Studies of the properties and decays of the B_c^+ meson at LHCb

Niels Tuning

on behalf of the LHCb collaboration

18 July 2013
EPS2013, Stockholm

Outline

1) Overview B_c^+ measurements at LHCb
2) LHCb detector
3) Recent measurements
   - ❑ $B^+_c \to J/\psi K^+$
   - ❑ $B^+_c \to B_s^0 \pi^+$

PDG poorly filled ...

$B_c^\pm$ $I(J^P) = 0(0^-)$ *I, J, P* need confirmation.

Quantum numbers shown are quark-model predictions.

Mass m = 6.277 ± 0.006 GeV , (S = 1.6)

Mean life τ = $(45.3 \pm 4.1) \times 10^{-14}$ s

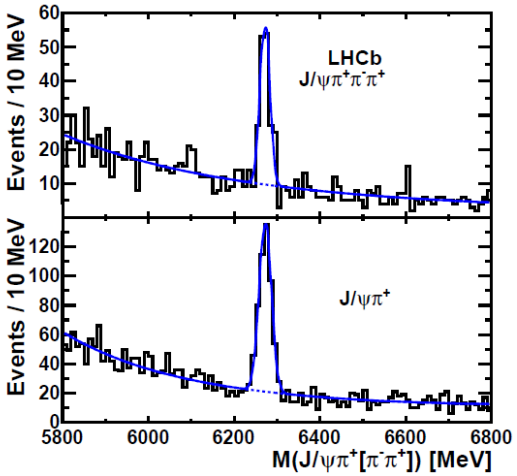
B_c^+ **DECAY MODES** × $B(\bar{b} \to B_c)$

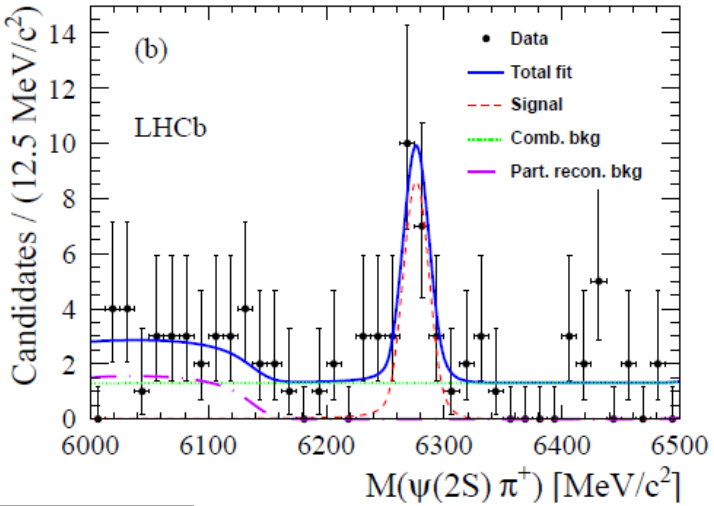
B_c^- modes are charge conjugates of the modes below.

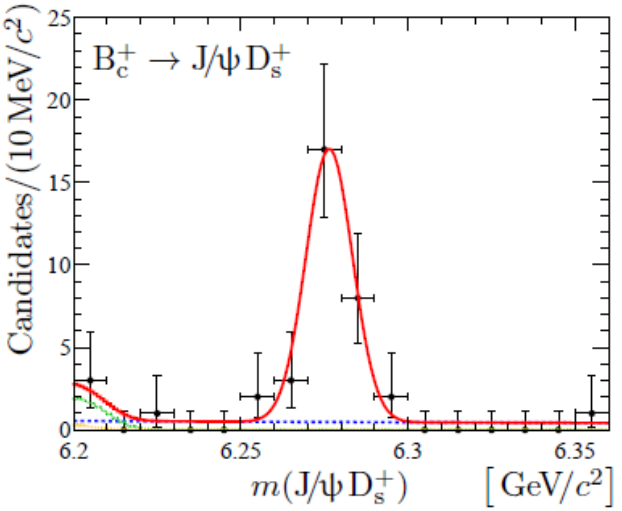
Γ_i	Mode	Fraction (Γ_i / Γ)	Scale factor/ Confidence level	p (MeV/c)
Γ_1	$J/\psi(1S)\ l^+\ \nu_l$ anything	$(5.2^{+2.4}_{-2.1}) \times 10^{-5}$		—
Γ_2	$J/\psi(1S)\ \pi^+$	$<8.2 \times 10^{-5}$	CL=90%	2372
Γ_3	$J/\psi(1S)\ \pi^+\ \pi^+\ \pi^-$	$<5.7 \times 10^{-4}$	CL=90%	2352
Γ_4	$J/\psi(1S)\ a_1(1260)$	$<1.2 \times 10^{-3}$	CL=90%	2171
Γ_5	$D^*(2010)^+\ \overline{D}^0$	$<6.2 \times 10^{-3}$	CL=90%	2468

B_c^+ observations at LHCb

3)	Observation of $B^+_c \to J/\psi D^+_s$ and $B^+_c \to J/\psi D_s^{+*}$ decays	arXiv:1304.4530 PRD87 (2013) 112012
4)	Observation of the decay $B^+_c \to \psi(2S)\pi^+$	arXiv:1303.1737 PRD87 (2013) 071103
5)	Measurements of B^+_c production and mass with the $B^+_c \to J/\psi\pi^+$ decay	arXiv:1209.5634 PRL109 (2012) 232001
6)	First observation of the decay $B^+_c \to J/\psi\pi^+\pi^-\pi^+$	arXiv:1204.0079 PRL108 (2012) 251802







$$\frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 2.41 \pm 0.30 \pm 0.33$$

