B_d and B_s mixing at DØ

BEAUTY 2005, Assisi, Perugia

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Outline

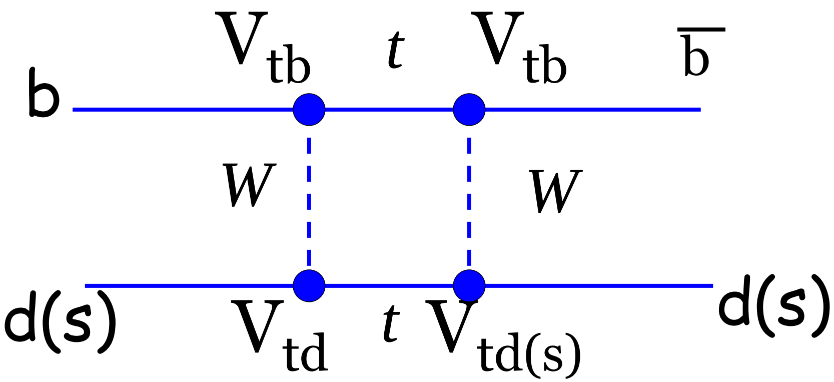
- Introduction
- Data taking, Triggers
- Bd mixing measurement
  - Reconstruction
  - Flavor Tagging
- Bs mixing measurement
  - Decay modes
  - Amplitude scan
  - Sensitivity studies.

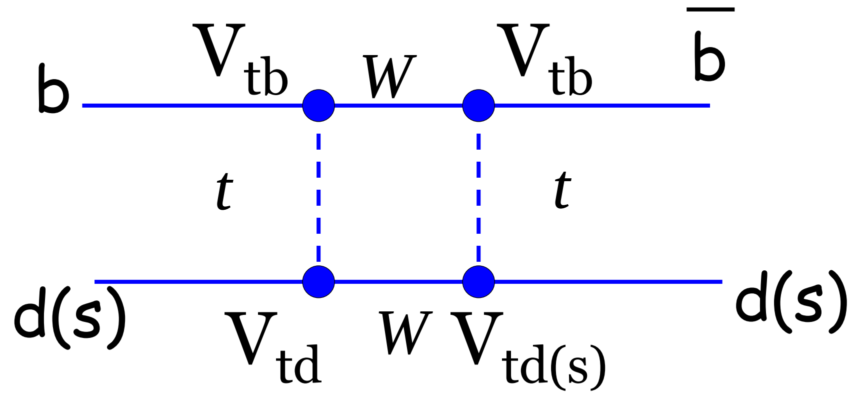
Introduction

- Oscillations in the B0-$\overline{B0}$ system first observed by ARGUS in 1987 (18 years since then!)
  - Signalled a large top mass
  - CP violation in B decays.
- Many measurements on Bd mixing – LEP, SLD, CDF, DØ, Belle, Babar
- Tevatron has unique opportunity to measure Bs mixing in 2 complementary analyses. Δm_s (This talk) and $\Delta\Gamma_s/\Gamma_s$ (Alberto Sanchez's talk)

B_d and Bs Mixing

- B mixing implies a B0 transition to $\overline{B0}$ (second order weak interactions)





- Light and heavy B meson mass eigenstates differ from flavor eigenstates:

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

$$\sqrt{p^2 + q^2} = 1$$

Time evolution follows the Schrodinger equation

$$i\frac{d}{dt}\begin{pmatrix} |B(t)\rangle \\ |\overline{B}(t)\rangle \end{pmatrix} = \begin{pmatrix} M_{11} - i\Gamma_{11} & M_{12} - i\Gamma_{12} \\ M_{21} - i\Gamma_{21} & M_{22} - i\Gamma_{22} \end{pmatrix} \begin{pmatrix} |B(t)\rangle \\ |\overline{B}(t)\rangle \end{pmatrix}$$

B_d, B_s mixing

Time evolution of B^0 and $\overline{B}^0$ states,

$$P(B \to B) = \frac{e^{-\Gamma t}}{2}\left(\cosh\frac{\Delta\Gamma t}{2} + \cos\Delta m t\right)$$

$$P(B \to \overline{B}) = \frac{e^{-\Gamma t}}{2}\left(\cosh\frac{\Delta\Gamma t}{2} - \cos\Delta m t\right)$$

$$m = \frac{M_H + M_L}{2}, \Gamma = \frac{\Gamma_H + \Gamma_L}{2}$$
$$\Delta m = M_H - M_L, \Delta\Gamma = \Gamma_L - \Gamma_H$$

- The case with $\Delta\Gamma \to 0$, mixed and unmixed decay probabilities become,

$$P_{u,m}(t) = \frac{1}{2}\Gamma e^{-\Gamma t}\left(1 \pm \cos\Delta m t\right)$$

- Extract mixing parameter Δm from asymmetry

$$A = \frac{P_{umix} - P_{mix}}{P_{umix} + P_{mix}} = \cos\Delta m t$$

Ultimate Goal – Constraing the CKM matrix - complex phase in the CKM matrix (CP violation).

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Wolfenstein parametrisation - expansion in λ ~ 0.22

$$\begin{pmatrix} 1-\lambda^2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2 & A\lambda^2 \\ A\lambda^3(\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\lambda = \sin\theta_C$$

$$\bar{\rho} = (1-\lambda^2/2)\rho$$

$$\bar{\eta} = (1-\lambda^2/2)\eta$$

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

complex

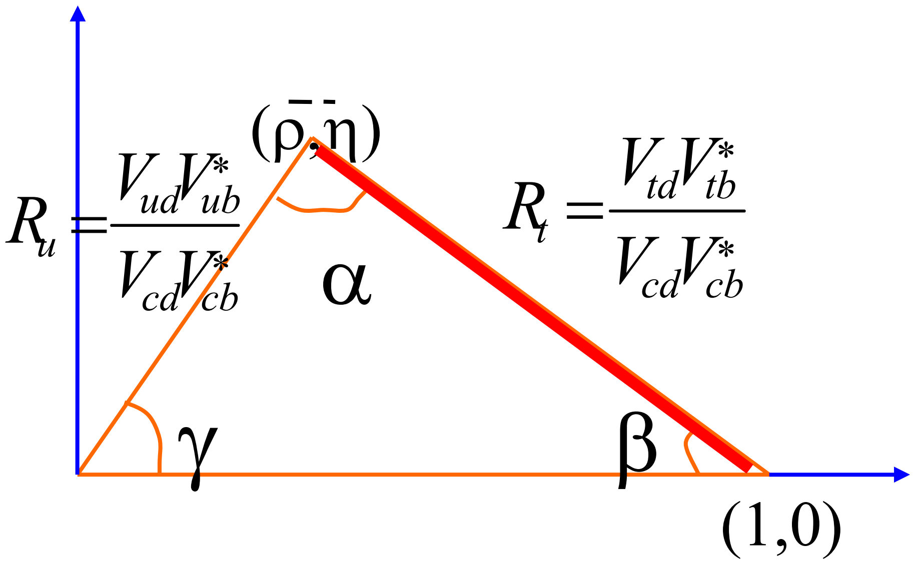
$$V_{ub} = |V_{ub}|e^{-i\beta} \qquad V_{td} = |V_{td}|e^{-i\gamma}$$

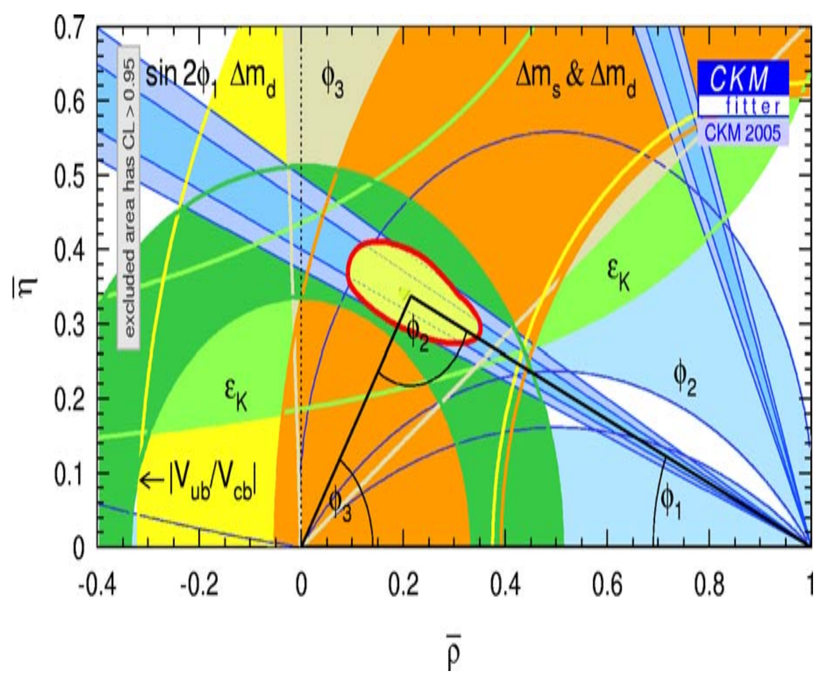
$$-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} - \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 1$$

Δm_d, Δm_s, and CKM

$$R_u = \sqrt{\bar{\rho}^2 + \bar{\eta}^2} = \left(1 - \frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|$$

$$R_t = \sqrt{(1-\bar{\rho}^2)^2 + \bar{\eta}^2} = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right|$$



