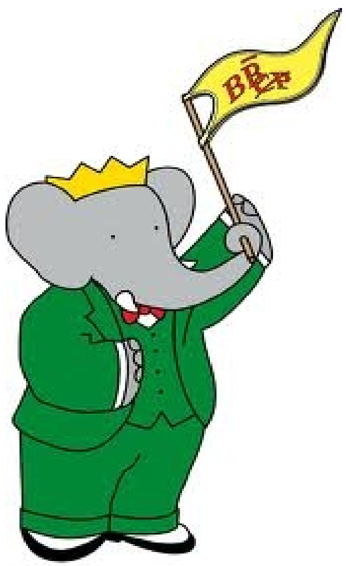
SSP2012 - 5th International Symposium on Symmetries in Subatomic Physics

Groningen NL · 18-22 June 2012

Branching Fractions of $B \to D^{(*)} \tau \nu_\tau$ (and $B \to \tau \nu_\tau$) at *BABAR* and Implications for New Physics



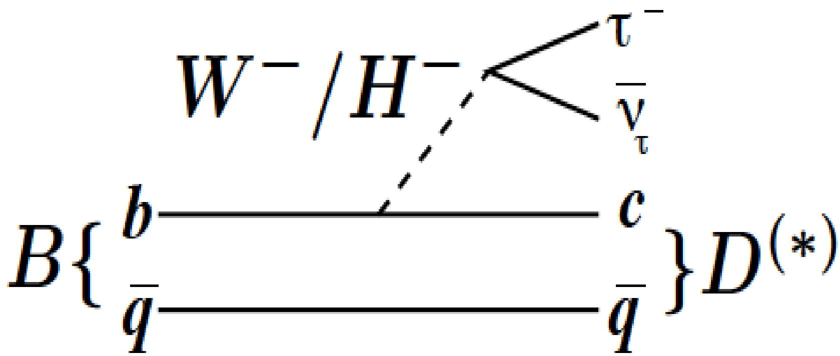
Marcello Rotondo

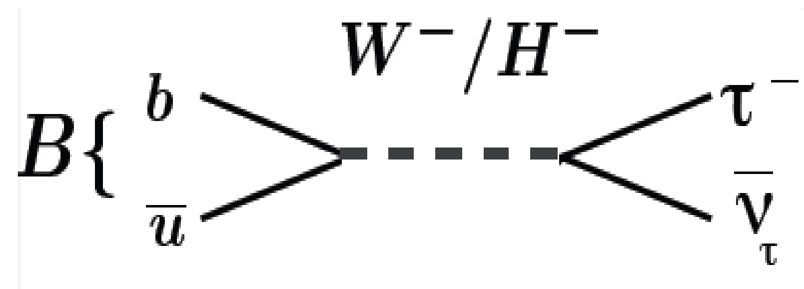
I.N.F.N. Padova

on behalf of the BaBar Collaboration

Motivation for $B \to D^{(*)} \tau \nu_\tau$ and $B \to \tau \nu_\tau$

- In the SM, semileptonic decays $B \to D^{(*)} \tau \nu_\tau$ and the leptonic $B \to \tau \nu_\tau$ are both mediated by the W boson
- Both decays are sensitive to charged Higgs
  - Tree level contribution: New Physics at O(1)
  - $H^- - \ell$ coupling $\propto m_\ell$





• $B \to D^{(*)} \tau \nu_\tau$

- Theoretical uncertainty: 2-5%
- Branching Fraction 1-2%: $|V_{cb}|$ mediated and no helicity suppression
- 3-body decays → many observables:
  - q^2-distribution, τ-polarization, D* polarization

• $B \to \tau \nu_\tau$

- Theoretical uncertainty ~20%: $|V_{ub}|$ & f_B
- Branching Fraction: ~0.01%
  - Helicity suppressed

Submitted to Phys.Rev.Lett. arXiv:1205.5442

To be submitted shortly

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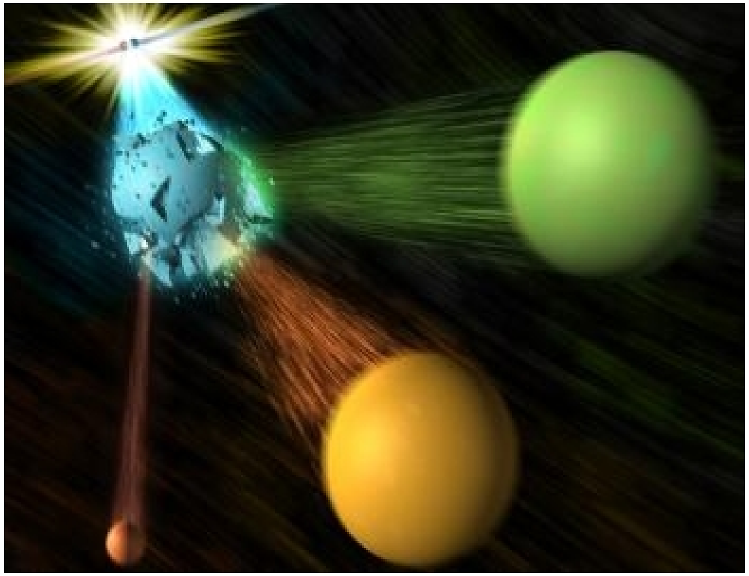
BaBar Data Hint at Cracks in the Standard Model

June 18, 2012

by Lori Ann White

Recently analyzed data from the BaBar experiment may suggest possible flaws in the Standard Model of particle physics, the reigning description of how the universe works on subatomic scales. The data from BaBar, a high-energy physics experiment based at SLAC, show that a particular type of particle decay called "B to D-star-tau-nu" happens more often than the Standard Model says it should.



The latest results from the BaBar experiment may suggest a surplus over Standard Model predictions of a type of particle decay called "B to D-star-tau-nu." In this conceptual art, an... (*Image by Greg Stewart, SLAC National Accelerator Laboratory*) view »

In this type of decay, a particle called the B-bar meson decays into a D meson, an antineutrino and a tau lepton. While the level of certainty of the excess (3.4 sigma in statistical language) is not enough to claim a break from the Standard Model, the results are a potential sign of something amiss and are likely to impact existing theories, including those attempting to deduce the properties of Higgs bosons.

"The excess over the Standard Model prediction is exciting," said BaBar spokesperson Michael Roney, professor at the University of Victoria in Canada. The results are significantly more sensitive than previously published studies of these decays, said Roney. "But before we can claim an actual discovery, other experiments have to replicate it and rule out the possibility this isn't just an unlikely statistical fluctuation."

18 June 2012

https://news.slac.stanford.edu/features/babar-data-hint-cracks-standard-model

Outline

- $B \rightarrow D^{(*)} \tau \nu_\tau$ analysis strategy
- Event reconstruction
- Results
  - Systematics
- Interpretation
  - Standard Model
  - Type II - Two Higgs Doublet Model (2HDM)
  - Connection with purely leptonic $B \rightarrow \tau \nu_\tau$
- Conclusions and Outlook

*In the following, charge conjugate decay modes are implied

Ratio of $B \to D^{(*)} \tau \nu_\tau$ vs $B \to D^{(*)} \ell \nu_\ell$

- Semileptonic decays involving a heavy lepton have an additional helicity amplitude

$$\frac{d\Gamma(\overline{B} \to D^* \ell^- \overline{\nu}_\ell)}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |p| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[\left(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2\right) \left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2} |H_{0t}|^2 \right]$$

  - H_{0t} calculated using HQS relations or L-QCD. We use:
    - $B \to D \tau \nu_\tau$ from Tanaka et al. 2010
    - $B \to D^* \tau \nu_\tau$ from Fajfer et al. 2012

For $B \to D \tau \nu_\tau$ only H_{00} and H_{0t} contribute

- We measure directly the $\mathcal{R}$(D) and $\mathcal{R}$(D*) ratios

$$\mathcal{R}(D) = \frac{\Gamma(B \to D\tau\nu_\tau)}{\Gamma(B \to D\ell\nu_\ell)_{\ell = e, \mu}}$$

$$\mathcal{R}(D^*) = \frac{\Gamma(B \to D^*\tau\nu_\tau)}{\Gamma(B \to D^*\ell\nu_\ell)_{\ell = e, \mu}}$$

Signal (numerator)

Normalization (denominator)

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

Ratio of $B \to D^{(*)} \tau \nu_\tau$ vs $B \to D^{(*)} \ell \nu_\ell$

- Semileptonic decays involving a heavy lepton have an additional helicity amplitude

