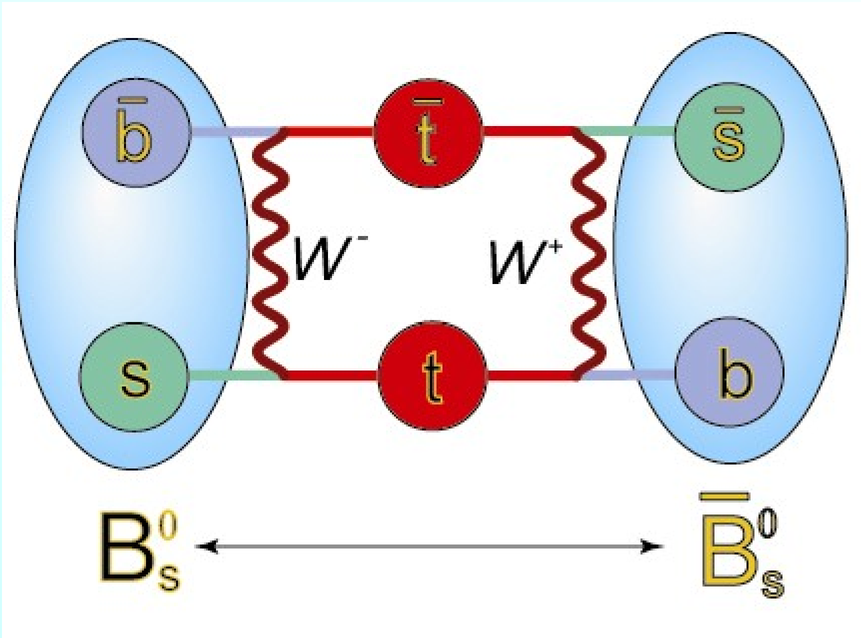
Study of B_s mixing in DØ

G.Borissov (DØ collaboration)
Lancaster University

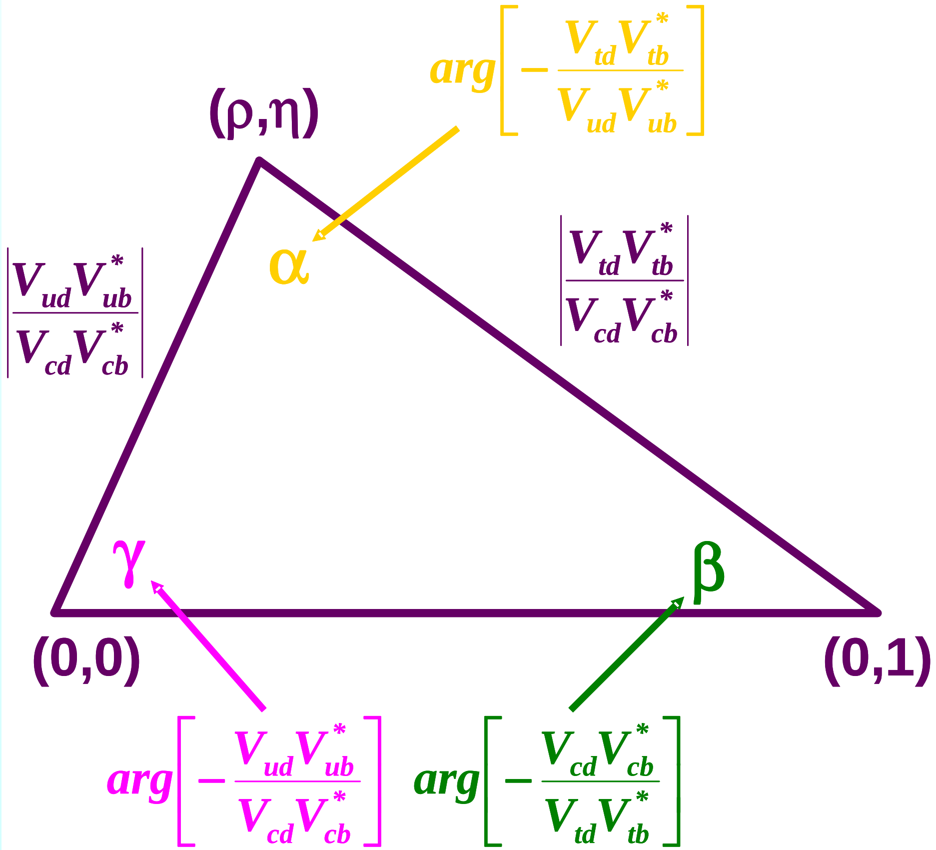


Unitarity Triangle

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

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

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

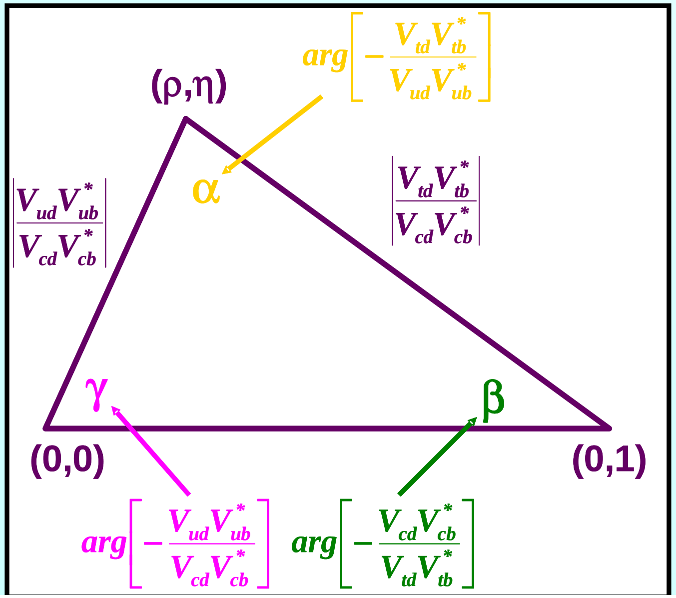


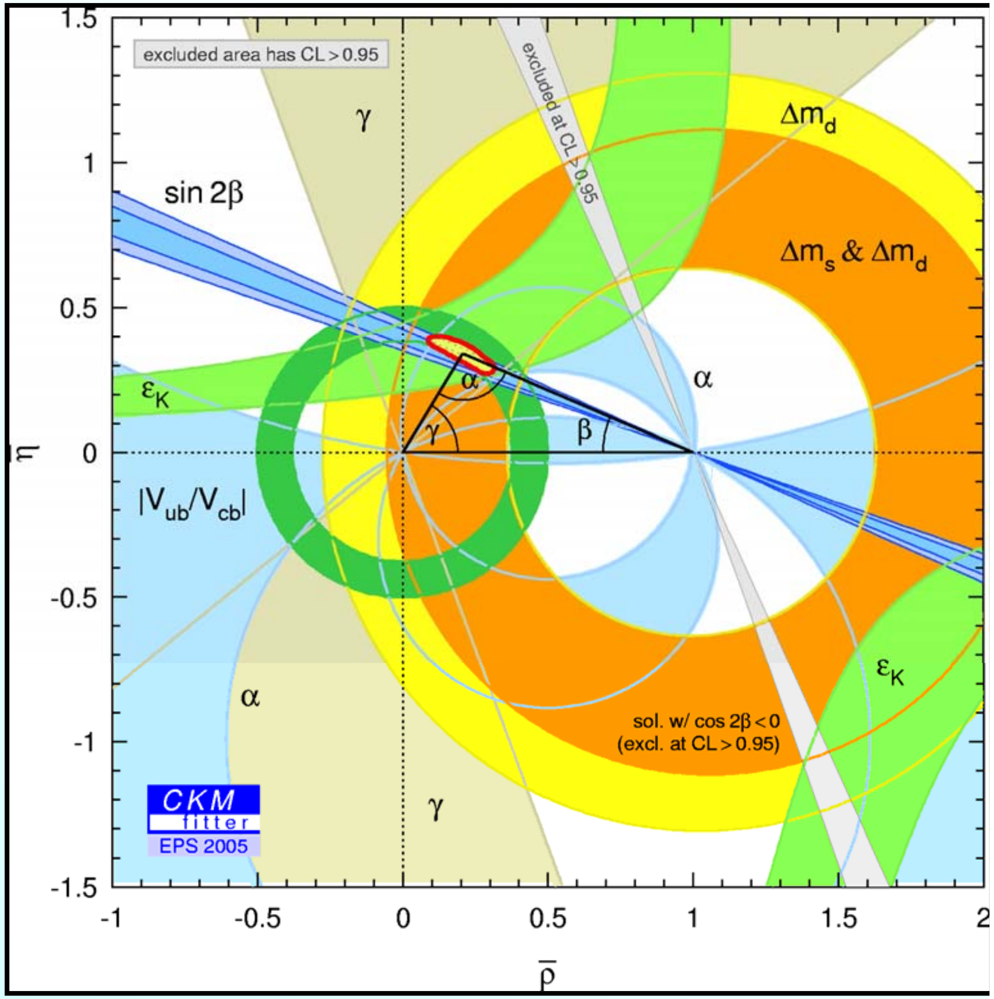
Constraint from Bs mixing

