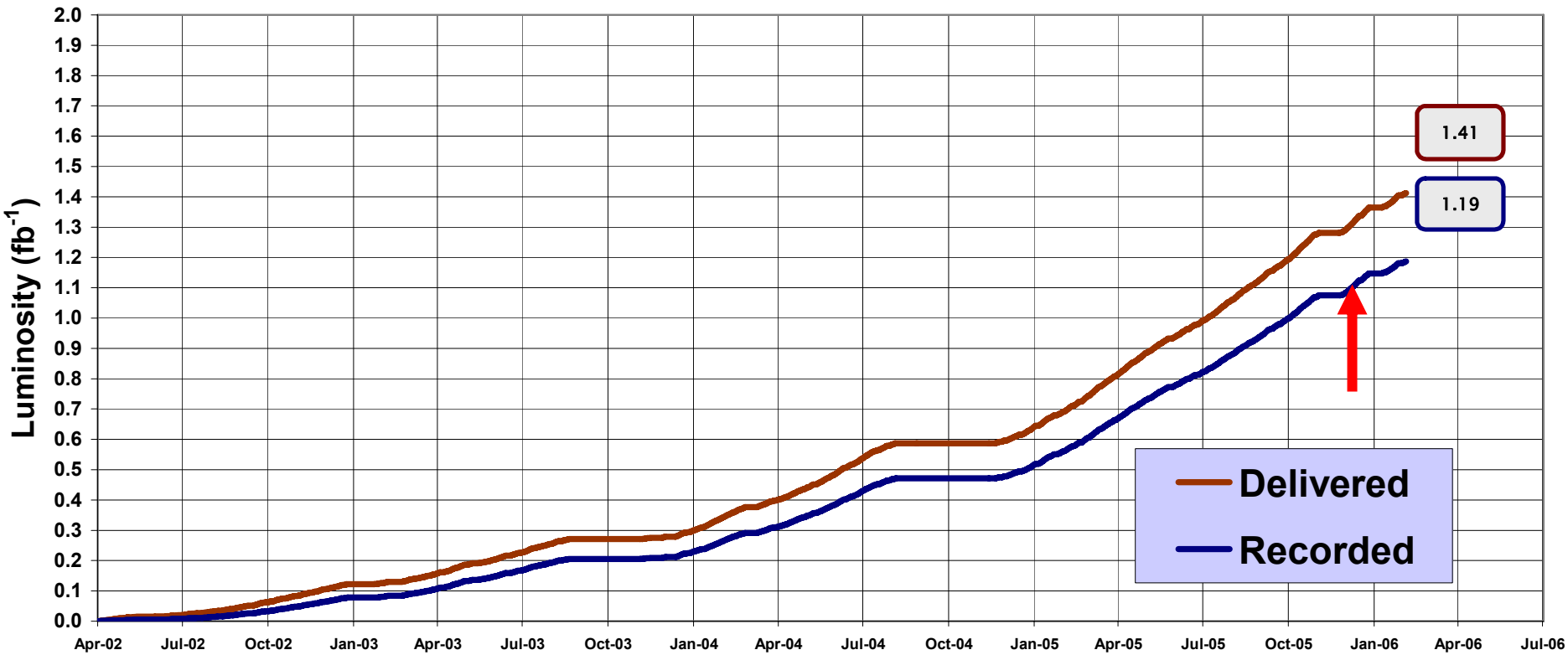
Hot Topics at D0

David Buchholz
(Northwestern Univ)
On behalf of the DØ Collaboration

D0 Results

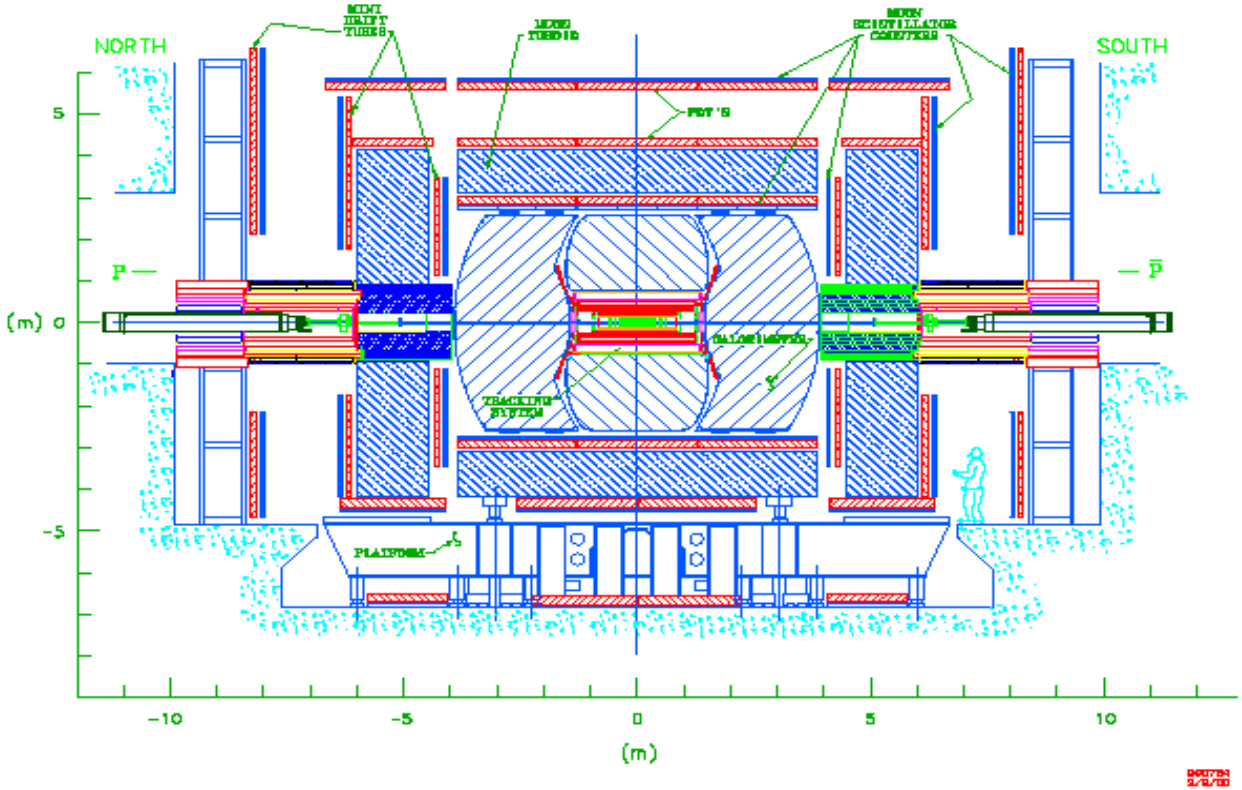
- **D0 Talks at this conference-**
  - **b physics**
    - ✓ B mixing and lifetimes- Piedra
    - ✓ B_s decays and B leptonic decays- Van Kooten
  - **t physics**
    - ✓ Top Physics – Clement
- **Many new b and t physics results**
  - **Watch for these in other talks**
- **Hot Topics at D0**
  - **B_s and B_d mixing**
  - **CP violation result in B decays**
  - **Flavor Changing Neutral Current results ($D^{\pm} \rightarrow \pi^{\pm}\mu^{+}\mu^{-}$)**

Excellent Tevatron Performance



- Data sample corresponding to over 1 fb^{-1} of the integrated luminosity used for the Bs mixing analysis
- Results are being reported on this 1 fb^{-1} sample

D0 Detector



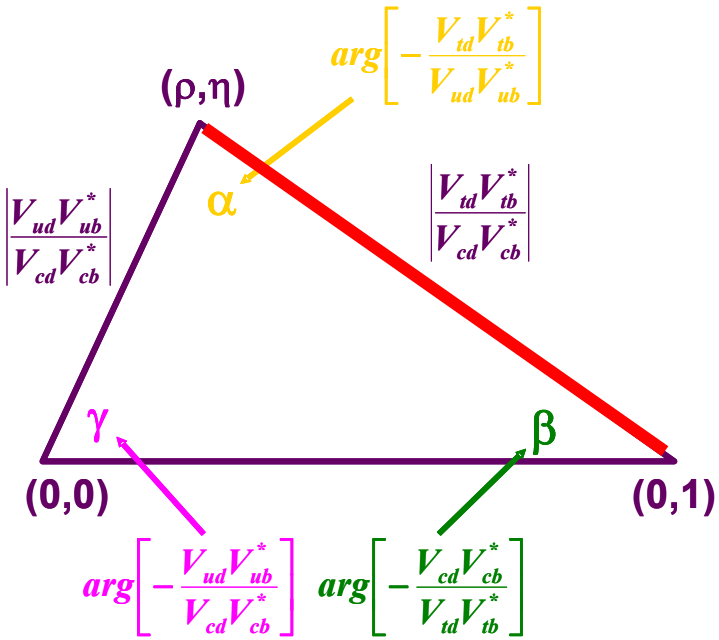
B Physics Program based on excellent performance of

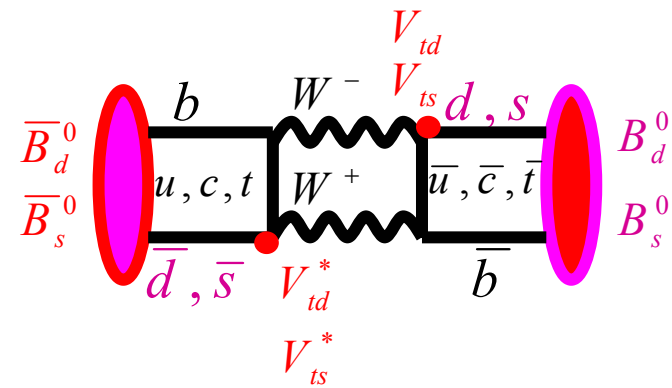
1) muon system, *$|\eta|<2.0$, $p_T > 3,4,5$ GeV*

2) silicon microstrip tracker

3) Good single and dimuon triggers

Unitarity Triangle- B Mixing Contribution





$$\Delta m_d \sim (\text{lots of QCD}) \times |V_{td}|$$

$$\Delta m_s \sim (\text{lots of QCD}) \times |V_{ts}|$$

$$\Delta m_s / \Delta m_d \sim (\text{much less QCD}) \times |V_{ts}| / |V_{td}|$$

Measurement of Δm_s contributes to better determination of V_{td}

$B - \overline{B}$ Mixing and Oscillations

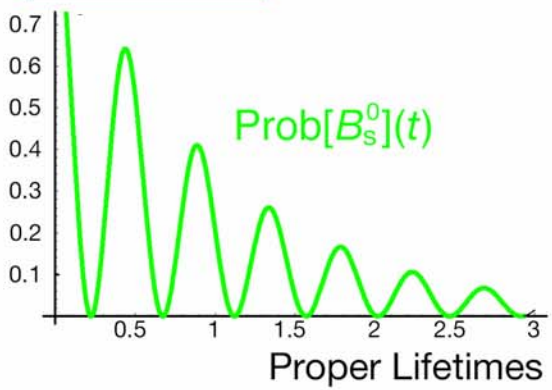
- If initially start with a B_s^0

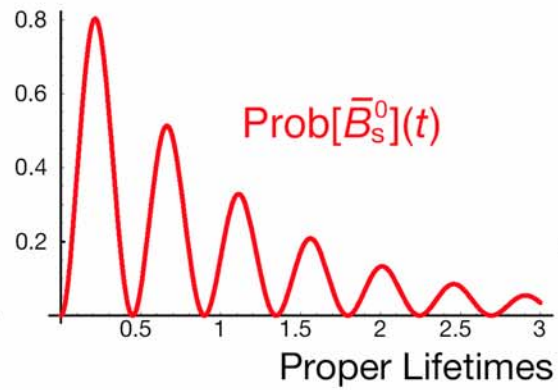
Extract frequency

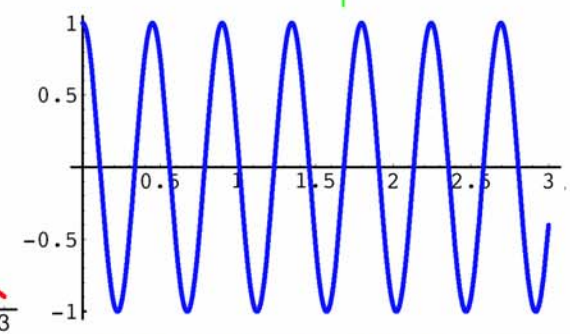
$$\mathrm{Prob}[B_s^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) + 2\exp(-\Gamma t)\cos(\Delta m_s t)\right]$$

$$\mathrm{Prob}[\bar{B}_s^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) - 2\exp(-\Gamma t)\cos(\Delta m_s t)\right]$$

- For B_s^0







Take asymmetry of two:

$$A = \frac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$$

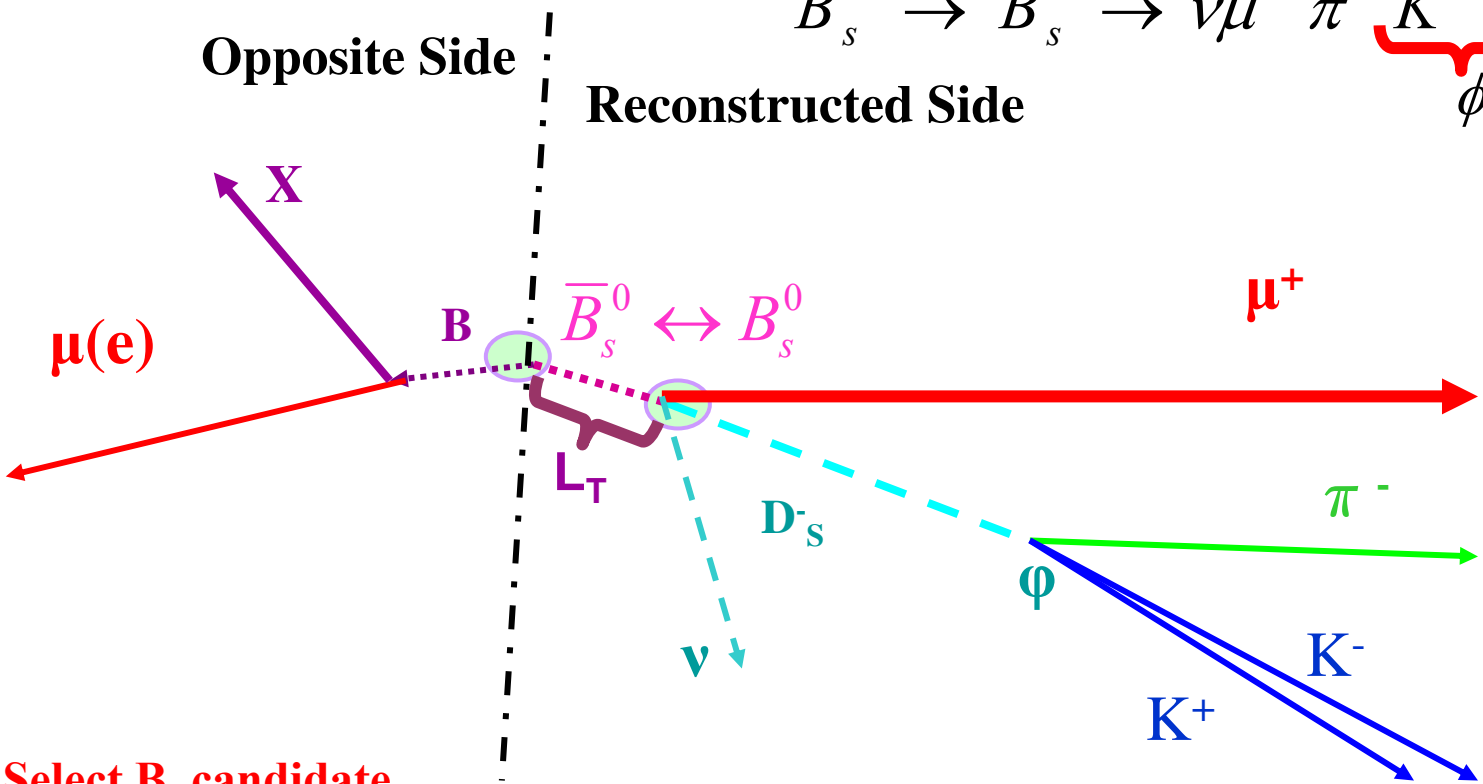
$$A \propto \cos(\Delta m_s t)$$

- What we get from it: $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$

- $\Delta m_d \propto |V_{tb}^* V_{td}|^2$ ~1 tiny
- $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$ ~1 still small, but larger than V_{td}

