Rare Electroweak Penguin Decays from Belle

9th September 2010

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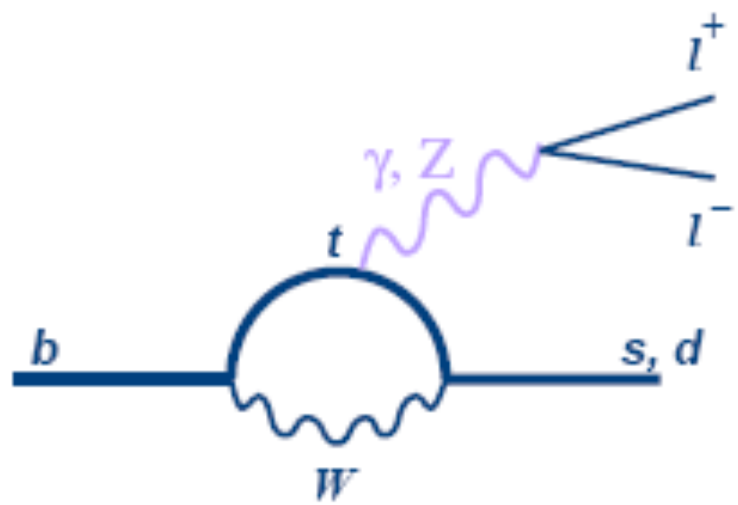
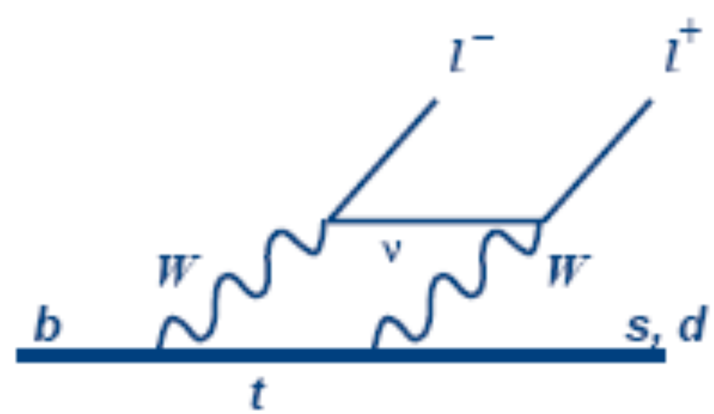
- Summary

Introduction : FCNC process

- Flavor Changing Neutral Current (FCNC) process
  - Forbidden at tree level in Standard Model (SM)
  - Loop-induced FCNC is possible



penguin



box

- This electroweak penguin B decays are sensitive to the new physics beyond SM A. Ali et al., Phys. Rev. D66, 034002 (2002); T. Hurth, Rev. Mod. Phys. 75, 1159 (2003); U. Egede et al., JHEP11(2008) 032; J Matias, Nucl. Phys. Proc. Suppl. 185, 68 (2008)

Introduction : Wilson coefficients

- In the effective Hamiltonian, Wilson coefficient is the strength of corresponding short distance operator

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} \underline{C_i(\mu)} O_i(\mu)$$

- New physics effects can be parameterized as deviations from SM in Wilson coefficients C_7, C_9, C_{10}
  - C_7 : for electromagnetic operator
  - C_9 : for semi-leptonic vector operator
  - C_{10} : for semi-leptonic axial vector operator

- Constraining Wilson coefficients by $b \rightarrow s\, \ell^+\ell^-$ decay can probe New Physics
  - $b \rightarrow s\, \ell^+\ell^-$: sensitive to C_7 sign, C_9, C_{10}

Introduction : Observables

- $B \to K^{*} \ell^{+}\ell^{-}$ and Wilson coefficients
  - Lepton forward-backward asymmetry (A_{FB})

$$A_{FB}(\hat{s}) = -C_{10}^{eff}\xi(\hat{s})\left[\mathrm{Re}(C_9^{eff})F_1 + \frac{1}{\hat{s}}C_7^{eff}F_2\right]$$

  - Angular distribution to extract A_{FB}
    - K^{*} longitudinal polarization F_L from $\cos\theta_{K^*}$, (θ_{K^*} is the angle between the kaon direction and the direction opposite to the B meson in the K^* rest frame)
    - A_{FB} from $\cos\theta_{B\ell}$, ($\theta_{B\ell}$ is the angle between the ℓ^{+} (ℓ^{-}) and the opposite of the B (B-bar) direction in the dilepton rest frame)
- $B \to X_s \ell^{+}\ell^{-}$ and Wilson coefficients
  - Branching fraction and q^2 distribution

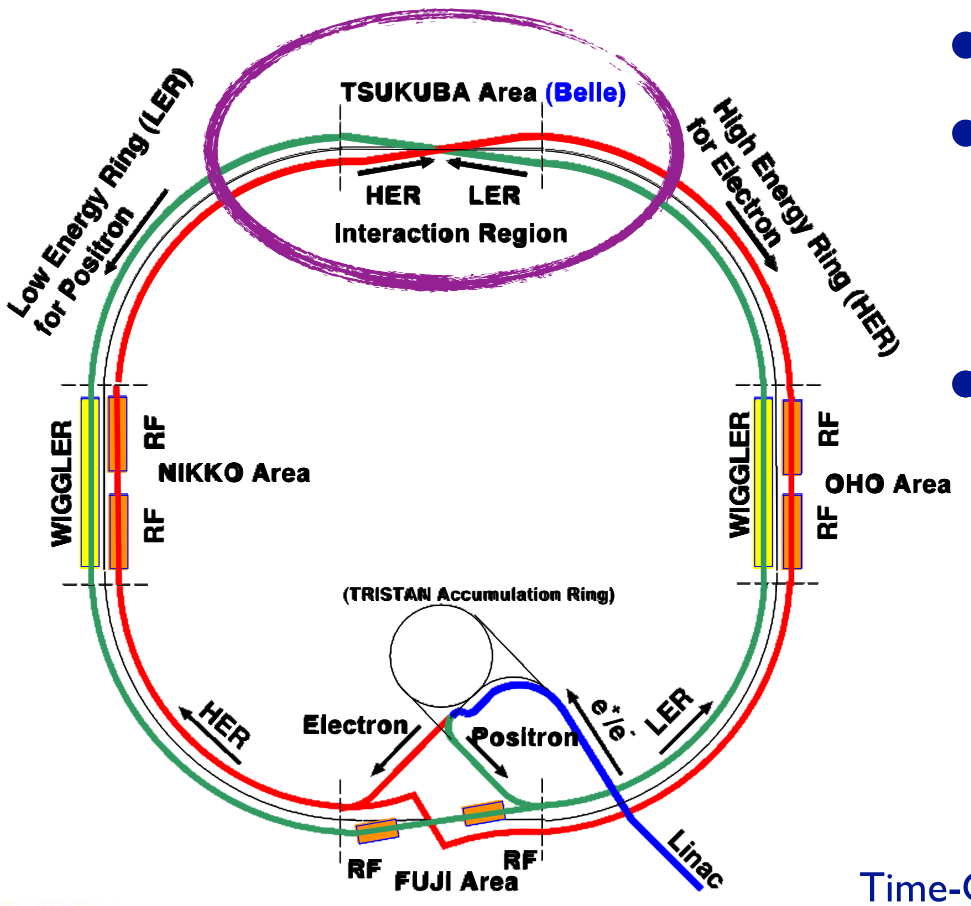
$$\frac{d\Gamma(b \to s\ell^{+}\ell^{-})}{d\hat{s}} = \left(\frac{\alpha_{EM}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 |V_{ts}^{*}V_{tb}|^2}{48\pi^3}(1-\hat{s})^2$$

