Lattice Meets Experiment Workshop 2010

FNAL, April 26-27

Experimental Status of Semileptonic B Decays $|V_{cb}|$ & $|V_{ub}|$

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

- Differential decay rate:

$$\frac{d\Gamma}{dw}(B\to D\ell\nu) \propto (\text{PhaseSpace})\,|V_{cb}|^2\,G(w)^2 \qquad w=\frac{m_B^2+m_D^2-q^2}{2m_Bm_D}$$

$$\frac{d\Gamma}{dw}(B\to D^*\ell\nu) \propto (\text{PhaseSpace})\,|V_{cb}|^2\,F(w)^2 \sum_{i=+,0,-}|H_i(w)|^2$$

- All recent measurements have adopted the Form factor ansatz by Caprini et al.

$$G(w) = G(1)[1-8\rho^2 z+(51\rho^2-10)z^2-(252\rho^2-84)z^3] \qquad z=\frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w-1}+\sqrt{2}}$$

$$F(w) = \ldots$$

From Experiment

$|V_{cb}| \times FF(w=1)$

FF parameters:
ρ_D for D, ρ_{D^*}, R_1, R_2 for D^*

From Lattice

G(1) = 1.074 ± 0.024 (error ~2.2%)
Okamoto et al., NPPS 140, 461 (2005)

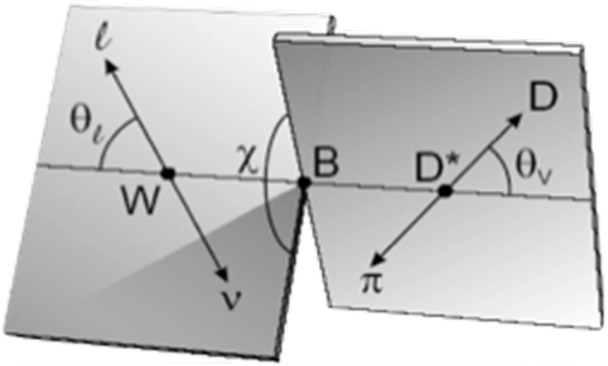
F(1) = 0.921 ± 0.024 (error ~2.6%)
C. Bernard et al., Phys. Rev. D79, 014506 (2009)

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

arXiv: 0810.1657 [hep-ex]

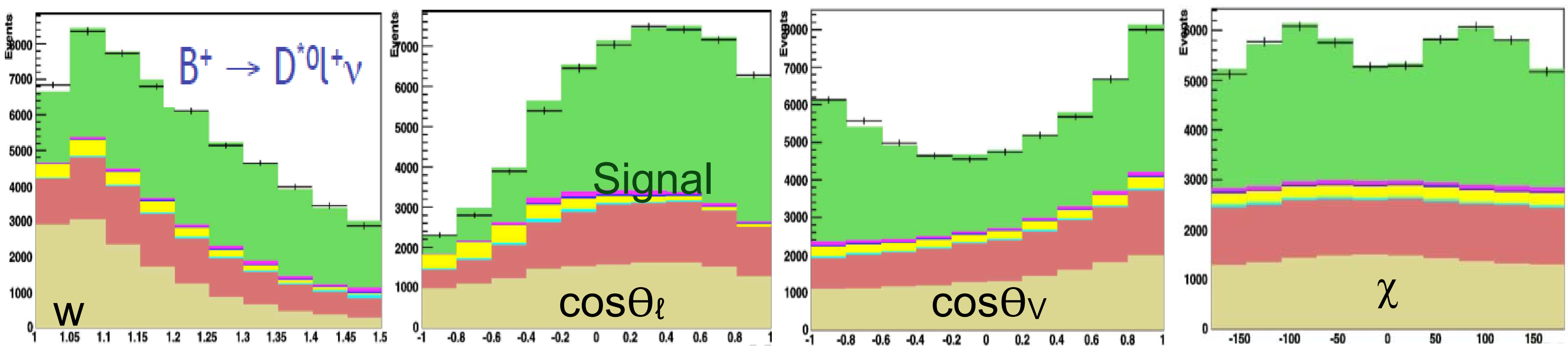
Belle preliminary, EPS09

- Study charged and neutral B decays:
  - $B^0 \to D^{*-}\ell^+\nu$, $D^{*-} \to D^0\pi^-_{soft}$
  - $B^+ \to D^{*0}\ell^+\nu$, $D^{*0} \to D^0\pi^0_{soft}$



- Fit to projections in w and decay angles θ_ℓ, θ_V, χ

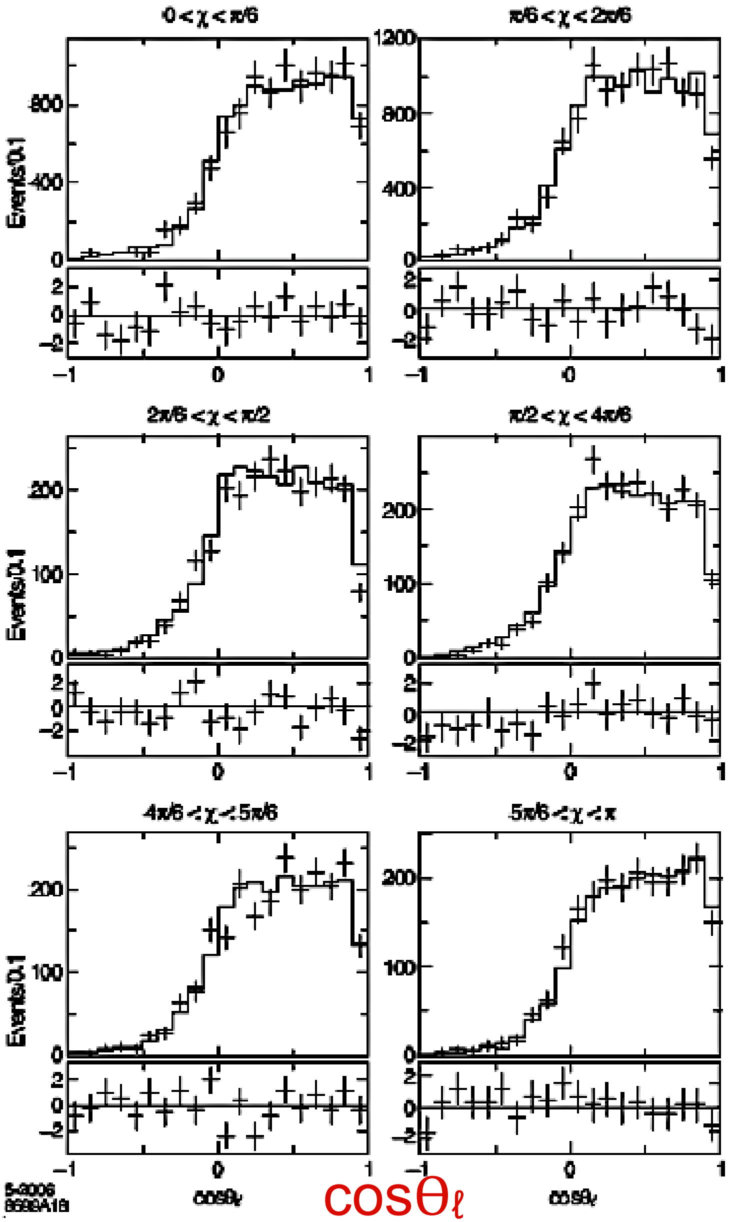
	$B^0 \to D^{*-}\ell\nu$	$B^+ \to \bar{D}^{*0}\ell\nu$
ρ^2	$1.293 \pm 0.045 \pm 0.029$	$1.376 \pm 0.074 \pm 0.056$
$\mathcal{B}(B \to D^*\ell^+\nu_\ell)$	$(4.42 \pm 0.03 \pm 0.25)\%$	$(4.84 \pm 0.04 \pm 0.56)\%$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert \times 10^3$	$34.4 \pm 0.2 \pm 1.0$	$35.0 \pm 0.4 \pm 2.2$
$\chi^2/\text{n.d.f.}$	$138.8/155$	$187.8/155$
error on $F(1)\lvert V_{cb}\rvert$	~3%	~6%



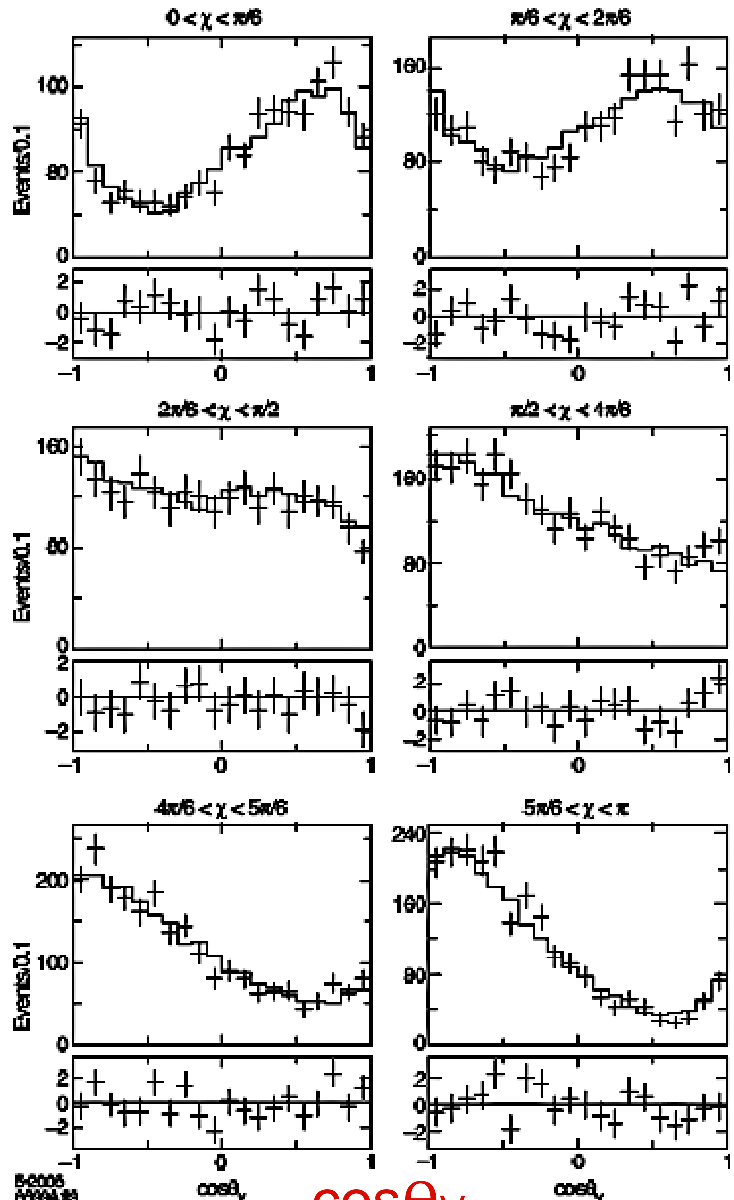
B→D*ℓν (BaBar)

Phys. Rev. D74:092004 (2006)

Full 4-dim fit to *w*, cosθ$_\ell$, cosθ$_{V}$,χ ⇒ sensitivity to interference effects



cosθ$_\ell$



cosθ$_V$

Projections for background subtracted data compared to fit result, for different intervals in χ;

Increased sensitivity to relative size of helicity terms: R1 and R2!

