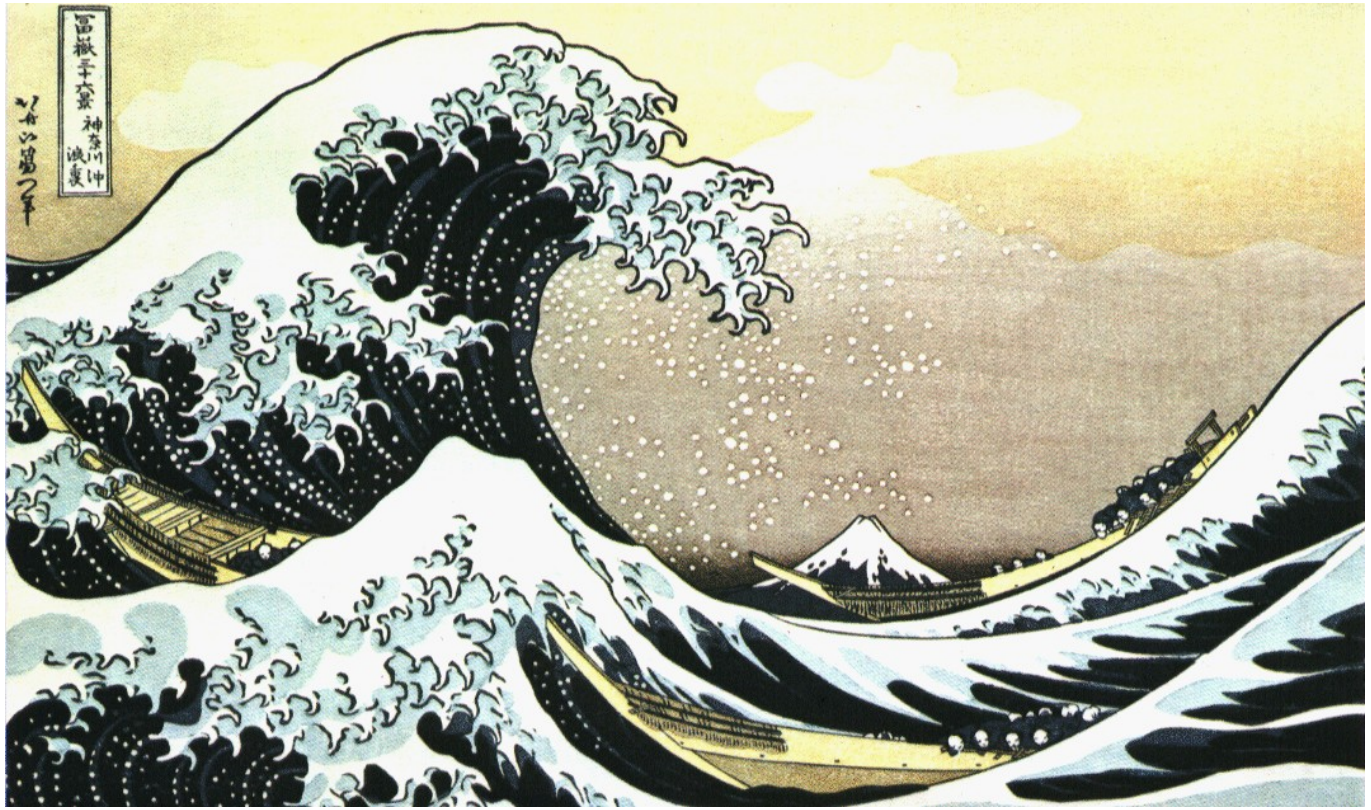
Results at the $\Upsilon(5S)$ resonance

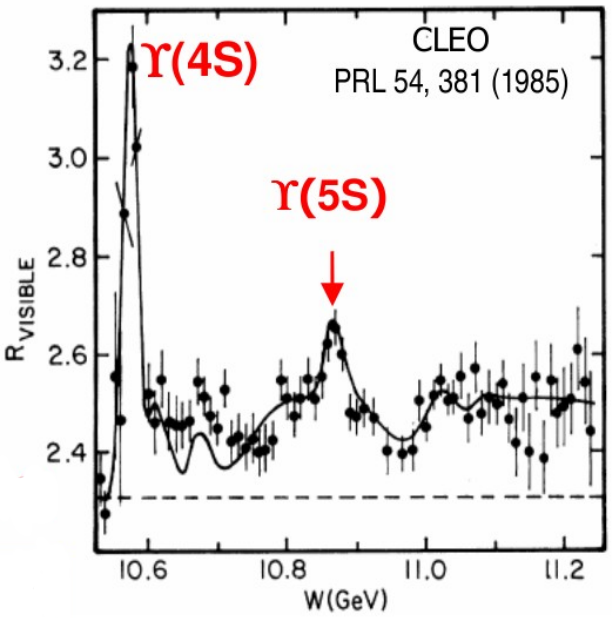


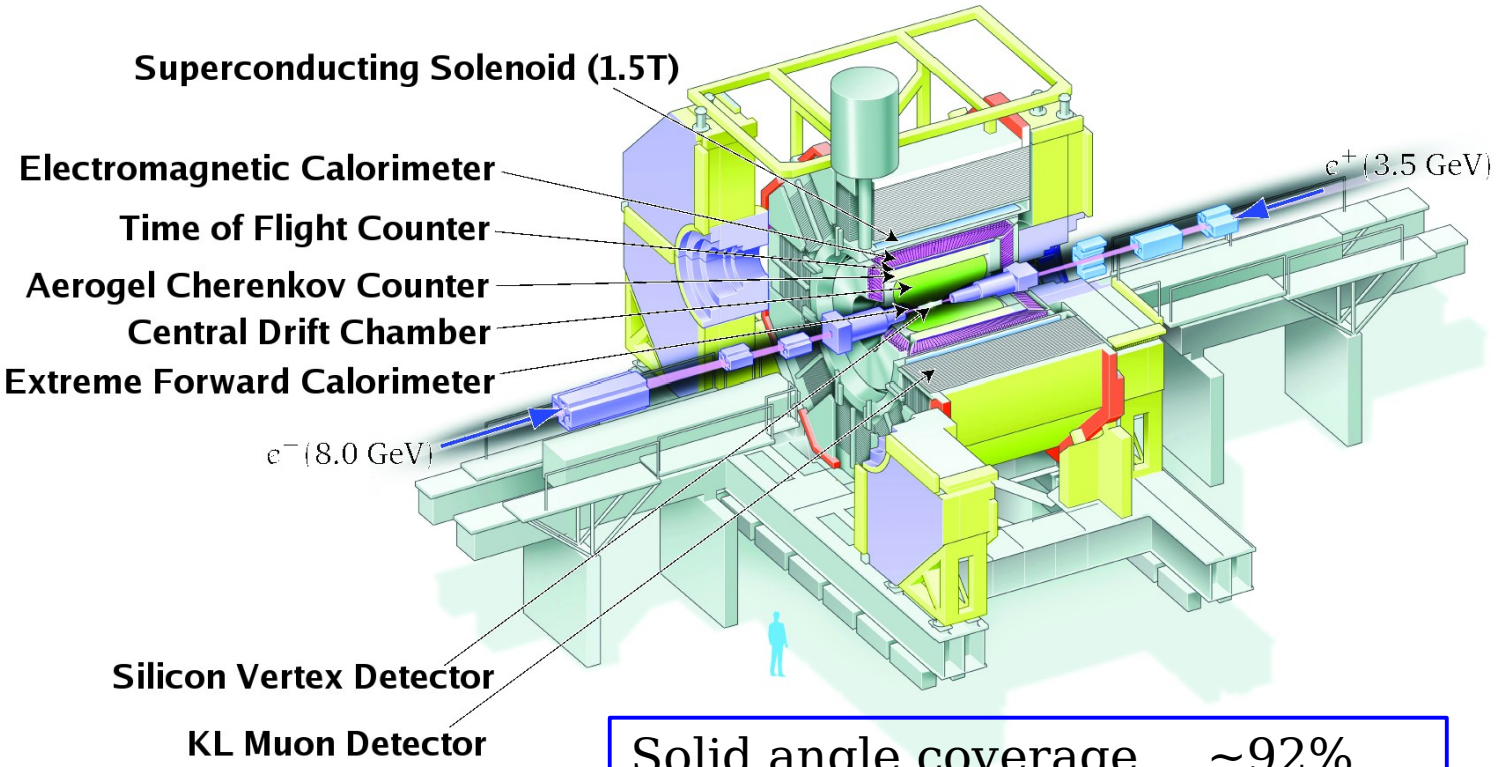
Jean Wicht
JSPS fellow
KEK

Heavy Quarks & Leptons 2008
Melbourne, 05-10 June 2008

KEKB and Belle detector

KEKB : asymmetric e^+e^- collider (3.5 on 8.0 GeV): Tsukuba, Japan
B meson factory: $e^+e^- \rightarrow \Upsilon(\{4,5\}S) \rightarrow BB$





