CP Violation, Mixing and Rare Decays at the Tevatron Now and in Run II

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Heavy Quarks at Fixed Target ’98

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Outline

1. **Introduction: b-physics in the $p\bar{p}$ environment**
2. **Run I:**
   - **detector, trigger, analysis strategies**
   - **mixing results**
   - $B^0/\bar{B}^0 \to J/\psi K_s^0 \;\Rightarrow\; \sin(2\beta)$
3. **Upgrades for Tevatron Run II**
   - **accelerator**
   - **DØ**
   - **CDF**
4. **Run II:**
   - $\sin(2\beta)$
   - $B^0/\bar{B}^0 \to \pi^+\pi^- \;\Rightarrow\; \sin(2\alpha)$
   - B_s **mixing (Run I result)**
   - **rare B decays (Run I results)**
5. **Conclusion**

B physics at the Tevatron

- $\sigma_{b\bar{b}} \sim 100\,\mu b$

  $\Rightarrow$ 10^{11} $b\bar{b}$ **pairs per year (**$1\,\mathrm{fb}^{-1}$**)**

  $\Rightarrow$ **all species produced:**
  B^0**,**B^+**,**B_s**,** b**-baryons,** B_c**,**Υ_{4s}

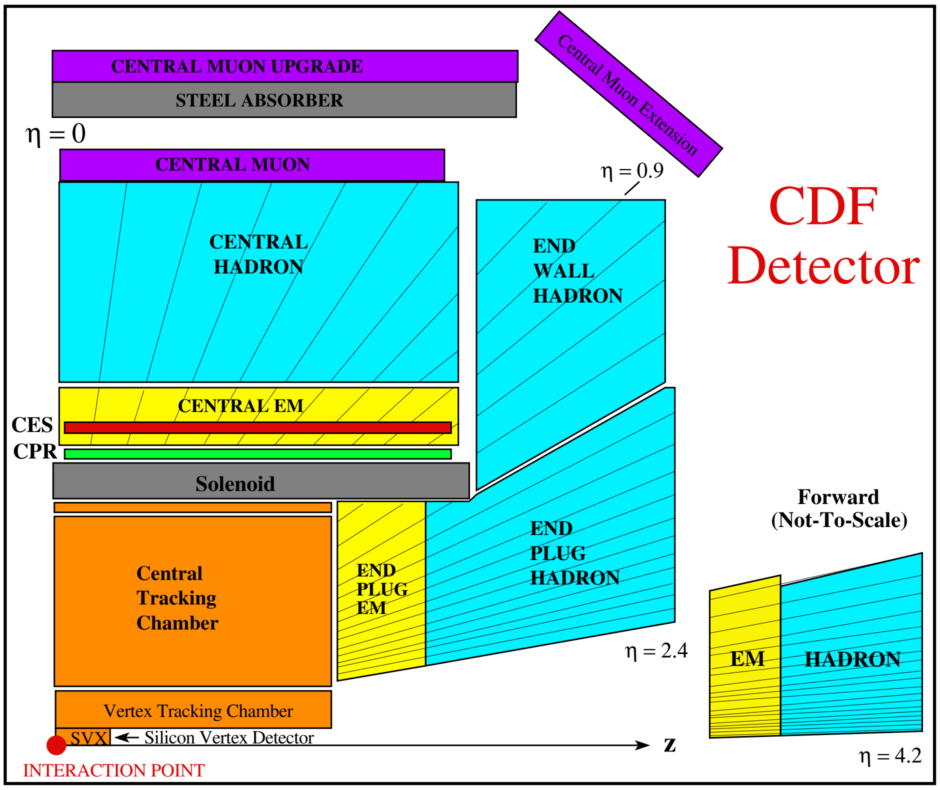
- $\sigma_{b\bar{b}}/\sigma_{inelastic} \sim 10^{-3}$
  - **trigger on leptons from** B **decays**
    - $b \to l\nu c$
    - $b \to J/\psi X$**,** $J/\psi \to \ell^+\ell^-$
  - **utilize long lifetime** $\tau_B = 1.6\,\mathrm{ps}$ **(**$= 462\mu m$**)**
  - **good mass resolution improves S/B**

- $p_T(B)$ **spectrum is soft**
  - **mean** $p_T(B) \sim 10\,\mathrm{GeV/c}$
    - $B \to J/\psi K^0_S$**, with** $2\,\mathrm{GeV}$ **trigger requirement on both muons from** J/ψ
  - **tracking at low** p_T **(few hundred MeV/c)**
  - **forward tracking coverage**

Lessons from Run 0 & Run 1

- large b hadron samples available
  - precision lifetime measurements ($B^{0,+}$, B_s,Λ_B)
  - cross section and branching ratio measurements
  - measurements of heavier B hadrons (Λ_B,B_c)
  - limits on rare processes
- mixing and CP measurements:
  - need to tag B^0-meson flavor at production
  - measure flavor asymmetry (or decay rate) vs. proper time
- crucial hardware:
  - central tracking (momentum & mass resolution)
  - precision vertexing (decay length)
  - trigger (high bandwidth, lepton ID)
  - lepton ID

Run I Detectors



- **CDF features:**
  - **Silicon vertex detector (SVX)**
    (~ 50cm long, 2-D, only 60% coverage)
  - **Central tracking chamber (CTC)**
    (covers $|\eta| < 1$)
  - **Muon systems**
    ($|\eta| < 1.1$, but CMX has holes)
  - **Electron calorimetry**
    ($|\eta| < 2.4$, but tracks only for $|\eta| < 1$)
- **DØ features:**
  - **Excellent calorimetry, but...**
  - **No magnetic field, no silicon**

Run I trigger system

Example: CDF

beam crossing

~ 300 kHz — rate at $\mathcal{L} = 2 \times 10^{31}$

Level 1 — subsystems *(muon chambers, calorimeters...)*

2000 Hz

Level 2 — combine subsystems *(muon and electrons + tracking info)*

30 Hz

Level 3 — full event reconstruction

10 Hz

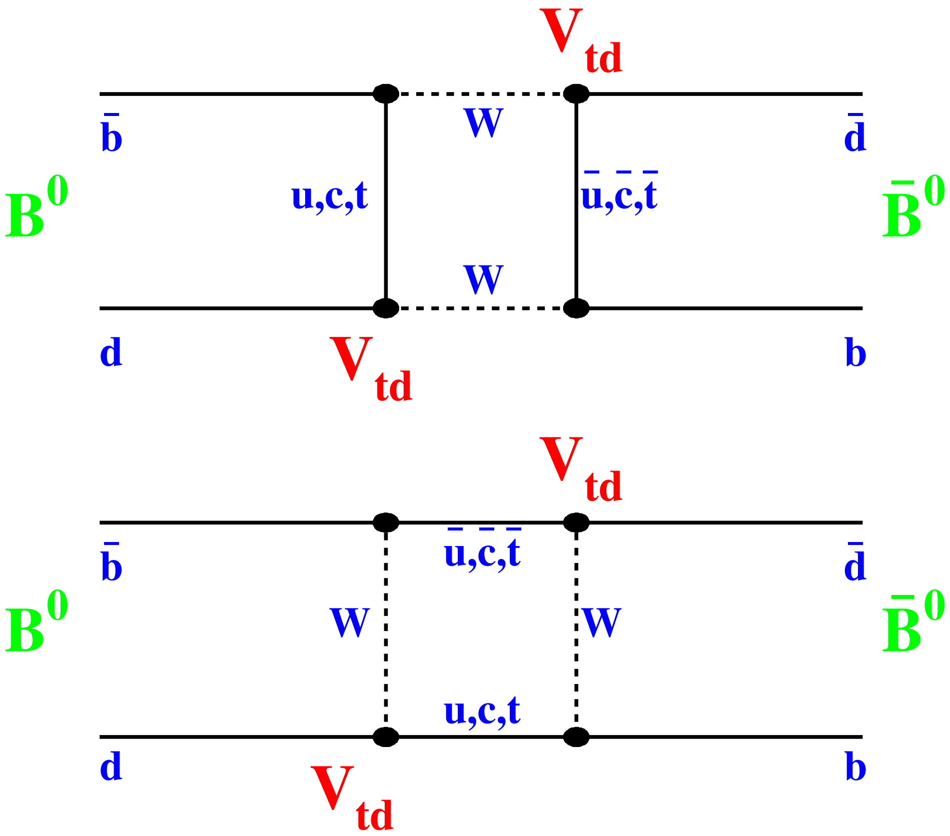
out to tape

Central Fast Tracker: (unique to CDF)

- uses lookup table of hit patterns
- returns p_T of the best match

$\Longrightarrow$ cut on $p_T(\mu)$ and $p_T(e)$ at Level 2

$B^0/\bar{B}^0$ Mixing



$B^0, \overline{B^0}$: Flavor Eigenstates

$B_H^0, B_L^0 : CP$: Eigenstates

$$\Delta m_s = m_L - m_H$$

$$\Delta\Gamma = \Gamma_L - \Gamma_H \, (\simeq 0)$$

For initial state $= B^0$**:**

$$P(B^0(t)) = \frac{1}{2}\Gamma e^{-\Gamma t}(\cosh(\frac{1}{2}\Delta\Gamma t) + \cos(\Delta m t))$$

$$P(B^0(t)) \simeq \frac{1}{2}\Gamma e^{-\Gamma t}(\quad 1 \quad + \cos(\Delta m t))$$

B^0 **fully mixes to** $\overline{B^0}$ **after** $\Delta m t = \pi \simeq 4.4$ **lifetimes**

Tagging Strategies

- **"tagging by the trigger":**
  require flavor tag as a part of the trigger

- **"tagging offline":**
  collect data first, then find flavor tags offline

Tagging is described by:

- **efficiency**

$$\epsilon \equiv \frac{N_{tag}}{N_{total}}$$

- **dilution**

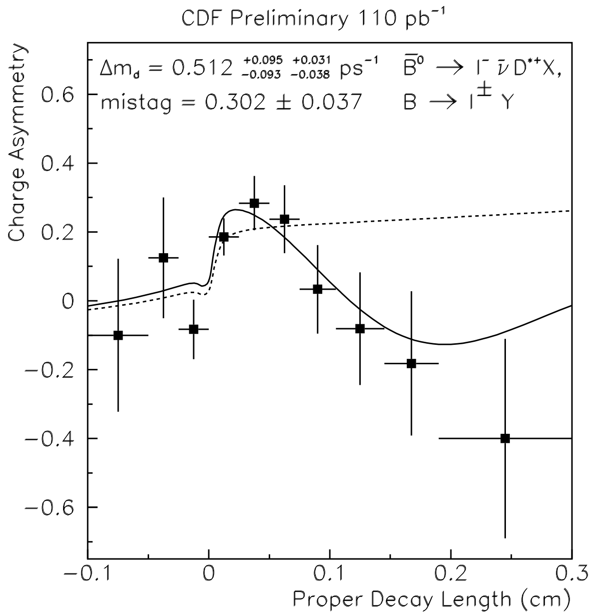
$$\mathcal{D} \equiv \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$

  - $\mathcal{D} = 1 - 2w$, w **is the mistag rate**
  - $e.g.$ **40% mistag rate** $\Rightarrow$ **20% dilution**