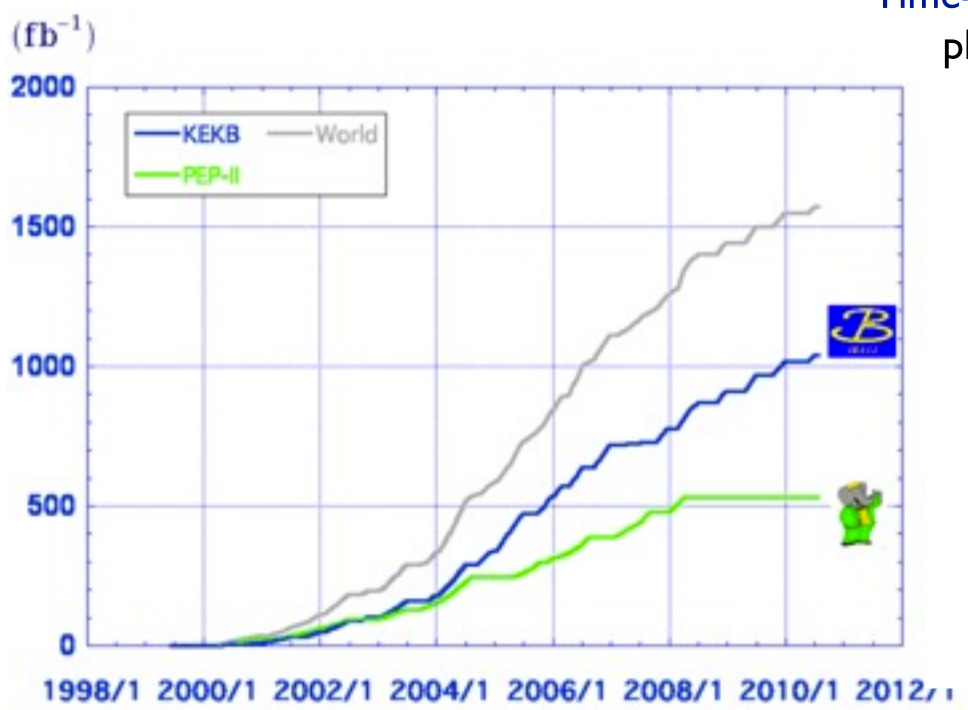
$$\times\left[(1+2\hat{s})\left(\left|C_9^{eff}\right|^2 + \left|C_{10}^{eff}\right|^2\right) + 4\left(1+\frac{2}{\hat{s}}\right)\left|C_7^{eff}\right|^2 + 12\mathrm{Re}\left(C_7^{eff}C_9^{eff*}\right)\right]$$

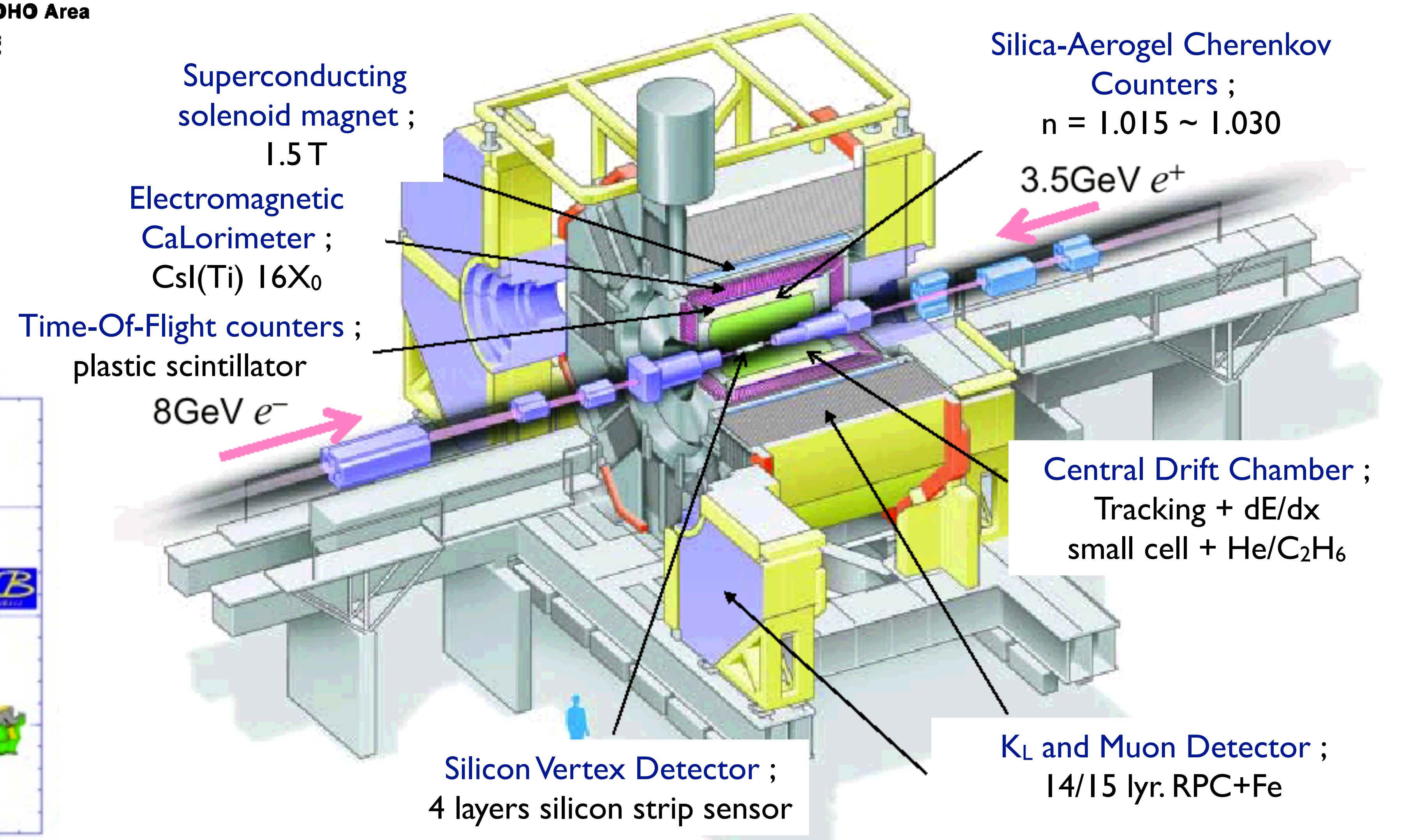
where $\hat{s} = M_{l^+l^-}^2 / m_{b,pole}^2$

