B Tagging and Mixing at Tevatron

(Focusing on Bs mixing prospect)

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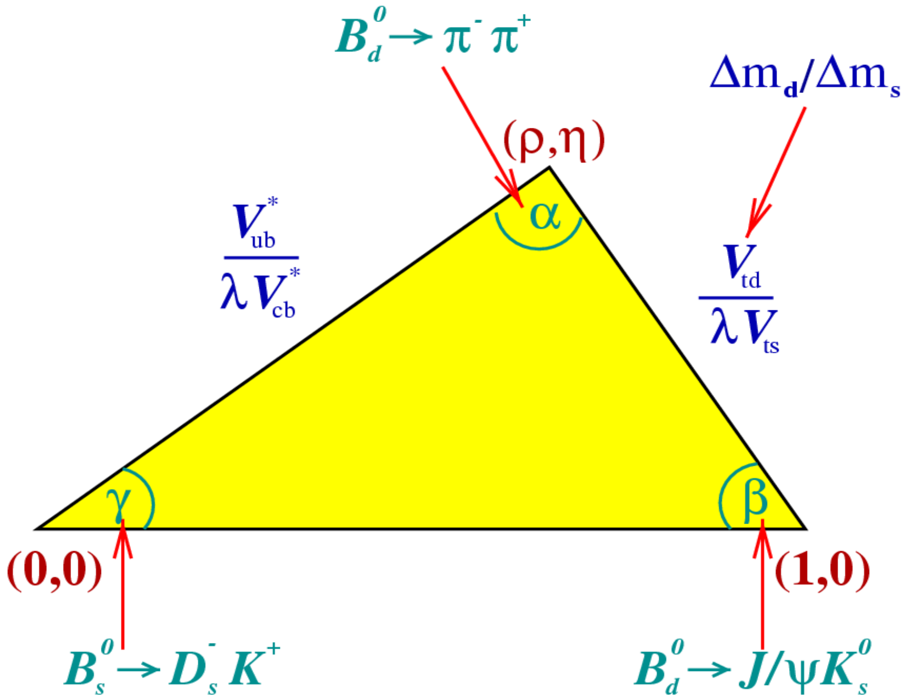
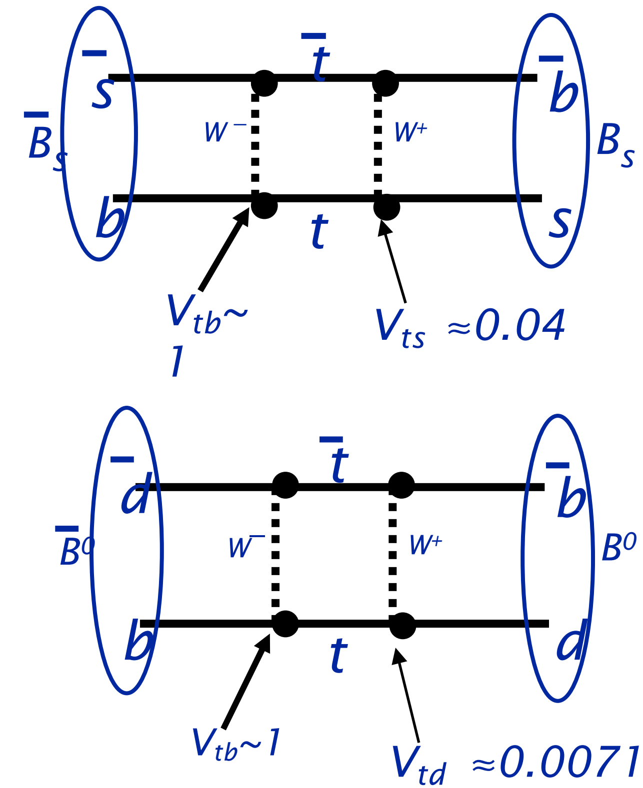
- Key issues for B mixing analyses
- Current flavor tagging and Bs yield results
- Prospect in the next few years

B mixing and CKM matrixes

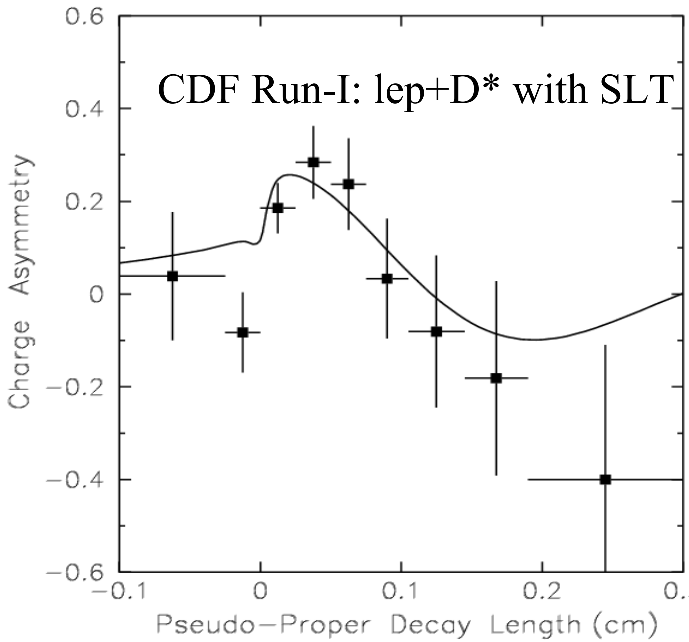
- $\Delta m_s/\Delta m_d = (M_{Bs}/M_{B0})\ \xi\ |V_{ts}/V_{td}|^2$
- Exploring one side of CKM triangle





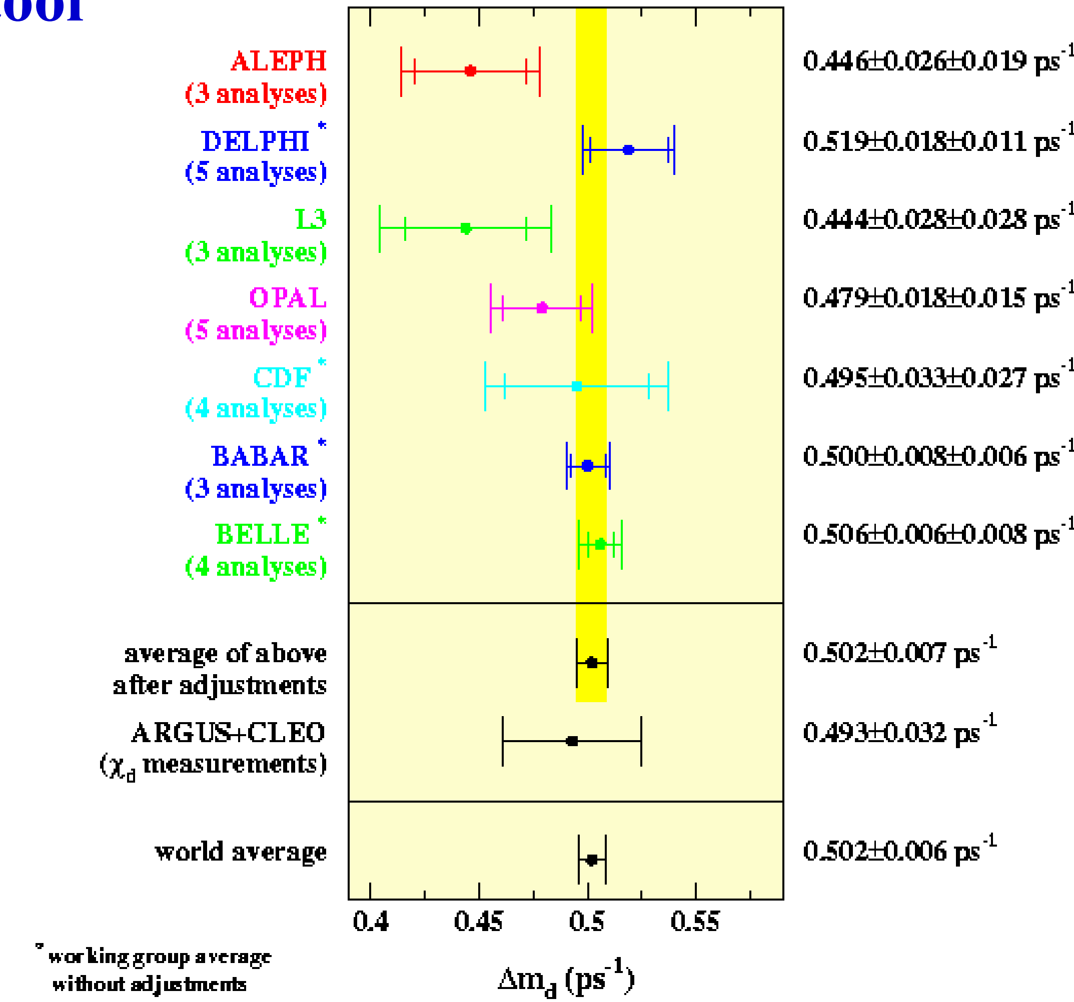
B^0 mixing

Δm_d is well measured and serves
CDF/D0 as nice calibration tool



$\Delta m_d = 0.512 \pm 0.09 \pm 0.04\ ps^{-1}$

$\Delta m_d = 0.502 \pm 0.006 ps^{-1}$ (HFAG 2003)



