Inclusive $|V_{cb}|$ and global fits

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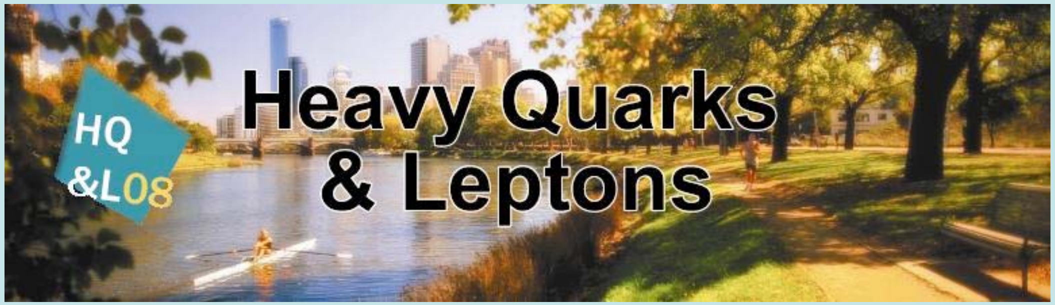


June 5-9, 2008,
Melbourne, Australia

The CKM matrix

- Couplings of the charged current interaction in the SM

$$-\mathcal{L}_{W^\pm} = \frac{g}{\sqrt{2}} \overline{u_{Li}} \, \gamma^\mu \, (V_{\rm CKM})_{ij} \, d_{Lj} \, W_\mu^+ + {\rm h.c.}$$

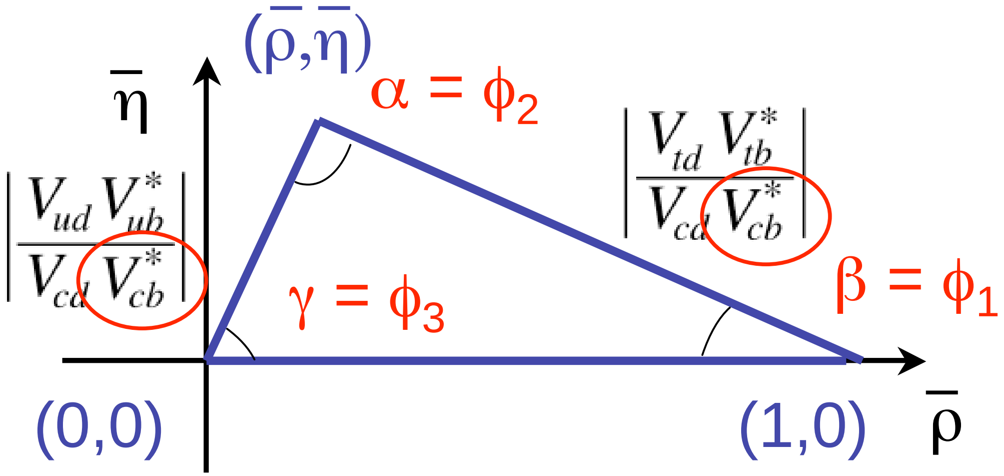
$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- V_{CKM} is a unitary 3x3 matrix;
  it contains three real parameters and one complex phase

[Kobayashi, Maskawa, Prog. Theor. Phys. 49, 652 (1973)]

- The unitarity of V_{CKM} can be probed by measuring the sides and angles of the unitarity triangle

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



$$\alpha \equiv \varphi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta \equiv \varphi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

$$\gamma \equiv \varphi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- In this presentation, I'll focus on the determination of $|V_{cb}|$ from inclusive semileptonic B decays

The semileptonic width

- $\Gamma(B \to X_c l \nu)$ can be systematically calculated with the operator production expansion (OPE)

$$\Gamma_{sl}(b \to c) = \frac{G_F^2 m_b^5(\mu)}{192\pi^3} |V_{cb}|^2 (1 + A_{ew}) A^{pert}(r, \mu)$$

$$\left[z_0(r) \left(1 - \frac{\mu_\pi^2(\mu) - \mu_G^2(\mu) + \frac{\rho_D^3(\mu) + \rho_{LS}^3(\mu)}{m_b(\mu)}}{2m_b^2(\mu)} \right) - 2(1-r)^4 \frac{\mu_G^2(\mu) - \frac{\rho_D^3(\mu) + \rho_{LS}^3(\mu)}{m_b(\mu)}}{m_b^2(\mu)} + d(r) \frac{\rho_D^3(\mu)}{m_b^3(\mu)} + \ldots \right]$$

from [Benson et al., Nucl. Phys. B665, 367 (2003)]

$r = m_c^2(\mu)/m_b^2(\mu)$

◯ … HQ parameters (non-calculable; contain soft QCD physics)

- At each order in $1/m_b$, the expectation values of local operator products (heavy quark parameters) are multiplied by perturbatively calculable coefficients

Other observables in B decays

- Moments of the lepton energy spectrum in $B \to X_c l\nu$

$$R_n(E_{\rm cut},\mu) = \int_{E_{\rm cut}} (E_\ell - \mu)^n \, \frac{{\rm d}\Gamma}{{\rm d}E_\ell} \, {\rm d}E_\ell \,, \quad \langle E_\ell^n \rangle_{E_{\rm cut}} = \frac{R_n(E_{\rm cut},0)}{R_0(E_{\rm cut},0)}$$

