Assisi, 23 June 2005

Leptonic and EW Penguins

BEAUTY 2005

10^{th} International Conference on B-Physics at Hadron Machines

Francesca Di Lodovico

Queen Mary, University of London

on behalf of the BaBar Collaboration

BABAR TM & © L. de Brunhoff

Outline

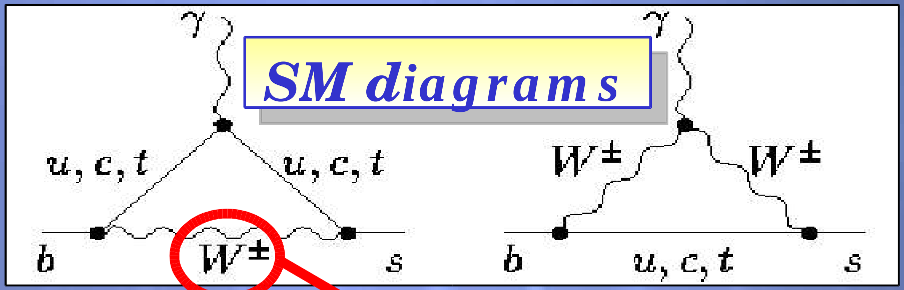
Radiative and EW decays

- $b \to s\gamma$
- $B \to \rho/\omega\,\gamma$
- $B \to K^{(*)} ll$

Leptonic Decays

- $B \to l\nu$
- $B \to K(\pi)\nu\bar{\nu}$
- $B \to \nu\bar{\nu}(\gamma)$

$b \to s\gamma$ Decays

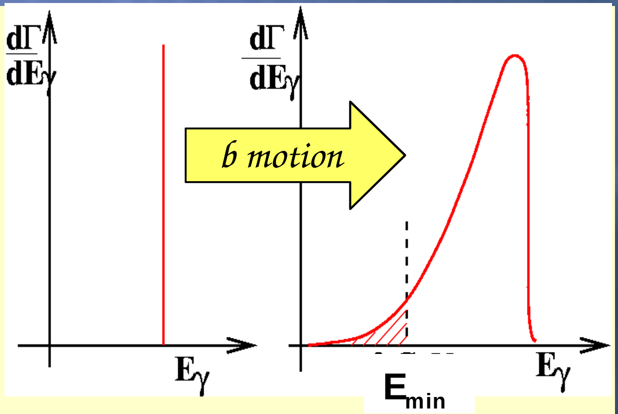


New physics: additional diagrams with H, $\chi^{\pm}$ …

- ***Standard Model***
  - **$b \to s\gamma$ not allowed at tree level (FCNC)**
  - **via a one-loop penguin diagram with t or W**
- ***New physics***
  - ***new particles may appear in the loop***
  - ***modification of SM expectations (both rate and phase)***

- ***In SM, V–A coupling produces an approximately left-handed photon***
- ***New physics (SUSY, L-R symmetry, etc.) can enter with right-handed couplings***

Photon spectrum in $b \to s\gamma$



Reflects the dynamics of the b inside B

- ***Specified by parameters of the Operator Product Expansion (OPE)***
  - ***Mass of the b-quark (m_b)***
  - ***Fermi-momentum squared of the b-quark (μ^2_π)***

Needed for the measurement of $|V_{ub}|$ from inclusive semileptonic $b \to u\, l\, \nu$ decays

- ***OPE parameters determined by moments of the E_γ spectrum***

Smaller theory uncertainties on m_b and μ^2_π at lower E_γ

Moments of the E_γ spectrum

$$m_N = \langle (E_\gamma - \langle E_\gamma \rangle)^N \rangle$$

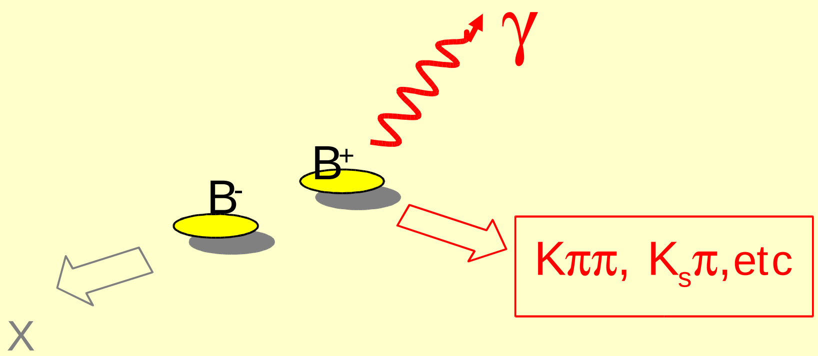
OPE parameters

$$\overline{\Lambda}(\mu) = M_B - m_b(\mu)$$

$$\lambda_1(\mu) = -\mu^2_\pi(\mu)$$

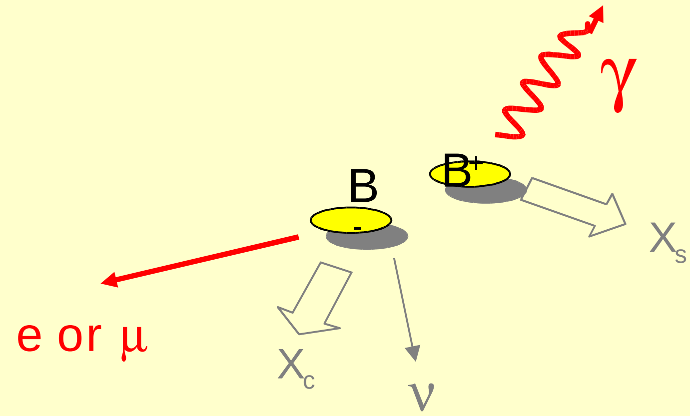
$b\rightarrow s\gamma$ Experimental Techniques

Sum of Exclusive Modes



- *Sum of 38 modes with $K^{(0)}$, $\pi^{(0)}$, η , KKK*
- *Kinematic constraints of fully-reconstructed B meson effectively reduces background*
- *Photon energy measured directly in B rest frame superior resolution*
- *Primary systematic from missing modes (fragmentation)*

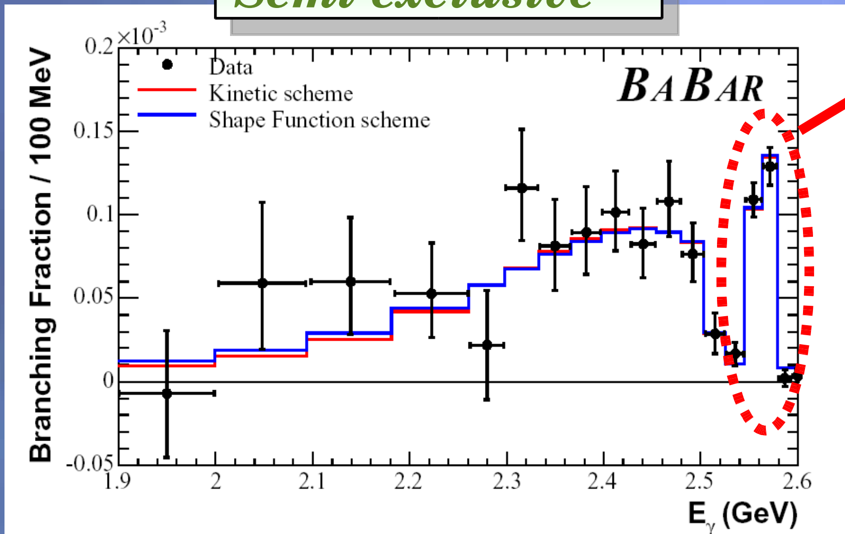
Inclusive with tag of recoil B



- *Reconstruct high-energy photon (1.8-2.8 GeV)*
- *Suppress huge background with lepton tagging*
- *Main systematic from subtraction of $B\bar{B}$ background*
- *Subtract $b\rightarrow d\gamma$ (~4%)*

$b \to s\gamma$ Preliminary Results

Semi-exclusive



Peak corresponding to K^* resonance ($M(X_s) < 1.1\ GeV/c^2$)

$\mathcal{B}(E_\gamma > 1.6\ GeV) = (3.38 \pm 0.19\ ^{+0.64}_{-0.41}\ ^{+0.07}_{-0.08}) \cdot 10^{-4}$

SM expectation (Nucl. Phys B 631, 219 (2002)):

$\mathcal{B}(b \to s\gamma\ E_\gamma > 1.6\ GeV) = (3.57 \pm 0.30) \cdot 10^{-4}$

