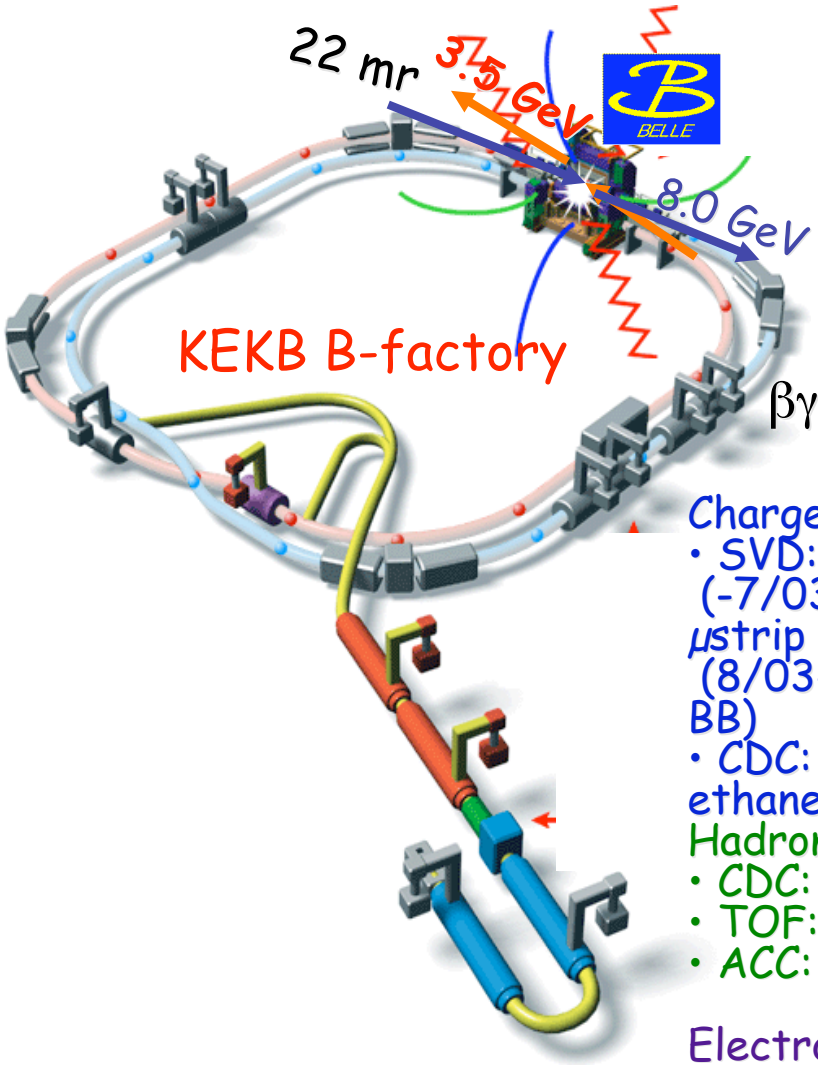
Lake Louise Winter Institute, February, 2008

Results from Υ(5S) at Belle: Strange Beauty and other Beasts

- B-factory and Υ(4S) Resonance
- Υ(5S) Resonance
  - motivation
  - recent results
  - prospects

Kay Kinoshita
University of Cincinnati
Belle Collaboration

the hardware (KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, Japan)



- L_{max} = 1.71 X 10^{34} $cm^{-2}s^{-1}$ (world record)
- Data (6/1999–12/2007)
- $\int Ldt$ = 760 fb^{-1}@{Υ(4S)+off(~10%)}
- (>7.6x10^8 B events)
- $\int Ldt$ = 23.6 fb^{-1}@Υ(5S)