Solid angle coverage	~92%
Particle identification	π,K,e,μ,p

Luminosity

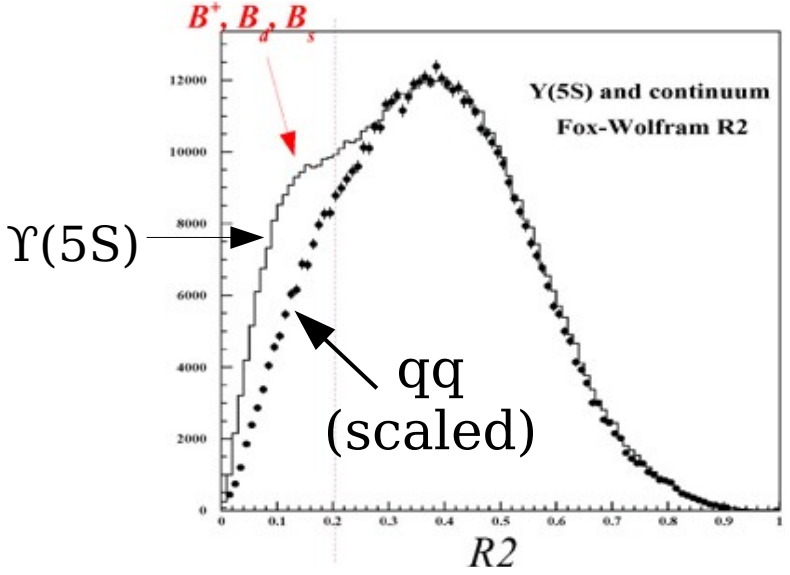
Peak	$1.71 \times 10^{34}/cm^2/s$
Daily	up to 1.2 fb^{-1}
Integrated	>840 fb^{-1}

~750 fb^{-1} at Υ(4S) (~825M BB pairs, B=B^+ or B^0)
24 fb^{-1} at Υ(5S) (~2.8M B_s mesons)

June 2005: 2 fb^{-1}
June 2006: 22 fb^{-1}

Events at the Υ(5S): σ

bb cross-section measured with continuum (qq) subtraction



Hadronic events at Υ(5S)

bb events

u,d,s,c continuum

$$\sigma_{b\bar{b}}^{\Upsilon(5S)} = (0.302 \pm 0.015)\ \text{nb}$$

σ_{bb} ~ 1.1 nb at Υ(4S)

2 fb^{-1} at Υ(5S)

A. Drutskoy et al. (Belle), PRL 98, 052001 (2007)

Events at the $\Upsilon(5S)$: f_s

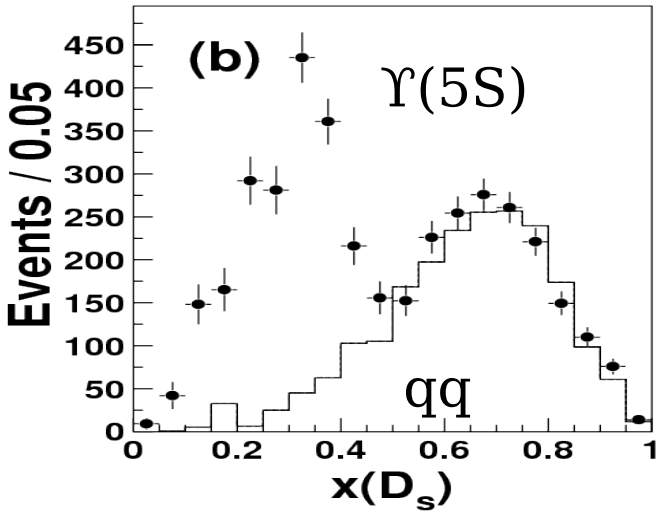
B_s production fraction measured with inclusive D_s and D^0

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

$f_s \cdot \mathcal{B}(B_s \to D_s X)$ → theory

$(1 - f_s) \cdot \mathcal{B}(B \to D_s X)$ → PDG

Continuum subtraction to get D_s from $\Upsilon(5S)$



Hadronic events at $\Upsilon(5S)$

bb events

u,d,s,c continuum

B_s events

B^+ or B^0 events

$$\sigma_{b\bar{b}}^{\Upsilon(5S)} = (0.302 \pm 0.015)\ \text{nb}$$

2 fb^{-1} at $\Upsilon(5S)$

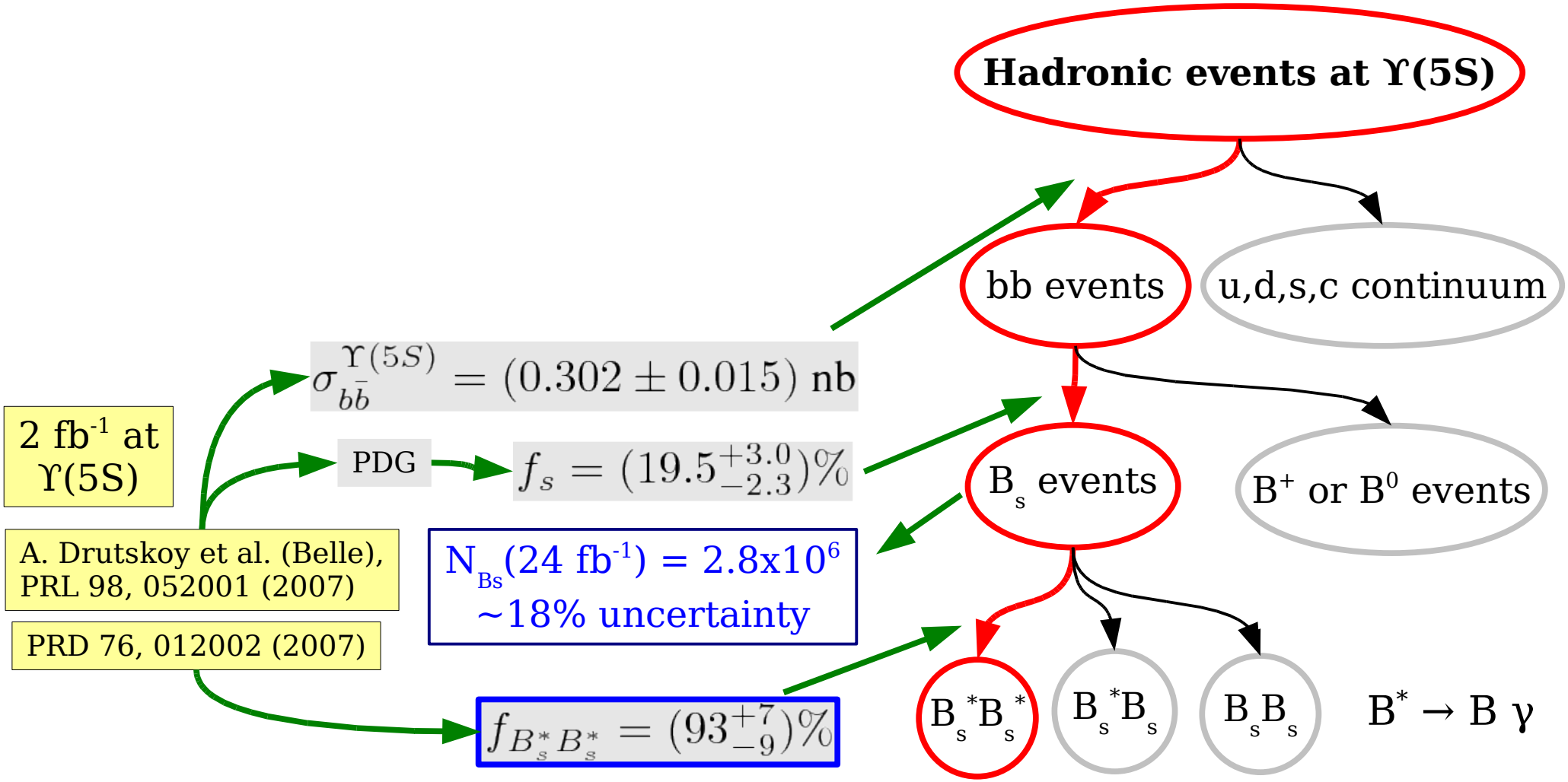
PDG → $f_s = (19.5^{+3.0}_{-2.3})\%$

A. Drutskoy et al. (Belle), PRL 98, 052001 (2007)

$N_{Bs}(24\ fb^{-1}) = 2.8 \times 10^6$
~18% uncertainty

Events at the Υ(5S)

$B_s^{(*)}B_s^{(*)}$ production fractions using fully reconstructed B_s mesons (example later)

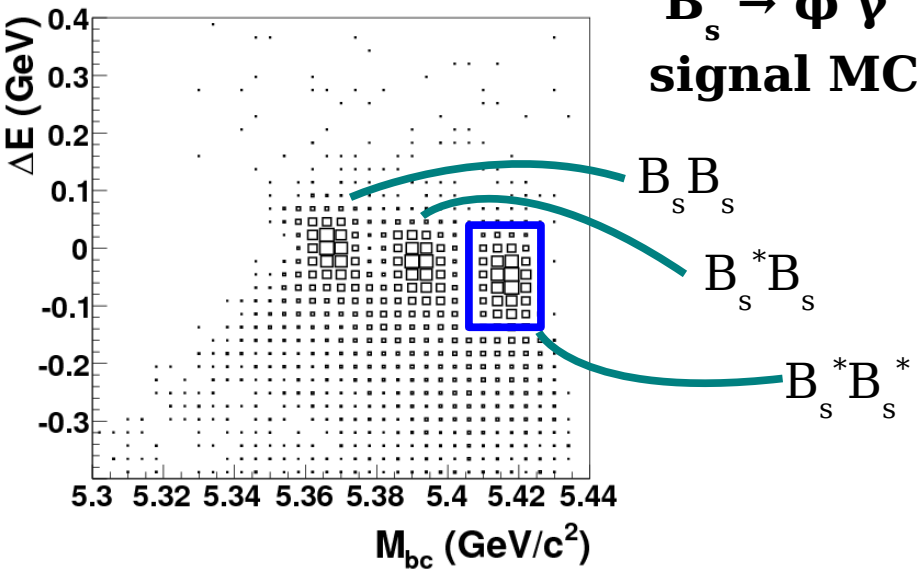


Methods: B_s selection

- **Standard "B-factory" analysis techniques:**
  B_s selected using the $\mathbf{M_{bc}}$ (M_{ES}) and $\mathbf{\Delta E}$ variables:
  Very difficult to fully reconstruct $\mathbf{B_s^*}$: de-excitation γ too soft.

