B_s Physics

$\Delta\Gamma_s$ and Δm_s
at LEP, SLD and CDF

Combinations from B-oscillation (BOSC) working group

Gaëlle Boix   CERN
BCP4, Ise-Shima
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B_s Samples

✓ LEP	~160K B_s decays/exp.	~300 D_s-l cand.	1991-1995
✓ SLD	~16K B_s decays	~360 D_s-had cand. (~40 D_s-l)	1996-1998
✓ CDF	~150K $B_s \to l$ decays (~1.5M B_s)	~600 D_s-l cand.	1992-1995

But always diluted with 9 times more other b-hadrons...

Analyses at LEP and SLD are still going on...
Experimentally tricky!...

Why Are B_s' Interesting?

They oscillate

Get information on CKM and $\cancel{CP}$

$\Delta m_s \sim |V_{tb} V_{ts}|, \quad \Delta m_d / \Delta m_s \sim \sqrt{(1-\rho)^2 + \eta^2}$

Test bench for new physics
What if $\Delta m_s \gg \Delta m_s^{SM}$??

Δm_s

Direct search for oscillations

Through $\Delta \Gamma_s$: $\dfrac{\Delta \Gamma_s}{\Delta m_s} \sim \dfrac{m_b^2}{m_t^2}$ is computable with lattice

$\Delta\Gamma_s \equiv \Gamma_s^{short} - \Gamma_s^{long}$ Analyses

Methods used

B_s lifetime
- Inclusive
- Semileptonic
- Enriched CP-even ($B_s \to J/\psi\phi$ / D_s-had)
- Exclusive* CP-even ($B_s \to D_s^{(*)+}D_s^{(*)-}$)

$$\tau_{B_s^{incl}} = \frac{1}{\Gamma_s}\frac{1}{1-(\frac{\Delta\Gamma_s}{2\Gamma_s})^2} \quad L$$

$$\tau_{B_s^{semi}} = \frac{1}{\Gamma_s}\frac{1+(\frac{\Delta\Gamma_s}{2\Gamma_s})^2}{1-(\frac{\Delta\Gamma_s}{2\Gamma_s})^2} \quad \begin{array}{c}A\ D\\O\ C\end{array}$$

$$\tau_{B_s^{CP-enri}} = f_{short}\tau_{B_s^{short}} + (1-f_{short})\tau_{B_s^{long}} \quad \begin{array}{c}D\\C\end{array}$$
$$/D_sD_s \qquad\qquad +(1-f_{D_sD_s})\tau_{B_s^{semi}}$$

$$\tau_{B_s^{short}} = \frac{1}{\Gamma_s}\frac{1}{1+\frac{\Delta\Gamma_s}{2\Gamma_s}} \quad A$$

