a place of mind

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INSTITUTE OF PARTICLE PHYSICS

BaBar measurements of B decays to τ

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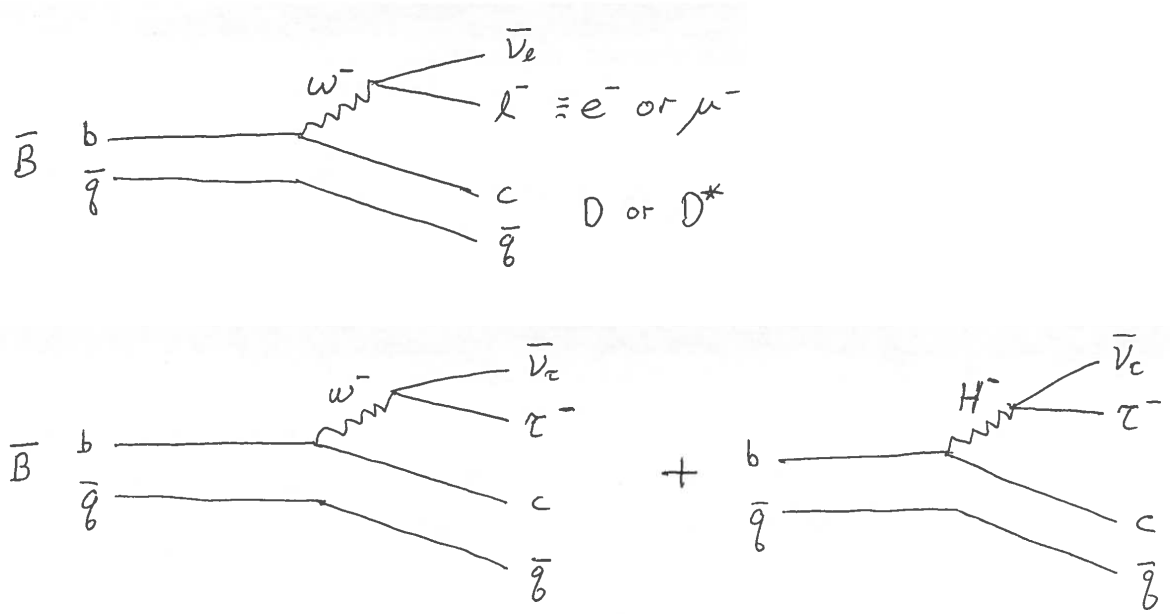
on behalf of the BaBar collaboration

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

Phys. Rev. Lett. 109, 101802 (2012)
Phys. Rev. D 88, 072012 (2013)

- Look for new physics effects in decays to 3rd generation.



- H^- contribution to e^- or μ^- final state is negligible.

- The corresponding branching ratios can be precisely calculated in the standard model.

$$\mathcal{R}(D) \equiv \mathcal{B}\left(\bar{B} \to D\tau^-\bar{\nu}_\tau\right) / \mathcal{B}\left(\bar{B} \to D\ell^-\bar{\nu}_\ell\right)$$
$$\mathcal{R}(D^*) \equiv \mathcal{B}\left(\bar{B} \to D^*\tau^-\bar{\nu}_\tau\right) / \mathcal{B}\left(\bar{B} \to D^*\ell^-\bar{\nu}_\ell\right)$$

$D \equiv D^0 \text{ or } D^+$

$D^* \equiv D^{*0} \text{ or } D^{*+}$

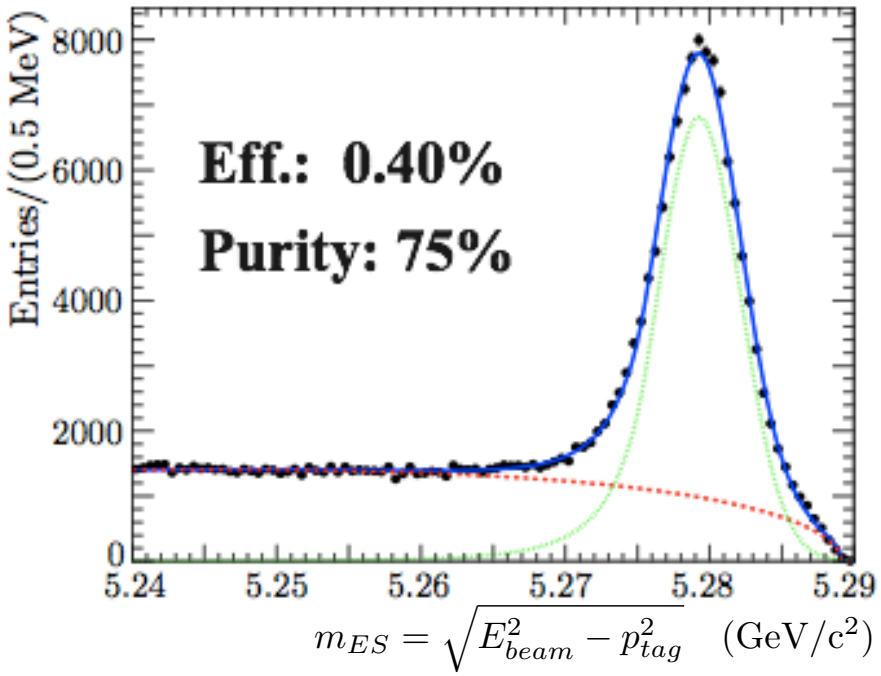
$\ell^- \equiv e^- \text{ or } \mu^-$

- Experimentally, use only the leptonic tau decays $\tau^- \to e^-\nu_\tau\bar{\nu}_e$ and $\tau^- \to \mu^-\nu_\tau\bar{\nu}_\mu$.

- Signal mode = $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$
  and normalization mode = $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$
  have the same final state particles.

Method

- Uses full BaBar Y(4S) dataset, 426 fb^{-1} / 471M $B\overline{B}$ events
- Fully reconstruct one B using 1680 hadronic modes.



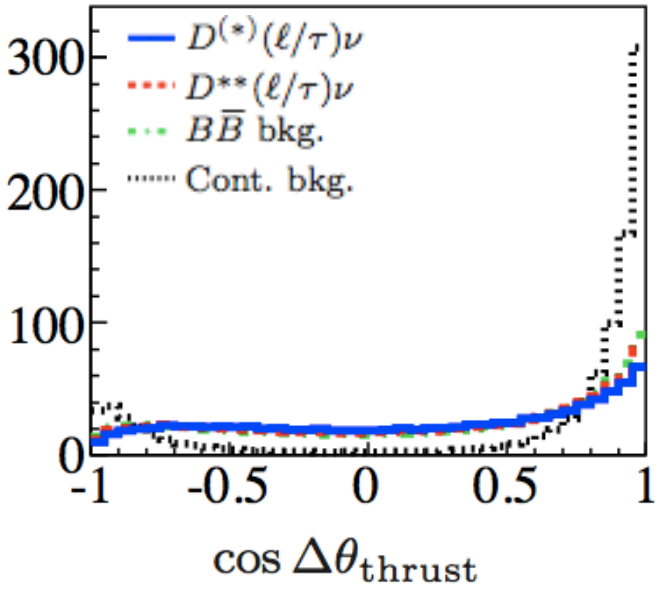
- Efficiency is double our earlier publication.

Phys. Rev. Lett. 100, 021801 (2008).