$$M_{\rm bc} = \sqrt{(E^{\rm CM}_{\rm beam})^2 - (p^{\rm CM}_{B^0_s})^2}$$
$$\Delta E = E^{\rm CM}_{B^0_s} - E^{\rm CM}_{\rm beam}$$

Beam energy: 5.44 GeV at Υ(5S)



Signal from $B_s^*B_s^*$ peaks at
$M_{bc} = m_{Bs^*} \approx 5.42$ GeV/c^2 and
$\Delta E = m_{Bs} - m_{Bs^*} \approx -50$ MeV.

- **Main background is continuum:** $e^+e^- \to \{u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}\}$

$B_s \to \phi\,\gamma$ and $B_s \to \gamma\,\gamma$

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

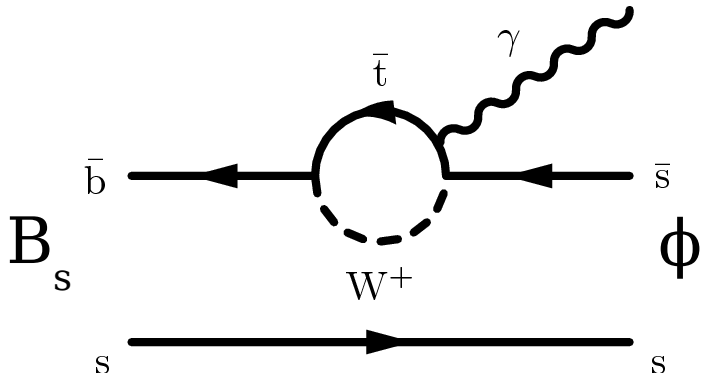
Penguin decays involve loop diagrams

Good probe for New Physics:
new particles can move observables away from their SM expectations

$B_s \to \phi \gamma$

- Standard Model: electromagnetic penguin
  BF=(40±10)x10^{-6}

  Ball, Jones, Zwicky, PRD 75, 054004 (2007)
  Ali, Pecjak, Greub, arXiv:0709.4422 (2007)

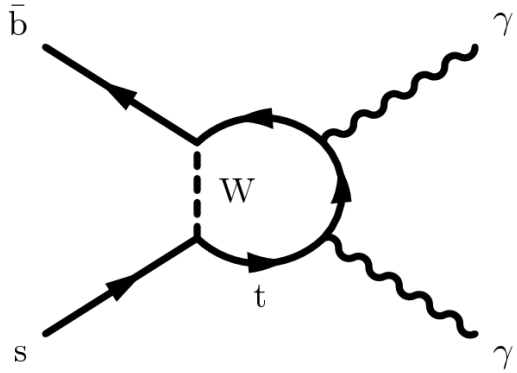


- We do not really expect to see NP in the rate; good agreements in:
  - Partner of $B^{+/0} \to K^*(892)^{+/0} \gamma$
  - Inclusive $b \to s \gamma$

$B_s \to \gamma \gamma$

- SM: annihilation penguin
  BF=(0.5-1.0)x10^{-6}

  Reina, Riccardi, Soni, PRD 56, 5805 (1997)
  Bosch, Buchalla, JHEP 0208 054 (2002)



- Very sensitive to NP!
  SUSY with broken R-parity

  Gemintern, Bar-Shalom, Eilam, PRD 70, 035008 (2004)

  4th quark generation

  Huo, Lu, Xiao, arXiv:hep-ph/0302177 (2003)

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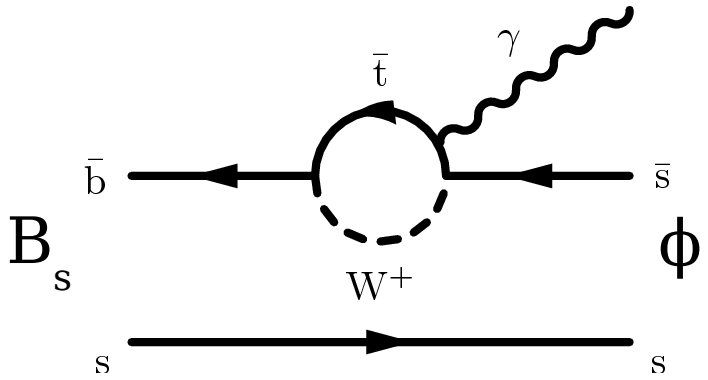

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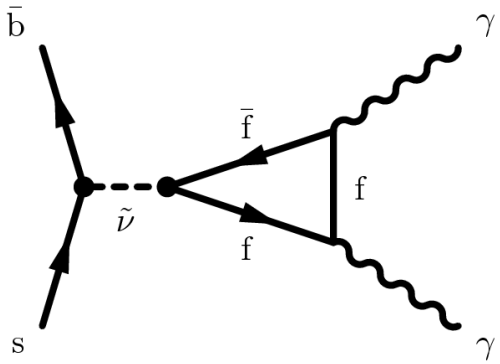

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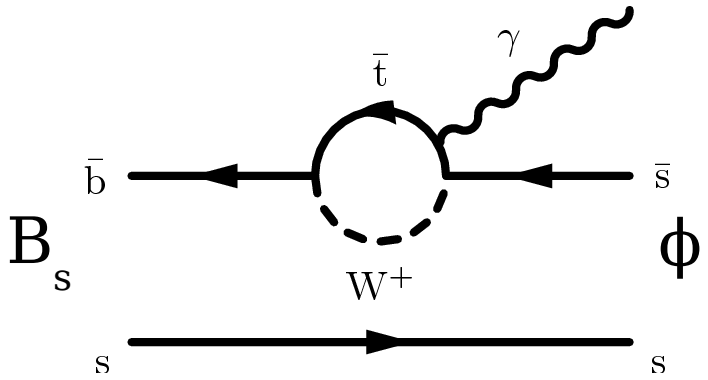

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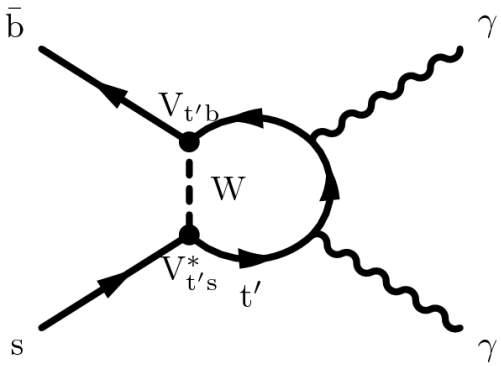

