B_s and *b*-Baryon Decays

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(on behalf of the CDF and DØ Collaborations)

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Outline

- Motivation

- Recent B_s and b-Baryon Decay Topics:
  - $B_s \to D_s K$: First Observation and BF
  - $B_s \to D_s^{(*)+} D_s^{(*)-}$: Worldwide status
  - $B_s \to D_{s1}(2536)\mu\nu X$: First Observation and BF
  - Radiative Penguins $B_s \to \phi\gamma / \gamma\gamma$: First Observation and BF/limit
  - $B_s \to h^- h^+$: Updated BFs
  - $\Lambda_b \to p(K,\pi)$: First Observation and BFs

- Related Topics not covered in this talk

- Concluding Remarks

Motivation

- Heavier b-flavoured hadrons are a fecund source of physics:
  - Rich interplay between **strong** and **electroweak** effects
  - Proving ground: *e.g.*, for Effective Theories, QCD Factorization, Lattice Methods, and Potential Models
  - Opportunities to uncover **physics beyond the SM**

- Measuring observables from b-baryons and strange B mesons:
  - Complementary to the wealth of physics from the $\Upsilon(4S)$
  - When compared to non-strange $B_{u,d}$ decays:
    - Hadronic uncertainty cancellations
    - SU(3) flavour symmetry tests
    - Decay amplitude disentanglement
    - Improved access to Electroweak parameters!

CDF: $B_s \to D_s K$

- Contributions from both upper- and lower-vertex charm

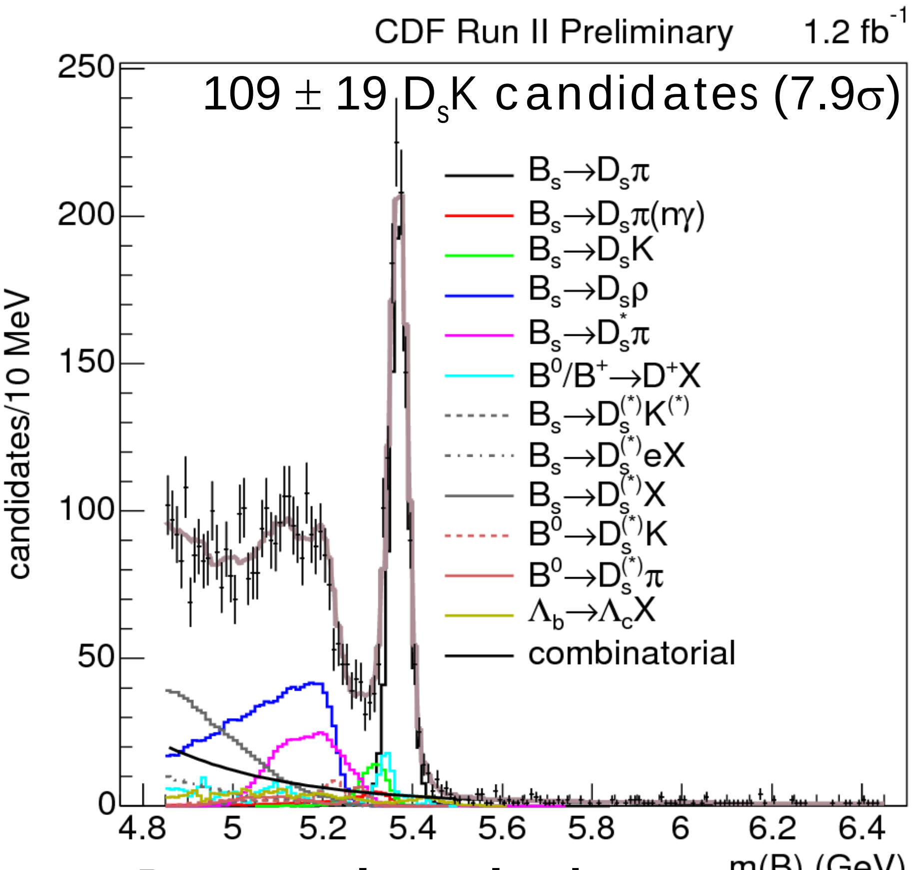
- Compared with $B^0 \to D^- K^+$ analogue:
  - Same B_s state can decay to both $D_s^+ K^-$ and $D_s^- K^+$
  - Decay amplitude interference through B_s mixing

- Relative weak phase is the CKM angle γ

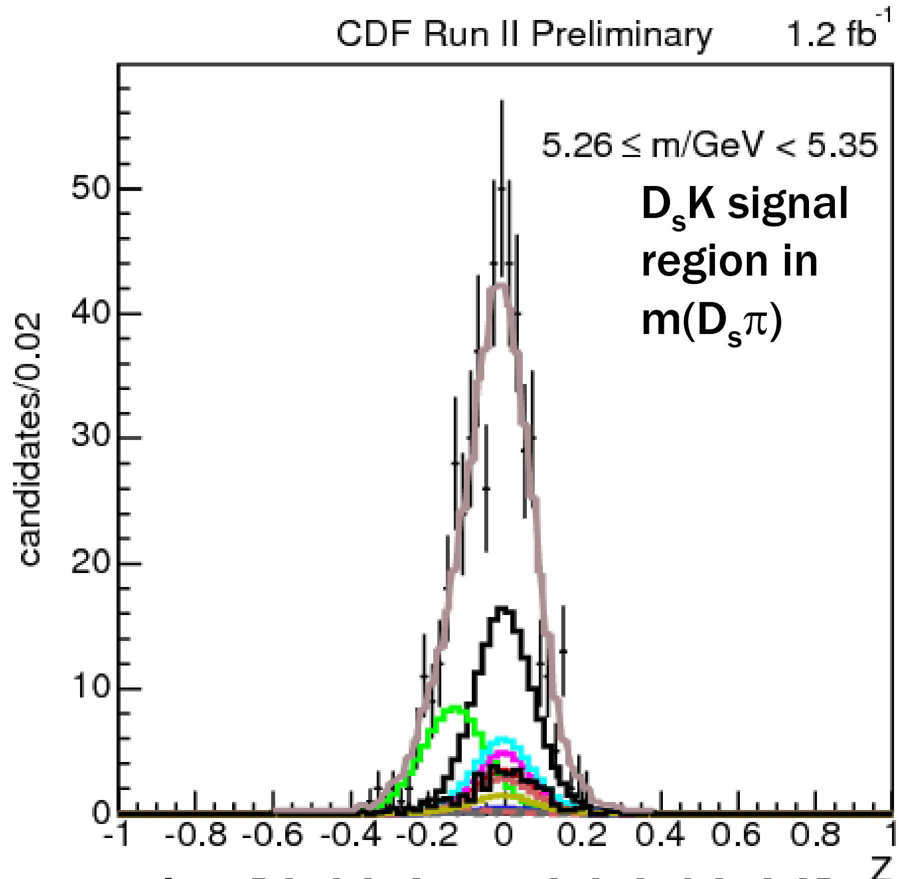
- First must observe this Cabibbo-suppressed decay and distinguish it from the Cabibbo-favoured $D_s\pi$ mode

