

LHCb News

Patrick Robbe (LHCb Collaboration), LAL Orsay, 8 Apr 2014

Outline

- Highlights of results of the LHCb experiment
 - Rare decays
 - Measurement of γ
 - Charm physics
- LAL-Tsinghua project
 - Quarkonium
 - B_c physics

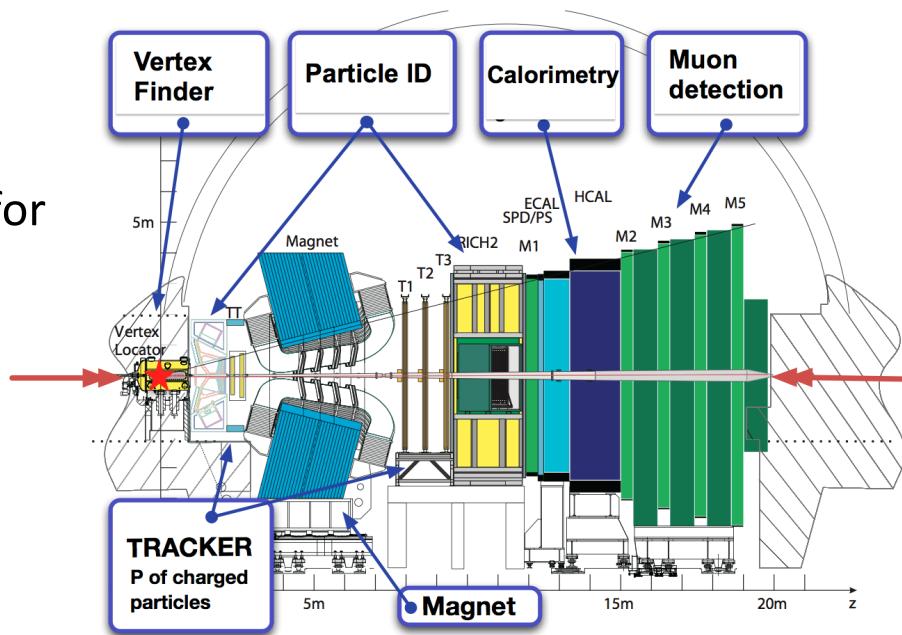
LHCb Collaboration



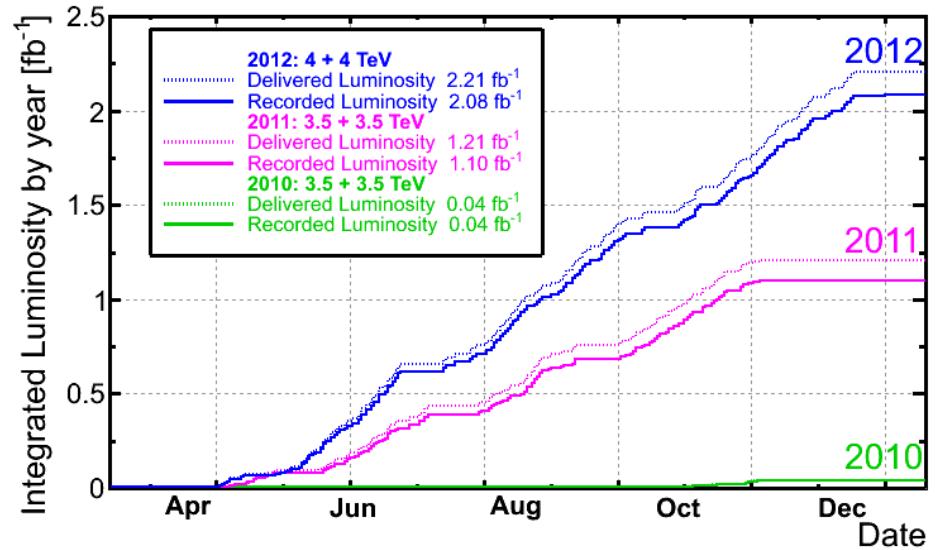
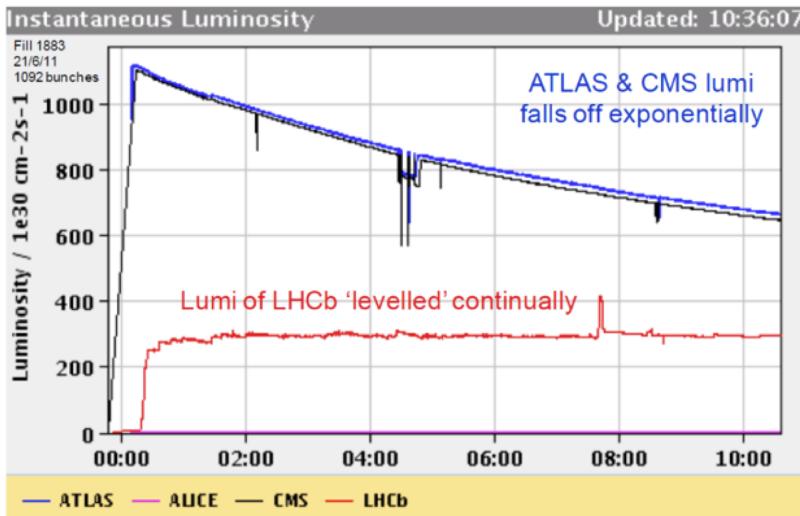
- 16 countries
- 900 members from 67 institutes
- 170 publications

LHCb detector essential features

- Optimized for B physics:
 - Forward acceptance,
 - Efficient (hardware + software) trigger for leptonic and hadronic decay modes
 - Acceptance down to 0 p_T
 - Precision vertexing and tracking
 - Excellent PID
- Proven excellent performances for general purpose physics in the forward region.



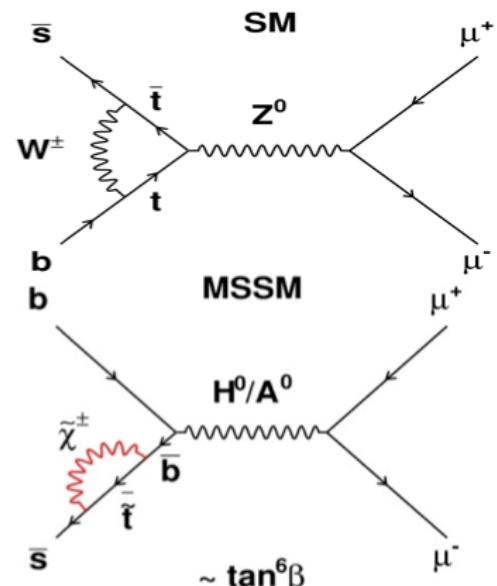
Running conditions



- LHCb is designed to run at lower instantaneous luminosity than ATLAS or CMS:
 - Tracking, PID performances degrade with pile-up (occupancy)
- pp beams displaced to reduce luminosity and moved closer to keep it constant:
 - $2.7 \cdot 10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}$ in 2011
 - $4.0 \cdot 10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}$ in 2012
- Huge heavy quark cross-sections:
 - $10^{11} \text{ b} / \text{fb}^{-1}$ in acceptance
 - $10^{12} \text{ c} / \text{fb}^{-1}$ in acceptance

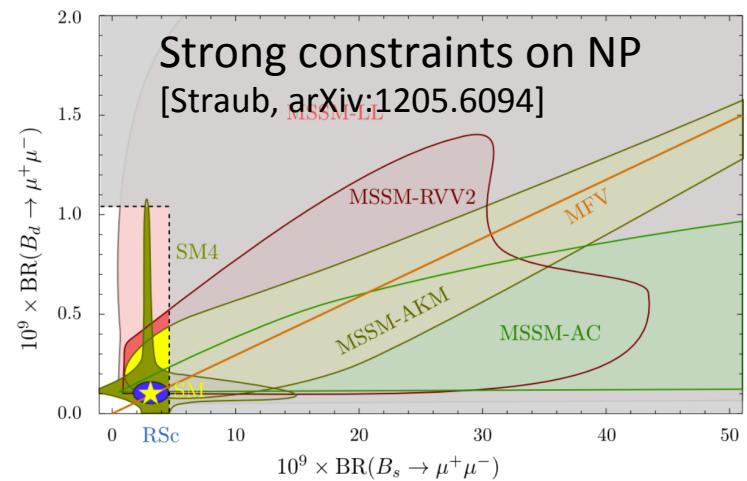
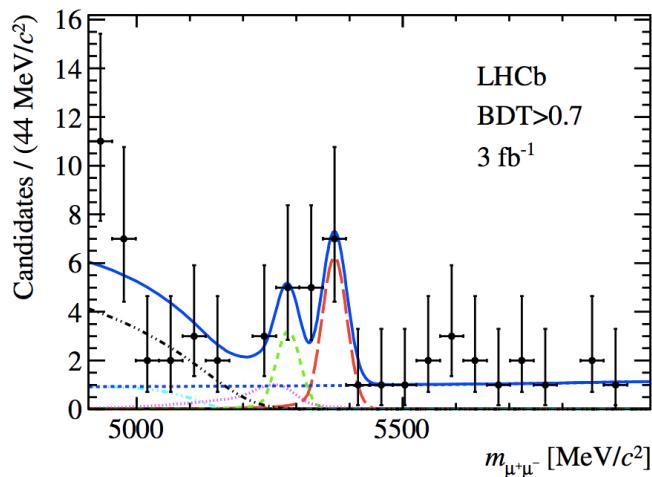
Rare decays: $B \rightarrow \mu^+ \mu^-$

- Highly suppressed in standard model:
 - FCNC (Flavour changing neutral current)
 - Helicity suppressed $\sim (M_\mu/M_B)^2$
- Precisely predicted:
 - $B(B_s \rightarrow \mu^+ \mu^-) = (3.35 \pm 0.28) \times 10^{-9}$ [Buras et al., EPJC72 (2012) 2172]
 - Should be corrected up by few percent since measurement is of the time-integrated branching fraction [De Bruyn, Fleischer et al., PRL 109 (2012) 041801]
 - $B(B^0 \rightarrow \mu^+ \mu^-) = (1.07 \pm 0.10) \times 10^{-10}$
- Sensitive to New Physics: in MSSM, $BR \sim \tan^6 \beta$
- Very clean signature, studied at all hadron colliders.



