# $b \to s l^+ l^-$ and $b \to s \nu \bar{\nu}$ at Super-B

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# Outline

- Theoretical Introduction;
- Branching ratio measurements:
  - $B \rightarrow K(*)\nu\nu$ exclusive;
  - $B \rightarrow X_s ll$ inclusive;
- Other measurements:
  - $A_{FB}$, $A_{CP}$, etc...

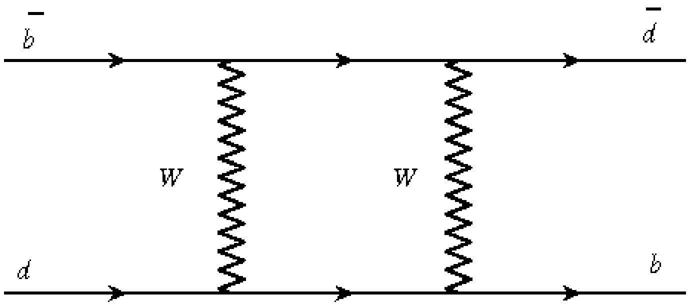
# Theoretical Introduction

# Theoretical Interest

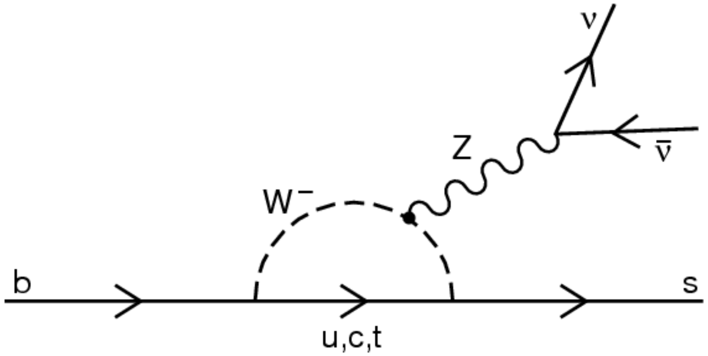
FCNC – A STANDARD PROBE FOR NP

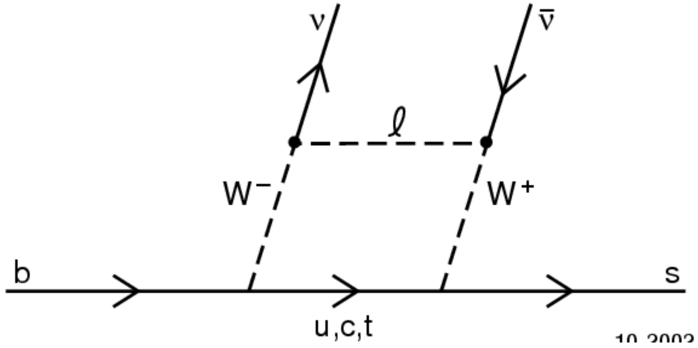
- $\Delta F = 2$ transitions:
  - well tested (BB mixing, KK mixing);
- $\Delta F = 1$ transitions:
  - deeper studies needed;
  - B sector cleaner than K sector;
  - $b \to s\gamma$, sll, $s\nu\nu$.

$\Delta F = 2$, B mixing




$\Delta F = 1$, $b \to s\ \nu\nu$



# NP Contributions

If NP appears above a scale $\Lambda_x$...

- 3 kinds of operators can appear in b → sll and b → s νν:
  - 4-fermion (integrate out new particles) $\propto 1/\Lambda_x^2$;
  - magnetic (effective quark-gauge coupling) $\propto 1/\Lambda_x$;
  - non-standard Z coupling $\propto 1$;

**Buchalla, Hiller, Isidori hep-ph/0006136**

$$\mathcal{L}^{Z}_{FC} = \frac{G_F}{\sqrt{2}}\frac{e}{\pi^2}M_Z^2\frac{\cos\Theta_W}{\sin\Theta_W}Z^\mu\left(Z^L_{sb}\,\bar{b}_L\gamma_\mu s_L + Z^R_{sb}\,\bar{b}_R\gamma_\mu s_R\right) + \text{h.c.}$$

$$Z^R_{sb}|_{\rm SM} = 0$$

$$x_t = m_t^2/m_W^2$$

$$Z^L_{sb}|_{\rm SM} = V^*_{tb}V_{ts}C_0(x_t)$$

SM Z-Penguin

$$\mathcal{B}(B\to X_s\ell^+\ell^-) = 1.76\times10^{-3}\left(\left|Z^L_{sb}\right|^2+\left|Z^R_{sb}\right|^2\right)$$

$$\mathcal{B}(B\to X_s\nu\bar{\nu}) = 1.05\times10^{-2}\left(\left|Z^L_{sb}\right|^2+\left|Z^R_{sb}\right|^2\right)$$

# Effective Hamiltonian

- In other words...

Contribute to B → $X_s ll$ (i=7,9,10)

$$\mathcal{H}_{eff} = -\frac{G_F}{\sqrt{2}} V_{ts}^* V_{tb} \left( \sum_{i=1}^{10} [C_i Q_i + C'_i Q'_i] + C_L^\nu Q_L^\nu + C_R^\nu Q_R^\nu \right) + \text{h.c.}$$