15,000 Events

Simultaneous B→D/D*ℓν (BaBar)

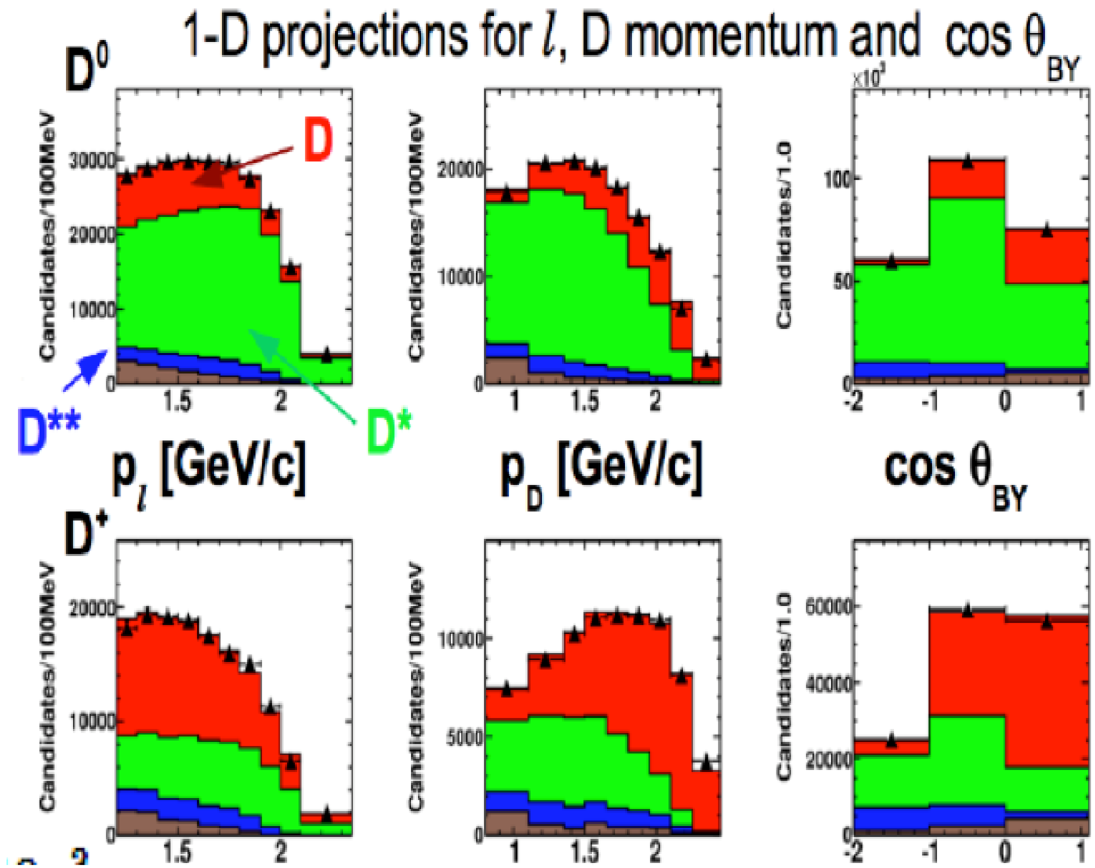
Phys. Rev. D79, 012002 (2009)

- Untagged analysis ("global fit"):
  Select Dℓν and D*ℓν
  (no $\square_{soft}$ reco.!)

- Binned 3D fit to p_ℓ, p_D and $\cos\theta_{BY}$

- Measure Dℓν,D*ℓν rates and
  FF parameters ρ_D, ρ_{D^*} (,R_1, R_2)

- Extract $|V_{cb}|G(1)$, $|V_{cb}|F(1)$



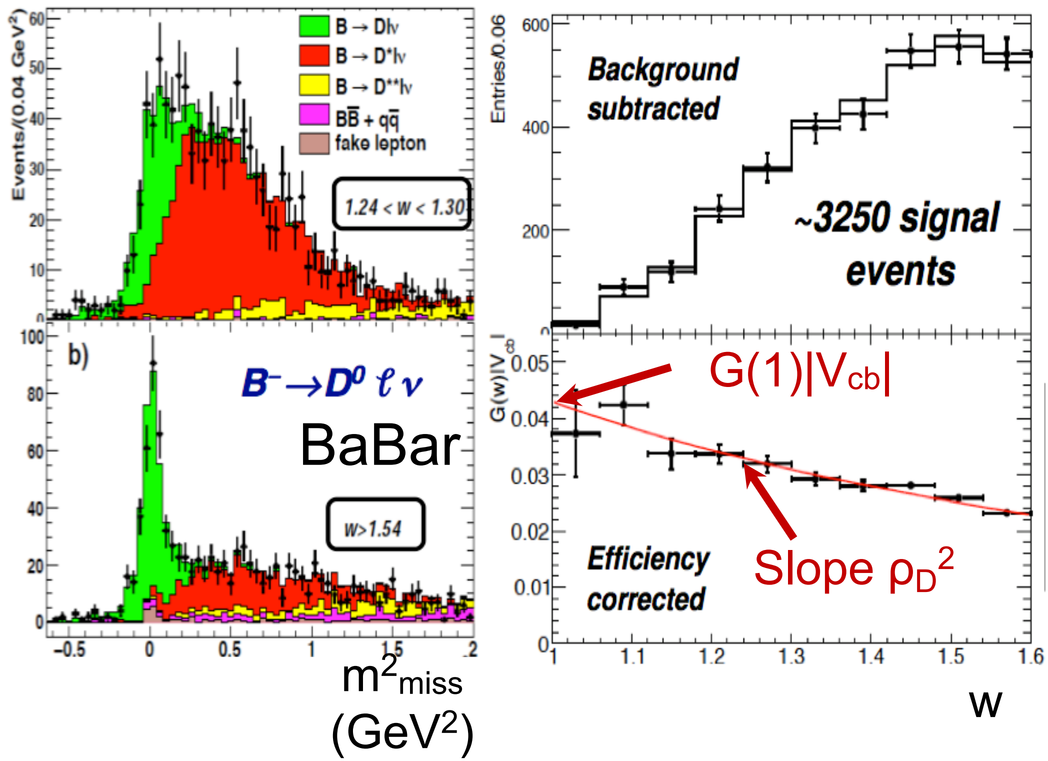
$$\mathcal{G}(1)|V_{cb}| = (43.1 \pm 0.8 \pm 2.3) \times 10^{-3}$$
$$\mathcal{F}(1)|V_{cb}| = (35.9 \pm 0.2 \pm 1.2) \times 10^{-3}$$

B→Dℓν (BaBar)

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

- Hadronic-tag analysis, 3200 Events!

- Extract signal from missing mass in 10 w bins



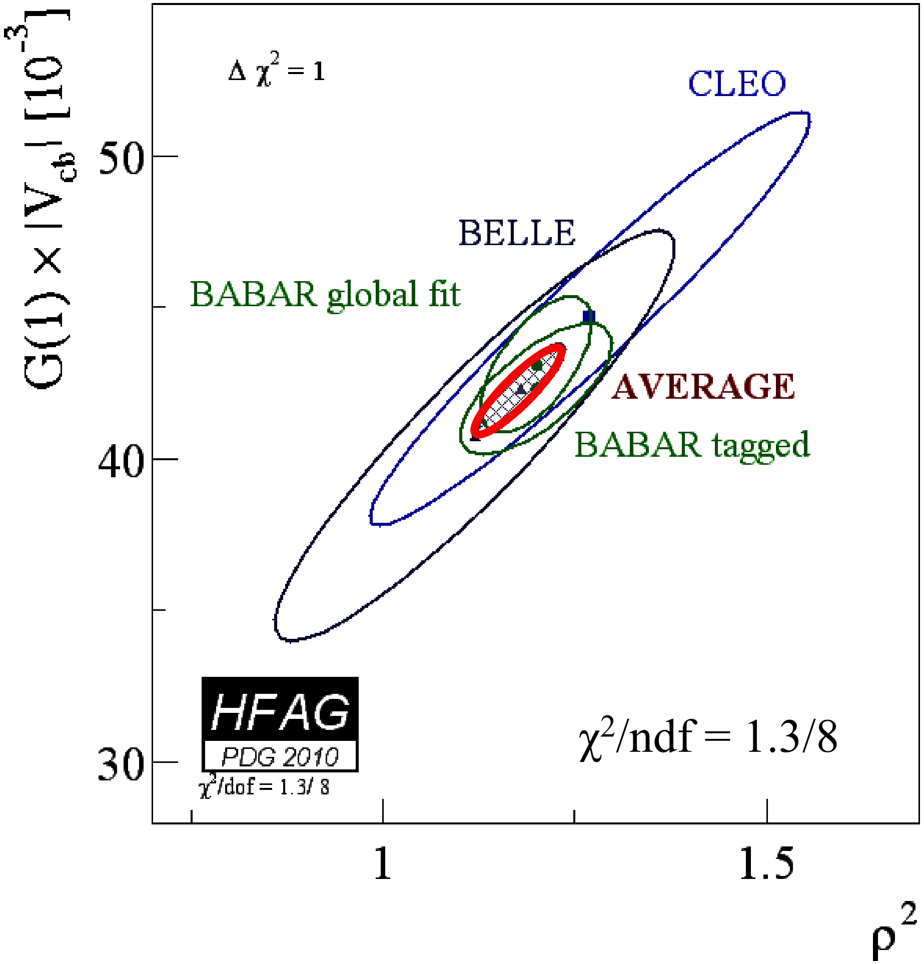
- Combined results of both BaBar B ➡ Dℓν analyses:

$$G(1)|V_{cb}| = (42.4 \pm 0.7 \pm 1.6) \times 10^{-3}$$
$$\rho^2 = 1.18 \pm 0.04 \pm 0.04$$
$$Br(B^0 \to D\ell\nu) = (2.16 \pm 0.08)\%$$

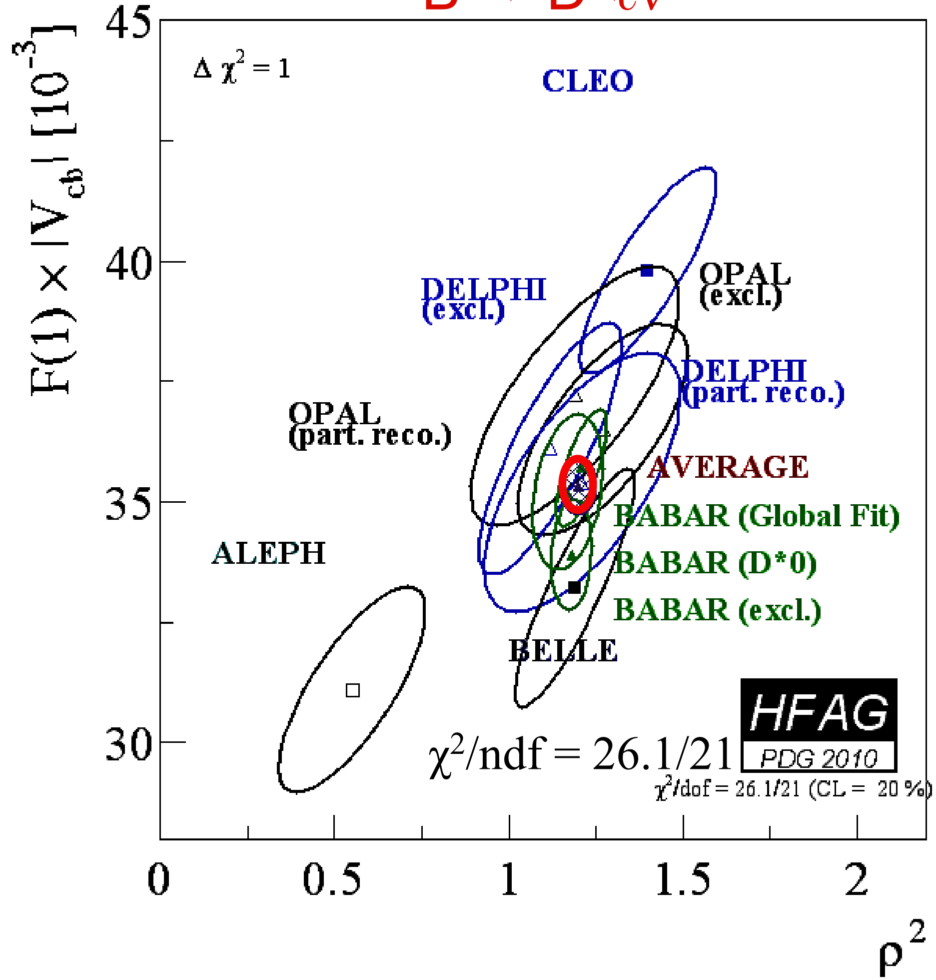
Error on $G(1)|V_{cb}|$ reduced to 4%
(1-2 years ago: >10%)