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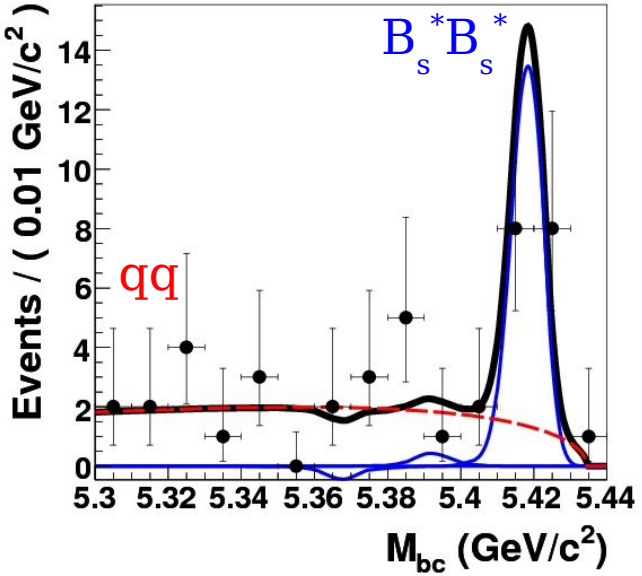
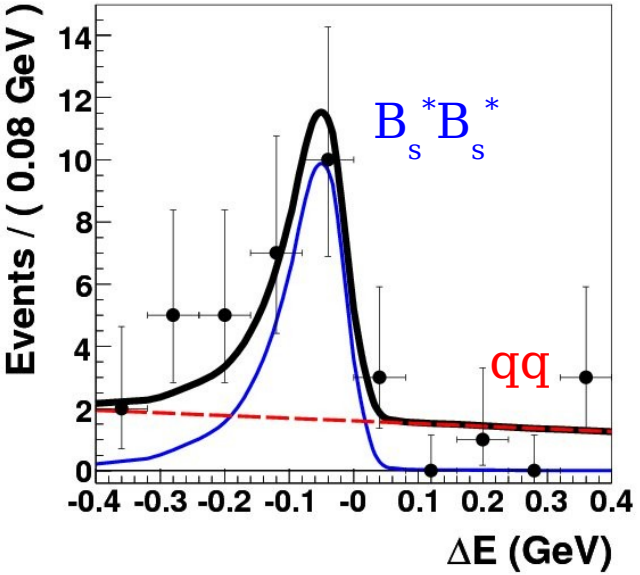
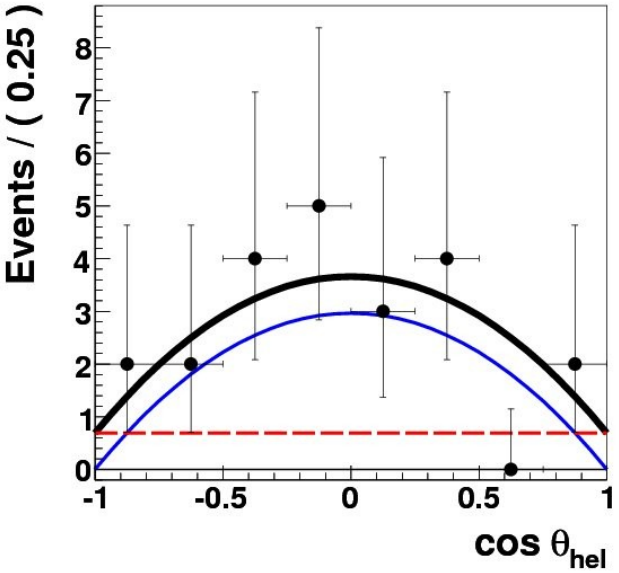
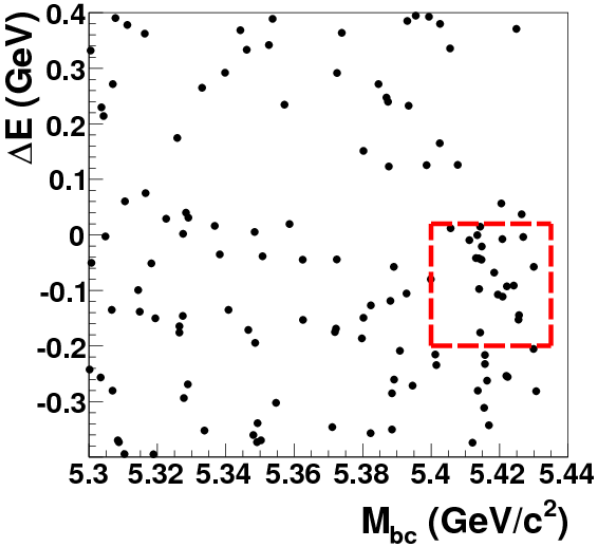
Result: $B_s \to \phi\gamma$







$\theta_{hel} = \sphericalangle(B_s, K^+)$ in ϕ CM



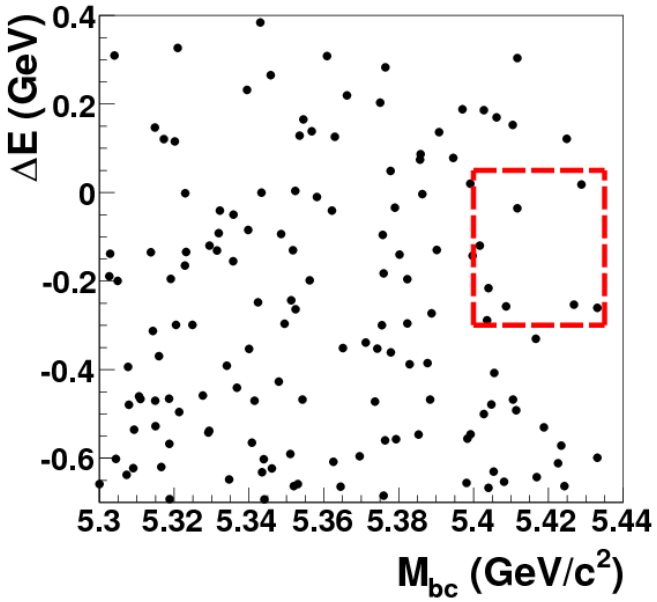
First observation of a B_s radiative penguin decay!

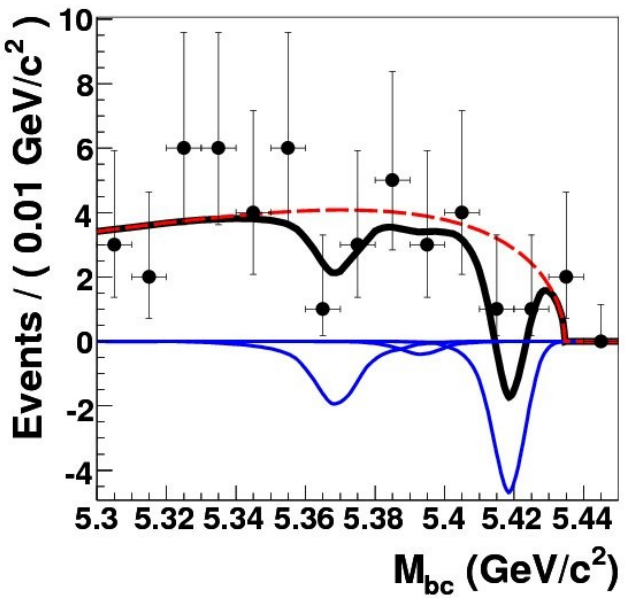
18±6 signal events

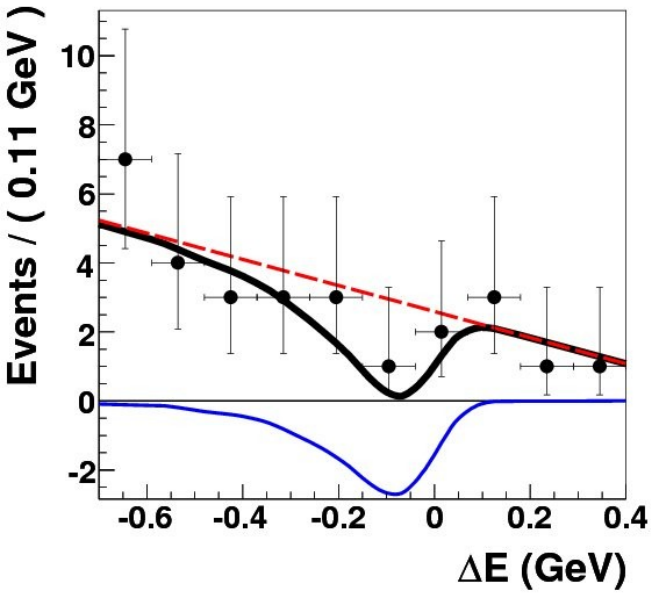
$$\mathcal{B}(B_s^0 \to \phi\gamma) = (57^{+18+12}_{-15-11}) \times 10^{-6}$$

compatible with SM

Result: $B_s \to \gamma\gamma$







No signal!

$$\mathcal{B}(B_s^0 \to \gamma\gamma) < 8.7 \times 10^{-6}\ (90\%\ \mathrm{CL})$$

~6x lower than previous limit (Belle, 2fb^{-1} at Υ(5S))
~10x higher than SM!
Above the interesting NP region!

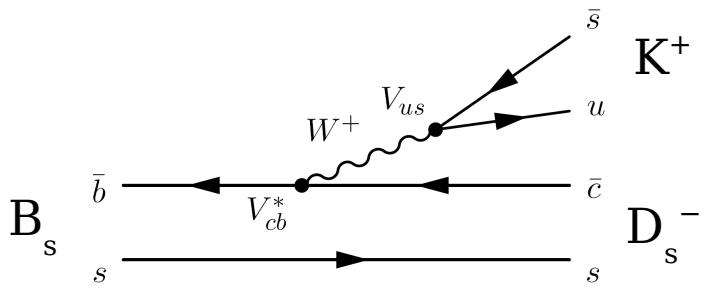
Need a Super B factory!

