Preparing for $\mathrm{B_s}$ mixing at CDF

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MIT @ CDF

- relevance of the measurement
- what CDF has to offer
- prospects in the near future

November 27, 2001

The CKM Matrix:

Weak interactions can change quark flavor:

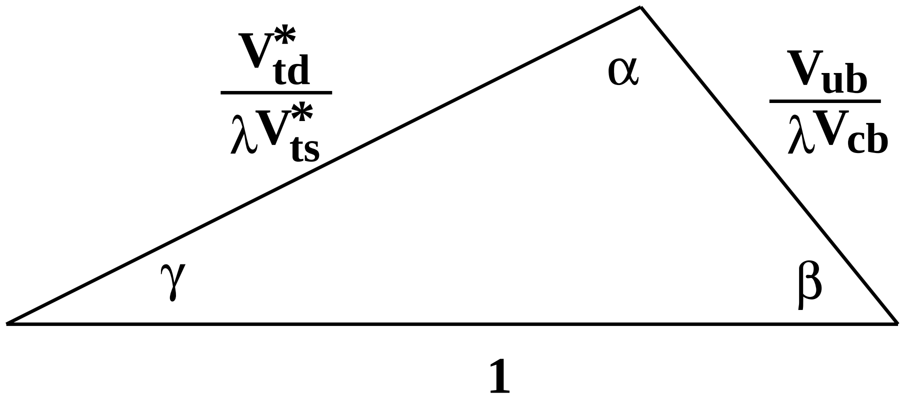
$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix}_L = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}_L$$

weak eigenstates $\neq$ mass eigenstates

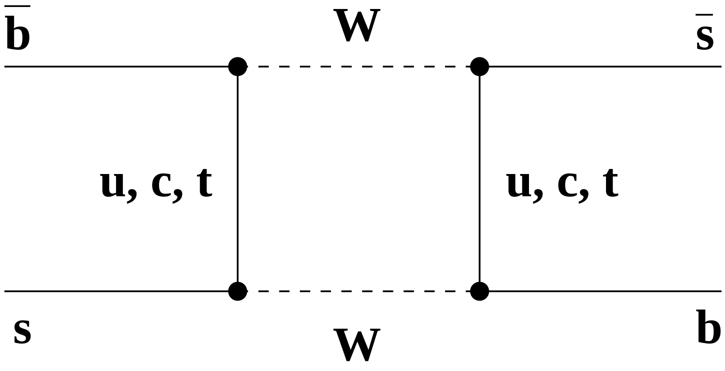
CKM matrix unitarity: $\mathrm{V}^\dagger \mathrm{V} = \mathrm{V}\mathrm{V}^\dagger = 1$

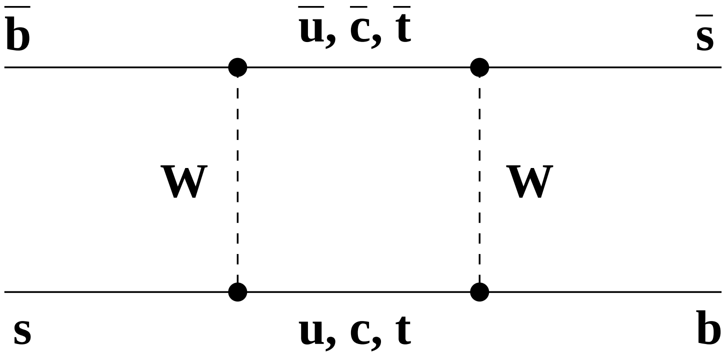
$$\mathrm{V_{ud}V_{td}^*} + \mathrm{V_{us}V_{ts}^*} + \mathrm{V_{ub}V_{tb}^*} = 0$$

$$1 + \frac{\mathrm{V_{td}^*}}{\lambda \mathrm{V_{ts}^*}} - \frac{\mathrm{V_{ub}}}{\lambda \mathrm{V_{cb}}} = 0$$



B_s mixing:





$$N_{UMX}(t) = N_0 e^{-t/\tau_s} \cdot \frac{1}{2}[1 + \cos(\Delta m_s t)]$$

$$N_{MIX}(t) = N_0 e^{-t/\tau_s} \cdot \frac{1}{2}[1 - \cos(\Delta m_s t)]$$

$$x_s = \frac{\Delta m_s}{\Gamma_S}$$

$$A(t) = \frac{N_{UMX}(t) - N_{MIX}(t)}{N_{UMX}(t) + N_{MIX}(t)} = \cos(x_s t/\tau_s)$$

What do we learn from this measurement?

.. well, obviously that $\mathrm{B_s}$ mesons mix and $\Delta \mathrm{m_s} = ..$

But also:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \cdot \xi_s \cdot \left| \frac{V_{ts}}{V_{td}} \right|^2$$

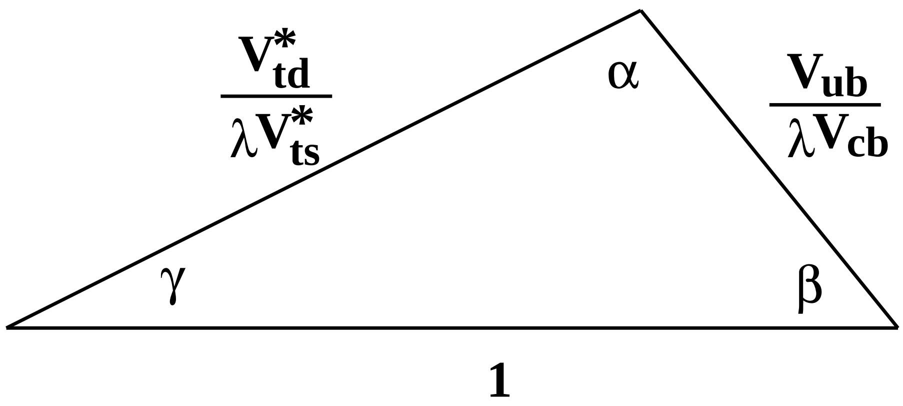
($\xi_s \simeq 1.14 \pm 0.08$ **from lattice QCD**)

