B_s Oscillation at LEP and SLC

YORAM ROZEN

Physics Department

Technion, Israel Institute of Technology

CONTENT:

- Introduction
- Basic recipe for oscillation measurement
- LEP measurements
- SLD measurements
- Combined result
- Summary and outlook

Time Dependant B Mixing

The CKM matrix in Wolfenstein parametrisation:

$$\begin{array}{cc} & \begin{array}{ccc} d & s & b \end{array} \\ \begin{array}{c} u \\ c \\ t \end{array} & \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \end{array}$$

with $\lambda = \sin\theta_c = 0.2205 \pm 0.0018$

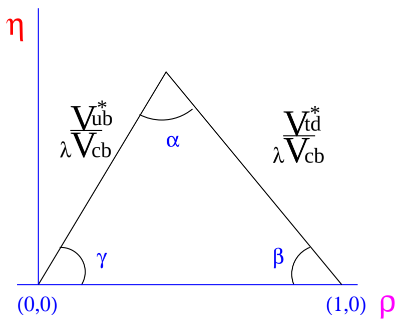
– ρ and η need to be determined.

– $\eta \neq 0 \quad \longrightarrow$ CP violation exists.

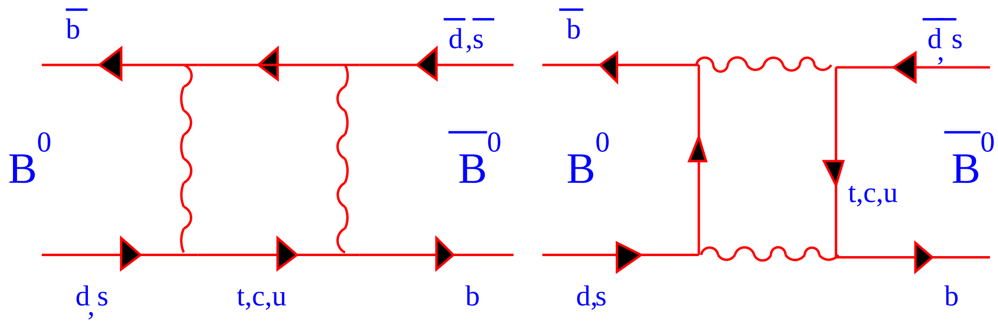
With the unitarity condition:

$$\mathrm{V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0},$$

a triangle is defined in the (ρ, η) plane.



Neutral B mesons can oscillate into their anti-particles via a box diagram



These flavour eigenstates B^0 and $\overline{\mathrm{B}^0}$ have CP eigenstates (like in the K^0 system)

$$|\mathrm{B}_1 >= 1/\sqrt{2}\left(|\mathrm{B}^0 > +|\overline{\mathrm{B}}^0 >\right) \quad \mathrm{CP\ \ even}$$
$$|\mathrm{B}_2 >= 1/\sqrt{2}\left(|\mathrm{B}^0 > -|\overline{\mathrm{B}}^0 >\right) \quad \mathrm{CP\ \ odd}$$

with time dependence governed by Schrödinger eq

Starting with a B^0

$$P(\mathrm{B}^0 \rightarrow \mathrm{B}^0) = 1/2\,\mathrm{e}^{-\Gamma\mathrm{t}}(1 + \cos\Delta\mathrm{mt})$$
$$P(\mathrm{B}^0 \rightarrow \overline{\mathrm{B}}^0) = 1/2\,\mathrm{e}^{-\Gamma\mathrm{t}}(1 - \cos\Delta\mathrm{mt})$$

where Δm is the mass difference between the two mass eigenstates.

...From the box diagram

$$\Delta m_q = \frac{G_F^2}{6\pi^2} m_B m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) \eta_{QCD} B f_B^2 |V_{tb}^* V_{tq}|^2$$

But knowledge of V_{tq} is limited by m_t and Bf_B^2 regardless of Δm_q accuracy.