KEKB & Belle

- KEKB : Asymmetric e^+e^- collider operating at the $\Upsilon(4S)$
- Belle detector : a large solid angle magnetic spectrometer consisting of SVD, CDC, ECL, ACC, TOF, and KLM
- Accumulated total integrated $\mathcal{L}$ ~1000 fb^{-1} (4S : 711 fb^{-1})







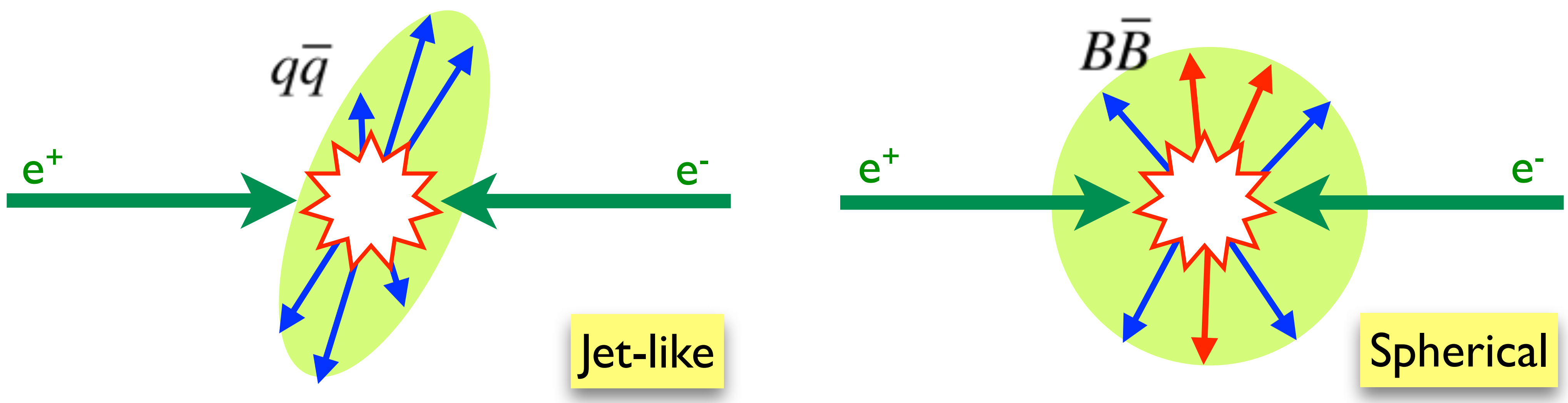
Analysis

- Large sample of $\Upsilon(4S) \rightarrow$ BB-bar used : 657M BB-bar pairs

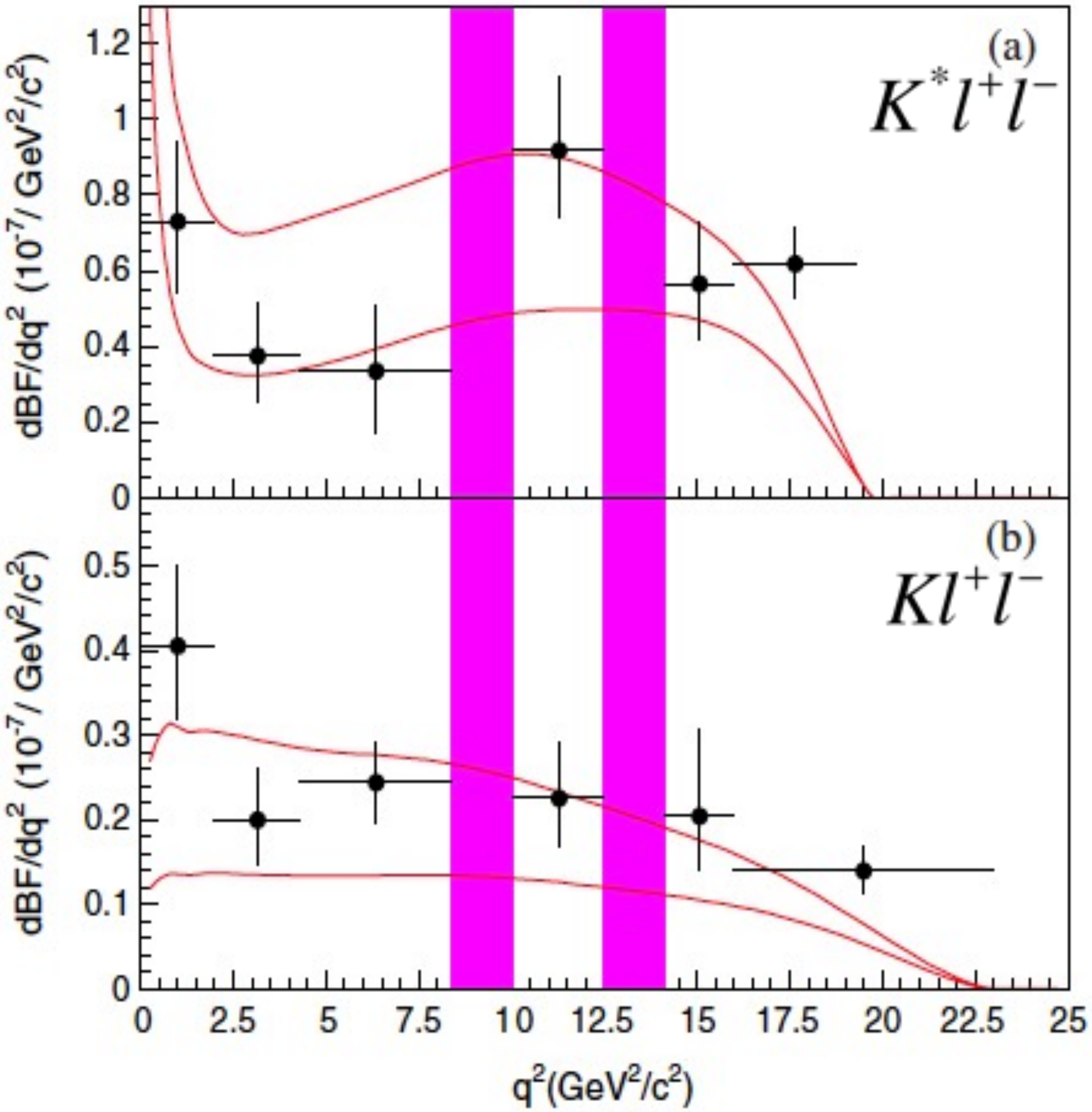
- Event reconstruction with kinematic variables
  - Beam constrain mass : $$M_{bc} = \sqrt{(E_{beam})^2 - |P_B|^2}$$
  - Energy difference : $$\Delta E = E_B - E_{beam}$$

  where E_{beam} is beam energy,
  P_B and E_B are momentum and energy of B candidate in the c.m.s frame

- Continuum background suppression with event topology variables



Exclusive : B ➔ $K^{(*)}\ell^+\ell^-$



: J/ψ(ψ′) veto regions

: SM predictions with the minimum and maximum allowed form factors

$$\mathfrak{B}(B \to K^* l^+ l^-) = (10.7^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7}$$
$$\mathfrak{B}(B \to K l^+ l^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$$

- Differential branching fractions as a function of q^2
- Lepton flavor ratio
  - Sensitive to Higgs emission and predicted to be larger than the SM value in the Higgs doublet model at large tanβ (>44) Y. Wang and D. Atwood, Phys. Rev. D 68, 094016 (2003)

$$R_{K^{(*)}} = \frac{\mathfrak{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathfrak{B}(B \to K^{(*)} e^+ e^-)}$$

	measurement	prediction	
		SM	Higgs doublet model
R_{K^*}	0.83 ± 0.17 ± 0.08	~ 0.95	> 1.4 at tanβ>44
R_K	1.03 ± 0.19 ± 0.06		

Exclusive : B → $K^{(*)}\ell^+\ell^-$

- K^* longitudinal polarization (F_L)

$$\frac{d\Gamma}{d\cos\theta_{K^*}} = \frac{3}{2}F_L\cos^2\theta_{K^*} + \frac{3}{4}(1-F_L)\sin^2\theta_{K^*}$$

- Forward-backward asymmetry (A_{FB})