CDF: $B_s \to D_s$ K Fit Projections

- Level 2 Silicon Vertex 2-track Trigger
- Also analyze $D^{*-}K^+$ and D^-K^+ control samples
- $D\pi$ radiative tail accounted for in fit
- Simultaneous mass and dE/dx ML fit
- Mass PDFs from MC (except combinatorial)
- dE/dx PDFs mainly from inclusive D* data



$D_s\pi$ mass hypothesis



$Z \equiv \log [dE/dx(meas) / dE/dx(\pi)]$

CDF: $B_s \to D_s K$ First Observation

- 7.9σ statistical significance

- Measure preliminary branching fraction w.r.t. the Cabibbo-favoured mode:

CDF Run II Preliminary

$$\frac{Br(B_s^0 \to D_s K)}{Br(B_s^0 \to D_s \pi)} = 0.107 \pm 0.019 \pm 0.008$$

- Statistically compatible with the analogous B^0 branching-fraction ratio ⇒ interference effects not yet observable

- $Br(B_s \to D_s \pi)$ normalization mode also extracted from CDF measurements
  - CDF, Phys. Rev. Lett. **98** 061802 (2007)
  - Refer to the next talk (Chunlei Liu) for lifetime analysis

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

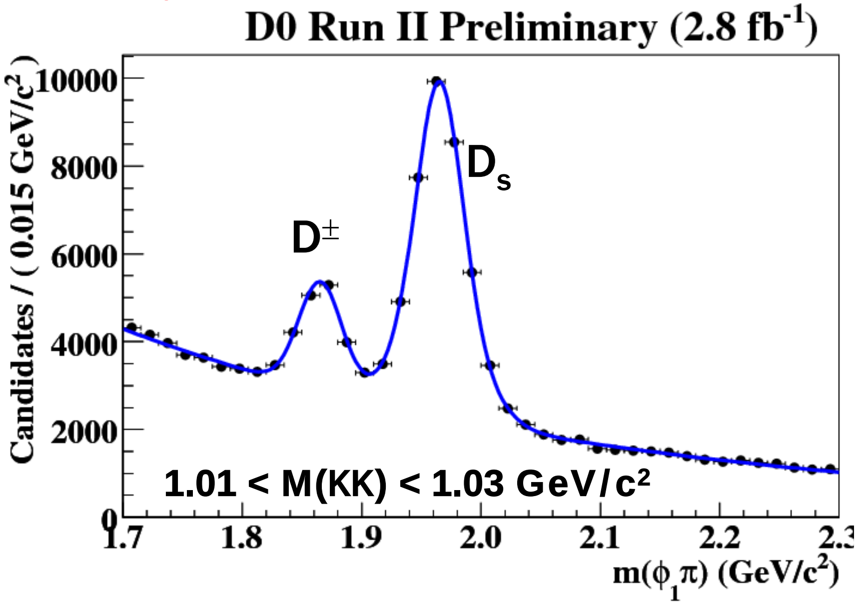
- Decays are considered to be principal contributors to the **rate difference** between the odd and even B_s CP eigenstates
- $D_s^{(*)+} D_s^{(*)-}$ is expected to be **mostly CP-even** ($\pm$~5%)
- Sensitive to New Physics causing **large** ϕ_s mixing phase
- **Experimentally challenging:** small fully hadronic charm-meson branching fractions

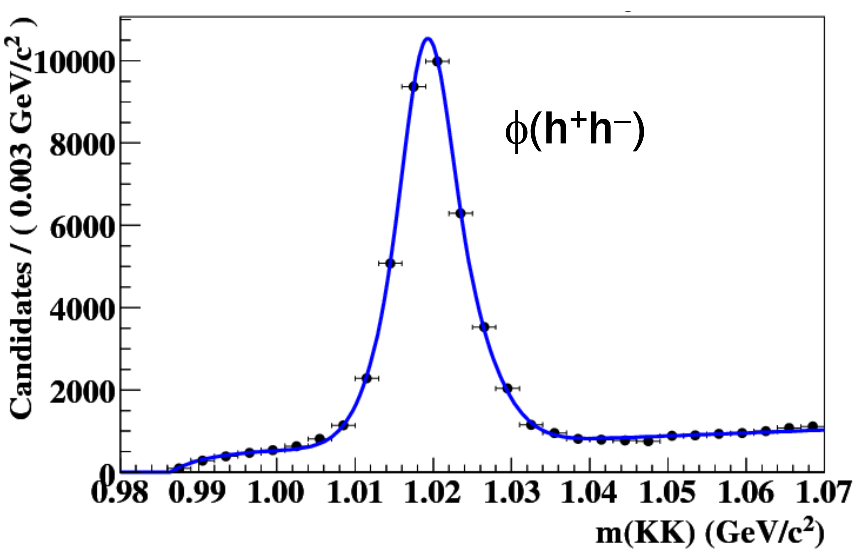
Refer to yesterday's DØ Hot-Topic talk by Sung Woo Youn

DØ : Partial reconstruction: $(\phi\pi) \otimes (\phi\mu\nu)$
Inclusive sum of D_sD_s, $D_s^*D_s$, and $D_s^*D_s^*$ measured
Normalization mode: $B_s \to D_s^{(*)}\mu\nu$