First evidence for $B \rightarrow \mu^+\mu^-$

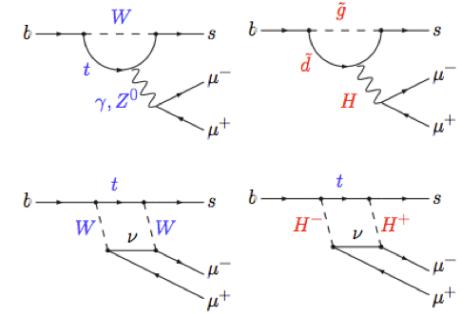
	$\mathcal{B}(B_s^0 \rightarrow \mu\mu) \times 10^{-9}$	$\mathcal{B}(B^0 \rightarrow \mu\mu) \times 10^{-9}$	
LHCb	$2.9^{+1.1+0.3}_{-1.0-0.1}$	$3.7^{+2.4+0.6}_{-2.1-0.4}$	PRL 111 101805 (2013)
CMS	$3.0^{+1.0}_{-0.9}$	$3.5^{+2.1}_{-1.8}$	PRL 111 101804 (2013)
Combined	2.9 ± 0.7	$3.6^{+1.6}_{-1.4}$	LHCb-CONF-2013-012 CMS-PAS-BPH-13-007



- Additional handle on New Physics through effective lifetime of $B_s \rightarrow \mu^+\mu^-$. Will be feasible with the upgraded LHCb [Buras, Fleisher et al., arXiv:1303.3820]

$b \rightarrow s$ transitions: $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

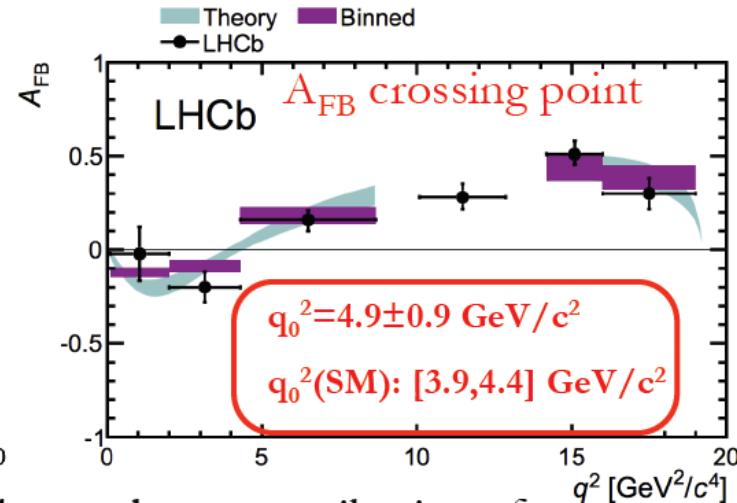
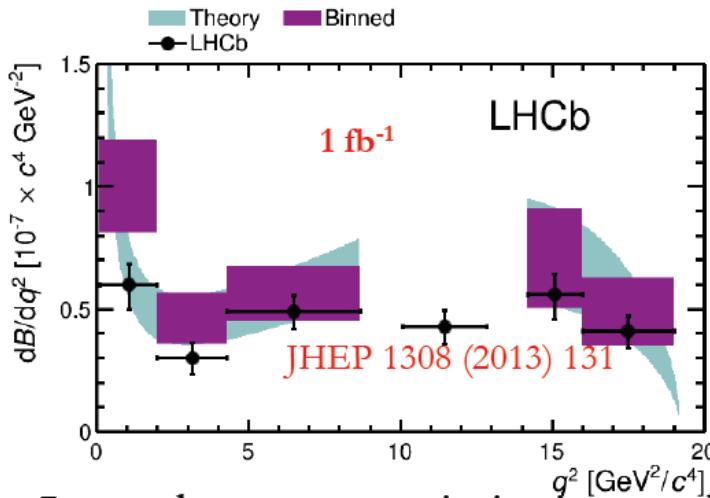
- $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ is a FCNC decay proceeding only via loop and boxes
- Rich phenomenology, with several observables
- New Physics can appear at the same level of Standard Model processes
- Theoretical framework via an effective Hamiltonian:
 - Wilson coefficients (C_i) describing short distance interactions, sensitive to new physics
 - Operators (O_i) describing long distance interactions
 - In Standard Model, contributions from O_7, O_9, O_{10} .



$$H_{eff} = \frac{4\tilde{G}_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} (C_i^{SM} + \Delta C_i^{NP}) O_i$$

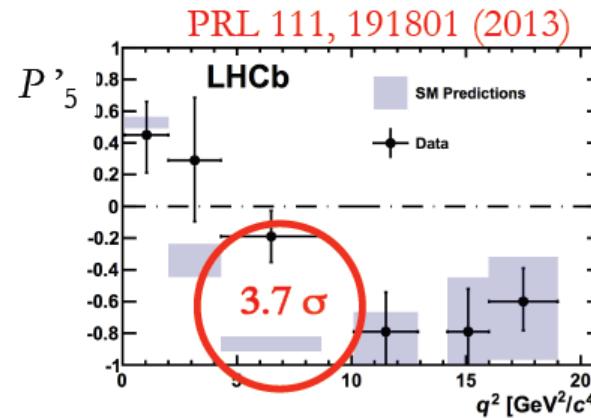
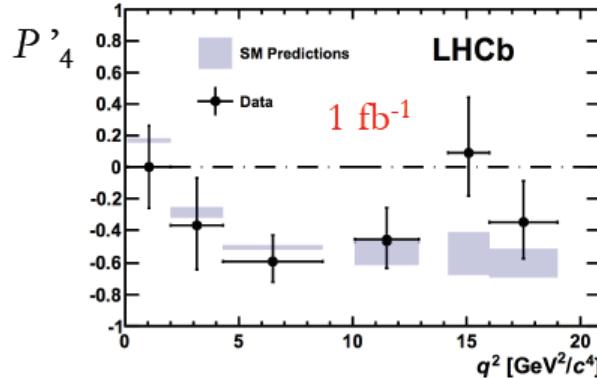
$b \rightarrow s$ transitions: $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

- Rates, angular distributions and asymmetries sensitive to New Physics



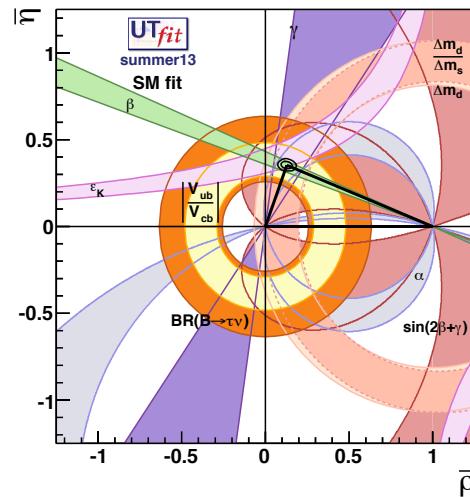
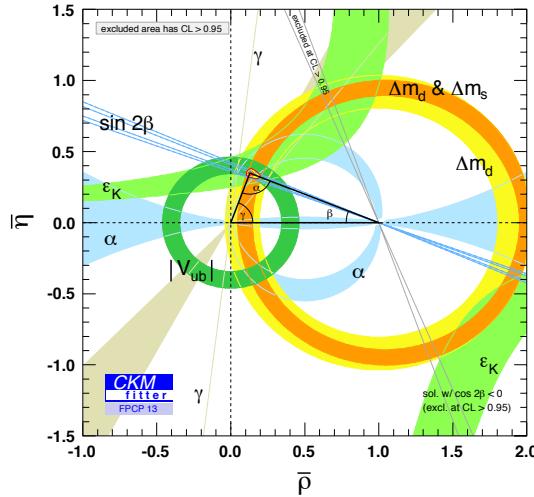
- Large theory uncertainties in part due to large contributions from hadronic form factors
- In Standard Model, AFB changes sign at a well defined value q_0^2
- First measurement of q_0^2 , consistent with Standard Model.

