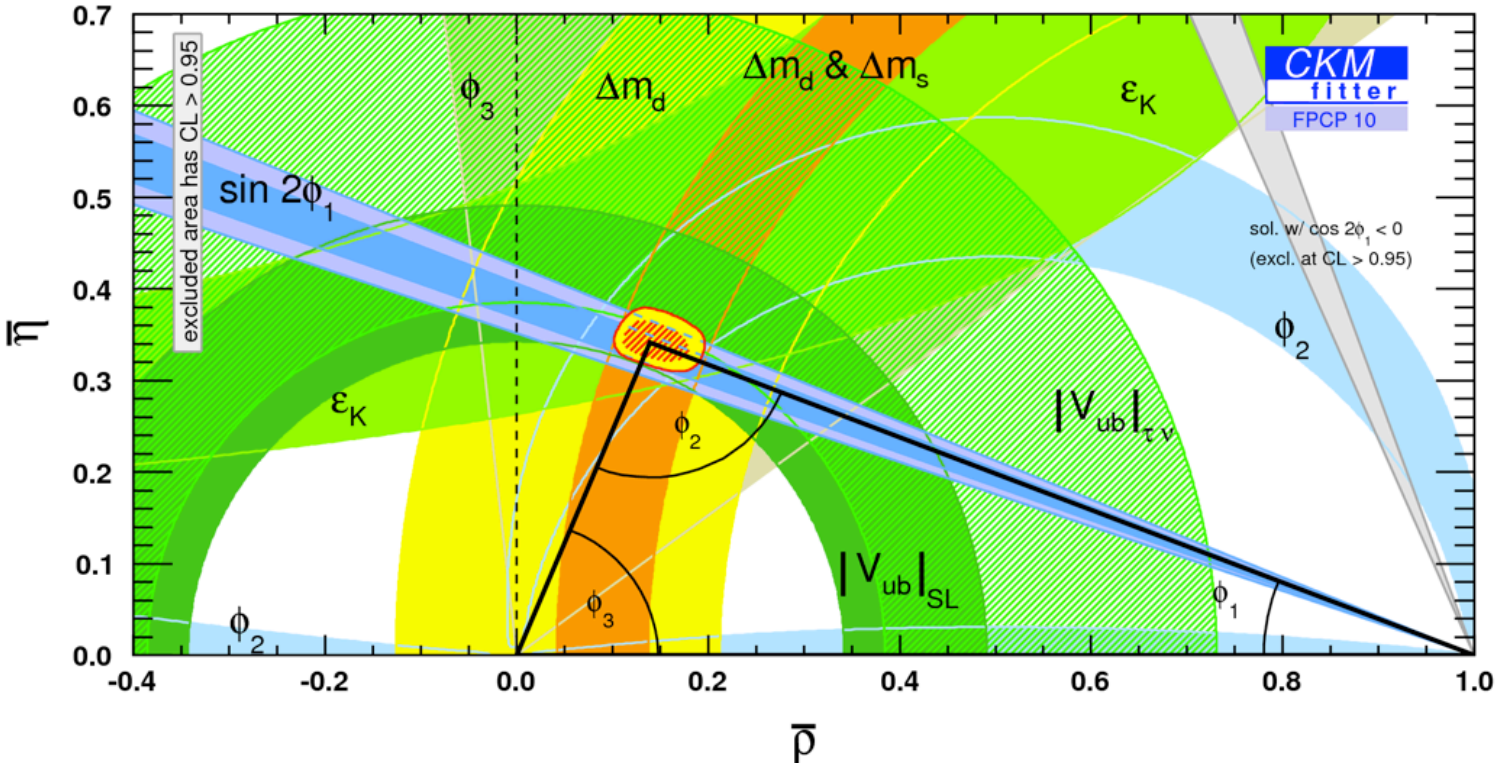
Leptonic and semileptonic B decays at the B-factories

E.Barberio, University of Melbourne

Blois 2010

New physics?

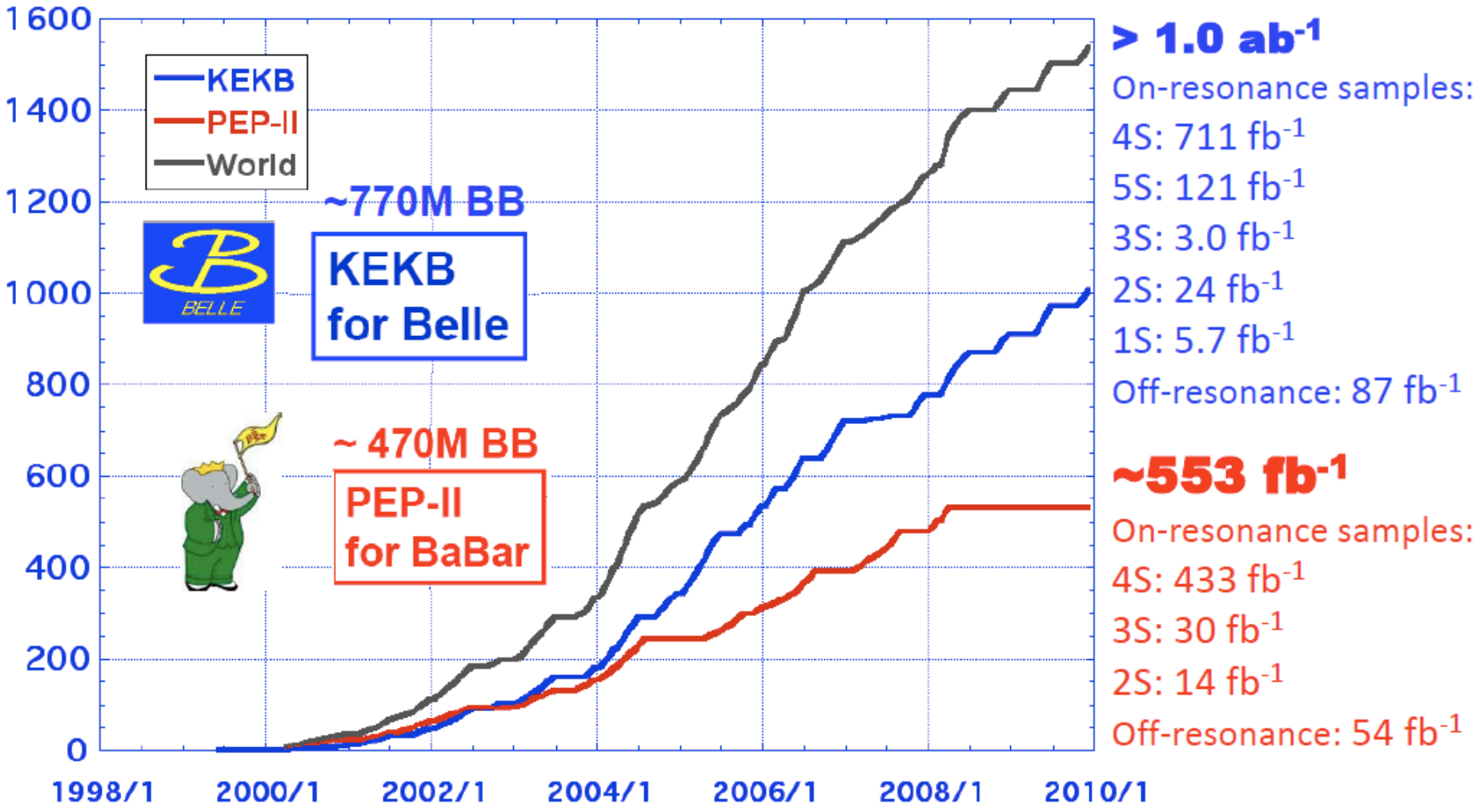
Exploit the unitarity constraint to look for new physics



Precision era where new physics may appear as a few percent disagreement:

- Large new physics contributions to penguins would have been seen
- New physics contributions to decays such as $B \to \tau\ \nu$ are still open

Integrated luminosity



> 1.0 ab^{-1}

On-resonance samples:

4S: 711 fb^{-1}

5S: 121 fb^{-1}

3S: 3.0 fb^{-1}

2S: 24 fb^{-1}

1S: 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

~553 fb^{-1}

On-resonance samples:

4S: 433 fb^{-1}

3S: 30 fb^{-1}

2S: 14 fb^{-1}

Off-resonance: 54 fb^{-1}

leptonic and semileptonc decays

I. Leptonic decays

$B \to \tau \ \nu$

$B \to \mu \ \nu$

$B \to e \ \nu$

II. Semileptonic decays

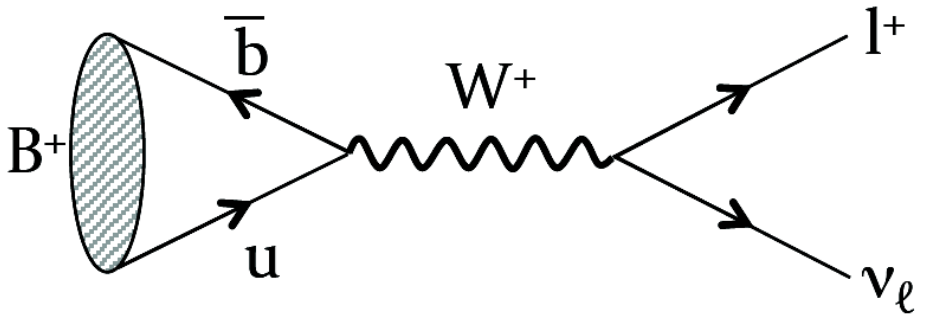
$B \to D^{(*)} \tau \ \nu$

III. Radiative leptonic decays

$B \to \gamma \ l \ \nu$

leptonic decays

- **Standard Model:**
  Helicity suppressed
  - $B \to \tau\bar{\nu} \approx 10^{-4}$
  - $B \to \mu\bar{\nu} \approx 10^{-7}$
  - $B \to e\bar{\nu} \approx 10^{-12}$



Theoretically clean:
small hadronic effects

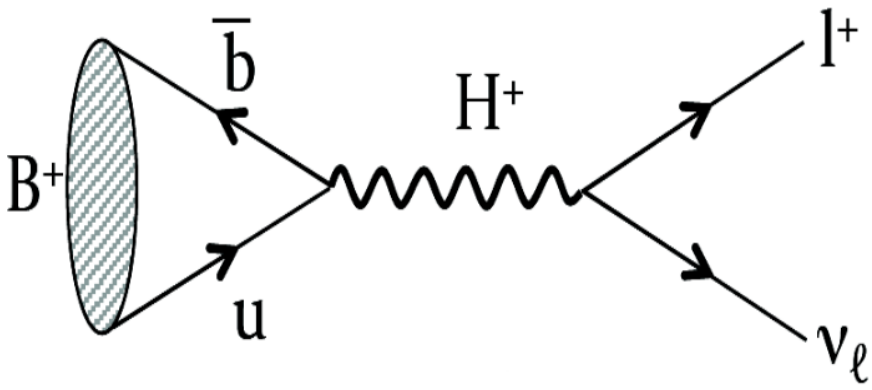
$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B}{8\pi} m_\ell^2 (1 - \frac{m_\ell^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

From measurements + theory
$|V_{ub}|=(3.53 \pm 0.15)\times 10^{-3}$ [HFAG summer 2010]

From lattice f_B = 190 ± 13 MeV [HPQCD arXiv:0902.1815]

Tauonic decays

New Physics: charge Higgs mediation is NOT helicity suppressed



Model dependent predictions:

$$\mathcal{B}(B \to \ell\nu)_{2HDM} = \mathcal{B}(B \to \ell\nu) \times (1 - \tan^2\beta \frac{m_B^2}{m_H^2})^2$$ **Type II Higgs doublet model**

$$\mathcal{B}(B \to \ell\nu)_{SUSY} = \mathcal{B}(B \to \ell\nu) \times (1 - \frac{\tan^2}{1 + \eta_0 \tan\beta} \frac{m_B^2}{m_H^2})^2$$

W.S. Hou, Phys.Rev.D., 48 (1993) 2342

Akeroyd,Recksiegel J.Phys.G29:2311-2317, 2003

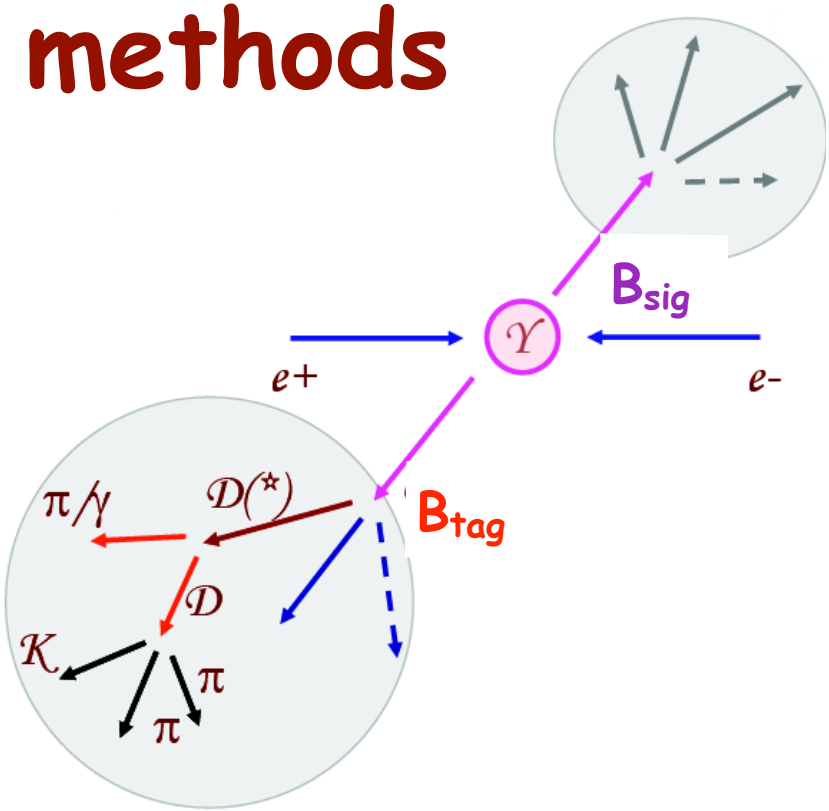
Amplitude of charged Higgs diagram proportional to $m_b\, m_\tau \tan^2\beta$

Enhancement for large $\tan\beta$ or small m_{H^+}

Tagging methods

Fully reconstruct a B (B_{tag}):

Remove the corresponding particles from the event to reduce combinatorial background



I. Hadronic tag

More pure, less efficient ~0.2%

No "missing" energy

II. Semileptonic tag

Less pure, more efficient ~1.5%

ν gives "missing" energy

B decay of interest (B_{sig}): signal from remaining energy distribution

Challenge: neutrinos in τ and l decays

$B \to \tau \nu$ hadronic tag

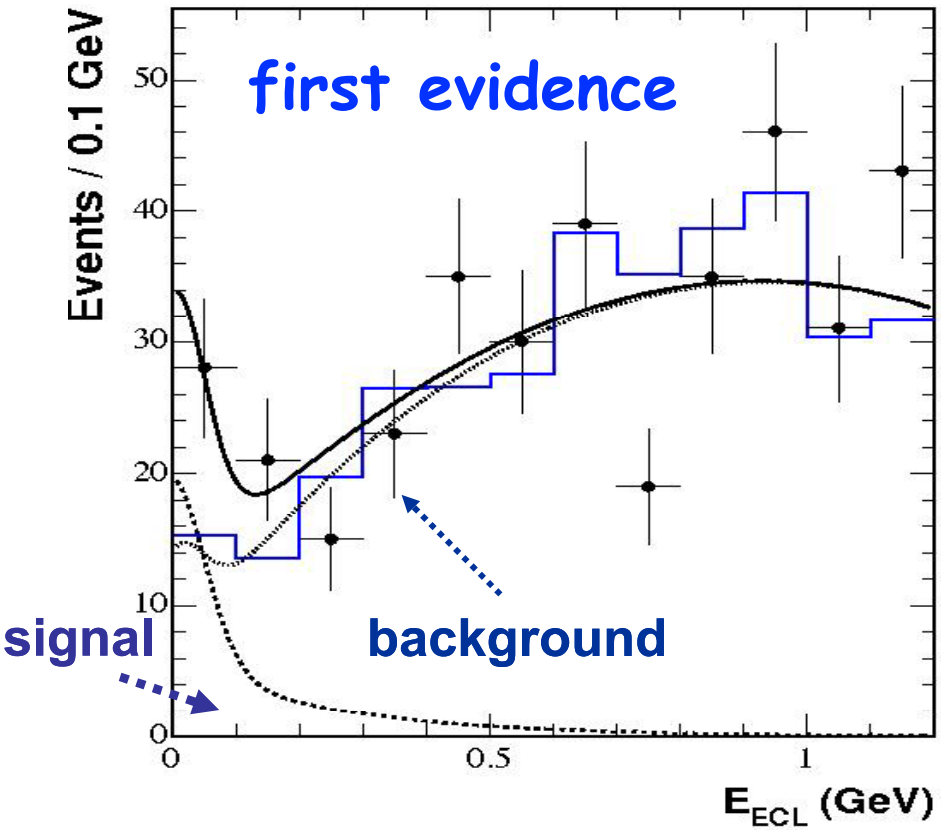
Decay modes: $e\nu\nu$, $\mu\nu\nu$, 1,2 and 3 prongs

