B-Physics at DØ
Recent Results & Plans

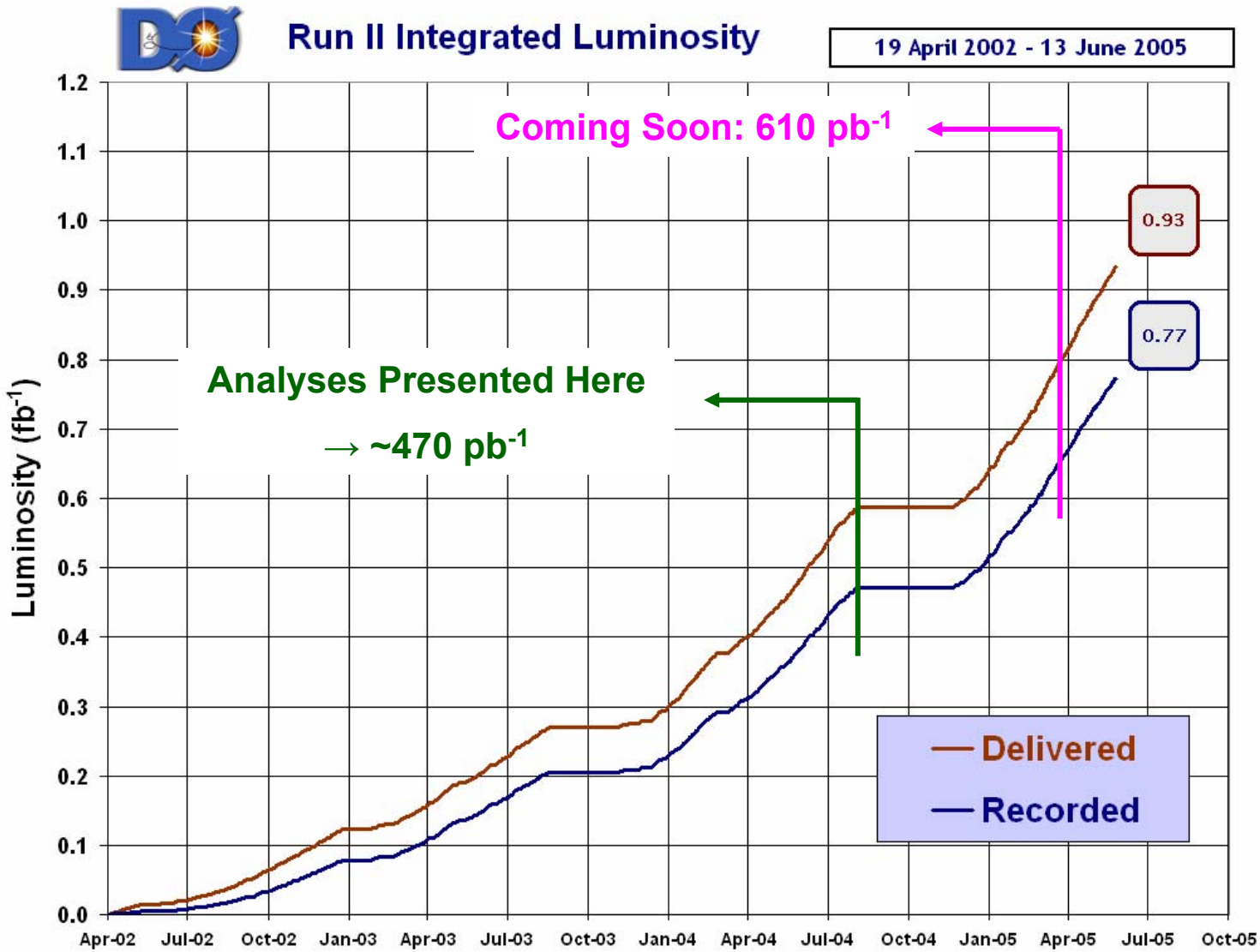
Hal Evans **(for the DØ B group)** **Columbia U.**

1. **B-Physics & the DØ Detector**

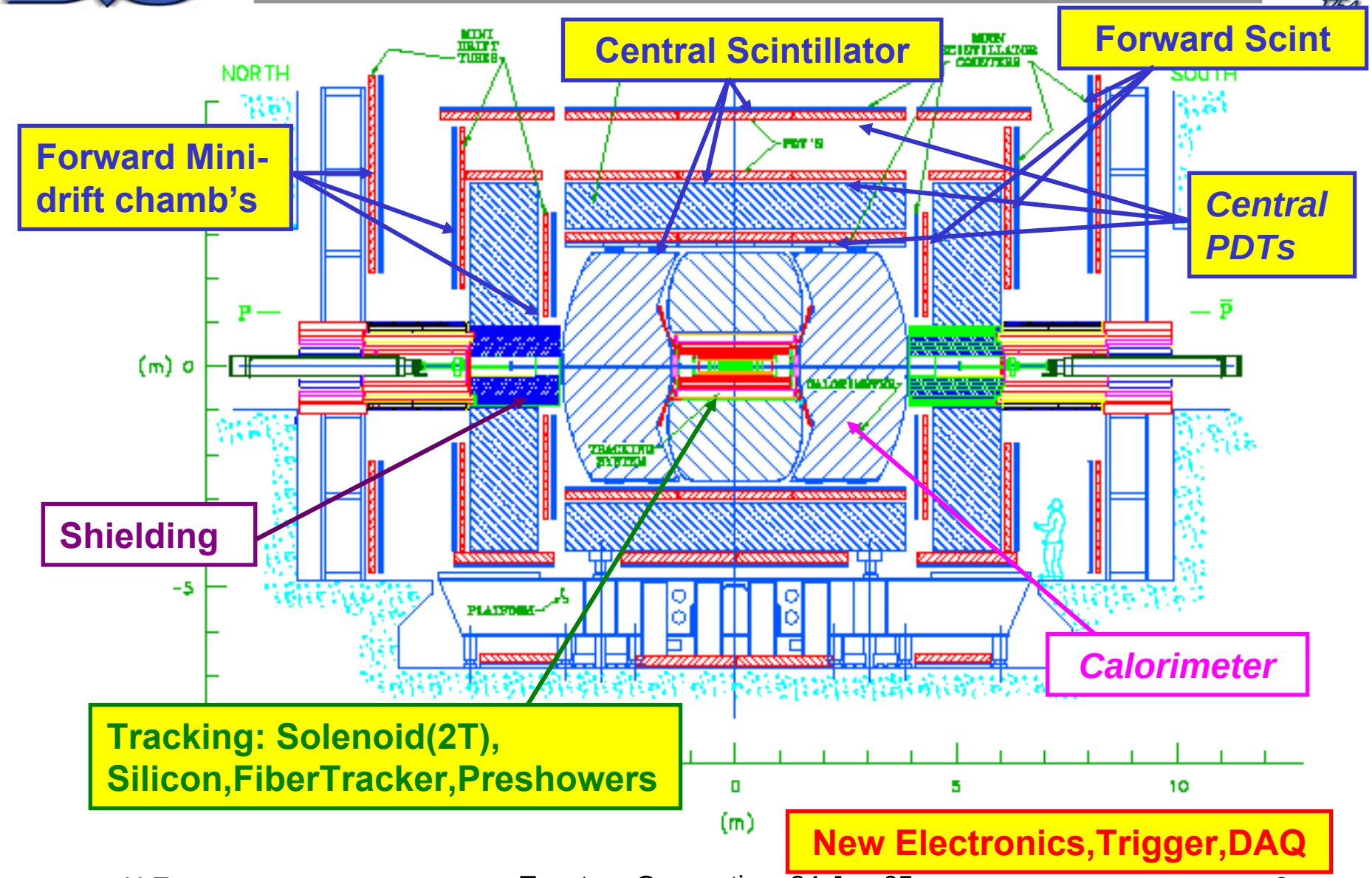
2. **Recent B-Physics Results**
   - **Rare Decays**
   - **Lifetimes**
   - **Mixing**

3. **Planning for the Future**

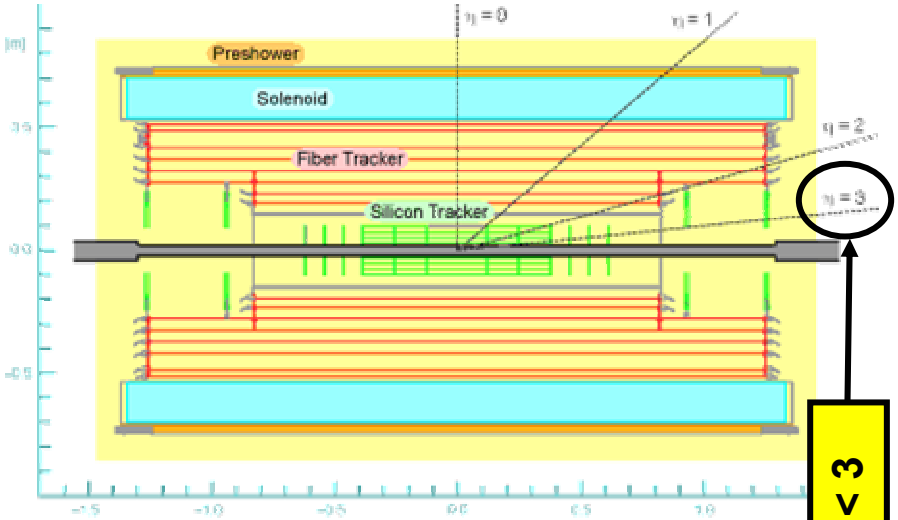
The Data Set


Run II Integrated Luminosity
19 April 2002 - 13 June 2005
Coming Soon: 610 pb-1
Analyses Presented Here
→ ~470 pb-1
0.93
0.77
Delivered
Recorded
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

DØ Detector (the cartoon)



Tracking



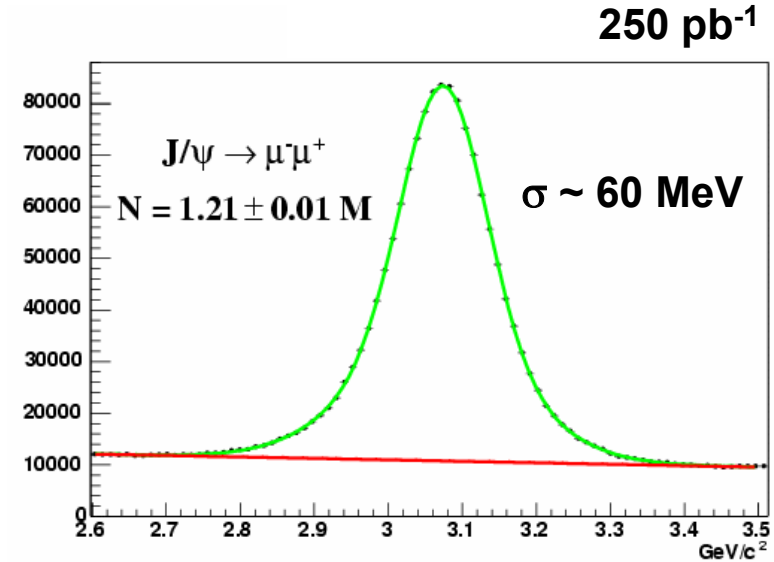
Large Acceptance: |η| < 3

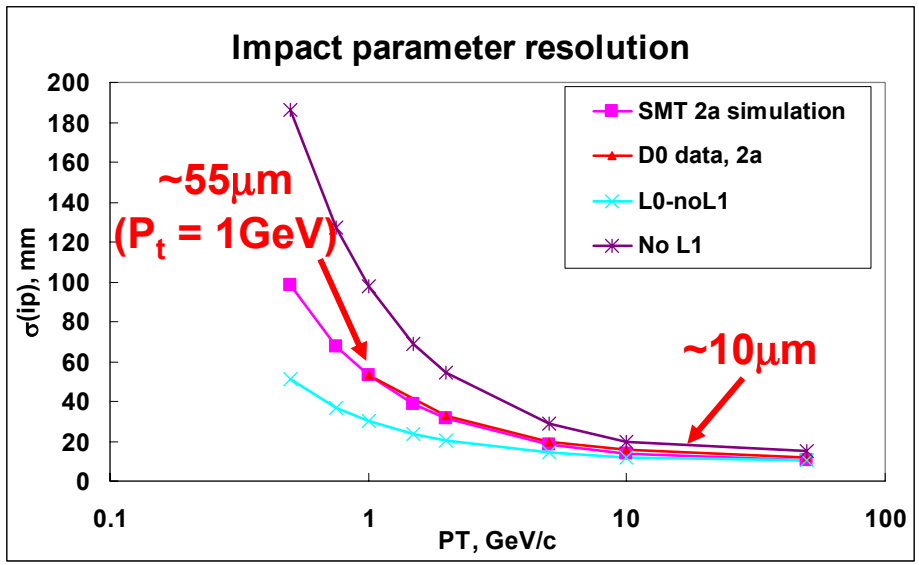
2 T Magnetic Field
- track reco to P_T = 180 MeV

