$B \to D^{(*)} \tau \nu$ and Other New Physics Searches

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on behalf of the BaBar collaboration

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Outline

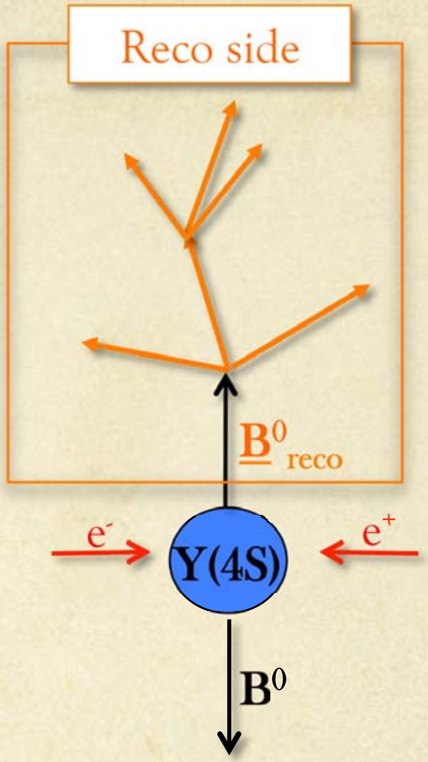
- Recoil Method
- BaBar results with full dataset
  - $B \to D^{(*)}\tau\nu$ [Phys. Rev. Lett. 109, 101802 (2012), 471×10^6 $B\underline{B}$ pairs]
  - $B \to \tau\nu$ [arXiv: 1207.0698, Submitted to PRD, 467.8×10^6 $B\underline{B}$ pairs]
  - $B \to$ invisible(γ) [Phys.Rev. D86, 051105 (2012), 471×10^6 $B\underline{B}$ pairs]
  - $B \to K^{(*)}\nu\nu$ [BaBar preliminary, 471×10^6 $B\underline{B}$ pairs]
- Conclusions

[charge-conjugation is implied throughout these slides]

Recoil Analysis Method

Recoil Method

- B_{reco} side: full/partial reconstruction of SL/HAD B final states
  - collect as many reconstructed B mesons as possible to study the recoil decay

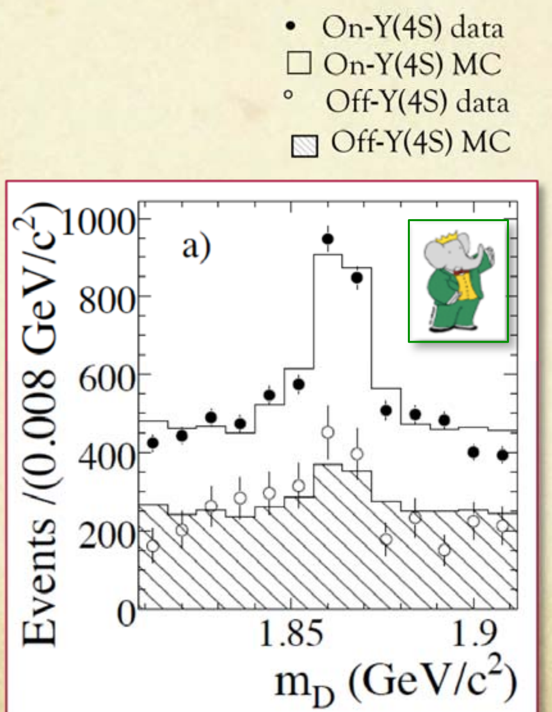


Recoil Method

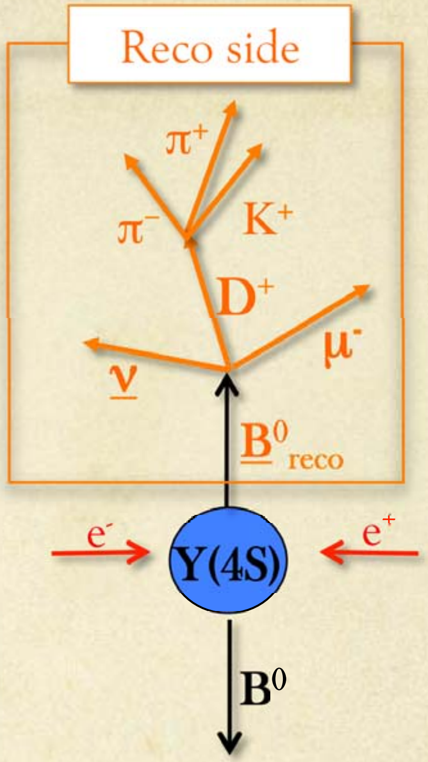
- B_{reco} side: full/partial reconstruction of SL/HAD B final states
  - collect as many reconstructed B mesons as possible to study the recoil decay

$B \rightarrow D^{(*)} \ell \nu$: semileptonic (SL) B_{reco}

- ℓ= e, μ
- ~ 30 B modes (charged+ neutral)
- 1 missing ν → unconstrained B kinematics
- ~2% reconstruction efficiency
- Also used in B→invisible(γ) analysis



[Phys.Rev. D78 , 072007 (2008)]



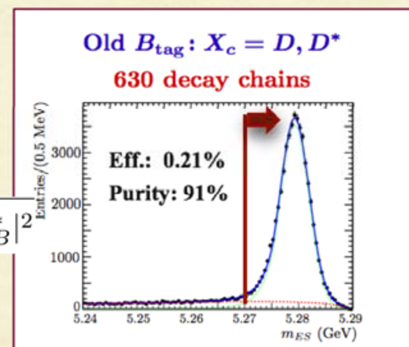
Recoil Method

- B_{reco} side: full/partial reconstruction of SL/HAD B final states
  - collect as many reconstructed B mesons as possible to study the recoil decay

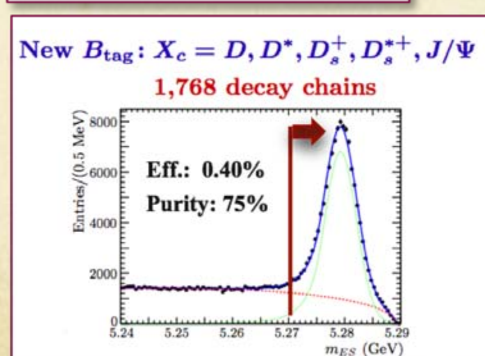
$B \to X_c X$: hadronic (HAD) B_{reco}

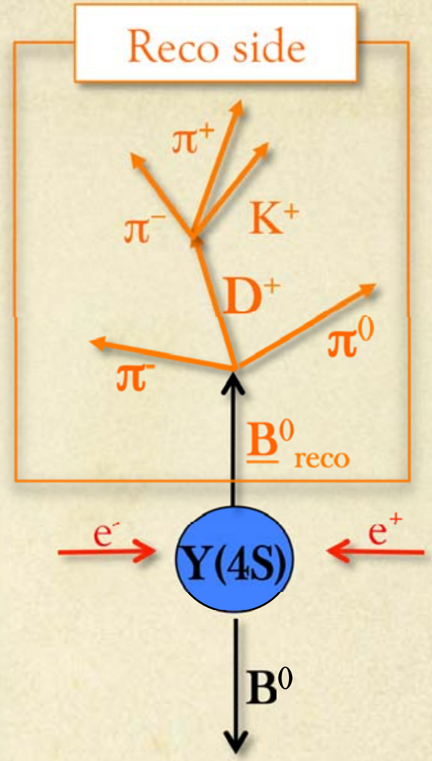
- X_c = D, D*, D_s, D^*_s, J/Ψ
- X= nπ mK pK_S $q\pi^0$
- Full B_{reco} reconstruction
- ~0.4% reconstruction efficiency, lower wrt SL reconstruction
- Improved algorithm wrt previous BaBar measurements
- Also used in $B \to D^{(*)}\tau\nu$, $B \to \tau\nu$, and $B \to K^{(*)}\nu\nu$ analyses