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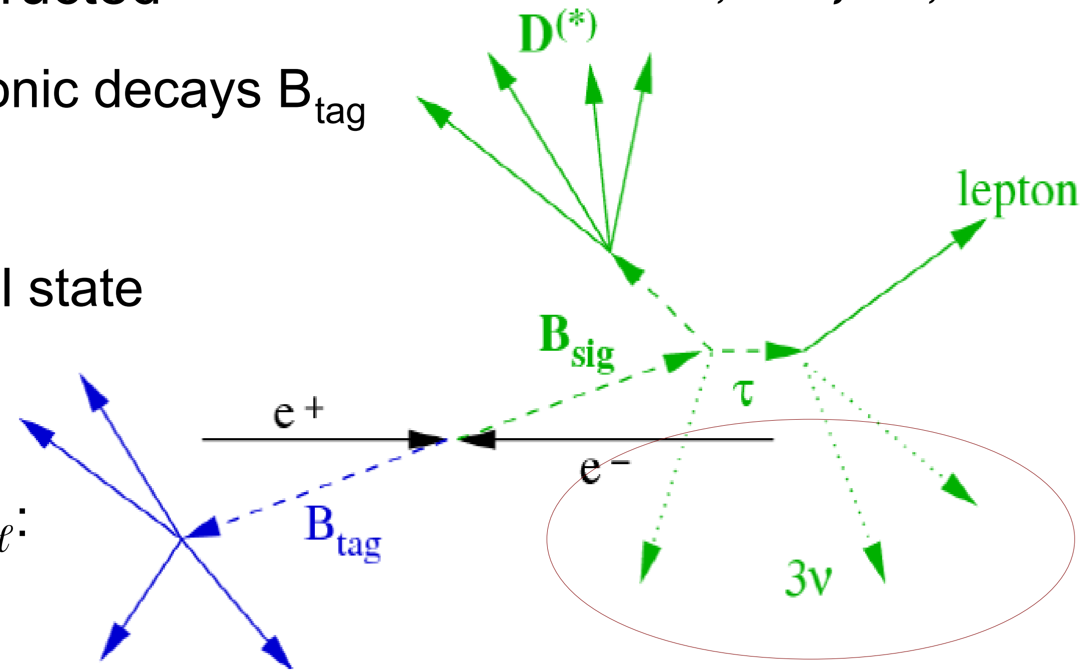
$$\mathcal{R}(D^*) = \frac{\Gamma(B \to D^*\tau\nu_\tau)}{\Gamma(B \to D^*\ell\nu_\ell)_{\ell = e, \mu}}$$

Several experimental AND theoretical uncertainties cancel in the ratio
$\rightarrow$ SM predictions affected by small uncertainty (2-5%)

Event Reconstruction

- $\Upsilon(4S) \rightarrow BB$ events are fully reconstructed
  - Full reconstruction of one B in hadronic decays B_{tag}
  - Reconstruction of $D^{(*)}$
  - $\tau \rightarrow \ell\nu\nu$ (ℓ=e or μ) $\rightarrow$ 3 ν in the final state
  - No additional charged particles

D^0, D^{*0}, D^+, D^{*+}



- Largest background from $B \rightarrow D^{(*,**)}\ell\nu_\ell$:
  ℓ=e or μ
  - Hardest lepton spectrum
  - Only one neutrino in the final state!

- Previous measurements from BaBar and Belle exceed SM predictions (~1.0σ)

Low significance (statistical limited)

PRL99,191807 - PRL100,021801
ArXiv:0910.401 - PRD82,072005

- Experimental challenge: 3 ν in the final state
- Signal characterized by:
  - Large missing mass
  - Soft lepton from secondary $\tau \rightarrow \ell\nu\nu$ decays

Event Reconstruction

- Υ(4S) → BB events are fully reconstructed
  - Full reconstruction of one B in hadronic decays B_{tag}
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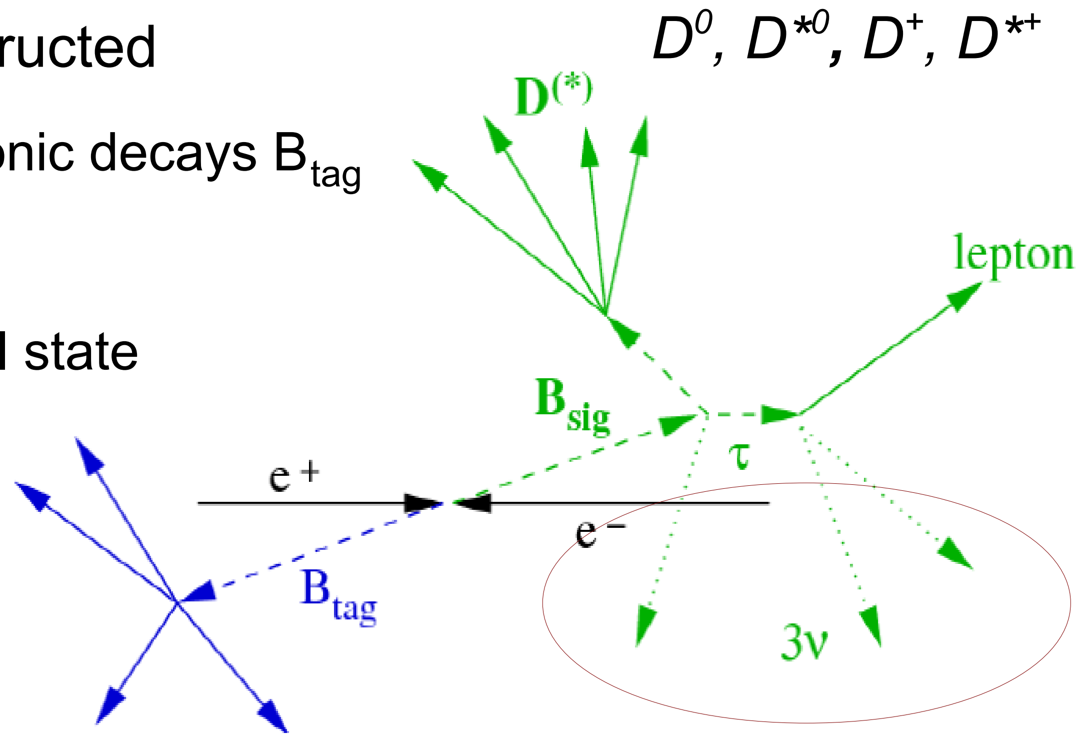


New Measurement (arXiv:1205.5442)

- Full BABAR Υ(4S) data sample: 471M BB
- Improved B-tagging
  - More B_{tag} modes and looser cuts
  - Tag efficiency improved 2x
- Improved μ efficiency
  - reconstruction of μ extended to lower momenta

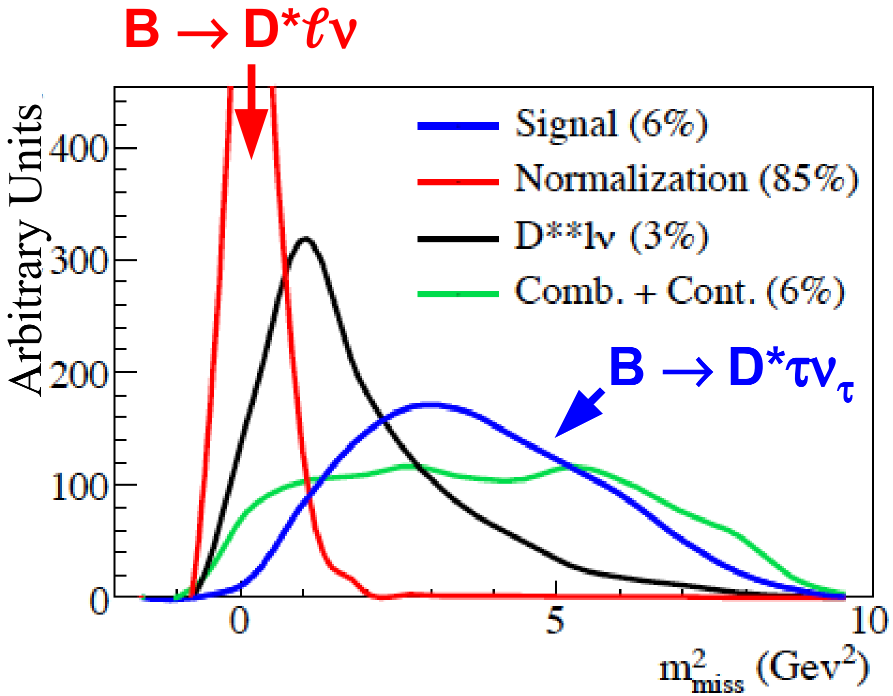
- Experimental challenge: 3 ν in the final state
- Signal characterized by:
  - Large missing mass
  - Soft lepton from secondary $\tau \rightarrow \ell\nu\nu$ decays