Silicon: 2.7 – 9.5 cm (barrel)
- 6 barrels / 4 layers + disks
- 793K chan's (most 2-sided)
- Layer 0 this fall (r ~ 1.7 cm)

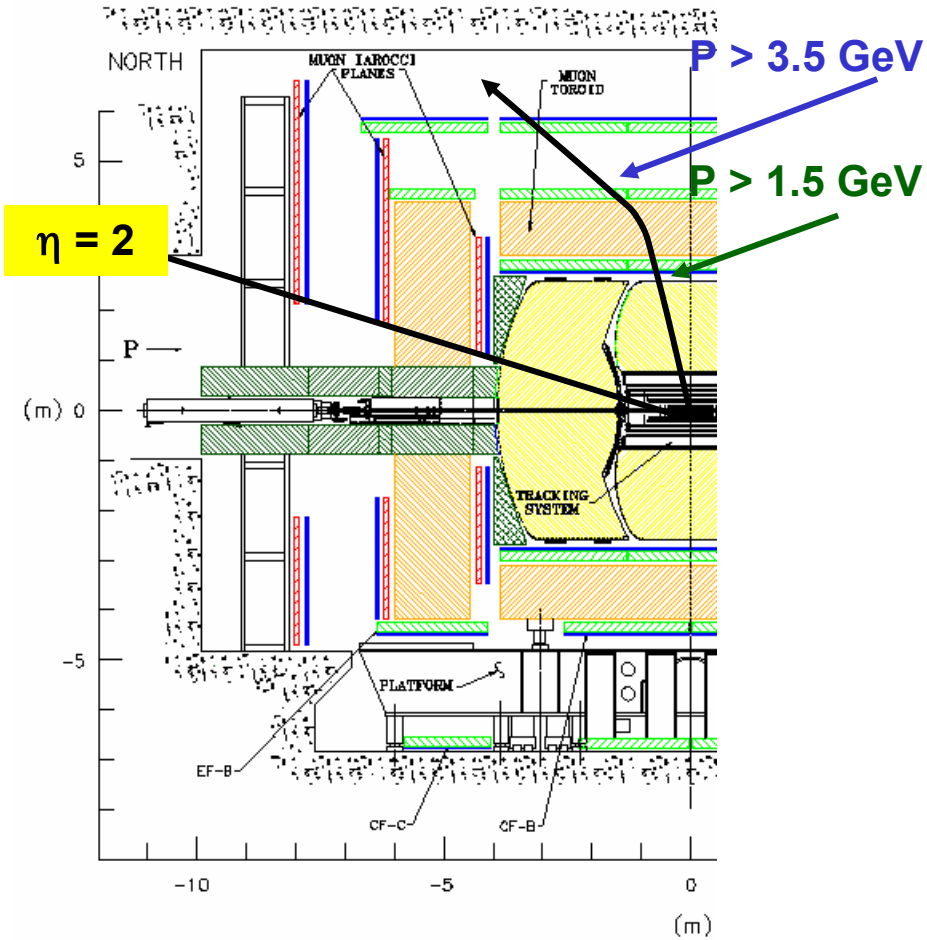
Fiber Tracker: 20 – 51 cm
- 8 double layers: axial & stereo
- 77K channels

Pre-Shower
- scintillating strips
- central & forward / axial & stereo

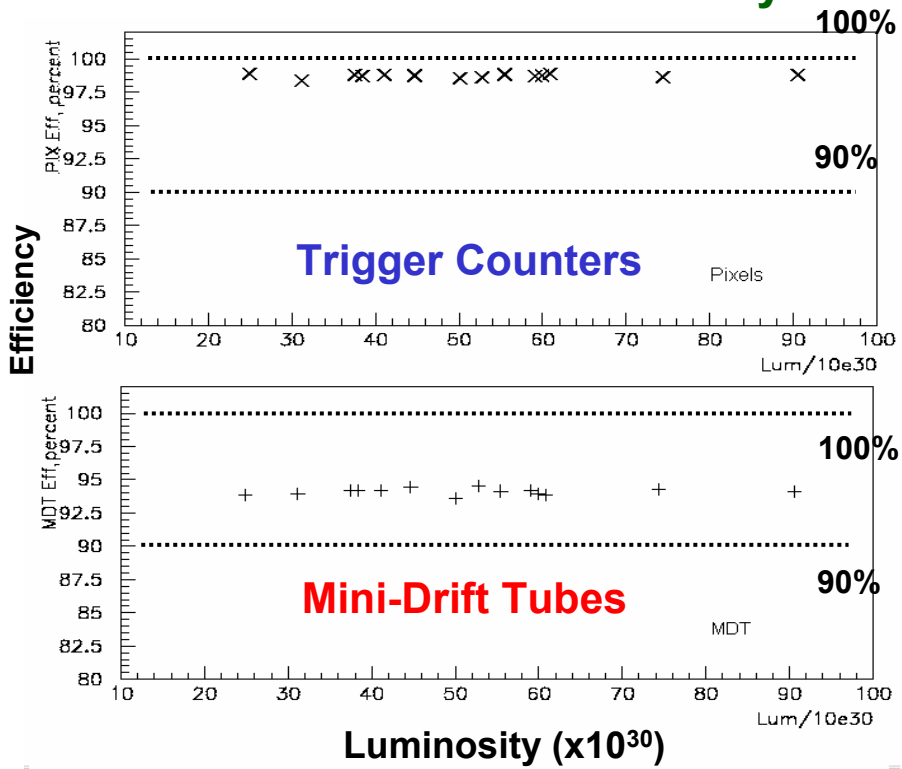




Muons

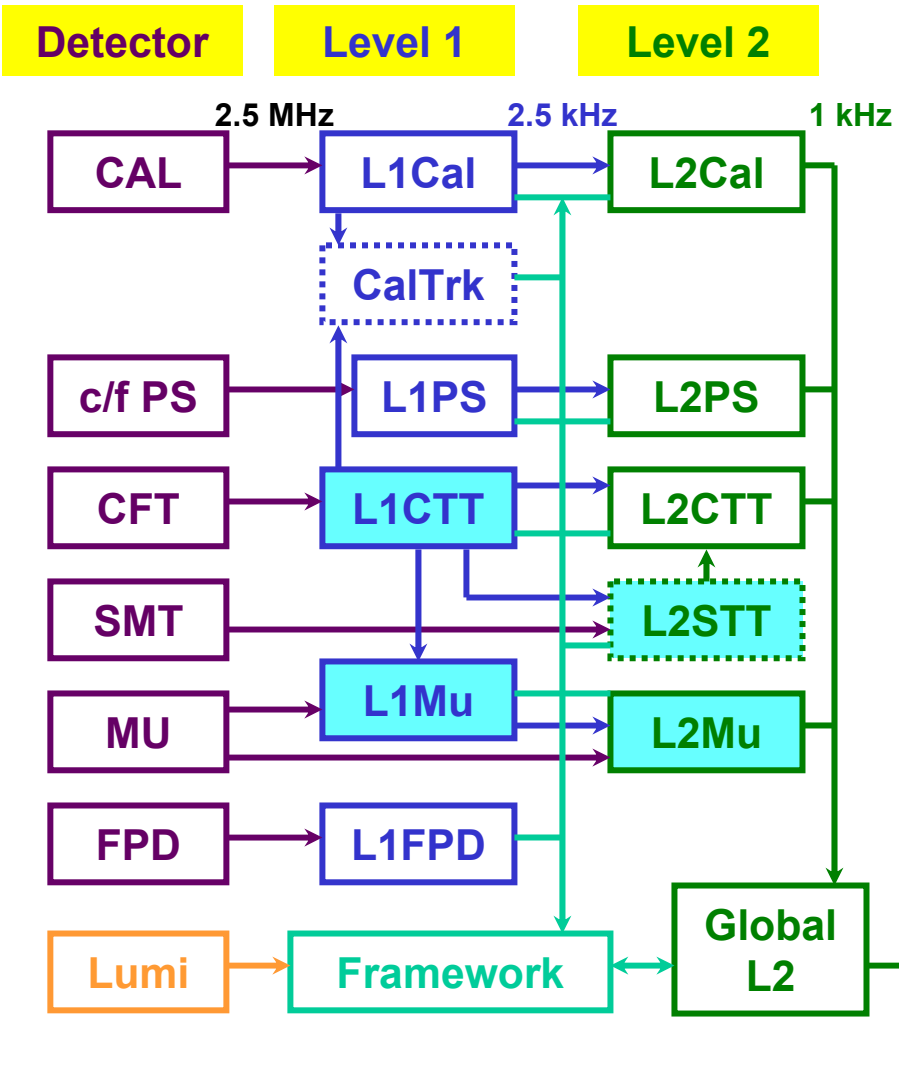


Forward Muon Efficiency



- Large Coverage $|\eta| < 2$
- High Efficiency
- High Purity >60% 1-μ @ L1

Trigger



Main B-Physics Triggers Single- and Di-Muon

B_s Mixing Data Set

- ~67% Di-Muon
- ~25% Single-Muon
- ~8% other (μ+jet)

Typical Rates (Hz) at $L = 4\times10^{31}$ cm^{-2}s^{-1}			
Trigger	L1	L2	L3
dimuon	50	15	4
single mu	120	100	50
Total	1600	800	60

L3 limit ~ 50 Hz

$\Rightarrow$ prescale !

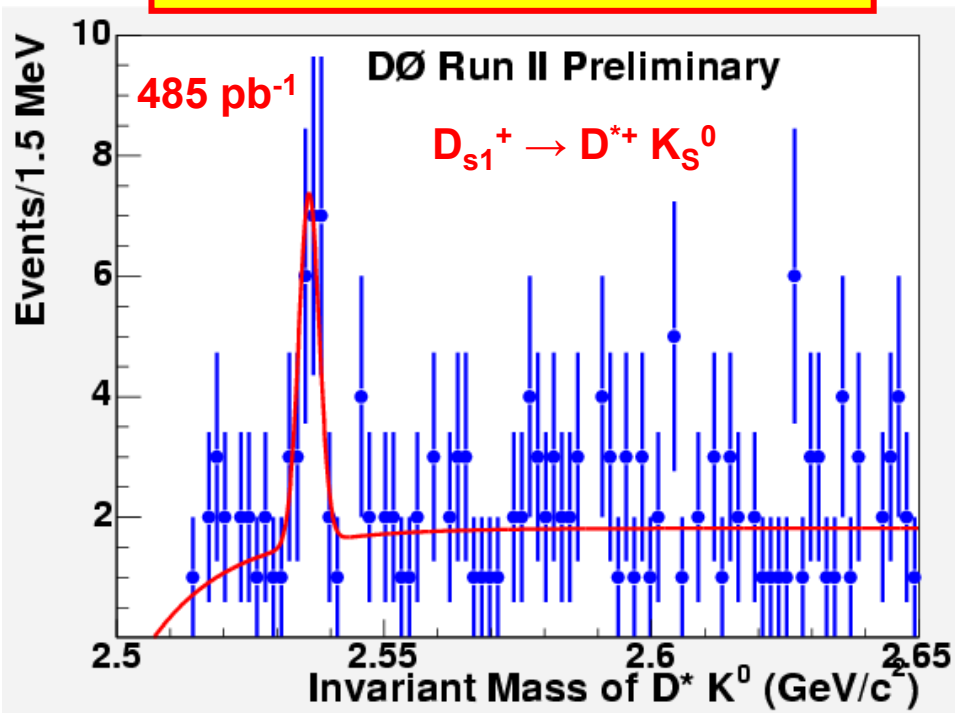
DØ B-Physics Results

Υ Differential X-Section	160 pb^{-1}	PRL 94 (2005)
$B_s \rightarrow D_{s1}(2536)\ \mu\ \nu\ X$	485 pb^{-1}	preliminary
B_c Semileptonic	210 pb^{-1}	preliminary
$B \rightarrow D^{**}$	250 pb^{-1}	preliminary
B^{**}	350 pb^{-1}	preliminary
X(3872)	230 pb^{-1}	PRL 93 (2004)
$D_s \rightarrow \phi\ \pi$ and $D^- \rightarrow \phi\ \pi$	508 pb^{-1}	preliminary
$B_s \rightarrow \mu^+\ \mu^-\ \phi$	300 pb^{-1}	preliminary
$B_s \rightarrow \mu^+\ \mu^-$	300 pb^{-1}	preliminary
	240 pb^{-1}	PRL 94 (2005)
$B_s\ \Delta\Gamma/\Gamma$	450 pb^{-1}	preliminary
$B_s \rightarrow D_s\ \mu\ X$ Lifetime	400 pb^{-1}	preliminary
B^+/B^0 Lifetime Ratio	440 pb^{-1}	PRL 94 (2005)
$\Lambda_b \rightarrow J/\psi\ \Lambda$ Lifetime	250 pb^{-1}	PRL 94 (2005)
$B_s \rightarrow J/\psi\ \phi$ Lifetime	220 pb^{-1}	PRL 94 (2005)
B_s Mixing using $D_s(\phi\pi)\ \mu\ X$ and OST	460 pb^{-1}	preliminary
$B_s \rightarrow D_s(K^*K)\ \mu\ X$ Reconstruction	200 pb^{-1}	preliminary
B_d Mixing	250 pb^{-1}	preliminary

B's Galore !

