# Search of New Physics in rare B decays including leptons and/or neutrinos at BaBar

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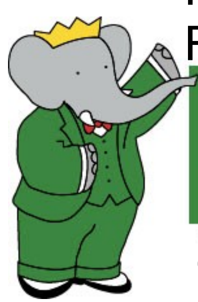
Representing



BABAR

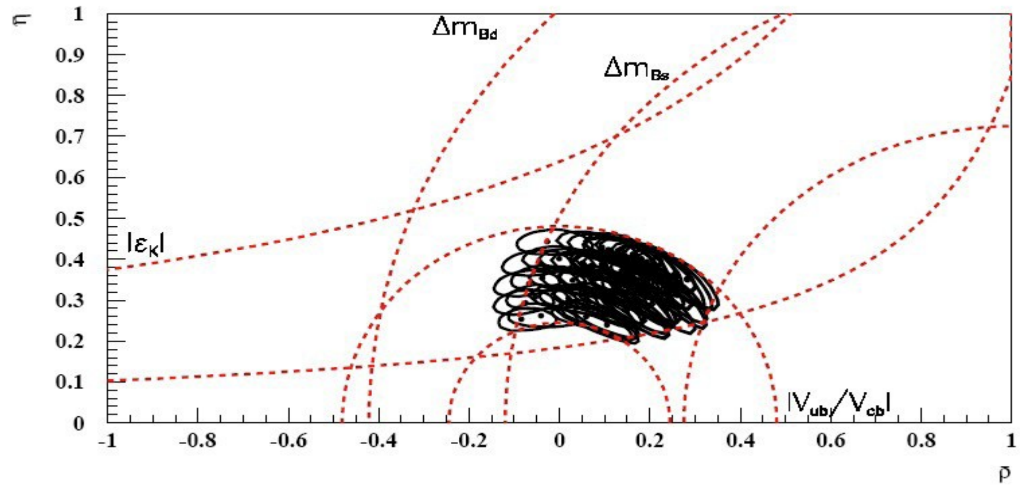


(Previously at Valencia University, IFIC- CSIC)

CERN Joint PP/EP Tuesday Seminar 20 JANUARY 2009

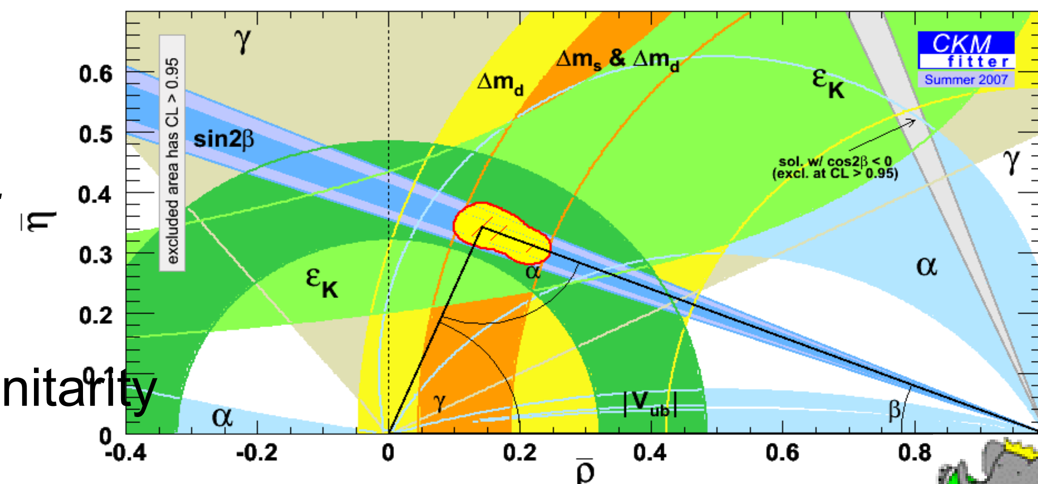
# A new era of flavour physics

~1998:
unitarity triangle
of the CKM matrix
weakly constrained




2008:
*thanks to the B factories,*
*Tevatron experiments,*
*and theoretical developments:*

precision measurements
Data ~ consistent with CKM Unitarity




Standard Model description of CP violation is a success!

# Where's the New Physics?

. Looking for something subtle

- Measurement precision limited by strong interaction (non-perturbative)
- Uncertainties are multiplicative
- To find something small, competing SM process must be small

***Rare decays!***

# Rare decays Probe New Physics

Rare decays

. forbidden or strongly suppressed in the SM

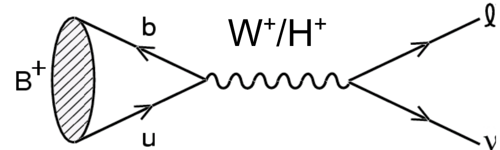
. decay not via the dominant transition

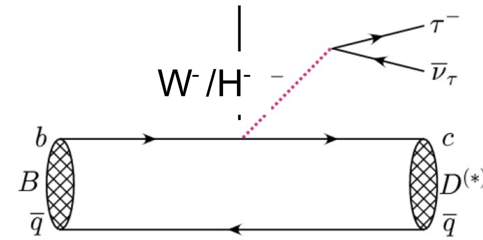
. could receive contributions from NP effects → probe of NP

Missing $\nu$ final state (leptonic/semileptonic) decays:

. sensitive to charged Higgs mass

. $B \rightarrow l\ \nu$ and $B \rightarrow D^{(*)}\ \tau\ \nu$



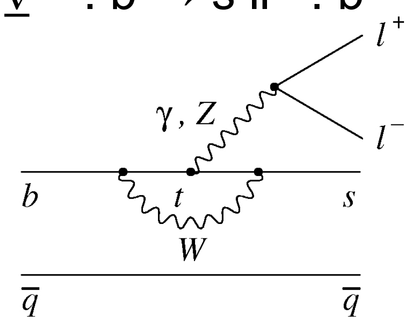



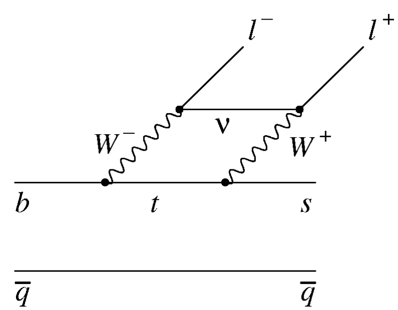

Electroweak penguin mediated processes :

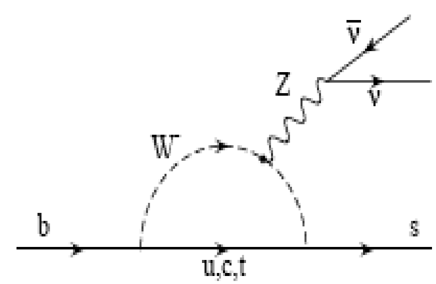
. Flavour Changing neutral current (FCNC) prohibited in SM at tree level

. sensitive to Higgs, SUSY particles, light dark matter

. $b \rightarrow K(*)\ \nu\ \underline{\nu}$ . $b \rightarrow s\ ll$ . $b \rightarrow s\ \gamma$



# Outline

Theoretical overview
B-factories and datasets
missing $\nu$ final state transitions:
. $B \rightarrow l\, \nu$ ($l = \tau, e, \mu$)
. $B \rightarrow D(^*)\, \tau\, \nu$
$b \rightarrow s$ transitions:
. $B \rightarrow K(^*)\, l\, l$
. $B \rightarrow K(^*)\, \nu\, \underline{\nu}$
Conclusions

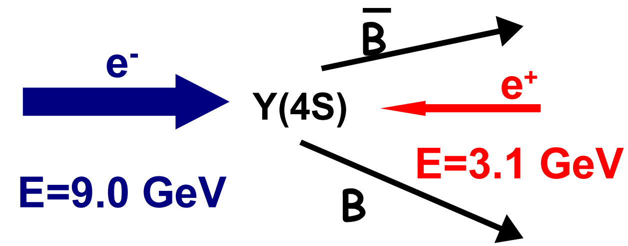
# PEP-II B Factory at SLAC

High Luminosity e+ e- asymmetric collider:

- Center-of-mass energy tuned ~ 10.58 GeV

- Y(4S) is a $b\bar{b}$ bound state, decays to B meson pairs:
  $B^+B^-$ or $B^0\bar{B}^0$

- Produces ≈ 10 $B\bar{B}$ pairs per second

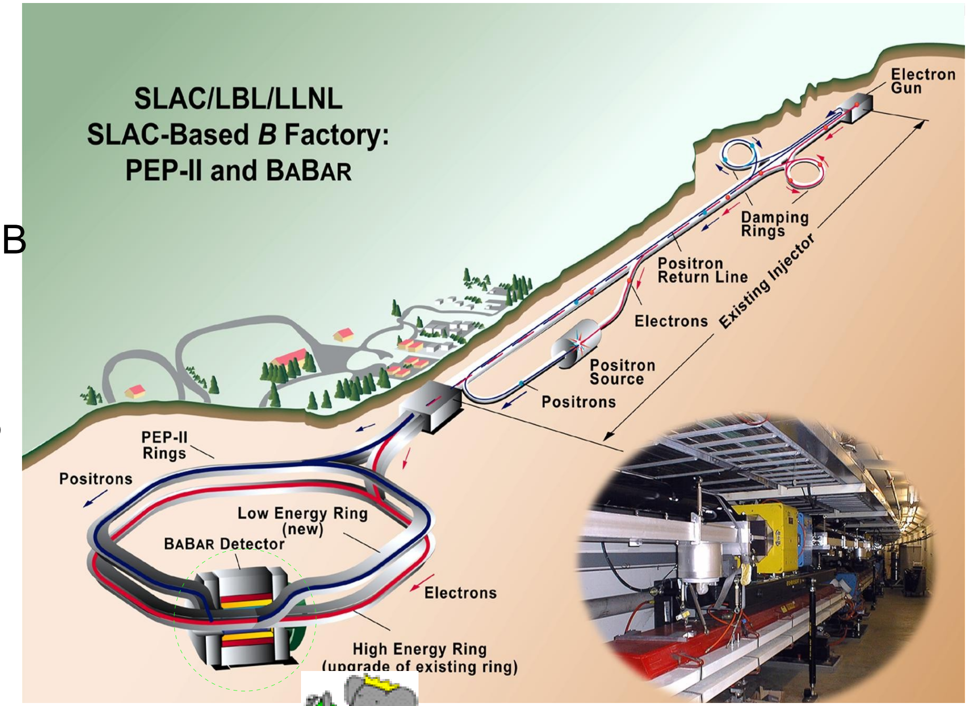


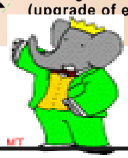

B Factories peculiarities:

- Asymmetry, lab frame boost ($\gamma\beta$ = 0.56):
  $\longrightarrow$ separation of the decays vertices of two B
  $\longrightarrow$ reco of decay vertex and time
  $\longrightarrow$ time dependent CP asymmetries

- $\mathcal{BR}$(Y(4S) -> $B^+B^-$)~ $\mathcal{BR}$(Y(4S) -> $B^0\bar{B}^0$) ~ 0.5
  $\longrightarrow$ clear environment
  $\longrightarrow$ high signal-to-bkg ratio, $\sigma_{b\bar{b}} / \sigma_{had}$ ≈ 0.28

- Absence of fragmentation
  $\longrightarrow$ combinatorial background reduction



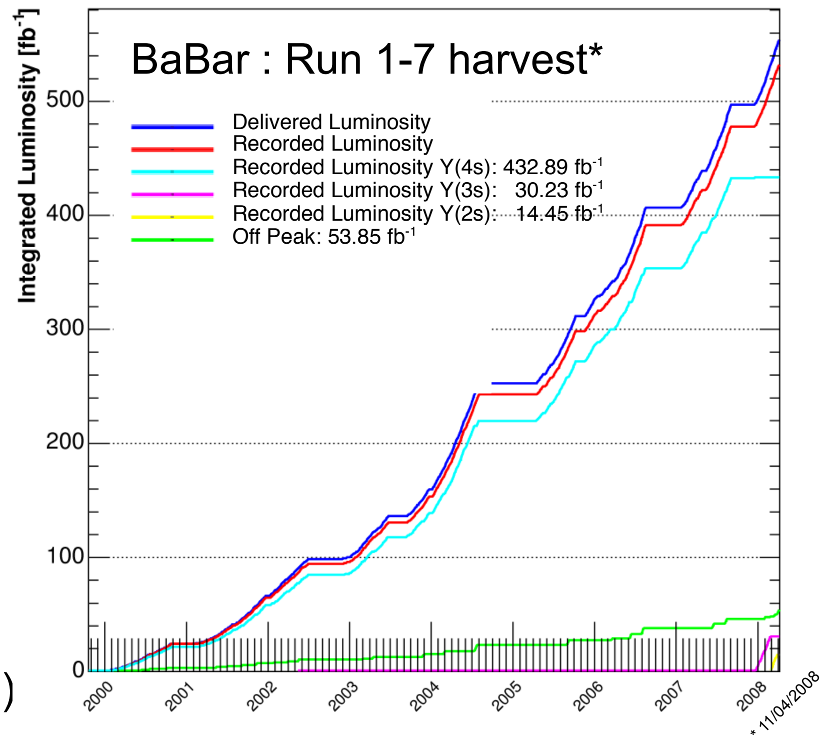



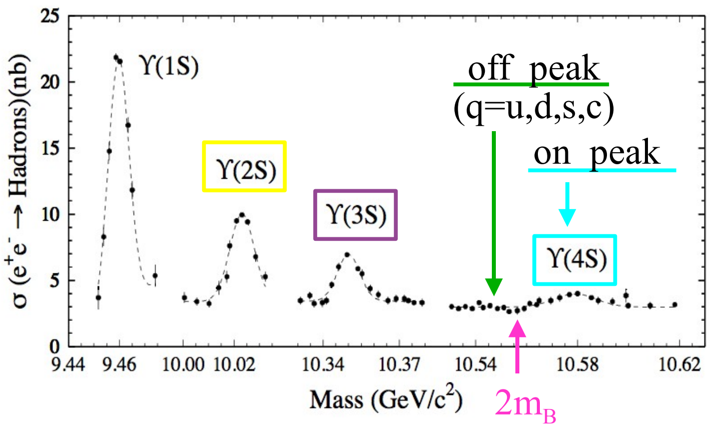
# PEP-II performance & BaBar Luminosity

. Peak $\mathcal{L}$ = 1.2x $10^{34}$ $cm^{-2}s^{-1}$
~ 4 times the design luminosity !
(design: $3.0 \times 10^{33}$ $cm^{-2}s^{-1}$)

. PEP-II Delivered 553.48 $fb^{-1}$
BABAR Recorded 531.43 $fb^{-1}$
> 530 M B$\underline{B}$ pairs Recorded

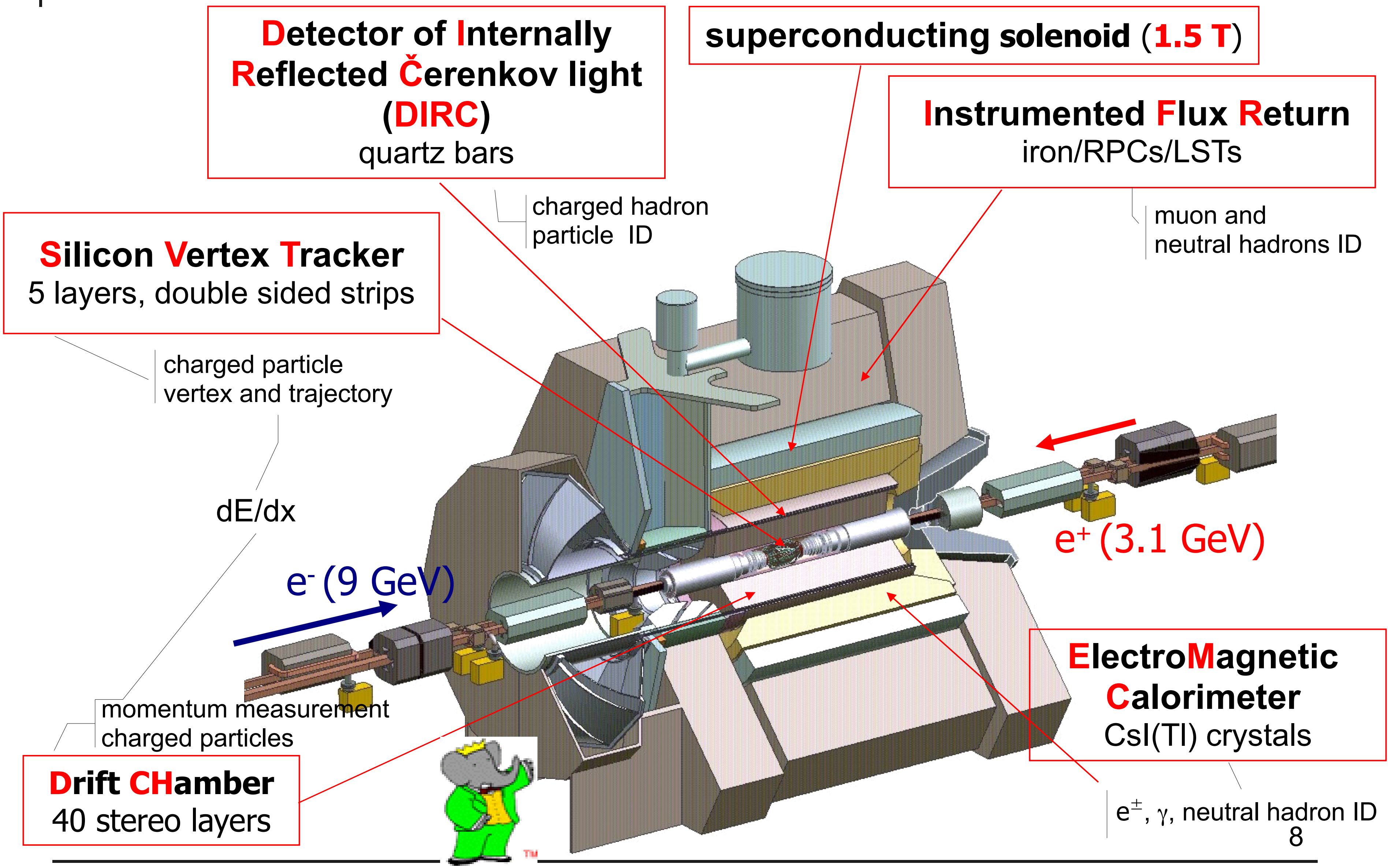
. Achieved Records
0.89 fb-1 in a day (~ 1M B$\underline{B}$ couples )
5.25 fb-1 in a week (~ 5.8 M B$\underline{B}$ couples)



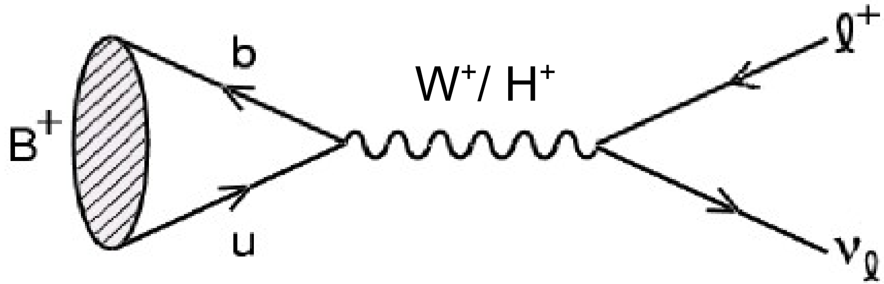



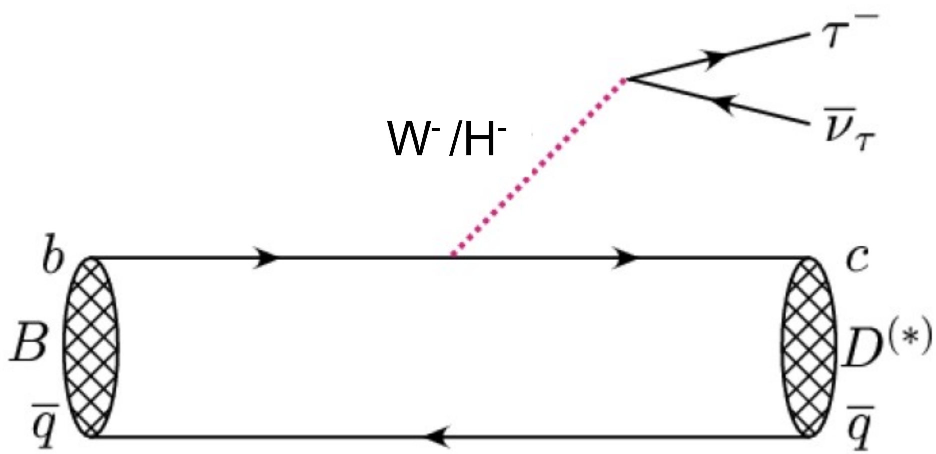

Υ(3S) and Υ(2S) data collected:
. search for rare decays (deviations from SM) and
.detailed bottonium spectroscopy with 140 million each

# the BaBar detector



# Missing ν final state transitions

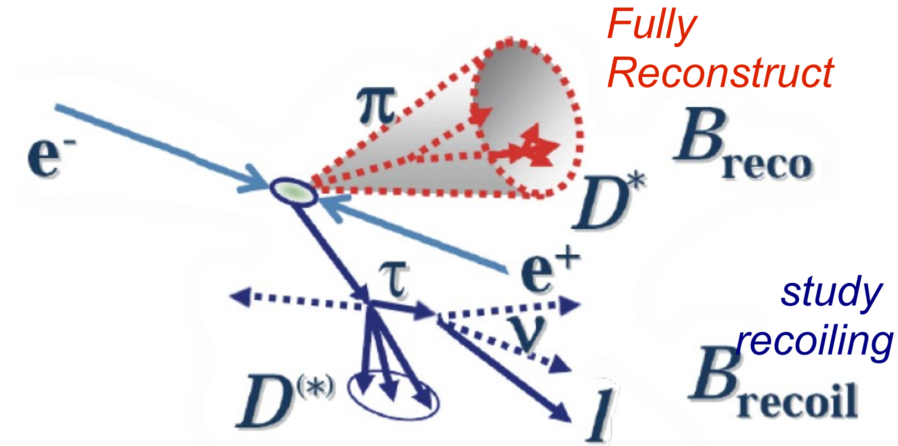



$b \rightarrow l\,\nu$ ($l = \tau, e, \mu$)

$B \rightarrow D(^*)\,\tau\,\nu$

# Experimental Technique: B tagging




. Lack of kinematic constraints:
1- 3 neutrinos in final state
- challenging!

. Two methods – “Tags”:

.. Hadronic: Breco → D(*)X
- X= hadrons ($\pi$, K, $\pi^0$, Ks)
- Low efficiency (~3x$10^{-3}$)
- Full reconstruction: high purity sample with kinematic constr.

.. Semileptonic: Breco→ D l $\nu$ X
- X = $\pi^0$, $\gamma$, nothing (assume 1 $\nu$ missing)
- lower purity
- Higher efficiency ~1% vs. ~0.3%

*First search for $b \rightarrow e\,\nu$, $b \rightarrow \mu\,\nu$ using this tag*

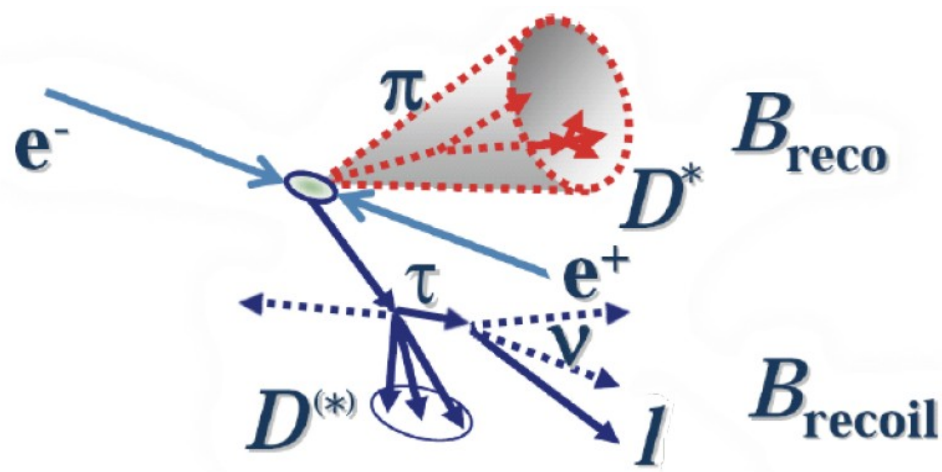
. No tags (Inclusive), applied to B → $\mu\,\nu$
.. Find highest momentum lepton, make a B with the rest of the event
.. High background, best limits

# Experimental Technique: recoil

. The $\tau$ is reconstructed in 4 modes in $B \rightarrow \tau\nu$

- $\tau^- \rightarrow e^- \nu_e \nu_\tau$
- $\tau^- \rightarrow \mu^- \nu_\mu \nu_\tau$
- $\tau^- \rightarrow \pi^- \nu_\tau$
- $\tau^- \rightarrow \rho^- \nu_\tau$ $(\rho \rightarrow \pi^- \pi^0)$

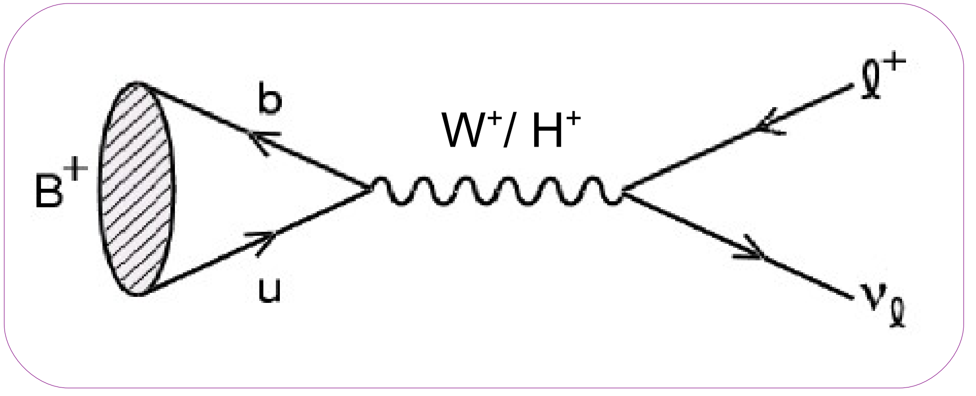
. Accounts for ~70% of $\tau$ decays

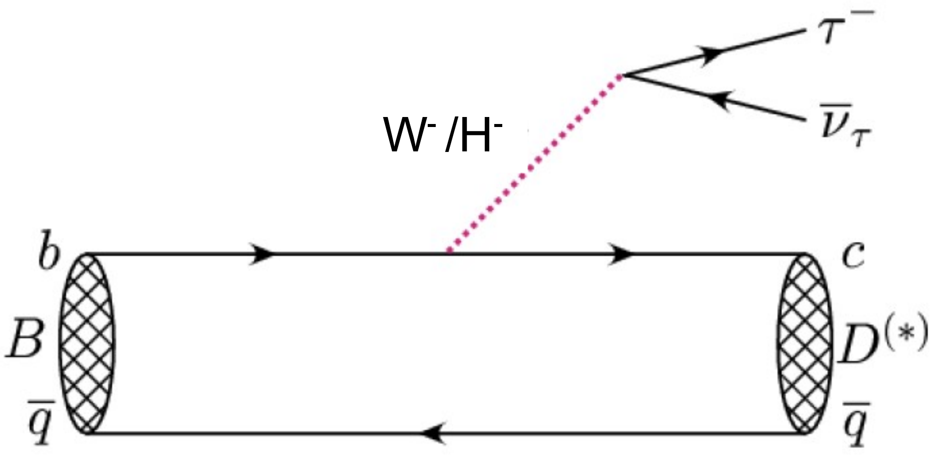



. Only Leptonic $\tau$ decays used in $B \rightarrow D^{(*)}\tau\nu$

. $B \rightarrow e\nu$, $\mu\nu$ decays classified on the base of $p'_l$ cut

# Missing ν final state transitions

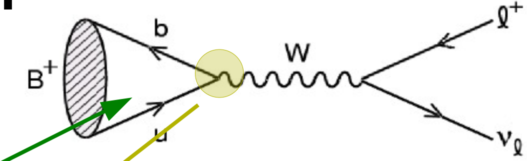



$b \rightarrow l\,\nu$ ($l = \tau, e, \mu$)

$B \rightarrow D(^*)\,\tau\,\nu$

# B → l ν motivation




$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

τ most favoured channel

$m_l$ leads to Helicity suppression

τ : μ : e = 1 : $5\times10^{-3}$ : $10^{-7}$

Vub : b→ulν ~8 % error

|Vub|=$(3.96\pm0.15^{+0.20}_{-0.23})\times10^{-3}$ *

+

. $f_B$: B-meson decay constant

- $f_B$ = 0.216 ± 0.022 GeV (Lattice QCD)

| | $B^+ \to e^+\nu_e$ | $B^+ \to \mu^+\nu_\mu$ | $B^+ \to \tau^+\nu_\tau$ |
|---|---|---|---|
| Prediction SM | $(1.4 \pm 0.3) \times 10^{-11}$ | $(5.8 \pm 1.3) \times 10^{-7}$ | $(1.3 \pm 0.3) \times 10^{-4}$ |
| PDG Values | $< 9.8 \times 10^{-7}$ | $< 1.7 \times 10^{-6}$ | $(1.4 \pm 0.4) \times 10^{-4}$ |

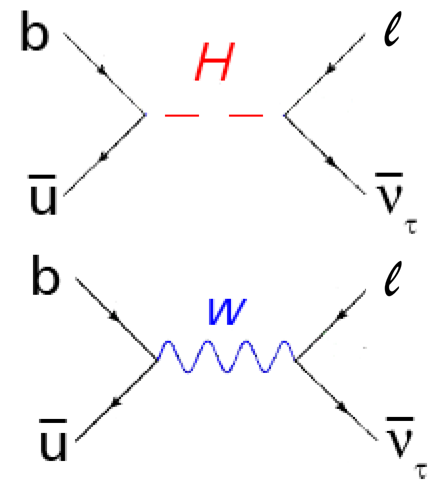
The SM prediction for B → τ ν is large!