- B mixing parameters Δm_s and Δm_d provide an important constraint of unitarity triangle:

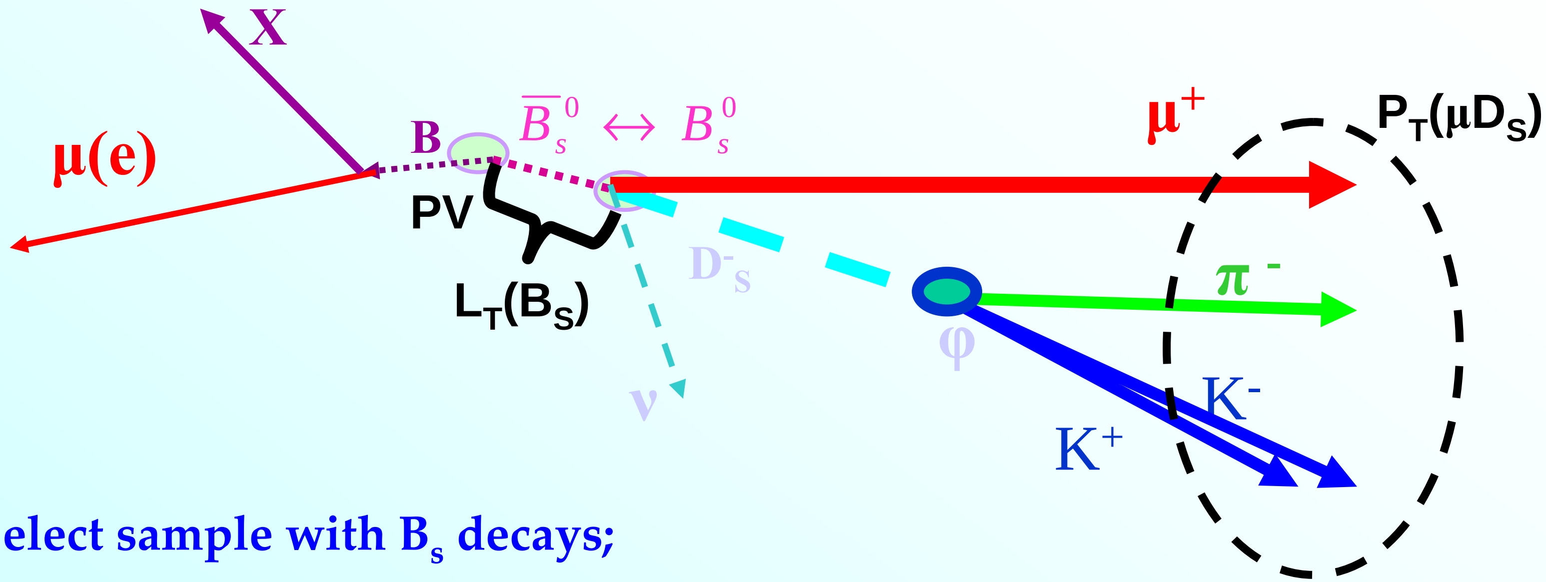
$$\frac{\Delta m_s}{\Delta m_d} \propto \left|\frac{V_{ts}}{V_{td}}\right|^2$$

- Many uncertainties cancel in this ratio;





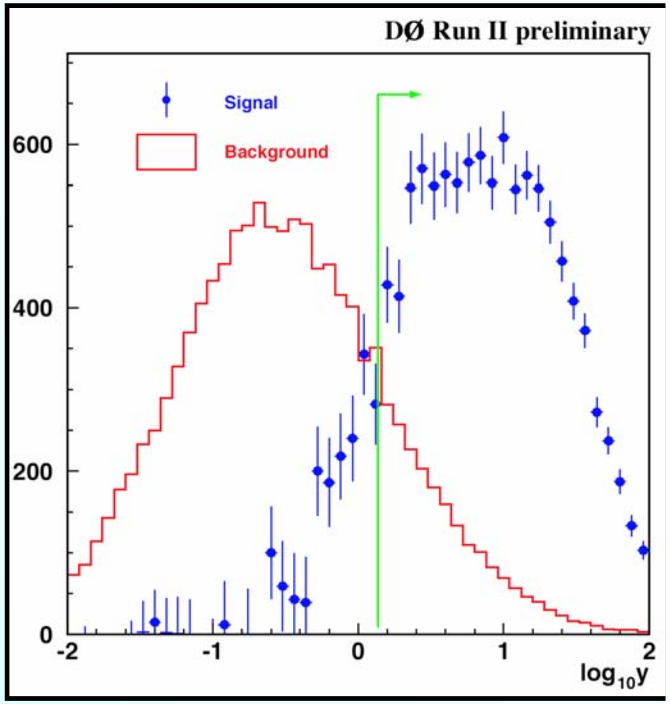
Analysis outline



- Select sample with B_s decays;
- Find sample composition;
- Measure B_s decay length;
- Determine efficiency of selection and 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;
- Extract B_s mixing parameter;

