

B_s^0 Measurements at Belle

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Outline

Overview

The Belle detector

Analyzing the $\Upsilon(5S)$ sample

Motivation

Results on dominant B_s^0 decay modes

$$B_s^0 \rightarrow D_s^- \pi^+$$

$$B_s^0 \rightarrow D_s^\mp K^\pm$$

$$B_s^0 \rightarrow D_s^{*-} \pi^+$$

$$B_s^0 \rightarrow D_s^- \rho^+$$

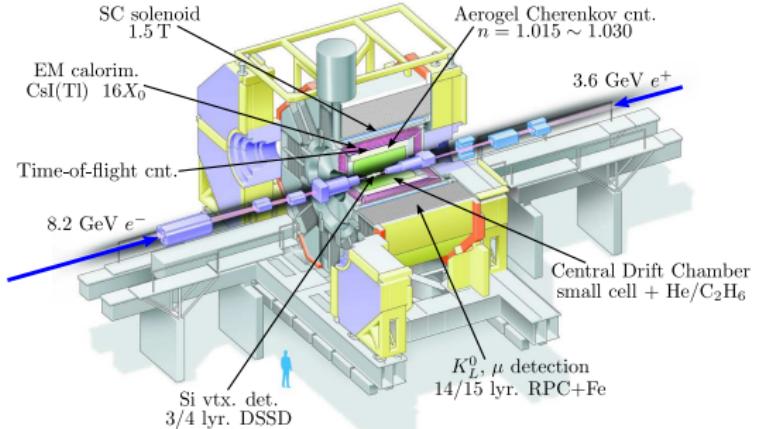
$$B_s^0 \rightarrow D_s^{*-} \rho^+$$

Conclusion

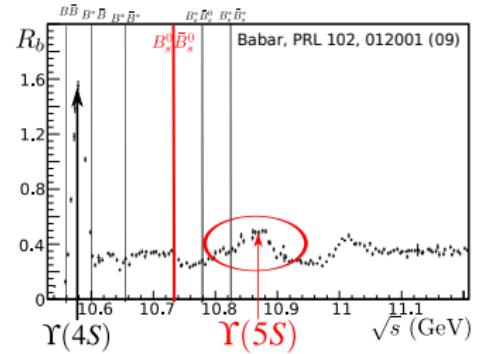
The Belle Experiment

The Belle detector

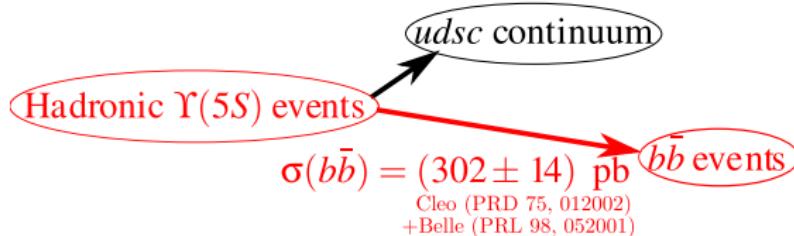
- ▶ Located at KEK B factory (Tsukuba, Japan)
- ▶ Large-solid-angle ($\sim 92\%$)
- ▶ Efficient particle ID ($p, \pi^\pm, K^\pm, \gamma, \mu, e, K_L^0$)
- ▶ World luminosity record
 $L_{\text{peak}} = 21.1 \text{ nb}^{-1} \text{s}^{-1}$ last June



- ▶ Data taken at $\Upsilon(5S)$ ($\sqrt{s} = 10867 \pm 1 \text{ MeV}$)
- ▶ The only large data sample at this energy:
 - ▶ $\sim 23.6 \text{ fb}^{-1}$ (06/05 & 06/06) → **this talk**
 - ▶ Total sample: $\sim 120 \text{ fb}^{-1}$ (up to now)
- ▶ $\Upsilon(5S)$ is above $B_s^0 \bar{B}_s^0$ threshold
Study of B_s^0 meson possible !