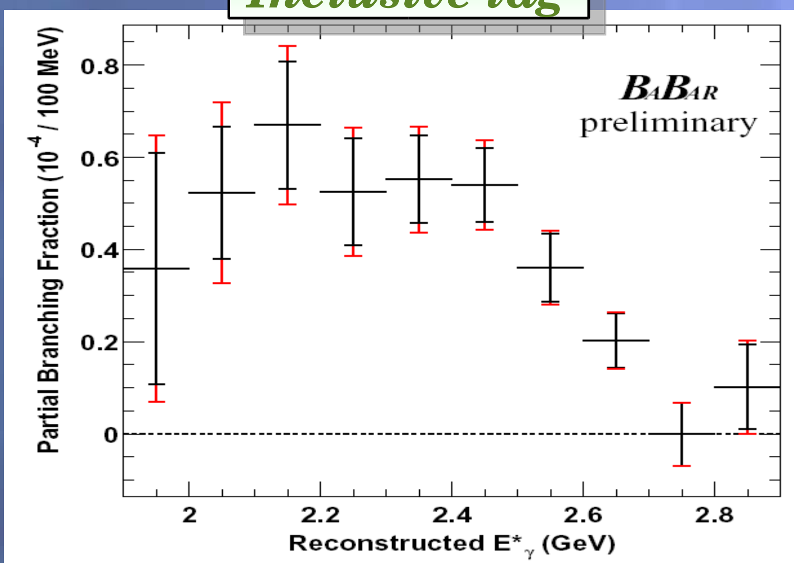
PRL 93 021804 (2004)

$A_{CP}(b \to s\gamma) = (0.025 \pm 0.0.50 \pm 0.015)$

"simpler" version of the analysis

SM expectation: $A_{CP}(b \to s\gamma) < 1\%$

Inclusive tag



$A_{CP}(b \to s\gamma + b \to d\gamma) = (-0.010 \pm 0.115 \pm 0.017)$

SM expectation $A_{CP}(b \to s\gamma + b \to d\gamma) \sim 0$

A total of 89M $B\bar{B}$ events are used

$b \to s\gamma$ Preliminary Results

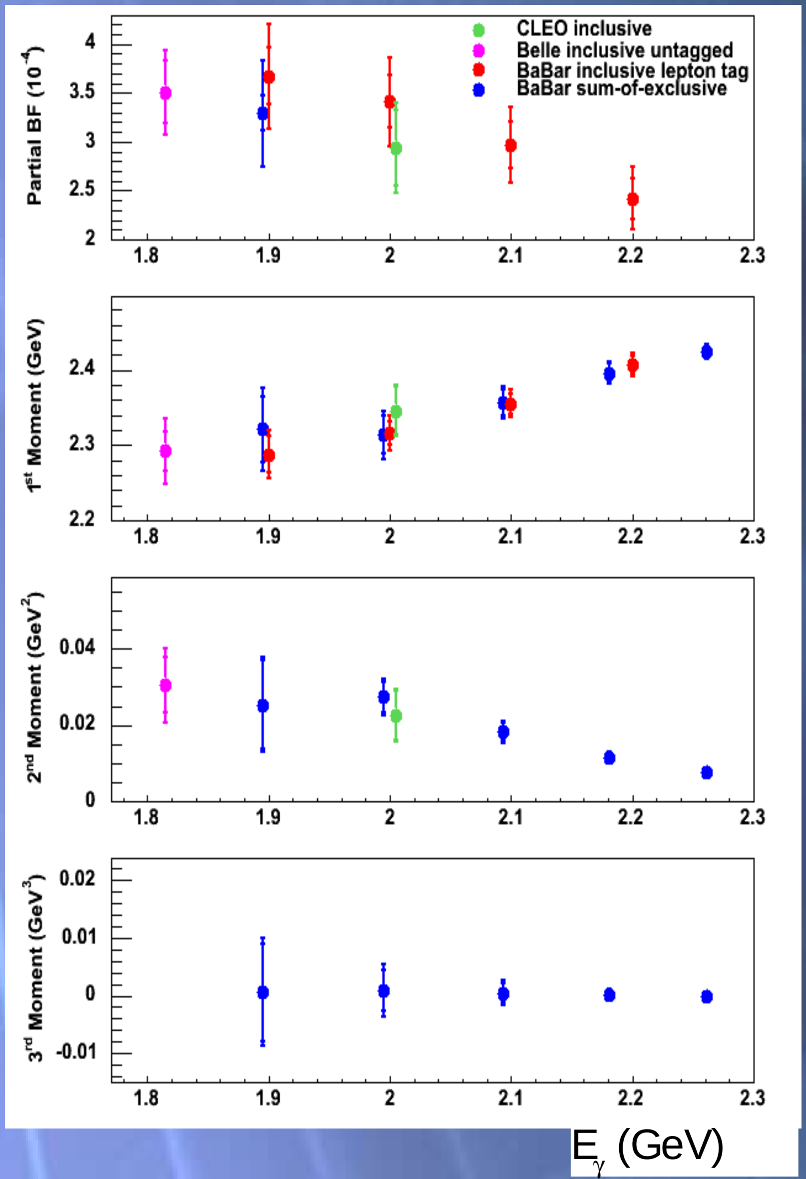
Fitting the photon spectrum:

Semi-exclusive

Scheme	$\bar{\Lambda}$ (GeV)	μ^2_π(GeV²)
Kinetic	$0.59\ ^{+0.05}_{-0.04}$	$0.30\ ^{+0.05}_{-0.04}$
Shape Function	0.63 ±0.04	$0.19\ ^{+0.05}_{-0.04}$

Kinetic Scheme: Nucl. Phys. B 710 371 (2005)
Shape Function Scheme: Nucl. Phys. B 699, 335 (2004)

Photon Moments:



Studying separately the B^0 versus $B^\pm$ states:

Semi-exclusive

- ***No isospin breaking from the dominant penguin diagram***
- ***Isospin breaking effects at order /m_b***
- ***In the $K^*\gamma$ mode: $\Delta_{0\pm} \approx 5 - 10$ %***

$$\Delta_{0\pm} \equiv [\Gamma(B^0) - \Gamma(B^\pm)] / [\Gamma(B^0) + \Gamma(B^\pm)]$$
$$= -0.006 \pm 0.058\ ^{+0.009}_{-0.008} \pm 0.024 \ (*)$$

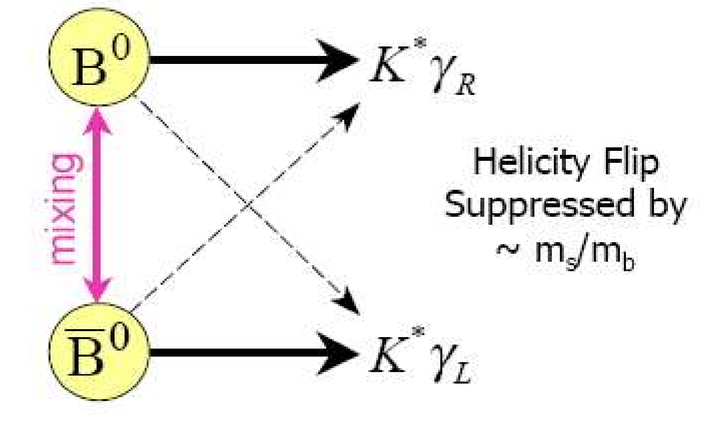
(*): Errors sta t.+syst.+uncertainty on B production ratio

Time Dependent CPV in $B^0 \to K_s \pi^0 \gamma$

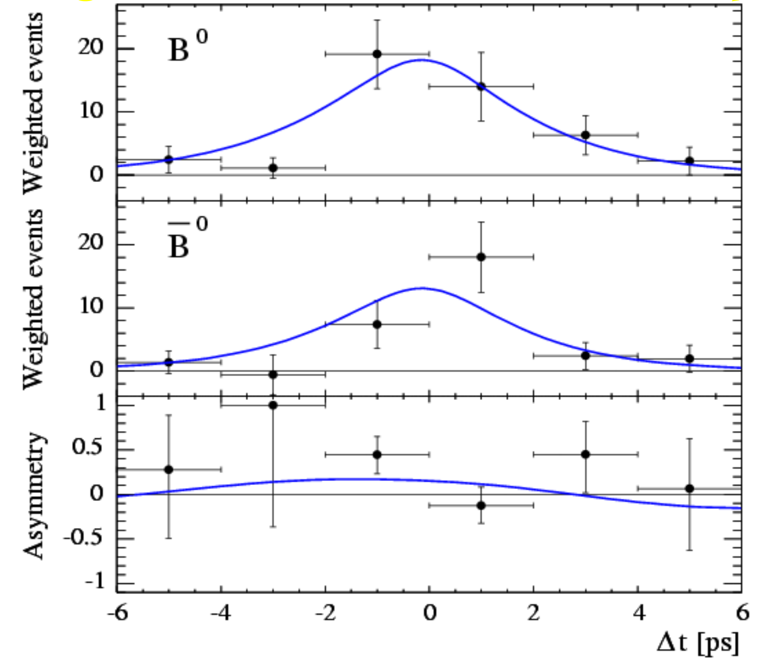
As in $B^0 \to J/\psi K_S$, interference between mixed and non-mixed decay to same final state required for CPV(Phys. Rev. Lett. 79, 185 (1997))

In the SM, mixed decay to $K^*\gamma$ requires wrong photon helicity, thus CPV is suppressed:

In SM: $C = -A_{CP} \sim -1\%$ $\quad S \sim -2(m_s/m_b)\sin 2\beta \sim -4\%$



Background-subtracted distribution for Δt



A total of 232M $B\overline{B}$ events are used

Measuring Δt of $K^*(\to K_S\pi^0)\,\gamma$ events requires novel beam-constrained vertexing technique

(Phys. Rev. Lett. 93 131805 (2004))

$0.8 < m_{K\pi} < 1.0$ GeV/c^2

$S = -0.21 \pm 0.40 \pm 0.05$

$C = -0.40 \pm 0.23 \pm 0.04$

$m_{K\pi} > 1.1$ GeV/c^2

$S = 0.9 \pm 1.0 \pm 0.2$

$C = -1.0 \pm 0.5 \pm 0.2$

$B \to K\pi\pi\gamma$

Motivations:

method to measure photon polarization in $b \to s\gamma$ (Phys. Rev. Lett. 88 051802 (2002)).