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

$B \to D\ell\nu$



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



$$B \to D l \nu: \quad |V_{cb}|\,G(1) = (42.3 \pm 0.7 \pm 1.3)\times 10^{-3}$$
$$\Rightarrow \quad |V_{cb}| = (39.4 \pm 1.4(\text{exp}) \pm 0.9(\text{FF}))\times 10^{-3}$$

precision: 4.2%

$$B \to D^* l \nu: \quad |V_{cb}|\,F(1) = (35.33 \pm 0.59)\times 10^{-3}$$
$$\Rightarrow \quad |V_{cb}| = (38.4 \pm 0.6(\text{exp}) \pm 1.0(\text{FF}))\times 10^{-3}$$

precision: 3.0%, agreement not satisfactory

Problem with BF and FF for $B \to X_c \ell \nu$ Decays

- Additional s.l. decays with D** (narrow: D_1, D_2^*, broad D_1', D_0^*)
  - Narrow states agree for Belle (tagged), BaBar (tagged+untagged), D0
  - Broad states not well known: D_0^* agrees for BaBar+Belle, D_1' not seen by Belle
  - Contribution from broad states larger than predicted!
- Sum of $D/D^*/D^{**}\ell\nu$ does not saturate total $B \to X_c \ell \nu$ branching fraction

$$\mathcal{B}(B^0 \to X_c \ell \nu) > \mathcal{B}(B^0 \to D \ell \nu) + \mathcal{B}(B^0 \to D^* \ell \nu) + \mathcal{B}(B^0 \to D^{**} \ell \nu)$$

$$[10.1 \pm 0.4]\% > [2.17 \pm 0.12]\% + [5.16 \pm 0.11]\% + [1\text{-}2]\%$$

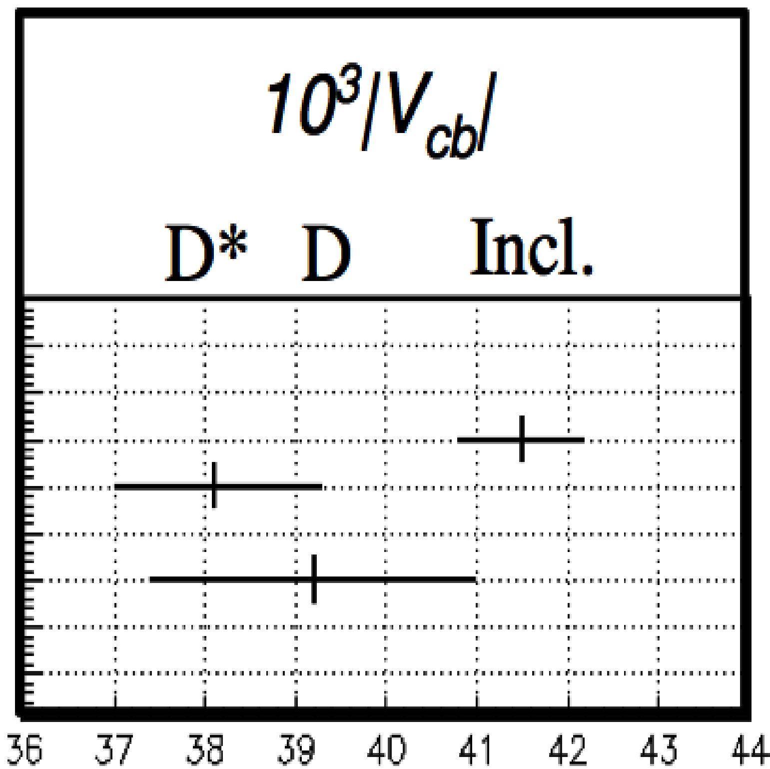
$\Rightarrow$ ~15% missing

- Explanations for missing BF::
  - non-resonant $(D/D^* + n\pi)\ell\nu$ $(n \geq 2)$
  - non-resonant $(D/D^* + \eta)\ell\nu$
  - radial excitations (?)
  - unmeasured D** decay modes (not all D** branching fractions known)?

But: so far no evidence for non-resonant charm states, but sensitivity remains limited

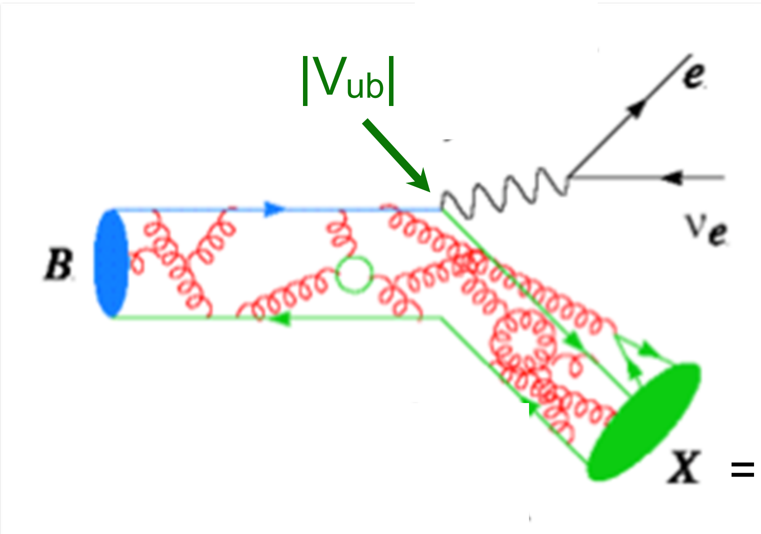
Conclusions for $|V_{cb}|$

- F(1) $|V_{cb}|$ determined by fit over entire w range, requires parameterization!
- Thus $|V_{cb}|$ depends on F(1) from LQCD, and also on FF parametrization!
- Predictions for w>1 from LQCD would reduce uncertainty!
- Desired experimental improvements:
  - Analyses on full B-Factory data sets, e.g. $B\to D\ell\nu$ from Belle (720 fb^{-1})
  - $B\to D^*\ell\nu$ measurement with fit in 4 dimensions, interference terms! higher sensitivity to R_1, R_2, and ρ^2
  - Hadronic-tag measurements at SuperB measurements of D** states



Exclusive $|V_{cb}|$ ~ 2σ lower than inclusive $|V_{cb}|$!

$|V_{ub}|$ from $B\to\pi\ell\nu$



= π,η,η',ρ,ω

$$\frac{d\Gamma}{dq^2}(B\to\pi l\nu) = \frac{G_F^2}{24\pi^3}\, p_\pi^3\, |V_{ub}|^2 |f_+(q^2)|^2$$

- Tagging events via 2nd B decays
  - untagged (with ν econstruction)
  - semileptonic B tags
  - hadronic B tags

Independent samples: different systematic uncertainties

- Form-factor calculations using different methods (LQCD, LCSR, quark models)

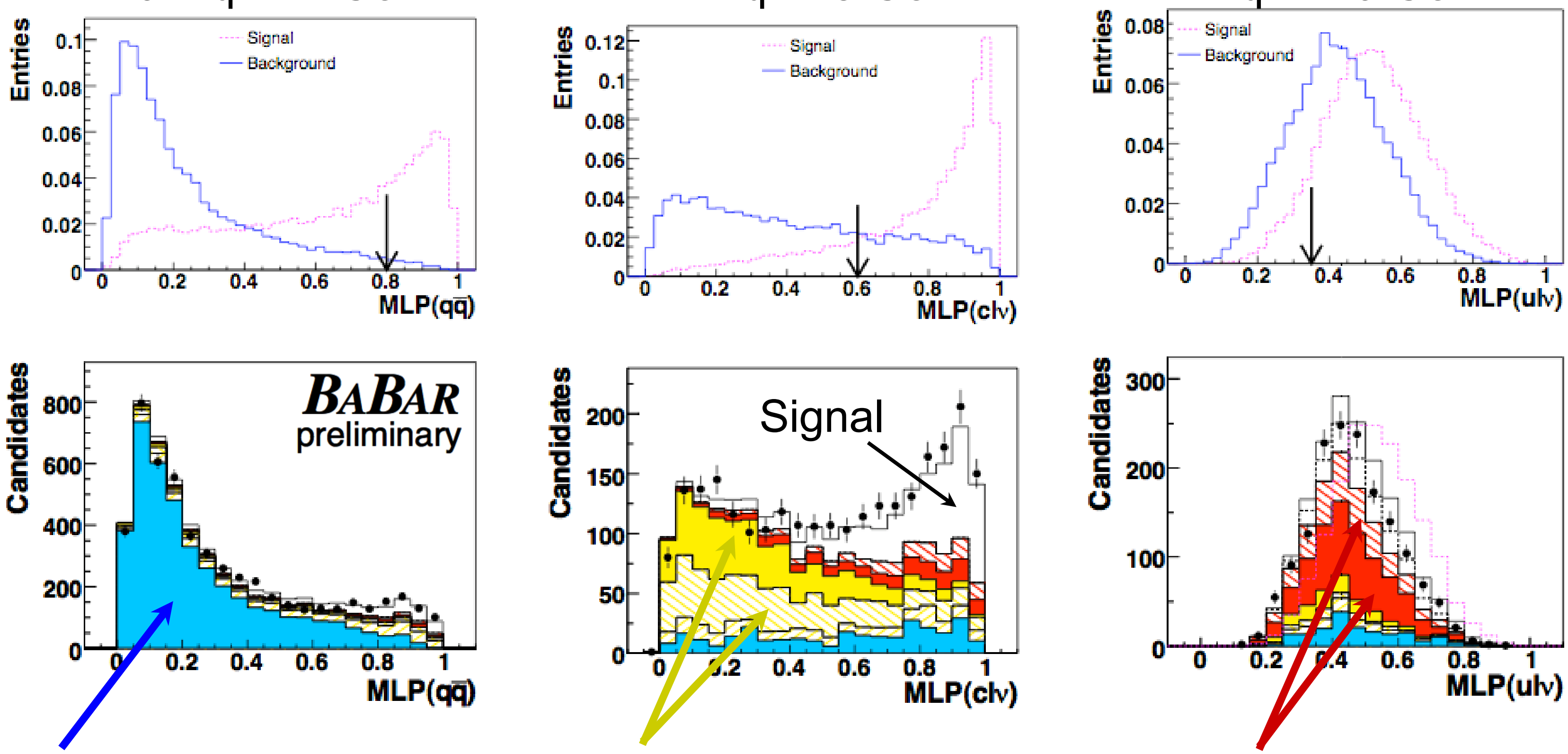
Measurement in bins of q^2
⇒ reduce model dependence

New untagged measurement from BaBar (presented at Moriond QCD)

Background Suppression

- Neural-Net discriminators for each q^2 bin for each of 3 main backgrounds

$0 < q^2 < 4$ GeV^2 | $4 < q^2 < 8$ GeV^2 | $q^2 > 20$ GeV^2



Continuum background
- large uncertainty
-off-resonance sample, very small, used as cross-check for MC simulation