Mode	evts / 100pb^{-1}
$J/\psi \to \mu^+ \mu^-$	1.14 M
$B^+ \to J/\psi K^+$	1700
$B_d \to J/\psi K^{*0}$	740
$B_d \to J/\psi K^0_S$	40
$B_s \to J/\psi \phi$	100
$\Lambda_b \to J/\psi \Lambda$	25
$B_c \to J/\psi \mu X$	65
$X(3872) \to J/\psi \pi^+ \pi^-$	230
$B \to D^{**} \mu \nu$	210
$B^{**} \to B \pi$	150
$B_s \to D_{s1} \mu X$	4
$B^+ \to D^0 \mu^+ X$	46.2 K
$B_d \to D^{*-} \mu^+ X$	10 K
$B_s \to D_s(\phi\pi) \mu X$	2900
$B_s \to D_s(K^*K) \mu X$	2500

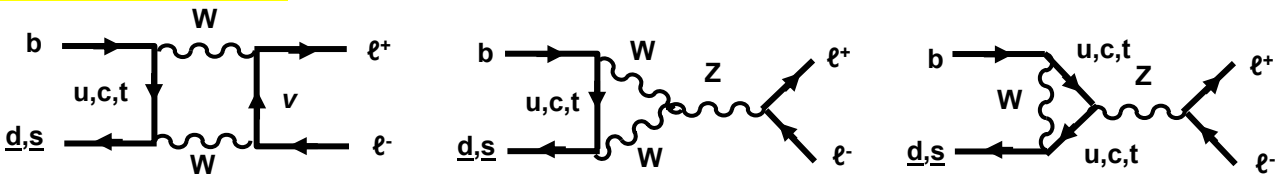
$B_s \to D_{s1}(2536) \mu \nu X$



Signal: 18.5 ± 5.5 (3.4σ)

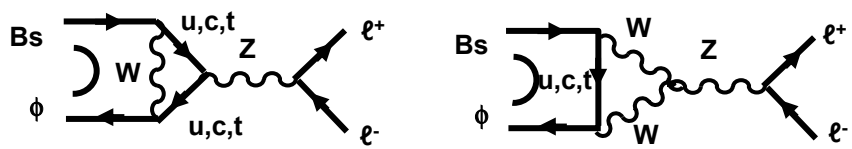
FCNC Heavy Flavor Decays

$B_s \rightarrow \mu^+ \mu^-$



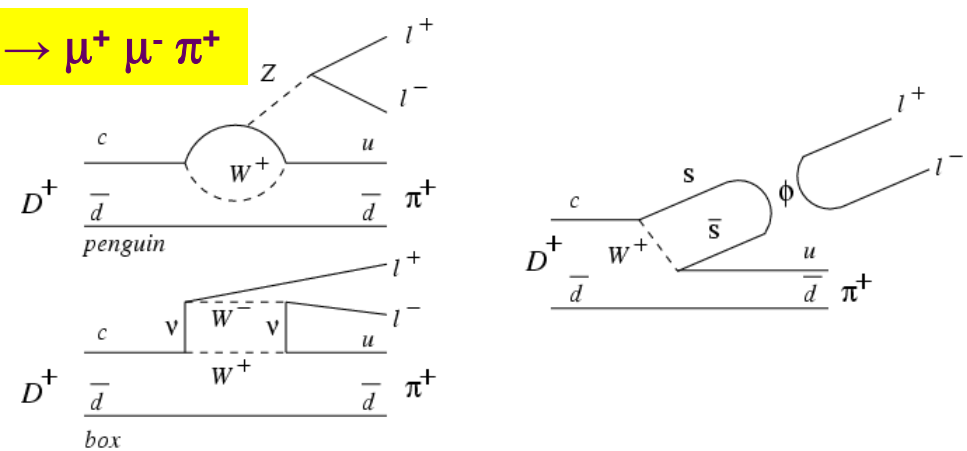
- SM BR = $(3.4 \pm 1.5) \times 10^{-9}$
- Enhanced at large $\tan\beta$ (MSSM $\alpha \tan^6 \beta$)
- CDF-II: BR < 1.5×10^{-7}

$B_s \rightarrow \mu^+ \mu^- \phi$



- SM BR ~ 1.6×10^{-6}
- Smaller Enhance at large $\tan\beta$
- CDF-I: BR < 6.7×10^{-5}

$D^+ \rightarrow \mu^+ \mu^- \pi^+$



short distance

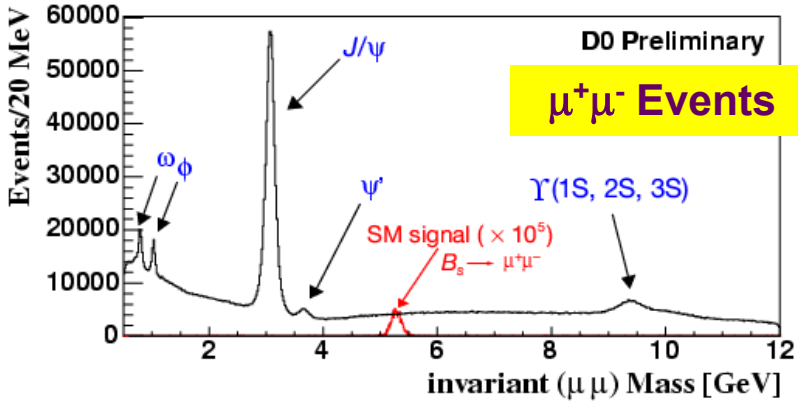
BF ~9.4×10^{-9}

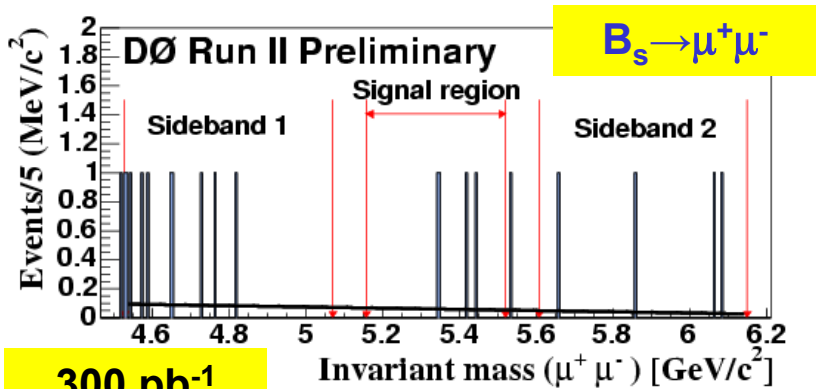
long distance

BF ~1.0×10^{-6}

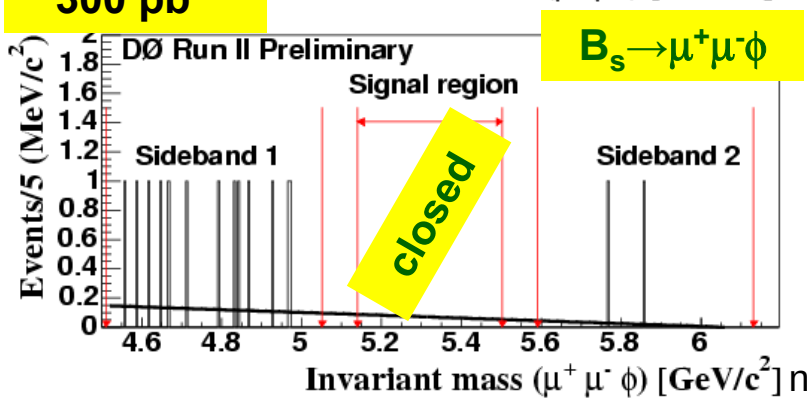
- SM BR ~ 1.0×10^{-6} (dominated by long distance)
- Enhanced in e.g. RPV SUSY
- FOCUS: BR < 8.8×10^{-6}

$B_s \rightarrow \mu^+\mu^-$ and $\mu^+\mu^-\phi$





300 pb^{-1}



Preselection

- vertexed $\mu^+\mu^-$
  $P_T^{\mu} > 2.5$ GeV, $|\eta| < 2.0$
- pair of opp chrg tracks (ϕ)
- $P_T^B > 5$ GeV

Final Selection Discriminants

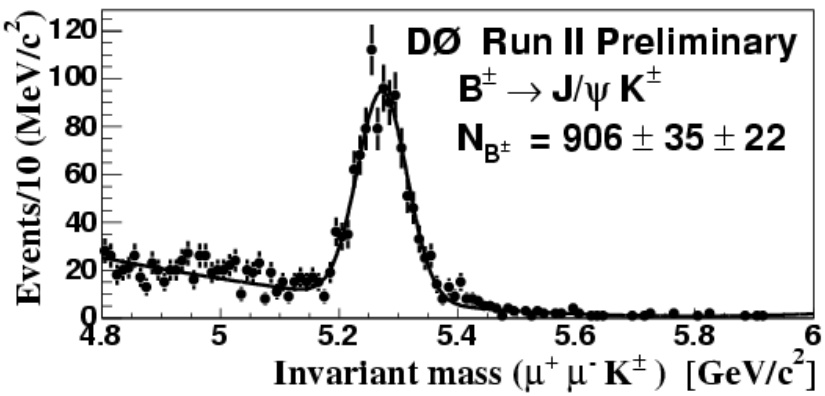
- Isolation of $\mu^+\mu^-(\phi)$
- Pointing Angle: $\alpha(L_{vtx}, P)$
- L_{xy} Signif: $L_{xy} / \delta L_{xy}$

Normalization Channels

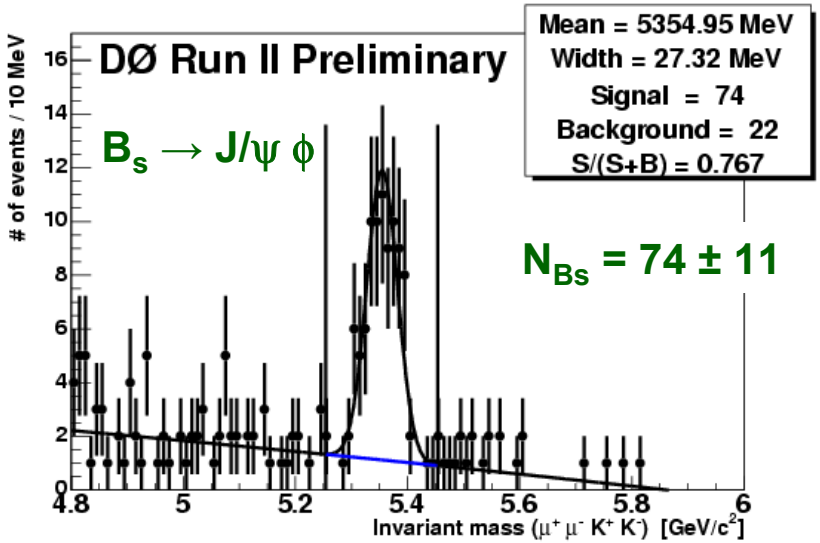
- $\mu^+\mu^-$ $\quad B^+ \rightarrow J/\psi\, K^+$
- $\mu^+\mu^-\,\phi$ $\quad B_s \rightarrow J/\psi\, \phi$

