Recent Belle Results

Brookhaven Forum, May 26-28, 2010

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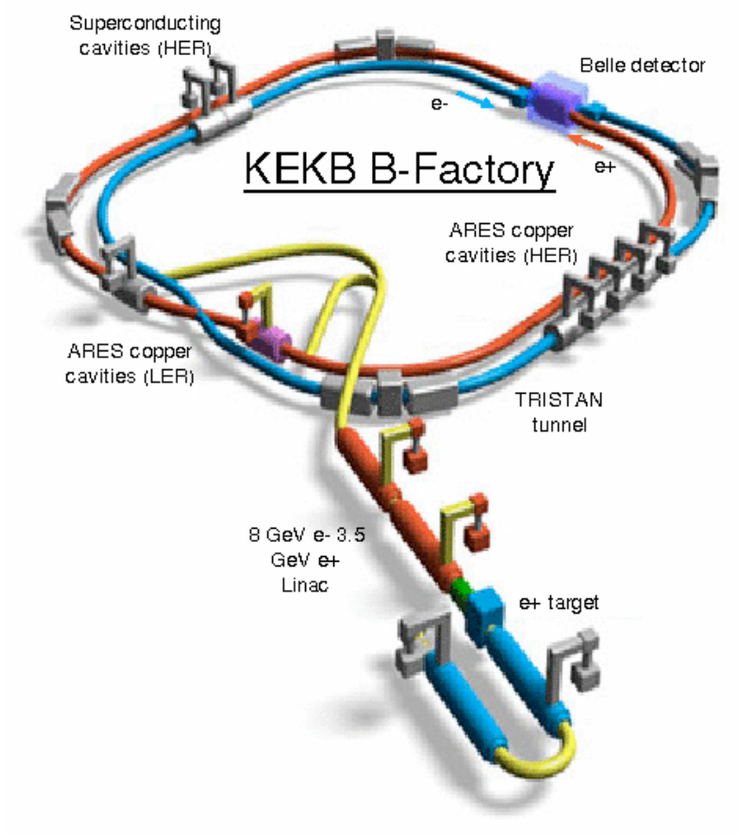
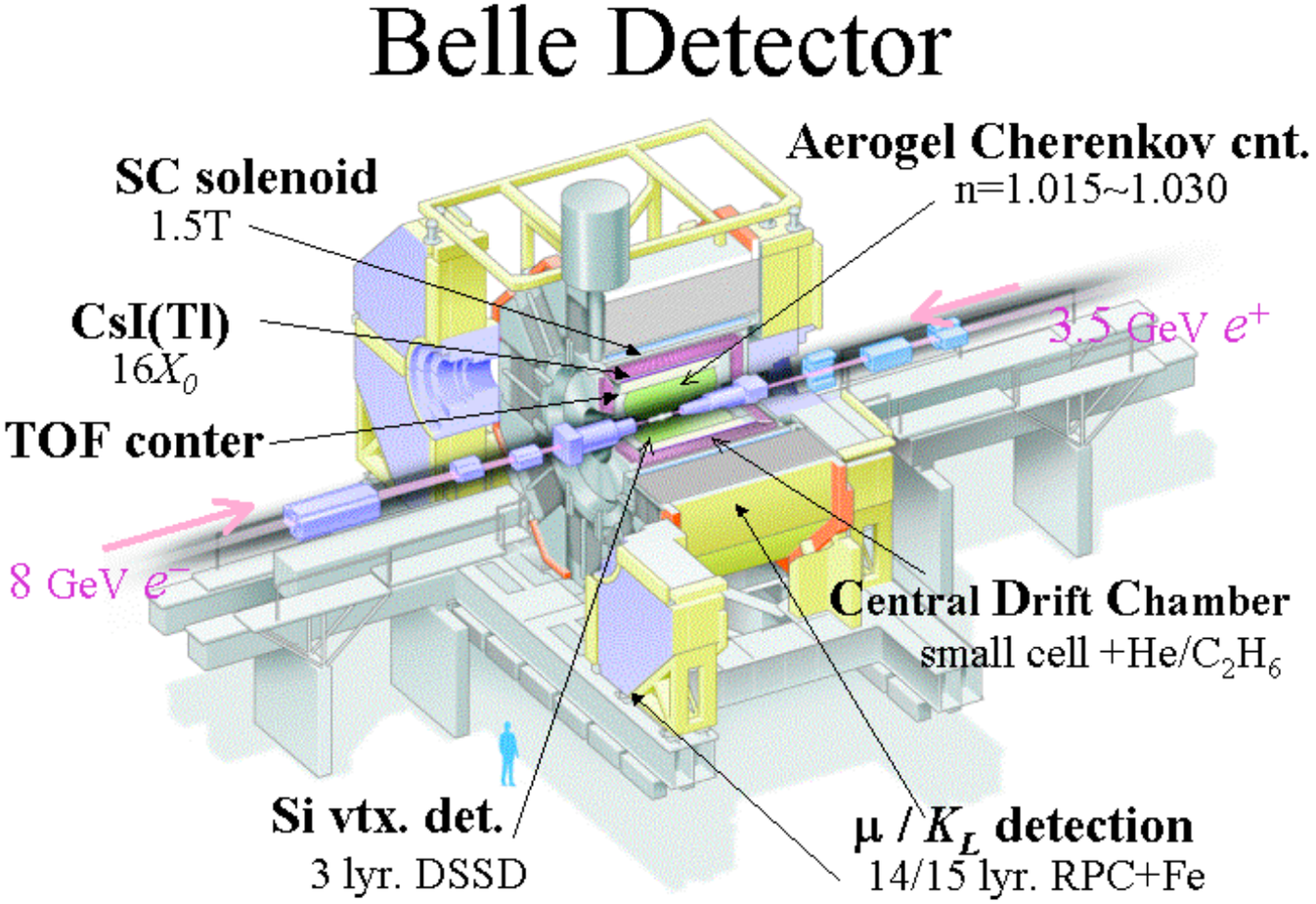
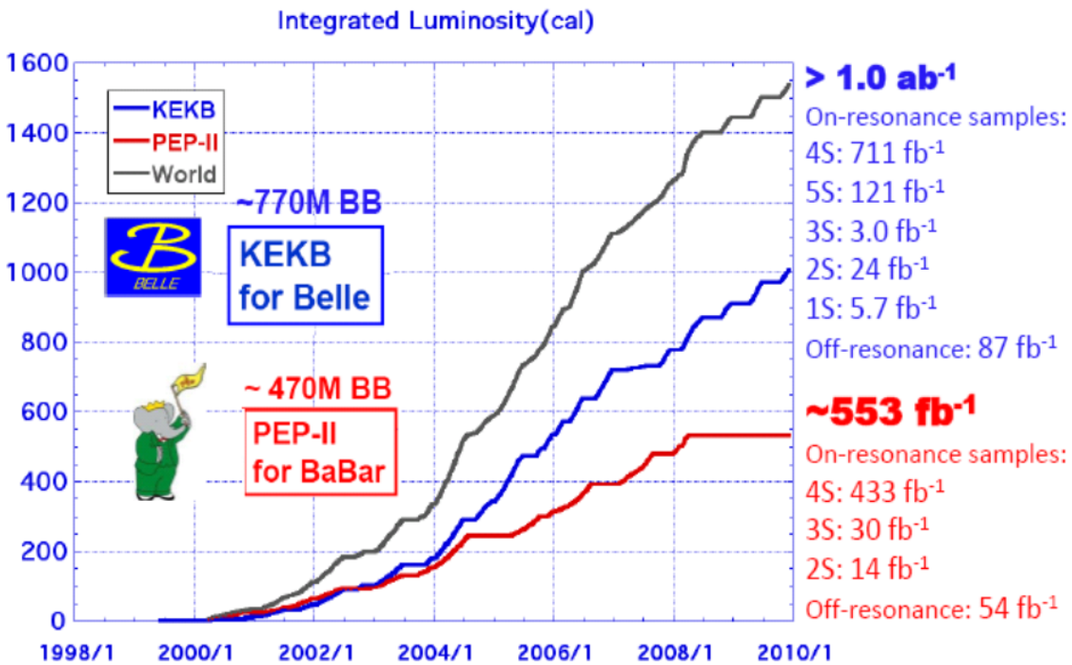
Virginia Tech
on behalf of the Belle Collaboration