$$m_{ES} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$$



• MC
signal
bkg
tot

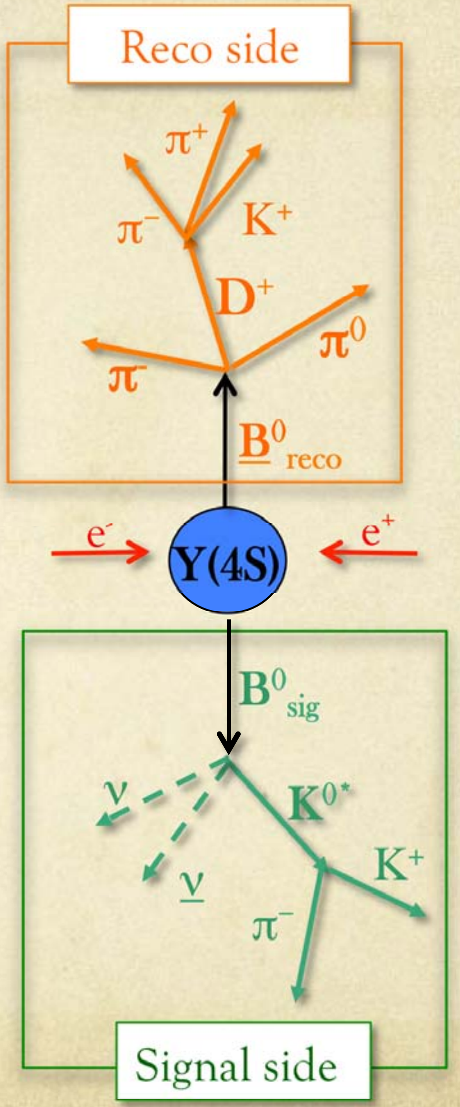




Recoil Method

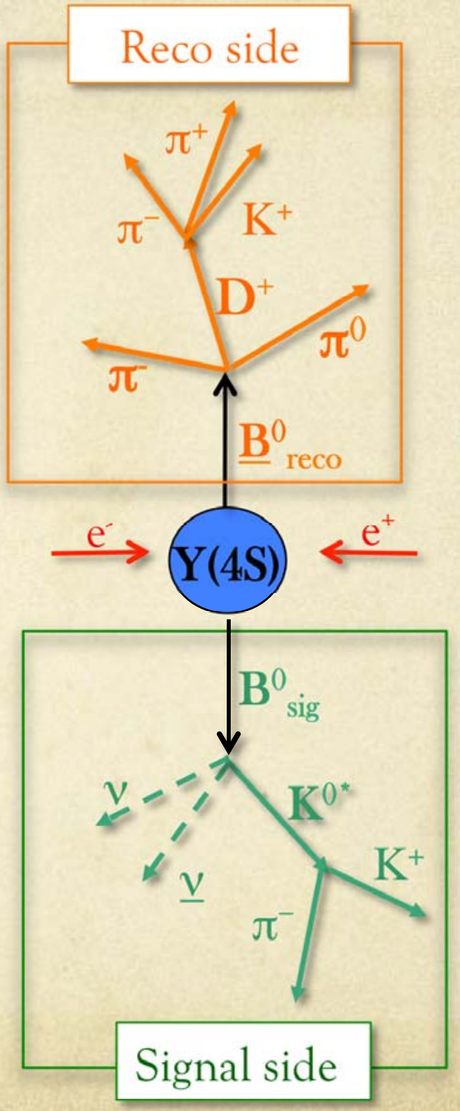
- B_{reco} side: full/partial reconstruction of SL/HAD B final states
  - collect as many reconstructed B mesons as possible to study the recoil decay

- B_{sig} side: search for a combination of tracks and neutrals + missing energy, in the B_{reco} recoil, compatible with the signal B decay under study



Recoil Method

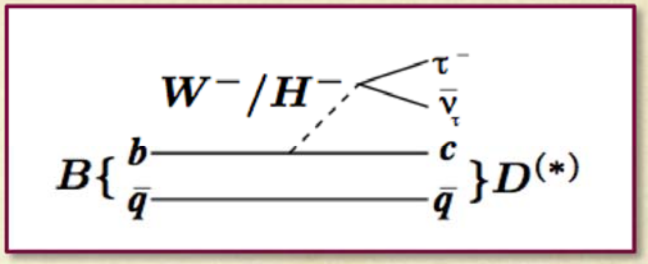
- B_{reco} side: full/partial reconstruction of SL/HAD B final states
  - collect as many reconstructed B mesons as possible to study the recoil decay
- B_{sig} side: search for a combination of tracks and neutrals + missing energy, in the B_{reco} recoil, compatible with the signal B decay under study
- RECOIL TECHNIQUE @ b FACTORIES → search for decays with missing energy, not feasible at hadron machines



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

Theoretical motivations (I)

- $b \to c\tau\nu$ transitions sensitive to New Physics (NP) models with charged Higgs, e.g. type II 2-Higgs Doublet Model (2HDM-II)



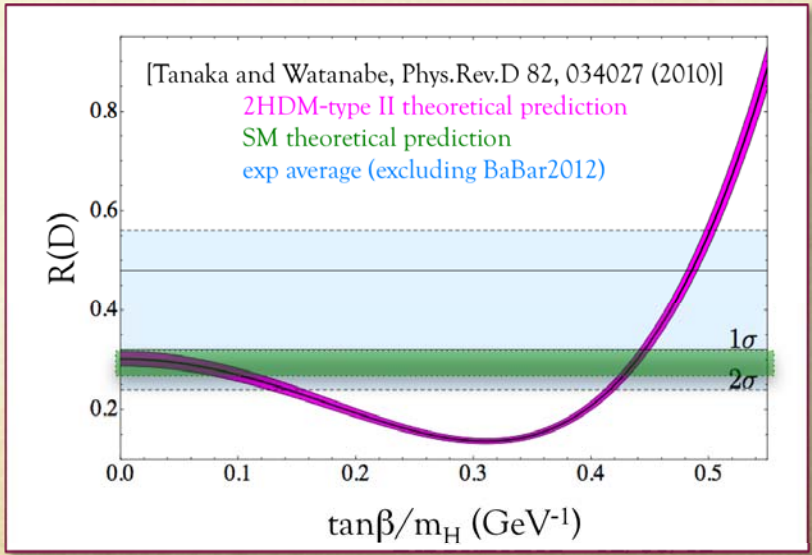
- Measuring the ratios:

$$\boxed{R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}}$$

  - some uncertainties from experiment (same reco'd final states for norm and sig) and theory (V_{cb}, form factors, ..) cancel

- SM predictions [Phys.Rev.Lett. 109,101802 (2012)]:
  - R(D) = 0.297 ± 0.017
  - R(D*) = 0.252 ± 0.003

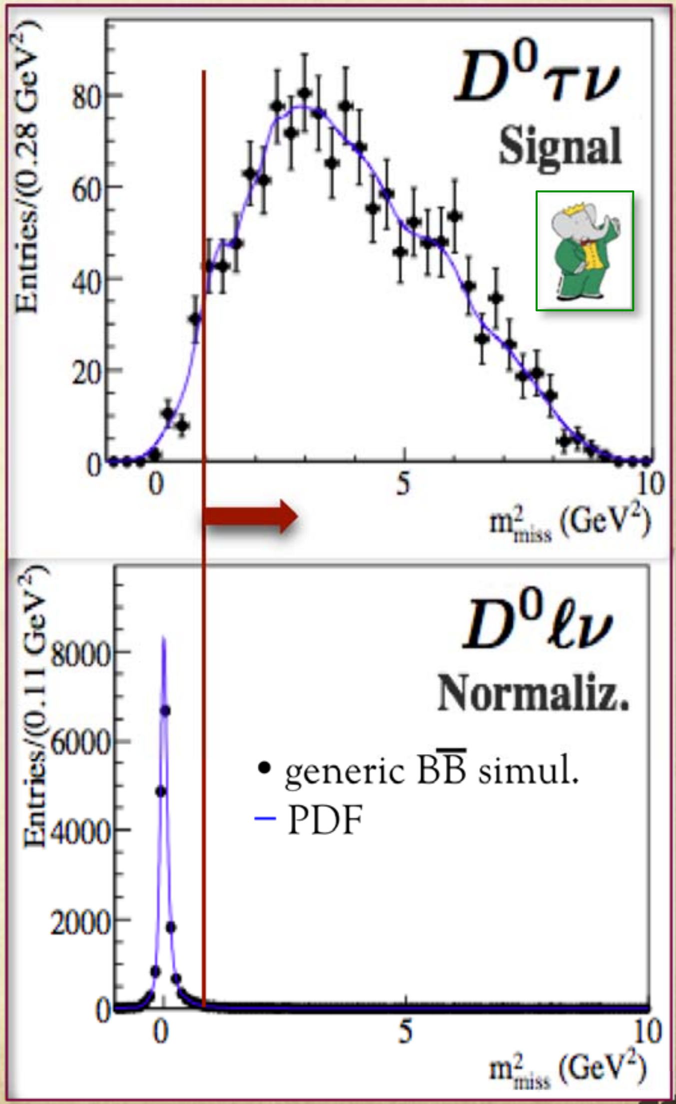
- 2HDM-II vs SM:
  - R(D) vs $\tan\beta/m_H$



