Properties and decays of b hadrons at LHCb

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on behalf of the LHCb collaboration

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RÉGION AUTONOME VALLÉE D'AOSTE
Assessorat de l'Éducation et de la Culture

INFN Istituto Nazionale di Fisica Nucleare

Outline

- LHCb detector
- First observation of $B_{s2}^{*}(5840)^{0} \to B^{*+}K^{-}$
- First observation of $B_{s}^{0} \to \psi(2S)\eta$ and $B_{(s)}^{0} \to \psi(2S)\pi^{+}\pi^{-}$ **First time presented**
- Λ_{b}^{0} baryon production polarization
- J^{PC} of $X(3872)$ determination in B^{+} decay **First time presented**
- Conclusions

See followed YSF session for

B_c physics at LHCb by Lucio Anderlini

b-baryon masses by Raphael Maerki

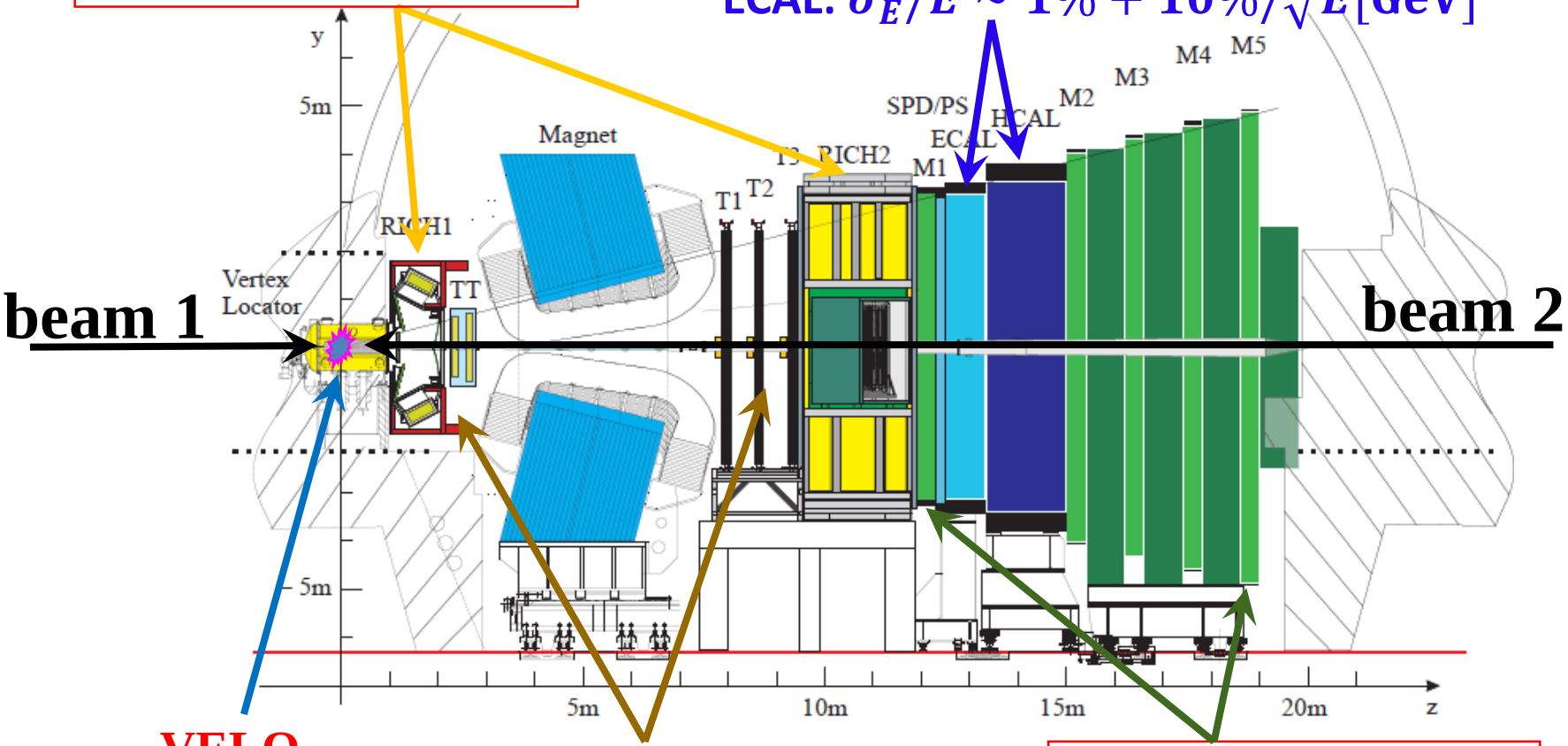
LHCb detector

JINST 3 (2008) S08005

Pseudorapidity acceptance
$2 < \eta < 5$

RICH1 & RICH2
$\epsilon(K \to K) \sim 95\%$
$\pi \to K$ mis-id: $\sim 5\%$

Calorimeters
ECAL: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\text{GeV}]}$

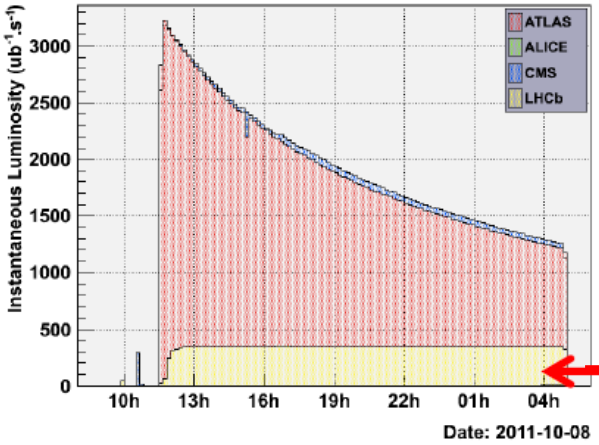


VELO
$\sigma_{IP} \sim 20$ μm
for high-p_T tracks

Tracking System
$\Delta p/p = 0.4\%@5\ \text{GeV}/c$
to $0.6\%@100\ \text{GeV}/c$

Muon System
$\epsilon(\mu \to \mu) \sim 97\%$
$\pi \to \mu$ mis-id: $1 \sim 3\%$

LHCb data taking

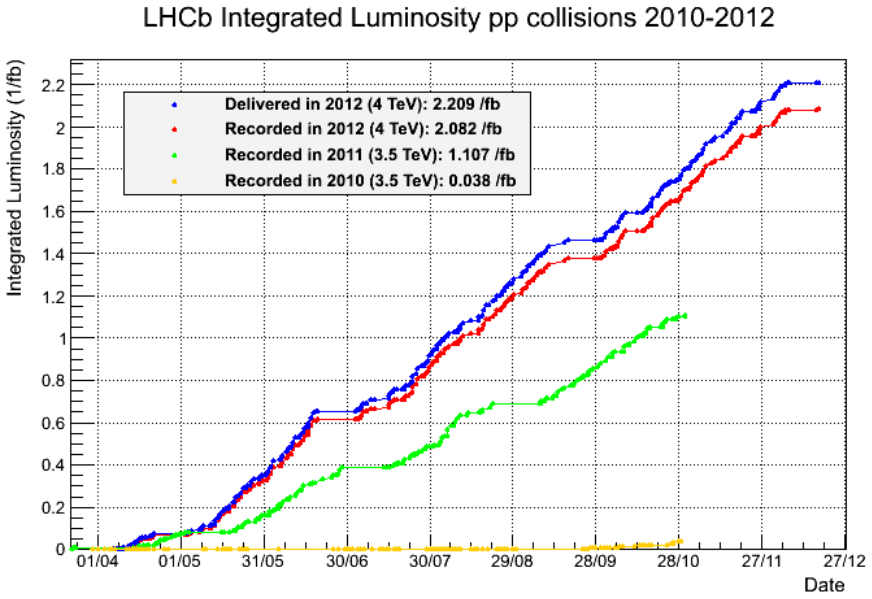


The Instantaneous luminosity

Luminosity leveling

- $\mathcal{L} \sim 4 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ ($2 \times$ design)
- Average pile-up rate ~ 2 ($4 \times$ design)

  (much lower than CMS and ATLAS)
- Beam overlap continuously adjusted to keep luminosity flat at optimal level



2012 ($2.1\ \mathrm{fb}^{-1}$ @8 TeV)

2011 ($1.0\ \mathrm{fb}^{-1}$ @7 TeV)

Results shown followed based on 2011 dataset

2010 ($37\ \mathrm{pb}^{-1}$ @7 TeV)

Stable and efficient (> 90%) data taking

First observation of $B_{s2}^{*}(5840)^{0} \to B^{*+}K^{-}$

[LHCb-PAPER-2012-030; arXiv: 1211.5994]

(Accepted by PRL)

Motivation

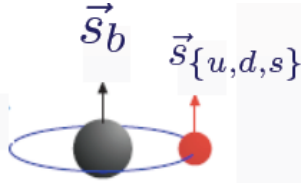
- HQET is an important tool for heavy quark physics
- Sensitive test to make precise measurements of *B* meson properties

Total angular momentum of B meson:

$$\vec{J} = \vec{j} + \vec{s}_b$$

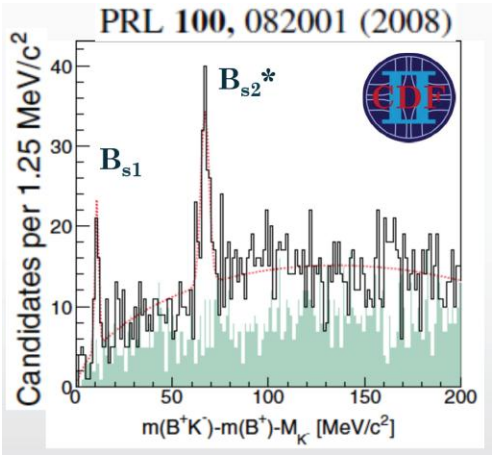
$$\hookrightarrow = \vec{L} + \vec{s}_{\{u,d,s\}}\ ,$$ angular momentum of the light quark

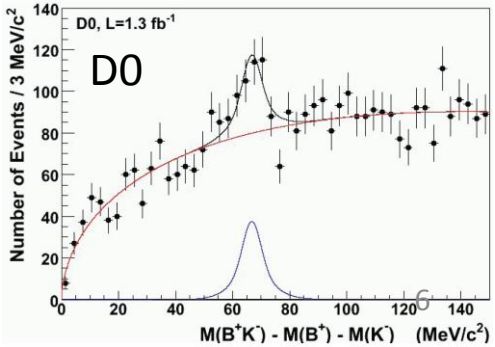
↳ relative orbital angular momentum of the two quarks



Orbitally excited B_s^0 states ($L = 1$)

	j_s	J^P	Allowed mode B^+K^-	Allowed mode $B^{*+}K^-$	Mass (MeV/c^2)
B_{s0}^*	$1/2$	0^+	Yes	No	Unobserved
B_{s1}'	$1/2$	1^+	No	Yes	Unobserved
B_{s1}	$3/2$	1^+	No	Yes	5829.4 ± 0.7
B_{s2}^*	$3/2$	2^+	Yes	Yes	5839.7 ± 0.6





