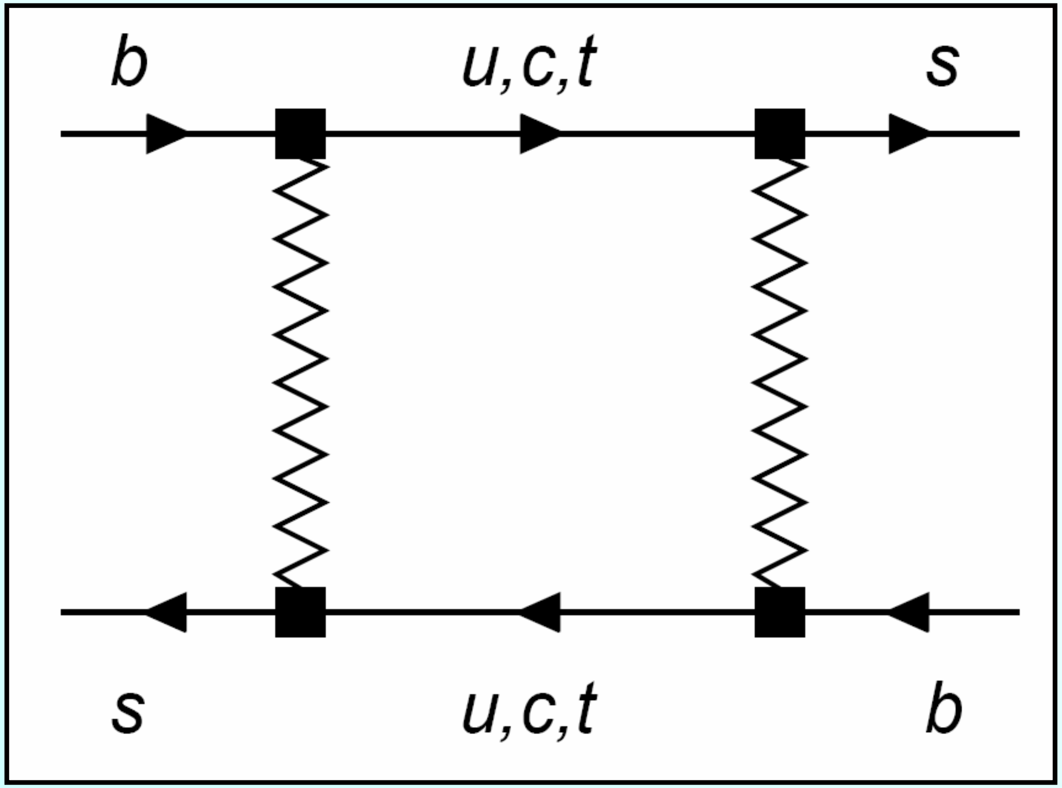
# Study of $B_s$ mixing in DØ

G.Borissov (DØ collaboration)
Lancaster University

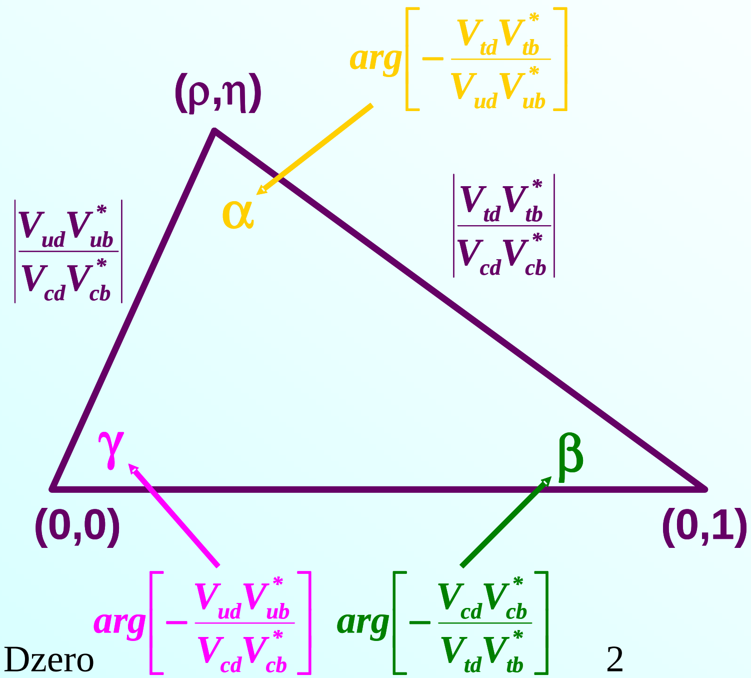


# Unitarity Triangle

- Verifying unitarity of CKM matrix of quark mixing is an important test of SM;
- Unitarity triangle - geometrical presentation of one of unitarity relations:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