Analysis Outline

$$\overline{B}_s^0 \rightarrow B_s^0 \rightarrow \nu\mu^+ \overbrace{\pi^- \underbrace{K^+ K^-}_{\phi}}^{D_s^-}$$



- **Select B_s candidate**
  - *Concentrate on the most clean decay mode $B_s \rightarrow \nu\mu D_s(\rightarrow\varphi\pi)$*
- **For each B_s candidate**
  - *B_S flavor at decay time from muon sign at the reconstructed side*
  - *Transverse length L_T and its error*
  - *Transverse momentum $P_T(B_s)$ (use $P_T(D_s\mu)$)*
  - *B-hadron flavor at the opposite side (indicates B_S flavor at production time)*

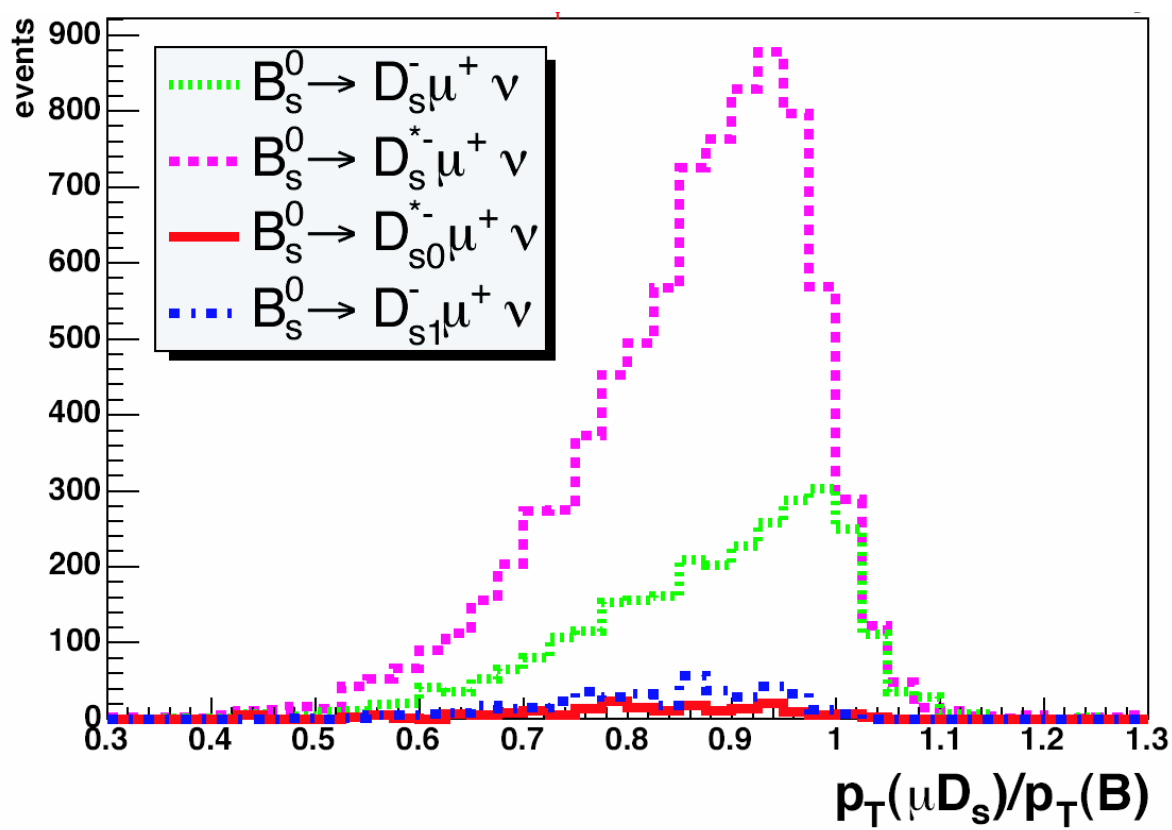
Proper Decay Length

$$ct_{B_s} = x^M K \Leftarrow K = p_T^{D_s\mu} / p_T^{B_s}$$

- Proper Decay Length is determined from the Visible Proper Decay Length
- K-factor takes into account the escaping neutrino and other missing particles

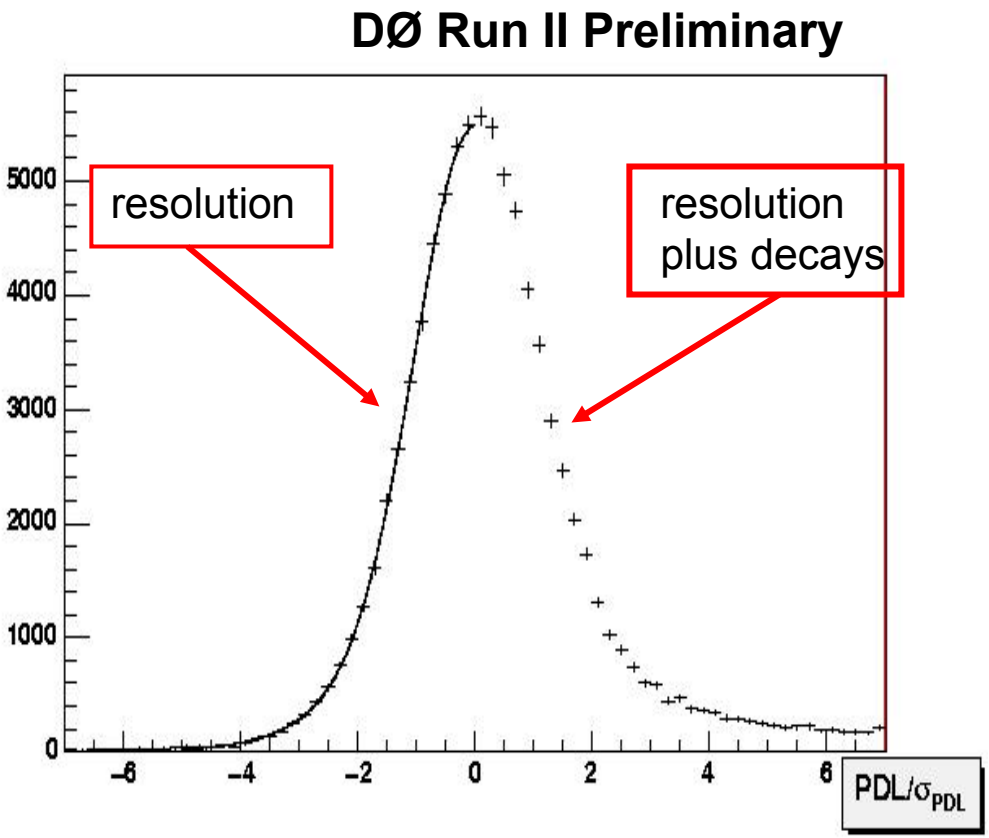
$$B_s^0 \to D_s^{*-}\mu^+\nu$$
$$\hookrightarrow D_s^-\gamma$$

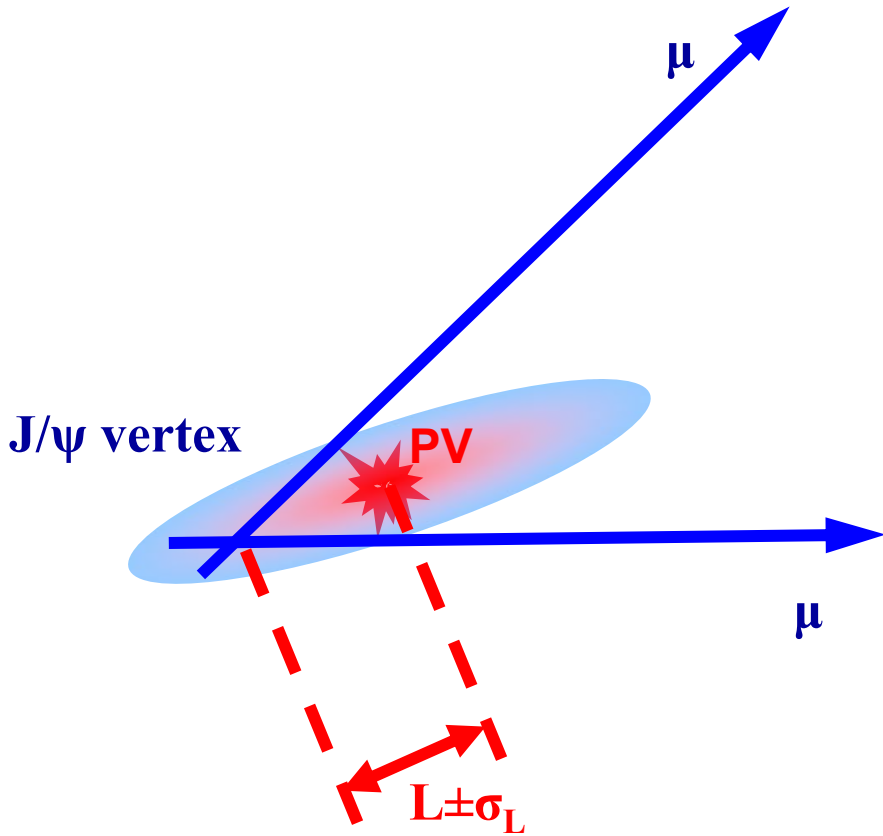
- From MC for each decay mode- different excited states



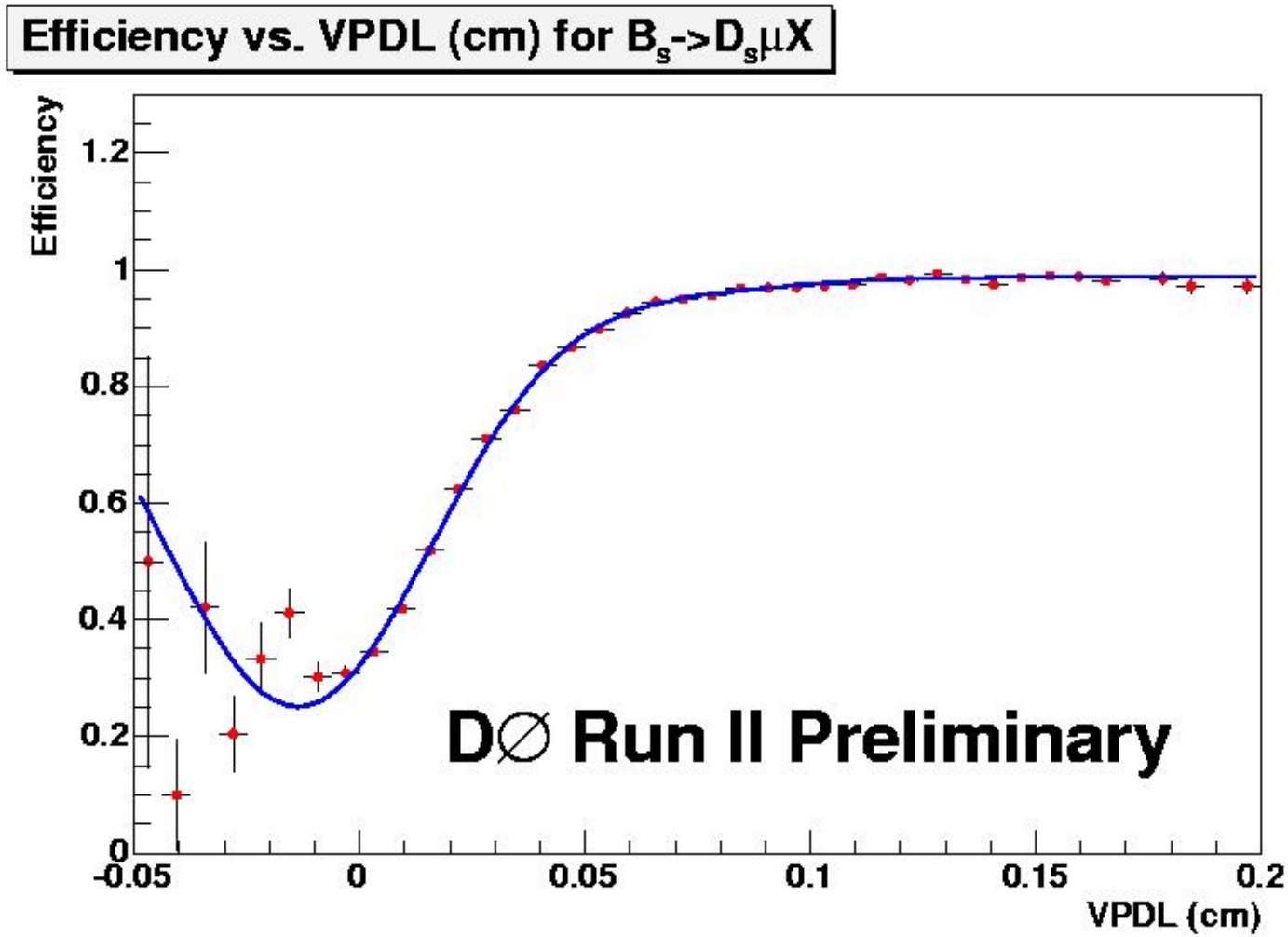
Resolution Calibration Using Data

- **Use J/ψ→μμ sample**
  - Fit pull distribution for J/ψ Proper Decay Length with 2 Gaussians
  - Resolution Scale Factor is 1.0 for 72% of the events and 1.8 for the rest
  - Confirmed by Impact Parameter tuning procedure in MC



