NEW RESULTS ON B_s MIXING FROM LEP

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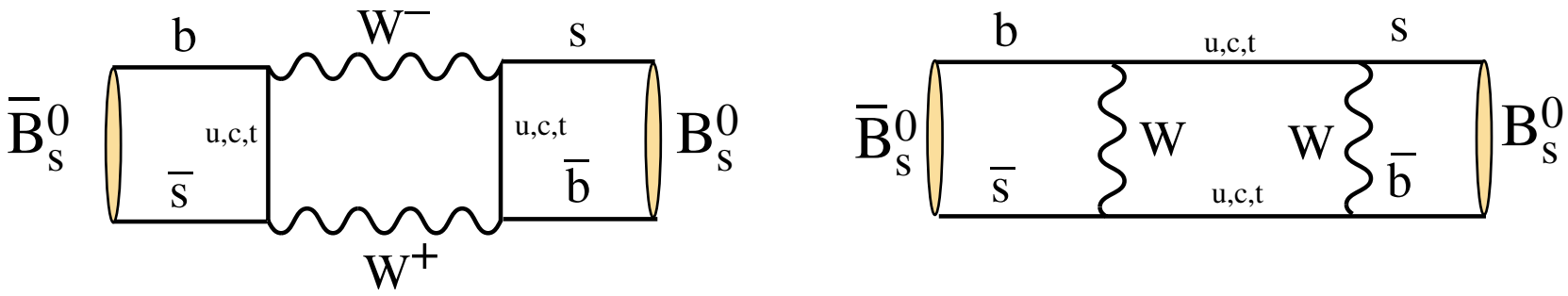
OUTLINE

- B_S Mixing Phenomenology
- LEP and the LEP Experiments
- Experimental Strategy
- New/Improved Analyses from ALEPH (2002)
- Results and Interpretation
- Conclusion

B_s MIXING PHENOMENOLOGY

- B_s^0 - $\bar{B}_s^0$ oscillation frequency proportional to mass difference Δm_s



- Measurement of Δm_s (and Δm_d) permits extraction of CKM elements

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \cdot \frac{|V_{ts}|^2}{|V_{td}|^2} \cdot \frac{F_{B_s}^2 B_{B_s}}{F_{B_d}^2 B_{B_d}}$$

ξ^2 *contains theo. uncertainties roughly 6%*

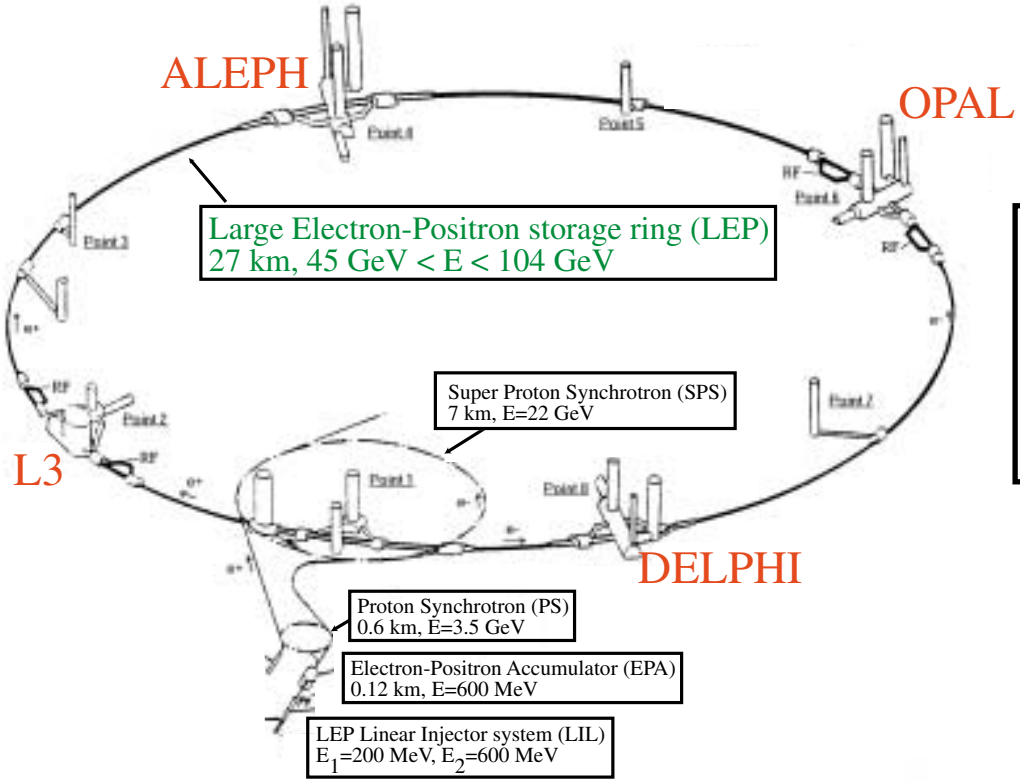
- Time-dependent asymmetry between "mixed" and "unmixed" decays

$$P_{\text{unmix}}^{\text{mix}}(t) = P_{B_s \to \overline{(-)}{B_s}}(t) = \Gamma_s \frac{e^{-\Gamma_s t}}{2}[1 \mp \cos(\Delta m_s t)]$$