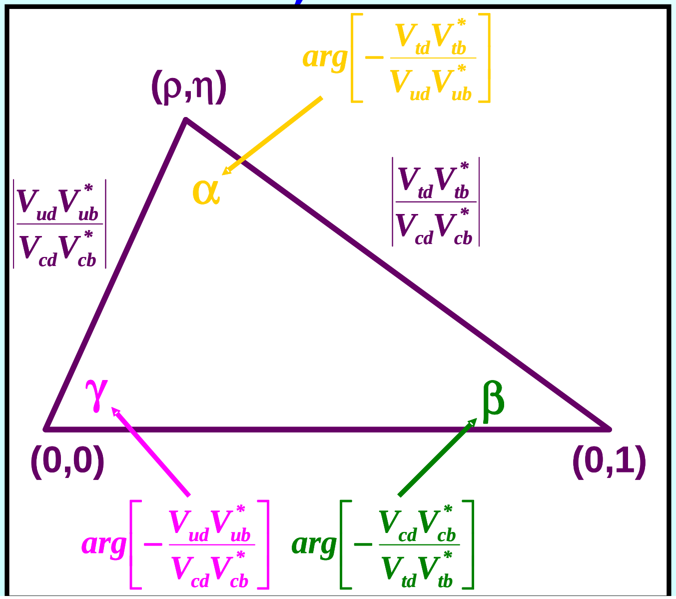


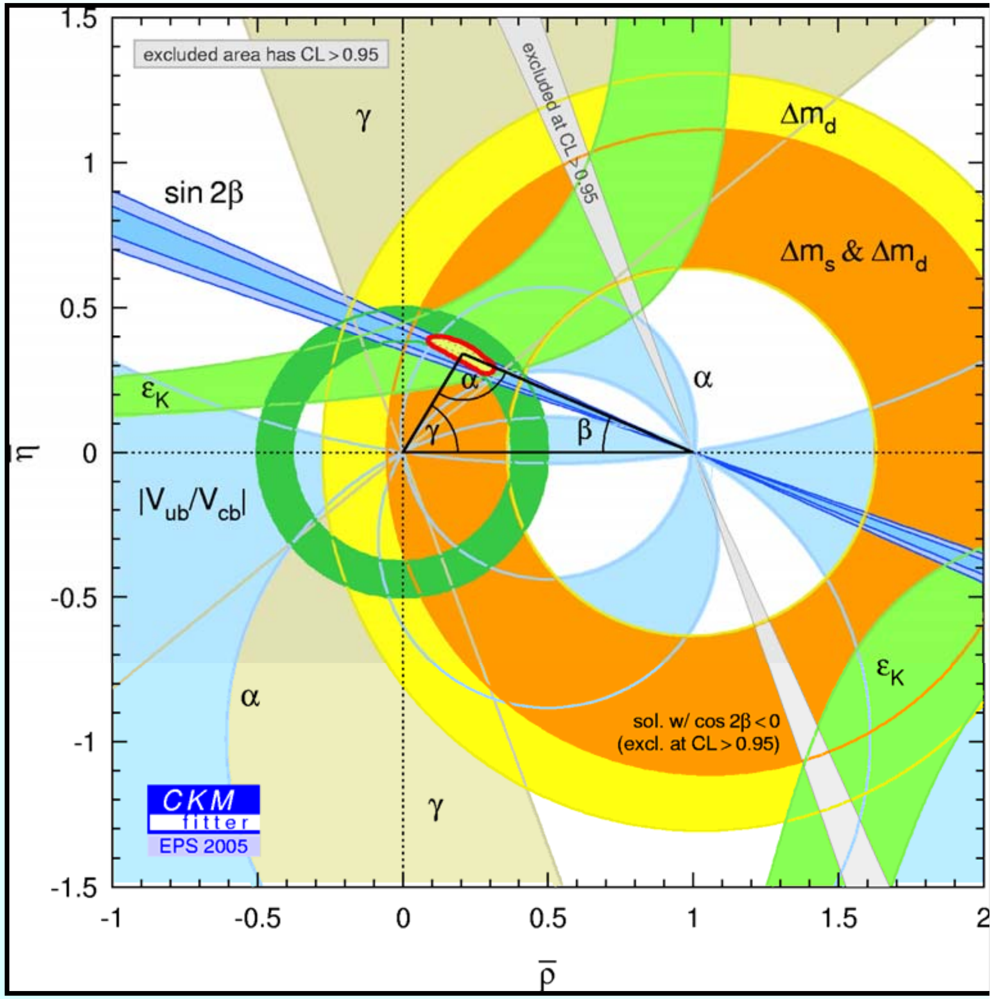
# Constraint from Bs mixing

- B mixing parameters $\Delta m_s$ and $\Delta m_d$ provide an important constraint of unitarity triangle:

$$\frac{\Delta m_s}{\Delta m_d} = \left|\frac{V_{ts}}{V_{td}}\right|$$

- Many uncertainties cancel in this ratio;



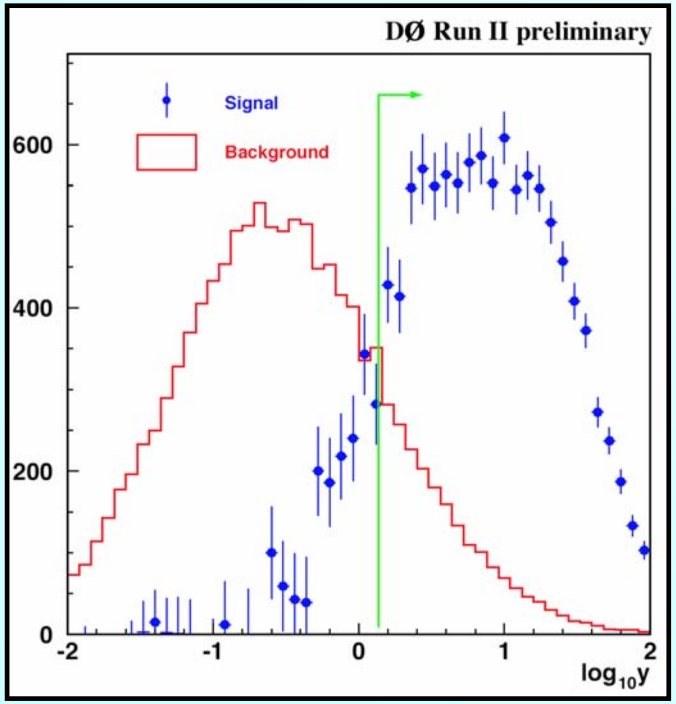



# Analysis outline

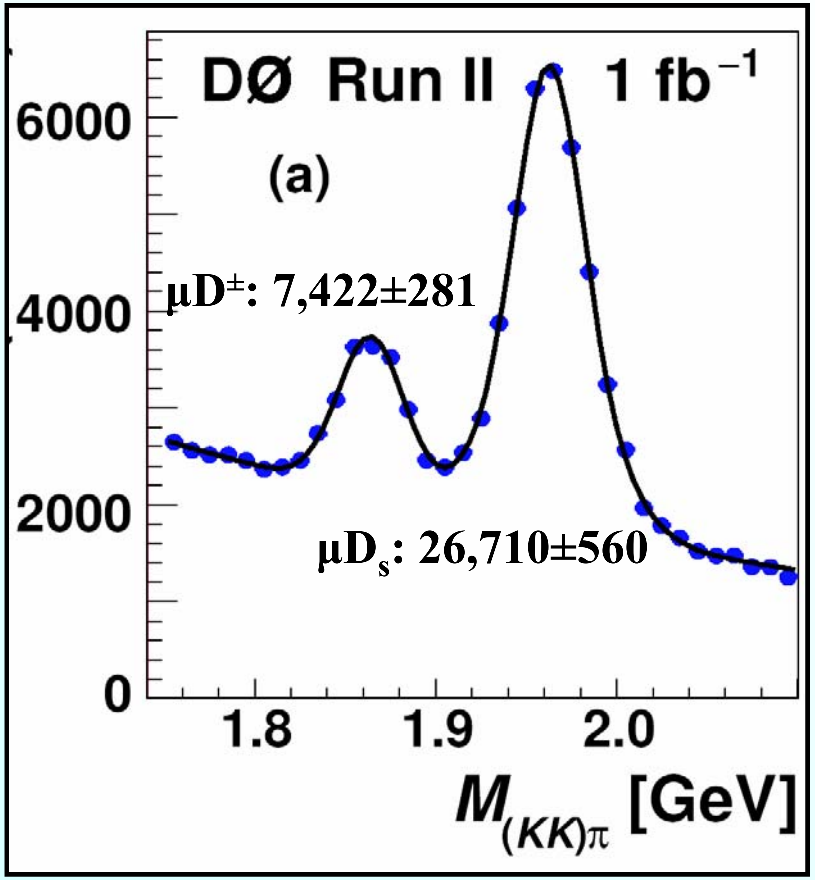
- **Select a sample with $B_s$ decays;**
- **Determine a sample composition;**
- **Measure $B_s$ decay length;**
- **Determine efficiency of selection and the decay length resolution;**
- **Estimate $B_s$ momentum and proper decay length;**
- **Determine its flavor at the production point;**
- **Combine all information in the unbinned fit;**
- **Estimate $B_s$ mixing parameter;**

