New results in heavy flavour physics from LEP

Andrea Sciabà

INFN - CNAF

XXXVII Rencontres de Moriond
Electroweak Interactions
And Unified Theories
9-16 March 2002

- **HF results at LEP: summary**
- **B_s oscillations (ALEPH)** **(CERN-EP-2002-016)**
- **A^b_{FB} (ALEPH) (see talk of V. Ciulli)**

Heavy Flavours at LEP

- **Main goal: measure V_{ij}**
- **V_{cb}:**
  - **Inclusive BR($b \to l^- \bar{\nu} X_c$) b lifetimes**

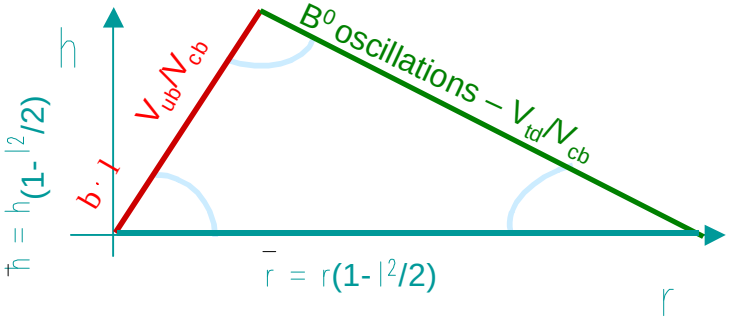
$$\Gamma_{sl}(b \to X_c l \nu) = \frac{BR(b \to X_c l \nu)}{\tau_b} \propto |V_{cb}|^2$$

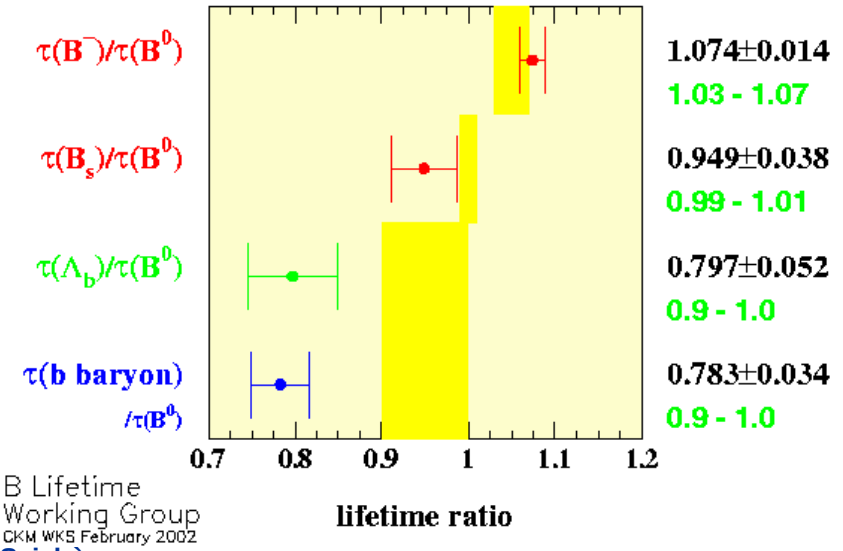
$$|V_{cb}|^{incl} = (40.9 \pm 0.5_{exp} \pm 2.4_{theo}) \cdot 10^{-3}$$

  - **$B_d \to D^* l \nu$ decays**

$$|V_{cb}|^{excl} = (40.5 \pm 1.9_{exp} \pm 2.3_{theo}) \cdot 10^{-3}$$

  - **Theoretical error dominates**





Andrea Sciabà
INFN-CNAF

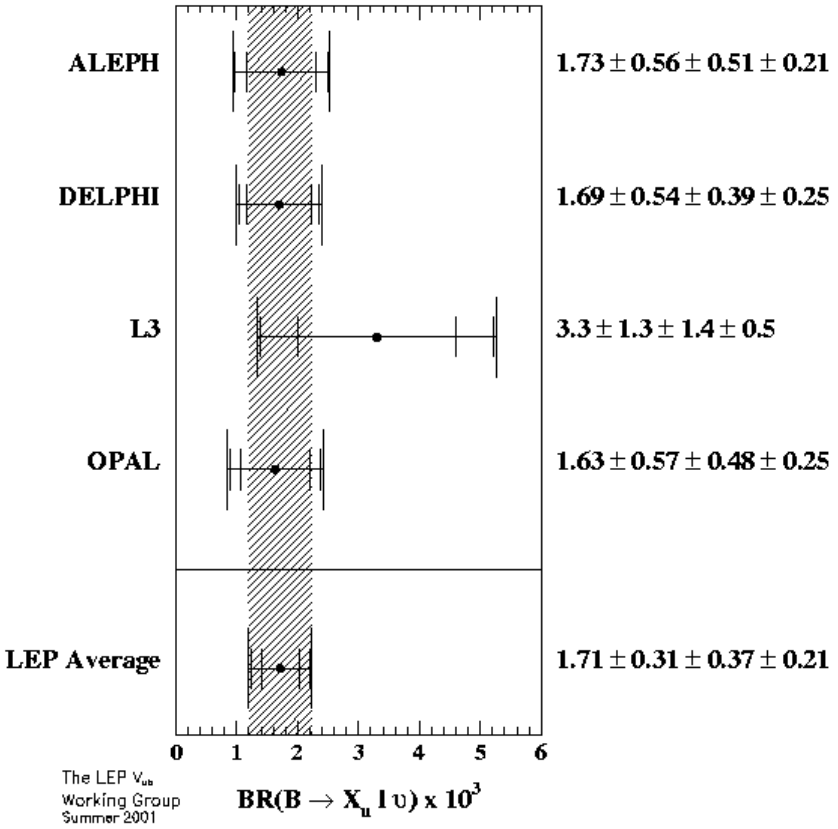
Heavy Flavours at LEP

- V_{ub}
  - b . u / b . c discrimination

    $|V_{ub}| = (4.09 \pm 0.65)\ 10^{-3}$

  - Experimental error dominates

- V_{td}
  - B_s-B^0 oscillation measurement



Andrea Sciabà
INFN-CNAF

B_s oscillations: Basic concepts

- **Main motivation:**

. 15% theor. error

$$\Delta m_q \propto |V_{tq} V_{tb}^*|^2 M_{B_q} B_{B_q} f_{B_q}^2$$

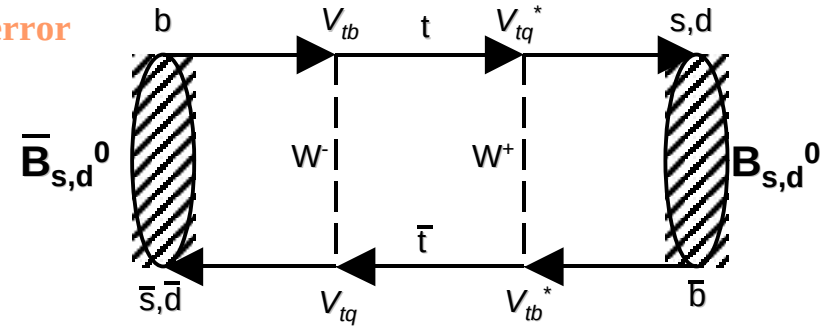
. m_d . $|V_{td}|$ gives a large error

. $|V_{cb}|^2$

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \left| \frac{V_{ts}}{V_{td}} \right|^2 \xi_s^2$$

SU(3) ~ 5% error

. m_d / . m_s . $|V_{td}|$ with a 3 times better theoretical error!



- **Need to measure:**
  - **Decay proper time**
  - **Flavour state at production**
  - **Flavour state at decay**

- **Oscillation probability:**

$$P(t)_{B_s^0 \to \bar{B}_s^0} = \frac{1}{2\tau_s} e^{-\frac{t}{\tau_s}} \left[1 - A \cos(\Delta m_s t) \right]$$

Andrea Sciabà
INFN-CNAF

Amplitude method

- **The amplitude of the oscillation term is fitted for any assumed value . of the oscillation frequency**
  - $. << \Delta m_s \Rightarrow A \to 0$
  - $w @ \Delta m_s \Rightarrow A \to 1$
- **Easy to combine analyses**
- **95% CL limit:** $A(w) + 1.645 \hat{I} \sigma_A(w) = 1$
- **Sensitivity:** $1.645 \hat{I} \sigma_A(w) = 1$

$$S = \frac{1}{\sigma_A} \sim \sqrt{N} f_{B_s} (1 - 2\eta) \exp\left[-\frac{1}{2}(w\sigma_t)^2\right]$$

$$\sigma_t = \sqrt{\left(\frac{\sigma_{m_\ell}}{p}\right)^2 + t^2 \left(\frac{\sigma_p}{p}\right)^2}$$

ALEPH analyses

- **Reprocessed LEP1 data using better tracking and particle identification**
- **Fully reconstructed B_s (NEW!)**