Large statistics

Higher sensitivity to $\Delta\Gamma_s$

$BR(B_s \to D_s^{(*)+}D_s^{(*)-})$

$$BR = \frac{\Delta\Gamma_s}{\Gamma_s}\frac{1}{1+\frac{\Delta\Gamma_s}{2\Gamma_s}} \quad A$$
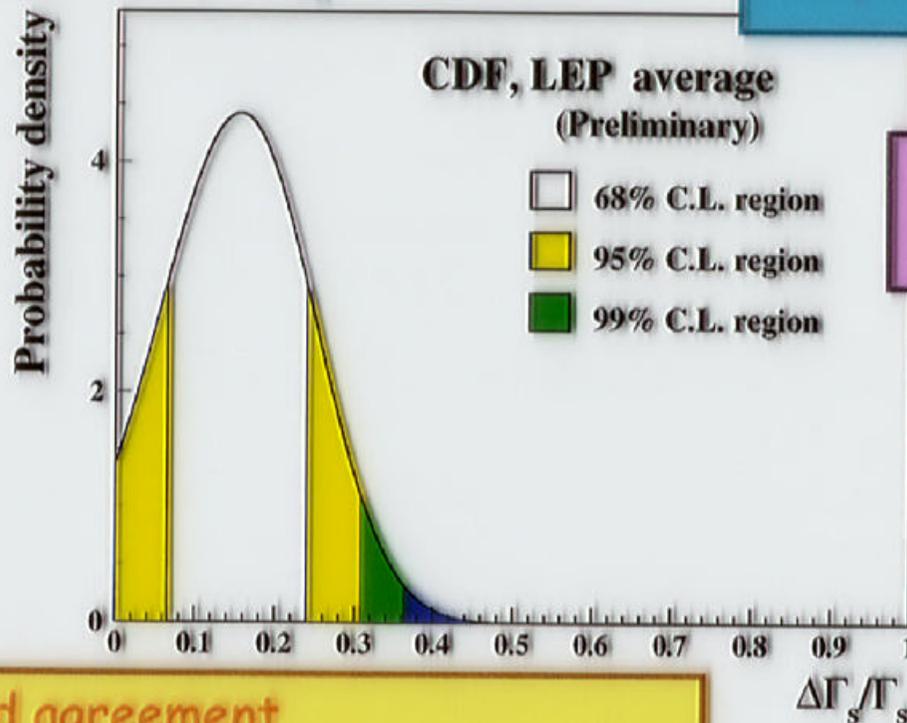
*Aleksan et al., Phys. Lett. B **316** (1993) 567

A: Aleph, D: Delphi, L: L3, O: Opal, C: Cdf

$\Delta\Gamma_s$ World Average

With the $1/\Gamma_s = \tau_{B_d}$ constraint

$$\Delta\Gamma_s/\Gamma_s = 0.16^{+0.08}_{-0.09}$$

CDF, LEP average
(Preliminary)

☐ 68% C.L. region
🟨 95% C.L. region
🟩 99% C.L. region

Probability density

$\Delta\Gamma_s/\Gamma_s$

NLO+Lattice**:
$$\Delta\Gamma_s/\Delta m_s = (6.5 \pm 2) \times 10^{-3}$$

$\Delta m_s = 16 \pm 10$ ps^{-1}
or
$\Delta m_s < 36$ ps^{-1} @ 95 CL

In good agreement
with theory*: $\Delta\Gamma_s^{theo}/\Gamma_s = 0.09 \pm 0.04$

Dominated by: scale dependence
and $1/m_b$ corrections

* Beneke *et al.* hep-ph/0012222
** Beneke, update of Phys Lett B **459** (1999)

Δm_s: The Amplitude Method

Method used to facilitate limit setting and combinations

$$\text{Prob}_{u,m}(t) = \frac{\Gamma e^{-\Gamma t}}{2}\left[1 \pm \cos(\omega t)\right] \quad \Rightarrow \quad \text{Prob}_{u,m}(t) = \frac{\Gamma e^{-\Gamma t}}{2}\left[1 \pm A\cos(\omega t)\right]$$

A is measured (Likelihood fit) for fixed values of the frequency ω

Where it is expected:

$A = 0.$ (far) below the true oscillation frequency

$A = 1.$ at the true oscillation frequency

Exclude at 95% CL values of ω where $\quad A + 1.645\,\sigma_A \leq 1.$

$\Delta m_s = 17$ ps^{-1} p = 32 GeV/c

$\sigma_p/p = 0.15$ $\sigma_L = 250\,\mu m$
$\sigma_p/p = 0.10$ $\sigma_L = 200\,\mu m$
$\sigma_p/p = 0.10$ $\sigma_L = 150\,\mu m$
$\sigma_p/p = 0.10$ $\sigma_L = 70\,\mu m$
$\sigma_p/p = 0.02$ $\sigma_L = 70\,\mu m$
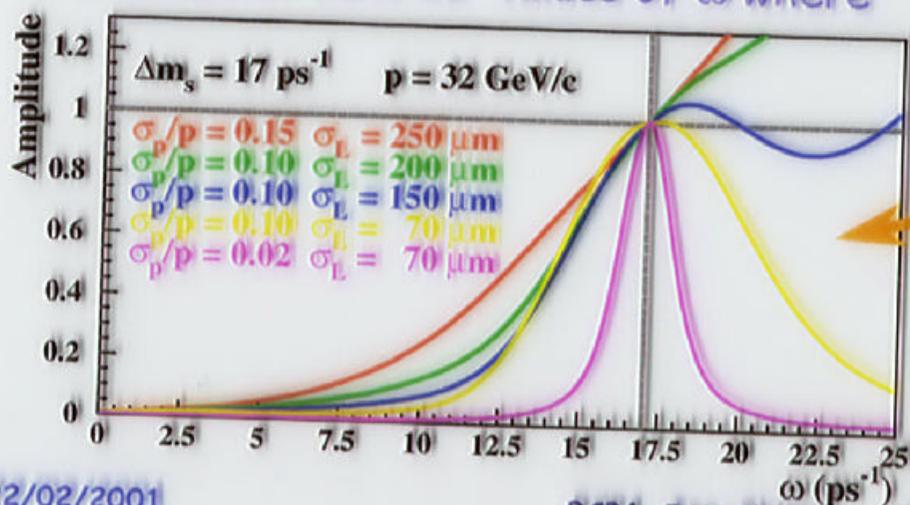
Expected Amplitude shape
for different resolution values
from analytical calculations
taking $\Delta m_s = 17$ps^{-1} and p=32GeV/c

Δm_s Analysis Steps

★ Data selection   → Final State tag

★ Initial state tag

  Total mistag $\eta = \eta_I(1-\eta_F) + \eta_F(1-\eta_I)$

★ B_s enrichment

  } **Statistical power**

★ t measurement, resolution on l & p } **Behaviour at large frequency**

Analysis significance

$$S = \sigma_A^{-1} \propto \sqrt{N}\, f_{B_s}(1-2\eta)\,\Im(\omega,\sigma_t)$$

where: $\sigma_t = (m/p)\,\sigma_l \oplus (\sigma_p/p)$

Function increasing fast with ω

Δm_s Analysis Methods-1

B_s Fully reconstruction

Only at LEP

Performed by ALEPH, DELPHI
Very low Statistics
B_s decay chain: *e.g.* $B_s \rightarrow D^-_s \pi^+$, $B_s \rightarrow D^-_s a_1^+$
Very good resolution (no neutrino)
Very high B_s purity ~60%
Final State tag: perfect!

ALEPH

Semi-inclusive: D_s-l, D_s-X, ϕ-l

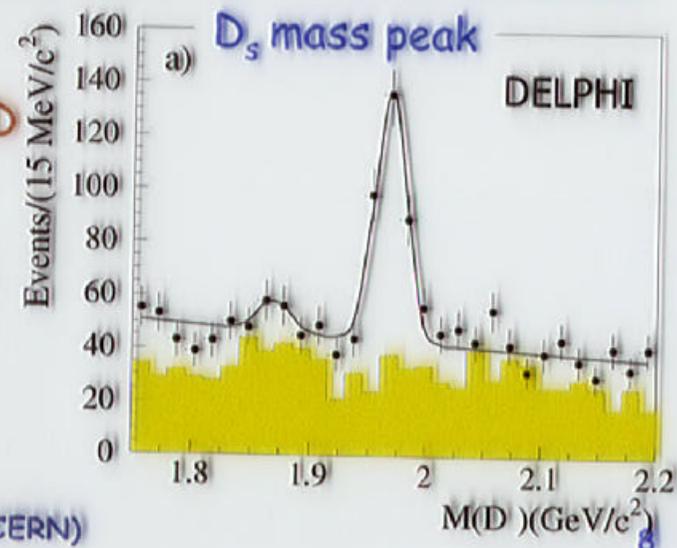Performed by ALEPH, CDF, DELPHI, OPAL, SLD
Low Statistics
B_s = D_s resonance + lepton
Good resolution
High B_s purity ~40%
Final State tag: lepton/D_s sign

