Prospects for $B \to hh$ at LHCb

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On behalf of the LHCb Collaboration

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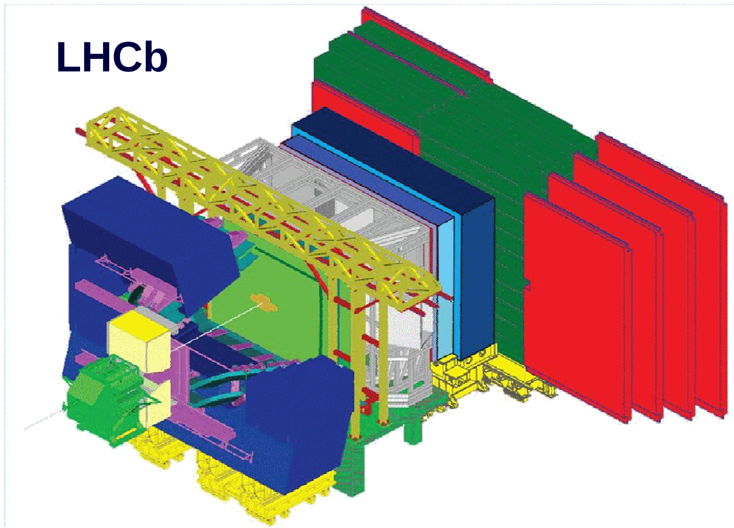


LHCb

Forward spectrometer

Acceptance: $1.8 < \eta < 4.9$

Luminosity: $2 \bullet 10^{32}\ cm^{-2}\ s^{-1}$

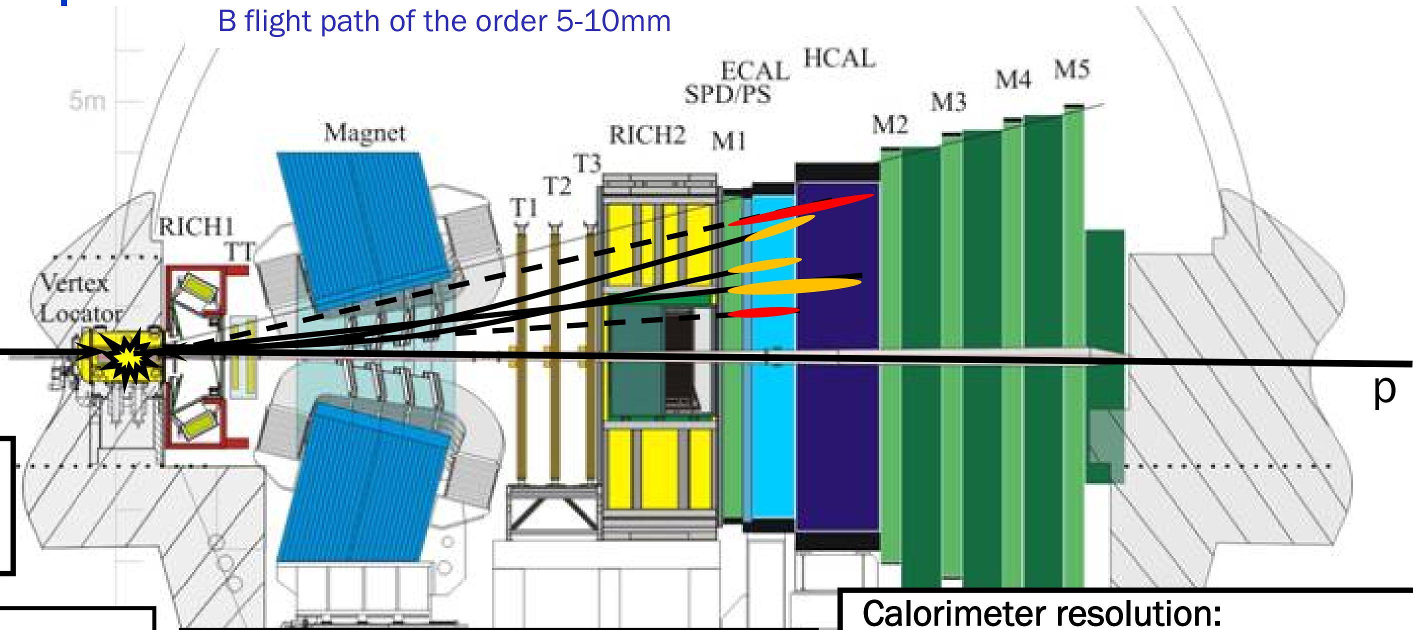
Nr of B's / 2fb^{-1} (nominal year)**:** 10^{12}