Form factor independent variables in $B^0 \rightarrow K^{*0}\mu^+\mu^-$



- Combinations of observables provide reduced form-factor uncertainties at low q^2 :
 - For example, $P'_{i=4,5,6,8} = \frac{s_{i=4,5,6,8}}{\sqrt{F_L(1-F_L)}}$ with $F_L = K^{*0}$ longitudinal polarization fraction [Matias et al, arXiv:1303.5794]
- P'_6 and P'_8 measured by LHCb close to Standard Model predictions (0) over full q^2 range
- But deviation in P'_5 (across 24 bins, the significance drops to 2.8σ)
- Most likely scenario: statistical fluctuation or theory uncertainties underestimated [Jager, Camalich, JHEP 05 (2013) 043]

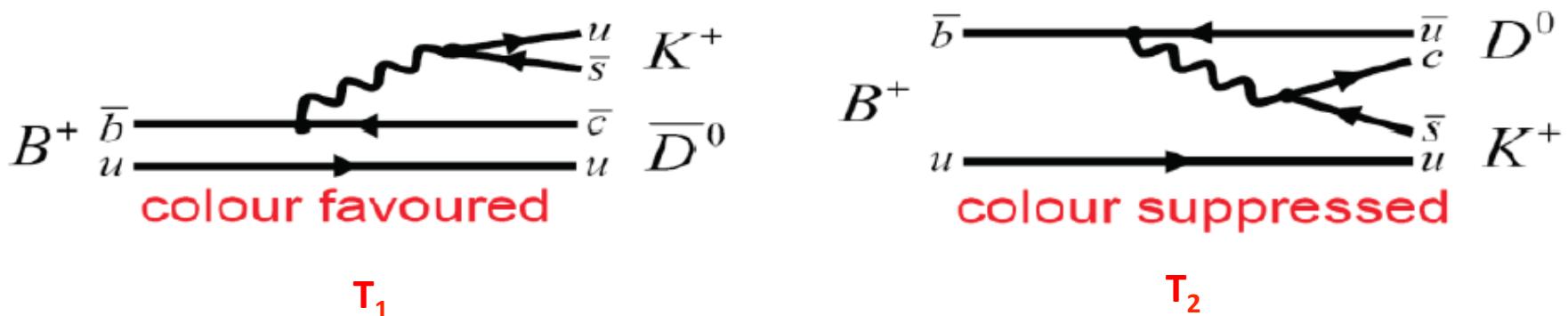
γ Measurement: state of the art



- Consistent and more and more precise picture of CP violation through CKM mechanism
- But γ still with large uncertainties, experimental measurement's uncertainties is $\sim 15^\circ$ from tree decays (not sensitive to new physics)
- Theory uncertainty negligible

How to measure γ in tree decays

- Need two interfering paths to the same final state: the largest interference (and CP violation effect) is obtained when the 2 paths are of similar amplitudes.



« GLW »

D^0 in CP mode: $D^0 \rightarrow K^+K^-$, $D^0 \rightarrow \pi^+\pi^-$

« ADS »

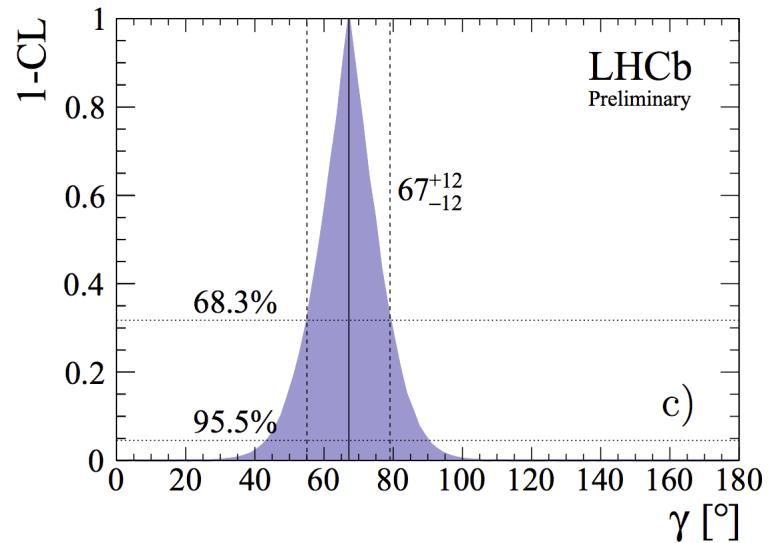
D^0 in flavour quasi-specific mode: $D^0 \rightarrow K^-\pi^+/\pi^-K^+$, $D^0 \rightarrow K^-\pi^+\pi^-\pi^+/\pi^-K^+\pi^-\pi^+$

« GGSZ »

D^0 in three-body decays: $D^0 \rightarrow K_s^0\pi^+\pi^-/K_s^0K^+K^-$ (ie a mixture of the two cases above, depending on which resonance the decay goes through -- for example $D^0 \rightarrow K_s^0\rho^0$ is a CP mode and $D^0 \rightarrow K^{*-}\pi^+/K^{*+}\pi^-$ is quasi-specific)

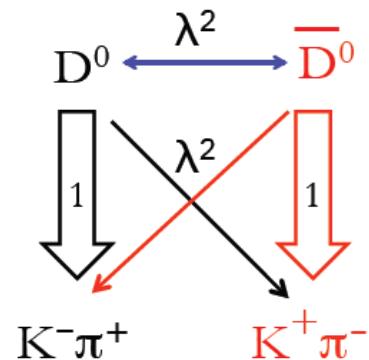
γ results

- Combine measurements
 - 1fb^{-1} , 2011, $B \rightarrow DK$, with $D \rightarrow KK, \pi\pi, K\pi, K3\pi$ [PRL 712 (2012) 203]
 - 3fb^{-1} $B \rightarrow DK$, with $D \rightarrow K_s\pi^+\pi^-$ [PLB 718 (2012) 43]
- $\gamma = (67 \pm 12)^\circ$
- Expect 7° uncertainty with final analysis of the 3 fb^{-1}
- LHCb sensitivity in 2018: 4°



Measurement of D^0 mixing and CPV

- Very small CPV in charm mixing and in decays expected in Standard Model: sensitive test of CKM in the charm sector
- However, mixing effects not easily calculable
- Reconstruct $D^0 \rightarrow K\pi$:
 - Right Sign: $D^{*+} \rightarrow D^0 \pi^+ \rightarrow (K^-\pi^+)\pi^+$, 54M events in 3fb^{-1} (Cabibbo favoured)
 - Wrong Sign: $D^{*+} \rightarrow D^0 \pi^+ \rightarrow (K^+\pi^-)\pi^+$, 0.23M events in 3fb^{-1} (Doubly Cabibbo suppressed (DCS), or Cabibbo favoured + mixing)
- Ratio of wrong to right sign vs time separates suppressed decays from oscillations



$$R(t) \equiv \frac{N_{WS}(t)}{N_{RS}(t)} \approx R_D + \sqrt{R_D} y' t + \frac{1}{4} (x'^2 + y'^2) \cdot t^2$$

Direct CPV, DCS Interference Mixing

$$\begin{aligned}
 x &= \Delta m / \Gamma, \quad y = \Delta \Gamma / 2\Gamma \\
 x' &= x \cos \delta + y \sin \delta \quad y' = y \cos \delta - x \sin \delta \\
 R_D &\text{ ratio suppressed-to-favoured rates}
 \end{aligned}$$