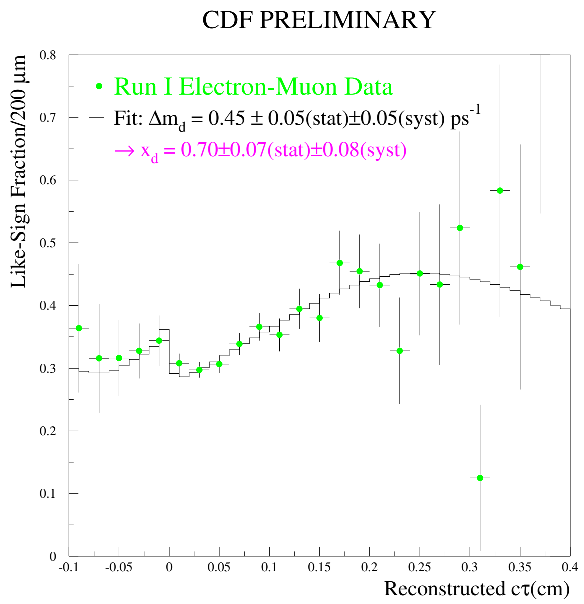
- **figure of merit is** $\epsilon\mathcal{D}^2 \Rightarrow \delta\mathcal{A} \sim \frac{1}{\sqrt{\epsilon\mathcal{D}^2 S}}$

Examples of “tagging by the trigger”

Mixing analyses in dilepton samples



ℓD^{*+} **with** ℓ **OST**
(ℓ/ℓ **trigger)**
($\mathcal{A} = \frac{N_{OS}-N_{SS}}{N_{OS}+N_{SS}}$ **vs.** ct**)**
$\mathcal{A} \sim \mathcal{D}\cos(\Delta m_d t)$



displaced e **or** μ **vertex with a** μ **or** e **OST**
(e/μ **trigger)**
($\mathcal{A} = \frac{N_{SS}}{N_{OS}+N_{SS}}$ **vs.** ct**)**
$\mathcal{A} \sim \mathcal{D}\sin(\Delta m_d t)$

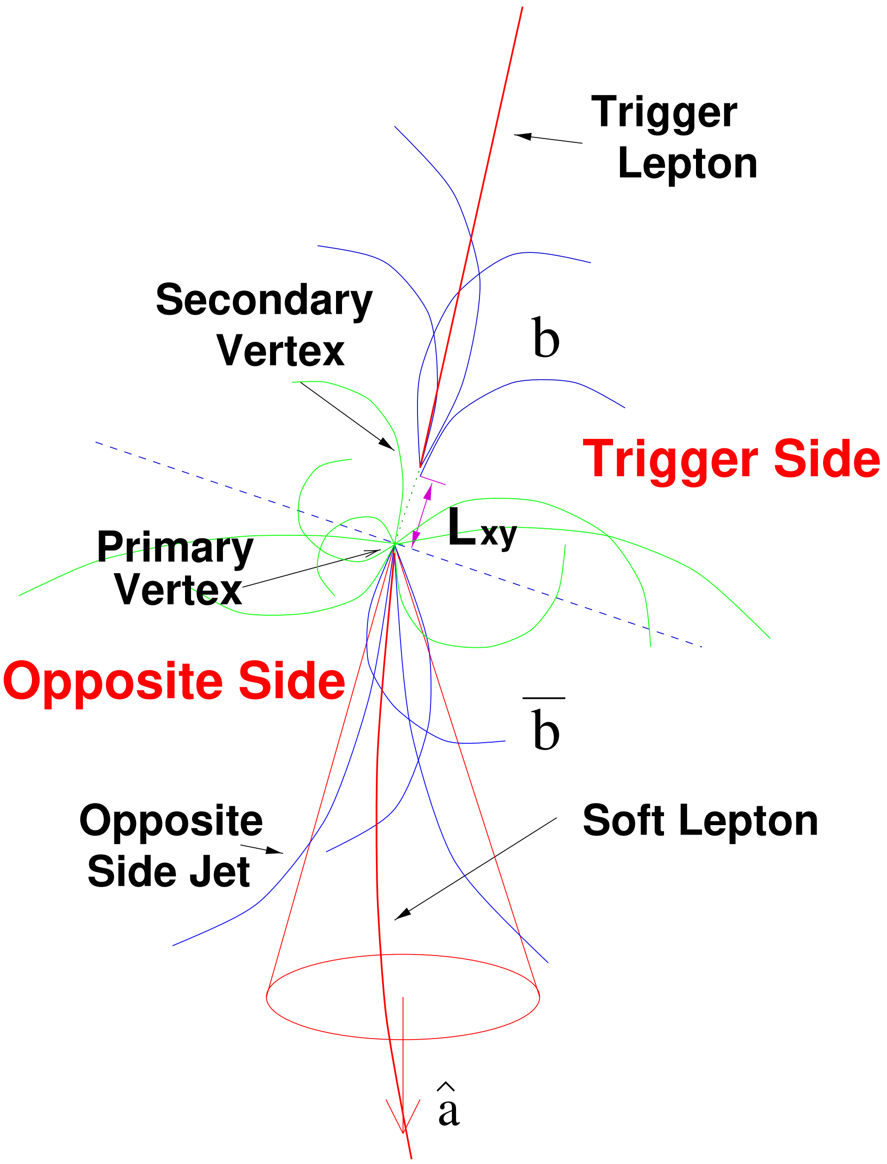
Inclusive Lepton Analysis

- Single lepton trigger

  8 GeV/c electrons 12 GeV/c muons

- Reconstruct secondary vertex associated with trigger lepton

- use other information in the event for flavor tagging

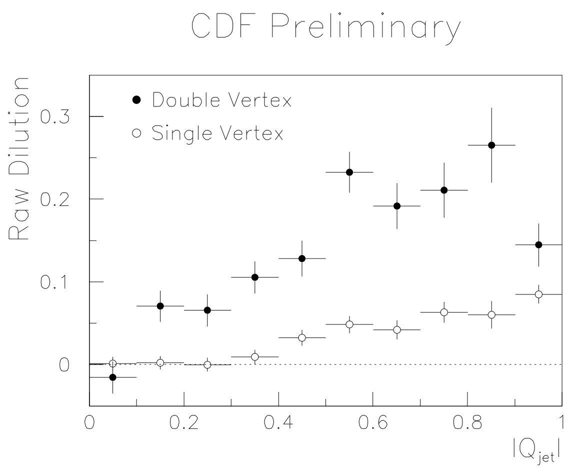


Opposite Side Tagging

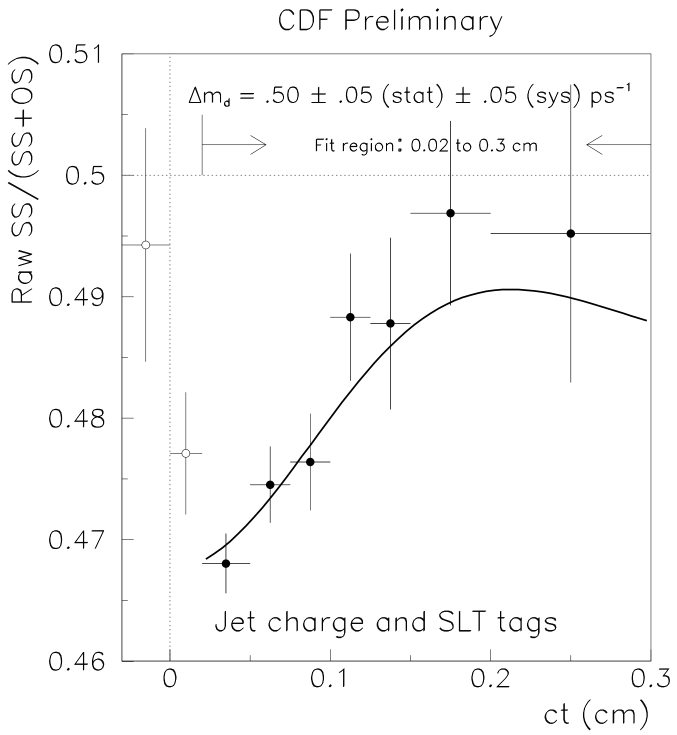
- **Soft Lepton Tagging (SLT)**
  single lepton trigger, find tagging lepton offline
  very high dilution, very low efficiency

- **Jet Charge Tagging (JetQ)**
  single lepton trigger, find jet offline
  $$Q_{jet} = \frac{\sum_{i=1}^{N_{tracks}} q_i \cdot (\vec{\mathbf{p}}_i \cdot \hat{\mathbf{a}})}{\sum_{i=1}^{N_{tracks}} (\vec{\mathbf{p}}_i \cdot \hat{\mathbf{a}})}$$
  higher efficiency, but lower dilution

Applied to inclusive lepton sample (e or μ)



- **$\ell+$secondary vertex on one side**
- **JetQ on opposite side**
- **$\mathcal{D}$ versus Q_{jet}**



($\mathcal{A} = \frac{N_{SS}}{N_{OS}+N_{SS}}$ vs. ct)

$$\mathcal{A} \sim \mathcal{D} \sin(\Delta m_d t)$$

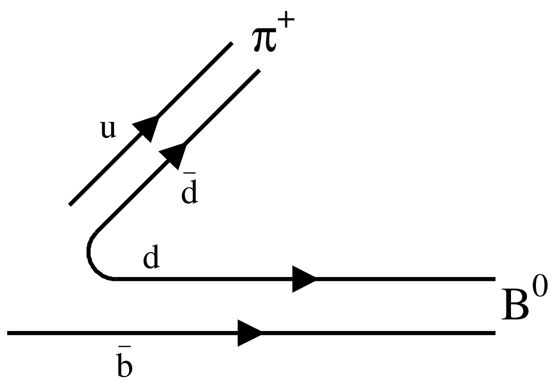
"Same-side" Tagging

Problems with opposite-side tagging:

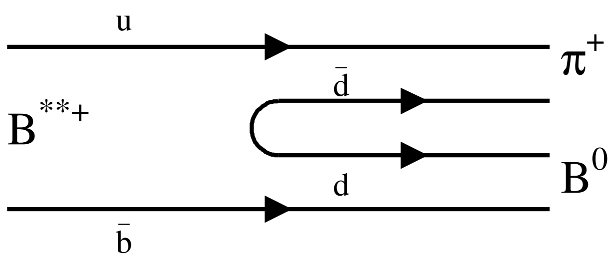
- **opposite b-hadron is central only 40% of the time**
- **if opposite b-hadron is B^0 or B_s, might have mixed**

Same Side Tagging (SST):

- **use charged particles around B meson to get the b flavor**
  - **correlation could be through fragmentation**
  - **or through excited states (B^{**})**