- Remainder of the event must have a $D^{(*)}$, e or μ, no other charged tracks.

- Use Boosted Decision Trees BDT as final selection

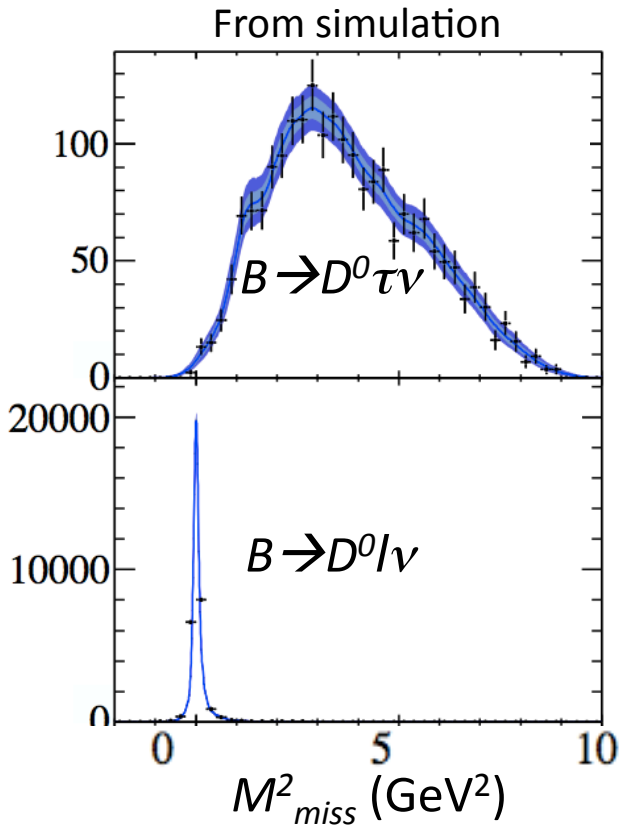
  - masses, energies, thrust axes



- Two kinematic variables then used in a fit to distinguish signal from normalization.

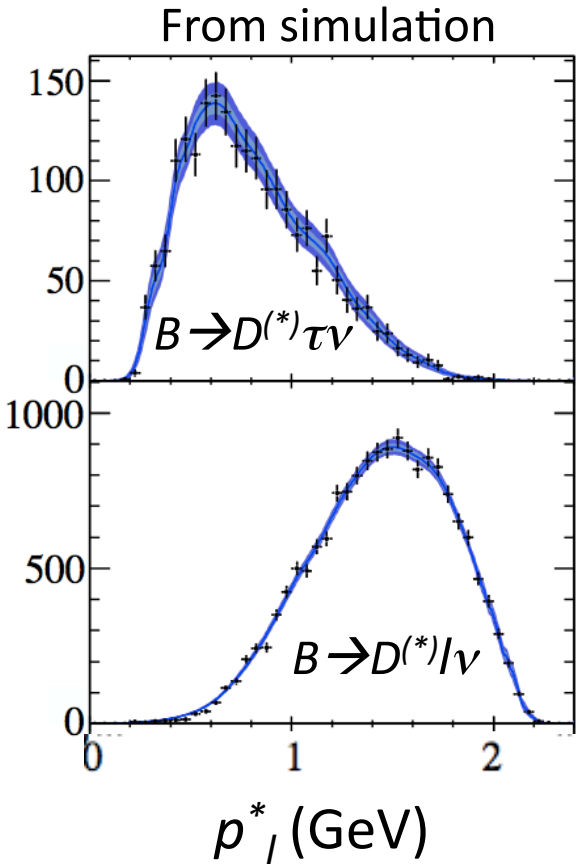
Missing mass

- $M^2_{miss} \equiv \left(p_{e^+e^-} - p_{B_{tag}} - p_{D^{(*)}} - p_\ell\right)^2$
- For the normalization sample, this is just the mass^2 of the single neutrino in the final state. i.e. = 0 within resolution.
- For the signal, it is the mass^2 of the three neutrinos.



Lepton momentum

- $|\vec{p}^{*}_{\ell}| \equiv$ momentum of the lepton in the B rest frame.
- Typically lower for signal leptons than control leptons.



Backgrounds and control samples

- Backgrounds include
  - decays of heavier charm states.
  - charge cross feed. i.e. signal or control events reconstructed with the wrong charge.
    - feed down, D^* reconstructed as D, is included in fit.
  - Other $B\overline{B}$ events
  - continuum (e^+e^- annihilations other than $B\overline{B}$)

D** background

- Use similar BDTs to select four control samples that include an extra π^0: $D^0\pi^0\ell^-$, $D^{*0}\pi^0\ell^-$, $D^+\pi^0\ell^-$, $D^{*+}\pi^0\ell^-$
- Higher mass charm states D** — anything heavier than a D*, e.g. $D_0^*(2400)^0$, $D_0^*(2400)^+$, $D_1(2420)^0$...
- D** can be a source of background under the signal:

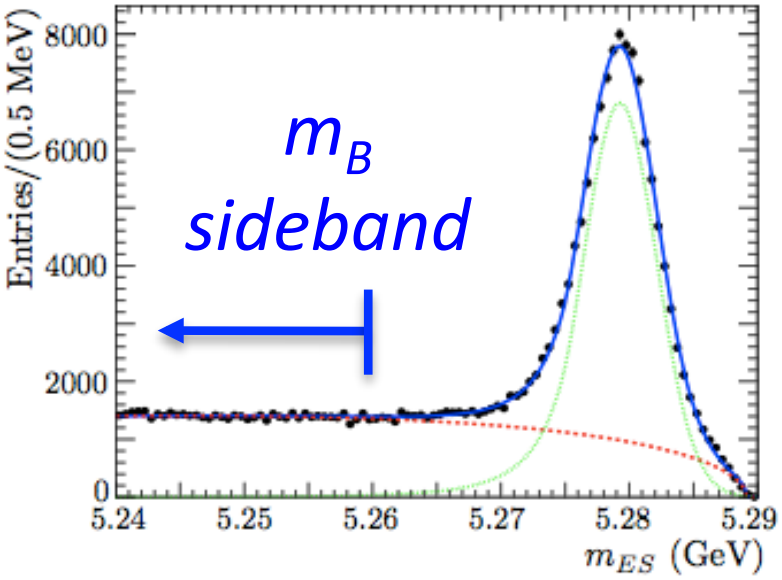
$$\bar{B} \to D_0^*(2400)^+\ell^-\bar{\nu}_\ell$$
$$\to D^+\pi^0$$