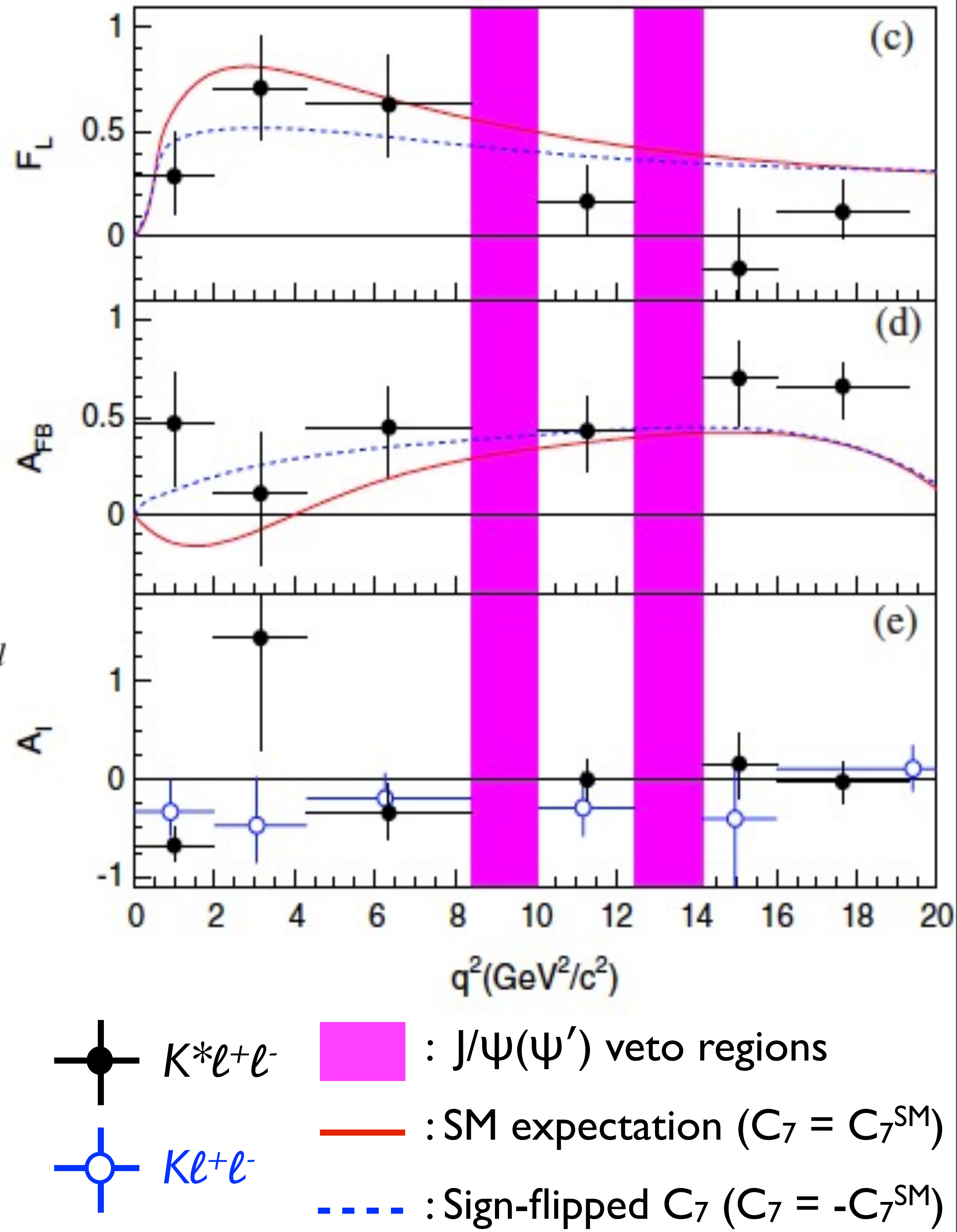
$$\frac{d\Gamma}{d\cos\theta_{Bl}} =$$

$$\frac{3}{4}F_L\sin^2\theta_{Bl} + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{bl}) + A_{FB}\cos\theta_{Bl}$$

- Isospin asymmetry (A_I)

$$A_I \equiv \frac{(\tau_{B^+}/\tau_{B^0})\mathfrak{B}(K^{(*)0}l^+l^-) - \mathfrak{B}(K^{(*)\pm}l^+l^-)}{(\tau_{B^+}/\tau_{B^0})\mathfrak{B}(K^{(*)0}l^+l^-) + \mathfrak{B}(K^{(*)\pm}l^+l^-)}$$

where $(\tau_{B^+}/\tau_{B^0}) = 1.071 \pm 0.009$



Inclusive : $B \to X_s \ell^+\ell^-$

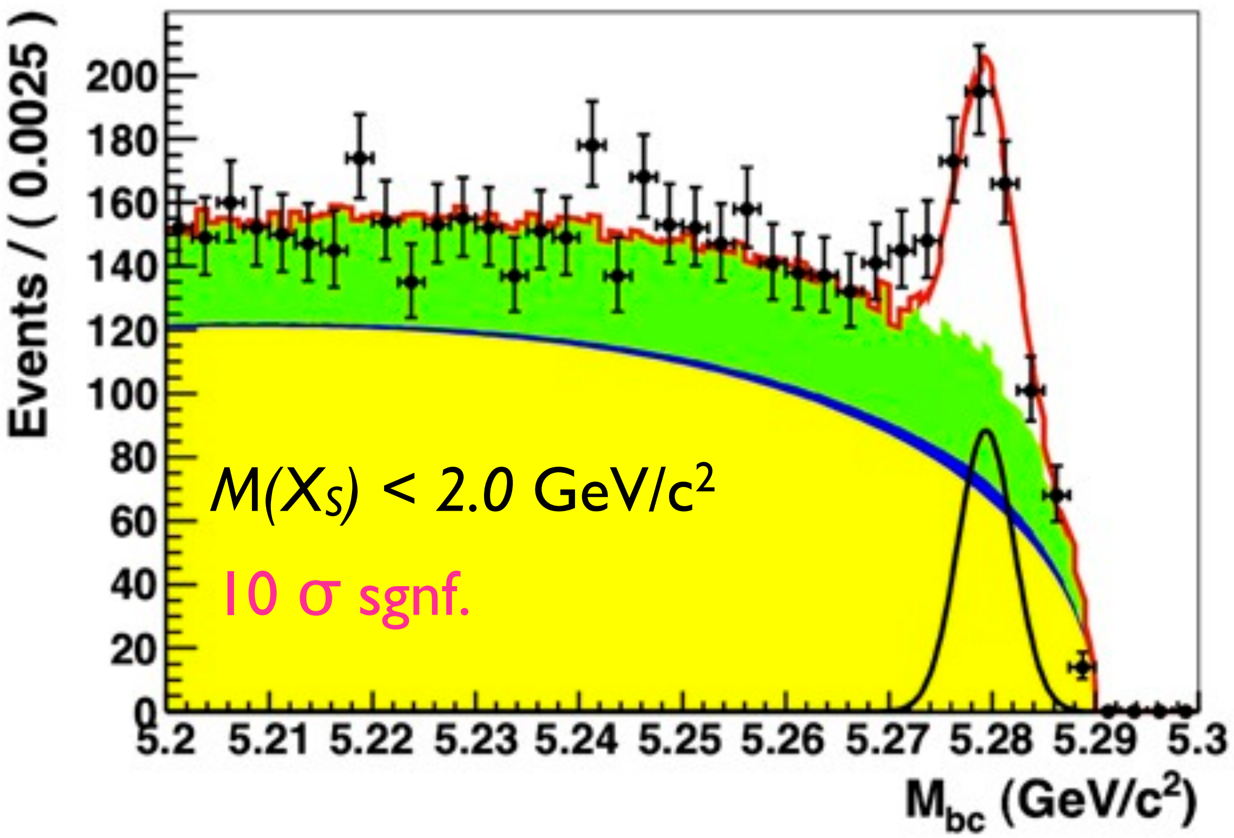
- For $B \to X_s \ell^+\ell^-$ analysis, 36 exclusive modes are summed up
  - Hadronic system consists of one K or K^0_s and up to four pions (at most one pion can be neutral)