Detector: excellent tracking
excellent PID

Reconstruction:
- muons: easy
- hadronic tracks: fine
- electrons: OK
- π^0's: OK, though difficult
- neutrinos: no

Mission statement

- **Search for new physics probing the flavour structure of the SM**
- **Study CP violation and rare decays in the B-meson sector**



Tracking:
Expected tracking resolution
$\delta p/p$=0.35% to 0.55%

Vertexing:
Expected primary vertex resolution
~10μm transverse plane and
~50μm in the longitudinal one
Expected Impact parameter resolution σ_{IP}=14μm+35μm/p_T

RICH performance:
Cherenkov angle resolution 0.6-1.8 mrad
Particle identification in p range 1-100 GeV
π, K ID efficiency > 90%, misID<~10%

Calorimeter resolution:
Design ECAL resolution
$\sigma(E)/E = 10\%\sqrt{E} + 1\%$ (E in GeV)
HCAL resolution from test-beam data
$\sigma(E)/E = (69\pm5)\%\sqrt{E} + (9\pm2)\%$ (E in GeV)

$B \to h^+h'^-$ decays – a rich physics program

- **$B^0 \to \pi\pi$: time-dependent asymmetry**
  - **- so far inconsistency in direct CP contribution ($C_{\pi\pi}$) between BaBar and Belle**
- **$B^0 \to K^+\pi^-$: direct CP violation measurement**
- **$B_s \to \pi^+K^-$: direct CP violation, branching ratio measurement**
- **$B_s \to KK$: time-dependent asymmetry, branching ratio measurement, lifetime measurement**

- **Gronau, Lipkin and Rosner relation**

$$\left|A\left(B_s \to \pi^+K^-\right)\right|^2 - \left|A\left(\overline{B}_s \to \pi^-K^+\right)\right|^2 = \left|A\left(\overline{B}^0 \to \pi^+K^-\right)\right|^2 - \left|A\left(B^0 \to \pi^-K^+\right)\right|^2$$

- **$B^0 \to K^+\pi^-$, $B^+ \to K^+\pi^0$: $\neq$ in CP asymmetry hard to understand theoretically**
- **$B^0 \to \pi\pi$, $B_s \to KK$: determination of the CP angle γ exploiting U-spin symmetry**

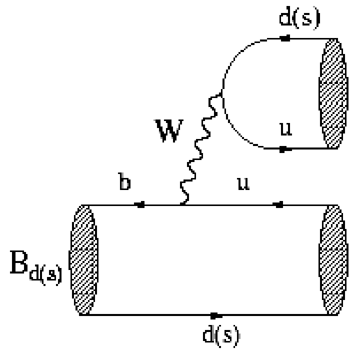
- **Rare $B \to h^+h'^-$: h = π, K … but also a h = baryon such as p, Λ**