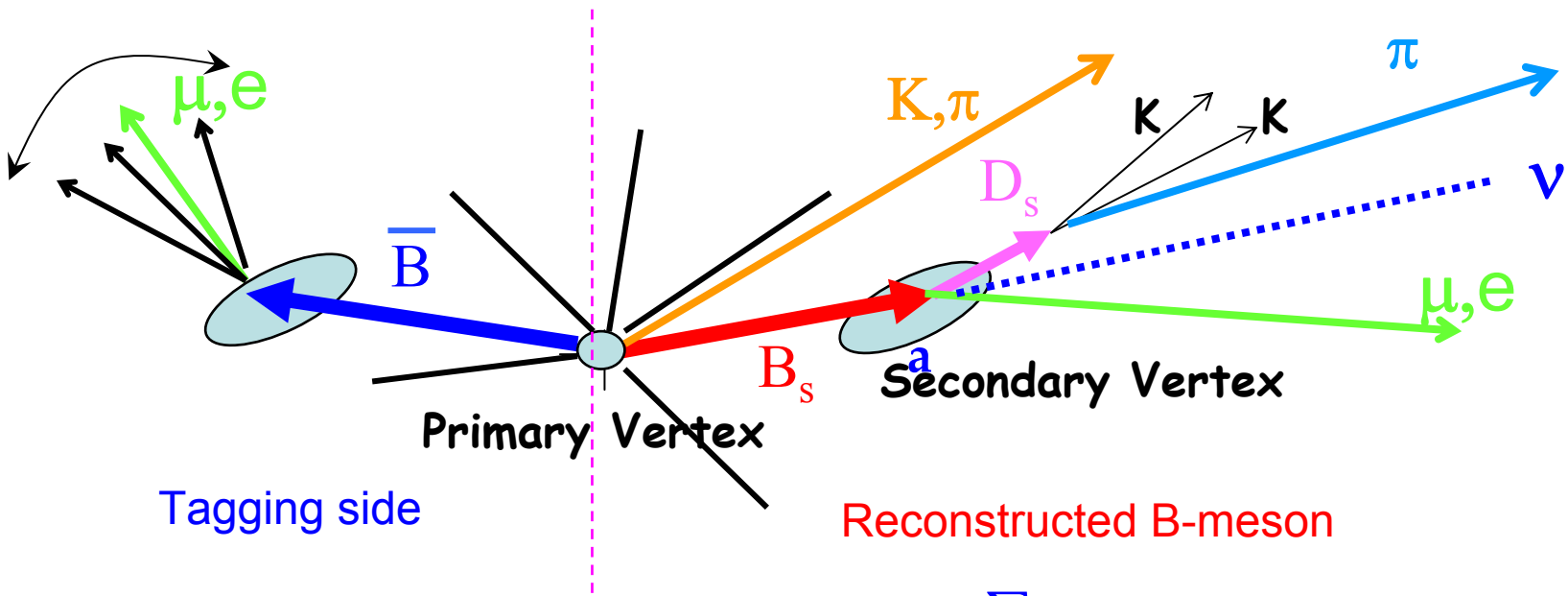


Efficiency Dependence on VPDL



- **From MC**
  - Cross-checked and tuned using data
- **Note that efficiency at VPDL=0 is not 0**

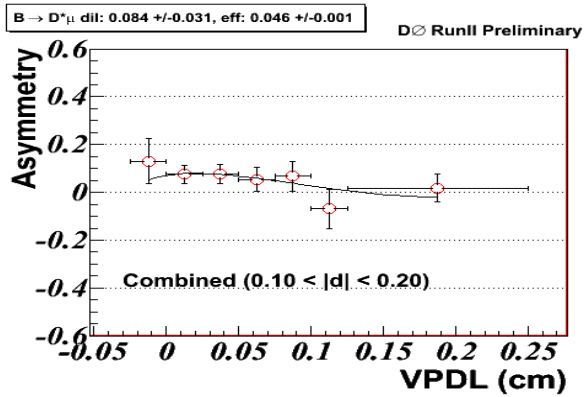
Opposite Side Tagging

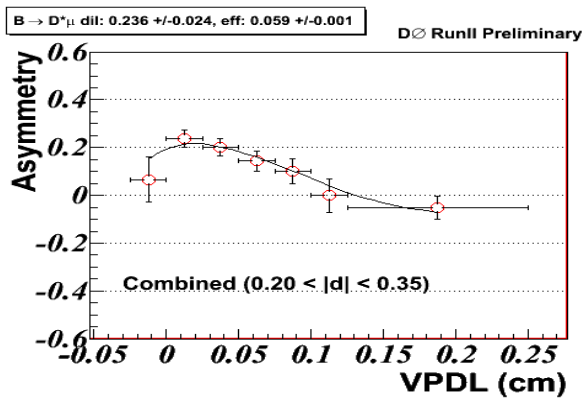


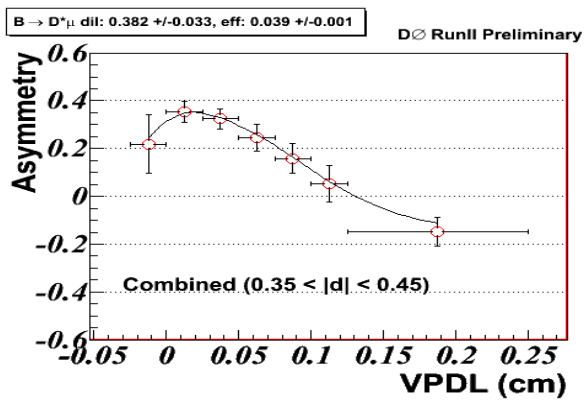
- Muon (electron) jet charge defined as: $Q_\mu = \frac{\sum (p_t \cdot q)}{\sum p_t}$
  - Sum is taken over all tracks in the cone ΔR<0.5 around muon;
- SV Charge: $Q_{SV} = \frac{\sum p_{\parallel}^{0.6} \cdot q}{\sum p_{\parallel}^{0.6}}$
- Event charge: $Q_{ev} = \frac{\sum (p_t \cdot q)}{\sum p_t}$
  - all tracks with ΔR < 1.5 w.r.t. reconstructed B direction are used

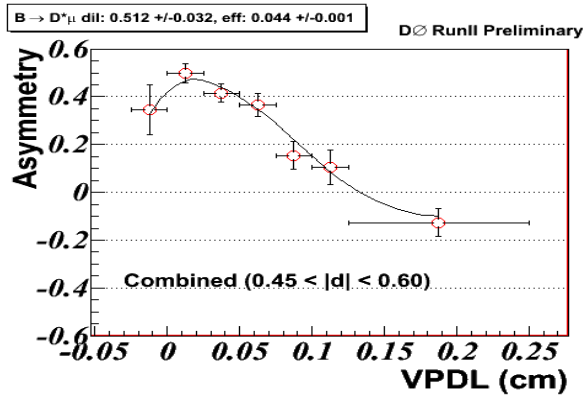
Calibration of Dilution Using $B_d \rightarrow D^{*\pm}\mu\nu X$

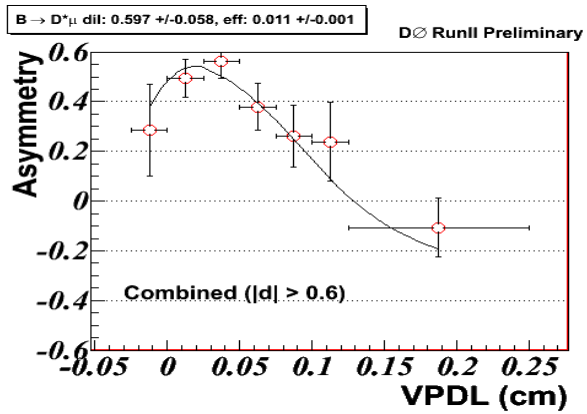
Increasing dilution











Increasing dilution

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

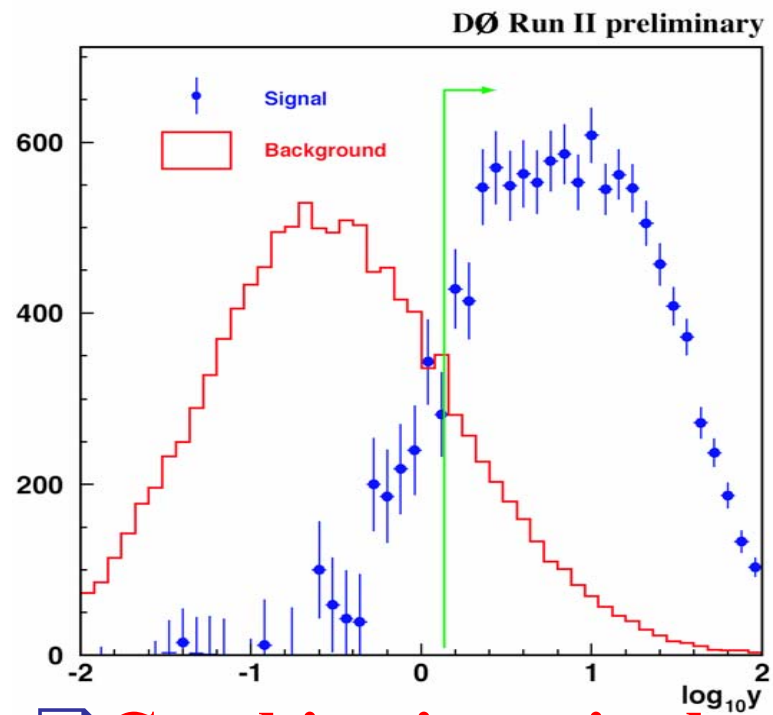
$\varepsilon \mathcal{D}^2 = (2.48 \pm 0.21)$ (%) (stat.)

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

$\Delta m_{HFAG} = 0.507 \pm 0.004\ ps^{-1}$

Final Signal Selection

- **Use likelihood ratio method**
  - *Set of discriminating variables x_i constructed for each event*
    - ✓ Helicity Angle (D_s,K_1)
    - ✓ μD_s Isolation
    - ✓ $p_T(K_1K_2)$
    - ✓ $m(\mu D_s)$
    - ✓ χ^2 of D_s Vertex Fit
    - ✓ $m(K_1K_2$ or $K_1\pi)$
  - *Construct likelihood ratio for each variable*
    - ✓ bgrd from $m(D_s)$ sidebands
    - ✓ signal from bgrd-sub peak

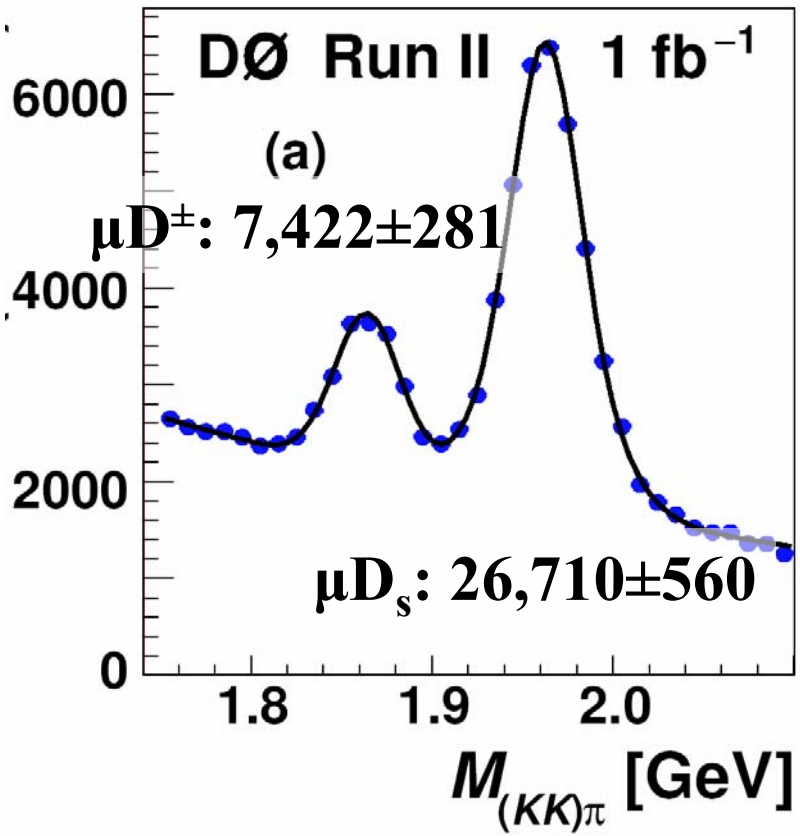


- **Combine into single variable**
  - *Use for final selection*

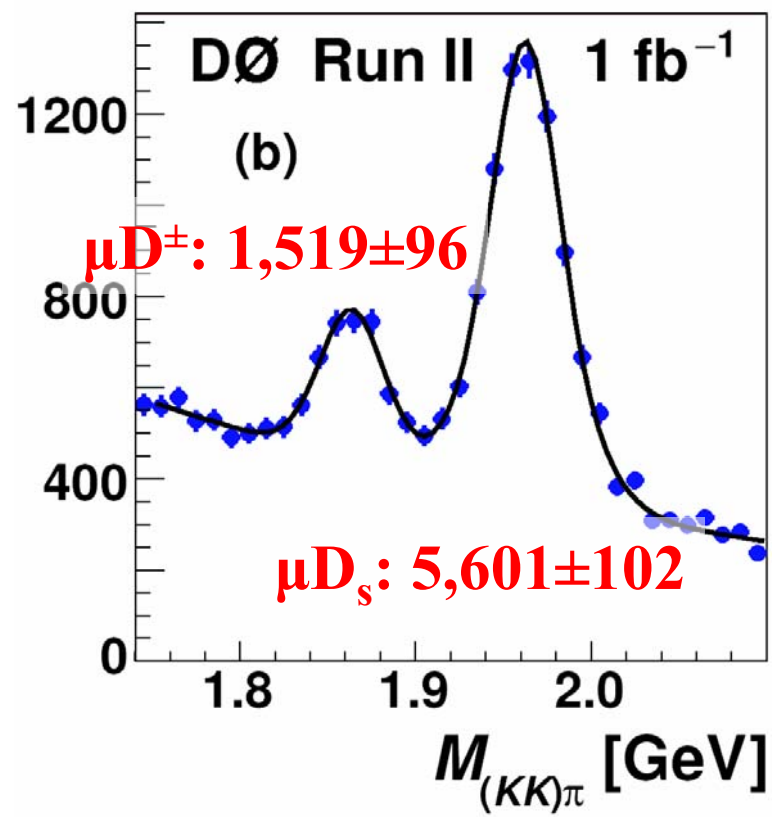
$$y_i = \frac{f_i^S(x_i)}{f_i^B(x_i)}$$

$$Y = \prod_i^n y_i$$

$\mu\phi\pi$ sample @ D0 (~1 fb^{-1})