Limits

$B_s \rightarrow \mu^+ \mu^-$ Normalization



$B_s \rightarrow \mu^+ \mu^- \phi$ Normalization

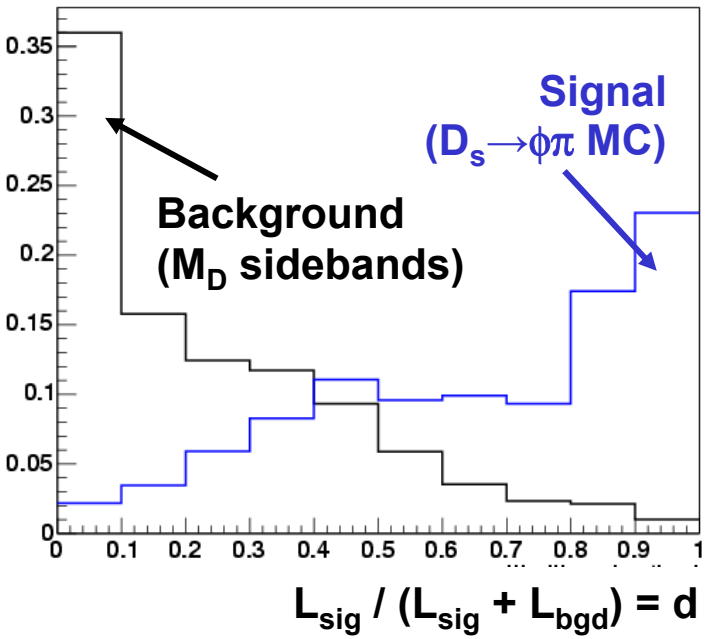


Channel	Eff wrt Pre-Sel	N(bgrd)	N(data)	BR Limit (95% CL)	SM Pred
$\mu^+ \mu^-$	38.6%	4.3 ± 1.2	4	3.7×10^{-7}	3.4×10^{-9}
$\mu^+ \mu^- \phi$	52%	5.1 ± 1.0	blind	1.2×10^{-5} (ave)	1.6×10^{-6}

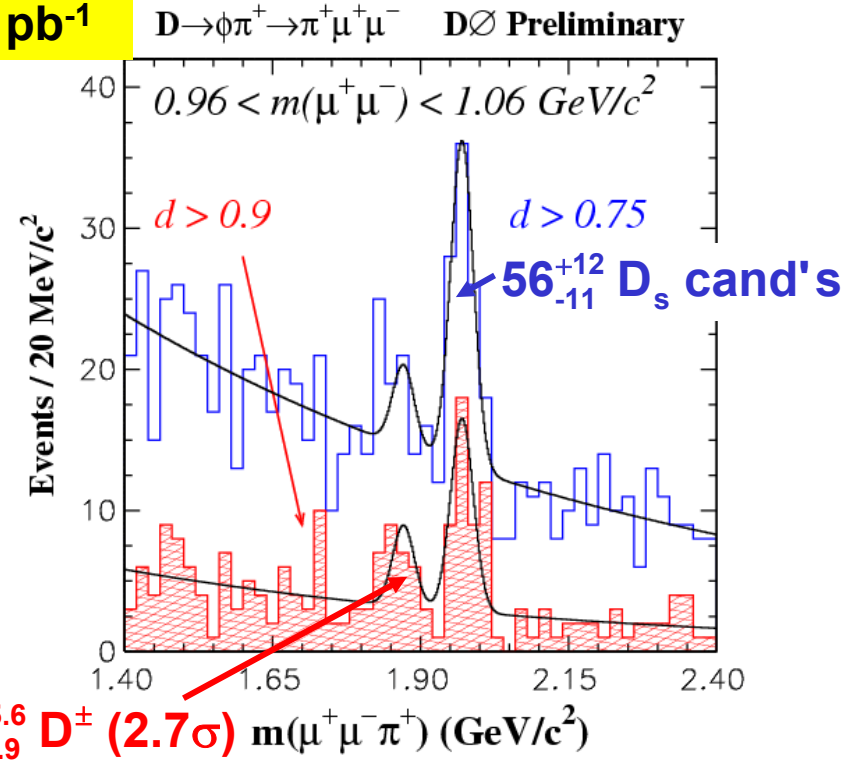
$D_s^+ \to \mu^+\mu^-\pi^+$ and $D^+ \to \mu^+\mu^-\pi^+$

Select $D_{(s)}$ Signal from $\phi(\mu^+\mu^-)\pi$ cand's w/ Likelihood

- D Isolation: $P_T(D)/\Sigma P_T(\text{cone})$
- L_{xy} Signif: $S_D = L_{xy}/\delta L_{xy}$
- Pointing Angle: $\alpha(L_{xy}, P_T)$
- Signif Ratio: $S_\pi(\text{imp-par})/S_D$



508 pb^{-1}



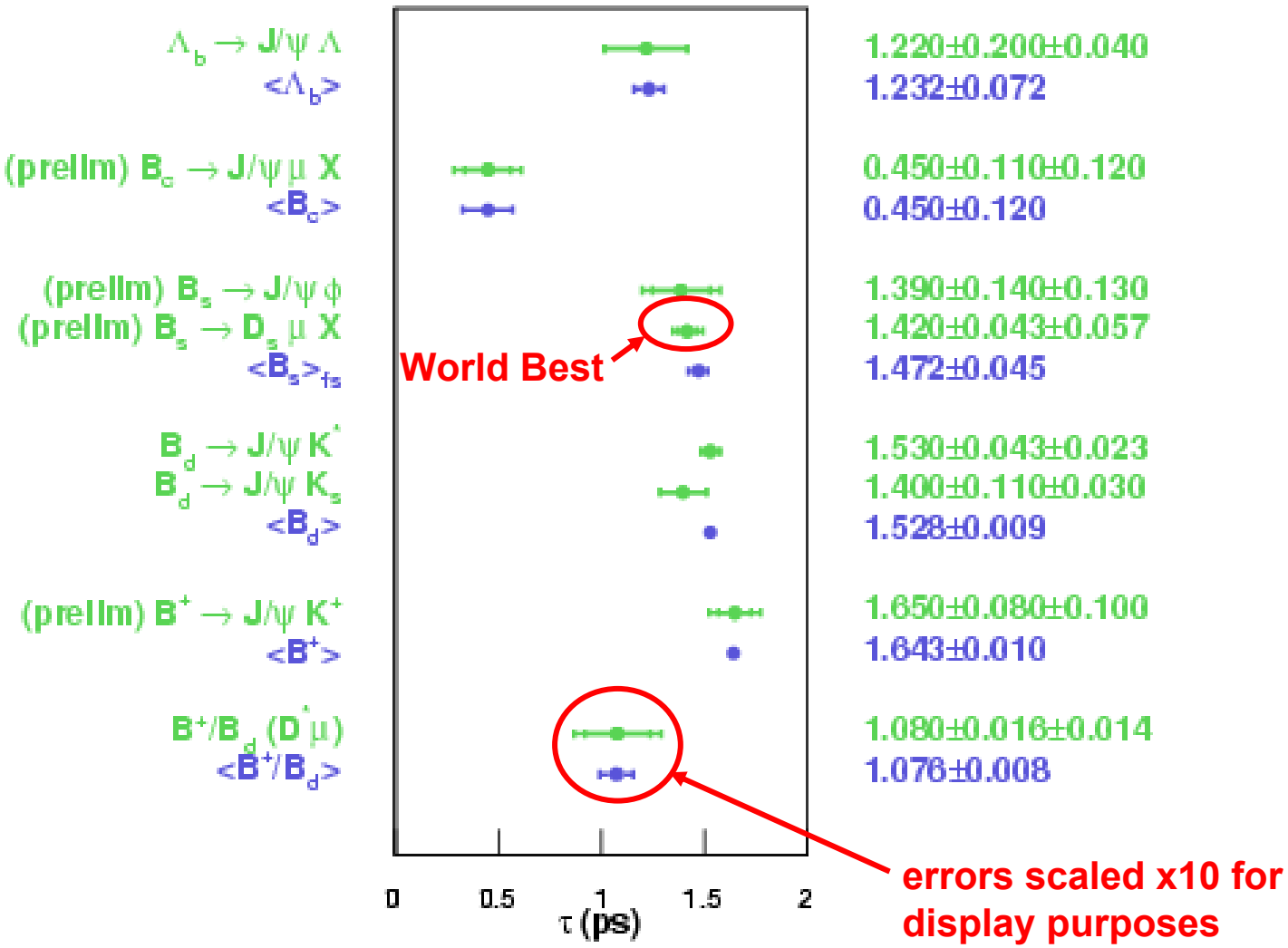
$$\frac{B(D^+ \to \phi(\mu^+\mu^-)\pi^+)}{B(D_s \to \phi(\mu^+\mu^-)\pi^+)} = 0.17\ ^{+0.08}_{-0.07}\ ^{+0.06}_{-0.07}$$

$$B(D^+ \to \phi(\mu^+\mu^-)\pi^+) < 3.1 \times 10^{-6}\ (90\%\ \text{CL})$$

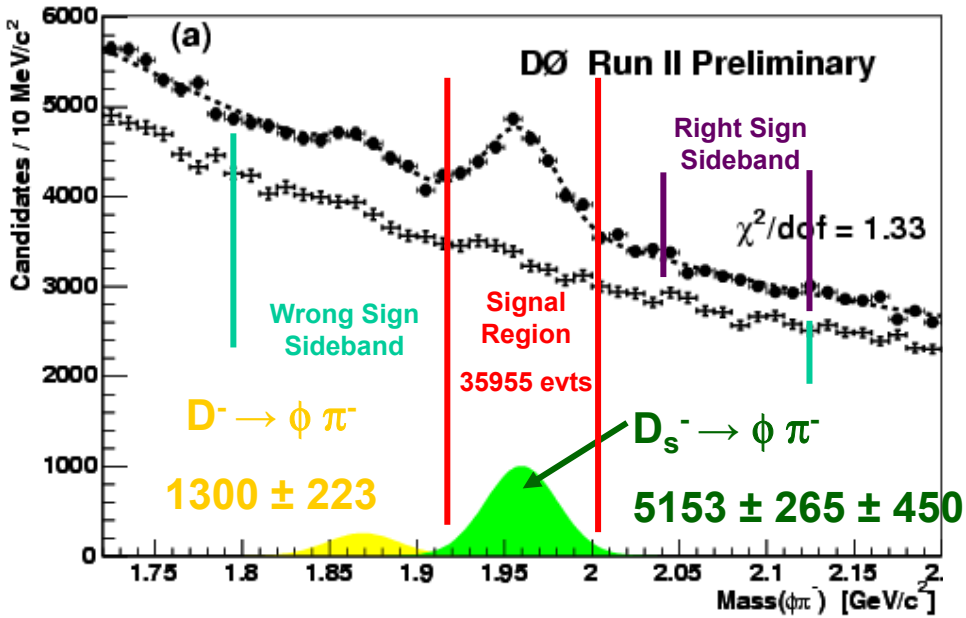
World Best Limit

Lifetime Roundup

DØ Lifetime Measurements vs HFAG World Averages

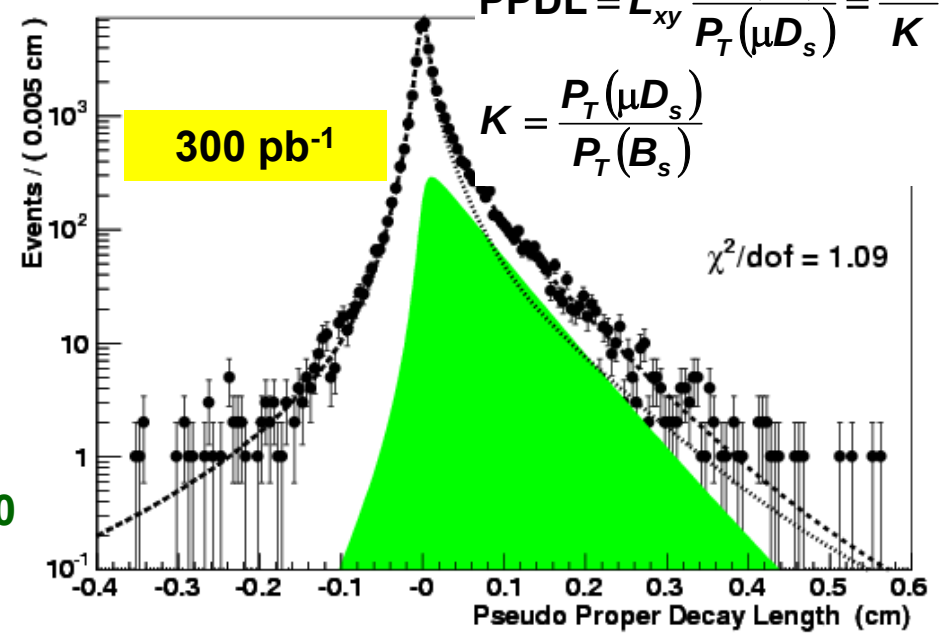


$B_s \rightarrow D_s \mu \nu X$ Lifetime



$$\text{PPDL} = L_{xy} \frac{M(B_s)}{P_T(\mu D_s)} = \frac{ct_0}{K}$$

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



$B_s \rightarrow D_s(\phi\pi) \mu \nu X$ Selection

- no lifetime biasing cuts

Unbinned logL Fit for τ using

- signal region
- wrong- & right-sign sidebands (to constrain bgrd PDFs)
- f(signal) from Mass fit

