$B \to \overline{D}^{(*)}\tau\nu$ and Constraints on Charged Higgs Models

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on behalf of the BaBar Collaboration by

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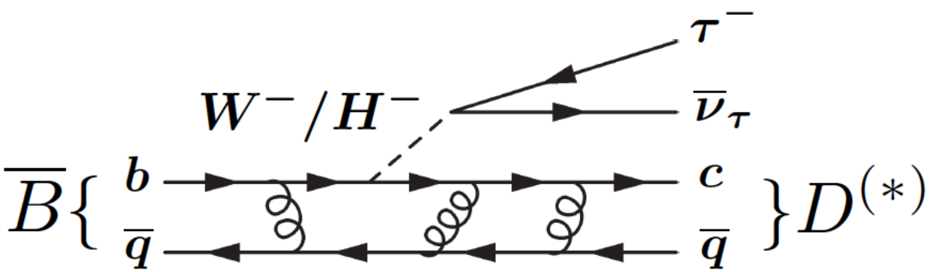
INTRODUCTION

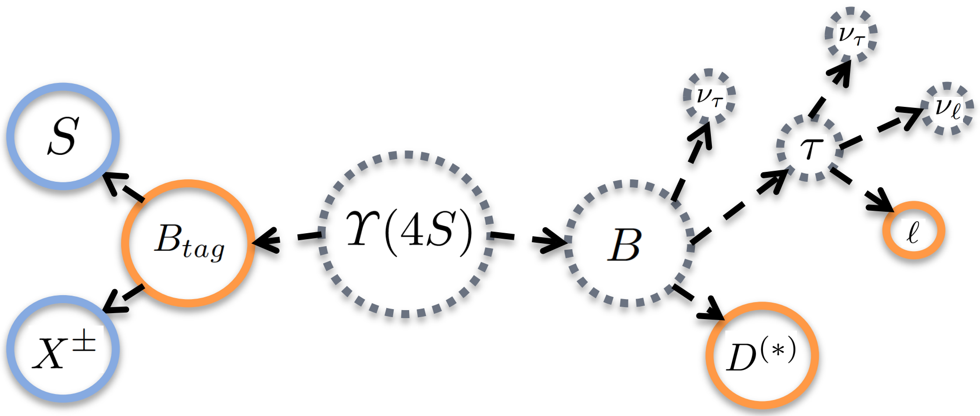


- The $B \to \overline{D}^{(*)}\tau\nu_\tau$ decay is sensitive to New Physics at tree level in the form of a charged Higgs boson.
- Using the large sample of B mesons collected at BABAR , we measure the quantity:

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

- Theoretical uncertainties on $\mathcal{R}(D^{(*)})$ are reasonably small and well understood in the Standard Model (SM).
- Systematic uncertainties of the experiment cancel in this ratio.

EVENT SELECTION



$S = D,\ D^*,\ D_s$, or D_s^* $\qquad X^{\pm} =$ up to 5 π, K, π^0, or K_S^0

- For each event, we reconstruct all possible $B_{tag} D^{(*)} \ell$ candidates.
- We then choose the lowest E_{extra} candidate to represent the event, where E_{extra} is defined to be the energy sum of all photons that are not part of the reconstructed candidate.
- The signal efficiency is 3 times larger than the previous *BABAR* analysis, *Phys. Rev. Lett. 100, 021801 (2008)*.
  - More modes are reconstructed for the seed meson S.
  - Improved lepton PID for ℓ.