449M BB

Signal: e μ $\pi^{-/+}$ + nothing

Sum of neutral energy not associated to B_{tag} or π^0 from τ decays

$17.2^{+5.3}_{-4.7}$ signal events

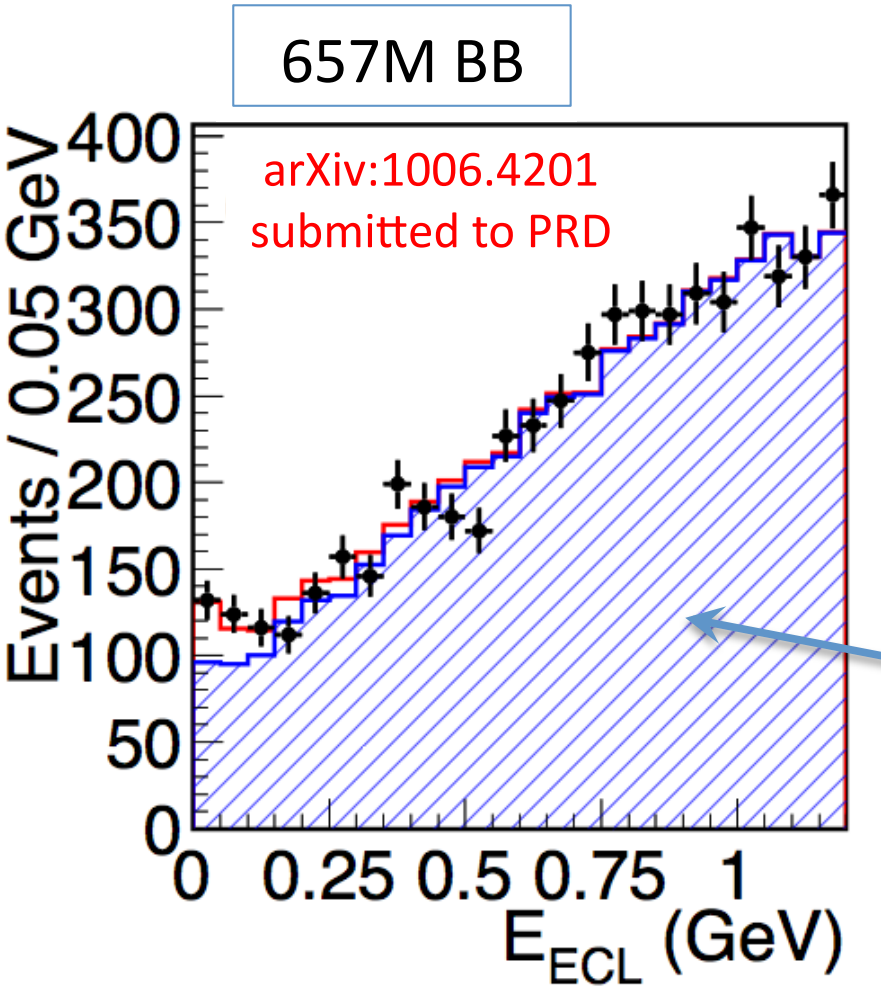


$Br(B \to \tau \nu) = (1.79^{+0.56}_{-0.49(stat)}{}^{+0.46}_{-0.51(syst)}) \times 10^{-4}$

$3.5\,\sigma$ significance including systematics

PRL 97, 251802 (2006)

$B \to \tau \nu$ semileptonic tag



Tag-side

$B^+ \to D^{*0} l^+ \nu$, $B^+ \to D^0 l^+ \nu$ with fully reconstructed D^{*0} and D^0

Signal-side:

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

EM calorimeter (E_{ECL}) signal shape calibrated with double semileptonic events

143^{+36}_{-35} signal events

$Br(B \to \tau \nu) = (1.54^{+0.38}_{-0.37(stat)}{}^{+0.29}_{-0.31(syst)}) \times 10^{-4}$

$3.6\,\sigma$ significance including systematics

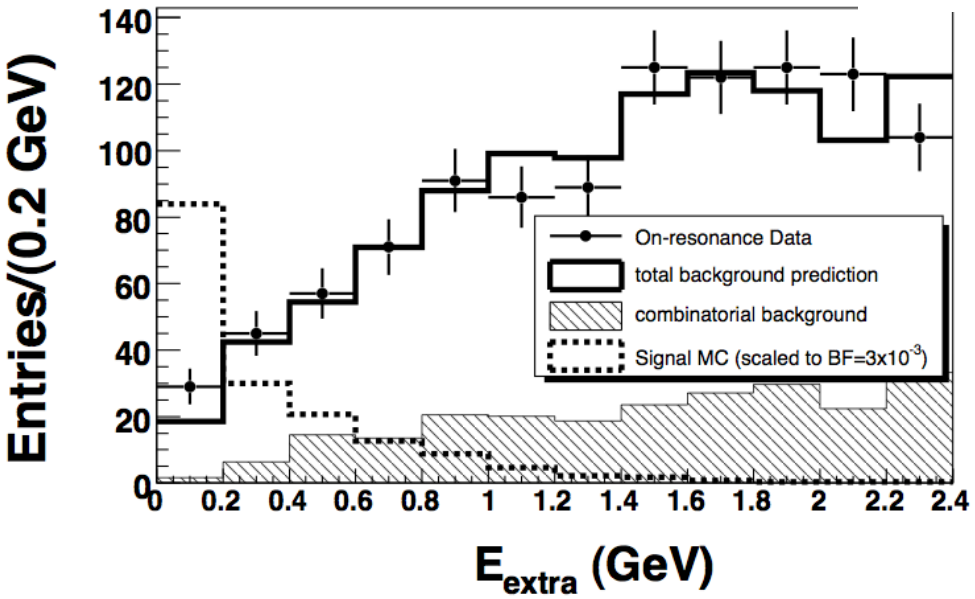
$B \to \tau \nu$ BaBar results

PRD 77, 011107(2008)
PRD 81, 051101 (2010)

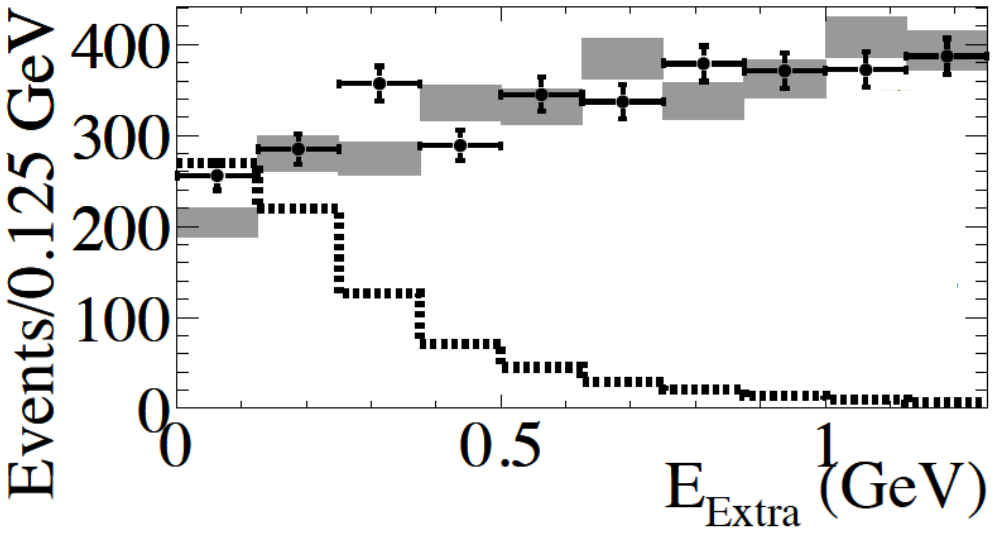
383M BB

459M BB

Hadronic tag



Semileptonic tag



$Br(B \to \tau \nu) = (1.8^{+0.9}_{-0.8(stat)} \pm 0.4_{(bck)} \pm 0.2_{(syst)}) \times 10^{-4}$

