Prospettive di Fisica del B a Fermilab

Donatella Lucchesi
University and INFN Padova

XII Convegno sulla Fisica a LEP

Trieste, 26 - 28 Aprile 2000

- Run II Starting March 1, 2001
  - experiments: CDF and D0
- Beyond Run II "Before and during LHC ?"
  - experiments: CDF, D0 and BTeV (proposal for May 2000)

Why at Hadron Collider?

- Very large cross section:

$$\Upsilon(4S): \ \sigma\left(B\bar{B}\right) \sim 1 \text{ nb } (B^0 \text{ and } B^\pm \text{ only})$$
$$Z^0: \ \sigma\left(b\bar{b}\right) \sim 7 \text{ nb}$$
$$p\bar{p}: \ \sigma\left(p\bar{p} \to b\bar{b}X\right) \sim 100 \ \mu\text{b (at } \sqrt{s} = 1.8 \text{ TeV)}$$

- BUT inelastic cross section $\sim 10^3$ times larger
- Specialized trigger is required

Run I CDF D0

- Inclusive lepton or dilepton triggers; "low" statistics due to branching ratio and high momentum of the lepton;

Run II

- CDF displaced tracks trigger: all hadronic B decays could be collected
- D0 lepton + tracks trigger under study

Beyond Run II

- CDF D0 upgraded?
- BTeV dedicated experiment with displaced tracks trigger at Level 1 and vertex trigger at Level 2

CDF Upgrade for Run II

- New silicon tracking system:
  - SVXII: 5 layers, 96 cm long, $r - \phi$ and $r - z$
  - ISL: 2 additional layers to cover for $|\eta| < 2$
  - L00: an inner layer at $r = 1.4$ cm

  3D Vertex, 2 times more acceptance, improved impact parameter resolution

- New central drift chamber

  Maintain Run I tracking efficiency and resolution

- New dead-timeless trigger
  - Track trigger moved to Level 1
  - Silicon information at Level 2 to trigger on displaced tracks