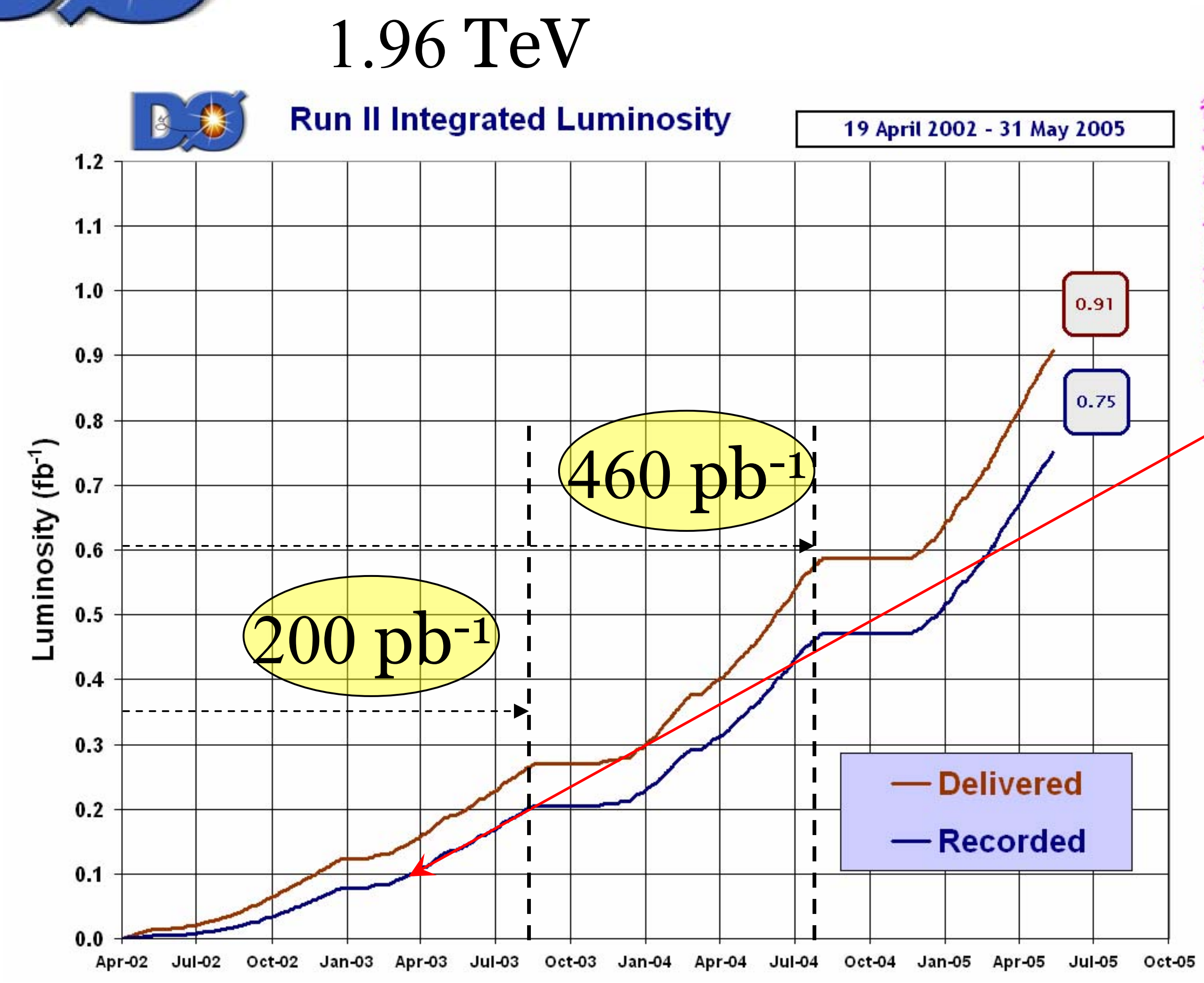


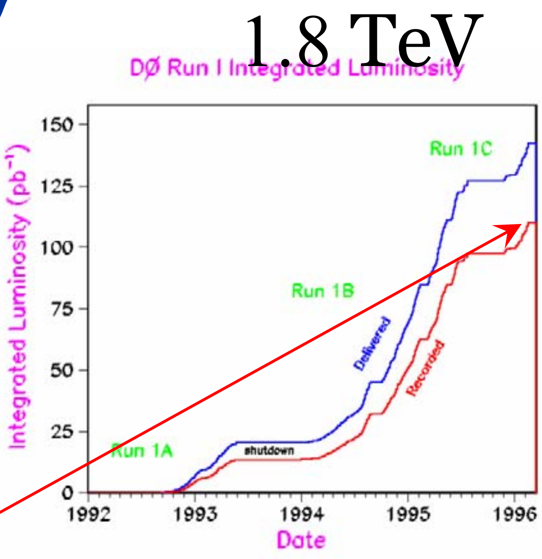
$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_b m_t^2 F\left(\frac{m_t^2}{m_W^2}\right)\eta_{QCD} \times B_{B_d} f_{B_d}^2 \left|V_{tb}^* V_{td}\right|^2$$

$$\frac{\Delta m_s}{\Delta m_d} = \frac{M_{Bs}}{M_{Bd}} \frac{\eta_{Bs}}{\eta_{Bd}} \frac{f_{Bs}^2}{f_{Bd}^2} \frac{B_{Bs}}{B_{Bd}} \left|\frac{V_{ts}}{V_{td}}\right|^2 \qquad |V_{ts}| \cong |V_{cb}|$$

ξ^2 ($\xi = 1.24 \pm 0.04 \pm 0.06$)

Data Taking

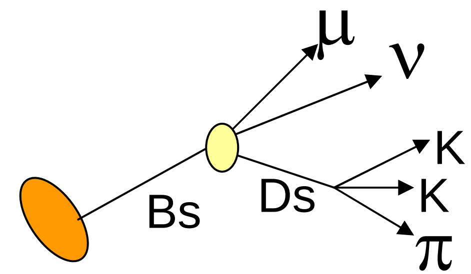


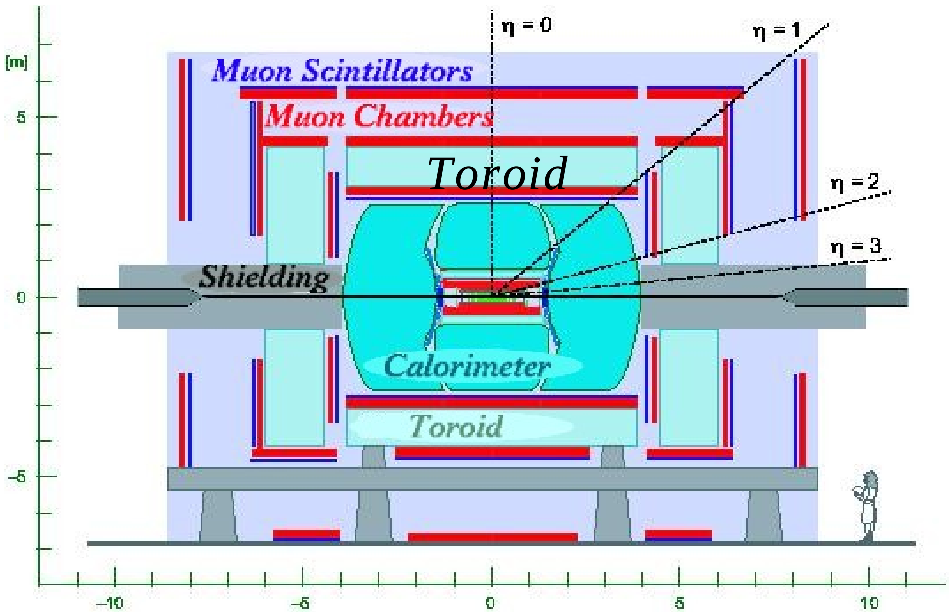


Data taking

$\varepsilon = 80 - 88\%$

B physics triggers



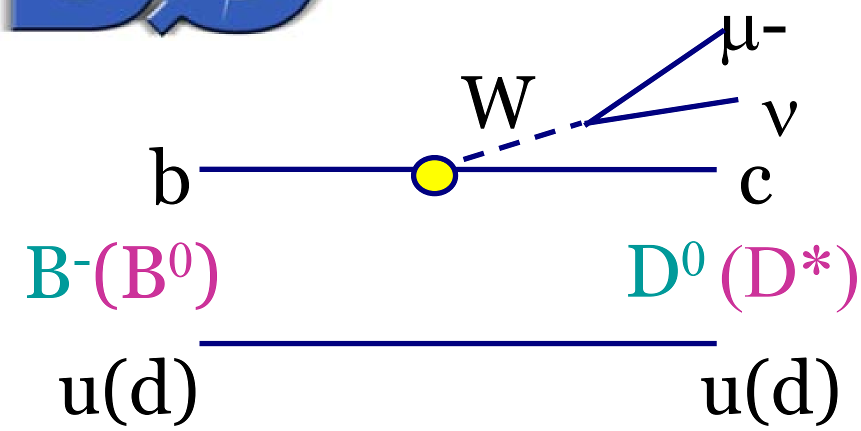


Muon system → Layers of drift chambers and scintillators.

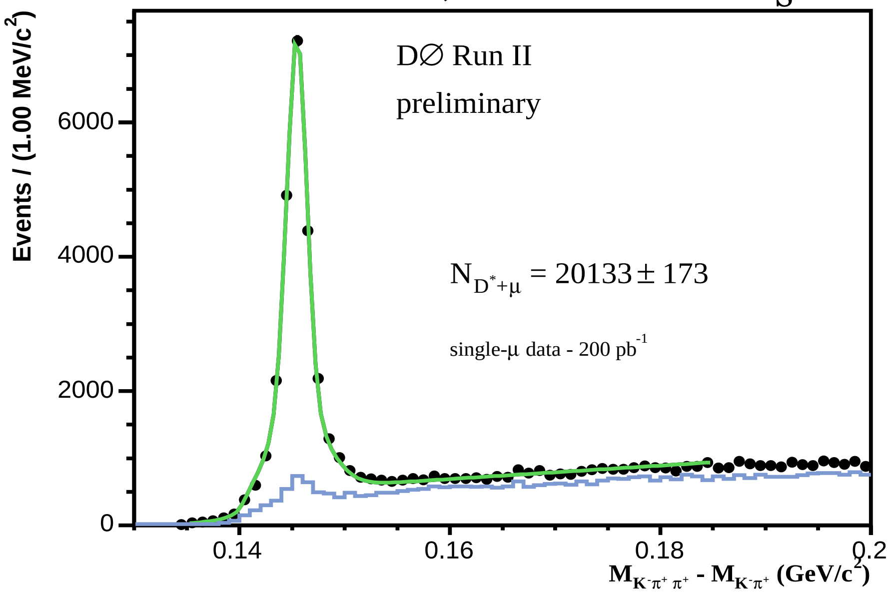
Trigger (B mixing) → Single inclusive muon trigger with $|\eta| < 2.0$, $P_T > 3,4,5$ GeV, Dimuon trigger (second muon for tagging)

- Single muon → Muon + track match at Level 1 and a muon at L2
  - Unbiased single muon triggers(P_T>3,4,5) – Bd and Bs mixing, prescaled or turned off depending on luminosity.
  - Impact parameter biased triggers – Hadronic decays (Not being used yet).

Bd mixing – Motivation and Main ingredients



$D0 \rightarrow K\pi,\ D^* \rightarrow D0\ \pi_s$

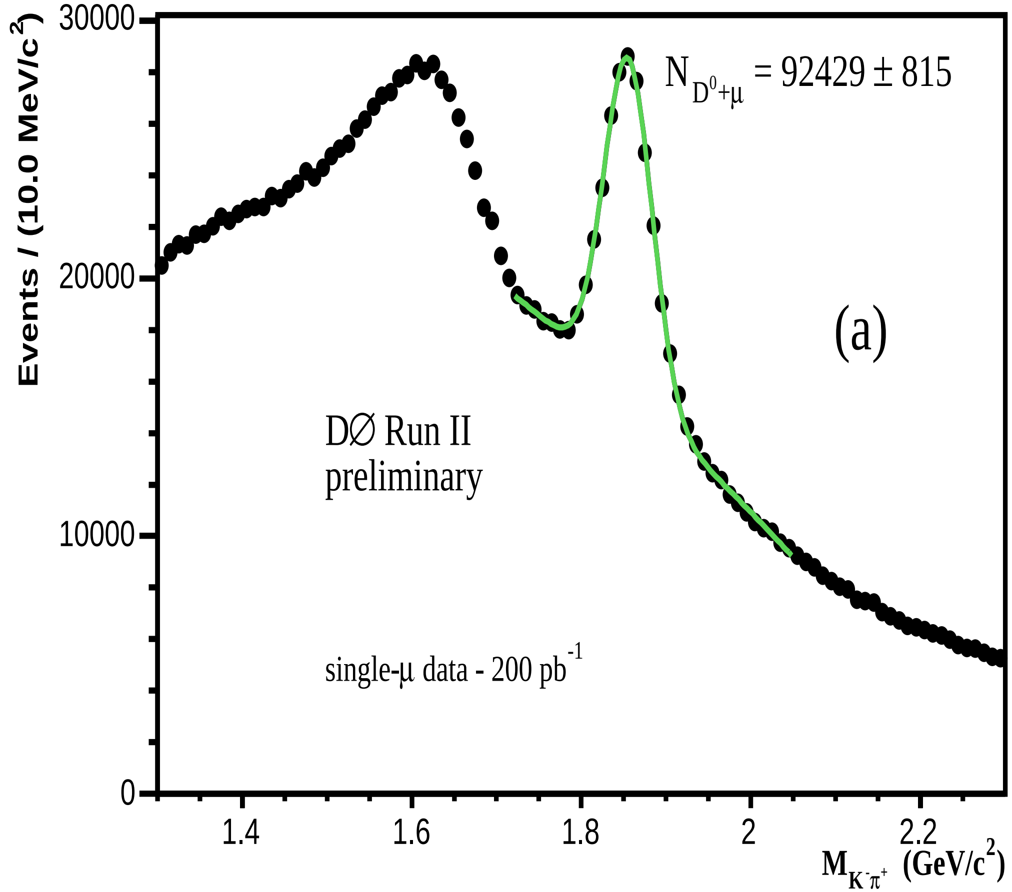


- High statistics sample
- μ- determines charge of the B on reconstruction side.
- Flavor tagging – determine charge of opposite B
- Sample composition – Other B decays contribute to the same final state.
- Validate flavor tagging to be used for main analysis, Bs mixing.

