Study of Exclusive B $\rightarrow D^{(*)}\ell\,\nu$ Decays

$B \rightarrow D\ell\nu$ and $B \rightarrow D^{*}\ell\nu$

$B \rightarrow D\tau\nu$ and $B \rightarrow D^{*}\tau\nu$

Vera Lüth
SLAC - Stanford University

Workshop on B Decays into D** and Related Issues

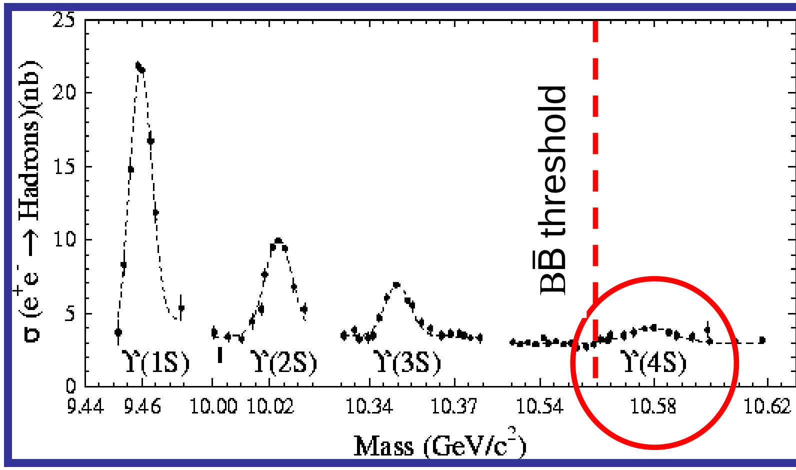
Paris, November 26-28, 2012

Semileptonic Decays at B-Factories @ 10.58 GeV

- Cleanest source of B mesons: $e^+e^- \to \Upsilon(4S) \to B\bar{B}$

  $\sigma_{\Upsilon(4S)} \approx 1.05\,nb \qquad (24\% \text{ of } \sigma_{had})$

$b\bar{b}$ Spectroscopy



- Reconstruction of S.L. decays
  - charged lepton: e , μ
  - hadron: D, D*, π, ρ, ω, …, X_c, X_u
  - ν: E_{miss}, $\vec{p}_{miss}$

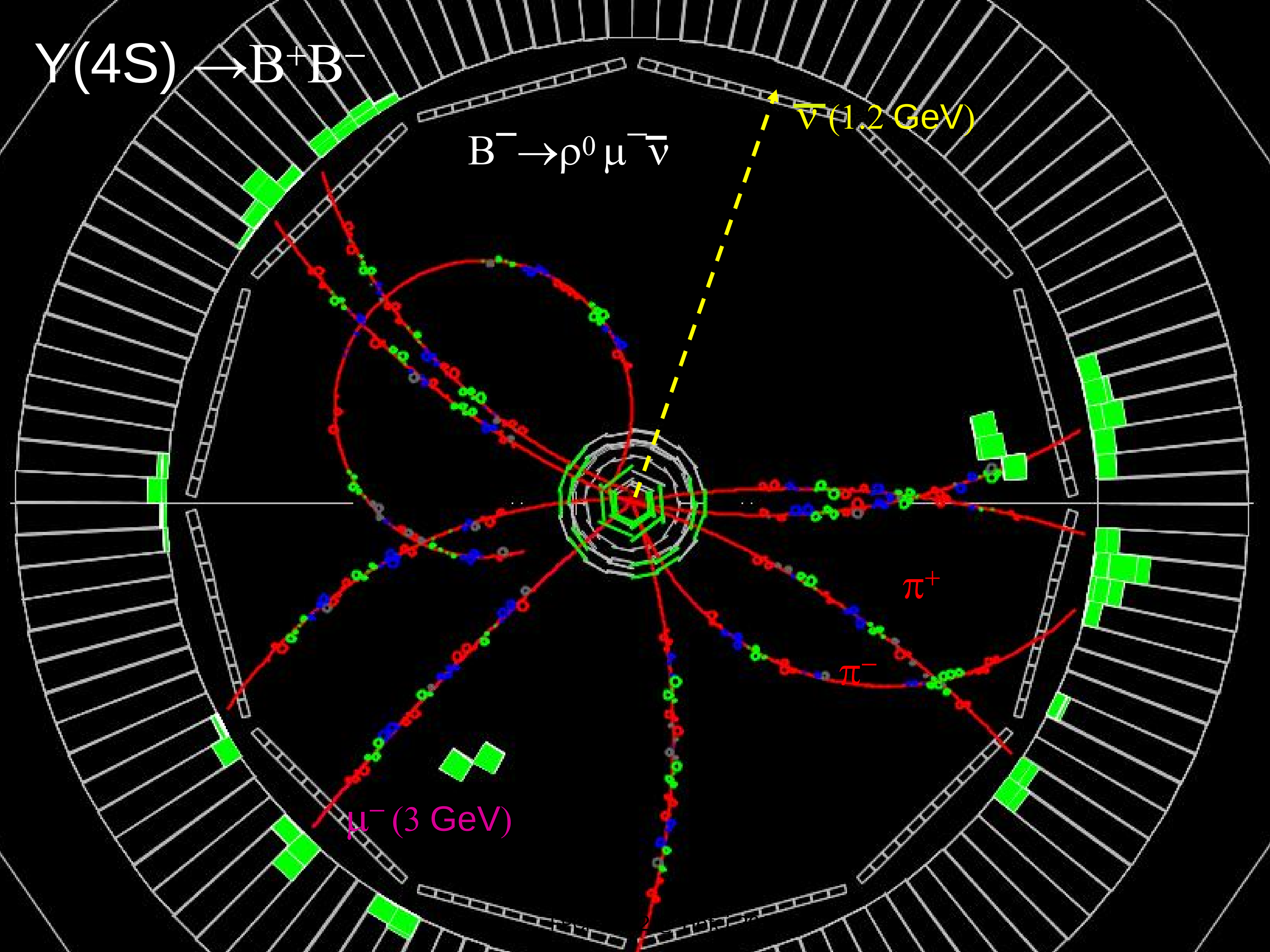
  $$(E_{\text{miss}}, \vec{p}_{\text{miss}}) = (E_{e^+e^-}, \vec{p}_{e^+e^-}) - \left(\sum_i E_i, \sum_i \vec{p}_i\right)$$

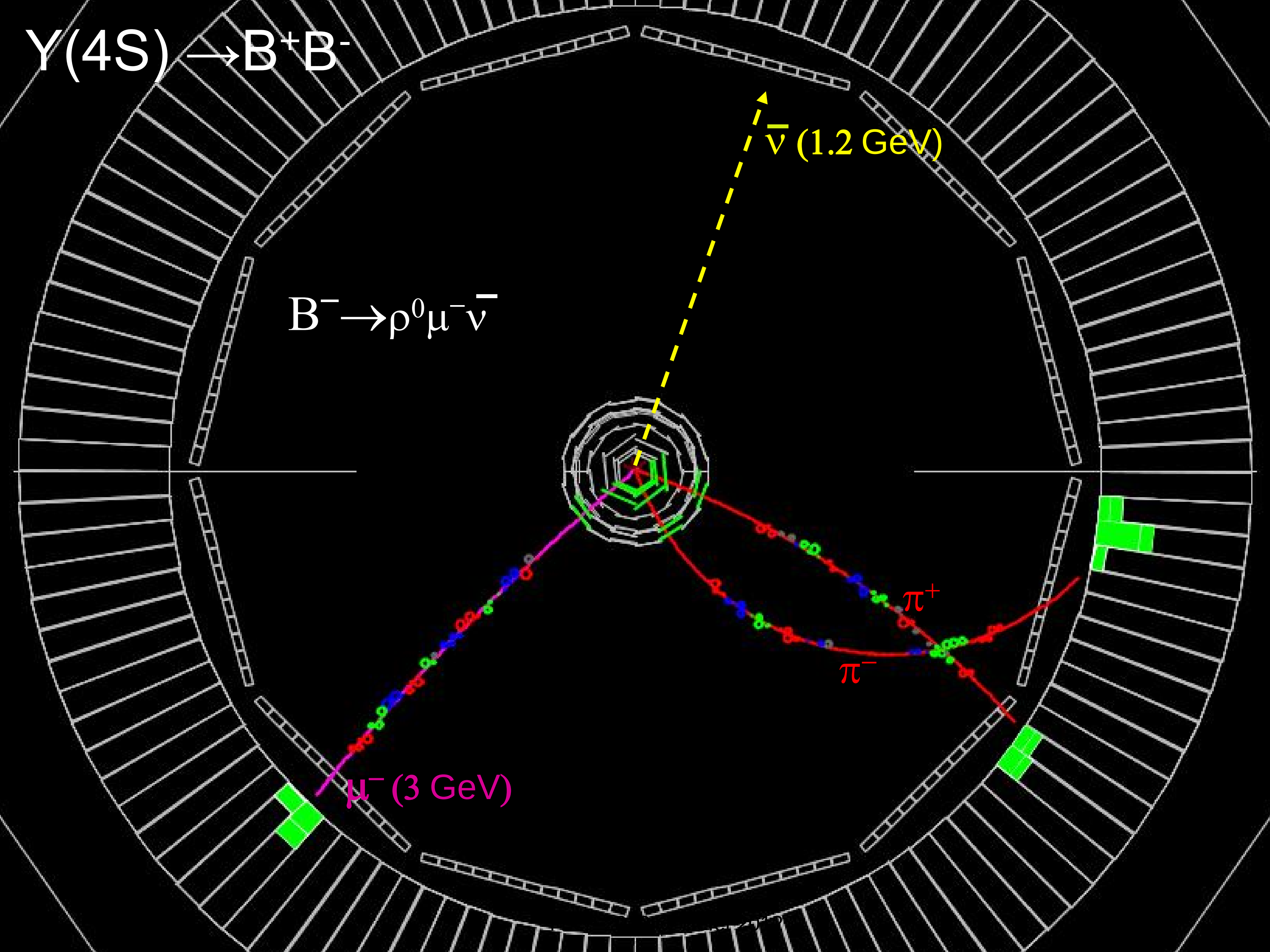
- Exclusive B decays:
  - kinematic variables:

  $\Delta E = E_B^* - E_{beam}^*$ signal at $\Delta E \approx 0$

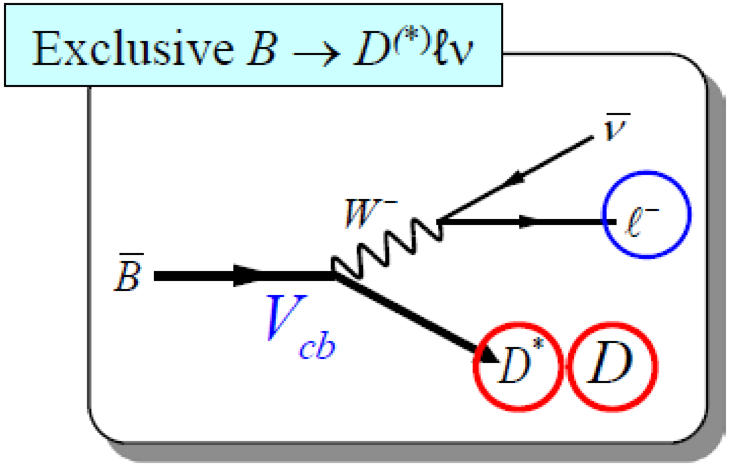
  $m_{ES} = \sqrt{E_{beam}^{*2} - \vec{p}_B^{\,*2}}$ signal at $m_{ES} \approx m_B$

- $B\bar{B}$ tag: full reconstruction of one B decay: $B^+_{tag} \to D^- \pi^+ \pi^+$
  - Significant reduction in comb. backgrounds, improvement in E_{miss}, $\vec{p}_{miss}$
  - Low tag efficiency , 0.2 – 0.5 %


Υ(4S) →B⁺B⁻
B⁻→ρ⁰ μ⁻ ν̄
ν̄ (1.2 GeV)
π⁺
π⁻
μ⁻ (3 GeV)



Υ(4S) →B⁺B⁻
$\bar{\nu}$ (1.2 GeV)
$B^- \to \rho^0 \mu^- \bar{\nu}$
π^+
π^-
μ^- (3 GeV)



B Factory Averages: (BFLB 2012)

BF($D^{*+}\ell^- \nu$)= ($4.83 \pm 0.02_{stat} \pm 0.12_{syst}$) 10^{-2}
BF($D^+ \ell^- \nu$)= ($2.14 \pm 0.03_{stat} \pm 0.06_{syst}$) 10^{-2}

For BF($D^{*+}\ell^- \nu$), there used to be a very poor agreement between measurements, now fairly good consistency !

