CEA Saclay, March 15, 2010

Strange Beauty and Other Beasts: At and Above the $\Upsilon(5S)$ with Belle

- Belle/KEKB, $\Upsilon(4S)$ Resonance, B meson
- $\Upsilon(5S)$ Resonance and B_s
  - motivation
  - Belle data & results
  - prospects

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Belle Collaboration

The people

Belle collaboration

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Ewha Womans U.
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EPF Lausanne
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Princeton U.
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Saga U.
USTC
Seoul National U.
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Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
U. of Tsukuba
VPI
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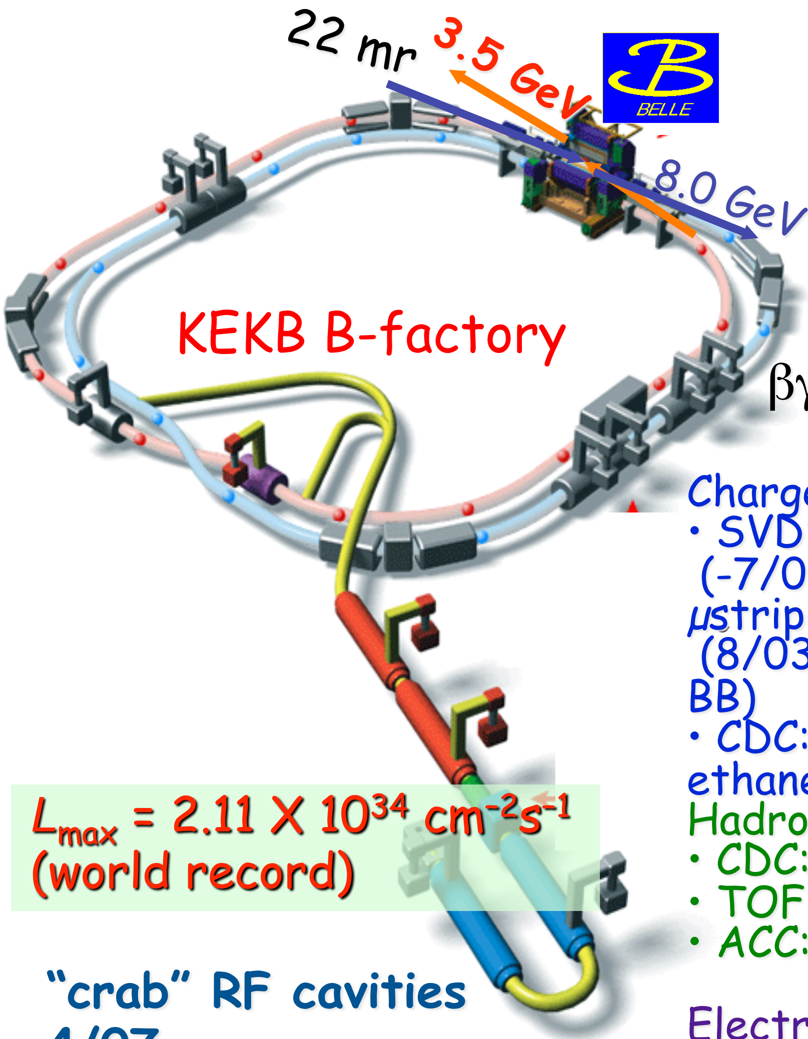
~14 nations, 55 institutes, ~400 collaborators

(authors vary, each paper)

... the hardware



$\beta\gamma$ = 0.425

L_{max} = 2.11 X 10^{34} $cm^{-2}s^{-1}$
(world record)

"crab" RF cavities
4/07-

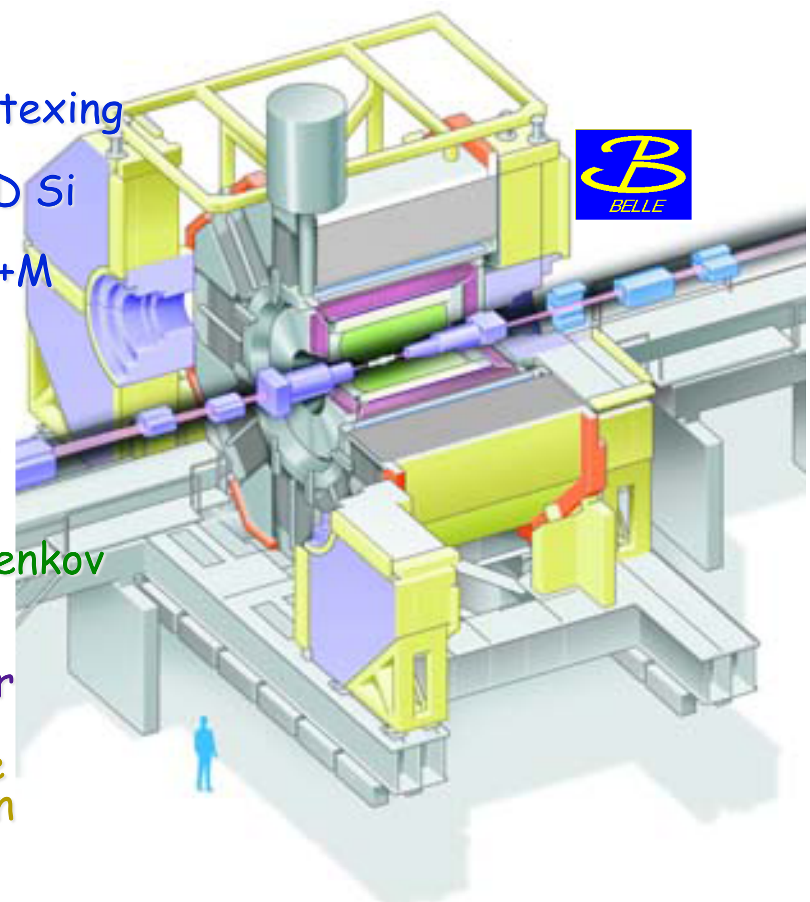
4/07- COPPER pipelined DAQ system

Charged tracking/vertexing
- SVD:
  (-7/03) 3-layer DSSD Si μstrip (152M B pairs)
  (8/03-) 4-layer (550+M BB)
- CDC: 50 layers (He-ethane)

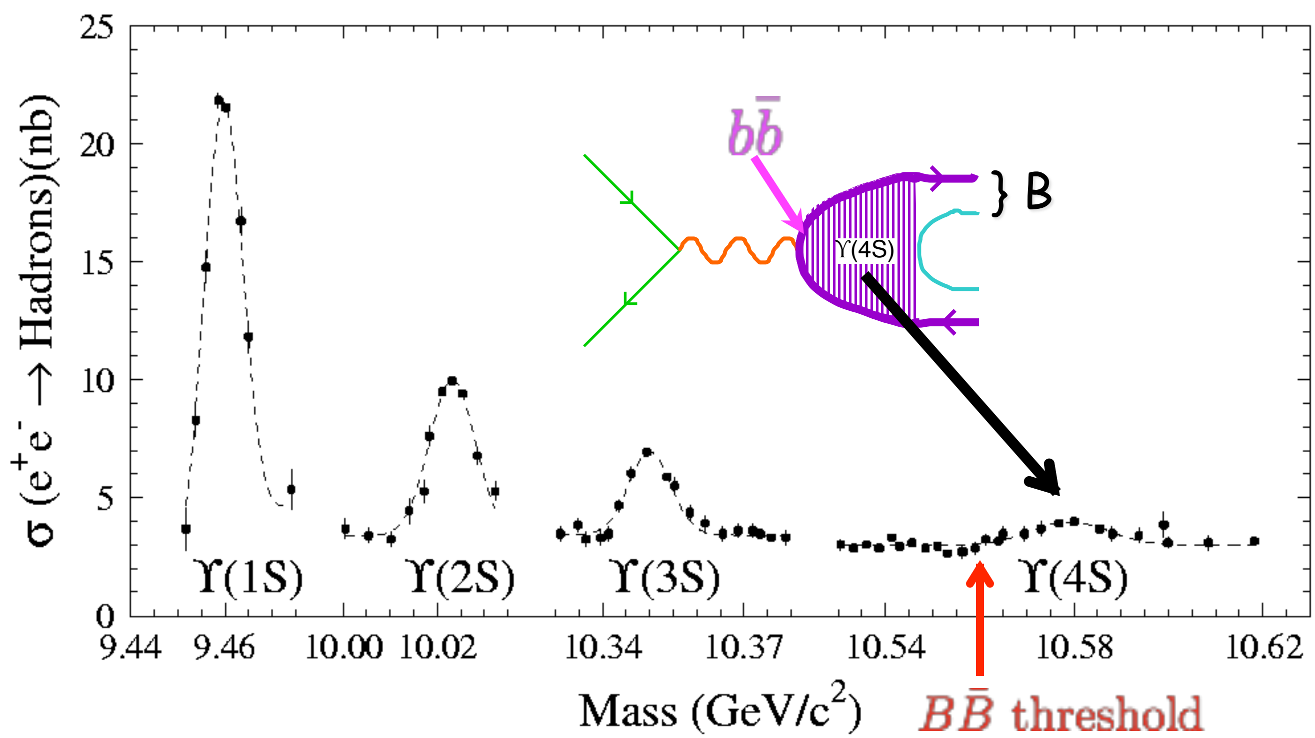
Hadron identification
- CDC: dE/dx
- TOF: time-of-flight
- ACC: Threshold Cerenkov (aerogel)

Electron/photon
- ECL: CsI calorimeter

Muon/K_L
- KLM: Resistive plate counter/iron



… the Physics $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ (mostly)



Primary goal: discover CP violation in weak decays of B meson

DONE!

… but there's much more!

Data

1000 fb^{-1} = 1 ab^{-1} recorded by Belle as of 12/09

$\int L dt$ since 6/1999

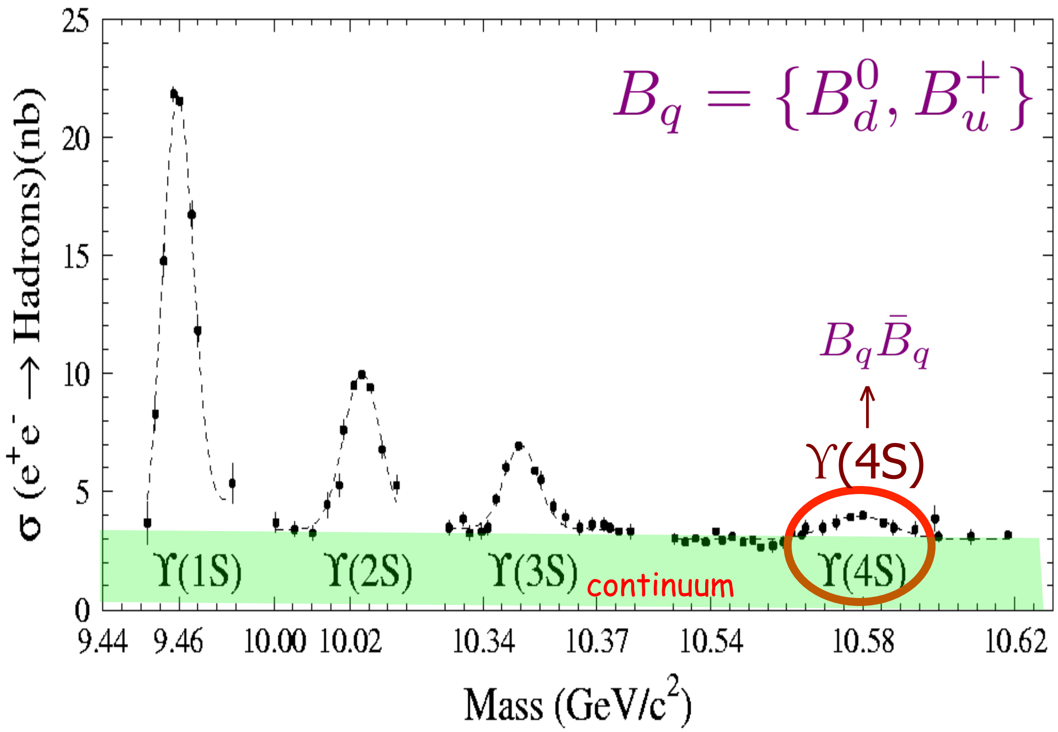
- Υ(4S)
  710 fb^{-1}
- Υ(4S) continuum
  83 fb^{-1}
- Υ(5S)
  ~120 fb^{-1}
- Υ(3S), Υ(2S) , Υ(1S)
  ~34fb^{-1}
- Υ(5S)+ scan
  ~8 fb^{-1}

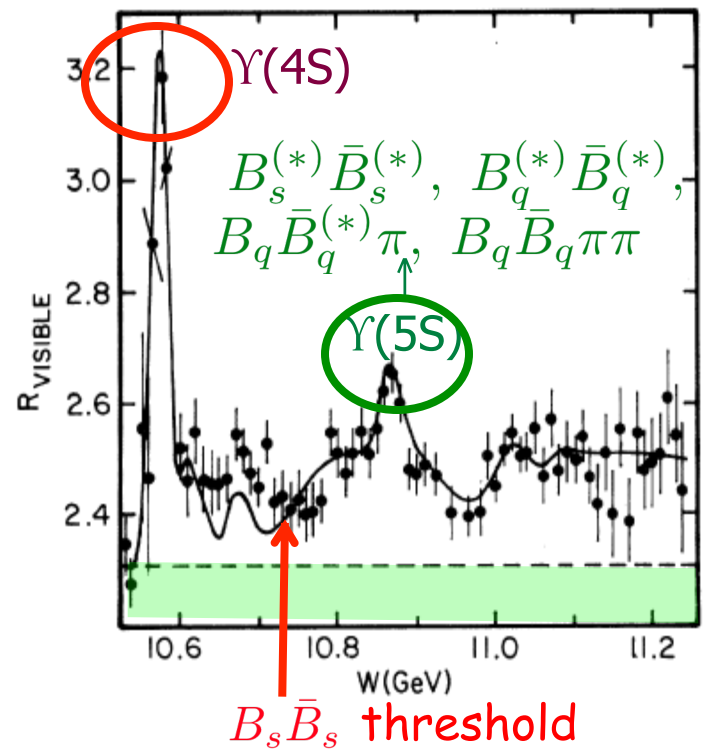
- B (7.7 x 10^{8} events)
- charm (1.1 x 10^{9} events)
- tau (~8 x 10^{8} events)
- 2-photon
- B_s (~7 x 10^{6} events)

Physics topics: CP, CKM, QCD, HQ spectroscopy, ...