$$\sin \theta_{\mathrm{C}} = 0.2196 \pm 0.0023$$

$$\mathrm{V_{ub}/V_{cb}} \simeq 1.01 \pm 0.02$$

$\sin 2\beta$ **measured precisely at b-factories and CDF**

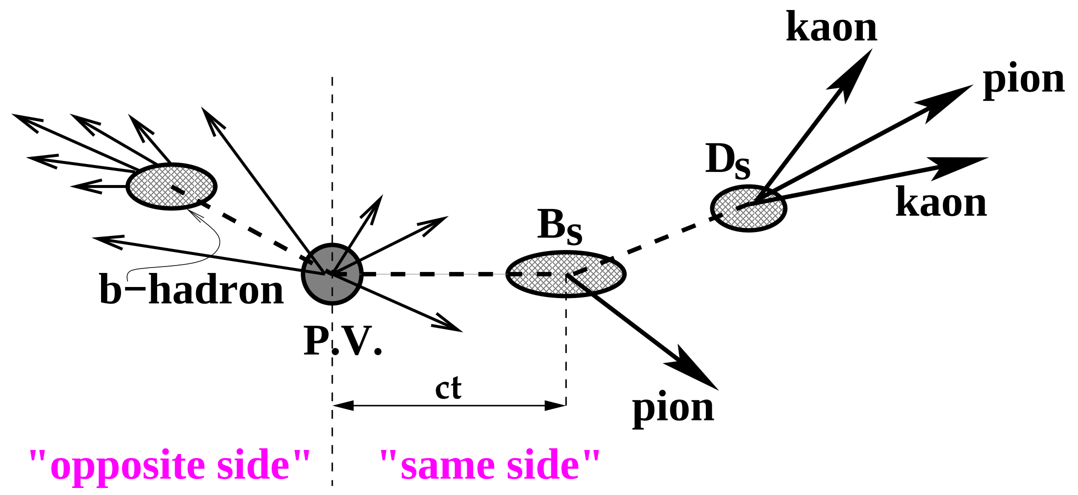
$\rightarrow$ **test the unitarity triangle!**



Current knowledge:

- **PDG:** $x_s > 19.2$ **,** $\Delta \mathrm{m_s} > 13.1\ \mathrm{ps^{-1}}$ **(95 % C.L.)**
- **best single measurement:** $\Delta \mathrm{m_s} > 9.6\ \mathrm{ps^{-1}}$ **(ALEPH)**
- **Combines analyses:**
  - **semileptonic** $\mathrm{B_s}$ **decays**
  - **hadronic** $\mathrm{B_s}$ **decays**
  - **inclusive lepton events**
- **Tagging methods:**
  - **opposite hemisphere charge**
  - **opposite lepton tag**
  - **fragmentation kaon tag**

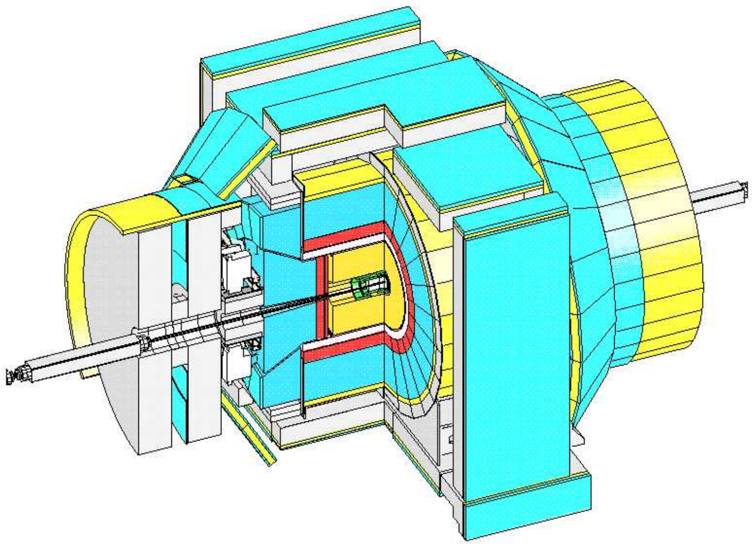
Principle of the measurement:



- D_s **final state(s):** $\phi\pi$, K^*K, 3π
- B_s **flavor specific state(s):** $D_s\pi$, $D_s3\pi$
- **measure** ct **of the** B_s **decay**
- **tag b quark flavor at production (** $\mathcal{D} = 2\mathcal{P} - 1$ **)**
- **measure mixing asymmetry**

$$\mathcal{A}_{mix}(t) = \frac{N_{RS}(t) - N_{WS}(t)}{N_{RS}(t) + N_{WS}(t)} = \mathcal{D} \cdot \cos(\Delta m_{B_s} \cdot t)$$

CDF Detector:



Relevant for reconstruction:

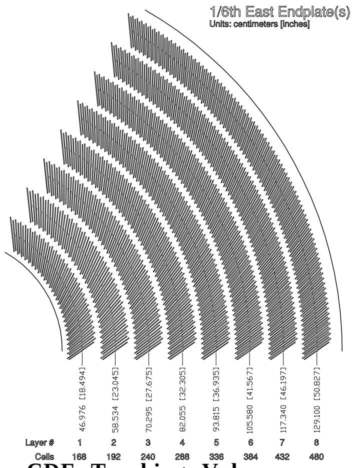
- **Tracking systems: L00, SVX, ISL, COT**

Relevant for tagging:

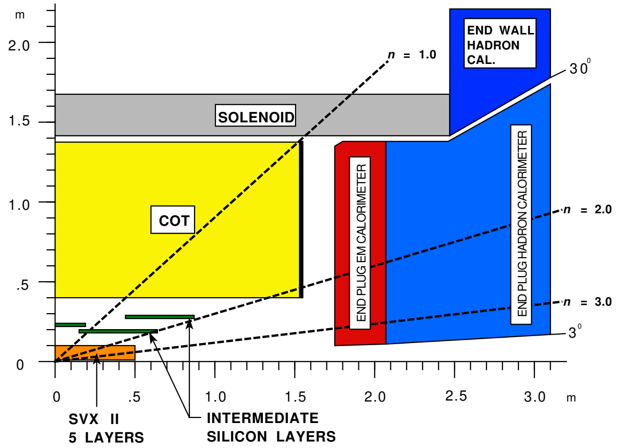
- **Particle ID: Time Of Flight, COT dE/dx**
- **ECal, HCal**
- **Muon systems**