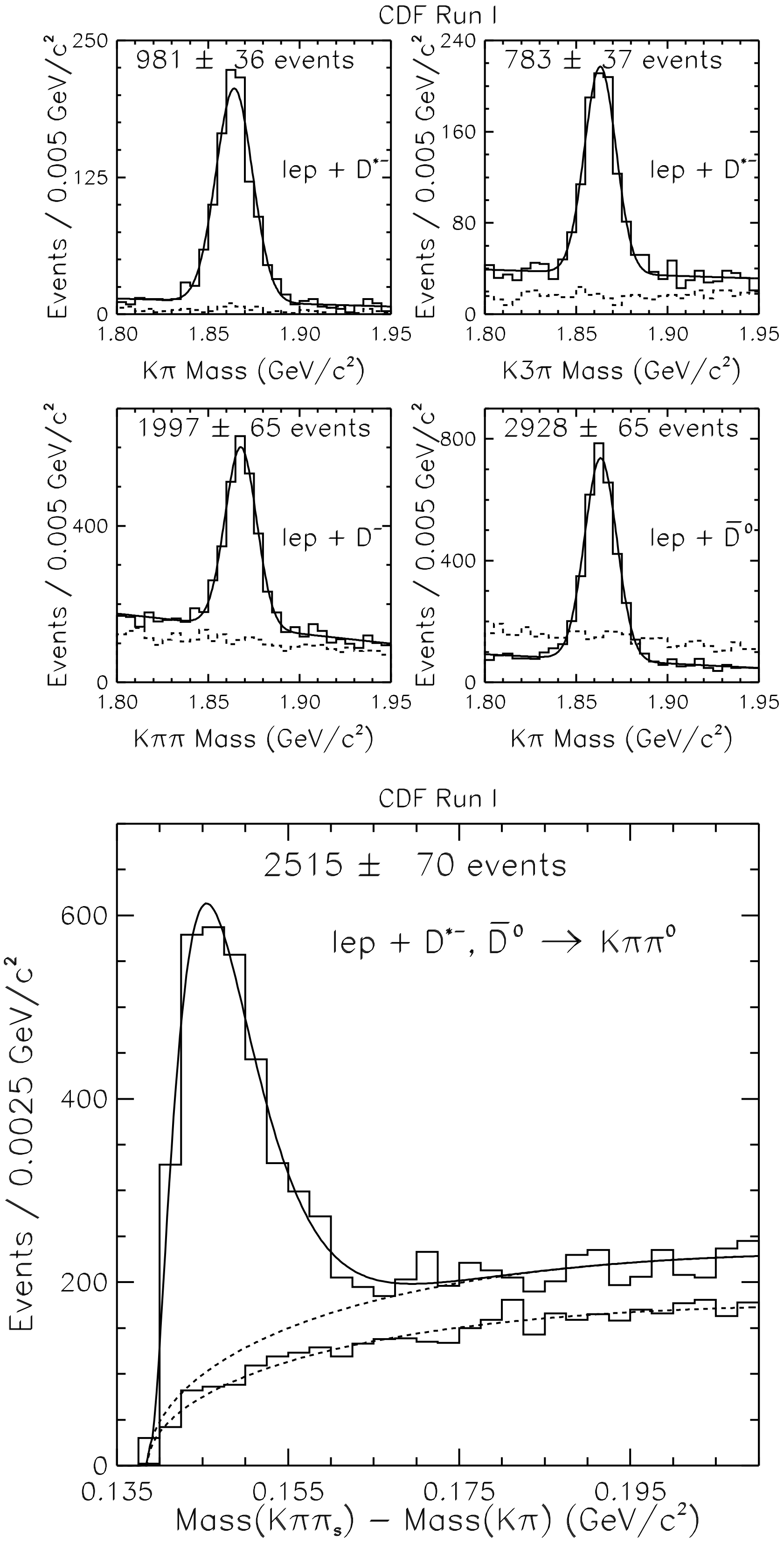
fragmentation



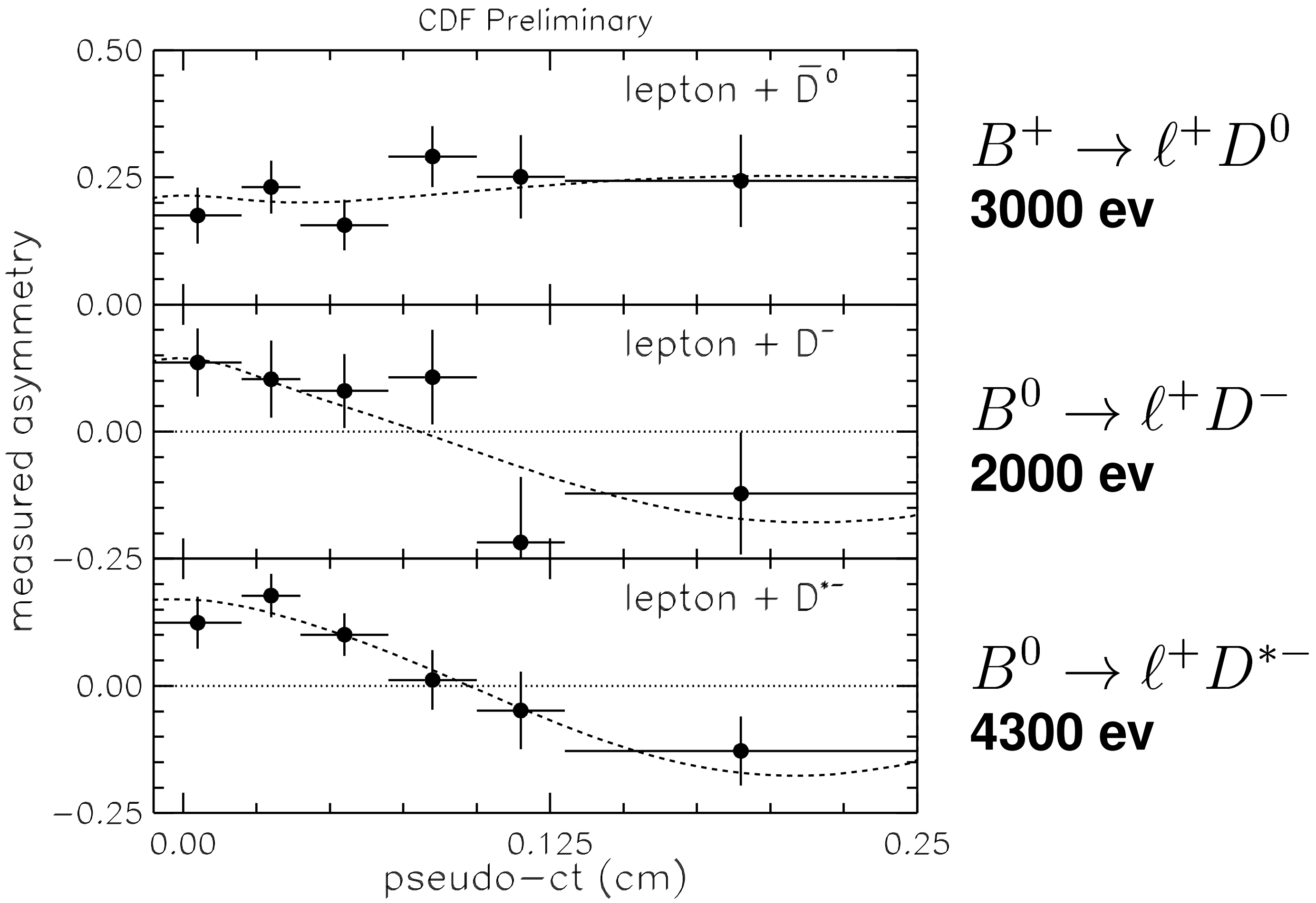
via B**

- **high tagging efficiency ($\sim 70\%$)**
- **no requirement on second B**

Run I Lepton+Charm Samples

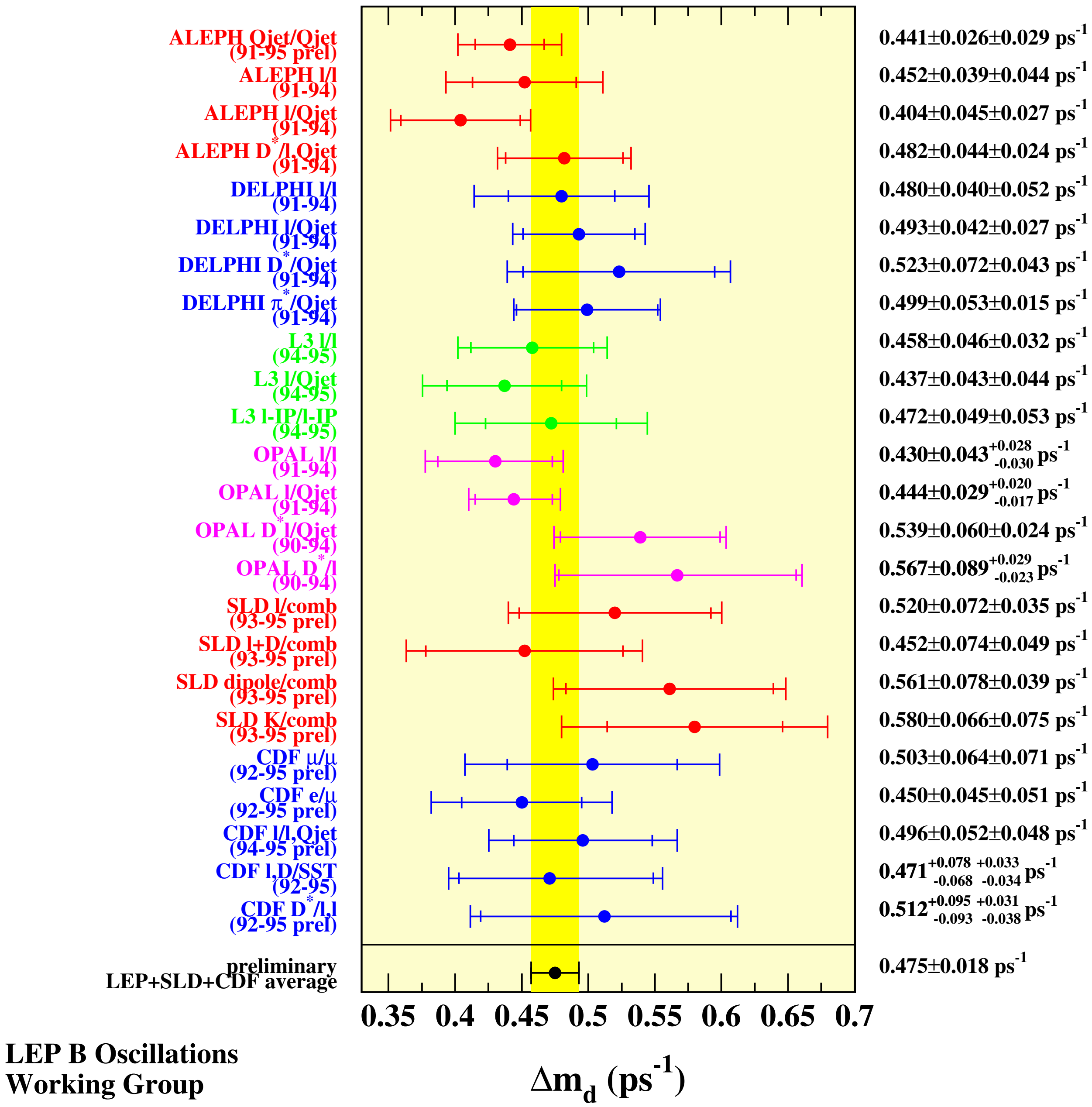


Same Side Tagging in the ℓD Sample



- $B^\pm \to \ell^\pm \nu D^0 (D^{*0})$
  - $\mathcal{D}^+ = 0.27 \pm 0.03(\mathrm{stat}) \pm 0.02(\mathrm{syst})$
- $B^0/\overline{B}^0 \to \ell^\pm \nu D^\mp (D^{*\mp})$
  - $\mathcal{D}^0 = 0.18 \pm 0.03(\mathrm{stat}) \pm 0.02(\mathrm{syst})$
  - $\Delta m_d = 0.47^{+0.078}_{-0.068}(\mathrm{stat}) \pm 0.034(\mathrm{syst})\,\mathrm{ps}^{-1}$