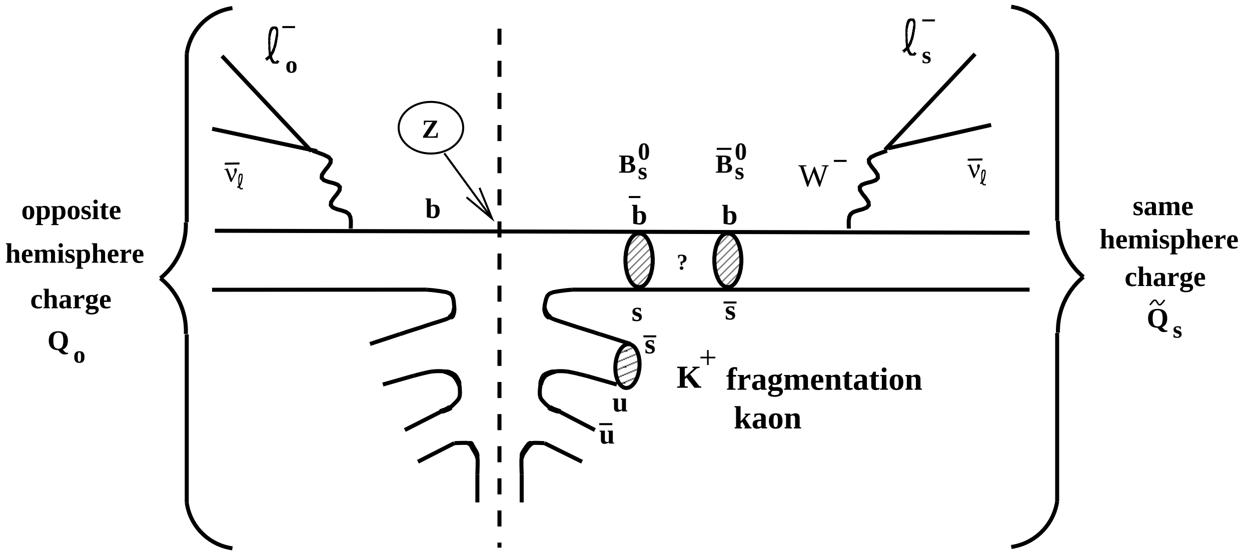
However, the ratio

$$\frac{\Delta m_d}{\Delta m_s} \propto \left|\frac{V_{td}}{V_{ts}}\right|^2 = \lambda^2[(1-\rho)^2 + \eta^2]$$

is free from most of the uncertainties.

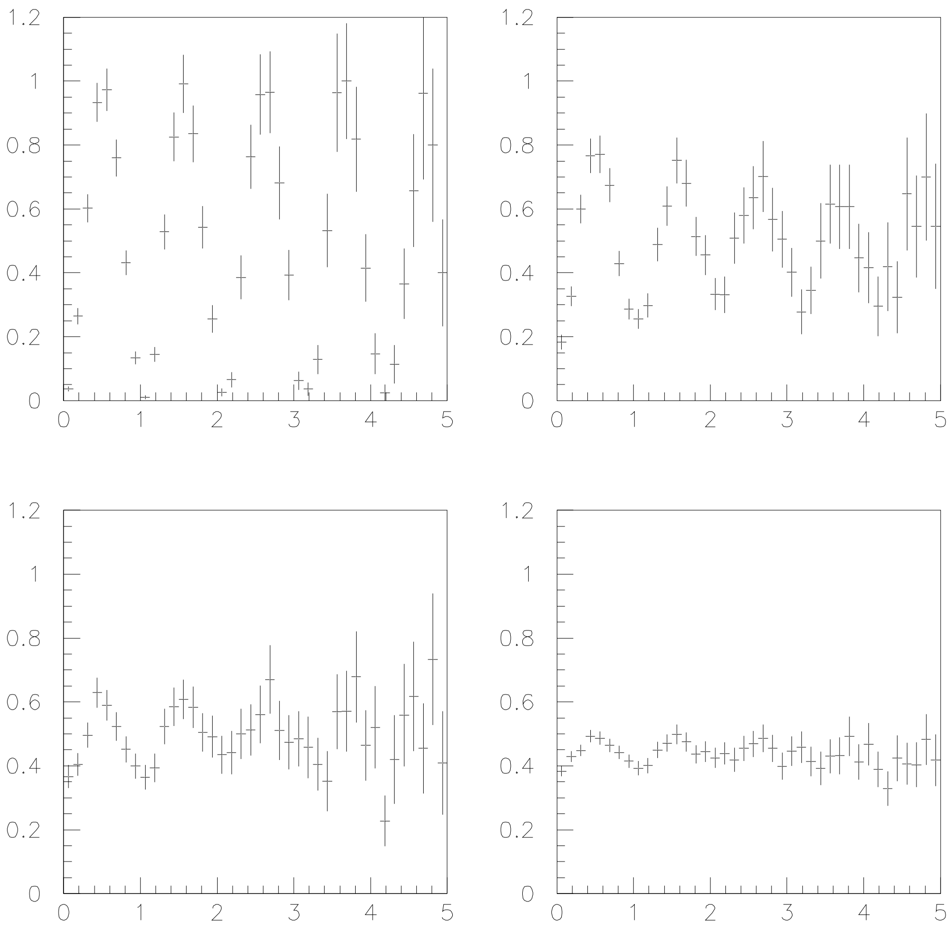
How to Measure B Oscillation

- Find a B_s (background)
- Measure the decay time (resolution)
- Find decay flavour (B_s or $\overline{B}_s$)
- Find production flavour (mistag)



- Fit

$$R(t) = \frac{N_{\pm\pm}}{N_{\pm\pm} + N_{+-}} = f + (1-2f)\cdot\sin^2\left(\frac{\Delta m \cdot t}{2}\right)$$



Amplitude method

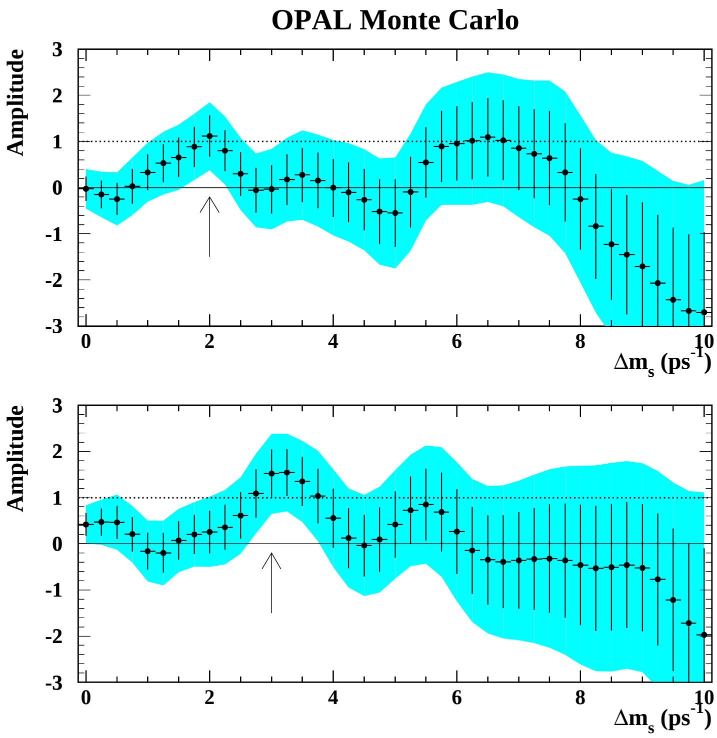
- Subtitute in likelihood function:

$$1 \pm \cos \Delta m_s t \rightarrow 1 \pm A \cos \Delta m_s t$$

- Fit amplitude A for **fixed** Δm_s.
- Expect $A = 1$ for true value of Δm_s and $A = 0$ (far) below true Δm_s.
- Values of Δm_s excluded (95% C.L.) if

$$A + 1.645\sigma_A < 1.$$

- Sensitivity is defined for $A + 1.645\sigma_A = 1.$



Search Methods for B oscillation

- Inclusive.
- Semi-Inclusive:

Single Lepton.

Dileptons.

- Semi-exclusive:

Lepton-kaon.

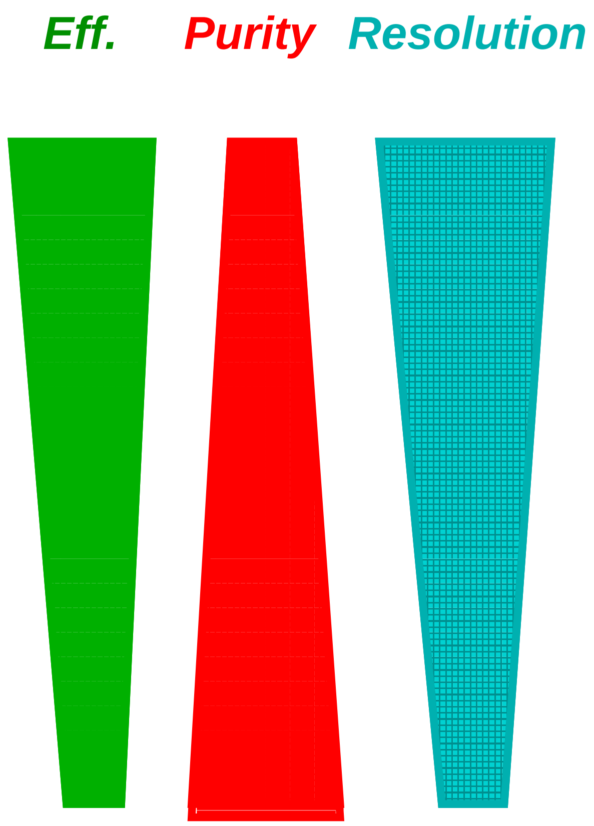
ϕ lepton.

Lepton+"D".

- Exclusive:

D_s-hadron.

D_s-lepton.



Fully inclusive search - DELPHI

- Event selection: soft leptons and inclusively reconstructed vertices (120K/500K)
- Decay time reconstruction:

1. E/p constraint to rescale B momentum and estimate ν momentum - global fit using direction and mass constraint
2. Inclusive B reconstruction based on B track probability (NN)

- Decay flavour:

1. Lepton charge (special care for b/c origin due to softness)
2. For inc. vtx. use the dipole charge of charm/bottom tracks in the B rest-frame.

- Production flavour: Jet-charge, leptons, kaon and protons.

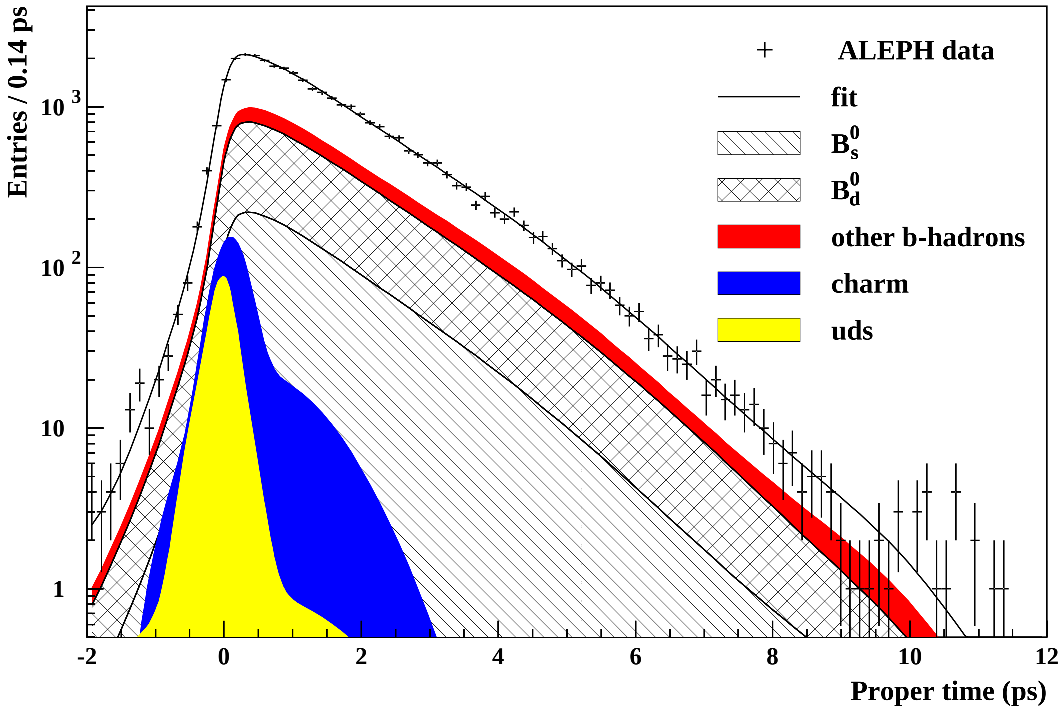
- Result: $\Delta m_s > 1.1\,ps^{-1}$ (sensitivity $6.1\,ps^{-1}$)