$B_s^0 \to D_s^{(*)-} a_1^+$

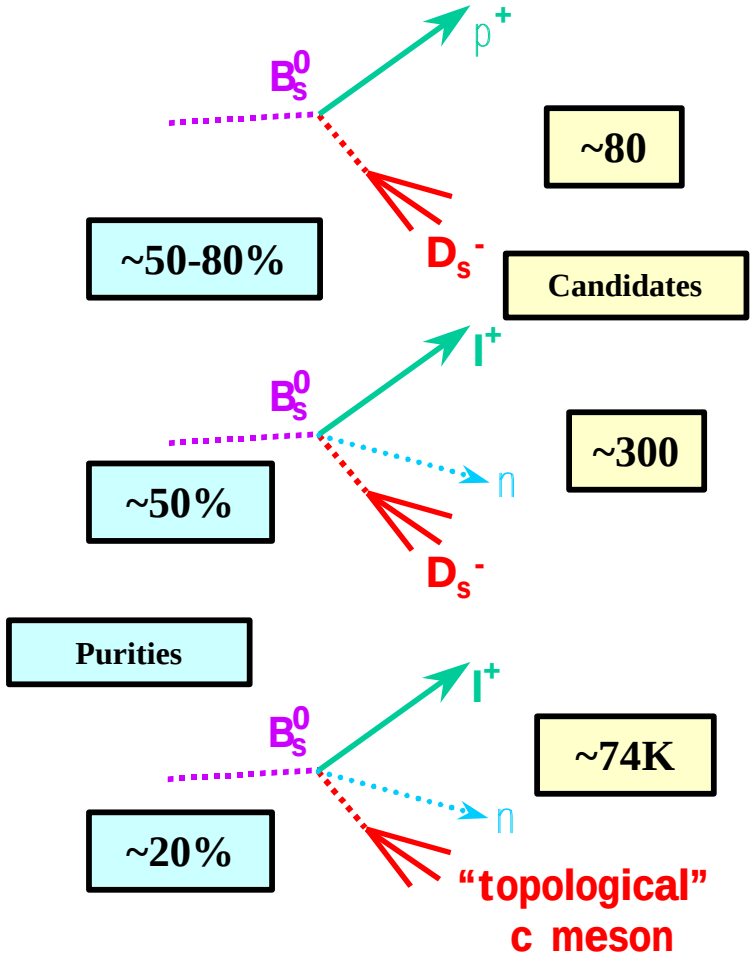
$B_s^0 \to D_s^{(*)-} p^+$

- **$D_s^+ \ell^-$ pairs**

$B_s^0 \to D_s^- \ell^+ \nu_\ell X$

- **Inclusive semileptonic**

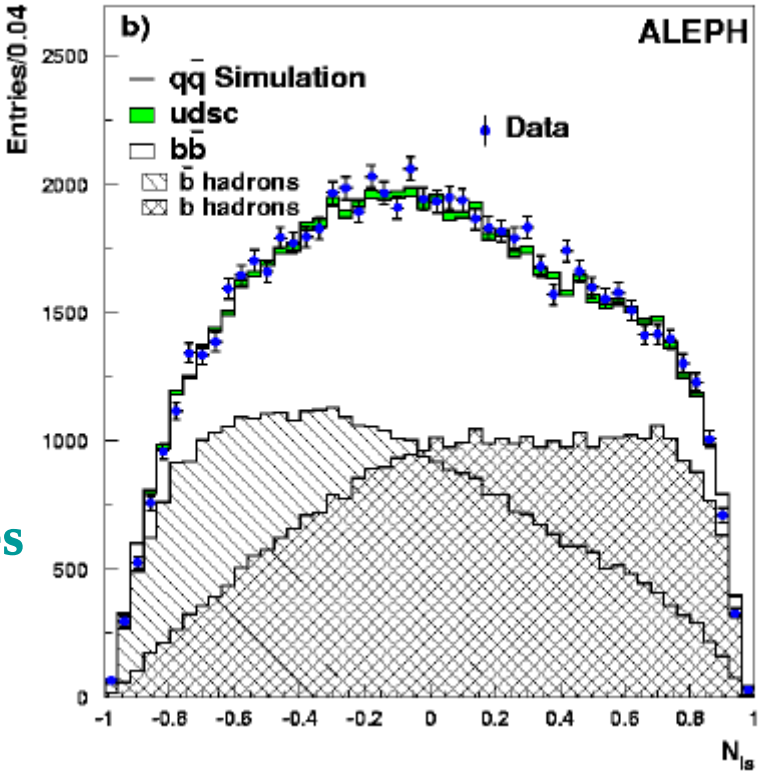
$B_s^0 \to$ "D" $\ell^+ X$



Andrea Sciabà
INFN-CNAF

Initial state tag in ALEPH

- **Opposite side info**
  - Jet and vertex charges
  - Lepton charge
  - “fast” kaon charge (b . c . s)
- **Same side info**
  - Charge of fragmentation kaon
  - Total charge of fragmentation particles
- **Additional variables**
  - cos $_{Bs}$ (because of A^{b}_{FB}!)
- **Mistag ~ 23%**



Neural network output

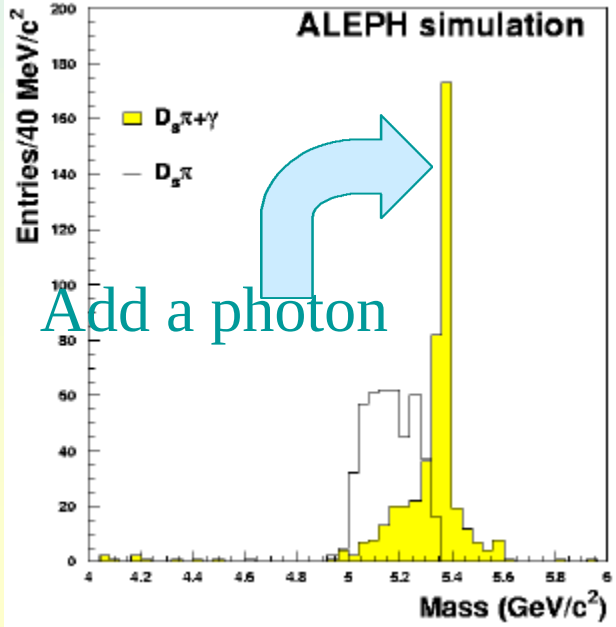
Fully reconstructed B_s (new!)

$B_s^0 \to \bar{D}_s^{(*)-} p^+$, $\bar{D}_s^{(*)-} a_1^+$, $\bar{D}_s^{(*)-} r^+$