  Purely hadronic trigger will be possible

- Time-of-Flight
  - 2σ separation for K and π for $P_T < 1.6$ GeV/c

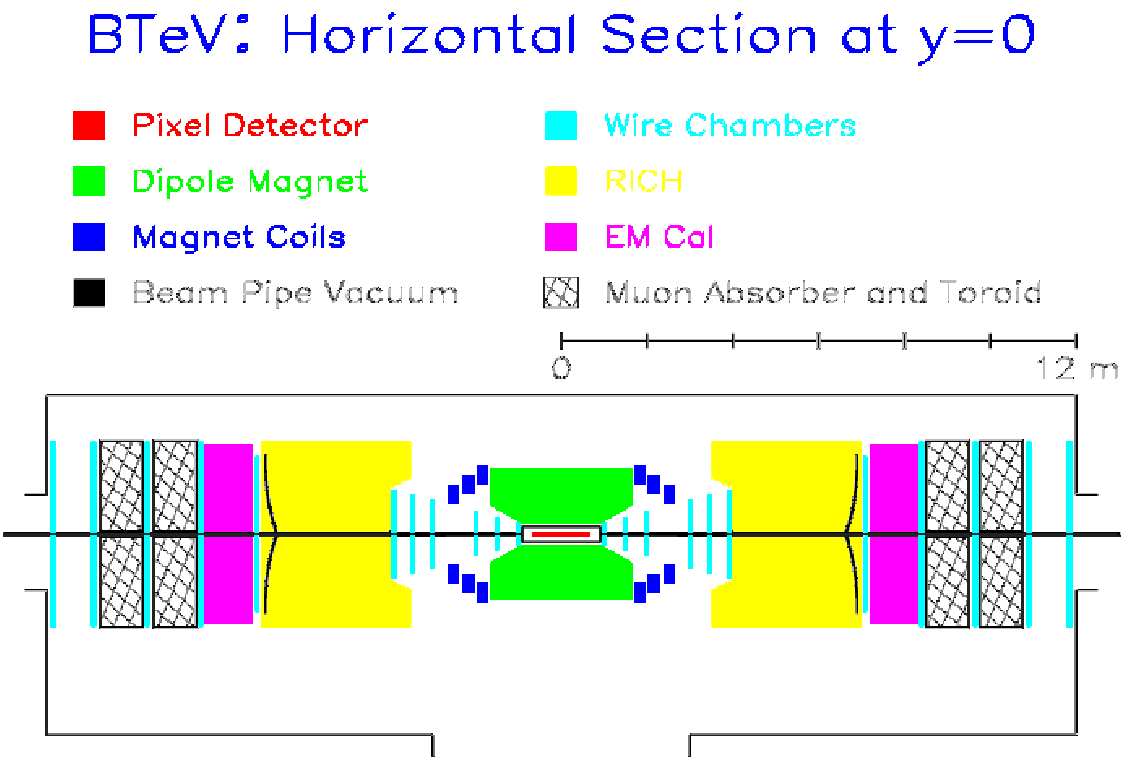
D0 Upgrade for Run II

- Superconducting Solenoid (B=2 Tesla)
- Central Fiber tracker
  - 8 super-layers of scintillating fibers
  - full coverage in $|\eta| < 1.7$

  Charged particle momentum measurement
- Silicon Microstrip tracker
  - 6 barrels, each 4 layers, $r - \phi$ $r - z$
  - 16 disks out to $|z| < 1.2$ m

  Tag B decays with displaced vertices
- Other improvements to muon system and trigger

Beyond Run II: BTeV



- vertex region: 31 silicon pixel (50 μm$\times$400 μm) doublets along 90 cm – 28 million channels
- tracking: 7 straw tube stations/arm, 3 views/station, 3 planes/view + SSDs in center of first 3 stations – 120,000 + 60,000 channels
- 1.6 T, 3.2 m dipole centered on interaction region
- RICH for hadron separation
- EM Calorimeter – 10-20,000 $PbWO_4$ crystals
- Muon detector – 2 1 m toroidal iron filters 3 stations/arm, 3 views/station and 2 layers/view – 60,000 prop tubes
- DAQ buffers every beam crossing and Level 1 trigger uses vertex trigger, dimuon trigger, and maybe combination loose vertex plus single muon

B physics measurements

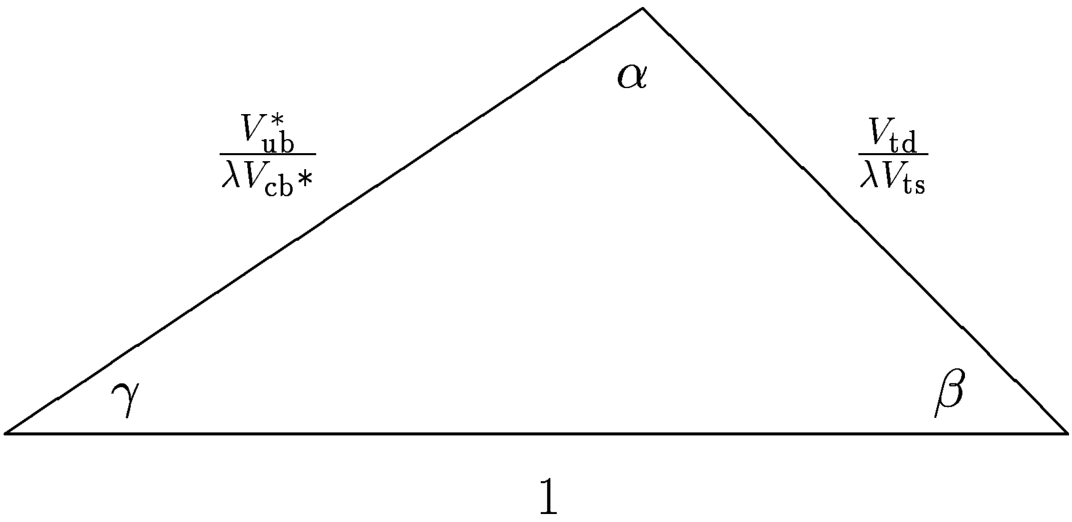
At the Tevatron in Run II and Beyond Run II:

- Quantitative Study of QCD
- New Physics from Rare decays
- Study of Weak decays

Some measurements belonging to the last two items in this talk:

- Determination of $\sin(2\beta)$
  $B^0/\bar{B}^0 \to J/\psi K^0_S$
- Measurement of $|V_{td}/V_{ts}|$
  $B^0_s - \bar{B}^0_s$ flavor oscillations
  Radiative decays $B^0_d \to K^{*0}\gamma$ vs. $B^0_s \to \phi\gamma$