B_{sig} reconstruction and event selection

- Search for a $D^{(*)}$ + e/μ in the HAD B_{reco} recoil
  - improved particle-ID: extend to lower p_ℓ region wrt to previous analysis
  - q^2>4GeV^2 and $|p_{miss}|$>200 MeV/c to reject D$\ell\nu$ and neutrino-less ($B\underline{B}$ combinatorial + $q\underline{q}$) events, respectively
- Combine discriminant variables in a Boosted Decision Tree algorithm
- Sample composition in the signal-enriched m^2_{miss} region (>1 GeV^2/c^4)

sample	evt frac (%)
$D^{(*)}\tau\nu$	39
$D^{(*)}\ell\nu$	10
$q\bar{q}$	19
$D^{**}\ell/\tau\nu$	13
other $B\bar{B}$	19



Fit Procedure

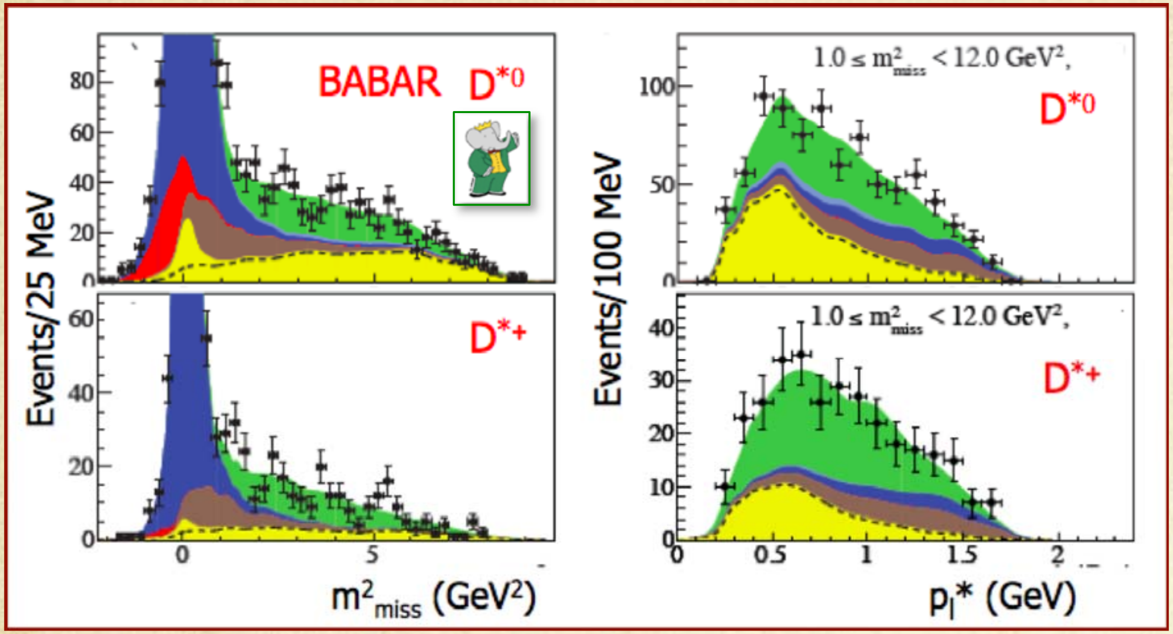
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)} = \frac{N_{sig}}{N_{norm}} \cdot \frac{\varepsilon_{norm}}{\varepsilon_{sig}}$$

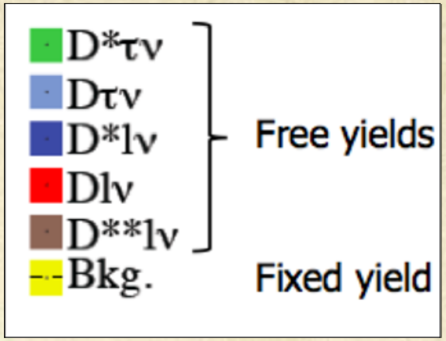
from MC simulation

- Signal and Normalization yields from 2D Extended Unbinned Maximum Likelihood (EUML) fits to m^2_{miss} and p^*_l
- 8 simultaneously fitted samples: 4 $D^{(*)}\ell$ (ℓ from normalization or signal channels) + 4 $D^{(*)}\pi^0\ell$
- Fitted yields : 4 $D^{(*)}\tau\nu$ + 4 $D^{(*)}\ell\nu$ + 4 $D^{**}\ell\nu$
- Fixed Yields (from MC simulation): Charge cross-feed + $B\underline{B}$ combinatorial + e+e- → $q\underline{q}(\gamma)$
- Fit uses 56 fully 2D PDFs
  - approximated using non-parametric kernel estimators
  - shapes derived from MC simulation and fixed in the fit to data

Results

Phys. Rev. Lett. 109, 101802 (2012)





- Largest syst uncertainty on yield ratio due to D**ℓν and other bkg knowledge
- Main syst error on efficiency ratio due to limited MC sample size

Decay	$R(D^{(*)})$	$\Sigma(\Sigma_{stat})$
$B^- \to D^{*0}\tau^-\bar{\nu}_\tau$	$0.322 \pm 0.032 \pm 0.022$	9.4(11.3)
$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$	$0.355 \pm 0.039 \pm 0.021$	10.4(11.6)
$\bar{B} \to D^{*}\tau^-\bar{\nu}_\tau$	$0.332 \pm 0.024 \pm 0.018$	13.2(16.4)
$B^- \to D^{0}\tau^-\bar{\nu}_\tau$	$0.429 \pm 0.082 \pm 0.052$	4.7(5.5)
$\bar{B}^0 \to D^{+}\tau^-\bar{\nu}_\tau$	$0.469 \pm 0.084 \pm 0.053$	5.2(6.1)
$\bar{B} \to D\tau^-\bar{\nu}_\tau$	$0.440 \pm 0.058 \pm 0.042$	6.8(8.4)

First 5σ observation for B→Dτν !

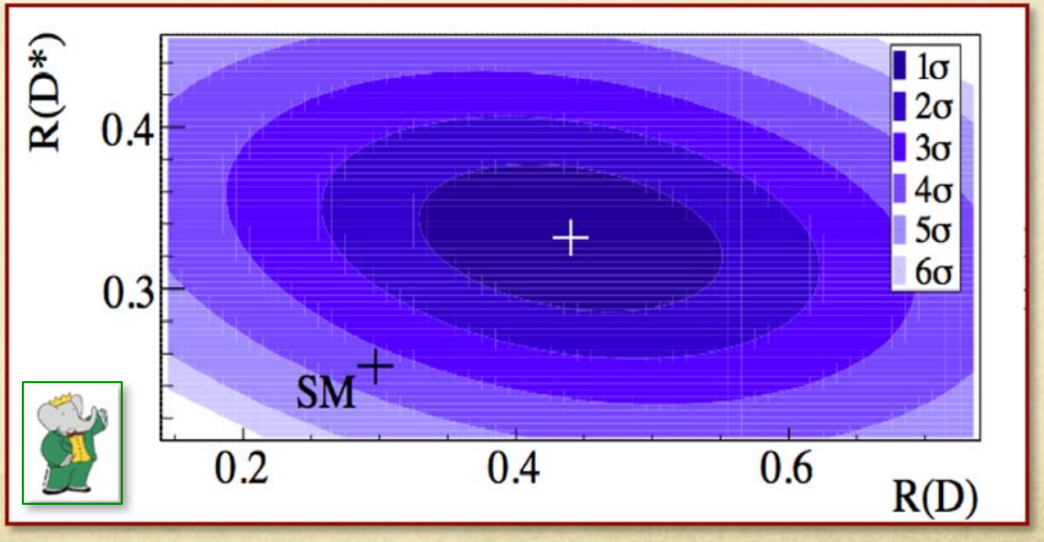
Experimental results and SM predictions

- BaBar measurements vs SM predictions:

	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	2.0 σ	2.7 σ

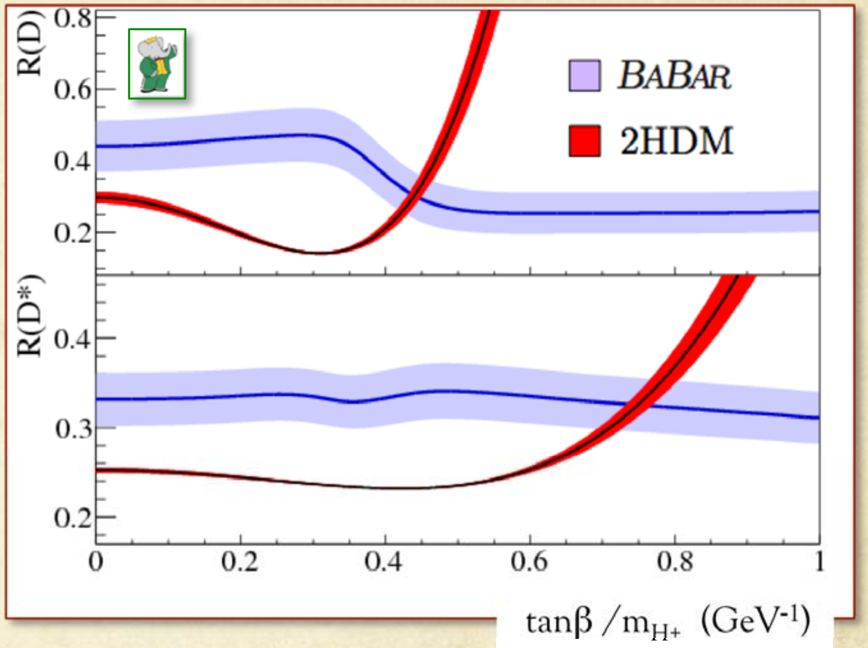
- Combining the 2 measurements and accounting for their -0.27 correlation:

Experimental results (stat+syst errors) deviate from SM predictions by 3.4σ



Experimental results and 2HDM-II predictions

- Re-weight BaBar simulation to account for changes in the hadronic currents due to 2HDM-II
  - re-compute efficiencies and PDFs and repeat the fit
  - large change of signal yield for $\tan\beta/m_H > 0.4\ \mathrm{GeV}^{-1}$
- Experimental data vs 2HDM-II predictions:
  - $R(D)$: $\tan\beta/m_{H+} = (0.44 \pm 0.02)\ \mathrm{GeV}^{-1}$
  - $R(D^*)$: $\tan\beta/m_{H+} = (0.75 \pm 0.04)\ \mathrm{GeV}^{-1}$



- 2HDM-II excluded in the full $\tan\beta$ vs m_{H+} plane at 99.8% C.L.
  - computation for $m_{H+} > 10$ GeV
  - lower mass region already excluded by $B \to X_s \gamma$ measurement at B factories

$B \rightarrow \tau\nu$

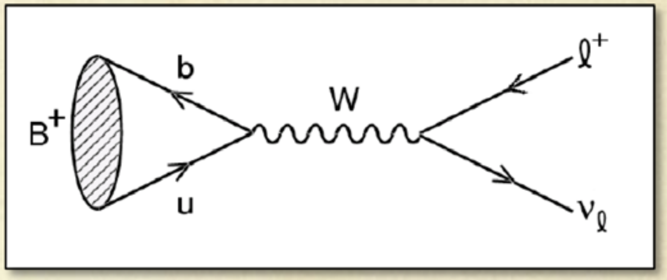
Theoretical Motivations

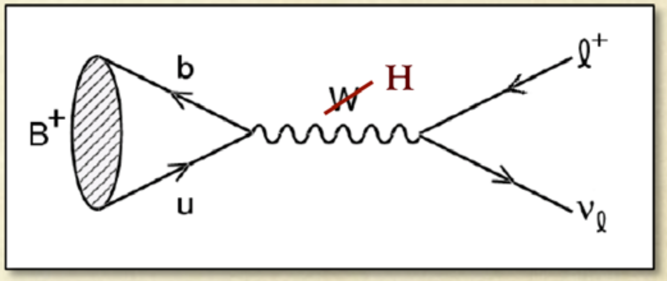
- SM prediction: $\boxed{\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)_{SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 \left|V_{ub}\right|^2 \tau_B}$
- Inputs and numerical predictions:
  - f_B = (189 ± 4) MeV [HPQCD coll. hep-lat/12024914]
  - excl. $|V_{ub}|$

    [M.F. Sevilla(BaBar collab.), PoS(EPS-HEP2011)155 2011]

    $\mathcal{B}(B\to\tau\nu)_{SM}$ = (0.62 ± 0.12) x 10^{-4}
  - incl. $|V_{ub}|$ [BaBar, Phys.Rev. D86, 032004, 2012]

    $\mathcal{B}(B\to\tau\nu)_{SM}$ = (1.18 ± 0.16) x 10^{-4}





- 2HDM-II:

$$\boxed{\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)_{2HDM-II} = \mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)_{SM}\left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2}$$

Analysis strategy

- HAD B_{reco} + 1 single track: $\tau \to e\nu$, $\mu\nu$, $\pi\nu$, $\rho(\pi\pi^0)\nu$, ~ 70% of τ final states

- Cut-based selection + likelihood ratios for τ modes with π: surviving bkg from SL B decays, charmless /charmed B decays ($\tau \to \pi\nu$/ $\rho(\pi\pi^0)\nu$)

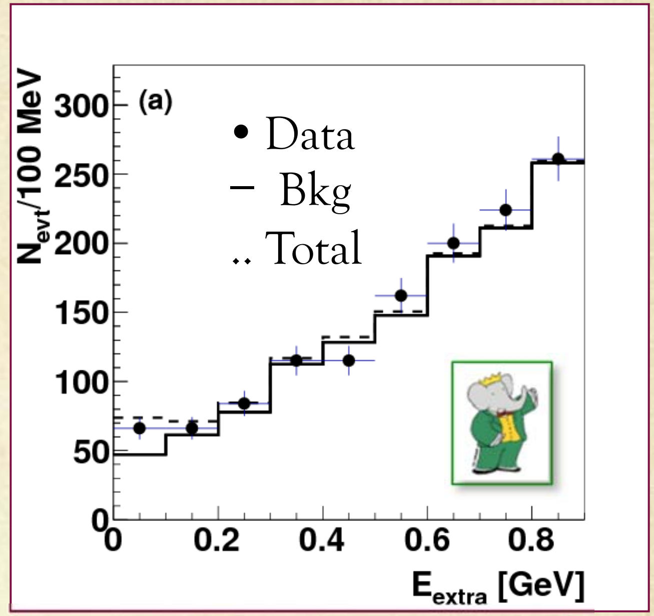
- $\mathcal{B}$ extracted from EUML fit to E_{extra} distribution

neutral energy not associated to B_{sig} nor to B_{tag}

- Bkg shape fixed from m_{ES} sideband and $B\underline{B}$ MC, signal shape coming from MC and control samples

- E_{extra} shape validated by using double-tag sample (2 B's reco'd in HAD modes)

- Main syst uncertainties on $\mathcal{B}$ due to: bkg PDF parameterization, data/MC disagreement in E_{extra} shape, B_{reco} efficiency correction



Decay Mode	$\mathcal{B}(\times 10^{-4})$
$\tau^+ \to e^+\nu\bar{\nu}$	$0.35^{+0.84}_{-0.73}$
$\tau^+ \to \mu^+\nu\bar{\nu}$	$1.12^{+0.90}_{-0.78}$
$\tau^+ \to \pi^+\nu$	$3.69^{+1.42}_{-1.22}$
$\tau^+ \to \rho^+\nu$	$3.78^{+1.65}_{-1.45}$
Combined	$1.83^{+0.53}_{-0.49} \pm 0.24$

stat errors only

stat syst

Result and comparison with theory

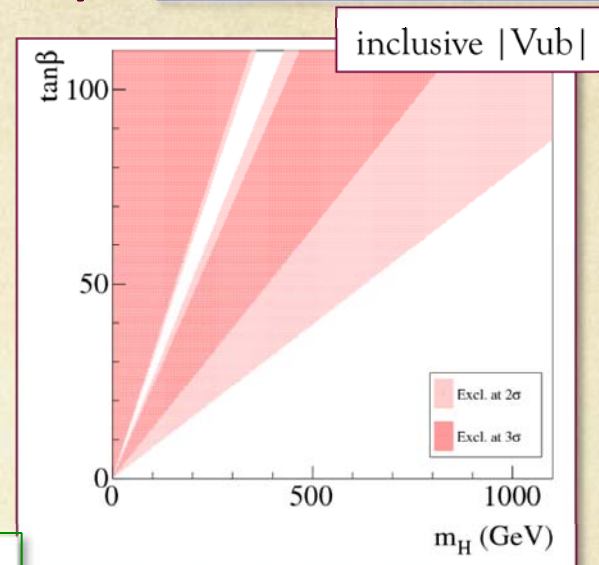
arXiv: 1207.0698, submitted to Phys.Rev.D

