Measurement of an excess of $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ and implications for charged Higgs bosons

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Outline

What are we talking about?

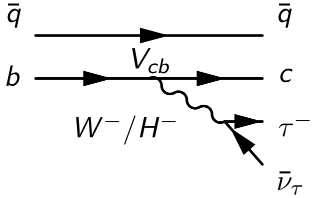


Figure : Decay $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$

- Decays involving τ are sensitive to additional amplitudes e.g. charged Higgs
- Measure ratio $R(D^{(*)}) = \frac{B(\bar{B}\to D^{(*)}\tau^-\bar{\nu}_\tau)}{B(\bar{B}\to D^{(*)}l^-\bar{\nu}_l)} \quad l = e, \mu$
- Potential influence of type II and type III 2HDM (Two-Higgs-Doublet-Model)

Standard Model calculation

$$M(q^2,\theta_\tau) = \frac{G_F V_{cb}}{\sqrt{2}} \sum_{\lambda_W=0,\pm,s} \eta_{\lambda_W} L_{\lambda_W}(q^2,\theta_\tau) H_{\lambda_W}(q^2)$$

$$\eta_{\lambda_{\pm,0,s}} = \{1,1,-1\}, \theta_\tau \sphericalangle \tau, D^*$$

- The matrix element factorizes:
  - L_{λ_W} leptonic current, analytically solvable
  - H_{λ_W} hadronic current $\rightarrow$ form factors
- ratio independent of V_{cb}

Result of the SM calculation

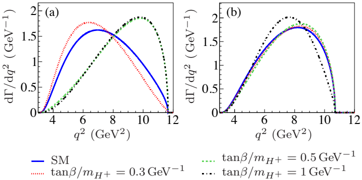
$$R(D)_{SM} = 0.297 \pm 0.017$$
$$R(D^*)_{SM} = 0.252 \pm 0.003$$

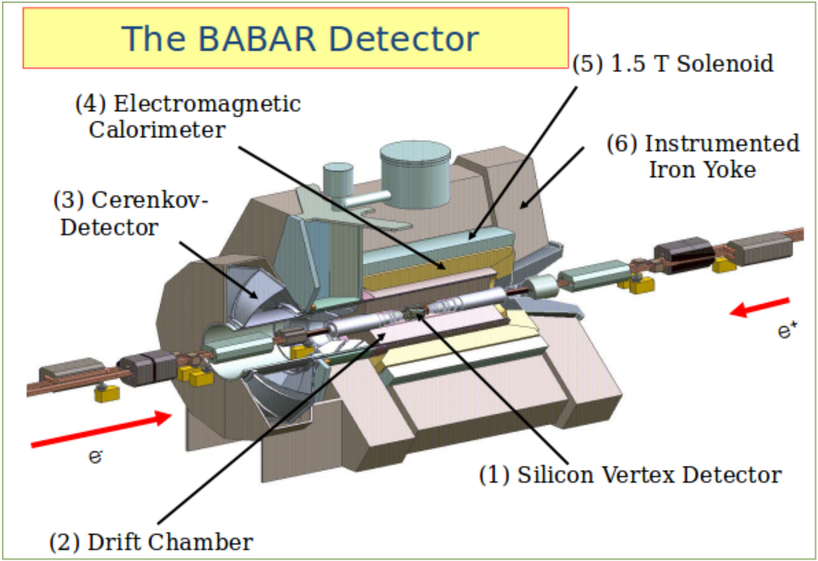
Two-Higgs-doublet models

- 8 dof $\rightarrow h, H, A, H^{\pm}$ + 3 Goldstone bosons
- corrections to the Hamiltonian $\rightarrow R$
- $R(D^{(*)})_{2HDM} = R(D^{(*)})_{SM} + A_{D^{(*)}} \frac{\tan^2\beta}{m^2_{H^\pm}} + B_{D^{(*)}} \frac{\tan^4\beta}{m^4_{H^\pm}}$
- bigger influence on decay to $D \rightarrow$ why?
  - charged Higgs only contributes to scalar amplitude
  - D^* also has contributions $H_\pm$