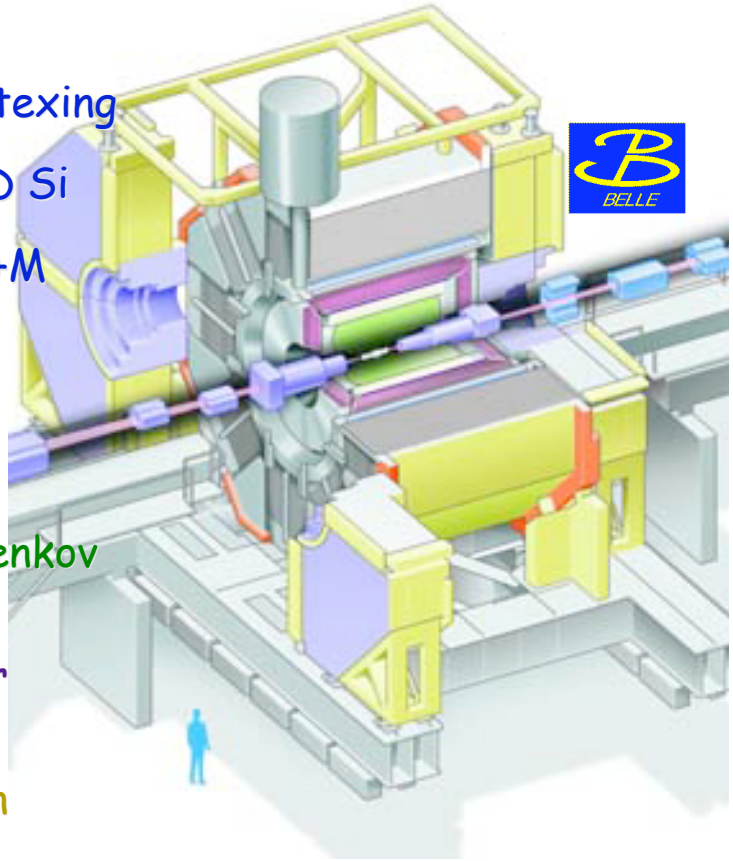
$\beta\gamma = 0.425$

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



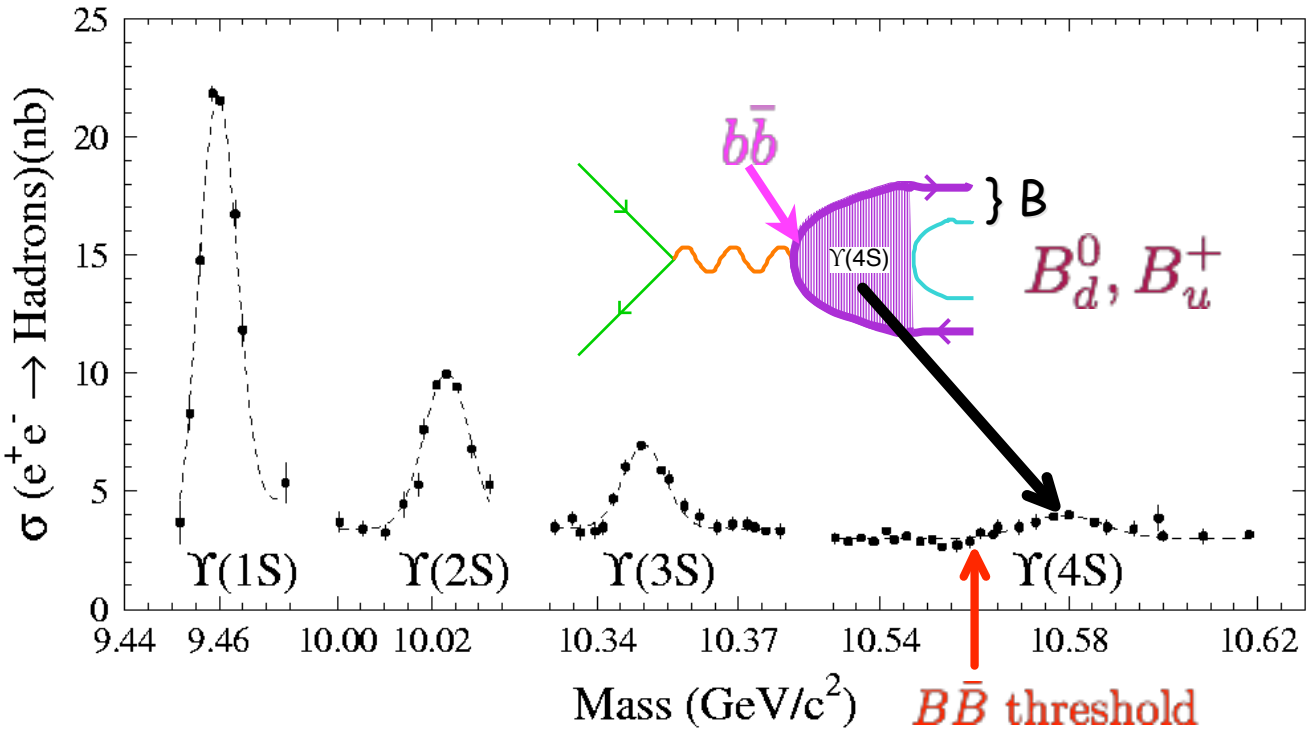
… the people

BINP
Chiba U.
U. of Cincinnati
Ewha Womans U.
Fu-Jen Catholic U.
U. of Giessen
Gyeongsang Nat'l U.
Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow
IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne
Nagoya U.
Nara Women's U.
National Central U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Nova Gorica
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC
Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

14 countries, 55 institutes, ~400 collaborators

(authors vary, each paper)

B factory: $e^+e^- \to \Upsilon(4S) \to B\bar{B}$



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

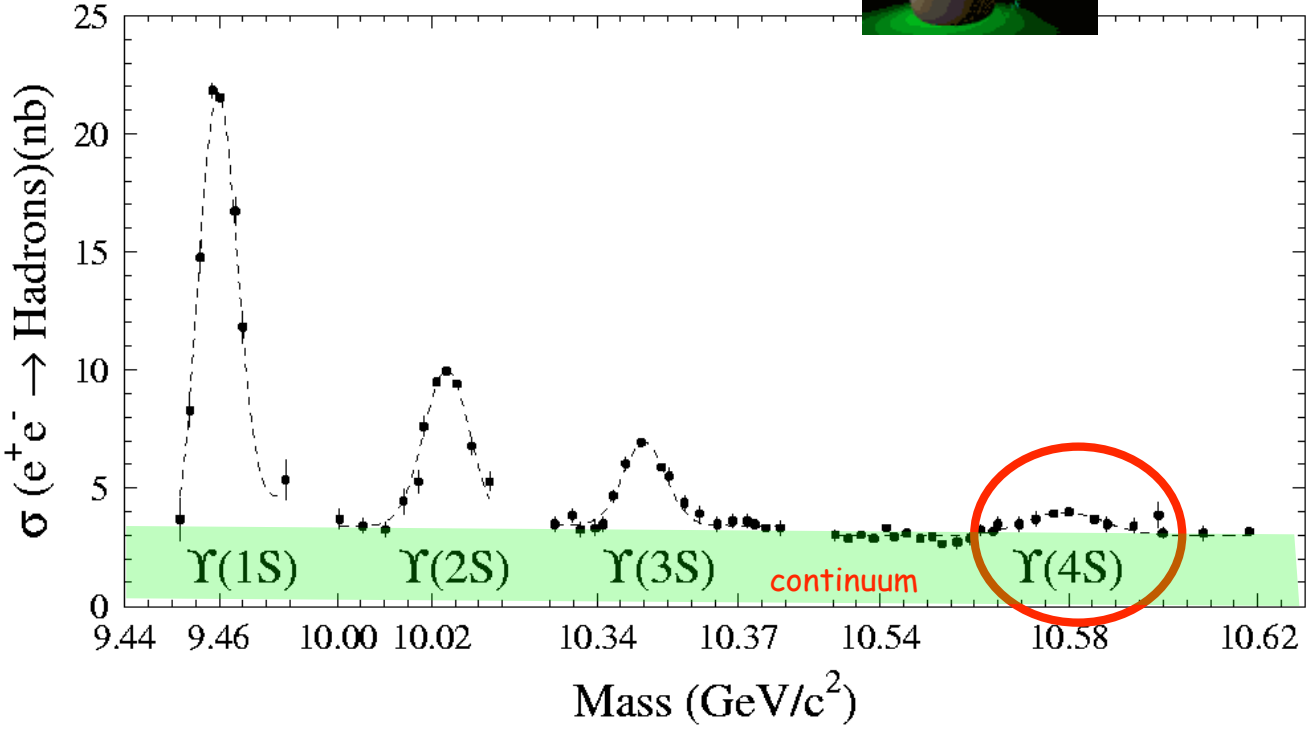
... but there's MUCH more!

245±5 papers published or in press (#1 in 3/2001)

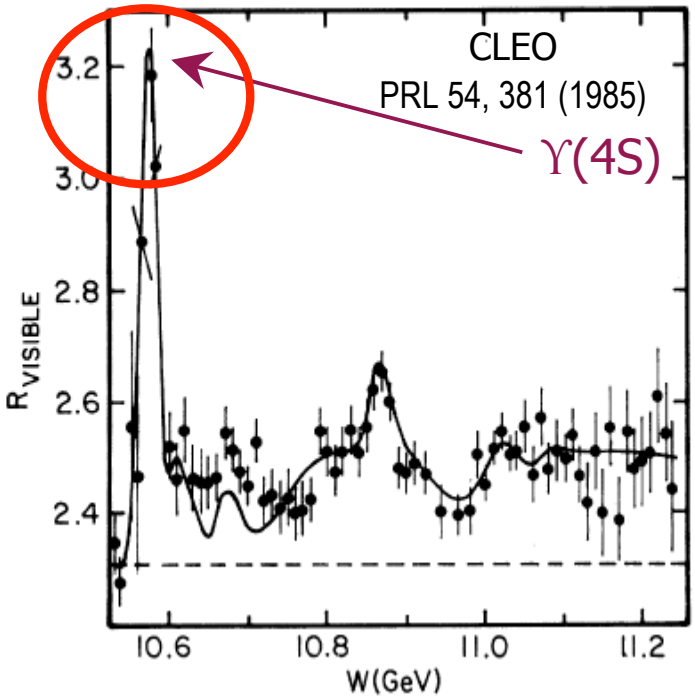
- CP asymmetry in B decay
- B decays
- charm
- tau
- 2-photon
- addressing CP, CKM, QCD, HQ spectroscopy, ...

- ... and now, Υ(10860), "5S"
  - B_s decays & CP, search for New Physics
  - Upsilon, B_s spectroscopy

... more: Υ(5S)


σ (e+e- → Hadrons)(nb)
25
20
15
10
5
0
9.44
9.46
10.00
10.02
10.34
10.37
10.54
10.58
10.62
Mass (GeV/c2)
Υ(1S)
Υ(2S)
Υ(3S)
continuum
Υ(4S)

... more: Υ(5S)

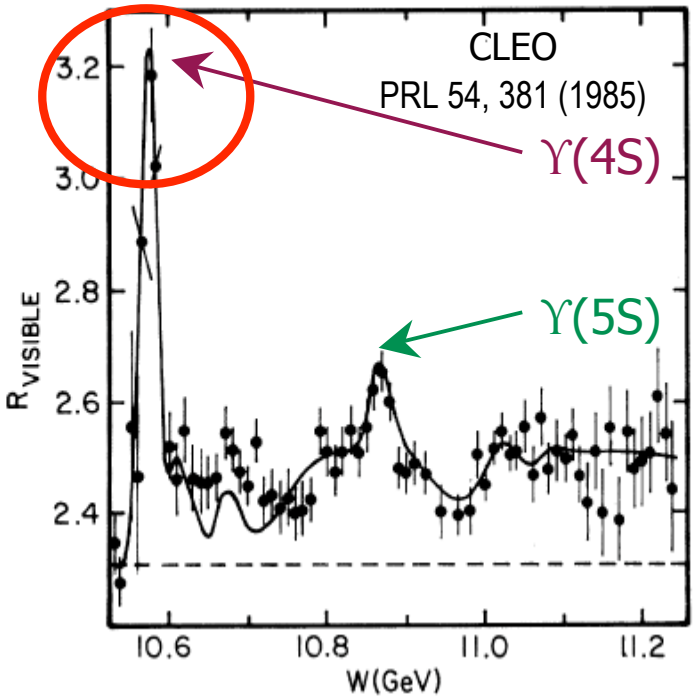


$\rightarrow B^+B^-,\ B^0\bar{B}^0$

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

M=10580±1 MeV/c^2, Γ=20.5±2.5MeV

... more: Υ(5S)