- Moments of the hadronic mass spectrum in $B \to X_c l\nu$

$$\langle m_X^{2n} \rangle_{E_{\rm cut}} = \frac{\displaystyle\int_{E_{\rm cut}} (m_X^2)^n \, \frac{{\rm d}\Gamma}{{\rm d}m_X^2} \, {\rm d}m_X^2}{\displaystyle\int_{E_{\rm cut}} \frac{{\rm d}\Gamma}{{\rm d}m_X^2} \, {\rm d}m_X^2}$$

- Moments of the photon energy spectrum in $B \to X_s \gamma$

$$\langle E_\gamma^n \rangle_{E_{\rm cut}} = \frac{\displaystyle\int_{E_{\rm cut}} E_\gamma^n \, \frac{{\rm d}\Gamma}{{\rm d}E_\gamma} \, {\rm d}E_\gamma}{\displaystyle\int_{E_{\rm cut}} \frac{{\rm d}\Gamma}{{\rm d}E_\gamma} \, {\rm d}E_\gamma}$$

The OPEs of these inclusive observables contain the same HQ parameters

Global analysis of B decays

- Dedicated predictions for each observable
  - $<E^n_l>_{El>Ecut} = f^{(n)}(E_{cut}, m_b, \text{HQ param.})$
  - $<M^{2n}_X>_{El>Ecut} = g^{(n)}(E_{cut}, m_b, \text{HQ param.})$
  - $<E^n_\gamma>_{E\gamma>Ecut} = h^{(n)}(E_{cut}, m_b, \text{HQ param.})$

- Determine HQ parameters by performing a minimum χ^2 fit to all available moment measurements

- Take into account correlated experimental and theoretical errors

- External input: average B lifetime τ_B = (1.585 +/- 0.006) ps

Available calculations

- Kinetic running mass
  - [P.Gambino, N.Uraltsev, Eur.Phys.J. C34, 181 (2004)]
  - [D.Beson, I.Bigi, N.Uraltsev, Nucl.Phys. B710, 371 (2005)]

both calculations up to $O(1/m^3_b)$

- 1S mass
  - [C.Bauer, Z.Ligeti, M.Luke, A.Manohar, M.Trott, Phys.Rev. D70, 094017 (2004)]

- Non-perturbative parameters in the $1/m_b$ expansion

	Kinetic scheme	1S scheme
$O(1)$	m_b, m_c	m_b
$O(1/m^2_b)$	μ^2_π, μ^2_G	λ_1, λ_2
$O(1/m^3_b)$	ρ_D, ρ_{LS}	ρ_1, τ_{1-3}