Summary of Mixing Measurements



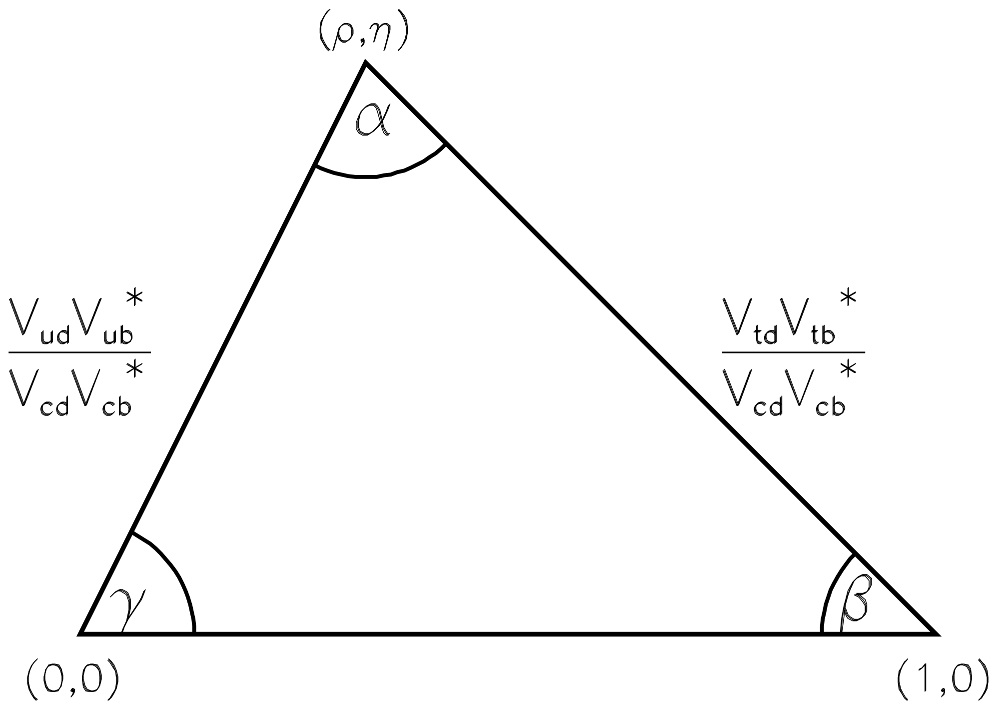
- **CDF average:**
  $$\Delta m_d = 0.481 \pm 0.028(\mathrm{stat}) \pm 0.027(\mathrm{syst})\ \mathrm{ps}^{-1}$$
- **World average:**
  $$\Delta m_d = 0.475 \pm 0.010(\mathrm{stat}) \pm 0.014(\mathrm{syst})\ \mathrm{ps}^{-1}$$
  (includes CDF results)

The Cabibbo-Kobayashi-Maskawa Matrix

The Wolfenstein parameterization:

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

- $\lambda = sin\theta_C$, **sine of the Cabibbo angle**
  - $\Gamma(K \to \pi) \sim |V_{us}|^2 \simeq sin^2\theta_C = \lambda^2$
- **unitarity** $\Rightarrow V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0$



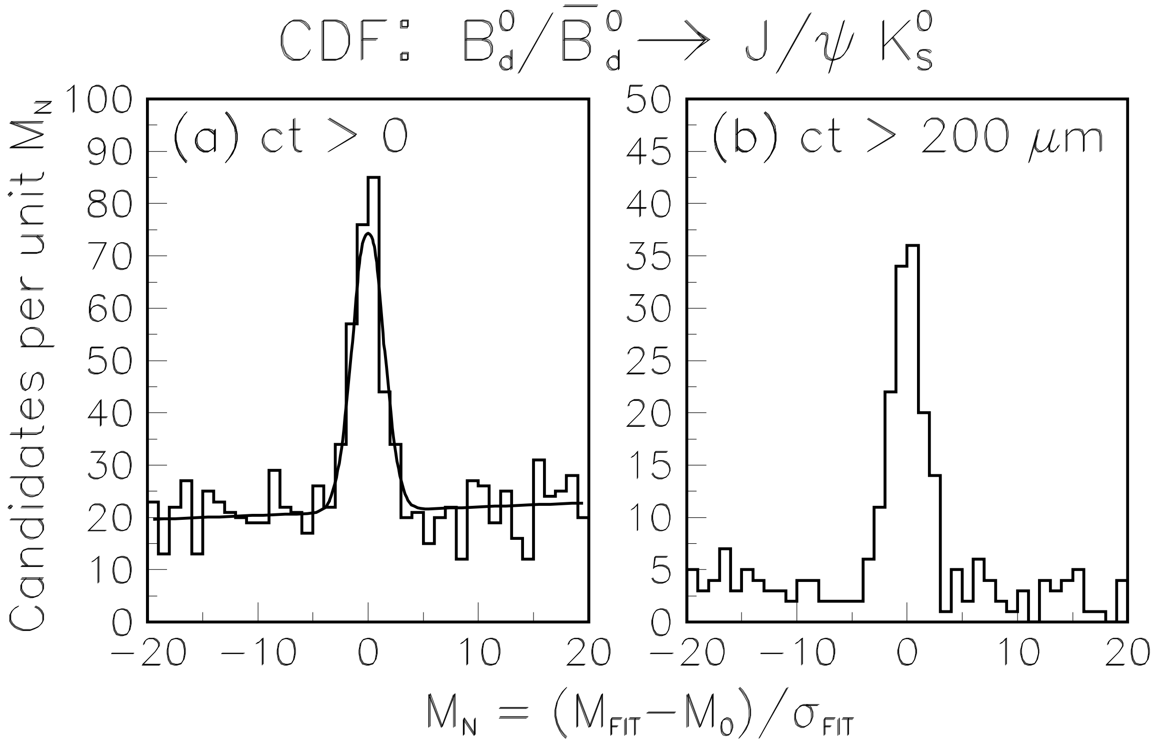
The unitarity triangle

CP Violation in $B \to J/\psi K_s^0$

$$A_{CP} = \frac{N(\overline{B}^0 \to \psi K_S^0) - N(B^0 \to \psi K_S^0)}{N(\overline{B}^0 \to \psi K_S^0) + N(B^0 \to \psi K_S^0)}$$

- $A_{CP}(t) = sin2\beta \times sin(\Delta m t)$
- **time integrated:** $A_{CP} = \frac{x_d}{1+x_d^2} sin2\beta \simeq 0.47 sin2\beta$
- $A_{CP}^{obs} = \mathcal{D} A_{CP}$
  - $\mathcal{D}$ **is the "tagging dilution"**
  - $\mathcal{D} = (N_R - N_W)/(N_R + N_W)$
  - $N_R(N_W)$ = **number of correct (incorrect) tags**
- $\delta \sin(2\beta) \approx \frac{1+x_d^2}{x_d} \frac{1}{\sqrt{\epsilon \mathcal{D}^2 S}} \sqrt{\frac{S+B}{S}}$
  - ϵ **is the "tagging efficiency" (fraction of events that can be tagged)**
  - $x_d = \Delta m_d / \Gamma$
  - S =**signal,** B =**background**

Run I $B \to J/\psi K_s^0$ Sample



- $J/\psi \to \mu\mu$ **trigger**
- **both muons required to be contained in SVX**

  $\Rightarrow$ **time dependent analysis**

- 198 ± 17 **events**

Another ~ 200 events not contained in the SVX (not used in this analysis) from which we can still measure a time-integrated asymmetry.

SST $sin(2\beta)$ Analysis

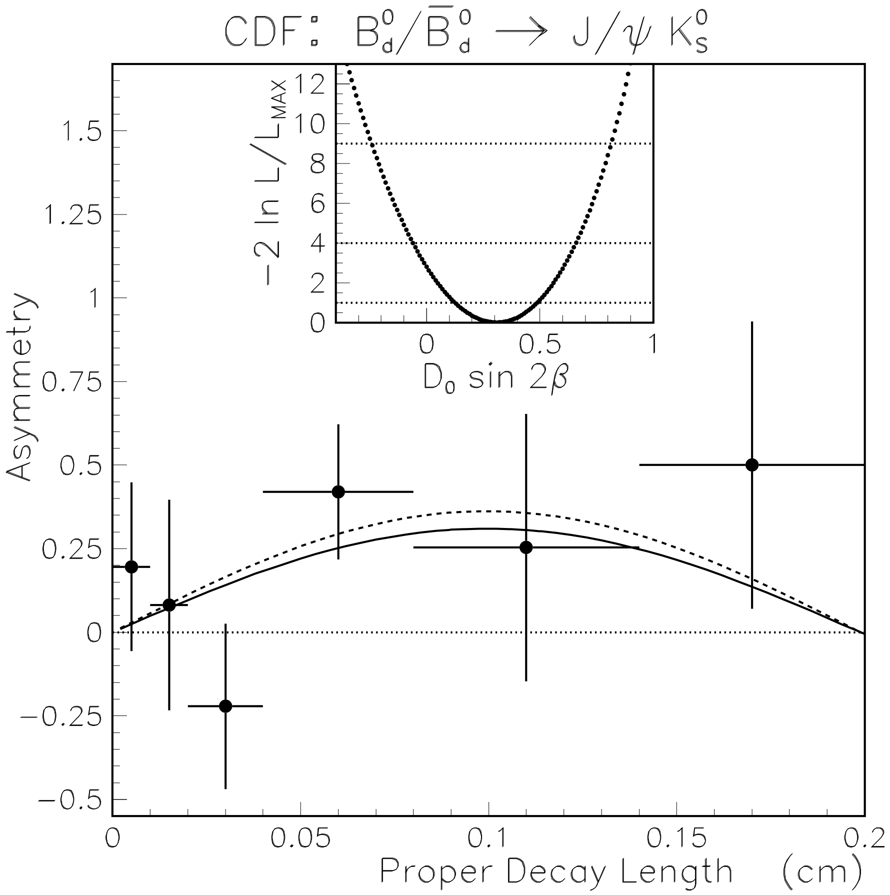
Maximum Likelihood fit in mass and lifetime

- most background is at low lifetime ($\mathcal{A}$ small)
- good S/N at long lifetime ($\mathcal{A}$ is larger)
- time dependent analysis reduces $\delta sin(2\beta)$ by about 30% relative to time-integrated

External inputs:

- same-side tagging dilution
  - calibrated on $\ell D^{(*)}$ samples
  - extrapolated to $J/\psi K_s^0$ using MC
- same-side tagging charge asymmetry
  - few $\%$ at low tagging track p_T
  - negligible above $p_T \sim 750\,\mathrm{MeV}$
  - measured in the inclusive $B \to J/\psi X$ sample

Run I SST/SVX $sin(2\beta)$ Result

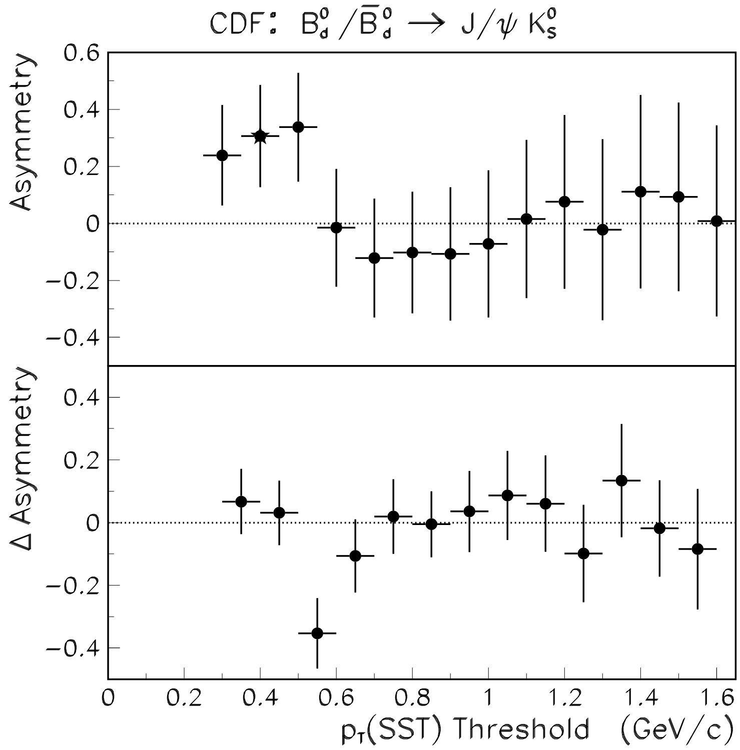


Fit is for $\mathcal{A} = Dsin(2\beta)$

- $\mathcal{A} = 0.31 \pm 0.18(\mathrm{stat}) \pm 0.03(\mathrm{syst})$
- $D = 0.166 \pm 0.018(\mathrm{stat}) \pm 0.013(\mathrm{syst})$
- $sin(2\beta) = 1.8 \pm 1.1(\mathrm{stat}) \pm 0.3(\mathrm{syst})$
  - **statistics limited**
  - **dominant systematic error comes from dilution uncertainty**

