B_d mixing and prospects for B_s mixing at DØ

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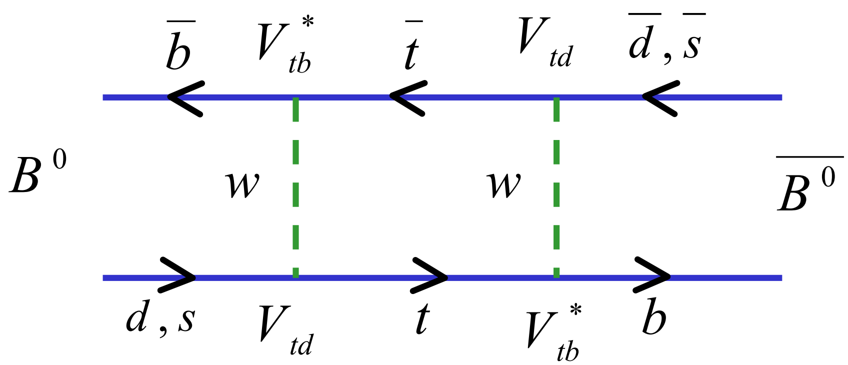
- Motivation for mixing studies
- DØ @ Tevatron
- B_d mixing measurements
  - Different approaches
- Prospects for B_s mixing

What is mixing?

Neutral meson transition from particle to anti-particle, and vice-versa

Caused by higher order flavor changing weak interactions:



$\Delta m_q = m(B^o_{heavy}) - m(B^o_{light})$

$\Delta m_q \propto |V_{tb}V_{tq}|^2$

Mixing parameters $x_q = \Delta m_q/\Gamma_q$ and $y_q = \Delta\Gamma_q/\Gamma_q$ where q=d,s

First oscillations observed at ARGUS ('87) in the B_d system

$\Rightarrow$ signaled a large top quark mass (later verified by CDF and DØ)

Δm_d and V_{td}

Δm_d has been precisely measured: the world average is

$$\Delta m_d = 0.502 \pm 0.007 \; ps^{-1}$$

$$\Delta m_{B_d} = \frac{G_F^2}{6\pi^2} |V_{tb}|^2 |V_{td}|^2 \; m_t^2 m_{B_d} f_{B_d}^2 B_{B_d} \eta_B F(\frac{m_t^2}{m_W^2})$$

Large uncertainty

$$|V_{CKM}| = \begin{pmatrix} 0.9739-0.9751 & 0.211-0.227 & 0.0029-0.0045 \\ 0.221-0.227 & 0.9730-0.9744 & 0.039-0.044 \\ 0.0048-0.014 & 0.037-0.043 & 0.9990-0.9992 \end{pmatrix}$$

Phys. Rev. D (2004)

Large uncertainty

Precise measurement of V_{td} is important:

properly constrain the CKM matrix

yield info on CP-violating phase

Why do we care about B_s mixing ?

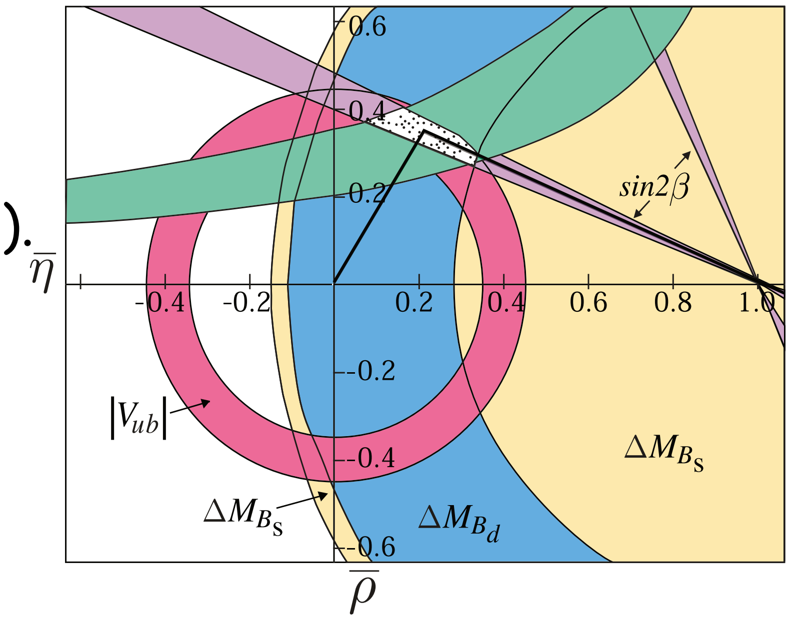
∴ consider ratio $$\frac{\Delta m_s}{\Delta m_d} = \frac{M_{B_s}}{M_{B_d}} \cdot \frac{\hat{B}_{B_s} f_{B_s}^2}{\hat{B}_{B_d} f_{B_d}^2} \cdot \left|\frac{V_{ts}}{V_{td}}\right|^2$$

Theoretical error on the ratio expected to drop faster

from Lattice QCD

Measure $\Delta m_s \Rightarrow$ constrain V_{td}

We *think* we understand the mixing of *B*s.
A deviation from this simple diagram
may be a deviation from SM (New Physics).



K mixing ⇒ direct & indirect CPV
B_d mixing ⇒ heavy top mass
ν mixing ⇒ neutrino mass ≠ 0

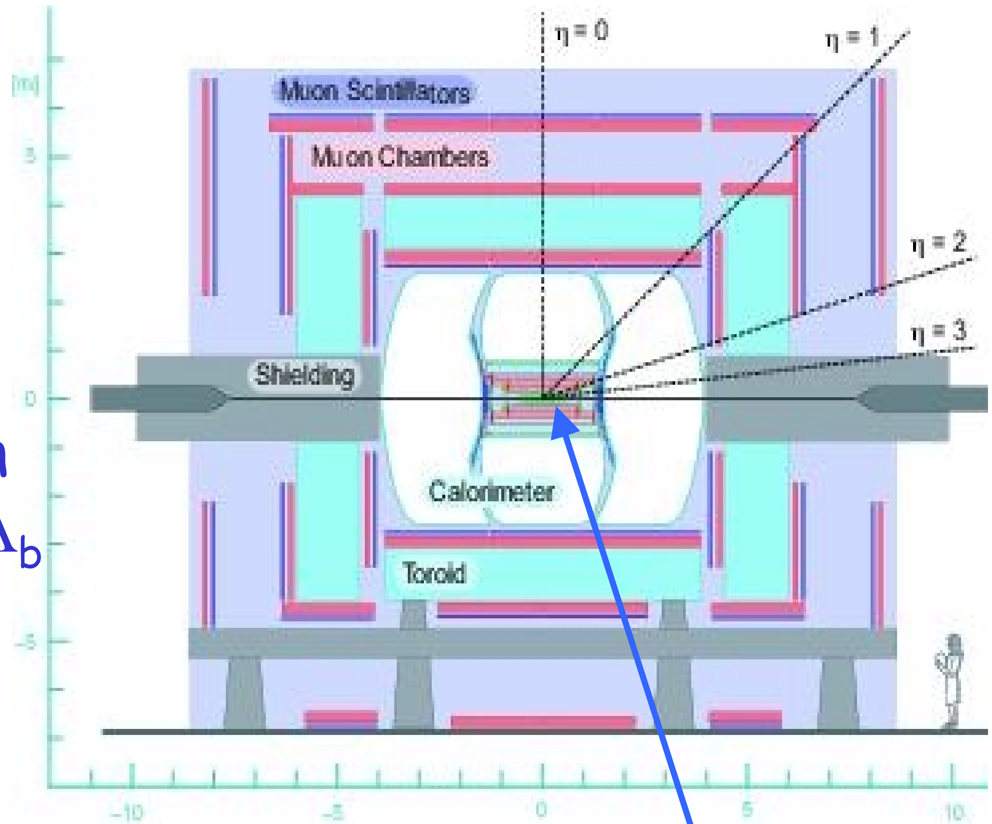
B_s mixing ⇒ ????

