# *Radiative and Leptonic Rare B-Decays*

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# Rare B decays

**FCNC:**
no **tree-level** contribution in SM

**Leptonic decays:**
**helicity** suppression and/or $|V_{ub}|^2$ dependence

→ **sensitivity to New Physics** ←

➢ **Radiative decays:** $b \to s\gamma$ and $b \to d\gamma$

- $B \to X_s\gamma$ Br ($A_{cp}$): flavour dynamics test, $m_b, \lambda_1$ from $E_\gamma$ spectrum
- $B \to K^*(892)\gamma$ $A_{cp}$
- $B \to \omega(\rho)\gamma$ Br : sensitive to $|V_{td}|$

➢ **Electroweak decays:** $b \to s l^+ l^-$

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

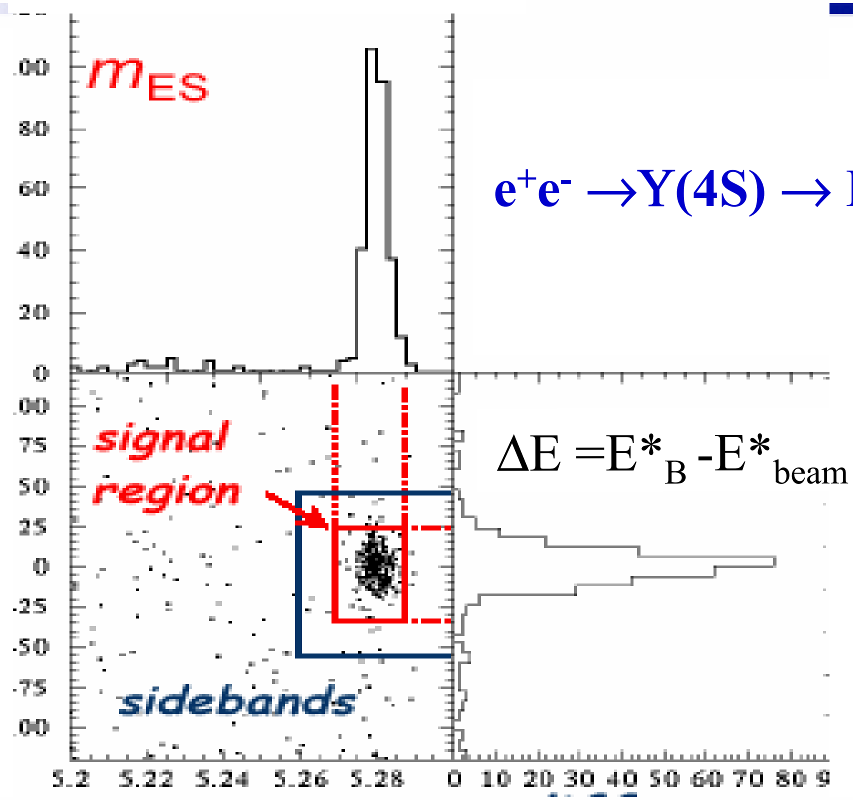
} $M^2_{inv}(l^+l^-)=q^2$ & $A_{FB}$ :constraints on NP

➢ **Challenging modes with neutrino and/or helicity suppression:**

- $B \to K\nu\nu$ Br : theoretically cleaner than $K^{(*)}l^+l$
- $B \to \tau(\mu)\nu$ Br : sensitive to $|V_{ub}|\cdot f_b$
- $B \to l^+ l^-$ Br

# Analysis techniques

$$m_{ES} = \sqrt{\left(E_{beam}^2 - P_B^2\right)}$$

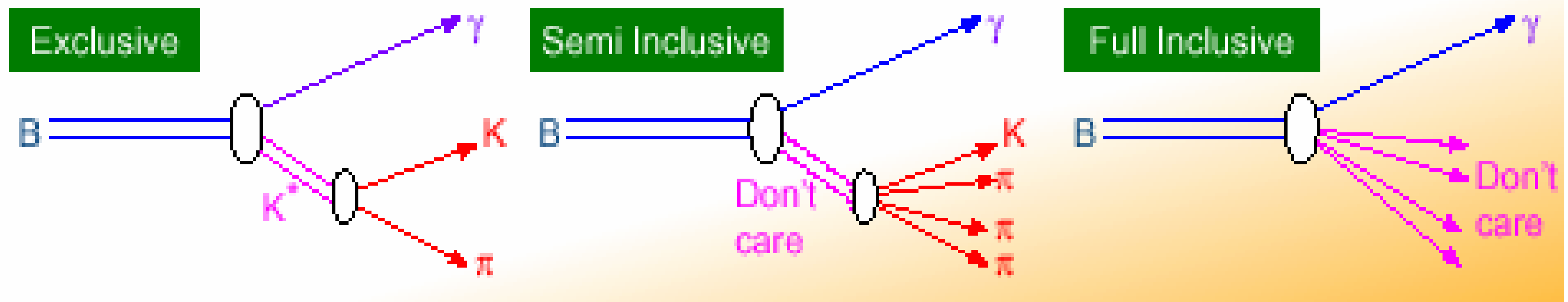



$e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB$

$\Delta E = E^*_B - E^*_{beam}$

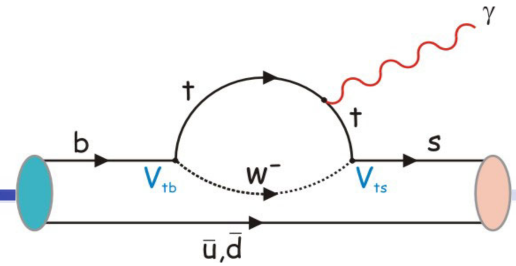
- **Exclusive:**
  **e,K, μ,γ,π PID** and
  **mass and energy constraints: $m_{ES}$,ΔE**
  **theories are not so reliable**

- **Inclusive**
  - ***Semi-Inclusive***
    **(e.g. $B \to X_s\gamma$ with $X_s = K + n(\pi)$)**
    **large model dependence**
  - ***Fully Inclusive***
    **(e.g. the γ only in $B \to X_s\gamma$)**
    **very huge background**



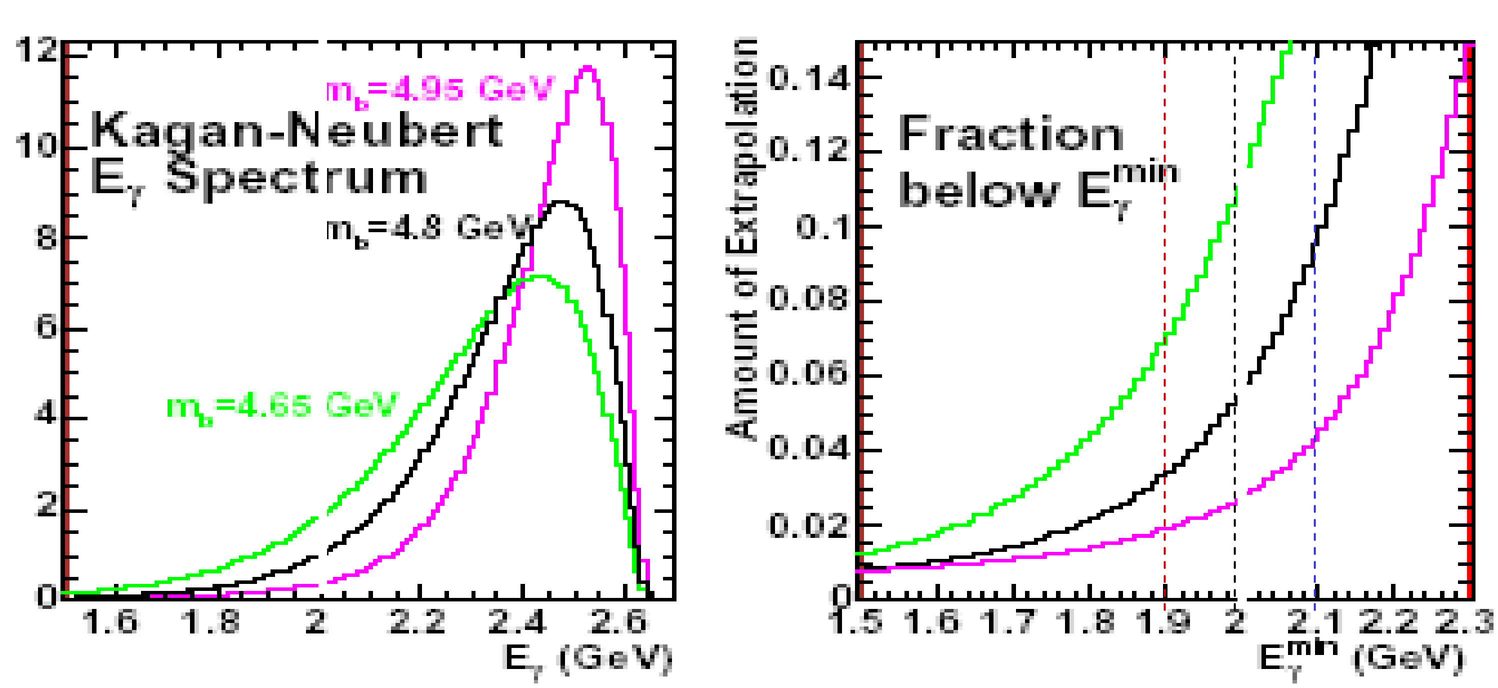

**$e^+e^- \to qq(g)$ suppression: event shape variables(Fisher or Neural Network)**

# $B \to X_s \gamma$




➢Monochromatic spectrum ($E_\gamma \sim m_b/2$) smeared by b-s interaction & confinement ⇒ Fermi motion