$\tau(Bs) = 1.420 \pm 0.043 \pm 0.057$ ps

World Best Measurement ! – HFAG ave now: 1.472 ± 0.045

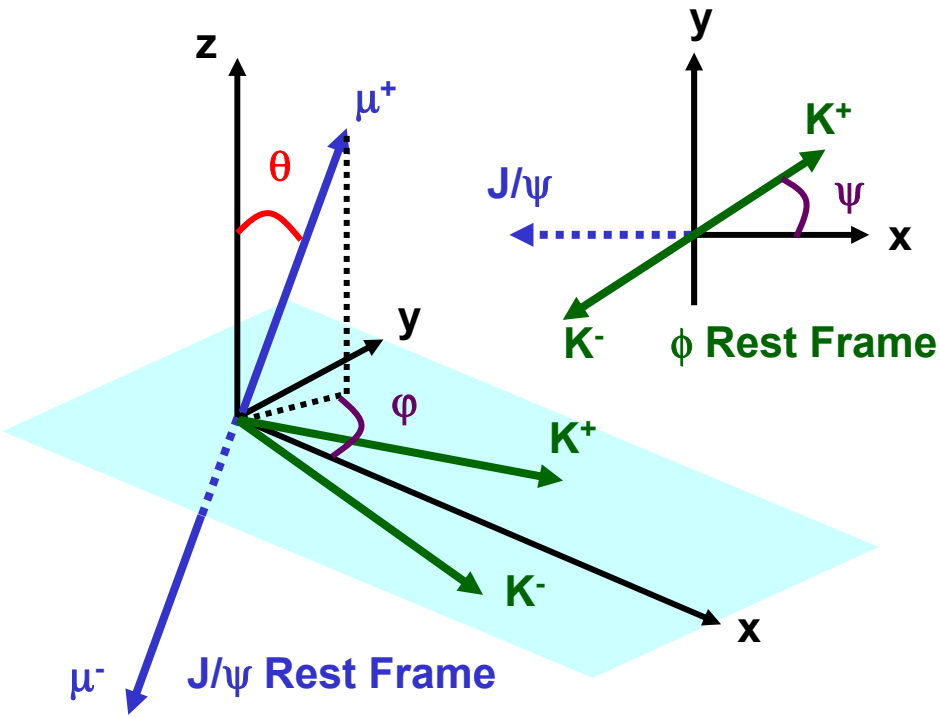
B_s Lifetime Difference

$B_s \rightarrow J/\psi\ \phi$ $(P \rightarrow V\ V)$

- CP-Even: S,D waves
- CP-Odd: P wave
- relative contributions
  $\Rightarrow$ CP states of B_s

Observed Distribution

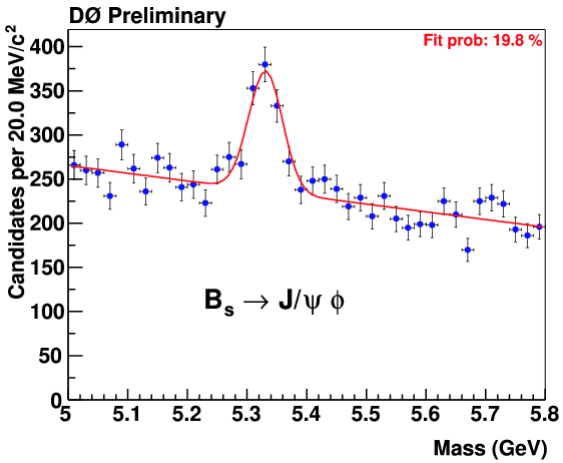
$$\frac{d^3\Gamma(t)}{d\cos\theta\, d\varphi\, d\cos\psi} = f\left(\cos\theta, \varphi, \cos\psi; \overbrace{|A_0(0)|^2, |A_{\parallel}(0)|^2}^{\text{CP-Even}}, \overset{\text{CP-Odd}}{|A_{\perp}(0)|^2}\right) \times \underbrace{G(\cos\theta)\, F(\varphi)\, H(\cos\psi)}_{\text{Detector effects}}$$

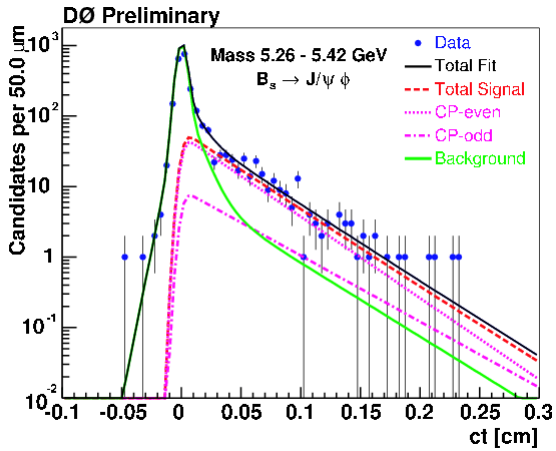


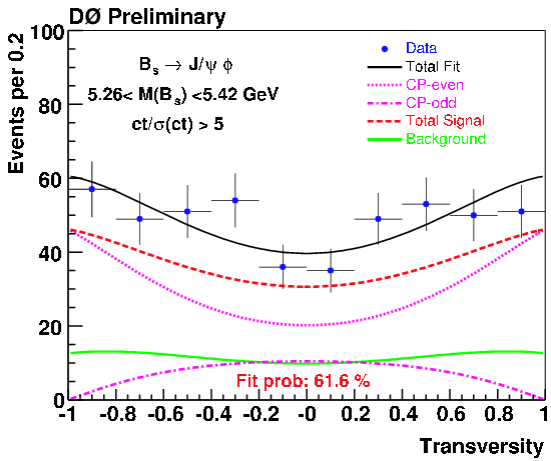
Transversity Angle Fit

- $\Rightarrow$ $\Delta\Gamma$ b/w M eigenstates
- $\Rightarrow$ $R_{\perp} = |A_{\perp}(0)|^2$

Fits to Data







Data Set: 450 pb^{-1}

- 9699 candidate events
- 483±32 $B_s \to J/\psi(\mu^+\mu^-)\ \phi(K^+K^-)$
- Fit to: $M(B_s)$, ct_0, $\cos\theta$
- Free params
  - f_{sig}, τ_{ave}, $R_\perp$, $\Delta\Gamma/\Gamma$, $M(B_s)$
  - + resolution & bgrd params

Fit Results

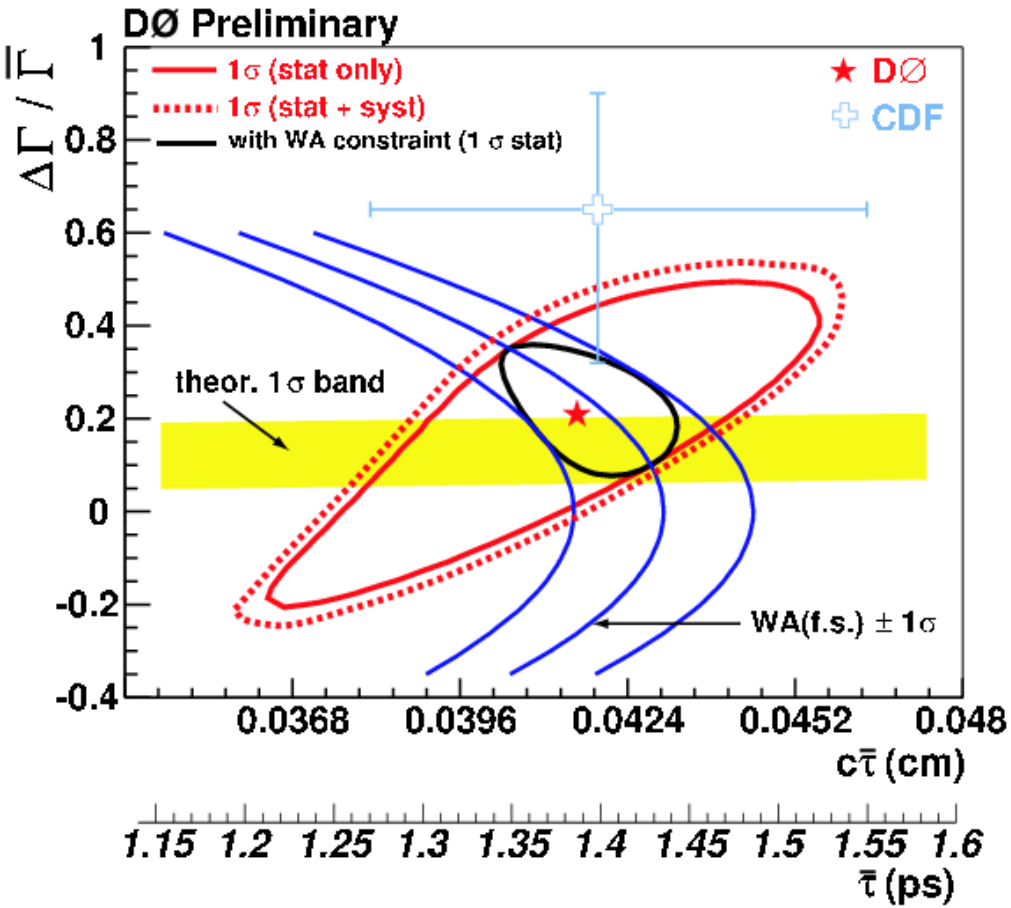
$$\bar{\tau}(B_s) = 1.39\ ^{+0.13}_{-0.14} \pm 0.08$$

$$\frac{\Delta\Gamma}{\bar{\Gamma}} = 0.21\ ^{+0.27}_{-0.40} \pm 0.20$$

$$R_\perp = 0.17 \pm 0.10 \pm 0.02$$

$$M(B_s) = 5.331 \pm 0.002_{stat}\ \text{GeV}$$

Comparing to the SM



Flavor Specific Decays also constrain $\Delta\Gamma/\Gamma$

$$\Gamma_{fs} \sim \overline{\Gamma} - \Delta\Gamma^2 / 2\overline{\Gamma}$$

Using PDG $\tau(B_s \rightarrow D_s l\nu X)$

$$\overline{\tau}(B_s) = 1.39\ ^{+0.05}_{-0.06}\ (\text{stat} + \text{syst})$$

$$\frac{\Delta\Gamma}{\overline{\Gamma}} = 0.23\ ^{+0.16}_{-0.17}\ (\text{stat} + \text{syst})$$

Assuming SM $\Rightarrow$ CPV $\delta\phi$

$$|\cos\delta\phi| = 1.46\ ^{+0.73}_{-0.69}$$

B_s Mixing Analysis

Data Selection

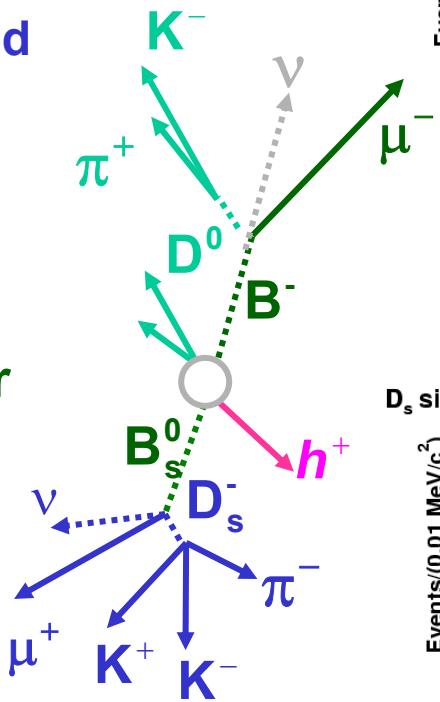
- $B_s \rightarrow D_s^- \mu^+ \nu X$
  $D_s^- \rightarrow \phi(K^+K^-)\pi^-$
- no explicit trigger required
- some τ-dependent cuts (effects ~cancel in Asym)