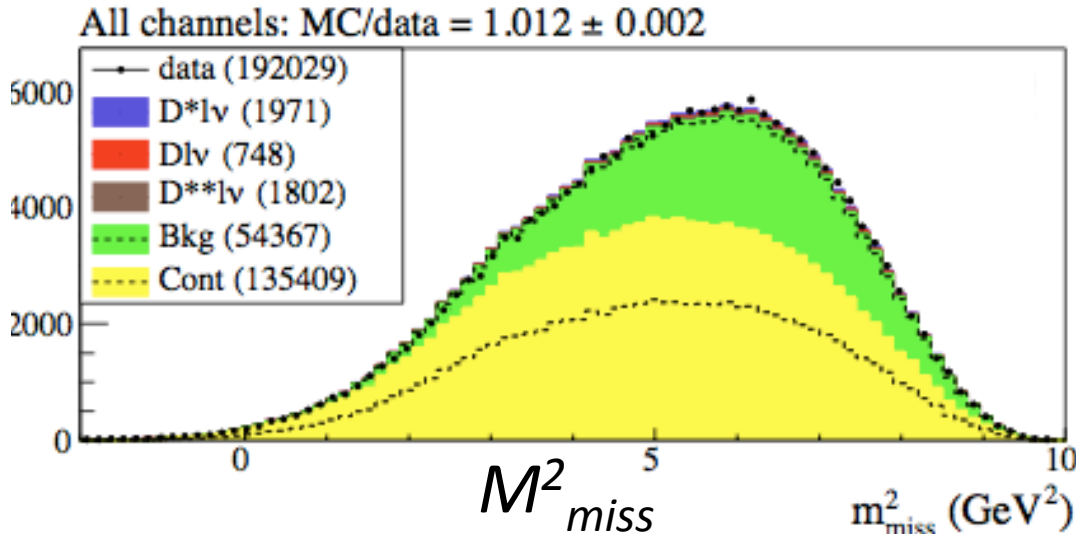
lost

- Explicitly reconstruct these events and include in fit to constrain this background.

Other control samples

- Data recorded below the Y(4S) resonance used to study continuum events.
- Sideband of m_{ES} selects other $B\bar{B}$ events.





The fit

- Simultaneous 2D fit to missing mass and lepton momentum to eight samples:

  signal + normalization $D^0\ell^-,\ D^{*0}\ell^-,\ D^+\ell^-,\ D^{*+}\ell^-$

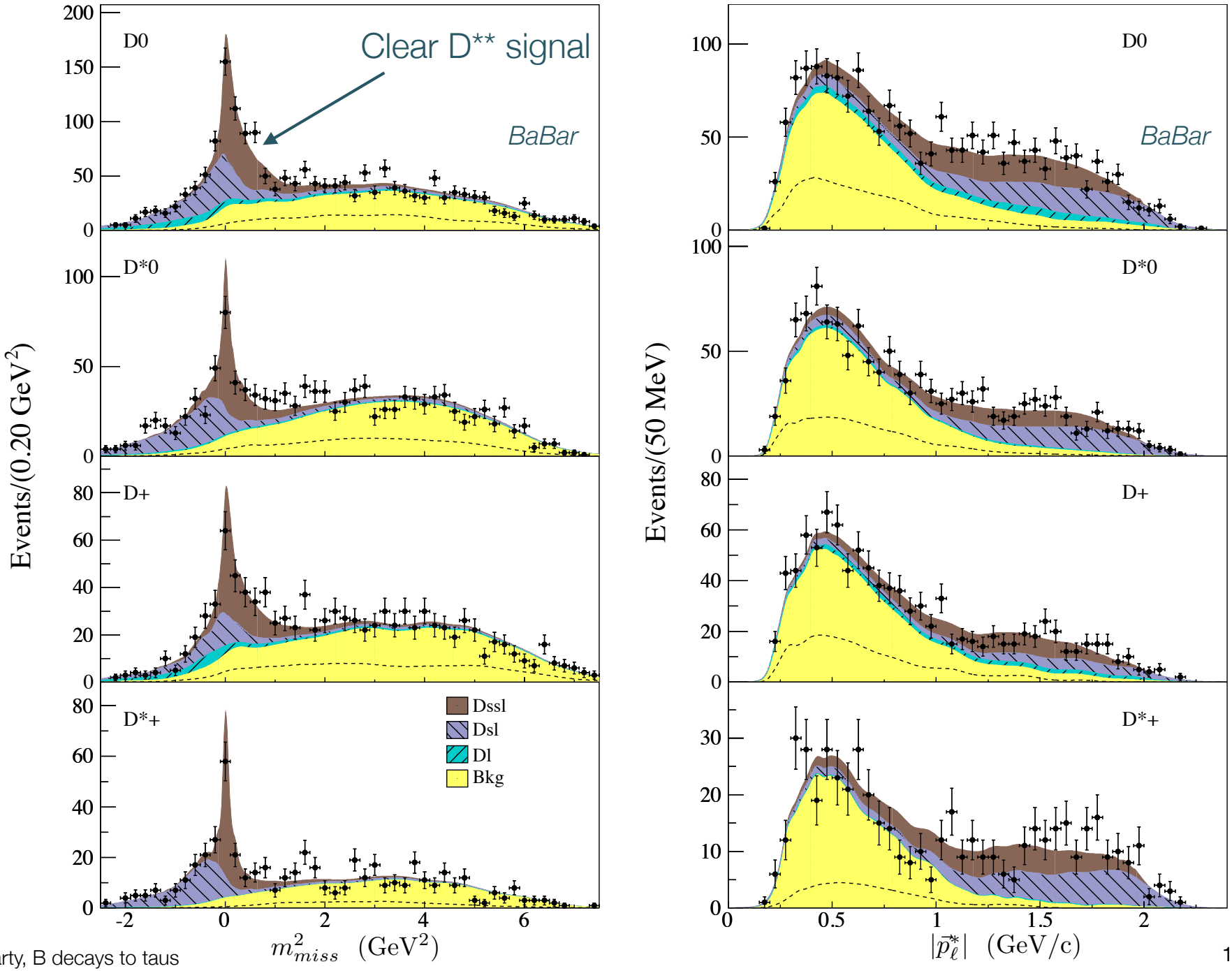
  D** control sample $D^0\pi^0\ell^-,\ D^{*0}\pi^0\ell^-,\ D^+\pi^0\ell^-,\ D^{*+}\pi^0\ell^-$

- Cross feed, other $B\overline{B}$, and continuum are fixed to expected values.