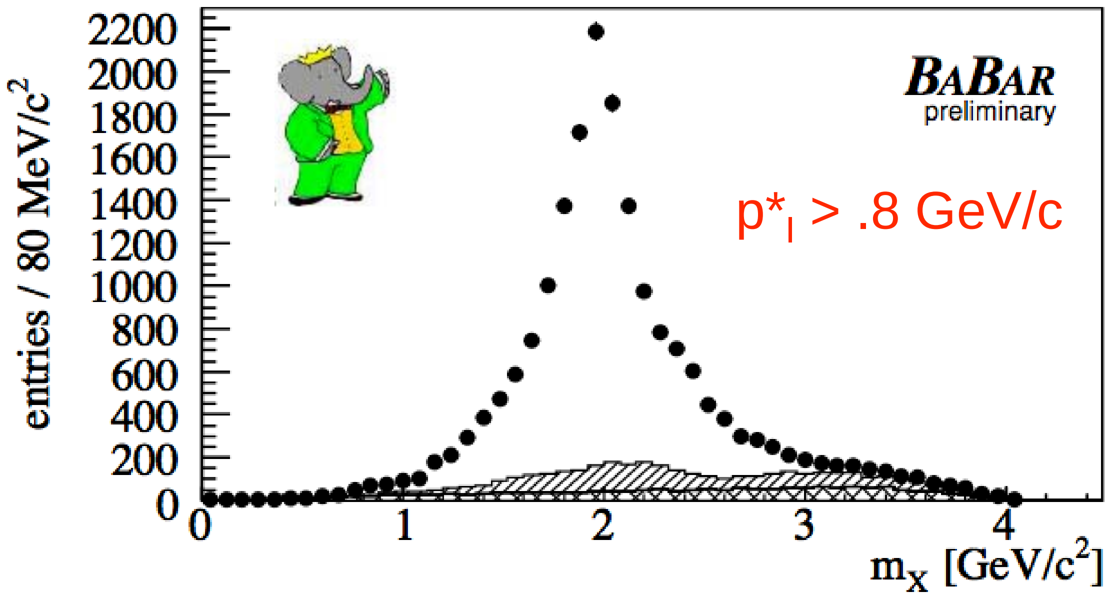
Available measurements

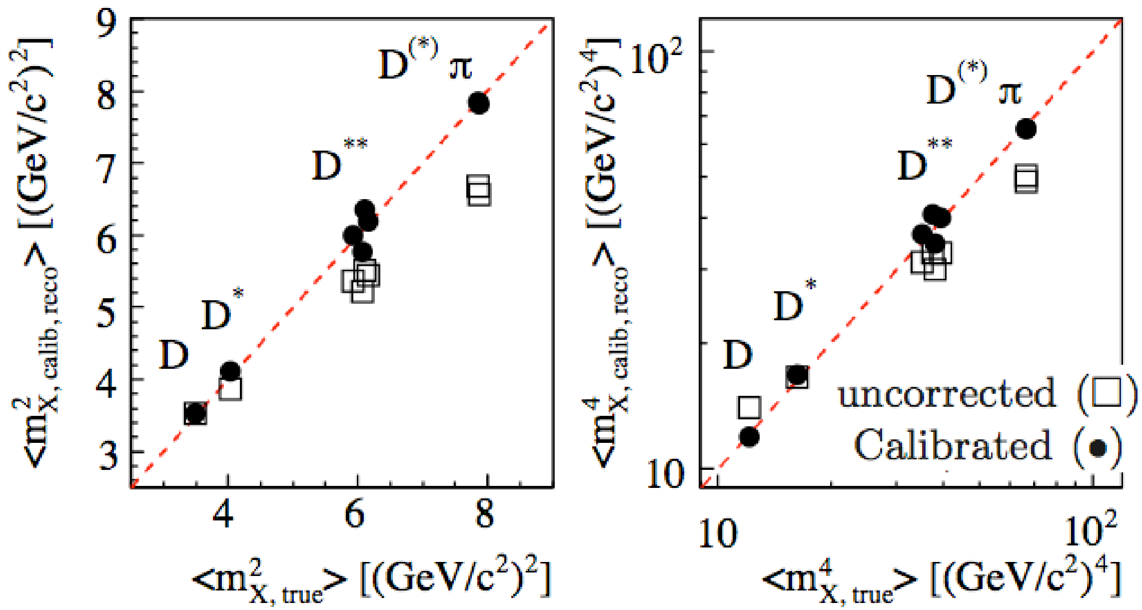
- Belle E_γ, 605/fb [arXiv:0804.1580] preliminary
- BaBar E_l, M^2_X, 210/fb [arXiv:0707.2670] preliminary
- Belle E_l, 140/fb [PRD 75, 032001 (2007)]
- Belle M^2_X, 140/fb [PRD 75, 032005 (2007)]
- DELPHI E_l, M^2_X, 3.4M Z [EPJ C45, 35 (2006)]
- BaBar, E_γ, 82/fb [PRL 97, 171803 (2006)]
- BaBar, E_γ, 82/fb [PRD 72, 052004 (2005)]
- CDF, M^2_X, 180/pb [PRD 71, 051103 (2005)]
- Belle, E_γ, 140/fb [PRL 93, 061803 (2004)]
- CLEO, M^2_X, 9/fb [PRD 70, 032002 (2004)]
- BaBar, E_l, 47/fb [PRD 69, 111104 (2004)]
- BaBar, M^2_X, 89M BB [PRD 69, 111103 (2004)]
- CLEO, E_γ, 9/fb [PRL 87, 251807 (2001)]

BaBar M^2_X moments

[arXiv:0707.2670] preliminary

- 210/fb of Υ(4S) data
- Hadronic decay of one B meson fully reconstructed
- Semileptonic decay of other B selected by requiring identified lepton (e/μ)
- Reconstructed moments corrected event-by-event for detector effects
- $\langle M^k_X \rangle$ measured for k=1,…,6 and p^*_{cut} from 0.8 to 1.9 GeV/c