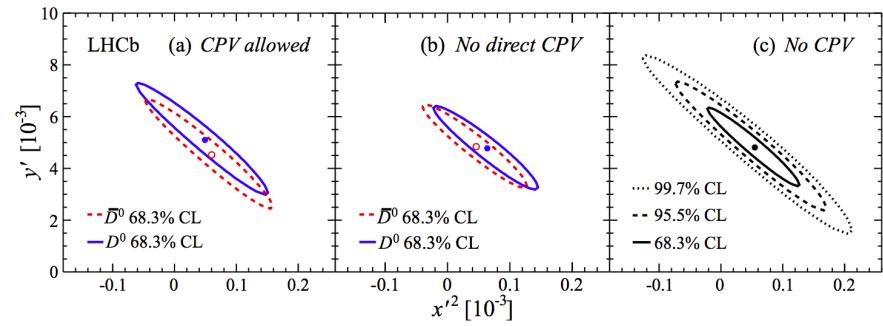
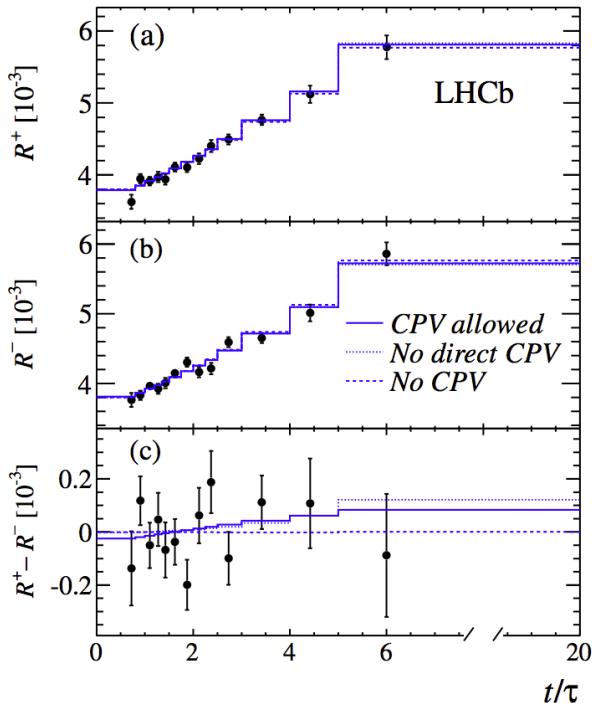
- Fit ratios separately for D^0, \bar{D}^0 to search for CP violation

$$\left(R^+, R^-, A_D = \frac{R^+ - R^-}{R^+ + R^-} \right)$$

Measurement of D^0 mixing and CPV

PRL 111 (2013) 251801

3fb⁻¹



$$x'^2 = (5.5 \pm 4.9) \cdot 10^{-5}$$

$$y' = (4.8 \pm 1.0) \cdot 10^{-3}$$

$$R_D = (3.568 \pm 0.066) \cdot 10^{-3}$$

$$0.75 < |q/p| < 1.24 \text{ @ 68% CL}$$

$$A_D = (-0.7 \pm 1.9)\%$$

- No evidence for CP violation
- Best determination of mixing parameters

Effective D^0 lifetime asymmetry

- Study of indirect CP violation in $D^0 \rightarrow K^+K^-/\pi^+\pi^-$ from asymmetry:

$$A_\Gamma \equiv \frac{\hat{\Gamma} - \bar{\hat{\Gamma}}}{\hat{\Gamma} + \bar{\hat{\Gamma}}} \approx \eta_{CP} \left(\frac{A_m + A_d}{2} y \cos \phi - x \sin \phi \right)$$

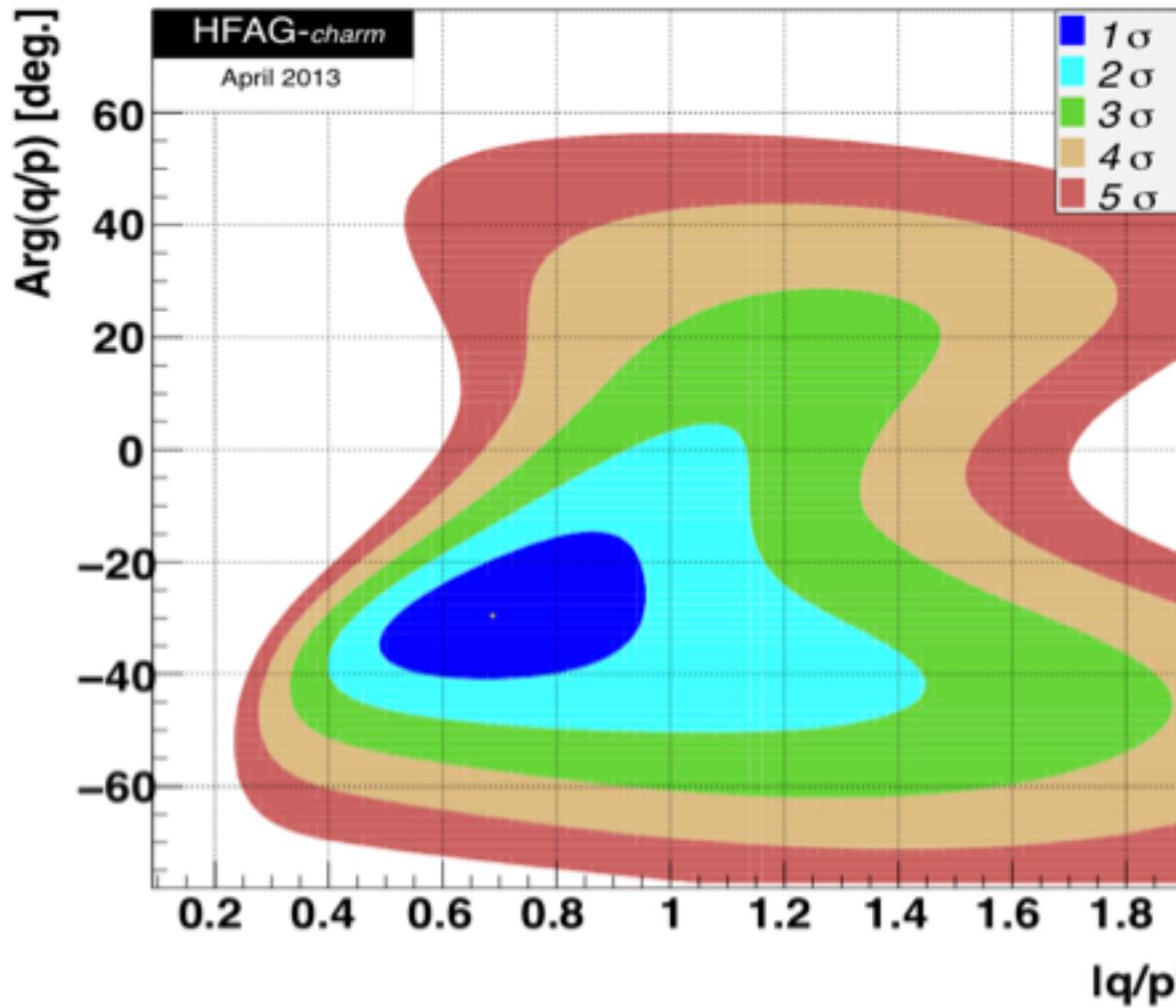
$$A_m \equiv \frac{|q/p|^2 - |p/q|^2}{|q/p|^2 + |p/q|^2}, \quad A_d \equiv \frac{|A_f|^2 - |\bar{A}_f|^2}{|A_f|^2 + |\bar{A}_f|^2}, \quad \lambda_f \equiv \frac{q \bar{A}_f}{p A_f} = -\eta_{CP} \frac{q}{p} \frac{|\bar{A}_f|}{|A_f|} e^{i\phi}$$

- Non zero if CP violation in mixing (A_d is small)
- D flavour tagged from D^* decays and time-dependent measurement
- With 1fb^{-1} , 3M $D^0 \rightarrow K^+K^-$ and 1M $D^0 \rightarrow \pi^+\pi^-$

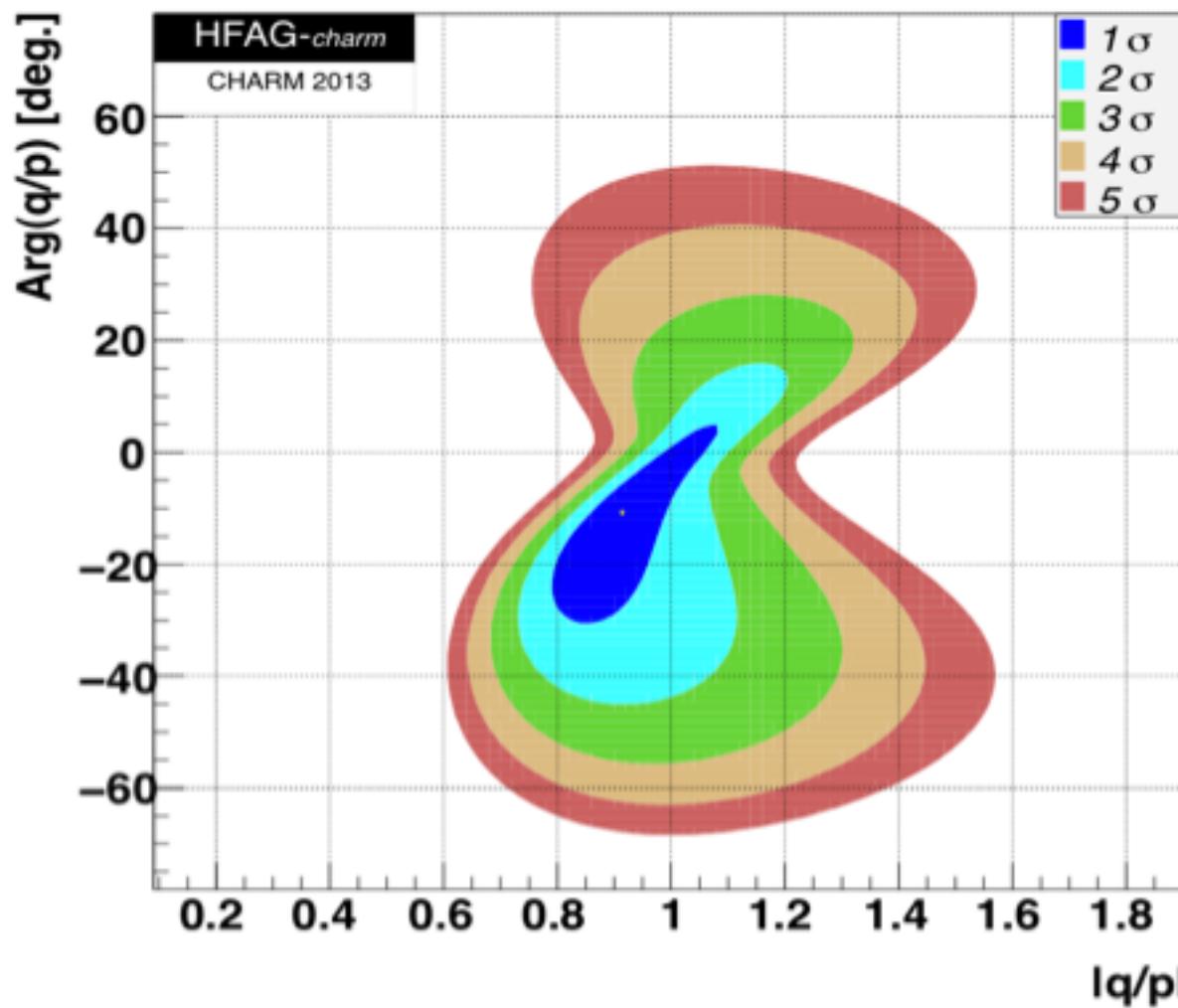
$$A_\Gamma(K^+K^-) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}$$