The Tevatron *B-factory*

$\sigma(p\,\bar{p} \to b\,\bar{b}) \approx 150\ \mu b$ **@1.96 TeV**

$\sigma(e^+e^- \to b\bar{b}) \approx 7nb$ @ Z^0

$\sigma(e^+e^- \to B\bar{B}) \approx 1nb$ @ $\Upsilon(4S)$



Tracking: Solenoid, Silicon, Fiber Tracker, Preshowers

Large production cross-section

All B species, including B_s, B_c, Λ_b

Rich B Physics program at DØ benefits from :

- Large muon acceptance: $|\eta| < 2$
- Forward tracking coverage: $|\eta| < 1.7$ (tracking), $|\eta| < 3$ (Si)
- Robust muon trigger

Essential Ingredients

A typical oscillation analysis involves:

- Proper time reconstruction for each meson candidate
- Selection of final states suitable for the study

  - Tagging of the meson flavor at decay time (final state)

$$B_d^0 \to D^{*-}\mu^+\nu_\mu$$

$$\bar{B}_d^0 \to D^{*+}\mu^-\bar{\nu}_\mu$$

final state particles provide tag

  - Tagging of the meson flavor at production time (initial state)

Initial state tagging

Soft lepton tagging (SLT) :

Opposite side: $b \to \mu^-$

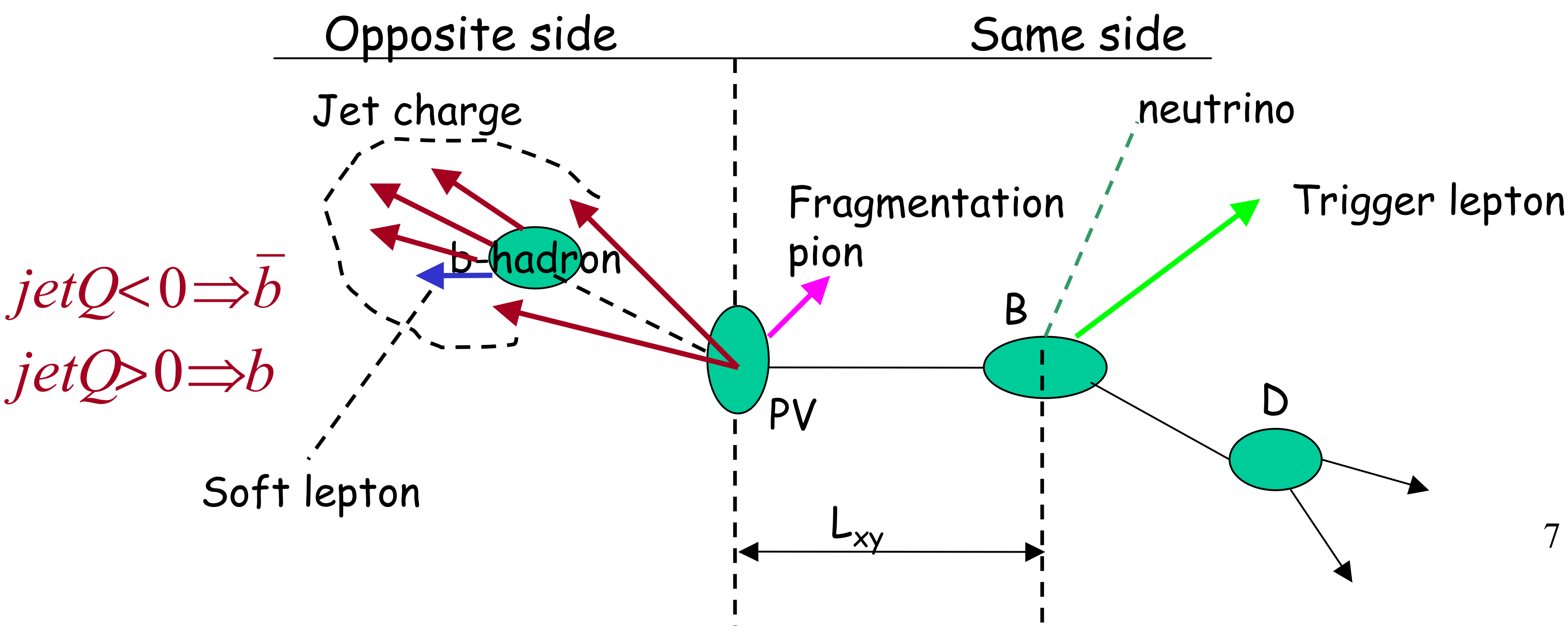
Same side tagging (SST) :

Same side: $b \to \overline{B}^0 \to \pi^-$ $b \to B^- \to \pi^+$

Jet charge tagging (JetQ) :

Opposite side: $jetQ > 0 \Rightarrow b$

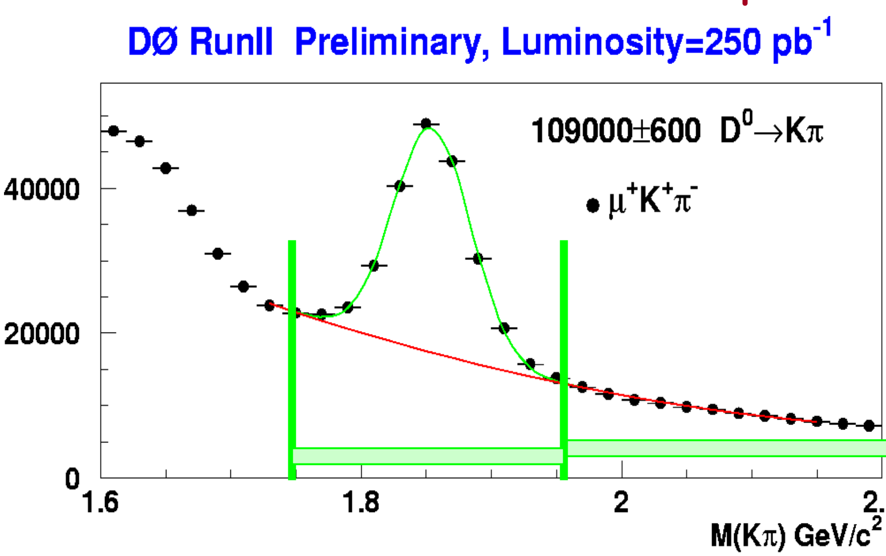
$$jetQ \equiv \frac{\sum p_T^i q^i}{\sum p_T^i}$$



