B mixing at DØ
WIN 2005
Delphi, Greece

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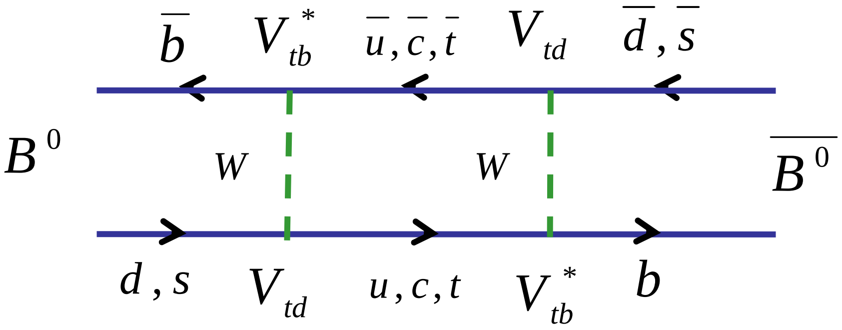
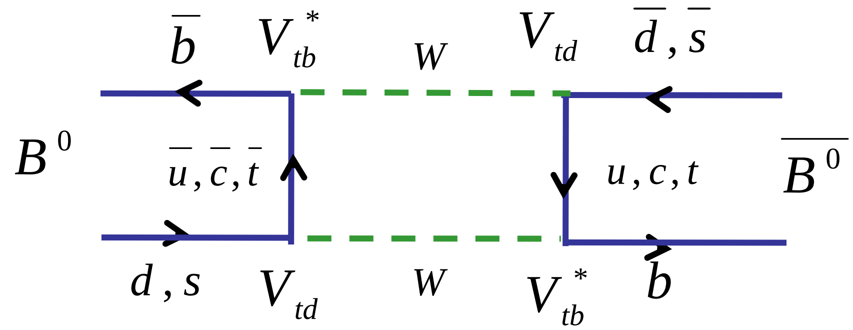
Outline

- Mixing phenomenology
- Tevatron
- DØ detector
- Flavour tagging
- B_d cross-checks
- B_s mixing and limit
- Prospects
- Summary

Mixing

- Transition of neutral mesons between particle and antiparticles





- Mass eigenstates superpostion of flavour eigenstates

$$|B_L\rangle = p|B^0\rangle + q|\bar{B}^0\rangle \qquad |B_H\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$$

$$\Delta m = m_H - m_L$$

- An initial B^0 will oscillate in time between B^0 and $\bar{B}^0$

$$p(B^0) = \frac{1}{2}\Gamma e^{-\Gamma t}[1+\cos(\Delta m t)] \qquad p(\bar{B}^0) = \frac{1}{2}\Gamma e^{-\Gamma t}[1-\cos(\Delta m t)]$$

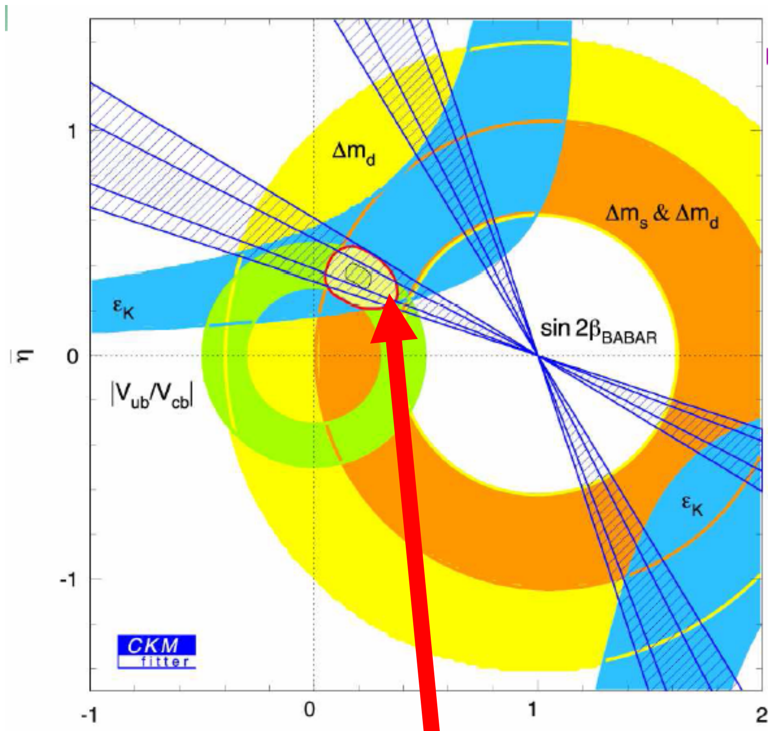
Motivation

- Why study mixing?

$$\frac{\Delta m_s}{\Delta m_d} \Rightarrow \frac{|V_{ts}|^2}{|V_{td}|^2}$$ Some theoretical uncertainties cancel

- In standard parameterisation unitarity approximated by

$$|V_{ub}|e^{+i\gamma} + |V_{td}|e^{-i\beta} \approx \lambda V_{cb}$$



$|V_{td}|$

- Mixing constrains least known side of unitarity triangle
- Experimental limit $\Delta m_s > 14.5\, ps^{-1}$
- SM predicts (incl exp) $15.6 < \Delta m_s < 22.2\, ps^{-1}$

Experimental issues

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- Need to tag initial flavour of B

  Tagging power εD^2 with efficiency ε and dilution $D = \frac{N_{correct-tag} - N_{wrong-tag}}{N_{correct-tag} + N_{wrong-tag}}$

  D = 2*purity – 1

- Need excellent propertime resolution σ_t – decay length and p resolution
- The average significance of a measurement is given by