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

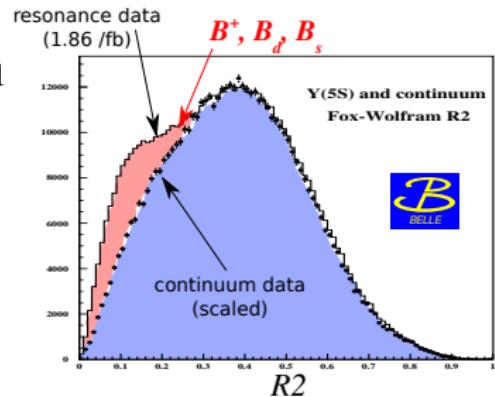


- ▶ $b\bar{b}$ cross section: subtraction of data taken below open-beauty threshold ($\sigma = N/L_{\text{int}}$)

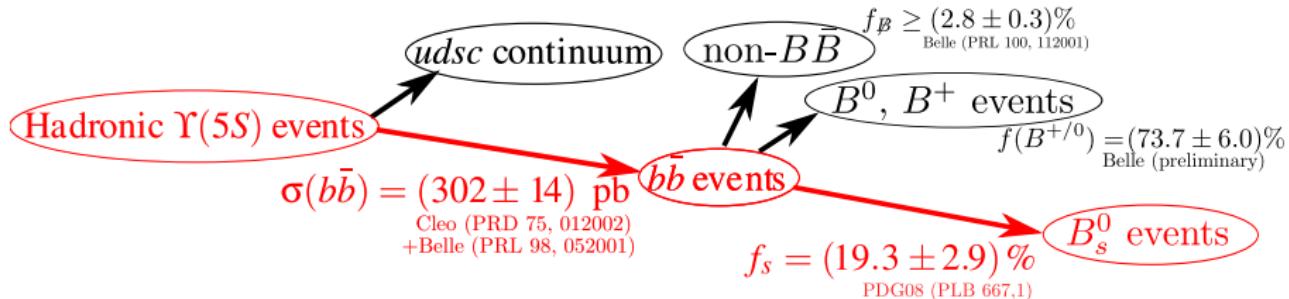
$$N_{5S}^{b\bar{b}} = \frac{1}{\epsilon_{5S}^{b\bar{b}}} \left(N_{5S}^{\text{had}} - N_{\text{cont}}^{\text{had}} \underbrace{\frac{\mathcal{L}_{5S}}{\mathcal{L}_{\text{cont}}} \frac{E_{\text{cont}}^2}{E_{5S}^2} \frac{\epsilon_{5S}^{\text{con}}}{\epsilon_{\text{cont}}^{\text{con}}}}_{\text{scaling factor}}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

On resonance data continuum data below
open-beauty threshold

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:

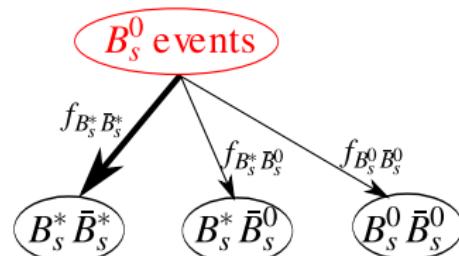
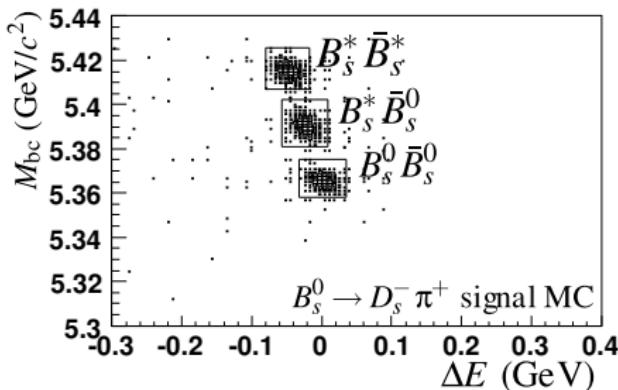
$$\frac{1}{2} \overbrace{\mathcal{B}(\Upsilon(5S) \rightarrow D_s X)}^{\text{EXPERIMENT at } \Upsilon(5S)} = f_s \times \overbrace{\mathcal{B}(B_s \rightarrow D_s X)}^{\text{THEORY estimate}} + (1 - f_s) \times \frac{1}{2} \overbrace{\mathcal{B}(\Upsilon(4S) \rightarrow D_s X)}^{\text{EXPERIMENT at } \Upsilon(4S)}$$

- ▶ 15% uncertainty, **completely dominated by systematics**.
- ▶ Alternative methods under consideration. The most promising:
 - ▶ f_s can be deduced from di-lepton events: B_s^0 oscillate faster than B^0
(R. Sia and S. Stone, PRD 74, 031501)
- ▶ Current normalization, in 23.6 fb^{-1} (today's data set):

$$N_{B_s^0} = 2 \cdot L_{\text{int}} \cdot \sigma(b\bar{b}) \cdot f_s = (2.75 \pm 0.43) \cdot 10^6$$