$2.2\,\sigma$ excess

$Br(B \to \tau \nu) = (1.7 \pm 0.8_{(stat)} \pm 0.2_{(syst)}) \times 10^{-4}$

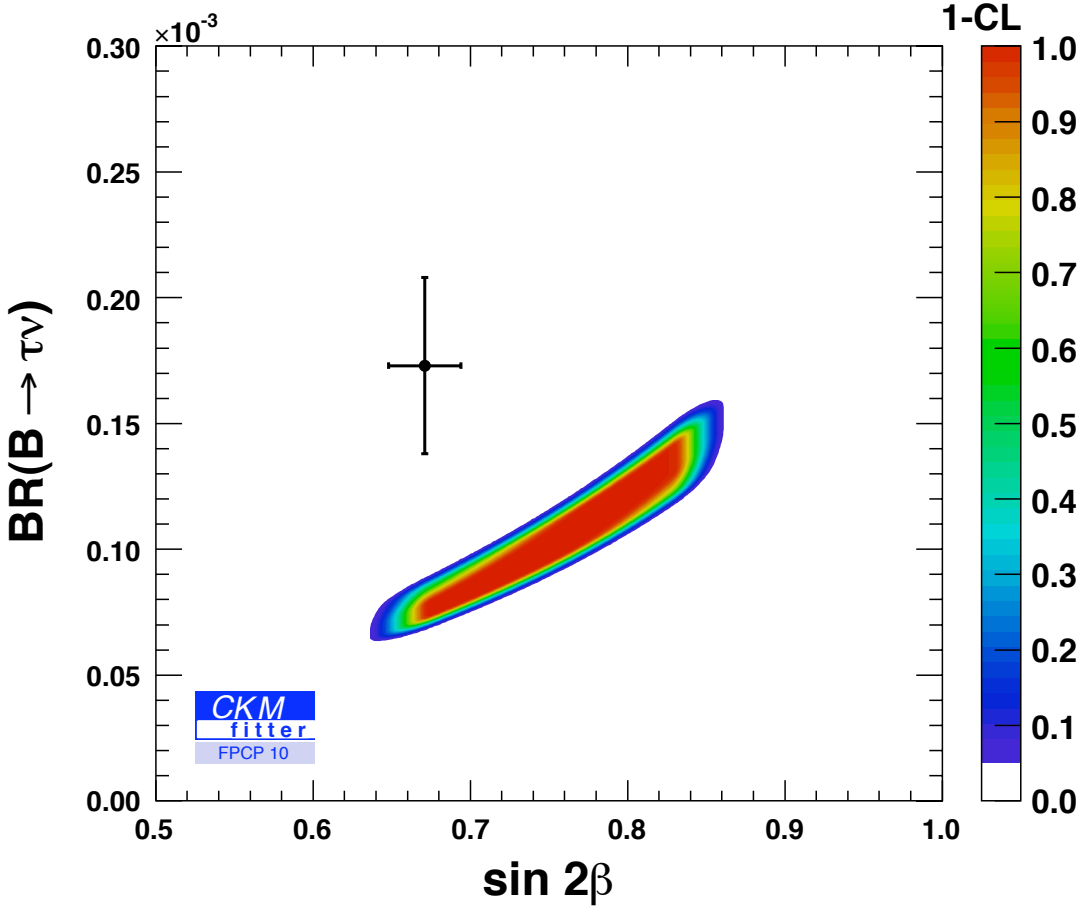
$2.4\,\sigma$ excess

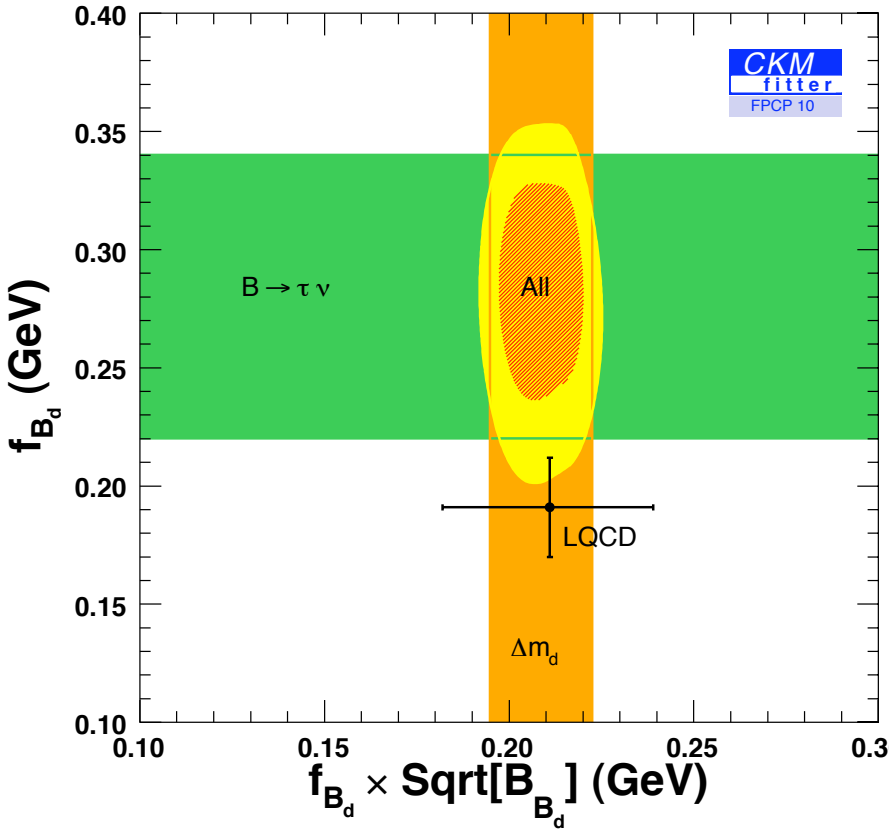
$B \to \tau \nu$ constraints on new physics

Naïve world average: $Br(B \to \tau \nu) = (1.73 \pm 0.35) \times 10^{-4}$

CKM Fitter 2010: $Br(B \to \tau \nu) = (0.845^{+0.103}_{-0.096}) \times 10^{-4}$

2.6σ between measured BR and CKM fit without $B \to \tau \nu$ and V_{ub}





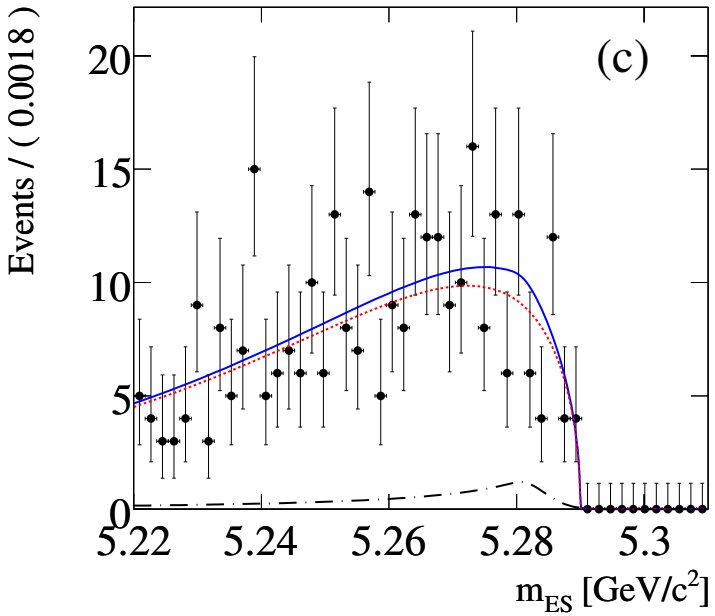
B $\rightarrow e/\mu\,\nu$

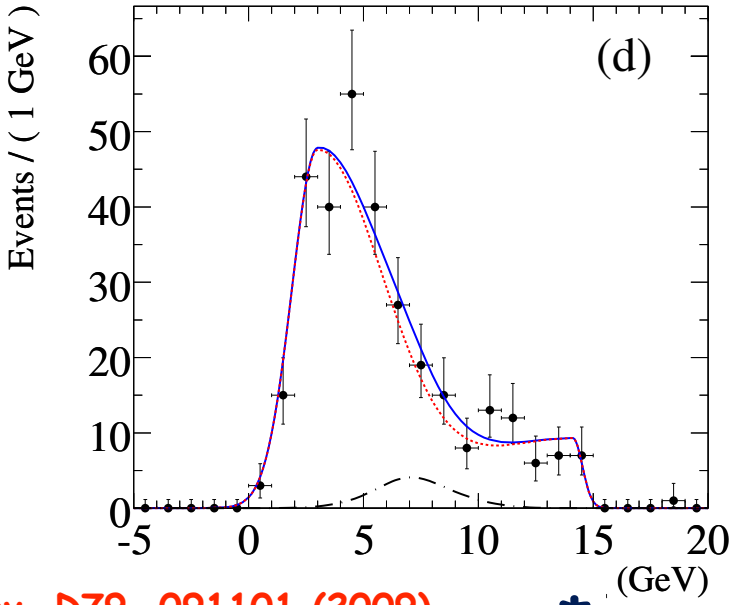
Very rare → inclusive measurement
High efficiency but high background

Signal: single monochromatic e/μ in B rest frame

signal extracted from a simultaneous fit to the momentum in the CM frame (p_l^*) and 4-momentum of everything else in the event (m_{ES}).