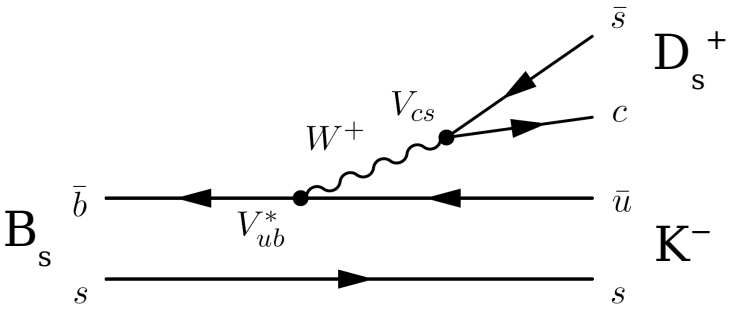
$B_s \to D_s \pi$ and $B_s \to D_s K$

preliminary results contributed to LLWI 2008

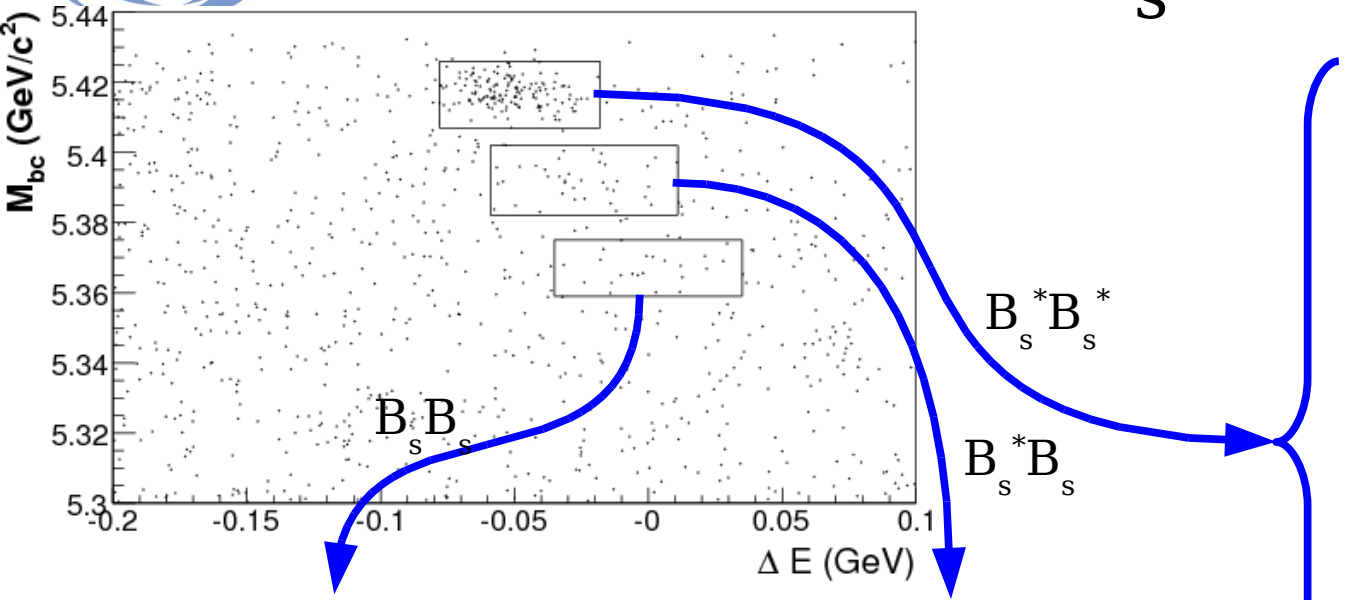
$B_s \to D_s \pi/K$

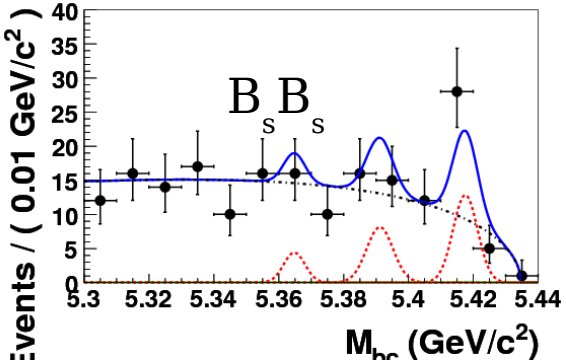
- **$B_s \to D_s \pi$**
  - Hadronic B_s decay mode with the largest BF
    - Measure B_s and B_s^* masses
    - Measure $B_s^{(*)}B_s^{(*)}$ production fractions at the $\Upsilon(5S)$
    - Help hadron collider experiments to normalize their B_s BF
- **$B_s \to D_s K$**
  - Cabibbo-suppressed decay: BF ~10x smaller than $D_s \pi$.
  - Two interfering diagrams: $b \to c$ and $b \to u$ **⇒ access φ_3 (γ)!**

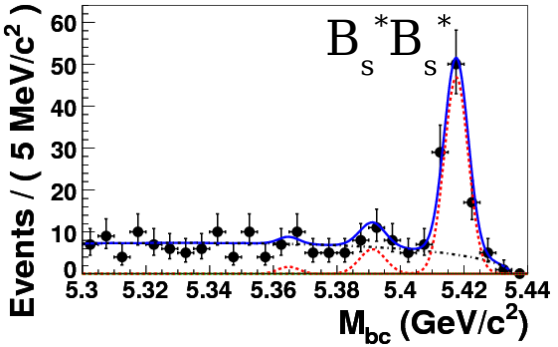


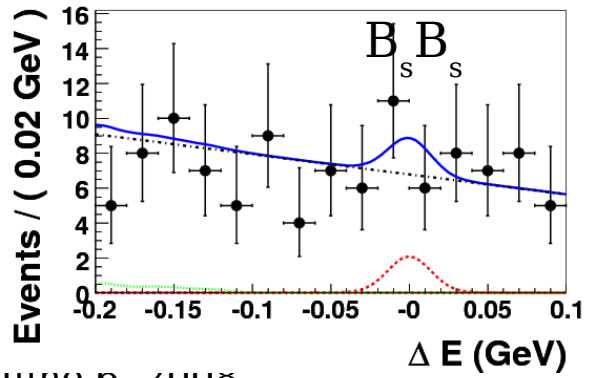


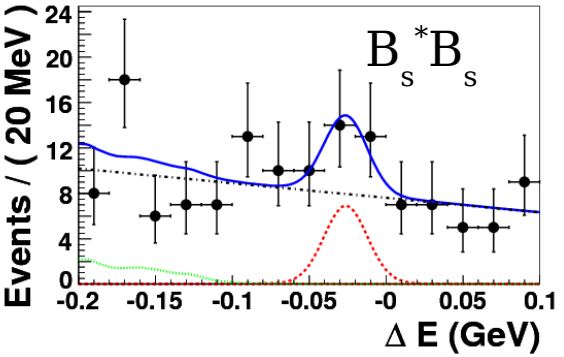
Results: $B_s \to D_s \pi$

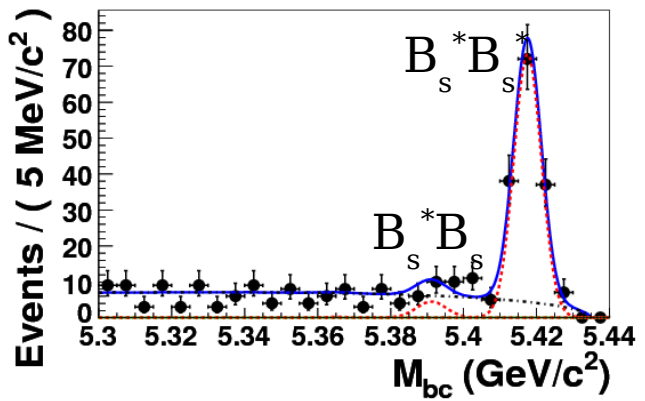


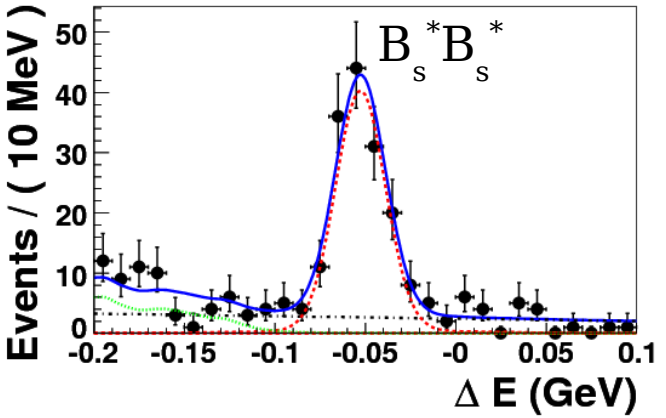












Projections

>10σ $B_s^*B_s^*$
2.9σ $B_s^*B_s$
0.1σ B_sB_s

Results: $B_s \to D_s \pi$

We measure: $\mathcal{B}(B_s \to D_s\pi) = (3.41^{+0.33+0.70}_{-0.31-0.67}) \times 10^{-3}$

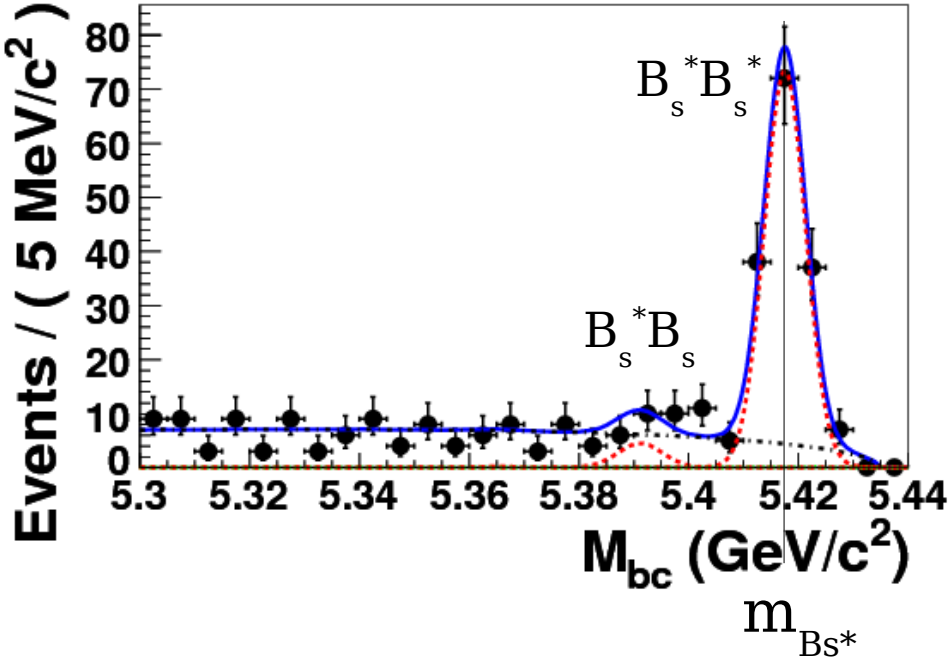
$f_{B_s^* B_s^*} = (89.8^{+3.8}_{-4.0})\%$ ⟷