Assuming CP conservation and small lifetime differences

Large Electron Positron (LEP) Collider

LEP1:1989-1995 at E_{cm} close to 91 GeV
LEP2: 1995-2000 at E_{cm} = 130-209 GeV

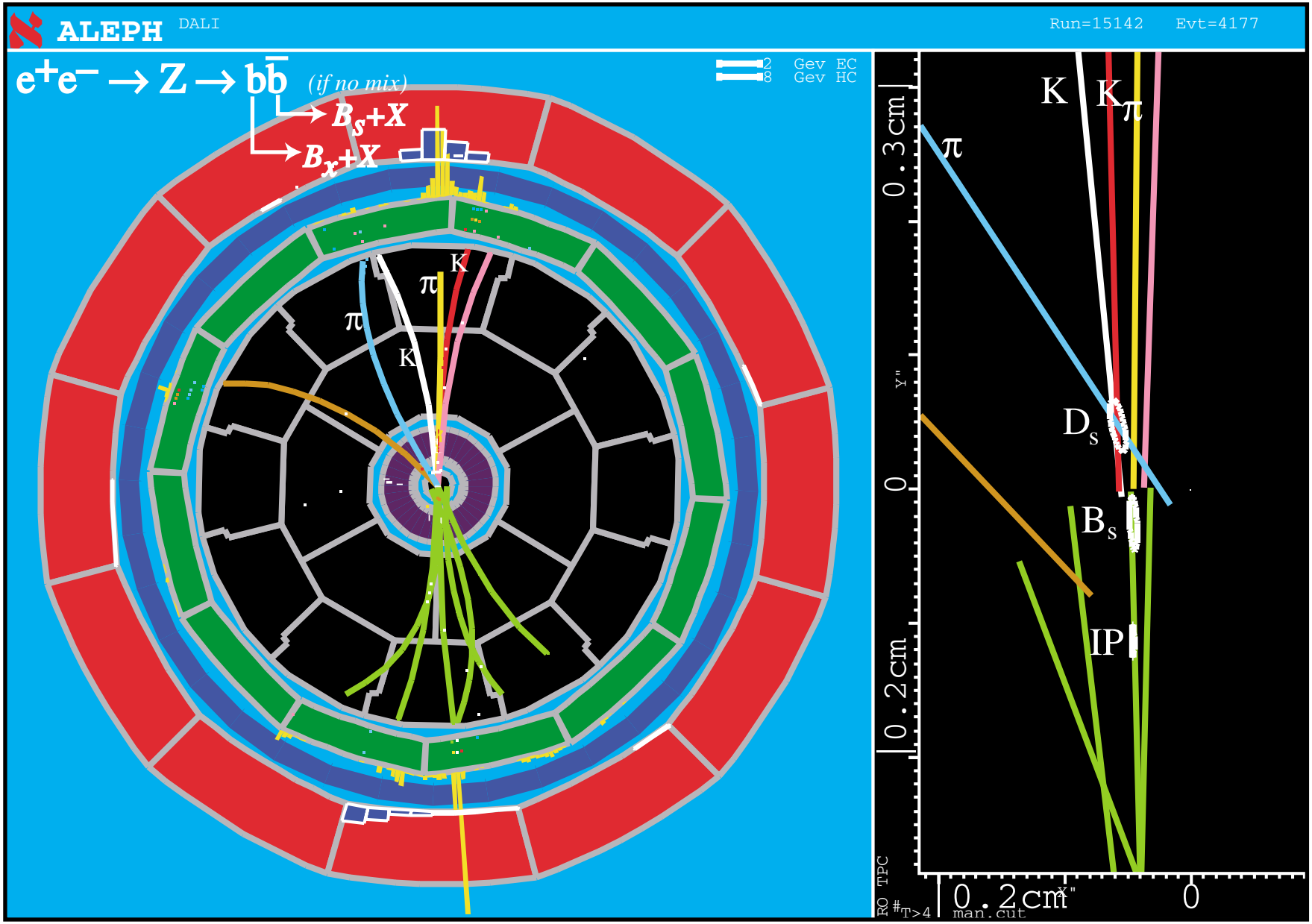


LEP1 Data used for Heavy Flavour Analyses: 1991-1995

4 Million Hadronic Z Decays per exp.

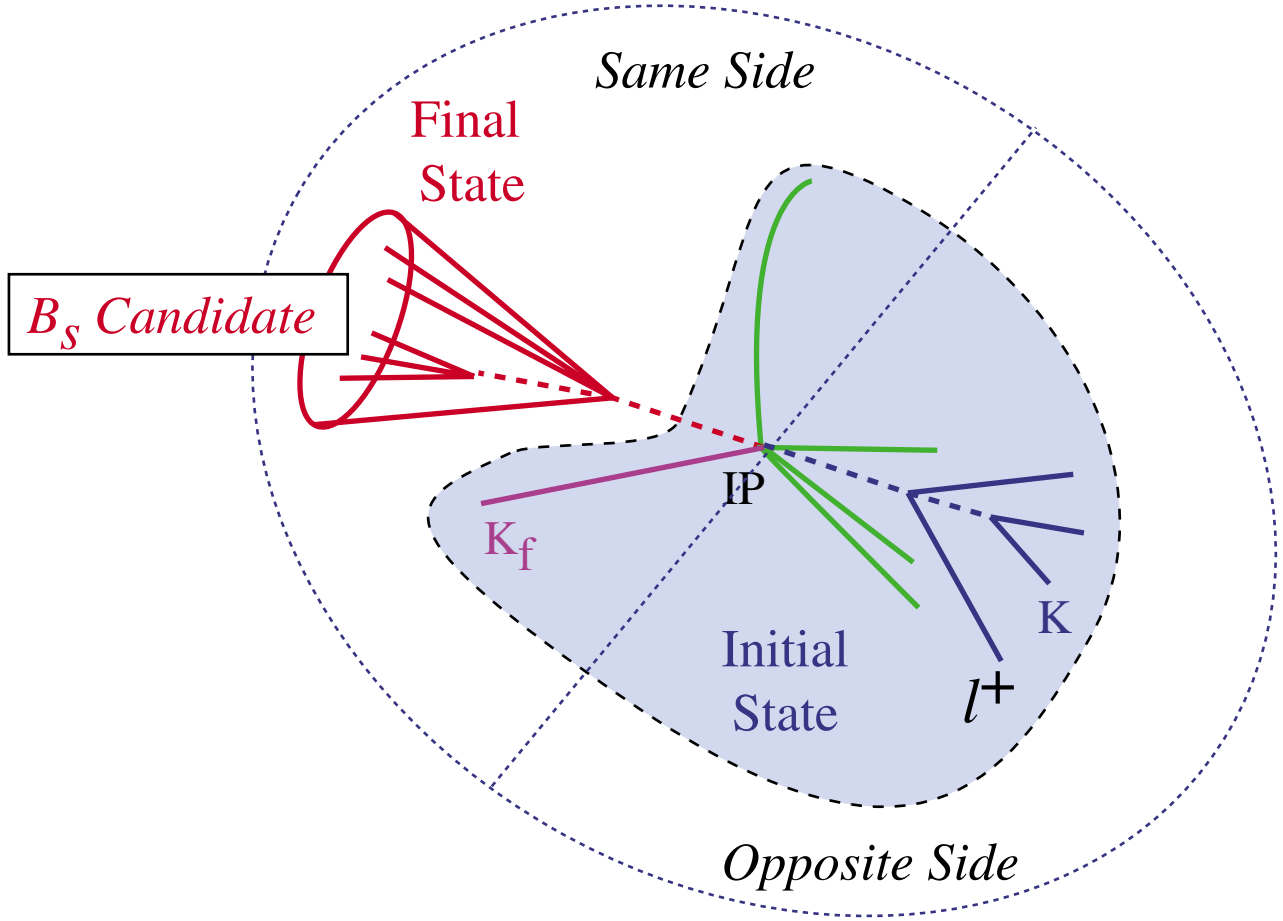
LEP Accelerator and Experiments dismantled to make way for LHC

A B_s CANDIDATE EVENT



EXPERIMENTAL STRATEGY

Select B_s Candidates and Determine their Event Purity → **Tag Initial and Final States** → **Measure Proper Time** → **Fit Δm_s**