DØ: $B_s \to D_s^{(*)+} D_s^{(*)-}$

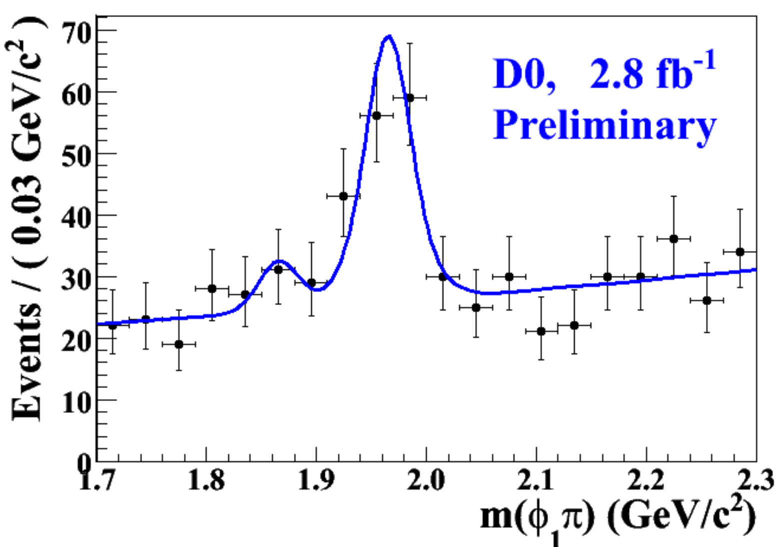
Inclusive $D_s^{(*)}$ reconstruction in the μ sample.

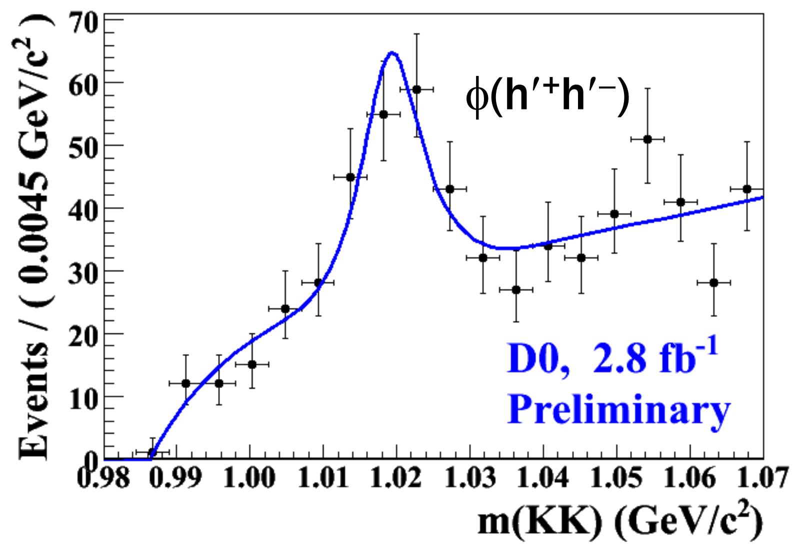




Reconstruction when requiring the second ϕ candidate in the event.

Signal Fit: 3.7σ





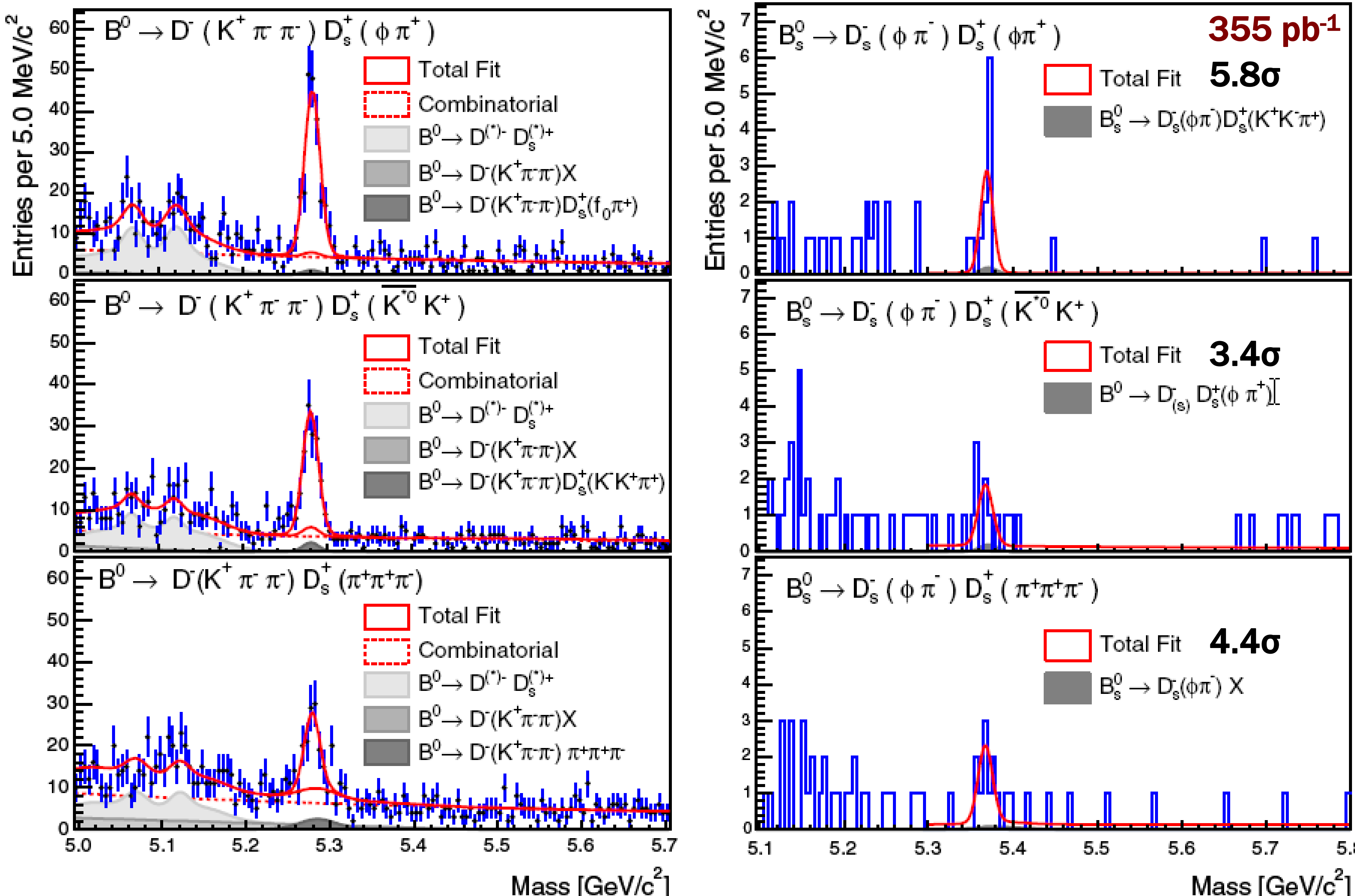
CDF: First Observation $B_s \to D_s^- D_s^+$