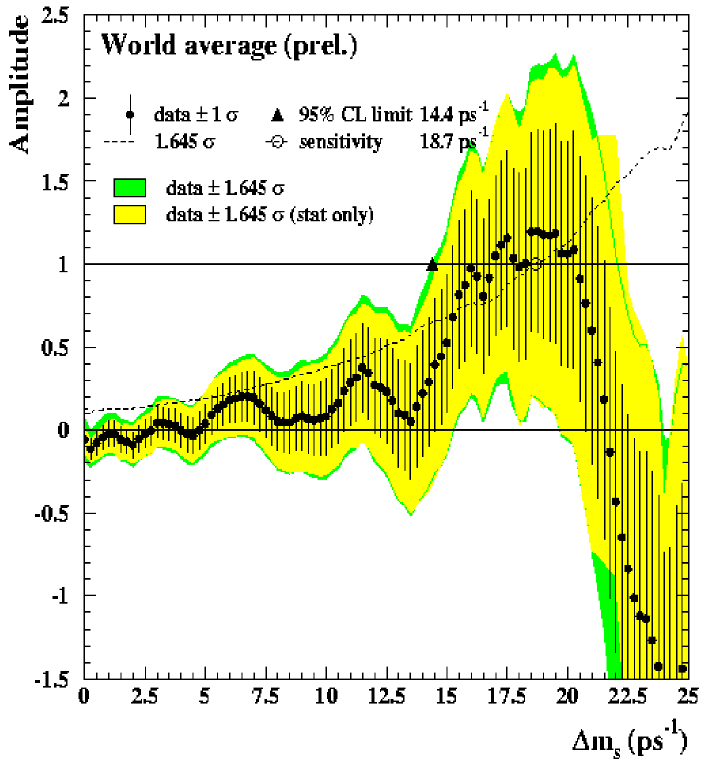
Bs mixing

- B_s mixing is the top priority for B physics at Tevatron
- A challenging measurement due to the rapid oscillation

  Δms>14.4 ps^{-1}@ 90% CL (HFAG 03)

  4 oscillations per lifetime cycle

- Unique Tevatron opportunity

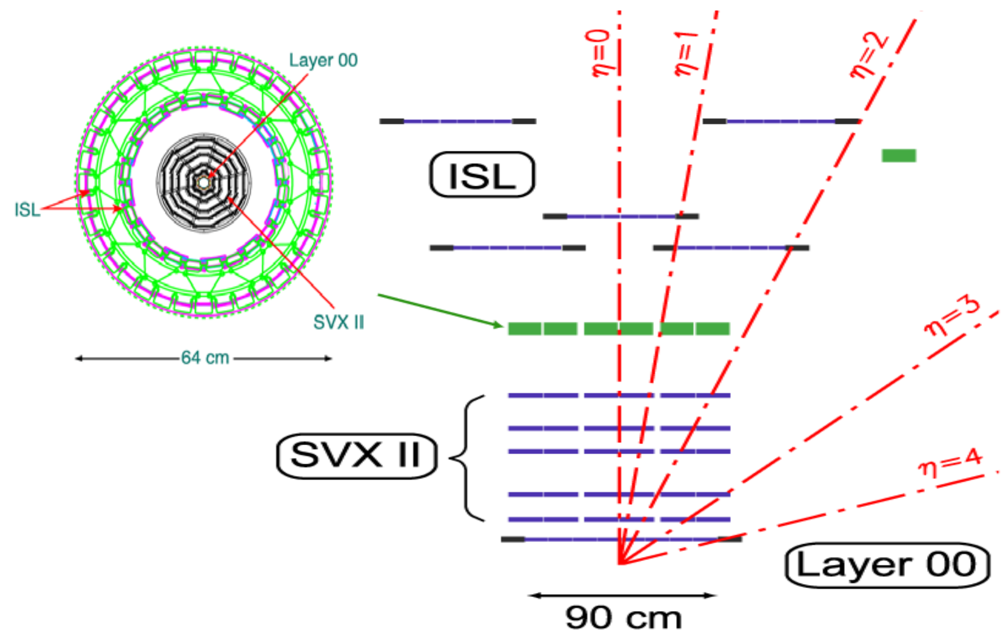


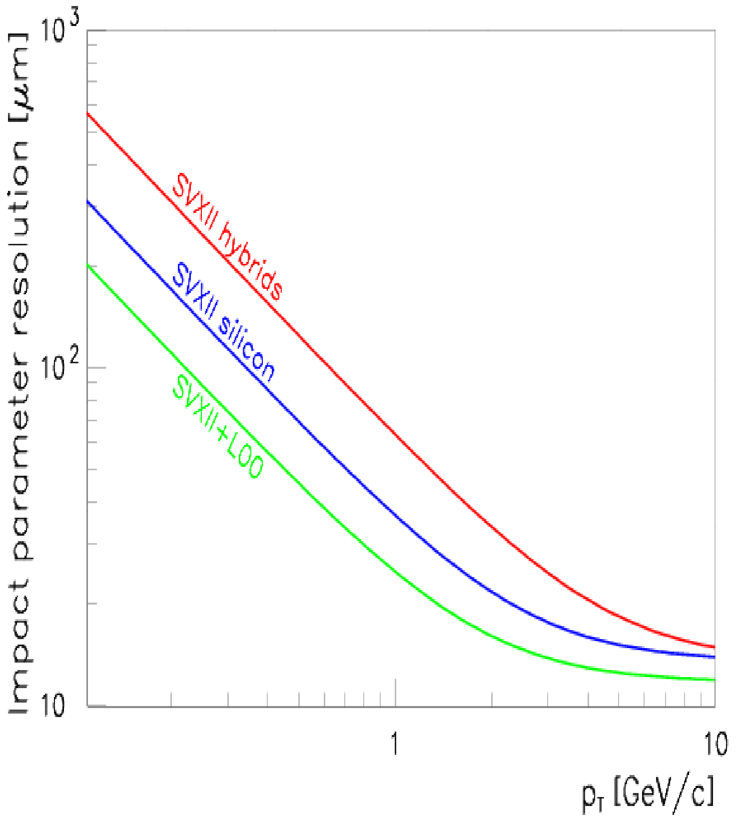
Combined limits of indirect measurements using amplitude methods from LEP, SLD & CDF Run I

Key issues for Bs mixing

- **High statistics with good signal-to-background ratio**
  - Efficient triggering and fine mass resolution
  - Trigger on high pT leptons and displaced tracks (SVT/STT)
- **Efficient Initial B flavor identification**
  - Only 20-40% chance for both B in the detector acceptance
  - e/μ coverage (SLT), tracking (JetQ/SST) and PID (Kaon)
- **Excellent proper decay length**
  - Momentum and vertex resolution
  - Utilize the fully reconstructed decays

CDF Silicon Detector





- 8 layers with improved 3D ability
- L00 improves impact parameter resolution by 30-50%
- ISL extends tracking coverage for e/μ systems to |η|=2

CDF Silicon Vertex Trigger at Level-2

First Run II paper!

