Heavy Flavour Averages

Summary of present activities

… what, why and how

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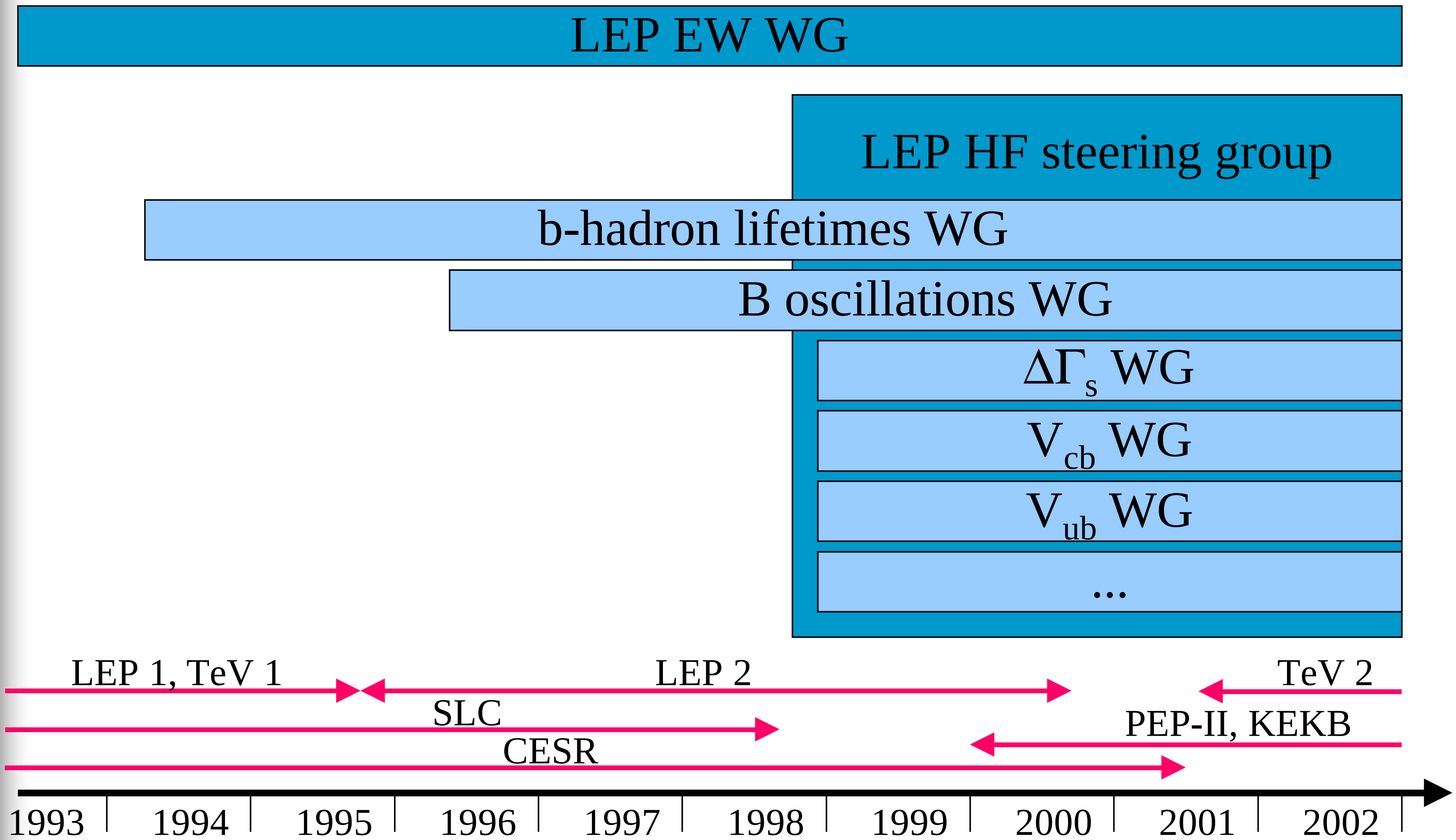
on behalf of
the LEP Heavy Flavour Steering group
and various working groups

CKM workshop, CERN, February 15, 2002

CERN-based working groups performing Heavy Flavour averages



Why these averaging WGs ?

- LEP has 4 experiments
  - Common experimental methods
  - Close in space (CERN)
- Many "inclusive" measurements
  (hence with non-negligible systematics)
- Some measurements with significant systematics
  - important to understand correlations
- Quite a few measurements not statistically limited
  - can decrease the error by combining

b-hadron lifetime WG

- Started at LEP in 1994
- Combination methods quickly established (in 1994)
- Contact people from CDF and SLD joined
- Products:

  $\tau(B^+)$, $\tau(B^0)$, $\tau(B+)/\tau(B^0)$, $\tau(B_s)$
  τ(b-baryon), $\tau(\Lambda_b)$, $\tau(\Xi_b)$
  weighted averages of above at high energy: τ^{incl}, τ^{sl}, ...