Event Selection

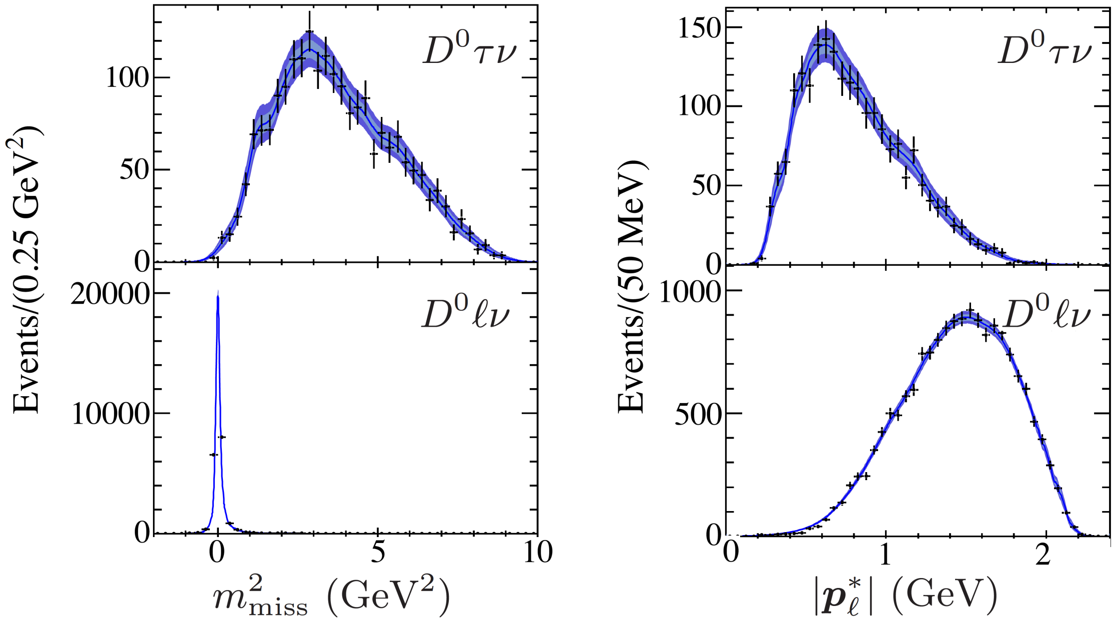
- At this point, each event belongs to one of four samples: $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, and $D^{*+}\ell$. This group is referred to as the $D^{(*)}\ell$ samples.
- In order to constrain the large D^{**} background, we also reconstruct $D^0\pi^0\ell$, $D^{*0}\pi^0\ell$, $D^+\pi^0\ell$, and $D^{*+}\pi^0\ell$ control samples. They are referred to as the $D^{(*)}\pi^0\ell$ samples.
  - For each sample in $D^{(*)}\ell$, we separate out a subset of events that can be combined with a well reconstructed π^0.

Event Selection

- Each event belongs to one of the following categories:
  - $D^{(*)}\tau$: Signal
  - $D^{(*)}\ell$: Normalization
  - $D^{**}(\ell/\tau)$: D^{**} background.
  - $B\overline{B}$ and continuum backgrounds.
- For each of the $D^{(*)}\ell$ samples, we train a boosted decision tree to separate out signal and normalization events and to reject background events.
- For each of the $D^{(*)}\pi^0\ell$ samples, we train a boosted decision tree to separate out D^{**} events and to reject others.

Yield Extraction

- To extract the signal and normalization yields, we perform an unbinned extended maximum likelihood fit to the 2D distribution in m^2_{miss} vs $|\boldsymbol{p}^*_\ell|$.
- Each sample has contribution from all event types. For each such contribution, we estimate its distribution in m^2_{miss} vs $|\boldsymbol{p}^*_\ell|$ using non-parametric kernel estimators.



Yield Extraction

- The fit is performed on all $D^{(*)}\ell$ and $D^{(*)}\pi^0\ell$ samples simultaneously.
- The fit gives us the number of signal and normalization events selected. We then compute the desired quantity:

$$\mathcal{R}(D^{(*)}) = \frac{N_{\rm sig}}{N_{\rm norm}} \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}}$$

$\varepsilon_{\rm norm}/\varepsilon_{\rm sig}$ is the ratio of efficiencies taken from Monte Carlo.