- **Trigger on displaced tracks from b**

  L1 track + Si hits = L2 SVT

- **Excellent L2 impact parameter resolution**

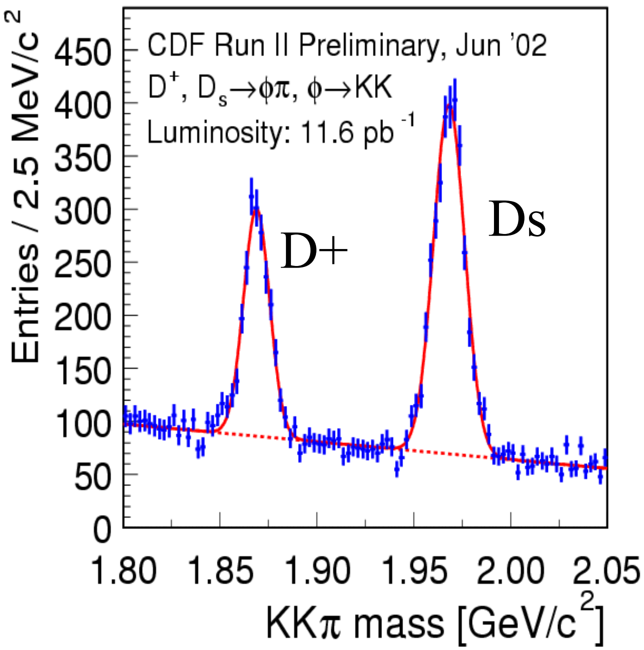
σ = 35μm ⊕ 33 μm (resol⊕ beam) = 48 μm

- **2-track trigger for $B_s \rightarrow D_s\,\pi$ etc.**

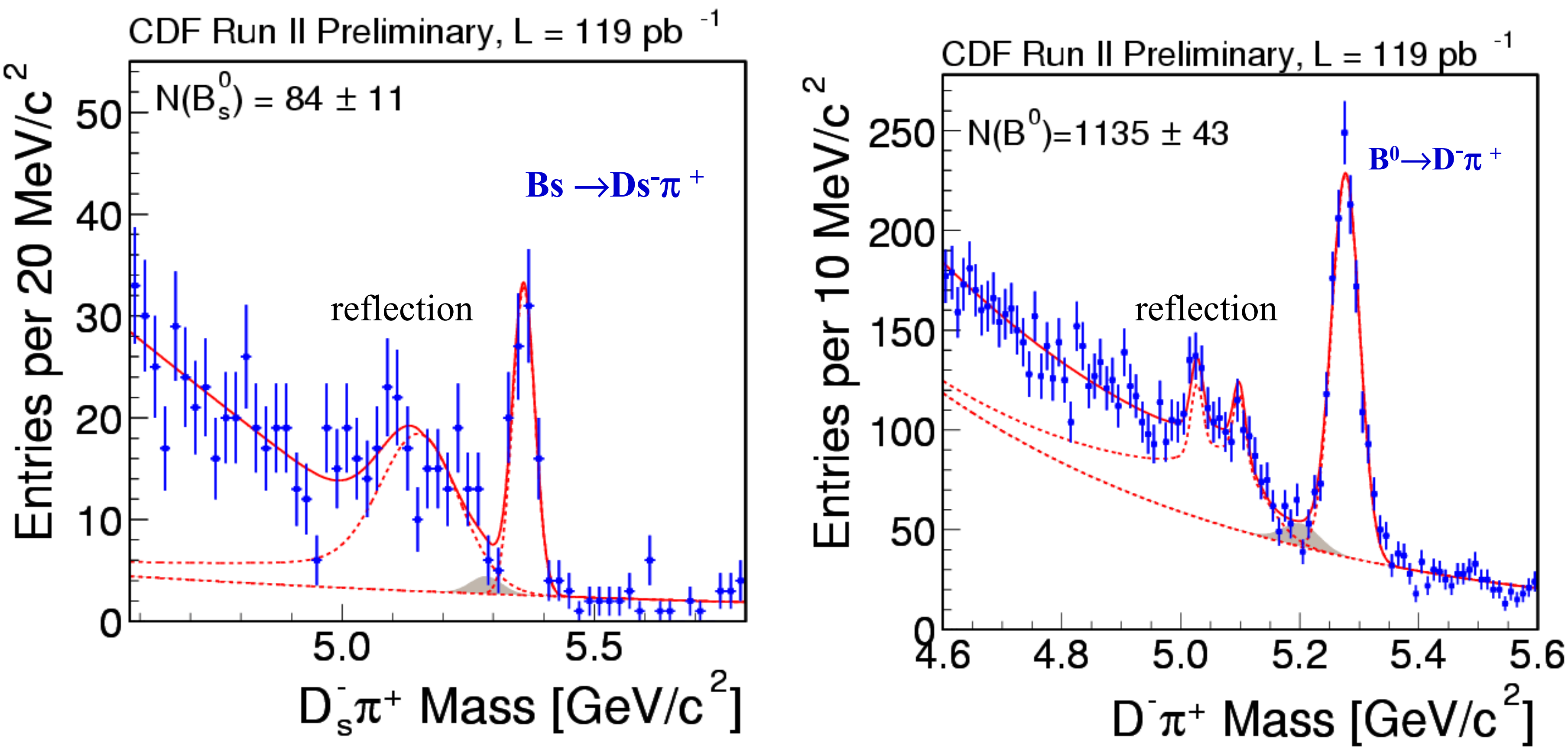
  Tracks: p_T>2 GeV, d_0>120 μm

- **e/μ + displaced track trigger**

  pT (e/μ)>4 GeV with pT (track)>2 GeV, d_0>120 μm



Bs→Ds π reconstruction



- **700 event per fb^{-1} of *$Bs \to Ds\pi$ with $Ds \to \phi\pi$, $\phi \to K^+K^-$***
- **$Br(Bs \to Ds^-\pi^+)/Br(B^0 \to D^-\pi^+)=1.4 \pm 0.2(stat) \pm 0.2(syst) \pm 0.4\ (Br) \pm 0.2(PR)$**

$B_s \rightarrow D_s \pi$ yield (CDF)

- **Results so far are using early CDF data**
- **Detector coverage and SVT efficiency improved since**
  - SVX-II coverage (now ~90%)
  - SVT hits requirement optimization (4/4 →4/5)
  - Better use of L2 trigger bandwidth (dynamic pre-scales)
- **We are seeing a factor of 2 increase on Bs yield**
- **Current condition produces Bs at a rate 1600/fb^{-1}**
- **Not count additional Bs/Ds channels yet**
  - $B_s \rightarrow D_s \text{-} \pi^+ \pi^- \pi^+$ / $D_s \rightarrow K^*K$, KsK

Proper time resolution (CDF)

- $\sigma_t = (\sigma_{Lxy}/\beta\gamma) \oplus (\sigma_{pT}/pT)\cdot t$
  - Proper time $t = Lxy / \beta\gamma$, $\beta\gamma = m/pT$
- σ_{Lxy} dominates for fully reconstructed events
- $\sigma_{pT}/pT = 15\%$ for semileptonic decay
- From $Bs \to Ds\pi$ sample $\sigma_{Lxy} \approx 50\mu m$ with run-averaged beam line and without using L00 hits
  - $\sigma_{lxy} \approx 40 \oplus 30\mu m$ (SVX $\oplus$ beam)
- $\sigma_t = 0.067ps$ now for $Bs \to Ds\,\pi$
- $\sigma_t = 0.050ps$ achievable (L00+event-by-event beam line)

Initial B flavor tagging at CDF/D0

- **Soft lepton tagging (SLT)**
  - Semileptonic decay from the 2^{nd} B
  - High purity and lepton can be part of a trigger
- **Jet Charge Tagging (JetQ)**
  - Correlation of b-flavor and charge of a b-jet
  - High efficiency but Low purity
- **Opposite-side Kaon Tagging (OKT)**
  - $N(B^0/B+\rightarrow K^+)/ N(B^0/B+\rightarrow K^-)\approx 5$ due to the $b\rightarrow c\rightarrow s$
  - Need PID for tagging purity

Flavor tagging at CDF/D0

- **Same Side Tagging (SST)**
  - (π^- B+, π^+ B^0, K^+ Bs) correlations from b fragmentation or from B** decays
  - No need for 2nd B in the acceptance
  - High efficiency and reasonable purity
  - PID will enhance purity

- **εD^2 = effective tagging efficiency**
  - $\varepsilon = N_{tag}/N_{total}$ (efficiency of finding a tagger)
  - $D = (N_R - N_W)/N_{tag}$ (ability for a right decision)

Flavor tagging results from D0

- **Tested on $B^+ \to J/\Psi K^+$ events**

D0 preliminary

SST: $\varepsilon D^2 = (5.5 \pm 2.0)\%$

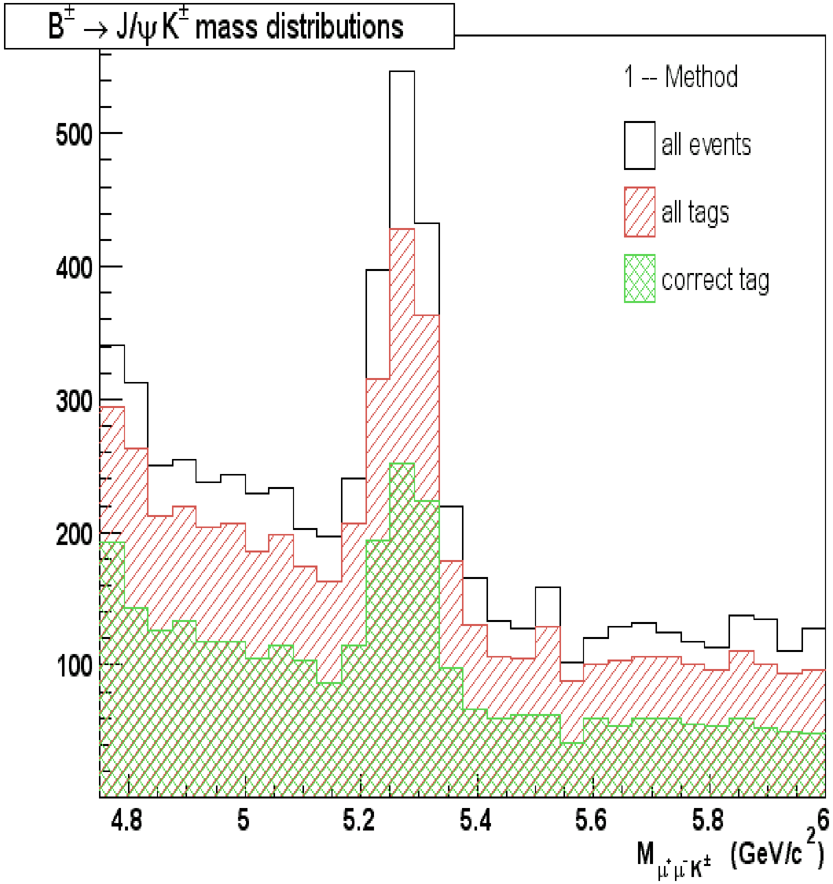
($\varepsilon = 79.2 \pm 2.1\%$ and $D = 26.4 \pm 4.8\%$)

Muon: $\varepsilon D^2 = (1.6 \pm 1.1)\%$

($\varepsilon = 5.0 \pm 0.5\%$ and $D = 57.0 \pm 19.3\%$)

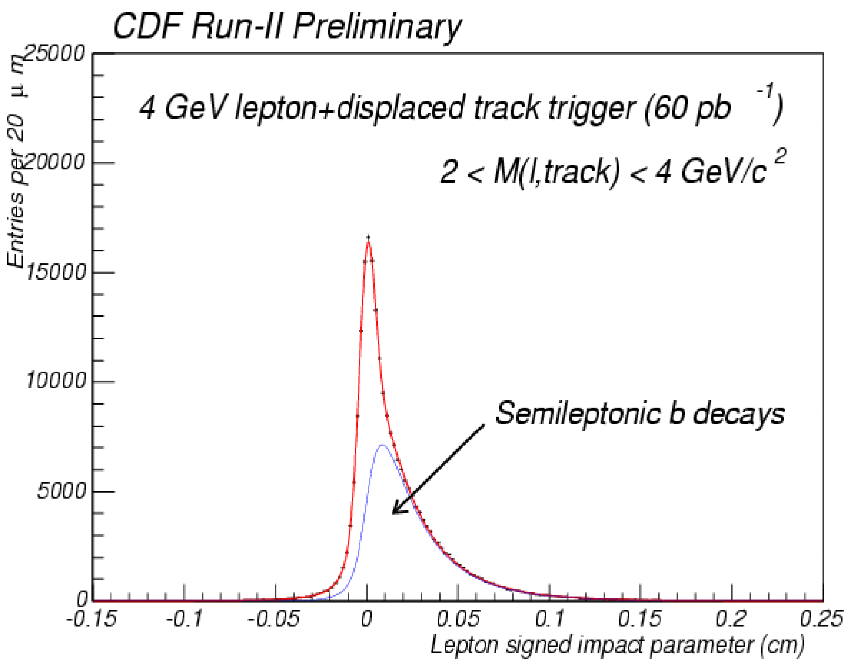
Jet-Q: $\varepsilon D^2 = (3.3 \pm 1.7)\%$