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

- Experimentally useful to define asymmetry

$$A(t) = \frac{N^{no-osc}(t) - N^{osc}(t)}{N^{no-osc}(t) + N^{osc}(t)}$$

$$A(t) = D\cos(\Delta m t)$$

Setting limits

Amplitude method

- Fit to data - A free parameter

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

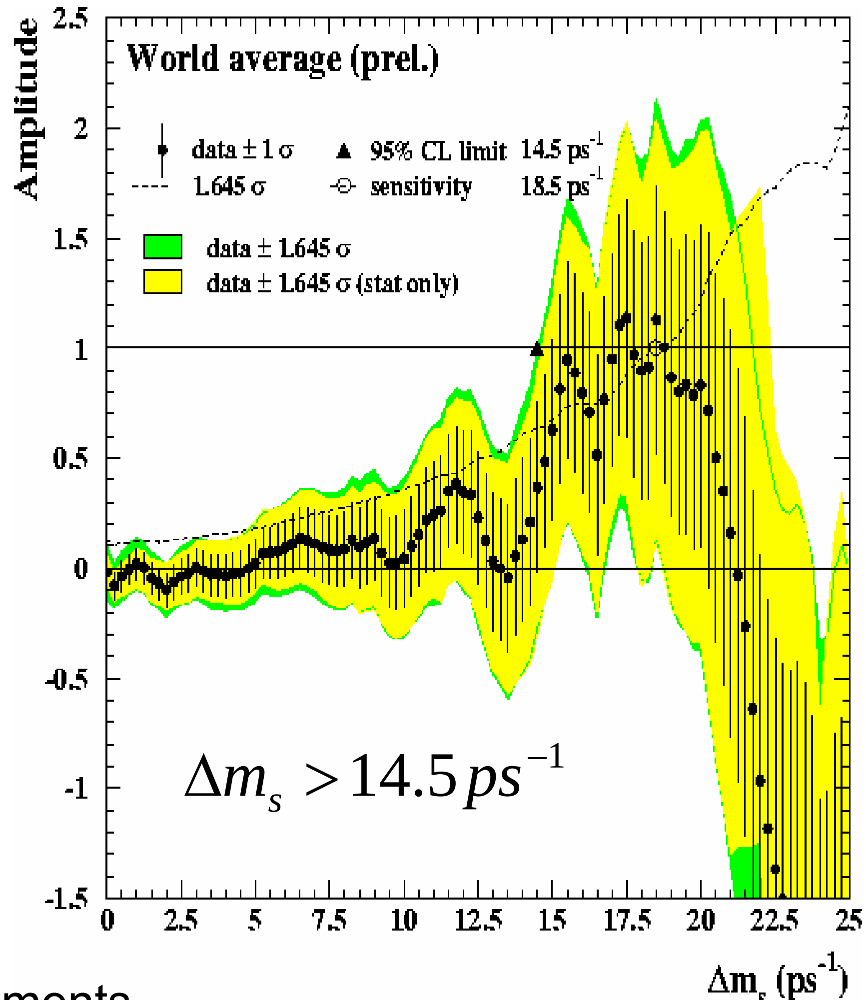
- Obtain A as a function of Δm_s

- Measurement of Δm_s gives $A = 1$ and $A = 0$ otherwise

- At 95% CL

  sensitivity $1.645\sigma_A = 1$

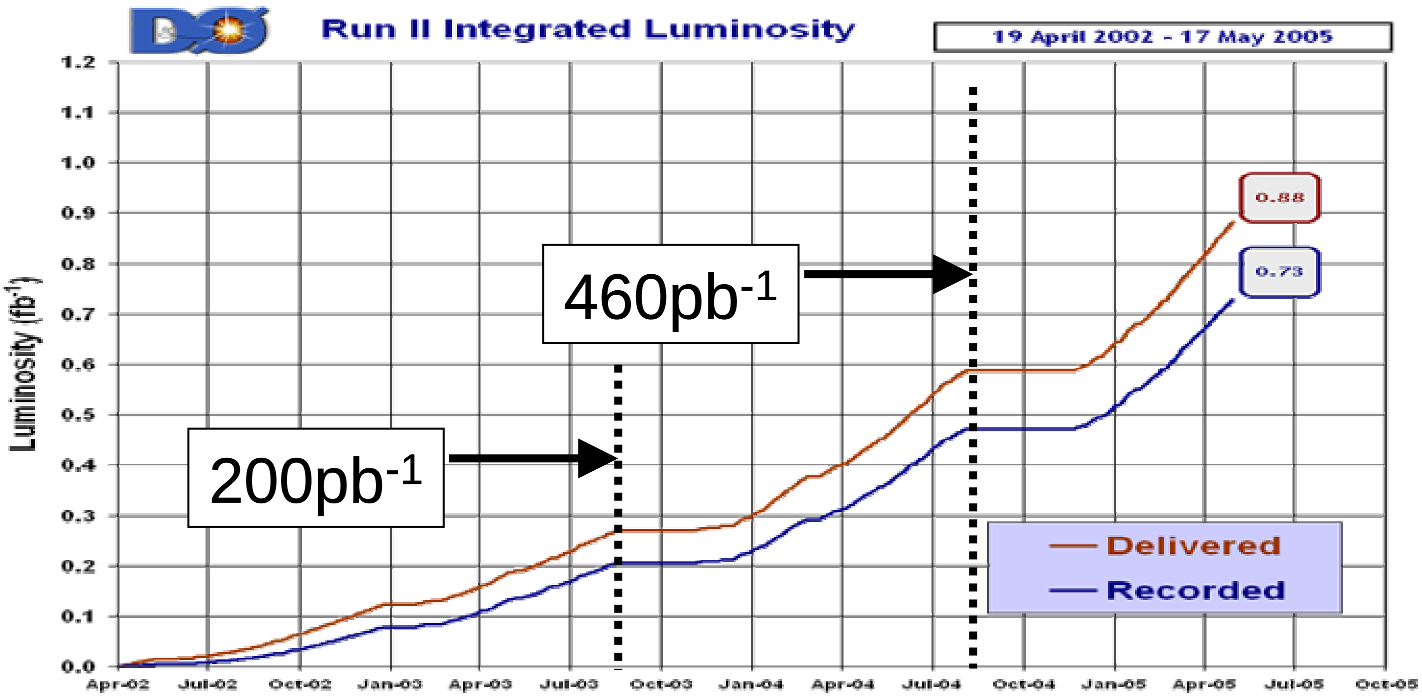
  excluded $A + 1.645\sigma_A < 1$



- Combine measurements from experiments

Tevatron

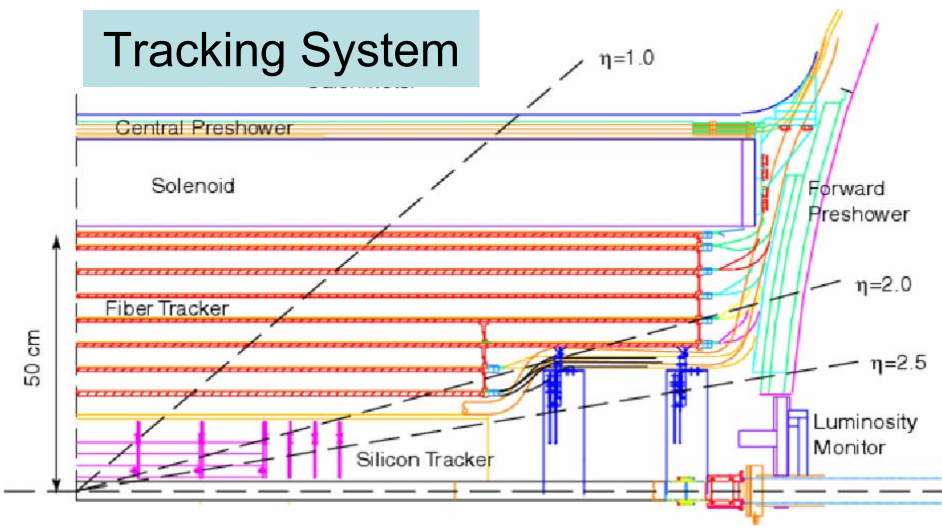
- Only place in world to study B_s mesons
- Tevatron performing well
  - Inst L reached ~1.2×10^{32} cm/s^2 ($1.5 – 3 \times10^{32}$ cm/s^2 design)

