Oscillations of the B_d^0 Mesons

Valery Andreev*

Louisiana State University

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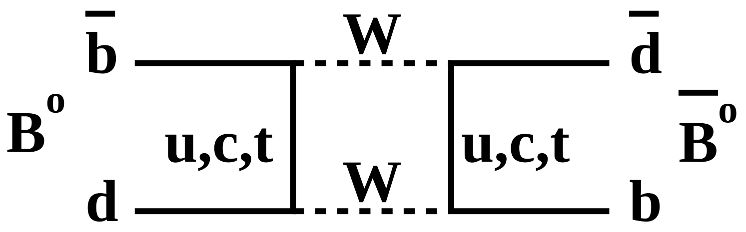
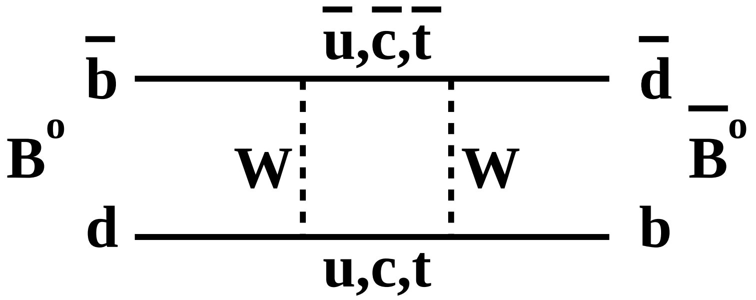
0* on leave from Petersburg Nuclear Physics Institute, e-mail address: Valeri.Andreev@cern.ch

Outline

- Introduction
- Experimental methods
- Results on B_d^0 oscillation measurements
- Implication of Δm_d measurements on CP violation studies and New Physics
- Conclusion

Motivation





Time dependence of mixing:

$$P(t \mid B_d^0 \to \bar{B}_d^0) = \frac{1}{\tau}\, e^{-\frac{t}{\tau}}\, \frac{1 - \cos \Delta m_d\, t}{2}$$

Oscillation frequency Δm_d:

$$\Delta m_d = |V_{tb}^* V_{td}|^2 \frac{G_F^2}{6\pi^2}\, m_{B^0}\, m_W^2\, F(\frac{m_t^2}{m_W^2})\, \eta_B\, f_{B^0}^2\, B_{B^0}$$

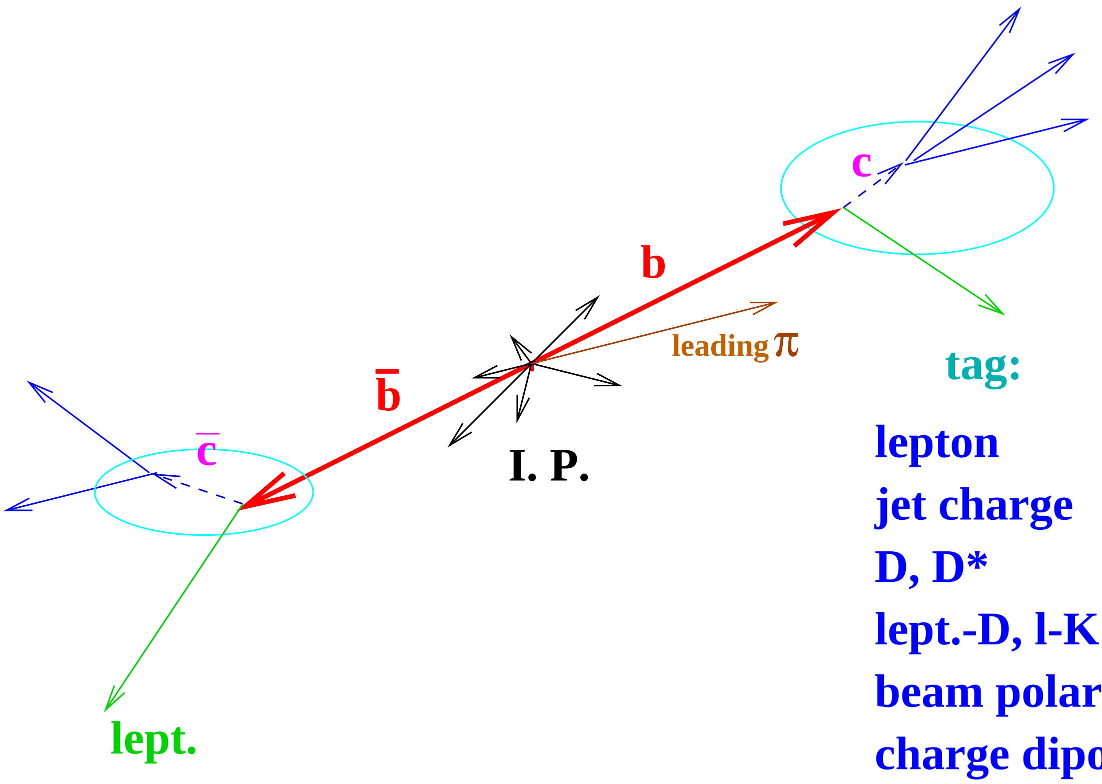
better control for the ratio:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s^0}}{m_{B_d^0}} \xi^2 |\frac{V_{ts}}{V_{td}}|^2,$$

$\xi = 1.10 \pm 0.07$ (lattice QCD)

NEW PHYSICS could manifest through an additional term: $\overline{\Delta m_d} = \Delta m_d \times (1 + \Delta_{NP})$

The method



lepton
jet charge
D, D*
lept.-D, l-K corr.
beam polarization
charge dipole
...