➢Kagan-Neubert parametrization: $E_\gamma$ spectrum function of $m_b$ and $P_F$, universal at low order in ($\Lambda_{QCD}/m_b$) ⇒ same $b \to u l \nu$ shape function ⇒ $V_{ub}$

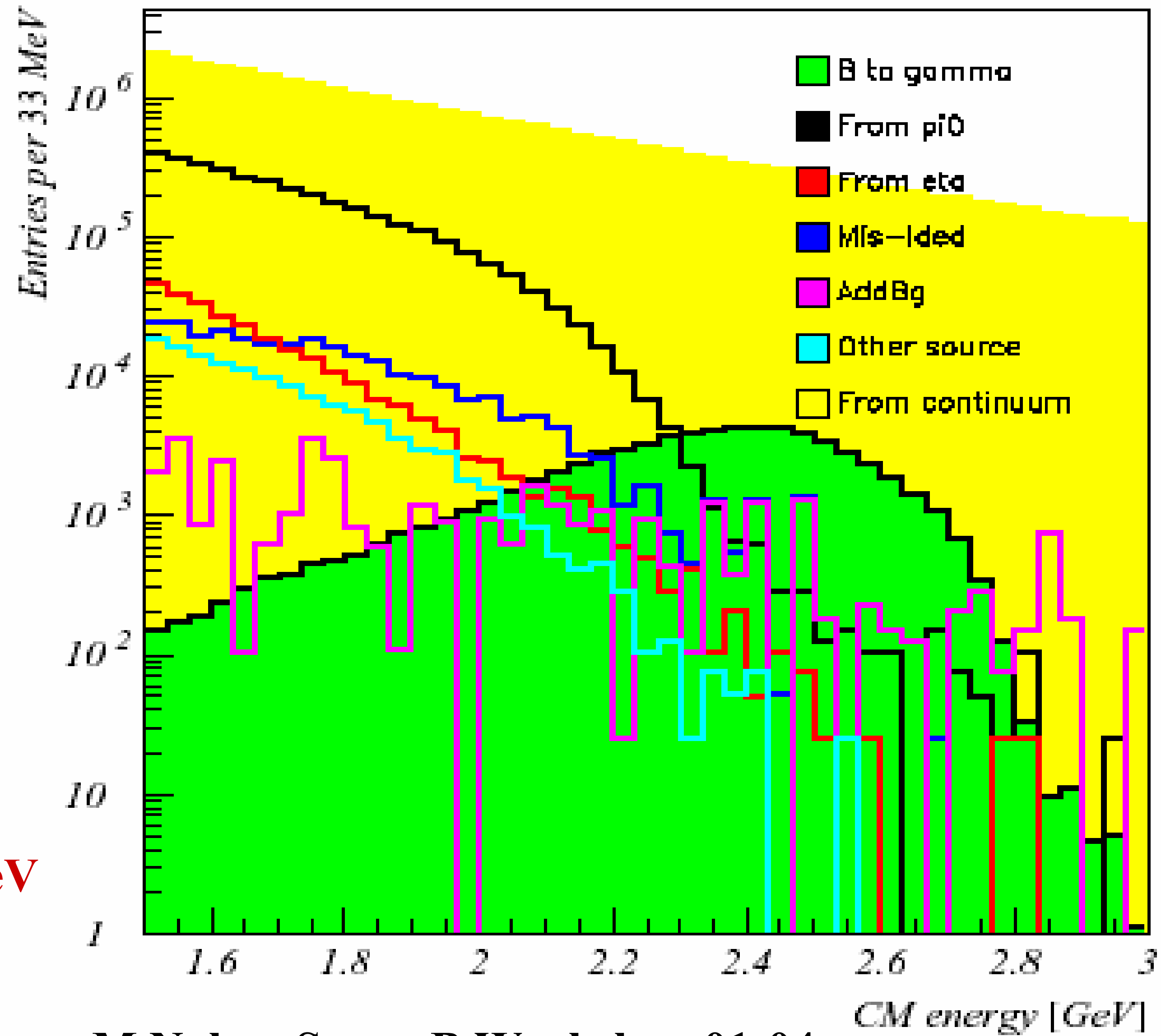



➢ $E_\gamma$ spectrum model dependent ⇒ as few cuts on $E_\gamma$ and $M_{XS}$ as possible

➢ Spectrum modified to include K*(892) resonance

# Experimental challenge

- **Continuum bkgd:**
  **$q\bar{q} \rightarrow X + \pi^0/\eta^0/\omega^0$**
- **BB bkgd:**
  **•$\gamma$ from $\pi^0$,$\eta$**
  **•mis-id hadronic decays**
- **$E_{MIN}$ as low as possible**
  **⇒ model dependence**
- **Roughly x2 bkgd when $E_{MIN}$ lowered by 0.1 GeV**



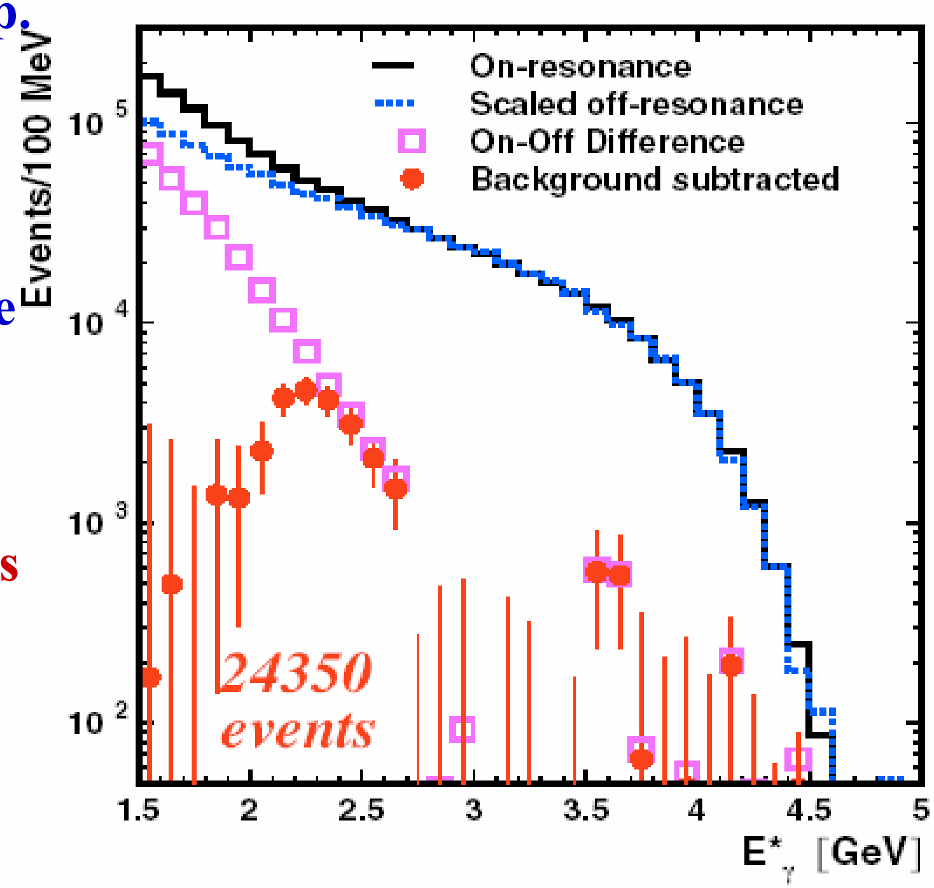

**M.Nakao Super B Workshop 01-04**

# Belle: Fully Inclusive $B \to X_s \gamma$

**$140\ fb^{-1}$**

- **High energy photon:**
  **Emc shower profile consistent with $\gamma$ hyp.**
  **$\pi^0$ and $\eta$ veto**
- **$e^+e^-$ -> qq: Fisher discriminant**
- **Subtract continuum using off-resonance data**
- **Subtract BB bkgd using MC efficiency corrected and scaled by measured yields on data ($\pi^0$ and $\eta$ spectrum)**
- $B \to X_d \gamma$ events subtracted using theory prediction: $R_{d/s}$= (3.8±0.6)%

**Signal region: $E_\gamma$ [1.8; 2.7] GeV**



# Fully Inclusive $B \to X_s \gamma$

**Theory:** $Br(B \to X_s\gamma) = (3.73 \pm 0.30) \cdot 10^{-4}$

*(Gambino & Misiak Nucl.Phys. B 611, 2001)*

**Belle ($140 fb^{-1}$): hep-ex 0403004**

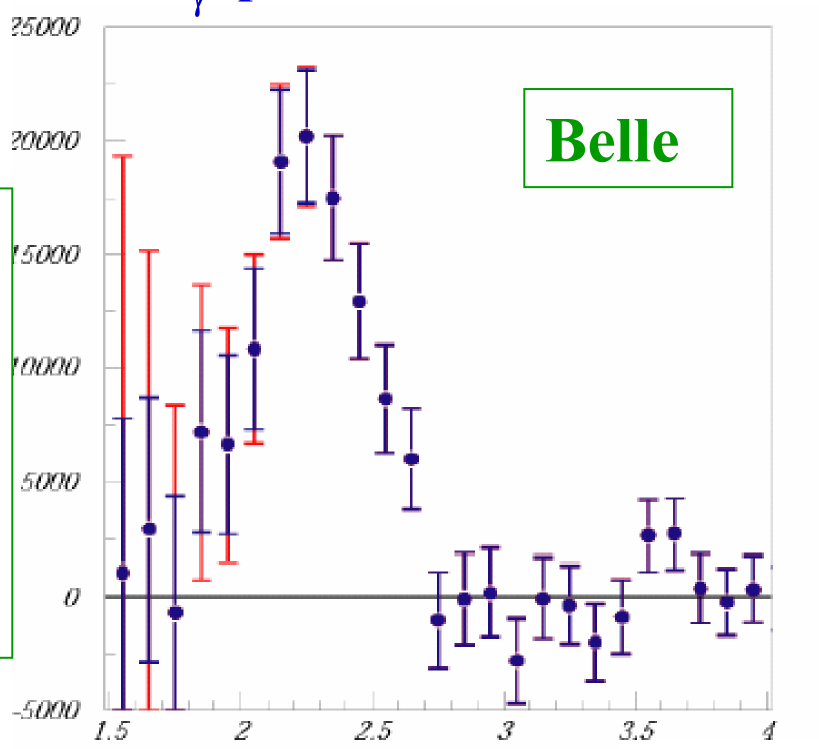
$Br(B \to X_s\gamma) = (3.59 \pm 0.32\ ^{+0.30}_{-0.31}\ ^{+0.11}_{-0.07}) \cdot 10^{-4}$