- Purely $B_s^L \to D_s^- D_s^+$, CP-even (due to quark-level effects)
- **Approach**: exclusive, hadronic reconstruction
- **3 D_s modes** to enhance sensitivity: $\phi\pi$, **K^*K**, $\pi\pi\pi$
- Also reconstruct $B^0 \to D^- D_s^+$ normalization mode
- **Measure:**

$$\frac{\mathcal{B}(B_s^0 \to D_s^- D_s^+)}{\mathcal{B}(B^0 \to D^- D_s^+)} = \frac{N_{B_s^0}}{N_{B^0}} \frac{\epsilon_{B^0}}{\epsilon_{B_s^0}} \frac{f_d}{f_s} \frac{\mathcal{B}(D^- \to K^+\pi^-\pi^-)}{\mathcal{B}(D_s^- \to \phi\pi^-)}$$

CDF: $B_s \to D_s^+ D_s^-$

CDF, Phys. Rev. Lett. **100** , 021803 (2008)



Combined Significance: 7.5σ

$B_s \to D_s^{(*)+} D_s^{(*)-}$: Branching-Fraction Synopsis

- **DØ, 3.7σ, 2.8 fb^{-1},** Preliminary (DØ Note 5651-CONF):

$$Br(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 0.042 \pm 0.015(\mathrm{stat}) \pm 0.017(\mathrm{syst})$$

- **CDF, 7.5σ, 355 pb^{-1},** Phys. Rev. Lett. **100** , 021803 (2008):

$$\mathcal{B}(B_s^0 \to D_s^- D_s^+) = (9.4^{+4.4}_{-4.2}) \times 10^{-3}$$

- **Belle, 1.86 fb^{-1} Υ(5S),** hep-ex/0610003v4 (submitted to PRL):

<6.7% (D_sD_s), <12.1% ($D_s{}^*D_s$), <25.7% ($D_s{}^*D_s{}^*$) [90% CL]

- **ALEPH (PDG'08),** Phys. Lett. **B486** 286 (2000):

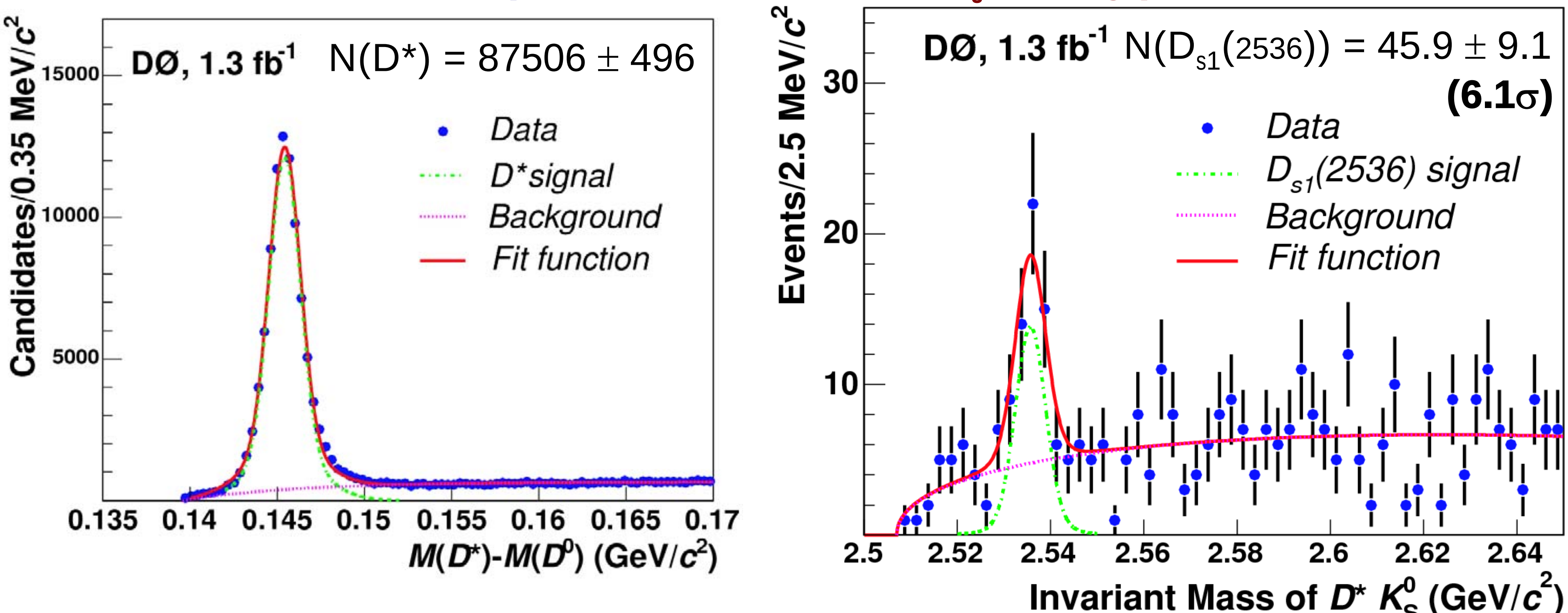
$$\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 0.12 \pm 0.05^{+0.10}_{-0.04}$$

Note: DØ and PDG use different ways of updating ALEPH

DØ: First Observation $B_s \to D_{s1}(2536)\mu\nu X$

Significant fraction of B_s mesons decay to P-wave D_s^{**} mesons.