Semileptonic samples

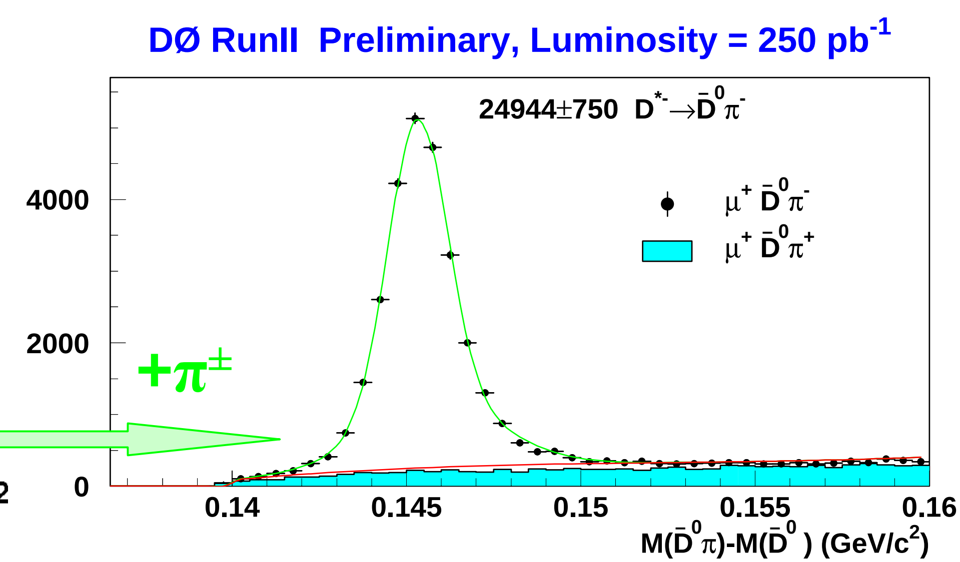
- Reconstruct semileptonic decay $B \to \mu D^0 X$
  - Select D^0 candidates ($D^0 \to K^- \pi^+$)
  - Search for a pion track which in combination with D^0 gives D^* invariant mass ($D^{*+} \to D^0 \pi^+$)
  - Divide the $\mu D^0 X$ sample into 2 sub-samples:

No D^* was found: D^0 sample



Dominated by B^+ decays

D^* was found: D^* sample



Dominated by B^0 decays

Proper time reconstruction

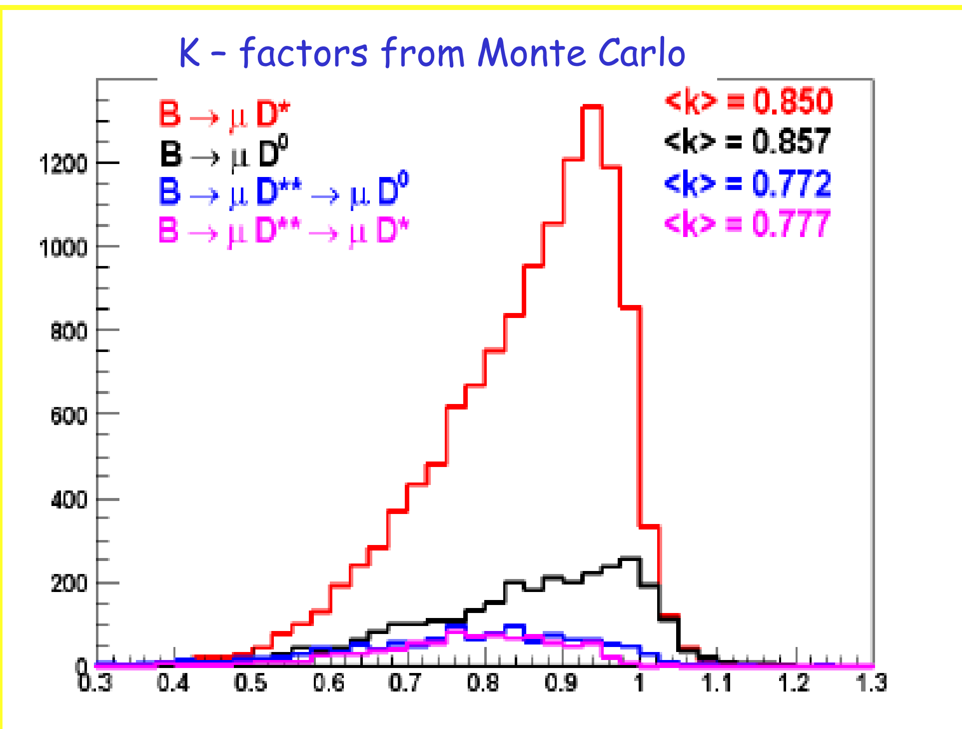
B_d proper lifetime determined using $ct_{B_d} = \lambda_{B_d} \cdot K$

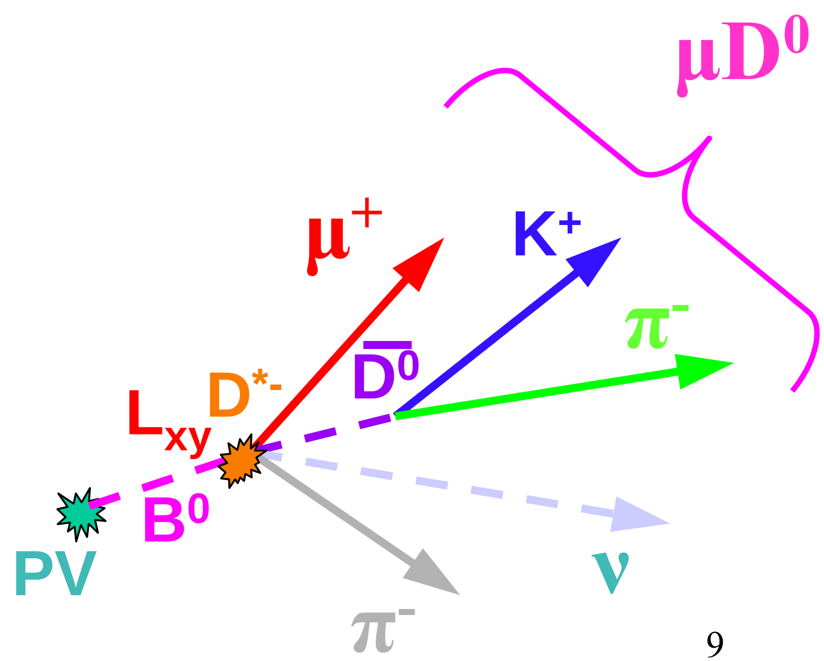
$$K \equiv \frac{p_T(D^0 + \mu)}{p_T(B_d)}$$

Correction factor
(for missing ν)

$$\lambda_{B_d} \equiv \frac{L_{xy} \cdot M_{B_d}}{p_T(D^0 + \mu)}$$

Visible proper decay length
(VPDL)





Soft Lepton Tagging (SLT)

If $Q_{\mu\ opposite} * Q_{\mu} > 0 \Rightarrow$ B hadron oscillated
If $Q_{\mu\ opposite} * Q_{\mu} < 0 \Rightarrow$ Not oscillated

$B^0 \rightarrow \mu^+ X$
$\overline{B}^0 \rightarrow \mu^- X$

$$\text{Efficiency } \varepsilon = \frac{N_{correct} + N_{wrong}}{N_{correct} + N_{wrong} + N_{notag}}$$

