Measurement of $B \to D^{(*)}\tau\nu$ @ BaBar

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Outline

PRL 109, 101802 (2012)

Motivations
Experimental Technique
Event Reconstruction and Fit Strategy
Results
Conclusions

Motivations

$B \to D^{(*)}\tau\nu$ typical example of B decay sensitive to New Physics:

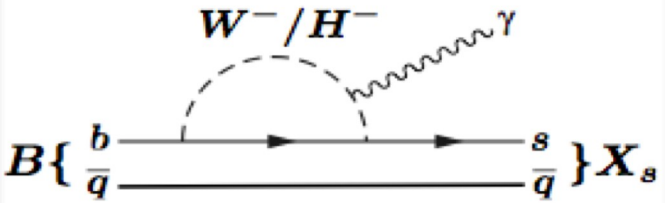
→ same Feynman diagrams as the light leptons, but the decay can also be mediated by a charged Higgs boson

→ Spin zero Higgs does not couple to all helicity states, affect D and D* differently

→ Use of τ hadronic modes can give interesting information on charged Higgs couplings (Phys. Rev. D78:015006, 2008)

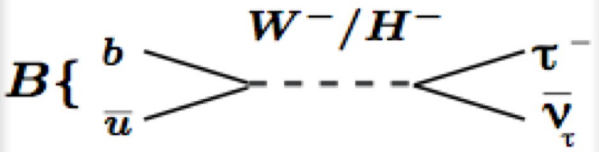
$B \to X_s\gamma$

- ☑ **Small σ_{SM}** ~ 7%
- ☐ H^- enters in a **loop**
- ☐ **BF ~ 0.03%**
- ☐ **Inclusive** measurement difficult



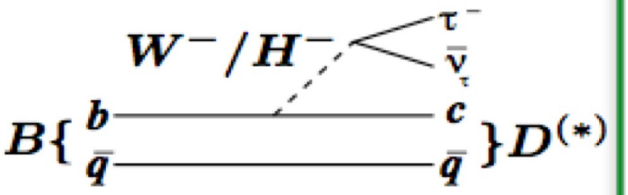
$B^- \to \tau^- \bar{\nu}_\tau$

- ☐ **Large σ_{SM}** ~ 25%
- ☑ H^- enters at **tree level**
- ☐ **BF ~ 0.01%**
  - ☐ Helicity suppressed



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

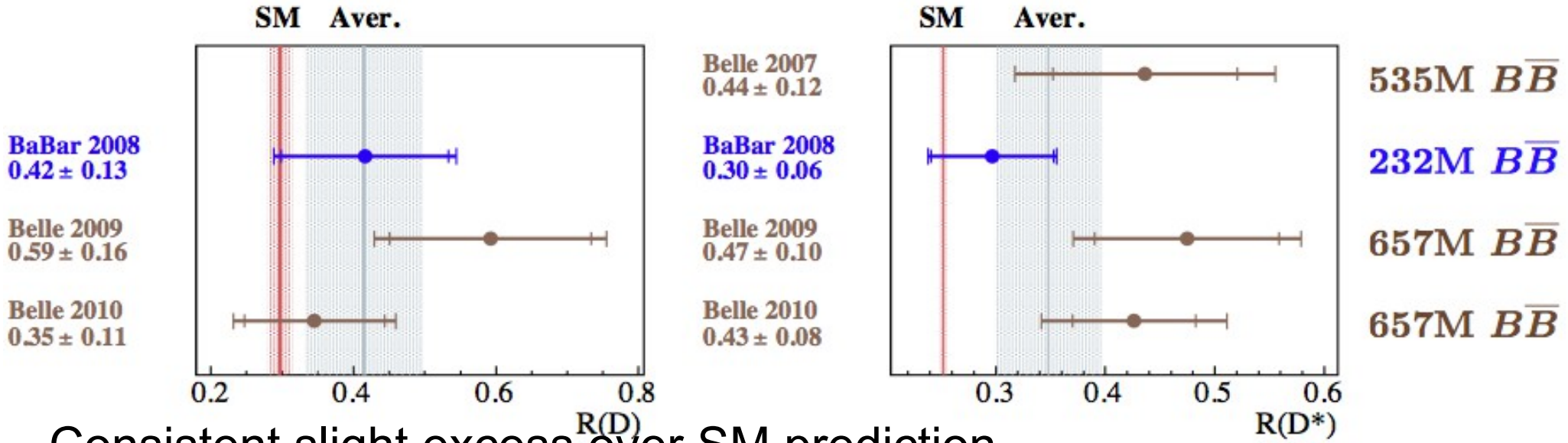
- ☑ **Small σ_{SM}** ~ 2-5%
- ☑ H^- enters at **tree level**
- ☑ **BF ~ 1-2%**
- ☑ $D^{(*)}$ provides constraint



Previous Measurements

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

Measure ratios of BF: several uncertainties cancel in the ratio
Use only leptonic τ decays



Consistent slight excess over SM prediction
Large uncertainties! Measurements statistically limited
Update previous BaBar measurement (2008) to full dataset

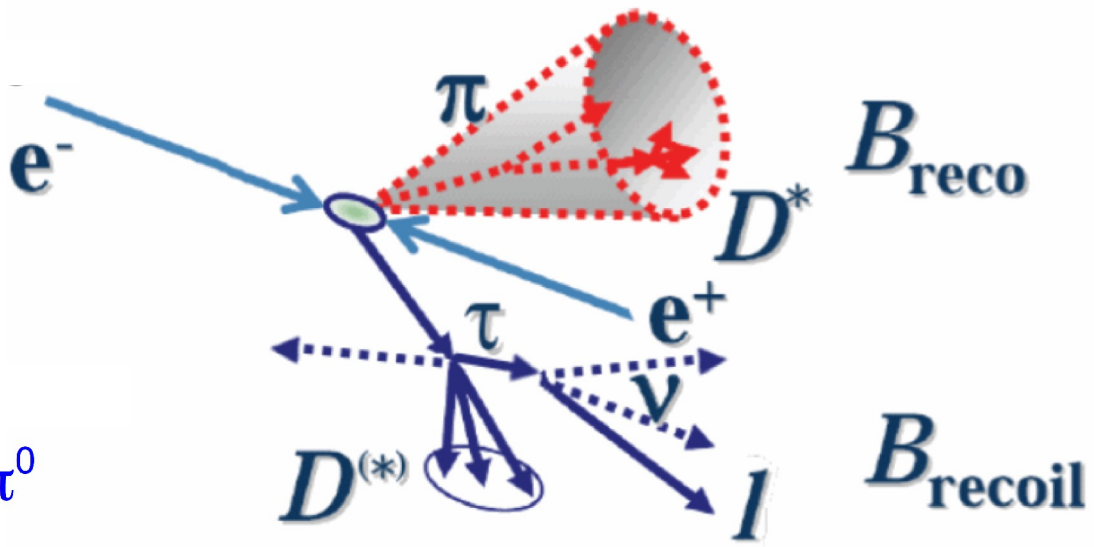
Experimental Technique: B Tagging

τ decays, multiple neutrinos in final state, very challenging

Fully reconstruct one B in the event

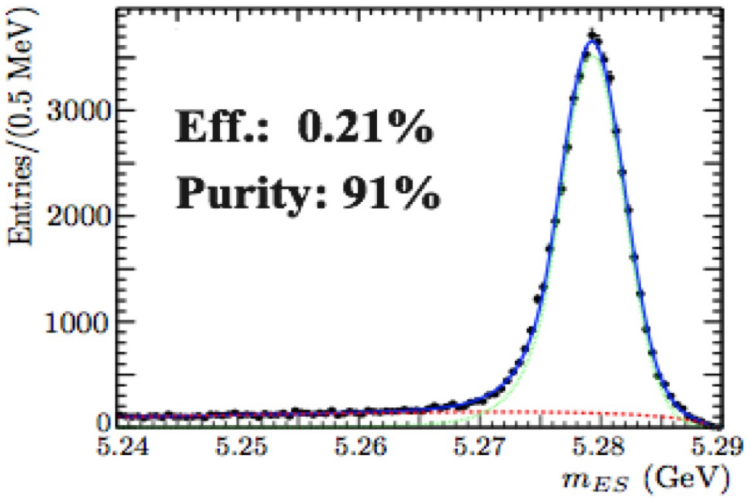
Reconstruct a $D^{(*)}$ meson in hadrons