D0 and B+ selection

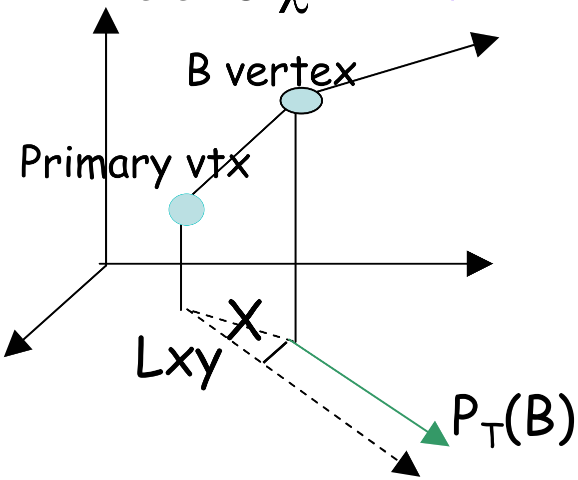
- D0 selection:
  - 2 tracks, opposite charge,
  - Pt>0.7, $|\eta|<2.0$
  - Displaced vertex:
    - $d0/\sigma(d0)$ of tracks > 2
    - $Lxy/\sigma(lxy) > 4$,
  - $\cos(\alpha) > 0.9$
  - Good vertex fit.
- D0μ (B+) selection:
  - If $lxy_B/\sigma(lxy_B) > 4$, then $\cos(\alpha_B) > 0.95$
  - $lxy_B < lxy_D$ within 3σ
  - Does not form a D* with a soft pion.

92 K total in 200 pb $^{-1}$



Bd mixing measurement

- Fit the χ^2 in VPDL bins to extract Δm and purity of tag



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

Measured

Expected

$$A_i = \frac{N_{OS} - N_{SS}}{N_{OS} + N_{SS}}$$

Visible Proper Decay Length:

$$c\tau_B = \frac{L_{XY}^B}{(\beta\gamma)_T^B} = L_{XY}^B \cdot \frac{M_B}{P_T^B}$$

Charge of B determined from μ charge on reconstructed side

Opposite B charge from Flavor Tag

Expected Asymmetry

- Distribution of oscillated and non-oscillated events are function of K-factor,η, Δm

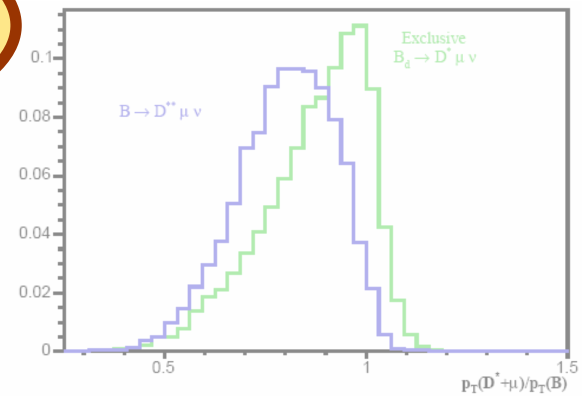
$$n_d^{osc,non-osc}(x) = \frac{K}{c\tau} \cdot 0.5 \cdot (1 \mp (2\eta - 1) \cdot \cos(\Delta m \cdot Kx/c))$$

$$N_{d,u,s}^{osc,non-osc}(x^M) = \int dx\delta(x - x^M) \cdot \varepsilon_j(x) \int dK D_j(K) \cdot \theta(x) \cdot n_{(u,d,s)}^{osc,non-osc}(x, K)$$

VPDL resolution

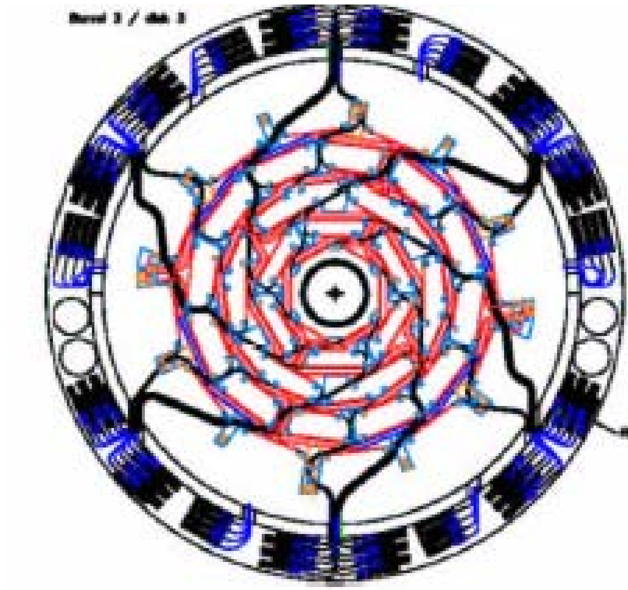
Reconstruction efficiency of jth channel

K-factor

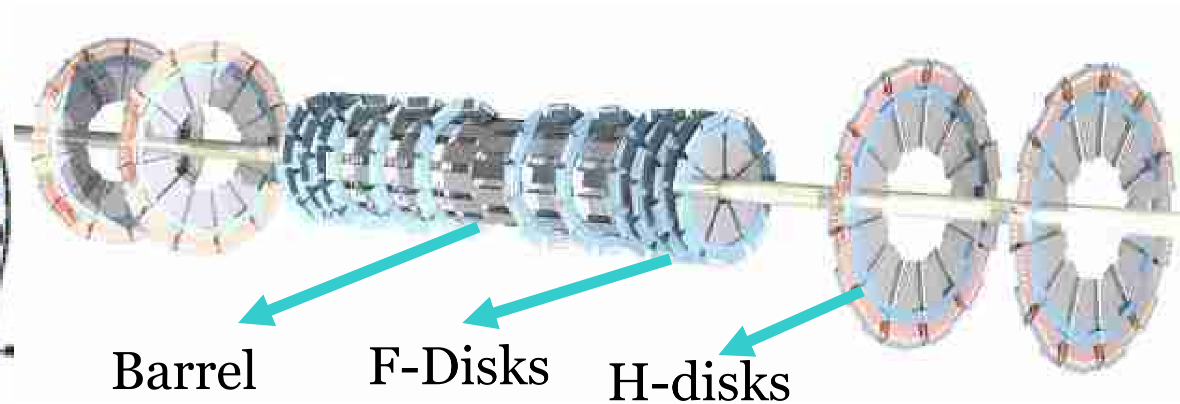


- B not fully reconstructed. Measure average k-factor K = Pt(μD0)/Pt(B)

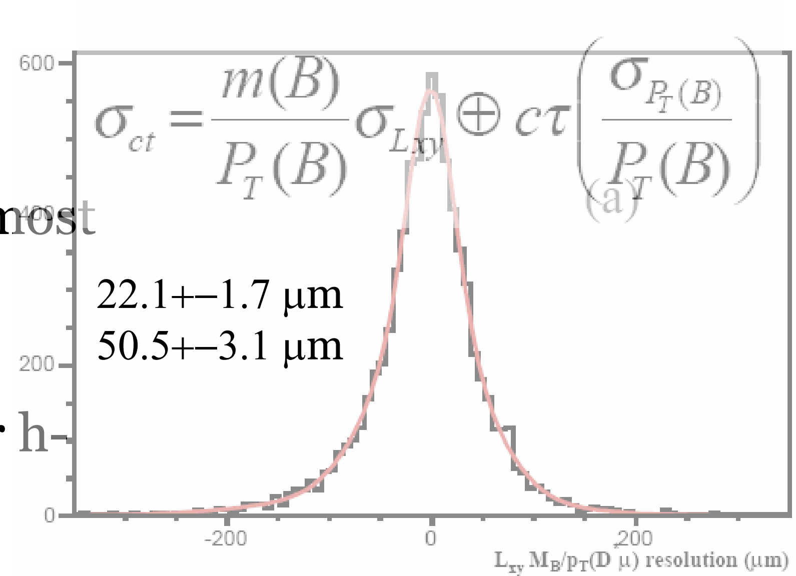
Bd mixing – Decay length resolution



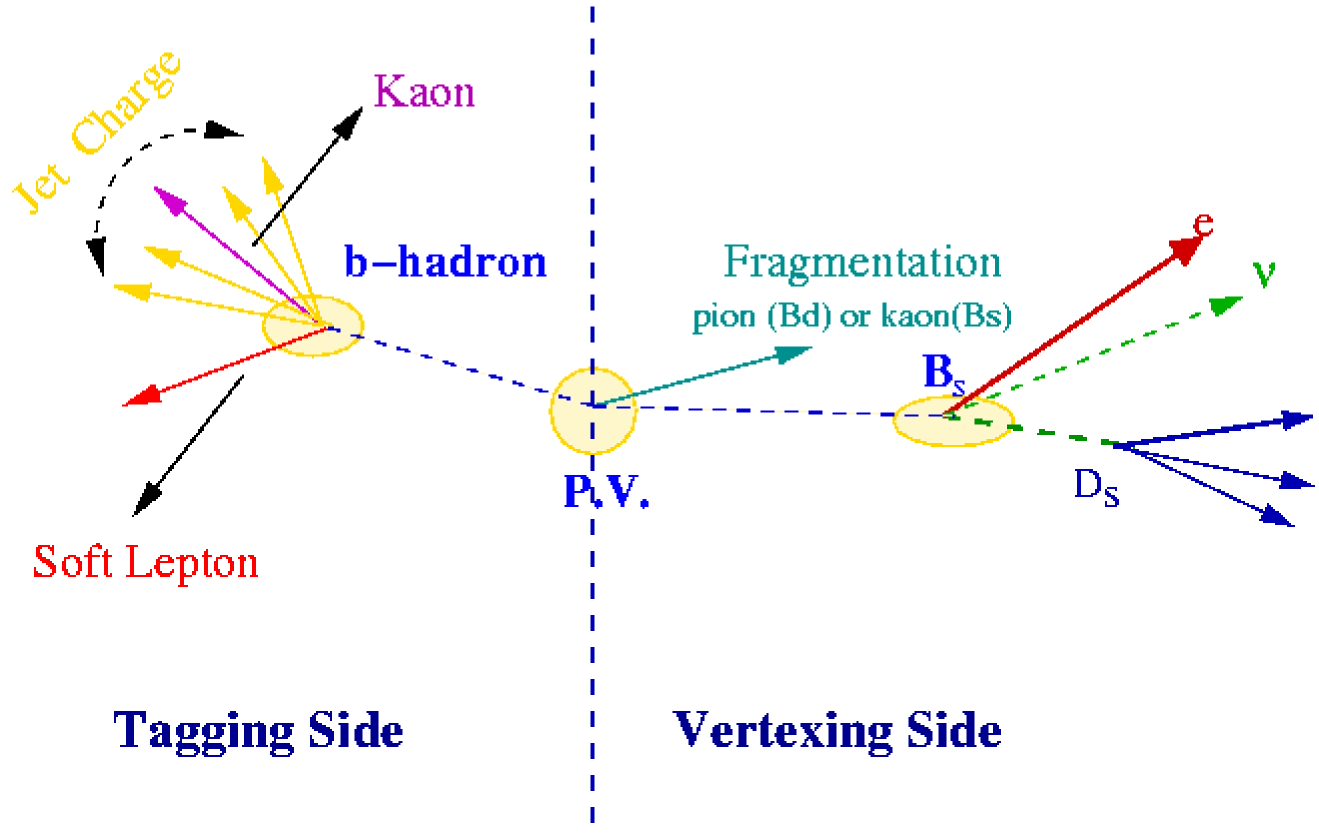
793 K readout channels



- 6 Barrels – 4 layers, Double sided except for layers 1 and 3 of the outermost barrels.
- Interspersed F disks – double sided
- H disks – single sided, 24 wedges per h-disk