Tracking: Central Outer Tracker

- **drift chamber**
- **250** $\mu\mathrm{m}$ **resolution per wire**
- **12 layers of wires = SuperLayer**
- **8 Superlayers: 4 axial, 4 stereo**
- **tracking based on SL segments**
- $\mathrm{p_t}$ **resolution** $0.321\% \cdot \mathrm{p_t^2}[\mathrm{GeV}^2]$
- $\mathrm{d_0}$ **resolution** $\sim 500\mu\mathrm{m}$
- $\mathrm{z_0}$ **resolution** $\sim 1\mathrm{cm}$
- **efficient tracking for** $|\eta| < 1$
- **seeds tracks for silicon tracking**

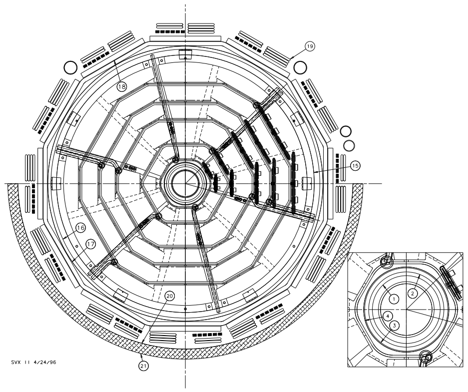


CDF Tracking Volume

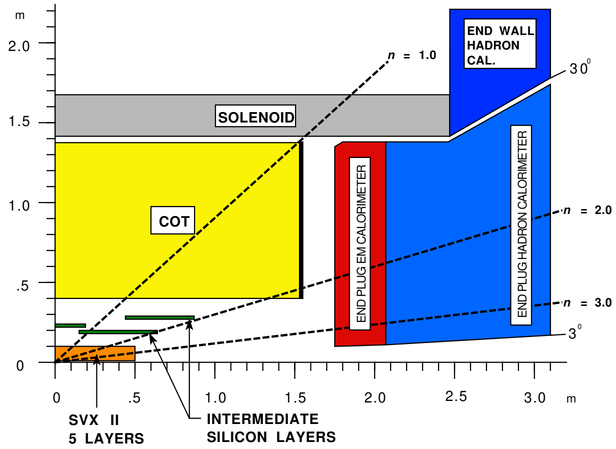


Tracking: Silicon

- **Main tracker: SVX**
- **double sided silicon microstrip tracker**
- **3 barrels, 5 layers each**
- $\mathrm{r} - \phi$ **measurement at each layer**
- **3 layers are stereo, 2 small angle**
- **tracking volume up to** $|\eta| < 2$
- **ISL:**
  - **1 central, 2 forward barrels**
  - **track seeds for forward region**
- **L00: additional d0 precision**

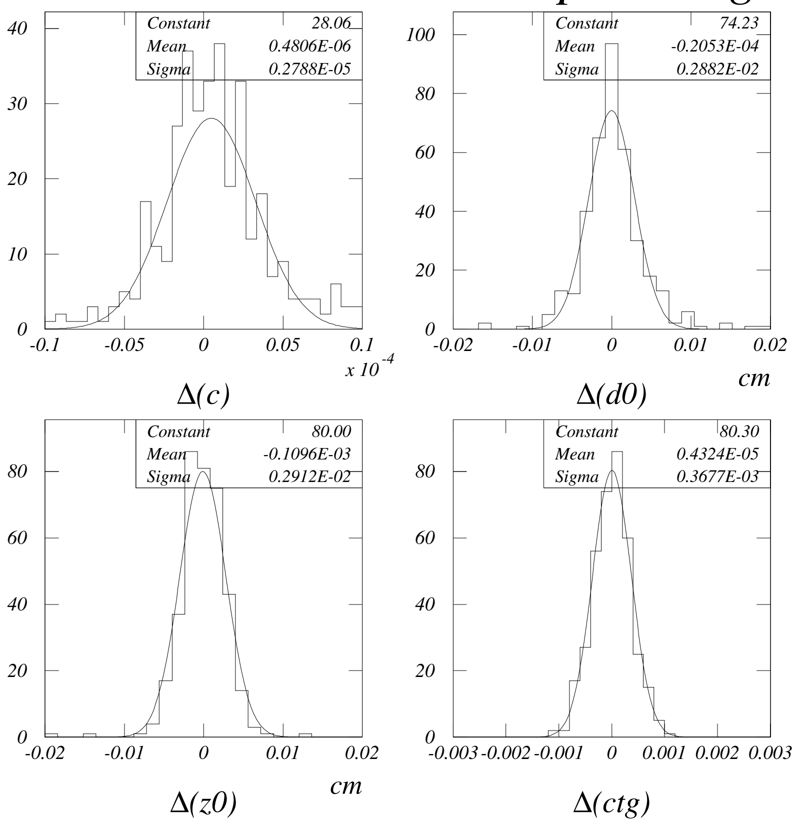


CDF Tracking Volume



Tracking: Integrated

COT-SVXii Resolutions: Top b-daughters



- **expected** d_0 **resolution = 30** $\mu\mathrm{m}$
- **expected** $\mathrm{p_t}$ **resolution =** $0.132\% \cdot \mathrm{p_t^2}[\mathrm{GeV}^2]$

$\rightarrow$ expect good ct resolution for fully reconstructed $\mathrm{B_s}$ mesons

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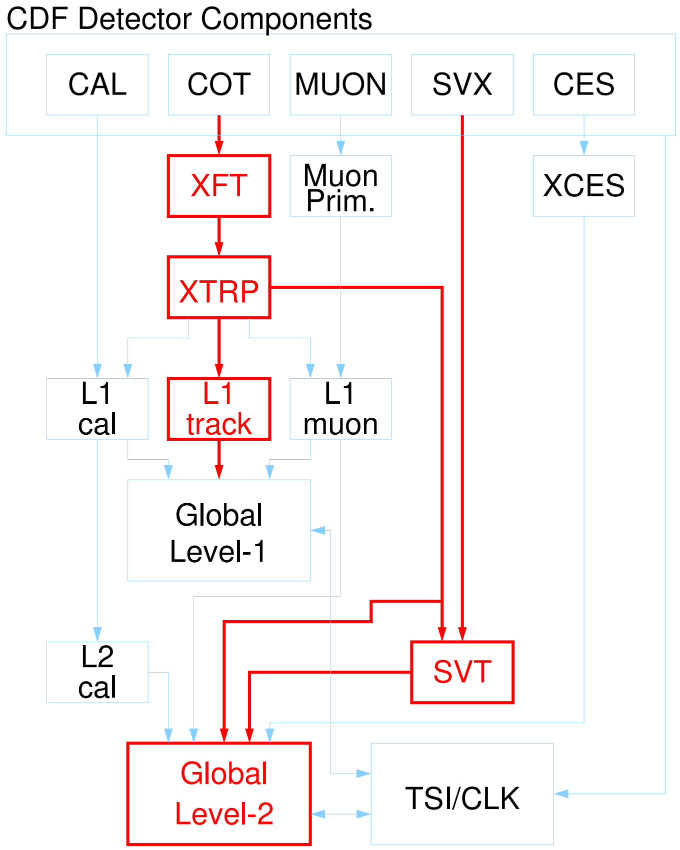
.. but need to trigger on them first ..

