B_s^0 Decays at Belle

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for the Belle collaboration

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

BELLE

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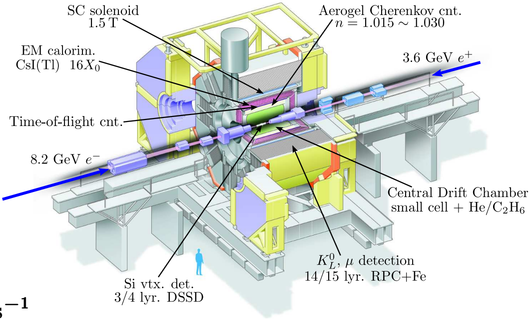
The Belle Experiment

The Belle detector

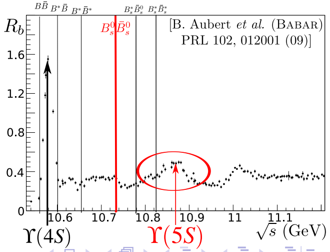
- e^+e^- collisions
- Located at KEK B factory (Tsukuba, Japan)
- Large-solid-angle ($\sim 92\%$)
- Efficient particle ID (p, $\pi^\pm$, $K^\pm$, γ, μ, e, K_L^0)
- World luminosity record



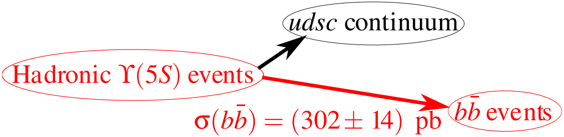
$$\mathbf{L_{peak} = 2.11 \cdot 10^{34} cm^{-1} s^{-1}}$$

- Data taken at $\Upsilon(5S)$ ($\sqrt{s} = 10867 \pm 1$ MeV)
- The only large data sample at this energy:
  - $\boxed{\sim 23.6\,\mathbf{fb^{-1}}}$ $\rightarrow$ **this talk**
  - Total sample: $\sim \mathbf{120\,fb^{-1}}$
- $\Upsilon(5S)$ is above $B_s^0 \bar{B}_s^0$ threshold

  Study of $\mathbf{B_s^0}$ meson possible !



Physics at $\Upsilon(5S)$: B_s^0 Production

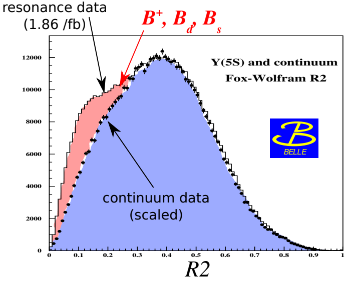


$\sigma(b\bar{b}) = (302 \pm 14)$ pb
Cleo (PRD 75, 012002)
+Belle (PRL 98, 052001)

- $b\bar{b}$ cross section: subtraction of data taken below open-beauty threshold

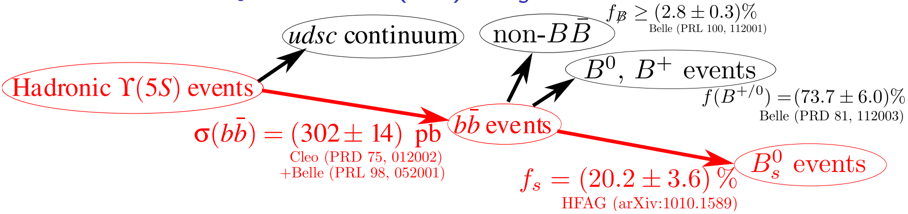
On resonance data; continnum data below open-beauty threshold

$$\sigma(b\bar{b}) = \frac{N_{5S}^{b\bar{b}}}{\mathcal{L}_{5S}} = \frac{1}{\mathcal{L}_{5S}} \frac{1}{\epsilon_{5S}^{b\bar{b}}} \left(N_{5S}^{\text{had}} - N_{\text{cont}}^{\text{had}} \underbrace{\frac{\mathcal{L}_{5S}}{\mathcal{L}_{\text{cont}}} \frac{E_{\text{cont}}^2}{E_{5S}^2} \frac{\epsilon_{5S}^{\text{rec}}}{\epsilon_{\text{cont}}^{\text{rec}}}}_{\text{scaling factor}} \right)$$



R_2: 2nd Fox-Wolfram moment $\sim$ event "jettiness"
$\rightarrow$ smaller values for $B\bar{B}$ events (more spherical)