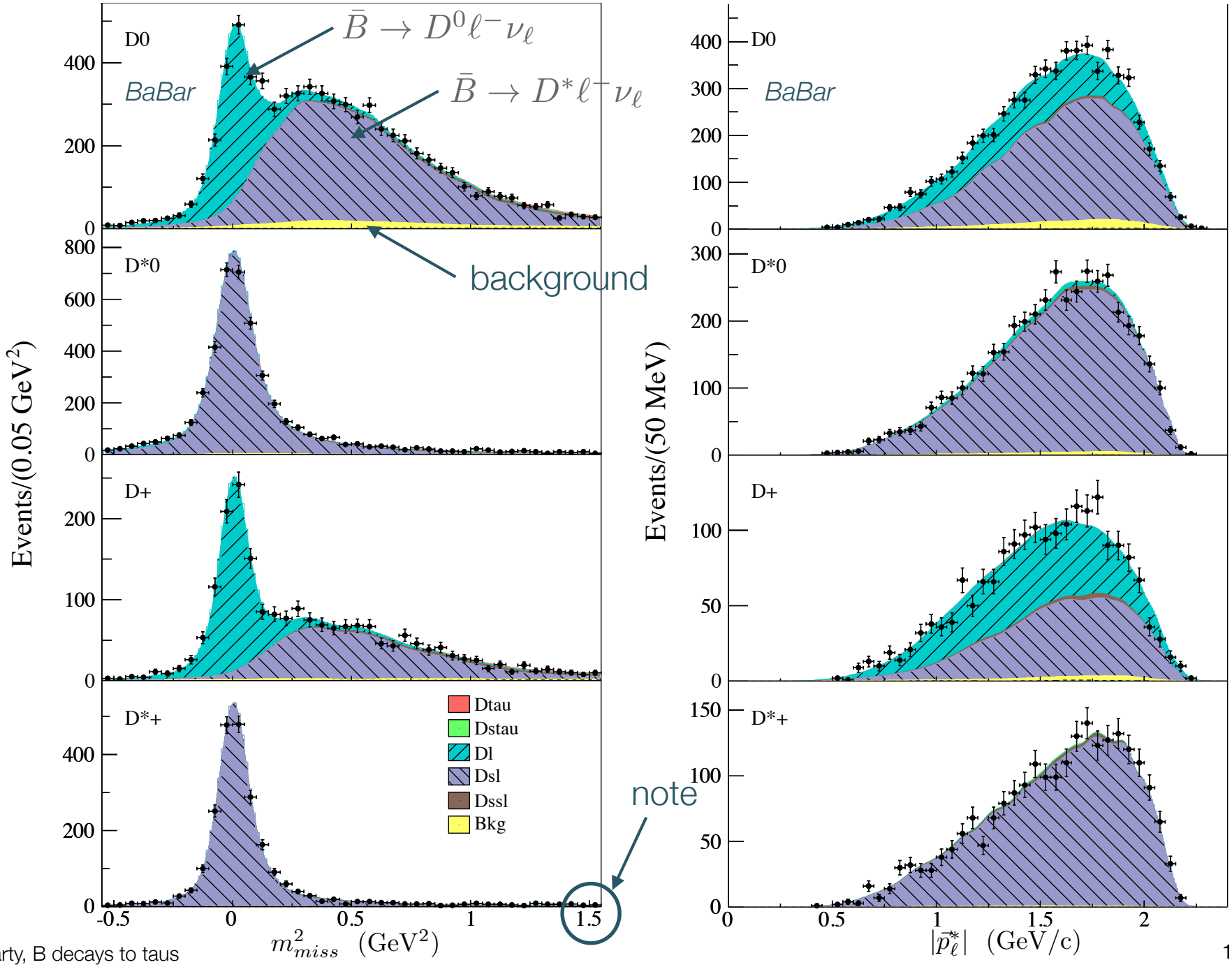
- $D^* \to D$ feed down for signal is constrained to be the same as for normalization

- Ratios of D** events in signal+normalization samples to D** events in control samples are constrained.

