B decays with neutrinos and implications on NP models

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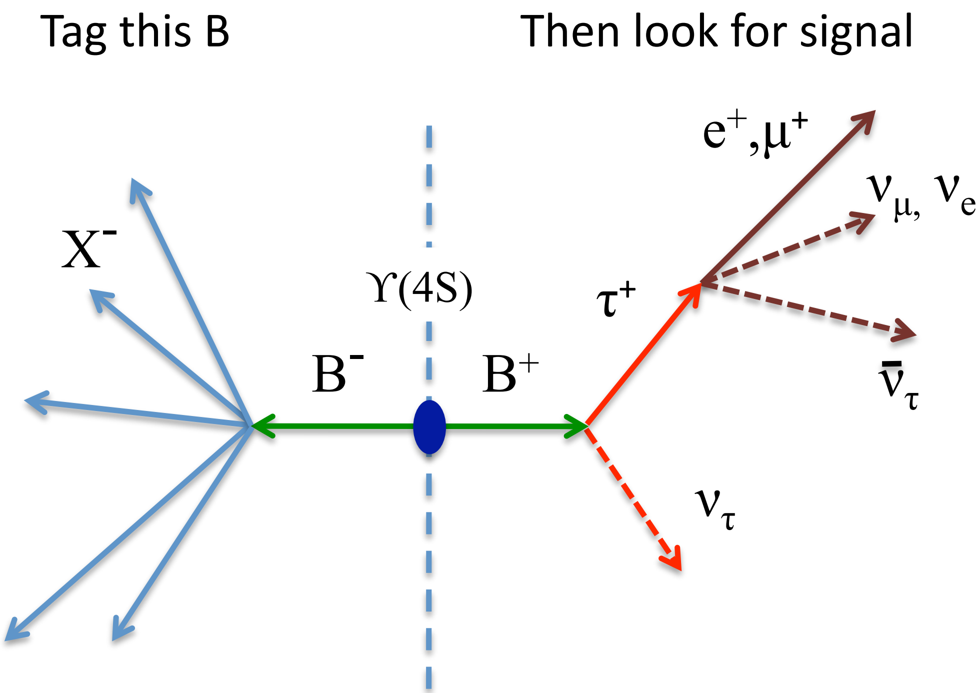
Outline

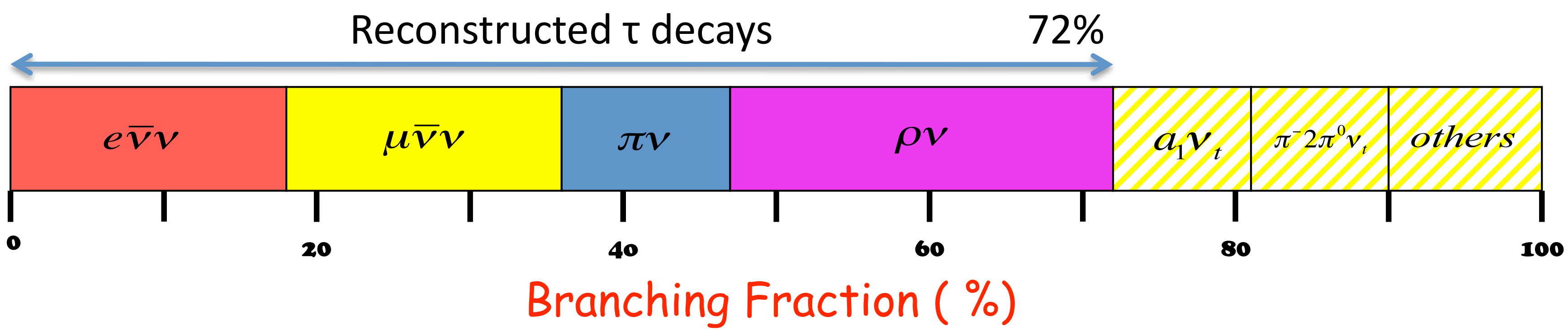
- Description of the tagging method
- Leptonic B decays
  - Experimental status
  - Implications on NP models (Charged Higgs search)
  - Extrapolation of Super Flavour Factories sensitivity
- $b \rightarrow s \nu \nu$ decays
  - Experimental status
  - Implication on NP models
  - Extrapolation of Super Flavour Factories sensitivity

Tagging method

Tagging method

- Weak signal signature
  - Decay with missing momentum (many neutrinos in the final state)
  - Lack of kinematics constraints in final state
- background rejection improved identifying the companion B
- Look for signal in the rest of the event
  - Expect to find nothing more than visible signal decay products and no extra activity in the calorimeter

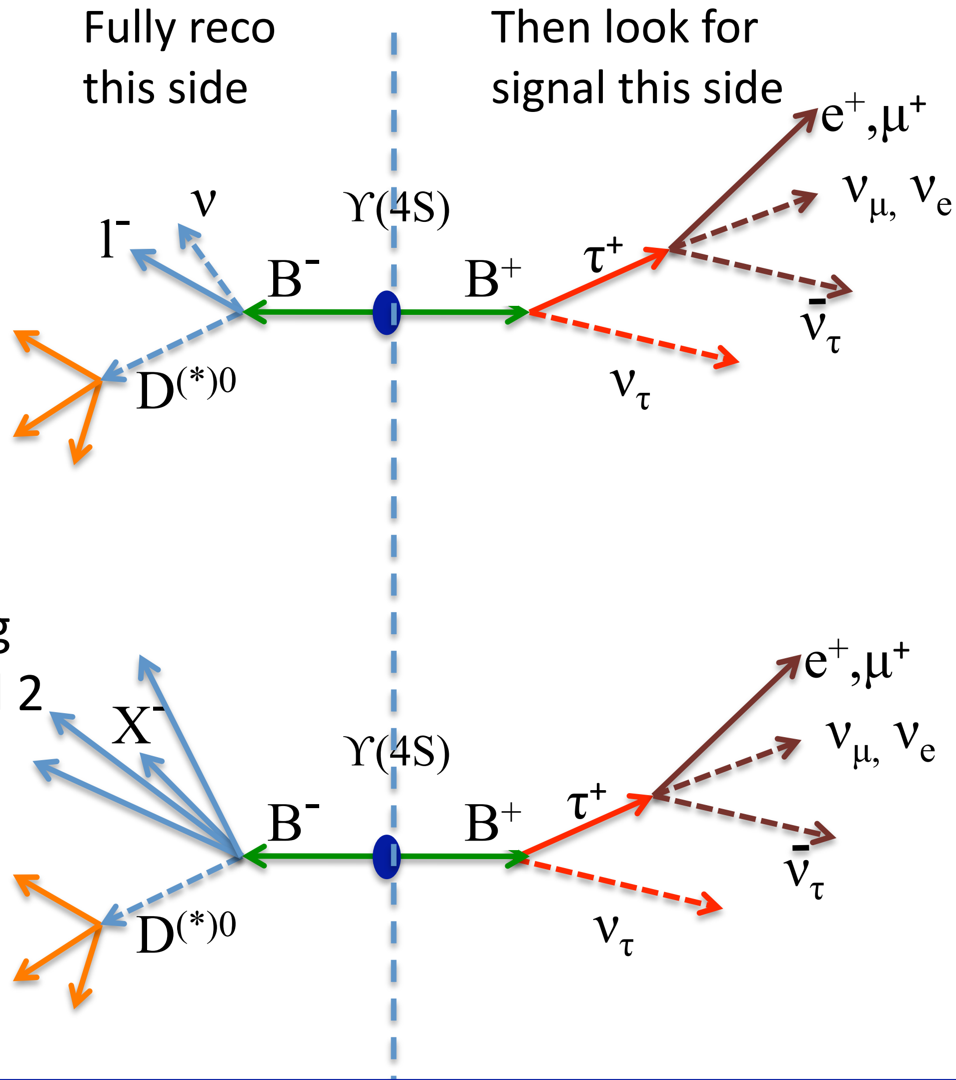




Fully reconstructed hadronic and semileptonic modes

- Semileptonic B decays
  - $B \rightarrow D^{*} l \nu$
  - PRO: Higher efficiency ε_{tag} ~ 1.5%
    CON: more backgrounds, B momentum unmeasured

- Hadronic B decays with charm
  $B^{+} \rightarrow D^{(*)0} X^{+}$ or $B^{0} \rightarrow D^{(*)+} X^{-}$
  X is a charged system of hadrons among (π, K, π^{0}, K_{s}) up to 5 charged particles and 2 neutrals
  - PRO: cleaner events,
    B momentum reconstructed
    CON: smaller efficiency ε_{tag} ~ 0.15%



Fully reconstructed hadronic and semileptonic modes

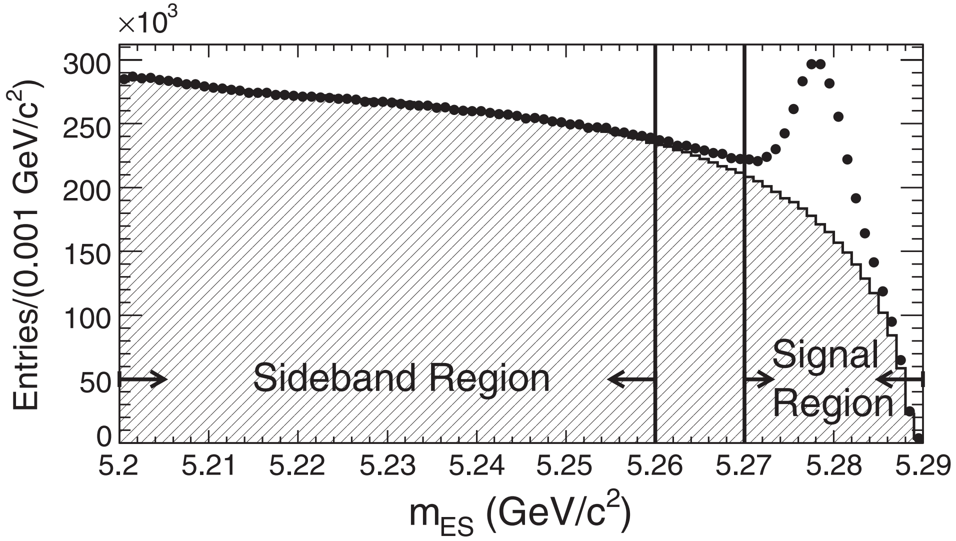
Hadronic tags:

Full reconstruction of the B decay chain.

Requirements on the quality of the tag are analysis dependent

Possible to separate the “combinatorial” wrong tags from correct (peaking) tags in data

$$m_{\mathrm{ES}} = \sqrt{s/4 - p_B^2}$$

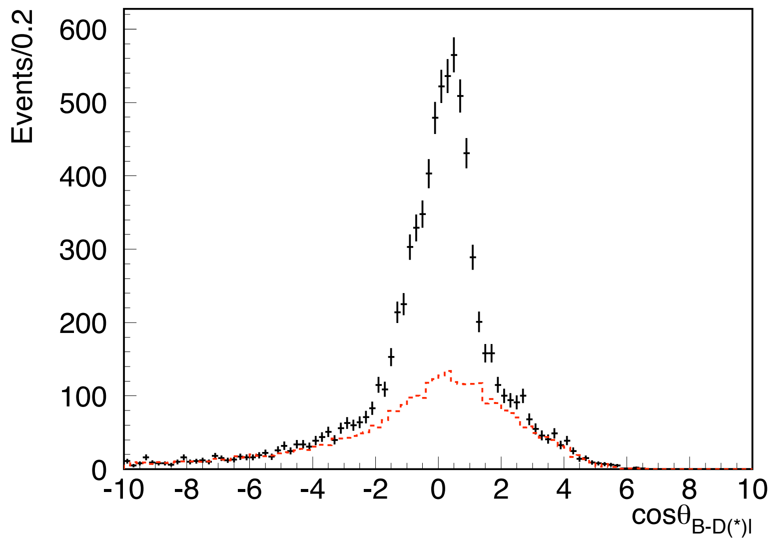


Semileptonic tags:

Recontruct Y = D-l pair.