$$A_\Gamma(\pi^+\pi^-) = (0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$$

Impact

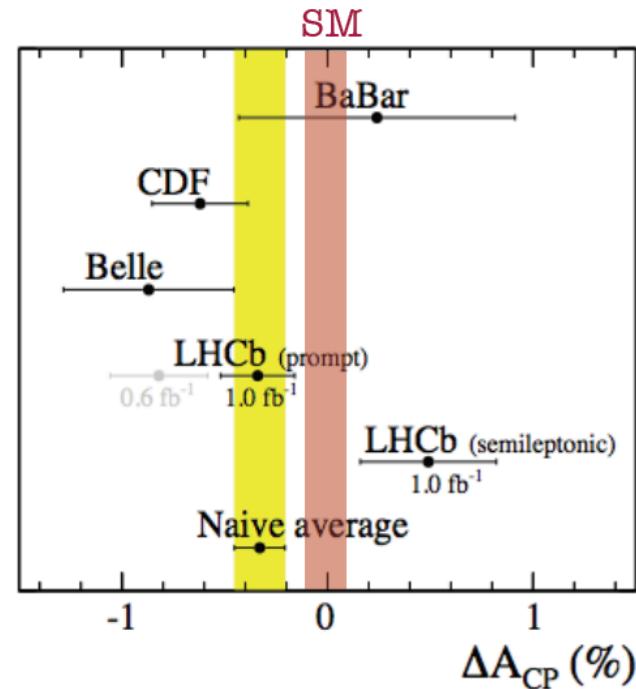


Impact



DACP: direct CP violation in $D^0 \rightarrow K^+K^-$, $D^0 \rightarrow \pi^+\pi^-$

- Intriguing large difference in CP asymmetry between $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$, not expected
- Two methods:
 - Tagged $D^{*+} \rightarrow D^0\pi^+$ [PRL 108 (2012) 111602 and 1fb⁻¹ in LHCb-CONF-2013-003]
 - D^0 produced in semi-leptonic B decays [PLB 723 (2013) 33, 1fb⁻¹]
- No clear experimental and theoretical picture

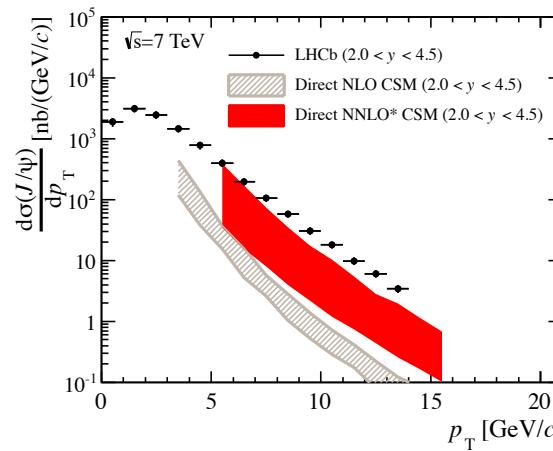
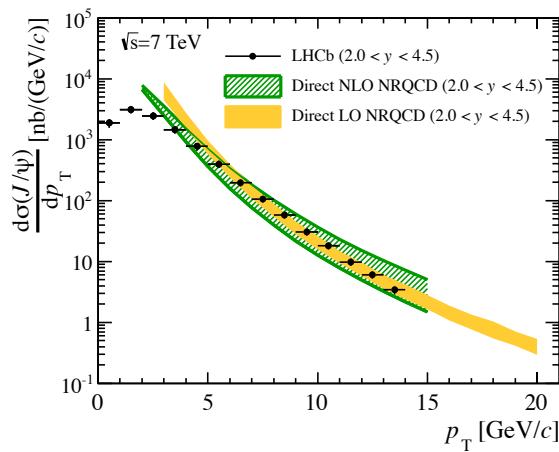


LAL/Tsinghua collaboration

- Started in 2006
- Current members:
 - LAL: Patrick Robbe, Marie-Helene Schune, Sergey Barsuk
 - Tsinghua: Yuanning Gao, Zhenwei Yang, Yiming Li, Liupan An
- Activities, data analysis at LHCb:
 - Quarkonium production
 - Measurements of the B_c meson
- Long term exchanges:
 - Jibo He, CNRS post-doc (now CERN fellow)
 - Wenbin Qian, Embassy co-tutelle PhD (now post-doc at LAPP Annecy)
 - Bo Liu, CSC grant, one year at LAL (now post-doc in Cagliari)

Quarkonium Production

- Initially meant as first step towards B_c^+ analyses: understand detector, trigger, J/ψ reconstruction,
- But developed as major part of the LHCb physics program.
- Measurement of J/ψ production (prompt and from B decays), as a function of p_T and y , for 2.76 TeV, 7 TeV and 8 TeV energies.

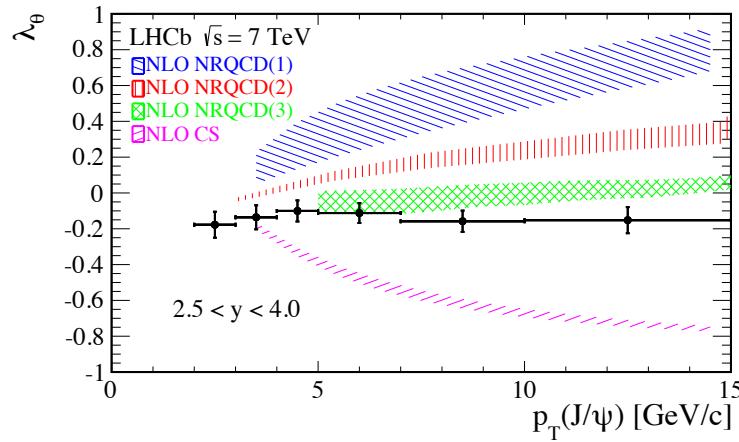


Thesis of Wenbin Qian, Eur.Phys.J.C71 (2011) 1645, one of the most cited paper of LHCb

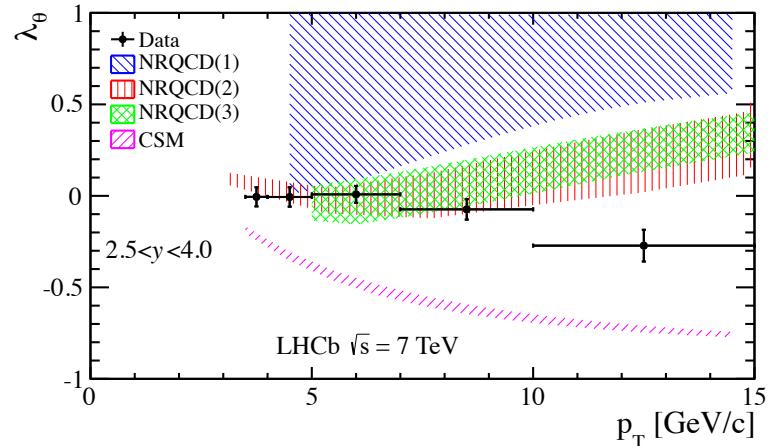
Quarkonium Polarization

- Quarkonium production mechanisms not so clear, test them with measurement of polarization.