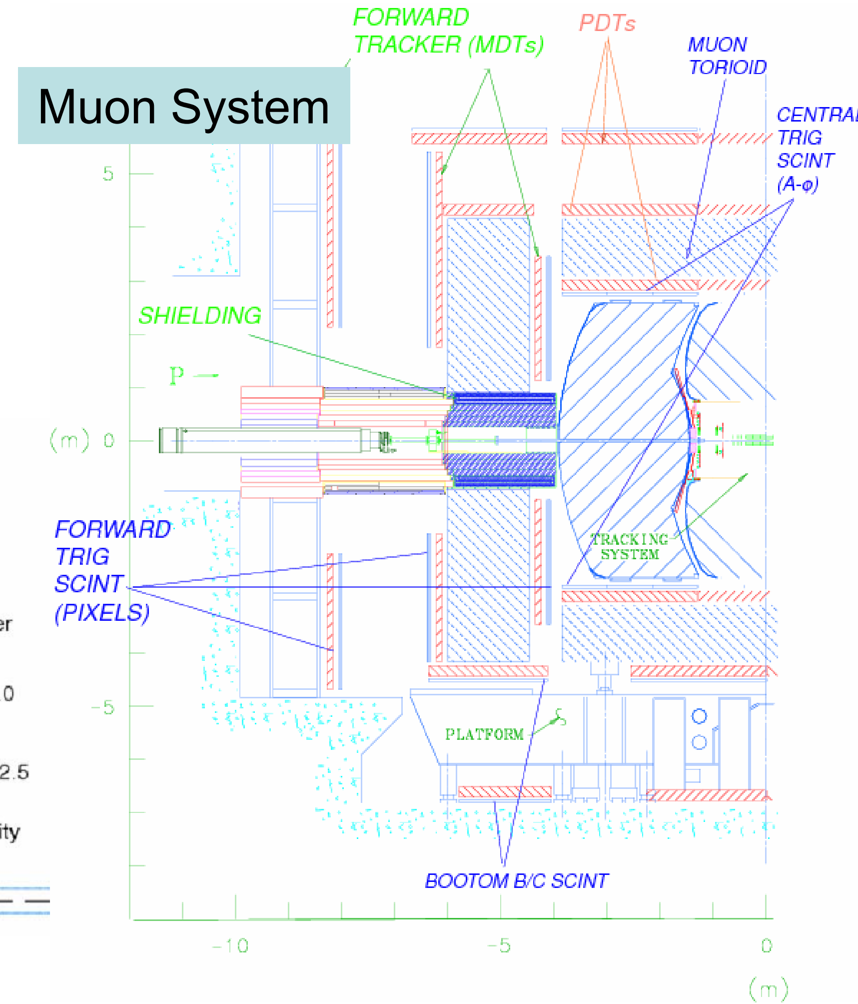


Total integrated L = 4-8 fb^{-1} in Tevatron Run II programme

DØ Detector

- Excellent coverage
  - Muon $|\eta| < 2$
  - Tracking $|\eta| < 3$
- Robust muon triggers
- All B physics events require muons





Samples

200 pb^{-1}

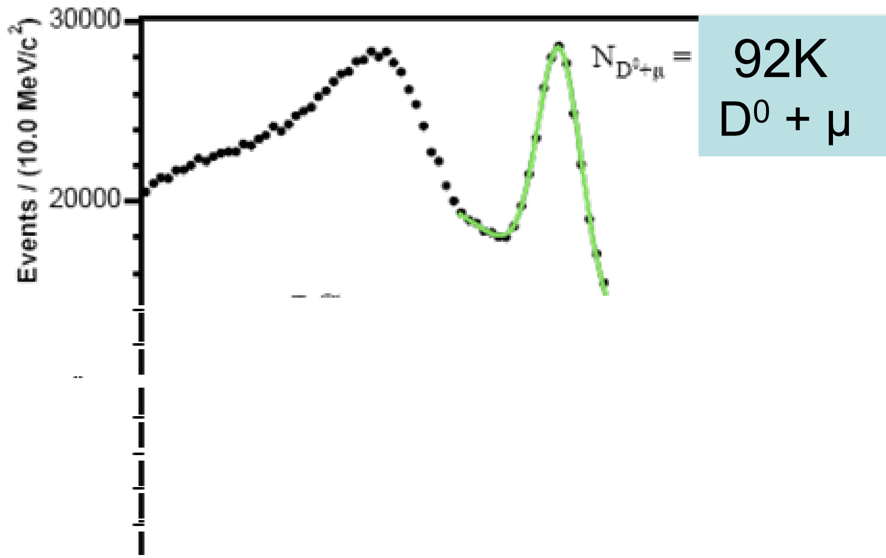
$B^{+} \rightarrow \overline{D}^{0}\mu^{+}\nu_{\mu}$

$B_{d}^{0} \rightarrow D^{*}(2010)^{-}\mu^{+}\nu_{\mu}$

$D^{*-} \rightarrow \overline{D}^{0}\pi^{-}$ $\overline{D}^{0} \rightarrow K^{+}\pi^{-}$