Belle Experiment





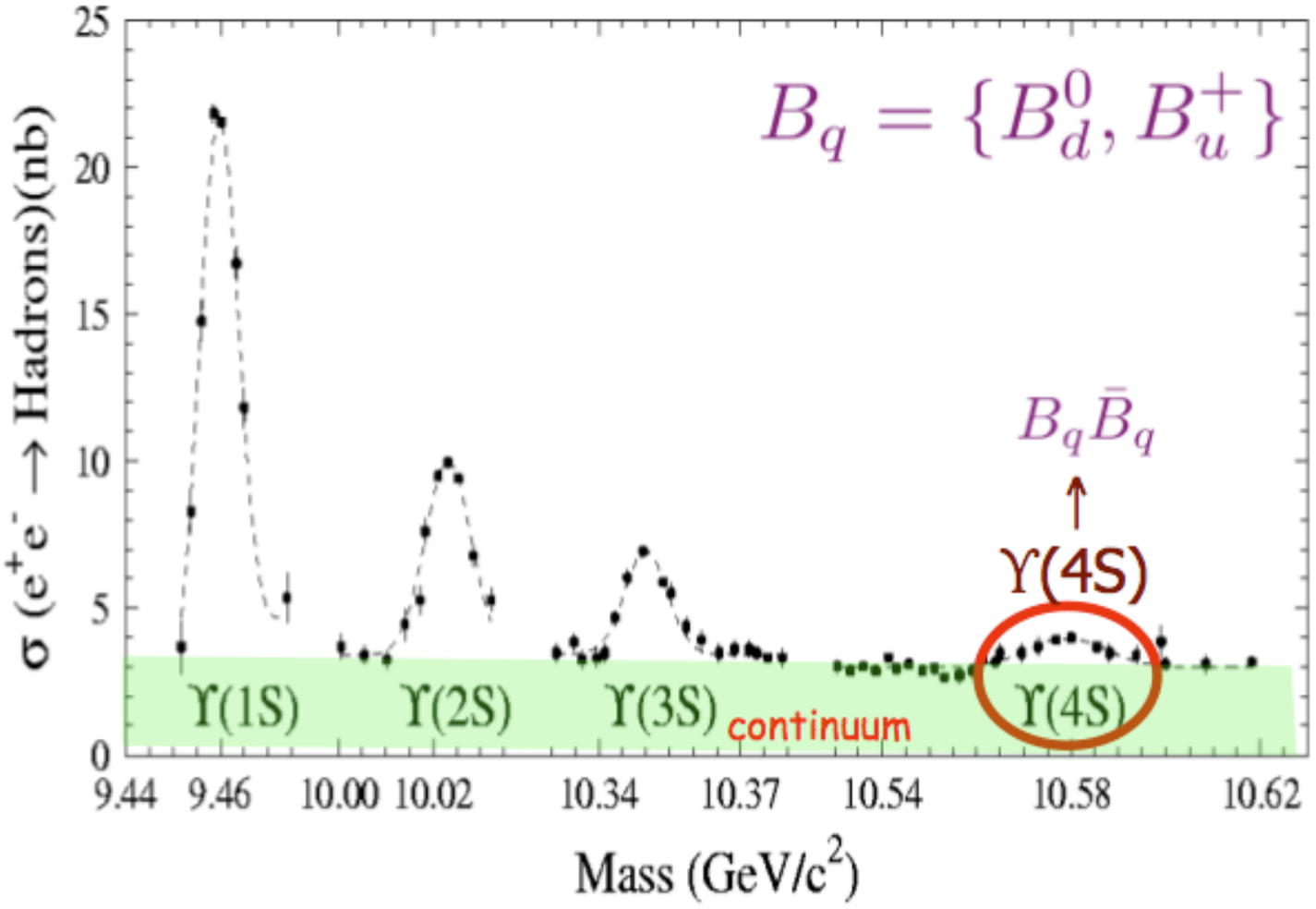


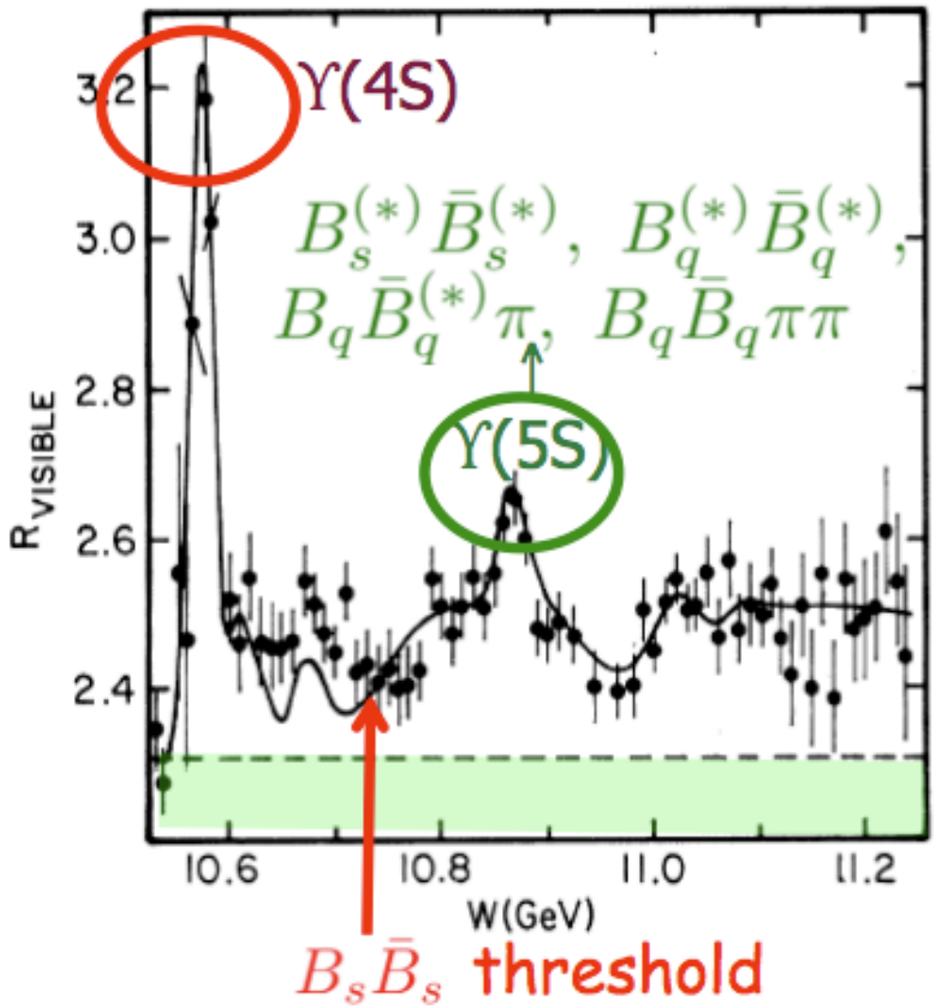
Data samples for this talk:

605 fb^{-1} at $\Upsilon(4s)$

and 23.6 fb^{-1} at $\Upsilon(5s)$

Recent Belle Results



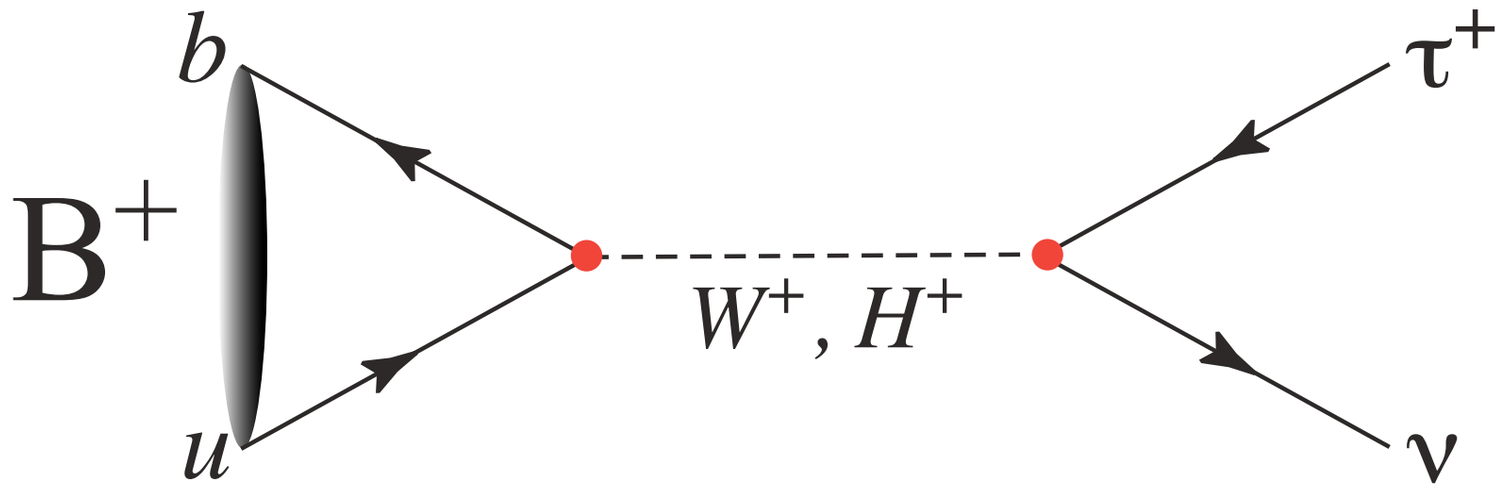


- Measurement of $B^- \to \tau^- \bar{\nu}_\tau$ decay with semileptonic tag
- Observation of $B^+ \to \bar{D}^{*0}\tau^+\nu$ and evidence for $B^+ \to \bar{D}^0\tau^+\nu$
- Observation of $B_s^0 \to D_s^{*-}\pi^+$ and $B_s^0 \to D_s^{(*)-}\rho^+$
- $\frac{\Delta\Gamma_s}{\Gamma_s}$ from $B_s^0 \to D_s^{(*)+}D_s^{(*)-}$

$B \to \tau\nu$

hep-ex/0809.3834

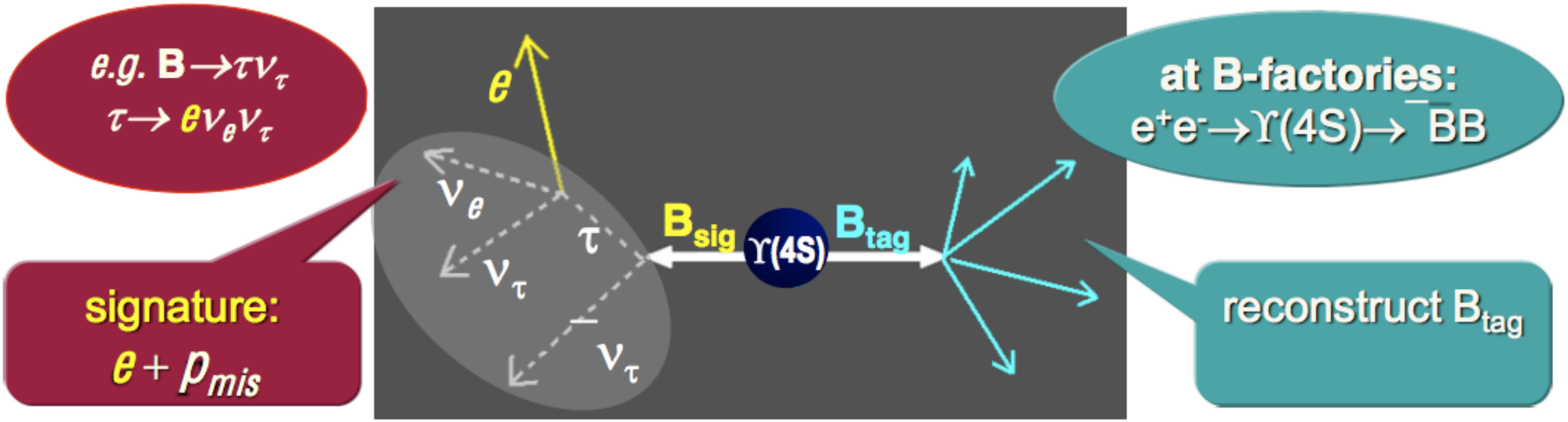
$B \to \tau\nu$



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 {f_B}^2 \left|V_{ub}\right|^2 \tau_B$$

- Purely leptonic decay through W annihilation
- Sensitive to New Physics, e.g. extended Higgs sector
- Physics beyond the SM could suppress or enhance $B \to \tau\nu$ BF via charged Higgs.
- Direct experimental determination of f_B