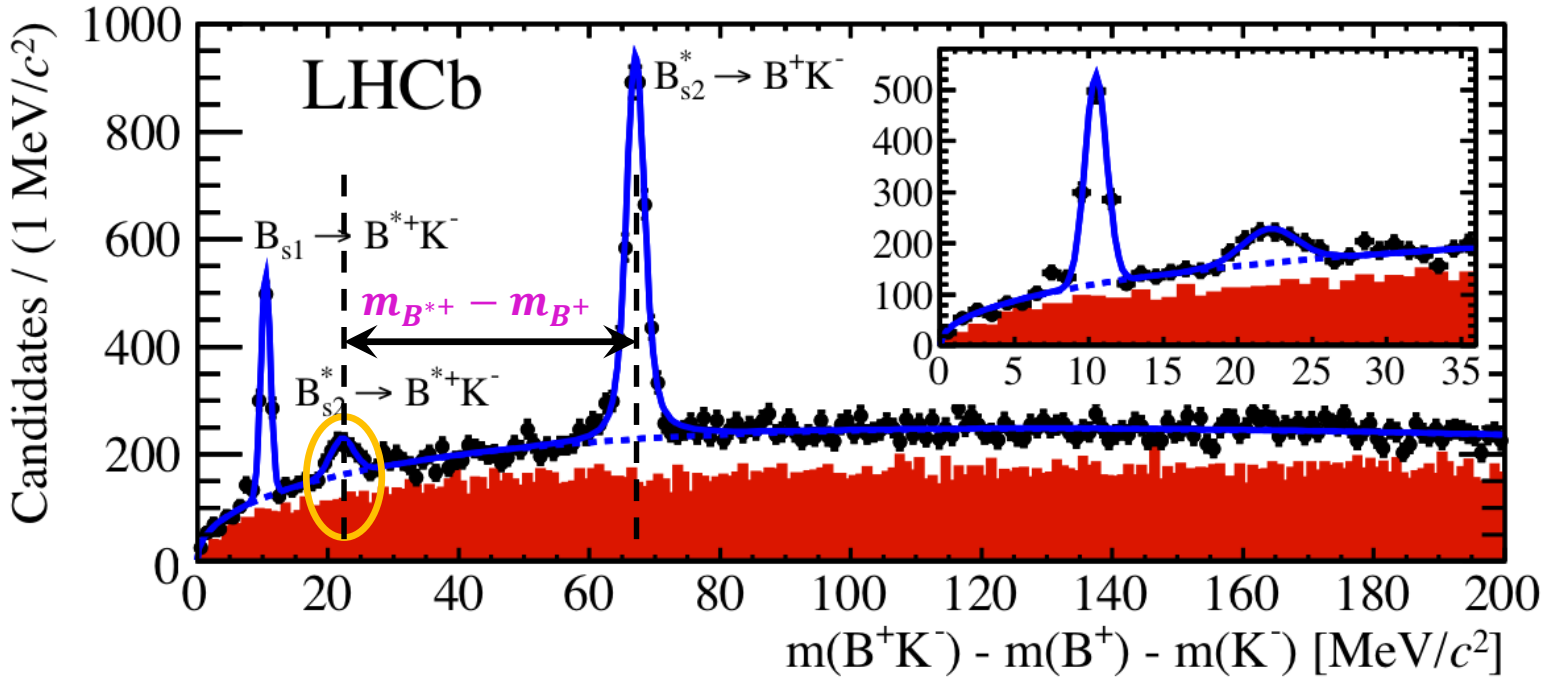
- **CDF observed two narrow peaks in B^+K^- mass spectrum**: $B_{s2}^* \to B^+K^-$ and feed-down of $B_{s1} \to B^{*+}K^-$
- **D0 confirmed B_{s2}^*, but not B_{s1}**

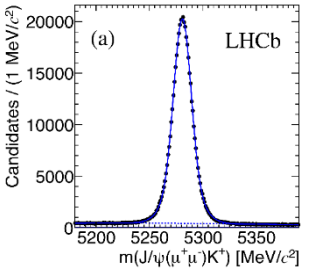
Selection of B^+K^- candidates

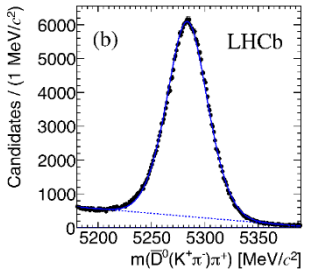
LHCb-PAPER-2012-030
arXiv: 1211.5994

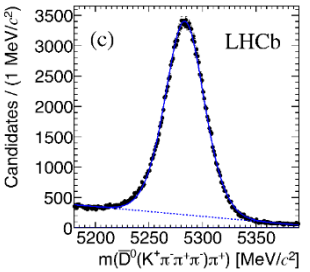
$B^+ \to J/\psi(\to \mu^+\mu^-)K^+$
$B^+ \to \overline{D}^0(\to K^+\pi^-)\pi^+$
$B^+ \to \overline{D}^0(\to K^+\pi^-)\pi^+\pi^-\pi^+$
$B^+ \to \overline{D}^0(\to K^+\pi^-\pi^+\pi^-)\pi^+$

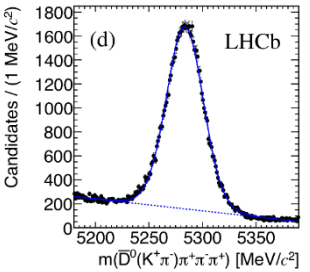
- High purity B^+ samples in 4 decay modes
  - ✓ ~ 1 M of B^+ candidates, purity $\sim 90\%$
- BDT is used for optimization











- $B^*_{s2} \to B^+K^-$ and $B_{s1} \to B^{*+}K^-$ peaks observed
- New structure seen around 20 MeV, identified as $B^*_{s2} \to B^{*+}K^-$

Results

LHCb-PAPER-2012-030
arXiv: 1211.5994

$$m(B^{*+}) = 5324.26 \pm 0.30_{\text{stat}} \pm 0.23_{\text{syst}} \pm 0.17_{B^+\text{ mass}} \quad \text{MeV}/c^2$$
$$m(B_{s1}) = 5828.40 \pm 0.04_{\text{stat}} \pm 0.04_{\text{syst}} \pm 0.41_{B^{*+}\text{ mass}} \quad \text{MeV}/c^2$$
$$m(B^*_{s2}) = 5839.99 \pm 0.05_{\text{stat}} \pm 0.11_{\text{syst}} \pm 0.17_{B^+\text{ mass}} \quad \text{MeV}/c^2$$
$$\Gamma(B^*_{s2}) = 1.56 \pm 0.13_{\text{stat}} \pm 0.47_{\text{syst}} \quad \text{MeV}/c^2$$
$$\frac{\mathcal{B}(B^*_{s2}\to B^{*+}K^-)}{\mathcal{B}(B^*_{s2}\to B^{+}K^-)} = \left(9.3 \pm 1.3_{\text{stat}} \pm 1.2_{\text{syst}}\right)\%$$
$$\frac{\sigma(pp\to B_{s1}X)\times\mathcal{B}(B_{s1}\to B^{*+}K^-)}{\sigma(pp\to B^*_{s2}X)\times\mathcal{B}(B^*_{s2}\to B^{+}K^-)} = \left(23.2 \pm 1.4_{\text{stat}} \pm 1.3_{\text{syst}}\right)\%$$

(Accepted by PRL)

Systematics are mostly dominated by mass resolution and selection of B^+.

- Confirmation of the B_{s1} state
- Most precise mass measurements for B_{s1}, B^*_{s2} and B^{*+}
- First observation of $B^*_{s2} \to B^{*+}K^-$ decay (8.0σ)
- First measurement of B^*_{s2} natural width
- The measured branching ratio and B^*_{s2} natural width favours $J^P = 2^+$

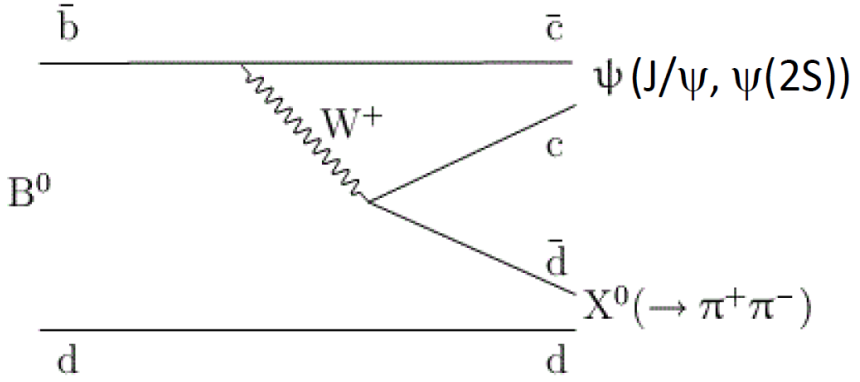
First time presented

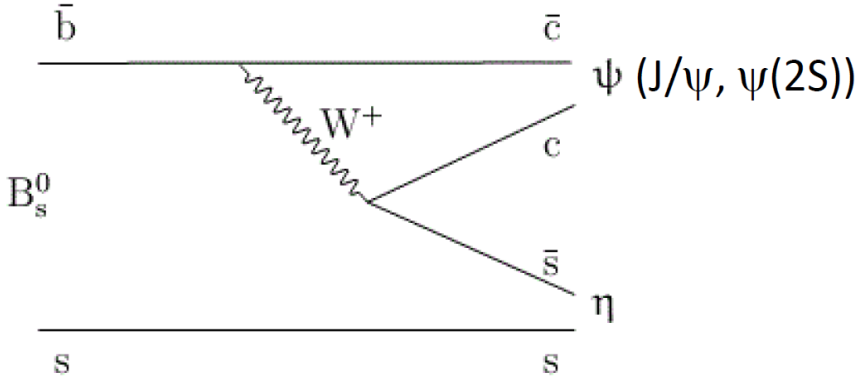
First observation of $B_s^0 \to \psi(2S)\eta$
and $B_{(s)}^0 \to \psi(2S)\pi^+\pi^-$
[LHCb-PAPER-2012-053]

Motivation

➢ B meson decays containing J/ψ or $\psi(2S)$ in final state play a crucial role in CP violation study and in precise measurement of neutral B meson mixing parameters

- Sensitive for electroweak transitions study
- Direct probe of charmonium properties
- Possible future measurement of B_s mixing phase φ_s in $B_s \to \psi(2S) f_0(980)$
- Possible channel for CP-asymmetry measurements in $B_s \to J/\psi\eta$ and $B_s \to \psi(2S)\eta$

