B mixing and flavor oscillations at DØ

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Outline

- Motivation
- Mixing and Oscillation
- Tevatron and DØ Detector
- Flavor tagging
- B_d Mixing Limit
- B_s Mixing Limit
- Prospects and plans
- Summary

Motivation

- The ratio $\Delta m_s/\Delta m_d$ constrains one side of the unitarity triangle
- also study CP violation in B_s system
  - studied in Kaon and B_d system

- Belle and Babar not sensitiv
- LHCB not running
- Tevatron currently only place to study B_s Mixing

Mixing

The transition of a neutral particle into its antiparticle is called Mixing.

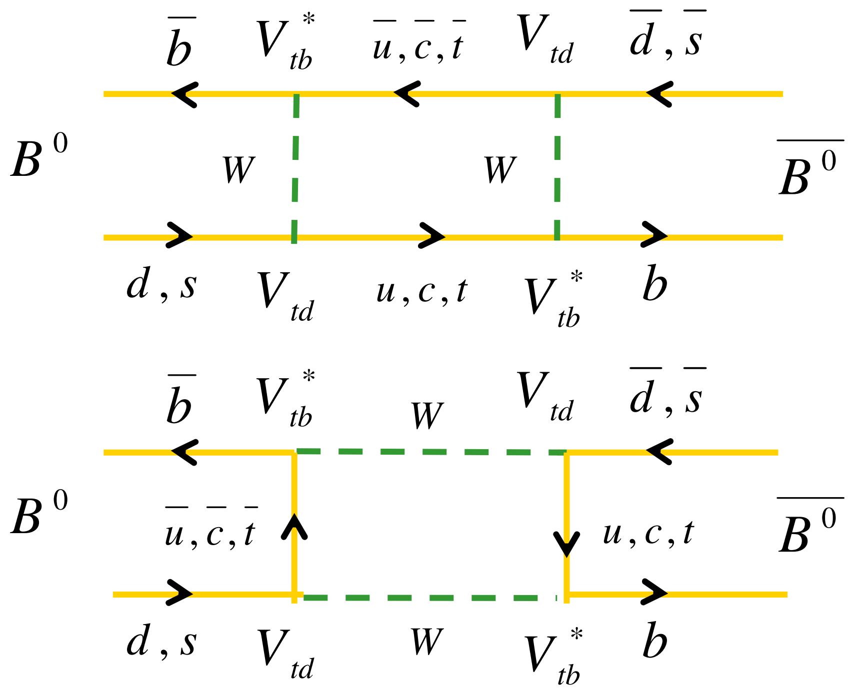
$$|B_{l,h}\rangle = p|B^0_{s.d}\rangle \pm q|\overline{B^0_{s,d}}\rangle$$

$$\Rightarrow \Delta m_{s,d} = m_h - m_l$$

$$\Delta\Gamma_{s,d} = \Gamma_h - \Gamma_l$$

$$\underset{pure\ B_s^0\ at\ t=0}{P(\Delta m_q, \tau_q, t)} = \frac{\exp^{(-t/\tau_q)}}{\tau_q} \cdot \frac{1 \pm \cos(\Delta m_q t)}{2} \cdot dt$$

Particle ↔ Antiparticle



"+": B_s^0

"−": $\overline{B_s^0}$

Unitarity triangle

Standard Model expectation:

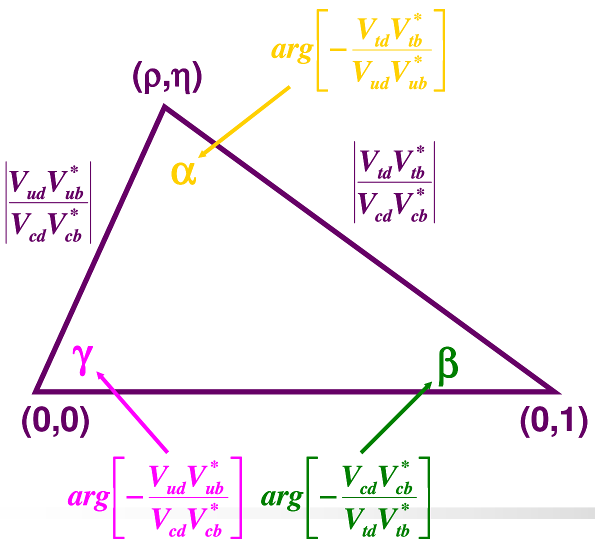
$$\Delta m_s = 14 \;....28 ps^{-1}$$

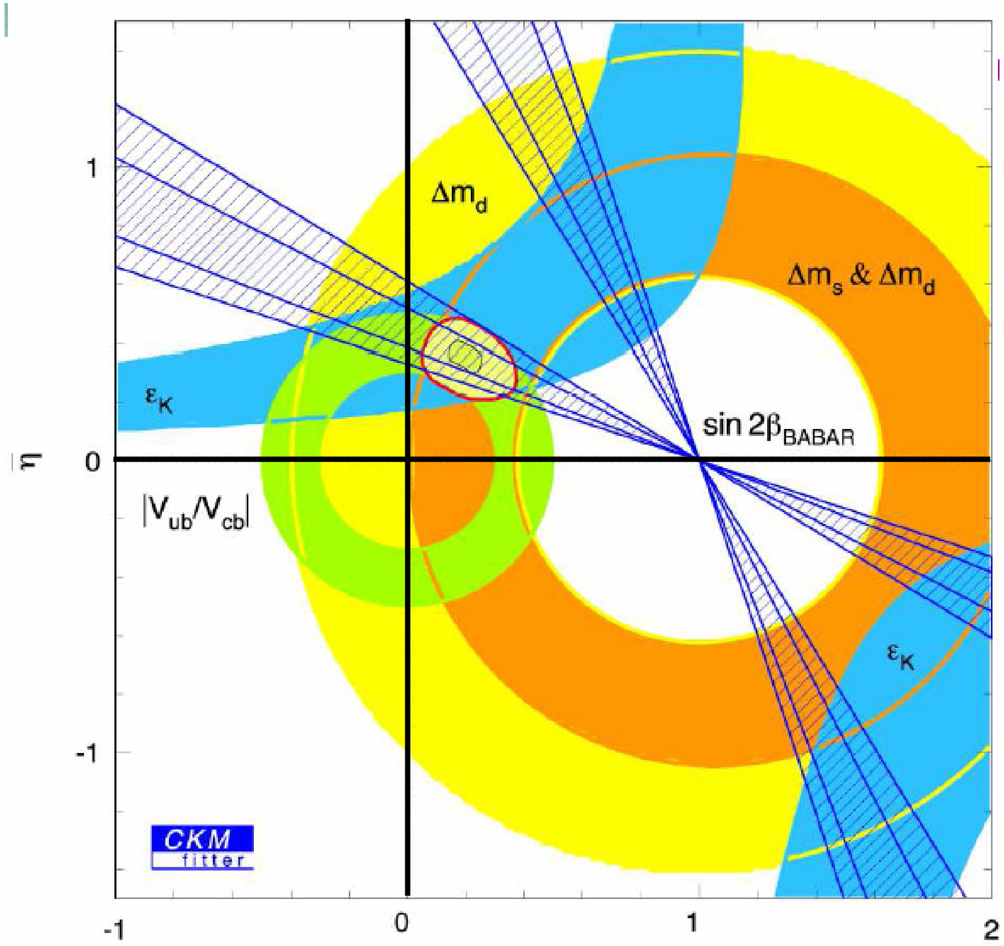
$$\Delta m_d = 0.5 ps^{-1}$$

measurement of $\Delta m_s / \Delta m_d$

$\rightarrow V_{ts}/V_{td}$

constrain unitarity triangle





Mixing (2)

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_B m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) \eta_{QCD} B_{B_d} f_{B_d}^2 \left|V_{tb}^* V_{td}\right|^2$$

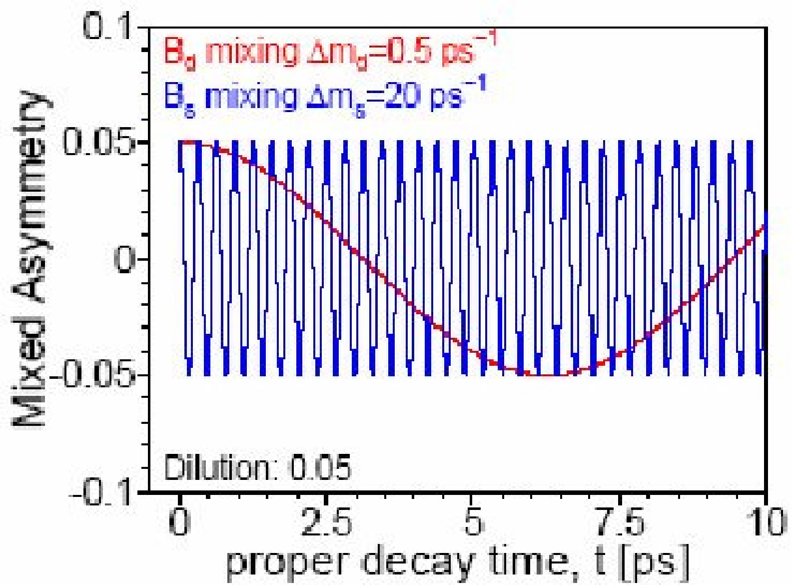
high uncertainties f(QCD)

reduce uncertainties by taking ratio

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

Measure Δm
$\rightarrow$ asymmetry

$$A_{mix}(t) = \frac{N_{unmix}(t) - N_{mix}(t)}{N_{unmix}(t) + N_{mix}(t)} = D \cdot \cos(\Delta m t)$$

