B Semileptonic Decays at BaBar

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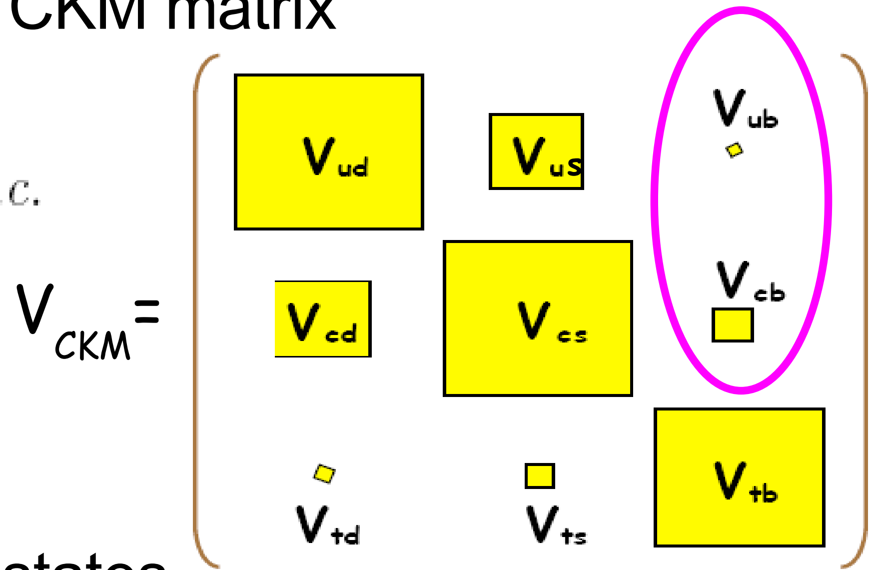
Outline

- Motivations
- Inclusive vs Exclusive
- BaBar
- V_{cb}
  - Inclusive Decays: $B \to X_c l\nu$
  - Exclusive Decays: $B \to D/D^*/D^{**}l\nu$
- V_{ub}
  - Inclusive Decays: $B \to X_u l\nu$
  - Exclusive Decays: $B \to \pi l\nu$

Framework: the CKM matrix

- B decays allow detailed studies of the CKM matrix

$$\mathcal{L} = -\frac{g}{\sqrt{2}} (\bar{u}_L \bar{c}_L \bar{t}_L)\, \gamma^\mu V_{CKM} \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix} W^+_\mu + h.c.$$



  - Connects the weak to the mass eigenstates
- 3 real parameters + 1 complex phase
  - Is this the complete description of the CP violation?
  - Is everything consistent with a single unitary matrix?

Only source of CPV in Minimal SM

CKM Picture: the Unitary Triangle

Unitary of $V_{CKM} \rightarrow V_{CKM} V^{\dagger}_{CKM} = 1 \rightarrow V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$

Angles can be measured with CP violation of B decays:

α: $B \rightarrow \pi\pi/\rho\pi/\rho\rho$

β: $B \rightarrow J/\Psi\, K_S$

γ: $B \rightarrow DK/D\pi$

Sides from SemiLeptonic B decays, B mixing, rare B decays

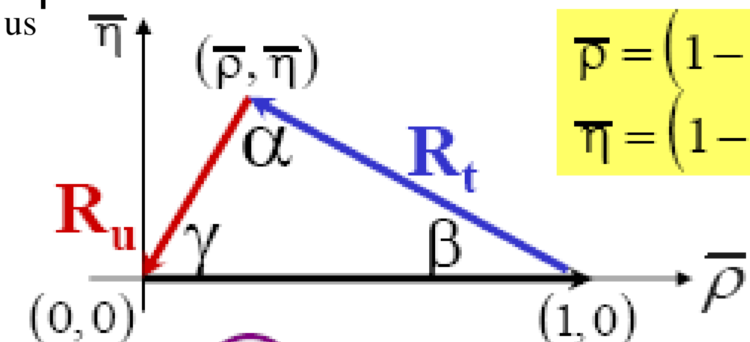
Complementary constraints from CP violation in K_L

Unitarity: $1 + R_t + R_u = 0$

$\lambda = |V_{us}|$

$\bar{\rho} = (1 - \lambda^2/2)\rho$

$\bar{\eta} = (1 - \lambda^2/2)\eta$



$$R_u = \frac{V_{ud} V^*_{ub}}{V_{cd} V^*_{cb}} \approx -\sqrt{\bar{\rho}^2 + \bar{\eta}^2}\; e^{i\gamma}$$

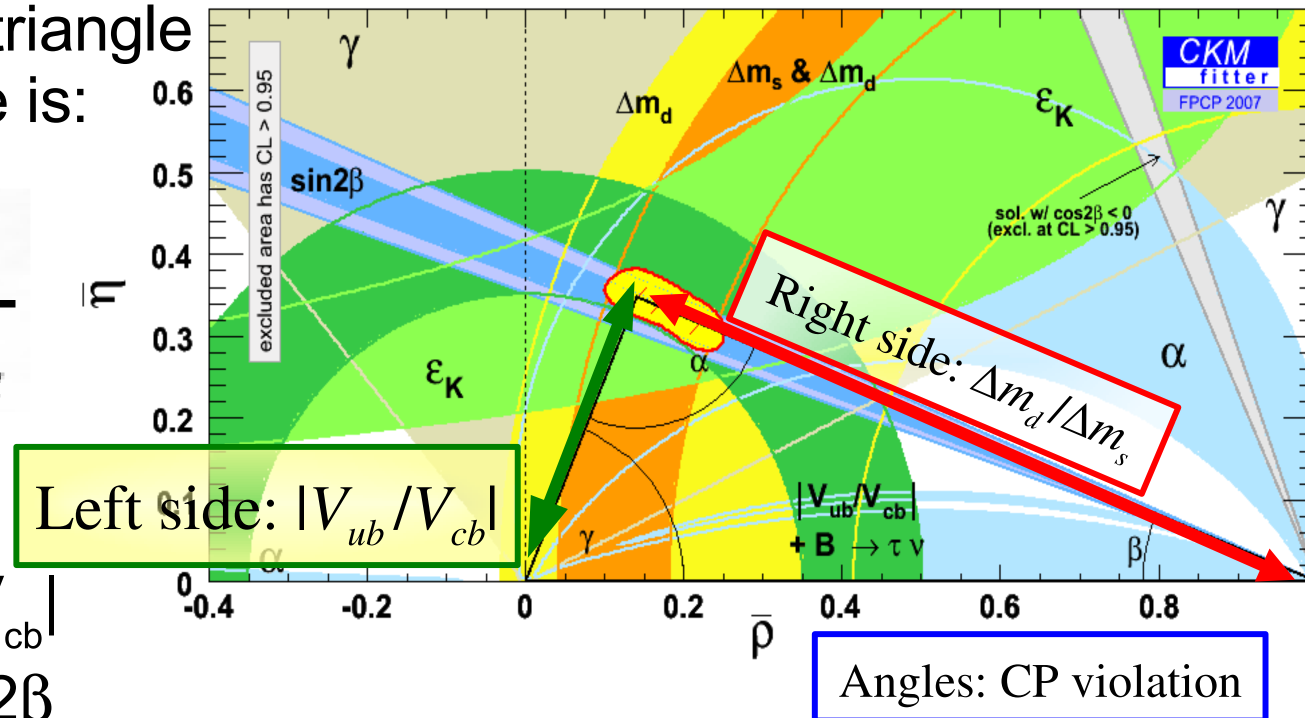
$$R_t = \frac{V_{td} V^*_{tb}}{V_{cd} V^*_{cb}} \approx -\sqrt{(1-\bar{\rho})^2 + \bar{\eta}^2}\; e^{-i\beta}$$

$$\gamma = \arg V^*_{ub}, \quad \alpha = \pi - \gamma - \beta$$

$|V_{ub}/V_{cb}|$ measurements @ B-factories

- Precise determination of $|V_{ub}/V_{cb}|$ necessary ingredient to further constraint the unitary triangle
- Left side of the triangle is:

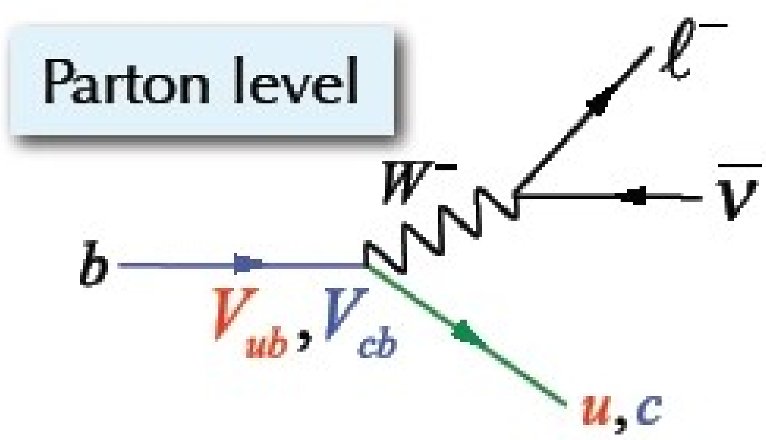
$$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| = \left|\frac{V_{ub}}{V_{cb}}\right|\frac{1}{\tan\theta_C}$$

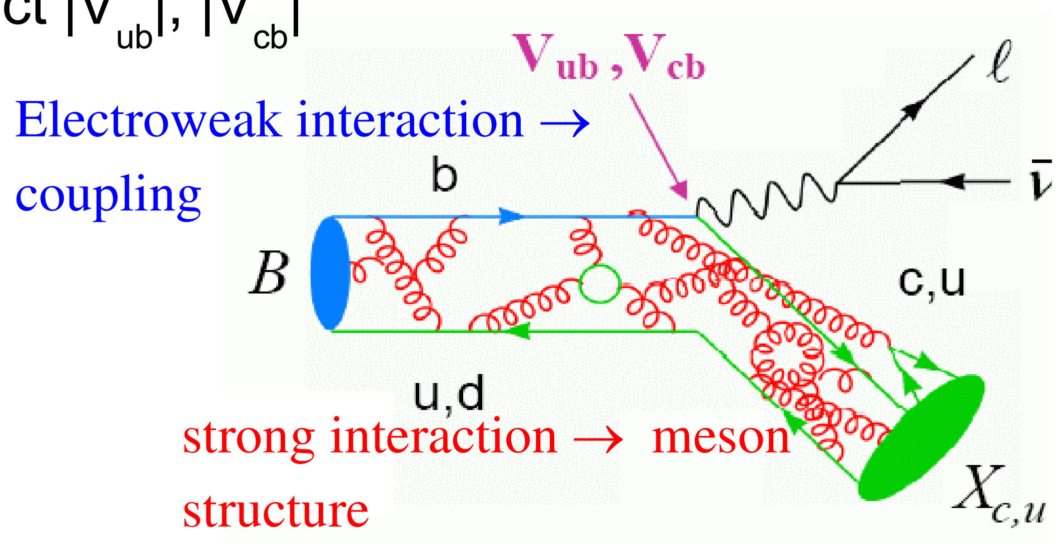


- Measurement of $|V_{ub}/V_{cb}|$ complementary to sin 2β
- Current accuracy on $|V_{ub}|$ is 9%, on $|V_{cb}|$ 2%.
- sin 2β (all charmonium) = 0.680 ± 0.025 ~ 3.7% accuracy (HFAG)
- Should we just focus on
- $|V_{cb}|$ sector still puzzling for several aspects!

Semileptonic B Decays

- Semileptonic B $\rightarrow X_{c,u}\, l\, \nu$ decays offer clear view of the b quark in the B meson
- Decay rates $\Gamma_x = \Gamma(B \rightarrow X l \nu) \propto |V_{xb}|^2$
- Presence of a single hadronic current allows better control of theoretical uncertainties
- Must understand them to extract $|V_{ub}|$, $|V_{cb}|$





- Allows test of HQET predictions and OPE
- Test of non-perturbative QCD effects
- Spectroscopy of D** (orbitally excited D meson) states complementary to hadronic decays

Inclusive Decays

- $\Gamma(b \to c(u) l \nu)$ described by Heavy Quark Expansion in $(1/m_b)^n$ and α_S^k

$$\Gamma(B \to X_{c(u)} \ell^- \bar{\nu}_\ell) \propto \frac{G_F^2}{192\pi^3} m_b^5 |V_{c(u)b}|^2 [1 + A_{ew}] A_{pert} A_{nonpert}$$

Free quark decay

Perturbative corrections (α_s^k dependent)

Non-Perturbative corrections ($1/m_b^n$ dependent)

- Non perturbative parameters need to be measured
  - The expansion depends on the m_b definition
- Use low-order moments of inclusive distributions over large ranges on phase space to avoid problem with quark-hadron duality
- Moments can be calculated for various cuts on kinematical variables

$$\langle E_l^n \rangle = \frac{1}{\Gamma_{c(u)}} \int (E_l - \langle E_l \rangle)^n \frac{d\Gamma_{c(u)}}{dE_l} dE_l \qquad \langle m_X^n \rangle = \frac{1}{\Gamma_{c(u)}} \int m_X^n \frac{d\Gamma_{c(u)}}{dm_X} dm_X$$

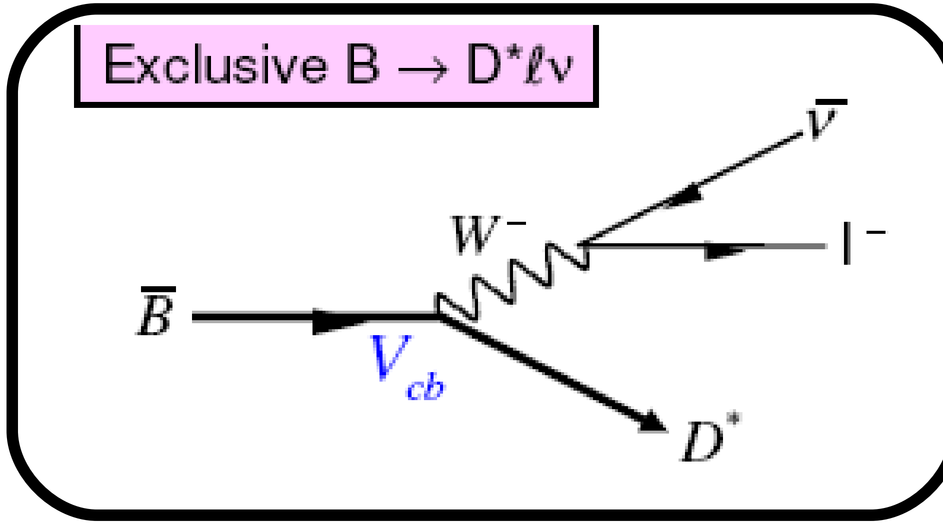
- Calculations available in “kinetic” (Benson,Bigi,Gambino,Mannel,Uraltsev, Nucl. Phys. B665:367) and “1S” (Bauer,Ligeti,Manohar,Trott, Phys.Rev.D70:094017,2004) mass schemes
- > 60 measured moments available from DELPHI,CLEO,BaBar,BELLE, CDF

Exclusive Decays

- Matrix element for semileptonic decays:

$$\mathcal{M} = -i\frac{G_F}{\sqrt{2}}V_{q'Q}L^{\mu}H_{\mu}$$

- Hadronic current described by Form-Factors (FF):

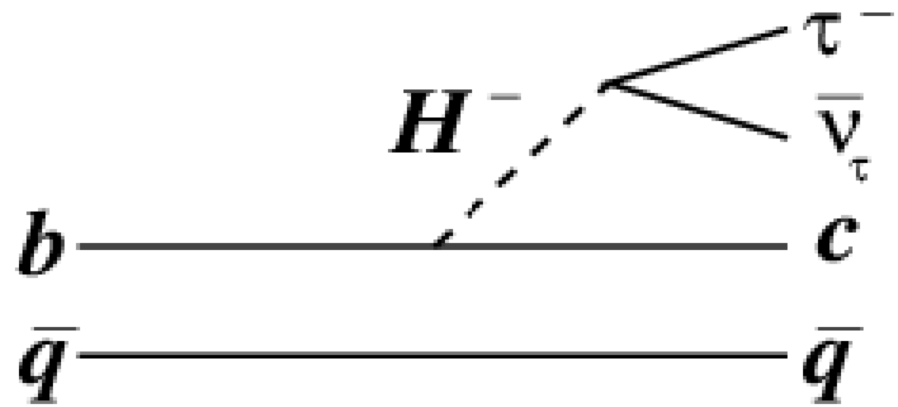


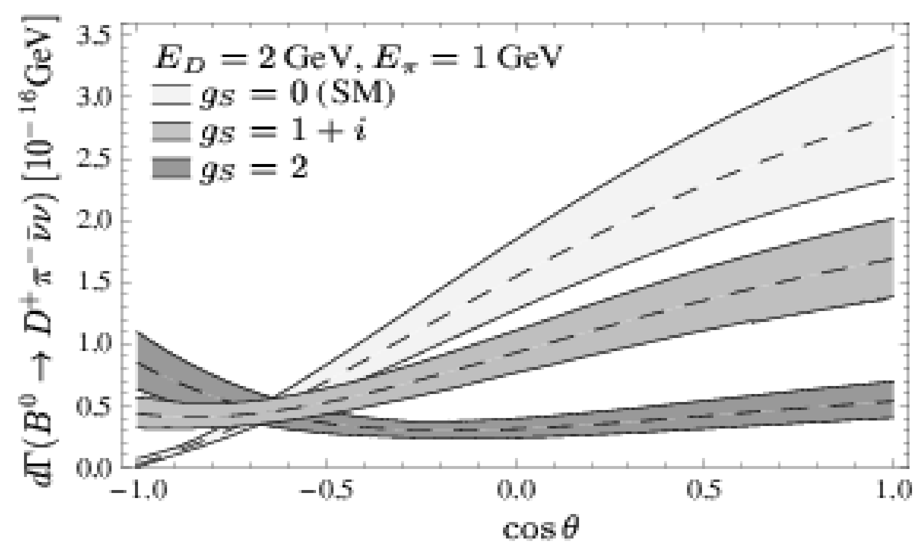
$$\langle P'(p')|V^{\mu}|P(p)\rangle = f_+(q^2)(p+p')^{\mu} + f_-(q^2)(p-p')^{\mu}$$