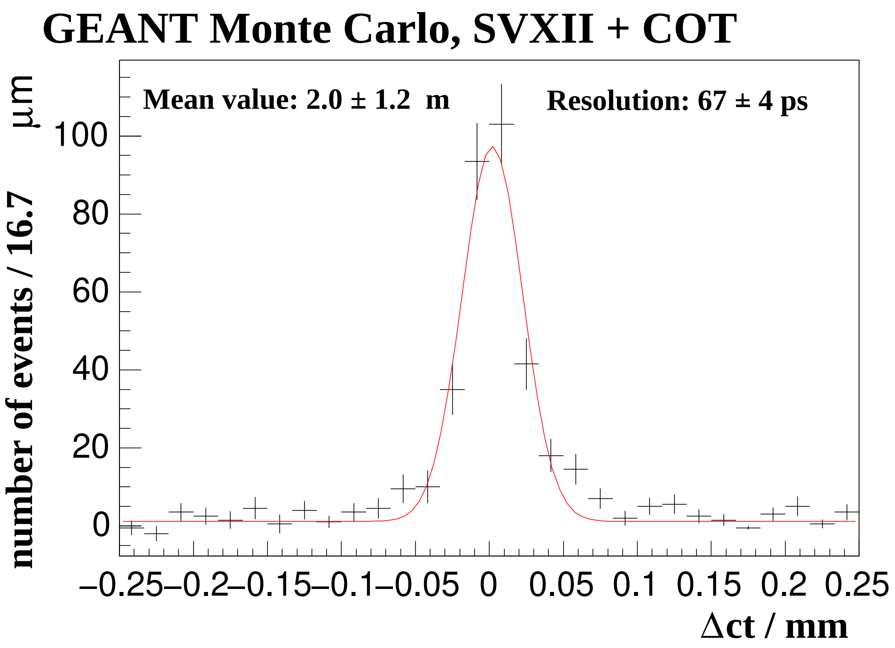
Trigger: Dedicated 2-track strategy

- **L1: two tracks,** $p_t > 2\mathrm{Gev}$
- **opposite charge,** $\delta\phi < 135^o$
- **L2: require** $100\mu\mathrm{m} < d_0 < 1\mathrm{mm}$
- **good for hadronic B decays!**

Bs **decay**	D_s **decay**	**Events/2fb**
$D_s\pi$	$\phi\pi$	**16100**
$D_s\pi$	K^*K	**15300**
$D_s\pi$	**both**	**31400**
$D_s3\pi$	$\phi\pi$	**15100**
$D_s3\pi$	K^*K	**17000**
$D_s3\pi$	**both**	**32100**



ct measurement

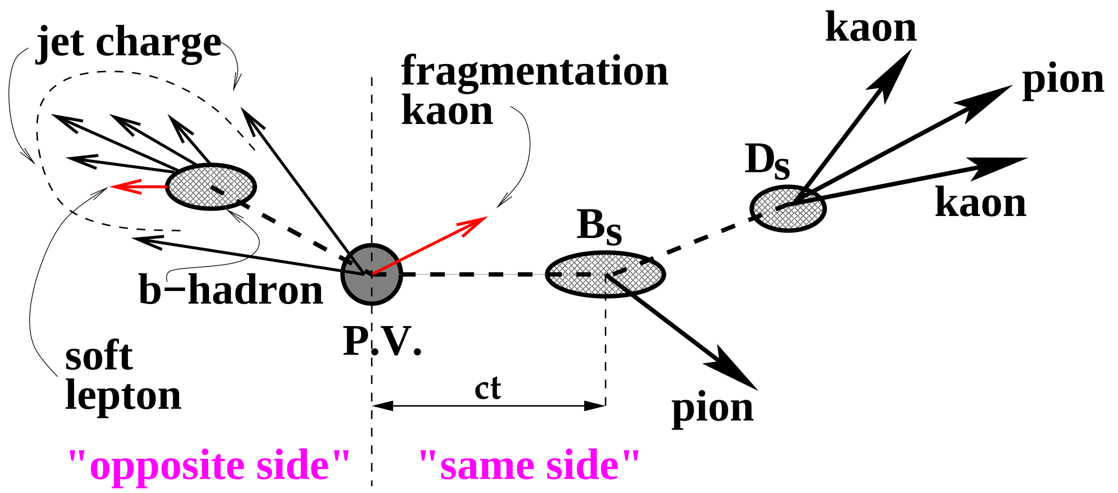


$B_s \rightarrow D_s\pi$, $D_s \rightarrow \phi\pi$, $\phi \rightarrow K^+K^-$:

- generator level trigger simulation
- GEANT simulation for COT+SVXII only
- Resolution: $67 \pm 4\mathrm{fs}$
- Projection for COT+SVXII+L00: 45 fs
- SVXII and L00 are being commissioned