- *requires three-body decay*
- *requires interference, such as $(K\pi^+)\pi^0\gamma \leftrightarrow (K\pi^0)\pi^+\gamma$*

$B \to K\pi^+\pi^0\gamma$ has not been observed

Analysis Strategy

Select candidates in four modes:

- $K^+\pi^-\pi^+\gamma$
- $K^+\pi^-\pi^0\gamma$
- $K_S\pi^+\pi^-\gamma$
- $K_S\pi^+\pi^0\gamma$

- *Main background from other $b \to s\gamma$ events*
- *$e^+e^- \to q\bar{q}$ reduced using shape variables in a Fisher Discriminant*
- *To extract signal perform likelihood unbinned fit to ΔE, m_{ES} distributions*

Branching fractions and mass spectra of B→Kππγ

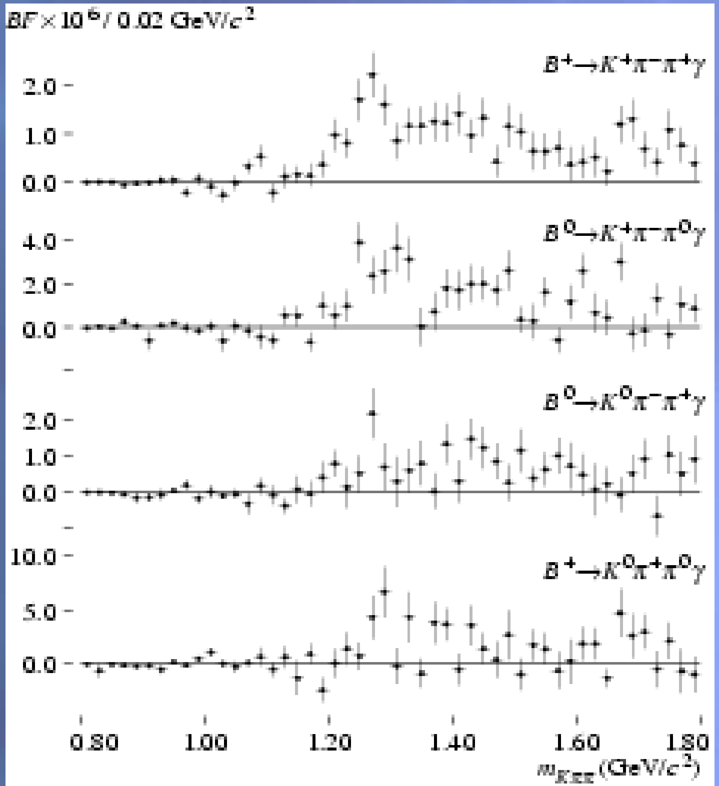
Preliminary

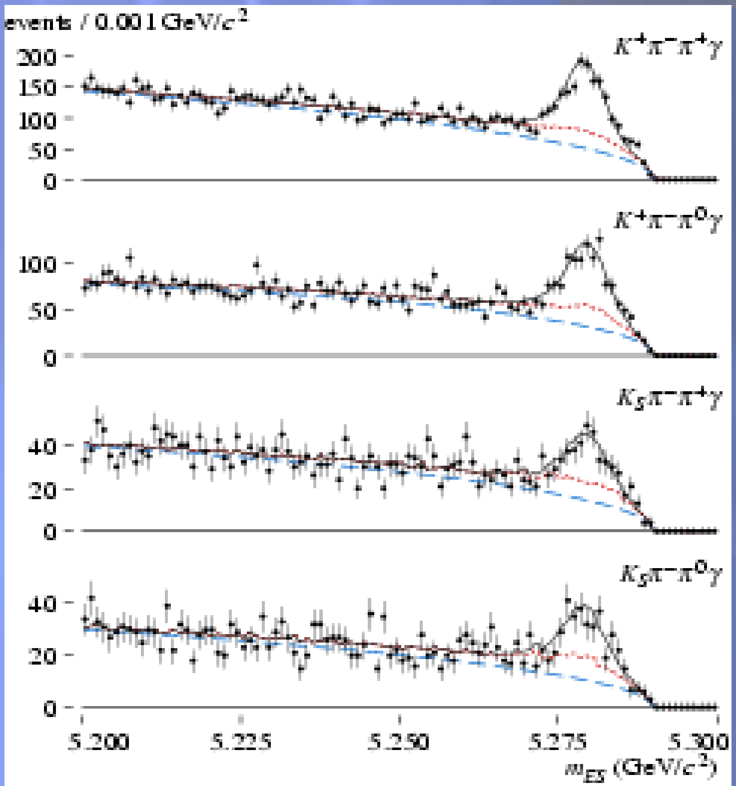
$\mathcal{B}(B^+ \to K^+ \pi^- \pi^+ \gamma) = (2.95 \pm 0.13 \pm 0.20) \times 10^{-5}$

$\mathcal{B}(B^0 \to K^+ \pi^- \pi^0 \gamma) = (4.07 \pm 0.22 \pm 0.31) \times 10^{-5}$ — *First measurement*

$\mathcal{B}(B^0 \to K^0 \pi^+ \pi^- \gamma) = (1.85 \pm 0.21 \pm 0.12) \times 10^{-5}$

$\mathcal{B}(B^+ \to K^0 \pi^+ \pi^0 \gamma) = (4.56 \pm 0.42 \pm 0.31) \times 10^{-5}$ — *First measurement*





232M $B\bar{B}$

PRL 92, 111801 (2004)

Search for B →ρ/ωγ

Simplest and most "common" b →dγ exclusive decays are ργ and ωγ

Ratio of exclusive b → dγ and b→ sγ decay rates measures $|V_{td}/V_{ts}|$

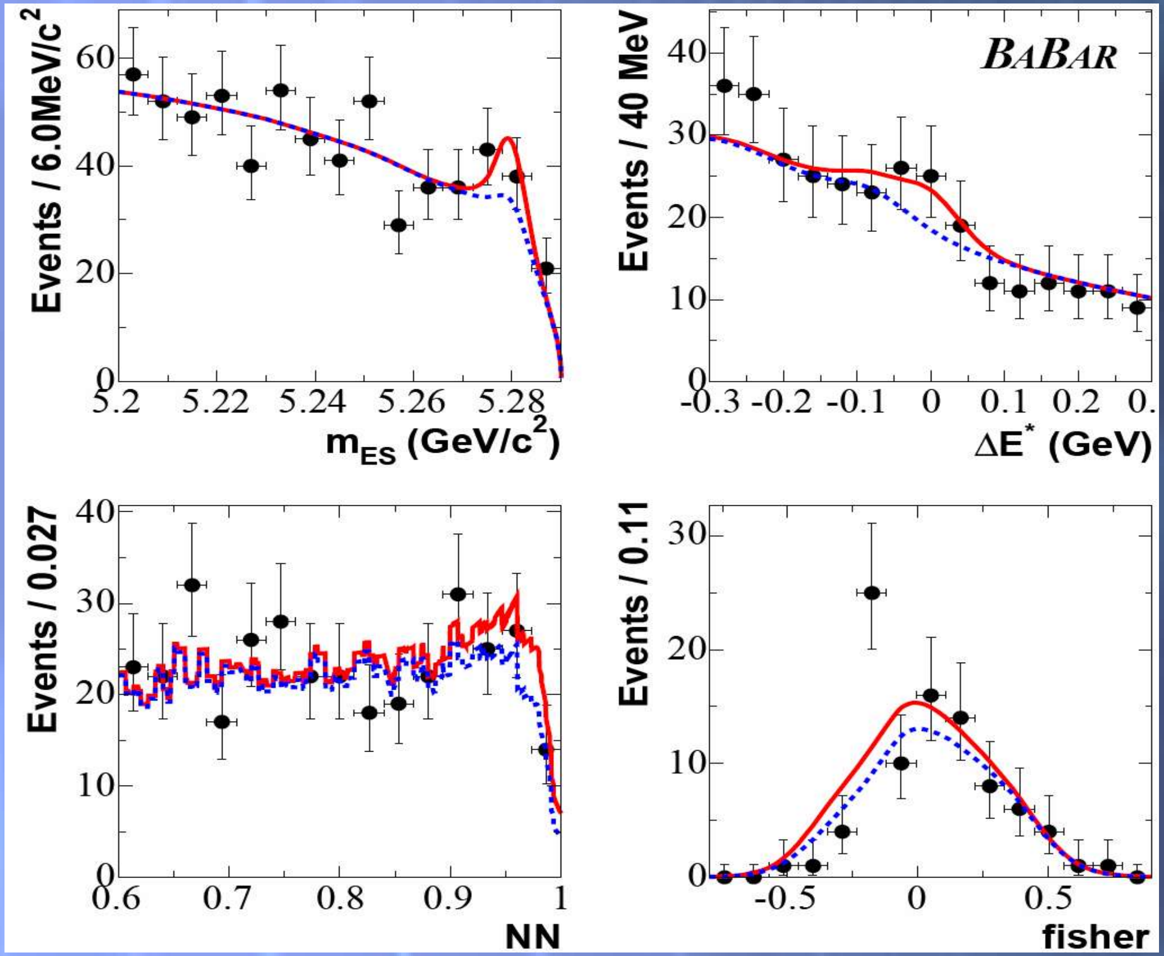
Simultaneous fit to all three samples with the constraint:

Combined $\mathcal{B}(\rho,\omega\gamma) \equiv$
$\mathcal{B}(\rho^+\gamma)$ =
$2(\tau_+/\tau_0)\ \mathcal{B}(\rho^0\gamma)$ =
$2(\tau_+/\tau_0)\ \mathcal{B}(\omega\gamma)$

$\mathcal{B} < 1.2 \bullet 10^{-6}$ 90% CL

Fitting individual $\mathcal{B}$:

- **$\mathcal{B}(\rho^\pm\gamma)<1.8\bullet10^{-6}$ 90%CL**
- **$\mathcal{B}(\rho^0\gamma)<0.4\bullet10^{-6}$ 90%CL**
- **$\mathcal{B}(\omega\gamma)<1.0\bullet10^{-6}$ 90%CL**



A total of 211M $B\bar{B}$ events are used

CKM matrix constraint

SU(3) breaking of form factors $\xi = 1.2 \pm 0.1$

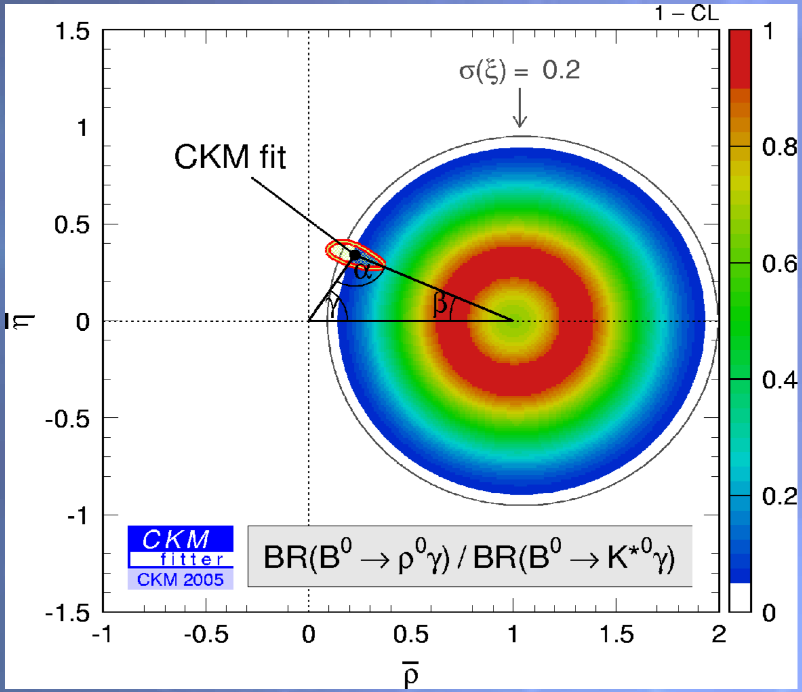
Subleading contribution $\Delta < 0.4$

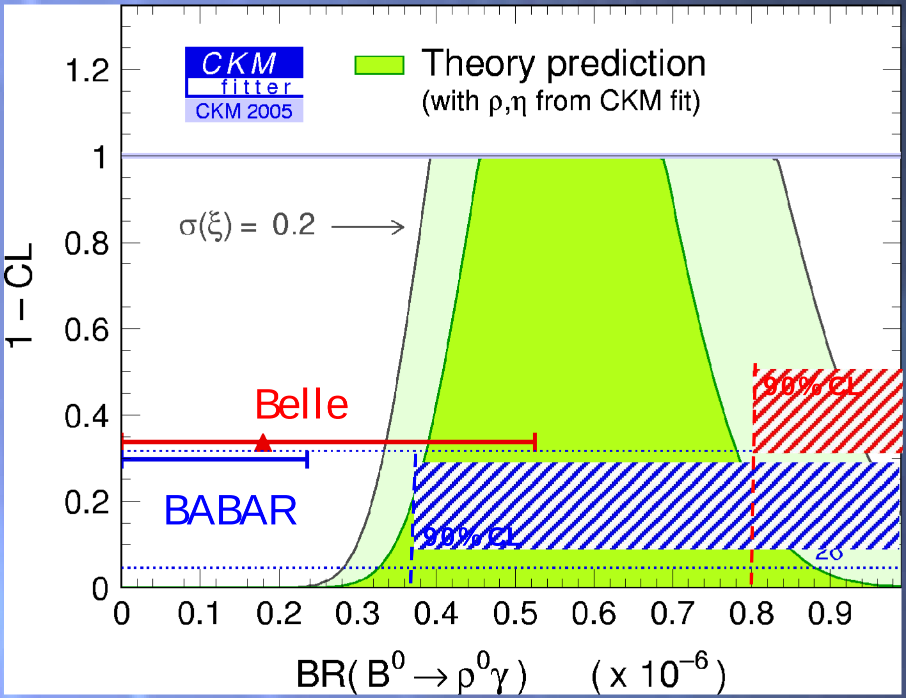
$$\frac{BR(B^0 \to \rho^0\gamma)}{BR(B^0 \to K^{*0}\gamma)} \propto \frac{1}{2}\left|\frac{V_{td}}{V_{ts}}\right|^2 \xi^{-2}(1+\Delta)$$

Eur.Phys.J. C23 (2002) 89

Nucl. Phys. B 621 459 (2002) and later papers

$B \to \rho\gamma$ observation should be imminent!

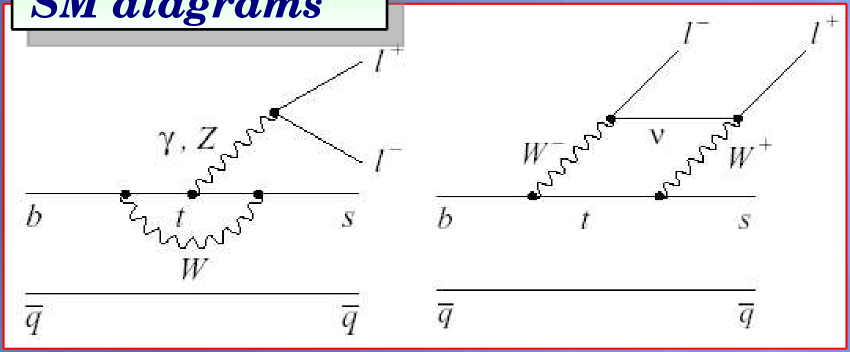




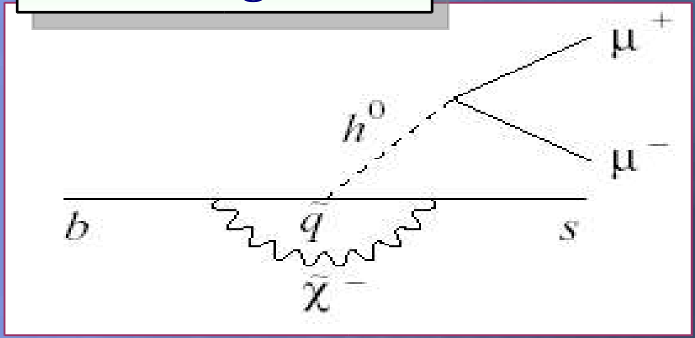
Penguins are starting to provide meaningful CKM constraint
Reduction of theory errors necessary to be competitive with B_d, B_s mixing

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

SM diagrams



SUSY diagram



Suppressed decays in the SM:

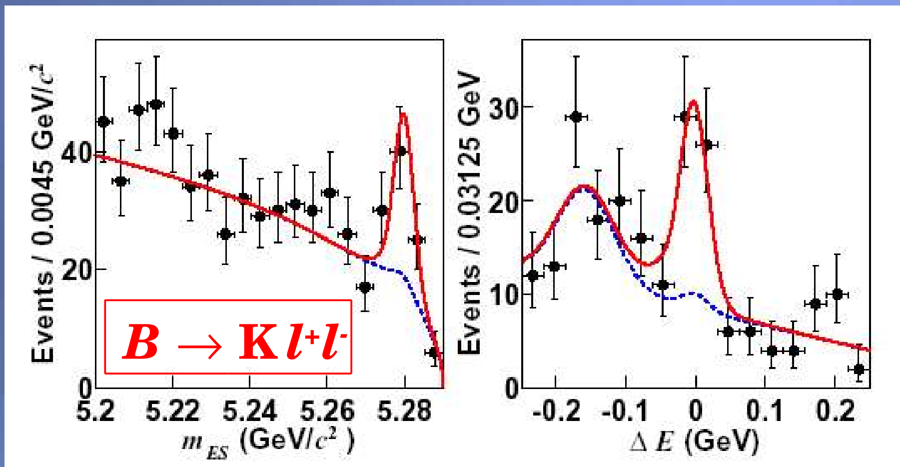
- $\mathcal{B} \sim 10^{-6}$
- ***Negligible direct CP asymmetry***
- $R_K = \mathcal{B}(B \to K\mu^+\mu^-) / \mathcal{B}(B \to K e^+e^-) \approx 1$
- $R_{K^*} = \mathcal{B}(B \to K^*\mu^+\mu^-) / \mathcal{B}(B \to K^* e^+e^-) \approx 0.75$