Reconstruct $B \rightarrow X_c + \pi, K, K_S, \pi^0$



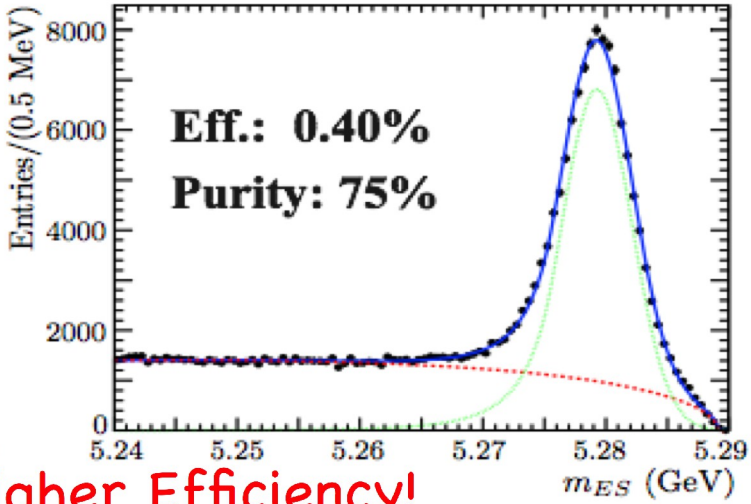
Old B_{tag}: $X_c = D, D^*$

630 decay chains



New B_{tag}: $X_c = D, D^*, D_s^+, D_s^{*+}, J/\Psi$

1,768 decay chains



2x Higher Efficiency!

Event Reconstruction

Require hadronic B_{tag}

Reconstruct $\tau \rightarrow \ell \nu_\tau \nu_\ell$ (ℓ = e,μ)

→ improved PID, increase acceptance at low momentum

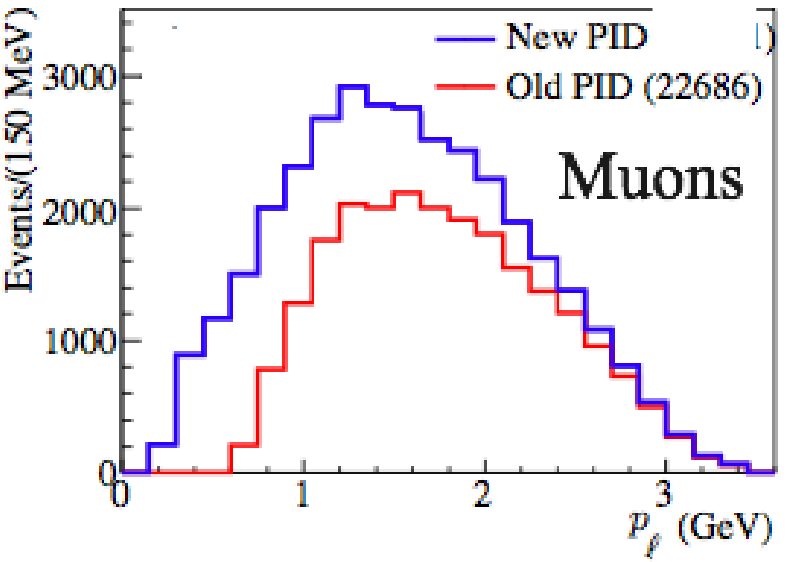
Charge correlation between B_{tag},$D^{(*)}$,ℓ

Reject combinatoric Background:

$q^2 = (p_B - p_{D(*)})^2 > 4\ GeV^2$

$P_{miss} > 200$ MeV

If multiple $B_{tag}+D^{(*)}+\ell$ combinations, select the one with smallest E_{extra}



Use Boosted Decision Tree to suppress background

Dedicated Data control region for BB/continuum background

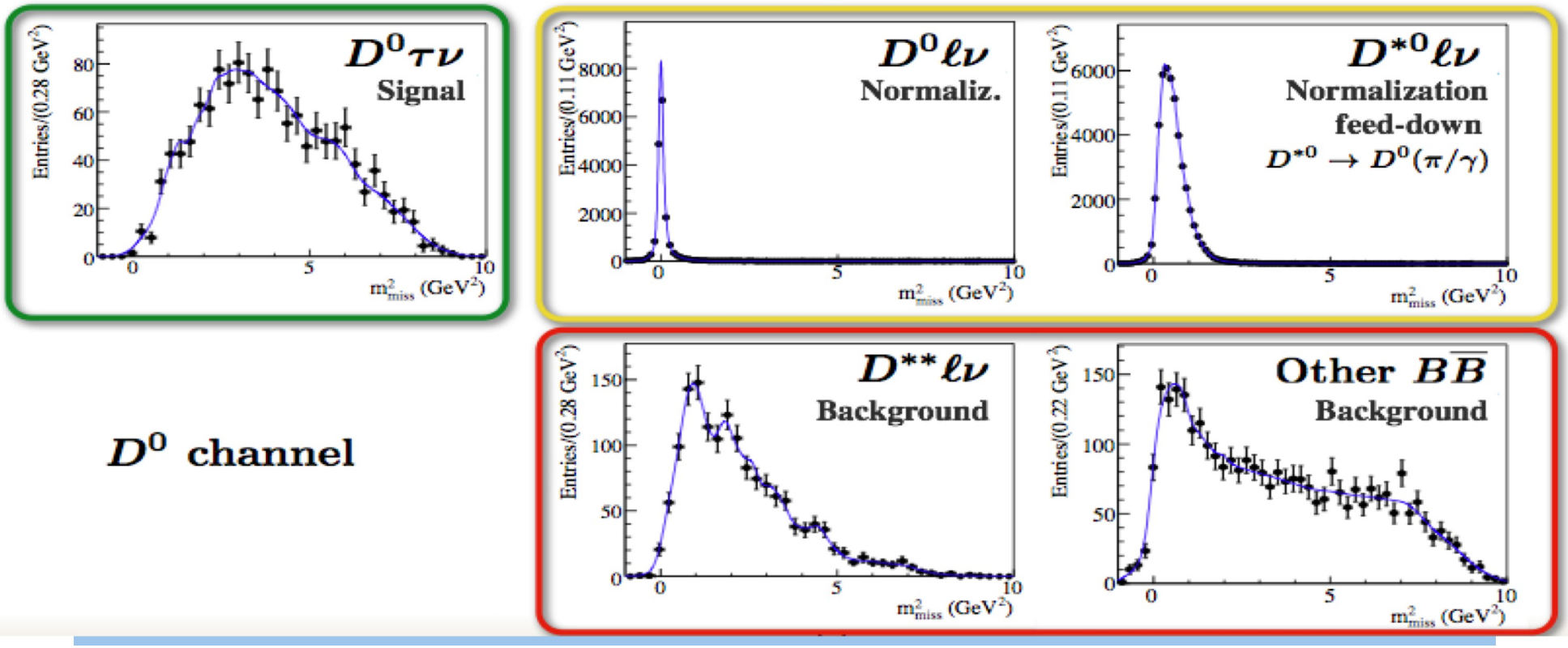
Missing Mass and Backgrounds

Use m^2_{miss} to discriminate signal from background:

$$m^2_{miss,D^{(*)}} = \left(p_\Upsilon - p_{B_{tag}} - p_{D^{(*)}} - p_\ell\right)^2$$

Largest background from $B \to D^{(*)}\ell\,\nu$, either fully reco or feed-down

($B \to D^{(*,**)}\ell\,\nu$ reco as $B \to D^{(*)}\ell\,\nu$)



D^0 channel

Fit Structure

Unbinned ML fit

2D: m^2_{miss} , p^*_ℓ

→ 4 Signal channels
D^0, D^{*0}, D^+ ,D^{*+}

→ 4 $D(^*)\pi^0$ channels

Fitted Yields:

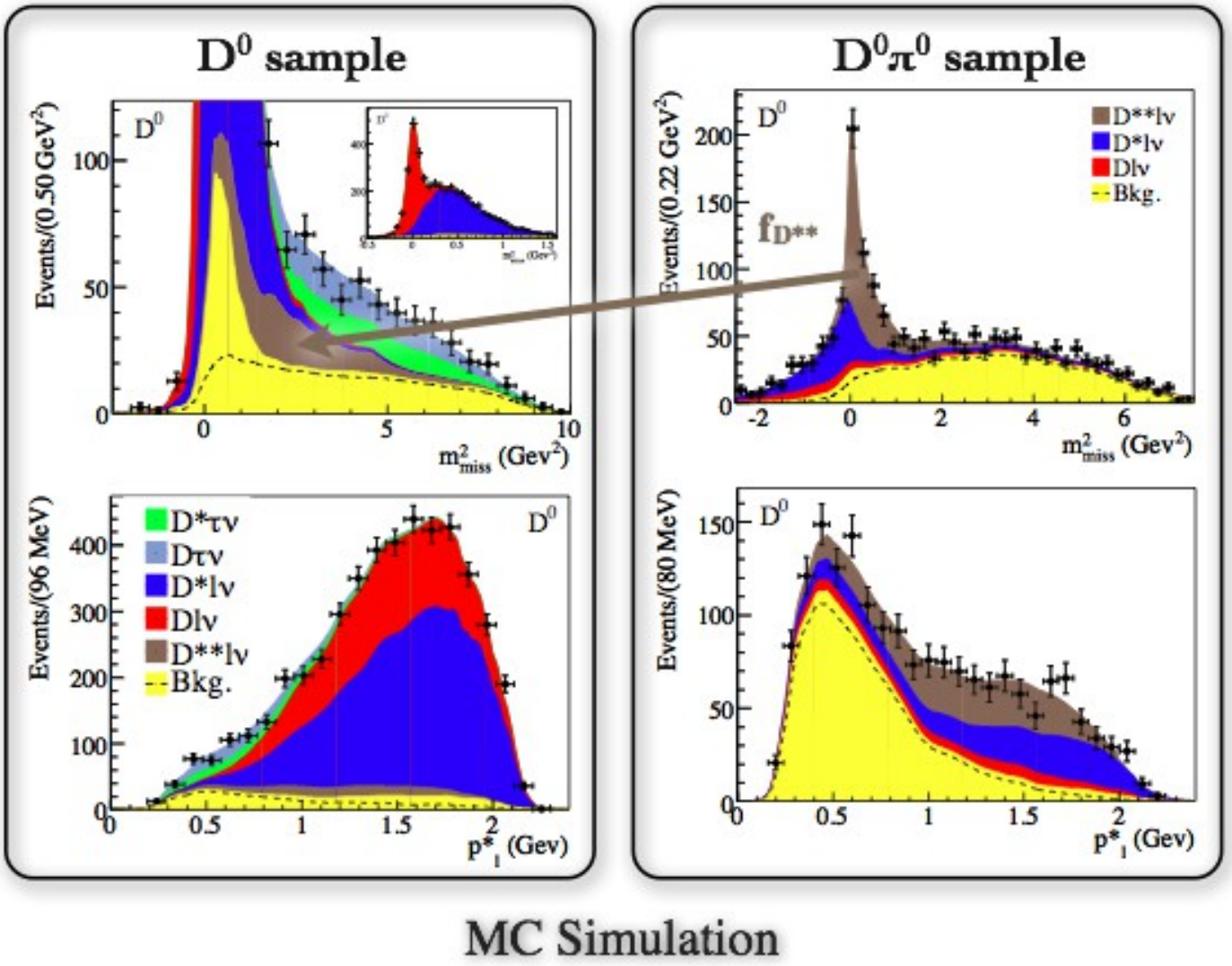
4 $D^*\tau\nu$

4 $D^*\ell\nu$

4 $D^{**}\ell\nu$

Fixed Yields (yellow):

Charge cross-feed
combinatorial BB
continuum

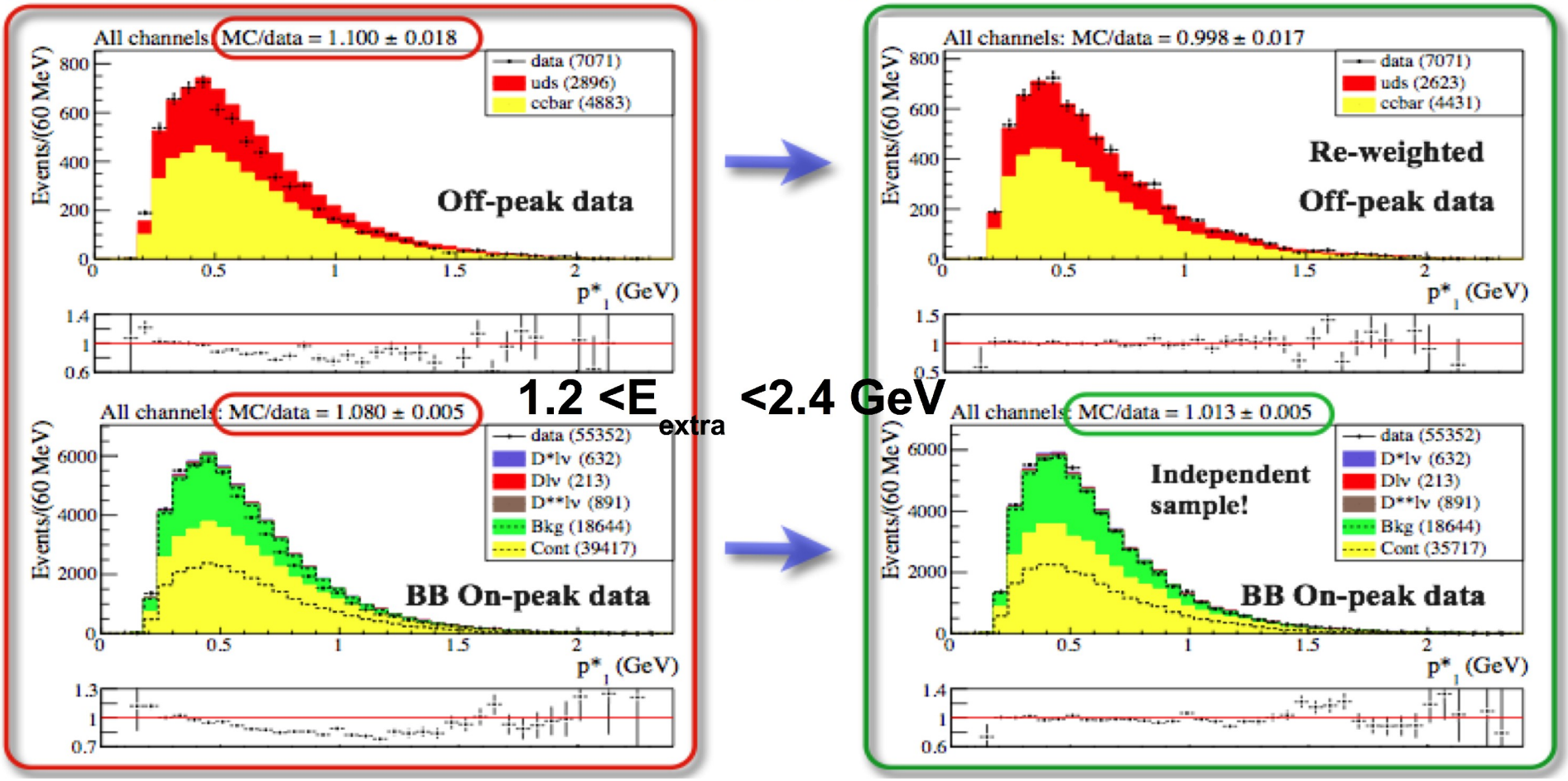


Continuum and BB bkg

Poor Data/MC agreement for p^*_ℓ shape and normalization for continuum events

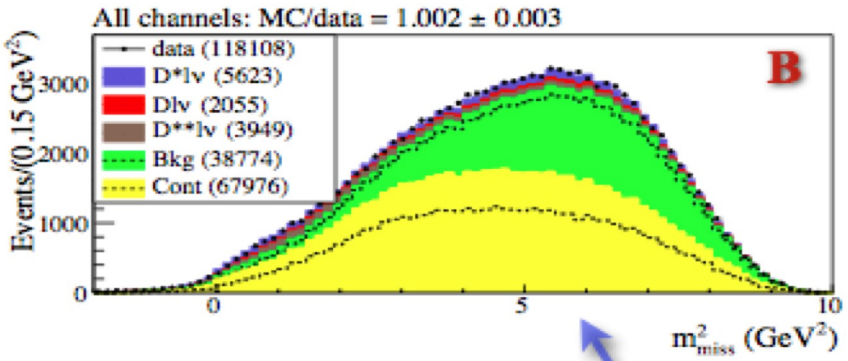
Use off-peak data to re-weight continuum events