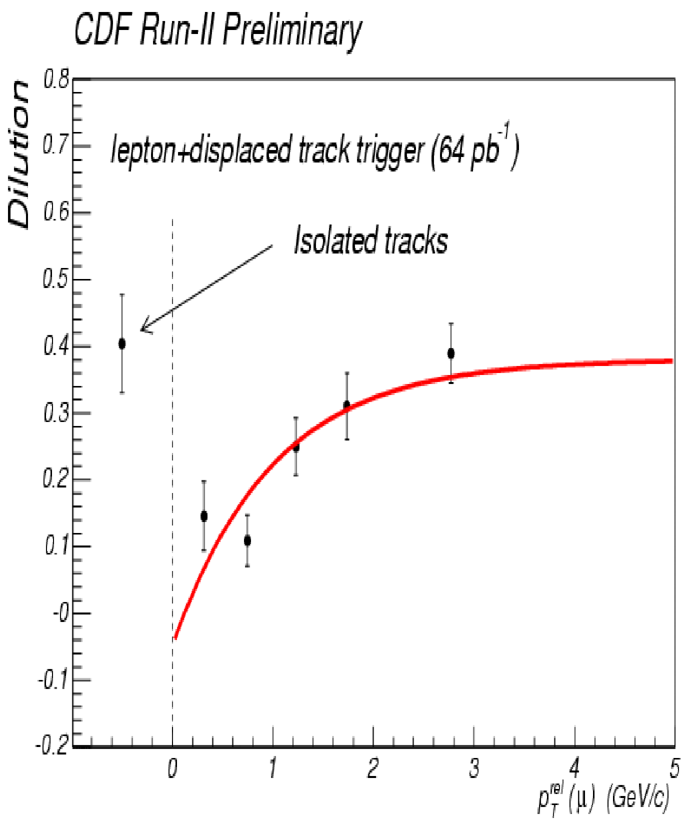
($\varepsilon = 46.7 \pm 2.7\%$ and $D = 26.7 \pm 6.8\%$)



SLT result from CDF

- **Test on high statistics *l*+SVT events**





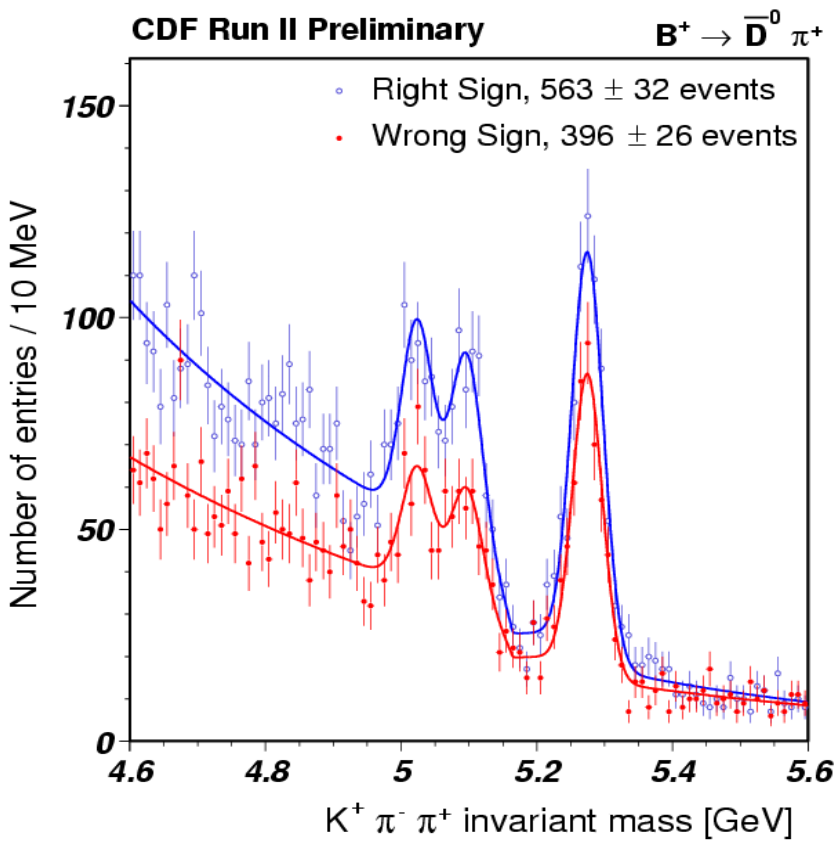
- **Need to correct the Dilution (64%) from triggered lep+SVT pair due to mixing and charm/prompt background**

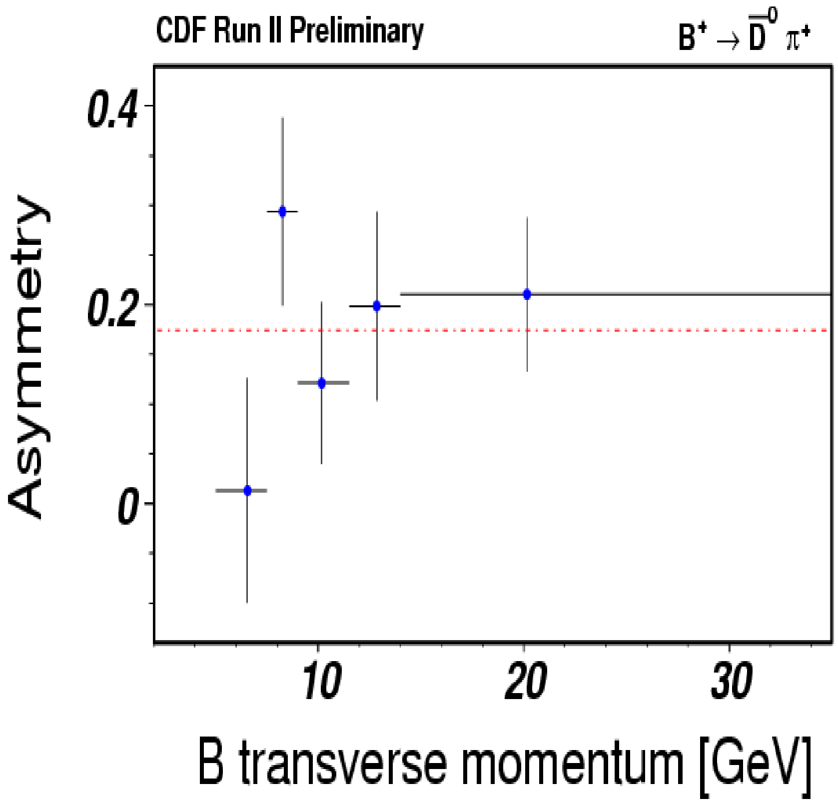
Tagging efficiency:

εD^2(mu)=(0.7±0.1)% (ε=1%)