Kinematics and known B meson energy determine the angle between B and Y.

$$\cos\theta_{B,Y} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2|\vec{p}_B||\vec{p}_Y|}$$

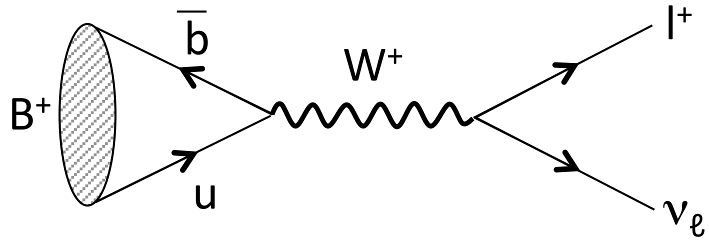


Leptonic B decays

Leptonic B decays

- B $\rightarrow$ lν very clean theoretically. The only uncertainty in the B decay constant fB

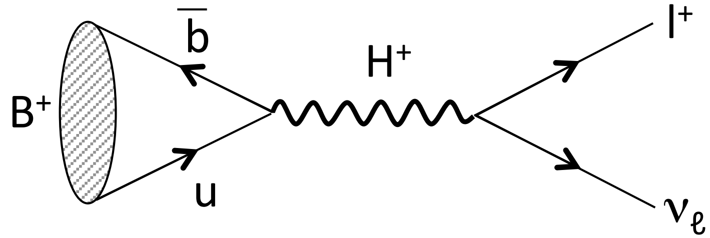
$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$



- Interesting probe physics beyond the SM, since also a charged Higgs can mediate the decay

$$\mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2$$

$$\mathcal{B}(B \to l\nu)_{SUSY} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - \frac{tan^2\beta}{1 + \epsilon_0 tan\beta} \frac{m_B^2}{m_H^2})^2$$



- B $\rightarrow$ τν used in global UT fits. B $\rightarrow$ μν out of reach of current B-factories
- Current measurements already exclude regions of M_H – tan β plane

Tipical signal selection and fit strategy

- Exploit kinematics and topology of in the signal side
  - Single charged tracks passing particle identification criteria
  - Requirement on CMS momentum for 1 prong modes
  - More constraints for $\tau \to \pi\pi^0\nu$

- Most discriminating variable residual energy in the calorimeter (E_{extra})
  - Defined as the total energy of clusters passing a minimum energy requirement
  - Used in a maximum likelihood fit to determine the branching fraction
- E_{extra} distribution validated with the use of double-tagged events
- Simultaneous fit of the BF to E_{extra}

$$\mathcal{L}_k = e^{-(n_{s,k}+n_{b,k})} \prod_{i=1}^{N_k} \left\{ n_{s,k}\mathcal{P}_k^s(E_{i,k}) + n_{b,k}\mathcal{P}_k^b(E_{i,k}) \right\}$$

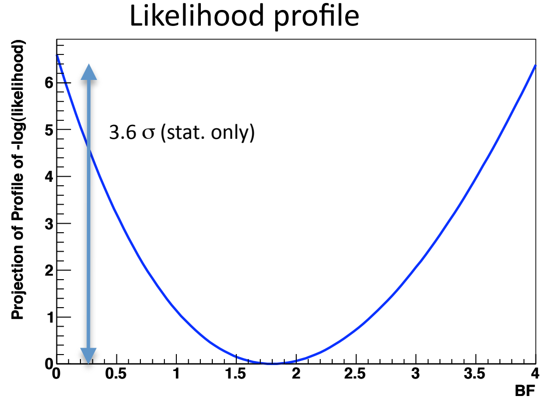
$$n_{s,k} = N_{B\overline{B}} \times \epsilon_k \times BF$$

Branching ratio with hadronic tags from BaBar

- Combinatorial background estimated from data, B^+ background shape from MC
- Fit to E_{extra} distribution show an excess of events consistent with null hypothesis at 3.3 σ only

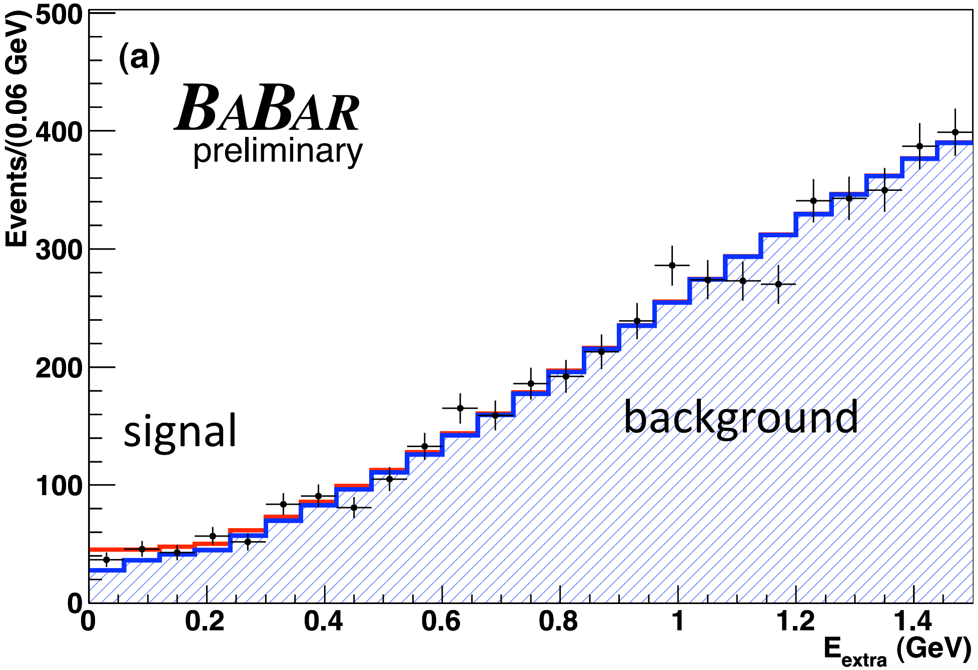
arXiv:1008.0104[hep-ex]

468 M B pairs

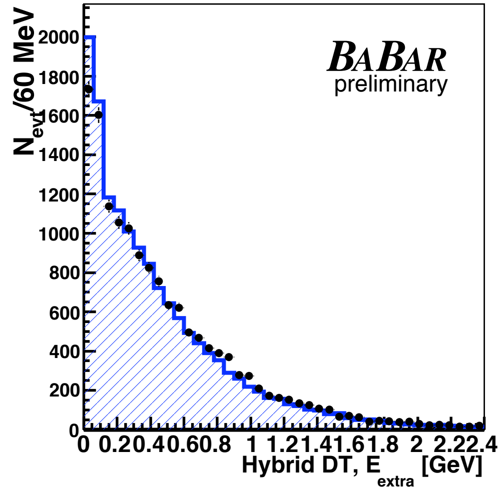


PRELIMINARY

$$\mathcal{B}(B \to \tau\nu) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$$



MC modelling of signal E_{extra} PDF checked with double tags



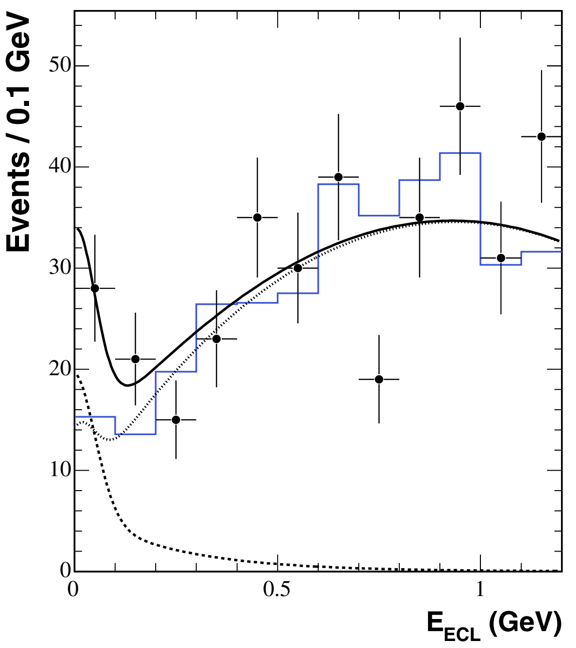
Branching ratio with hadronic tags from Belle

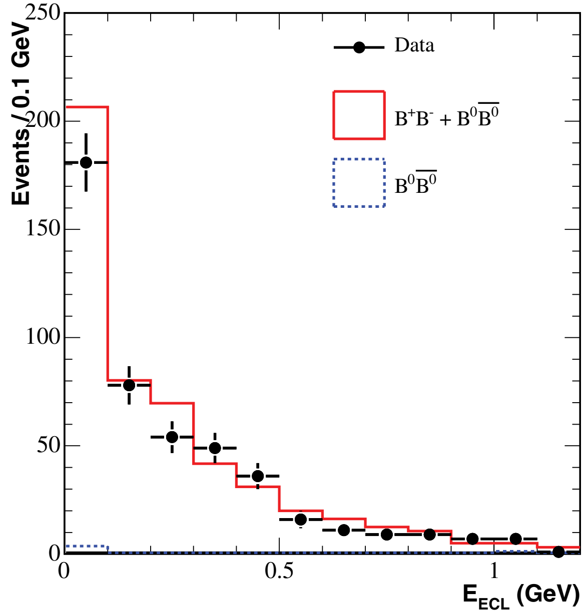
- Combinatorial background estimated from data
- Polynomial PDF for background, plus a peaking background form MC. Gaussian PDF for signal
- Excess of events excludes null hypothesis at 3.3 σ

Phys. Rev. Lett. 97, 251802 (2006)
449 M B pairs

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

MC modelling of E_{extra} checked with double tags



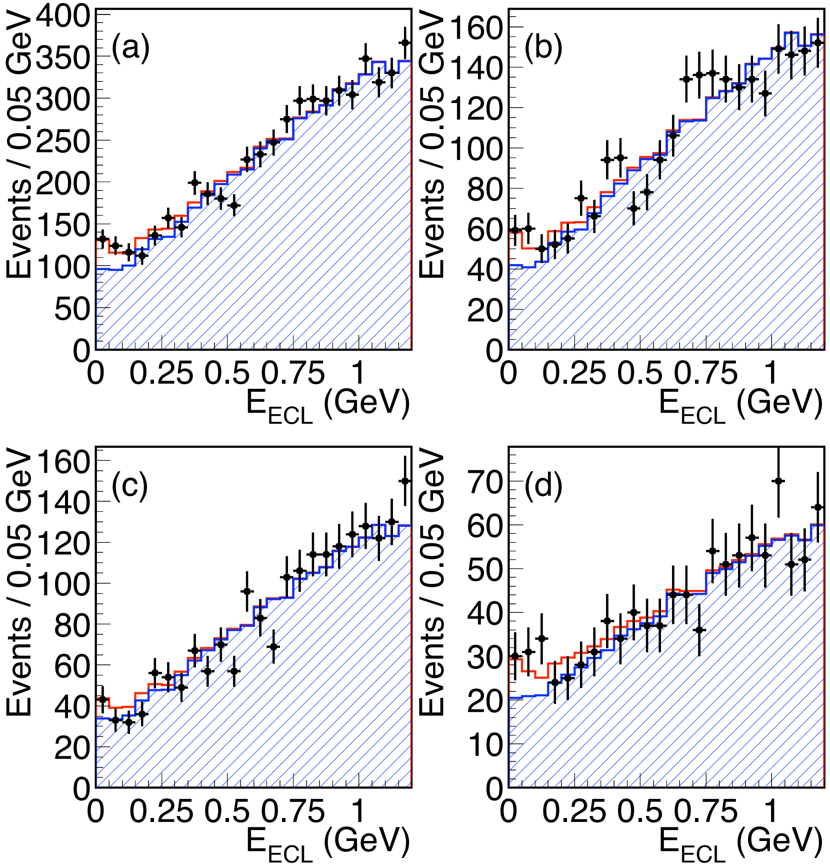


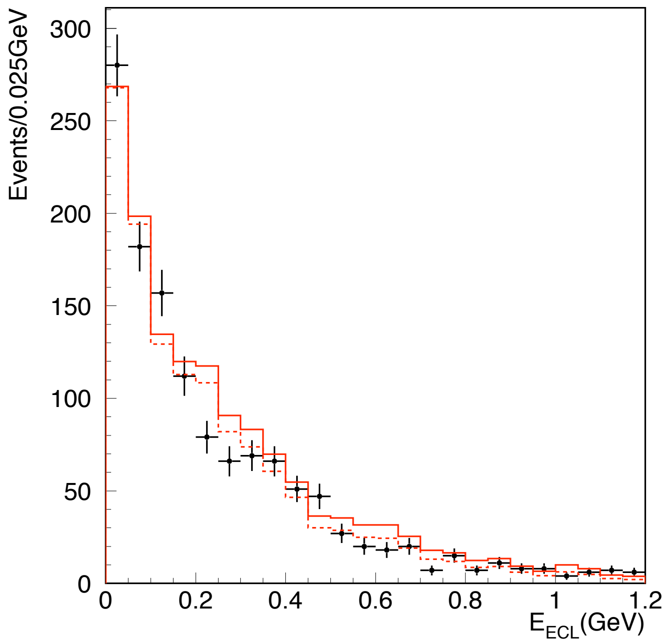
Branching ratio with semileptonic tags from Belle