Systematic Uncertainties

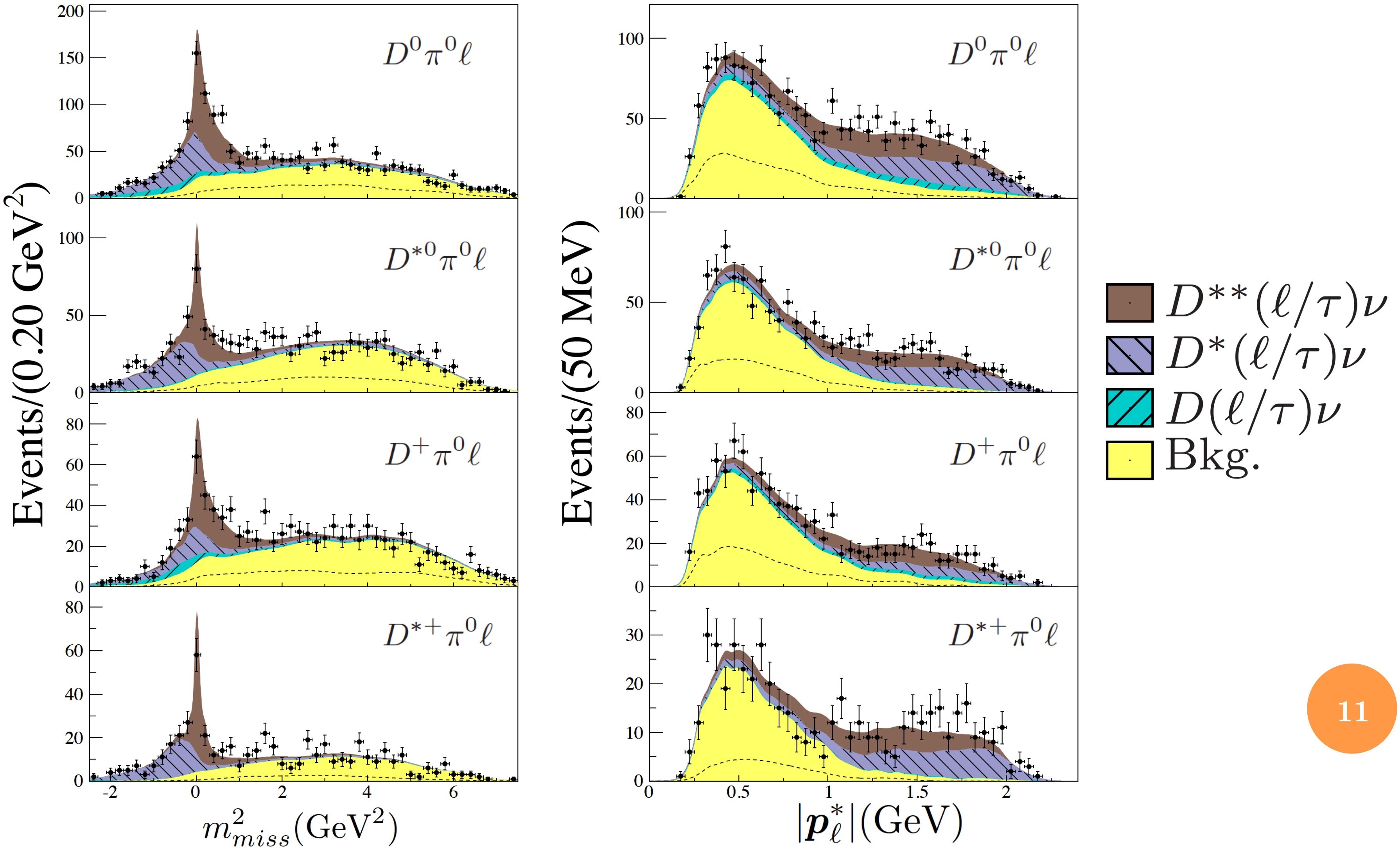
- To assess the impact of systematic uncertainties, we vary each source following a certain distribution and repeat the fit for each such variation. The uncertainty is assigned to be the standard deviation of the resulting $\mathcal{R}(D^{(*)})$ values.
- There are two types of systematic uncertainties:
  - Additive: These affect the yield of the fits, which influence the significance.
    - Monte Carlo (MC) statistics to estimate PDF shapes.
    - Fit constraints for fixing backgrounds and cross-feed contributions. The dominant source comes from D^{**} cross-feed constraints.
  - Multiplicative: These affect the $\varepsilon_{\mathrm{norm}}/\varepsilon_{\mathrm{sig}}$ ratio and do not affect the significance.
    - MC statistics is the dominant source of uncertainty.