Good at LEP

D_s mass peak

DELPHI

a)

Events/(15 MeV/c²) — y-axis: 0, 20, 40, 60, 80, 100, 120, 140, 160

$M(D_s)(GeV/c^2)$ — x-axis: 1.8, 1.9, 2, 2.1, 2.2

Δm$_s$ Analysis Methods-2

Inclusive lepton

Performed by ALEPH, DELPHI, OPAL, SLD
High Statistics
B$_s$ = lepton + tracks
Reasonable resolution
B$_s$ purity = f$_s$ ~10%
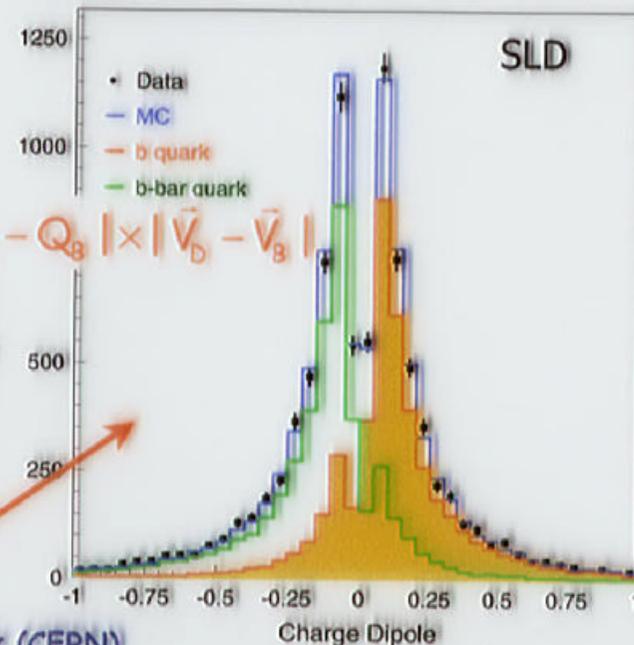Final State tag: lepton sign

Good at LEP & SLD
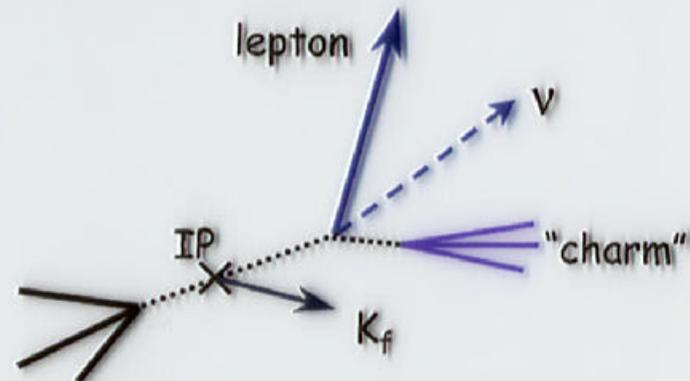
Fully Inclusive

Performed by SLD, DELPHI
Very high Statistics
"B" and "D" vertices
Reasonable resolution
B$_s$ purity = f$_s$ ~10%
Final State tag: inclusive technique
$$B_s \rightarrow D^-_s / \ \bar{B}_s \rightarrow D^+_s$$