Measurements of semileptonic B_s decay channels: are needed to make inclusive/exclusive comparisons and CKM and B_s-mixing parameter extractions



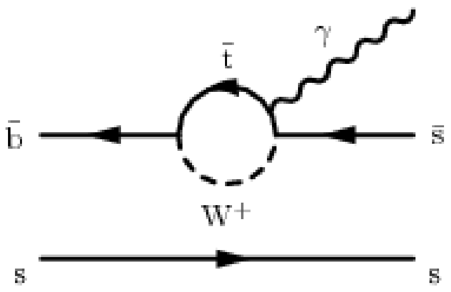
$$f(\bar{b} \to B_s^0) \cdot Br(B_s^0 \to D_{s1}^- \mu^+ \nu X) \cdot Br(D_{s1}^- \to D^{*-} K_S^0) = \\ = [2.66 \pm 0.52\,(\text{stat}) \pm 0.45\,(\text{syst})] \times 10^{-4}$$

$$m(D_{s1}) = 2535.7 \pm 0.6\,(\text{stat}) \pm 0.5\,(\text{syst})\,\text{MeV}/c^2$$

arXiv:0712.3789
Submitted to PRL

Belle: First Observation of $B_s \to \phi\gamma$

- SM: Radiative Penguin Diagram

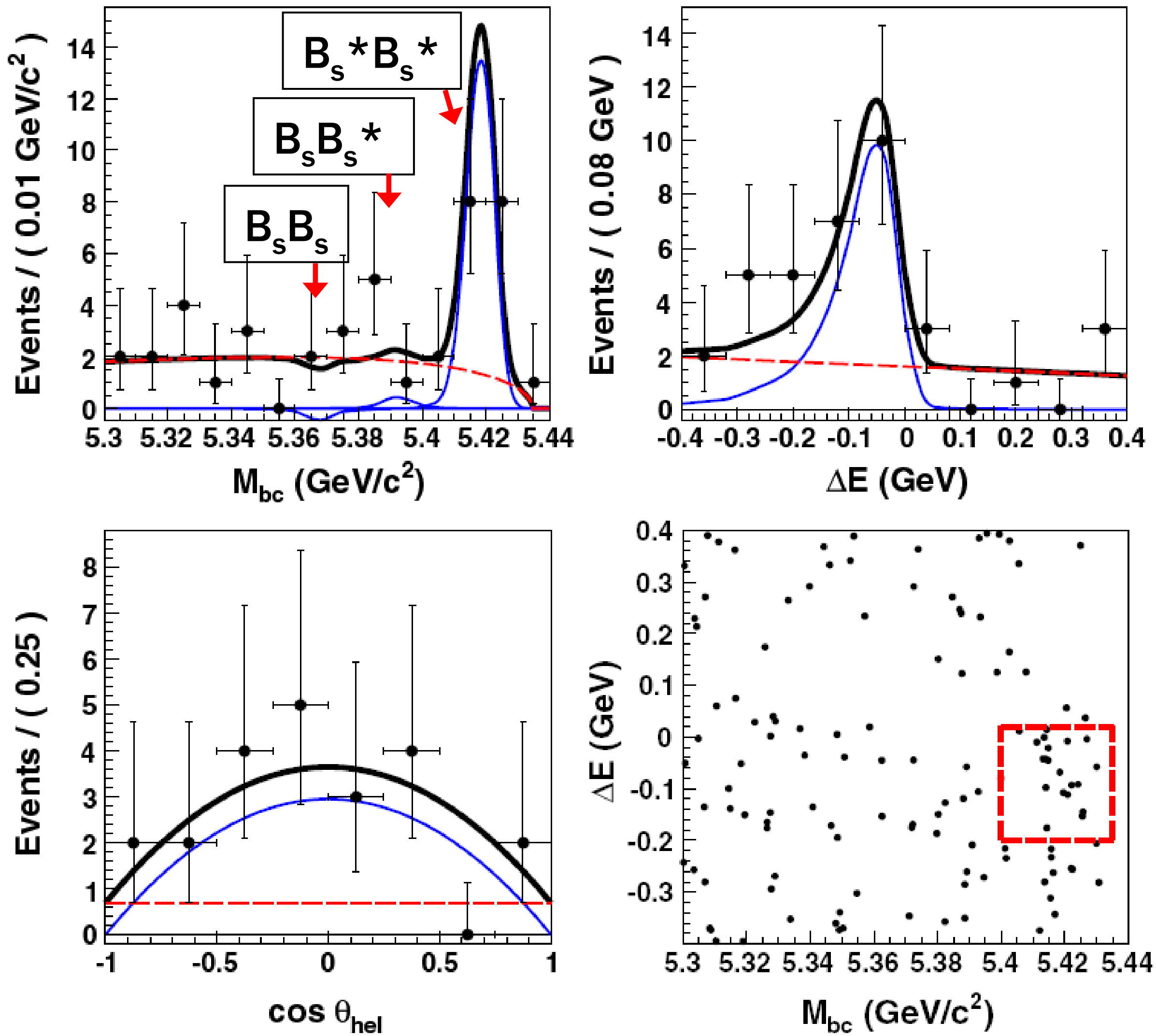


- Strange analogue of $B^0 \to K^*\gamma$

- $\Rightarrow$ predictions well constrained for $B_s \to \phi\gamma$:
  - $BF_{theory} = 40 \times 10^{-6}$ ($\pm$~30%)
    [Ball, Jones, Zwicky (2007) / Ali, Pecjak, Greub (2007)]
  - Previous $BF_{exp't} < 120 \times 10^{-6}$ (90% CL)
    [CDF, Phys. Rev. D 66, 112002 (2002)]

Belle: First Observation of $B_s \to \phi\gamma$

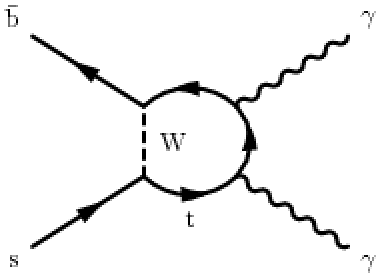
- Υ(5S), 23.6 fb^{-1}
- Unbinned 3D ML fit
- 18^{+5}_{-6} candidates (**5.5σ**)
- **Branching Fraction:**



$$\mathcal{B}(B_s^0 \to \phi\gamma) = (57^{+18}_{-15}(\text{stat})^{+12}_{-11}(\text{syst})) \times 10^{-6}$$