<u>Signature of mixing</u> – like ('right') sign leptons, lepton / jet charge, pion-(l-D correlation), ...

Time dependent

$$\frac{N^{like}}{N^{like}+N^{unlike}}(t) \text{ or } \frac{N^{like}-N^{unlike}}{N^{like}+N^{unlike}}(t)$$

Decay length reconstruction

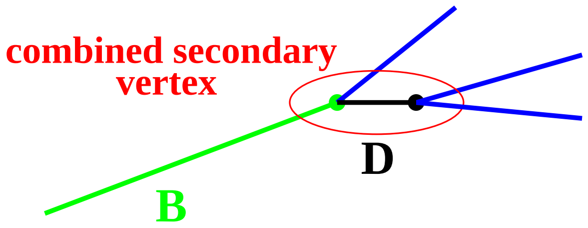
$$l^{3D}_{decay} \text{ or } l^{3D}_{decay} = \frac{l^{2D}_{decay}}{\sin\theta_{jet}}$$

Primary vertex

- **Event by event with N events vertex constraint**
  (150 × 10μm @LEP, 35 × 35μm @CDF, very strong @SLD - 1 × 1μm)
- **N events vertex**

Secondary vertex

- **Combine tracks of B and D vertex**



- **B vertex tracks and direction of D**
- **Lepton impact parameter**

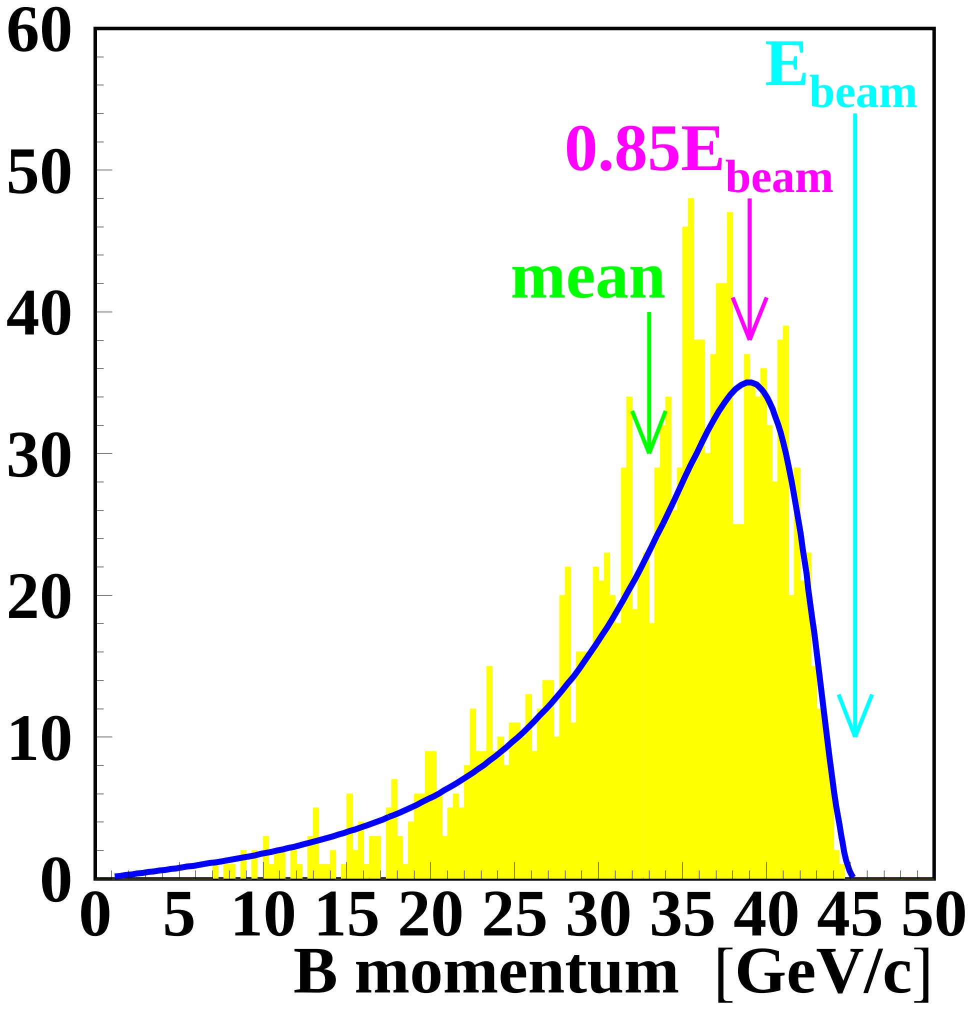
$$\sigma_l \sim 200 - 300\mu m, (50 - 100\mu m \text{ @SLD})$$

Proper time reconstruction

$$t_{decay} = l_{decay}\,\frac{m_B}{p_B}$$

p_B through the energy flow:

$E_{lept} \oplus E_{charged} \oplus E_{neutral} \oplus (E_{mis} = E_\nu) \simeq E_{beam}$



$\frac{\sigma_p}{p} \sim 10 - 20\%$;

$\sigma_t \sim 0.1 - 0.3ps$, $(0.06 - 0.1ps$@SLD$)$

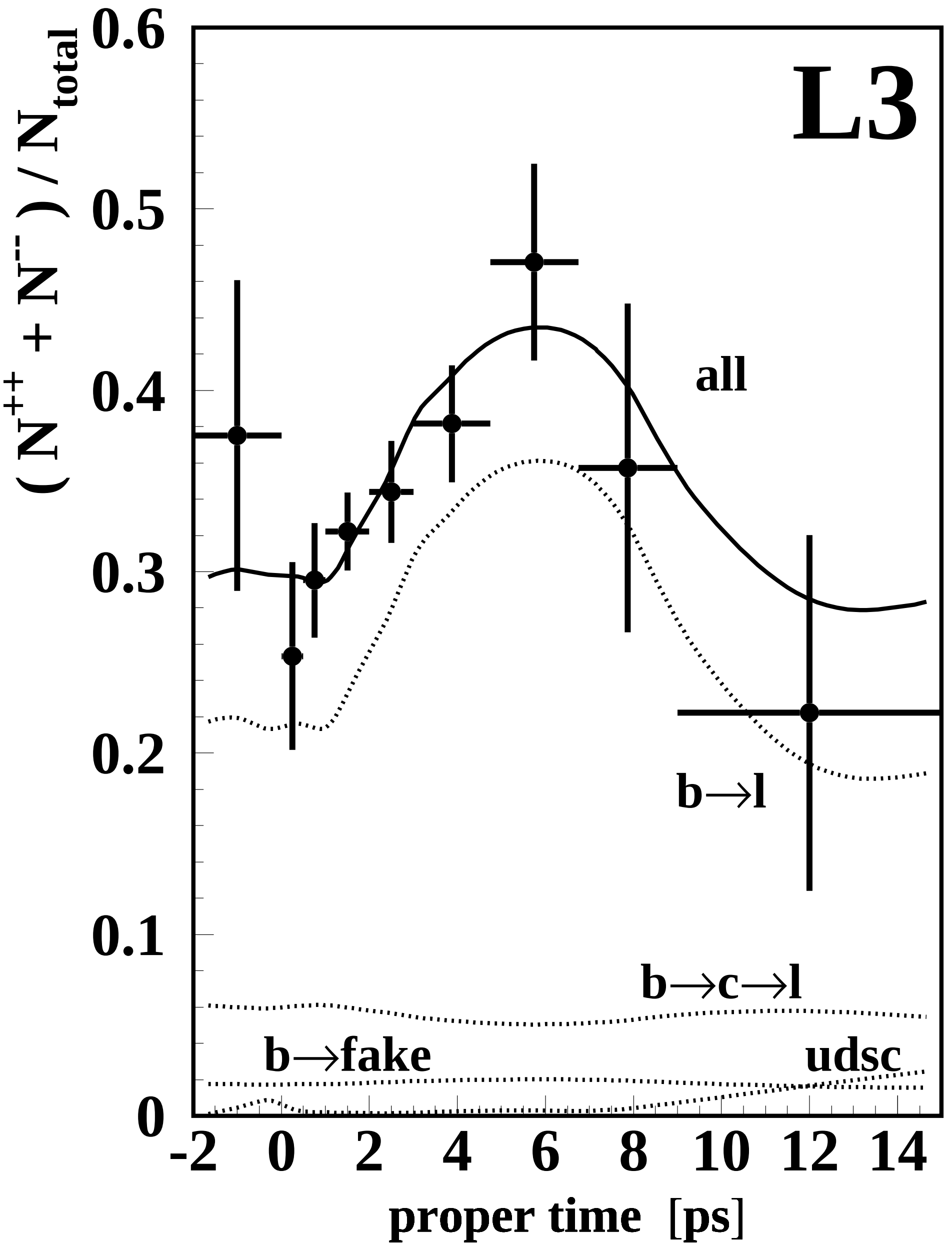
Likelihood function
(Very complicated)

Ingredients:

$q_1 \cdot q_2$	**like/unlike sign event**
Δm_d, Δm_s	B_d^0 **and** B_s^0 **frequencies**
f_d, f_s, f_{Λ_b}	B_d^0, B_s^0, **b-baryons fractions**
F_{ij}	**tag source fractions** $i = b \to l,\ b \to c \to l, ...$ $j = 1, 2$ – **side**
w_{ij}	**"mistag" rates** $i = b \to l,\ b \to c \to l, ...$ $j = 1, 2$ – **side**
τ_k	B **lifetime** $(B_d^0, B^\pm, B_s^0, \Lambda_b)$
$R(t, t')$	**resolution function**
$\epsilon(t')$	**efficiency**

