Inclusive moment measurements and determination of $|V_{cb}|$ and m_b

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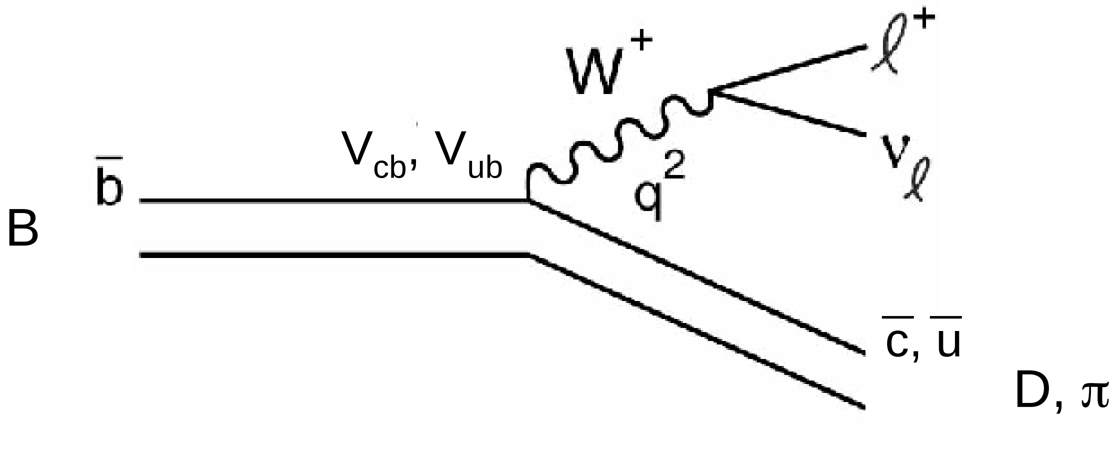
Semileptonic decays

- $|V_{cb}|$ and $|V_{ub}|$ are determined from semileptonic B decays



- "Old physics": tree diagrams, no 'pollution' from New Physics contributions
- A precise determination of $|V_{ub}/V_{cb}|$ is crucial to be able to observe deviations from the CKM mechanism due to New Physics

The semileptonic width

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

$$\Gamma_{\rm sl}(b\rightarrow c) = \frac{G_F^2\, m_b^5(\mu)}{192\,\pi^3}\, |V_{cb}|^2\, (1+A_{\rm ew})\, A^{\rm pert}(r,\mu)$$
$$\left[z_0(r)\left(1 - \frac{\mu_\pi^2(\mu) - \mu_G^2(\mu) + \frac{\rho_D^3(\mu)+\rho_{LS}^3(\mu)}{m_b(\mu)}}{2m_b^2(\mu)}\right) - 2(1-r)^4\, \frac{\mu_G^2(\mu) - \frac{\rho_D^3(\mu)+\rho_{LS}^3(\mu)}{m_b(\mu)}}{m_b^2(\mu)} + d(r)\, \frac{\rho_D^3(\mu)}{m_b^3(\mu)} + \ldots \right]$$

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 → $X_c l \nu$

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

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

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

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

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

The OPEs of these inclusive observables contain the same HQ parameters

Global analysis of B decays

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

- 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, $\tau_{1\text{-}3}$

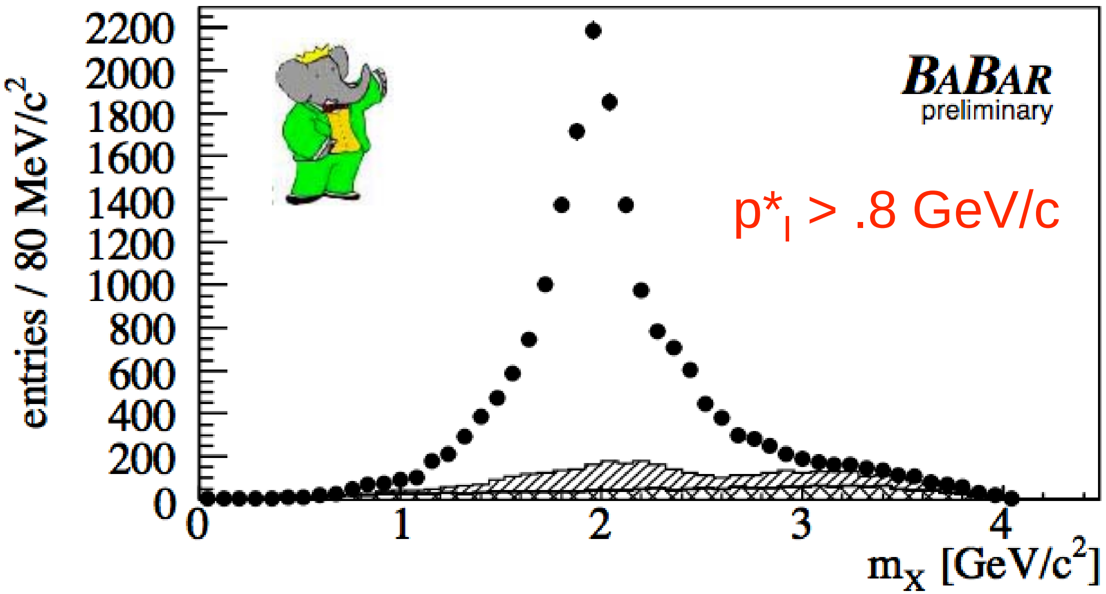
Available measurements

- 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)]