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

- ▶ Full reconstruction of the B_s^0 . Observables: $(2 \times E_b^* = \sqrt{s})$
 - ▶ Beam-constrained mass: $M_{bc} = \sqrt{E_b^{*2} - p_{B_s^0}^{*2}}$
 - ▶ Energy difference: $\Delta E = E_{B_s^0}^* - E_b^*$
- ▶ 3 production modes ($B_s^* \rightarrow B_s^0 \gamma$):
 $\Upsilon(5S) \rightarrow B_s^* \bar{B}_s^*$, $\Upsilon(5S) \rightarrow B_s^* \bar{B}_s^0$ and $\Upsilon(5S) \rightarrow B_s^0 \bar{B}_s^0$.
 - ▶ 3 signal regions in $(M_{bc}, \Delta E)$ plane (B_s^* can't be reconstructed):



- ▶ Signal yield extraction: 2D unbinned maximum likelihood fit

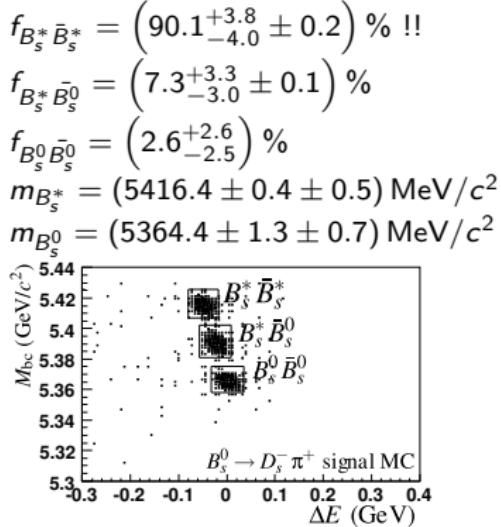
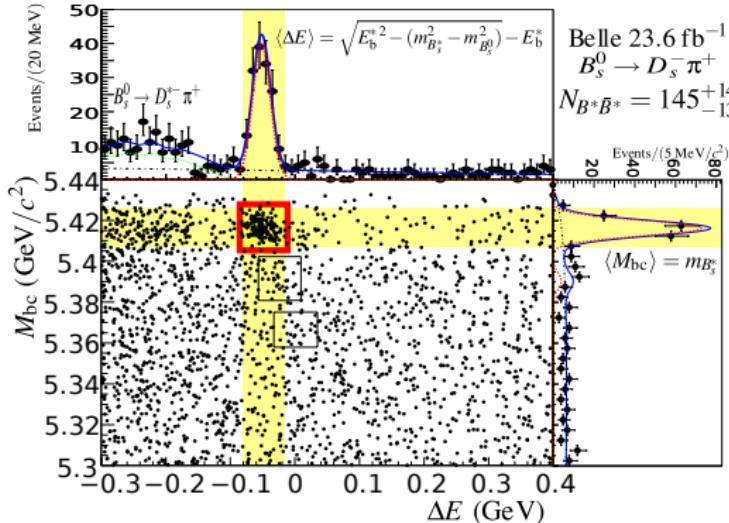
Why dominant B_s^0 decay modes?

- ▶ CKM-favored modes provide a lot of fully-reconstructed B_s^0 .
It's useful for:
 - ▶ Measurements of precise exclusive modes
→ LHC(b) needs 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
→ tests of HQET, factorization, etc.
 - ▶ Measurements of $\Upsilon(5S) \rightarrow B_s^{(*)} \bar{B}_s^{(*)}$ properties.
- ▶ In this talk:
 - ▶ Study of the $B_s^0 \rightarrow D_s^- \pi^+$ and $B_s^0 \rightarrow D_s^\mp K^\pm$ modes
 - RL *et al.* (Belle collaboration),
Phys. Rev. Lett. **102**, 021801 (2009); arXiv:0809.2526
 - ▶ First Observations of $B_s^0 \rightarrow D_s^{*-} \pi^+$, $B_s^0 \rightarrow D_s^- \rho^+$ and $B_s^0 \rightarrow D_s^{*-} \rho^+$
Contribution to Euroconf. on HEP, Kraków, July 2009
 - RL, PoS(EPS-HEP2009)170; arXiv:0909.2160
 - with update of $B_s^0 \rightarrow D_s^{*-} \rho^+$: polarization measurement (New !)