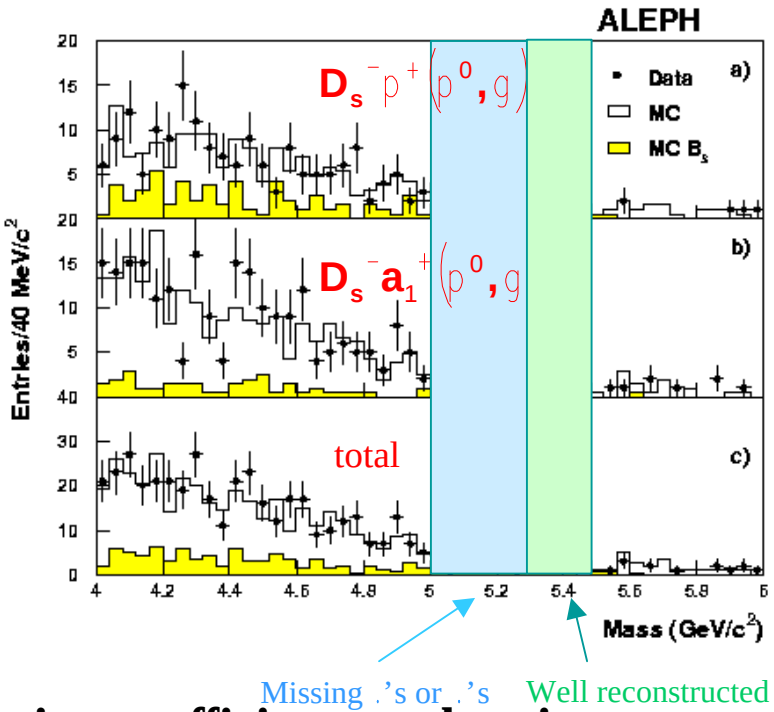
$D_s^{*-} \to D_s^- g$

$D_s^- \to \phi p^-$, $\bar{K}^{*0} K^-$, $K_S^0 K^-$

$a_1^+ \to r^0 p^+$ $r^0 \to p^+ p^-$ $r^+ \to p^+ p^0$



Add a photon



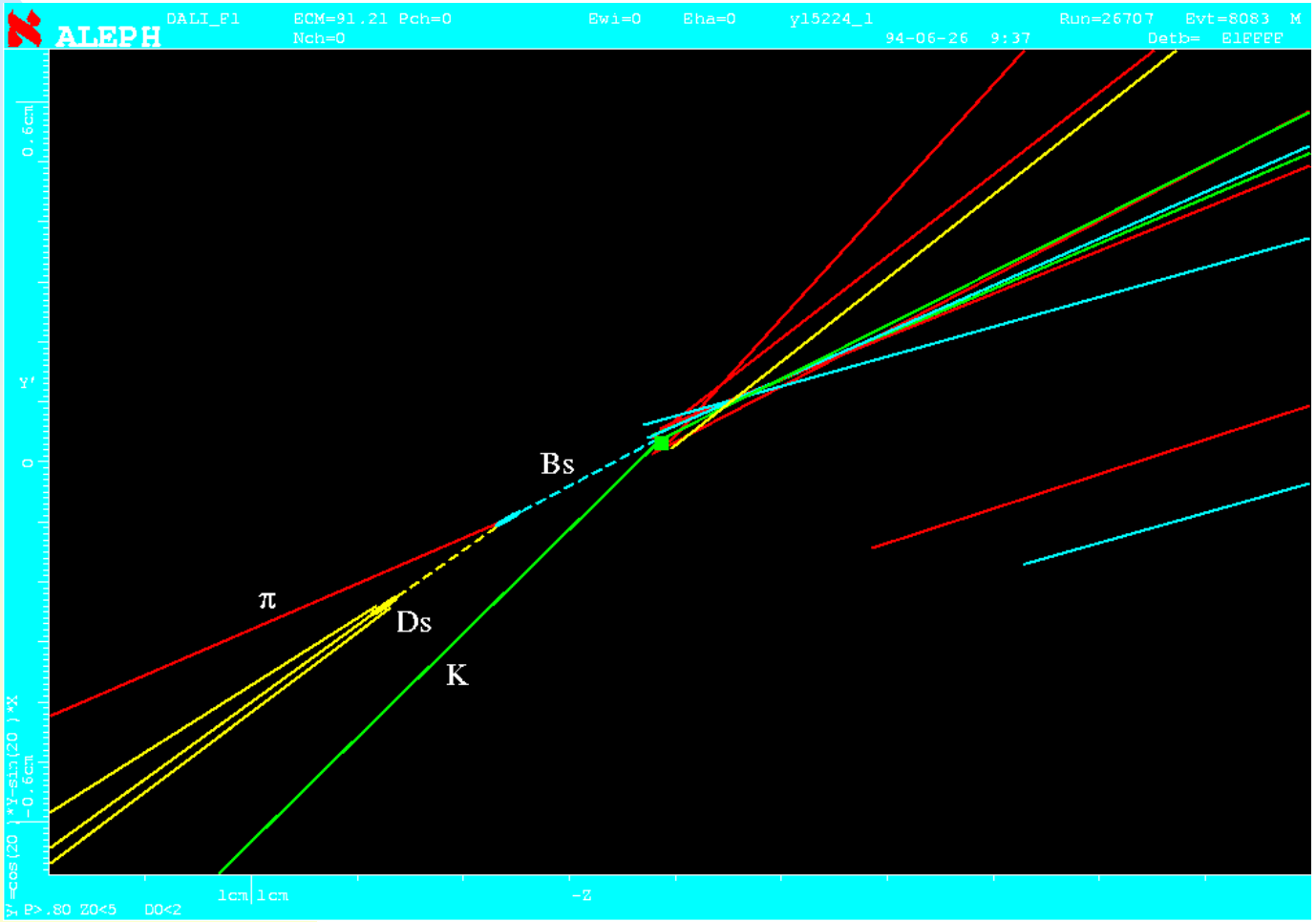
- γ and π^0 reconstruction $\rightarrow$ **efficiency and purity increase**
- ℓ $\rightarrow$ 180 μm
- p/p $\rightarrow$ 0.5 – 3 %

σ_t 0.08 ps

Excellent proper time resolution!

Andrea Sciabà
INFN-CNAF

A fully reconstructed B_s decay



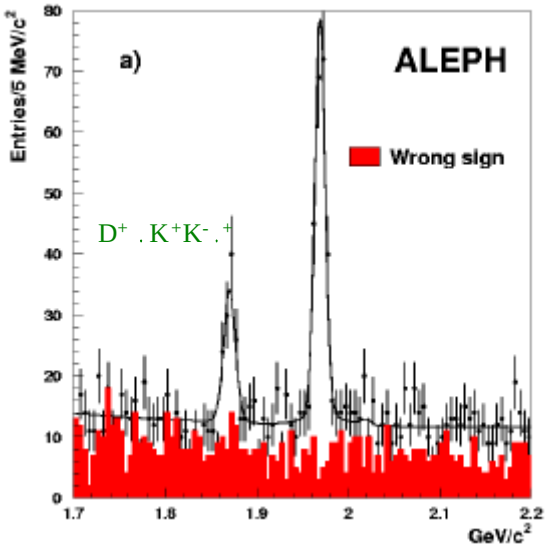
Andrea Sciabà
INFN-CNAF

$D_s^+ \ell^-$ pairs

$\bar{B}_s^0 \to D_s^+ \ell^- \bar{\nu}_\ell X$

$D_s^+ \to \phi\pi^+$
$D_s^+ \to \bar{K}^{*0}K^+$
$D_s^+ \to K_S^0 K^+$
$D_s^+ \to \phi\pi^+\pi^+\pi^-$
$D_s^+ \to \phi\pi^+\pi^0$
$D_s^+ \to \bar{K}^{*0}\bar{K}^+$

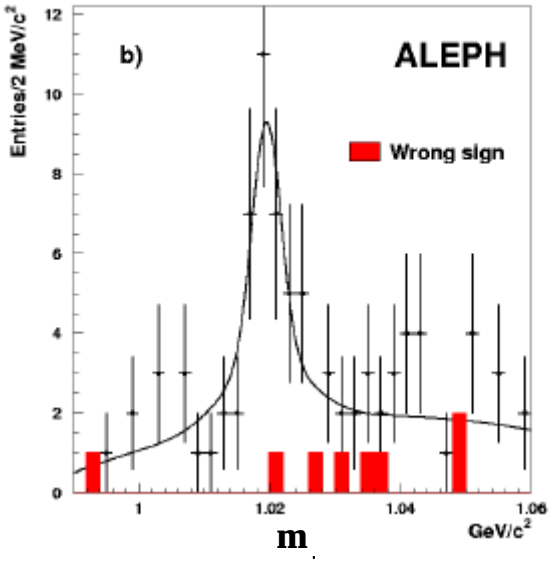
Hadronic modes



m_{Ds}

$D_s^+ \to \phi e^+ \nu$; $\phi \to K^+K^-$
$D_s^+ \to \phi\mu^+\nu$; $\phi \to K^+K^-$