- Excluding null hypothesis at 3.6 σ

Phys. Rev. D 82,071101(R) (2010)
657 M B pairs

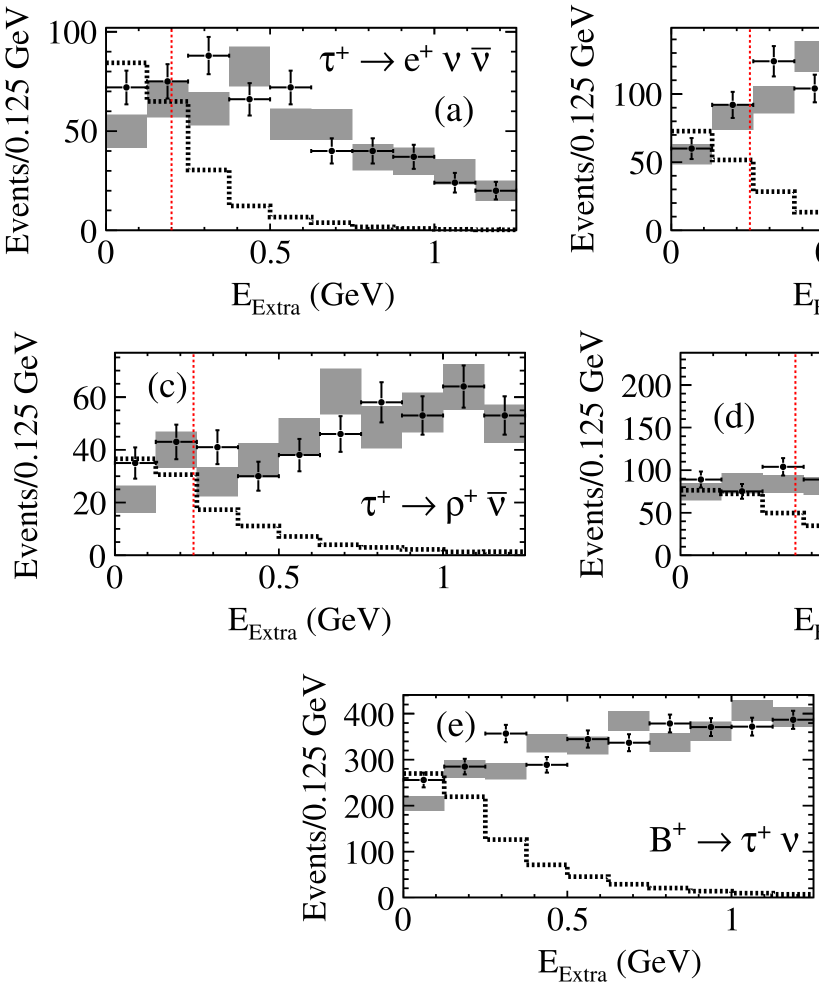
$$\mathcal{B}(B \to \tau\nu) = (1.54^{+0.38}_{-0.37}(\text{stat.})^{+0.29}_{-0.31}) \times 10^{-4}$$





Decay Mode	Signal Yield	ε, 10^{-4}	$\mathcal{B}$, 10^{-4}
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$	73^{+23}_{-22}	5.9	$1.90^{+0.59}_{-0.57}{}^{+0.33}_{-0.35}$
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$	12^{+18}_{-17}	3.7	$0.50^{+0.76}_{-0.72}{}^{+0.18}_{-0.21}$
$\tau^- \to \pi^- \nu_\tau$	55^{+21}_{-20}	4.7	$1.80^{+0.69}_{-0.66}{}^{+0.36}_{-0.37}$
Combined	143^{+36}_{-35}	14.3	$1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31}$

Branching ratio with semileptonic tags from BaBar



Phys. Rev. D 81,051101(R) (2010)

459 M B pairs

Excludes null hypothesis at 2.3 σ

Mode	$\mathcal{N}_{bg}^{data}$	N_{obs}	Branching fraction ($\times 10^{-4}$)
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$	81 ± 12	121	(3.6 ± 1.4)
$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$	135 ± 13	148	$(1.3^{+1.8}_{-1.6})$
$\tau^+ \to \rho^+ \bar{\nu}_\tau$	59 ± 9	71	$(2.1^{+2.0}_{-1.8})$
$\tau^+ \to \pi^+ \bar{\nu}_\tau$	234 ± 19	243	$(0.6^{+1.4}_{-1.2})$
$B^+ \to \tau^+ \nu_\tau$	509 ± 30	583	$(1.7 \pm 0.8 \pm 0.2)$
$B^+ \to \mu^+ \nu_\mu$	13 ± 8	12	<0.11 (90% C.L.)
$B^+ \to e^+ \nu_e$	24 ± 11	17	<0.08 (90% C.L.)

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

Branching fractions summary

BABAR Hadronic tags

$$\mathcal{B}(B \to \tau\nu) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$$

arXiv:1008.0104[hep-ex]

BABAR Semi-leptonic tags

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

Phys. Rev. D 81, 051101(R) (2010)

BABAR combined

$$\mathcal{B}(B \to \tau\nu) = (1.76 \pm 0.49) \times 10^{-4}$$

BELLE Hadronic tags

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

Phys. Rev. Lett. 97, 251802 (2006)

BELLE Semi-leptonic tags

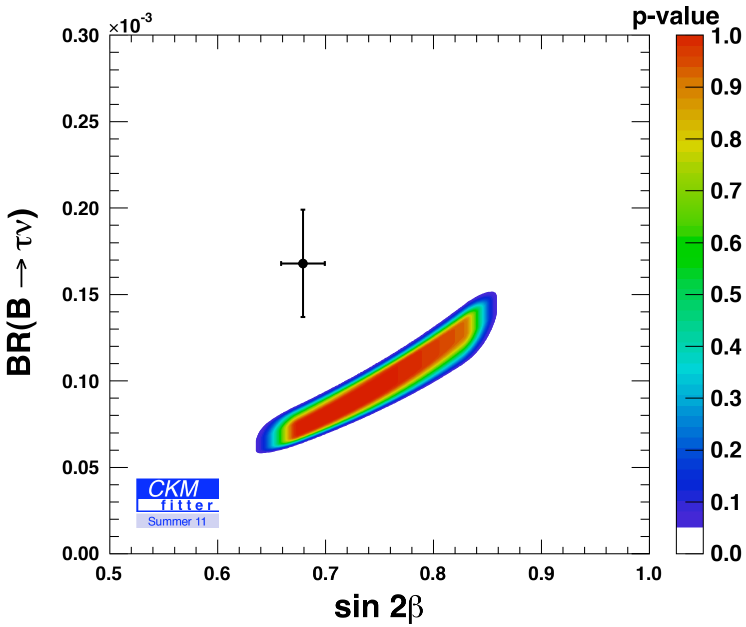
$$\mathcal{B}(B \to \tau\nu) = (1.54^{+0.38}_{-0.37}(\mathrm{stat.})^{+0.29}_{-0.31}) \times 10^{-4}$$

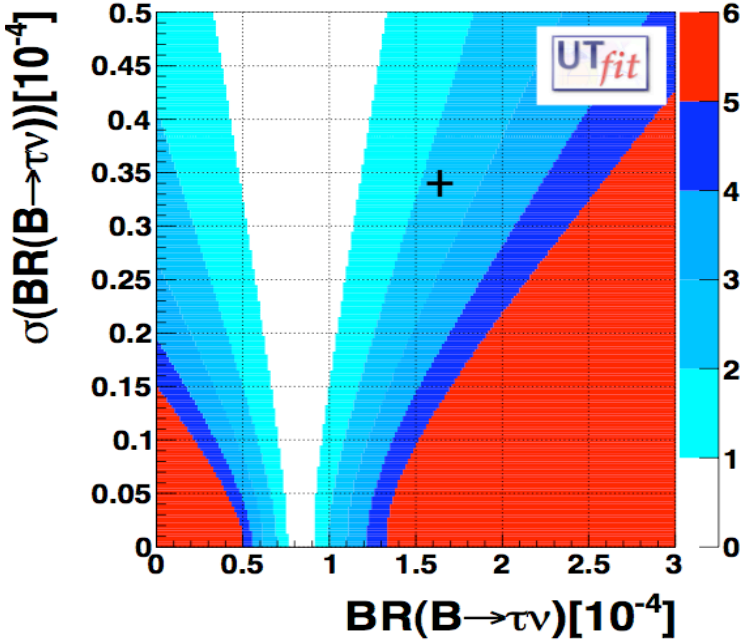
Phys. Rev. D 82, 071101(R) (2010)

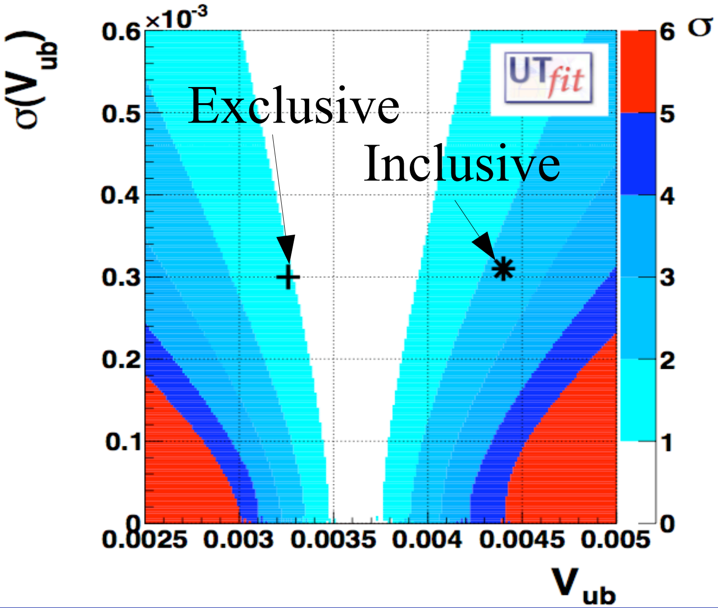
HFAG average: $\mathcal{B}(B \to \tau\nu) = (1.64 \pm 0.34) \times 10^{-4}$

HFAG does not use the 2006 Belle hadronic tag result

Tensions in the Global Fit

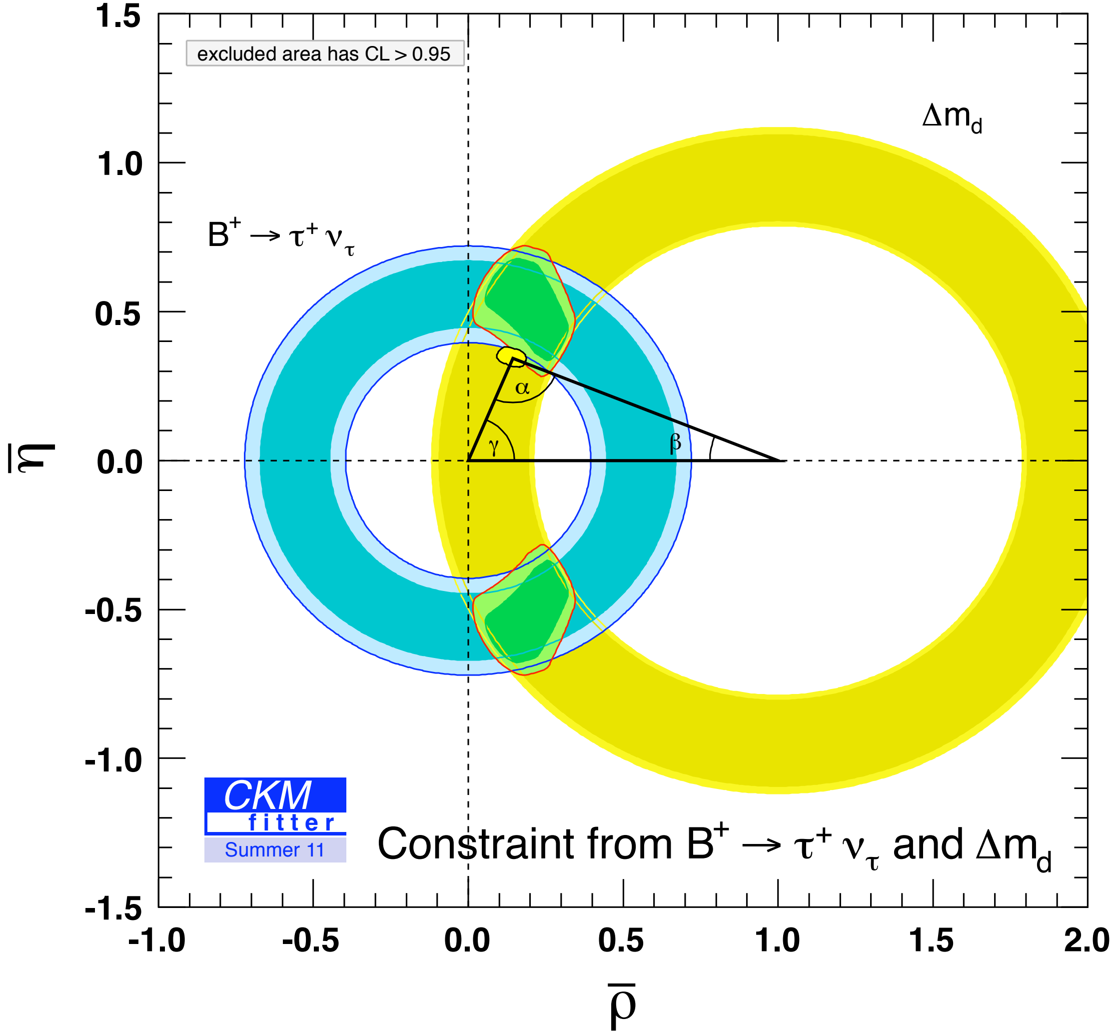


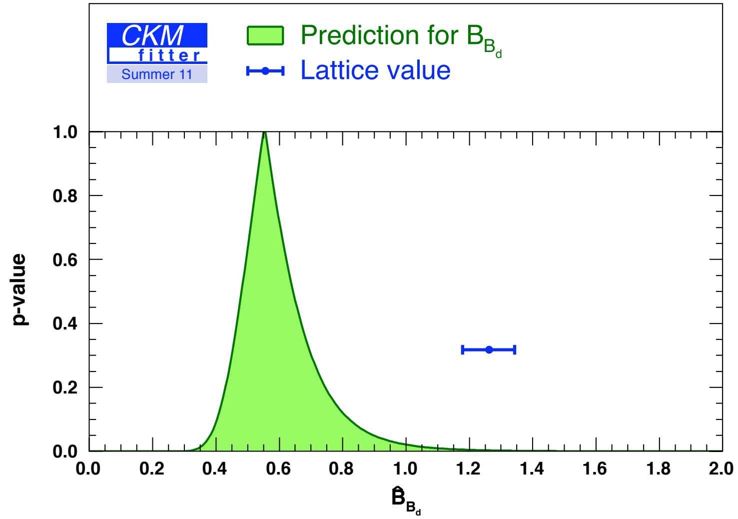




- Despite the striking overall consistency of the UT constraints some measurements show “tensions”
- Statistical fluctuations, unknown systematic uncertainties or hints of New Physics around the corner?