# Select $B_s$ decay

- Semileptonic $B_s \to \mu \nu D_s$ ($D_s \to \phi \pi$) decays were used;
- Their selection was done by combining different properties of $B_s$ decay using the likelihood ratio method;

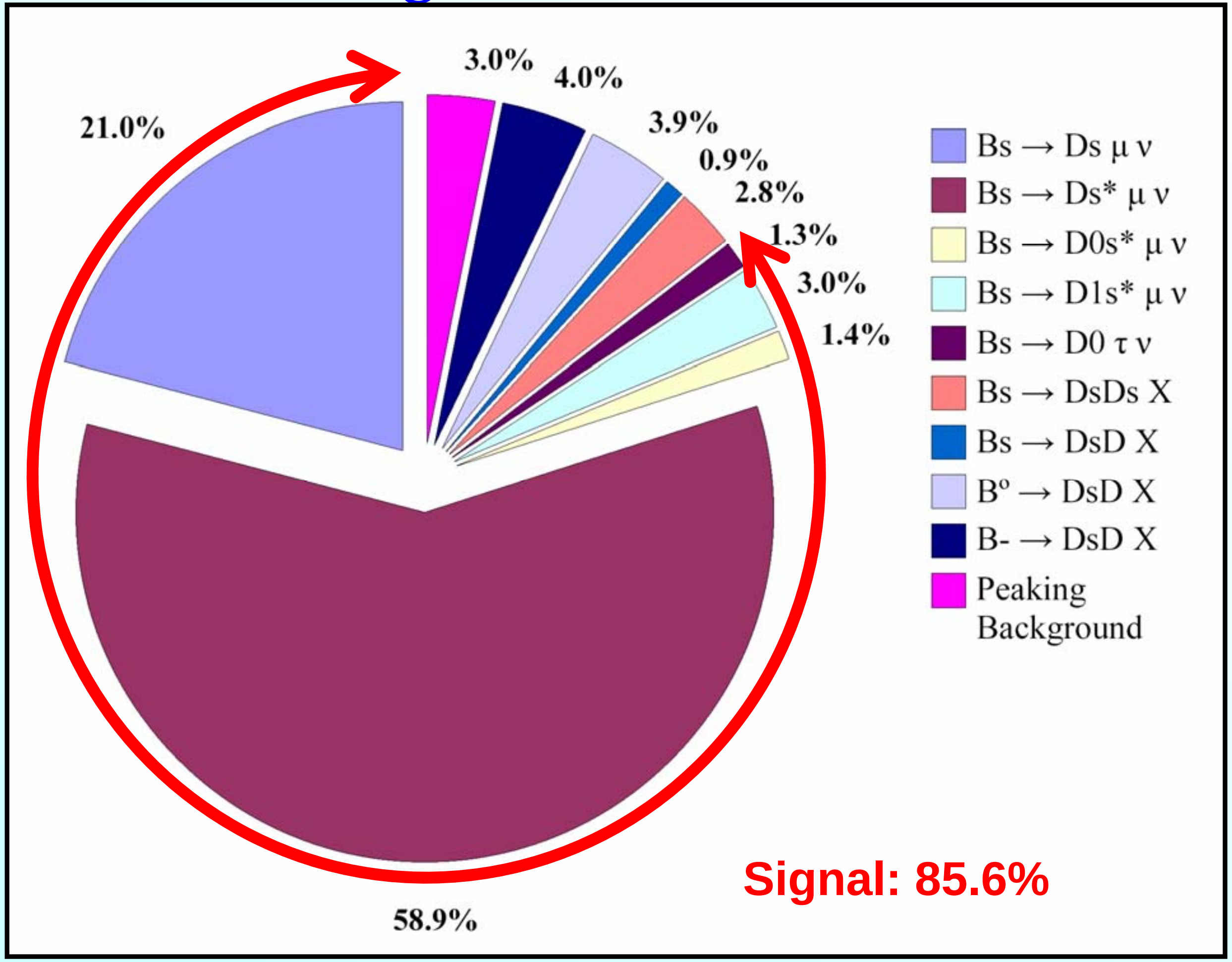



Likelihood ratio



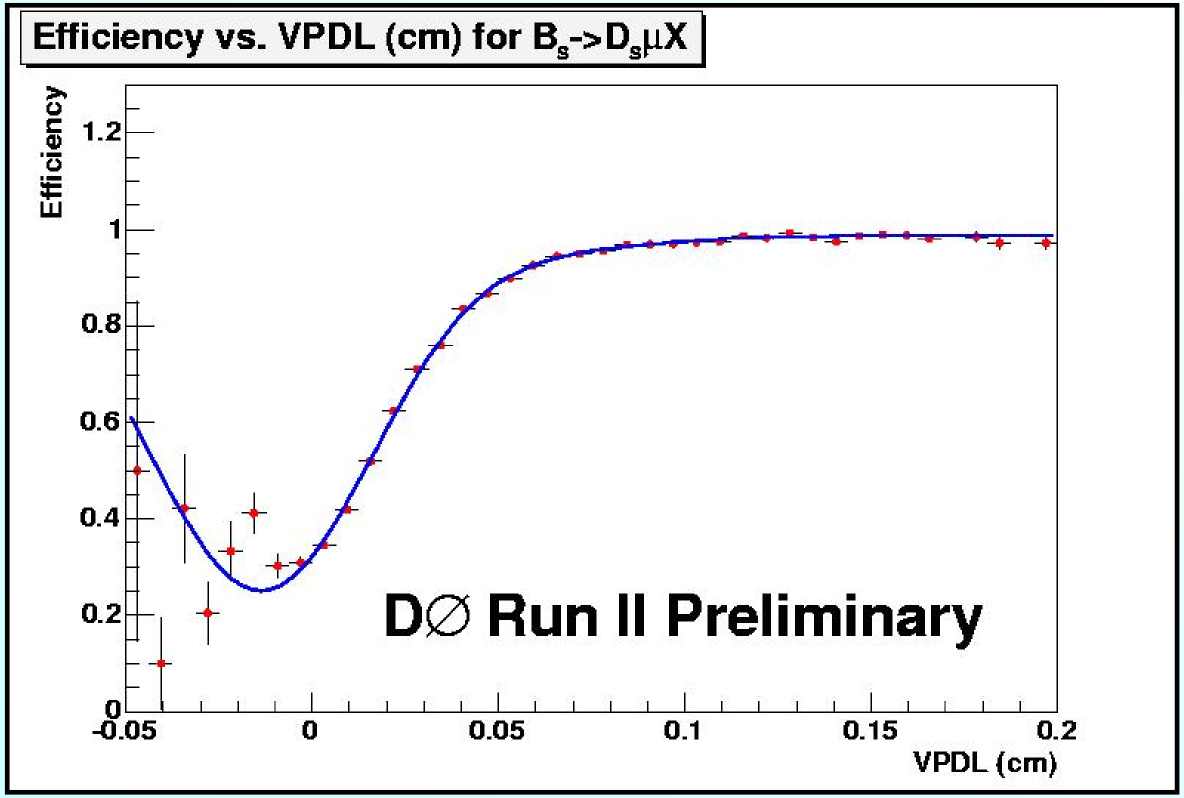
# Sample Composition

- Sample composition is determined using MC and PDG branching ratios;



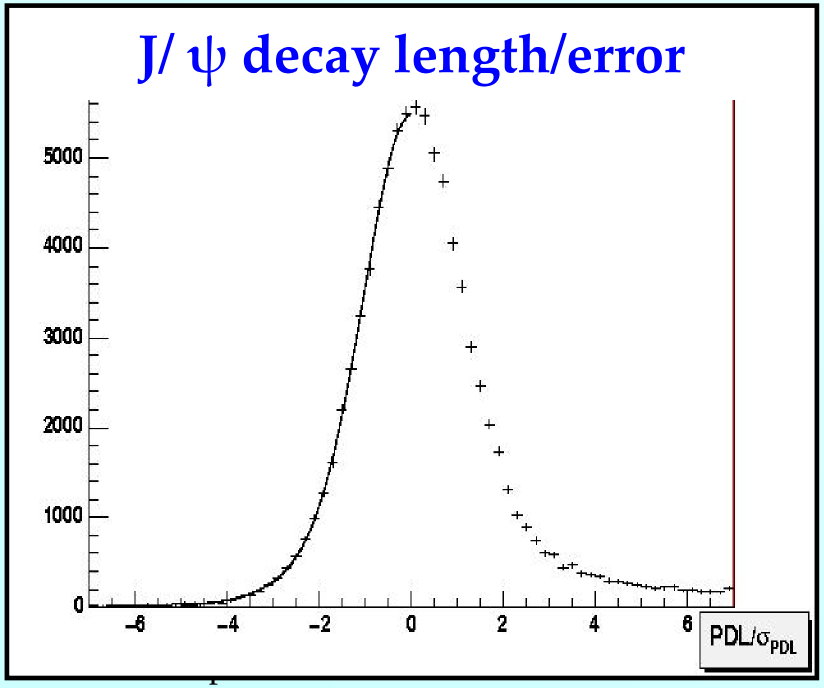