$B \to \tau\nu$ Analysis Method

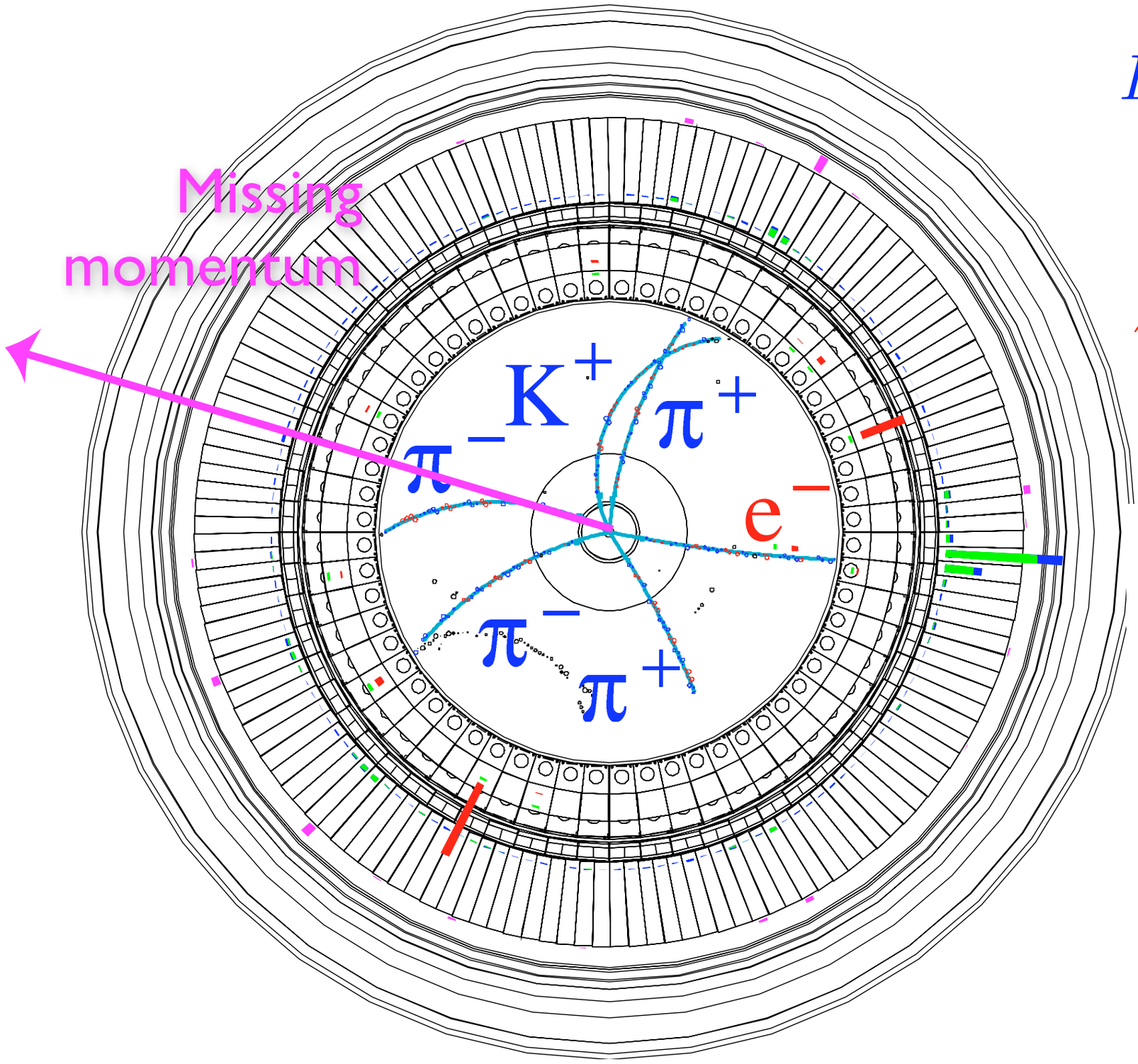


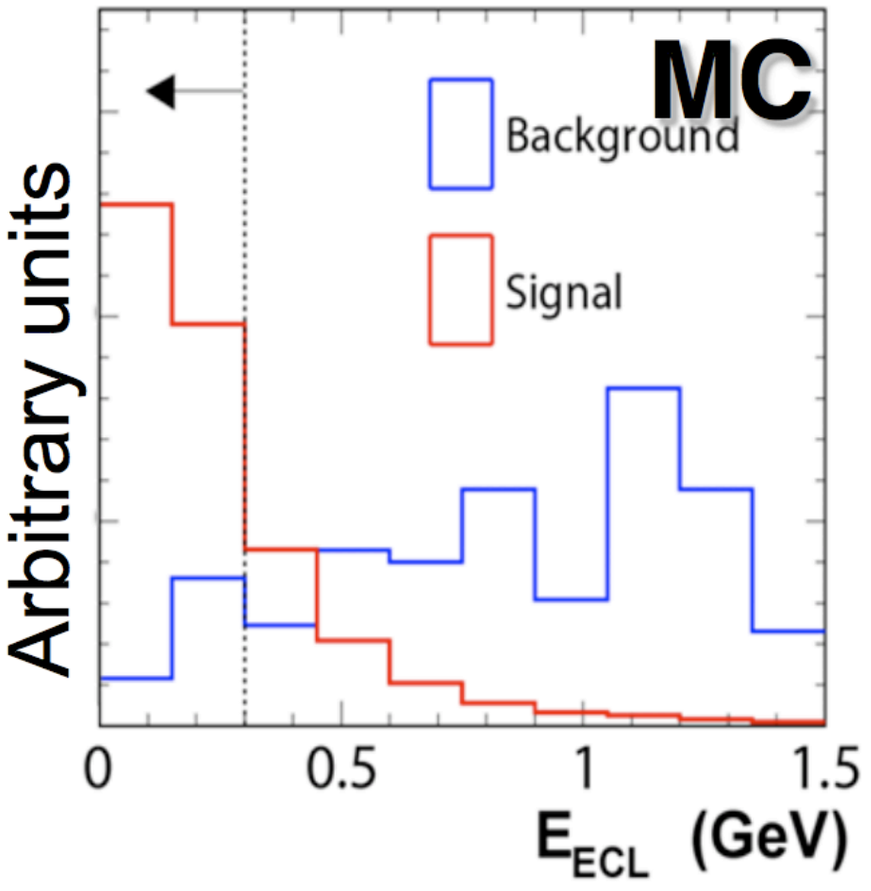
- Reconstruct either hadronic $B^+ \to \bar{D}^{*0} X^+$ or semileptonic $B^+ \to \bar{D}^{*0} \ell \nu_\ell$
  - $\bar{D}^{*0} \to \bar{D}^0 \pi^0$ and $\bar{D}^{*0} \to \bar{D}^0 \gamma$
  - $\bar{D}^0 \to K^+ \pi^-$, $\bar{D}^0 \to K^+ \pi^- \pi^0$ and $\bar{D}^0 \to K^+ \pi^- \pi^+ \pi^-$
- Search for recoil signal $B^- \to \tau^- \bar{\nu}_\tau$
  - $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$
  - $\tau^- \to \pi^- \nu_\tau$

$B \to \tau\nu$ Candidate Event

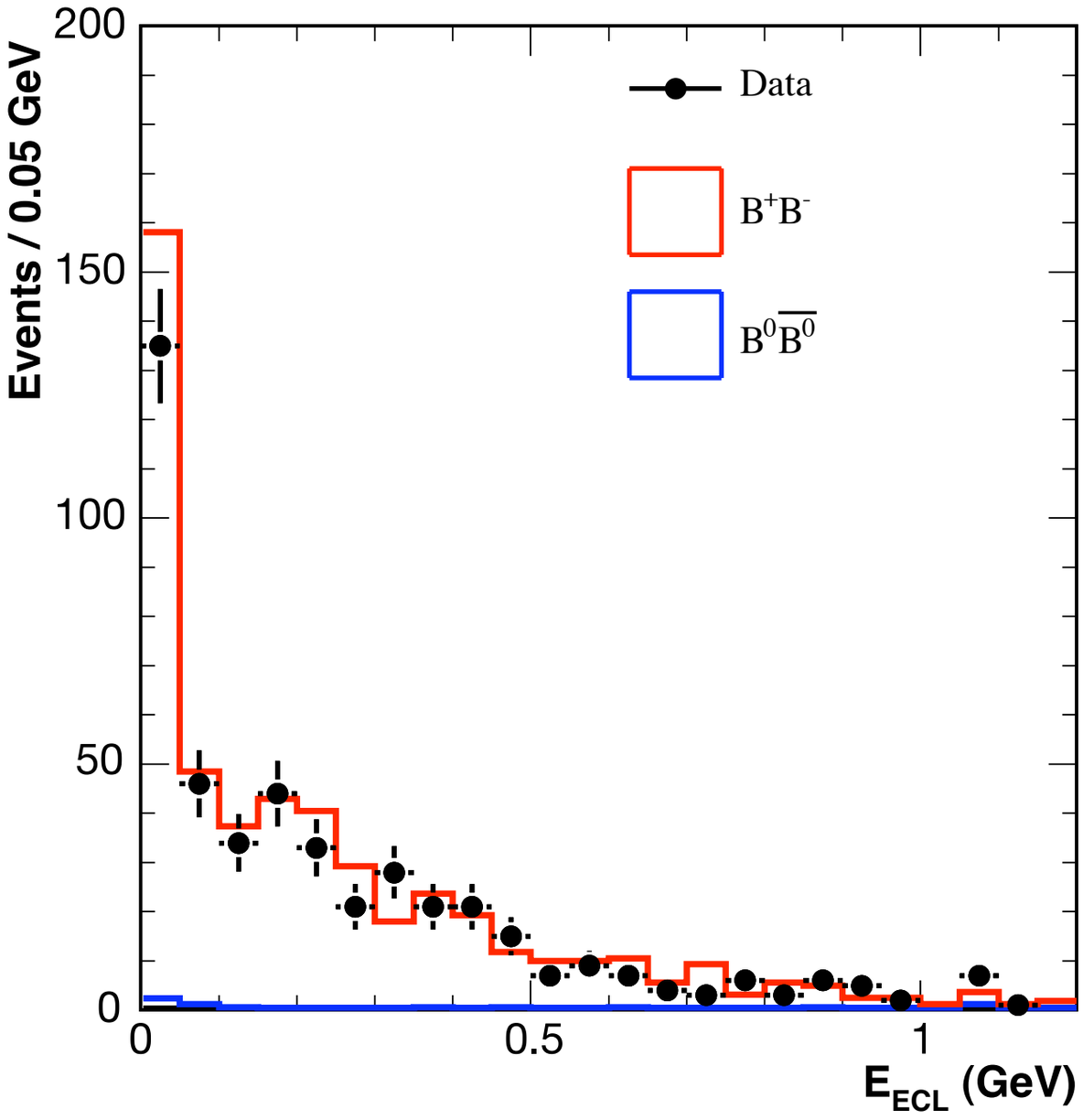
$$B^+ \to \bar{D}^0\pi^+$$
$$\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$$

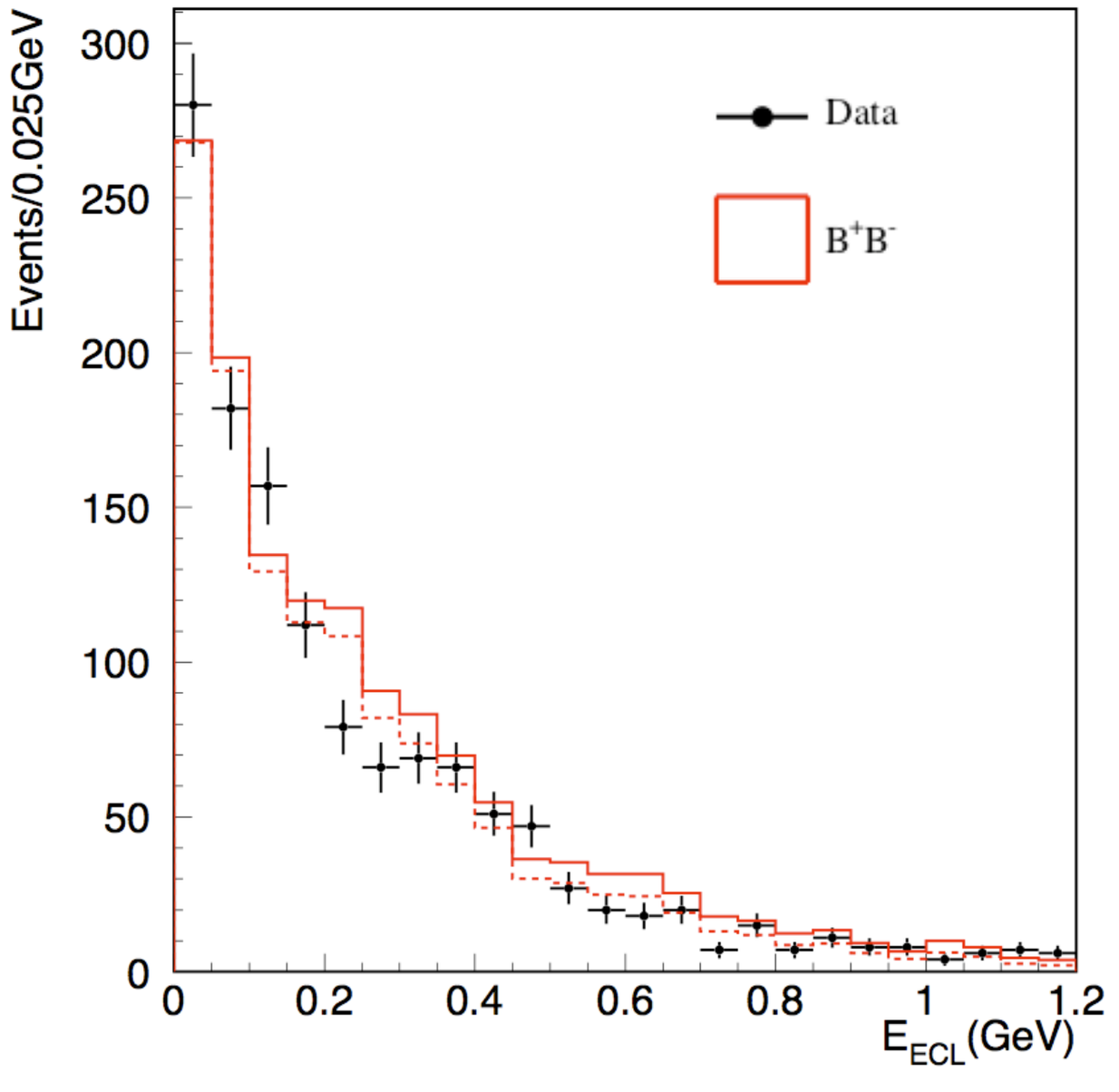
$$\tau^- \to e^-\bar{\nu}_e\nu_\tau$$



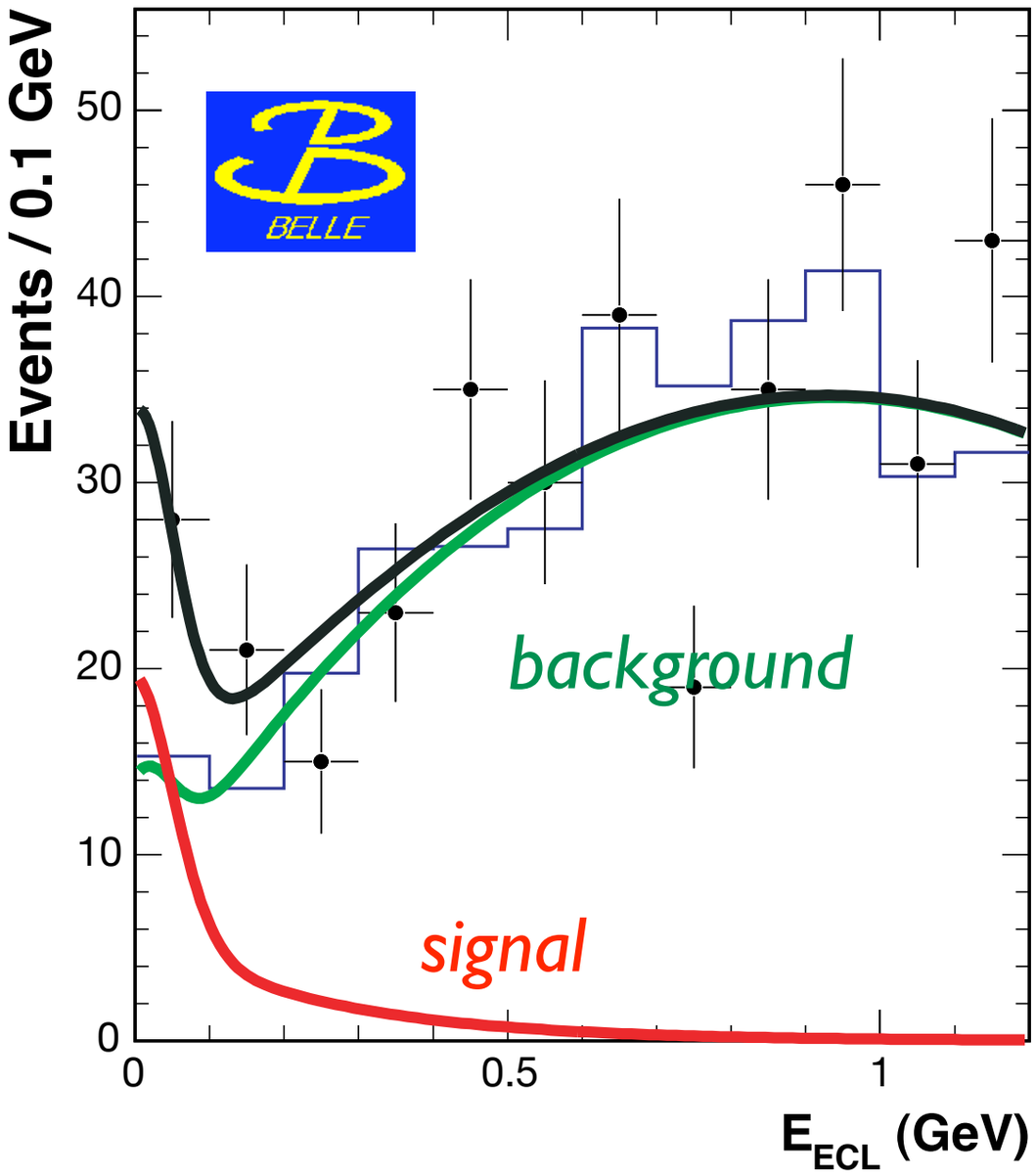


Validation of the ECL simulation using double tagged events (with $B \to D^{(*)}\ell\nu$ on the "signal" side)