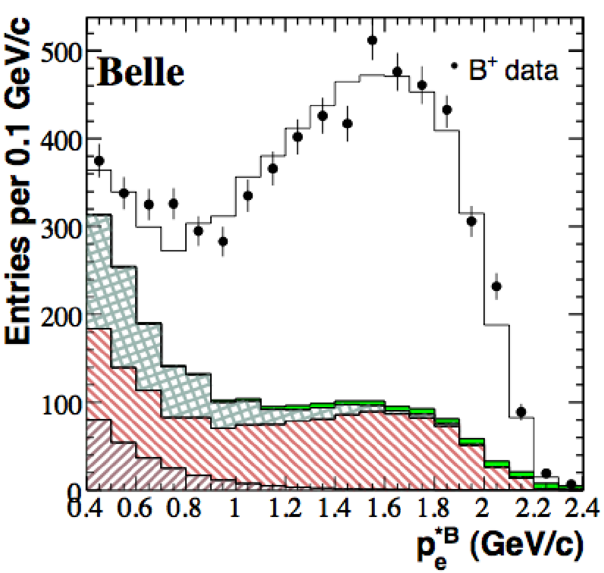


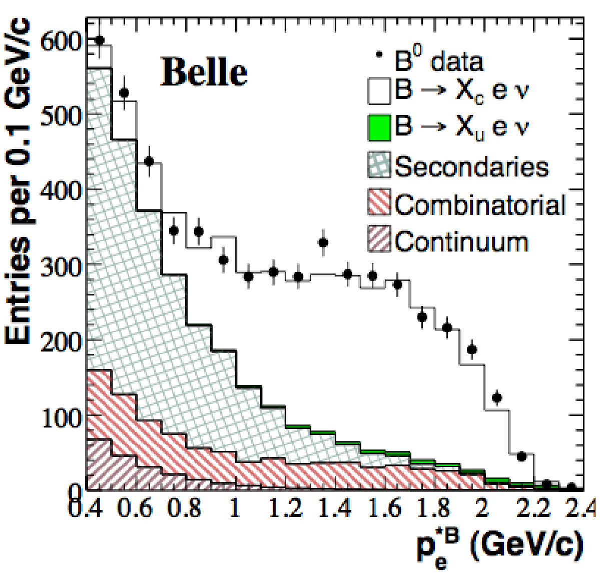


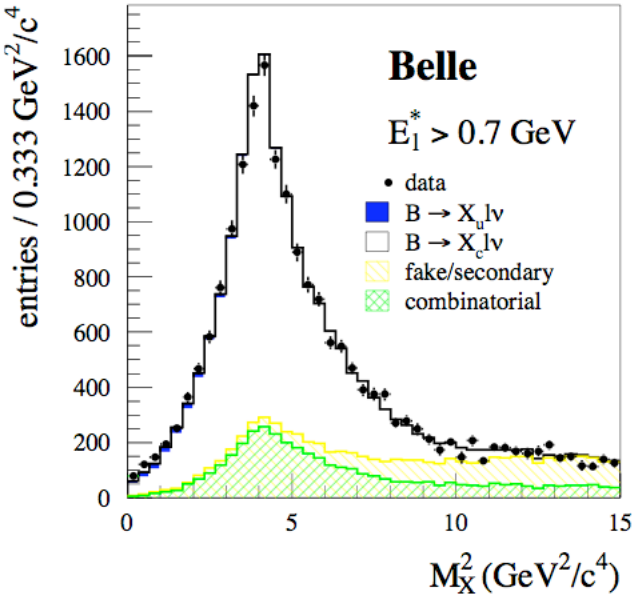
Belle E_l and M^2_X moments

[PRD 75, 032001 (2007)]
[PRD 75, 032005 (2007)]

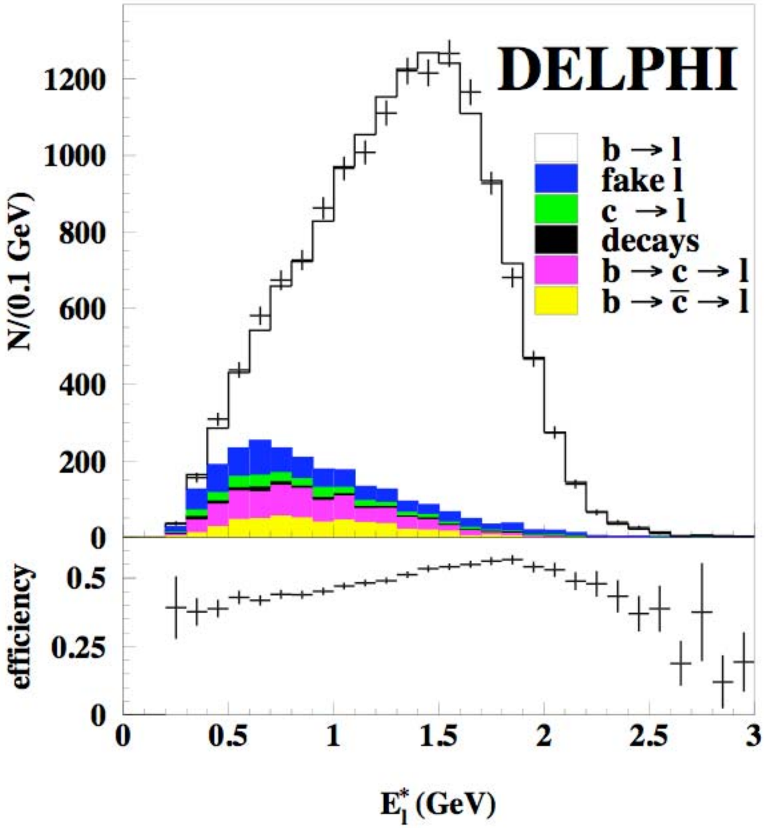
- 140/fb of Y(4S) data
- Measurement also done with fully reconstructed events
- The finite detector resolution is unfolded with SVD algorithm [NIM A372, 469 (1996)]
- $\langle E^n_e \rangle$ measured for n=0,…,4 and E_{cut}=0.4-2.0 GeV
- $\langle M^{2n}_X \rangle$ measured for n=1,2 and E_{cut}=0.7-1.9 GeV