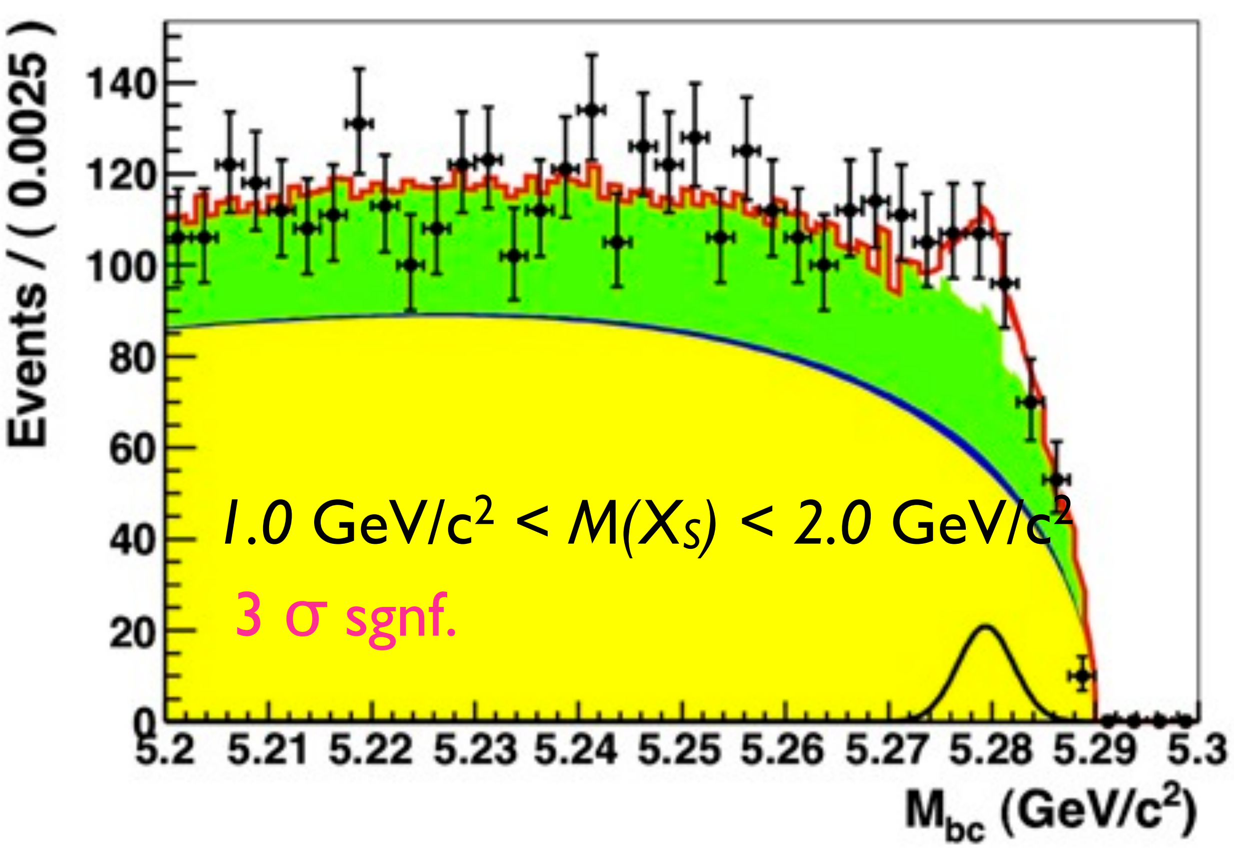
$B^0 \to K^+\pi^-\ell^+\ell^-$	$B^0 \to K^0_s\ell^+\ell^-$
$K^+\pi^-\pi^0\ell^+\ell^-$	$K^0_s\pi^0\ell^+\ell^-$
$K^+\pi^-\pi^+\pi^-\ell^+\ell^-$	$K^0_s\pi^+\pi^-\ell^+\ell^-$
$K^+\pi^-\pi^+\pi^-\pi^0\ell^+\ell^-$	$K^0_s\pi^+\pi^-\pi^0\ell^+\ell^-$
	$K^0_s\pi^+\pi^-\pi^+\pi^-\ell^+\ell^-$
$B^+ \to K^+\ell^+\ell^-$	$B^+ \to K^0_s\pi^+\ell^+\ell^-$
$K^+\pi^0\ell^+\ell^-$	$K^0_s\pi^+\pi^0\ell^+\ell^-$
$K^+\pi^+\pi^-\ell^+\ell^-$	$K^0_s\pi^+\pi^-\pi^+\ell^+\ell^-$
$K^+\pi^+\pi^-\pi^0\ell^+\ell^-$	$K^0_s\pi^+\pi^-\pi^+\pi^0\ell^+\ell^-$
$K^+\pi^+\pi^-\pi^+\pi^-\ell^+\ell^-$	

+ charge conjugated mode

- ~ 60% coverage of all X_S state
  ~ 80% coverage assuming $B.F.(K^0_L X_S) = B.F.(K^0_S X_S)$