Systematic Uncertainties

- The impact on the uncertainty of $\mathcal{R}(D^{(*)})$ due to correlations between any pair of systematic sources is small.
- However, the correlation between the uncertainties of $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ is large.
  - For each source of uncertainty, its contribution to the total correlation is estimated from the 2D $\mathcal{R}(D)$ vs $\mathcal{R}(D^*)$ distribution that results from the fit variations.
  - Since each source of uncertainty is uncorrelated, we add their covariance matrices to estimate the total covariance.

Results: Fit yields and marginal distributions for the $D^{(*)}\pi^0\ell$ sample

Phys. Rev. Lett. 109, 101802 (2013)
+ follow up submission to PRD



Results: Fit yields and marginal distributions for the $D^{(*)}\ell$ sample

Decay	$\mathcal{R}(D^{(*)})$	N_{sig}	N_{norm}
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	$0.440 \pm 0.058 \pm 0.042$	489 ± 63	2981 ± 65
$\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau$	$0.332 \pm 0.024 \pm 0.018$	888 ± 63	11953 ± 122

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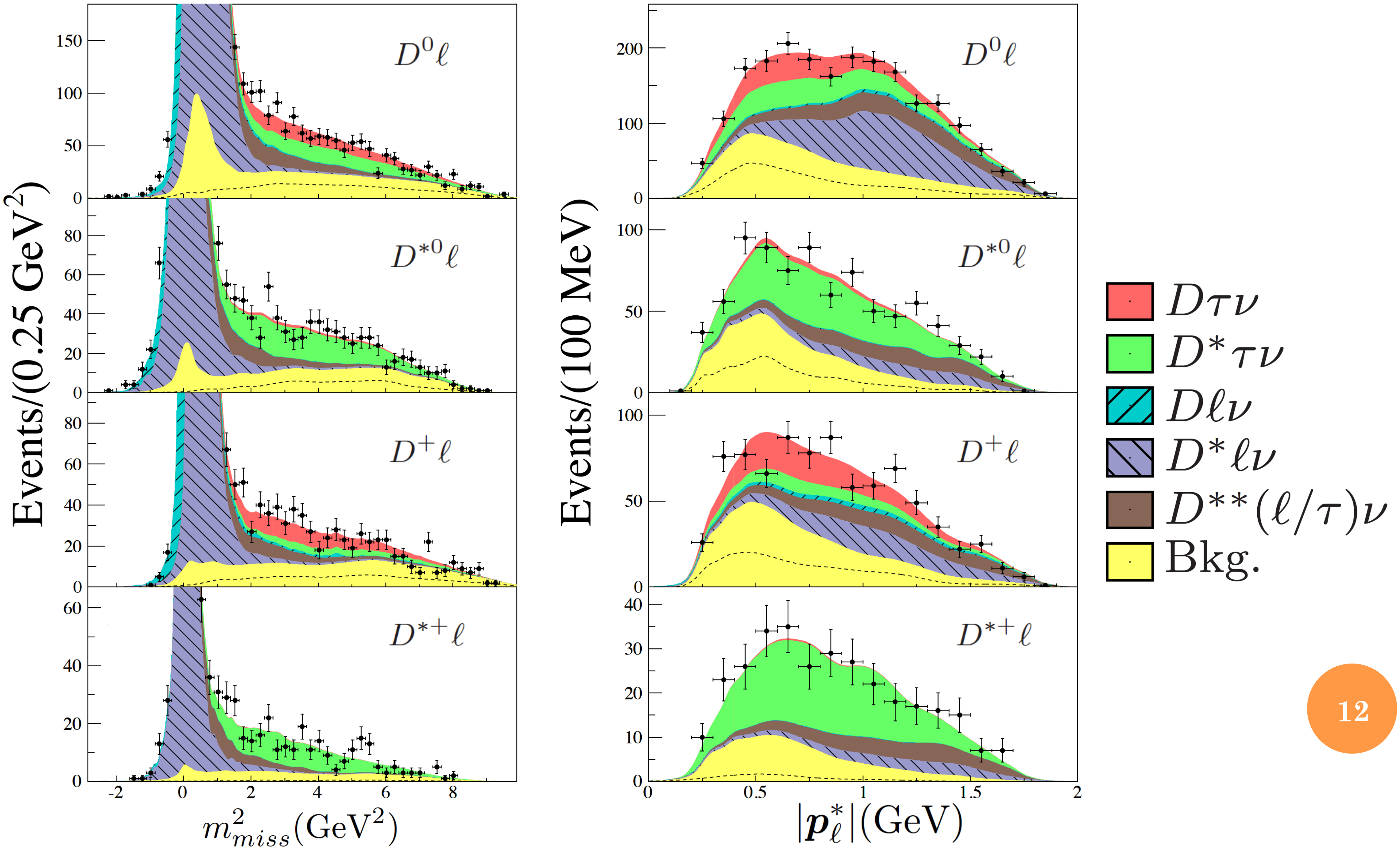