305 papers published since 3/2001

Υ(10860), or Υ(5S)





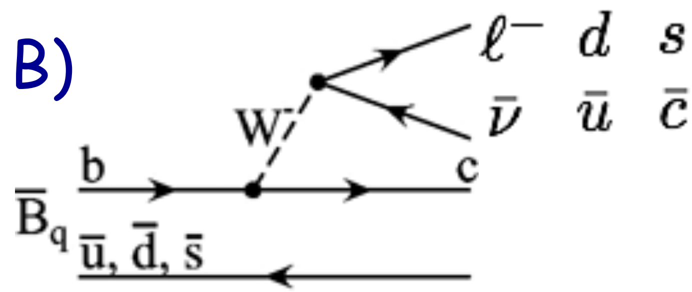
B_s are produced copiously in pp(bar) collisions (FNAL, LHC) – can studying B_s at the Υ(5S) be competitive?

pro's

- CLEAN events, energy definition, γ's; ~100% trigger efficiency
- high luminosity, established detector, Υ(4S) data for comparison

B_s in Standard Model

- CP-asymmetry ~ 0 -> window to New Physics
- $\Delta\Gamma/\Gamma_{CP}/\Gamma$=O(10%)
- Spectator decay (as w non-strange B)
  -> quark-hadron duality
- absolute BF's, modes w π^0, γ



spectroscopy

- $B_s^{(*)}$ mass
- $B_{(s)}^{(*)}(\pi)$ event fractions
- bottomonium, bottomonium-like states

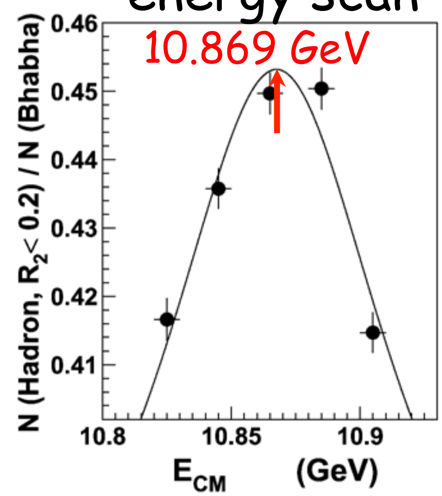
Data at Υ(5S)

June 2005: 3-day "engineering" run

- basic Υ(5S), $B_s^{(*)}$ properties,
- test KEKB at Υ(5S) - L_{max}~$1.39 \times 10^{34} cm^{-2} s^{-1}$
- 1.86 fb^{-1} at peak (10869 MeV)
  = 4 x largest previous sample (CLEO)

A. Drutskoy et al., PRL 98, 052001 (2007)
A. Drutskoy et al., PRD 76, 012002 (2007)

energy scan



June 2006: 20-day run

- + 21.7 fb^{-1} on resonance

K.F. Chen et al., PRL 100, 112001 (2008)
J. Wicht et al., PRL 100, 121801 (2008)
R. Louvot et al., PRL 102, 021801 (2009)
A. Drutskoy et al., arXiv:0909.5223
R. Louvot et al., arXiv:0909.2160
J. Li et al., arXiv:0912.1434
C.-C. Peng et al., BELLE-CONF-0904
S. Esen et al., NEW

December 2007: scan 6 pts

- + 7.9 fb^{-1} above resonance

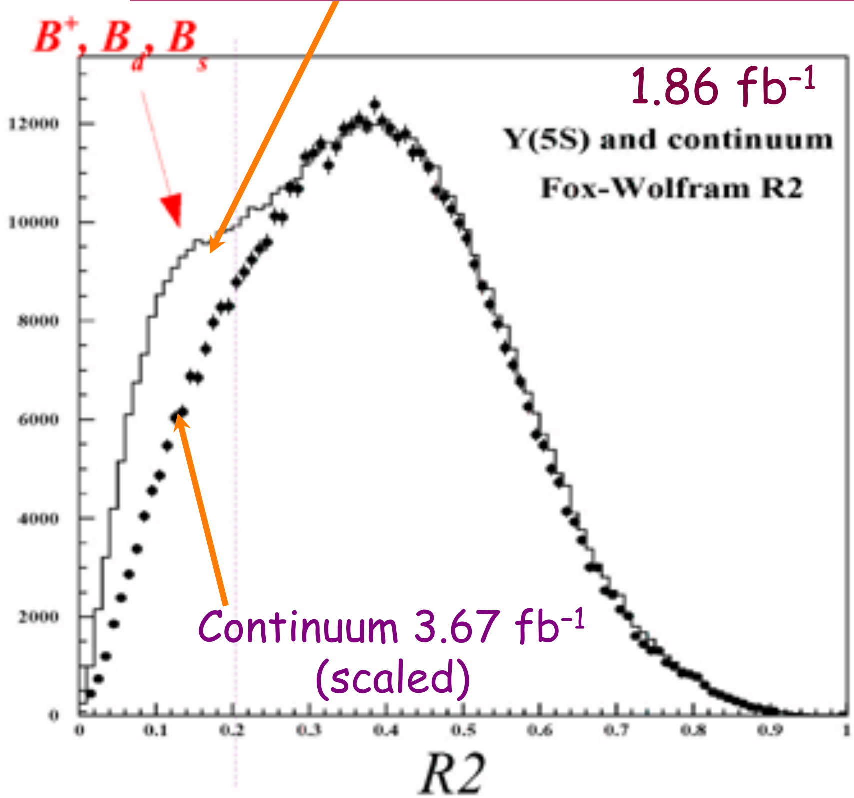
K.F. Chen et al., arXiv:0808.2445

Oct 2008-Dec 2009: extended run

- ~100 fb^{-1} on resonance

Event count

$(3.01 \pm 0.02 \pm 0.16) \times 10^5$ events/fb^{-1}



Event shape parameter
(Fox-Wolfram moments)

$$R_2 = \frac{\sum_{i,j} |p_i||p_j| P_2(\cos\theta)}{\sum_{i,j} |p_i||p_j| P_0(\cos\theta)}$$

P_2: $3x^2-1$; P_0: 1

2-jet $e^+e^- \rightarrow q\bar{q}$ $R_2 \rightarrow 1$

$e^+e^- \rightarrow B\bar{B}$ $R_2 \rightarrow 0$

Fundamentals

B_s fraction in $\Upsilon(5S)$ events

inclusive D_s production

(model estimate) $(92 \pm 11)\%$

(measured) $(8.7 \pm 1.2)\%$

$$\frac{\mathcal{B}(\Upsilon(5S) \to D_s X)}{2} = f_s \cdot \mathcal{B}(B_s \to D_s X) + (1 - f_s) \cdot \mathcal{B}(B \to D_s X)$$

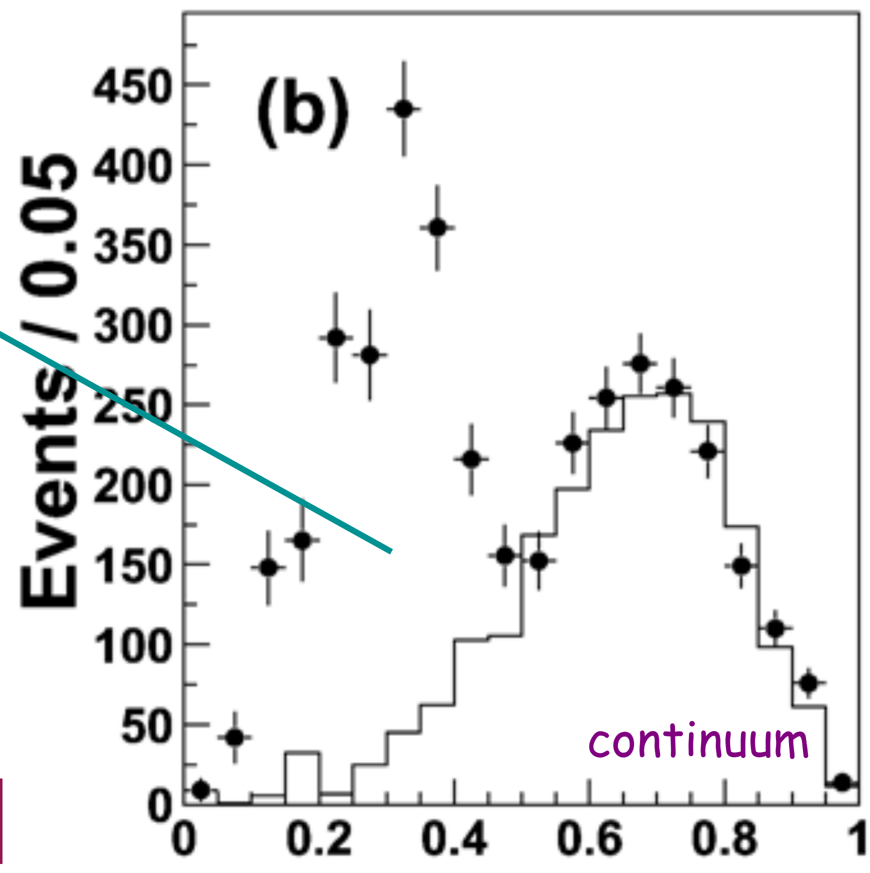
$(23.6 \pm 1.2 \pm 3.6)\%$

$$f_s = (17.9 \pm 1.4 \pm 4.1)\%$$

similar analysis using inclusive D^0:
$f_s=(18.1\pm3.6\pm7.5)\%$

combined:

$$f_s = (18.0 \pm 1.3 \pm 3.2)\%$$



$$x = p_{D_s} / \sqrt{E_{beam}^2 - M_{D_s}^2}$$

B_s at Υ(5S): $B_s\bar{B}_s + B_s^*\bar{B}_s + \bar{B}_s^* B_s + B_s^*\bar{B}_s^*$

Full reconstruction of B_s candidates: E, p

example: $B_s \to D_s^- \pi^+$

$B_s\bar{B}_s$

$$E_{B_s} = E_{beam}$$

$$p_{B_s} = \sqrt{E_{B_s}^2 - M_{B_s}^2}$$

$B_s^* \to B_s\gamma$

$$\Delta M \equiv M_{B_s^*} - M_{B_s} \approx 50\ \mathrm{MeV}/c^2$$

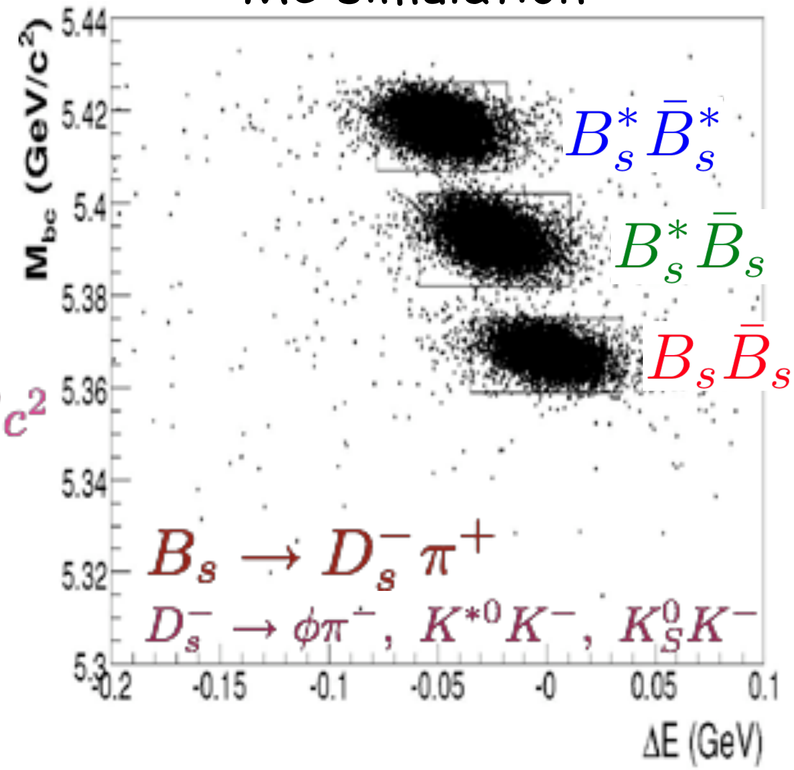
$B_s^*\bar{B}_s$

$$E_{B_s} \approx E_{beam} - \Delta M/2$$

$B_s^*\bar{B}_s^*$

$$E_{B_s} \approx E_{beam} - \Delta M$$

MC simulation



$$M_{bc} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$$

$$\Delta E \equiv E_{cand} - E_{beam}$$

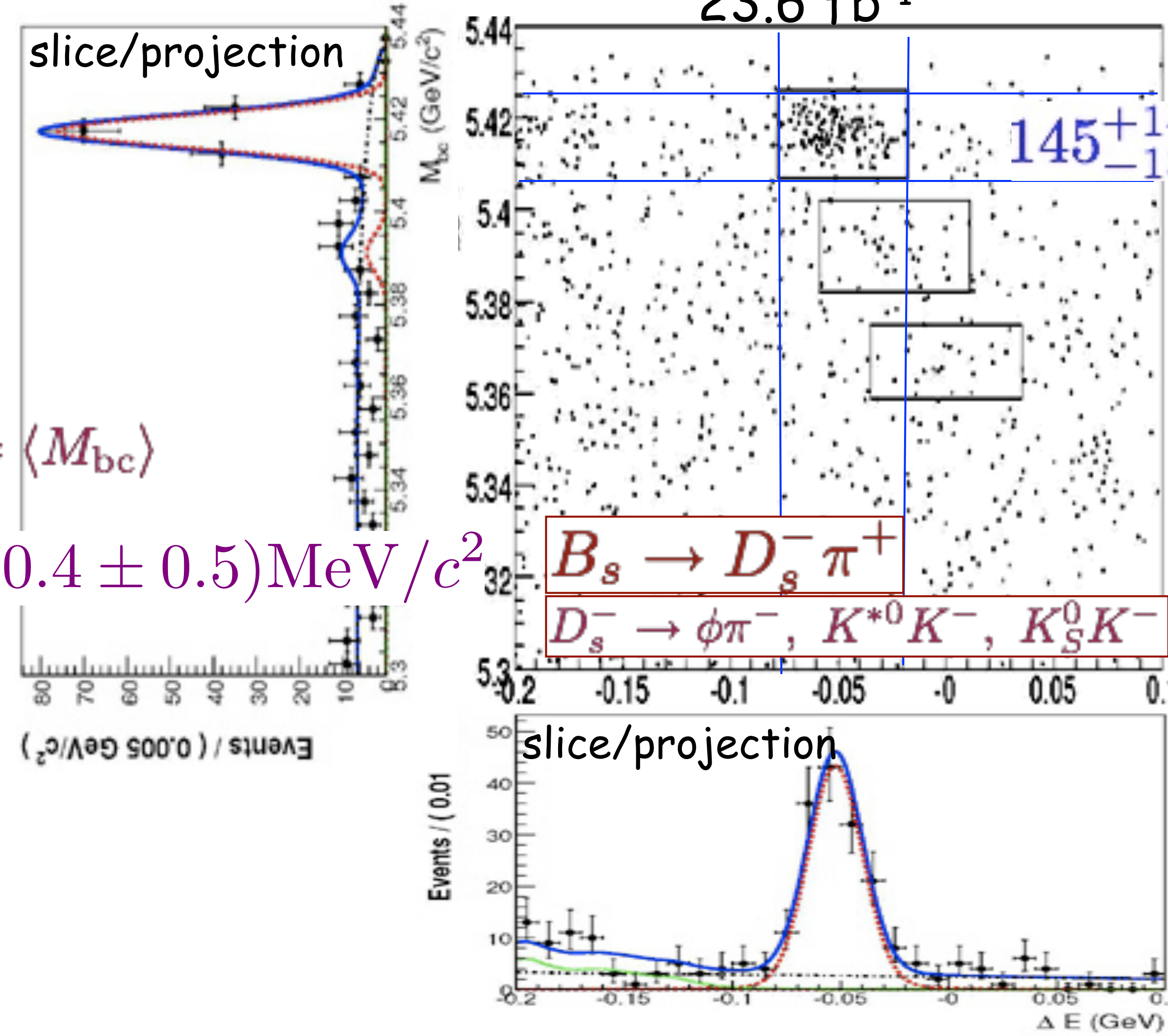
B_s at Υ(5S): $B_s\bar{B}_s + B_s^*\bar{B}_s + \bar{B}_s^* B_s + B_s^*\bar{B}_s^*$

Full reconstruction of B_s candidates

$B_s^*\bar{B}_s^*$

[PRL 102, 021801 (2009)]

23.6 fb^{-1}



masses:

$\langle p_{Bs}\rangle = p_{B^*}$

$\Rightarrow M_{B_s^*} = \langle M_{\rm bc}\rangle$

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

$M_{\rm bc} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$

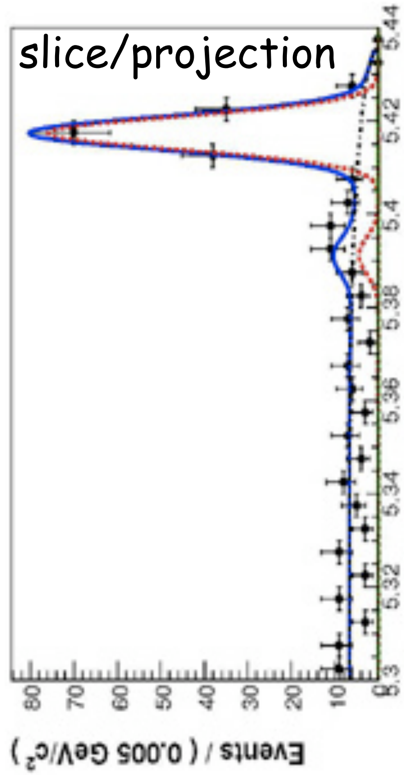
B_s at Υ(5S): $B_s\bar{B}_s + B_s^*\bar{B}_s + \bar{B}_s^* B_s + B_s^*\bar{B}_s^*$