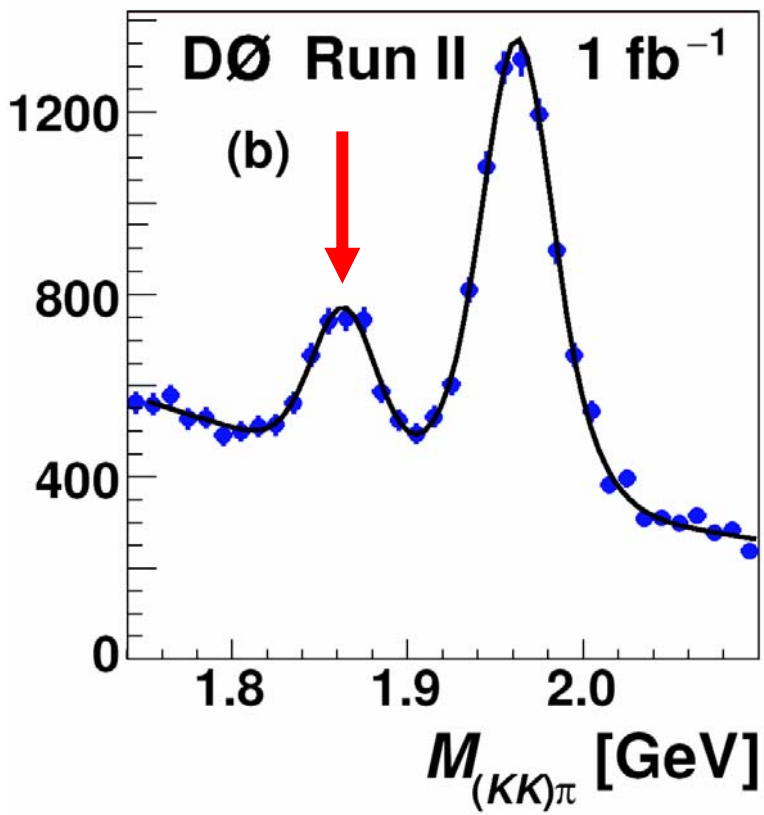


Opposite-side flavor tagging

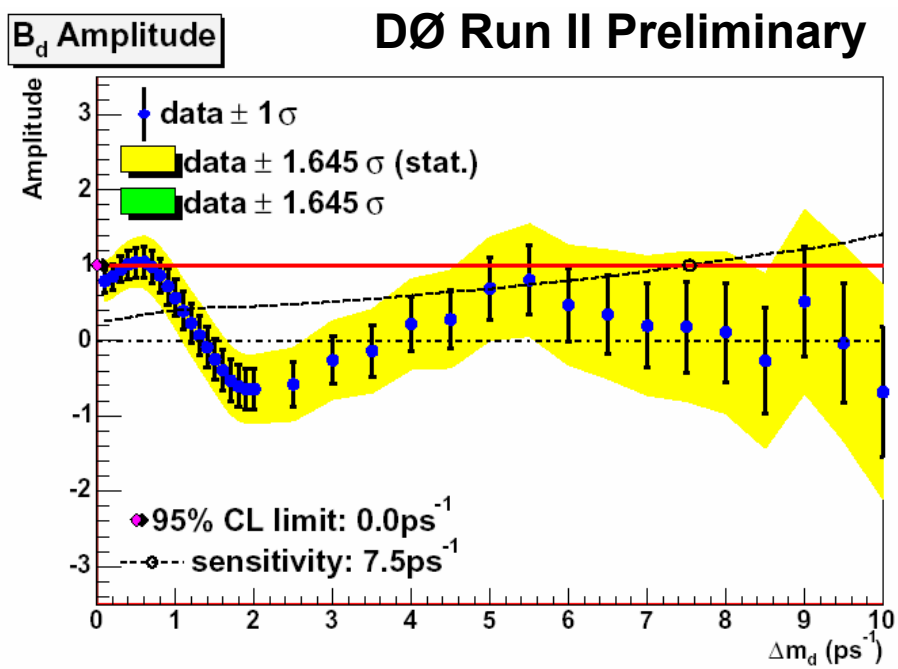


Tagging efficiency ~20%

Cross-check Using $B_d \rightarrow X\mu D^{\pm}(\rightarrow \phi\pi)$



Amplitude Scan



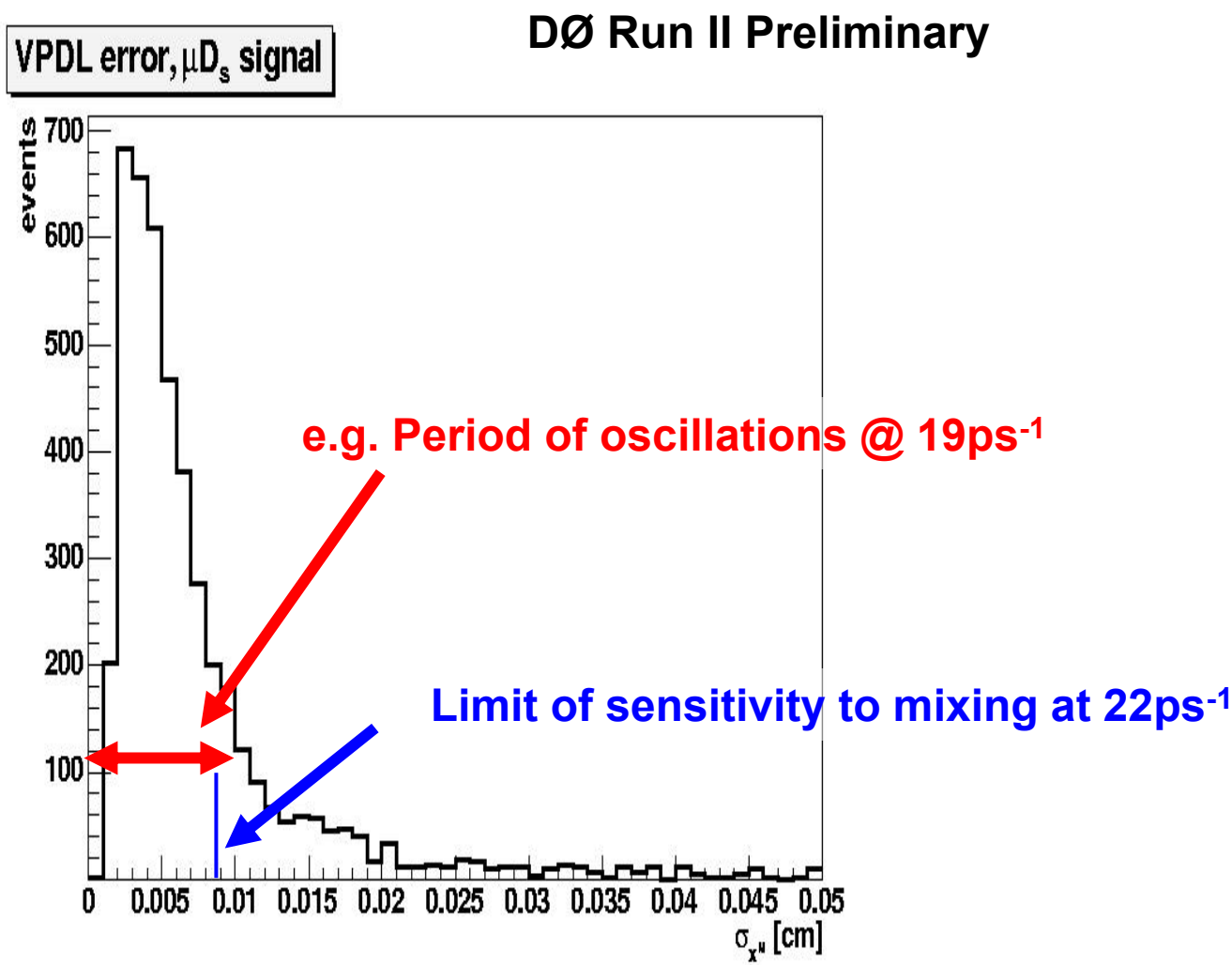
- **The Amplitude Scan reveals the Bd oscillations**
  - at correct place → no lifetime bias
  - with correct amplitude → correct dilution calibration

Event-by-Event Fit

- **Minimize the Likelihood function**

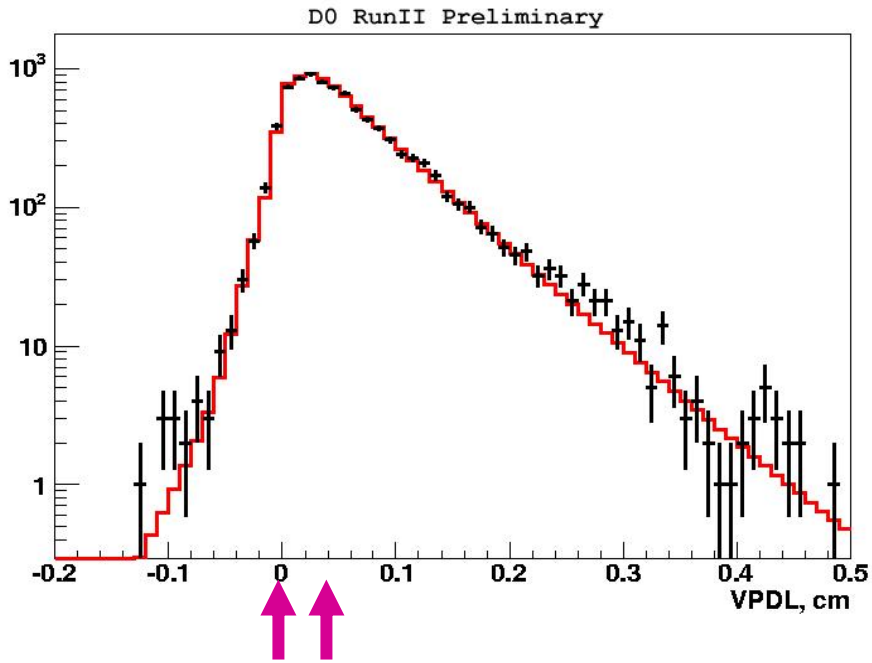
- **Probability Density Functions (PDF) for each source**
  - Proper Decay Length
  - Dilution
  - Proper Decay Length Error
  - Mass
  - Signal Selection Variable

Vertex Resolution



- **Determined by vertex fitting procedure**

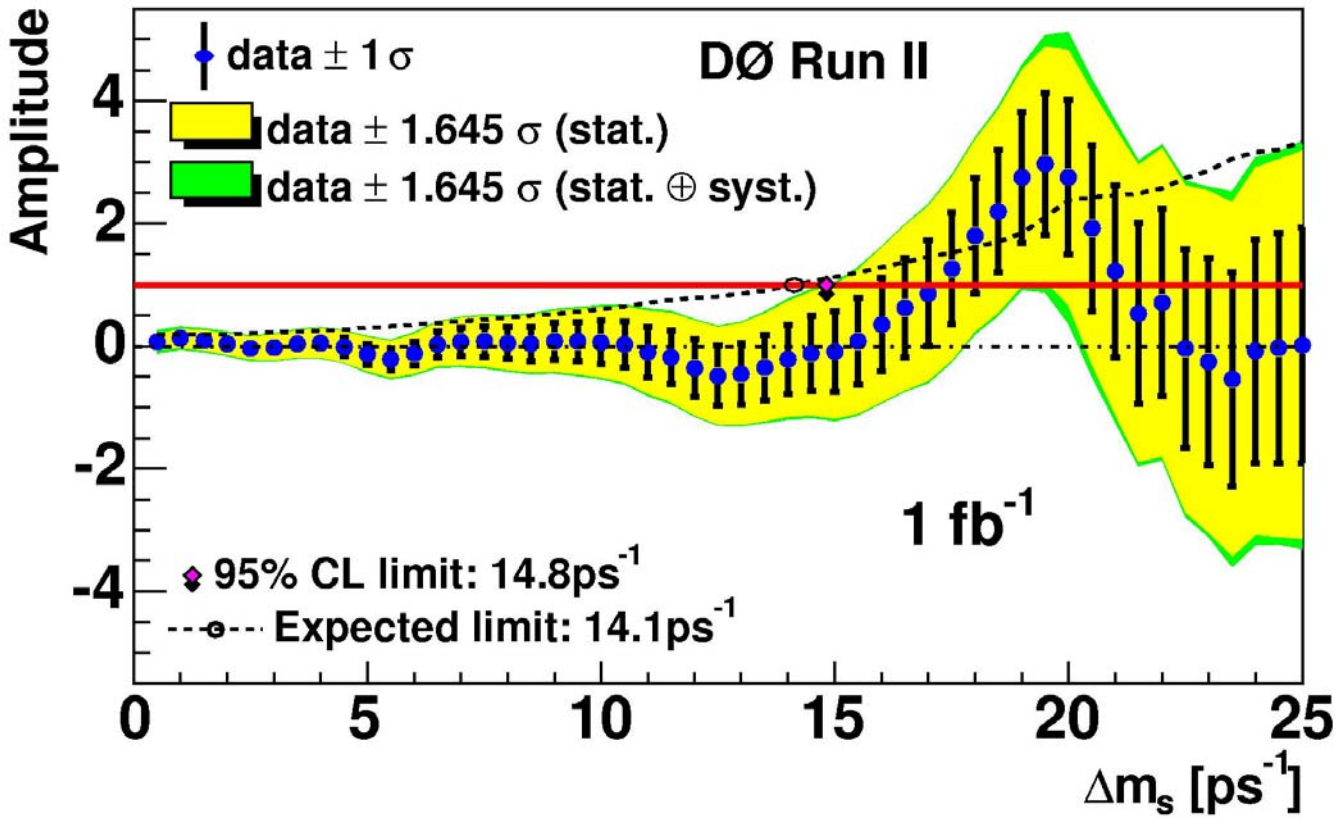
Results of the Lifetime Fit



Most important region

- Different background models are used for cross-check and systematic errors
- Trigger biases have been studied
  - Different efficiency models
- Central values for $c\tau_{Bs} = 404 - 416\ \mu m$
  - Statistical error ~10 μm
  - HFAG value $c\tau_{Bs} = 438 \pm 12\ \mu m$