$D^{*}(2010)\mu$ 85% B_d, 15% B^+

$D^{0}\mu$ 85% B^+, 15% B_d



92K
D^0 + μ

20K
D^* + μ

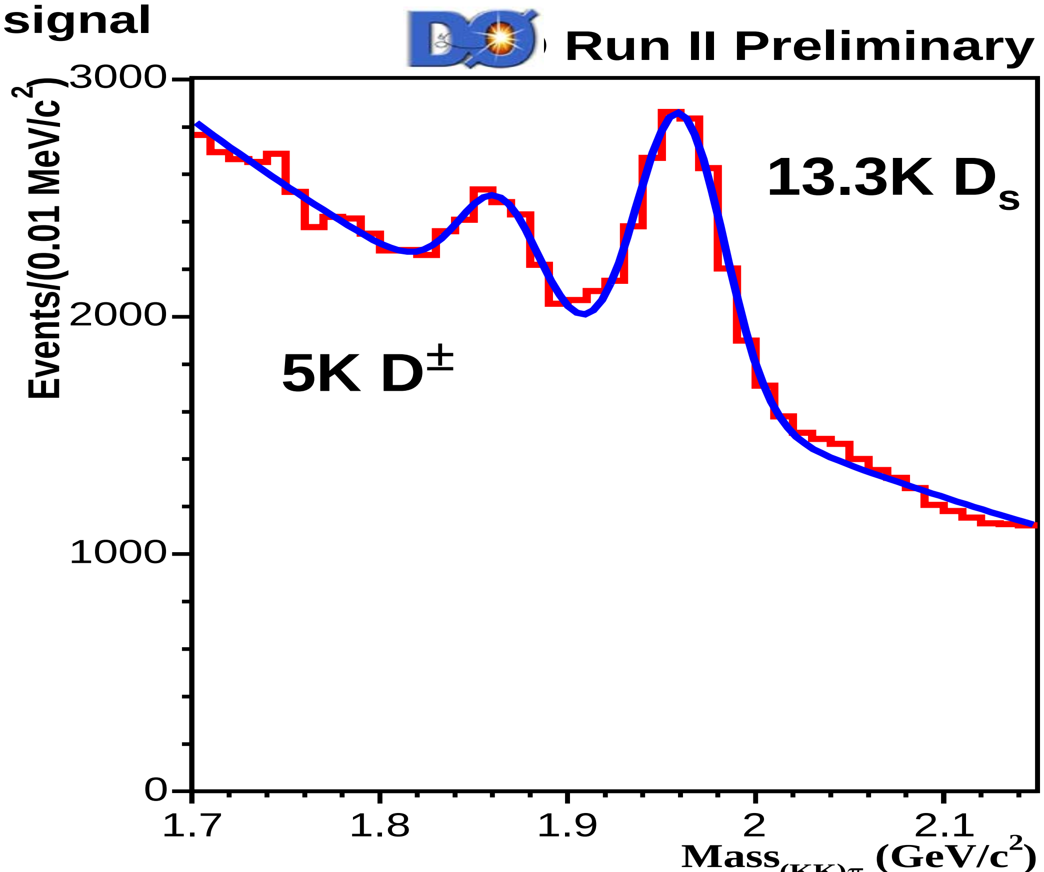
Samples

460 pb^{-1}

$$B_s^0 \to D_s^- \mu^+ X$$

$$D_s^- \to \phi\pi^- \quad \phi \to KK$$

D_s signal



B reconstruction

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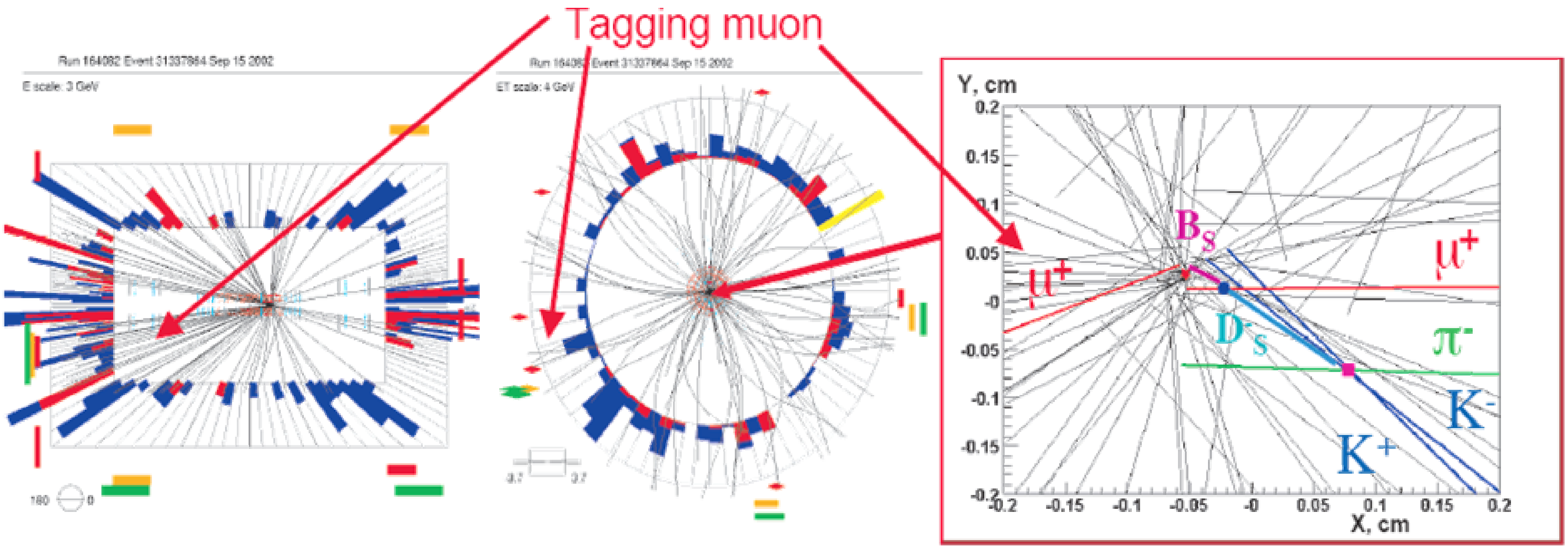
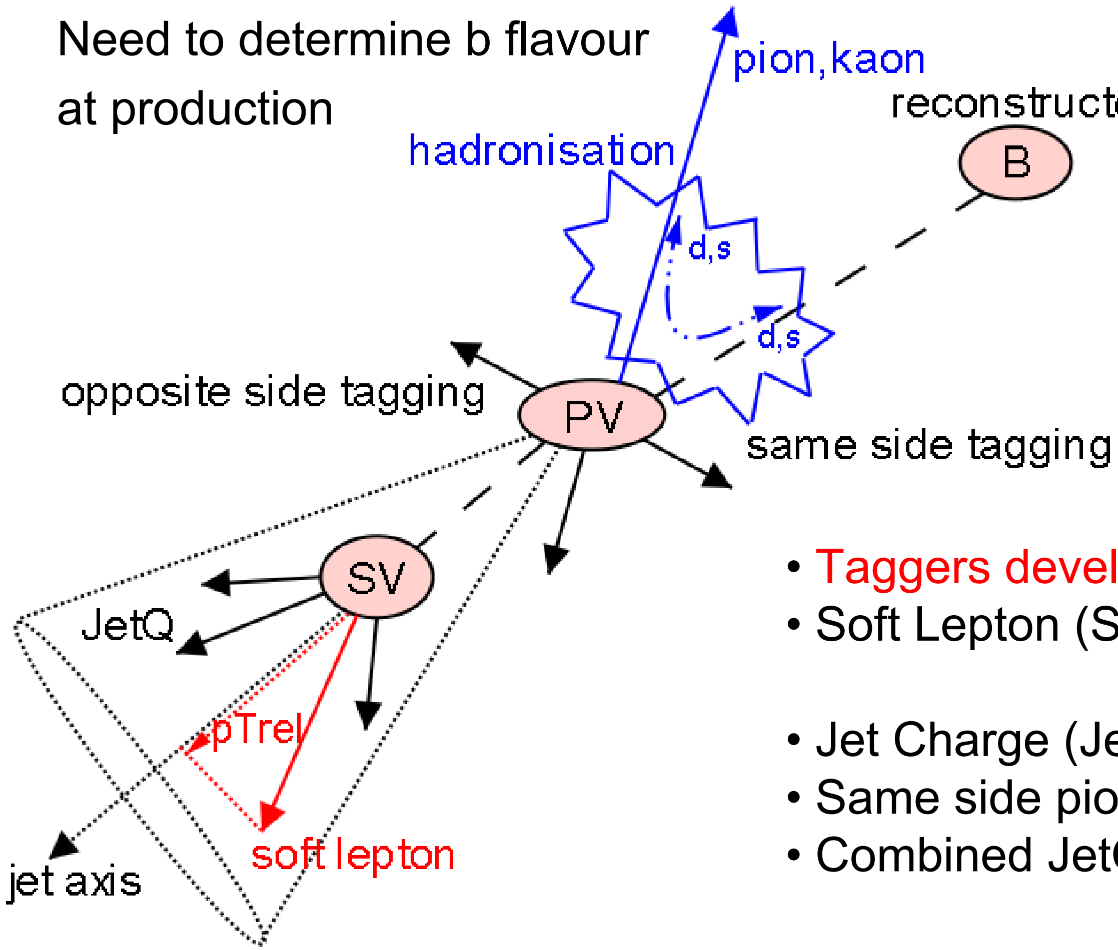
$$B_s^0 \to D_s^- \mu^+ X$$



- Hadronic environment – large backgrounds

Flavour Tagging

- Need to determine b flavour at production



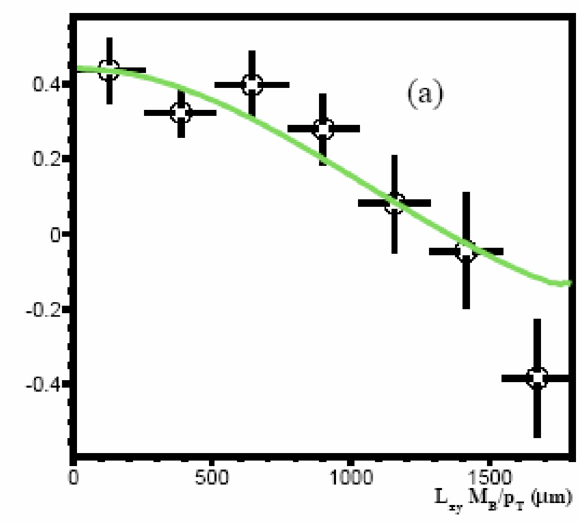
- Taggers developed
- Soft Lepton (SLT): ε = (5.0 ± 0.2) %
- Jet Charge (JetQ) $Q_J = \sum_i q^i p_T^i / \sum_i p_T^i$
- Same side pion (SST)
- Combined JetQ + SST: ε = (68.3 ± 0.9) %
- Opposite side μ + SV tagging