Good at SLD

$$dq = | Q_D - Q_B | \times | \vec{V}_D - \vec{V}_B |$$
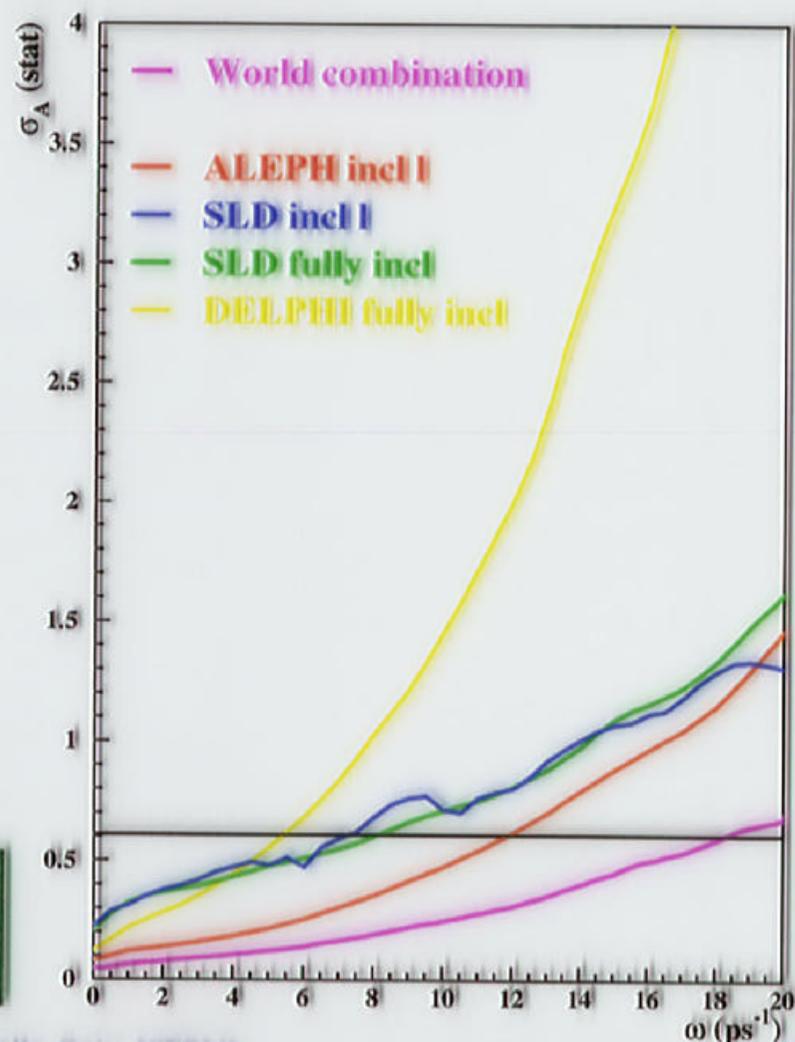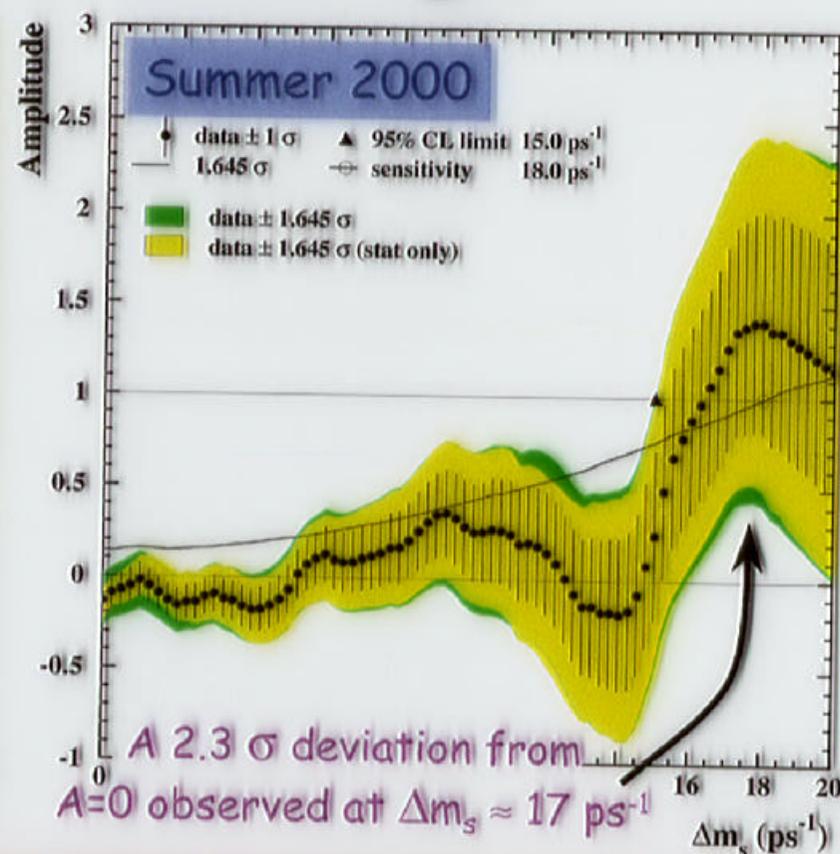