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M=10580±1 MeV/c², Γ=20.5±2.5MeV

$\rightarrow B_s^{(*)}\bar{B}_s^{(*)},\ B_q^{(*)}\bar{B}_q^{(*)},\ B_q\bar{B}_q^{(*)}\pi,$
$B_q\bar{B}_q\pi\pi$

M=10865±8 MeV/c², Γ=110±13 MeV

B_s produced copiously in pp(bar) collisions (FNAL, LHC) –
could B-factories (competitively) study B_s at the Υ(5S)?

pro's

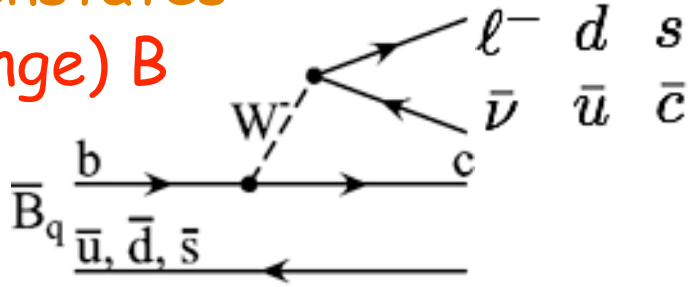
- MUCH cleaner, better energy definition, event efficiency, clean γ's
- B-factory: high luminosity, established detector, compare w Υ(4S)

Υ(5S) physics

B_s studies

- Low CP-asymmetry in SM
  -> sensitivity to New Physics

  "SM CP violation is insufficient to explain baryon asymmetry"
  Mod. Phys. Lett A9, 75 (1994); PRD 51, 379 (1995); Nucl.Phys. B287, 757 (1987)
- $\Delta\Gamma/\Gamma_{CP}/\Gamma$=O(10%) in SM
  -> differences in CP, flavor eigenstates
- Similarity/difference w (non-strange) B
  -> quark-hadron duality,
  fine-tune hadronic models
- Υ(5S) spectroscopy:
  $B_{(s)}^{(*)}(\pi)$ event fractions
  $B_s^{(*)}$ mass
  Other bottomonium-like states?

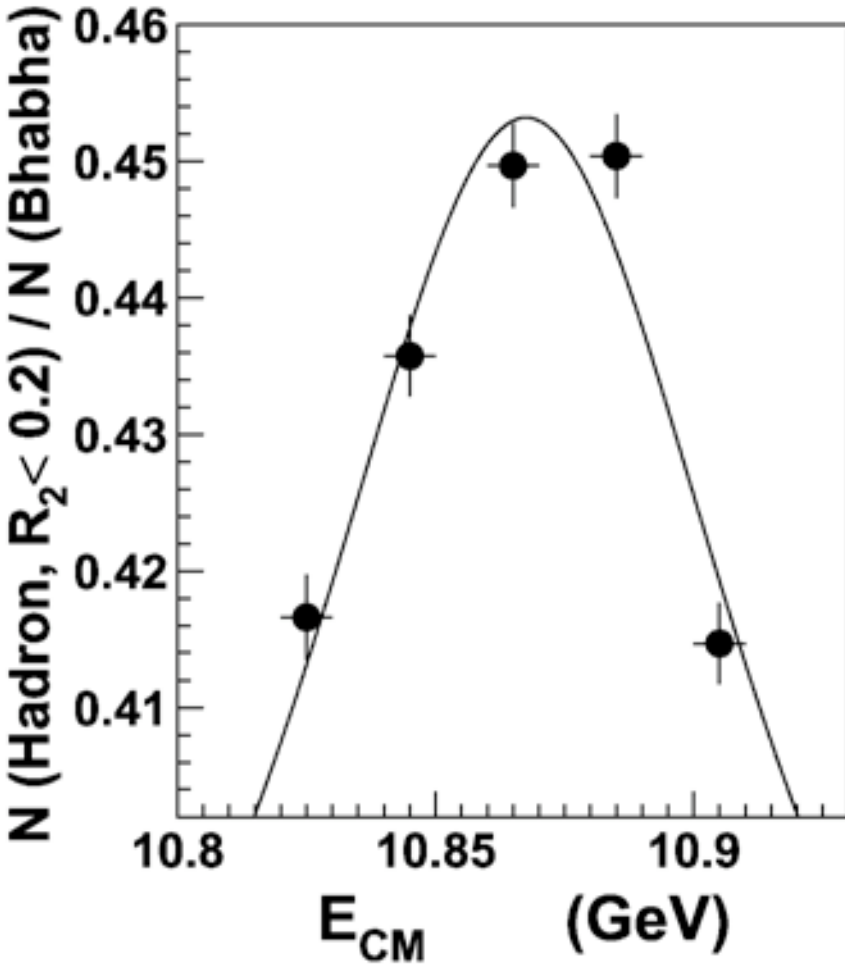


data

June 2005: 3-day "engineering" run

- study basic $\Upsilon(5S)$, $B_s^{(*)}$ properties,
- test KEKB at $\Upsilon(5S)$ - L_{max}~$1.39 \times 10^{34} cm^{-2} s^{-1}$
- energy scan, 5 points, 30 pb^{-1} each
- 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)



June 2006: 20-day run

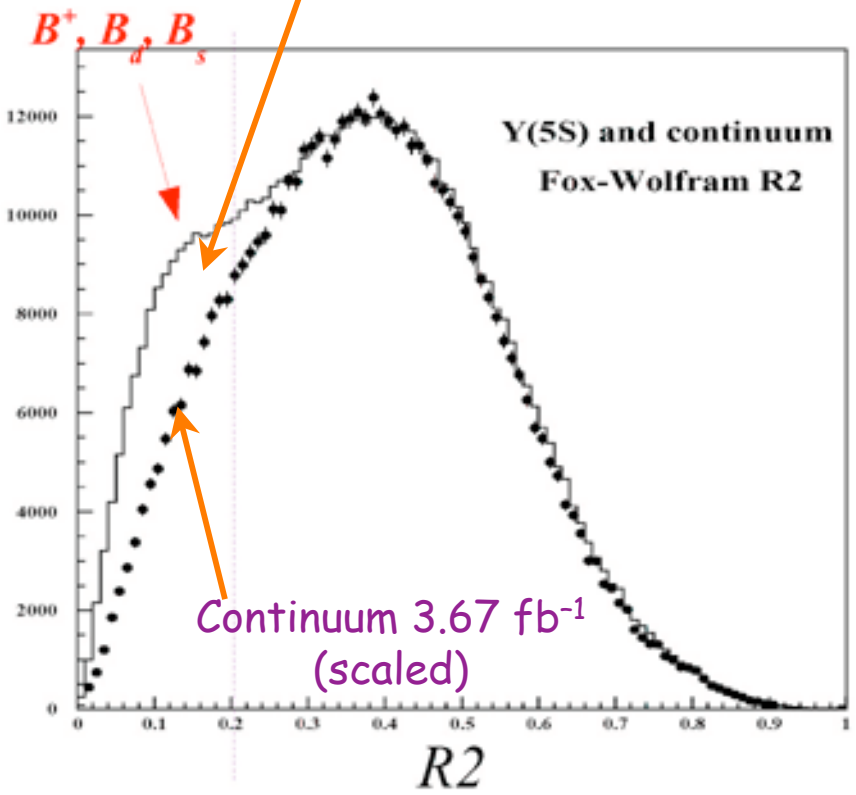
- 21.7 fb^{-1} on resonance
- first results