# Selection Efficiency

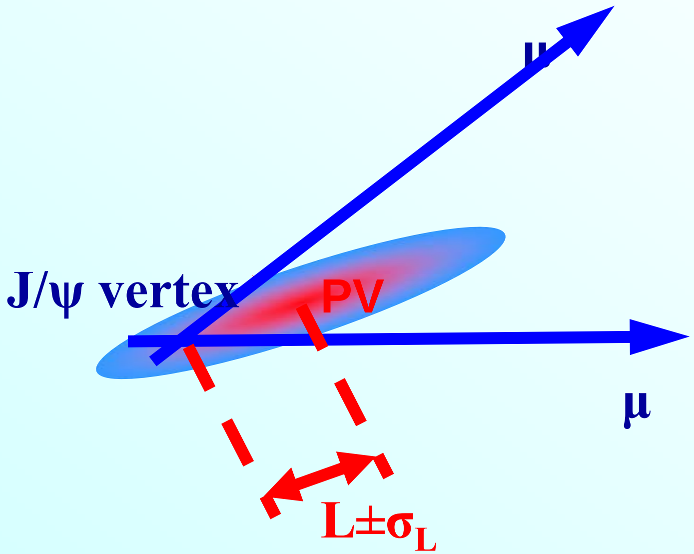
- Selection efficiency was determined from MC;
- Verified by the fit of $B_s$ lifetime (412 ± 9 μm) and comparing it with PDG value (433 ± 20 μm);



# Decay Length Resolution

- The most essential parameter for large $\Delta m_s$;
- Was determined from prompt $J/\psi \to \mu\mu$ decays;
- Verified in the separate procedure to measure the impact parameter resolution;