It can be easily enhanced or suppressed by a factor of 1.5 from NP effects



*=HFAG

# $B \rightarrow l\,\nu$ motivation.. beyond the SM




. Additional Feynman diagram from Higgs boson: assuming $f_B$ and |Vub|, constrain charged Higgs

. Two Higgs Doublet Model (2HDM) and Minimal Supersymmetry(MSSM) lead to modified Branching fraction:

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2\beta\right)^2$$

**2HDM: Isidori and Paradisi PL B639 (2006)**
**W.S.Hou PRD 48 2342 (1993)**

$m_H$ – charged Higgs Mass

$\tan\beta$ – ratio of vacuum expectation values for the u and d type Higgs bosons of 2HD

# $B \to l \nu$ : Event selection

. require a good Tag-B (Use both hadronic and semileptonic tags)

. Cannot reconstruct $B_{recoil}$ mass, use simultaneously optimized cuts on:

.. $E_{extra}$, sum of energies of remaining neutrals

.. the momentum of signal lepton in *B* rest frame ($p'_l$)

.. little presence of "extra" particles ($K_L^0$, tracks, $\pi^0$)

.. continuum rejection through event shape requirements

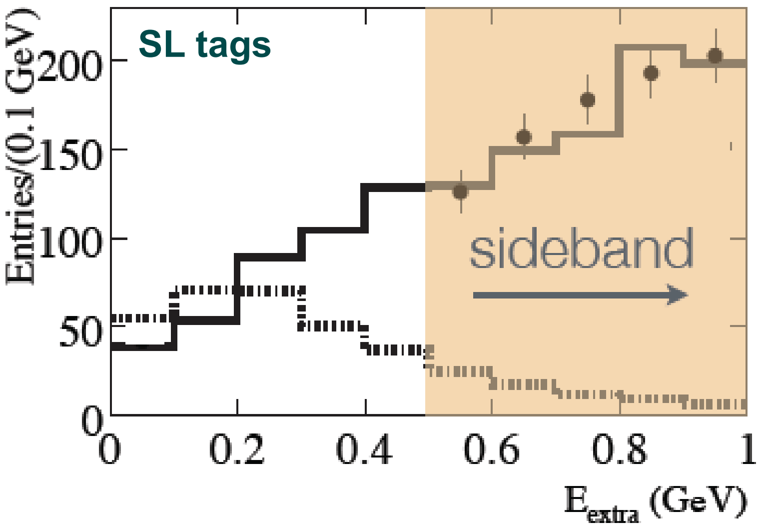
... for the semileptonic tag, take extra care of $\tau\,\tau$ events: if they enter final sample, they peak in $E_{extra}$!

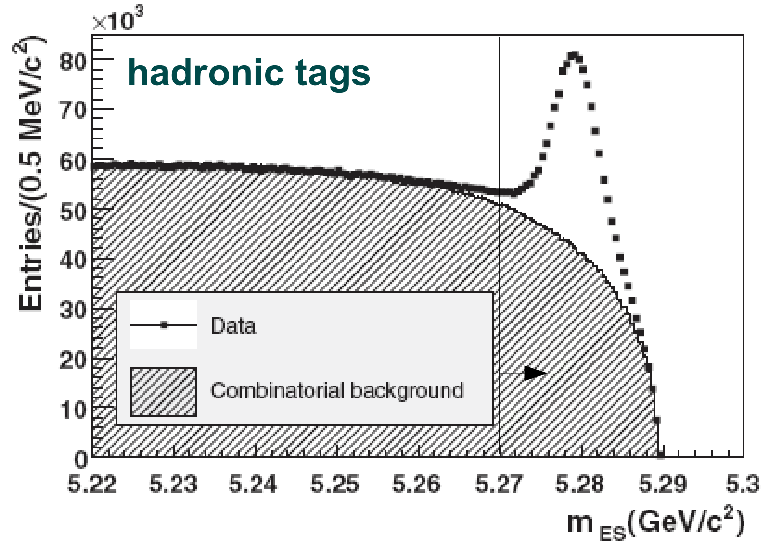
. selection efficiencies of ~1-5% in each channel, total of 10(HAD)-13(SL)% (after tagging and signal-B reconstruction)

# $B \to l \nu$ : Background Estimation

383M BB
PRD77,011107(2008)[HAD]
arXiv:0705.1820 [SL]

. Use sidebands in data to estimate background yield
 - $E_{extra}$, $B_{tag}$ mass sidebands



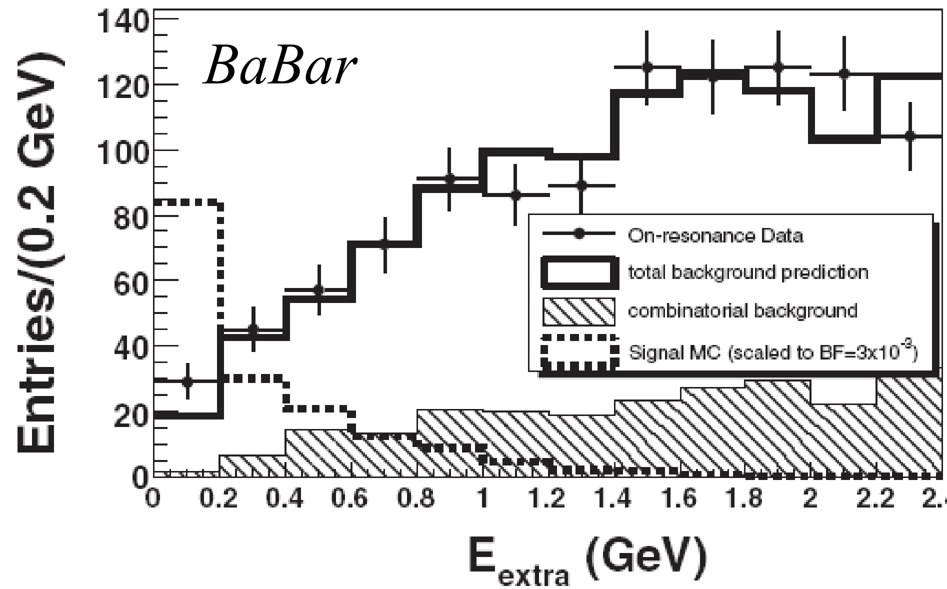




. Scale the amount of data in the $E_{extra}$ SB region by the ratio of MC bkg events in the signal and SB region:

$$N_{\text{exp,Sig}} = N_{\text{data,SideB}} \cdot \frac{N_{\text{MC,Sig}}}{N_{\text{MC,SideB}}}$$

# $B \rightarrow \tau \nu$ : Hadronic Tag Signal Yields

$E_{extra}$ distribution
after all the selection criteria,
all modes combined




Expected BG = 14 ± 3, Observed 24
Measure Branching Fraction

| $\tau$ decay mode | Expected background | Observed |
|---|---|---|
| $\tau^+ \rightarrow e^+\nu\overline{\nu}$ | $1.47 \pm 1.37$ | 4 |
| $\tau^+ \rightarrow \mu^+\nu\overline{\nu}$ | $1.78 \pm 0.97$ | 5 |
| $\tau^+ \rightarrow \pi^+\overline{\nu}$ | $6.79 \pm 2.11$ | 10 |
| $\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}$ | $4.23 \pm 1.39$ | 5 |
| All modes | $14.27 \pm 3.03$ | 24 |

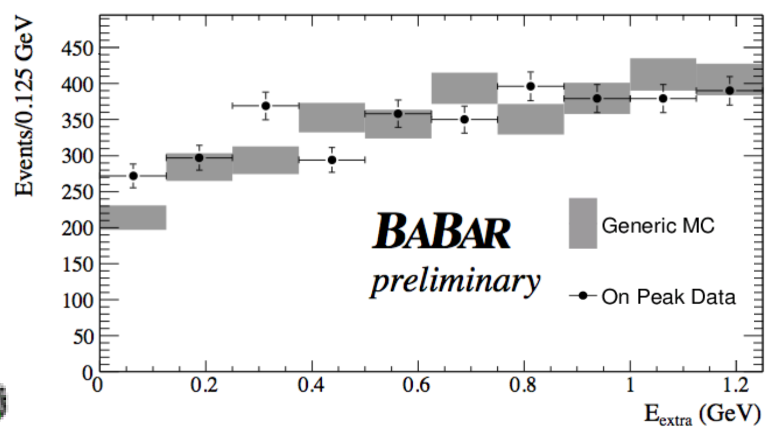
# $B \to \tau \nu$ : SL Tag Signal Yields

**458M B$\underline{B}$ New: arXiv:0809.4027 hep-ex (CKM 2008)**
**383M B$\underline{B}$ publ:PRD 76, 052002 (2007)**

Total $E_{extra}$ energy
after all cuts
all modes combined

BG shape taken from MC, normalization taken from $E_{extra}$ sideband and cross-checked with control samples

| Mode | Expected Background ($N_{BG}$) | Observed Events ($N_{obs}$) |
|---|---|---|
| $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$ | $91 \pm 13$ | 148 |
| $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$ | $137 \pm 13$ | 148 |
| $\tau^+ \to \pi^+\overline{\nu}_\tau$ | $233 \pm 19$ | 243 |
| $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ | $59 \pm 9$ | 71 |

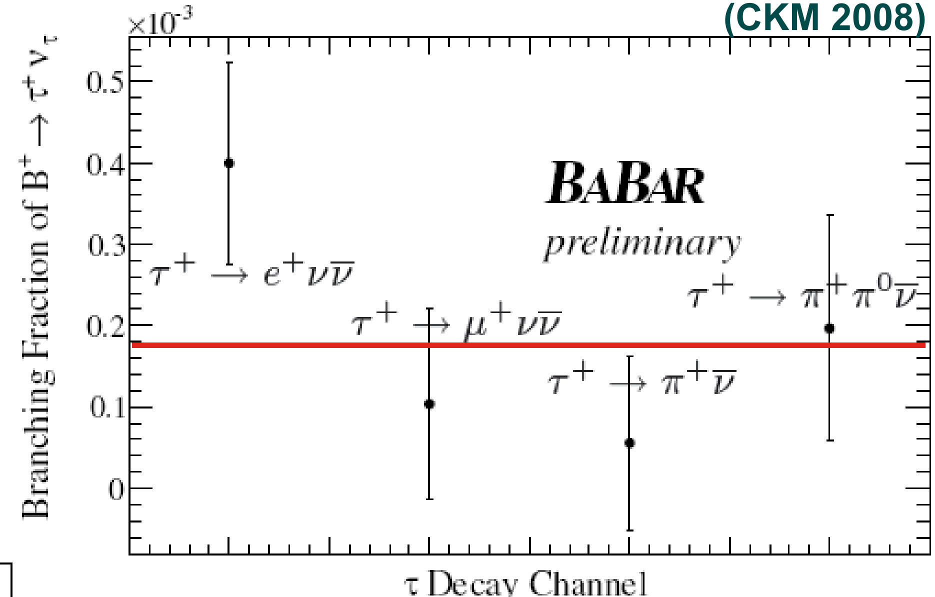



Expected BG = 521±31,
Observed 610
Measure Branching Fraction

# $B \rightarrow \tau \nu$ : SL Tag Branching fraction

**458M $B\underline{B}$ New: arXiv:0809.4027 hep-ex (CKM 2008)**

. Fill histogram of separate BFs
. Fit to constant → probability of 18%




| Mode | Branching Fraction |
|---|---|
| $\tau^+ \rightarrow e^+\nu_e\overline{\nu}_\tau$ | $(4.0 \pm 1.2) \times 10^{-4}$ |
| $\tau^+ \rightarrow \mu^+\nu_\mu\overline{\nu}_\tau$ | $\left(1.0^{+1.2}_{-0.9}\right) \times 10^{-4}$ |
| $\tau^+ \rightarrow \pi^+\overline{\nu}_\tau$ | $\left(0.6^{+1.1}_{-0.5}\right) \times 10^{-4}$ |
| $\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}_\tau$ | $\left(2.0^{+1.4}_{-1.3}\right) \times 10^{-4}$ |

$P(\chi 2)$ = 18% probability

447M $B\bar{B}$
arXiv:0807.4187 [hep-ex]

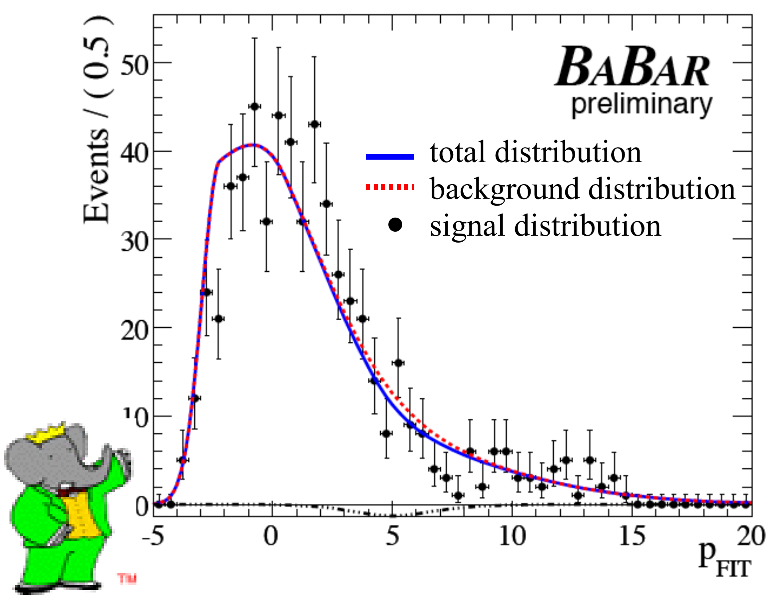
# B → μ ν : Inclusive Signal Yield

. Look for highest momentum muon in the signal, make a $B_{tag}$ with the rest of the event (through 4-momenta addition)

. Tag B: selection on ΔE and $m_{ES}$ and additional lepton requirements

.. Candidate lepton momentum very discriminating, both in B rest frame ($p_{REST}$) and in CM frame ($p_{CM}$)

. Background (continuum, B→Xu l ν with lepton at spectrum limit): suppression through topological Fisher discriminant




. Signal and background yields: extracted from a Fisher discriminant distr. built up from $p_{CM}$ and $p_{REST}$

$S_{obs}$: -12 ±15 ev  ($S_{exp}$: 10 from MC)

$B_{obs}$: 600 ± 29 ev

set up upper limit in a Bayesian approach

(assuming a flat prior for the BF up to a maximum of $\mathcal{B}(B^\pm \to \mu^\pm \nu) = 1.3 \times 10^{-6}$

# $B \to e\ \nu$, $B \to \mu\ \nu$ : SL Tag Signal Yields

**458M $B\bar{B}$ New: arXiv:0809.4027 hep-ex (CKM 2008)**

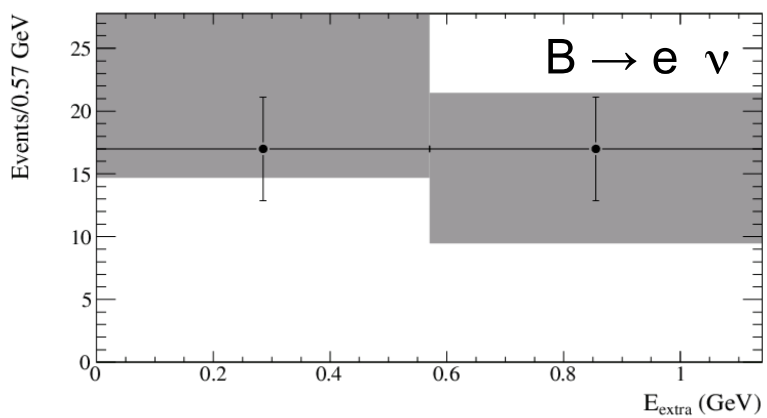
. Pioneered by Babar

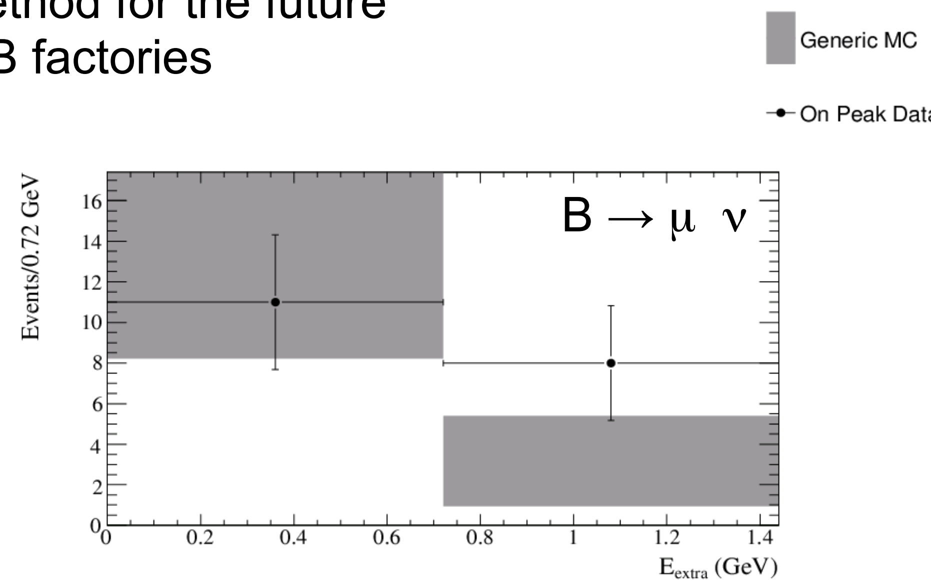
. Reconstruct one B meson

.. less sensitive to signal than inclusive approach,

.. much lower background (<<1),

.. suppressed by SM, but excellent method for the future precision studies in high luminosity B factories




Expected BG = 24 ± 11,
Observed 17
Set upper limit

Expected BG = 15 ± 10,
Observed 11
Set upper limit

# $B \to l\,\nu$ : Results

. SM using $|V_{ub}|=(3.96 \pm 0.15\ ^{+0.20}_{-0.23})\times 10^{-3}$

$f_B=216 \pm 22$ MeV

$\longrightarrow$

$\mathcal{B}(B \to \tau\,\nu)_{SM} = (1.3\pm0.3)\times 10^{-4}$

$\mathcal{B}(B \to \mu\nu)_{SM} = (5.8\pm1.3)\times 10^{-7}$

$\mathcal{B}(B \to e\nu)_{SM} = (1.4\pm0.3)\times 10^{-11}$

. BaBar results:

- Hadronic tag $\mathcal{B}(B^+ \to \tau^+\,\nu)_{HAD} = (1.8^{+0.9}_{-0.8}\pm0.4\pm0.2)\times 10^{-4}$ **PRD77, 011107 (2008)**
- SL * tag $\mathcal{B}(B^+ \to \tau^+\,\nu)_{SL} = (1.8\pm0.8\pm0.1)\times 10^{-4}$
  - Average $\mathcal{B}(B^+ \to \tau^+\,\nu)_{AVERAGE(SL+HAD)} = (1.8\pm0.6)\times 10^{-4}$

    HAD & SL statistically independent

**arXiv:0809.4027 hep-ex**

**Excludes zero at 3.2s**

- SL tag $\mathcal{B}(B^+ \to e^+\nu)_{SL} < 7.7\times 10^{-6}$

  $\mathcal{B}(B^+ \to \mu^+\nu)_{SL} < 11\ \times 10^{-6}$ **arXiv:0809.4027 hep-ex**
- inclusive $\mathcal{B}(B^+ \to \mu^+\nu)_{INCL} < 1.3\ \times 10^{-6}$ **arXiv:0807.4187 hep-ex**

. Belle results:

- Hadronic tag $\mathcal{B}(B^+ \to \tau^+\,\nu)_{HAD} = (1.79\ ^{+0.56}_{-0.49}\ ^{+0.46}_{-0.51})\times 10^{-4}$ **PRL99, 251802 (2006)**
- SL tag $\mathcal{B}(B^+ \to \tau^+\,\nu)_{SL} = (1.65\ ^{+0.38}_{-0.37}\ ^{+0.35}_{-0.37})\times 10^{-4}$

**arXiv:0809.3834v1 hep-ex**

**Excludes zero at 3.8σ**

* measured also $f_B$=255±58MeV

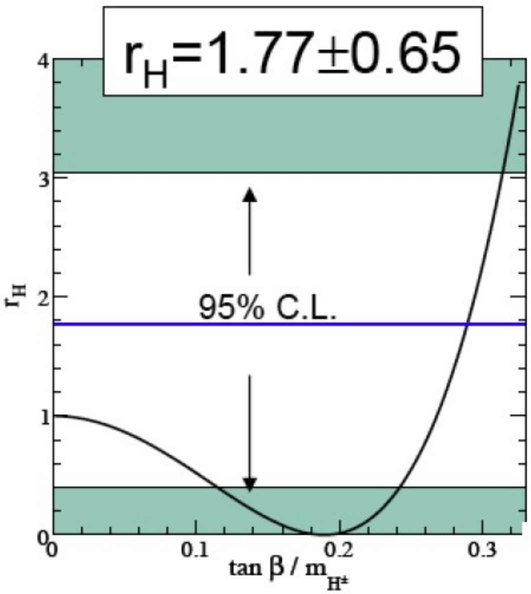
# $B \to \tau \nu$ : Implication for NP

. Charged Higgs contribution may enhance/reduce the branching ratio

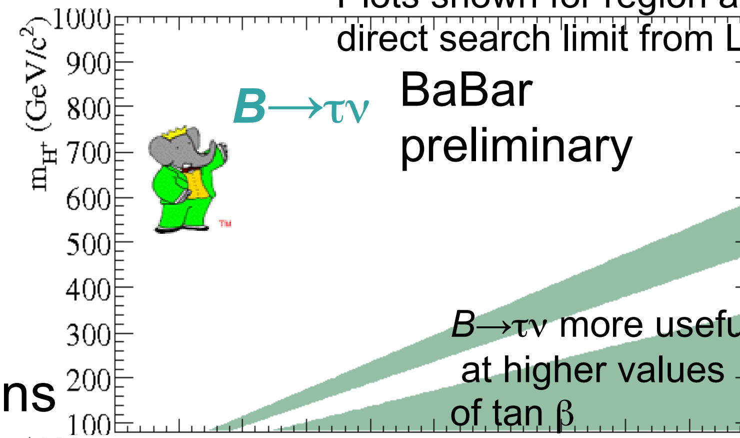
$\mathcal{B}(B \to \tau \nu) = (1.8 \pm 0.6) \times 10^{-4}$ exclude zero at 3.2σ

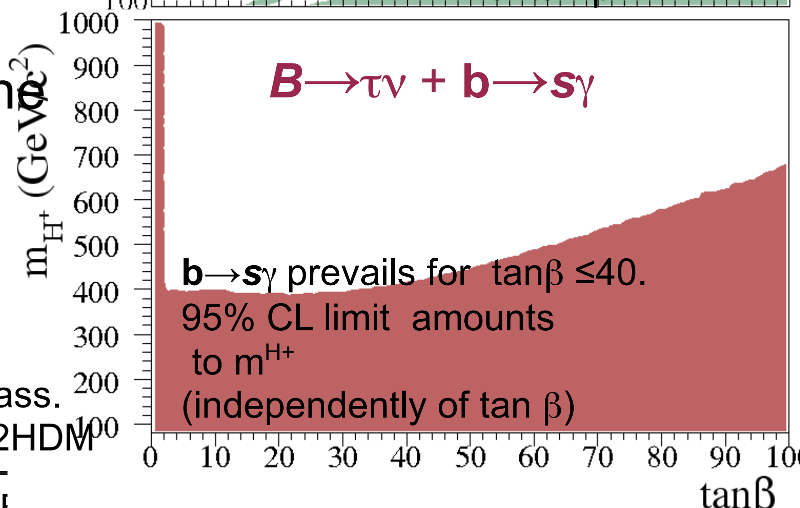
$\mathcal{B}(B \to e \nu) < 7.7 \times 10^{-6}$, $\mathcal{B}(B \to \mu \nu) < 11 \times 10^{-6}$ consistent with predictions

. $B_{measured} > B_{SM}$ suggests that the H+ dominates




95 % CL exclusions regions in $m_H$ – tan β plane

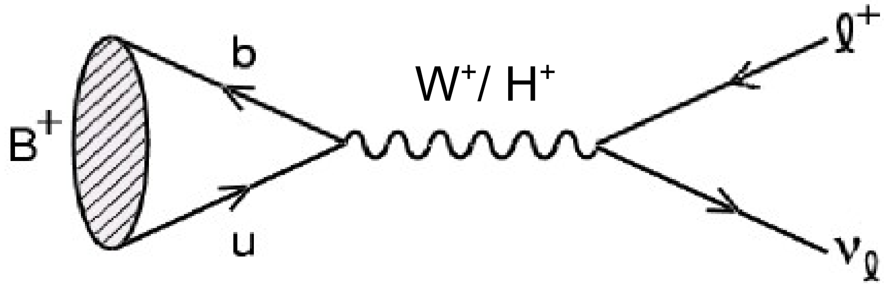


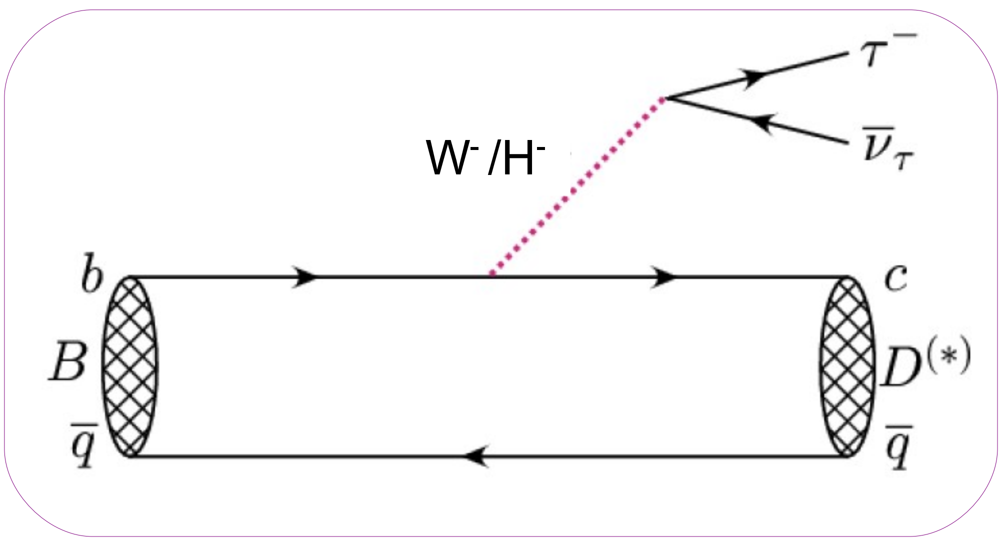




$$r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta\right)^2$$

.. mH – Charged Higgs mass.
.. tan β – ratio of v.e.v. of 2HDM

# Missing ν final state transitions



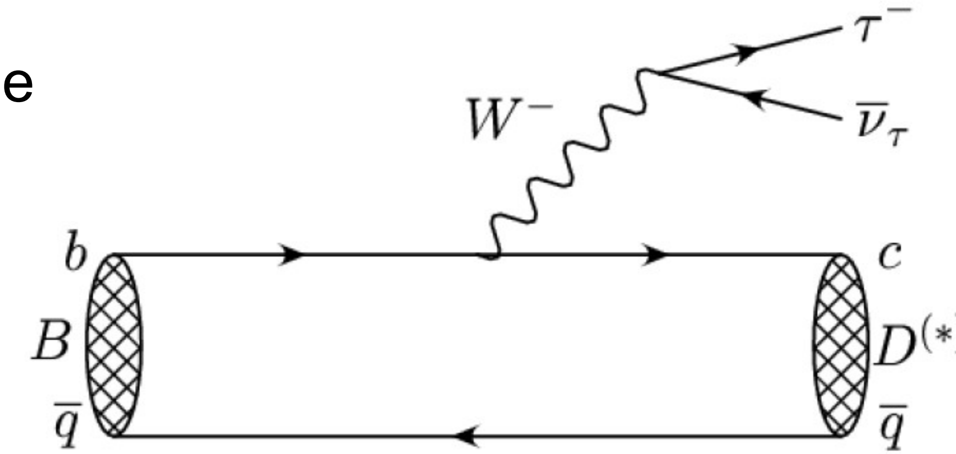




$b \rightarrow l\,\nu$ ($l = \tau$, e, $\mu$)

$B \rightarrow D(*)\,\tau\,\nu$

# B → D(*) τ ν : motivation

Same Feynman diagram as the light leptons...