$\langle E_\gamma \rangle = 2.289 \pm 0.026 \pm 0.034$

$\langle E^2_\gamma \rangle - \langle E_\gamma \rangle^2 = 0.0311 \pm 0.0073 \pm 0.0063$

$1.8 < E_\gamma < 2.7$ GeV

$E_\gamma$ spectrum eff. corrected




**Babar ($54.4 fb^{-1}$): hep-ex 0207076**

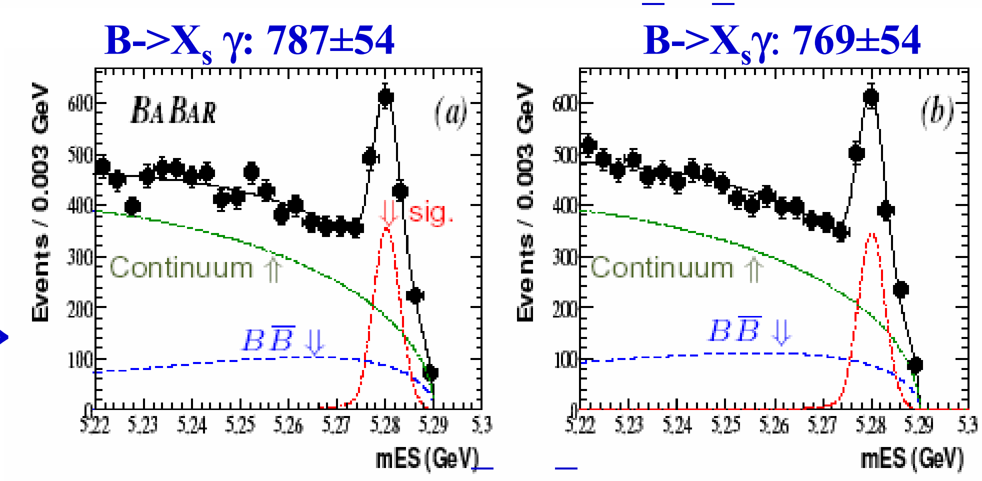
$Br(B \to X_s\gamma) = (3.88 \pm 0.36 \pm 0.37\ ^{+0.43}_{-0.23}) \cdot 10^{-4}$

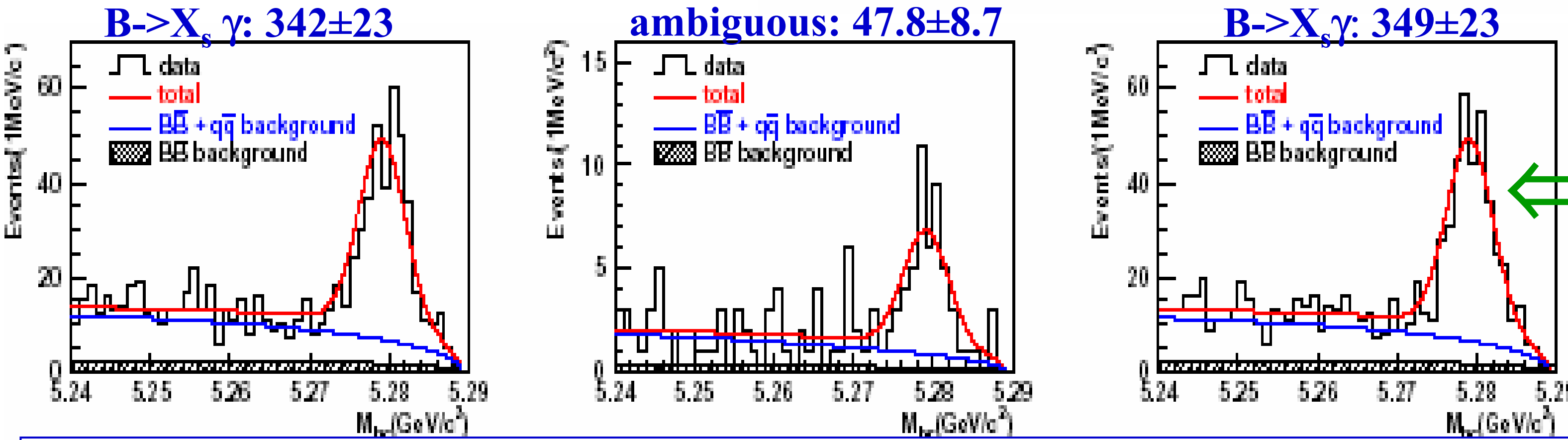
$2.1 < E_\gamma < 2.7$ GeV

# $A_{CP}(B \to X_s \gamma)$: Semi-Incl. technique

- Reconstruct $X_S$ as:
  $(K^{\pm}, K_S \to \pi^- \pi^+) + 0\text{-}3\ \pi\ (2\ \pi^0)$
- Yield: from an $m_{ES}$ fit

**Babar: 81.9 $fb^{-1}$** ⇒



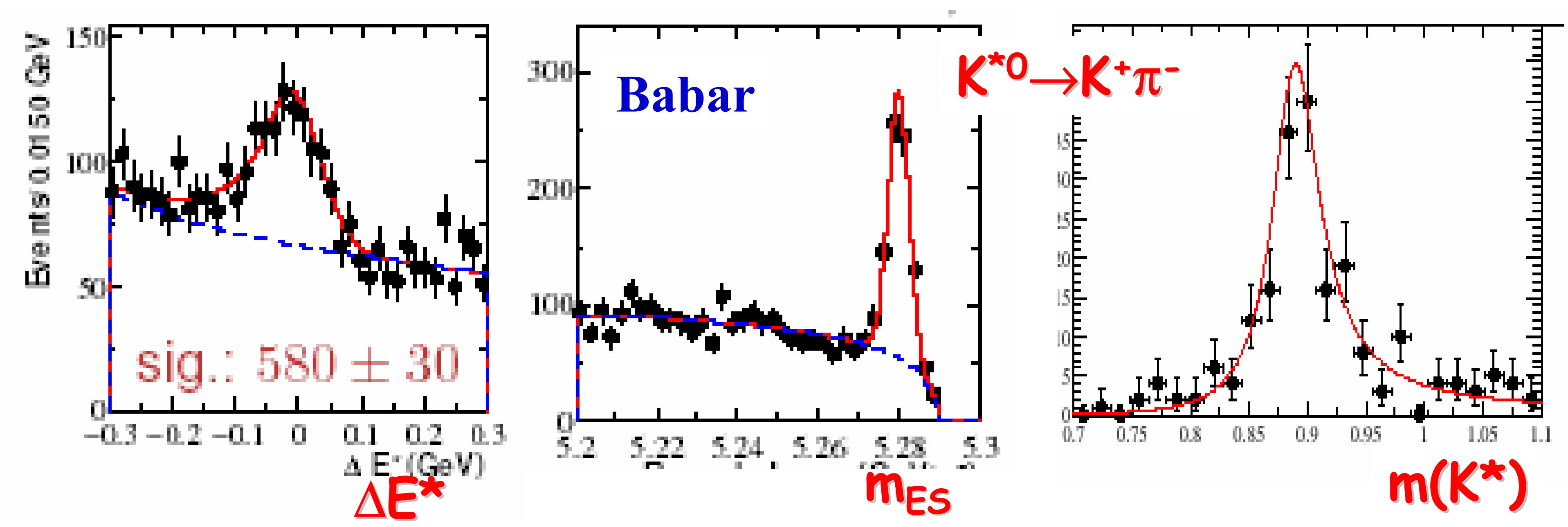




⇐ **Belle: 140 $fb^{-1}$**

| | | |
|---|---|---|
| Belle (140 $fb^{-1}$) | $A_{CP} = 0.002 \pm 0.050 \pm 0.030$ | hep-ex 0308038 |
| Babar (81.9 $fb^{-1}$) | $A_{CP} = 0.025 \pm 0.050 \pm 0.015$ | hep-ex 0403035 submitted to PRL |
| Theory | $A_{CP} = 0.0044^{+0.0019}_{-0.0009} \pm 0.0003^{+0.0015}_{-0.0010}$ | hep-ph 0310282 |

# $A_{CP}(B \to K^* \gamma)$

- $K^{*+} \to K^+\pi^0$, $K_S{}^0\pi^+$, $K^{*0} \to K^+\pi^-$, $K_S{}^0\pi^0$ (not self-tagging modes used for isospin & Br analysis)
- Signal extraction : 2(1)-D UML fit to $\Delta E$ ($m_{ES}$)