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 2.90 \pm 0.57 \pm 0.24$$

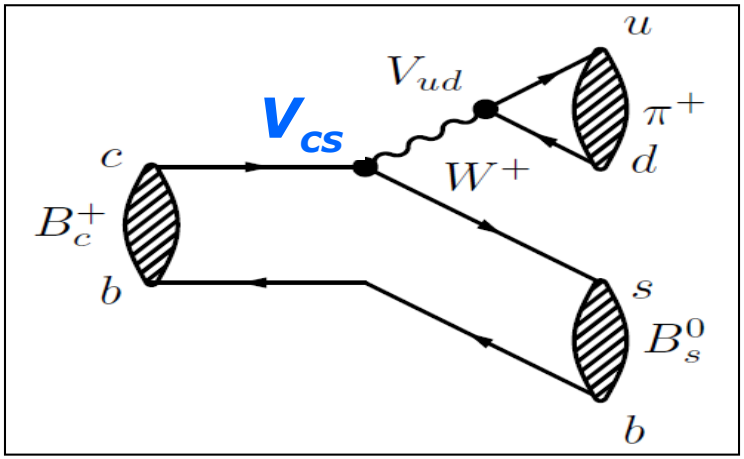
$$\frac{\mathcal{B}(B_c^+ \to \psi(2S)\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 0.250 \pm 0.068\,(\text{stat}) \pm 0.014\,(\text{syst}) \pm 0.006\,(\mathcal{B})$$

Single world best mass measurement: $m_{B_c^+} = 6276.28 \pm 1.44\,(\text{stat}) \pm 0.36\,(\text{syst})\ \text{MeV}/c^2$ [3]

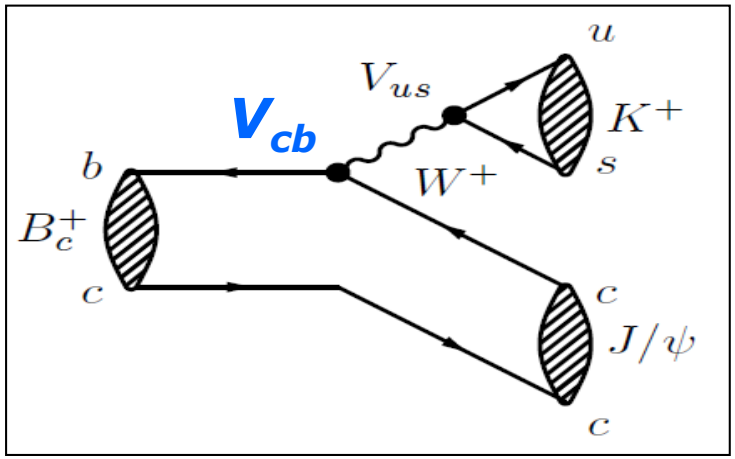
B_c^+ observations at LHCb

√ 1)	Observation of the decay $B^+_c \to B_s^0 \pi^+$	LHCb-PAPER-2013-044
√ 2)	First observation of the decay $B^+_c \to J/\psi K^+$	arXiv:1306.6723
5)	Observation of $B^+_c \to J/\psi D^+_s$ and $B^+_c \to J/\psi D_s^{+*}$ decays	arXiv:1304.4530 PRD87 (2013) 112012
6)	Observation of the decay $B^+_c \to \psi(2S)\pi^+$	arXiv:1303.1737 PRD87 (2013) 071103
7)	Measurements of B^+_c production and mass with the $B^+_c \to J/\psi\pi^+$ decay	arXiv:1209.5634 PRL109 (2012) 232001
8)	First observation of the decay $B^+_c \to J/\psi\pi^+\pi^-\pi^+$	arXiv:1204.0079 PRL108 (2012) 251802

Two tree diagrams:

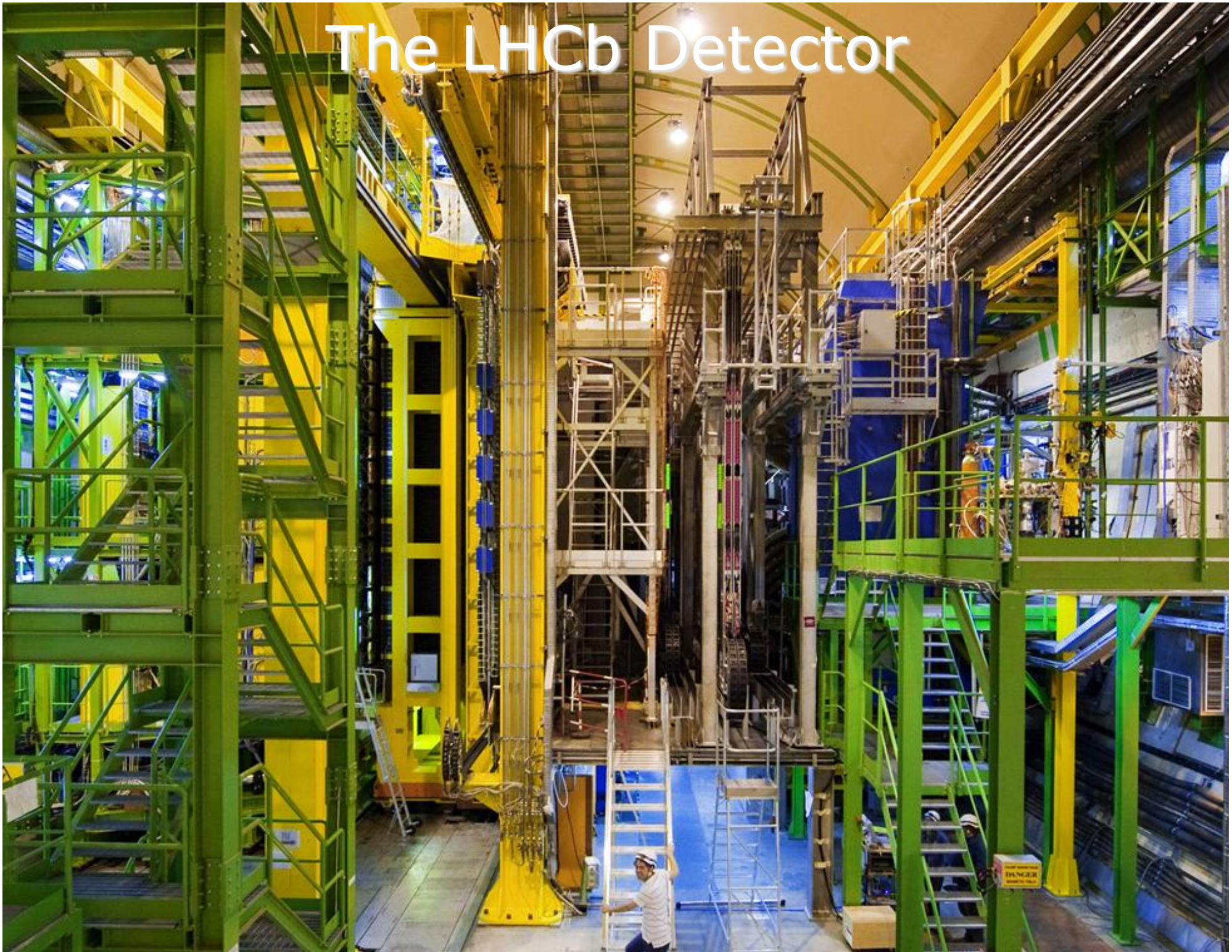


c→s

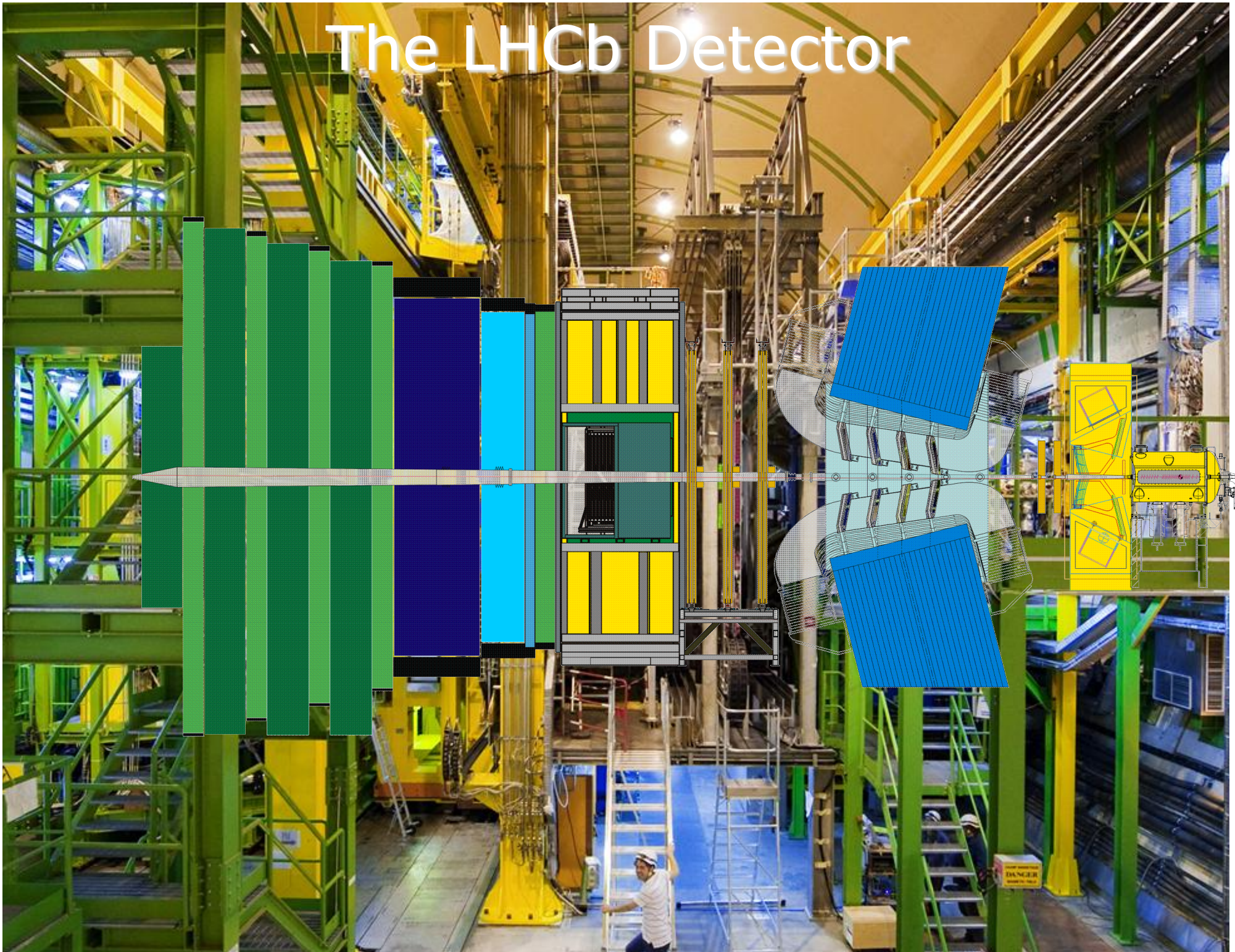


b→c

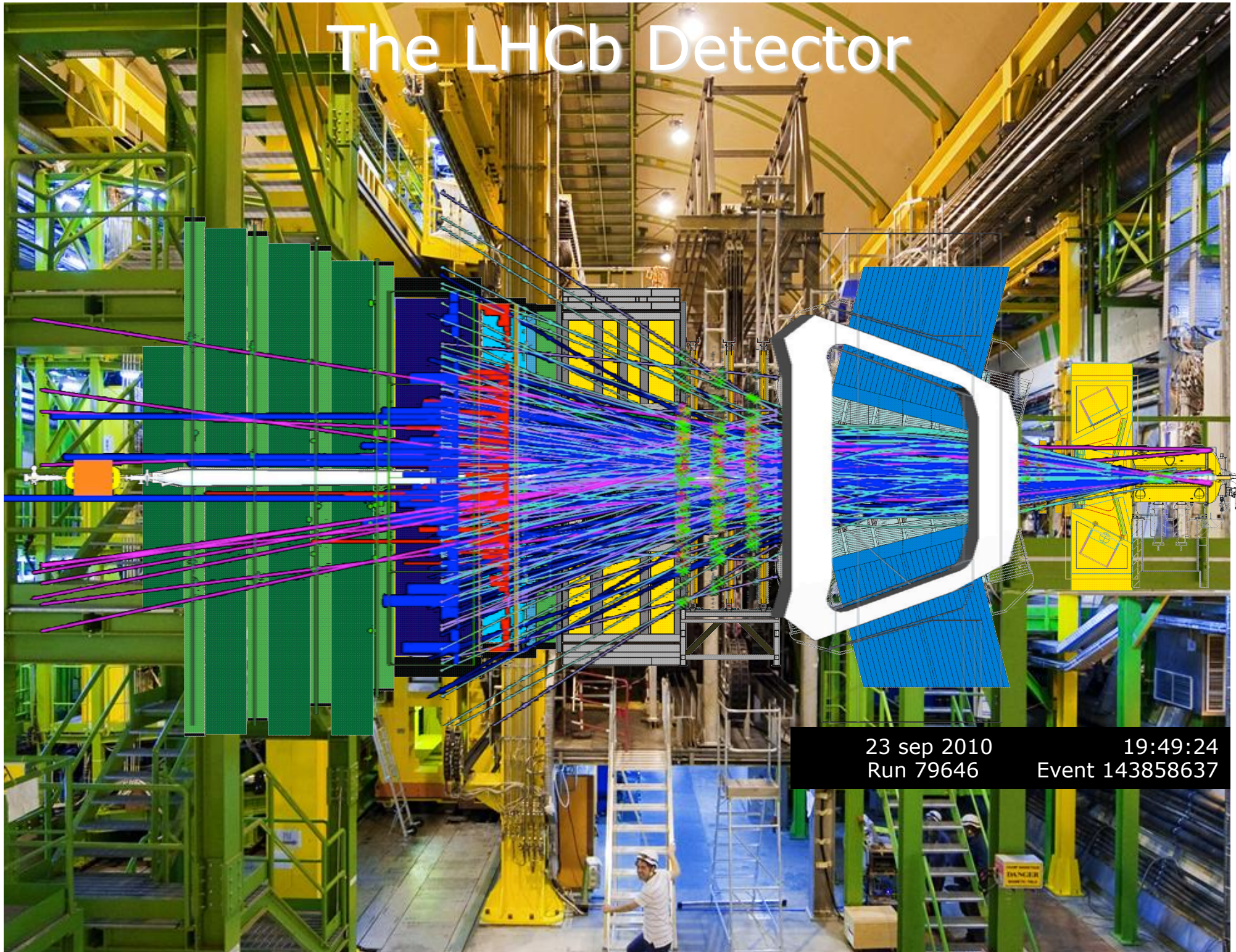
The LHCb Detector



The LHCb Detector



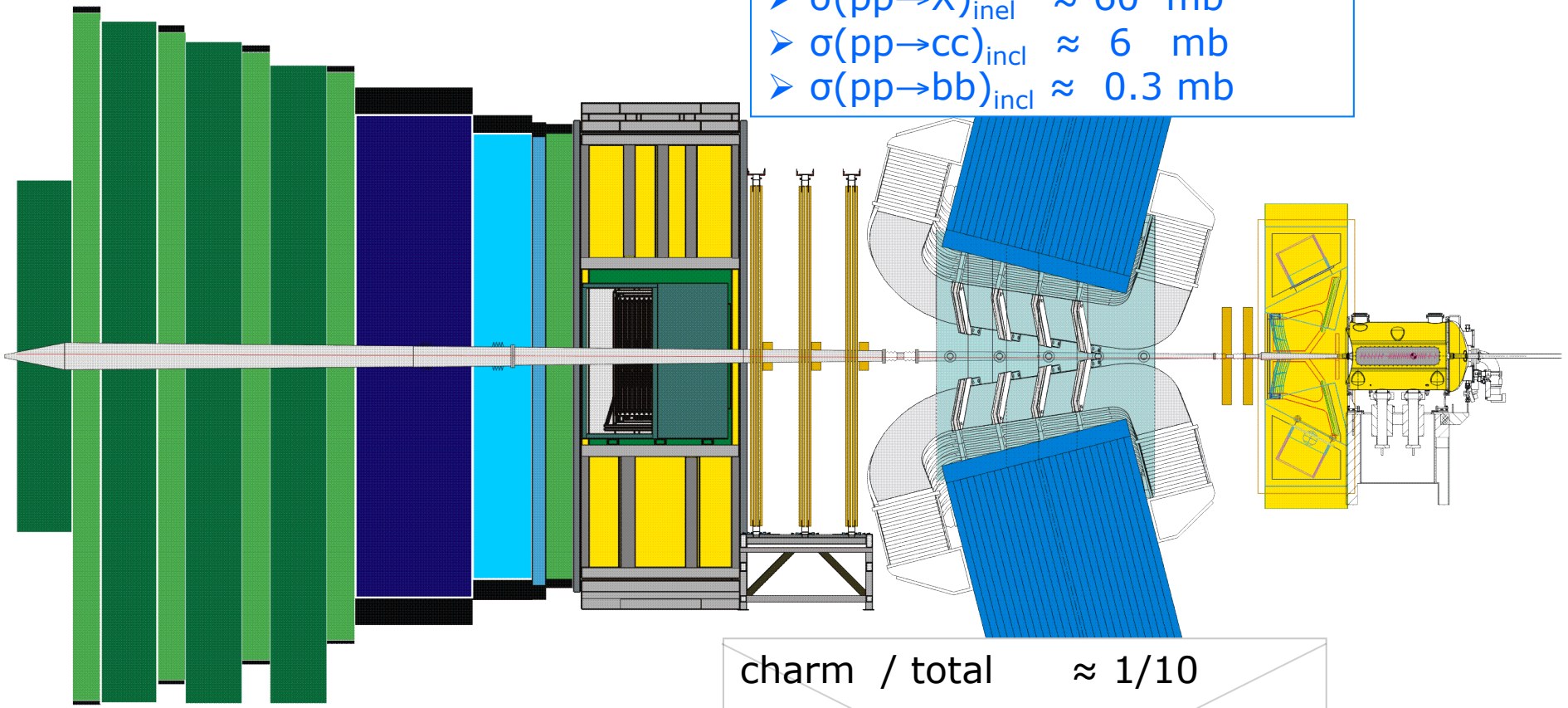
The LHCb Detector



The LHCb Detector

2011: $\sqrt{s}$=7 TeV, L=1 fb^{-1}
2012: $\sqrt{s}$=8 TeV, L=2 fb^{-1}

Forward arm spectrometer
- $2<\eta<5$
- $\sigma(pp\rightarrow X)_{inel} \approx 60$ mb
