Measurement of $B \rightarrow D(*)\ell\nu$ Decays and Status of $B \rightarrow D^{**}(D(*)n\pi)\ell\nu$

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CKM Workshop, Warwick, UK
9 September 2010

Exclusive B → D(*)ℓν

$$\frac{d\Gamma}{dw}(\overline{B} \to D^{*}\ell\overline{\nu}_{\ell}) = \frac{G_F^2}{48\pi^3}|V_{cb}|^2 m_{D^*}^3 (w^2-1)^{1/2} P(w) \boxed{(\mathcal{F}(w))^2}$$

$$\frac{d\Gamma}{dw}(\overline{B} \to D\ell\overline{\nu}_{\ell}) =$$

form factor

$$\frac{G_F^2}{48\pi^3}|V_{cb}|^2 (m_B+m_D)^2 m_D^3 (w^2-1)^{3/2} \boxed{(\mathcal{G}(w))^2} \qquad w \equiv v \cdot v'$$

- The F(w) and G(w) form factors can be parameterized based on HQET and dispersion relations (Caprini et al, Nucl.Phys. B530, 153 (1998))
- Form-factor parameters are ρ^2,R_2,R_2 (ρ^2) for D*(D)
- F(1) and G(1) from lattice QCD
- Experiments fit the FF parameterization over nearly the entire phase space
- Up to now, B → D*ℓν uncertainty dominated by theory error (lattice), B → Dℓν by experimental uncertainty

F(1) = 0.921 +/- 0.013 +/- 0.020	C.Bernard et al. [Phys.Rev.D79, 014506 (2009)]
G(1) = 1.074 +/- 0.018 +/- 0.016	M.Okamoto et al. [Nucl.Phys.Proc.Suppl. 140, 461 (2005)]

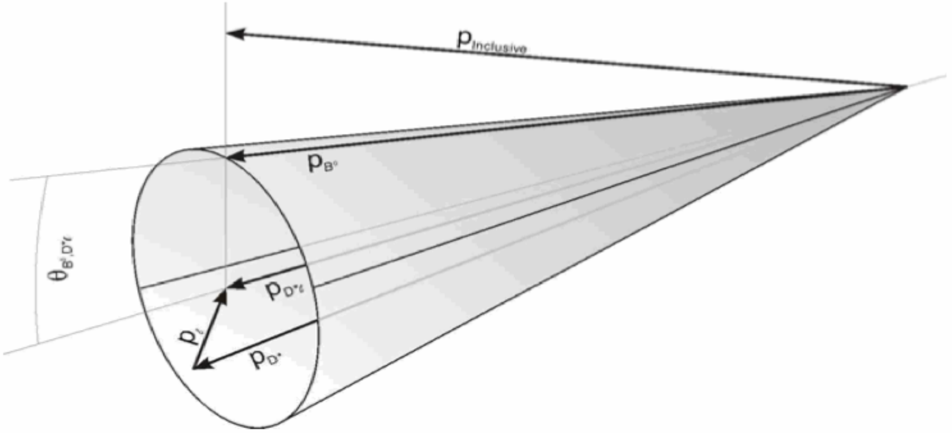
New !

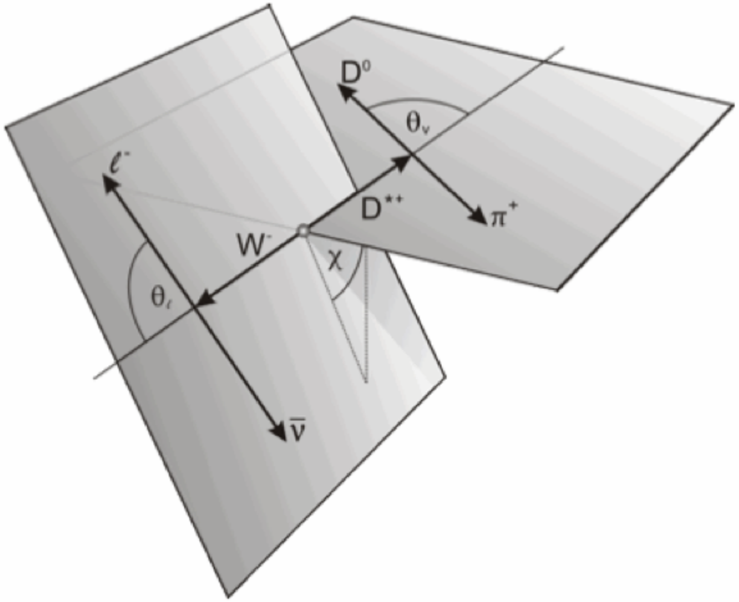
$B \to D^* \ell \nu$ Recent Results

ICHEP 2010 [arXiv:0810.1657] preliminary

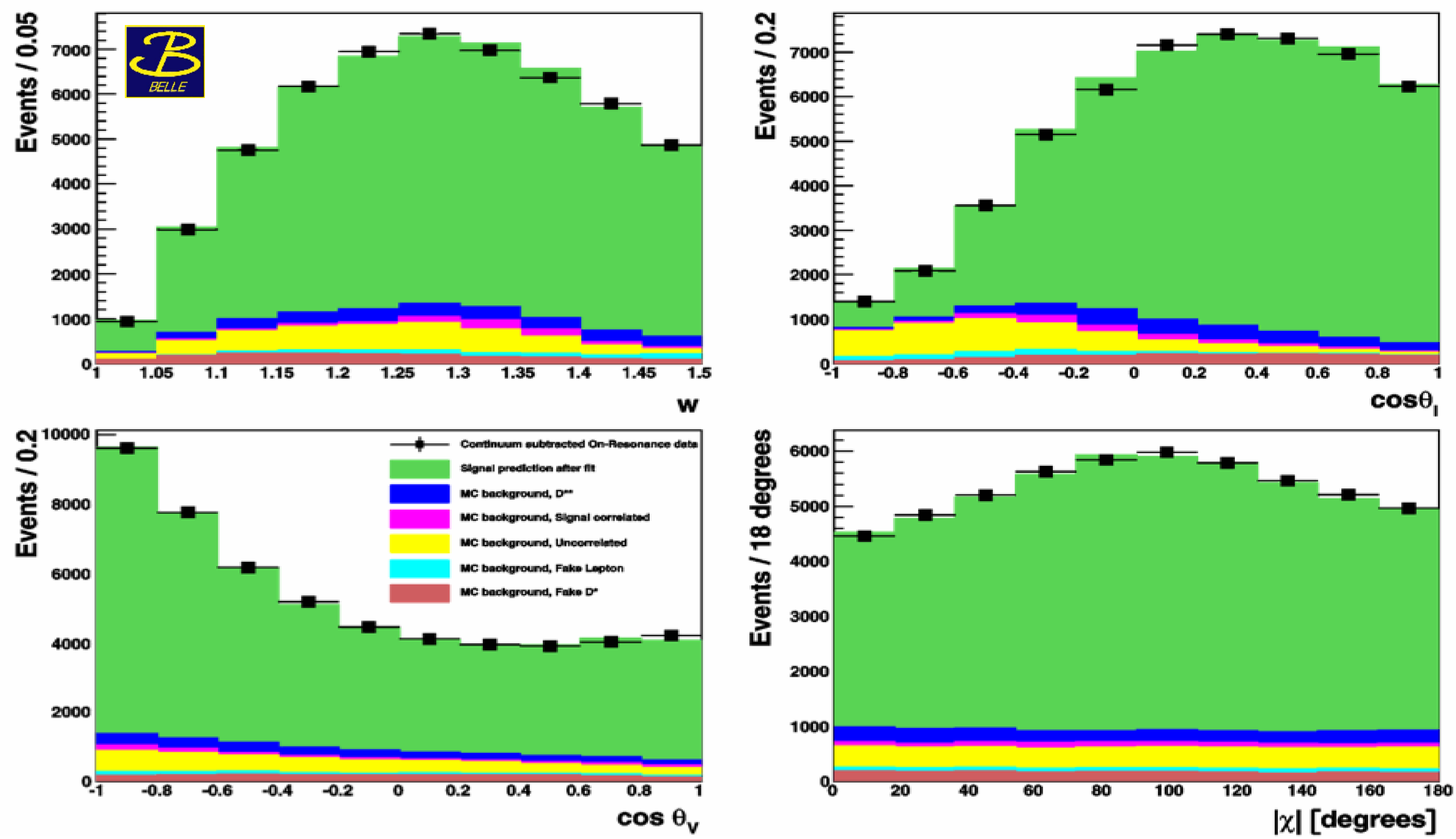
[arXiv:0910.3534] preliminary

- Untagged analysis of $B^0 \to D^{*+} \ell \nu$ based on 711 fb^{-1} (B^+ : 140fb^{-1}),
- Reconstruct $D^{*+} \to D^0 \pi_s$, $D^0 \to K\pi$ (B^+: $D^{*0} \to D^0 \pi^0_s$, also $D^0 \to K3\pi$)
- Reconstruct B momentum using kinematics and the remaining particles in the event
- Calculate w and three angles that fully describe the decay
- Fit these 4 variables to the differential width (binned fit to the projections in w, $\cos\theta_\ell$ $\cos\theta_V$ and χ)



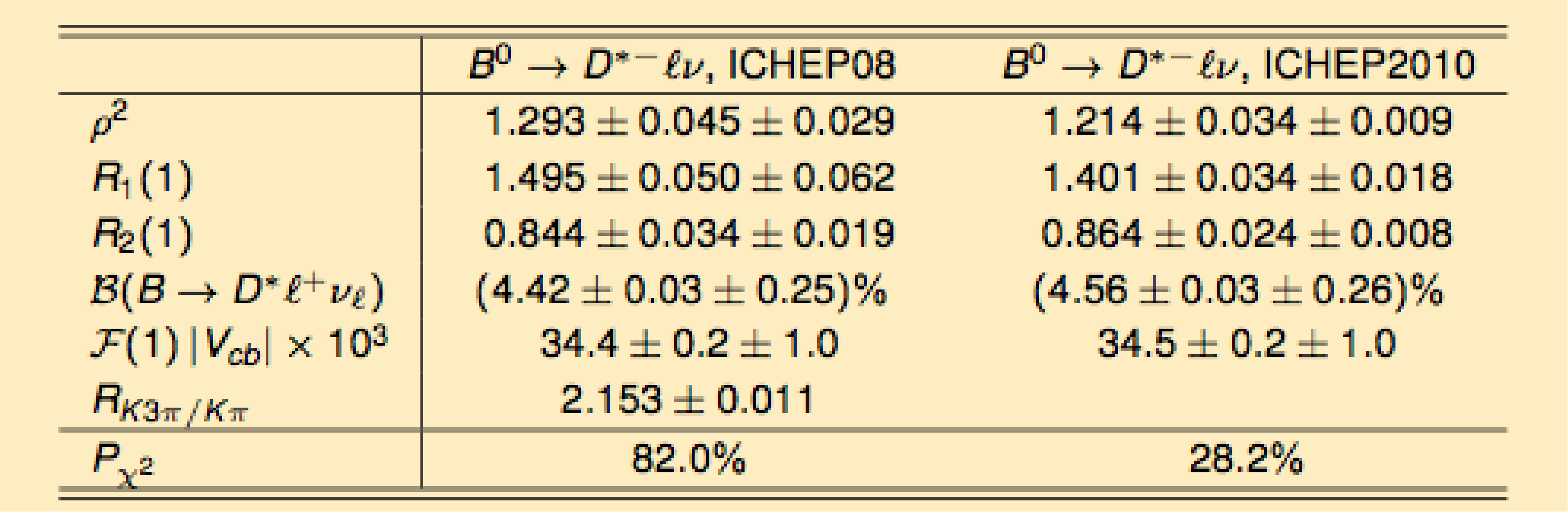


$B \rightarrow D^{*}\ell\nu$ Recent Results



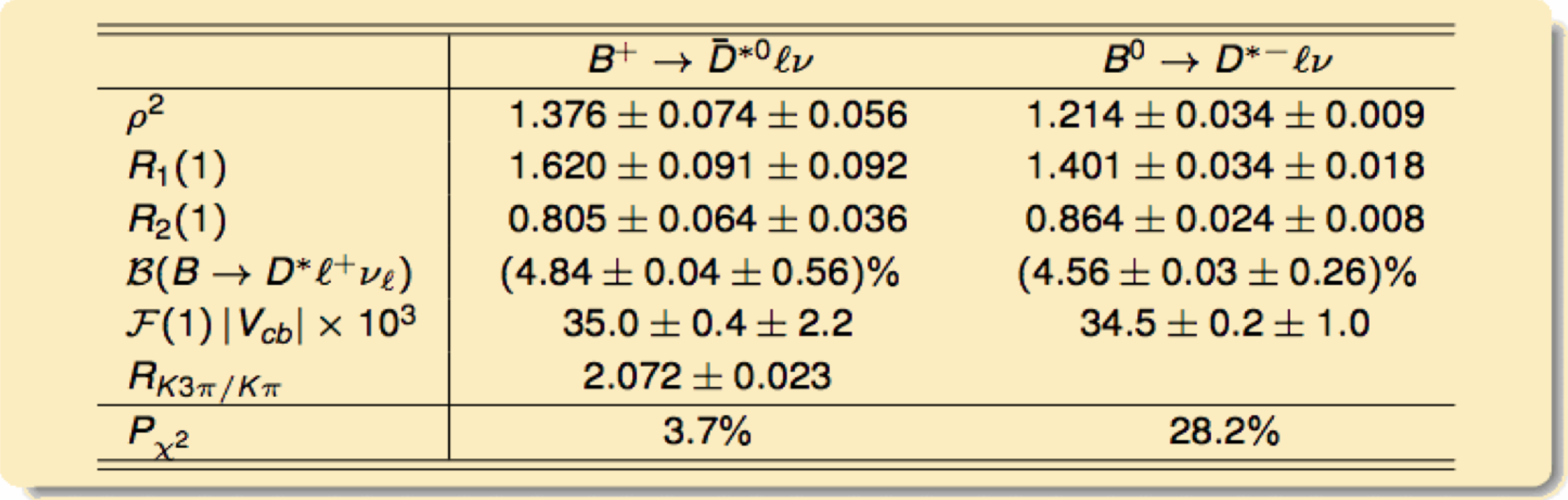
$B \to D^*\ell\nu$ Recent Results

- Differences between the 2 Belle analysis:
- Data sample ($140\text{fb}^{-1} \to 711\text{fb}^{-1}$), D^0 modes ($K\pi$, $K3\pi$ vs $K\pi$ only)
- Enhanced background calibration
- Soft π investigation
- Newer PDG numbers for D branching ratios etc.