Flavor Tagging



----We have explored ---

Jet charge, Soft muon, Same side tagging

Flavor Tagging Definitions

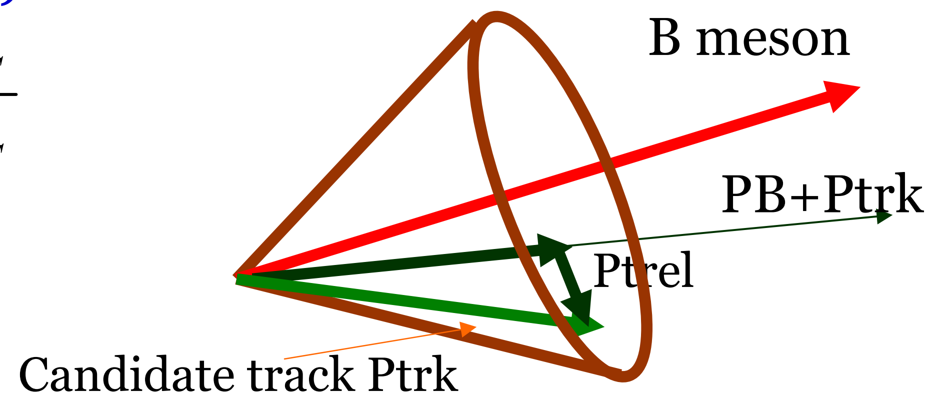
- Flavor tagging merit ($\varepsilon\mathcal{D}^2$)

$$\varepsilon = \frac{N_{tag}}{N_{total}} \qquad D = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$

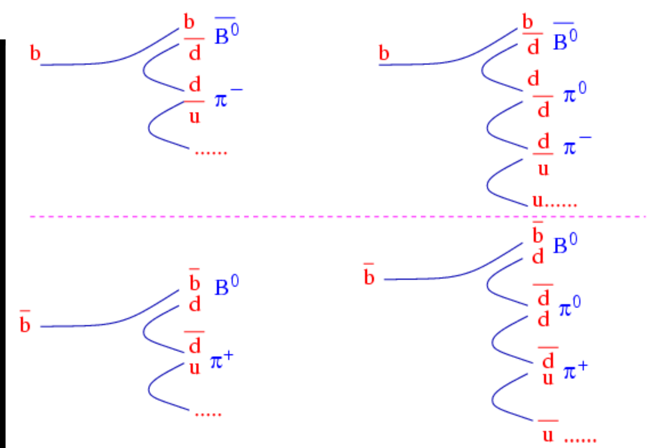
Jet Charge

$$Q_{jet} = \frac{\sum P_T(i) * q(i)}{\sum P_T(i)}$$

Same side Tagging

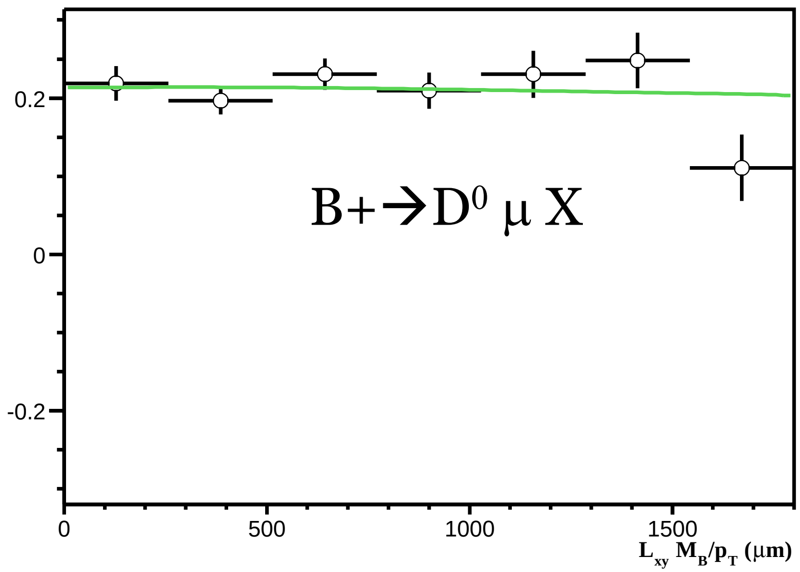


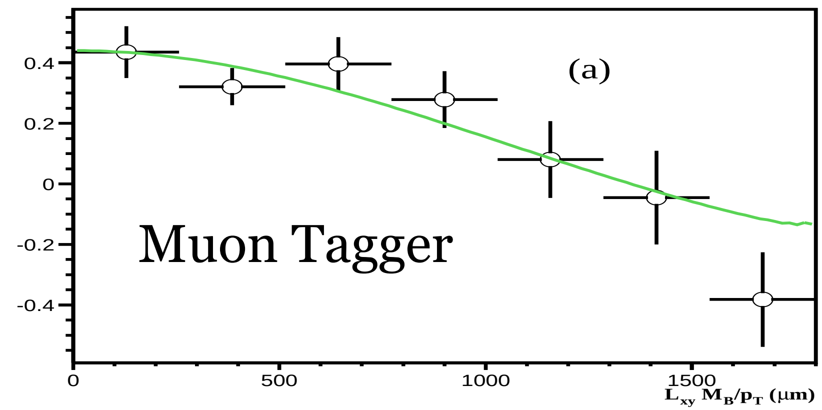
Tagger	ε (%)	$\mathcal{D}$	$\varepsilon\mathcal{D}^2$(%)
SLT	5.0±0.2	44.8±5.1	1.0±0.1
jetQ+SST	68.3±0.9	14.9±1.5	1.5±0.5

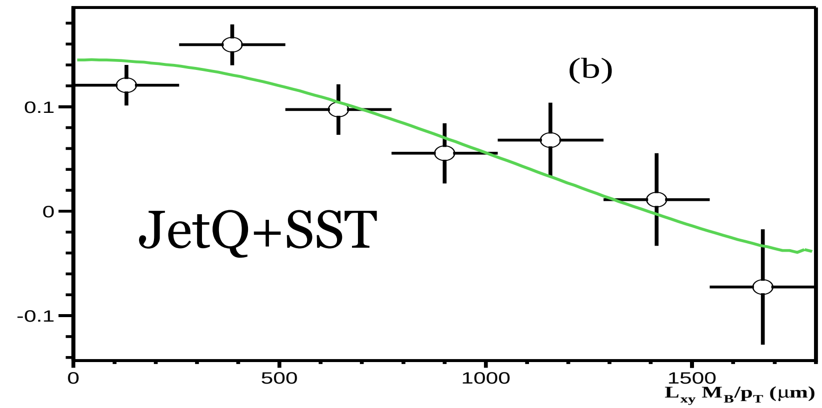


Fitted asymmetry

- Simultaneous fit to D* and D0 sample to extract Δm.







$\Delta m = 0.456 \pm 0.034 \pm 0.025\ ps^{-1}$

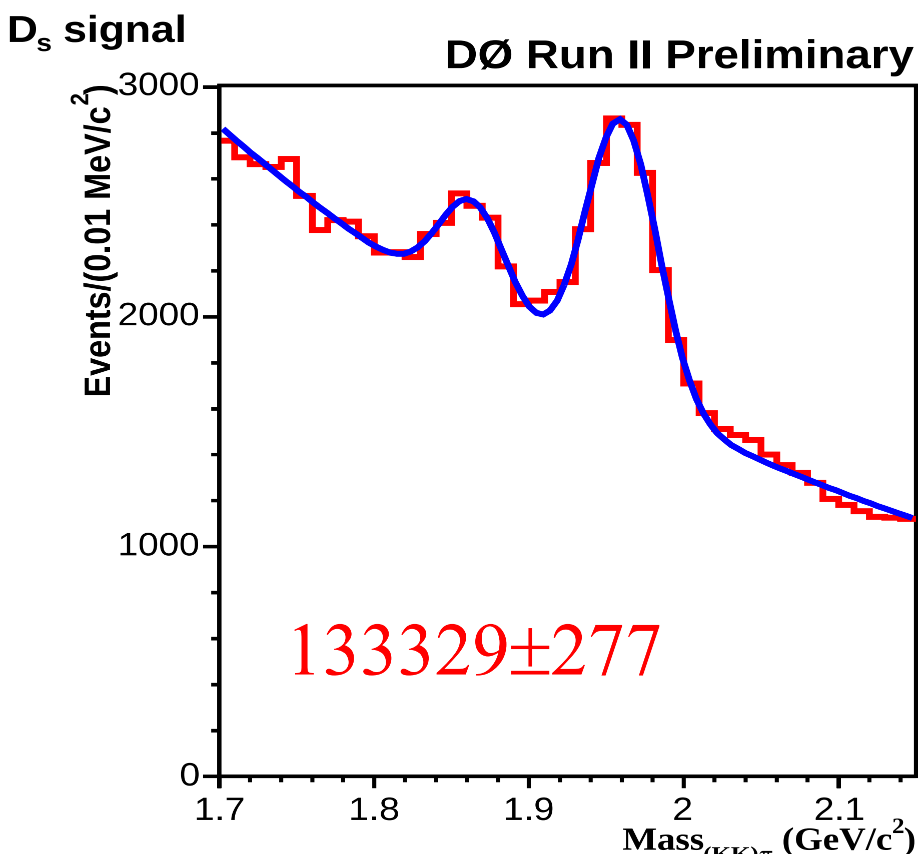
$(D^*)^-$ B_d contribution ~83%

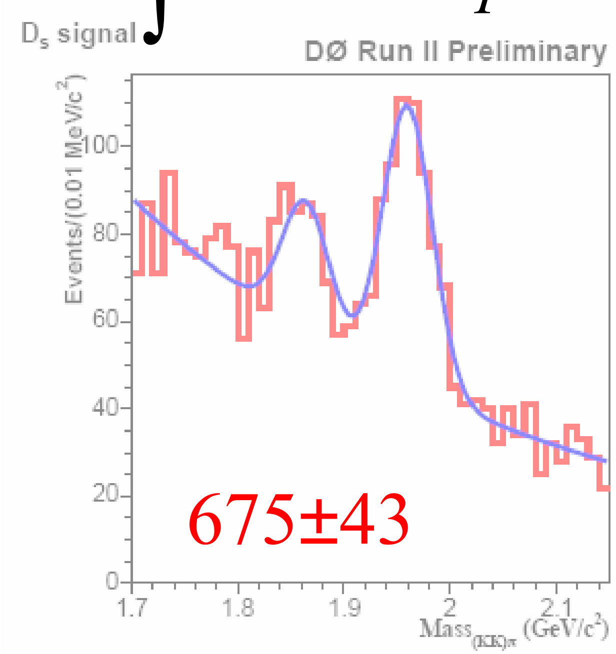
(D0) – B+ contribution ~76%

Bs Mixing

- Very similar analysis to the Bd mixing. Decay mode used: Bs → Ds μ ν, Ds→ϕπ, ϕ→K+K−