Extraction of $|V_{cb}|$ from $B \to D^{(*)}\ell\nu$ Decays

- The differential decay rate

Universal Form Factor

Phase Space

$$\frac{d\Gamma(B \to D^{*}\ell\nu_{\ell})}{dw\,d\cos\theta_{\ell}\,d\cos\theta_{V}\,d\chi} = \frac{G_F^2}{48\pi^3}|V_{cb}|^2 \eta_{EW}^2 F^2(w,\theta_{\ell},\theta_V,\chi) K(w)$$

$$w \equiv \frac{M_B^2 + M_{D^*}^2 - q^2}{2M_B M_{D^*}}$$

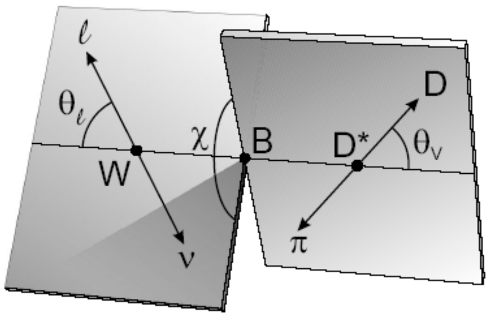
$$\eta_{EW} = 1.0066$$

  - $B \to D\,\ell\nu$: a single FF: $\mathcal{G}(w)$
  - $B \to D^{*}\ell\nu$: $\mathcal{F}(w,\theta_{\ell},\theta_V,\chi)$ incorporates 3 non-trival form factors, $A_1(w)$, $A_2(w)$, $V(w)$

- HQ Symmetry predicts a unique universal F(w) with
  - Common shape given by ρ^2, constraints by analyticity and unitarity
  - Normalization at zero-recoil: $\mathcal{F}(w=1)=\mathcal{G}(w=1)=1.0$

    So, QCD corrections to $\mathcal{F}(1)$ and $\mathcal{G}(1)$ needed

Caprini. Lellouch, Neubert: Nucl. Phys. B530. 152 (1998)



- Extract FF parameters by fits to differential decay rates
  - $B \to D\,\ell\nu$: Fit: 1-dim. decay distribution $\mathcal{G}(w)$:

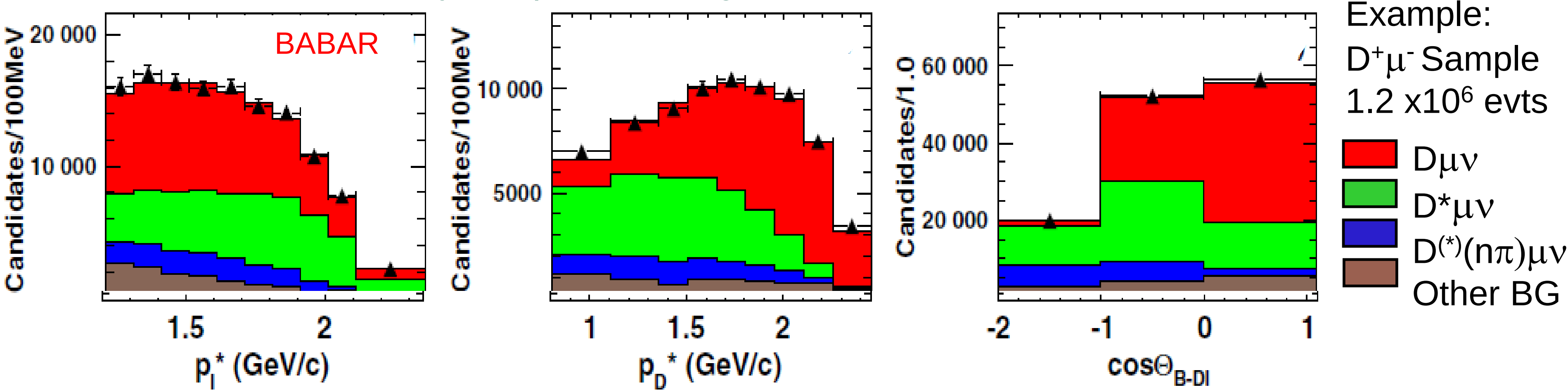
    parameters: $|V_{cb}|\,\mathcal{G}(1)$ and slope ρ^2
  - $B \to D^{*}\ell\nu$: 4-dim. decay distribution $\mathcal{F}(w,\theta_{\ell},\theta_V,\chi)$

    parameters: $|V_{cb}|\,\mathcal{F}(1)$, slope ρ^2, $R_1(w=1)$ and $R_2(w=1)$

Global Analysis of $B \to DX\ell\nu$ Decays w/o $B\bar{B}$ Tag

BABAR: Phys. Rev. D79, 012002 (2009)

- Select samples of $D^0\ell$ and $D^+\ell$, with p_ℓ>1.2 GeV, p_D>0.8 GeV
- Global 3D fit (e ,μ) to kinematic variables p_ℓ, p_D, $\cos\theta_{B\text{-}D\ell}$ to extract
  - BF measurements for $B \to D^{(*)}\ell\nu$ decays
  - FF slopes ρ^2_D and ρ^2_{D*} with fixed input for R_1 (w) and R_2(w)
  - Constrain decay rates for B^0 and B^+ by isospin relations
- Syst. uncertainties dominated by
  - PID and Tracking D efficiencies (insensitive to $D^* \to D\pi$ detection) and backgrounds
  - BF for B and D decays, in particular higher-mass charm mesons



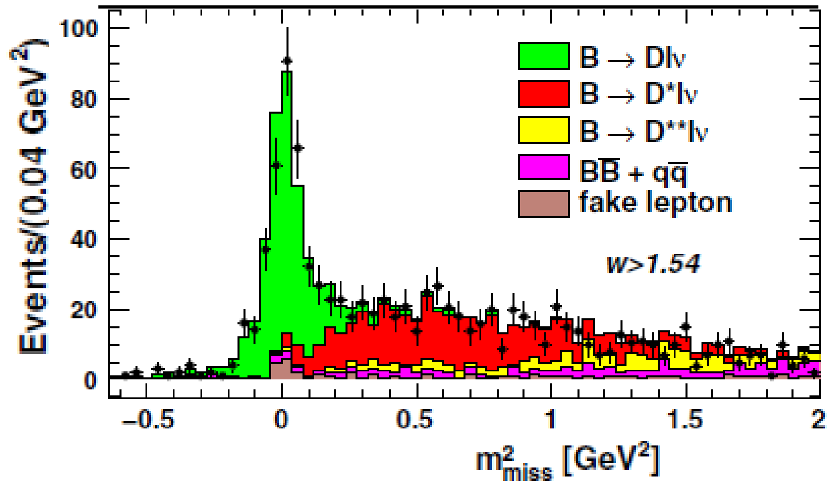
B→D $\ell^+\nu$ Decays from $B\bar{B}$ Tagged Events

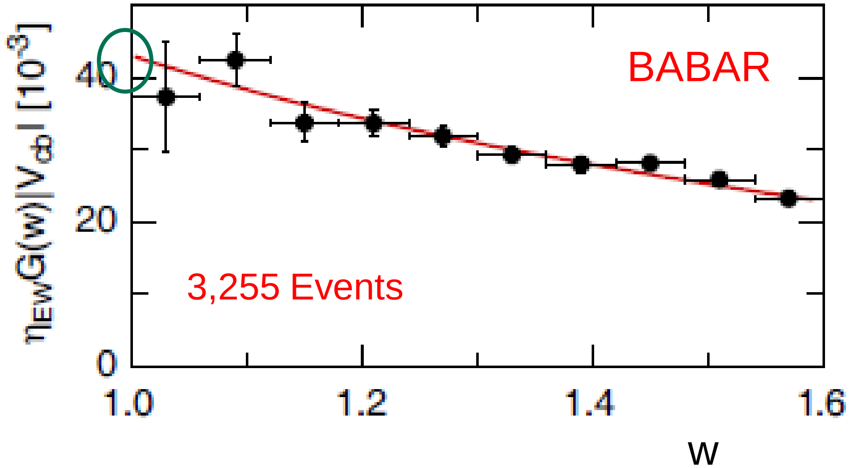
BABAR: Phys. Rev. Lett. 104, 011802 (2010)

- Analysis technique
  - Reconstruct: D decays plus e or μ (>0.6 GeV)
  - Tag $B\bar{B}$ by hadronic decay of 2nd B meson
  - Excellent resolution in q^2 and w (~0.01)
  - Normalization to inclusive B → X $\ell^+\nu$ decays
- Binned ML fit to m^2_{miss} in 10 w bins, B^+ and B^0
- Systematic uncertainties smaller than w/o tag, dominated by
  - B, D and D*, D** BF
  - event reconstruction and yield extraction
- Fit to $d\Gamma/dw$ with 2 parameters: ρ_D^2, $\eta_{EW}\mathcal{G}(1)$