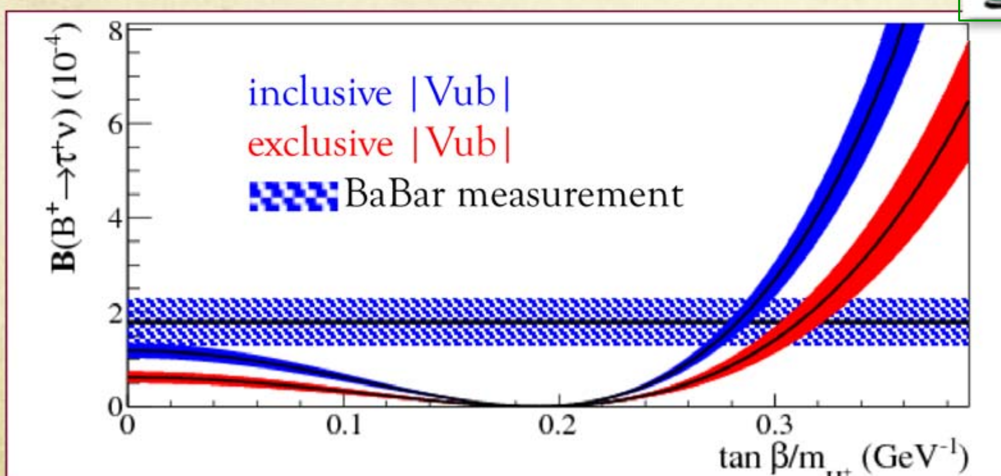
- Result combined with SL B_{reco} analysis [Phys. Rev. Lett. 109, 101802 (2012)] (stat+syst error):

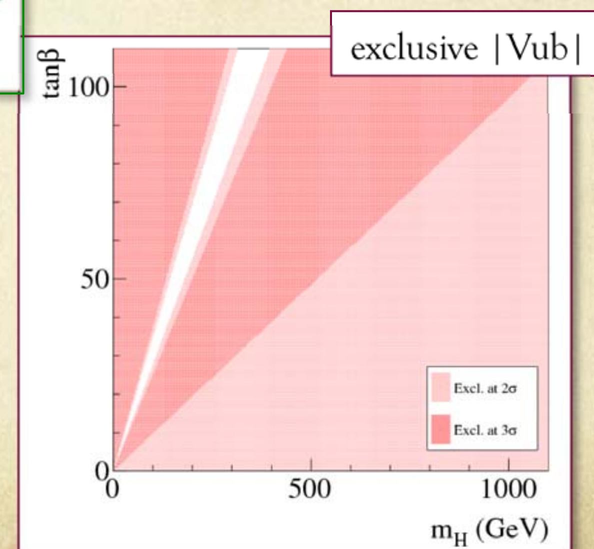
$$\boxed{\mathcal{B}(B\rightarrow\tau\nu) = (1.79 \pm 0.49) \times 10^{-4}}$$

- 1.6 σ (2.4 σ) excess wrt SM prediction with exclusive (inclusive) $|V_{ub}|$

- Limits on 2HDM-II parameter space:



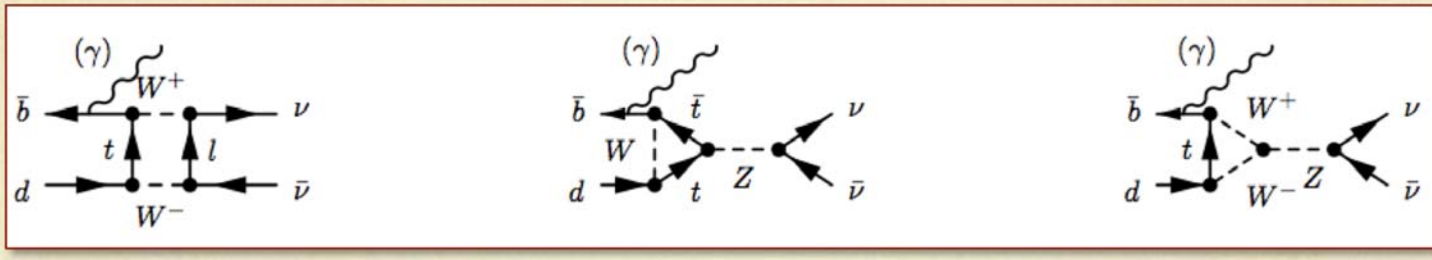




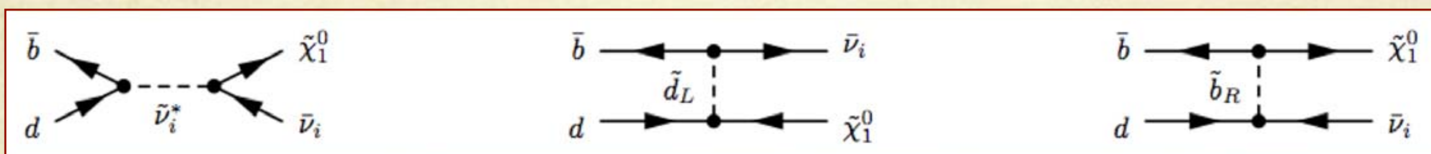
$B \to invisible(\gamma)$

Theoretical motivations

- Search for "disappearance decays" of B^0 with/without a photon
  - SM: $B^0 \to \nu\bar{\nu}$ suppressed by a factor $(m_\nu/m_B)^2$, $\mathcal{B}(B^0 \to \nu\bar{\nu}\gamma) \sim O(10^{-9})$



  - SUSY: $\mathcal{B}(B^0 \to \text{invisible})$ enhanced up to 10^{-7}-10^{-6} due to neutrino+neutralino production [Dedes et al., Phys.Rev.D 65, 015001 (2001)]

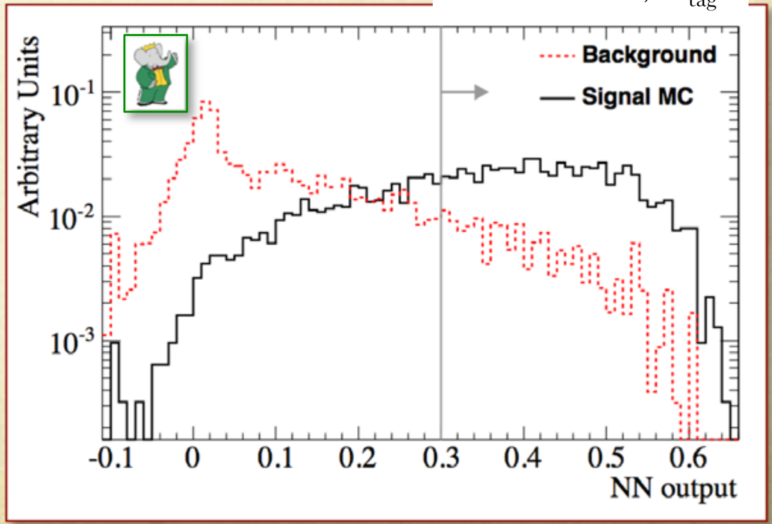


- Previous BaBar measurement with 88.5 fb^{-1} [Phys. Rev. Lett. 93, 091802 (2004)]:
  - $\mathcal{B}(B^0 \to \text{invisible}) < 22 \times 10^{-5}$
  - $\mathcal{B}(B^0 \to \text{invisible}\ \gamma) < 4.7 \times 10^{-5}$

Analysis steps

- SL B_{reco} reconstruction + no extra tracks
  - + 1 high energy photon, E_γ>1.2 GeV ($B^0 \to$invisible γ)
- Pre-selection on kinematic variables (e.g. $D^{(*)}$ properties, missing momentum, γ energy in $B^0 \to$invisible γ)
- Most discriminant variables used as input for 4 Neural Networks
  - (D_{tag},D_{tag}*) x (inv., inv.γ)