- Needs FF to describe hadronization process and relate the rate to $|V_{cb}|$ and $|V_{ub}|$
- Theoretically calculable at kinematical limits
- Lattice QCD works if hadron/meson is at rest relative to B
- Empirical extrapolation is necessary to extract $|V_{cb}|$, $|V_{ub}|$
- Measure differential rates to constrain the FF shape, then use normalization from theory

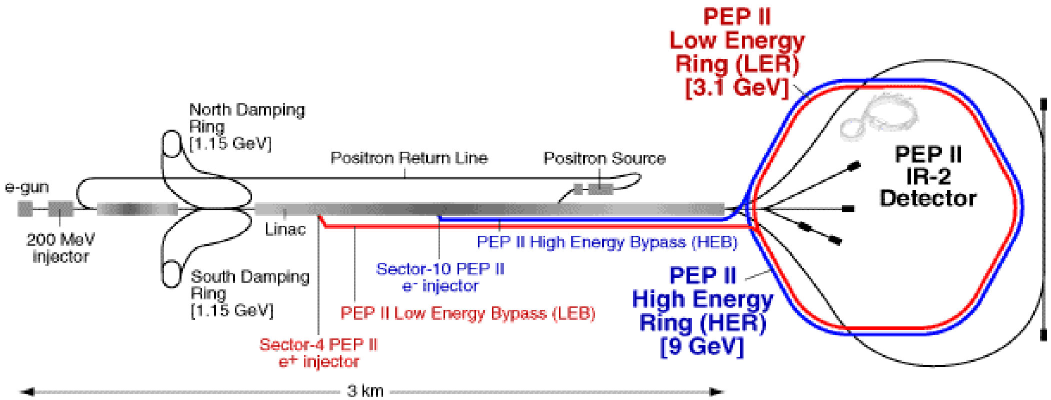
New Physics

- Same Feynman diagrams as the light leptons, but the decays can also be mediated by a charged Higgs boson
- Clean probe of New Physics Effects:
- NP contributes at tree level
- Spin zero Higgs does not couple to all helicity states, affect D and D* differently, τ polarization
- Use of τ hadronic modes can give interesting information on charged Higgs couplings (arXiv:0801.4938)

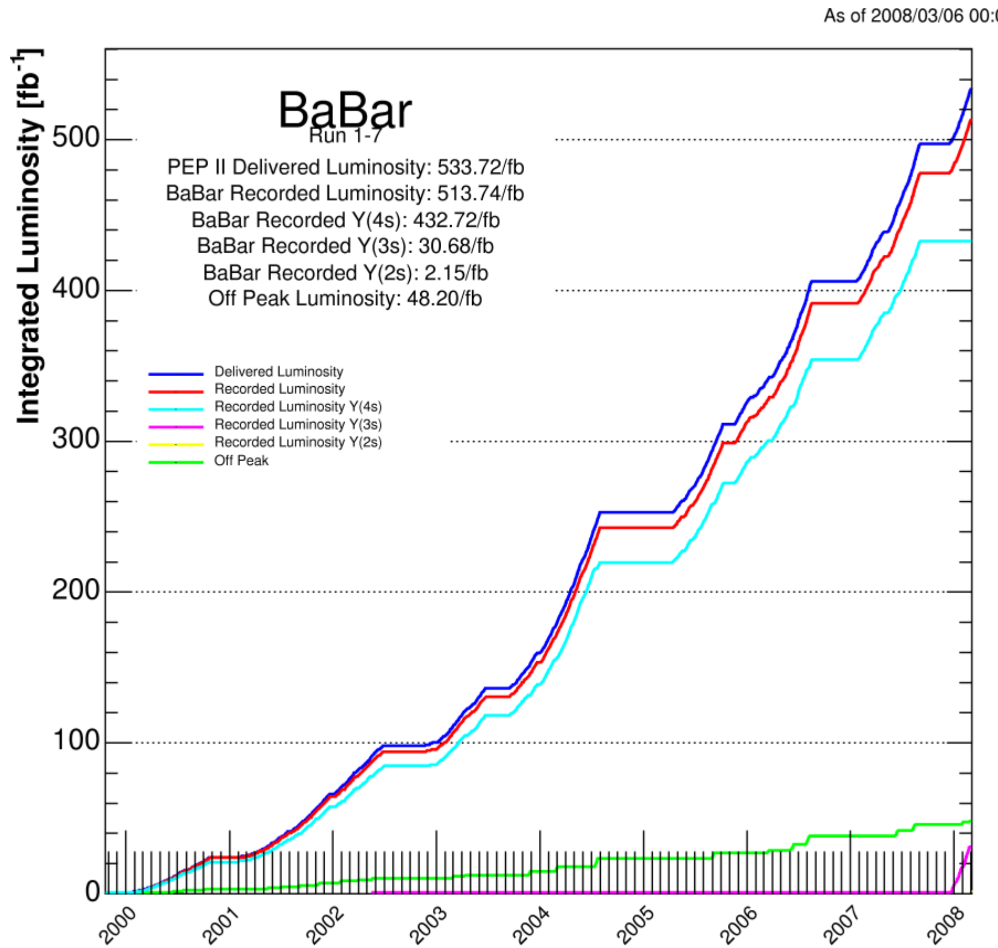




PEP-II Performance



March 2008	PEP-II
Lpeak[$cm^{-1}s^{-1}$]	1.2×10^{34}
$\int$ Ldt [fb^{-1}]	> 530



- Υ(4S) run ended on December 21
- Υ(3S) run completed
- Υ(2S) run ongoing

The BaBar Detector

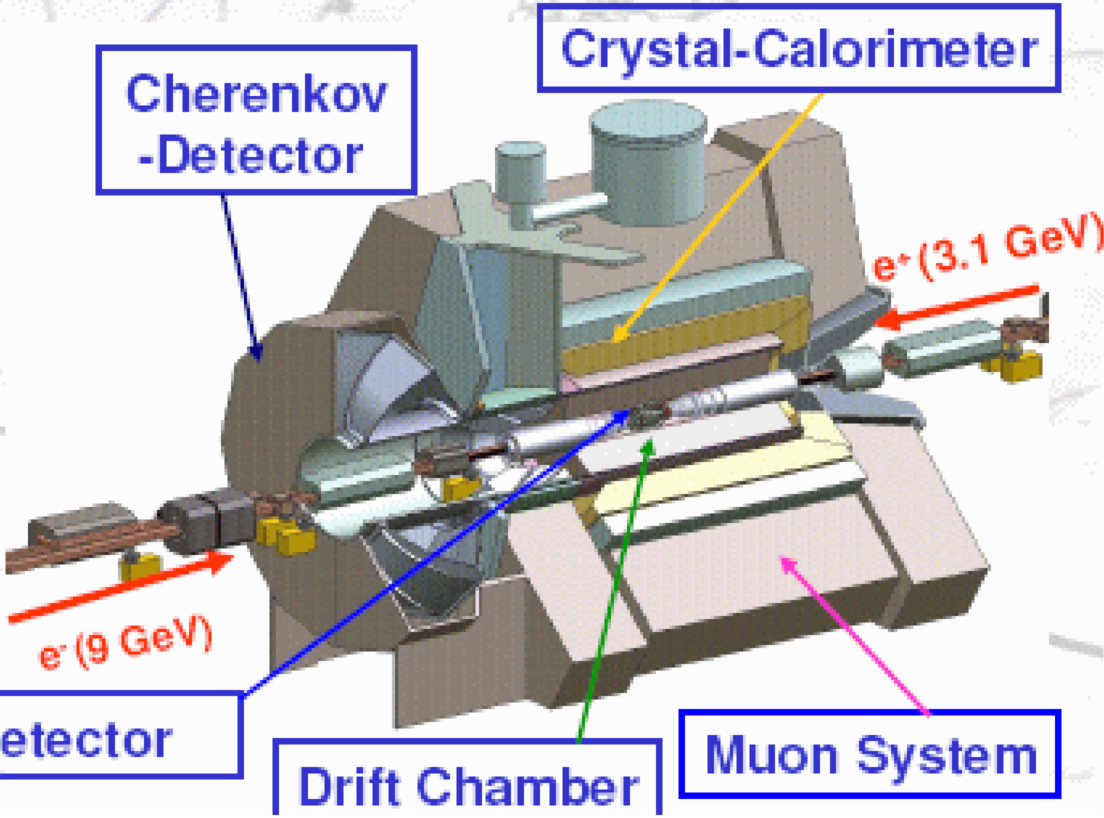
$B \to X_{c,u} \ell \nu$

$\to \pi^{\pm}$'s, $K^{\pm}$'s, γ's

$\ell = e, \mu, \tau$

- Good e, μ ID ($p^*_\ell > 1$GeV)
- Good hadron ID (e.g. π/K separation)
- Angular coverage ≈ 91% of 4π in CMS (challenge for ν reconstruction)

- 5-layer SVT tracker
- 40-layer Drift Chamber → dE/dx
- DIRC (RICH) for particle ID
- CsI(Tl) crystal calorimeter ($e^{\pm}$, γ)
- Instrumented Flux Return for muon ID



Tagging Techniques

Untagged

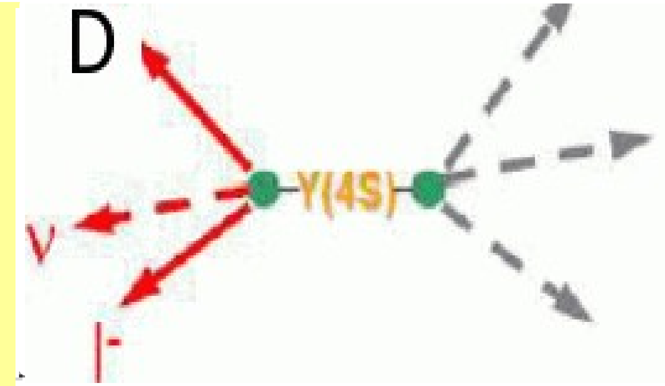
- Initial 4-momentum known
- Missing 4-momentum = ν
- Reconstruct $B \to X\ell\nu$ using m_B (beam-constrained) and $\Delta E = E_B - E_{beam}$

Pros

- High efficiency

Cons

- ν resolution problematic
- Rel. high backgrounds (relatively low purity)



Semileptonic (SL) Tag

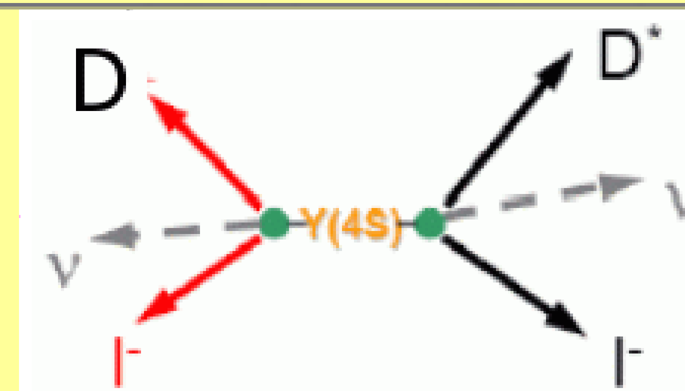
- One B reconstructed in a selection of $D^{(*)}\ell\nu$ modes
- Two missing ν in event
- Use kinematic constraints

Pros

- Lower backgrounds (higher purity)

Cons

- Relatively low efficiency



Full Recon Tag (Breco)

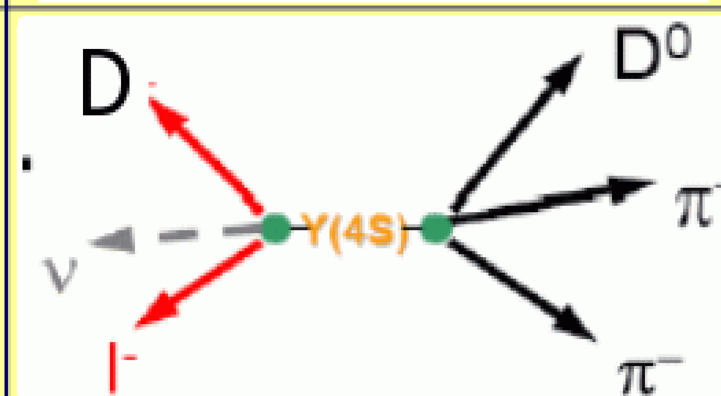
- One B reconstructed completely in known $b \to c$ mode.
- Many modes used.

Pros

- Very good ν resolution
- Very low backgrounds

Cons

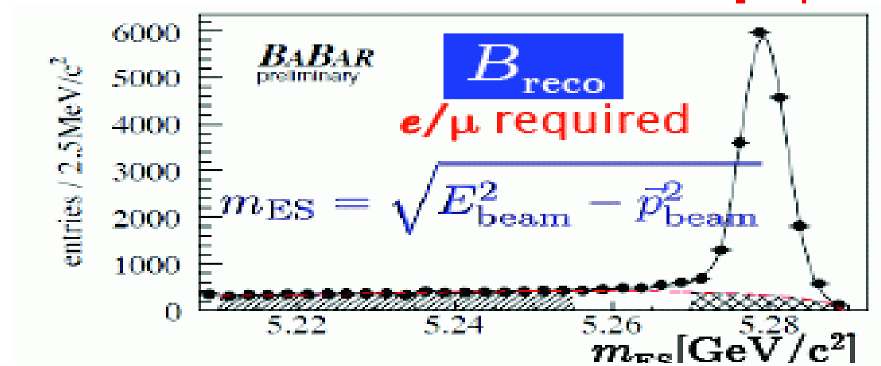
- Very low efficiency

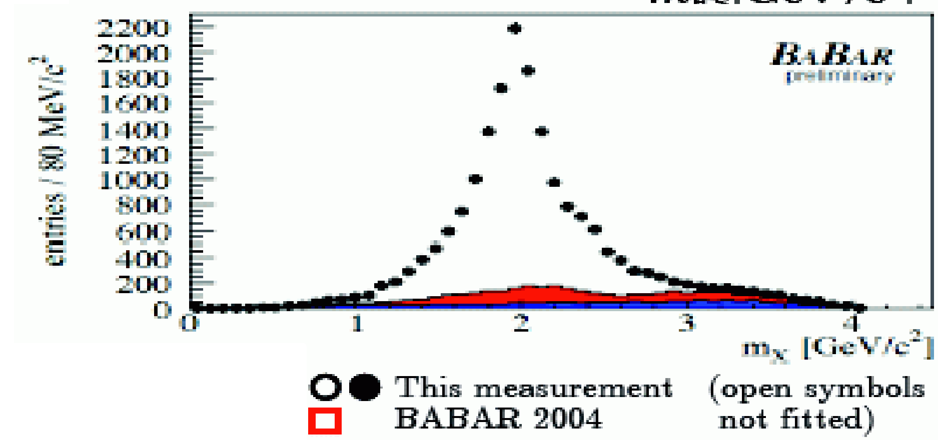


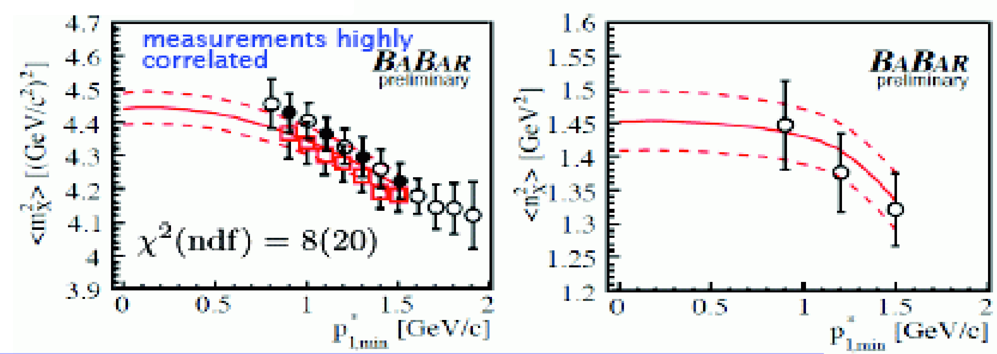
Moments in $B \to X_c l \nu$

ArXiv:0707.2670 [hep-ex]

- Inclusive reconstruction in tagged events, subtract background with m_{ES}
- Require 1 lepton (e,μ) with energy >0.8 GeV/c in B rest frame
- Remaining charged and neutral particles form X_c system
- Improve resolution with kinematic fit
- Energy-momentum conservation
- E_{miss}, p_{miss} consistent with n
- No unfolding, but event-by-event calibration
- Dominant systematic uncertainty: efficiency on inclusive event reconstruction
- Mixed moments