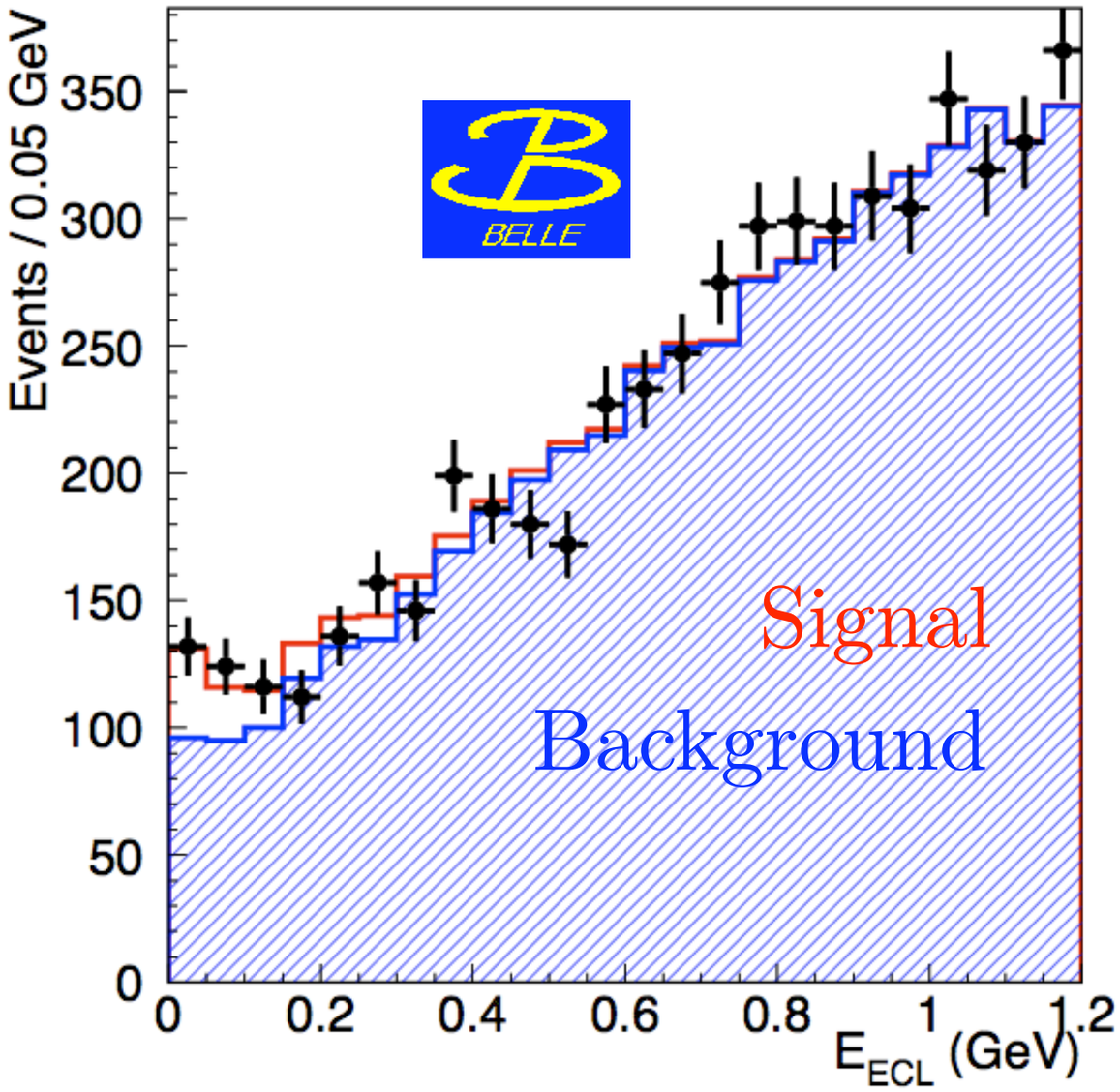
$B \to \tau\nu$ results with Hadronic Tag



- First evidence
- $449 \times 10^6 B\overline{B}$
- PRL **97**, 251802 (2006)

- $17.2^{+5.3}_{-4.7}$ signal events from a fit of 54 events
- Significance 3.5σ (incl. systematics)
- $\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = 1.79^{+0.56+0.46}_{-0.49-0.51} \times 10^{-4}$

$B \to \tau\nu$ results with Semileptonic Tag



To be submitted

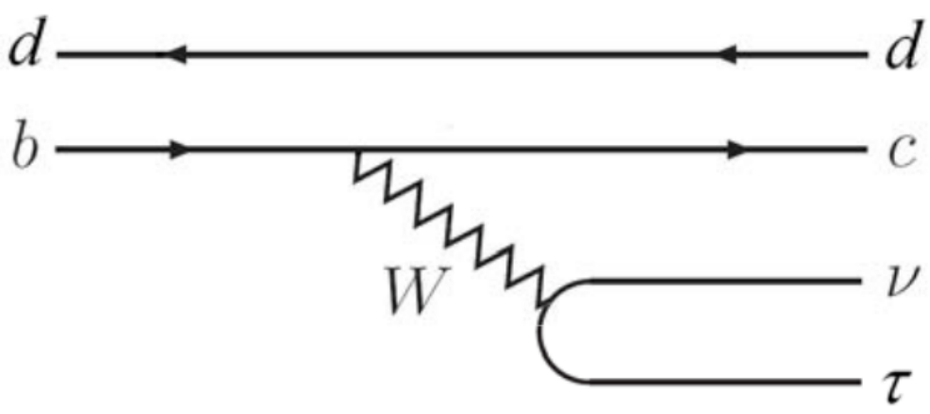
$657 \times 10^6 B\overline{B}$

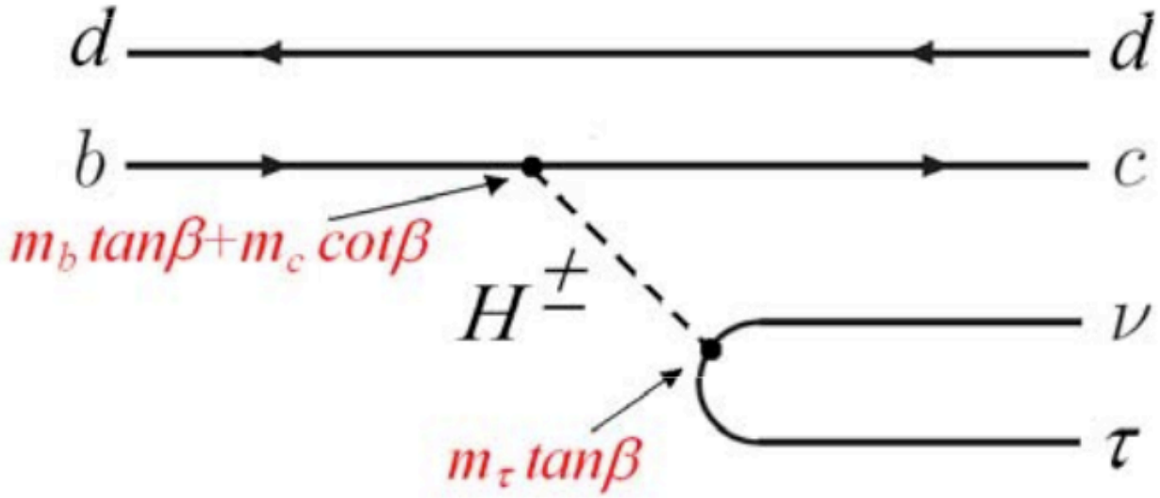
- $154^{+36}_{-35}(stat)^{+20}_{-22}(syst)$ signal events
- Significance: 3.8σ (incl. systematics)
- $\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = (1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$