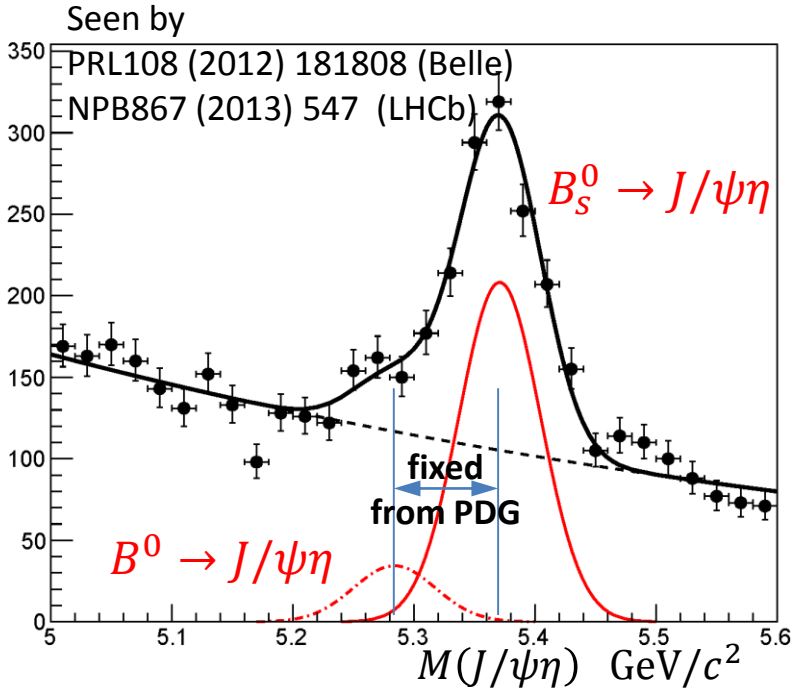


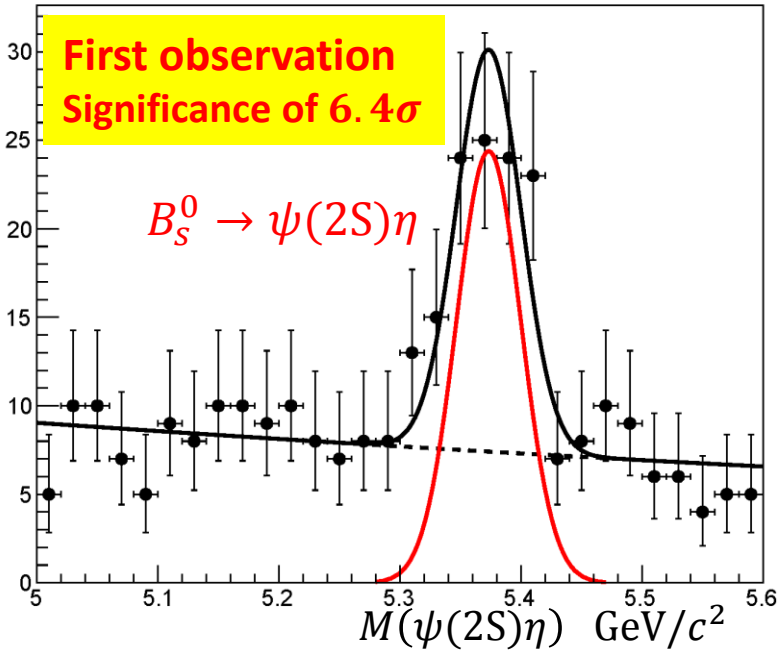


Observation of $B_s^0 \to \psi(2S)\eta$

LHCb-PAPER-2012-053

LHCb preliminary





- Signal: Gaussian ; Background: **exponential**
- $J/\psi\eta$: additional Gaussian for contribution from B^0, same mass resolution to B_s^0, and fixed $\Delta M = M_{B_s^0}^{\mathrm{PDG}} - M_{B^0}^{\mathrm{PDG}}$

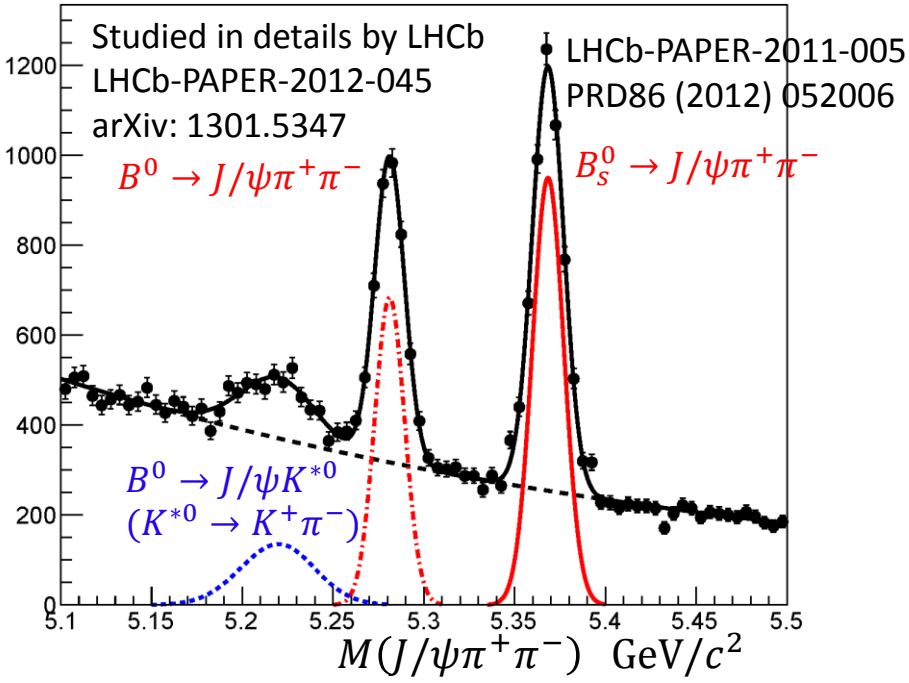
Mode	N_B	$M_B[\mathrm{MeV}/c^2]$	$\sigma_B[\mathrm{MeV}/c^2]$	Significance
$B_s^0 \to J/\psi\eta$	863 ± 52	5370.9 ± 2.3	33.7 ± 2.3	
$B_s^0 \to \psi(2S)\eta$	76 ± 12	5373.4 ± 5.0	26.6 fixed	$6.4\,\sigma$

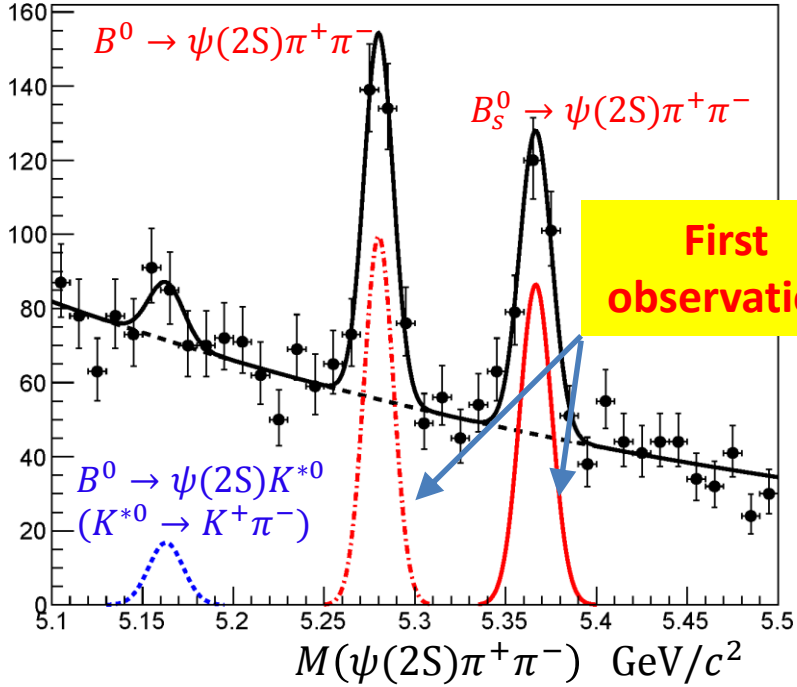
$$\sigma_{\mathrm{DATA}}^{\psi(2S)\eta} = \sigma_{\mathrm{DATA}}^{J/\psi\eta} \times \sigma_{\mathrm{MC}}^{\psi(2S)\eta} / \sigma_{\mathrm{MC}}^{J/\psi\eta}$$

Observation of $B^0_{(s)} \to \psi(2S)\pi^+\pi^-$

LHCb-PAPER-2012-053

LHCb preliminary





- Signal: Gaussian ; Background: **exponential**
- Bifurcated Gaussian for contribution from $B^0 \to J/\psi K^{*0}$ or $B^0 \to \psi(2S)K^{*0}$, where $K^{*0} \to K^+\pi^-$ and kaon misidentified as pion

Mode	N_B	$M_B[\mathrm{MeV}/c^2]$	$\sigma_B[\mathrm{MeV}/c^2]$	Significance
$B^0 \to J/\psi\pi^+\pi^-$	2801 ± 85	5281.1 ± 0.3	8.2 ± 0.3	
$B^0_s \to J/\psi\pi^+\pi^-$	4096 ± 86	5368.4 ± 0.2	8.7 ± 0.2	
$B^0 \to \psi(2S)\pi^+\pi^-$	202 ± 23	5280.3 ± 1.0	8.4 ± 1.1	$10.5\,\sigma$
$B^0_s \to \psi(2S)\pi^+\pi^-$	178 ± 22	5366.3 ± 1.2	9.1 ± 1.4	$9.3\,\sigma$

Results

LHCb-PAPER-2012-053

LHCb preliminary

NEW!

- First observed $B_s \to \psi(2S)\eta$ with significance of 6.4 σ
- $B^0 \to \psi(2S)\pi^+\pi^-$ with significance of 10.5 σ
- $B_s^0 \to \psi(2S)\pi^+\pi^-$ with significance of 9.3 σ

Dominant contributions from $B^0_{(s)} \to \psi(2S)\rho^0(770)$ and $B^0_{(s)} \to \psi(2S)f_0(980)$

- Measured relative branching ratios with respect to J/ψ channels

$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)\eta)}{\mathcal{B}(B_s^0 \to J/\psi\eta)} = 0.83 \pm 0.14_{\text{stat}} \pm 0.12_{\text{syst}} \pm 0.02_{\mathcal{B}}$$

$$\frac{\mathcal{B}(B^0 \to \psi(2S)\pi^+\pi^-)}{\mathcal{B}(B^0 \to J/\psi\pi^+\pi^-)} = 0.56 \pm 0.07_{\text{stat}} \pm 0.05_{\text{syst}} \pm 0.01_{\mathcal{B}}$$

$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\pi^+\pi^-)} = 0.34 \pm 0.04_{\text{stat}} \pm 0.03_{\text{syst}} \pm 0.01_{\mathcal{B}}$$

- Systematics dominated by data-MC disagreement
- The last uncertainties come from the use of the ratio

$$\frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{\mathcal{B}(\psi(2S) \to \mu^+\mu^-)} = \frac{\mathcal{B}(J/\psi \to e^+e^-)}{\mathcal{B}(\psi(2S) \to e^+e^-)} = 7.69 \pm 0.19$$

by invoking lepton universality.

Production polarisation of Λ_b^0 baryon

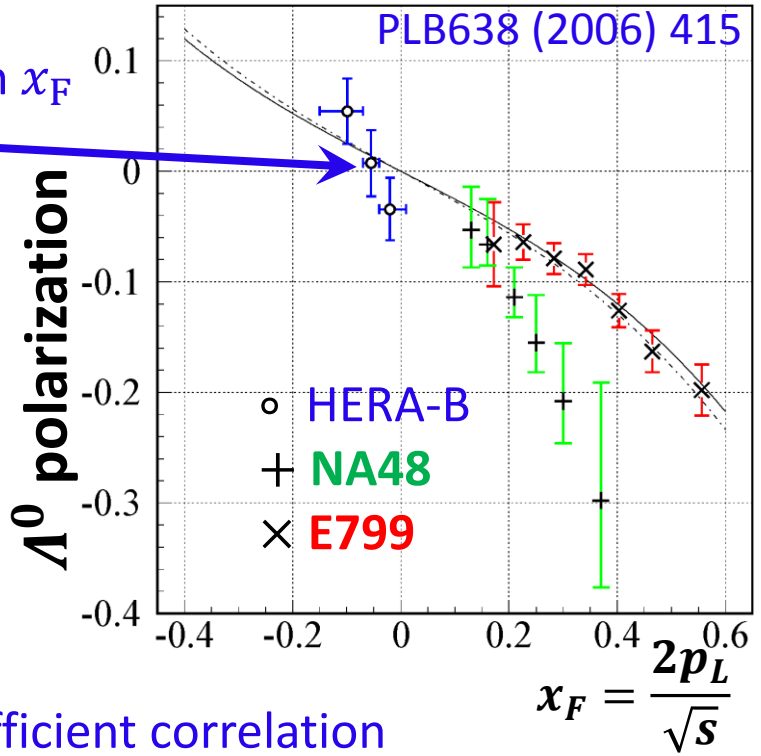
[LHCb-PAPER-2012-057; arXiv:1302.5578]

Motivation

- Λ_b^0 longitudinal polarisation vanishes, but transverse polarization could be large (~20%) [PLB 614 (2005) 165]
- Measured in $e^-e^+ \to Z^0 \to b\bar{b}$ (at LEP)
  But not yet at any hadron collider

- Hints from fixed target experiments:
  - ✓ Baryon polarization strongly depends on x_F
  - ✓ vanishes at $x_F \sim 0$ (Λ^0)

LHC: $x_F(\Lambda_b^0) \sim 0.02$ ➔ ?