Combining $B \rightarrow \tau\nu$ and Δm_d



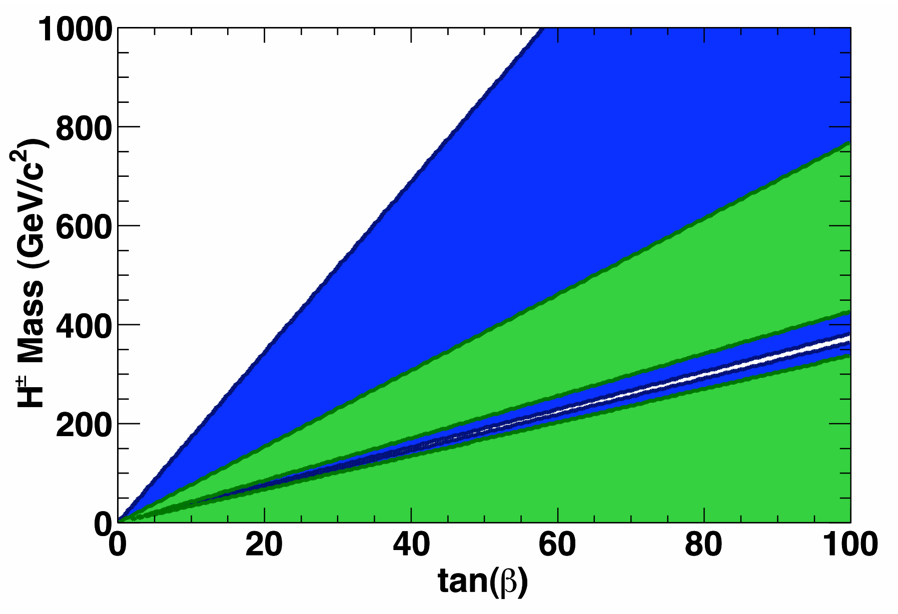


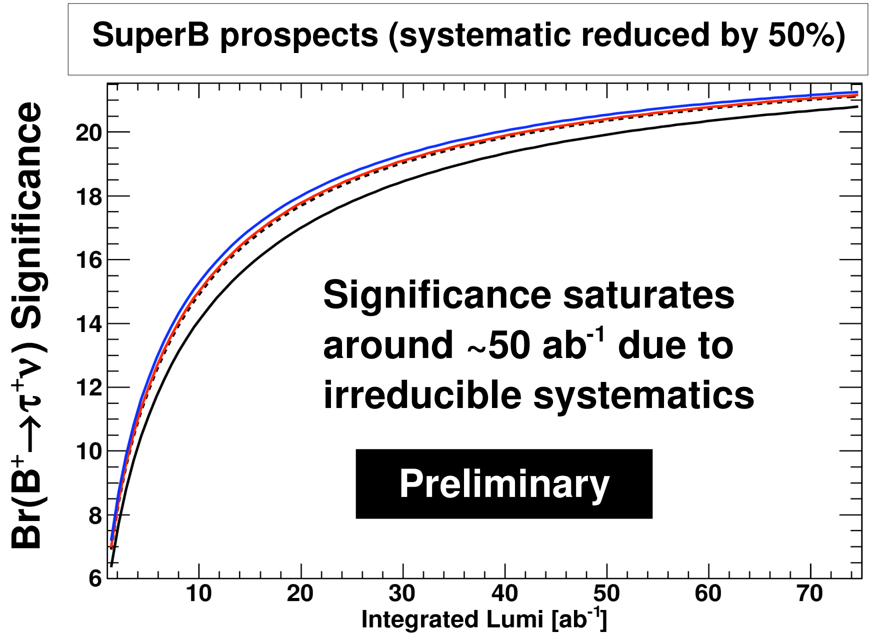
Extract B_{Bd} experimental value from the ratio of $B \rightarrow \tau\nu$ and Δm_d

SuperB extrapolations

- The measurements will rapidly become systematically limited
- Expect a final precision of 4% (systematic dominated) well before $75ab^{-1}$
- Caveat: 4% is half of the current systematic uncertainty
  - We assess most of systematics from data so it may be conservative

From Alejandro Perez @ HQL 2010

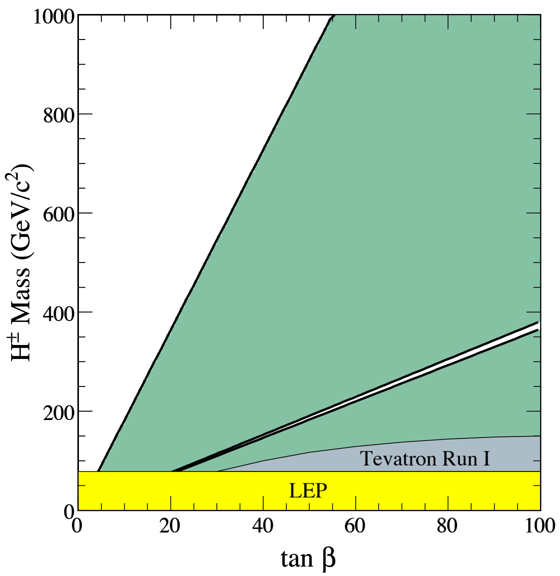




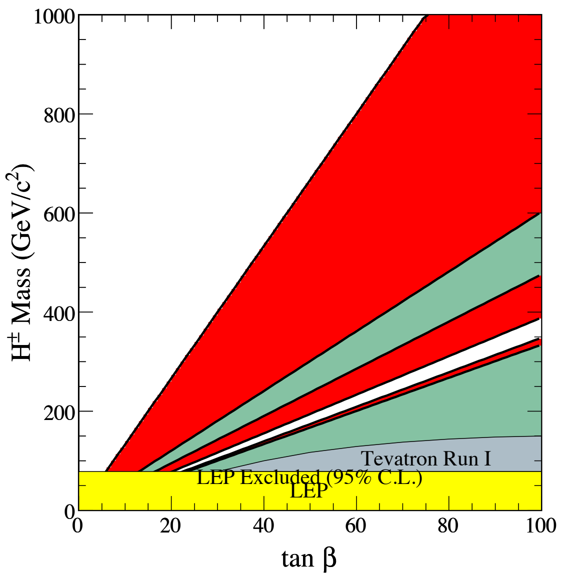
Belle II extrapolations

- From Belle-II collaboration Physics Report (arXiv:1002.5012)
- Scale both the statistical and systematical uncertainty by luminosity
- Resulting in a 4% total uncertainty with the full dataset of 50 ab^{-1}

95% excl. 50ab^{-1}



5σ observation regions



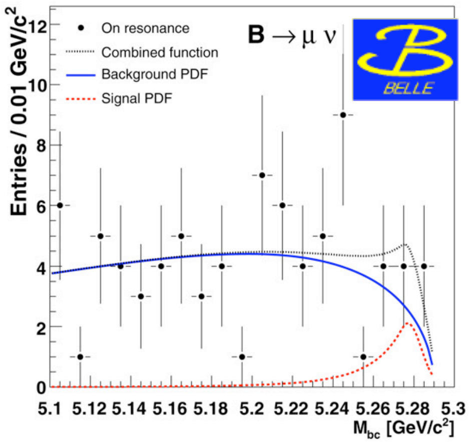
B →eν, μν untagged analysis

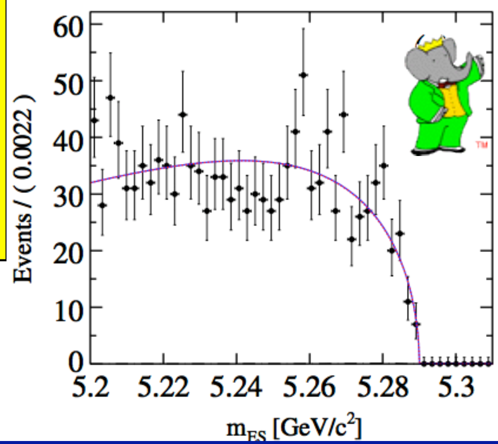
- Monochromatic e or μ in B rest frame
- NO tag reconstruction but exploit kinematics and and topology of the rest of the event
- No significant signal seen

Phys. Rev. D 79,091101 (2009)
Phys. Lett. B 647 (2007) 67

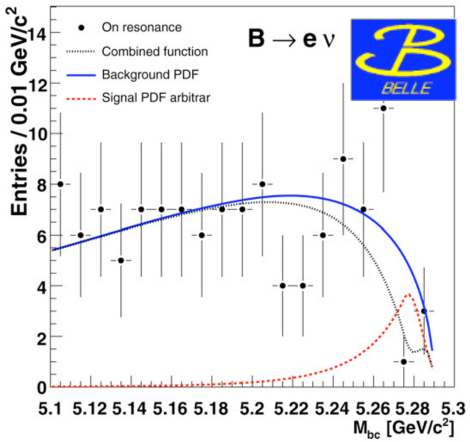
B (r.o.e.) mass

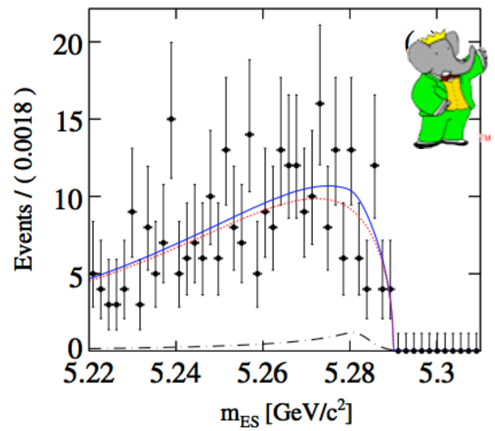
B →eν





B →μν





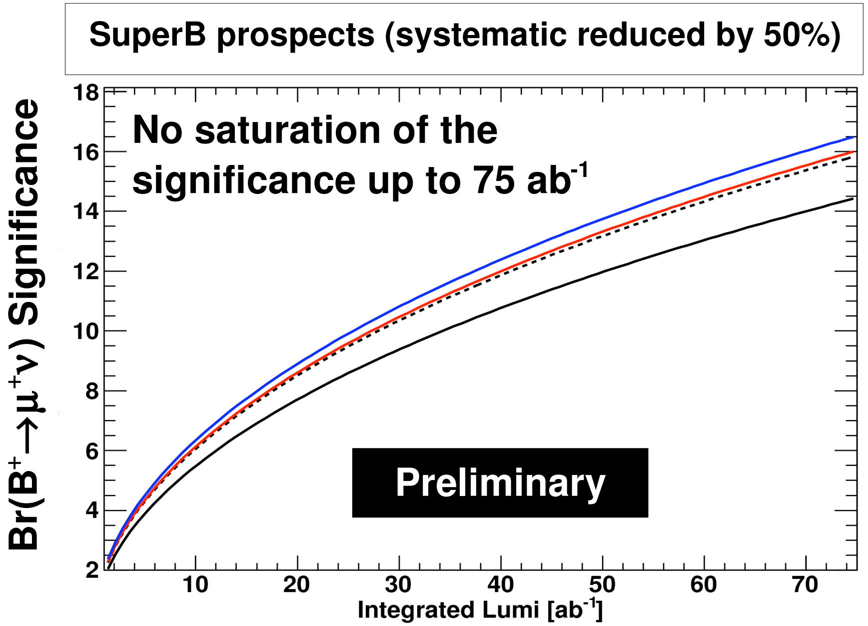
90% C.L. limits:

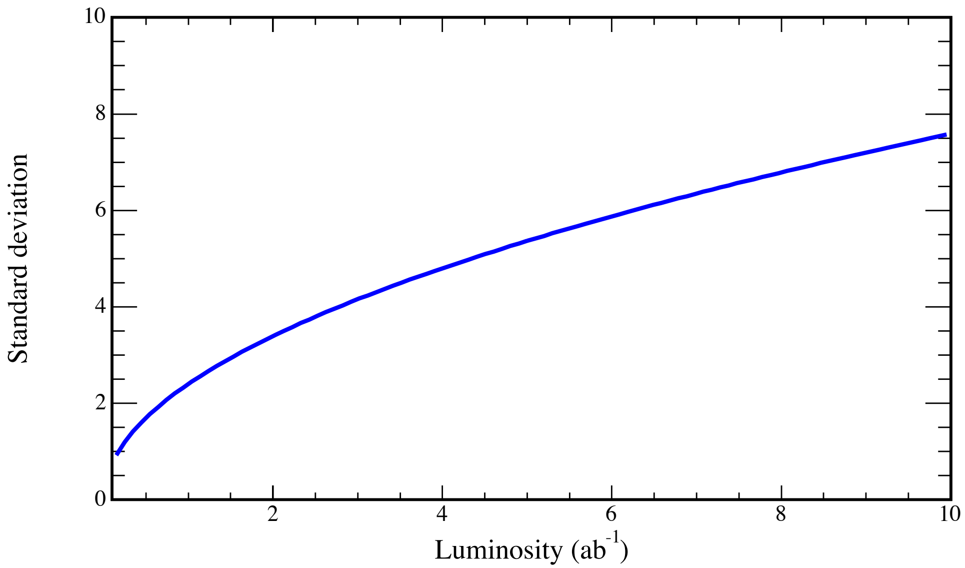
BF(B → eν) < 1.9 × 10^{-6} BABAR
BF(B → eν) < 0.98 × 10^{-6} BELLE

BF(B → μν) < 1.0 × 10^{-6} BABAR
BF(B → μν) < 1.7 × 10^{-6} BELLE

Prospects of B→μν in SuperB and Belle-II

- Scaling the statistical uncertainty of the untagged method with luminosity
- Assuming a moderate improvement in systematic uncertainty
- Both collaborations assume that an hadronic tagging will perform better

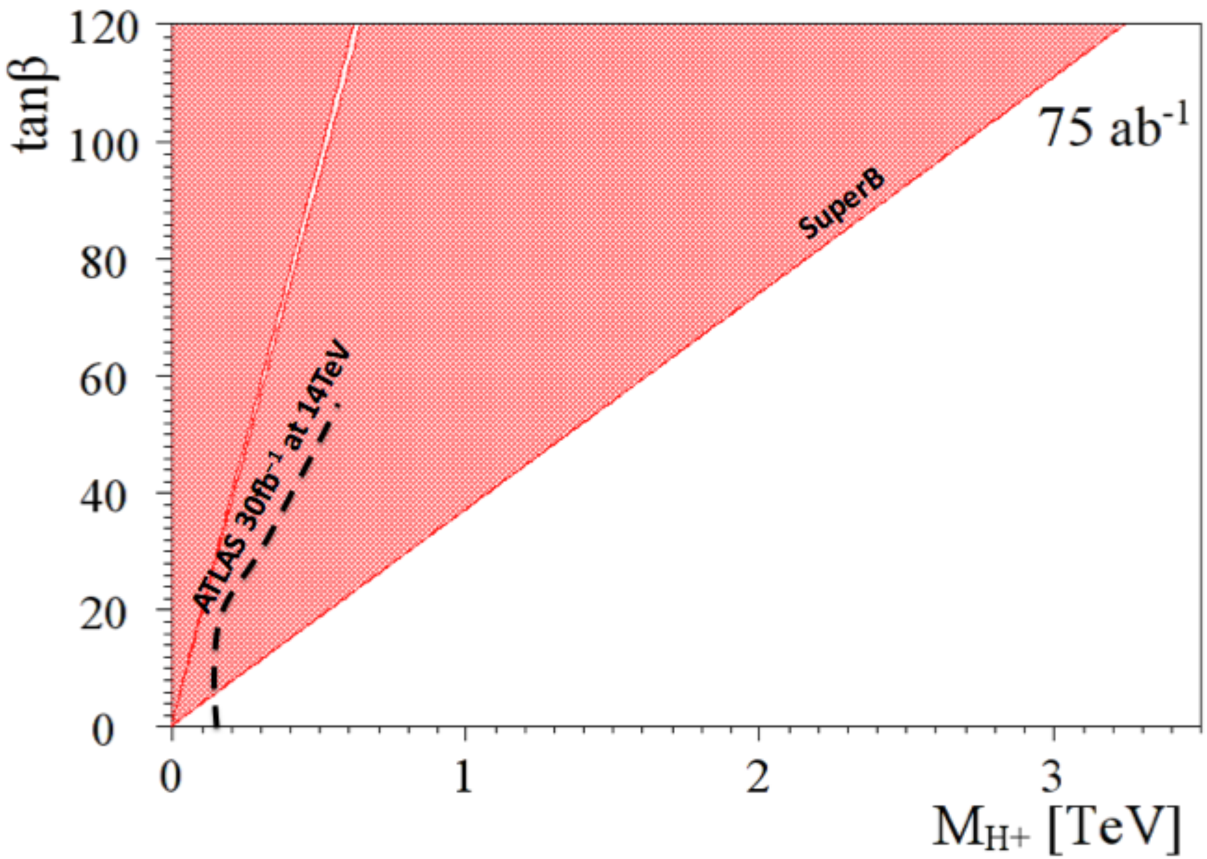




Both SuperB and Belle-II extrapolate a 5σ observation within SM before 10ab^{-1}
Scaling to 75 ab^{-1} expect SuperB to measure BF(B→μν) at 4%
Scaling to 50 ab^{-1} expect Belle-II to measure BF(B→μν) at 6%

SuperB B→τν + B→μν

- 75 ab-1 SuperB expected exclusion region on 2HDM parameters from “the impact of SuperB on flavour Physics” arXiv:0901.0512
- ATLAS constraint from arXiv:0901.0512



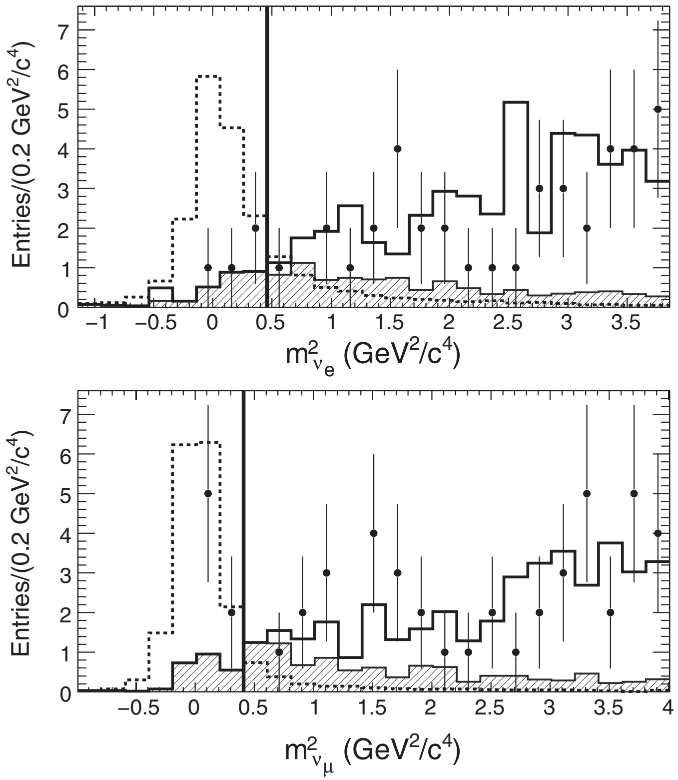
$B \to l\nu\gamma$ with hadronic tags from BaBar

- Small excess for muon channel consistent with a 2.1 σ background fluctuation

Phys. Rev. D 80, 111105 (2009)

Missing mass

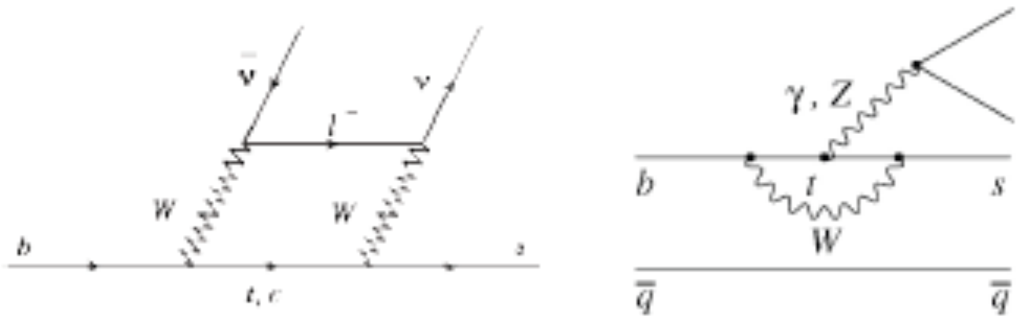
	$B \to e\nu\gamma$	$B \to \mu\nu\gamma$
Expected bkg	2.7 ± 0.3 ±0.4	3.4 ± 0.7 ±0.7
Observed events	4	7
Signal efficiency	(7.8 ± 0.1 ±0.3) %	(8.1 ± 0.1 ±0.3)%
FC confidence limit	$<17 \times 10^{-6}$	$<26 \times 10^{-6}$
	$<15 \times 10^{-6}$	



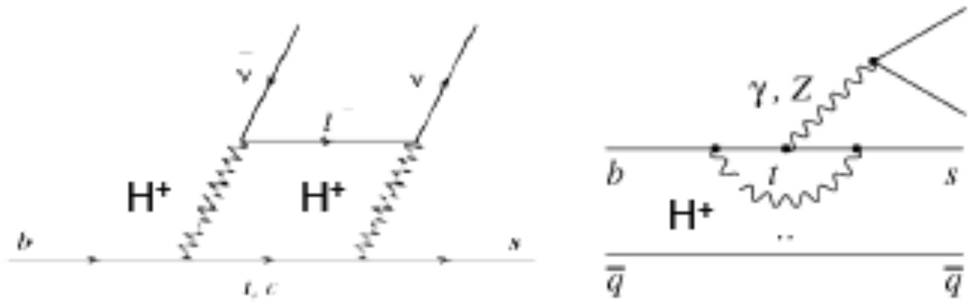
$B \to K^{(*)}\nu\nu$

Physics Motivation

- FCNC b → s transition in the SM by W box or Z penguin
- Small SM branching fraction
- 2ν final state make it theoretically cleaner than other b → s modes
- Many new physics models may enhance the BF.



$BF(B^+ \to K^+ \nu \nu) \sim 4 \times 10^{-6}$



$B \to h \nu\nu$ experimental measurements

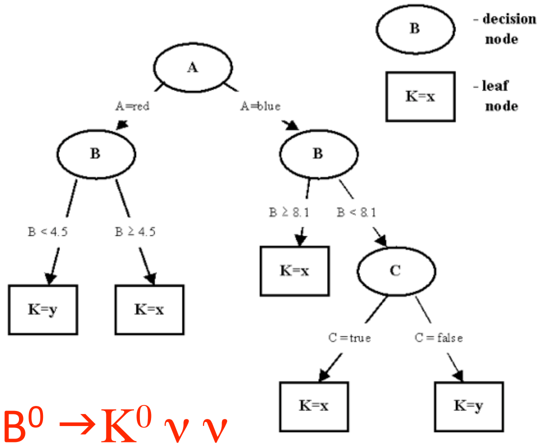
Mode	BaBar Had tag	BaBar SL tag	Belle Had tag	Belle SL tag
$K^+ \nu \nu$	✓	✓	✓	
$K_S \nu \nu$		✓	✓	
$K^{*+} \nu \nu$	✓	✓	✓	
$K^{*0} \nu \nu$	✓	✓	✓	
$\pi^+ \nu \nu$			✓	
$\pi^0 \nu \nu$			✓	
$\rho^+ \nu \nu$			✓	
$\rho^0 \nu \nu$			✓	
$\phi \nu \nu$			✓	

- Babar uses both tags – Belle hadronic tags only
- Belle searched also for other non-kaonic modes

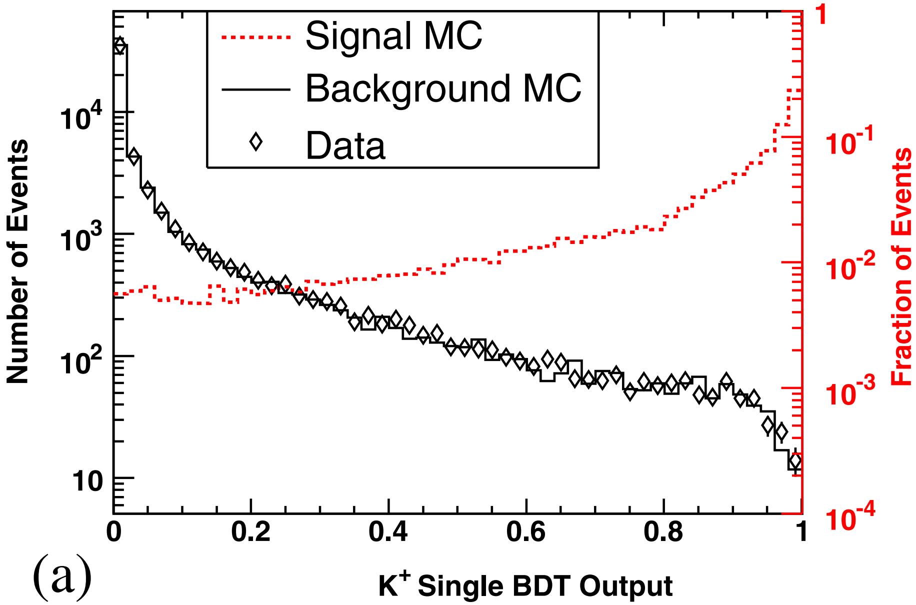
$B^+ \to K^+ \nu \nu$ and $B^0 \to K_S \nu \nu$ with SL tags from BaBar