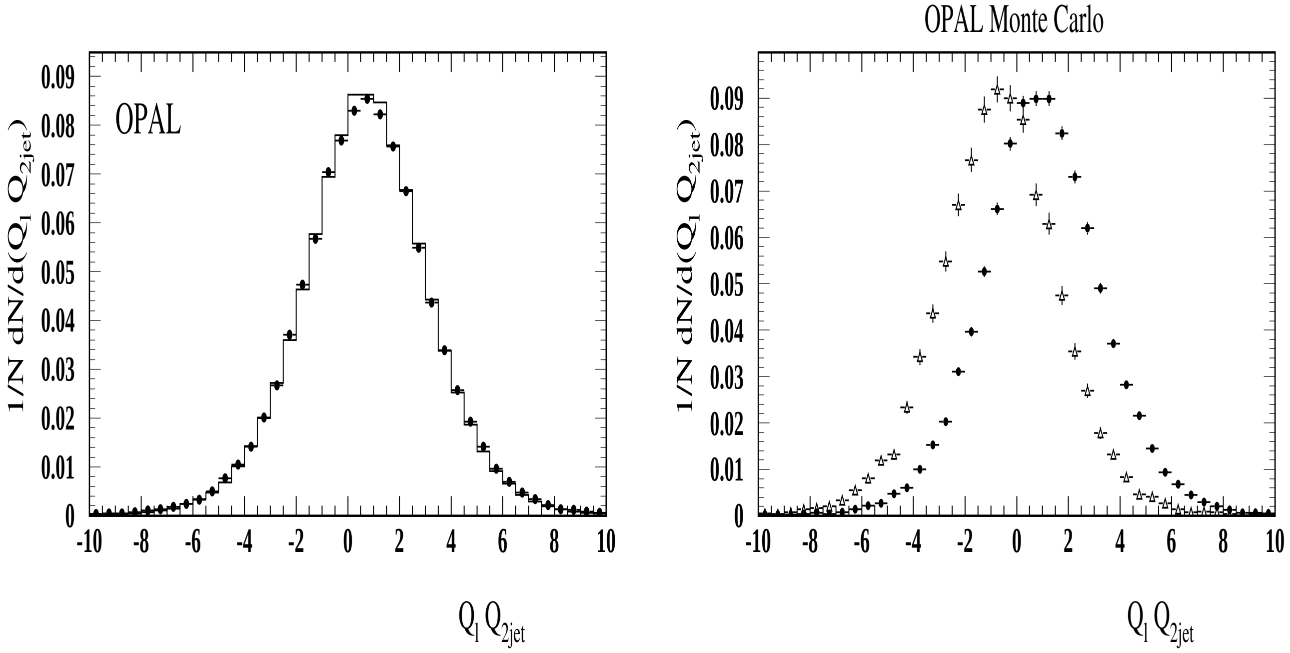
Oscillation picture

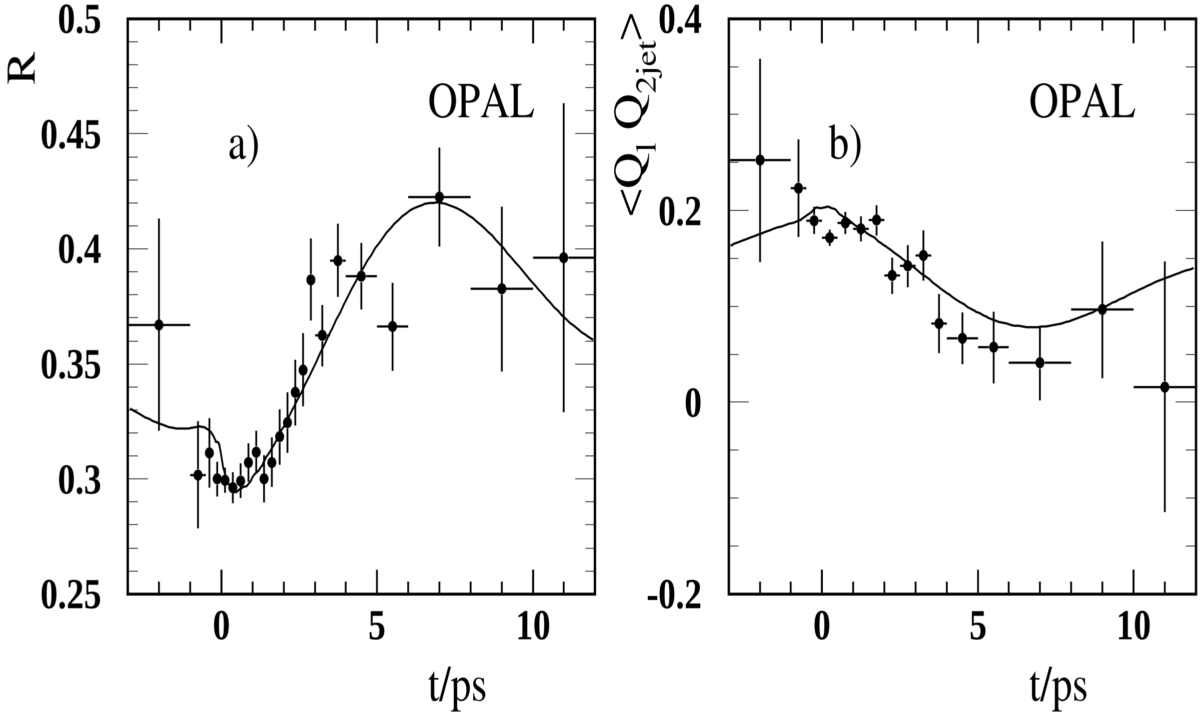
lepton-lepton tag



$$\Delta m_d = 0.458 \pm 0.046(\text{stat}) \pm 0.032(\text{syst})\text{ps}^{-1}$$

