Les Rencontres de Physique de la Vallée d'Aoste

La Thuile, March 3-9 2002

B_s Oscillations

Results from CDF, SLD and the LEP experiments

New results from ALEPH at this conference

CERN-EP/2002-016
Submitted to EPJ

Combinations from BOSC working group

(many thanks to O. Schneider)

Conclusions

Phenomenology

Time-dependent asymmetry between "mixed" and "unmixed" decays

$$P(t)_{B_s^0 \to \overline{B_s}^0} = \frac{\Gamma e^{-\Gamma t}}{2}\left(1 - \cos \Delta m_s t\right)$$

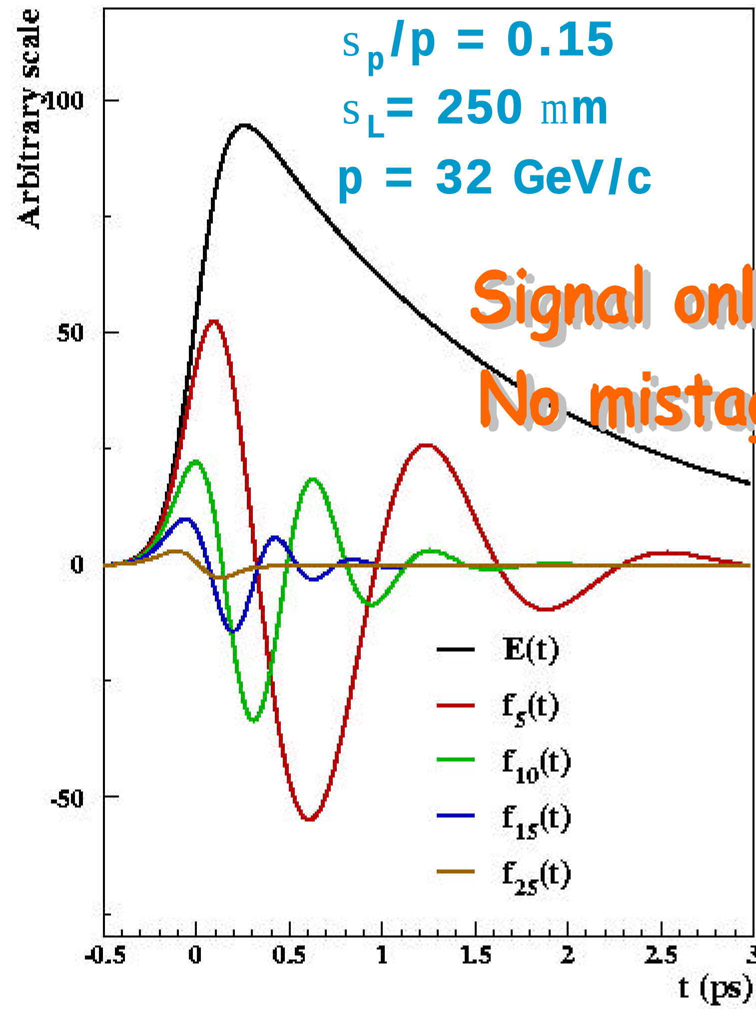
$$P(t)_{B_s^0 \to B_s^0} = \frac{\Gamma e^{-\Gamma t}}{2}\left(1 + \cos \Delta m_s t\right)$$

Oscillating term damped by the exponential decay and proper time resolution effects

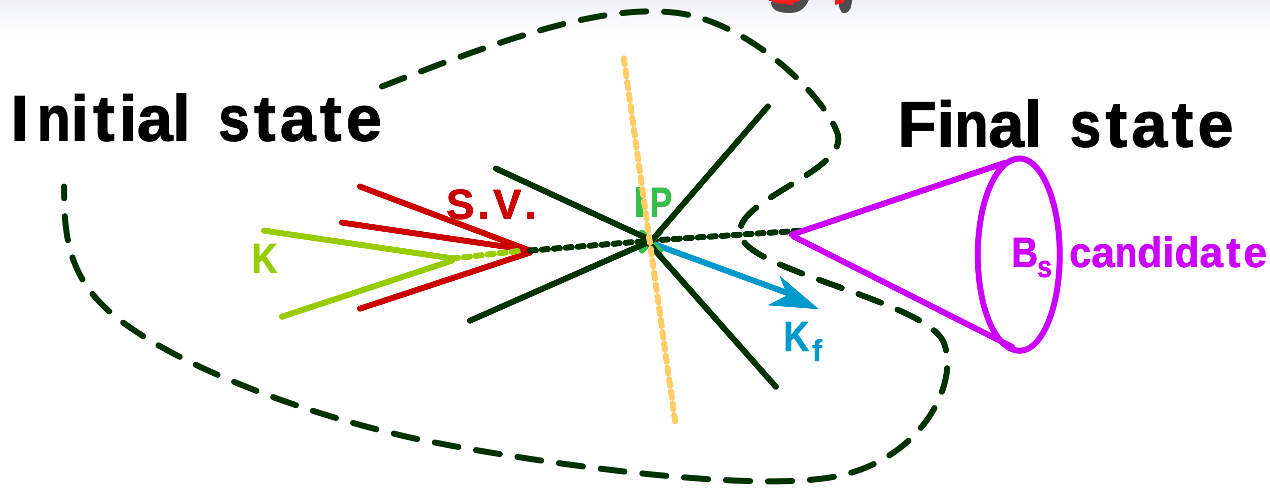
$$\sigma_t = (m/p)\, \sigma_L \oplus (\sigma_p/p)\, t$$

Example:

(LEP-like numbers)



The basic strategy



- **Choose a selection criterion**

  determines directly the final state tag method and signal fraction

- **Tag initial and final state**

  total mistag $\eta = \eta_i(1-\eta_f) + \eta_f(1-\eta_i)$ →

- **Measure proper time**

  resolution: $\sigma_t = (m/p)\,\sigma_L \oplus (\sigma_p/p)\,t$

- **Maximum likelihood fit to Δm_s**

  (or to the oscillation amplitude with fixed frequency)

Opposite hemisphere

P.V. charge, S.V. charge, Jet charges, Kaon charge, Lepton charge & kinematics

Same hemisphere

P.V. charge, K_f charge

Overall

F-B asymmetry (very effective @ SLD!)

$\eta \sim$ 25% @ LEP

$\eta \sim$ 15% @ SLD

Selection methods

Statistics

❋ **Fully inclusive** Delphi, SLD

FS tag from dipole or NN

Very high statistics (N ~ 10^5 @ LEP, N ~ 10^4 @ SLD)

“Natural” signal purity (f_s = 10%)

❋ **Semi-inclusive** Aleph, Delphi, Opal, CDF, SLD

Inclusive l, ƒ-l, K

Still high statistics (N ~ 10^4¸ 10^5 @ LEP, N ~ 10^3 @ SLD)

Signal purity “natural” or slightly enhanced.

❋ **Semi-exclusive** Aleph, Delphi, Opal, SLD

D_s-h, D_s-l

Lower statistics (N ~ 10^2¸ 10^3 @ LEP, N ~ 10^2 @ SLD)

Signal purity up to 60%, controlled from data.

❋ **Fully exclusive** Aleph, Delphi

Little statistics (N ~ 50 events)

Purity ~ 50%, excellent proper time resolution!