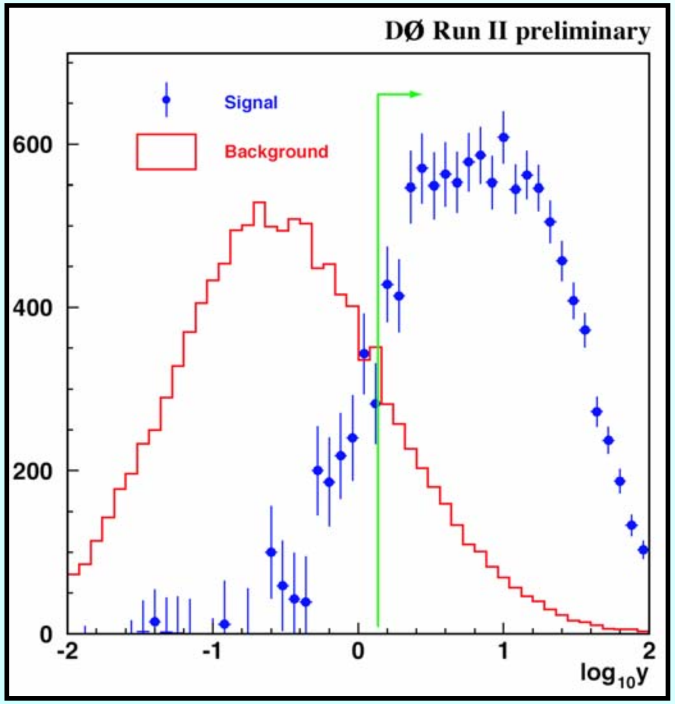
Select B_s decay

- 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:
  - isolation;
  - helicity angle of Ds decay;
  - M(KK);
  - $M(\mu D_s)$;
  - $p_t(\phi)$;
  - $\chi^2(D_s \text{ vertex})$;