Contribute to B → K(*)νν

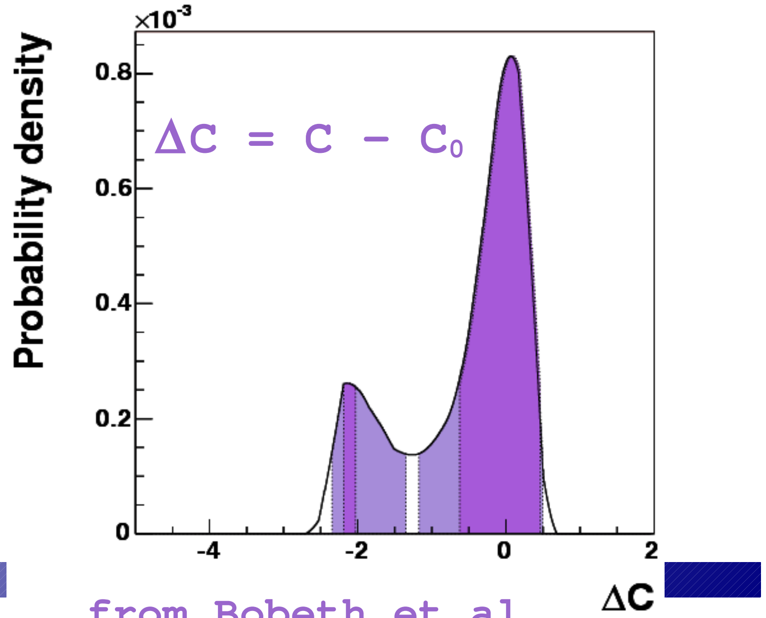
... where the Wilson Coefficient are related to $Z_{sb}^{L,R}$.

$$C_R^\nu|_{\rm SM} = 0$$

$$C_L^\nu|_{\rm SM} = \frac{4B_0(x_t) - C_0(x_t)}{\sin^2\Theta_W}$$

SM boxes

SM Z-penguins




from Bobeth et al, hep-ph/0505110

# Exotic NP

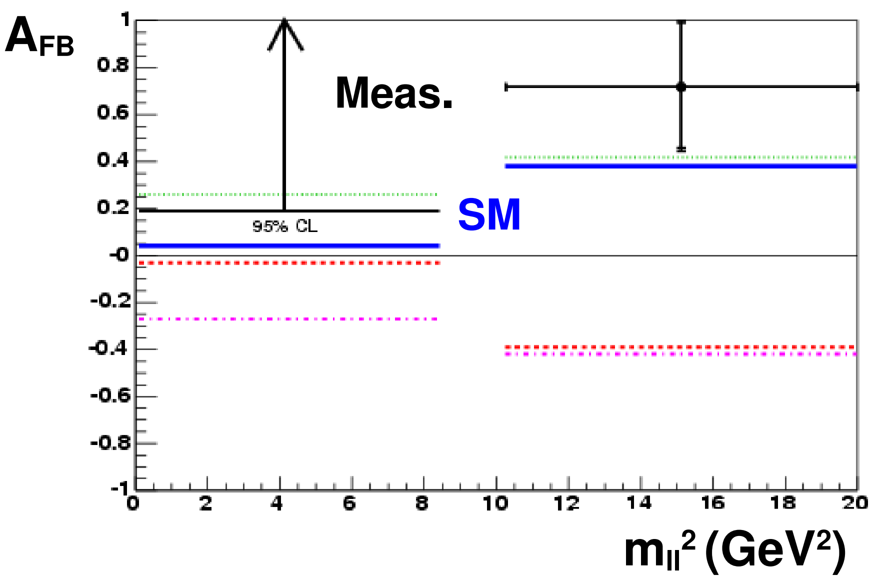
- $b \to s \nu\nu$ transitions also sensitive to exotic sources of invisible energy:
  - *NEW "INVISIBLE" PARTICLES FROM Z DECAY (C.Bird et al, "Dark Matter Particle Production in b → s Transitions with Missing Energy", Phys. Rev. Lett. 93,201803 (2004));*
  - *UNPARTICLE PHYSICS (H.Georgi, "Unparticle Physics", Phys. Rev. Lett. 98:221601 (2007); T.M.Aliev et al, "B → K(*) + missing energy in Unparticle physics", JHEP 0707:072 (2007)).*

# Exclusive B decays (I)

- Exclusive decays:
  - easier to access w.r.t. the inclusive ones, due to the better bkg rejection (inclusive $B \rightarrow X_s \nu\nu$ almost impossible to access);
  - BR estimate theoretically less clean (Form Factors);
  - *Other quantities* accessible (asymmetries, kinematical spectra) and theoretically cleaner;
- Kinematics is changed by NP:
  - Kinematical cuts affect the theoretical interpretation;
  - Kinematical cuts' efficiency can depend on the underlying physics → model dependence;
  - In presence of form factors, kinematic measurements (e.g. *FB asymmetry*) could give a cleaner evidence for NP w.r.t. the BR.

# Exclusive B decays (II)

- By Using Exclusive Decays, we can measure:
  - dilepton mass spectrum (both K(*) $\nu\nu$ and K(*) l l);
  - Forward-Backward asymmetry $A_{FB}$ in B → K(*) l l;
  - CP asymmetries (small in the SM);
  - Lepton flavor asymmetry (SUSY neutral Higgs);