Semileptonic modes



m

- **Decay length error** σ_l **240 m**
- **Boost relative error 11 %**

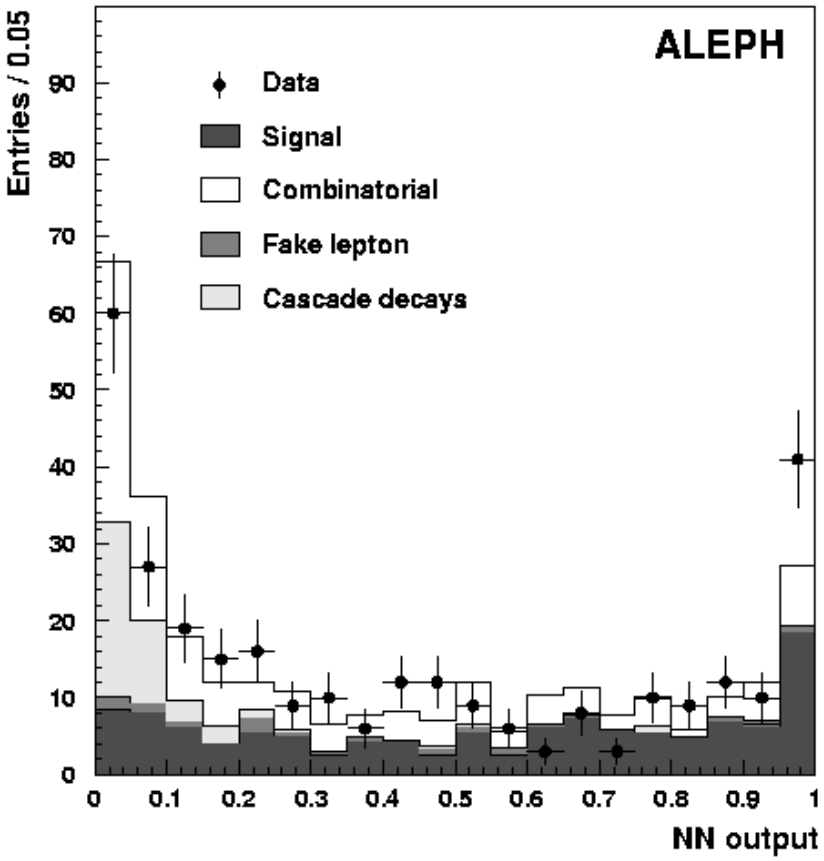
$D_s^+ \ell^-$ sample purity

- **Cascade decays like**

  $b \rightarrow D_s^{\pm} DX$

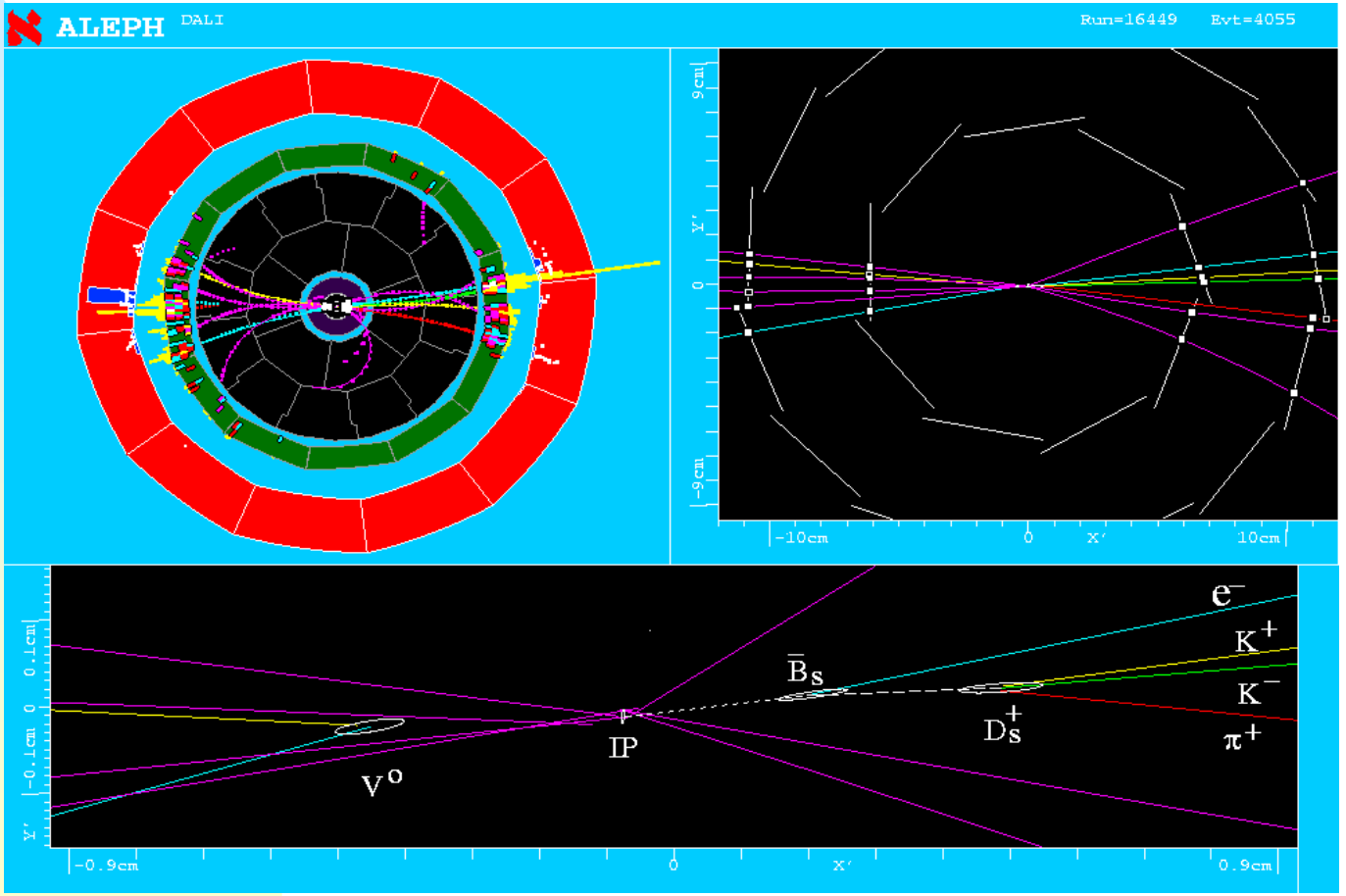
  $\hookrightarrow \ell^{\mp} X$

  discriminated using NN
  - **lepton p and p$_t$**
  - **B_s momentum**
  - **D_s-ℓ invariant mass**
  - **vertex topology**



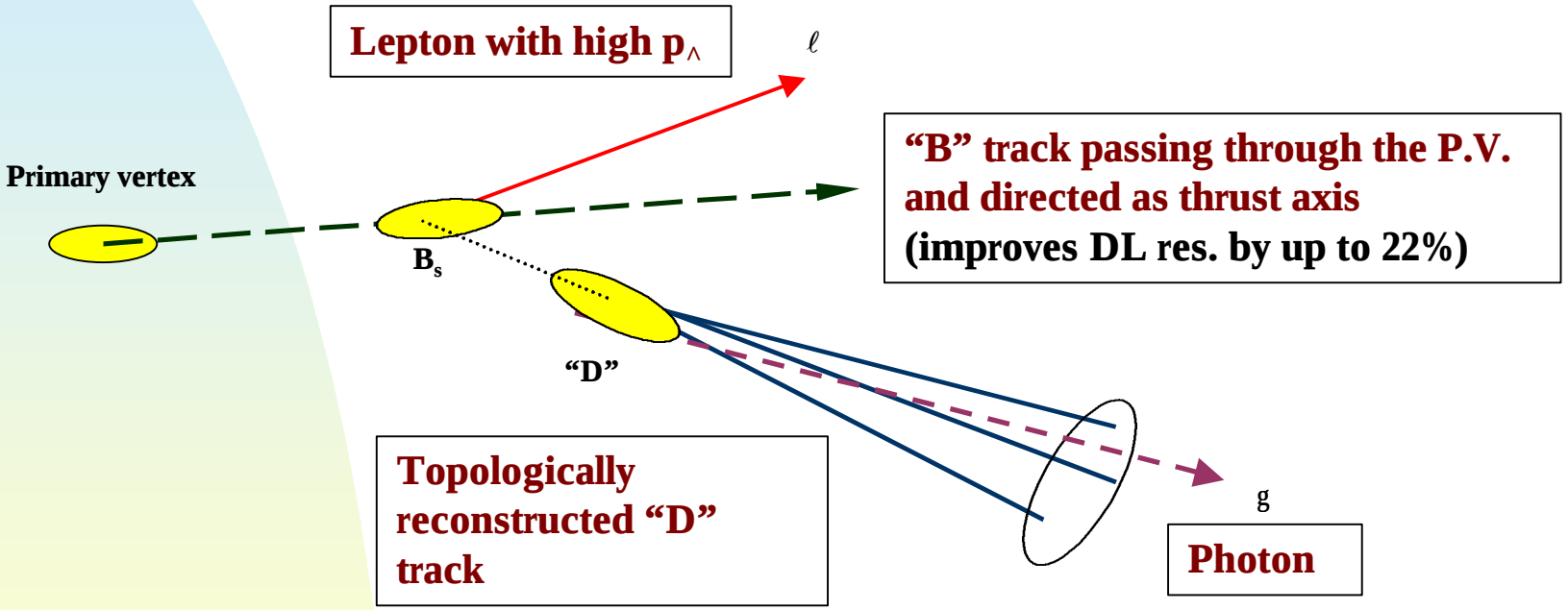
Andrea Sciabà
INFN-CNAF

A D_s-ℓ candidate



Andrea Sciabà
INFN-CNAF

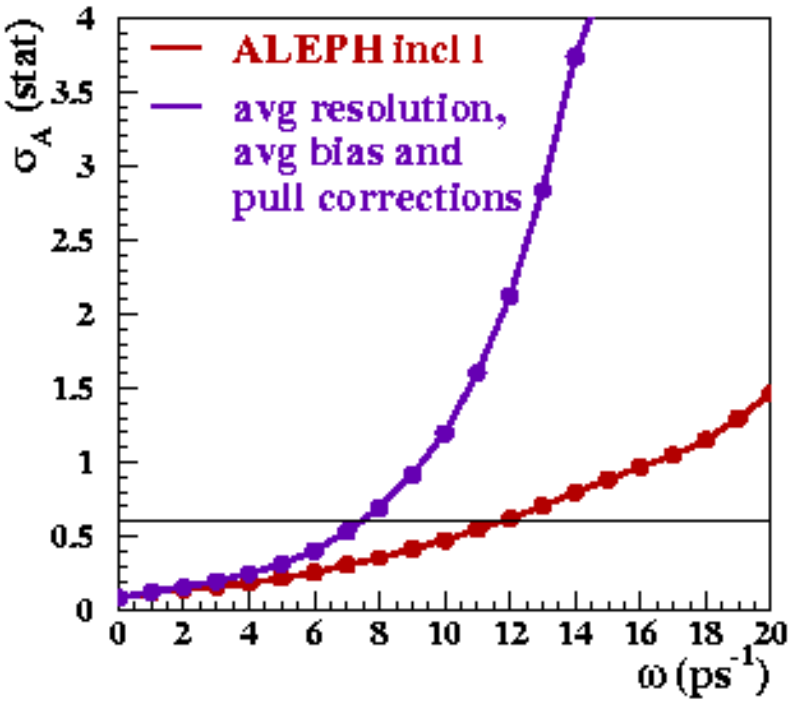
Inclusive semileptonic decays



Andrea Sciabà
INFN-CNAF

Main improvements

- **Increased statistics (~2.2 times)**
- **New vertexing algorithm**
  - s_{DL}~350 mm
- **Topological classification of events (vertex classes)**
- **Initial and final state tag**
- **event-by-event determination of purity, biases, errors…**
  Þ **huge sensitivity enhancement!**