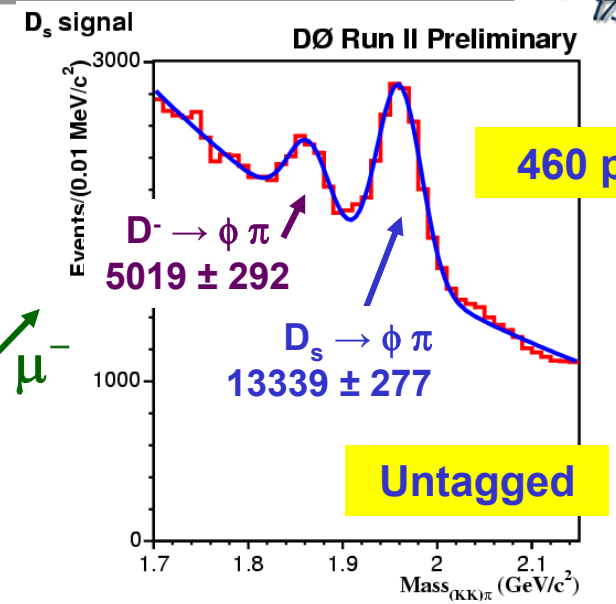
Opposite Side (Muon) Tagger

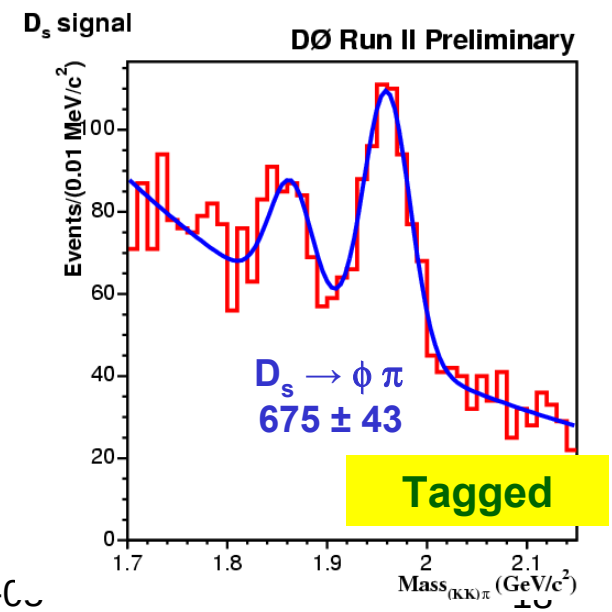
- Q(jet) containing muon
- $P_T^{rel} \times Q(\mu)$
- Q(secondary vertex)

Eff & Dilution from Data

- $\varepsilon = N_{tag}/N_{tot} = 5.1\%$
- $D = 2\eta - 1 \quad = 44.8\%$
  $(\eta = N_{correct}/N_{tag})$

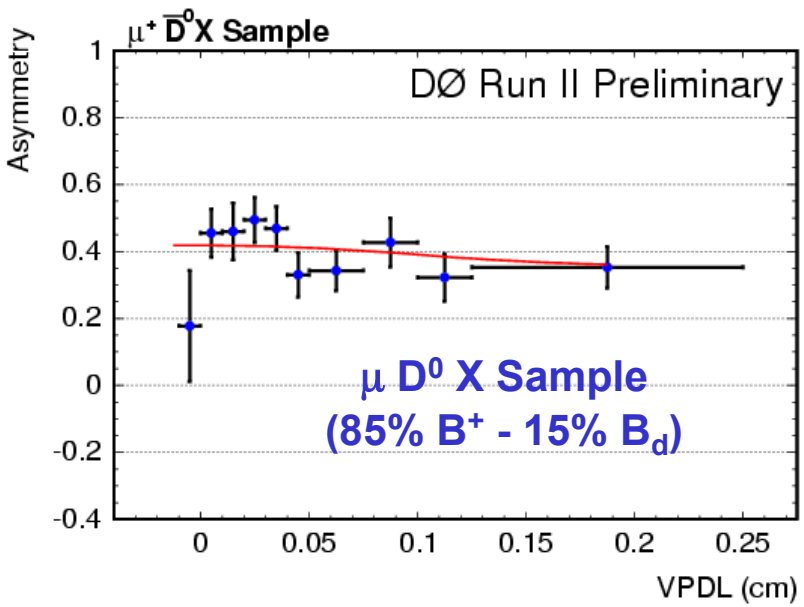


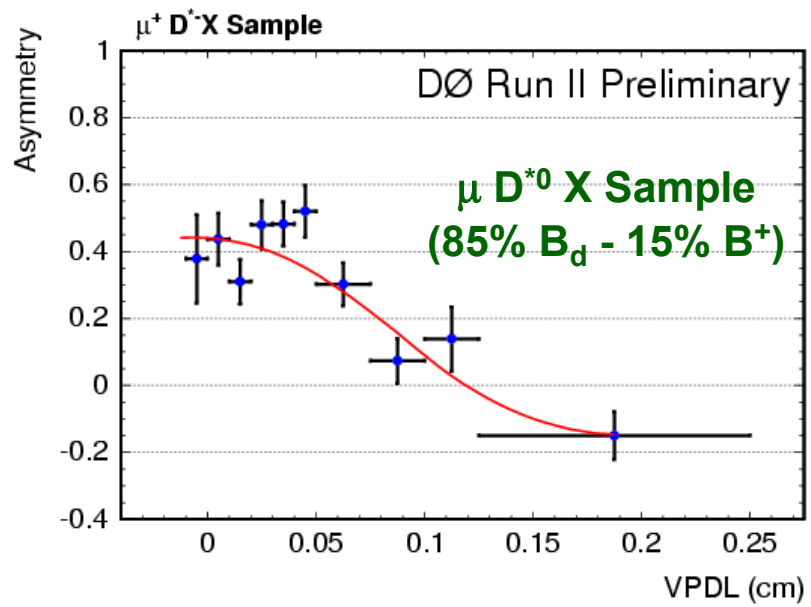




Measure Tagging using B_d and B^+

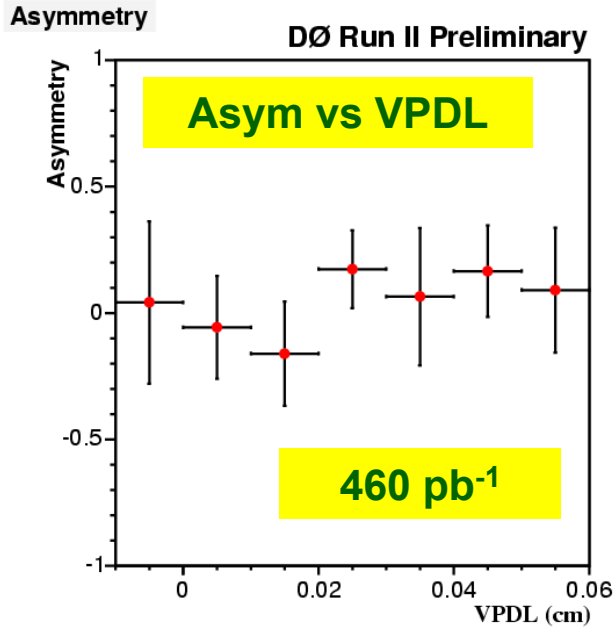
$$\text{Asymmetry} = \frac{N^{unmix} - N^{mix}}{N^{unmix} + N^{mix}} \propto \cos(\Delta m \cdot t)$$





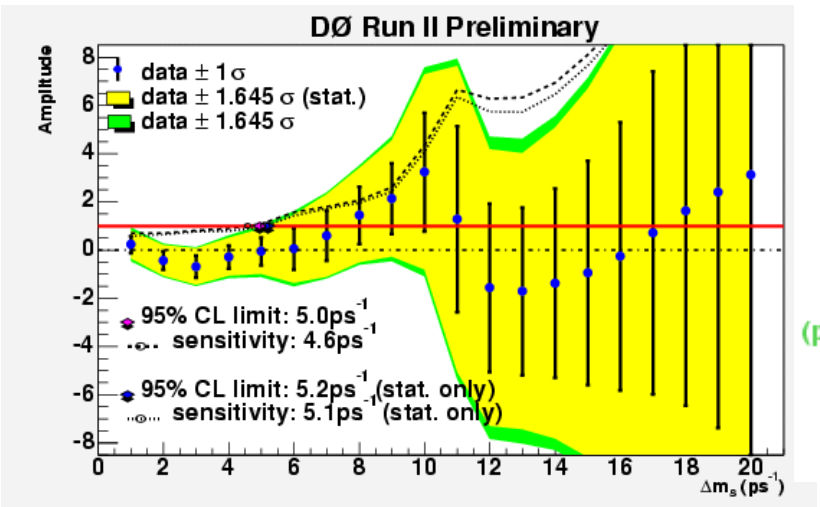
η_u	0.734 ± 0.015	
η_d	0.724 ± 0.021	use in B_s fits
Δm_d	0.558 ± 0.048 ps^{-1}	
(HFAG	0.509 ± 0.004 ps^{-1}	winter 05)

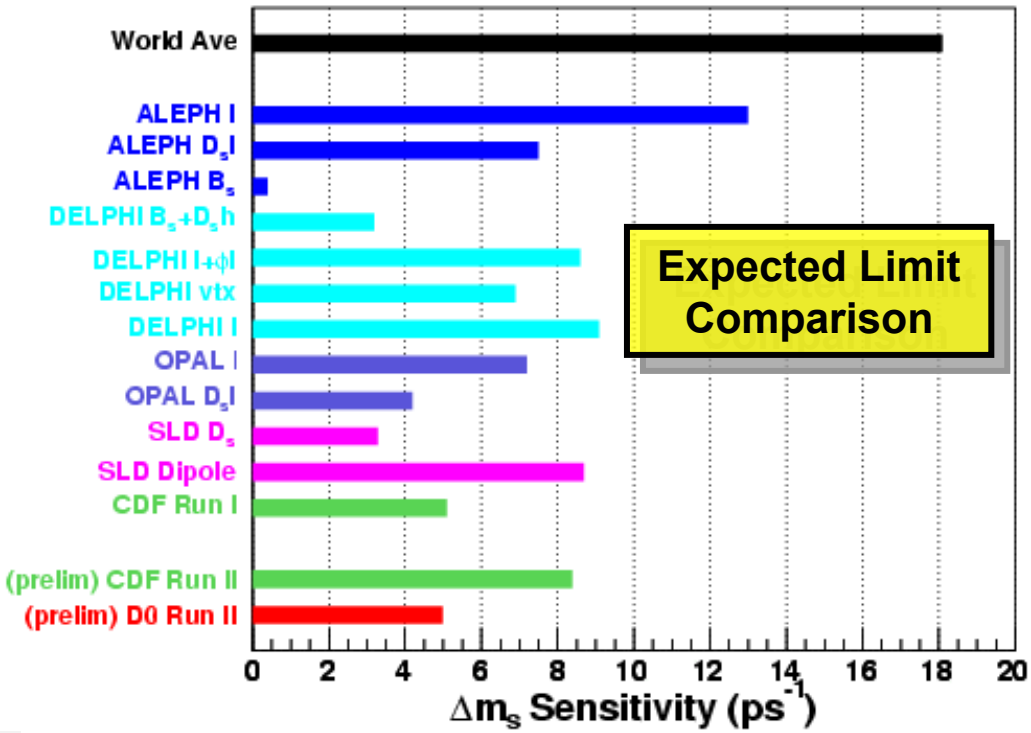
B_s Results



DØ Prelim Result

95% CL: $\Delta m_s > 5.0\ ps^{-1}$
sensitivity: $4.6\ ps^{-1}$

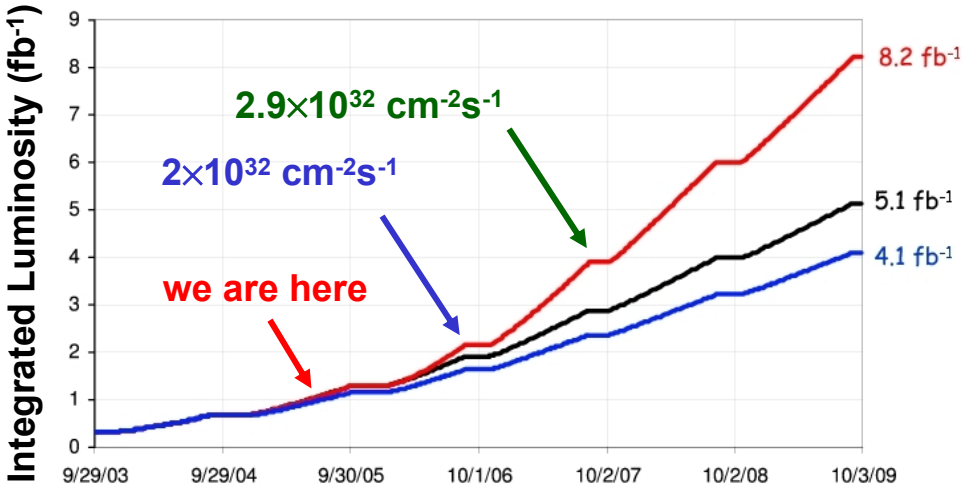




Expected Limit Comparison

DØ Upgrades for High Luminosity

www.fnal.gov/directorate/DOE_TeVOps05_Review.html



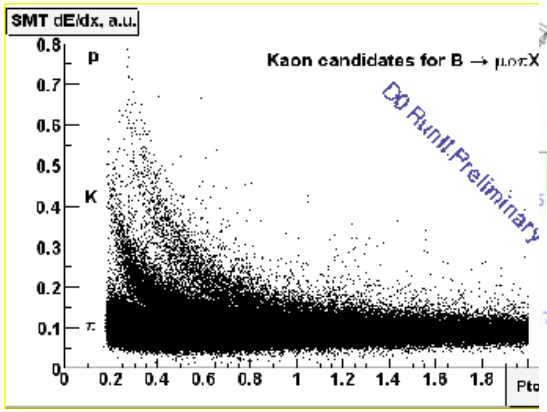
Trigger (mainly L1)