- **Etc. List non exhaustive**

$B \to h^+h'^-$ decays in LHCb

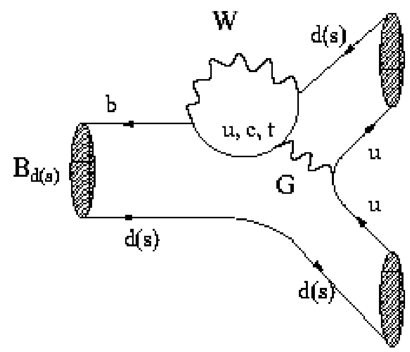
LHCb Note 2007-059

- LHCb has focussed so far on:
  - determination of CP asymmetry observables
  - determination of γ exploiting U-spin symmetry
    (R. Fleisher, Phys. Lett. B459 (1999) 306)



- $B^0 \to \pi\pi$, $B_s \to KK$:

- γ from interference between
  tree-level ($b \to u$) and penguin ($b \to d,s$) diagrams



- Complex analysis involving a sophisticated
  fit of many $B \to hh$ decays in mass and propertime

- Loop diagrams sensitive to New Physics

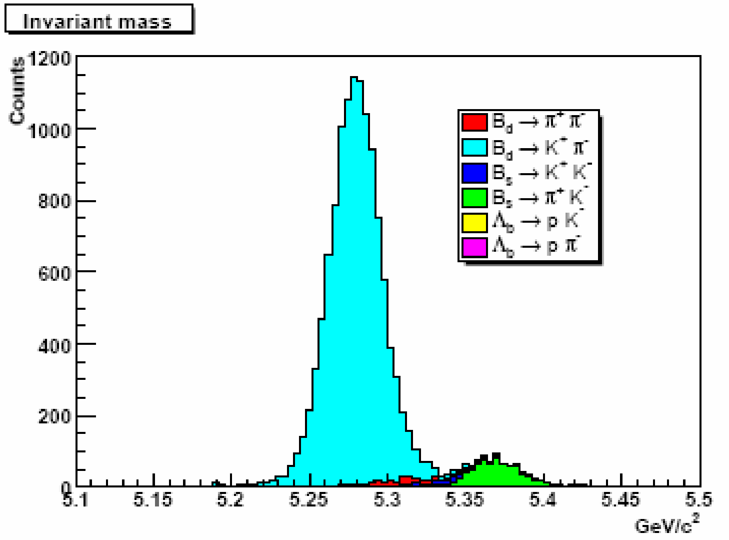
- Comparison with other determinations of γ using tree-level decays
  (such as $B^0 \to D_q u_q$) can evidence inconsistencies and hint at New Physics

Combined selection of $B \to h^+h'^-$ decays

LHCb Note 2007-059

Signal(s) selection:

- Standard selection based on transverse momentum, IP and displacement significances, vertex χ^2
- Particle identification to distinguish between ≠ modes
- Excellent B propertime resolution ~40 fs
- Tagging power εD^2: 4-5 / 7-9 for B^0 / B_s



Backgrounds:

- Every charmless charged 2-body decay of B^0, B_s or Λ_b is a potential background to another cousin $B \to h^+h'^-$ mode
  - B.R.s differ by up to 1 order of magnitude
  - Suppressed with excellent PID
- b-bbar inclusive

Latest Monte Carlo studies agree with these predictions

Expected (untagged) yields and background-to-signal ratios for $2fb^{-1}$:

	$B \to \pi\pi$	$B \to K\pi$	$B_s \to KK$	$B_s \to \pi K$
yields	36k	140k	36k	10k
B/S	0.5	0.15	< 0.06	1.9

Combined fit & sensitivity studies (1/3)

LHCb Note 2007-059

Inputs to toy MC study - extracted from full detector simulation :

- B invariant mass and propertime distributions for signal and background
- B invariant mass and propertime resolutions
- Flavour tagging performance
- Propertime acceptance

Setting in toy MC study – physics observables:

- CP-violating observables measured by BaBar, Belle, CDF
- Non-measured CP parameters estimated assuming U-spin symmetry

Toy MC :

- Generation of signals and backgrounds in mass and propertime taking into account the above
  $\Rightarrow$ Likelihood fit

