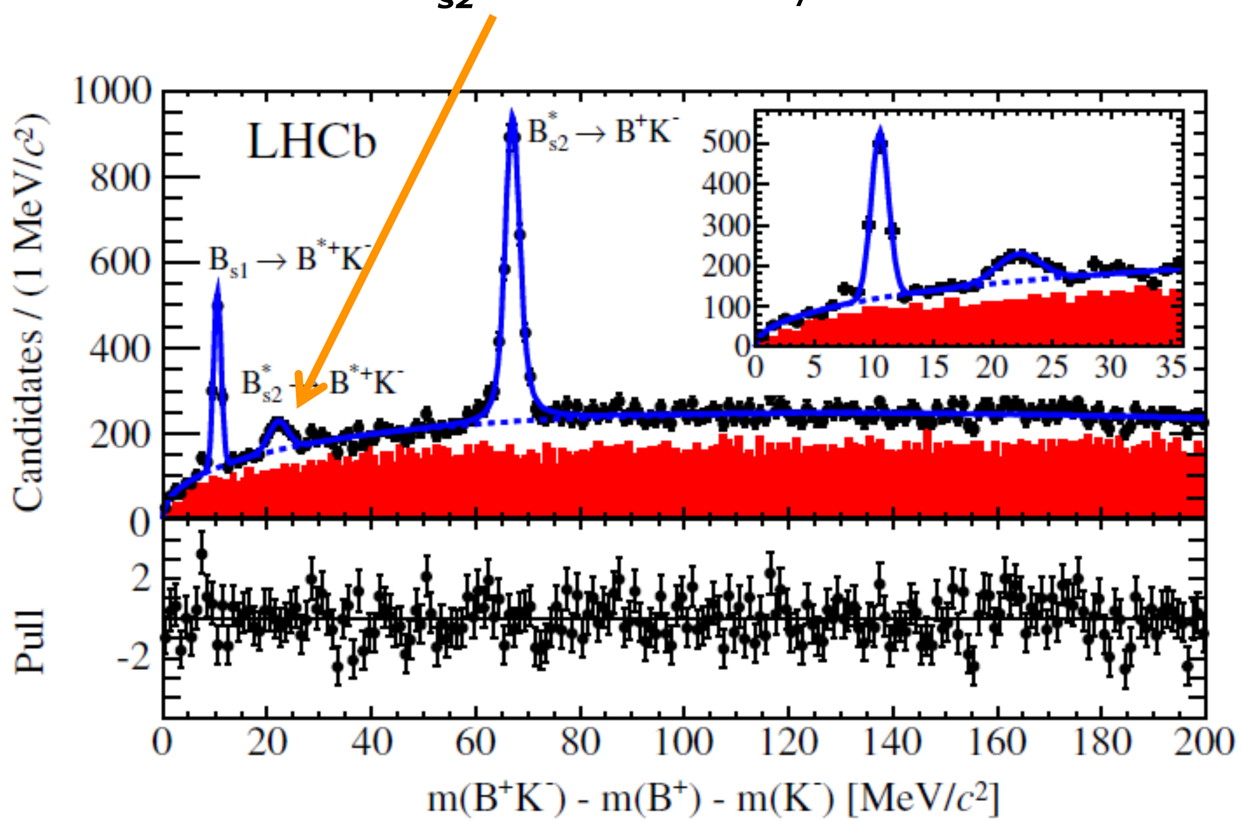
- Use BK mass spectrum to study the excited states
- ***B*$^+$** selected using a number of different decay channels
- Purity of the selected sample improved by the multivariate classifiers



LHCb - PRL 110 (2013) 151803

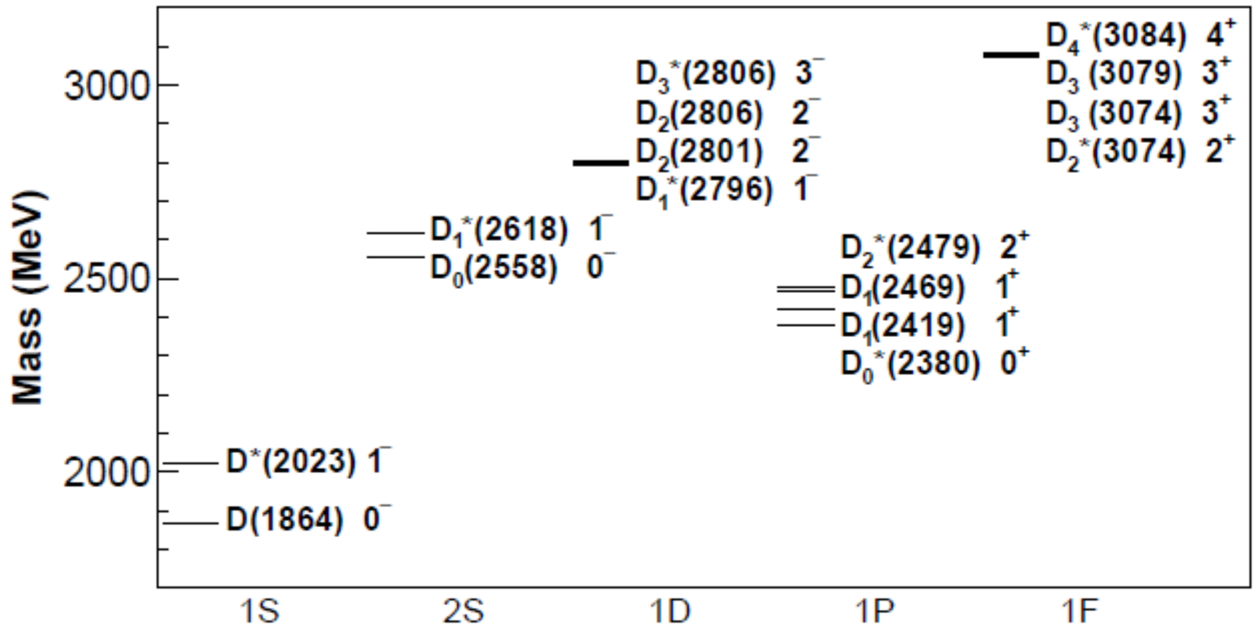
Study of the B_s^{**} states @ LHCb

- $\boldsymbol{B_{s1}}$ state confirmed by LHCb
- **World best** measurements of the $\boldsymbol{B_{s1}}$*,* $\boldsymbol{B_{s2}^{*}}$ ***and*** $\boldsymbol{B^{*}}$ masses
- **First observation** of the $\boldsymbol{B_{s2}^{*} \rightarrow B^{*+}K^{-}}$ decay



D_J meson spectroscopy – Motivation and Status

- Can be used for testing the static quark model of hadrons
- Before LHCb only a few states observed out of those predicted theoreticaly in 80s (**S. Godfrey and N. Isgur PR D32 (1985) 189**)
- Presented results obtained with 1 fb^{-1} of collision data using inclusive reactions: $pp \rightarrow D^{+}\pi^{-}X, D^{0}\pi^{+}X, D^{*+}\pi^{-}X$