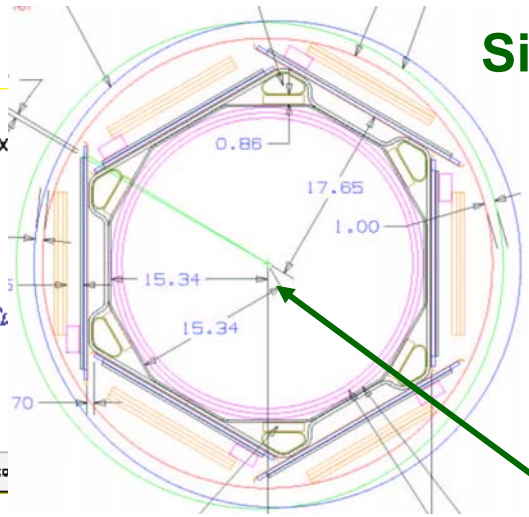
- allows viable trigger list as $L > 2\times10^{32}$

L3 Bandwidth Upgrade

- current limit for B-Physics triggers is at L3
- proposal: add dedicated 50 Hz of output bandwidth

dE/dx using SMT





Silicon Layer-0

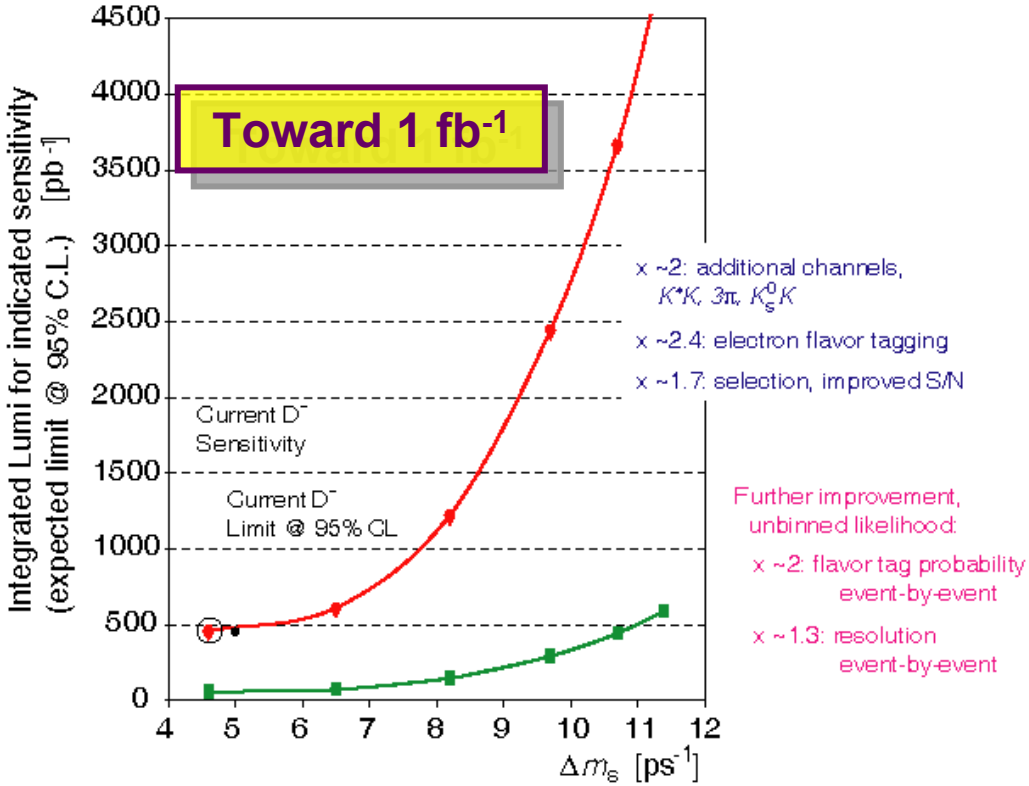
- integrated radiation dose ⇒ inner SMT layer dies
- add new, rad hard Layer-0 at R = 1.7 cm
- Impact Param: 55→35 μm at 1 GeV

~golf ball size !

Reach in B_s Mixing

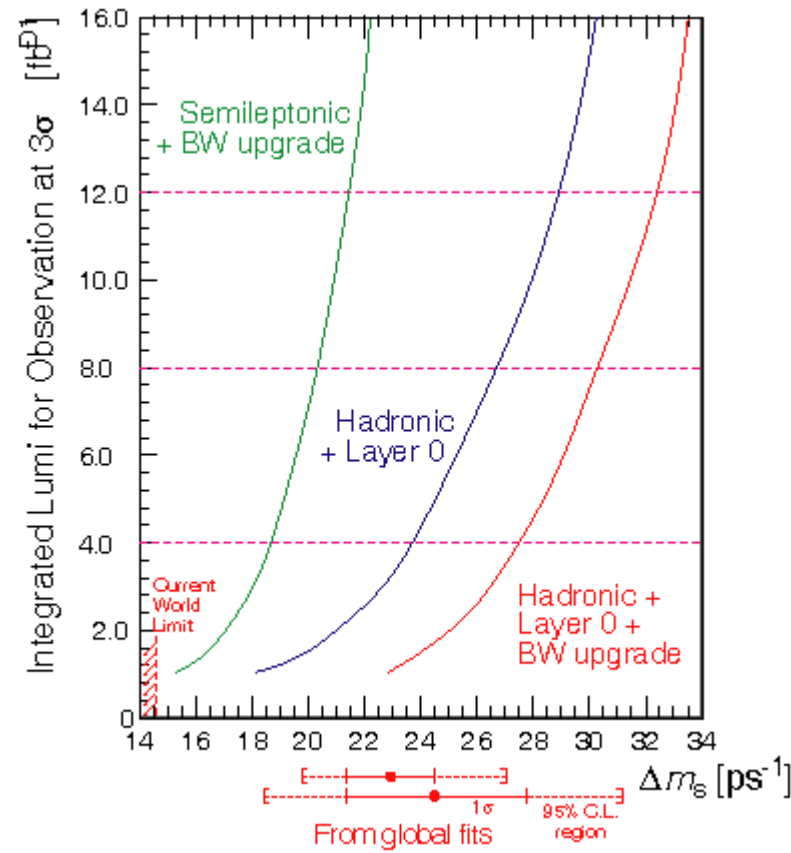
In Review Now (for EPS 05)

- add K^*K mode
- improved tagging (add electrons + more var's)



semileptonic sens ~ 12 ps^{-1} with 1 fb^{-1}s

Further Down the Road

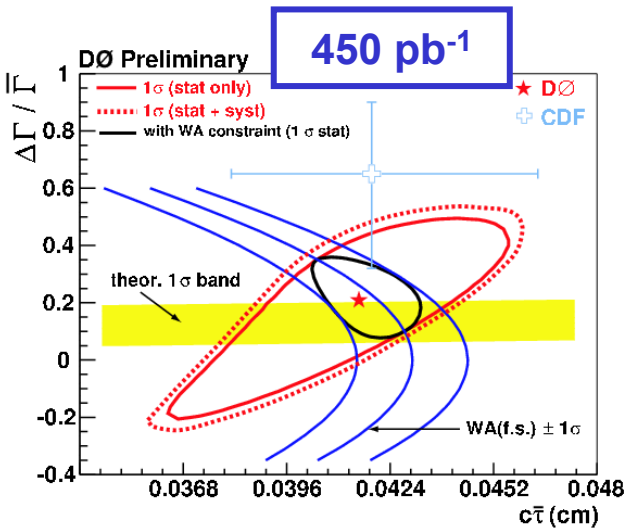


cover ~full SM range (but need to establish hadronic modes)

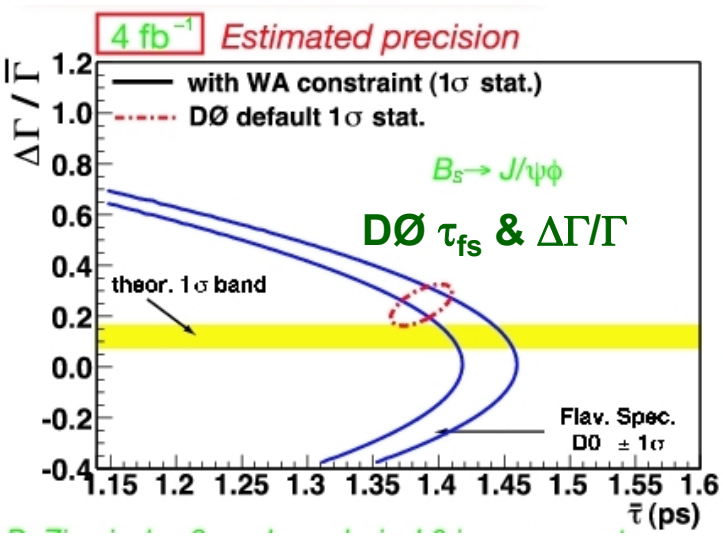
Lifetime Futures

B_s Lifetime Projections				
Mode	Lumi (fb^{-1})	Stat (ps)	Syst (ps)	Tot (ps)
$D_s \mu X$	0.4	0.043	0.057	0.071
	4.0	0.013	0.03	0.034
$D_s \pi$	4.0	0.04	0.01	0.04

reduction coming soon



$\Delta\Gamma/\Gamma$ Projections	
Lumi (fb^{-1})	Error on $\Delta\Gamma/\Gamma$
0.45	0.45
2	0.12
4	0.08
8	0.06
Theory	0.12 ± 0.05



Assumes:

- **Layer-0 + 3-angle Fit for $\Delta\Gamma/\Gamma$**

More Crystal Ball Gazing

Most DØ B-Physics Results are Statistics Limited

Rare Decays

- reoptimize selections, F-B Asym's, $K_S\mu^+\mu^-$, $K^*\mu^+\mu^-$, …
- broaden charm FCNC analysis

$\Delta\Gamma/\Gamma$

- 3-angle fits, Separate Lifetimes for CP-state ($\phi\phi$, $D_s^{(*)}D_s^{(*)}$)
- Integrated CP asym in semileptonic, β_s, …

B_s Mixing

- more modes: K^*K,3π,K_sK + $B_s \rightarrow D_s\,\pi$
- better tagging: *electrons, more variables*
- event-by-event likelihood fits

(some) Others

- B^{**}, D^{**}, D_{s1}: move from observation → measure properties
- J/ψ & Υ Polarization and b cross-section
- B_c semileptonic and hadronic decays
- make more use of neutral particles (γ, π^0, $\chi_c \rightarrow J/\psi\,\gamma$ …)
- more decay modes

Conclusions (Beginnings ?)