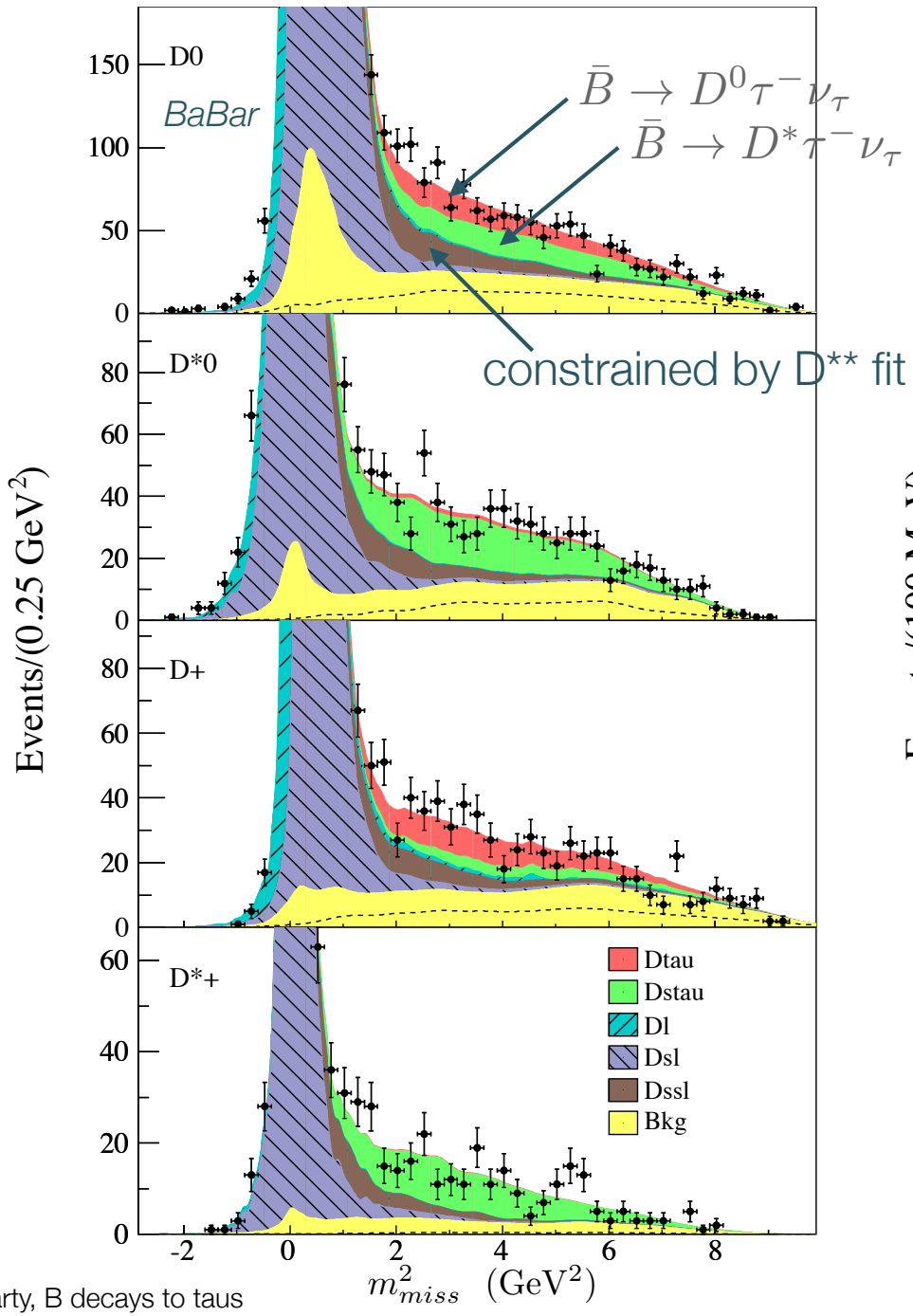
Fit to D** control sample

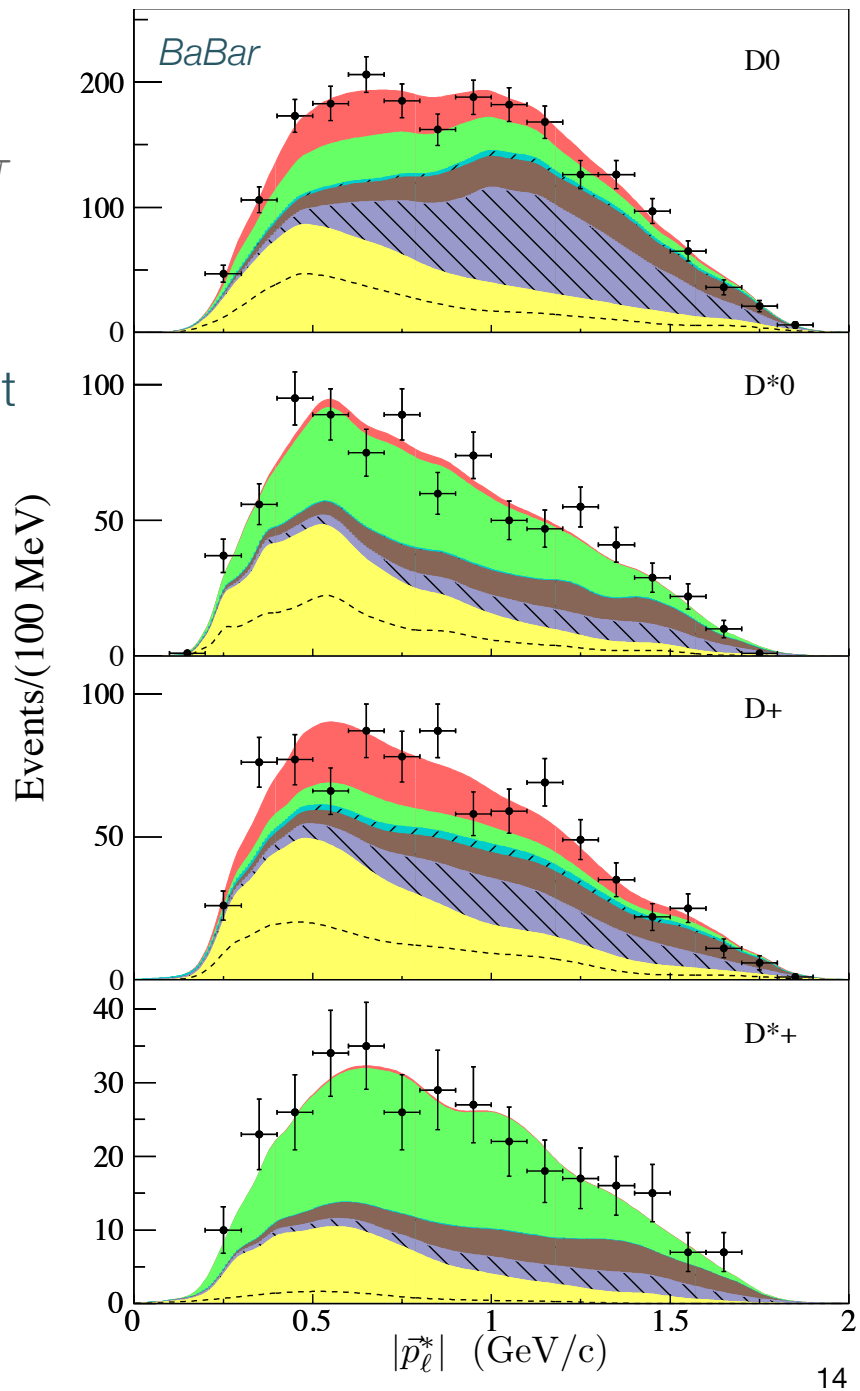


Fit to signal + normalization sample; low missing mass region