Signal purity
Resolution

The oscillation fit

For every event:

$$\mathcal{L} = \sum_{j}^{\text{Comp.}} f_j \left[P_u^j \mathcal{F}_u^j(t) + (1 - P_u^j) \mathcal{F}_m^j(t) \right]$$

Key point

$$\mathcal{F}(t) = \epsilon(t_0) \times \mathcal{F}(t_0) \otimes \text{Res}(t, t_0)$$

σ_L, σ_p

σ_L, σ_p, f_j, P_j **estimated event-by-event**

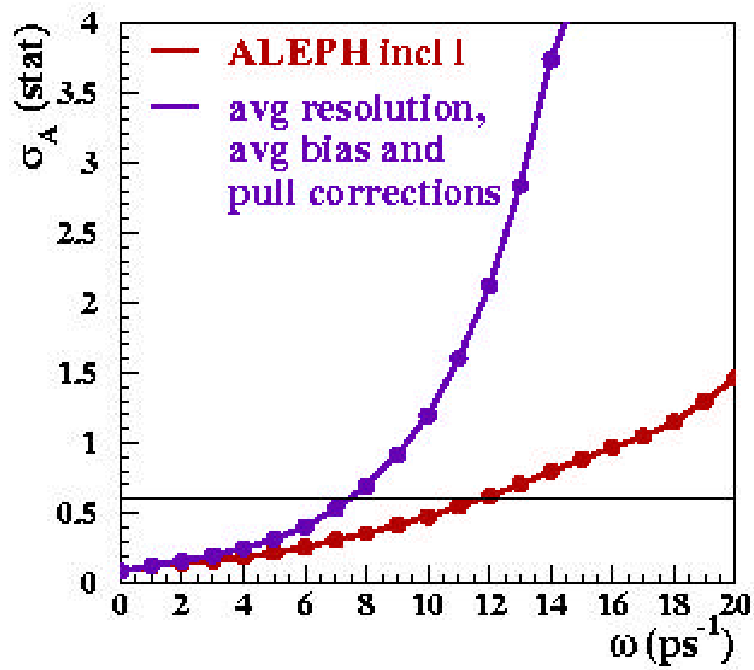
Each event is treated as a single experiment!

Crucial for inclusive analyses

Resolution, bias corrections and **pull corrections** vary **WIDELY** as a function of the event topology.

Careful **event-by-event treatment** is **essential** especially for the **vertexing**.

The **statistical power** at **high frequency** depends **crucially** on a **careful description** of the sample.



The amplitude method

P(t) = ½ Ge^{-Gt} [1 ± cos(Dm_st)] → P(t) = ½ Ge^{-Gt} [1 ± A cos(wt)]

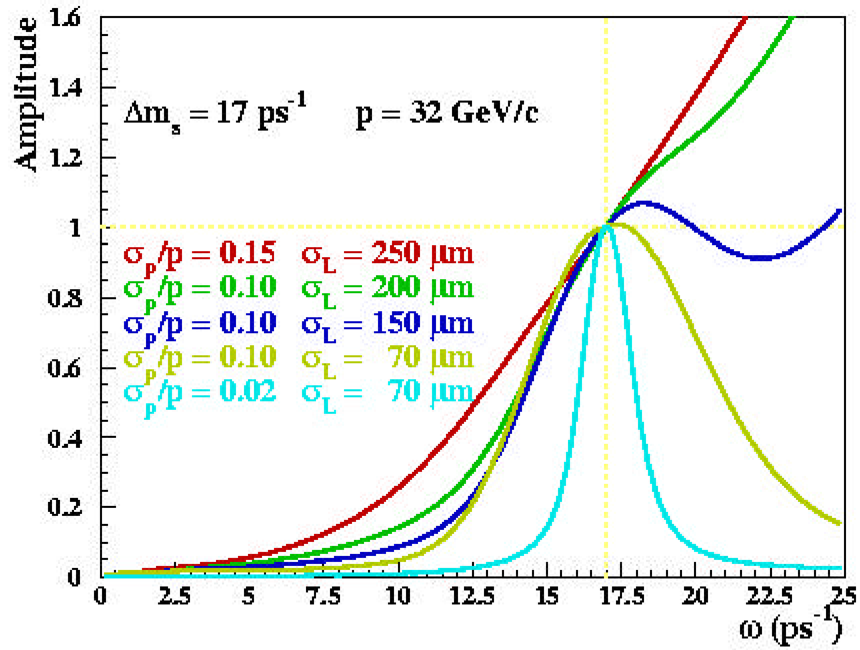
Fit for the amplitude of an oscillation with a given frequency*

Set a limit by combining analyses unable to resolve oscillations:

A =0 for Dm_s » w

A =1 for Dm_s = w

→ All w values for which A + 1.645 s_A < 1 are excluded at 95% C.L.



s_A^{-1}(w) µ N½ f_s (1-2h) F (s_p, s_L)

F (s_p, s_L) ~ exp(- s_t w)

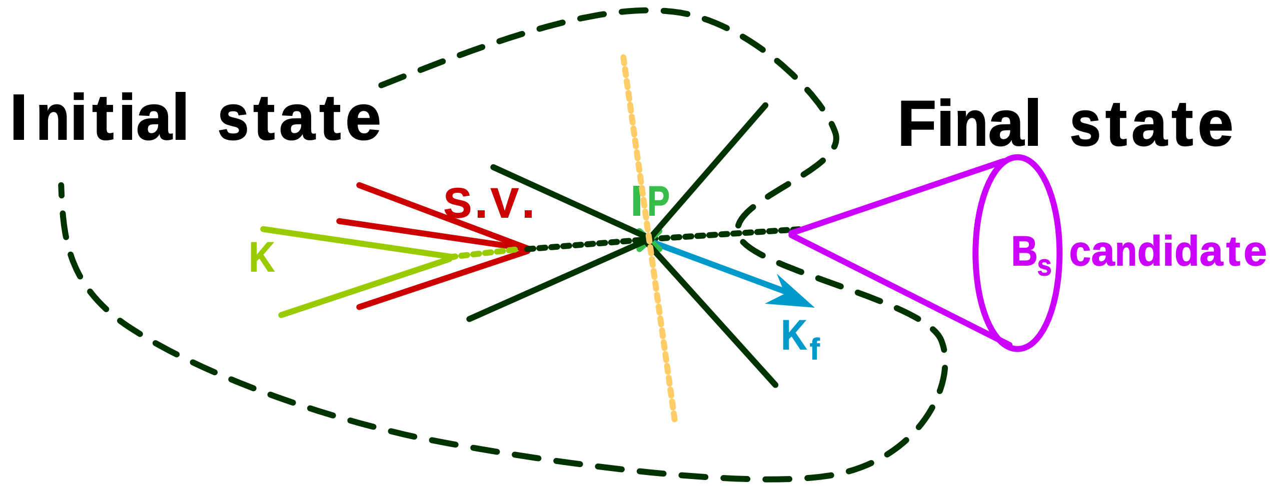
For w ³ Dm_s, the shape A (w) depends on the details of the analysis, and can be calculated analytically** in simple cases

* Moser and Roussarie NIM A 384 (1997) 491

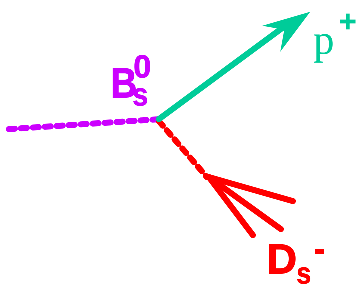
** Abbaneo and Boix JHEP 08 (1999) 004

The three ALEPH analyses

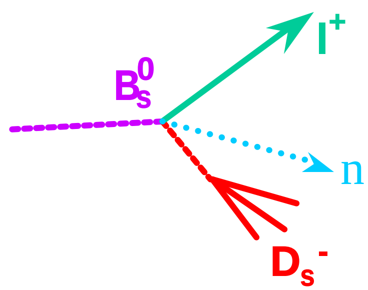
Released as preliminary in 2000 - now improved and submitted for publication