SST result from CDF

SST on B+→J/ΨK+ and B+→D^0K+

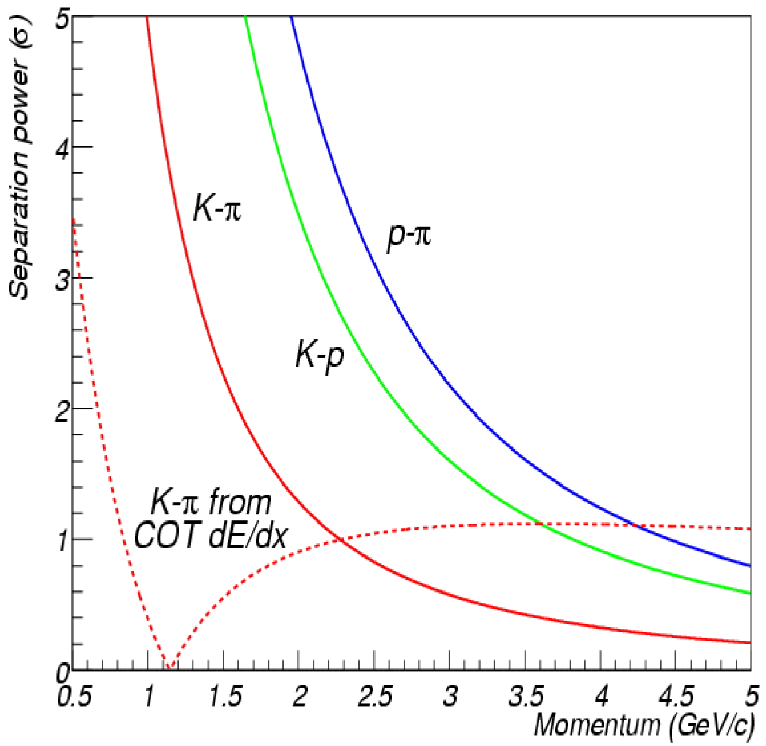


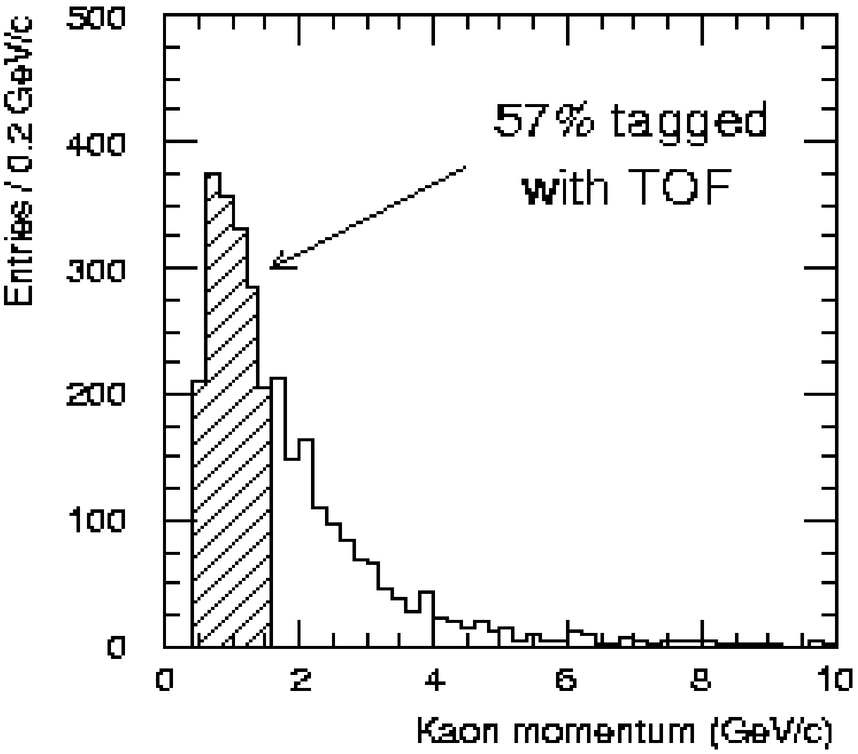


$\varepsilon D^2=(2.1\pm0.7)\%$ (ε=~62%)

TOF and flavor tagging

- **TOF has big effect on tagging purity**
  - 2σ K-π separation for p<1.6 GeV/c which covers ~57% of the B tracks
  - Important for both OKT and SST-K (εD^2 2→4.2% for SST)





Tagger Summary (CDF)

εD^2(%)	Run-I	Run-II	Projection w/o TOF	Projection with TOF	Key improvement
SST-π/K	1.5±0.4	2.1±0.7	2.0	2.0 - 4.2	SVX/TOF
SLT-μ	0.6±0.1	0.7±0.1	1.0	1.0	CMX/IMU/ISL
SLT-e	0.3±0.1		0.7	0.7	Plug Cal/ISL
JetQ	1.0±0.3		3.0	3.0	COT/SVX
OKT				2.4	TOF

- **Measurements with early data are consistent with projections**
- **Update soon with improved detector coverage and performance**
- **Projection for CDF Bs mixing sensitivity will use:**

εD^2= 4% (w/o TOF) $\rightarrow$5% (with TOF)

Bs mixing sensitivity formula

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

S = number of signal events

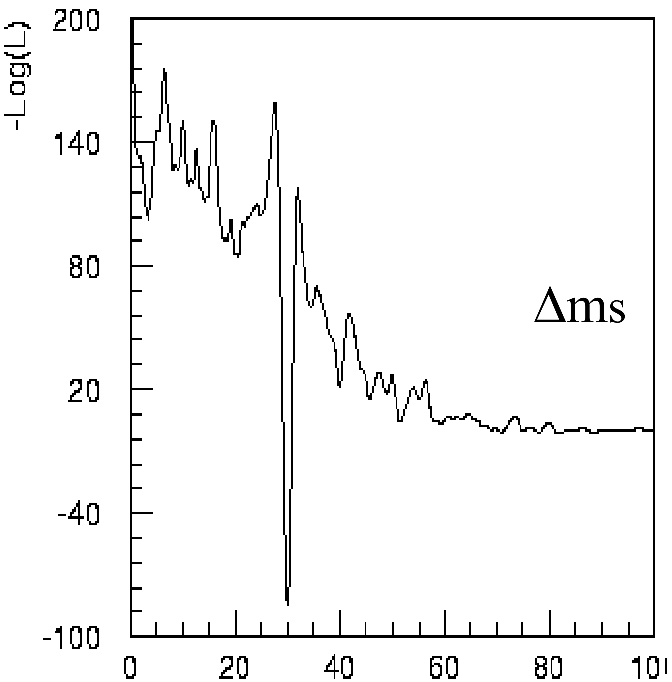
S/B = signal/background ratio

σ_t = proper time resolution

εD^2 = effective tagging efficiency

- **It is the "averaged" significance of analyses using likelihood fittings**

$$significance = \sqrt{2\Delta \log L} \quad \Rightarrow$$



CDF Bs mixing prospect with $500pb^{-1}$

- **With current performance**
  - $S=1600$ event/fb^{-1}
  - $S/B=2/1$
  - $\varepsilon D^2 = 4\%$ (SLT+SST+JetQ)
  - $\sigma_t = 0.067$ps
- **2σ measurement if $\Delta ms=15ps^{-1}$ from $500pb^{-1}$ data**
  - Expect $590pb^{-1}$ - $680pb^{-1}$ from Tevatron by 2004
  - Beat current limit from indirect measurements
  - Reach Standard Model favored region

CDF Bs mixing prospect with $2fb^{-1}$

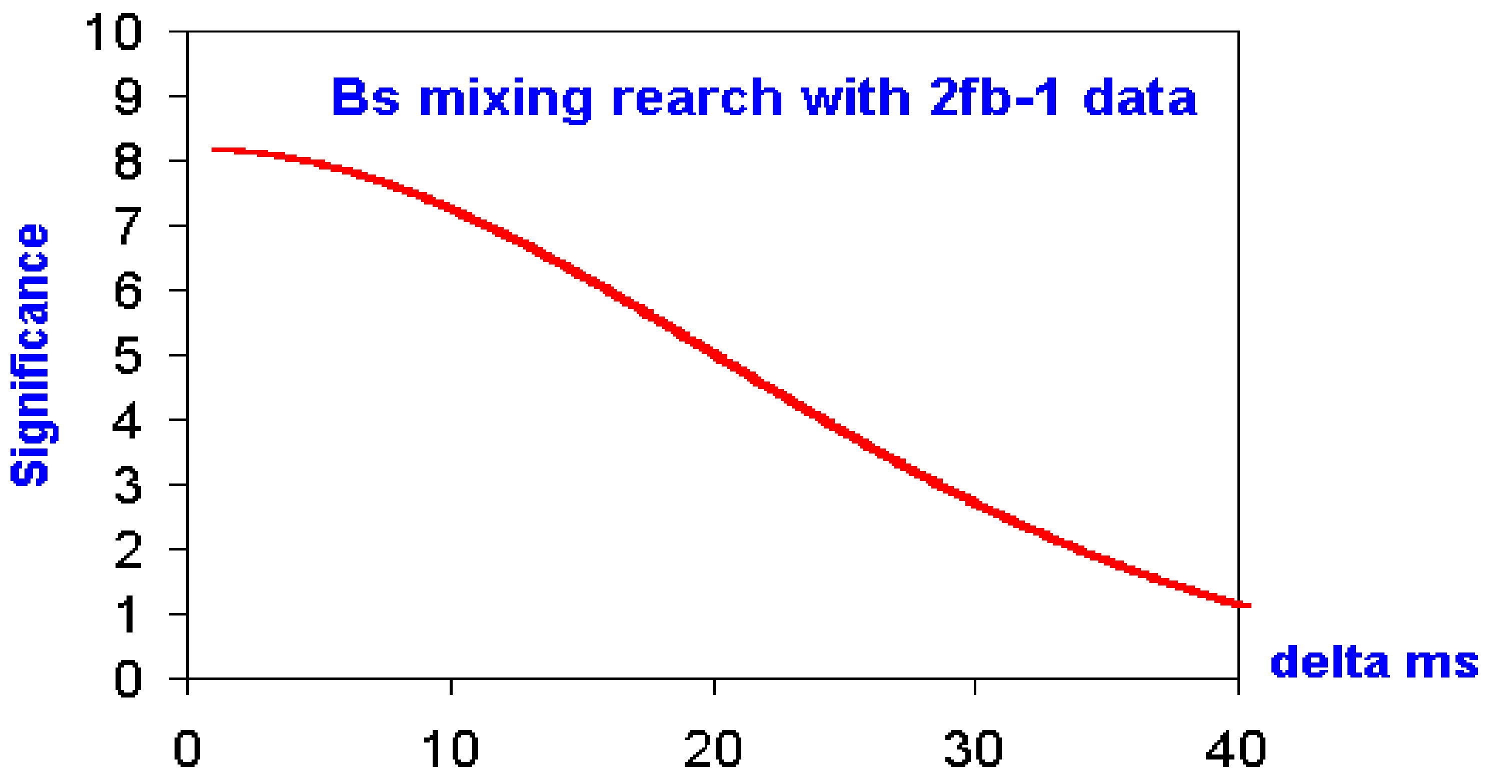
- **Expect Tevatron to deliver luminosity of**
  - $2.11fb^{-1}$ (based line) and $3.78fb^{-1}$(design) by 2007
- **With modest improvement for CDF**
  - Add Ds $\rightarrow$K*K, KsK and Bs$\rightarrow$Ds-π + π -π +

    S=1600$\rightarrow$2000 event/fb^{-1}
  - With improved TOF to enhance both SST and OKT

    $\varepsilon D^2 = 4\% \rightarrow 5\%$
  - With L00 silicon and event-by-event beamline