- $\sigma(pp\rightarrow cc)_{incl} \approx 6$ mb
- $\sigma(pp\rightarrow bb)_{incl} \approx 0.3$ mb



Back-of-the-envelope:

charm / total ≈ 1/10

bottom / charm ≈ 1/20

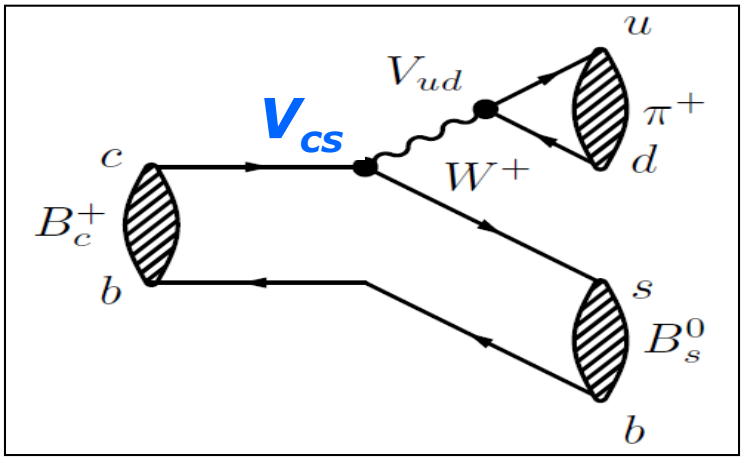
B_c^+ / bottom ≈ 1/1000

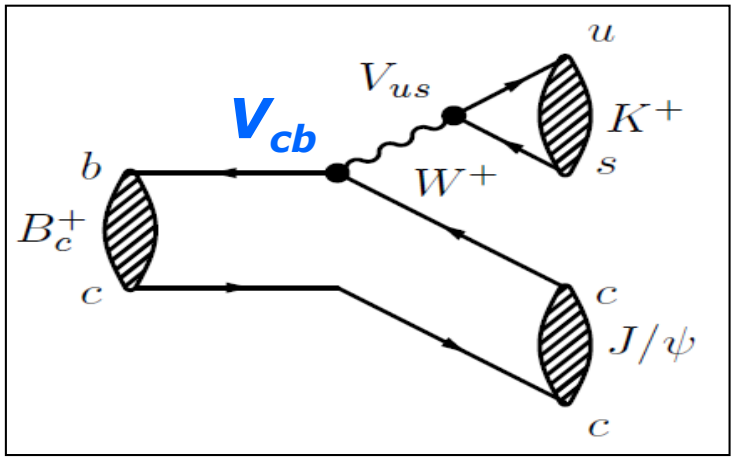
Two recent B_c^+ observations at LHCb

✓ 1) Observation of the decay $B^+_c \to B_s^0 \pi^+$ LHCb-PAPER-2013-044