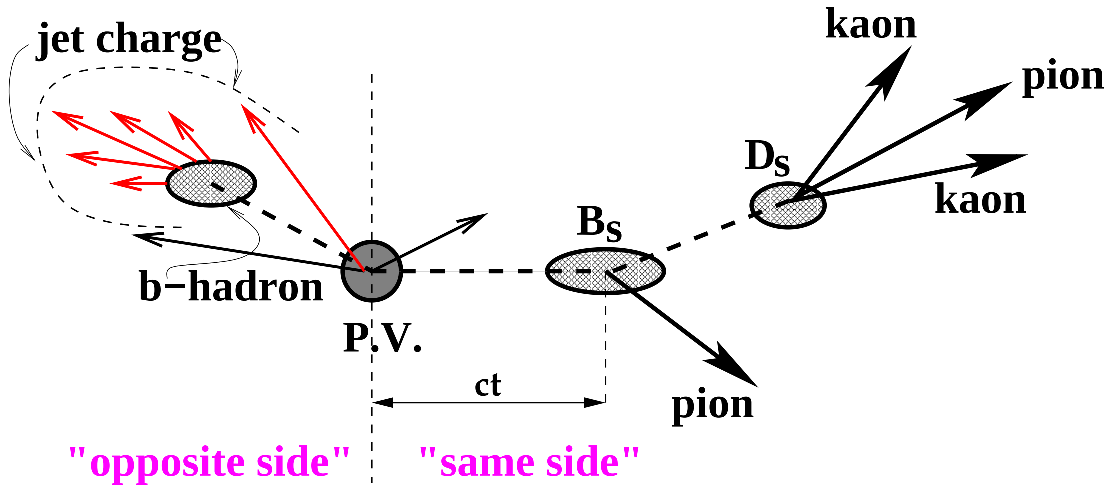
Flavor tagging

- methods of guessing the b quark flavor at creation
- Efficiency of making a guess: ϵ
- Probability of correct guess: $\mathcal{P}$, $\mathcal{D} = 2\mathcal{P} - 1$
- Statistical power $\sim \epsilon\mathcal{D}^2$



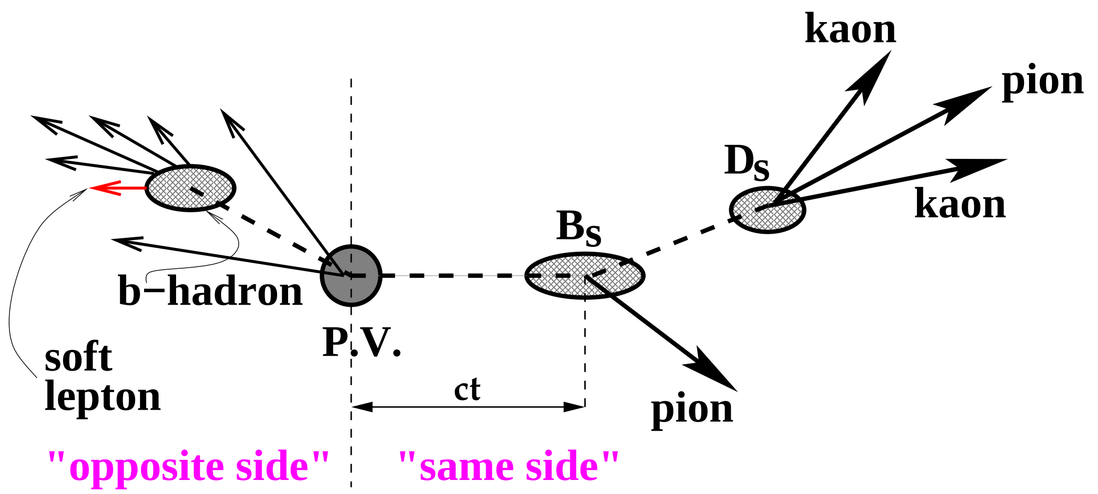
- Opposite Side: Lepton, Jet Charge, Kaon Tags
- Same Side: Kaon Tag

Opposite Side Jet Charge Tagging



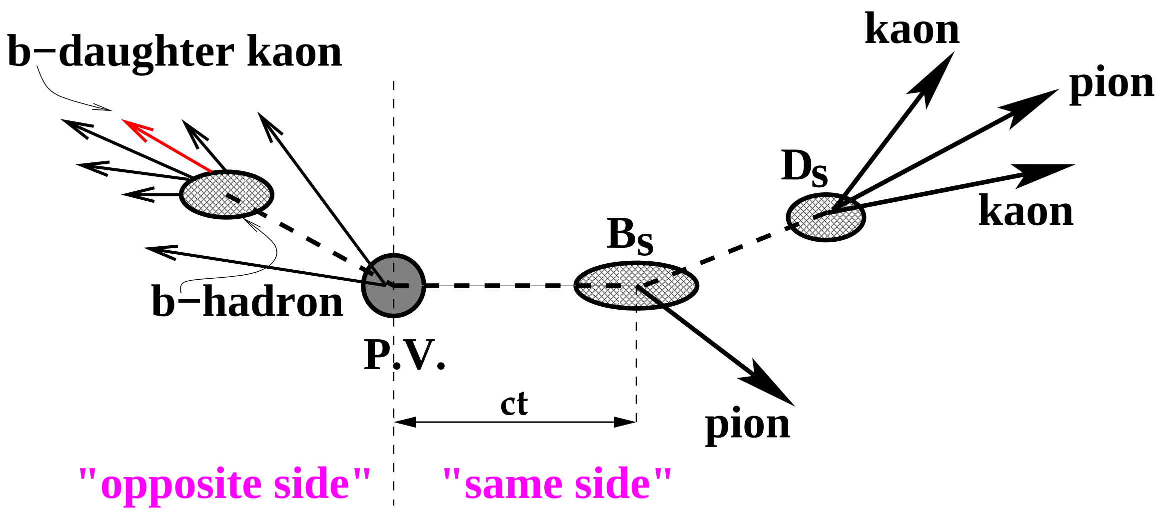
- **correlates weighted charge of B jet to b quark flavor**
- **track clustering into jets (seed $\mathrm{p_t}$ = 1.75 GeV)**
- **calculate** $Q_{jet} = \frac{\sum_{tracks} q_i (p_t)_i^{\kappa} (2-(T_p)_i)^{\gamma}}{\sum_{tracks} (p_t)_i^{\kappa} (2-(T_p)_i)^{\gamma}}$
- Q_{jet} **correlated to opposite side b quark flavor**
- **expected efficiency:** $45.5 \pm 1.8\%$
- **expected dilution:** $22.2 \pm 6.0\%$
- **expected** $\epsilon\mathcal{D}^2 = 2.24 \pm 1.24$