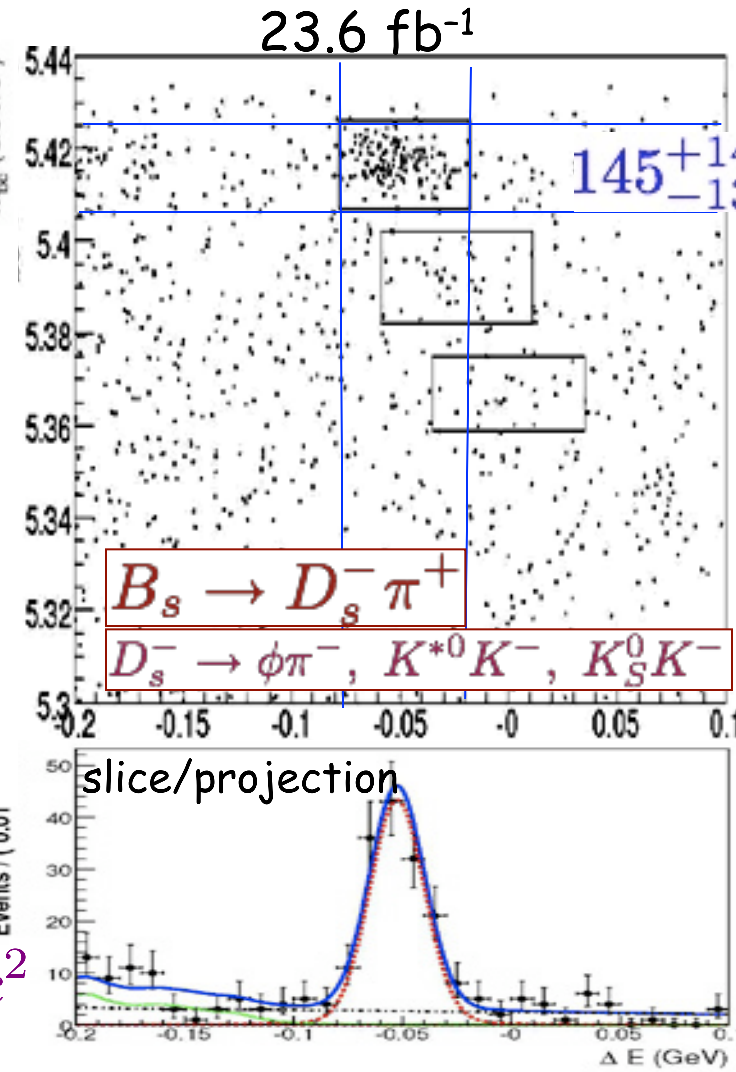
Full reconstruction of B_s candidates

$B_s^*\bar{B}_s^*$

[PRL 102, 021801 (2009)]

masses:





$$M_{bc} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$$

$\langle E_{Bs} \rangle$
$= E_{beam} - \langle \Delta E \rangle$

$\Rightarrow M_{B_s}$

$$= \left\langle \sqrt{(E_{beam} - \langle \Delta E \rangle)^2 - p_{cand}^2} \right\rangle$$

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

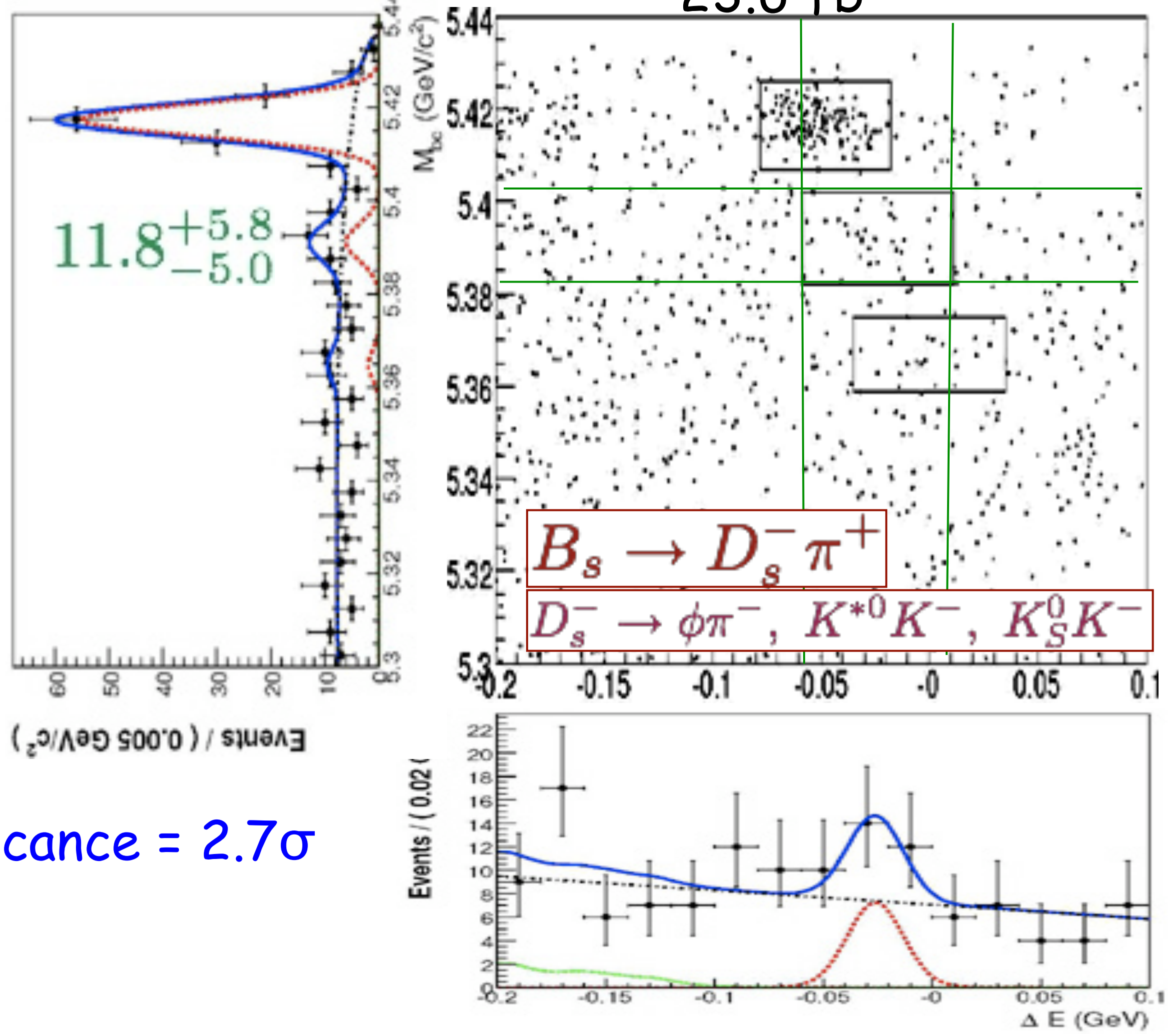
B_s at Υ(5S): $B_s\bar{B}_s + B_s^*\bar{B}_s + \bar{B}_s^*B_s + B_s^*\bar{B}_s^*$

Full reconstruction of B_s candidates

$B_s^*B_s$

[PRL 102, 021801 (2009)]

23.6 fb^{-1}



$$M_{\rm bc} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$$

significance = 2.7σ

B_s at Υ(5S): $B_s\bar{B}_s + B_s^*\bar{B}_s + \bar{B}_s^* B_s + B_s^*\bar{B}_s^*$

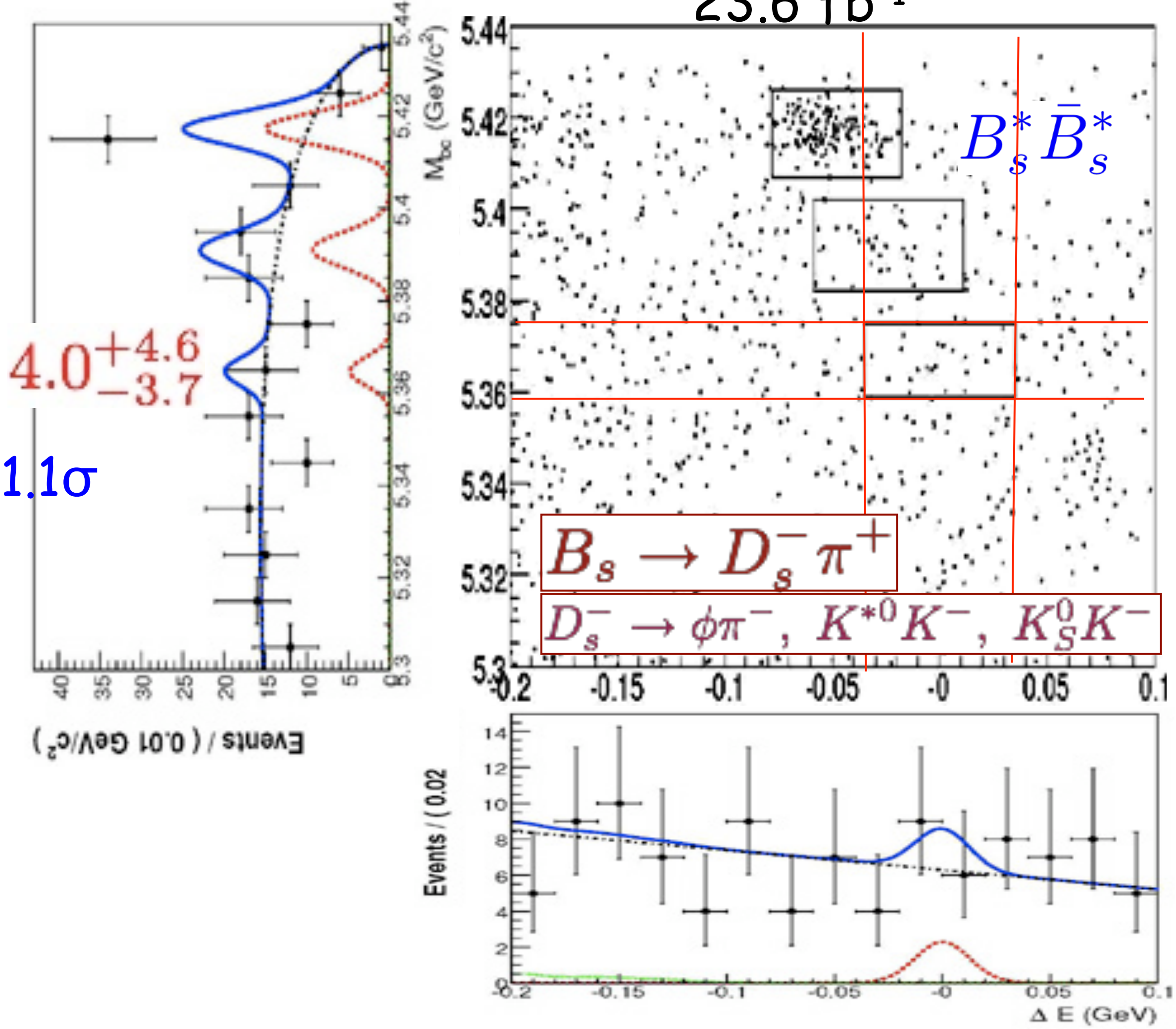
Full reconstruction of B_s candidates

B_sB_s

[PRL 102, 021801 (2009)]

23.6 fb^{-1}

significance 1.1σ



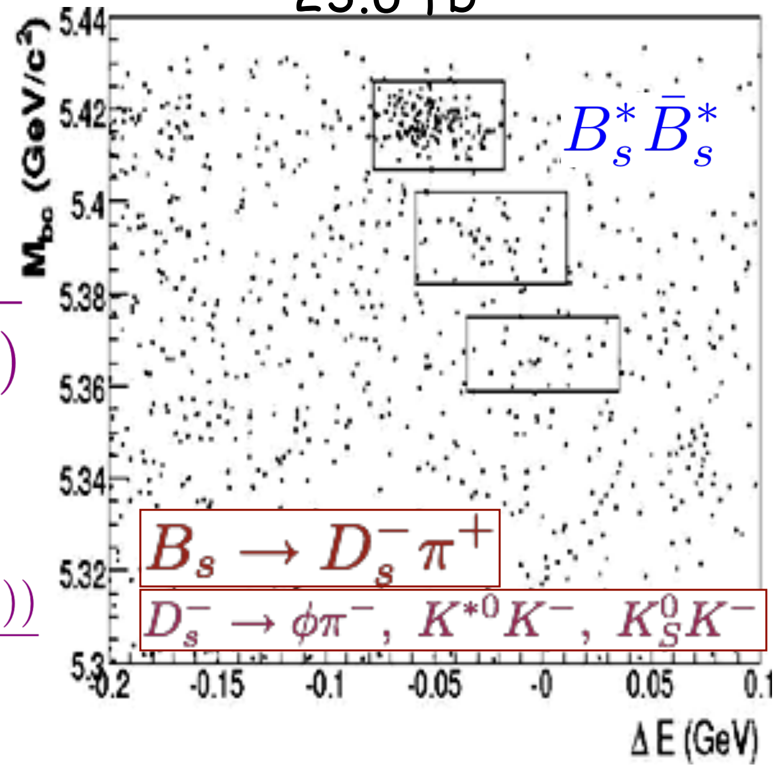
$$M_{bc} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$$

B_s at Υ(5S): $B_s\bar{B}_s + B_s^*\bar{B}_s + \bar{B}_s^* B_s + B_s^*\bar{B}_s^*$

Full reconstruction of B_s candidates

[PRL 102, 021801 (2009)]

23.6 fb^{-1}



$$M_{bc} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$$

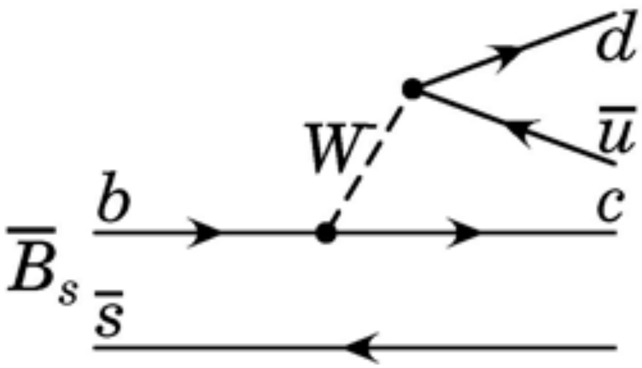
$$\Delta E \equiv E_{cand} - E_{beam}$$

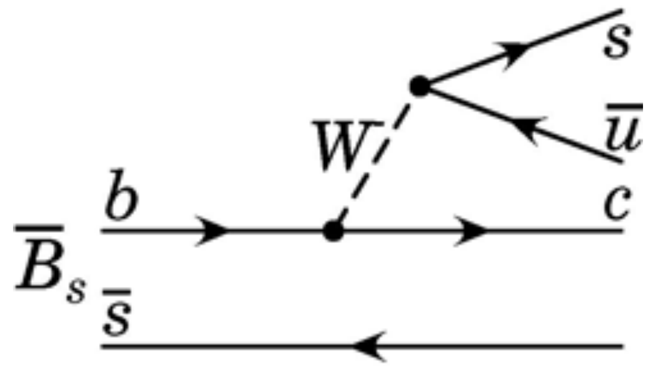
Comparing rates:

$$f_{B_s^* B_s^*} \equiv \frac{\sigma(e^+e^- \to B_s^*\bar{B}_s^*)}{\sigma(e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)})} = (90.1^{+3.8}_{-4.0} \pm 0.2)\%$$

$$f_{B_s^* B_s} \equiv \frac{\sigma(e^+e^- \to B_s^*\bar{B}_s + B_s\bar{B}_s^*))}{\sigma(e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)})} = (7.3 \pm 0.3 \pm 0.1)\%$$

$$\mathcal{B}(B_s \to D_s\pi) = (3.67^{+0.35+0.43}_{-0.33-0.42}) \times 10^{-3}$$





Other Spectator decays

$$\bar{B}_s \to D_s^+ K^-$$

R. Louvot, J. Wicht, O. Schneider, et al.
PRL 102, 021801 (2009)

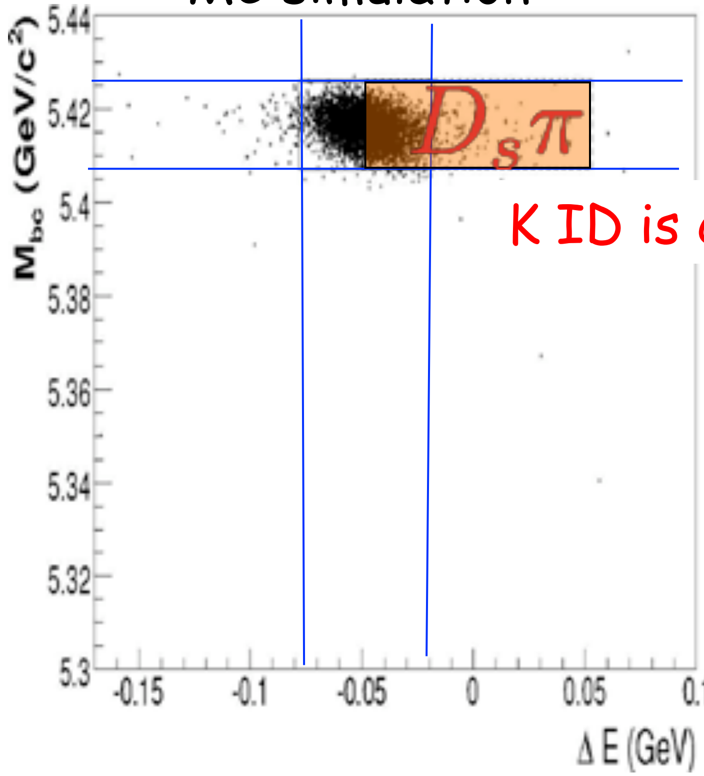
$$B_s \to D_s^{*-}\pi^+,\ D_s^{(*)-}\rho^+$$

arXiv:0909.2160 R. Louvot

$B_s \to D_s^- K^+$

$B_s^* B_s^*$ only
(statistics)