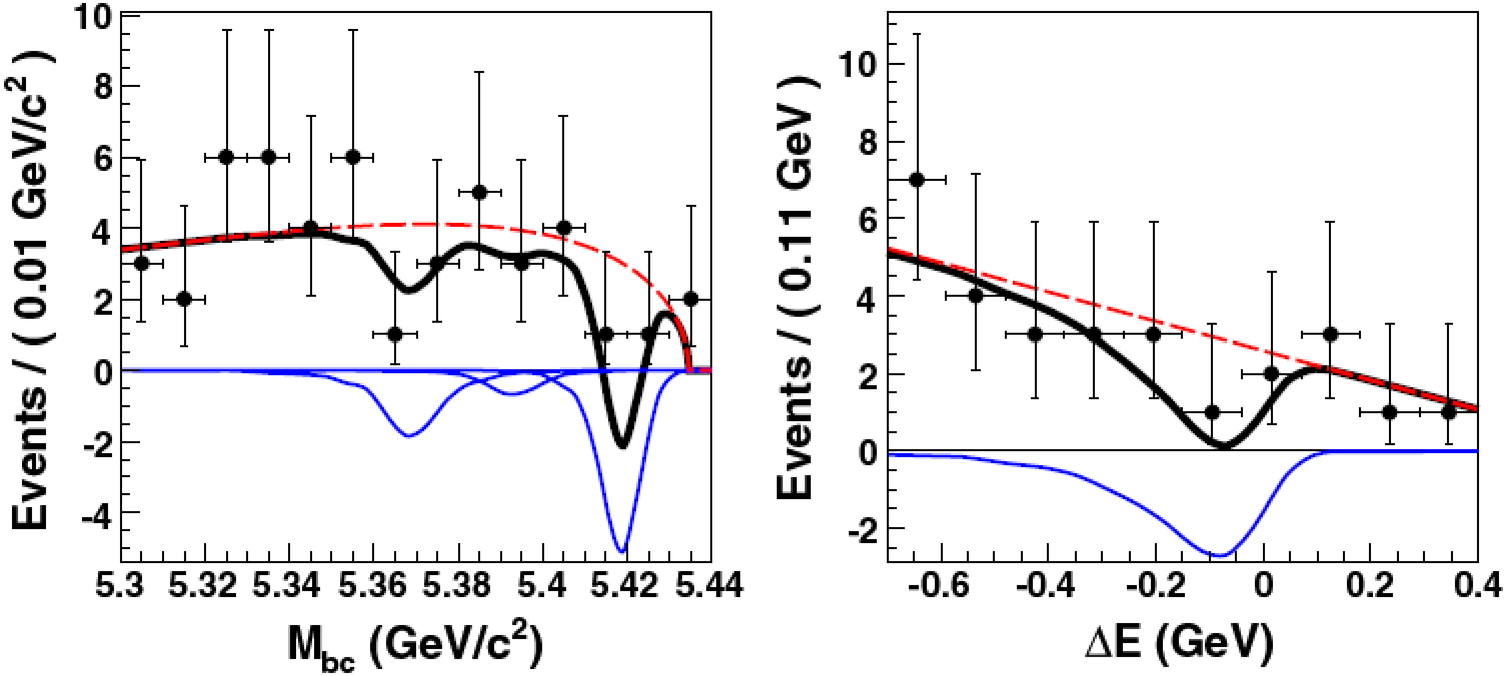
Belle, Phys. Rev. Lett. **100** , 121801 (2008)

Belle: Search for $B_s \to \gamma\gamma$ Penguin



- SM: Penguin annihilation diagram
- Similarly constrained by $B^0 \to K^*\gamma$ [Bertolini, Matias (1998)]:
  - $BF_{theory} = (0.5 - 1.0) \times 10^{-6}$ [Chang, Lin, Yao (1997) / Reina, Ricciardi, Soni (1997) / Bosch, Buchalla (2002)]
  - Previous $BF_{exp't} < 53 \times 10^{-6}$ (90% CL) [Belle, Phys. Rev. D 67, 112002 (2007)]
- However: New Physics can satisfy $B^0 \to K^*\gamma$ constraints while increasing the $B_s \to \gamma\gamma$ BF by up to ~10×, *e.g.*:
  - SUSY with broken R-parity [Gemintern, Bar-Shalom, Eilam (2004)]
  - 4^{th} Quark Generation [Huo, Lu, Xiao (2003)]
  - Two-Higgs Doublet Model with FCNC [Aliev, Iltan (1998)]

Belle: Search for Radiative $B_s \to \gamma\gamma$



- $\Upsilon(5S)$, 23.6 fb^{-1}
- Unbinned 2D ML fit
- No signal seen
- Branching Fraction 90% CL Limit: $\mathcal{B}(B_s^0 \to \gamma\gamma) < 8.7 \times 10^{-6}$

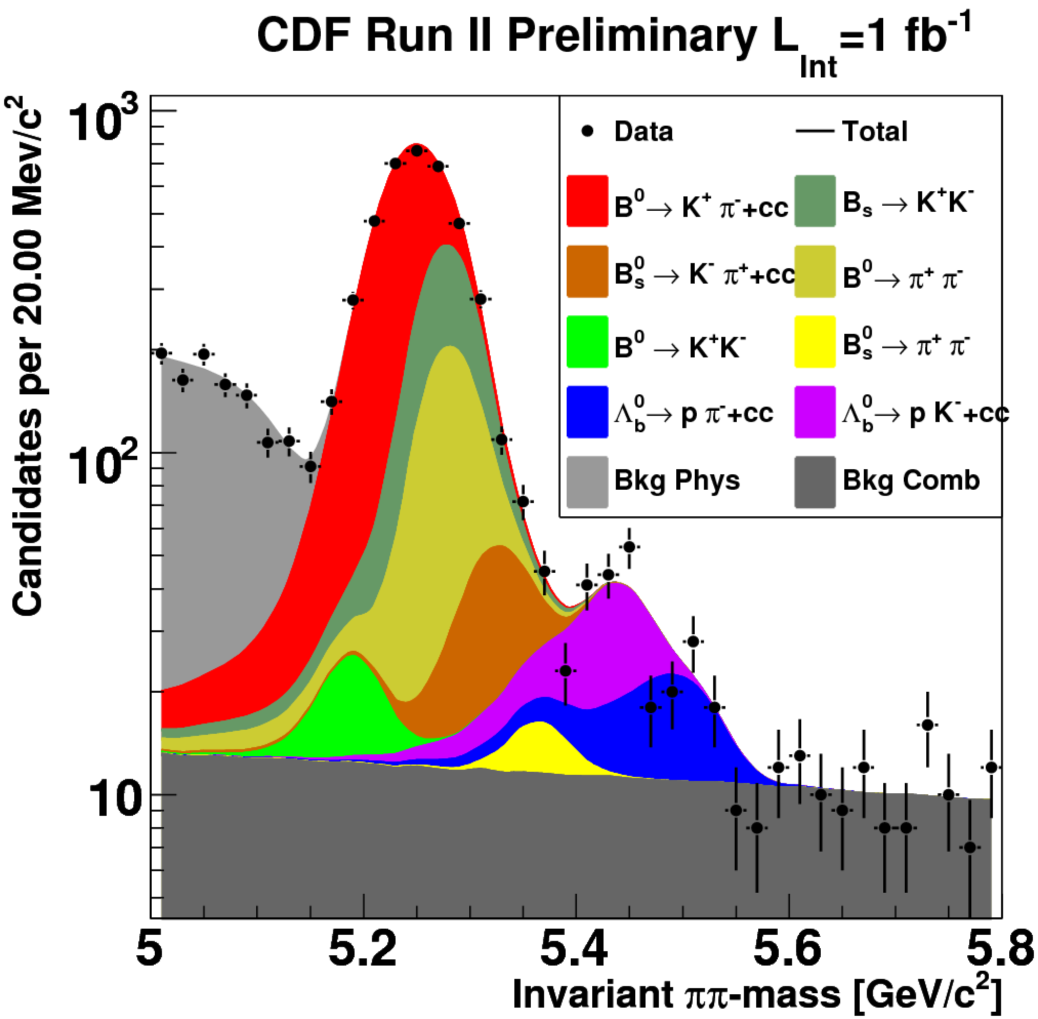
Belle, Phys. Rev. Lett. **100** , 121801 (2008)