$B \to D^{(*)} \tau \nu_\tau$: Extraction of Yields

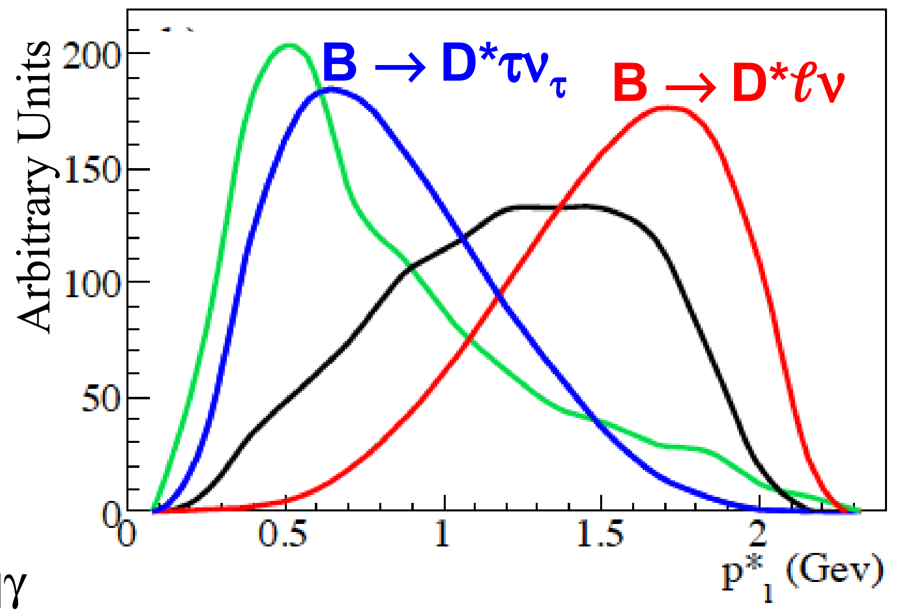
- Simultaneous un-binned M.L. Fit
  - 4 signal samples $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, $D^{*+}\ell$
  - 4 $D^{(*)}\pi^0\ell\nu$ Control samples
  - 2 dimensional distributions:

$m_{miss}^2 = (p_{e+e-} - p_{tag} - p_{D(*)} - p_\ell)^2$

p^*_ℓ = B_{sig} rest-frame lepton momentum)



- PDFs from MC: approximated using KEYS function
  - $\mathcal{L}umi_{MC} \sim 9 \times \mathcal{L}umi_{data}$
- Fitted Yields
  - 4 $D^{(*)}\tau\nu$ + 4 $D^{(*)}\ell\nu$ normalizations + 4 $D^{**}\ell\nu$
- Fixed Backgrounds
  - B^0-B^+ cross feed
  - BB combinatorial Bkg & continuum $e^+e^- \to q\bar{q}\gamma$

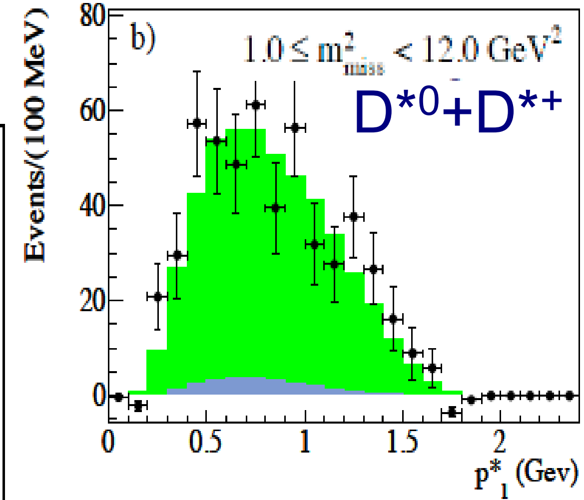


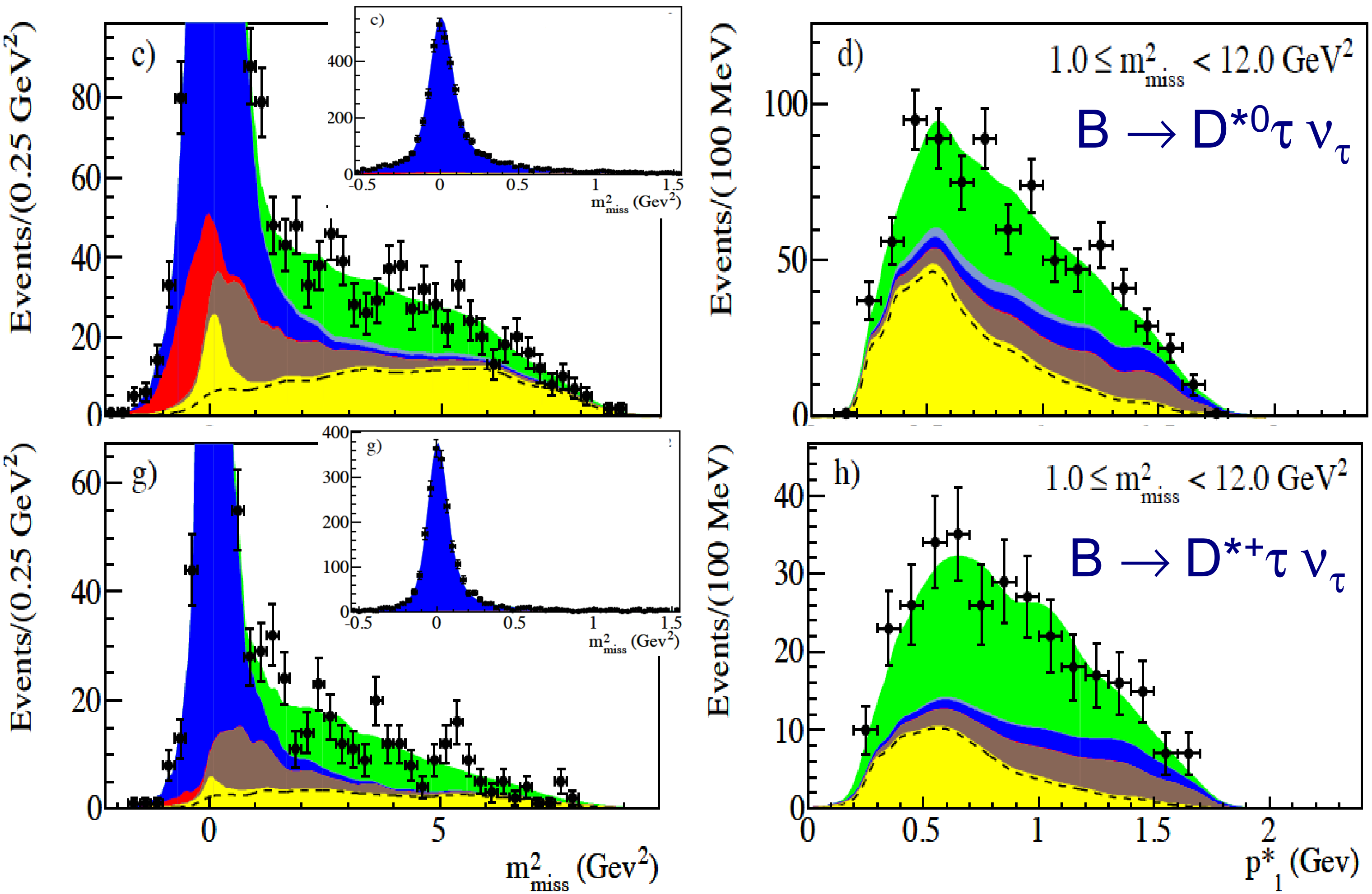
Results of Fit $B \to D^* \tau \nu_\tau$

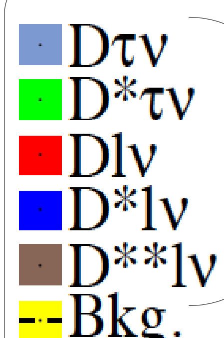
Isospin Constrained

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^{*}\tau\nu$
$N_{\rm sig}$	639 ± 62	245 ± 27	888 ± 63
Significance (σ)	11.3	11.6	16.4
$R(D^*)$	0.322 ± 0.032	0.355 ± 0.039	0.332 ± 0.024