How often the tagging algorithm 'fires'

$$\text{Dilution } D = \frac{N_{correct} - N_{wrong}}{N_{correct} + N_{wrong}}$$

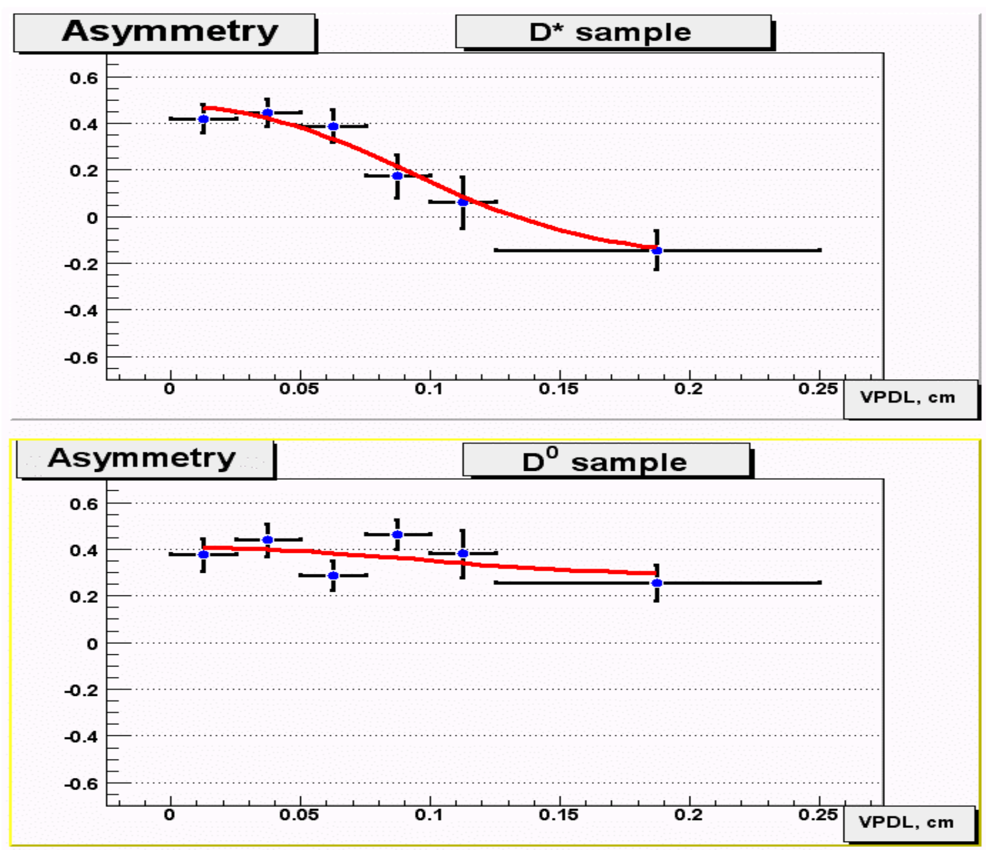
How often the tagging algorithm gives the correct answer

Maximize tagging power: εD^2

Measured Asymmetry

Obtain # of D^* , D^0 events tagged as "non-oscillated" & "oscillated" for different VPDL bins:

$\Rightarrow$ Measured Asymmetry $$A_i = \frac{N_i^{non-osc} - N_i^{osc}}{N_i^{non-osc} + N_i^{osc}}$$



D^* sample

- Expect to see oscillations
- Level is offset by B^+ contribution

D^0 sample

- Expect to see no oscillations
- Some variation from oscillations due to B^0 contribution in sample composition

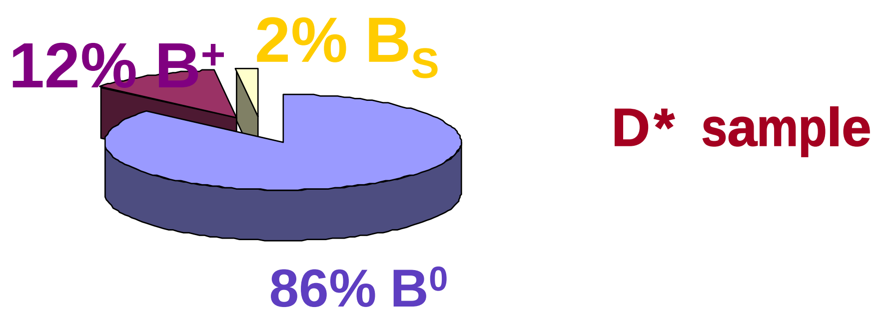
Expected Asymmetry

Calculate expected value of asymmetry: $A_i^e(\Delta m, \eta) = \frac{N_i^{e,non-osc} - N_i^{e,osc}}{N_i^{e,non-osc} + N_i^{e,osc}}$

B meson lifetimes and branching rates from PDG
K-factor distributions, decay length resolution, reconstruction efficiencies from MC

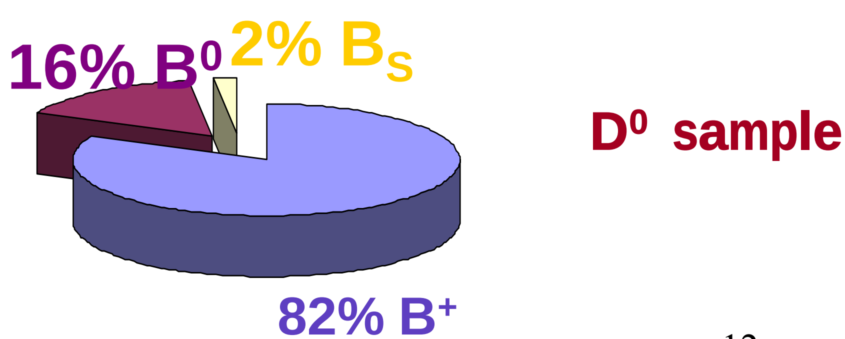
For D^* sample:

- $B^0 \to D^{*-}\mu\nu$;
- $B^0 \to D^{**}\mu\nu \to D^{*-}\mu\nu X$;
- $B^+ \to D^{**}\mu\nu \to D^{*-}\mu\nu X$;
- $B_s^0 \to D_s^{**}\mu\nu \to D^{*-}\mu\nu X$;