- Extraction of γ using UTfit Bayesian approach

Combined fit & sensitivity studies (2/3)

- **Time-dependent asymmetries**

$$A_{CP}(t) = \frac{A_{dir}\cos(\Delta m t) + A_{mix}\sin(\Delta m t)}{\cosh(\Delta\Gamma t/2) - A_{\Delta\Gamma}\sinh(\Delta\Gamma t/2)}$$

- **Asymmetry observables depend in total on 7 parameters:**
  γ, mixing phase β_d (β_s), penguin-to-tree amplitudes ratio P/T = d $e^{i\theta}$
  - **β_d, (β_s) from other measurements $\Rightarrow$ 5 unknowns**

- **U-spin symmetry assumptions (neglecting annihilation and exchange diagrams) :**
  - **strong assumption: $d_{\pi\pi} = d_{KK}$, $\theta_{\pi\pi} = \theta_{KK}$**

    $\Rightarrow$ solve 3 unknowns for γ using 4 ($A_{dir/mix}$) measurements
  - **weak assumptions : $d_{\pi\pi} = d_{KK}$ or $d_{\pi\pi} = d_{KK} \pm 20\%$, $\theta_{\pi\pi}$ and θ_{KK} independent**

    $\Rightarrow$ solve 4 unknowns for γ using 4 measurements

- **But U-spin assumptions introduce uncertainties …**

Combined fit & sensitivity studies (3/3)

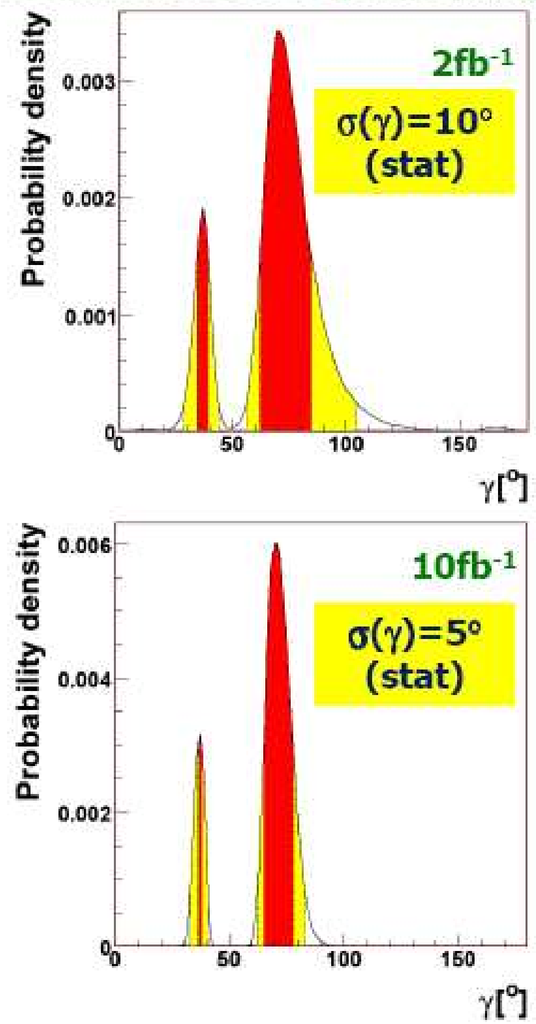
Weak assumptions :

$d_{\pi\pi} = d_{KK} \pm 20\%$, $\theta_{\pi\pi}$ and θ_{KK} independent

Fits allow for 20% U-spin breaking

Sensitivities for $2fb^{-1}$

	$B \to \pi\pi$	$B_s \to KK$
$\sigma(A_{dir})$	0.043	0.042
$\sigma(A_{mix})$	0.037	0.044



- **Weak assumptions: $\sigma(\gamma) \sim$ 7-10 degrees**
- **Strong assumption: $\sigma(\gamma) \sim$ 4 degrees**

❑ **Under way: fit study with introduction of PID PDFs, where PID info taken directly from data with a D* sample**