$B \to D^{(*)} \tau \nu$

hep-ex/1005.2302
submited to PRL

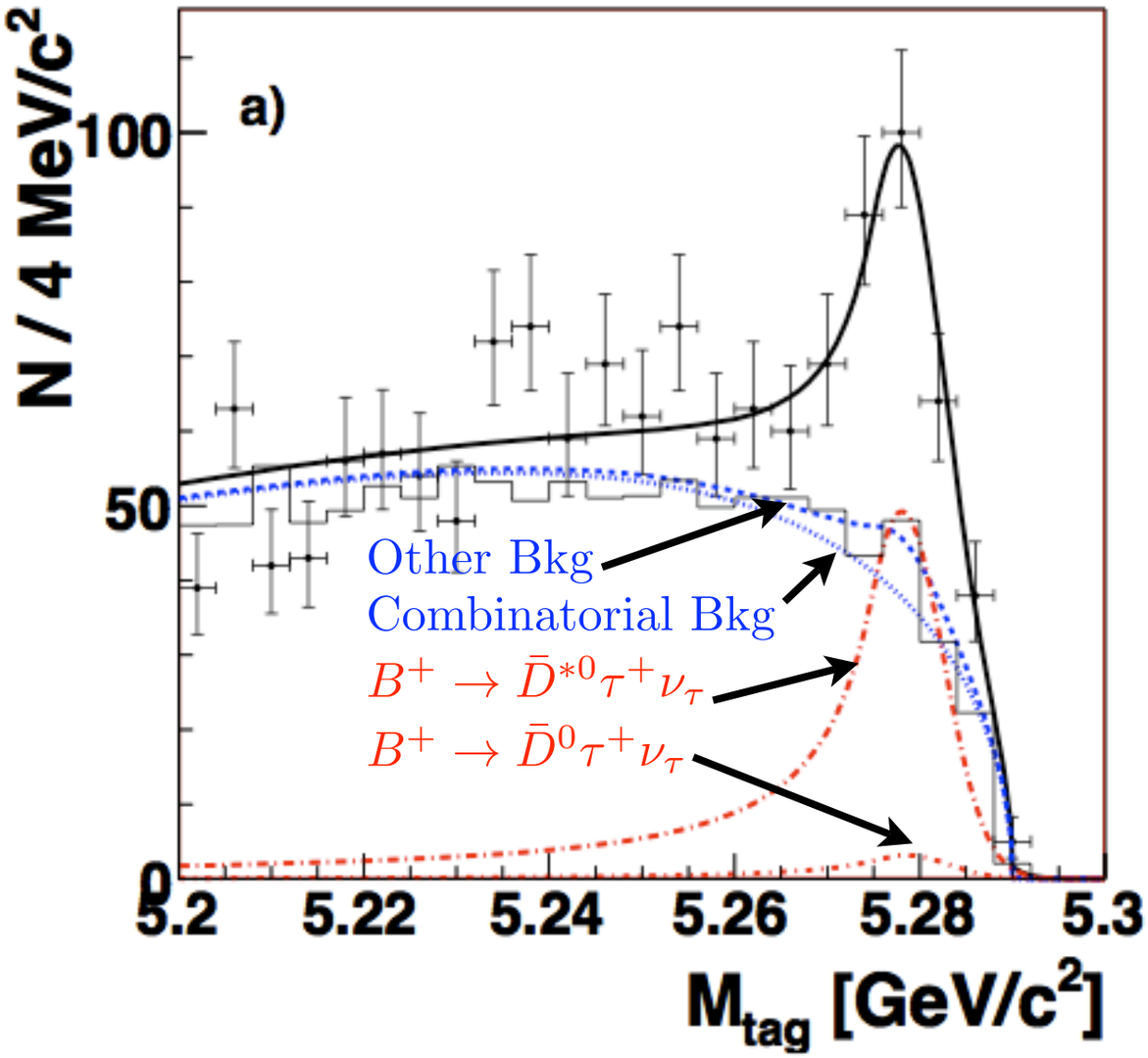
$B \to D^{(*)}\tau\nu$

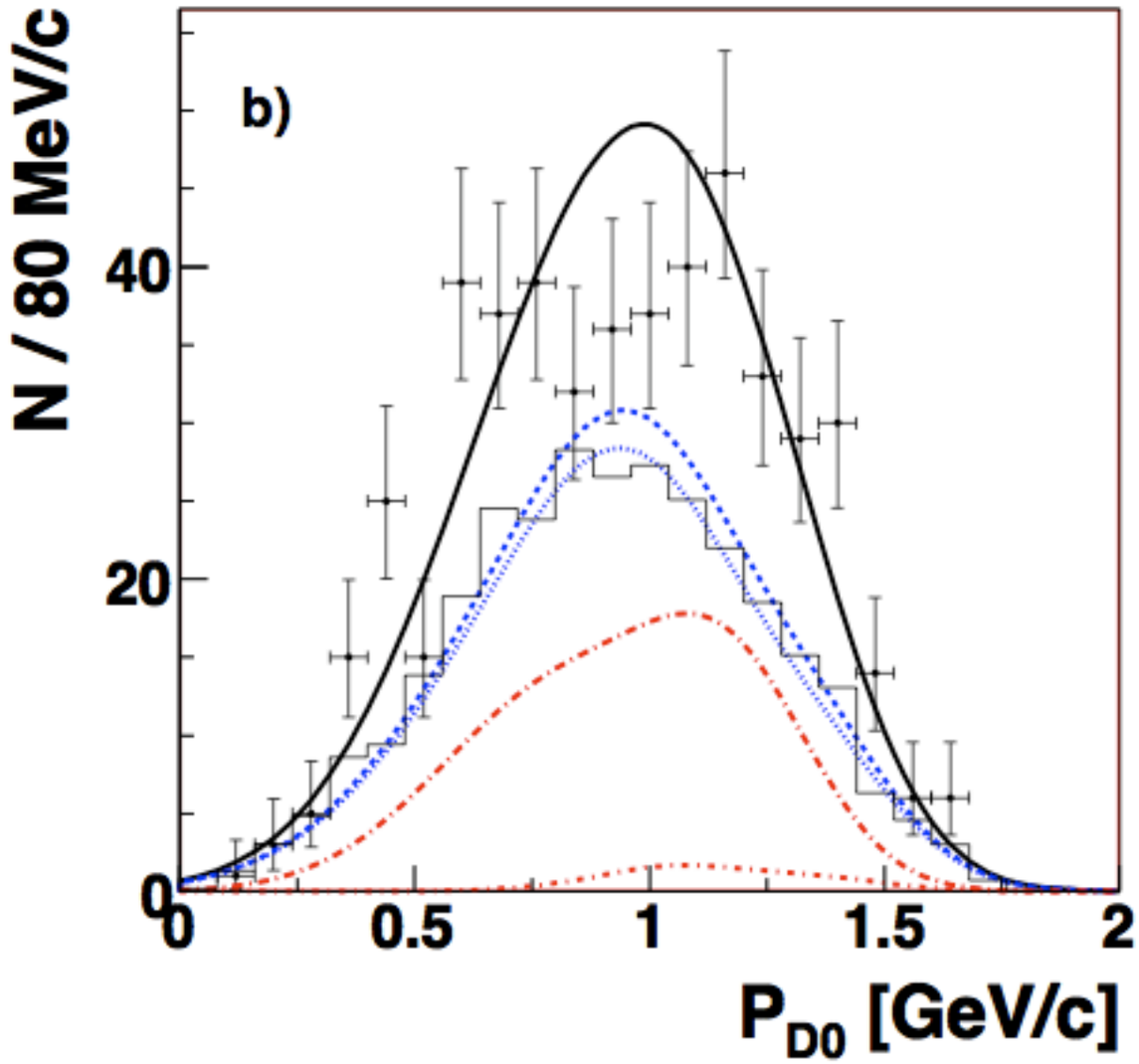




- Sensitive to charged Higgs
- complimentary to $B \to \tau\nu$
- Free from f_B, depends on $B \to D^*\tau\nu$ form factor
- $|V_{cb}|$ independent ratio: $R = \frac{\mathcal{B}(B \to D^*\tau\nu)}{\mathcal{B}(B \to D^*\ell\nu)}$
- 3-body decay $\to$ more observables:
  - q^2 Distribution
  - τ Polarization
  - D^* Polarization

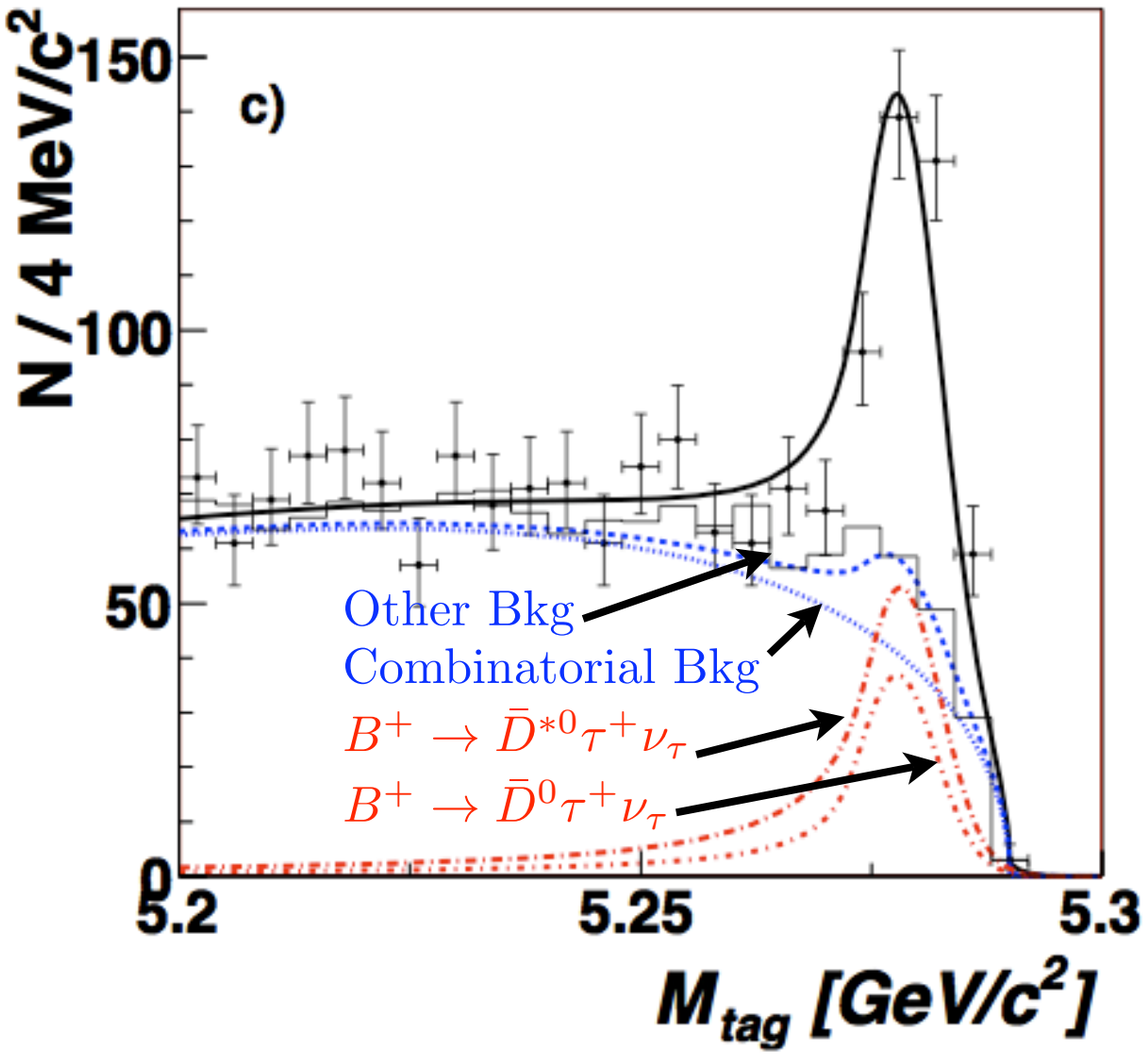
Observation of $B^+ \to \bar{D}^{*0}\tau^+\nu_\tau$

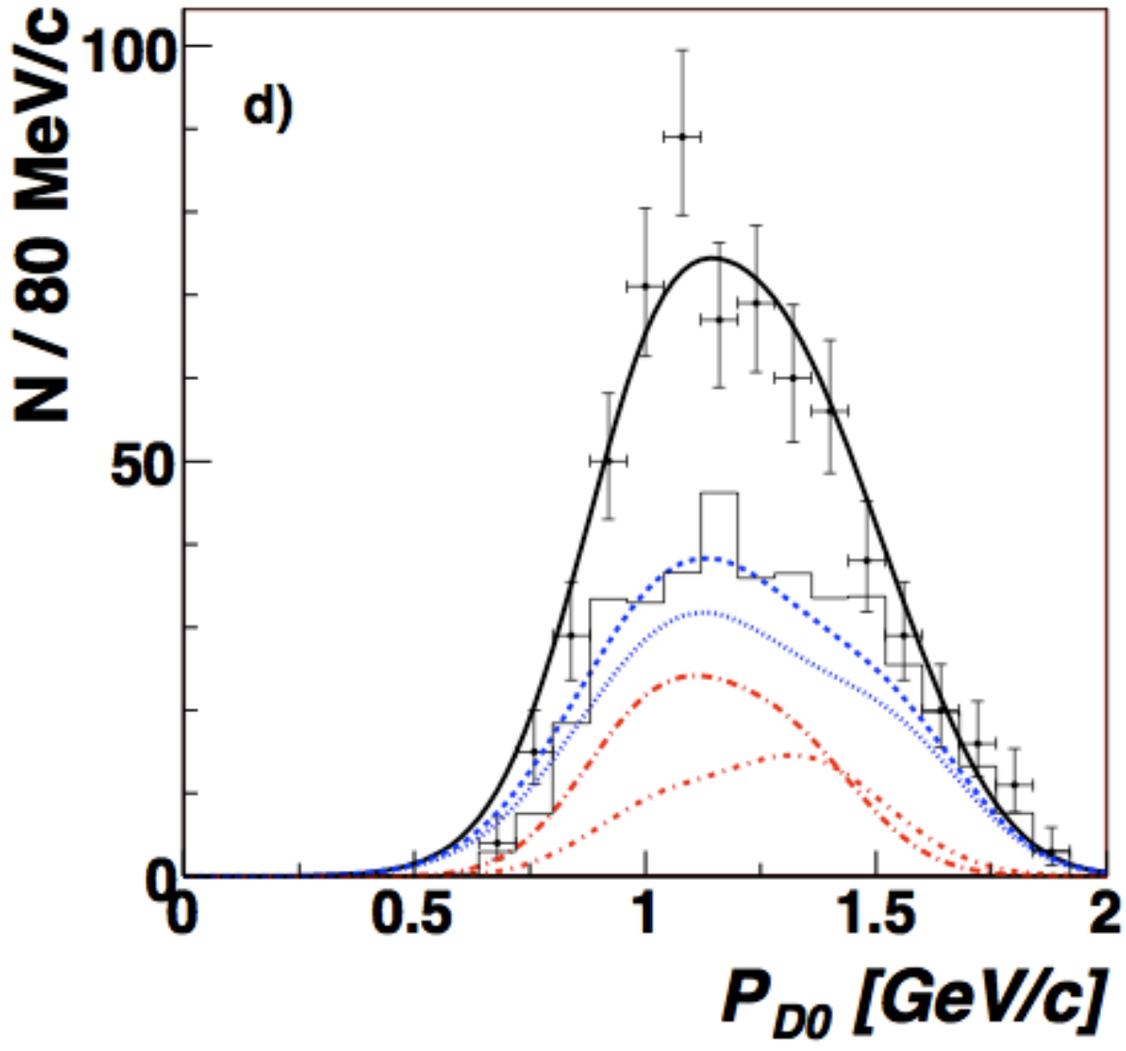




- $N_{sig}(B^+ \to \bar{D}^{*0}\tau^+\nu_\tau) = 446^{+58}_{-56}$ at 8.1σ
- $\mathcal{B}(B^+ \to \bar{D}^{*0}\tau^+\nu_\tau) = (2.12^{+0.28}_{-0.27} \pm 0.29) \times 10^{-2}$