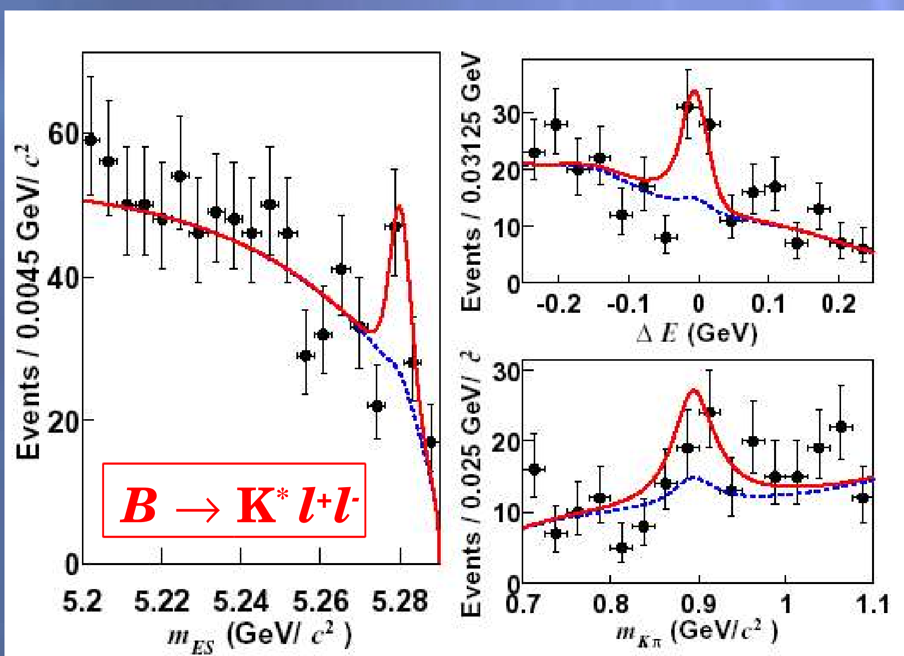
Contribution from a pole in EM penguin for the e^+e^- final state at q^2~0

New Physics can change

- ***the Branching Fraction***
- ***direct CP violation***
- ***forward-backward di-lepton asymmetry***

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





$BF(B \to K l^+ l^-) = (0.34 \pm 0.07 \pm 0.03) \bullet 10^{-6}$

$BF(B \to K^* l^+ l^-) = (0.78^{+0.19}_{-0.17} \pm 0.12) \bullet 10^{-6}$

$R_K = 1.06 \pm 0.48 \pm 0.05$

$R_{K^*} = 0.93 \pm 0.46 \pm 0.12$

$A_{CP}(B^+ \to K^+ l^+ l^-) = -0.08 \pm 0.22 \pm 0.11$

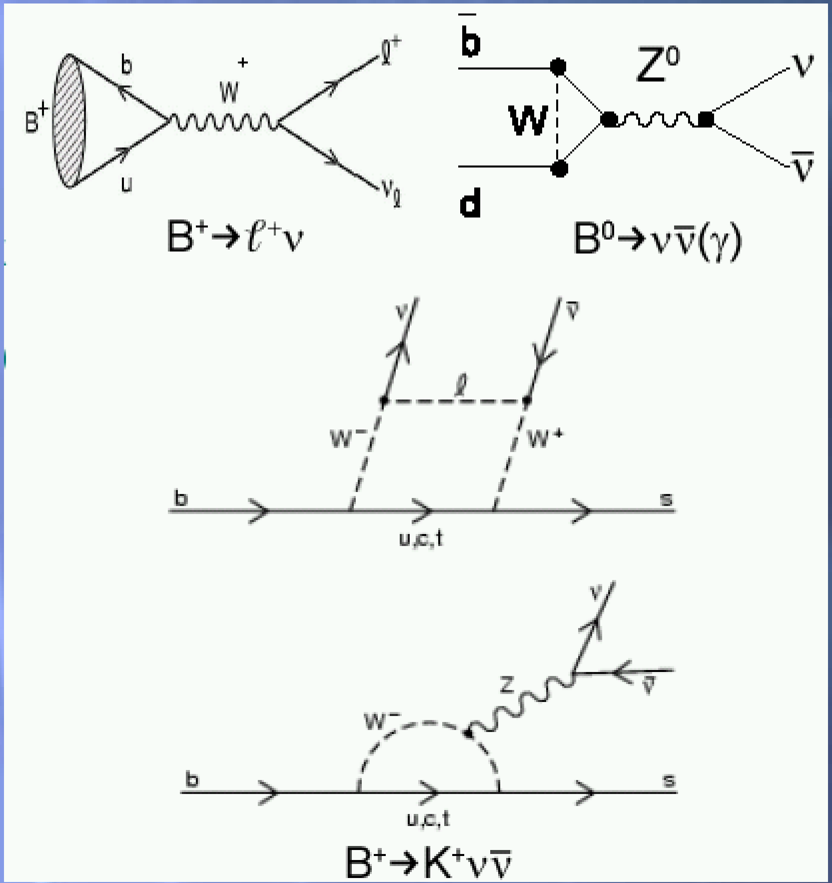
$A_{CP}(B \to K^* l^+ l^-) = 0.03 \pm 0.23 \pm 0.12$

A total of 229M $B\bar{B}$ events are used

Rare Leptonic Decays

B→lν, B→(K/π)ν$\bar{\nu}$, B→ν$\bar{\nu}$(γ)...

- ***Proceeding through W-boson annihilation or electroweak penguin and box diagrams in the SM***
- ***Are theoretically clean***
- ***Are suppressed in the SM by CKM matrix elements, helicity suppression or by penguin/loop domination***
- ***Probe for new physics***



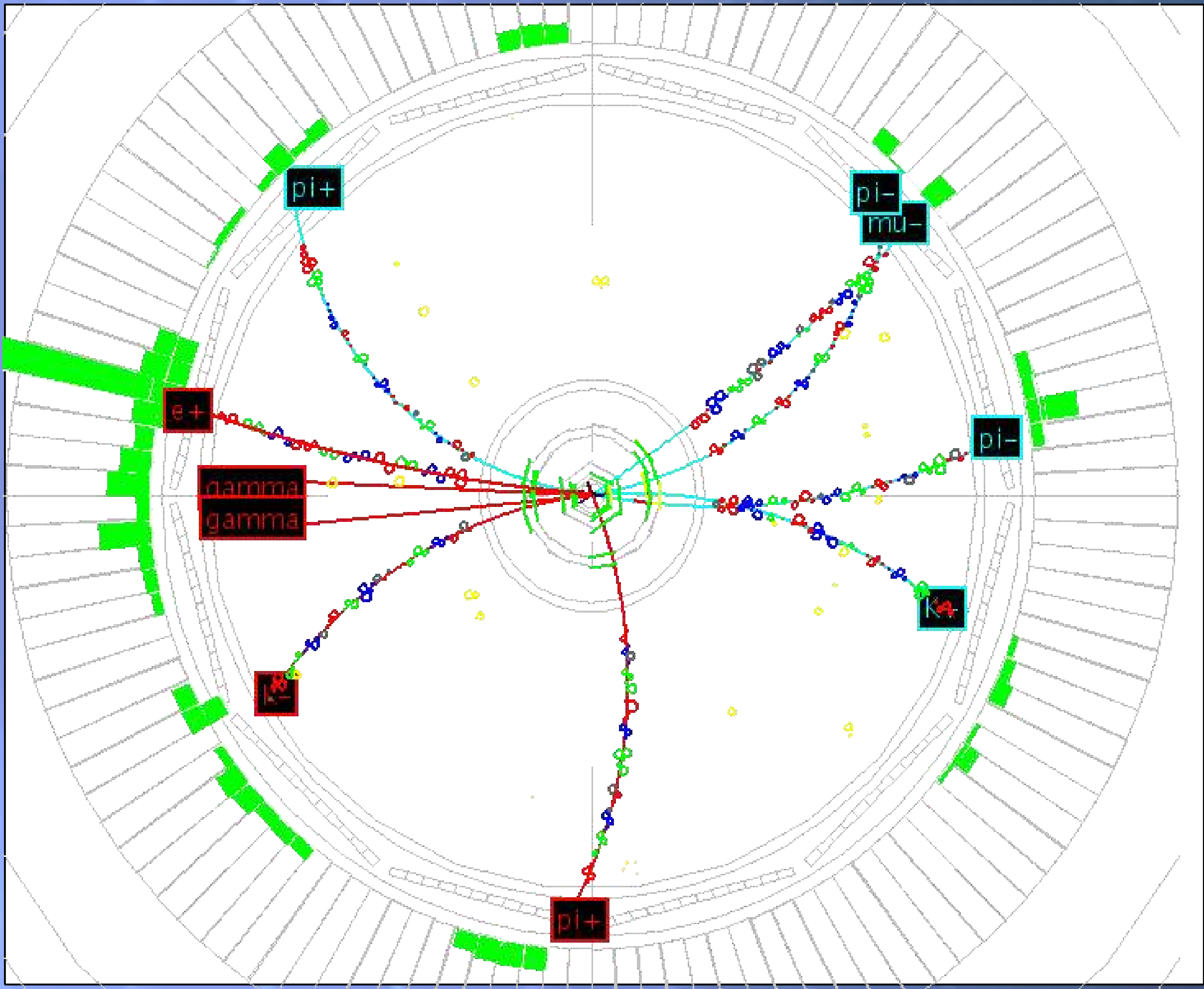
Event Reconstruction Method

Reconstruct ("tag") one B in either a semileptonic or leptonic final state:

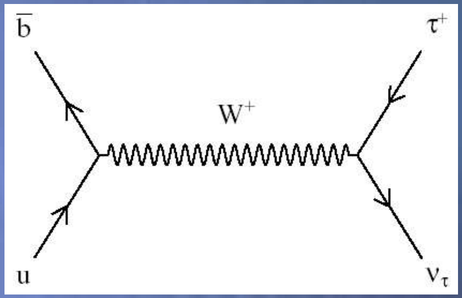
- *$B \to D^{(*)}X$, X is a combination of $K_{(s)}$, π, π^0*
- *$B \to D^{(*)}l\nu$*

Statistically independent samples

Constrain the "recoil" to determine its consistency with a signal hypothesis



Search for $B^+ \to \tau^+ \nu$



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

- ***$B^+ \to \tau^+ \nu$ in the SM***
  - ***Via quark annihilation into a W^+ boson***
  - ***Decay with μ or e are helicity-suppressed***
- ***New physics in $B^+ \to \tau^+ \nu$***
  - ***Charged Higgs boson (H) as propagator: SUSY, two-Higgs doublet models***
  - ***Enhancement of the $\mathcal{B}$***
    - ***Up to a factor of 5***
- ***Experimentally challenging due to neutrinos in the final state***

Sensitive to $f^2_B |V_{ub}|^2$
SM expectation $\approx 9 \bullet 10^{-5}$

- ***Measurement of f_B***
  Assuming $|V_{ub}|$ known from semileptonic decays
- ***Measurement of $|V_{ub}|^2/|V_{td}|^2$***
  From $\mathcal{B}(B \to \tau^+ \nu)/\Delta m$ (*)
  - ***Gives a constraint on the CKM unitarity triangle***

(*) *Δm= mass difference between the heavy and light states of the neutral B*

Search for $B^+ \to \tau^+ \nu$

- *Exclusive reconstruction with a semileptonic B "tag"*

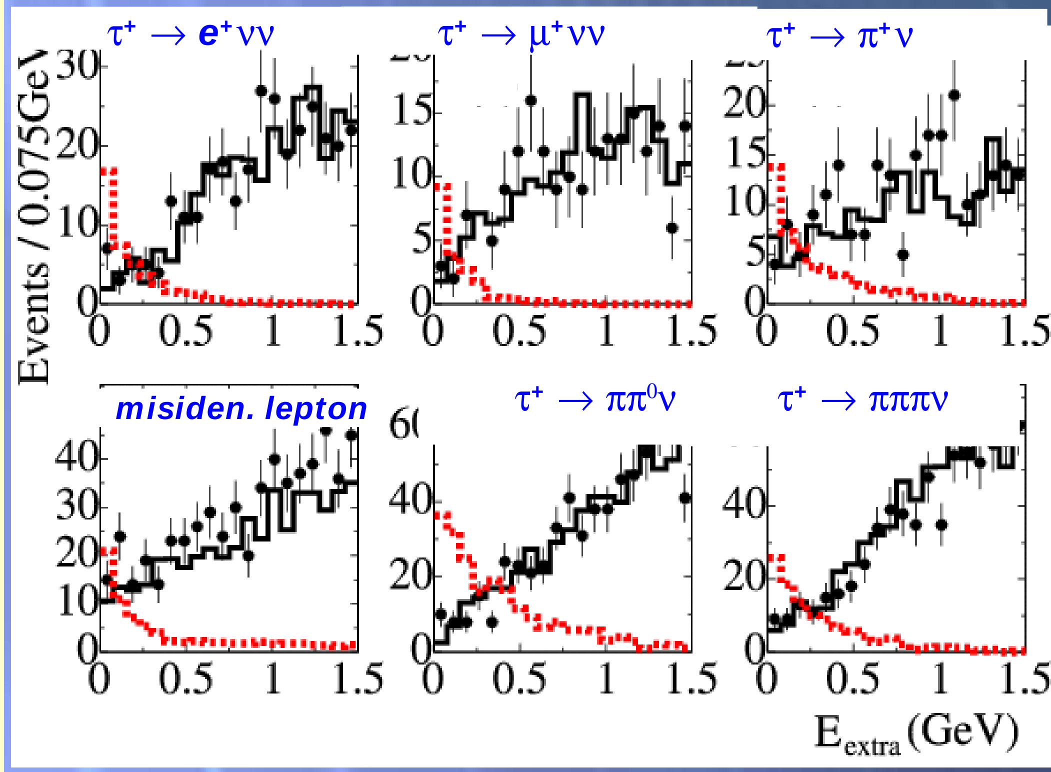
- *Search for a $B \to \tau^+ \nu$ signal in the rest of the event:*

$\tau^+ \to e^+\nu\nu, \mu^+\nu\nu, \pi^+\nu, \pi^+\pi^0\nu, \pi^+\pi^-\pi^+\nu$

- *Main background from hadronic or semileptonic B decays with correcly tagged events*

- *Key variable: residual energy in the calorimeter (E_{extra}): to peak at very low values for signal*

E_{extra} for selected events



A total of 232M $B\bar{B}$ events are used

$B^+ \to \tau^+ \nu$: *preliminary results*

Expected background	130.9 ± 9.3
Observed events	150 ± 12

$\mathcal{B}(B^+ \to \tau^+ \nu) < 2.8 \times 10^{-4}$ **@ 90% C.L.**

Combined with a previous result with hadronic tag ($\mathcal{B}(B^+ \to \tau^+ \nu) < 4.2 \times 10^{-4}$)

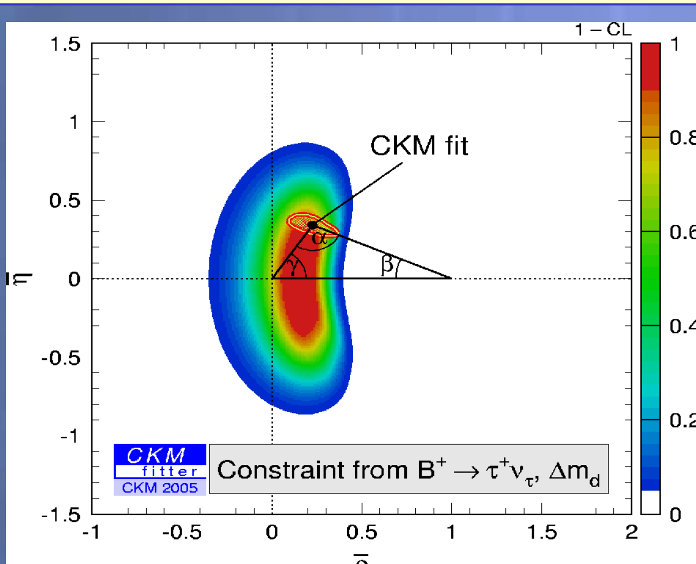
$\mathcal{B}(B^+ \to \tau^+ \nu) < 2.6 \times 10^{-4}$ **@ 90% C.L.**

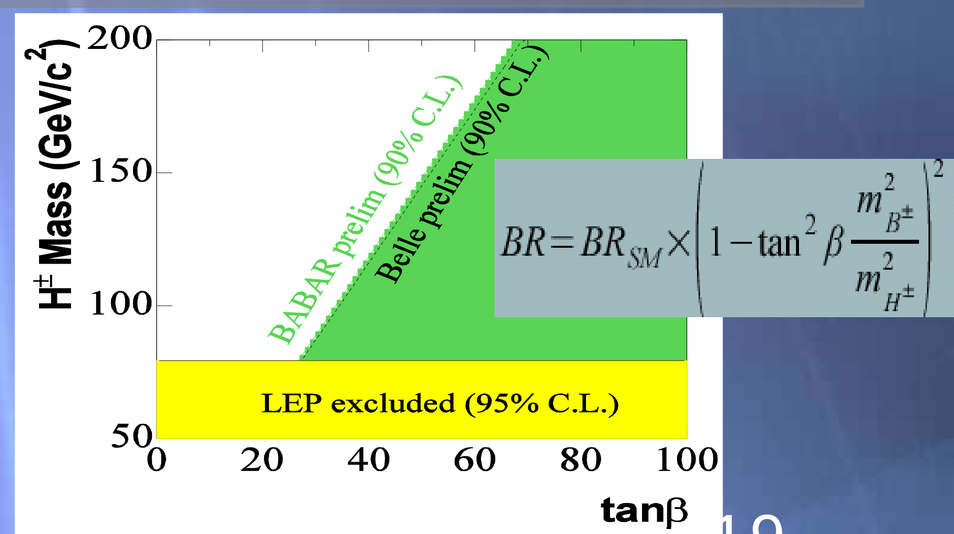
$f_B < 0.41$ **GeV @ 90% C.L.**

Constraint on the CKM parameters in agreement with present CKM fit

Constraint on the charged Higgs boson in the two charged Higgs-Doublet model:

$\tan\beta / m_{H+} < 0.34$ (GeV/c²)

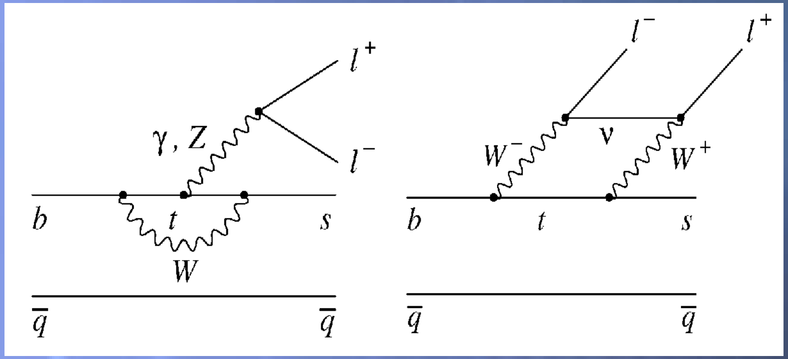




PRL 94 101801 (2005)

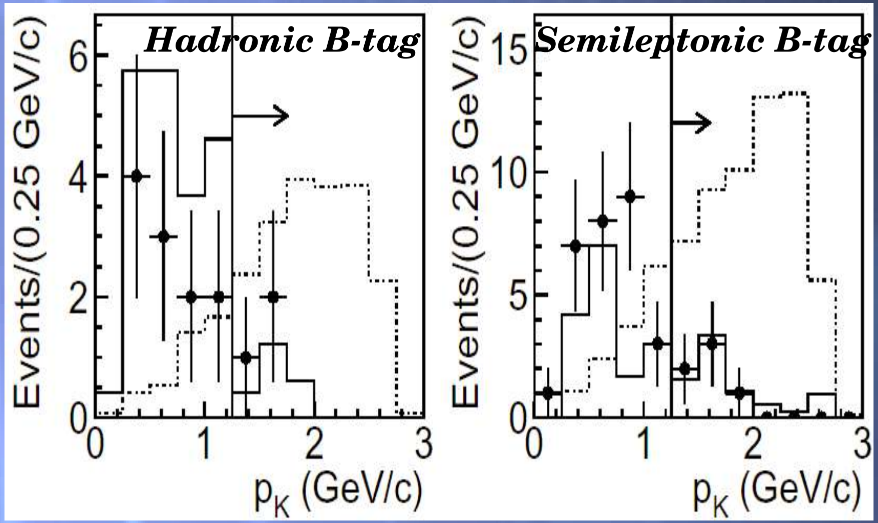
Search for $B\to K(\pi)\nu\bar{\nu}$

- ***Flavour Changing neutral-current process, allowed via EW box/penguin diagrams.***
- ***SM: $\mathcal{B}(B\to K\nu\bar{\nu}) \sim 4\bullet10^{-6}$***
- ***$b\to d\nu\bar{\nu}$ is suppressed over $b\to s\nu\bar{\nu}$ by $|V_{tb}|/|V_{ts}|$***



BaBar Analysis strategy

- ***Use hadronic and semileptonic B-tags***
- ***Ask for only a track for signal B***
- ***Event shape variables used to suppress $e^+e^-\to q\bar{q}$, $\tau^+\tau^-$***



89M $B\bar{B}$

	$K\nu\bar{\nu}$	$\pi\nu\bar{\nu}$
Expected background	3.8 ± 1.1	24.1 ± 3.6
Observed events	3	21
$\mathcal{B}<$ @ 90%CL	$5.2\bullet10^{-5}$ (*)	$1.0\bullet10^{-4}$

(*) Hadronic and Semileptonic Tags

PRL 93 091802 (2004)

Search for $B \to \nu\bar{\nu}(\gamma)$

- *$B \to \nu\bar{\nu}$ is strongly helicity m_ν^2/m_B^2 suppressed*
- *.. whereas for such decays with a photon in the final state*
- *SM BF($B \to \nu\bar{\nu}\gamma$) ~ 10^{-9}*
- *Both are below the sensitivity of existing experiments*
- *Clear observation would be a sign of new physics*
- *No direct searches so far*

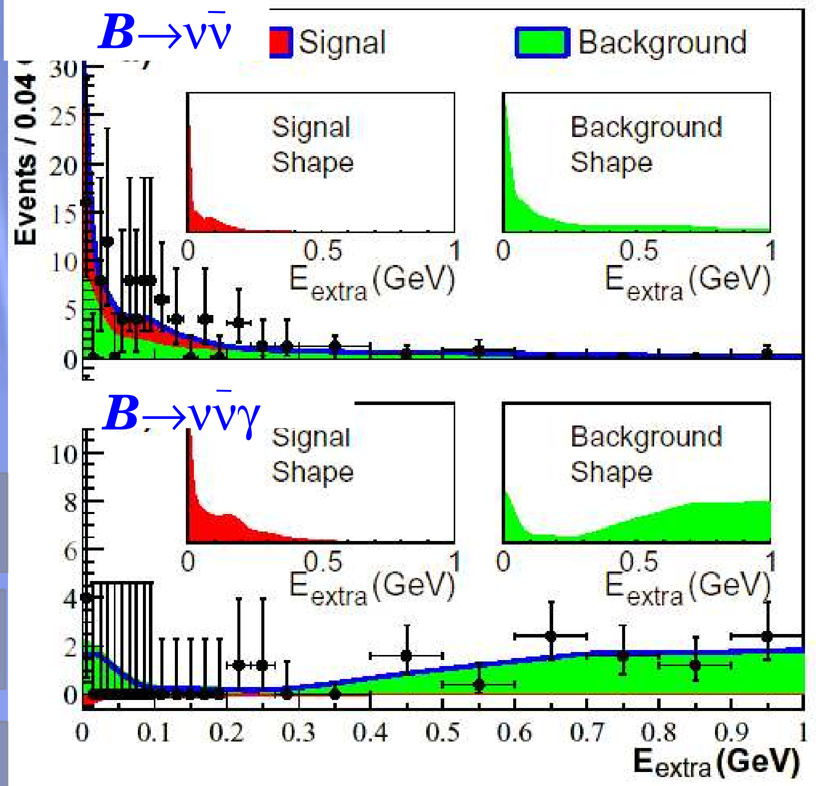
BaBar Analysis strategy

- *Use Semileptonic tag*
- *Ask for no tracks in signal B*
- *Background dominated by B decays with lost or unreconstructed particles*

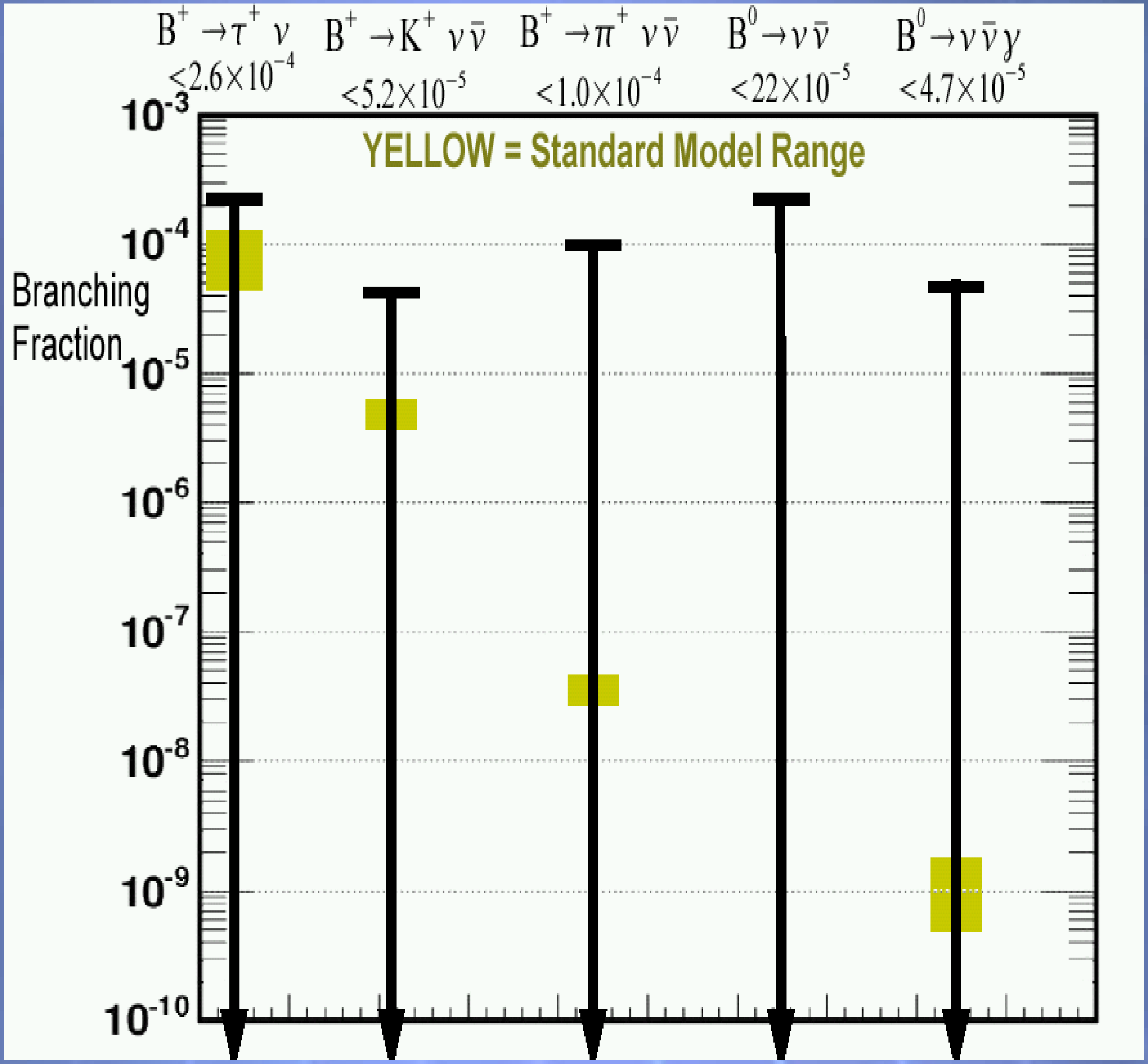
$\mathcal{B}(B^+ \to \nu\bar{\nu}) < 22\times 10^{-5}$ @ 90% C.L.