Physics at $\Upsilon(5S)$: B_s^0 Production



- f_s = fraction of B_s. Inclusive measurements:

$$\frac{1}{2}\overbrace{\mathcal{B}(\Upsilon(5S)\to D_sX)}^{\Upsilon(5S)\text{ data}} = f_s \times \overbrace{\mathcal{B}(B_s \to D_sX)}^{\text{THEORY estimate}} + (1-f_s)\times\frac{1}{2}\overbrace{\mathcal{B}(\Upsilon(4S)\to D_sX)}^{\Upsilon(4S)\text{ data}}$$

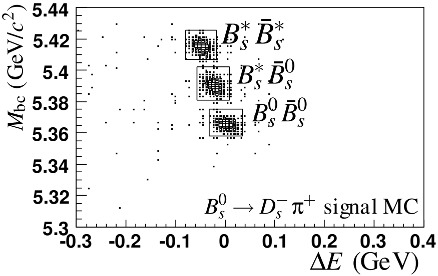
  - 15% uncertainty, mainly due to model-dependent estimates.
  - **Dominant systematics for our branching fractions.**
  - Current normalization, in 23.6 fb^{-1} (today's data set):

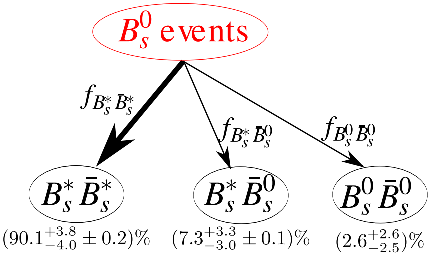
$$\mathbf{N_{B_s^0} = 2 \cdot L_{int} \cdot \sigma(b\bar{b}) \cdot f_s \approx 2.8 \cdot 10^6}$$

  - Alternative methods under consideration. The most promising:
    - B_s^0 oscillate faster than B^0: informations on $N(B_s^0)/N(B^{+/0})$ from fraction of same sign dileptons [Sia & Stone, PRD 74, 031501 (06)]

Physics at $\Upsilon(5S)$: B_s^0 Production

- Full reconstruction of the B_s^0. Observables: ($E_{\rm b}^* = \sqrt{s}/2$)
  - Beam-constrained mass: $M_{\rm bc} = \sqrt{{E_{\rm b}^*}^2 - {p_{B_s^0}^*}^2}$
  - Energy difference: $\Delta E = E_{B_s^0}^* - E_{\rm b}^*$
- 3 production modes:
  $\Upsilon(5S) \to B_s^* \bar{B}_s^*$, $\Upsilon(5S) \to B_s^* \bar{B}_s^0$ and $\Upsilon(5S) \to B_s^0 \bar{B}_s^0$.
- $\boldsymbol{B_s^*} \to B_s^0\gamma$ **cannot be reconstructed** (γ too soft)
- In the $(M_{\rm bc}, \Delta E)$ plane, $\boldsymbol{B_s^0}$ candidates are in **3 signal regions**

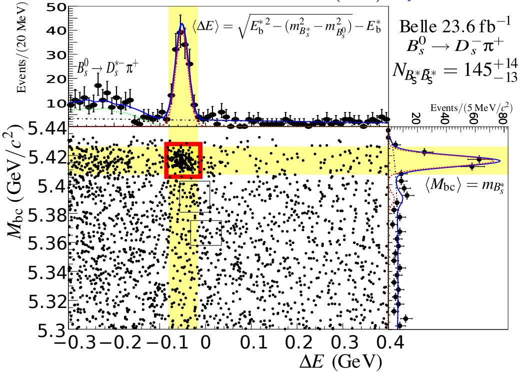




[RL *et al.* (Belle) PRL 102, 021801 (09)]

A "standard candle" for B_s^0: $B_s^0 \to D_s^- \pi^+$

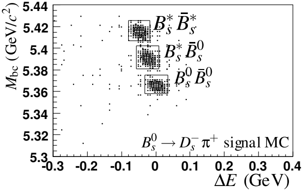
RL *et al.* (Belle) Phys. Rev. Lett. **102**, 021801 (2009)



$$f_{B_s^* \bar{B}_s^*} = \left(90.1^{+3.8}_{-4.0} \pm 0.2\right)\,\%$$

$$m_{B_s^*} = (5416.4 \pm 0.4 \pm 0.5)\ \mathrm{MeV}/c^2$$

$$m_{B_s^0} = (5364.4 \pm 1.3 \pm 0.7)\ \mathrm{MeV}/c^2$$



$$\mathcal{B}(B_s^0 \to D_s^- \pi^+) = \left(3.67^{+0.35}_{-0.33}(\mathrm{stat.})^{+0.43}_{-0.42}(\mathrm{syst.}) \pm 0.49(f_s)\right) \times 10^{-3}$$