Statistical errors only







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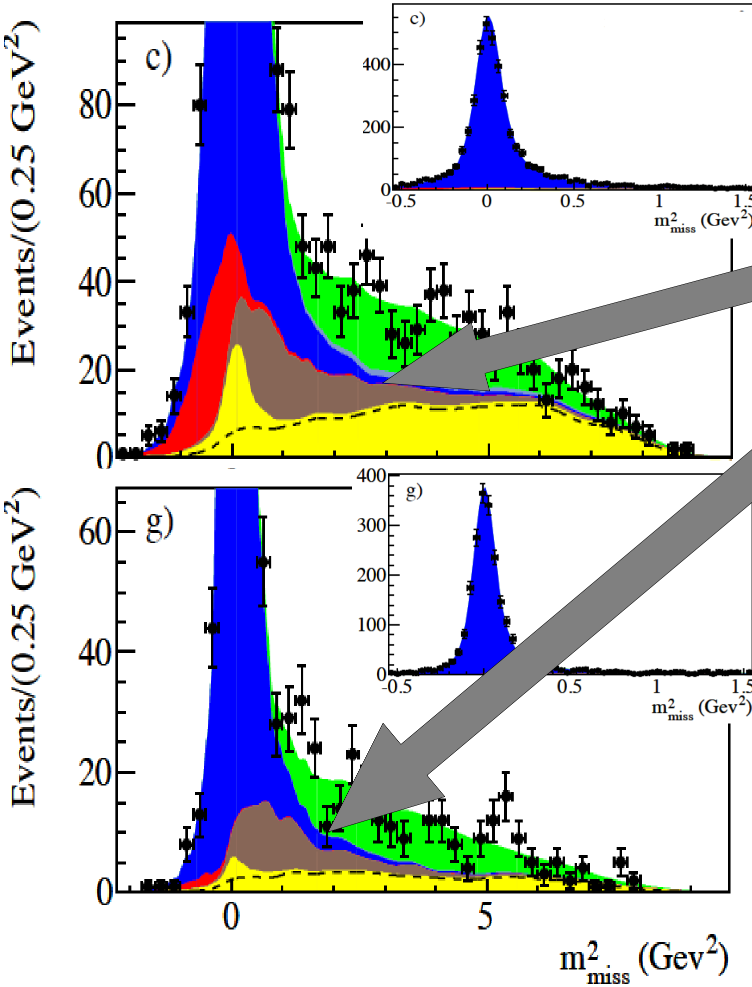
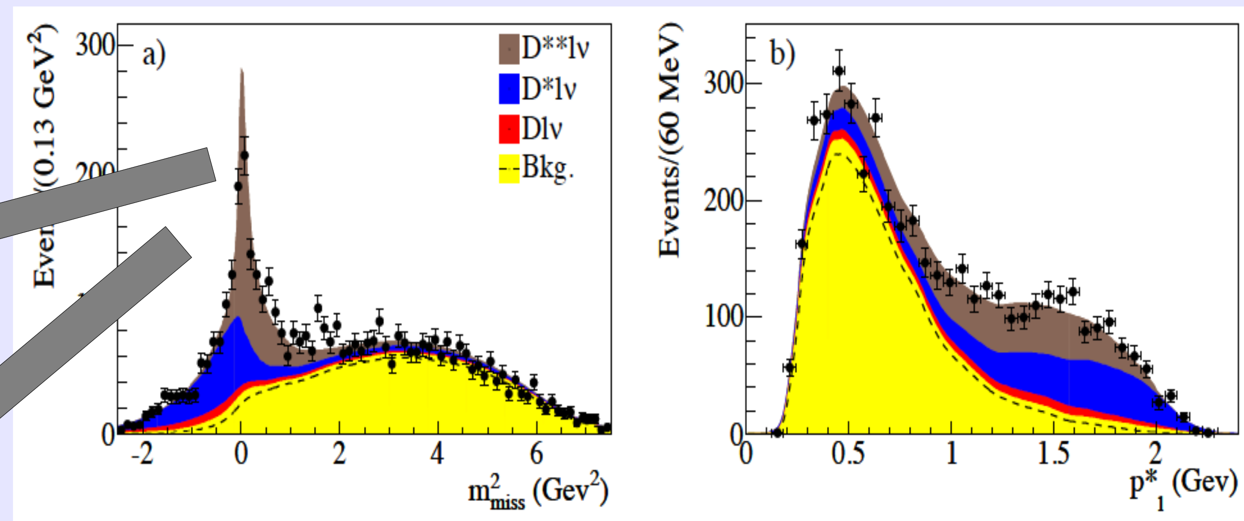
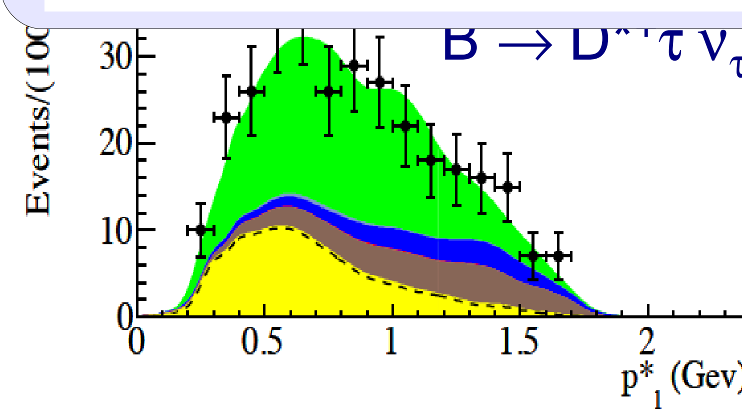


Fit results for $B \to D^{**}\ell\nu_\tau$

Sum of the 4 channels: $D^0\pi^0\ell\nu$, $D^{*0}\pi^0\ell\nu$
$D^+\pi^0\ell\nu$, $D^{*+}\pi^0\ell\nu$





Dlν
D*lν
D**lν
Bkg.