✓ 2) First observation of the decay $B^+_c \to J/\psi K^+$ arXiv:1306.6723

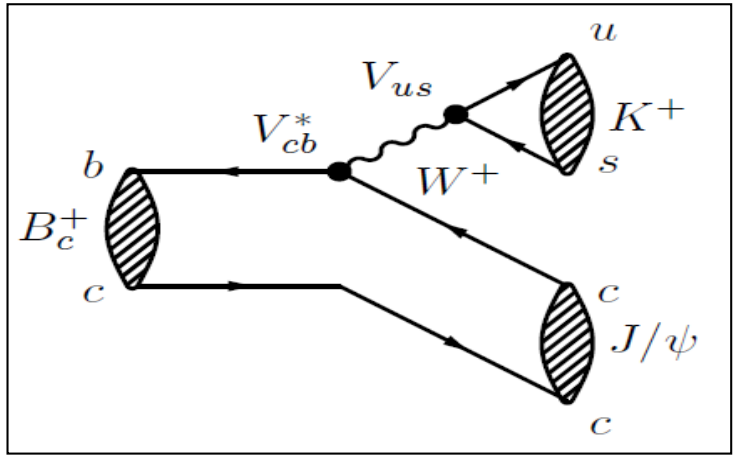
Two tree diagrams:





- B_s^0 physics:
  - Perfect tagging
  - Disturbance for proper time
- Weak B-to-B decay:
  - Never observed
  - Transition through V_{cs}, expect large BR
- QCD:
  - Heavy-heavy quarkonium system
  - Factorization
  - Large range of BR predictions