- 20% uncertainties, f_s is a crucial source of systematics
- large $f_{B_s^* B_s^*}$ confirmed (1st Belle value: $(93^{+7}_{-9} \pm 1)\%$ [PRD 76, 012002 (07)])

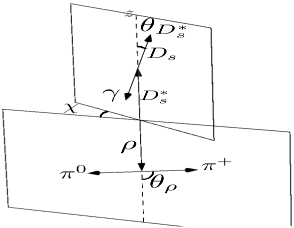
- $m_{B_s^*}$ is 2.6σ larger than CLEO [O. Aquines *et al.* (CLEO) PRL 96, 152001 (06)].
- $m_{B_s^*}$ ($m_{B_s^0}$) is the 1st (2nd) most precise measurement so far.

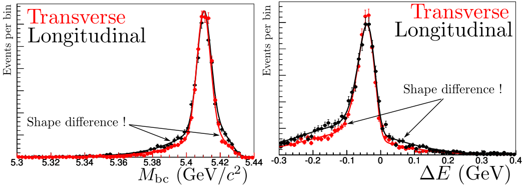
Study of $B_s^0 \to D_s^{*-} \rho^+$

RL *et al.* (Belle) Phys. Rev. Lett. **104**, 231801 (2010)

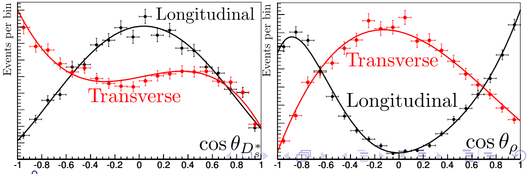
- Scalar $\to$ Vector + Vector: Longitudinal and Transverse polarizations are possible.
- Decay width depends on the "longitudinal polarization fraction" f_L

$$\frac{d^2\Gamma}{d\cos\theta_{D_s^*}\, d\cos\theta_\rho} \propto 4f_L \sin^2\theta_{D_s^*} \cos^2\theta_\rho + (1-f_L)\left(1+\cos^2\theta_{D_s^*}\right)\sin^2\theta_\rho$$





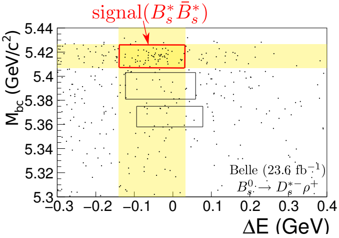
In signal simulations: **Longitudinal ($f_L = 1$) and transverse ($f_L = 0$) events have different $M_{\rm bc}/\Delta E$ distributions**

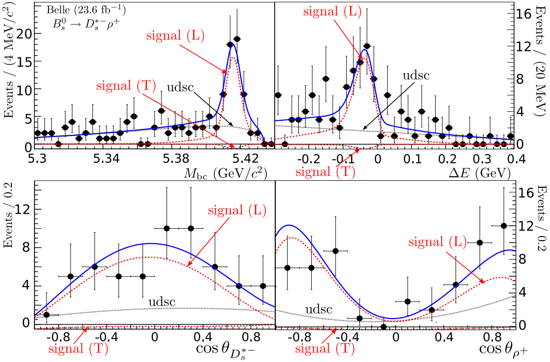


- Need to measure f_L
- Simultaneous extraction of $\mathcal{B}(B_s^0 \to D_s^{*-}\rho^+)$ and $f_L(B_s^0 \to D_s^{*-}\rho^+)$ with a 4D fit
- $(M_{\rm bc}, \Delta E, \cos\theta_{D_s^*}, \cos\theta_\rho)$

Observation of $B_s^0 \to D_s^{*-}\rho^+$

RL *et al.* (Belle) Phys. Rev. Lett. **104**, 231801 (2010)





- $N(B_s^* \bar{B}_s^*) = 77.8^{+14.5}_{-13.4}(\text{stat.}) \pm 3.3(\text{fit})$ events (7.4σ significance)

$$\mathcal{B}(B_s^0 \to D_s^{*-}\rho^+) = \left(11.8^{+2.2}_{-2.0}(\text{stat.}) \pm 1.7(\text{syst.}) \pm 1.8(f_s)\right) \times 10^{-3}$$

$f_L = 1.05^{+0.08\,+0.03}_{-0.10\,-0.04}$ or $f_L \in [0.93, 1.00]$ at 68% C.L.