Comparison with the Standard Model

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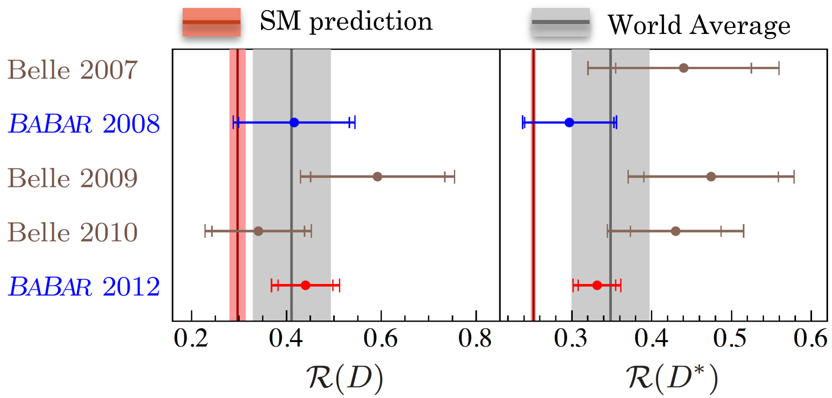
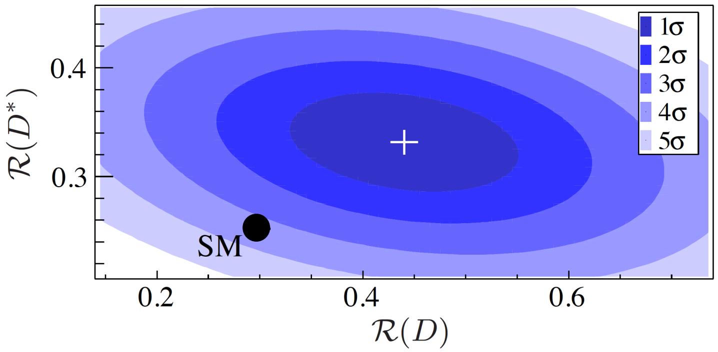




$$\mathcal{R}(D)_{\text{exp}} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\text{exp}} = 0.332 \pm 0.030$$
$$\mathcal{R}(D)_{\text{SM}} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\text{SM}} = 0.252 \pm 0.003$$