- World averages in PDG since 1996

http://home.cern.ch/~claires/blife.html

Lifetime averages at 1994 winter conf.: an interesting anecdote

- Two B_s lifetime averages based on same data:
  - ❶ weighted average using weights = $(1/\sigma_{\tau i})^2$
    $\tau(B_s) = 1.38 \pm 0.17$ ps (La Thuile, 1994)
  - ❷ weighted average using weights = $(\tau_i/\sigma_{\tau i})^2$
    $\tau(B_s) = 1.66 \pm 0.22$ ps (Moriond, 1994)
- Exponential distributions have $\sigma \propto \tau$:
  - ❶ leads to negative bias,
    especially for small sample and high resolution
  - ❷ leads to positive bias,
    especially for small sample and low resolution
  - – Confirmed and quantified by toy MC studies
    [R.Forty, CERN-PPE/94-144]

Averaging methods for lifetimes

- COMBINE:
  - based on a Best Linear Unbiased Estimator (BLUE) technique using a "relative error matrix E"

$$\chi^2=\sum_{i,j}(\bar{\tau}-\tau_i)(E^{-1})_{ij}(\bar{\tau}-\tau_j) \qquad \bar{\tau}=\sum_{i,j}\tau_i\,(E^{-1})_{ij}\Big/\sum_{i,j}(E^{-1})_{ij} \qquad (\bar{\sigma}/\bar{\tau})^2=1\Big/\sum_{i,j}(E^{-1})_{ij}$$

  - can take statistical and systematic correlations into account
  - can handle symmetric uncertainties only

- COMBY:
  - based on a model for the likelihood (knowing pdf is exponential convoluted with gaussian resolution)
  - reconstruct an approximate likelihood for each measurement given its asymmetric errors and maximize total likelihood
  - treat systematic errors in an absolute way

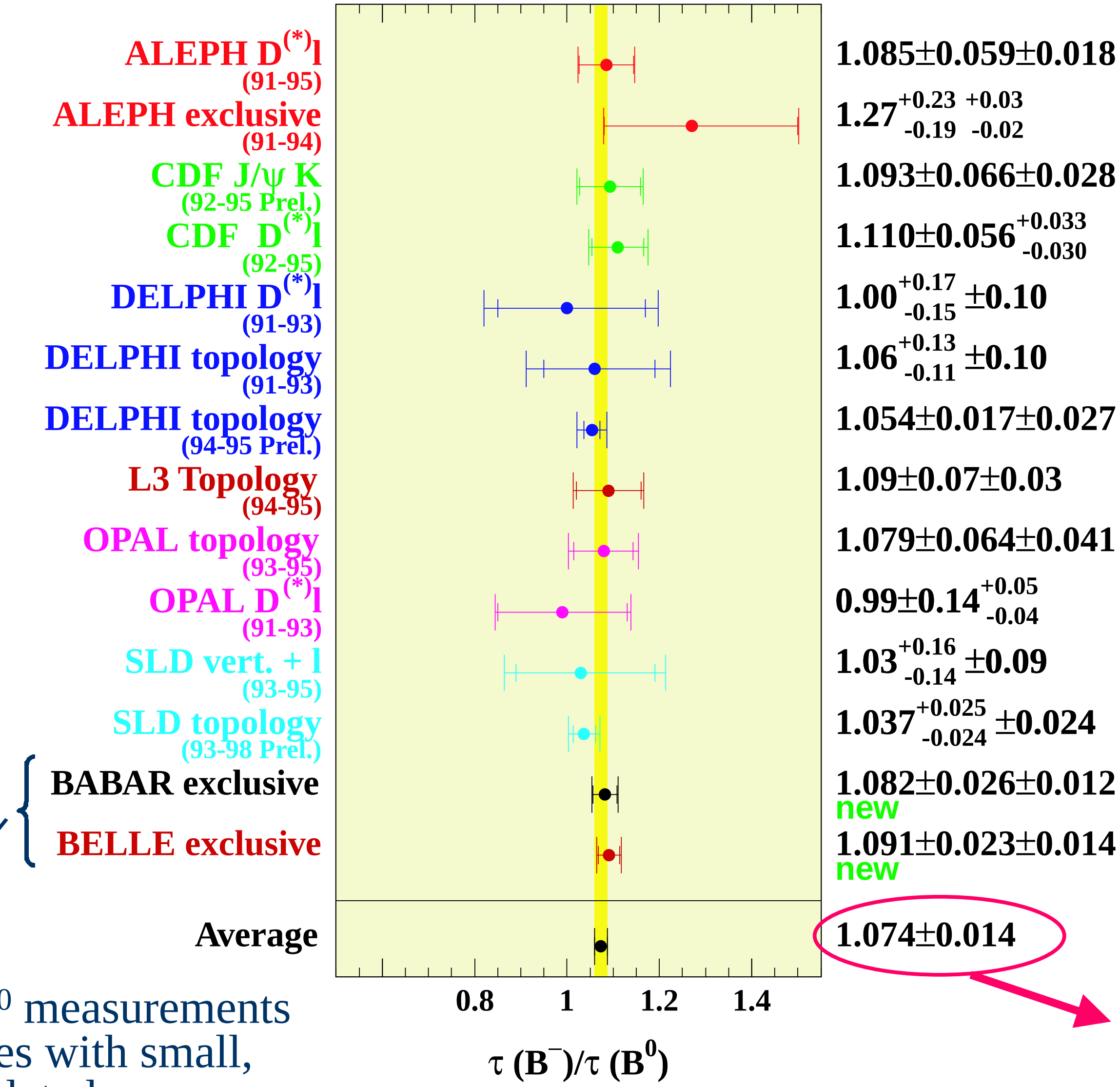
- In practice, very small differences for sufficiently large statistics

Correlated systematics between lifetime analyses

- detector effects
  - vertex reconstruction, ...
- physics backgrounds
  - BR($B \to D^{**} l \upsilon$)
  - b-hadron fractions, ...
- momentum estimate
  - b fragmentation
  - decay model, multiplicities
  - BRs of b- and c-hadrons
  - b-baryon polarization and mass, ...