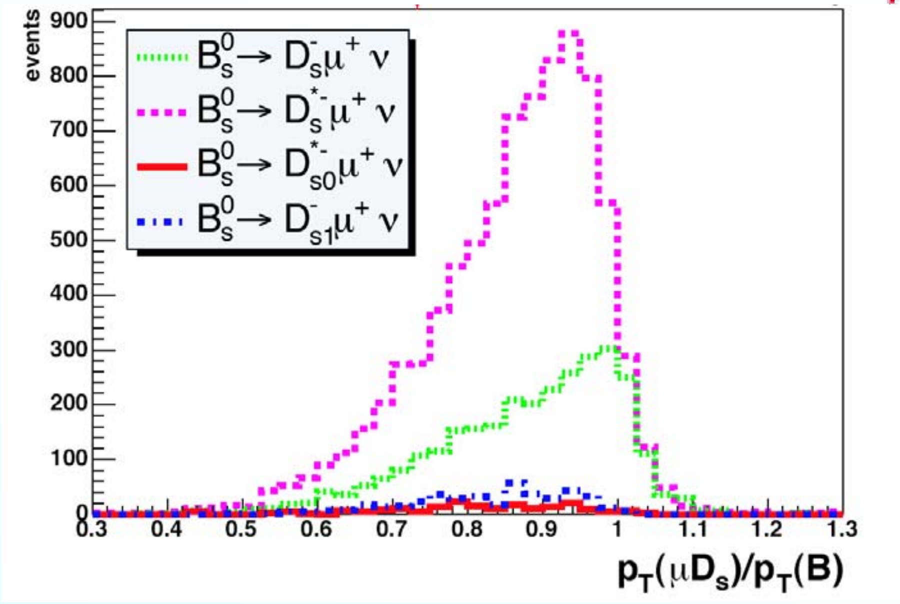



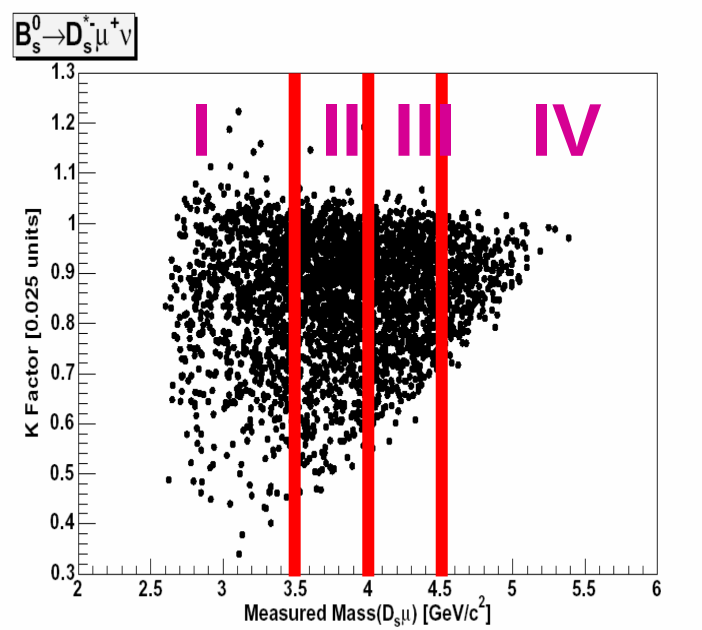
# Proper Decay Length

- Proper decay length:
  $$L = M_B \cdot L_{xy} / P_t^B$$
- Neutrino in semileptonic decays escapes undetected;
- K factor takes into account the energy of all missing particles:

$$L = M_B \cdot L_{xy} / P_t^{\mu D_s} \cdot K; \quad K = P_t^{\mu D_s} / P_t^B$$

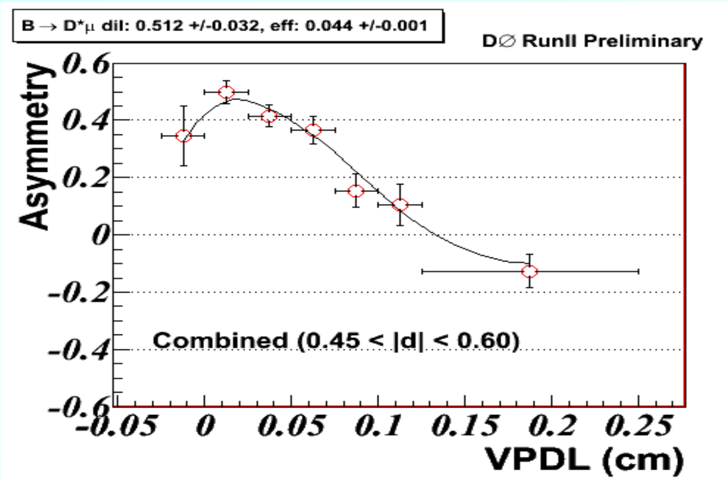
- Its distribution was taken from MC;
- To improve the K-factor resolution, its distribution was determined separately for different M(μ$D_s$);



# Flavor Tagging

- Very important component of analysis;
- Determines the flavor of $B_s$ at the production point;
- Was calibrated using well known $B_d \to \mu\nu D^*$ decays;
- Discussed in detail in the previous talk (Phil Lewis);




$\Delta m = 0.506 \pm 0.020 \text{ (stat.) } ps^{-1}$

$\varepsilon D^2 = (2.48 \pm 0.21)\ (\%)\ \text{(stat.)}$

$\varepsilon = (19.9 \pm 0.2)\ (\%)\ \text{(stat.)}$

# Unbinned Likelihood fit

- **Combine all information on $B_s$ in the unbinned likelihood fit.**
- **Minimize: $-2 \ln f$**

$$f = \prod_{candidates} \left( (1-\mathcal{F}_{sig}) f_{i,bg} + \mathcal{F}_{sig} f_{i,sig} \right)$$

$$f_i = P^{x_M}\left(x_M, \sigma_{x_M}, d_{pr}\right) P^{\sigma_{x_M}} P^{d_{pr}} P^{M_{\phi\pi}} P^{-\log_{10} y}$$