K.F. Chen et al., arXiv:0710.2577[hep-ex]
J. Wicht et al., arXiv:0712.2659[hep-ex]
R. Louvot et al., (preliminary)

fundamentals 1.86 fb^{-1} PRL 98, 052001 (2007)

Event count

$(3.01\pm0.02\pm0.16)\times10^5$ events/fb^{-1}

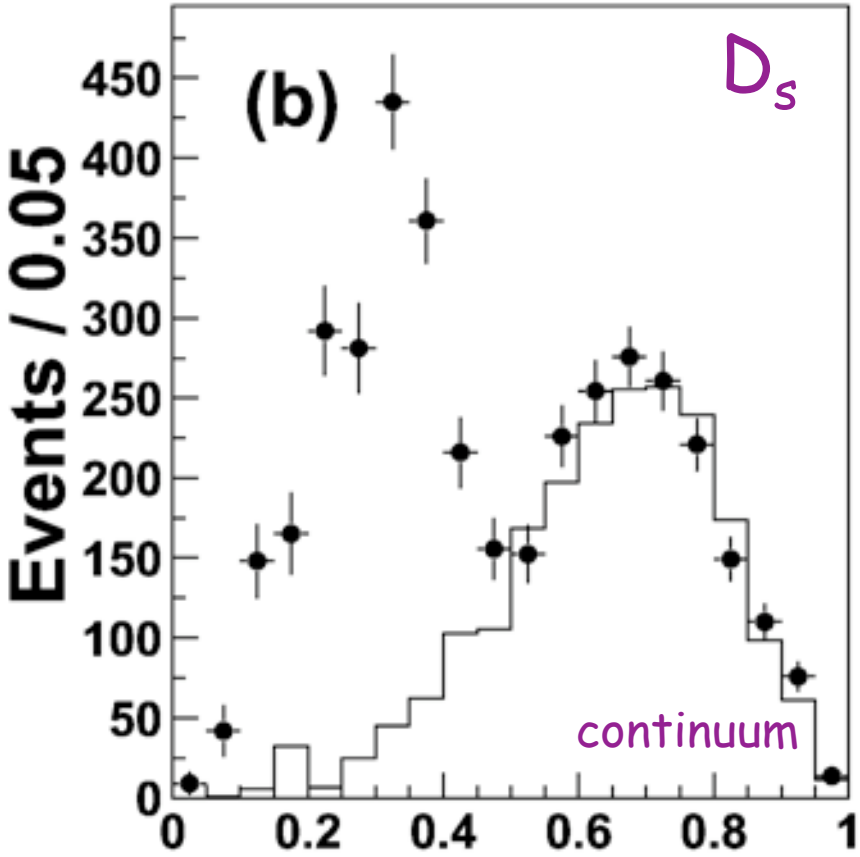


$$R_2 = \frac{\sum_{i,j} |p_i||p_j| P_2(\cos\theta)}{\sum_{i,j} |p_i||p_j| P_0(\cos\theta)}$$

Fox-Wolfram moments

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

inclusive D_s, D^0 production



$$x = p_{D_s} / \sqrt{E^2_{beam} - M^2_{D_s}}$$

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

$$B_s \to D_s^- \pi^+, \; D_s^- K^+$$

B_s at $\Upsilon(5S)$: mix of $B_s\bar{B}_s : B_s^*\bar{B}_s / B_s\bar{B}_s^* : B_s^*\bar{B}_s^*$

Candidate reconstruction:
energy, momentum -> ΔE, M_{bc}

$$B_s\bar{B}_s$$

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

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

$$B_s^* \to B_s\gamma$$

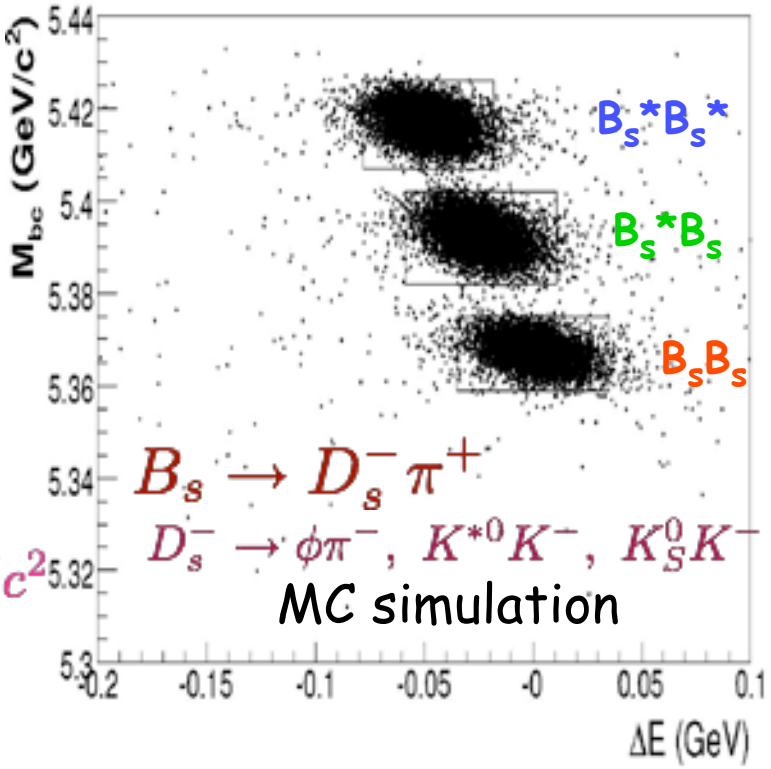
$$\Delta M \equiv M_{B_s^*} - M_{B_s} \approx 50\ \mathrm{MeV}/c^2$$

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

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

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

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



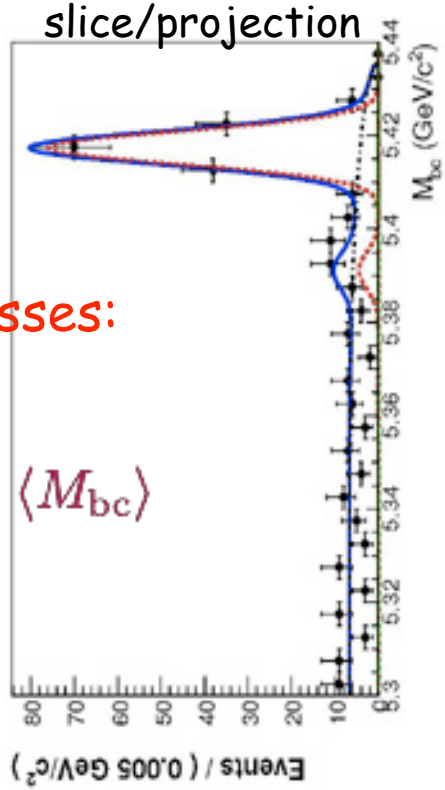
$$M_{\mathrm{bc}} \equiv \sqrt{E_{beam}^2 - p_{cand}^2}$$