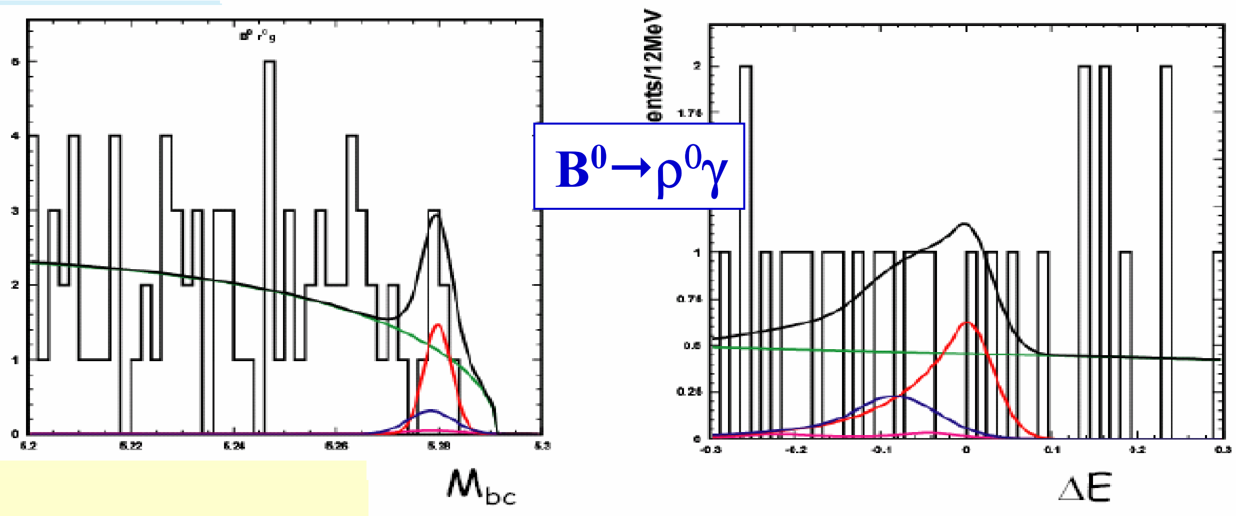

| | | |
|---|---|---|
| Babar (81.9 $fb^{-1}$) | $-0.015 \pm 0.036 \pm 0.010$ | Preliminary: submitted to PRL soon |
| Belle (78 $fb^{-1}$) | $-0.015 \pm 0.044 \pm 0.012$ | hep-ex 0402042 submitted to PRD |

# $B \to \rho/\omega\,\gamma$

- Sensitive to $|V_{td}|$
- Bkgd from $B\to K^{*}\gamma$, $B\to\rho\pi^0$, $e^+e^- \to qq$
- A 2(3)-UML fit is used to extract signal yields: $\Delta E$, $m_{ES}$, ($m_\rho$)
- Assume isospin symmetry: $A(B\to\omega\gamma) = A(B^0\to\rho^0\gamma) = 1/\mathrm{sqrt}(2) \times (B^\pm\to\rho^\pm\gamma)$

| Br ($\cdot 10^6$) | $B^0\to\rho^0\gamma$ | $B^\pm\to\rho^\pm\gamma$ | $B^0\to\omega\gamma$ | Combined | |
|---|---|---|---|---|---|
| Babar (78 $fb^{-1}$) | <1.2 | <2.1 | < 1.0 | < 1.9 | P.R.L 92:111801,04 |
| Belle (78 $fb^{-1}$) | <2.6 | <2.7 | < 4.4 | < 3.0 | Moriond 03 |
| Theory | 0.49±0.21 | 0.85±0.40 | 0.49±0.18 | | hep-ph 0209346 |
| | $0.76^{+0.26}_{-0.23}$ | $1.53^{+0.53}_{-0.46}$ | $0.76^{+0.26}_{-0.23}$ | | Nucl.Phys.B 621,459 02 |

New Belle result (140 $fb^{-1}$)
$Br(B\to\rho(\omega)\gamma) =$
$(1.8^{+0.6}_{-0.5} \pm 0.1)\cdot 10^{-6}$
3.5 $\sigma$ (Moriond EW)

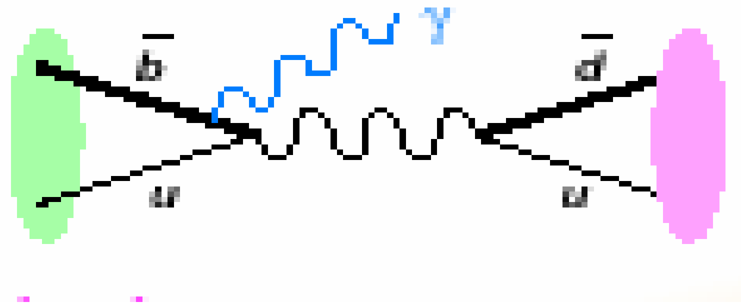


# $|V_{td}|/|V_{ts}|$ Extraction

- $|V_{td}|/|V_{ts}|$ from $Br(B\rightarrow \rho\gamma)/Br(B\rightarrow K^*\gamma)$ (alternative method to $\Delta M_{Bd} / \Delta M_{Bs}$ ):

$$Br(B\rightarrow \rho\gamma)/Br(B\rightarrow K^*\gamma) = |V_{td}/V_{ts}|^2 \; z^2 |1+\Delta R| (1-m_r{}^2/M_B{}^2)^3/(1-m_{K^*}{}^2/M_B{}^2)^3$$

z: SU(3) symmetry breaking
$\Delta R$: <u>annihilation diagram contribution</u>~15/20%



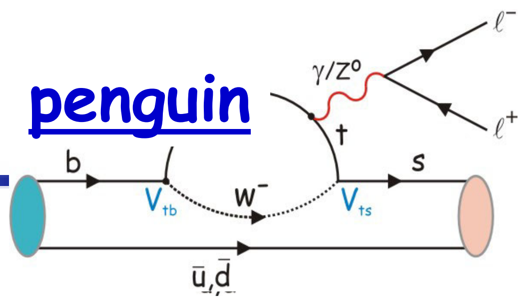

- Using $z=0.76\pm0.06$, $\Delta R=0.0\pm0.2$ (Ali & Parkhomenko Eur. Phys. J. C.23, 89 2002)

$$|V_{td}|/|V_{ts}|<0.34 \text{ @ } 90\% \text{ CL}$$

- Projection: 300 $fb^{-1}$ $\Rightarrow$ 5 $\sigma$ *in* $Br(B\rightarrow \rho\gamma) \Rightarrow \sigma(|V_{td}/V_{ts}|)/|V_{td}/V_{ts}| = 15/20\%$
Already at level of theory uncertainty

# Electroweak decays:
# $b \to s l^+ l^-$

# b->sl⁺l⁻

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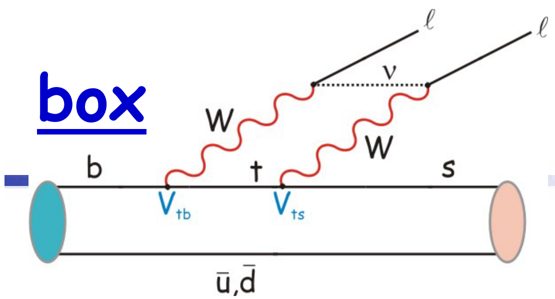
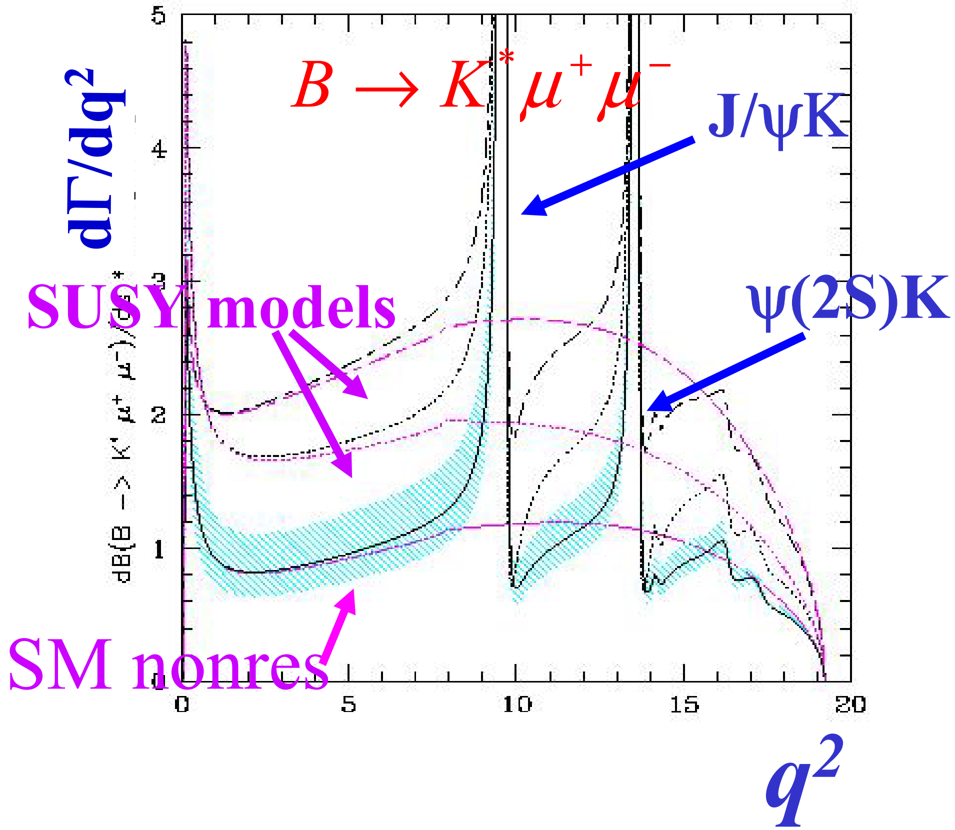
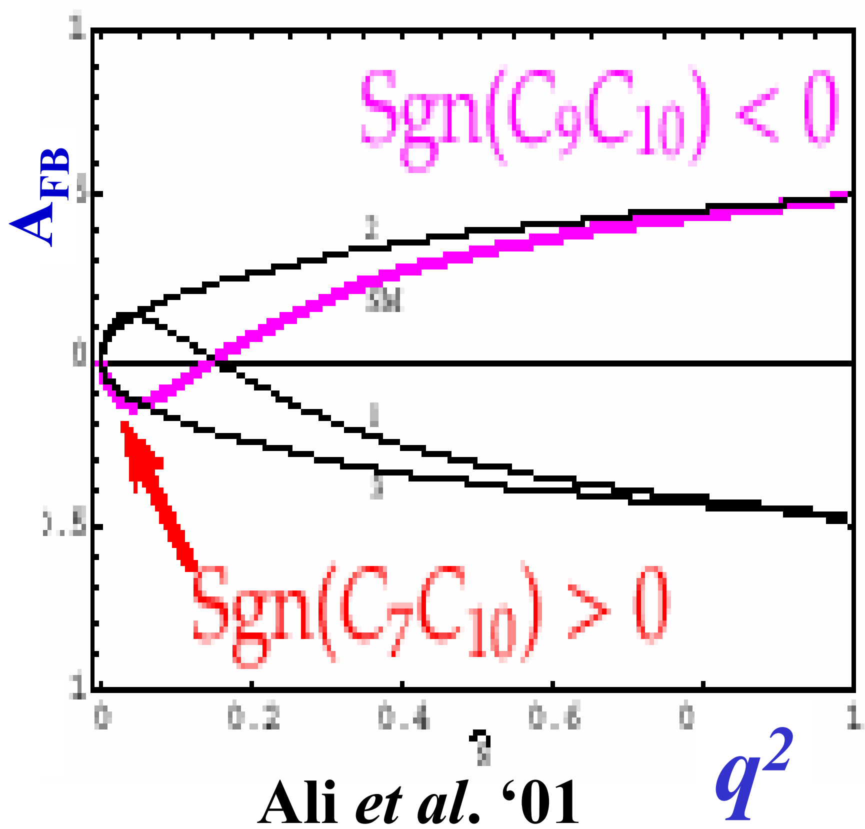