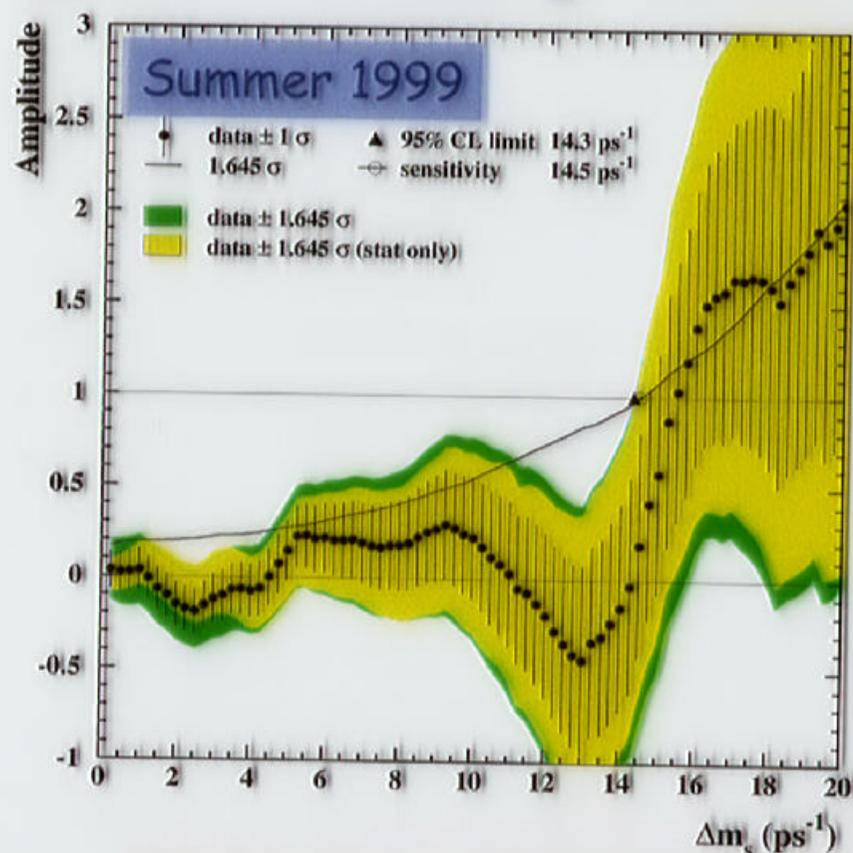
Analyses comparison @ LEP
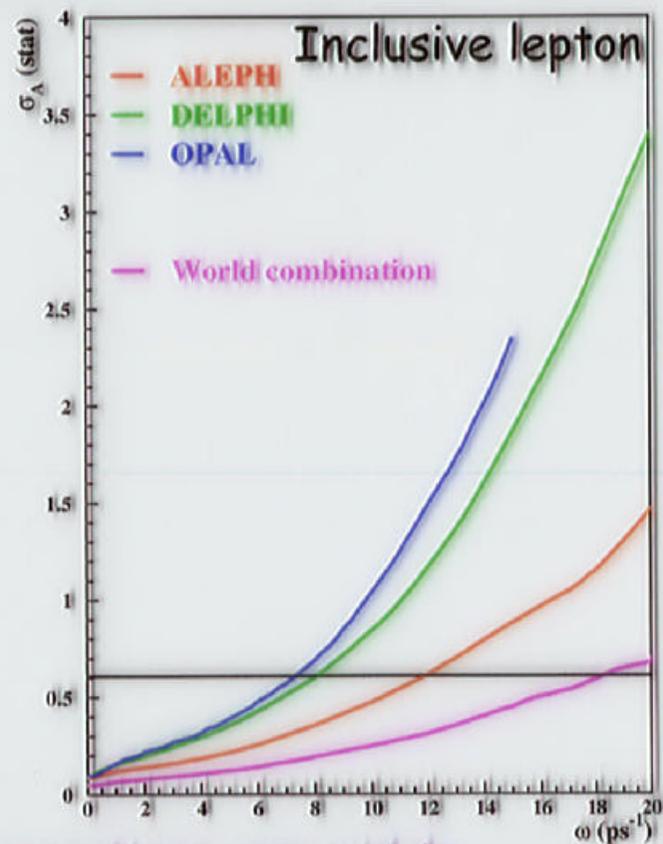