$$\frac{d^2 N}{d \cos \theta \, d\phi}(\lambda_\theta, \lambda_{\theta\phi}, \lambda_\phi) \propto 1 + \lambda_\theta \cos^2 \theta + \lambda_{\theta\phi} \sin 2\theta \cos \phi + \lambda_\phi \sin^2 \theta \cos 2\phi,$$



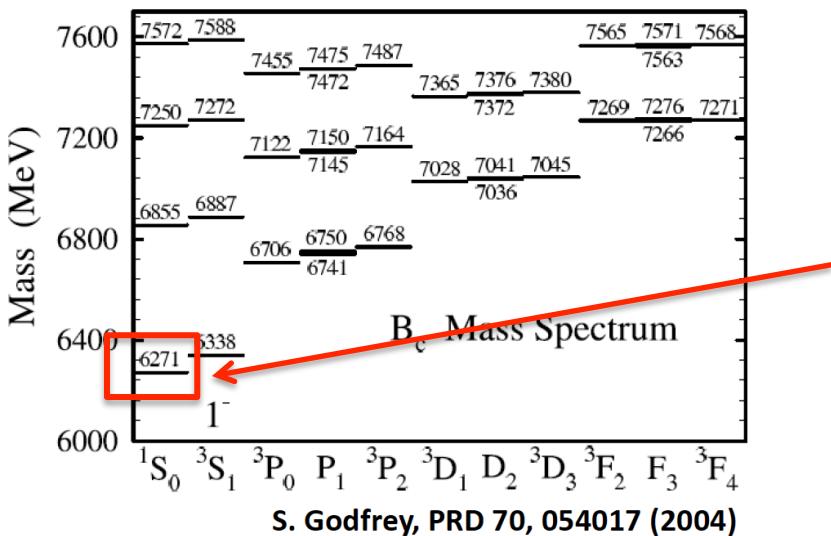
J/ψ polarization [[Eur. Phys. J. C 73 \(2013\) 2631](#)]



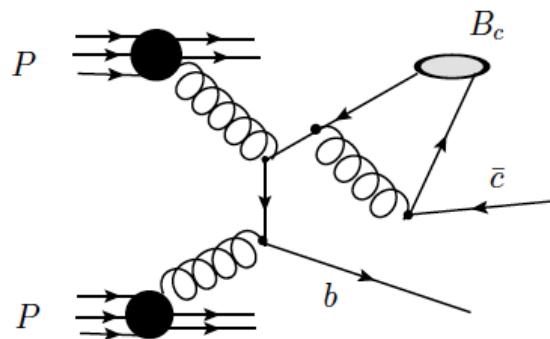
$\psi(2S)$ polarization [[arXiv:1403.1339](#)]

B_c Meson

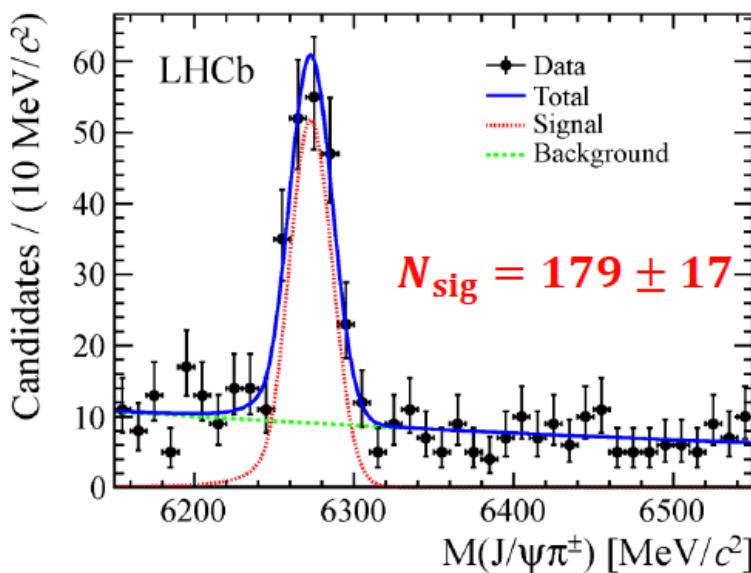
- Unique family of meson formed with 2 different heavy flavours: ($\bar{b}c$).
- It is considered as a quarkonium state, because the study of its production properties can give constraints for the understanding of production mechanisms of heavy-quark states.
- Study of its mass, lifetime and decay channels can be used to test and constrain QCD calculations similar to these in the quarkonium sector.



B_c Production



Typical production diagram (α_s^4)



Measured with the decay mode $B_c^+ \rightarrow J/\psi \pi^+$, relative to the B^+ production ($B^+ \rightarrow J/\psi K^+$)

$$\mathcal{R}_{c/u} = \frac{\sigma(B_c^+) \times \mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)}{\sigma(B^+) \times \mathcal{B}(B^+ \rightarrow J/\psi K^+)}$$

$$\mathcal{R}_{c/u} = (0.68 \pm 0.10_{\text{stat}} \pm 0.03_{\text{syst}} \pm 0.05_{\text{lifetime}})\%$$

For $p_T < 4$ GeV/c and $2.5 < \eta < 4.5$

The absolute BR of $B_c^+ \rightarrow J/\psi \pi^+$ is not known, but using theoretical estimates, this means
 $\sigma(B_c^+) \sim \sigma(B^+)/100$

LHCb: PRL 109 (2012) 232001, PhD Thesis of Bo Liu.

The analysis is repeated to obtain a different cross-section (p_T and y), in an extended collaboration with Cagliari (Giulia Manca)

B_c Decays

- Very little is known about them !
- PDG 2012 sections for B_c^+ and B_c^0 :

BOTTOM, CHARMED MESONS ($B = C = \pm 1$)

$$B_c^+ = c\bar{b}, B_c^- = \tau b, \text{ similarly for } B_c^* \text{'s}$$

B_c^\pm

$$I(J^P) = 0(0^-)$$

I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

$$\text{Mass } m = 6.277 \pm 0.006 \text{ GeV } (S = 1.6)$$

$$\text{Mean life } \tau = (0.453 \pm 0.041) \times 10^{-12} \text{ s}$$

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

$B_c^+ \text{ DECAY MODES} \times B(\bar{b} \rightarrow B_c)$	Fraction (Γ_i/Γ)	Confidence level (MeV/c)	p
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The following quantities are not pure branching ratios; rather the fraction

$$\Gamma_i/\Gamma \times B(\bar{b} \rightarrow B_c).$$

$J/\psi(1S) \ell^+ \nu_\ell \text{ anything}$	$(5.2^{+2.4}_{-2.1}) \times 10^{-5}$	—	p
$J/\psi(1S) \pi^+$	$< 8.2 \times 10^{-5}$	90%	2372
$J/\psi(1S) \pi^+ \pi^+ \pi^-$	$< 5.7 \times 10^{-4}$	90%	2352
$J/\psi(1S) a_1(1260)$	$< 1.2 \times 10^{-3}$	90%	2171
$D^*(2010)^- \bar{D}^0$	$< 6.2 \times 10^{-3}$	90%	2468