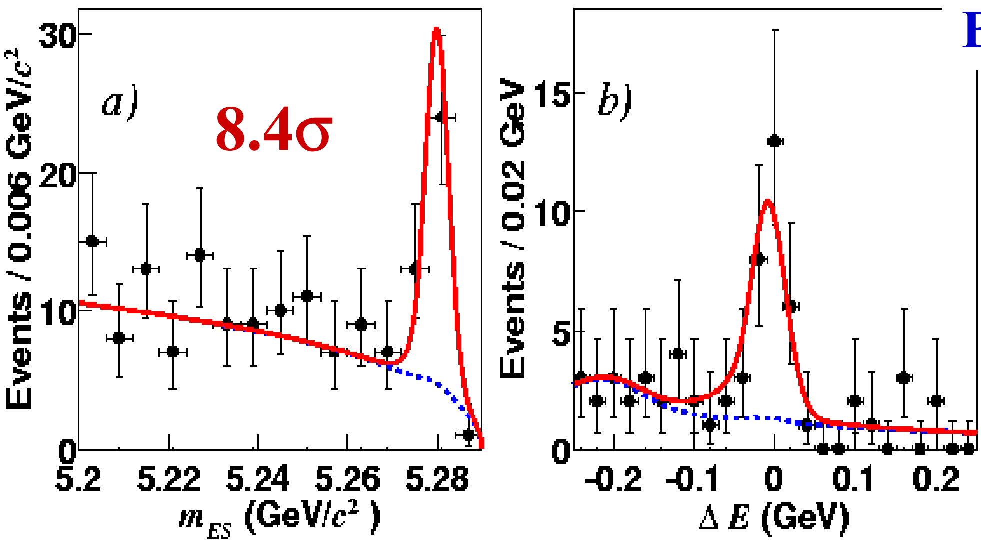

- BF: $\alpha_{em} \cdot BR(b \to s\gamma) \approx 10^{-6}$ but much less bkgd than $b \to s\gamma$
- Interplay between Z and $\gamma$ => $q^2$ dependence
  - Forward-backward lepton asymmetry $A_{FB}(q^2)$ sensitive to non SM effect even if *rates agree* ($b \to s(ll)\gamma$)



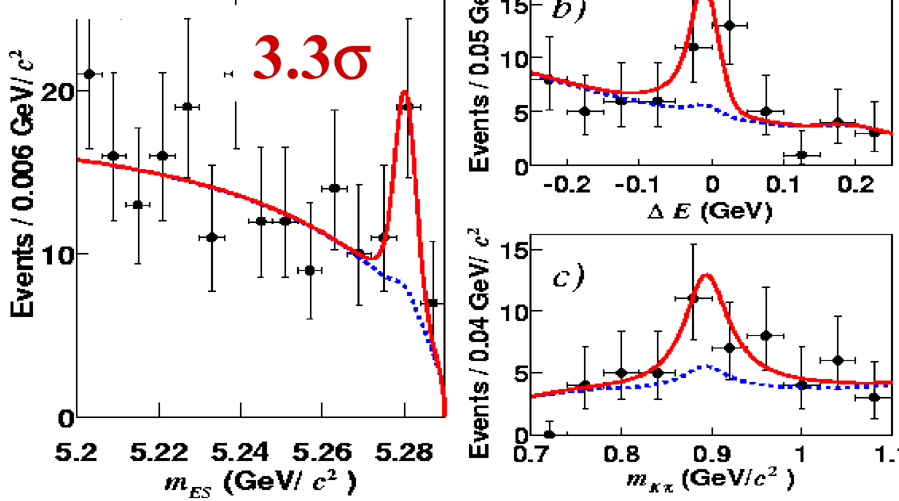
# $B \to K^{(*)} l^+ l^-$

- Reconstruct $K^+$, $K_s \to \pi^+\pi^-$, $K^{*0} \to K^+\pi^-$, $K^{*+} \to K_s \pi^+$
- Bkgd: $B \to J/\psi(l^+l^-) K^{(*)}$, $B \to K^{(*)}\gamma(l^+l^-)$, $B \to h^+h^- K^{(*)}$, Semi-leptonic, $e^+e^- \to qq$
- Signal yield: 2(3)-D UML fit to $m_{ES}$ & $\Delta E$, ($m_{K\pi}$)




B -> Kl+l-

Babar

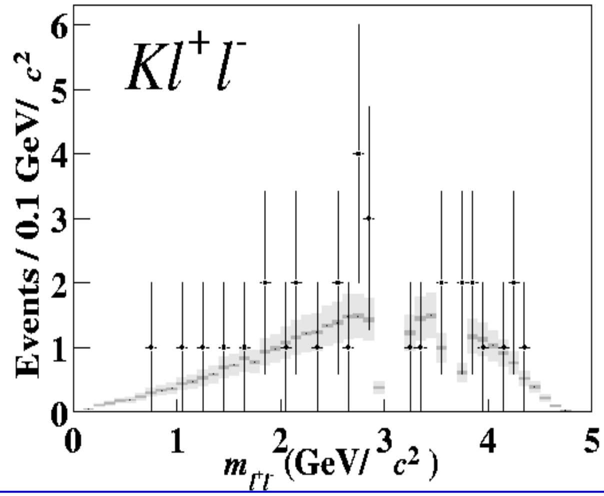


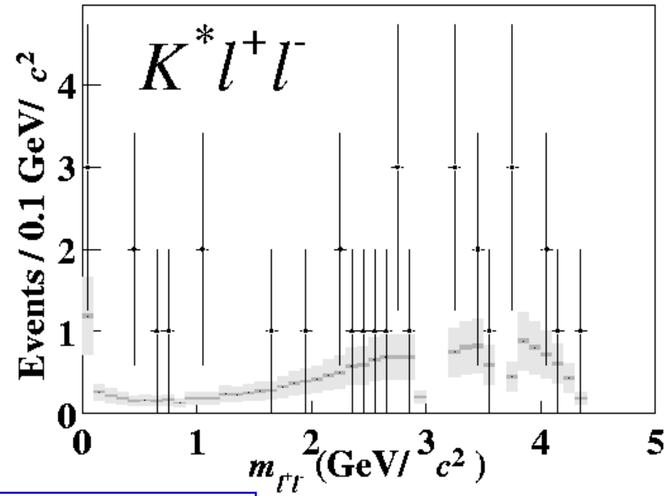

B -> K*l+l-

| Br($10^7$) | B -> Kl+l- | B -> K*l+l- | |
|---|---|---|---|
| Babar(113 $fb^{-1}$) | $6.5^{+1.4}_{-1.3} \pm 0.4$ | $8.8^{+3.3}_{-2.9} \pm 1.0$ | Phys.Rev.Let. 91:221802,03 |
| Belle (140$fb^{-1}$) | $4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1$ | $11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2$ | Phys.Rev.Let.91:261601,03 |
| Theory | $3.5 \pm 1.2$ | $11.9 \pm 3.9$ | Phys.Rev.D. 66:034002,02 |