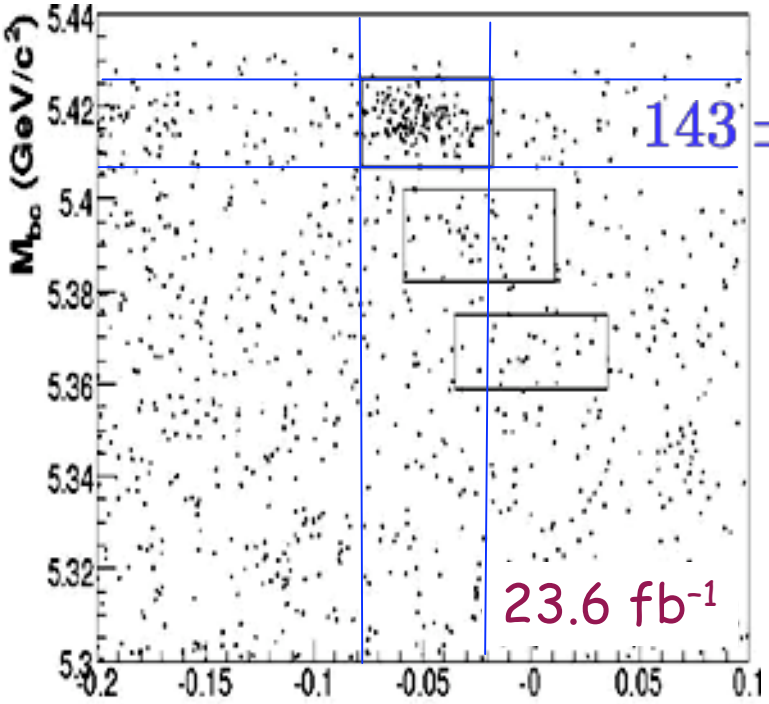
$$\Delta E \equiv E_{cand} - E_{beam}$$

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

$B_s^* B_s^*$

slice/projection





measure masses:

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

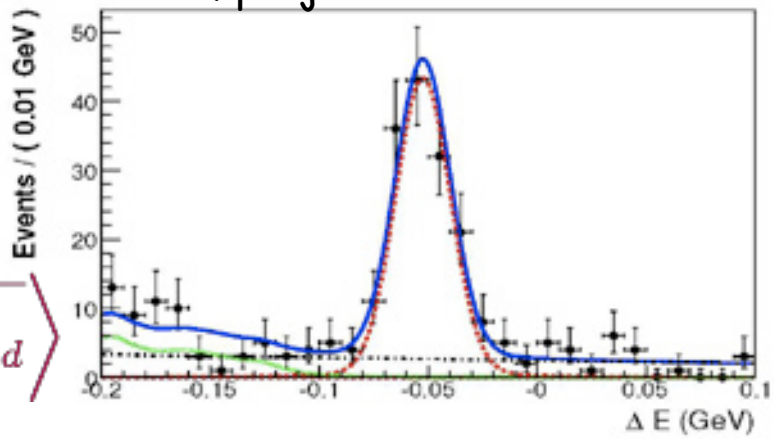
$\Rightarrow M_{B_s^*} = \langle M_{\rm bc} \rangle$

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

$\Rightarrow M_{B_s}$

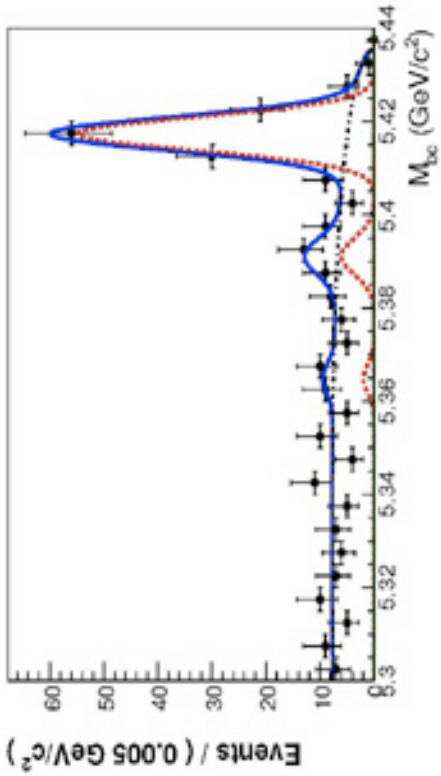
$$= \left\langle \sqrt{(E_{beam} - \langle \Delta E \rangle)^2 - p^2_{cand}} \right\rangle$$