    $\sigma_{ct} = 0.067 \rightarrow 0.05ps$

CDF Bs mixing prospect by 2007



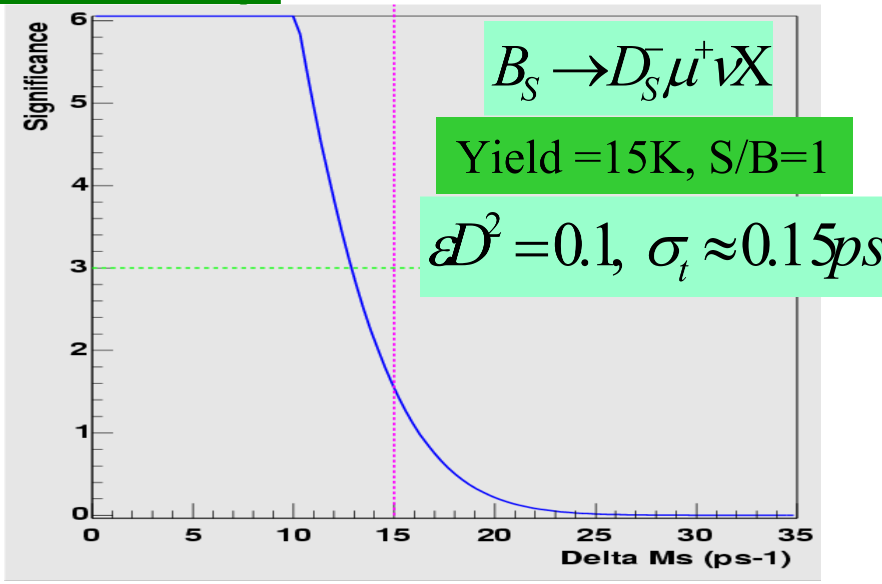
- **Go beyond standard model preferred range**

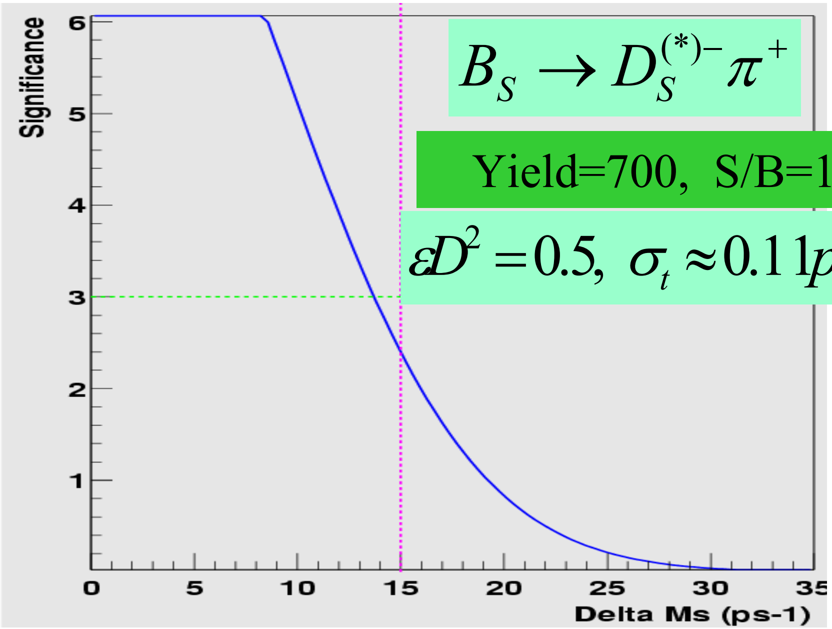
5σ measurement if Δms=18ps^{-1} with 1.7fb-1 data

5σ measurement if Δms=24ps^{-1} with 3.2fb-1 data

D0 Bs mixing sensitivity

- **Detail in Vivek Jain's talk on Tuesday**
- **Projections with 500 pb^{-1} data of inclusive muon trigger**
  - Triggered muon used to reconstruct 15K Bs→Ds μ ν
  - Triggered muon used as flavor tagger for 700 Bs →Ds π





$\Delta\Gamma_s/\Gamma_s$ - Bs lifetime difference

- **The mass difference Δm_s and lifetime difference $\Delta\Gamma_s$ of the two CP eigenstates are linked by**

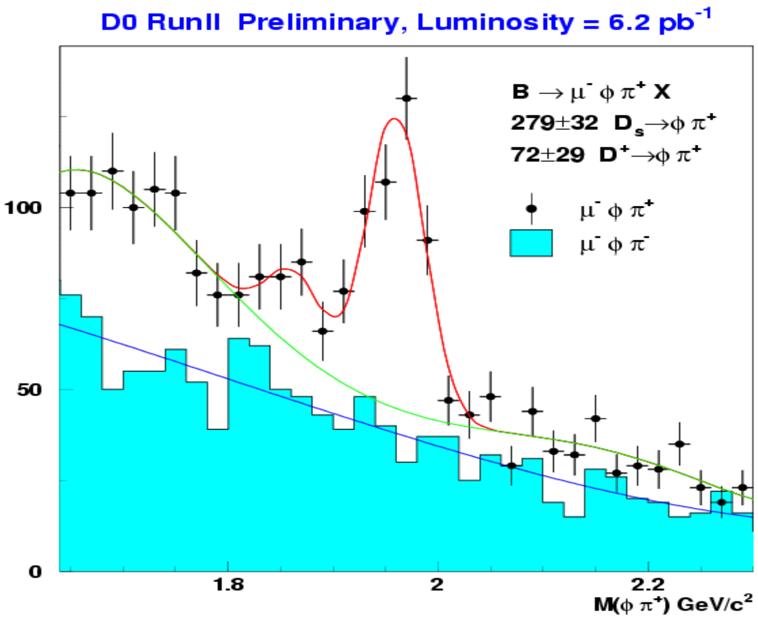
$$\Delta\Gamma_s / \Delta m_s = -3\pi/2 \cdot m_b^2/m_t^2 \cdot \eta(\Delta\Gamma_s) / \eta(\Delta m_s)$$

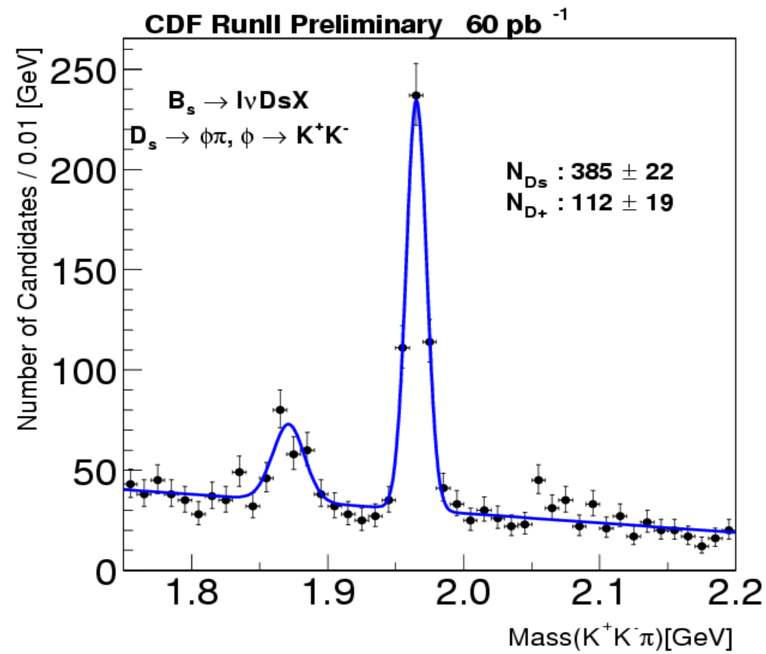
- **The QCD factor doesn't depend on CKM**
- **Δm_s and $\Delta\Gamma_s$ measurements are complementary**
- **$\Delta\Gamma_s$ could be large enough to be detectable ($\Delta\Gamma_s/\Gamma_s \sim 15\%$)**

$\Delta\Gamma_s/\Gamma_s$ Measurements

- **Three methods suggested for extracting $\Delta\Gamma_s/\Gamma_s$**
- **Fitting well-defined decay with two lifetimes**
  - Fit $e^{-\Gamma_L t} + e^{-\Gamma_H t}$ for $Bs \to Ds\, l\, \nu$ or $Bs \to Ds^+ \pi^-$
- **Separate CP-even/odd states by transversity analysis**
  - $Bs \to J/\Psi\phi$ is the familiar channel to CDF/D0
- **Branching ratio from a pure CP state decay**
  - $Bs \to Ds+Ds-$ a pure CP-even and triggered by CDF SVT trigger
  - $Br(Bs \to Ds+Ds-) = \Delta\Gamma_s/[\Gamma_s(1+\Delta\Gamma_s/2\Gamma_s)]$
  - Need to separate $Bs \to Ds^{+(*)}Ds^{-(*)}$ with fine mass resolution