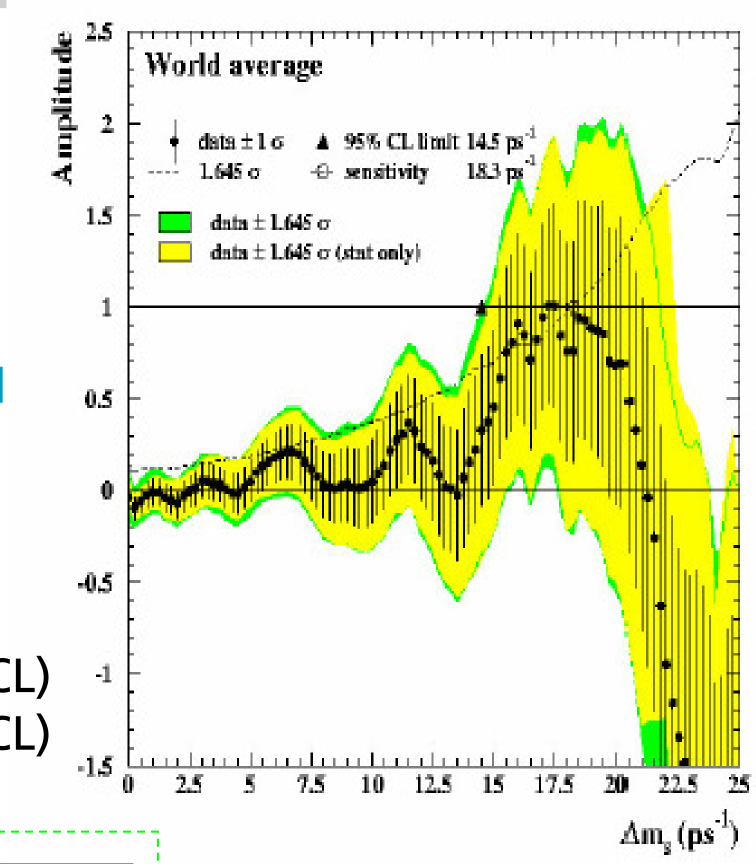


Mixing (3)

- **From the CKM fit: $\Delta m_s \sim 18\ ps^{-1}$**
- **Heavy Flavor Averaging group:**

combined LEP, SLD, CDF1 results

$\Delta m_s > 14.5\ ps^{-1}$



Mixing limit obtained using „Amplitude“ Method

- Fit data to $P = \frac{\Gamma}{2} e^{-\Gamma t}\left[1 \pm A\cos(\Delta m_s t)\right]$
- Fit for A as a function of Δm_s
  - A peaks at 1 for a measurement
  - Sensitivity given by $1.645\sigma_A = 1$ (95% CL)
  - Limit given by $A<1-1.645\sigma_A$ (95% CL)

$$sensitivity \propto \sqrt{\frac{N\varepsilon D^2}{2}}\, e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

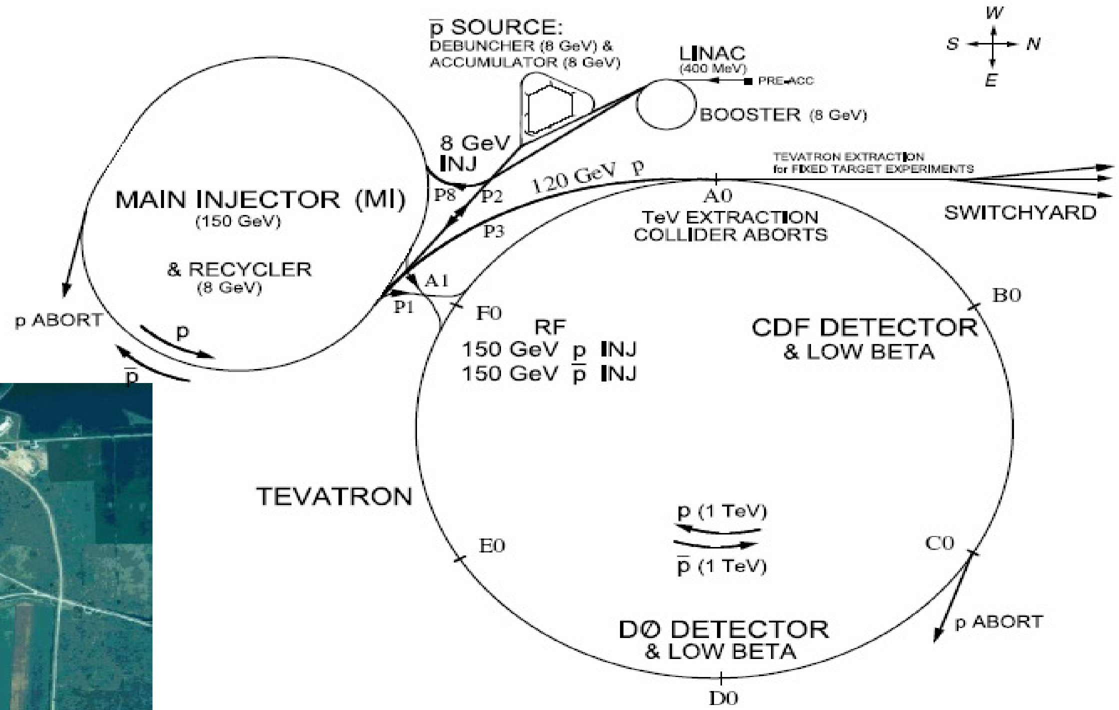
$$Dilution\quad D = \frac{N_{RT} - N_{WT}}{N_{RT} + N_{WT}}$$

flavor tagging performance — **resolution** — selection

Tevatron

Achieved :