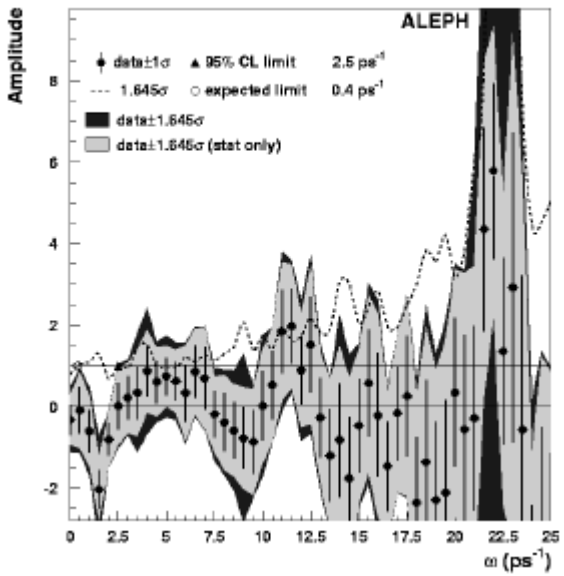


Andrea Sciabà
INFN-CNAF

Amplitude plots

Fully reconstructed B_s

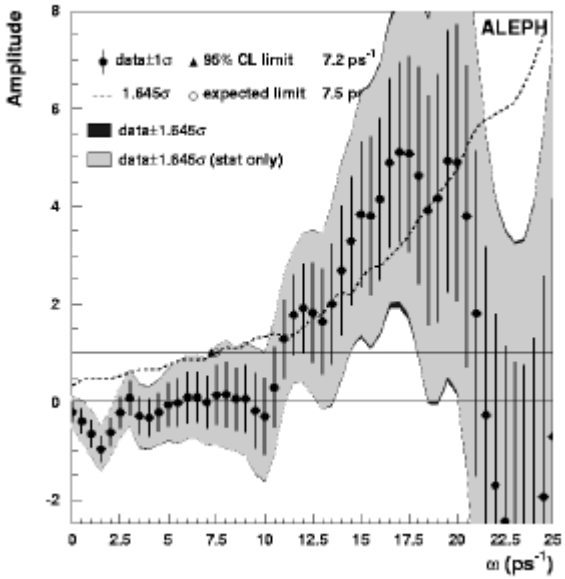
Sensitivity = 0.4 ps^{-1}
95% CL limit: 2.5 ps^{-1}



Relatively small amplitude uncertainty at high frequencies

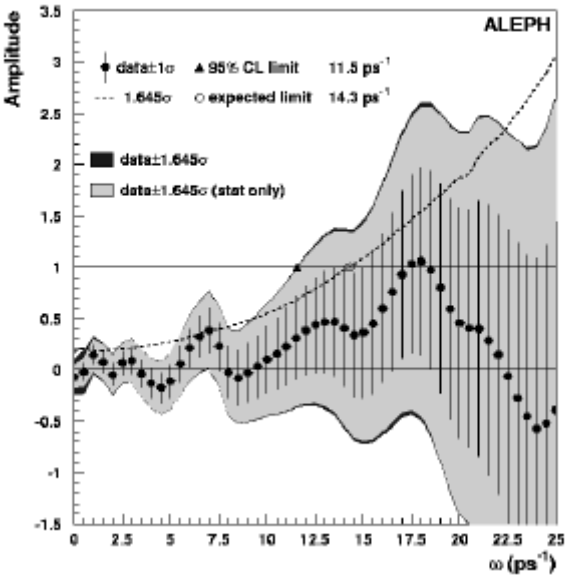
D_s-ℓ pairs

Sensitivity = 7.5 ps^{-1}
95% CL limit: 7.2 ps^{-1}



Inclusive leptons

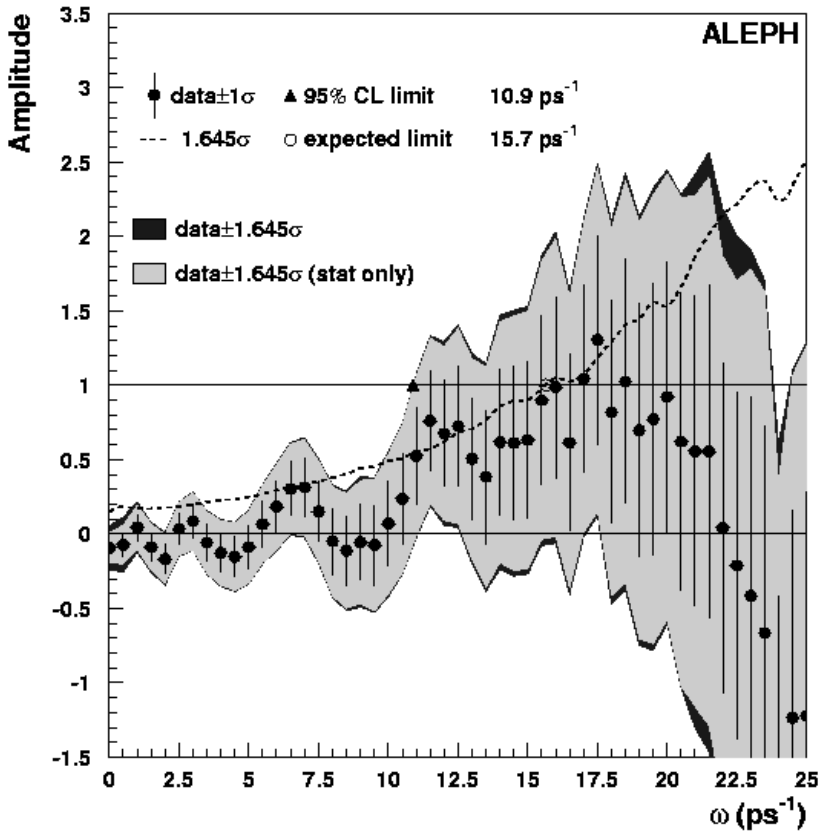
Sensitivity = 11.5 ps^{-1}
95% CL limit: 14.3 ps^{-1}