$\mathcal{B}(B^+ \to \nu\bar{\nu}\gamma) < 4.7\times 10^{-5}$ @ 90% C.L.

89M $B\bar{B}$



Summary of Leptonic Decays



Conclusions

New preliminary results from BaBar on electro-weak penguins and leptonic decays

- ***Favourite place to search for new physics beyond the SM***
- ***Useful for precise determinations of theoretical parameters m_b , μ_π^2***
- ***Looking forward to more statistics and finding $B\rightarrow\rho/\omega\gamma$ and leptonic decays!***

Spare Slides

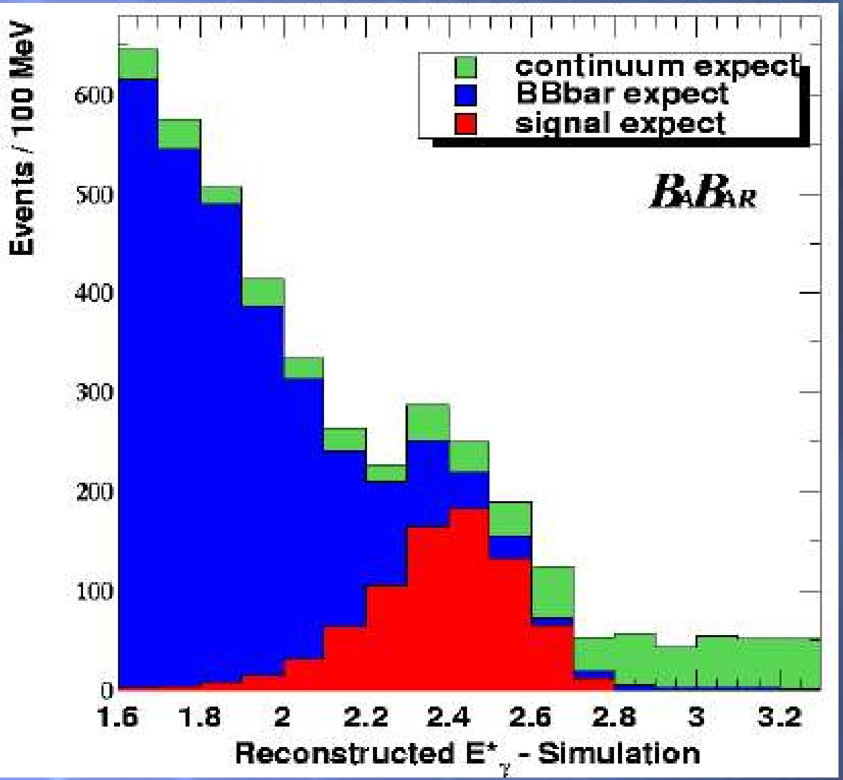
$b \to s\gamma$ Background contributions

Continuum Background

- *Neural Network*
- *M_{ES}, ΔE*
- *Lepton tagging*
- *Event-shape cuts*
- *Off-peak data subtraction*

BB Background

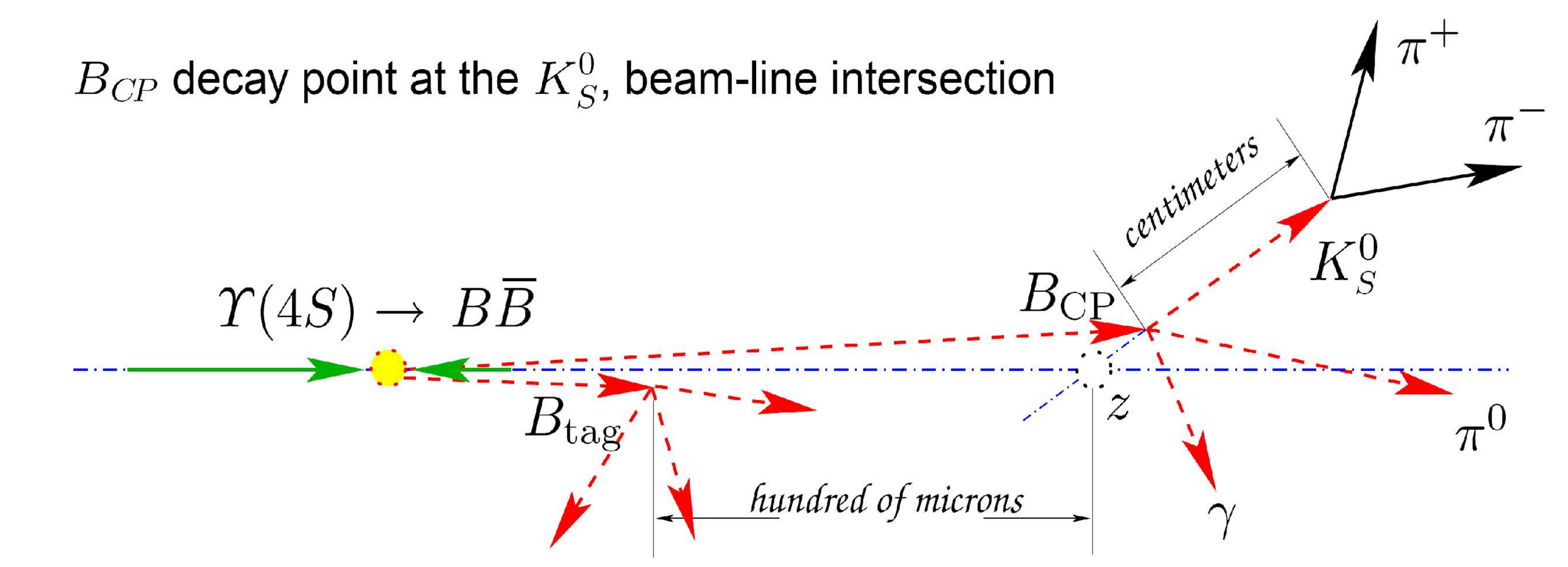
- *80% from π^0, η decays*
- *explicit π^0/ η vetoes*
- *Remaining subtracted using MC simulation*
- *M_{ES}, ΔE*



Time Dependent CPV in $B^0 \to K_s \pi^0 \gamma$

Measuring Δt of $K^*(\to K_S\pi^0)\,\gamma$ events requires novel beam-constrained vertexing techinque:

- ***Vertex signal B with intersection of K_S trajectory and beam-line***
- ***Usable resolution for K_S decaying inside the silicon tracker***
- ***Validated with $B^0 \to J/\psi\, K_S$ events***



Analysis strategy for $B \to K^{(*)} l^+ l^-$

Reconstructed modes

- $l = e, \mu$
- $K = K$ or $K_s (\to \pi^+\pi^-)$
- $K^* \to K\pi^{\pm}$

Background rejection

- Combinatorial from continuum
  - event shape variables
- Combinatorial from B decays
  - mostly semileptonic
  - missing energy

Final selection

- ΔE and m_{ES} variables
  - 2-dim. fit for $B \to K l^+ l^-$
  - 3-dim. fit for $B \to K^* l^+ l^-$
    - Includes $K\pi$ invariant mass

- **Efficiency is mode-dependent:**

  From 9% ($K^{*+} \mu^+ \mu^-$) to 26% ($K^+ e^+ e^-$)

- Challenge: peaking background in (ΔE, m_{ES})
  - Same final state as signal
  - $B \to K^{(*)} J/\psi$, $B \to K^{(*)} \psi(2S)$, $B \to D(\to K\pi)\pi$
  - J/ψ veto, hadronic D decay veto