- Decay chain

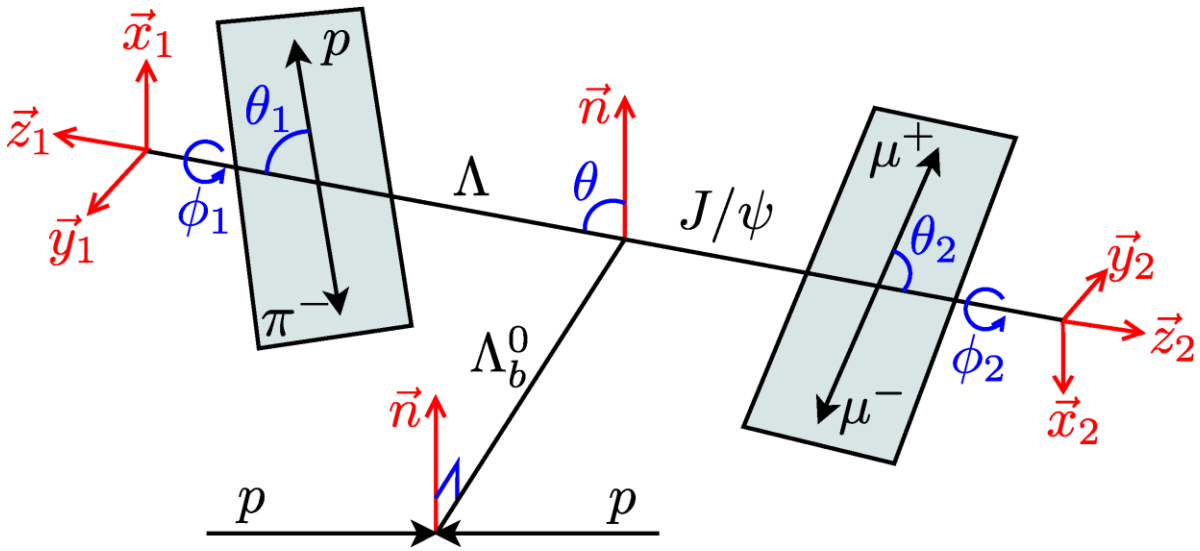
$$\Lambda_b^0 \to J/\psi \quad \Lambda$$
$$\hookrightarrow \mu^+\mu^- \quad \hookrightarrow p\pi^-$$

- ✓ J: $1/2 \to 1 + 1/2$ decay
- ✓ Final state angular distribution contains sufficient correlation to measure polarization and decay amplitudes

Definition of Angles

- The angular distribution depends on
  - ✓ Transverse polarization parameter P_b
  - ✓ $\Lambda \to p\pi^-$ decay asymmetry parameter α_Λ
  - ✓ 4 helicity amplitudes $(\mathcal{M}_{+\frac{1}{2},0}, \mathcal{M}_{-\frac{1}{2},0}, \mathcal{M}_{-\frac{1}{2},-1}, \mathcal{M}_{-\frac{1}{2},+1})$
  - ✓ 5 angles $(\theta, \theta_1, \theta_2, \phi_1, \phi_2)$

- θ : polar angle of $\vec{p}_\Lambda$ in Λ_b^0 rest-frame wrt $\vec{n} = \vec{p}_{\Lambda_b^0} \times \vec{p}_{\text{beam}}$
- θ_1, ϕ_1: polar and azimuthal angles of $\vec{p}_p$ in Λ rest-frame
- θ_2, ϕ_2: polar and azimuthal angles of $\vec{p}_{\mu^+}$ in J/ψ rest-frame



Angular distribution

After integrating over ϕ_1, ϕ_2 and amplitudes parameterization

$$\frac{d\Gamma}{d\Omega}(\cos\theta, \cos\theta_1, \cos\theta_2) = \frac{1}{16\pi}\sum_{i=0}^{7} f_i(\alpha_b, r_0, r_1)\, g_i(P_b, \alpha_\Lambda)\, h_i(\cos\theta, \cos\theta_1, \cos\theta_2)$$

Amplitudes parameterization
[Sov. J. Nucl. Phys. 43 (1986) 817]

$$r_0 \equiv |\mathcal{M}_{+\frac{1}{2},0}|^2 + |\mathcal{M}_{-\frac{1}{2},0}|^2$$
$$r_1 \equiv |\mathcal{M}_{+\frac{1}{2},0}|^2 - |\mathcal{M}_{-\frac{1}{2},0}|^2$$
$$\alpha_b \equiv r_1 + |\mathcal{M}_{-\frac{1}{2},-1}|^2 - |\mathcal{M}_{+\frac{1}{2},+1}|^2$$

Parity violation asymmetry
Parameter of $\Lambda_b^0 \to J/\psi\Lambda$

i	$f_i(\alpha_b, r_0, r_1)$	$g_i(P_b, \alpha_\Lambda)$	$h_i(\cos\theta, \cos\theta_1, \cos\theta_2)$
0	1	1	1
1	α_b	P_b	$\cos\theta$
2	$2r_1 - \alpha_b$	α_Λ	$\cos\theta_1$
3	$2r_0 - 1$	$P_b\alpha_\Lambda$	$\cos\theta\cos\theta_1$
4	$\frac{1}{2}(1 - 3r_0)$	1	$\frac{1}{2}(3\cos^2\theta_2 - 1)$
5	$\frac{1}{2}(\alpha_b - 3r_1)$	P_b	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta$
6	$-\frac{1}{2}(\alpha_b + r_1)$	α_Λ	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$
7	$-\frac{1}{2}(1 + r_0)$	$P_b\alpha_\Lambda$	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta\cos\theta_1$

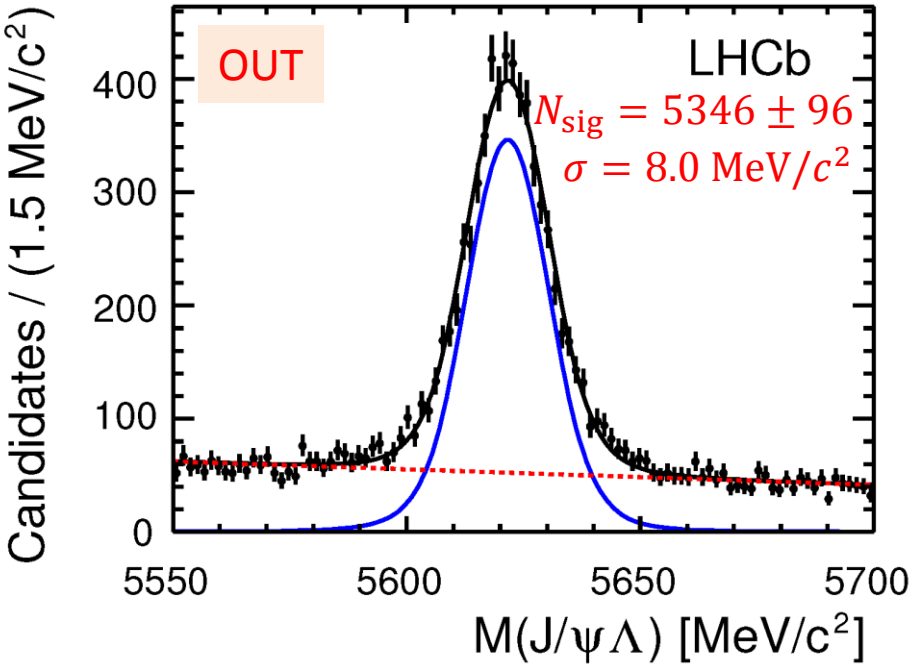
Λ decay asymmetry parameter $\alpha_\Lambda = 0.642 \pm 0.013$ (fixed to PDG value)

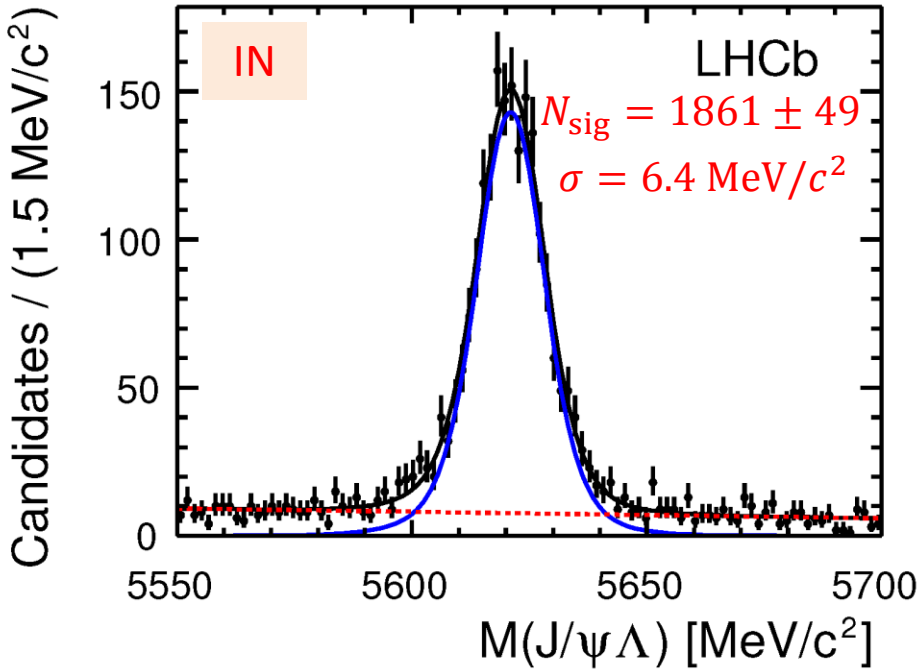
Four parameters $(P_b, \alpha_b, r_0, r_1)$ have to be measured simultaneously from the angular distribution.

$\Lambda_b^0 \to J/\psi\Lambda$ signals

LHCb-PAPER-2012-057
arXiv: 1302.5578

- Λ can decay inside (IN) or outside (OUT) of the vertex detector
- BDT used after pre-selection to suppress background





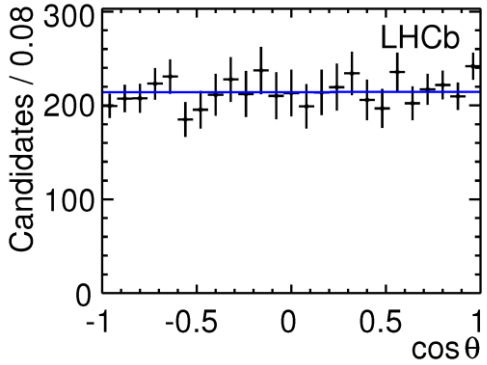
- Signal: sum of two Crystal ball sharing same mean and width
- Background: 1st order polynomial