Evidence for $B^+ \to \bar{D}^0 \tau^+ \nu_\tau$



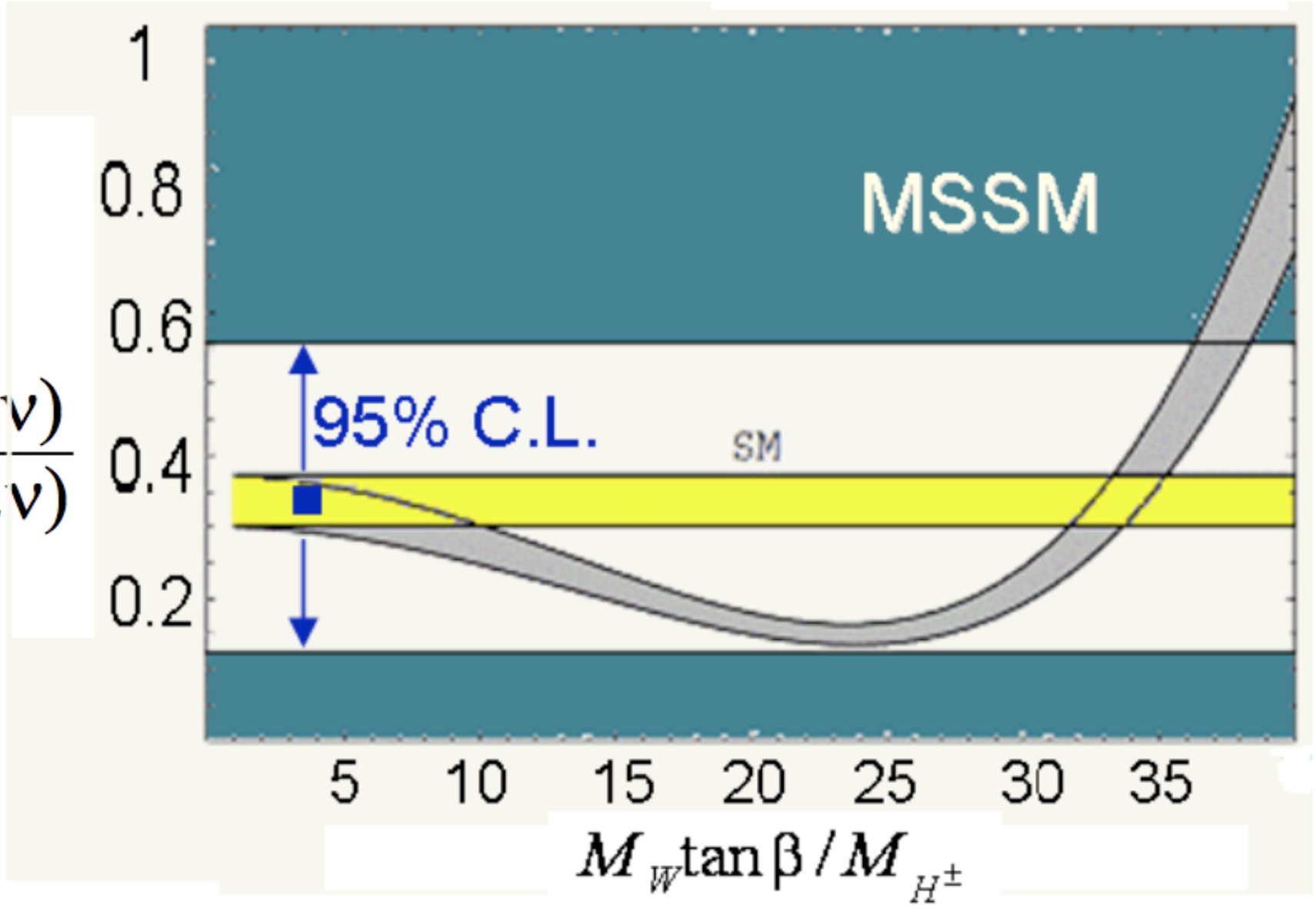


- $N_{sig}(B^+ \to \bar{D}^0 \tau^+ \nu_\tau) = 146^{+42}_{-41}$ at 3.5σ (First evidence)
- $\mathcal{B}(B^+ \to \bar{D}^0 \tau^+ \nu_\tau) = (0.77 \pm 0.22 \pm 0.12) \times 10^{-2}$

Constraints on the charged Higgs boson

T. Miura, M. Tanaka, arXiv: hep-ph/0109244

$$\frac{BF(B \to D\tau\nu)}{BF(B \to D\mu\nu)}$$



Physics at $\Upsilon(5S)$

Observation of $B_s \to D_s^- \pi^+$

Phys. Rev. Lett. **102**, 021801 (2009)

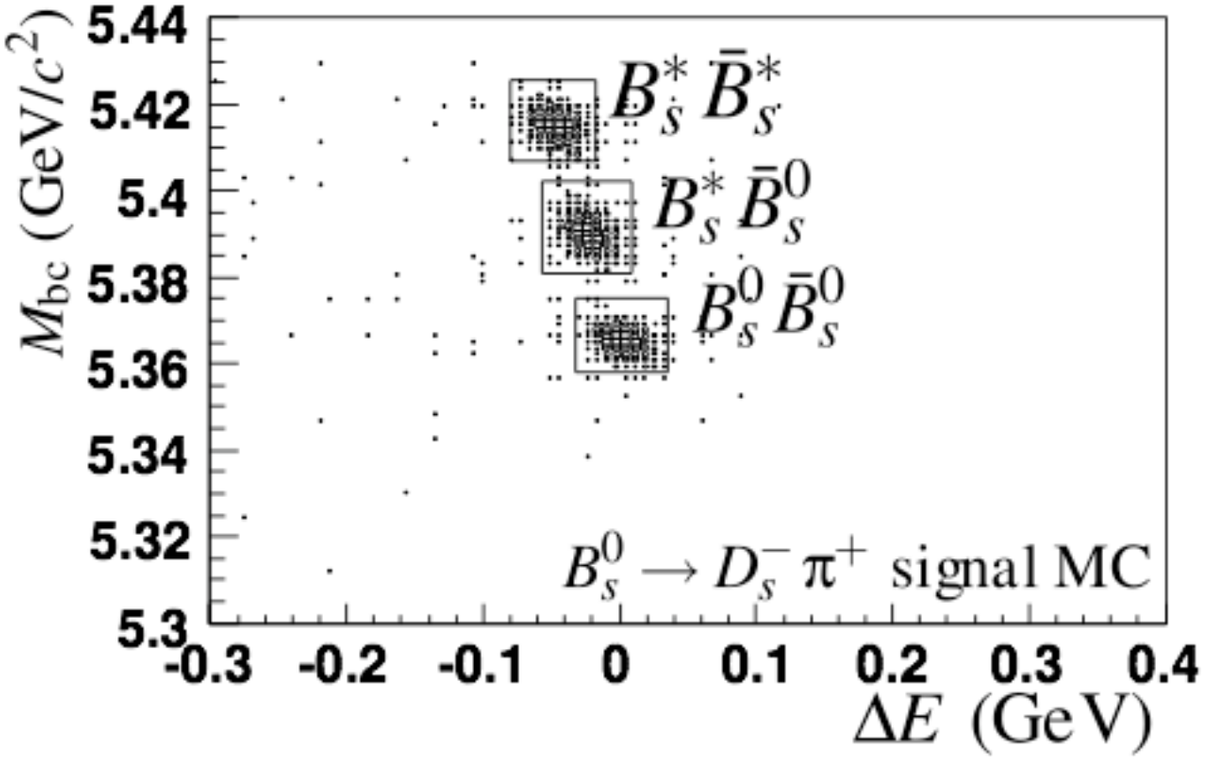
Observation of $B_s \to D_s^- \rho^+$

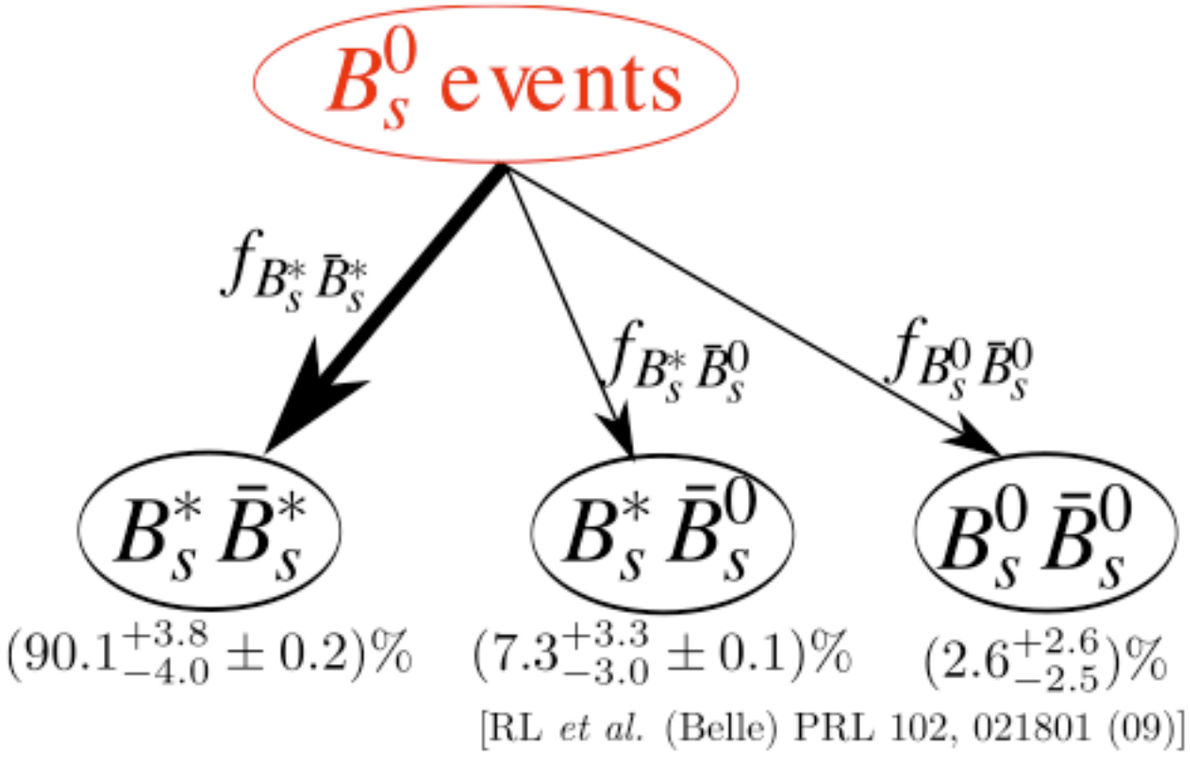
Phys. Rev. Lett. (in press), arXiv:1003.5312

$\frac{\Delta\Gamma_s}{\Gamma_s}$ from $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

Physics at $\Upsilon(5S)$

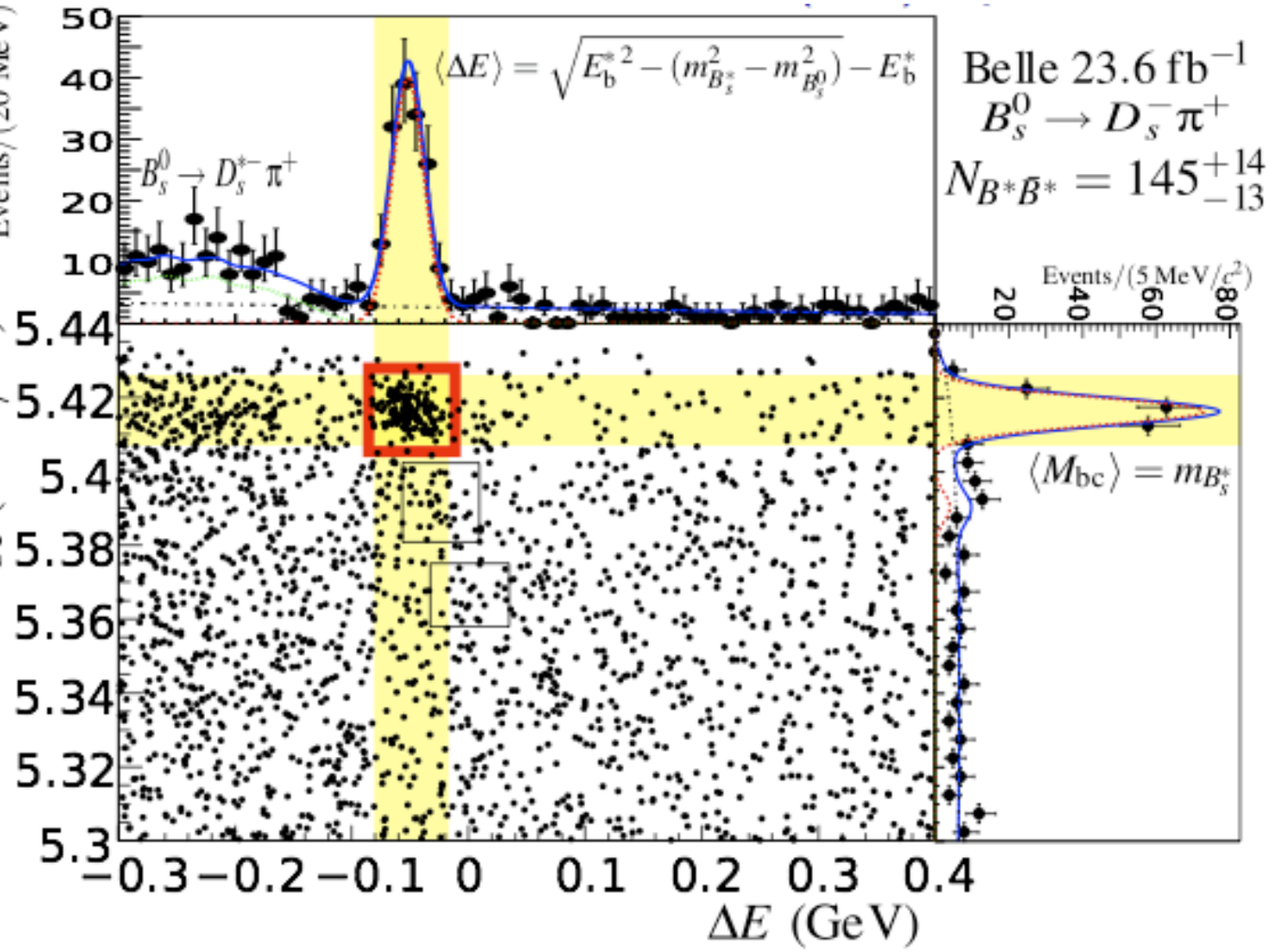
- Full reconstruction of the B_s^0. Observables: $(2 \times E_{\rm b}^* = \sqrt{s})$
  - Beam-constrained mass: $M_{\rm bc} = \sqrt{E_{\rm b}^{*2} - p_{B_s^0}^{*2}}$
  - Energy difference: $\Delta E = E_{B_s^0}^* - E_{\rm b}^*$
- 3 production modes ($B_s^* \to B_s^0 \gamma$):
  $\Upsilon(5S) \to B_s^*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