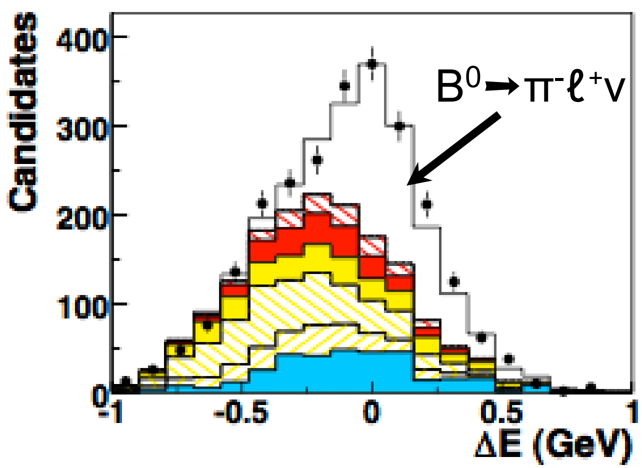
BB background
(D*ℓν, D$^{(**)}$ℓν, non-semilep. B)
- Relatively easy to separate
- Uncertain BF and FF for D*ℓν BF, D**ℓν,
- Xcℓν data control samples

B→X$_u$ℓν background
- excl. BF: > 15% uncertainty
- incl. BF : ~ 10% uncertainty
- shape sensitive to SF param.
- no good data control sample

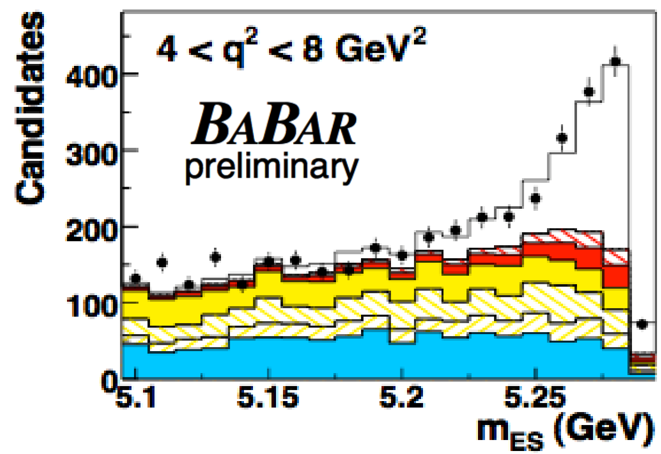
$B \to \pi/\rho \ell \nu$ Signal Extraction

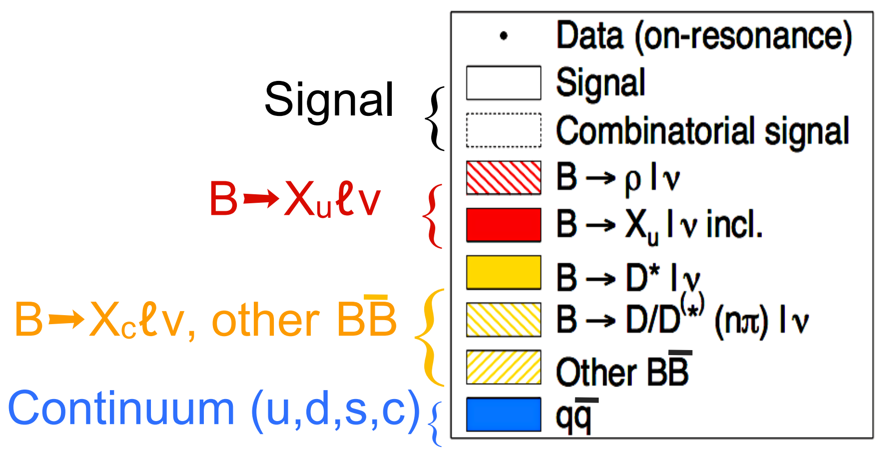
- Extract signal yield in bins of q^2 from fit to 2D $\Delta E - m_{ES}$ distribution
- Simultaneous 4-mode fit ($\pi^\pm, \pi^0, \rho^\pm, \rho^0$) assuming isospin symmetry

$$\Delta E = E_B^* - \sqrt{s}/2$$



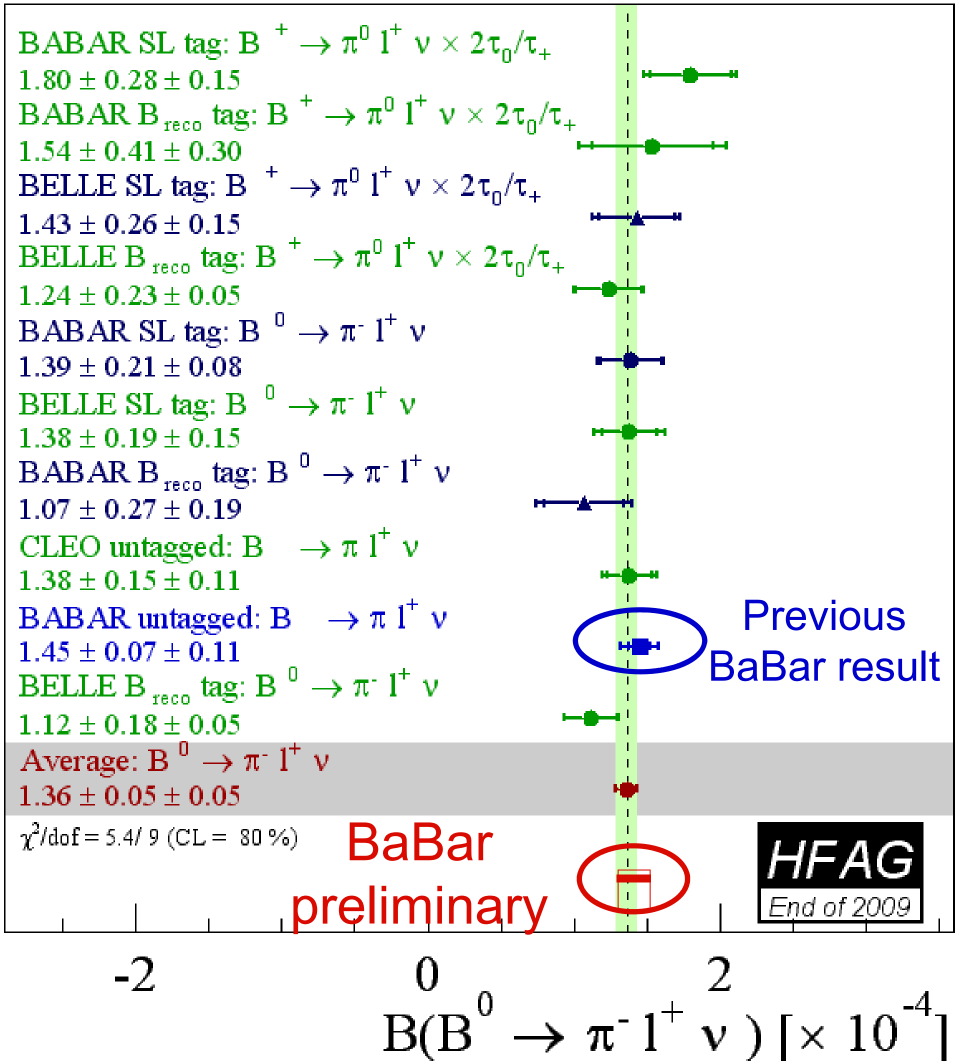
$$m_{ES} = \sqrt{s/4 - |\vec{p}_B^{\,*}|^2}$$



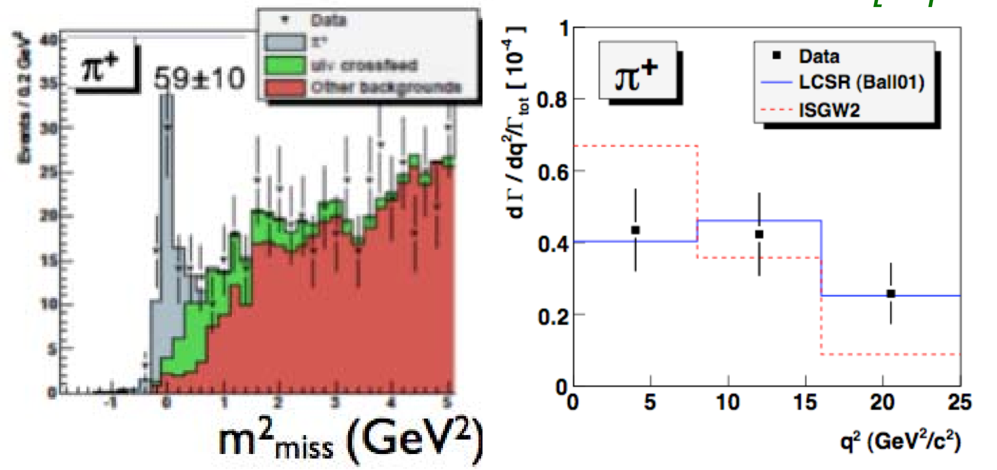


Decay Mode	# Signal Cand.
$B^0 \to \pi^- \ell^+ \nu$	7555 ± 286
$B^+ \to \pi^0 \ell^+ \nu$	4356 ± 362
$B^0 \to \rho^- \ell^+ \nu$	1948 ± 116
$B^+ \to \rho^0 \ell^+ \nu$	2731 ± 147

B→πℓν Branching Fraction



Belle: arXiv: 0812.1414 [hep-ex]



- Hadronic tag events provide very low background sample, B charge, flavor, and momentum!
- Yield of had. tagged events very low: ~100 $B^0 \to \pi^\pm \ell \nu$ / ab^{-1}
- Need ~10 ab^{-1} (~1000 $B^0 \to \pi^\pm \ell \nu$) to measure shape of distribution!

BaBar preliminary:

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.41 \pm 0.05 \pm 0.07) \times 10^{-4}$$

HFAG average:

$$\mathcal{B}(B^0 \to \pi^- l^+ \nu) = (1.36 \pm 0.05 \pm 0.05) \times 10^{-4}$$

$B \to \pi \ell \nu$ Systematic Errors

q^2 range (GeV^2)	0-4	12-16	>20
Reco./ID efficiencies (tracks, γ, e, μ)	5%	5%	4%
K_L production and interactions	2%	6%	5%
$B \to X_u \ell \nu$ BF and SF param.	<1%	<1%	6%
Continuum bkg	5%	2%	6%
Total	8%	8%	11%

ν reco.

What can be improved?