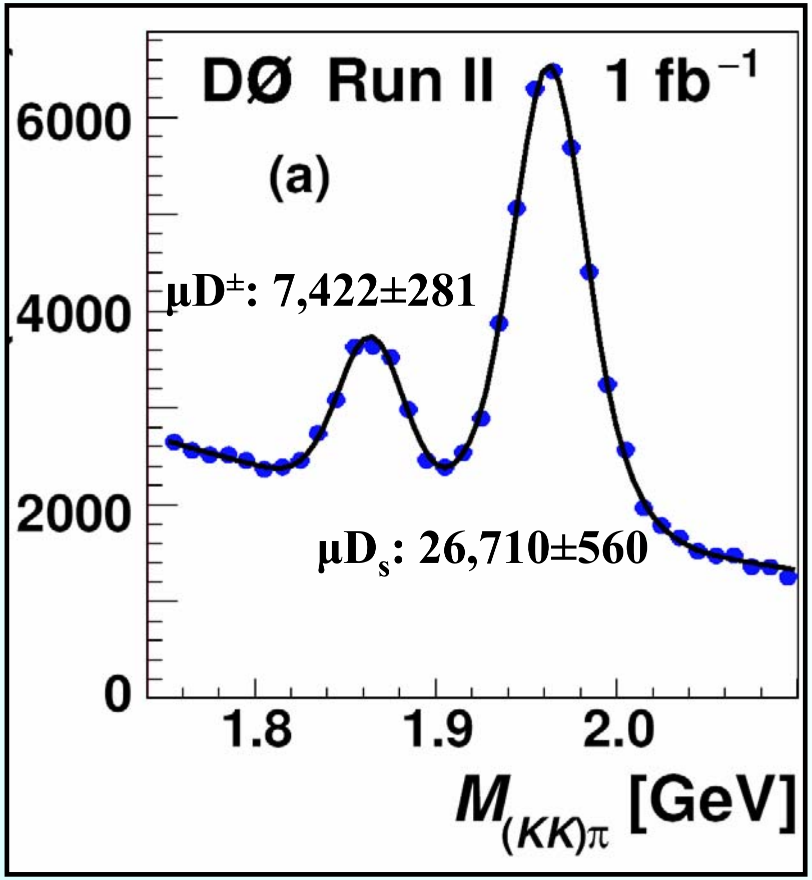


Likelihood ratio

Selected Sample

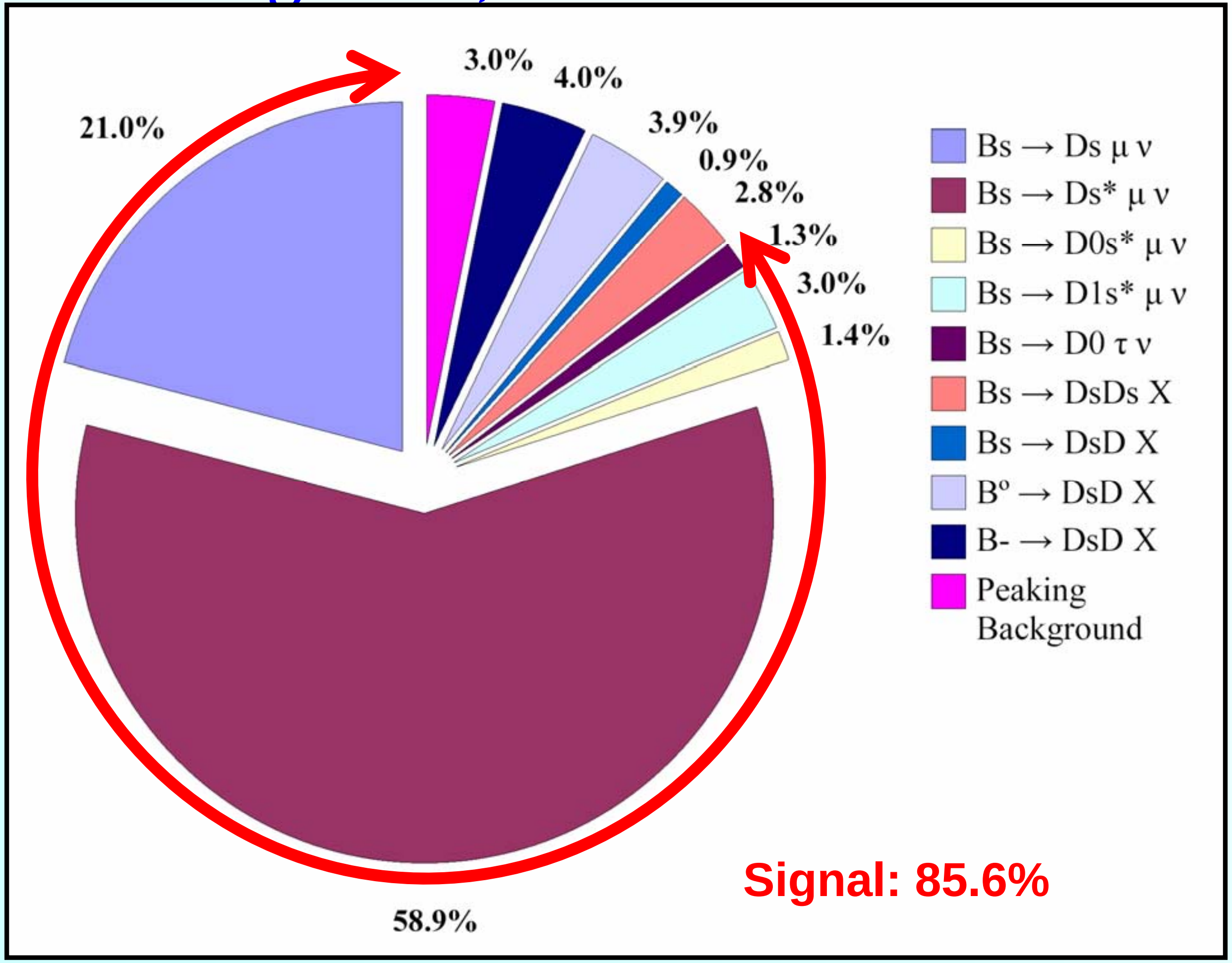


Likelihood ratio



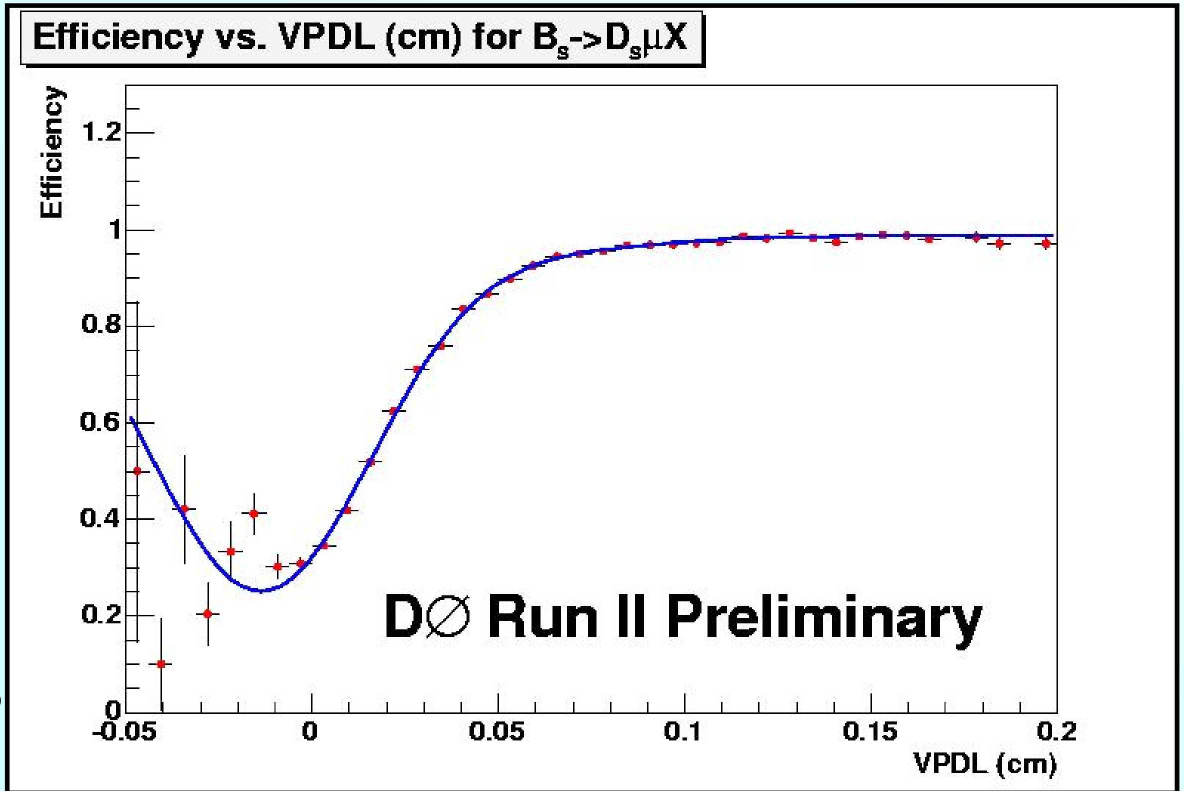
Sample Composition

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



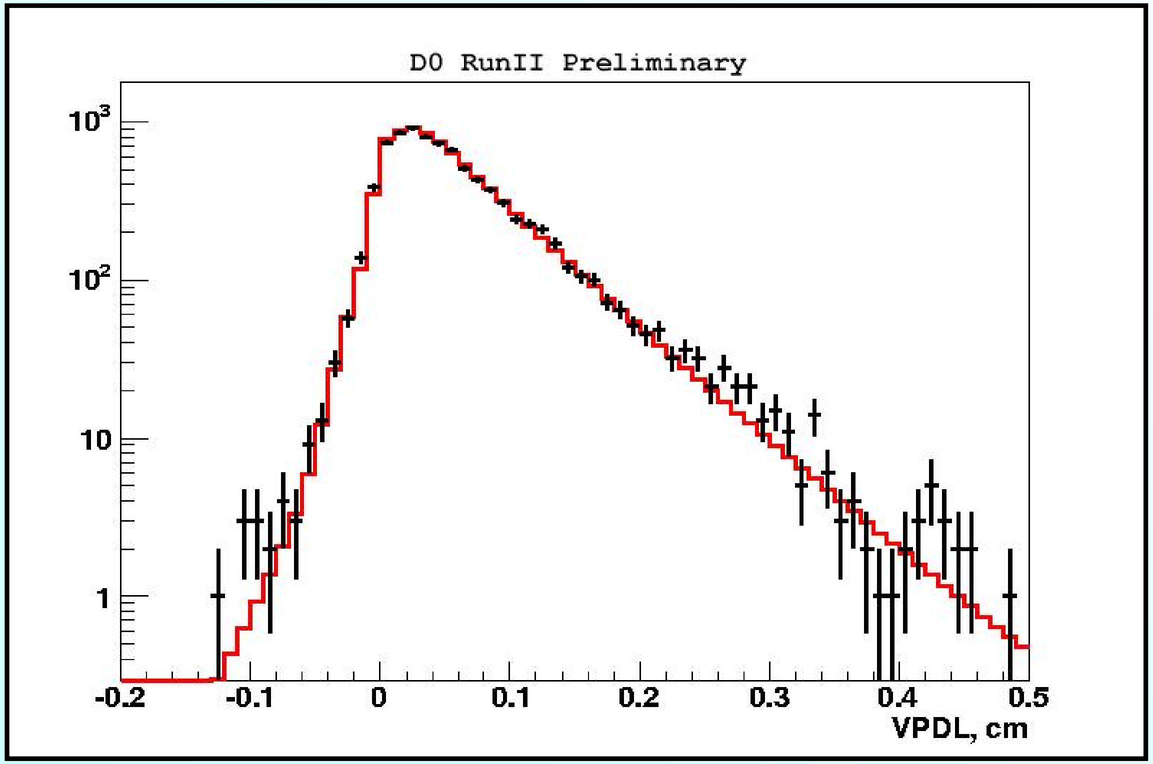
Selection Efficiency

- Lifetime dependent efficiency is unavoidable in absence of particle ID;
- Selection efficiency was determined from MC;
- Efficiency is non-zero for $c\tau=0$ - the most important region for B_s mixing;