Run I SST/SVX $sin(2\beta)$ Result

Asymmetry versus tagging track p_T cutoff:



Limits using Feldman/Cousins frequentist:

- **exclude $sin(2\beta) < -0.20$ at 95% CL**

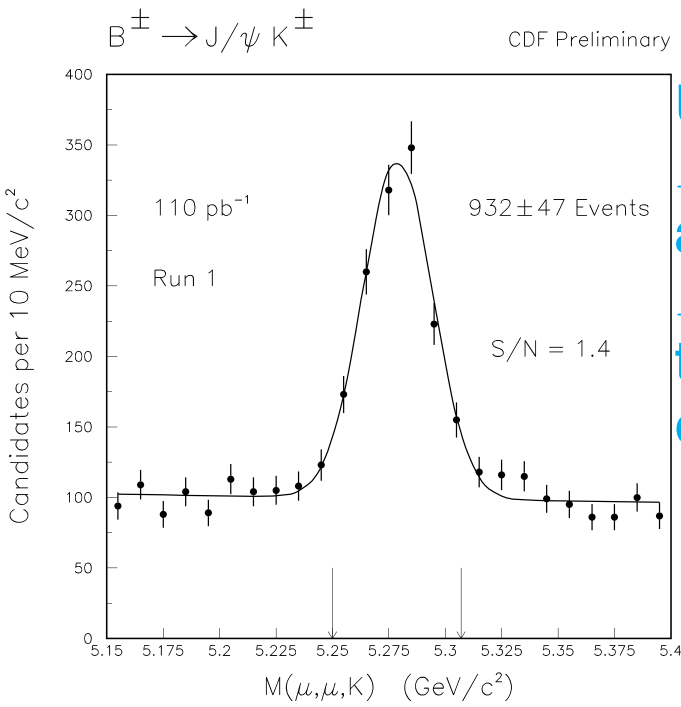
If true $sin(2\beta) = 1$ then

- **expect to exclude $sin(2\beta) < -0.89$ at 95% CL**

Improving the Run I $sin(2\beta)$ Measurement

Work in progress:

- **include non-SVX events**
  - some lifetime information
  - time-integrated contribution non-negligible
- **add in opposite-side tagging**
  - soft-lepton tagging
  - jet charge tagging
- **dilution varies on an event-by-event basis**
  - depends upon the number and type of tag(s)
  - tagging correlations are not a problem



Use
$B^+ \to J/\psi K^+$
and
$B^0 \to J/\psi K^*$
to calibrate
opposite side taggers

Tevatron upgrade

- **Main Injector, debuncher, recycler**
- **More bunches**

  1. **initial:** $36 \times 36 \Rightarrow 396$ns **between beam-X**
     - $\mathcal{L} = 1 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
       ($\bar{N} \sim 3$ interactions per crossing)
  2. **later:** $108 \times 108 \Rightarrow 132$ns **between beam-X**
     - $\mathcal{L} = 2 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
       ($\bar{N} \sim 2$ interactions per crossing)

- **Higher energy,** $\sqrt{s} = 2$ TeV
- $\Rightarrow 2\mathrm{fb}^{-1}$ **delivered in** ~ 2 **years**

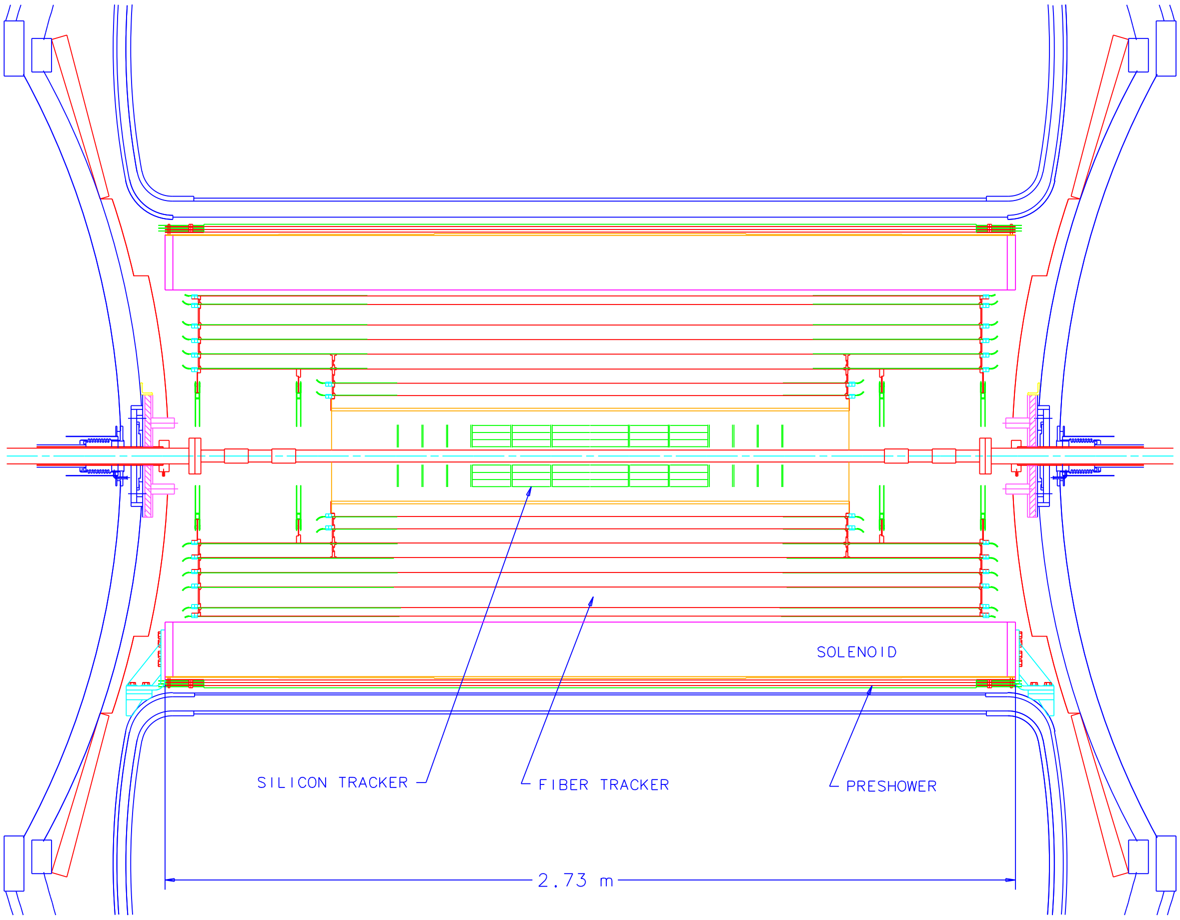
Much *shorter* bunch crossing interval requires:

- **faster detectors**
- **faster signal integration**
- **pipelined readout**
  (*e.g.* silicon detectors $\approx 750k$ channels)
- **time stamps**
  (to keep pipelines in sync)

Detector Upgrades

- DØ and CDF
  - new front end electronics and trigger to handle higher event rates
  - new tracking systems
  - double-sided silicon microvertex detectors $r-\phi$, $r-z$ and small angle stereo
- DØ
  - 2T solenoid
  - 4 layer silicon microvertex detector (+disks)
  - scintillating fiber tracker covers to $\eta = 1.7$
- CDF
  - new drift chamber
  - 5 layer microvertex detector (additional forward strips)
  - impact parameter trigger at Level 2
  - particle ID via dE/dx in drift chamber

The DØ Tracking Volume

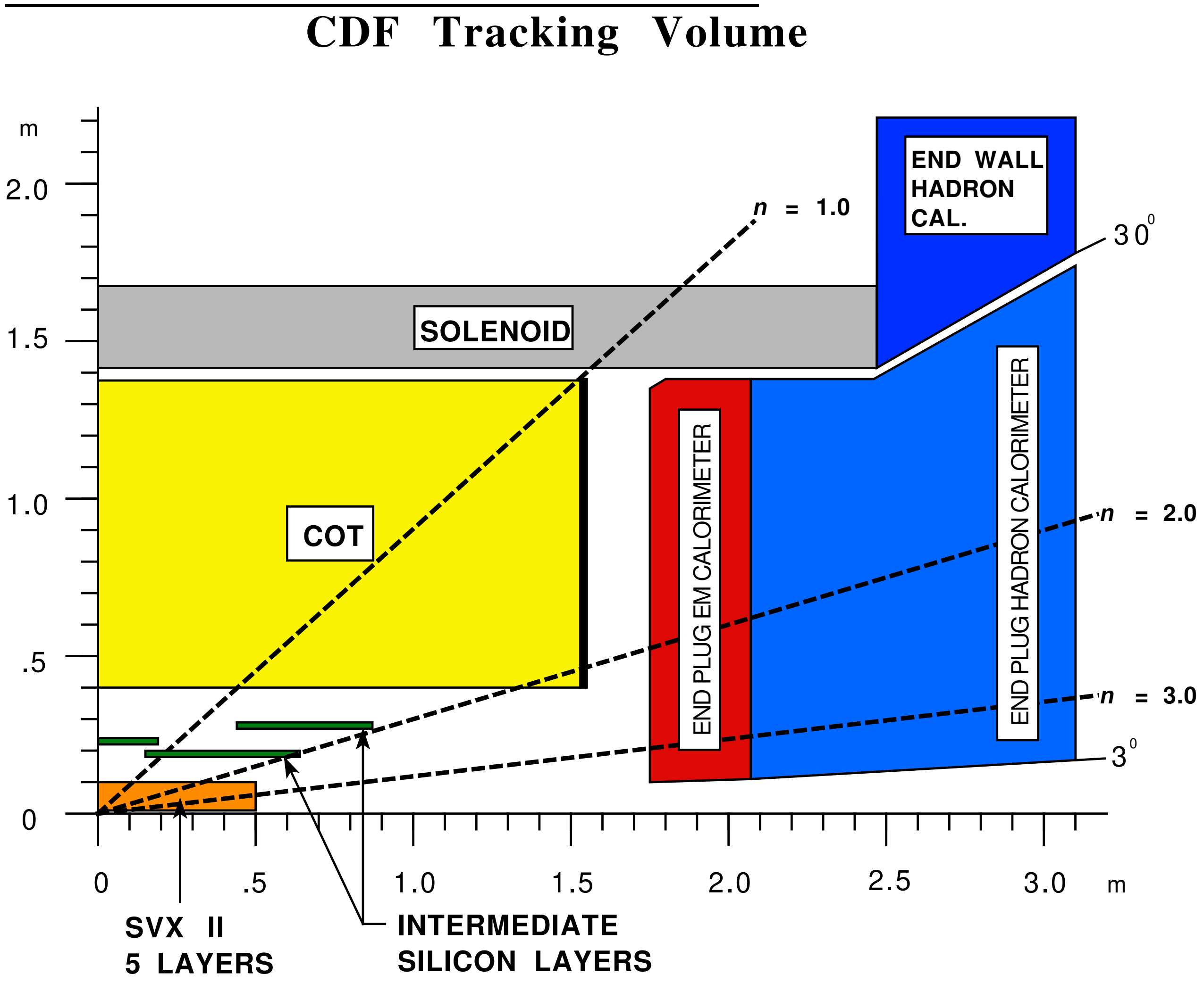


- **4 layer double sided silicon strips ($r-\phi$,$r-z$, $\pm 2^\circ$ stereo)**
- **silicon disks for forward tracking**
- **Sci-Fi tracker**
- **2T magnetic field**