Summary

- ▶ Collision of 8.2 GeV e^- on 3.6 GeV e^+ , $\sqrt{s} = 10.87$ GeV = $M_{\Upsilon(5S)}$
- ▶ Production of resonant $b\bar{b}$ pair: $\Upsilon(5S)$
- ▶ Production of $B_s^{(*)}$ by hadronization of the $\Upsilon(5S)$
- ▶ Full reconstruction of exclusive $B_s^0 \rightarrow D_s^{(*)-} h^+$ decay
 - ▶ for today: $h^+ = K^+, \pi^+$ or ρ^+
 - ▶ Detection and identification of photon, π^+ and K^+
 - ▶ Reconstruction of dominant and clean sub-channels:
 $D_s^- \rightarrow \phi\pi^-$, $K^{*0}K^-$ or $K_S^0K^-$, $D_s^- \rightarrow D_s^-\gamma$, etc.
- ▶ 2 Observables, M_{bc} and ΔE — 2D maximum likelihood fit

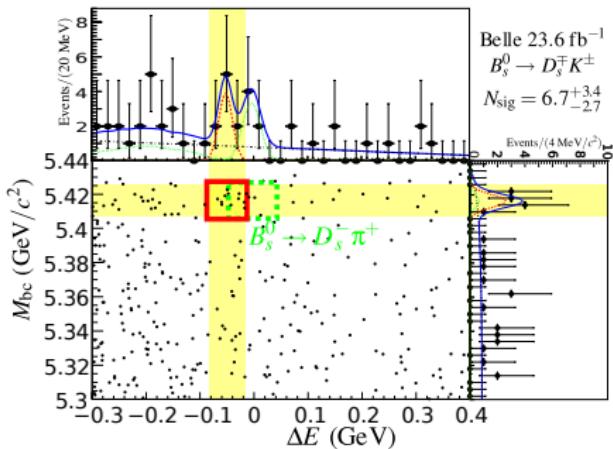
Measurement of $B_s^0 \rightarrow D_s^- \pi^+$



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

- ▶ 20% uncertainties, f_s is a crucial source of systematics
- ▶ large $f_{B_s^* B_s^*}$ confirmed
- ▶ $m_{B_s^*}$ is 2.6σ larger than CLEO.
- ▶ $m_{B_s^*}$ ($m_{B_s^0}$) is the 1st (2nd) most precise measurement so far.

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

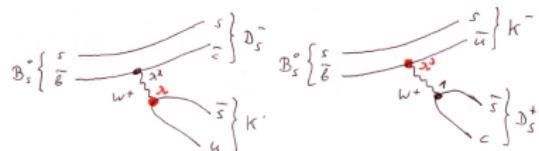


- Replace a π by a K .

- Cabbibo suppressed.

- Not flavor specific

2 tree diagrams in $\sim \lambda^3$:



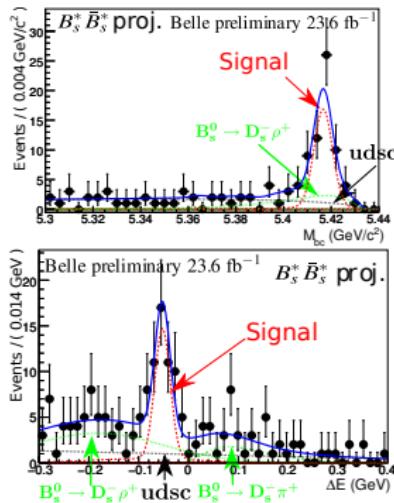
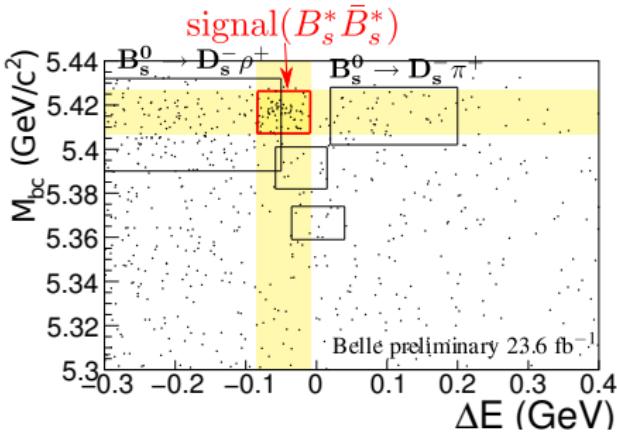
- Misidentified pions are important background