B_s lifetime fit

- Selection efficiency was verified by measuring the B_s lifetime - it is very sensitive to the efficiency;
- fit result: $c\tau = 412 \pm 9$ μm (stat); PDG value: $c\tau = 433 \pm 20$ μm;
- Reasonably good agreement;

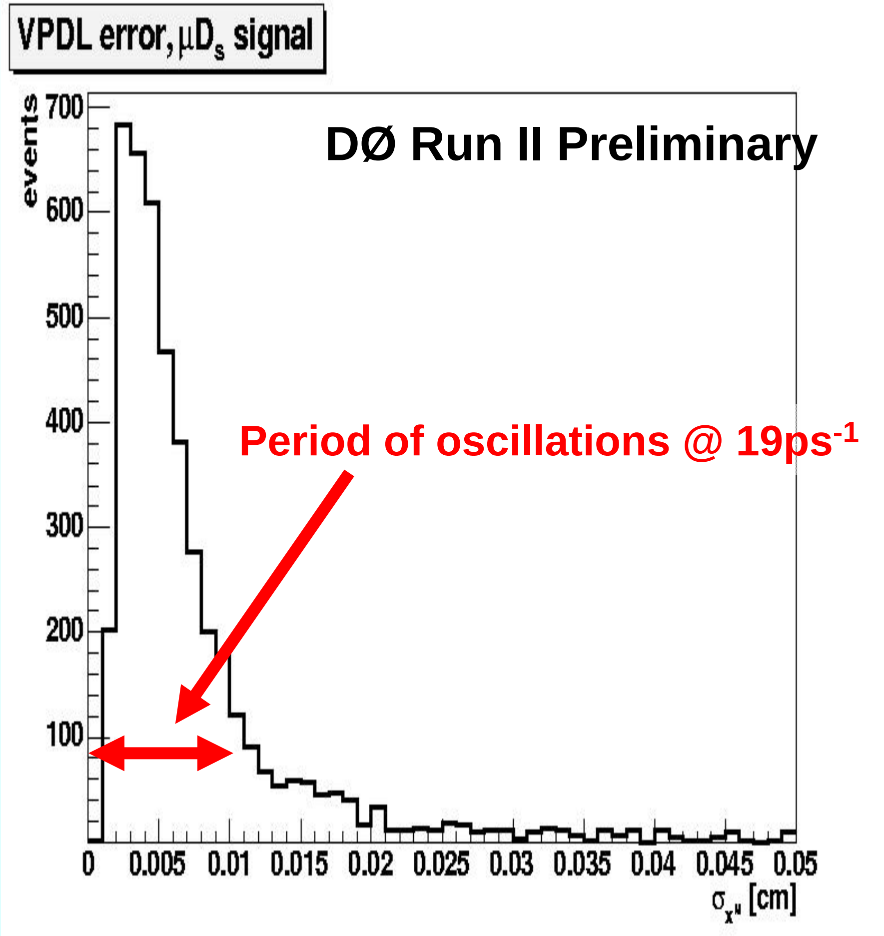


Decay length resolution

- The most important ingredient of analysis:

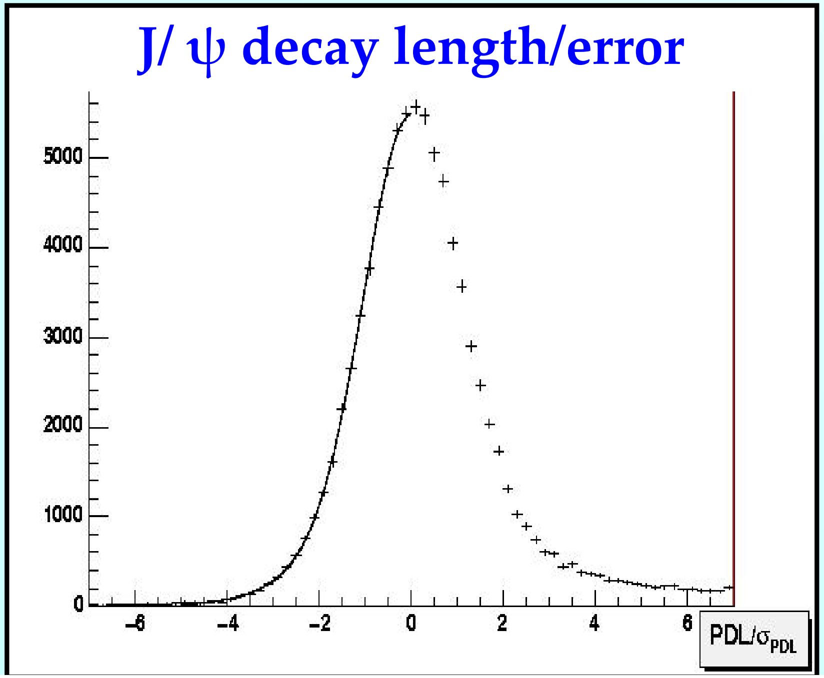
$$Significance \approx f_{sig} D\ e^{-(\Delta m_s \sigma_\tau)^2/2}$$

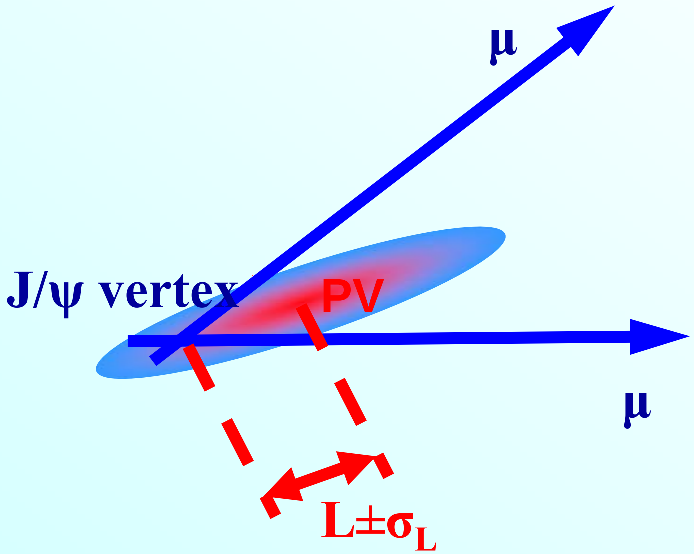
- Events with small resolution provide the main contribution to result;
- We have reasonable number of events to be sensitive to oscillations with Δm_s~19 ps^{-1};



Calibration of Resolution

- Scale factor for resolution was determined using the prompt $J/\psi \rightarrow \mu\mu$ decays;
- Resolution scale factor is ~1.0 for 72% of events and 1.8 for remaining events;
- Independently, the procedure to tune the resolution using QCD events was developed;
- Both of them give consistent results on scale factor;