$1.17\times10^{32}\,cm^{-2}s^{-1}$

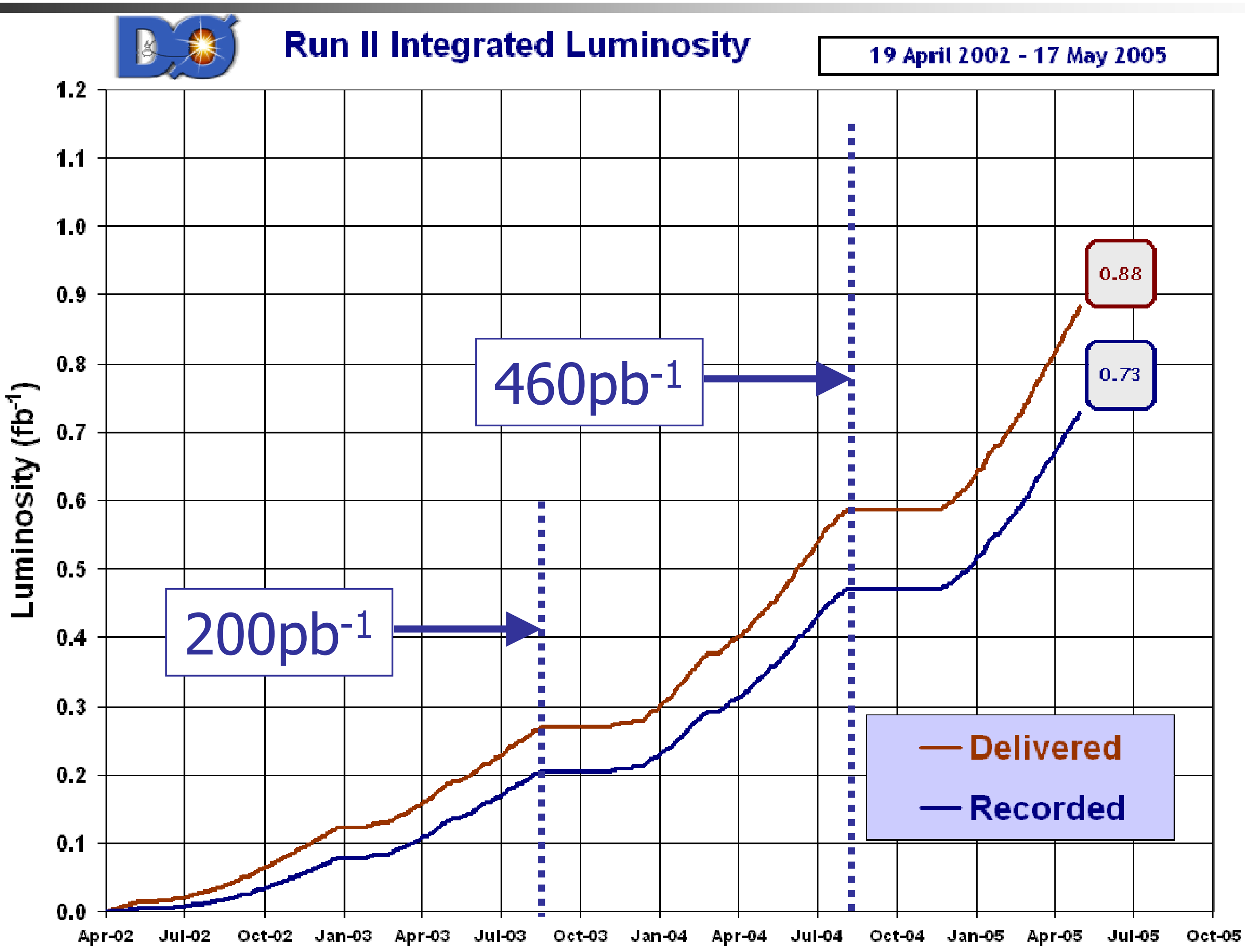


expected $\mathcal{L}:\ 1.5-3\times10^{32}\,cm^{-2}s^{-1}$

$\Rightarrow 4-8\ fb^{-1}$ before LHC

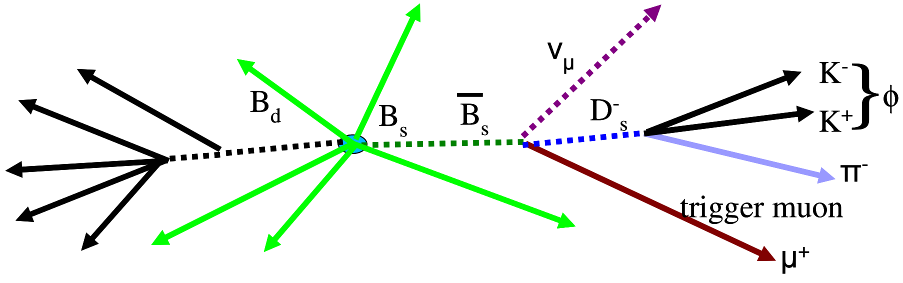
Big advantage for B physics : B_s meson production

Luminosity



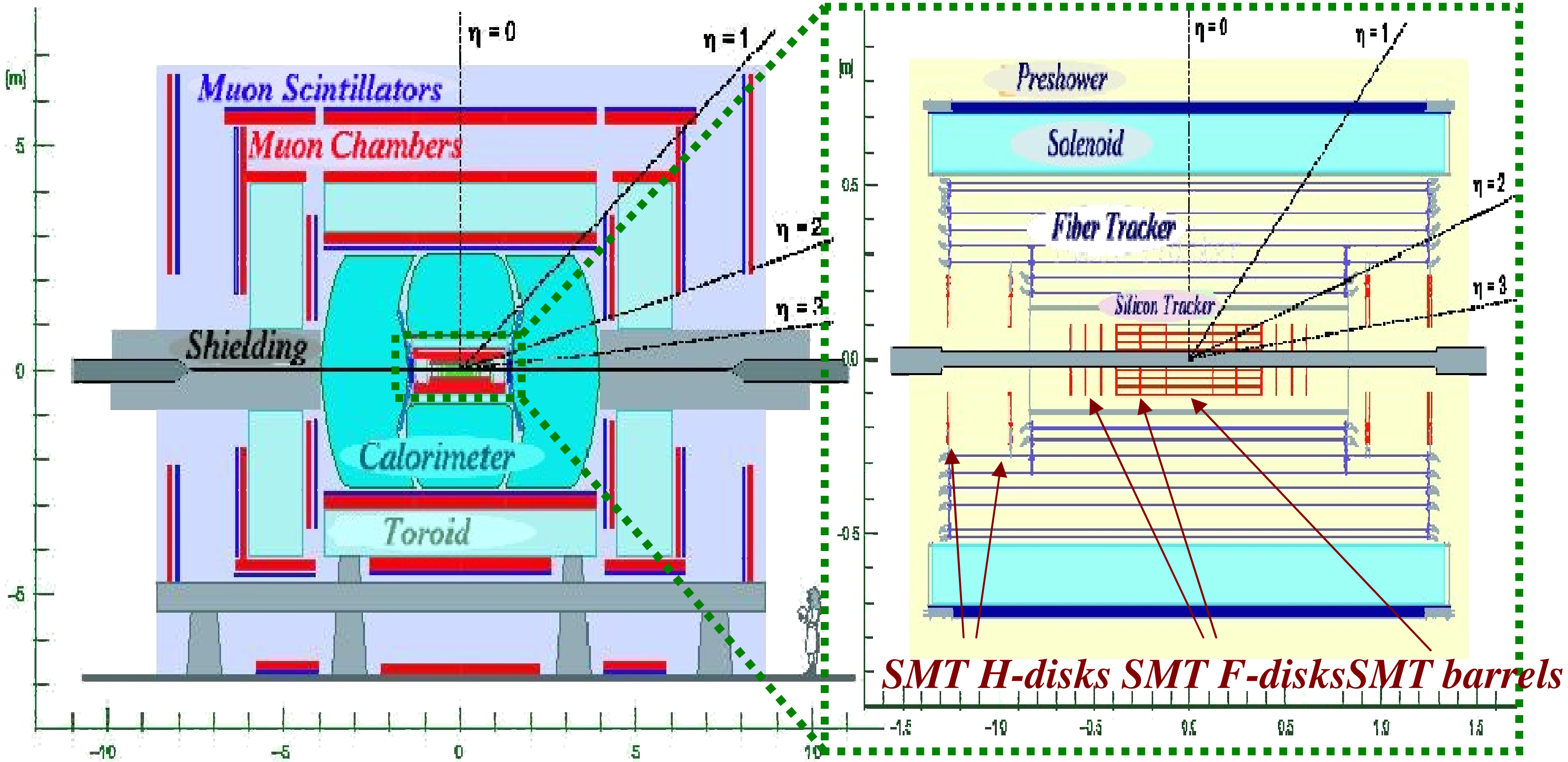
Run II Integrated Luminosity
19 April 2002 - 17 May 2005
Luminosity (fb-1)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
460pb-1
200pb-1
0.88
0.73
Delivered
Recorded

D0 Detector

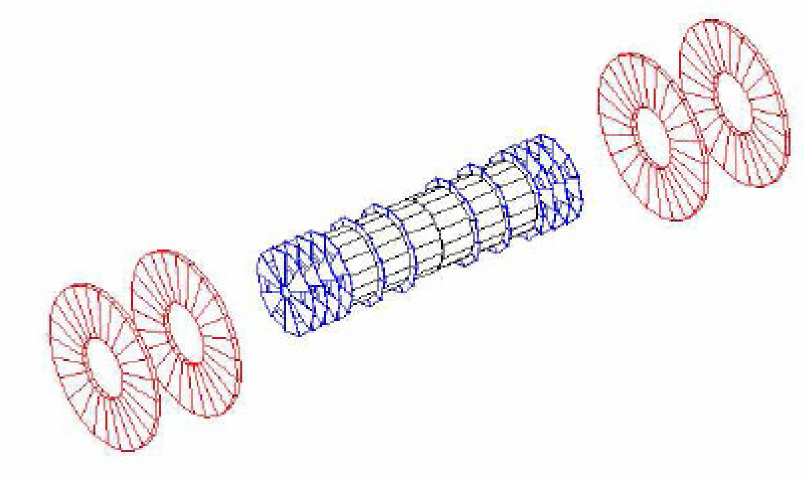


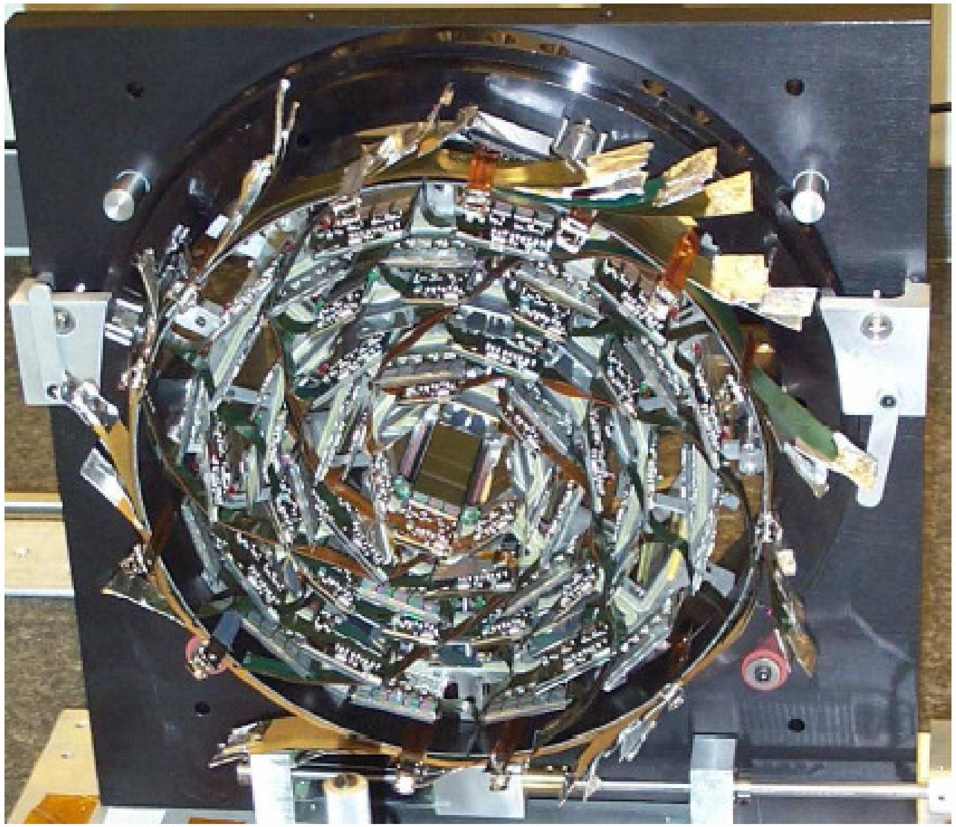
Semileptonic decays:

- trigger on muon
  - ➢ good muon system
- reconstruct tracks and vertex
  - ➢ good tracking system



Silicon Microstrip Tracker (SMT)



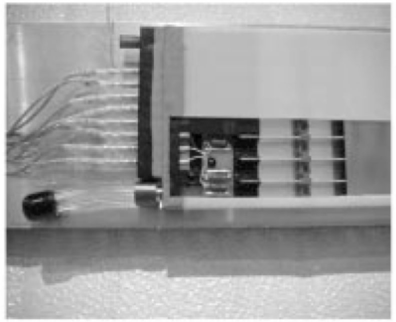


- Silicon Microstrip Tracker
  - ~800.000 channels
  - point resolution: 10μm
  - Secondary vertex resolution
    - 40μm (r-ϕ)
    - 80μm (r-z)

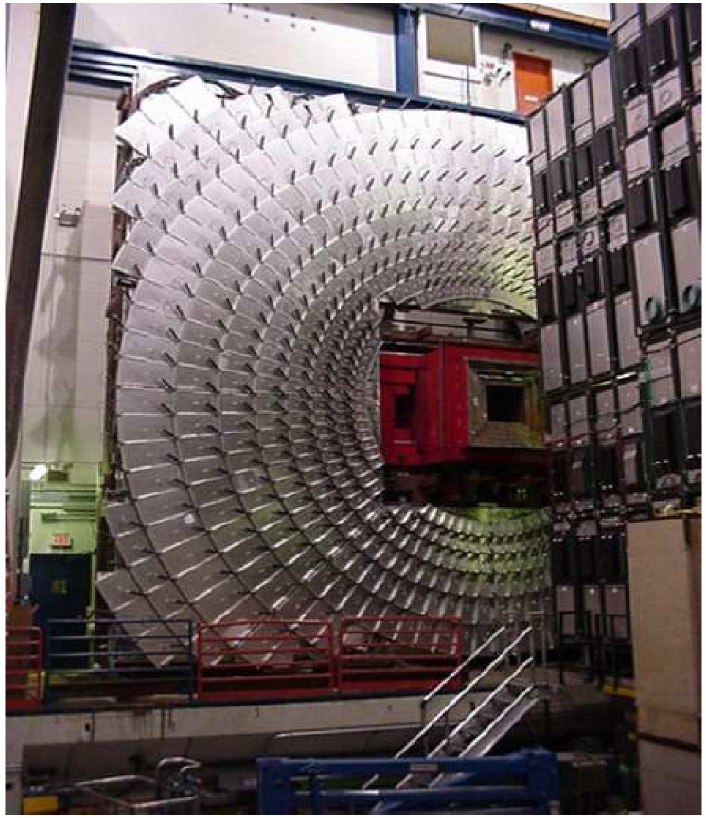
- Trackers
  - Silicon Tracker: $|\eta|<3$
  - Fiber Tracker: $|\eta|<2$
- Magnetic field 2T

Muon Sytem

- 2 Tesla toroid magnet between A und BC Layer → Muon momentum
  - propotional drift tubes
  - pixel scintillators



A minidrift tube with cover partially removed



- Muon system coverage |η|<2 and good shielding

B production and decay

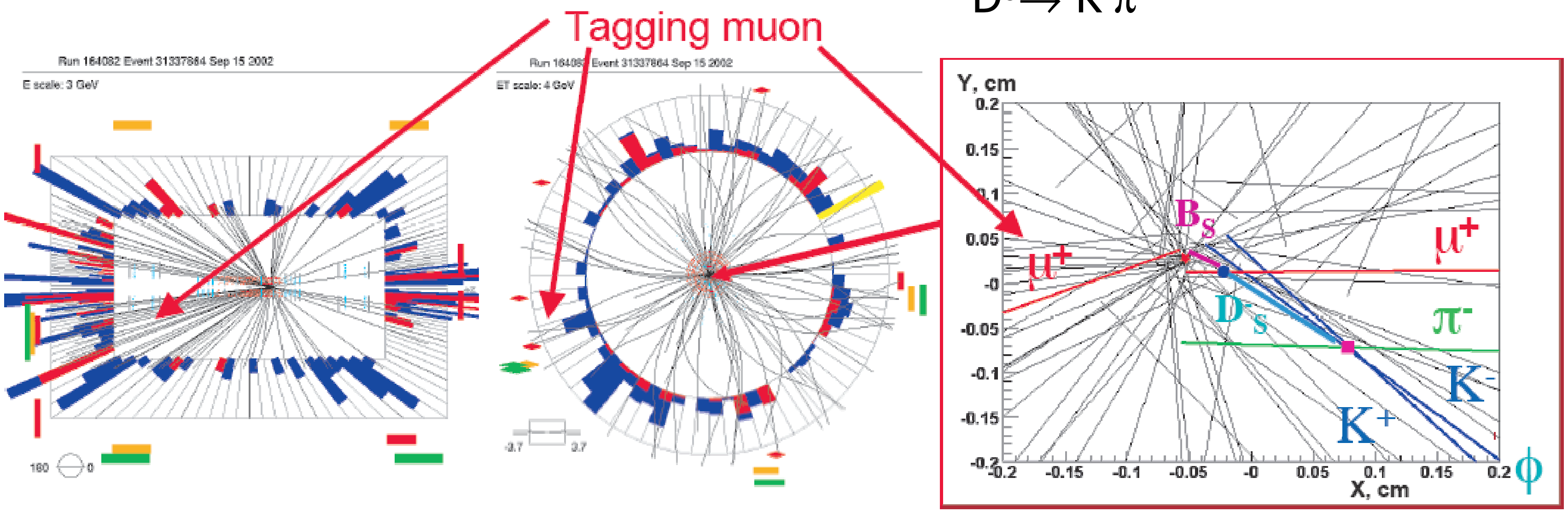
<u>B production Fermilab:</u> $\sigma \approx O(100\mu b)$
<u>L1 Trigger acceptance (DØ: Muon) :</u> $\sigma \approx O(3\text{-}5\mu b)$

Used Decays:

$B^0_s \rightarrow D^-_s \mu\nu_\mu$
$D^-_s \rightarrow \phi(K^+K^-)\pi^-$

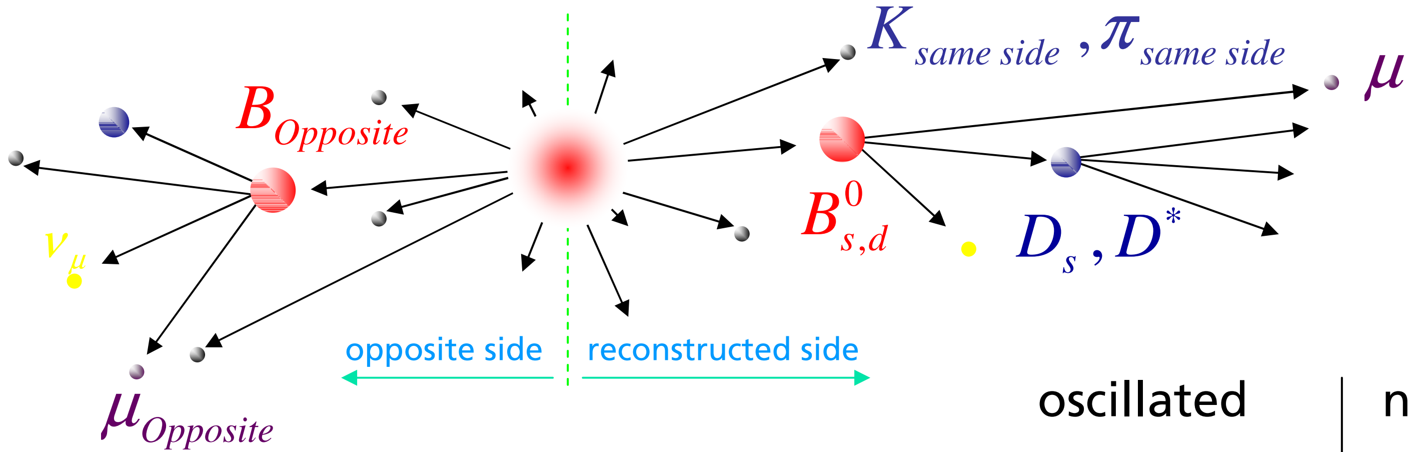
$B^0_d \rightarrow D^*(2010)^-\mu^+ \nu_\mu$
$D^*(2010)^- \rightarrow D^0(K^+\pi^-)\pi^-$

$B^+ \rightarrow \bar{D}^0\mu^+ \nu_\mu$
$\bar{D}^0 \rightarrow K^-\pi^+$



Flavor tagging

Flavor tagging : determine b-flavor at production time!