(most important for (semi-)inclusive analyses)

New B^+/B^0 lifetime ratio (Feb 2002)



$\tau(B^+) \neq \tau(B^0)$

New B^+ and B^0 measurements from B factories with small, almost uncorrelated errors

B oscillations WG

- EPS-HEP 1995 (Brussels):
  - ALEPH proposes amplitude method for Δm_s analyses
- WG setup in 1996 by LEP collaborations
  - main goal and motivation: combine Δm_s limits
  - other goals quickly added: Δm_d average + b-hadron fractions
- SLD+CDF joined in 1997
- Products:

  $f(B_s)$, $f(B_d)$, $f(B_u)$, f (b-baryon) and correlations
  Δm_d, χ_d
  Δm_s limit, combined amplitude spectrum

- World averages in PDG since 1998

http:/www.cern.ch/LEPBOSC/

Determination of b-hadron fractions

Fractions of different species in an unbiased sample of weakly-decaying b-hadrons produced at high energy

- Assumptions:

  $f(B_u) + f(B_d) + f(B_s) + f(\text{b-baryon}) = 1$
  $f(B_u) = f(B_d)$
  fractions identical in Z decays and at Tevatron

- Values from BR measurements, compiled and averaged by WG:

  $f(B_s) = (9.2 \pm 2.4)\%$, $f(\text{b-baryon}) = (10.6 \pm 2.0)\%$

- Improve fractions using:
  - average $\chi = f'(B_s)\,\chi_s + f'(B_d)\,\chi_d = 0.1197 \pm 0.0040$ from LEP EW fit
  - world average $\chi_d = 0.184 \pm 0.004$ by WG
  - $\chi_s = 1/2$

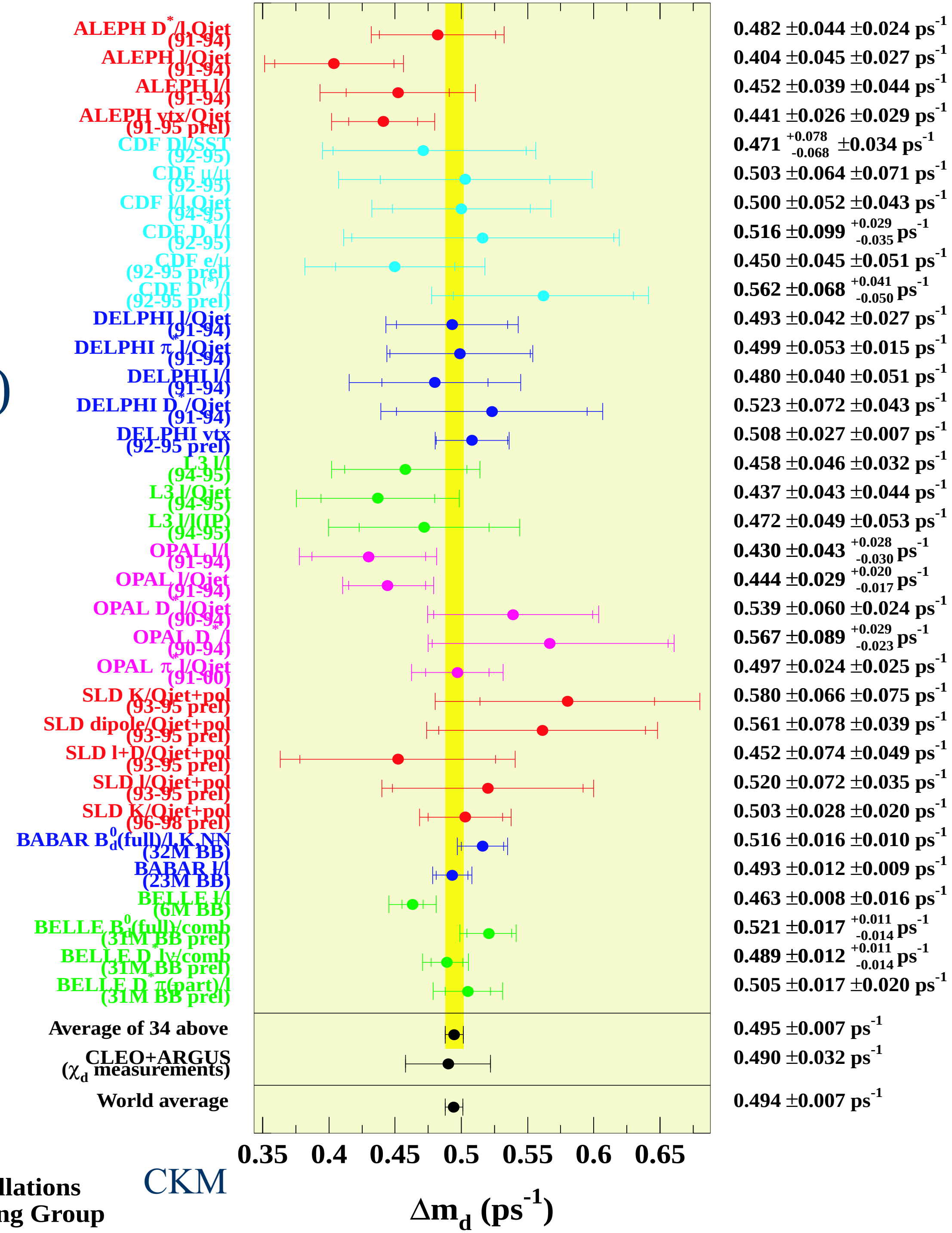
  $f(B_s) = (9.7 \pm 1.1)\%$, $f(\text{b-baryon}) = (10.3 \pm 1.8)\%$ **best estimates**

factor 2 improvement

34 measurements of Δm_d by 8 experiments !

(22 published + 12 prelim.)

new B factory measurements



Main issues for Δm_d combination

- Several correlated systematic (and statistical) uncertainties
- Several systematics depend on physics parameters
  - b-hadron lifetimes
  - b-hadron fractions,
  - integrated mixing (!), ...
- Dependence on physics parameters not always explicit
- Results are not "homogeneous"
  - different sets of physics parameters used (e.g. lifetime ratios instead of lifetimes) } too late to avoid this !
  - different central values and uncertainties assumed for these physics parameters
- Average Δm_d is used to determine the fractions

Combination method for Δm_d

- Adjust individual measurements (both central values and appropriate systematic uncertainties) to a common set of physics parameters
  - b-hadron lifetimes
  - b-hadron fractions
  - ...