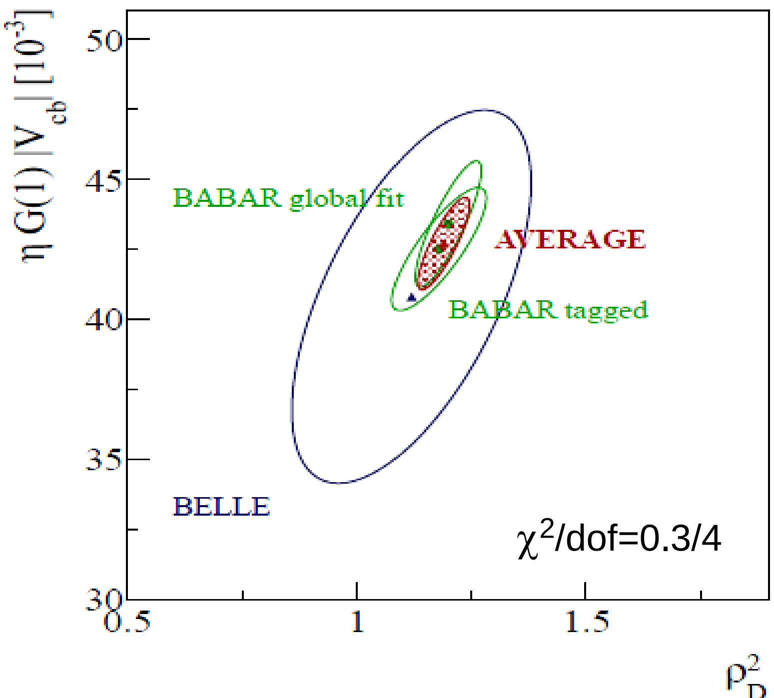
$$\mathcal{G}(w) = \mathcal{G}(1)[1 - 8\rho_D^2 z + (51\rho_D^2 - 10)z^2 - (252\rho_D^2 - 84)z^3]$$

based on CLN





Results on $B \to D \ell^+ \nu$ Decays



$$\eta_{EW}\mathcal{G}(1)|V_{cb}| = (42.68 \pm 1.67) \times 10^{-3}$$
$$\rho_D^2 = 1.186 \pm 0.057\ ,$$

total exp. errors incl. correlations

$\eta_{EW}\ \mathcal{G}(1) = 1.081 \pm 0.024$

LQCD: Yamamoto et. al. NP Suppl. 140,461 (2005)

$$|V_{cb}| = (39.46 \pm 1.54_{\rm exp} \pm 0.88_{\rm th}) \times 10^{-3}$$

$\eta_{EW}\ \mathcal{G}(1) = 1.047 \pm 0.020$

HQE: Uraltsev PL B585.53 (2004)

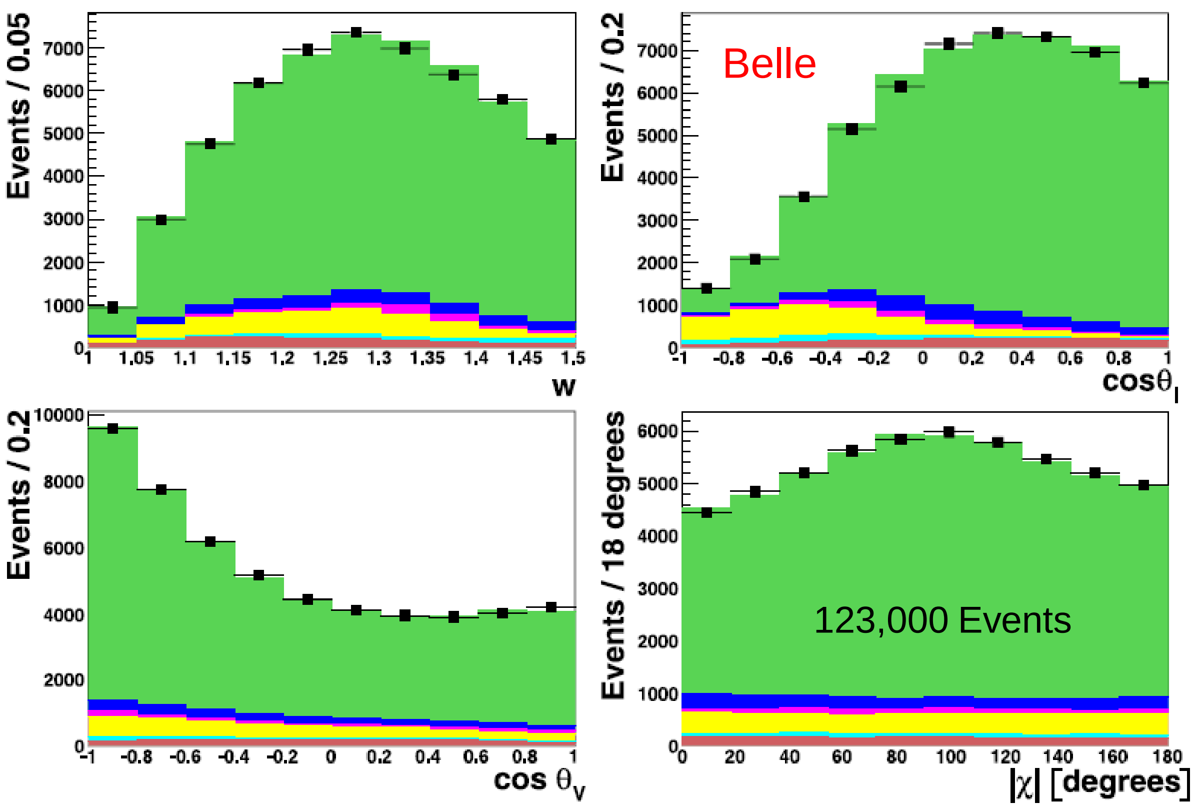
$$|V_{cb}| = (40.75 \pm 1.59_{\rm exp} \pm 0.78_{\rm th}) \times 10^{-3}$$

DATA $10^6 B\bar{B}$	$\overline{B} \to D\ell^-\overline{\nu}_\ell$	$\eta_{EW}\mathcal{G}(1)\lvert V_{cb}\rvert\ (10^{-3})$	ρ_D^2	$\mathcal{B}(B^0 \to D^-\ell^+\nu)$ (%)
11	Belle [11]	$40.8 \pm 4.4 \pm 5.0$	$1.12 \pm 0.22 \pm 0.14$	$2.07 \pm 0.12 \pm 0.52$
230	BABAR $DXl\nu$ [12]	$43.4 \pm 0.8 \pm 2.1$	$1.20 \pm 0.04 \pm 0.06$	$2.18 \pm 0.03 \pm 0.13$
460	BABAR tagged [6]	$42.5 \pm 1.9 \pm 1.1$	$1.18 \pm 0.09 \pm 0.05$	$2.12 \pm 0.10 \pm 0.06$
	Average	$42.7 \pm 0.7 \pm 1.5$	$1.19 \pm 0.04 \pm 0.04$	$2.14 \pm 0.03 \pm 0.10$

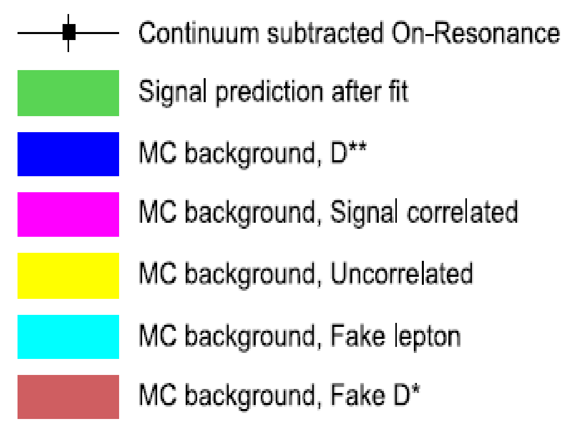
Measurement of $B^0 \to D^{*-} \ell^+ \nu$ Decays w/o $B\bar{B}$ Tag

Belle: Phys. Rev. D82, 112007 (2010)

- Most precise results from full Belle data sample (722 $B\bar{B}$ events)
- Untagged events, only $D^*(D^0 \to K\pi)+\pi^-_s)\ \ell^+\nu$ decays, kinematic separation
- Reconstruct B rest frame using momenta of both B



- To extract event yield, χ^2 fit to 4 one-dim. distributions, correlations are assessed
- free CLN parameters: $\rho_{D^*}^2$, $\mathcal{F}(1)\ |V_{cb}|$, R_1, R_2
- Dominant errors:
  - track efficiencies (fast and slow)
  - BF and distributions: B, D, D*, D**



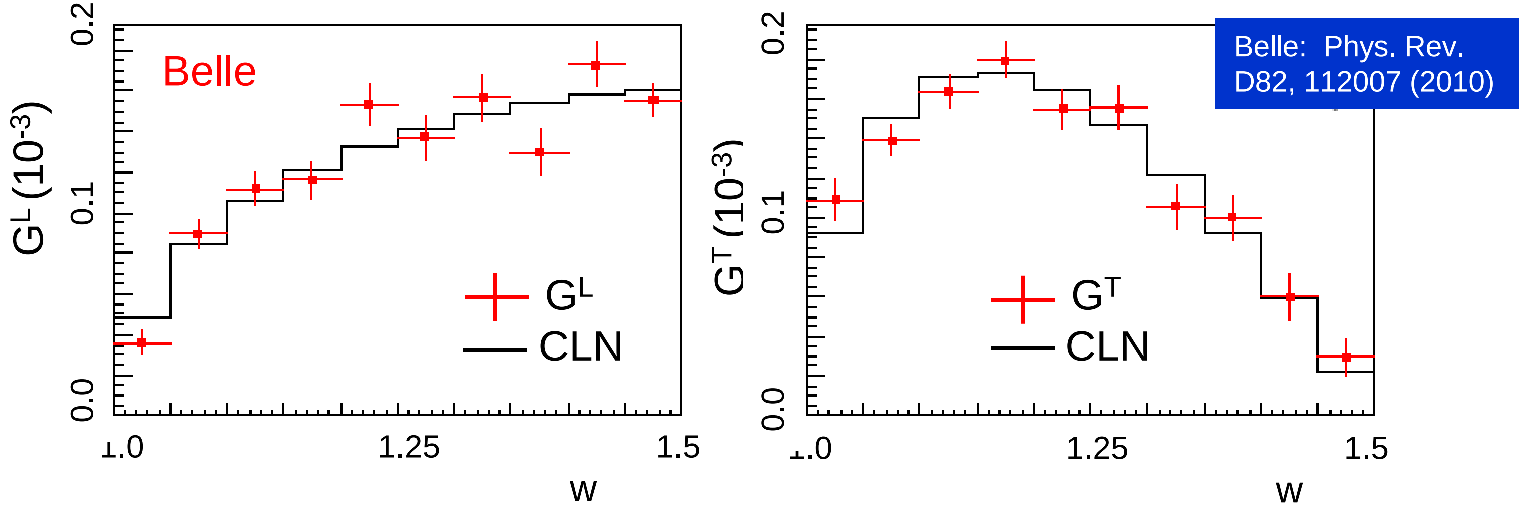
Helicity Functions for $B^0 \rightarrow D^{*-} \ell^+ \nu$ Decays

- Integration over angles θ_ℓ and χ, project out w-dependent terms g^{xy}:
  Transverse and Longitudinal Helicity Functions: G^T and G^L:

$$\frac{d^2\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\, d\cos\theta_V} = F_\Gamma[\underbrace{\sin^2\theta_V(g^{++} + g^{--})}_{G^T} + \underbrace{2\cos^2\theta_V g^{00}}_{G^L}]$$

$$F_\Gamma = \frac{G_F^2(m_B - m_{D^*})^2 m_{D^*}^3}{4^3\pi^3}$$

- Taking into account detection efficiencies, comparison $G^T(w)$ and $G^L(w)$ with the CLN parameterization obtained from the fit :