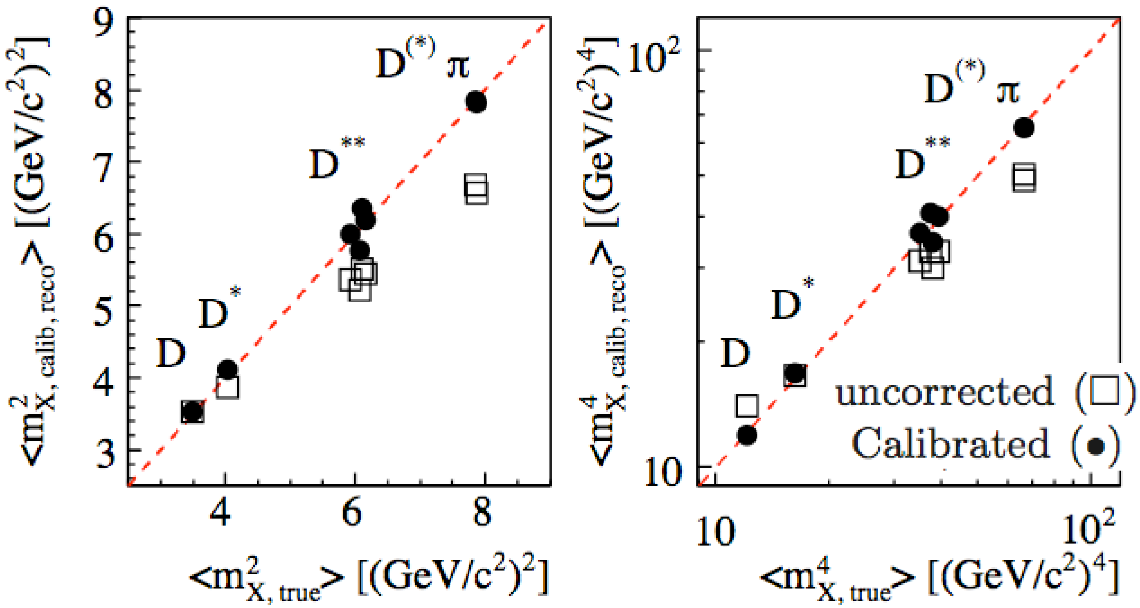
BaBar M^2_X moments

[arXiv:0707.2670] preliminary

- 210/fb of Y(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



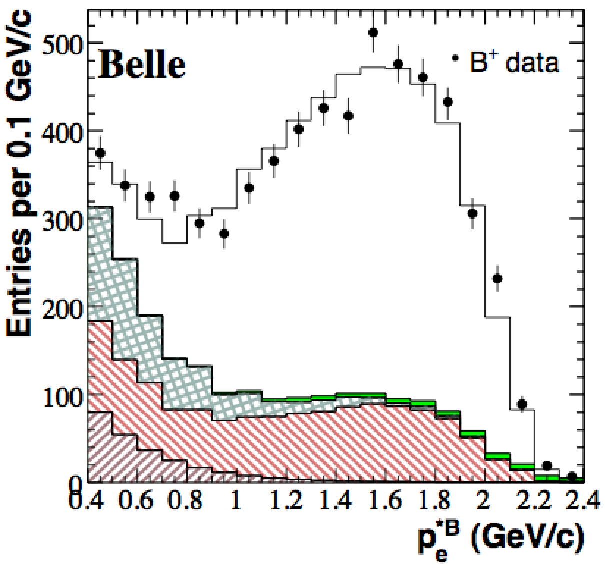
$p^*_l > .8$ GeV/c

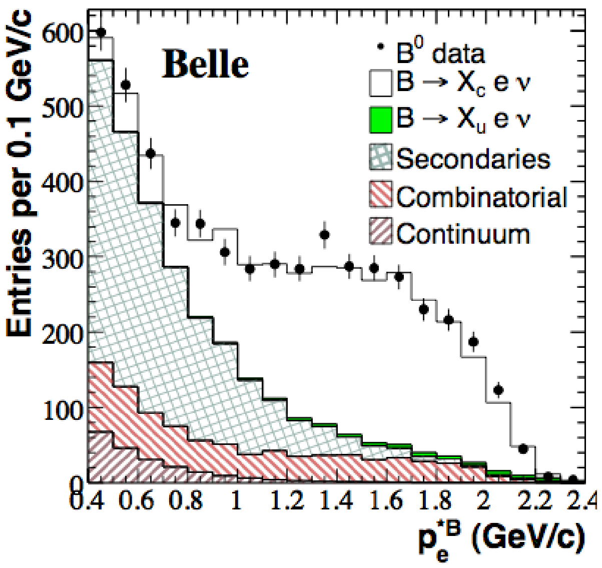


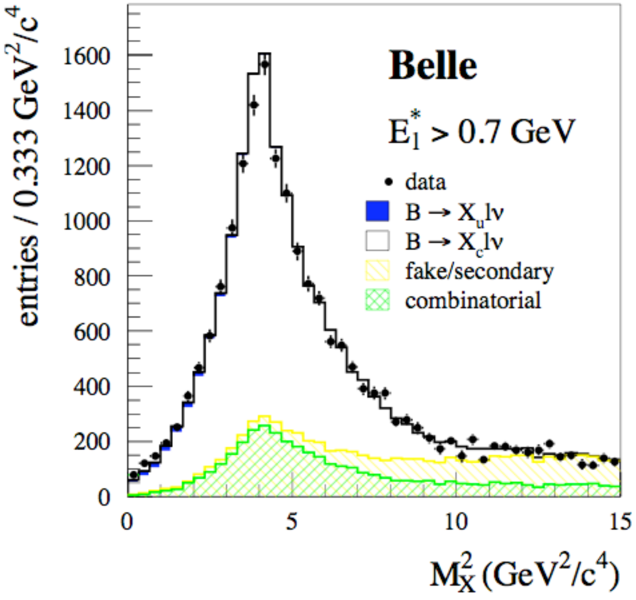
Belle E_l and M^2_X moments

[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