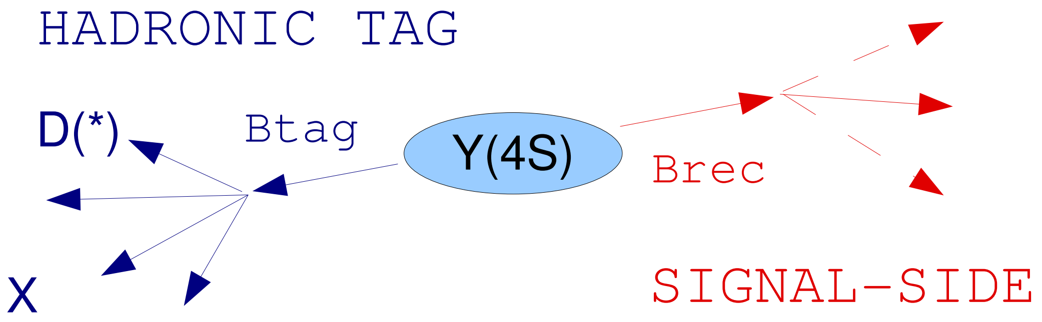

*Hint of deviation from the SM in the K* l l FB asymmetry at low $m_{ll}$*

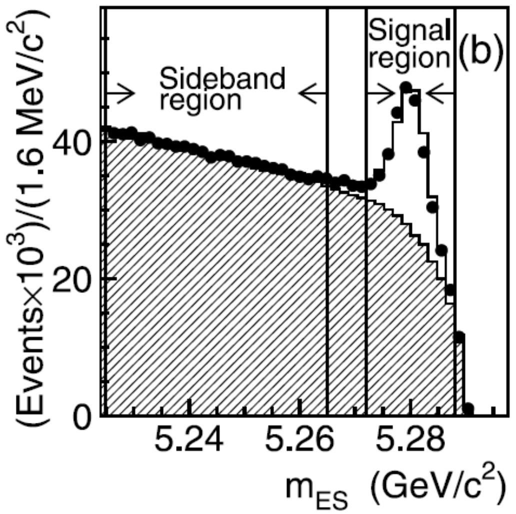
**BaBar Collab. hep-ex/0604007**

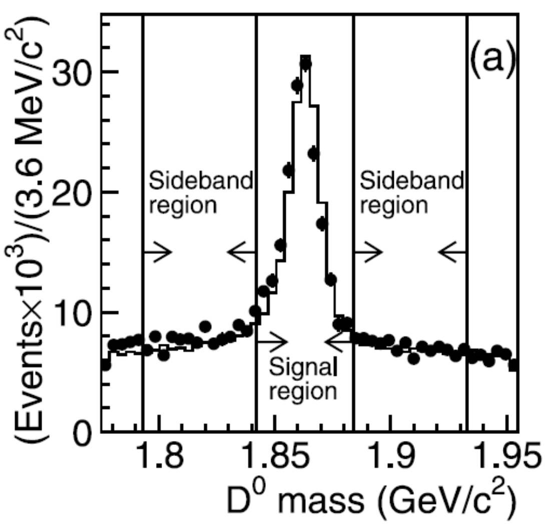
# BR Measurements at Super-B

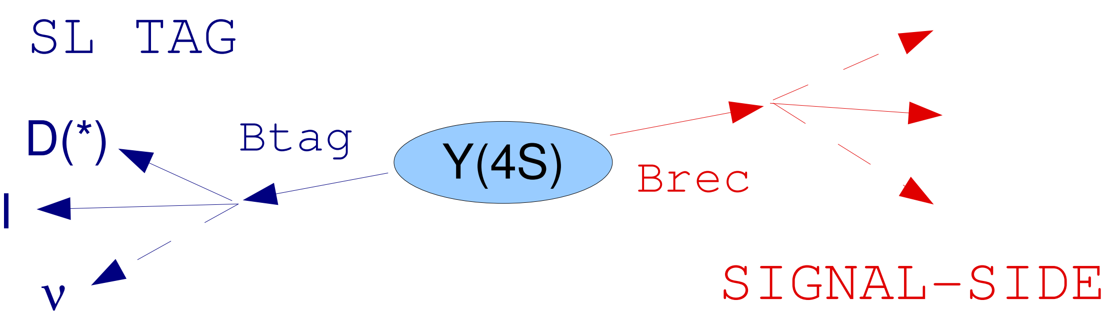
# Recoil Technique (I)

- Most of the searches for rare B decays performed by exploiting the Recoil Technique:



# Recoil Technique (II)

EXPECTED IMPROVEMENTS at SUPER-B

- The Super-B detector design would introduce significant improvement in the recoil performances;
- HERMITICITY:
  - helps to reduce the background when applying a cut on the track multiplicity in the recoil (see M. Mazur talk in Paris ) → *30% bkg reduction is realistic*
  - modify the distribution of Eextra (the most important cut) → *effect to be established, see next slide*
- VERTEXING:
  - vertexing informations poorly used at present;
  - bkg reduction is probably possible applying vertexing requirements and secondary vertex informations;
- OTHER (PID, $K_L^0$ veto, etc.).

# Recoil Technique (II)

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  - modify ... t important cut) → ... *slide*
- VERTEXING:
  - vertexing informations poorly used at present;
  - bkg reduction is probably possible applying vertexing requirements and secondary vertex informations;
- OTHER (PID, $K_L^0$ veto, etc.).

**Detailed Simulations Needed to have precise estimates of improvements**

# Recoil Technique (III)

IMPACT OF THE HERMITICITY ON Eextra

- $E_{extra}$ (most important variable for the signal selection):
  - *EMC energy that remains after all tag side tracks and neutral clusters have been accounted for;*
- INCREASED HERMITICITY increases the number of photons reconstructed in both signal and background, so the Eextra distributions is smeared.
- TEST:
  - Smear the distributions, adding a Poisson number of random energy photons to each event (average number of ph. from acceptance calculation; energy spectrum from MC)
  - Extended ML Fit, w/ and w/o smearing, and compare the errors on the yields.

**NO SIGNIFICANT IMPACT ON THE ERRORS**

# Simulation Approach

- Toy MC simulations has been performed assuming realistic (hopefully...) scenarios to estimate the expected yields;
- Conservative approach:
  - Assume the BaBar analysis techniques with no improvement;
- PERFORMANCES – Three scenarios:
  - BaBar efficiency & BaBar BKG;
  - BaBar efficiency & 30% less BKG;
  - BaBar efficiency & 50% less BKG;
- LUMINOSITY – 6 scenarios, from 1 $ab^{-1}$ to 50 $ab^{-1}$.