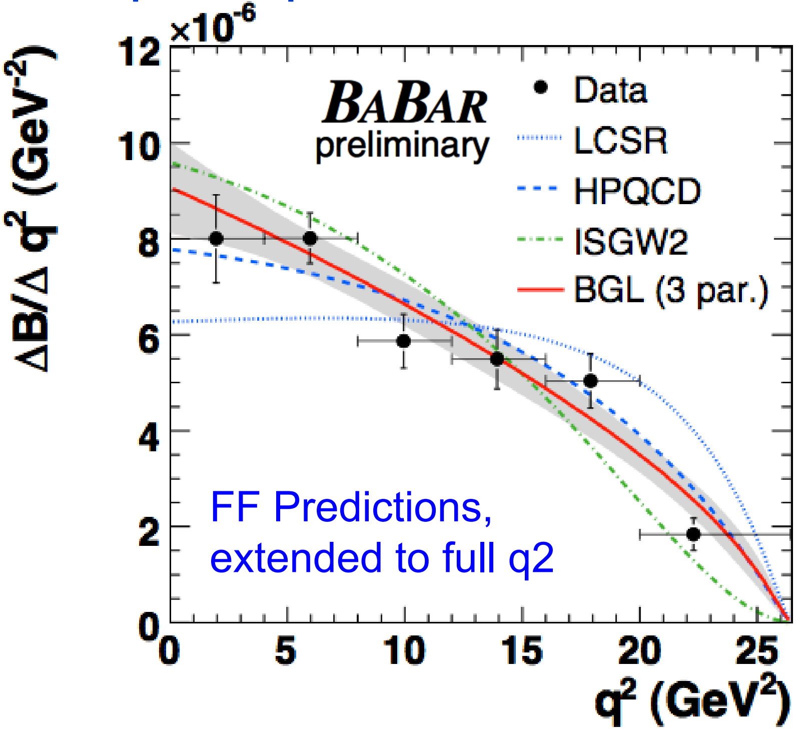
- track & photon reconstruction, KL rates ⇒ better ν reconstruction
- study of charm fragmentation to correct simulation (untagged only)
- More precise measurements of incl. and excl. $B \to X_u \ell \nu$
- BF and dynamics, FF, of $B \to X_u \ell \nu$ background

$|V_{ub}|$ from "Classic Method"

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(q^2_{min}, q^2_{max})}{\tau_0\ \Delta\zeta(q^2_{min}, q^2_{max})}}$$

$$\Delta\zeta(q^2_{min}, q^2_{max}) = \frac{G_F^2}{24\pi^3}\int_{q^2_{min}}^{q^2_{max}} p_\pi^3 |f_+(q^2)|^2 dq^2$$

Requires parametrization of $f_+(q^2)$



	q^2 Range (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\|V_{ub}\|$ (10^{-3})
$B \to \pi\ell\nu$			
LCSR [15]	$0-16$	5.44 ± 1.43	$3.63\pm0.12^{+0.59}_{-0.40}$
HPQCD [22]	$16-26.4$	2.02 ± 0.55	$3.21\pm0.17^{+0.55}_{-0.36}$

Exp. error: 3-5%
Theory error dominant: -11%, +17%

$|V_{ub}|$ results for LCSR, HPQCD consistent with previous BaBar publication

Phys. Rev. Lett. 98, 091801 (2007)

⇒ expect no significant improvement for $|V_{ub}|$ for this method)
⇒ make use of improved shape measurement in data

Form-Factor Parameterizations

1. Becirevic-Kaidalov (BK)

$$f_+(q^2) = \frac{f_+(0)}{(1-q^2/m_{B^*}^2)(1-\alpha_{BK}q^2/m_{B^*}^2)}$$

2. Ball-Zwicky (BZ)

$$f_+(q^2) = f_+(0)\left[\frac{1}{1-q^2/m_{B^*}^2} + \frac{r_{BZ}q^2/m_{B^*}^2}{(1-q^2/m_{B^*}^2)(1-\alpha_{BZ}q^2/m_{B^*}^2)}\right]$$

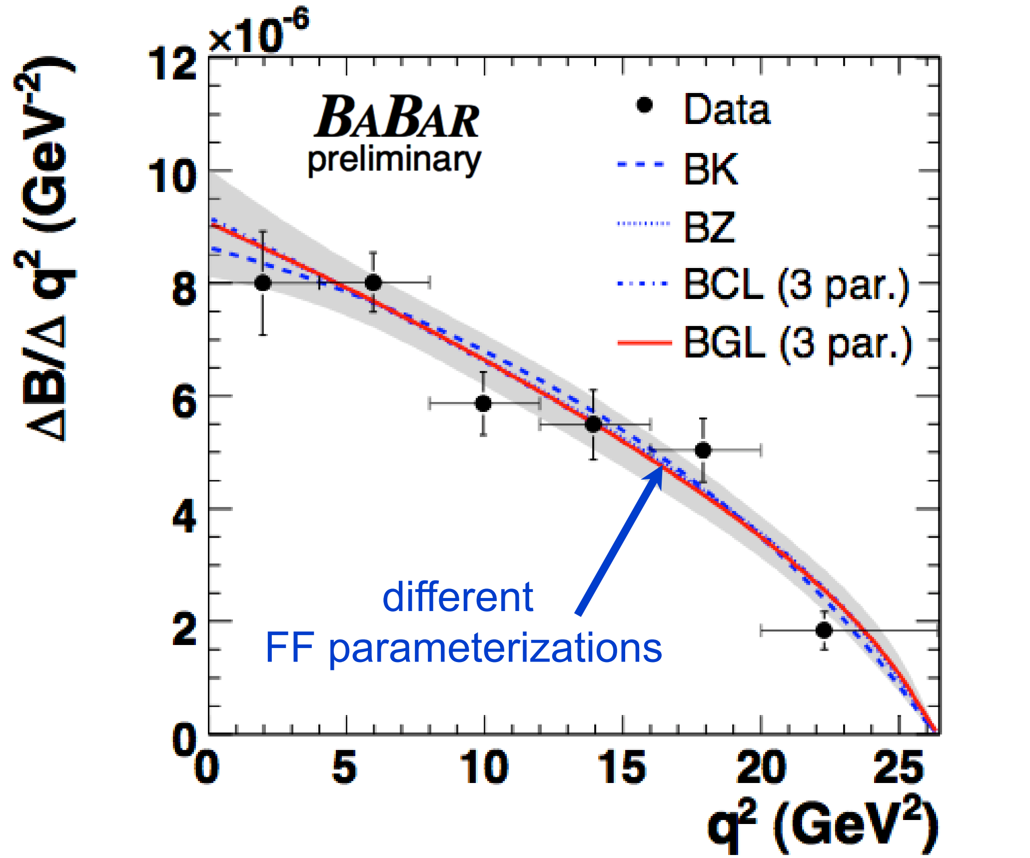
3. Boyd, Grinstein, Lebed (BGL)

$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\Phi(q^2,q_0^2)}\sum_{k=0}^{\infty} a_k(q_0^2)[z(q^2,q_0^2)]^k$$

$$z(q^2,q_0^2) = \frac{\sqrt{m_+^2-q^2}-\sqrt{m_+^2-q_0^2}}{\sqrt{m_+^2-q^2}+\sqrt{m_+^2-q_0^2}}$$

4. Bourrely, Caprini, Lellouch (BCL)

$$f_+(q^2) = \frac{1}{1-q^2/m_{B^*}^2}\sum_{k=0}^{k_{max}} b_k(q_0^2)\{[z(q^2,q_0^2)]^k - (-1)^{k-k_{max}-1}\frac{k}{k_{max}+1}[z(q^2,q_0^2)]^{k_{max}+1}\}$$

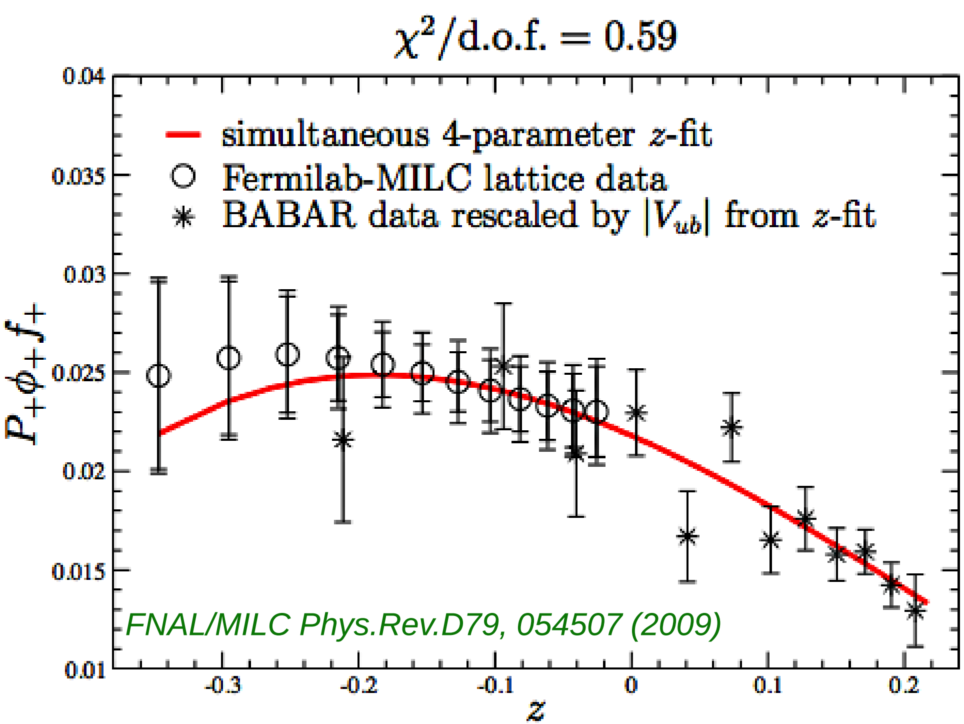


- Fit to data very similar for all four parametrizations
- Current exp. precision cannot constrain more than 3 shape parameters

Some Comments on "PΦf₊ vs. z"

$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\Phi(q^2,q_0^2)} \sum_{k=0}^{\infty} a_k(q_0^2)[z(q^2,q_0^2)]^k$$

$$z(q^2,q_0^2) = \frac{\sqrt{m_+^2 - q^2} - \sqrt{m_+^2 - q_0^2}}{\sqrt{m_+^2 - q^2} + \sqrt{m_+^2 - q_0^2}}$$



Presentation of data in term of PΦf+(z) is not without problem and combined fit of data and LQCD prediction is problematic:

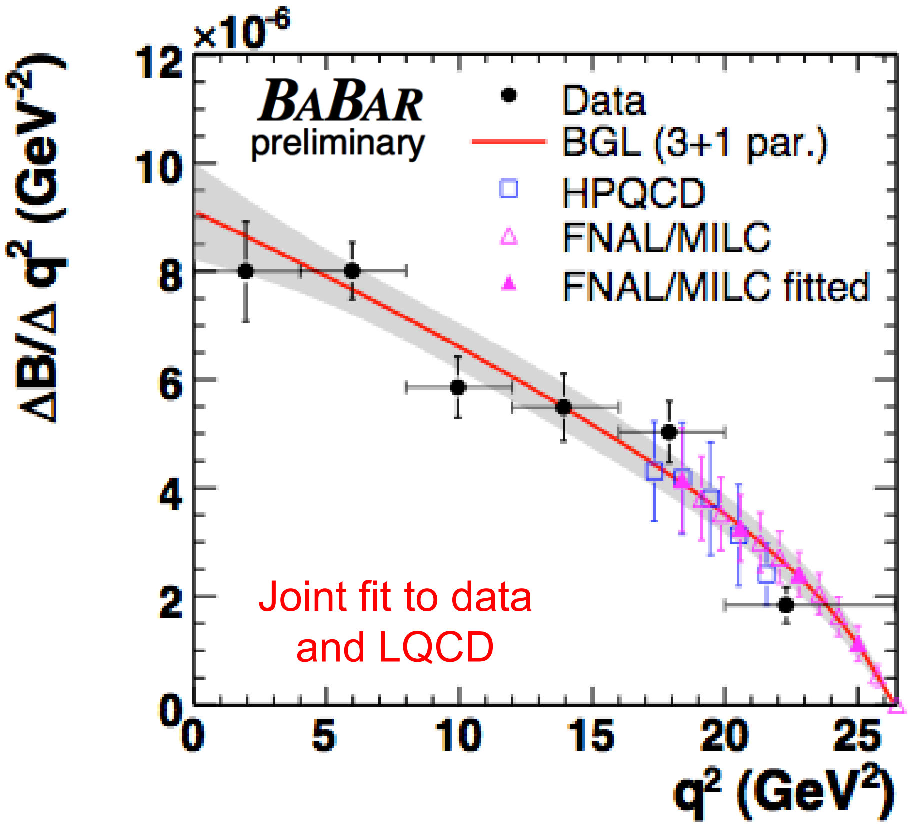
1. Translation of binned $\Delta B/\Delta q^2$ data spectrum to $P\Phi f_+$:
   $P=P(q^2)$, $\Phi=\Phi(q^2)$, $p_\pi=p_\pi(q^2)$
   ⇒ prefer fit to $\Delta B/\Delta q^2$

2. Large correlations between LQCD points result in instability of fit:
   For FNAL/MILC:
   - neighboring points : ρ=99%
   - next neighbor still : ρ=95%

   ⇒ reduce # LQCD points in fit

Theorists, please provide values for all relevant parameters (masses, numerical factors, etc.) used in your calculation in the publication!