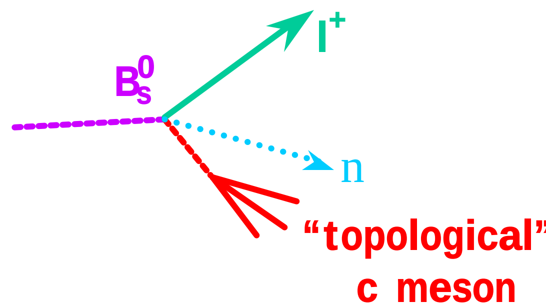
Fully reconstructed candidates



D_s - lepton final states



Inclusive lepton final states



Old D_s – hadron analysis dropped

Fully reconstructed candidates

$B_s^0 \rightarrow D_s^- \pi^+$, $B_s^0 \rightarrow D_s^- a_1^+$

$D_s^-, a_1^+ \rightarrow$ charged particles

$B_s^0 \rightarrow D_s^{*-} \pi^+$, $B_s^0 \rightarrow D_s^{*-} a_1^+$

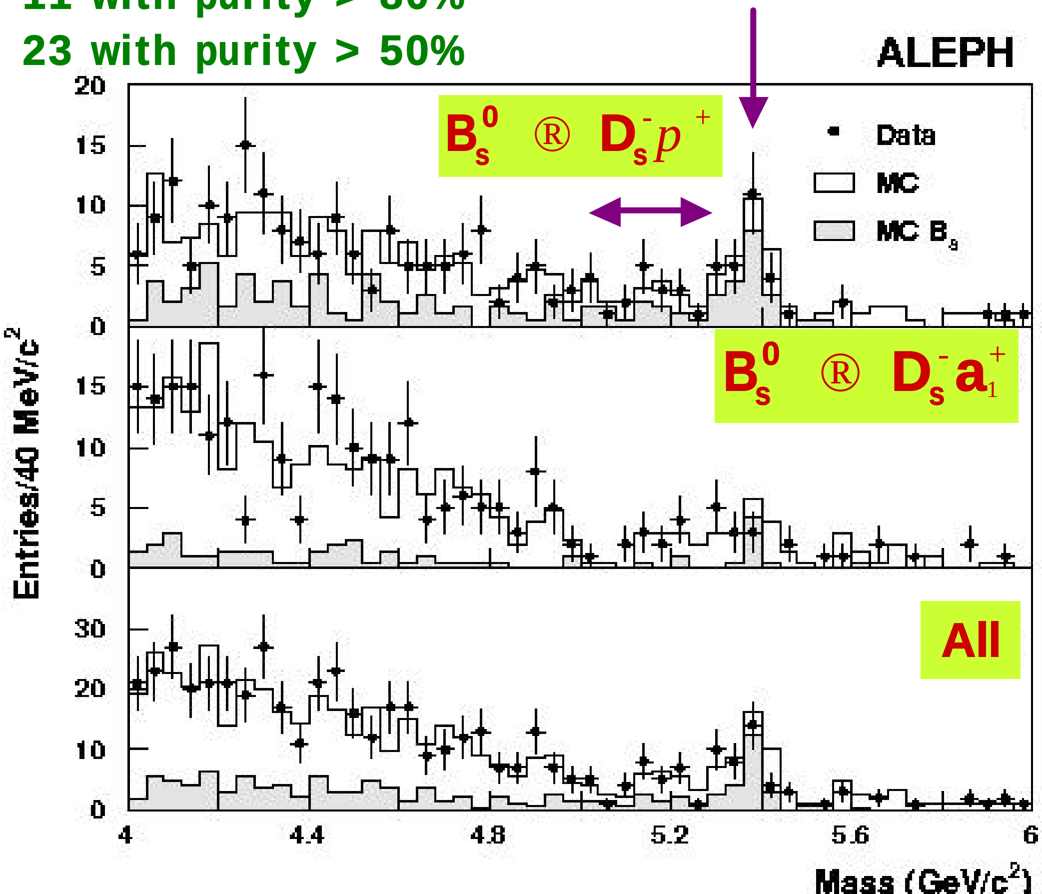
$B_s^0 \rightarrow D_s^- \rho^+$

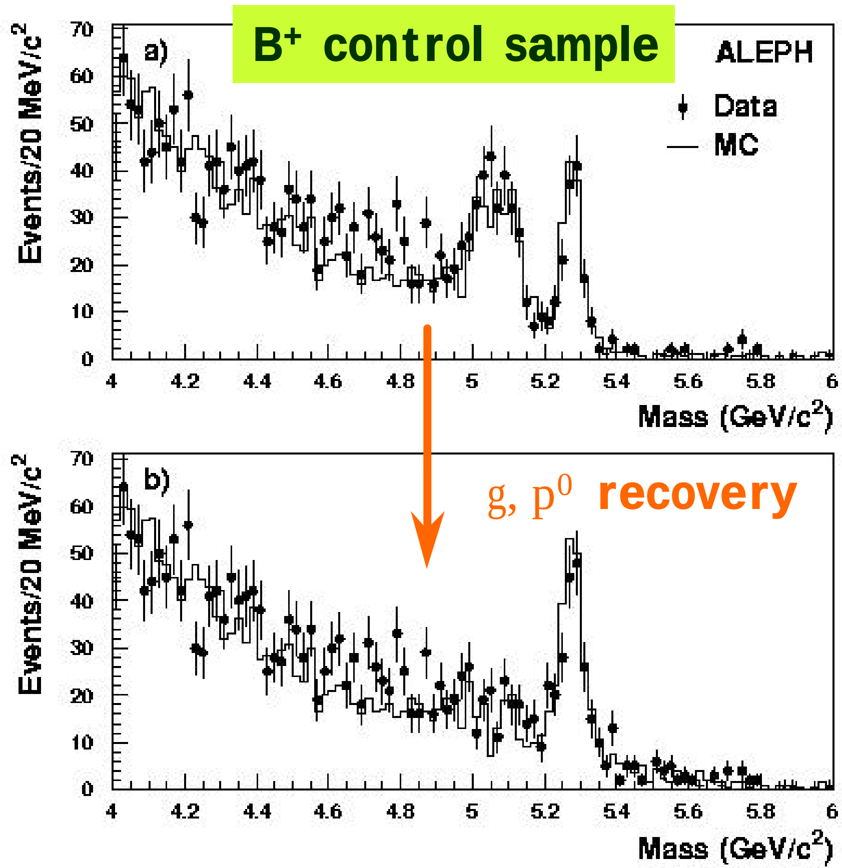
$B_s^0 \rightarrow D_s^{*-} \rho^+$

80 candidates (32 in the main peak)