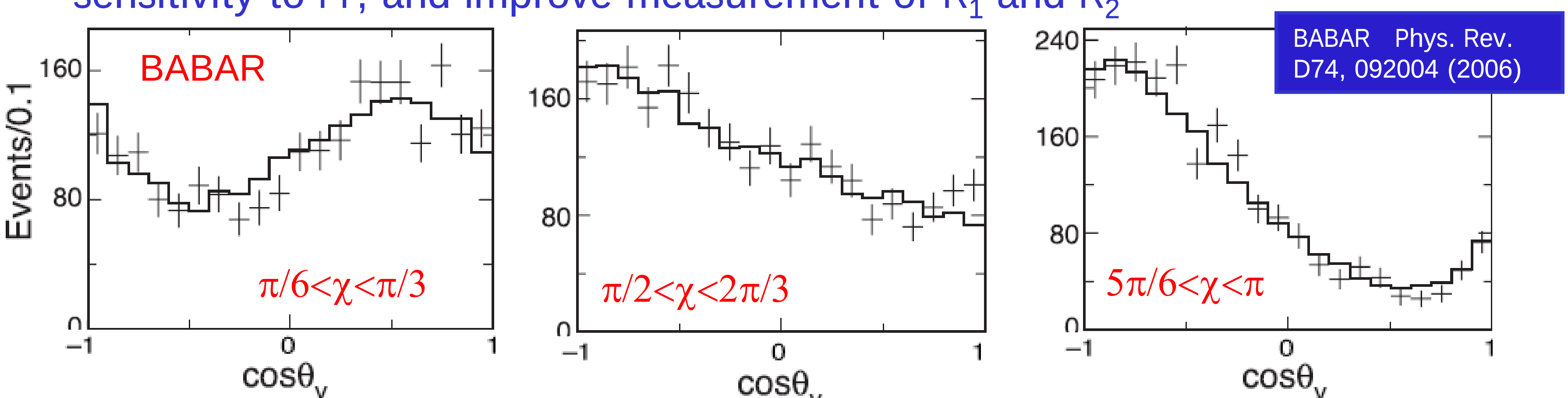


Extraction of FF from $D^*\ell\nu$ Decay Distributions

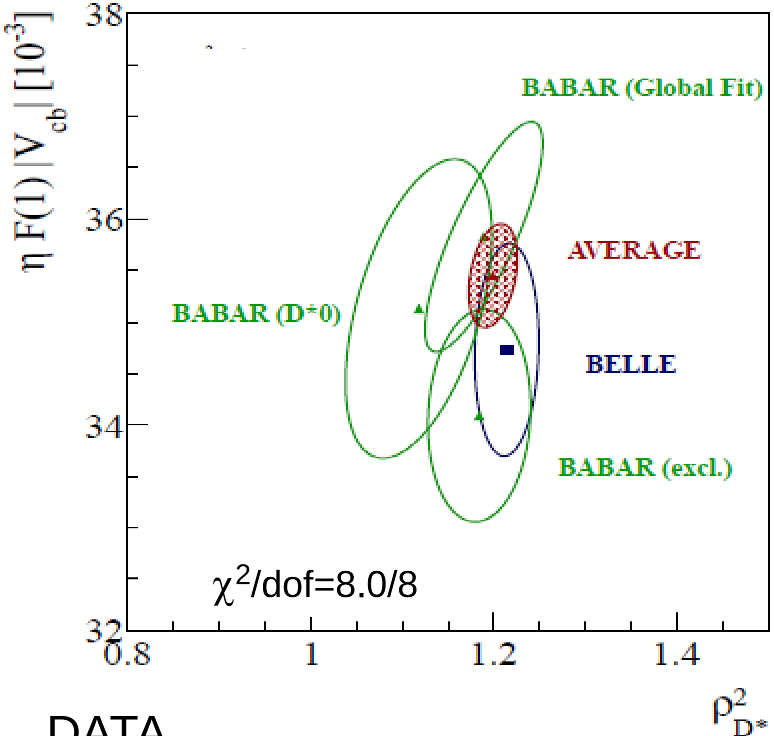
- For a decay to a vector meson, the differential decay rate depends on 3 helicity amplitudes H_i, q^2 and angles θ_V, θ_ℓ, χ:

$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_V d\chi} = \frac{3G_F^2|V_{cb}|^2 \wp_{D^*} q^2}{8(4\pi)^4 M_B^2} \mathcal{B}_{D^*D} \times [H_+^2(1-\cos\theta_\ell)^2\sin^2\theta_V + H_-^2(1+\cos\theta_\ell)^2\sin^2\theta_V$$
$$+ 4H_0^2\sin^2\theta_\ell\cos^2\theta_V - 2H_+H_-\sin^2\theta_\ell\sin^2\theta_V\cos 2\chi$$
$$- 4H_+H_0\sin\theta_\ell(1-\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi$$
$$+ 4H_-H_0\sin\theta_\ell(1+\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi],$$

- BABAR exploited angular distributions $\Gamma(q^2, \cos\theta_V, \cos\theta_\ell, \chi)$ to enhance sensitivity to FF, and improve measurement of R_1 and R_2



Results on $B \to D^* \ell^+\nu$ Decays



$$\eta_{\rm EW}\mathcal{F}(1)|V_{\rm cb}| = (35.45 \pm 0.50) \times 10^{-3}$$
$$\rho^2_{D^*} = 1.199 \pm 0.027\ ,$$
$$R_1(1) = 1.396 \pm 0.033\ ,$$
$$R_2(1) = 0.860 \pm 0.020\ .$$

total exp. errors incl. correlations

$\eta_{\rm EW}\ \mathcal{F}(1) = 0.908 \pm 0.017$

LQCD: Bernard et al. Phys. Rev. D79, 014506 (2009)

$$|V_{\rm cb}| = (39.04 \pm 0.55_{\rm exp} \pm 0.73_{\rm th}) \times 10^{-3}$$

$\eta_{\rm EW}\ \mathcal{F}(1) = 0.865 \pm 0.020$

HQSR: Gambino et al. Phys. Rev. D81, 013002 (2010)

$$|V_{\rm cb}| = (40.93 \pm 0.58_{\rm exp} \pm 0.95_{\rm th}) \times 10^{-3}$$

DATA $10^6 B\bar{B}$	$\overline{B} \to D^* \ell^- \overline{\nu}_\ell$	$\eta_{\rm EW}\mathcal{F}(1)\|V_{cb}\|\ (10^{-3})$	$\rho^2_{D^*}$	$\mathcal{B}(B^0 \to D^{*-}\ell^+\nu)$ (%)
82	BABAR $D^{*-}\ell^+\nu$ [7]	$34.1 \pm 0.3 \pm 1.0$	$1.18 \pm 0.05 \pm 0.03$	$4.58 \pm 0.04 \pm 0.25$
230	BABAR $\bar{D}^{*0}e^+\nu$ [13]	$35.1 \pm 0.6 \pm 1.3$	$1.12 \pm 0.06 \pm 0.06$	$4.95 \pm 0.07 \pm 0.34$
230	BABAR $DXl\nu$ [12]	$35.8 \pm 0.2 \pm 1.1$	$1.19 \pm 0.02 \pm 0.06$	$4.96 \pm 0.02 \pm 0.20$
772	Belle [8]	$34.7 \pm 0.2 \pm 1.0$	$1.21 \pm 0.03 \pm 0.01$	$4.59 \pm 0.03 \pm 0.26$
	Average	$35.5 \pm 0.1 \pm 0.5$	$1.20 \pm 0.02 \pm 0.02$	$4.83 \pm 0.01 \pm 0.12$

Status and Outlook for $B \to D^{(*)}\ell^+\nu$

- Considerable progress in experiment and theory
  - $D^*\ell\nu$: Untagged analyses: limited by systematics: $|V_{cb}|$: σ(syst)=3% σ(stat)=0.6%
    FF predictions differ by Δ(theory): 4.7% σ(theory)=2%
  - $D\ell\nu$: Tagged analysis: limited by statistics: $|V_{cb}|$: σ(syst)=2.6% σ(stat)=4.5%
    FF predictions differ by Δ(theory): 3.2% σ(theory)=2%
  - Differences in BF($B\to D^*\ell\nu$) reduced, and now consistent within syst. uncertainties.

- Future improvements with larger data samples
  - Full 4-dim. analysis for $D^*\ell\nu$ to improve sensitivity to all FF and parameterization
  - Employ fully tagged samples to reduce uncertainties on background and ν reconstruction
  - Study other exclusive s.l. decays and spectroscopy of higher-mass charm mesons
    BF: $B^0\to(D+D^*)\ell\nu$: (6.97±0.16)% $B^0\to X_C\ell\nu$: (10.11±0.13)% ΔBF_C: (3.1±0.2)%
  - Improve QCD calculations of FF – how can experimenters assist?

- Goal: 1% uncertainty on $|V_{cb}|$ - challenging, but not impossible!

Exclusive vs Inclusive $|V_{cb}|$ Measurements: Tension!!

(HFAG averages for B Factory results only)

- $|V_{cb}|$ Exclusive (D*$\ell\nu$)
  - expt. error: 1.4 %
  - QCD normalization: 1.9 %

$$|V_{cb}| = (39.04 \pm 0.55 \pm 0.73) \cdot 10^{-3}$$ LQCD

$$|V_{cb}| = (40.93 \pm 0.58 \pm 0.95) \cdot 10^{-3}$$ HQSR

- $|V_{cb}|$ Inclusive
  - expt. error: 1.1 %
  - Theory error 1.4 %

$$|V_{cb}| = (42.01 \pm 0.47 \pm 0.59) \cdot 10^{-3}$$

- $|V_{ub}|$ Exclusive ($\pi\ell\nu$)
  - expt. error: 5.5 %
  - LQCD normalization 7.5 %

$$|V_{ub}| = (3.23 \pm 0.18 \pm 0.24) \cdot 10^{-3}$$

2.7σ

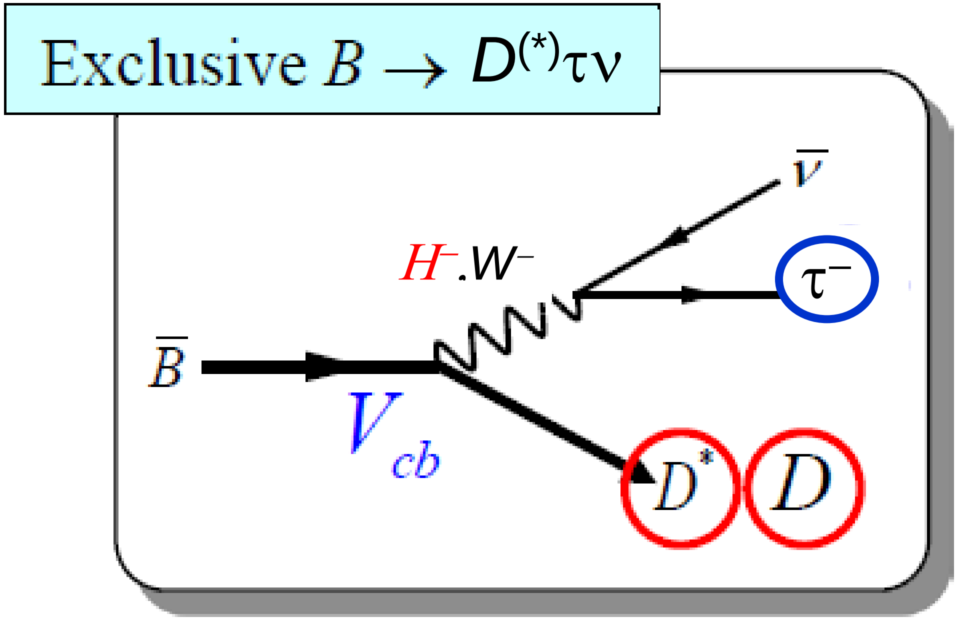
- $|V_{ub}|$ Inclusive
  - improved expt. error: 3.6 %
  - much improved theory 3.9 %

$$|V_{ub}| = (4.42 \pm 0.20 \pm 0.15) \cdot 10^{-3}$$

- Another Problem: $B \rightarrow \tau\nu$

Caveat: Based on BF average of 4 low statistics BF measurements with considerable backgrounds!
Wait for more data!