Inclusive lepton analysis - ALEPH

- **Event selection:** High $p,\ p_T$ leptons.
- **Decay time reconstruction:**

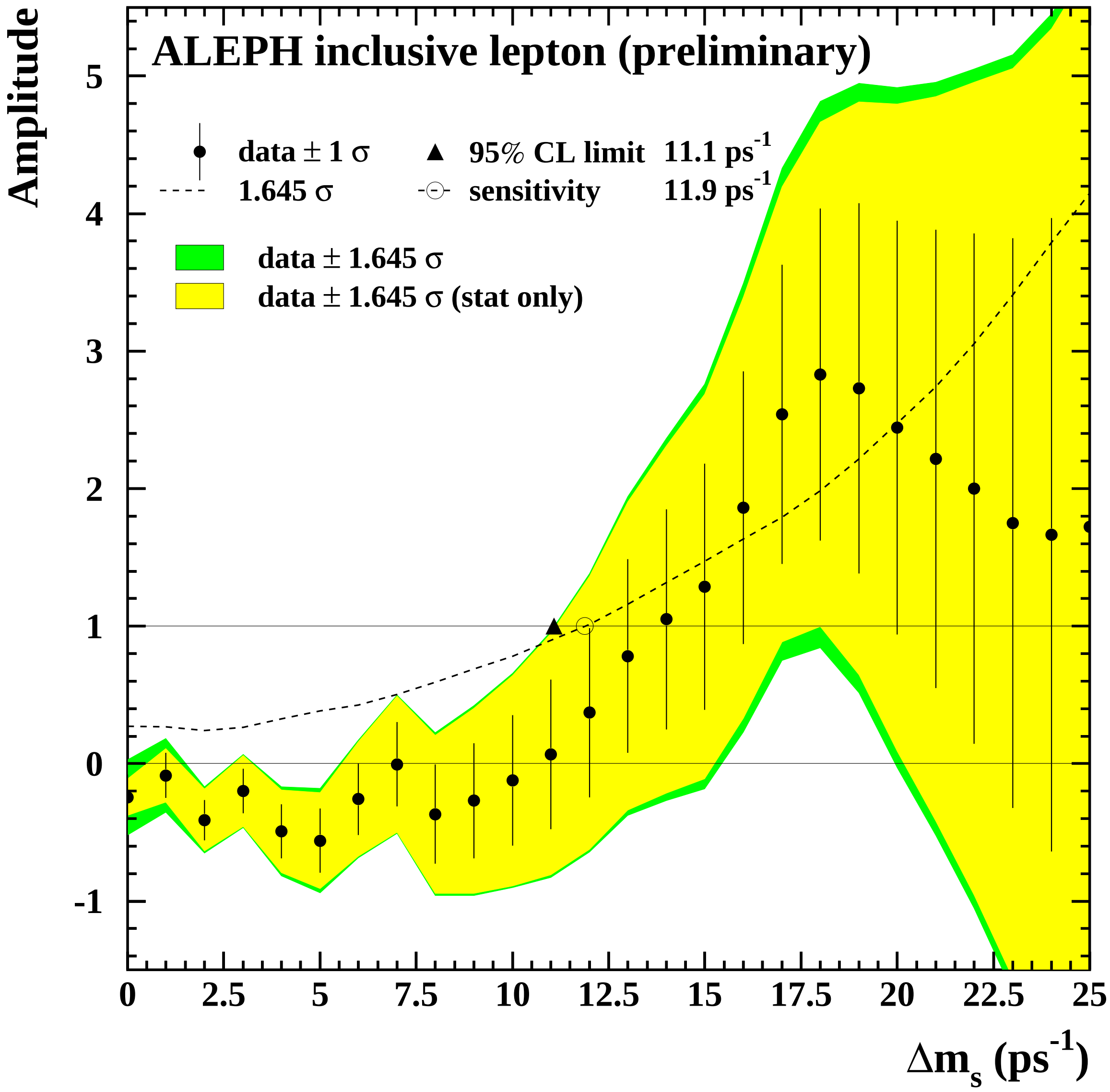
charm vtx combined with the lepton for decay length and momentum is estimated with the addition of the hemisphere missing energy (ν)