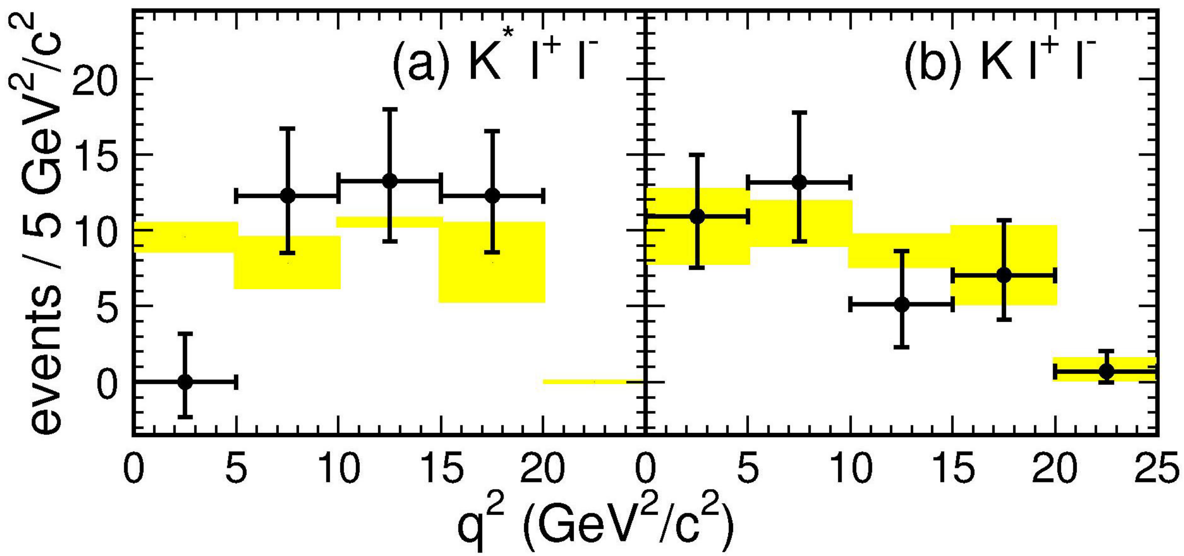
# $B \to K^{(*)} l^+ l^-$ distributions

**BaBar (113 $fb^{-1}$) :**
**$M_{ll}$ data comparison with SM predictions**



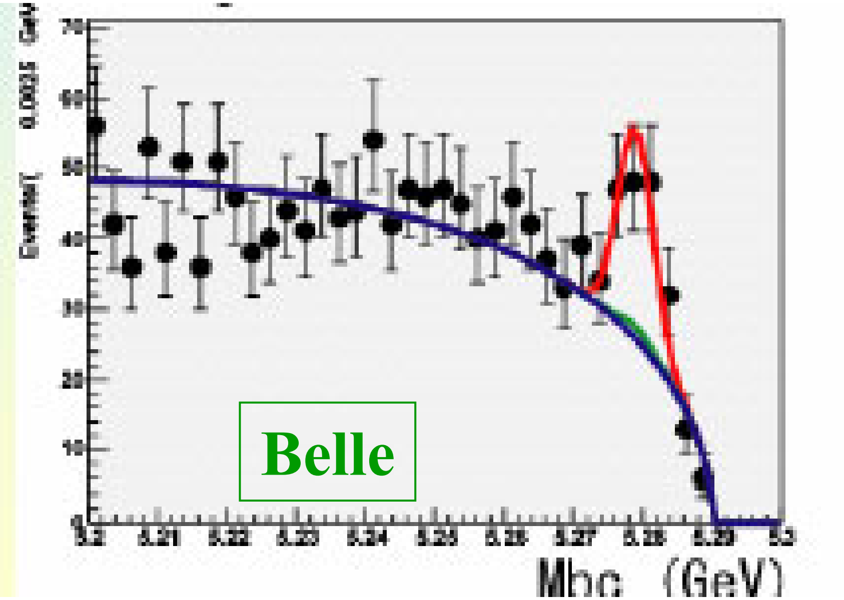

**$M^2_{inv}(l^+l^-)=q^2$: note different variable on horizontal axis**

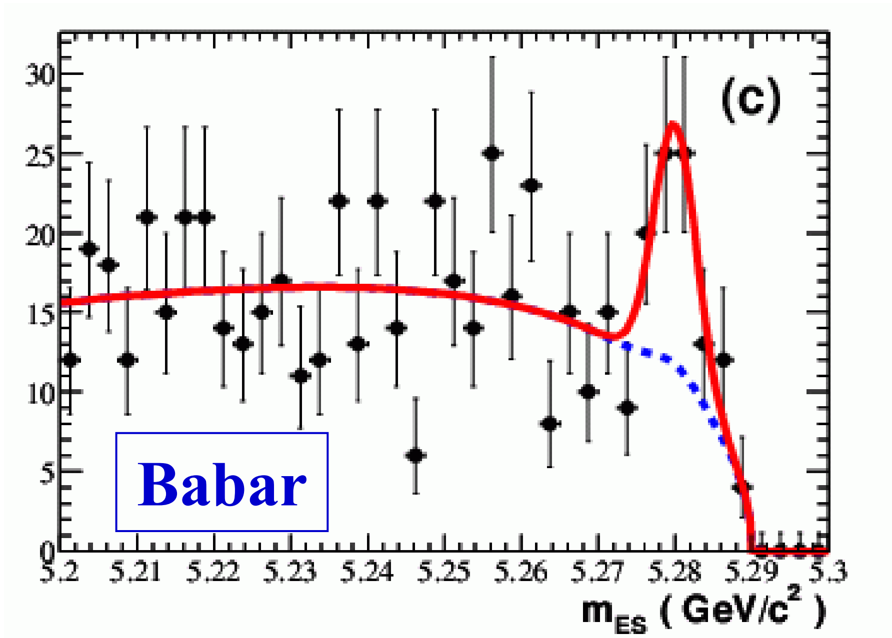



**Belle (140$fb^{-1}$):**
**$M^2_{ll}$ data comparison with SM predictions from a bin by bin fit to $M_{es}$**

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

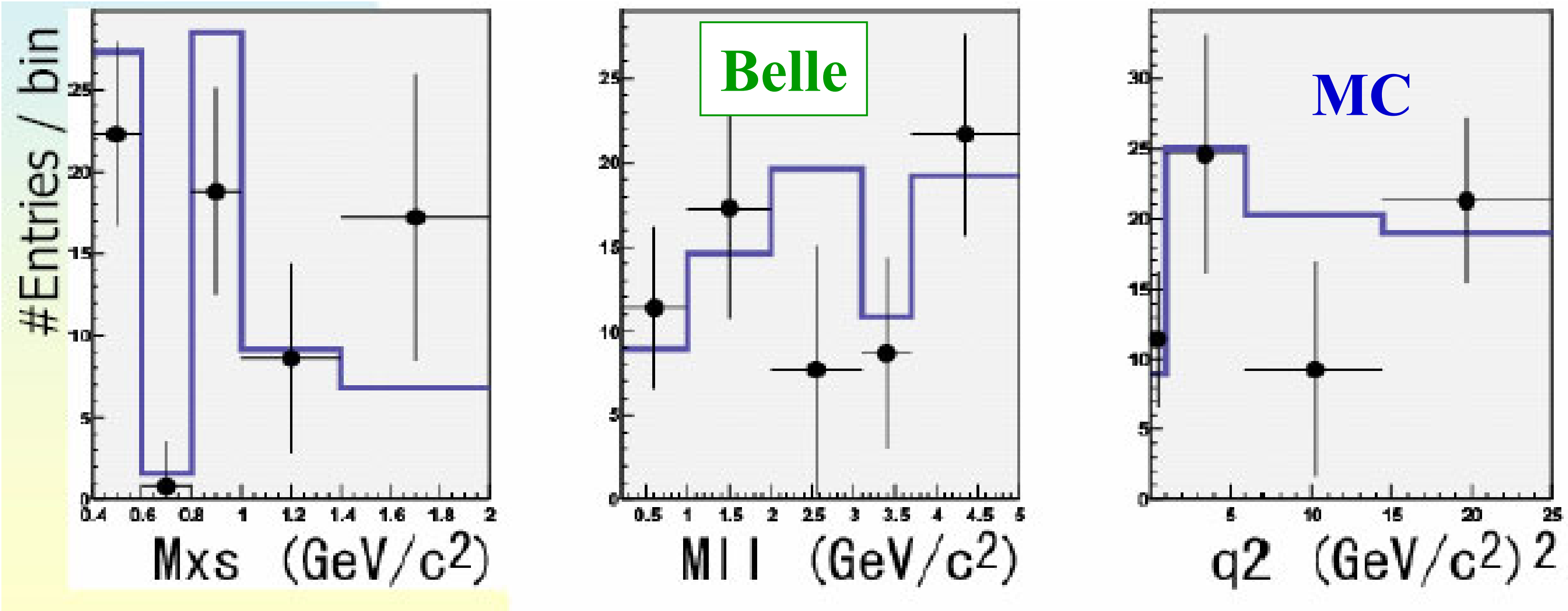
- Reconstruct $X_S$ as: $(K^+, K_s)$ +0-2 $\pi$ (up to 1 $\pi^o$ )
- Bkgd similar to $B \to K^{(*)}l^+l^-$ but more severe
- Yield from $m_{ES}$ fit



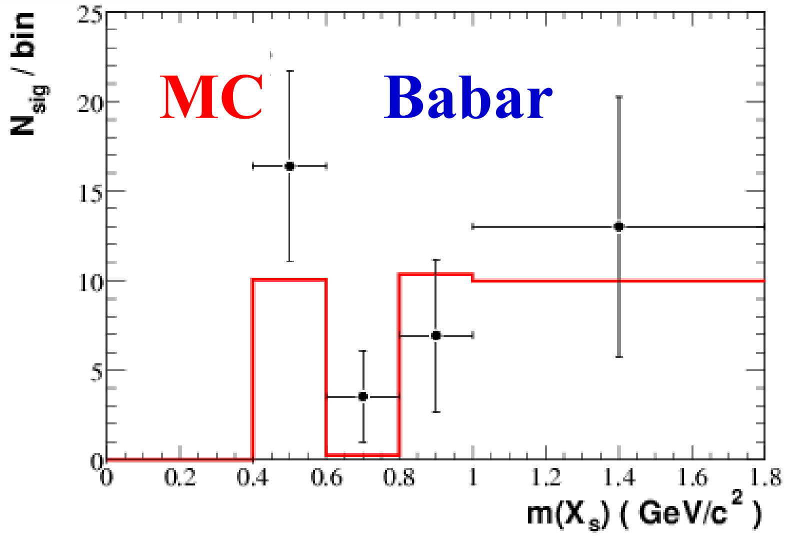

| $Br(10^6)$ | $B \to X_s l^+ l^-$ | |
|---|---|---|
| Babar (81.9 $fb^{-1}$ ) | $6.3 \pm 1.6 \pm^{1.8}_{1.5}$ | hep-ex/0308016 submitted toPRL |
| Belle (140$fb^{-1}$ ) | $4.39 \pm 0.84 \pm^{0.78}_{0.73}$ | preliminary result (Moriond EW) |
| Theory | $4.2 \pm 0.7$ | J.Mod.Phys.A 18,1959, 03 |