S.L. Decays Involving the Heavy Lepton τ



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

Study of B→D(*)τν Decays

Z. Phys, C46, 93 (1990)

- S.L. decays involving a τ have an additional helicity amplitude (for D*τν):

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \left[(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2) \left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}\frac{m_\tau^2}{q^2} |H_S|^2 \right]$$

For $D\tau\nu$, only H_{00} and H_S contribute!

- To test the SM Prediction, we measure

$$R(D) = \frac{\Gamma(\bar{B} \to D\tau\nu)}{\Gamma(\bar{B} \to D\ell\nu)} \qquad R(D^*) = \frac{\Gamma(\bar{B} \to D^*\tau\nu)}{\Gamma(\bar{B} \to D^*\ell\nu)}$$

Leptonic τ decays only

Several experimental and theoretical uncertainties cancel in the ratio!

- $B\bar{B}$ events are fully reconstructed:
  - hadronic B tag (tag efficiency improved 2x)
  - e or μ : (extend to lower momenta, $p_\ell^*>0.2$ or 0.3 GeV)
  - no additional charged particles, $E_{extra}< 0.5$GeV (not a cut)
  - kinematic selections: $q^2 > 4$ GeV^2

  Background suppression by BDT (combinatorial BG ($B\bar{B}$,$q\bar{q}$) and $D^{**}\ell\nu$)

- Full BABAR data sample, MC correction based on data control samples

B→ $D^{(*)}\tau\nu$: Extraction of Yields from M.L. Fit

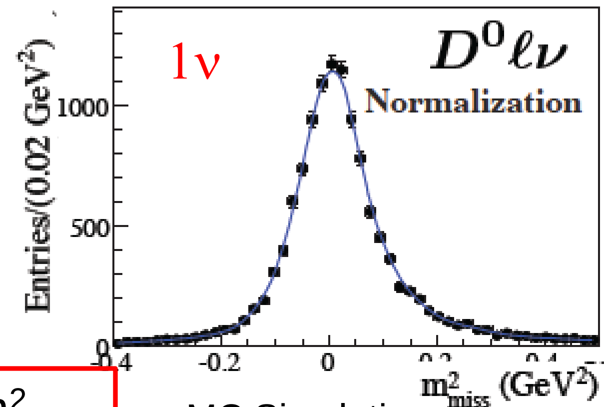
- Unbinned M.L. fit
  - 2-D distributions:

$$m^2_{miss} = (P_{ee} - P_{Btag} - P_{D(*)} - P_\ell)^2$$

Missing mass sq

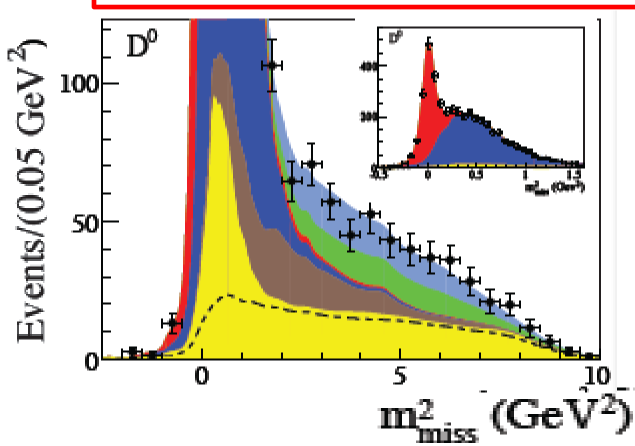
p^*_ℓ Lepton momentum in B rest frame

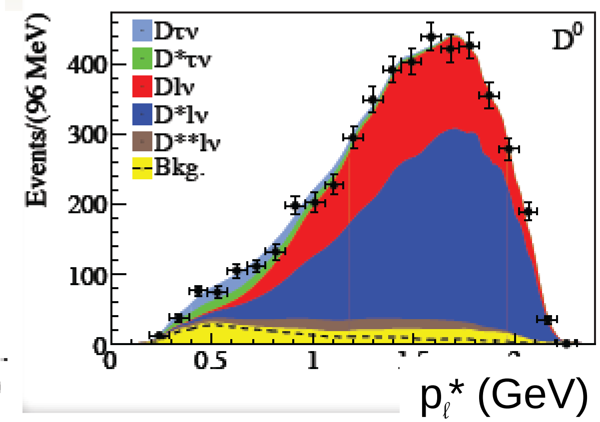
  - 4 signal samples: $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, $D^{*+}\ell$, (e or μ)
  - 4 $D^{(*)}\pi^0\ell\nu$ control samples
- PDFs from MC (approximated using KEYS fct.)
- Fitted Yields
  - 4 $D^{(*)}\tau\nu$ Signal
  - 4 $D^{(*)}\ell\nu$ Normalization
  - 4 $D^{**}\ell\nu$ Background
- Fixed Backgrounds
  - B^0–B^+ cross feed
  - $B\overline{B}$ combinatorial BG
  - Continuum $e^+e^-\to f\,\overline{f}(\gamma)$



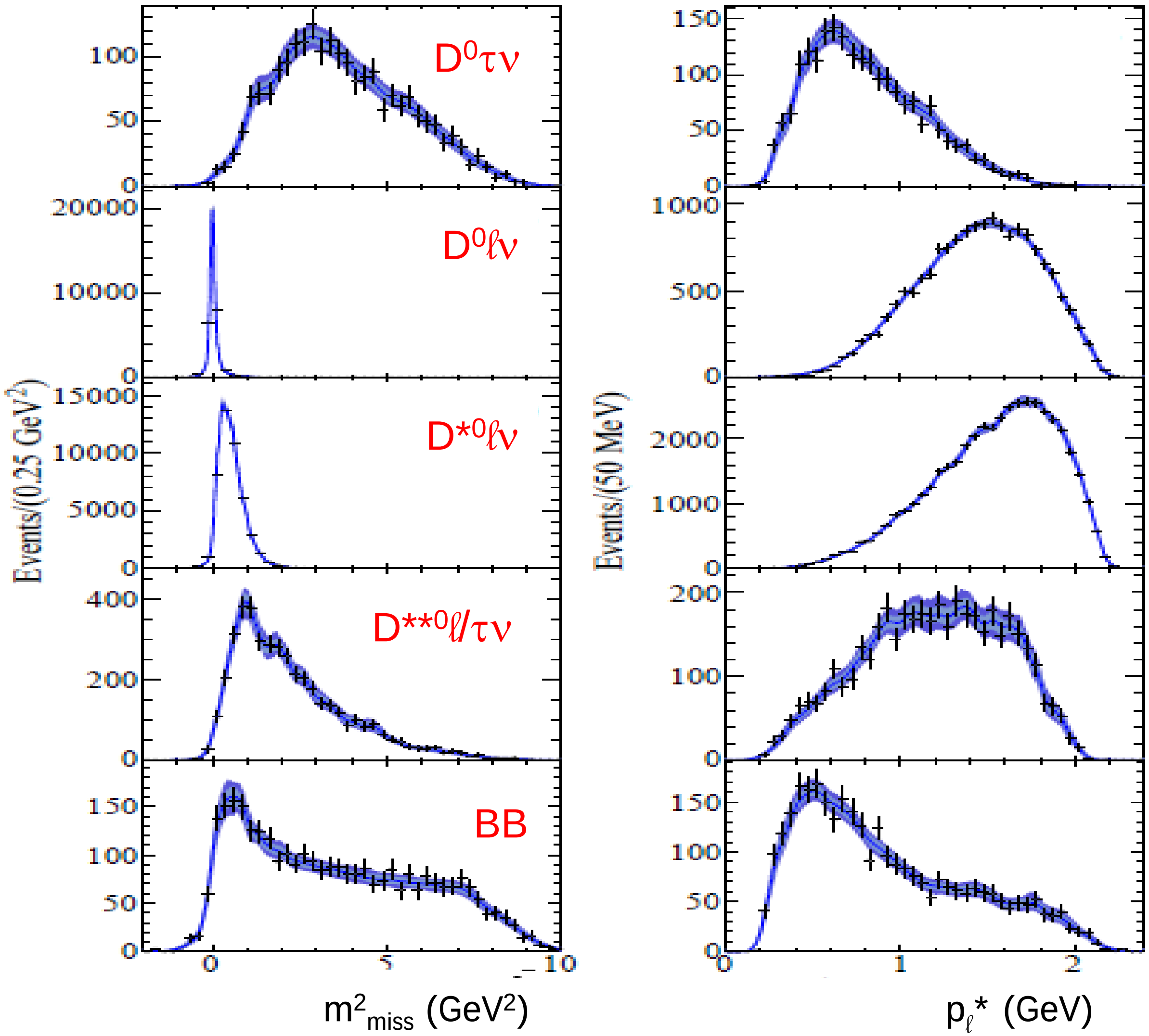
MC Simulation

$D^{(*)}\tau\,\nu$ Signal at larger m^2_{miss}





2-D PDFs Based on KEYS Functions



- 2-D m^2_{miss} vs p^*_ℓ, difficult to describe analytically
  - correlations
  - irregular functions
- Solution
  - non-parametric Kernel Estimators (KEYS)
  - optimize bias vs variance (smoothing)

Blue bands mark 2σ variations due to the stat. uncertainties of MC samples

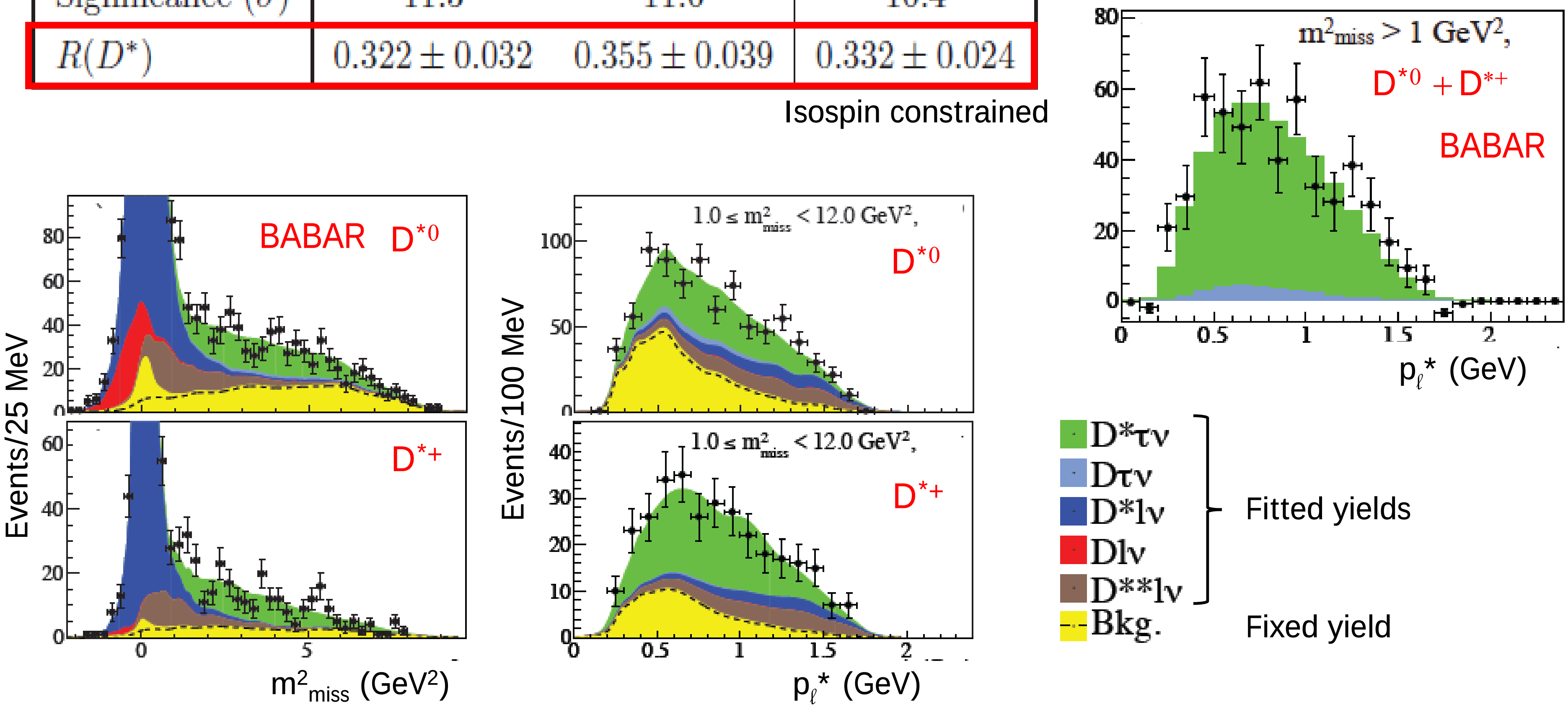
Results of Fit: $B \to D^*\tau\nu$

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

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^*\tau\nu$
N_{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