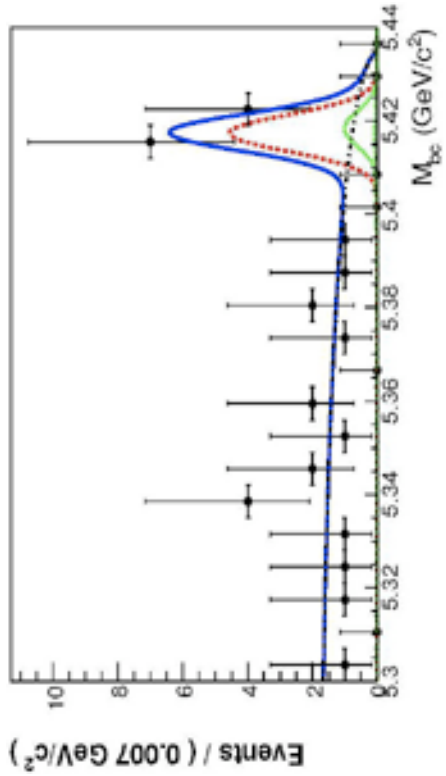
MC simulation

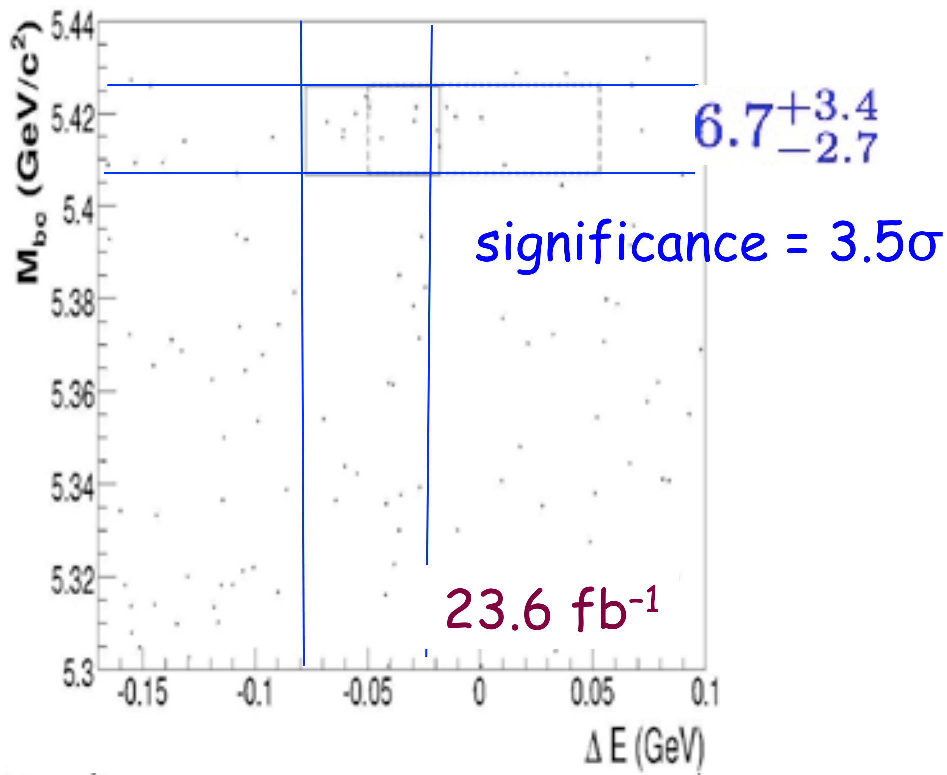


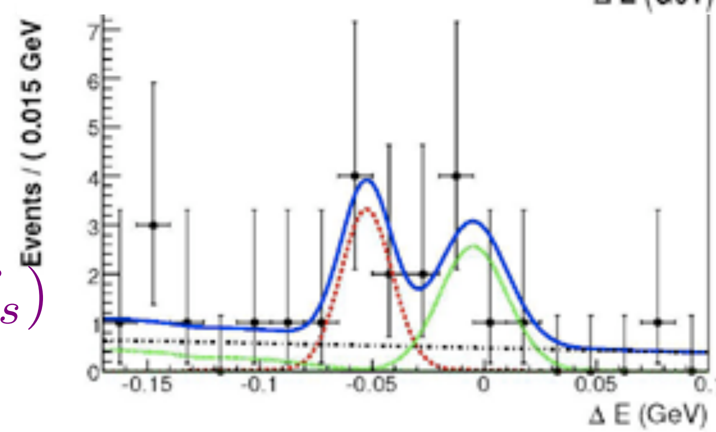
K ID is crucial

data $B_s \to D_s^- K^+$

$B_s^* B_s^*$



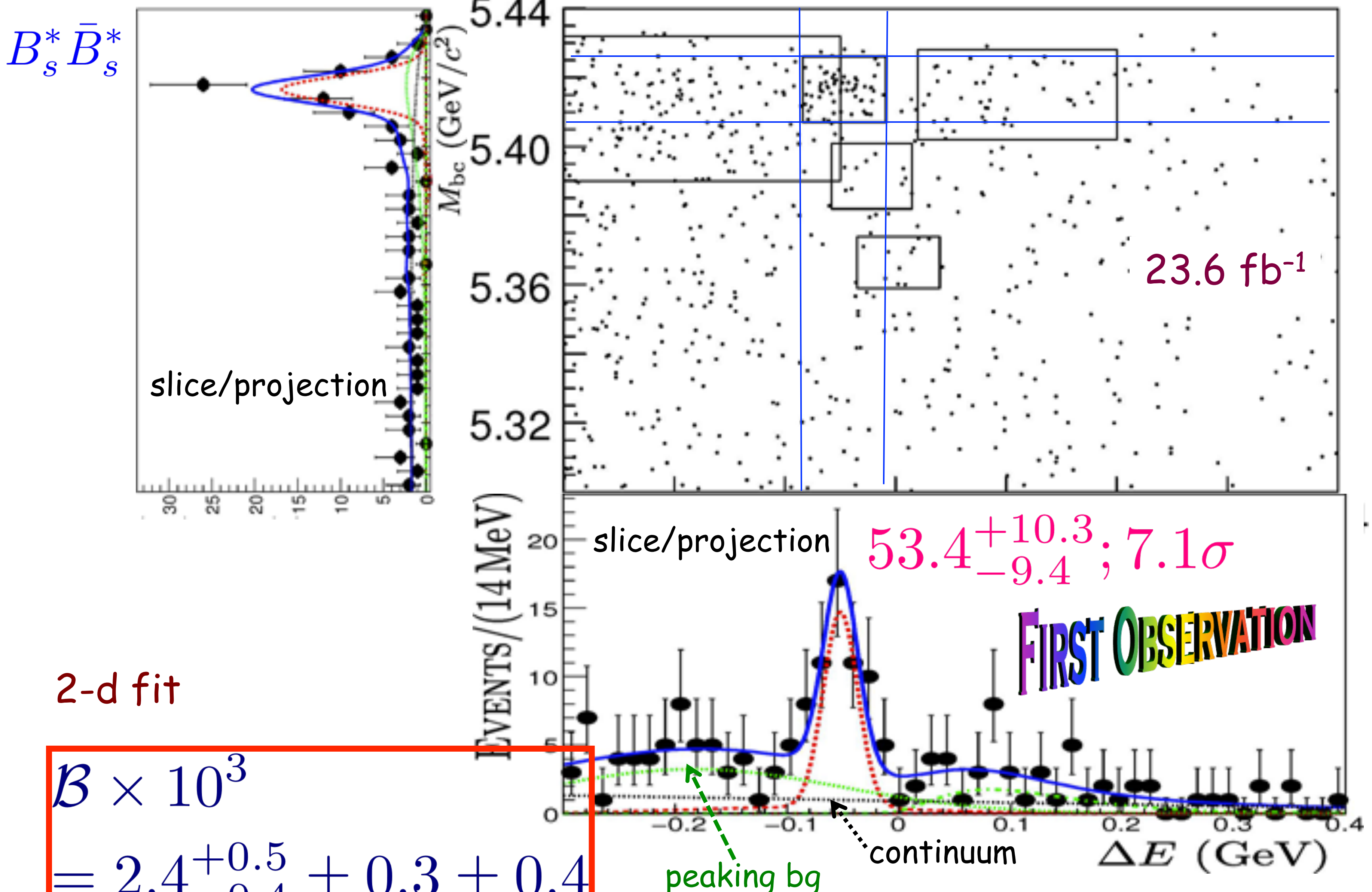




$$\mathcal{B}(B_s \to D_s K) \times 10^4$$

$$= 2.4^{+1.2}_{-1.0} \pm 0.3(\mathrm{sys}) \pm 0.3(f_s)$$

data $B_s \to D_s^{*-}\pi^+$

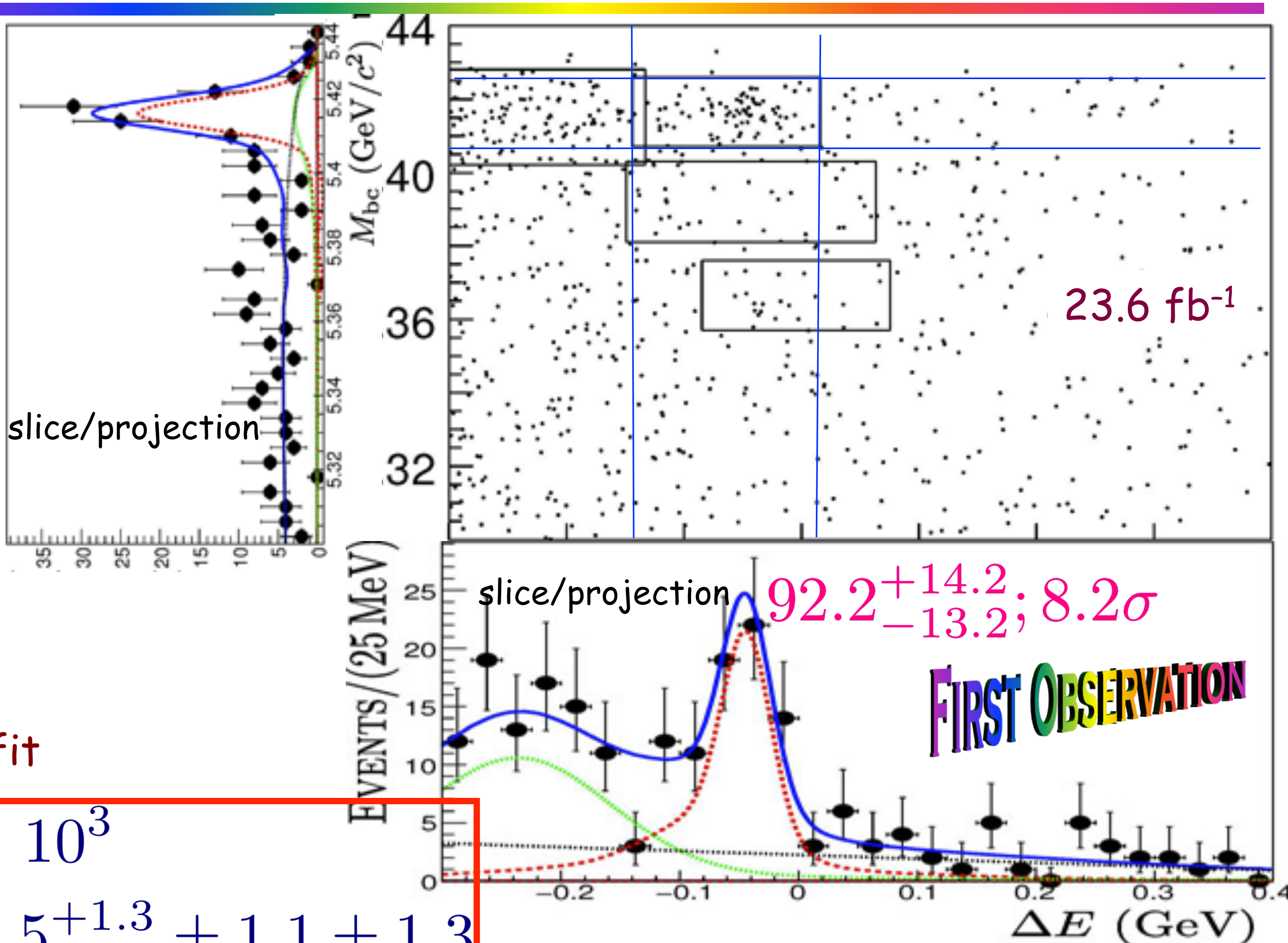


2-d fit

$$\mathcal{B} \times 10^3 = 2.4^{+0.5}_{-0.4} \pm 0.3 \pm 0.4$$

data $B_s \to D_s^- \rho^+$

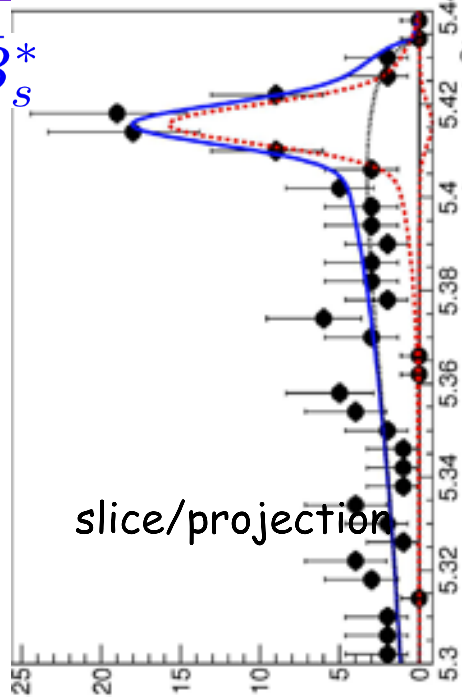
$B_s^* \bar{B}_s^*$

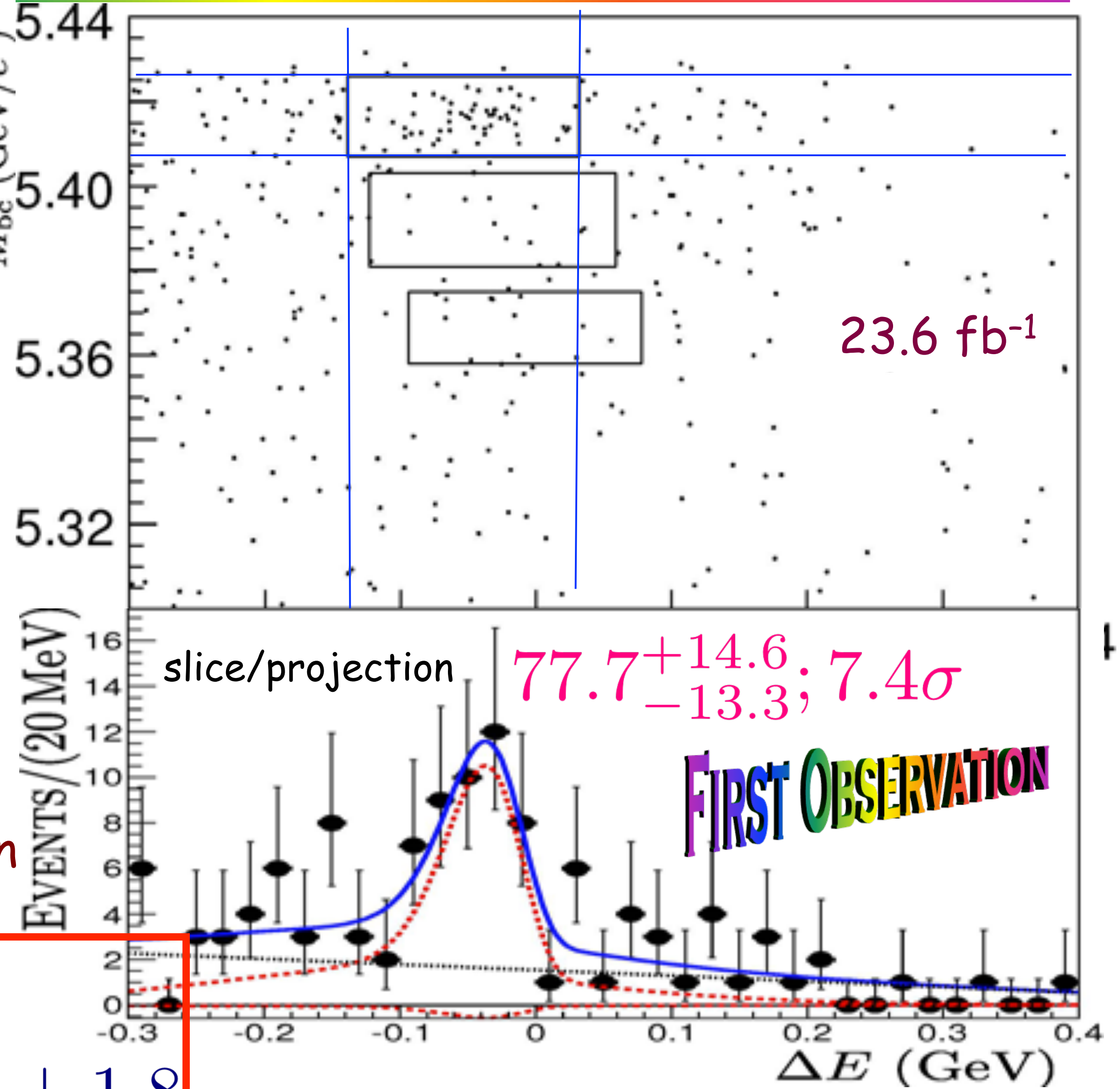


2-d fit

$$\mathcal{B} \times 10^3 = 8.5^{+1.3}_{-1.2} \pm 1.1 \pm 1.3$$

data $B_s \to D_s^{*-} \rho^+$





4-d fit incl. polarization

$$\mathcal{B} \times 10^3 = 11.8^{+2.2}_{-2.0} \pm 1.7 \pm 1.8$$

Data $B_s \to D_s^{*-}\rho^+$ polarization

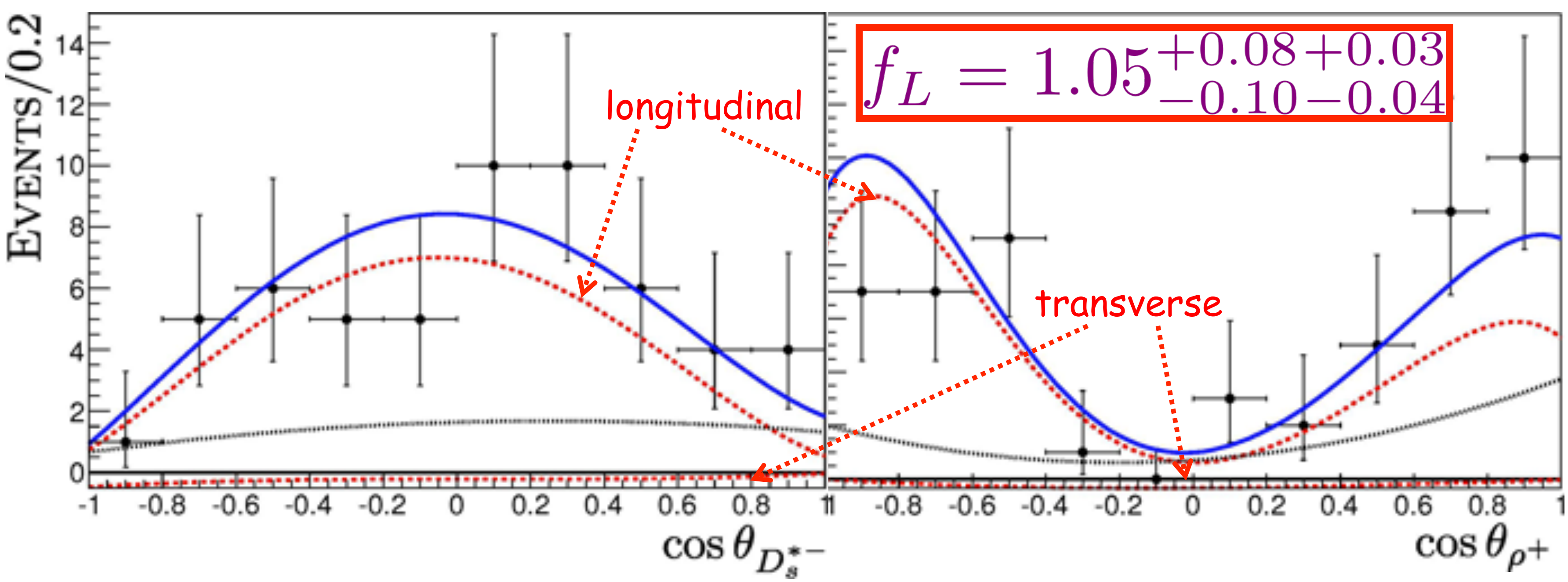
$B_s^* \bar{B}_s^*$

P-> VV decay: Polarization depends on hadronization detail
-> test of factorization hypothesis $f_L \approx 88\%(PRD\mathbf{42}, 3732(1990)$

$$\frac{d^2\Gamma(B_s^0 \to D_s^{*-}\rho^+)}{d\cos\theta_{D_s^{*-}}\, d\cos\theta_{\rho^+}}$$

helicity angles

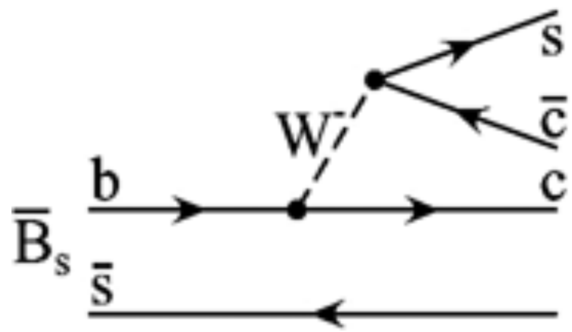
$$\propto 4 f_L \sin^2\theta_{D_s^{*-}} \cos^2\theta_{\rho^+} + (1-f_L)(1+\cos^2\theta_{D_s^{*-}})\sin^2\theta_{\rho^+}$$



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

S. Esen

- CKM-favored AND flavor-neutral
  CP=+1 in heavy quark limit, $m_c \to \infty$
  ~ saturated by 2-body $D_s^{(*)+} D_s^{(*)-}$
  -> difference in widths of CP=±1



$$\frac{\Delta\Gamma_{CP}}{\Gamma} \approx \frac{2\mathcal{B}(B_s \to D_s^{(*)+} D_s^{(*)-})}{1 - \mathcal{B}(B_s \to D_s^{(*)+} D_s^{(*)-})}$$

Aleksan, Dunietz, Kayser Z. Phys., C54, 653 (1992)

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

Reconstruction

$$D_s^{*+} \to D_s^+ \gamma$$

$$D_s^+ \to \phi\pi^+ \qquad \phi \to K^+K^-$$

$$D_s^+ \to K_S^0 K^+ \qquad K_S^0 \to \pi^+\pi^-$$