Phys. Rev. D 82, 112002 (2010)
459 M B pairs

- Multivariate analysis using bagged decision trees
- Trained on MC simulated signal and background events
- 26 (K^+) and 38(K_S) variables exploiting missing energy, event shape, kinematics and quality of the tag reconstruction

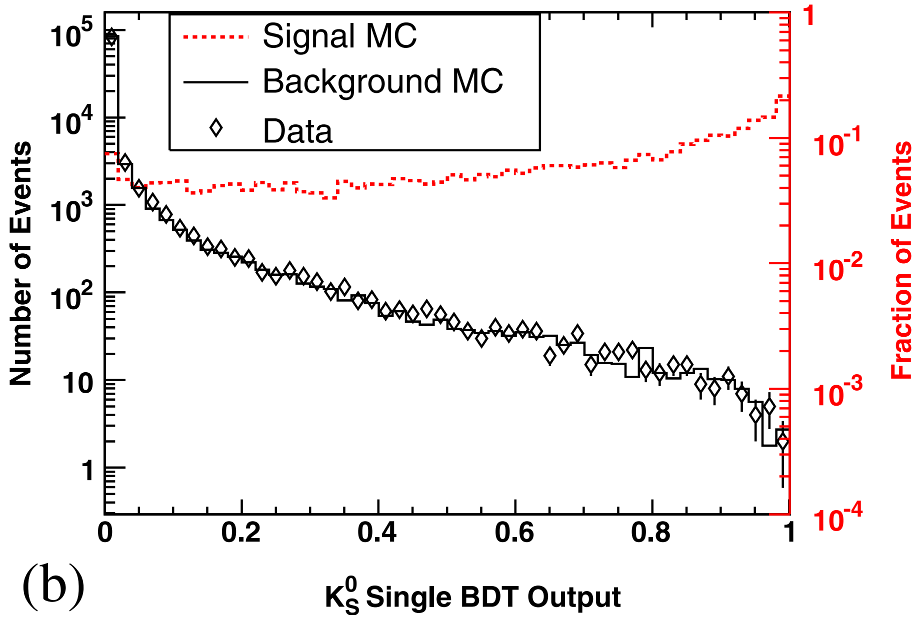


$B^+ \to K^+ \nu \nu$



(a)

$B^0 \to K^0 \nu \nu$

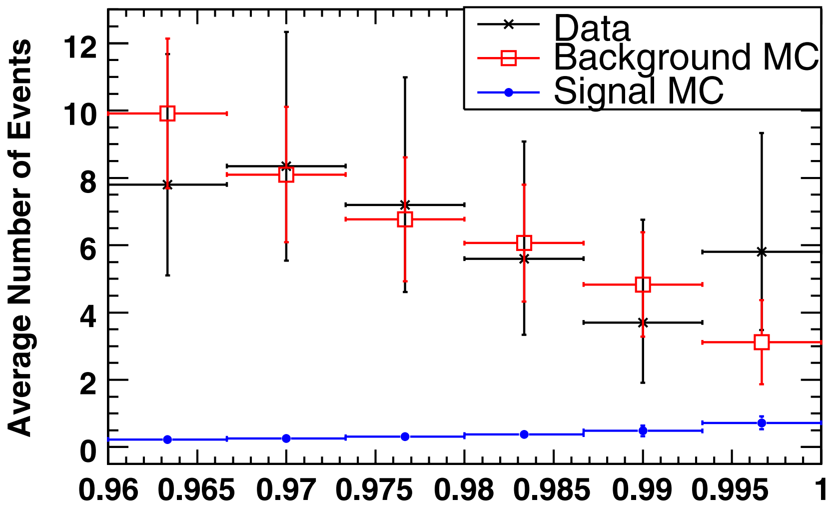


(b)

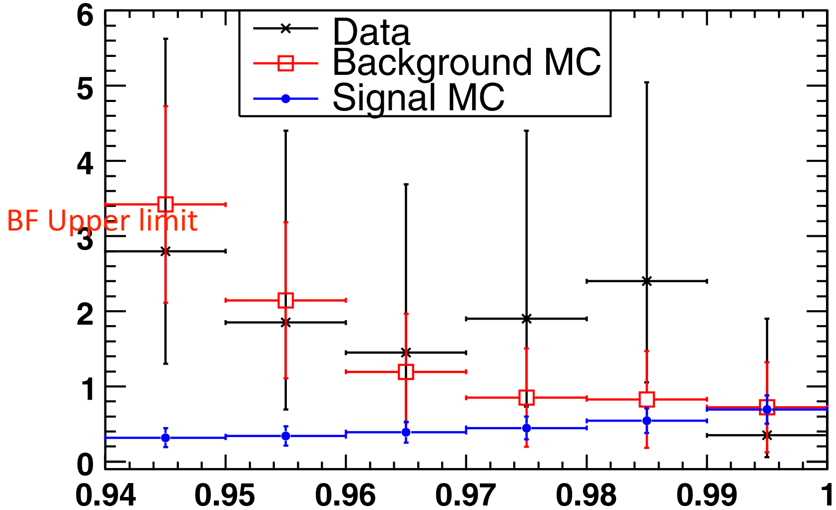
- Signal not significant, upper limits set to
  $B(B^+ \to K^+ \nu \nu) < 16 \times 10^{-6}$
  $B(B^0 \to K^0 \nu \nu) < 56 \times 10^{-6}$

Zoom in the signal region

$B^+ \to K^+ \nu \nu$



$B^0 \to K^0 \nu \nu$



$B \rightarrow h^{(*)} \nu \nu$ with hadronic tags from Belle

Phys. Rev. Lett. 99, 221802 (2007)
535 M B pairs

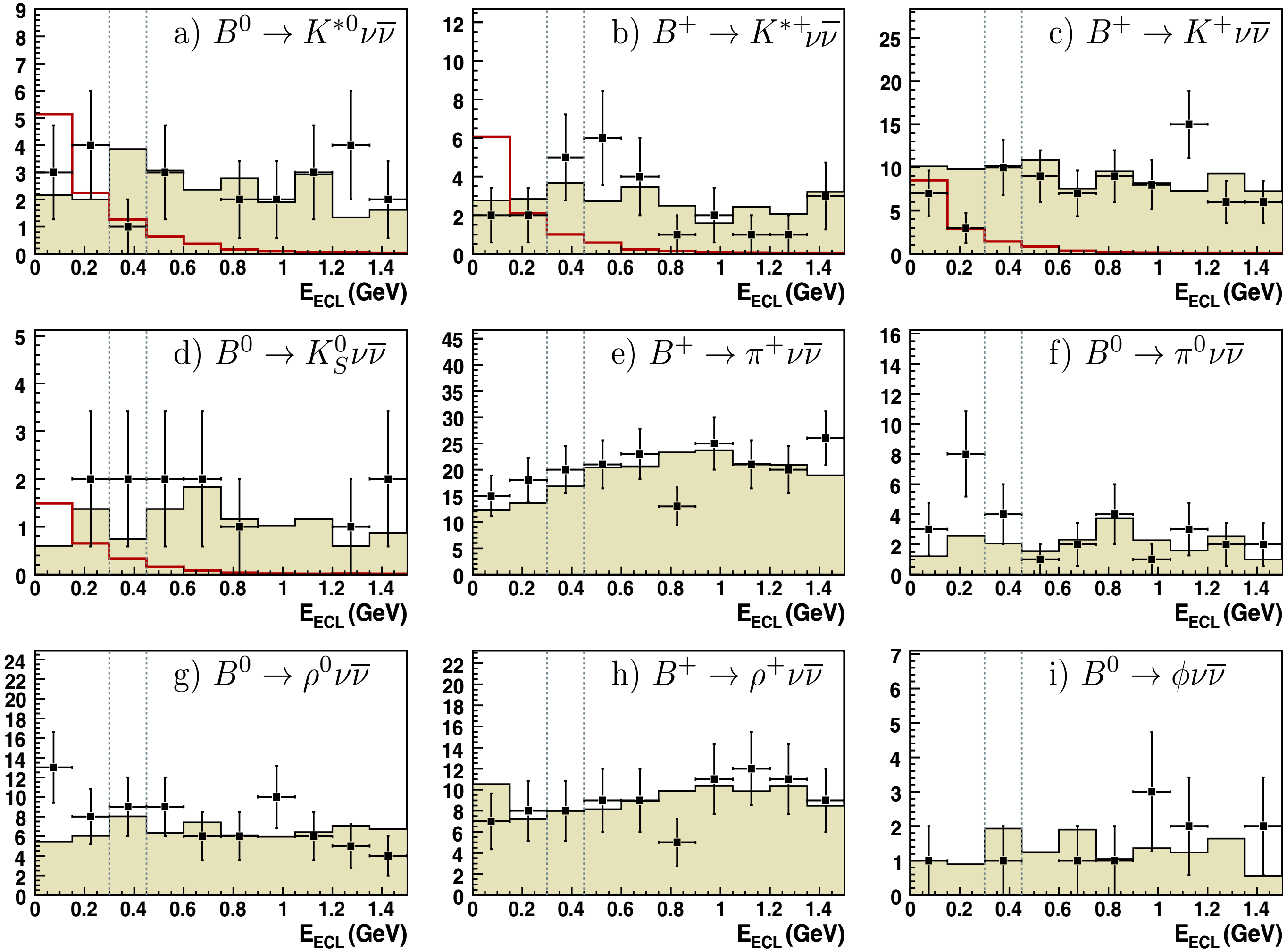
- Reconstruction of many final states in the rest of the event
  - K^+, π^+, $K^{*+}(K\pi)$, $K^{*0}(K\pi)$, $K_S(\pi^+\pi^-)$, ρ^+, ρ^0, ϕ (KK)
- Selection requirements on kinematics and veto of extra charged particles or π^0.
- Extra energy in the calorimeter defines the signal region
  - Signal region is residual calorimeter energy E_{extra} < 300 MeV
  - Sideband region 450 MeV < E_{extra} < 1.5 GeV
- Cut and count analysis
  - Background yield measured on the sideband and scaled using MC

No evidence of signal, upper limits set:

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

$\mathcal{B}(B \to K^{*+} \nu \nu) < 140 \times 10^{-6}$

$\mathcal{B}(B \to K^{*0} \nu \nu) < 340 \times 10^{-6}$



$B \to K^{(*)} \nu \nu$ with hadronic and semileptonic tags BaBar

Phys. Rev. D 78, 072007 (2008)
454 M B pairs

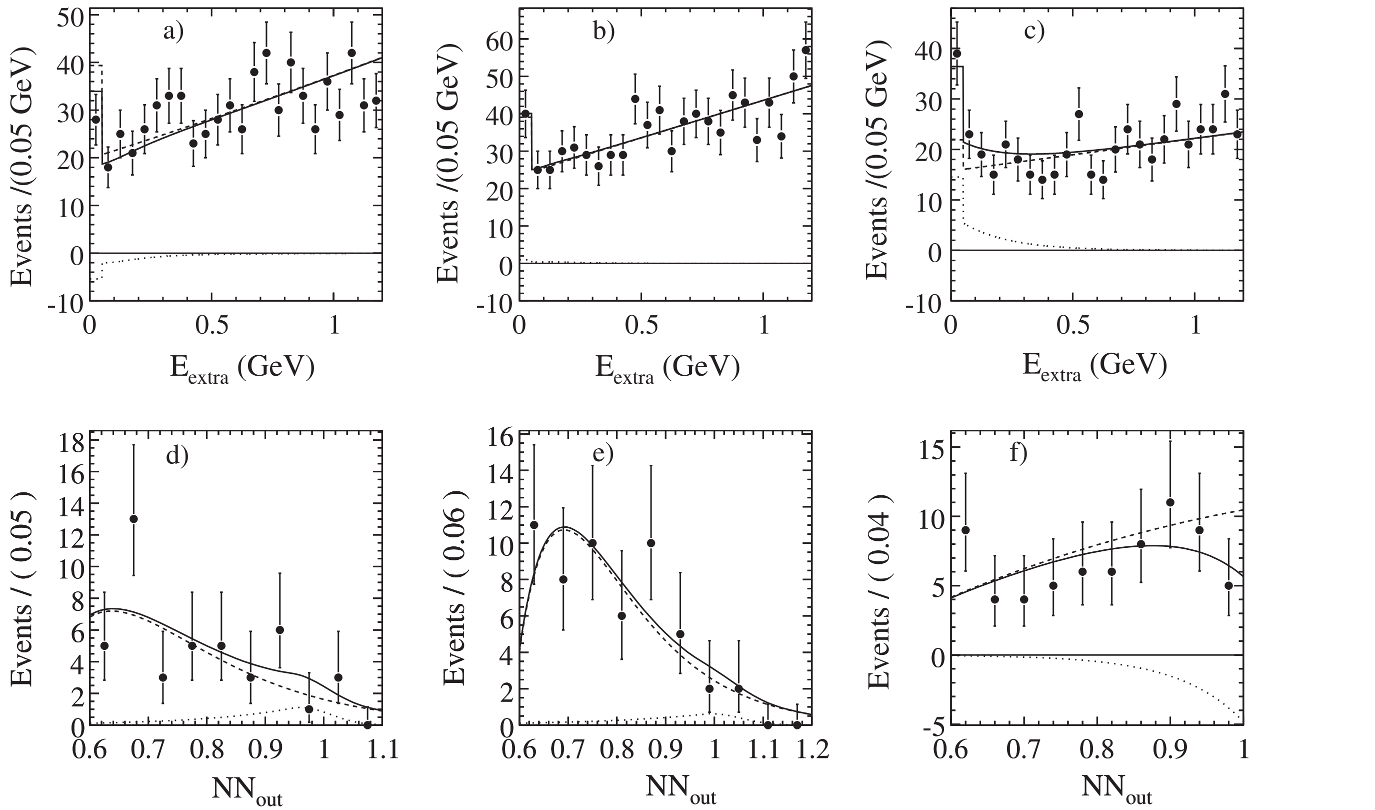
- Final state K^{*+} ($K^+\pi^0$, $K_s\pi^+$) and $K^{*0}(K\pi)$
- Signal selection based on event shape, tag reconstruction quality, missing momentum
- Hadronic tag analysis combines the variables in a Neural net