CDF: Updated $B_s \to h^- h^+$ Branching Fractions

- h $\in$ (π, K)
- As for D_sK: profitable use of CDF's online Silicon Vertex 2-track Trigger
- Also: Isolation criterion

$$I(B) \equiv \frac{p_T(B)}{p_T(B) + \sum_i p_T(\text{track}^i)}$$

Where the sum is over all non-B charged tracks within a cone of radius R = 1 around the candidate B-meson direction



- I(B) > 0.5: reduces background by ~4$\times$ with ~80% efficiency
- New: Improved precision of B^0/B_s isolation efficiency ratio
  (Measured using $B_d \to J/\psi K^{*0}$, $B_s \to J/\psi \phi$, $B_s \to D_s\pi$, and $B_u \to J/\psi K$ modes)

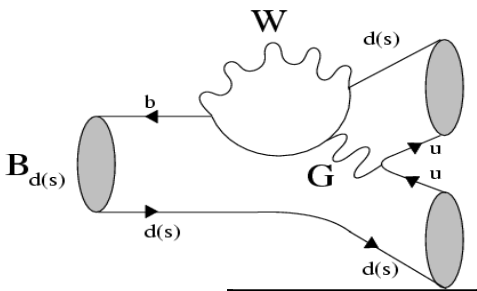
CDF: $B_s \to$ hh Branching Fractions with 1 fb^{-1}

Updated 2008.Apr.10

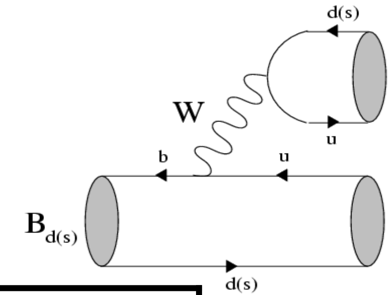
Mode	N_s	Measurement	BF × 10^6 ‡
$B_s^0 \to K^+K^-$	1307 ± 64	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$ $0.347 \pm 0.020 \pm 0.021$	$25.8 \pm 1.5 \pm 3.9$
$B_s^0 \to K^-\pi^+$	$230 \pm 34 \pm 16$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)}$ $0.071 \pm 0.010 \pm 0.007$	$5.27 \pm 0.74 \pm 0.90$
$B_s^0 \to \pi^+\pi^-$	$26 \pm 16 \pm 14$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$ $0.007 \pm 0.004 \pm 0.005$	$0.52 \pm 0.29 \pm 0.38$ (< 1.3 @ 90% CL)

‡ **BFs derived using HFAG2008 input**

For details:
http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/public_note/cdf8579_bhh_1fb_public_v1.ps



$B_s \to h^- h^+$ Measurements & Example Predictions



BF × 10^6	CDF II Preliminary 1 fb^{-1}	Beneke & Neubert ‡* Nucl. Phys. B 675, 333 (2003)	Chiang & Zhou ‡ JHEP0612, 027 (2006)
$B_s \to K^+ K^-$	25.8 ± 1.5 ± 3.9	28 ↔ 36	(18.8 ± 1.0) ↕ (19.0 ± 4.0)
$B_s \to K^+ \pi^-$	5.27 ± 0.74 ± 0.90	6.8 ↔ 10.4	5.0 ± 1.0
$B_s \to \pi^+ \pi^-$	<1.3 [90% CL]	0.027 ↔ 0.155	0

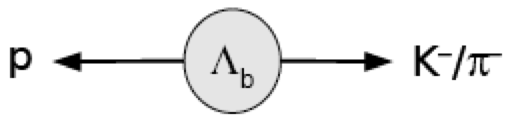
See CDF, Phys. Rev. Lett. 97, 211802 (2006) for more theoretical citations.

‡ Ranges cover multiple theory parameter fit scenarios.
* Theoretical uncertainties not shown here.

Bigger Picture: Need to compare to analogous B^+ and B^0 mode BFs (also A_{CP})!
Results suggest: larger SU(3) breaking in strong phases or a breakdown of QCD factorization

See talk yesterday → [Cheng-Wei Chiang, M. Gronau, J.L. Rosner, arXiv:0803.3229]