Effects of a heavy τ:

. Reduces phase space

. One additional helicity state for the *W**

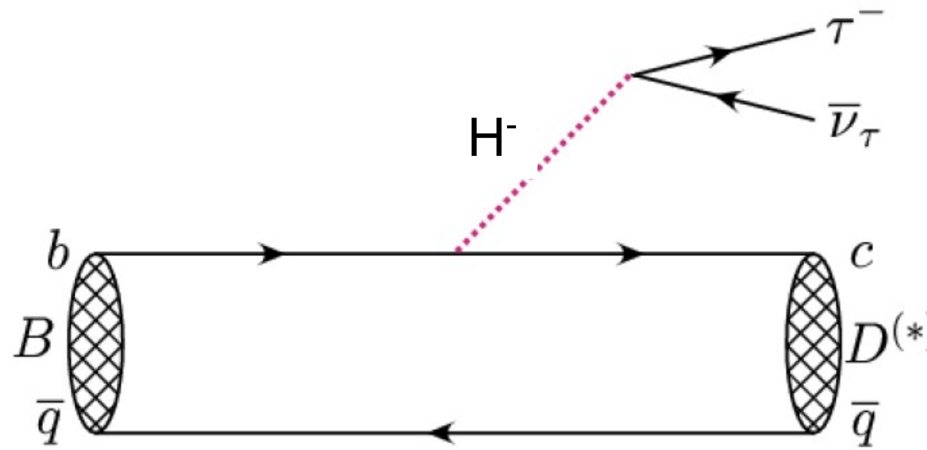
.. Need two form factors to describe *D*τν, four for *D**τν

.. HQET relates these extra FF's to the "light lepton" ones

. τ decays ~immediately & 2-3 ν → experimental challenge!

# $B \to D(*) \tau \nu$ : motivation

... but the decay can also be mediated by a charged Higgs boson




Very clean probe of new physics

- New physics contributes at tree level
- Measurements of FF's for light leptons allow for very precise predictions for the $\tau \to$ hadronic behavior under control
- Spin-zero Higgs does not couple to all helicity states →affects *D* and *D** differently, $\tau$ polarization

# B → D(*) τ ν : motivation

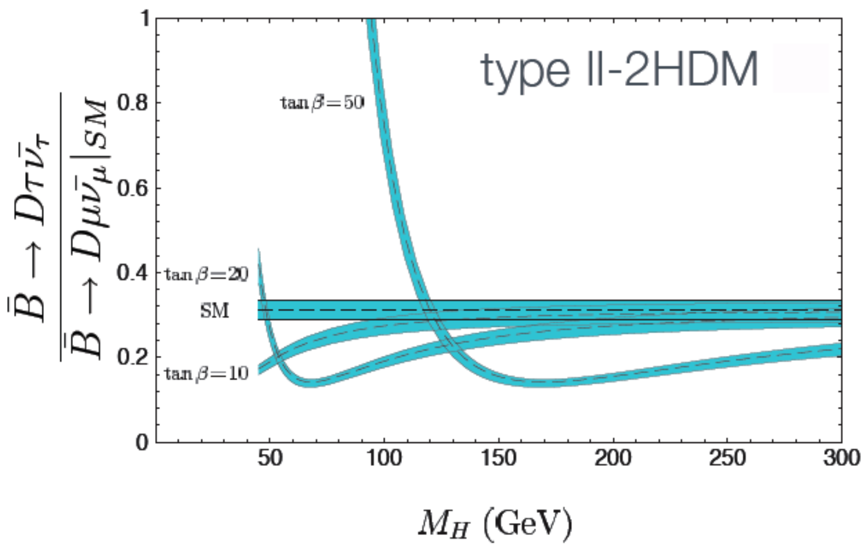
Beyond SM .... charged Higgs

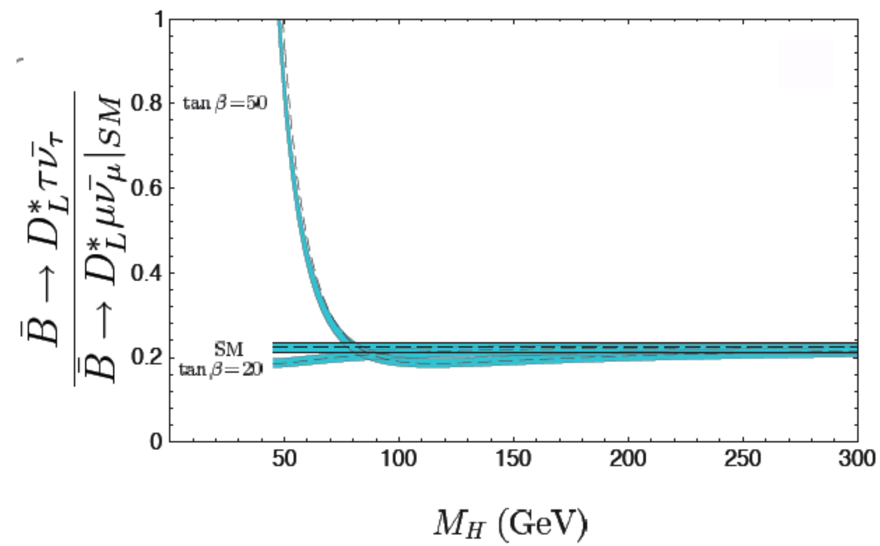
. Higgs couples to mass
→ larger effect than in B → D(*) l ν (l=e,μ)

. Ratio of B →D(*)τν/B →D(*)μ ν
shown for 2HDM-type II

| Decay Mode | | $\mathcal{B}$ (%) |
|---|---|---|
| $\overline{B}^0$ | $\to D^- \tau^- \overline{\nu}_\tau$ | $0.69 \pm 0.04$ |
| $\overline{B}^0$ | $\to D^{*-} \tau^- \overline{\nu}_\tau$ | $1.41 \pm 0.07$ |
| $B^-$ | $\to D^0 \tau^- \overline{\nu}_\tau$ | $0.64 \pm 0.04$ |
| $B^-$ | $\to D^{*0} \tau^- \overline{\nu}_\tau$ | $1.32 \pm 0.07$ |
| $B$ | $\to X_c \tau^- \overline{\nu}_\tau$ | $2.3 \pm 0.25$ |

**Chen and Geng, JHEP 061053 (2006)**
**Falk et al. PL B 326 145 (1994)**




qualitatively
similar behaviour
in other models

**plots from Tanaka,**
**Z Phys C67 321 (1995)**

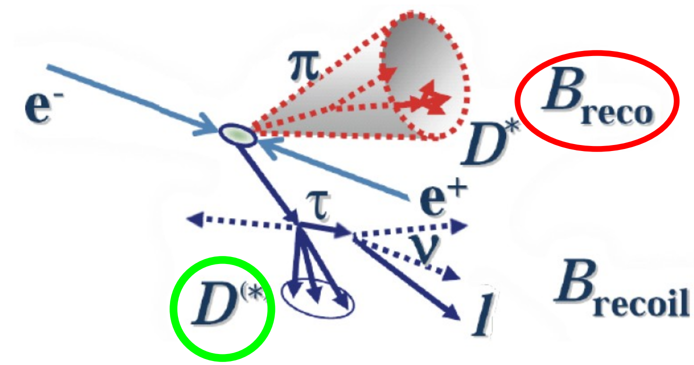
232M $B\bar{B}$
PRL100,021801(2008)

# $B \to D(*) \tau \nu$ : analysis outline

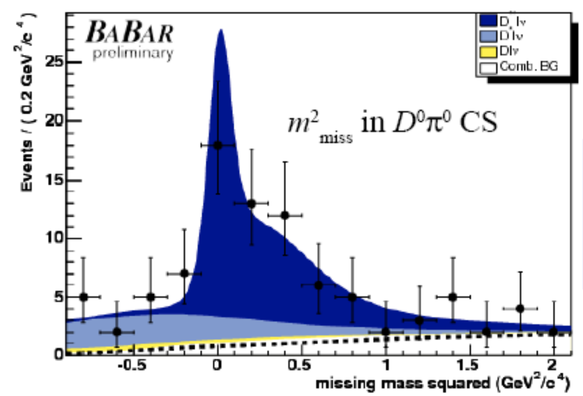
. Hadronic tags used, D/D* + lepton in recoil

. Charge correlation between D(*) and Breco

. Simultaneous measurement 4 D channels:
$D^0\tau\nu$, $D^{*0}\tau\nu$, $D^+\tau\nu$, $D^{*+}\tau\nu$
.. Reconstruct $\tau$ as $\tau \to l\nu\nu$




. Main background $B \to Dl\nu$, $B \to D^*l\nu$
. Use $m^2_{miss}$ to discriminate signal from BG
.. Light lepton BG has 1 $\nu \to m^2_{miss} \approx 0$
.. Signal events have 3 $\nu \to$ very large $m^2_{miss}$
. $B \to D^{**}l\nu$ BG constrained using control samples
.. Add a $\pi^0$ to signal reconstruction
.. Reduce sensitivity to details of D** model ($D_1$, $D_2^*$, $D_0^*$, $D_1'$, non-resonant)



# $B \to D(*) \tau \nu$ : signal fit

232M $B\overline{B}$
PRL100,021801(2008)

. Unbinned maximum likelihood fit:

.. Two discriminating variables, $m^2_{miss}$ and lepton momentum, $p^*_l$

.. Simultaneous fit to 4 D(*) signal channels,4 *D*** control samples

.. Constrain D**lν background with independent data control sample

. Measure

$$R \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau^- \overline{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell^- \overline{\nu}_\ell)}$$

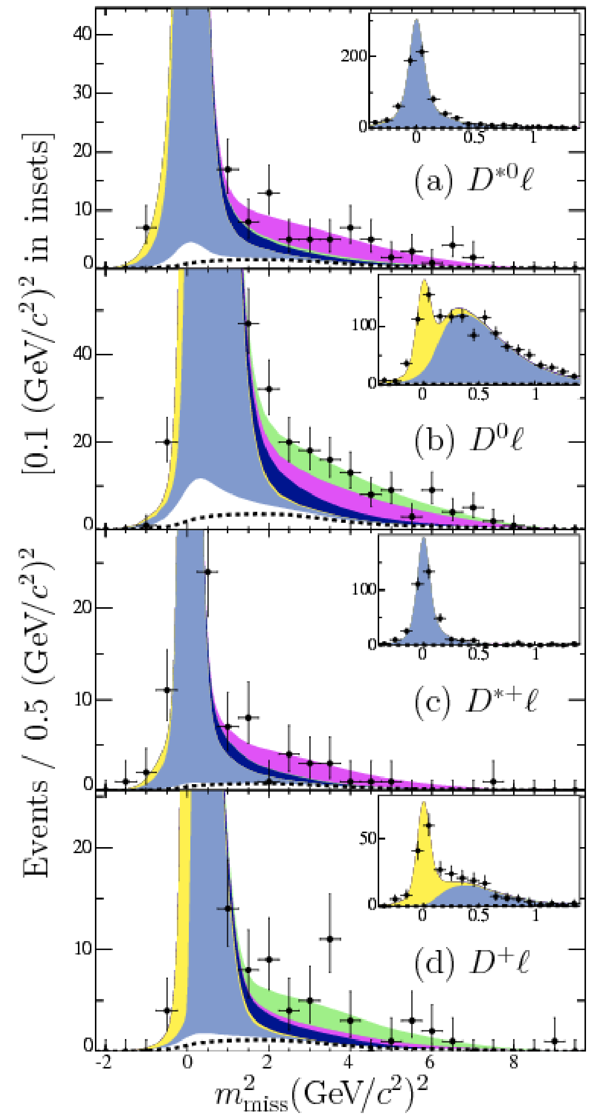
. Fit

66.9±18.9 Dτν signal

101.4±19.1 D*τν signal

signal {
- $D^*\tau\nu$
- $D\tau\nu$

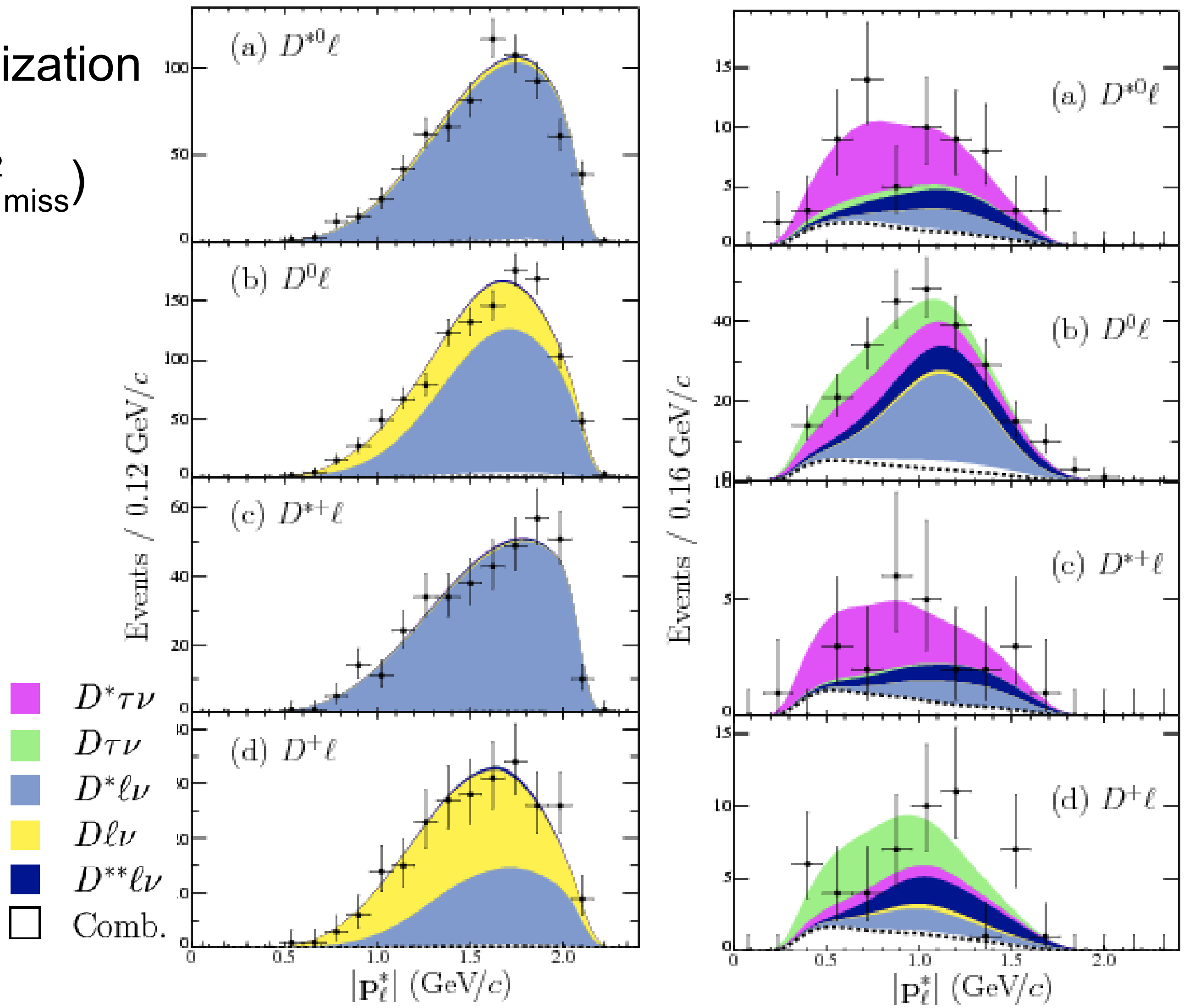
background {
- $D^*\ell\nu$
- $D\ell\nu$
- $D^{**}\ell\nu$
- Comb.



232M $B\bar{B}$
PRL100,021801(2008)

# $B \rightarrow D(*)\,\tau\,\nu$ : $p^*_l$ projections

Normalization region (low $m^2_{miss}$)




Signal region (high $m^2_{miss}$)

# $B \to D(*) \tau \nu$ : Results

Standard Model

| Decay Mode | $\mathcal{B}$ (%) |
|---|---|
| $\overline{B}^0 \to D^- \tau^- \overline{\nu}_\tau$ | $0.69 \pm 0.04$ |
| $\overline{B}^0 \to D^{*-} \tau^- \overline{\nu}_\tau$ | $1.41 \pm 0.07$ |

**Chen and Geng, JHEP 10 053 (2006)**

BaBar

**232M BB, PRL 100, 021801 (2008)**

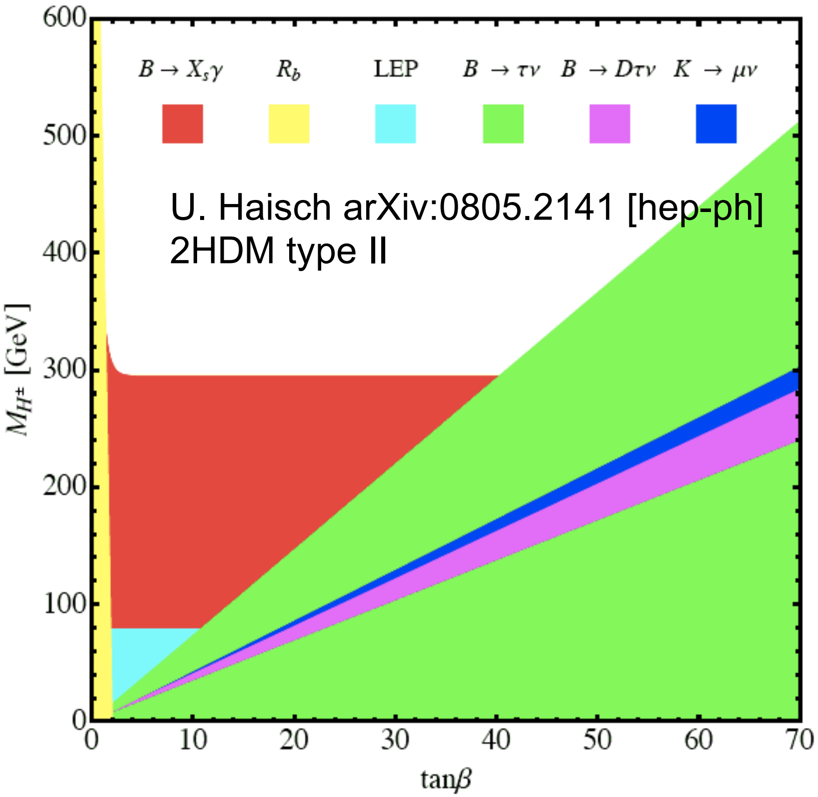
| Mode | $\mathcal{B}$ [%] | |
|---|---|---|
| $B^- \to D^0 \tau^- \overline{\nu}_\tau$ | $0.67 \pm 0.37 \pm 0.11 \pm 0.07$ | |
| $B^- \to D^{*0} \tau^- \overline{\nu}_\tau$ | $2.25 \pm 0.48 \pm 0.22 \pm 0.17$ | |
| $\overline{B}^0 \to D^+ \tau^- \overline{\nu}_\tau$ | $1.04 \pm 0.35 \pm 0.15 \pm 0.10$ | |
| $\overline{B}^0 \to D^{*+} \tau^- \overline{\nu}_\tau$ | $1.11 \pm 0.51 \pm 0.04 \pm 0.04$ | |
| $B \to D \tau^- \overline{\nu}_\tau$ | $0.86 \pm 0.24 \pm 0.11 \pm 0.06$ | **3.6$\sigma$** |
| $B \to D^* \tau^- \overline{\nu}_\tau$ | $1.62 \pm 0.31 \pm 0.10 \pm 0.05$ | **6.2$\sigma$** |

Belle

$$\mathcal{B}(\overline{B}^0 \to D^{*+} \tau^- \overline{\nu}_\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37)\%$$ **5.2$\sigma$**

**535M BB, PRL 99 191807 (2007)**

# $B \to \tau \nu$ & $B \to D \tau \nu$ : Implication for NP




In general, $B \to X_s \gamma$ lower bound on $M_{H\pm}$ stronger than all direct & indirect constraints

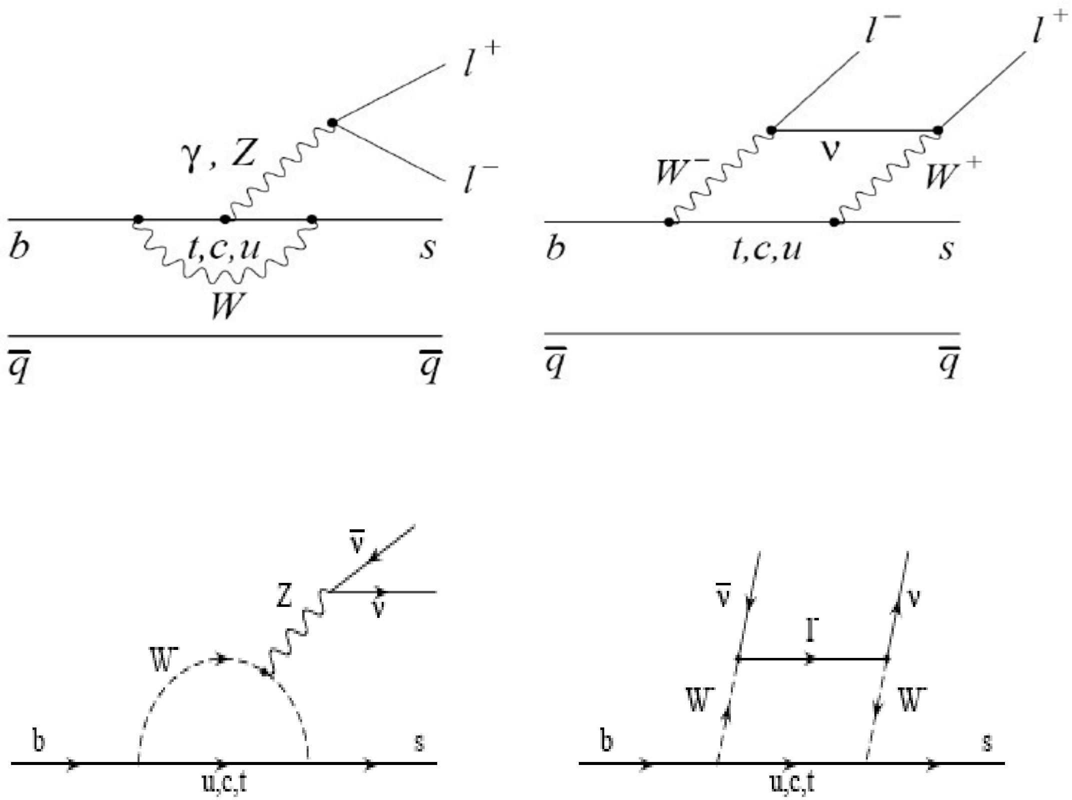
In particular,
$B \to X_s \gamma$ still prevails over $B \to \tau\nu$[57-59],
$B \to D\tau\nu$[58],
and $K \to \mu\nu$ [60] for values of $\tan\beta$ <40.

The derived 95% confidence level (CL) limit (shaded regions) amounts to MH± > 295GeV independently of $\tan\beta$


[57] B. Aubert et al. [BaBar Collaboration], hep-ex/0608019; Phys. Rev. D 76, 052002 (2007),
K. Ikado et al. [Belle Collaboration], Phys. Rev. Lett. 97, 251802 (2006);
[58] J. F. Kamenik and F. Mescia, 0802.3790 [hep-ph]
[60] M. Antonelli et al. [FlaviaNet Working Group on Kaon Decays], 0801.1817 [hep-ph].