The DØ Upgrade

- **2T Solenoid**
  - $2.7\,\mathrm{m}$ **long;** $r = 60\,\mathrm{cm}$
  - $\Delta p_T/p_T^2 \simeq 0.002$
- **Central Fiber Tracker (CFT)**
  - $835\,\mu\mathrm{m}$ **fibers in a doublet structure**
  - **4 axial layers;4** $\pm 2^\circ$ **stereo layers**
  - **72k channels, VLPC readout**
- **Muon systems**
  - **adding scintillator inside toroids**
  - **mini-drift tubes and scintillator forward**
- **Electrons**
  - **preshower detector surrounding solenoid**
- **Silicon detectors:**
  - **4 layers;(**$r\phi, 90^\circ$**),(**$r\phi, 2^\circ$**), (**$r\phi, 90^\circ$**),(**$r\phi, 2^\circ$**),**
  - **disks** $\pm 15^\circ$**,** $\pm 7.5^\circ$ **forward**
  - $\sim 800k$ **channels, SVXII readout chip**

The CDF Tracking Volume



- 5 layer double sided silicon strips ($r-\phi$,$r-z$, $\pm 3^\circ$ stereo)
- additional silicon strips (ISL) for forward tracking
- Central Outer Tracker (COT) open-cell drift chamber
- 1.5T magnetic field

The CDF Upgrade

- Central open chamber (COT)
  - 4 axial layers (resolution $\approx$ Run I)
  - 4 stereo layers, more wires
    (improved z, $\cot\theta$)
- Muon systems
  - complete CMX
  - IMU: new, extends η coverage
- Electrons
  - plug EM
- Silicon detectors:
  - SVXII – 1.7 times longer than SVX$'$
  - SVXII – 5 layers of silicon, 3-D
  - ISL (intermediate silicon layer): one to two layers of silicon between SVXII and COT

SVXII + ISL: tracking coverage beyond $|\eta| = 1.0$

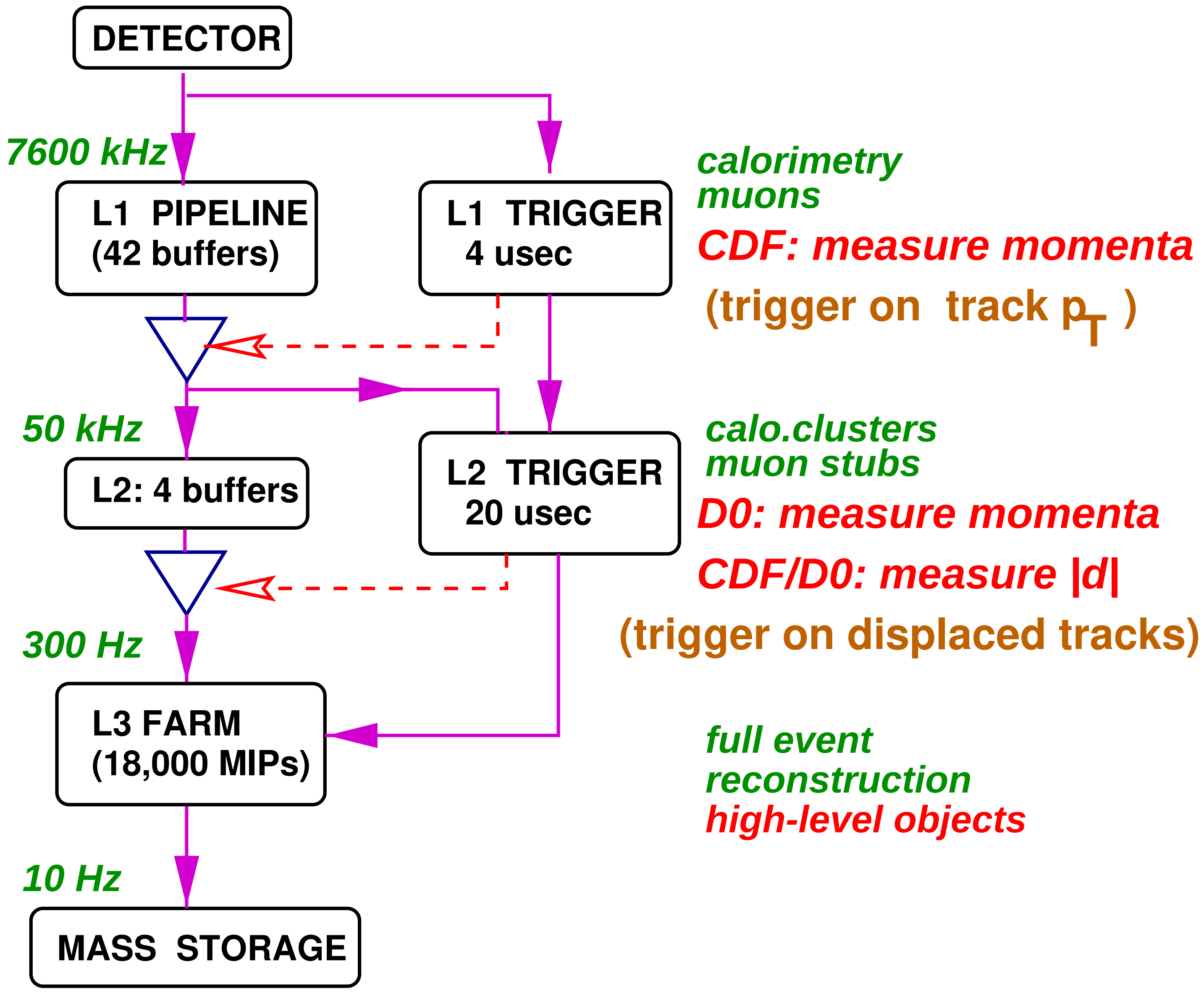
$\Rightarrow$ improved e, μ reconstruction for Soft Leptons

$\Rightarrow$ improved coverage for Jet Charge

Trigger & DAQ overview

Goal: collect as many B's as possible

$\Rightarrow$ **Trigger + SVX DAQ run in deadtimeless mode**



b-physics triggers

- **Level 1: use lepton info + tracking trigger**
- **Level 2: use Secondary Vertex Tracker (SVT) (find displaced tracks!)**
- **Level 3: some potential algorithms:**
  - **find secondary vertex seeded by SVT track(s)**
  - **(semi)exclusive B meson reconstruction**

New trigger paths

- **XFT, SVT, DAQ: two displaced tracks (*e.g.* for $B^0 \to \pi^+\pi^-$, $B_s \to D_s\pi$)**
- **XFT, SVT: lepton $+$ displaced track(s) (*e.g.* $B_s \to D_s\pi$ with a flavor tag)**

Flavor tagging improvements

For “offline” tagging

tagger	$\epsilon\mathcal{D}^2$ [%] measured Run I	$\epsilon\mathcal{D}^2$ [%] expected Run II	Relevant upgrade
Same Side π	1.8 ± 0.4	2.0	new tracking
Soft μ	0.72 ± 0.12	1.0	extend coverage
Soft e	0.35 ± 0.04	0.7	new tracking
Jet Charge	0.78 ± 0.15	3.0	new tracking
Opp.Side Kaon	–	3.0	Time-Of-Flight
All combined	3.7	6.7 (9.7)	

$J/\psi K_S$ sample size

$J/\psi \to \mu^+\mu^-$:

1. Run I: 200 events in SVX
2. $\times 2000/110$ for total $\int \mathcal{L}dt$
3. $\times 1.5$ for longer SVX
4. $\times 2$ for extended $\mu\mu$ acceptance

$\Rightarrow \approx 10,000\ J/\psi K_S$ events in Run II

$J/\psi \to e^+e^-$: much harder to estimate

$\Rightarrow$ Expect up to 50% more $J/\psi K_S$ events

Error on $\sin 2\beta$

Error for a *naive* time-integrated analysis:

$$\sigma(\sin 2\beta) \approx \frac{1+x_d^2}{x_d}\frac{1}{\sqrt{S\epsilon\mathcal{D}^2}}\sqrt{1+\frac{B}{S}}$$

However, extrapolate from Run I errors

- **from** $\mathcal{A}_{CP} = \mathcal{D}\sin 2\beta \Rightarrow$

$$\sigma(\sin 2\beta) = \frac{\sigma(\mathcal{A}_{CP})}{\mathcal{D}} \oplus (\sin 2\beta_{true})\frac{\sigma(\mathcal{D})}{\mathcal{D}}$$

- **statistical:** $\sigma(\mathcal{A}_{CP})/\mathcal{D}$

- **systematic:** $(\sin 2\beta_{true}) \times (\sigma(\mathcal{D})/\mathcal{D})$
  from uncertainty on the dilution

- **in Run II measure dilutions in:**

tagger	$\epsilon\mathcal{D}^2$ [%]	cal.sample	size
SST	2.0	$J/\psi K^{*0}$	18,400
SLT	1.7	$J/\psi K^+$	42,700
JetQ	3.0	$J/\psi K^+$	42,700

- **by definition have enough $J/\psi K^+$ and $J/\psi K^{*0}$ to calibrate $\mathcal{D}$**

Error on $\sin 2\beta$ – cont'd

- $\sin 2\beta_{true}$ = the ***true*** value of $\sin 2\beta$
  (assume worst case: $\sin 2\beta_{true} = 1$)
- assume same relative yields between samples
- assume same S/B as in Run I in all samples
- error on $\sin 2\beta$ broken by tagger:

tagger	$\epsilon\mathcal{D}^2$ [%]	calibration sample	$\sigma(\sin 2\beta)$
SST	2.0	$J/\psi K^{*0}$	0.17
SLT	1.7	$J/\psi K^{+}$	0.16
JetQ	3.0	$J/\psi K^{+}$	0.12

- all taggers combined:

$$\sigma(\sin 2\beta) = 0.08$$

(for $N(J/\psi K_S) = 10,000$)

Error on $\sin 2\alpha$

Main problems:

- **Low branching fraction:**
  $BR(B^0 \to \pi^+\pi^-) \approx 0.5 \times 10^{-5}$

- **Trigger: use XFT+SVT to tag displaced $\pi^\pm$**

  ($p_T > 3$ and 2 GeV$/c$, $|d_0| > 100\mu\mathrm{m}$)

  (rate high but acceptable)

  $\Rightarrow$ **expect signal $S \approx 9,200$ with $S/B \approx 1/4$**

- **$K\pi$, KK backgrounds: estimate from combined dE/dx and $m(\pi^+\pi^-)$ fit in full sample (before tagging)**

- **Theoretical uncertainties: still a problem**

Error on integrated $\mathcal{A}_{CP}$:

$$\sigma(\mathcal{A}_{CP}(B \to \pi\pi)) \approx \frac{1}{0.82} \times \frac{1}{\sqrt{S\epsilon\mathcal{D}^2}} \times \sqrt{1 + \frac{B}{S}}$$

($|d_0|$ cut bias $\Rightarrow (1 + x_d^2)/x_d \to 0.82$)

$$\Rightarrow \sigma(\mathcal{A}_{CP}(B \to \pi\pi)) \approx 0.11$$

Expect improvement from time-dependent analysis.