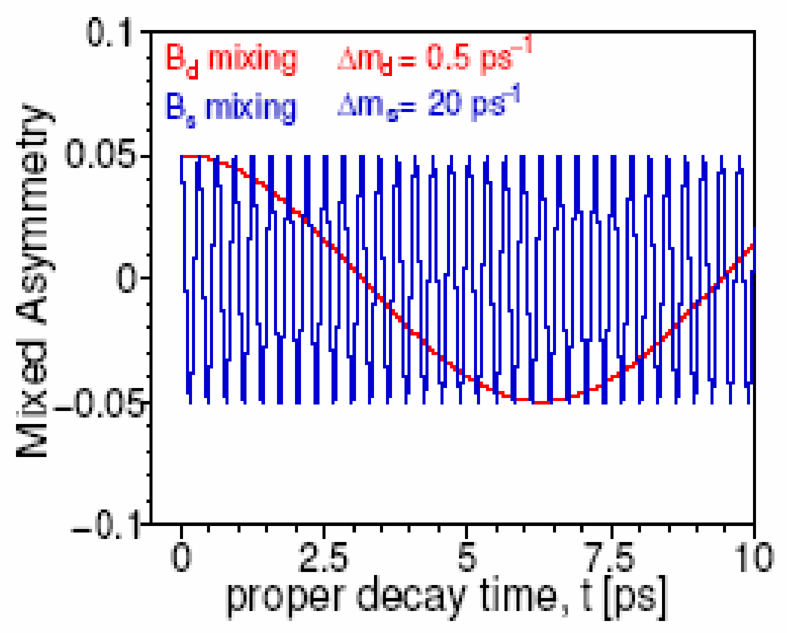
$$\int \mathcal{L}\, dt = 460\, pb^{-1}$$





For…Bs mixing observation

S = *signal events*
εD^2 = *tagging power*
S/B = *signal/background*
σ_t = *proper time resolution*



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

Significant Improvements to flavor tagging

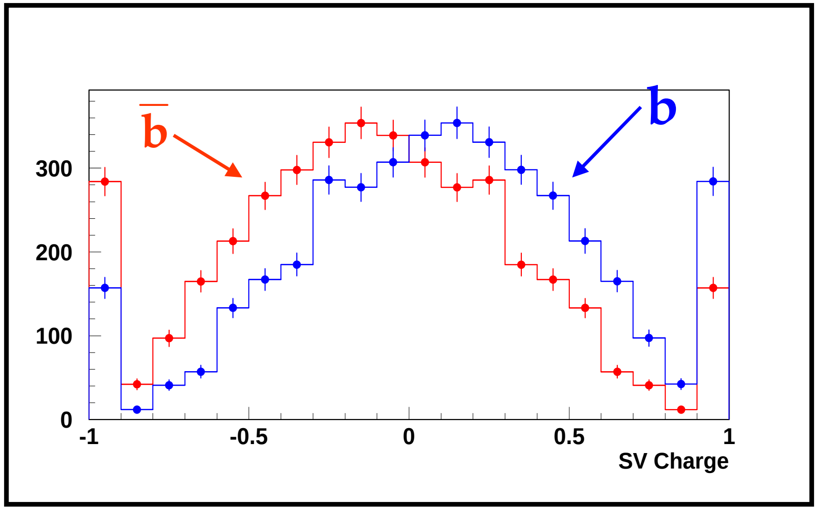
Add Secondary Vertex Charge Tagging

$$Q_{SV} = \frac{\sum p_{\parallel}^{0.6} \cdot q}{\sum p_{\parallel}^{0.6}}$$

Likelihood ratios for variables discriminating between b and $\bar{b}$ → ptrel.q, svcharge,jetcharge

$$y = \prod_{i}^{n} y_i \; ; y_i = \frac{f_i^{\bar{b}}(x_i)}{f_i^{b}(x_i)}$$

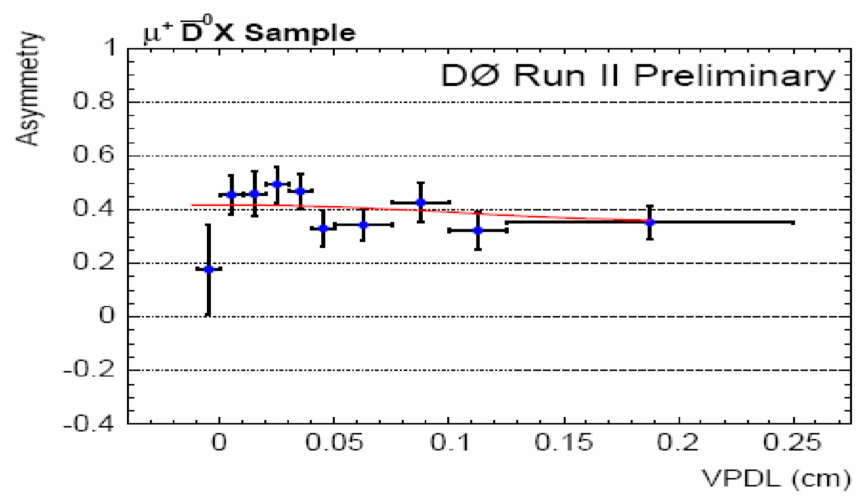
$$d = \frac{1-y}{1+y}$$

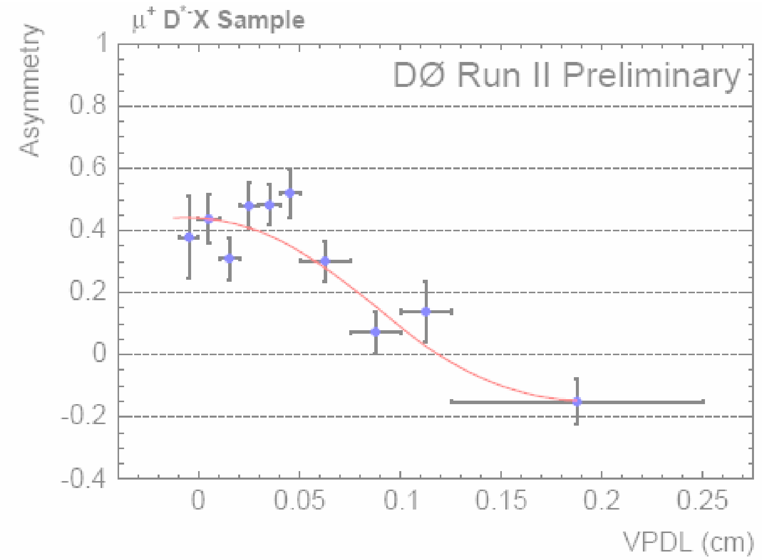


Normalized Tagging variable d → Monotonic function between (-1,1)

d>0 (b) , d<0($\bar{b}$)

"Proof of principle" – Δm_d measurement





Δm_d = 0.558+-0.048(stat.) ps^{-1}

$\varepsilon\mathcal{D}^2$ = 1.0% (OST Tagging only)

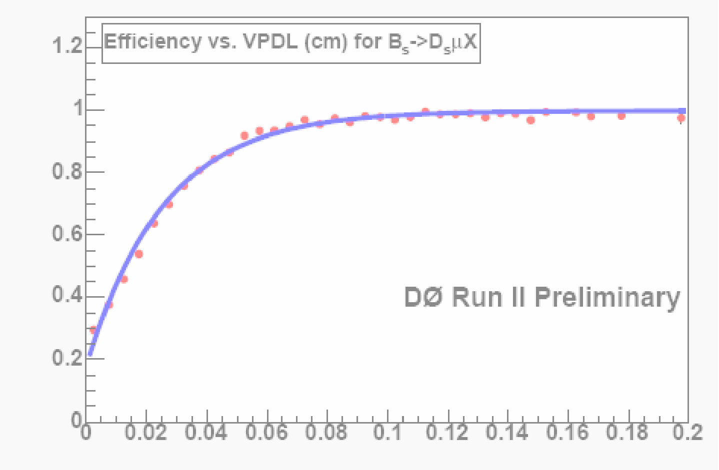
Bs mixing limit – Amplitude fit method

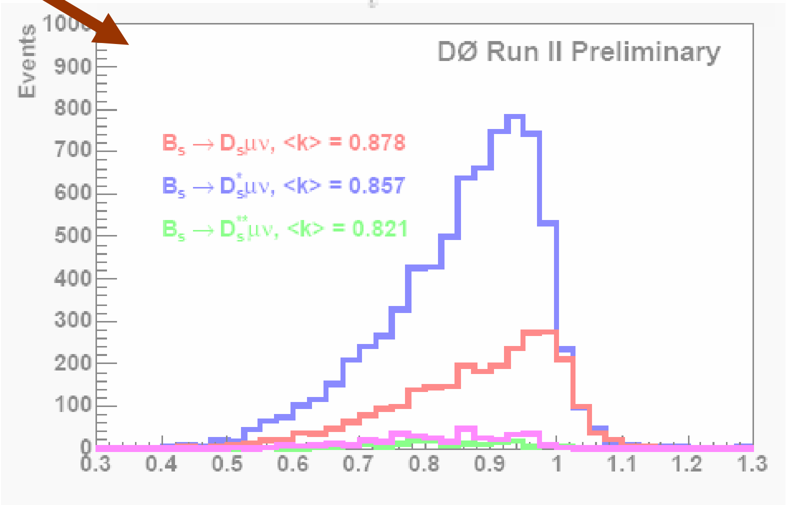
Ideal non-osc/osc number of events as a function of VPDL (x) → Fit for Amplitude $\mathcal{A}$

$$n_s^{non-osc/osc}(x) = \frac{K}{c\tau B_s}\exp\left(-\frac{Kx}{c\tau B_s}\right)\cdot 0.5\cdot\left(1\pm(2\eta-1)\cos(\Delta m_s\cdot Kx/c)\cdot \mathcal{A}\right)$$

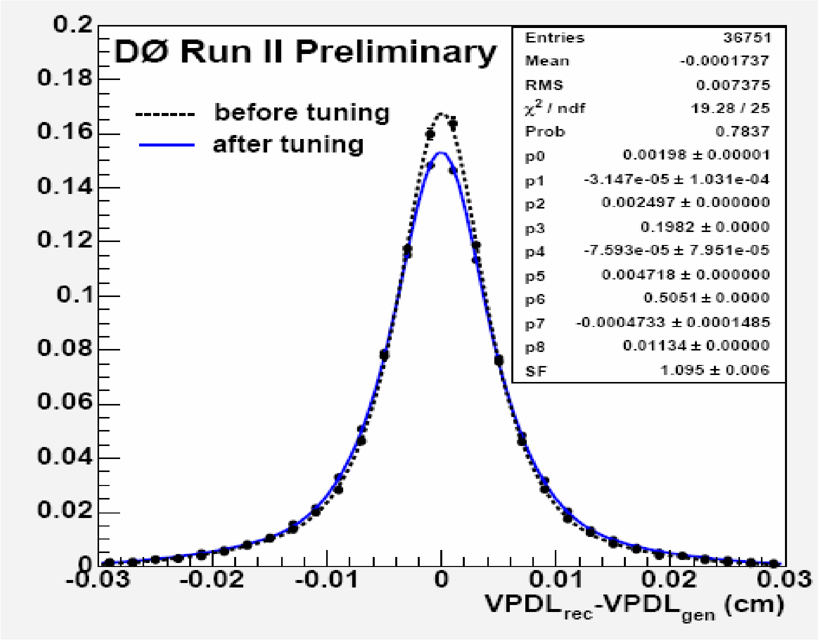
Fit for $\mathcal{A}$ as a function of Δms (in steps of 1 ps^{-1})

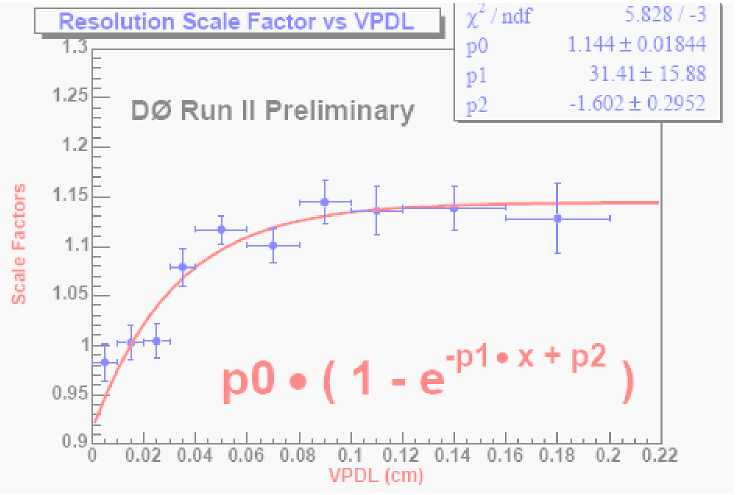
$$\chi^2(\mathcal{A}) = \sum_i \frac{(A_i - A_i^e(\mathcal{A}))^2}{\sigma^2(A_i)}$$





Impact parameter resolution and tuning.