$B \to D \tau \nu$ : **PRL100, 021801(2008)**
$B \to \tau \nu$ : **arXiv:0809.4027 [hep-ex]**

# Electroweak  Penguins



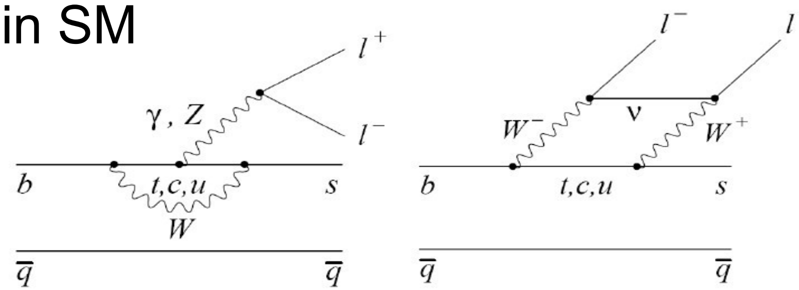

$b \to s\, l^{+}\, l^{-}$

$b \to s\, \nu\, \underline{\nu}$

# $b \to s\, ll$, $\nu\bar{\nu}$ : Motivation

. FCNC process forbidden at tree level in SM

. Operator Product Expansion




$$H_{eff} = -\, 4G_F/\sqrt{2}\, (V_{tb}V_{ts}^*)\, \Sigma_i\, C_i\, O_i$$

.. 3 short distance Wilson coeff. $C_i$

- $C_7$ EM photon penguin

constrained $b \to s\gamma$ BF measurement
$|C_7| \approx 0.33$ (arXiv:0704.3575)

- $C_9$ ($C_{10}$) Vector (Axial-Vector) parts of the Z penguin,WW box

$|C_9|^2 + |C_{10}|^2$ constrained $b \to s\, l^+l^-$ BF, but not relative sign

. Rich phenomenology for standard model tests

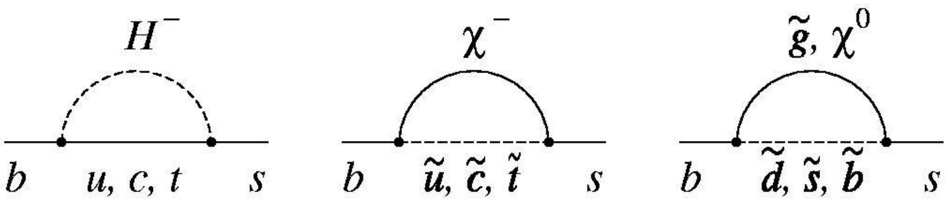
. SM BF prediction:

| decay | $BR_{SM}$ |
|---|---|
| $B \to K^* l^+ l^-$ | $1.2 \times 10^{-6}$ |
| $B \to K l^+ l^-$ | $0.4 \times 10^{-6}$ |
| $B \to \pi l^+ l^-$ | $3.3 \times 10^{-8}$ |
| $B \to K^* \nu\nu$ | $1.3 \times 10^{-5}$ |
| $B \to K \nu\nu$ | $4 \times 10^{-6}$ |

# b $\rightarrow$s ll, $\nu\bar{\nu}$ : Motivation ... beyond the SM

. Modification of magnitude and relative sign of $C_i$ wrt SM prediction

. NP contributions can appear in the loop affecting both rates and kinematic distributions




| | |
|---|---|
| Higgs | New particles in loop may enhance B($b\rightarrow s\gamma$) |
| Chargino | Affects mostly EW penguins (C7 & C9) |
| Gluino/Neutralino | EM penguins (C7) enhanced by $m_{\tilde{g}}/m_b$ |

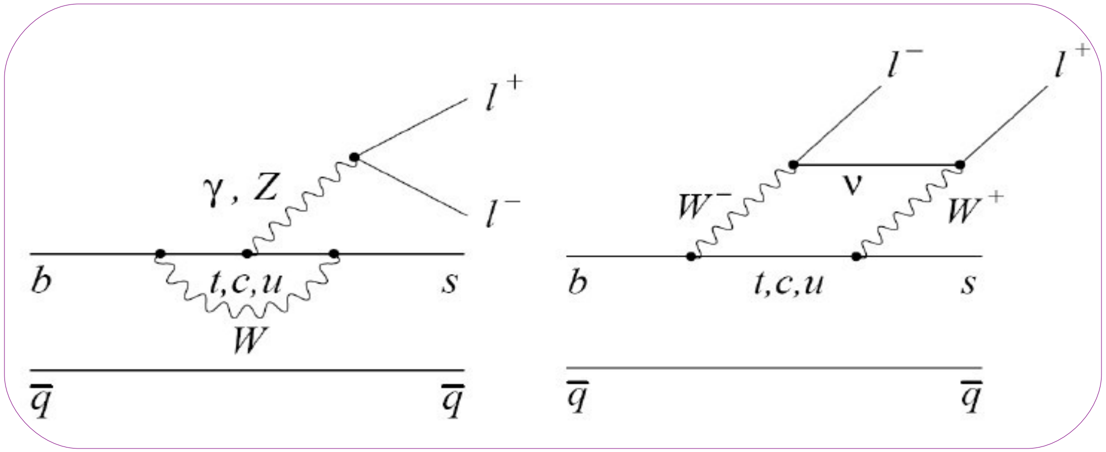
.. Sensitive to *non-standard* Z *couplings*, new particles in Z-loop [1]

.. B $\rightarrow X_s \nu\nu$ sensitive to other exotic models:

- *New sources of missing energy*: production of *light dark matter* in BR(B→K*+missing energy) via Higgs mediated vertex ($BR_{NP}$ up $50xBR_{SM}$ for given values of model parameters)[2]
- *Unparticle operators* : existence of NP fields (Banks-Zaks fields) that, in the low energy limit of an effective field theory, represent invisible particles contributing to BR(B→K*+ missing energy)[3]

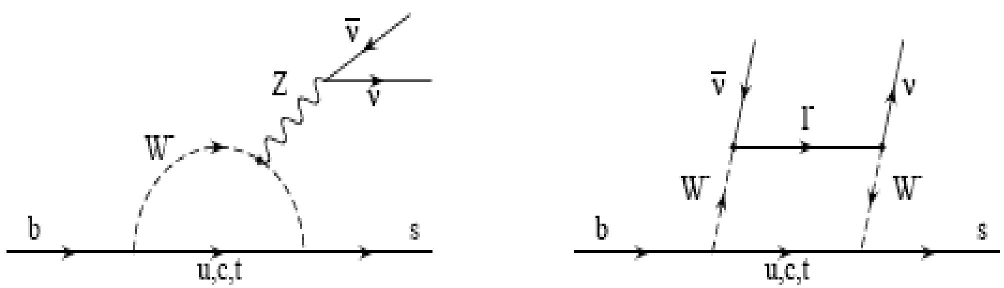

*[1] G.Buchalla, G. Hiller, G. Isidori Phys. Rev. D 63, 014015,2000* [2]C. Bird et al. Phys.Rev.Lett.93:201803,2004
[3]T.M. Aliev et al JHEP 0707:072,2007

# Electroweak Penguins




$b \rightarrow s\, l^+\, l^-$

$b \rightarrow s\, \nu\, \underline{\nu}$



# $B \to K^{(*)} l^+l^-$ : Experimental Tag Methods

384M $B\bar{B}$
arXiv:0804.4412 hep-ex
arXiv:0807.4119 hep-ex

. Fully reconstruction of 10 $B\to K^{(*)}l^+l^-$ final states:
... [$K^\pm \pi^\mp$, $K^\pm \pi^0$ or $K^0_S\pi^\pm$] recoiling against pairs [$e^+e^-$, $\mu^+\mu^-$]

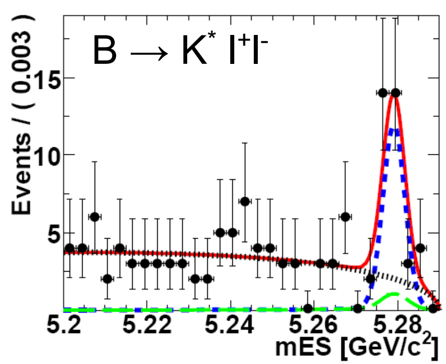
. Backgrounds suppression:
.. di-lepton bkg from B and D
.. continuum ll → cc, c → slν

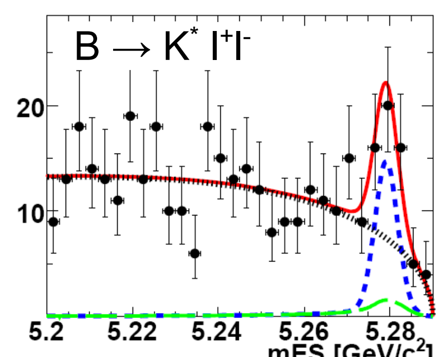
2 different Neural Networks (cc,BB) with event shape variables, missing energy and vertexing infos, for each $q^2$ region

.. $B\to K^{(*)}J/\psi$ and $B\to K^{(*)}\psi(2S)$ : veto by cutting on $m_{ll}^2$
.. $B\to D(D\to K^{(*)}\pi)\pi$ with $\pi \to \mu$ mis-ID: veto on $m_{K(*)\pi}$ close to $m_D$

. Signal yield extraction: unbinned maximum likelihood fit to $m_{ES}$

Low $q^2$ region:
$q^2 < 6.25$ Gev²/c⁴




data; signal; peaking; combinatorial; total

High $q^2$ region:
$q^2 > 10.24$ Gev²/c⁴

384M BB
arXiv:0804.4412 hep-ex
arXiv:0807.4119 hep-ex

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

. Branching fractions

. $q^2$ distributions

. Direct CP asymmetry:

$$A_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)} \ell^+ \ell^-) - \mathcal{B}(B \to K^{(*)} \ell^+ \ell^-)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)} \ell^+ \ell^-) + \mathcal{B}(B \to K^{(*)} \ell^+ \ell^-)}$$

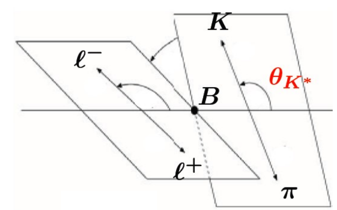
. Lepton Flavour ratio:

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

. CP-averaged isospin asymmetry

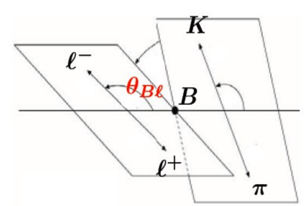
$$A_I^{K^{(*)}} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0} \ell^+ \ell^-) - r\mathcal{B}(B^\pm \to K^{(*)\pm} \ell^+ \ell^-)}{\mathcal{B}(B^0 \to K^{(*)0} \ell^+ \ell^-) + r\mathcal{B}(B^\pm \to K^{(*)\pm} \ell^+ \ell^-)}$$

. Longitudinal K* polarization, $f_L$




Extracted from angular fit to $\cos_{\theta\_K}$ in each $q^2$ bin

. Forward-backward Asymmetry, $A_{FB}$

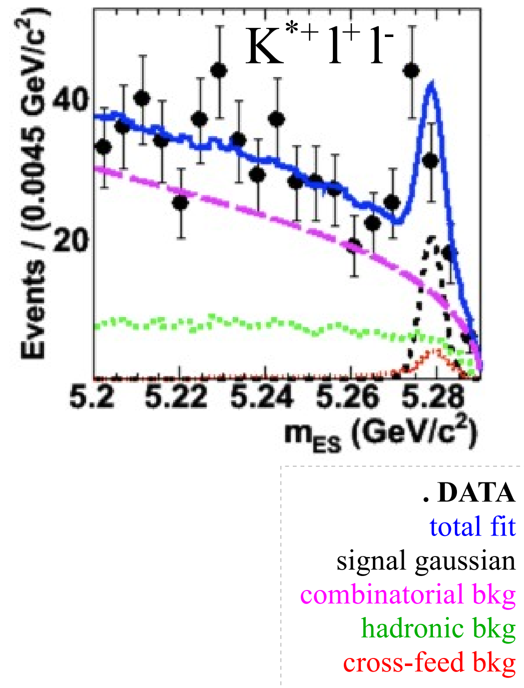


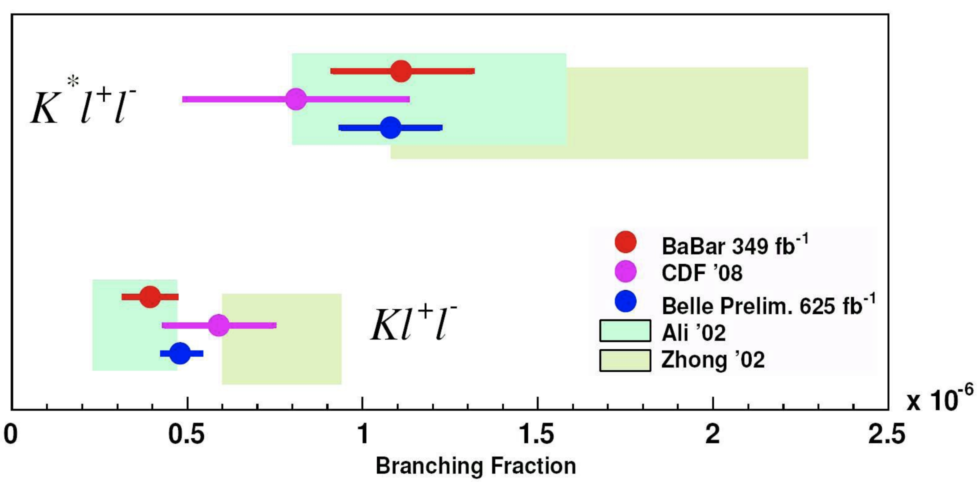

Extracted from angular fit to $\cos_{\theta\_l}$ in each $q^2$ bin

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

SM BF prediction: $BF(B \to K^{(*)}l^+l^-) \sim 10^{-6}$
Total branching fractions:

| | BELLE<br>657M $B\bar{B}$ New<br>arXiv:0810.0335 (2008) | BABAR<br>384M $B\bar{B}$ New<br>arXiv:0807.4119 (2008) |
|---|---|---|
| Mode | $\mathcal{B}(\times 10^{-7})$ | $\mathcal{B}(\times 10^{-7})$ |
| $K^*\ell^+\ell^-$ | $10.8 \pm 1.0 \pm 0.9$ | $11.1 \pm 1.9 \pm 0.7$ |
| $K\ell^+\ell^-$ | $4.8 \pm ^{0.5}_{0.4} \pm 0.3$ | $3.9 \pm 0.7 \pm 0.2$ |



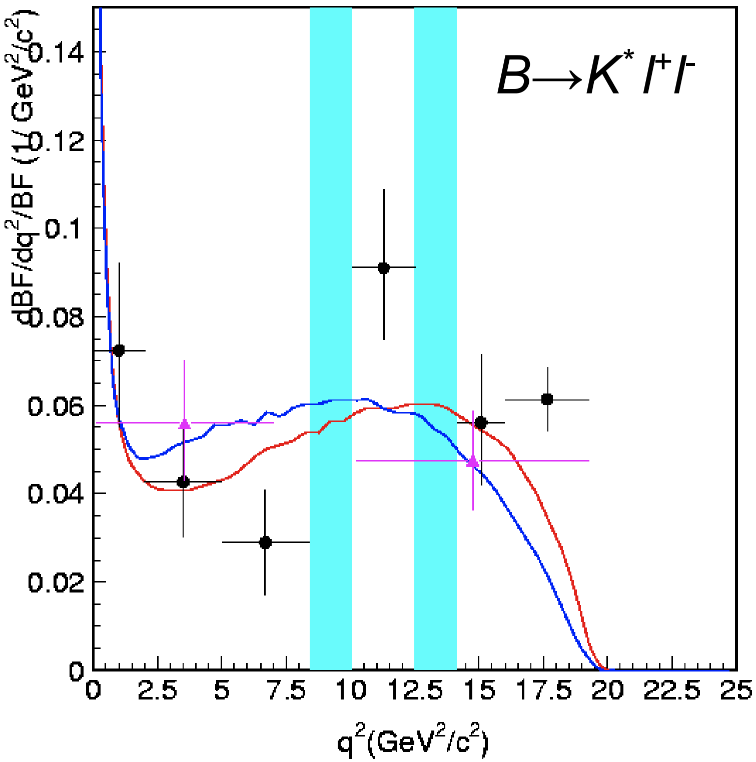

- Precision is at ~5% level
- BABAR $\mathcal{B}(B \to K^{(*)}l^+l^-)$ results lie ~1$\sigma$ lower than Belle's
- results consistent with SM expectations

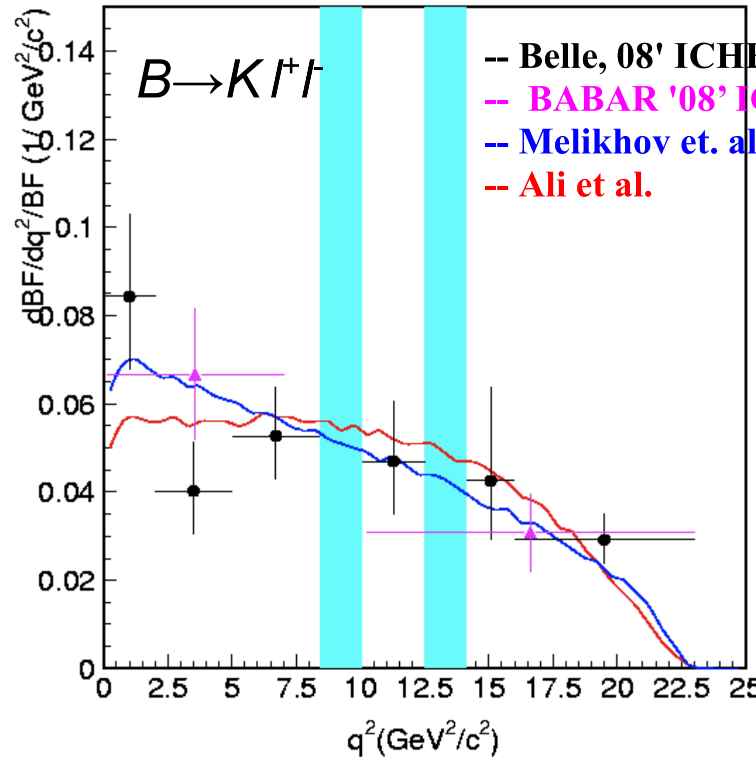
Ali et al: PRD 66, 034002 (2002)
Zhong et al: IJMO A18, 1959 (2003)

384M $B\bar{B}$
arXiv:0807.4119

# $B \to K^{(*)} l^+l^-$ : $q^2$ Distributions

$$q^2 = m^2_{\ell\ell}$$




Consistent with SM expectations

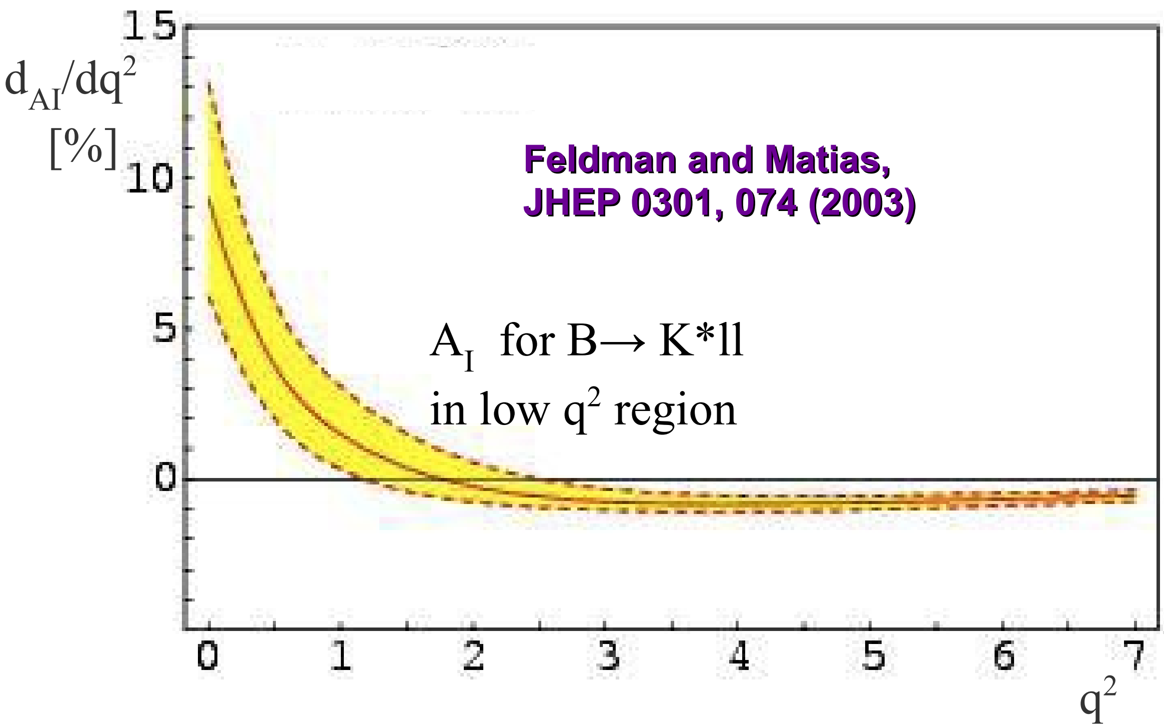
Ali et al: PRD 66, 034002 (2002)
Melikhov et al: PLB 410, 290 (1997)

384M B$\bar{B}$
arXiv:0807.4119

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

Define isospin asymmetry in different $q^2$ bins:

$$A_I \equiv \frac{\mathrm{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - (\frac{\tau_0}{\tau_+})\mathrm{B}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}{\mathrm{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + (\frac{\tau_0}{\tau_+})\mathrm{B}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}$$




SM Isospin asymmetry is expected to be 0 for $B \to Kll$ at low $q^2$

For $B \to K^*ll$: Small (< 15%) with some variation at low $q^2$, near 0 for high $q^2$

calculations*: $A_I^{K^*} = -0.005 \pm 0.020$

$A_I$ exhibits $q^2$-dependence in low $q^2$ region

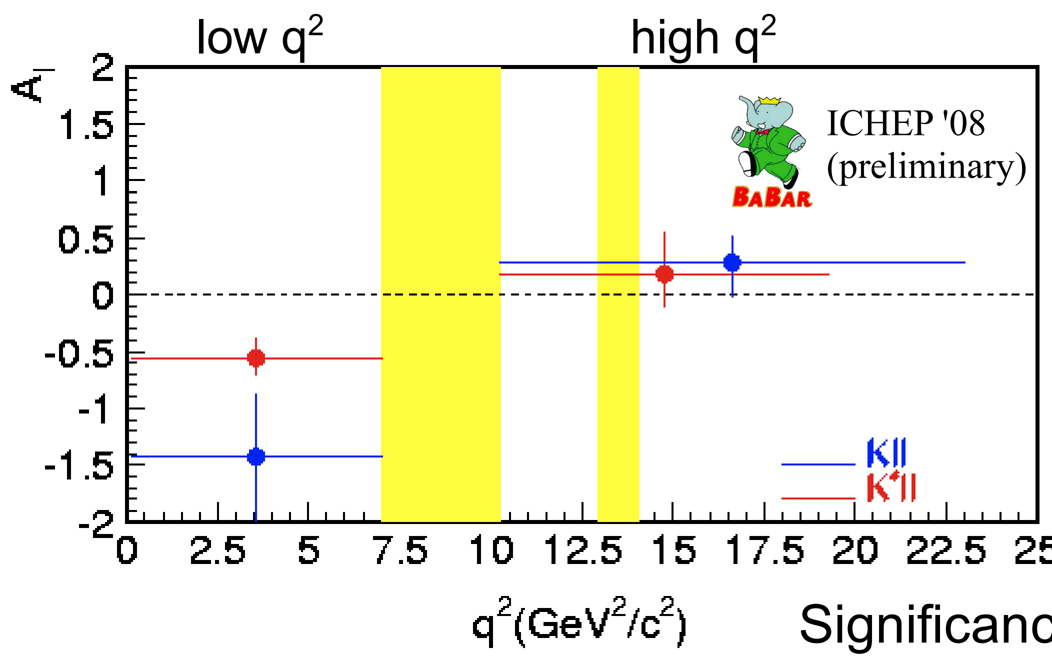
Some sensitivity to the sign of $C_7$

M. Beneke et al. Eur. Phys. J.C41, 173 (2005)

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

384M $B\bar{B}$
arXiv:0807.4119

- No significant asymmetry in the high $q^2$ region, consistent with zero
- BaBar sees significant negative isospin asymmetries in the low $q^2$ region, suggest insensitive to hadronic final state -> combine Kll & K*ll
- BaBar and Belle's * results are consistent




| Mode | low $q^2$ | Significance (syst included) to exclude $A^{K(*)}_I = 0$ : |
| --- | --- | --- |
| K* ll | $-0.56\ ^{+0.17}_{-0.15} \pm 0.03$ | $2.7\sigma$ |
| K ll | $-1.43\ ^{+0.56}_{-0.85} \pm 0.05$ | $3.2\sigma$ |

$A^{K(*)}_I = -0.64\ ^{+0.15}_{-0.14} \pm 0.03$ $3.9\sigma$

**Belle*:675M $B\bar{B}$, arxiv:0810:0335**
**@ $q^2 < 8.68\ \mathrm{Gev}^2/c^2$**
**$A^{K(*)}_I = -0.30\ ^{+0.12}_{-0.11} \pm 0.04$ $2.24\sigma$**

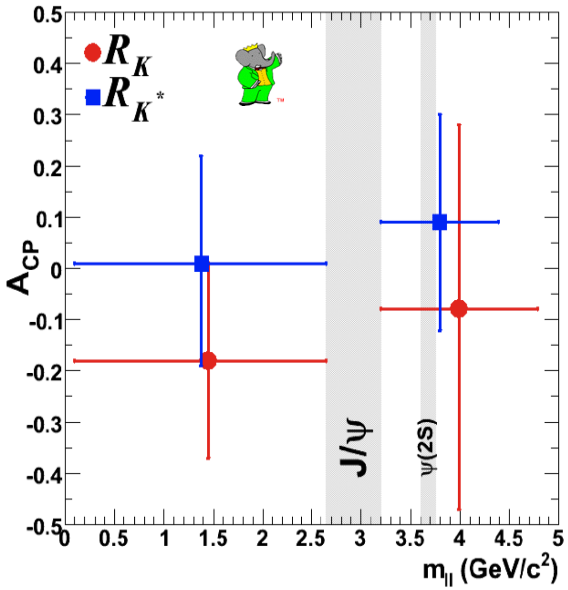
384M BB
arXiv:0807.4119

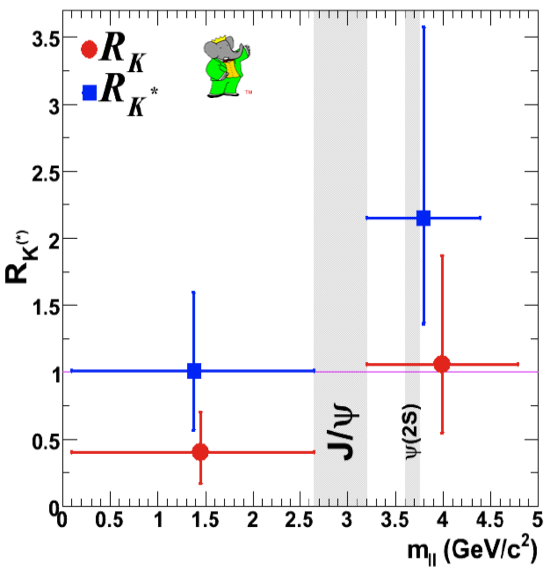
# $B \to K^{(*)} l^+l^-$ : $A^{K(*)}_{CP}$ & $R_{K(*)}$

Define

$$A_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)}$$

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



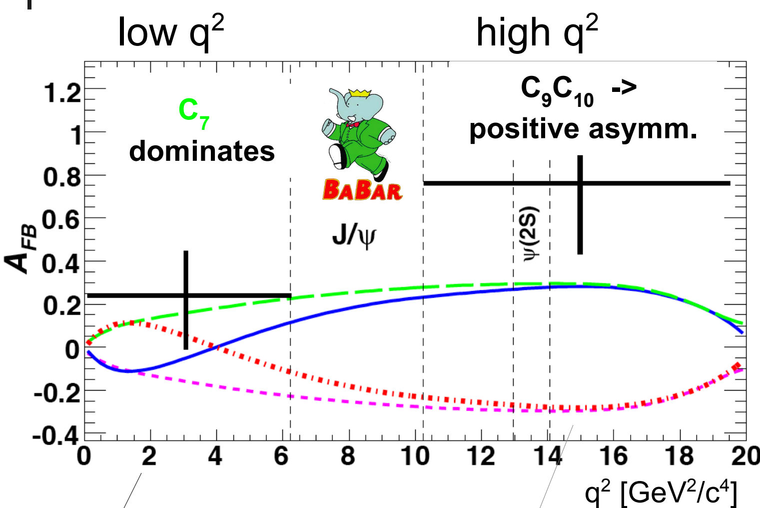



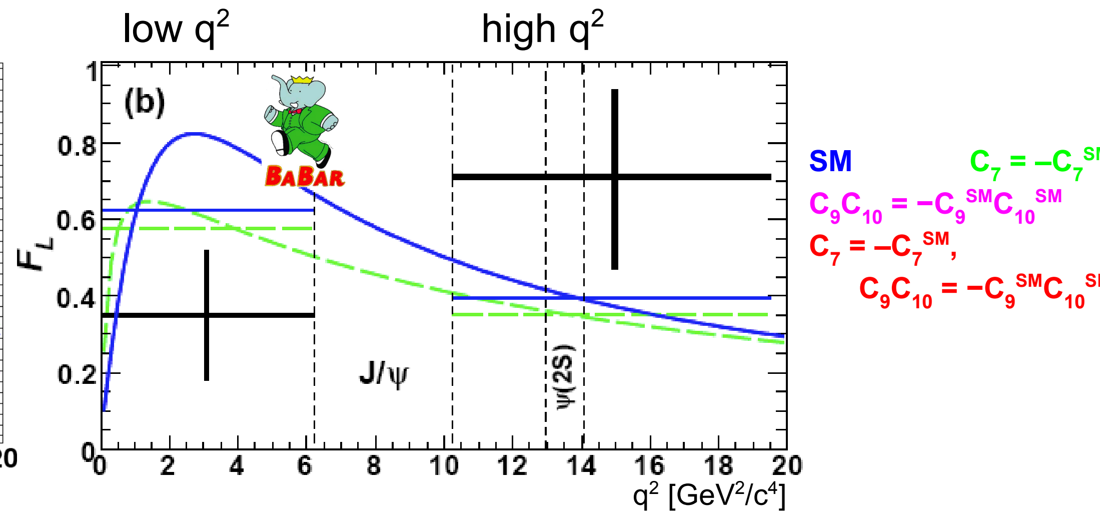

**Direct CP Asymmetry** : expected O($10^{-4}$) in SM but possible significant enhancement from NP at the EW scale (**arXiv:0805.2525**).
Results consistent with SM

**Lepton Flavor Ratio**: In SM $R_K \sim 1$, $R_{K^*} \sim 0.75$; in 2HDM & SUSY sensitive to neutral Higgs at large tan β (**hep-ph/0004262**).
Results consistent with SM.