$\Delta\Gamma_s/\Gamma_s$ from Bs semileptonic decays

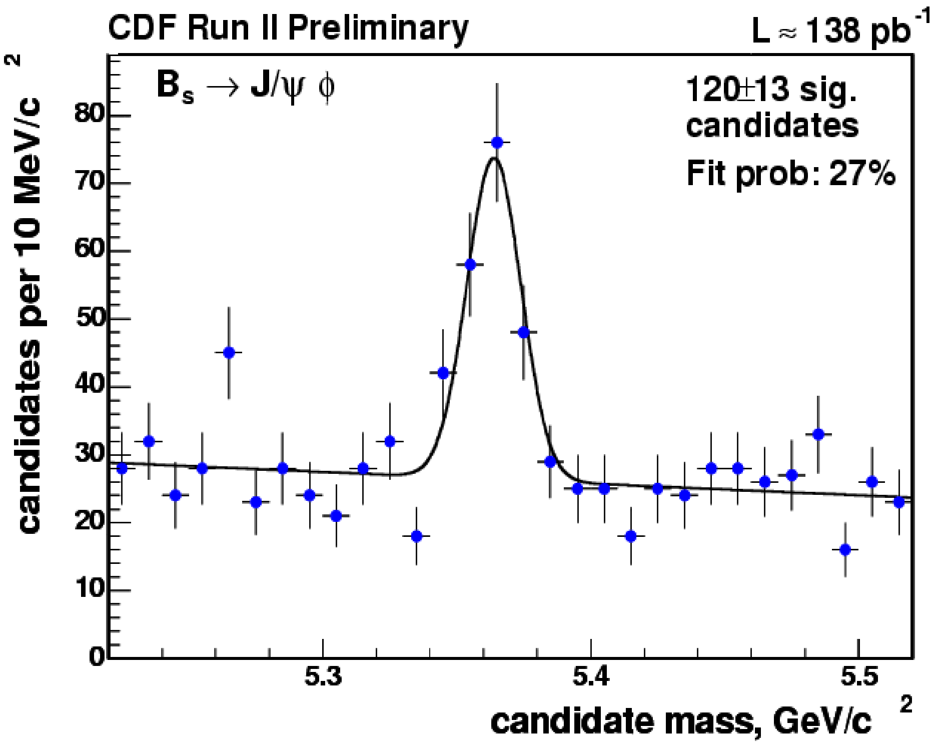




- **Plenty statistics from semileptonic decays**
- **Suffer from poor lifetime resolution due to partial reconstruction**
- **Useful for limits** $\Delta\Gamma_s/\Gamma_s<0.83$ @95% CL from 600 Run-I signals

  $\Delta m_s>5.8\ ps^{-1}$@ 95%CL from 700 SLT-tagged Run-I signals

$\Delta\Gamma s/\Gamma s$ from Bs $\rightarrow$J/Ψϕ



- **CP states follow distributions:**

$3/8\cdot(1+\cos^2\Theta_T)$ → CP-even

$3/4\cdot(1-\cos^2\Theta_T)$ → CP-odd

Θ_T =Transversity angle

- **Run-I with 58 events gives $\Gamma^{CP\text{-}even}/\Gamma$=0.778±0.090±0.012**

- **With 4K event ⇒ an error of 0.05 if $\Delta\Gamma s/\Gamma s$=15%** (Run II B workshop)

- **CDF result with 300 events from 220pb^{-1} is coming**

Summary

- A lot of progress on flavor tagging from CDF/D0
- We are collecting $Bs \rightarrow Ds^{-}\pi^{+}$ at 1600 event/fb^{-1}
- With 500 pb^{-1} data, Bs mixing measurement reaches the Standard Model preferred region ($\Delta m_s = 15 ps^{-1}$)
- With 2fb^{-1} data, Bs mixing measurement will go beyond the preferred region ($\Delta ms > 18 ps^{-1}$)
- Precise $\Delta\Gamma_s / \Gamma_s$ measurements are also underway

Backup slides

CDF/D0 Detectors

Both detectors have very nice silicon device (lifetime), central tracking (mass) , calorimeter & muon system (e/μ ID) and high bandwidth trigger/DAQ system

CDF

Silicon vertex trigger (SVT)