- Signal yield extracted by a maximum likelihood fit to
  - Residual energy in the calorimeter (SL tag analysis)
  - NN distribution (hadronic tags)

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

SL tags

Had tags

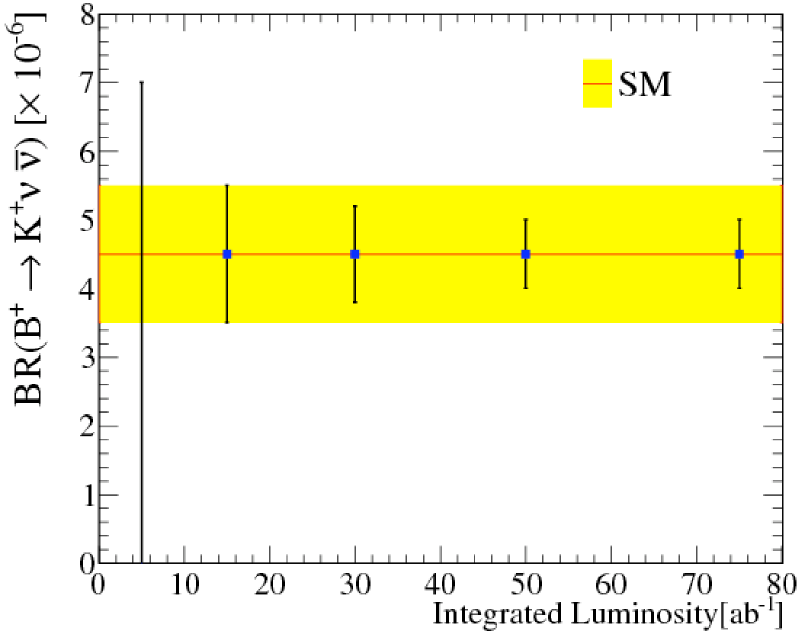


$B(B^+ \rightarrow K^{*+} \nu) < 80 \times 10^{-6}$ $B(B^0 \rightarrow K^{*0} \nu) < 120 \times 10^{-6}$

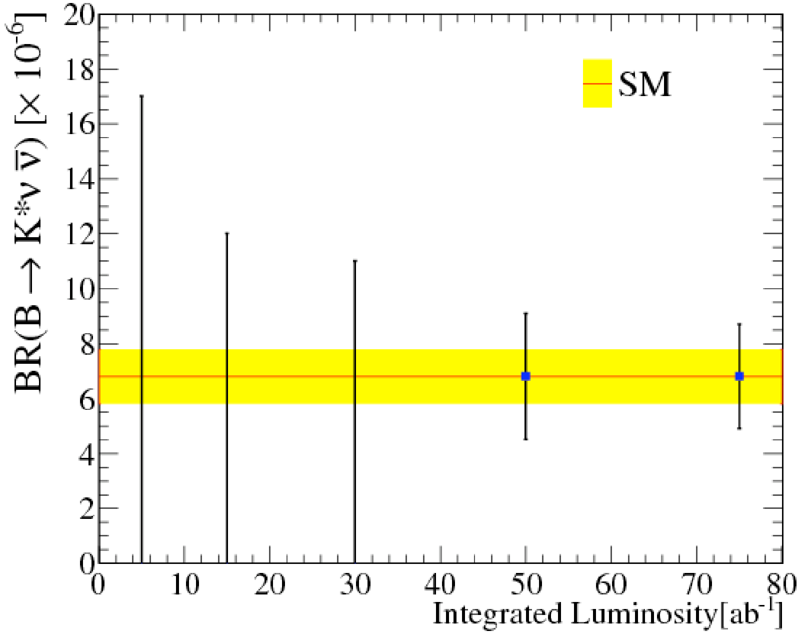
SuperB and Belle-II extrapolations

- Benefits of lower boost and dectector improvements:
  - educated guesses by Belle-II point to 30-35% precision
    - Extrapolating performances of $B \to \tau\nu$ and assuming 70% improvements in reconstruction due to detector improvements
  - fast simulation studies by SuperB point to 15-20% precision

$B^+ \to K^+ \nu$



$B^+ \to K^{*+} \nu$



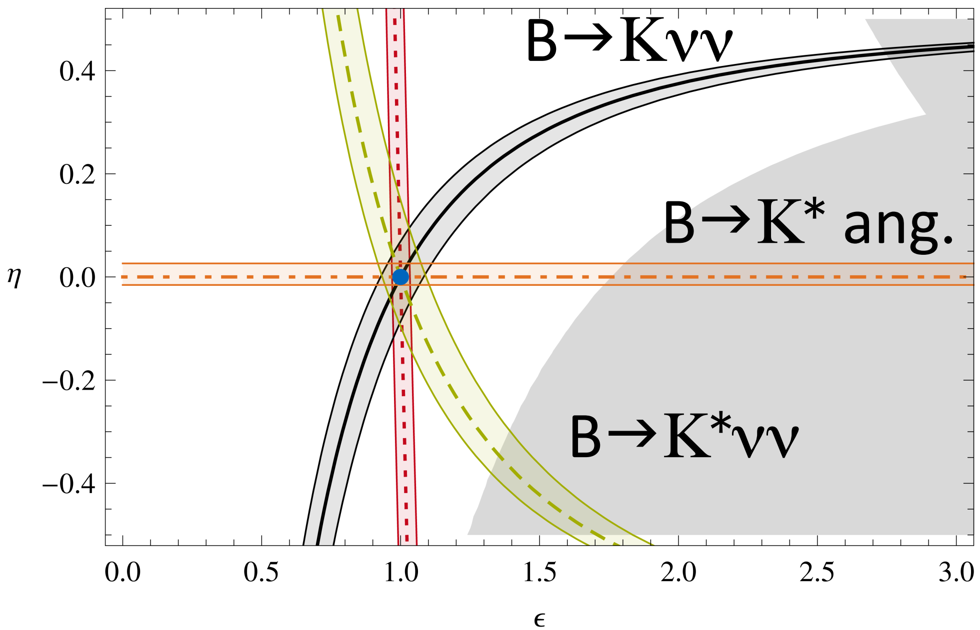
Model independent NP Constraints

- Model independent NP constraints by measurements of branching fraction and K* polarization

Altmannshofer, Buras et al. JHEP 04, 022 (2009)

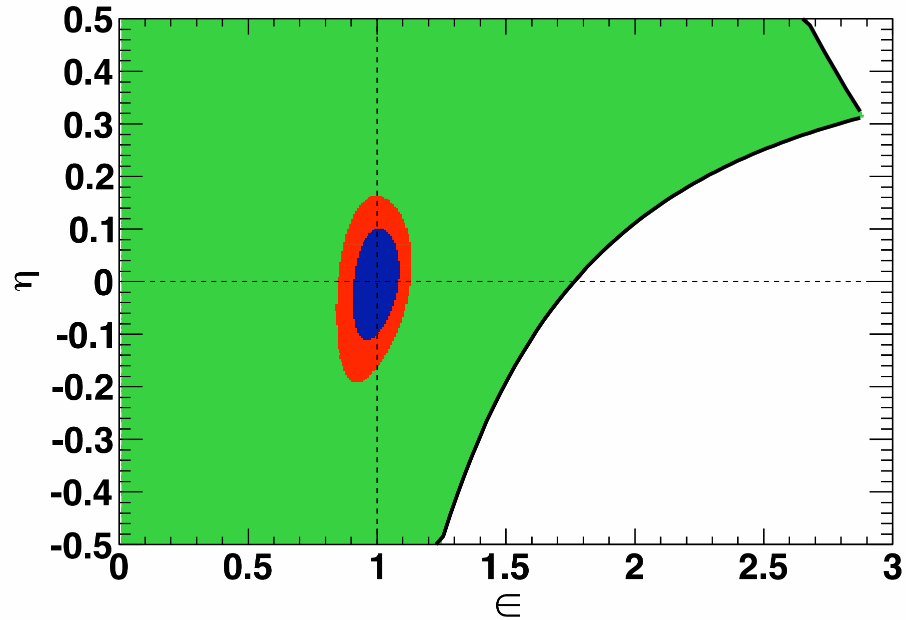
$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\mathrm{SM}}|}, \qquad \eta = \frac{-\mathrm{Re}\,(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

$B \to X_s \nu\nu$



SuperB 75 ab-1

arXiv:0901.0512



Conclusions – Leptonic decays

- Leptonic B decays allow NP searches reasonably clean from theoretical complications
- $B \rightarrow \tau\nu$ BF is $O(10^{-4})$: not rare but experimentally challenging. As today, we still lack a single publication with a 5σ observation.
- To overcome the weak decay signature fruitful tagging methods have been exploited
- 4 statistically independent measurements provide a combined result with 20% accuracy. Consistent but not perfectly fitting within SM
  - Statistical fluctuation, overlooked systematics or new physics?
- $B \rightarrow \mu\nu$ still below the sensitivity of current B-factories
- Future B-factories will measure both the $B \rightarrow \tau\nu$ and $B \rightarrow \mu\nu$ branching fractions precisely (much better than 5%)

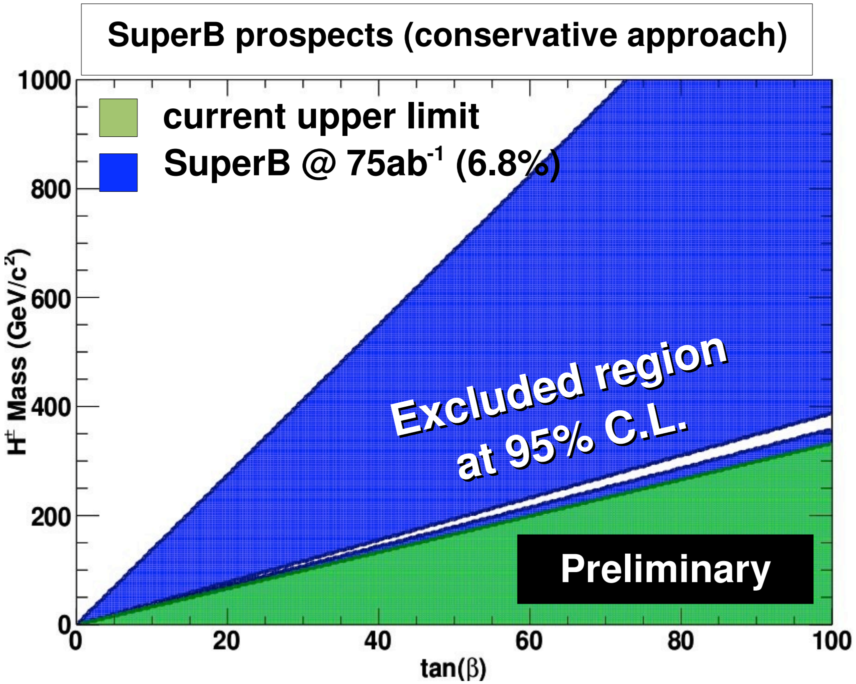
Conclusions - B $\rightarrow K^{(*)}\nu\nu$