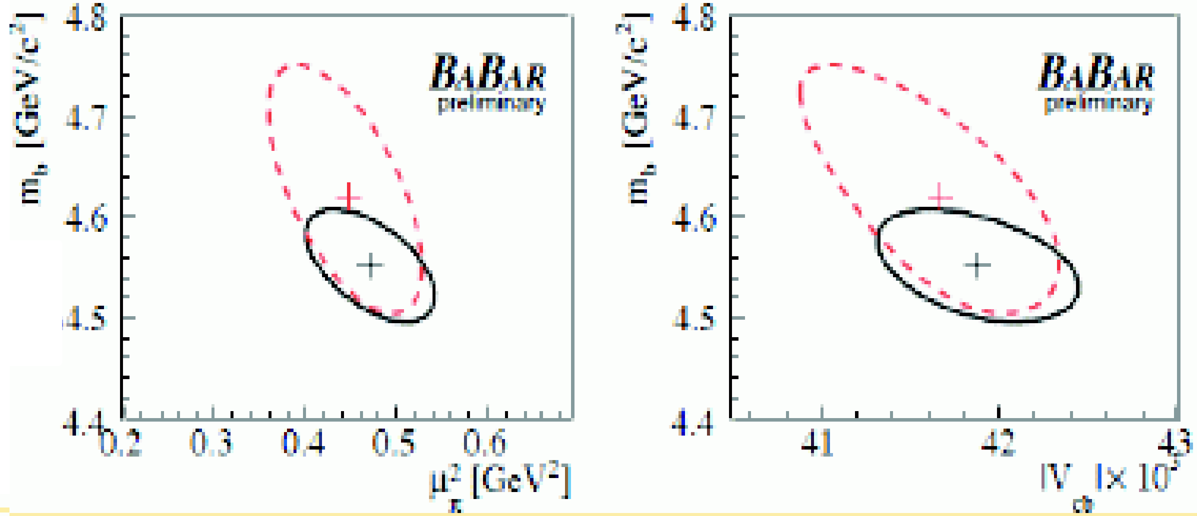






OPE Fit: Kinetic Scheme

All Moments ——
Without $b \to s\gamma$ – – –



- 27 input moments:
  - 8 mass moments (this analysis)
  - 13 E_l moments (Phys. Rev. D69 111104 (2004))
  - 6 E_γ moments (Phys. Rev. D 72, 052004 (2005), Phys. Rev. Lett. 97 171803 (2006))
- Further input: τ_B
- 8 fit parameters:
  - $|V_{cb}|$, m_b, m_c, $\mathcal{B}_{sl}$
  - 4 HQE parameters

	$\|V_{cb}\| \times 10^3$	m_b [GeV/c^2]	m_c [GeV/c^2]	$\mathcal{B}$ [%]	μ_π^2 [GeV^2]	μ_G^2 [GeV^2]	ρ_D^3 [GeV^3]	ρ_{LS}^3 [GeV^3]
Results	41.88	4.552	1.070	10.597	0.471	0.330	0.220	-0.159
Δ_{exp}	0.44	0.038	0.055	0.171	0.034	0.042	0.021	0.081
Δ_{theo}	0.35	0.040	0.065	0.053	0.062	0.043	0.042	0.050
$\Delta\Gamma_{SL}$	0.59							
Δ_{tot}	0.81	0.055	0.085	0.179	0.070	0.060	0.047	0.095
$\|V_{cb}\|$	1.00	-0.42	-0.27	0.75	0.42	-0.28	0.25	0.10
m_b		1.00	0.96	0.09	-0.56	-0.07	-0.38	-0.24
m_c			1.00	0.15	-0.63	-0.32	-0.51	-0.15
$\mathcal{B}$				1.00	0.09	-0.10	0.02	-0.04
μ_π^2					1.00	0.40	0.87	0.10
μ_G^2						1.00	0.41	-0.05
ρ_D^3							1.00	-0.21
ρ_{LS}^3								1.00

Global OPE Fits

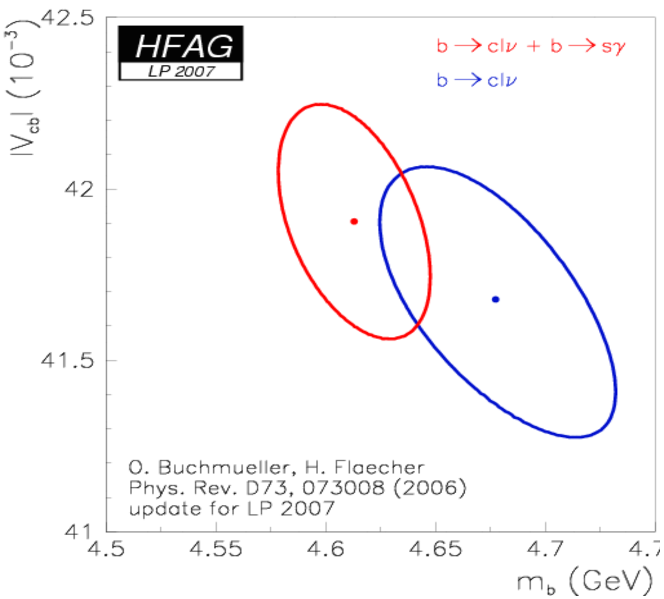
- Extraction of $|V_{cb}|$ and OPE parameters

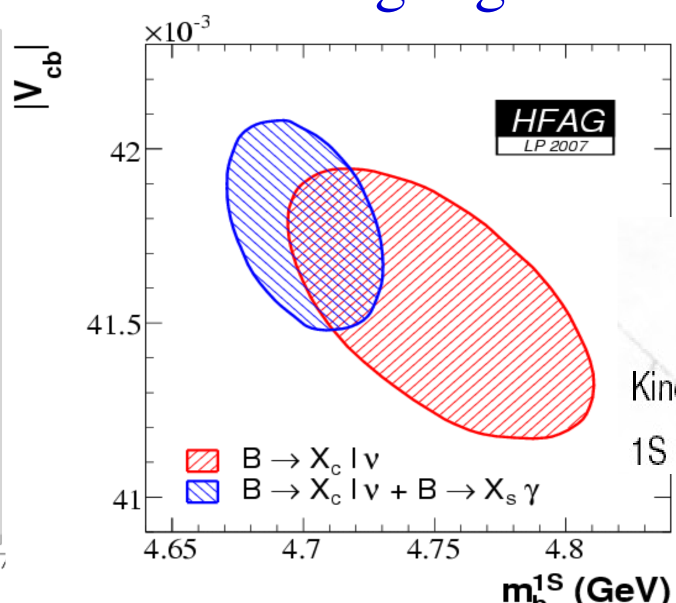
  BaBar kinetic scheme: arXiv:0707.2670

  Belle 1S scheme and kinetic scheme: ICHEP 06, updated
- Global Fit – use all available infos
  - Kinetic scheme:

    Buchmuller-Flacher (PRD73,073008(2006)) + update
  - 1S scheme:

http://www.slac.stanford.edu/xorg/fag/semi/LP07/gbl_fits/1S/





	m_b (GeV)	m_b (GeV)
	$b \to c\ell\nu$ $b \to s\gamma$	$b \to c\ell\nu$
Kinetic scheme	4.613 ± 0.035	4.677 ± 0.053
1S scheme	4.701 ± 0.030	4.751 ± 0.058

Status of Exclusive $B \to X_c l \nu$

- Despite large BF, 20% of $B \to X_c l \nu$ affected by large uncertainties

Decay Mode	Branching Fraction
$B^0 \to \ell^- \bar{\nu}_\ell$ + anything	10.33 ± 0.28 %
$\bar{B}^0 \to D^+ \ell^- \bar{\nu}_\ell$	2.08 ± 0.18 %
$\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell$	5.29 ± 0.19 %
$\bar{B}^0 \to D_1(2420)^+ \ell^- \bar{\nu}_\ell$	??
$\bar{B}^0 \to D_2(2460)^+ \ell^- \bar{\nu}_\ell$	??
$\bar{B}^0 \to D^0 \pi^+ \ell^- \bar{\nu}_\ell$	0.32 ± 0.10 %
$\bar{B}^0 \to D^{*0} \pi^+ \ell^- \bar{\nu}_\ell$	0.65 ± 0.15 %
$\bar{B}^0 \to D^{(*)} n\pi \ell^- \bar{\nu}_\ell$	??

Decay Mode	Branching Fraction
$B^- \to \ell^- \bar{\nu}_\ell$ + anything	10.99 ± 0.28 %
$B^- \to D^0 \ell^- \bar{\nu}_\ell$	2.15 ± 0.22 %
$B^- \to D^{*0} \ell^- \bar{\nu}_\ell$	6.5 ± 0.5 %
$B^- \to D_1(2420)^0 \ell^- \bar{\nu}_\ell$	0.56 ± 0.16 %
$B^- \to D_2(2460)^0 \ell^- \bar{\nu}_\ell$	<0.8 % 90CL
$B^- \to D^+ \pi^- \ell^- \bar{\nu}_\ell$	0.52 ± 0.10 %
$B^- \to D^{*+} \pi^- \ell^- \bar{\nu}_\ell$	0.63 ± 0.15 %
$B^- \to D^{(*)} n\pi \ell^- \bar{\nu}_\ell$	??

PDG07

- Actual measurements somewhat puzzling!

Puzzle 1: Inclusive – Exclusive disagreement

$\mathrm{BF}(B \to X_c l \nu) \neq \mathrm{BF}(D l \nu) + \mathrm{BF}(D^* l \nu) + \mathrm{BF}(D^{**} l \nu)$

5(10)% of $B \to X_c l \nu$ missing for B^-(B^0)

Puzzle 2: $B \to D^* l \nu$ Branching Fractions

$\mathrm{BF}(B^- \to D^{*0} l \nu)/\mathrm{BF}(B^0 \to D^{*-} l \nu) = 1.23 \pm 0.10 \neq 1.071$ (**isospin** constrain)

Status of Exclusive $B \to X_c l\nu$

Puzzle 3: Role of $B \to D^{**} l\nu$ Decays

- If $B \to D/D^*/D^{**} l\nu$ saturates $B \to X_c l\nu$ rate, we should have:

$$BF(B^- \to D^{**} l\nu)_{subt} = BF(B^- \to X_c l\nu) - BF(B^- \to D^0 l\nu) - BF(B^- \to D^{*0} l\nu) = (2.26 \pm 0.58)\%$$

$$BF(B^0 \to D^{**} l\nu)_{subt} = BF(B^0 \to X_c l\nu) - BF(B^0 \to D^+ l\nu) - BF(B^0 \to D^{*+} l\nu) = (2.80 \pm 0.31)\%$$

- Recent results give:

$BF(B^- \to D^{(*)}\pi l\nu) = (1.81 \pm 0.28)\%$

$BF(B^0 \to D^{(*)}\pi l\nu) = (1.47 \pm 0.26)\%$

Liventsev et al, PRD 72 (2002) 051109

$BF(B^- \to D^{(*)}\pi l\nu) = (1.52 \pm 0.16)\%$

$BF(B^0 \to D^{(*)}\pi l\nu) = (1.37 \pm 0.20)\%$

ArXiv:0712.3503, submitted to PRL

$BF(B^- \to D^{(*)}\pi l\nu) = (1.56 \pm 0.21)\%$

$BF(B^0 \to D^{(*)}\pi l\nu) = (1.47 \pm 0.36)\%$

605 fb^{-1}

ArXiv:0711.3252

Decay Distribution for $B^0 \to D^{*-} l^+ \nu$

- Differential decay rate :

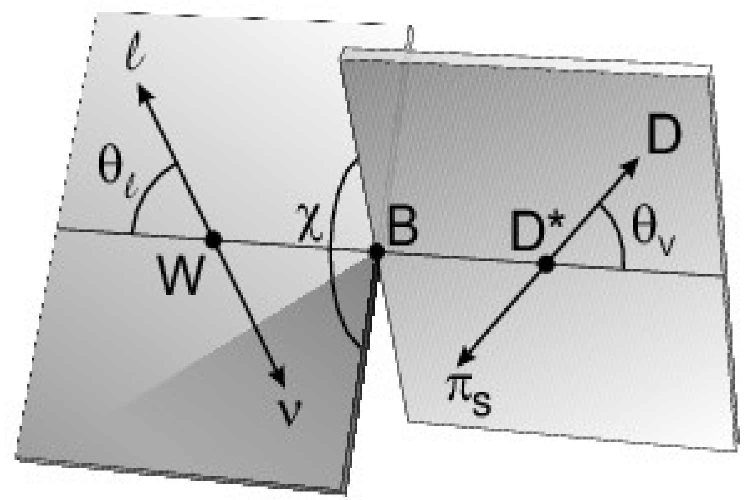
Form Factor — Phase space

$$\frac{d\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\, d\cos\theta_\ell\, d\cos\theta_V\, d\chi} = \frac{G_F^2 |V_{cb}|^2}{48\pi^3} F(w,\theta_\ell,\theta_V,\chi) G(w)$$

- $F(w,\theta_l,\theta_V,\chi)$ incorporates 3 non-trivial form factors, $A_1(w)$, $A_2(w)$, $V(w)$

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

- Perfect HQ symmetry predicts unique universal FF, normalized to 1.0 at zero-recoil. QCD (and QED) corrections neeed!



- Introduce 3 parameters:
- amplitude ratios: $R_1(w)=V/A_1$
  $R_2(w)=V/A_2$
- curvature $\rho^2 = dF/dw|_{w=1}$
- w dependence can be constrained, e.g.

$$h_{A_1}(w) = h_{A_1}(1)\left[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right]$$

$$z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

- Goal is to measure $R_1(w=1)$, $R_2(w=1)$, ρ^2

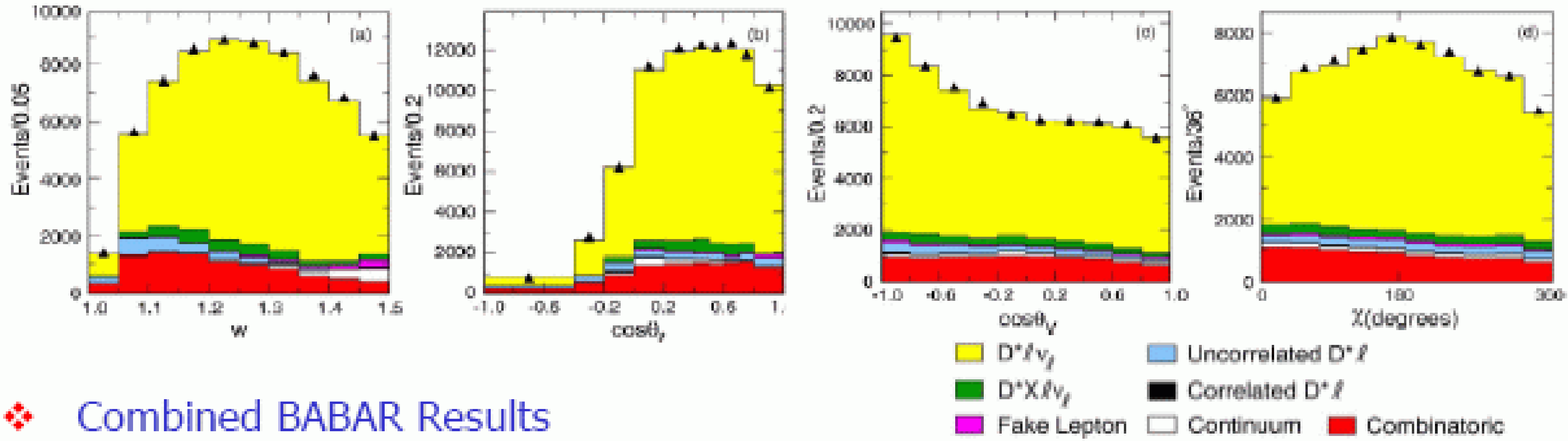
Caprini, Lellouch, Neubert NPB530 (1998) 153

$B \to D^*\ell\nu$: Fit to Diff. 4-dim Cross-section

- Two BaBar parallel analysis combined:
- Max likelihood fit to 4-dim decay rate to get ρ^2, $R_1(1)$, $R_2(1)$
- χ^2 fit to 4 projections to get BF and $F(w)\,|V_{cb}|$

ArXiv:0705.4008

PRD 74 092004(2006)



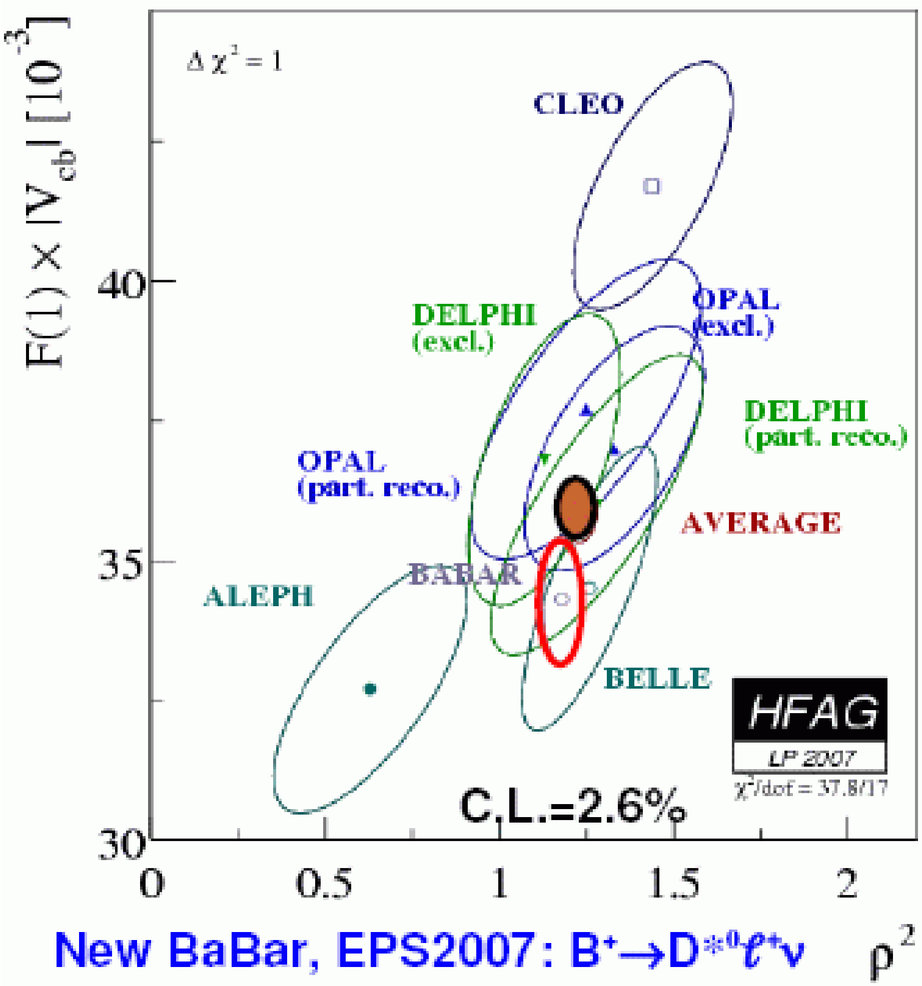
Combined BABAR Results

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

Syst. Uncertainties dominated by detector efficiencies, Bg, R_1, R_2

Results consistent with $R_1(w)$ and $R_2(w)$ parameterization by CLN

Summary: Incl vs Excl $|V_{cb}|$



New BaBar, EPS2007: $B^+ \to D^{*0}\ell^+\nu$

$F(1)|V_{cb}|=(35.9\pm0.6_{stat}\pm1.4_{syst})\times10^{-3}$

$\rho_{A1}^2 = 1.15\pm0.06_{stat}\pm0.08_{syst}$

HFAG average:

$F(1)|V_{cb}|=(35.89\pm0.56)\times10^{-3}$

$\rho_{A1}^2 = 1.23\pm0.05$

$F(1)=0.924\pm0.023$ (J.Laiho, LAT07)

$|V_{cb}|=(38.84\pm0.61_{exp}\pm0.96_{theo})\times10^{-3}$

1.6% 2.5%

Buchmuller, Fleacher, update for LP07:

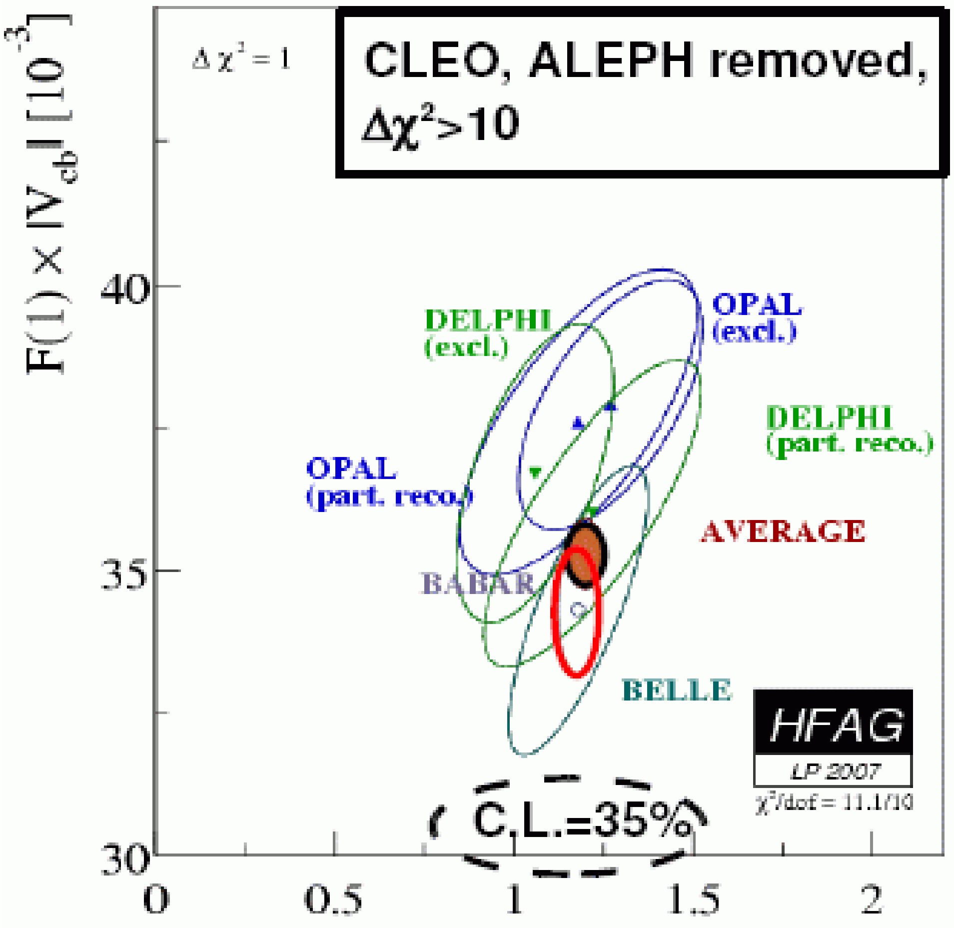
$|V_{cb}|=(41.91\pm0.19_{exp}\pm0.28_{HQE}\pm0.59_{\Gamma SL})\times10^{-3}$

Δ=Incl-Excl=3.07±1.32 (2.3σ difference)

(exp. and theo. errors assumed uncorrelated)

Loose internal consistency: χ^2/ndof=37.8/17
Cons. not expected to improve in the future
Scale exp.error according to PDG recipe?

Summary: Incl vs Excl $|V_{cb}|$



New BaBar EPS2007: $B^+ \to D^{*0} \ell^+ \nu$

$F(1)|V_{cb}|=(35.9\pm0.6_{stat}\pm1.4_{syst})\times10^{-3}$

$\rho_{A1}^2 = 1.15\pm0.06_{stat}\pm0.08_{syst}$

HFAG average:

$F(1)|V_{cb}|=(35.28\pm0.61)\times10^{-3}$

$\rho_{A1}^2 = 1.20\pm0.05$

$F(1)=0.924\pm0.023$ (J.Laiho, LAT07)

$|V_{cb}|=(38.18\pm0.66_{exp}\pm0.95_{theo})\times10^{-3}$

Buchmuller, Fleacher, update for LP07:

$|V_{cb}|=(41.91\pm0.19_{exp}\pm0.28_{HQE}\pm0.59_{\Gamma SL})\times10^{-3}$

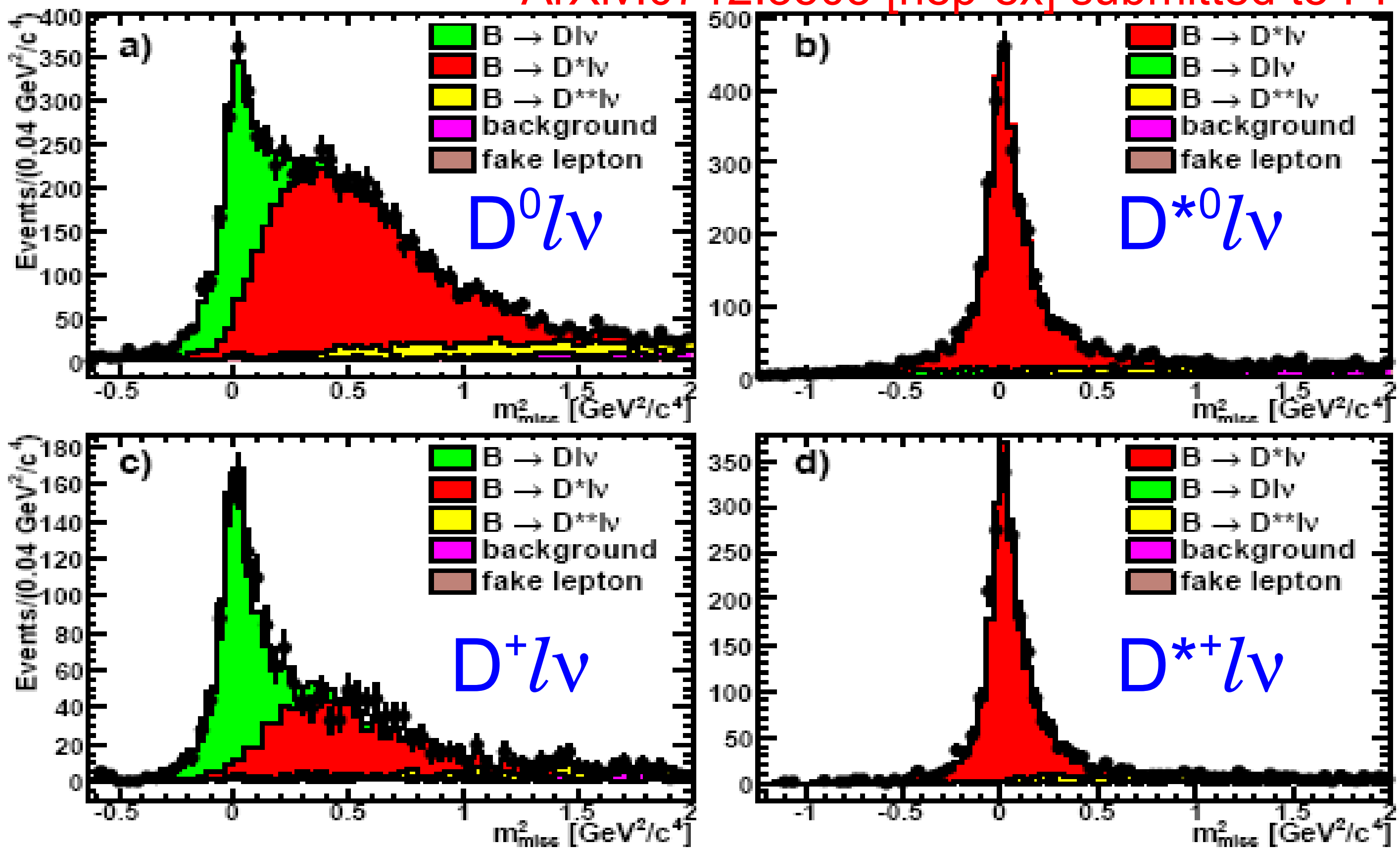
Δ=Incl-Excl=3.73±1.35 (2.8σ difference)

(exp. and theo. errors assumed uncorrelated)

$B \to D/D^{*}l\nu$ Branching Fractions

ArXiv:0712.3503 [hep-ex] submitted to PRL

- Reconstruct $B \to D/D^{*}/D^{(*)}\pi l\nu$ in events tagged by a fully reconstructed B in a hadronic decay mode
- Identify semileptonic B decays through the missing mass squared in the event
- Dominant systematic due to tag, $D^{(*)}$ BF and detector



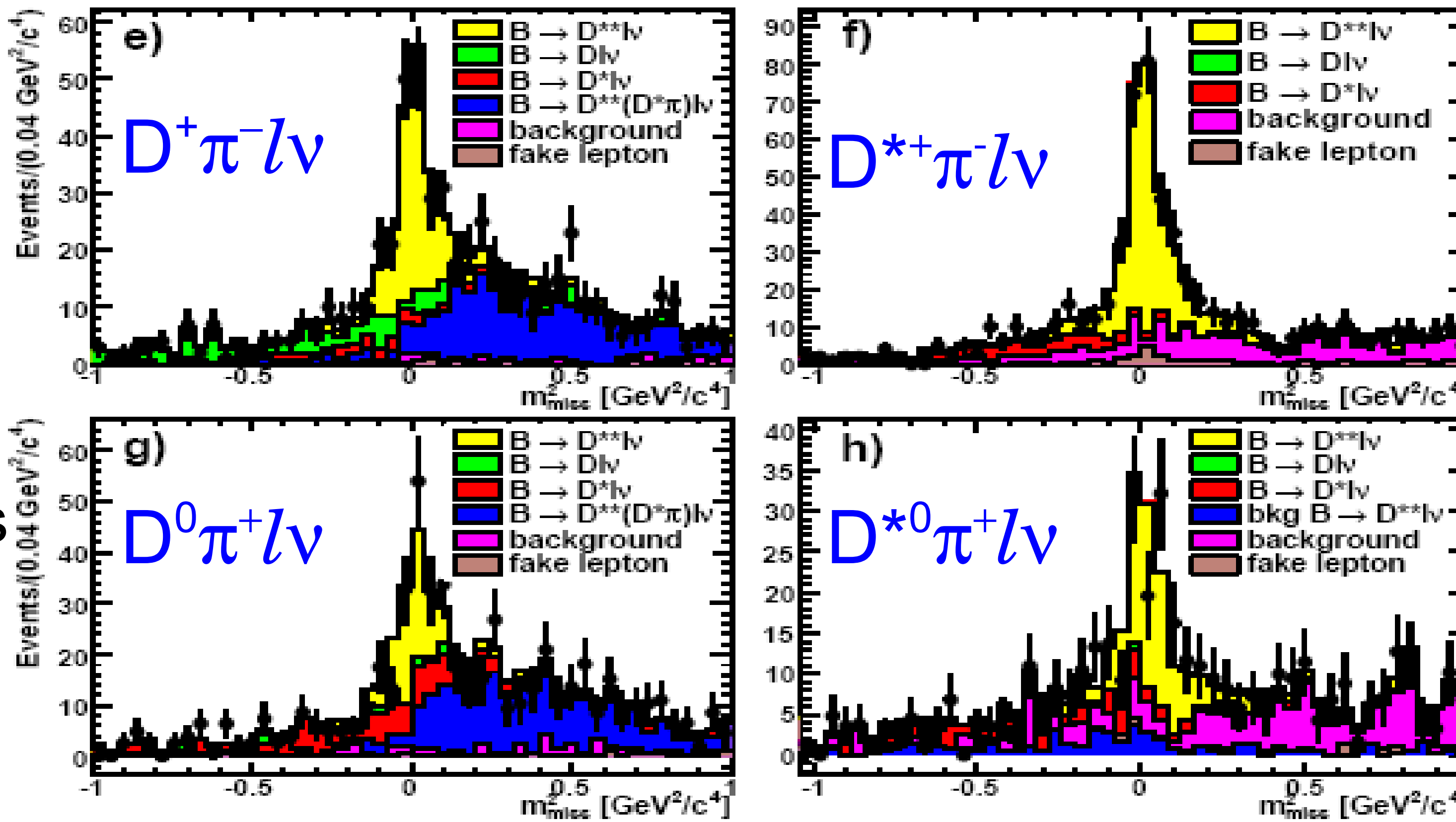
$$\mathcal{B}(B^- \to D^0\ell^-\bar{\nu}_\ell) = (2.33 \pm 0.09_{stat.} \pm 0.09_{syst.})\%$$
$$\mathcal{B}(B^- \to D^{*0}\ell^-\bar{\nu}_\ell) = (5.83 \pm 0.15_{stat.} \pm 0.30_{syst.})\%$$
$$\mathcal{B}(\overline{B}^0 \to D^+\ell^-\bar{\nu}_\ell) = (2.21 \pm 0.11_{stat.} \pm 0.12_{syst.})\%$$
$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell) = (5.49 \pm 0.16_{stat.} \pm 0.25_{syst.})\%$$

- Isospin respected
- Best precise single measurement (tagged sample!)

$B \to D^{(*)}\pi l \nu$ Branching Fractions

ArXiv:0712.3503 [hep-ex] submitted to PRL

- Clean samples of $B \to D^{(*)}\pi l \nu$ events, accurate measurement of branching fractions
- Next step: study of $B \to D^{**} l \nu$ SL decays



$$\mathcal{B}(B^- \to D^{(*)}\pi\ell^-\bar{\nu}_\ell) = (1.52 \pm 0.12_{stat.} \pm 0.10_{syst.})\%$$
$$\mathcal{B}(\overline{B^0} \to D^{(*)}\pi\ell^-\bar{\nu}_\ell) = (1.37 \pm 0.17_{stat.} \pm 0.10_{syst.})\%,$$

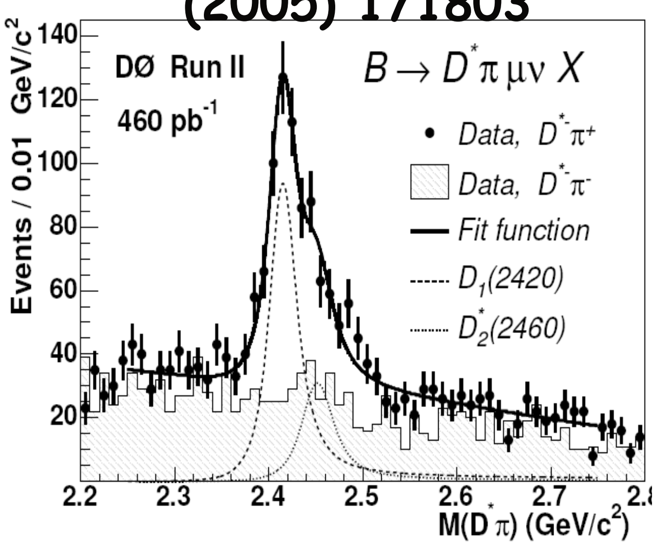
- Incl – Σ Excl($D/D^*/D^{(*)}\pi l \nu$) = **(1.2 ± 0.4)%**!!
- What is missing?