$$D_s^+ \to \bar{K}^{*0} K^+ \qquad \bar{K}^{*0} \to K^-\pi^+$$

$$D_s^+ \to \phi\rho^+ \qquad \rho^+ \to \pi^+\pi^0$$

$$D_s^+ \to K^{*+} K_S^0 \qquad K^{*+} \to K_S^0\pi^+$$

$$D_s^+ \to K^{*+} \bar{K}^{*0}$$

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

Reconstruction

- Candidate selection

$$5.2 < M_{\rm bc}c^2/\mathrm{GeV} < 5.45$$
$$-0.15 < \Delta E/\mathrm{GeV} < 0.1$$

- One candidate (all channels) per event

  selection: lowest chisquare based on $M(D_s), M(D_s^*) - M(D_s)$

$$D_s^+ D_s^- \qquad \chi^2 = \frac{1}{2}\Sigma\left[\frac{m_{D_s^\pm} - m_{D_s^\pm}^{PDG}}{\sigma_{m_{D_s^\pm}}}\right]^2$$

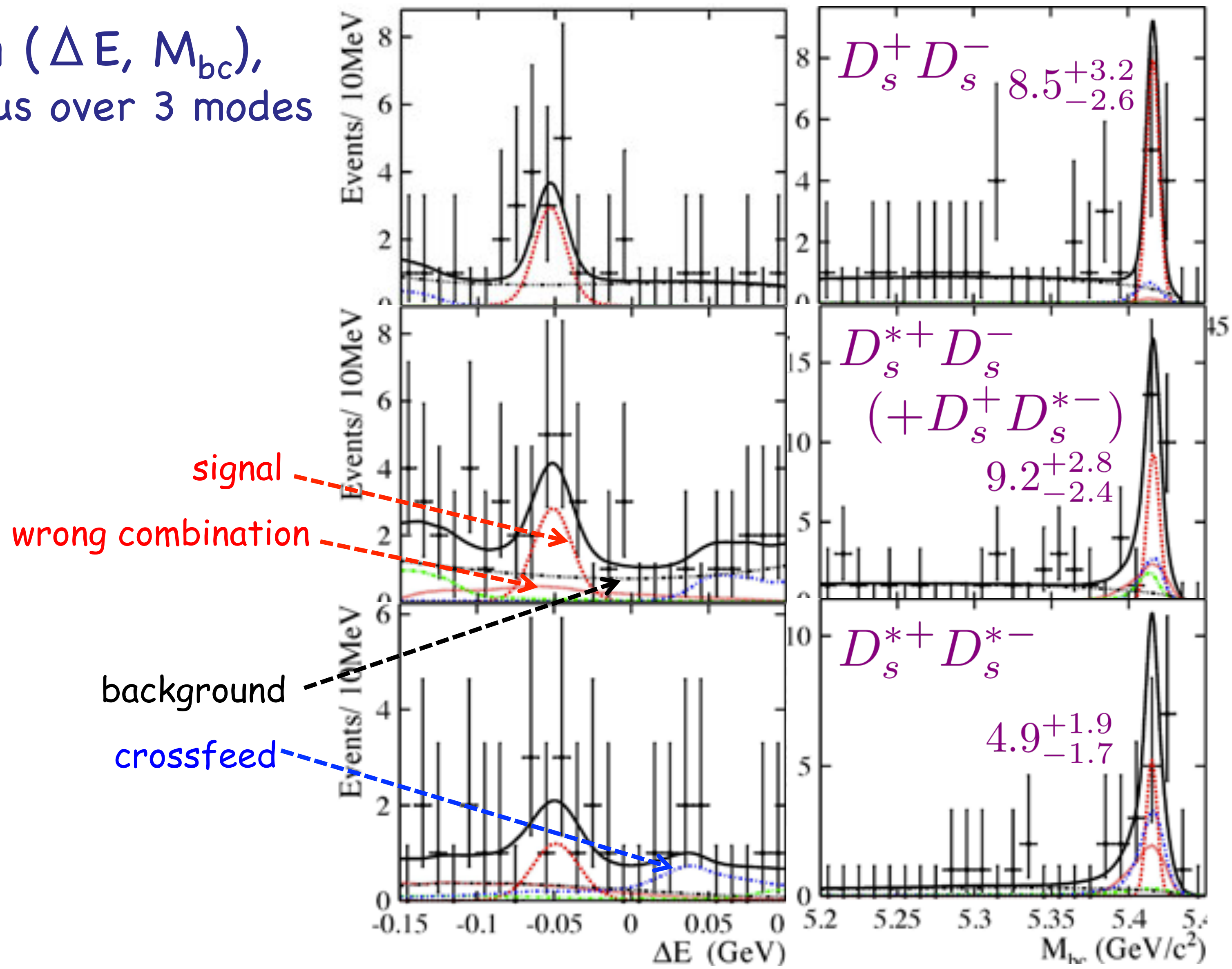
$$D_s^{*+} D_s^- \qquad \chi^2 = \frac{1}{3}\left[\Sigma\left[\frac{m_{D_s^\pm} - m_{D_s^\pm}^{PDG}}{\sigma_{m_{D_s^\pm}}}\right]^2 + \left[\frac{\Delta M_{D_s^*} - \Delta M_{D_s^*}^{PDG}}{\sigma_{\Delta M_{D_s^*}}}\right]^2\right]$$

$$D_s^{*+} D_s^{*-} \quad \chi^2 = \frac{1}{4}\left[\Sigma\left[\frac{m_{D_s^\pm} - m_{D_s^\pm}^{PDG}}{\sigma_{m_{D_s^\pm}}}\right]^2 + \Sigma\left[\frac{\Delta M_{D_s^*} - \Delta M_{D_s^*}^{PDG}}{\sigma_{\Delta M_{D_s^*}}}\right]^2\right]$$

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

23.6 fb^{-1}

2-d fit in (ΔE, M_{bc}), simultaneous over 3 modes



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

Branching fraction PRELIMINARY

Mode	Y (events)	$\mathcal{B}$ (%)	S (σ)
$D_s^+ D_s^-$	$8.5^{+3.2}_{-2.6}$	$1.0^{+0.4}_{-0.3}{}^{+0.3}_{-0.2}$	6.2
$D_s^* D_s$	$9.2^{+2.8}_{-2.4}$	$2.8^{+0.8}_{-0.7} \pm 0.7$	6.6 FIRST OBSERVATION
$D_s^* D_s^*$	$4.9^{+1.9}_{-1.7}$	$3.1^{+1.2}_{-1.0} \pm 0.8$	3.2 FIRST EVIDENCE
Sum	$22.6^{+4.7}_{-3.9}$	$6.9^{+1.5}_{-1.3} \pm 1.9$	

$$\frac{\Delta\Gamma_{CP}}{\Gamma} = \frac{2\mathcal{B}}{1-\mathcal{B}} = 0.147^{+0.036}_{-0.030}{}^{+0.044}_{-0.042} \pm 0.004$$

$$[PDG : 0.092^{+0.051}_{-0.054}]$$

[theory; Aleksan et al., PLB 316, 567 (1993)

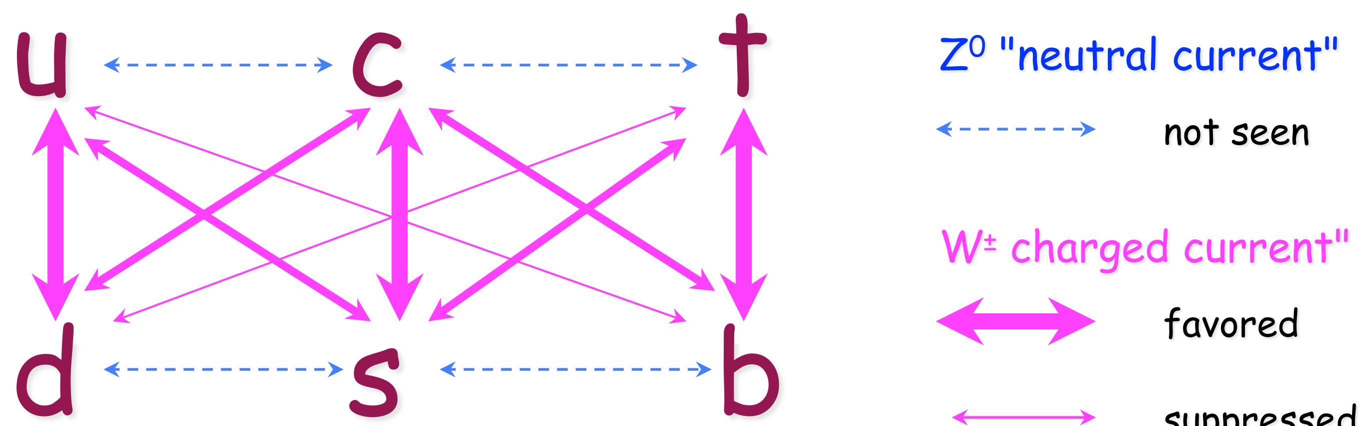
Need updated theory input!

Other CP Eigenstates

What about CP violation? ... look at weak couplings in SM...