$B_c^0 \text{ DECAY MODES}$	Fraction (Γ_i/Γ)	Confidence level	Scale factor / Confidence level (MeV/c)	p
$\ell^+ \nu_\ell \text{ anything}$	[ppp]	(10.33 ± 0.28) %	—	
$e^+ \nu_e X_c$	[ppp]	(10.1 ± 0.4) %	—	
$D \ell^+ \nu_\ell \text{ anything}$	[ppp]	(9.2 ± 0.8) %	—	
$D^- \ell^+ \nu_\ell$	[ppp]	(2.18 ± 0.12) %	2309	
$D^- \pi^+ \nu_\tau$	[ppp]	(1.1 ± 0.4) %	1909	
$D^*(2010)^- \ell^+ \nu_\ell$	[ppp]	(4.95 ± 0.11) %	2257	
$D^*(2010)^- \pi^+ \nu_\tau$	[ppp]	(1.5 ± 0.5) %	S=1.4	1837
$D_0^*(2400)^- \ell^+ \nu_\ell$	[ppp]	(4.3 ± 0.6) $\times 10^{-3}$	2308	
$D_0^*(2400)^- \ell^+ \nu_\ell \times B(D_0^+ \rightarrow \bar{D}^0 \pi^-)$	[ppp]	(3.0 ± 1.2) $\times 10^{-3}$	S=1.8	—
$D_0^*(2400)^- \ell^+ \nu_\ell \times B(D_0^+ \rightarrow \bar{D}^0 \pi^-)$	[ppp]	(1.21 ± 0.33) $\times 10^{-3}$	S=1.8	2065
$\bar{D}^*(*) \pi^+ \ell^+ \nu_\ell (\geq 1)$	[ppp]	(2.3 ± 0.5) %	—	
$\bar{D}^0 \pi^- \ell^+ \nu_\ell$	[ppp]	(4.9 ± 0.8) $\times 10^{-3}$	2256	
$D_1(2420)^- \ell^+ \nu_\ell \times B(D_1^+ \rightarrow \bar{D}^0 \pi^-)$	[ppp]	(2.80 ± 0.28) $\times 10^{-3}$	—	
$D_1(2430)^- \ell^+ \nu_\ell \times B(D_1^+ \rightarrow \bar{D}^0 \pi^-)$	[ppp]	(3.1 ± 0.9) $\times 10^{-3}$	—	
$D_2^*(2460)^- \ell^+ \nu_\ell \times B(D_2^+ \rightarrow \bar{D}^0 \pi^-)$	[ppp]	(6.8 ± 1.2) $\times 10^{-4}$	2065	
$\rho^- \ell^+ \nu_\ell$	[ppp]	(2.34 ± 0.28) $\times 10^{-4}$	2583	
$\pi^- \ell^+ \nu_\ell$	[ppp]	(1.44 ± 0.05) $\times 10^{-4}$	2638	
Inclusive modes				
$K^\pm \text{ anything}$		(78 ± 8) %	—	
$D^0 X$		(8.1 ± 1.5) %	—	
$\bar{D}^0 X$		(47.4 ± 2.8) %	—	
$D^+ X$		< 3.9 %	CL=90%	—
$D^- X$		(36.9 ± 3.3) %	—	
$D_s^+ X$		(10.3 ± 2.1) %	—	
$D_s^- X$		< 2.6 %	CL=90%	—
$\Lambda_c^0 X$		< 3.1 %	CL=90%	—
$\bar{\Lambda}_c^0 X$		(5.0 ± 2.1) %	—	
τX		(95 ± 5) %	—	
$c X$		(24.6 ± 3.1) %	—	
$\bar{c} \bar{c} X$		(119 ± 6) %	—	
$D, D^*,$ or D_s modes				
$D^- \pi^+$		(2.68 ± 0.13) $\times 10^{-3}$	2306	
$D^- \rho^+$		(7.8 ± 1.3) $\times 10^{-3}$	2235	
$D^- K^0 \pi^+$		(4.9 ± 0.9) $\times 10^{-4}$	2259	
$D^- K^*(892)^+$		(4.5 ± 0.7) $\times 10^{-4}$	2211	
$D^- \omega \pi^+$		(2.8 ± 0.6) $\times 10^{-3}$	2204	
$D^- K^+$		(1.97 ± 0.21) $\times 10^{-3}$	2279	
$D^- K^+ K^0$		< 3.1 $\times 10^{-4}$ CL=90%	2188	
$D^- K^+ K^*(892)^0$		(8.8 ± 1.9) $\times 10^{-3}$	2070	
$\bar{D}^0 \pi^+ \pi^-$		(8.4 ± 0.9) $\times 10^{-4}$	2301	
$D^*(2010)^- \pi^+$		(2.76 ± 0.13) $\times 10^{-3}$	2255	
$D^+ \pi^+ \pi^+ \pi^-$		(6.4 ± 1.0) $\times 10^{-3}$	2287	
$(D^- \pi^+ \pi^+ \pi^-)$ nonresonant		(3.9 ± 1.9) $\times 10^{-3}$	2287	
$D^- \pi^+ \rho^0$		(1.1 ± 1.0) $\times 10^{-3}$	2206	
$D^- a_1(1260)^+$		(6.0 ± 3.3) $\times 10^{-3}$	2121	
$D^*(2010)^- \pi^+ \pi^0$		(1.5 ± 0.5) %	2247	
$D^*(2010)^- \rho^+$		(6.8 ± 0.9) $\times 10^{-3}$	2180	
$D^*(2010)^- K^+$		(2.14 ± 0.16) $\times 10^{-4}$	2226	
$D^*(2010)^- K^0 \pi^+$		(3.0 ± 0.8) $\times 10^{-4}$	2205	

+

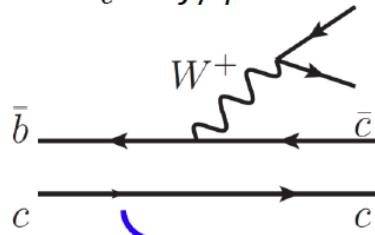
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B_c Decays

- They decay through weak interaction.
- Different processes:

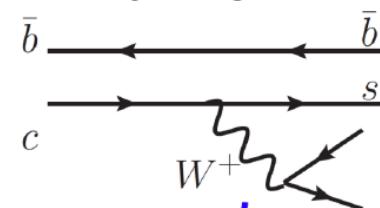
➤ $\bar{b} \rightarrow \bar{c}$ transition

$$B_c^+ \rightarrow J/\psi l^+ \nu_l$$
$$B_c^+ \rightarrow J/\psi \pi^+$$



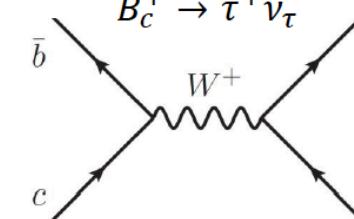
➤ $c \rightarrow s$ transition

$$B_c^+ \rightarrow B_s^0 l^+ \nu_l$$
$$B_c^+ \rightarrow B_s^0 \pi^+$$



➤ $c\bar{b} \rightarrow W^+$ annihilation

$$B_c^+ \rightarrow \bar{K}^{*0} K^+$$
$$B_c^+ \rightarrow \phi K^+$$
$$B_c^+ \rightarrow \tau^+ \nu_\tau$$



Spectator modes

annihilation modes

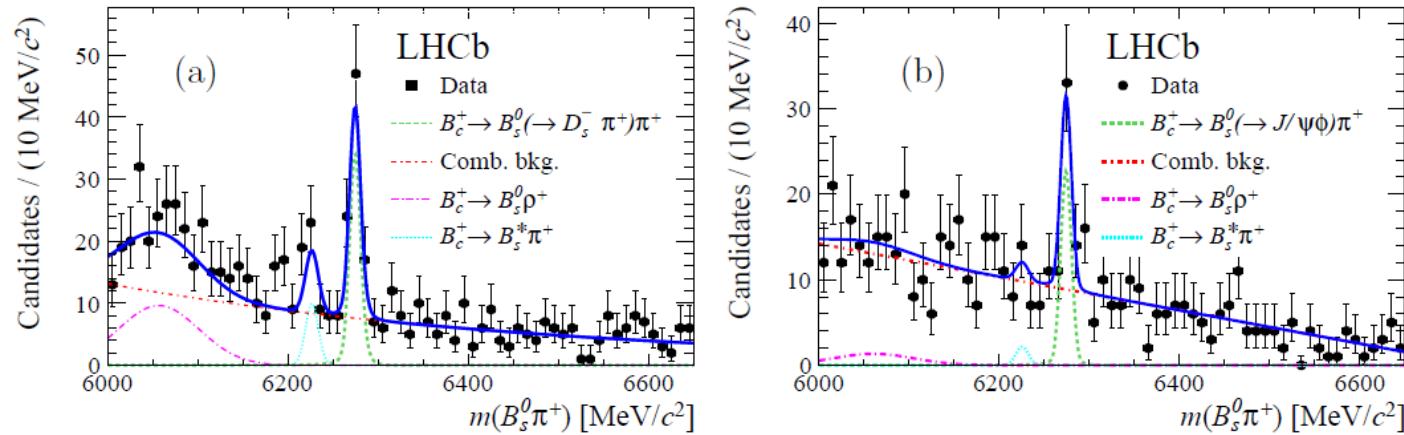
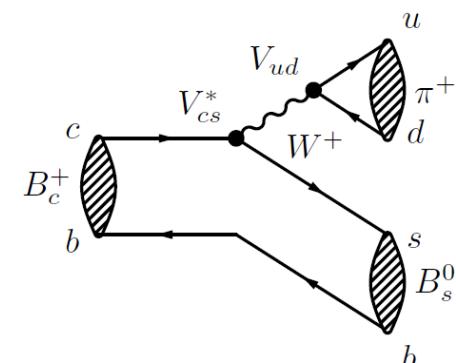
4

- Proportion of the different modes is linked to the B_c lifetime (~ 0.4 ps): important to measure precisely its lifetime.

$B_c^+ \rightarrow B_s^0 \pi^+$

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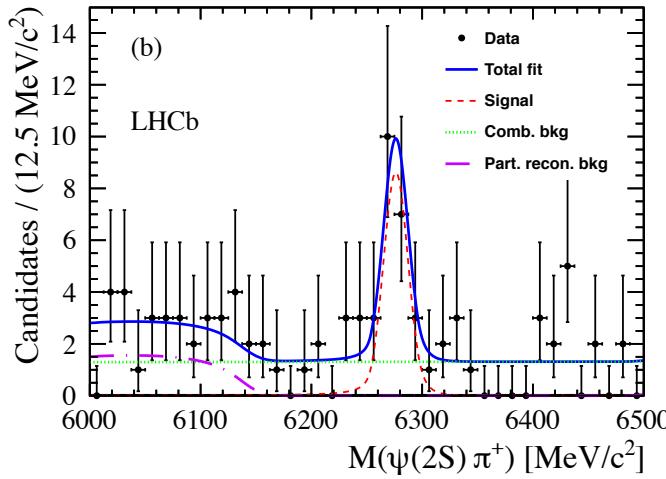
- First observation of a decay with a b spectator quark.
- Important to know dilution due to B_s^0 from B_c^+ decays in B_s^0 CP violation measurements
- B_s^0 reconstructed in the $J/\psi \phi$ and $D_s \pi$ modes.