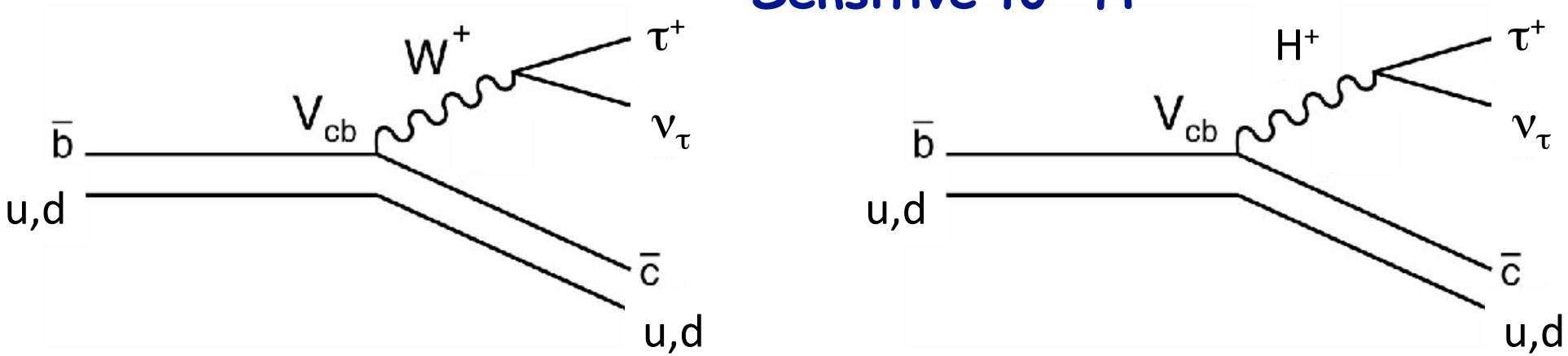
- $B \rightarrow e\bar{\nu}$
  - $\mathcal{B}$ at 90% CL $< 1.9 \times 10^{-6}$
  - $\mathcal{B}$ at 90% CL $< 0.98 \times 10^{-6}$
- $B \rightarrow \mu\bar{\nu}$
  - $\mathcal{B}$ at 90% CL $< 1.0 \times 10^{-6}$
  - $\mathcal{B}$ at 90% CL $< 1.7 \times 10^{-6}$





Phys. Rev. D79, 091101 (2009)
Phys. Lett. B647, 67 (2007)

$B \to D^{(*)} \tau \nu$ and new Physics



Theory uncertainties

- Dependence from form factors but no dependence on f_B
- $|V_{cb}|$ cancels in the ratio $Br(B \to D^{(*)} \tau \nu)/Br(B \to D^{(*)} l \nu)$

- 3 body decays hence more observables:
  q^2-distribution, τ polarization, D* polarization

First observation: $B^0 \to D^{*-} \tau^+ \nu$

PRL 99, 191807 (2007)

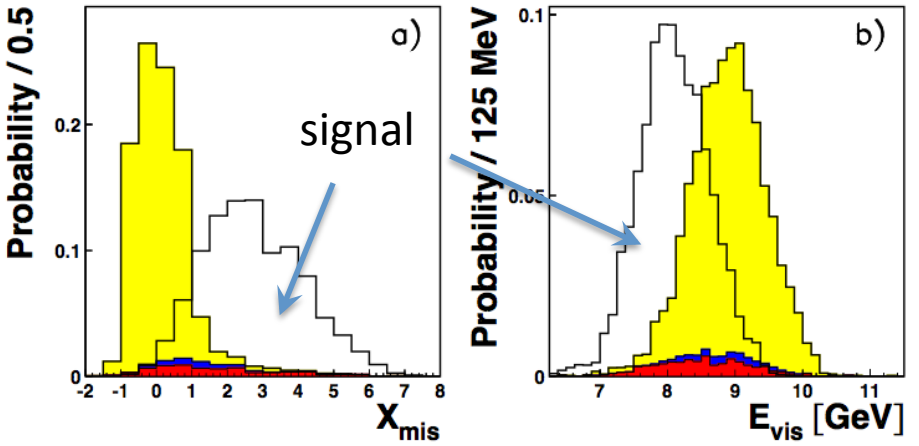
Signal

$D^{*+} \to D^0 \pi^+$ with $D^0 \to K^- \pi^+$, $K^- \pi^+ \pi^0$ and $\tau^+ \to e^+ \nu \nu$, $\pi^+ \nu$

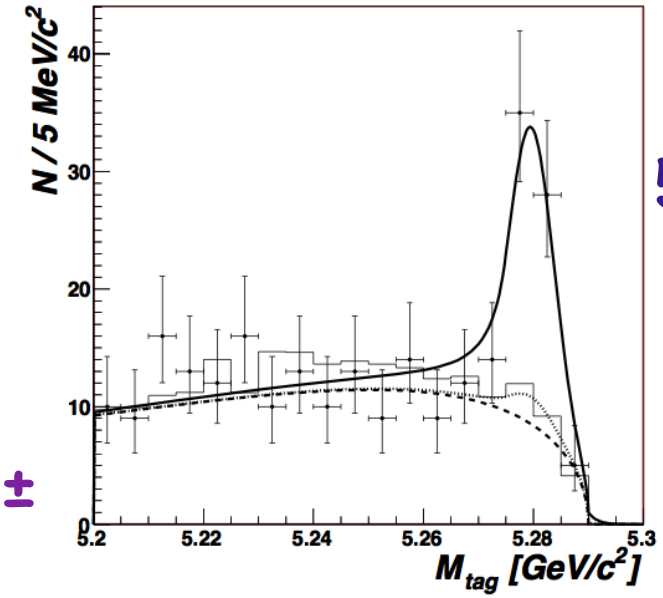
tag side

$P_{tag} = \Sigma P_i$, $E_{tag} = \Sigma E_i$

$M_{tag}^2 = E_{beam}^2 - P_{tag}^2$



$$X_{\rm mis} \equiv (E_{\rm mis} - |\mathbf{p}_{D^*} + \mathbf{p}_{e/\pi}|)/\sqrt{E^2_{\rm beam} - m^2_{B^0}}$$



535M BB

60^{+12}_{-11} signal events

$5.2\,\sigma$ significance

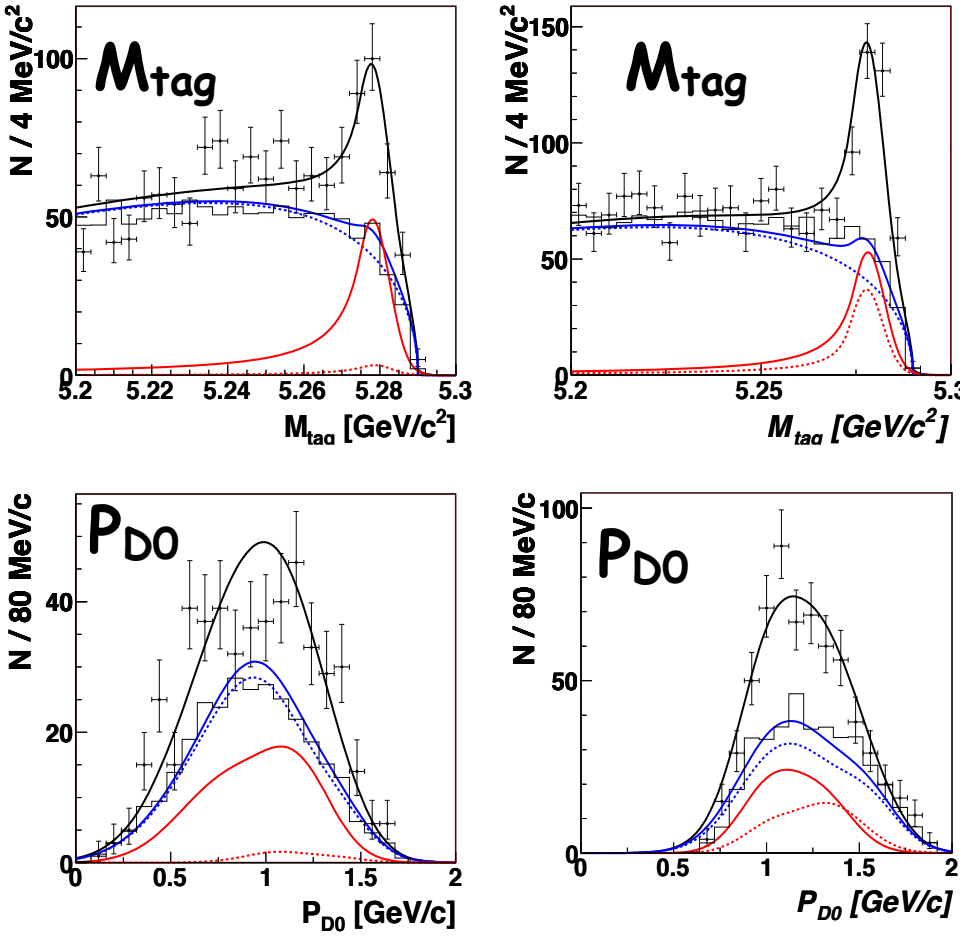
$Br(B^0 \to D^{*-} \tau^+ \nu) = (2.02^{+0.40}_{-0.37(stat)} \pm 0.37_{(syst)})\%$