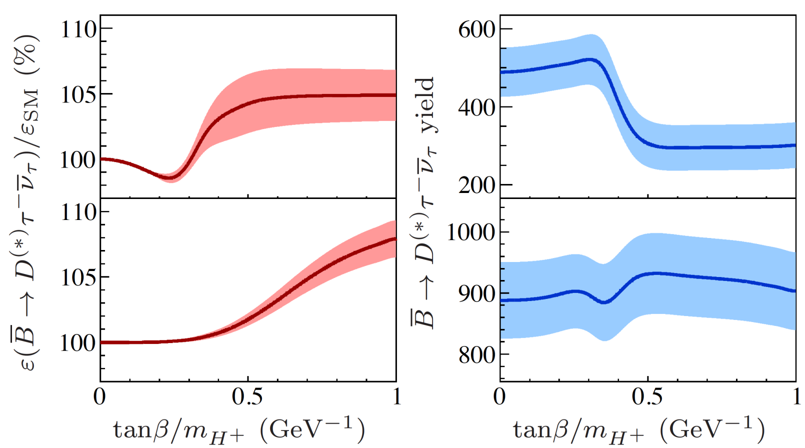
- We compare our results to those predicted in the Standard Model (SM), and find that $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ are in excess over the SM predictions at the level of 2.0σ and 2.7σ respectively.
- We perform a χ^2 test between the theory and experimental result using the covariance matrices determined previously and find that the possibility of both measurements agreeing with the SM is excluded at the 3.4σ level.

Comparison with Type-II 2HDM

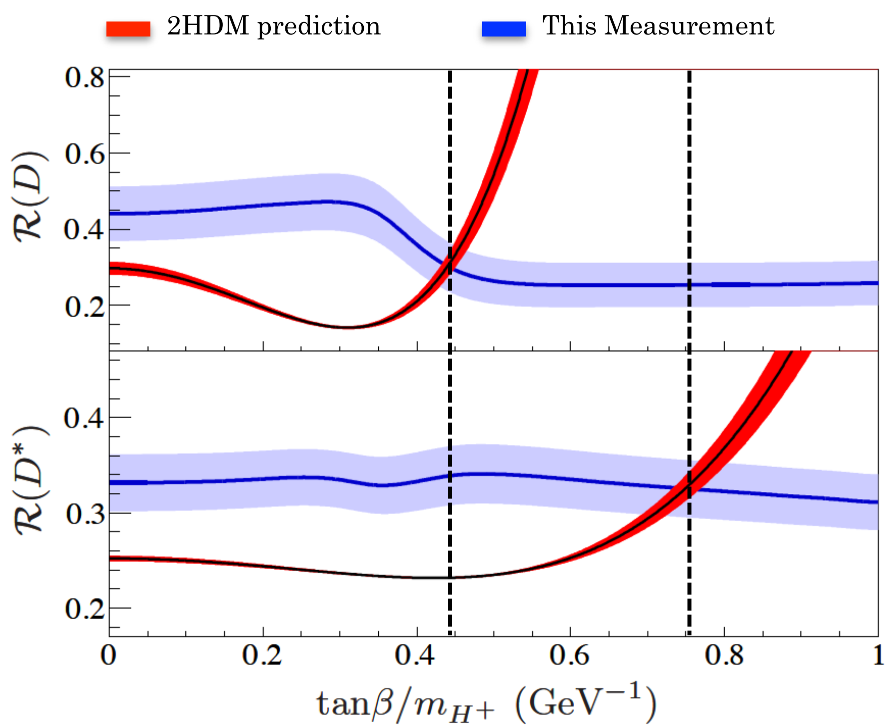
- In the type-II 2HDM, $\mathcal{R}(D)$ is affected as a function of $\tan\beta/m_{H^+}$ as follows:

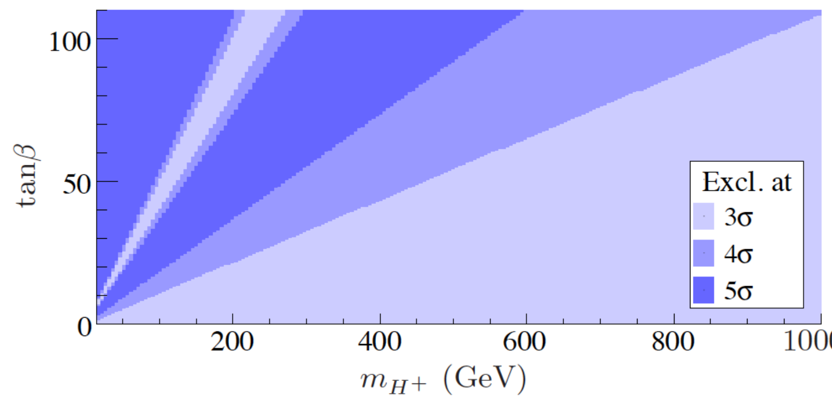
$$\mathcal{R}(D^{(*)})_{\mathrm{2HDM}} = \mathcal{R}(D^{(*)})_{\mathrm{SM}} + A_{D^{(*)}}\frac{\tan^2\beta}{m_{H^+}^2} + B_{D^{(*)}}\frac{\tan^4\beta}{m_{H^+}^4}$$