Combining with PR D76 051101 (2007), likely candidate is $B \to D^{(*)} n\pi l \nu$

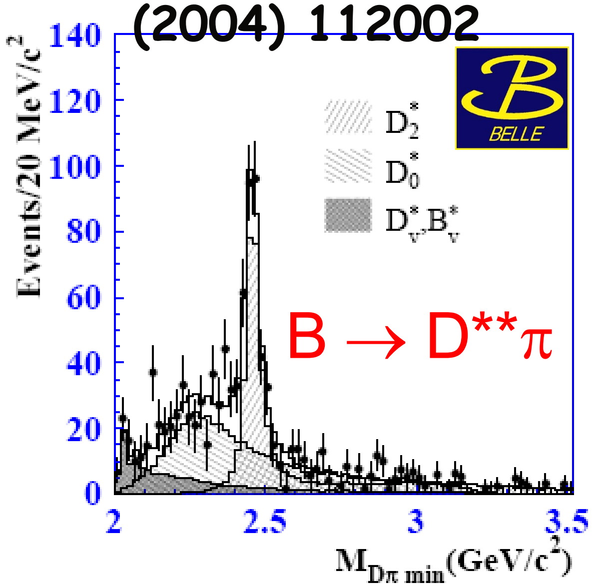
Spectroscopy of excited D mesons

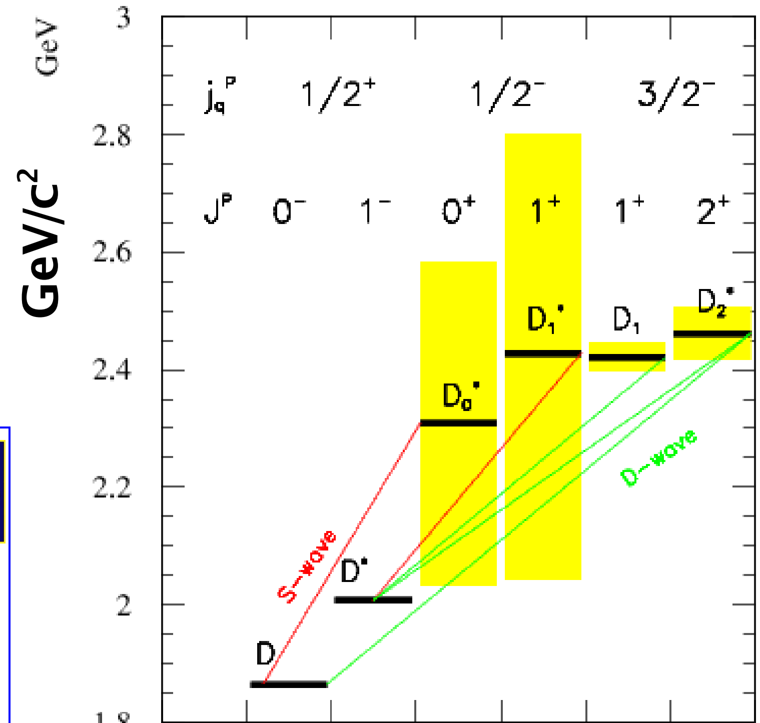
- Use D^{**} as nickname for states $D^{(*)}(n\pi)$ with $n>0$ including:
  - Narrow resonances D_1, D_2^*
  - Broad resonances D_0^*, D_1'
  - Non-resonant?
- Need help from hadronic $B \to D^{**}\pi$ to characterize D** broad states

Abazov et al, PRL 95 (2005) 171803



Abe et al, PRD 69 (2004) 112002





Charm States

- Large uncertainties in $B \to D^{**}l\nu$ Branching Fractions

$B \to D^{**} l \nu$ Branching Fractions

Experiment	$\mathcal{B}(B^- \to D_1^0 \ell^- \bar{\nu}_\ell)$ [%]	$\mathcal{B}(B^- \to D_2^0 \ell^- \bar{\nu}_\ell)$ [%]
CLEO	0.56 ± 0.16	< 0.8 @90 C.L.
Experiment	$\mathcal{B}(B \to D_1^0 \ell^- \bar{\nu}_\ell X)$ [%]	$\mathcal{B}(B \to D_2^0 \ell^- \bar{\nu}_\ell X)$ [%]
ALEPH	0.71 ± 0.15	< 0.2 @90 C.L.
OPAL	1.00 ± 0.33	< 1.76 @90 C.L.
D0	0.33 ± 0.06	0.44 ± 0.16

DELPHI: $\mathcal{B}(B \to D_1^* \ell \nu) = (1.25 \pm 0.37)\%$
$\mathcal{B}(B \to D_0 \ell \nu) = (0.42 \pm 0.40)\%$

BF($B^- \to D_1 l^- \nu$)= (0.45± 0.04)%

BF($B^0 \to D_1 l^+ \nu$)= (0.36± 0.06)%

BF($B^- \to D_2 l^- \nu$)= (0.35± 0.06)%

BF($B^0 \to D_2 l^+ \nu$)= (0.27± 0.06)%

BaBar Preliminary, shown @DPF 2006

Experiment: Rate for broad large!

Theory: Γ (narrow) >> Γ(broad) !!!

In the heavy quark limit (m_b and $m_c \to \infty$), only two independent form factors (generalised Isgur-Wise functions) $\tau_{1/2}$ and $\tau_{3/2}$ for

j_l= 1/2, 3/2.

$\Gamma(B \to D^*_2 l \nu ; D_1 l \nu) \propto |\tau_{3/2}(w)|^2$ $w = (p_B^\mu . p_{D^{**}}^\mu)/(m_B m_{D^{**}})$

$\Gamma(B \to D^*_0 l \nu ; D^*_1 l \nu) \propto |\tau_{1/2}(w)|^2$

$$\Sigma_n \varepsilon^{(n)}_{3/2} |\tau^{(n)}_{3/2}(1)|^2 = 4 \; \Sigma_n \varepsilon^{(n)}_{1/2} |\tau^{(n)}_{1/2}(1)|^2$$

more to the puzzle from Belle

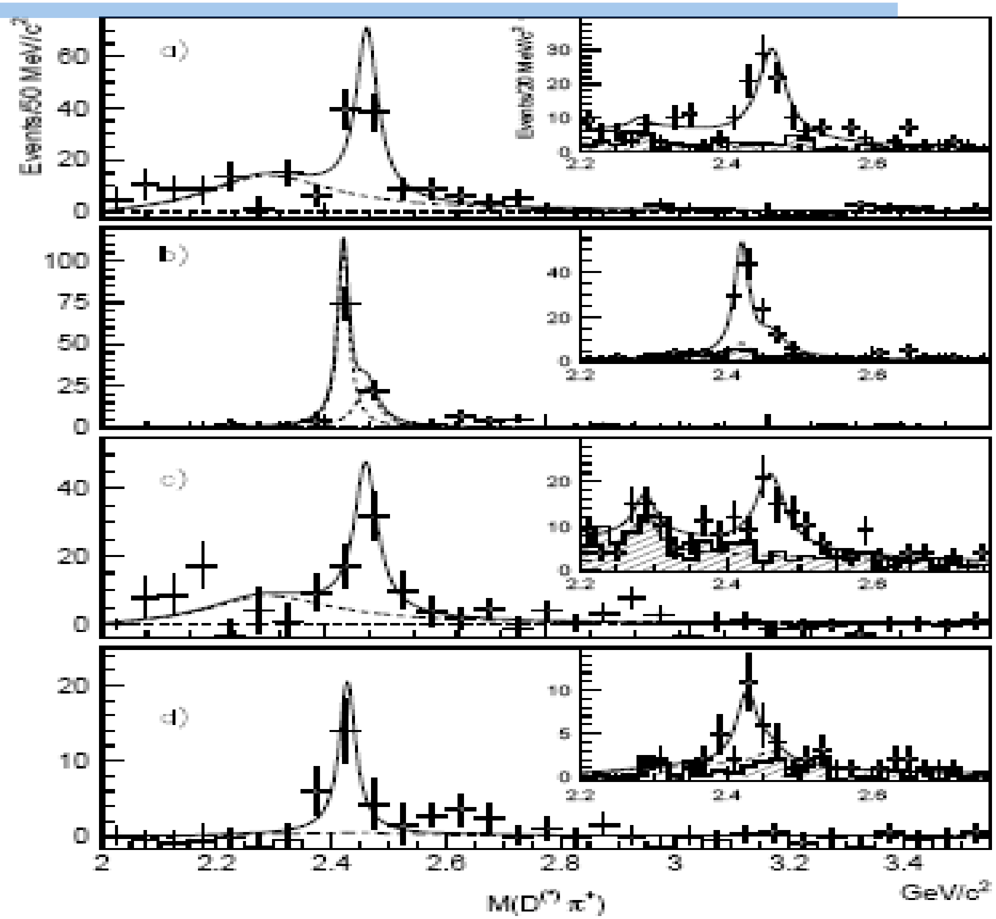
$$\mathcal{B}(\text{mode}) \equiv \mathcal{B}(B \to D^{**}\ell\nu) \times \mathcal{B}(D^{**} \to D^{(*)}\pi^+)$$

$D\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to \bar{D}_0^{*0}\ell^+\nu$	102 ± 19	$0.24 \pm 0.04 \pm 0.06$	5.4
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	94 ± 13	$0.22 \pm 0.03 \pm 0.04$	8.0
$B^0 \to D_0^{*-}\ell^+\nu$	61 ± 22	$0.20 \pm 0.07 \pm 0.05$	2.6
$B^0 \to D_2^{*-}\ell^+\nu$	68 ± 13	$0.22 \pm 0.04 \pm 0.04$	5.5

$D^*\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to \bar{D}_1^{\prime 0}\ell^+\nu$	-5 ± 11	< 0.07 @ 90% C.L.	
$B^+ \to \bar{D}_1^0\ell^+\nu$	81 ± 13	$0.42 \pm 0.07 \pm 0.07$	6.7
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	35 ± 11	$0.18 \pm 0.06 \pm 0.03$	3.2
$B^0 \to D_1^{\prime -}\ell^+\nu$	4 ± 8	< 0.5 @ 90% C.L.	
$B^0 \to D_1^-\ell^+\nu$	20 ± 7	$0.54 \pm 0.19 \pm 0.09$	2.9
$B^0 \to D_2^{*-}\ell^+\nu$	1 ± 6	< 0.3 @ 90% C.L.	

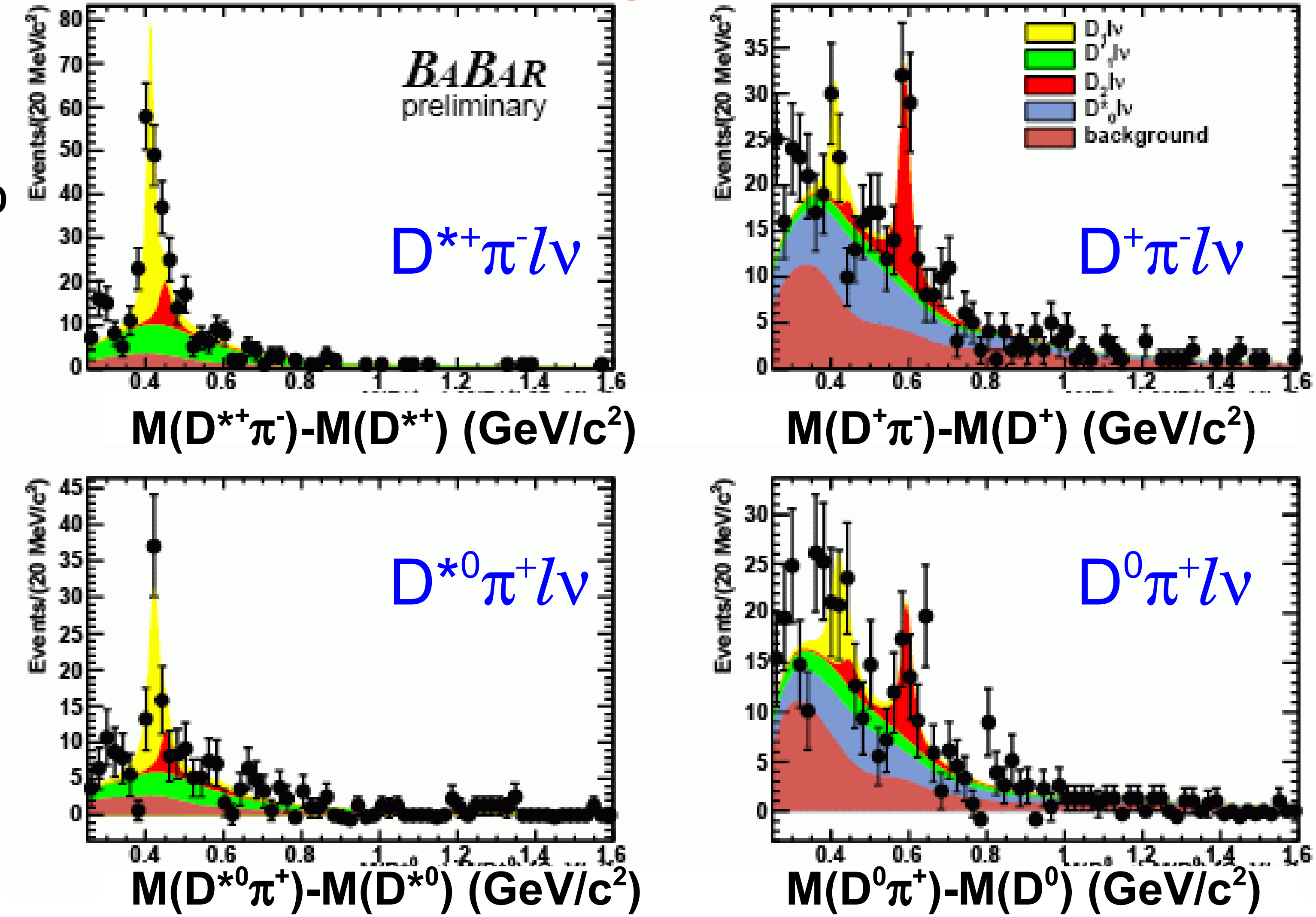


- Hadronic tag analysis from Belle, 605 fb^{-1}, arXiv:0712.3252
- Confirm signals for narrow D_1 and D_2, sees only broad D_0^*, no D_1'
- Against theoretical predictions and previous results (DELPHI)

$B \to D^{**}\ell\nu$ Branching Fractions

Just shown @ Moriond 08

- Simultaneous unbinned ML fit to four channels, including cross-feed
- Background constrained from fit to m_{ES} distributions
- See large broad components



$B \to D^{**} l \nu$ Branching Fractions

Decay Mode	$\mathcal{B}(\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell) \times \mathrm{B}(D^{**} \to D^{(*)}\pi)$ %(BELLE)	BABAR Branching Fraction
	$D\pi$ invariant mass fit	
$B^- \to D_0^{*0}\ell^-\bar{\nu}_\ell$	$0.24 \pm 0.04 \pm 0.06$	$0.28 \pm 0.05 \pm 0.04$
$B^- \to D_2^{*0}\ell^-\bar{\nu}_\ell$	$0.22 \pm 0.03 \pm 0.04$	$0.16 \pm 0.03 \pm 0.01$
$\bar{B}^0 \to D_0^{*+}\ell^-\bar{\nu}_\ell$	$0.20 \pm 0.07 \pm 0.05$	$0.47 \pm 0.09 \pm 0.07$
$\bar{B}^0 \to D_2^{*+}\ell^-\bar{\nu}_\ell$	$0.22 \pm 0.04 \pm 0.04$	$0.08 \pm 0.04 \pm 0.02$
	$D^*\pi$ invariant mass fit	
$B^- \to D_1'^0\ell^-\bar{\nu}_\ell$	< 0.07 @ 90CL	$0.27 \pm 0.05 \pm 0.05$
$B^- \to D_1^0\ell^-\bar{\nu}_\ell$	$0.42 \pm 0.07 \pm 0.07$	$0.29 \pm 0.03 \pm 0.03$
$B^- \to D_2^{*0}\ell^-\bar{\nu}_\ell$	$0.18 \pm 0.06 \pm 0.03$	$0.07 \pm 0.01 \pm 0.01$
$\bar{B}^0 \to D_1'^+\ell^-\bar{\nu}_\ell$	< 0.5 @ 90CL	$0.37 \pm 0.07 \pm 0.05$
$\bar{B}^0 \to D_1^+\ell^-\bar{\nu}_\ell$	$0.54 \pm 0.19 \pm 0.09$	$0.25 \pm 0.05 \pm 0.03$
$\bar{B}^0 \to D_2^{*+}\ell^-\bar{\nu}_\ell$	< 0.3 @ 90CL	$0.04 \pm 0.02 \pm 0.01$

- First simultaneous observation of the four D** predicted by HQET
- Result for the D_0^* broad state consistent between BaBar and BELLE
- BaBar observes the D_1', not present in the BELLE data
- Large rate for the broad states, 1/2 vs 3/2 puzzle lingers

Exclusive $B \to X_c l\nu$:Summary

- My personal averages

Decay Mode	Branching Fraction
$\bar{B}^0 \to \ell^- \bar{\nu}_\ell$ + anything	10.33 ± 0.28 %
$\bar{B}^0 \to D^+ \ell^- \bar{\nu}_\ell$	2.15 ± 0.12 %
$\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell$	5.29 ± 0.14 %
$\bar{B}^0 \to D_1(2420)^+ \ell^- \bar{\nu}_\ell$	$\simeq 0.38 \pm 0.05$ %
$\bar{B}^0 \to D_2(2460)^+ \ell^- \bar{\nu}_\ell$	$\simeq 0.26 \pm 0.04$ %
$\bar{B}^0 \to D_1'^+ \ell^- \bar{\nu}_\ell$	$\simeq 0.44 \pm 0.09$ %
$\bar{B}^0 \to D_0^{*+} \ell^- \bar{\nu}_\ell$	$\simeq 0.48 \pm 0.09$ %
$\bar{B}^0 \to D^0 \pi^+ \ell^- \bar{\nu}_\ell$	0.38 ± 0.07 %
$\bar{B}^0 \to D^{*0} \pi^+ \ell^- \bar{\nu}_\ell$	0.53 ± 0.08 %
$\bar{B}^0 \to D^{(*)} n\pi \ell^- \bar{\nu}_\ell$	$\simeq 1.2 \pm 0.4$ %