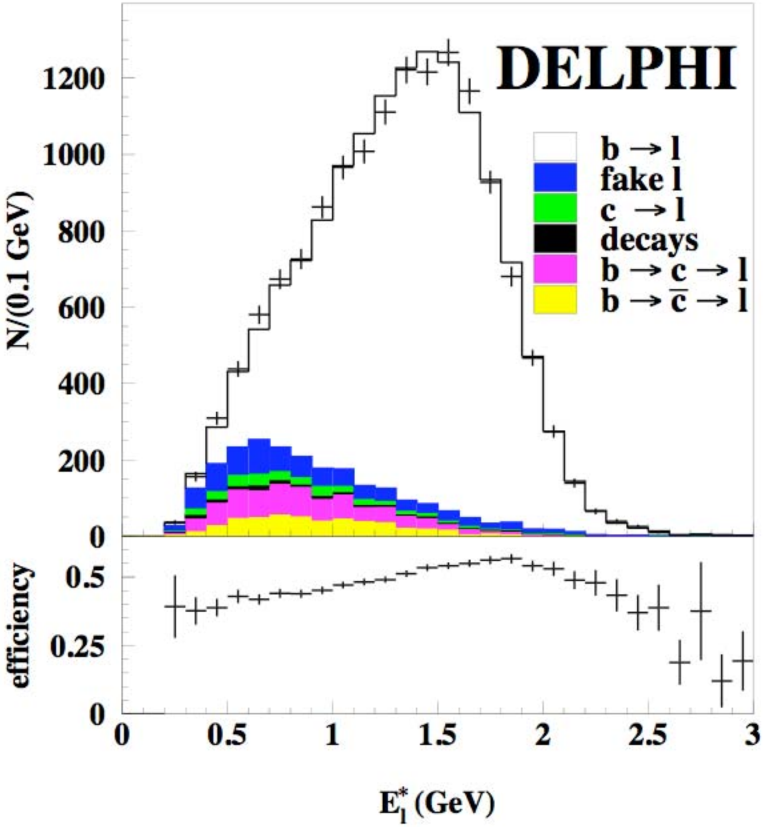


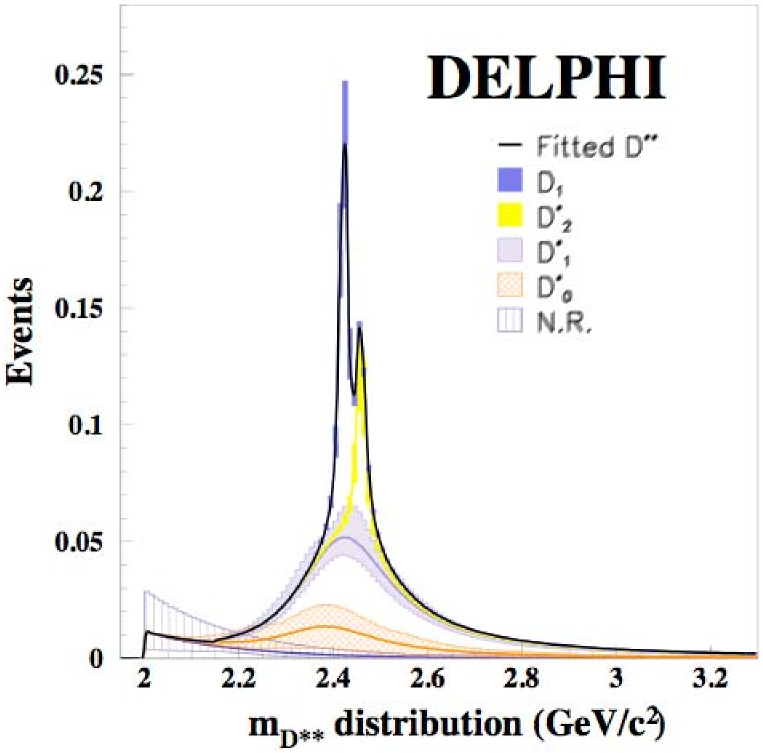




DELPHI E_l and M^2_X moments

[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

New !

[Phys. Rev. D78, 032016 (2008)]

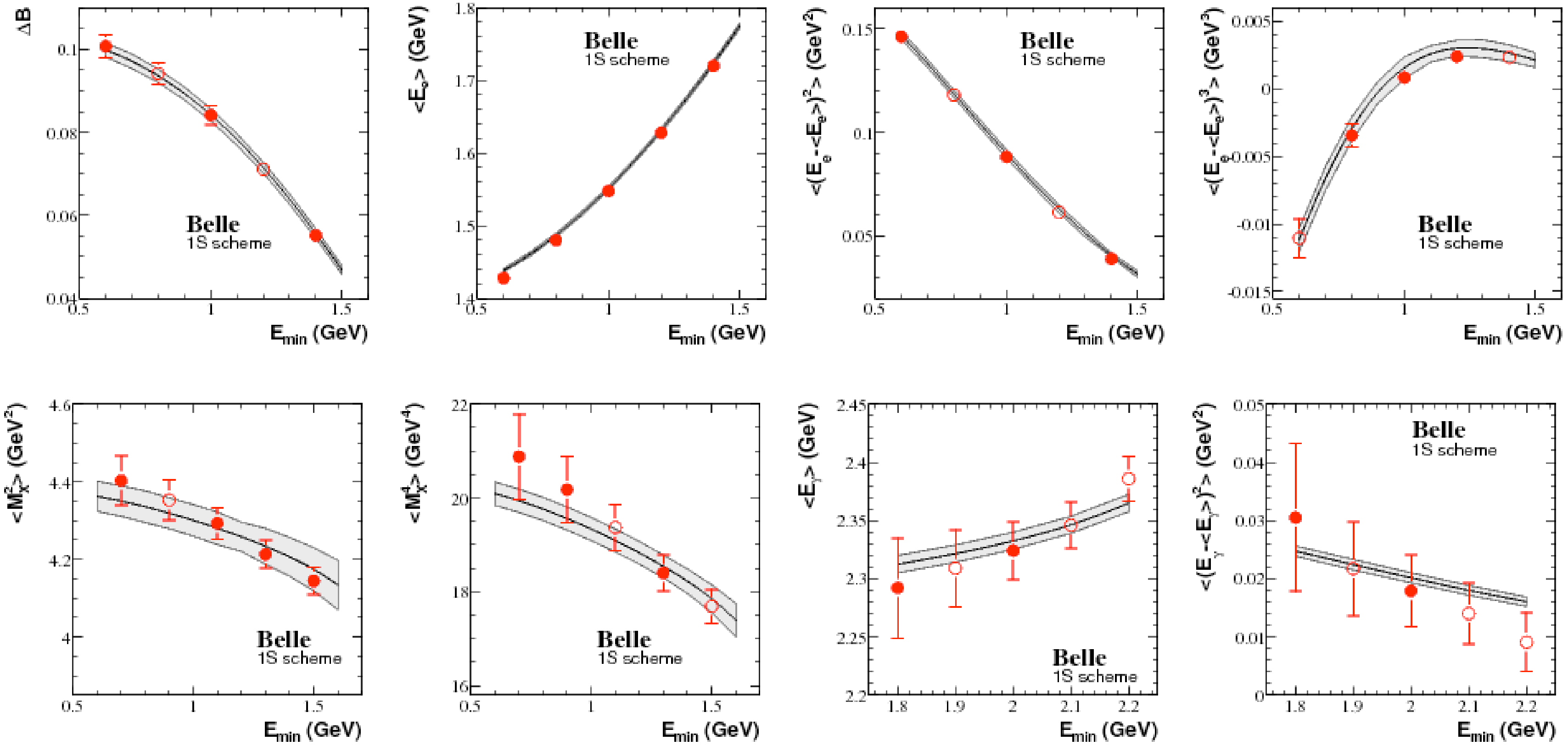
Similar analysis recently done on the BaBar moment data [arXiv:0707.2670] preliminary