B_d mixing

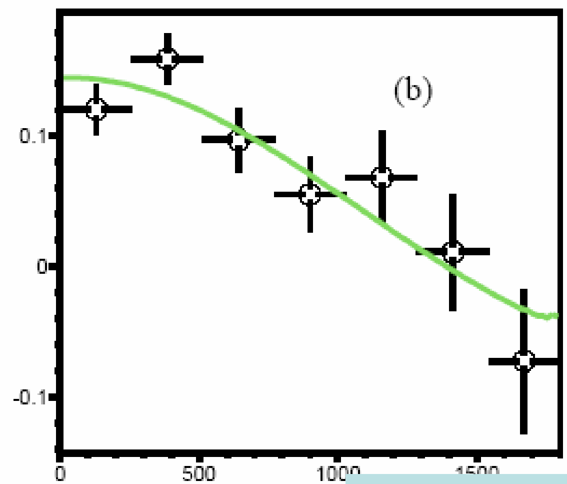
$$B_d^0 \rightarrow D^*(2010)^- \mu^+ \nu_\mu$$

$$B^+ \rightarrow \overline{D}^0 \mu^+ \nu_\mu$$

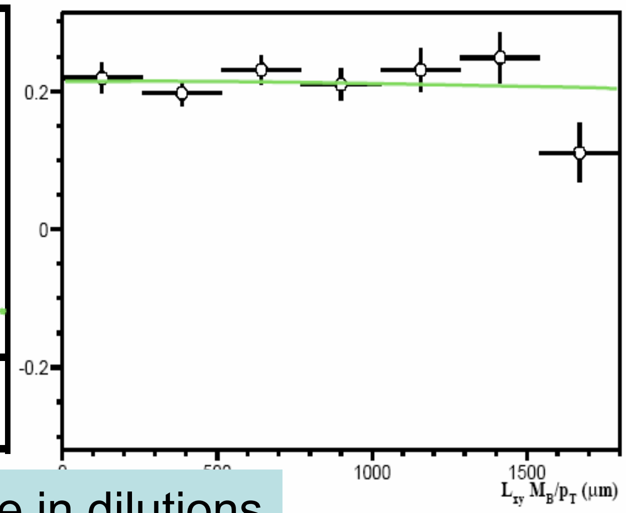
SLT
D_0 = 0.448 ± 0.051



JetQ+SST
D_0 = 0.149 ± 0.015



JetQ+SST
D_+ = 0.279 ± 0.012



difference in dilutions

Δm_d = 0.456 ± 0.034 (stat) ± 0.025 (sys) ps^{-1}
World average = 0.502 ± 0.007 ps^{-1}

Flavour Tagging

- Opposite side combined μ+SV tagging
- Require muon with angular separation $\cos\Delta\varphi < 0.8$
- Use discriminating variables x_i - combine using likelihood ratio
  - Charge of jet containing the muon

$$JetQ = \frac{\sum p_T^i q^i}{\sum p_T^i}$$

  - p_T^{rel} weighted muon charge

$$p_T^{rel} \cdot q_\mu$$

  - SV charge
    - Look for SV in event (muon not included)

$$Q_{SV} = \sum_i (q^i p_T^i)^{0.6} / \sum_i (p_T^i)^{0.6}$$

Flavour Tagging

- Likelihood ratio
- For each variable x_i, x > 0 tags initial B flavour as b quark
- Construct tagging variable d $d = (1 - y)/(1 + y)$

- Where y is a product of ratios of probability density fns to give wrong and right tags $$y = \prod_{i=1}^{n} y_i; \quad y_i = \frac{f_i^w(x_i)}{f_i^r(x_i)}$$

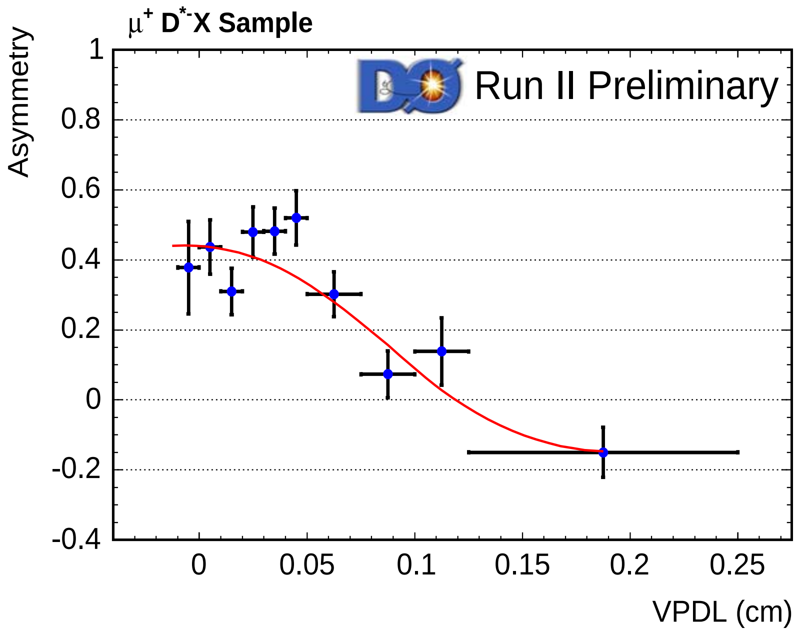
$f_i^w(x_i)$ $(f_i^r(x_i))$ pdfs of variable x_i for wrong and right tags

|d| related to dilution for an event

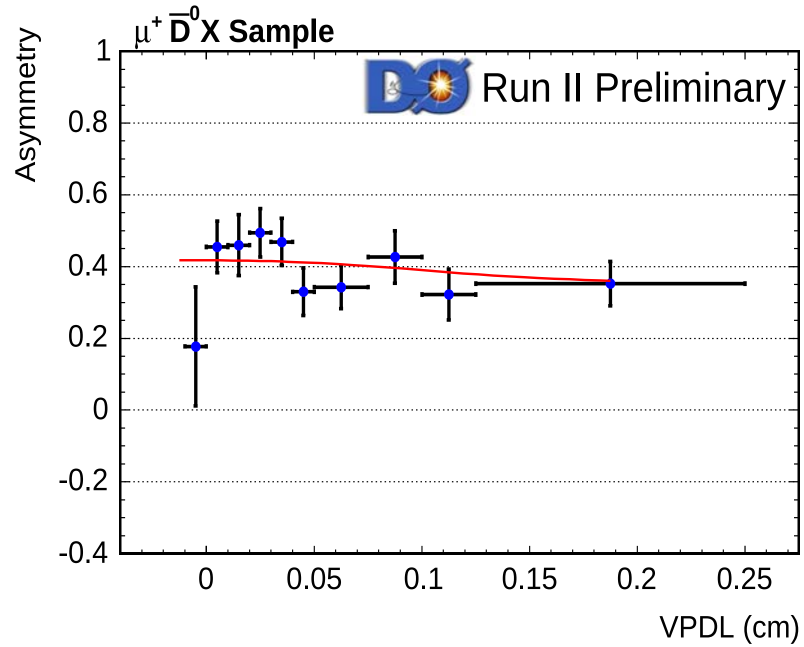
- PDFs determined from reconstructed $B_d \rightarrow D^{*-}\mu^+ X$ data small decay lengths - minimal oscillations