Proper Decay Length

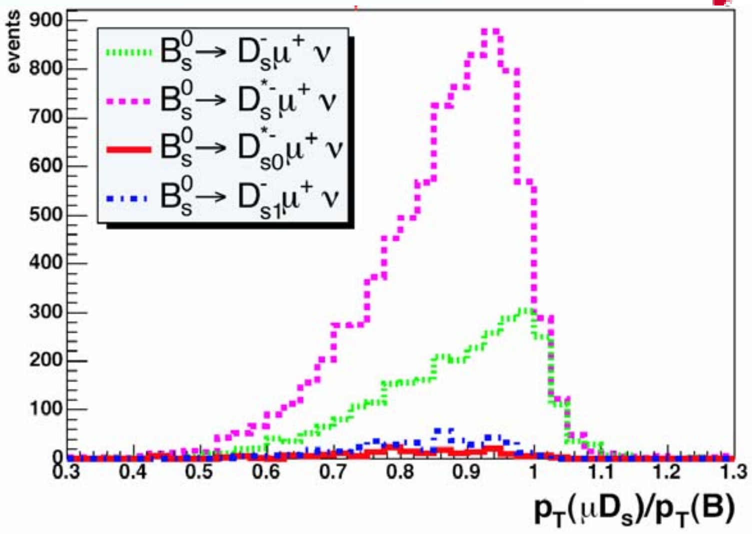
- Proper decay length:

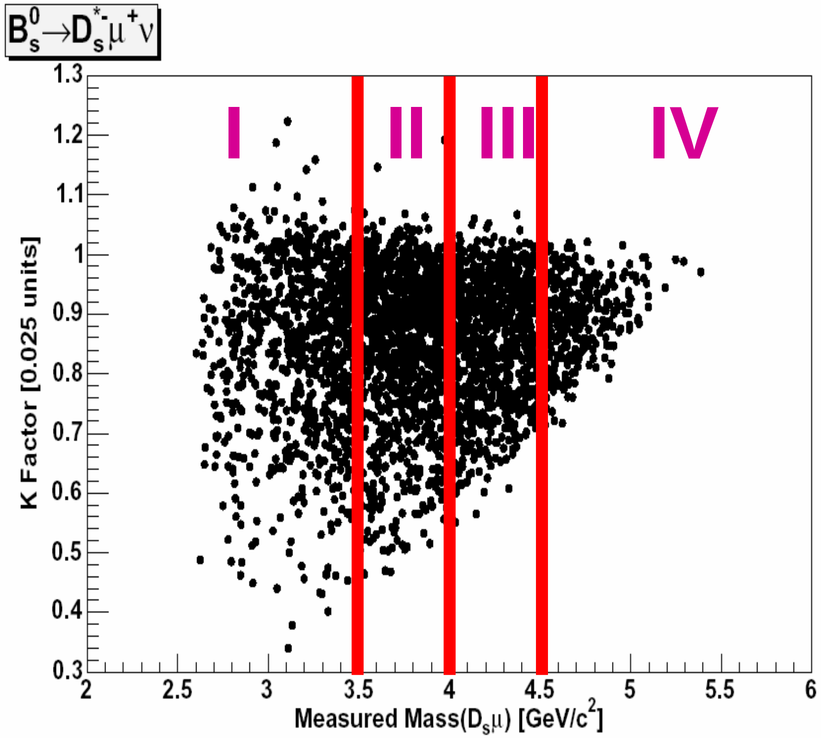
$$L = M_B \cdot L_{xy} / P_t^B$$

- Neutrino in semileptonic decays escapes undetected;
- K factor takes into account the energy of all missing particles:

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

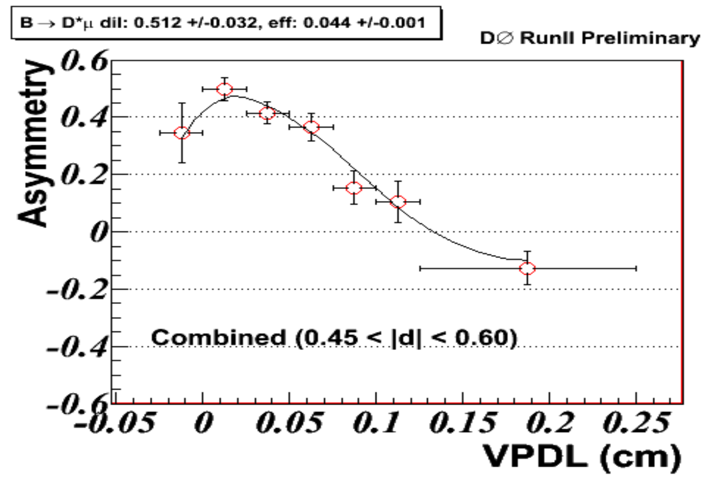
- Its distribution was taken from MC;
- To improve the K-factor resolution, its distribution was determined separately for different $M(\mu D_s)$;





Flavor Tagging

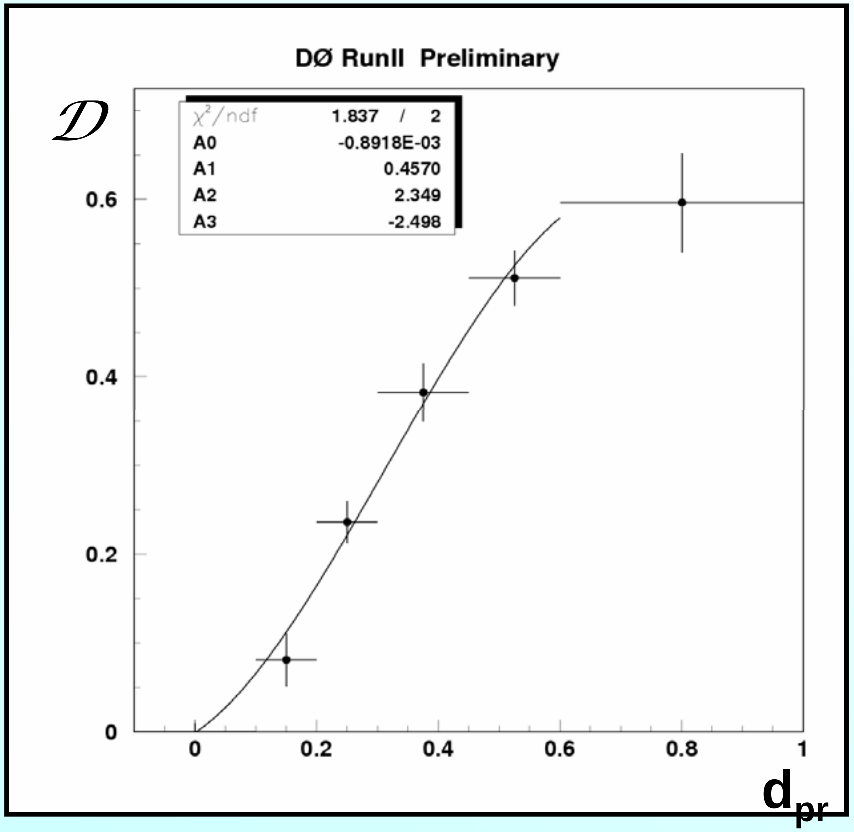
- Very important component of analysis;
- Determines the flavor of B_s at the production point;
- Opposite side flavor tagging is used for the moment:
  - opposite muon;
  - opposite electron;
  - opposite secondary vertex;
- Calibrated using well known $B_d \rightarrow \mu \nu D^*$ decays;



$$\Delta m = 0.506 \pm 0.020 \text{ (stat.) } ps^{-1}$$
$$\varepsilon D^2 = (2.48 \pm 0.21)\ (\%)\ (\text{stat.})$$
$$\varepsilon = (19.9 \pm 0.2)\ (\%)\ (\text{stat.})$$