Comparison of B Factory Expectations

Summary of SOME CP Violation Measurements for the next generation of B experiments after $\sim$1 year of running:

		BELLE	BaBar	Hera-B	DØ	CDF
$\int \mathcal{L}dt\,(\mathrm{fb}^{-1})$		100	30	100	1	1
N($B \to \psi K_S^0$)		2000	1100	1500	4k	5k
$\delta(sin2\beta)$	ψK_S^0	0.080	0.098	0.13	0.20	0.12
	all modes	0.062	0.059	0.12	0.20	0.12
N($B \to \pi^+\pi^-$)		650	350	800	–	4.6k
$BR(B \to \pi^+\pi^-)^*$ ($\times 10^{-5}$)		1.3	1.2	1.5	–	0.5
$\delta(sin2\alpha)^\dagger$	$\pi^+\pi^-$	0.147	0.20	0.16	–	0.16
	all modes	0.089	0.085	0.16	–	0.16

* assumed branching ratio
CLEO limit: $BR(B^0 \to \pi^+\pi^-) < 1.5 \times 10^{-5}$ (90% CL)

† assuming that penguin contamination can be unfolded

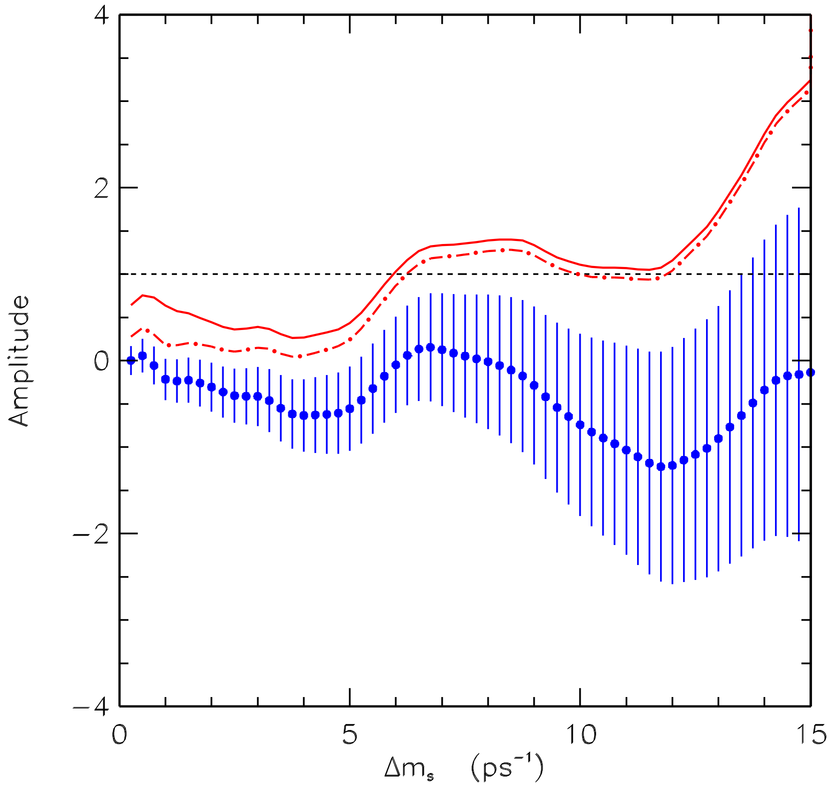
An incomplete list for EVERY experiment.

CLEO-III should not be forgotten:

- Measure (or limit) the CP asymmetry in $B^- \to D^0K^-/\overline{D}^0K^-/D_{CP}K^-$ ($sin2\gamma$)
- measurements of $BR(B^0 \to K\pi)$ & $BR(B^0 \to \pi\pi)$ will help disentangle the penguin contribution to $B^0 \to \pi^+\pi^-$

B_s Mixing in Run I

- rely on dilepton sample (trigger tag)
- reconstruct a displaced ϕ+track
  - $B_s \to \phi \ell X \nu$
  - $\phi \to K^+ K^-$
  - apply kinematic cuts to ϕ+track requiring that they be consistent with a D_s decay
- 1068 candidates, B_s purity 61%
- using amplitude fit method
- $\Delta m_s > 5.8\,\mathrm{ps}^{-1}$ at 95% CL



B_s mixing in Run II

- Necessary for $|V_{ts}/V_{td}|$

- B_s flavor tagging:
  - assume the same $\epsilon\mathcal{D}^2$ as for B^0
  - OK for SLT, JetQ
  - expect that Same Side Tagging tuned on Kaons will work better,

    but assume $\epsilon\mathcal{D}^2 \approx 2\%$ for now

    $\Rightarrow \epsilon\mathcal{D}^2 = 6.7\%$

- B_s data sample:
  1. use two-track trigger at Level 1 + Level 2

     ($p_T > 1.5$ GeV$/c$, $|d_0| > 150\mu$m)
  2. fully reconstruct B_s at Level 3

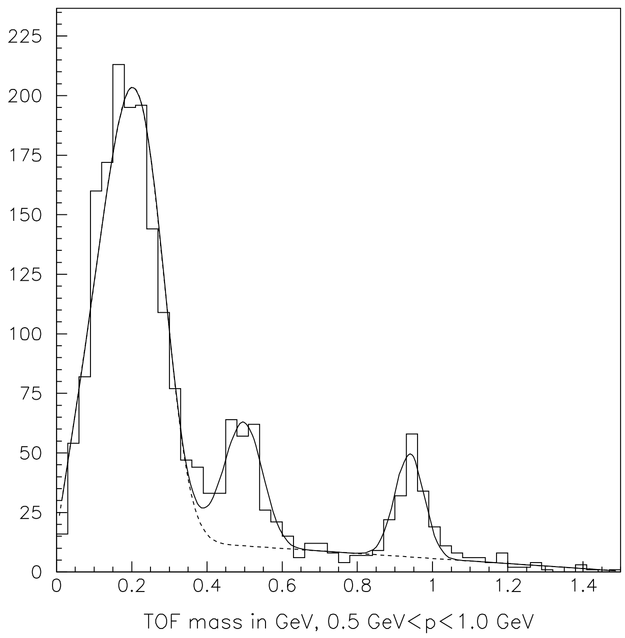
     Possibilities:
     - $B_s \to D_s\pi$, $B_s \to D_s 3\pi$
     - $B_s \to D_s^*\pi$, $B_s \to D_s^* 3\pi$
     - Expect $\approx 20,000$ B_s candidates
  3. option: opposite side lepton

     (reduces the rate $\Rightarrow$ loosen up cuts)

“Beyond the Baseline” Upgrades

CDF is proposing two upgrades to the upgrades which would, among other things, significantly improve the anticipated reach in x_s.

1. **A Time-of-Flight system**
   - **significantly improves tagging and reconstruction by separating π/K at 2σ or better for $p_T < 1.6\,\mathrm{GeV/c}$**



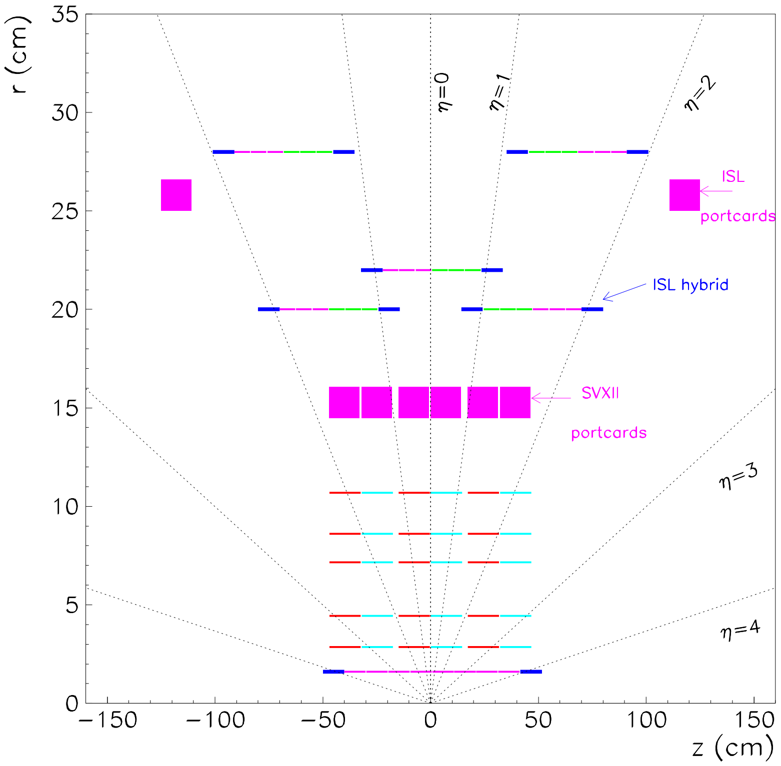
$\pi/K/p$ separation with prototype TOF system.

Colliding beam data taken late in Run I.

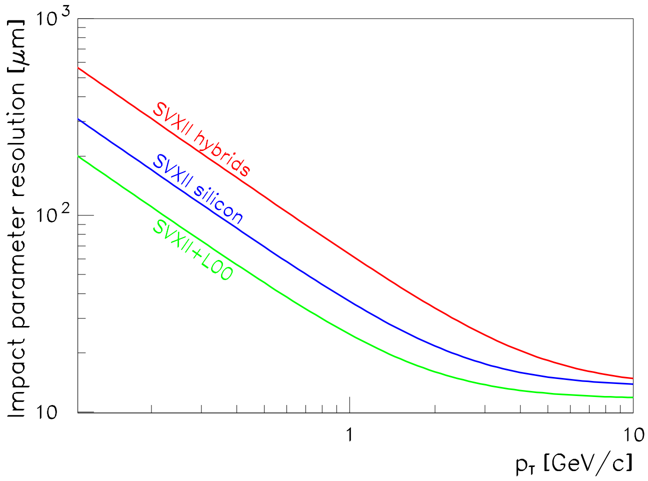
2. **An additional layer of silicon (L00) mounted on the beampipe**
   - **significantly improves impact parameter resolution, particularly for tracks that traverse material (hybrids) in the outer silicon layers.**

“Beyond the Baseline” Silicon L00

Baseline silicon system has 7 layers:



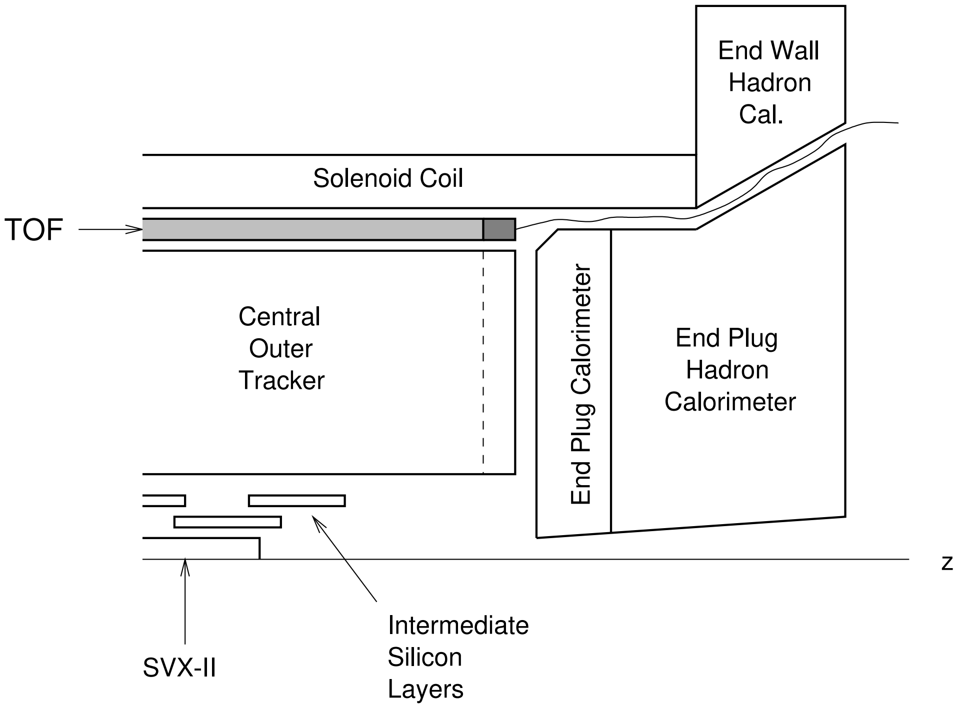
The Layer 00 proposal adds a layer of silicon at a radius of $1.6\,\mathrm{cm}$ from the beamline.