$|V_{ub}|$ from "LQCD+BaBar Fit"



To be submitted to PRD

BaBar prelim. 2010 + FNAL (4 points):

$$a_0 = (2.22 \pm 0.21) \times 10^{-2}$$
$$a_1/a_0 = -0.86 \pm 0.23$$
$$a_2/a_0 = -0.97 \pm 1.36$$
$$|V_{ub}| = (2.95 \pm 0.31) \times 10^{-3}$$

Previous fit by FNAL Lattice Group:
BaBar 2007 data + FNAL (12 points):

$$|V_{ub}| = (3.38 \pm 0.36) \times 10^{-3}$$

$|V_{ub}| = (2.87 \pm 0.28) \times 10^{-3}$ FNAL/MILC (6 points)

$|V_{ub}| = (2.95 \pm 0.31) \times 10^{-3}$ FNAL/MILC (4 points)

$|V_{ub}| = (2.93 \pm 0.31) \times 10^{-3}$ FNAL/MILC (3 points)

$|V_{ub}| = (2.92 \pm 0.37) \times 10^{-3}$ FNAL/MILC (1 point)

$|V_{ub}| = (2.99 \pm 0.35) \times 10^{-3}$ HPQCD (1 point)

Error composition:

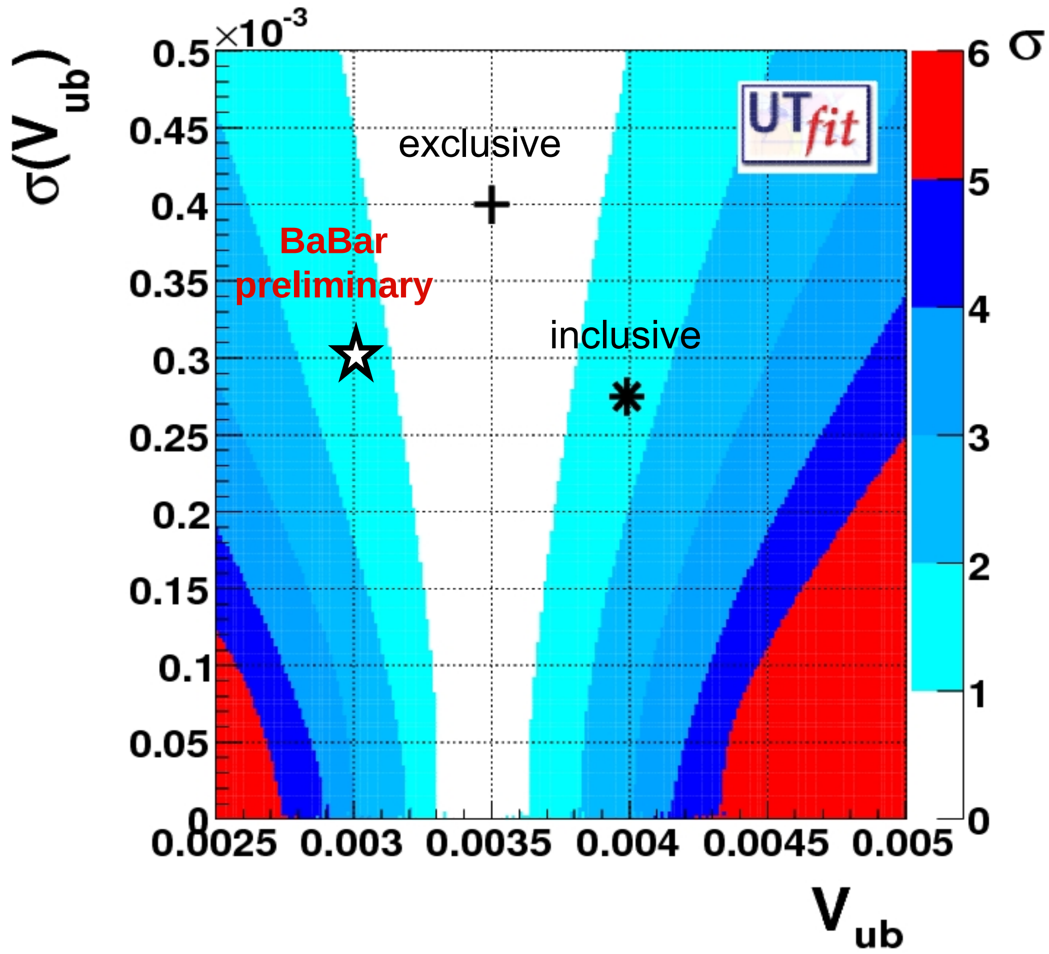
~3% Measured total BF

~5% Shape (from data)

~ 8.5% FF norm. (from LQCD)

Currently most precise exclusive $|V_{ub}|$ determination: ~10%

Inclusive vs. Exclusive $|V_{ub}|$



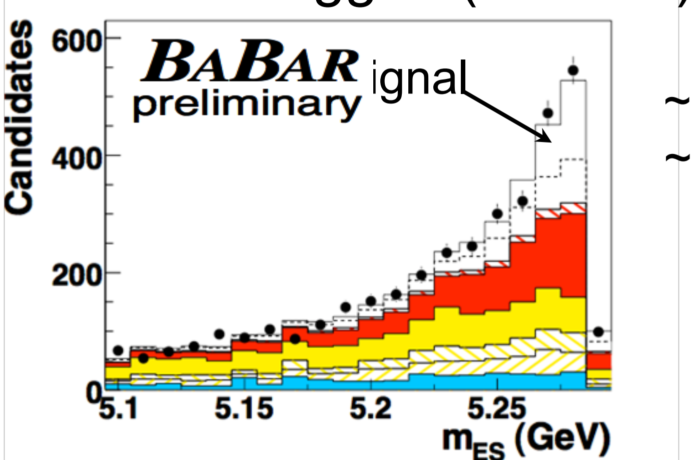
Difference between inclusive and exclusive $|V_{ub}|$ determinations has increased again !

BABAR: B→ρℓν - A Cross-Check?

BABAR: to be submitted to PRD

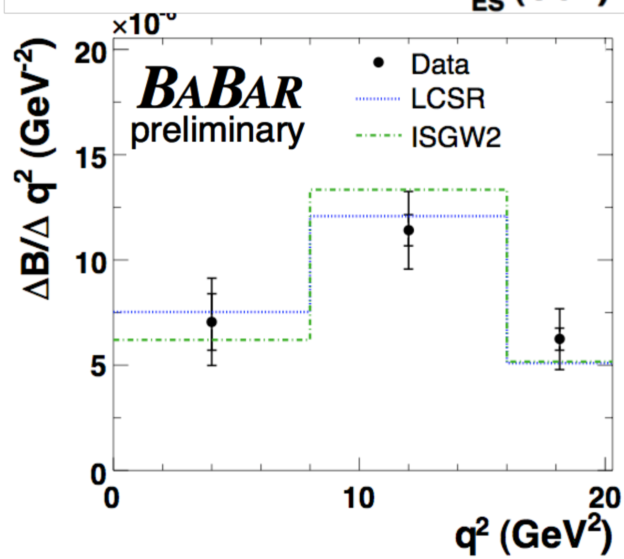
Belle: arXiv: 0812.1414 [hep-ex]

BaBar untagged (350 fb^{-1})

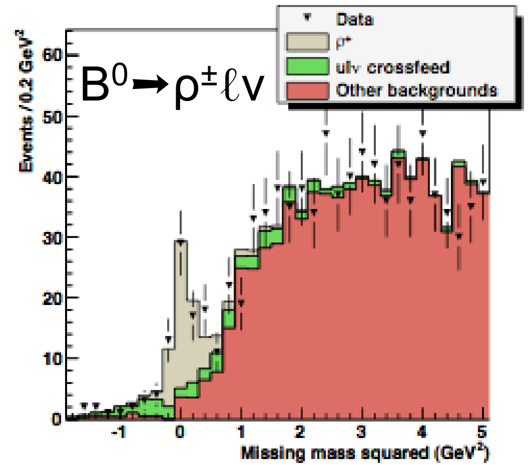


~ 2,000 $\rho^{\pm}$

~ 2,700 ρ^{0}



Belle hadronic tag (604 fb^{-1})



65 $\rho^{\pm}$

80 ρ^{0}

BaBar prelim.

	q^2 Range (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})
LCSR [16]	$0 - 16.0$	13.79	2.75 ± 0.24
ISGW2 [14]	$0 - 20.3$	14.20	2.83 ± 0.24

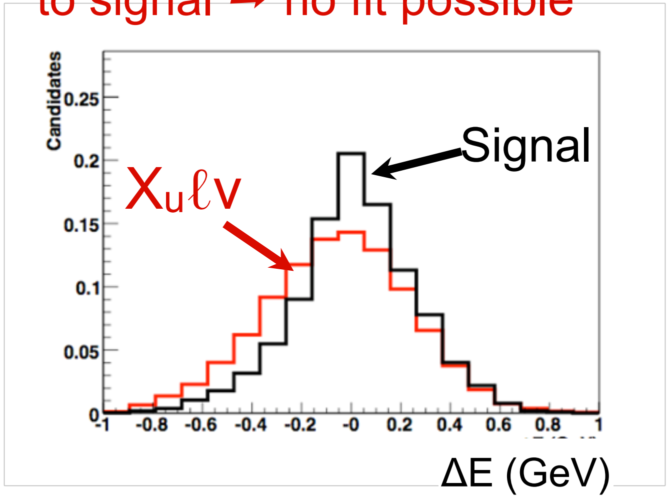
Need calculations with reliable theory error!

$B \to \rho \ell \nu$ (untagged) Systematics

q^2 range	0-8	8-16	16-20.3
$B \to X_u \ell \nu$ BF and SF param.	14%	11%	17%
$B \to \rho \ell \nu$ FF's (A_1,A_2,V)	14%	8%	6%
K_L production and interactions	11%	6%	9%
Continuum bkg	9%	4%	5%
Total	26%	16%	21%

Much larger syst. errors than for π !

$B \to X_u \ell \nu$ background very similar to signal ➞ no fit possible



What can be improved?

- Extend measurement over larger phase space (lower p_ℓ cut, currently at 1.8 GeV.
  ⇒ reduce FF model dependence
- Suppress or improve knowledge of $B \to X_u \ell \nu$ background
  - Need high-statistics tagged sample (Super B Factory)
  - Constrain combinatorial background from data, e.g. $M_{\pi\pi}$ sidebands

Other Resonances: $B \to \eta/\eta'/\omega \ell \nu$

- Current signal yields for untagged and tagged measurements:

	Untagged		Tagged	
Mode	N(signal)	Experiment	N(signal)	Experiment
$\pi^{\pm}+\pi^{0}$	~ 12000	BaBar (~350 fb^{-1})	110	Belle Breco(~600 fb^{-1})
$\rho^{\pm}+\rho^{0}$	~ 5000	BaBar (~350 fb^{-1})	145	Belle Breco (~600 fb^{-1})
η	~ 660*	BaBar (~420* fb^{-1})	55	BaBar sl. tag (~350 fb^{-1})
η'	~ 125*	BaBar (~420* fb^{-1})	-	BaBar sl. tag (~350 fb^{-1})
ω	~ 500	BaBar (~350 fb^{-1})	25	Belle Breco (~600 fb^{-1})

Close to “last word” from BaBar
(expectation, unofficial)*

Update of Belle Breco analyses
⇒ N ×1.5 ?