11 with purity > 80%

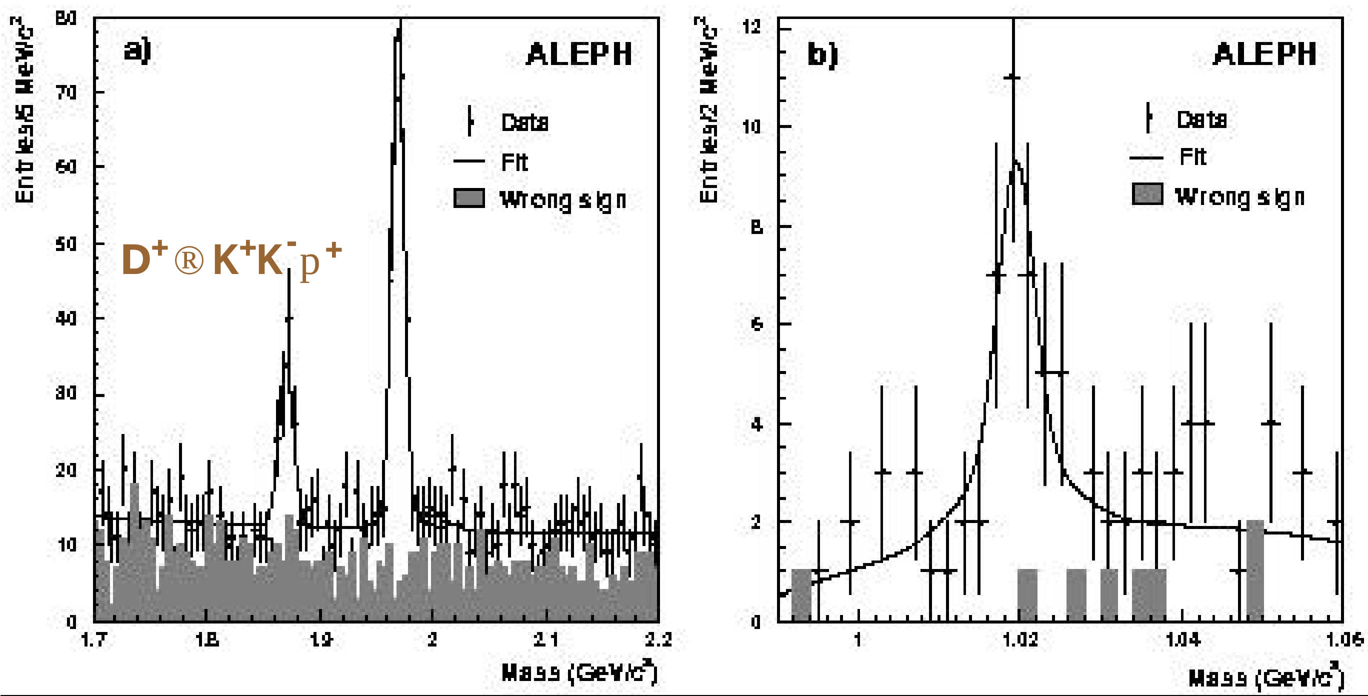
23 with purity > 50%





(D_s-l) candidates: the channels

D_s^- ® hadronic   **D_s^- ® *f l*$^-$**



Over 300 candidates

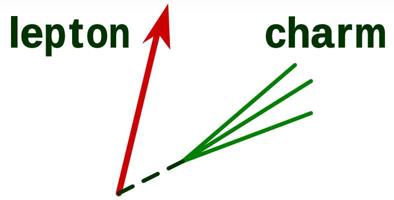
Fraction of the resonant component estimated from the data

NN to discriminate resonant background   **b ® $D_s^{\pm}$D(X)**

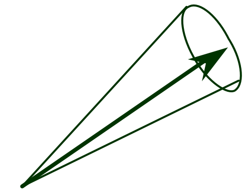
D ® Xℓ

Decay length for the inclusive l analysis

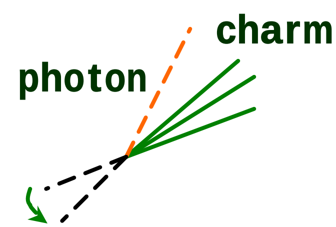
Basic idea:



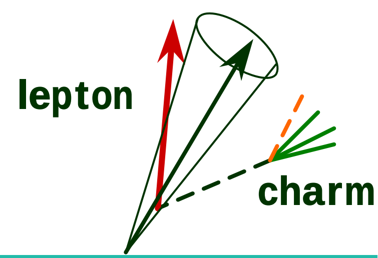
Reconstruct inclusively a “D track” and fit it with the lepton



Define a “B track” passing through the PV,
with angular uncertainties parameterized from the simulation



Look for photons around the D track with $m(D,g)<1.8$ GeV
Improve the D direction



Fit the D track, the B track and the lepton
to find the B decay vertex

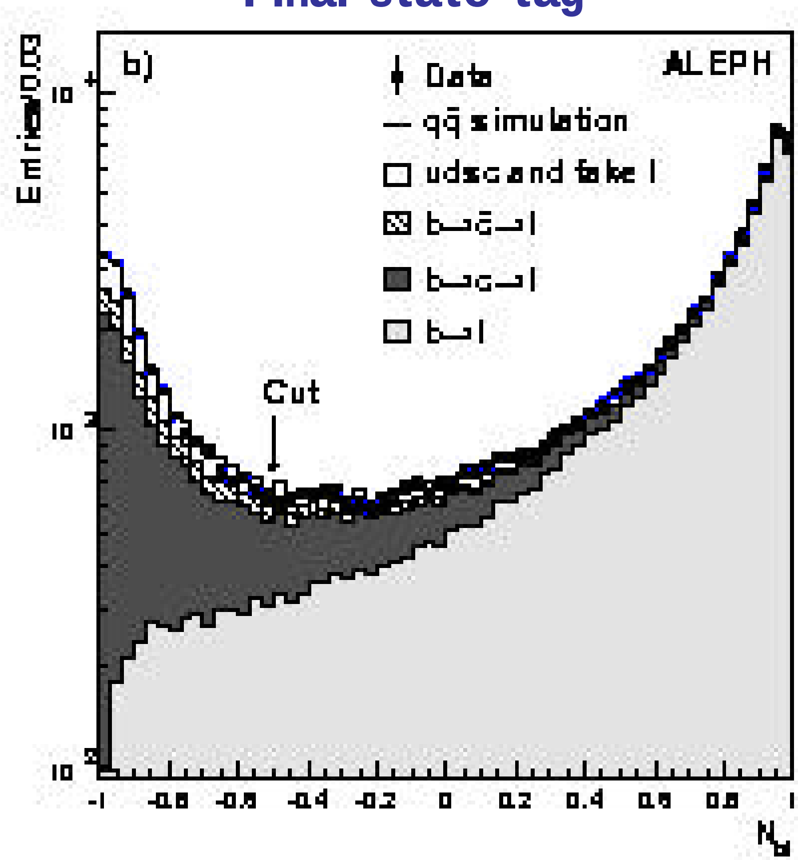
Event-by-event treatment for the incl l analysis

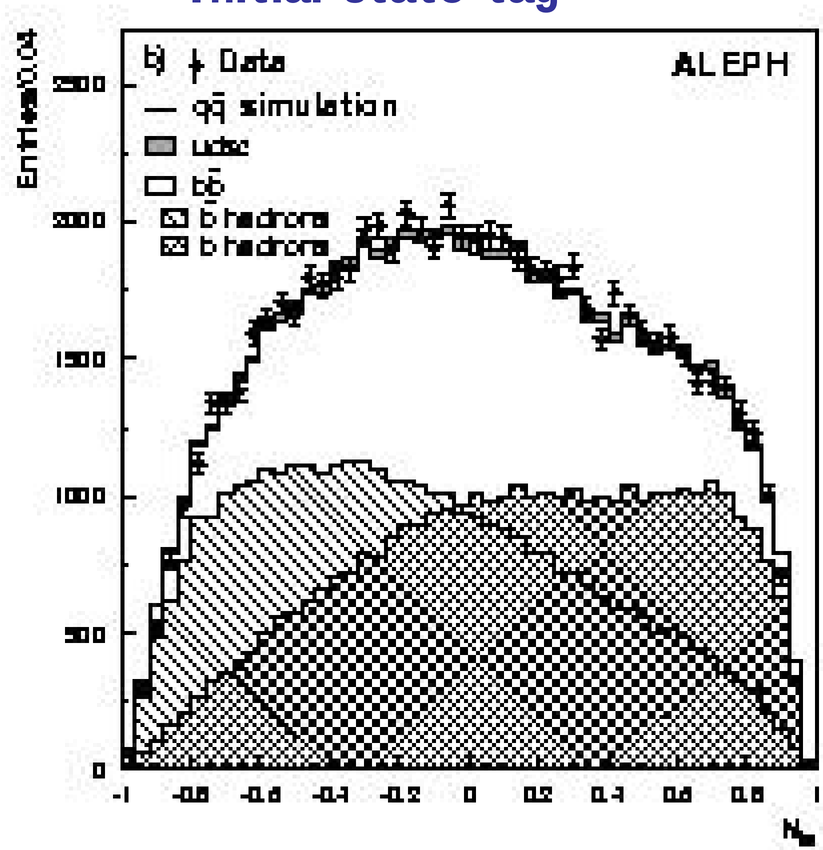
Divide events in classes according to topological properties [vertex classes]

m(D), $\cos\theta$(l,D), n_{tr}(D), χ^2(D), χ^2(B)