# $M_{ll}$ and $M_{Xs}$ in $B \to X_s\, l^+ l^-$




- From a bin by bin fit to $M_{ES}$
- No deviation from SM
  but more statistics needed

=> measure $A_{FB}$



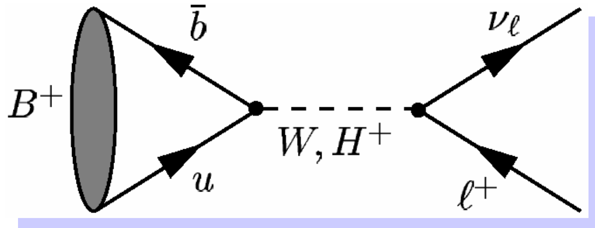
# Decays with:
# neutrino and/or helicity suppression

# $B^0 \rightarrow K\nu\nu$ & $B \rightarrow l\nu$

- $K\nu\nu$ : theoretically cleaner than $B \rightarrow K^* ll$ because of no cc resonance effect

- $B \rightarrow l\nu$: sensitive to $f_B |V_{ub}|$ & new physics (e.g. charged Higgs)

$$Br(B \rightarrow l\nu) = \frac{1}{8\pi} G_F^2 m_B m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$




- Measurement difficult due to missing neutrinos $\Rightarrow$
Common technique: Reconstruct one B & look for signal in the recoil side

**Two statistics independent analyses:**

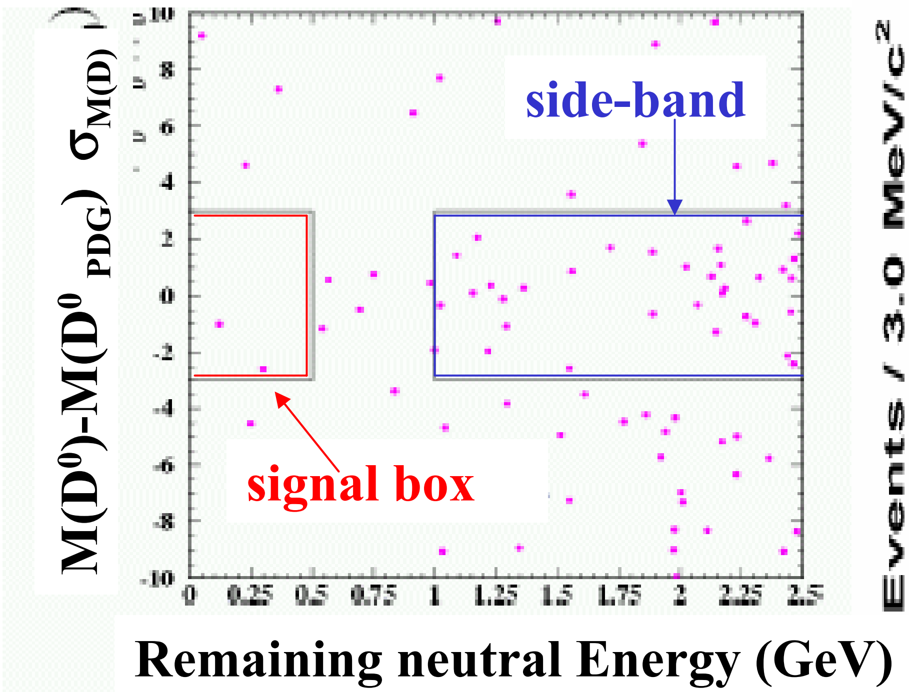
- Hadronic tag: $B^+ \rightarrow D^{(*)} X_{had}$ , tagging efficiency $\sim 2 \cdot 10^{-3}$
- Semileptonic Tag: $B^+ \rightarrow D^0 l\nu(\pi^0,\gamma)$, tagging efficiency $\sim 5 \cdot 10^{-3}$

# $B^0 \rightarrow K\nu\nu$

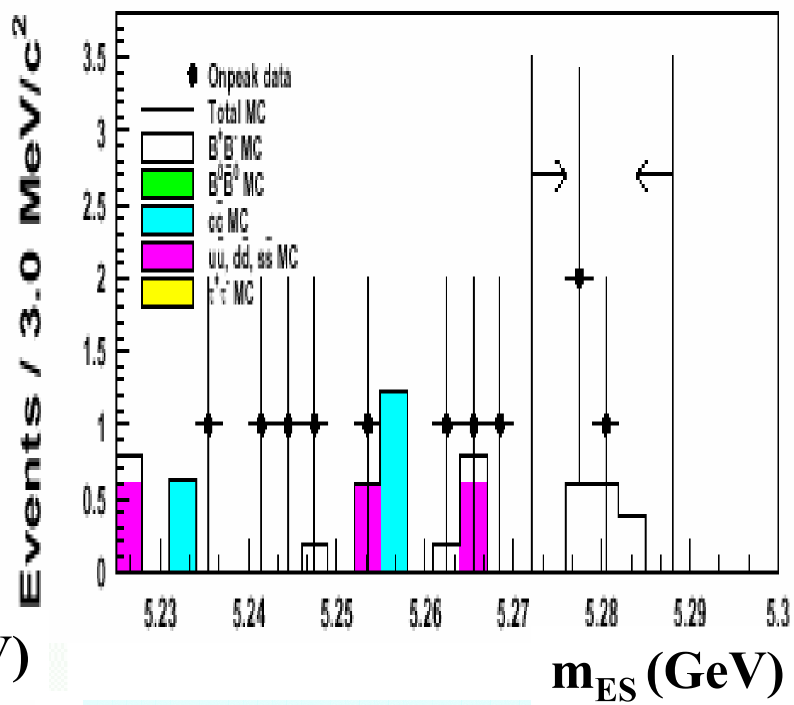
**Babar**

•Only one K in the final state( require p*>1.25GeV)+ missing energy

**Semileptonic B tag**




**Hadronic B tag**




50.7 $fb^{-1}$: Br< $9.4\times10^{-5}$ @ 90% CL

80.7 $fb^{-1}$ :Br < 1.05 $\times10^{-4}$ @ 90% CL

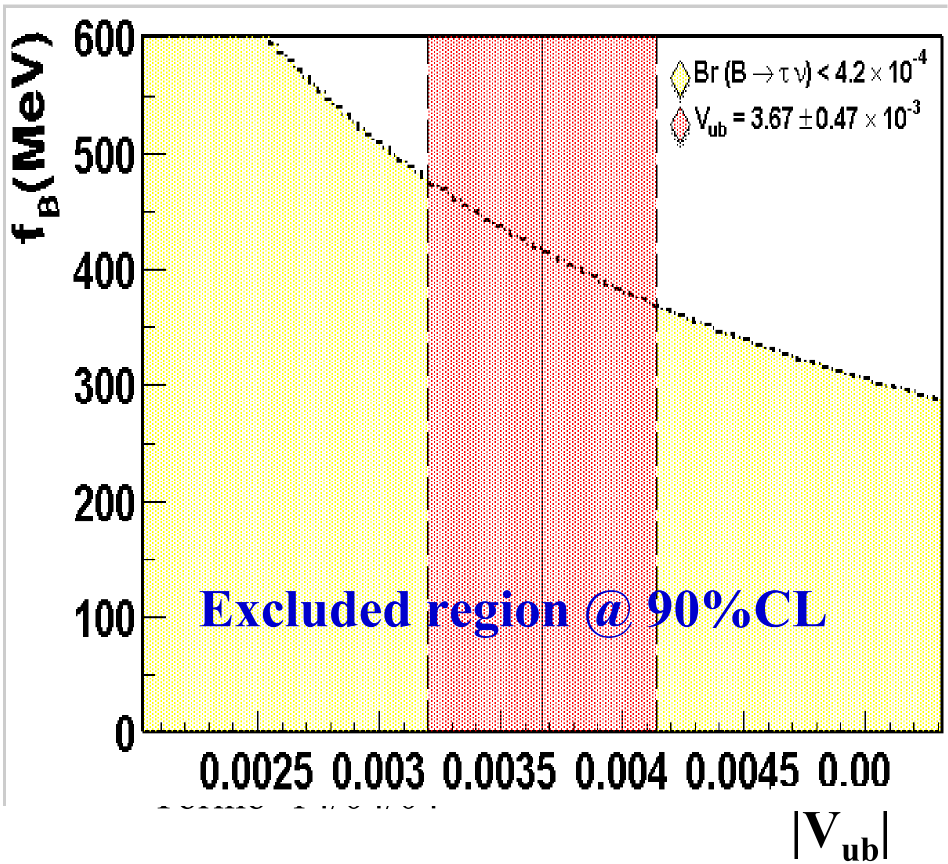
**Combined limit @ 90% CL < 7.0 x $10^{-5}$ hep-ex 0304020**