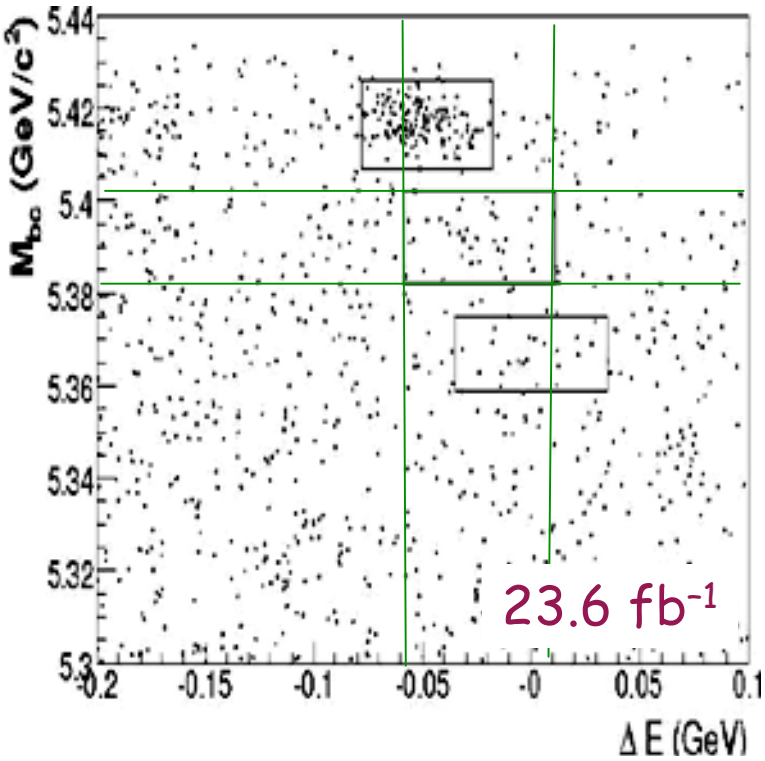
slice/projection



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

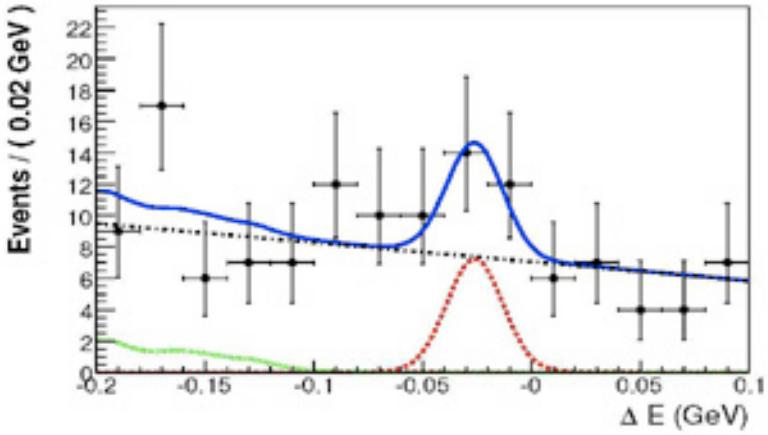
$B_s^* B_s$





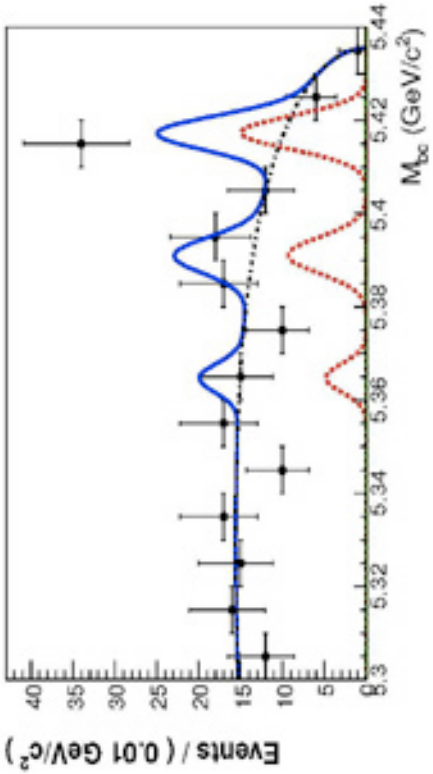
$12^{+5.6}_{-4.8}$

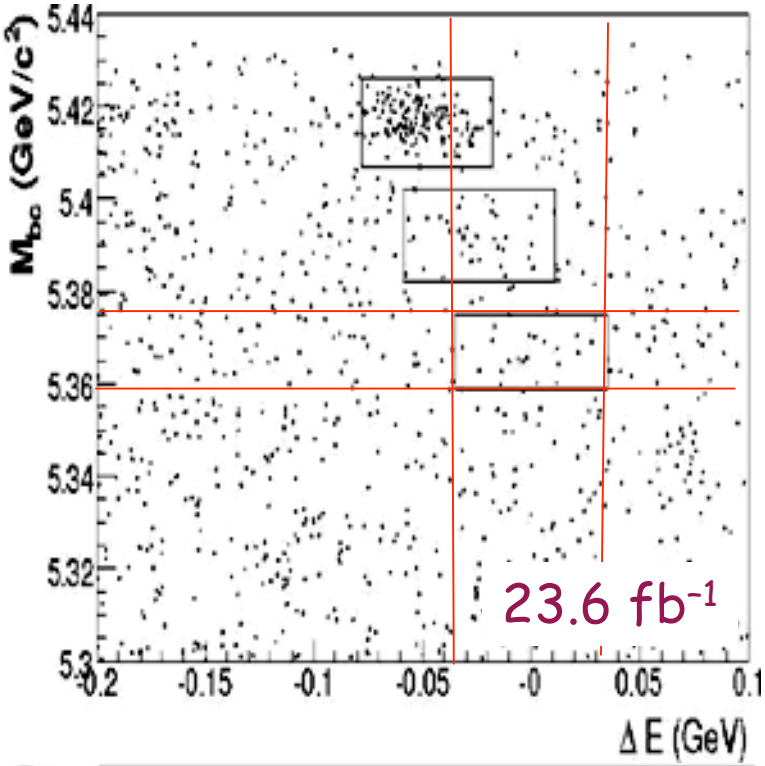
significance = 2.9σ



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

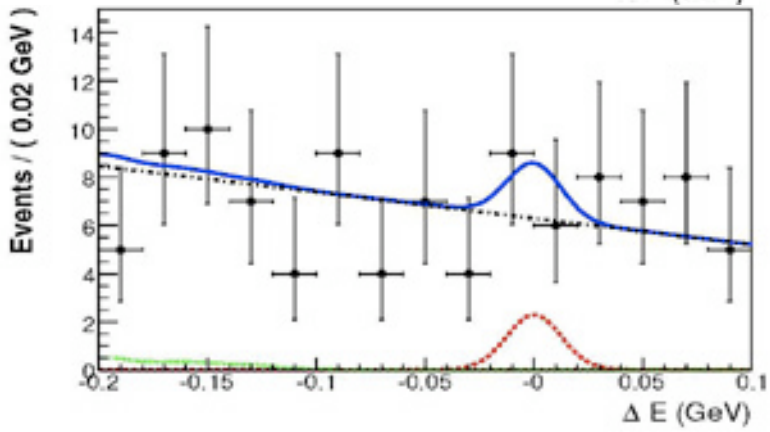
$B_s B_s$





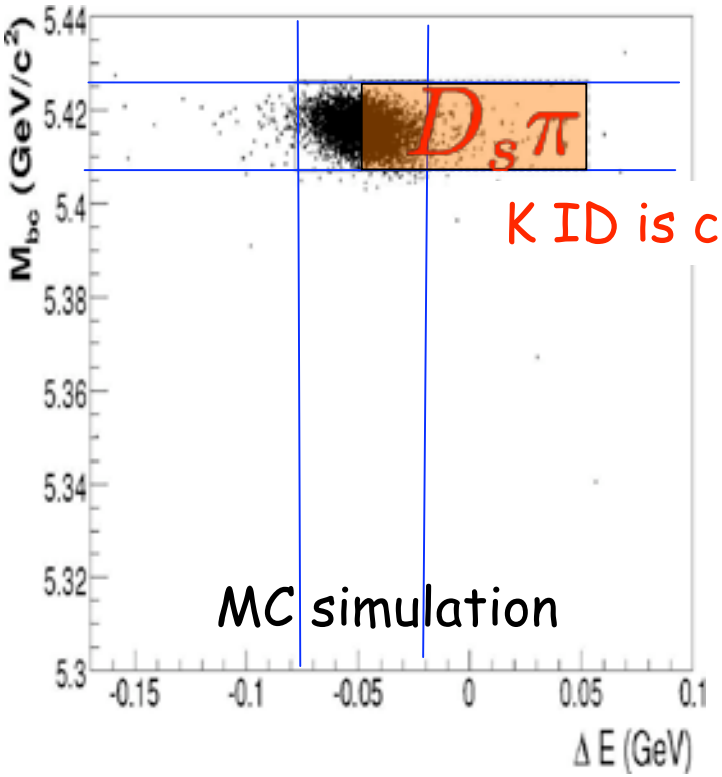
$3.8^{+4.3}_{-3.4}$

significance < 0.1σ



$B_s \to D_s^- K^+$

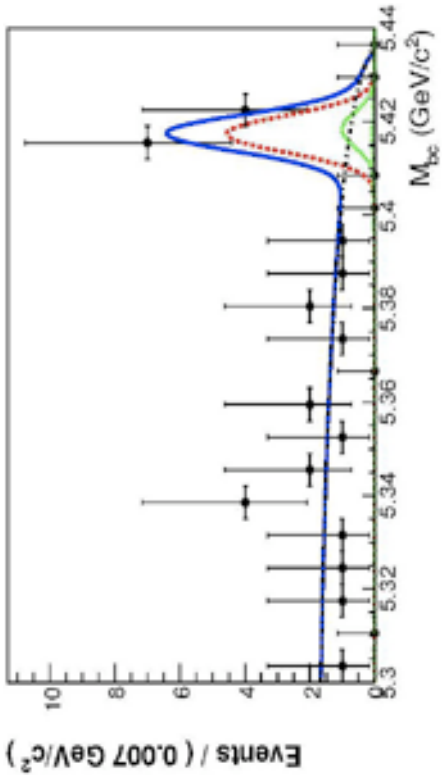
$B_s^* B_s^*$ only

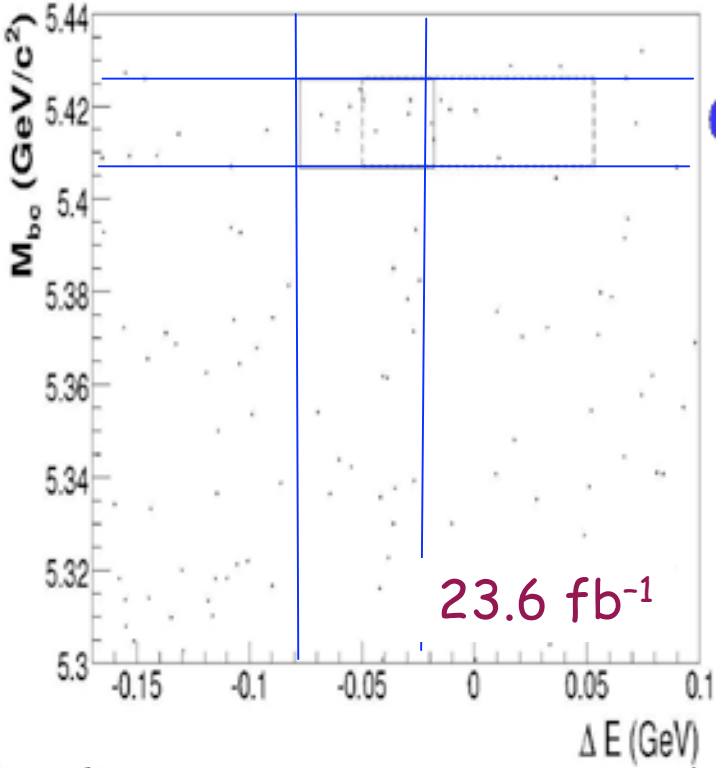


K ID is crucial

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

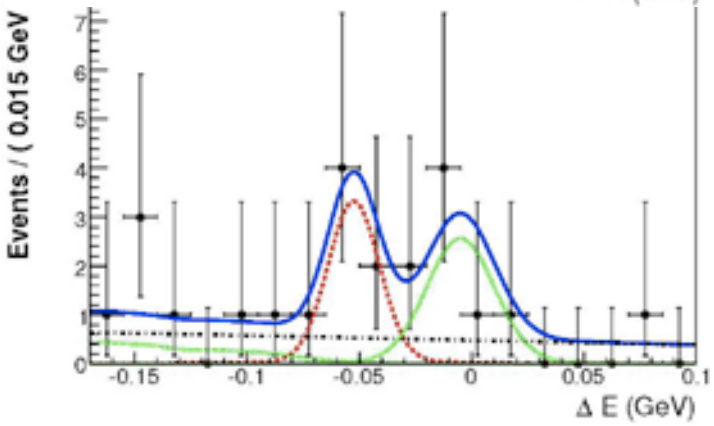
$B_s^* B_s^*$





$6.3^{+3.3}_{-2.6}$

significance = 3.7σ



results $D_s^- \pi^+$, $D_s^- K^+$

	Unit	Our fit result			1.86fb^{-1} Belle analysis[1]	PDG value [3]
$\mathcal{B}(B_s \to D_s\pi)$	10^{-3}	3.31	$^{+0.31}_{-0.30}$	$^{+0.67}_{-0.64}$	$6.8 \pm 2.2 \pm 1.6$	3.0±0.7
$f_{B_s^* B_s^*}$	%	90.0	$^{+3.7}_{-3.9}$		93^{+7}_{-9}	-
$f_{B_s^* B_s}$	%	7.6	$^{+3.3}_{-2.9}$		-	-
m_{B_s}	MeV/c^2	5364.8	±1.2		5370±1 ± 3	5366.1±0.6
$m_{B_s^*}$	MeV/c^2	5417.2	±0.4	±1.0	5418±1 ± 3	5412.0±1.2
$\mathcal{B}(B_s \to D_s K)$	10^{-4}	2.2	$^{+1.1}_{-0.9}$	$^{+0.5}_{-0.4}$	-	-
$\frac{\mathcal{B}(B_s \to D_s K)}{\mathcal{B}(B_s \to D_s \pi)}$	%	6.6	$^{+3.4}_{-2.8}$		-	10.7±2.1 (CDF prel.)