Zoom vertical scale and expand m_{miss} region to show signal





Results

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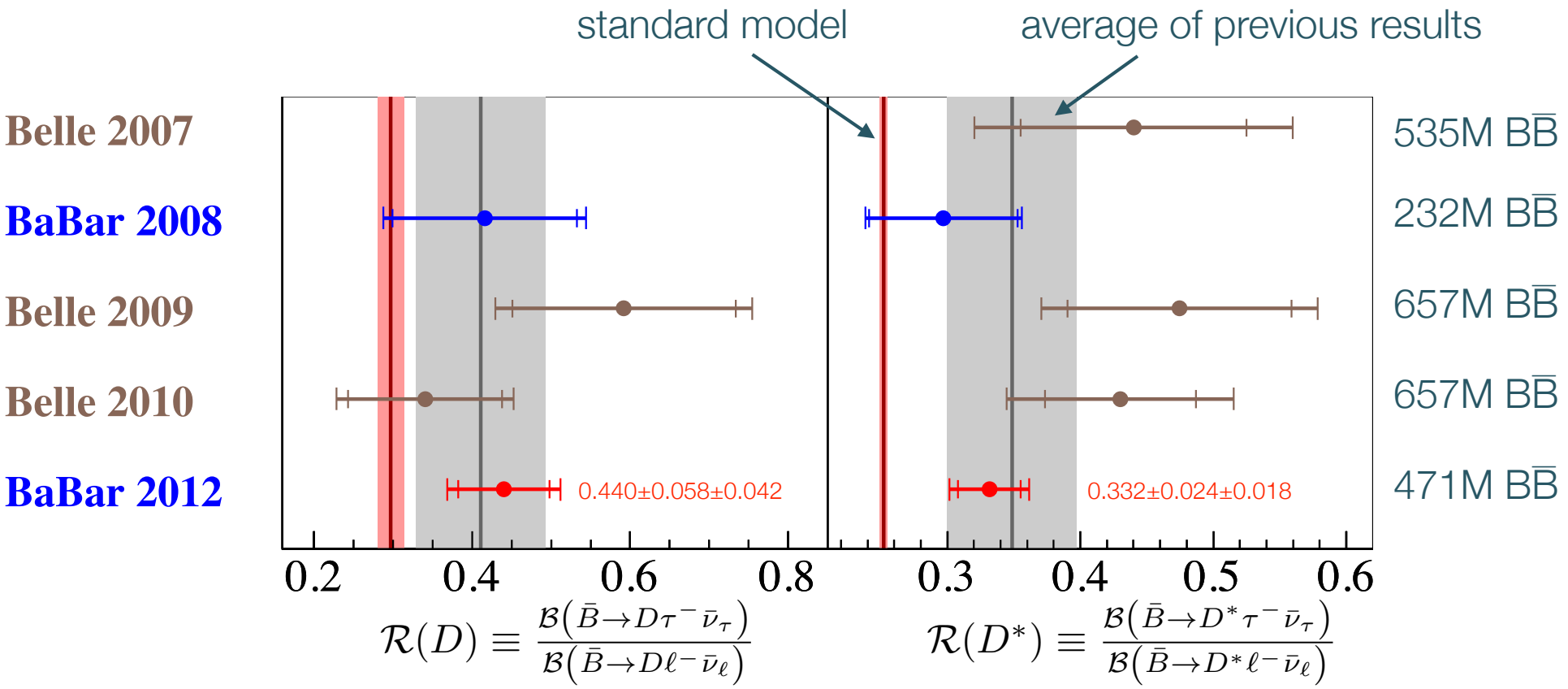
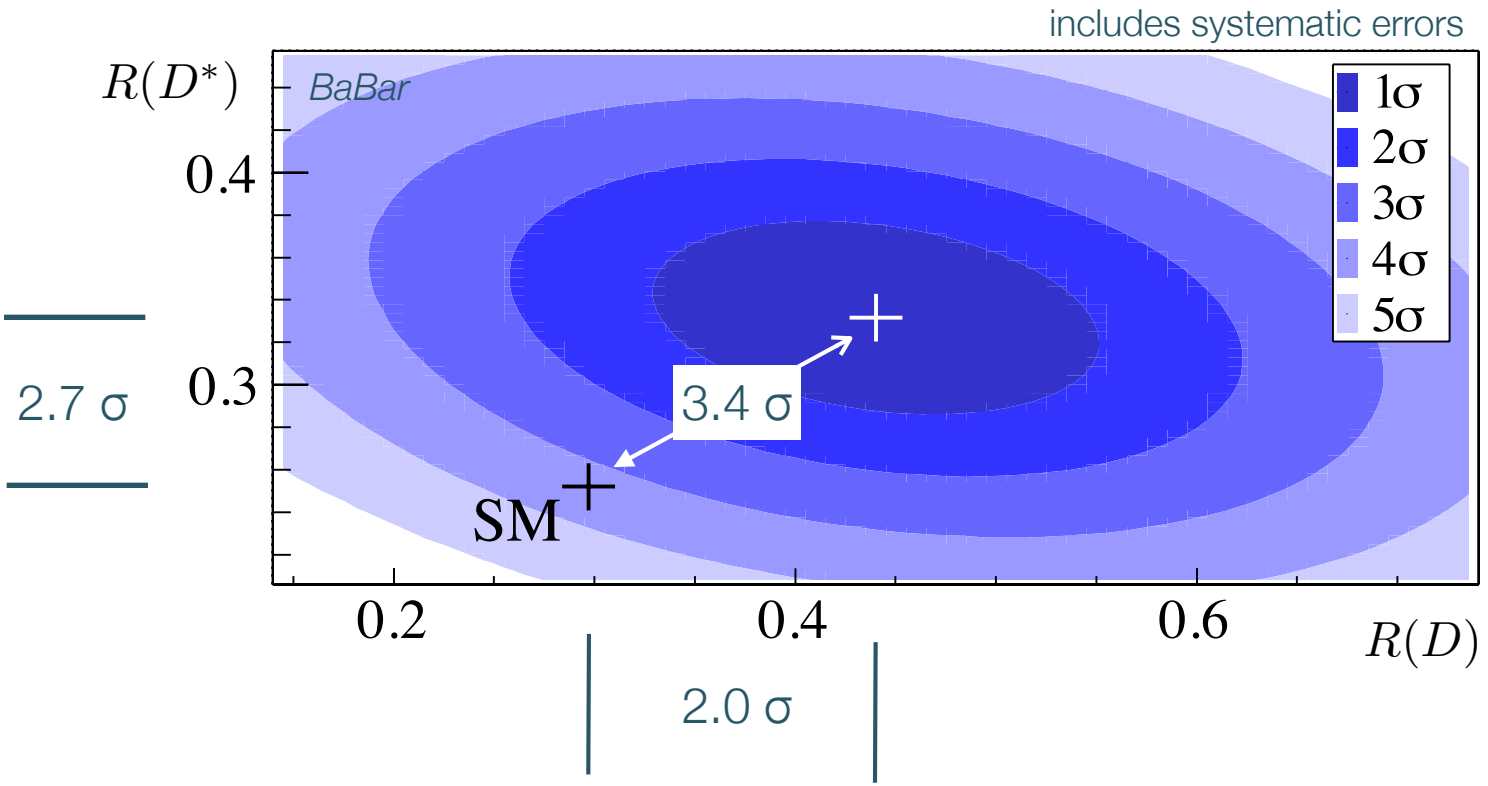