Variable scale factor for VPDL resolution (s.σ)– Overall scale factor = 1.10

Tune track errors for data and MC taking taking into account dependence on:

- **Track momentum**
- **Track angles**
- **Silicon detector hit configuration**
- **Silicon cluster width**

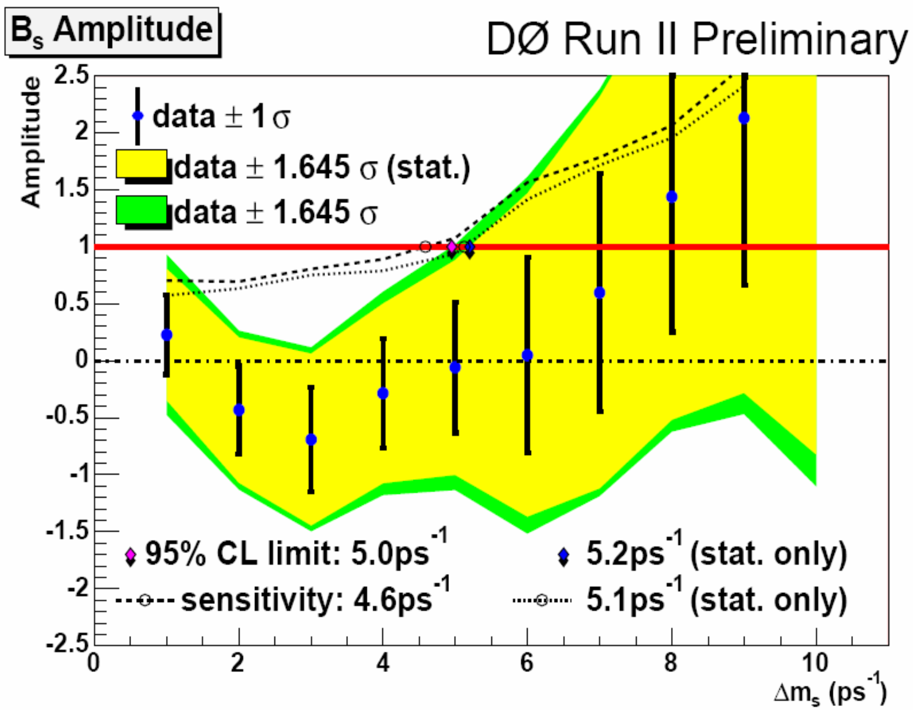
Sample composition

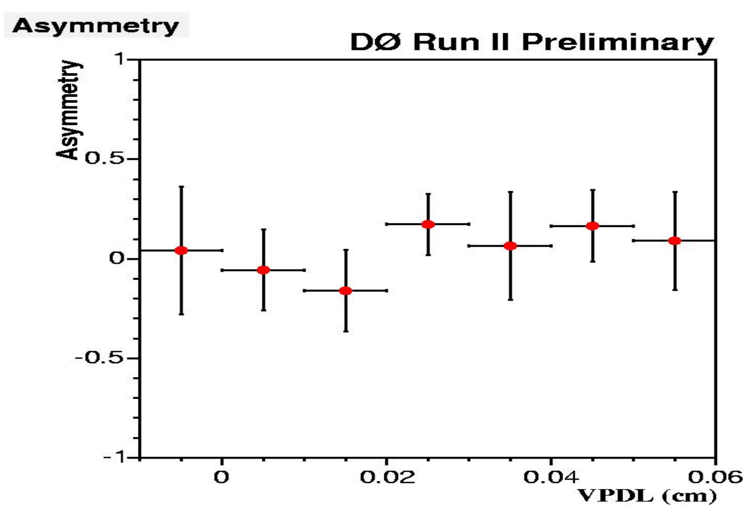
Decay	Sample composition
$B_s \rightarrow D_s \mu\nu$	20.6%
$B_s \rightarrow D^*_s \mu\nu$	57.2%
$B_s \rightarrow D^*_{0s} \mu\nu$	1.4%
$B_s \rightarrow D^*_{1s} \mu\nu$	2.9%
$B_s \rightarrow D_s D_s X$	11.3%
$B^0 \rightarrow D_s D X$	3.2%
$B^- \rightarrow D_s D X$	3.4%

Bs mixing Limit (460 pb^{-1})

- Expect A=1, for freq = trueΔm_s,

  A=0 for freq ≠ trueΔm_s
- 95% C.L
  - smallest value of Δm_s at which, $A+1.645\sigma_A = 1$
- Sensitivity:
  - Δms value with $1.645\sigma_A = 1$



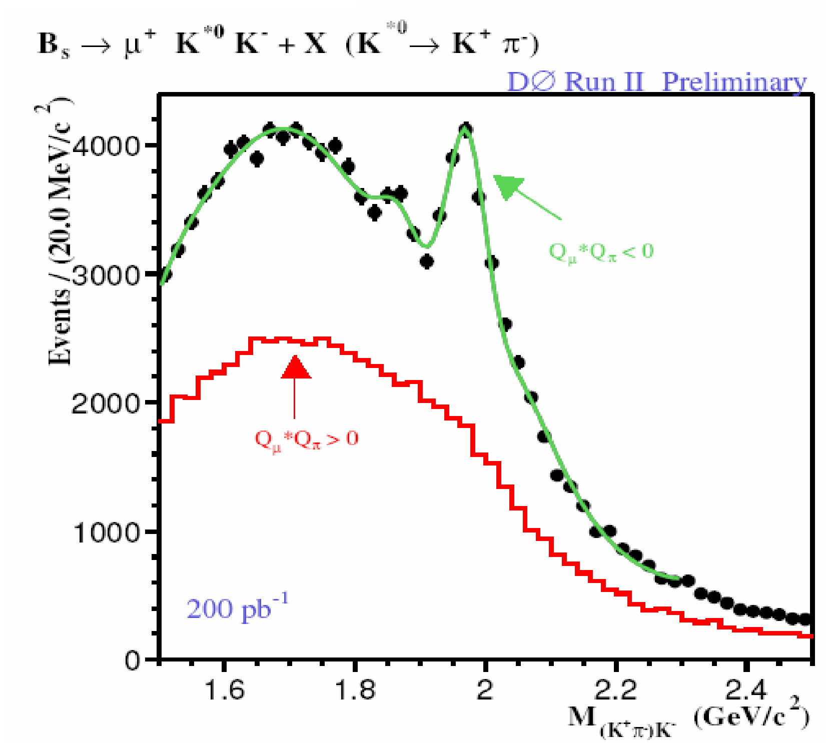


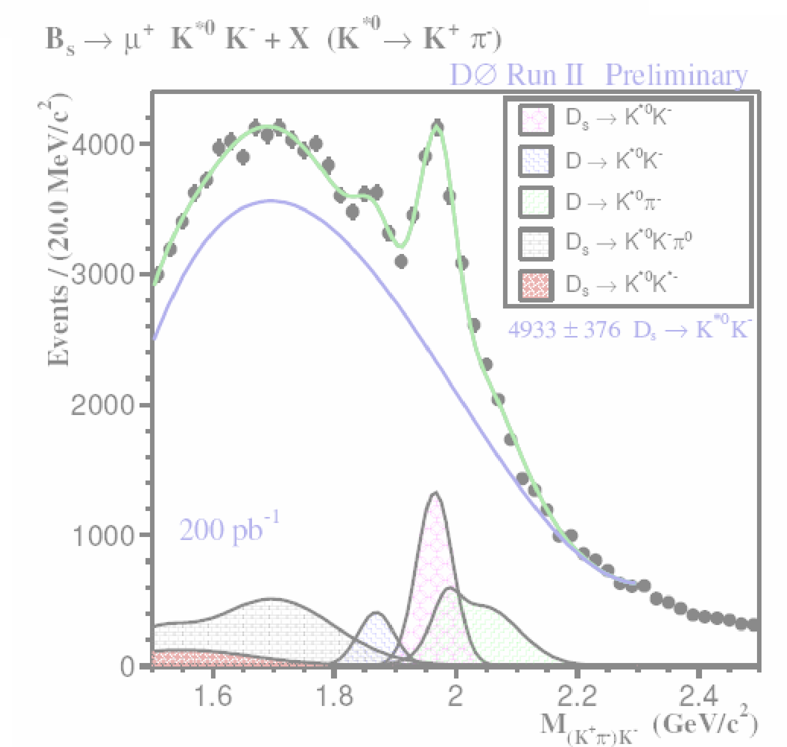
$\Delta m_s > 5.0\ ps^{-1}$

Sensitivity = 4.6 ps^{-1}

To be Added…

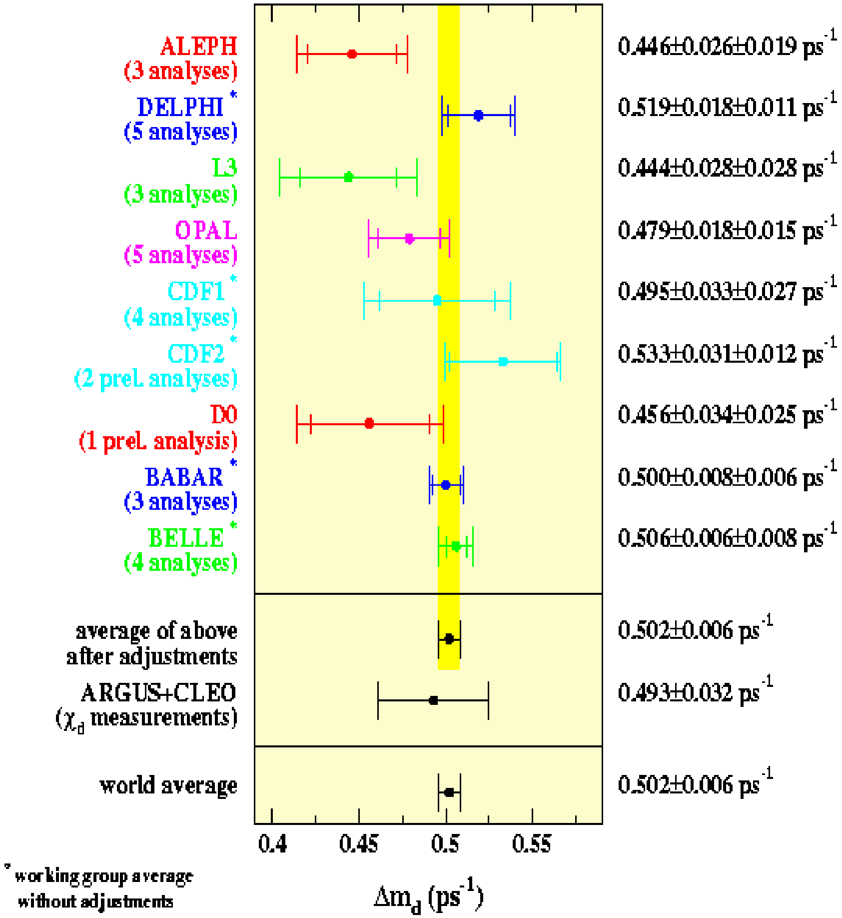
$$B_s^0 \to D_s^- \mu^+ X \; (D_s^- \to K^{*0} K^- \;)$$