**Proper decay length**

**Flavor tag**

**Proper decay length resolution**

**Mass ($\phi\pi$) distribution**

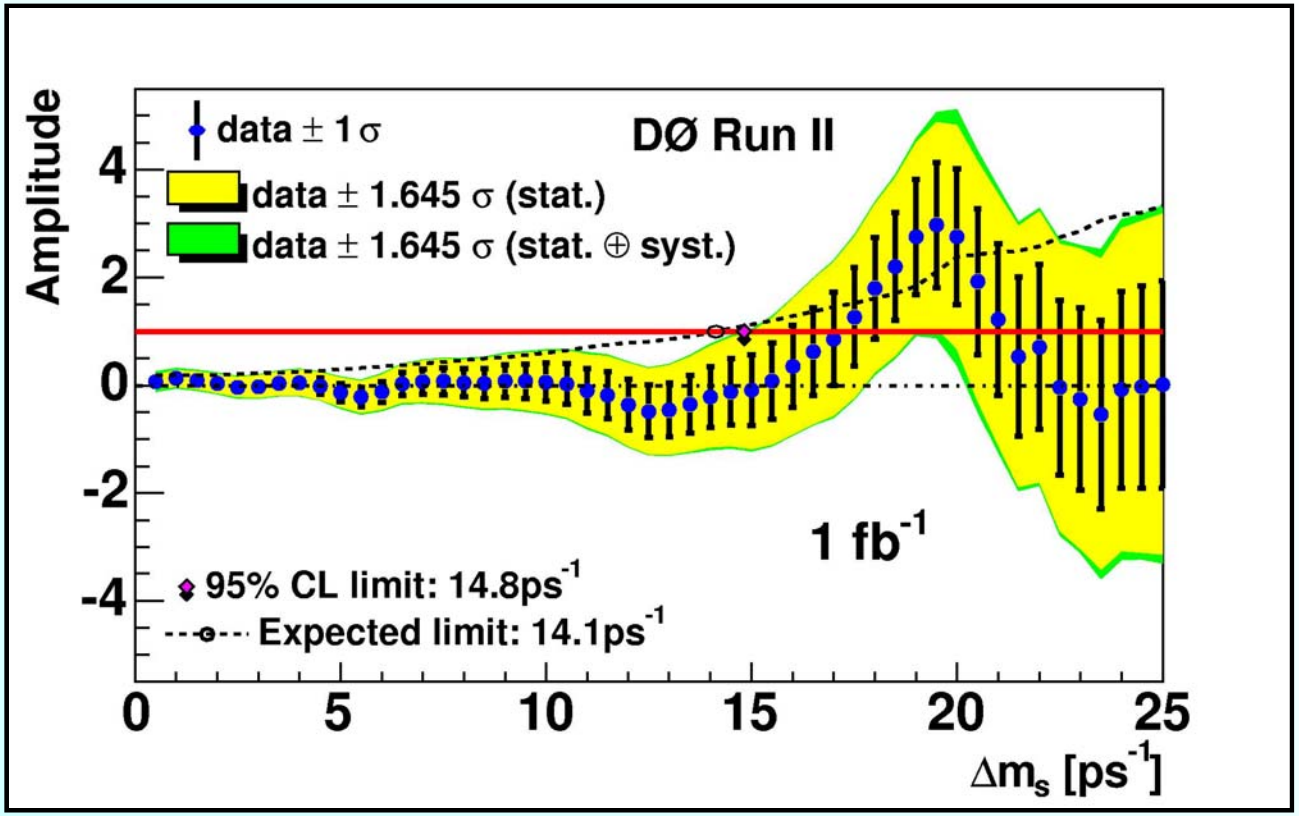
# Amplitude Method

- **Usual method for $B_s$ mixing analysis;**
- **Very useful to set the lower limit and combine different result;**
- **Express a signal probability as:**

$$p_s^{nos/osc} = \frac{K}{c\tau_{B_s}} e^{-\frac{Kx}{c\tau_{B_s}}} \cdot 0.5 \cdot \left(1 \pm \mathcal{D} \cos\left(\Delta m_s \cdot Kx/c\right) \cdot \mathcal{A}\right)$$

- **Fit amplitude for each given value of $\Delta m_s$;**
- **For signal: A=1, otherwise it should be compatible with zero within errors;**

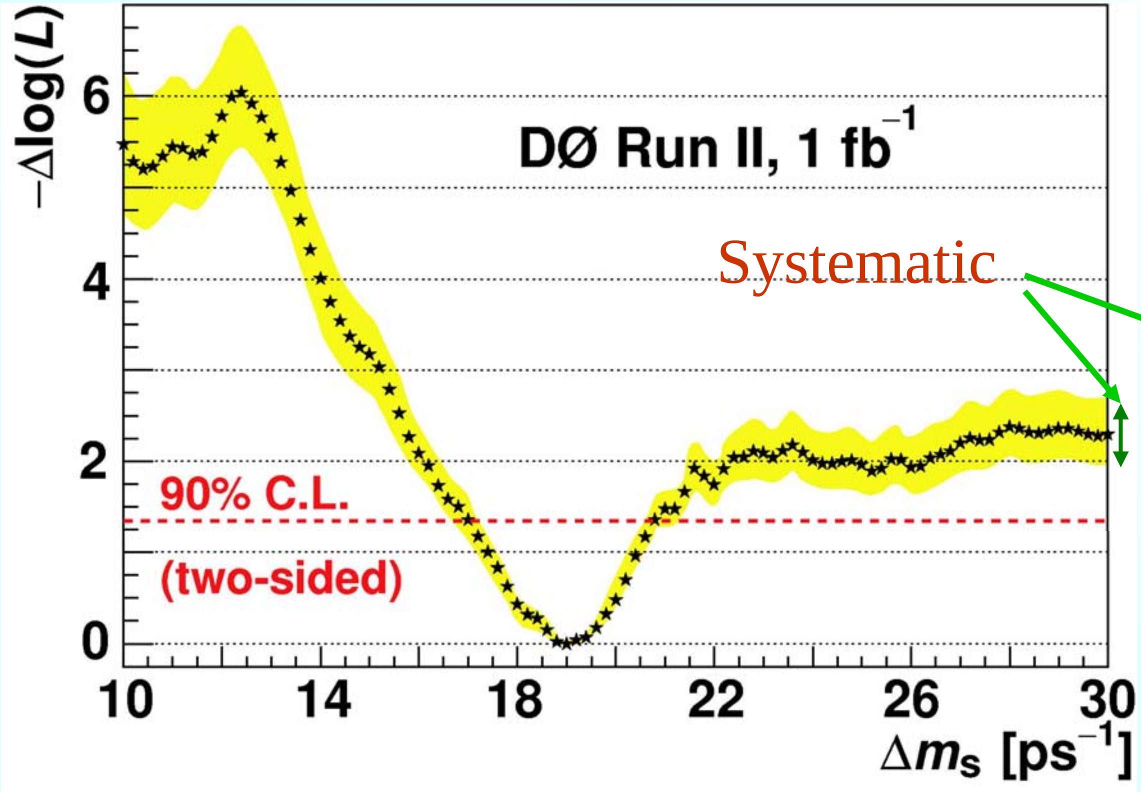
# Amplitude Scan Results




- **Deviation of amplitude from zero for $\Delta m_s$~19 ps$^{-1}$:**
  - 2.5 σ deviation from zero;
  - 1.6 σ deviation from 1;