[RL *et al.* (Belle) PRL 102, 021801 (09)]

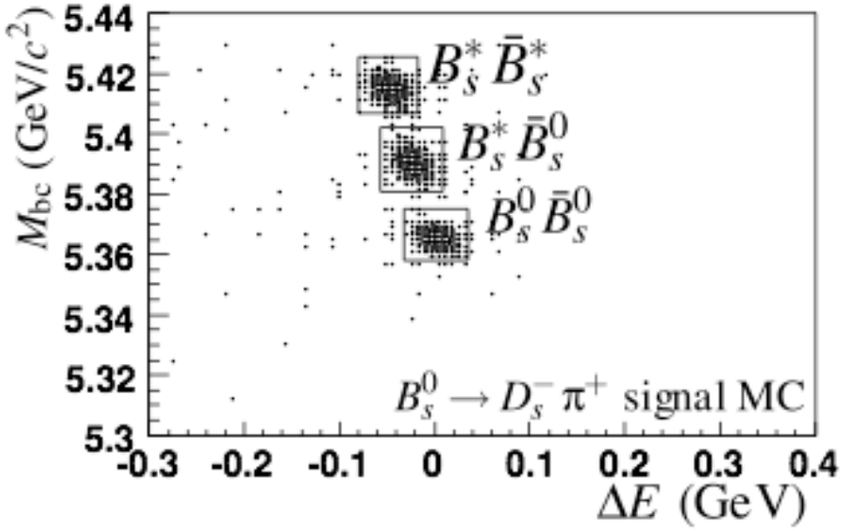
Observation of $B_s \to D_s^- \pi^+$



$$f_{B_s^* \bar{B}_s^*} = \left(90.1^{+3.8}_{-4.0} \pm 0.2\right) \%$$

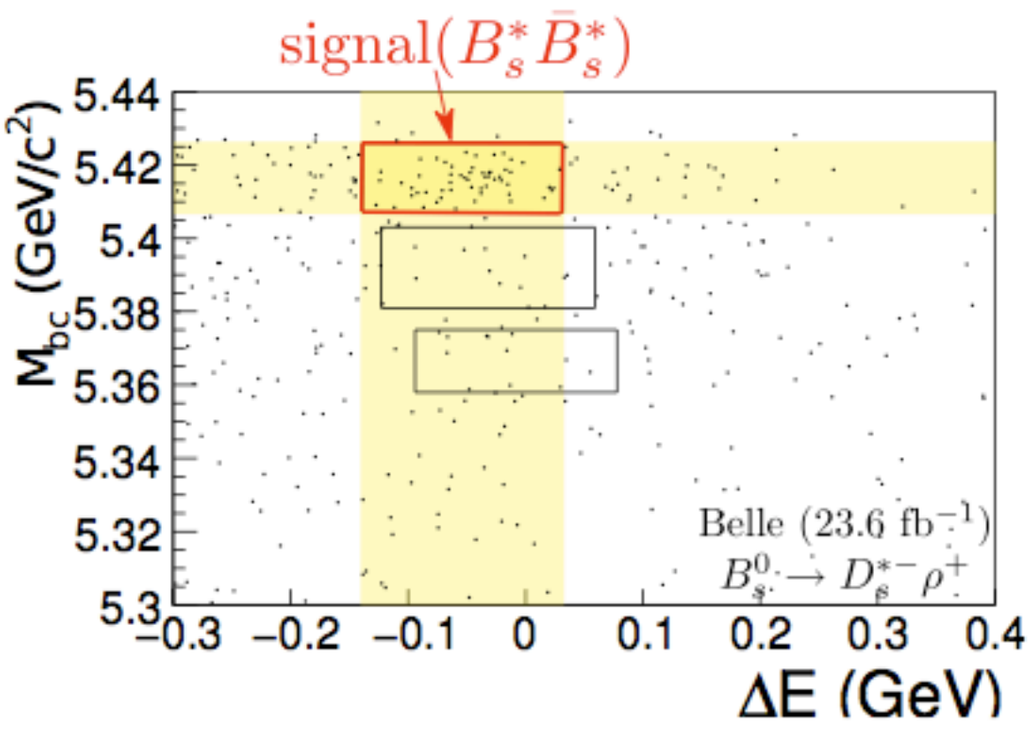
$$m_{B_s^*} = (5416.4 \pm 0.4 \pm 0.5)\,\text{MeV}/c^2$$

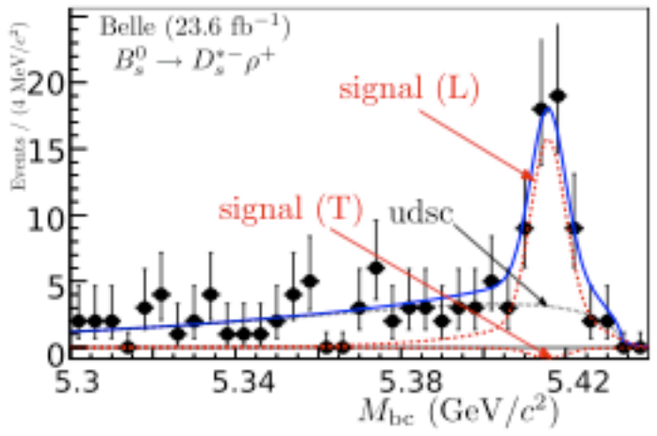
$$m_{B_s^0} = (5364.4 \pm 1.3 \pm 0.7)\,\text{MeV}/c^2$$

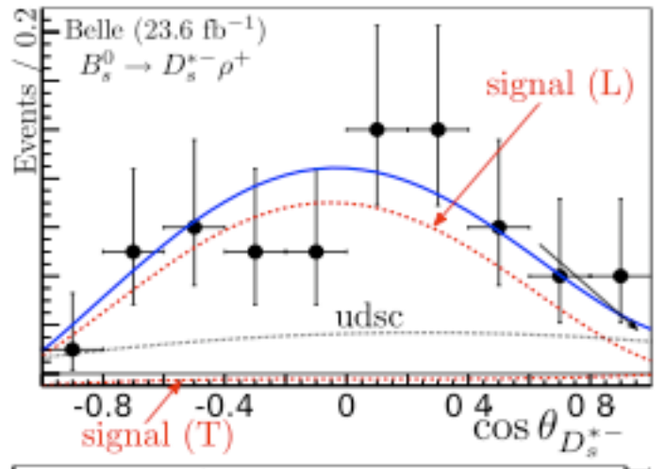


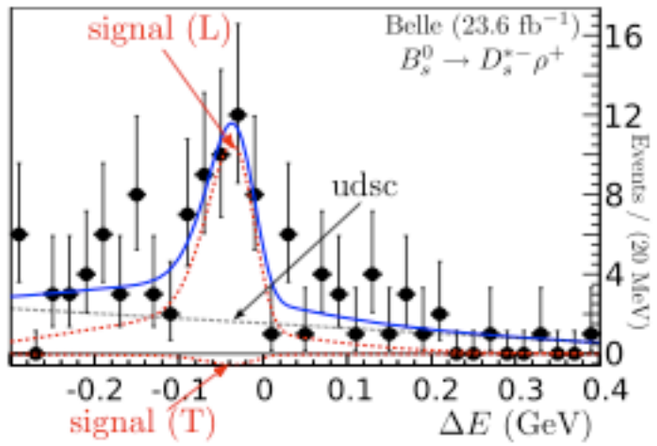
$$\mathcal{B}(B_s^0 \to D_s^- \pi^+) = \left(3.67^{+0.35}_{-0.33}(\text{stat.})^{+0.43}_{-0.42}(\text{syst.}) \pm 0.49(f_s)\right) \times 10^{-3}$$

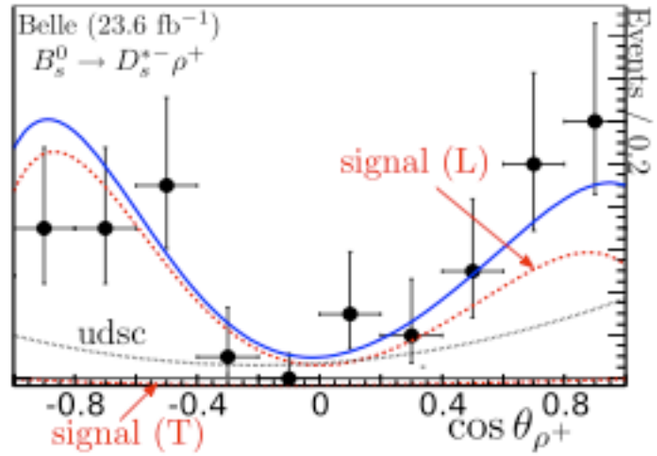
Observation of $B_s \to D_s^- \rho^+$











$$N(B_s^* \bar{B}_s^*) = 77.8^{+14.5}_{-13.4}(\text{stat.}) \pm 3.3(\text{fit}) \text{ events } (7.4\sigma \text{ significance})$$

$$\boxed{\mathcal{B}(B_s^0 \to D_s^{*-} \rho^+) = \left(11.8^{+2.2}_{-2.0}(\text{stat.}) \pm 1.7(\text{syst.}) \pm 1.8(f_s)\right) \times 10^{-3}}$$

$$\boxed{f_L = 1.05^{+0.08\,+0.03}_{-0.10\,-0.04}} \quad \text{or} \quad f_L \in [0.93, 1.00] \text{ at } 68\% \text{ C.L.}$$

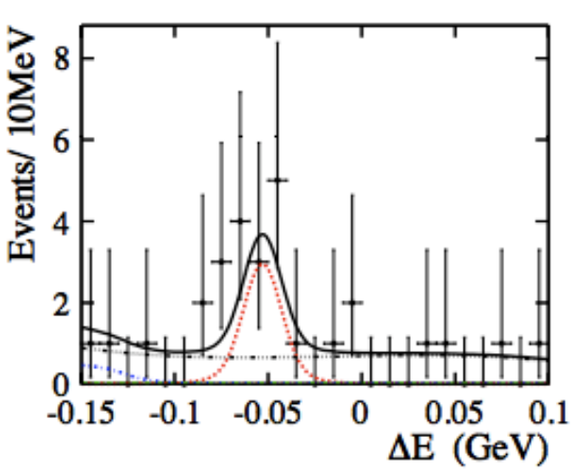
$\frac{\Delta\Gamma_s}{\Gamma_s}$ from $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

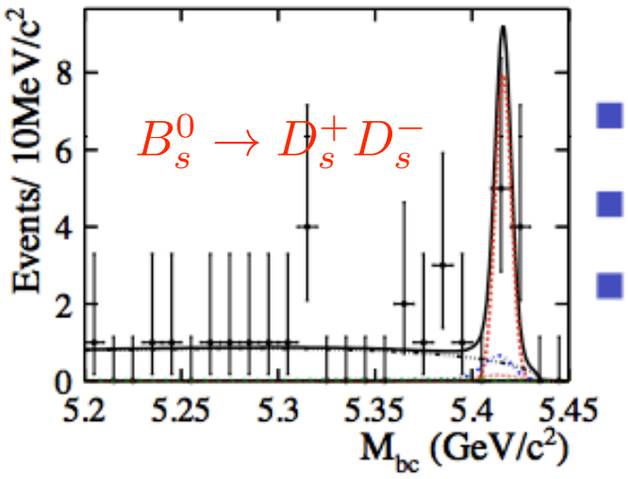
- CKM-favored **and** *CP*-even eigenstate (in heavy-quark limit).
- Dominates $\Delta\Gamma$ [Aleksan *et al.* Phys.Lett.B 316, 567]:

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = \frac{2 \times \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}{1 - \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}$$