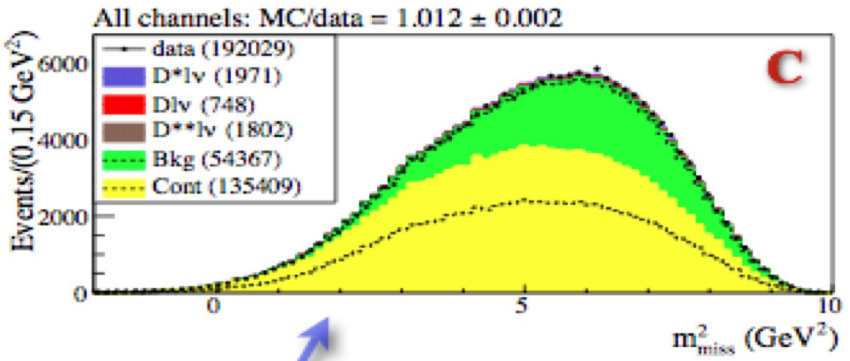
Build Data Control Regions (see next slide) to estimate BB background

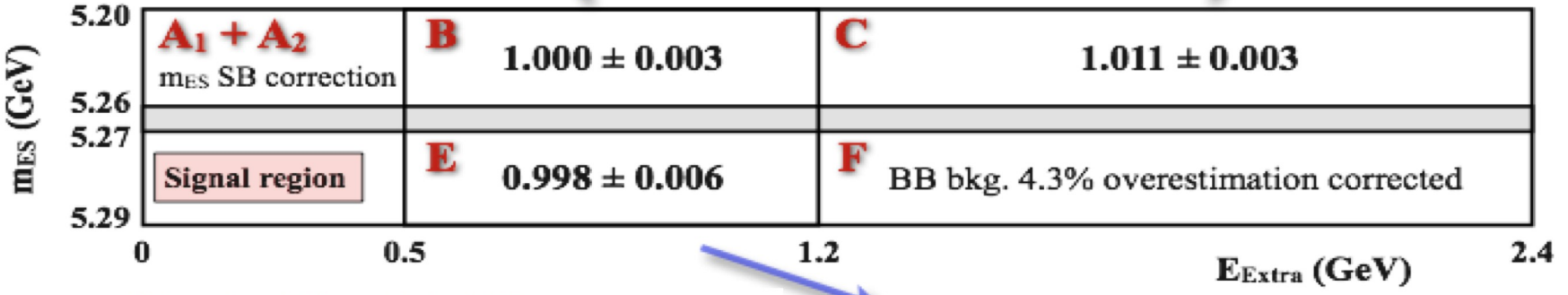


BB bkg Control Region

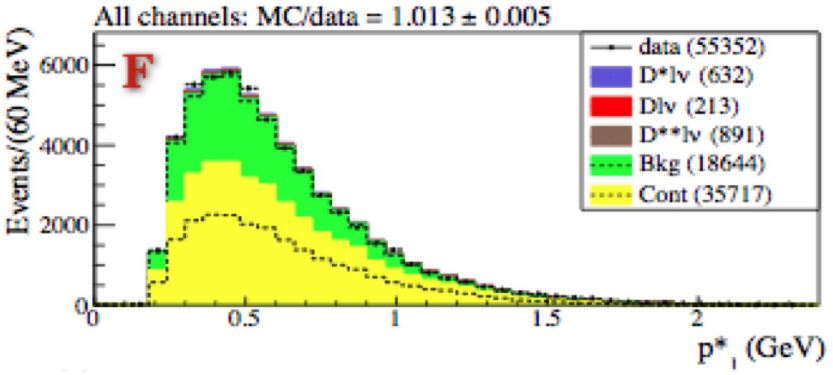
Build data control regions in mES sideband and large Eextra region
→ Background very well described for large Eextra

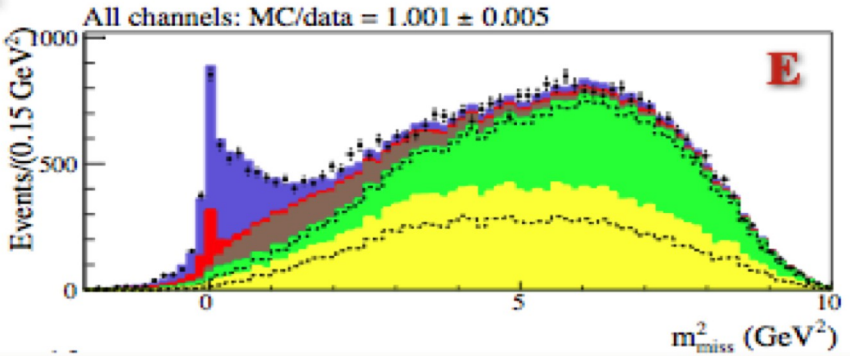






MC/data for $m^2_{miss} > 1.5\ GeV^2$





$B \to D^{*}\tau\nu$ Fit Results

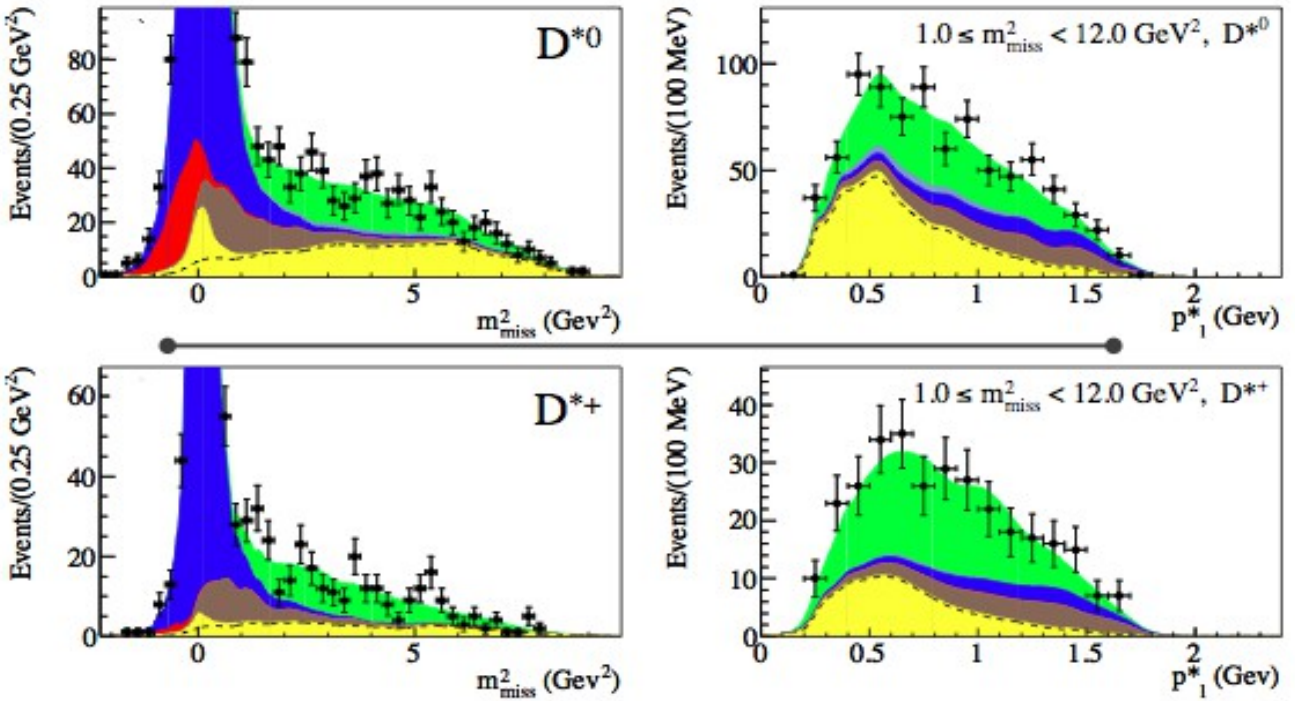
- **Good fit** agreement
- Uncertainties statistical

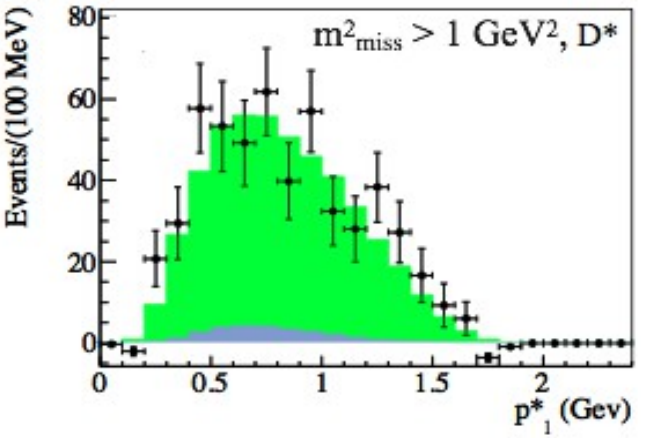
Free in the fit: $D^{*}\tau\nu$, $D\tau\nu$, $D^{*}l\nu$, $Dl\nu$, $D^{**}l\nu$

Fixed: Bkg.