Results in agreement with Belle (ICHEP'08)

# $B \to K^* l^+l^-$ : $F_L$ & $A_{FB}$




SM @ Low $q^2$:
$A_{FB}$ expected to be small,
with zero crossing point at
$q^2$<4GeV$^2$/c$^4$ .
$C_7$ constrained $b \to s\ \gamma$,
but change in sign is allowed.

*non-SM contributions:*
- *change the magnitudes and relative signs of $C_7$, $C_9$ & $C_{10}$*
- *introduce complex phases between them.*

| $q^2$ | $F_L$ |
|---|---|
| low | $0.35 \pm 0.16 \pm 0.04$ |
| high | $0.71^{+0.20}_{-0.22} \pm 0.04$ |

| $q^2$ | $A_{FB}$ |
|---|---|
| low | $0.24^{+0.18}_{-0.23} \pm 0.05$ |
| high | $0.76^{+0.52}_{-0.32} \pm 0.07$ |

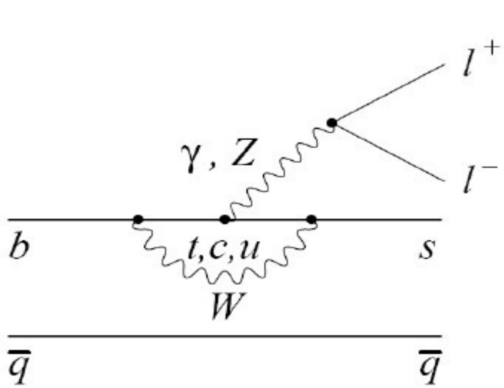
SM @ High $q^2$:
$C_9C_{10}$ expected give pos. asymm.
Right-handed weak currents
have an opposite-sign $C_9C_{10}$
would → negative $A_{FB}$

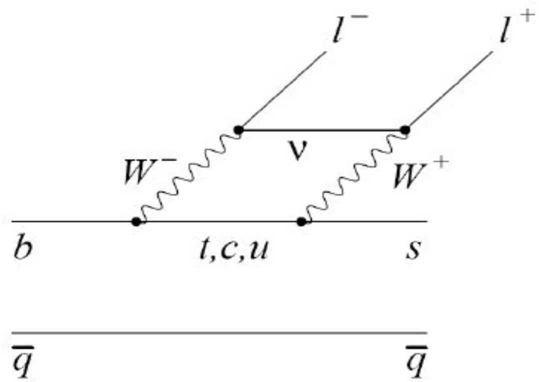
Results:
. $A_{FB}$ results exclude @ > 3 $\sigma$ significance
a wrong-sign $C_9C_{10}$ from purely R-H weak currents
. BaBar's results consistent with Belle*

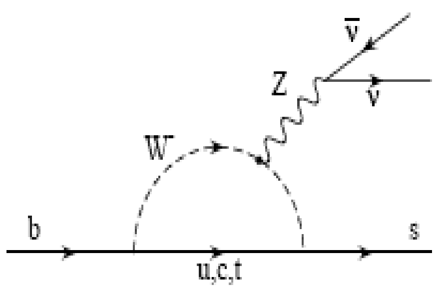
Kruger and Matias: PRD 71, 094009 (2005)

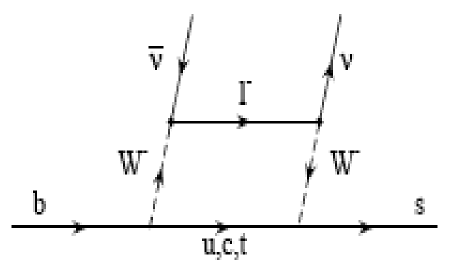

Belle*:675M $B\bar{B}$, arxiv:0810:0335

# Electroweak Penguins




$b \to s\, l^+ l^-$

$b \to s\, \nu\, \underline{\nu}$

# $B \to K^{(*)} \nu \underline{\nu}$: B tagging

[1]: 2008 update @ 351M B$\underline{B}$ PRL94,101801(2005)
[2]: NEW 2008 @ 454M B$\underline{B}$ PRD78,072007(2008)

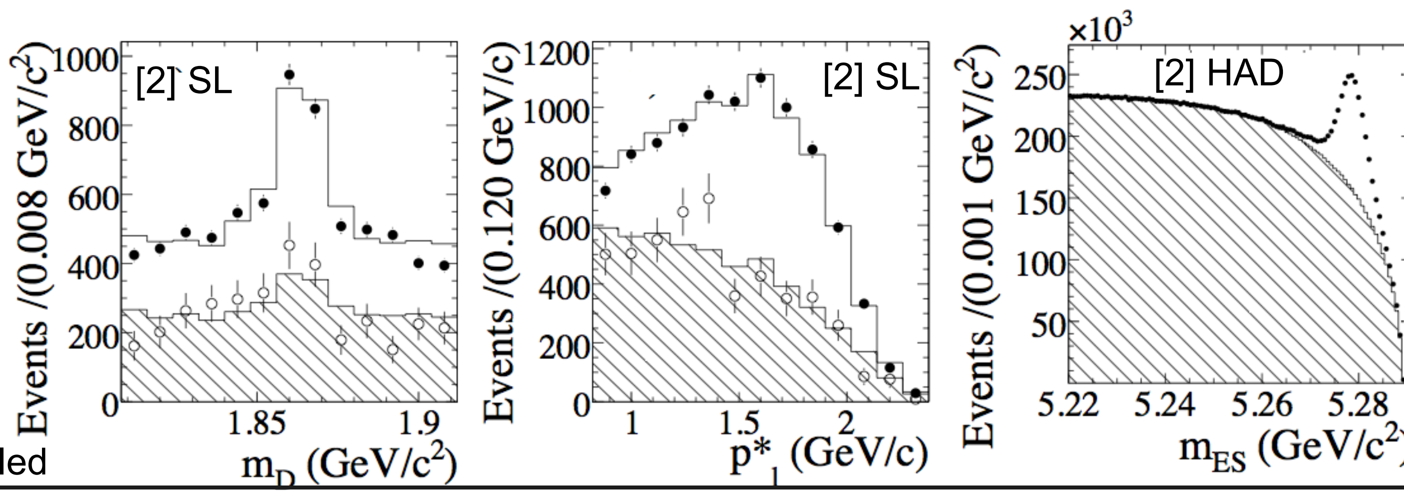
Presence of 2 neutrinos→ lack of kinematic constraints on signal side
Full reconstruction of $B_{tag}$ meson in hadronic or semileptonic decays and
Use rest of event to reconstruct $B_{sig} = K^{(*)}$ + missing energy

tag side selection :

$B \to K \nu \underline{\nu}$ semileptonic: $m_{Dl}$, $\cos\theta_{Dl,B}$, $p_D$ [1]

$B \to K^* \nu \underline{\nu}$ semileptonic: $m_D$, $\cos\theta_{Dl,B}$, $p^*_l$ [2]

$B \to K^* \nu \underline{\nu}$ hadronic: $m_{ES}$, $\Delta E$ [2]




_ MC simul
continuum
● on-peak
○ off-peak $\mathscr{L}$ scaled

# $B \to K^{(*)} \nu \underline{\nu}$: signal selection

- $B \to K \nu \underline{\nu}$ selection [1]:
  - combine 22 variables in a multivariate classification tool (Random Forest) and cut on the output to optimize S/[3/2+sqrtB]
  - combinatorial bkg estimation from data $m_{D0}$ sideband
  - peaking bkg estimation from MC Random Forest output sideband (correcting for data/MC ratio)
  - *yield estimation* by cut and count in the $D^0$ mass signal region

- $B \to K^* \nu \underline{\nu}$ selection [2]:
  - search for a K* candidate (neutral K*in $K^+\pi^-$, charged K* in $K^0_S\pi^+$ & $K^+\pi^0$)[2 HAD]
  - continuum bkg: $\cos\theta^*_{B,T}$, $R_2$
  - combinatorial K* bkg: $m_{K^*}$ , $m_{K0\_S}$, $E^*_{miss}$- $|p^*_{miss}|$, $E_{extra}$
  - *yield estimation* [SL] extended maximum likelihood fit of $E_{extra}$ distribution
  - *yield estimation* [HAD] NN fit of all discrimination variables

- Both: signal efficiency taken from MC

# $B \to K^{(*)} \nu \underline{\nu}$: Results

[1]: 2008 update @ 351M $B\underline{B}$
PRL94,101801(2005)
[2]: NEW 2008 @ 454M $B\underline{B}$
PRD78,072007(2008)

**Standard Model**

| mode | BF | |
|---|---|---|
| $\mathcal{B}(B \to K \nu\underline{\nu})_{SM}$ | $= (3.8^{+1.2}_{-0.6})\text{x } 10^{-6}$ | [A] |
| $\mathcal{B}(B \to K \nu\underline{\nu})_{best}$ | $<1.4 \text{ x } 10^{-5}$ | [B] |
| $\mathcal{B}(B \to K^* \nu\underline{\nu})_{SM}$ | $= (1.3^{+0.4}_{-0.3})\text{x } 10^{-5}$ | [A] |

*[A] G.Buchalla et al. PRD 63, 014015,2000*
*[B] K.F. Chen, arXiv:0708.4089*

**BaBar**

| mode | BF UL | |
|---|---|---|
| $\mathcal{B}(B^+ \to K^+ \nu\underline{\nu})$ | $< 4.2\text{x}10^{-5}$ | [1] |
| $\mathcal{B}(B^+ \to K^{*+} \nu\underline{\nu})_{SL+HAD}$ | $< 8 \text{ x } 10^{-5}$ | [2] |
| $\mathcal{B}(B^0 \to K^{*0} \nu\underline{\nu})_{SL+HAD}$ | $< 12 \text{ x } 10^{-5}$ | [2] |
| $\mathcal{B}(B \to K^* \nu\nu)_{SL+HAD}$ | $< 8 \text{ x } 10^{-5}$ | [2] |

. [1] Because $N_{obs\text{-}bkg}$ is consistent with $B_{expect\text{-}bkg}$ → results in the SM & set an UL on BF
. improvement of the previous BaBar measurement of this mode, but not at the level [B]

. [2] Because no constraints applied on K* final state, or undetected $\nu\underline{\nu}$ system → context of NP models, other invisible particles are responsible for the missing energy [C-E].
→ results presented are model independent
. They are the most stringent upper limits reported at date & still SM consistent

**[C]C. Bird et al. PRL93, 201803 (2004) [D] H. Georgi, PRL 98, 221601 (2007) [E] T. M. Aliev et al.,JHEP 0707 (2007) 072**

# Conclusions

. Rare B decays are probing the Standard Model deeper and deeper for NP

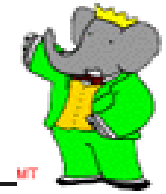
. B Factories are a unique place for looking for NP effects in rare B and $\tau$ decays
(inclusive channels, channels with large amount of missing energy)

. BaBar produced competitive results in several channels, we have presented some of the recent BaBar updated measurements in:
**leptonic** and **semileptonic** $\nu$ final states, $b \rightarrow l\,\nu$ ($l$= $e,\mu,\tau$), $b \rightarrow c\,\tau\,\nu$,
**electroweak penguins**, $b \rightarrow s\,X$ ($X$= $l^+l^-$,$\nu\underline{\nu}$)

. Results **consistent** in general with SM expectations
There is disagreement with SM (hints to new physics?) in Isospin Asymmetry in
$B \rightarrow K(*)l+l-$ decays

. Need an order of magnitude more luminosity to pin down some of NP effects

. B physics @ LHC, for some, and Super Flavor factories, for other measurements, will be advantageous for NP sensitive modes with photons, leptons and neutrinos

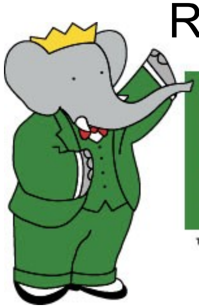


Thank you all

(sorry if I missed your topics of interest)

Virginia Azzolini

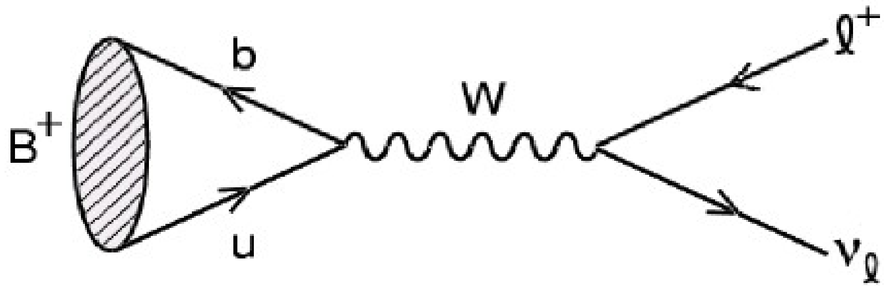
Helsinki University - HIP
Representing

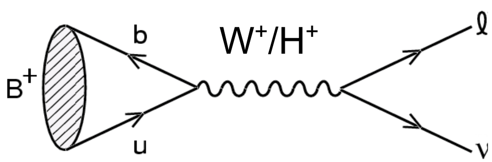


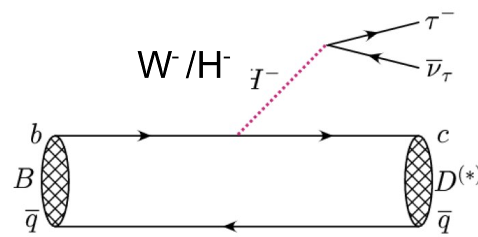
BABAR

Back up

# Missing $\nu$ final state transitions



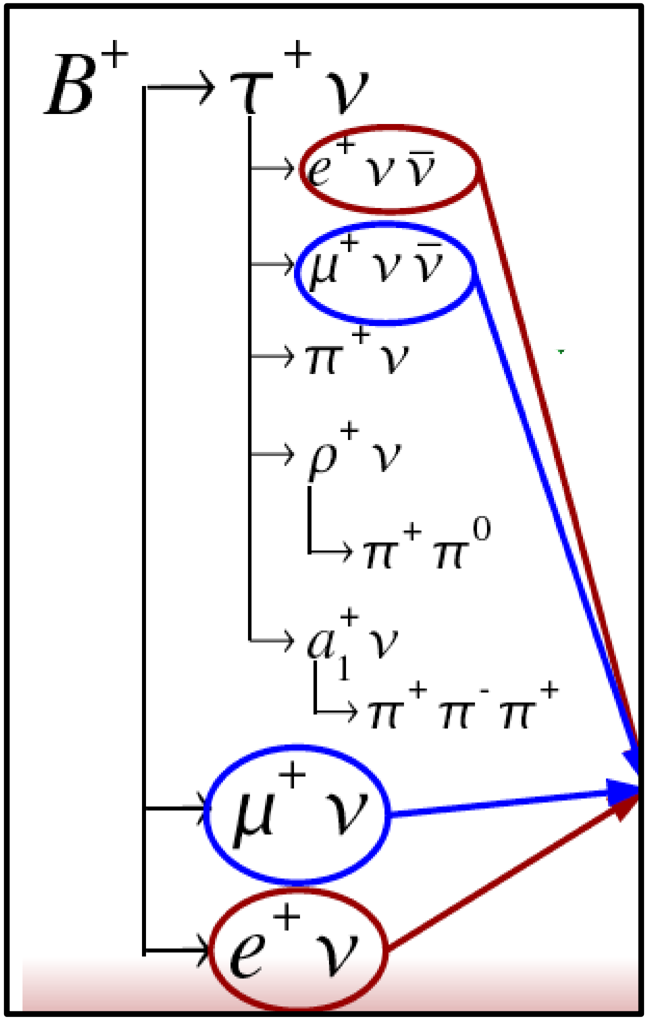



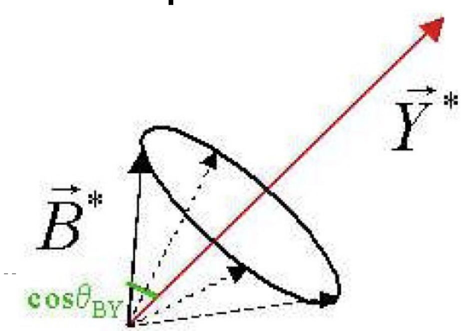

$b \to l\,\nu$ ($l = \tau, e, \mu$)

$B \to D(*)\,\tau\,\nu$

# Experimental Technique: recoil




- The τ is reconstructed
  - ..in 4 modes in B → τν
  - .. only Leptonic τ decays used in B→ $D^{(*)}\tau\nu$
- Accounts for ~70% of τ decays.
- in eν and μν calculate $|p_l|$ at several points around BY cone
- $|p'_l|$ = average of all results



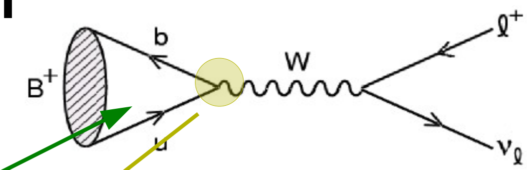

use $|p'_l|$ x separation

Two body ⇒ $|p'_l| = m_B/2$=2.64 GeV

$|p'_l| \leq$ 2.25 GeV ⇒ τ →eνν

$|p'_l| \leq$ 2.30 GeV ⇒ τ →μνν

# $B \to l\,\nu$ motivation




$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B = (1.6 \pm 0.4)\mathrm{x}10^{-4} \Big|_{SM}$$

. most favoured channel

$m_l$ leads to Helicity suppression

$\tau : \mu : e = 1 : 5\mathrm{x}10^{-3} : 10^{-7}$

Vub : $b \to u l \nu$ ~8 % error

+

. $f_B$: B-meson decay constant

- Accessible: purely leptonic decays + lattice QCD

. assuming $f_B$ and |Vub|, can use $B \to \tau\,\nu$ to constrain charged Higgs:

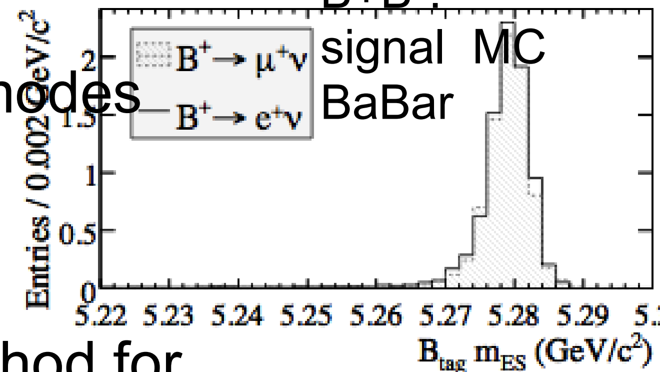
$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

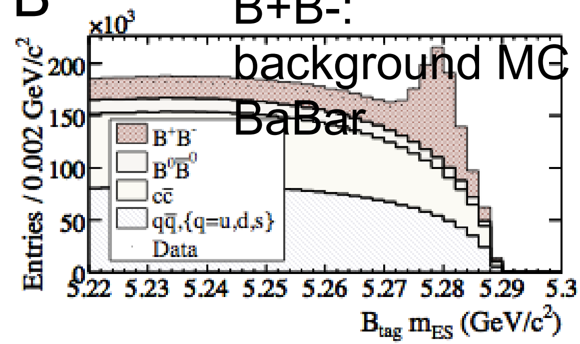
2HDM: Isidori and Paradisi PL B639 (2006)

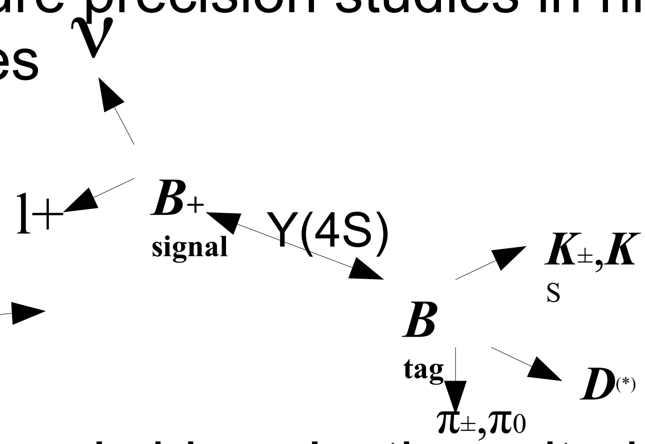
. SM prediction huge BF $\to$ ? NP enhance

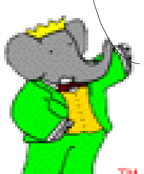
# $B \to l\ \nu\ (\nu = e, \mu)$ SL Tag

. Pioneered by Babar
. Reconstruct one B meson in hadronic modes
.. less sensitive to signal than inclusive approach,
.. much lower background (<<1),
.. suppressed by SM, but excellent method for the future precision studies in high luminosity B factories



Signal side selection criteria:
. monoenergetic lepton in signal B frame.
. missing momentum (carried by the neutrino),
. extra energy in the calorimeter (should be close to zero)

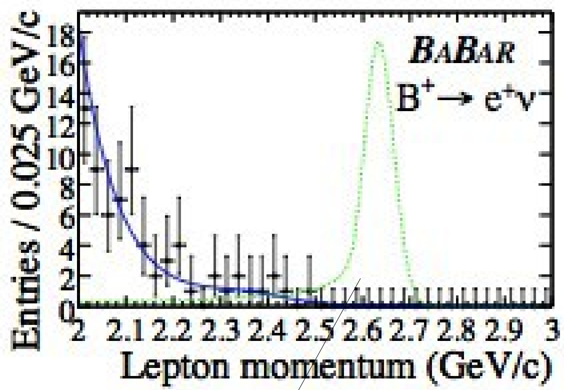
Should be zero for an ideal, fully reconstructed,event

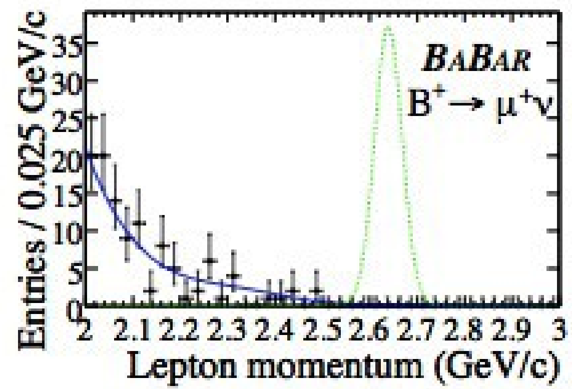
# $B \to l\ \nu\ (\nu = e, \mu)$ SL tag

Unbinned maximum likelihood (ML) fit on lepton momentum in the signal B rest frame

$$\mathcal{L}(n_s, n_b) = \frac{e^{-(n_s+n_b)}}{N!} \prod_{i=1}^{N} [n_s f_s(i) + n_b f_b(i)],$$

. data points
signal: CB modeled
B→ℓν bkg: exponentian & Gaussian modeled




(number of events "under the peak")

| | $e^+\nu$ | $\mu^+\nu$ |
|---|---|---|
| $\epsilon_{tot} \times 10^5$ | $135 \pm 4$ | $120 \pm 4$ |
| $n_b^*$ MC | $2.66 \pm 0.13$ | $5.74 \pm 0.25$ |
| $n_b^*$ | $2.67 \pm 0.19$ | $5.67 \pm 0.34$ |
| $n_s^*$ | $-0.07 \pm 0.03$ | $-0.11 \pm 0.05$ |
| $\mathcal{B} \times 10^{-6}$ | $-0.1^{+2.6}_{-1.7}$ | $-0.2^{+2.7}_{-1.8}$ |
| $\mathcal{B}^{90\%\ C.L.}$ | $5.2 \times 10^{-6}$ | $5.6 \times 10^{-6}$ |

$$0.90 = \int_0^{\mathcal{B}^{90\%}} \mathcal{L}(\mathcal{B})d\mathcal{B} / \int_0^{\infty} \mathcal{L}(\mathcal{B})d\mathcal{B}$$

The 90% CL upper limit on the BF is det solving for 90% in for events lying in the signal regions of 2.40GeV/c <p∗ <2.75GeV/c

Main uncertainties
PDF shape, B tagging, statistics

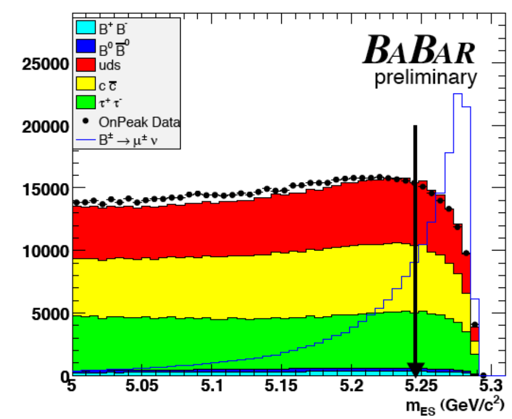
447M B$\bar{B}$
arXiv:0807.4187 [hep-ex]

# $B \to \mu \nu$ : Inclusive Selection

. Look for highest momentum muon in the signal,
make a $B_{tag}$ with the rest of the event (through 4-momenta addition)

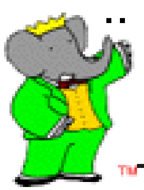
. Additional Lepton Selection:
. track quality and fiducial volume cuts
.. require tight muon ID
.. Tight pREST requirement
.. No additional lepton on tag side

Tag B Selection on $\Delta E$ and mES




. Typical background
.. qq
.. B→Xu l v with lepton at spectrum limit
.. B→ X h+ with misID on h+

Background suppression through topological Fisher discriminant



447M BB
arXiv:0807.4187 [hep-ex]

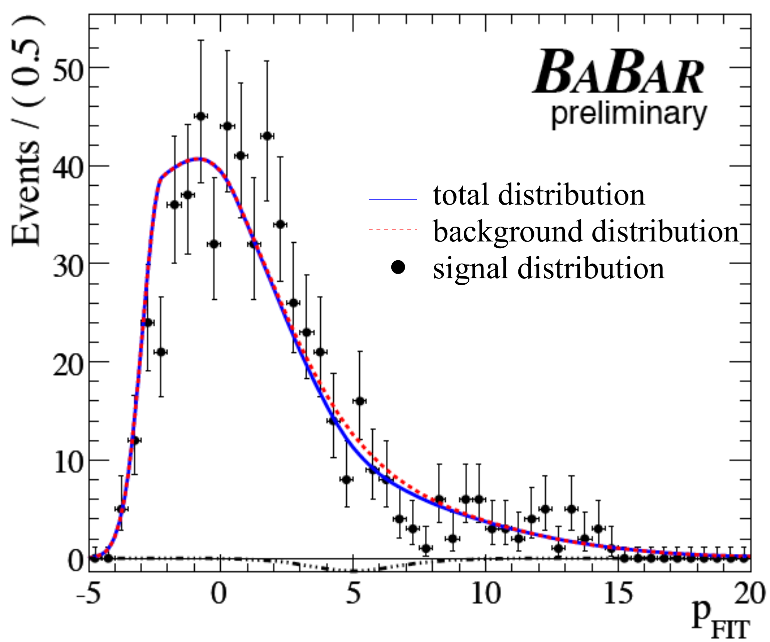
# $B \rightarrow \mu\, \nu$ : inclusive Signal Yield

. Candidate lepton momentum very discriminating, both in B rest frame ($p_{REST}$) and in CM frame ($p_{CM}$)

. Signal and background yields extracted from a Fisher discriminant distribution built up from $p_{CM}$ and $p_{REST}$

$$p_{FIT} = a1 + a2 \cdot p_{CM} + a3 \cdot p_{Rest}$$

a1 = −60.5203,
a2 = 6.6544 and a3 = 18.272




UL @ 90% CL in Bayesian approach (assuming a flat prior for the BF up to a maximum of $\mathcal{B}(B^{\pm} \rightarrow \mu^{\pm}\nu) = 1.3 \times 10^{-6}$

$$\mathcal{B}(B^{+} \rightarrow \mu^{+}\nu) < 1.3 \times 10^{-6}$$

These results are more restrictive than previous measurements from BABAR and Belle*



Belle*:Phys Lett B 647,(2007) 67

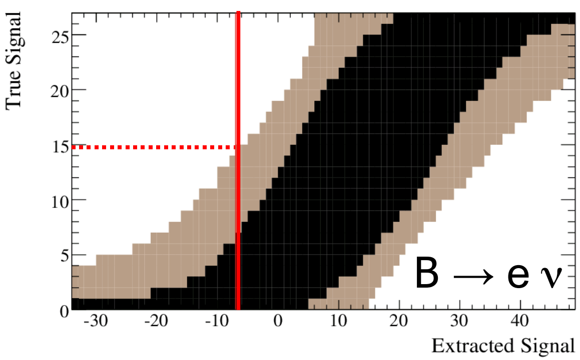
# $B \to \tau \nu$ : SL Tag CL histograms

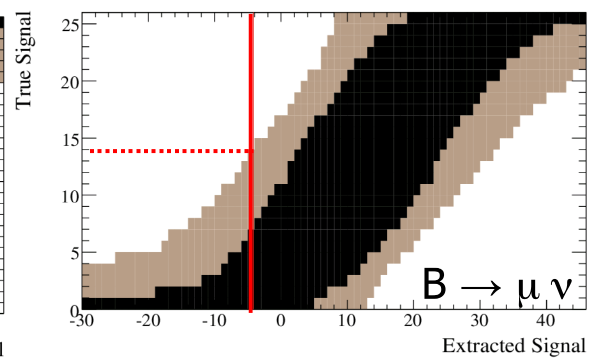
. How do we convert raw numbers in BF and upper limits?