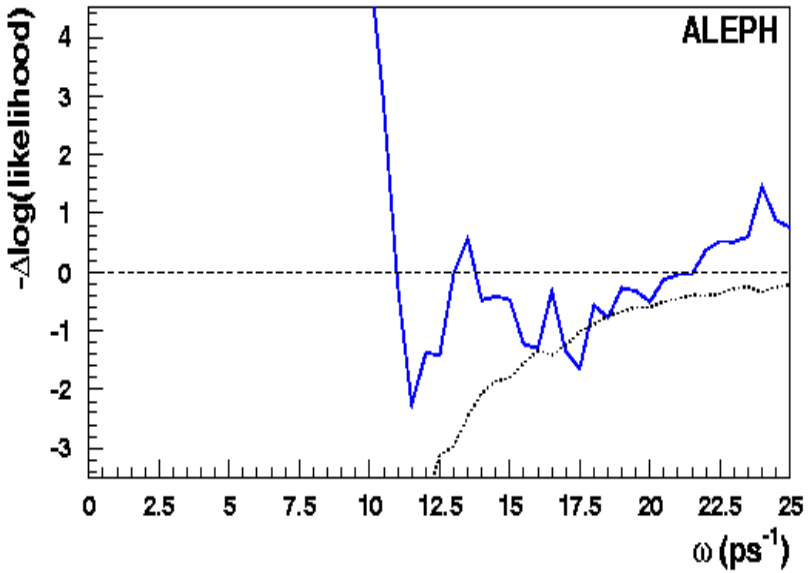
HUGE improvement in amplitude error

Andrea Sciabà
INFN-CNAF

ALEPH combined results



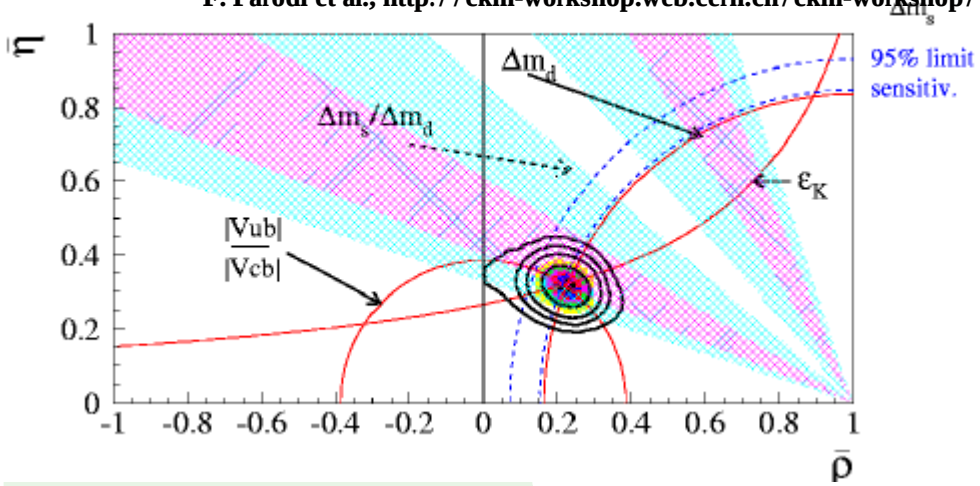
- **Improvement w.r.t. previous published results:**
  - **sensitivity: 10.6 ® 15.7 ps^{-1}**
  - **95% C.L. limit: 9.6 ® 10.9 ps^{-1}**

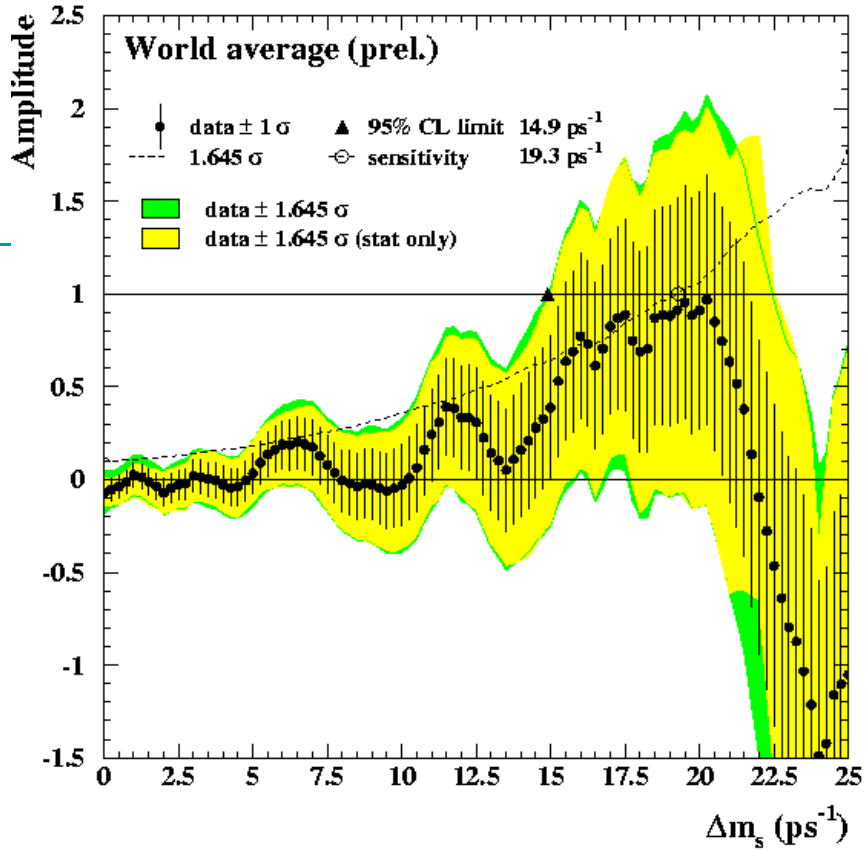


Andrea Sciabà
INFN-CNAF

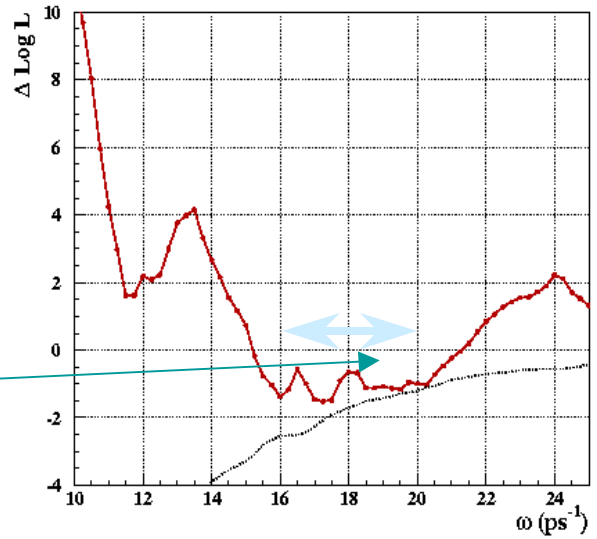
New world combination

F. Parodi et al., http://ckm-workshop.web.cern.ch/ckm-workshop/





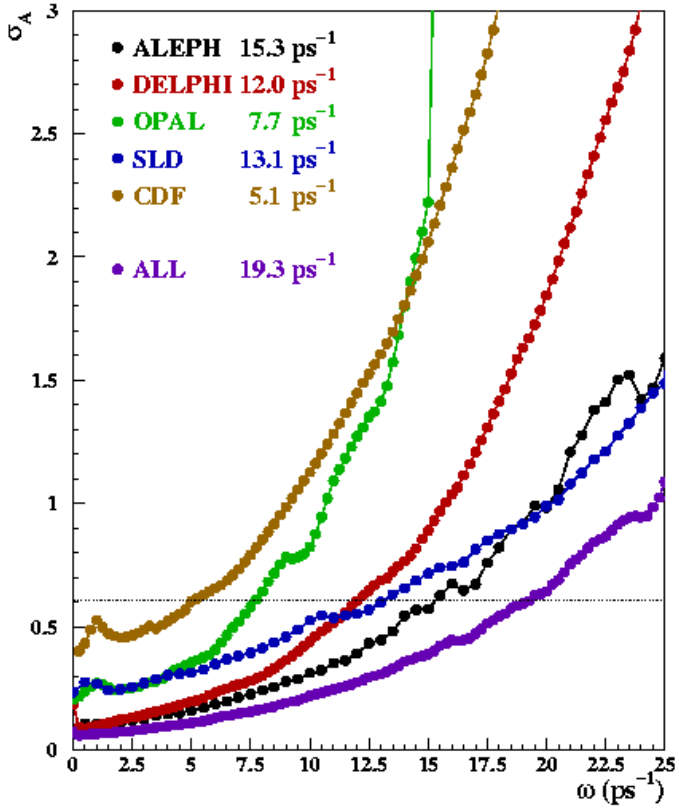
- **Indirect Δm_s estimate:** $(17.8^{+3.2}_{-2.8})\ ps^{-1}$
- **Δm_s estimate from $\Delta G_s/G$:** $(16^{+8}_{-9} \pm 5)\ ps^{-1}$
- **Δm_s 95% CL:** $14.9\ ps^{-1}$
- **Weak indication of a minimum**