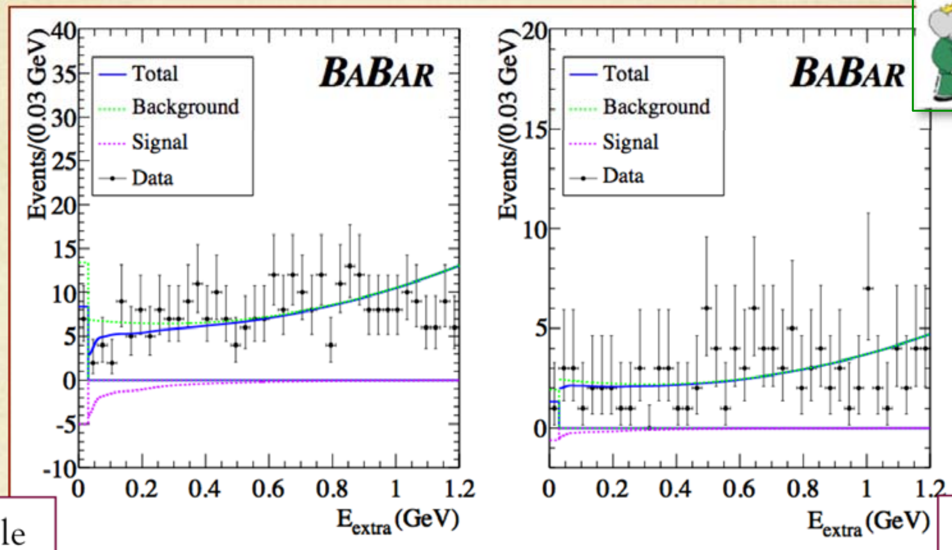
$B \to$invisible , D_{tag}



- Yield extraction from EUML fit to Eextra
  - signal shape from MC
  - bkg shape from m_D (D_{tag} channels) and $\Delta m = m_{D^*} - m_D$ (D^*_{tag} channels) On-Y(4S) peak data sidebands

Results

Phys. Rev. D86, 051105 (2012)



$B^0 \to$invisible

$B^0 \to$invisible γ

- Main syst error affecting $\mathcal{B}$ due to bkg parameterization in the fit
- UL @ 90% Confidence Level (C.L.) :

$$\mathcal{B}(B^0 \to \text{invisible}) < 2.4 \times 10^{-5}$$

$$\mathcal{B}(B^0 \to \text{invisible } \gamma) < 1.7 \times 10^{-5}$$

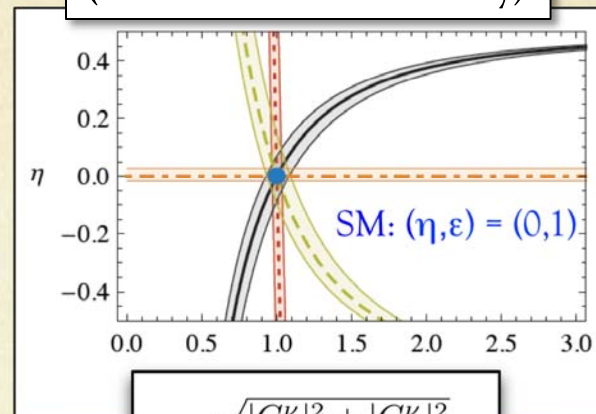
- Factor 9 (inv.) and 4 (inv. γ) improvement wrt previous BaBar measurement
- Still 1 order of magnitude from NP sensitivity

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

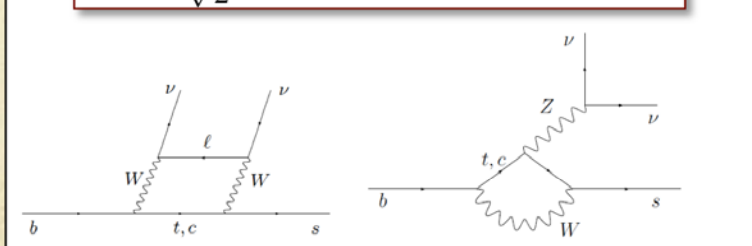
Theoretical motivations : B→K$^{(*)}$νν

- Standard Model (SM) predictions [Altmannshofer et al. JHEP 0904, 022 (2009)]:
  - $\mathcal{B}$(B→Kνν)=(4.5±0.7)x10^{-6} (1-2η)ε^2
  - $\mathcal{B}$(B→K*νν)=(6.8±1.1)x10^{-6} (1+1.31η)ε^2
  - F$_L$(B→K*νν)=(0.54±0.01) (1+2η)/(1+1.31η)

(theoretical errors only)



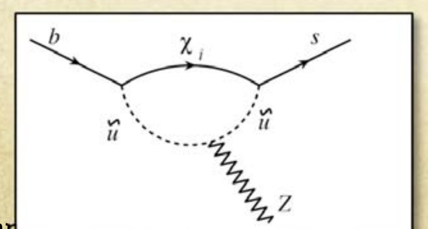
$$\mathcal{H} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^*(\mathcal{C}_L^\nu \mathcal{O}^\nu{}_L + \mathcal{C}_R^\nu \mathcal{O}^\nu{}_R) + h.c.$$

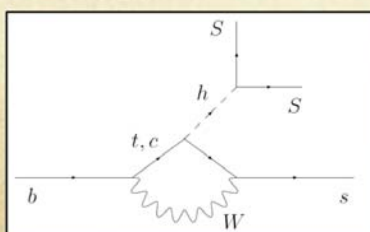


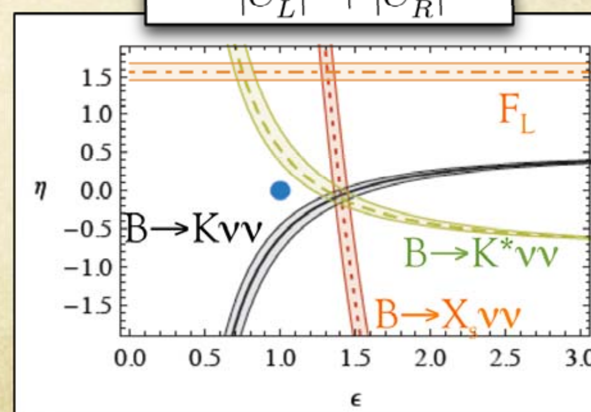
$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{SM}|}$$

$$\eta = \frac{-Re(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

- New Physics (NP) effects
  - non Standard Z-couplings
  - new sources of missing energy





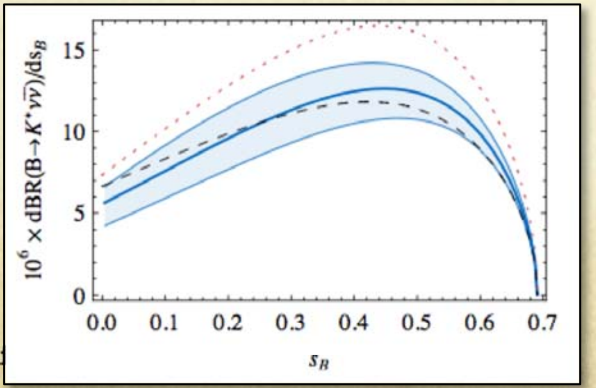


Analysis strategy

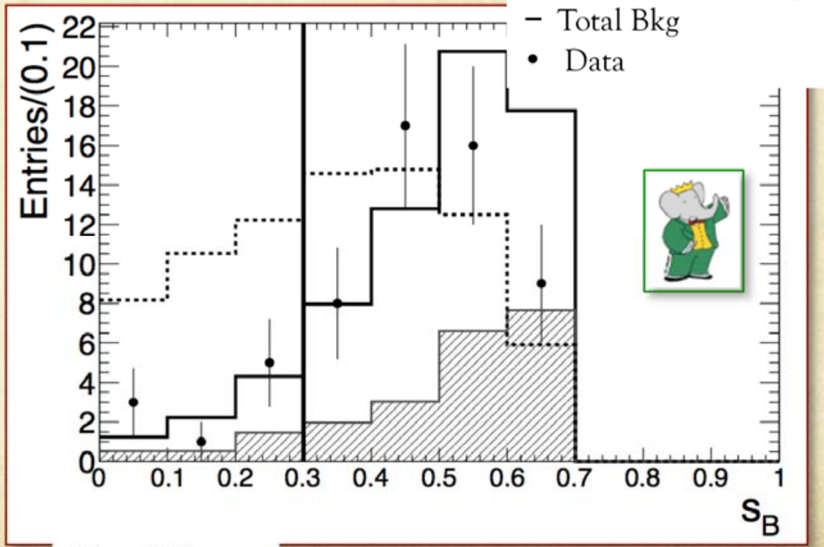
- HAD B_{reco} reconstruction + $K^+/K_s(\pi\pi)/K^{*+}(K\pi^0,K_s\pi)/K^{*0}(K\pi,K_s\pi^0)$ and no extra tracks
- Missing momentum, event shape variables, and B_{reco} kinematics combined in a multivariate likelihood selector
- normalized neutrino pair invariant mass: $s_B=q^2/m_B$
  - low s_B region used to extract SM UpperLimit
  - full s_B range used to quote model-independent partial $\mathcal{B}$ ($\Delta\mathcal{B}_i$)