Weak couplings of quarks

- neutral current – universal, generation-conserving
- charged current – approx. generation-conserving, but different



Matrix of CC couplings shows no universality…

$$g_F \times \begin{array}{c} \\ u \\ c \\ t \end{array} \begin{array}{c} \begin{array}{ccc} d & s & b \end{array} \\ \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \end{array}$$

9 complex couplings
-> 18 free parameters

Unless viewed via **GIM** (Glashow-Iliopoulos-Maiani) picture:

"weak eigenstates" ≠ mass eigenstates d, s, b

-> need linear transformation between 2 sets:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \mathcal{M} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Cabibbo-Kobayashi-Maskawa (CKM) matrix

complex, preserves metric " orthogonality } ≡ unitary

So matrix is then

$$g_F \times \begin{array}{c|ccc} & d' & s' & b' \\ \hline u & 1 & 0 & 0 \\ c & 0 & 1 & 0 \\ t & 0 & 0 & 1 \end{array}$$

universal, generation-conserving

Explains

- suppression of flavor-changing neutral currents
- multiplicity of charged current couplings
- AND …….

Irreducible complexity follows from unitarity for >2 generations
--> proposed as explanation of CP violation in K_L

e.g. for 3 generations,
4 free parameters, including
1 irreducible **imaginary** part

(Kobayashi-Maskawa 1973)

explicit parametrization(Wolfenstein):

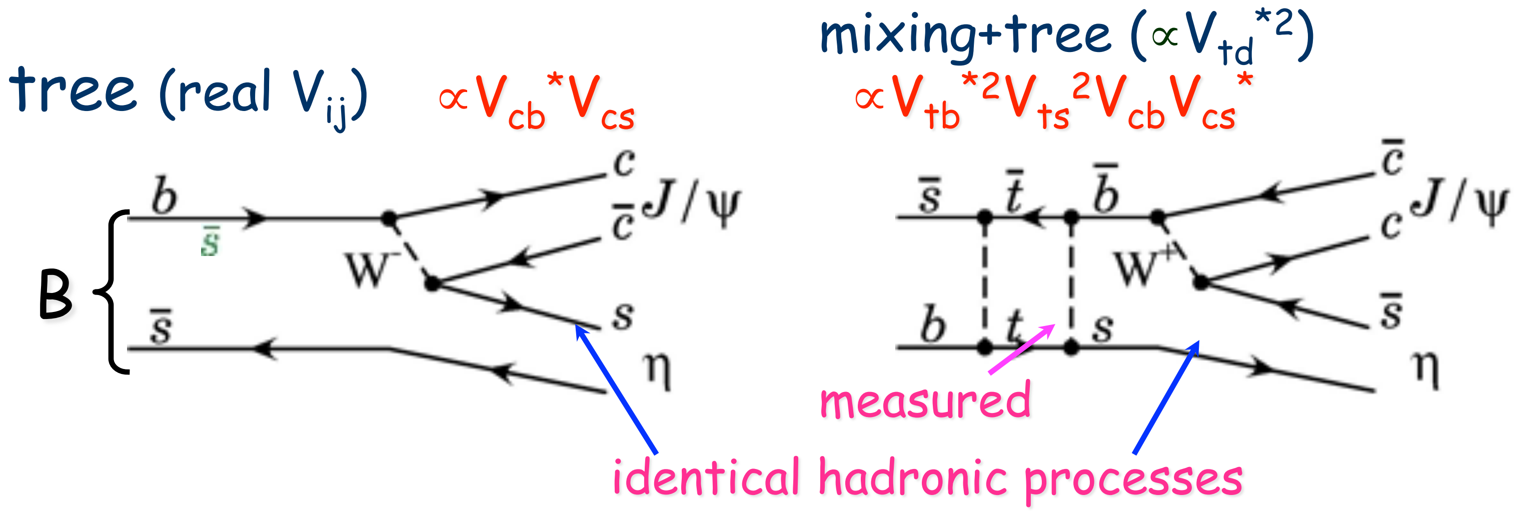
$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

irreducibly complex > **CP Violation**

First 3rd- generation particle (τ) seen in 1975
CP-violation measured in B-decays 2002

CP asymmetry in B_s -> $J/\psi\ \eta$

Analogous to B -> $J/\psi\ K_s$(Sanda/Bigi/Carter)



CP-dependent oscillation in time from cross-term(s)
- no theoretical uncertainty: $\arg(V_{tb}^{*2} V_{ts}^{2}) = 0$

$\Rightarrow$No mixing-mediated CP violation in SM -> any CP asymmetry is NP
... something for the future...

CP asymmetry in B_s -> $J/\psi\ \eta$

Why is non-CKM CP violation of interest?

- matter-antimatter asymmetry of the universe requires CP-violating interactions (Sakharov 1967)
- CP asymmetry in CKM is insufficient

$B_s \to J/\psi\eta^{(\prime)}$

arXiv:0912.1434

J. Li

CP eigenstate; expectation

$\mathcal{B}(B_s \to J/\psi\eta) \approx 3.5 \times 10^{-4}$ $\mathcal{B}(B_s \to J/\psi\eta') \approx 4.9 \times 10^{-4}$

Based on flavor SU(3) symmetry + PDG: $\mathcal{B}(B_d^0 \to J/\psi K^0) = 8.71 \times 10^{-4}$

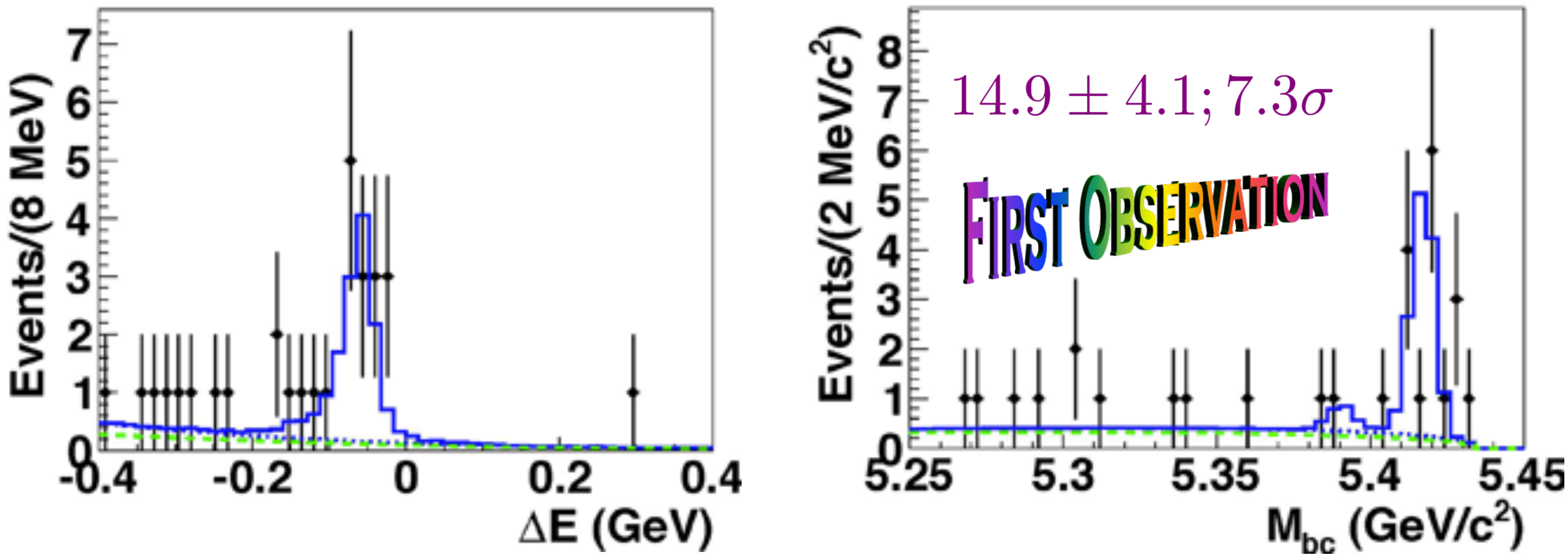
Reconstruction

$$J/\psi \to e^+e^-,\ \mu^+\mu^-$$
$$\eta \to \gamma\gamma,\ \pi^+\pi^-\pi^0$$
$$\eta' \to \eta\pi^+\pi^-,\ \rho^0\gamma$$

$B_s \to J/\psi\eta$

2-d fit in (ΔE, M_{bc}), simultaneous over sub-modes

23.6 fb^{-1}

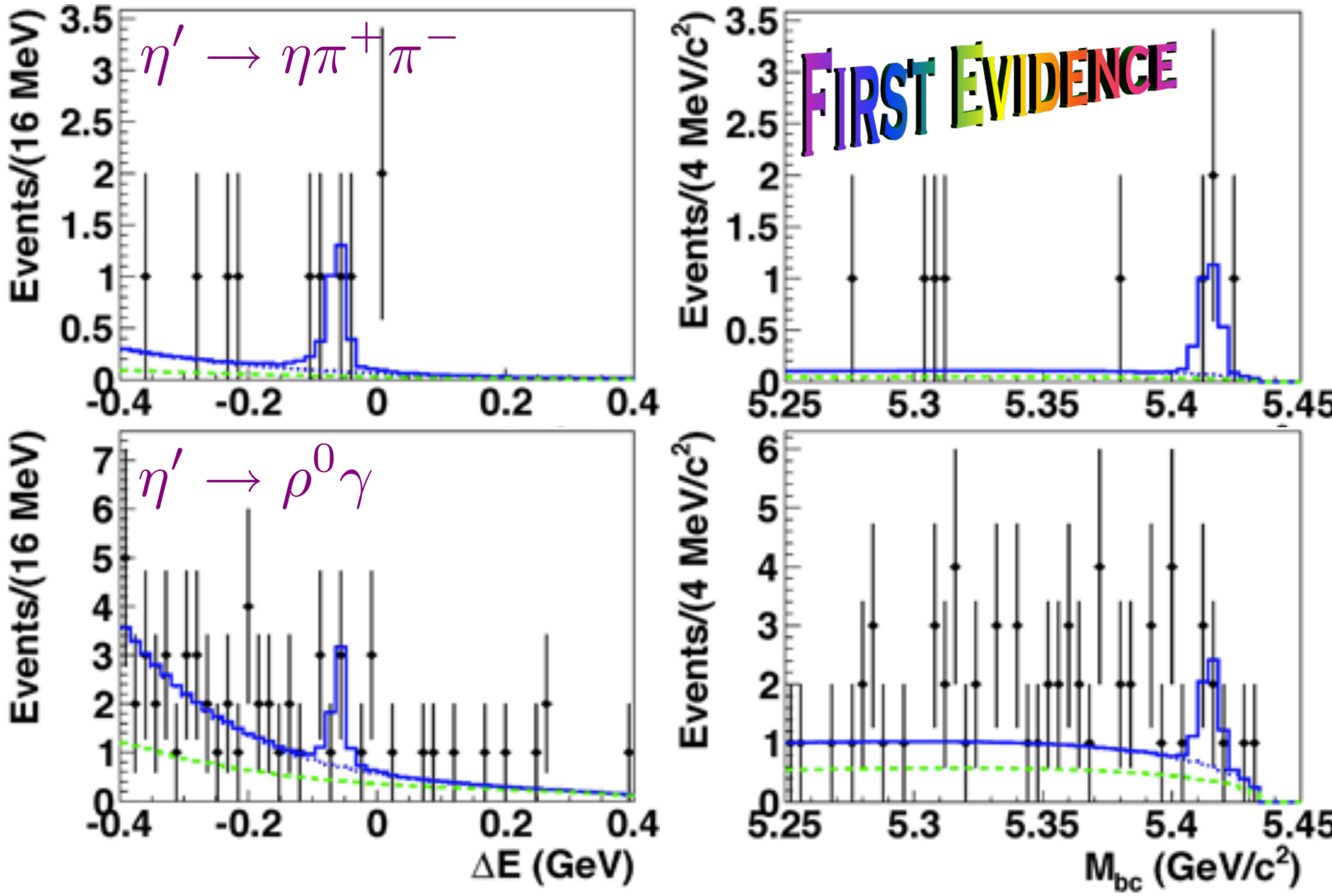


$$\mathcal{B}(B_s \to J/\psi\eta) = (3.32 \pm 0.87(stat)^{+0.32}_{-0.28}(sys) \pm 0.42(f_s)) \times 10^{-4}$$

$B_s \to J/\psi\eta'$

2-d fit in (ΔE, M_{bc}), simultaneous over sub-modes

$$\mathcal{B}(B_s \to J/\psi\eta') = (3.1 \pm 1.2(stat)^{+0.5}_{-0.6}(sys) \pm 0.38(f_s)) \times 10^{-4}$$



3.8σ

23.6 fb^{-1}

$B_s \to hh$

C. C. Peng

$B_s \to hh$

CP eigenstates

$\mathcal{B}(B_s \to K^+K^-) \times 10^5$

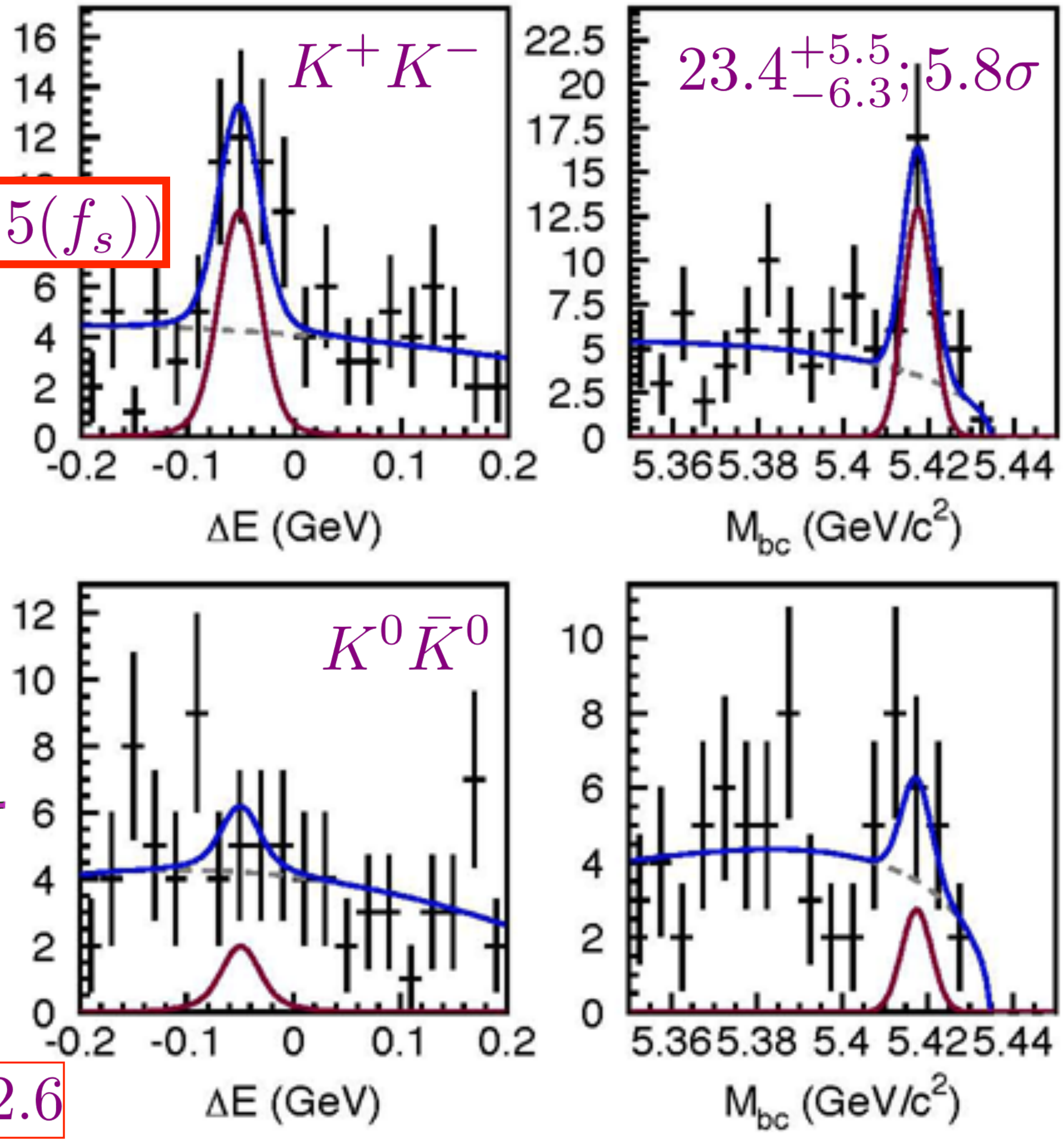
$= (3.8^{+1.0}_{-0.9}(stat) \pm 0.5 \pm 0.5(f_s))$

FIRST ABSOLUTE BF

$\mathcal{B}(B_s \to K^0\bar{K}^0) \times 10^5$

< 6.6

FIRST LIMIT



Also:

$\mathcal{B}(B_s \to K^-\pi^+) \times 10^5 < 2.6$

$\mathcal{B}(B_s \to \pi^-\pi^+) \times 10^5 < 1.2$

Searches for radiative modes of B_s

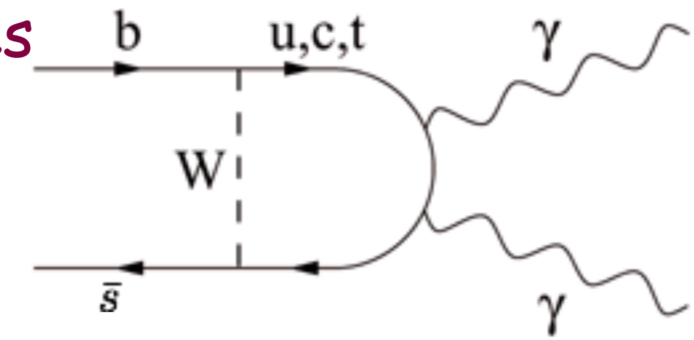
J. Wicht, et al.
PRL 100, 121801 (2008)

Searches for new modes of B_s

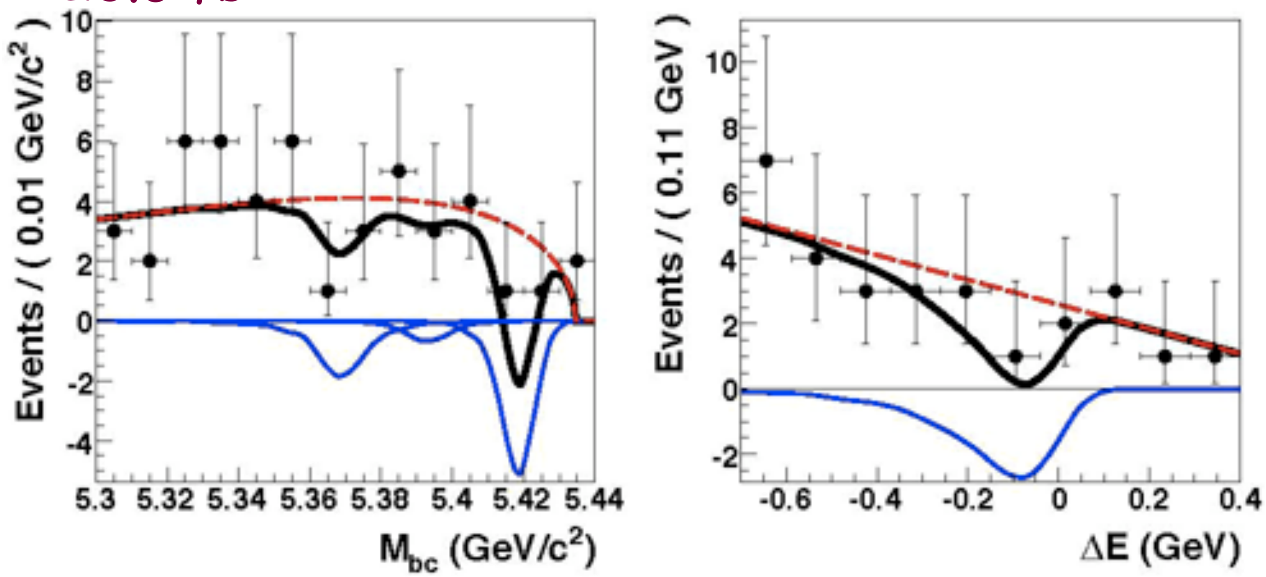
γγ: difficult for hadron machines

$$\mathcal{B}_{SM} \sim (0.4 - 1.0) \times 10^{-6}$$

beyond SM: up to 5×10^{-6}



23.6 fb^{-1}

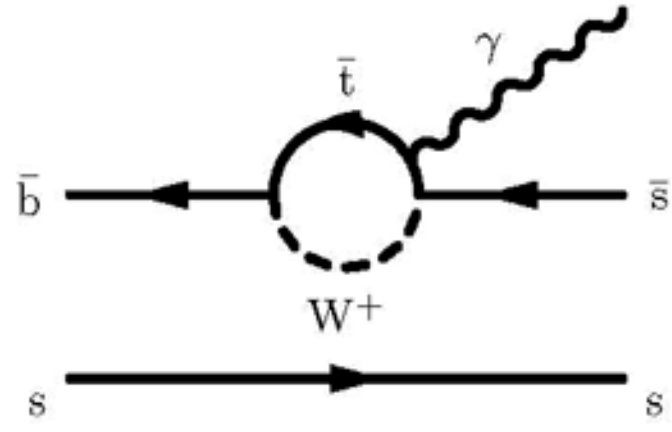


$$\mathcal{B} < 8.7 \times 10^{-6} \; (90\% \; CL)$$ (prev. Belle: $< 5.3 \times 10^{-5}$)

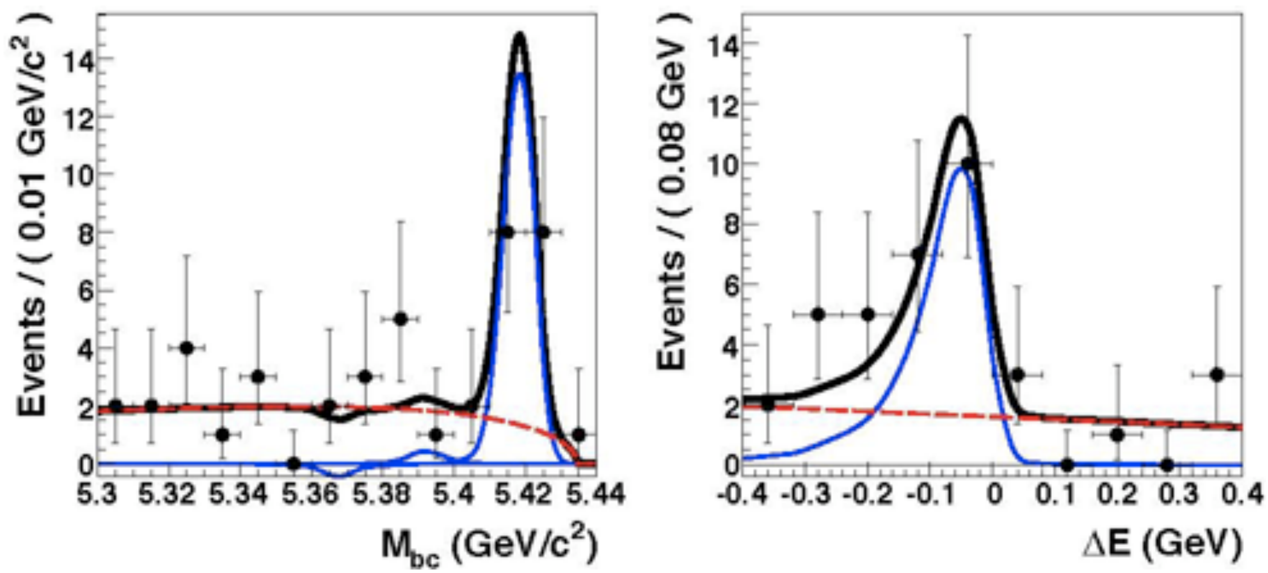
φγ

γ: difficult for hadron machines

Analogue: $B^0 \to K^{*0}\gamma$



23.6 fb^{-1}



$$\mathcal{B} = (57^{+18}_{-15}(stat)^{+12}_{-11}(sys)) \times 10^{-6}$$

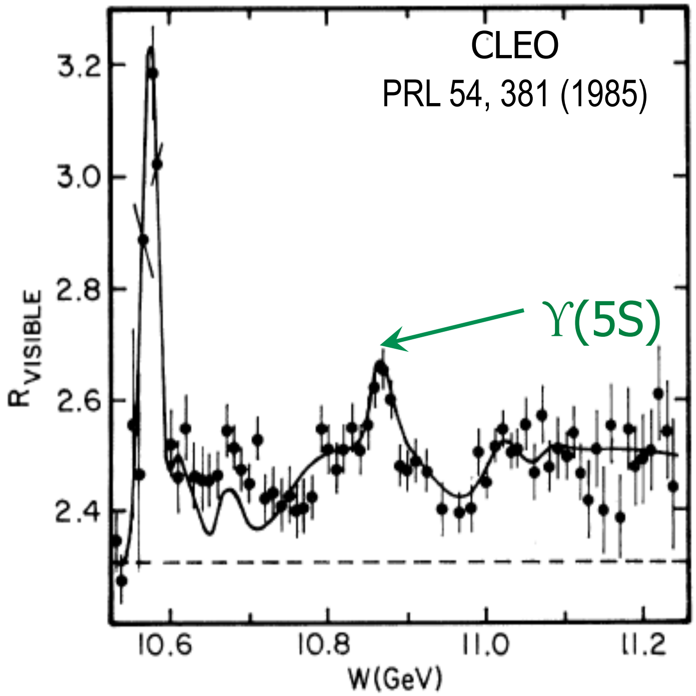
First observation

K. Kinoshita Saclay 3/2010

$$\Upsilon(5S) \to B\bar{B}X$$

arXiv:0909.5223
A. Drutskoy

$\Upsilon(5S) \to B\bar{B}X$



$B_q = \{B_d^0, B_u^+\}$

$B_s^{(*)}\bar{B}_s^{(*)}$

$B_q^{(*)}\bar{B}_q^{(*)}$

$B_q\bar{B}_q^{(*)}\pi$

$B_q\bar{B}_q\pi\pi$

Relative rates: hadronization/spectroscopy

+ account for all events at Υ(5S)

reconstruction

$$B^+ \to J/\psi K^+ \qquad J/\psi \to e^+e^-, \mu^+\mu^-$$

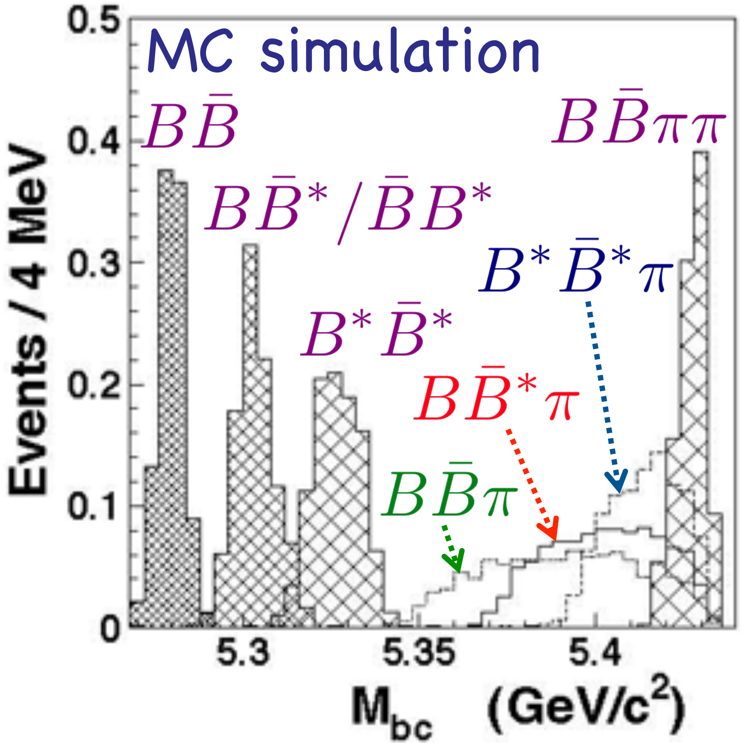
$$B^0 \to J/\psi K^{*0} \qquad K^{*0} \to K^+\pi^-$$

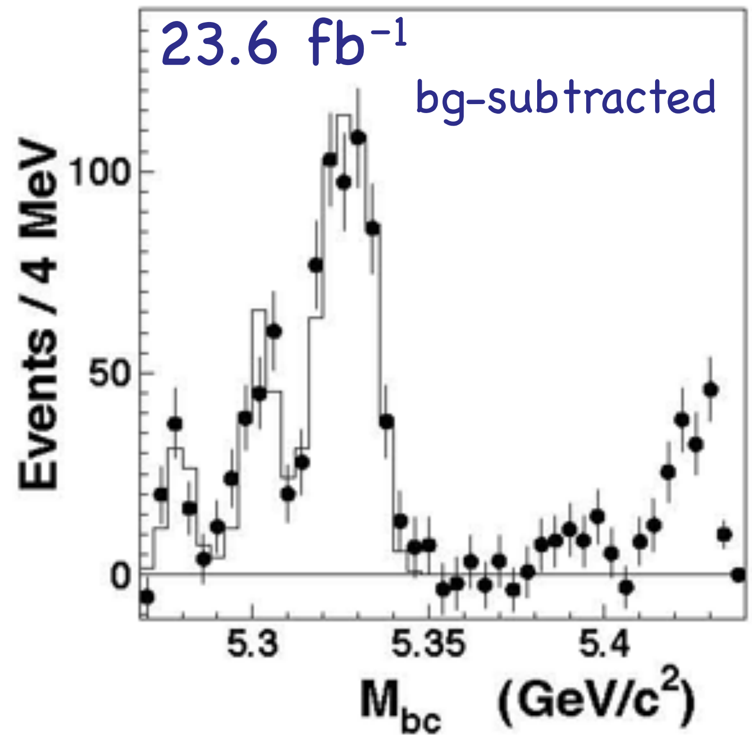
$$B^+ \to \bar{D}^0\pi^+ \qquad \bar{D}^0 \to K^+\pi^-, K^+\pi^+\pi^-\pi^-$$

$$B^0 \to D^-\pi^+ \qquad D^- \to K^+\pi^-\pi^-$$

$\Upsilon(5S) \rightarrow B\bar{B}X$

Distributions in M_{bc}





Channel	Fraction, %
$B\bar{B}$	$5.5\,^{+1.0}_{-0.9} \pm 0.4$
$B\bar{B}^*{+}B^*\bar{B}$	$13.7 \pm 1.3 \pm 1.1$
$B^*\bar{B}^*$	$37.5\,^{+2.1}_{-1.9} \pm 3.0$
Large M_{bc}	$17.5\,^{+1.8}_{-1.6} \pm 1.3$

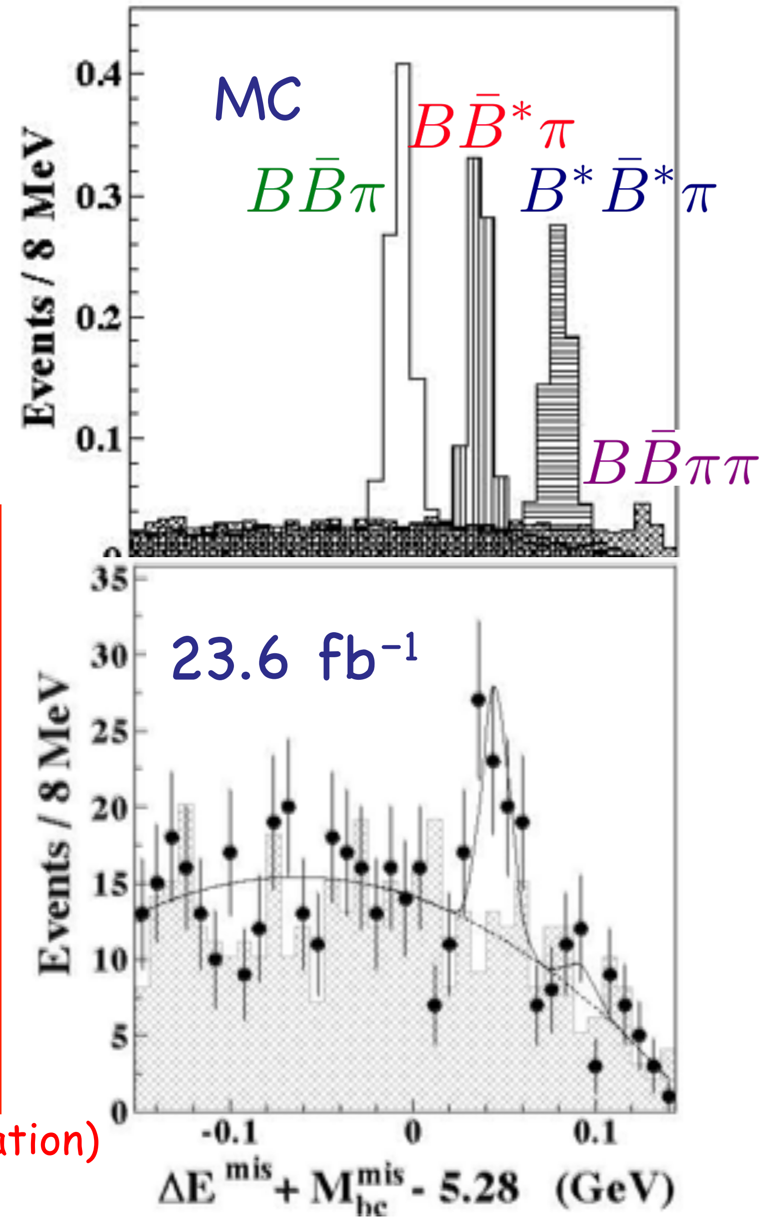
$\Upsilon(5S) \to B\bar{B}X$

$B\bar{B}\pi^+X$

Reconstruct $B\pi$, look for $B^{(*)}$ in missing ΔE, M_{bc}

Channel	Yield, events	Fraction, per $b\bar{b}$ event, %
$B\bar{B}\pi^+$	$0.2^{+7.2}_{-6.9}$	$0.0 \pm 1.2 \pm 0.3$
$B\bar{B}^*\pi^+ + B^*\bar{B}\pi^+$	$38.3^{+10.5}_{-9.8}$	$7.3^{+2.3}_{-2.1} \pm 0.8$
$B^*\bar{B}^*\pi^+$	$4.8^{+6.4}_{-5.9}$	$1.0^{+1.4}_{-1.3} \pm 0.4$
Residual		$9.2^{+3.0}_{-2.8} \pm 1.0$
Large M_{bc}	$228.7^{+22.9}_{-22.3}$	$17.5^{+1.8}_{-1.6} \pm 1.3$

initial state radiation (new interpretation)



$$\Upsilon(10860) = \Upsilon(5S)?$$

K.-F. Chen, W.-S. Hou, M. Shapkin, A. Sokolov, et al.
PRL 100, 112001 (2008)

Is the Υ(10860) purely Υ(5S)?