Isospin constrained

Statistical errors only



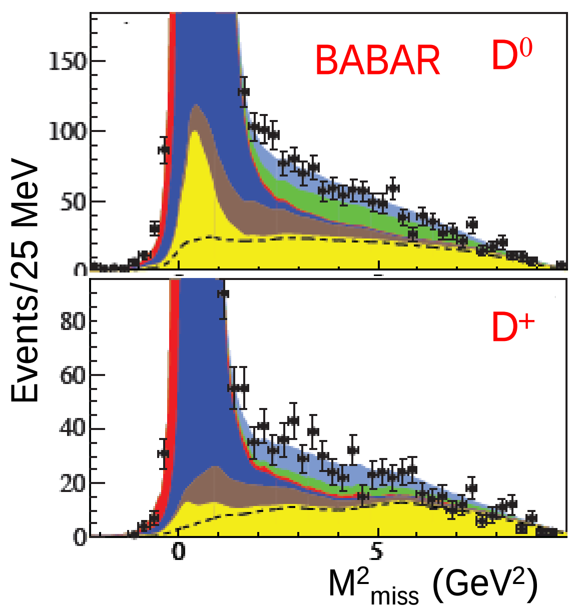
Results of Fit: B → Dτν

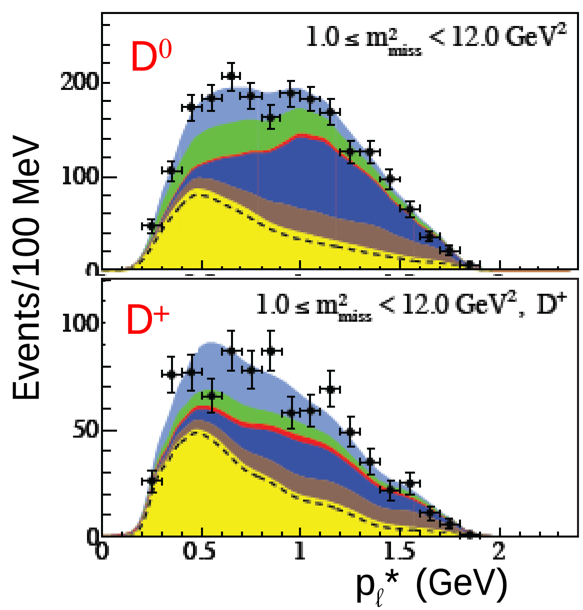
BABAR, Phys. Rev. Lett. 101802 (2012)

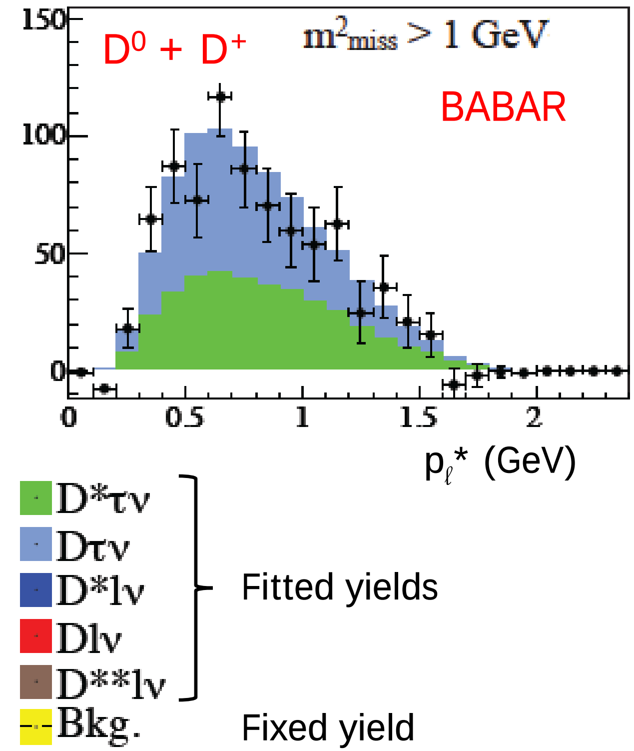
	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
$N_{\rm sig}$	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

Isospin constrained

Statistical errors only







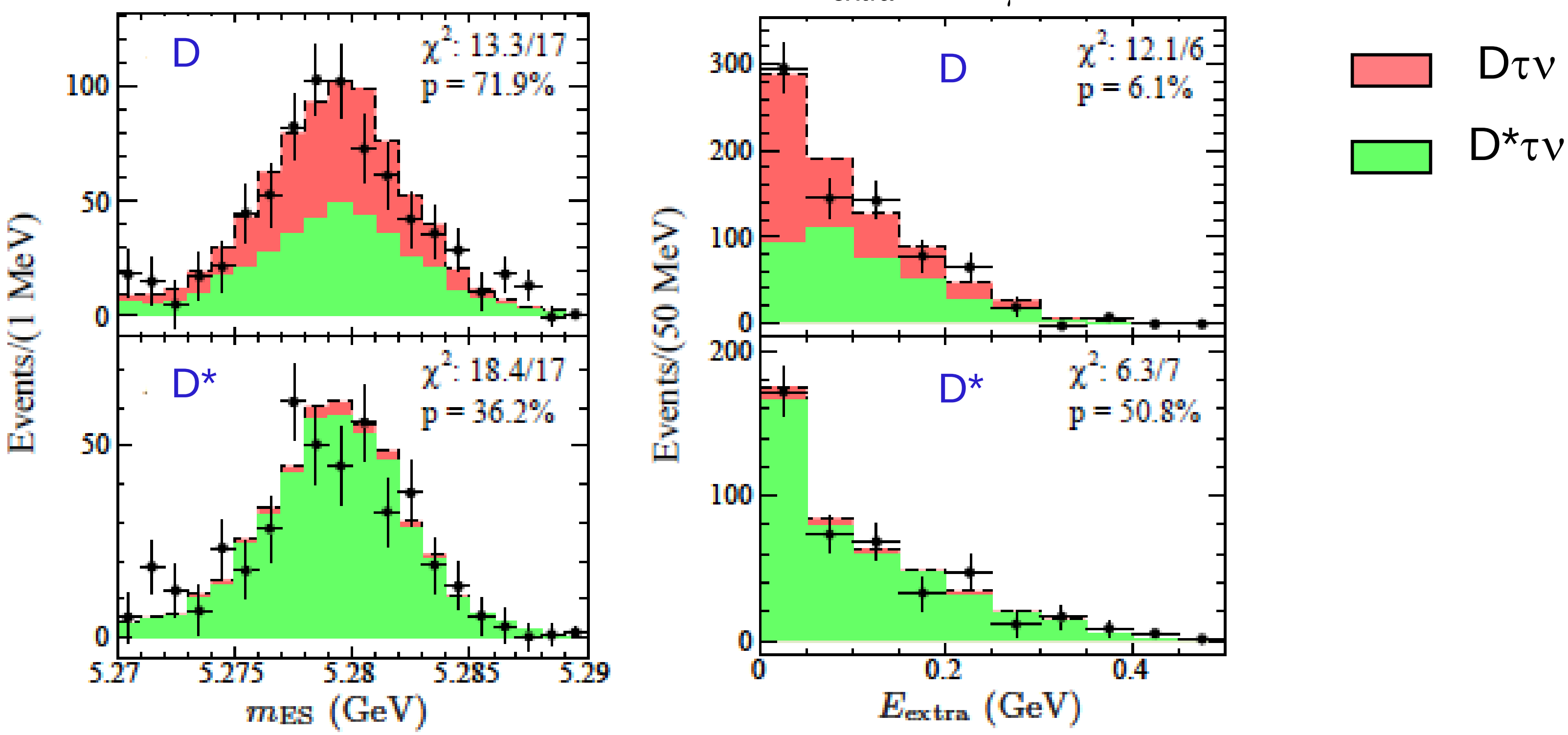
Cross Check on MC for Signal and Backgrounds

Detailed comparisons of data control samples with MC

- Prior to fit (off and on resonance data) rescale distributions: p^*_ℓ, m_{ES}, E_{extra}
- Post fit (unfitted distributions in signal region)

Background subtracted distributions $B \rightarrow D^{(*)}\tau\nu$ (post-fit)

$m_{ES}=\sqrt{E^2_{beam}- p^2_B}$ $\qquad$ $E_{extra} =\Sigma E_\gamma(\text{unused})$



Systematic Uncertainties

ρ   Correlation between R(D) and R(D*)

Principal Uncertainties:

- $D^{**}\ell\,\nu$: conservative 15%

  constraints and fit to $D\pi$ sample,

- Limited MC signal samples

  2-dim PDFs with ~2000 events

- Continuum and BB background

  Corrections and MC statistics

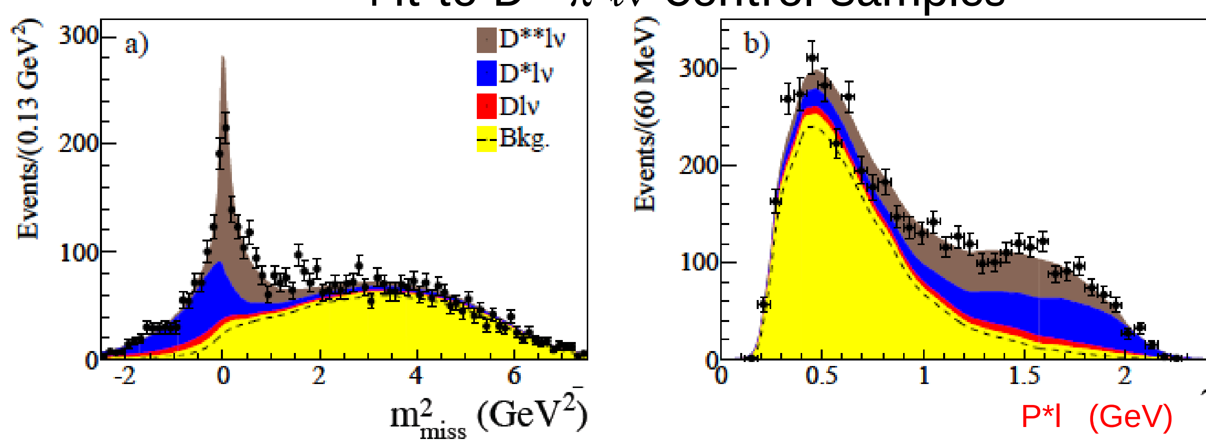
Largest errors are Gaussian distributed!