- Establish list of correlated systematics
  - for each such systematics assume full (anti-) correlation between analyses:
    - b-hadron fractions, experimental effects, ...
  - if not possible, add certain systematic errors in quadrature to form "lumps" assumed to be fully correlated across analyses:
    - uncertainties due to b-hadron lifetimes
    - uncertainties due to b-fragmentation
    - uncertainties due to cascade decays ($b \to l$, $b \to c \to l$,...)
    - ...

- Symmetrize all uncertainties (using quadratic average)

Combination method for Δm_d (cont.)

- `MINUIT`mize (a modified version* of) the following χ^2 with respect to X and Y_α:

$$\chi^2 = \sum_{i,j=1}^{n} \left(X_i + \sum_{\alpha=1}^{m} \Delta_{\alpha i} Y_\alpha - X \right) (E^{-1})_{ij} \left(X_j + \sum_{\beta=1}^{m} \Delta_{\beta j} Y_\beta - X \right) + \sum_{\gamma=1}^{m} Y_\gamma^2$$

$$E_{ij} = \rho_{ij} \sigma_i^{stat} \sigma_j^{stat} + \delta_{ij} \sigma_i^{syst} \sigma_j^{syst}$$

$X_i \pm \sigma_i^{stat} \pm \sigma_i^{syst}$ = central values, stat. err., uncorrelated syst. err.

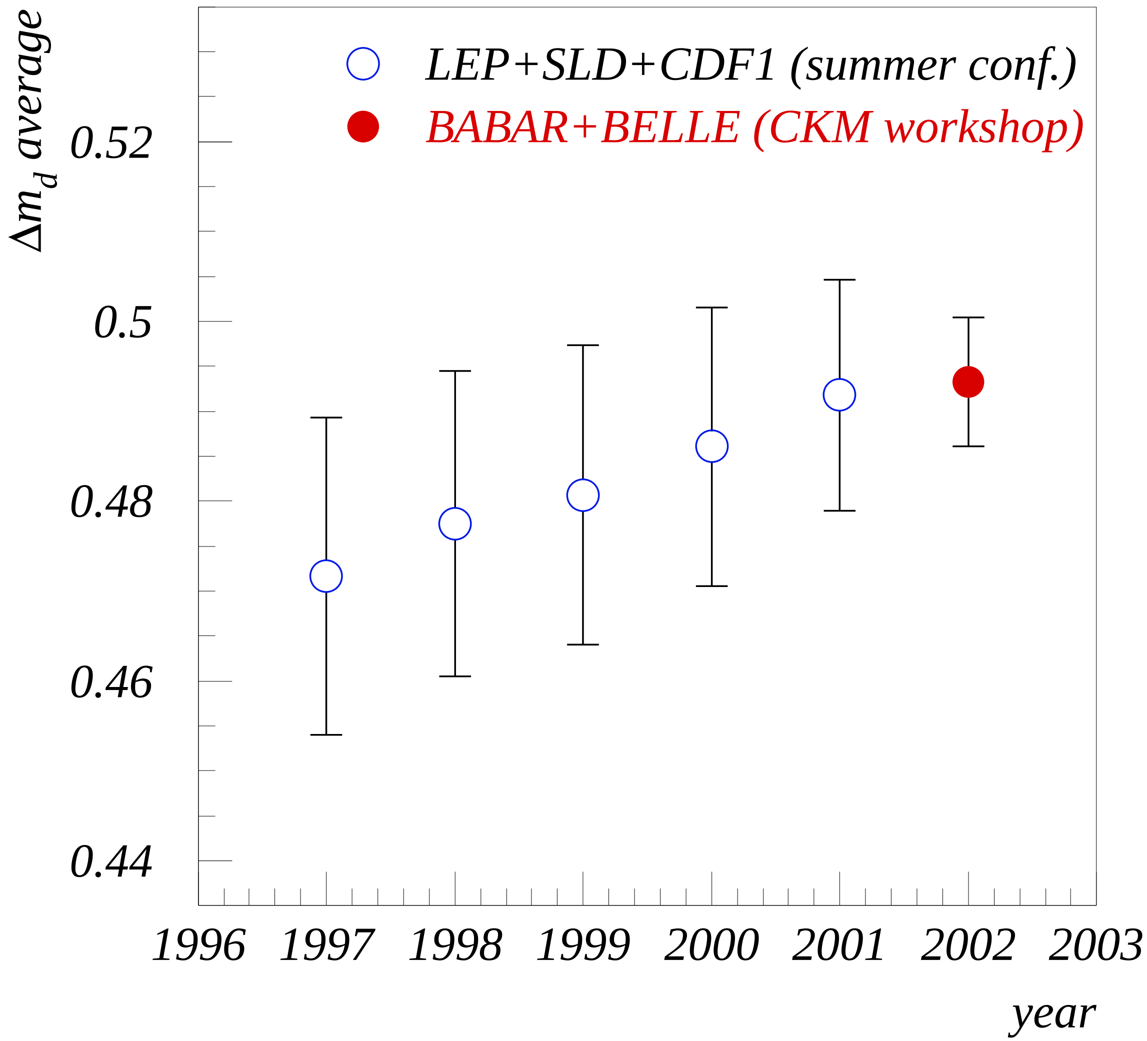
ρ_{ij} = statistical correlations

$\Delta_{\alpha i}$ = correlated systematic errors

- Quote fitted X as the Δm_d average and ignore fitted Y_α

* Modification for each systematics related to a b-hadron fraction:
  - remove the $Y_\alpha{}^2$ constraints
  - redefine Y_α as a function of X and appropriate physics parameters (e.g. χ, τ's)
  - add gaussian constraints on these parameters (if not already in)