# Inclusive $B \to X_s \nu \nu$

$$\text{SM: } \mathcal{BR}(B \to X_s \nu\bar{\nu}) < (4.43 \pm 0.06) \times 10^{-5}$$

G. Buchalla and A. Buras
Nucl.Phys.B400:225-239,1993

- No current exp. result;
- No feasibility study available in BaBar;
- Need for a complete study to evaluate the SuperB reach.
- Anyway...
  - *General feeling is that the analysis would be essentially unable to reach an interesting sensitivity due to huge backgrounds.*

# $B^+ \rightarrow K^+ \nu \nu$ (I)

SM: $\mathcal{BR}(B \to K\nu\bar{\nu}) = (3.8^{+1.2}_{-0.6}) \times 10^{-6}$

HFAG: $\mathcal{BR}(B^+ \to K^+\nu\bar{\nu}) < 14 \times 10^{-6}$

PUBLISHED and ON-GOING BABAR ANALYSES

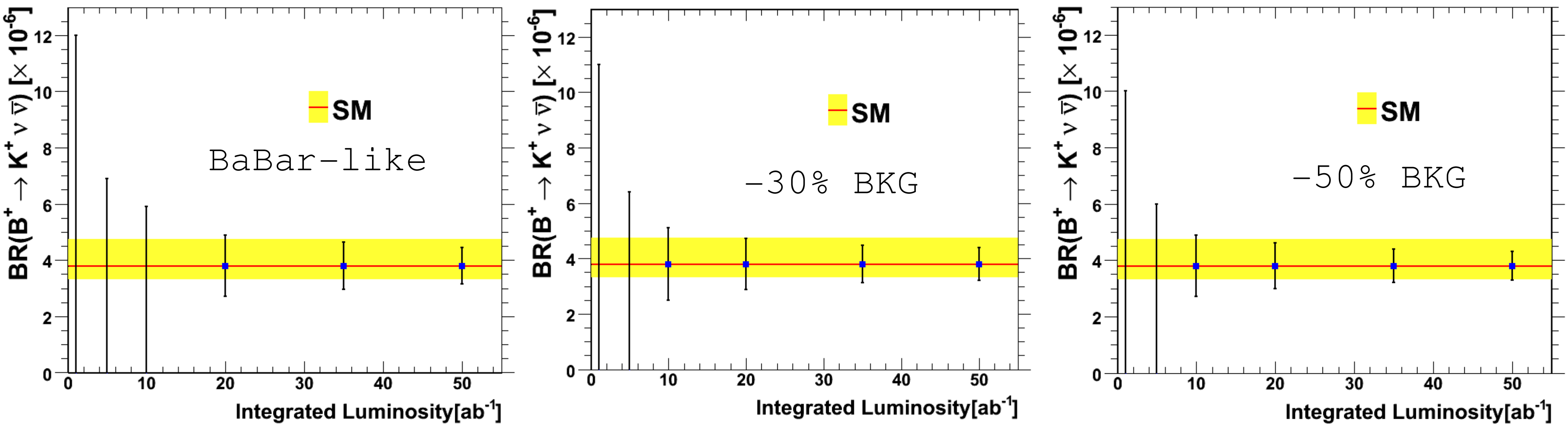
- Recoil Technique (both HAD and SL);
- Kinematics: cut on the K CM momentum;
- Cut-and-count technique;

EXPECTED YIELDS PER $ab^{-1}$

| SL RECOIL | HAD RECOIL |
|---|---|
| $N_{\rm sig} = 6.4 \quad (\varepsilon = 0.00164)$ | $N_{\rm sig} = 2.6 \quad (\varepsilon = 0.000678)$ |
| $N_{\rm bkg} = 84$ | $N_{\rm bkg} = 60$ |

# $B^+ \to K^+ \nu \nu$ (II)

## RESULTS at SUPER-B




*Observation between 10 and 20 $ab^{-1}$;*

*Exp. error ~ theoretical error around 30 $ab^{-1}$;*

*18% error at 50$ab^{-1}$ in the most conservative scenario.*

# $B^0 \rightarrow K^{*0}\,\nu\,\nu$ (I)

$$\text{SM: } \mathcal{BR}(B \to K^* \nu\bar{\nu}) = (1.3^{+0.4}_{-0.3}) \times 10^{-5}$$

$$\text{HFAG: } \mathcal{BR}(B^0 \to K^{*0} \nu\bar{\nu}) < 34 \times 10^{-5}$$

ON-GOING BABAR ANALYSES

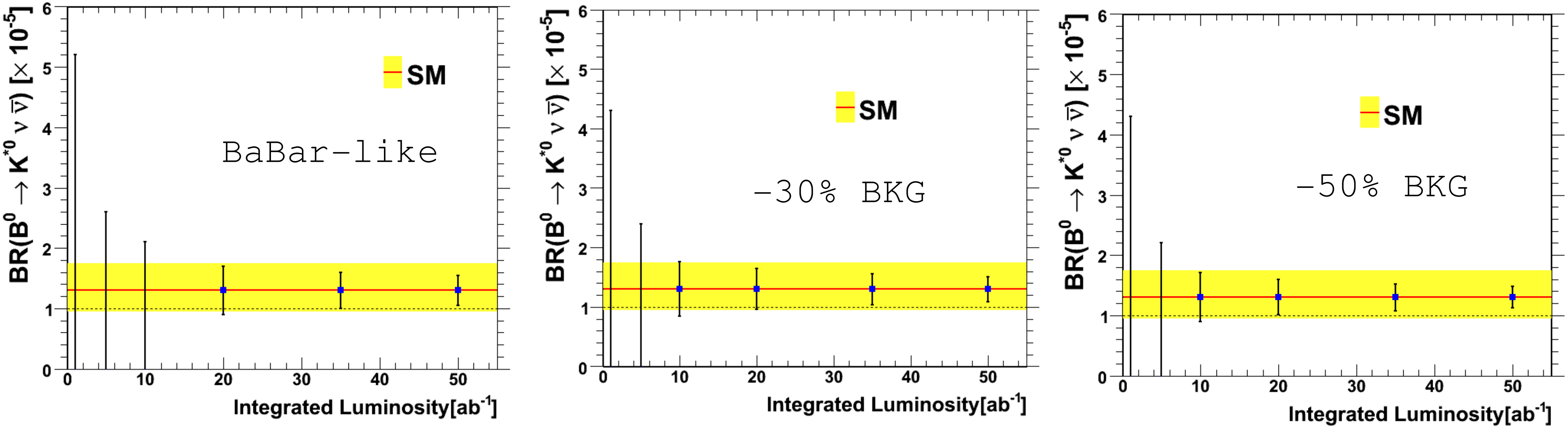
- Recoil Technique (both HAD and SL);
- No Kinematical cut;
- ML Fit on $E_{extra}$ (SL) and cut-and-count (HAD);