	$B^0 \to D^{*-}\ell\nu$, ICHEP08	$B^0 \to D^{*-}\ell\nu$, ICHEP2010
ρ^2	$1.293 \pm 0.045 \pm 0.029$	$1.214 \pm 0.034 \pm 0.009$
$R_1(1)$	$1.495 \pm 0.050 \pm 0.062$	$1.401 \pm 0.034 \pm 0.018$
$R_2(1)$	$0.844 \pm 0.034 \pm 0.019$	$0.864 \pm 0.024 \pm 0.008$
$\mathcal{B}(B \to D^*\ell^+\nu_\ell)$	$(4.42 \pm 0.03 \pm 0.25)\%$	$(4.56 \pm 0.03 \pm 0.26)\%$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert \times 10^3$	$34.4 \pm 0.2 \pm 1.0$	$34.5 \pm 0.2 \pm 1.0$
$R_{K3\pi/K\pi}$	2.153 ± 0.011	
P_{χ^2}	82.0%	28.2%

$B \to D^*\ell\nu$ Comparison



	$B^+ \to \bar{D}^{*0}\ell\nu$	$B^0 \to D^{*-}\ell\nu$
ρ^2	$1.376 \pm 0.074 \pm 0.056$	$1.214 \pm 0.034 \pm 0.009$
$R_1(1)$	$1.620 \pm 0.091 \pm 0.092$	$1.401 \pm 0.034 \pm 0.018$
$R_2(1)$	$0.805 \pm 0.064 \pm 0.036$	$0.864 \pm 0.024 \pm 0.008$
$\mathcal{B}(B \to D^*\ell^+\nu_\ell)$	$(4.84 \pm 0.04 \pm 0.56)\%$	$(4.56 \pm 0.03 \pm 0.26)\%$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert \times 10^3$	$35.0 \pm 0.4 \pm 2.2$	$34.5 \pm 0.2 \pm 1.0$
$R_{K3\pi/K\pi}$	2.072 ± 0.023	
P_{χ^2}	3.7%	28.2%

$$\begin{aligned} \mathcal{F}(1)\lvert V_{cb}\rvert &= (34.4 \pm 0.3 \pm 1.1) \times 10^{-3} \\ \rho^2 &= 1.191 \pm 0.048 \pm 0.028 \\ R_1(1) &= 1.429 \pm 0.061 \pm 0.044 \\ R_2(1) &= 0.827 \pm 0.038 \pm 0.022. \end{aligned}$$

$D^{*+}l\nu$, Phys.Rev.D77:032002,2008

$$F(1)\lvert V_{cb}\rvert = 35.9 \pm 0.2 \pm 1.2$$

$$\rho^2(D^*) = 1.22 \pm 0.02 \pm 0.07$$

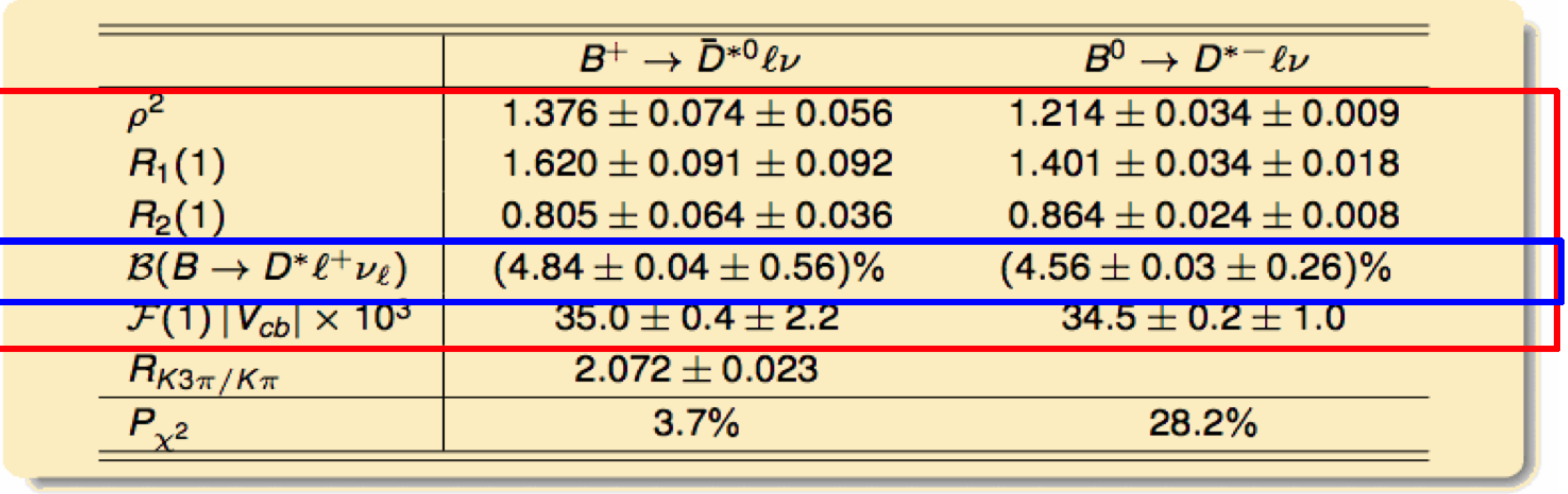
Global $DXl\nu$, Phys.Rev.D79:012002, 2009

$$F(1)\lvert V_{cb}\rvert = 35.9 \pm 0.6 \pm 1.4$$

$$\rho^2(D^*) = 1.16 \pm 0.06 \pm 0.08$$

$D^{*0}l\nu$, Phys.Rev.Lett. 100, 231803, 2008

$B \to D^*\ell\nu$ Comparison



	$B^+ \to \bar{D}^{*0}\ell\nu$	$B^0 \to D^{*-}\ell\nu$
ρ^2	$1.376 \pm 0.074 \pm 0.056$	$1.214 \pm 0.034 \pm 0.009$
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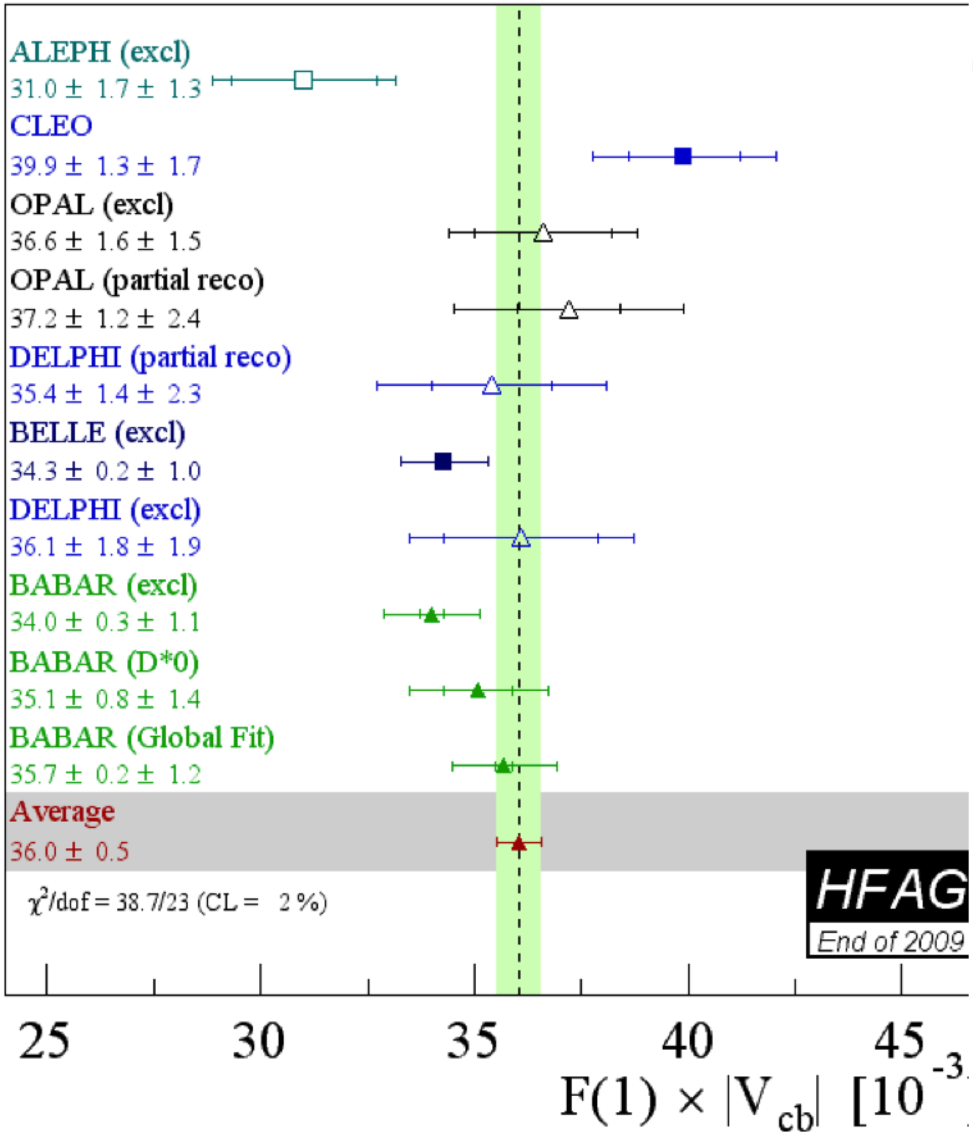
$$
\begin{aligned}
\mathcal{F}(1)|V_{cb}| &= (34.4 \pm 0.3 \pm 1.1) \times 10^{-3} \\
\rho^2 &= 1.191 \pm 0.048 \pm 0.028 \\
R_1(1) &= 1.429 \pm 0.061 \pm 0.044 \\
R_2(1) &= 0.827 \pm 0.038 \pm 0.022.
\end{aligned}
$$

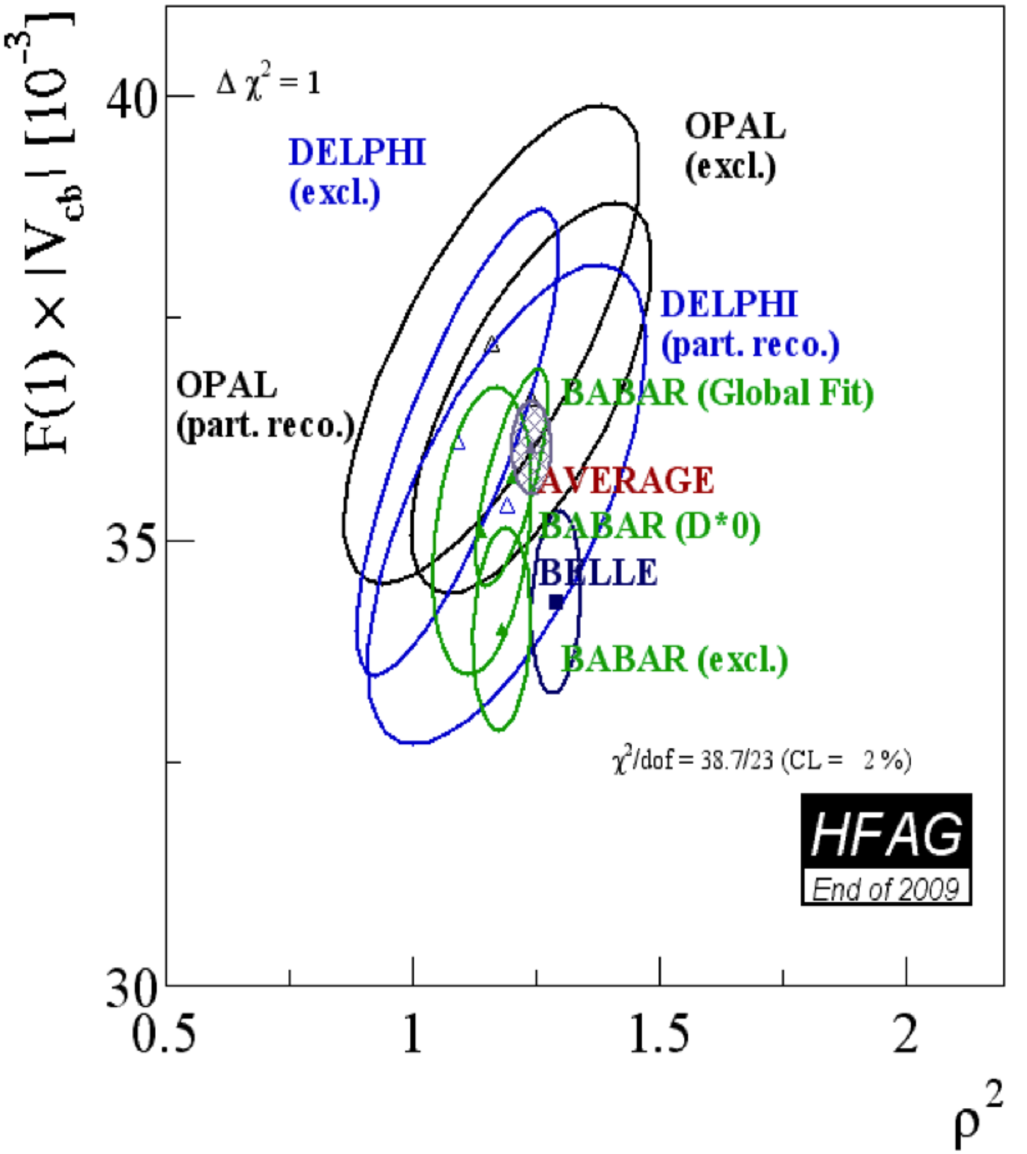
Phys.Rev.D77:032002,2008

$$
\begin{aligned}
\mathcal{B}(B^- \to D^{*0}\ell\overline{\nu}) &= (5.49 \pm 0.19)\% \\
\rho^2_{D^*} &= 1.20 \pm 0.04 \\
\mathcal{F}(1)|V_{cb}| &= (34.8 \pm 0.8) \times 10^{-3}.
\end{aligned}
$$