CP violation in B_s^0 decays

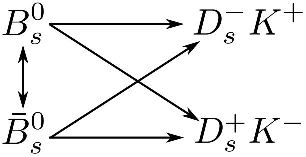
- B_s^0 decays are interesting for SM tests and for NP searches.
  They can provide tests of the CKM source of CP violation.

  Dunietz, Phys. Rev. D 52, 3048 (1995)
  Dunietz, Fleischer & Nierste, Phys. Rev. D 63, 114015 (2001)

- Non-flavor specific tree decay (not sensitive to NP).
  For instance $\boldsymbol{B_s^0 \to D_s^{\mp} K^{\pm}}$, $\mathcal{B} \sim \mathcal{O}(10^{-4})$, can be used
  - to measure γ

    Aleksan, Dunietz & Kayser, Z. Phys. C 54, 653 (1992)
    Fleischer, Nucl. Phys. B 671, 459 (2003)
  - to resolve the ambiguity on the $\Delta\Gamma_s$ sign.

    Nandi & Nierste, Phys. Rev. D 77, 054010 (2009)



$$|\lambda| = \left| \frac{q}{p} \frac{\langle D_s^- K^+ | \bar{B}_s^0 \rangle}{\langle D_s^- K^+ | B_s^0 \rangle} \right| \sim 0.3 - 0.4$$

$B_s^0 \to CP$-eigenstate Decays

- Charmless $B_s^0 \to K^+K^-$ decay (penguin)
  - may be sensitive to NP

    London & Matias, Phys. Rev. D 70, 031502 (2004)
  - can measure $\phi_1(\beta)$ and $\phi_3(\gamma)$ (with $B^0 \to \pi^+\pi^-$)

    Fleischer, Phys. Lett. B 459, 306 (1999)
- $b \to c\bar{c}s$ transition are very small in the SM $\longrightarrow$ NP may be sizeable

  Ball & Fleischer, Phys. Lett. B 475, 111 (2000)

$$B_s^0 \to D_s^{(*)+} D_s^{(*)-},\ B_s^0 \to J/\psi\,\phi,\ B_s^0 \to J/\psi\,K_S^0,\ B_s^0 \to J/\psi\,\eta^{(\prime)},\ B_s^0 \to J/\psi\,f_0,\ \ldots$$

- $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ dominates $\Delta\Gamma_s$

$$\Delta\Gamma^{CP} = \Gamma\left(CP\mathrm{-even}\right) - \Gamma\left(CP\mathrm{-odd}\right) \approx \Gamma\left(B^0_{s,\mathrm{short}} \to D_s^{(*)} D_s^{(*)}\right)$$

Aleksan *et al.*, Phys. Lett. B 316, 567 (1993)

The first step is to establish these modes!

- Decays with π^0 and/or γ are hard for hadron-colliders experiments

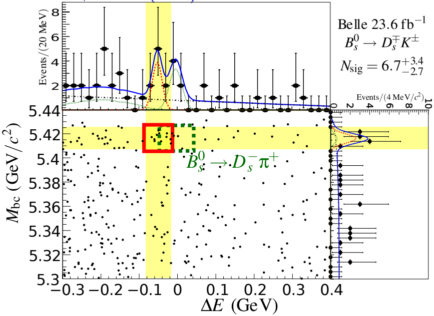
Belle can contribute!

- *CP*-violation analysis need more statistics and better time resolution ~ 0.06 ps (~ 30 times better than for B^0 !).

Prospects and workarounds: arXiv:1008.1541 (SuperB), arXiv:1005.5012 (Belle II)

Evidence for $B_s^0 \to D_s^\mp K^\pm$

RL *et al.* (Belle) Phys. Rev. Lett. **102**, 021801 (2009)



- reco. similar to $B_s^0 \to D_s^- \pi^+$
- Replace the π^+ by a K^+.
- Cabbibo suppressed
  $\to \mathcal{O}(10)$ times less signal
- π misidentification !

$N(\text{Signal}) \sim N(B_s^0 \to D_s^- \pi^+, \pi \text{ misid.})$

- Fit Result: $N(\text{Signal}) = 6.7^{+3.4}_{-2.7}$
  3.5σ evidence (w/ systematics) !
- Direct measurement of branching fraction:

$$\mathcal{B}(B_s^0 \to D_s^\mp K^\pm) = \left(2.4^{+1.2}_{-1.0}(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.3(f_s)\right) \times 10^{-4}$$

- Ratio with $B_s^0 \to D_s^- \pi^+$: $\mathcal{B}(B_s^0 \to D_s^\mp K^\pm)/\mathcal{B}(B_s^0 \to D_s^- \pi^+) = (6.5^{+3.5}_{-2.9})\%$
  $\to$ compatible with CDF (102 events): $(9.7 \pm 2.0)\%$