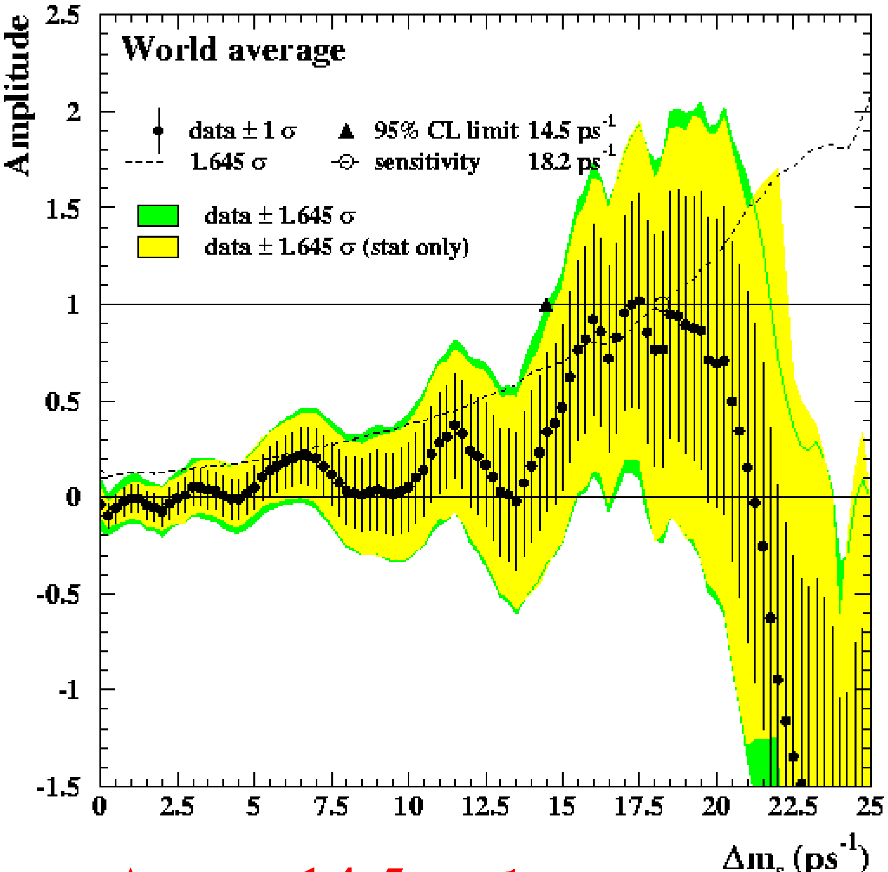




- Reconstructed candidates = 4933 ±376

World averages for Δm_d world B_s mixing limit





$0.502 \pm 0.006 \ ps^{-1}$

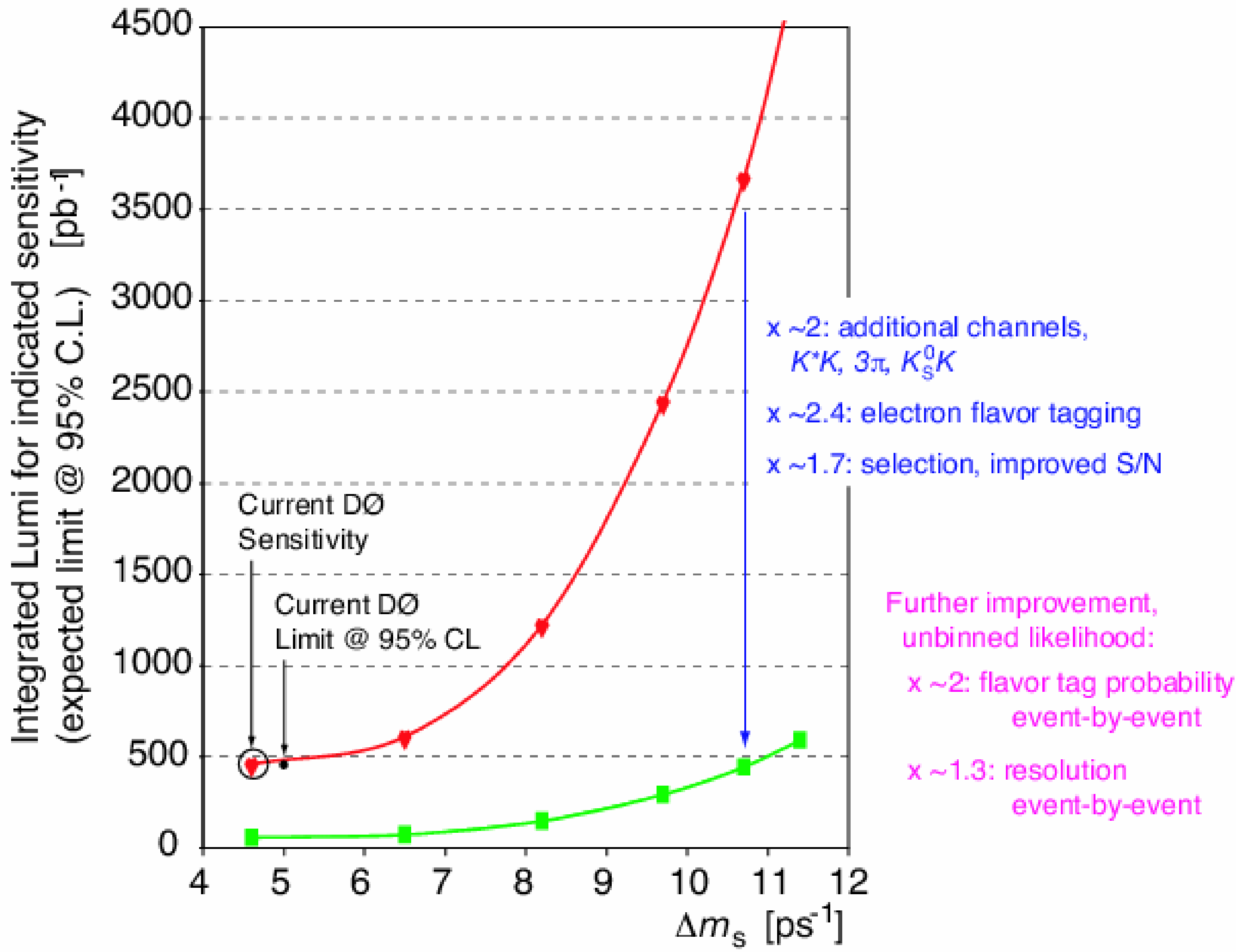
$\Delta m_s > 14.5 \ ps^{-1}$

Sensitivity = $18.2 \ ps^{-1}$

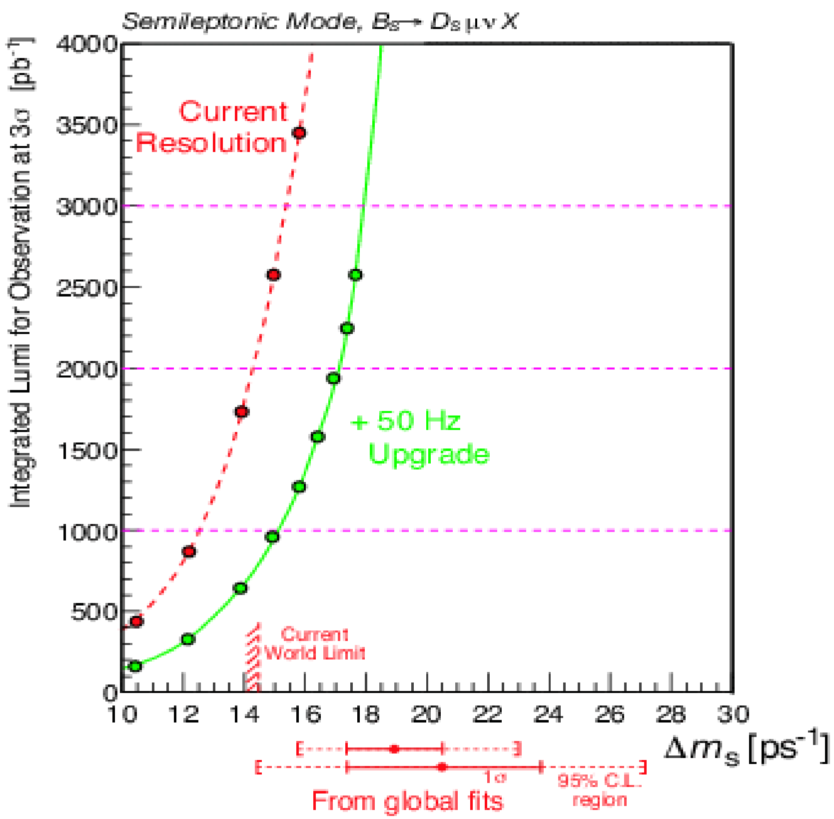
Future Perspectives

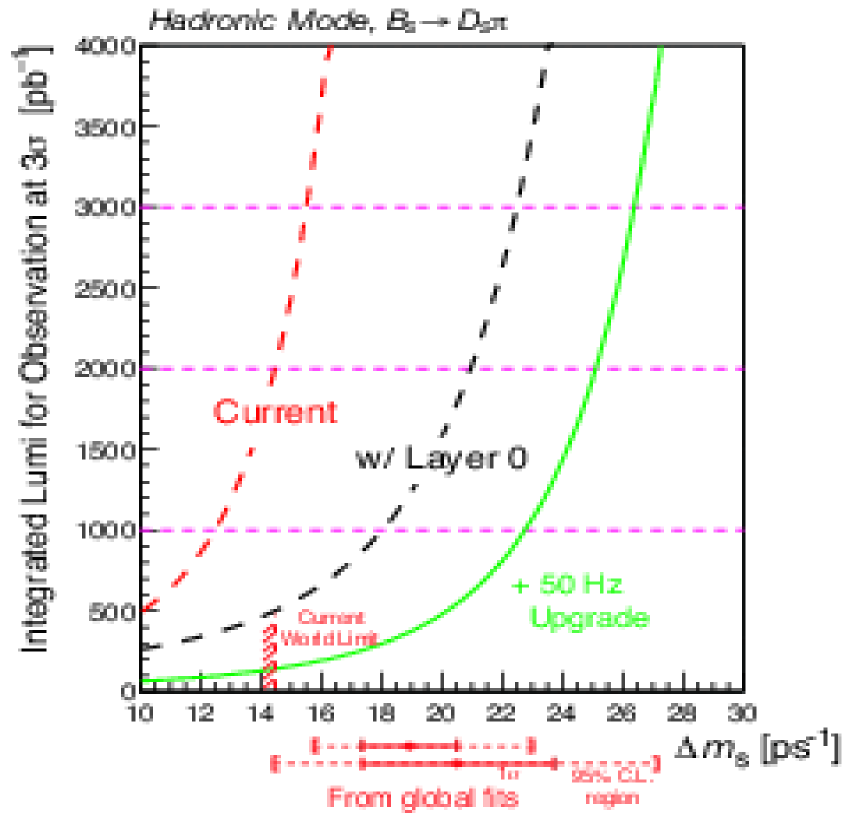
With additional Channels and Improvements In flavor tagging

Δm_s upto 11 ps^{-1} Within reach at 3.5 fb^{-1}



Future perspectives





With increase in bandwidth Δm_s upto 18 ps-1

Addition of hadronic decay Modes and Layer0 + 50 Hz Bandwidth Δm_s upto 26 ps^{-1}