Dilution cross-check

- Opposite side tagging dilution should be same for all B species
- Cross-check performed on B_d B_u



D = 0.448 ± 0.021



D = 0.468 ± 0.015

- Dilutions consistent
- Use value of D = 0.468 ± 0.015 in B_s mixing fits

B_s mixing analysis

Strategy

- One decay mode $B_s \to D_s\ \mu\ X$, $D_s \to \varphi\ \pi$, $\varphi \to KK$
- Opposite side μ+SV tagging
- Binned asymmetry in **V**isible **P**roper **D**ecay **L**ength

$$x^M = \frac{\vec{L}_{xy} \bullet \vec{P}_{xy}^{\mu D_s}}{(P_{xy}^{\mu D_s})^2} \bullet M_B$$

- Minimise observed and expected values of asymmetry
- Inputs to fitting procedure
  - Sample composition MC
  - K factors (corrections for non-reconstructed particles) MC
  - Efficiencies MC
  - Dilution obtained from B_d mixing
  - VPDL resolution MC/DATA

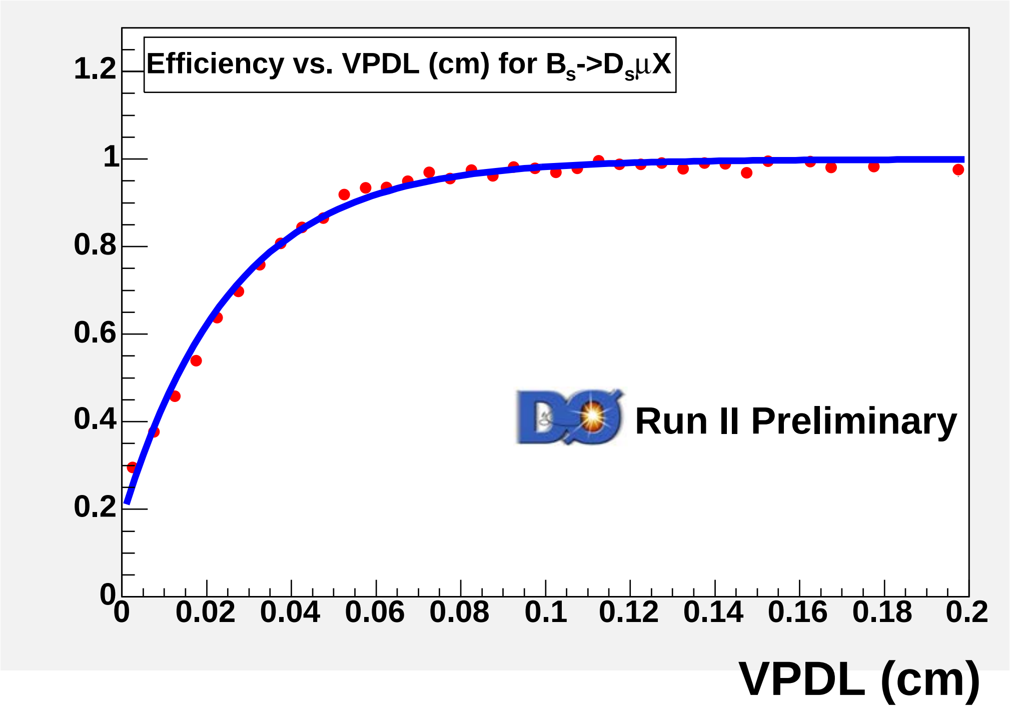
Fit parameters

Sample composition

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%

cc estimated at ~ 3.5 ± 2.5 %

Efficiency correction due to impact parameter cuts on tracks from D_s

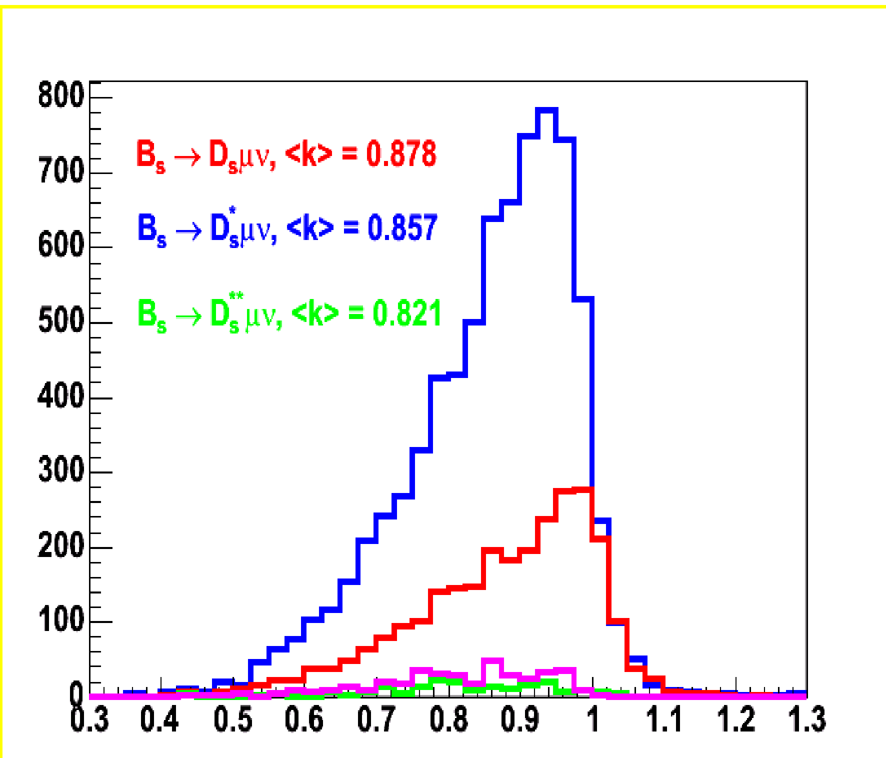