Decay time resolution $\approx 1/4 - 1/3\ ps$



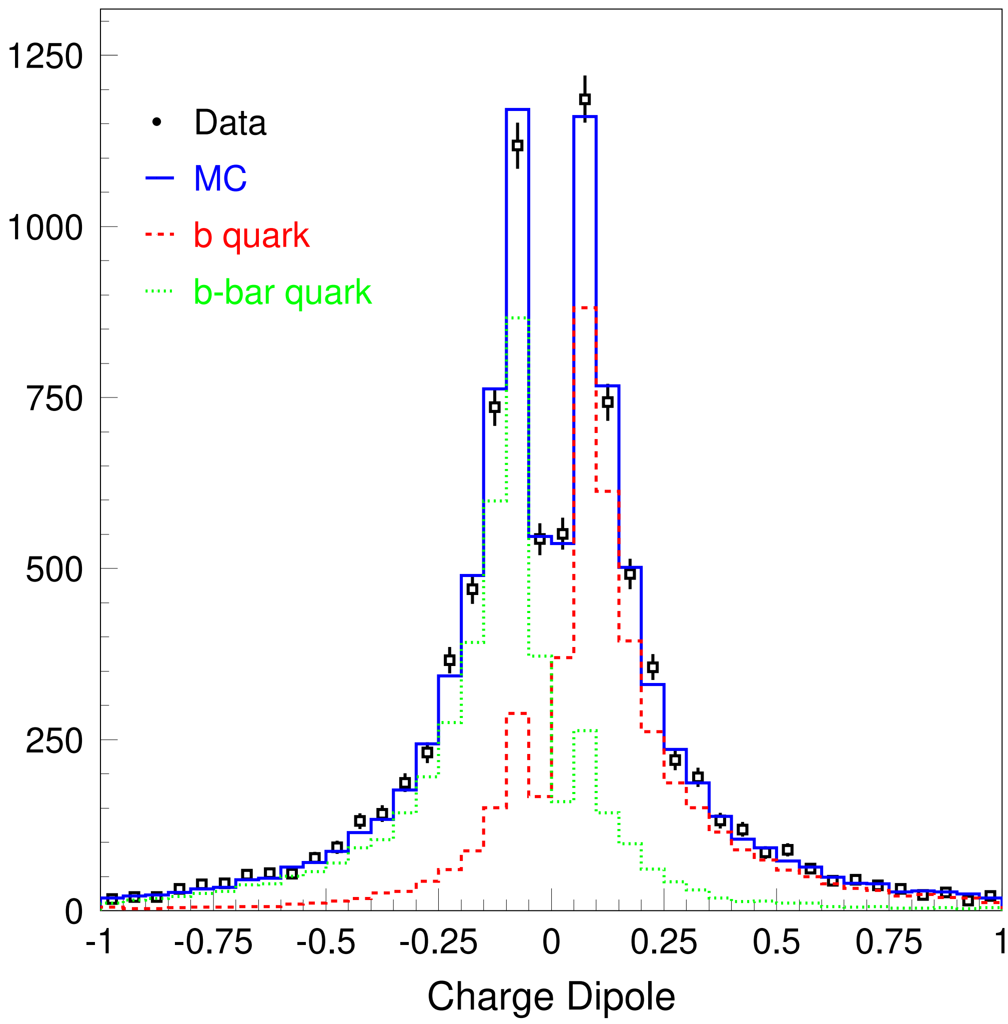
- Decay flavour: Directly from the lepton charge.
- Decay flavour: Opp. hem. lepton, frag. kaon, jet-charge.

- Result: $\Delta m_s > 11.1\, ps^{-1}$
  (sensitivity $11.9\, ps^{-1}$)