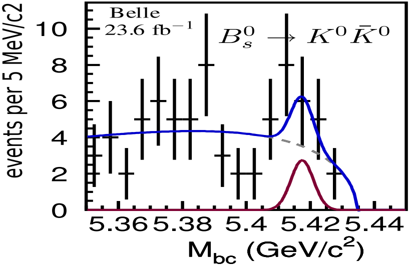
[T. Aaltonen *et al.* (CDF) PRL 103, 191802 (09)]

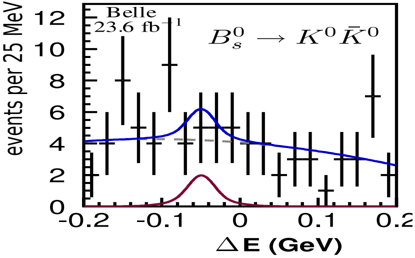
- Better precision expected with 120 /fb ...

$B_s^0 \to KK$

C.C. Peng *et al.* (Belle) Phys. Rev. D **82**, 072007 (2010)

- First limit on $\boxed{\mathcal{B}(B_s^0 \to K^0 \bar{K}^0) < 6.6 \times 10^{-5}}$





- Observation of $23.4^{+5.5}_{-6.3}$ $B_s^0 \to K^+K^-$ events (5.8σ)

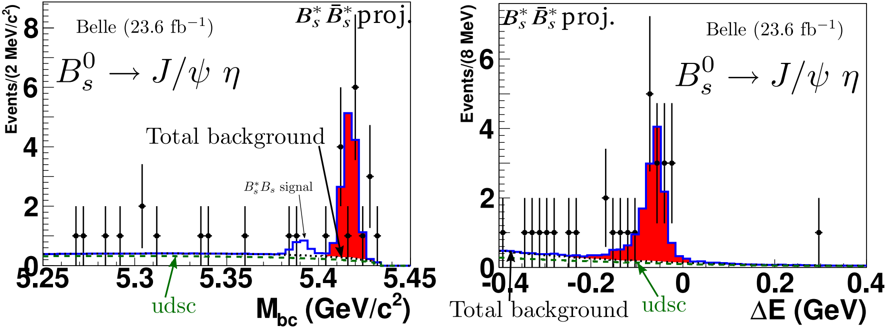
Direct BR measurement:

$$\boxed{\mathcal{B}(\mathbf{B_s^0} \to \mathbf{K^+K^-}) = \left(\mathbf{3.8^{+1.0}_{-0.9} \pm 0.5 \pm 0.5(f_s)}\right) \times \mathbf{10^{-5}}}$$

confirms CDF results (102 events): $(2.44 \pm 0.14 \pm 0.46) \times 10^{-5}$ [M. Morello, Nucl. Phys. B (Proc. Suppl.) 170, 39 (07)]

Observation of $B_s^0 \to J/\psi\,\eta$

Belle, Belle-conf-0902, arXiv:0912.1434 (2009)

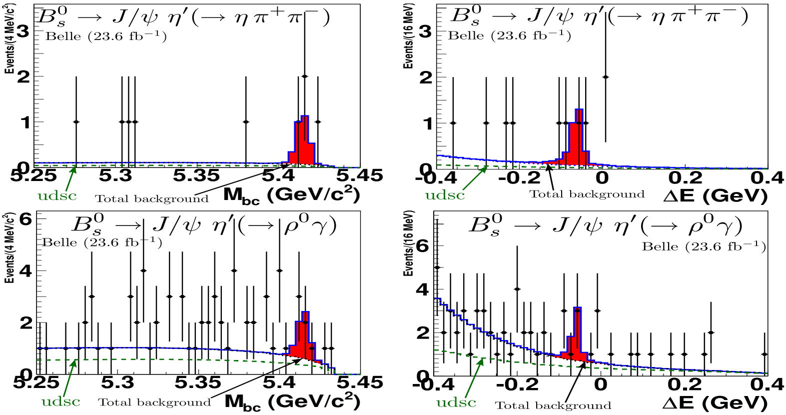


- $\eta \to \gamma\gamma + \eta \to \pi^0\pi^+\pi^-$ channels
- First Observation of 14.9 ± 4.1 events (7.3σ)

$$\mathcal{B}\left(\mathbf{B_s^0} \to \mathbf{J}/\psi\eta\right) = \left(\mathbf{3.32} \pm \mathbf{0.87}^{+0.32}_{-0.28} \pm \mathbf{0.42(f_s)}\right) \times \mathbf{10^{-4}}$$