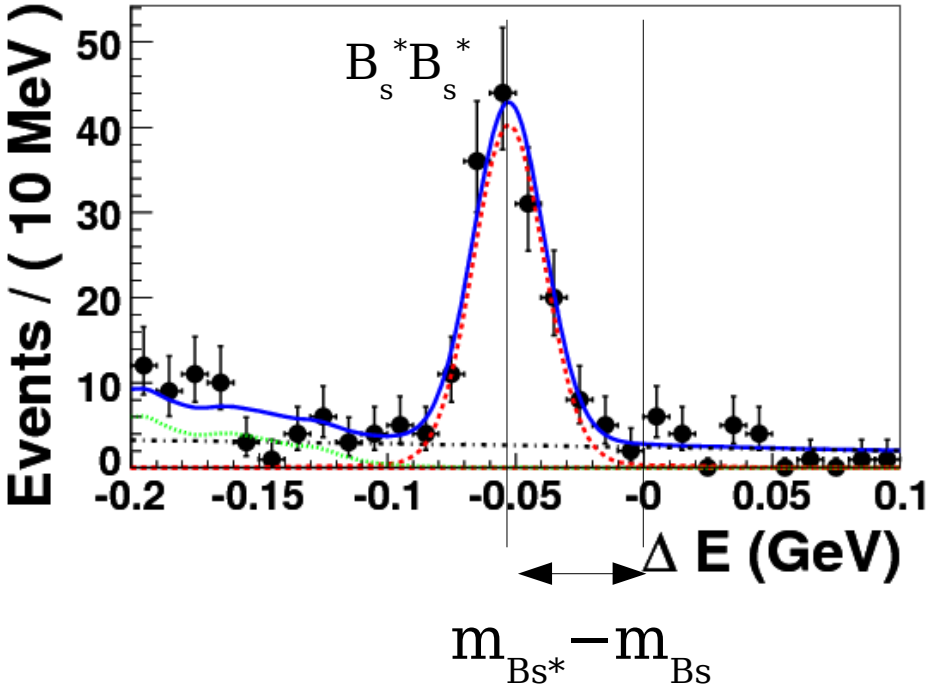
$f_{B_s^* B_s} = (7.8^{+3.3}_{-3.0})\%$

Heavy-quark effective theory or unitarized quark model predict ~70%. Why?

Grozin, Neubert, PDR 55, 272 (1997)

Tornqvist, PRL 53, 878 (1984)



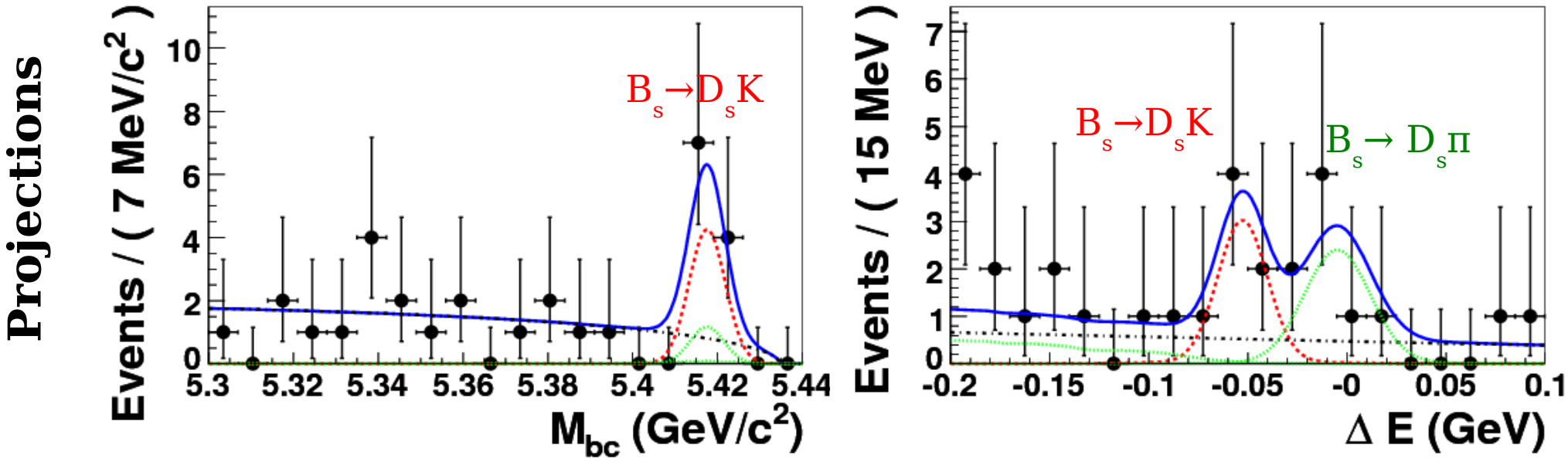


$m_{B_s} = (5364.8 \pm 1.3 \pm 2.4)\ \mathrm{MeV}/c^2$

$m_{B_s^*} = (5417.6 \pm 0.4 \pm 0.5)\ \mathrm{MeV}/c^2$

Results: $B_s \to D_s K$

Only $B_s^* B_s^*$ signal is considered



3.7σ signal

$$N(B_s \to D_s K) = 6.8^{+3.4}_{-2.7}$$

$$\mathcal{B}(B_s \to D_s K) = (2.2^{+1.1}_{-0.9} \pm 0.5) \times 10^{-4}$$

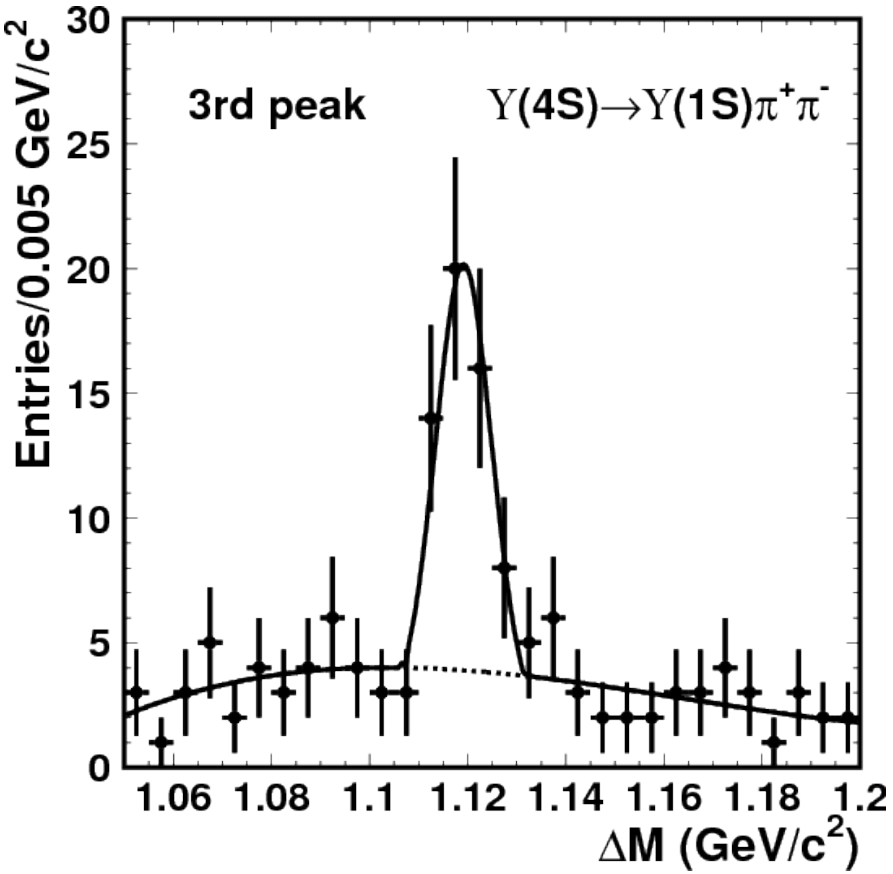
$$\frac{\mathcal{B}(B_s \to D_s K)}{\mathcal{B}(B_s \to D_s \pi)} = (6.5^{+3.3}_{-2.7})\%$$