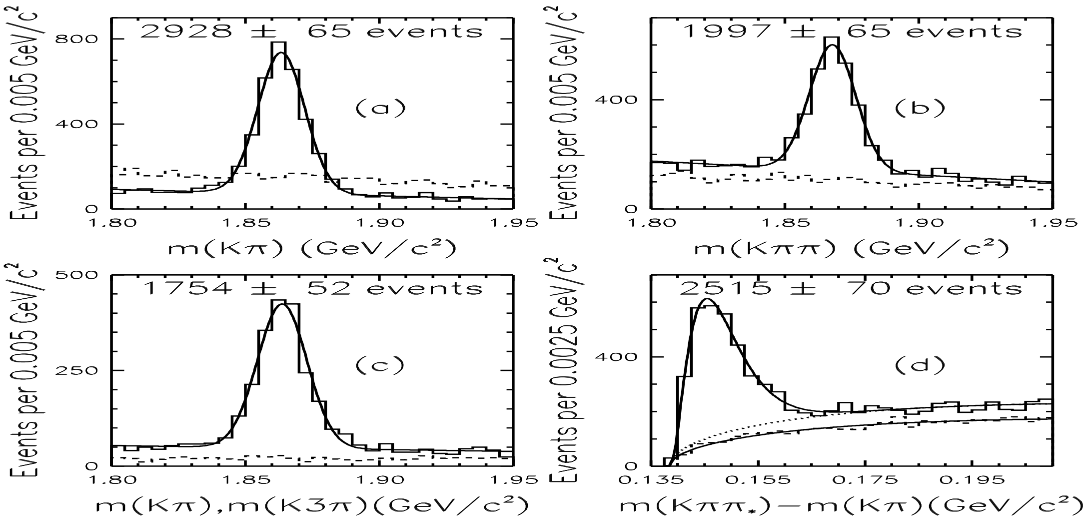
lepton - jet charge tag

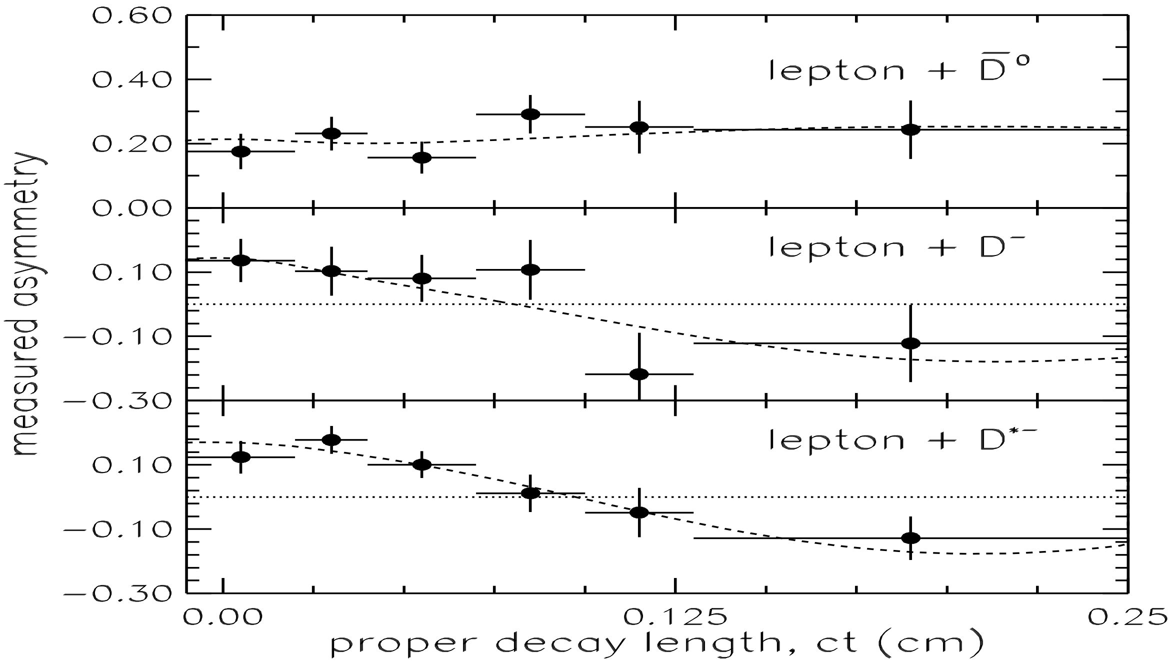




$$\Delta m_d = 0.444 \pm 0.029(\text{stat}) \,{}^{+0.020}_{-0.017}\, (\text{syst})\text{ps}^{-1}$$

Same side tagging result (CDF)