Rare $B \to h^+h'^-$ modes

- Rare modes such as $B^0 \to KK$ or $B_s \to \pi\pi$ not yet found

- Early discovery potential for these rare modes under consideration …

Back-of-the-envelope calculation:

- Normalize to # of observed decays of similar (exclusive) B-decay
- Assuming equal efficiencies for trigger, selection, etc.:

$$\frac{\mathrm{N}_{rec}(B_{d,s} \to hh)}{\mathrm{N}_{rec}(B_s \to K^+K^-)} = \frac{f(b \to B_{d,s})}{f(b \to B_s)} \times \frac{\mathrm{BR}(B_{d,s} \to hh)}{\mathrm{BR}(B_s \to K^+K^-)} \cong \frac{f(b \to B_{d,s})}{f(b \to B_s)} \times \frac{\mathrm{BR}(B_{d,s} \to hh)}{2 \cdot 10^{-5}}$$

$$\Rightarrow \quad \mathrm{N}_{rec}(B_{d,s} \to hh) \cong \frac{f(b \to B_{d,s})}{f(b \to B_s)} \times 9 \cdot 10^5 \times \mathrm{BR}(B_{d,s} \to hh) \quad \text{in } 1\,\mathrm{pb}^{-1}$$

Assuming the B. R.s to be 10^{-7} we should see these rare signals with a few 100 pb^{-1} !

(the reconstruction efficiencies will be lower than for standard $B \to hh$ modes)

- We expect ~36k $B \to KK$ triggered and untagged events per nominal year (LHCb-2007-059) $\Rightarrow$ ~18 events in $1\mathrm{pb}^{-1}$

Charmless baryonic 2-body decays (1/2)

- What about $B \to hh$ decays, where $h = p, \Lambda$?
- Many 3-body decays already discovered …

  … but no 2-body decay yet

No 2-body decay discovered

Heavy Flavor Averaging Group
April 2008

Compilation of B^0 Baryonic Branching Fractions

All branching fractions are in units of 10^{-6}; limits are 90% CL

In PDG2006 New since PDG2006 (preliminary) New since PDG2006 (published)

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
266	$p\overline{p}$	< 0.27	< 0.27	< 0.11	< 1.4	< 0.11
274	$\Lambda\overline{\Lambda}$	< 0.69		< 0.32	< 1.2	< 0.32

Compilation of B^+ Baryonic Branching Fractions

All branching fractions are in units of 10^{-6}; limits are 90% CL

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
295	$p\overline{\Lambda}$	< 0.49		< 0.32	< 1.5	< 0.32

Charmless baryonic 2-body decays (1/2)

- Theoretical calculations are challenging and uncertain
- Several predictions in disagreement

	Ref. [3]	Ref. [7]	Ref. [10]	Ref.[11] non-local	Ref.[11] local	This work	Expt.
$\overline{B}^0 \to p\bar{p}$	4.2×10^{-6}	1.2×10^{-6}	7.0×10^{-6}	2.9×10^{-6}	2.7×10^{-5}	$1.1 \times 10^{-7\dagger}$	$< 1.2 \times 10^{-6}$
$\overline{B}^0 \to \Lambda\bar{\Lambda}$			2×10^{-7}			$0^\dagger$	$< 1.0 \times 10^{-6}$
$B^- \to \Lambda\bar{p}$		$\lesssim 3 \times 10^{-6}$				$2.2 \times 10^{-7\dagger}$	$< 2.2 \times 10^{-6}$