EXPECTED YIELDS PER $ab^{-1}$

| SL RECOIL | HAD RECOIL |
|---|---|
| $N_{\text{sig}} = 10 \quad (\varepsilon = 0.0007501)$ | $N_{\text{sig}} = 2.4 \quad (\varepsilon = 0.0001713)$ |
| $N_{\text{bkg}} = 1584$ | $N_{\text{bkg}} = 53$ |

# $B^0 \rightarrow K^{*0}\,\nu\,\nu$ (II)

## RESULTS at SUPER-B




*Observation between 10 and 20 $ab^{-1}$;*

*Exp. error ~ theoretical error around 20 $ab^{-1}$;*

*20% error at 50$ab^{-1}$ in the most conservative scenario.*

# $B^+ \to K^{*+} \nu \nu$ (I)

SM: $\mathcal{BR}(B \to K^* \nu\bar{\nu}) = (1.3^{+0.4}_{-0.3}) \times 10^{-5}$

HFAG: $\mathcal{BR}(B^0 \to K^{*0} \nu\bar{\nu}) < 14 \times 10^{-5}$

ON-GOING BABAR ANALYSES

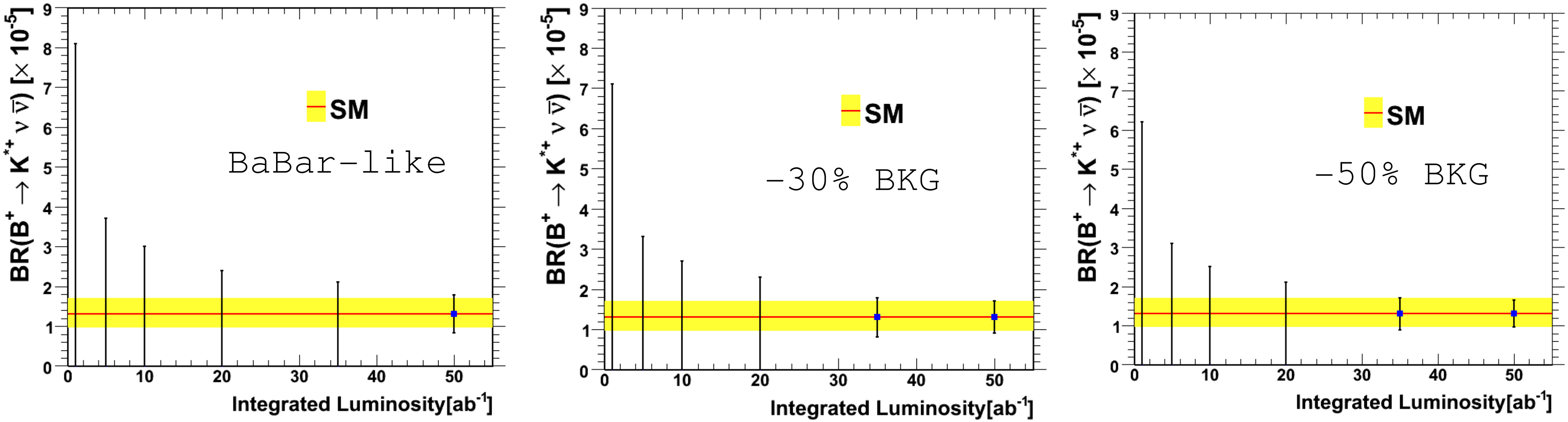
- See the neutral channel;

EXPECTED YIELDS PER $ab^{-1}$

| K*+ channel | SL RECOIL | HAD RECOIL |
|---|---|---|
| $K_S^0 \pi^+$ | $N_{sig} = 6$ $(\varepsilon = 0.0004205)$<br>$N_{bkg} = 2057$ | $N_{sig} = 1$ $(\varepsilon = 0.0000695)$<br>$N_{bkg} = 19$ |
| $K^+ \pi^0$ | $N_{sig} = 8.5$ $(\varepsilon = 0.0005950)$<br>$N_{bkg} = 2171$ | $N_{sig} = 1.4$ $(\varepsilon = 0.0000993)$<br>$N_{bkg} = 31$ |