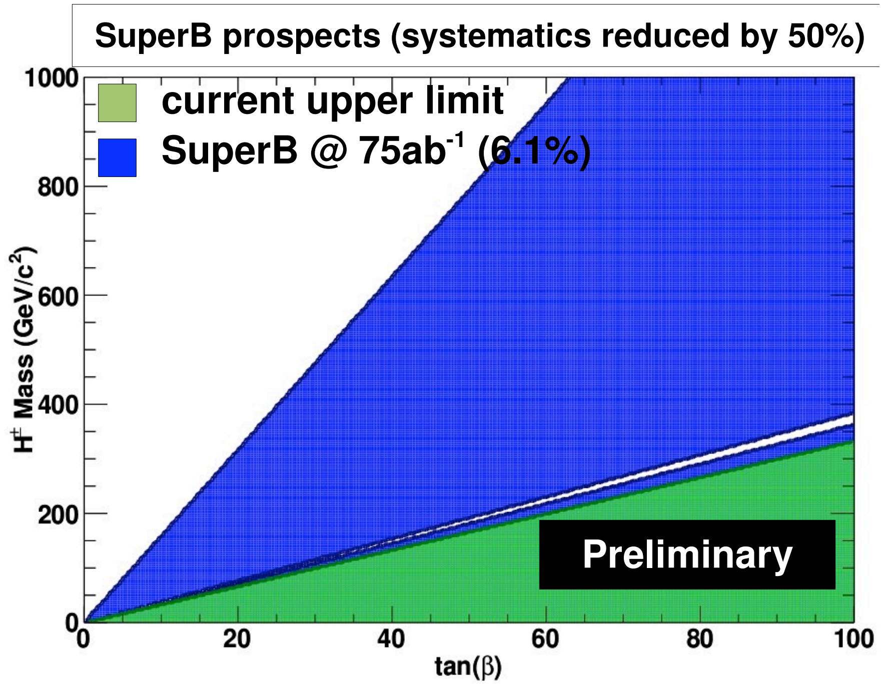
- FCNC b → s transitions are rare in the SM and new physics may enter enhancing the branching fraction
- Among them the B → $K^{(*)}\nu\nu$ are the cleanest theoretically
- Experimentally they are as challenging as B → $\tau\nu$
- At current B-factories we didn't see any significant signal.
  The $B^+ \rightarrow K^+\nu\nu$ search being the most sensitive at 4x SM prediction
- At future B factories we expect to observe a SM signal with the full dataset
- Moreover with the hadronic tagging will be possible to perform angular analysis of B $\rightarrow K^*\nu\nu$ decays
- Combining several observables NP contributions may be constrained (a la UT fits)

Backup

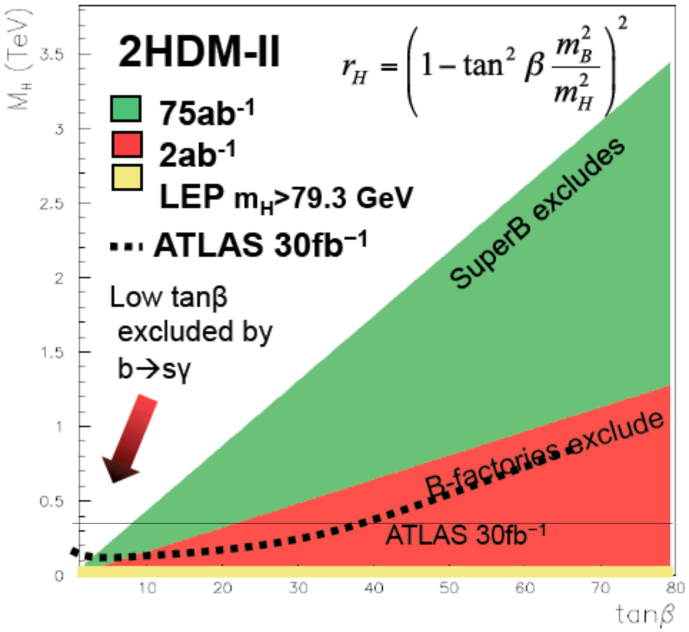
Muon mode extrapolation on 2HDM

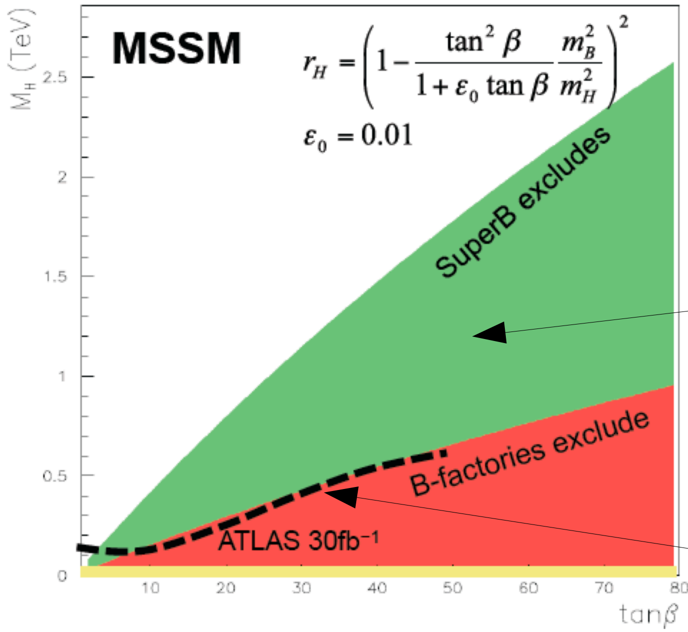
From Alejandro Perez @ HQL 2010

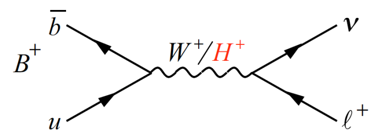


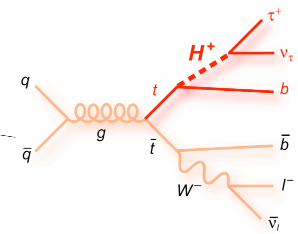


- From S.Robertson @ Miami workshop
  - Potential enhancement or suppression of branching fraction by H^+



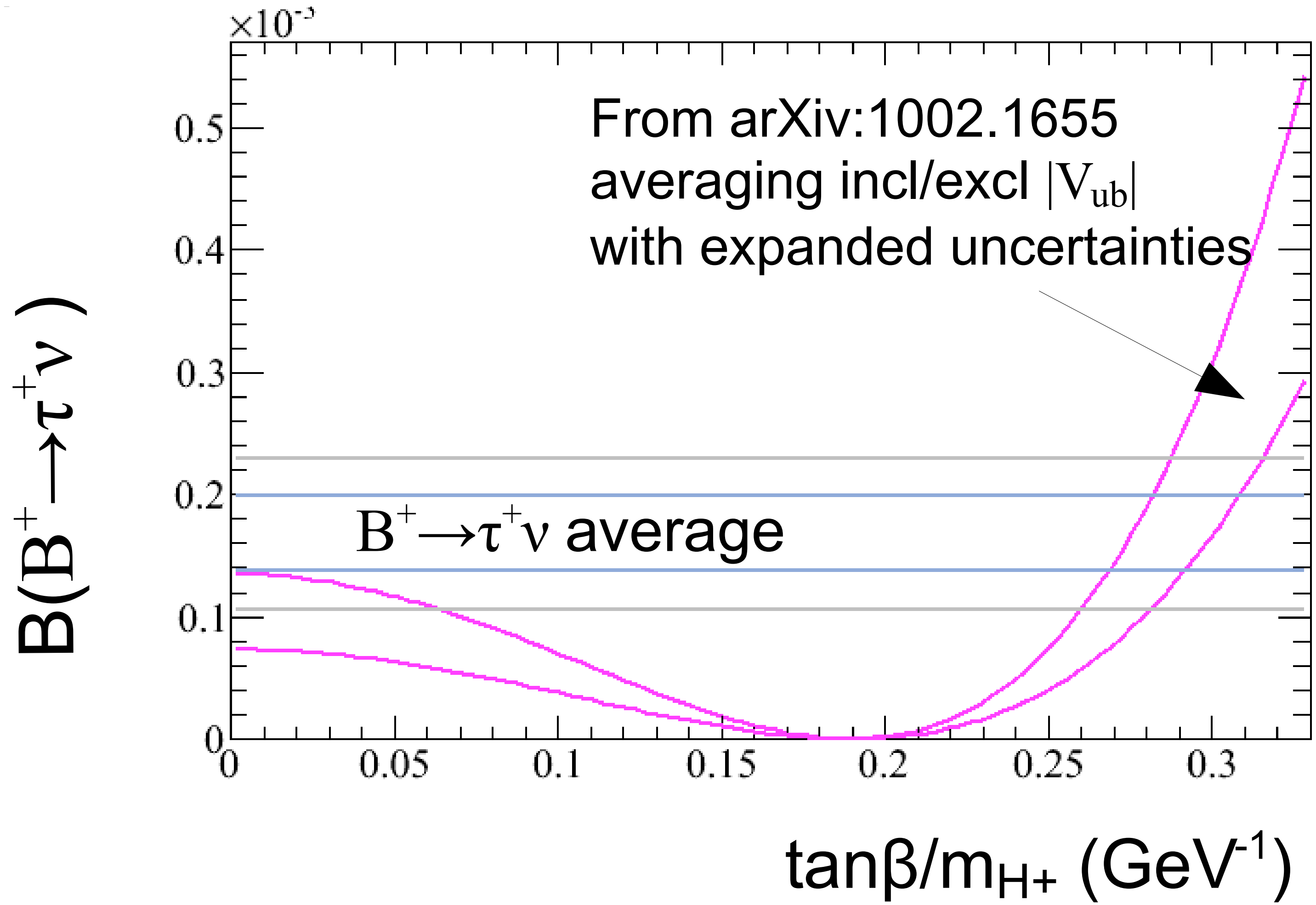






  - Precision measurements of both **$B^+\to\tau^+\nu$** and **$B^+\to\mu^+\nu$** feasible at SuperB (presumably $B \to D^{(*)}\tau\nu$ also, but not yet studied)

B → τν exclusion plot



BABAR $B^+ \to K^+ \tau^+ \tau^-$

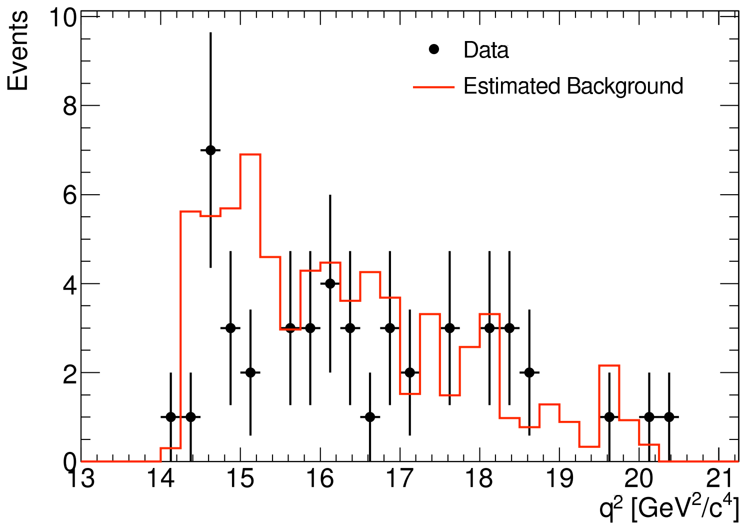
460 M B pairs

- Hadronic tag
- 1 prong τ decays, exactly three tracks, particle ID
- Requirements on q^2, track momentum, event shape, missing momentum, residual energy in calorimeter

- Expected background events: 65 ± 7
- Observed events: 47
- Signal efficiency 4.4 x 10^{-4}

- No excess of events seen
- 90% CL upper limit set to BF < 3.3 10^{-3}

Momentum transfer to lepton pair q^2



Belle B → h$^{(*)}$ ν ν

- No evidence of signal in any mode
- Assessed 90% U.L. with Feldman-Cousins prescriptions

Mode	N_{obs}	N_{side}	N_b	$\epsilon(\times 10^{-5})$	U.L.
$K^{*0}\nu\bar{\nu}$	7	16	4.2 ± 1.4	5.1 ± 0.3	$<3.4 \times 10^{-4}$
$K^{*+}\nu\bar{\nu}$	4	18	5.6 ± 1.8	5.8 ± 0.7	$<1.4 \times 10^{-4}$
$\to K_S^0\pi^+$	1	7	2.3 ± 1.2	2.8 ± 0.3	
$\to K^+\pi^0$	3	11	3.3 ± 1.4	3.0 ± 0.4	
$K^+\nu\bar{\nu}$	10	60	20.0 ± 4.0	26.7 ± 2.9	$<1.4 \times 10^{-5}$
$K^0\nu\bar{\nu}$	2	8	2.0 ± 0.9	5.0 ± 0.3	$<1.6 \times 10^{-4}$
$\pi^+\nu\bar{\nu}$	33	149	25.9 ± 3.9	24.2 ± 2.6	$<1.7 \times 10^{-4}$
$\pi^0\nu\bar{\nu}$	11	15	3.8 ± 1.3	12.8 ± 0.8	$<2.2 \times 10^{-4}$
$\rho^0\nu\bar{\nu}$	21	46	11.5 ± 2.3	8.4 ± 0.5	$<4.4 \times 10^{-4}$
$\rho^+\nu\bar{\nu}$	15	66	17.8 ± 3.2	8.5 ± 1.1	$<1.5 \times 10^{-4}$
$\phi\nu\bar{\nu}$	1	9	1.9 ± 0.9	9.6 ± 1.4	$<5.8 \times 10^{-5}$