Free yields

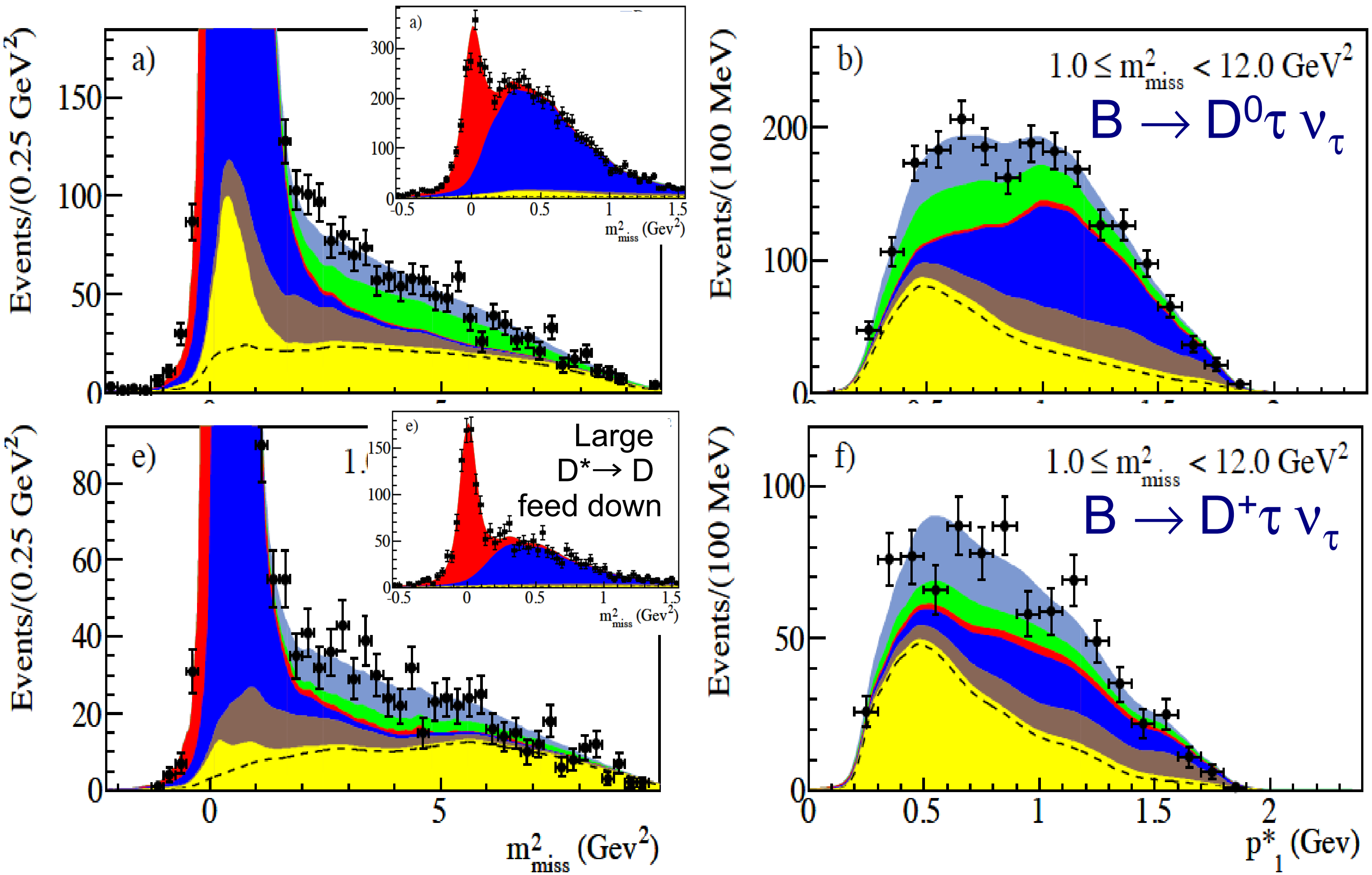
Fixed

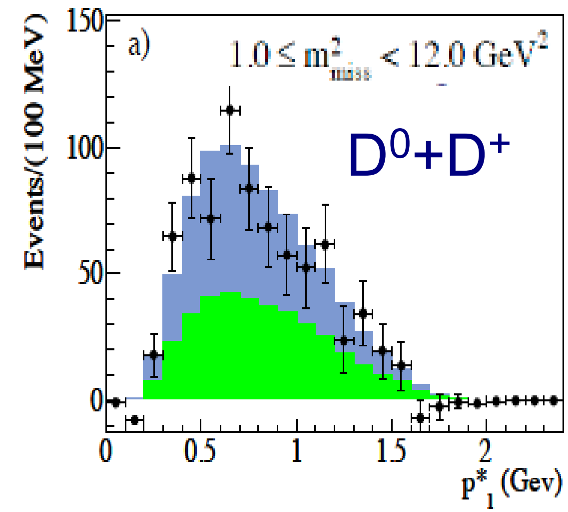
Results of Fit $B \rightarrow D \tau \nu_\tau$

Isospin Constrained

	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

Statistical errors only





- $D\tau\nu$
- $D^*\tau\nu$
- $Dl\nu$
- $D^*l\nu$
- $D^{**}l\nu$
- Bkg.

Free yields (Dτν, D*τν, Dlν, D*lν, D**lν)

Fixed (Bkg.)

Results and Systematics Uncertainties

Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

- B $\to$ D τ ν established with 6.8σ significance
- Principal Uncertainties
  - B $\to$ D** τ/ℓ ν
    - Studies various models for the D**$\ell\nu$ composition: including non-resonant & D(*)$\pi\pi$ final states
  - MC statistics for the signal sample
  - Continuum and BB background

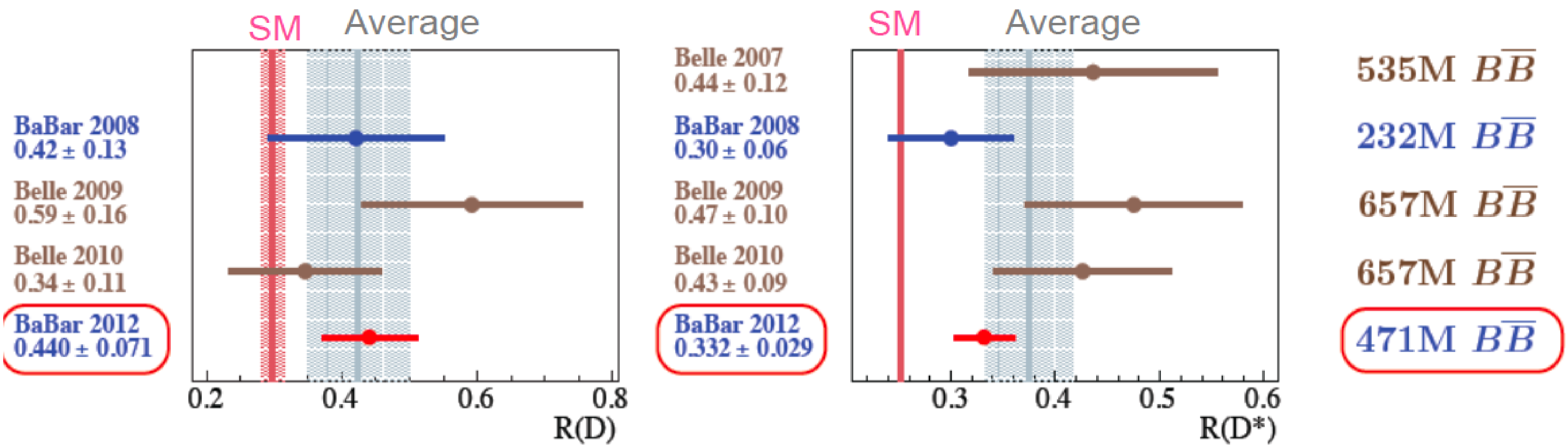
	R(D)	R(D*)	ρ_{corr}
D** τ/l ν	5.8	3.7	0.62
MC statistics	5.0	2.5	-0.48
Continuum and BB bkg	4.9	2.7	-0.30
$\varepsilon_{sig}/\varepsilon_{norm}$	2.6	1.6	0.22
Syst. Uncertainty	9.5	5.3	0.05
Stat. Uncertainty	13.1	7.1	-0.45
Total Uncertainty	16.2	9.0	-0.27

Uncertainties due to FFs, PID, tracks, photons and soft pion reconstruction cancel in the ratio: contribution ~1%

SM Predictions of R(D) and R(D*)

- The new measurements are fully compatible with earlier results

Average does not include this measurement



SM Predictions of R(D) and R(D*)

[*] Kaminik Mescia 2008
Fajfer et al 2012

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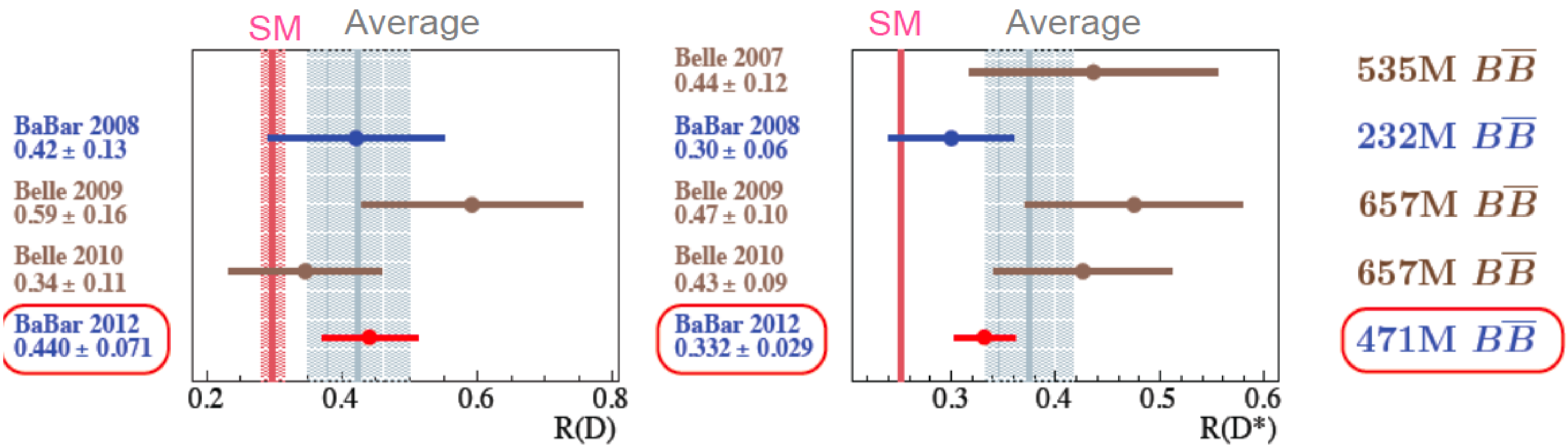
Average does not include this measurement

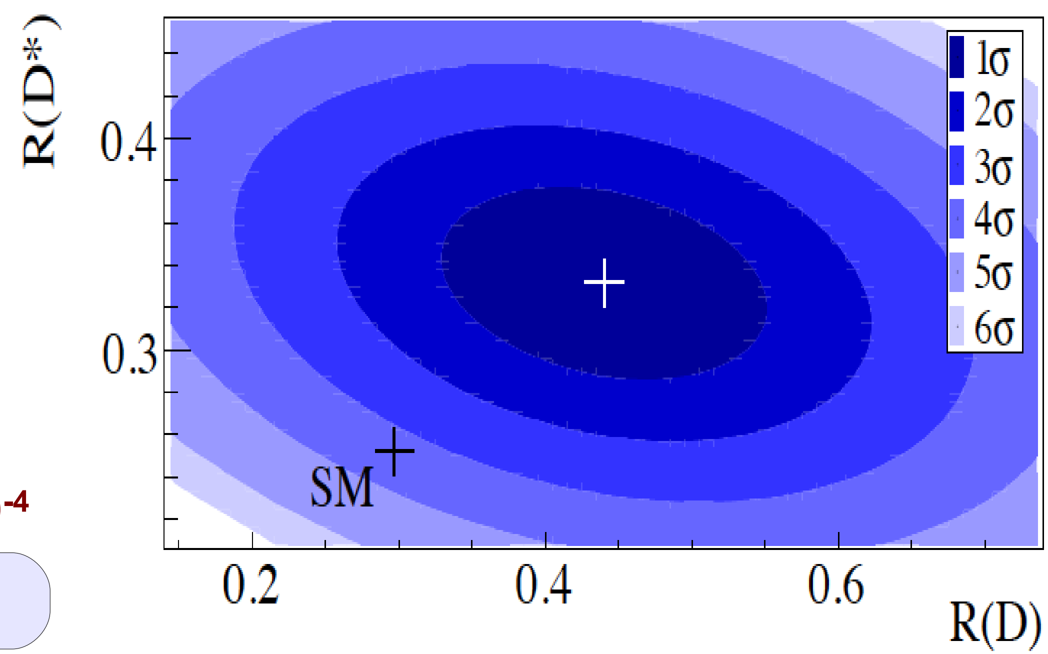


- And above the SM prediction!