Opposite Side Soft Lepton Tagging



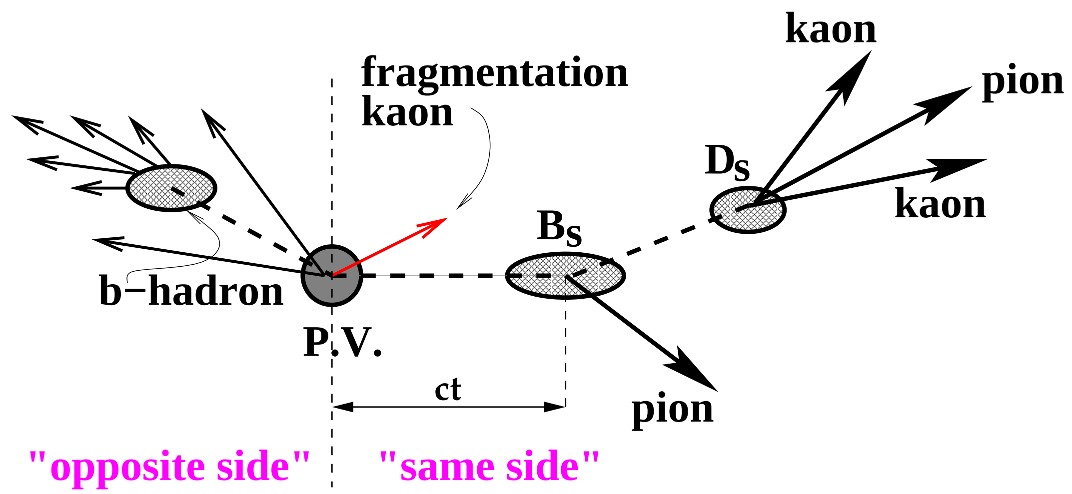
- **opposite side b quark decay:** $\mathrm{b} \to \mathrm{c} l \nu$
- **detect soft lepton from decay:** e **or** μ
- **electron ID: EM shower in calorimeter + track**
- **muon ID: match between muon system & track**
- **expected efficiency:** $6.89 \pm 0.88\%$
- **expected dilution:** $57.2 \pm 13.9\%$
- **expected** $\epsilon\mathcal{D}^2 = 2.26 \pm 1.09$

Opposite Side Kaon Tagging



- **opposite side b quark decay:** $\mathrm{b} \rightarrow \mathrm{c} \rightarrow \mathrm{s}$
- **define "opposite side":** $\Delta R_{\eta\phi}(\mathrm{track}, \mathrm{B_s}) > 1$
- **ToF consistent with kaon**
- $w_{d0z0} = p(d0, 0, \sigma_{d0}) \cdot p(z0, 0, \sigma_{z0})$
- **require that kaons have** $w_{d0z0} < 0.01$
- **expected efficiency:** $11.2 \pm 0.3\%$
- **expected dilution:** $46 \pm 2\%$
- **expected** $\epsilon\mathcal{D}^2 = 2.4 \pm 0.2\%$

Same Side Kaon Tagging



- **kaon produced during** $\mathrm{B_s}$ **fragmentation**
- **"same side":** $\Delta R_{\eta\phi}(\mathrm{track}, \mathrm{B_s}) < 0.7$
- **select track with minimum** $\mathrm{p_t^{rel}}$
- **ToF consistent with kaon**
- **expected efficiency:** $17.0 \pm 0.6\%$
- **expected dilution:** $50 \pm 2\%$
- **expected** $\epsilon\mathcal{D}^2 = 4.2 \pm 0.3\%$

Overview of relevant parameters:

SVX + L00 $c\tau$ resolution: 45 fs

Tagger	$\epsilon(\%)$	$\mathcal{D}(\%)$	$\epsilon\mathcal{D}^2$
JQT	45.5 ± 1.8	22 ± 6	2.2 ± 1.2
SLT	6.9 ± 0.9	57 ± 14	2.3 ± 1.1
OSK	11.2 ± 0.3	46 ± 2	2.4 ± 0.2
SSK	17.0 ± 0.6	50 ± 2	4.2 ± 0.3
Total	—	—	11.1 ± 1.7

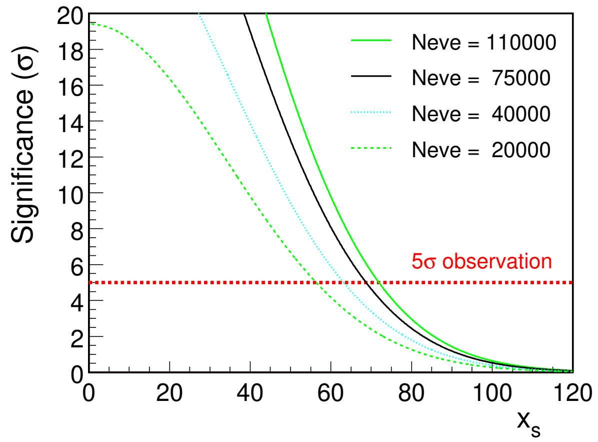
- Signal / Background ratio not studied in detail
- sample composition unknown
- multiple collisions

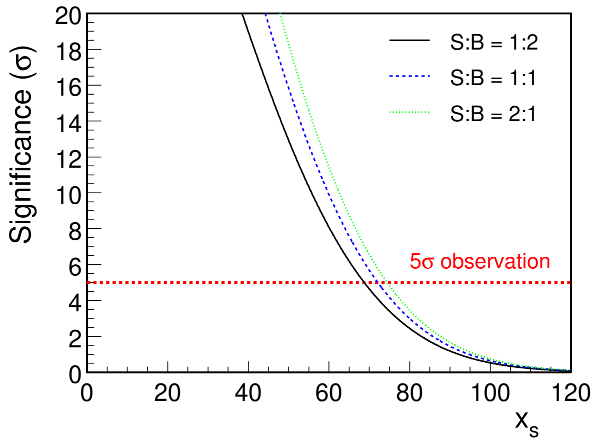
Scenario	S/B
Optimistic	2:1
Reasnoable	1:1
Pessimistic	1:2

Projections for RunIIa

Assumptions:

- 2 fb luminosity through trigger
- COT seeded tracking
- L00 operational, 45 fs ct resolution
- all taggers operational, combined