Δm_d averages: “old vs new”



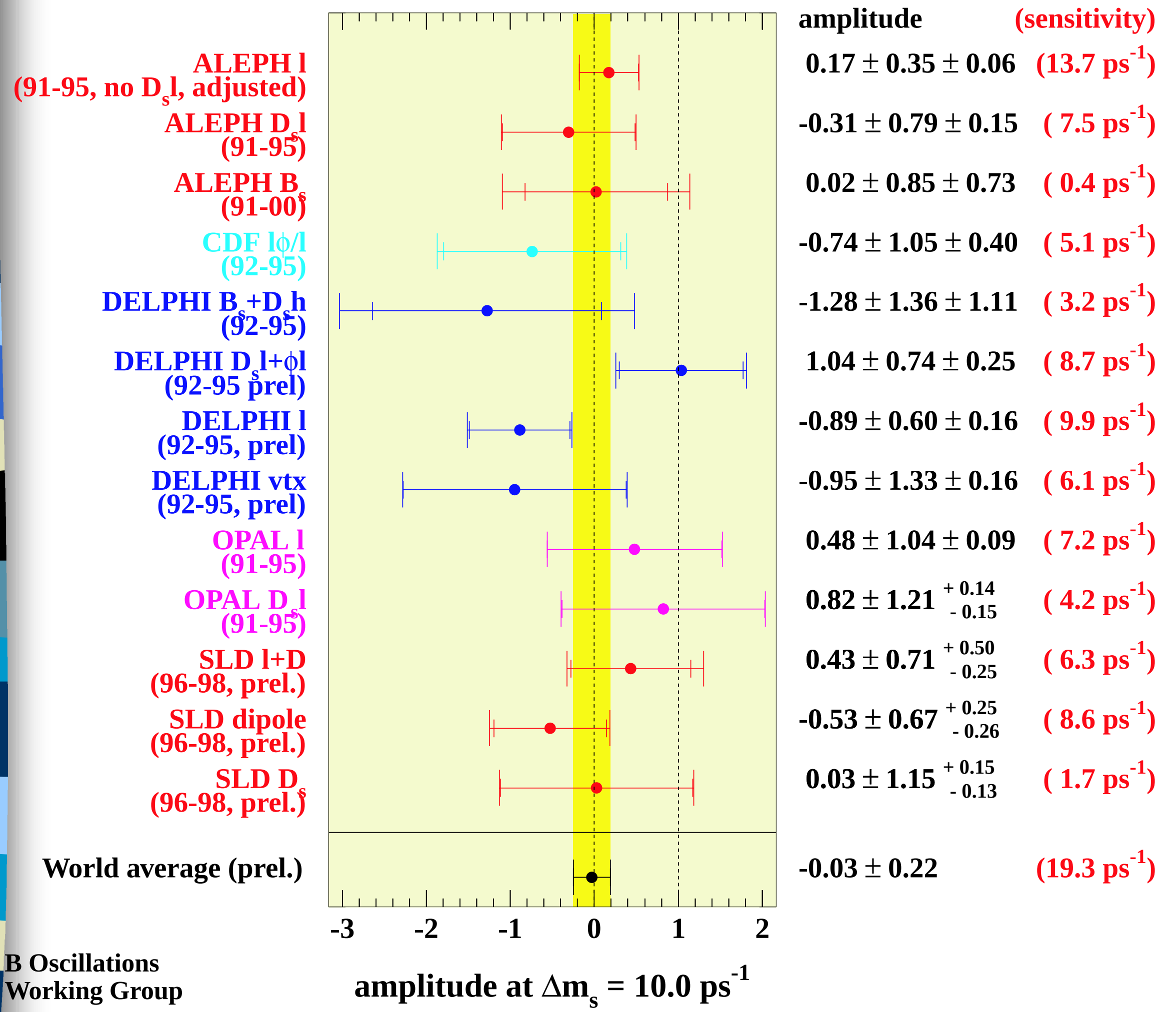
Δm_d averages (Feb 2002)

- Standard procedure:
  0.4923 ± 0.0128 ps^{-1} (LEP+SLD+CDF1)
  0.4947 ± 0.0076 ps^{-1} (BABAR+BELLE)
  0.4947 ± 0.0067 ps^{-1} (LEP+SLD+CDF1+BABAR+BELLE)
  0.4944 ± 0.0066 ps^{-1} (same + time-integrated meas.)

- Without lumping b-lifetime systematics
  (after asking BABAR to use same input parameters as BELLE):
  $\Delta m_d = 0.4933 \pm 0.0072$ (BABAR+BELLE)
  → takes advantage of anti-correlations in the systematics due to $\tau(B^0)$ and $\tau(B^+)/\tau(B^0)$

- Lessons:
  - lumping is "conservative"
  - important to have experiments quote their results in the same way
  - B-factory average might become better than world average (!), if treatment of lifetime systematics not improved