- 3.5 σ evidence (including systematics)
- $\mathcal{B}(B_s^0 \rightarrow D_s^\mp K^\pm) = (2.4^{+1.2}_{-1.0}(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.3(f_s)) \times 10^{-4}$
- Ratio with $B_s^0 \rightarrow D_s^- \pi^+$: (compatible with CDF: $(9.7 \pm 2.0)\%$, PRL 103, 191802)

$$\frac{\mathcal{B}(B_s^0 \rightarrow D_s^\mp K^\pm)}{\mathcal{B}(B_s^0 \rightarrow D_s^- \pi^+)} = (6.5^{+3.5}_{-2.9})\%$$

Needs more statistics...

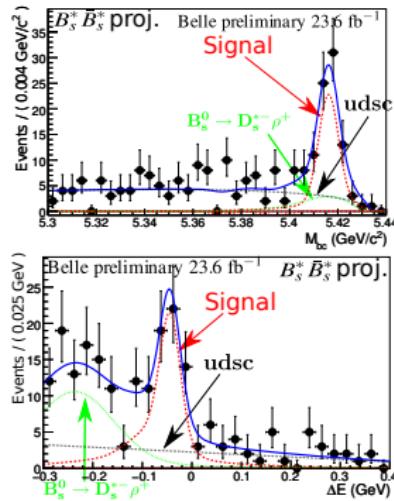
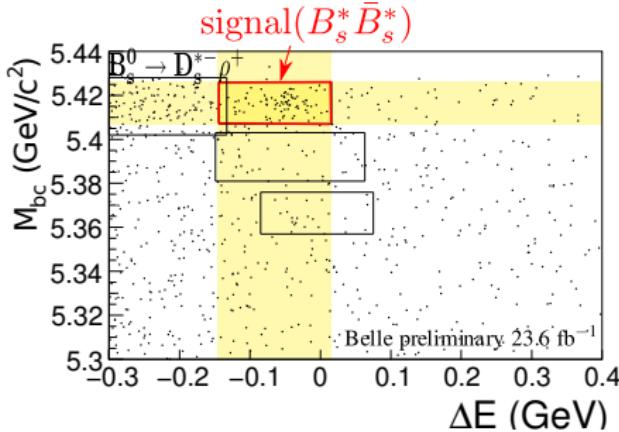
Observation of $B_s^0 \rightarrow D_s^{*-} \pi^+$



- ▶ Contamination from $B_s^0 \rightarrow D_s^- \pi^+$ and $B_s^0 \rightarrow D_s^- \rho^+$
- ▶ $N(B_s^* \bar{B}_s^*) = 53.4^{+10.3}_{-9.4} (\text{stat.})^{+2.4}_{-2.6} (\text{fit})$ events (8.4σ)
- ▶ $\mathcal{B}(B_s^0 \rightarrow D_s^{*-} \pi^+) =$

$$(2.4^{+0.5}_{-0.4} (\text{stat.}) \pm 0.3 (\text{syst.}) \pm 0.4 (f_s)) \times 10^{-3}$$

Observation of $B_s^0 \rightarrow D_s^- \rho^+$

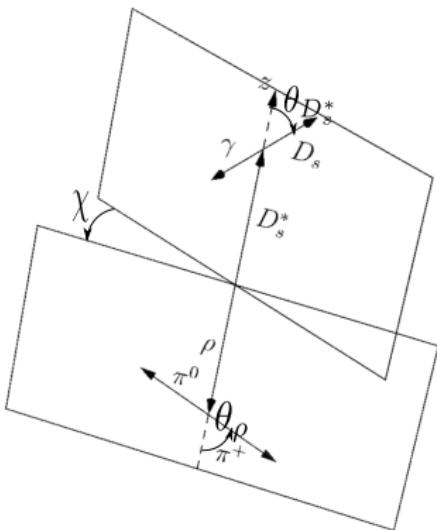


- ▶ Contamination from $B_s^0 \rightarrow D_s^{*-} \rho^+$
- ▶ $N(B_s^* \bar{B}_s^*) = 92.2^{+14.2}_{-13.2}(\text{stat.})^{+4.3}_{-4.2}(\text{fit})$ events (10.6σ)
- ▶ $\mathcal{B}(B_s^0 \rightarrow D_s^- \rho^+) =$

$$\left(8.5^{+1.3}_{-1.2}(\text{stat.}) \pm 1.1(\text{syst.}) \pm 1.3(f_s)\right) \times 10^{-3}$$