# Log Likelihood Scan

In agreement with the amplitude scan

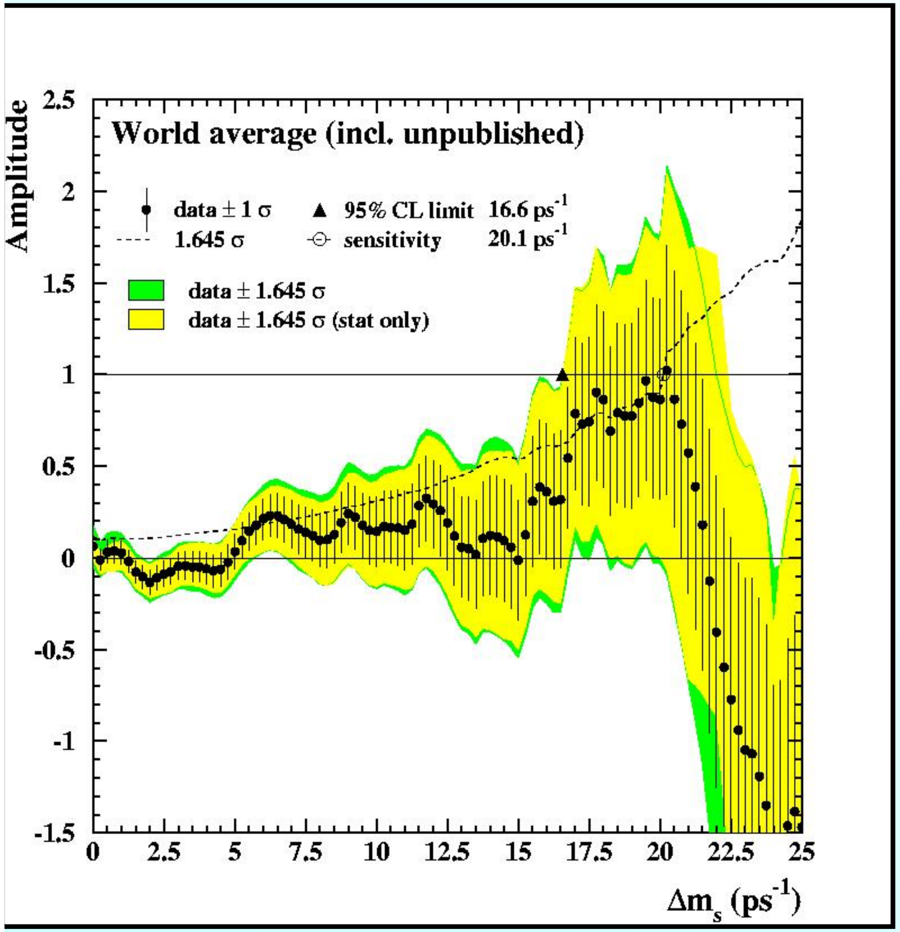


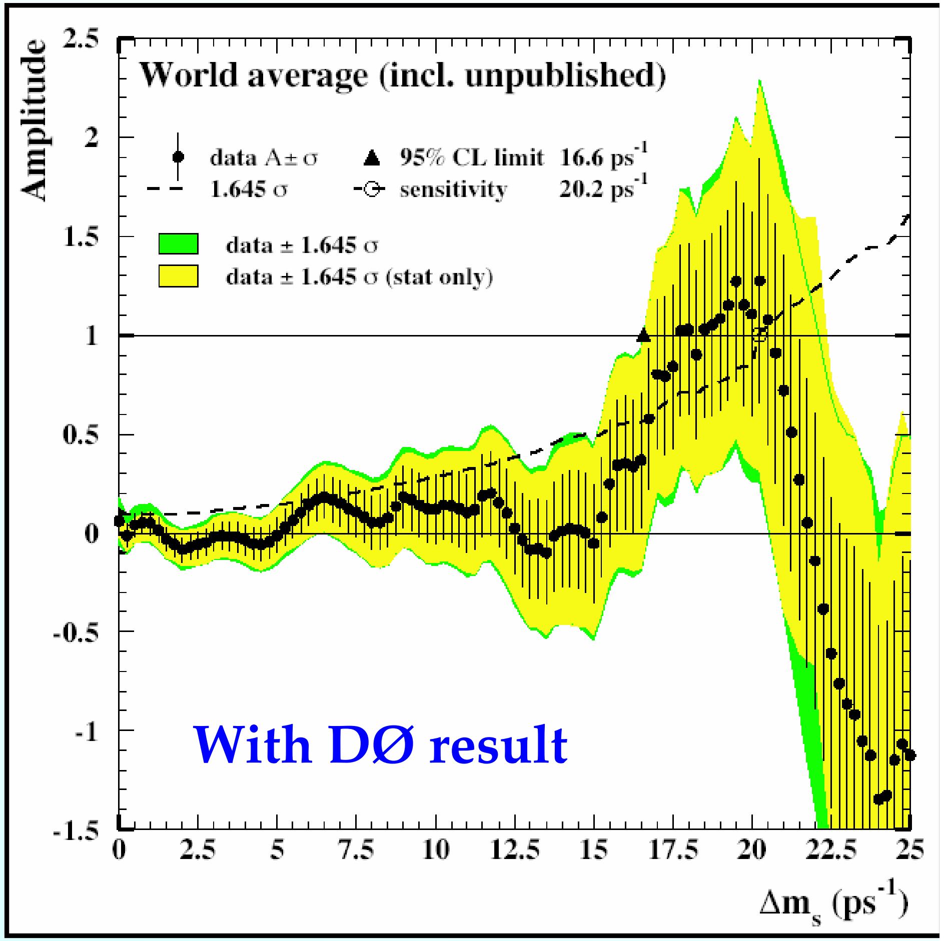

- Resolution
- K-factor variation
- BR ($B_s \to \mu D_s X$)
- VPDL model
- BR ($B_s \to D_s D_s$)