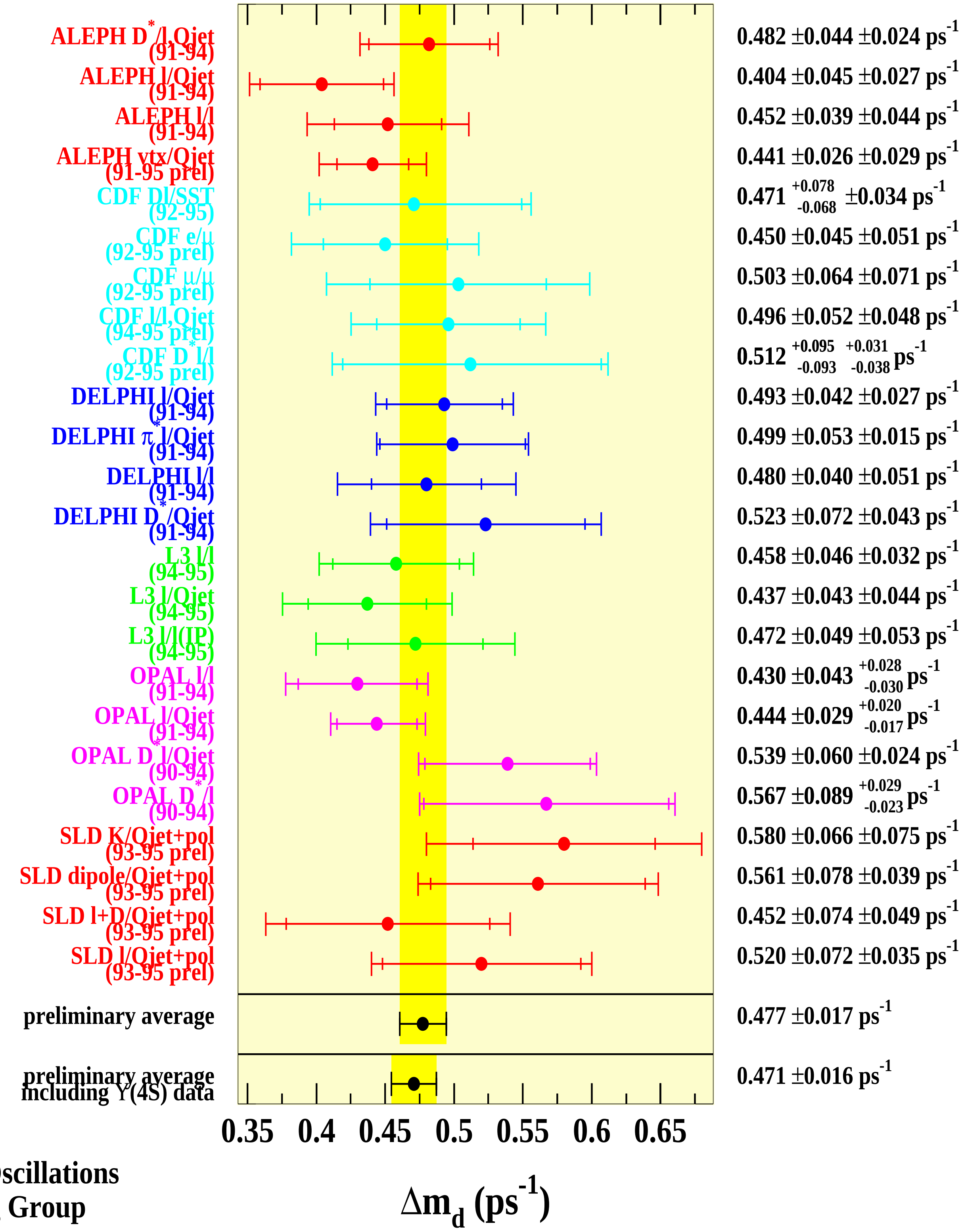




$$\Delta m_d = 0.471^{+0.078}_{-0.068}(\textbf{stat}) \pm 0.034(\textbf{syst})\textbf{ps}^{-1}$$

Results

24 measurements



LEP B Oscillations Working Group

Combined LEP+SLD+CDF+$\Upsilon(4S)$ result

$$\Delta m_d = 0.471 \pm 0.016 \mathbf{ps}^{-1} (.010 \mathbf{(stat)}, .013 \mathbf{(syst)})$$

$$\chi_d = 0.175 \pm 0.009$$

by-product:

Using Δm_d, $\bar{\chi}$, $\chi_s = 0.5$, $f_{b-baryon}$ and b-lifetimes and assuming