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

Isospin constrained





D^{*0} and D^{*+} channels combined.
Background subtracted

$B \to D\tau\nu$ Fit Results

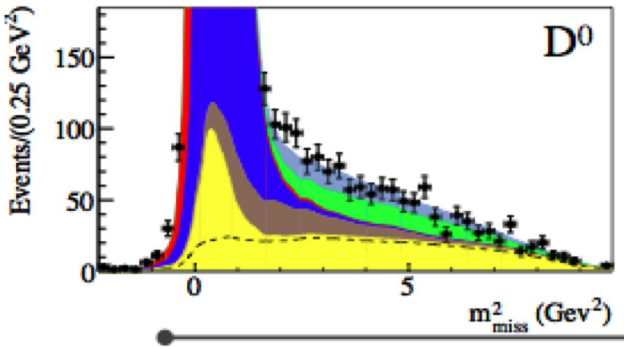
- First **5σ observation**
- Uncertainties statistical

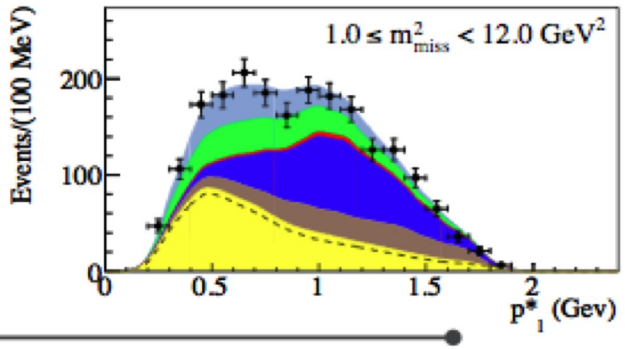
Free in the fit: $D^*\tau\nu$, $D\tau\nu$, $D^*l\nu$, $Dl\nu$, $D^{**}l\nu$
Fixed: Bkg.

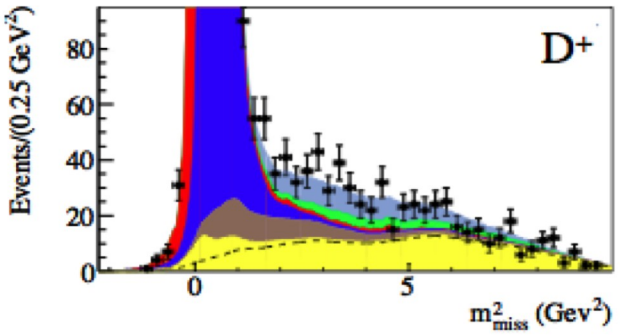
	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Signif.	5.5 σ	6.1 σ	8.4 σ
R(D)	**0.429 ± 0.082**	**0.469 ± 0.084**	**0.440 ± 0.058**

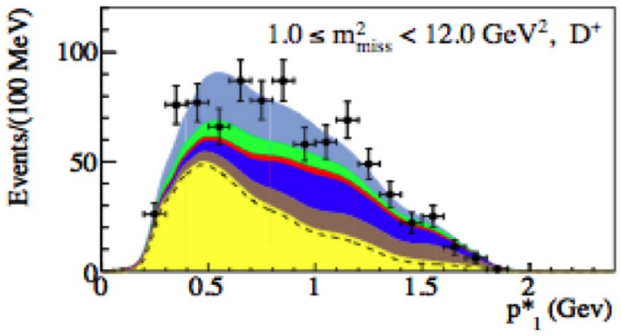
First observation!

Isospin constrained

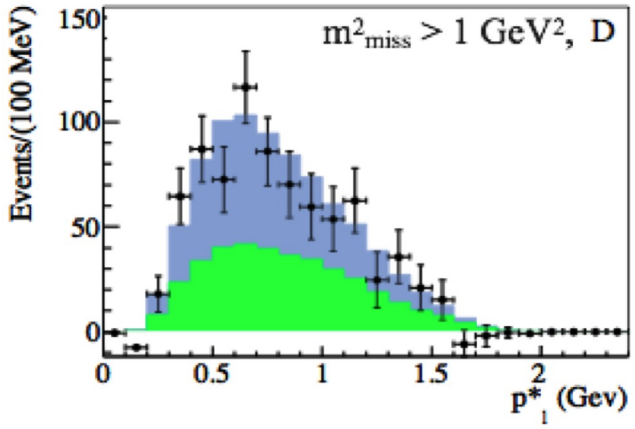








-45% correlation D-D*



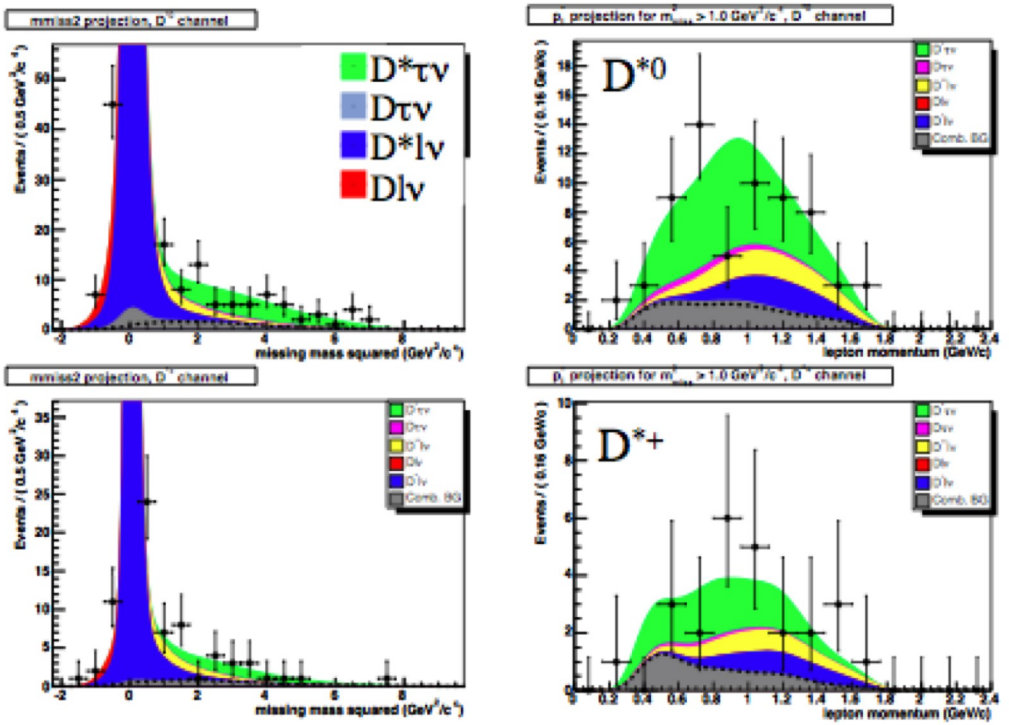
D^0 and D^+ channels combined.
Background subtracted