Observation of $B_s^0 \to J/\psi\,\eta'$

Belle, Belle-conf-0902, arXiv:0912.1434 (2009)



- 3 η' channels: $\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$, $\eta' \to \eta(\to \pi^0\pi^+\pi^-)\pi^+\pi^-$ and $\eta' \to \rho^0\gamma$
- First Evidence of 10.7 ± 4.6 events (3.8σ)

$$\mathcal{B}\left(\mathbf{B_s^0} \to \mathbf{J}/\psi\,\eta'\right) = \left(\mathbf{3.1 \pm 1.2^{+0.5}_{-0.6} \pm 0.4(f_s)}\right) \times \mathbf{10^{-4}}$$

The $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ Analysis

S. Esen *et al.* (Belle) Phys. Rev. Lett. **105**, 201802 (2010)

- CKM-favored **and** *CP*-even eigenstate (in heavy-quark limit).
- Dominates $\Delta\Gamma$ (this relation has ∼3% theoretical uncertainty):

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = \frac{2 \times \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}{1 - \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}$$

R. Aleksan *et al.*, Phys. Lett. B 316, 567 (1993)

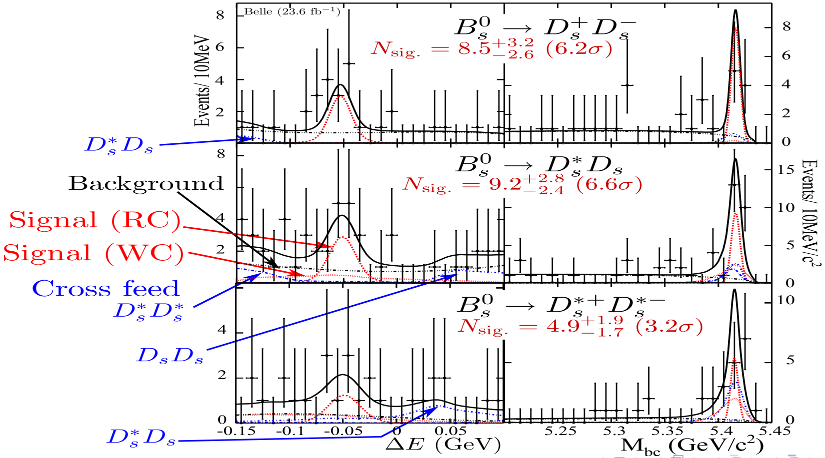
- Full reconstruction of $B_s^0 \to D_s^{(*)} D_s^{(*)}$
- Large B.R. ($\sim 10^{-2}$) but low efficiency ($\sim 10^{-4}$)
- D_s^+ reconstructed in 6 final states: $\phi\pi^+$, $K_S^0 K^+$, $\bar{K}^{*0} K^+$, $\phi\rho^+$, $K_S^0 K^{*+}$ and $\bar{K}^{*0} K^{*+}$
- Selection of one candidate (all channels) per event.
- $D_s^{*+} \to D_s^+ \gamma$: photon energy is low ($E_\gamma < 150$ MeV)!
- Contamination between the 3 modes ("cross feed")

  when a photon is missing or added by error.

$B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ Fit

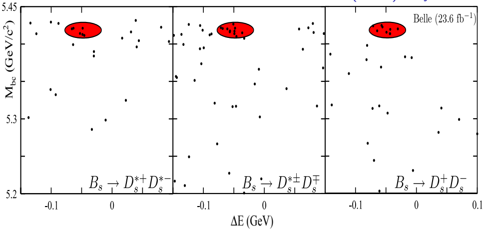
S. Esen *et al.* (Belle) Phys. Rev. Lett. **105**, 201802 (2010)

- Simultaneous fit of the 3 modes. For one mode, cross feed from the 2 others is included
- Signal has 2 components: right and wrong combinations