	R(D)	R(D*)
BaBar	0.440 ± 0.071	0.332 ± 0.029
SM [*]	0.293 ± 0.017	0.252 ± 0.003
Δ	2.0σ	2.7σ

The combination of the two measurements (-0.27 Correlation) yields χ^2/NDF=14.6/2 –> **Prob=6.9 x 10^{-4}**

SM prediction is excluded at 3.4σ



Can we explain the excess events?

- A charged Higgs (Type II 2HDM) of spin 0 coupling with the τ will affect H_{0t}

$$H_{0t}^{2HDM} \approx H_{0t}^{SM} \times \left(1 - \frac{\tan^2\beta}{m_{H+}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$

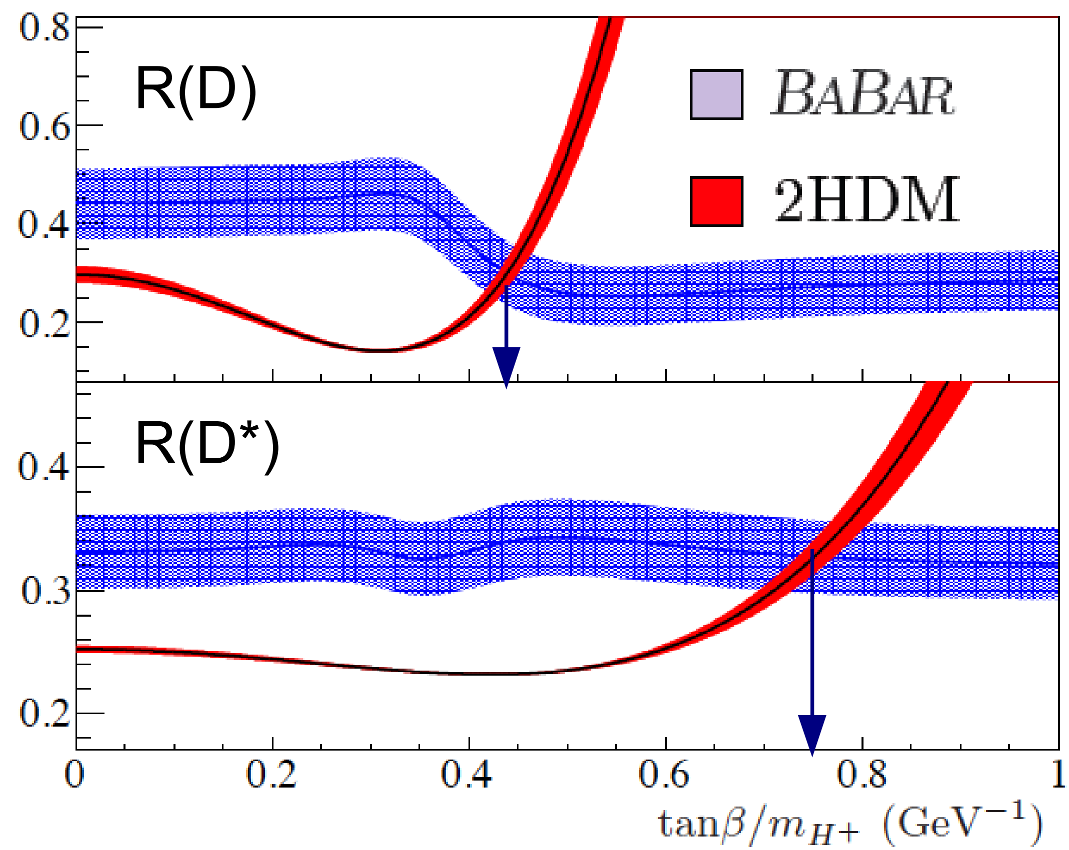
– for $B \to D\tau\nu_\tau$

+ for $B \to D^*\tau\nu_\tau$

- We estimate the effect of 2HDM accounting for the difference in efficiency and its uncertainty

- The data match Type II 2HDM at

$$\mathcal{R}(D) \Longrightarrow \tan\beta/m_H = 0.44 \pm 0.02$$
$$\mathcal{R}(D^*) \Longrightarrow \tan\beta/m_H = 0.75 \pm 0.04$$

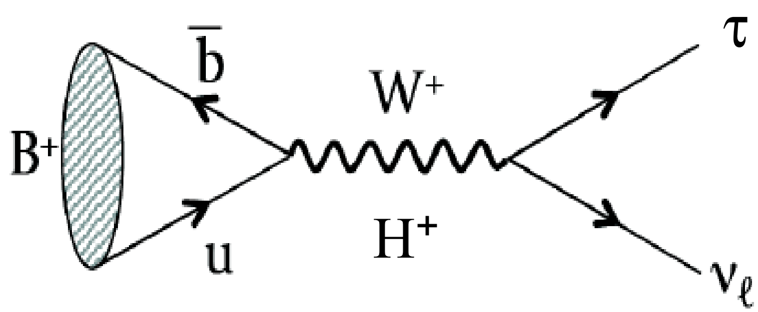


- The combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space (with m_H>10 GeV) with a probability >99.8%

- Low m_H range (m_H<~300 GeV) already excluded by $B \to X_s\gamma$ data!

Connection with $B \to \tau \nu_\tau$

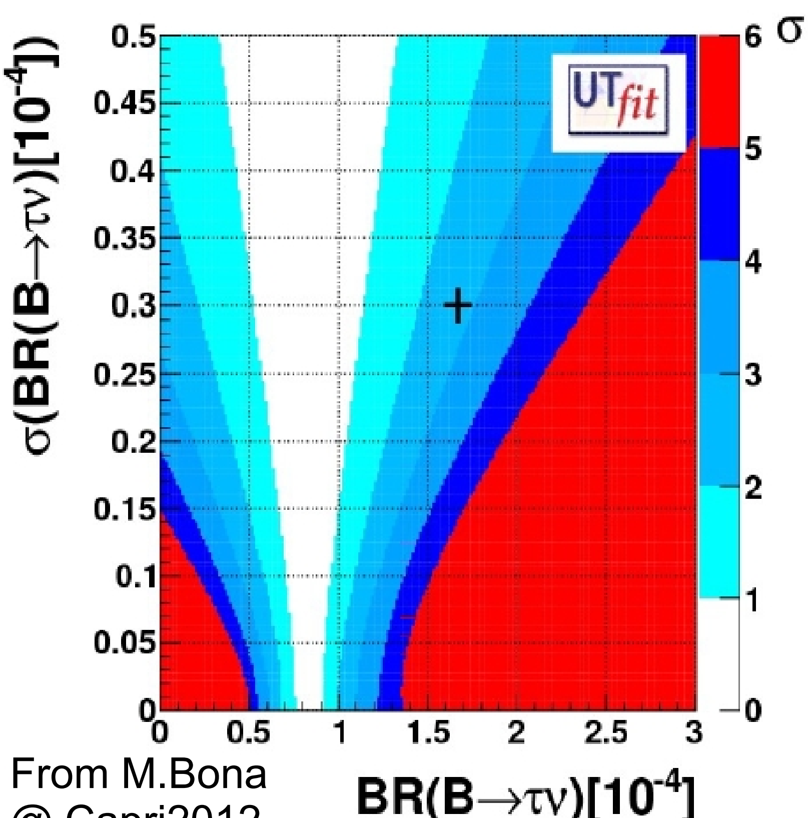
- In the SM annihilation process mediated by W, but could be affected by charged Higgs



$$\mathcal{B}_{2HDM}(B \to \tau\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \times \left(1 - m_B^2 \frac{\tan^2\beta}{m_H^2}\right)^2$$