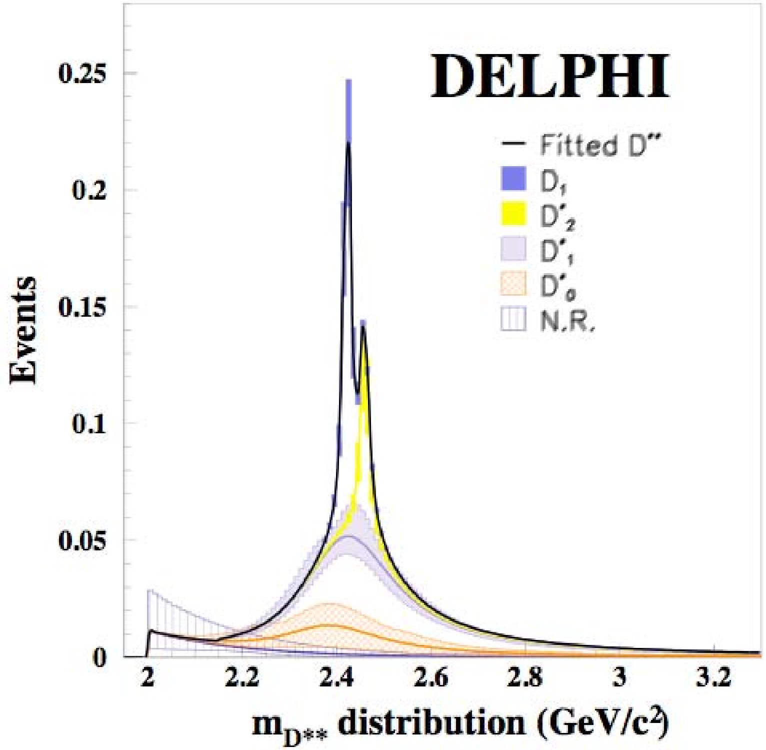






DELPHI E_l and M^2_X moments [EPJ C45, 35 (2006)]





- $\langle E^n_l \rangle$, n=1,…,3 and $\langle M^{2n}_X \rangle$, n=1,…,5 measured at $E_{cut} = 0$ as in Z events the b-quark is produced with a boost
- The hadronic moments are derived from the fitted D** mass spectrum; assumptions on the D** decay are made

$|V_{cb}|$ and m_b from the fit to the Belle moment data

[arXiv:0803.2158] submitted to Phys.Rev.D

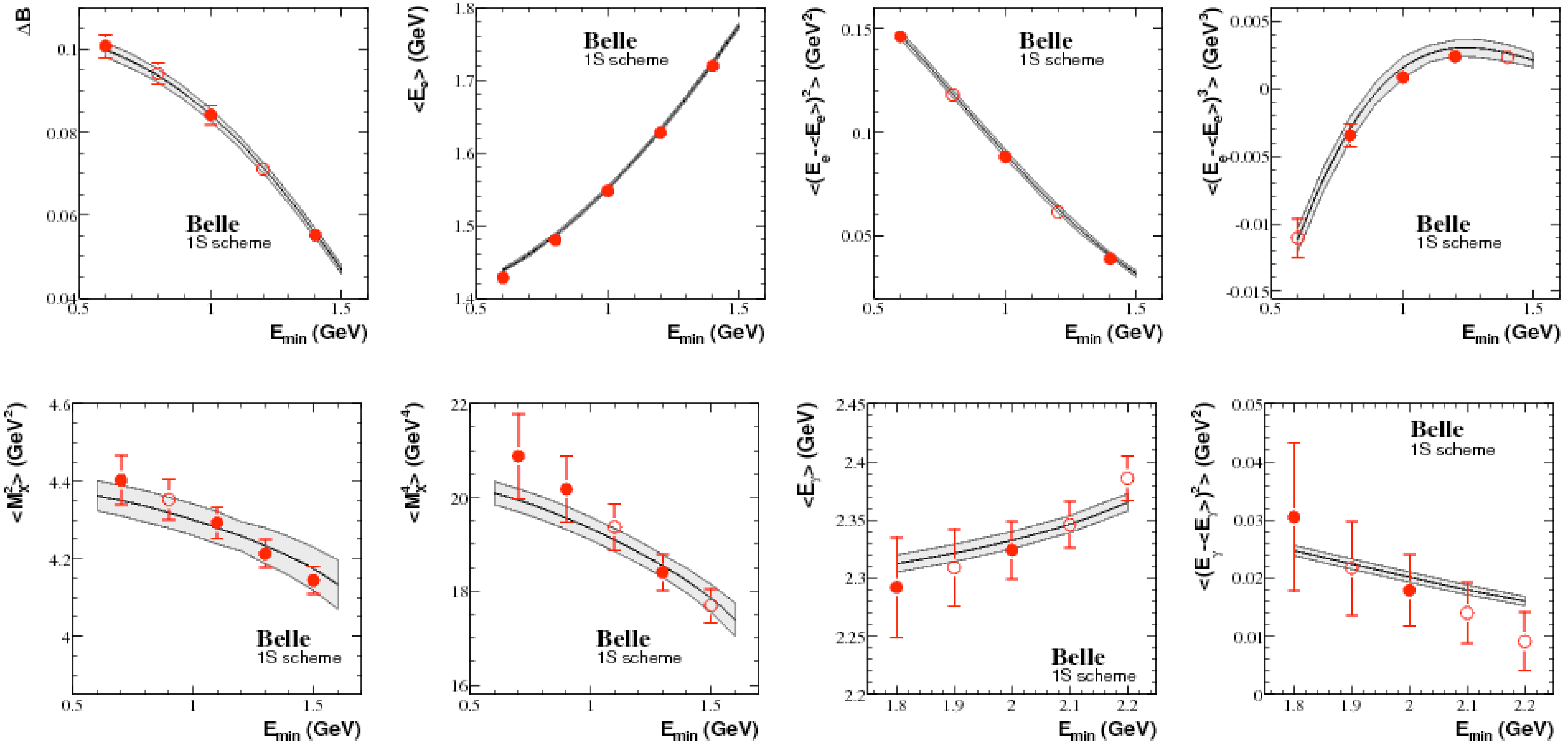
Similar analysis recently done on the BaBar moment data [arXiv:0707.2670] preliminary