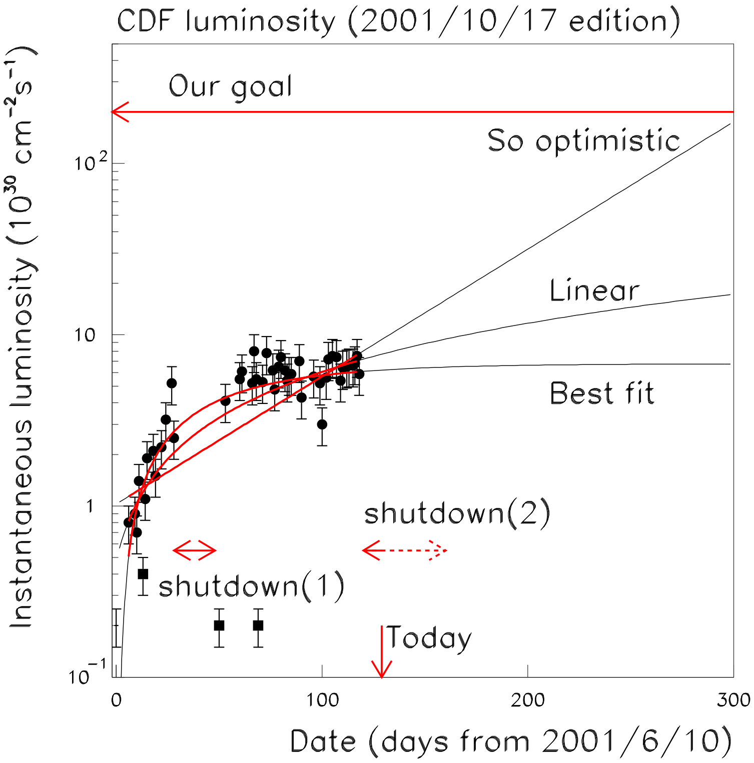




Reach for 5σ discovery: $\mathrm{x_s} = 72$ **(**$\Delta m_s = 49ps^{-1}$**)**

- When will all this be in place?

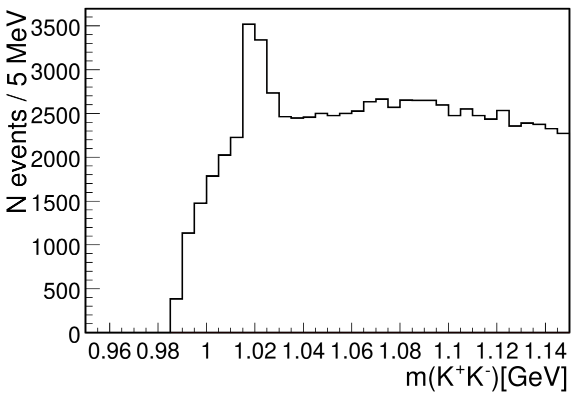
Tevatron status

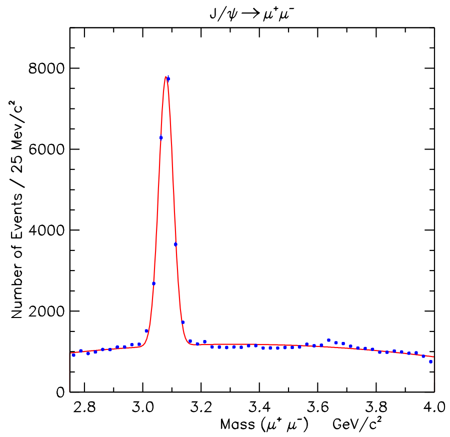


- **luminosity far from nominal**
- $200\mathrm{pb}^{-1}$ **promised for 2002**
- **SVT is being commissioned**
- **Level2 triggering is being commissioned**
- **trigger commissioning should be done by Jan**
- **physics running from then**

Detector status

- **COT tracking is in good shape**
- **SVX tracking getting into shape**
- **two track trigger has taken test runs**
- $D^0,\ \phi^0, D^*$ **seen in 2track data**

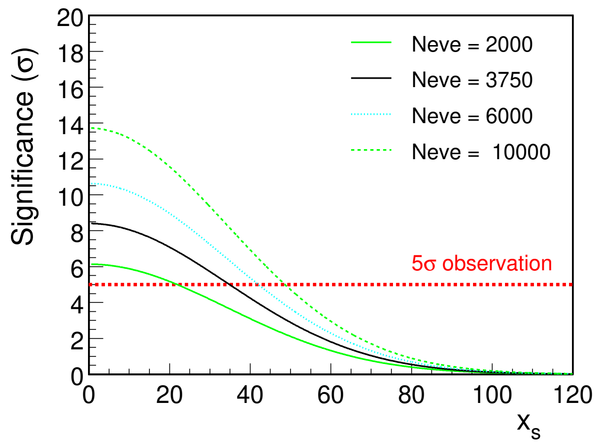


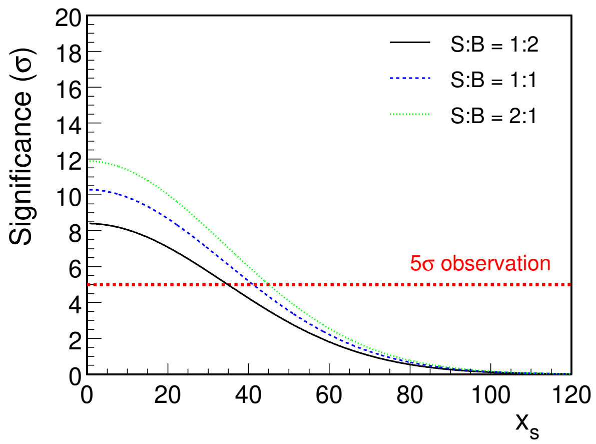


- **muon systems produced J/**Ψ **peak**
- **Ecal systems see J/**Ψ **too**
- $B^+ \to J/\Psi K^+$ **seen**
- **TOF getting calibrated, 100 ps seems reachable**

What can be done by summer?

- **assume 200 pb for 2002 $\rightarrow$**
- **assume 100 pb available by summer**
- **scale down 75000 events $\rightarrow$ 3750**
- **assume taggers will work as planned**





- 5σ **reach up to** $\mathrm{x_s} \sim 35$ **(**$\Delta m_s = 23.3ps^{-1}$**)!**
- **Pessimistic (2k events):** $x_s \sim 25$ **(**$\Delta \mathrm{m_s} = 17.1\mathrm{ps}^{-1}$**)**
- **a relevant measurement is possible**