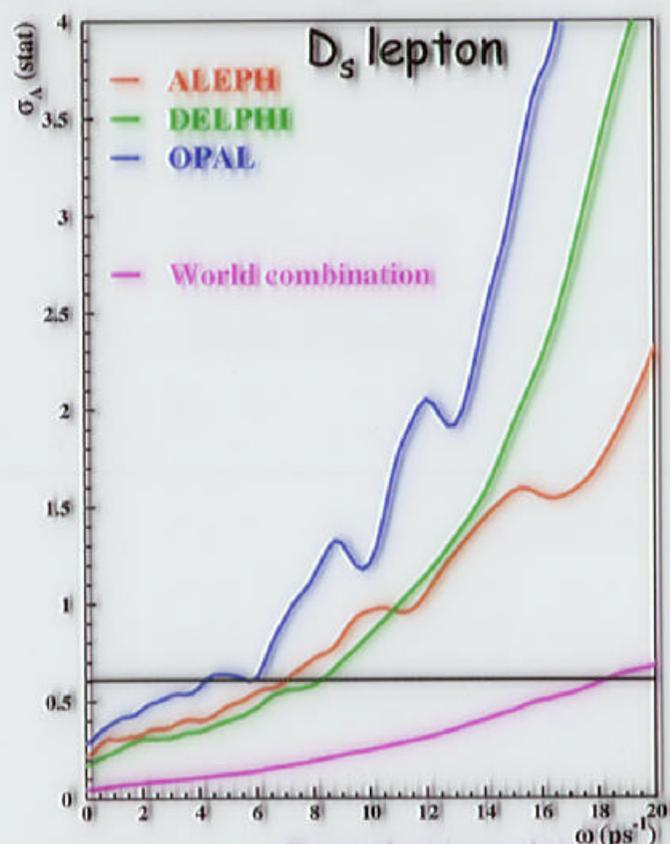
Resolution, bias and pull corrections vary widely
as a function of the event topology and kinematics