Phys.Rev.D79:012002, 2009

B → D*ℓν : HFAG Averages





$B \to D^*\ell\nu$ Comments

- Can we still improve the sensitivity for $B \to D^*\ell\nu$?
  (In)-famous HFAG puzzle on the $|V_{cb}|$ average
- More disturbing, at least for the Branching Fractions, is the tagged-untagged disagreement:
  Belle untagged: $BF(D^{*+}\ell\nu) = (4.6 \pm 0.3)\%$, $BF(D^{*0}\ell\nu) = (4.8 \pm 0.6)\%$
  BaBar untagged: $BF(D^{*+}\ell\nu) = (5.1 \pm 0.2)\%$, $BF(D^{*0}\ell\nu) = (5.5 \pm 0.2)\%$
  BaBar tagged: $BF(D^{*+}\ell\nu) = (5.4 \pm 0.3)\%$, $BF(D^{*0}\ell\nu) = (5.8 \pm 0.3)\%$
- Connected to the incl - excl BF puzzle (see later)
- BaBar $|V_{ub}|$ analysis on tagged samples clearly favors higher BF (>5%) for $B \to D^*\ell\nu$
- It would be important to get an update on the tagged samples from Belle (e.g. Belle Phys. Rev. D 72, 051109 (2005), $BF(D^{*0}\ell\nu) = (6.1 \pm 0.3)\%$)

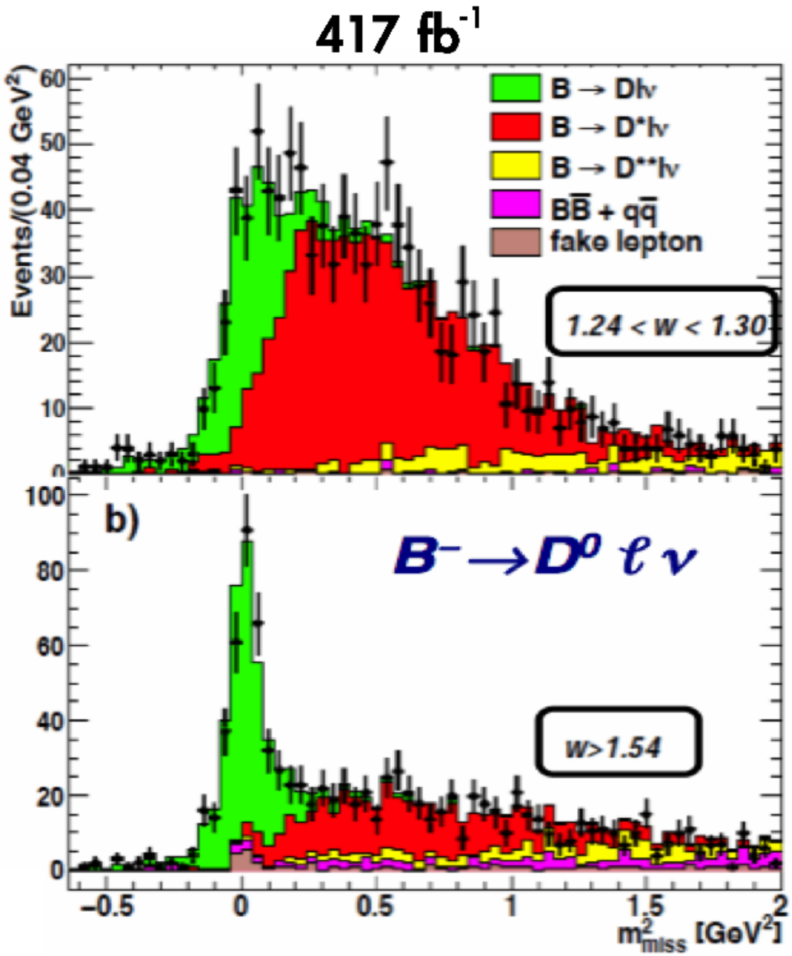
$B \rightarrow D\ell\nu$ Recent Results

- Hadronic tag:
  Reduced background (higher S/N)
  Fully exploit kinematic constraints (w resolution ~0.01)
  Avoid neutrino reconstruction
- Identify semileptonic B decays through the missing mass squared in the event:

$$m^2_{\text{miss}} = [p(\Upsilon(4S)) - p(B_{\text{tag}}) - p(D) - p(\ell)]^2$$

- Binned maximum likelihood fit, MC shapes to different signal and background components
- Inclusive $B \rightarrow X\ell\nu$ used as normalization

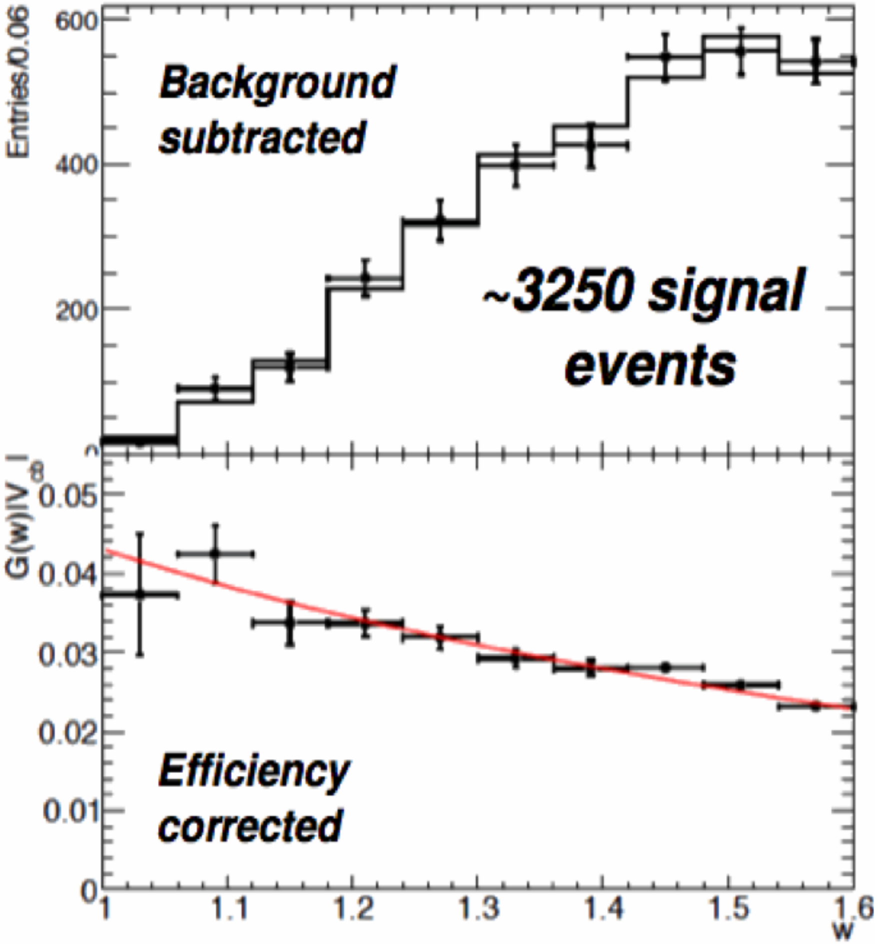
Phys.Rev.Lett. 104:011802,2010



$B \to D\ell\nu$ Recent Results

Extract w spectrum by fitting m_{2miss} in 10 w bins

χ^2 fit to w spectrum to measure $G(1)|V_{cb}|$ and ρ^2, reweighting MC template



$$G(1)|V_{cb}| = (42.3 \pm 1.9 \pm 1.4)\times 10^{-3}$$

$$\rho^2 = 1.20 \pm 0.09 \pm 0.04$$

$$Br(B^0 \to D\ell\nu) = (2.15 \pm 0.06 \pm 0.07)\%$$

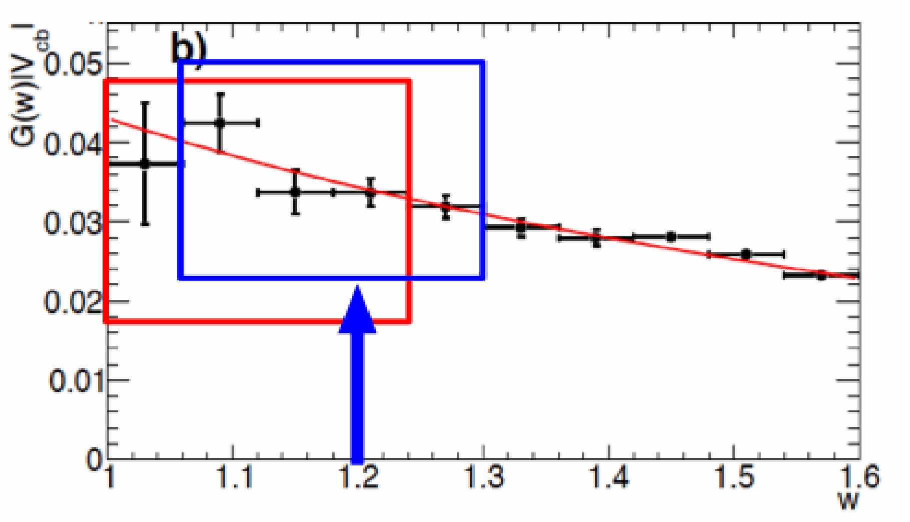
Normalization of the FF at w=1 available in quenched and unquenched (2+1) calculations

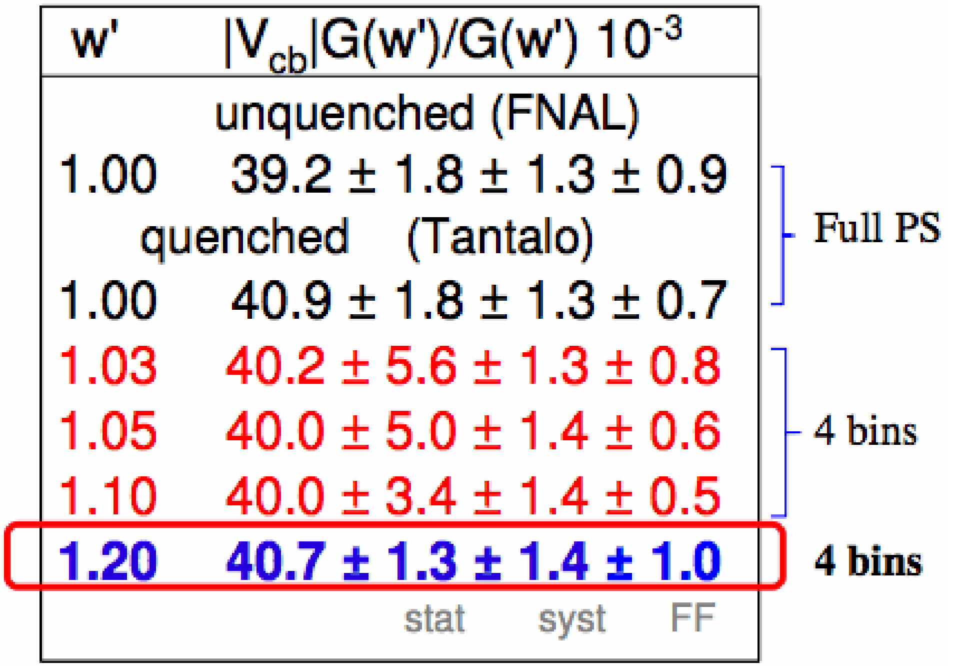
Computation of G(w) at w>1 start to be available Tantalo et al. (PLB655,45 (2007)) with quenched approximation, and more recently T. Mannel et al. (arXiv:0809.0222) using LCSR

w	G(w)		
1.00	1.074±0.024	unquenched	LAT05 (Okamoto) ←
1.00	1.058±0.020	quenched	PRD61,014502 (2005)
1.00	1.026±0.017	quenched	PLB655, 45 2007
1.03	1.001±0.019	“	“
1.05	0.987±0.015	“	“
1.10	0.943±0.011	“	“
1.20	0.853±0.021	“	“
w_{max}	0.61±0.16	LCSR	arXiv.0809.0222 (2008)

$B \to D\ell\nu$ Recent Results

Reduce the model dependence determining $G(w')|V_{cb}|$ from a fit in a limited region of phase-space