trigger displaced track and e/μ

TOF for particle ID

2σ K-π separation at 1.5 GeV

Excellent mass resolution

DØ

Excellent muon coverage

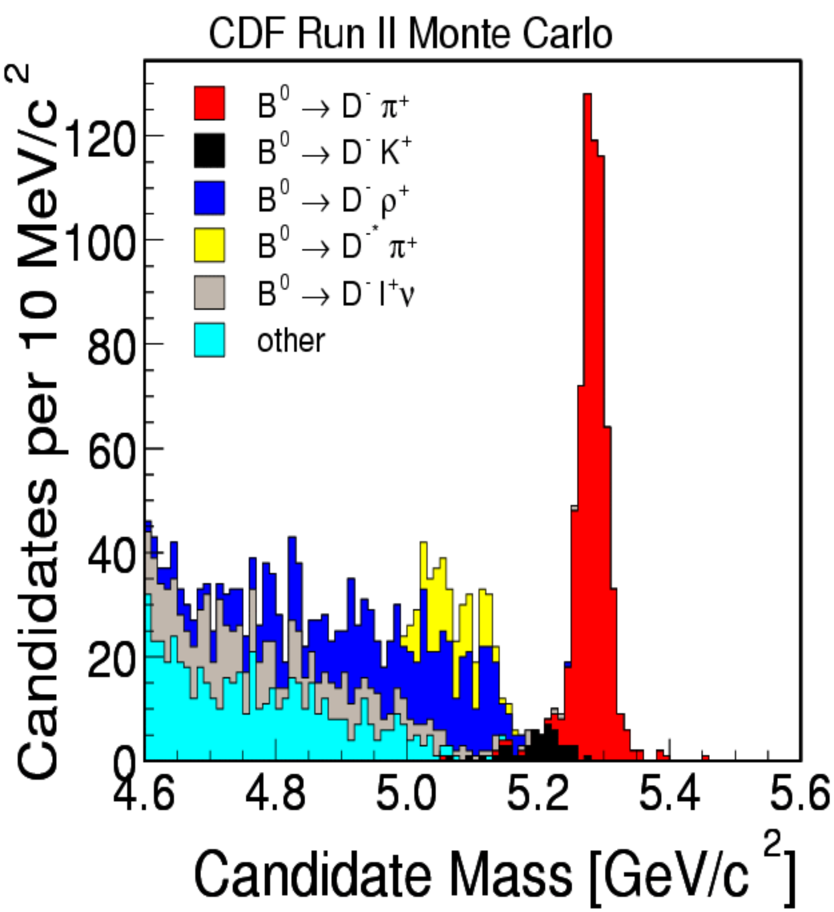
trigger μ for pT>1.5 and |η|<2.0

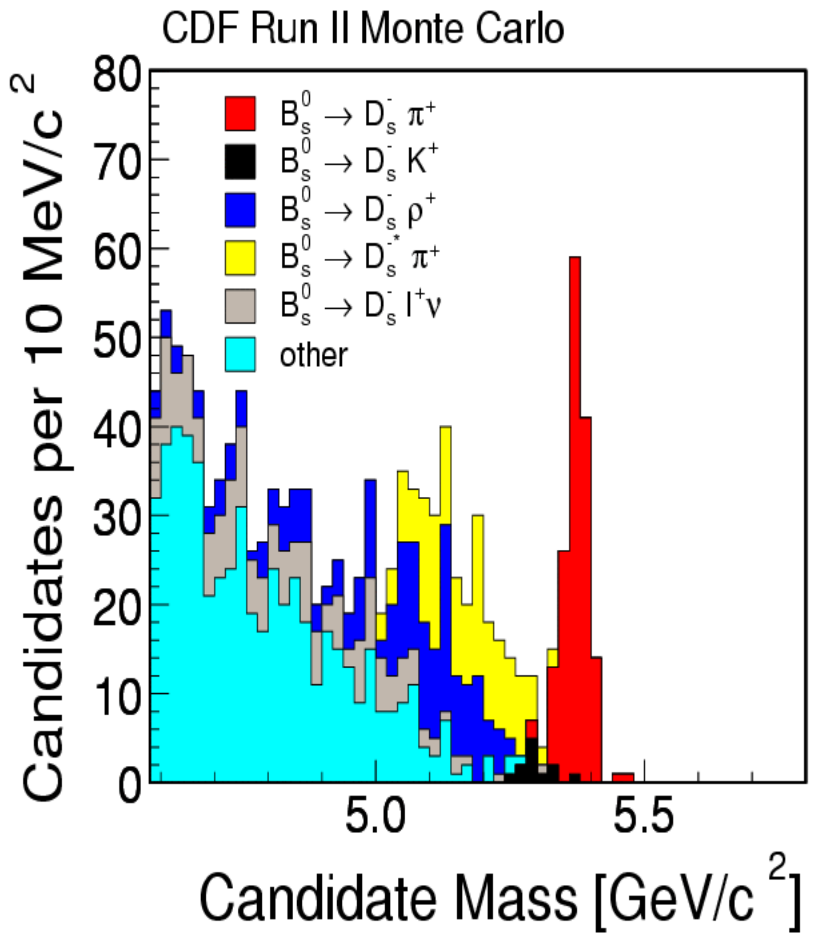
Excellent tracking acceptance

SMT+SFT covers |η|<1.6

Silicon track trigger is coming

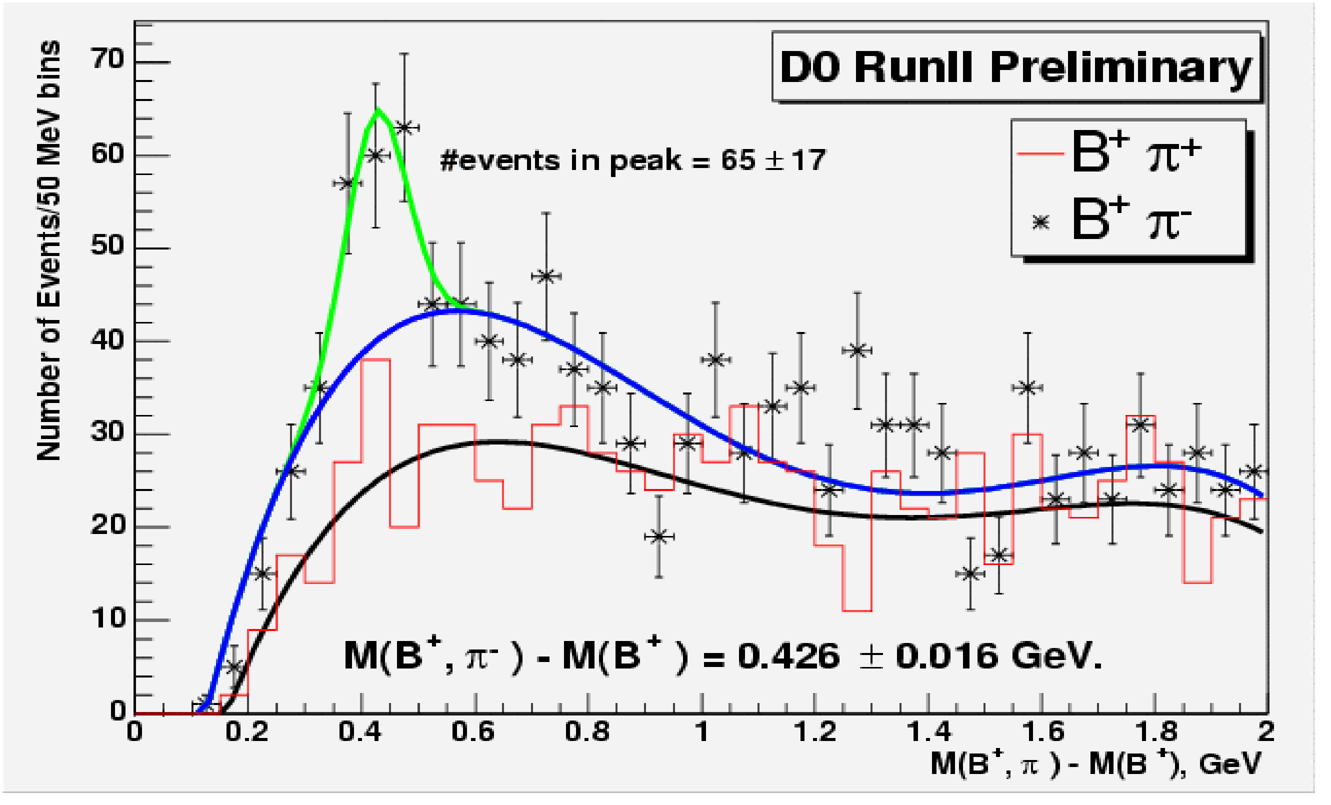
Separating Bs→Ds π from other B reflections





- **Mass resolution is crucial in achieving decent S/B**

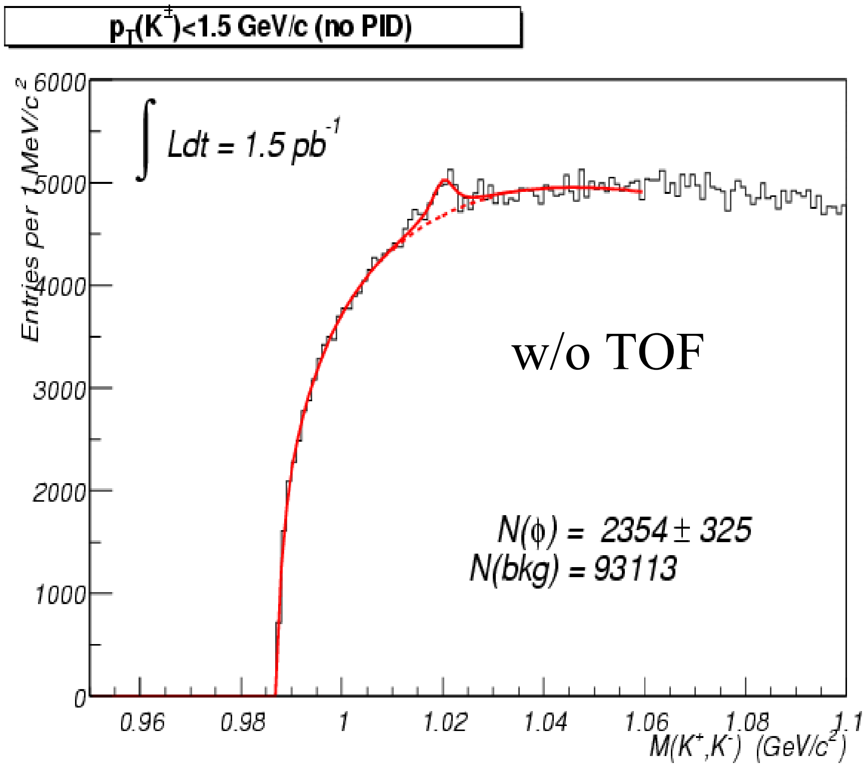
New B** result from D0

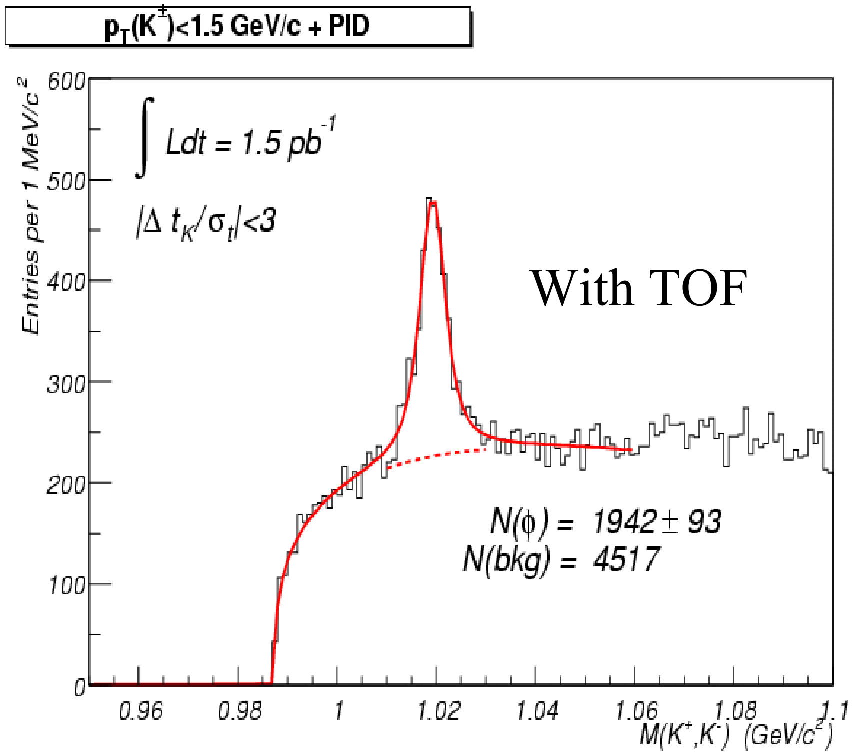


- **D0 uses fully reconstructed B+**
  - 65±17 out of 1193 B could be due from $B^{**0} \rightarrow B^+\pi^-$
- **CDF Run-I used B semileptonic decays**
  - Fraction of B from B** = 0.28 ±0.06 ±0.03

TOF performance

- **TOF is working and we are working on to improve its reconstruction efficiency**





$\phi \to$ K K decays

$\Delta\Gamma_s/\Gamma_s$ from Bs →Ds+Ds-

- **Br(Bs→Ds+Ds-) = $\Delta\Gamma_s/[\Gamma_s(1+\Delta\Gamma_s/2\Gamma_s)]$**

  Theory uncertainty could be large

- **Separates background of Ds* →Ds γ using fine mass resolution**

  Also introduce 3% error on proper time

- **32±17 Bs→$Ds^{+(*)}Ds^{-(*)}$→φ φ**

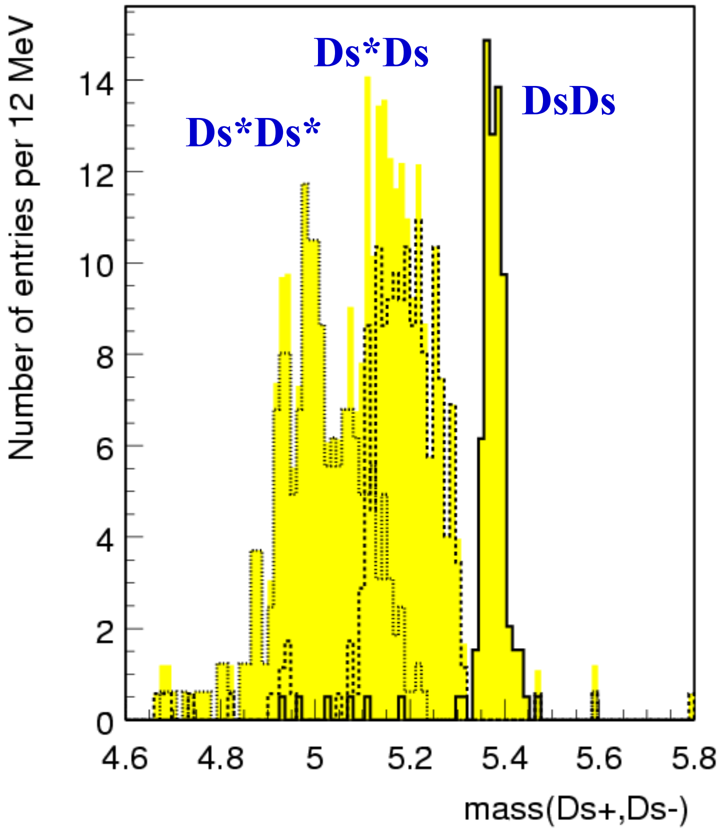
  $\Delta\Gamma_s/\Gamma_s$=0.25 +0.21-0,14 (ALEPH)

- **Channel is trigged with SVT of CDF**

  Br (Bs→Ds+Ds-)/Br(Bs→Ds+π-)≈2

  Reconstruction efficiency will be lower

GEANT for CDF



(Run II B workshop)