Inclusive : B ➔ $X_s \ell^+\ell^-$





: Data

: Fitted curve

: Signal component

: Combinatorial background

: Combinatorial peaking background

: Self-cross-feed

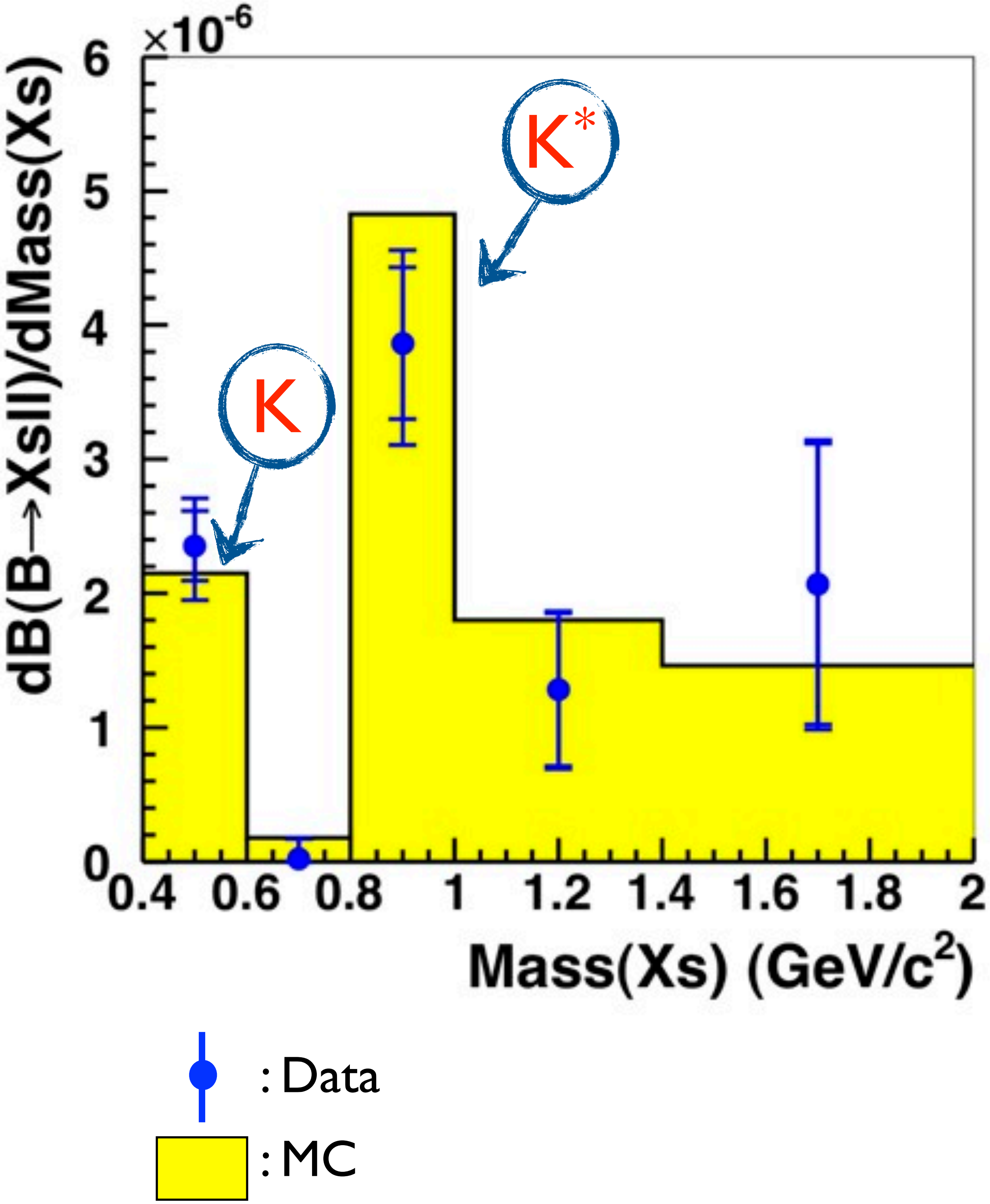
For all $M(X_S)$ region and $M(\ell^+\ell^-) > 0.2$ GeV/c²

Mode	Branching Fraction ($\times 10^{-6}$)
B ➔ $X_s e^+e^-$	4.56 ± 1.15 (stat.) $^{+0.33}_{-0.40}$ (syst.)
B ➔ $X_s \mu^+\mu^-$	1.91 ± 1.02 (stat.) $^{+0.16}_{-0.18}$ (syst.)
B ➔ $X_s \ell^+\ell^-$	3.33 ± 0.80 (stat.) $^{+0.19}_{-0.24}$ (syst.)

SM NNLO prediction : $(4.4 \pm 0.7) \times 10^{-6}$

Gambino et al., Phys. Rev. Lett. 94, 061803 (2005)