$\Upsilon(5S) \to \Upsilon(nS)\,\pi\pi$
$\hookrightarrow \mu\mu$

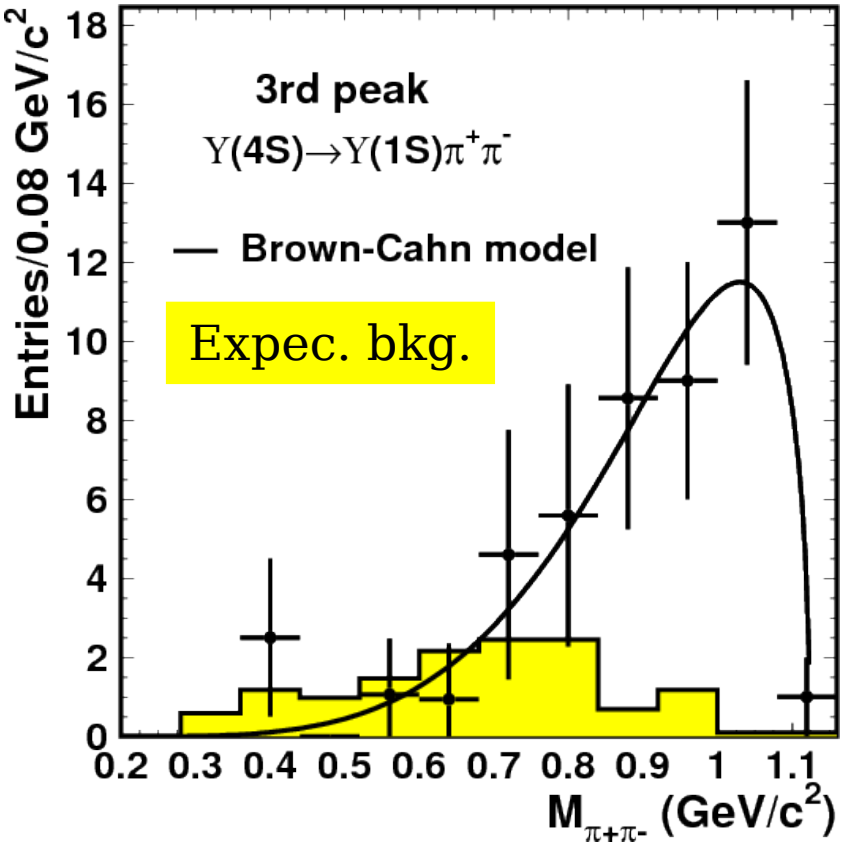
K.-F. Chen et al. (Belle), PRL 100, 112001 (2008)

Extrapolations from $\Upsilon(4S)$

Belle with 477 fb^{-1}: A. Sokolov et al., PRD 071103 (2007)



~40 events observed

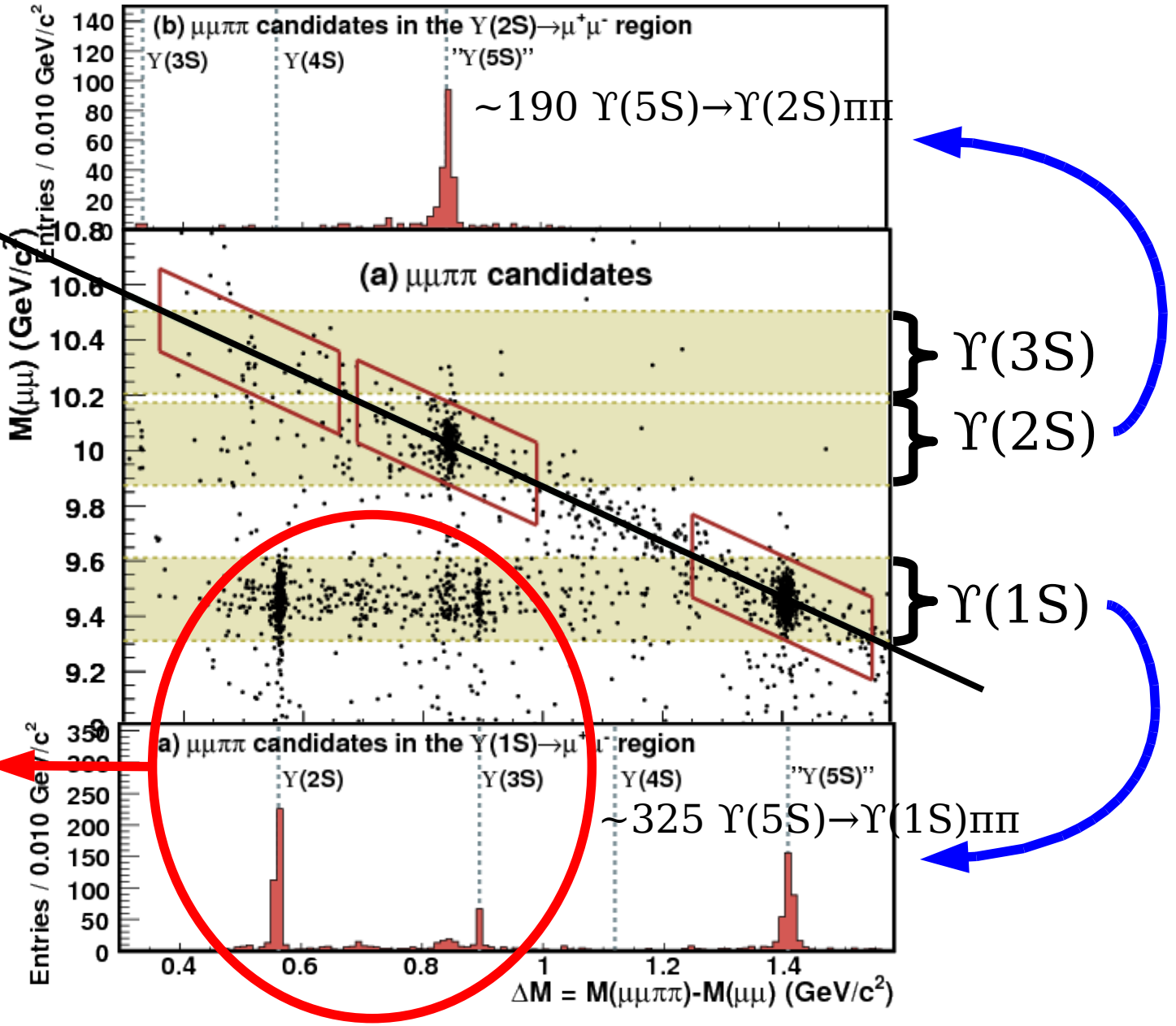


Compatible with some theoretical model

⇒ expect nothing with 20 fb^{-1} at $\Upsilon(5S)$

Results: huge signals!

M(μμππ)=E$_{CM}$

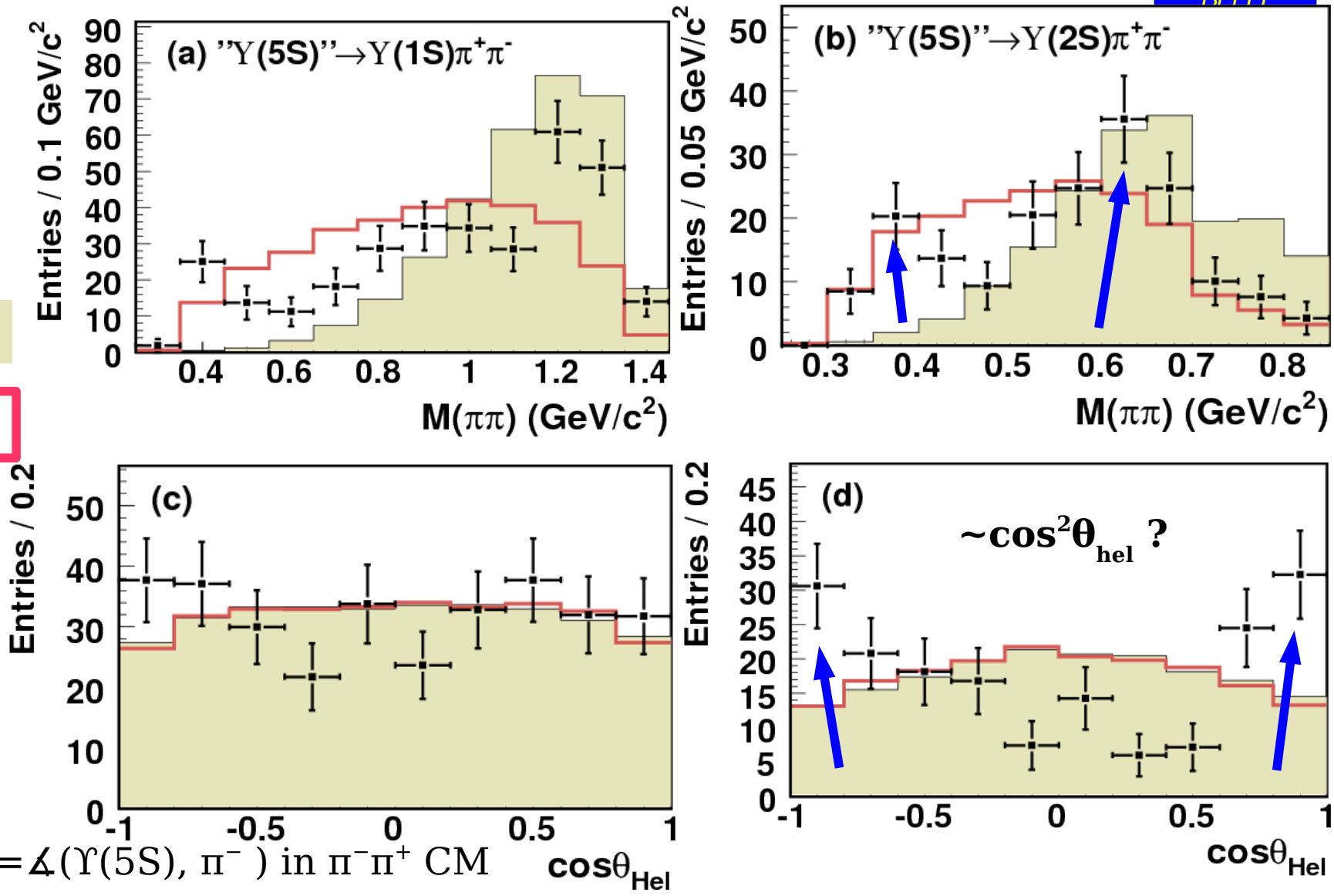


Radiative return
Ex: Υ(5S) → Υ(4S)γ

Results: distributions

Brown-Cahn

phase-space



θ_{hel} = ∠(Υ(5S), π^-) in $\pi^-\pi^+$ CM

Moreover, models don't well really agree with data

Rates and interpretation

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
"$\Upsilon(5S)$" $\to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

Rates of Υ(nS) → Υ(1S) π π

More than 100 times larger!