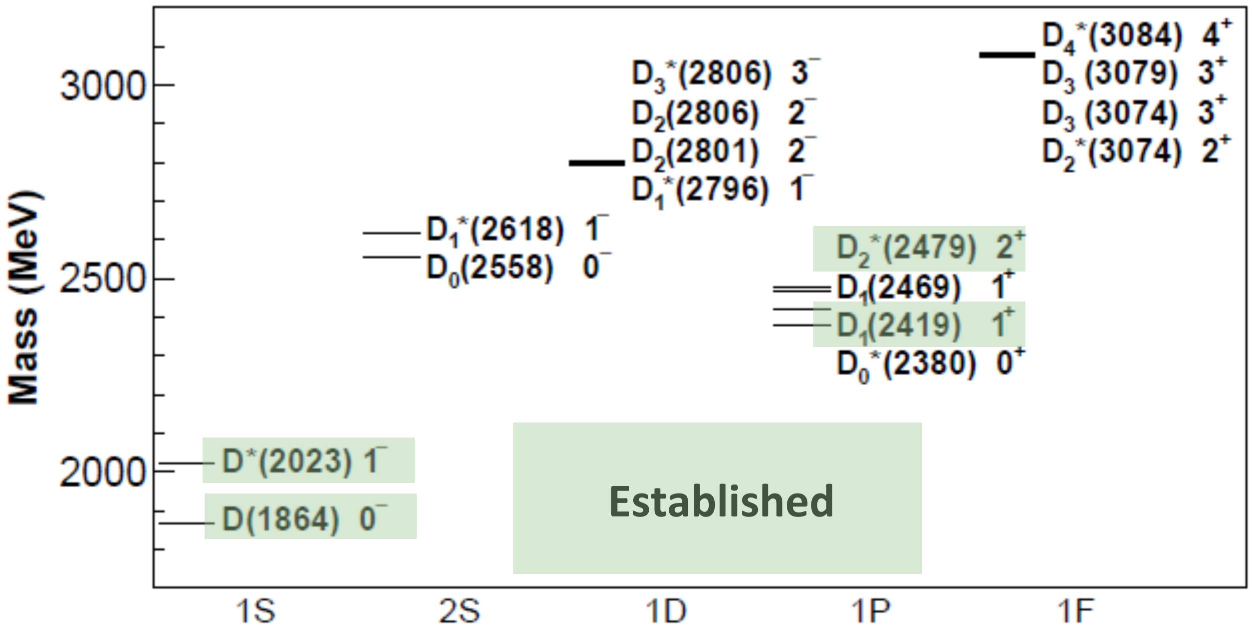


D_J meson spectroscopy – Motivation and Status

- Can be used for testing the static quark model of hadrons

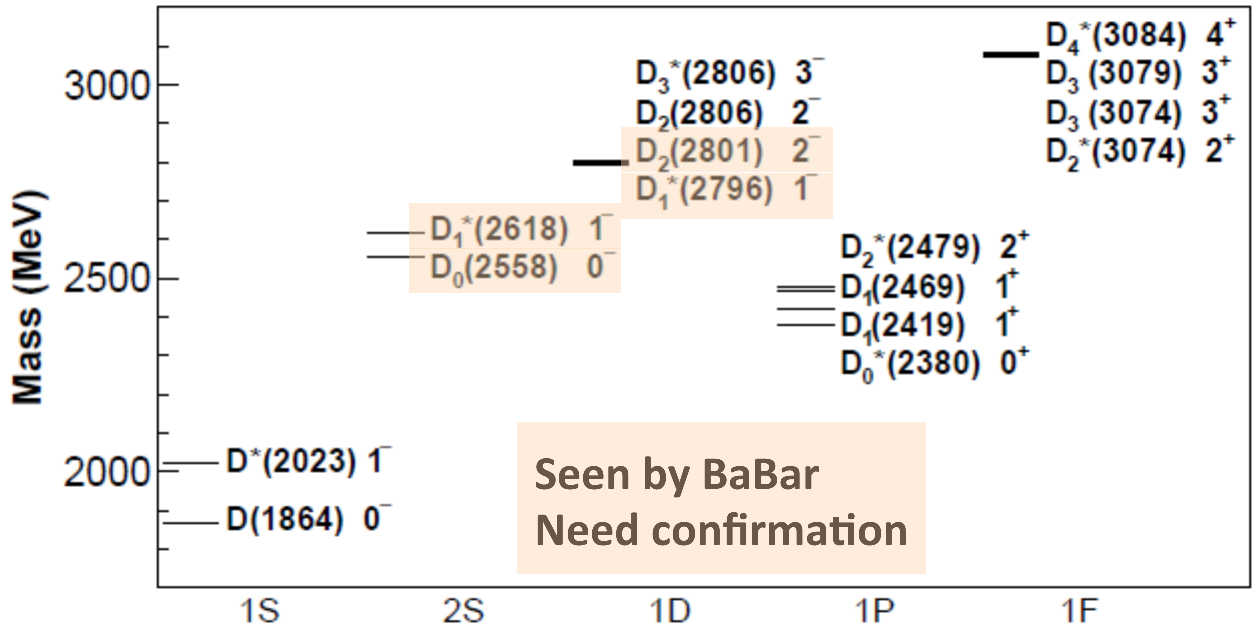
- Before LHCb only a few states observed out of those predicted theoreticaly in 80s (**S. Godfrey and N. Isgur PR D32 (1985) 189**)

- Presented results obtained with 1 fb^{-1} of collision data using inclusive reactions: $pp \to D^+\pi^- X, D^0\pi^+ X, D^{*+}\pi^- X$



D_J meson spectroscopy – Motivation and Status

- Can be used for testing the static quark model of hadrons
- Before LHCb only a few states observed out of those predicted theoreticaly in 80s (S. Godfrey and N. Isgur PR D32 (1985) 189)
- Presented results obtained with 1 fb^{-1} of collision data using inclusive reactions: $pp \to D^{+}\pi^{-}X, D^{0}\pi^{+}X, D^{*+}\pi^{-}X$