<u>For each class:</u>

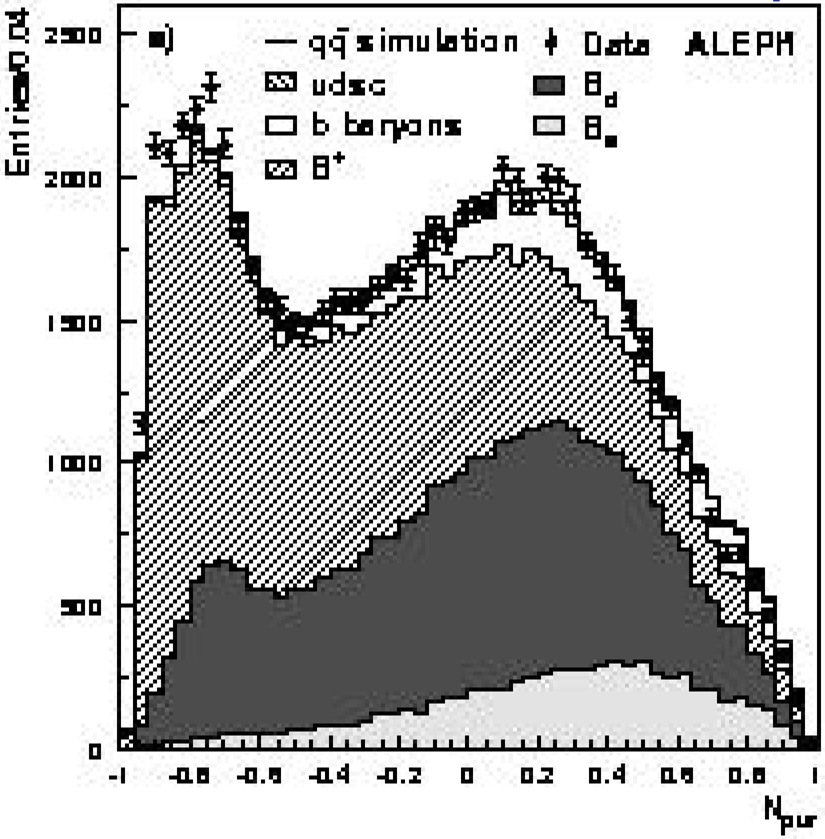
Final state tag	Initial state tag

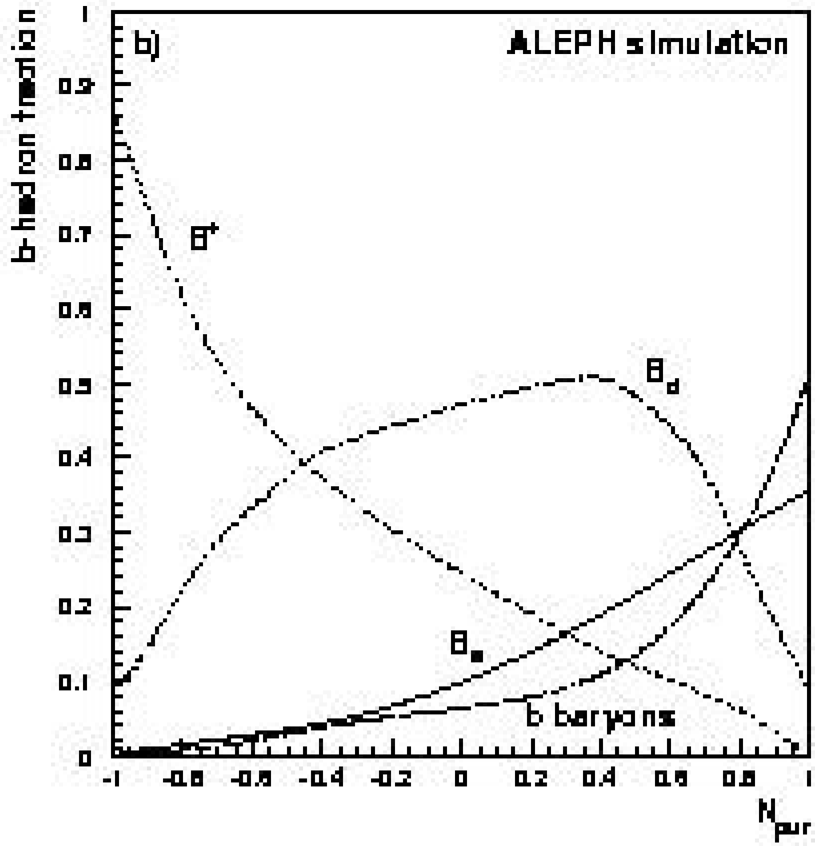




Event-by-event treatment for the incl l analysis

Sample composition





Decay length uncertainty from the vertex fit [data]

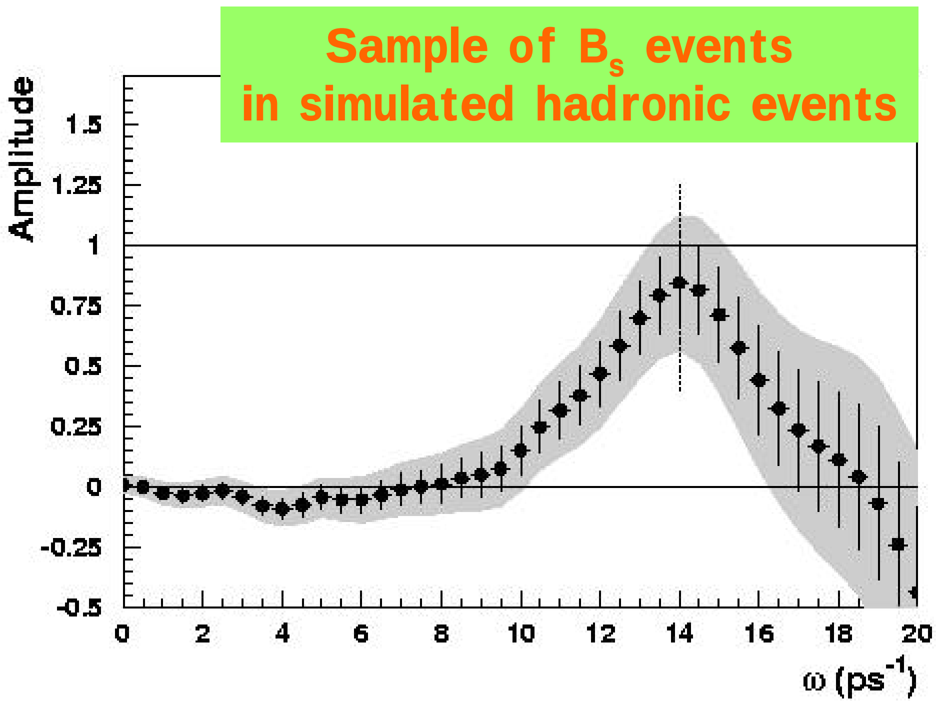
Decay length bias correction and pull correction