**SM Expectation: $(3.8\ ^{+1.2}_{-0.6}) \times 10^{-6}$ (Buchalla, Isidori,2000)**

# $B \to \tau\nu$

**Babar:81.9 $fb^{-1}$**

- **Reco. modes:** $\tau^+ \to e^+ \nu_e \nu_\tau$, $\mu^+ \nu_\mu \nu_\tau$, $(\pi^+, \pi^+\pi^0, \pi^+\pi^-\pi^+)\,\nu$ **(Hadronic Tag only)**
- **Combined upper limit:** $BR(B^+ \to \tau^+\nu_\tau) < 4.2\times 10^{-4}$ **(90% CL) to PRL soon**
- **Theory:** $Br(B^+ \to \tau^+\nu_\tau) \approx 7.5\times 10^{-5}$

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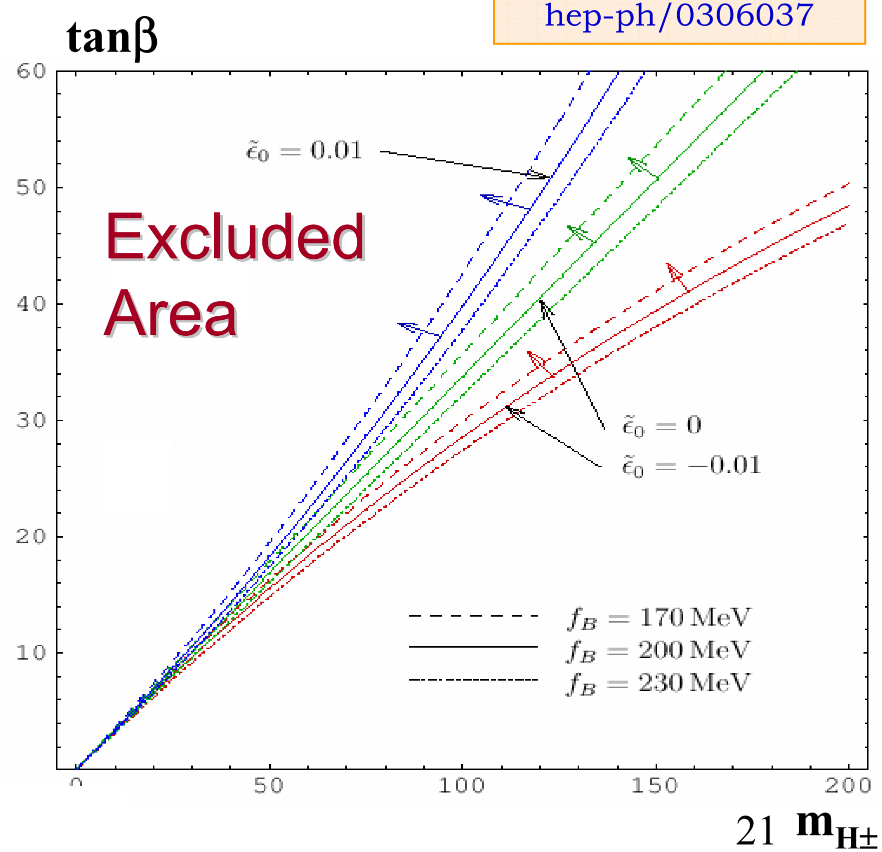
hep-ph/0306037



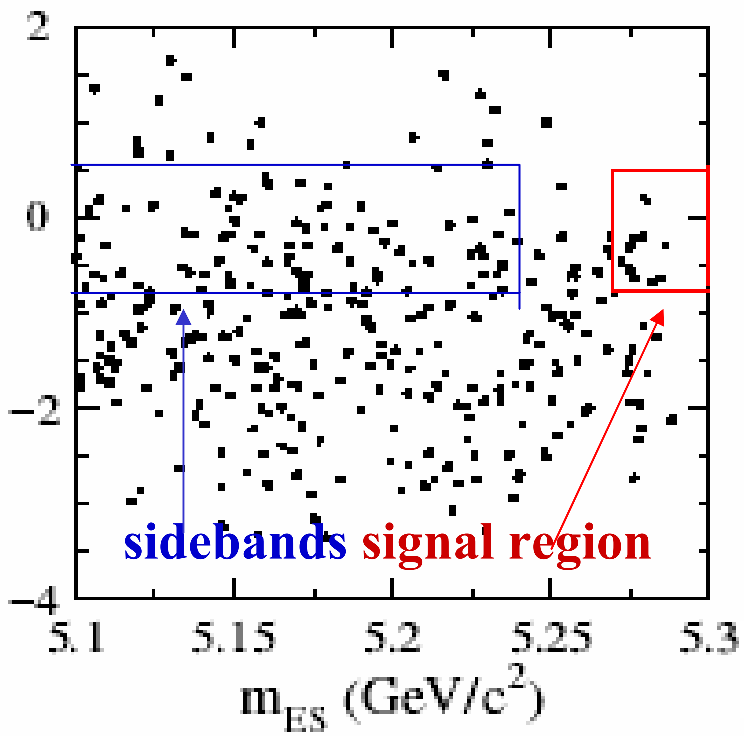
# $B \to \mu\nu$

Submitted to PRL (hep-ex/0401002)

**Analysis outline:**

- Identify a single muon
- All remaining particles associated to the tag B
- Signal B rest frame: 2.25GeV/c< $p_\mu$<2.95 GeV/c
- Continuum rejection: event shape variable

**Babar 81.9 $fb^{-1}$**




**Background sources:**

- Semileptonic decays with $b \to u\mu\nu$
- qq events: $\pi$ mis-identified as a $\mu$.

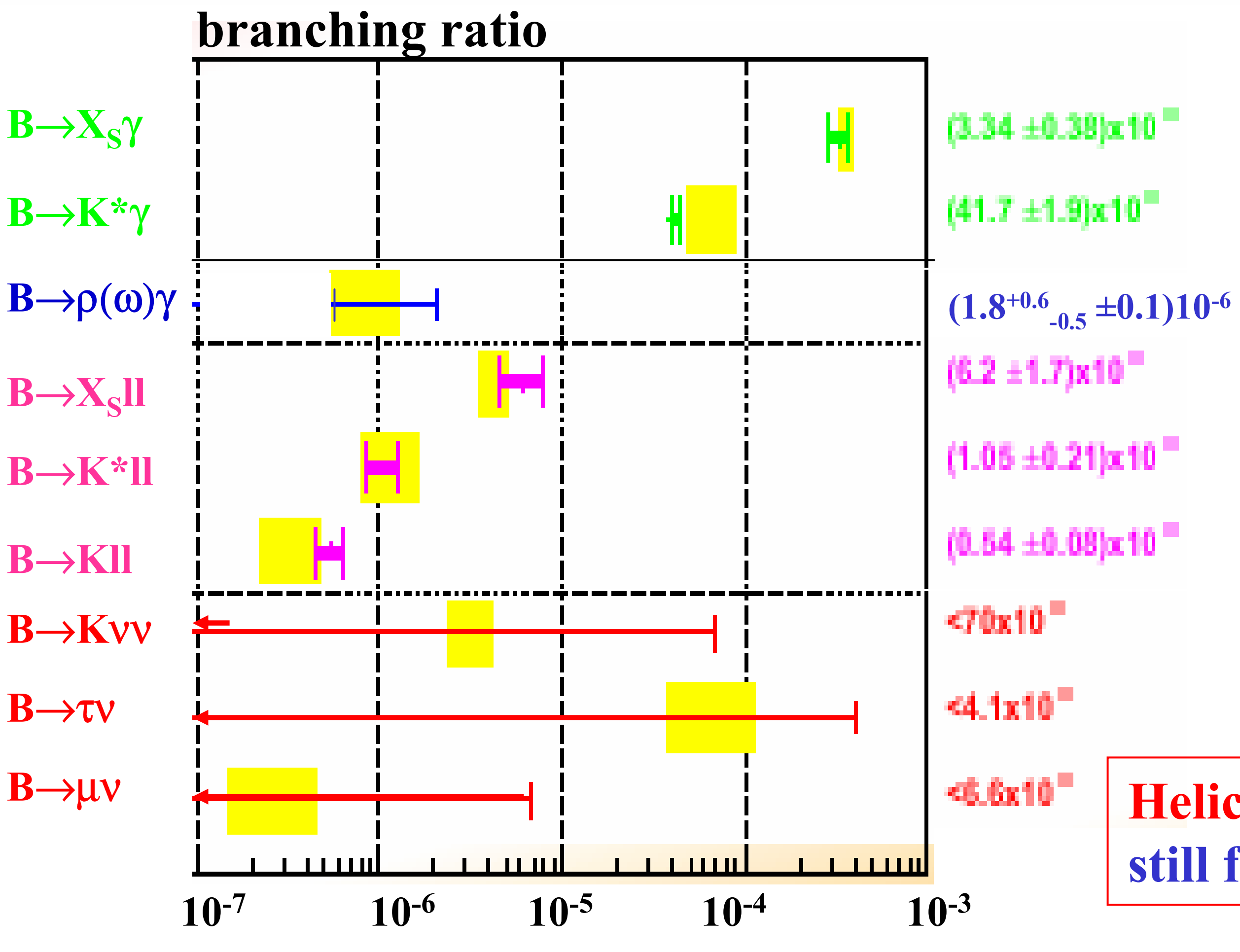
Selected events: 11

Expected background events: 5+1.8/-1.4

$BR(B^+ \to \mu^+\nu_\mu) < 6.6\times 10^{-6}$ (90% CL)

Theory: $Br(B^+ \to \mu^+\nu_\mu) \approx 4\times10^{-7}$

# Summary of current results




**Radiative &EW decays:**

- $\sigma(Br) \sim \sigma(theory)$ not much to learn from exclusive Br
- $A_{cp}$, $M^2_{inv}(l^+l^-)$, $A_{FB}$ : very promising but more statistics needed

**Helicity suppressed decays:**
**still far from theory expectation**

- $B \to \tau\tau^- \approx 10^{-8}$ (no result yet), $B \to \mu\mu(ee) \approx 10^{-10(15)}$ (current result $\approx 10^{-7}$)