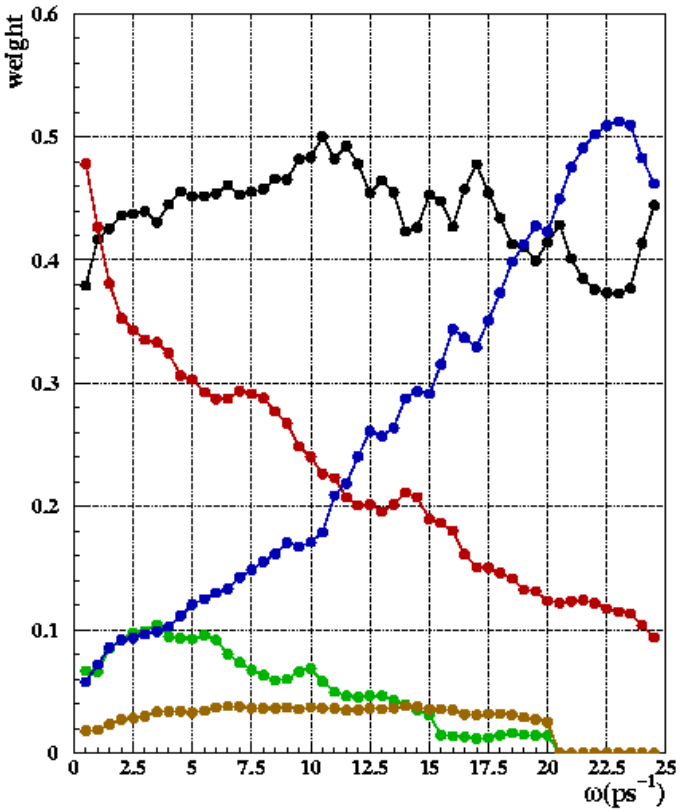
Andrea Sciabà
INFN-CNAF

World combination details

Sensitivities



Weights



Andrea Sciabà
INFN-CNAF

Conclusions

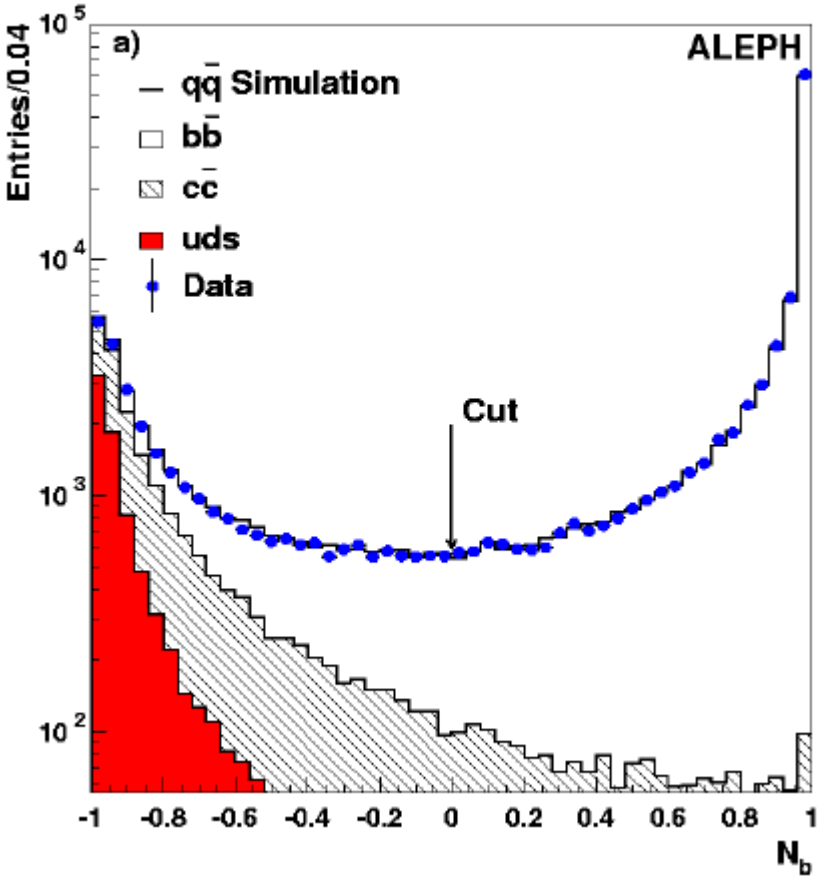
- **<u>Final</u> ALEPH results on B_s oscillations**
  - Substantial improvement over previous results
- **LEP sensitivity limit on Δm_s almost reached (waiting for DELPHI results); since Budapest**
  - sensitivity: 18.3 ps^{-1} $\rightarrow$ 19.3 ps^{-1}
  - 95% CL limit: 14.6 ps^{-1} $\rightarrow$ 14.9 ps^{-1}

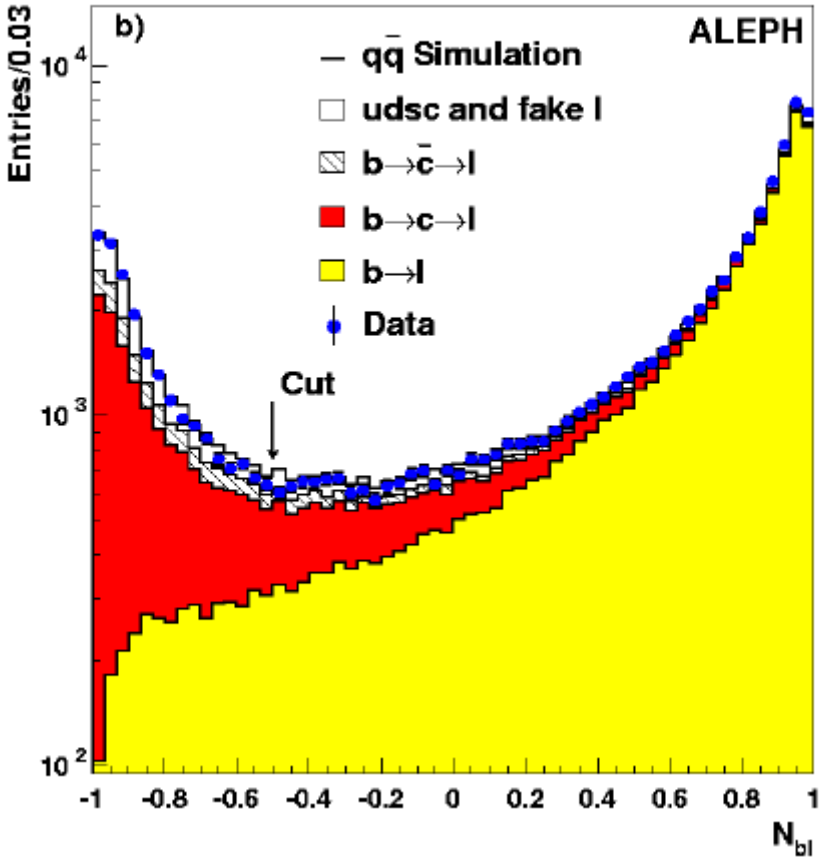
Andrea Sciabà
INFN-CNAF

Sample composition (I)

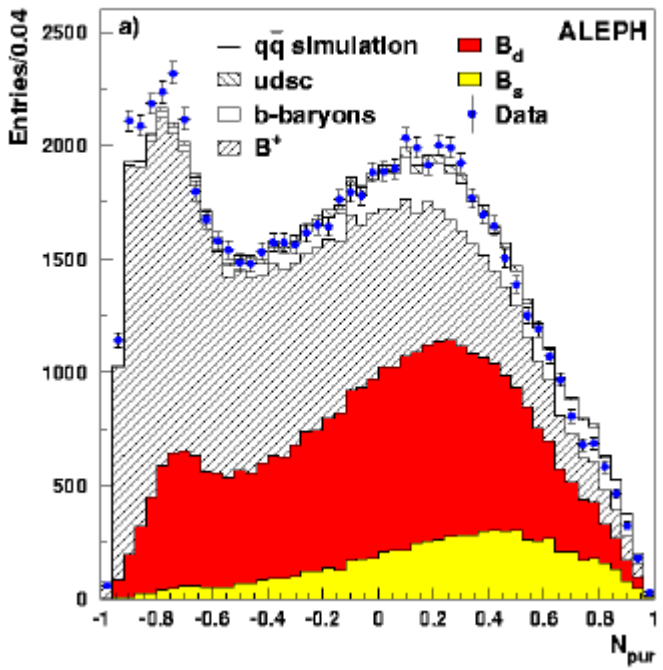
Z ® bb selection: NN
lifetime-mass b-tag, lepton properties

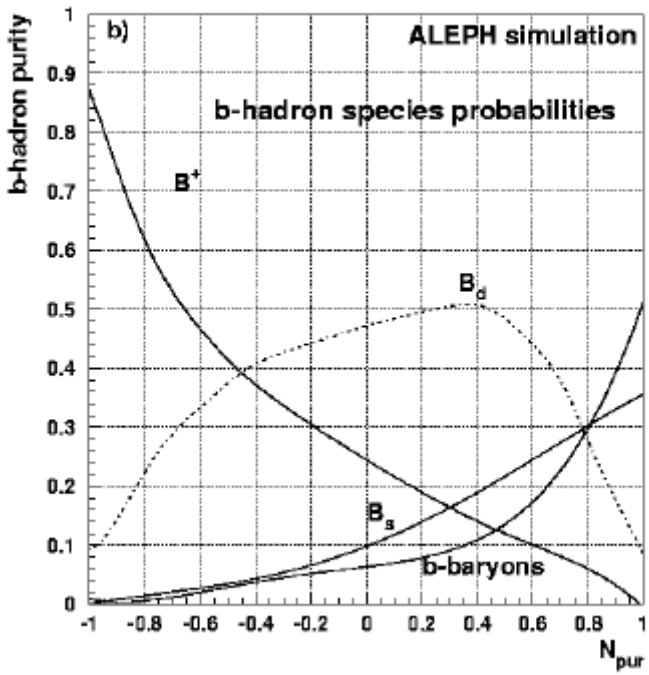
b ® ℓ selection w.r.t b ® c ® ℓ:
lepton properties (p, $p_\wedge$)
neutrino energy
lepton i.p. w.r.t the "D" vertex