K-factors

- Correction factor to p_T accounting for non-reconstructed particles

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

$$c\tau = K \times VPDL$$

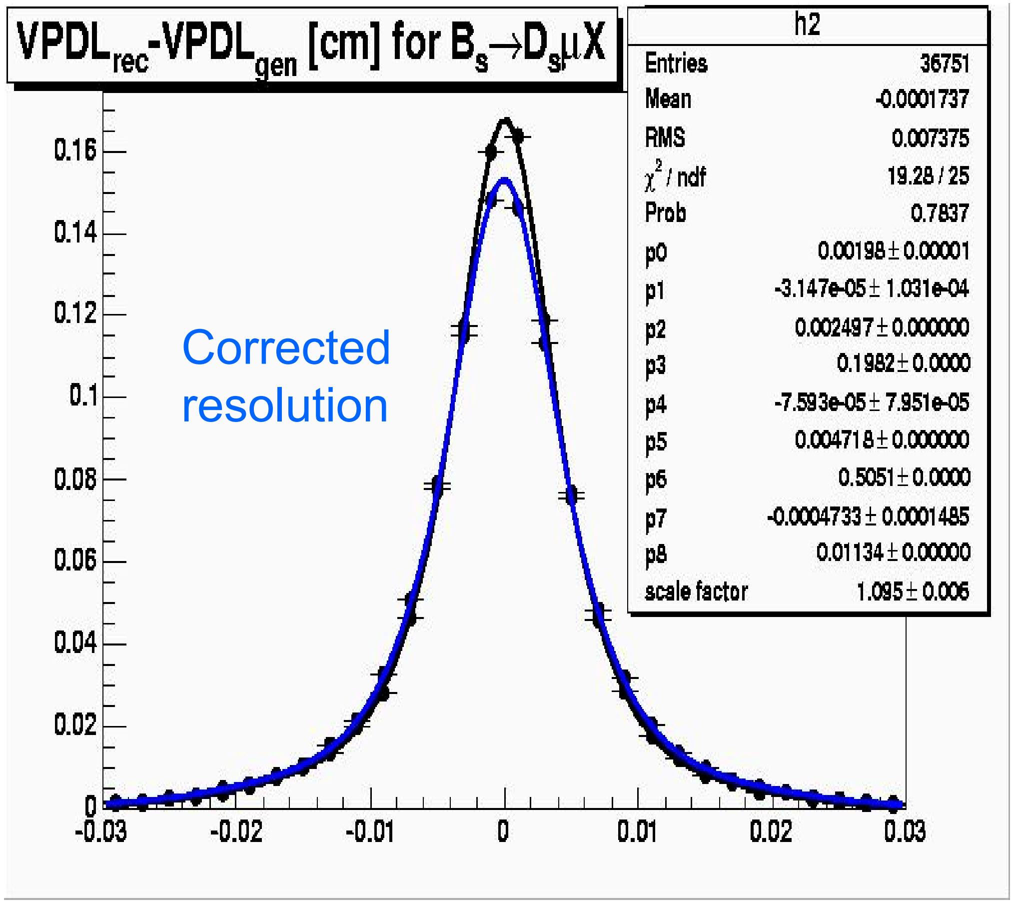


Decay	<k>
$B_s \to D_s \mu\nu$	0.878
$B_s \to D^*_s \mu\nu$	0.857
$B_s \to D^*_{0s} \mu\nu$	0.829
$B_s \to D^*_{1s} \mu\nu$	0.817
$B_s \to D_s D_s X$	0.738
$B^0 \to D_s D X$	0.681
$B^- \to D_s D X$	0.687

VPDL resolution

- VPDL resolution parametrised with three Gaussians
- Track impact parameter errors tuned on data
- Correction dependent on number of vertex hits, location of hits, track polar angle and momentum
- Tuning results in one scale factor applied to all three Gaussians

SF = 1.095



Systematics

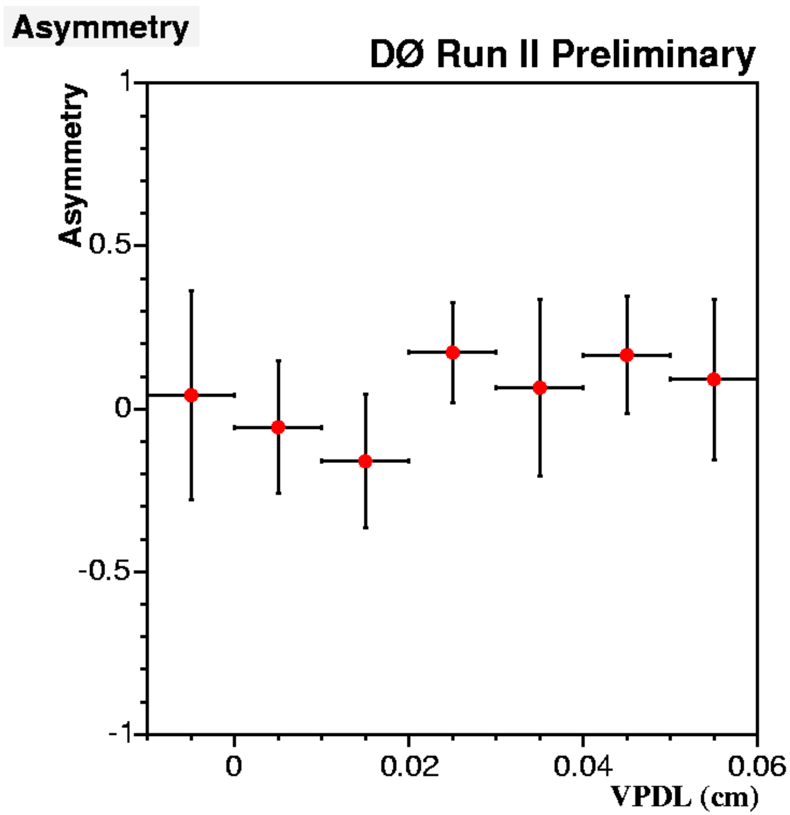
- Uncertainty on input fit parameters contribute to systematic error

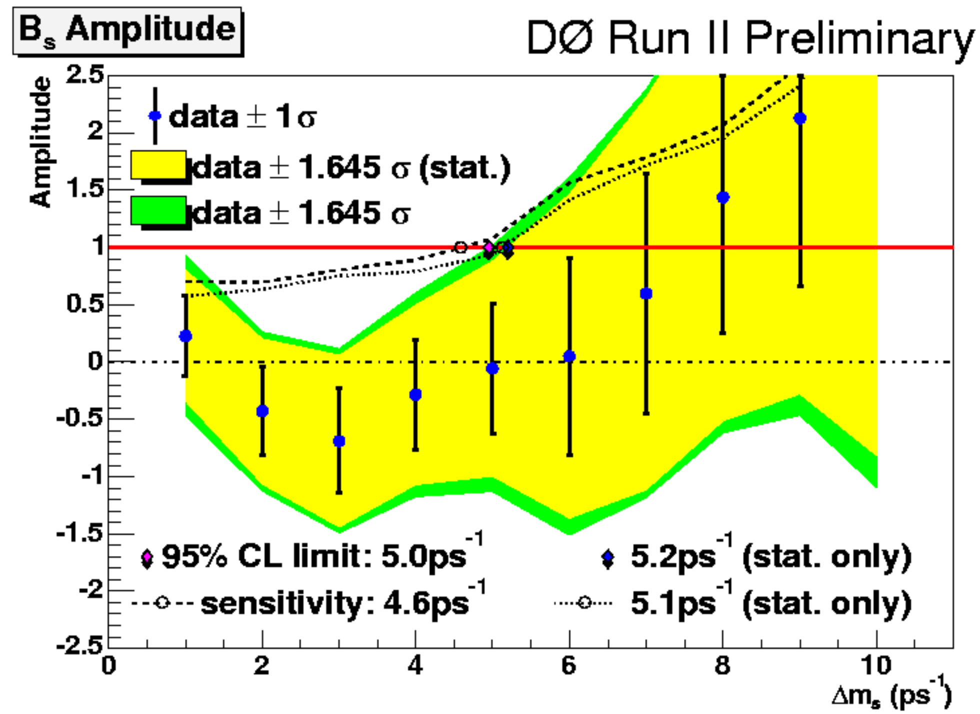
$$\sigma_A^{sys} = \Delta A + (1 - A)\frac{\Delta A}{\sigma_A}$$

- Uncertainties in variables included
  - Dilution
  - Mass fits
  - Resolution
  - Sample composition
  - K-factor
  - $\Delta\Gamma$
  - Efficiencies