# $B^+ \rightarrow K^{*+}(K_S^0\pi^+)\ \nu\ \nu$

RESULTS at SUPER-B



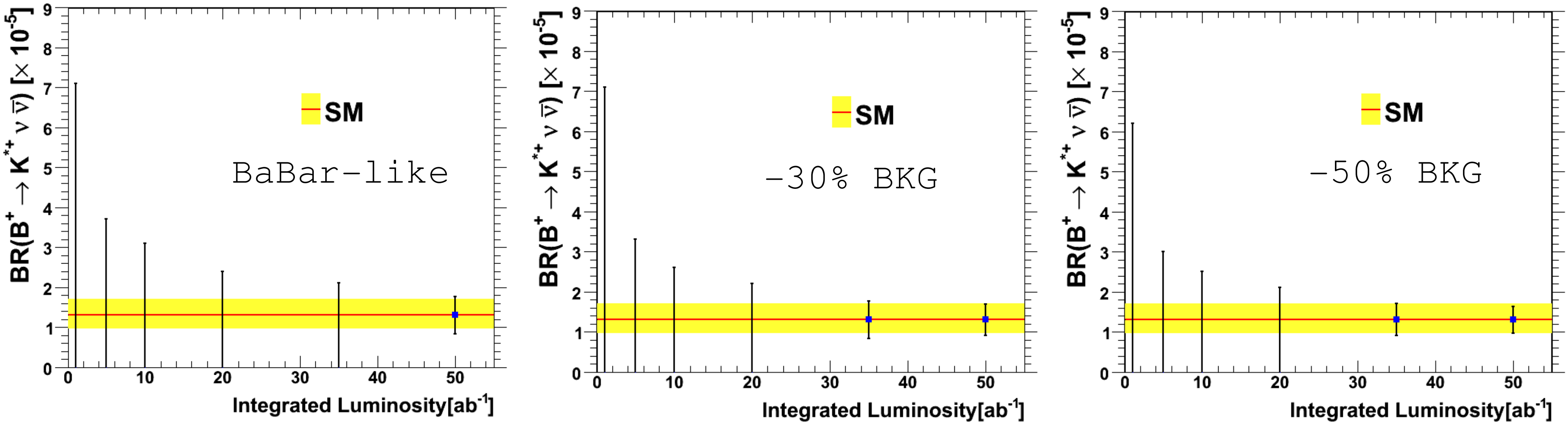

*Observation between 30 and 50 ab$^{-1}$;*

*Exp. error ~ theoretical error around 50 ab$^{-1}$;*

*35% error at 50ab$^{-1}$ in the most conservative scenario.*

# $B^+ \rightarrow K^{*+}(K^+\pi^0)\ \nu\ \nu$

## RESULTS at SUPER-B




*Observation around 30 $ab^{-1}$;*

*Exp. error ~ theoretical error around 50 $ab^{-1}$;*

*35% error at 50$ab^{-1}$ in the most conservative scenario.*

# $B \to \tau\nu$ background

- $B \to \tau\nu$ is an irreducible source of background for $B^+ \to K(*)^+ \nu\nu$;
- Small component (~ few per mille) of the background, but *peaking in Eextra and ~25% of signal or more;*
- Impact negligible at low statistics (absorbed by other bkg fluctuations) but can be significant at high statistics.
- In the previous simulations:
  - $B \to \tau\nu$ included in the bkg yields → *cut-and-count simulations are correct*
  - No peaking parameterization for $B \to \tau\nu$ in the Eextra fit → *sensitivity of SL $B^+ \to K^{*+} \nu\nu$ analysis could be much worse and affected by a large systematics*
- Anyway, observation of $B^+ \to K^{*+} \nu\nu$ should be guaranteed.

# $B \rightarrow X_s l^+ l^-$

CAVEAT

- At present, $b \rightarrow s l^+ l^-$ analyses does NOT adopt the recoil technique (but with higher statistics recoil would become competitive) → conservatively, I assume current techniques;
- Background reduction can be different for non-recoil analyses (30% and 50% reductions could be not realistic);

I WILL SHOW THAT...

- The inclusive $B \rightarrow X_s l^+ l^-$ will be well accessible at Super-B.
- Semi-inclusive approaches will becomes not competitive due to the systematic uncertainties on the decay models;
- Exclusive measurements will be mainly useful for other measurements (e.g. asymmetries).

# Inclusive $B \to X_s l^+ l^-$ (I)

Many Thanks to G. Eigen, I. Ofte and L. Sun!!!

SM: $\mathcal{BR}(B \to X_s l^+ l^-) = (4.18 \pm 0.70) \times 10^{-6}$ **A. Ali, hep-ph/0210183**

HFAG: $\mathcal{BR}(B \to X_s l^+ l^-) = (4.5 \pm 1.0) \times 10^{-6}$

- A feasibility study for a fully inclusive $B \to X_s l^+ l^-$ has been performed in BaBar:
  - Multivariate Analysis (Boosted Decision Tree);
  - $m_{ll} > 0.2$ GeV;
  - Cut & Count approach;

EXPECTED YIELDS PER $ab^{-1}$

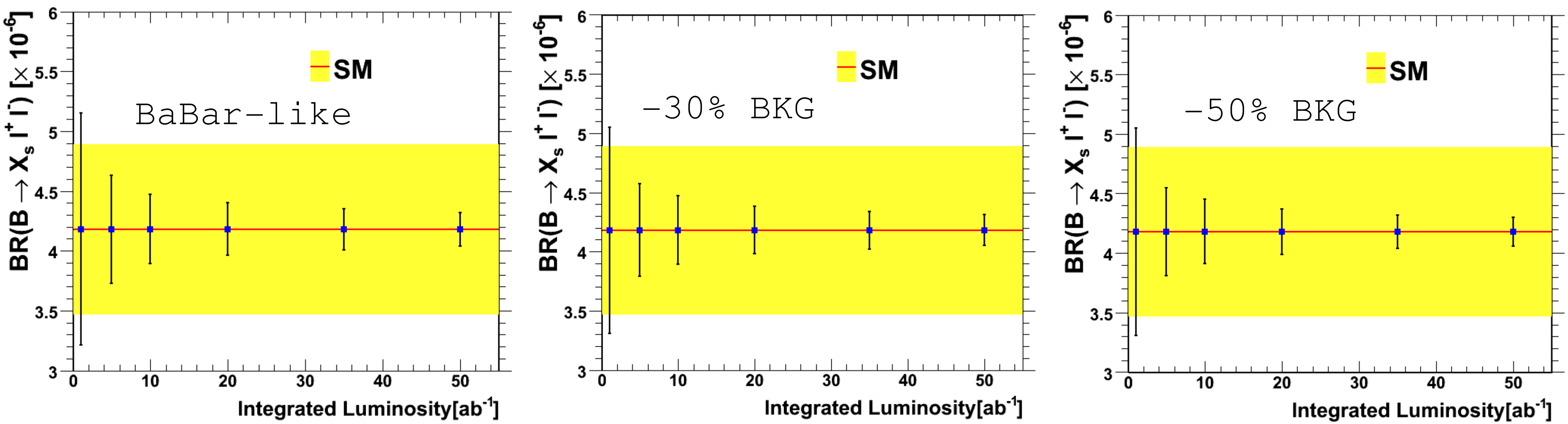
$$N_{\rm sig} = 43 \quad (\varepsilon = 0.0103)$$

$$N_{\rm bkg} = 65$$

*A recoil analysis would become competitive with several $ab^{-1}$*

# Inclusive $B \rightarrow X_s l^+ l^-$ (II)

RESULTS at SUPER-B




*Exp. error ~ theoretical error with few $ab^{-1}$;*

*Few percent stat. error can be reached;*

*Could become systematics dominated, and in any case the theoretical error will limit any interpretation.*

# Semi-Incl. $B \rightarrow X_s l^+ l^-$

- $X_s$ = 1K + $n\pi$, $n \le 3$;
- Current BaBar result (~82 $fb^{-1}$, *hep-ex/0404006*):

$$\mathcal{BR}(B \to X_s l^+ l^-) = (5.64 \pm 1.46_{\rm stat} \pm 0.60_{\rm syst} \pm 1.06_{\rm model}) \times 10^{-6}$$

that is expected to become completely systematics dominated around 1 $ab^{-1}$;

- Dominant systematics (~1 x $10^{-6}$) from the signal model, in particular the ratio:

$$\frac{\mathcal{BR}(B \to K^{(*)} l^+ l^-)}{\mathcal{BR}(B \to X_s l^+ l^-)}$$

to be taken from the theory.