- Can the Υ(5S) (1^{--} bb state) have such rate? "Maybe yes" ↴

Meng, Chao, PRD 77, 074033 (2008)

Simonov, JETP Lett. 87, 121 (2008)

- But this could also be a new Y_b particle!
  - The "b" analogous to many Y_c particles that decay to ψ({1,2}S) π π

Hou, PRD 74, 017504 (2006)

- December 2007: **energy scan**
  - **~Υ(5S) → ~Υ(6S)**
    - Look at the Υ({1,2}S)ππ distributions
      - **Results soon!**

Belle Discovers More "New Particles"

A Y_b state ?: Observation of an anomalously large rate for "Upsilon(5S)" → Upsilon(1,2S) $\pi^+\pi^-$
K.F.Chen et al., PRL 100, 112001 (2008) (arXiv:0710.2577)

Z(4430): A *charged* charmonium-like resonant structure
S.K. Choi, S.L. Olsen et al., PRL 100, 142001 (2008) (arXiv:0708.1790)
Press release (English , Japanese) CERN Courier article

Y(4660): X. L. Wang et al, PRL 99, 142002 (2007) (arXiv:0707.3699)

Y(4008): C.Z. Yuan et al, PRL 99, 182004 (2007) (arXiv:0707.2541)

X(4160): P. Pakhlov et al., arXiv:0708.3812 (to appear in PRL)

psi(4415)->DD_2: G.Pakhlova et al, PRL 100, 062001 (2008) (arXiv:0708.3313)

D_{sJ}(2700): J. Brodzicka et al., PRL 100, 092001 (2008) (arXiv:0707.3491)

Semileptonic B_s decays

$B_s \to X^- l^+ \nu$

Preliminary results contributed to EPS 2007
arXiv:0710.2548 [hep/ex]

$B_s \to X^- l^+ \nu$

- Using same sign D_s tag: $\Upsilon(5S) \to B_s^0 \bar{B}_s^0$

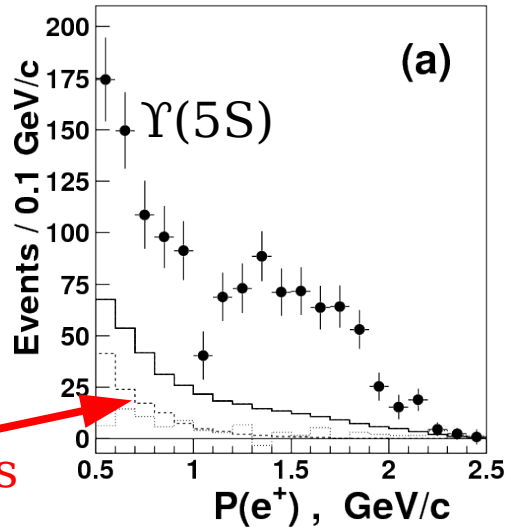
$$B_s^0 \to X l^+ \bar{\nu}$$

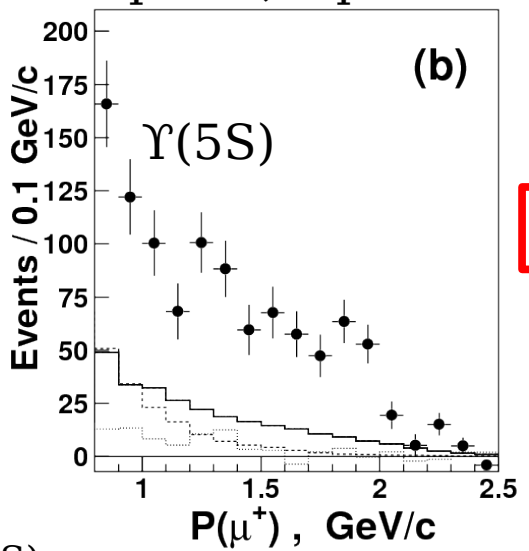
$$\bar{B}_s^0 \xrightarrow{50\%\ \text{mix}} B_s^0 \to Y D_s^+$$

- It makes backgrounds small and reducible:
  1. BB: low prob for B^0 mixing (subtracted using Υ(4S) data)
  2. Continuum is small (subtracted using continuum data)
  3. Other bkgs subtracted using MC: mis-id leptons, leptons from J/ψ, ...

electrons

backgrounds



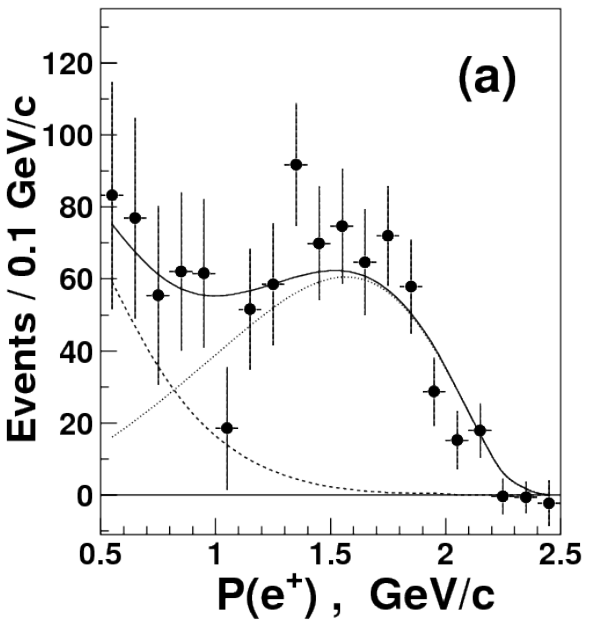


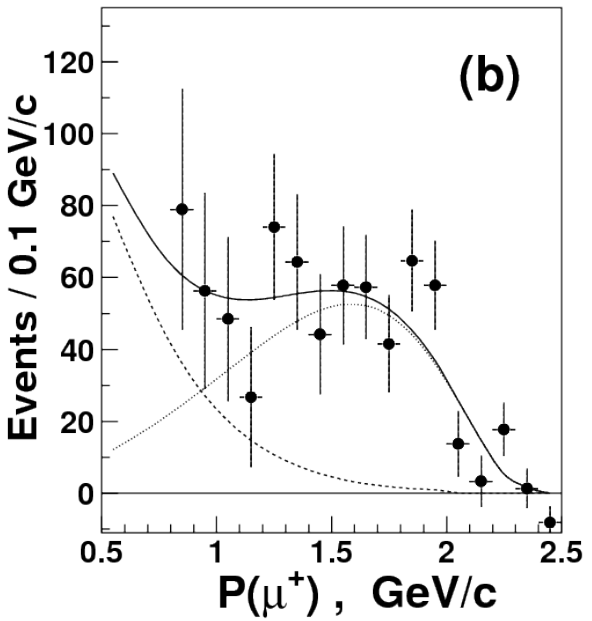
muons

Results: $B_s \to X^- l^+ \nu$

- Disentangle with a fit: primary leptons (signal, high momentum) and secondary leptons (ex.: $B_s \to D_s^+(l^+)$, low momentum)

electrons





muons

- We measure:

$$\mathcal{B}(B_s^0 \to X^- e^+ \bar{\nu}) = (10.9 \pm 1.0 \pm 0.9)\%$$
$$\mathcal{B}(B_s^0 \to X^- \mu^+ \bar{\nu}) = (9.2 \pm 1.0 \pm 0.8)\%$$
$$\mathcal{B}(B_s^0 \to X^- l^+ \bar{\nu}) = (10.2 \pm 0.8 \pm 0.9)\%$$

- Good agreement with PDG: $\mathcal{B}(B^0 \to X^- l^+ \bar{\nu}) = (10.33 \pm 0.28)\%$

Conclusion

- With a 24 fb^{-1} data sample recorded at the $\Upsilon(5S)$, Belle has obtained many interesting results:
  - **$B_s \to D_s \pi$**: study of the decay $\to m_{Bs}$, m_{Bs^*}, $B_s^{(*)}B_s^{(*)}$ production fractions
  - **$B_s \to D_s K$**: evidence for this interesting mode
  - **$B_s \to \phi\gamma$**: first observation of a radiative Penguin decay of the B_s meson
  - **$B_s \to \gamma\gamma$**: best upper limit, observation only possible at an e^+e^- collider!
  - **$B_s \to X^- l^+ \nu$**: first measurement of the inclusive semileptonic decay of the B_s
  - **$\Upsilon(5S) \to \Upsilon(nS)\pi\pi$**: should we really speak of a 5S resonance?
    - Results of the scan for this summer!