Each error added in quadrature

Result





No obvious oscillations

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

Sensitivity

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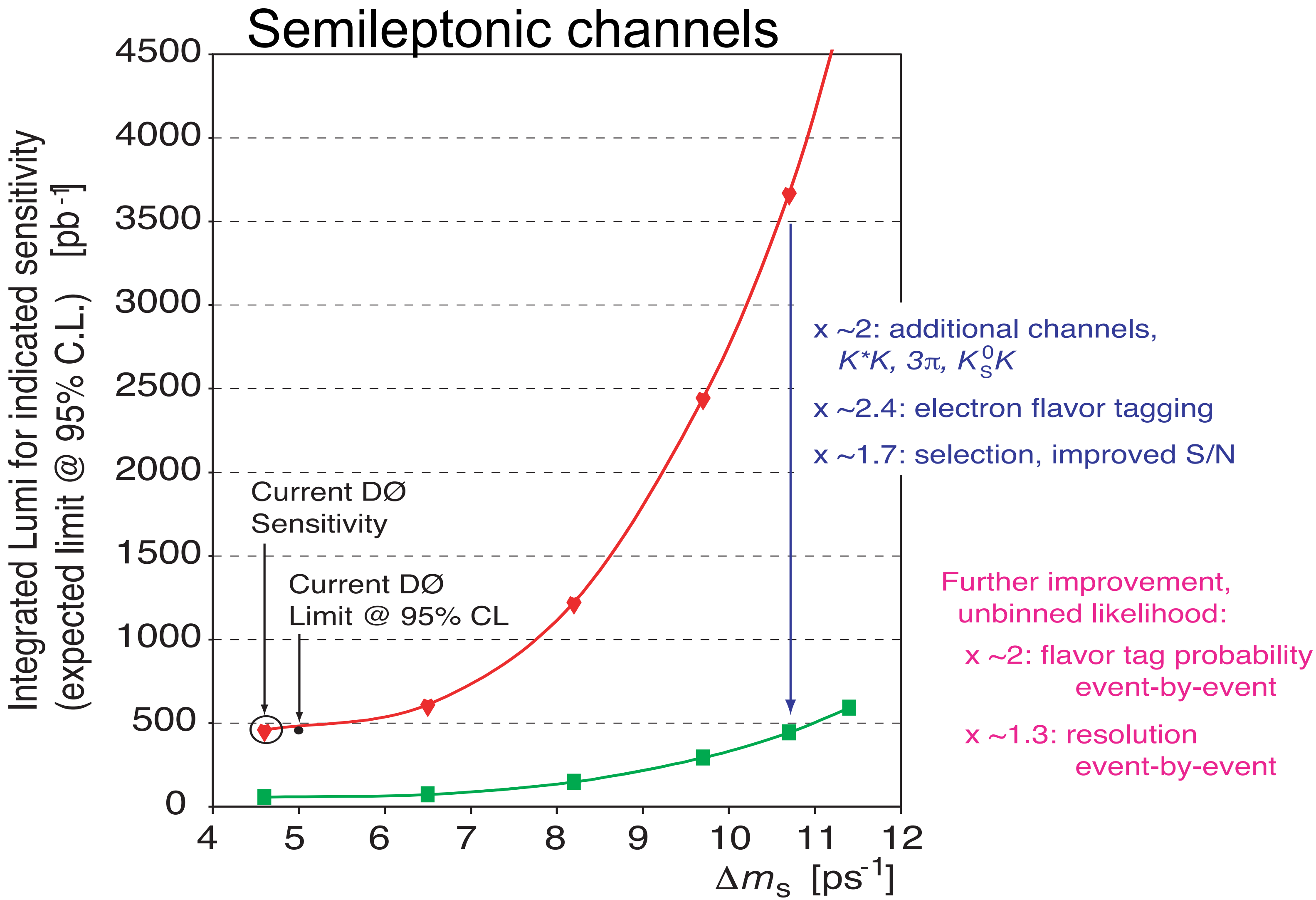


Projections

- Include hadronic B_s sample
  - Better proper decay time resolution in hadronics (no ν)
  - Hadronic events at DØ triggered by opposite side muon

  Provides high efficiency tag (~1)

- Detector addition summer 2005:

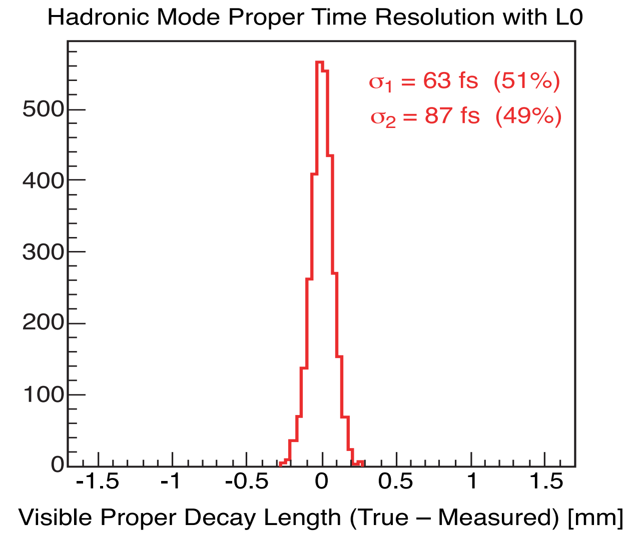
  "Layer 0" Silicon detector

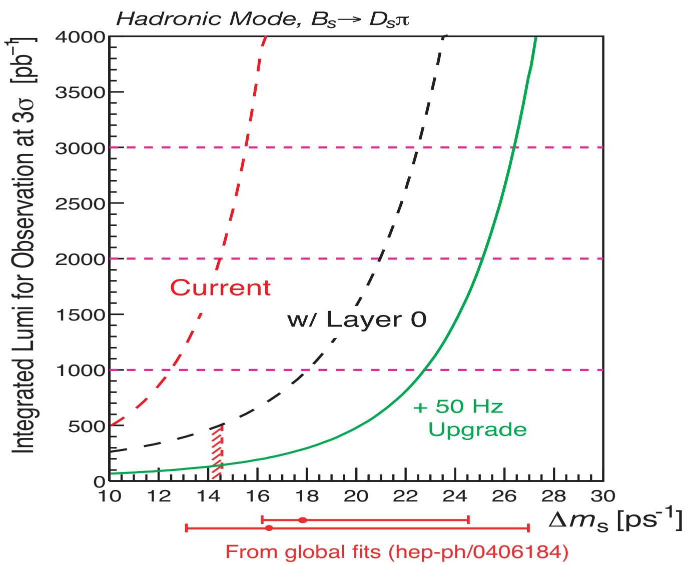
  ~25% gain in σ_t

- Proposal to increase rate to tape from 50 to 100 Hz later in 2005
  - Dedicated B-physics bandwidth
  - Lower trigger thresholds

  ~ factor 3 gain in statistics

- Expect to cover full SM range





Summary

- Developed all tools to perform mixing measurement
- Flavour tagging demonstrated on $B_d \to D^* \mu X$

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

- Using 460 pb^{-1} peformed first B_s mixing analysis at DØ
- Decay mode $B_s \to D_s \mu X$

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

Future

- Layer-0 and increased L3 bandwidth
- Improve tagging - electrons, more variables, possibly SST?
- Additional semileptonic modes
- Hadronic mode