Observation of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

S. Esen *et al.* (Belle) Phys. Rev. Lett. **105**, 201802 (2010)

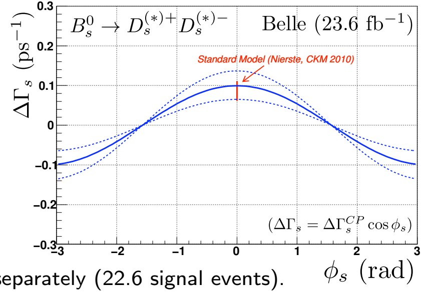


- $\mathcal{B}(B_s^0 \to D_s^+ D_s^-) = \left(1.0^{+0.4}_{-0.3}{}^{+0.3}_{-0.2}\right)\%$
  consistent with CDF [PRL 100, 021803]
- $\mathcal{B}(B_s^0 \to D_s^{*\pm} D_s^{\mp}) = \left(2.8^{+0.8}_{-0.7} \pm 0.7\right)\%$
  first observation
- $\mathcal{B}(B_s^0 \to D_s^{*+} D_s^{*-}) = \left(3.1^{+1.2}_{-1.0} \pm 0.8\right)\%$
  first evidence

$$\mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right) = \left(6.9^{+1.5}_{-1.3} \pm 1.9\right)\%$$

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = \left(14.7^{+3.6}_{-3.0}{}^{+4.4}_{-4.2}\right)\%$$

CDF: $(12 \pm 10)\%$ [PRL 100, 121803]
D0: $(7.2 \pm 3.0)\%$ [PRL 102, 091801]



- The 3 modes are seen separately (22.6 signal events).
- Competitve precision on $\Delta\Gamma/\Gamma$ with 23.6 fb^{-1} !

Search for $B_s^0 \to J/\psi\, f_0(980)$

Contribution to FPCP 2010 (arXiv:1009.2605)

- CP-eigenstate (odd) mode with a final state with only 4 charged particles
- Expectations:
  - $\frac{\mathcal{B}(B_s^0 \to J/\psi\, f_0)\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\, \phi)\mathcal{B}(\phi \to K^+K^-)} \approx 0.2$ (Stone+Zhang [PRD 79, 074024])
  - $\frac{\mathcal{B}(B_s^0 \to J/\psi\, f_0)\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\, \phi)\mathcal{B}(\phi \to K^+K^-)} = 0.42 \pm 0.11$ (CLEO ($D_s \to f_0 e^+ \nu_e$) [PRD 80, 052009])

$$\to \mathcal{B}(\mathbf{B_s^0} \to \mathbf{J}/\psi\, \mathbf{f_0})\mathcal{B}(\mathbf{f_0} \to \pi^+\pi^-) \approx (\mathbf{1.3} - \mathbf{2.7})\, \mathbf{10^{-4}}$$

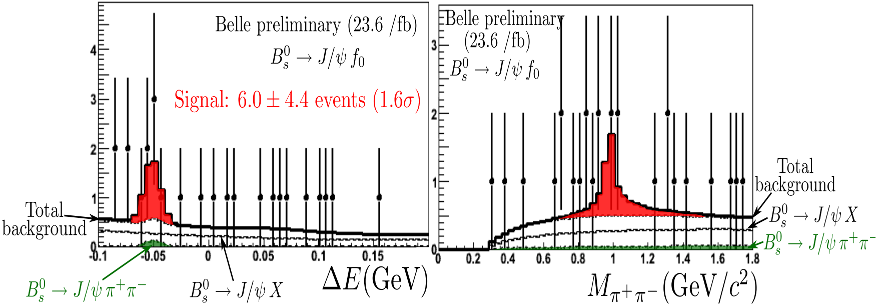
  - $\mathcal{B}(B_s^0 \to J/\psi\, f_0) = (3.1 \pm 2.4)\, 10^{-4}$ QCD (LO) [PRD 81, 074001]
    with $\mathcal{B}(f_0 \to \pi^+\pi^-) = \left(50^{+7}_{-9}\right)$ % BES data [CLEO, PRD 80, 052009]

$$\to \mathcal{B}(\mathbf{B_s^0} \to \mathbf{J}/\psi\, \mathbf{f_0})\mathcal{B}(\mathbf{f_0} \to \pi^+\pi^-) = (\mathbf{1.6} \pm \mathbf{1.3})\, \mathbf{10^{-4}}$$

- Our analysis:
  - $J/\psi \to e^+e^-$ or $\mu^+\mu^-$; $f_0 \to \pi^+\pi^-$
  - $(\Delta E, M_{\pi^+\pi^-})$ 2D fit in -0.1 GeV$< \Delta E < 0.2$ GeV and $M_{\pi^+\pi^-} < 1.8$ GeV$/c^2$
  - includes backgrounds from $B_s^0 \to J/\psi \pi^+\pi^-$ (peaks in ΔE) and others J/ψ modes.

Search for $B_s^0 \to J/\psi\, f_0(980)$

Contribution to FPCP 2010 (arXiv:1009.2605)



$$\mathcal{B}(\mathbf{B_s^0} \to \mathbf{J}/\psi\, \mathbf{f_0}) \times \mathcal{B}(\mathbf{f_0} \to \pi^+\pi^-) < \mathbf{1.63 \times 10^{-4}} (\text{at } 90\% \text{ C.L.})$$

- We are sensitive to the region of interest !
- More to come with 120 fb^{-1} + improved analysis ...