Dependence of R on $\frac{\tan\beta}{m_{H^\pm}}$

	$\bar{B} \rightarrow D\tau^- \bar{\nu}_\tau$	$\bar{B} \rightarrow D^*\tau^- \bar{\nu}_\tau$
$A_{D(*)}(GeV^2)$	-3.25 ± 0.32	-0.230 ± 0.029
$B_{D(*)}(GeV^2)$	16.9 ± 2.0	0.643 ± 0.085



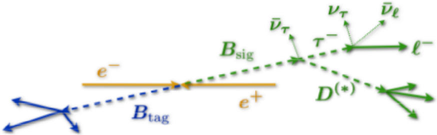

The BABAR Detector
(5) 1.5 T Solenoid
(4) Electromagnetic Calorimeter
(6) Instrumented Iron Yoke
(3) Cerenkov-Detector
e^+
e^-
(1) Silicon Vertex Detector
(2) Drift Chamber

Event Selection

- Categories:
  - Signal: $B \to D^{(*)}\tau\nu_\tau$ (τ decay leptonically)
  - Normalization: $B \to D^{(*)}l\nu$ ($l = \mu, e$)
  - Backgrounds:
    - combinatorial background: $B\bar{B}$ events
    - continuum $e^+e^- \to q\bar{q}(\gamma)$
    - $B \to D^{**}(\tau/l)\nu$
    - charge-crossfeed (wrong charge reconstruction)
  - Control samples: $B \to D^{(*)}\pi^0 l\nu$

- All events selected go one out of 4 samples: $D^{(*)0}l$ and $D^{(*)+}l$

Event selection



- $\Upsilon(4S)$ resonance decays to $B\bar{B}$
- hadronic decay of B_{tag} (1680 decay chains)
- use kinematic variables
  - $m_{ES} = \sqrt{E_{beam}^2 - p_{tag}^2}$ with E_{beam} c.m. energy of a single beam particle
  - $\Delta E = E_{tag} - E_{beam}$
  - require $m_{ES} > 5.27\,\mathrm{GeV}$ and $|\Delta E| < 0.072\,\mathrm{GeV}$
- semileptonic decay of second B meson
- further background reduction

  $\rightarrow$ mass reconstruction of decay products, vertex position,...

Fit

- Maximum likelihood fit in $m^2_{miss} - |p^*_l|$
- 56 PDFs to fit with four samples of $D^{(*)}l$ an of $D^{(*)}\pi^0 l$
- Constraints:
  - free: signal and normalization
  - fixed: $B\bar{B}$ and continuum backgrounds
  - to other samples: $B \to D^{**}(\tau/l)\nu$ background and feed up/down
  - updated by iteration: cross-feed background
  - isospin: repeat fit using $R(D^{(*)0}) = R(D^{(*)+}) = R(D^{(*)})$
- Iteration: PDFs are updated with constraints of each iteration till the fit does not change more than 0.01%
- PDFs: described by non-parametric kernel estimators, smoothered by the width of Gaussian functions
- Result: $R(D^{(*)}) = \frac{N_{sig}}{N_{norm}} \frac{\epsilon_{norm}}{\epsilon_{sig}}$

Fit Results

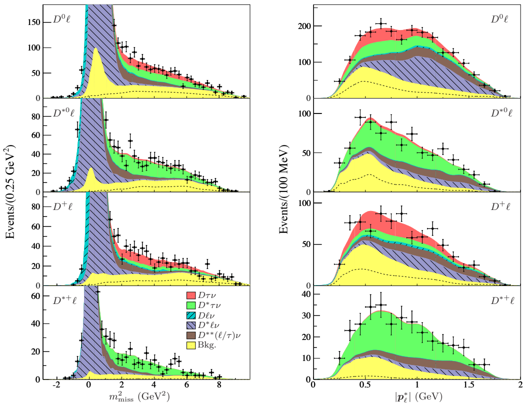


Figure : PDFs after the fit.