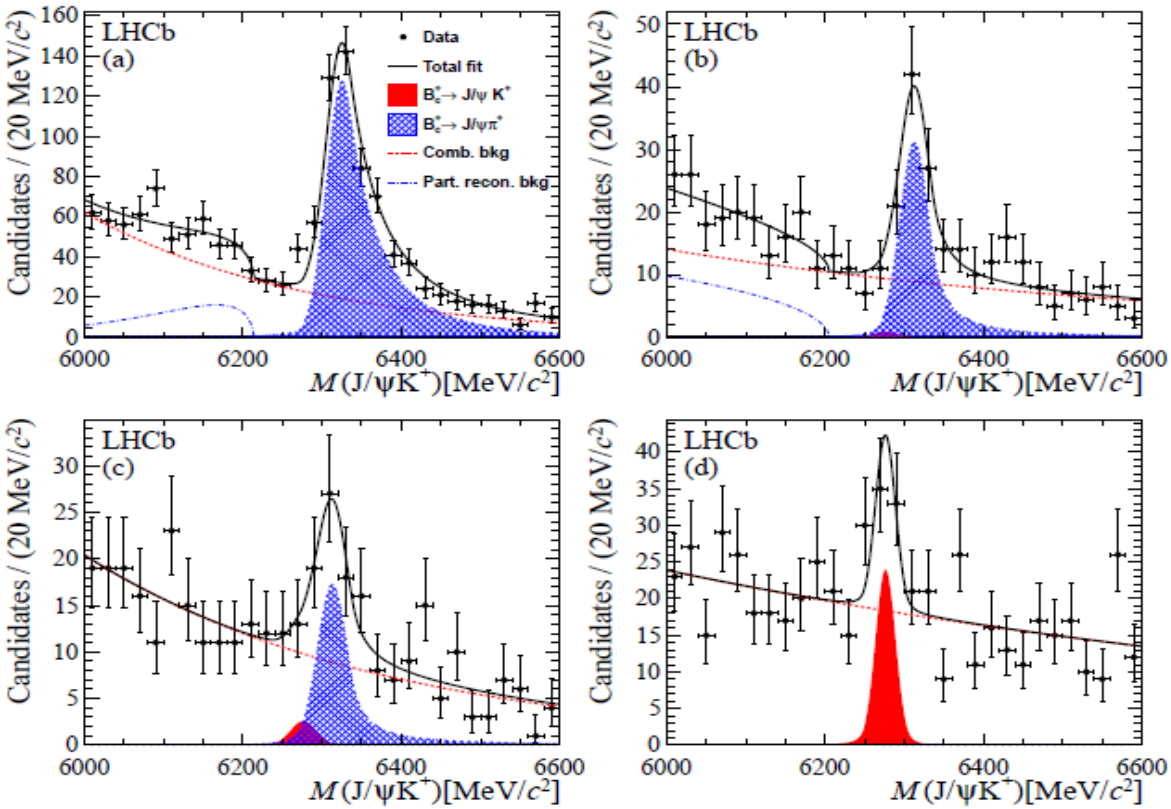
First observation of the decay $B^+_c \to J/\psi K^+$



- Models predict large range for $\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)}$: 0.054 to 0.088
- Use 2011 data, 1 fb^{-1}
- Strategy
  - Bin in discriminating PID variable

First observation of the decay $B^+_c \to J/\psi K^+$

← ***Pion-like***



Kaon-like →

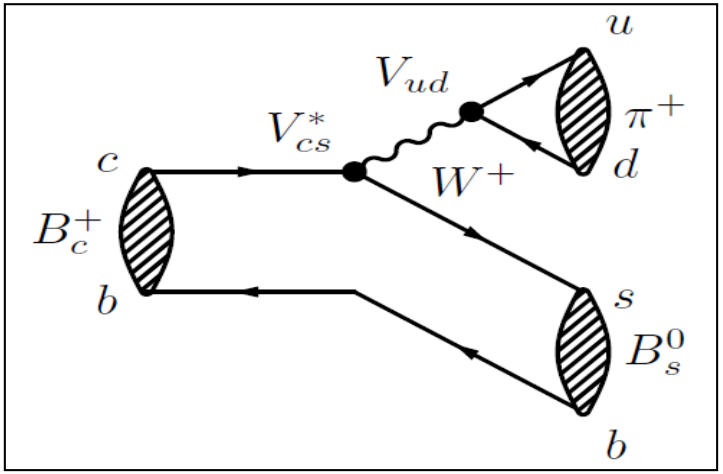
- Found in total 46 ± 12 events
- Significance 5.0σ

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.069 \pm 0.019 \pm 0.005$$

arXiv:1306.6723

➢ In agreement with naïve factorisation, $\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} \approx \left|\frac{V_{us} f_{K^+}}{V_{ud} f_{\pi^+}}\right|^2 = 0.077$

Observation of the decay $B^+_c \to B_s^0 \pi^+$



1) Models predict large range of BR($B_c^+ \to B_s^0 \pi^+$) [2.5 – 16.4]%

2) Source of B_s^0 mesons
   - ✓ Flavour tagging
   - ❖ Decay time determination

Kiselev, Kovalsky, Likhoded, NP B585 (2000) 353, arXiv:hep-ph/0002127

Ivanov, Korner, Santorelli, PRD73 (2006) 054024, arXiv:hep-ph/0602050

and references therein

- Use 2011+2012 data, 3 fb^{-1}
- Strategy
  - Measure N($B_c^+ \to B_s^0 \pi^+$) relative to N(B_s^0)
  - Use two B_s^0 decay channels: ($D_s^+ \pi^-$) & ($J/\psi \phi$)

$$(\sigma(B_c^+)/\sigma(B_s^0)) \times \mathcal{B}(B_c^+ \to B_s^0 \pi^+)$$

$B^+_c \to B_s^0 \pi^+$: Strategy

1) Design B_s^0 selection (BDT1)
2) Mass fit for B_s^0 yield
3) Design B_c^+ selection (BDT2)
4) Mass fit for B_c^+ yield
5) Relative efficiency

$$(\sigma(B_c^+)/\sigma(B_s^0)) \times \mathcal{B}(B_c^+ \to B_s^0\pi^+) = \frac{N(B_c^+ \overset{(3+4)}{\to} (B_s^0 \overset{(1)}{\to} X)\pi^+)/\epsilon(B_c^+ \overset{(5)}{\to} B_s^0\pi^+)}{N(B_s^0 \to X)_{(1+2)}}$$