- Overall efficiency ~3x previous BaBar result
- First $\bar{B} \to D\tau^-\nu_\tau$ result with >5σ significance.

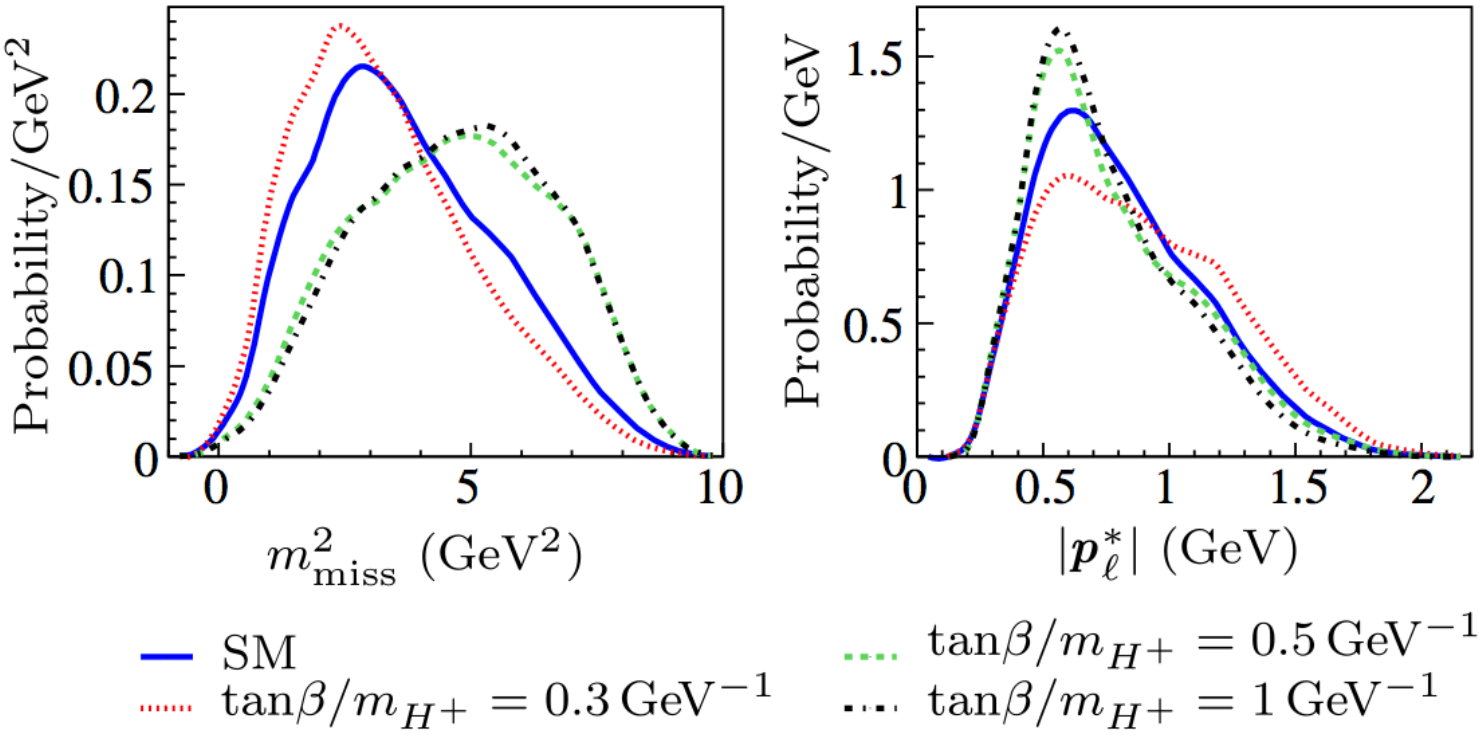
Comparison to standard model

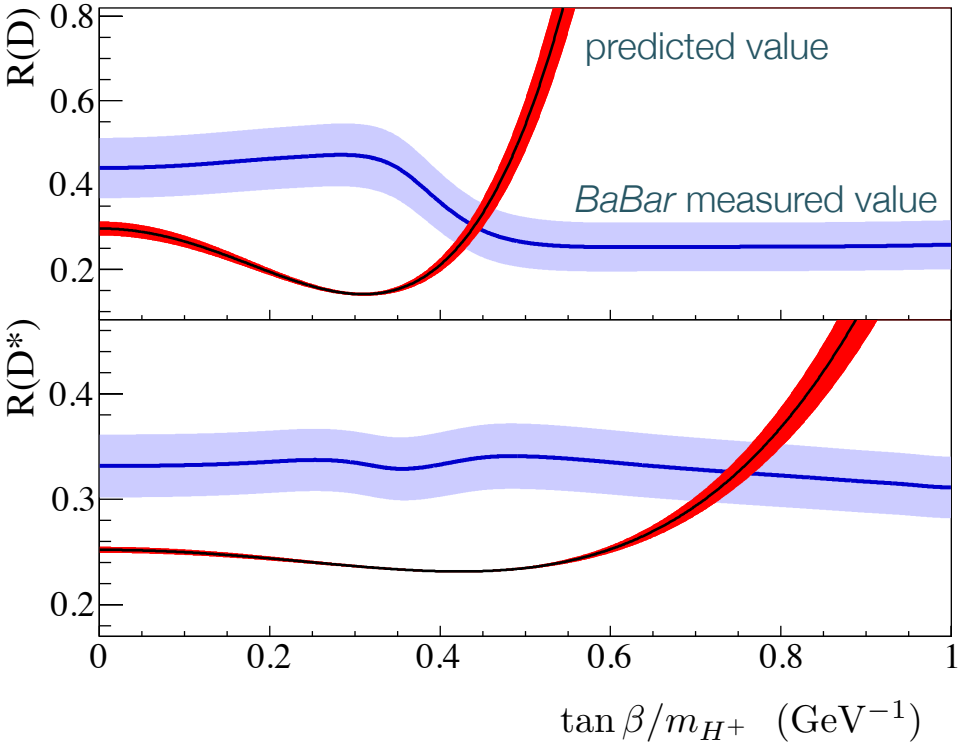


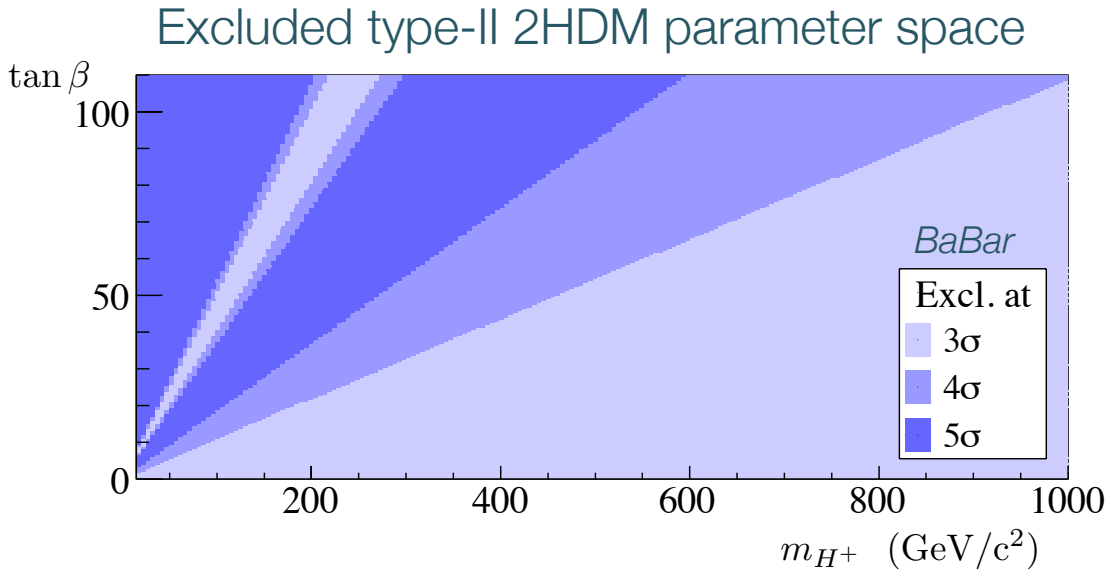
- R(D) and R(D*) are anti correlated due to feed down.
- Largest systematic is modeling of D** backgrounds.

Comparison with type II two-Higgs-doublet model

- A charged Higgs would change the predicted values for R(D) and R(D*), but also the signal kinematics (and therefore efficiency and event yield).







- Not compatible at the 99.8% level with any value of $\tan\beta/m_{H^+}$ for a type-II 2HDM.
- There are regions of parameter space in more general 2HDM that match both R(D) and R(D*)

Measurement of $\bar{B} \to D^{(*)}\pi^+\pi^-\ell^-\bar{\nu}_\ell$

- There are no τ's in this analysis.
- Has not been measured previously. A better understanding of D** decays could reduce systematics errors in future $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ analyses.
- Inclusive charm meson BF: $\mathcal{B}(B \to X_c X) = (10.98 \pm 0.14)\%$
- Sum of exclusive BFs:
  $\mathcal{B}(B \to DX) + \mathcal{B}(B \to D^* X) + \mathcal{B}(B \to D^{**} X) = (9.41 \pm 0.22)\%$
  where $D^{**} \to D^{(*)}\pi$
- Difference = (1.57 ± 0.26)% "gap problem"

- Twelve reconstructed samples:

  $D^{(*)}\ell^-\bar{\nu}_\ell$ — used for normalization

  $D^{(*)}\pi^+\ell^-\bar{\nu}_\ell$

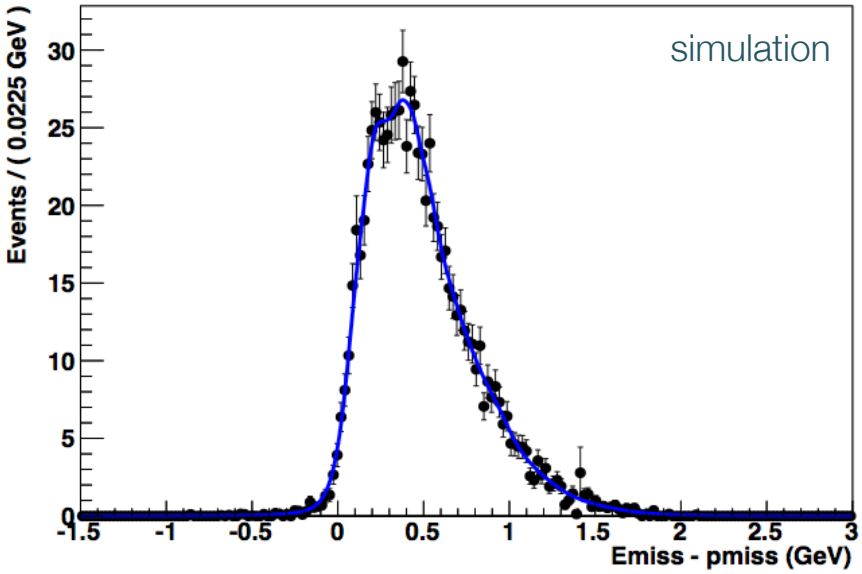
  $D^{(*)}\pi^+\pi^-\ell^-\bar{\nu}_\ell$

- Fully reconstructed B sample used to tag the event.