B(τν) In the SM

In the Type-II 2HDM



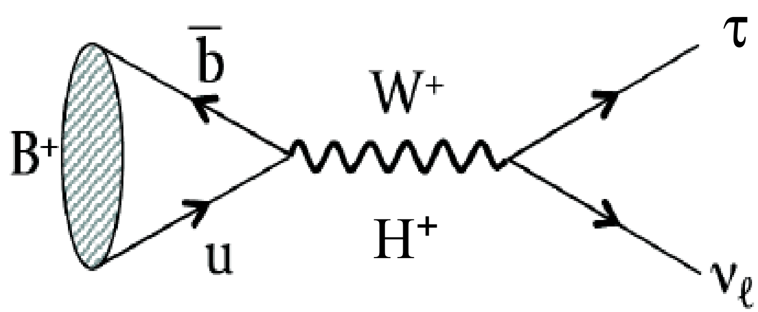
From M.Bona @ Capri2012

$B(B \to \tau \nu_\tau) \cdot 10^4$	
1.67 ± 0.30	HFAG average (4 low statistics BF meas.)
0.83 ± 0.09	UTfit indirect determination Affected by f_B and $\lvert V_{ub}\rvert$
Δ = 2.7σ	

- Discrepancy can be explained in the Type II-2HDM but results are not compatible with R(D) and R(D*)
- Expect new results with reconstruction and B_{tag} improvements from BaBar and Belle

Connection with $B \to \tau \nu_\tau$

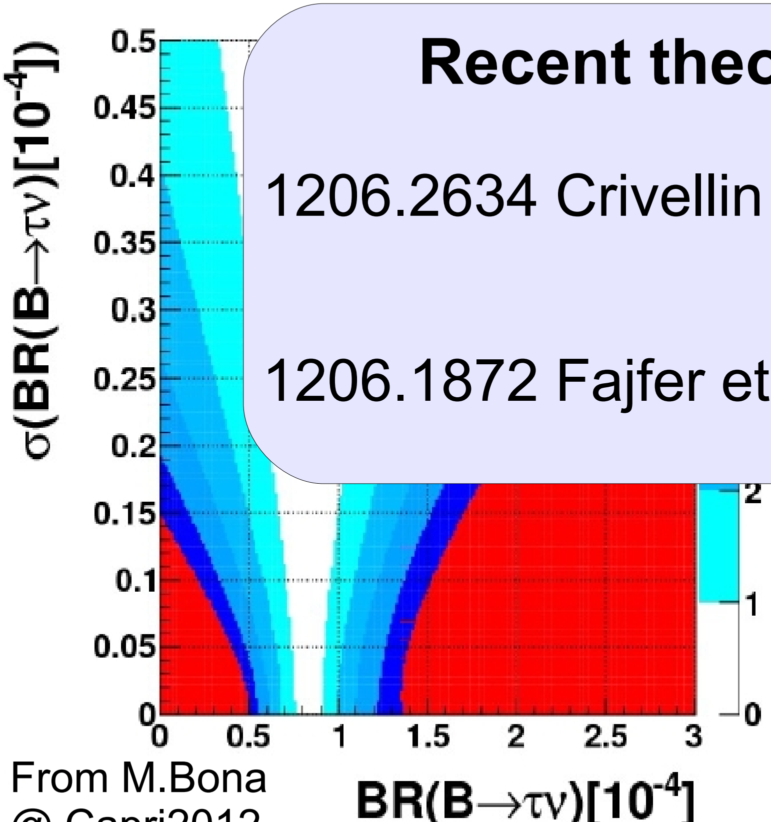
- In the SM annihilation process mediated by W, but could be affected by charged Higgs



$$\mathcal{B}_{2HDM}(B \to \tau\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

B(τν) In the SM

In the Type-II 2HDM



From M.Bona @ Capri2012

Recent theoretical papers in arXiv

1206.2634 Crivellin et al: possibile explanation with Type III 2DHM

1206.1872 Fajfer et al: 2DHM with leptoquarks

meas.)

termination nd $|V_{ub}|$

$\Delta = 2.7\sigma$

- Discrepancy can be explained in the Type II-2HDM but results are not compatible with R(D) and R(D*)
- Expect new results with reconstruction and B_{tag} improvements from BaBar and Belle

Conclusions and Outlook

- $B \to D\tau\nu_\tau$ and $B \to D^*\tau\nu_\tau$: significant improvements!
  - error reduced by a factor 2 and $B \to D\tau\nu_\tau$ observed at 6.8σ
- Excess of $B \to D(^*)\tau\nu_\tau$ decays
  - Combined results: 3.4σ from the Standard Model predictions
- Cannot be explained by charged Higgs in the widely discussed Type II 2DHM
  - Full parameter space excluded @ 3.1σ
- Corresponding excess also in $B \to \tau\, \nu_\tau$, hint of NP?

- New Belle measurements with improved B_{tag} (NeuroBayes®) welcome!
- Confirmation? Look for other observables:
  - q^2 distribution, τ polarization using $\tau \to \pi\nu_\tau$, D^* polarization from D^* decay angular analysis => Rich physics for future SuperB factories!

BACK UP

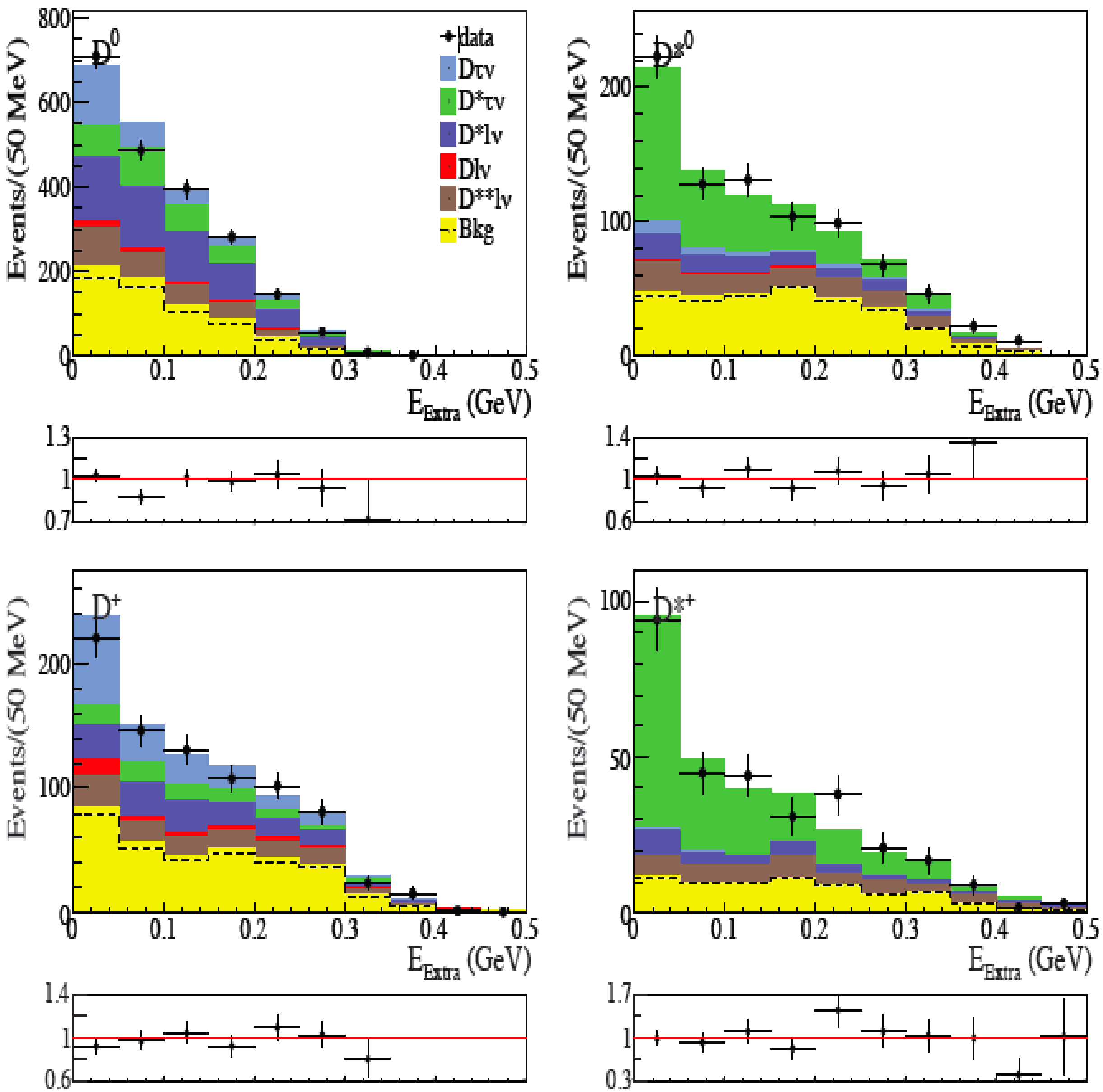
Event Reconstruction: Details

- B_{tag} reconstructed in $B \to D^{(*)}X$, $B \to D_s^{(*)}X$, $B \to J/\psi X$ ($X=\pi,K$ modes with $n_X<6$) and selected using
  - beam energy substituted mass
  - the energy difference

$$m_{ES} = \sqrt{(E^*_{beam})^2 - (\mathbf{p}^*_{tag})^2}$$
$$\Delta E = E^*_{tag} - E^*_{beam}$$