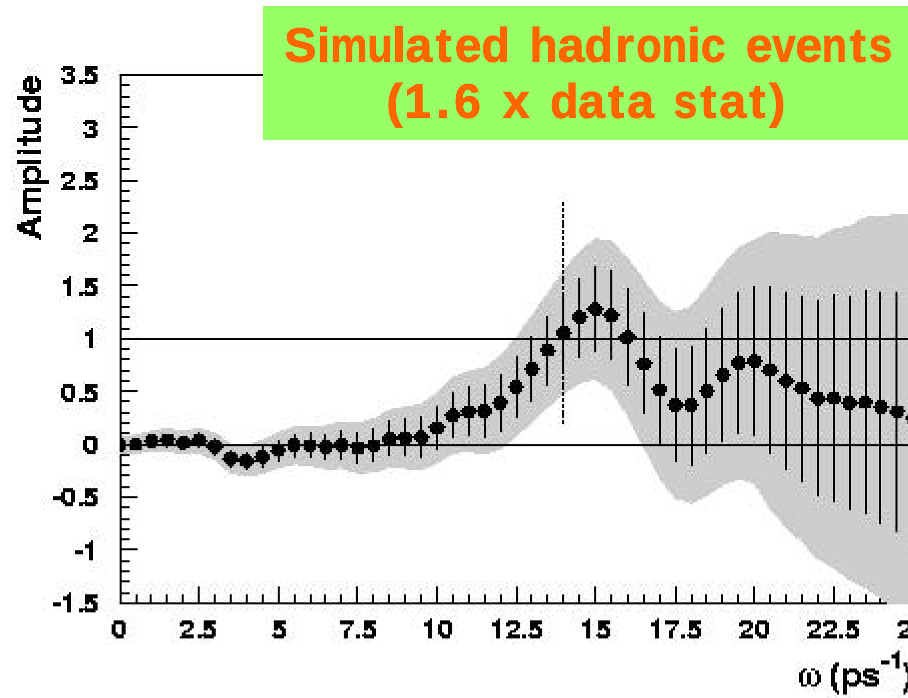
Momentum uncertainty and bias correction

} **Parameterized as a function of event properties**

Building a reliable analysis

- **Control reliability of parameterizations [MC]**





- **Control reliability of simulation**

Use control samples to check IS tag, decay length and momentum reconstruction

$$B^0 \rightarrow D^- \ell^+ \nu\,(X), \quad B^- \rightarrow D^0 \ell^- \bar{\nu}\,(X) \quad \text{etc.}$$

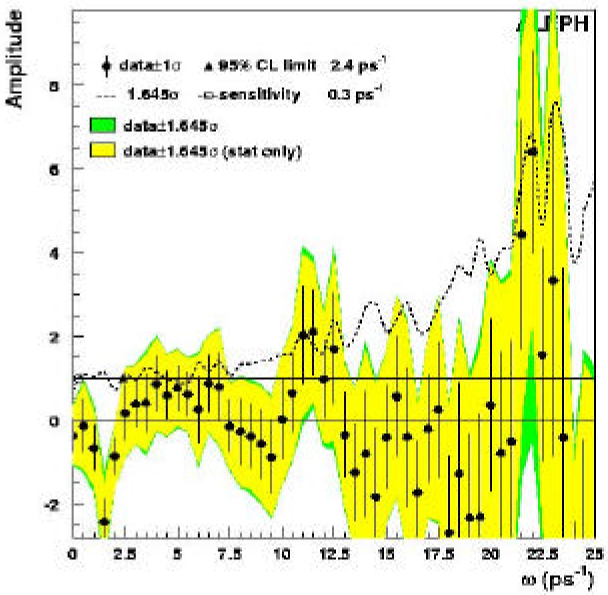
The estimate of the systematic uncertainties

For each source considered, both a change of the amplitude and of its statistical error are observed

Calculate the total error taking into account both effects by means of toy experiments

The three analysis results

Exclusive

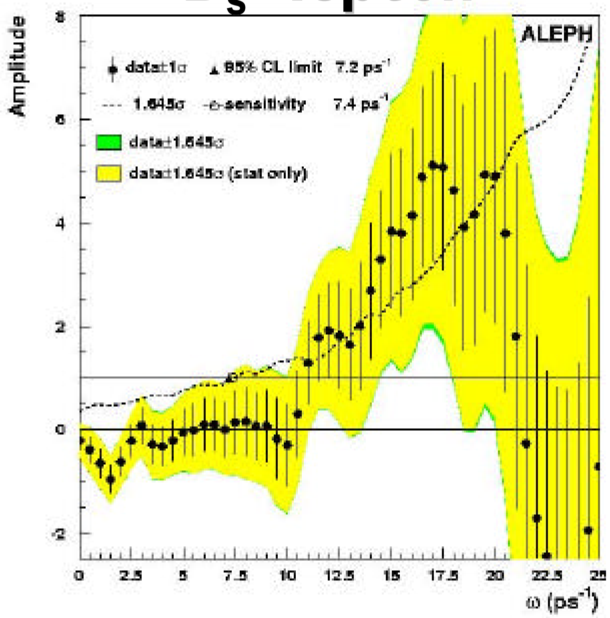


Obs. limit: Dm_s>2.4 ps^{-1}

Exp. limit: Dm_s>0.3 ps^{-1}

1.645s $_A$@15ps^{-1}: 2.1

D_s - lepton

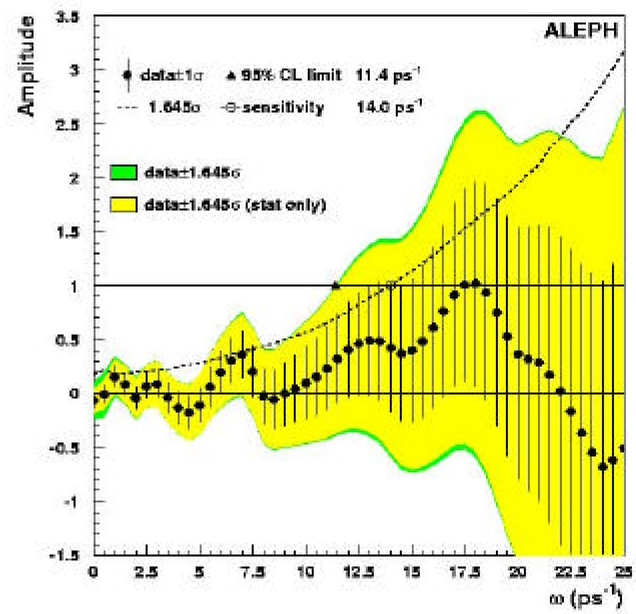


Dm_s>7.2 ps^{-1}

Dm_s>7.4 ps^{-1} (was 6.6 ps^{-1})

1.645s $_A$@15ps^{-1}: 2.5

Inclusive lepton



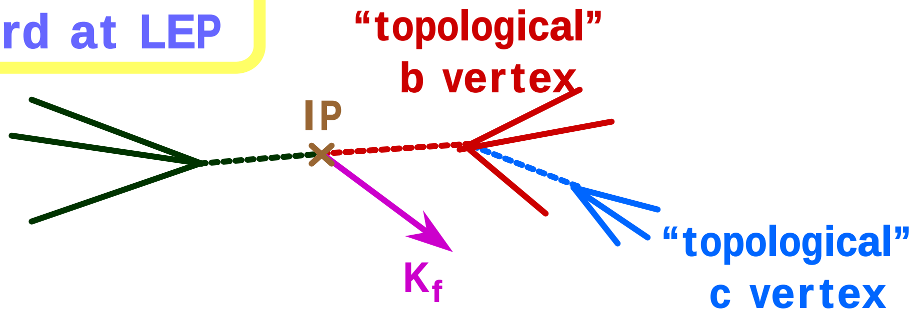
Dm_s>11.4 ps^{-1} (was 9.5 ps^{-1})

Dm_s>14.0 ps^{-1} (was 9.8 ps^{-1})