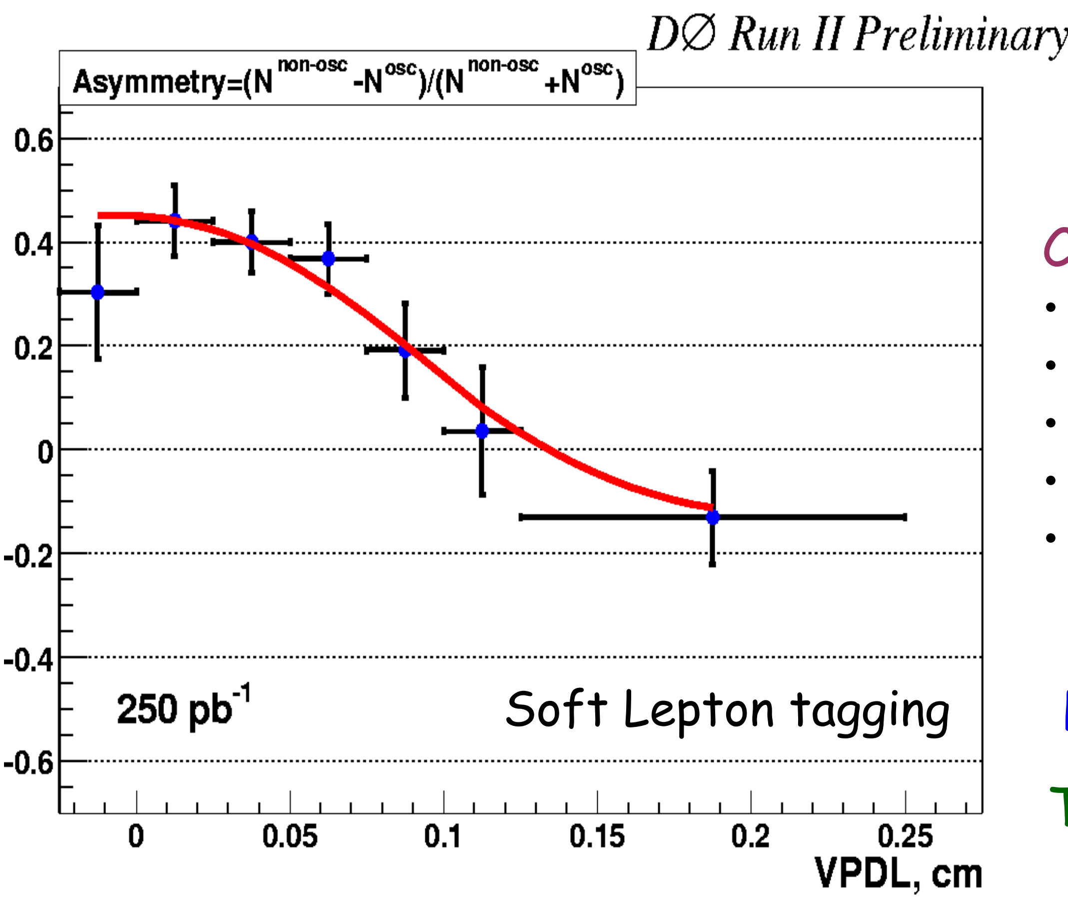
For D^0 sample:

- $B^+ \to D^0\mu\nu$;
- $B^+ \to D^{*0}\mu\nu$;
- $B^+ \to D^{**}\mu\nu \to D^0\mu\nu X$;
- $B^+ \to D^{**}\mu\nu \to D^{*0}\mu\nu X$;
- $B^0 \to D^{**}\mu\nu \to D^0\mu\nu X$;
- $B^0 \to D^{**}\mu\nu \to D^{*0}\mu\nu X$;
- $B_s^0 \to D_s^{**}\mu\nu \to D^0\mu\nu X$, $B_s^0 \to D_s^{**}\mu\nu \to D^{*0}\mu\nu X$;



Δm_d (SLT)

250pb^{-1}



$$\chi^2(\Delta m, \eta) = \sum_i \frac{(A_i - A_i^e(\Delta m, \eta))^2}{\sigma^2(A_i)}$$

Chief systematics:

- Fitting procedure for $D^*\mu$ candidates
- VPDL resolution function
- modelling of MC efficiencies
- branching rates of B mesons
- k-factor variations

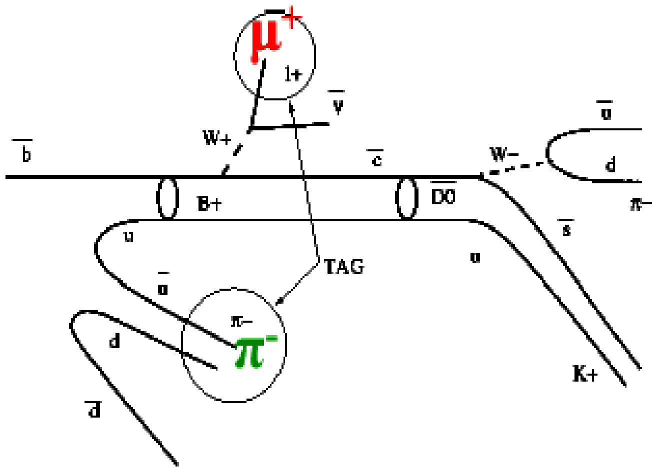
Preliminary results:

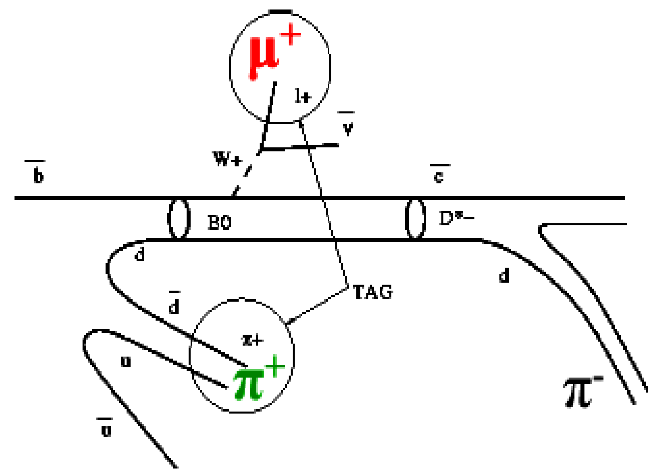
Tagging efficiency: 4.8 ± 0.2 %
Dilution : 46.0 ± 4.2 %

$\Delta m_d = 0.506 \pm 0.055(\text{stat}) \pm 0.049(\text{syst})\ \text{ps}^{-1}$

Same Side Tagging (SST)