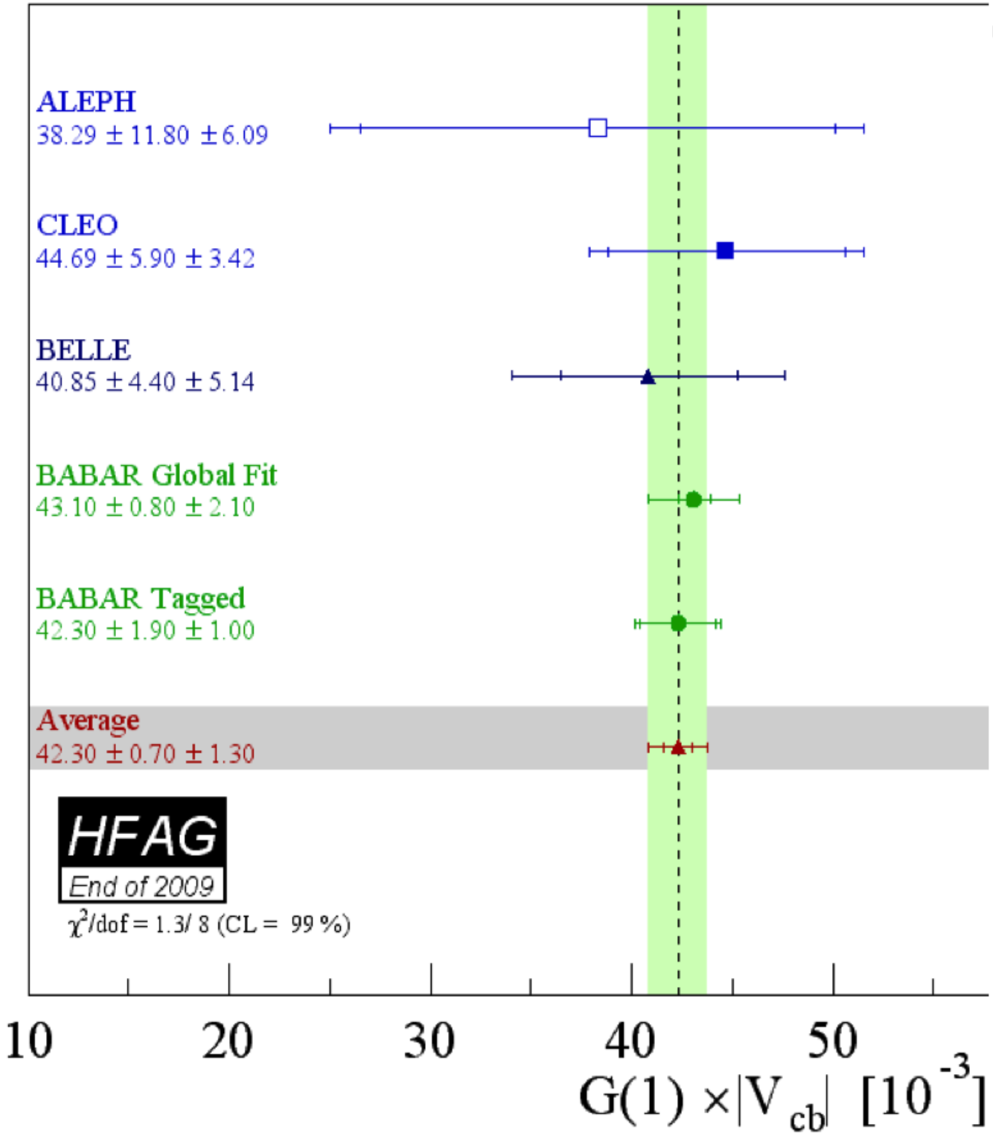


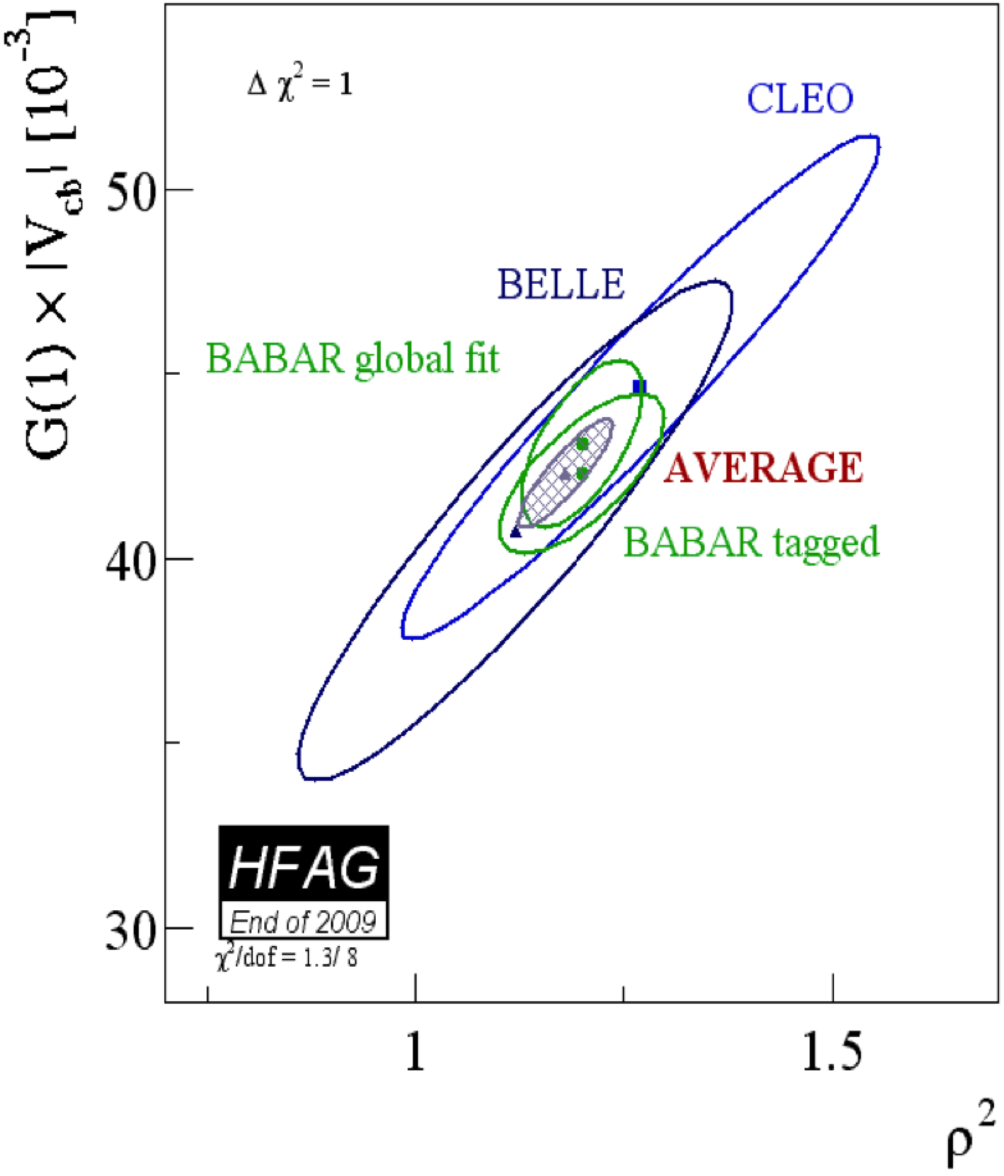
w'	$\lvert V_{cb}\rvert G(w')/G(w')\ 10^{-3}$	
	unquenched (FNAL)	
1.00	39.2 ± 1.8 ± 1.3 ± 0.9	Full PS
	quenched (Tantalo)	
1.00	40.9 ± 1.8 ± 1.3 ± 0.7	
1.03	40.2 ± 5.6 ± 1.3 ± 0.8	4 bins
1.05	40.0 ± 5.0 ± 1.4 ± 0.6	
1.10	40.0 ± 3.4 ± 1.4 ± 0.5	
1.20	**40.7 ± 1.3 ± 1.4 ± 1.0**	**4 bins**
	stat syst FF	

Experimental error interpolating 4 bins around w=1.2 is competitive with the extrapolation to w=1 using the full phase-space

We expect lattice community provide un-quenched (2+1) computation of the FF at w=1 and at w>1

$B \to D\ell\nu$: HFAG Averages





$B \to D(*)\ell\nu$ Uncertainty

$B \to D^*\ell\nu$	Untagged	Tagged
Yield	~10e5	~10e3
Measured	BF, ρ^2,$\|V_{cb}\|$, R_1,R_2	BF
Uncertainty	4% (BF),~3% (FF)	5% (BF)
$B \to D\ell\nu$		
Yield	~ 10e4	~10e3
Measured	BF, ρ^2, $\|V_{cb}\|$	BF, ρ^2, $\|V_{cb}\|$
Uncertainty	5% ($\|V_{cb}\|$) 6% (ρ^2)	5% ($\|V_{cb}\|$), 8% (ρ^2)

$B \to D^*\ell\nu$ $\sigma(|V_{cb}|) \sim$ 1.5% $\oplus$ 2.6 %

$B \to D\ell\nu$ $\sigma(|V_{cb}|) \sim$ 3.5% $\oplus$ 2.2 % (unquenched)

1.7% (quenched)

$B \rightarrow D(*)\ell\nu$ Future (2011)

- $B \rightarrow D^*\ell\nu$

  Can untagged analysis reduce the uncertainties?

  → Still, 4-d $B \rightarrow D^*\ell\nu$ on BaBar full dataset highly desirable

  Can tagged analysis measure FF? Tough, need very high statistics

  → new tagged analysis from Babar (new tag, 2.5-3x more efficient) will attempt it

- $B \rightarrow D\ell\nu$

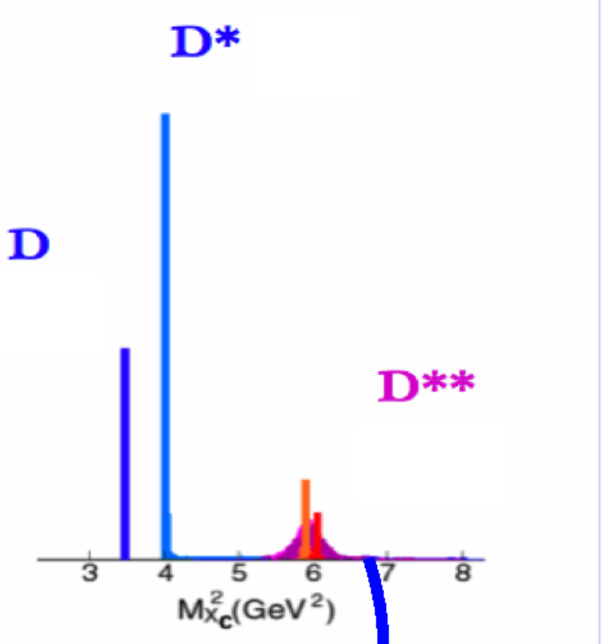
  → Untagged analysis on full dataset necessary from BaBar and Belle

  → new tagged analysis from BaBar expected

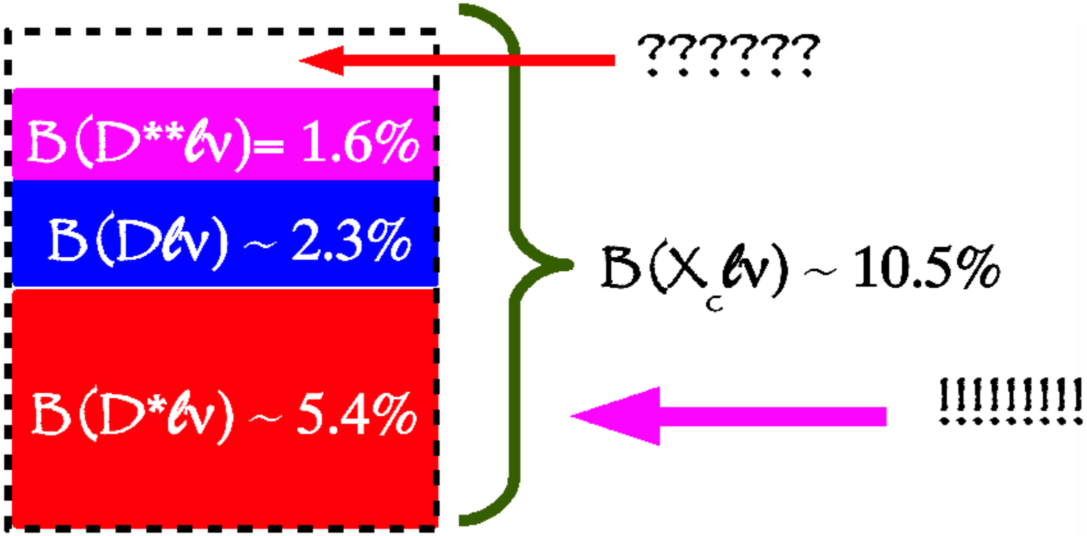
(personal) Claim: $|V_{cb}|$ from $B \rightarrow D\ell\nu$ can go down to ~ 1.5-2%

The X_c System in $B \rightarrow X_c \ell\nu$ Decays

$BR(B \rightarrow X_c l\, \nu) \sim 10.5\%$



- In addition to the “well” measured $D^{(*)}$ states, there are the D** states, orbital excitations of the D-mesons
- Heavy Quark Symmetry predicts 4 D** states, 2 narrow and 2 broad, all observed in hadronic decays
- The naïve assumption X_c=D+D*+D** is contradicted by the experiments that show a 10-15% difference (or more!!!) between direct measurements of the inclusive $X_c\ell\nu$ rate and the sum of the D/D*/D**$\ell\nu$ rates



??????