1. **Soft Lepton Tag (SLT)**
2. **Opposite Jet charge (Jetq)**

$$Q_J = \sum_i q_i (p_T)_i^\kappa \Big/ \sum_i (p_T)_i^\kappa$$

3. **Same Side Tag**
   (currently only used for B_d)

oscillated	not oscillated
$Q_{\mu_{Opposite}} \cdot Q_\mu > 0$	$Q_{\mu_{Opposite}} \cdot Q_\mu < 0$
$Q_J \cdot Q_\mu > 0$	$Q_J \cdot Q_\mu < 0$
$Q(\pi_{same\ side}) \cdot Q_\mu < 0$	$Q(\pi_{same\ side}) \cdot Q_\mu > 0$

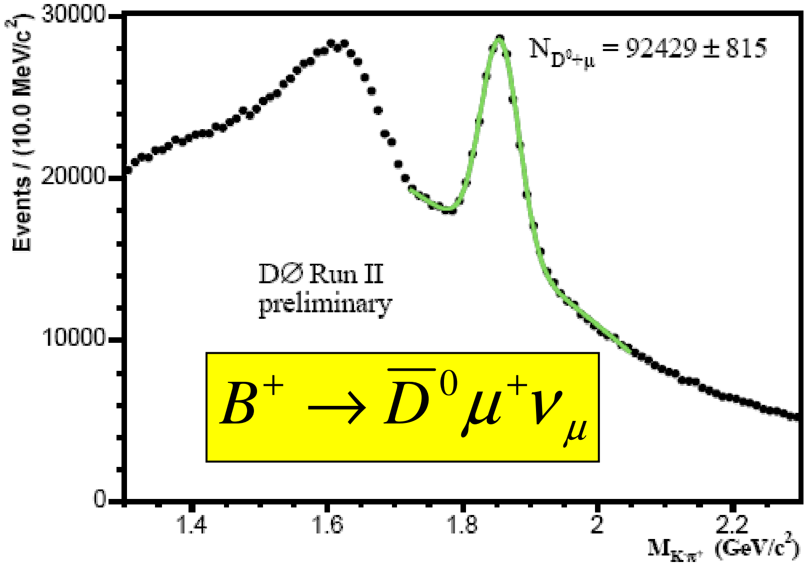
B_d Sample

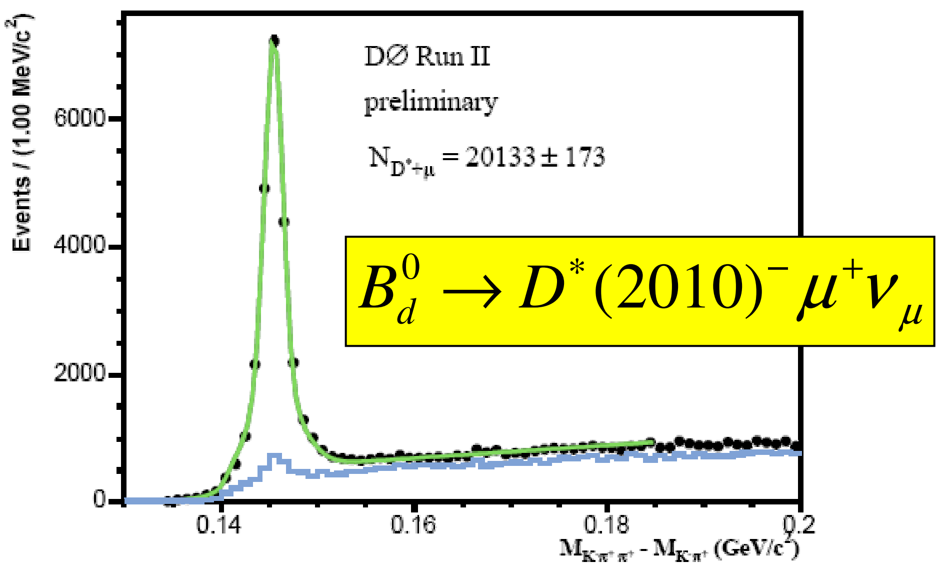
- **Charged tracks:**
  - **p_T > 0.65 GeV/c**
- **impact parameter significance:**

$$(dca/\sigma_{dca})^2 + (zca/\sigma_{zca})^2 > 3$$

- **angle and distance :**
  - **distance PV → D Vertex (xy-plane)**
  - **D Vertex not before B Vertex**
  - **Angle between PV → B Vertex and PV → D Vertex**

Single μ data – 200pb^{-1}



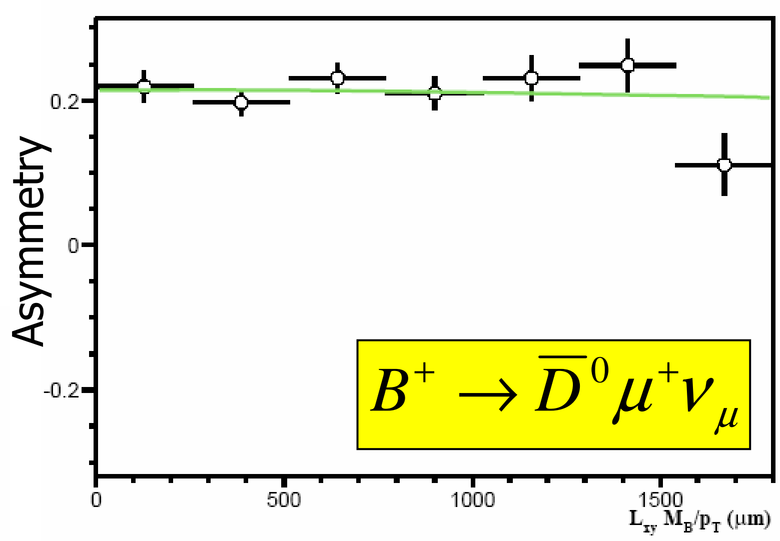


B_d Mixing Limit

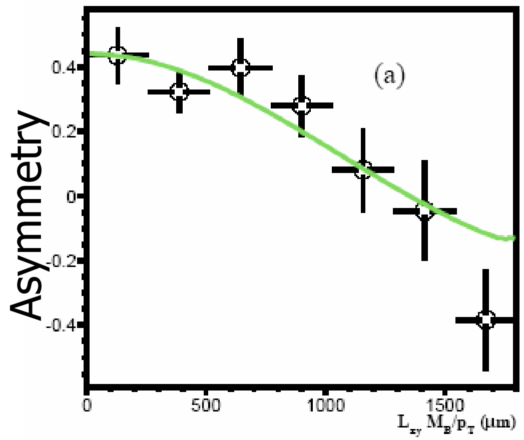
SLT : $D_0 = (44.8 \pm 5.1)\%$
Jetq+SST: $D_0 = (14.9 \pm 1.5)\%$

Jetq+SST: $D_\pm = 27.9\%$

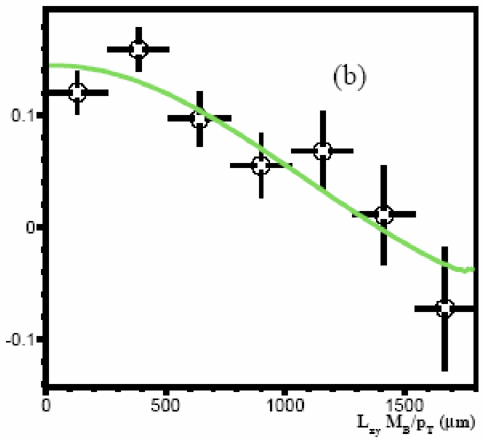
$Jetq + SST$



SLT



$Jetq + SST$



$B_d^0 \to D^*(2010)^- \mu^+ \nu_\mu$

$\Delta m_d = 0.456 \pm 0.034 ps^{-1}$(stat) $\pm 0.025 ps^{-1}$(syst)

consistent with $\Delta m_d = 0.502 \pm 0.007 ps^{-1}$ (world average)