# Other Measurements at Super-B

# Generalities

- Several *asymmetries* and *rate ratios* can be defined, usually as functions of $m_{ll}^2$;
- These quantities, and their dependence on $m_{ll}^2$, can be affected by NP effects;
- Some theoretical uncertainties cancel out:
  - cleaner predictions w.r.t. BR

Forward–Backward Asymmetry

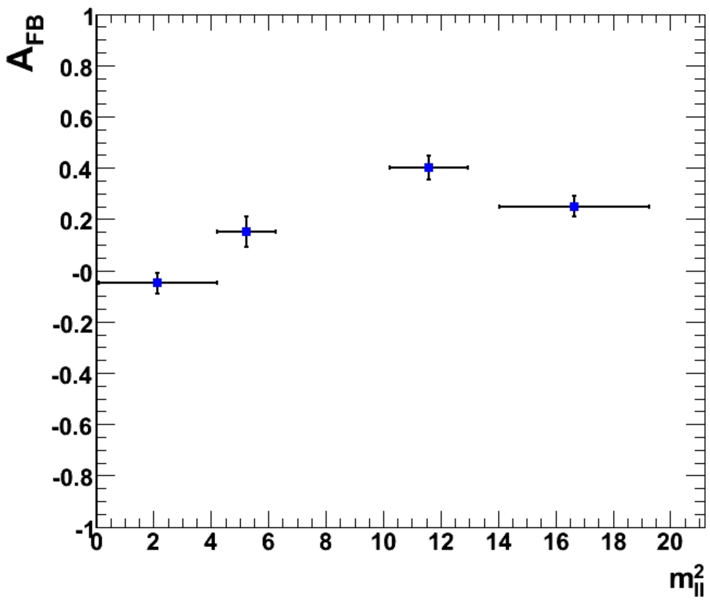
Direct CP Asymmetry

Lepton flavor asymmetry

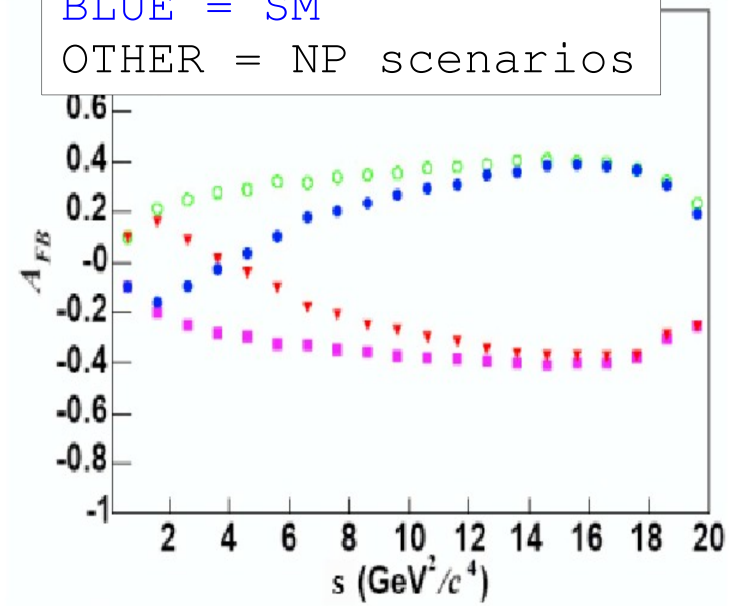
...

# $A_{FB}$ in $B \to K^{*0} l^+ l^-$

RESULTS at SUPER-B




Theory:
BLUE = SM
OTHER = NP scenarios




*50 ab$^{-1}$, BaBar Efficiency & BKG*

*Cut & Count (possible improvements by fitting the angular distribution)*

# Conclusions

- $b \to s l^+ l^-$ and $b \to s \nu \nu$ transitions are good probes for NP:
  - Non-standard Z-couplings (e.g. in SUSY);
  - Exotic NP (light dark matter, unparticles);
- All the most interesting exclusive channels can be accessed at Super-B;
- The inclusive $B \to X_s l^+ l^-$ BR can be measured with a few percent stat. error → syst. & theo. dominant
- Exclusive $B \to K(*) l^+ l^-$ modes can be used to measure, with good precision, theoretically clean quantities (e.g. asymmetries) that are sensitive to NP.

*A systematic phenomenological effort is needed to completely assess the physics reach in this sector.*