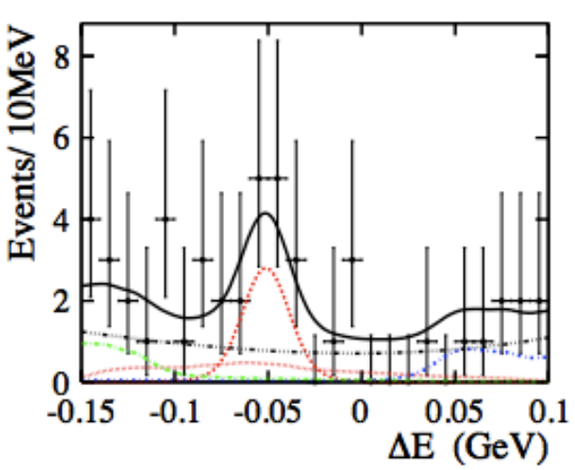
- Full reconstruction of $B_s^0 \to D_s^{(*)} D_s^{(*)}$
- D_s^+ reconstructed in 6 final states: $\phi\pi^+$, $K_S^0 K^+$, $\bar{K}^{*0} K^+$, $\phi\rho^+$, $K_S^0 K^{*+}$ and $\bar{K}^{*0} K^{*+}$
- $D_s^{*+} \to D_s^+ \gamma$ with $E_\gamma > 50$ MeV and $\left|M(D_s^+\gamma) - M(D_s^{*+})^{\mathrm{PDG}}\right| < 12\,\mathrm{MeV}/c^2$
- One candidate (all channels) per event:
  lowest χ^2 based on $M(D_s^+)$ and $M(D_s^{*+}) - M(D_s^+)$.
- Continuum rejection ($> 80\%$) (Fox-Wolfram moments), 95% of the signal remains.
- Overall signal efficiencies, including internal Branching fractions:
  3.3×10^{-4} $(D_s D_s)$, 1.4×10^{-4} $(D_s^* D_s)$, 0.6×10^{-4} $(D_s^* D_s^*)$

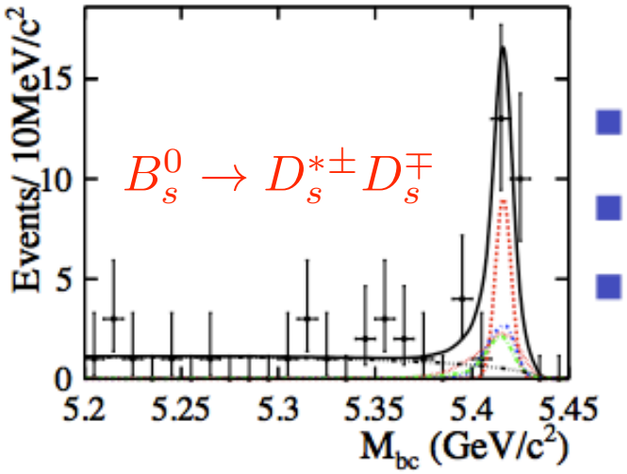
Observation of $B_s \to D_s^{(*)+} D_s^{(*)-}$



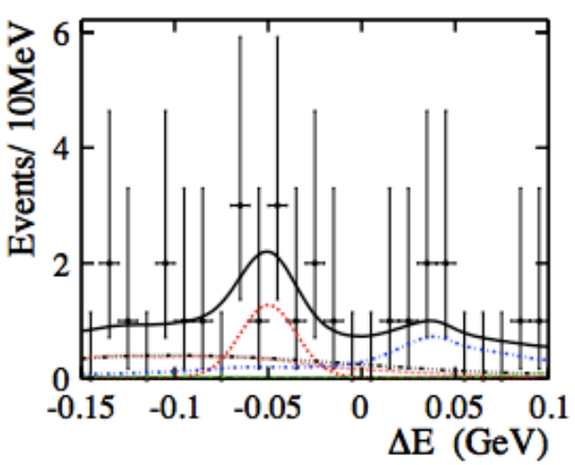


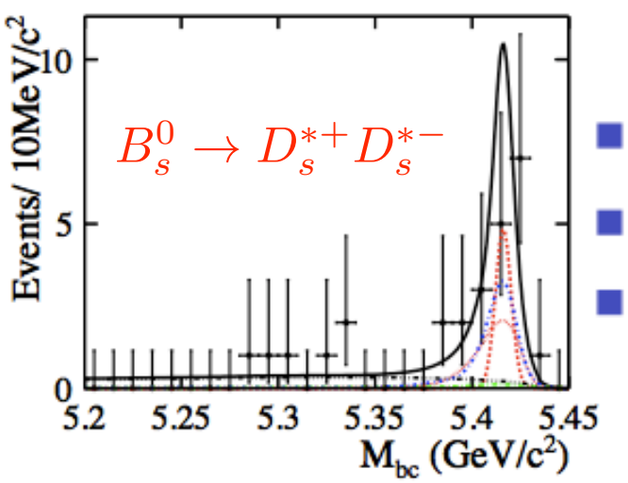
- $N_{sig}(B_s^0 \to D_s^+ D_s^-) = 8.5^{+3.2}_{-2.6}$ at 6.2σ
- $\mathcal{B}(B_s^0 \to D_s^+ D_s^-) = 1.03^{+0.39+0.15}_{-0.32-0.13} \pm 0.21 \times 10^{-2}$
- Consistent with CDF PRL **100**, 021803 (2008)





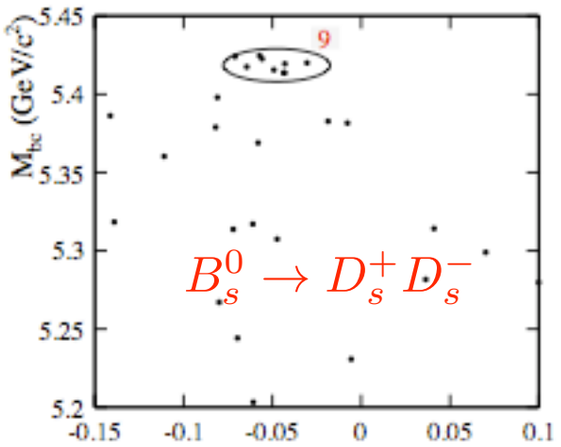
- $N_{sig}(B_s^0 \to D_s^{*\pm} D_s^{\mp}) = 9.2^{+2.8}_{-2.4}$ at 6.6σ
- $\mathcal{B}(B_s^0 \to D_s^+ D_s^-) = 2.75^{+0.83}_{-0.71} \pm 0.040 \pm 0.56 \times 10^{-2}$
- First observation

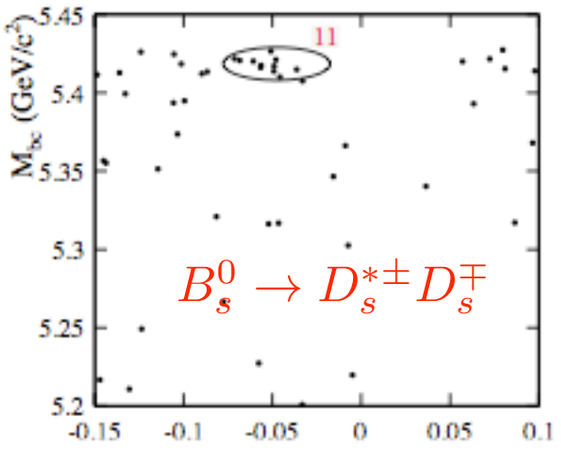


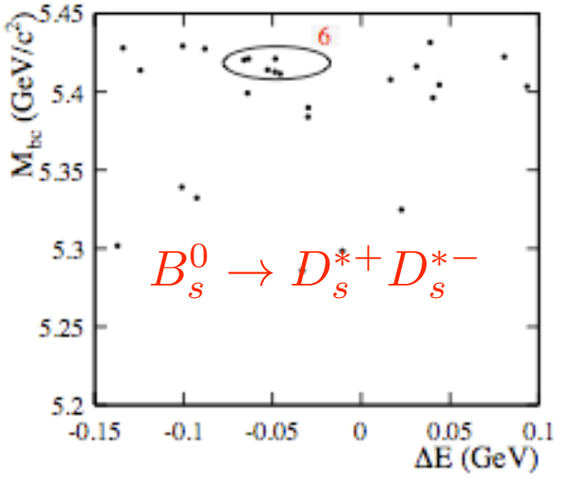


- $N_{sig}(B_s^0 \to D_s^+ D_s^-) = 4.9^{+1.9}_{-1.7}$ at 3.2σ
- $\mathcal{B}(B_s^0 \to D_s^+ D_s^-) = 3.08^{+1.22}_{-1.04} \pm 0.56 \pm 0.63 \times 10^{-2}$
- First evidence

$\frac{\Delta\Gamma_s}{\Gamma_s}$ from $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$







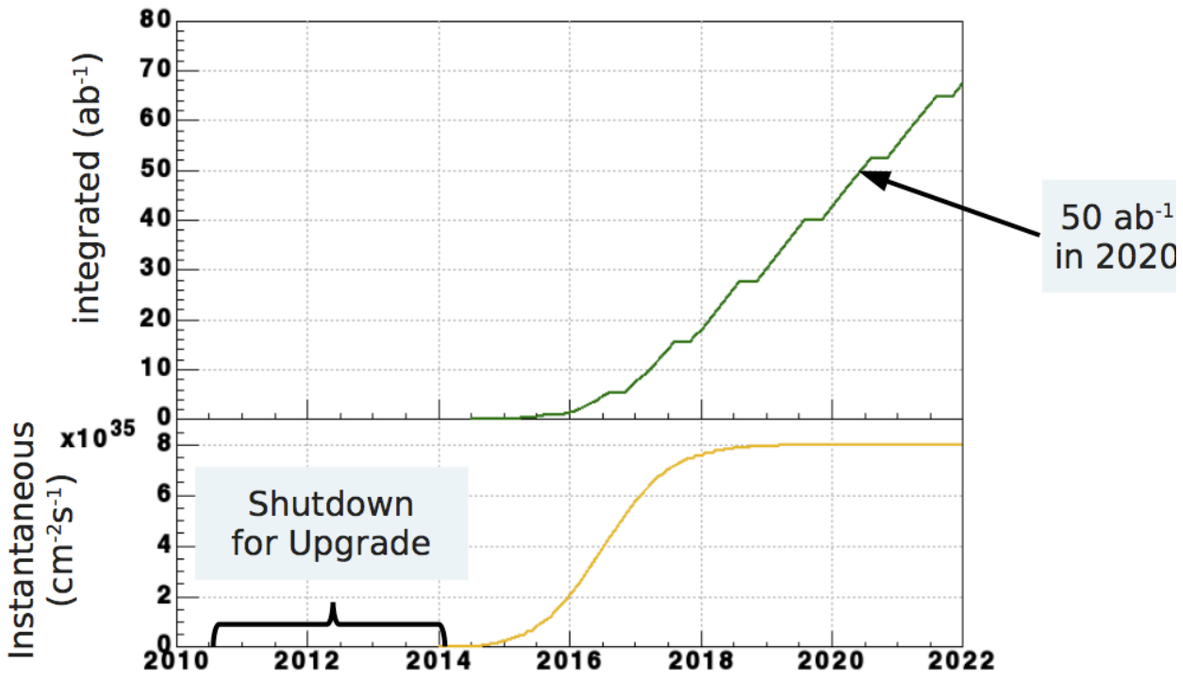
- $N_{sig}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) = 22.6^{+4.7}_{-3.9}$
- $\mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) = 6.85^{+1.53+1.26}_{-1.30-1.25} \pm 1.41 \times 10^{-2}$

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = \frac{2 \times \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}{1 - \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.147^{+0.036+0.044}_{-0.030-0.042}$$

Summary

- $B \to \tau\nu$ decays are now well established and provide constraints on charged Higgs.
  - $\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = 1.65^{+0.38\,+0.35}_{-0.37\,-0.37} \times 10^{-4}$ (semileptonic tag)
- Belle found evidence for $B^+ \to \bar{D}^{(*)}\tau^+\nu_\tau$
  - $\mathcal{B}(B^+ \to \bar{D}^{*0}\tau^+\nu_\tau) = (2.12^{+0.28}_{-0.27} \pm 0.29) \times 10^{-2}$
  - $\mathcal{B}(B^+ \to \bar{D}^{0}\tau^+\nu_\tau) = (0.77 \pm 0.22 \pm 0.12) \times 10^{-2}$
- Belle measures $\frac{\Delta\Gamma_s}{\Gamma_s} = 0.147^{+0.036\,+0.044}_{-0.030\,-0.042}$ in $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$



e^+e^- has advantages in…	LHCb has advantages in…
CPV in $B \to \phi K_S$, $\eta' K_S$,…	CPV in $B \to J/\psi K_S$
CPV in $B \to K_S \pi^0 \gamma$	Most of B decays not including ν or γ
$B \to K\nu\nu$, $\tau\nu$, $D^{(*)}\tau\nu$	Time dependent measurements of B_S
Inclusive $b \to s\mu\mu$, *see* $\tau \to \mu\gamma$ and other LFV	$B_{(s,d)} \to \mu\mu$
$D^0\overline{D^0}$ mixing	B_c and bottomed baryons