- The presence of a charged Higgs can affect the m_{miss}^2 and $|\boldsymbol{p}_\ell^*|$ signal distributions significantly. We assess and account for its impact as a function of $\tan\beta/m_{H^+}$ in order to examine whether the observed excess is consistent with the type-II 2HDM.



Comparison with Type-II 2HDM





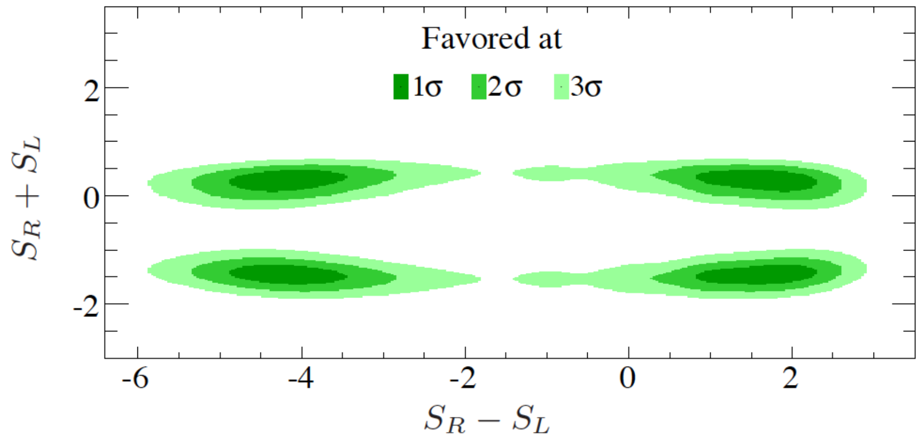
- We exclude the type-II 2HDM at 99.8% confidence level in the full $\tan\beta - m_{H+}$ parameter space.

Comparison with Type-III 2HDM

- In the type-III 2HDM, a right handed current is included in the effective Hamiltonian. The relative contributions between left and right handed current are parameterized with S_L and S_R .
- In this model, $\mathcal{R}(D^{(*)})$ take the form:

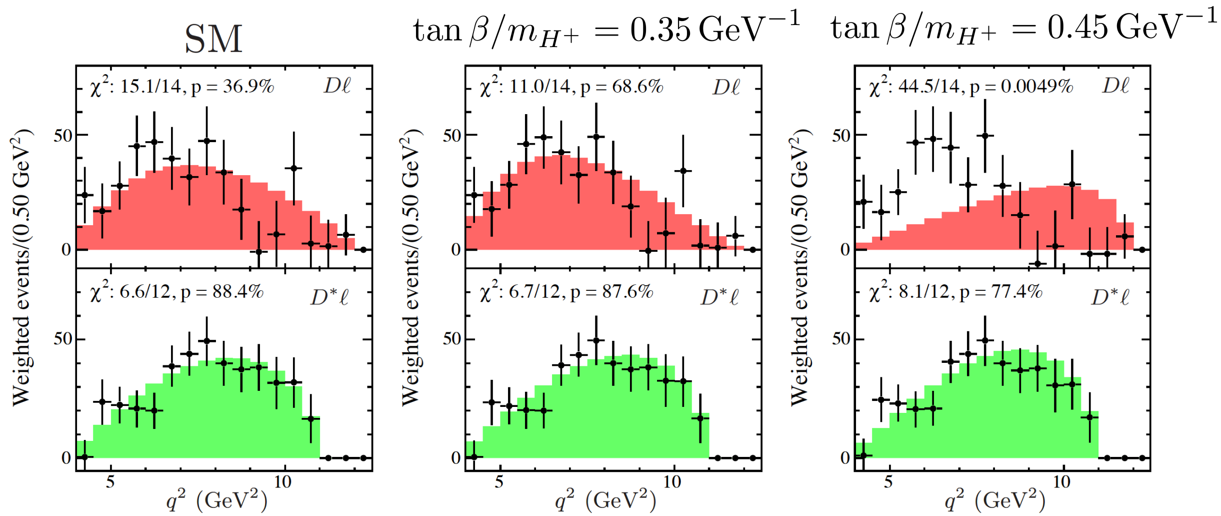
$$\mathcal{R}(D) = \mathcal{R}(D)_{\rm SM} + A'_D \mathrm{Re}(S_R + S_L) + B'_D |S_R + S_L|^2,$$
$$\mathcal{R}(D^*) = \mathcal{R}(D^*)_{\rm SM} + A'_{D^*} \mathrm{Re}(S_R - S_L) + B'_{D^*} |S_R - S_L|^2.$$