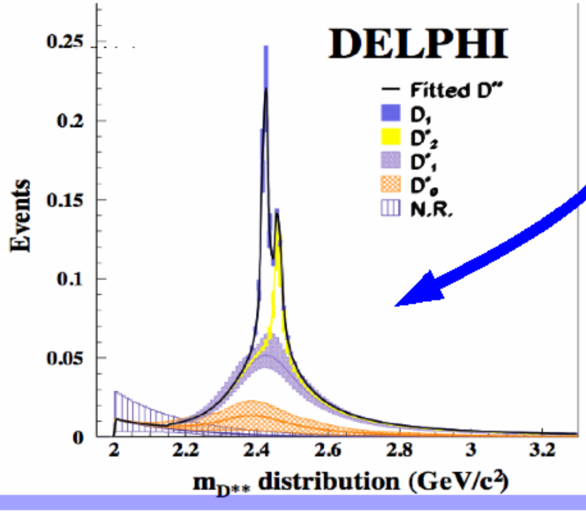
$B(D^{**}\ell\nu) = 1.6\%$

$B(D\ell\nu) \sim 2.3\%$

$B(D^{*}\ell\nu) \sim 5.4\%$

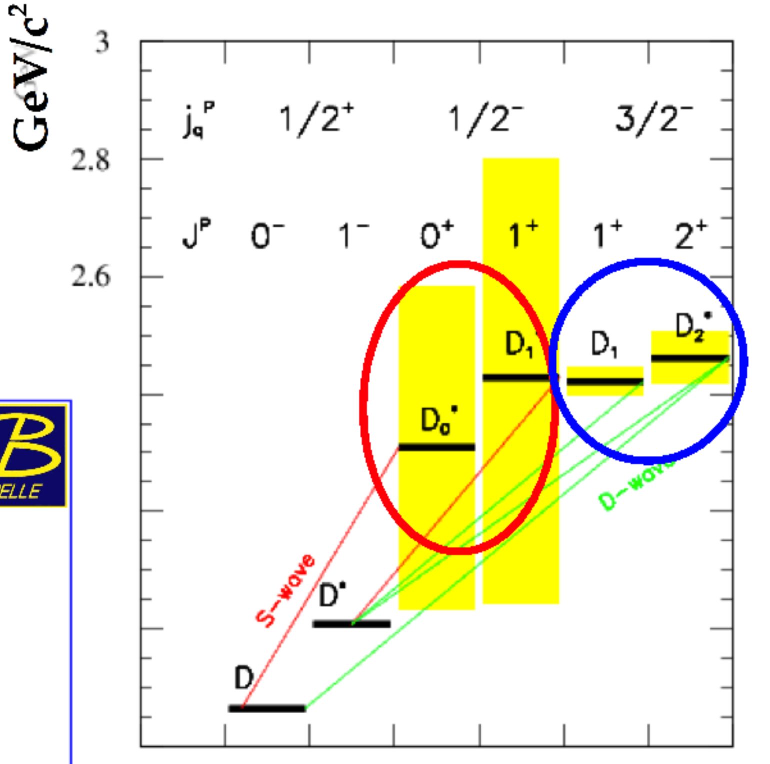
$B(X_c\ell\nu) \sim 10.5\%$

!!!!!!!!!



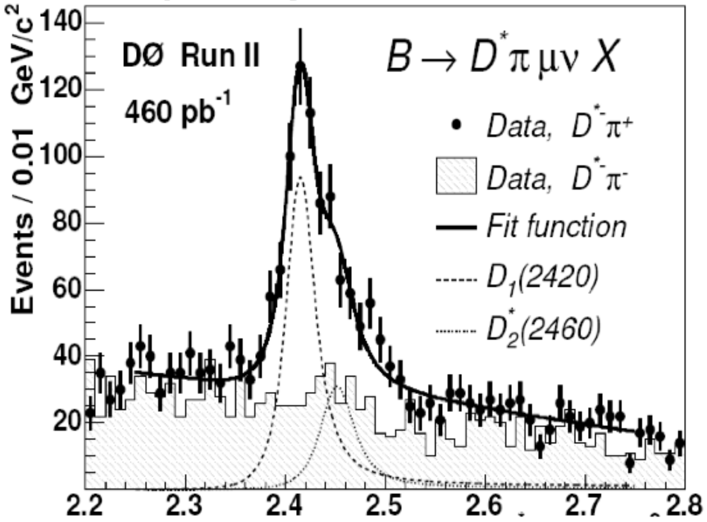
Spectroscopy of excited D mesons

- Use D** as nickname for states $D^{(*)}(n\pi)$ with n>0 including:
  - Narrow resonances D_1, D_2^*
  - Broad resonances D_0^*, D_1'
  - Non-resonant?
- Need help from hadronic B → D**π to characterize D** broad states



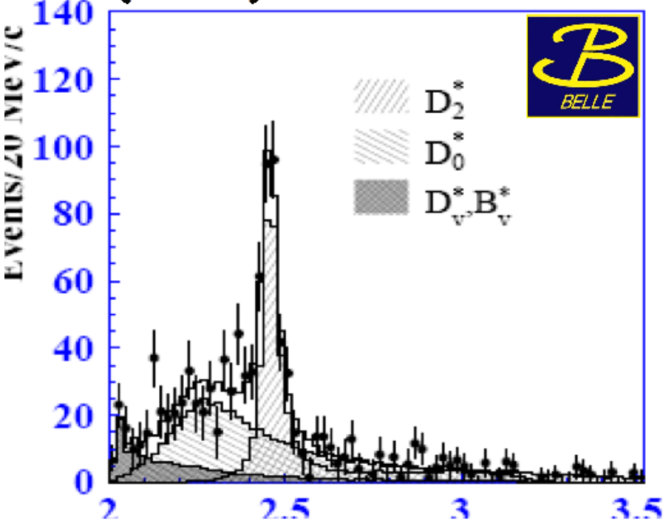
Charm States

Abazov et al, PRL 95 (2005) 171803



D*π Invariant Mass [GeV/c²]

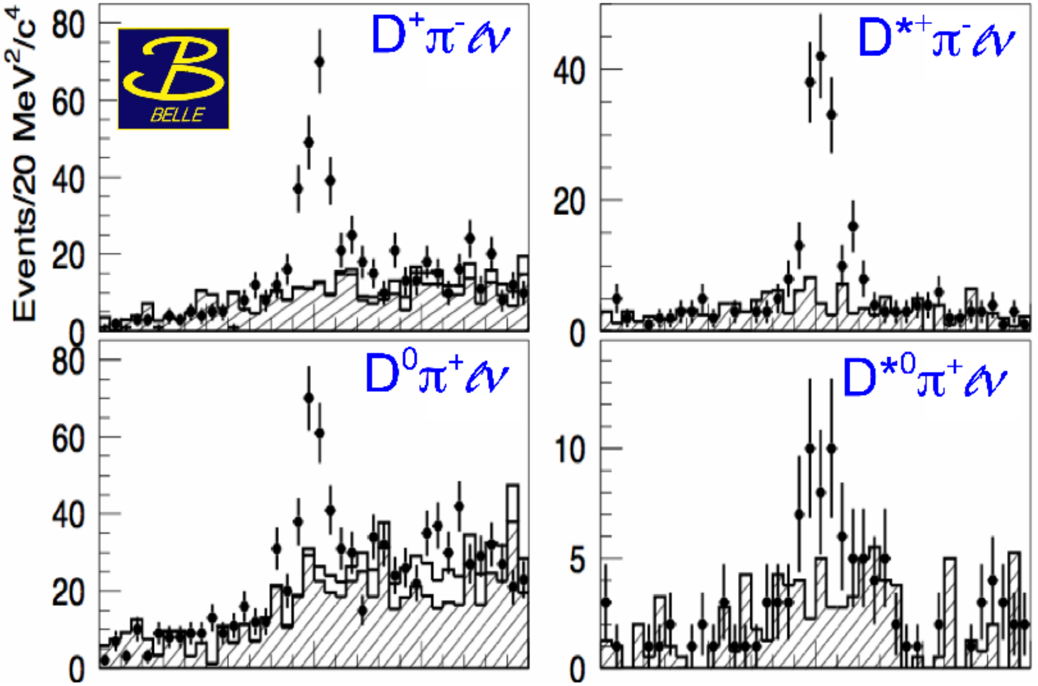
Abe et al, PRD 69 (2004) 112002



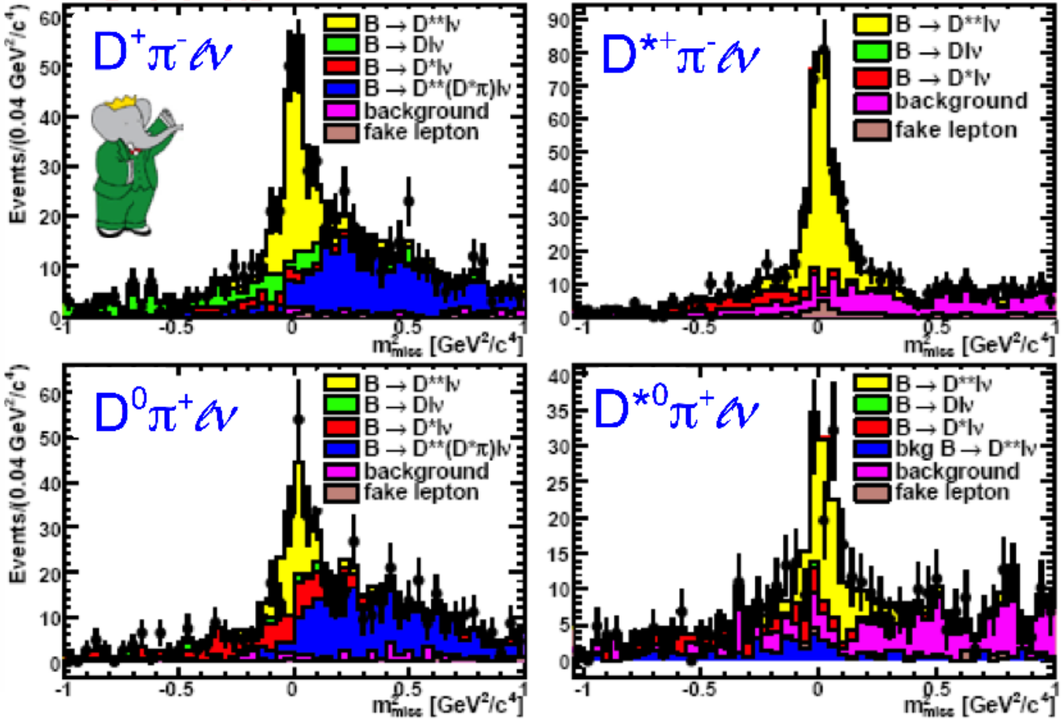
Dπ Invariant Mass [GeV/c²]

$B \rightarrow D^{(*)}\pi\ell\nu$ Branching Fractions

605 fb^{-1} PRD 77: 091503 (2008)



341 fb^{-1} PRL 100: 151802 (2008)



- Clean samples of B → $D^{(*)}\pi\ell\nu$ events in both BaBar and Belle analysis, similar techniques and excellent agreement in the measurement of branching fractions

HFAG 2010

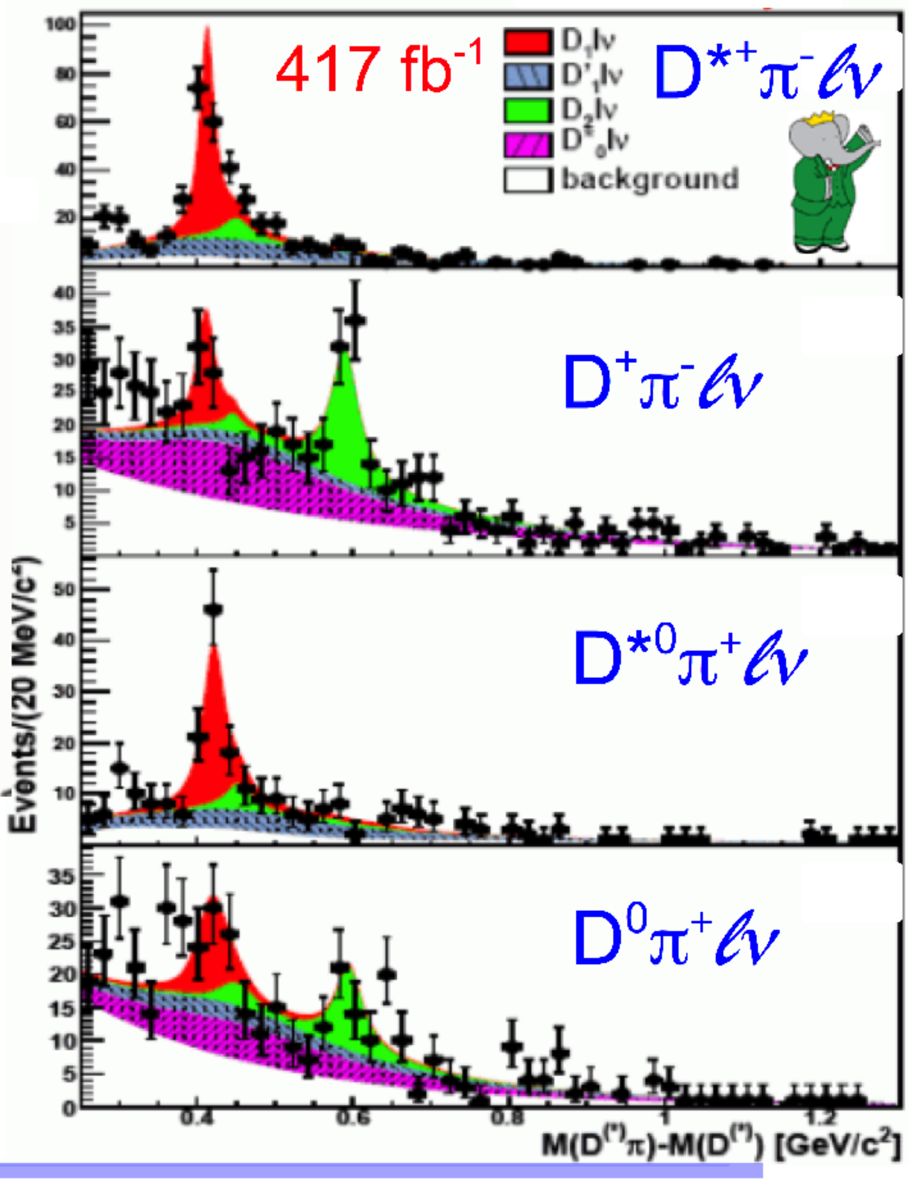
$$\mathcal{B}(B^- \rightarrow D^{(*)+}\pi\ell^-\bar{\nu}_\ell) = (1.55 \pm 0.10)\%$$

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{(*)0}\pi\ell^-\bar{\nu}_\ell) = (1.38 \pm 0.14)\%$$

$B \to D^{**}\ell\nu$ (BaBar)

- Reconstruct $B \to D^{(*)}\pi^{\pm}\ell\nu$ in events tagged by hadronic B
- Simultaneous fit to $M(D^{(*)}\pi)$-$M(D^{(*)})$, including cross-feed
- Background yield constrained from fit to m_{ES}, shape checked on wrong-sign data combinations
- Large rate for broad states!!