Belle measurements used

Electron moments $\langle E^n_l \rangle$	n=0: E_{cut}=0.6, 1.0, 1.4 GeV n=1: E_{cut}=0.6, 0.8, 1.0, 1.2, 1.4 GeV n=2: E_{cut}=0.6, 1.0, 1.4 GeV n=3: E_{cut}=0.8, 1.0, 1.2 GeV
Hadron moments $\langle M^{2n}_X \rangle$	n=1: E_{cut}=0.7, 1.1, 1.3, 1.5 GeV n=2: E_{cut}=0.7, 0.9, 1.3 GeV
Photon moments $\langle E^n_\gamma \rangle$	n=1: E_{cut}=1.8, 2.0 GeV n=2: E_{cut}=1.8, 2.0 GeV

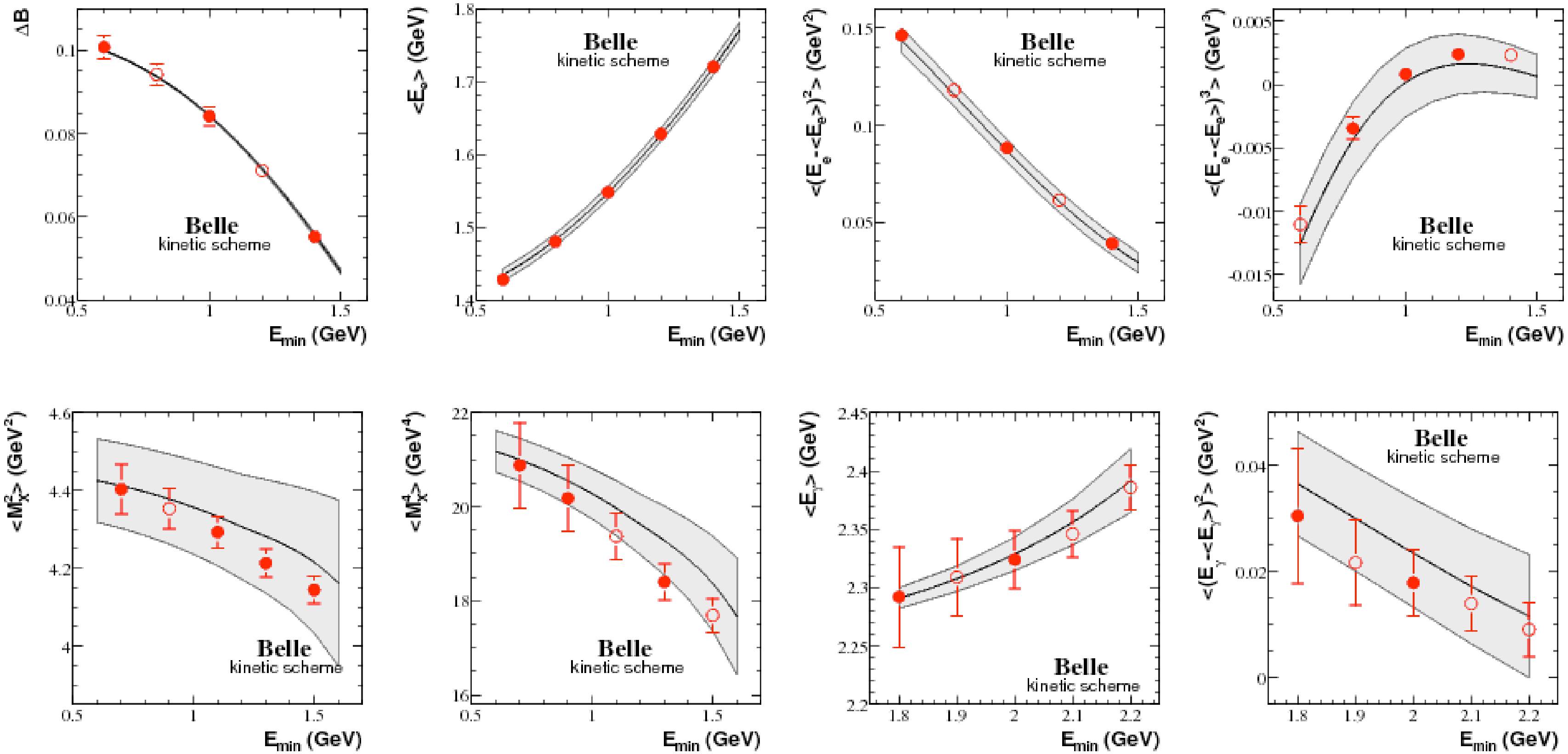
- Exclude measurements
  - with no (reliable) theory prediction
  - with excessive correlations

Fit result in the 1S scheme



χ^2/ndf. = 7.3 / (25-7)

Fit result in the kinetic scheme



χ^2/ndf. = 4.7 / (25-7)