Source	Uncertainty (%) $R(D)$	Uncertainty (%) $R(D^*)$	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

Fit to $D^{(*)}\pi^0\ell\nu$ Control Samples

Fit to D(*)$\pi^0\ell\,\nu$ control sample for the sum of the 4 channels:

$D^0\pi^0\ell\nu$, $D^{*0}\pi^0\ell\,\nu$,
$D^+\pi^0\ell\nu$, $D^{*+}\pi^+\ell\,\nu$



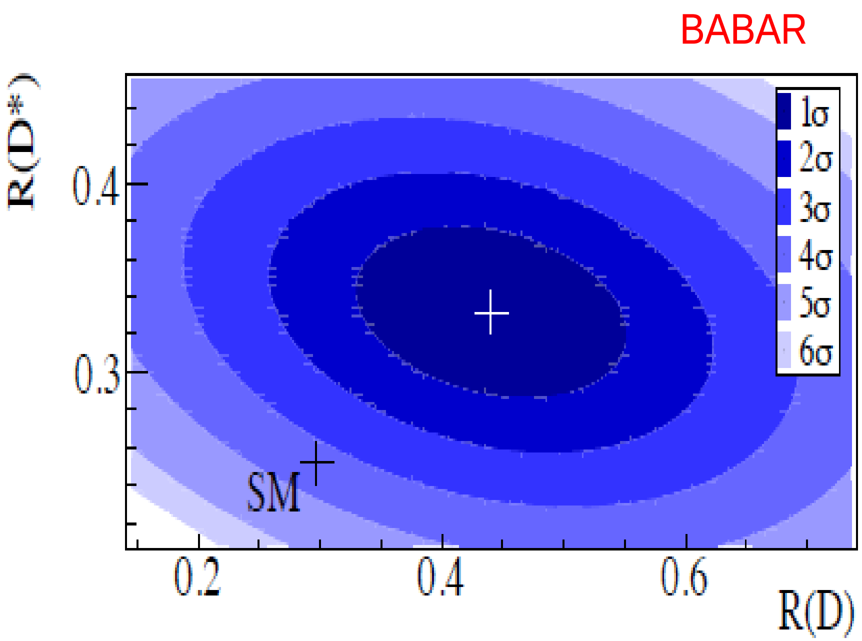
S.M. Predictions of R(D) and R(D*)

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

Comparison with S.M. calculation:

Z. Phys, C46, 93 (1990)
PRD 82, 0340276 (2010)
PhD 85, 094025 (2012)
and recent updates

	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	2.0 σ	2.7 σ

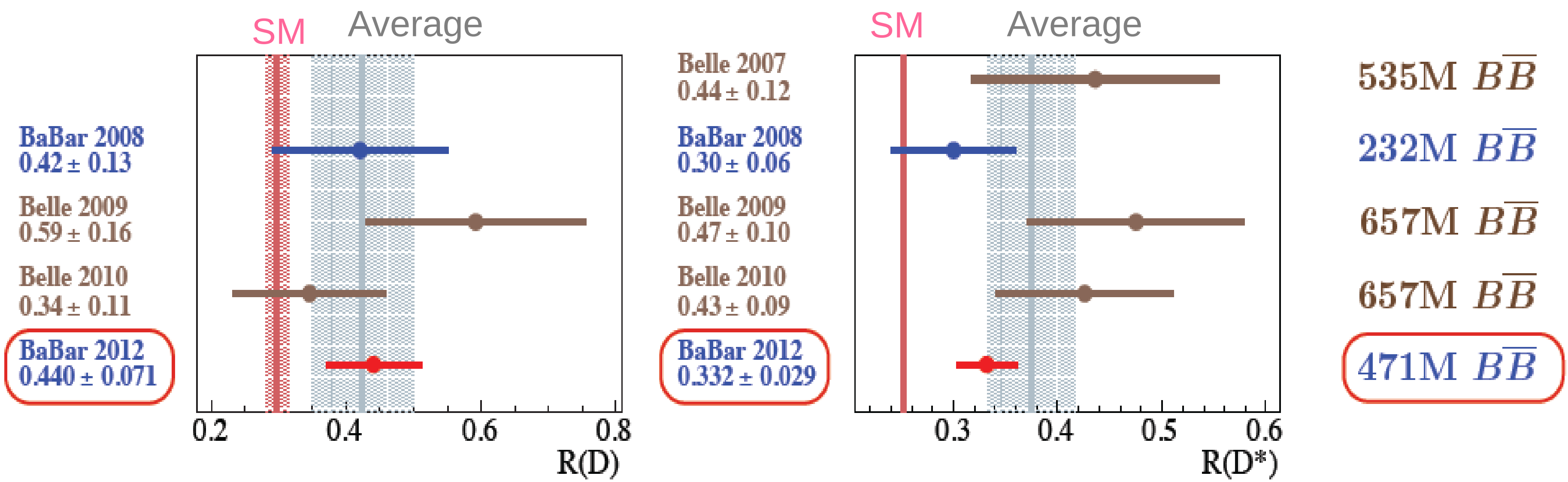


The combination of the two measurements (-0.27 correlation) yields χ^2/NDF=14.6/2, i.e. Prob. = 6.9 x10^{-4} !!

Thus the data are inconsistent with the SM prediction at 3.4 σ

Comparison to Previous Measurements

NB: Average does not include this measurement



The new measurements are fully compatible with earlier results!

Can we explain the excess events?

- A charged Higgs (2HDM type II) of spin 0 coupling to the τ will only affect H_s

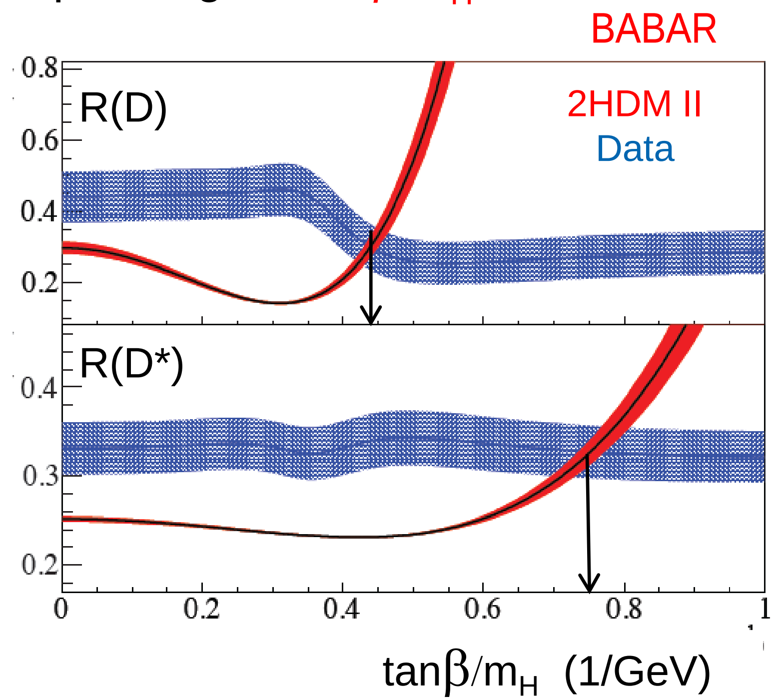
$$H_s^{2HDM} = H_s^{SM} \times \left(1 - \frac{\tan^2\beta}{m^2_{H\pm}} \frac{q^2}{1 \mp m_c/m_b}\right)$$

- for $D\tau\nu$
+for $D^*\tau\nu$

PRD 78, 015006 (2008)
PhD 85, 094025 (2012)

This could enhance or decrease the ratios R(D*) depending on $\tan\beta/m_H$

- We estimate the effect of 2HDM, accounting for difference in signal yield and efficiency.
- The data match 2HDM Type II at
  $\tan\beta/m_H = 0.44 \pm 0.02$ for R(D)
  $\tan\beta/m_H = 0.75 \pm 0.04$ for R(D*)
- The combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space with a probability of >99.8%, provided M_H>15 GeV !

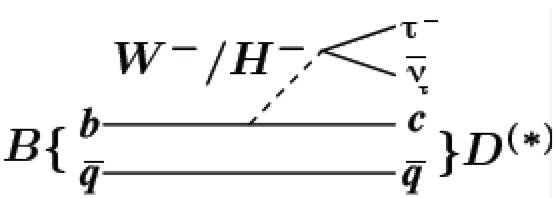


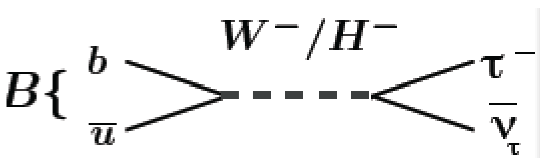
Summary

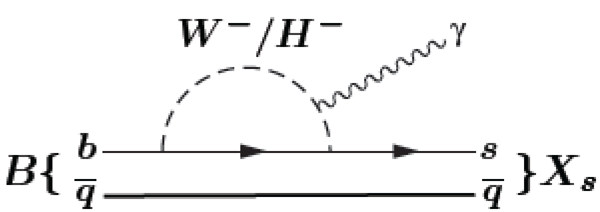
- Studies of semileptonic decays have been challenging for both theory and experiment - considerable progress in the past decade!
- At present, there are two interesting puzzles:
  - Some "tension" between inclusive and exclusive analyses remains, while stated uncertainties on BFs and $|V_{cb}|$ and $|V_{ub}|$ are being reduced.
  - The search for non-SM B decay rates by BABAR has revealed a significant excess (3.4 σ) of events in $B \to D\tau\nu$ and $B \to D^*\tau\nu$. This feature cannot be explained by contributions expected from a 2HDM Higgs of Type II, though extensions of 2HDM appear to work, as do NP processes with spin 1 coupling.
- To solve these puzzles, we need
  - more data – full exploitation of current and future data @ B Factories
  - continued close collaboration between experimenters and theorists, for both inclusive and exclusive decays, with and without charm!