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

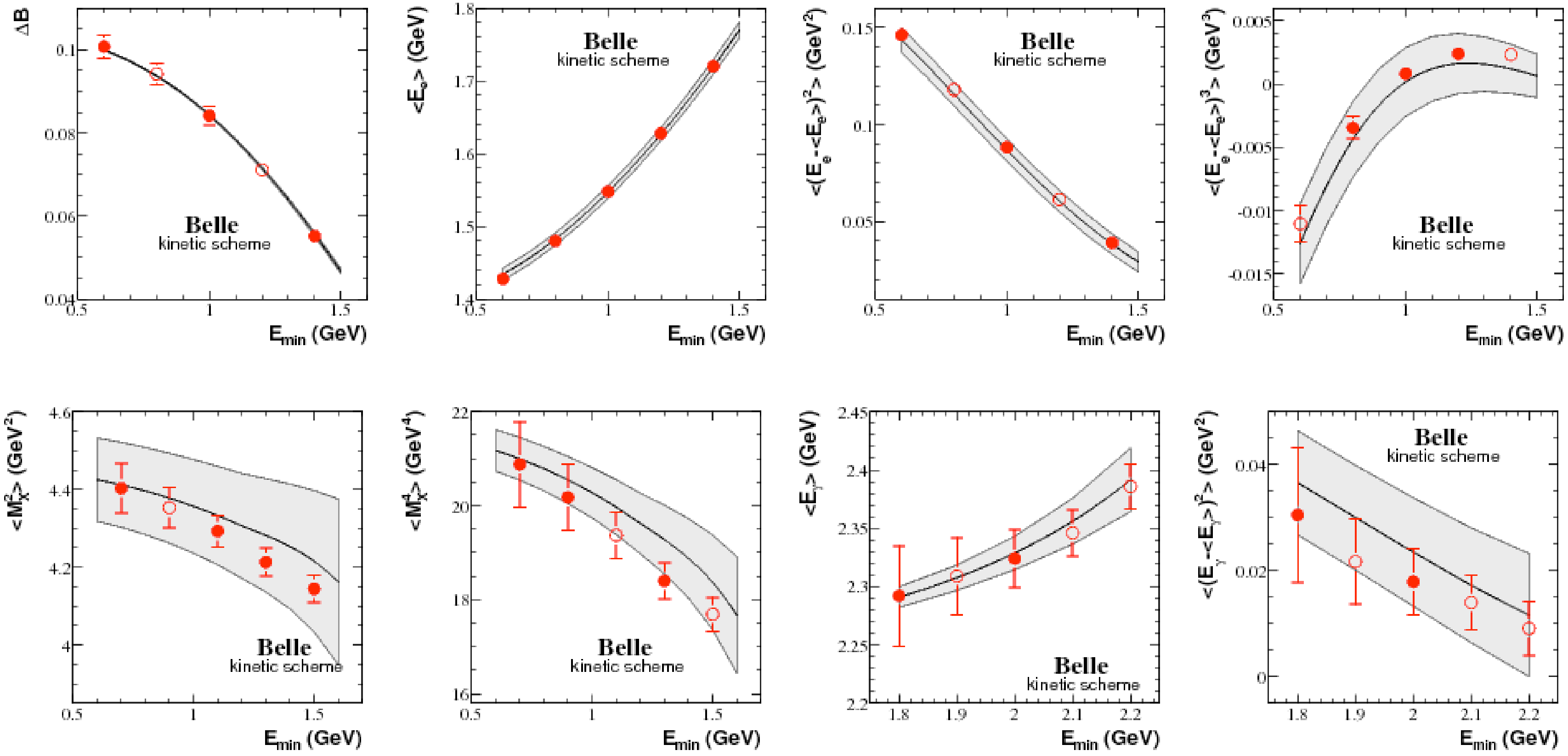
- Exclude measurements
  - with no (reliable) theory prediction
  - with excessive correlations

Fit result in the 1S scheme



χ^2/ndf. = 7.3 / (25-7)

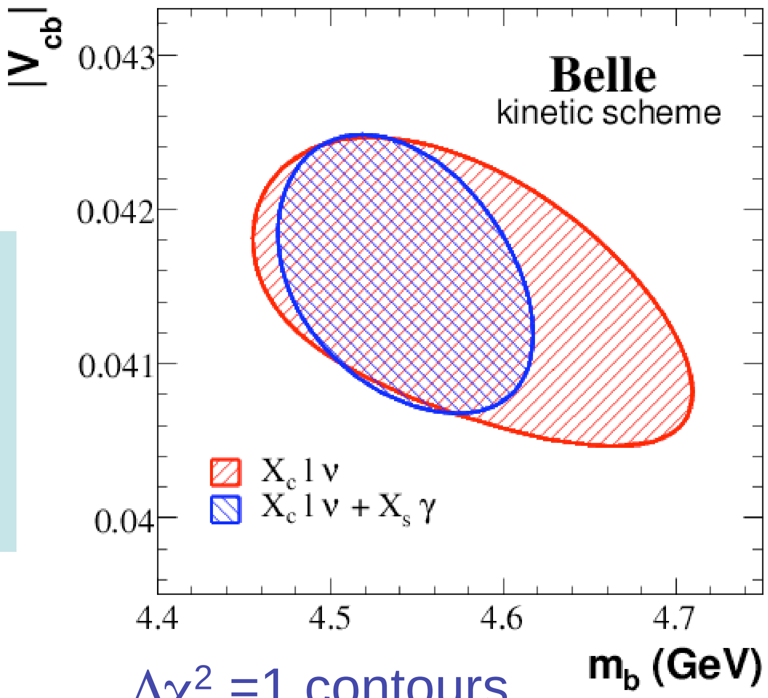
Fit result in the kinetic scheme



χ^2/ndf. = 4.7 / (25-7)