Cheng & Yang, arXiv:hep-ph/0112245v3

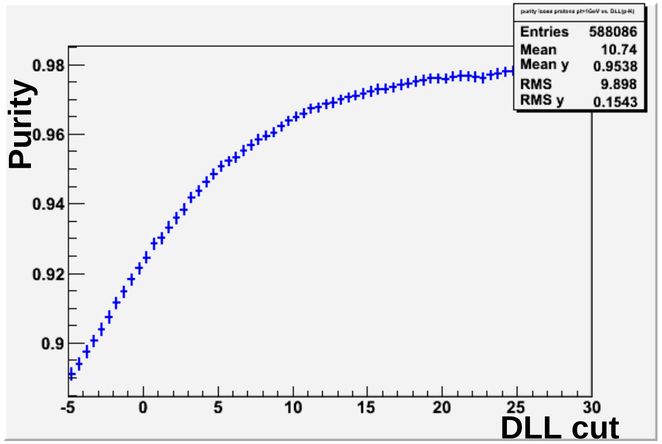
B $\rightarrow$ p$\bar{\text{p}}$ decay:

- Simplest 2-body charmless baryonic B decay
- LHCb has potential for a first discovery with early data

B → $p\bar{p}$ mode in LHCb

- On a B-signal event we expect ~3.5 real proton tracks
  ⇒ should not have to deal with large combinatorics …
  given that the PID is excellent

Purity versus DLL(p-K), p_T > 1 GeV



Note: distributions for events with both MC B-daughter protons in LHCb acceptance

- Back-of-the-envelope calculation
- Normalize to # of observed decays of similar (exclusive) B-decay
- Assuming equal efficiencies for trigger, selection, etc.:

$$\frac{N_{rec}(B^0 \to p\bar{p})}{N_{rec}(B_s \to K^+K^-)} = \frac{f(b \to B^0)}{f(b \to B_s)} \times \frac{BR(B^0 \to p\bar{p})}{BR(B_s \to K^+K^-)} \cong \frac{0.4}{0.1} \times \frac{BR(B^0 \to p\bar{p})}{2 \cdot 10^{-5}}$$

$$\Rightarrow \quad N_{rec}(B^0 \to p\bar{p}) \cong 36 \cdot 10^5 \times BR(B^0 \to p\bar{p}) \quad \text{in } 1\,\text{pb}^{-1}$$

Assuming the branching ratio to be 10^{-7}

we should see a signal with 100 pb^{-1} !

- We expect ~36k B → KK triggered and untagged events per nominal year (LHCb-2007-059) ⇒ ~18 events in $1pb^{-1}$

Conclusions and Outlook

- LHCb provides unprecedented sensitivity to all B $\rightarrow$ hh modes

- A large and rich program is being investigated

- sensitivity to γ ~5° with 10fb^{-1} of data

- Other modes will be exploited to complement γ measurement

- Looking forward to seeing all these developments "in action" using LHC data …!

Back-up slides

HFAG summaries (1/2)

Heavy Flavor Averaging Group
April 2008

Compilation of B^0 Baryonic Branching Fractions
All branching fractions are in units of 10^{-6}; limits are 90% CL

In PDG2006 — New since PDG2006 (preliminary) — New since PDG2006 (published)

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
266	$p\bar{p}$	< 0.27	< 0.27	< 0.11 *	< 1.4	< 0.11
268	$p\bar{p}K^0$	$2.1^{+0.6}_{-0.4}$	$3.0 \pm 0.5 \pm 0.3$ †	$2.51^{+0.35}_{-0.29} \pm 0.21$ ‡		$2.66^{+0.34}_{-0.32}$
269	$\Theta^+\bar{p}$ *	< 0.23	< 0.05	< 0.23		< 0.05
–	$f_J(2221)K^0$ *	New	< 0.45			< 0.45
270	$p\bar{p}K^{*0}$	< 7.6	$1.47 \pm 0.45 \pm 0.40$ †	$1.18^{+0.29}_{-0.25} \pm 0.11$ ‡		$1.24^{+0.28}_{-0.25}$
–	$f_J(2221)K^{*0}$ *	New	< 0.15			< 0.15
271	$p\bar{\Lambda}\pi^-$	2.6 ± 0.5	$3.30 \pm 0.53 \pm 0.31$	$3.23^{+0.33}_{-0.29} \pm 0.29$	< 13	$3.25^{+0.36}_{-0.34}$
–	$p\bar{\Sigma}(1385)^-$	New		< 0.26		< 0.26
–	$\Delta^0\bar{\Lambda}$	New		< 0.93		< 0.93
272	$p\bar{\Lambda}K^-$	< 0.82		< 0.82		< 0.82
273	$p\bar{\Sigma}^0\pi^-$	< 3.8		< 3.8		< 3.8
274	$\Lambda\bar{\Lambda}$	< 0.69		< 0.32	< 1.2	< 0.32