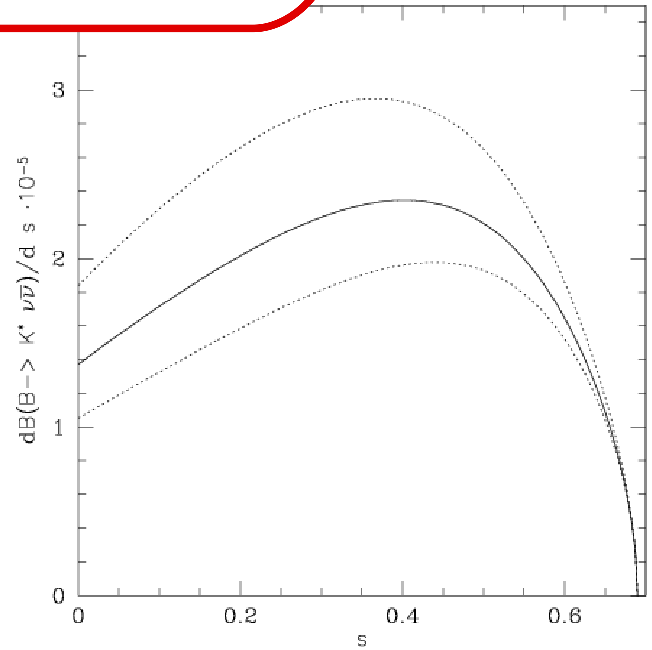
# Backup

# $K^*\nu\,\nu$ spectrum and BR

$$\frac{d\Gamma(B\to K^*\nu\bar\nu)}{ds} = \frac{G_F^2\alpha^2 m_B^5}{1024\pi^5}\,|V_{ts}^*V_{tb}|^2\,\lambda_{K^*}^{1/2}(s)\left\{\frac{8s\lambda_{K^*}(s)V^2(s)}{(1+\sqrt{r_{K^*}})^2}\,|C_L^\nu+C_R^\nu|^2\right.$$
$$+\frac{1}{r_{K^*}}\Big[(1+\sqrt{r_{K^*}})^2\,(\lambda_{K^*}(s)+12r_{K^*}s)\,A_1^2(s)+\frac{\lambda_{K^*}^2(s)A_2^2(s)}{(1+\sqrt{r_{K^*}})^2}$$
$$\left.-\,2\lambda_{K^*}(s)(1-r_{K^*}-s)A_1(s)A_2(s)\Big]\,|C_L^\nu-C_R^\nu|^2\right\}$$

$$\mathcal{B}(B\to K^*\nu\bar\nu) = (2.4^{+1.0}_{-0.5})\times 10^{-6}\left|\frac{C_L^\nu+C_R^\nu}{C_L|_{SM}^\nu}\right|^2 + (1.1^{+0.3}_{-0.2})\times 10^{-5}\left|\frac{C_L^\nu-C_R^\nu}{C_L|_{SM}^\nu}\right|^2$$

$$\mathcal{B}(B\to K^*\nu\bar\nu)\Big|_{\rm SM} = (1.3^{+0.4}_{-0.3})\times 10^{-5}$$

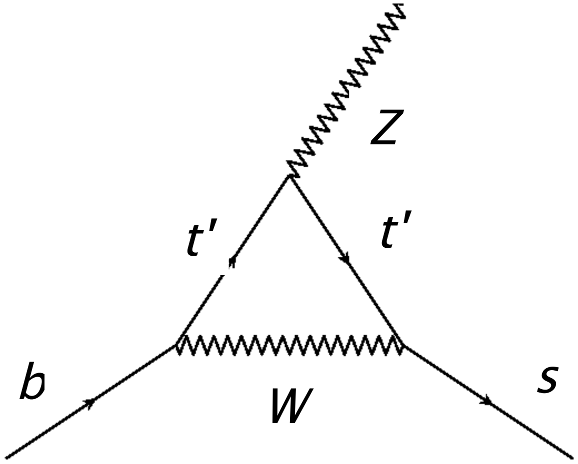


# Some Models

- Many models can produce non-standard Z couplings:
  - $4^{th}$ generation:

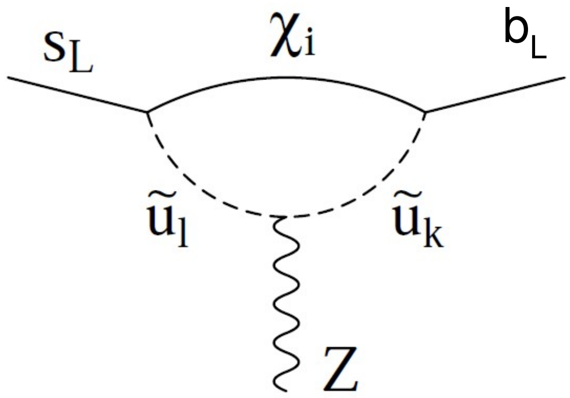
$$Z^R_{qb}|_{4^{\rm th}} = 0$$

$$Z^L_{qb}|_{4^{\rm th}} = V^*_{t'b} V_{t'q} C_0(x_{t'}) \simeq \frac{x_{t'}}{8} V^*_{t'b} V_{t'q}$$



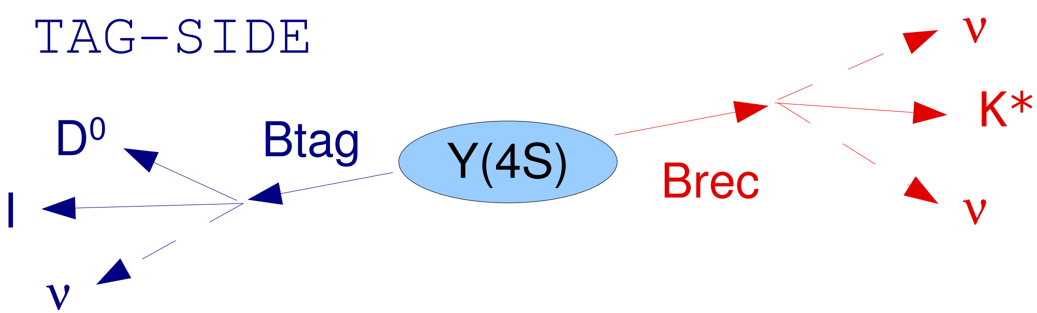

  - SUSY:
    - chargino-up-squark contribution:

$$\left| Z^L_{sb}|^{\rm RL}_{\rm SUSY} \right| \lesssim 0.1 \left| \frac{(M^2_U)_{t_R s_L}}{M^2_{\tilde{u}_L}} \right| = 0.1 \left| (\delta^U_{RL})_{32} \right|$$



# Analysis Method

- B → K* n n in the recoil (Semileptonic tag):




- Blind analysis – signal region defined by $E_{extra}$ and $D^0$ mass $M_D$:

$E_{extra}$: “neutral energy that remains after all tag side tracks and neutral clusters have been accounted for”