Conclusions on $|V_{ub}|$

- Improveed measurement of $B\rightarrow\pi l\nu$ form-factor shape from data combined with LQCD predictions in simultaneous fit to BGL ansatz reduced theory error, $\sigma|V_{ub}| \sim 10\%$
- Unfortunately LQCD predictions are only available in a region where data rate is small ($\propto p_\pi^3$) and experimental errors are large!
- Further improvement in LQCD predictions:
  - Yet more precise $f_+(q^2)$ calculations, if possible at lower q^2 and fewer points
  - Predictions for $B \rightarrow \rho/\omega/\eta l\nu$ FF to enable extraction of |Vub| from these processes and insight into cause for difference of inclusive-exclusive $|V_{ub}|$ measurements???.

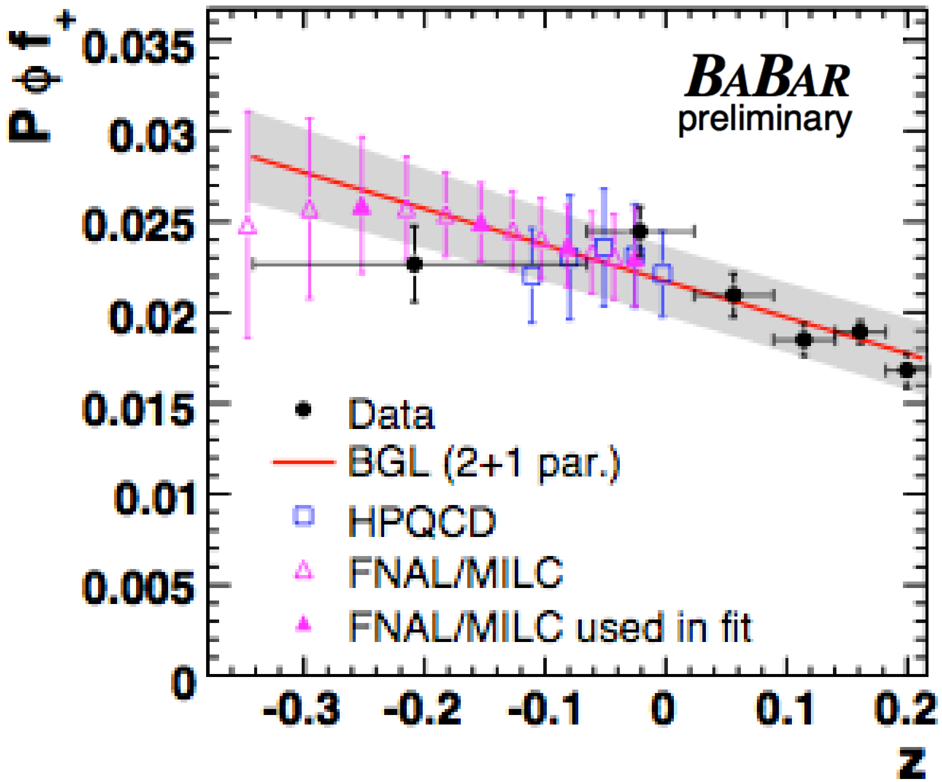
Many thanks to the lattice community for organizing this workshop and for close collaboration over many years on several topics!

My colleague Jochen Dingfelder and I have benefitted greatly from working with you!
Thank you!

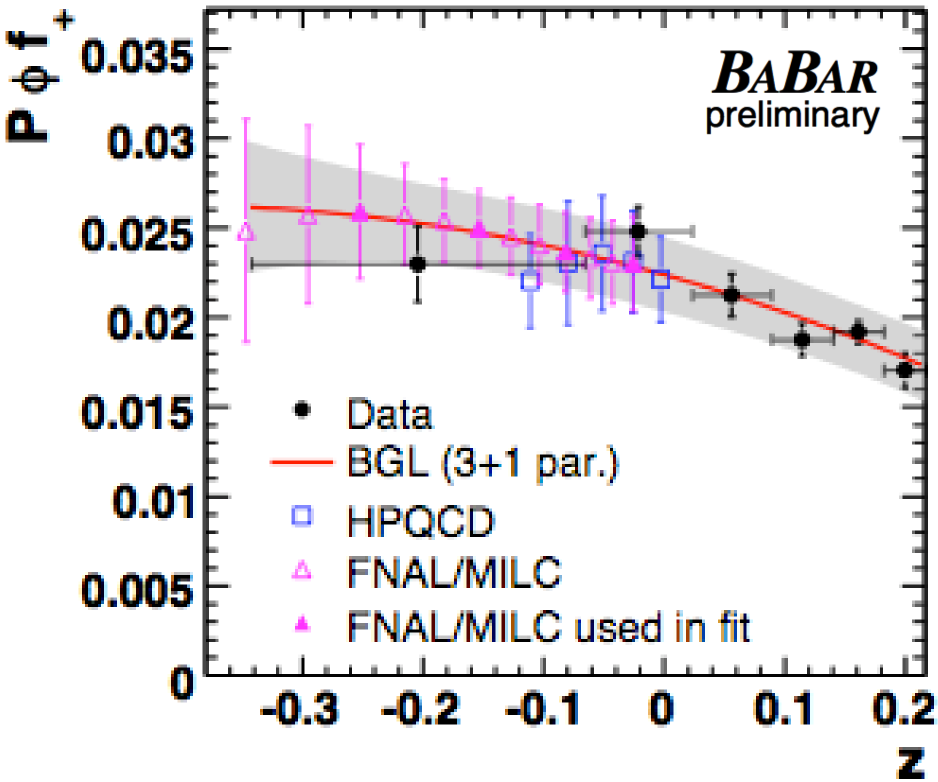
$|V_{ub}|$ Fit: $P\Phi f_+$ vs. z

- Translation of "$\Delta B/\Delta q^2$ vs. q^2" fit results to "$P\Phi f_+$ vs. z"

BGL 2+1 par

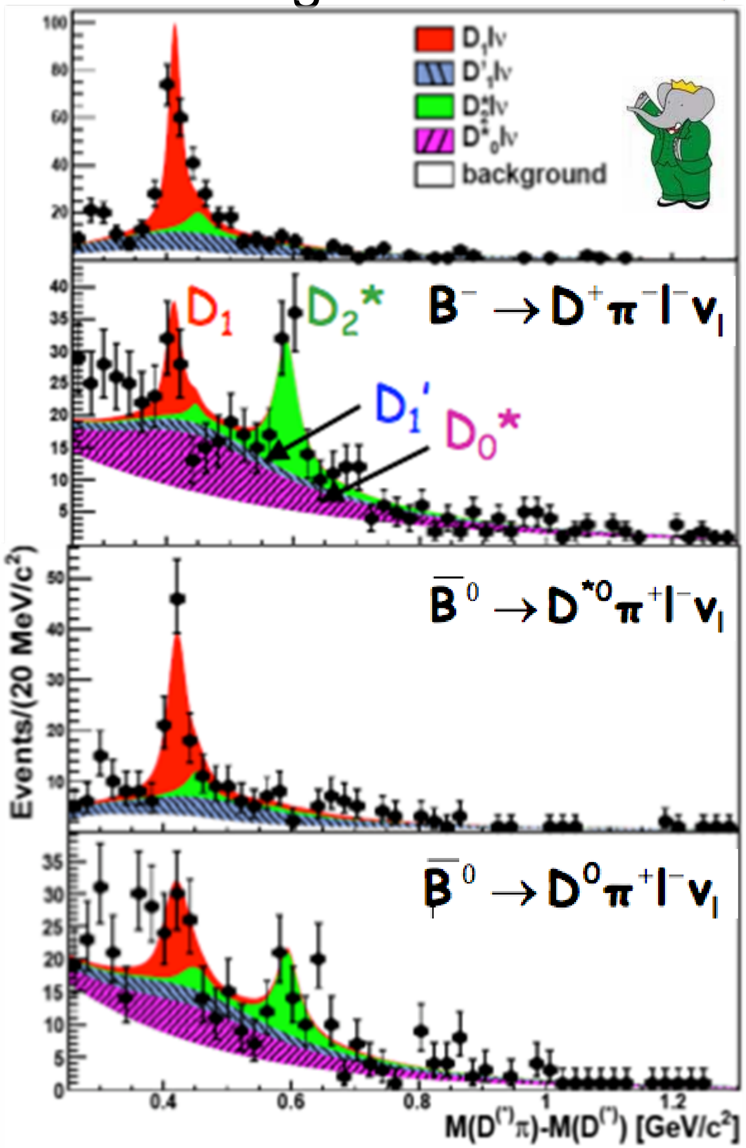


BGL 3+1 par



Higher-Mass States: $D^{**} \to D^{(*)}\ell\nu$

BaBar
hadronic tag



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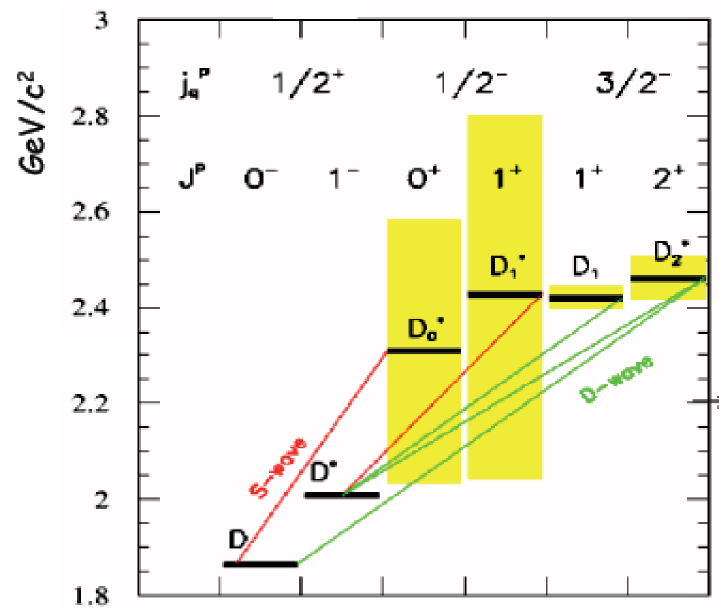


2 narrow states : D_1 , D_2^*

2 broad states : D_1' , D_0^*

- Hadronic-tag measurements of narrow and broad resonances from BaBar and Belle
  ⇒ use mass difference $M(D^{(*)}\pi)-M(D^{(*)})$
- Untagged measurement of narrow resonances from BaBar and D0