1.645s $_A$@15ps^{-1}: 1.2

Fully inclusive final states

Good at SLD
Hard at LEP



Final state tag based on charge flow between b and c vertices

$B_s^0 \to D_s^-$ $\quad$ $\overline{B_s^0} \to D_s^+$

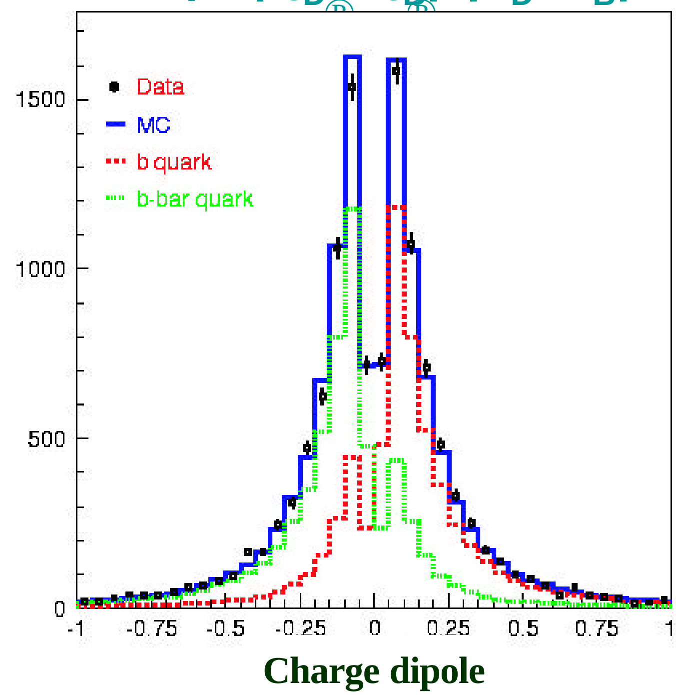
Needs excellent vertexing capability!

@ SLD:

σ_L = 72 μm (60%) & 265 μm
σ_p/p = 0.07 (60%) & 0.21

N = 8.5K decays
(4 × inclusive lepton)

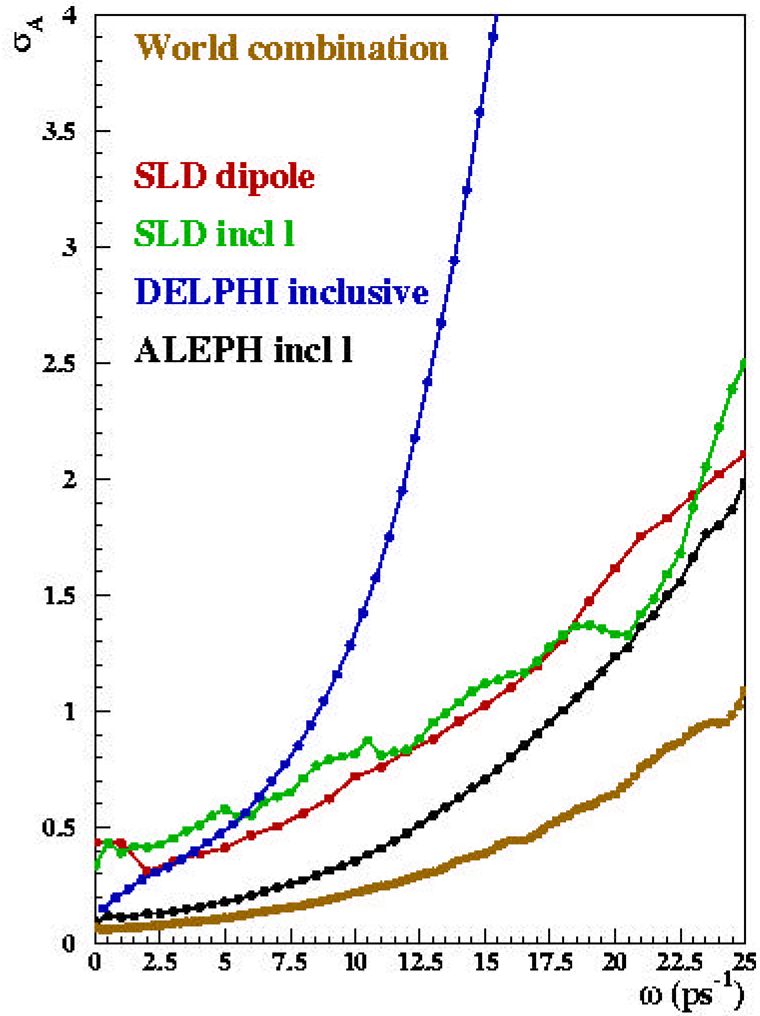
$dq = |Q_{D\to} - Q_{B\to}| \times |V_D - V_B|$



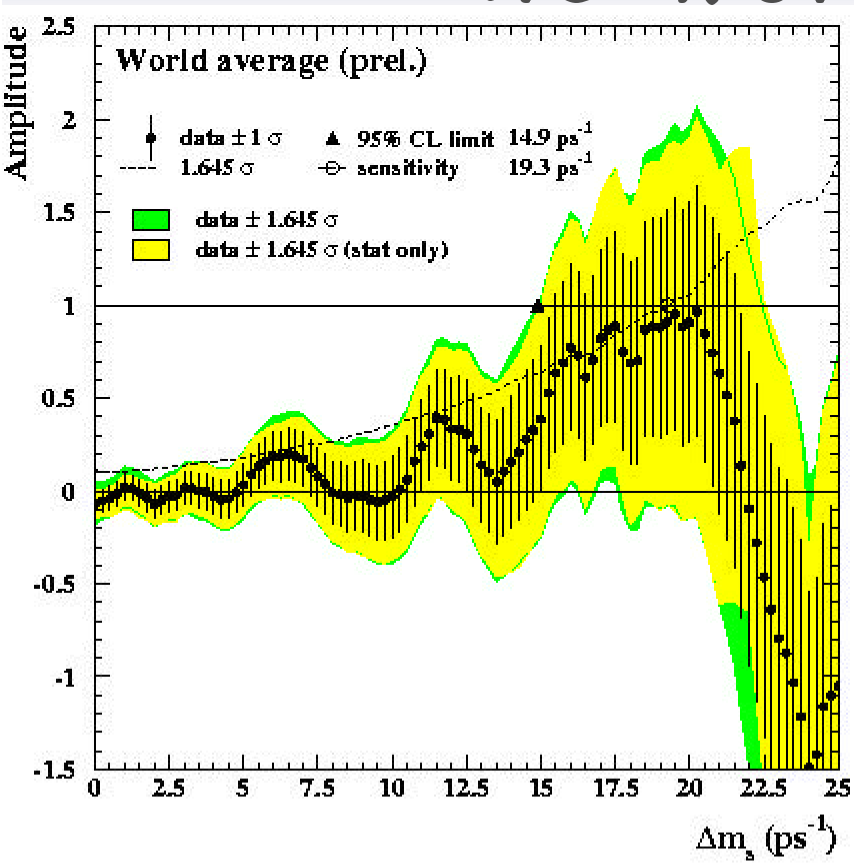
SLD versus LEP

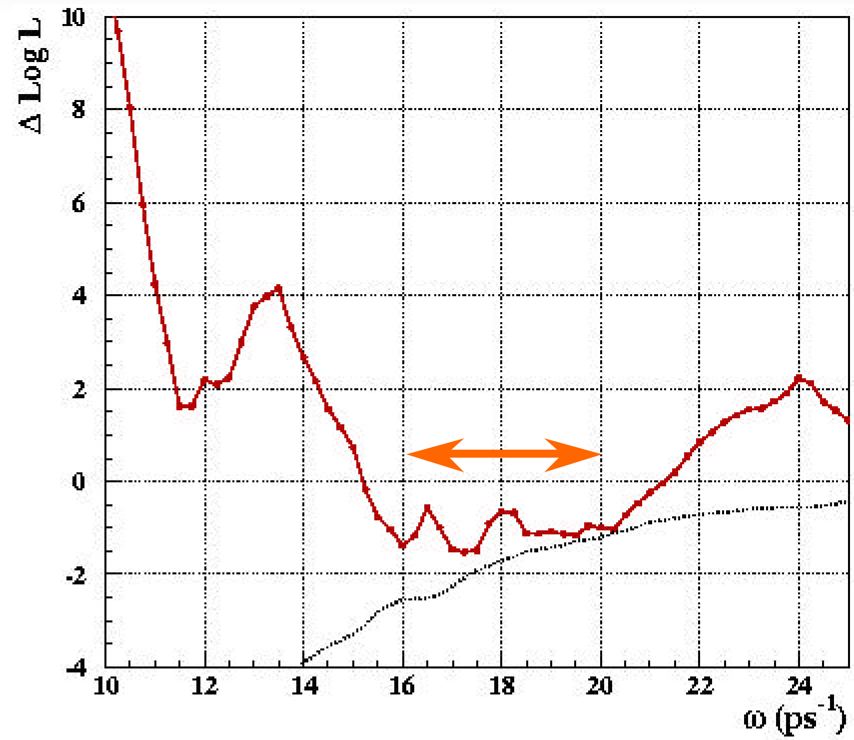
SLD privileged environment for B_s oscillation hunt