Sample composition (II)





- **charged-neutral b-hadron discrimination:**
  charge and charged multiplicity of the "D" vertex

- **B_s- B_d discrimination:**
  kaons from fragmentation and from B_s decays

Andrea Sciabà
INFN-CNAF

Proper time measurement

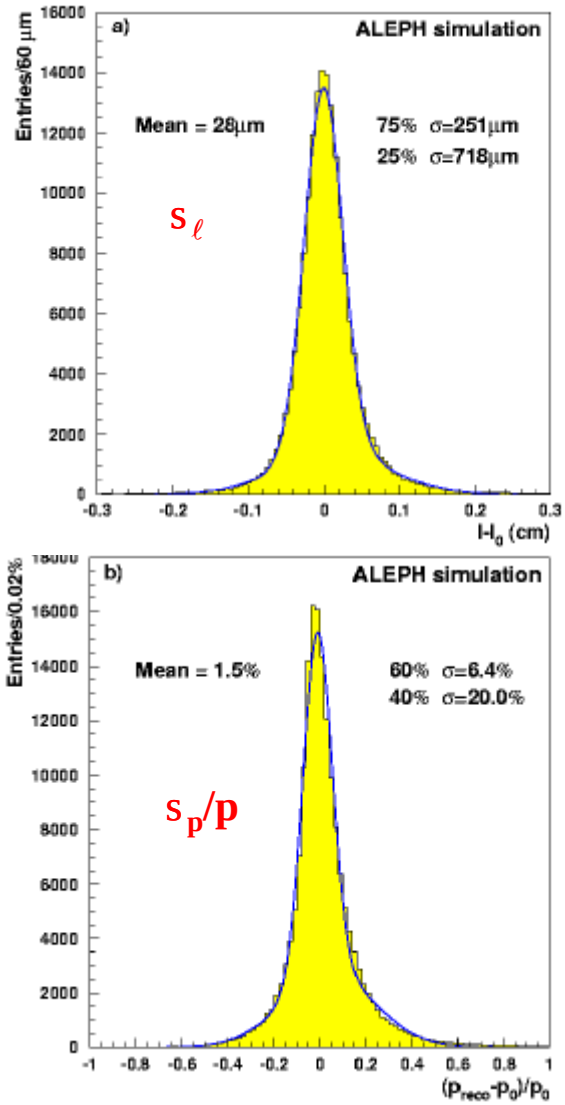
- **Decay length from the vertex fit**
  - **bias corr. function of decay length**
  - **error corr. function of decay length, "D" mass**
- **Boost**

$$P_{B_s} = \sqrt{(E_D + E_\ell + E_\nu)^2 - m^2}$$

E_D = energy of a jet clustered around "D" particles

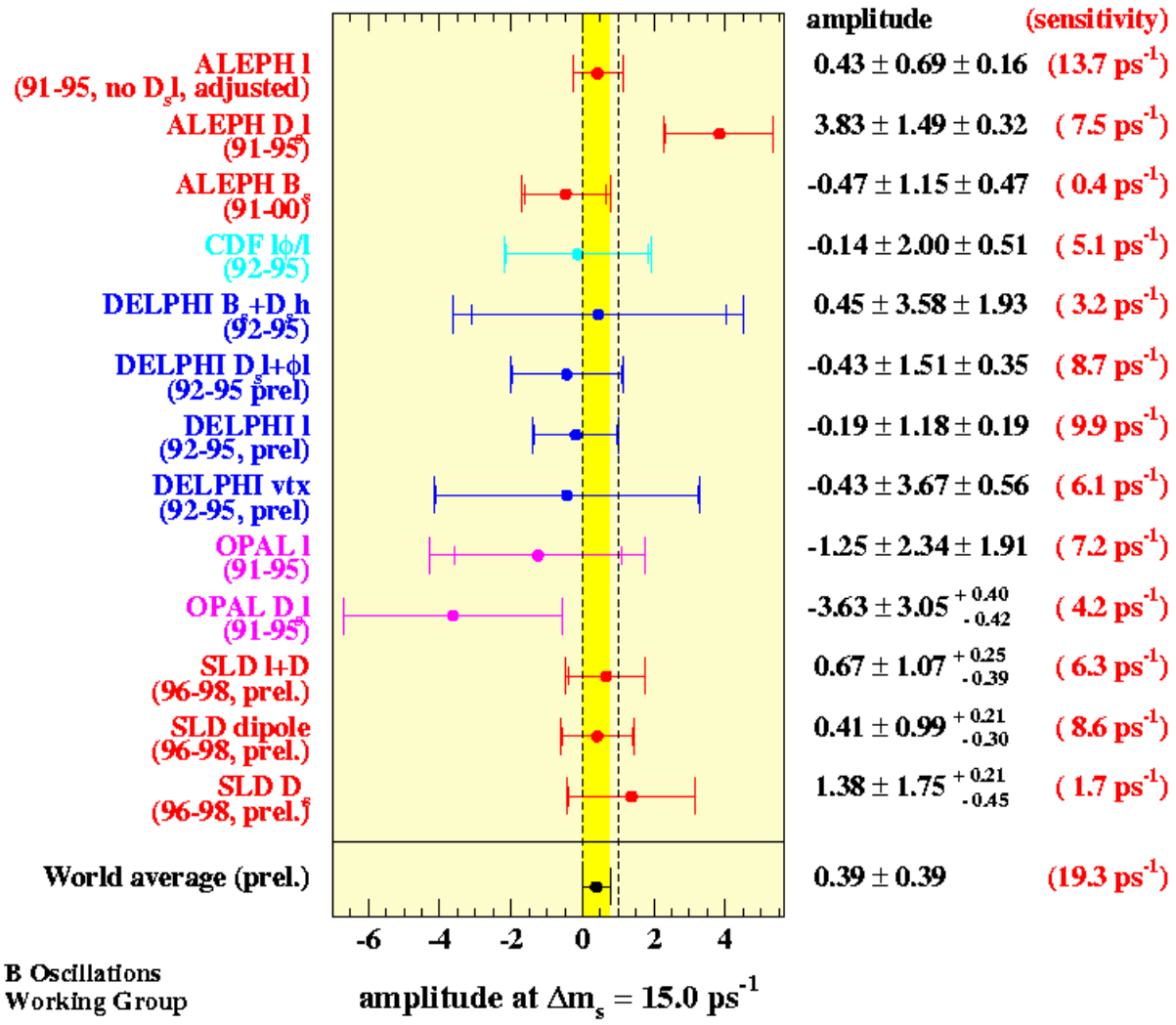
E_n = neutrino energy from missing energy

- **bias corr. function of E_n**
- **error param. function of P_{Bs}**



Andrea Sciabà
INFN-CNAF

Amplitude measurements



D_s-ℓ candidates

Decay mode	Eff. (%)	Signal	b®D_sDX	D^-	Comb. Bckg.	Cand.
ϕp^+	13.10	54	15.7	0	12.3	82
$K^{*0}K^+$	8.48	46	19.5	18	36.5	120
$K_S^0K^+$	2.33	5.8	2.0	0.4	8.8	17
ϕr^+	2.43	11.2	2.4	0.6	25.8	40
$K^{*0}K^{*+}$	3.36	9.4	2.6	0	9.0	21
$\phi p^+ p^+ p^-$	6.83	8.4	1.8	0	6.8	17
$\phi e^+\nu_e$	6.63	9.3	2.4	0	5.3	17
$\phi m^+\nu_m$	4.62	11.4	1.2	0	6.4	19

Andrea Sciabà
INFN-CNAF

Fully reconstructed B_s candidates

Class		Composition (%)				Data
Region	Channel	B_s^0	B^0	B^+	Non resonant	Candidates
Main peak	$\phi\pi^-$	81 ± 7	4	2	13	4
$D_s^-\pi^+(\pi^0,\gamma)$	$K^{*0}K^-$	50 ± 8	12	3	35	12
	$K_S^0K^-$	29 ± 8	47	0	24	5
Satellite peak	$\phi\pi^-$	82 ± 9	6	6	6	7
$D_s^-\pi^+(\pi^0,\gamma)$	$K^{*0}K^-$	32 ± 7	23	8	37	7
	$K_S^0K^-$	37 ± 7	21	0	42	9
Main peak	$\phi\pi^-$	38 ± 7	4	0	58	6
$D_s^-a_1^+(\pi^0,\gamma)$	$K^{*0}K^-$	29 ± 7	5	0	66	3
	$K_S^0K^-$	20 ± 7	16	0	64	2
Satellite peak	$\phi\pi^-$	21 ± 7	9	0	70	6
$D_s^-a_1^+(\pi^0,\gamma)$	$K^{*0}K^-$	12 ± 4	9	0	79	9
	$K_S^0K^-$	7 ± 4	9	0	84	10

Andrea Sciabà
INFN-CNAF