$$f_{B_d} = f_{B_u}; \; f_{B_d} + f_{B_u} + f_{B_s} + f_{b-baryon} = 1$$

one gets also

$$f_{B_s} = 10.8 \pm 1.4\%$$

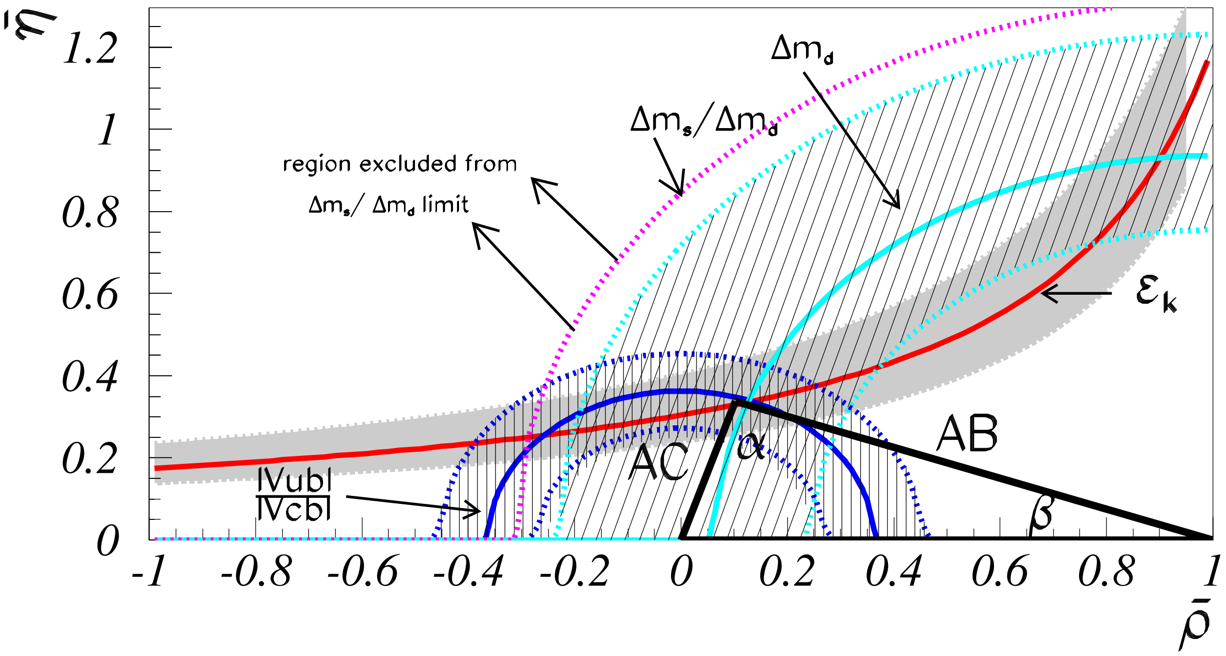
For completeness:

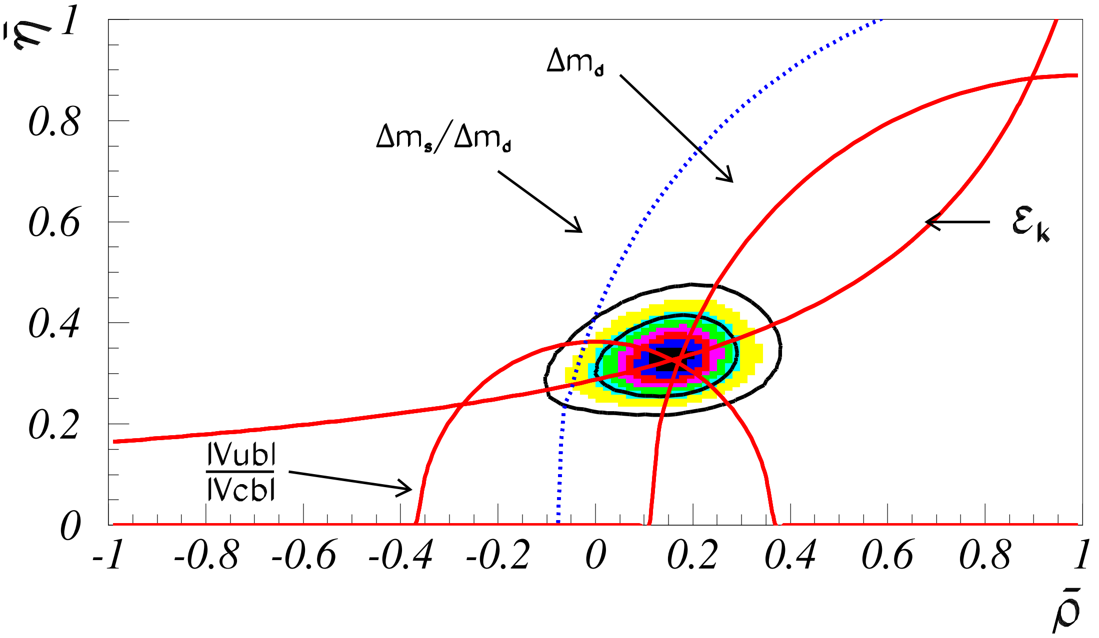
$$f_{b-baryon} = 10.2^{+2.3}_{-2.1}\%$$
$$\Rightarrow f_{B_d} = f_{B_u} = 39.5^{+1.3}_{-1.4}\%$$