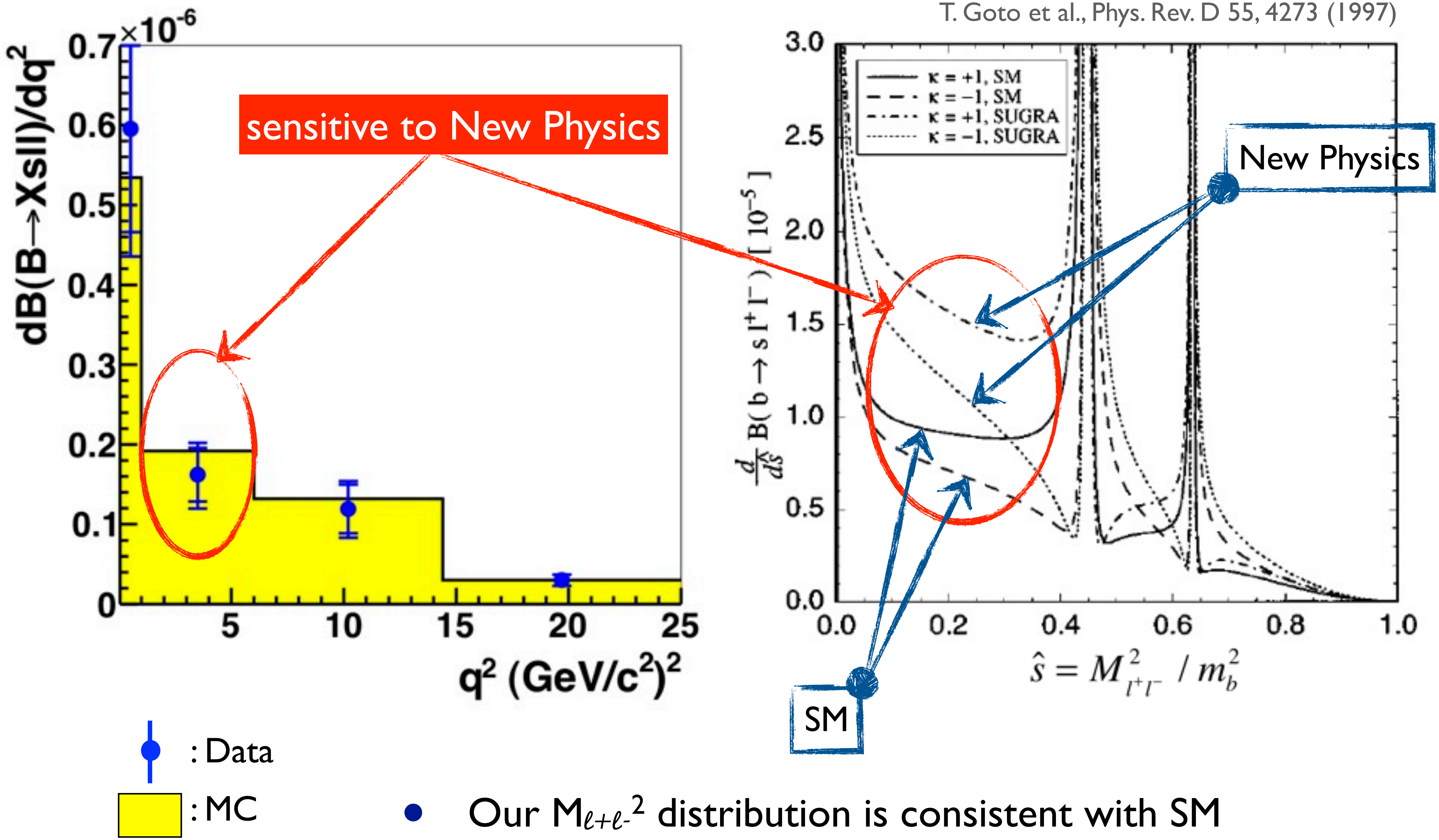
Inclusive : $B \to X_s \ell^+\ell^-$



- $dB(X_s \ell^+\ell^-)/dM(X_s)$
- MC normalization
  - for $B \to K^{(*)} \ell^+\ell^-$: based on HFAG world average (ICHEP08) (http://www.slac.stanford.edu/xorg/hfag/rare/index.html)
  - for $B \to X_s \ell^+\ell^-$: based on the measured branching fraction
- Our MC fragmentation model is consistent with data

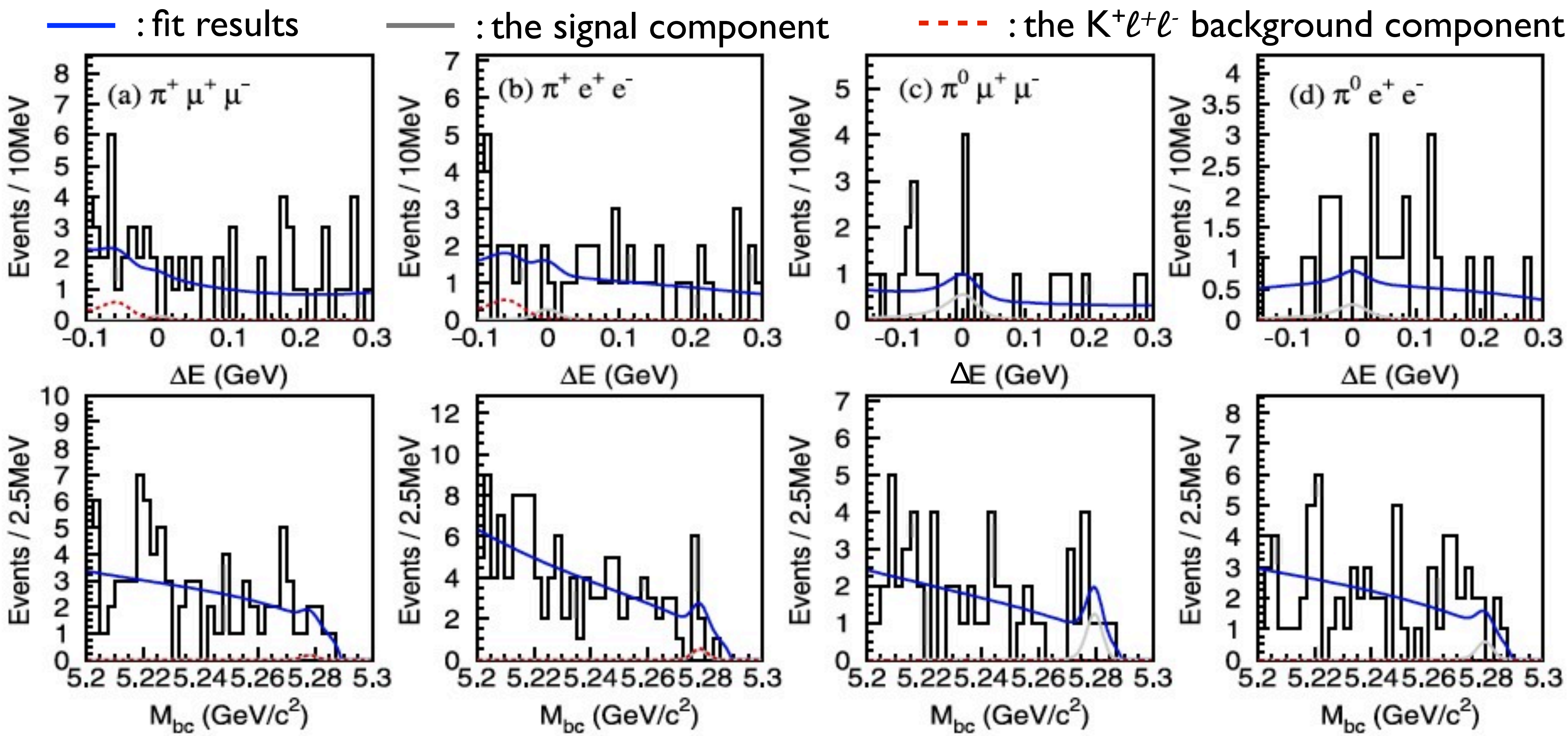
Inclusive : B → $X_s \ell^+\ell^-$

T. Goto et al., Phys. Rev. D 55, 4273 (1997)



- Our $M_{\ell^+\ell^-}^2$ distribution is consistent with SM

Exclusive : B → $\pi\ell^+\ell^-$



$$\mathfrak{B}(B \to \pi l^+ l^-) < 6.2 \times 10^{-8} @ 90\% \, C.L.$$

- The upper limit on the isospin-averaged branching fraction is two times larger than the SM expectation, and two-thirds of the *BABAR* measurement

Summary

- FCNC decays provide rich opportunities to test SM predictions and search for New Physics

- b ➔ s $\ell^+\ell^-$
  - Exclusive B ➔ $K^* \ell^+\ell^-$:
    - B.F., R_{K^*}, F_L and A_I are consistent with SM prediction, but A_{FB} needs more statistics
  - Inclusive B ➔ $X_s \ell^+\ell^-$:
    - B.F. is measured to be $(3.33 \pm 0.80\ ^{+0.19}_{-0.24}) \times 10^{-6}$ with 10.1σ significance
    - The distributions of $dB(X_s \ell^+\ell^-)/dM(X_s)$ and $dB(X_s \ell^+\ell^-)/dM(\ell^+\ell^-)^2$ are consistent with SM prediction

- Exclusive B ➔ $\pi \ell^+\ell^-$:
  - The upper limit on the isospin-averaged B.F. is about twice the SM expectation
  - Need significantly more statistics, event better PID

- SuperKEKB may reveal and elucidate the nature of New Physics