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

$|V_{cb}| = (41.58 \pm 0.69_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}) \times 10^{-3}$
$m_b^{kin} = 4.543 \pm 0.075$ GeV
$m_c^{kin} = 1.055 \pm 0.118$ GeV

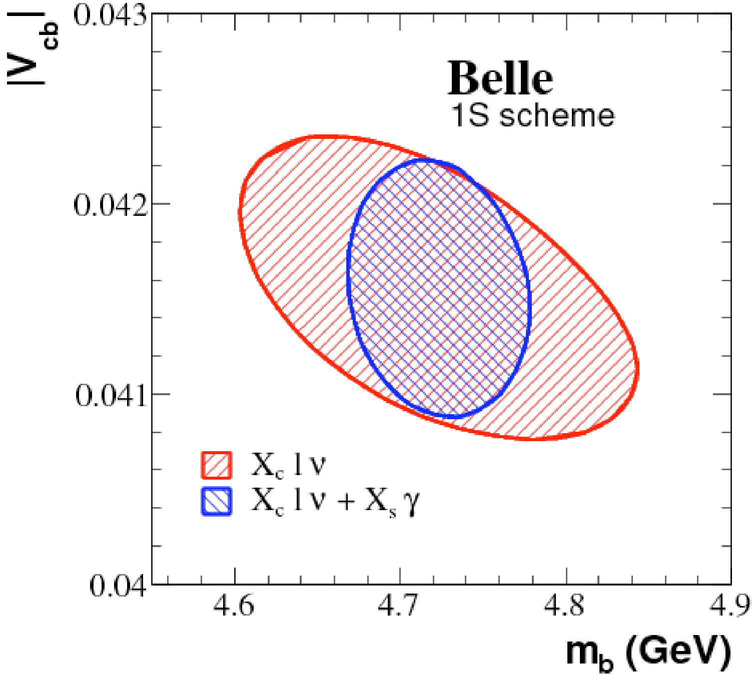


$\Delta\chi^2 = 1$ contours

Results for m_b compatible after scheme translation

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



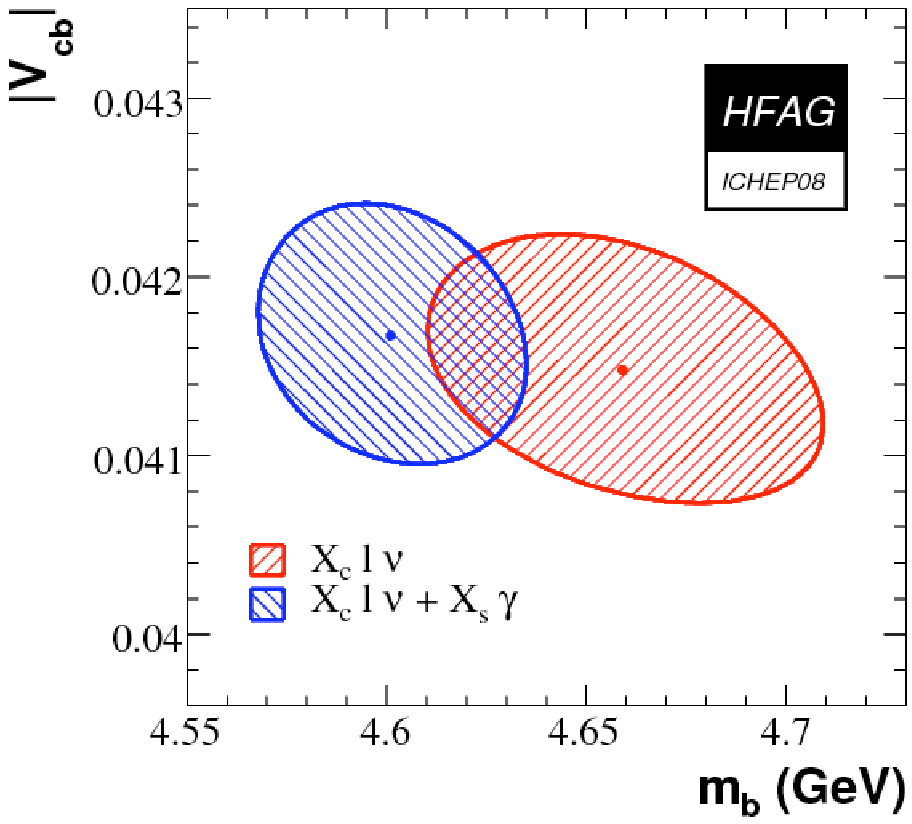
HFAG ICHEP08 fit
in the kinetic scheme

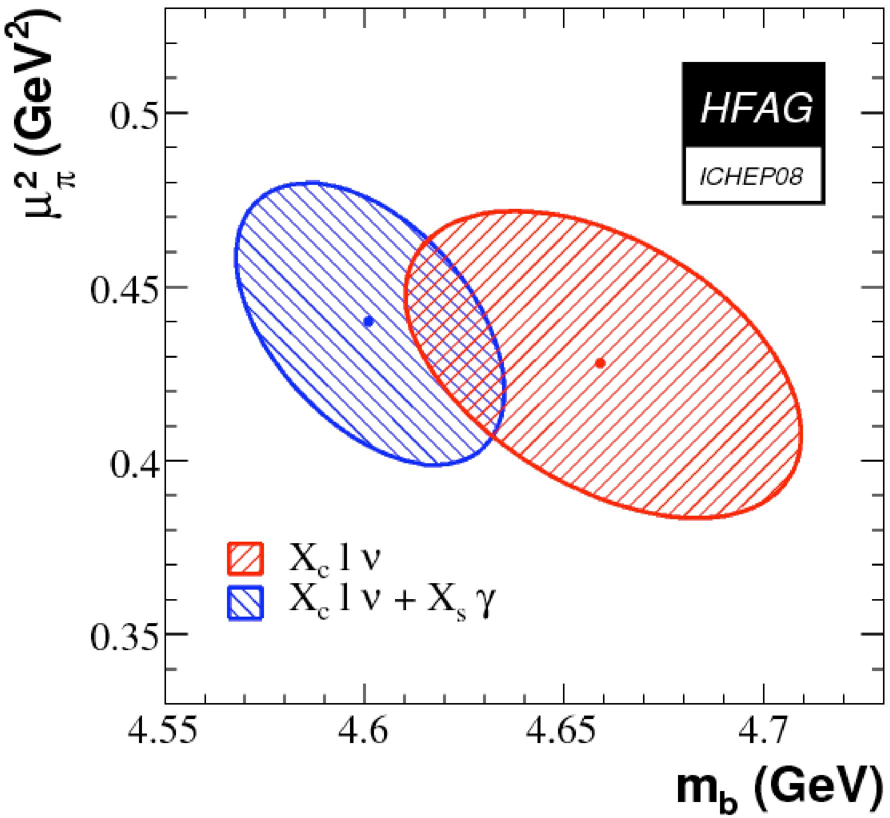
http://www.slac.stanford.edu/xorg/hfag/semi/ichep08/gbl_fits/kinetic/

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 [arXiv:0707.2670] preliminary $\langle E^{n}_{\gamma} \rangle$: 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)]