PRL 101,261802(2008)

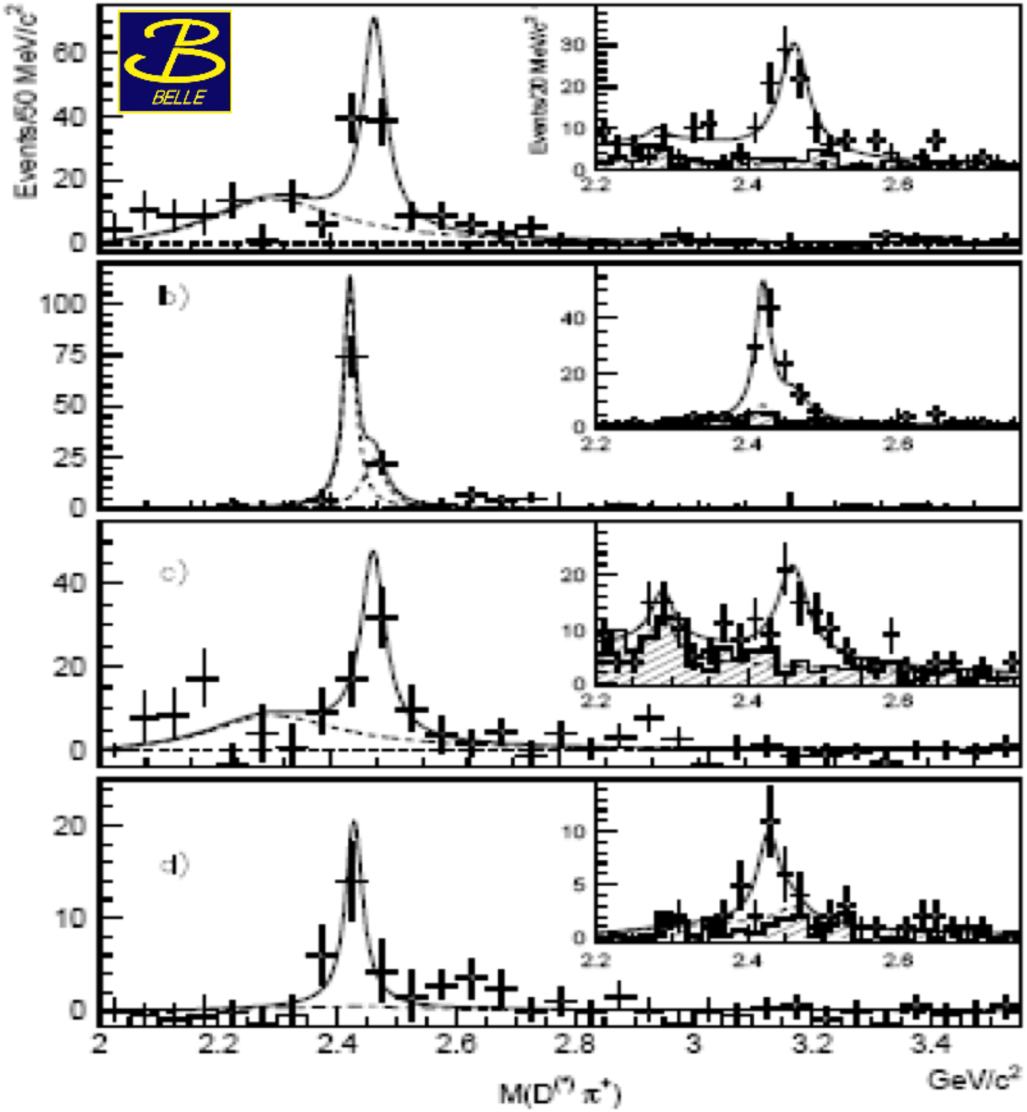


$B \to D^{**}\ell\nu$ (Belle)

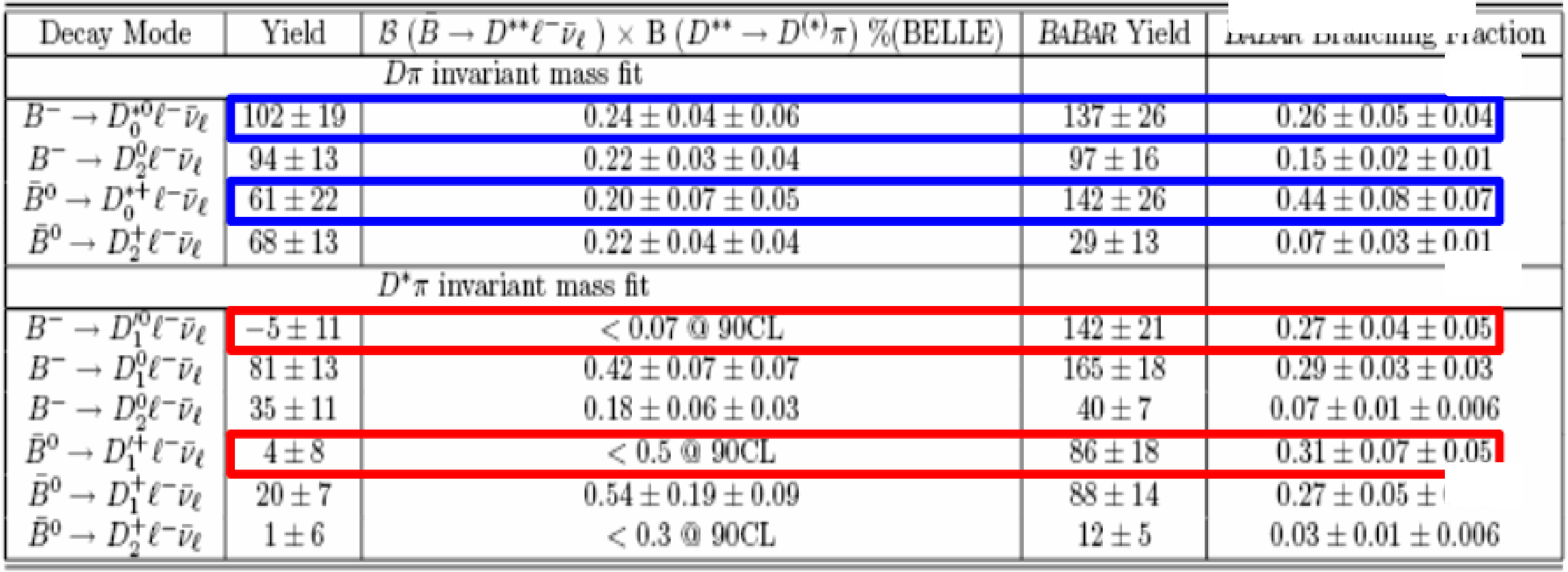
ArXiv:0711.3252 [hep-ex], PR D77,091503(2008)

605 fb^{-1}

- Hadronic tag analysis from Belle
- Similar technique to BaBar, independent fits for different final states
- Confirm signals for narrow D_1 and D_2, sees only broad D_0^*, no D_1'



Comparison BaBar-Belle

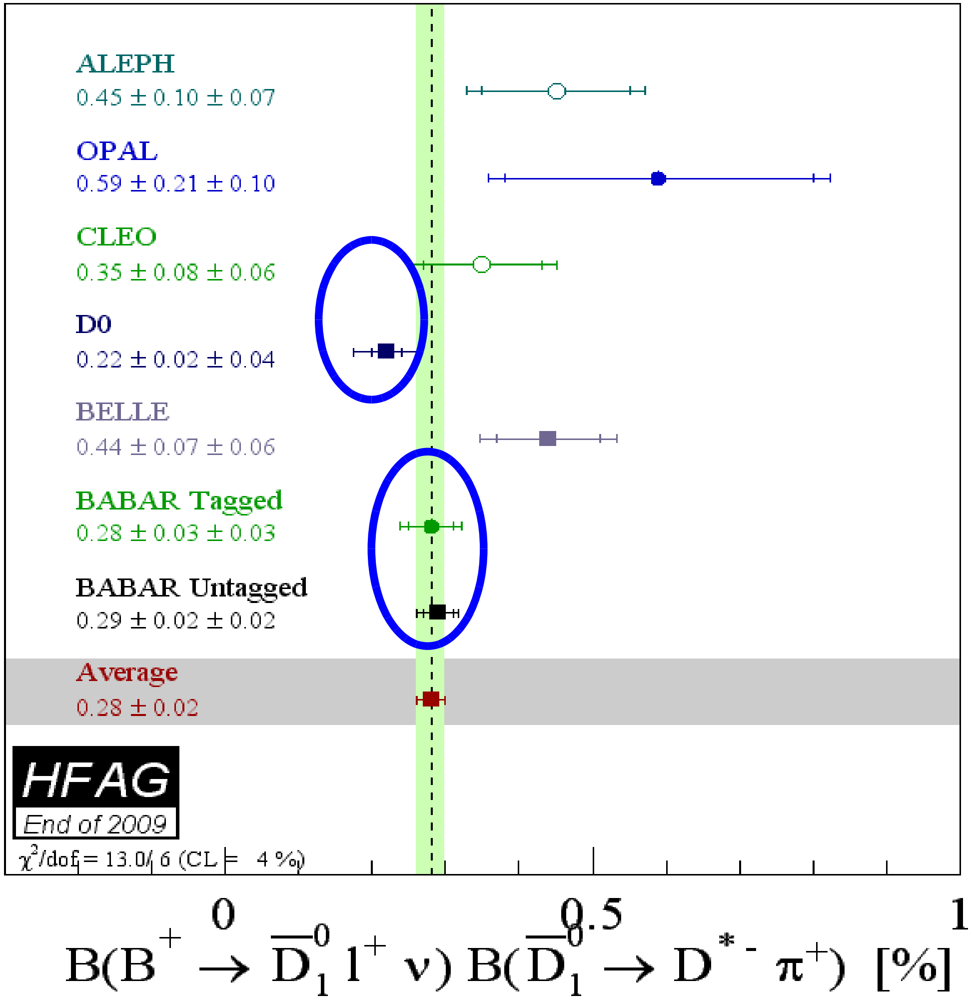


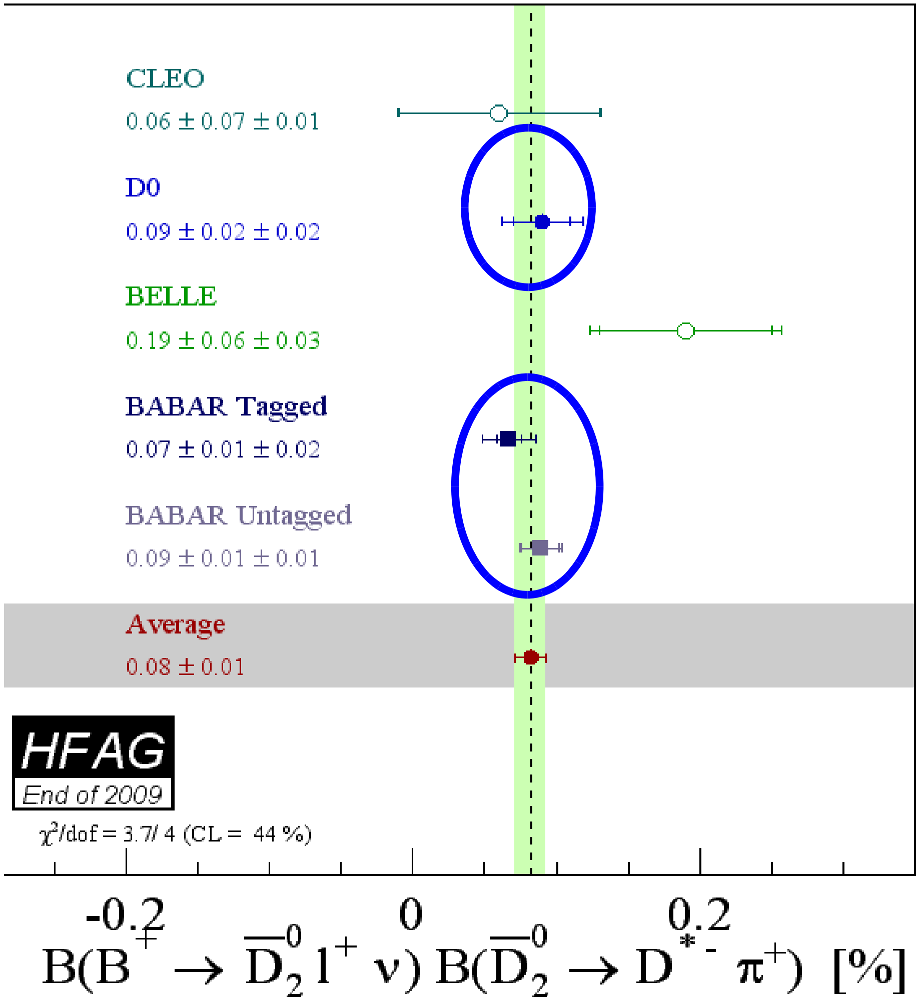
Decay Mode	Yield	$\mathcal{B}(\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell) \times \mathrm{B}(D^{**} \to D^{(*)}\pi)$ %(BELLE)	BABAR Yield	BABAR Branching Fraction
		$D\pi$ invariant mass fit		
$B^- \to D_0^{*0}\ell^-\bar{\nu}_\ell$	102 ± 19	$0.24 \pm 0.04 \pm 0.06$	137 ± 26	$0.26 \pm 0.05 \pm 0.04$
$B^- \to D_2^0\ell^-\bar{\nu}_\ell$	94 ± 13	$0.22 \pm 0.03 \pm 0.04$	97 ± 16	$0.15 \pm 0.02 \pm 0.01$
$\bar{B}^0 \to D_0^{*+}\ell^-\bar{\nu}_\ell$	61 ± 22	$0.20 \pm 0.07 \pm 0.05$	142 ± 26	$0.44 \pm 0.08 \pm 0.07$
$\bar{B}^0 \to D_2^+\ell^-\bar{\nu}_\ell$	68 ± 13	$0.22 \pm 0.04 \pm 0.04$	29 ± 13	$0.07 \pm 0.03 \pm 0.01$
		$D^*\pi$ invariant mass fit		
$B^- \to D_1^{\prime 0}\ell^-\bar{\nu}_\ell$	-5 ± 11	< 0.07 @ 90CL	142 ± 21	$0.27 \pm 0.04 \pm 0.05$
$B^- \to D_1^0\ell^-\bar{\nu}_\ell$	81 ± 13	$0.42 \pm 0.07 \pm 0.07$	165 ± 18	$0.29 \pm 0.03 \pm 0.03$
$B^- \to D_2^0\ell^-\bar{\nu}_\ell$	35 ± 11	$0.18 \pm 0.06 \pm 0.03$	40 ± 7	$0.07 \pm 0.01 \pm 0.006$
$\bar{B}^0 \to D_1^{\prime +}\ell^-\bar{\nu}_\ell$	4 ± 8	< 0.5 @ 90CL	86 ± 18	$0.31 \pm 0.07 \pm 0.05$
$\bar{B}^0 \to D_1^+\ell^-\bar{\nu}_\ell$	20 ± 7	$0.54 \pm 0.19 \pm 0.09$	88 ± 14	$0.27 \pm 0.05 \pm$
$\bar{B}^0 \to D_2^+\ell^-\bar{\nu}_\ell$	1 ± 6	< 0.3 @ 90CL	12 ± 5	$0.03 \pm 0.01 \pm 0.006$

- Result for the D_0^* broad state consistent between BaBar and BELLE
- BaBar observes the D_1', not present in the BELLE data
- Narrow D** results consistent with preliminary untagged BaBar results and D0 measurement (PRL 95, 171803 (2005)).