Charge of fragmentation pion correlates with the B flavor

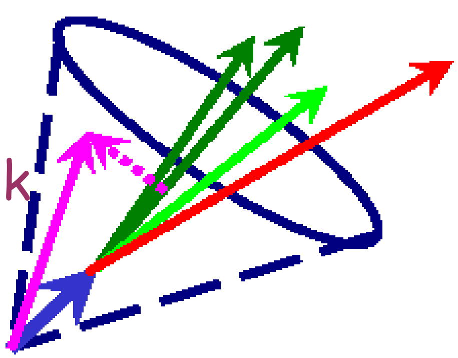




B^+: Correct tag $Q_{tag} \cdot Q_\mu < 0$
Non-oscillated

B^0: Correct tag $Q_{tag} \cdot Q_\mu > 0$
Non-oscillated

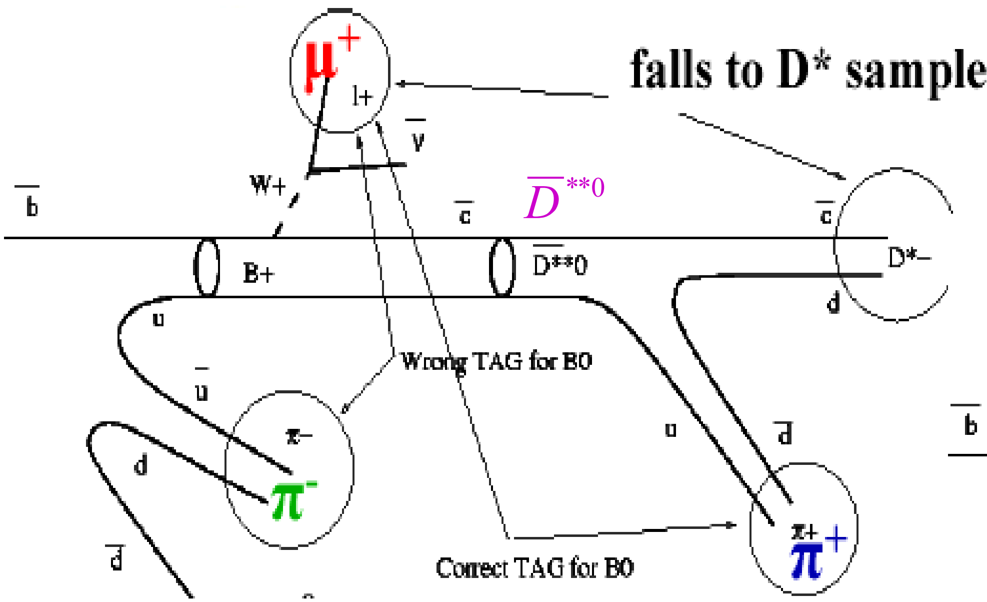
tagging track

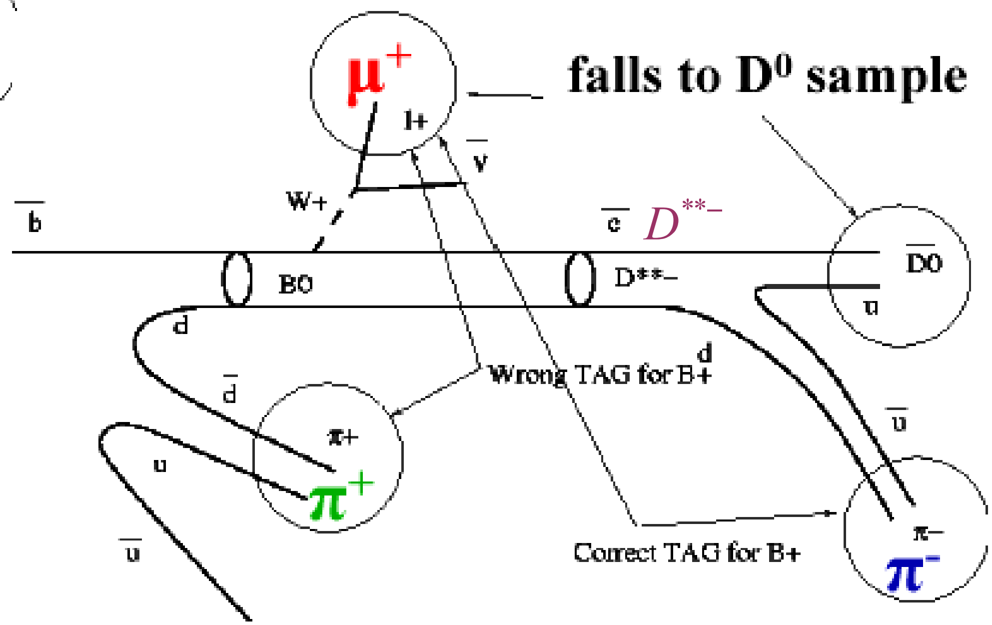


Different algorithms for selecting tagging track (in a $\Delta R < 0.7$ cone around B):

1. lowest Pt_{rel} (transverse momentum relative to B) track in a $\Delta R < 0.7$ cone around B
2. track with minimum ΔR wrt B-meson

D** complications





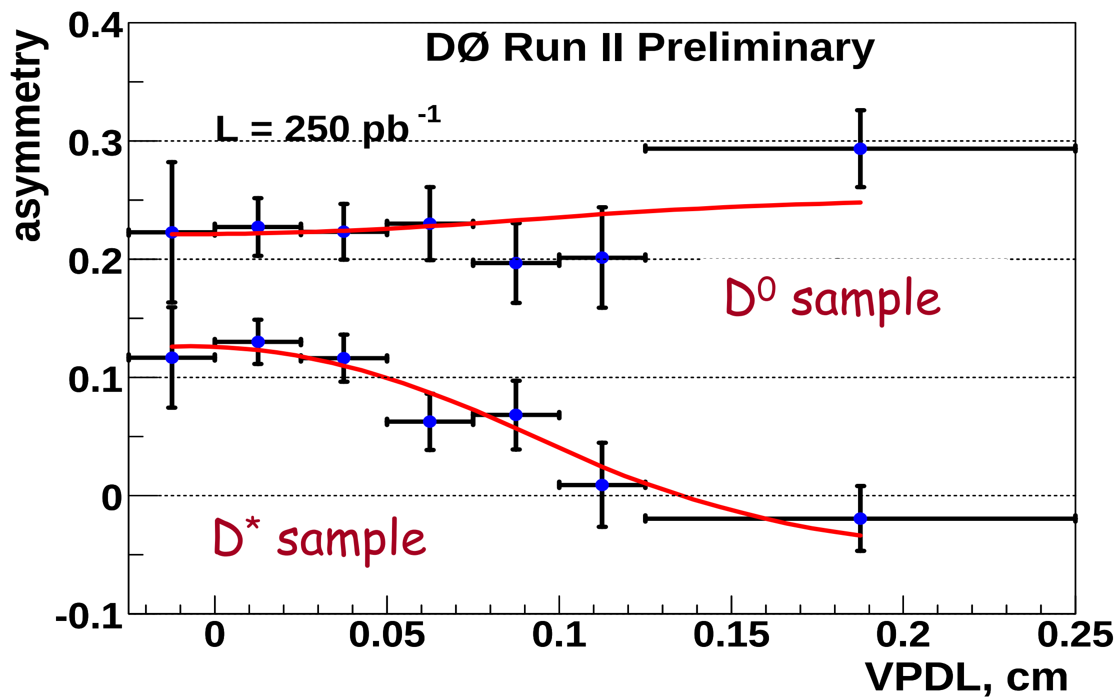
charged pion from D** may be taken as a tag

always gives "correct tag" for both B0 and B+ irrespective of oscillations

evaluated from D** topological analysis

Δm_d (SST) 250pb^{-1}

Simultaneous χ^2 fit to asymmetries in D^* and D^0 samples:



Chief systematics:

- D^{**} pion tagging probability
- branching rates of B mesons
- k-factor variations
- $D^*\mu$ and $D^0\mu$ fitting procedure
- VPDL resolution function
- modelling of MC efficiencies

D_0 : Dilution for D^* sample
$D_\pm$: Dilution for D^0 sample

Preliminary results:

Δm_d=0.488±0.066(stat)±0.044(syst) ps^{-1}

D_0=0.116 ±0.014(stat)±0.016(syst)
$D_\pm$=0.244 ±0.016(stat)±0.024(syst)

Combined tags analysis $200pb^{-1}$

Data sample split into two sets:

1) Tagged by soft muons (SLT)
2) Tagged by combined jetQ+SST algorithm

SST: track with min. ΔR wrt B-meson

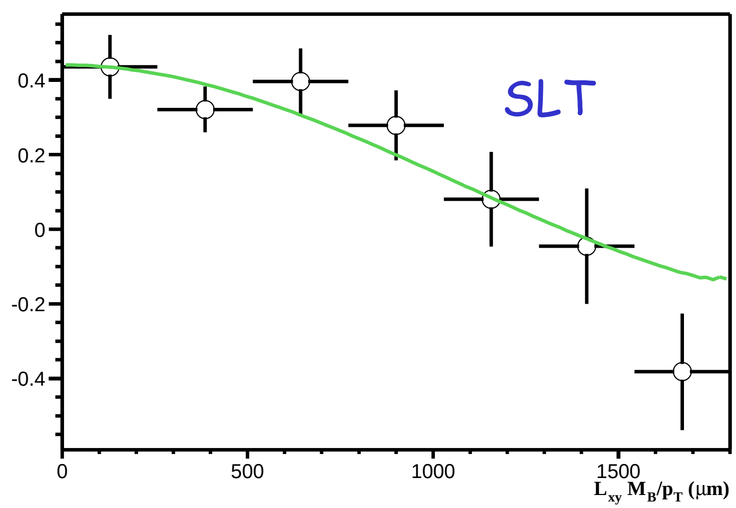
Combined algorithm produces non-zero answer if:

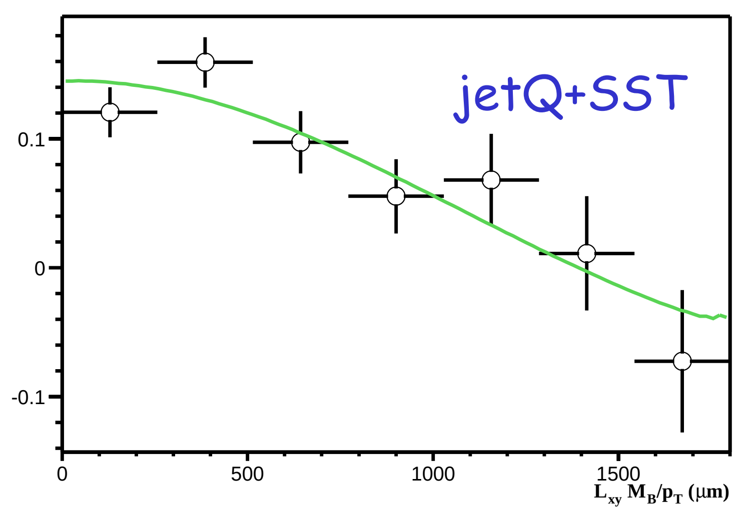
- Event not tagged by SLT
- At least one of jetQ and SST gives a non-zero answer
- jetQ and SST give same answer ($\Rightarrow$ better dilution)

Combined tagger result

200pb^{-1}

Simultaneous fit to SLT and jetQ+SST asymmetries





Chief systematics:

- D^* μ sample composition
- D^{**} pion tagging probability
- Charged B dilution determination

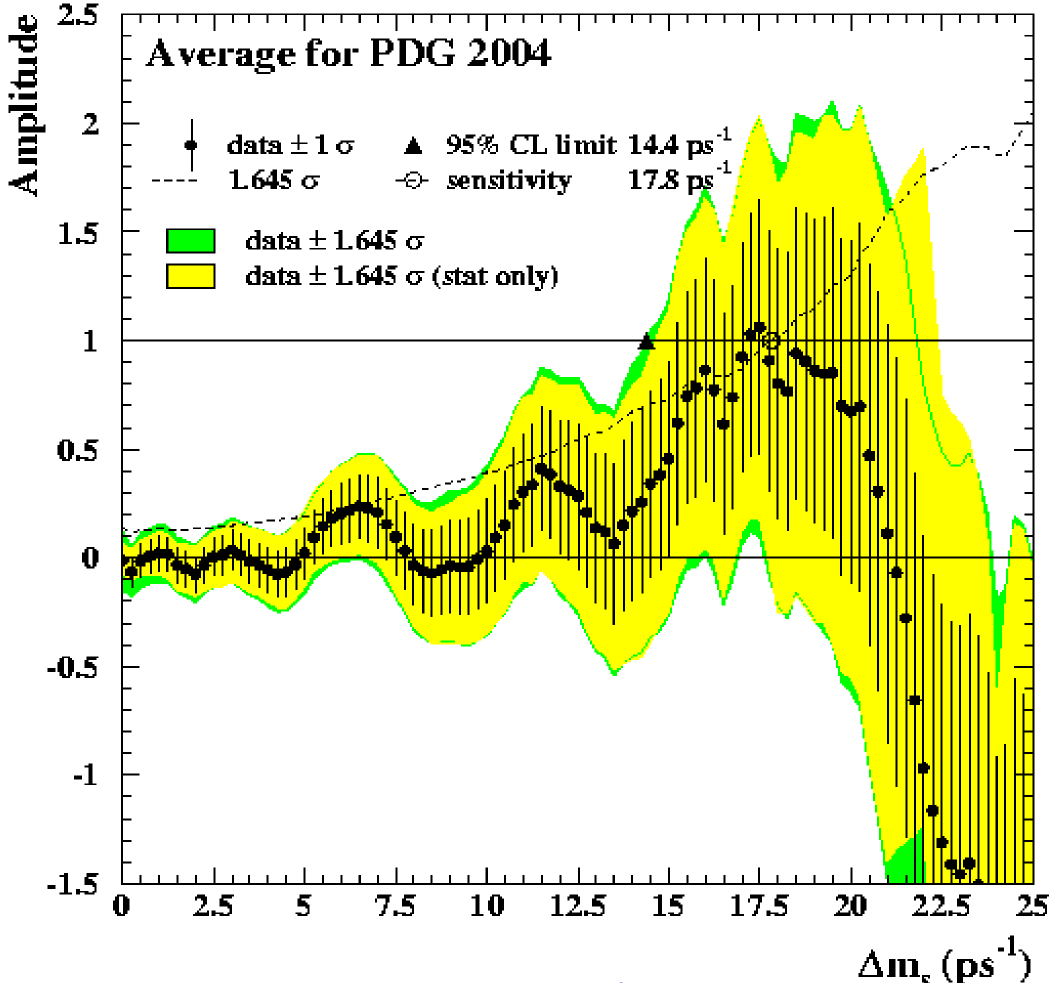
Preliminary results:

Δm_d=0.456 ± 0.034 (stat)± 0.025 (syst) ps^{-1}

D_0 = (44.8 ± 5.1) % SLT
D_0 = (14.9 ± 1.5) % jetQ+SST
$D_{\pm}$= (27.9 ± 1.2) % jetQ+SST

ε = (5.0 ± 0.2) % SLT
ε = (68.3 ± 0.9) % jetQ+SST

In search of B_s oscillations



("Amplitude method")

Fit data to

$$P = \frac{\Gamma}{2} e^{-\Gamma t} [1 \pm A \cos(\Delta m_s t)]$$

Fit for A as a function of Δm_s

Measurement: $A = 1$
Sensitivity: $1.645\sigma_A = 1$ (95%)
Limit: $A < 1 - 1.645\sigma_A$ (95%)

Current limit :
$\Delta m_s > 14.4\ ps^{-1}$ @95% CL

Sensitivity

Current limits :

B_s oscillates at least 30 times faster than B^0 !

$\Rightarrow$ A measurement of Δm_s is experimentally very challenging

Statistical Significance :

$$S(\Delta m, \sigma_t) = \sqrt{\frac{\varepsilon D^2 S}{2}} \sqrt{\frac{S}{S+B}} \times e^{-(\Delta m \sigma_t)^2/2}$$

Flavor tagging

Signal purity

For large Δm, proper time resolution (σ_t) becomes v. imp.