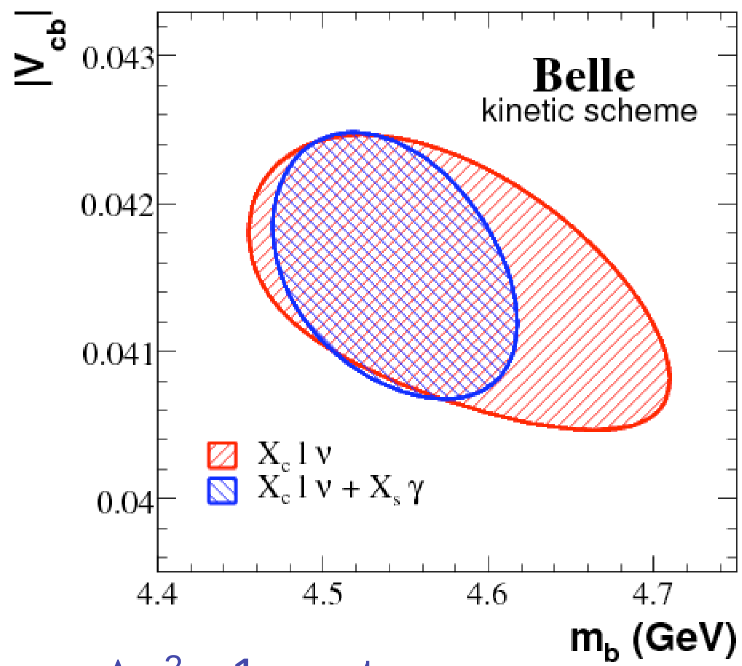
$|V_{cb}|$ and m_b

Kinetic scheme ($X_c l\nu + X_s\gamma$ data)

$|V_{cb}| = (41.52 \pm 0.69_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}) \times 10^{-3}$

$m_b^{kin} = 4.543 \pm 0.075$ GeV

$m_c^{kin} = 1.055 \pm 0.118$ GeV



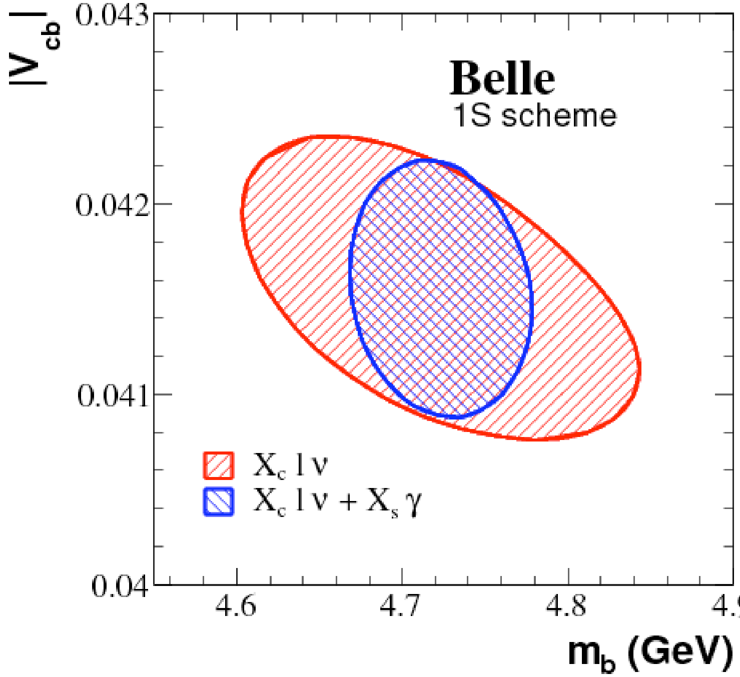
Results for m_b compatible after scheme translation

$\Delta\chi^2 = 1$ contours

1S scheme ($X_c l\nu + X_s\gamma$ data)

$|V_{cb}| = (41.56 \pm 0.68_{fit} \pm 0.08_{\tau B}) \times 10^{-3}$

$m_b^{1S} = 4.723 \pm 0.055$ GeV



$|V_{cb}|$ and m_b from the fit to all available moment measurements

New !

preliminary

Measurements used

BaBar	$\langle E^n_l \rangle$: n=0,1,2,3 [PRD 69, 111104 (2004)] $\langle M^{2n}_X \rangle$: n=1,2 [PRD 69, 111103 (2004)] $\langle E^n_\gamma \rangle$: n=1,2 [PRL 97, 171803 (2006)] and [PRD 72, 052004 (2005)]
Belle	$\langle E^n_l \rangle$: n=0,1,2,3 [PRD 75, 032001 (2007)] $\langle M^{2n}_X \rangle$: n=1,2 [PRD 75, 032005 (2007)] $\langle E^n \gamma \rangle$: n=1,2 [arXiv:0804.1580] preliminary
CDF	$\langle M^{2n}_X \rangle$: n=1,2 [PRD 71, 051103 (2005)]
CLEO	$\langle M^{2n}_X \rangle$: n=1,2 [PRD 70, 032002 (2004)] $\langle E^n_\gamma \rangle$: n=1 [PRL 87, 251807 (2001)]
DELPHI	$\langle E^n_l \rangle$: n=1,2,3 $\langle M^{2n}_X \rangle$: n=1,2 [EPJ C45, 35 (2006)]