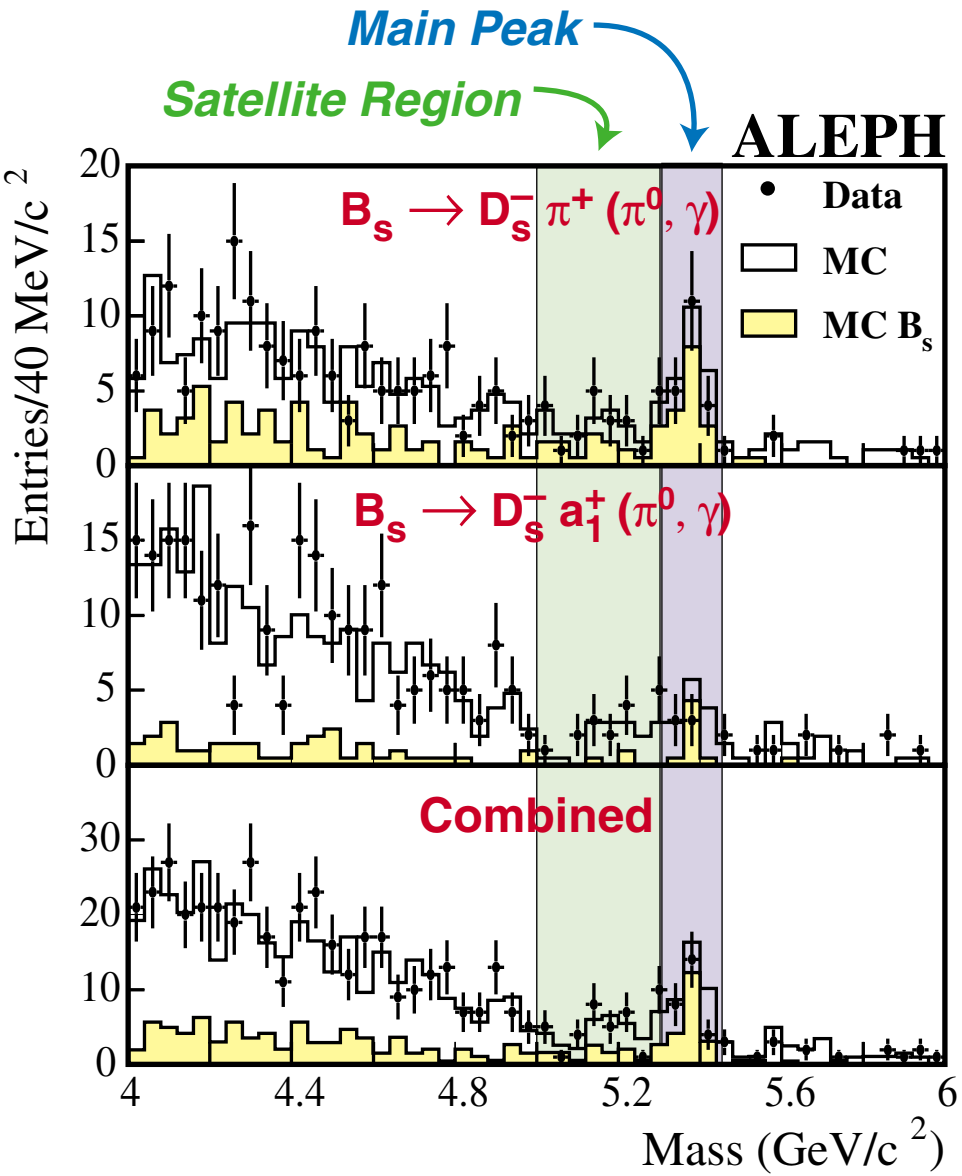
B_s SELECTION AT LEP

4 selection categories of increasing sample size/decreasing purity

3 new/improved ALEPH analyses

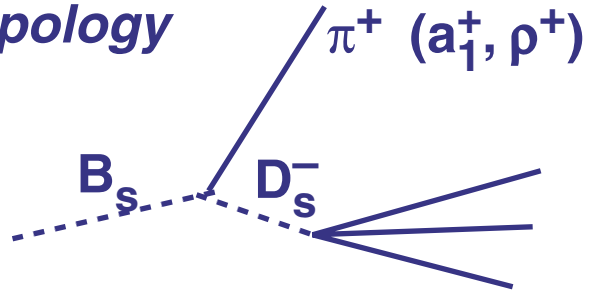
	Criteria	Sample Size/Purity
Fully Exclusive ALEPH, DELPHI	Fully reconstructed: $B_s \rightarrow D_s^{(*)-}(\pi^+, a_1^+, \rho^+)$ $B_s \rightarrow D^0 K^-(\pi^+, a_1^+)$	• 50 - 80 candidates • 50 - 80% purity • small sample size is compensated by excellent resolution
Semi-Exclusive ALEPH, DELPHI, OPAL	$B_s \rightarrow D_s^{(*)-} l^+ \nu_l$ $B_s \rightarrow D_s^{(*)-}$ + *hadrons*	• 10^2 - 10^3 candidates • 40 - 60% purity
Semi-Inclusive ALEPH, DELPHI, OPAL	$B_s \rightarrow l^+ + X$	• 10^4 - 10^5 candidates • 10 - 20% purity
Fully Inclusive DELPHI	Inclusive secondary vertices	• 5×10^5 candidates • 10% purity ("natural")

NEW ALEPH FULLY EXCLUSIVE B_s SELECTION



$B_s \rightarrow D_s^{(*)-} (\pi^+, a_1^+, \rho^+)$

Topology



Event Purity

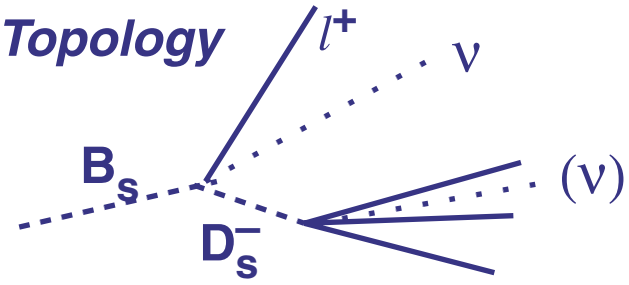
- 12 event classes based on decay
- Purity from helicity angle, m(D_s)

Candidate Events
32 candidates in main peak
48 candidates in satellite region

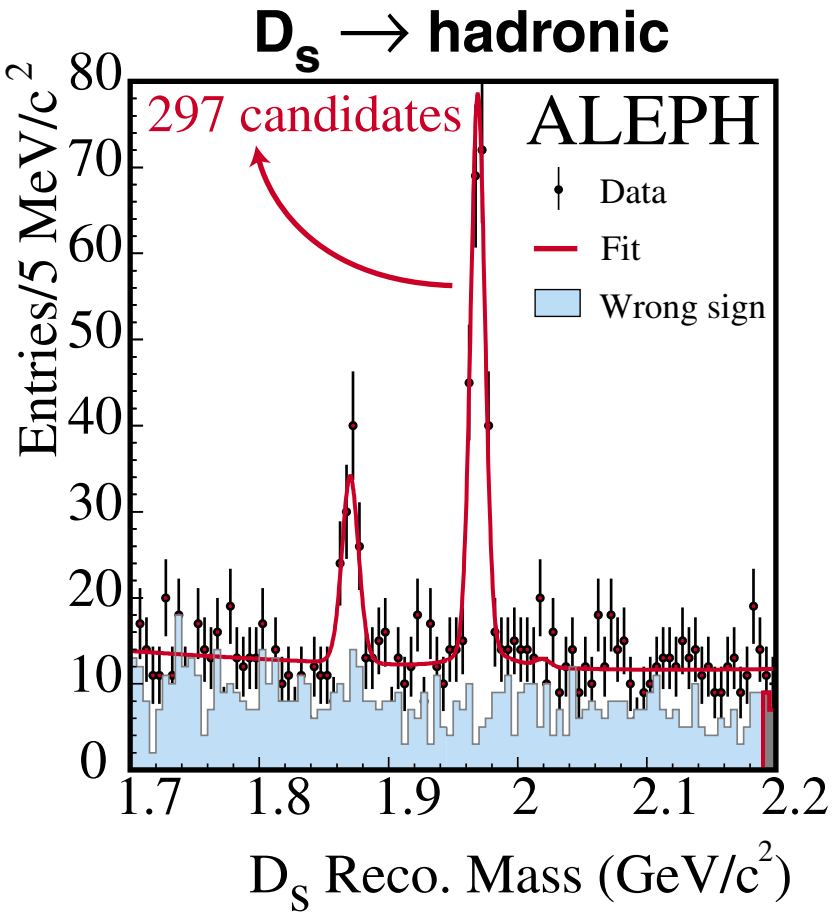
11 candidates with purity > 80%

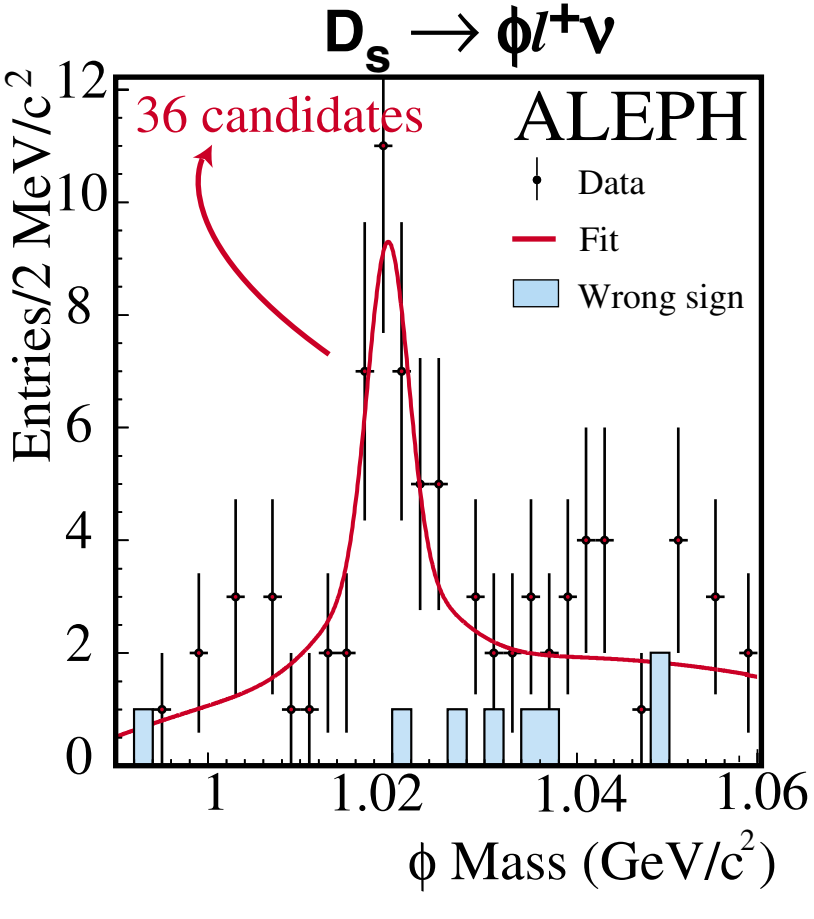
IMPROVED ALEPH SEMI-EXCLUSIVE B_s SELECTION

$B_s \rightarrow D_s^{(*)-} l^+ \nu_l$



Event Purity
- *$m(D_s$ or $\phi)$ resonant fraction*
- *NN based discriminant for signal vs $b \rightarrow D_s DX$ ($D \rightarrow l$)*