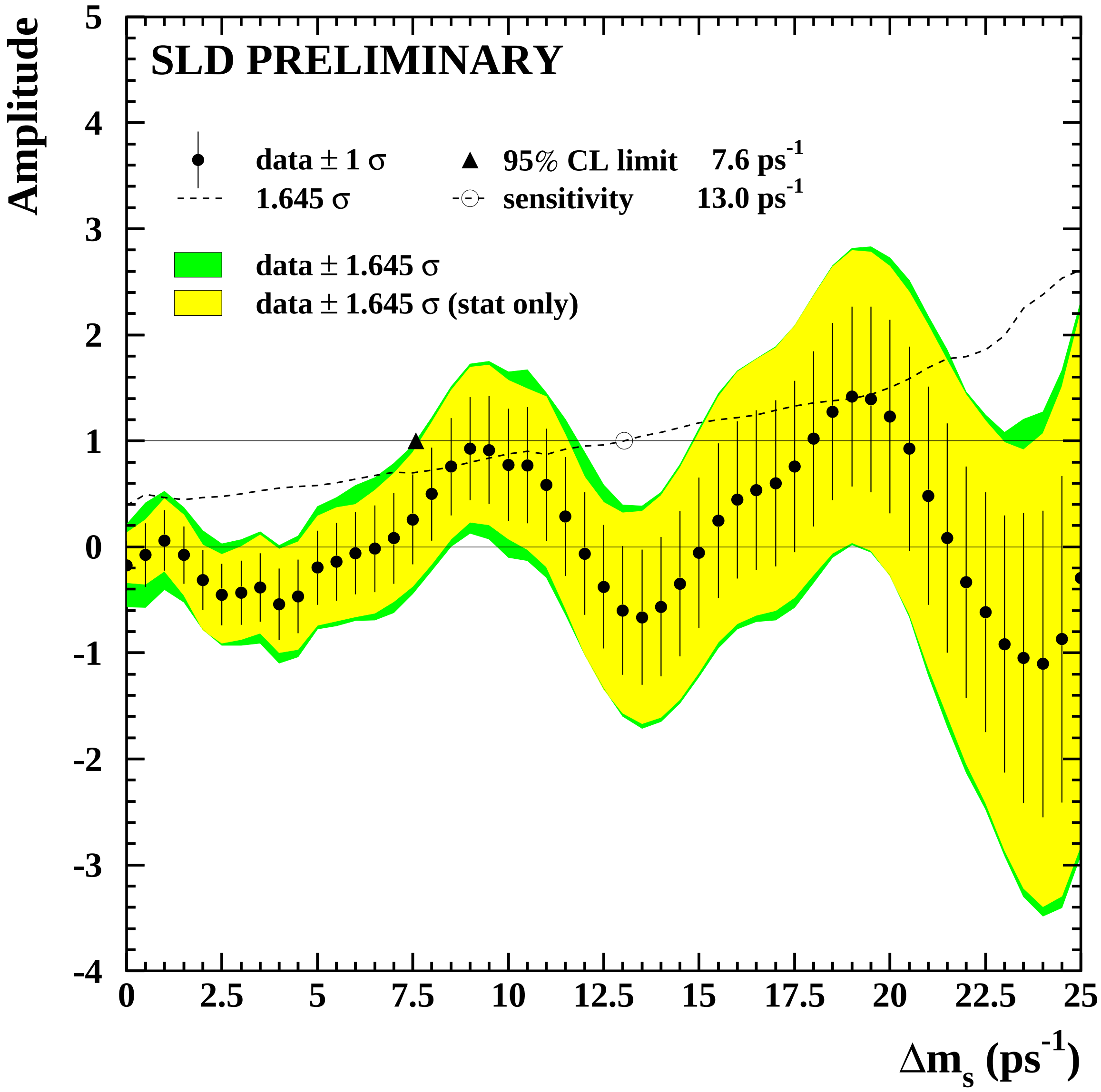
SLD analyses

- Much smaller Z sample (400K).
- Much better vtxing. $\longrightarrow$ at best $\sigma_t = 0.05ps$
- Polarised electrons.
- Three final states: lepton + "D", D_s+ tracks, dipole analysis.



- Unique tag from FB asymmetry - 100% efficient, 72% correct tag.

- Result: $\Delta m_s > 7.6\, ps^{-1}$
  (sensitivity $13.0\, ps^{-1}$)



Exclusive analysis from OPAL

- Four decay channels of the D_s:

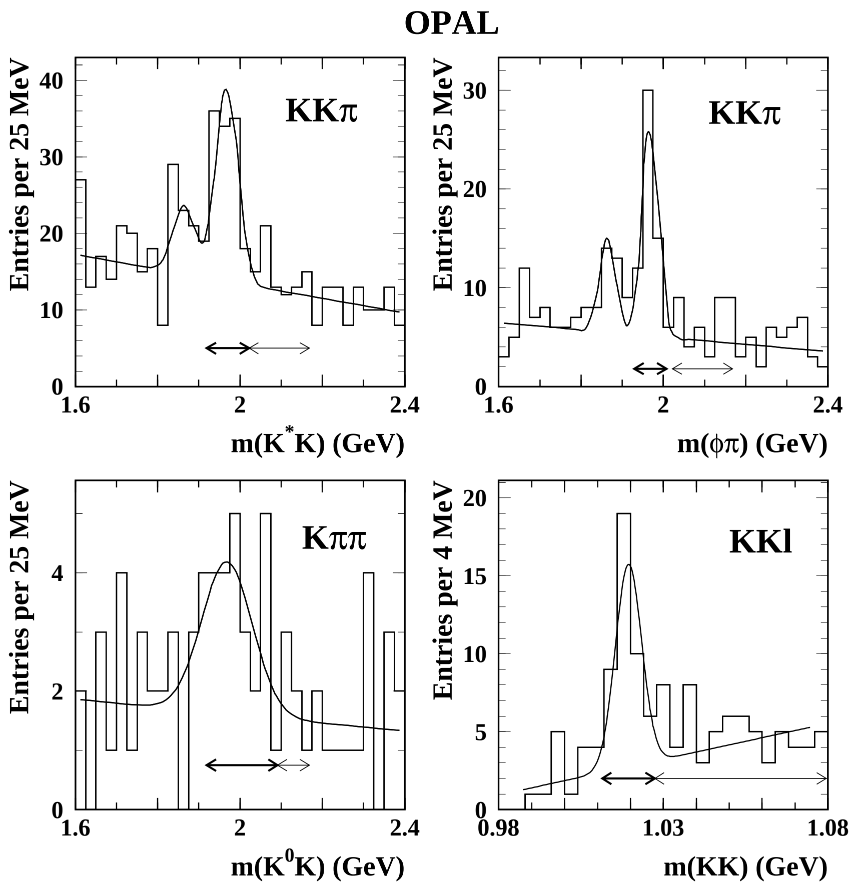
$$B_s \rightarrow D_s\, l^+\, \nu$$

$$\hookrightarrow K^{\star 0}K^-, \qquad K^{\star 0} \rightarrow K^+\pi^-$$

$$\hookrightarrow \phi\,\pi^-, \qquad \phi \rightarrow K^+K^-$$

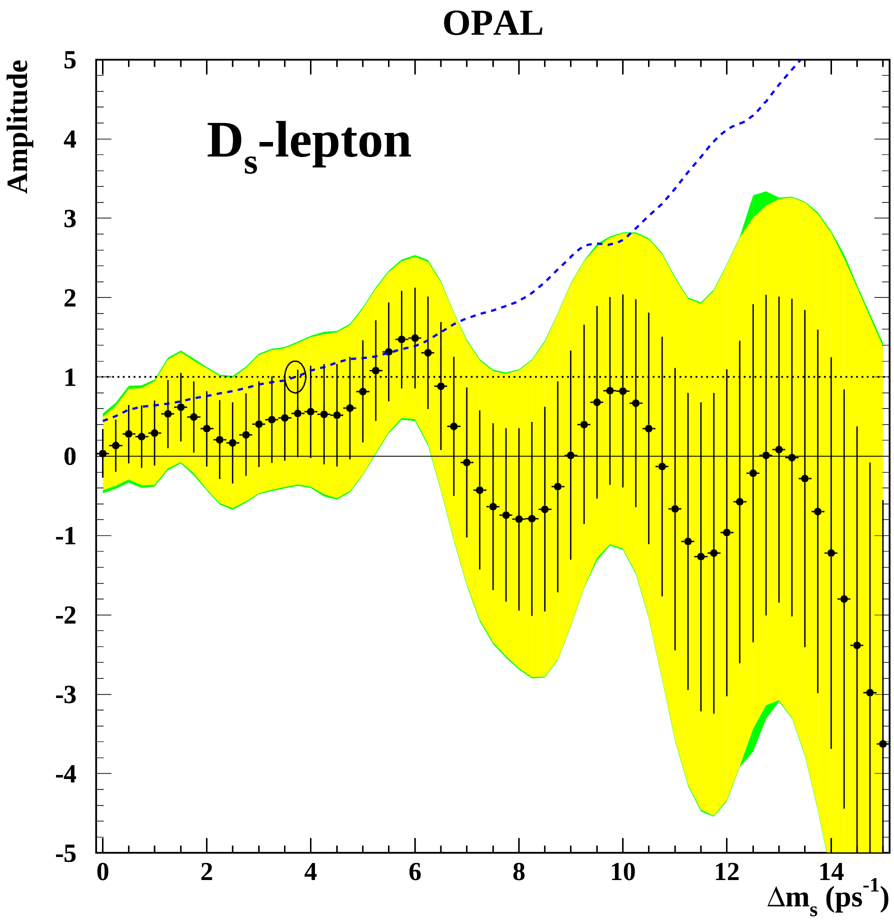
$$\hookrightarrow K^0\,K^-, \qquad K^0 \rightarrow \pi^+\pi^-$$

$$\hookrightarrow \phi l^-\bar{\nu}\,X, \qquad \phi \rightarrow K^+K^-$$



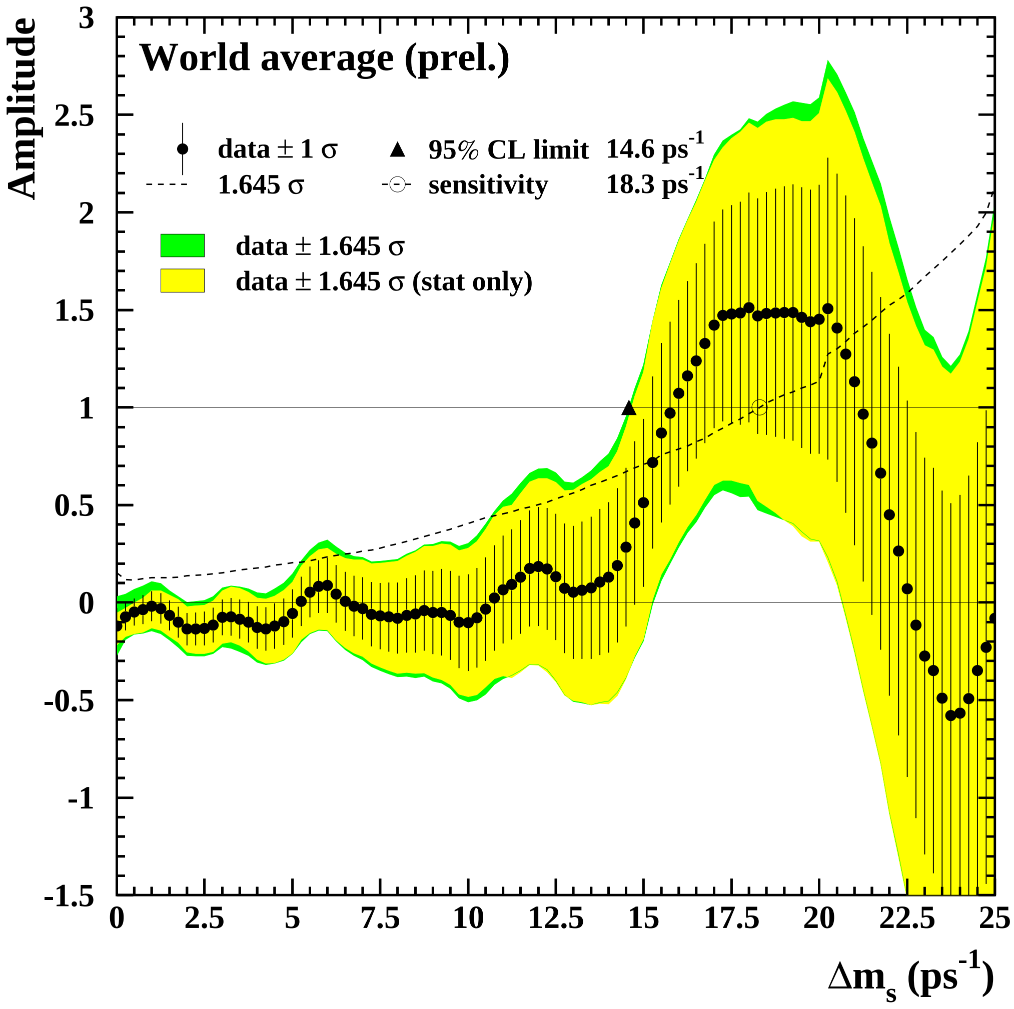
- Total of 116 $B_s \rightarrow D_s l$ events.