PRL 103,051803(2009)

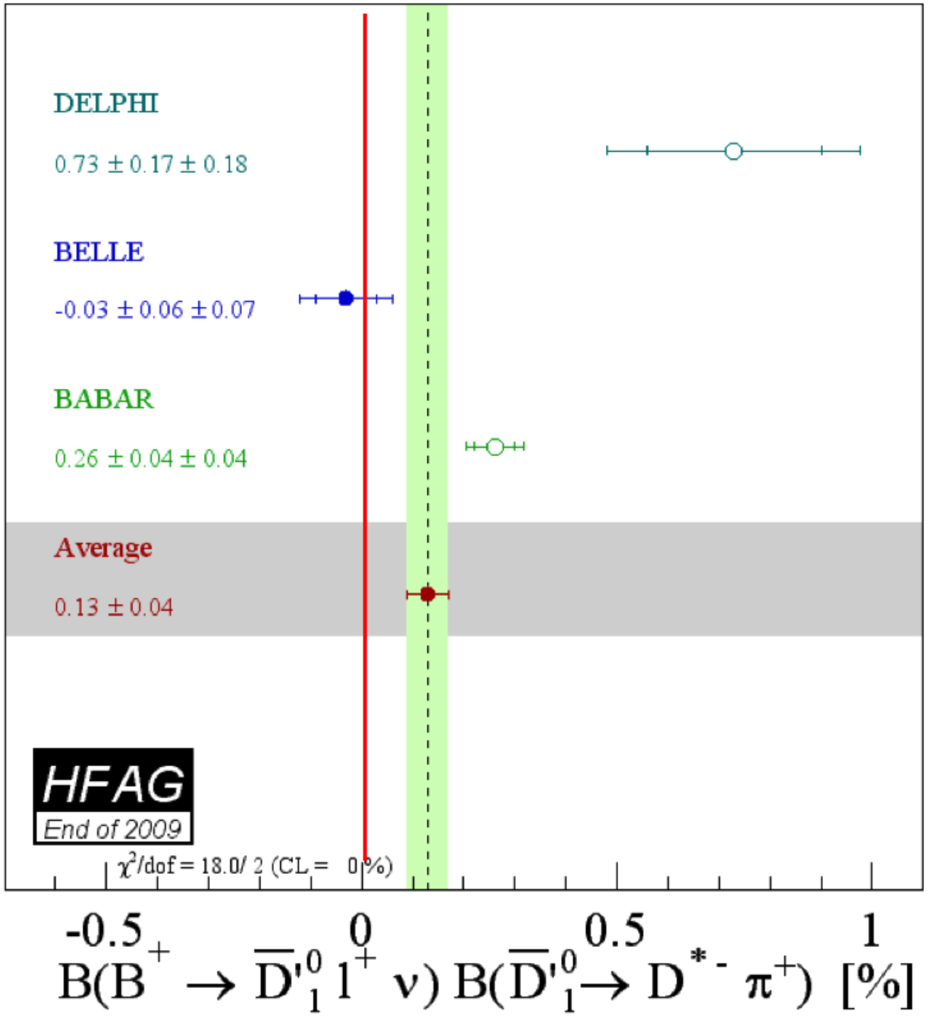
Consistency: the big Picture

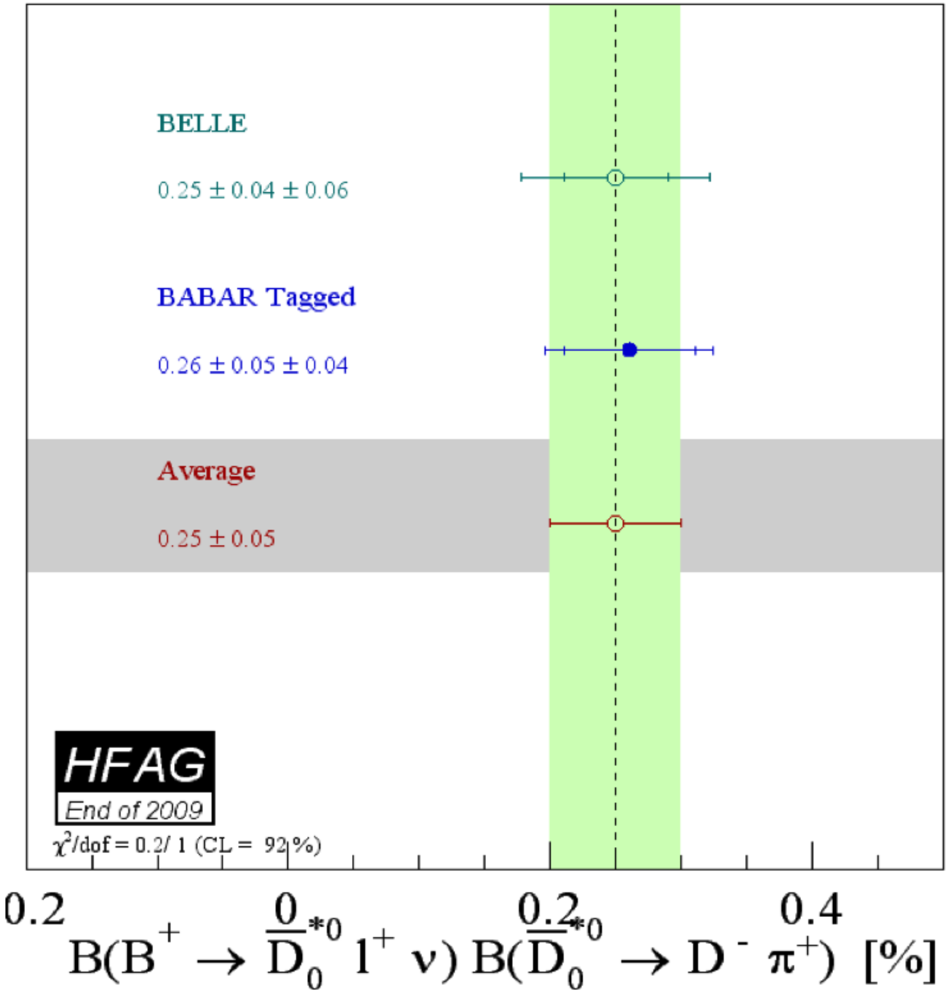




- Excellent agreement of the most precise measurements, in particular the tagged and untagged Babar analysis

Consistency: the big Picture





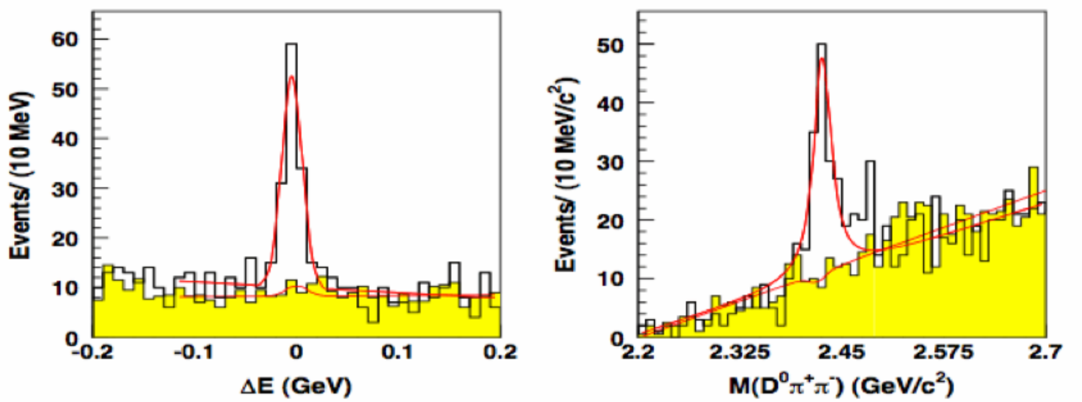
- Situation more complicated for the broad states.....

Comments

- BaBar and Belle measure $\mathcal{B}(B \rightarrow D^{(*)}\pi\ell\nu) \sim 1.5\%$
- About 0.6% of this rate is due to the narrow D_1 and D_2 states
- What is the rest?
- BaBar measures about 0.9% for the broad states
  Belle agrees for the D_0^*, while it sets a very stringent upper limit for the D_1'
- We are left with 2 puzzles:
- The broad rate is in contrast with theoretical predictions (3/2 vs 1/2 puzzle, see backup)
- What is the difference between the inclusive rate and the Σ Excl($D/D^*/D^{(*)}\pi\ell\nu$)?

On the Incl-Σ Excl puzzle

- The most likely candidate to fill the inclusive rate is $B \to D^{(*)} n\pi\ell\nu$,with n>1:
- We have already evidence for $D^{**} \to D\pi\pi$ decays, Belle PRL 94, 221805 (2005)

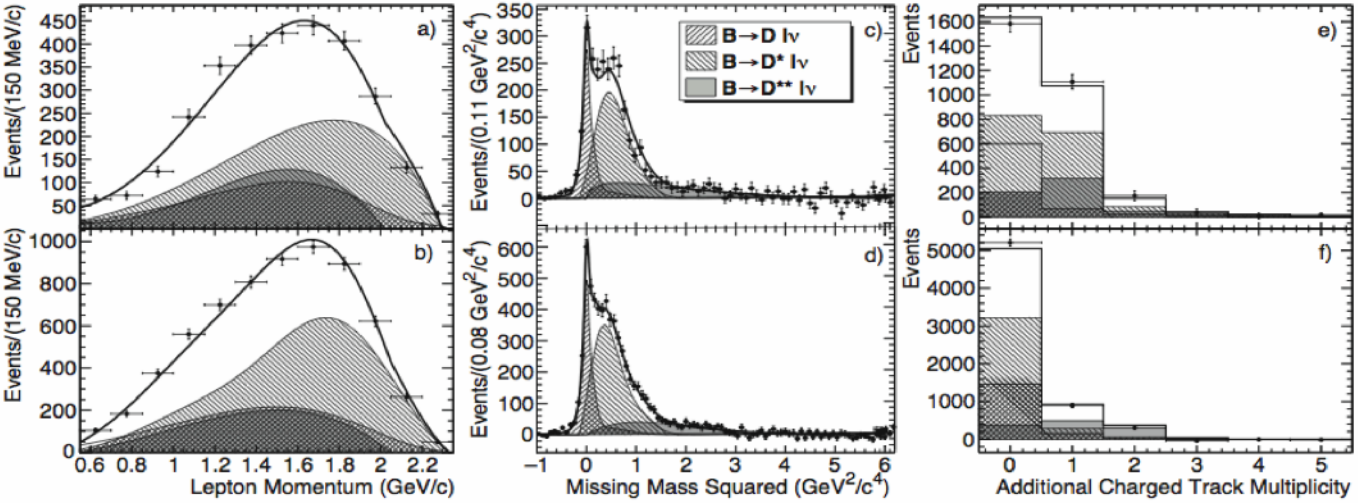


- BaBar measured the relative branching fraction

$\mathcal{B}(B \to D^{(*}(n\pi)\ell\nu)/$

$\mathcal{B}(B \to DX\ell\nu)$=0.197 ± 0.013 ± 0.013 ± 0.012,

PR D76, 051101 (2007)