- Signal side $D^{(*)}$ in D^0, D^{*0}, D^+, D^{*+} and require an identified lepton
- No additional charged particles
- Kinematic selection: $q^2 = (p_B - p_{D(*)})^2 = q^2 > 4\ \mathrm{GeV}^2$
- Boosted Decision Tree (BDT)
  - Reduce combinatorial and D** backgrounds
- Because the $B \to D^{**}(\ell,\tau)\nu$ have large uncertainties
  - We fit simultaneously also a sample of 4 $D^{(*)}\pi^0\ell\nu$
    - same selection as signal but added π^0: captures $D^{**} \to D^{(*)}\pi^0$
- Three control samples to validate and correct the simulation:
  - $E_{extra}>0.5$ GeV, $q^2<4$ GeV, $m_{ES}<5.26$ GeV
  - + off-peak data to correct lepton spectrum of simulated continuum events

Signal Peak in E_{extra}

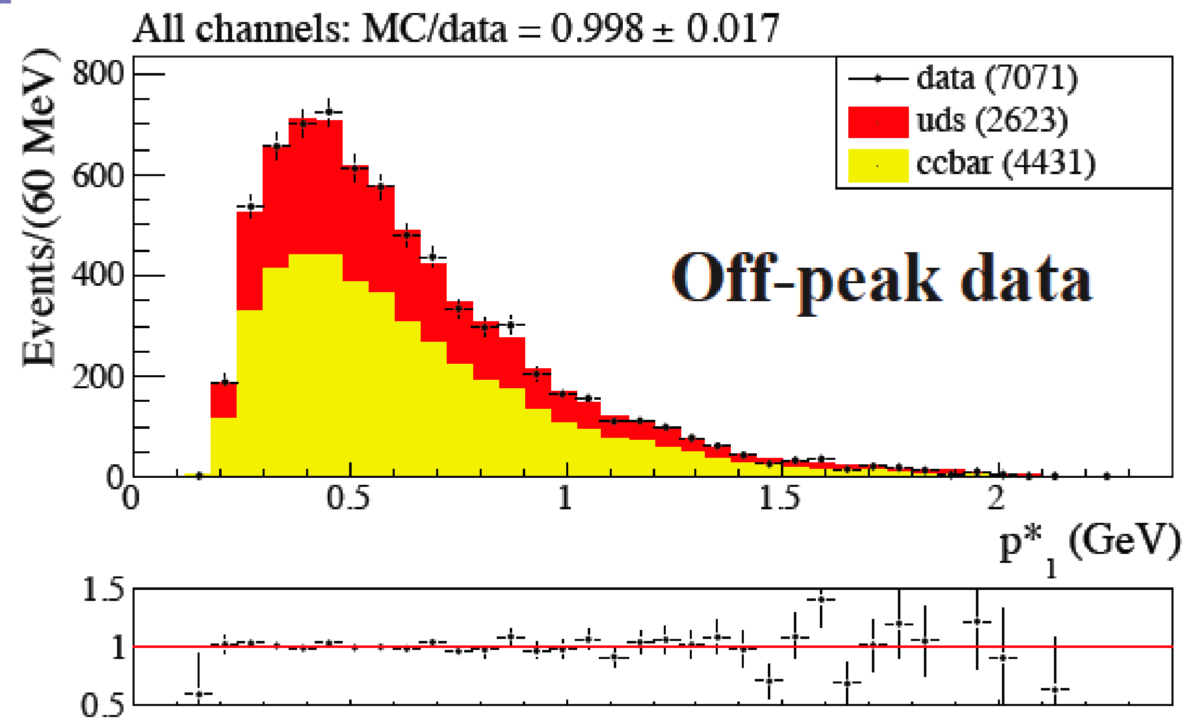


- Sum of the energies of all photon candidates not associated with reconstructed BB pair
- Not used in the fit
- Rescaled to the results of the fit
  - $m_{miss}^2 > 1$ GeV² (signal enhanced)

Background estimation

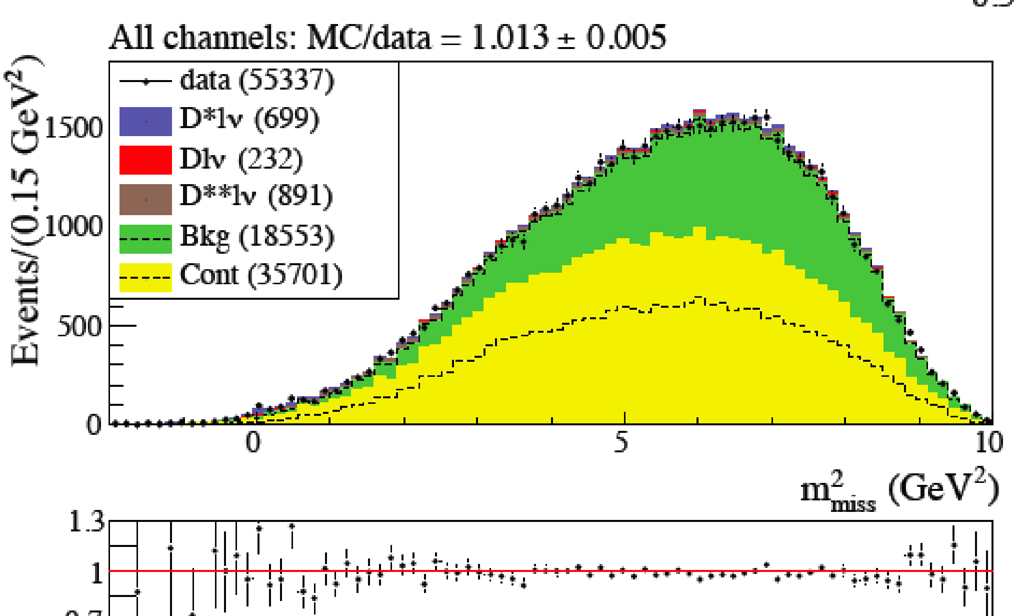
Continnum:

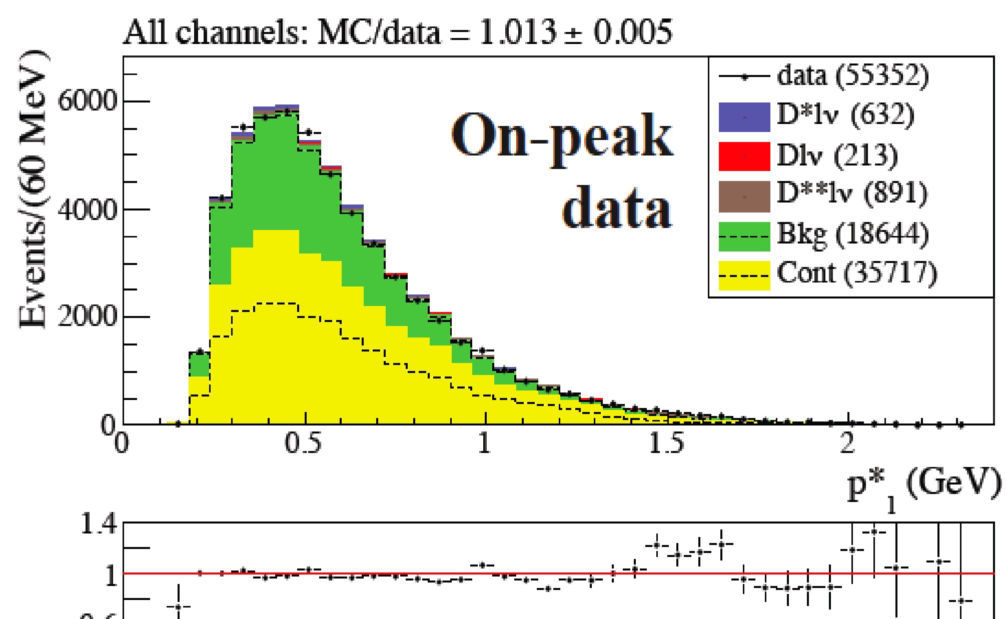
- Using off-peak data
- Special runs taken below the Y(4S) peak



BB background:

- Estimated in events with large E_{extra}





Two Higgs Doublet Model