Conclusion:

- Belle has analysed ~ 2.8 millions of B_s^0 (total on tape: $\sim$14 millions)
- Study of (experimentally) dominant CKM-favored decay modes.
  - Study of $B_s^0 \to D_s^- \pi^+$
  - First observations of $B_s^0 \to D_s^{*-} \pi^+$, $B_s^0 \to D_s^- \rho^+$ and $B_s^0 \to D_s^{*-} \rho^+$.
- B.F. precision suffers mainly from the imprecise fraction $f_s = N_{B_s^{(*)} \bar{B}_s^{(*)}} / N_{b\bar{b}}$
- Evidence for $B_s^0 \to D_s^{\mp} K^{\pm}$ but statistic is low!
- *CP*-eigenstate modes:
  - Analysis of $B_s^0 \to hh$, but not competitive with Tevatron
  - Evidences for $B_s^0 \to J/\psi\, \eta^{(\prime)}$
  - Competitive measurement of $\Delta\Gamma^{CP}/\Gamma$ with $B_s^0 \to D_s^{(*)} D_s^{(*)}$
  - Search for $B_s^0 \to J/\psi f_0$: First direct limit,

    very close to the expected signal!
- Our total $\Upsilon(5S)$ sample is **5 times larger** $\longrightarrow$ More to come soon!
- Good B_s^0 prospects at Belle2/superB $\to$ talks of A. Cervelli and S. Korpar

Thank you.

Di-lepton Asymmetry at Belle

- Rescale of existing results from Belle [PRD 73, 112002 (06)] and Babar [PRL 96, 251802 (06)] to the full Belle data sample (710 fb^{-1} at $\Upsilon(4S)$ and 120 fb^{-1} at $\Upsilon(5S)$)
- B_s^0 mixed with 50% probability $\rightarrow$ 3 times more same-sign leptons than $B^0 \bar{B}^0$.

$$a_{sl}^{B_s^0} \approx 1.2\%$$

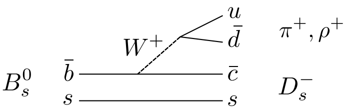
$$a_{sl}^{B_d} \approx 0.2\%$$

B_s^0 decay modes with large statistics?

- Measurements of precise exclusive modes
  $\longrightarrow$ LHC experiments need a reference point for B_s^0
- Measurements of B_s^0, B_s^* properties (masses, widths, angular distr.)
- Comparison between B^0 and B_s^0 is theoretically interesting
  $\longrightarrow$ tests of HQET, factorization, etc.
- Comparison between $\Upsilon(5S) \to B_s^* \bar{B}_s^*$, $\Upsilon(5S) \to B_s^* \bar{B}_s^0$ + c.c., $\Upsilon(5S) \to B_s^0 \bar{B}_s^0$

$B_s^0 \to D_s^{(*)-} h^+$ Summary

- At LO: 1 tree-level diagram



- Measurements compatible with
  - HQET predictions [A. Deandrea *et al.*, Phys. Lett. B 318, 549 (93)]
  - B^0 decays (as expected in the heavy-quark limit and small W-exchange ampl.)

Mode	$\mathcal{B}$ (Belle)	Theory (HQET)	B^0 partner (PDG)
$B_s^0 \to D_s^- \pi^+$	$3.67^{+0.35}_{-0.33}{}^{+0.43}_{-0.42} \pm 0.49$	2.8	2.68 ± 0.13
$B_s^0 \to D_s^{*-} \pi^+$	$2.4^{+0.5}_{-0.4} \pm 0.3 \pm 0.4$	2.8	2.76 ± 0.13
$B_s^0 \to D_s^- \rho^+$	$8.5^{+1.3}_{-1.2} \pm 1.1 \pm 1.3$	7.5	7.6 ± 1.3
$B_s^0 \to D_s^{*-} \rho^+$	$11.9^{+2.2}_{-2.0} \pm 1.7 \pm 1.8$	8.9	6.8 ± 0.9

- Large longitudinal polarization of $B_s^0 \to D_s^{*-} \rho^+$
  - also expected from theory: 83% [Li *et al.* Phys. Rev. D 78, 014018 (08)]
  - comparable with $B^0 \to D^{*-} \rho^+$: $88.5 \pm 2.0\%$, [CLEO PRD67, 112002].