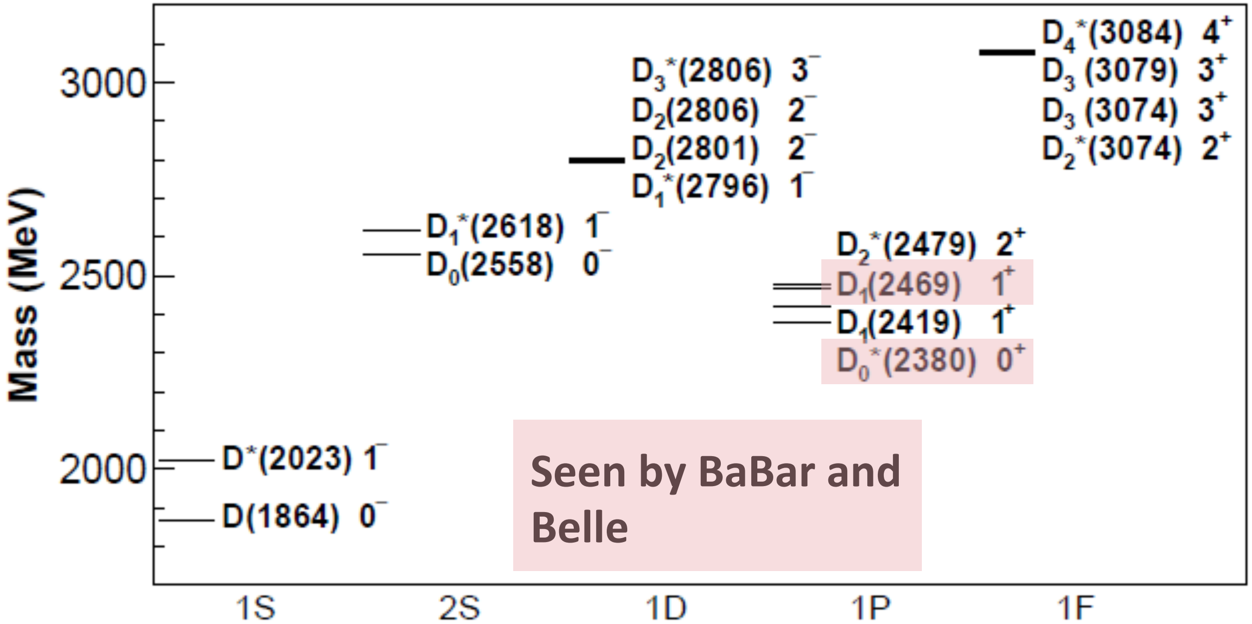


D_J meson spectroscopy – Motivation and Status

- Can be used for testing the static quark model of hadrons

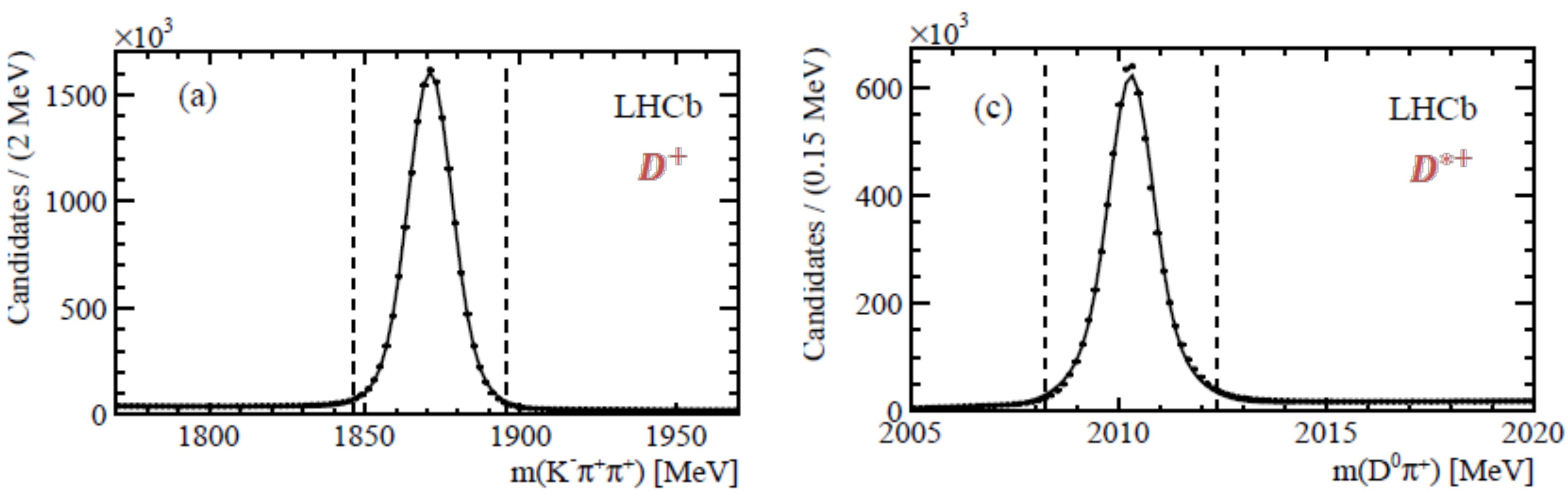
- Before LHCb only a few states observed out of those predicted theoreticaly in 80s (S. Godfrey and N. Isgur PR D32 (1985) 189)

- Presented results obtained with 1 fb^{-1} of collision data using inclusive reactions: $pp \to D^+\pi^-X, D^0\pi^+X, D^{*+}\pi^-X$



D_J meson spectroscopy – Event Selection Highlights

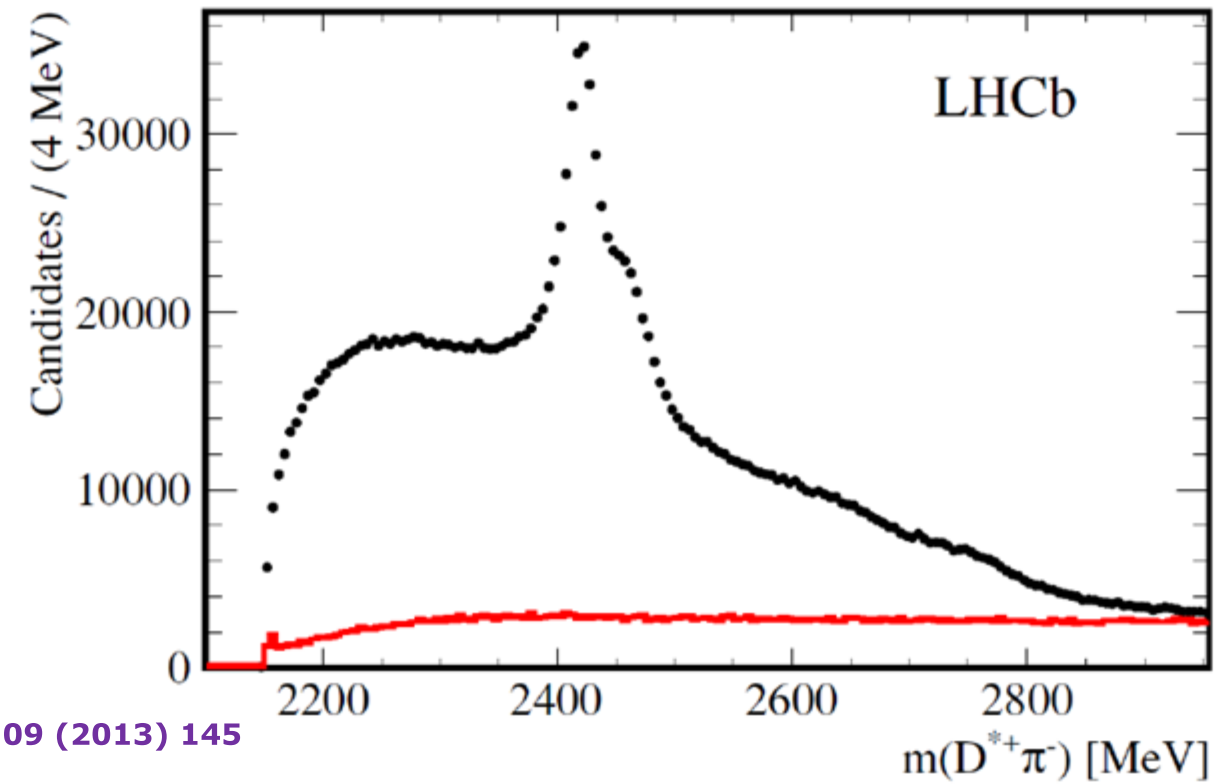
- Charmed mesons in the inclusive final states are reconstructed using
  - $D^{*+} \to D^0\pi^+, D^+ \to K^-\pi^+\pi^+, D^0 \to K^-\pi^+$
  - High quality charged tracks with *p > 3 GeV*, p_T *> 250 MeV*
  - All tracks used to reconstruct ***D*** mesons are required to have large impact parameter w.r.t the primary vertex
  - Topological cuts to reduce contamination from ***B*** decays
  - All decay products should be identified by RICH detectors



LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{*+}\pi^-$ Mass Spectra

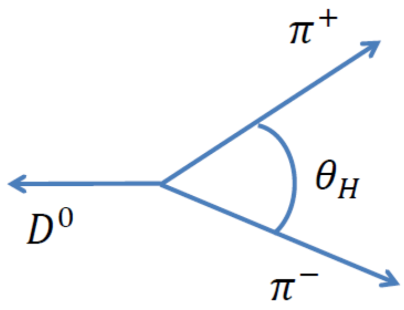
- Spectrum is dominated by signals coming from ***$D_1(2420)^0$*** and ***$D^*_2(2460)^0$***
- No structure seen in wrong-sign sample (i.e, $D^{*+}\pi^+$)
- Complicated structure seen in mass range (2600 – 2800) *MeV*