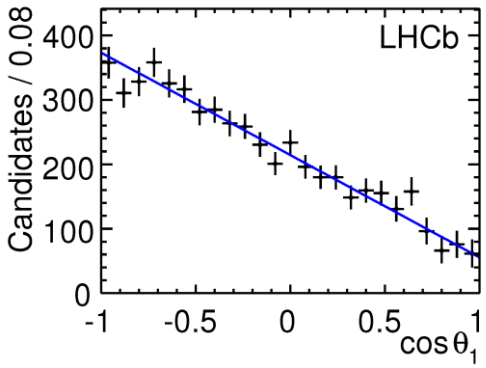
Angular distribution fit

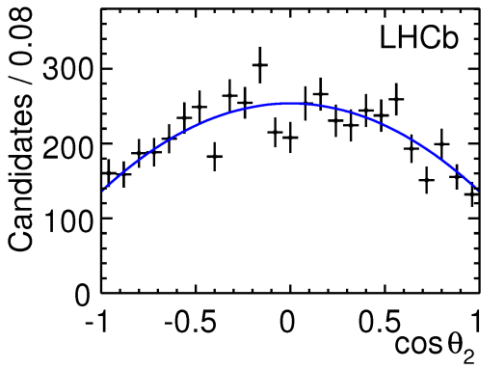
LHCb-PAPER-2012-057
arXiv: 1302.5578

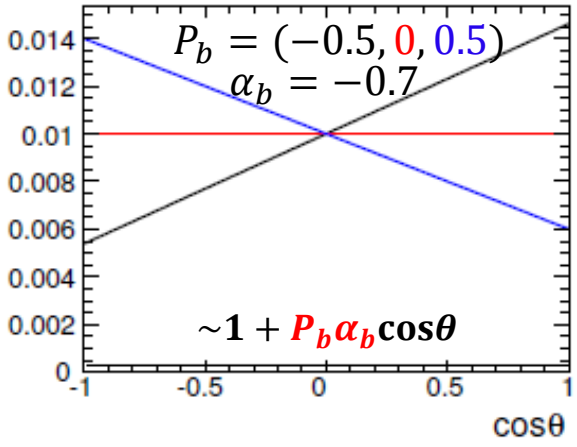
- Simultaneous (OUT + IN) unbinned likelihood fit
  - ✓ Background subtracted and acceptance corrected
  - ✓ Only signal PDF in the final fit

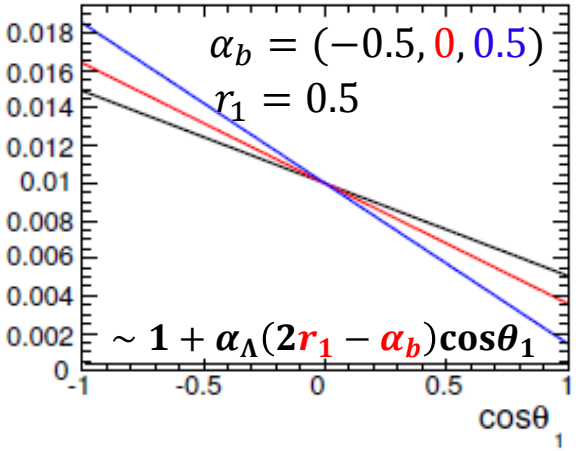
OUT (similar for IN)

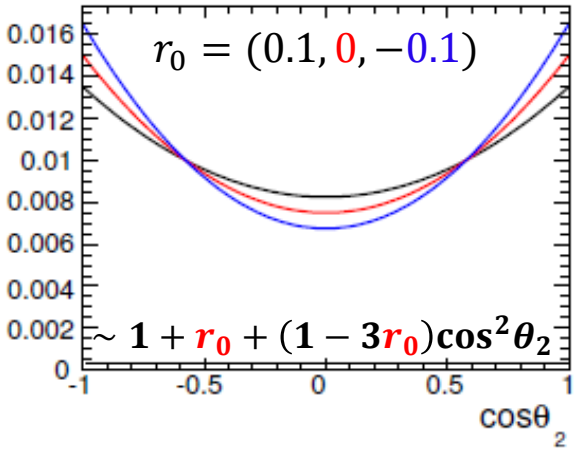












Since distribution of $\cos\theta$ is nearly flat, small polarization expected

Results

LHCb-PAPER-2012-057
arXiv: 1302.5578

➢ First measurements of the Λ_b^0 polarization P_b in pp collisions and parity-violation asymmetry parameter α_b

$$P_b = 0.05 \pm 0.07_{\text{stat}} \pm 0.02_{\text{syst}}$$
$$\alpha_b = -0.04 \pm 0.17_{\text{stat}} \pm 0.07_{\text{syst}}$$
$$r_0 = 0.57 \pm 0.02_{\text{stat}} \pm 0.01_{\text{syst}}$$
$$r_1 = -0.59 \pm 0.10_{\text{stat}} \pm 0.05_{\text{syst}}$$

- **Polarization parameter P_b**
  - ✓ cannot exclude order of 10% transverse polarization [PLB649 (2007) 152]
  - ✓ but disfavors 20% at the level of 2.7 σ [PLB614 (2005) 165]
- **Parity-violation asymmetry parameter α_b**
  - ✓ compatible with predictions ranging from -21% to -10% [PRD56 (1997) 2799 ; PRD58 (1998) 014016; PRD65 (2002)074030; PRD80 (2009) 094016; Prog. Theor. Phys. 101 (1999) 959]
  - ✓ but rejects HQET prediction of 77.7% at $6.1\ \sigma$ [PLB614 (2005) 165]

First time presented

J^{PC} of $X(3872)$ determination in B^+ decay

[LHCb-PAPER-2013-001]

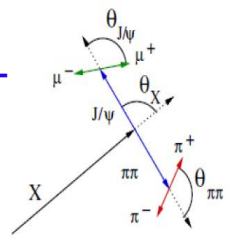
Motivation

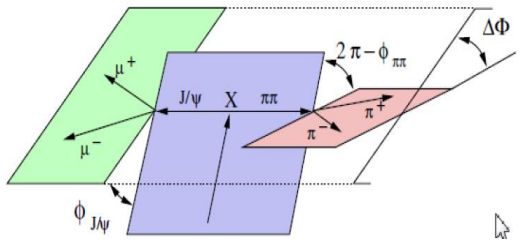
- **$X(3872)$ first discovered by Belle almost 10 years ago, but its nature still not clear**
  - ✓ C-parity is positive since $X(3872) \to J/\psi\gamma$ observed
  - ✓ CDF: excluded all but 1^{++} and 2^{-+} by binned 3D angular fit
    [PRL98 (2007) 132002]
  - ✓ BaBar: The observed mass distribution of ω in $X(3872) \to J/\psi\omega(\to \pi^+\pi^-\pi^0)$ favored 2^{-+}(CL=68%), but not ruled out 1^{++}(CL=7%)
    [PRD82 (2010) 011101]
  - ✓ Belle: 1D analysis on polarized $X(3872)$ could not distinguish between 1^{++} and 2^{-+}
    [PRD84 (2011) 052004]

- **Determination of quantum numbers is crucial for theoretical interpretation of this intriguing state**
  - ✓ 1^{++}: $\overline{D}^0 D^{*0}$ molecule? Tetra-quarks? $\chi_{c1}(2^3\mathrm{P}_1)$?
  - ✓ 2^{-+}: $\eta_{c2}(1^1D_2)$?

Analysis strategy

- Dataset: 2011 pp data, $\mathcal{L} = 1.0\ \mathrm{fb}^{-1}$
- Using decay chain $B^+ \to X(3872)\ K^+$
  $\hookrightarrow J/\psi\ \pi^+\pi^-$
  $\hookrightarrow \mu^+\mu^-$





- $B^+ \to \psi(2S)K^+$ as control channel
- Complete 5-dimensional angular correlations [PRL98 (2007) 132002]

$$|\mathcal{M}(\Omega|J_X)|^2 = \sum_{\Delta\lambda_\mu=-1,+1} \left| \sum_{\lambda_{J/\psi},\lambda_{\pi\pi}=-1,0,+1} A_{\lambda_{J/\psi},\lambda_{\pi\pi}} D^{J_X}_{0,\lambda_{J/\psi}-\lambda_{\pi\pi}}(\phi_X,\theta_X,-\phi_X) D^1_{\lambda_{\pi\pi},0}(\phi_{\pi\pi},\theta_{\pi\pi},-\phi_{\pi\pi}) D^1_{\lambda_{J/\psi},\Delta\lambda_\mu}(\phi_{J/\psi},\theta_{J/\psi},-\phi_{J/\psi}) \right|^2$$

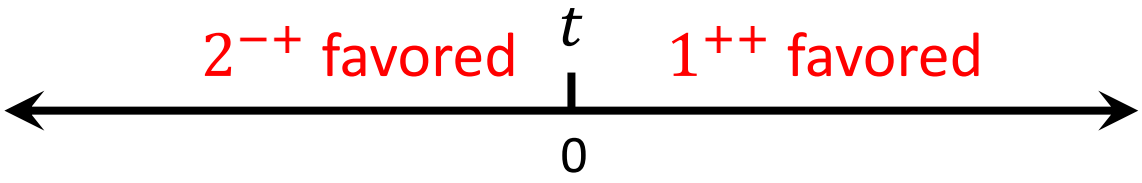
$\Omega \equiv (\cos\theta_X, \cos\theta_{\pi\pi}, \Delta\phi_{X,\pi\pi}, \cos\theta_{J/\psi}, \Delta\phi_{X,J/\psi})$

Helicity coupling $A_{\lambda_{J/\psi},\lambda_{\pi\pi}}$: no free parameter if 1^{++}

one complex parameter (α) if 2^{-+}

- Likelihood-ratio test to discriminate between 1^{++} and 2^{-+} hypotheses

$$t = -2\ln[\mathcal{L}(2^{-+})/\mathcal{L}(1^{++})]$$



Discriminant construction

- PDF in 5D angular space Ω

$$\mathcal{P}(\Omega|J_X) \propto |\mathcal{M}(\Omega|J_X)|^2 \epsilon(\Omega)$$

where $\mathcal{M}(\Omega|J_X)$: decay matrix element

$\epsilon(\Omega)$: efficiency

α to maximize $\mathcal{L}(2^{-+})$

Likelihood ratio test

$$t = -2\ln\left[\frac{\mathcal{L}(2^{-+})}{\mathcal{L}(1^{++})}\right] = -2s_w \sum_{i=1}^{N} w_i \ln \frac{\mathcal{P}(\Omega_i|2^{-+},\alpha)}{\mathcal{P}(\Omega_i|1^{++})}$$

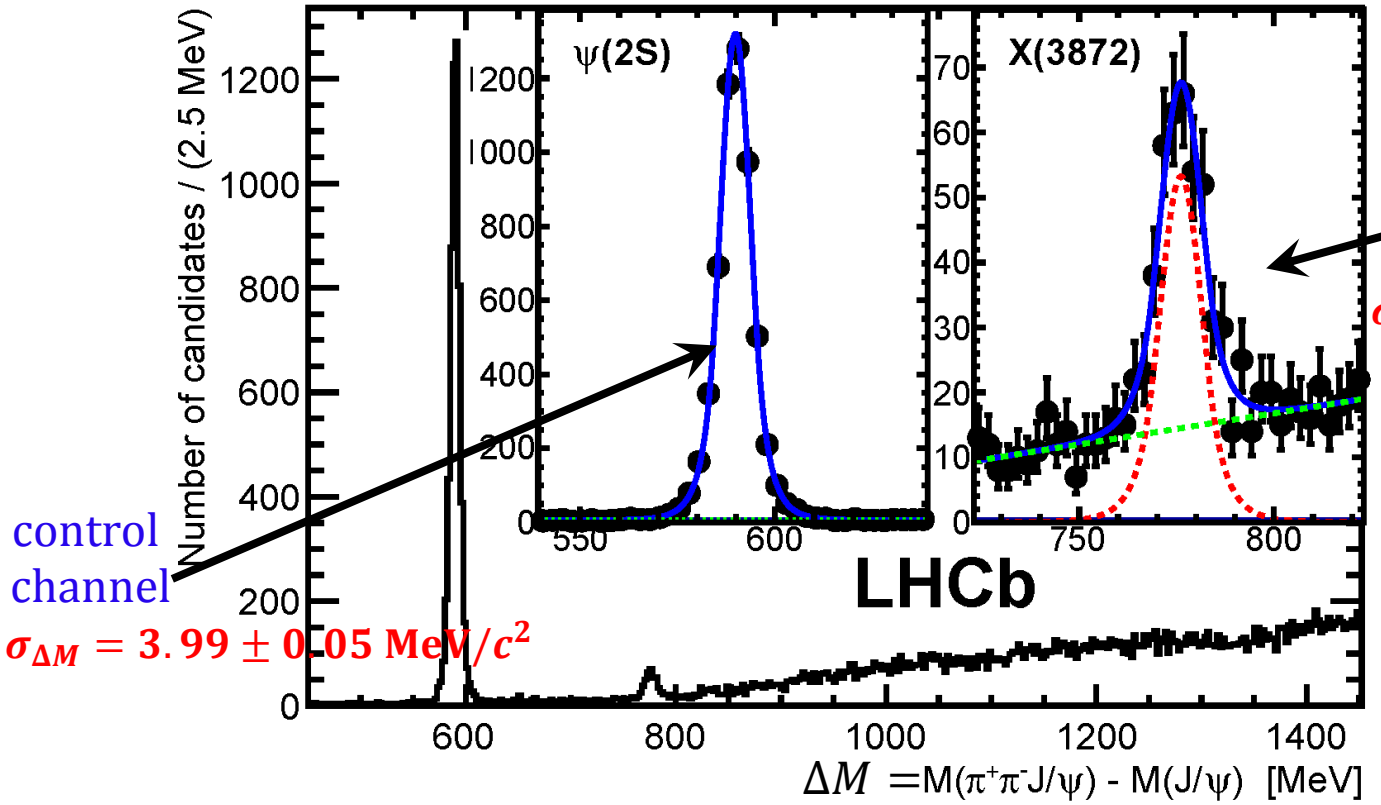
- ✓ Background subtracted by *sWeight*, w_i
- ✓ $s_w = \frac{\sum_{i=1}^{N_{\text{data}}} w_i}{\sum_{i=1}^{N_{\text{data}}} w_i^2}$: constant scaling factor accounts for statistical fluctuation in background subtraction