Careful event-by-event treatment is essential for the vertexing

Δm_s World Average

Summer 1999 — data ± 1 σ, 1.645 σ, data ± 1.645 σ, data ± 1.645 σ (stat only), ▲ 95% CL limit: 14.3 ps⁻¹, sensitivity 14.5 ps⁻¹

Summer 2000 — data ± 1 σ, 1.645 σ, data ± 1.645 σ, data ± 1.645 σ (stat only), ▲ 95% CL limit: 15.0 ps⁻¹, sensitivity 18.0 ps⁻¹

A 2.3 σ deviation from A=0 observed at $\Delta m_s \approx 17\ \mathrm{ps}^{-1}$

Impressive improvement!
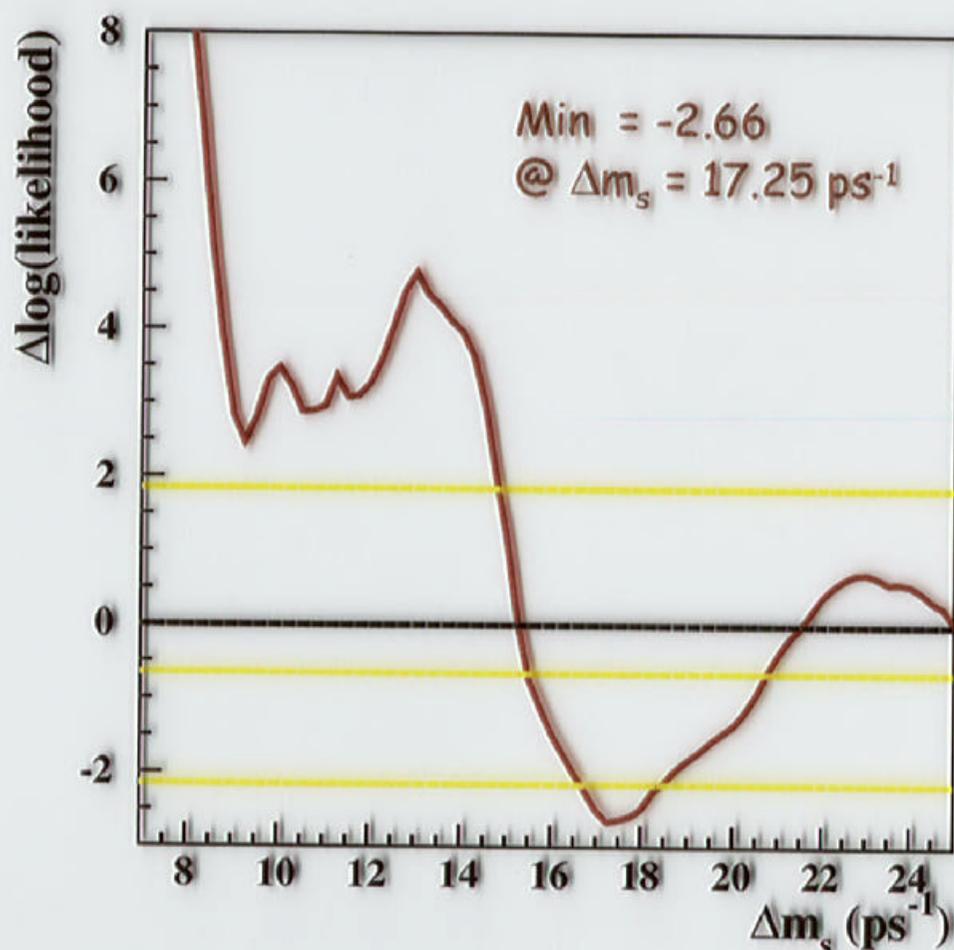The amplitude error at 20ps⁻¹ reduced by a factor of 2!

Δm_s Log Likelihood

The amplitude spectrum shape is studied with gedanken experiments.

The probability that $\Delta m_s \gg \omega$ and what we see is a fluctuation is estimated at

$P \approx 3\%$

Min = -2.66
@ Δm_s = 17.25 ps^{-1}

$\Delta \log(\text{likelihood})$

Δm_s (ps^{-1})

Δm_s In The Near Future

By next summer final results from present analyses
at LEP (ALEPH and DELPHI) and SLD are expected

In principle more studies could be made

The significance of the "hint" could increase

Δm_s: What Have We Learnt?

On the Δm_s value:

    ☆ Pushed the limit from 0 to ~ 15ps^{-1}

    ☆ A hint for a signal close to the sensitivity

Lessons for future analyses:

    ☆ Resolution is the issue

    ☆ Event-by-event treatment of errors is crucial

Conclusions

LEP, SLD and CDF have greatly contributed to B_s physics

m_{B_s} = 5369.6 ± 2.4 MeV

τ_{B_s} = 1.464 ± 0.057 ps

$\Delta\Gamma_s/\Gamma_s$ = 0.16 $^{+0.08}_{-0.09}$

Δm_s > 15 ps^{-1} @ 95%CL   with a hint for a signal at ~17ps^{-1}

Still some ongoing activities in LEP and SLD on Δm_s,
but soon CDF and DO will take over...