B_s Mixing analysis procedure

- Currently only using a single semileptonic decay of the Bs

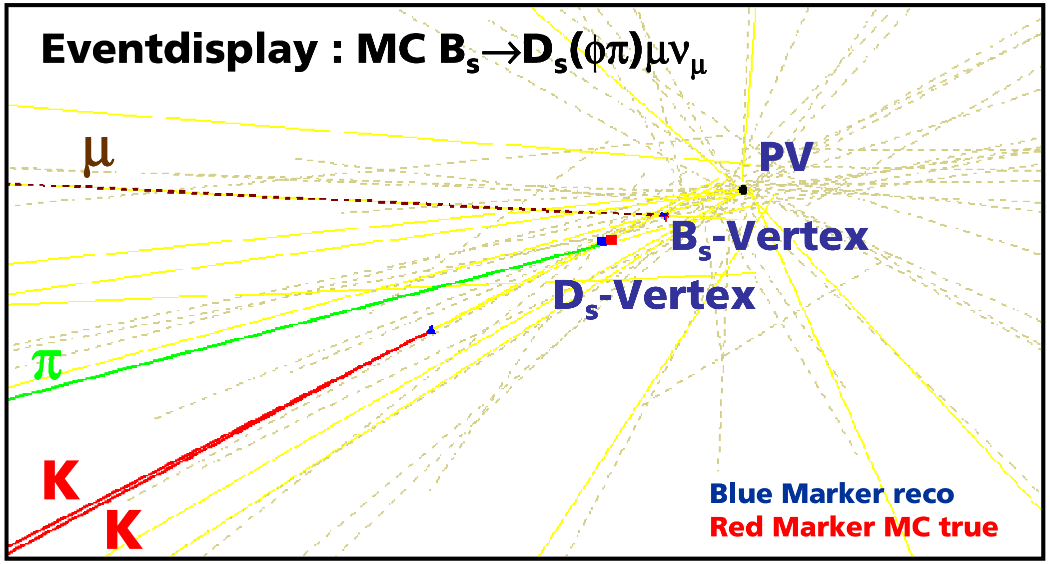
  $B_s \rightarrow D_s\, \mu\, X$ (Ds $\rightarrow \phi$ p) ($\phi \rightarrow$ K K)

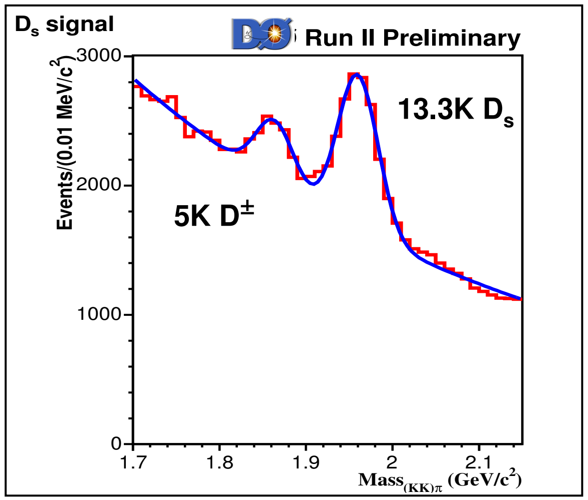
- Using μ + SV vertex tag (Opposite side tag, independent of reconstructed side)

- The goal was to develop tools and to allow a baseline to build on for the future

B_s Sample

- **Charged tracks:**
  - **$p_T > 0.7$ GeV/c**
  - **impact parameter significance**
- **Invariant KK mass**
  - **1.006 < M(KK) < 1.30**
- **angle and distance :**
  - **distance PV → D Vertex (xy-plane)**
  - **D Vertex not before B Vertex**
  - **Angle between PV → B Vertex and PV → D Vertex**
  - **Angle between PV → D Vertex and D momentum**
  - **...**





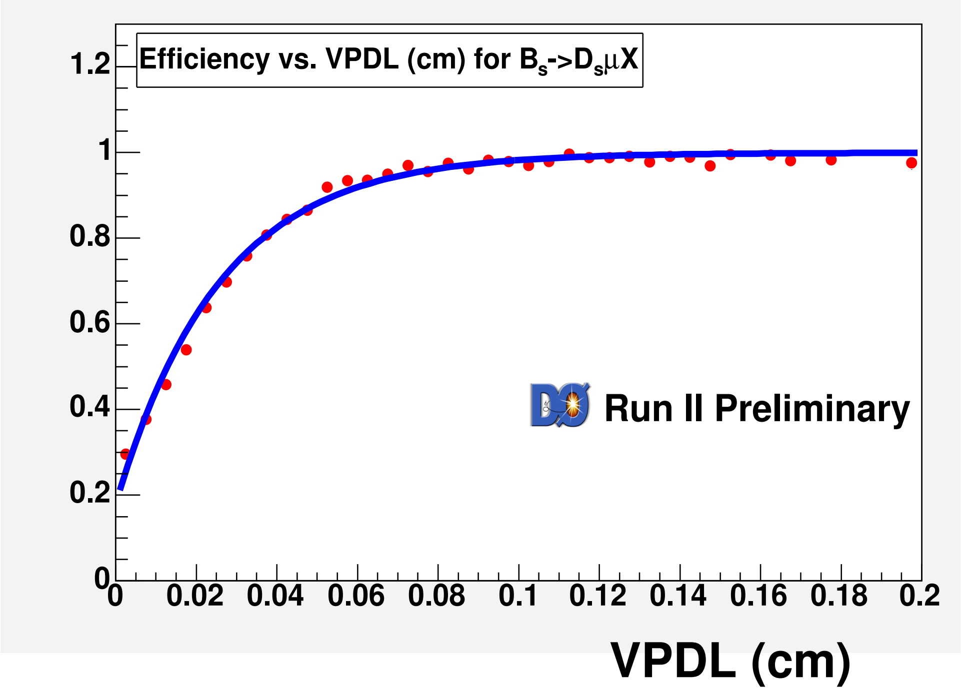
B_s Mixing fitting procedure

- Inputs to the fitting procedure
  - **MC**
    - **Sample composition**
    - **K-factor to take non-reconstructed particles into account**
    - **Efficiencies**
    - **Visible Proper Decay Length (VPDL) resolution**
  - **VPDL resolution** has been tuned using **data**
  - **Dilution** from B^0_d and B^+_u semileptonic samples

Sample Composition and efficiency

Decay	Sample composition
$B_s \to D_s \mu \nu$	20.6%
$B_s \to D^*_s \mu \nu$	57.2%
$B_s \to D^*_{0s} \mu \nu$	1.4%
$B_s \to D^*_{1s} \mu \nu$	2.9%
$B_s \to D_s D_s X$	11.3%
$B^0 \to D_s D X$	3.2%
$B^- \to D_s D X$	3.4%

$c\bar{c}$ estimated at ~ 3.5 ± 2.5 %

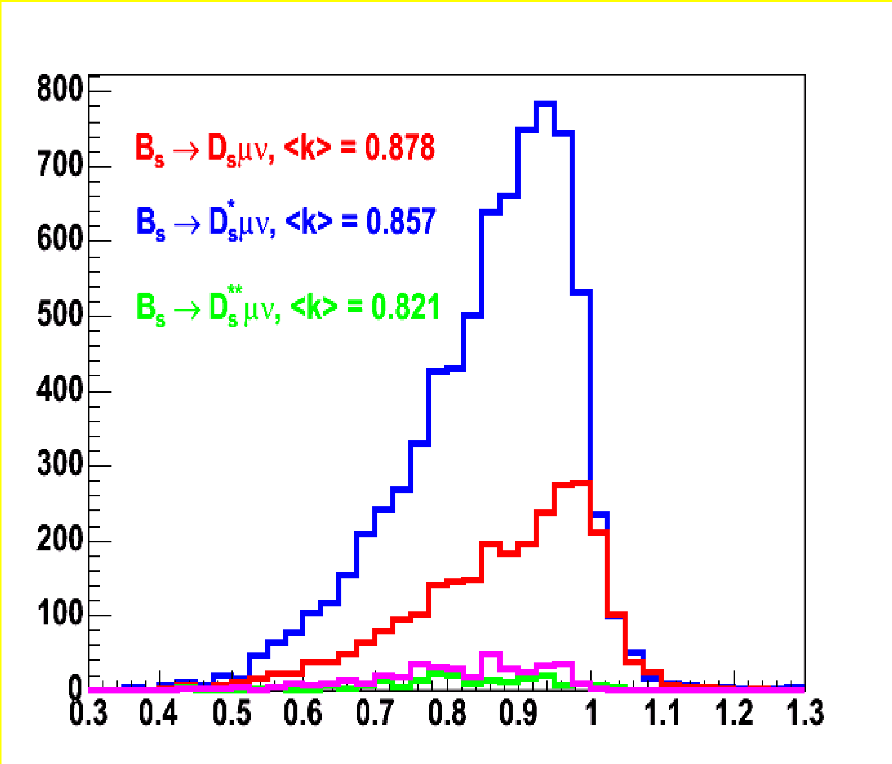


Efficiency drop at low VPDL due to impact parameter cuts on tracks from D_s decay