LHCb - JHEP 09 (2013) 145

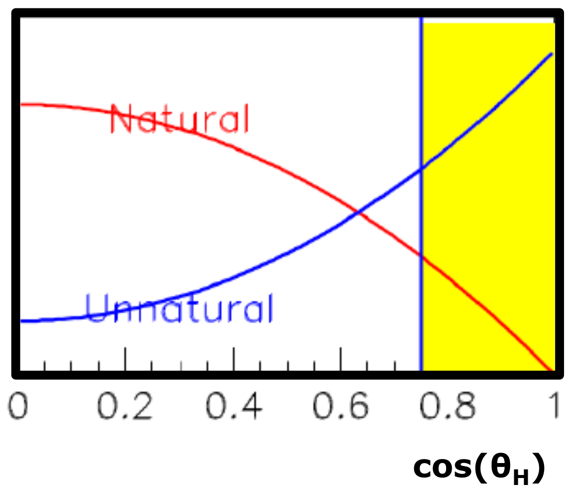
D_J meson spectroscopy – $D^{*+}\pi^-$, Helicity Angle θ_H

- Using the helicity angle information spin-parity analysis is possible by fitting the $D^{*+}\pi^-$ mass spectra

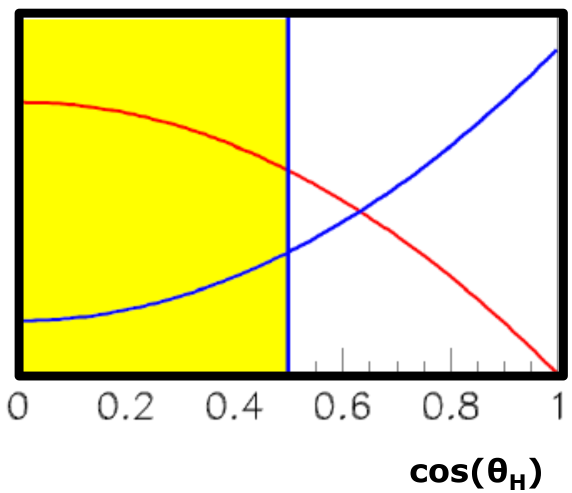


- Natural spin-parity for states with J^P = 0^+, 1^-, 2^+
  - Expect the angular distribution to be ~ **sin(θ_H)**
- Unnatural spin-parity for states with J^P = 0^-, 1^+, 2^-
  - Expect the angular distribution to be ~ **1 + h·cos(θ_H)**

Enhanced unnatural parity sample |cos(θ_H)| > 0.75

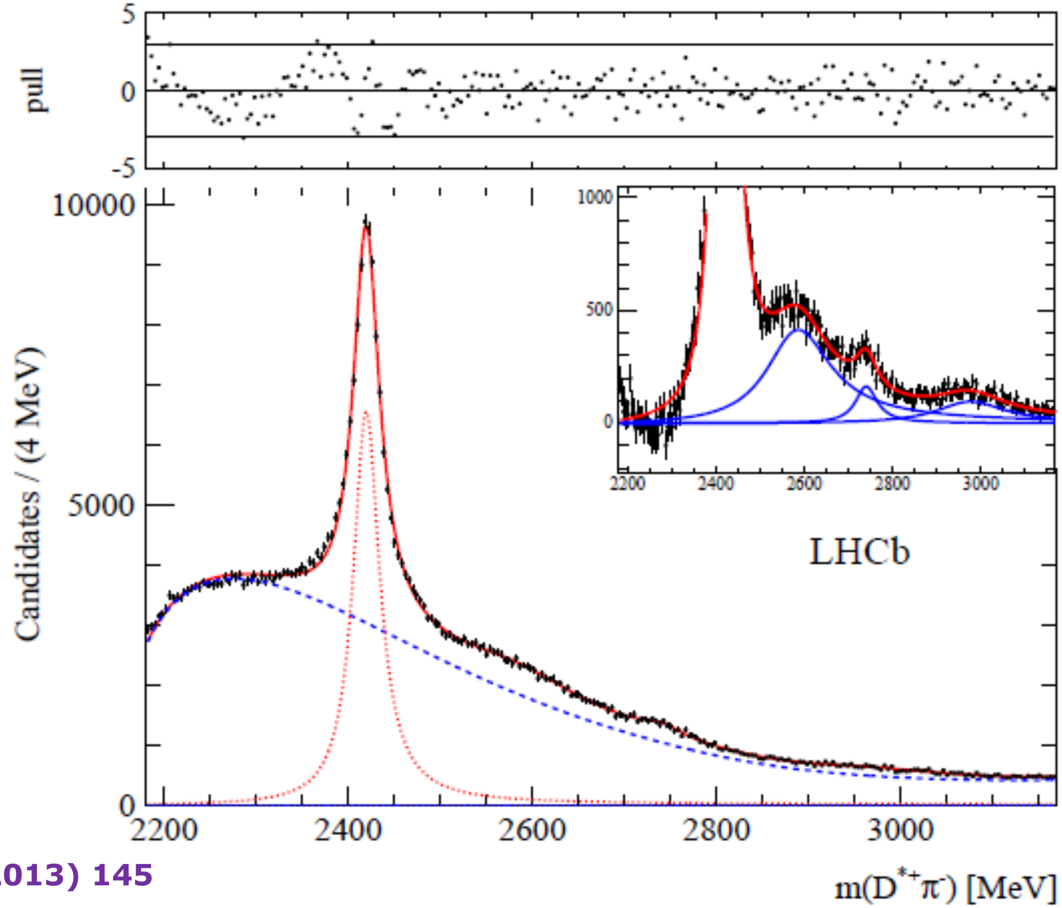


Enhanced natural parity sample | cos(θ_H)| < 0.75



D_J meson spectroscopy – $D^{*+}\pi^-$, Unnatural Parity Sample

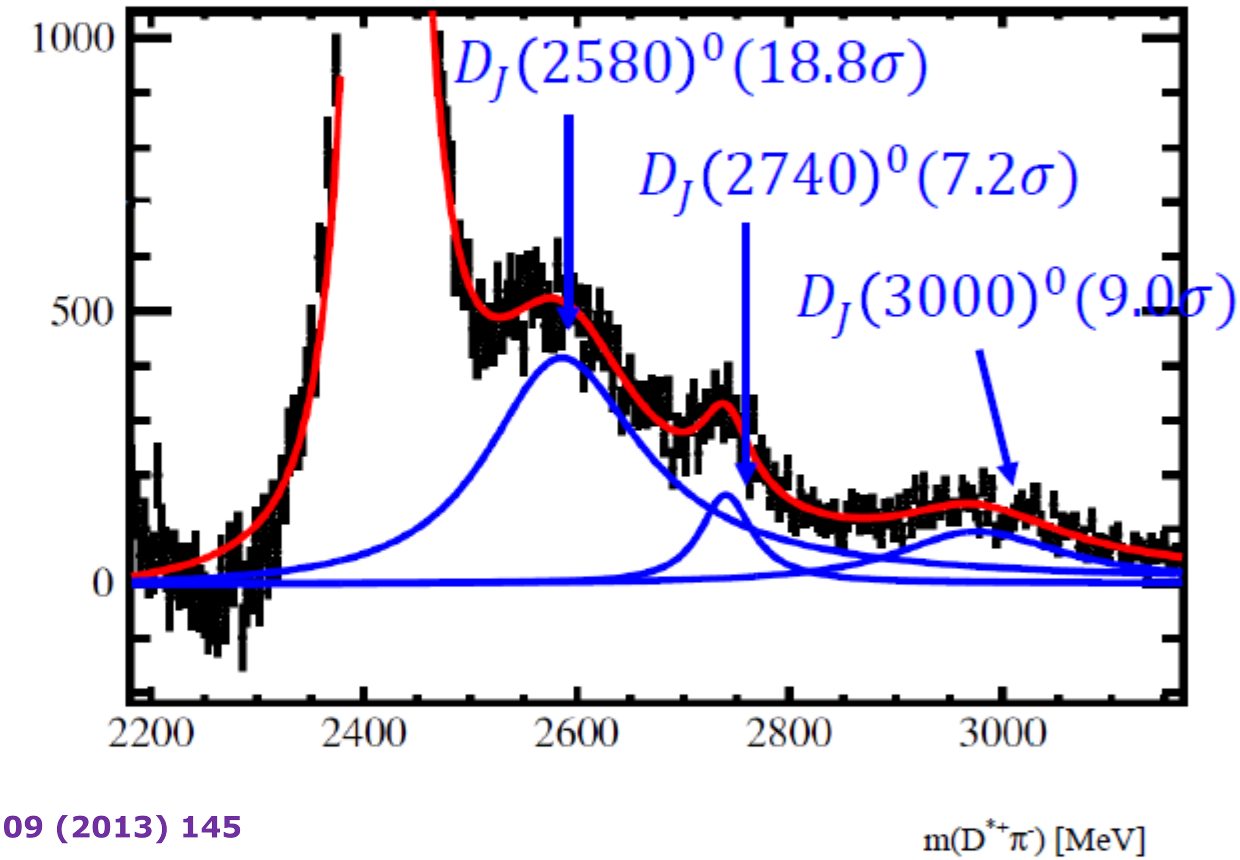
- Clear $D_1(2420)^0$ signal, contribution from $D^*_2(2460)^0$ highly suppressed
- New structures observed: $D_J(2420)^0$, $D_J(2740)^0$ and $D_J(3000)^0$



LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{*+}\pi^-$, Unnatural Parity Sample

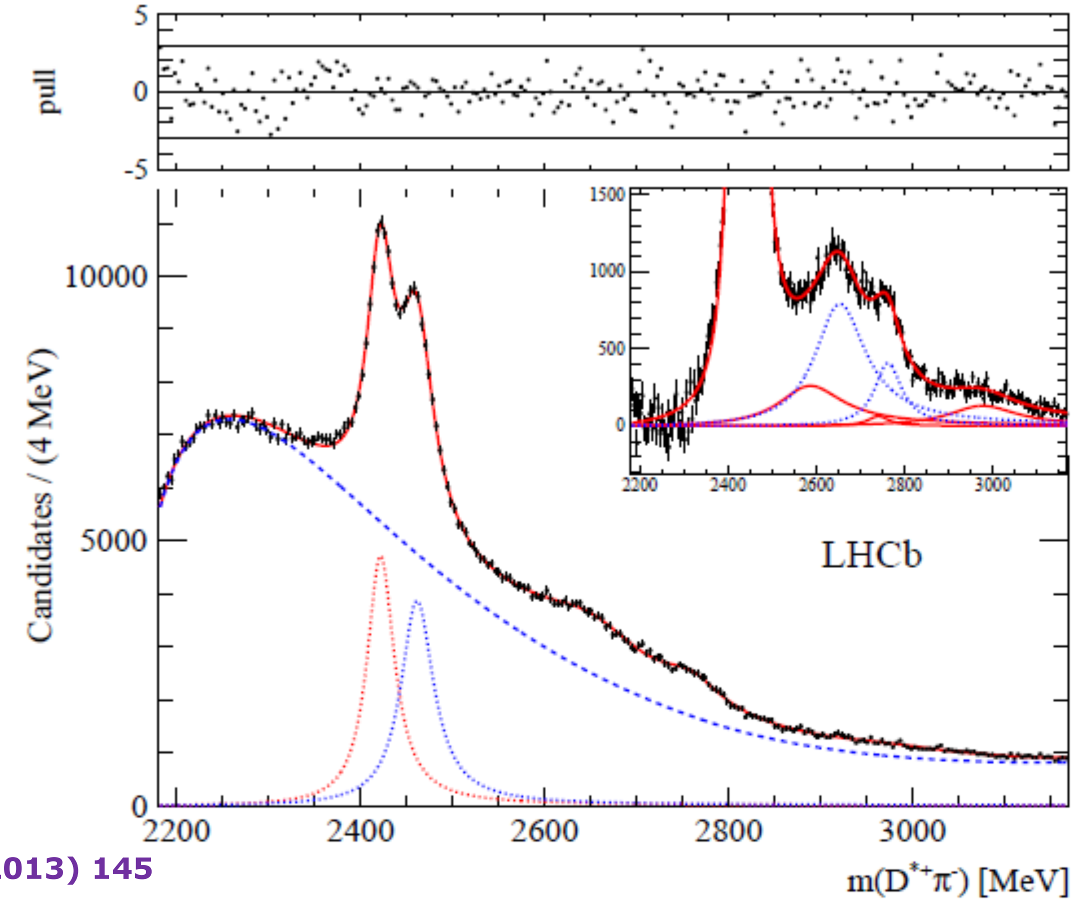
- Clear $D_1(2420)^0$ signal, contribution from $D^*_2(2460)^0$ highly suppressed
- New structures observed: $D_J(2580)^0$, $D_J(2740)^0$ and $D_J(3000)^0$



LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{*+}\pi^-$, Natural Parity Sample

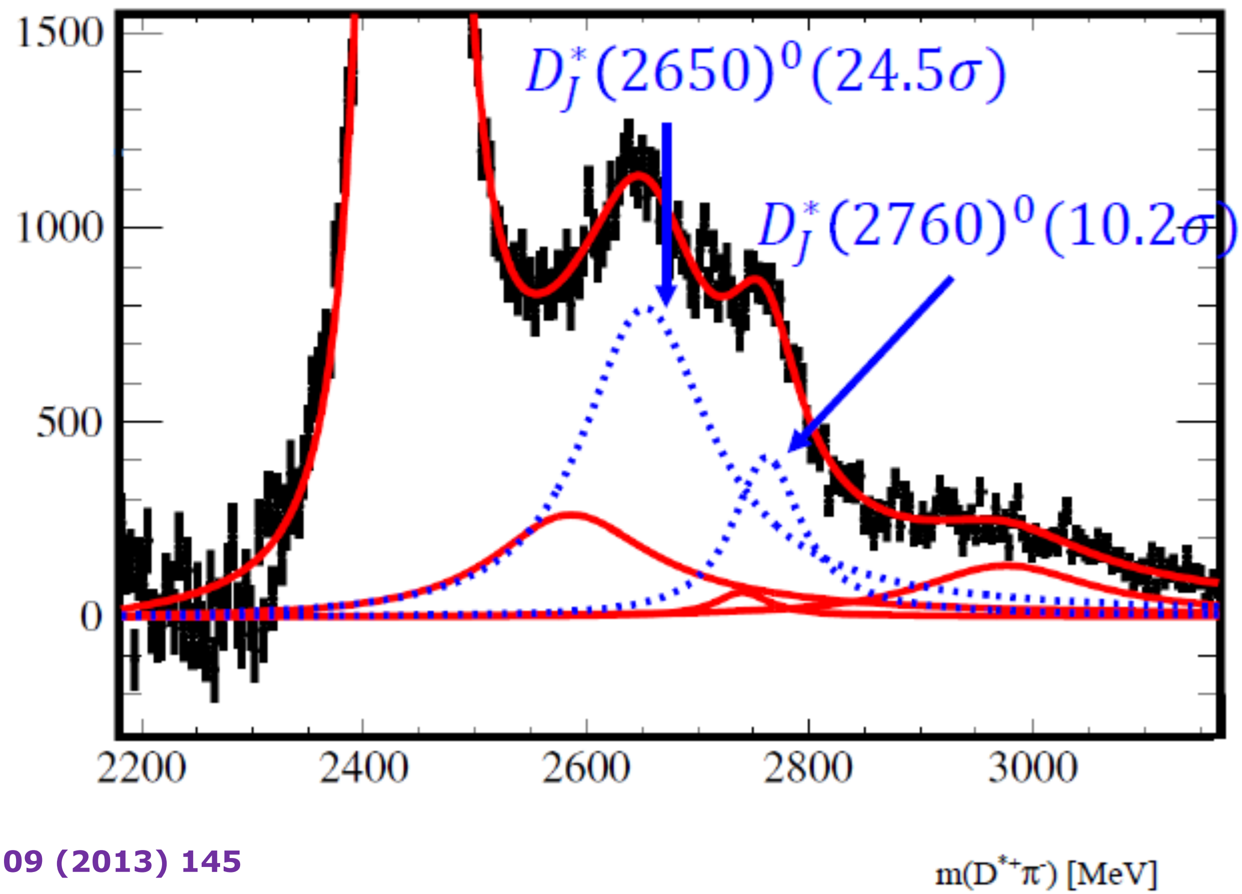
- Expect both parity types, clear signal from $D_1(2420)^0$ and $D^*_2(2460)^0$
- New structures observed: $D^*_J(2650)^0$ and $D^*_J(2760)^0$



LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{*+}\pi^-$, Natural Parity Sample

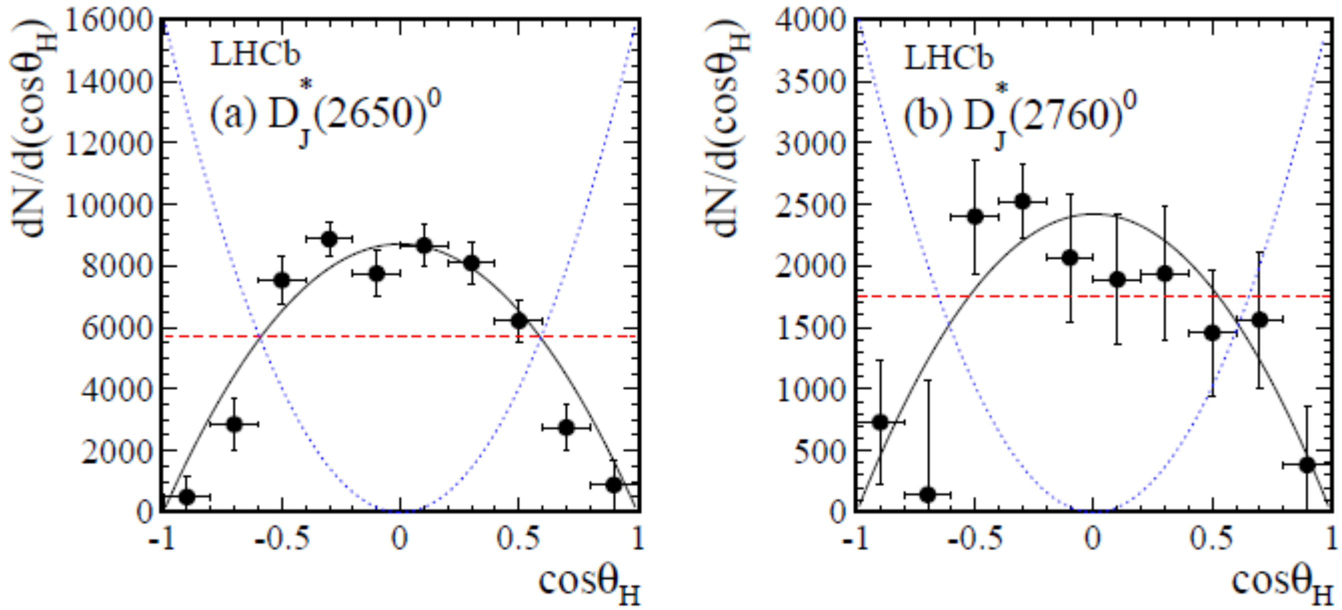
- Expect both parity types, clear signal from $D_1(2420)^0$ and $D^*_2(2460)^0$
- New structures observed: $D^*_J(2650)^0$ and $D^*_J(2760)^0$



LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{*+}\pi^-$, Angular Analysis (1)

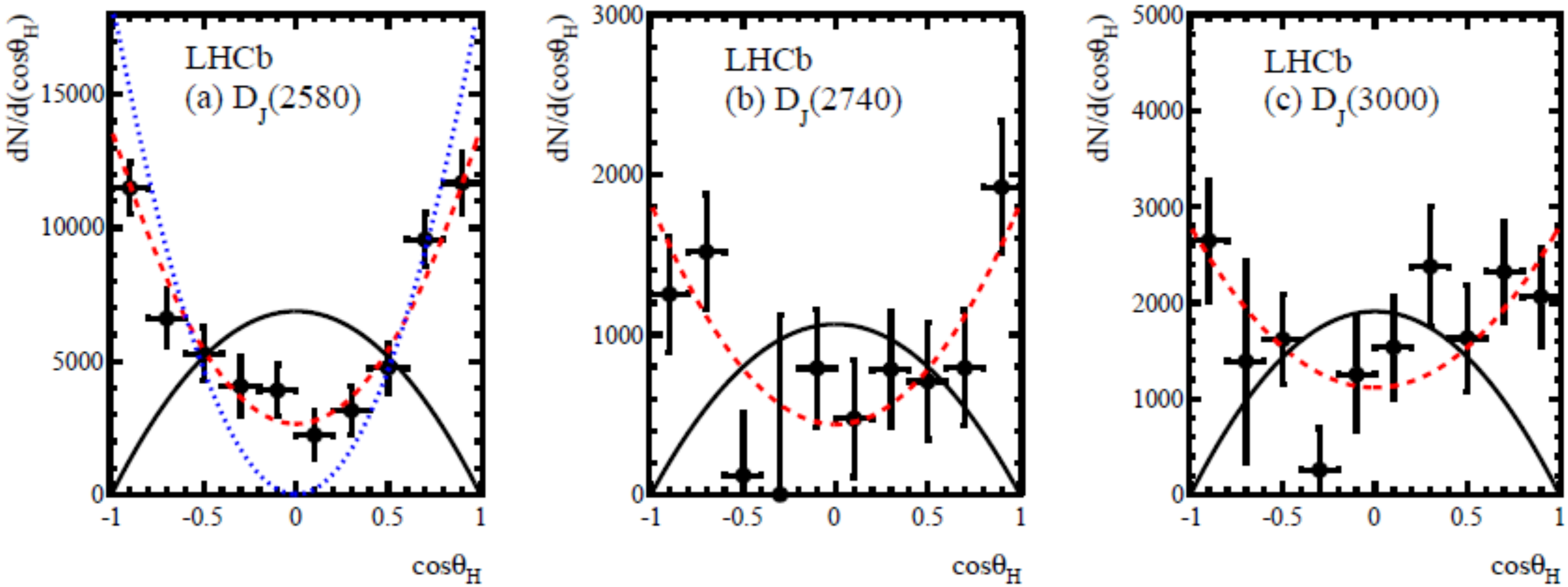
- New states $D^*_J(2650)^0$ and $D^*_J(2760)^0$ consistent with **natural** parity hypothesis



LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{*+}\pi^-$, Angular Analysis (2)