Merci de votre attention

Search for Charged Higgs Coupling in B Decays



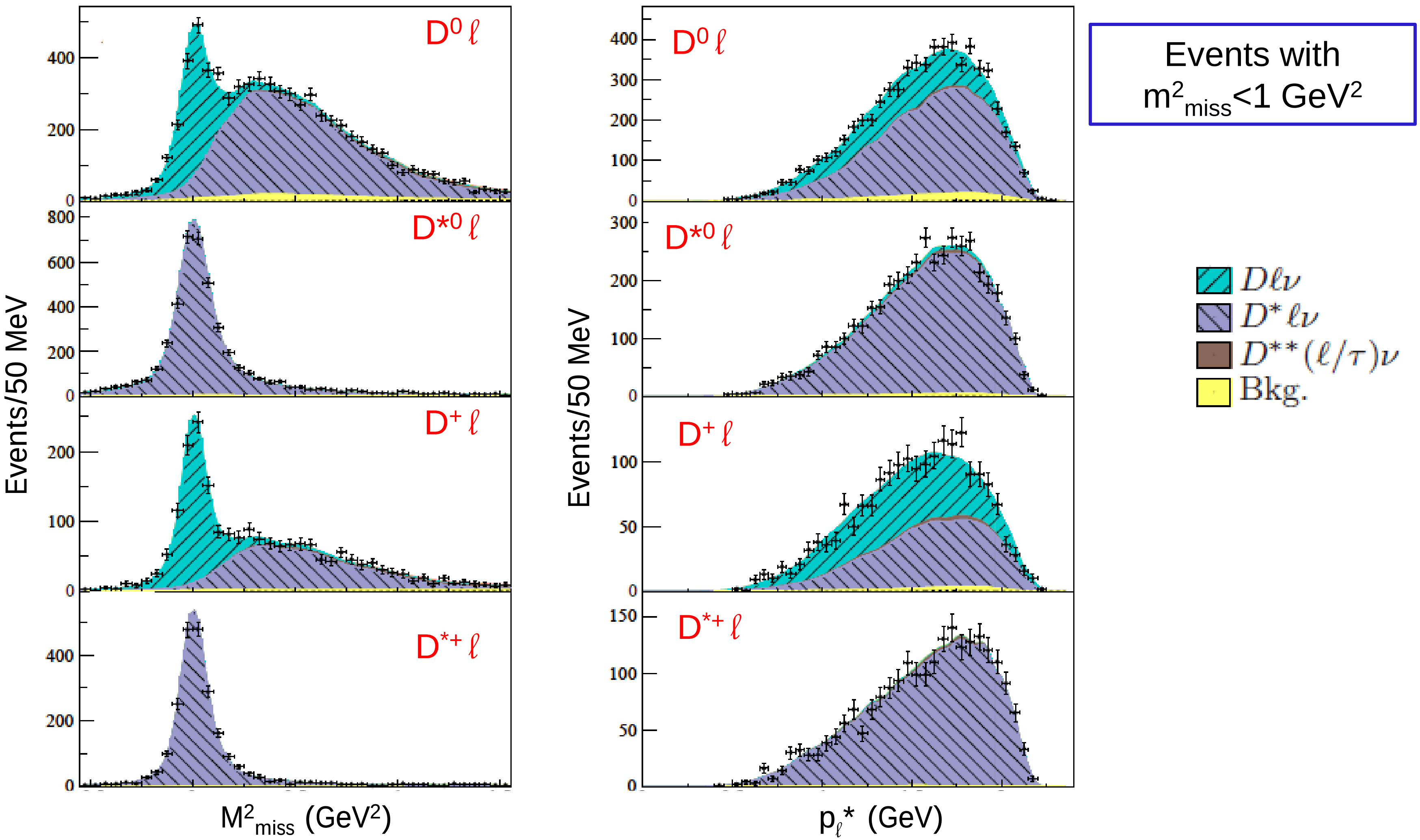




Decay	Theory	BF	Comments
B $\rightarrow D^{(*)}\tau\nu$	Tree level 7%	1-2 %	Excellent Normalization B$\rightarrow D^{(*)}\ell\nu$
B $\rightarrow \tau\nu$	Tree level 25%	0.01% helicity suppressed	2-3 neutrinos
B $\rightarrow X_s\,\gamma$	Loop 7%	0.03%	Inclusive measurement, backgrounds!

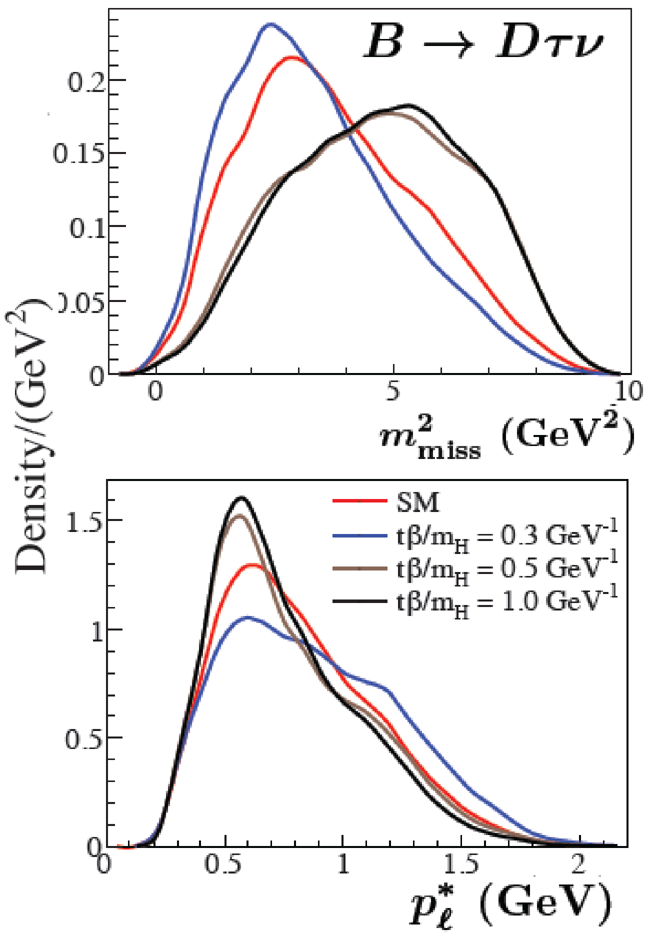
Cross Checks: Fit Normalization $B \to D^{(*)}\ell\nu$

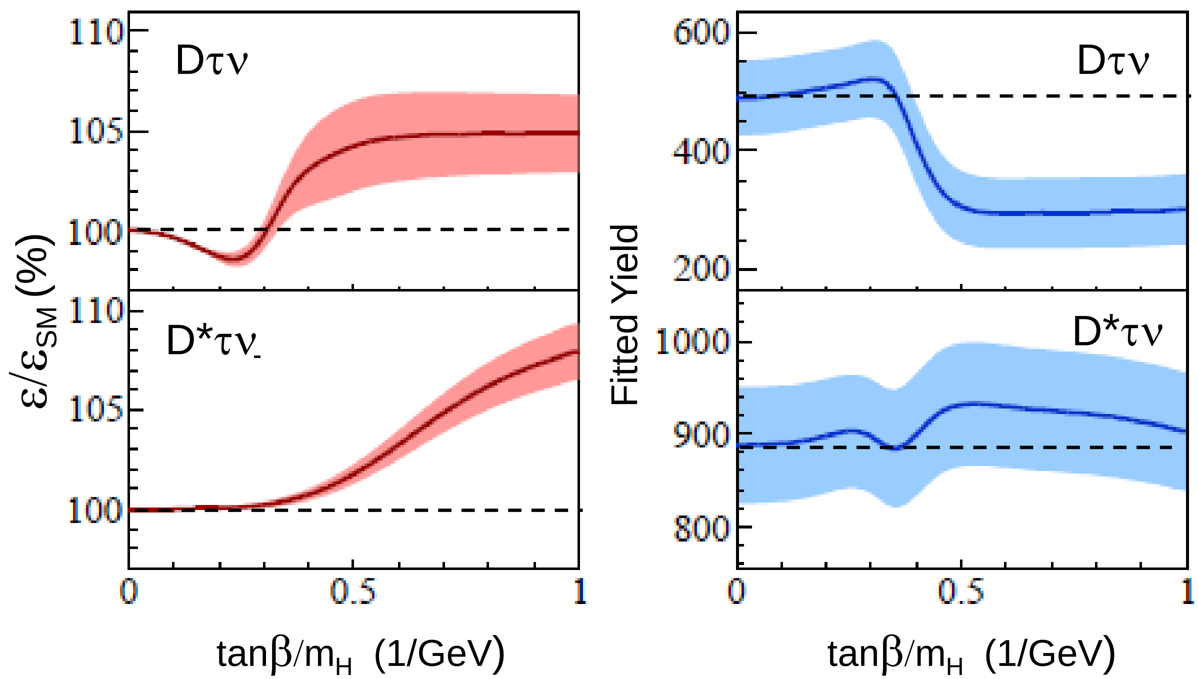
BABAR



Events with m^2_{miss}<1 GeV^2

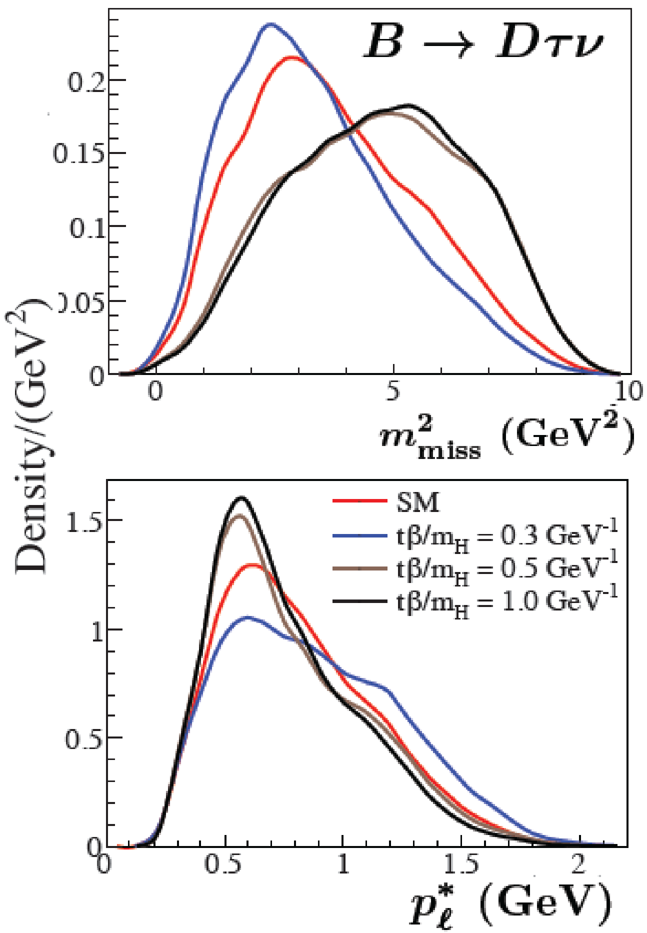
Dependence of MC Signal Yield on 2HDM II



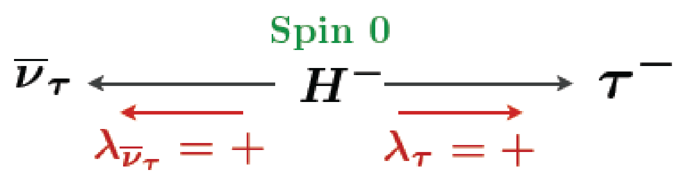


- Change in tanβ/m$_H$ impacts m^2_{miss} :
  - detection efficiency 5-10% for Dτν and D*τν
  - fitted signal yield 40% for Dτν

Dependence of MC Signal Yield on 2HDM II



- τ Polarization in B→Dτν Decays
  - SM LH: 70%. RH: 30%
  - 2HDM LH: 0% RH: 100%



- Impact on fitted distributions large for B→Dτν
  - missing mass sq: $m^2_{miss} \sim q^2$
  - p^*_ℓ, momentum of secondary lepton from $\tau^- \to \ell^- \overline{\nu}_\ell \nu_\tau$ decays in B rest frame