SM with “nominal” Form Factors
.. / − SM with different sets of FF

[Altmannshofer et al. JHEP 0904, 022 (2009)]



... Signal (arbitrary norm)
Combinatorial Bkg
− Total Bkg
• Data



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

Results and constraints on theory

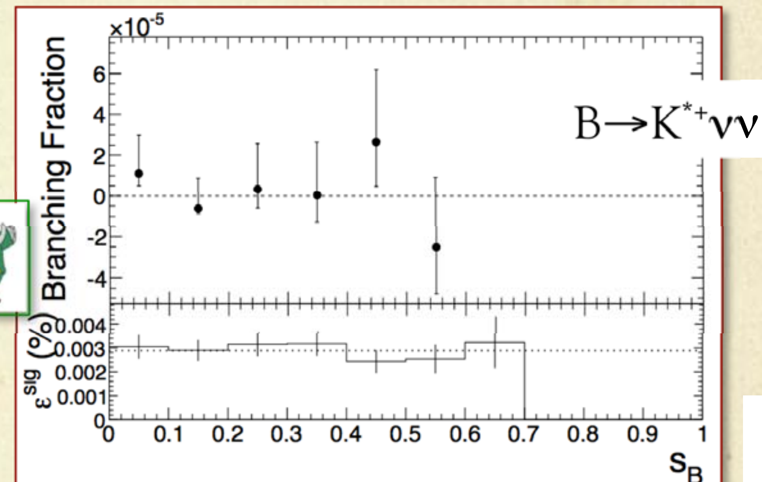
Preliminary results

Most stringent limits using HAD Breco technique

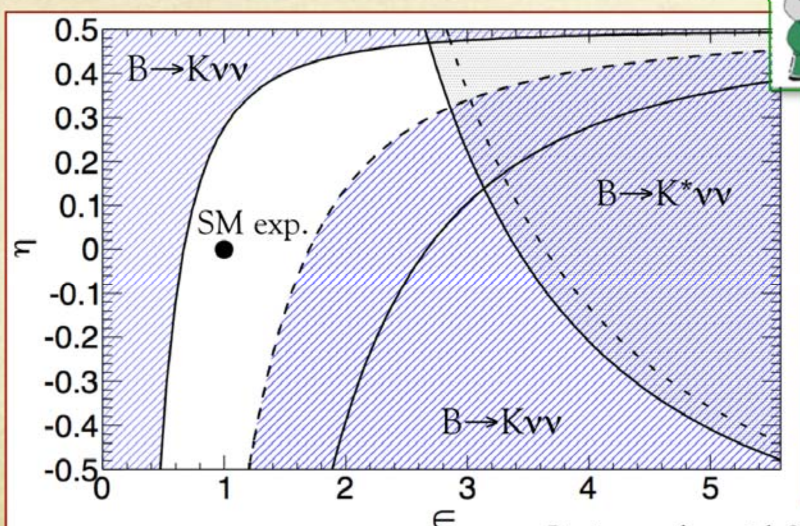
- SM UL (s_B<0.3) :

	$B \to K^+\nu\bar\nu$	$B \to K^0\nu\bar\nu$	$B \to K^{*+}\nu\bar\nu$	$B \to K^{*0}\nu\bar\nu$
$\mathcal{B}(\times 10^-5)$	$(> 0.4, < 3.7)$	< 8.1	< 11.6	< 9.3
Combined	$(> 0.2, < 3.2)$		< 7.9	

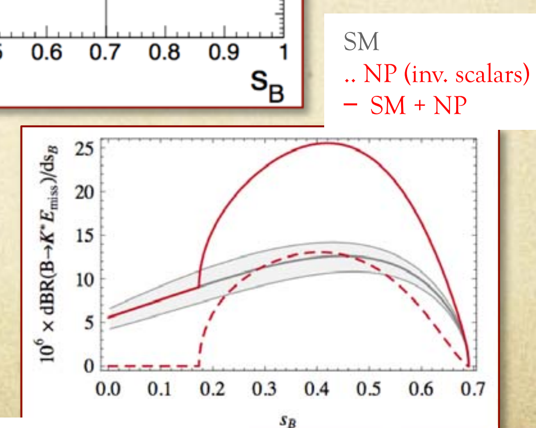
- Partial $\mathcal{B}$, in s_B bins of width 0.1 (model independent): $\Delta\mathcal{B} = \frac{N^{obs}_{bin} - N^{bkg}_{bin}}{N_{BB}\varepsilon^{sig}_{bin}} \cdot \frac{\varepsilon^{sig}_{bin}}{\varepsilon^{sig}_{full}}$



- Constraints on (η-ε) plane:



... Previous analyses with SL B_{reco}
Phys.Rev. D78 (2008) 072007
Phys.Rev. D82 (2010) 112002
– Preliminary 2012 analysis



[Altmannshofer et al. JHEP 0904, 022 (2009)]

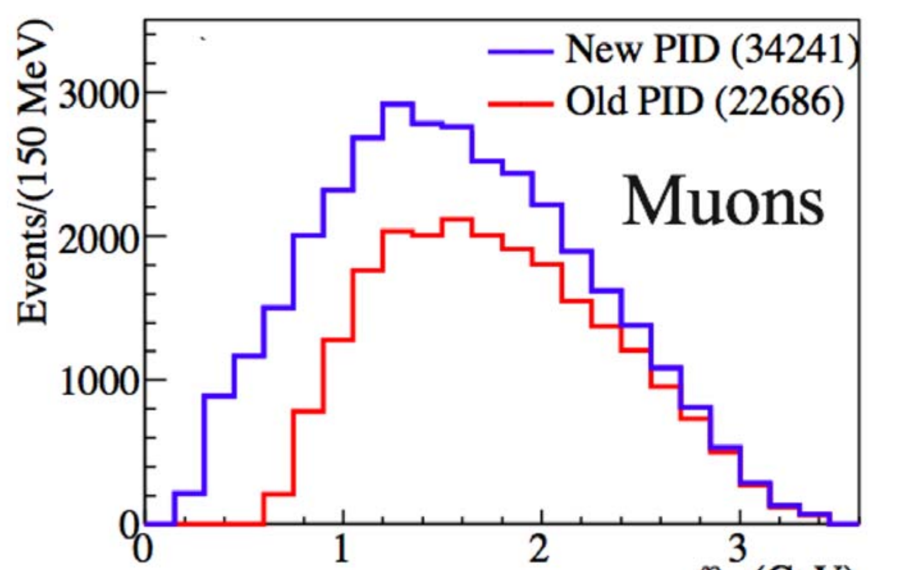
Conclusions

- Studies on some B decays with invisible particles in the final state updated with full BaBar dataset
- $B \to D^{(*)}\tau\nu$: deviations from SM expectations at 3.4 σ level; 2HDM-II excluded at 99.8 C.L. %
- $B \to \tau\nu$: excess wrt SM expectations, not accomodated by 2HDM-II
- $B \to$ invisible(γ): improved results wrt previous measurements, still 1 order of magnitude from NP sensitivity
- $B \to K^{(*)}\nu\nu$: best upper limits to date with HAD B_{reco}, consistent with SM expectations