$B^+ \to D^{*0} \tau^+ \nu$

Extension of the previous analysis to B^+

657M BB

$B^+ \to D^{*0} \tau^+ \nu_\tau$ $B^+ \to D^0 \tau^+ \nu_\tau$



Large D^{*0}/D^0 cross feed: simultaneous extraction of D^{*0} and D^0 form fit to M_{tag} and P_{D0}

$Br(B^+ \to D^{*0}\tau^+\nu) =$
$(2.12^{+0.28}_{-0.27}(stat) \pm 0.29(syst))\%$
446^{+58}_{-56} events (8.1σ significance)

$Br(B^+ \to D^{0}\tau^+\nu) =$
$(0.77 \pm 0.22(stat) \pm 0.12(syst))\%$
146^{+42}_{-41} events (3.5σ significance)

First evidence

arXiv:1005.2302v1 [hep-ex]

$B^{+/0} \to D^{*-} \tau^+ \nu / D^{*0} \tau^+ \nu$

232M BB

Hadronic tag

Signal has large missing mass (m_{miss})

Simultaneous extraction of D and D*

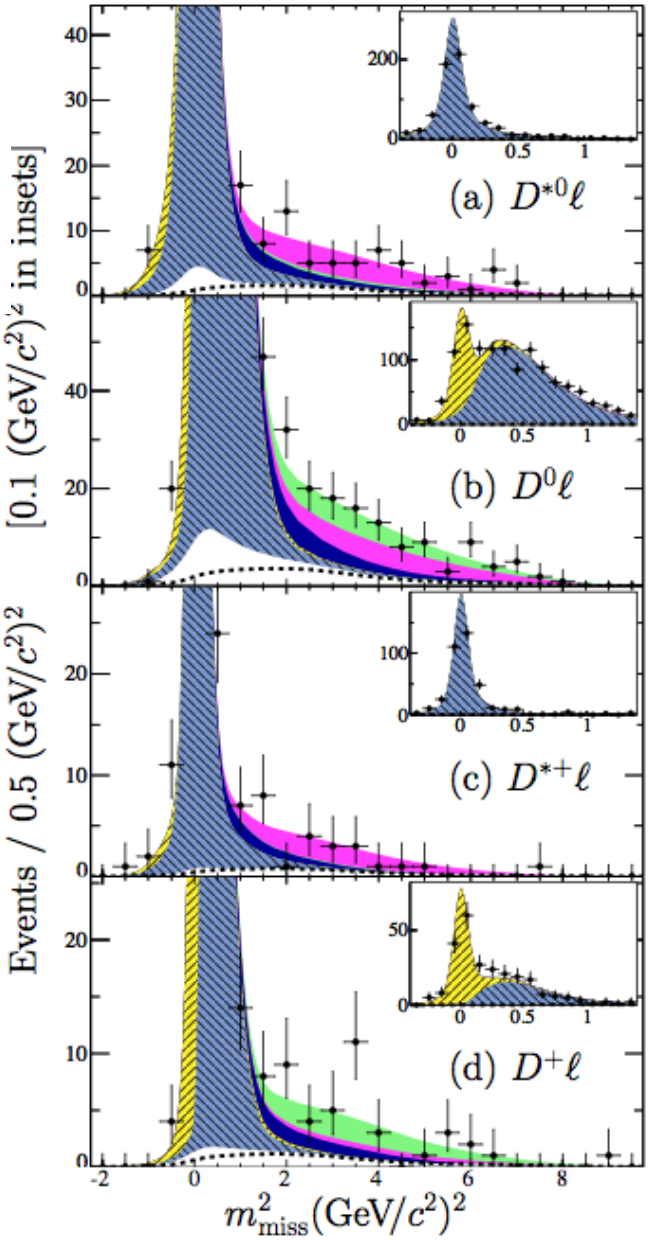
$Br(B^+ \to D^0 \tau^+ \nu)$ =
(0.67 ± 0.37(stat) ± 0.11(syst) ± 0.07(norm))%
35.6 ± 19.4 events (1.8σ significance)

$Br(B^+ \to D^{*0} \tau^+ \nu)$ =
(2.25 ± 0.48(stat) ± 0.22(syst) ± 0.17(norm))%
92.2 ± 19.6 events (5.3σ significance)

$Br(B^0 \to D^- \tau^+ \nu)$ = First evidence
(1.04 ± 0.35(stat) ± 0.15(syst) ± 0.10(norm))%
23.3 ± 7.8 events (3.3σ significance)

$Br(B^0 \to D^{*-} \tau^+ \nu)$ =
(1.11 ± 0.51(stat) ± 0.04(syst) ± 0.04(norm)%
15.5 ± 7.2 events (2.7σ significance)

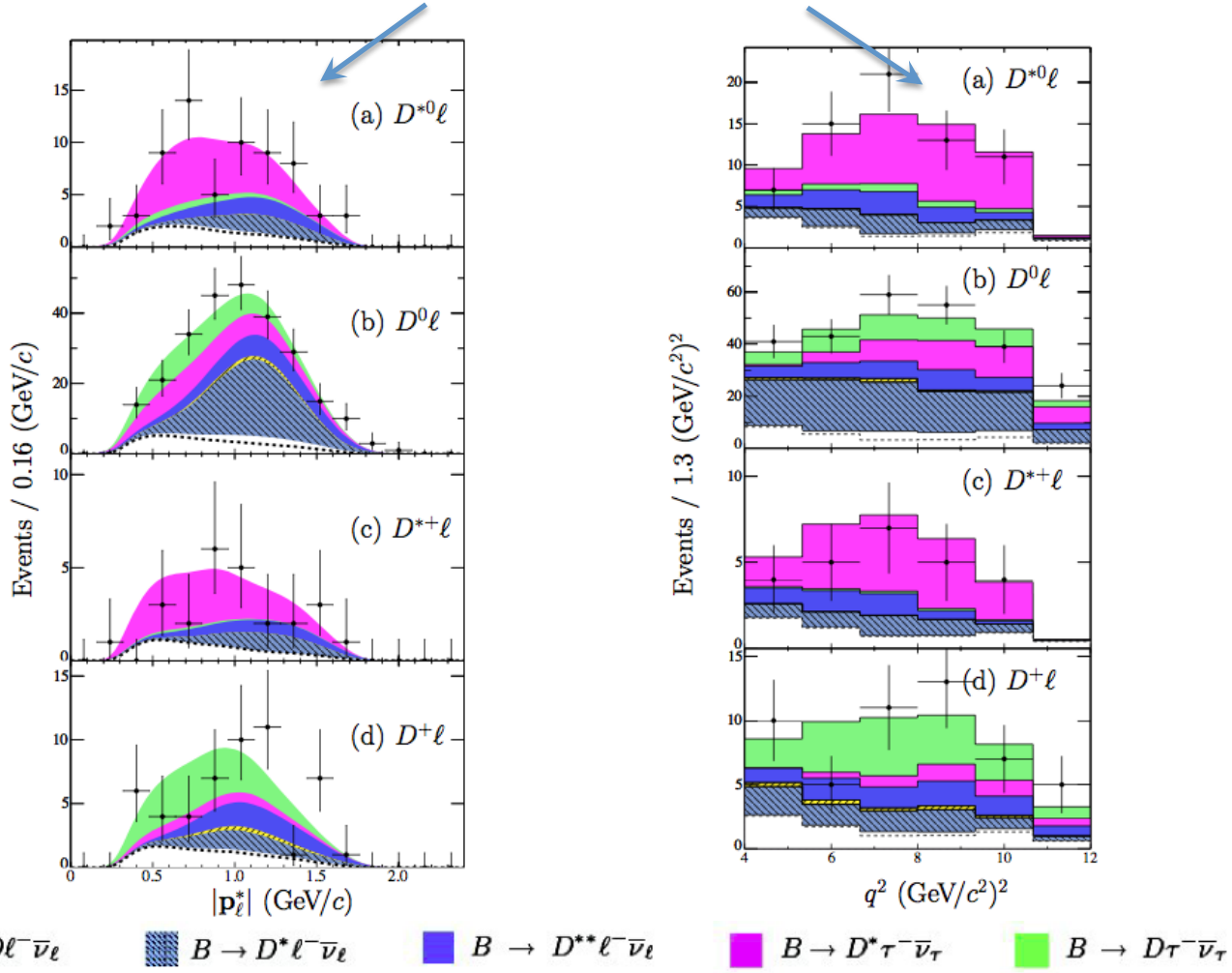
PRL 100, 021801 (2008)
PRD 79, 092002 (2009)