Decay Mode	Branching Fraction
$B^- \to \ell^- \bar{\nu}_\ell$ + anything	10.99 ± 0.28 %
$B^- \to D^0 \ell^- \bar{\nu}_\ell$	2.28 ± 0.11 %
$B^- \to D^{*0} \ell^- \bar{\nu}_\ell$	5.89 ± 0.24 %
$B^- \to D_1(2420)^0 \ell^- \bar{\nu}_\ell$	$\simeq 0.45 \pm 0.04$ %
$B^- \to D_2(2460)^0 \ell^- \bar{\nu}_\ell$	$\simeq 0.35 \pm 0.04$ %
$B^- \to D_1'^0 \ell^- \bar{\nu}_\ell$	$\simeq 0.47 \pm 0.09$ %
$B^- \to D_0^{0*} \ell^- \bar{\nu}_\ell$	$\simeq 0.52 \pm 0.09$ %
$B^- \to D^+ \pi^- \ell^- \bar{\nu}_\ell$	0.45 ± 0.06 %
$B^- \to D^{*+} \pi^- \ell^- \bar{\nu}_\ell$	0.60 ± 0.08 %
$B^- \to D^{(*)} n\pi \ell^- \bar{\nu}_\ell$	$\simeq 1.2 \pm 0.4$ %

- Several improvements, in particular due to new BaBar measurements:

  ArXiv:0712.3503 (B $\to$ D/D*/D*$\pi l\nu$)

  PR D76 051101 (2007) (B $\to$ D/D*/D**$l\nu$)

  ArXiv:0707.2655 (B $\to$ D$^{*0} l\nu$)

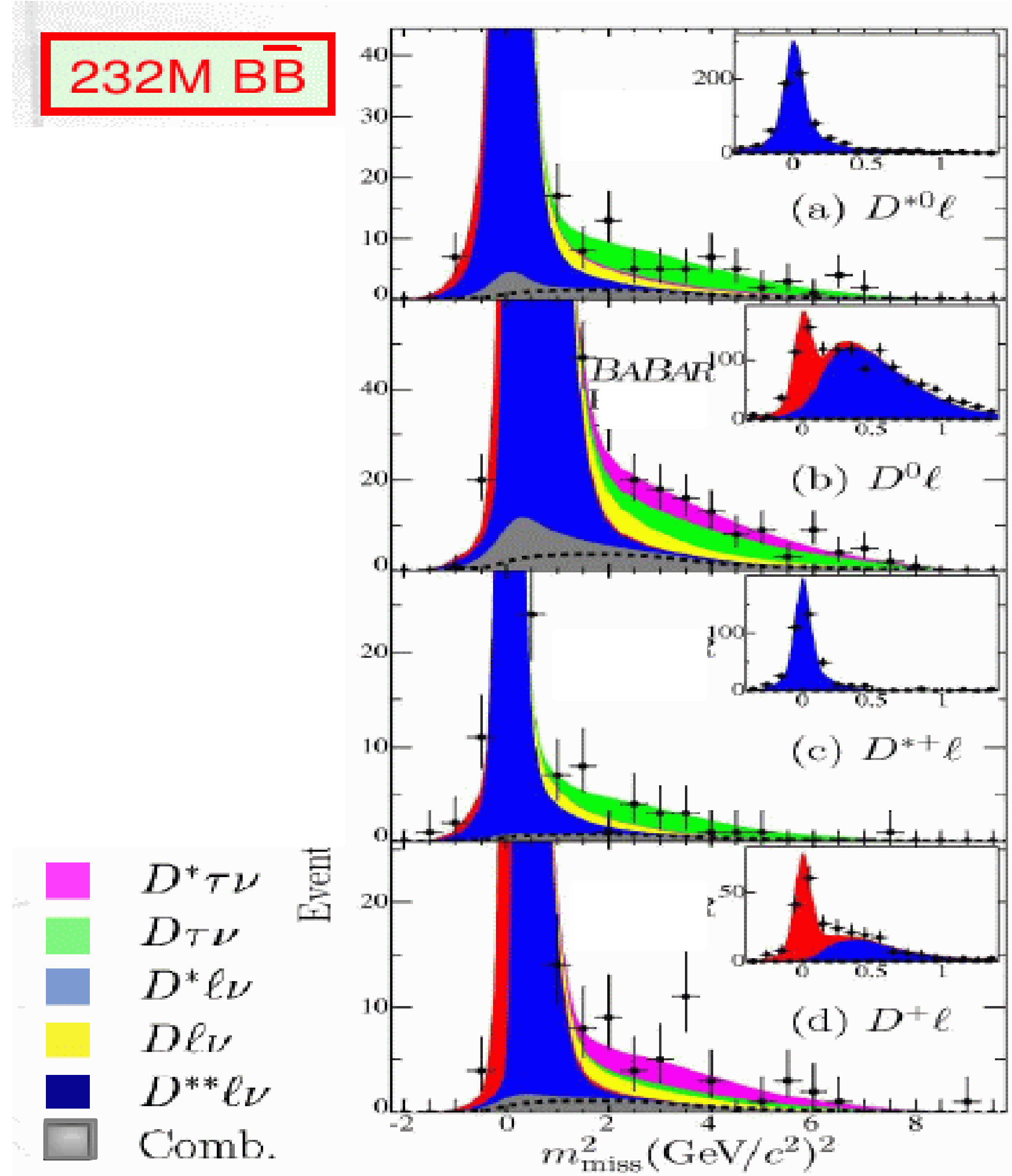
  and many more still to come.. and 1 puzzle (almost) resolved!

BF($B^- \to D^{*0} l\nu$)/BF($B^0 \to D^{*-} l\nu$)=1.11±0.05 !! (**isospin** constrain = 1.071)

Observation of $B \to D^{(*)}\tau\nu$

- Very challenging: $\tau \to e\nu_e\nu_\tau$, $\tau \to \mu\nu_\mu\nu_\tau$ produce tow additional neutrinos
- Select hadronic B events. identify $D^{(*)}$ plus lepton in the recoil
- Maximum likelihood fit with:
  - Missing mass Squared and lepton energy
  - 8 channels: 4 signal ($D^0\tau\nu$, $D^{*0}\tau\nu$, $D^+\tau\nu$, $D^{*+}\tau\nu$), simultaneous fit to $D^{**}(D^{(*)}\pi^0)l\nu$ to constrain D^{**} feeddown

232M $B\bar{B}$



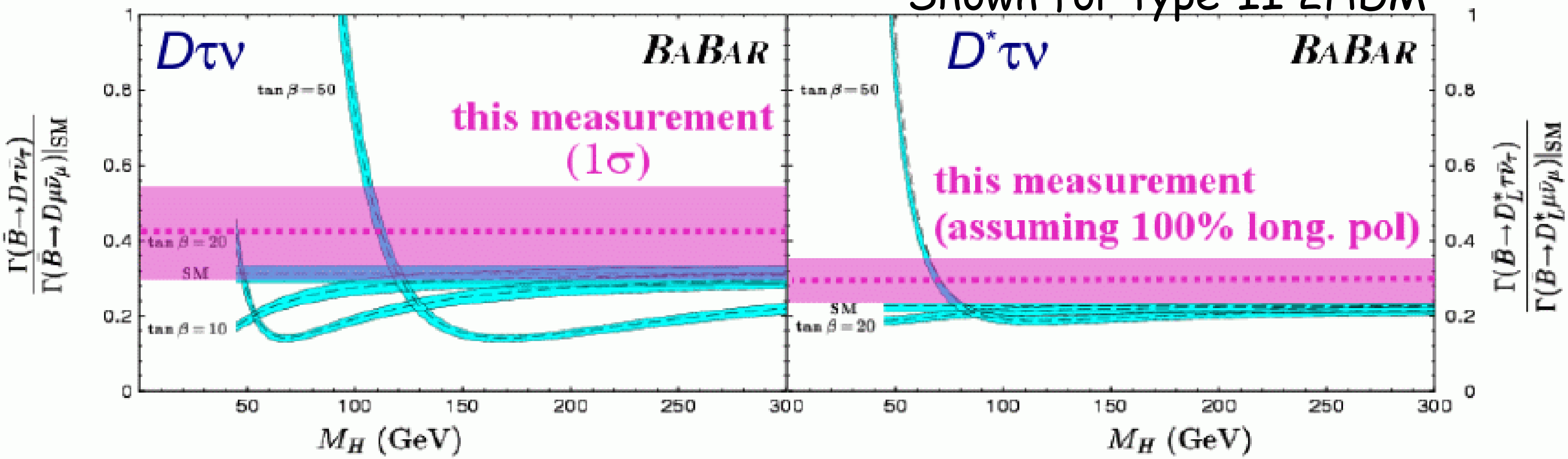
Observation of $B \to D^{(*)}\tau\nu$

Mode		$\mathcal{B}$ [%]
B^-	$\to D^0\tau^-\overline{\nu}_\tau$	$0.67 \pm 0.37 \pm 0.11 \pm 0.07$
B^-	$\to D^{*0}\tau^-\overline{\nu}_\tau$	$2.25 \pm 0.48 \pm 0.22 \pm 0.17$
$\overline{B}^0$	$\to D^+\tau^-\overline{\nu}_\tau$	$1.04 \pm 0.35 \pm 0.15 \pm 0.10$
$\overline{B}^0$	$\to D^{*+}\tau^-\overline{\nu}_\tau$	$1.11 \pm 0.51 \pm 0.04 \pm 0.04$
B	$\to D\tau^-\overline{\nu}_\tau$	$0.86 \pm 0.24 \pm 0.11 \pm 0.06$
B	$\to D^*\tau^-\overline{\nu}_\tau$	$1.62 \pm 0.31 \pm 0.10 \pm 0.05$

$$\mathcal{B}(\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37)\%$$

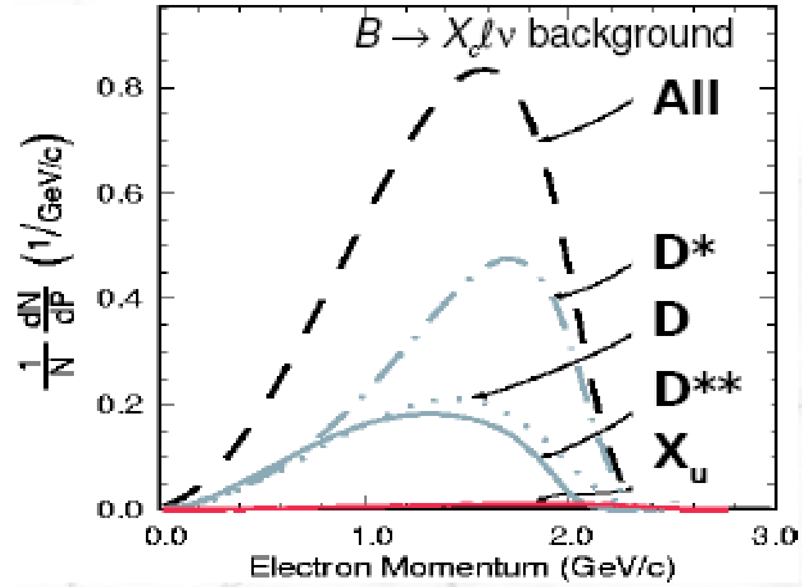
Belle 535M BB, PRL 99 191807 (2007)
BaBar 232M BB, PRL 100 021801 (2008)

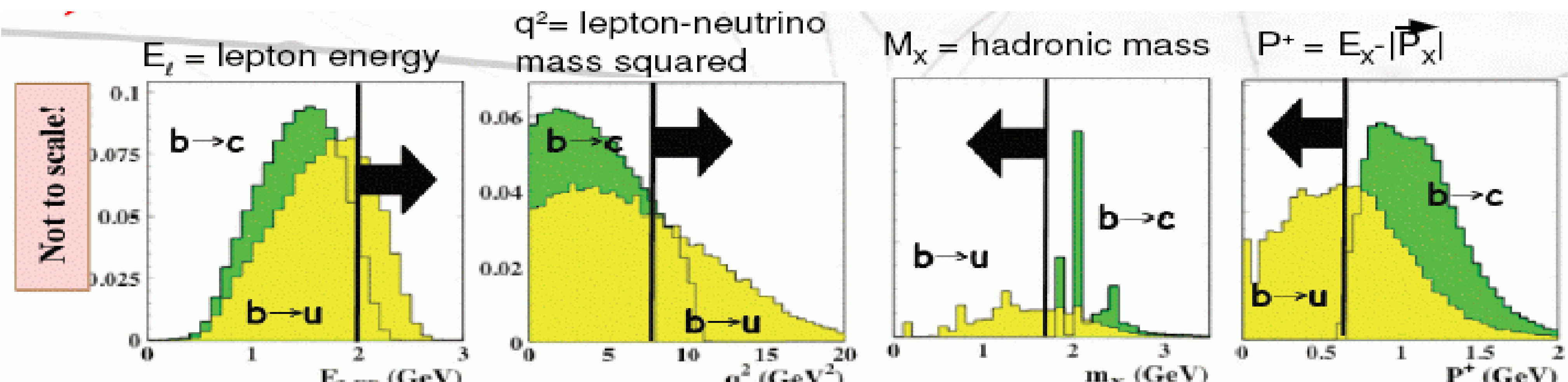
Shown for type-II 2HDM



Inclusive Measurement of $B \to X_u l\nu$

- $B \to X_c l\nu$ background is about 50 times larger than $B \to X_u l\nu$
- Major experimental challenge is to separate $B \to X_c l\nu$ from signal
- Achieved in regions of phase space where $B \to X_c l\nu$ background is suppressed partial decay rate





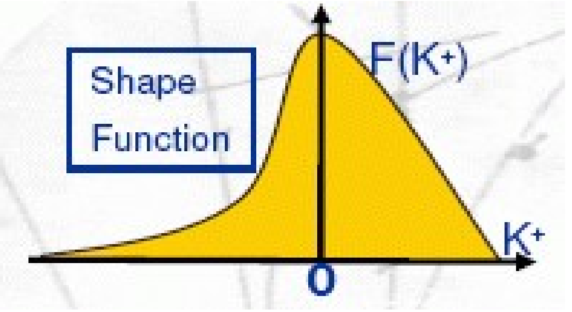
Restriction of phase space is a challenge to theory!

Inclusive Measurement of $B \to X_u l \nu$

- OPE predicts total rate

$$\Gamma(B \to X_u \ell \nu) \propto m_b^5 |V_{ub}|^2 (1 + A_{EW}) A_{pert} A_{non-pert}$$

- Restrict kinematic to suppress background from : OPE convergence compromised!
- Detailed information on b-quark bound in B meson is needed: light cone distribution (shape function)



Four QCD calculations:

- BLNP(2005): Bosch, Lange, Neubert, Paz: 3-scale OPE based on HQET,SCET
- GGOU(2007): Gambino, Giordano, Ossalo, Uraltsev: OPE in Kinetic mass scheme
- BLL(2001): Bauer, Ligeti, Luke, Reduce SF dependence by restricting mx-q2
- LNP(2005): Lange, Neubert, Paz, relate b± $u\ell\nu$ to $b \to s\gamma$, same leading SF

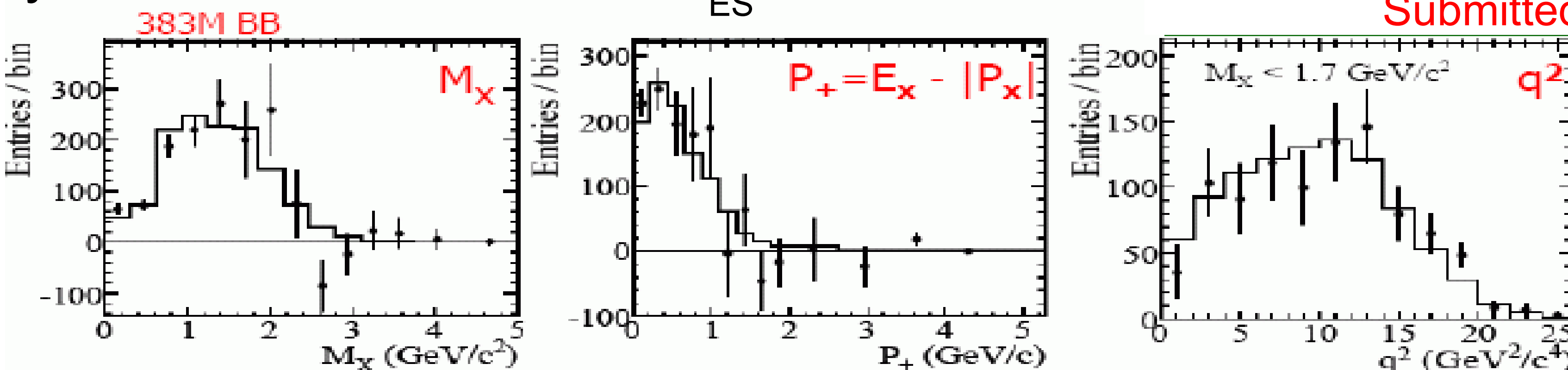
Two Parton Models:

- GDE(2006): Anderson, Gardi; Dressed gluon exponentiation
- AC(2006): Aglietti, Ferrara, Riccardi: Analytic coupling

Inclusive Measurement of $|V_{ub}|$

- Analysis with events tagged by a fully reconstructed hadronic B decay
- Extract kinematical distributions by m_{ES} fits
- Measure ΔBF, normalize to inclusive $B \to X l \nu$ sample; Major systematic from detector, m_{ES} fits, MC stat.