Comparison with 2008 analysis

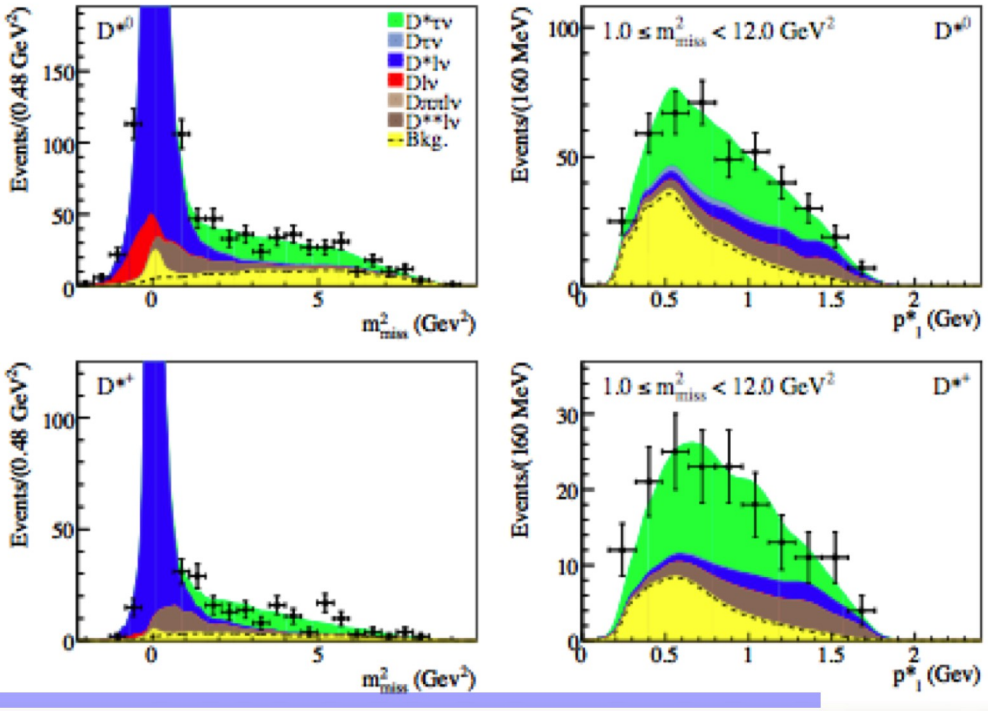
Efficiency 3x w.r.t. 2008 analysis
Good agreement on the overlapping dataset

	2008	
	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$
N_{sig}	92 ± 20	16 ± 7
Signif.	$5.8\ \sigma$	$2.7\ \sigma$
$R(D^*)$	0.35 ± 0.07	0.21 ± 0.17

2008



2012



E_{Extra} After the Fit

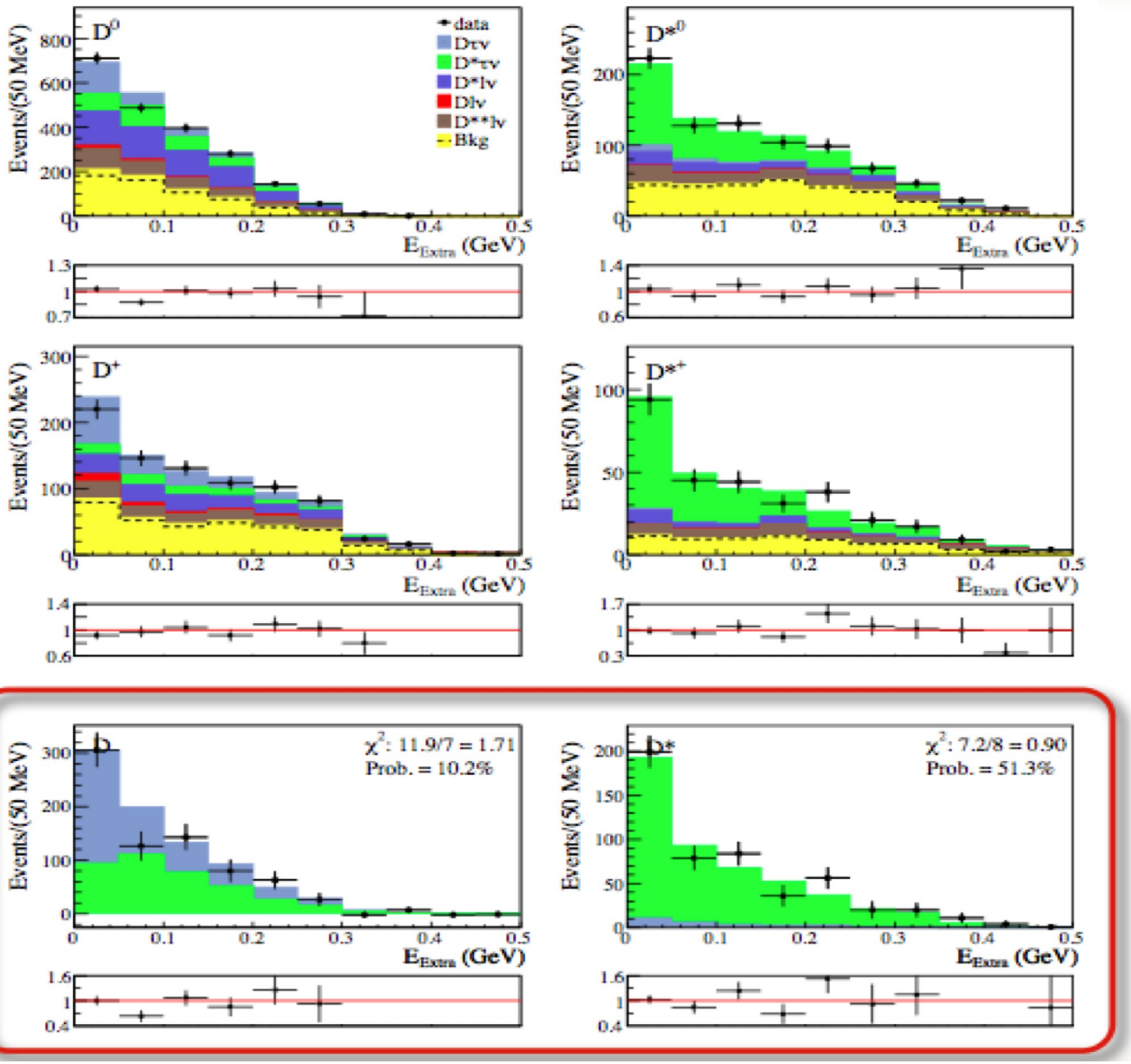
Unused ECAL energy most important variable in the BDT

$$E_{\mathbf{Extra}} = \sum_{\mathbf{unused}\ \gamma} E_{\gamma}$$

Signal peaks in E_{Extra}

Plots show E_{Extra} in m^2_{miss}>1.5 GeV rescaling different contributions to fit results

D and D* channels combined and bkg subtracted



Systematic Uncertainties

Source	Uncertainty (%) $R(D)$	$R(D^*)$	ρ
$D^{**}\ell\nu$ background	5.8	3.7	0.62
MC statistics	5.0	2.5	-0.48
Cont. and $B\overline{B}$ bkg.	4.9	2.7	-0.30
$\varepsilon_{\rm sig}/\varepsilon_{\rm norm}$	2.6	1.6	0.22
Systematic uncertainty	9.5	5.3	0.05
Statistical uncertainty	13.1	7.1	-0.45
Total uncertainty	**16.2**	**9.0**	**-0.27**

Correlation between $R(D)$ and $R(D^*)$

Largest systematic from backgrounds

Small uncertainty on efficiency ratio $\varepsilon_{sig}/\varepsilon_{norm}$

Statistical uncertainty still dominates → next generation B factories!