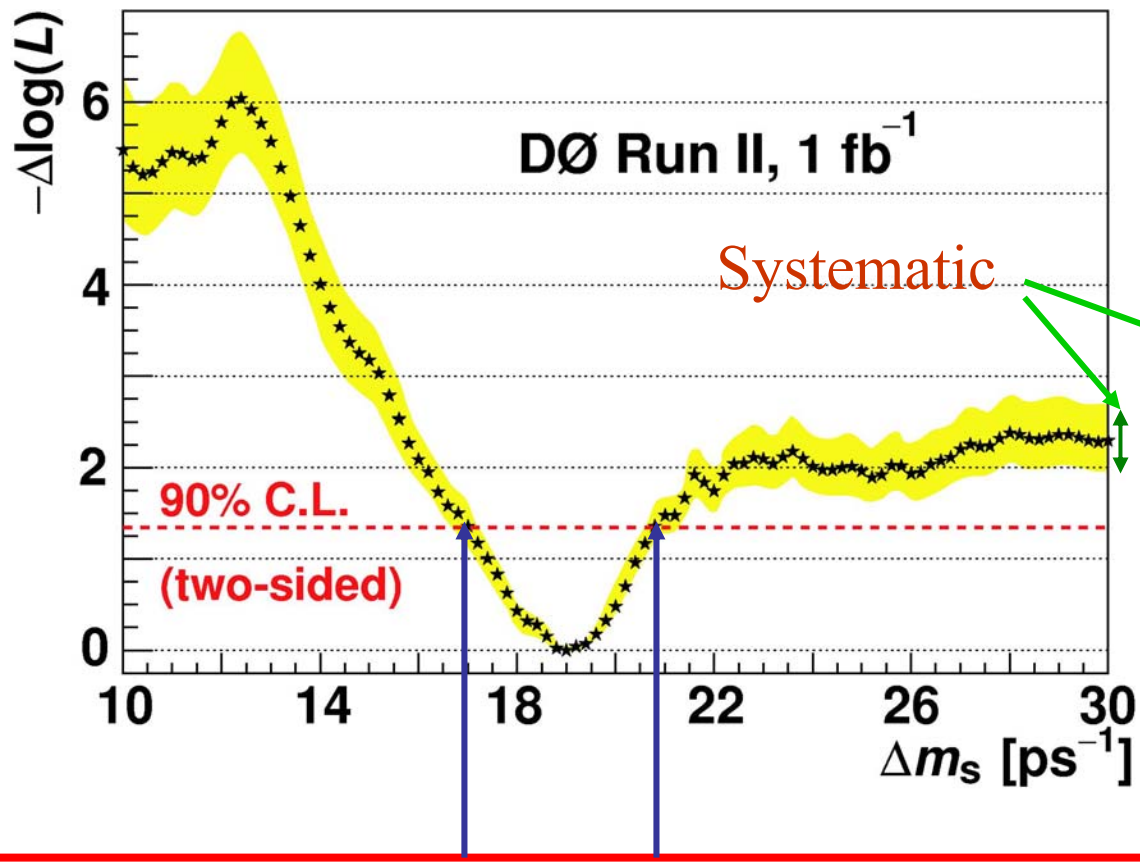
Amplitude Scan For B_s



- **Deviation of the amplitude at 19 ps-1**
  - 2.5σ from 0
  - 1.6σ from 1

Log Likelihood Scan

In agreement with the amplitude scan



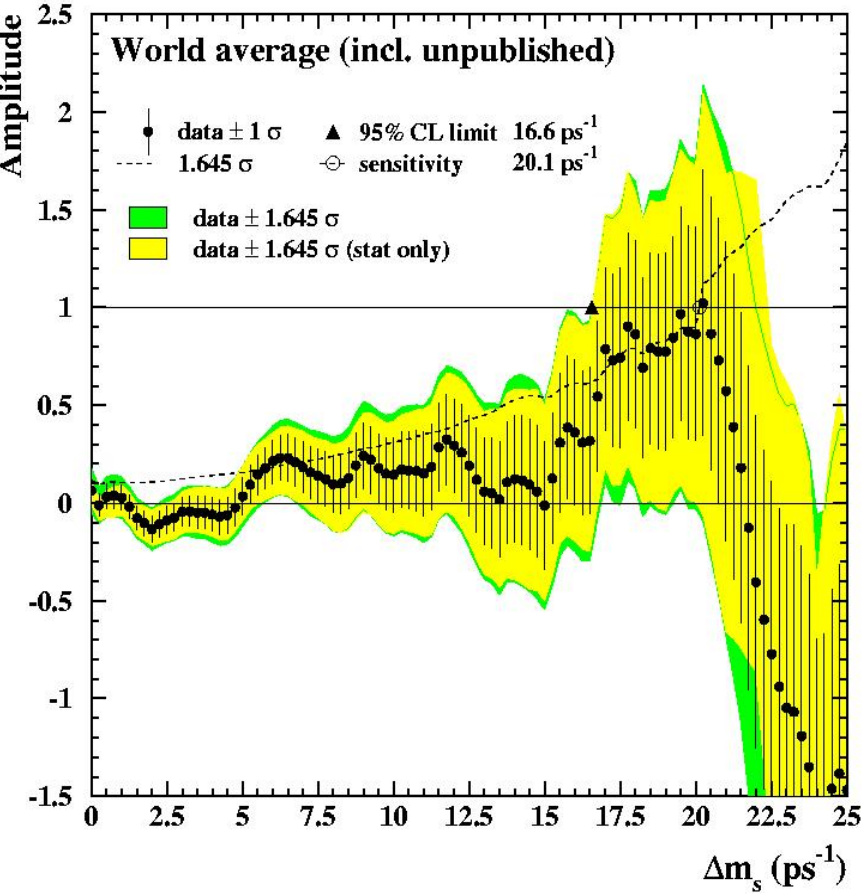
- Resolution
- K-factor variation
- BR ($B_s \to \mu D_s X$)
- VPDL model
- BR ($B_s \to D_s D_s$)

Have no sensitivity above 22 ps^{-1}

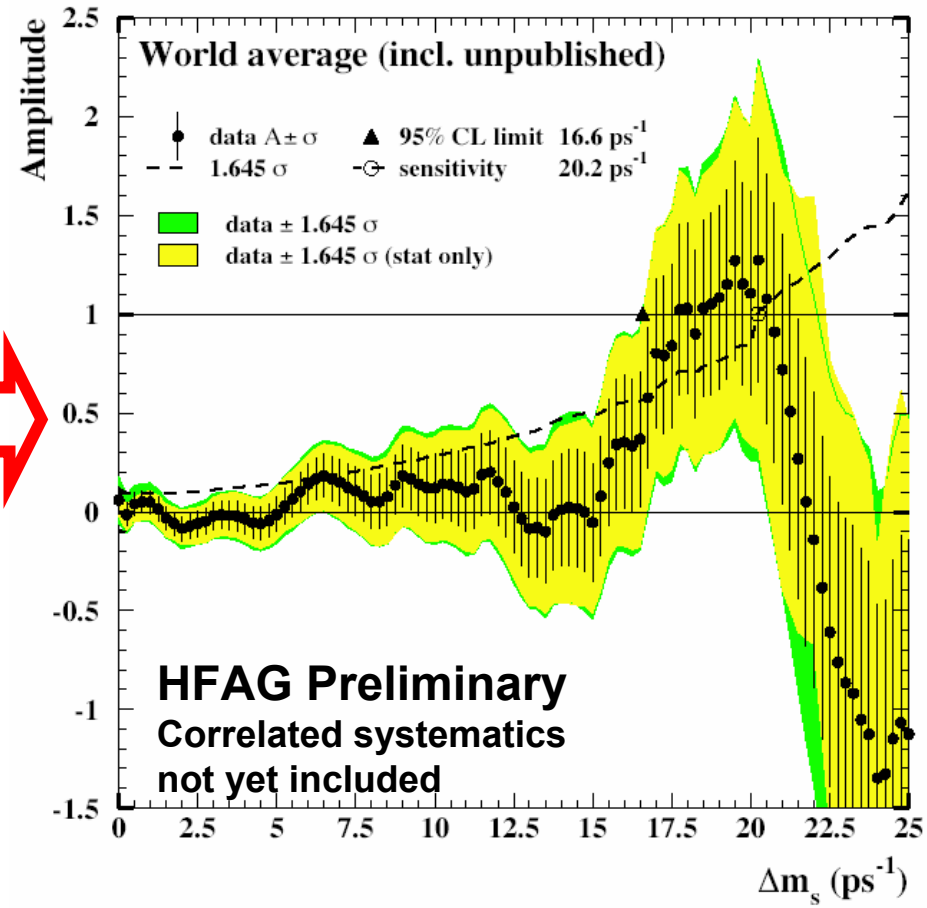
$17 < \Delta m_s <$ 21 ps^{-1} @ 90% CL assuming Gaussian errors