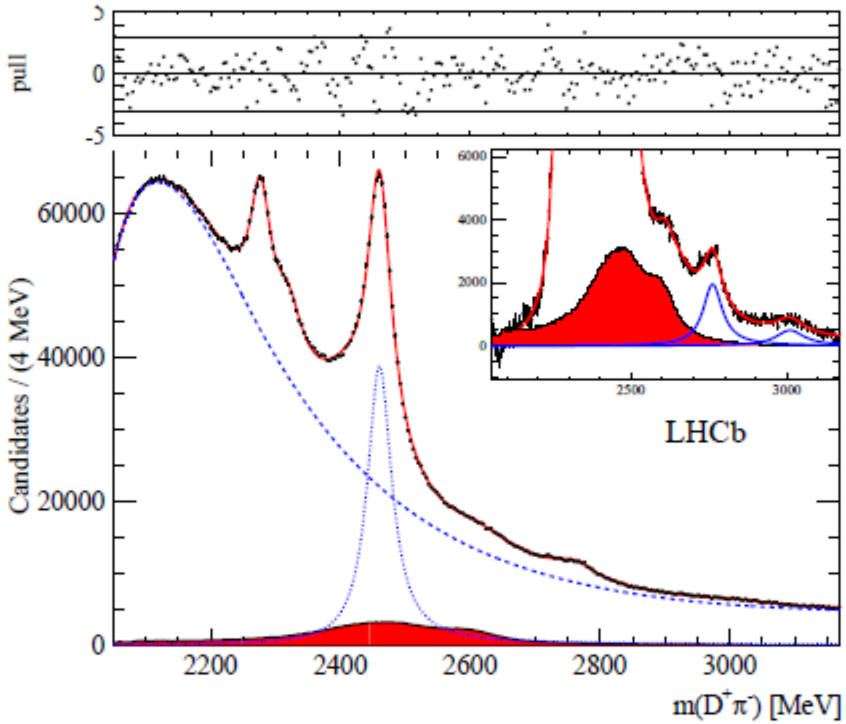
- New states ***$D_J(2420)^0$, $D_J(2740)^0$*** and ***$D_J(3000)^0$*** consistent with **unnatural** parity hypothesis

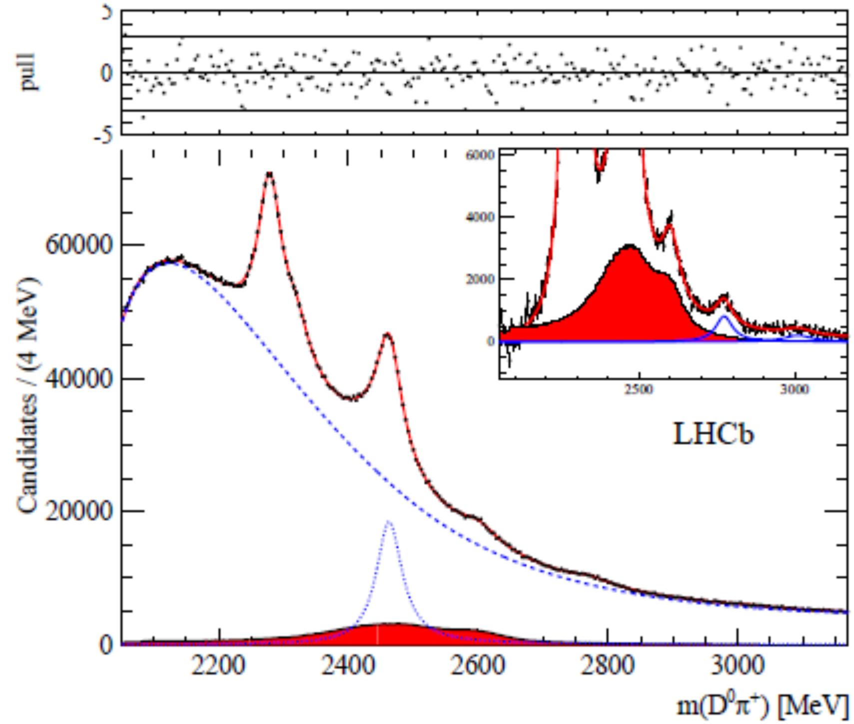


LHCb - JHEP 09 (2013) 145

D_J meson spectroscopy – $D^{0/+}\ \pi^{+/-}$ Mass Spectra

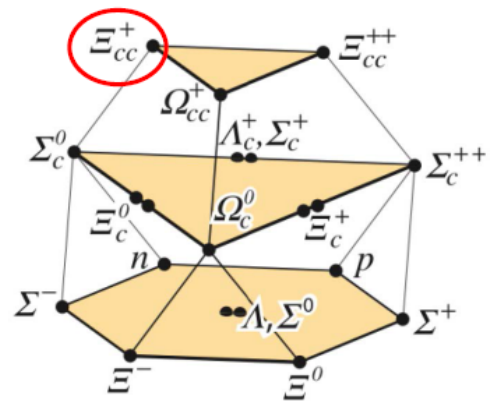
- Contribution from natural parity states only
- Significant cross-feed from excited resonances decaying to $D^*\pi$ final state
- Observed $D^*_J(2760)^{+/0}$ decays to $D^{0/+}\ \pi^{+/-}$
- In order to obtain good quality fit to the mass spectrum a broad structure around 3000 MeV/c^2 is added and labeled as $D^*_J(3000)^{+/0}$





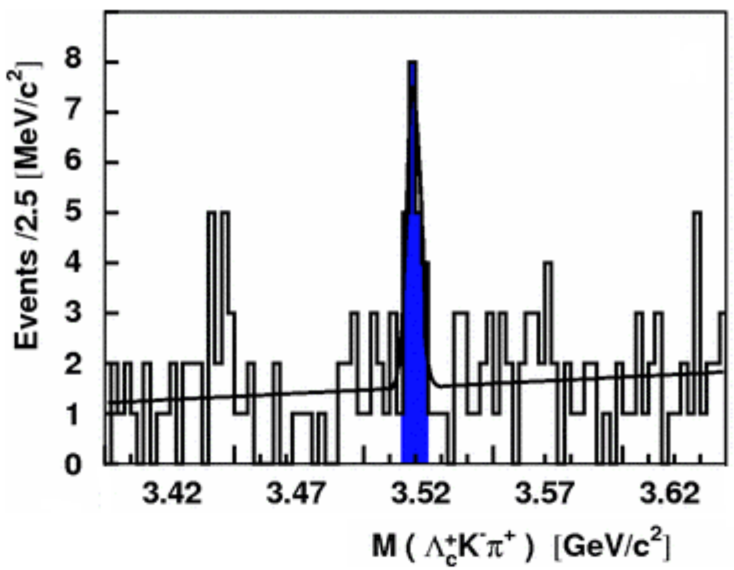
LHCb - JHEP 09 (2013) 145

Searches for doubly charmed Ξ^+_{cc} baryon - Status



- State predicted by the quark model
- A number of theoretical predictions exist
  - mass m(Ξ^+_{cc}) ~ (3500 – 3700) *MeV/c²*
  - life time τ (Ξ^+_{cc}) ~ (100 - 250) *fs*, i.e., weak decay
  - predicted cross-section @ LHC $\sigma \sim 10^2$ *nb*

- Unconfirmed observation done by **Selex** (not seen by Belle nor Babar)
- Two decay channels: $\Lambda^+_c K^- \pi^+$ and **pD^+K^-**
- Results published in two papers
  - **PRL 89 (2002) 112001**, **PLB 628 (2005) 18**
  - mass m(Ξ^+_{cc}) = 3519 *MeV/c²*
  - life time τ (Ξ^+_{cc}) = 33 *fs @ 90% C.L.*



Searches for doubly charmed Ξ^{+}_{cc} baryon – LHCb Results (1)

- Look for it in the $\Lambda^{+}_{c}K^{-}\pi^{+}$ decay channel with $\Lambda^{+}_{c} \rightarrow pK^{-}\pi^{+}$
- Construct an **observable R** (cross sections ration) using Λ^{+}_{c} decay as a control channel:

$$R = \frac{\sigma(\Xi^{+}_{cc}) Br(\Xi^{+}_{cc} \rightarrow \Lambda^{+}_{c} K^{-} \pi^{+})}{\sigma(\Lambda^{+}_{c})}$$