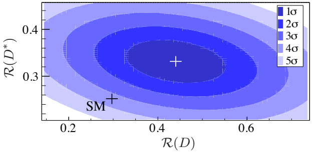
Uncertainties

Type	Source	R(D) (%)	R(D^*) (%)
	PDFs MC statistics	**4.4**	**2.0**
	$\bar{B} \to D^{(*)}(\tau^- / l^-)\bar{\nu}$ FFs	0.2	0.2
Additive	$B \to D^{**}(\pi^0 / pi^{\pm})$	0.7	0.5
	$B.R.(B \to D^{**} l^- \bar{\nu}_l)$	0.8	0.3
	$B.R.(B \to D^{**} \tau^- \bar{\nu}_l)$	1.8	1.7
	$D^{**} \to D^* \pi\pi$	2.1	2.6
	Cross-feed MC statistics	2.4	1.5
	$\mathbf{f_{D^{**}}}$	**5.0**	**2.0**
	Feed-up/down	1.3	0.4
	Isospin constraint	1.2	0.3
	Fixed Background MC statistics	3.1	1.5
	Fixed Background efficiency corrections	**3.9**	**2.3**
	MC statistics	1.8	1.2
	$\bar{B} \to D^{(*)}(\tau^- / l^-)\bar{\nu}$ FFs	1.6	0.4
Multiplicative	Lepton PID	0.9	0.9
	$\pi^0 / \pi^{\pm}$ from $D^* \to D\pi$	0.1	0.1
	Detection/Recontruction	0.7	0.7
	$B.R.(\tau^- \to l^- \bar{\nu}_l \nu_\tau)$	1.8	1.7
Total Statistics		**13.1**	**7.1**
Total Systematics		**9.6**	**5.6**
Total		**16.2**	**9.0**

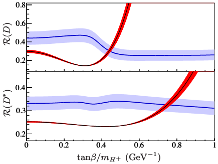
Results: SM and Type II 2HDM

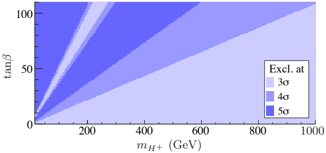
Result of the Fit

$R(D)_{exp} = 0.440 \pm 0.072$
$R(D^*)_{exp} = 0.332 \pm 0.030$



- Top right figure shows 3.4σ deviation from SM predictions

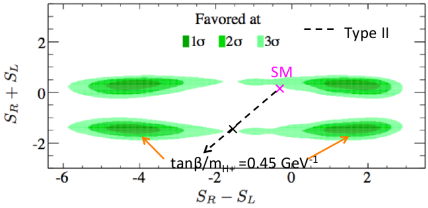




- As the $R(D)$ and $R(D^*)$ do not overlap, all type II 2HDM phase space is excluded at more than 3σ

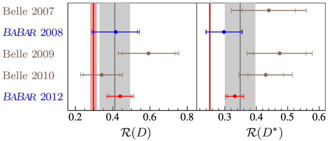
Results: Type III 2HDM

- Type III 2HDM including scalar and pseudoscalar constributions modifies $R(D^{(*)})$:
  - $R(D) = R(D)_{SM} + A'_D \mathrm{Re}(S_R + S_L) + B'_D |S_R + S_L|^2$
  - $R(D^*) = R(D^*)_{SM} + A'_{D^*} \mathrm{Re}(S_R - S_L) + B'_{D^*} |S_R - S_L|^2$
- As figure below shows 4 solutions, but the two lower are excluded by q^2 spectra



Conclusions

- These results agree with previous measurements from BABAR and Belle, but reduce the uncertainty by a factor of 2



- The measured values of $R(D^{(*)})$ exceed SM predictions in 2.0σ and 2.7σ
- Combined significance of the disagreement of 3.4σ
- Type II 2HDM is also excluded in all phase space at more than 3σ
- Type III 2HDM has 4 solutions, but 2 are excluded by q^2 distributions

Thank you for your attention.

Back-up

- q^2 distributions for the data and different values of $\frac{\tan\beta}{m_{H^\pm}}$ in the type II 2HDM (Left: SM; Center: $\frac{\tan\beta}{m_{H^\pm}} = 0.30\,\mathrm{GeV}^{-1}$; Right: $\frac{\tan\beta}{m_{H^\pm}} = 0.45\,\mathrm{GeV}^{-1}$)