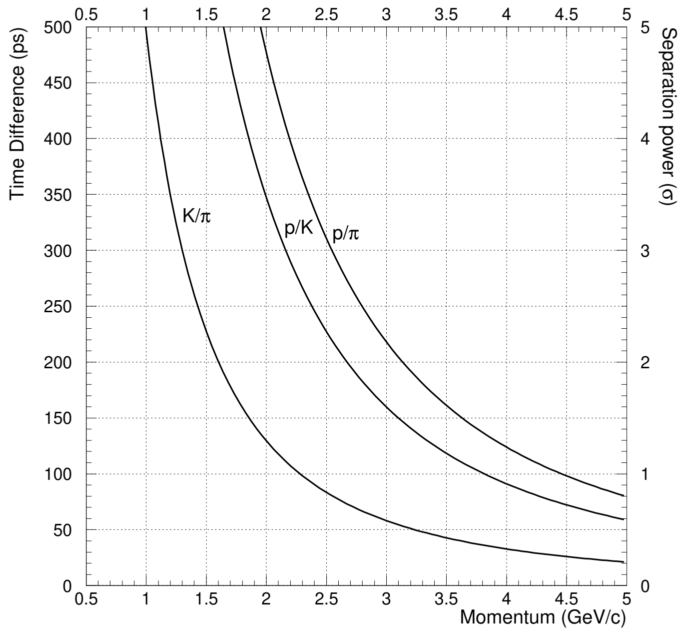
Impact parameter resolution is significantly improved...

especially for tracks which pass through additional material.

"Beyond the Baseline" Time of Flight



The TOF system would have $100\,\mathrm{ps}$ resolution with 216 $3\,\mathrm{m}$ scintillator bars.



π/K separation at 2σ or better for $p_T < 1.6\,\mathrm{GeV/c}$

B_s Mixing Sensitivity

Using $B_s \to D_s^+ \pi^-$ and $B_s \to D_s^+ \pi^- \pi^+ \pi^-$

- **tagging will be similar to B^0**
  - **except same-side tagging becomes more powerful with kaon ID**
- **expect $\sim 20k$ B_s candidate events**
  - **signal-to-noise is less certain**
- **Proper time resolution is important:**

$$\sigma(ct) = \sigma_{Lxy} \oplus \sigma_p ct$$

  - **detector resolution $\sigma_{Lxy} \approx 20\mu\mathrm{m}$ baseline ($\sigma_{Lxy} \approx 15\mu\mathrm{m}$ with L00)**
  - **momentum resolution $\Delta p_T / p_T(B_s) < 0.4\%$ (negligible effect on $\sigma(ct)$)**

exact Run II sensitivity is under study. Time of flight and silicon Layer 00 significantly improve x_s sensitivity.

Measuring $\Delta\Gamma_s$

- $\Delta\Gamma_s$ **related to** Δm_s **(in S.M.!) by a scale factor independent of CKM:**

$$\frac{\Delta\Gamma_s}{\Delta m_s} = -\frac{3\pi}{2}\frac{m_b^2}{m_t^2}\frac{\eta_{QCD}^{\Delta\Gamma_s}}{\eta_{QCD}^{\Delta m_s}}$$

- **two-component lifetime fit in** $B_s \to \nu\ell D_s$ **measures** $\Delta\Gamma_s$

or...

- **determine CP composition of** $B_s \to J/\psi\phi$ **by helicity analysis, and**

- **measure lifetime of each CP component in** $B_s \to J/\psi\phi$

$\mathcal{A}_{CP}(t)$ in $J/\psi\phi$

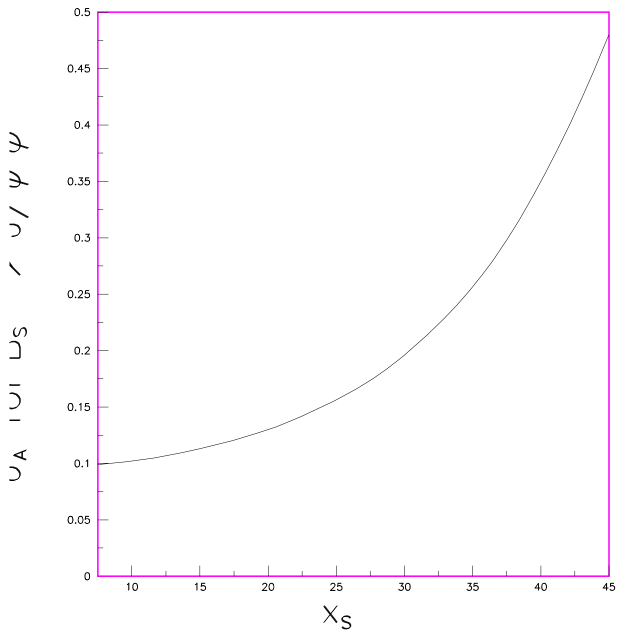
- Analogous to $B^0 \to J/\psi K_S$ (no penguins!)
- CP violation in B_s sensitive to some models beyond SM

  (B_s has no light quarks but mixes)
- CP asymmetry in $B_s \to J/\psi\phi$ proportional to η

  (apex of unitarity triangle)
- SM expectations: very small

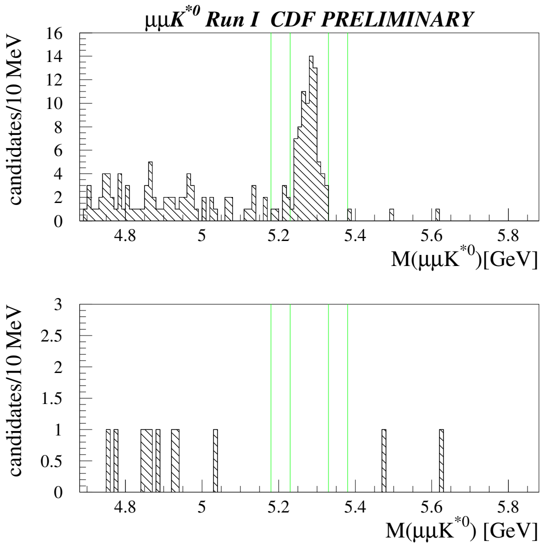
  $\Rightarrow$ *if $\mathcal{A}_{CP}$ is large, New Physics*
- needs: same as for B_s mixing:

  good tagging + good proper time resolution
- prerequisite: observation of B_s mixing



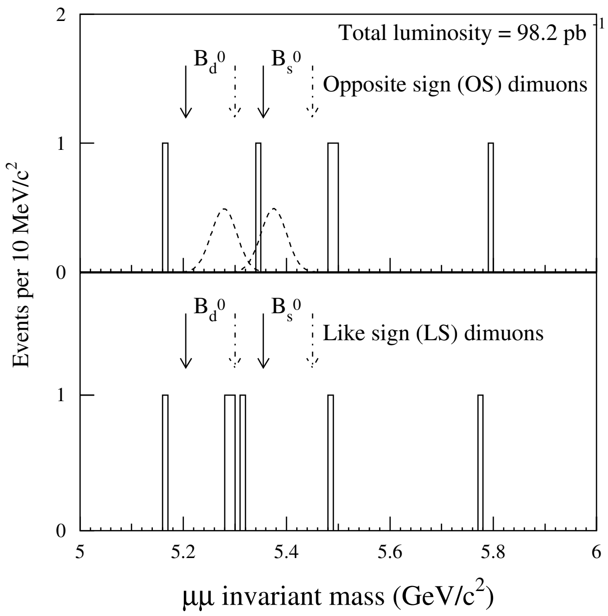
Rare B Decays, Run I

Using the dilepton triggers, we can search for rare B decays



nonresonant
$B^0 \rightarrow \mu^+\mu^- K^*$
$\leftarrow$

not shown:
$B^+ \rightarrow \mu^+\mu^- K^+$



$B^0 \rightarrow \mu^+\mu^-$
$B_s \rightarrow \mu^+\mu^-$
$\leftarrow$

not shown:
$B_s \rightarrow e\mu$

No rare decay modes observed as of yet.

Rare B Decays

As in the Kaon system, rare B decays are sensitive to physics beyond the Standard Model

Both experiments will search for (and possibly observe some) the following rare decays:

- $B^+ \to \mu^+\mu^- K^+$
- $B^0 \to \mu^+\mu^- K^{*0}$
- $B^0 \to \mu^+\mu^-$
- $B_S \to \mu^+\mu^-$

CDF existing limits and Run II estimates

B Decay Mode	Standard Model	CDF Run I	CDF II
$\mu^+\mu^- K^+$	(2 – 5)$\times 10^{-7}$	5.4×10^{-6}	2×10^{-7}
$\mu^+\mu^- K^{*0}$	(1 – 2)$\times 10^{-6}$	4.1×10^{-6}	2×10^{-7}
$B_d \to \mu^+\mu^-$	(0.6 – 2.4) $\times 10^{-10}$	6.8×10^{-7}	3×10^{-8}
$B_s \to \mu^+\mu^-$	(2.5 – 4.5)$\times 10^{-9}$	2.0×10^{-6}	1×10^{-7}

CDF/DØ Run II B physics goals

- **work towards overconstraining the CKM matrix**
- **make competitive measurements of β and α**
  - $\sin 2\beta$ **using** $B^0 \to J/\psi K_S$
  - $\sin 2\alpha$ **using** $B^0 \to \pi^+\pi^-$
- **study ways of measuring γ**
- **measure Δm_s**
- **exploit B_s to the fullest for other CP violation studies**
  - **untagged analysis – measure $\Delta\Gamma_s$**
  - **tagged analysis – measure η**
- **continue to search for rare B decays**

Conclusions

- CDF and DØ have shown that b-physics can be done in $p\bar{p}$ environment

  (cross sections, branching ratios, rare decay limits, lifetimes, $B^0_{d,s}$ mixing, B_c discovery, limit on $\sin 2\beta$)

- the outlook for Run II is bright and will likely (hopefully) yield:
  - an observation of CP violation in the B system
  - direct or indirect measurement of Δm_s
  - observation of "rare" decays
  - constraints on the CKM matrix and precision tests of the Standard Model