K-factors

$$K = \frac{P_t(\mu D_s)}{P_t(B_s)}$$

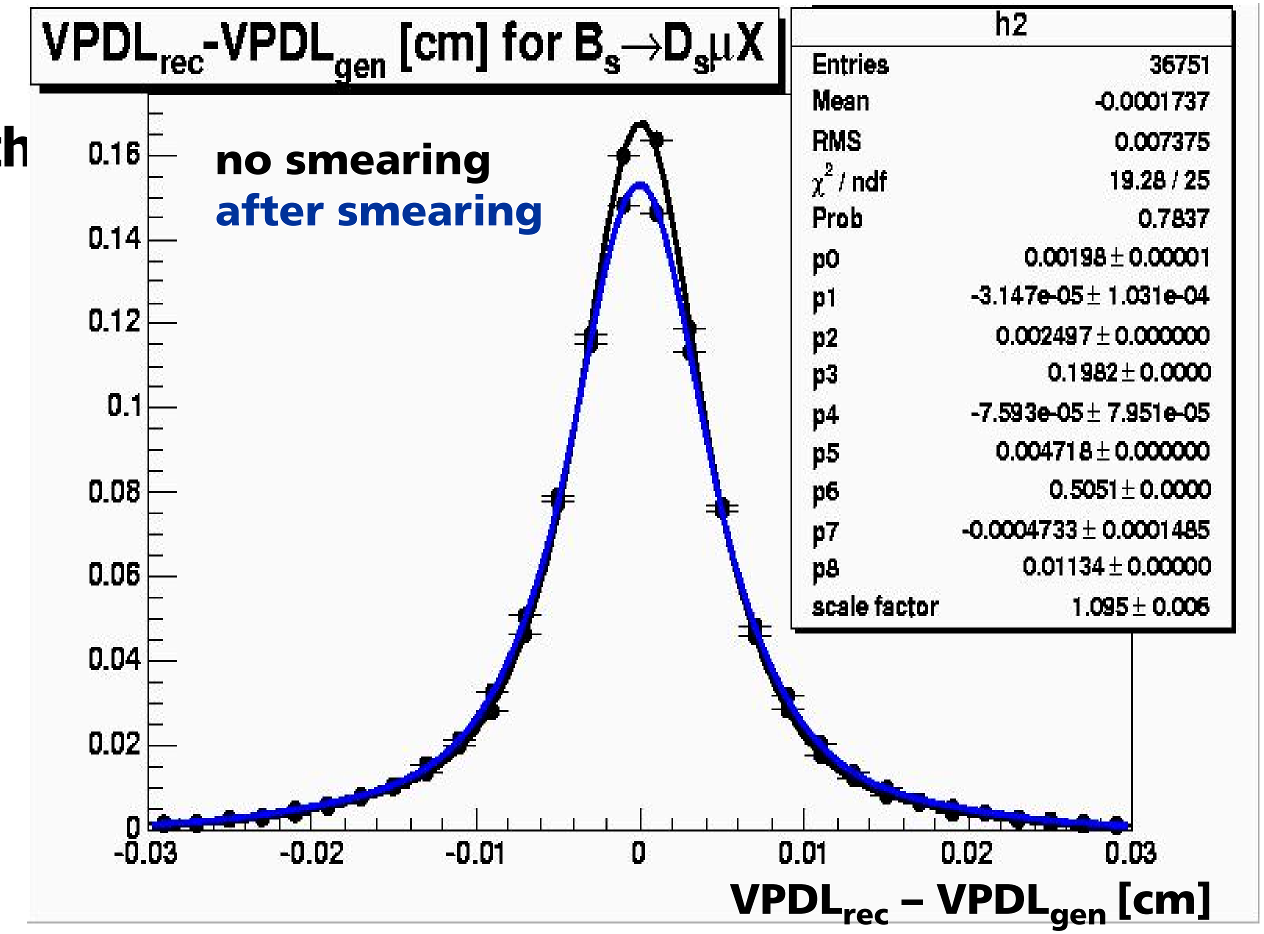
$$c\tau_{B_s} = K \times VPDL$$



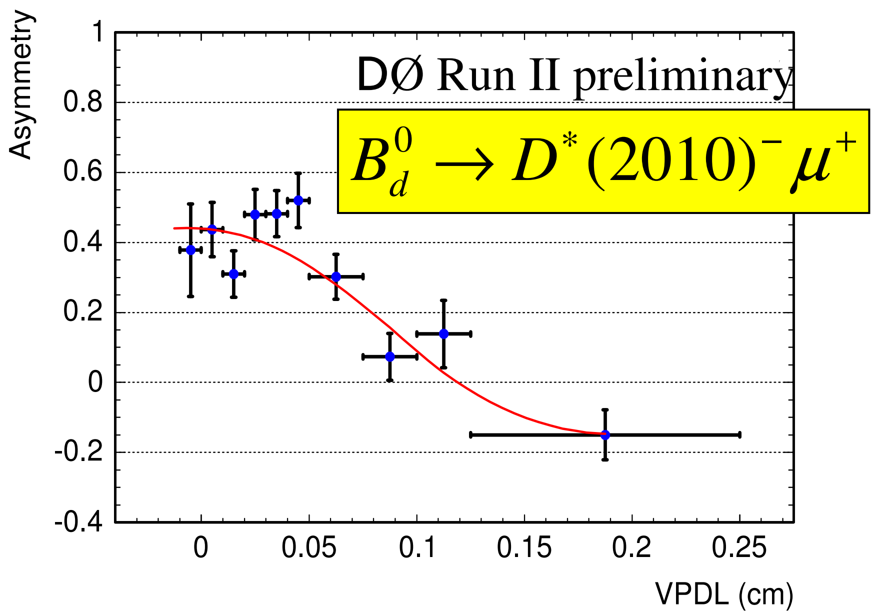
Decay	<k>
$B_s \to D_s\mu\nu$	0.878
$B_s \to D^*_s\mu\nu$	0.857
$B_s \to D^*_{0s}\mu\nu$	0.829
$B_s \to D^*_{1s}\mu\nu$	0.817
$B_s \to D_sD_sX$	0.738
$B^0 \to D_sDX$	0.681
$B^- \to D_sDX$	0.687

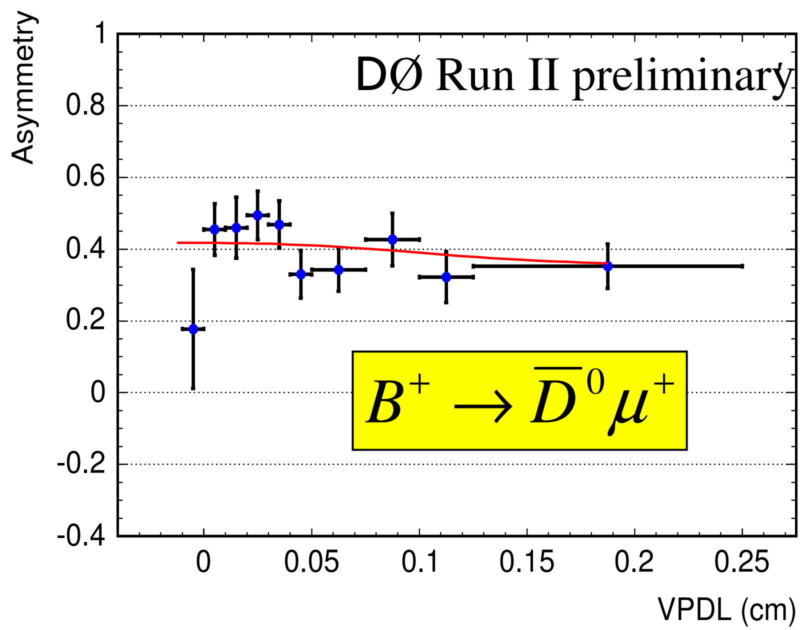
VPDL Resolution: MC tuned with data

- **VPDL resolution parametrized with three Gaussians**
- **Track by track**
- **smearing dependant on track momentum and polar angle**
- **Tuning results with one scale factor 1.095**