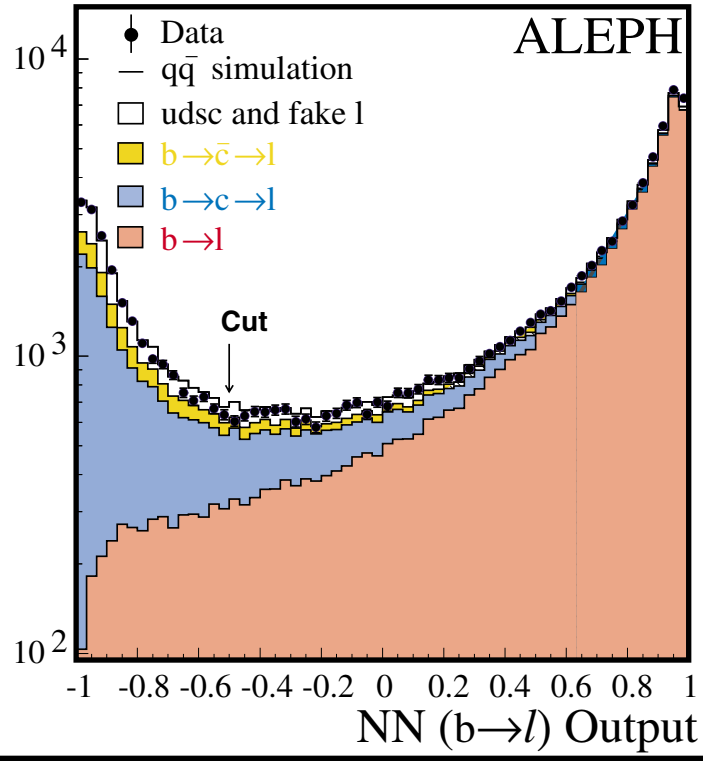




IMPROVED ALEPH SEMI-INCLUSIVE B_s SELECTION

NN-based $b \rightarrow l$ discriminant:

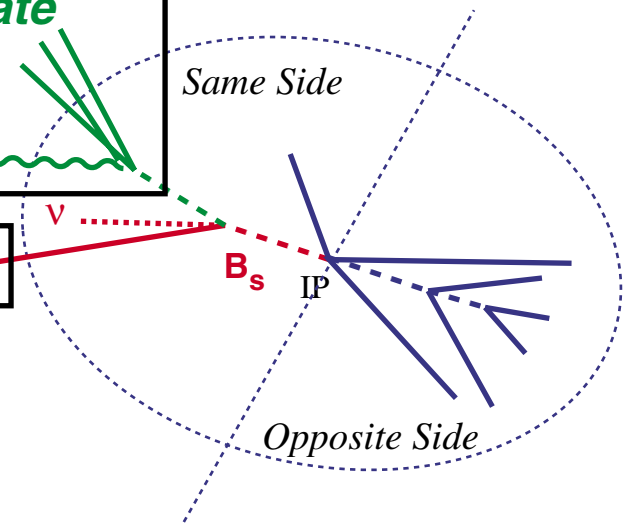
- lepton p and p_T
- $E_{miss} \approx E_\nu$
- Jet/Track kinematics
- lepton impact parameter w.r.t. Charm vertex



Inclusive Charm candidate

recovered photon

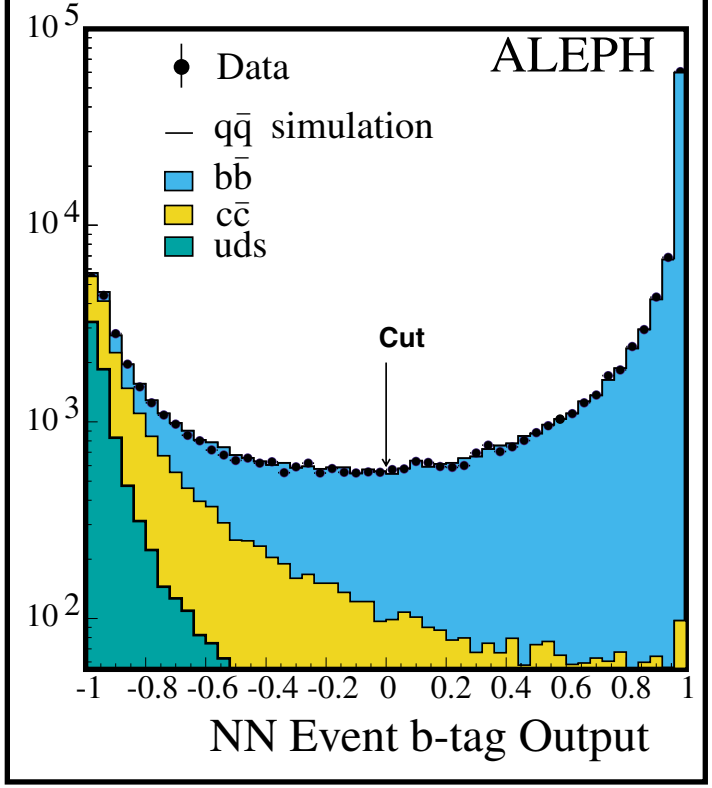
$B_s \rightarrow l^+ + X$



selection yields:
74, 026 candidates

NN-based Event b-tag using b-Hadron content of Same and Opposite Sides

- Track Impact Parameters
- Secondary Vertices
- b Hadron Mass
- lepton p and p_T