- 70 measurements in total

$|V_{cb}|$ and m_b

Kinetic scheme ($X_c l\nu + X_s\gamma$ data)

$|V_{cb}| = (41.55 \pm 0.43_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}) \times 10^{-3}$
$m_b^{kin} = 4.613 \pm 0.033$ GeV
$m_c^{kin} = 1.178 \pm 0.049$ GeV

χ^2/ndf. = 30.6 / (70-7)

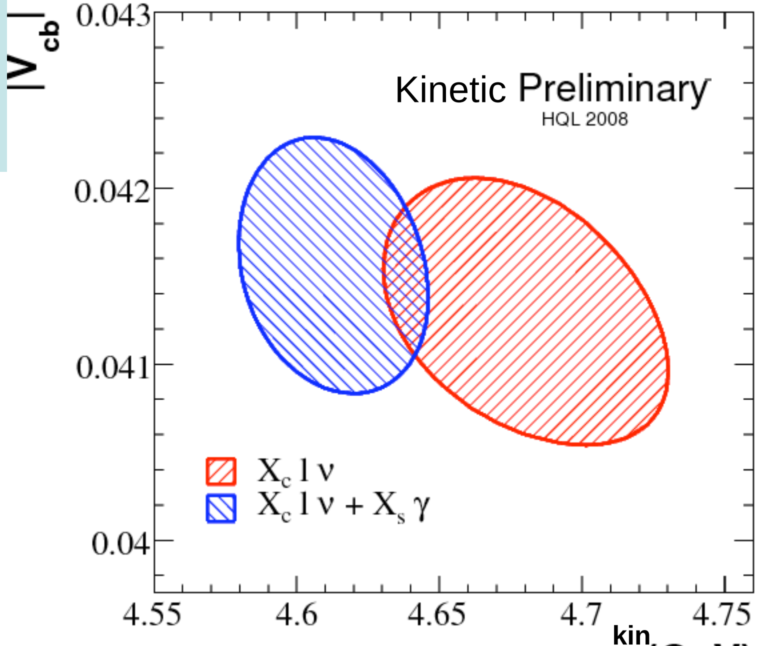
preliminary

New !

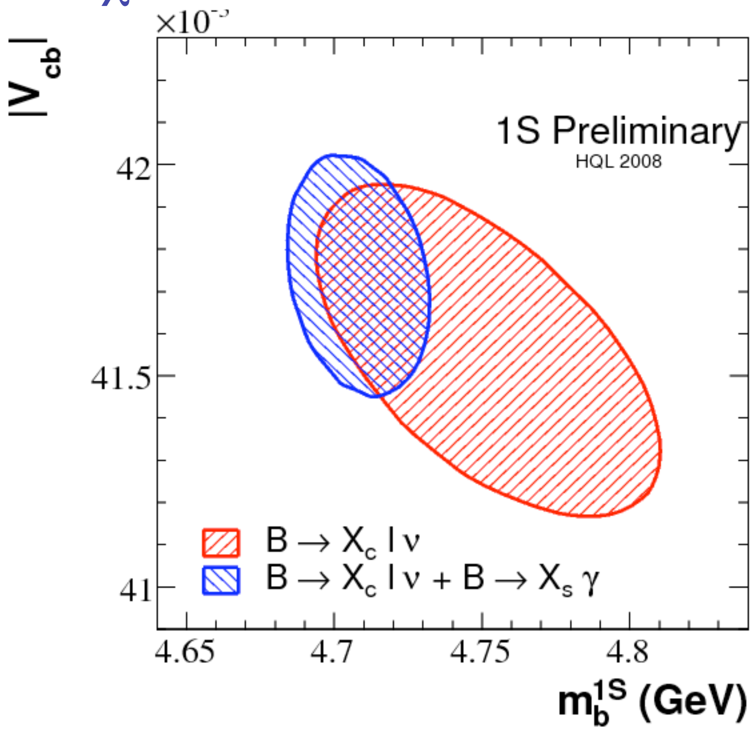
1S scheme ($X_c l\nu + X_s\gamma$ data)

$|V_{cb}| = (41.74 \pm 0.29_{fit} \pm 0.08_{\tau B}) \times 10^{-3}$
$m_b^{1S} = 4.708 \pm 0.024$ GeV

χ^2/ndf. = 26.1 / (70-7)



$\Delta\chi^2 = 1$ contours



Summary and conclusion

- Calculations based on heavy quark effective theory and operator product expansion can reproduce inclusive observables in B decays to a high degree of precision
- Results by experiment (kinetic scheme)

	$\lvert V_{cb}\rvert$ (10^{-3})	m_b (GeV)
BaBar [arXiv:0707.2670]	$41.88 \pm 0.56_{fit} \pm 0.08_{\tau B} \pm 0.59_{th}$	4.552 ± 0.055
Belle [arXiv:0803.2158]	$41.52 \pm 0.69_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}$	4.543 ± 0.075

- Fits to all available measurements (preliminary)

	$\lvert V_{cb}\rvert$ (10^{-3})
Kinetic scheme	$41.55 \pm 0.43_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}$
1S scheme	$41.74 \pm 0.29_{fit} \pm 0.08_{\tau B}$