Initial-state tagging algorithms being verified and optimized using Δm_d measurements

$B_s \rightarrow D_s \mu X$ decays being reconstructed in different modes. Hadronic modes are being studied too

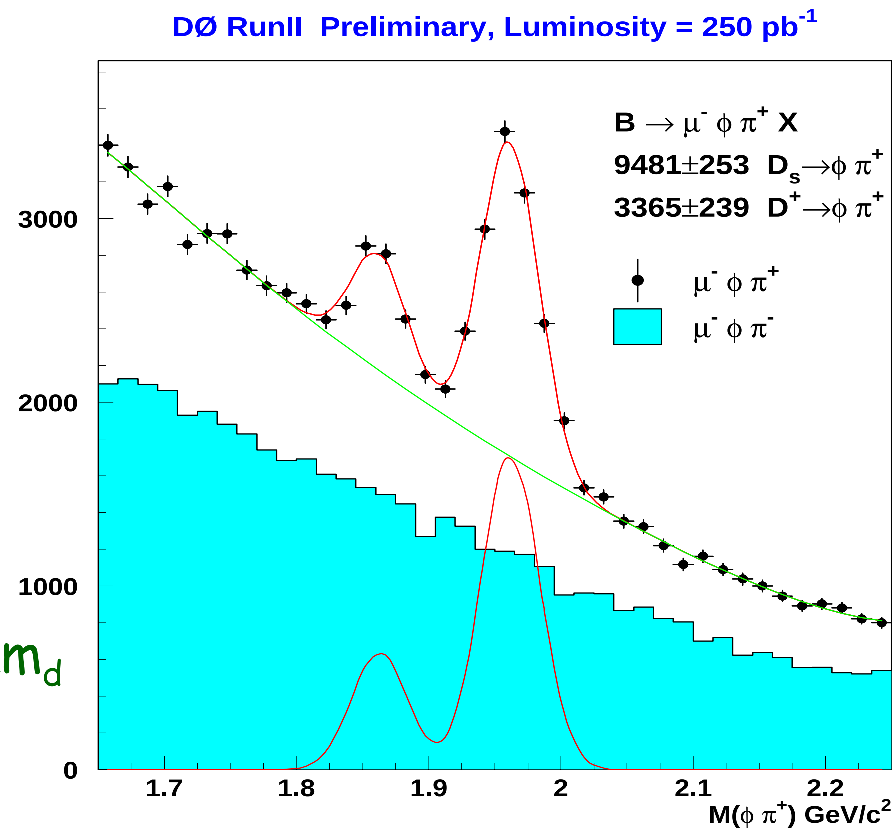
$B_s \to D_s \mu X$

Largest semileptonic yield in the world !!

$D_s \to \phi\pi$
BR= (3.6±0.9)%

~ 9481 events in 250pb^{-1}

- ✓ Large signal yield
- ✓ Cuts being optimized for S/S+B
- ✓ Flavor tagging being tested with Δm_d



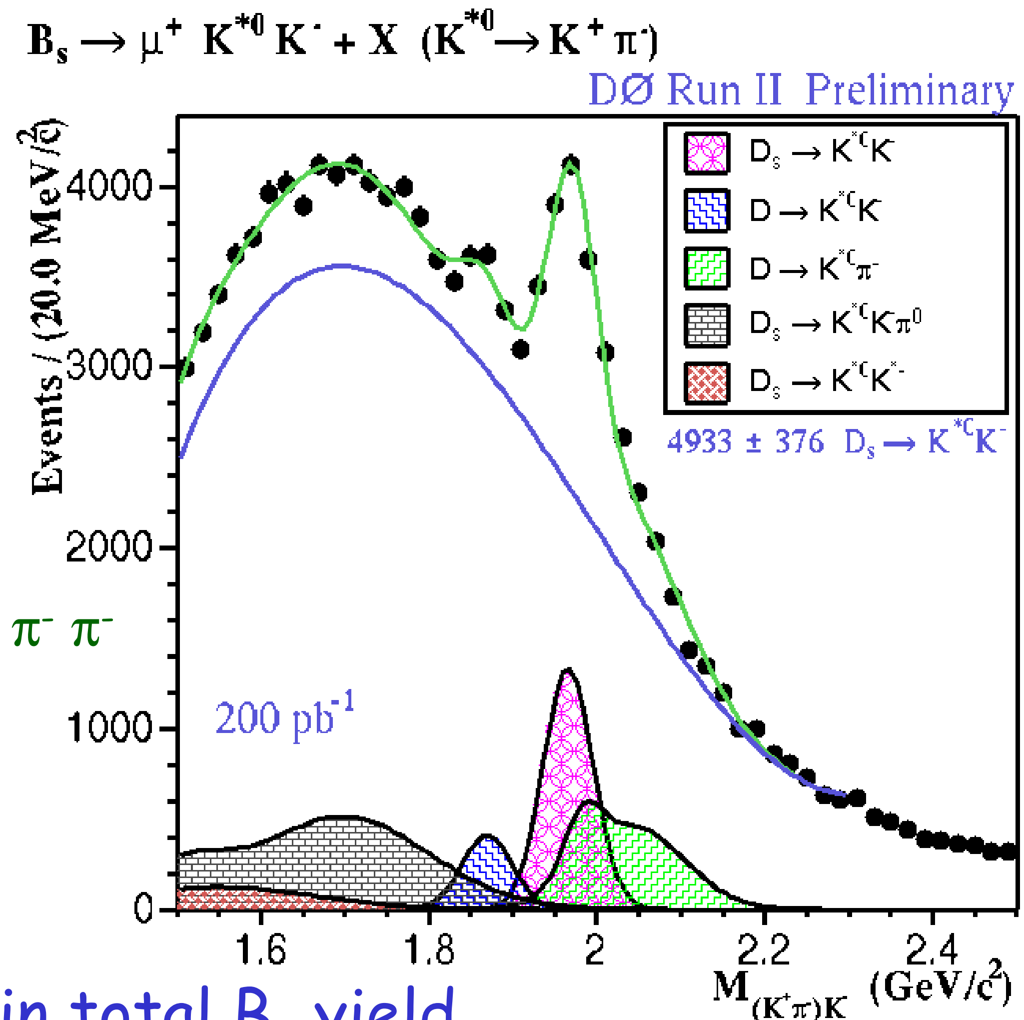
$B_s \rightarrow D_s \mu X$

$D_s^- \rightarrow K^{*0} K^-$

BR= (3.3±0.9)%
(BR comparable to $D_s \rightarrow \phi\pi$)

But larger backgrounds
- $D^- \rightarrow K^+ \pi^- \pi^-$
  - $D^- \rightarrow K^* \pi^-$
  - non-resonant $D^- \rightarrow K^+ \pi^- \pi^-$

~ 4933 events in 200 pb^{-1}



⇒ Significant increase in total B_s yield

Other D_s decays are being studied too

Summary

- We have preliminary measurements of Δm_d using different tagging techniques (250pb^{-1})
  - Δm_d=0.506±0.055(stat)±0.049(syst) ps^{-1} (SLT)
  - Δm_d=0.488±0.066(stat)±0.044(syst) ps^{-1} (SST)
- We have started to combine different taggers (200pb^{-1})
  - Δm_d=0.456±0.034(stat)±0.025(syst) ps^{-1} (SLT+jetQ+SST)
- We are optimizing our taggers for B_s mixing studies
- We have the largest $B_s \rightarrow D_s \mu X$ yields in the world
- Prospects for B_s mixing look good

Stay tuned…

BACKUP SLIDES