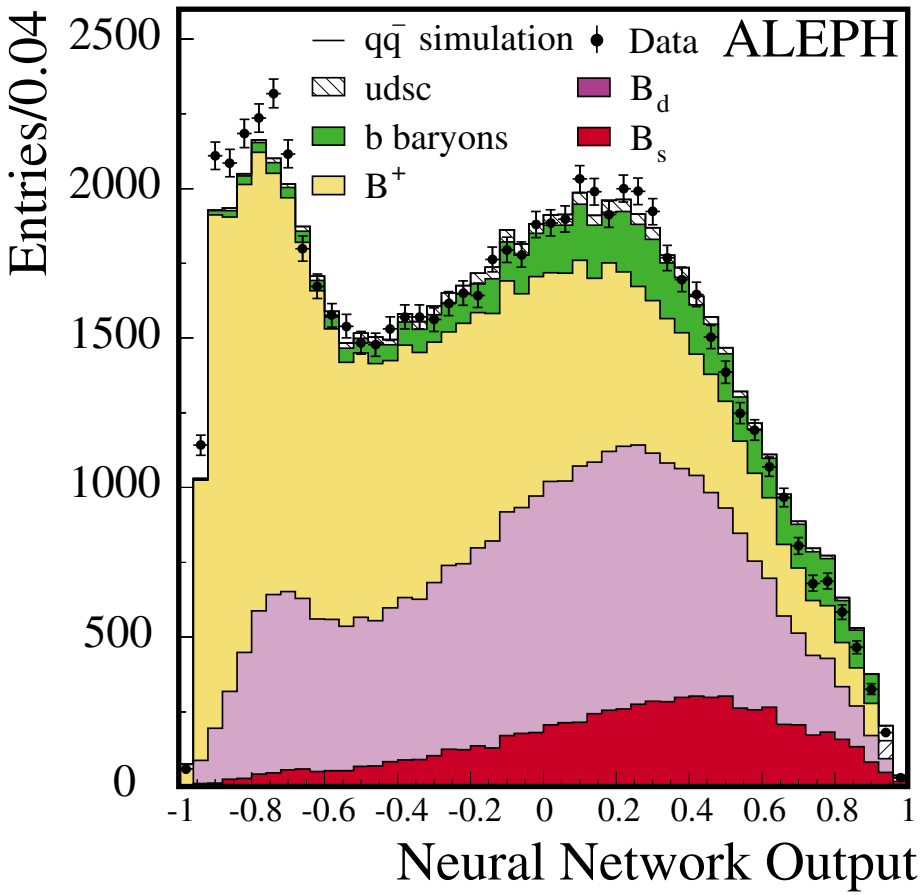


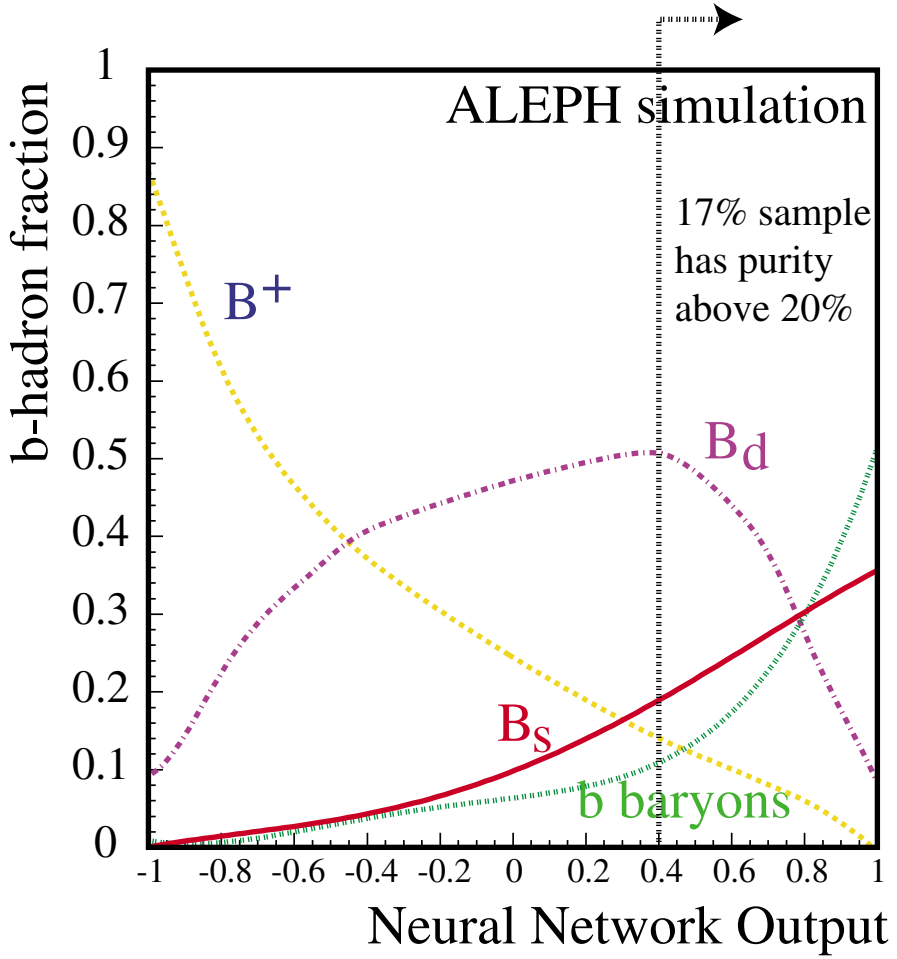
IMPROVED ALEPH SEMI-INCLUSIVE B_s SELECTION

Event Purity determined with NN-based discriminant

Vertex charge and charge multiplicity: $q_l \sum w_i^{\kappa(1)} q_i$, $\sum w_i^{\kappa(2)}$, $q_l \sum w_i p_i^{\kappa(3)} q_i$

K from Fragmentation and B Decay: $K^{\pm}$ (w.r.t. *l* charge), K^0 estimators, $m(K^+K^-)$





INITIAL AND FINAL STATE TAGGING

Determine Particle/Antiparticle State of B_s at Production (Decay)

FINAL STATE TAGGING

Fully Exclusive
ALEPH, DELPHI

$B_s \to D_s^{(*)-} (\pi^+, a_1^+, \rho^+)$

$B_s \to D^0 K^- (\pi^+, a_1^+)$

Charges of Decay Products

Semi-Exclusive
ALEPH, DELPHI, OPAL

$B_s \to D_s^{(*)-} l^+ \nu_l$: **lepton charge**

$B_s \to D_s^{(*)-}$ + *hadrons* : **$D_s^{(*)}$ charge**

Semi-Inclusive
ALEPH, DELPHI, OPAL

$B_s \to l^+ + X$: **lepton charge (account for b $\to$ c $\to$ l mistag)**

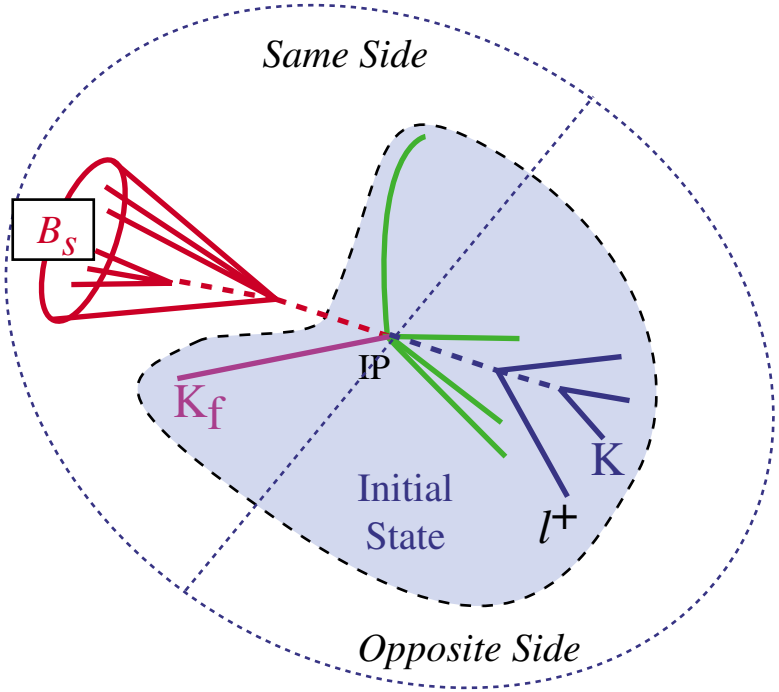
Fully Inclusive
DELPHI

NN-based charge dipole method

INITIAL STATE TAGGING

Draw upon information from both Same and Opposite sides

Same Side Information
- Primary Vertex charge
- Fragmentation Kaon

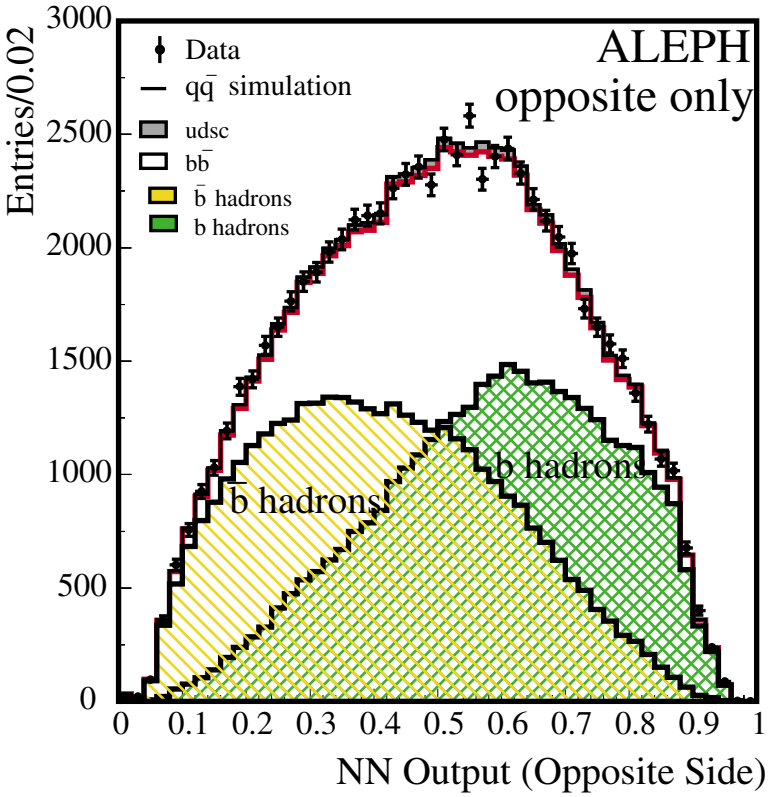


Opposite Side Information
- Hemisphere "Jet" charge
- Primary Vertex charge
- Secondary Vertex charge
- $K^{\pm}$ and $l^{\pm}$ charge(s)