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

- Scalar \rightarrow Vector + Vector:
Three helicity amplitudes:

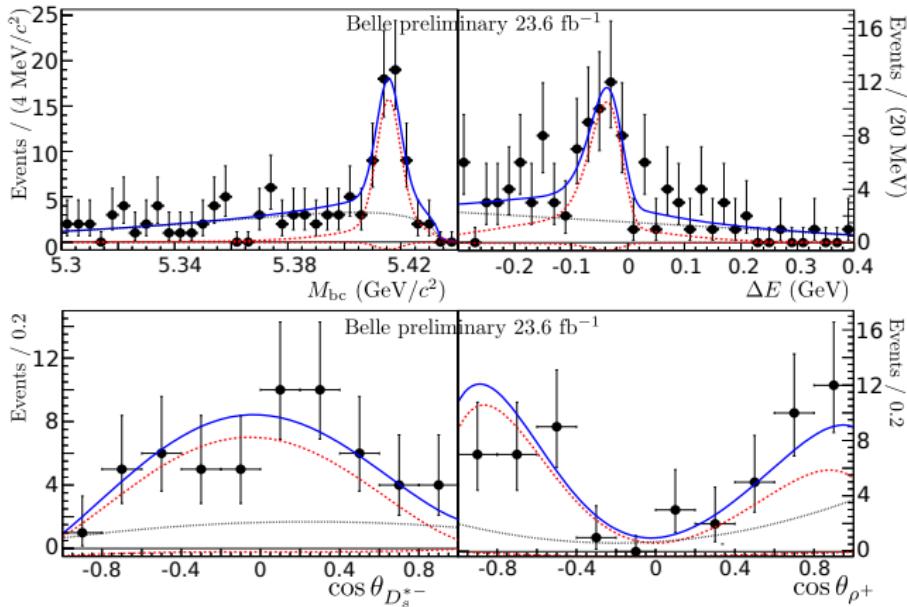


- Decay width depends on the “longitudinal polarization fraction” f_L :

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

- Longitudinal ($f_L = 1$) and transverse ($f_L = 0$) events have different M_{bc} , ΔE distribution
- Solution: access f_L and $\mathcal{B}(B_s^0 \rightarrow D_s^{*-} \rho^+)$ with a 4D (M_{bc} , ΔE , $\cos \theta_{D_s^*}$, $\cos \theta_\rho$) fit.

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



- $N(B_s^* \bar{B}_s^*) \approx 78$ events (9σ) ;
- $\mathcal{B}(B_s^0 \rightarrow D_s^{*-} \rho^+) \approx 12 \times 10^{-3}$; $f_L \approx 1$

Conclusion:

- ▶ Large sample of B_s^0 mesons $\sim 2.8 \cdot 10^6$ analyzed:
- ▶ Study of dominant CKM-favored decay modes.
 - ▶ Study of $B_s^0 \rightarrow D_s^- \pi^+$ and evidence for $B_s^0 \rightarrow D_s^\mp K^\pm$
Competitive values with 161 $B_s^0 \rightarrow D_s^- \pi^+$ events:
 - ▶ Masses of B_s^* and B_s^0
 - ▶ $\Upsilon(5S)$ properties: $f_{B_s^* \bar{B}_s^*}$, $f_{B_s^* \bar{B}_s^0}$ and $f_{B_s^0 \bar{B}_s^0}$
 - ▶ First Observations of $B_s^0 \rightarrow D_s^{*-} \pi^+$, $B_s^0 \rightarrow D_s^- \rho^+$ and $B_s^0 \rightarrow D_s^{*-} \rho^+$.
- ▶ B.F. precision suffers mainly from then imprecise fraction $f_s = N_{B_s^{(*)} \bar{B}_s^{(*)}} / N_{b\bar{b}}$
→ Not much information for theory at the moment....
- ▶ Full Belle $\Upsilon(5S)$ sample \geq **5 times larger** (120 fb^{-1})
than the currently analyzed sample → Better precision can be achieved !

Thank you.