http://www.cern.ch/LEPBOSC/combined_results/vancouver_1998

V_{CKM} constraints

F.Parodi, P.Roudeau, A.Stocchi — hep-ph / 9802289





$\bar{\rho} = 0.156 \pm 0.090, \bar{\eta} = 0.328 \pm 0.054$

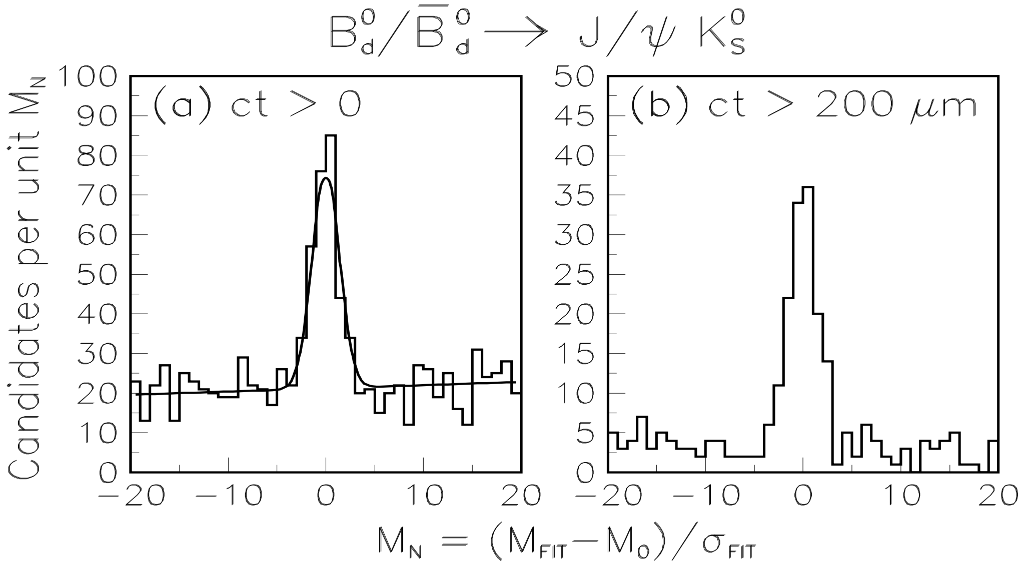
$\sin 2\alpha = 0.10 \pm 0.40, \sin 2\beta = 0.68 \pm 0.10,$

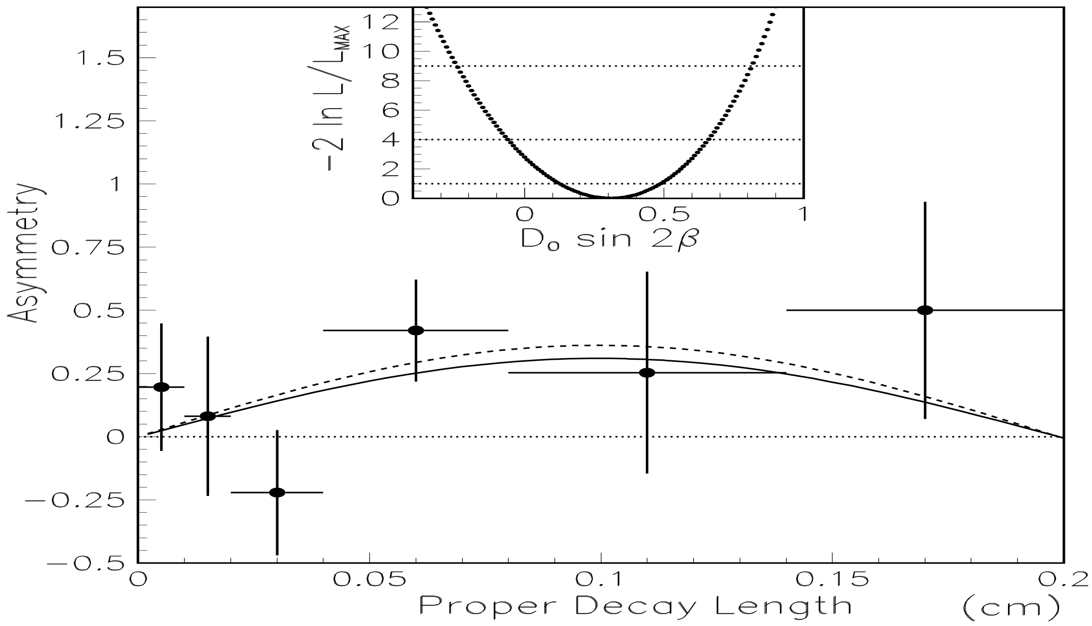
$\gamma = (64 \pm 12)^\circ$

All constraints are compatible, therefore
no New Physics for the moment.

Impact on CP violation measurement

$$A_{CP}(t) \equiv \frac{\bar{B}_d^0(t) - B_d^0(t)}{\bar{B}_d^0(t) + B_d^0(t)} = \sin(2\beta)\sin(\Delta m_d t)$$





$$\sin(2\beta) = 1.8 \pm 1.1(\mathrm{stat}) \pm 0.3(\mathrm{syst})$$

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Conclusion

- **New precise world average value of the B_d^0 oscillation frequency is**

$$\Delta m_d = 0.471 \pm 0.016 \mathbf{ps}^{-1}$$

- **The accuracy of about 3% gives an important constraint on CKM mixing matrix, especially in combination with the Δm_s limit**
- **The measurement might improve further, mainly now due to a better knowledge of the fit input parameters (fractions, lifetimes, $\bar{\chi}$, branching ratios)**

Acknowledgements

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