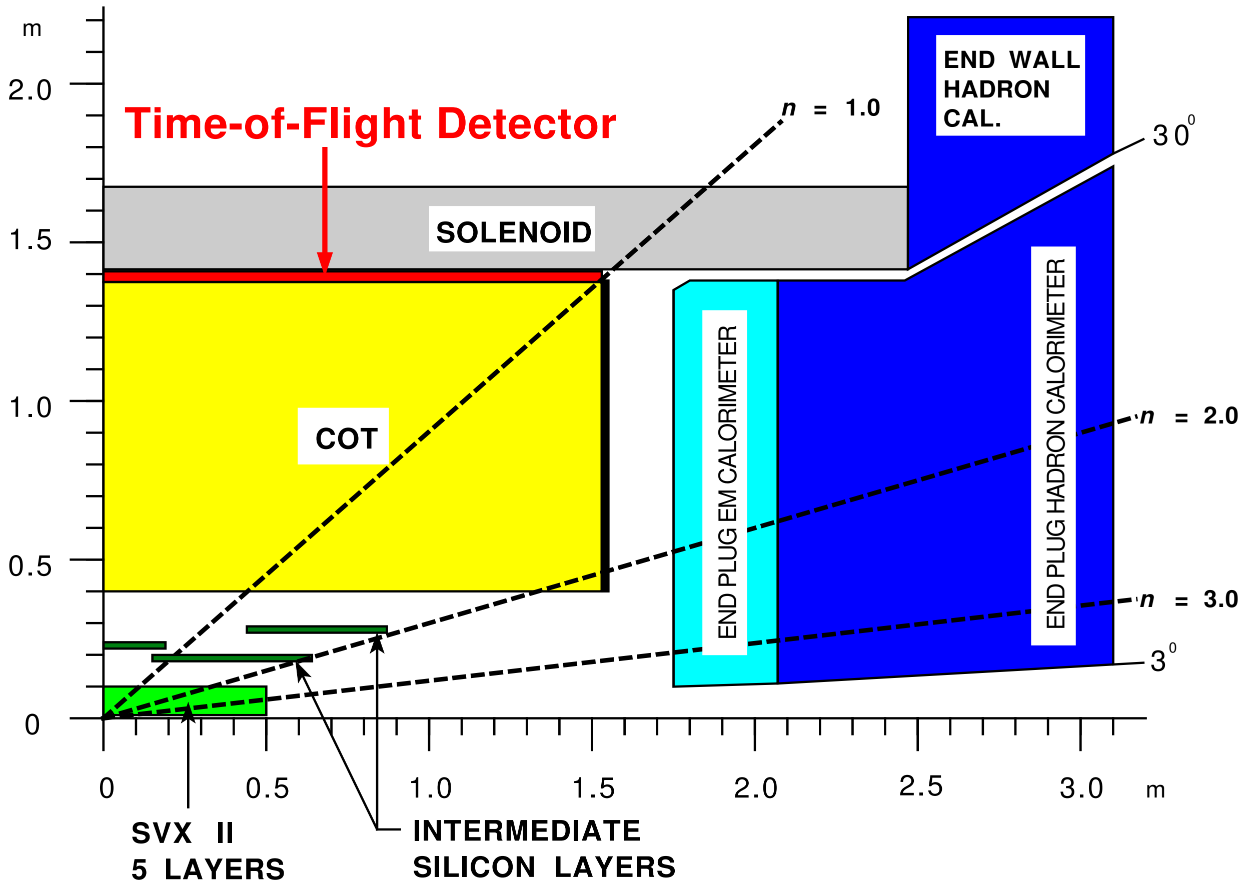
Involvement at CDF so far:

- **Level3 trigger run control development**
- **Time Of Flight test stand work**
- **Level3 + Event Builder expert on call**
- **participated in developing GenTrig**
- **two track trigger event yield for $\mathrm{B_s}$**
- **Time Of Flight installation**
- **Time Of Flight reconstruction software**
- **Level3 upgrade**
- **readout of first Time Of Flight data**
- **tracking data compression**
- **looking at two track trigger test data**
- **beamline for inclusive B $c\tau$ measurement**

Conclusions:

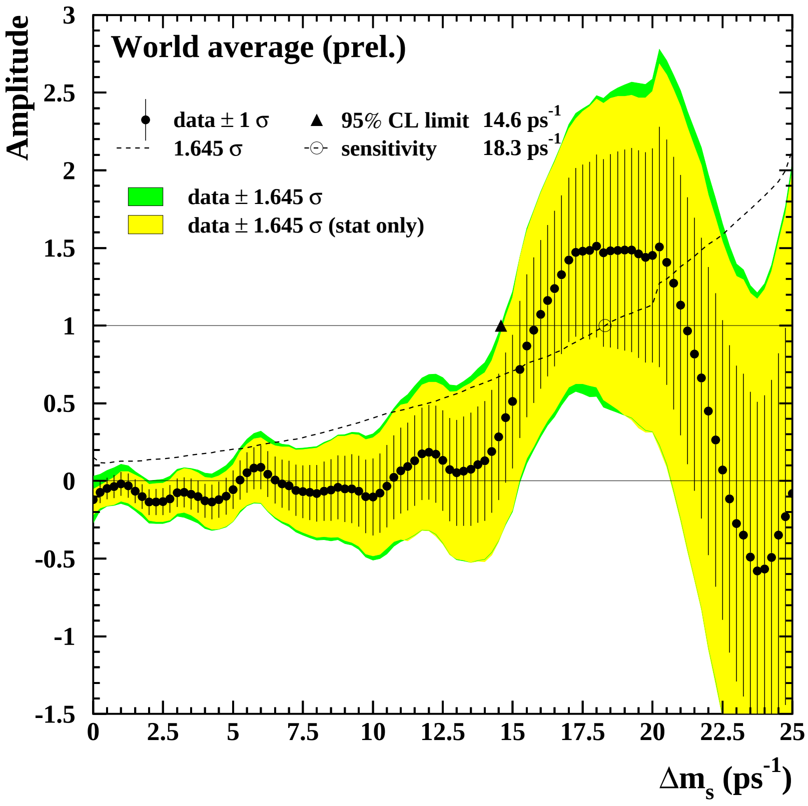
- $\mathrm{B_s}$ mixing interesting for understanding CKM
- key elements: ct measurement, tagging
- CDF can measure ct precisely
- various tagging strategies are available
- two track trigger gathers hadronic decays
- measurement in the relevant x_s area possible
- even with little data!
- propose to go ahead and do it

TOF, briefly:



- **216 scintillator bars, between COT and solenoid**
- **single bar bar covers** $\delta\phi = 5/3^{\mathrm{o}}$, $|\eta| < 1$
- **each bar read out by two PMT's**
- **design timing resolution** ≈ 100 ps
- 3σ **kaon - pion separation to 1.5 Gev**

The latest on Δm_s:



- **combined B_s amplitude as a function of Δm_s**
- **combined result: $\Delta m_s > 14.6\ \mathrm{ps}^{-1}$ (95% C.L)**
- **a value consistent with 1 is expected at the true value**