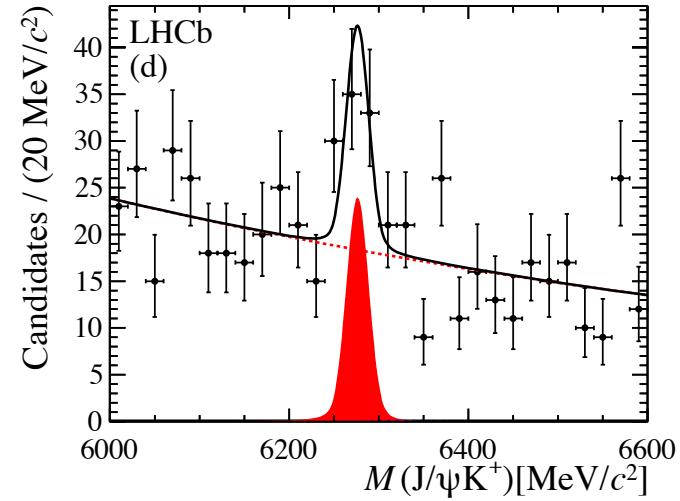
$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \rightarrow B_s^0 \pi^+) = (2.38 \pm 0.35 \text{ (stat)} \pm 0.11 \text{ (syst)} {}^{+0.17}_{-0.12} (\tau_{B_c^+})) \times 10^{-3}$$

$B_c^+ \rightarrow J/\psi \pi^+$ and friends

- $B_c^+ \rightarrow J/\psi \pi^+$ is the reference decay mode
- Similar modes discovered:
 - $B_c^+ \rightarrow \psi(2S) \pi^+$ [[Phys. Rev. D 87 \(2013\) 071103](#)]
 - Cabibbo suppressed counterpart, $B_c^+ \rightarrow J/\psi K^+$ [[J. High Energy Phys. 09 \(2013\) 075](#)]
 - Measured consistent with expectations



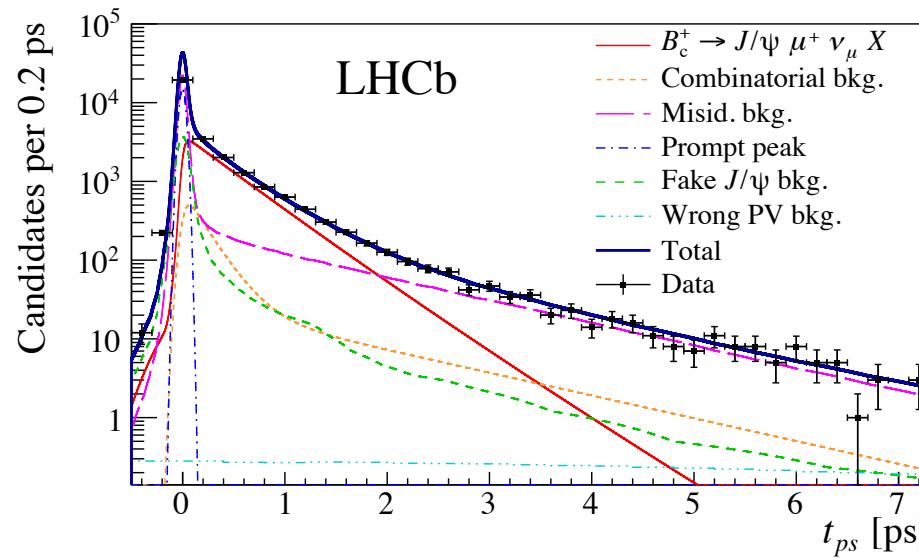
$$\frac{\mathcal{B}(B_c^+ \rightarrow \psi(2S)\pi^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi\pi^+)} = 0.250 \pm 0.068 \text{ (stat)} \pm 0.014 \text{ (syst)} \pm 0.006 \text{ } (\mathcal{B})$$



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

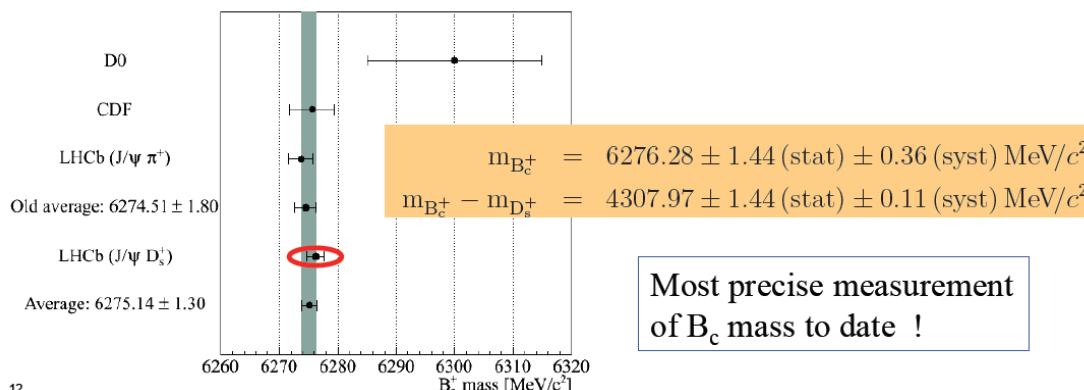
B_c^+ lifetime

- Measured with semi-leptonic decays [arXiv:1401.6932]
- $\tau=509\pm8\pm12$ fs, most precise measurement to date, with uncertainty half of the previous average
- Measurement ongoing with $B_c \rightarrow J/\psi \pi^+$ decays (smaller systematic uncertainty)



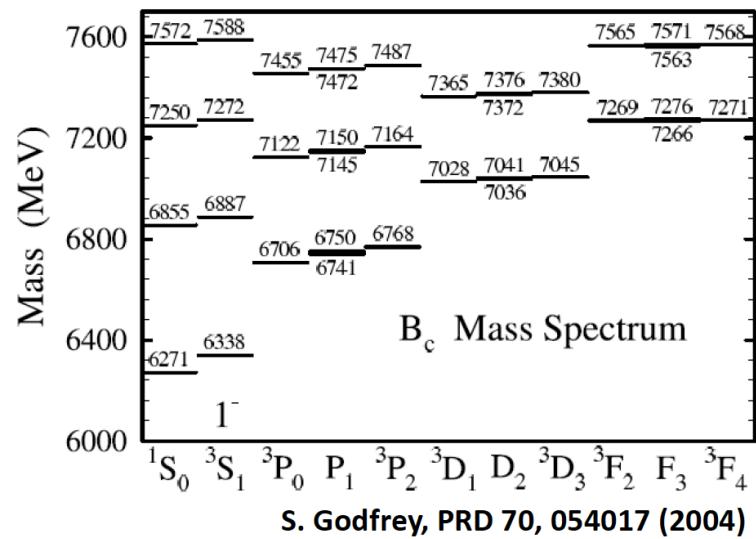
Other B_c^+ measurements in LHCb

- I showed only the measurements where we were involved but others were done with LHCb data:
 - Observation of $B_c^+ \rightarrow J/\psi K^+ K^- \pi^+$ [arXiv:1309.0587]
 - Observation of $B_c^+ \rightarrow J/\psi \pi^+ \pi^- \pi^+ \pi^- \pi^+$ [arXiv:1404.0287]
 - Observation of $B_c^+ \rightarrow J/\psi D_s^{(*)+}$ [[Phys. Rev. D 87 \(2013\) 112012](#)]
 - Mass measurement with $B_c^+ \rightarrow J/\psi \pi^+$ and $J/\psi D_s^+$



Future of our project

- Precise production cross-section: in collaboration with Cagliari (G. Manca), with 3fb^{-1} of data
- Search of excited states:
 - Decaying to $B_c\gamma$, $B_c\pi^0$, $B_c\pi^+\pi^-$ or BD if above threshold
 - Important to understand cross-section
 - There could be exotic (BD molecules or tetraquarks) similar to the $X(3872)$ in the charmonium sector
- No absolute branching fraction is known yet: measure as many modes as possible to constrain them:
 - In particular, annihilation modes, like $B_c^+ \rightarrow \phi K^+$
 - Triply charmed decays, like $B_c^+ \rightarrow J/\psi D^0 K^+$



Conclusions

- LHCb searching for indirect evidence of New Physics through precision measurements, excellent results, but no sign of deviation from Standard Model
- LAL/Tsinghua collaboration involved in many of the B_c results from LHCb
- Upgrade of the experiment will increase a lot the statistics available