Combination of B_s oscillation amplitudes



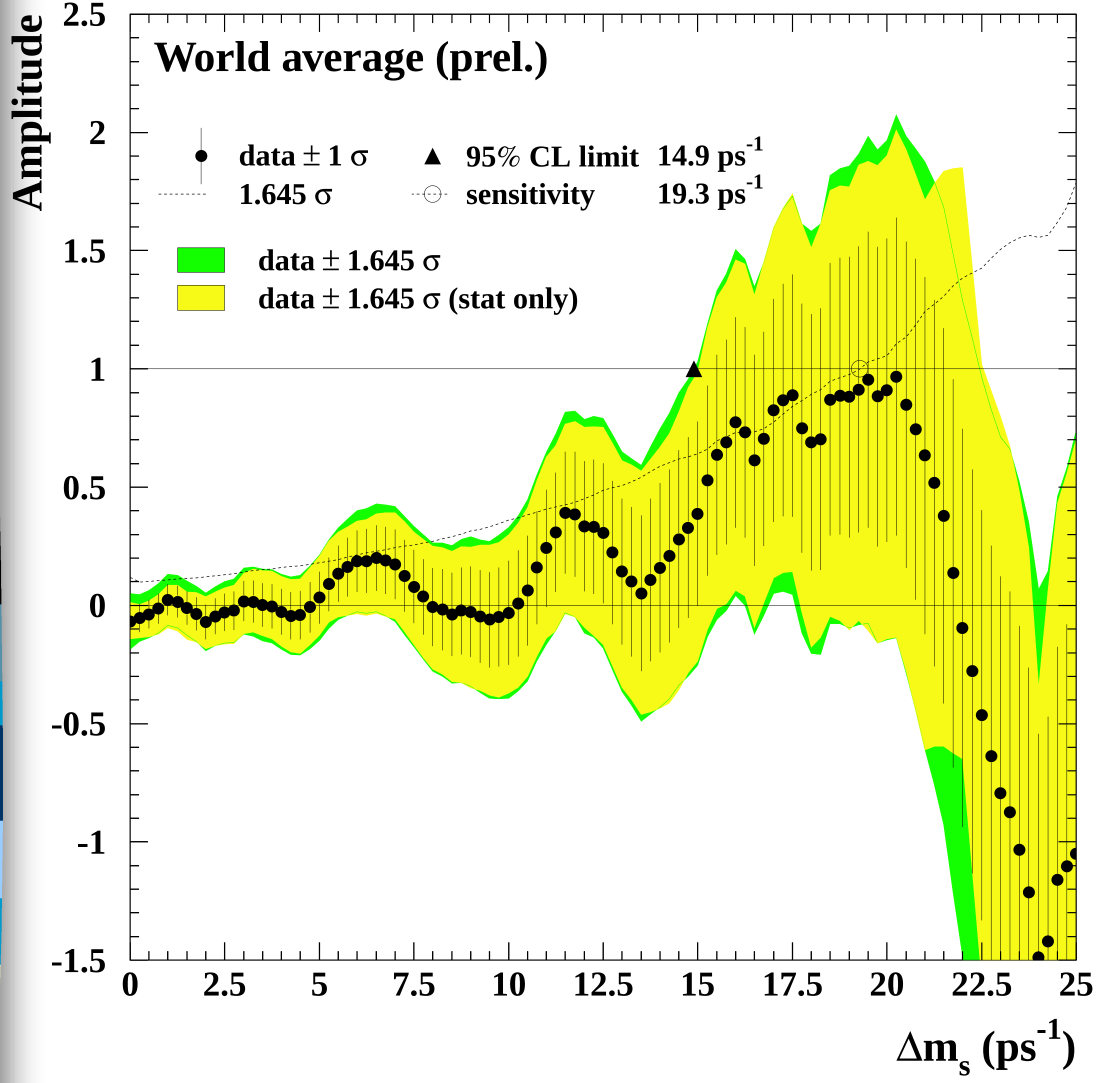
Use similar χ^2 method as for Δm_d averaging, with adjustments and lumping, as each value of the frequency

In addition, adjust statistical errors:

- new ALEPH analyses*
  $\rightarrow$ use quoted $\Delta\sigma$'s
- other inclusive analyses
  $\rightarrow$ assume $\sigma \propto 1/f(B_s)$
- other analyses
  $\rightarrow$ no adjustment of σ

Cl * use adjusted ΔA's as systematic errors, ignoring $\Delta\sigma$'s

Combined amplitude spectrum (Feb 2002)



$\Delta m_s > 14.9\ ps^{-1}$ @ 95% CL
expected limit = $19.3\ ps^{-1}$

(stat. only: $15.0\ /19.6\ ps^{-1}$)

With this sensitivity, we would expect:

- 5σ signal if $\Delta m_s = 9.5\ ps^{-1}$
- 3σ signal if $\Delta m_s = 13.5\ ps^{-1}$

LEP HF steering group

- Setup by the LEP collaborations at the end of 1998
  - 17 members, including representatives from SLD & CDF
- Goals:
  - coordinate HF averaging activities (production and decays)
  - encourage collaborations to present results in a way which will ease combination
  - identify areas where combined results are useful, and ensure that important HF physics opportunities are not missed

Effectively:

3 years after the end of LEP1 data-taking,
join remaining forces to complete HF analyses at LEP

LEP HF steering group (cont.)

- Coordinate WG activities:
  - old WGs (b lifetime, B oscillations)
  - new WGs ($\Delta\Gamma_s$, V_{cb} , V_{ub})
  - other activities
    (charm counting, b fragmentation, CKM fits, ...)