Dilution



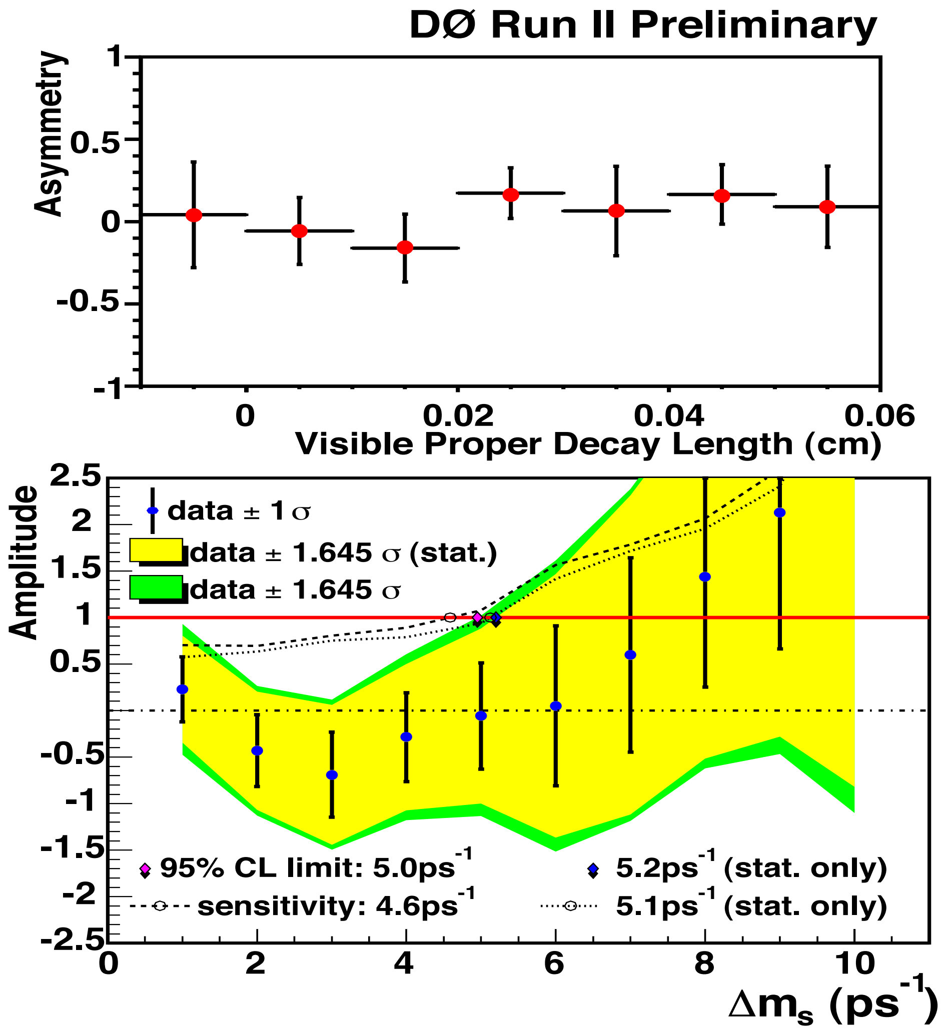


SLT + SV Jetq : D_0 = (39.0±3.2)% D± = (47.6±2.0)%

→ use mean : D_{avr}=(45.4±1.7)% for B_s asymmetry

B_s Mixing Limit

No obvious oscillations in the μD_s sample

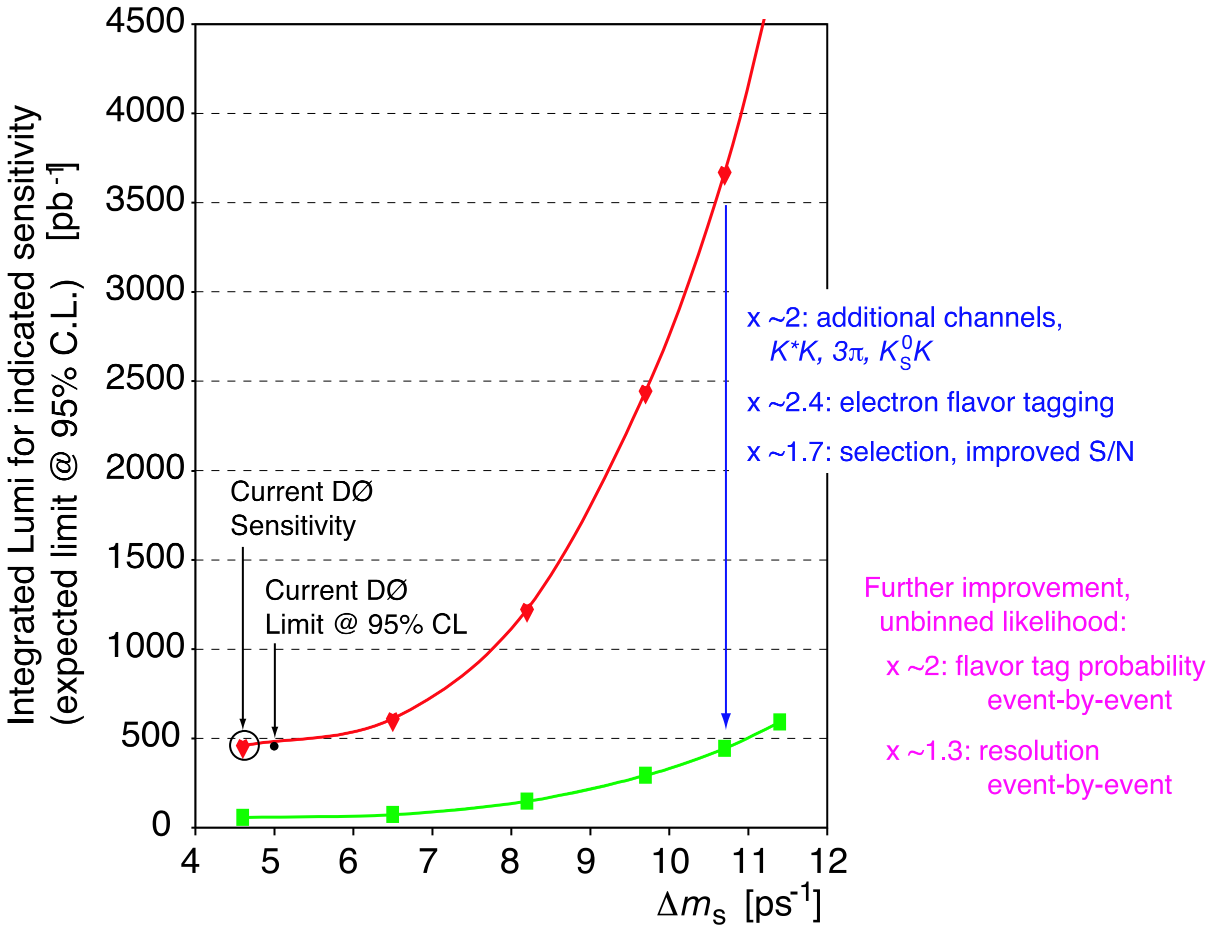


$\Delta m_s > 5.0\ ps^{-1}$ at 95% CL using "Amplitude" method

Sensitivity vs. Luminosity
Semileptonic channels

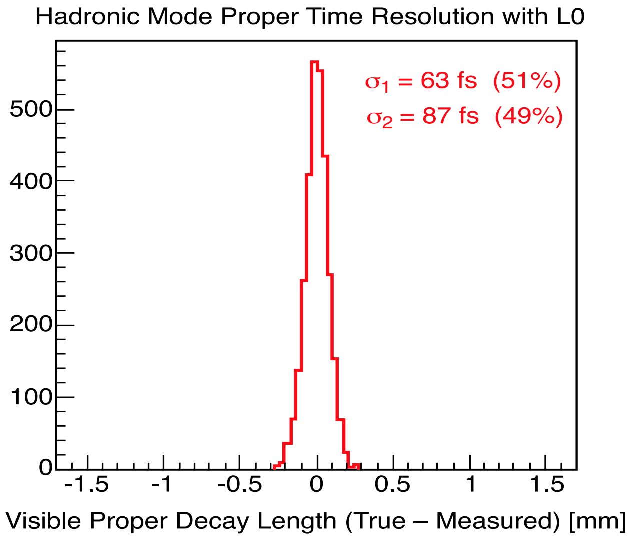
Scaling of the current sensitivity with luminosity

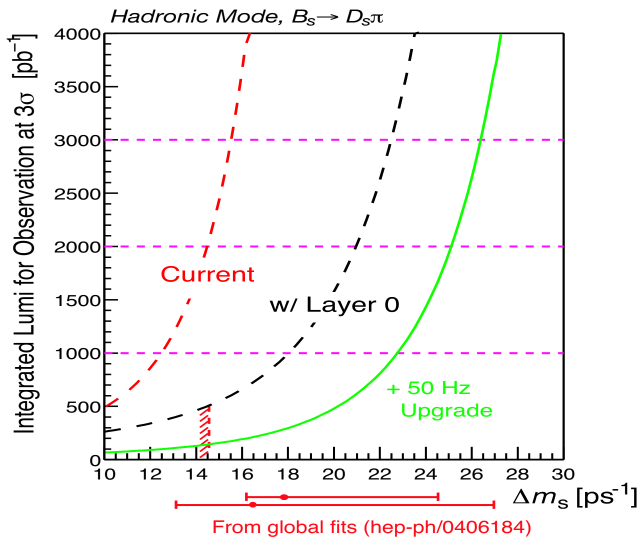
- **if analysis remains unchanged**
- **with expected improvements**



Bs Mixing Projections

- Use both semileptonic and hadronic Bs samples
  - More statistics in semileptonics
  - Better proper decay time resolution in hadronics (no ν)
- DZero has access to hadronic Bs sample triggering on opposite side muon
  - Muon is used as high purity tag
- Detector addition in fall:
  "Layer 0" Silicon detector
- Proposal to increase rate to tape from 50 to 100 Hz in fall
  - sample limited by L3 trigger and offline CPU – expect large gain in yield thanks
  - to dedicated B-physics bandwidth





Summary

- measured, which is in agreement with world average

  $\Delta m_d = 0.456 \pm 0.034 ps^{-1} (stat) \pm 0.025 ps^{-1} (syst)$

- developed a procedure to measure Δm_s using semileptonic channel $B_s \to D_s(\phi\pi)\mu\nu_\mu$

  $\Delta m_s > 5.0 ps^{-1}$ at 95% CL

- will add more semileptonic channels and hadronic channels
- „Layer 0“ Silicon detector and increasing L3 rate will improve resolution and increase statistics