Flavor Tagging

- Flavor tagging was used on event by event basis;
- Dilution (= 2η-1) was determined as a function of the tagging variable using $B_d \rightarrow \mu\nu D^*$ events ;
- It additionally improves the performance by ~10%;



Unbinned Likelihood fit

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

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

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

Proper decay length (x_M)

Proper decay length resolution (σ_{x_M})

Flavor tag (d_{pr})

Mass ($\phi\pi$) distribution ($P^{M_{\phi\pi}}$)

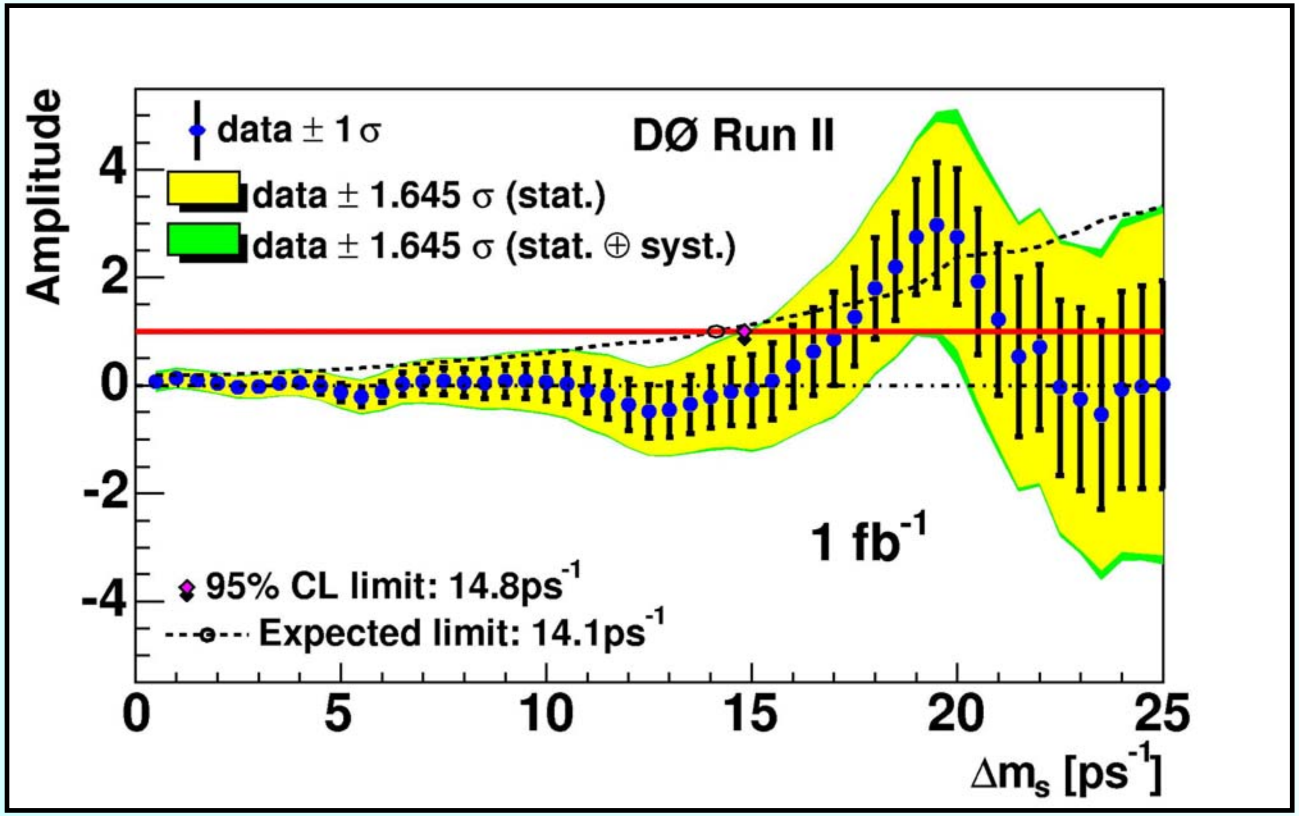
Amplitude Method

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

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

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

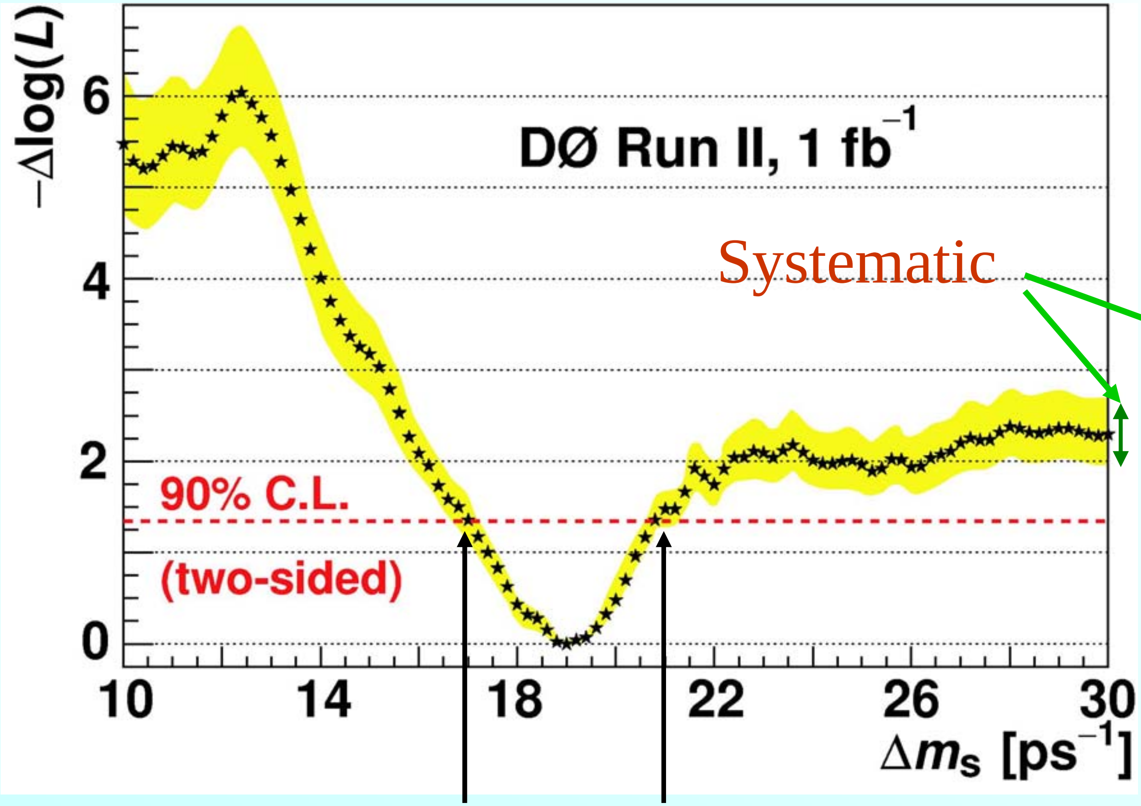
Amplitude Scan Results



- **Deviation of amplitude from zero for Δm_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 < Δm_s < 21 ps^{-1} 90% CL assuming Gaussian errors;