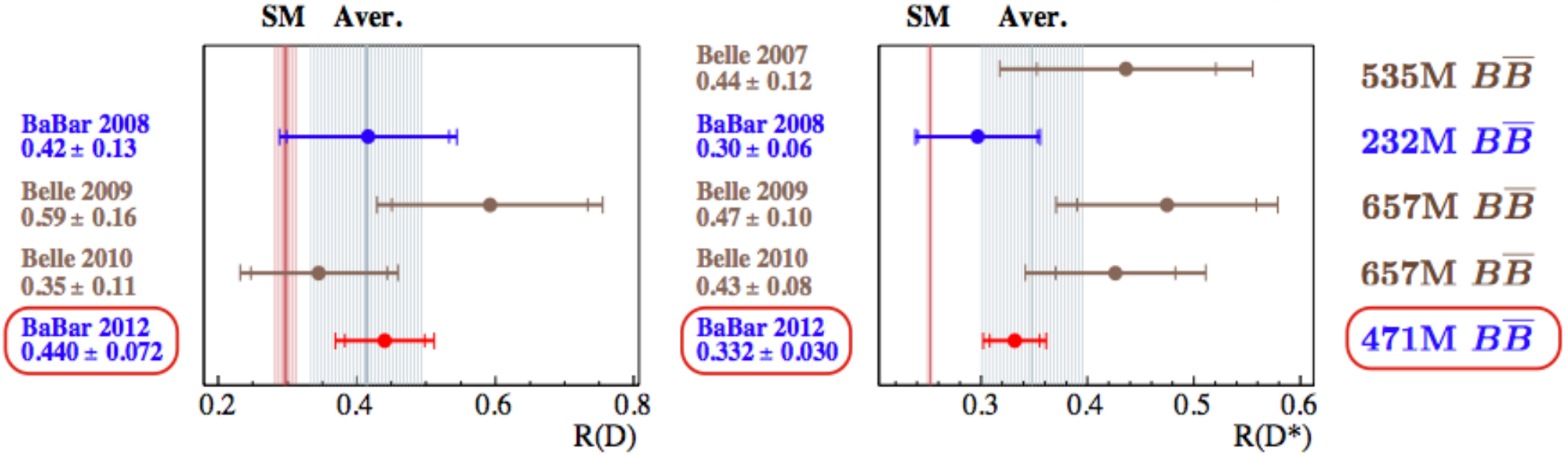
$B \to D^{(*)}\tau\nu$: Results

Decay	$N_{\rm sig}$	$N_{\rm norm}$	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)\,(\%)$	$\Sigma_{\rm tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	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

- **First 5σ observation of B→Dτν**
- **Agreement with previous measurements**

SM prediction from
Phys. Rev. D 85, 094025 (2012)

Average does not include this analysis

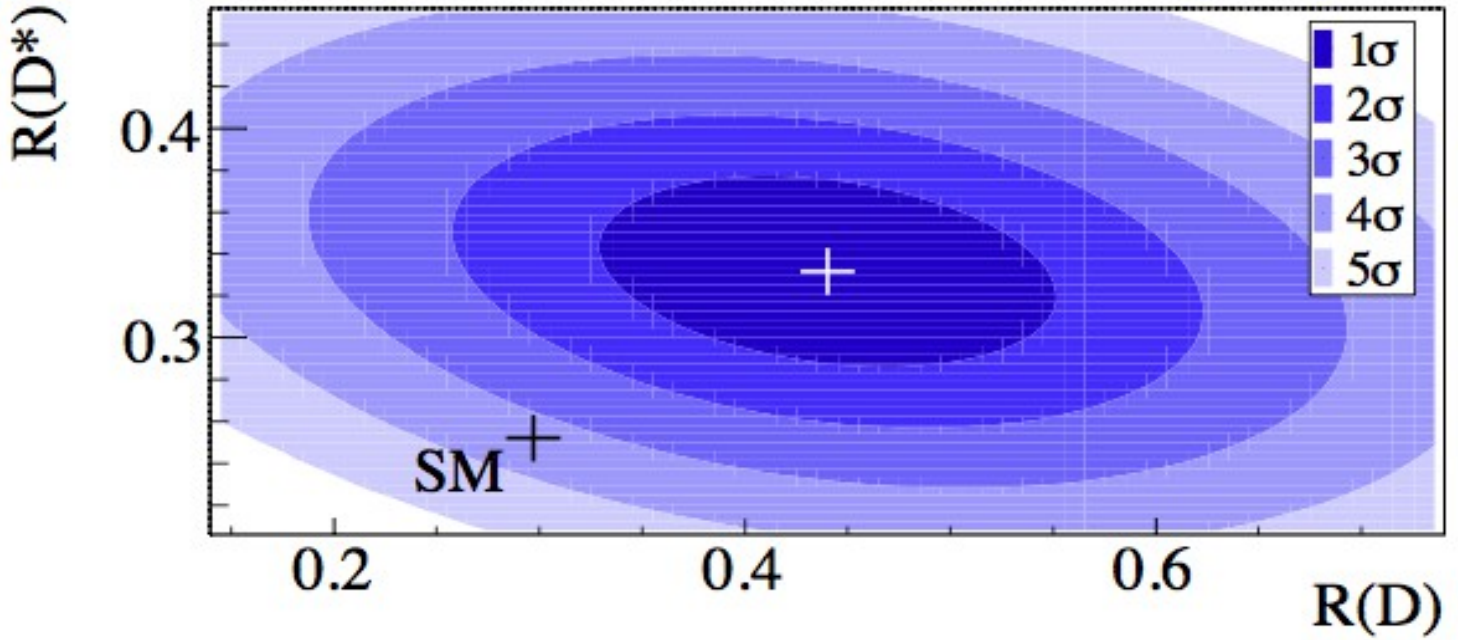


SM (in)consistency

$$R(D) = \left\{ \begin{array}{ll} 0.440 \pm 0.072 & \textit{BABAR} \\ 0.297 \pm 0.017 & \text{SM} \end{array} \right\} \; 2.0\sigma$$

$$R(D^*) = \left\{ \begin{array}{ll} 0.332 \pm 0.030 & \textit{BABAR} \\ 0.252 \pm 0.003 & \text{SM} \end{array} \right\} \; 2.7\sigma$$