$$f_{B_s^* B_s^*} \equiv \frac{\sigma(e^+e^- \to B_s^* \bar{B}_s^*)}{\sigma(e^+e^- \to B_s^{(*)} \bar{B}_s^{(*)})} \qquad f_{B_s^* B_s} \equiv \frac{\sigma(e^+e^- \to B_s^* \bar{B}_s + B_s \bar{B}_s^*))}{\sigma(e^+e^- \to B_s^{(*)} \bar{B}_s^{(*)})}$$

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

Is the Υ(10860) purely Υ(5S)?

- recently found in e^+e^- collisions:

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

New charmonium-like particle at 4260 GeV

Babar PRL 95, 142001 (2005)
Belle arXiv:0709.2565 (to appear in PRD(R)
CLEO PRD 74, 091104(R) (2006)

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

Others

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

+more - than predicted!

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

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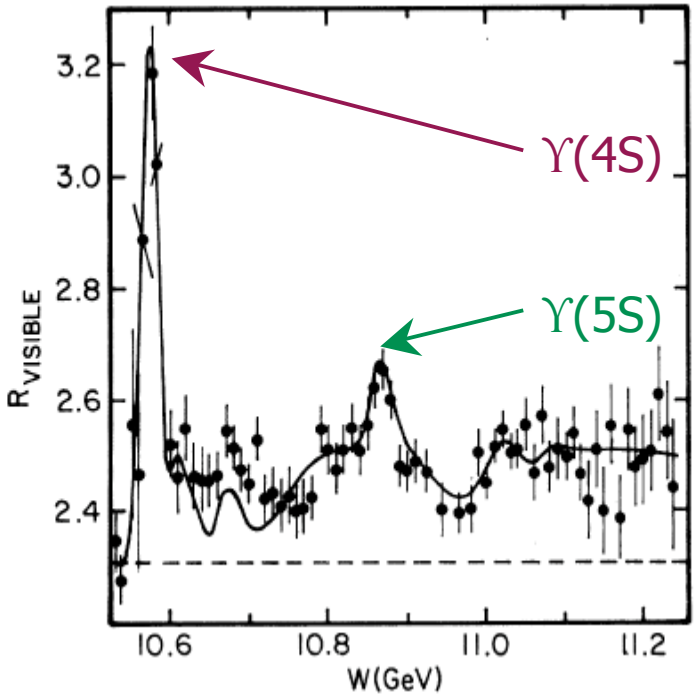

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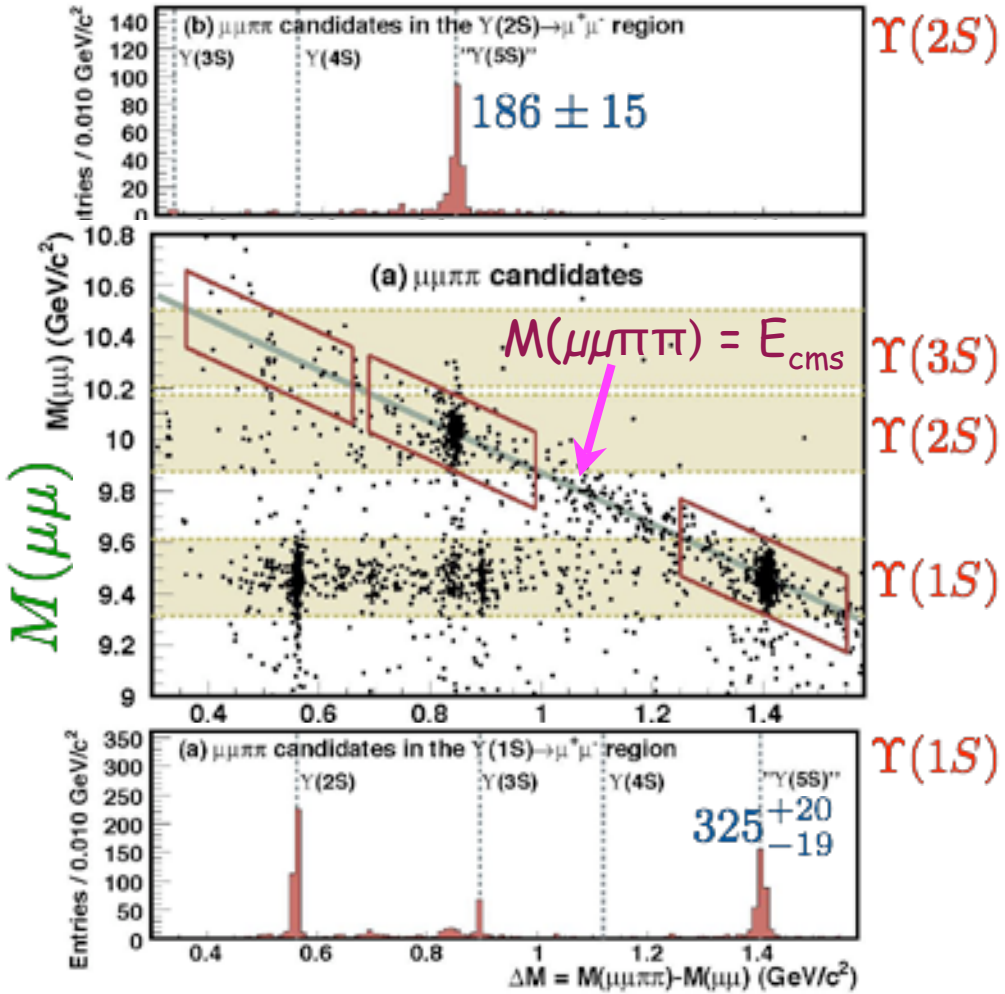
arXiv:0710.2577[hep-ex]
(accepted PRL)

-> 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 $\Upsilon(10860) \to \Upsilon(nS)h^+h^-$

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)

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

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

larger by > 10^2

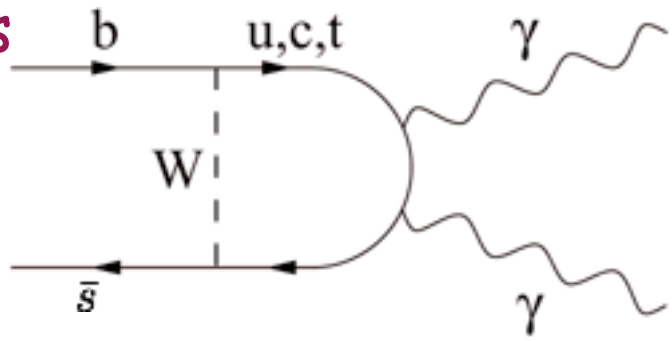
Conclusion: <u>not</u> pure Υ(5S)?