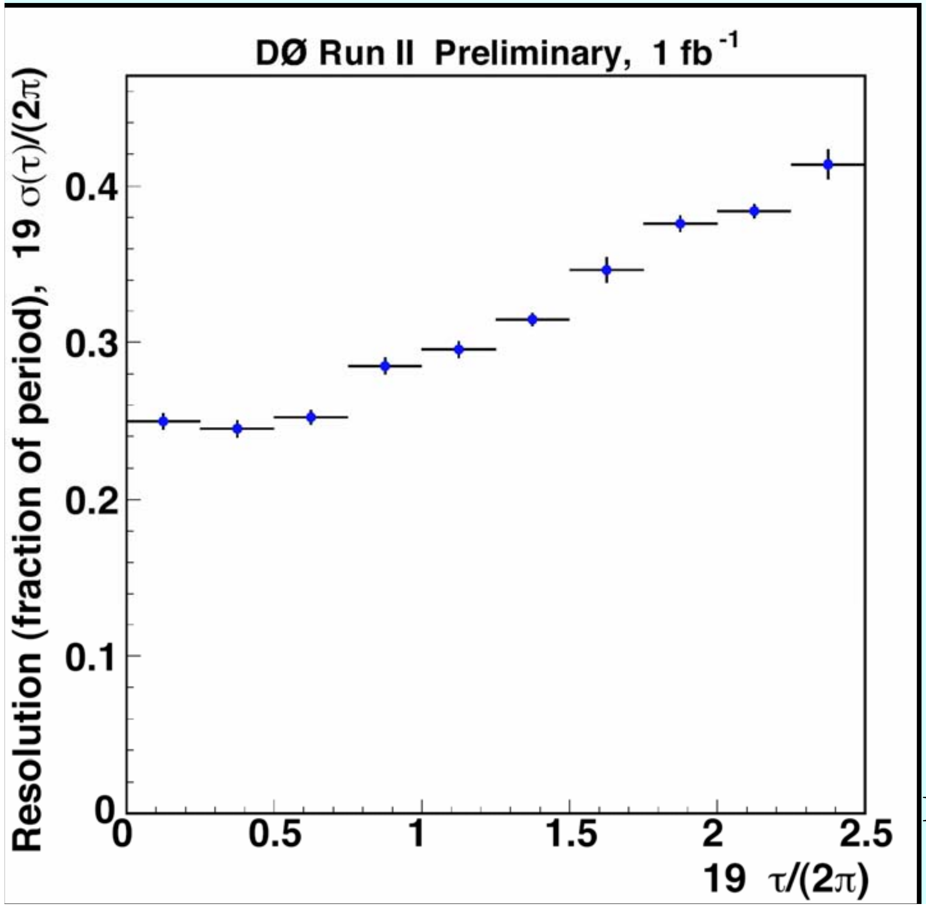
Most probable value Δm_s =19 ps^{-1};

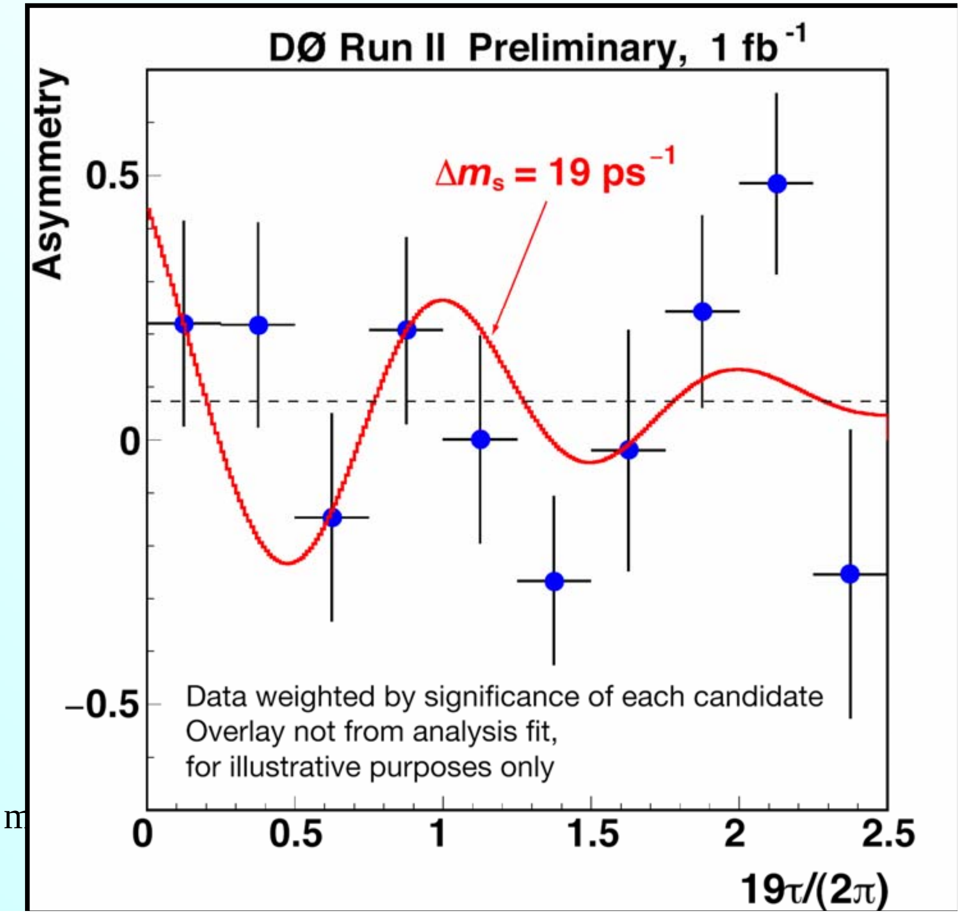
Consistency Tests

- **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%;
- **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}**

See oscillation by Eye

- Select events with large significance: $Significance \approx f_{sig} D\ e^{-(\Delta m_s \sigma_\tau)^2/2}$
- Build asymmetry for them;
- Result consistent with the amplitude scan: ~2σ deviation from "zero-asymmetry" hypothesis ;





Bs m

Future improvements:

- **Near term improvements:**
  - new semileptonic channels (eD_s; $D_s \rightarrow K^*K$);
  - hadronic decays;
  - Improved flavor tagging;
- **Detector improvement: SMT Layer 0 is installed:**
  - Significant improvement in the decay length resolution is expected:
    - ~60% for low p_t tracks;
    - ~20% for high p_t tracks;
- **More statistics from Run2b;**
- **B_s oscillation will be established in the near future, if its value is $\Delta m_s < 22$ ps^{-1};**

Conclusions

- **1 fb^{-1} of data from Tevatron analyzed by DØ;**
- **New B_s mixing study was performed;**
- **Amplitude deviates from zero by 2.5 σ at Δm_s=19 ps^{-1};**
- **90% CL range obtained assuming Gaussian errors:**

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

- **More improvements expected in the nearest future.**