$B^+_c \to B_s^0 \pi^+$: B_s^0 selection

$B_s^0 \to D_s \pi$

- No pointing cuts
- m_{Ds}: [1944:1990] MeV
- MVA:
  - Signal: (IP smeared) MC
  - Bkd: data upper sideband
- PID: K-from-D_s, π-from-B_s

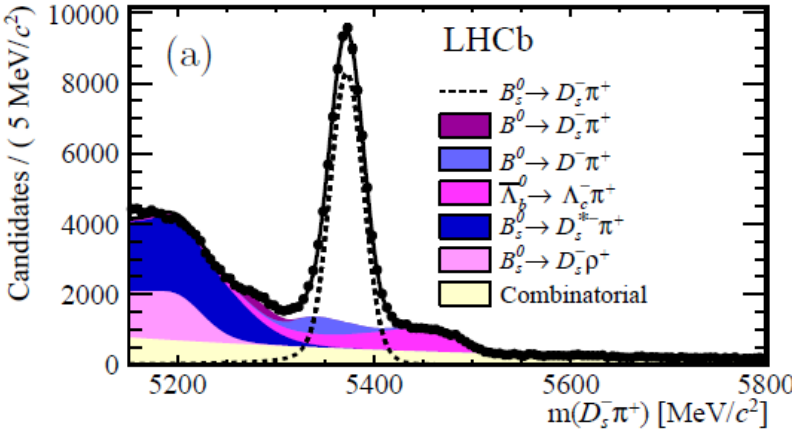
$B_s^0 \to J/\psi\phi$

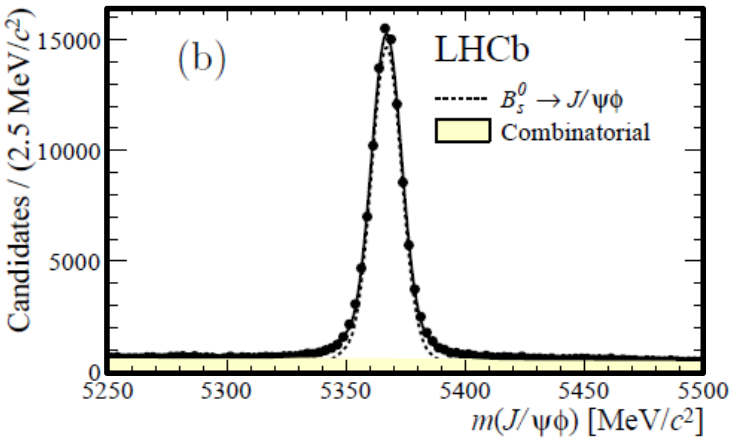
- No pointing cuts
- m_ϕ: [980:1050] MeV
- m_ψ: [m_ψ ±80] MeV
- MVA:
  - Signal: MC
  - Bkd: data upper sideband

Backgrounds:

- Partially reconstructed
- Misidentified decays

$B_s^0 \to D_s \pi$	$B_s^0 \to J/\psi\phi$	N_{events}
23,644	31,358	**2011**
57,497	71,771	**2012**



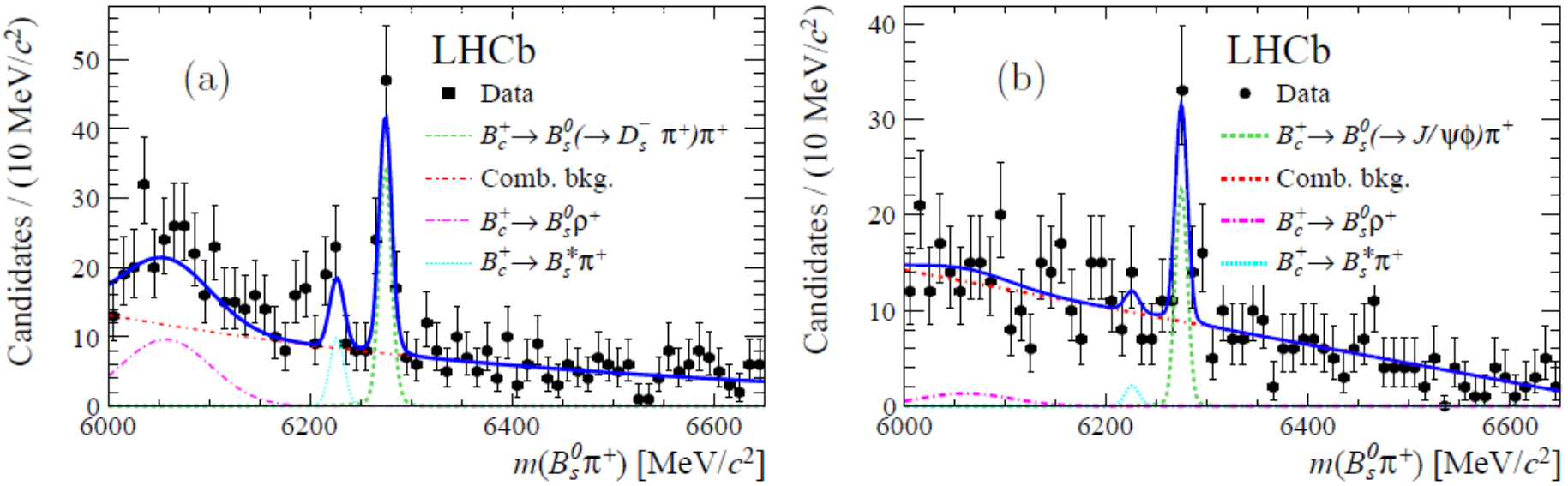


$B^+_c \to B^0_s \pi^+$: B_c^+ selection

- m_{Bs}: [m_{Bs} ±36] MeV
- MVA:
  - Signal: (IP smeared) MC
  - Bkd: data upper sideband
- PID: π-from-B_c

Backgrounds:

- Partially reconstructed ($B_s^*\pi$,$B_s\rho$,…): Shapes fixed; yield free



$B^+_c \to B^0_s \pi^+$: Systematic Uncertainties

Source	$D_s^- \pi^+$	$J/\psi\phi$
B_s^0 fit model	3.0%	1.2%
Total $N(B_s^0)$	3.0%	1.2%
B_c^+ mean mass	–	2.0%
B_c^+ mass resolution	–	5.2%
B_c^+ signal model	1.5%	1.7%
Comb. bkgd. model	1.8%	0.3%
Partially reconstructed bkgd.	1.8%	1.7%
Total $N(B_c^+)$	3.0%	6.1%
Data-simulation difference	3.7%	3.7%
B_c^+ lifetime	$^{+6.8}_{-3.5}$%	7.4%
Total $\epsilon(B_c^+ \to B_s^0 \pi^+)$	$^{+7.7}_{-5.1}$%	8.3%
Total	$^{+9.2}_{-7.1}$%	10.4%

Mean life $\tau = (45.3 \pm 4.1) \times 10^{-14}$ s

Depending on τ_{Bc}, reject more/fewer events

$B^+_c \to B_s^0 \pi^+$: Results

- Final result:

LHCb-PAPER-2013-044

$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \to B_s^0 \pi^+) = \left(2.38 \pm 0.35\,(\text{stat}) \pm 0.11\,(\text{syst}) \,^{+0.17}_{-0.12}\,(\tau_{B_c^+})\right) \times 10^{-3}$$

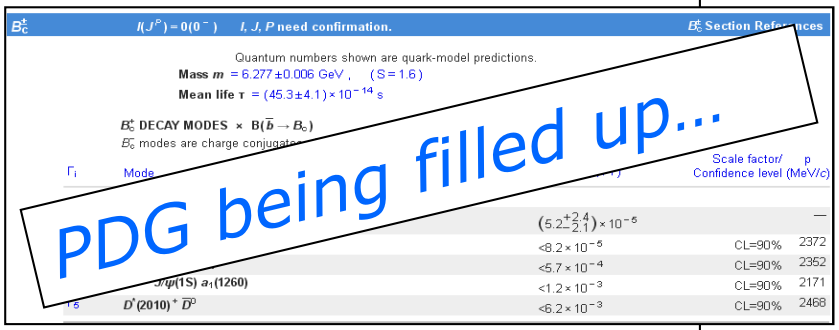
- First weak B-to-B decay
- ~ 1/500 B_s^0 originates from $B_c^+ \to B_s^0 \pi^+$

- To extract BR, need to know B_c^+ production rate
  - Using experimental & theoretical input from $B_c^+ \to J/\psi \pi^+$:
  - $BR(B_c^+ \to B_s^0 \pi^+)$ largest weak BR(B) measured

Conclusions

1) B_c^+ measurements at LHCb are maturing:

- $B^+_c \to J/\psi\pi^+$
- $B^+_c \to J/\psi\pi^+\pi^-\pi^+$
- $B^+_c \to \psi(2S)\pi^+$
- $B^+_c \to J/\psi D_s^+$ *(single best mass measurement)*



2) Recent measurements

- ***$B^+_c \to J/\psi K^+$***
  - Factorization holds

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.069 \pm 0.019 \pm 0.005$$

- ***$B^+_c \to B_s^0\pi^+$***
  - First weak B-to-B decay
  - 1/500 B_s^0 mesons comes from the decay $B^+_c \to B_s^0\pi^+$

$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \to B_s^0\pi^+) = \left(2.38 \pm 0.35\,(\text{stat}) \pm 0.11\,(\text{syst})\, ^{+0.17}_{-0.12}\,(\tau_{B_c^+})\right) \times 10^{-3}$$

Backup

Backup

- Measure:

$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \to B_s^0\pi^+) = \frac{N(B_c^+ \to (B_s^0 \to X)\pi^+)/\epsilon(B_c^+ \to B_s^0\pi^+)}{N(B_s^0 \to X)}$$

- Use this, to estimate:

$$\frac{\mathcal{B}(B_c^+ \to B_s^0\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = \frac{f_s}{f_d} \times \frac{\left(\frac{f_c}{f_s} \times \mathcal{B}(B_c^+ \to B_s^0\pi^+)\right)}{\frac{\sigma(B_c^+)\times\mathcal{B}(B_c^+\to J/\psi\pi^+)}{\sigma(B^+)\times\mathcal{B}(B^+\to J/\psi K^+)}} \times \frac{1}{\mathcal{B}(B^+ \to J/\psi K^+)}$$

0.259 ± 0.015 LHCb

$(0.68 \pm 0.12)\%$ LHCb

$(1.016 \pm 0.033)\times 10^{-3}$ PDG

Particle Data Group, J. Beringer *et al.*, *Review of particle physics*, Phys. Rev. **D86** (2012) 010001.

LHCb collaboration, R. Aaij *et al.*, *Measurements of B_c^+ production and mass with the $B_c^+ \to J/\psi\pi^+$ decay*, Phys. Rev. Lett. **109** (2012) 232001, arXiv:1209.5634.

LHCb collaboration, R. Aaij *et al.*, *Measurement of the ratio of fragmentation functions f_s/f_d and the dependence on B meson kinematics* , JHEP **1304** (2013) 001, arXiv:1301.5286.

$B_c^+ \to B_s^0 \pi^+$: comparison of B_s^0 decays

- Two analyses:

$B_s^0 \to J/\psi\phi$

✓ Experimentally cleaner (background, trigger, …)

❖ Smaller BR

$B_s^0 \to D_s\pi$

❖ More background (part. reconstructed, trigger on lifetime, …)

✓ Larger BR

➢ Similar sensitivity?

$$\mathcal{B}(B_s^0 \to J/\psi\,\phi) \times \mathcal{B}(J/\psi \to \mu^+\mu^-) \times \mathcal{B}(\phi \to K^+K^-) = (3.0 \pm 0.3) \times 10^{-5}$$

$$\mathcal{B}(B_s^0 \to D_s^-\pi^+) \times \mathcal{B}(D_s^- \to K^+K^-\pi^-) = (1.62 \pm 0.17) \times 10^{-4}$$