- 27 moments from BaBar, 25 moments from Belle and 12 moments from other experiments





Input	$\|V_{cb}\|$ (10^{-3})	m_b (GeV)	μ^2_π (GeV^2)	χ^2/ndf
All moments	41.67+/-0.43(fit)+/-0.08(τ_B)+/-0.58(th)	4.601+/-0.034	0.440+/-0.040	29.7/57
$X_c l\nu$ only	41.48+/-0.47(fit)+/-0.08(τ_B)+/-0.58(th)	4.659+/-0.049	0.428+/-0.044	24.1/46

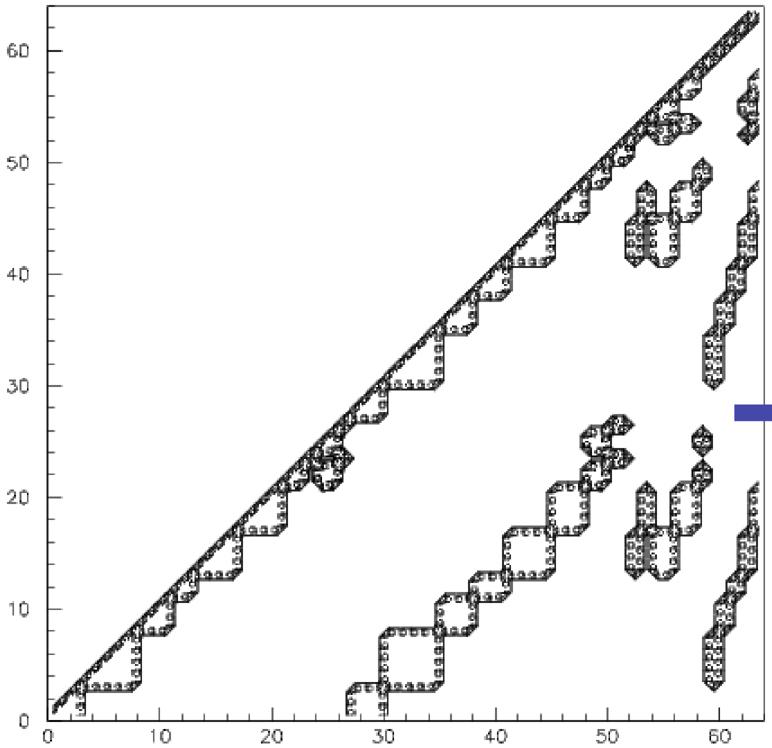
Outlook

Open issues in global fits

- χ^2 puzzle
  - χ^2/ndf. of global fits comes out much too low
  - Are (theory) errors overestimated?
  - Are correlations underestimated?
- $B \to X_s \gamma$ bias
  - Inclusion of the $B \to X_s \gamma$ data lowers the b-quark mass m_b

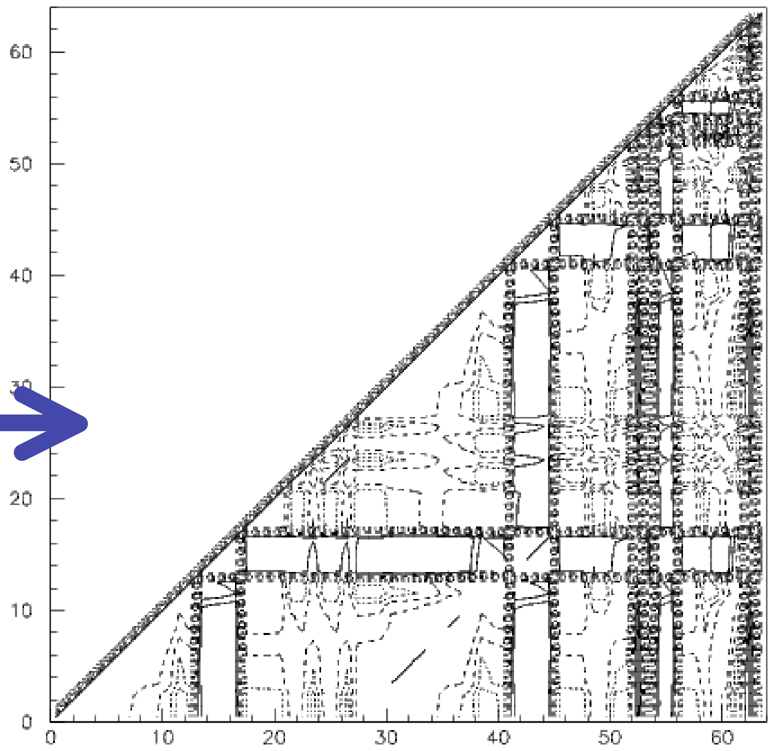
Theory correlation coefficients (HFAG data, kinetic scheme)