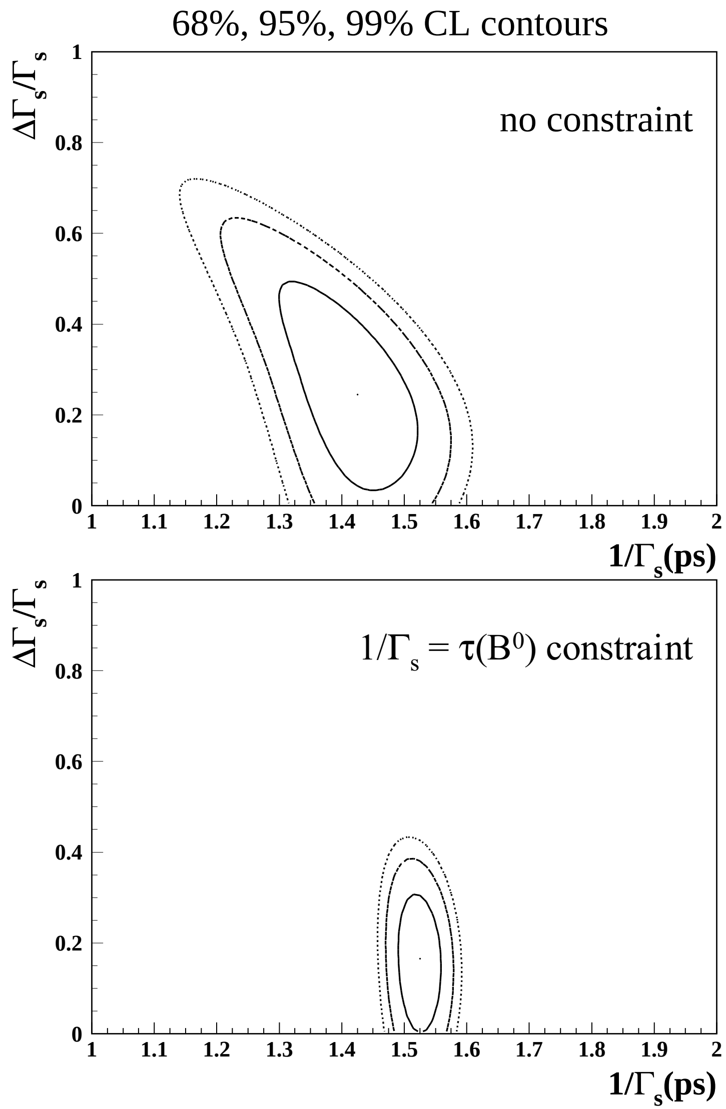
- Results summarized in CERN preprints:
  - ALEPH,CDF,DELPHI,L3,OPAL,SLD; CERN-EP/2000-096
  - ALEPH,CDF,DELPHI,L3,OPAL,SLD; CERN-EP/2001-050

http://www.cern.ch/LEPHFS

$\Delta\Gamma_s$ WG

LEP+CDF effort:

- Convert various B_s results (based on different mixture of CP-odd and CP-even) into a 2-D likelihood for $1/\Gamma_s$ and $\Delta\Gamma_s/\Gamma_s$
- Results for PDG since 2000



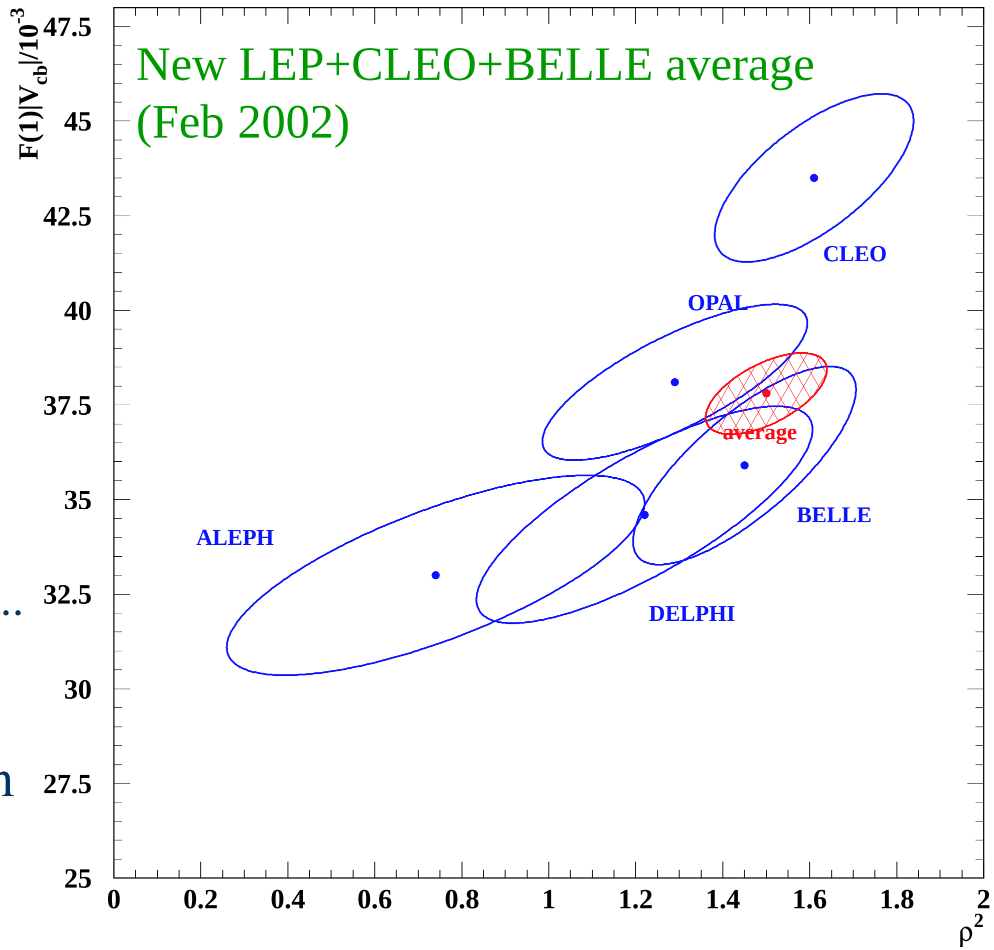
$\Delta\Gamma_s/\Gamma_s < 0.52$ at 95%CL

$\Delta\Gamma_s/\Gamma_s < 0.32$ at 95%CL
with $1/\Gamma_s = \tau(B^0)$ constraint

PDG 2001

V_{cb} WG

- $|V_{cb}|$ from $B^0 \to D^* l\nu$:
  - 2D average of $F(1)\,|V_{cb}|$ and ρ^2 (with error matrix)
  - generalisation of method used for Δm_d
  - adjustments & corr. syst:
    - R_b, $f(B^0)$, $BR(D \to \ldots)$, τ_b, …
    - $B \to D^{**} l\nu$ back. param.
    - R_1, R_2 (form factor ratios)
  - succeeded in using common form factor parametrization