Extra-slides

Improved particle ID

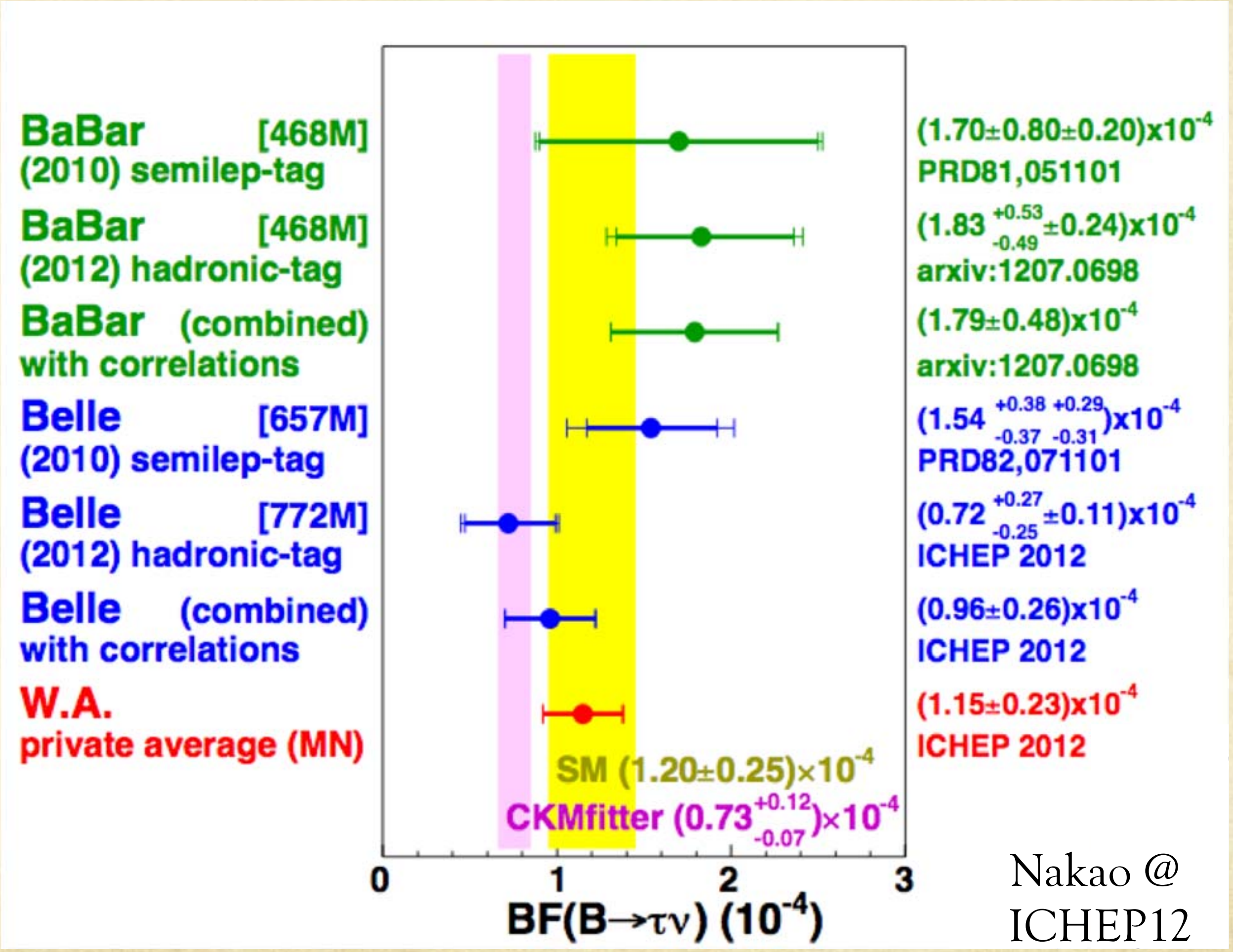
- Improved algorithm to identify μ's which adds electromagnetic calorimeter infos to muon system measurement
  - allow to reconstruct low momentum μ that does not reach the muon system



B$\underline{\text{B}}$ MC sample

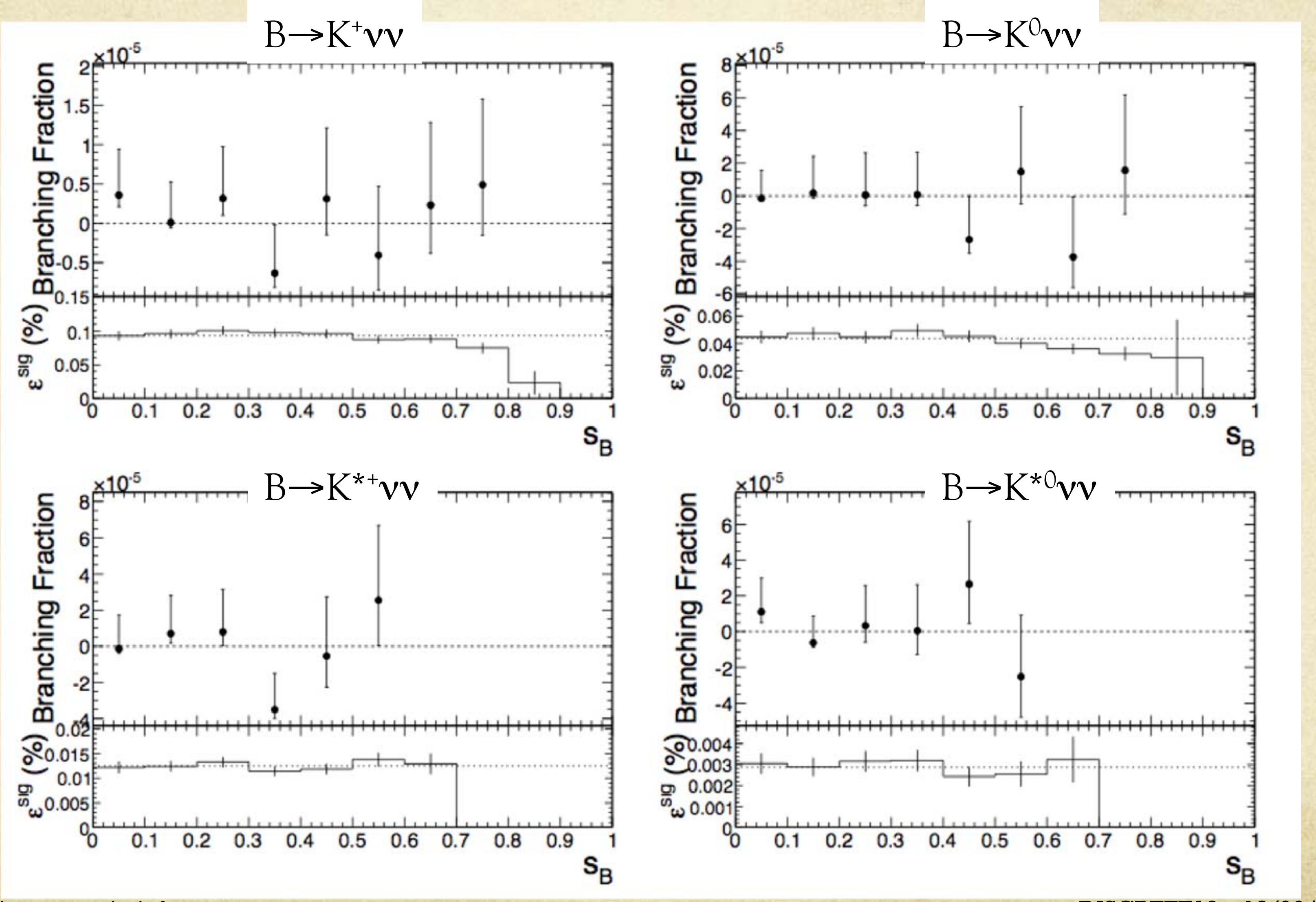
M.F. Sevilla
SLAC experimental seminar
(06/12/12)

B→τν: comparison among measurements



Nakao @ ICHEP12

$B \to K^{(*)}\nu\nu$: $\Delta\mathcal{B}$ for all channels



B→invisible(γ)

- Previous BaBar analysis:
  - B→Inv.
    - Signal Yield: $17\pm9_{(stat)}\pm7.4_{(sys)}$
    - Signal Efficiency: $(1.64\pm0.10_{(stat)}\pm0.18_{(syst)})x10^{-3}$
  - B→Inv.
    - Signal Yield: $-1.1^{+2.4}_{-1.9}(stat)\pm4.3(sys)$
    - Signal Efficiency: $(1.44\pm0.10_{(stat)}\pm0.16_{(syst)})x10^{-3}$
- Uls
  - B to Inv. : $22x10^{-5}$
  - B to Inv.+ γ : $4.7x10^{-5}$

88 .5 fb^{-1}

- This analysis:
  - B→Inv.
    - Signal Yield: $-22\pm9_{(stat)}\pm16_{(sys)}$
    - Signal Efficiency: $(1.78\pm0.02_{(stat)}\pm0.14_{(syst)})x10^{-3}$
  - B→Inv.
    - Signal Yield: $-3.1\pm5.2_{(stat)}\pm7.0_{(sys)}$
    - Signal Efficiency: $(1.60\pm0.02_{(stat)}\pm0.15_{(syst)})x10^{-3}$
- ULs:
  - B to Inv. : $2.4x10^{-5}$
  - B to Inv.+ γ : $1.7x10^{-5}$

424 fb^{-1}