- Extensively tested on simulated samples

Selected sample

LHCb-PAPER-2013-001

LHCb preliminary



control channel

$\sigma_{\Delta M} = 3.99 \pm 0.05\ \mathrm{MeV}/c^2$

68% signal purity in $\pm 2.5\sigma_{\Delta M}$ region

$\sigma_{\Delta M} = 5.5 \pm 0.5\ \mathrm{MeV}/c^2$

- Signal: **symmetric Crystal Ball function**
- Background: **linear**
- $B^+ \to \psi(2S)K^+$: $N_{\mathrm{sig}} = 5642 \pm 76$
- $B^+ \to X(3872)K^+$: $N_{\mathrm{sig}} = 313 \pm 26$

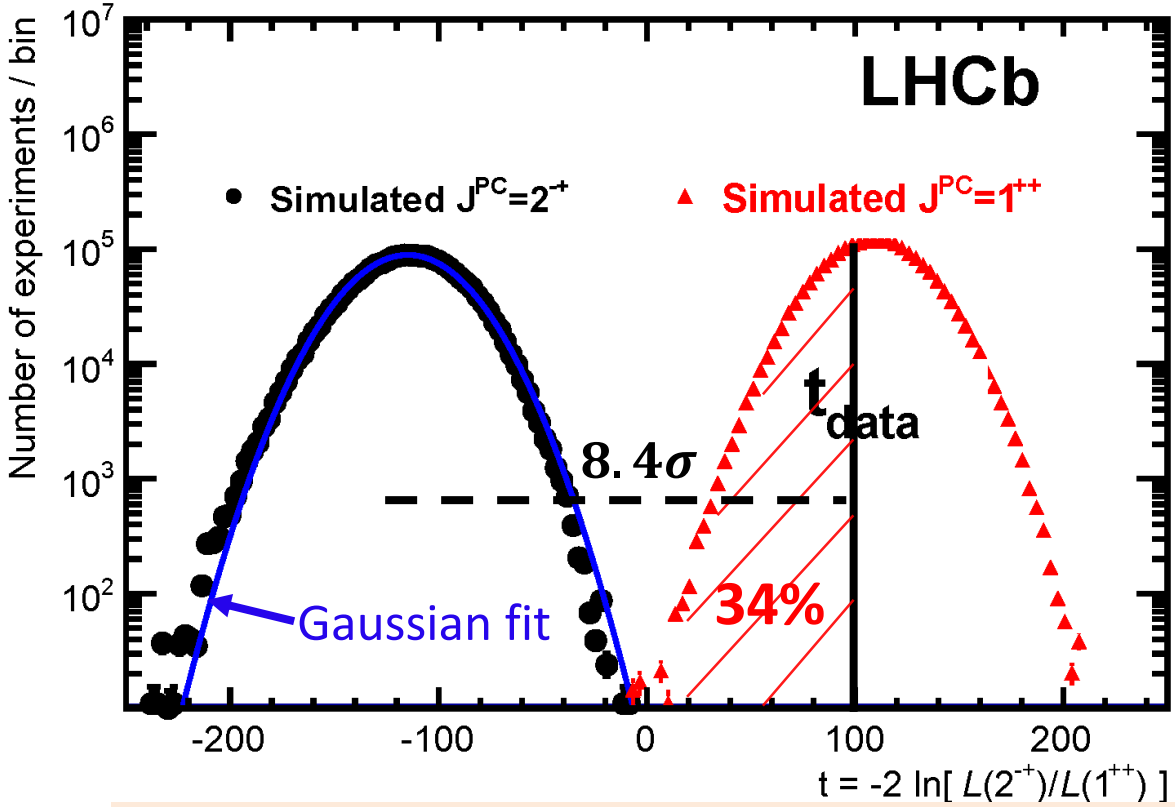
Results

LHCb-PAPER-2013-001

LHCb preliminary

NEW!

- $t_{\text{data}} = 99$ observed ➔ 1^{++} favored
- 2^{-+} rejected with a significance of 8.4σ
- 1^{++} p-value is high (34%)



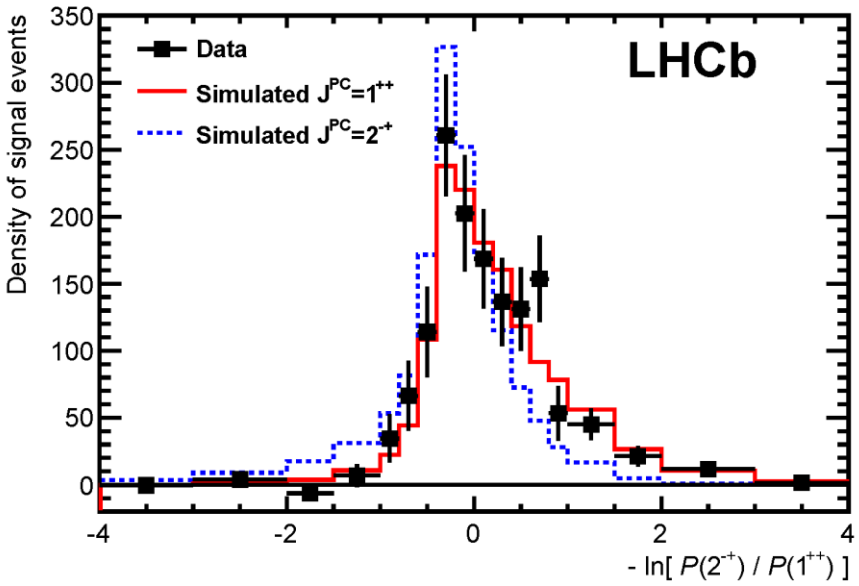
$\hat{\alpha} = 0.671_{\pm 0.046} + i\ 0.280_{\pm 0.046}$ maximize $\mathcal{L}(2^{-+})$, compatible with Belle $\alpha = 0.64 + i\ 0.27$

LHCb-PAPER-2013-001

LHCb preliminary

Additional checks

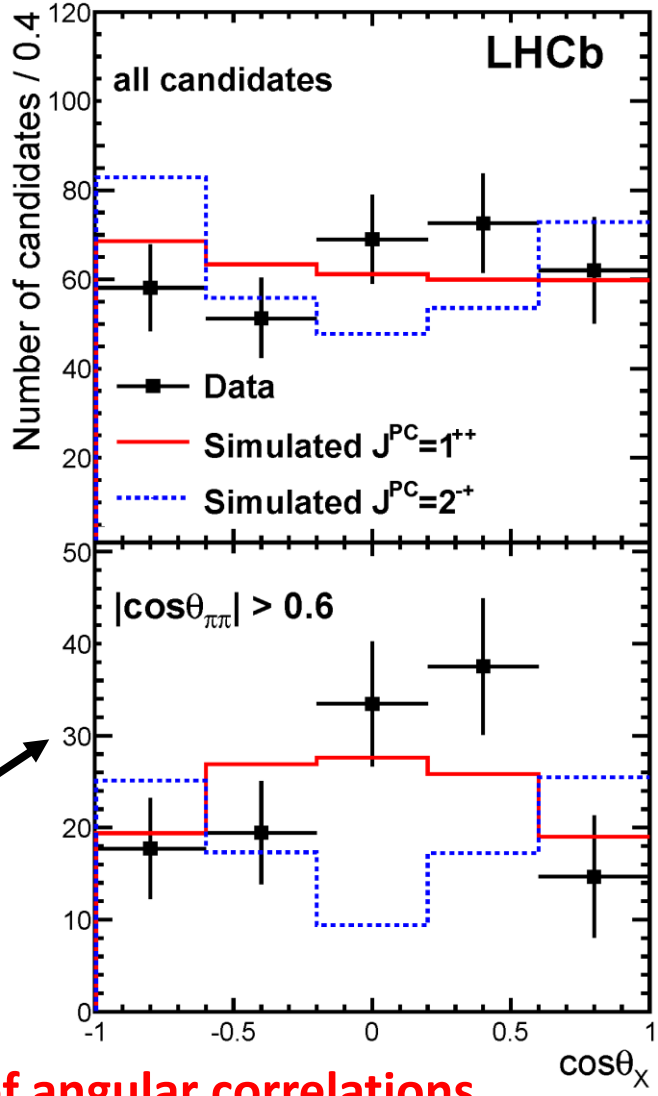
Binned distribution of single-event likelihood-ratios (background subtracted)



- Data shape consistent with 1^{++} simulation, inconsistent with 2^{-+}

➢ Separation between 1^{++} and 2^{-+} hypotheses increases when applying $|\cos\theta_{\pi\pi}| > 0.6$

1D projection onto $\cos\theta_X$ (Background subtracted)