12/07 energy scan, search for anomalous $e^+e^- \to \Upsilon(nS)h^+h^-$

Searches for radiative modes of B_s

Searches for new modes of B_s arXiv:0712.2659[hep-ex]

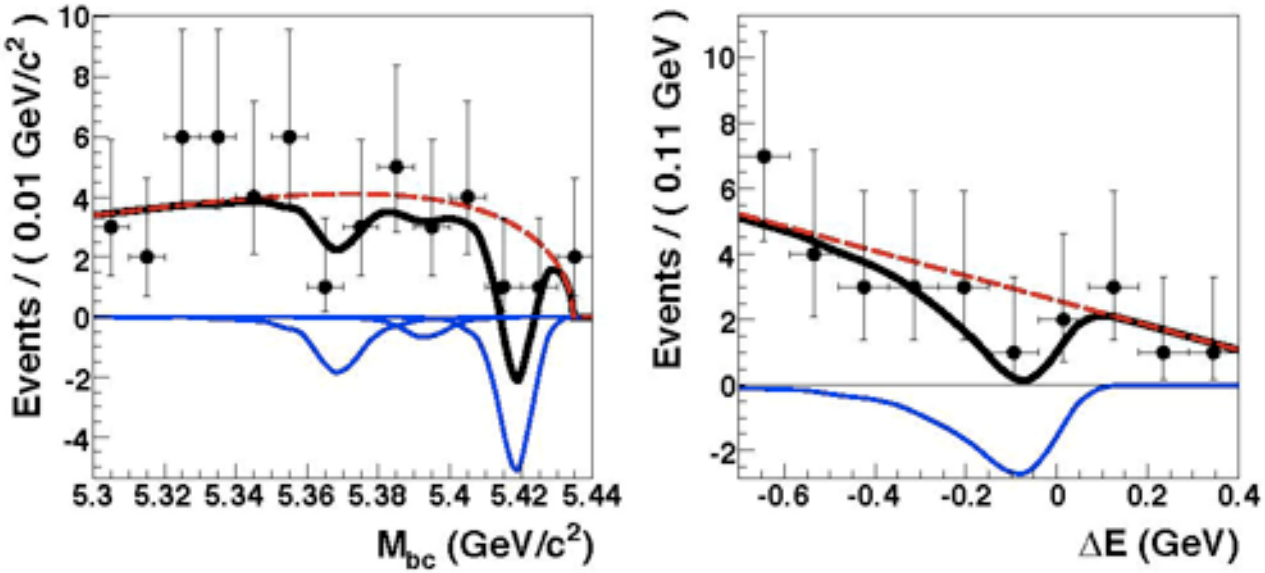
$\gamma\gamma$: difficult for hadron machines



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

beyond SM: up to 5×10^{-6}

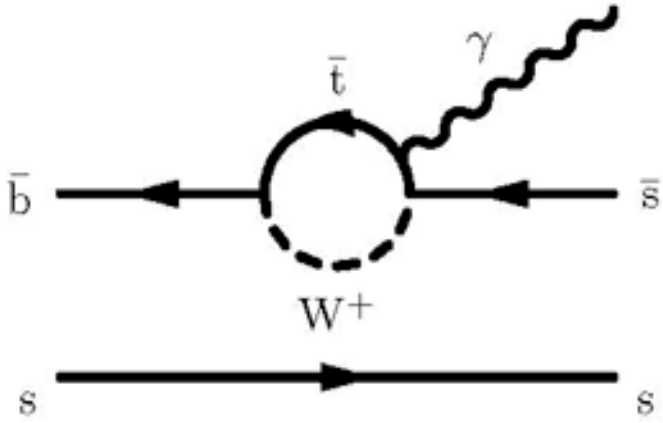
23.6 fb^{-1}



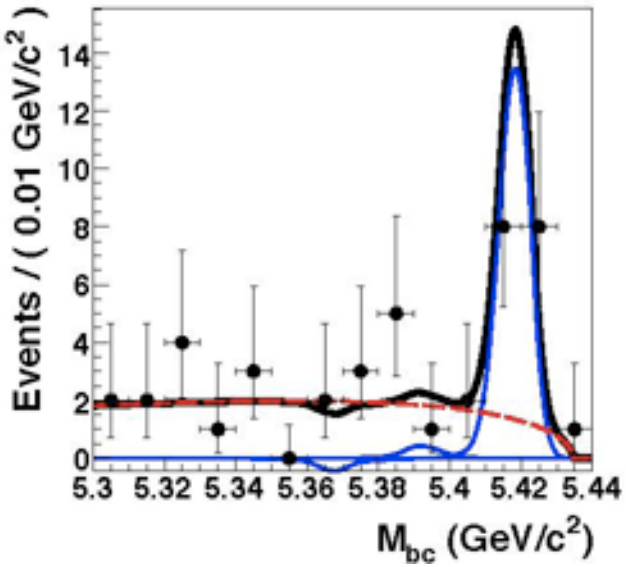
$\mathcal{B} < 8.7 \times 10^{-6}$ (90% CL) (prev. Belle: <5.3 x 10^{-5})

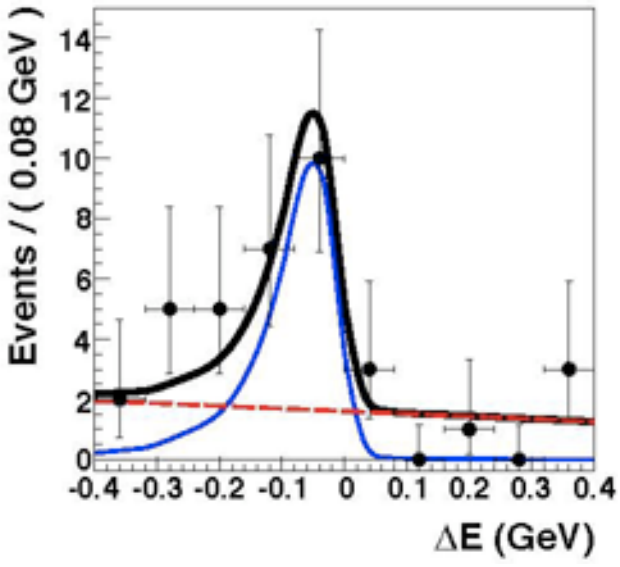
Searches for new modes of B_s

φγ



23.6 fb^{-1}





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

First observation

Summary

KEB and Belle at $\Upsilon(10860)$

- 23 days, 23.6 fb^{-1}, 1.3M B_s events
- Beast(s)
  - anomalous $\Upsilon(ns)\pi\pi$, ~10^2X expectation
  - -> $\Upsilon(10860)$: not pure $\Upsilon(5S)$? (energy scan, stay tuned)
- Strange beauty
  - large sample of B_s -> $D_s\pi$, evidence D_sK
  - best limit on B_s -> $\gamma\gamma$
  - first observation of B_s -> $\phi\gamma$
- more to come ...