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

World Average



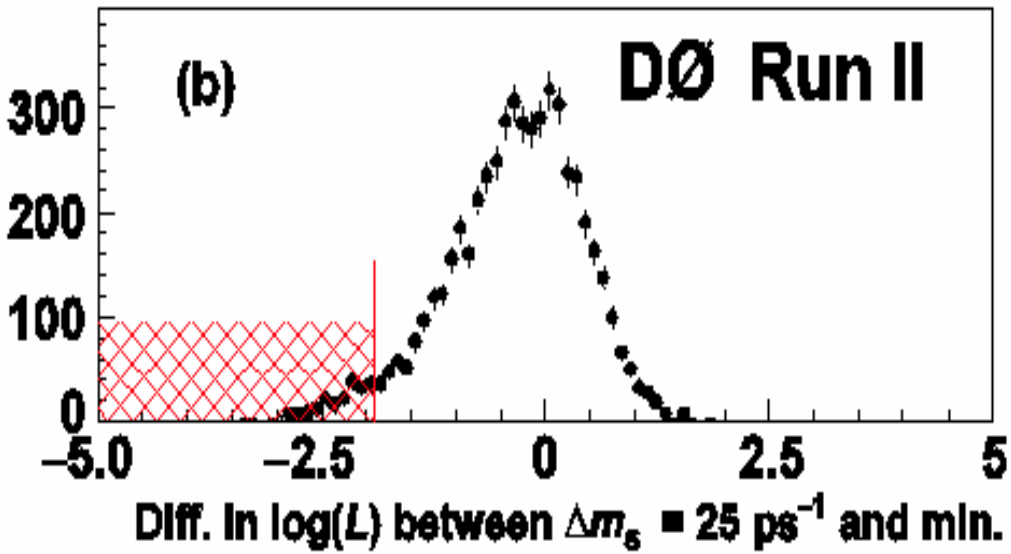
With current D0 result



@19ps^{-1}: 1.5σ → 2.3σ

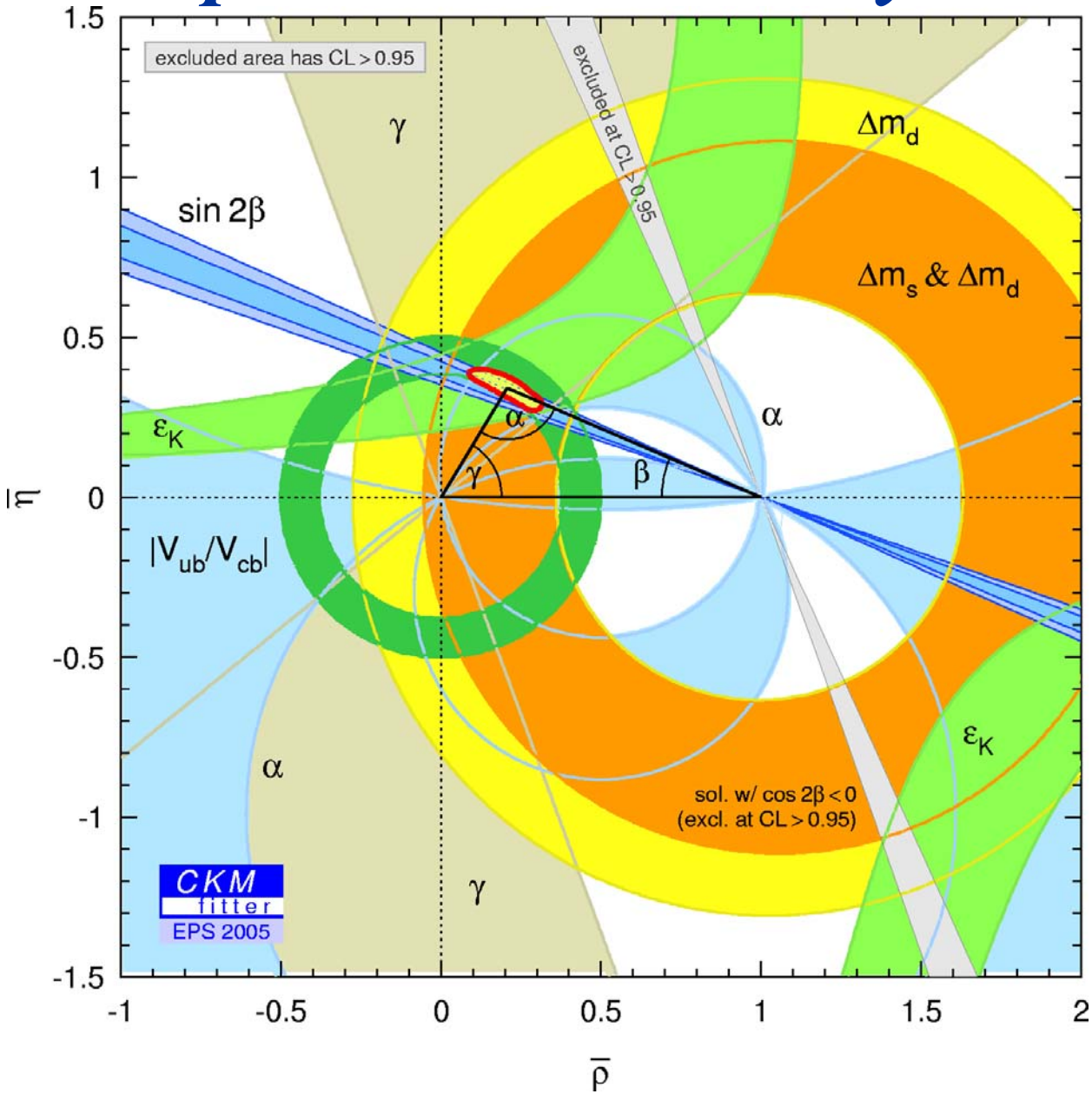
Ensemble Tests

- **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}

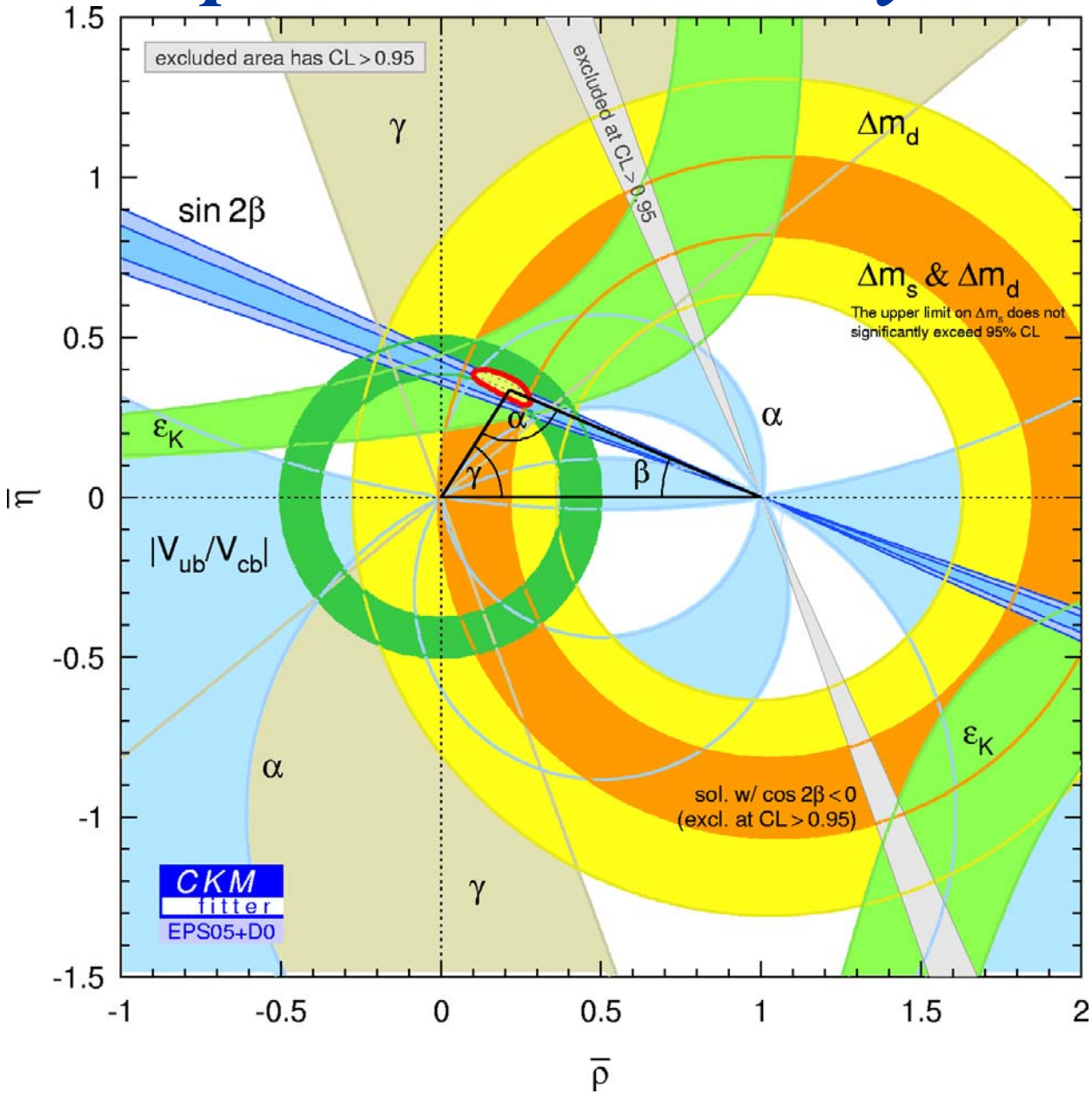


- **Using MC**
  - Probability to observe $\Delta\log(L) > 1.9$ for the true $\Delta m_s = 19\ ps^{-1}$ in the range $17 < \Delta m_s < 21\ ps^{-1}$ is 15%

Impact on the Unitarity Triangle



Impact on the Unitarity Triangle



CP Violation in Mixing

$$\left|M_{CP\pm}\right\rangle = p\left|M^0\right\rangle \pm q\left|\overline{M^0}\right\rangle$$

Three phenomenological signatures

$$\lambda = \frac{|q|}{|p|}\frac{|\overline{A_{\bar{f}}}|}{|A_f|}e^{-i\varphi}$$

First in K

CPV in Mixing

ε_K: $K_L \to \pi\pi$ ✓

ε_B: $l^+l^+ - l^-l^-$?

Last in B

CPV in Decay

ε'/ε: $K_L \to \pi^0\pi^0, \pi^+\pi^-$ ✓

A_{CP}: $K^+\pi^-, K^-\pi^+$ ✓

Mixing vs Decay

η: $K_L \to \pi^0\nu\nu$?

β/ϕ_1: $J/\psi\, K_s$ ✓

Analysis Strategy

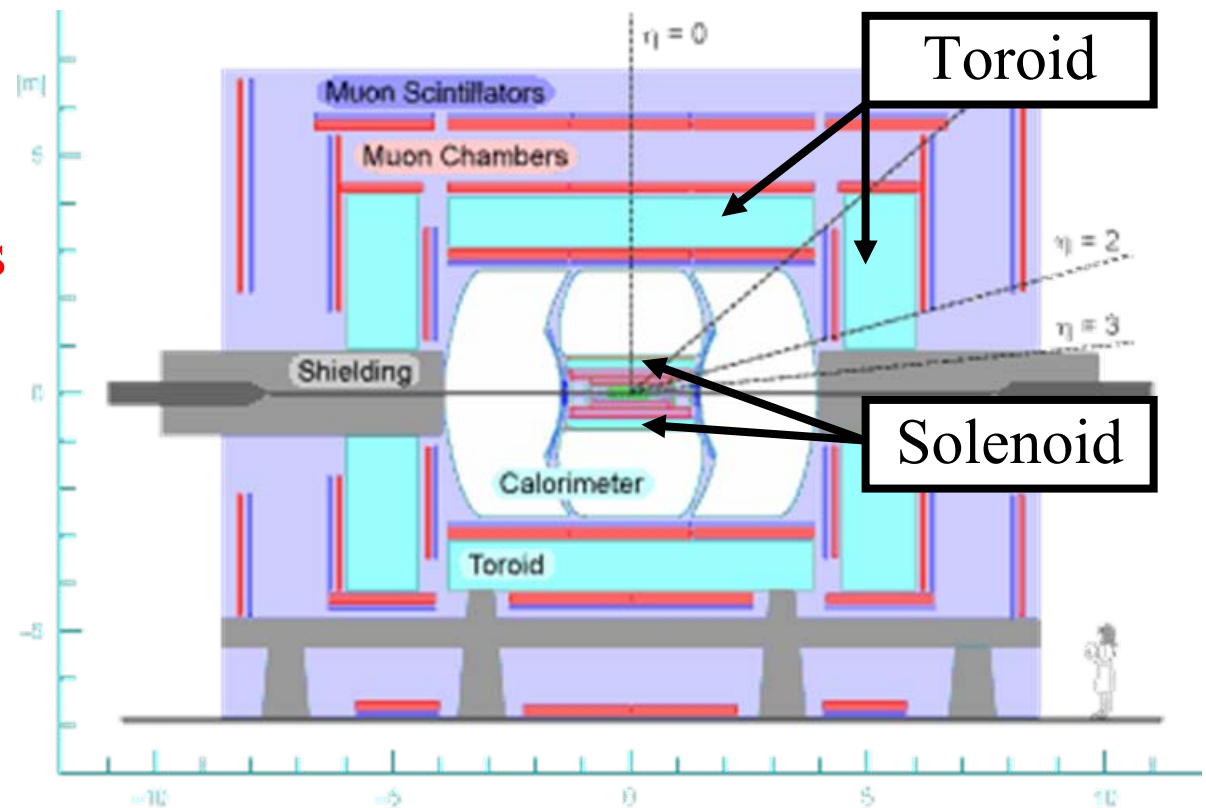
Goal is to measure ε_B with part per mil precision by looking for asymmetry in like-sign dimuons

$$A_{SL} = \frac{N(b\bar{b} \to \mu^+\mu^+X) - N(b\bar{b} \to \mu^-\mu^-X)}{N(b\bar{b} \to \mu^+\mu^+X) + N(b\bar{b} \to \mu^-\mu^-X)}$$

How?

Using independent spectrometers and reversing the polarities

Solenoid	Toroid
+	+
−	+
+	−
−	−



Raw Results

Tor*Sol polarity	-1	+1
N++	177,950	156,183
N--	176,939	156,148
N+-	1,175,547	1,029,604

After removing detector based asymmetries:

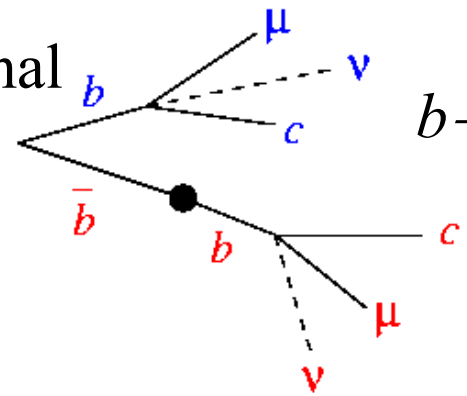
$$A = -0.0013 \pm 0.0012(stat) \pm 0.0008(syst)$$

Now need the fraction of μ from B

$$A_{SL} = f_B \times A$$

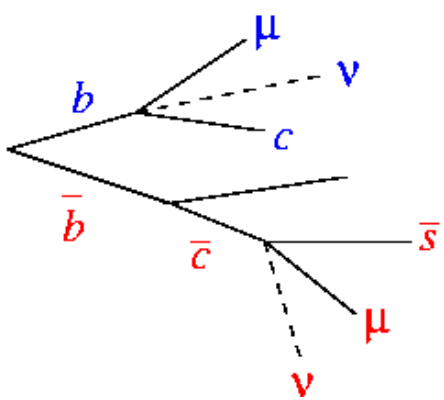
Sample Composition

signal

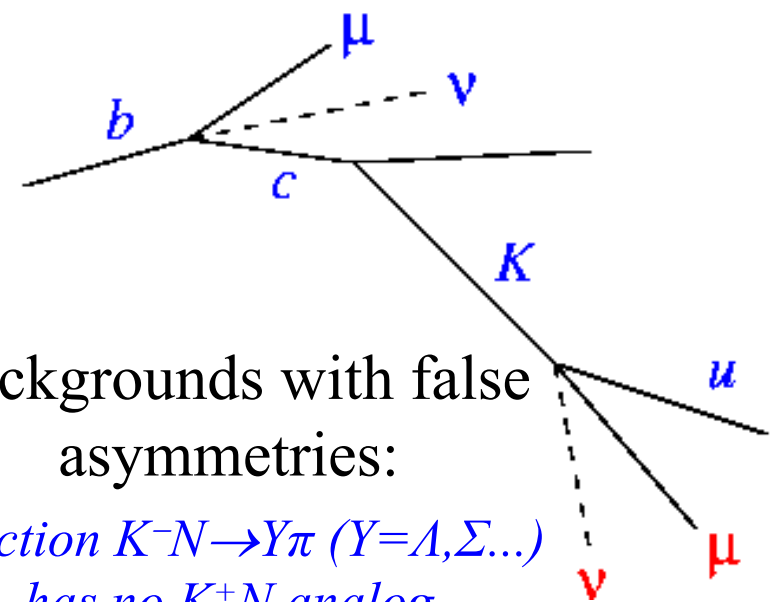


$b \to \mu^+;\ \bar{b} \to b \to \mu^+$

$b \to \mu^+;\ \bar{b} \to \bar{c} \to \mu^+$



Backgrounds that dilute the asymmetry

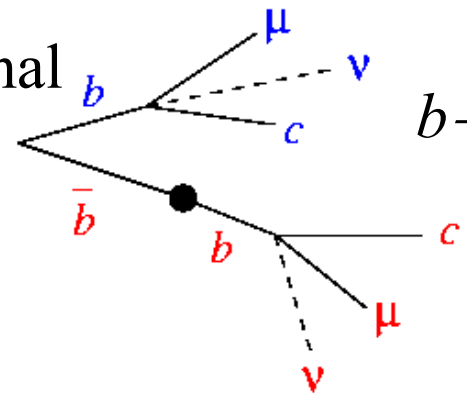


Backgrounds with false asymmetries:

Reaction $K^-N \to Y\pi$ ($Y=\Lambda,\Sigma...$) has no K^+N analog

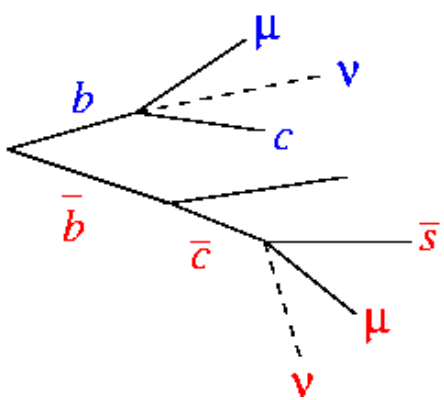
Sample Composition

signal



$b \to \mu^+;\ \bar{b} \to b \to \mu^+$

$b \to \mu^+;\ \bar{b} \to \bar{c} \to \mu^+$



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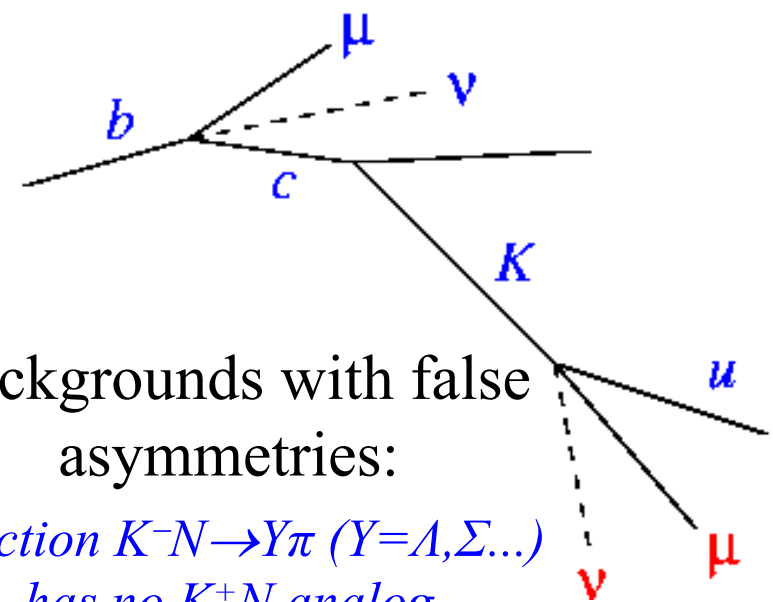


Backgrounds with false asymmetries:

Reaction $K^-N \to Y\pi$ ($Y=\Lambda,\Sigma\ldots$) has no K^+N analog

Cross-check:

$$\chi(D0) = 0.136 \pm 0.001 \pm 0.024$$

$$\chi(PDG) = 0.1281 \pm 0.0076$$

Results

Raw Asymmetry:

$$A = -0.0013 \pm 0.0012(\text{stat}) \pm 0.0008(\text{syst})$$

Asymmetry from Mixing:

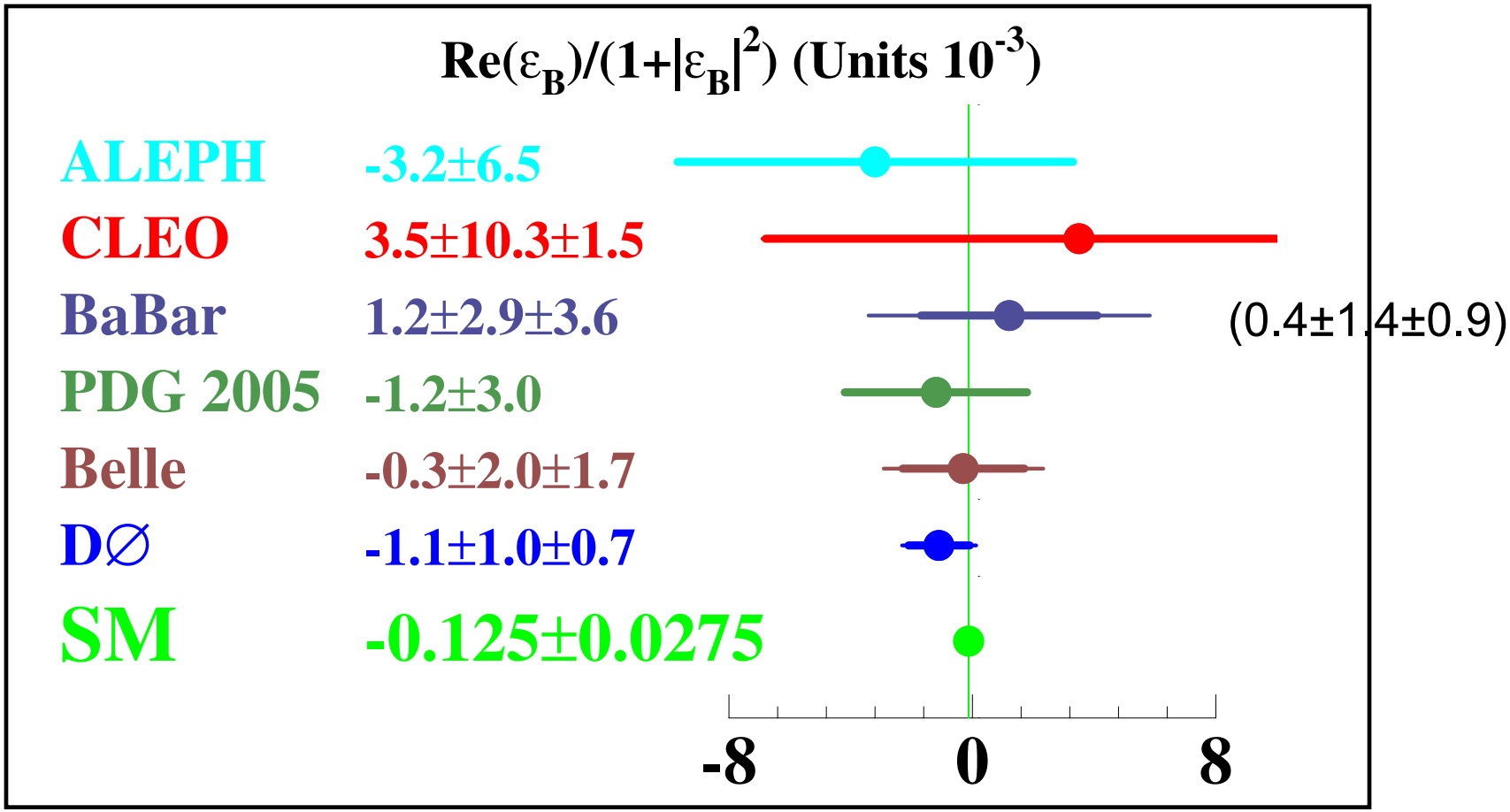
$$A_{SL} = -0.0044 \pm 0.0040(\text{stat}) \pm 0.0028(\text{syst})$$

CP Violation Parameter:

$$\frac{\text{Re}(\varepsilon_{B^0})}{1+\left|\varepsilon_{B^0}\right|^2} = \frac{A_{SL}}{4}$$

$$\frac{\text{Re}(\varepsilon_{B^0})}{1+\left|\varepsilon_{B^0}\right|^2} = -0.0011 \pm 0.0010(\text{stat}) \pm 0.0007(\text{syst})$$

Results

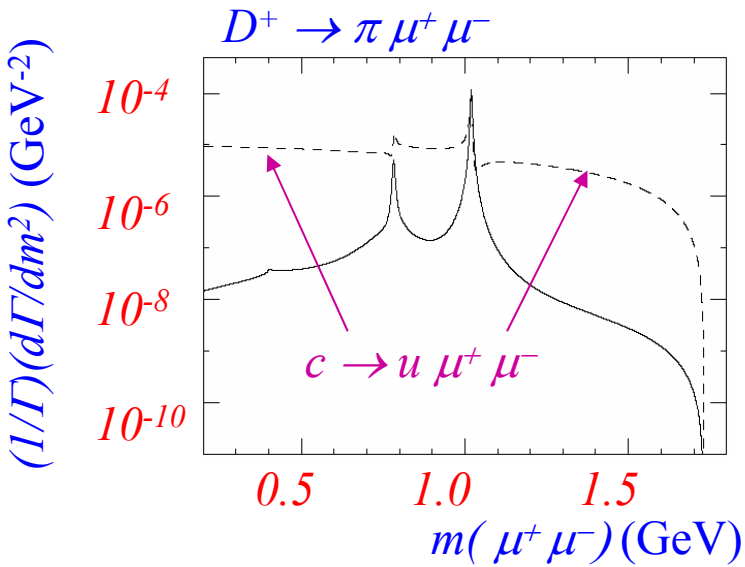


$$\frac{\mathrm{Re}(\varepsilon_{B^0})}{1+\left|\varepsilon_{B^0}\right|^2} = -0.0011 \pm 0.0010(\mathrm{stat}) \pm 0.0007(\mathrm{syst})$$

Flavor Changing Neutral Currents

Strict limits from $b \to s$ and $s \to d$

Possible to have effects in up sector and not down sector



RPV in the up sector and not the down sector

Burdman et al. hep-ph/0112235

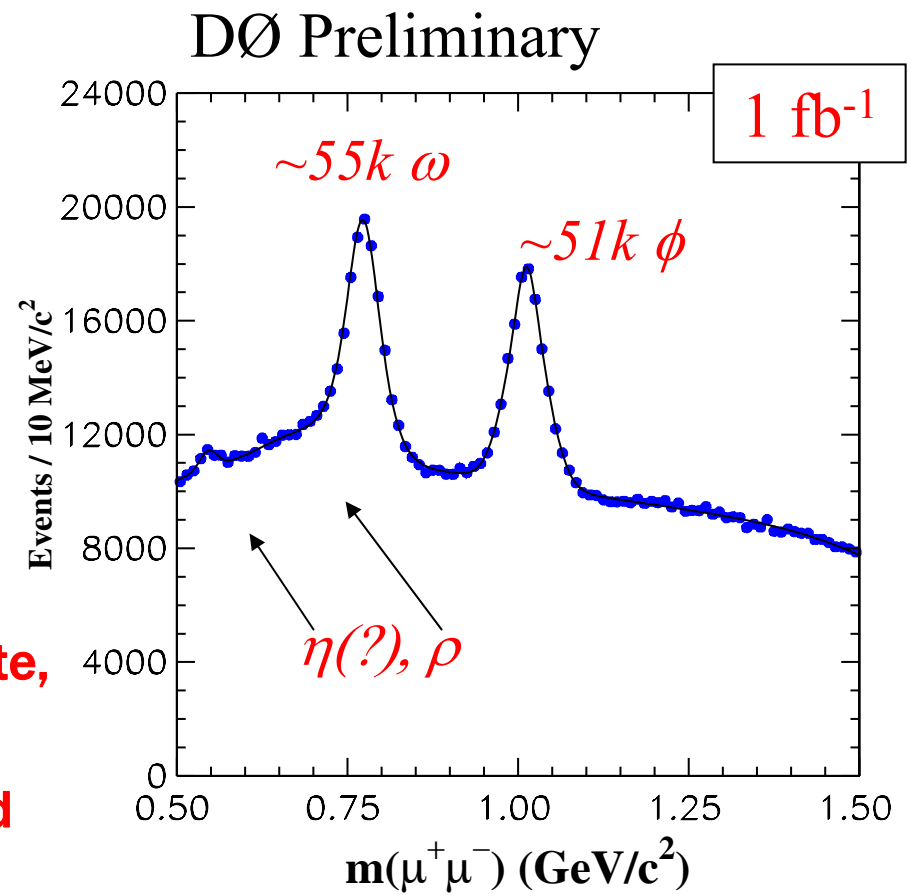
Little Higgs models with new up sector vector quark

Fajfer et al. hep-ph/0511048

factors of >1000 over SM not ruled out. Similar in magnitude to $B_s \to \mu\mu$ but orthogonal parameter space

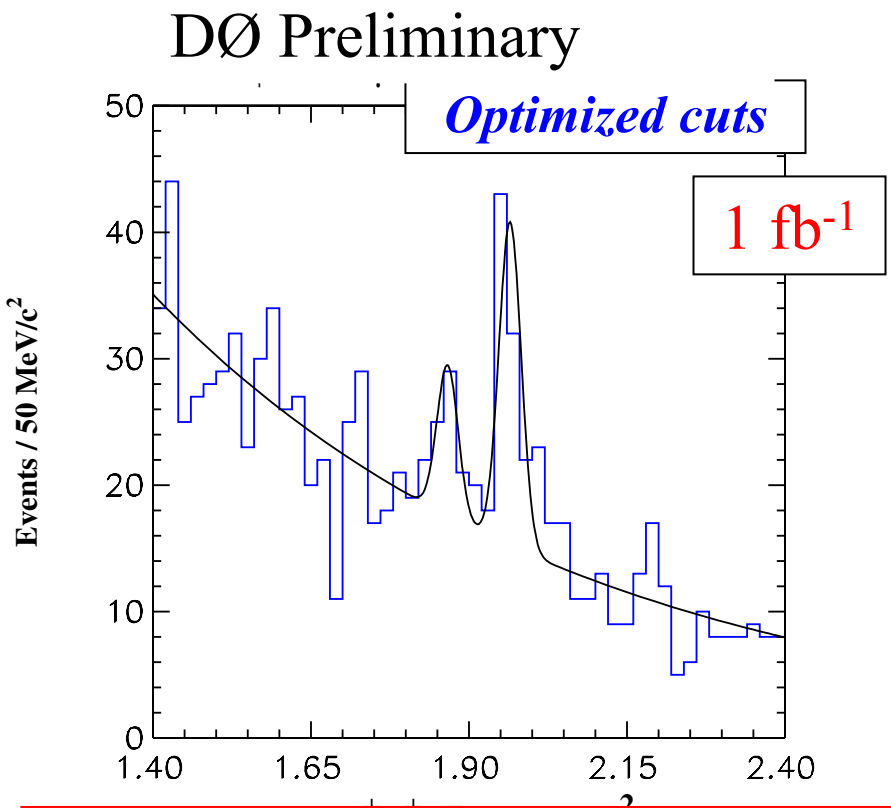
$c \to u\, \mu^+ \mu^-$ *Analysis Strategy*

- **First find $D_s \to \phi\, \pi$**
  - BF($D_s \to \phi\, \pi$) = (3.6 +/– 0.9)%
  - BF($\phi \to \mu^+\mu^-$) = (2.85 +/- 0.19) x 10^{-4}
  - Product ~ 1 x 10^{-5}
- **Then search for excess in the continuum region**
  - $D^+ \to \pi^+ \mu^+ \mu^-$ with $m(\mu\mu)$!= ϕ
- **Start with low mass dimuon candidate, add track to form *D* candidate**
- **Reduce background with lifetime and topological cuts**