- $|V_{cb}|$ inclusive
  - $BR(b \to l)$ from LEP EW fit, $BR(b \to ul\nu)$ from V_{ub} WG
  - τ_b from lifetime WG

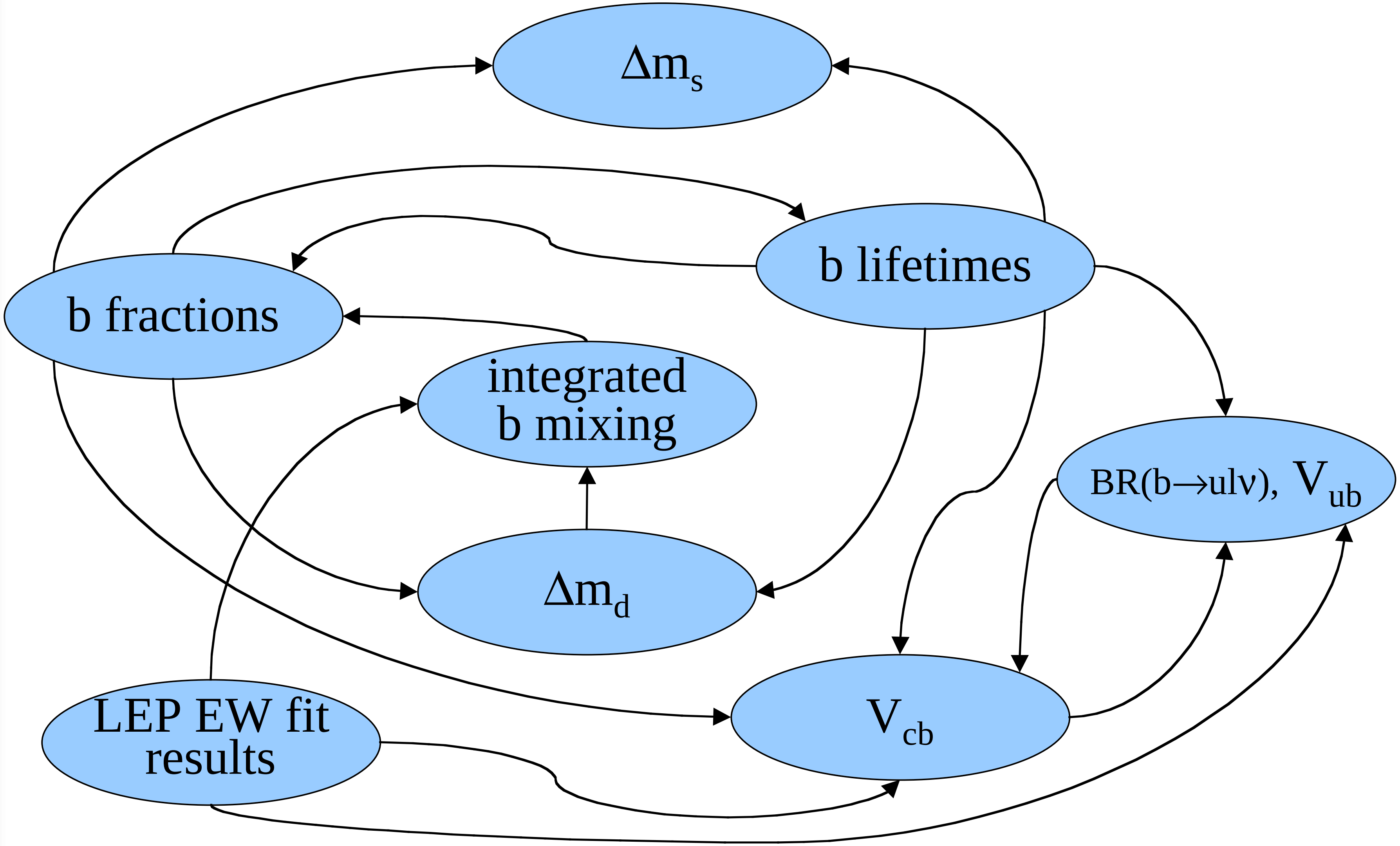
V_{ub} WG

- BR($b \to ul\nu$) average at LEP
  - use $|V_{cb}|$ from V_{cb} WG to convert DELPHI's $|V_{ub}|/|V_{cb}|$
  - significant correlated systematics:
    - $b \to u$ modelling, $b \to u$ modelling
  - use BLUE technique
  - in PDG since 2001
- $|V_{ub}|$ from inclusive decays
  - τ_b from lifetime WG

Software

- COMBOS program (http://www.cern.ch/LEPBOSC/combos)
  - Framework to perform combinations, developed originally by B oscillations WG
  - Quite general, several averaging methods implemented
  - Input data (individual measurements) are described in files which are read as input by COMBOS
  - Used for Δm_d, $A(\Delta m_s)$, $(F(1)|V_{cb}|, \rho^2)$, $BR(b \to ul\nu)$
- Other specific code:
  - for b-hadron lifetimes (could be done by COMBOS)
  - for b-hadron fractions
  - for $\Delta\Gamma_s$
  - ...

Dependencies ...



LEP HF steering group: summary and plan for the future

- HF averaging activities (and their associated structures) have been successful:
  - fulfilled specific needs of LEP experiments to combine data were uncertainties could be reduced
  - stimulated discussions and data (re)analysis
  - good collaboration/partnership with other experiments (including new generation)
  - world averages produced
- Plan:
  - PDG 2002 averages
  - continue until last publications of LEP1/SLD results
  - prepare final publication of LEP/SLD/CDF1 HF averages
  - ... then retire LEP HF steering group (~ end 2002)