Easy with LHCb?

§Di-baryon mass is less than 2.85 GeV/c^2; † Charmonium decays to $p\bar{p}$ have been statistically subtracted. ‡ The charmonium mass region has been vetoed. * Product BF - daughter BF taken to be 100%; $\Theta(1540)^+ \to pK^0$ (pentaquark candidate).

* Belle collab., hep-ex/0703048v1

HFAG summaries (2/2)

Heavy Flavor Averaging Group
April 2008

Compilation of B^+ Baryonic Branching Fractions
All branching fractions are in units of 10^{-6}; limits are 90% CL

In PDG2006 New since PDG2006 (preliminary) New since PDG2006 (published)

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
286	$p\overline{p}\pi^+$	$3.1^{+0.8}_{-0.7}$	$1.69 \pm 0.29 \pm 0.26$ †	$1.68^{+0.26}_{-0.22} \pm 0.12$ ‡	< 160	$1.68^{+0.23}_{-0.21}$
289	$p\overline{p}K^+$	5.6 ± 1.0	$6.7 \pm 0.5 \pm 0.4$ †	$5.98^{+0.29}_{-0.27} \pm 0.39$ ‡		$6.24^{+0.39}_{-0.38}$
290	$\Theta^{++}\overline{p}$ *	< 0.091	< 0.09	< 0.091		< 0.09
291	$f_J(2221)K^+$ *	< 0.41		< 0.41		< 0.41
292	$p\overline{\Lambda}(1520)$	< 1.5	< 1.5			< 1.5
294	$p\overline{p}K^{*+}$	$10.3^{+3.6+1.3}_{-2.8-1.7}$	$5.3 \pm 1.5 \pm 1.3$ †	$3.38^{+0.73}_{-0.60} \pm 0.39$ ‡		$3.64^{+0.79}_{-0.70}$
–	$f_J(2221)K^{*+}$ *	New	< 0.77			< 0.77
295	$p\overline{\Lambda}$	< 0.49		< 0.32	< 1.5	< 0.32
–	$p\overline{\Lambda}\pi^0$	New		$3.00^{+0.61}_{-0.53} \pm 0.33$		$3.00^{+0.69}_{-0.62}$
–	$p\overline{\Sigma}(1385)^0$	New		< 0.47		< 0.47
–	$\Delta^+\overline{\Lambda}$	New		< 0.82		< 0.82
299	$\Lambda\overline{\Lambda}\pi^+$	< 2.8		< 2.8 ‡		< 2.8 ‡
300	$\Lambda\overline{\Lambda}K^+$	$2.9^{+0.9}_{-0.7} \pm 0.4$		$2.9^{+0.9}_{-0.7} \pm 0.4$ ‡		$2.9^{+1.0}_{-0.8}$
301	$\overline{\Delta}^0 p$	< 380		< 1.42	< 380	< 1.42
302	$\Delta^{++}\overline{p}$	< 150		< 0.14	< 150	< 0.14

§Di-baryon mass is less than 2.85 GeV/c^2; † Charmonium decays to $p\bar{p}$ have been statistically subtracted.

‡ The charmonium mass region has been vetoed. * Product BF - daughter BF taken to be 100%: $\Theta(1540)^{++} \to K^+p$ (pentaquark candidate);