- Y: charmonium-like particle at 4260 GeV found in

$$e^+e^- \to \gamma_{ISR}\,\pi^+\pi^- J/\psi \qquad e^+e^- \to \pi^+\pi^- J/\psi$$

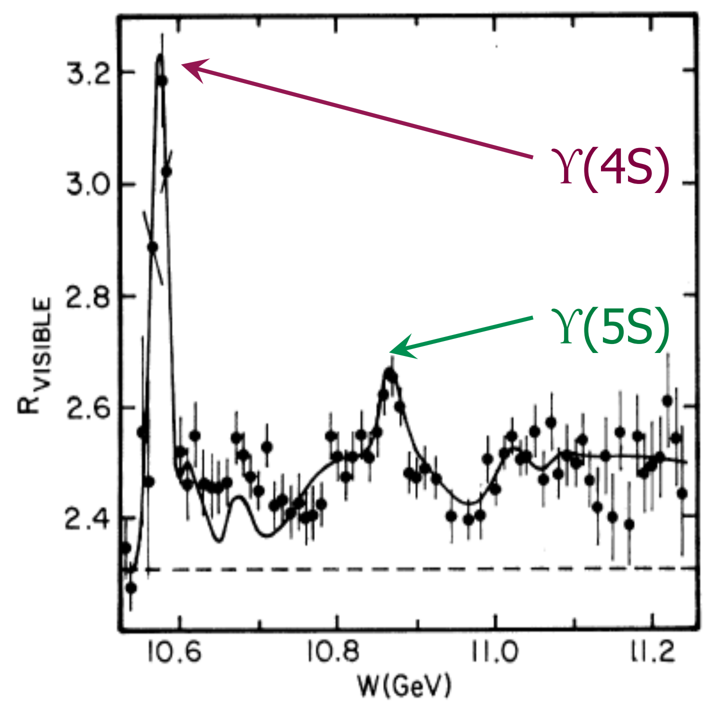
Babar PRL 95, 142001 (2005)
Belle PRD 77, 011105 (R) (2008)
CLEO PRD 74, 091104(R) (2006)

$$Y(4260) \to \pi^+\pi^- J/\psi$$

Others

$$Y \to \pi^+\pi^- \psi(2S)$$

+ many more!



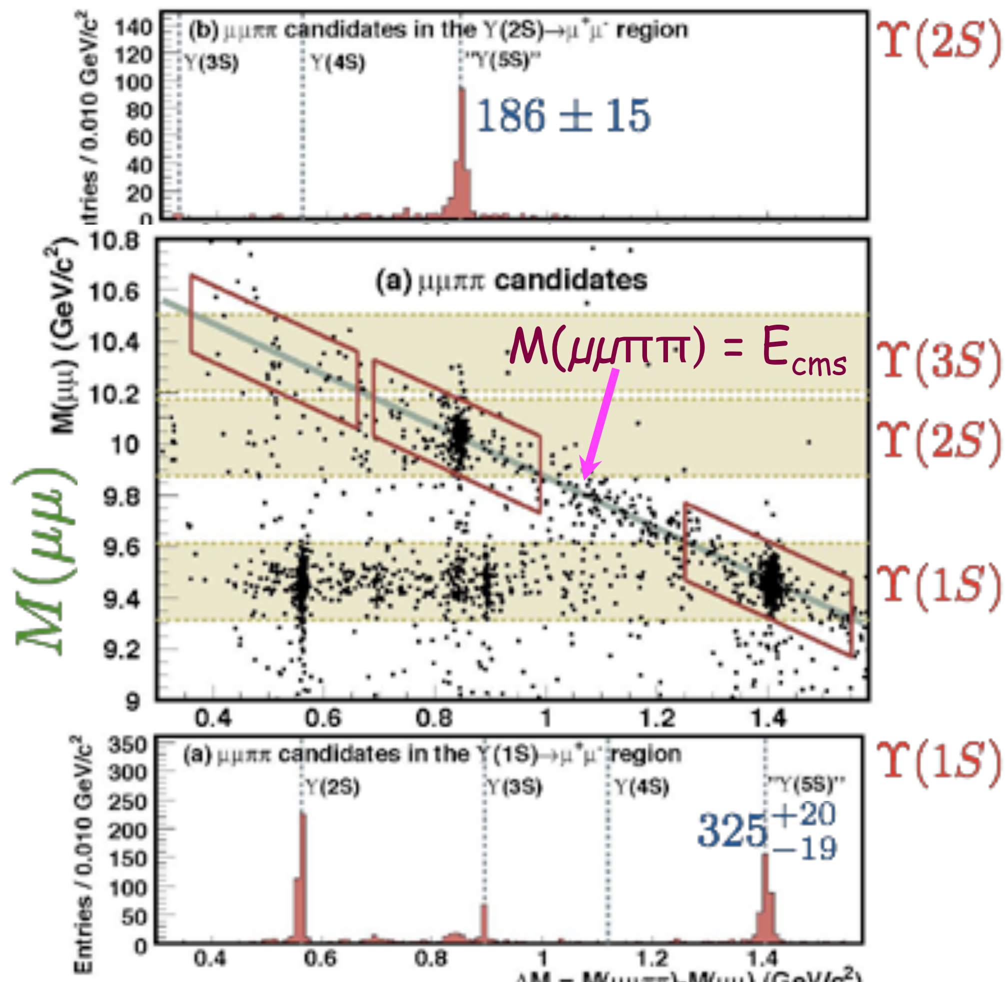
Does(do) analogous state(s) Y_b exist in Upsilon region?
[W.S. Hou, PRD 74, 017504 (2006)]

Is the ϒ(10860) purely ϒ(5S)?

-> look for: $\mu^+\mu^-h^+h^-$

$e^+e^- \to \Upsilon(1S)\pi^+\pi^-X$

$e^+e^- \to \Upsilon(2S)\pi^+\pi^-X$



$$\Delta M = M(\mu\mu\pi\pi) - M(\mu\mu)$$

Is the ϒ(10860) purely ϒ(5S)?

4 modes seen $\Upsilon(10860) \rightarrow \Upsilon(nS)h^+h^-$

Process	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

Expectation: ϒ(5S) width comparable to ϒ(2S/3S/4S)

Process	Γ_{total}	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \rightarrow \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \rightarrow \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by > 10^2

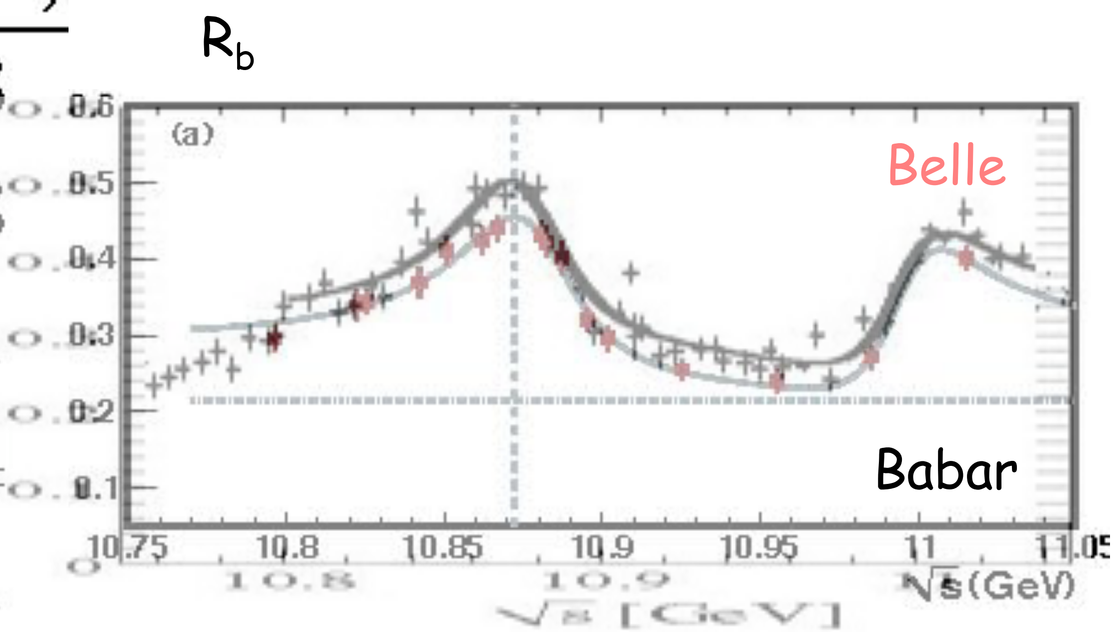
Conclusion: not pure ϒ(5S)?

12/07: energy scan, measure $e^+e^- \rightarrow \Upsilon(nS)h^+h^-$

Followup: scan above Υ(5S)

arXiv:0808.2445v2
KF Chen

$\sqrt{s}$(GeV)	$\mathcal{L}$(fb^{-1})
10.8275	1.68
10.8825	1.83
10.8975	1.41
10.9275	1.14
10.9575	1.01
11.0175	0.86



Followup: scan above $\Upsilon(5S)$

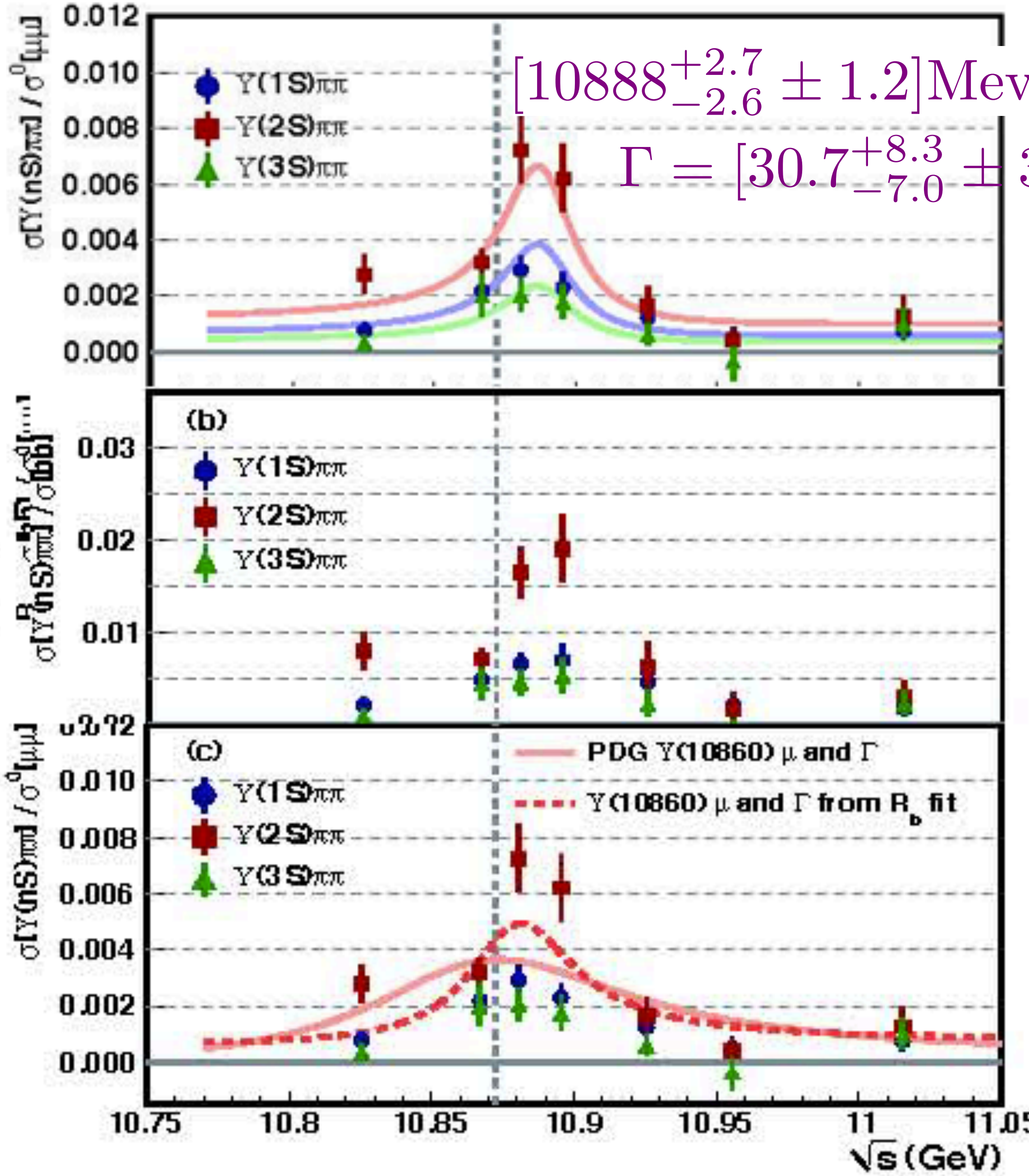
$$\frac{\sigma(\Upsilon(\mathrm{nS})\pi\pi)}{\sigma_{\mu\mu}}$$

$$\frac{\sigma(\Upsilon(\mathrm{nS})\pi\pi)}{\sigma(b\bar{b})}$$

$$\frac{\sigma(\Upsilon(\mathrm{nS})\pi\pi)}{\sigma_{\mu\mu}}$$

$$[10888^{+2.7}_{-2.6} \pm 1.2]\mathrm{Mev}/c^2$$

$$\Gamma = [30.7^{+8.3}_{-7.0} \pm 3.1]\mathrm{MeV}$$



Summary

KEKB and Belle at $\Upsilon(10860)$+

- 6/05, 6/06: 23 days, 23.6 fb^{-1}, 1.3M B_s events
- 12/07: energy scan, 6 pts, 8 fb^{-1}
- Beast(s)

  anomalous $\Upsilon(ns)\pi\pi$, ~10^2X expectation at $\Upsilon(10860)$
  $\Upsilon(ns)\pi\pi$ rate peaks ~ 20 MeV above hadronic peak
  -> $\Upsilon(10860)$: not pure $\Upsilon(5S)$?
  $B^{(*)}B^{(*)}(\pi)(\pi)$ rates

- Strange beauty

  spectator modes: $B_s \to D_s^{(*)}h$
  $B_s^*B_s^*$ rate, masses of B_s^*, B_s
  γ modes: $B_s \to \gamma\gamma$ (best limit), $B_s \to \varphi\gamma$ (first observation)
  absolute measurement $B(B_s \to D_s^{(*)}D_s^{(*)})(\sim \Delta\Gamma_{CP}/2\Gamma)$
  CP modes

Outlook

- more to come ...
  10/08-12/09: ~100 fb^{-1} at $\Upsilon(5S)$, ~6M B_s event, **ADDITIONAL**
  possible scan near/above $\Upsilon(5S)$ in Spring 2010
  SuperKEKB/Belle II ~2014