- We extrapolate the measured results obtained for $\mathcal{R}(D^{(*)})$ from the type-II 2HDM to the type-III 2HDM. For real values of S_L and S_R, we find 4 favored solutions.

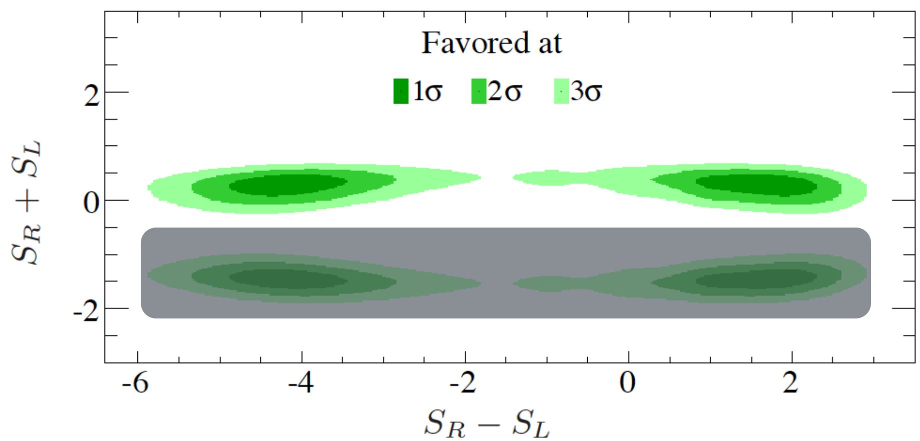


COMPARISON WITH TYPE-III 2HDM

- We compare the q^2 distribution of background subtracted data for three values of $\tan\beta/m_{H^+}$.



- $\tan\beta/m_{H^+} = 0.45\,\mathrm{GeV}^{-1}$ corresponds to the value of $S_L + S_R \sim 1.5$. We exclude the bottom 2 solutions at 2.9σ.



CONCLUSION

- We have measured the ratios $\mathcal{R}(D^{(*)})$ based on the full *BABAR* data sample:

$$\mathcal{R}(D) = 0.440 \pm 0.058 \pm 0.042$$
$$\mathcal{R}(D^*) = 0.332 \pm 0.024 \pm 0.018$$

  - $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ exceed the SM predictions by 2.0σ and 2.7σ respectively. Taken together, they disagree with the SM at the 3.4σ level.
  - We exclude the entire type-II 2HDM parameter space at the 99.8% confidence level.
  - More general charged Higgs models are compatible with our results. For instance, the type-III 2HDM is compatible with these results in regions where $|S_L + S_R| < 1.4$.
  - Updated results from Belle are expected soon.
  - For more details on this analysis, please refer to *Phys. Rev. Lett. 109, 101802 (2012) or arxiv: 1303.0571 (submitted to PRD).*