Conclusions and Summary

Bd mixing measurement

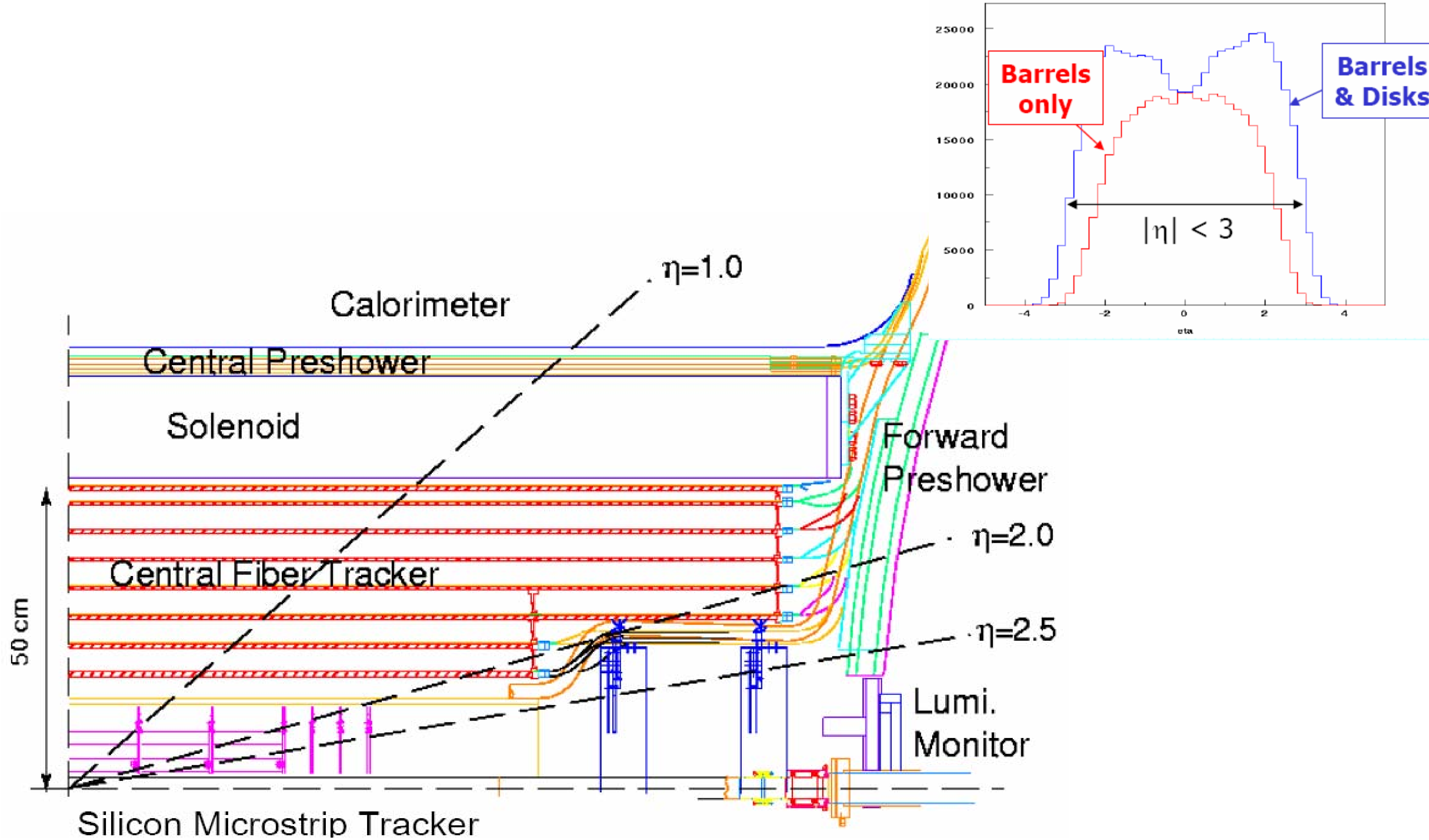
- We can contribute to the Bd mixing measurement in a small way and an important cross check of the measurement in a hadron collider environment. It is mainly important as a validation tool for our flavor tagging.

Bs mixing measurement

- More statistics
- Improvements in flavor tagging, introduction of electron tagging (Almost ready!), Unbinned likelihood fit
- More decay modes,
  - $Bs \rightarrow D_s\, e\, \nu\, X$
  - Addition of Ds → K*K
  - Addition of hadronic decay modes
- Addition of Layer0 → improvements in impact parameter resolution
- We are excited…. Lots more to come….

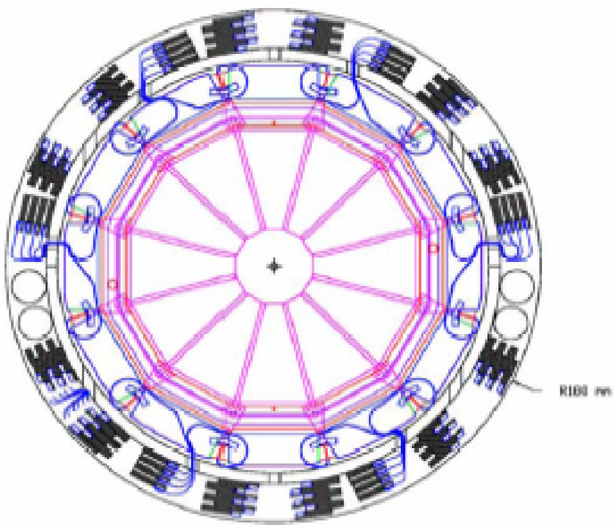
BACKUP

Inner Tracker

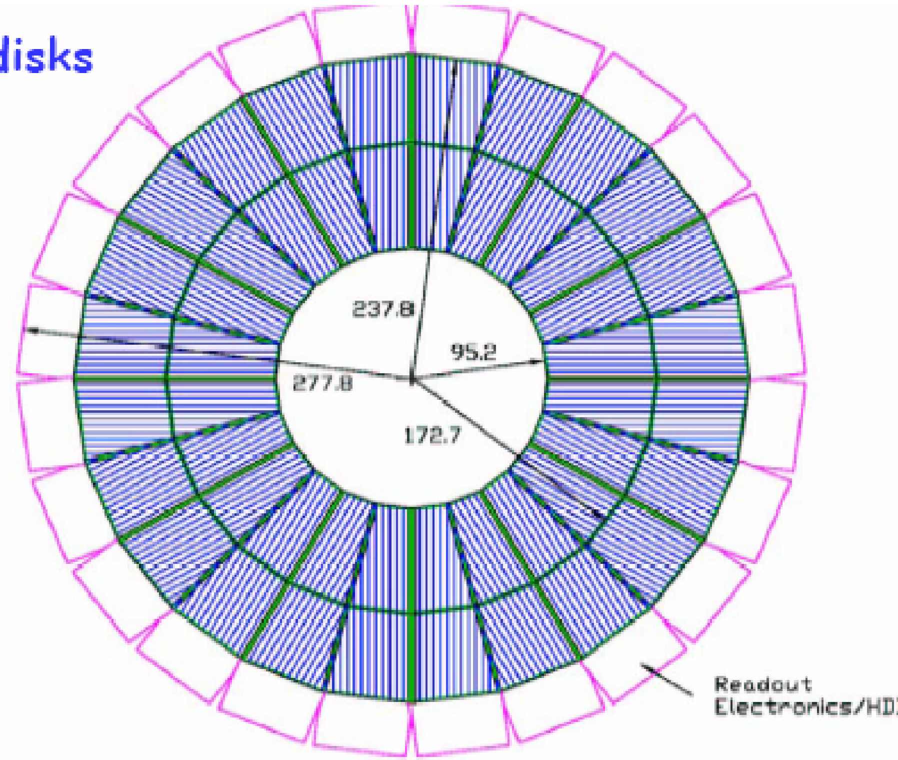


D0 Silicon – RunIIa disks

F-disks



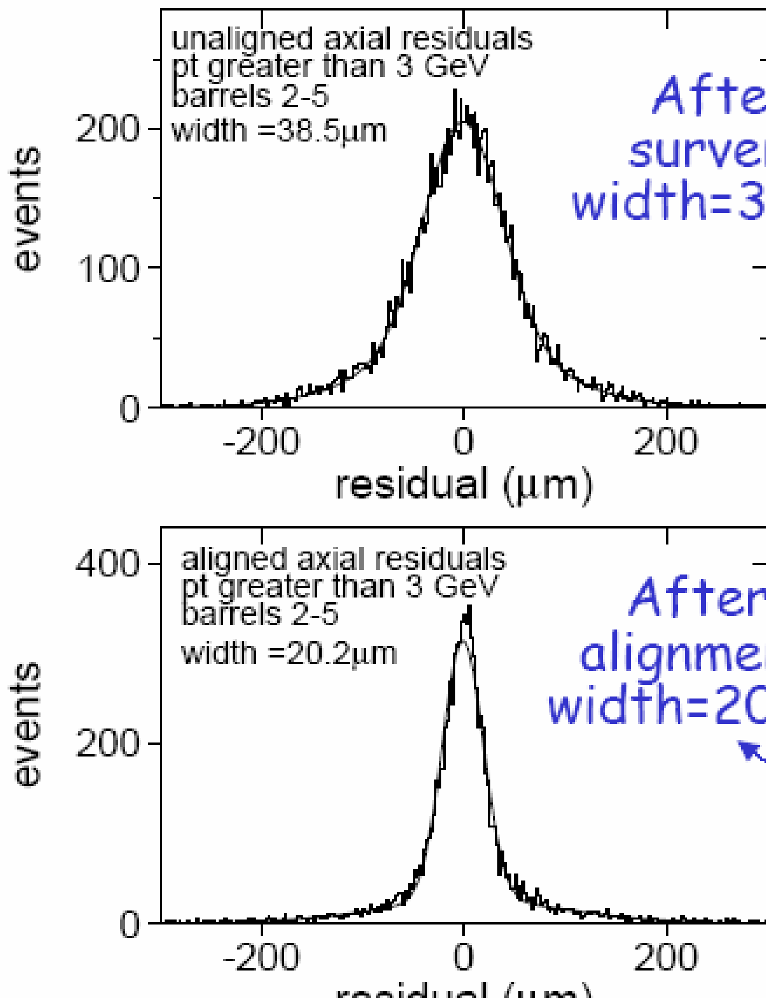
H-disks



- 0.9 m² silicon (0.7 m² active)
- 12 disks
- 144 sensors
- Double-sided

- 1.3 m² silicon (1.2 m² active)
- 4 disks
- 384 sensors
- Single-sided, mated back-to-back to form double-sided

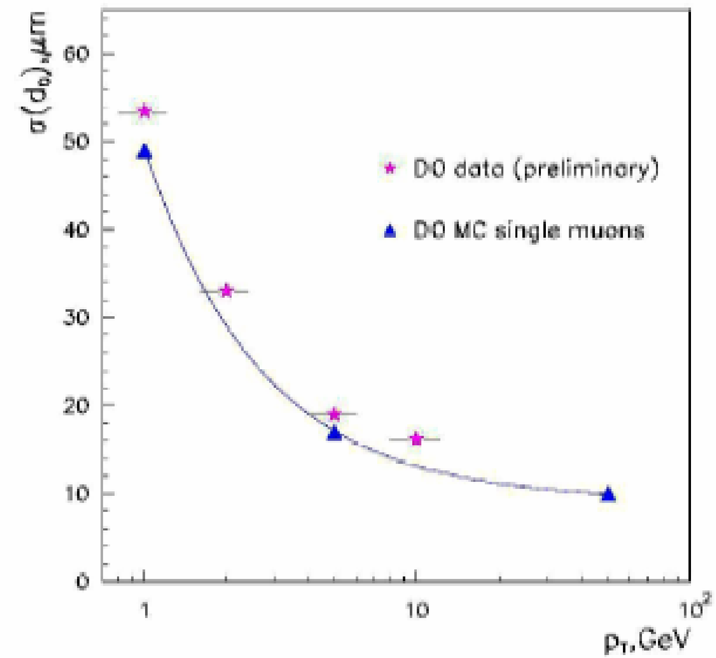
Silicon Alignment



After survery width=39µm

After alignment width=20µm

Perfect alignment in MC : 16µm



- Reasonably well aligned
  - Only a few µm of mis-alignment