Importance of angular correlations

Conclusions

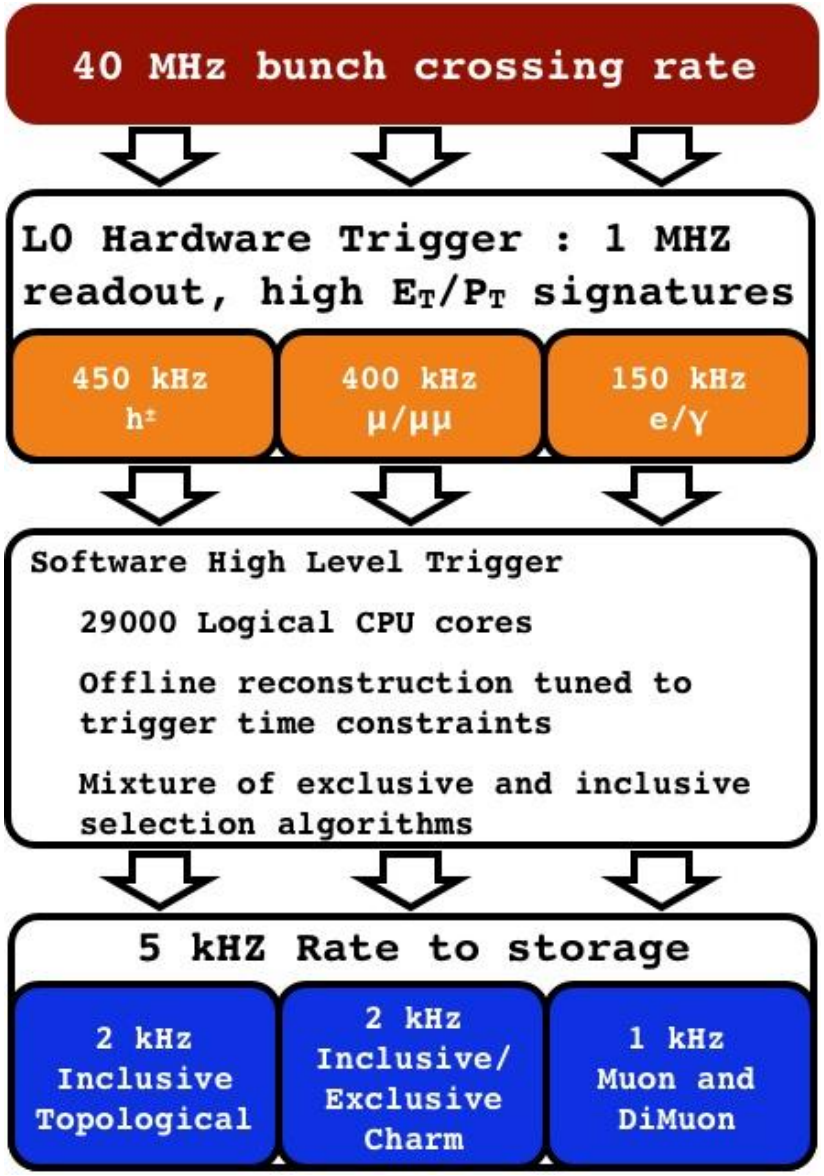
Thank you!

- **Orbitally excited B_s^0 states**
  - ✓ First observation of $B_{s2}^* \to B^{*+}K^-$ decay (8.0σ)
  - ✓ Most precise mass measurements for B_{s1}, B_{s2}^* and B^{*+}
  - ✓ First measurement of B_{s2}^* natural width
  - ✓ The measured branching ratio and B_{s2}^* natural width favors $J^P = 2^+$
- **First observation of $B_s^0 \to \psi(2S)\eta$ and $B_{(s)}^0 \to \psi(2S)\pi^+\pi^-$** NEW!
  - ✓ Measured relative branching ratios w.r.t. J/ψ channels LHCb preliminary
- **First measurements of the Λ_b^0 polarization P_b in pp collisions and parity-violation asymmetry parameter α_b**
  - ✓ $P_b = \quad 0.05 \pm 0.07_{\text{stat}} \pm 0.02_{\text{syst}}$
  - ✓ $\alpha_b = -0.04 \pm 0.17_{\text{stat}} \pm 0.07_{\text{syst}}$
- **Determined $J^{PC} = 1^{++}$ of $X(3872)$ in B^+ decay** NEW!
  - ✓ $J^{PC} = 2^{-+}$ rejected with a significance of 8.4σ LHCb preliminary
  - ✓ $J^{PC} = 1^{++}$ consistent with molecular, tetra-quark or $\chi_{c1}(2^3P_1)$-molecule mixture models

More results to come with 2012 dataset ($2.1\ \text{fb}^{-1}$, $\sqrt{s} = 8\ \text{TeV}$)

Backup slides

LHCb trigger



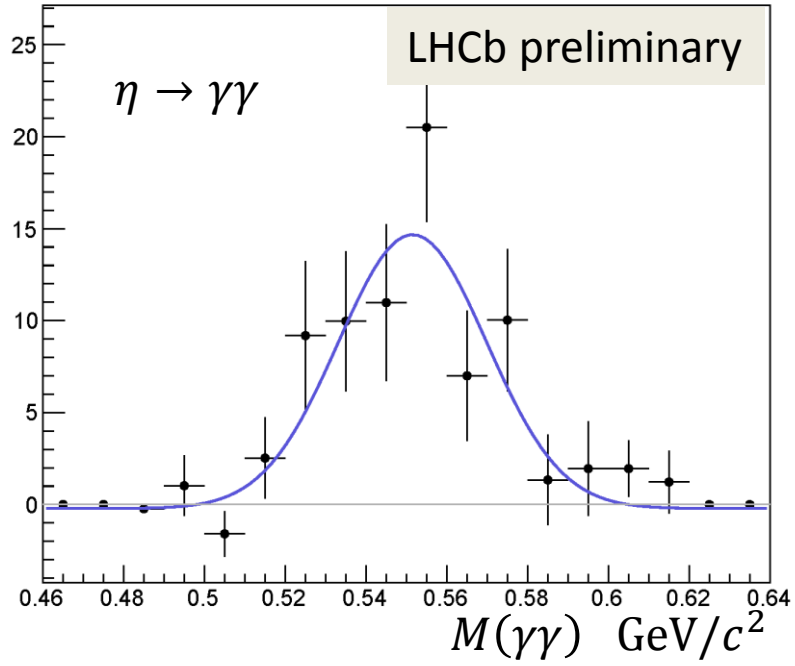
$B^0_{(s)}$ Selections

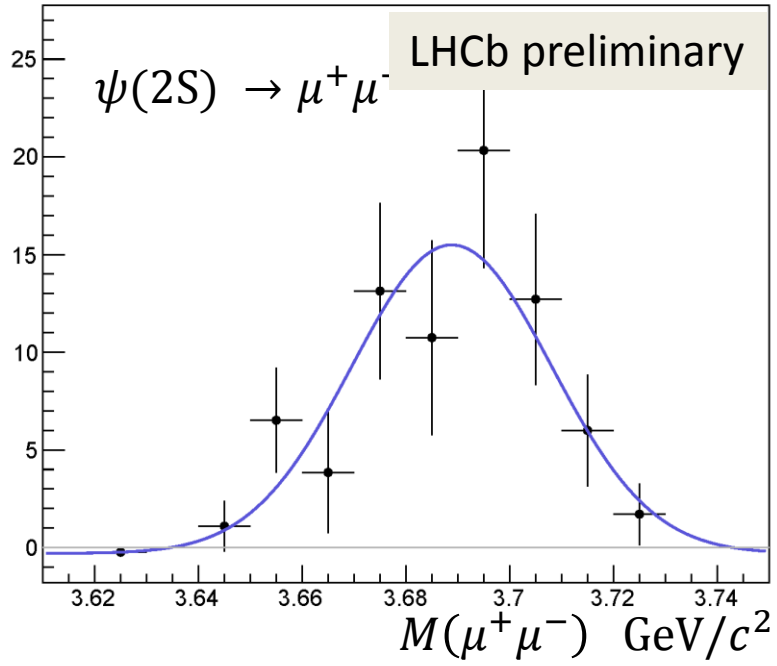
- Tracks ($\mu^\pm$, $\pi^\pm$)
  - ✓ $\chi^2_{\mathrm{tr}}/\mathrm{ndf} < 5$
  - ✓ $\chi^2_{\mathrm{IP}} > 9$
  - ✓ $p_{\mathrm{T}}(\mu) > 0.55\ \mathrm{GeV}/c$
  - ✓ $p_{\mathrm{T}}(\pi) > 0.25\ \mathrm{GeV}/c$
- PID
  - ✓ $\Delta\log\mathcal{L}_{\mu\mathrm{h}}(\mu) > 0$
  - ✓ $\Delta\log\mathcal{L}_{\pi K}(\mu) > 0$
- Photons
  - ✓ $E_{\mathrm{T}}(\gamma) > 0.4\ \mathrm{GeV}/c$
  - ✓ $p_{\mathrm{T}}(\eta) > 2.5\ \mathrm{GeV}/c$
- Vertices
  - ✓ $\chi^2_{\mathrm{VTX}}/\mathrm{ndf}(\psi) < 20$

- Mass windows
  - ✓ $M(\mu^+\mu^-)$ $\in [3020,3135]\ \mathrm{MeV}/c^2$ (J/ψ) $\in [3597,3730]\ \mathrm{MeV}/c^2$ $(\psi(2S))$
  - ✓ $M(\gamma\gamma) \in [480,620]\ \mathrm{MeV}/c^2$
  - ✓ π^0-VETO
- $B^0_{(s)}$ candidates
  - ✓ Kinematic fit performed
    - Mass constraints applied for J/ψ, $\psi(2S)$ and η
    - $\chi^2_{\mathrm{DTF}}/\mathrm{ndf} < 5$
  - ✓ Decay distance ($c\tau$) > 0.15 mm
  - ✓ Momentum vector points to associated primary vertex

Background subtracted $M(\gamma\gamma)$ and $M(\mu^+\mu^-)$

- To demonstrate $B_s^0 \to \psi(2S)\eta$ signals, sPlot technique is applied to obtain the intermediate resonances $\eta \to \gamma\gamma$ and $\psi(2S) \to \mu^+\mu^-$

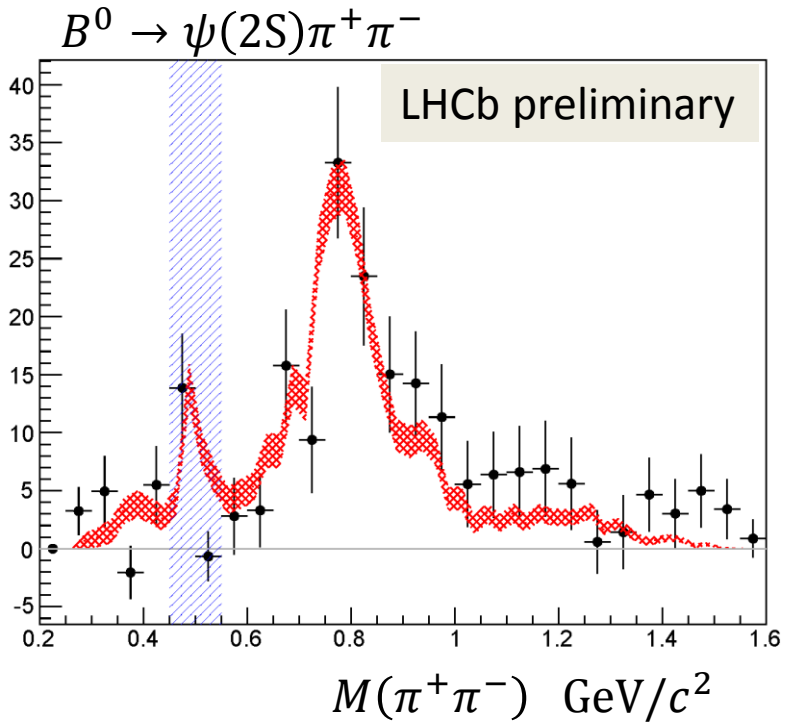


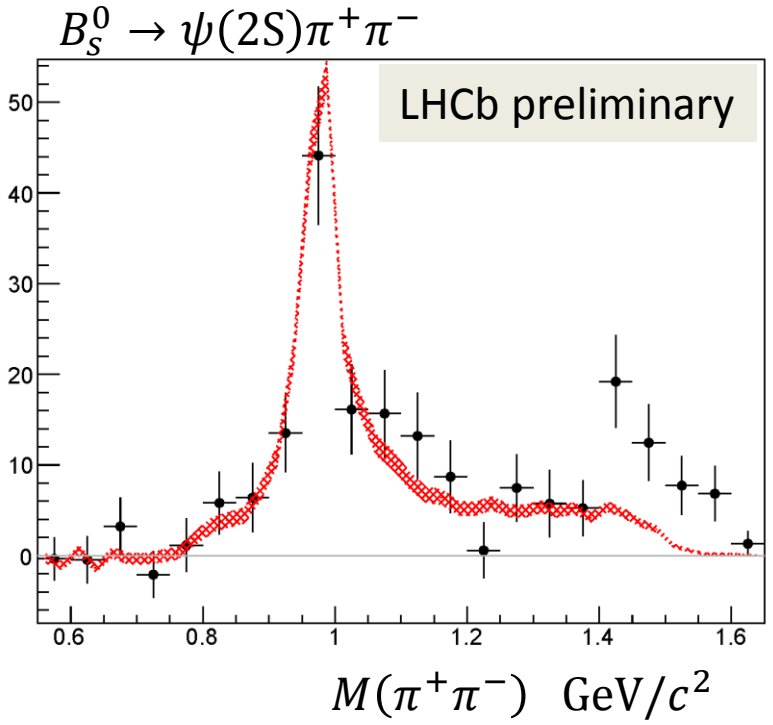


- Clear signals seen in both $\eta \to \gamma\gamma$ and $\psi(2S) \to \mu^+\mu^-$ decays
- Fitted by Gaussian plus constant
- Signal yields consistent with B mass fit, constant consistent with zero