**$17 < \Delta m_s < 21$ ps$^{-1}$ 90% CL assuming Gaussian errors;**

**Most probable value $\Delta m_s = 19$ ps$^{-1}$;**

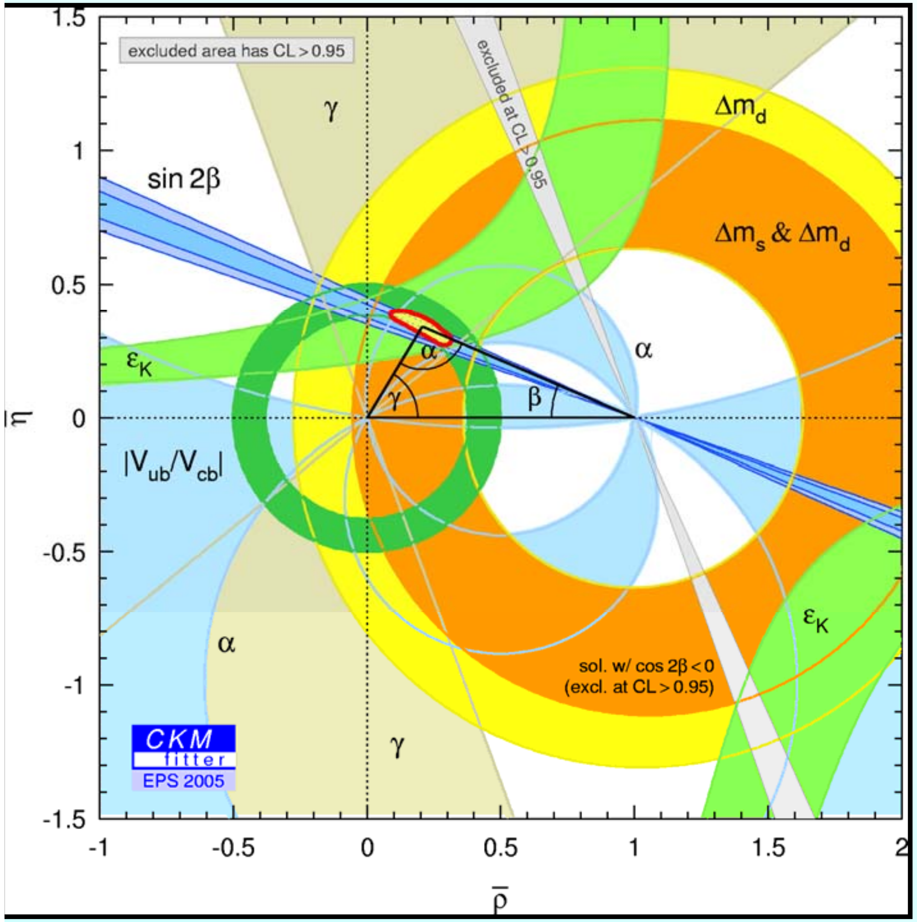
# World Average

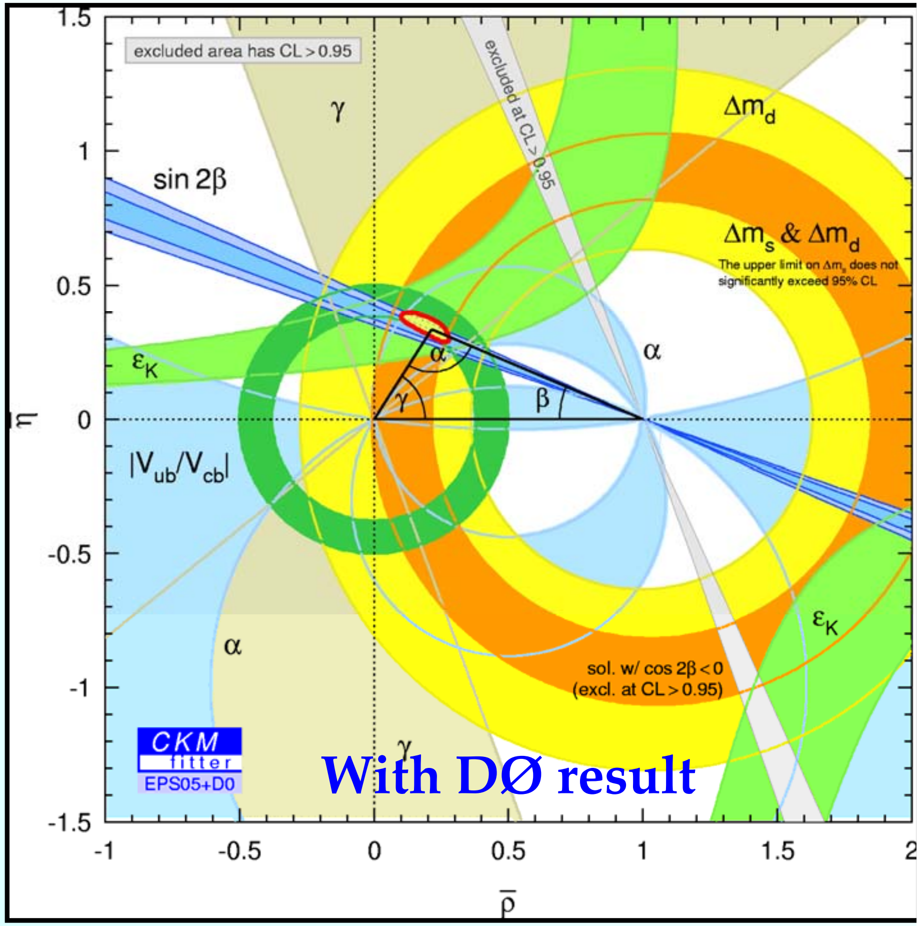



- 2.3 σ deviation from zero at $\Delta m_s$=19 $ps^{-1}$

# Impact on Unitarity Triangle



# Conclusions

- 1 $fb^{-1}$ of data from Tevatron analyzed by DØ;
- New $B_s$ mixing result was obtained;
- Amplitude deviates from zero by 2.5 σ at $\Delta m_s$=19 $ps^{-1}$;
- It agrees with log likelihood scan.
- First direct 90% CL range obtained assuming Gaussian errors:

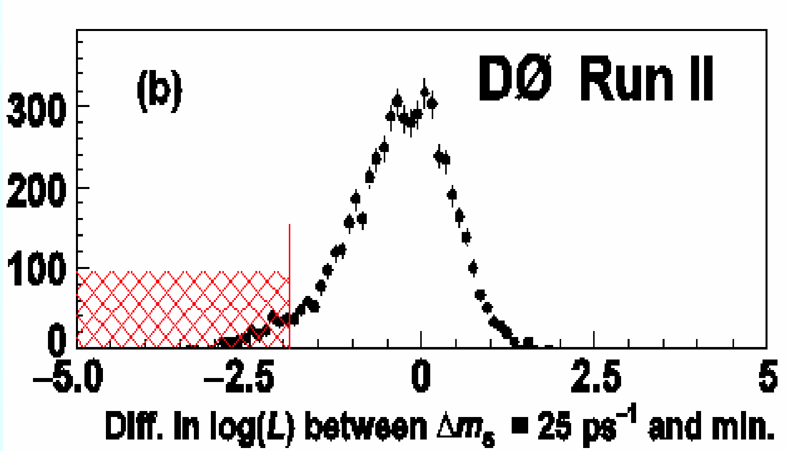
$$17 < \Delta m_s < 21\ ps^{-1}$$

- DØ result provides an important constraint for the test of unitarity of CKM.

# BACKUP slides

# Ensemble Tests

- **Using data**
  - Simulate $\Delta m_s = \infty$ by randomizing the sign of flavor tagging
  - Probability to observe $\Delta\log(L) > 1.9$ (as deep as ours) in the range $16 < \Delta m_s < 22$ ps$^{-1}$ is 3.8%
    - **5% using lower edge of syst. uncertainties band**
    - **Region below 16 ps$^{-1}$ is experimentally excluded**
    - **No sensitivity above 22 ps$^{-1}$**




- **Using MC**
  - Probability to observe $\Delta\log(L) > 1.9$ for the true $\Delta m_s = 19$ ps$^{-1}$ in the range $17 < \Delta m_s < 21$ ps$^{-1}$ is 15%