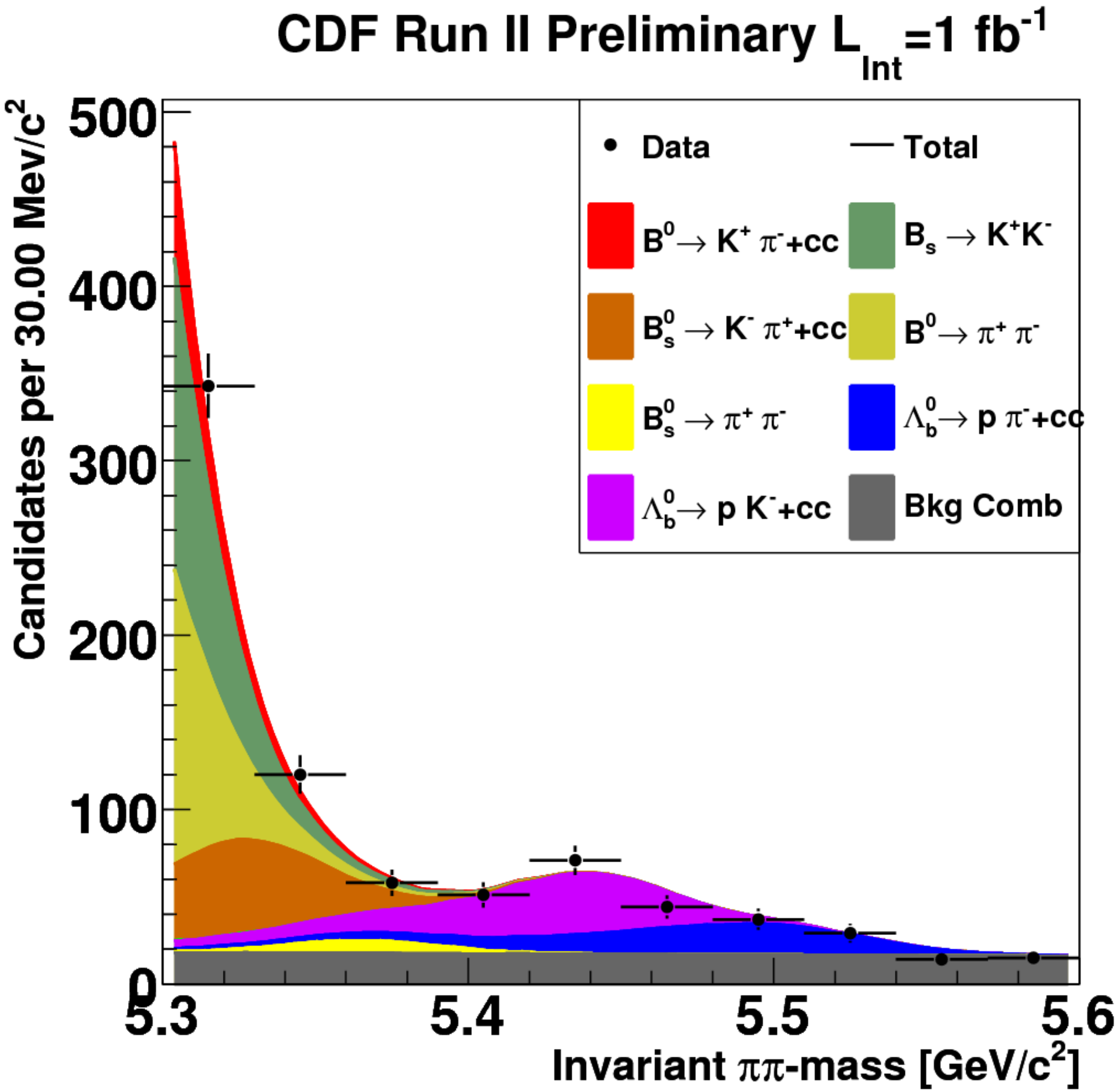
CDF: First Measurement of $\Lambda_b \rightarrow p\ (K,\pi)$



- Sensitive to **New Physics** scenarios:
  e.g., RPV MSSM
  [Mohanta, PRD63 056006 (2001)]
  $\Rightarrow$ BF = $BF_{SM} \times 100$

- Dedicated optimized analysis using same $B_{d,s} \rightarrow h^- h^+$ machinery

- Fit in terms of three kinematic variables and a particle-ID observable



CDF: First $\Lambda_b \to p(K,\pi)$ Branching Fractions

Choose $B^0 \to K^- \pi^+$ as the reference mode due to its abundance and B-factory precision

Measured relative branching fractions (CDF preliminary):

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6 \text{ GeV/c})}{\sigma(p\bar{p} \to B^0 X, p_T > 6 \text{ GeV/c})} \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0415 \pm 0.0074 \ (stat.) \pm 0.0058 \ (syst.)$$

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6 \text{ GeV/c})}{\sigma(p\bar{p} \to B^0 X, p_T > 6 \text{ GeV/c})} \frac{\mathcal{B}(\Lambda_b^0 \to pK^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0663 \pm 0.0089 \ (stat.) \pm 0.0084 \ (syst.)$$

Using (PDG'07): $f_{\text{b-baryon}}/f_d = 0.25 \pm 0.04$

Derived preliminary absolute branching fractions:

$$\mathcal{B}(\Lambda_b^0 \to p\pi^-) = (3.1 \pm 0.6 \ (stat.) \pm 0.7 \ (syst.)) \times 10^{-6}$$

$$\mathcal{B}(\Lambda_b^0 \to pK^-) = (5.0 \pm 0.7 \ (stat.) \pm 1.0 \ (syst.)) \times 10^{-6}$$

Consistent with Standard Model; exclude *O*(10^{-4}) RPV MSSM predictions.

Related Heavy b-Hadron Decay Topics Not Covered in this Talk

- Chunlei Liu (next talk): Lifetimes and Mixing
- D. Tsybychev (Thursday): Rare B/B_s Decays
  - $B_s \to \mu\mu$ (CDF, DØ) (see S. Donati's talk yesterday)
  - $B_s \to \mu\mu\phi$ (CDF, DØ)
- R. Van Kooten (Friday): b-Hadron Spectroscopy
  - P-Wave B_s^{**} decays (CDF, DØ)
  - $B_c \to J/\psi\, \pi$ (CDF, DØ)
  - Σ_b and Σ_b^* baryons (CDF)
  - Ξ_b baryon (CDF, DØ)
- Additional $\Upsilon(5S)$ B_s and B_s^* decays (CLEO, Belle)
- $\eta_b \to J/\psi\, J/\psi$ search (CDF)
- $B_s \to \psi(2S)\, \phi$ (CDF, DØ)
- $\Lambda_b \to \Lambda_c\, (\mu\nu / \pi)$ rate ratio (CDF)

Concluding Remarks

- Several new **B_s /b-Baryon** results in the past year, including
  - New results for three classes of $B_s \to D_s^{(*(*))} X$ modes
  - Radiative Penguin $B_s \to \phi\gamma$ observed
  - Updated $B_s \to h^- h^+$ results
  - $\Lambda_b \to p\,(K,\pi)$ branching fractions measured

- For the Future:
  - Improved measurements of f_s and $f_{b\text{-baryon}}$ are crucial!
  - Flavour-tagging possibilities with additional data
  - More data needed:
    - to answer **theoretical questions** raised by new results
    - to continue exploration of this rich sector of **flavour physics**!