Combine all information into single Tagging discriminant: performance evaluated as Mistag Rate η

NEW ALEPH INITIAL STATE TAGGING

Opposite Side Information combined using NN:



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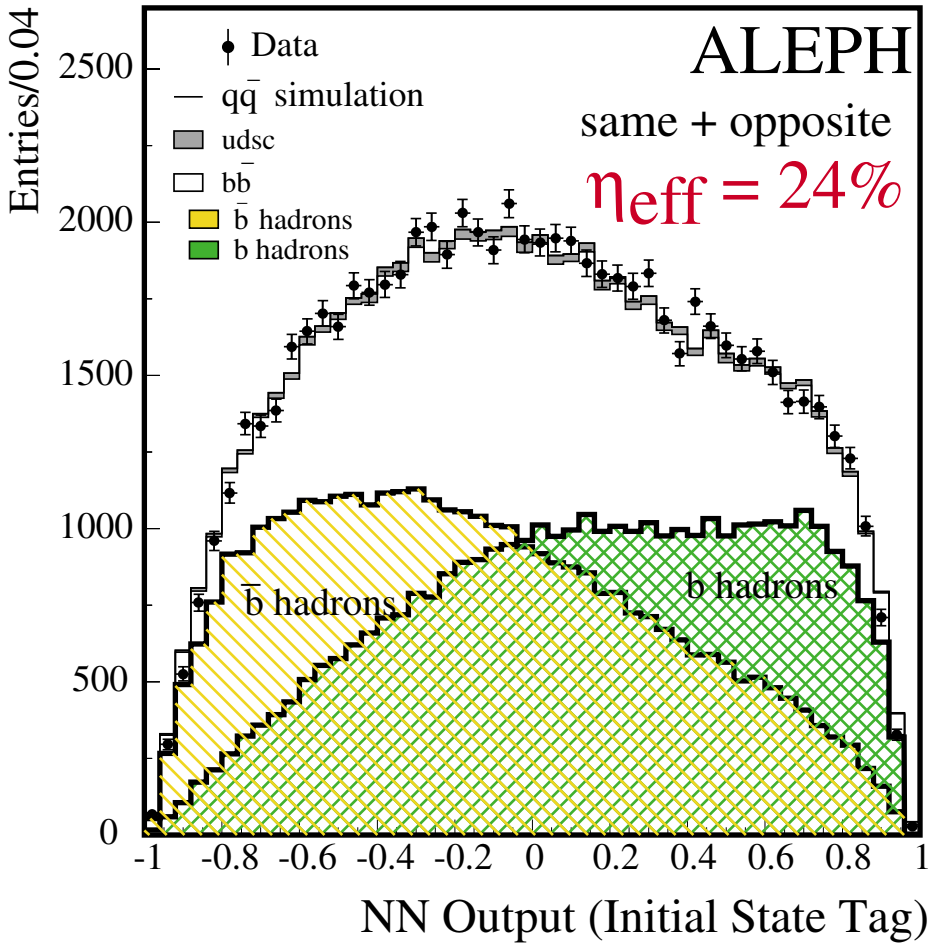
Additional Same Side Information:

- Fragmentation Kaon (NN selected, charge signed)
- "Jet" charges (excluding B_s decay products)
- cos $\theta(B_s)$, $p(B_s)$, N_{tracks}



PROPER TIME MEASUREMENT

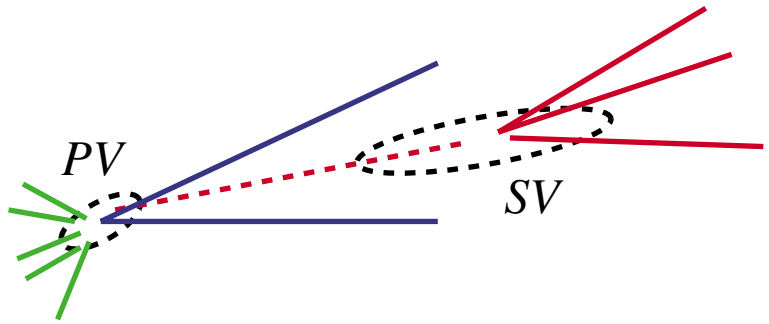
Determine Proper Time (i.e., B_S meson lifetime in its rest frame)

$$t = \frac{l\,m}{p} \qquad \sigma_t = \sqrt{\left(\frac{m}{p}\sigma_l\right)^2 + \left(t\,\frac{\sigma_p}{p}\right)^2}$$

Term diminished as B_S osc. << τ B_S

Two Ingredients

B_S Decay Length (l):
Distance from Primary to Seconary Vertex



- Primary Vertex independent of analysis
- Secondary Vertex dependent upon event selection (impact upon resolution)

typical σ_l = 250 μm

B_S Momentum (p)
Event Selection Dependent

- Fully Enclusive: sum of decay products
- Inclusive:
  - Jet momentum
  - Correct for p_ν in semileptonic (event energy-momentum cons.)

OSCILLATION FIT

Construct B_s Signal Likelihood:

for every candidate *i*: $$L_i = \sum_j^{N_{\text{comp}}} f_j^i \left[(1 - \eta_j^i) P_j^{unmix}(t_i) + \eta_j^i P_j^{mix}(t_i) \right]$$

j denotes signal and background components
- oscillating B_s
- oscillating B_d
- non-osc. b Hadrons
- udsc events

f_j^i : prob. of candidate *i* from *j* *(event-by-event purity)*

η_j^i : prob. of candidate *i* osc. if from *j* *(event-by-event initial and final state tag)*

p.d.f. of decay proper time for unmixed/mixed candidates in component *j* with experimental effects (e.g., σ_l, σ_p)

Elements of the Likelihood are evaluated event-by-event

THE AMPLITUDE METHOD

Introduce an Amplitude A into probabilities:

$$P^{\text{mix}}_{\text{unmix}}(t) = \Gamma_s \frac{e^{-\Gamma_s t}}{2}[1 \mp \cos(\Delta m_s t)] \quad \rightarrow \quad \Gamma_s \frac{e^{-\Gamma_s t}}{2}[1 \mp A\cos(\omega t)]$$

Maximize Likelihood with respect to Amplitude A for a given test frequency ω

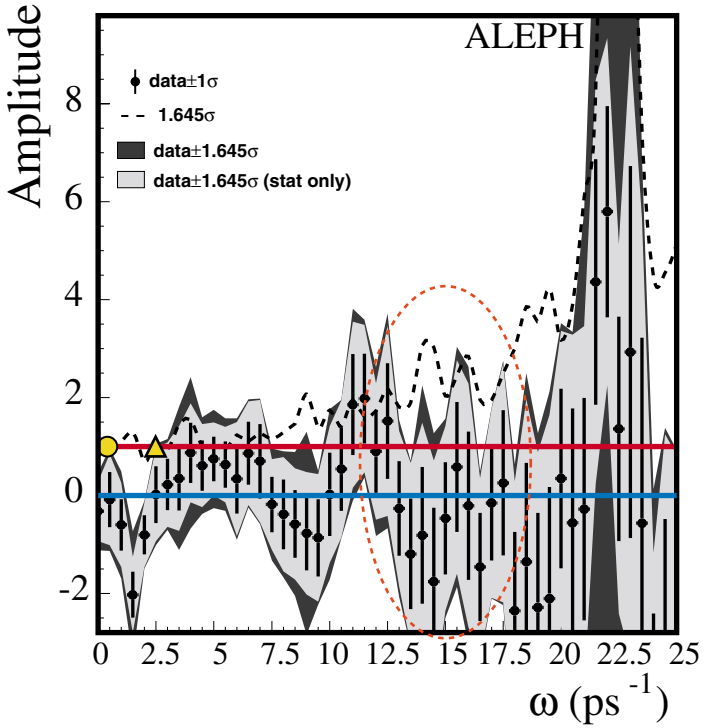
Permits combination of different analyses/experiments results

$A = 0$ for $\omega << \Delta m_s$ $A = 1$ for $\omega = \Delta m_s$	ω excluded at 95% C.L. if $A + 1.645\sigma_A < 1$