default



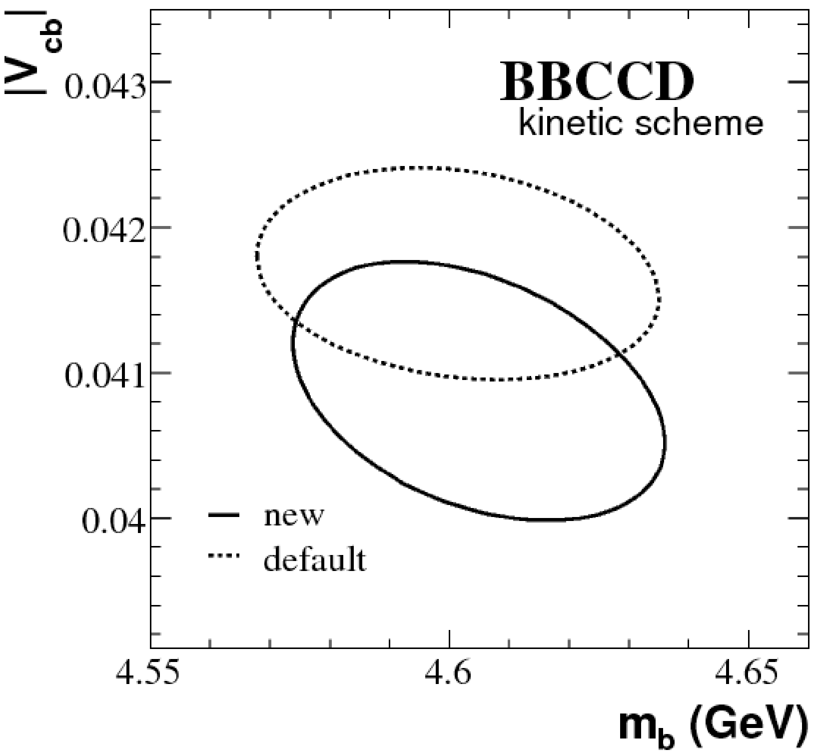
theory correlation coefficients in the present HFAG fit

new

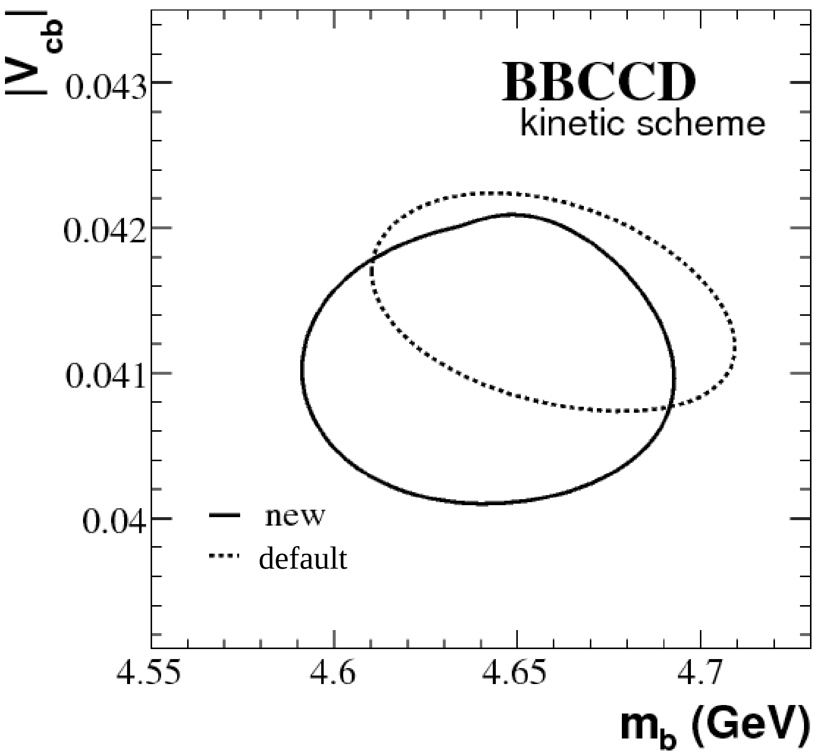


“actual correlations”, i.e., correlation coefficients derived from theory expressions using a toy MC approach