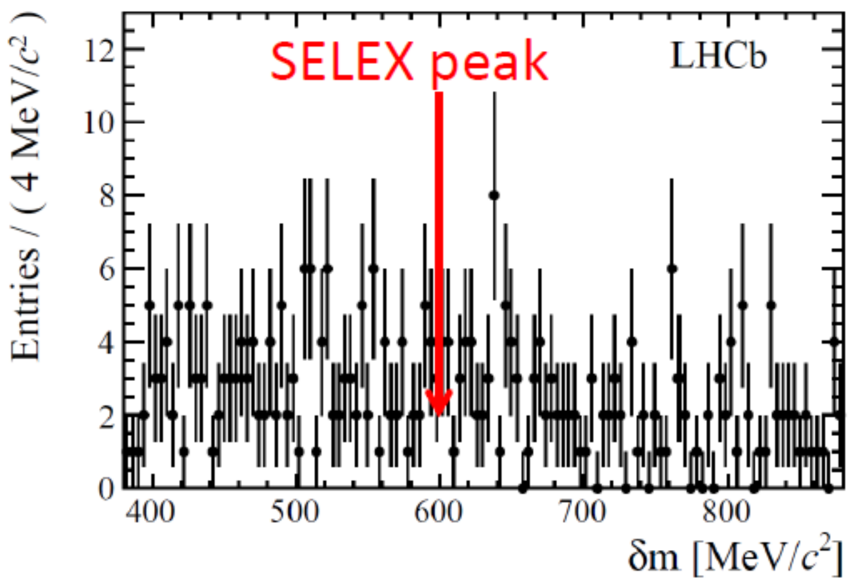
- Assume $Br(\Xi^{+}_{cc} \rightarrow \Lambda^{+}_{c} K^{-} \pi^{+}) \approx Br(\Lambda^{+}_{c} \rightarrow pK^{-}\pi^{+}) \approx 0.05$
- Expected R values @ LHCb in range (10^{-5} - 10^{-4})
- Collision data used for the analysis collected in 2011 @ $\sqrt{s}$ = 7 TeV
    - Data sample corresponding to 0.65 fb^{-1}
    - Relevant trigger lines operational only for half of the year

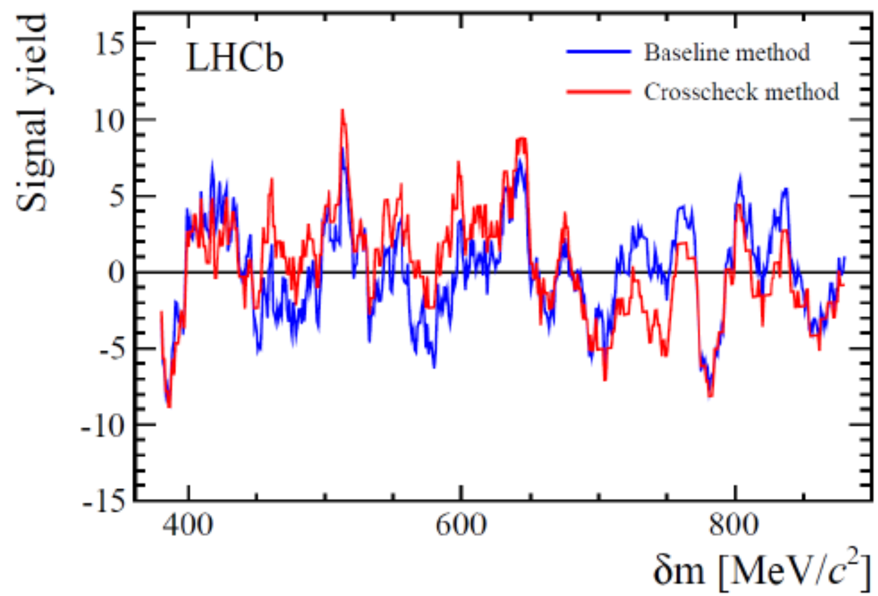
Searches for doubly charmed Ξ^{+}_{cc} baryon – LHCb Results (2)

- In order to enhance resolution use mass difference variable δm

$$\delta m = m(\Lambda_c^+ K^- \pi^+) - m(\Lambda_c^+) - m(K^-) - m(\pi^+)$$

- Used two independent methods to estimate yield
- **No significant signal observed**

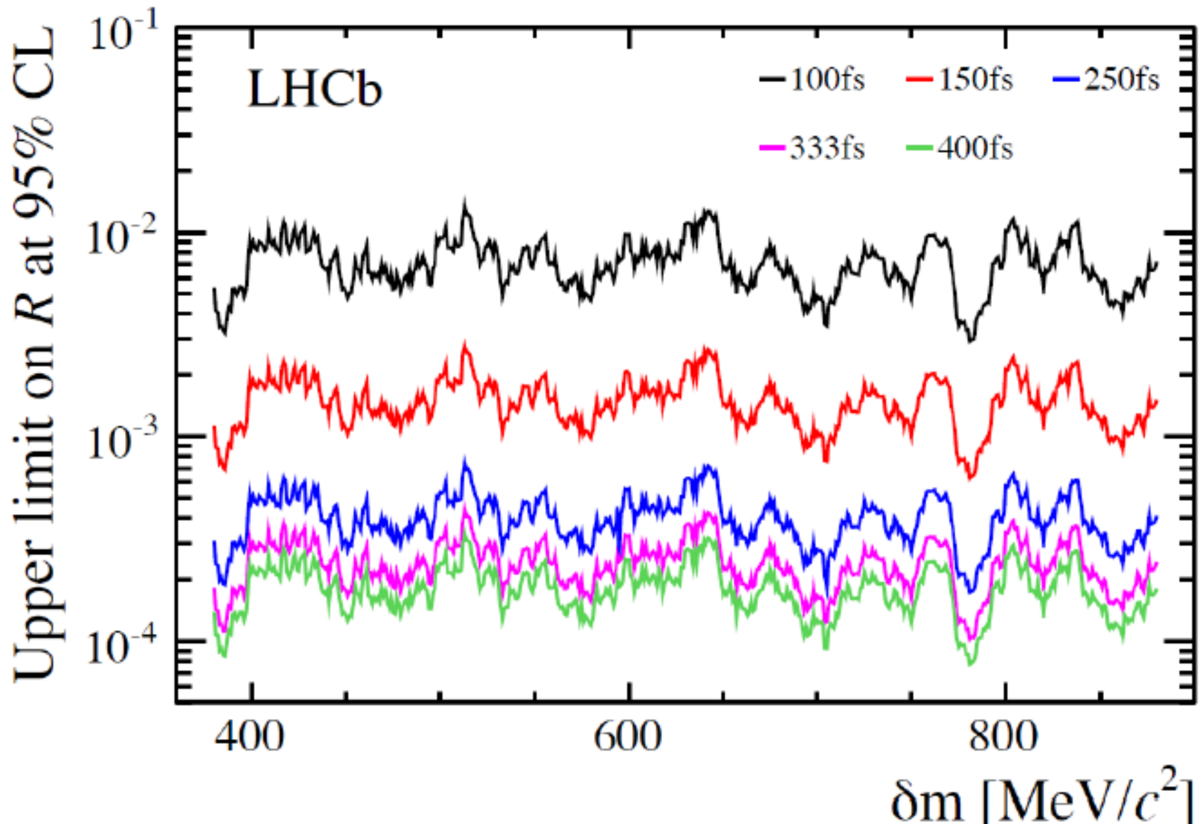




LHCb - JHEP 1312 (2013) 090

Searches for doubly charmed Ξ^{+}_{cc} baryon – LHCb Results (3)

- Upper limits on R variable as a function of the δm calculated
- **Strong dependence** on lifetime value hypothesis



LHCb - JHEP 1312 (2013) 090

Summary

- Higly excited B states seen @ LHCb
- First observation of the $B_{s2}^{*} \rightarrow B^{*+}K^{-}$ decay channel
- **LHCb** made Very important contribution to charm spectroscopy
- Four new states observed in the D_J sector
- Work on increasing the sensitivity with larger data sample ongoing
- No significant signal observed in Ξ^{+}_{cc} baryon searches
- Appropriate upper limits have been calculated