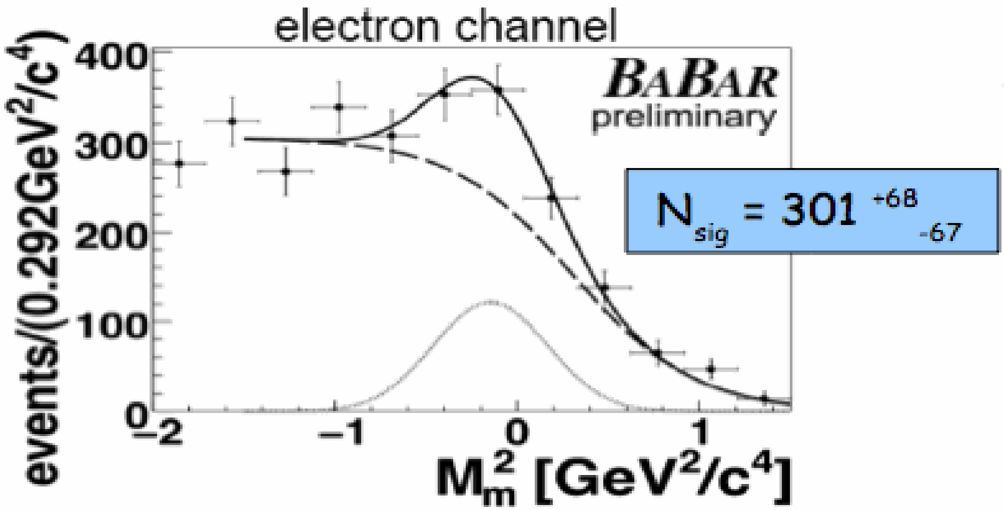
On the Incl-Σ Excl puzzle

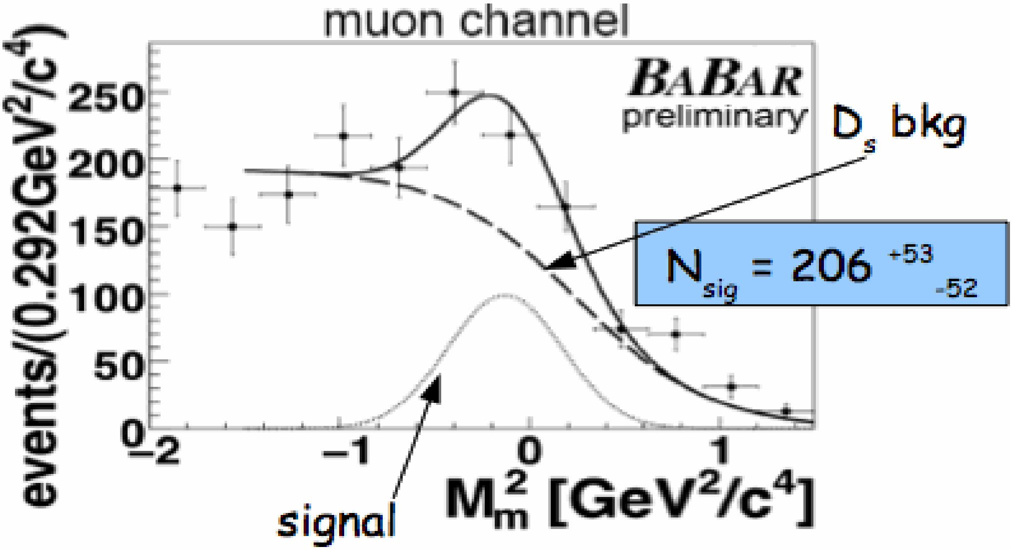
- How likely is that we will observe $B \rightarrow D^{(*)}\pi\pi\ell\nu$ decays?
- The hadronic tag is the most obvious choice
- Challenging however, high multiplicity on the SL side affects hadronic tag selection/purity
- If we assume a rate of 0.2% for $B \rightarrow D_{1,2}\ell\nu$, $D_{1,2} \rightarrow D^{(*)}\pi\pi$, we should see ~ tens of events in the full Belle dataset
- BaBar has a new hadronic tag algorithm, expect about >2x improvement in signal yield w.r.t. previous BaBar tagged analysis

Observation of $B \to D_s K \ell \nu$

- Signal yields extracted via unbinned extended maximum likelihood fit to Missing mass

$$M_m^2 = (E_{beam} - E_Y)^2 - |\vec{p}_Y|^2 = m_\nu^2 \qquad Y = D_s K\ell \text{ candidate}$$





- leading systematic uncertainty: signal MC modelling (~3%- 8% depending on channel) Signal MC statistics (~2%)

342 fb^{-1}

$$\mathcal{B}(B \to D_s^+ K^- \ell^- \bar{\nu}_\ell) = (6.13^{+1.04}_{-1.03} stat. \pm 0.43_{syst.} \pm 0.51(\mathcal{B}(D_s))) \times 10^{-4}$$

- Result in agreement with ARGUS measurement: $\mathcal{B}(B \to D_s^+ K^- \ell^- \bar{\nu}_\ell) < 5 \times 10^{-3}$
- BR too small to solve the BR puzzle

Conclusions

- Despite many years of measurements, puzzles in $B \rightarrow D^{(*,**)}\ell\nu$ remain
  - Branching fraction?
  - $|V_{cb}|$ and FF averages
  - Large rate for the broad components
  - Large difference between the BaBar and Belle results
  - Role of $D \rightarrow D^{(*)}\pi\pi$ decays
- $B \rightarrow D\ell\nu$ had a slow start, but can be potentially extremely interesting
  - We need unquenched lattice determinations of $G(w)$, $w=1$, $w>1$
- It is worth!!
  - $|V_{cb}|$ measurement is a B-factory legacy!!!

$$|V_{cb}| = (41.5 \pm 0.7) \times 10^{-3} \text{ (inclusive)}$$

$$|V_{cb}| = (38.7 \pm 1.1) \times 10^{-3} \text{ (exclusive)}$$

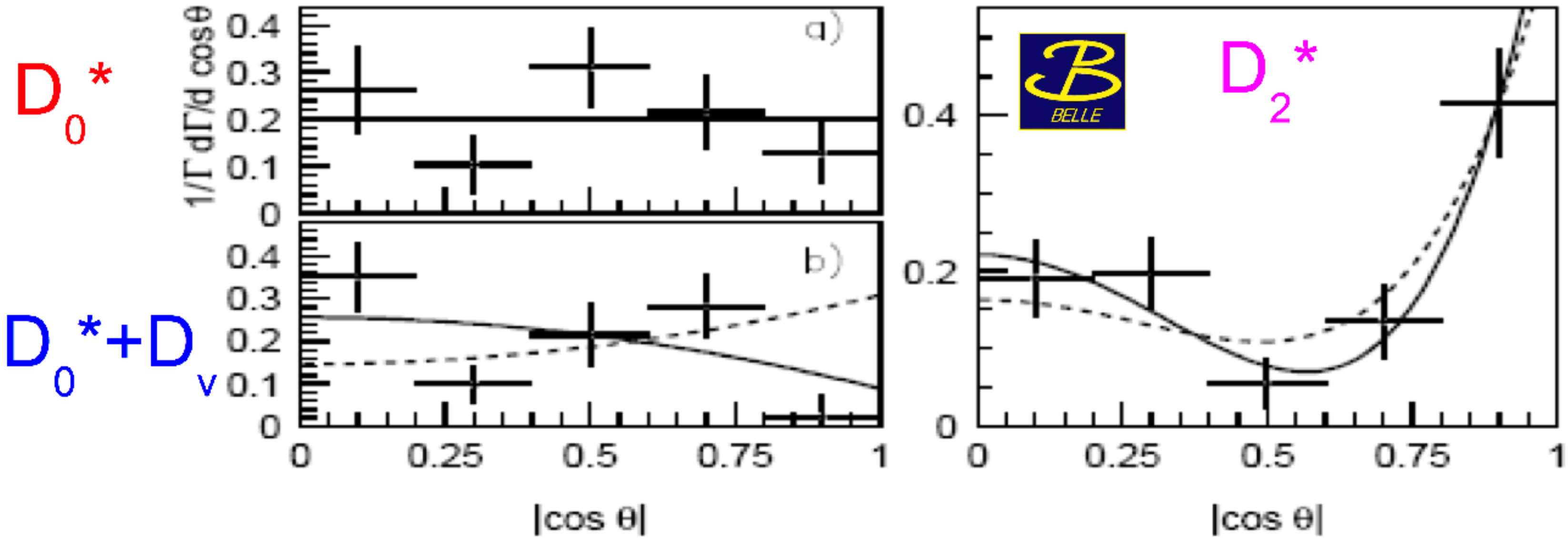
Backup Slides

On the 3/2 vs 1/2 puzzle

- Both Babar and Belle include the possibility for a non-resonant $D^{(*)}$ component, finding a rate consistent with zero
- A study of the helicity distribution can be used to confirm/not if the fitted "broad" component is consistent with the expected quantum numbers

  Belle only reports the helicity study for the $D_2(D\pi)$ and $D_0^*(D\pi)$ channels
- Fit of the invariant mass in helicity bins; fit |**hely**| with theoretical shapes for tensor and scalar states

  Confirm predictions for these two states



Theory – dashed line

D_v -- virtual D* produced off-shell

On the 3/2 vs 1/2 puzzle

- The helicity distributions can help in confirm the nature of the measured "broad" states, but current statistics is a problem
- It was also suggested (I. Bigi) that the measured broad states are radial excitations (p-wave)
- Also in this case, an helicity study could help, but statistics may be a limiting factor also for the full dataset/final measurement from BaBar and Belle

HFAG averages: Comments

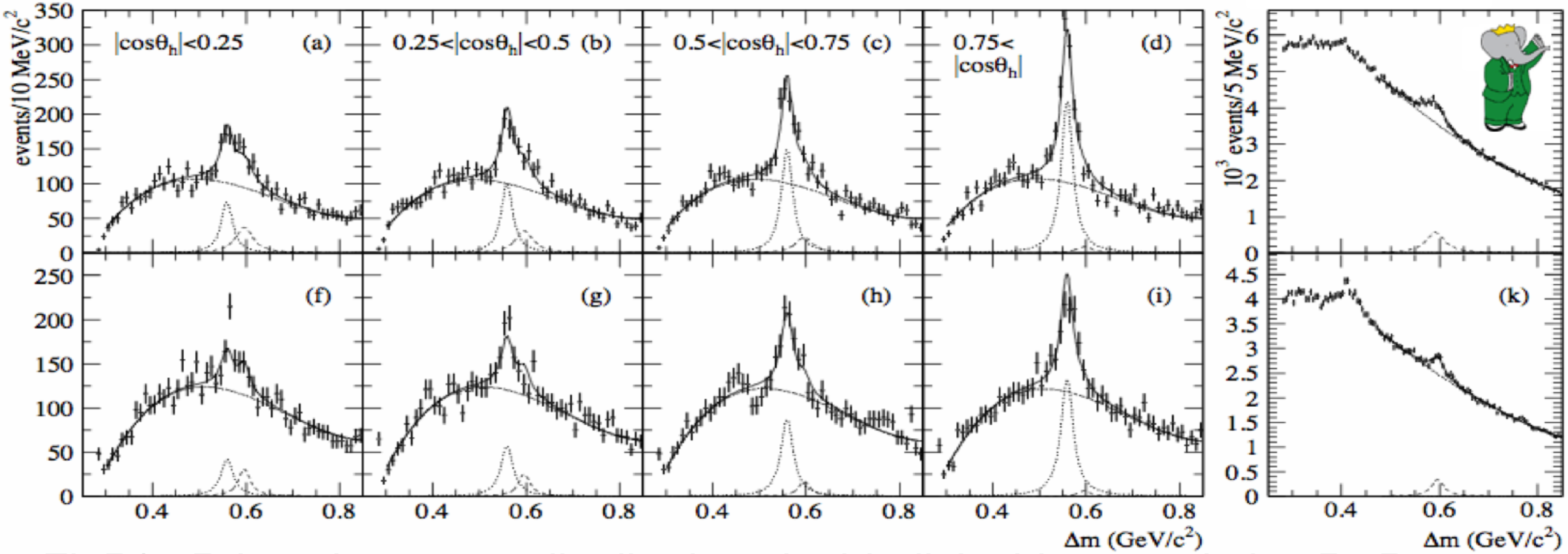
HFAG average for $|V_{cb}|$ from $B \to D^{*}\ell\nu$ very challenging (measurements from almost 2 decades, very different assumptions: FF, BF etc.)

historically affected by very low chi2 due to large spread of measurements

Subtle bug discovered, chi2 improved, but still low (especially adding latest, very precise, measurements)

$B \rightarrow D^{**}\ell\nu$ (Narrow States, BaBar)

ArXiv:0808.0333 [hep-ex], PRL 103,051803(2009)



Fit D*π-D invariant mass distributions in 4 helicity bins, maximize D_1-D_2 separation, also measure $\mathcal{B}(D_1 \rightarrow D\pi)/\mathcal{B}(D_1 \rightarrow D^*\pi)$ and D_1 polarization

$$\begin{aligned}
\mathcal{B}(B^+ \to D_1^0\ell^+\nu_\ell) \times \mathcal{B}(D_1^0 \to D^{*+}\pi^-) &= (2.97 \pm 0.17_{\rm stat} \pm 0.17_{\rm syst}) \times 10^{-3},\\
\mathcal{B}(B^+ \to D_2^{*0}\ell^+\nu_\ell) \times \mathcal{B}(D_2^{*0} \to D^{(*)+}\pi^-) &= (2.29 \pm 0.23_{\rm stat} \pm 0.21_{\rm syst}) \times 10^{-3},\\
\mathcal{B}(B^0 \to D_1^-\ell^+\nu_\ell) \times \mathcal{B}(D_1^- \to D^{*0}\pi^-) &= (2.78 \pm 0.24_{\rm stat} \pm 0.25_{\rm syst}) \times 10^{-3},\\
\mathcal{B}(B^0 \to D_2^{*-}\ell^+\nu_\ell) \times \mathcal{B}(D_2^{*-} \to D^{(*)0}\pi^-) &= (1.77 \pm 0.26_{\rm stat} \pm 0.11_{\rm syst}) \times 10^{-3}.
\end{aligned}$$

Observation of $B \to D_s K \ell \nu$

- Exclusive reconstruction

$$D_s \to \phi(K^+K^-)\pi$$
$$D_s \to \bar{K}^{*0}(K^\pm\pi^\mp)K$$
$$D_s \to K^0_s(\pi^+\pi^-)K$$

Feed Forward NN to suppress combinatorial bkg.

- lepton (p_{lep} > 0.8 GeV/c) and Kaon added to D_s candidate
- Bkg from B→DD_s reduced using angular correlation between D_s and D (signal events no correlation)

~30% of D_s bkg rejected