$$\Big\} \; 3.4\sigma$$

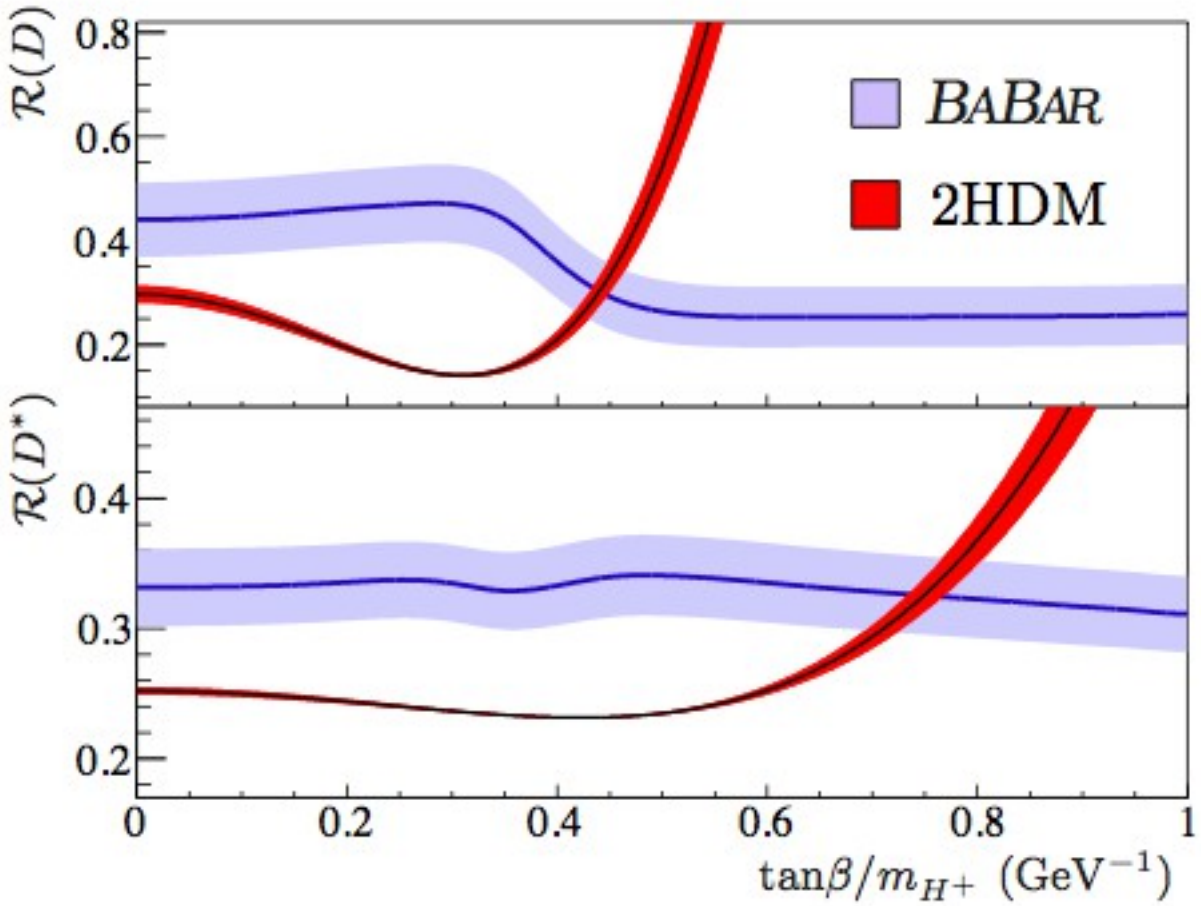


R(D) and R(D*) not independent

-27% correlation

2HDM Scan

Measure R(D*) in full 2HDM parameter space



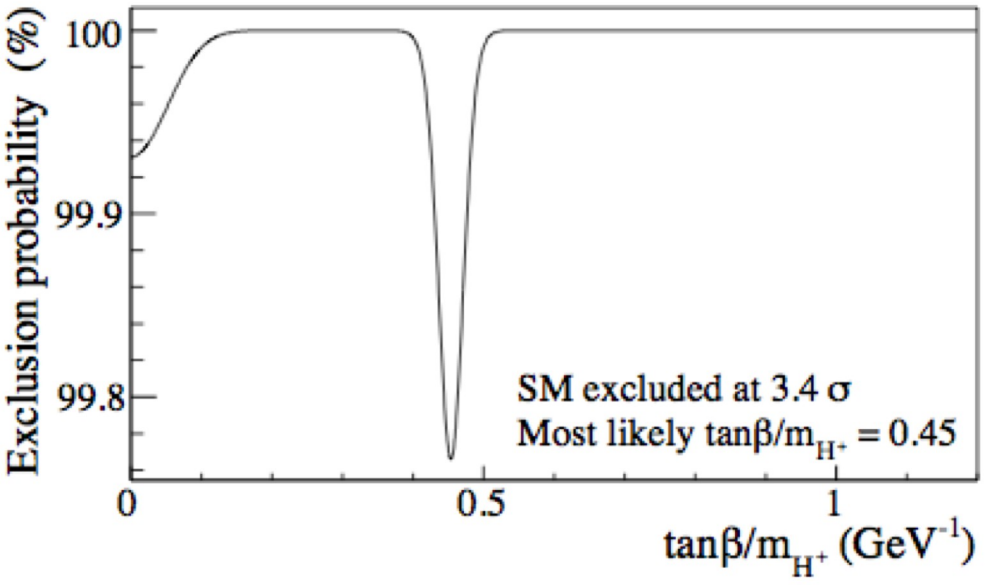
$$\tan\beta/m_{H^+} = 0.44 \pm 0.02 \text{ GeV}^{-1}$$

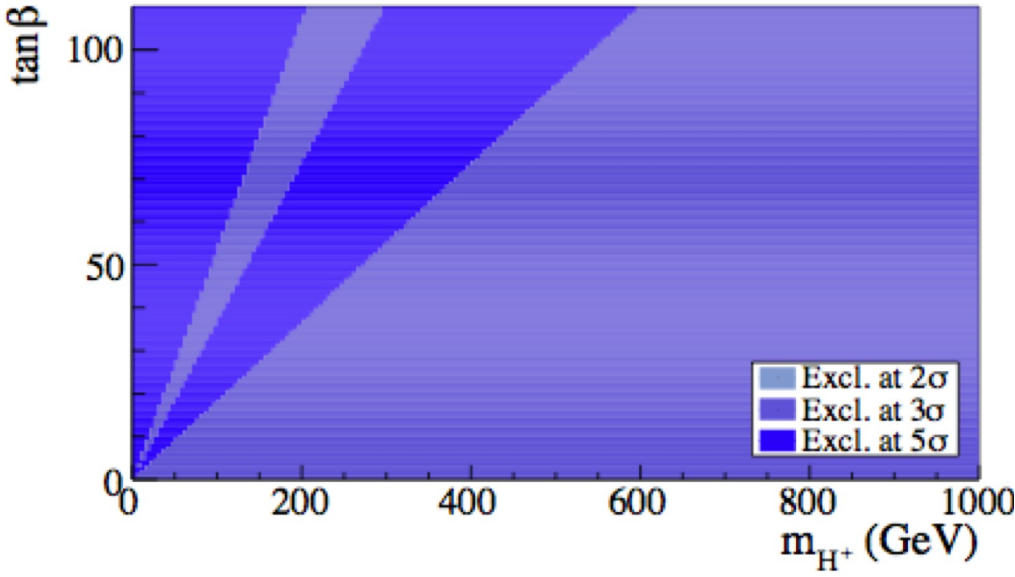
$$\tan\beta/m_{H^+} = 0.75 \pm 0.04 \text{ GeV}^{-1}$$

2HDM M_H-tan β Exclusion Regions

- Compatibility of $\Delta(D^{(*)}) = R(D^{(*)})_{\mathrm{exp}} - R(D^{(*)})_{\mathrm{2HDM}}$ given by a χ^2 for each 2HDM point

$$\chi^2(\tan\beta/m_{H^+}) = (\Delta(D), \Delta(D^*)) \begin{pmatrix} \sigma^2_{\mathrm{exp}} + \sigma^2_{\mathrm{th}} & \rho\,\sigma_{\mathrm{exp}}\sigma^*_{\mathrm{exp}} \\ \rho\,\sigma_{\mathrm{exp}}\sigma^*_{\mathrm{exp}} & \sigma^{*2}_{\mathrm{exp}} + \sigma^{*2}_{\mathrm{th}} \end{pmatrix}^{-1} \begin{pmatrix} \Delta(D) \\ \Delta(D^*) \end{pmatrix}$$



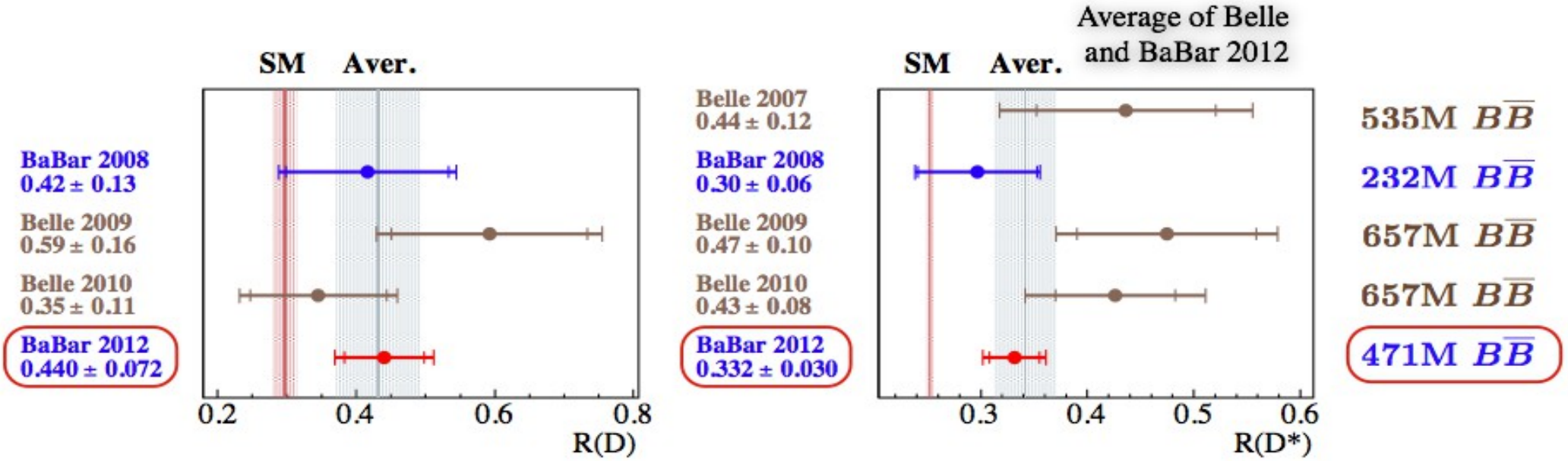


Type II 2HMD excluded at 99.8%, or equivalently, 3.1σ

Conclusions

Measurement of $B \to D^{(*)}\tau\nu$ on full BaBar dataset

→ Much larger improvement than $\sqrt{L}$



Scorecard:

→ First Observation of $B \to D\tau\nu$ with 6.8σ

→ 3.4σ excess over SM prediction (3.2σ w.r.t. PRL 109, 071802 (2012))

→ Not compatible with Type II 2HDM model

Backup Slides