DØ Physics Program is Hitting its Stride

- detector well-suited to many measurements

Several World Best Results

- $D^+ \rightarrow \mu^+ \mu^- \pi^+$; B_s Lifetime

Interesting New Results Just Around the Corner

- improved Δm_s, rare decays, … for EPS 05

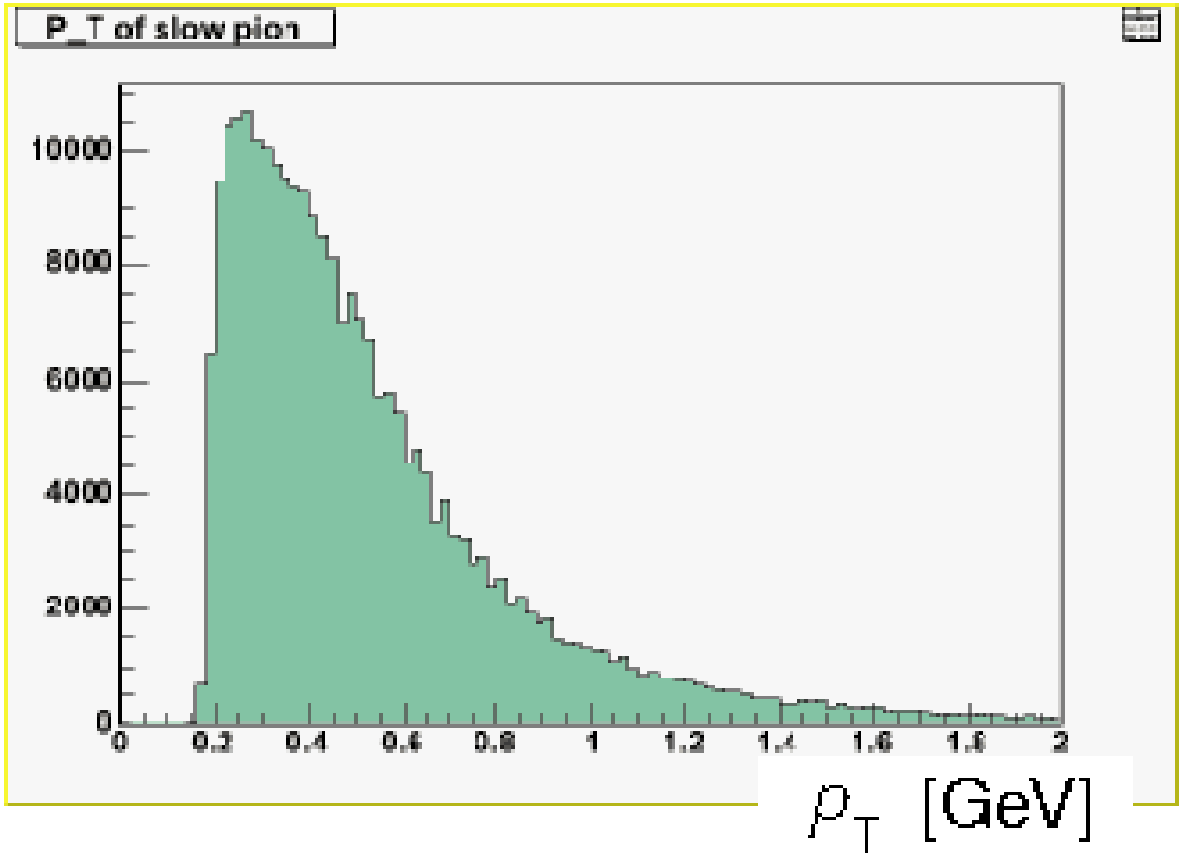
DØ Upgrades for High Lumi $\Rightarrow$ Improve Performance

- trigger, layer-0, L3 bandwidth upgrade

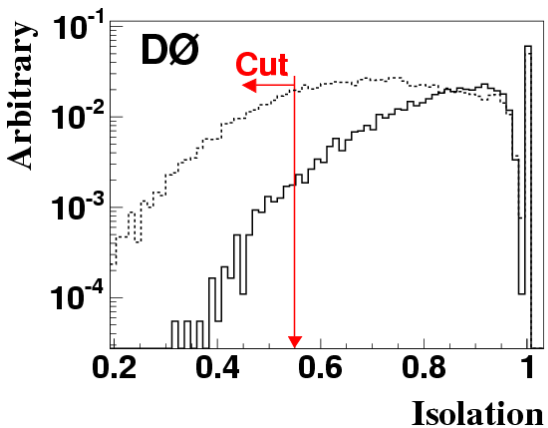
Stay Tuned !

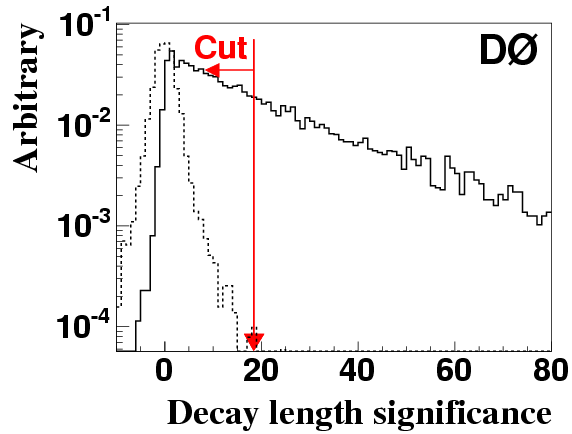
Backup Slides

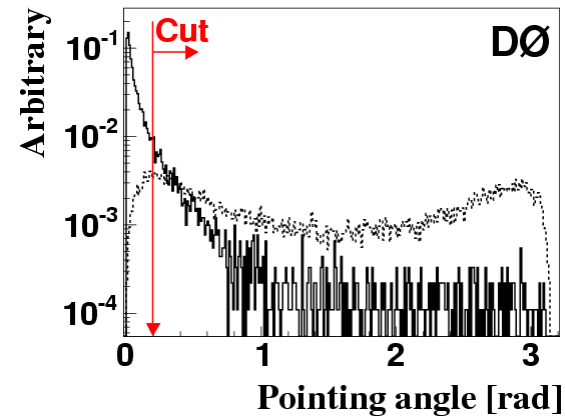
Low P_T Tracking



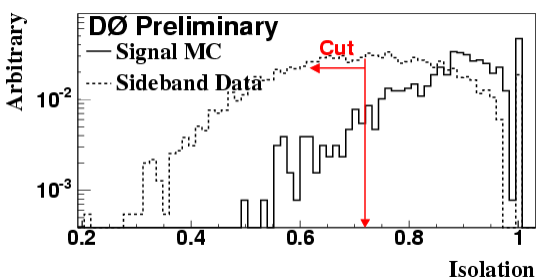
$B \rightarrow \mu^+ \mu^- (\phi)$ Final Discriminants

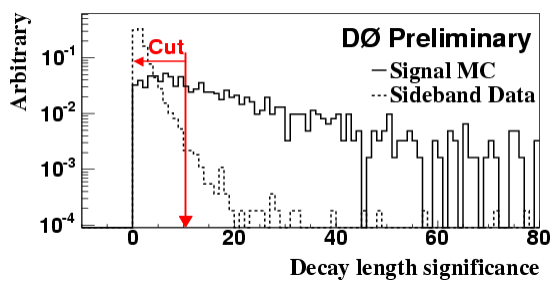


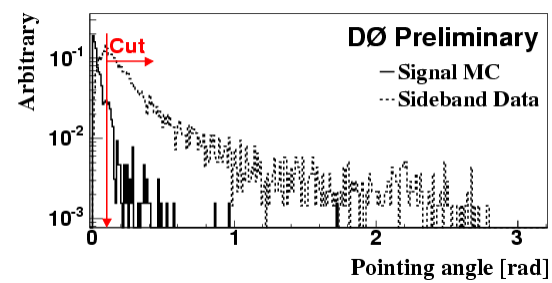


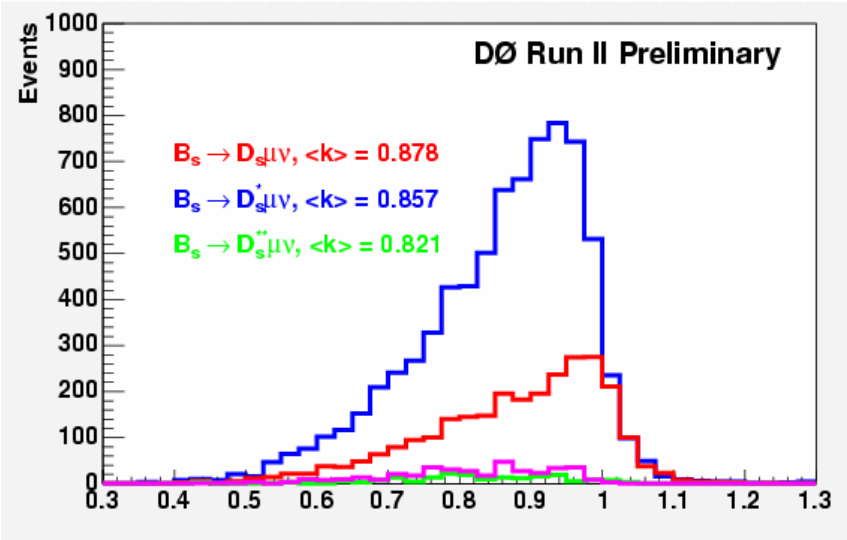
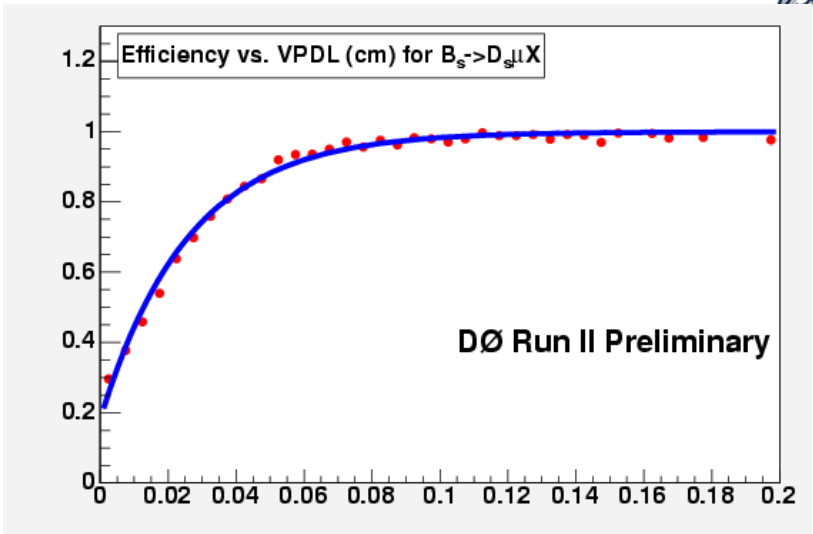
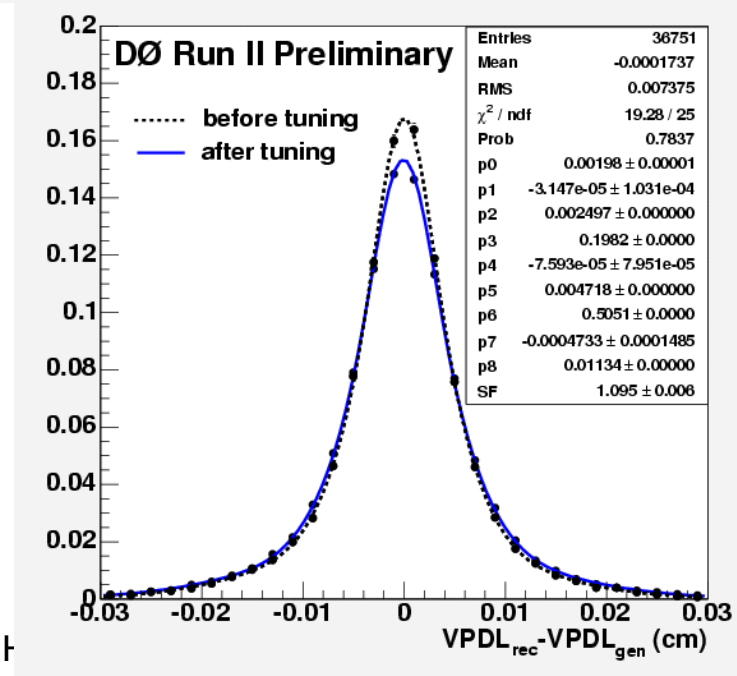
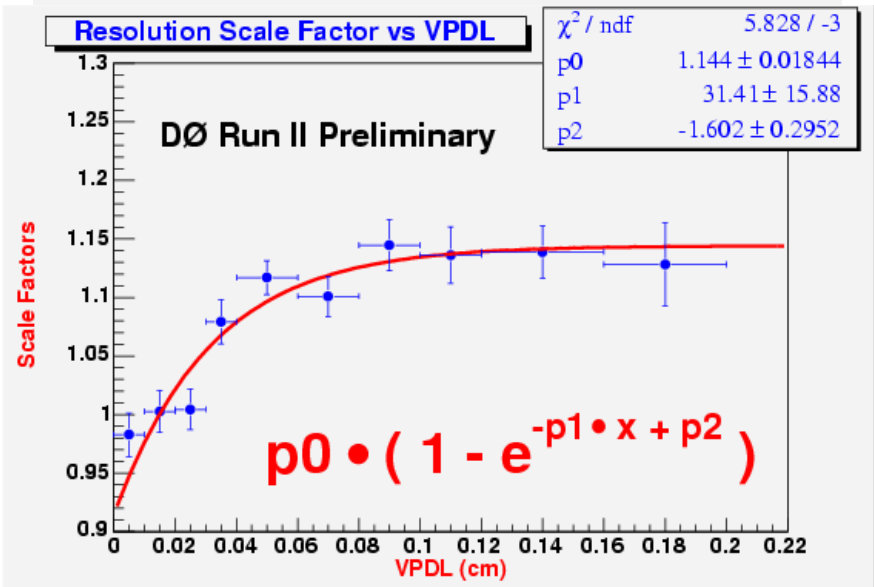


$B_s \rightarrow \mu^+ \mu^-$







$B_s \rightarrow \mu^+ \mu^- \phi$

B_s Mixing Details