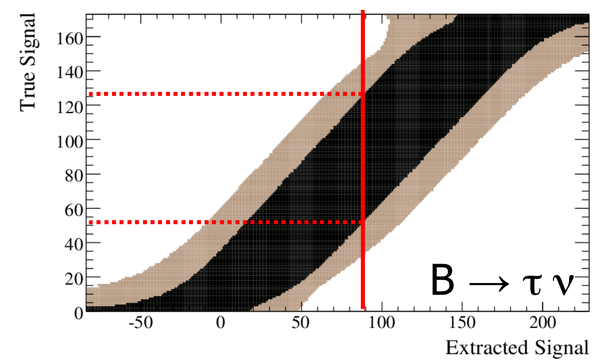
. We choose Feldman-Cousins* method

. Uses MC to set branching fraction or upper limit

. Works in high and low background environments



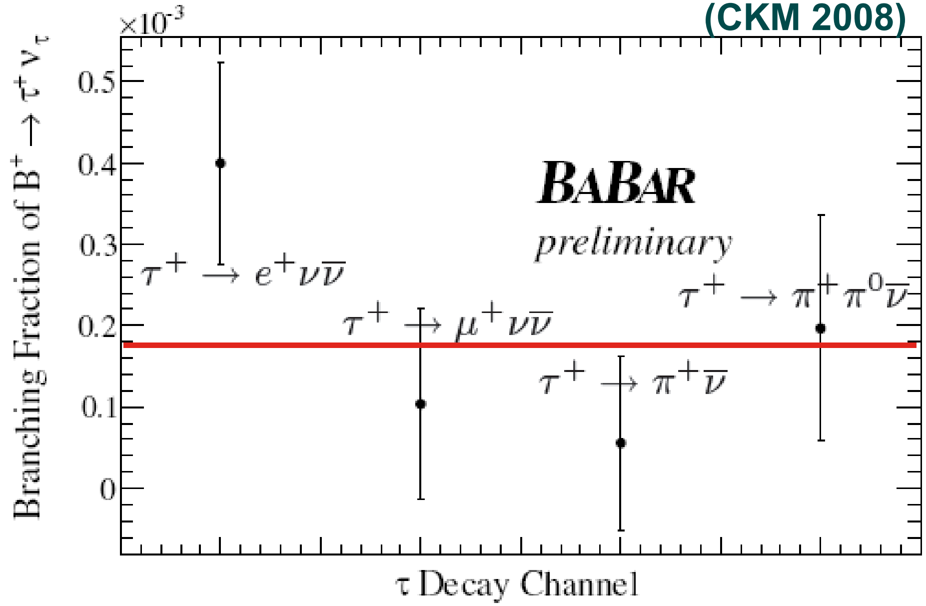

Red line is unblinded value
. Central Band = 1 $\sigma$
. Outer Band is 90% CL

* = ***Phys. Rev. D57:38733889***

# $B \to \tau \nu$ : SL Tag Branching fraction

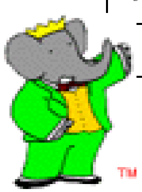
**458M BB New: arXiv:0809.4027 hep-ex (CKM 2008)**

. Fit histogram of separate BFs
. Fit to constant → probability of 18%

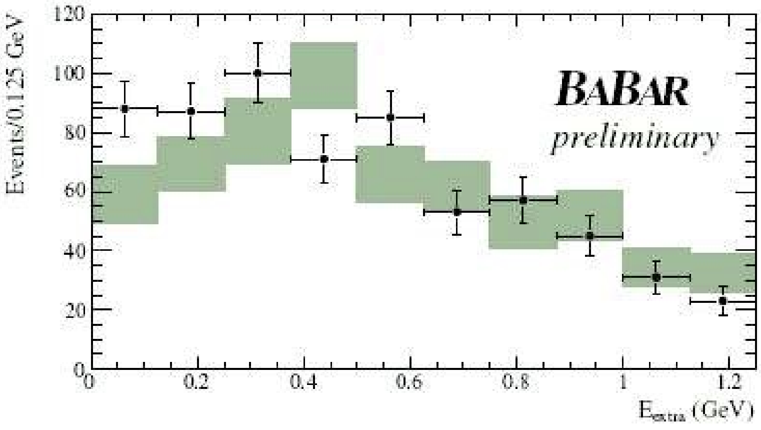


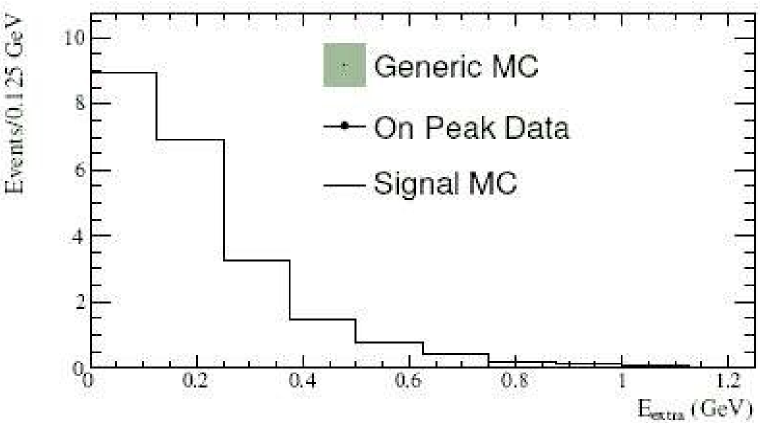

| Mode | Branching Fraction |
|---|---|
| $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$ | $(4.0 \pm 1.2) \times 10^{-4}$ |
| $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$ | $\left(1.0^{+1.2}_{-0.9}\right) \times 10^{-4}$ |
| $\tau^+ \to \pi^+\overline{\nu}_\tau$ | $\left(0.6^{+1.1}_{-0.5}\right) \times 10^{-4}$ |
| $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ | $\left(2.0^{+1.4}_{-1.3}\right) \times 10^{-4}$ |
| $B^+ \to \tau^+\nu_\tau$ | $(1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$ |

**$P(\chi_2)$ = 18% probability**



# $B \rightarrow \tau\nu$ : excess in $\tau \rightarrow e\nu\nu$




. Large excess in first 3 bins gives:
BF($B \rightarrow \tau\nu(\tau \rightarrow e\nu\nu$) = (4.0±1.2)10-4

. Many sideband/control sample studies performed:

.. two photon fusion QED events:
where a fake D0 is reconstructed and the e+,e- are reconstructed as the tag or signal leptons.
No excess seen in the D0 sidebands.

.. events that contain overlapping e+e- collisions:
study the separation of the reconstructed B vertices, $\Delta z$: possible excess at high $\Delta z$, however no excess found.

.. other samples studied include photon pair production and Bremstrahlung recovered e

.. Same number of e, $\mu$ from the tag B: expected for true signal

# B → l ν : Results

| | | | | |
|---|---|---|---|---|
| PDG Values [1] | | $< 9.8 \times 10^{-7}$ | $< 1.7 \times 10^{-6}$ | $(1.4 \pm 0.4) \times 10^{-4}$ |
| Inclusive Meas. | *BABAR* [9] | - | $< 1.3 \times 10^{-6}$ | N/A |
| | Belle [10] | $< 9.8 \times 10^{-7}$ | $< 1.7 \times 10^{-6}$ | N/A |
| Hadronic | *BABAR* | $< 5.2 \times 10^{-6}$ [11] | $< 5.6 \times 10^{-6}$ [11] | $(1.8^{+1.0}_{-0.9}) \times 10^{-4}$[12] |
| Tag Meas. | Belle | - | - | $(1.8 \pm 0.7) \times 10^{-4}$ [13] |
| Semilep. | *BABAR* | $< 7.7 \times 10^{-6}$ | $< 11 \times 10^{-6}$ | $(1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$ |
| Tag Meas. | Belle [14] | - | - | $(1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$ |

. B→ τ ν consistent with all recent measurements

. B→ μ ν 11 events in sig. region (Inclusive: 600)

.. Smaller backgrounds are more conducive to discovery

.. Precision measurement at Super B factory

[9] arXiv:0807.4187 [10] *Phys. Lett.* **B647**:6773 [11] arXiv:0801.0697
[12] *Phys. Rev.* **D77**:011107 [13] *Phys Rev. Lett*. **97**:251802 [14] arXiv:0809.3834

# B → l ν : Systematics

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{N_{\rm obs} - N_{\rm BG}}{N_{BB}\varepsilon_{\rm tag}\varepsilon_{\rm sig}}$$

1.1%

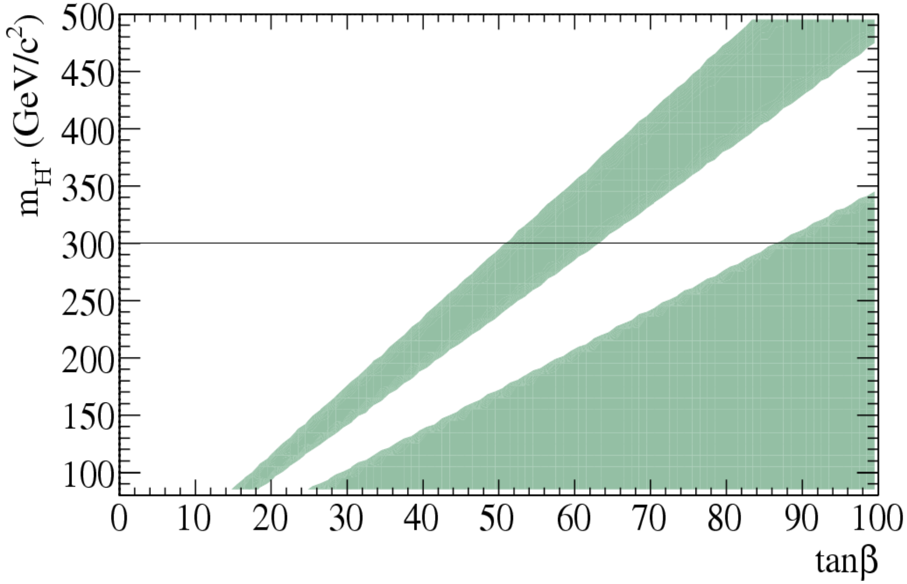
Tagging efficiency (correction)

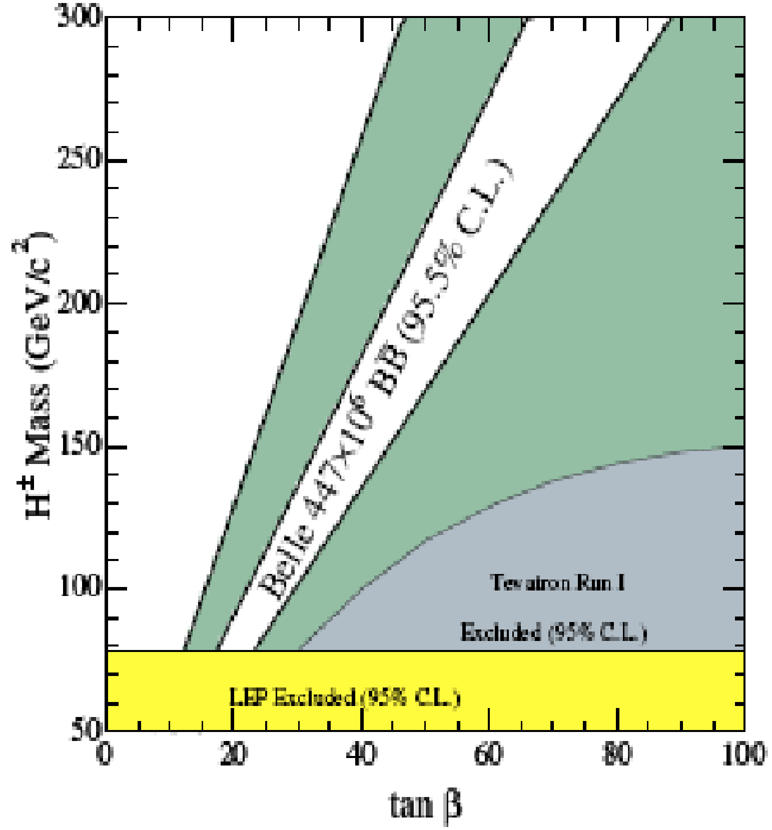
. $E_{extra}$ modeling
. $K_L^0$ veto efficiency: use double tag sample
  (Both *B* mesons reconstructed in a tag mode)
. Tracking Efficiency
  .. use ττ-events of a 1-3 topology
. Particle Identification
  .. correction as functions of particle momentum and angle, determined in clean samples
. $\pi^0$ efficiency
  .. use τ-decays: compare rates of $\pi^\pm$ to $\pi^\pm\pi^0$ decays

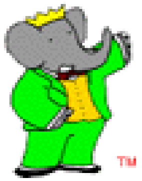
Data/MC agreement from sidebands

# B → τ ν : Implication for NP,Belle

Comparison of BaBar and Belle exclusions from *B*→τν



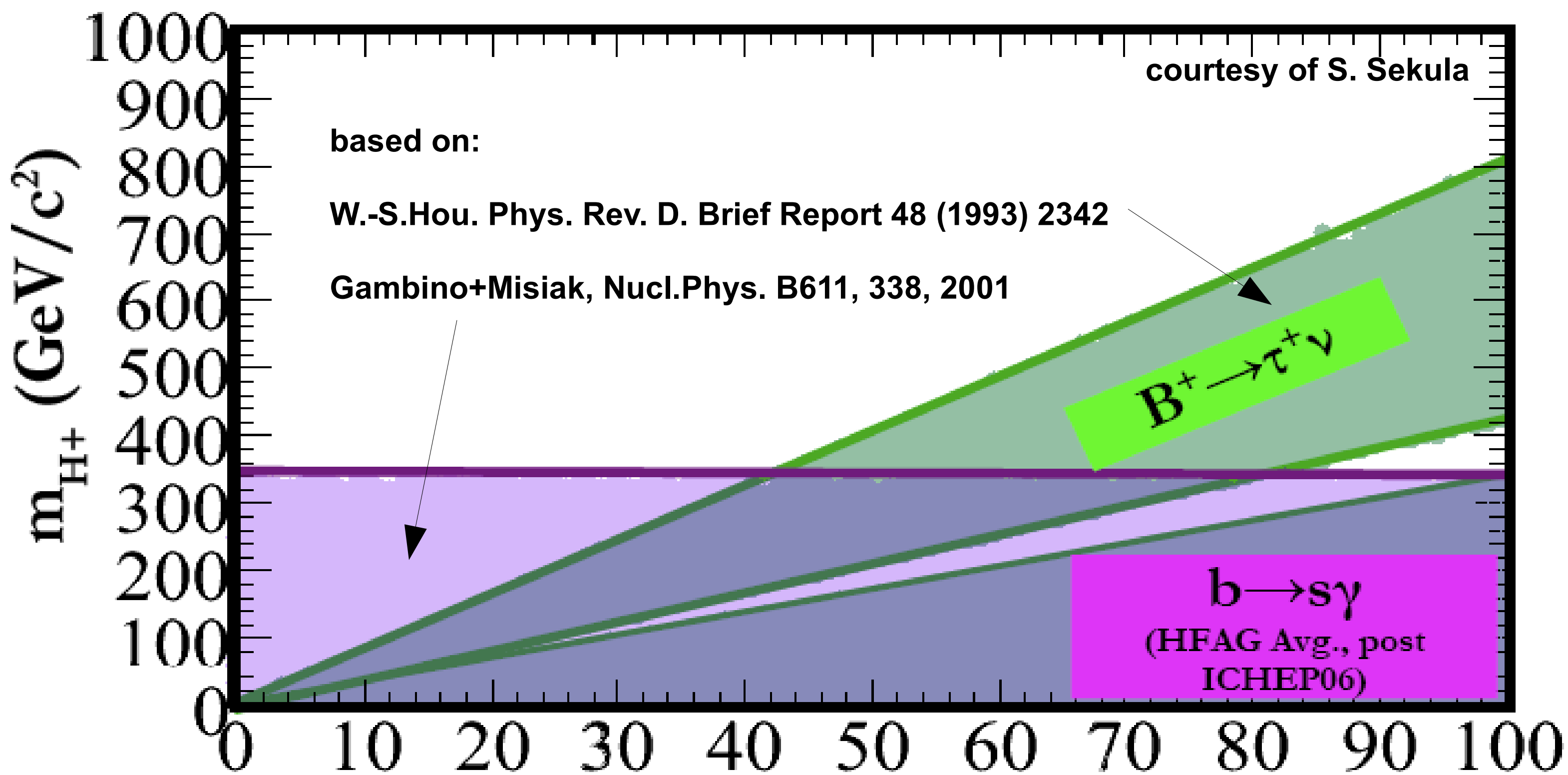



# Current 2HDM Constraints

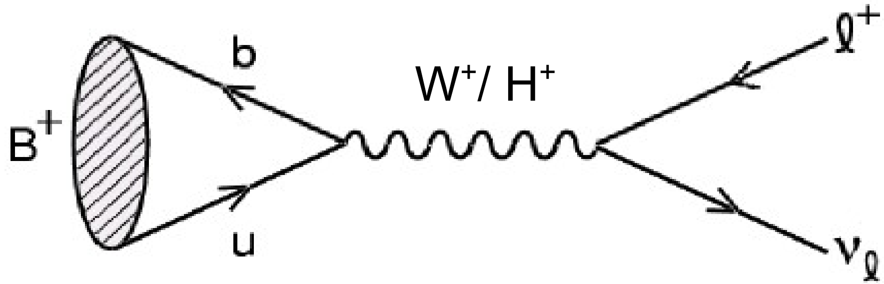
**Type II 2-Higgs Doublet Model**

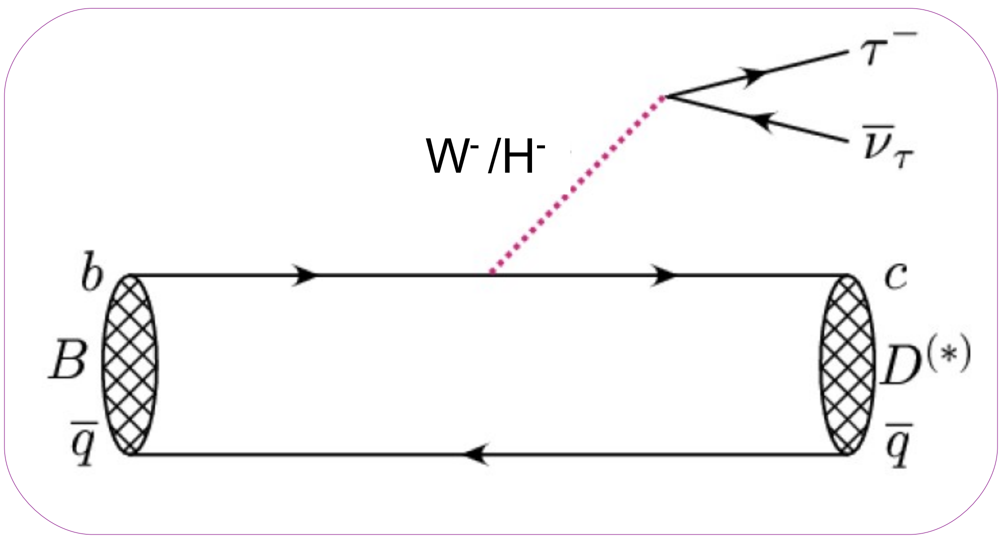
$$BR = BR_{SM} \times \left| 1 - \tan^2\beta \frac{m_{B^+}^2}{m_{H^+}^2} \right|^2$$




*Shaded regions are excluded at 90% CL*

# Missing ν final state transitions

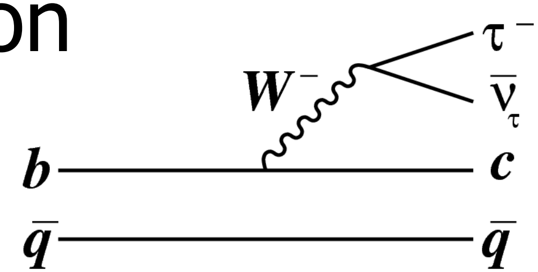



$b \rightarrow l\,\nu$ ($l = \tau$, e, $\mu$)

$B \rightarrow D(^*)\,\tau\,\nu$

# $B \to D(*) \tau \nu$ : motivation




Many Semileptonic B decays observed but

. $\tau$ are experimentally challenging (final 2-3 $\nu$)

. no helicity suppression → BF smaller wrt light lepton

.. Branching fractions can be accurately predicted:

| Decay Mode | | $\mathcal{B}$ (%) |
|---|---|---|
| $\overline{B}^0$ | $\to D^-\tau^-\overline{\nu}_\tau$ | $0.69 \pm 0.04$ |
| $\overline{B}^0$ | $\to D^{*-}\tau^-\overline{\nu}_\tau$ | $1.41 \pm 0.07$ |
| $B^-$ | $\to D^0\tau^-\overline{\nu}_\tau$ | $0.64 \pm 0.04$ |
| $B^-$ | $\to D^{*0}\tau^-\overline{\nu}_\tau$ | $1.32 \pm 0.07$ |
| $B$ | $\to X_c\tau^-\overline{\nu}_\tau$ | $2.3 \pm 0.25$ |

JHEP 0610, 053 (2006)
Phys. Lett. B 326 145 (1994)

.. Light lepton modes are very well studied

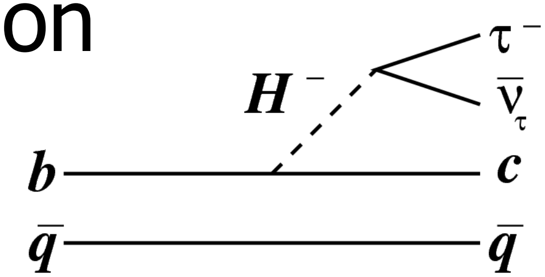
- QCD effects under control, very clean probe of NP

. 4 channels to be studied

. 3-body decay, study differential distributions as well as BF

.. q2, D* polarization, t polarization (daughter momentum)

# $B \to D(*)\, \tau\, \nu$ : motivation

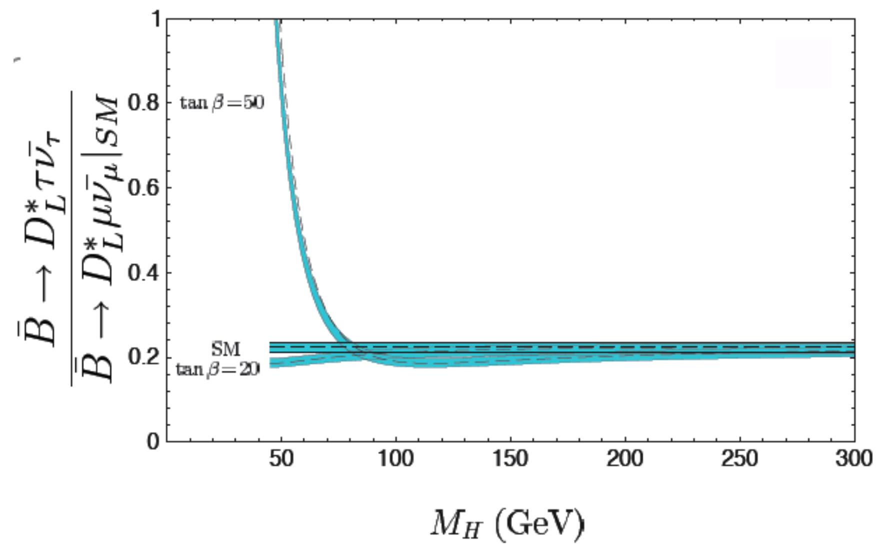


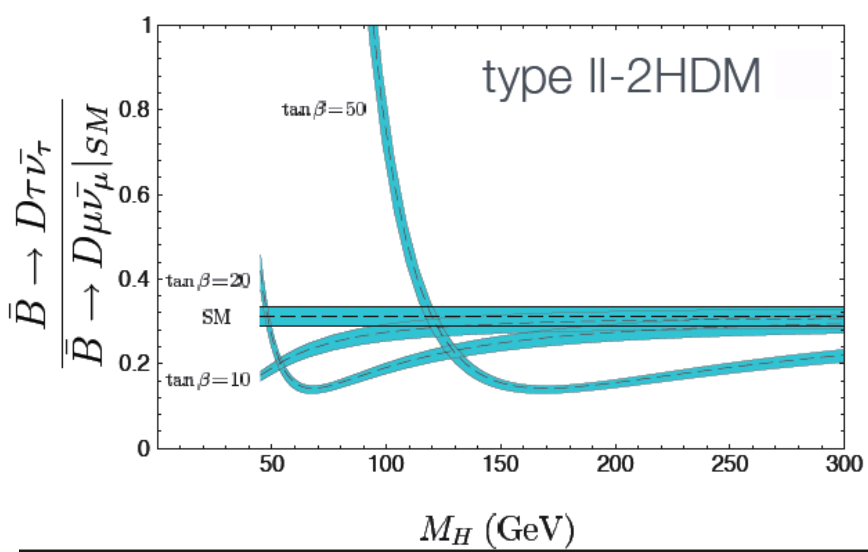

Beyond SM – charged Higgs.

