Observation of $B_s \rightarrow \phi \gamma$ and
Search for $B_s \rightarrow \gamma \gamma$ Decays at Belle

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KEKB and Belle detector

**KEKB**: asymmetric $e^+e^-$ collider (3.5 on 8.0 GeV) located in Tsukuba, Japan

**B meson factory**: $e^+e^- \rightarrow \Upsilon(\{4,5\}S) \rightarrow BB$

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**Luminosity**
- **Peak**: $1.71 \times 10^{34}$/cm$^2$/s
- **Integrated**: $>790$ fb$^{-1}$
  - $650$ fb$^{-1}$ at $\Upsilon(4S)$ ($\sim 720$M BB pairs, $B=B^+$ or $B^0$)
  - $23.6$ fb$^{-1}$ at $\Upsilon(5S)$ ($\sim 2.8$M $B_s$ mesons)
- **Daily**: up to $1.2$ fb$^{-1}$

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\( \Upsilon(5S) \) running at Belle

- Beam energies increased by 2.7% wrt. \( \Upsilon(4S) \)
  - No detector/trigger/... modifications: smooth running!
  - Belle has access to \( B_s \) physics!

- Two samples:
  - June 2005: 1.86 fb\(^{-1}\)
  - June 2006: 21.7 fb\(^{-1}\)

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

\[ f_s = (19.5^{+3.0}_{-2.3})\% \]

\[ N_{B_s}(23.6 \text{ fb}^{-1}) = 2.8 \times 10^6 \]

\[ f_{B_s^*B_s^*} = (93^{+7}_{-9})\% \]

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Penguin decays involve loop diagrams
Good probe for New Physics:
new particles can move observables away from their SM expectations

\[ B_s \rightarrow \phi \gamma \]

- **Standard Model**: electromagnetic penguin
  - \( BF = (40 \pm 10) \times 10^{-6} \) \( \text{PRD 75, 054004 (2007)} \) \( \text{arXiv:0709.4422 (2007)} \)
- **Not observed yet**: \( BF < 120 \times 10^{-6} \) (90% CL) \( \text{CDF, PRD 66, 112002 (2002)} \)
- We do not really expect to see NP in the rate:
  - Partner of \( B^{+0} \rightarrow K^{*}(892)^{+0} \gamma \)
    - replace spectator quark by \( u \) or \( d \)
  - Measured precisely by Belle and BABAR
    - Fits perfectly in the SM picture
    - Inclusive \( b \rightarrow s \gamma \)
  - Good agreement between experiments and SM theory

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$B_s \rightarrow \gamma \gamma$

- **Standard Model:**
  - Annihilation penguin
  - $\text{BF} = (0.5-1.0) \times 10^{-6}$  
    - $\rightarrow$ impossible with $2.8M B_s$

- **Not observed yet:** $\text{BF} < 5 \times 10^{-6}$ (90% CL)
  - Belle (2 fb$^{-1}$ at $\Upsilon(5S)$), PRD 76, 012002 (2007)

- **Very sensitive to New Physics!** Up to one order of magnitude enhancement.
  - SUSY with broken R-parity
    - PRD 70, 035008 (2004)
  - 4$^{\text{th}}$ quark generation
  - Two Higgs doublet model with FCNC
    - PRD 58, 095014 (1998)
**B_s candidates selection**

Standard “B-factory” analysis.

- **φ candidates**: BF(ϕ → K⁺K⁻) ≈ 50%, 2.5σ requirement on m_{KK}

- **B_s candidates** selected using the M_{bc} (M_{ES}) and ΔE variables:

\[ M_{bc} = \sqrt{(E_{beam})^2 - (p_{B_s^0})^2} \]
\[ ΔE = E_{B_s^0}^{CM} - E_{beam}^{CM} \]

Beam energy: 5.44 GeV at ϒ(5S)

- We cannot fully reconstruct B_s* candidates γ is too soft.

- **Main background is continuum**: \( e^+e^- \rightarrow \{u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}\} \)

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Continuum suppression

We use modified Fox-Wolfram moments describing event topology

\[ e^+ e^- \rightarrow q\bar{q} \]
\[ q = \{ u, d, s, c \} \]

Continuum: jet-like

\[ \Upsilon(5S): \text{spherical} \]
Result: $B_s \to \phi \gamma$

Unbinned extended maximum likelihood fit to

$$M_{bc} \quad \Delta E \quad \cos(\theta_{hel}).$$

**Signal** smoothed MC histogram $\times 1 - \cos^2(\theta_{hel})$

**Continuum** ARGUS $\times 1^{st}$ order polynomial $\times$ constant

$$\mathcal{B}(B_{s}^0 \to \phi \gamma) = \left(\frac{57+18+12}{-15-11}\right) \times 10^{-6}$$

$\leftrightarrow 18\pm6$ signal events

First observation of a $B_s$ radiative penguin decay! $\theta_{hel} = \Delta(B_s$ and $K^+$ in $\phi$ CM)
Sideband control: $B_s \to \phi \gamma$

Inclusive $m_{KK}$ in data

Fit to the data reconstructed in the $\phi$ mass sideband

$1.1 \text{ GeV/c}^2 < m_{KK} < 1.2 \text{ GeV/c}^2$.

No peaking background
Result: $B_s \rightarrow \gamma \gamma$

Unbinned extended maximum likelihood fit to $M_{bc}$, $\Delta E$

**Signal** smoothed MC histogram

**Continuum** ARGUS x 1$^{st}$ order polynomial

No signal!

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

\( B_s \to \phi \gamma \)

- With a \( 23.6 \text{ fb}^{-1} \) sample collected on the \( \Upsilon(5S) \) resonance, Belle has observed **for the first time** a radiative penguin decay of the \( B_s \) meson.

- We measure with a significance of \( 5.5\sigma \):

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

in agreement with the SM prediction and \( \text{BF}(B^{+/0} \to K^{*}(892)^{+/0} \gamma) \).

\( B_s \to \gamma \gamma \)

- We do not observe any significant signal and we set an upper limit:

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

- This limit is about 6 times more restrictive than the previous one.

- New Physics can enhance the branching fraction up to \( \sim 5 \times 10^{-6} \). We need more data! We need a **Super B factory**!