Signal shown in light green resp. magenta

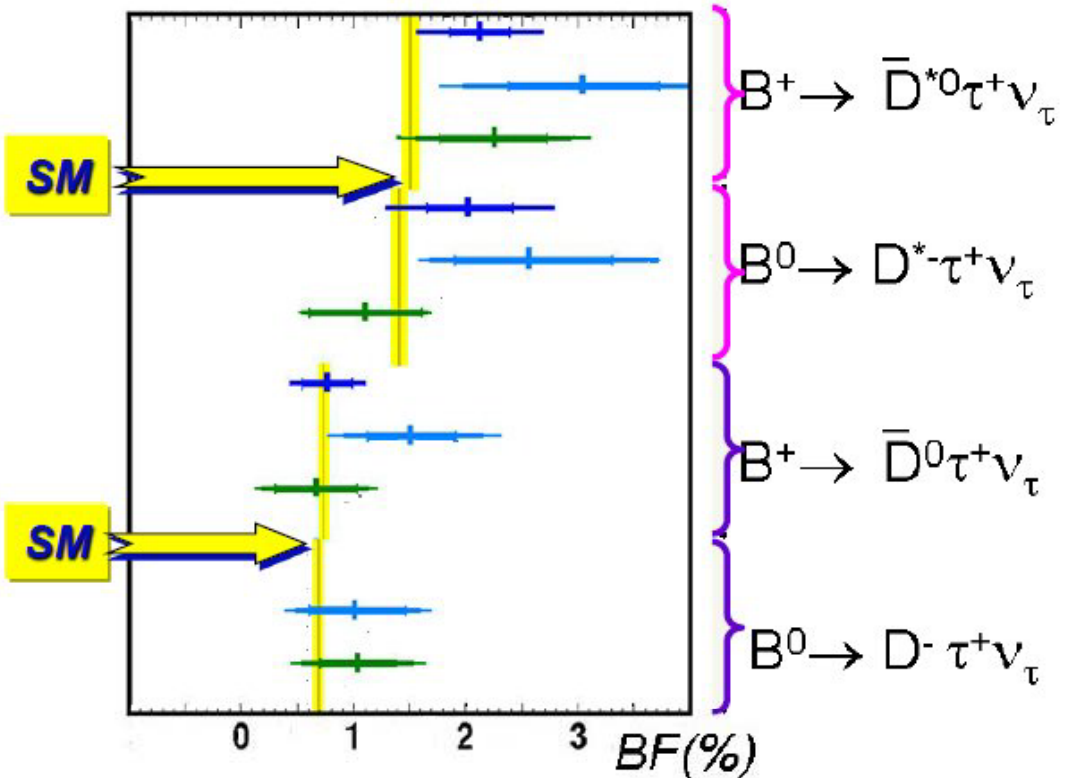
$B^{+/0} \to D^{*-} \tau^+ \nu / D^{*0} \tau^+ \nu$

Lepton momentum and q^2 distributions

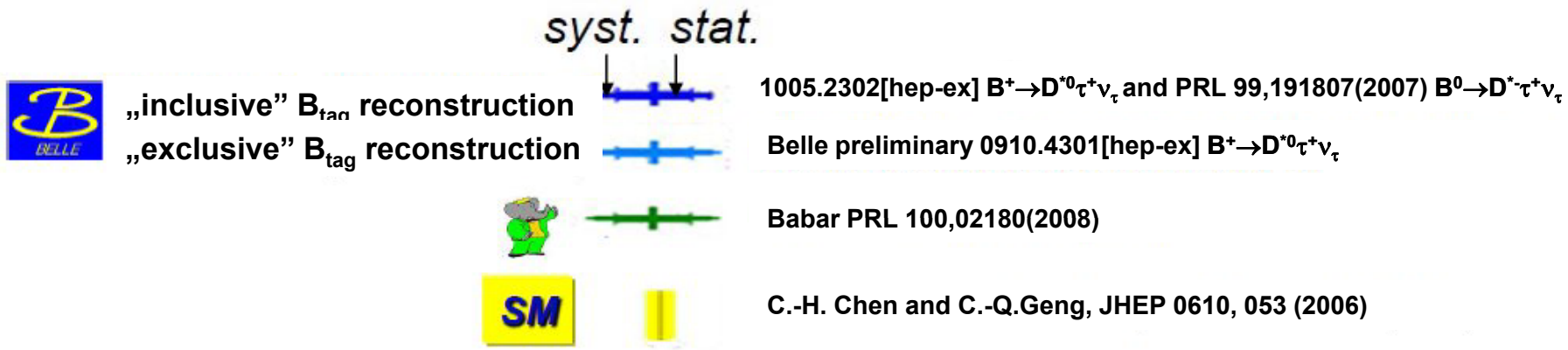


First measurement of decay distribution

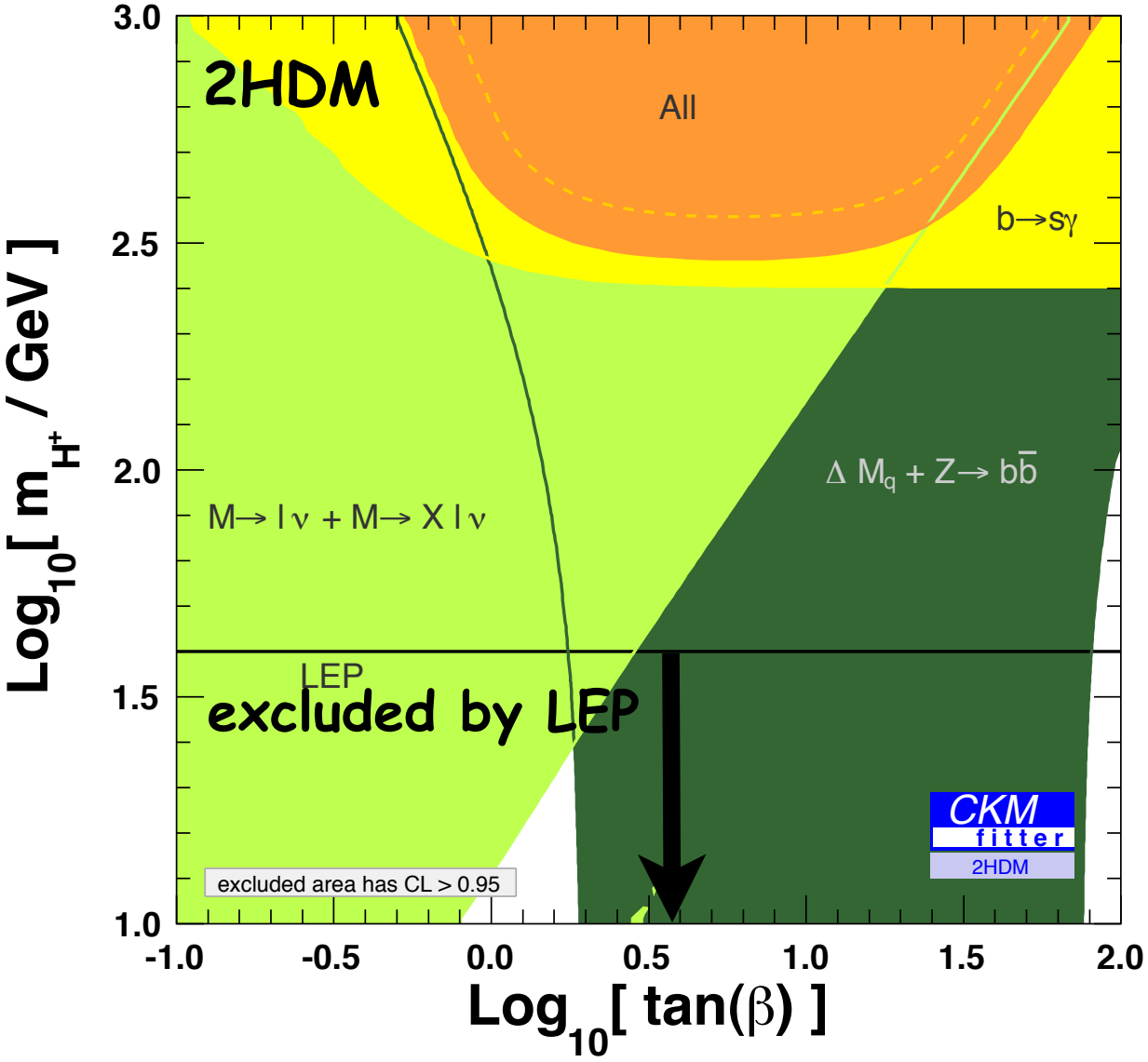
E. Barberio



Overlap between „inclusive" and „exclusive" B_{tag} reconstruction Belle analysis is negligible (~.2%)