Dimuon invariant mass

Results for $D \to \phi\,\pi \to \pi\,\mu\,\mu$



$n(D_s) = 65 \pm 11$

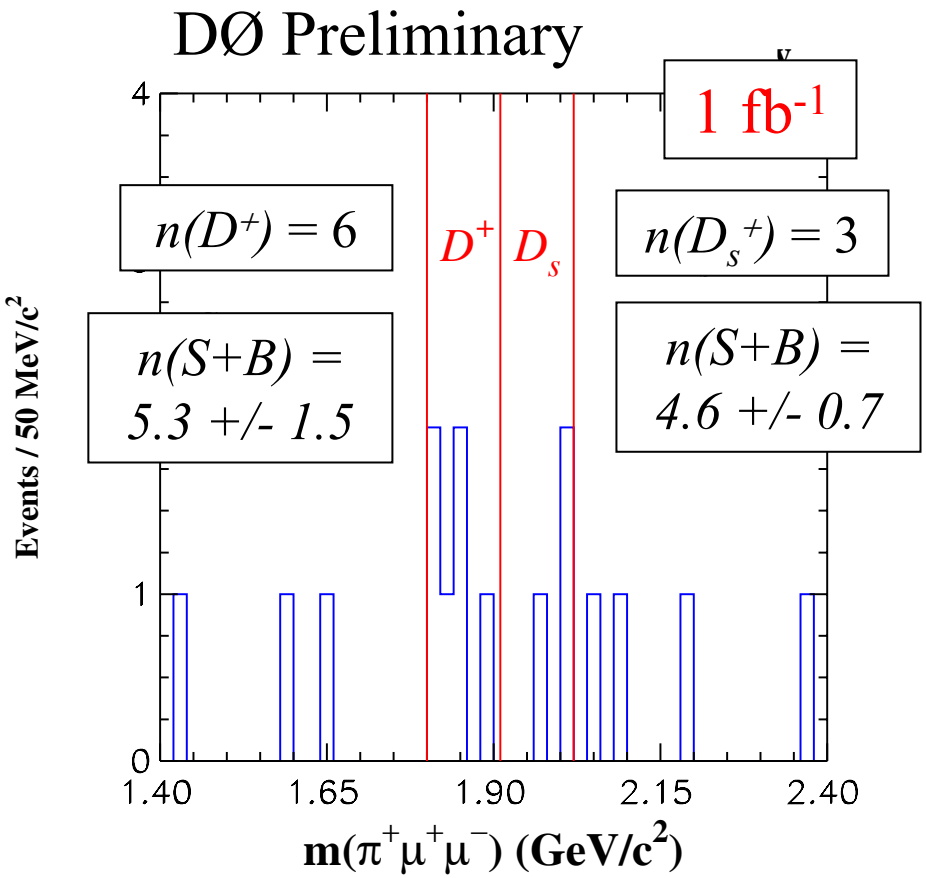
$n(D^+) = 26 \pm 9$

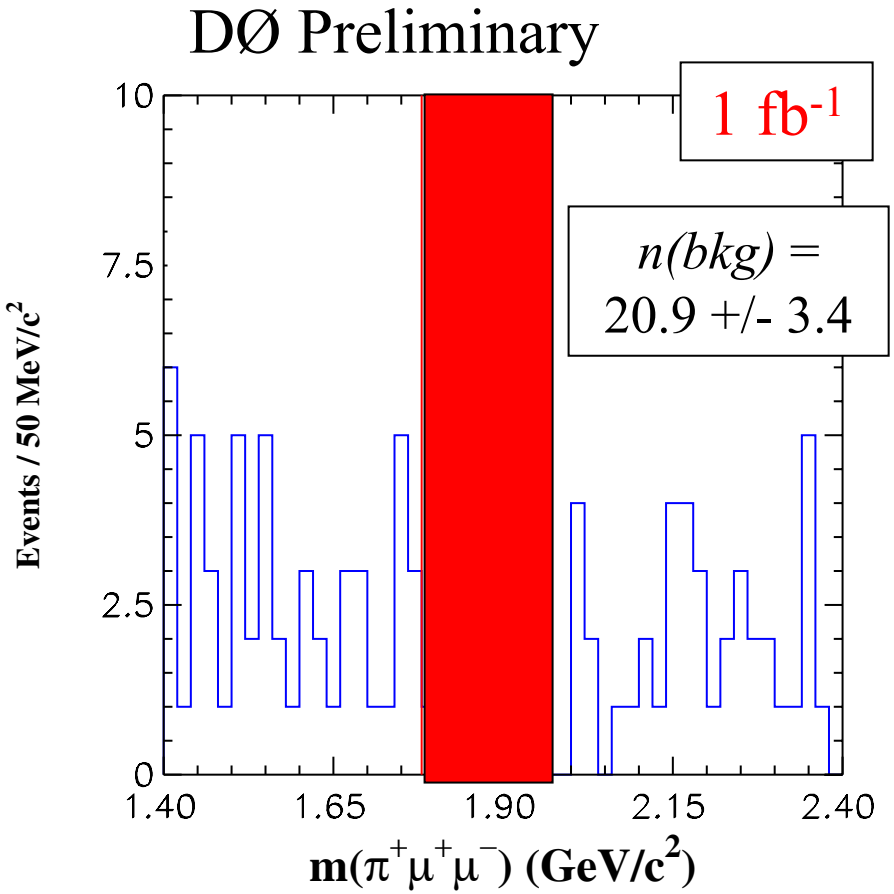
$m(\pi\mu\mu)$ GeV/c^2 for candidates with $0.96 < m(\mu\mu) < 1.06$ GeV/c^2

DØ: BF($D^+ \to \phi\,\pi \to \pi^+\,\mu^+\mu^-$) = (1.75 +/- 0.70 +/- 0.50) x 10^{-6}

CLEO-c: (2.7 +3.6 -1.8 +/- 0.2) x 10-6 Expected: 1.77 x 10-6

Results for $D^+ \to \pi^+\mu^+\mu^-$





$0.96 < m(\mu\mu) < 1.06$ GeV/c^2

Good agreement with expectations

$0.2 < m(\mu\mu) < 0.96$ GeV/c^2
$1.06 < m(\mu\mu) < 1.76$ GeV/c^2

Results for $D^+ \to \pi^+\mu^+\mu^-$

Branching fraction limit
$D^+ \to \pi^+ \mu^+\mu^-$:

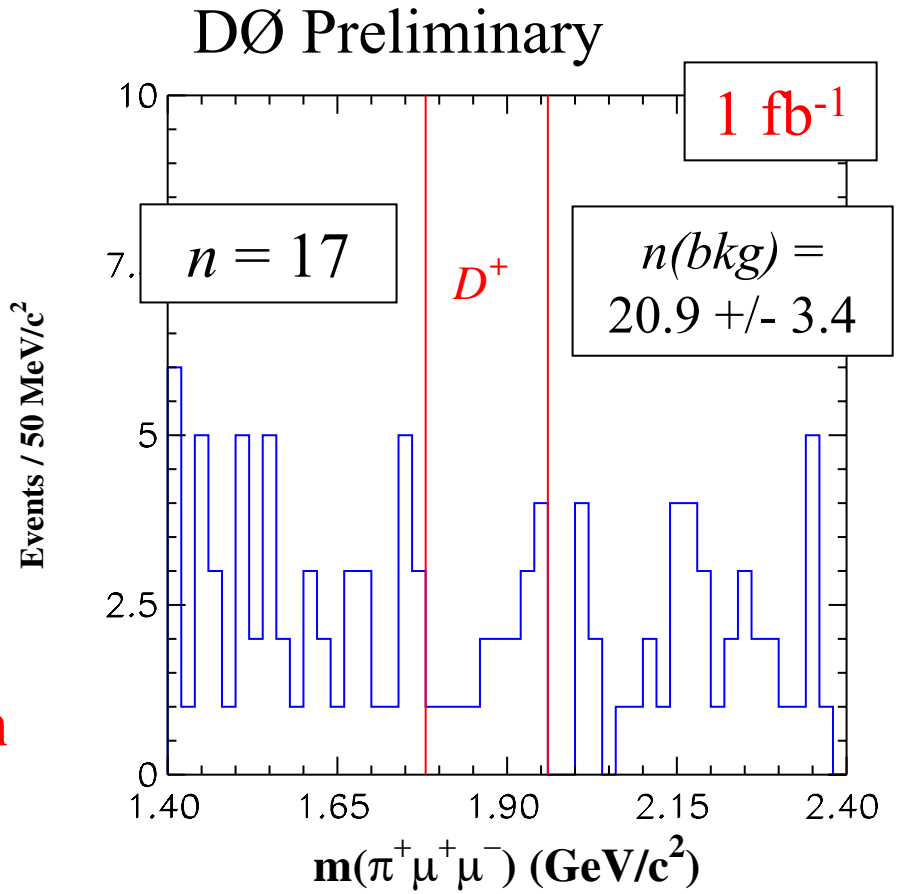
DØ: < 4.7 x 10^{-6} (at 90%)

CLEO-c(πe^+e^-): 7.4x 10^{-6} at 90%

FOCUS: 8.8 x 10^{-6} at 90%

New limit on second generation RPV couplings

$$\bar{\lambda}_{22k}\bar{\lambda}_{21k} < 0.002$$

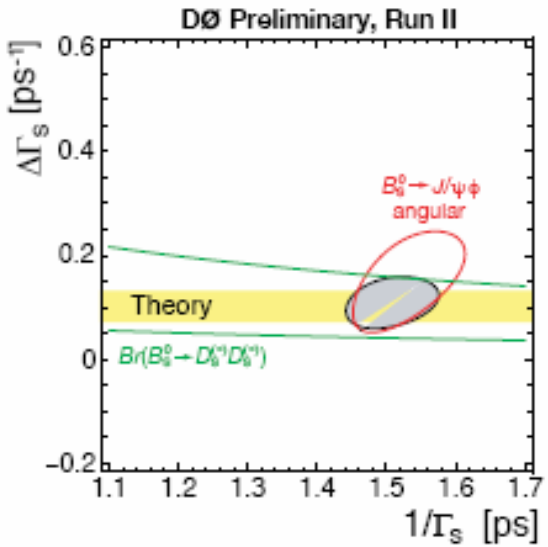


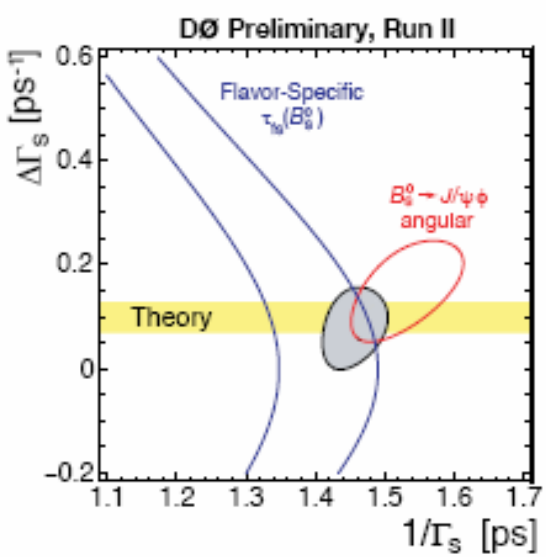
$0.2 < m(\mu\mu) < 0.96$ GeV/c^2
$1.06 < m(\mu\mu) < 1.76$ GeV/c^2

Check of SM with Lifetimes and BR

- In SM (with CP conserved) eigenstates are CP specific- check decay portion of matrix
- Measure of decay rates and widths in B_s^0-B_s^0 system
  - Γ_s measures lifetime average
  - $1/\Delta\Gamma_s$ measures off diagonal decay matrix element
- Measure
  - Flavor specific, e.g. $B_s^0 \to D_s^+ \mu^- \nu \Leftrightarrow \overline{B}_s^0 \to D_s^- \mu^+ \nu$
  - Branching ratios $B_s^0 \to D_s^{(*)} D_s^{(*)}$
  - Lifetimes Differences $B_s^0 \to J/\psi\phi$

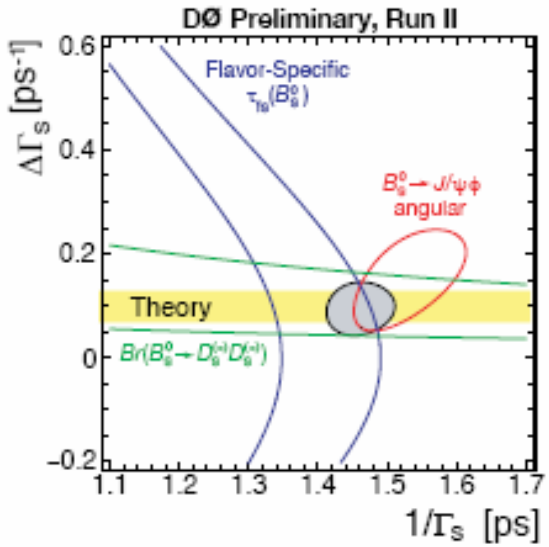
1 Sigma Contours on $\Delta\Gamma_s$ and $1/\Gamma_s$





DØ inputs only!

1-sigma contours ($\Delta(\log L) = 0.5$)



- "DØ-only" average

$$\Delta\Gamma_s = 0.093^{+0.047}_{-0.049}\ \text{ps}^{-1}$$

$$\bar{\tau} = \frac{1}{\Gamma_s} = 1.461^{+0.044}_{-0.042}\ \text{ps}$$

Conclusions

- **Tevatron's first fb^{-1} opening up several new opportunities in flavor physics**

- **Today, 3 world's best results**
  - ***Rare FCNC charm decays***
  - ***CP Violation in B mixing***
  - ***First double sided bound on Δm_s***

19 years after the observation of B_d mixing and 12 years after the first lower limit on Δm_s, we now have first direct double sided bound on the B_s oscillation frequency.

$$17 < \Delta m_s < 21 \text{ ps}^{-1} \text{ @ } 90\% \text{ CL}$$

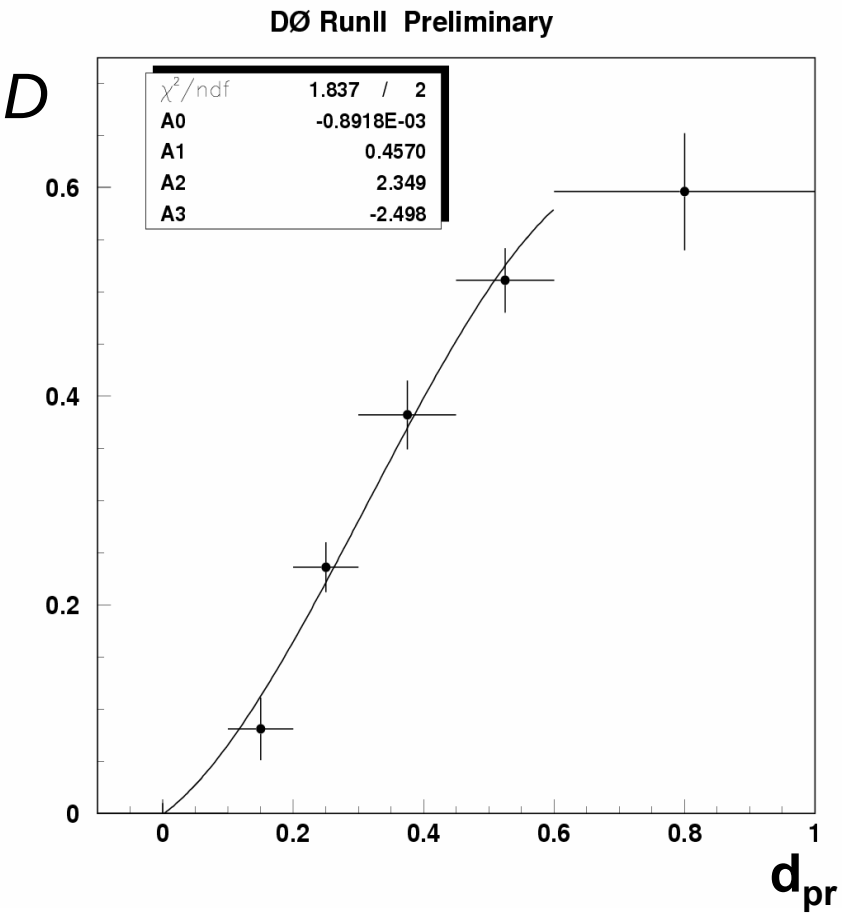
- ***More improvements this summer-***
  - ***extend analysis and new hardware = layer 0***

Backup Slides

Initial State Tagging

- Get best estimate for reconstructed B meson to contain b($\bar{b}$) at origin
- Definitions:
  - *Efficiency:* $$\varepsilon = \frac{N_{tagged}}{N_{total}}$$
  - *Dilution:* $$D = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$
  - *Tagging power:* $$\varepsilon \cdot D^2$$
    - ✓ use to compare the performance of taggers

Dilution



- Determine dilution on *event-by-event* basis from $B_d \rightarrow D^{*\pm}\mu\nu X$ events
- Use opposite side events
- Plot d_{pr} (predicted) versus D measured