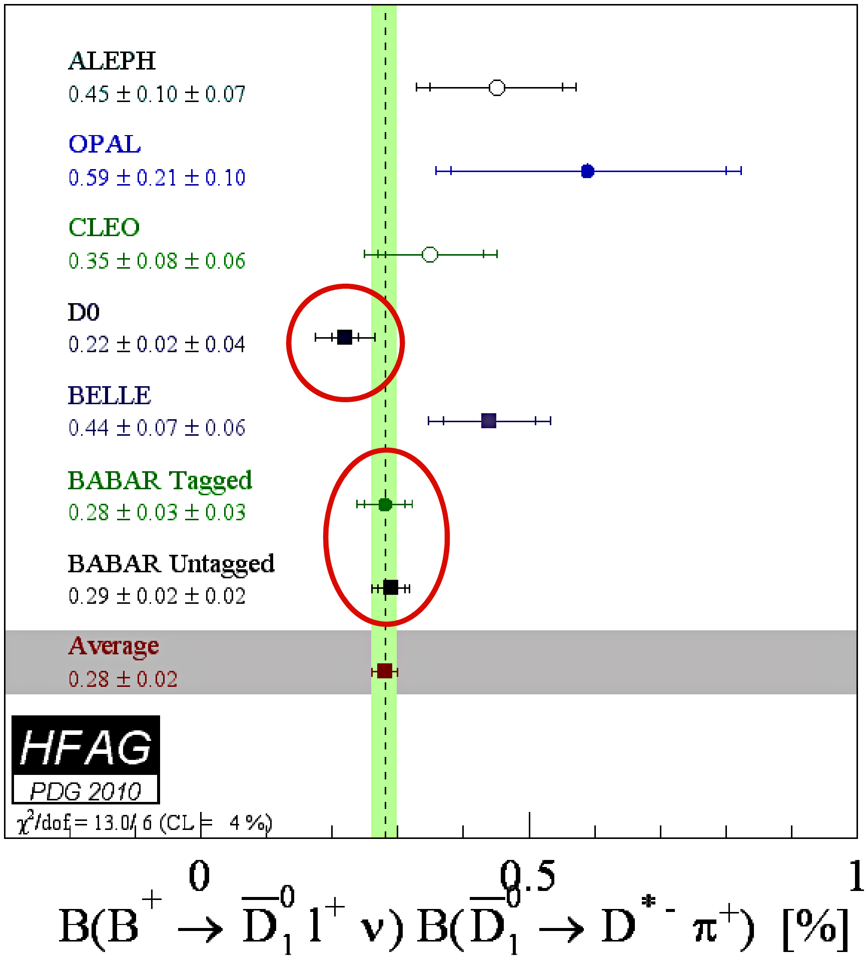
Higher-Mass States: $D^{**} \to D^{(*)}\ell\nu$

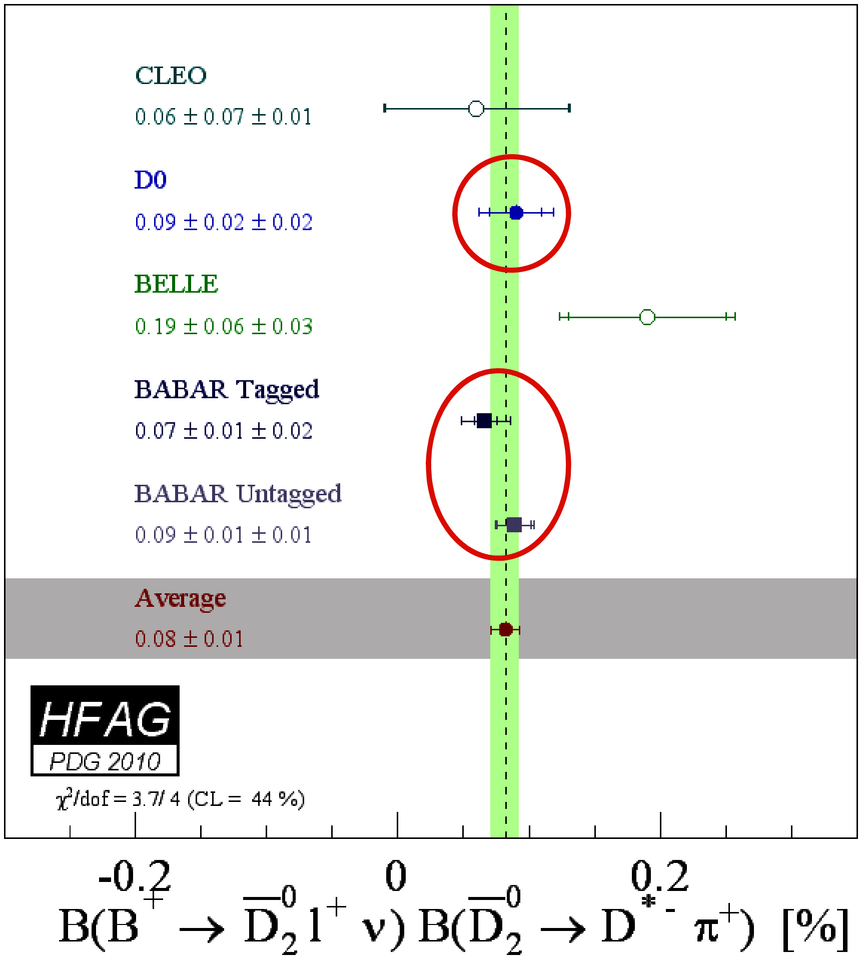
Decay Mode	Yield	$\mathcal{B}(\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell) \times \mathcal{B}(D^{**} \to D^{(*)}\pi)$ %(BELLE)	BABAR Yield	BABAR Branching Fraction
		$D\pi$ invariant mass fit		
$B^- \to D_0^{*0}\ell^-\bar{\nu}_\ell$	102 ± 19	$0.24 \pm 0.04 \pm 0.06$	137 ± 26	$0.26 \pm 0.05 \pm 0.04$
$B^- \to D_2^0\ell^-\bar{\nu}_\ell$	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	$0.27 \pm 0.05 \pm 0.03$
$\bar{B}^0 \to D_2^+\ell^-\bar{\nu}_\ell$	1 ± 6	< 0.3 @ 90CL	12 ± 5	$0.03 \pm 0.01 \pm 0.006$

- Narrow D** states agree for Belle, BaBar (tagged+untagged), D0
- Results for broad D_0^* consistent for BaBar and Belle
- BaBar observes D_1', Belle does not !
- Contribution from broad ($1/2^-$) states larger than predicted by theory!

"3/2 > 1/2 puzzle"

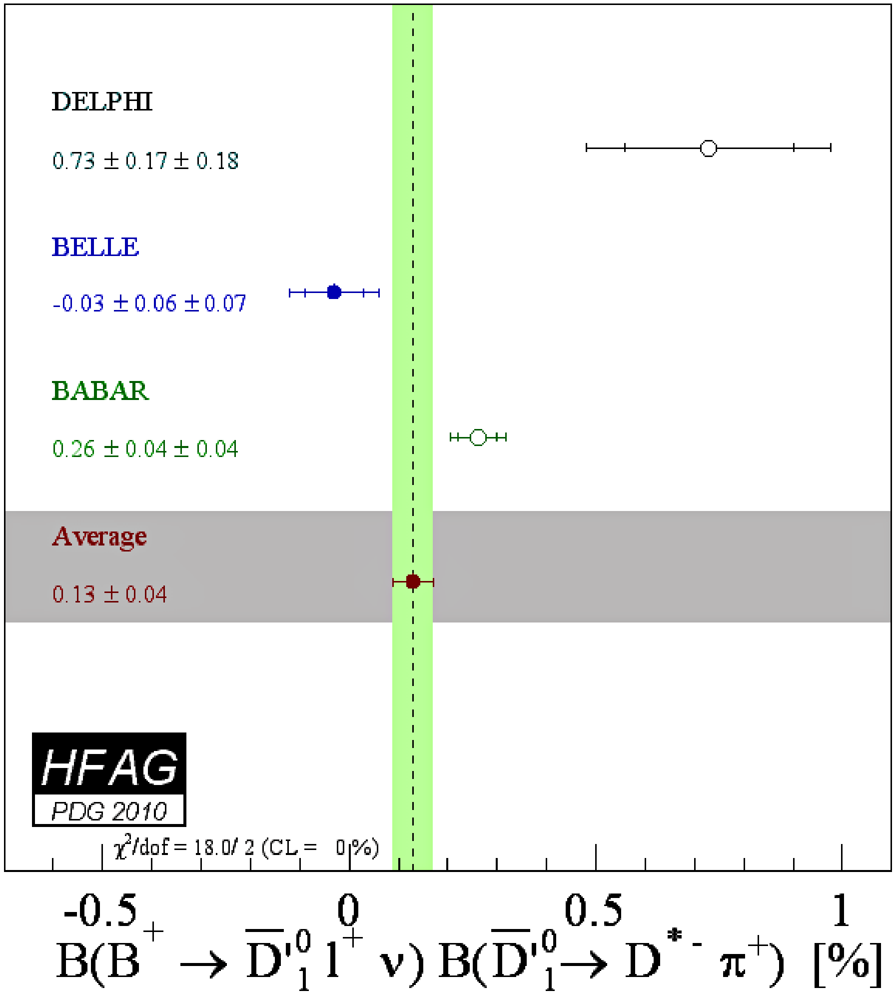
Narrow D** Resonances

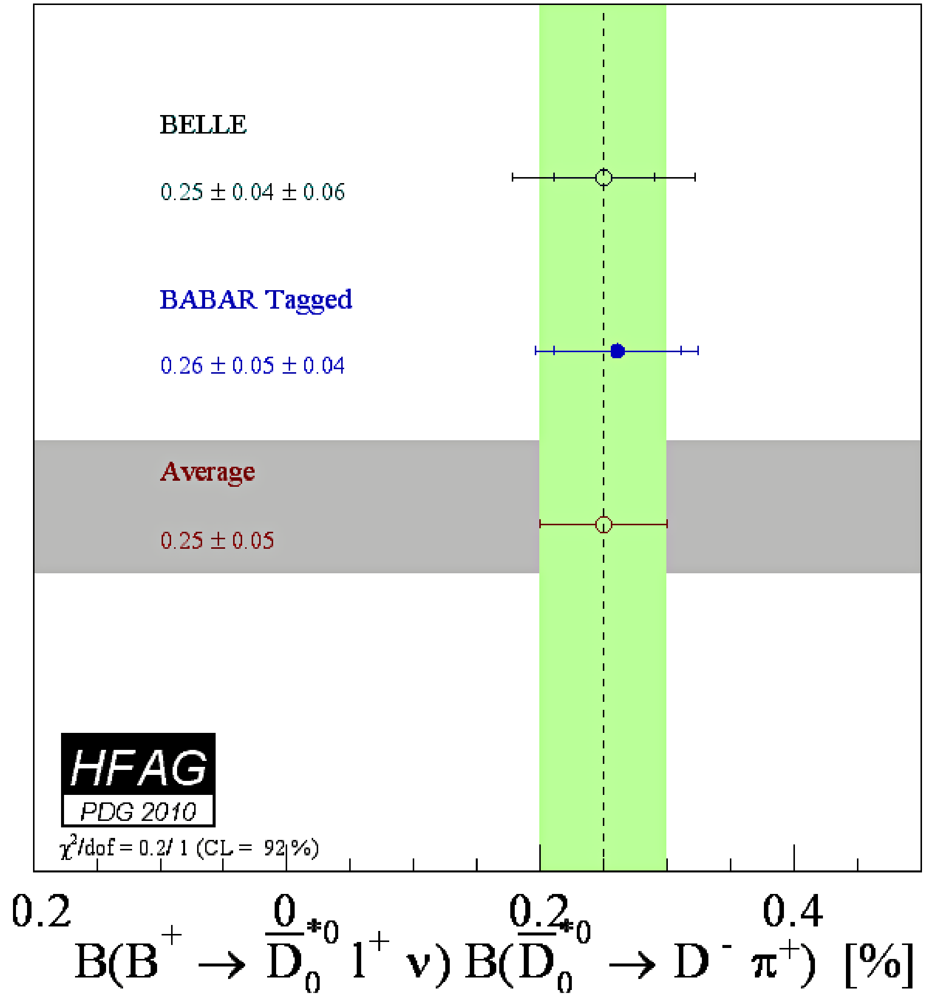




Recent measurements of narrow states in good agreement,
also for tagged and untagged methods!
Partial BF for D** still not known!

Broad D** Resonances





The situation is less clear for the broad states ... !

Masses, widths, and partial BFs of broad D** not well known!