. Higgs couples to mass → larger effect than in $B \to D(*)\, l\, \nu$

. Ratio of $B \to D(*)\tau\nu / B \to D(*)l\nu$ shown for 2HDM-type II

.. qualitatively similar behaviour seen in other models



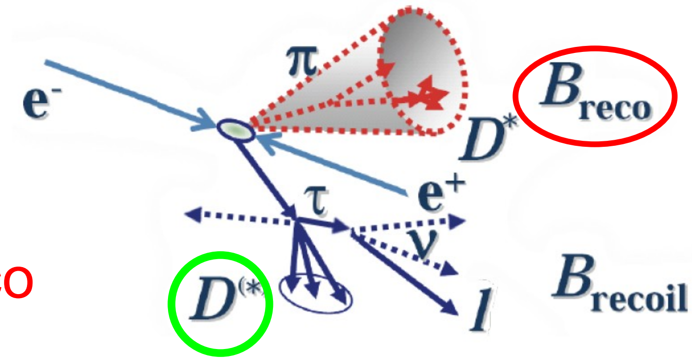

plots from Tanaka, Z Phys C67 321 (1995)

# $B \to D(*)\,\tau\,\nu$ : analysis outline

. Uses 232M B$\underline{B}$ pairs

. Hadronic tags used,D/D* + lepton in recoil

. Charge correlation between D(*) and Breco




. Simultaneous measurement 4 D channels:
$D^0\tau\nu$, $D^{*0}\tau\nu$, $D^+\tau\nu$,$D^{*+}\tau\nu$
.. Reconstruct $\tau$ as $\tau\to l\nu\nu$

. Look for events with large $m^2_{miss}$ - signal events have $3\nu$

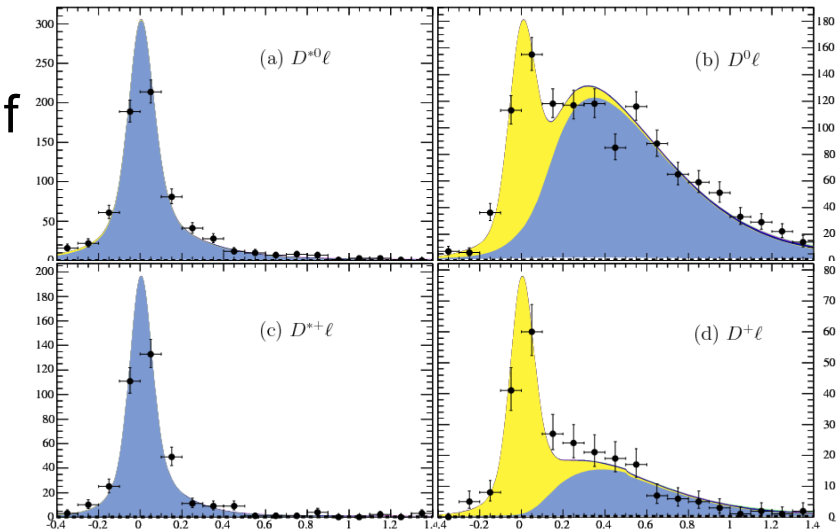
. BF normalised with respect to D(*)l $\nu$ = $m^2_{miss}$ ~0 region

# B → D(*) τ ν : cross-feeds and backgrounds

. D* events can feed down to D events if soft γ or $\pi^0$ is not reconstructed (well)
  .. true for both background and signal modes

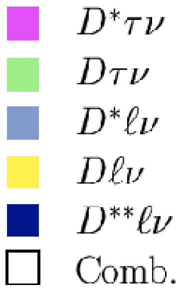
. smaller feed-up components are present

. other backgrounds
  .. D**, D(*) Ds(*), charge cross-feed
  .. construct D** control sample by requiring an extra $\pi^0$

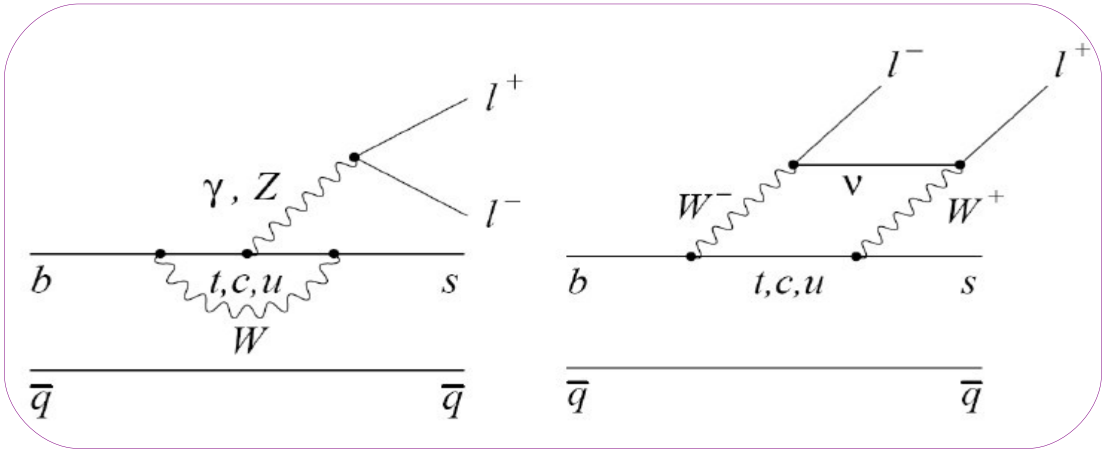



$m^2_{miss}$~0: normalization region

- charm resonances heavier than D*(2010)
- non-resonant D*nπ (n≥1)

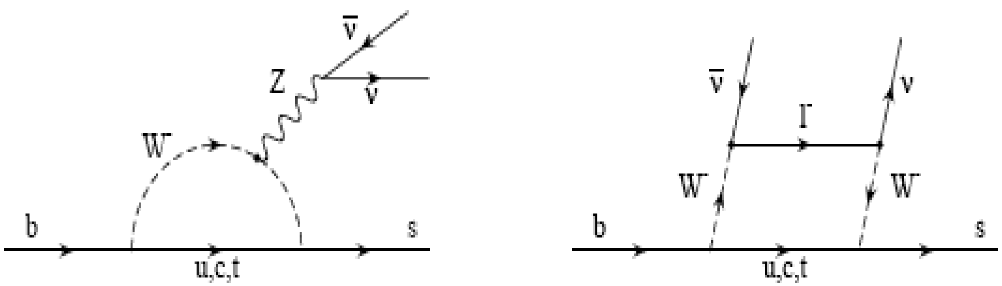


# Electroweak Penguins

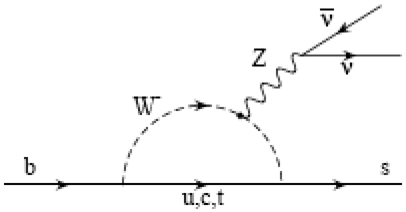


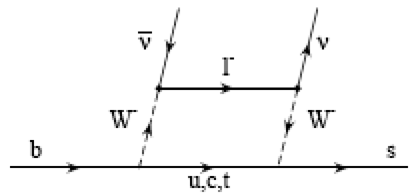

$b \to s\, l^+ l^-$

$b \to s\, \nu\, \bar{\nu}$



# $b \rightarrow s\, l^+ l^-$ : Theory




. Short-distance physics appears in the Wilson coefficients.

Operator Product Expansion:

$H_{eff} = - 4G_F/\sqrt{2}\ (V_{tb}V_{ts}^*)\ \Sigma_i\ C_i\ O_i$

CKM factors

Short-distance/ perturbative

Long-distance/ nonperturbative

. New physics may modify the $C_i$'s or introduce additional scalar (e.g pseudoscalar terms)

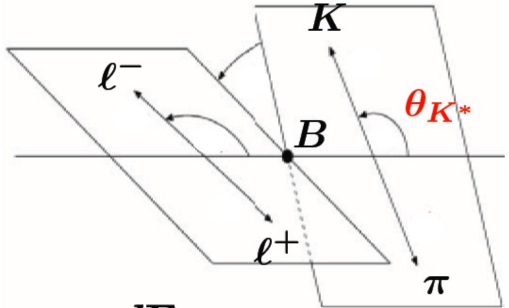
.Three short distant Wilson coeff.:

- $C_7$ *eff* from photon penguin
  Magnitude constrained by
  $b\rightarrow s\gamma$ BF measurement:
  $|C_7\ eff\ | \approx 0.33$
  (arXiv:0704.3575)

- $C_9^{eff}$ ($C_{10}^{eff}$) from vector (axial vector) parts of the Z,W box
  $|C_9|^2+ |C_{10}|^2$ constrained by
  $b \rightarrow s\ l^+l^-$ branching fraction,
  but not relative sign.

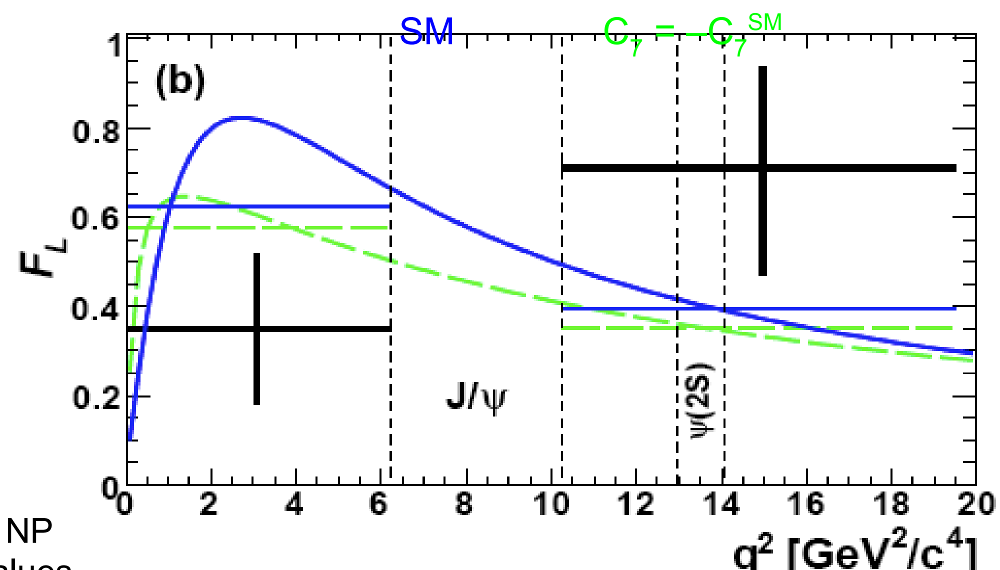
# $B \to K^* l^+l^-$ : K* longitudinal polarization

384M $B\bar{B}$
arXiv:0804.4412




Extracted from angular fit to $\cos_{\theta\_K}$ in each *q*2 bin

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

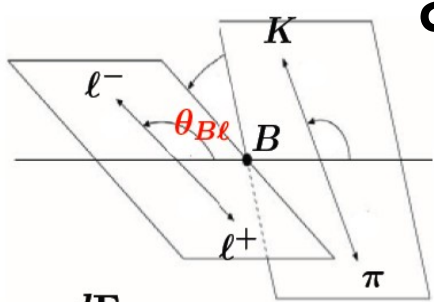



sensitive to NP at low $q^2$ values

Kruger and Matias: PRD 71, 094009 (2005)

384M $B\bar{B}$
arXiv:0804.4412

# $B \to K^* l^+l^-$ : lepton forward-backward asymmetry

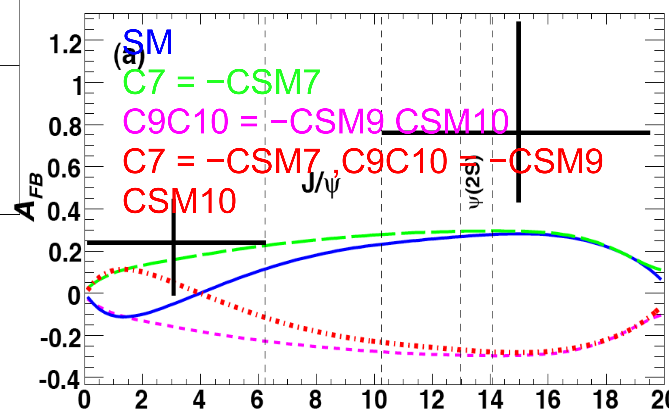



Extracted from angular fit to $\theta_{B\ell}$ in each $q^2$ bin.

$$\frac{d\Gamma}{d\cos\theta_{B\ell}} = \frac{3}{4}F_L \sin^2\theta_{B\ell} + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{K^*}) + A_{FB}\cos\theta_{B\ell}$$

| | SM expected | | measured | |
|---|---|---|---|---|
| | $A_{FB}$ | $F_L$ | $A_{FB}$ | $F_L$ |
| **low $q^2$** | $-0.03\pm0.01$* | $0.63\pm0.03$** | $0.24^{+0.18}_{-0.23} \pm 0.05$ | $0.35 \pm 0.16 \pm 0.04$ |
| **high $q^2$** | $0.26 \pm 0.01^{+0.00}_{-0.05}$*** | $0.40 \pm 0.03$** | $0.76^{+0.52}_{-0.32} \pm 0.07$ | $0.71^{+0.20}_{-0.22} \pm 0.04$ |

The AFB results exclude a wrong-sign C9C10 from purely right-handed weak currents at more than 3 standard deviations significance. Our results are consistent with measurements by Belle [14], and replace the earlier BABAR results in which only a lower limit on AFB was set in the low q2 region




* Huber, Hurth and Lunghi, arXiv:0712.3009 [hepph]
** Kruger and Matias, PRD 71, 094009 (2005)
*** Ali, Ball, Handoko and Hiller, PRD 61, 074024 (2000)
Hovhannisyan, Hou and Mahajan, PRD 77, 014016 (2008)

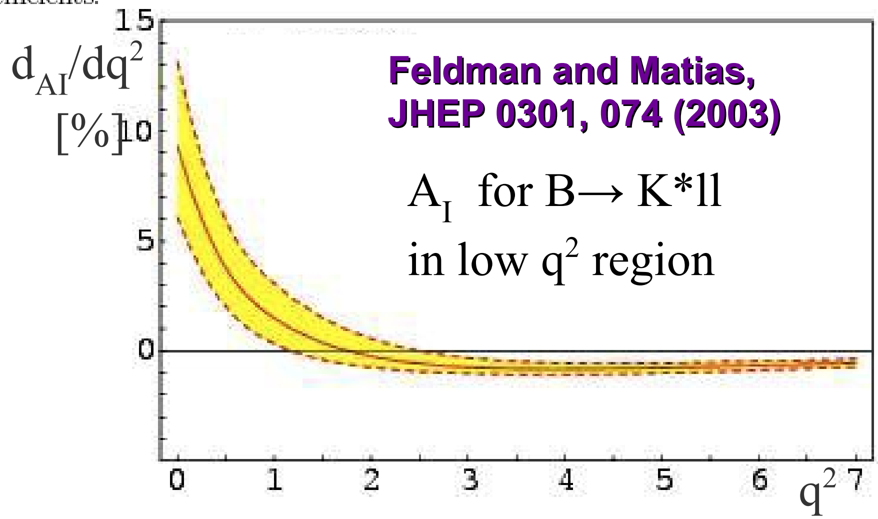
# $B \to K^{(*)} l^+l^-$ : Feldman & Matias

**384M $B\bar{B}$**
**arXiv:0807.4119**

Define isospin asymmetry in different s bins:

$$A_I \equiv \frac{B(B^0 \to K^{(*)0}\ell^+\ell^-) - (\frac{\tau_0}{\tau_+})B(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}{B(B^0 \to K^{(*)0}\ell^+\ell^-) + (\frac{\tau_0}{\tau_+})B(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}$$

integral $X_\perp^{(1)}$ ($\sim 1\%$). We thus confirm the conclusion in [26] that QCD factorization correctly reproduces the sign and magnitude of the experimentally measured isospin asymmetry ($A_I[B \to K^*\gamma] = 0.11 \pm 0.07$ [47, 48, 49]) with SM values for the Wilson coefficients.




For increasing values of $q^2$ the isospin-asymmetry decreases, and its central value becomes slightly negative above $q^2 = 2$ GeV$^2$ and stays basically at a constant value of about $-1\%$. Since the uncertainty related to the hadronic input parameters is reduced as well, this means that the measurement of a significant deviation from zero of the isospin asymmetry in the range 2 GeV$^2 < q^2 <$ 7 GeV$^2$ may still indicate new physics (although one would need to have a handle on even higher order effects, before drawing any definite conclusions). Note that in the SM the isospin asymmetry is sensitive to $C_5$ and $C_6$ at small $q^2$ but to $C_3$ and $C_4$ at larger $q^2$. Thus, in principle, the two momentum regions provide complementary tests of the four-quark penguin-operators (see also Fig. 6 below).

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

CP-averaged Isospin Asymmetry
$|A^{K(*)}_I|$ ~0.01 expected in SM
(T. Feldmann-J. Matias, JHEP 0301,074(2003))

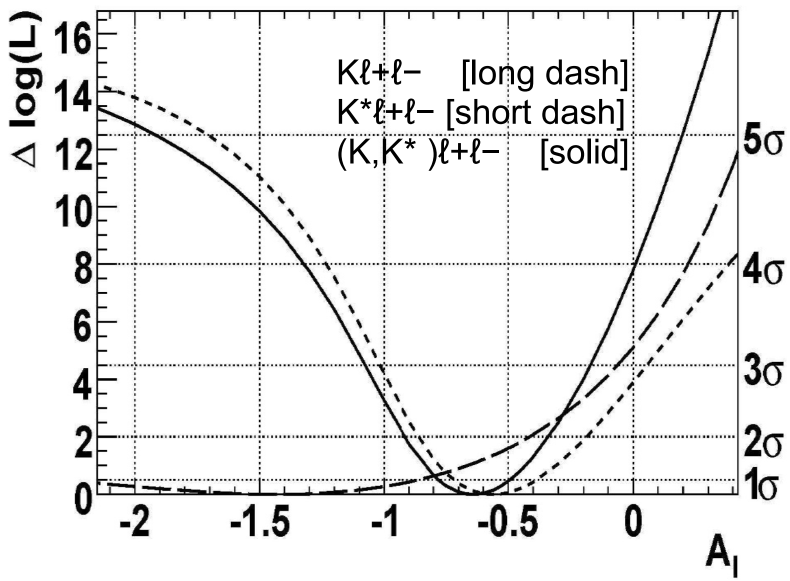
Measured in low, high and sum dilepton mass squared regions.

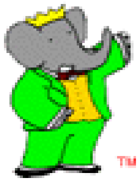
No deviation from SM in high mass and in combined regions

Significance (syst included) to exclude $A_{K(*)\,I}=0$ :

KII 3.2σ ,
K*II 2.7σ,
combined $K^{(*)}$II 3.9σ

Low q2 region $A^{K(*)}$I fit likelihood curves



Low $q^2$ : BaBar consistent with Belle results ICHEP'08

# $B \rightarrow K^{(*)} l^+l^-$ : Systematics

384M $B\overline{B}$
arXiv:0807.4119

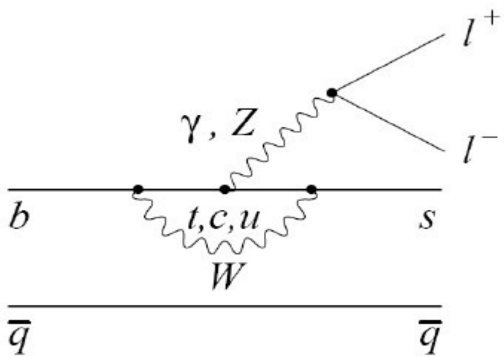
Reconstruction efficiencies
Hadronic background parameterization in di-muon final states
Peaking background contributions obtained from simulated events possible CP, lepton flavor and isospin asymmetries in the background pdfs.

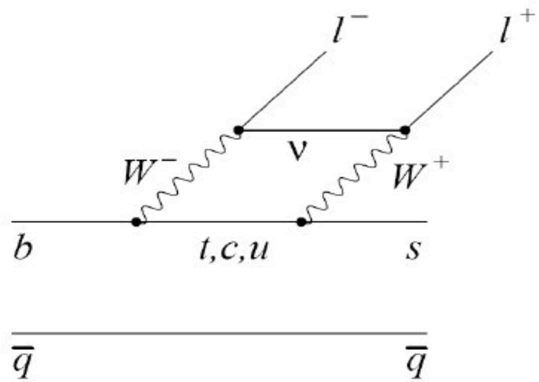
We quantify the efficiency systematics using the vetoed $J/\psi K(*)$ samples
(These include charged track, π0, and K0S reconstruction, particle identification, NN selection, and the E and K∗ mass selections.)

Systematic largest contributions: particle identification, the characterization of the hadronic bkg, and the signal mES pdf shape.

All of these cancel at least partially in the rate asymmetries, and the final systematic errors are small compared to the statistical errors

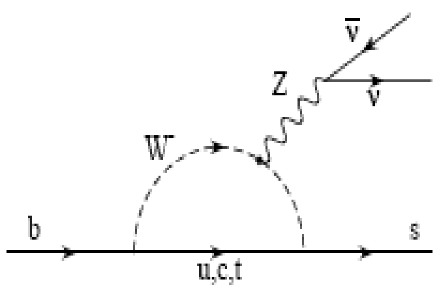
# Electroweak Penguins

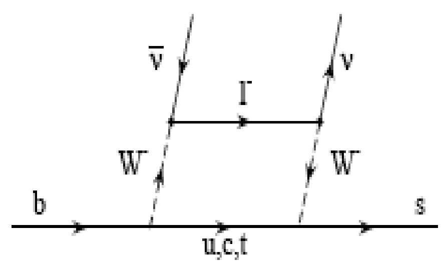



$b \to s\ l^+\ l^-$

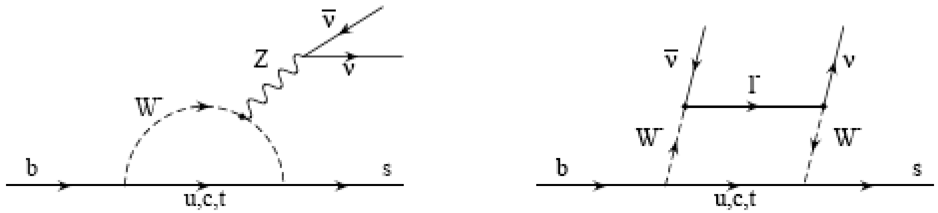
$b \to s\ \nu\ \underline{\nu}$



# $b \to s\,\nu\nu$: theoretical overview/motivation

$b \to s\nu\nu$ diagrams in the SM model




*G.Buchalla, G. Hiller, G. Isidori Phys. Rev. D 63, 014015,2000*

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

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

NP effects:

. Non-standard Z coupling: new particles in Z-loop $BR(B \to K^*\nu\nu) \sim 10^{-4}$
G.Buchalla et al. Phys. Rev. D 63, 014015,2000

. New sources of missing energy: production of light dark matter in $BR(B \to K^*$+missing energy) via Higgs mediated vertex ($BR_{NP}$ up $50 \times BR_{SM}$ for given values of model parameters)
C. Bird et al. Phys.Rev.Lett.93:201803,2004

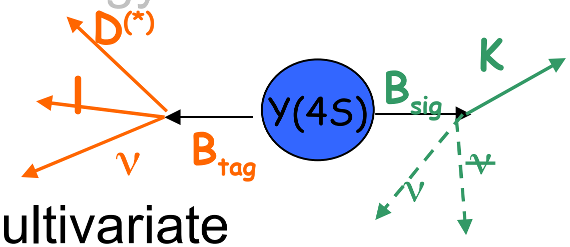
. Unparticle operators : existence of NP fields (Banks-Zaks fields) that, in the low energy limit of an effective field theory, represent invisible particles contributing to $BR(B \to K^*$+ missing energy)
T.M. Aliev et al JHEP 0707:072,2007

# $B \to K \nu \bar{\nu}$

preliminary
351 M $B\bar{B}$

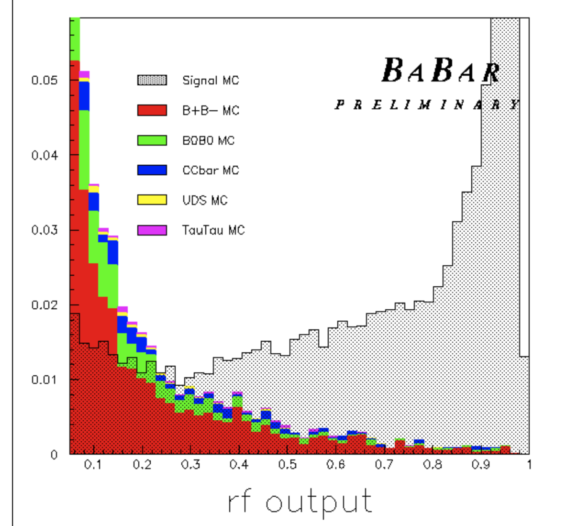
da elisa

. Full reconstruction of $B_{tag}$ meson in semileptonic decays;
. Use rest of event to reconstruct $B_{sig}$ = K + missing energy




. tag side selection : $m_{Dl}$, $\cos q_{DL,B}$, $p_D$
. signal side selection : combine 22 variables in a multivariate classification tool (Random Forest) and cut on the output
yield estimation by cut and counting in the $D_0$ mass signal region
- combinatorial bkg estimation from data mD0 sideband
- peaking bkg estimation from MC Random Forest output sideband (correcting for data/MC ratio)
- signal efficiency from MC

arbitrary signal normalization




Result:

| $B_{exp}$ | $N_{obs}$ | BR UL |
|---|---|---|
| 30.71±10.71 | 38 | $4.2\times10^{-5}$ |

# $B \to K \nu \bar{\nu}$ : Random Forest inputs [1]

TABLE I: The 22 different variables input to the Random Forest.

| Variable | Description |
|---|---|
| CosBY | Cosine of the angle between the tag side momentum of the combined $D^0 l$ and the momentum of the original $B$ meson |
| modenum | the $D^0$ decay channel (1=$K\pi$, 2=$K\pi\pi\pi$, 3=$K\pi\pi^0$) |
| isoftpi | index of the soft pion if there is one in the event ($D^{*+} \to D^0 + \pi^+$) |
| nUsedGam | the number of Gamma's used in the event (0, or 2 for the $\pi^0$) |
| nUsedTrk | the number of charged tracks used to reconstruct the tag side |
| nTrkLeft | the number of remaining charged tracks after reconstruction of the tag side |
| nGamLeft | the number of remaining Gammas > 50 MeV, after the reconstruction of the tag side |
| thetalab | the azimuthal angle of the highest indexed track |
| costhDl | the cosine of the thrust angle of the tag side |
| thDl | the thrust angle of the tag side |
| sumptDl | the total transverse momentum of the tag side |
| cosmomDl | the cosine of the momentum of the tag side |
| pstarlep | the center of mass momentum of the tag side lepton |
| npi0left | the number of remaining $\pi^0$ candidates after tag side reconstruction |
| Etotleftnew50 | the remaining neutral energy after tag side reconstruction |
| ptrkleft | the momentum of the signal side Kaon |
| r2all | the 2nd Fox-Wolfram moment |
| cosangKl | the cosine of the angle between the signal side Kaon, and the tag side lepton |
| cosangKD | the cosine of the angle between the signal side Kaon, and the tag side $D$ |
| xmmiss | the missing mass in the event |
| cosDlK | the cosine of the angle between the signal side Kaon and the tag side |
| eMissEvt | the missing energy in the event |
| angtogam | the smallest angle between a randomly selected charged track and the photons |