ArXiv: 0708.3702 [hep-ex]
Submitted to PRL



n.b.: Measured Distributions, not efficiency corrected

	N_u	$\lvert V_{ub}\rvert$ (10^{-3})	
M_X	803 ± 60	$4.27 \pm 0.16 \pm 0.13 \pm 0.30$	BLNP
		$4.56 \pm 0.17 \pm 0.14 \pm 0.32$	GDE
P_+	633 ± 63	$3.88 \pm 0.19 \pm 0.16 \pm 0.28$	BLNP
		$3.99 \pm 0.20 \pm 0.16 \pm 0.24$	GDE
$M_X - q^2$	562 ± 55	$4.48 \pm 0.22 \pm 0.19 \pm 0.30$	BLNP
		$4.53 \pm 0.22 \pm 0.19 \pm 0.25$	GDE
		$4.81 \pm 0.23 \pm 0.20 \pm 0.36$	BLL

One data set and 3 Calculations give 7 values for $|V_{ub}|$!

All errors correlated!
Stat: 3.8%
Syst: 3.0%
Theory: 7 % (shape function errors dominate, m_b)

Current Inclusive $|V_{ub}|$ Results

BLNP - HFAG

$m_b = 4.63 \pm 0.06$ GeV,
$\mu_p^2 = 0.18 \pm 0.06$ GeV^2

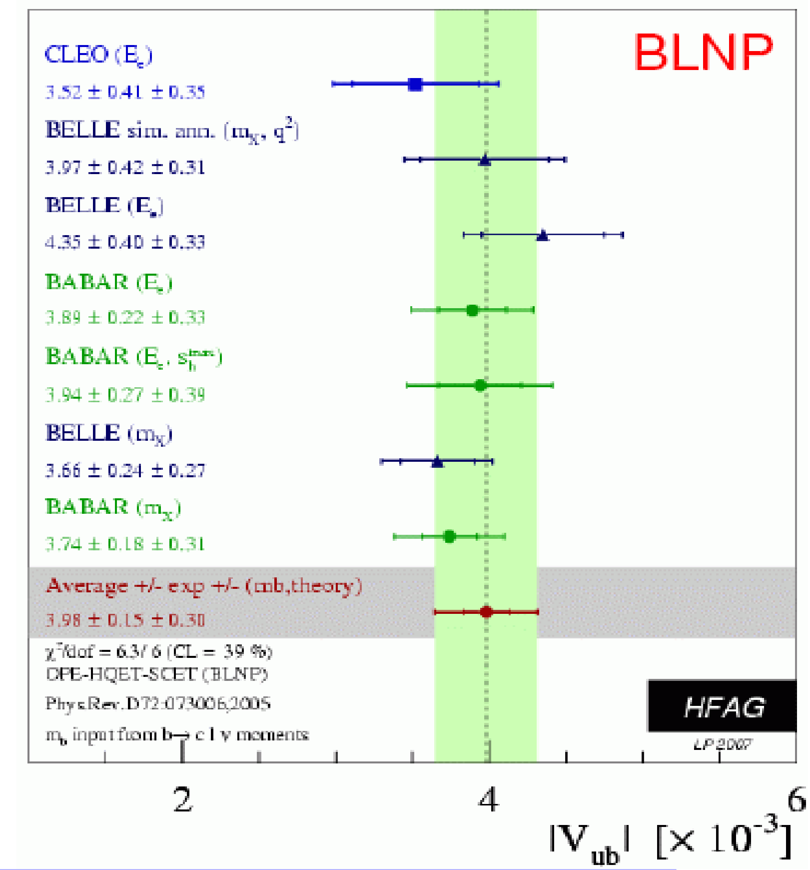
$|V_{ub}| = (4.31 \pm 0.17_{exp} \pm 0.35_{th}) \times 10\text{-}3$

SF w/o $B \to X_s \gamma$

$m_b = 4.71 \pm 0.05$ GeV,
$\mu_\pi^2 = 0.22 \pm 0.04$ GeV^2

$|V_{ub}| = (3.98 \pm 0.15_{exp} \pm 0.30_{th}) \times 10\text{-}3$

- Several different theoretical approaches, different $|V_{ub}|$ values for each analysis
-
- Ongoing discussion on use of $B \to X_s\gamma$ moments
- Subleading SF in $B \to X_s\gamma$ introduce theoretical uncertainties not under control?



Exclusive Decays: $B \to \pi/\rho/\eta/\eta' l\nu$

Decay Rate

- Pseudo-scalar: $\frac{d\Gamma}{dq^2} \propto |V_{ub}|^2 G(q^2) f_+^2(q^2)$ 1 FF for small m_l
- Vector: $\frac{d^4\Gamma}{dq^2\, d\chi\, d\cos\theta_\ell\, d\cos\theta_h} \propto |V_{ub}|^2 G(q^2) F(q^2, \chi, \cos\theta_\ell, \cos\theta_h)$ 3 FF for small m_l
- Absolute decay rates are proportional to $|V_{ub}|^2 F^2(q^2)$:
  - Determination of $|V_{ub}|$ requires knowledge of FF shape and normalization
- As measurements improved QCD calculation available

Small BF, i.e. Very large background – Strong reliance on MC

- $B \to D/D^*/D^{**} l\nu$ and combinatorics – reduced by BB tag
- Continuum – signal events are more jet-like – reduced by BB tag
- Combinatorics from $B \to X_u l\nu$

Missing neutrino- reliance on full event reco – much improved by BB tag

Untagged: yield 22000/10^9 BB	SL tag: yield 600/10^9 BB	Hadr tag: yield 100/10^9 BB
S/B 1/3-1/10	S/B 3/1	S/B 10/1

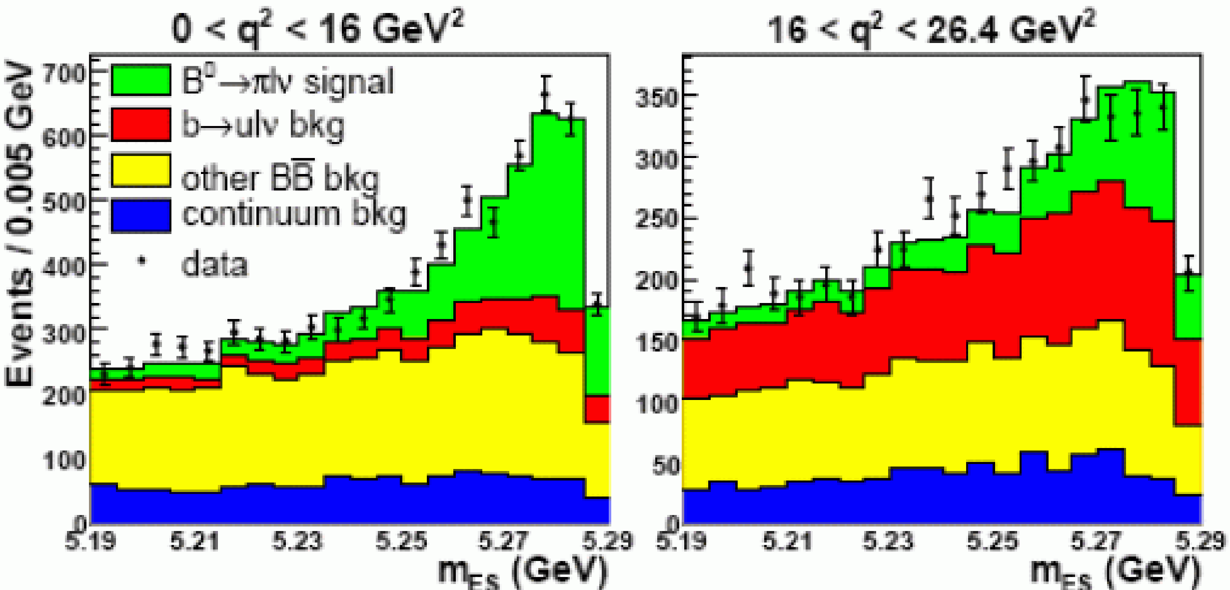
Exclusive Charmless Decays: $B^0 \to \pi l \nu$

PRL 98 091801(2007)

- Extract yields for signal and background from 2-dim. binned max-LH fit to ΔE, m_{ES} in 12 q^2 bins
- Signal and bkg shapes from MC

No Tags
- Very High yield 22,000/10^9 BB Events
- Low S/B 1:10 to 1:3

230M BB Events



5072 signal events

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

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

$$q^2 = (p_B - p_\pi)^2 = (p_\ell + p_\nu)^2$$

$$BF(B^0 \to \pi^- \ell^+ \nu) = (1.46 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-4}$$

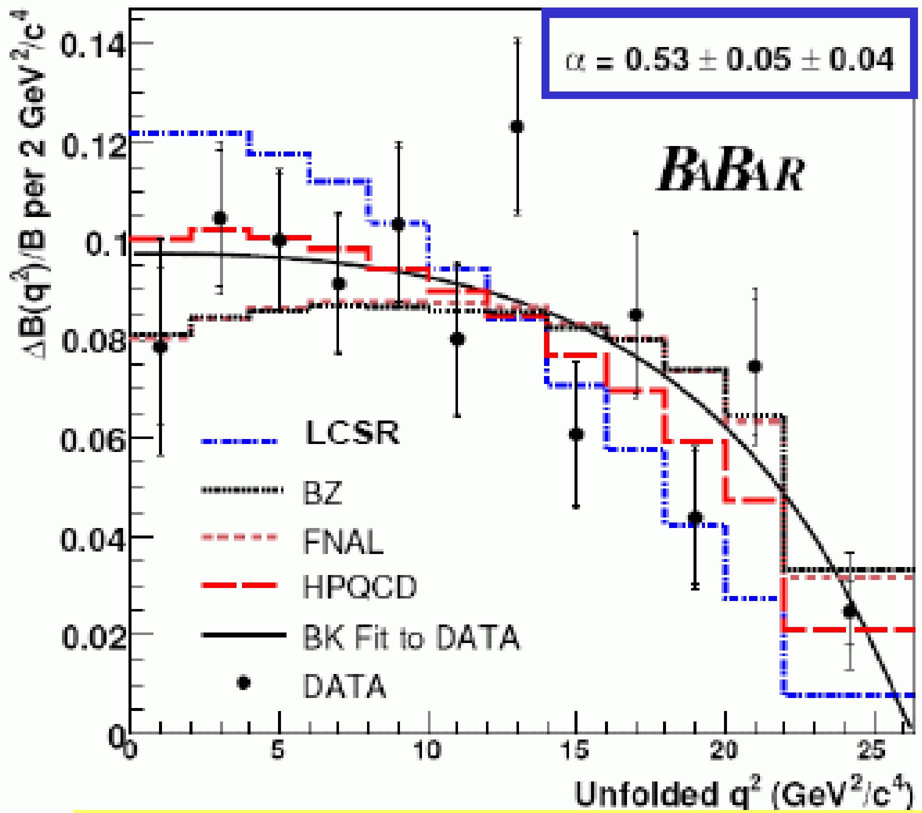
4.6% 5.5%

Diff. Decay Rate for B $\rightarrow \pi l \nu$

PRL 98 091801(2007)

- Light-Cone Sum Rules q^2<14 GeV^2
  - Ball-Zwicky (hep-ph/0406232) 10-13% uncertainty at q^2=0
- Lattice QCD q^2>15 GeV^2
  - Unquenched calculations by HPQCD (hep-lat/0408019) FNAL (help-ph/0409116)
  - Quenched calculations by APE (NP B619, 565)
- ISGW2 (PR D52, 2783)
  - Quark model
  - No uncertainty quoted

$$\frac{d\Gamma(B^0 \rightarrow \pi^- \ell^+ \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$



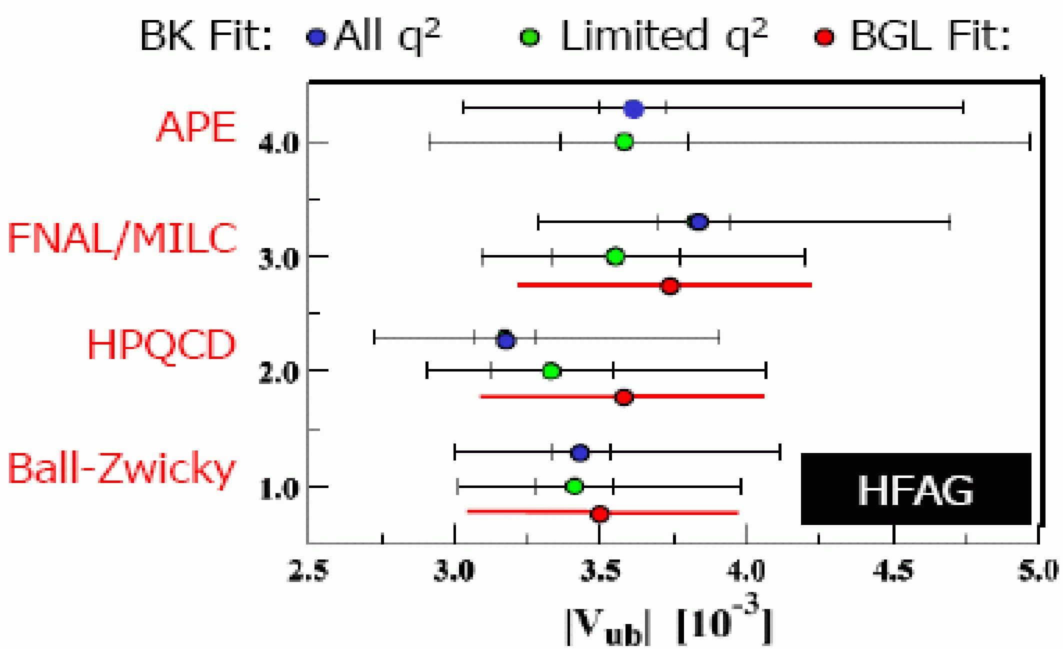
ISGW2 disfavored: P(χ^2) <0.1%

Extraction of $|V_{ub}|$ from $B \to \pi l \nu$

- Extraction of $|V_{ub}|$ relies on FF normalization, available in distinct q^2 ranges:
- LCSR: $q^2 < 16\ GeV^2$, LQCD: $q^2 > 16\ GeV^2$, Hill/Becher z expansion
- either restricted or whole q^2 range

$$|V_{ub}| = \sqrt{\Delta B / \tau_B \Gamma_{thy}}$$

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



BK Parameterization:

FNAL/MILC: $q^2 > 16\ GeV^2$

$$|V_{ub}| = (3.55 \pm 0.22_{exp} {}^{+0.61}_{-0.40\,LQCD}) \times 10^{-3}$$

FNAL/MILC: Extrapolated to all q^2

$$|V_{ub}| = (3.8 \pm 0.12_{exp} {}^{+0.90}_{-0.51\,LQCD}) \times 10^{-3}$$

±3.2% ±13-24%

BGL Parameterization:

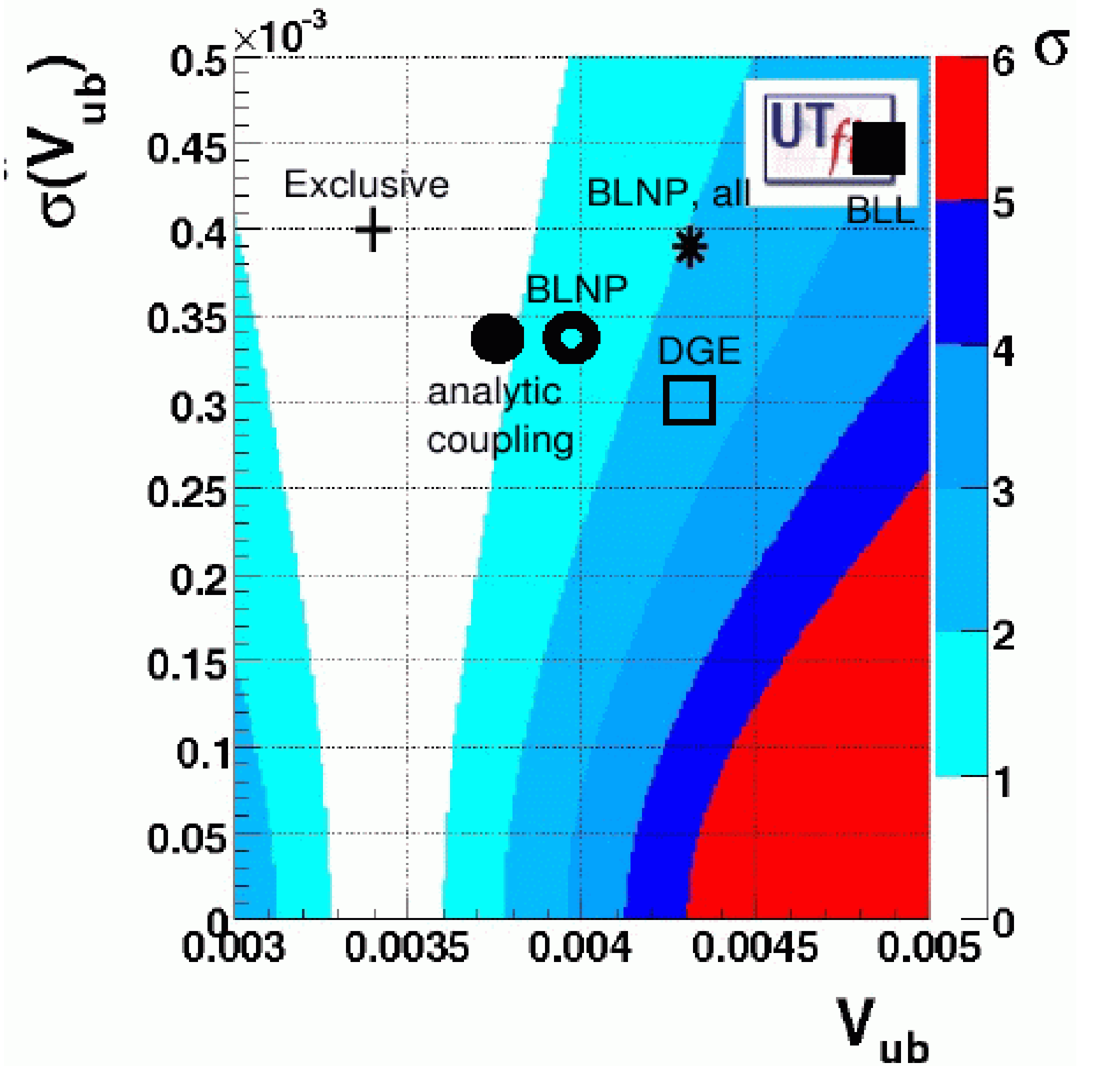
FNAL/MILC:

BALL arXiv:0705:2290

$$|V_{ub}| = (3.7 \pm 0.12_{exp} \pm 0.4_{FF}) \times 10^{-3}$$

$|V_{ub}|$:CKM Consistency

- Most probable value of $|V_{ub}|$ from measurements of other CKM SM parameters and exclusive states favours a value ~ 3.5×10^{-3}
- Steady work in the inclusive decays to improve $|V_{ub}|$ calculations
- **"Tension" with exclusive decays: is it really there?**
- Still a lot of work to be done!