$X_c l\nu + X_s\gamma$



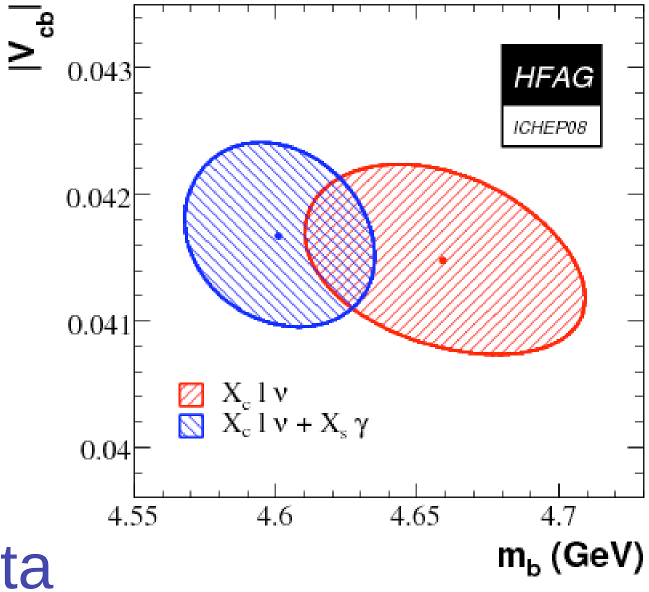
$X_c l\nu$ only



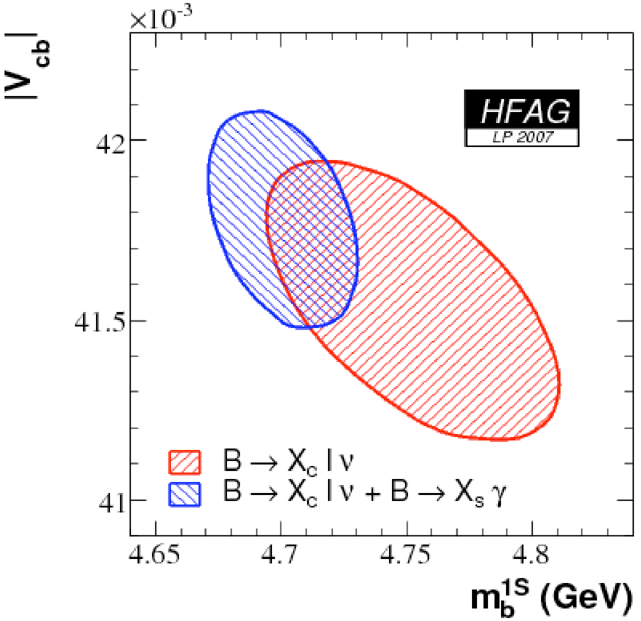
	$\lvert V_{cb}\rvert$ (10^{-3})	m_b (GeV)	μ^2_π (GeV^2)	χ^2/ndf
default	41.67+/-0.43(fit)+/-0.08(τ_B)+/-0.58(th)	4.601+/-0.034	0.440+/-0.040	29.7/57
new	40.85+/-0.68(fit)+/-0.08(τ_B)+/-0.57(th)	4.605+/-0.031	0.312+/-0.060	54.2/57

$B \to X_s\gamma$ bias

kinetic scheme

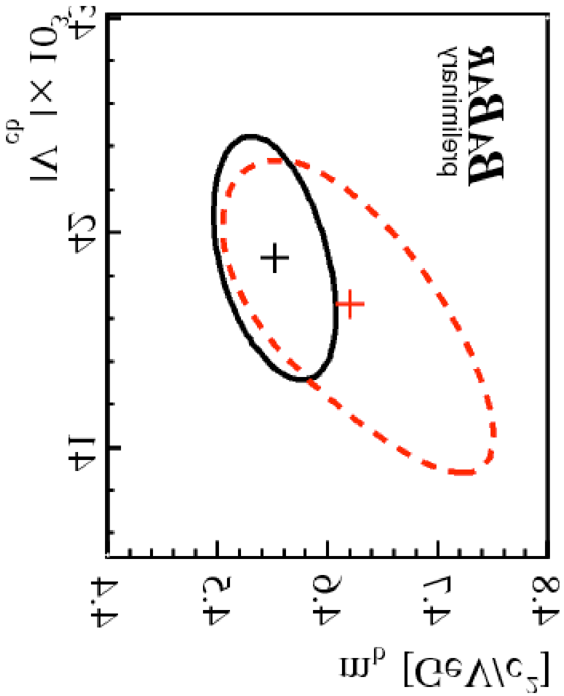


1S scheme

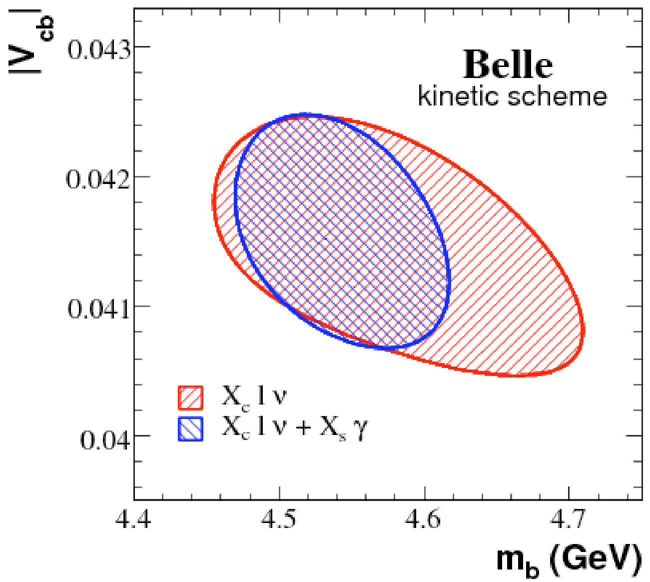


BaBar data

[arXiv: 0707.2670]



Belle data



[PRD78, 032016]

Summary and conclusions

- Calculations based on heavy quark effective theory and operator product expansion can reproduce inclusive observables in B decays to a high degree of precision
- Fits to the Belle/BaBar data in the kinetic scheme

	$\|V_{cb}\|$ (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 [PRD78, 032016]	$41.58 \pm 0.69_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}$	4.543 ± 0.075

- Fits to Belle data in the kinetic/1S schemes [PRD78, 032016]

	$\|V_{cb}\|$ (10^{-3})
kinetic scheme	$41.58 \pm 0.69_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}$
1S scheme	$41.56 \pm 0.68_{fit} \pm 0.08_{\tau B}$

- ICHEP08 HFAG result in the kinetic scheme

	$\vert V_{cb}\vert$ (10^{-3})	m_b (GeV)
HFAG ICHEP08	$41.67 \pm 0.43_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}$	4.601 ± 0.034

- Open issues
  - Theory error correlations
  - $B \to X_s \gamma$:
    Can we safely use this data in the fit?

Backup

Theory error in the kinetic scheme

- Non-perturbative corrections: consider the following variations in the HQ parameters
  - m_b/m_c: +/- 20 MeV
  - μ^2_π/μ^2_G: +/- 20%
  - ρ^3_D/ρ^3_{LS}: +/- 30%
- Perturbative corrections
  - $\alpha_S = 0.22 \pm 0.04$
- Bias correction uncertainty ($B \rightarrow X_s\gamma$)
  - 30% of the absolute value of the bias correction

Toy MC for theory correlations

1. For α_S, m_b, m_c and each HQ parameter, draw a Gaussian random number within the allowed range (previous slide)
2. Calculate the moment predictions x_i, $i=1,\ldots,64$ (HFAG data) for this set of parameters
3. Repeat step 1) and 2) 100,000 times
4. Calculate the theory correlations as:

$$\rho(x_i,x_j)=<(x_i-<x_i>)(x_j-<x_j>)>/\sigma_{xI}\sigma_{xj}$$