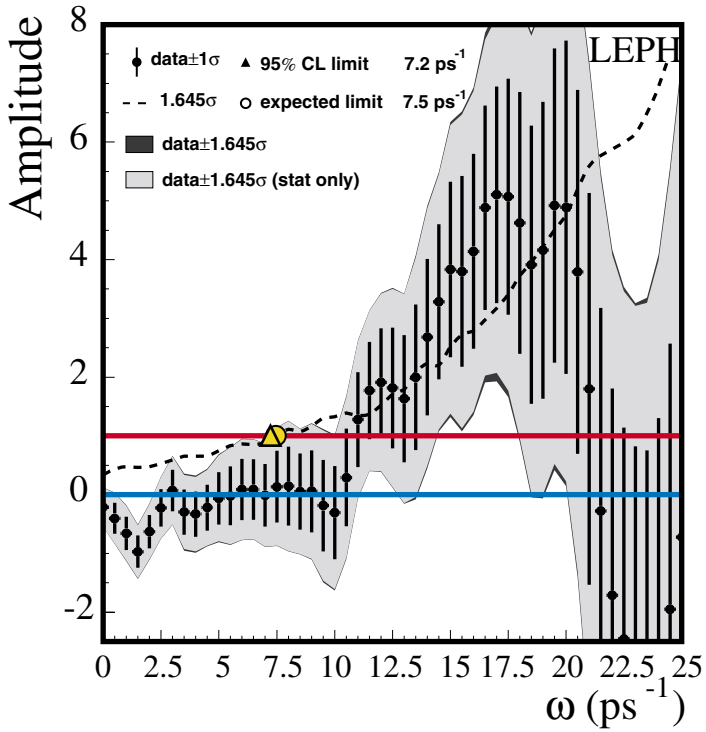
Analysis Sensitivity: expected limit at 95% C.L.

RESULTS OF THE THREE NEW ALEPH ANALYSES

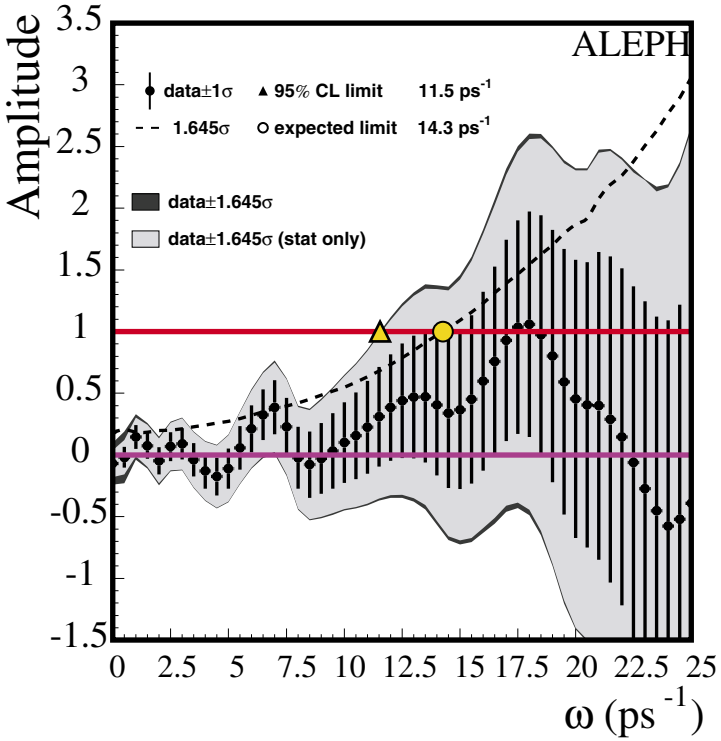
Fully Exclusive



Semi-Exclusive (D_s lepton)



Semi-Inclusive (lepton)



Δm_s Observed (Expected) Lower Limits at 95% C.L.

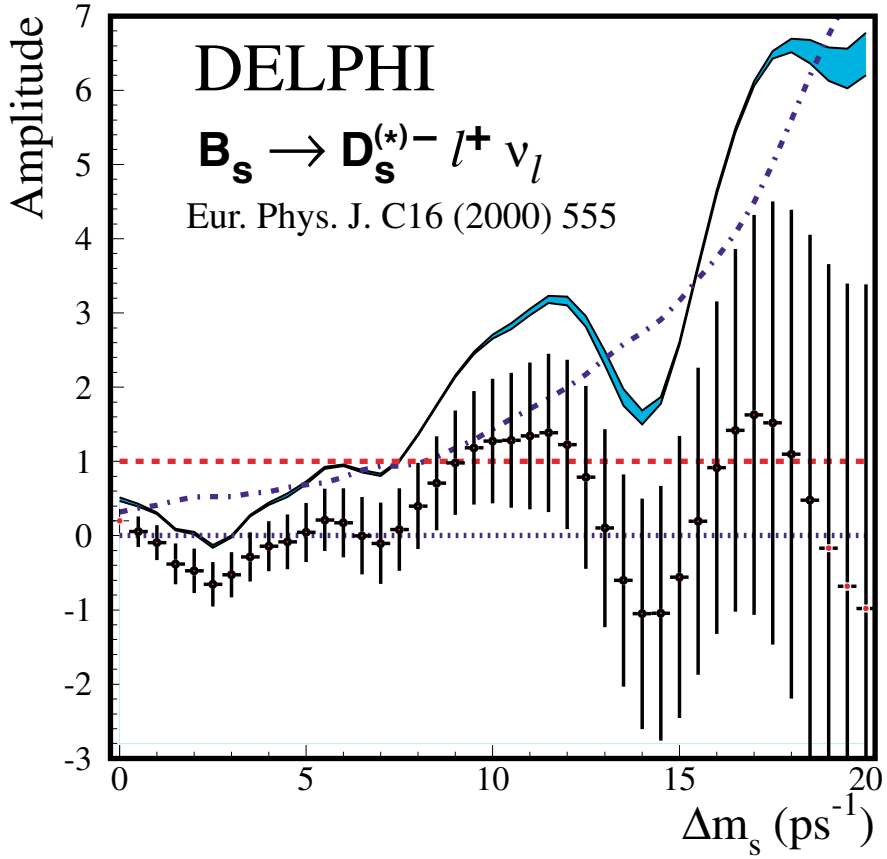
$\Delta m_s > 2.4\ ps^{-1}$ ($0.3\ ps^{-1}$)
NEW!

$\Delta m_s > 7.2\ ps^{-1}$ ($7.4\ ps^{-1}$)
(was $7.2\ ps^{-1}$ ($6.6\ ps^{-1}$))

$\Delta m_s > 11.4\ ps^{-1}$ ($14.0\ ps^{-1}$)
(was $9.5\ ps^{-1}$ ($9.8\ ps^{-1}$))

COMBINATION OF THREE ALEPH ANALYSES
$\Delta m_s > 10.9\ ps^{-1}$ ($15.7\ ps^{-1}$)

DELPHI AND OPAL RESULTS



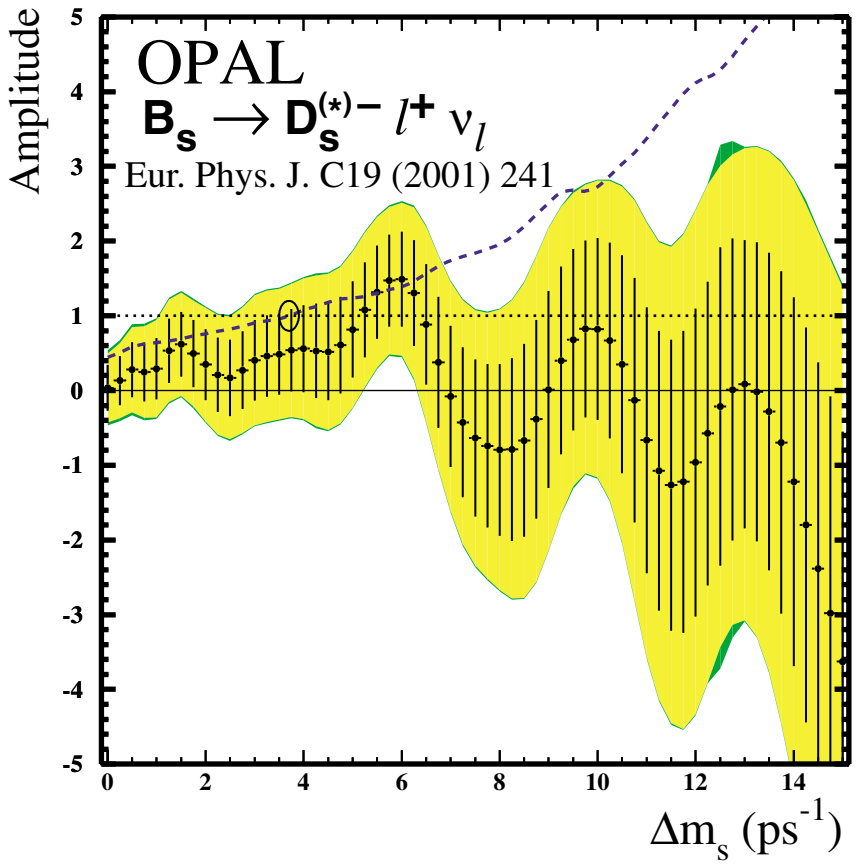
$\Delta m_s > 7.4\ ps^{-1}$ $(8.1\ ps^{-1})$