- Result: $\Delta m_s > 1\ ps^{-1}$
  (sensitivity $4.1\ ps^{-1}$)



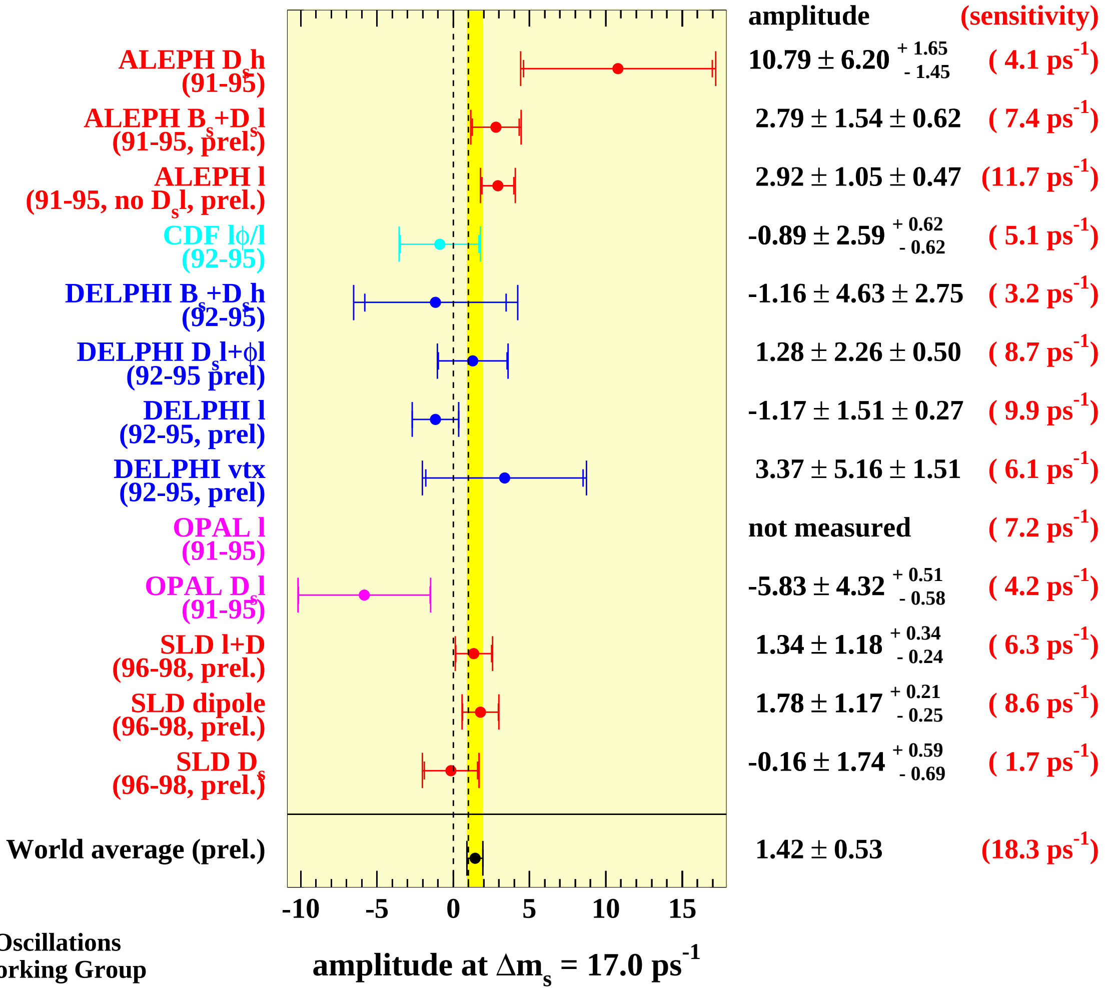
Summary

- World Combined Result



Limit at 14.6 ps^{-1} Sensitivity at 18.3 ps^{-1}

- Is there a hint at 17 ps^{-1} ?



- 2.6σ effect.
- No (real) improvement is expected before the onset of LHC
- ATLAS/CMS sensitivity $\approx 38ps^{-1}$