LEP	SLD
4M $q\bar{q}$ events per experiment	350K $q\bar{q}$ events
s_L ~ 250 mm (core)	s_L ~ 60-70 mm (core)
Initial State Tag h_{eff} ~ 25%	Initial State Tag h_{eff} ~ 10-15% (beam polarization)
Best analyses: D_s lepton Inclusive lepton	Best analyses: Inclusive lepton Fully inclusive



The world combination





Combined limit

Dm_s > 14.9 ps^{-1} @ 95% CL

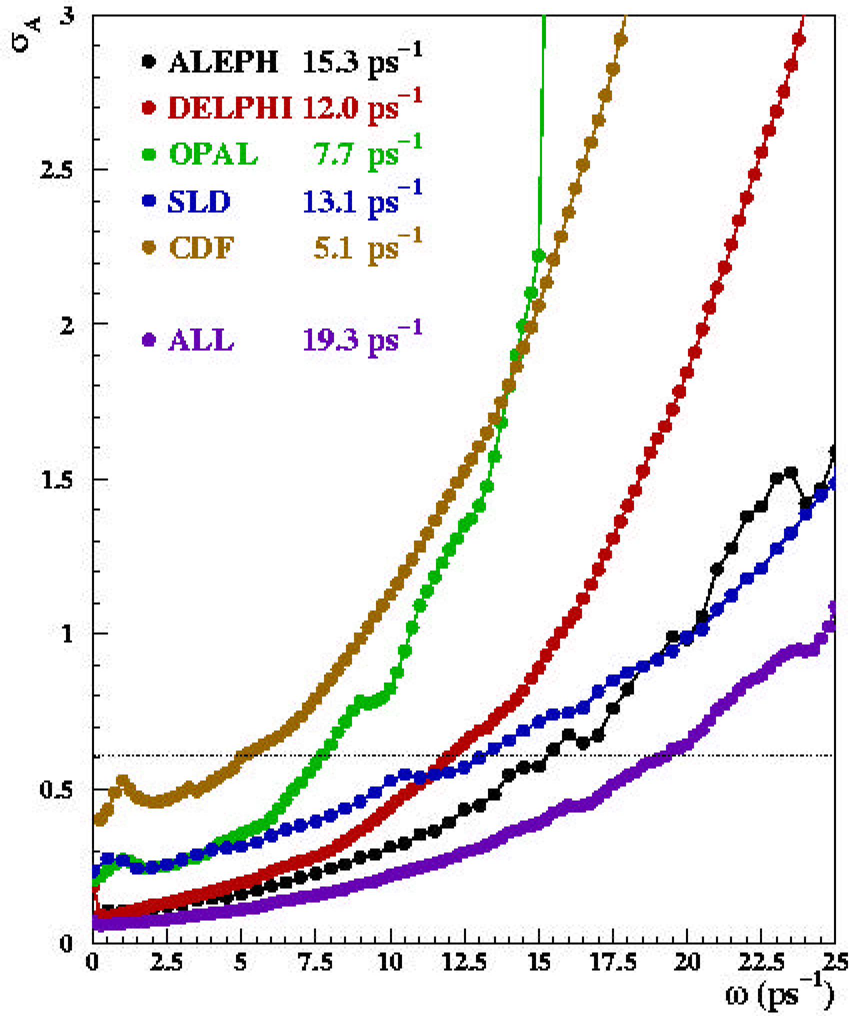
Expected limit Dm_s = 19.3 ps^{-1}

Amplitude error reduction

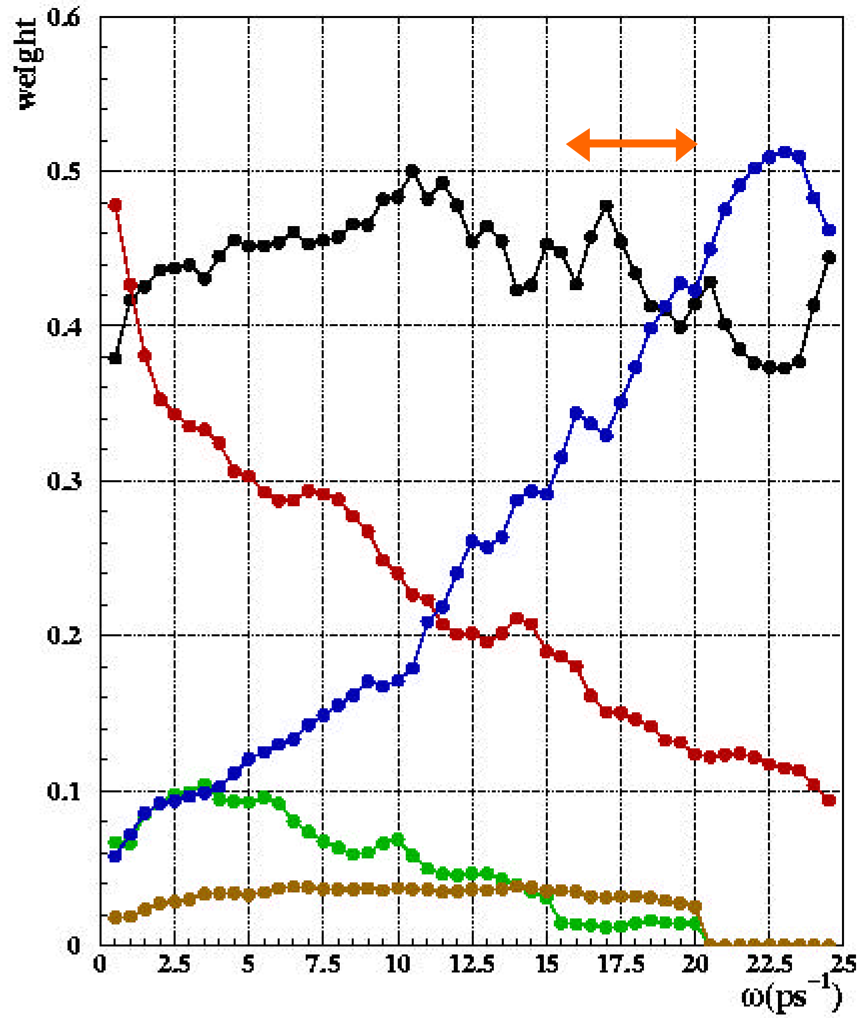
	Now	Summer99
@ 10 ps^{-1}	0.22	0.33
@ 15 ps^{-1}	0.39	0.66
@ 20 ps^{-1}	0.64	1.27

Comparison by experiment

Sensitivities



Weights in the combination



Conclusions

B_s oscillation searches have substantially improved over the last two years

<u>in the absence of new data!</u>

(e.g. the uncertainty at w » 20 ps^{-1} was reduced by a factor » 2)

Some improvements can still be expected, but not as significant

We know that Dm_s > 14.9 ps^{-1} @ 95% CL
and we have a (mild) indication of a signal at w between 16 and 20 ps^{-1}

The burden and the pleasure of continuing the hunt goes now to CDF and D0