# $B \to K \nu \bar{\nu}$ : signal systematics [1]

systematic uncertainties on the signal efficiency

| | Random Forest $\frac{\delta\epsilon}{\epsilon}$ |
|---|---|
| Kaon Momentum | 3.1% |
| Tracking Efficiency | 0.5% |
| Kaon PID | 3.5% |
| Tagging Efficiency | 6.5% |
| Selection Efficiency | 5.2% |
| Signal vs. Double Tag MC Event Difference | 9.3% |
| Total | 13.4% |

# $B \to K^* \nu \bar{\nu}$ : MC yields & data fit [2]

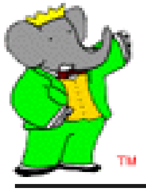
TABLE III: Expected signal and background yields ($N_s$ and $N_b$ respectively) from MC studies (assuming the SM $\mathcal{B}$ for the signal) and results of the data fit, along with signal efficiencies, corrected for systematic effects. Expected signal yields are evaluated according to the SM expected $\mathcal{B}$. The first error on the fitted signal yield and on $N_{B_{\rm had}}$ is statistical, the second is systematic. The corresponding upper limits are also quoted.

| $K^*$ mode | $K^+\pi^0$ | $K^0_S\pi^+$ | $K^+\pi^-$ |
|---|---|---|---|
| SL ANALYSIS | | | |
| Expected Yields | | | |
| $N_s$ | 3.31 | 2.54 | 4.07 |
| $N_b$ | 697 | 827 | 468 |
| $E_{\rm extra}$ Fit Results | | | |
| $N_s$ | -22 ± 16 ± 14 | 3 ± 17 ± 15 | 35 ± 13 ± 9 |
| $N_b$ | 754 ± 32 | 869 ± 34 | 476 ± 25 |
| $\varepsilon$ ($\times 10^{-4}$) | 5.6 ± 0.7 | 4.3 ± 0.6 | 6.9 ± 0.8 |
| $N_{B\bar{B}}$ ($\times 10^6$) | | 454 ± 5 | |
| UL (90% CL) | $9 \times 10^{-5}$ | | $18 \times 10^{-5}$ |
| HAD ANALYSIS | | | |
| Expected Yields | | | |
| $N_s$ | 0.87 | 0.77 | 1.64 |
| $N_b$ | 46 | 35 | 73 |
| NN Fit Results | | | |
| $N_s$ | 5 ± 6 ± 4 | 3 ± 7 ± 4 | -10 ± 9 ± 6 |
| $N_b$ | 39 ± 9 | 51 ± 10 | 77 ± 13 |
| $\varepsilon_{B_{\rm sig}}$ ($\times 10^{-2}$) | 5.8 ± 0.5 | 5.2 ± 0.6 | 16.6 ± 1.4 |
| $N_{B_{\rm had}}$ ($\times 10^5$) | 10.128 ± 0.010 ± 0.344 | | 7.175 ± 0.008 ± 0.222 |
| UL (90% CL) | $21 \times 10^{-5}$ | | $11 \times 10^{-5}$ |

# $B \rightarrow K^* \nu \bar{\nu}$ : systematics [2]

TABLE IV: Summary of systematic uncertainties on the signal efficiencies, signal yield, and normalization.

| | SL ANALYSIS | | | HAD ANALYSIS | | |
|---|---|---|---|---|---|---|
| $K^*$ mode | $K^+\pi^0$ | $K^0_S\pi^+$ | $K^+\pi^-$ | $K^+\pi^0$ | $K^0_S\pi^+$ | $K^+\pi^-$ |
| | | | Signal efficiency (%) | | | |
| MC statistics | 1.4 | 1.7 | 1.3 | 2.9 | 3.1 | 2.4 |
| Best pair selection | 0.2 | 0.0 | 0.0 | – | – | – |
| Tagging Efficiency | 10.0 | 10.0 | 10.0 | – | – | – |
| Tracking | 0.3 | 1.0 | 0.7 | 0.3 | 1.0 | 0.7 |
| $\pi^0$ reconstruction | 3.0 | – | – | 3.0 | – | – |
| $K^0_S$ reconstruction | – | 2.5 | – | – | 2.5 | – |
| Particle ID | 1.7 | – | 1.4 | 1.7 | – | 1.4 |
| Selection variables | 5.0 | 7.3 | 5.1 | 5.3 | 8.6 | 3.8 |
| Model dependence | 4.5 | 4.8 | 1.3 | 6.3 | 7.4 | 6.9 |
| | | | Signal yield (events) | | | |
| Signal PDF param. | 0.7 | 1.4 | 0.2 | 0.2 | 0.3 | 0.2 |
| Bkgd PDF param. | 11.0 | 11.0 | 7.7 | 2.8 | 2.8 | 4.5 |
| Signal PDF shape | – | – | – | 1.2 | 1.7 | 1.2 |
| Bkgd PDF shape | 6.4 | 4.9 | 2.8 | 2.1 | 1.6 | 3.4 |
| | | | Normalization factor (%) | | | |
| $N_{BB}$ or $N_{B_{\rm had}}$ | 1.1 | 1.1 | 1.1 | 3.4 | 3.4 | 3.1 |



# B → K* ν ν: results

No significant signal is observed in the 2 analysis B → K* ν ν

B → K* ν ν SL

B → K* ν ν HAD

Table 29: *Results of the unblinded fit.*

| | $K^{*0} \to K^+\pi^-$ | $K^{*+} \to K^0_S\pi^+$ ($K^0_S \to \pi^+\pi^-$) | $K^{*+} \to K^0_S\pi^+$ ($K^0_S \to \pi^0\pi^0$) | $K^{*+} \to K^+\pi^0$ |
|---|---|---|---|---|
| $N_s$ | $35 \pm 13$ | $3 \pm 17$ | $-9 \pm 8$ | $-22 \pm 16$ |
| $N_b$ | $476 \pm 25$ | $869 \pm 34$ | $338 \pm 20$ | $754 \pm 32$ |

Table 41: Values used to compute the expected and the measured ULs on $\mathcal{B}(B^+ \to K^{*+}\nu\overline{\nu})$ and $\mathcal{B}(B^0 \to K^{*0}\nu\overline{\nu})$

| | $K^{*+} \to K^+ \pi^0$ | $K^{*+} \to K^0_S \pi^+$ | $K^{*0} \to K^- \pi^+$ |
|---|---|---|---|
| $N_B^{tag}$ | $1\,012\,788 \pm 34\,580$ | $1\,012\,788 \pm 34\,580$ | $717\,490 \pm 22\,256$ |
| | | cut and count | |
| $\epsilon^{sig}_{K^*\nu\overline{\nu}}$ | $(4.0 \pm 0.4) \times 10^{-2}$ | $(3.0 \pm 0.3) \times 10^{-2}$ | $(10.3 \pm 1.0) \times 10^{-2}$ |
| $B_{exp}$ | $18.8 \pm 12.6$ | $8.5 \pm 6.1$ | $14.0 \pm 7.4$ |
| $N_{obs}$ | 20 | 11 | 19 |
| | | NN fit | |
| $\epsilon^{sig}_{K^*\nu\overline{\nu}}$ | $(5.8 \pm 0.5) \times 10^{-2}$ | $(5.2 \pm 0.6) \times 10^{-2}$ | $(16.6 \pm 1.4) \times 10^{-2}$ |
| $N_{sig,exp}$ | $1 \pm 6$ | $1 \pm 6$ | $2 \pm 10$ |
| $N_{sig,obs}$ | $5 \pm 7$ | $3 \pm 8$ | $-10 \pm 11$ |

## 11 Results

To estimate the sensitivity of the analysis, we compute the expected UL before unblinding. In Table 41 the quantities used in the UL estimation are listed. For the cut and count we assume that the number of observed events in data correspond to the expected number of background we estimate from MC. For the expected signal use Equation 28, with a BR equals to the SM prediction ($1.3 \times 10^{-5}$ ). For the NN fit we compute the UL assuming as signal yield and its statistical error the values obtained from the toy MC studies. We have the following results for the expected ULs at 90% of CL:

$$\begin{aligned}
\text{cut and count: } \mathcal{B}(B^+ \to K^{*+}\nu\overline{\nu}) &< 30 \times 10^{-5} \\
\mathcal{B}(B^0 \to K^{*0}\nu\nu) &< 19 \times 10^{-5} \\
\text{NN fit: } \mathcal{B}(B^+ \to K^{*+}\nu\nu) &< 14 \times 10^{-5} \\
\mathcal{B}(B^0 \to K^{*0}\nu\nu) &< 15 \times 10^{-5}
\end{aligned} \quad (36)$$

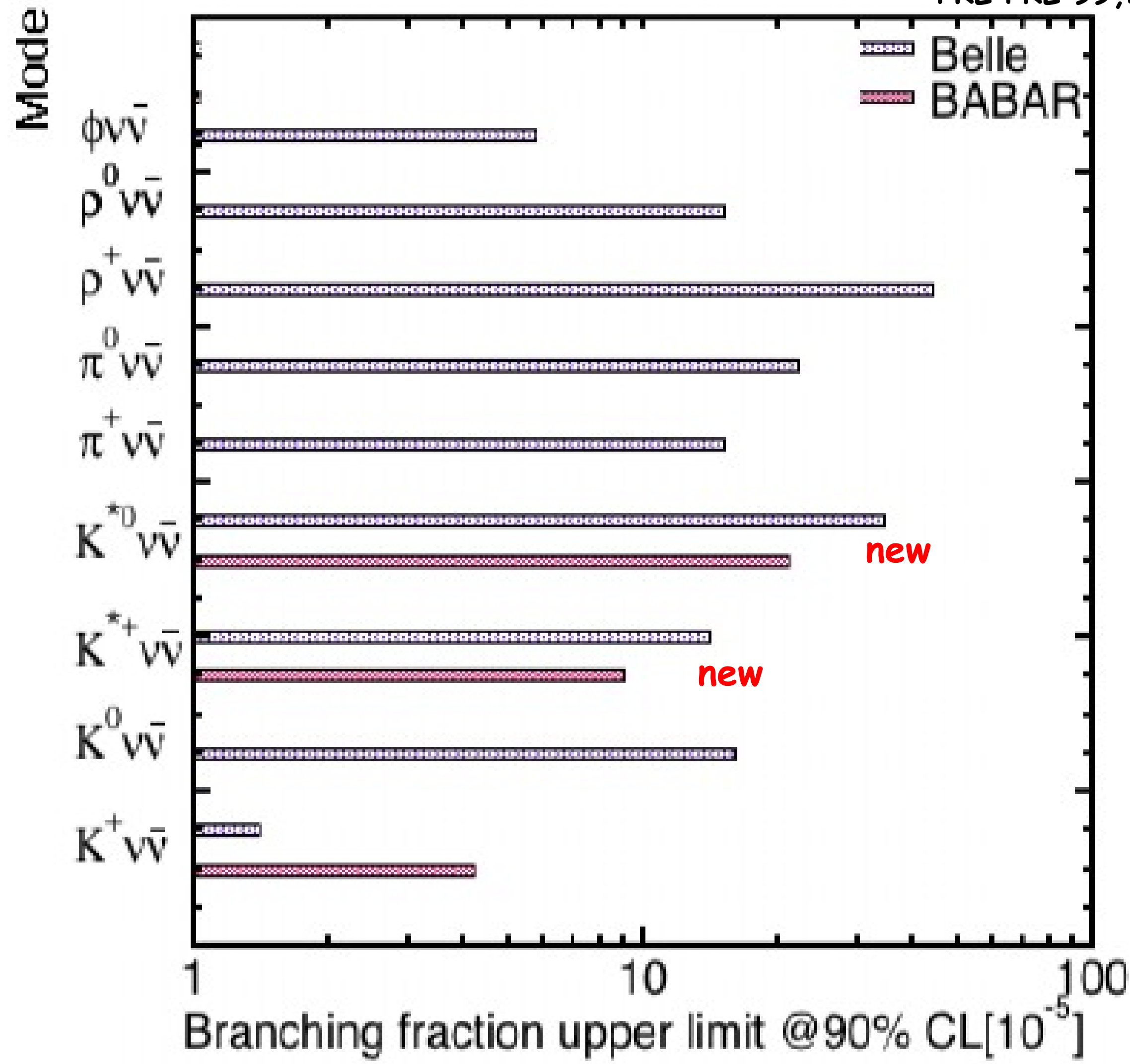
After unblinding, we measure the following ULs:

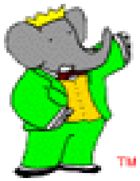
$$\begin{aligned}
\text{cut and count: } \mathcal{B}(B^+ \to K^{*+}\nu\overline{\nu}) &< 36 \times 10^{-5} \\
\mathcal{B}(B^0 \to K^{*0}\nu\overline{\nu}) &< 25 \times 10^{-5} \\
\text{NN fit: } \mathcal{B}(B^+ \to K^{*+}\nu\overline{\nu}) &< 21 \times 10^{-5} \\
\mathcal{B}(B^0 \to K^{*0}\nu\overline{\nu}) &< 11 \times 10^{-5}
\end{aligned} \quad (37)$$

$$\begin{aligned}
\mathcal{B}(B^+ \to K^{*+}\nu\overline{\nu}) &< 8 \times 10^{-5} \\
\mathcal{B}(B^0 \to K^{*0}\nu\overline{\nu}) &< 12 \times 10^{-5} \\
\mathcal{B}(B \to K^{*}\nu\overline{\nu}) &< 8 \times 10^{-5}.
\end{aligned}$$

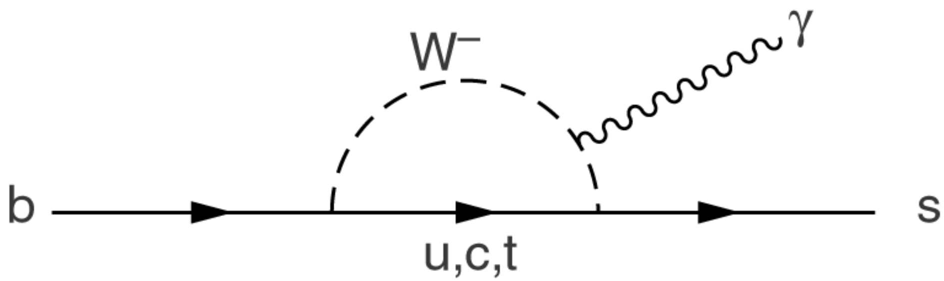
# $B \rightarrow K^{(*)} \nu \underline{\nu}$: comparisons

**Belle: 493 $fb^{-1}$**
PRL PRL 99,221802 (2007)



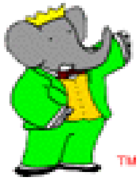



# Electroweak Penguins



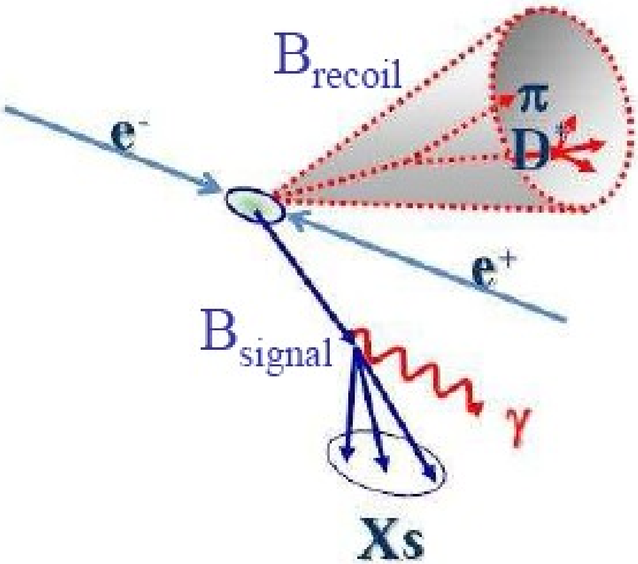

$b \rightarrow s\ \gamma$

**Please See:**
**April 7th, 2008 CERN EP Seminar Henning Flächer (CERN)**



# $B \to s\,\gamma$ Recoil Technique

PRD 77, 051103 (2008)

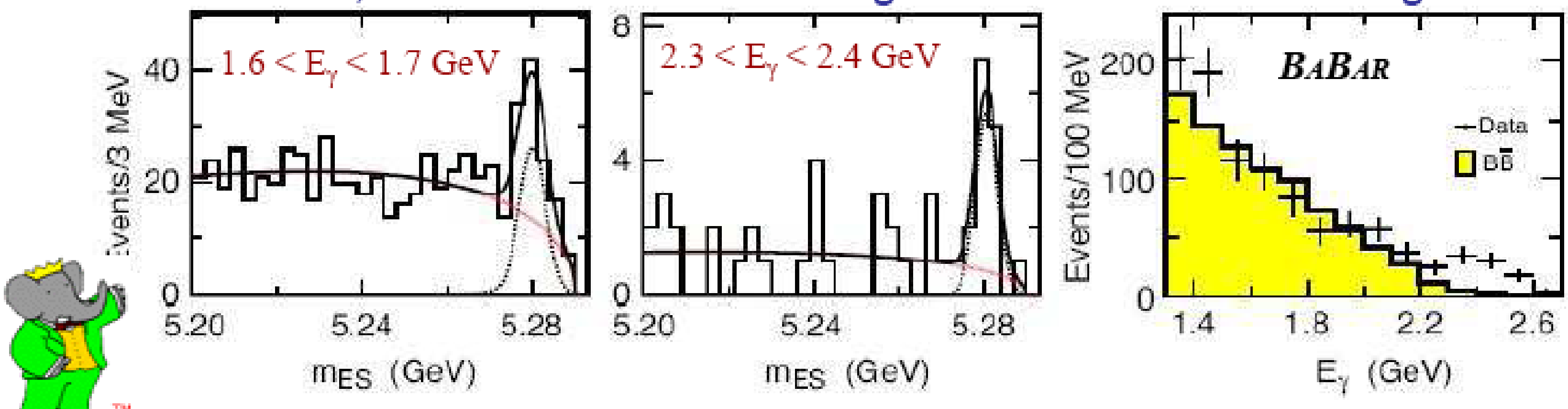



- 210 $fb^{-1}$ ↔ 232 M $B\bar{B}$ pairs
- Fully reconstructs $B \to D^{(*)}Y^{\pm}$
  - $Y^{\pm}$ is a combination of up to 9 pions and kaons.
  - Determines charge and flavor of the signal B.
- From the remaining particles in the event, require an isolated high-energy photon candidate.
- Allows determination of the photon energy spectrum in the rest frame of the signal B meson.
- However, the recoil reconstruction efficiency is low: about 0.3%.

# $B \to s\,\gamma$ Events selection

PRD 77, 051103 (2008)

- Require
  - $m_{ES} > 5.2$ GeV/$c^2$ } Tagged B
  - $|\Delta E| < 60$ MeV
  - Veto if signal photon is consistent with coming from a $\pi^0$ or $\eta$ decay.
  - Use a Fisher discriminant based on event-shape variables to veto $q\overline{q}$ backgrounds.
- Divide the surviving events into 100-MeV-wide bins from 1.3 – 2.7 GeV in photon energy.
- Extract the event yield in each bin using a fit to $m_{ES}$.
  - Fit parameters are allowed some dependence on $E_\gamma$.
- The region below 1.9 GeV is dominated by B backgrounds, so we scale the B events from a Monte Carlo simulation to the data below 1.9 GeV, then subtract the B background from the entire range.



# $B \rightarrow s\,\gamma$ Systematics

PRD 77, 051103 (2008)

- B background modeling
  - Evaluate uncertainty by comparing results with those obtained by varying the Monte Carlo shape:
    - Apply $E_\gamma$-dependent corrections to account for photons coming from $\pi^0$ and $\eta$ mesons.
    - Remaining backgrounds have a roughly linear slope in $E_\gamma$, so vary the slope by a conservative $\pm30\%$.
- Parameterization of $m_{ES}$ fits
  - Vary the dependence of the fit parameters on $E_\gamma$
  - Take the maximum variation in the result as the uncertainty.
- Include relatively smaller uncertainties due to detector response and efficiency related to the assumed $E_\gamma$ shape (model dependence).

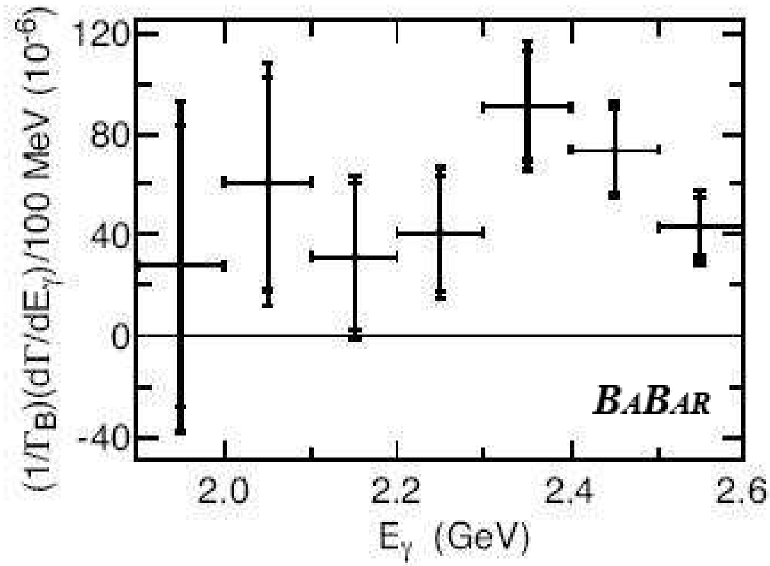
# $B \rightarrow s\,\gamma$ Results

PRD 77, 051103 (2008)

- Measured 119 ± 22 signal events over 145 ± 9 background.
- $\mathcal{B}(B \rightarrow X_s\gamma)$ = $(3.66 \pm 0.85 \pm 0.60) \times 10^{-4}$.
- World-average branching fraction measured by BaBar, Belle, and CLEO:
- $\mathcal{B}(B \rightarrow X_s\gamma)$ = $(3.55 \pm 0.26) \times 10^{-4}$.
  - E. Barberio *et al.* [Heavy Flavor Averaging Group (HFAG) Collaboration], arXiv:0704.3575 [hep-ex].
- Isospin asymmetry for $E_\gamma > 2.2$ GeV

  $\Delta_{0-} = -0.06 \pm 0.15 \pm 0.07$.
- CP Asymmetry for $E_\gamma > 2.2$ GeV

  $A_{CP} = 0.10 \pm 0.18 \pm 0.05$.

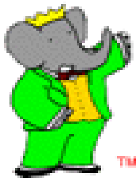



- Spectrum shape yields kinetic scheme parameters for $E_\gamma > 2.0$ GeV
- $m_b = 4.46^{+0.21}_{-0.23}$ GeV
- $\mu_\pi^2 = 0.64^{+0.39}_{-0.38}$ GeV$^2$
- Errors are the theoretical ones from D. Benson, I.I. Bigi, and N. Uraltsev, Nucl. Phys. B **710**, 371 (2005).

# $B \to s\,\gamma$ Conclusions

PRD 77, 051103 (2008)

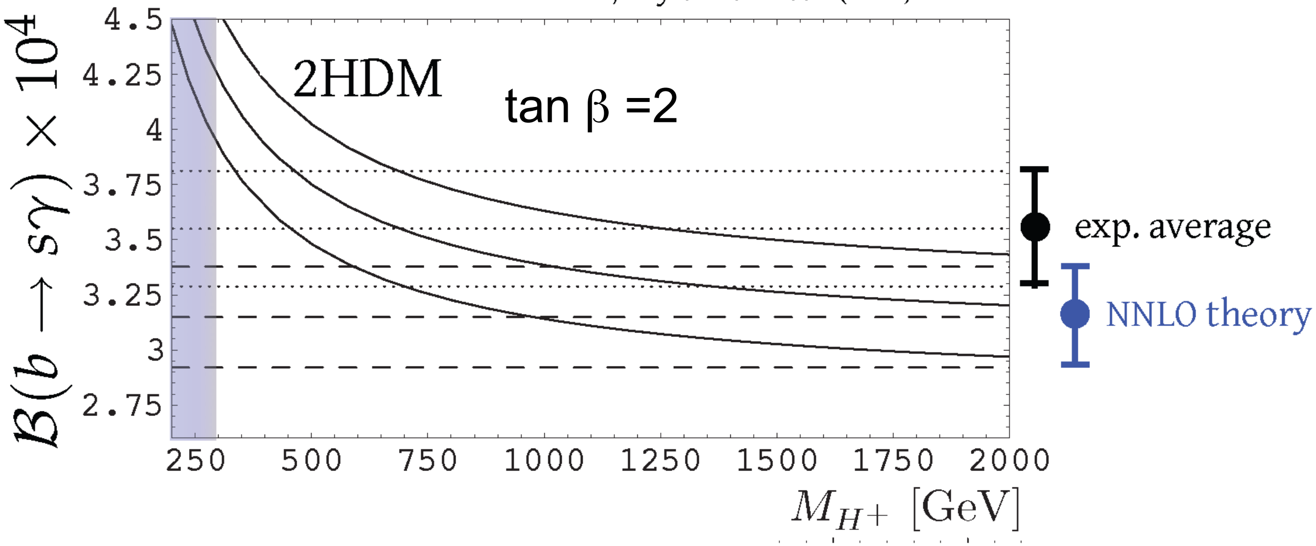
- These measurements test the standard model in all aspects of the $b \to s\,\gamma$ interaction
  - Rate, CP asymmetry, isospin asymmetry, photon spectrum, and photon polarization.
- Measured values are consistent with the standard model within their uncertainties.
- $B \to X_s\gamma$ Recoil technique
  - Much lower background than standard inclusive techniques.
  - Allows determination of $b \to s\,\gamma$ photon spectrum in the B rest frame.
  - Spectrum shape relates to b quark kinematics inside the B meson.

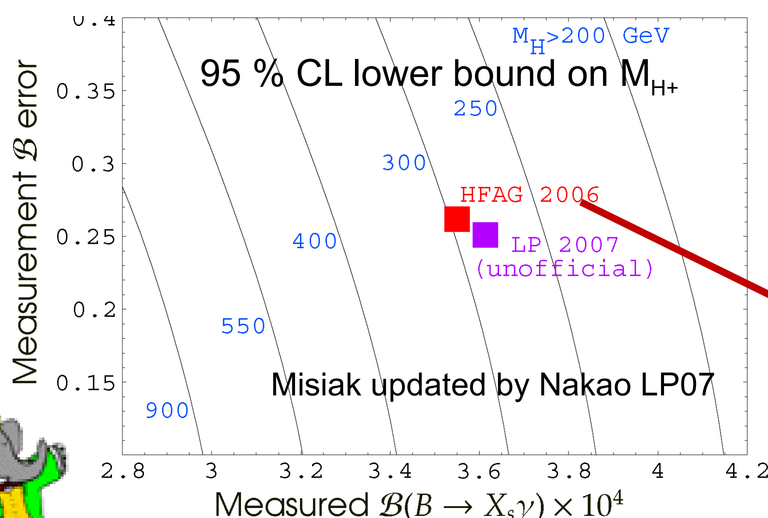


# $B \to s\gamma$ Charged Higgs Mass Implications

77, 051103 (2008)

Misiak etal, Phys.Rev.Lett. 98 (2007) 022002

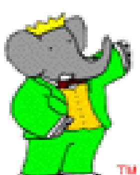



$b \to s\gamma$ gives a lower limit on a type-II Higgs for any tan β

$M_{H+}$ > 295 GeV (95%CL)

$M_{H+}$ ~ 650 GeV



# Search of New Physics in rare B decays including leptons and/or neutrinos at BaBar

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