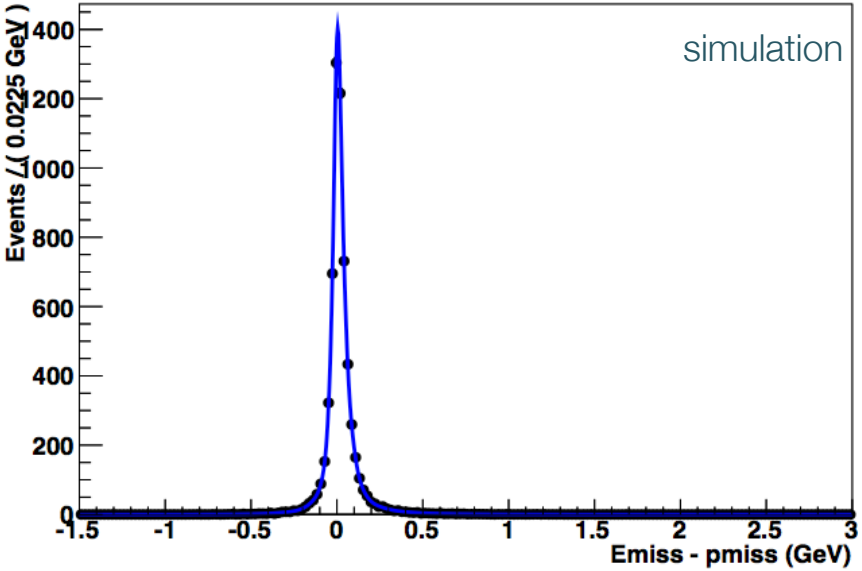
Signal extraction

- Fit to $E_{miss} - |\vec{p}_{miss}|$

$D^{(*)}\pi l\nu$ reconstructed as $D^0 l\nu$

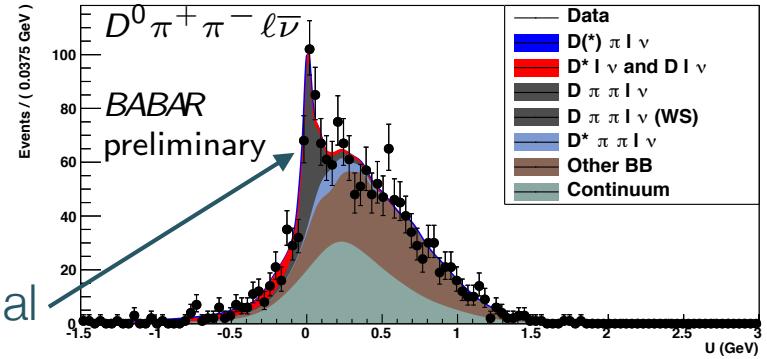


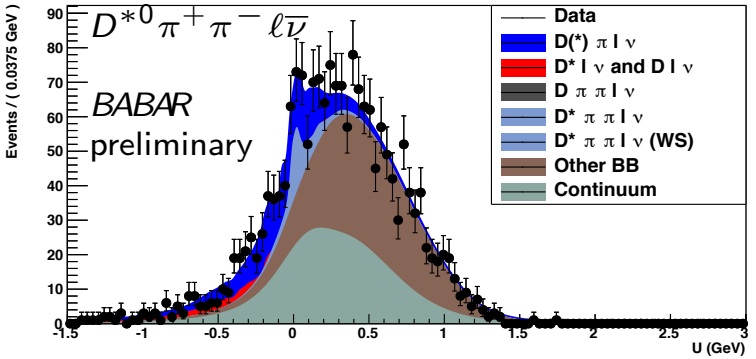
$D^0 l\nu$ reconstructed as $D^0 l\nu$

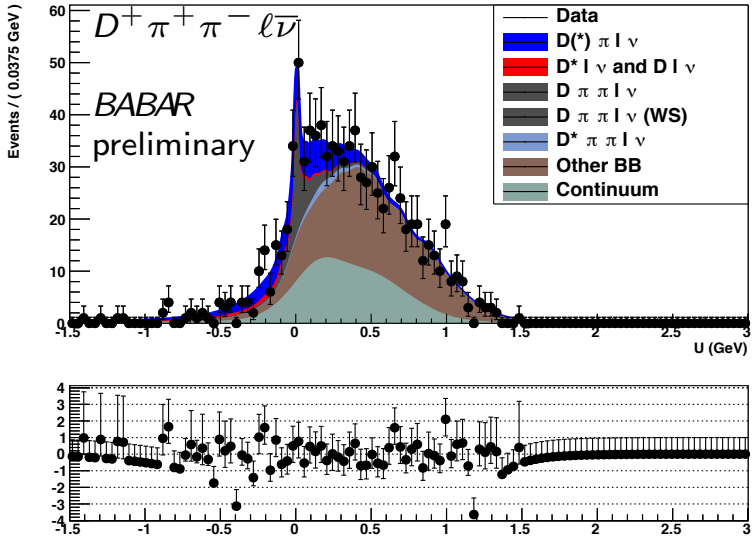


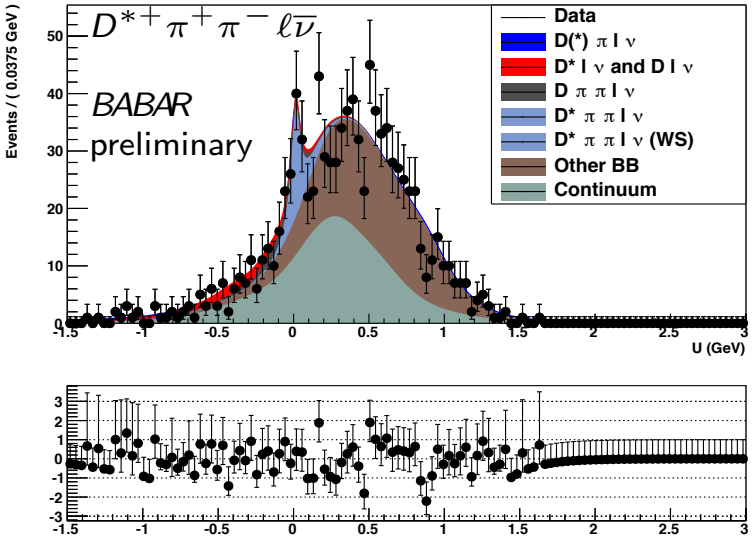
Fit to $\bar{B} \to D^{(*)}\pi^+\pi^-\ell^-\bar{\nu}_\ell$

clear $D^0\pi^+\pi^-l\nu$ signal
189 ± 39 events









Results (preliminary)

For more details, see T. Lueck's ICHEP2014 talk

$$\mathcal{B}\left(B \to D\pi^+\pi^-\ell^-\bar{\nu}_\ell\right) = (0.166 \pm 0.032 \pm 0.020 \pm 0.006)\%$$

$$\mathcal{B}\left(B \to D^*\pi^+\pi^-\ell^-\bar{\nu}_\ell\right) = (0.111 \pm 0.033 \pm 0.016 \pm 0.004)\%$$

errors are stat ± sys ± normalization

- Significance of $\mathcal{B}\left(B \to D\pi^+\pi^-\ell^-\bar{\nu}_\ell\right)$ = 5.1σ; first observation.
- Extrapolating gives $\mathcal{B}\left(B \to D^{(*)}\pi\pi\ell^-\bar{\nu}_\ell\right) = (0.71 \pm 0.12^{+0.14}_{-0.07})\%$
  - uses $\pi^+\pi^-/\pi\pi = 0.40^{+0.04}_{-0.07}$
- Reduces gap problem to ~3σ.

Summary

- Measurement of $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ reveals some tension with the standard model.

- Not compatible with a type-II two-Higgs-doublet model. A nice illustration of the sensitivity of B-factory measurements to high-energy phenomena.

- BaBar continues to study semileptonic final states, and should have a publication out shortly on $B \to D^{(*)}\pi^+\pi^-\ell^-\bar{\nu}_\ell$