Other $|V_{ub}|$ values not included here

Conclusions

Inclusive Decays:

$|V_{ub}| = (4.31 \pm 0.17_{exp} \pm 0.35_{thy})\ 10^{-3}$ $|V_{cb}| = (41.9 \pm 0.2_{exp} \pm 0.2_{HQE} \pm 0.6_{thy})\ 10^{-3}$

Exclusive Decays:

$|V_{ub}| = (3.8 \pm 0.1_{exp} \pm 0.9_{thy})\ 10^{-3}$ $|V_{cb}| = (37.8 \pm 0.7_{exp} \pm 0.8_{thy})\ 10^{-3}$

GLOBAL FIT of CKM Parameters – CKM Fitter

$|V_{ub}|_{Pred} = (3.57 \pm 0.17)\ 10^{-3}$ $|V_{cb}|_{pred} = (41.43 \pm 0.87)\ 10^{-3}$

- Our knowledge of $b \to c(u) l\nu$ transitions is drastically improved in the last 5 years
  - BaBar has released (and continues to) an impressive amount of results on $b \to c(u) l\nu$ decays
  - Most precise determination of $B^0 \to D^{*-} l\nu$ FF and $B \to D/D^*/D^*\nu\pi l\nu$ BF
  - Evidence/observation for $B \to D^{(*)}\tau\nu$
  - New inclusive $|V_{ub}|$ result
  - Discrepancy between inclusive and exclusive $|V_{cb}|$ determinations may hide underestimated problems
- Assuming that the inclusive approach is well understood, focus is on the exclusive decays: D** spectroscopy interesting for several reasons

Backup Slides

Moment Measurements

latest measurements

- Belle E_ℓ — 152M $B\overline{B}$, PRD75, 032001 (2007)
- Belle m_X — 152M $B\overline{B}$, PRD75,032005 (2007)
- BaBar m_X — 232M $B\overline{B}$, arXiv:0707.2670 (2007)
- DELPHI E_ℓ and m_X — 3.3M Z, EPJC45,35 (2006)

older measurements

- BaBar E_ℓ — 52M $B\overline{B}$, PRD69,111104(R) (2004)
- (BaBar m_X — 89M $B\overline{B}$, PRD69,111103(R) (2004))
- CLEO m_X —9.4 fb^{-1}, PRD70,032002 (2004)
- CDF m_X — 180 pb^{-1}, PRD71,051103(R) (2005)

Different Schemes (I)

Kinetic scheme

Gambino-Uraltsev, EPJC34,181(2004)
Benson-Bigi-Uraltsev, NPB710,371(2005)

- HQ expansion to $1/m_b^3$ with $m_b(\mu)$ and $m_c(\mu)$ at $\mu = 1$ GeV
  HQ parameters: μ_π^2 and μ_G^2 at $1/m_b^2$, ρ_{LS}^3 and ρ_D^3 at $1/m_b^3$

$$\Gamma_{c\ell\nu} = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2(1 + A_{ew})A_{pert}(r,\mu)$$
$$\times\left[z_0(r)\left(1 - \frac{\mu_\pi^2 - \mu_G^2 + \frac{\rho_D^3+\rho_{LS}^3}{m_b}}{2m_b^2}\right) - 2(1-r)^4\frac{\mu_G^2 + \frac{\rho_D^3+\rho_{LS}^3}{m_b}}{m_b^2} + d(r)\frac{\rho_D^3}{m_b^3} + O(1/m_b^4)\right].$$

  and similar analytical expansions for all other moments.
- External constraints (Gaussian term in χ^2)
  $\mu_G^2 = 0.35 \pm 0.07$ GeV^2, $\rho_{LS}^3 = -0.15 \pm 0.10$ GeV^3
- Theoretical errors and correlations
  - non-HQ errors and $O(1/m_b^4)$ errors: 1.4% overall
  - HQ correlation matrix from "uncorrelated" errors:
    20% for μ_π^2, μ_G^2, 30% for ρ_D^3, ρ_{LS}^3, ±20 MeV for m_b, m_c
  - 100% correlation between different E_{cut}

Different Schemes (II)

1S scheme

Bauer-Ligeti-Luke-Manohar PRD67,054012(2003)
Bauer-Ligeti-Luke-Manohar-Trott PRD70,094017(2004)

- HQ expansions to $1/m_b^3$ with $\Lambda = m_{\Upsilon(1S)}/2 - m_b^{1S}$
  HQ parameters: λ_1, λ_2 at $O(1/m_b^2)$, τ_1, τ_2, τ_3, τ_4, ρ_1, ρ_2 at $O(1/m_b^3)$
- B^*–B, D^*–D, B–D mass differences eliminate $m_b - m_c$, λ_2, ρ_2
  $(\lambda_2 = 0.1227 - 0.0145\lambda_1,\ \rho_2 = 0.1361 + \tau_2)$
- Linearized expressions for moments $\langle X\rangle = M_n^\ell$, M_n^H or M_n^γ with 17 coefficients $X^{(n)}$

$$\langle X\rangle = X^{(1)} + X^{(2)}\Lambda + X^{(3)}\Lambda^2 + X^{(4)}\Lambda^3 + X^{(5)}\lambda_1 + X^{(6)}\Lambda\lambda_1 + X^{(7)}\lambda_2 + X^{(8)}\Lambda\lambda_2 + X^{(9)}\rho_1 + X^{(10)}\rho_2 + X^{(11)}\tau_1 + X^{(12)}\tau_2 + X^{(13)}\tau_3 + X^{(14)}\tau_4 + X^{(15)}\varepsilon + X^{(16)}\varepsilon^2_{\mathrm{BLM}} + X^{(17)}\varepsilon\Lambda$$

- Constraints / Theory errors
  - $O(1/m_b^3)$ parameters not to exceed 0.5 GeV
  - Extra $(Af_n(m_B/2)^n \oplus B_i/2)$ term added to σ_i^{exp}
    No error like 1.4% in kinetic fit?
  - Same correlation matrix as experiments

Inclusive V_{cb}

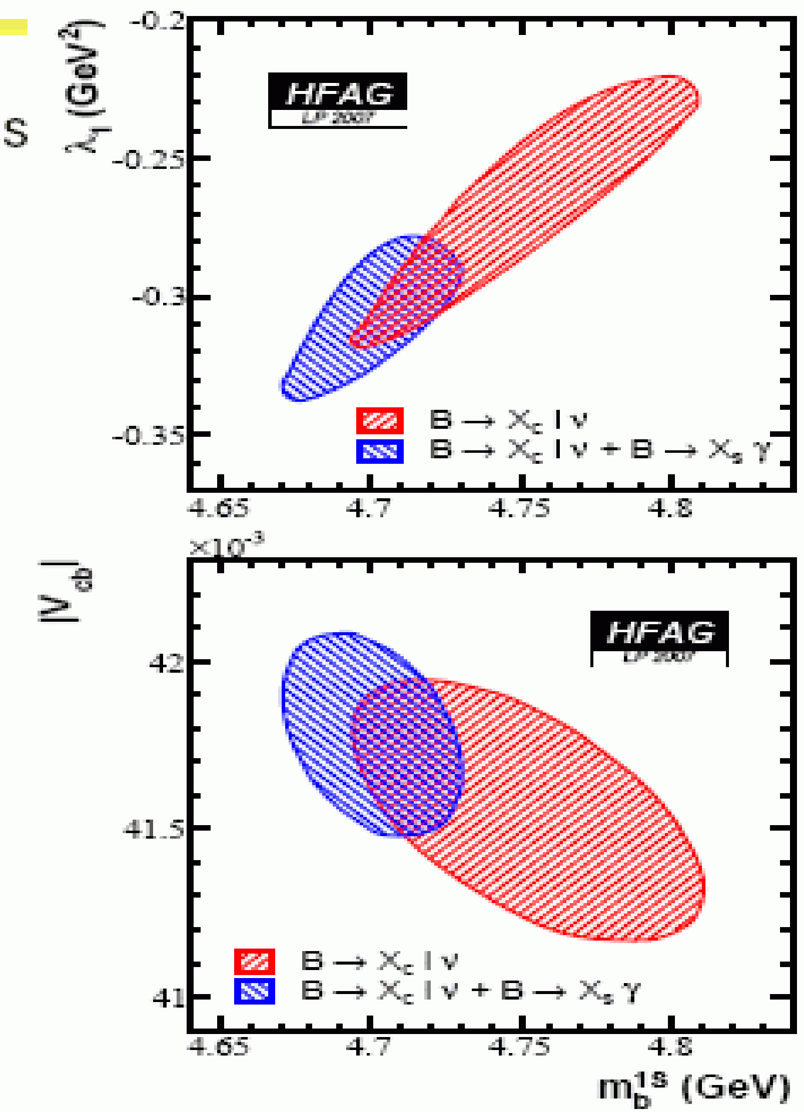
Global fit (1S scheme)

HFAG LP07

- Similar set of inputs, except BaBar's new results

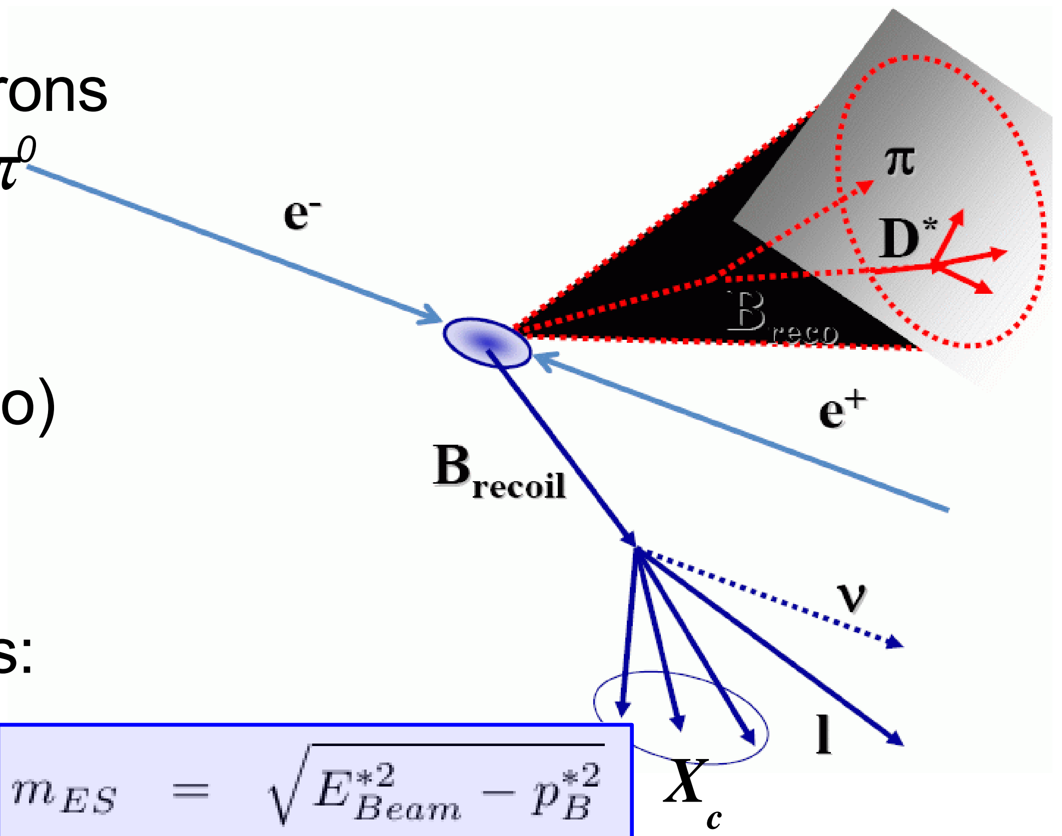
with/without $B \to X_s \gamma$

$$|V_{cb}| = (41.78 \pm 0.30 \pm 0.08) \times 10^{-3}$$
$$(41.56 \pm 0.39 \pm 0.08) \times 10^{-3}$$
$$m_b^{1S} = 4.701 \pm 0.030 \text{ GeV}$$
$$4.751 \pm 0.058 \text{ GeV}$$
$$\lambda_1 = -0.313 \pm 0.025 \text{ GeV}^2$$
$$-0.274 \pm 0.047 \text{ GeV}^2$$



The Hadronic Tag

- Reconstruct a $D^{(*)}$ meson in hadrons
- Reconstruct $B \to D^{(*)} n\pi m K p K_s q \pi^0$ through an iterative method , no request on intermediate resonances (Semi-Exclusive reco)



- Define signal using two variables:

$$m_{ES} = \sqrt{E^{*2}_{Beam} - p^{*2}_{B}}$$
$$\Delta E = E^{*}_{B} - E^{*}_{Beam}$$

- Finally ~1100 modes → ordered by purity
- Often multiple candidates, **standard** best one selection by:
  - Looking at the best ΔE within the same mode
  - Looking at the best purity if different modes

The j=3/2 vs j=1/2 puzzle

Experiment: Rate for broad large?

Exp.	Pub.	Enviroment	$\mathcal{B}(B \to D_1 \ell\nu)$	$\mathcal{B}(B \to D_2^* \ell\nu)$
ARGUS	1993	e^+e^- at $\Upsilon(4S)$	$\mathcal{B}(B \to D^{**}\ell\nu) = 2.7 \pm 0.7^{\dagger\ddagger}$	
ALEPH	1996	e^+e^- at Z	0.74 ± 0.16	< 0.2
CLEO	1997	e^+e^- at $\Upsilon(4S)$	0.56 ± 0.16	< 0.8
OPAL	2002	e^+e^- at Z	1.05 ± 0.35	< 1.85
DELPHI	2005	e^+e^- at Z	0.33 ± 0.17	0.37 ± 0.17
DØ	2005	$p\bar{p}$ at 1.96 GeV	0.33 ± 0.06	0.44 ± 0.16

DELPHI: $\mathcal{B}(B \to D_1^* \ell\nu) = (1.25 \pm 0.37)\%$
$\mathcal{B}(B \to D_0 \ell\nu) = (0.42 \pm 0.40)\%$

Theory: Γ (narrow) >> Γ(broad) !!!

- In the heavy quark limit (m_b and $m_c \to \infty$), only two independent form factors (generalised Isgur-Wise functions) $\tau_{1/2}$ and $\tau_{3/2}$ for

  j_l= 1/2, 3/2.

  - $\Gamma(B \to D^*_2 l \nu ; D_1 l \nu) \propto |\tau_{3/2}(w)|^2$ $w = (p_B^\mu . p_{D^{**}}^\mu)/(m_B m_{D^{**}})$
  - $\Gamma(B \to D^*_0 l \nu ; D^*_1 l \nu) \propto |\tau_{1/2}(w)|^2$

We need more data!!

Some Sum rules which are rigorously derived from QCD:

- Uraltsev sum rule: $\Sigma_n |\tau^{(n)}_{3/2}(1)|^2 - |\tau^{(n)}_{1/2}(1)|^2 = 1/4$ N. Uraltsev, *Phys. Lett.* **B501** (2001) 8
- Orsay sum rule: $4\Sigma_n \varepsilon^{(n)}_{3/2} |\tau^{(n)}_{3/2}(1)|^2 - \varepsilon^{(n)}_{1/2} |\tau^{(n)}_{1/2}(1)|^2 = -a_+^{(1)} > 0$ hep-ph/0003087
  where $\varepsilon^{(n)}_{3/2} = m\_D^{(n)}_{3/2} - m\_D$, $\varepsilon^{(n)}_{1/2} = m\_D^{(n)}_{1/2} - m\_D$.
  Combined with results from « QCD sum rule phenomenology » it gives

$\Sigma_n \varepsilon^{(n)}_{3/2} |\tau^{(n)}_{3/2}(1)|^2 = 4\ \Sigma_n \varepsilon^{(n)}_{1/2} |\tau^{(n)}_{1/2}(1)|^2$ M. Neubert, Phys. Rev. D46 (1992) 3914;