also

Fully and Semi-Exclusive: $\Delta m_s > 4.0\ ps^{-1}$ $(3.2\ ps^{-1})$

Semi-Inclusive: $\Delta m_s > 7.3\ ps^{-1}$ $(10.6\ ps^{-1})$

Fully Inclusive: $\Delta m_s > 1.1\ ps^{-1}$ $(6.1\ ps^{-1})$



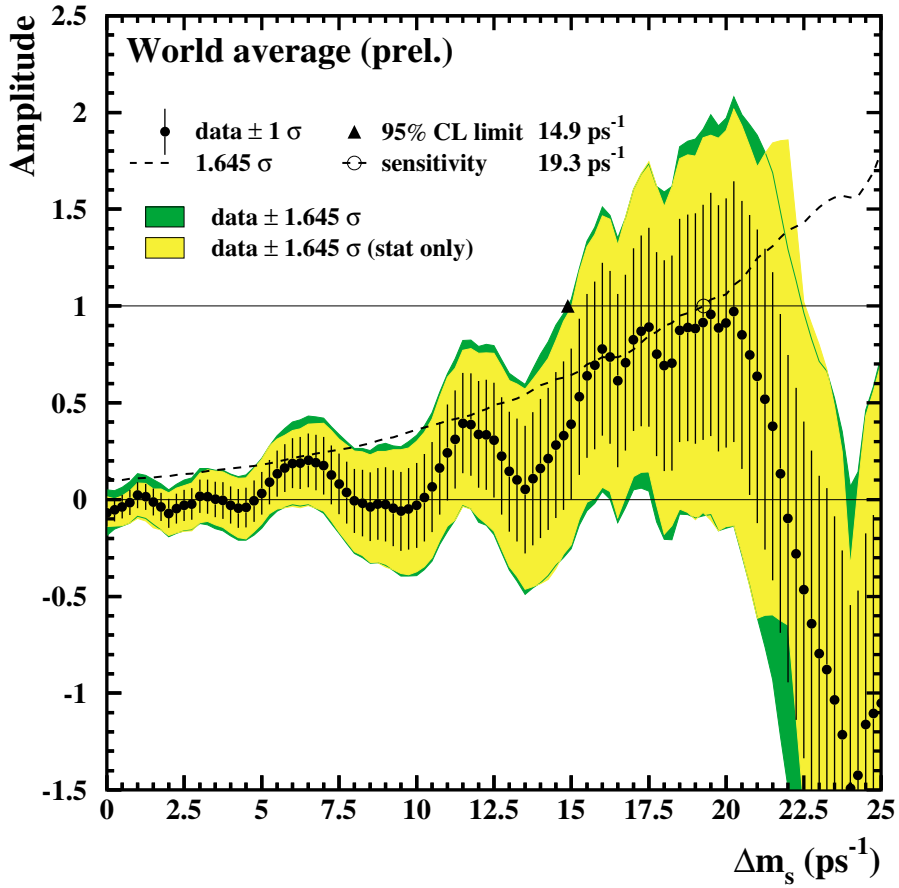
$\Delta m_s > 1.0\ ps^{-1}$ $(4.1\ ps^{-1})$

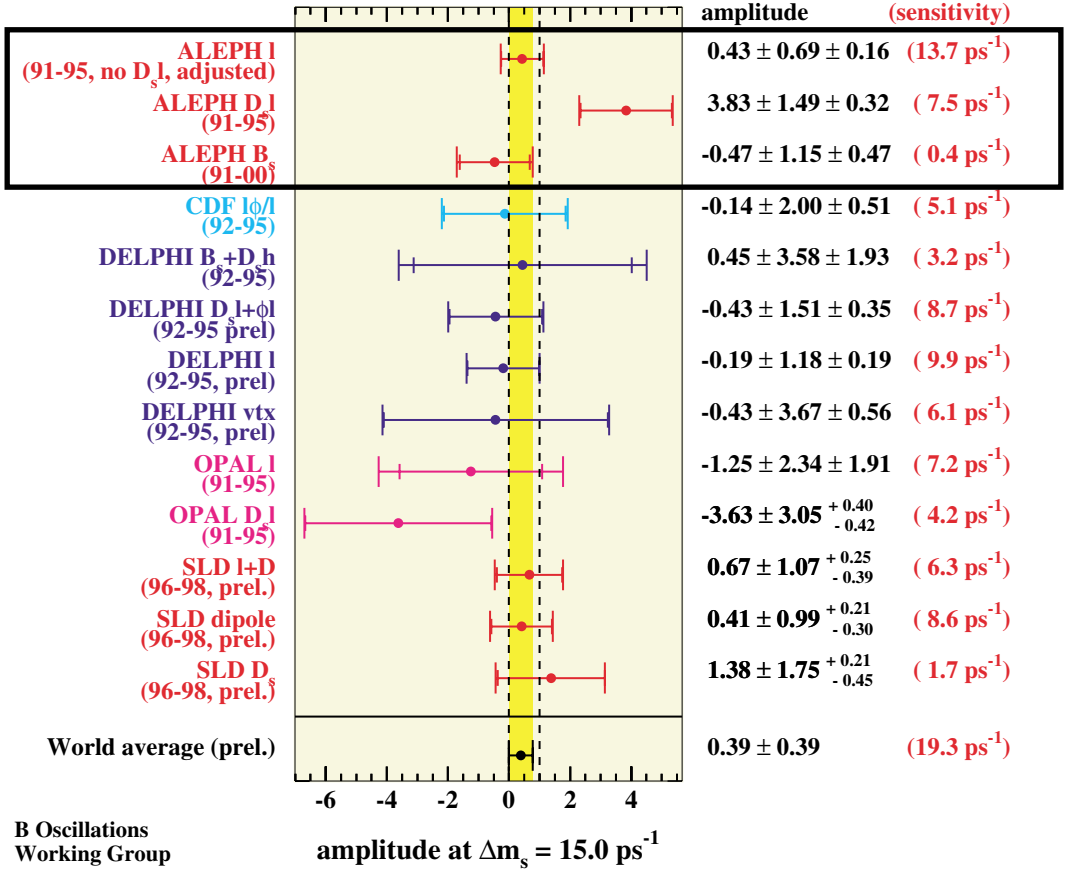
also

Semi-Inclusive: $\Delta m_s > 5.1\ ps^{-1}$ $(6.7\ ps^{-1})$

WORLD COMBINATION

Combine LEP (new ALEPH, DELPHI, OPAL) with CDF and SLD





$\Delta m_s > 14.9\ ps^{-1}$ ($19.3\ ps^{-1}$) *at 95% C.L.*

No measurement, but data are consistent with signal expectation around $\Delta m_s = 16$ *to* $18\ ps^{-1}$

CONCLUSIONS

- No observation of B_S mixing
- B_S mixing analyses continue to improve
  - New/Improved ALEPH results (2002)
- Lower Limit of $\Delta m_S > 14.9\ \text{ps}^{-1}$
  - far below sensitivity of $19.3\ \text{ps}^{-1}$
- Possibile hint of signal between $16 - 18\ \text{ps}^{-1}$
- Look forward to new results from CDF and DØ