Global constraints on m_{H^+} and $\tan\beta$ from all observables



m_{H^+}>316 GeV @ 95% CL

m_{H^+}>78.6 GeV @ 95% CL
[LEP for any value of tan β]

http://arxiv.org/pdf/0907.5135

Summary

- Tauonic and semitauonic decays
  Well established but tension with sin(2β)

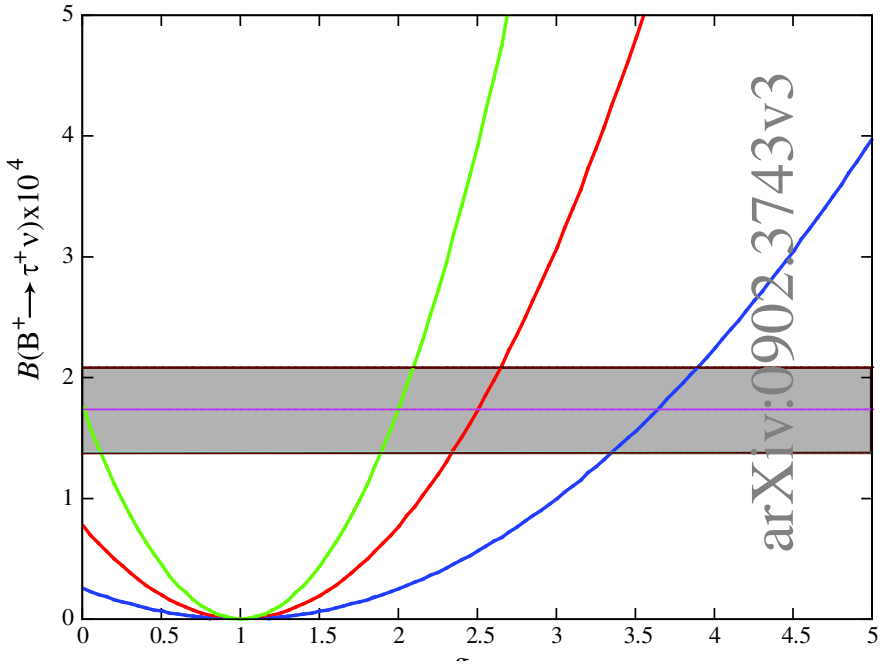
- B $\to \mu\,\nu$ Upper limit ...but at the edge of SM
- B $\to e\,\nu$ Upper limit
- B $\to \gamma\, l\,\nu$ Upper limit ...but at the edge of SM

All contribute to a stringent limit on m_{H+}

$B \to \tau \nu$ constraints on new Physics

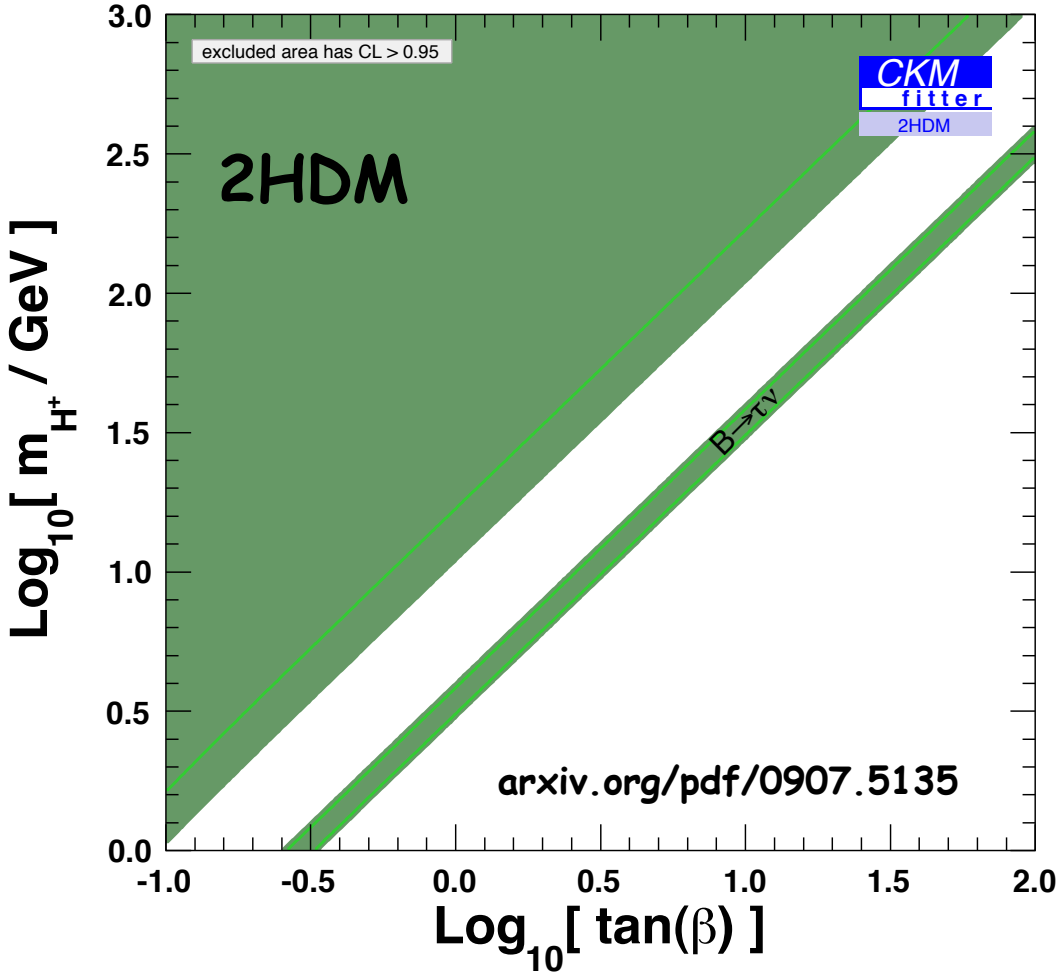
Naïve world average: $Br(B \to \tau \nu) = (1.73 \pm 0.35) \times 10^{-4}$

SM value: $Br(B \to \tau \nu) = (1.20 \pm 0.25) \times 10^{-4}$

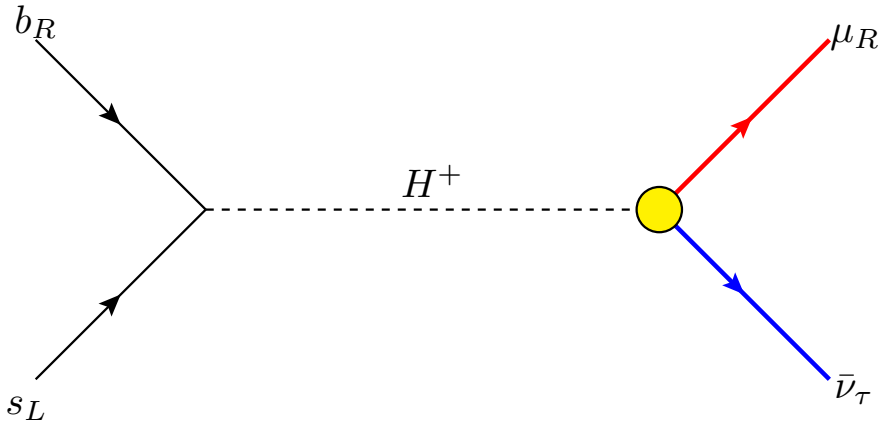


effective scalar coupling g_s

$$\frac{\mathcal{B}(B \to \tau\nu)}{\mathcal{B}(B \to \tau\nu)|_{SM}} = |1 - g_s|^2$$



Lepton Flavour Universality



.arge violations of LF universality
vithin the MSSM.

For large $\tan\beta$

$\Gamma(B\to\mu^+\nu)_{exp} = \Gamma(B\to\mu^+\nu_\mu)+\Gamma(B\to\mu^+\nu_e)+\Gamma(B\to\mu^+\nu_\tau)$

$\Gamma(B\to\mu^+\nu_\mu)$ = SM

$\Gamma(B\to\mu^+\nu_e) \approx 0$

$\Gamma(B\to\mu^+\nu_\tau)_\propto$ scalar LFV amplitude

Experimental probe out of reach of current B-factories:

$R\tau\mu = \Gamma B\to\mu\nu / \Gamma B\to\tau\nu \sim 10\% R\tau\mu,SM$

$R\tau e = \Gamma B\to e\nu / \Gamma B\to\tau\nu \sim 10^3 R\tau e,SM$

G.Isidori, P.Paradisi, Phys.Lett.B 639,499