Background subtracted $M(\pi^+\pi^-)$

➢ sPlot technique is applied to obtain the dipion mass distribution





- Red filled area: expected signal spectrum for $\psi(2S)$ channe derived from the measured spectrum of the J/ψ channel
- Read uncertainties corresponds to that of the histograms from J/ψ channel
- Blue vertical filled area shos the K_s^0 region that is excluded in the fit

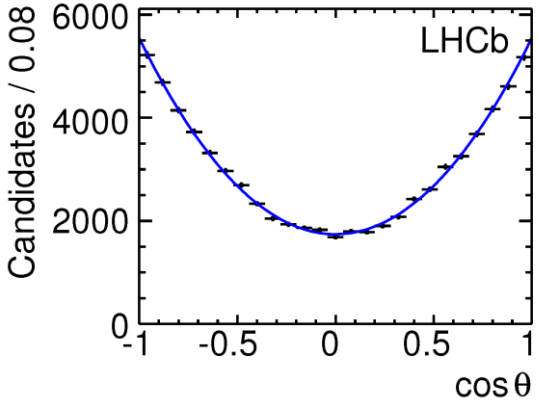
Acceptance

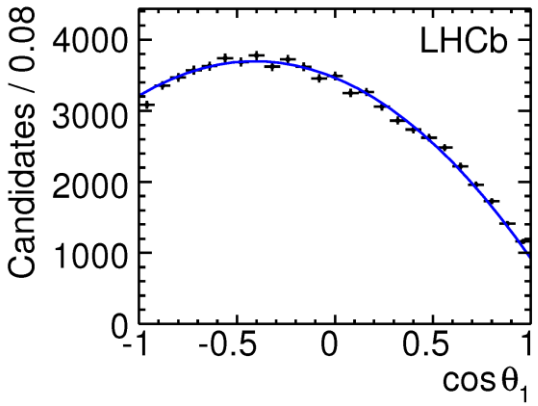
Acceptance modelled by a sum of products of Legendre polynomials

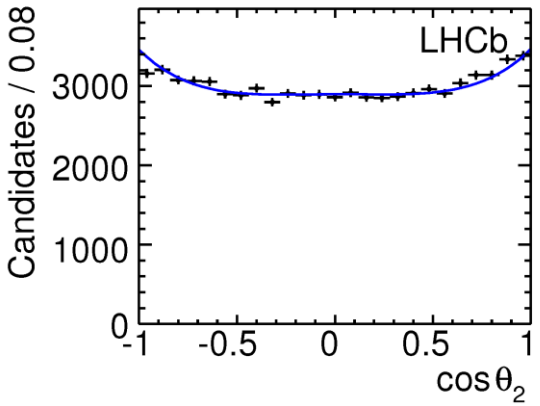
$$f_{\mathrm{acc}} = \sum_{i,j,k} c_{ijk} L_i(\cos\theta) L_j(\cos\theta_1) L_k(\cos\theta_2)$$

LHCb preliminary

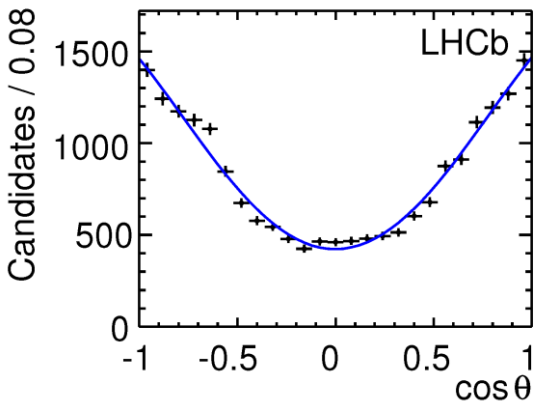
OUT

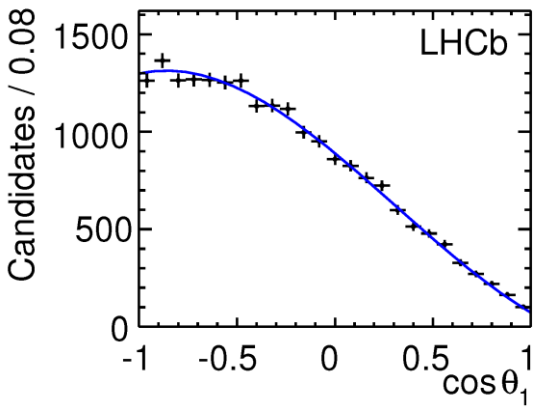


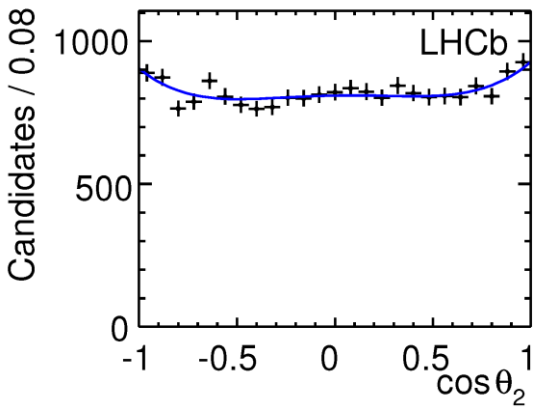




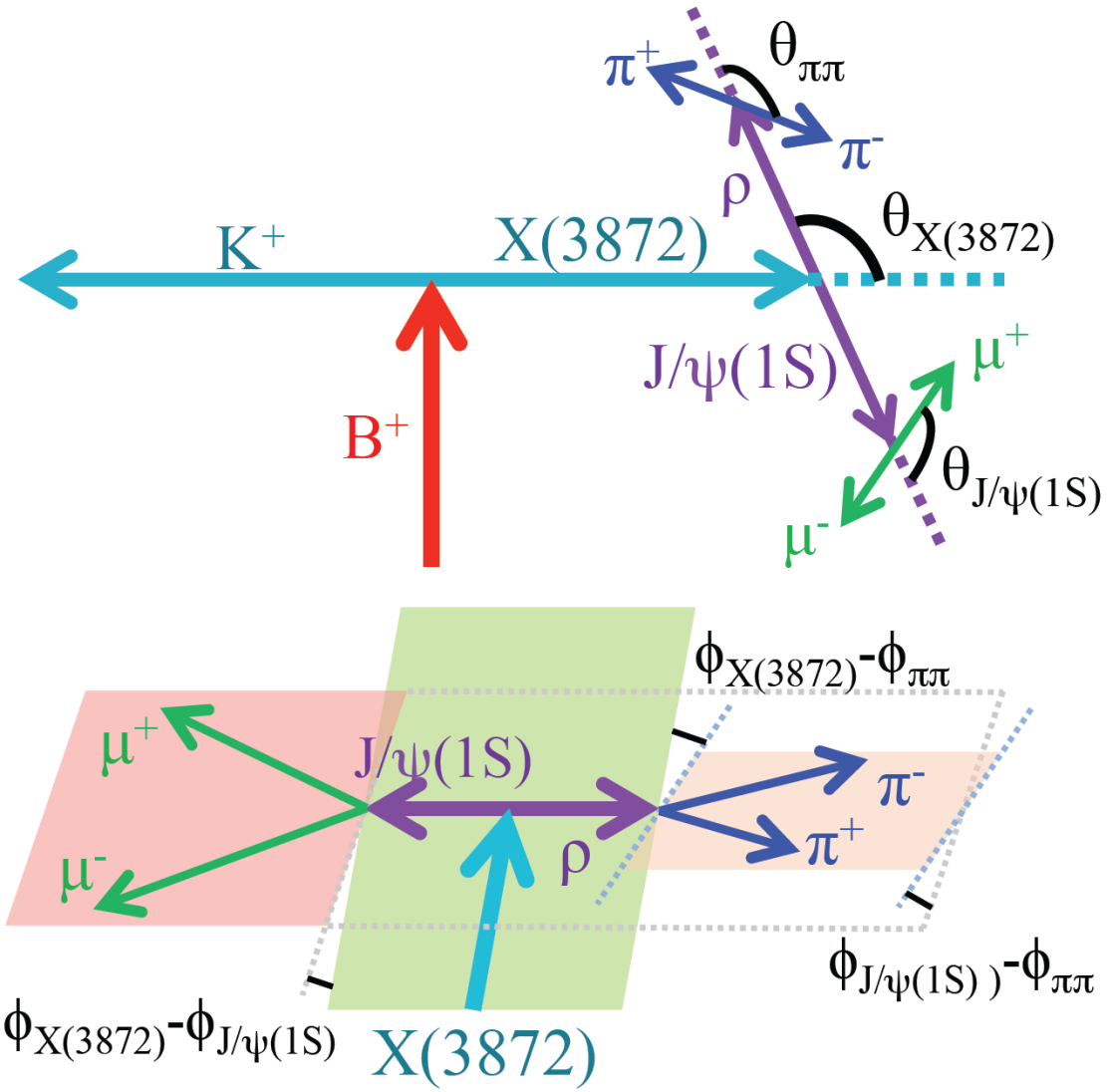
IN







X(3872) angles definition



X(3872) Selections

- Tracks ($\mu^{\pm}$, $\pi^{\pm}$)
  - ✓ $\chi^2_{\mathrm{tr}}/\mathrm{ndf} < 4$
  - ✓ $\chi^2_{\mathrm{IP}}(h) > 9$
  - ✓ $p_{\mathrm{T}}(\mu) > 0.9\ \mathrm{GeV}/c$
  - ✓ $p_{\mathrm{T}}(h) > 0.25\ \mathrm{GeV}/c$
- PID
  - ✓ $\Delta\log\mathcal{L}_{\mu\pi}(\mu) > 0$
  - ✓ $\Delta\log\mathcal{L}_{K\pi}(\pi) < 5$
  - ✓ $\Delta\log\mathcal{L}_{K\pi}(K) > 0$
- Dimuon
  - ✓ $\chi^2_{\mathrm{VTX}}/\mathrm{ndf} < 9$
  - ✓ $p_{\mathrm{T}} > 1.5\ \mathrm{GeV}/c$
  - ✓ $M(\mu^+\mu^-)$ $\in [3040,3150]\ \mathrm{MeV}/c^2$

- B^+ candidates
  - ✓ $M \in [5.261,5.300]\ \mathrm{GeV}/c^2$
  - ✓ $\chi^2_{\mathrm{VTX}}/\mathrm{ndf} < 9$
  - ✓ $p_{\mathrm{T}}(\mu) > 2.0\ \mathrm{GeV}/c$
  - ✓ Lifetime $\tau > 0.25$ ps
  - ✓ Momentum vector points to associated primary vertex