  A combination of these two may test the Unitarity



B physics measurements

- Measurement of $\frac{\Delta\Gamma}{\Gamma}$ by using $B_s^0 \to J/\psi\varphi$ and $B_s^0 \to D_s^- \pi^+$
  Moreover for BTeV: $B_s^0 \to D_s D_s$, $B_s^0 \to J/\psi\eta$
- Determination of CP Asymmetry in $B_s^0/\bar{B}_s^0 \to J/\psi\phi$
  Large asymmetry is sign of new physics beyond Standard Model
- Observation of CP Violation in $B^0/\bar{B}^0 \to \pi^+\pi^-$
  Precise measurement of the decay asymmetry (related to $\sin(2\alpha)$)
  BTeV: Time dependent analysis of interfering amplitudes in Daliz plot for:
  $B^0 \to \rho^-\pi^-, \rho^0\pi^0, \pi^+\pi^-\pi^0$
- Observation of decay modes related to angle γ and later γ measurement
  $B_s^0 \to D_s^\pm K^\mp$ or $B^+ \to \bar{D}^0 K^+$
- Rare Decays
  Observe $B^+ \to \mu^+\mu^- K^+$, $B^0 \to \mu^+\mu^- K^{*0}$, $B_s^0 \to \mu^+\mu^-\phi$

in red measurements **Unique to Hadron Machines**

$\sin(2\beta)$ measurement at D0

- Trigger:
  - Single muon, Di-muons : $P_T > 4$ GeV/c $\epsilon = 27\%$
  - Di-electrons: $P_T > 2$ GeV/c $\epsilon = 20\%$
- Efficiency reconstruction: $\sim 85\%$ J/ψ and $\sim 27\%$ K_s
- Flavor Tagging: Tag effectiveness $\epsilon D^2 = 9.8\%$ comb. (Same Side: 2.0% Soft Lepton: 3.1% Jet Charge: 4.7%)
- Expected number of events:

$$N = L \cdot 2 \cdot \sigma_B \cdot BR \cdot \epsilon_{trigger} \cdot \epsilon_{rec} = 40K$$

$L = 2$ fb^{-1}, BR from PDG and $\sigma_B = \sigma_{b\bar{b}} \cdot f_B \cdot Acc = 21$ μb

For a time dependent analysis:

$$\sigma(\sin(2\beta)) \approx e^{x_d^2 \Gamma^2 \sigma_t^2} \sqrt{\frac{1+4x_d^2}{2x_d}} \frac{1}{\sqrt{\epsilon D^2 N}} \sqrt{1+\frac{B}{S}}$$

Mode	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
S/B	~ 0.75	~ 0.75
σ_t	128 fs	128 fs
N events	40,000	30,000
$\sigma(\sin(2\beta))$	0.04	0.05

$\sigma(\sin(2\beta))$ =0.03 Combined

$\sin(2\beta)$ measurement at CDF

- Run I we measured: $\sin \mathbf{2}\beta = \mathbf{0.79}^{+0.41}_{-0.44}$ *stat.* $\oplus$ *sys.*
- We scale this error to Run II:

$$\sigma\left(\sin \mathbf{2}\beta\right) = \frac{\sigma(\mathcal{A})}{D} \oplus \sin 2\beta \cdot \sigma\left(D\right)/D$$

- Statistical error

  Run I: 198 ± 17 $J/\psi K^0_s$ (precise decay time)

  Run II 10,000 events $\Rightarrow \frac{\sigma(\mathcal{A})}{D} = 0.067$

- Systematic error

  Run I $\epsilon D^2 = (6.3 \pm 1.7)\,\%$
  Tagging calibration with: $B^{\pm} \rightarrow J/\psi K^{\pm}$ and $B^0 \rightarrow J/\psi K^{*0}$. Statistically limited

  Run II $\epsilon D^2 = 9.1\% \Longrightarrow \sigma\left(D\right)/D = 0.027$
  Tagging calibration: 40,000 $J/\psi K^{\pm}$ and 20,000 $J/\psi K^{*0}$. Systematic error scale with statistic

- Assuming $\sin 2\beta = 1$ $\quad$ $\delta\left(\sin \mathbf{2}\beta\right) = \mathbf{0.072}$

- By increasing the bandwidth for Di-leptons trigger: $N \sim 28,000$ $J/\psi K^0_s \Longrightarrow \delta\left(\sin \mathbf{2}\beta\right) = \mathbf{0.043}$

$\sin(2\beta)$ measurement at BteV

- Based on a fast simulation
- Trigger on muons and on secondary vertex
- Background as to be simulated more carefully
- Expected number of events

$$N = L \cdot 2 \cdot \sigma_B \cdot BR \cdot \epsilon_{trigger} \cdot \epsilon_{rec} = 109,000$$

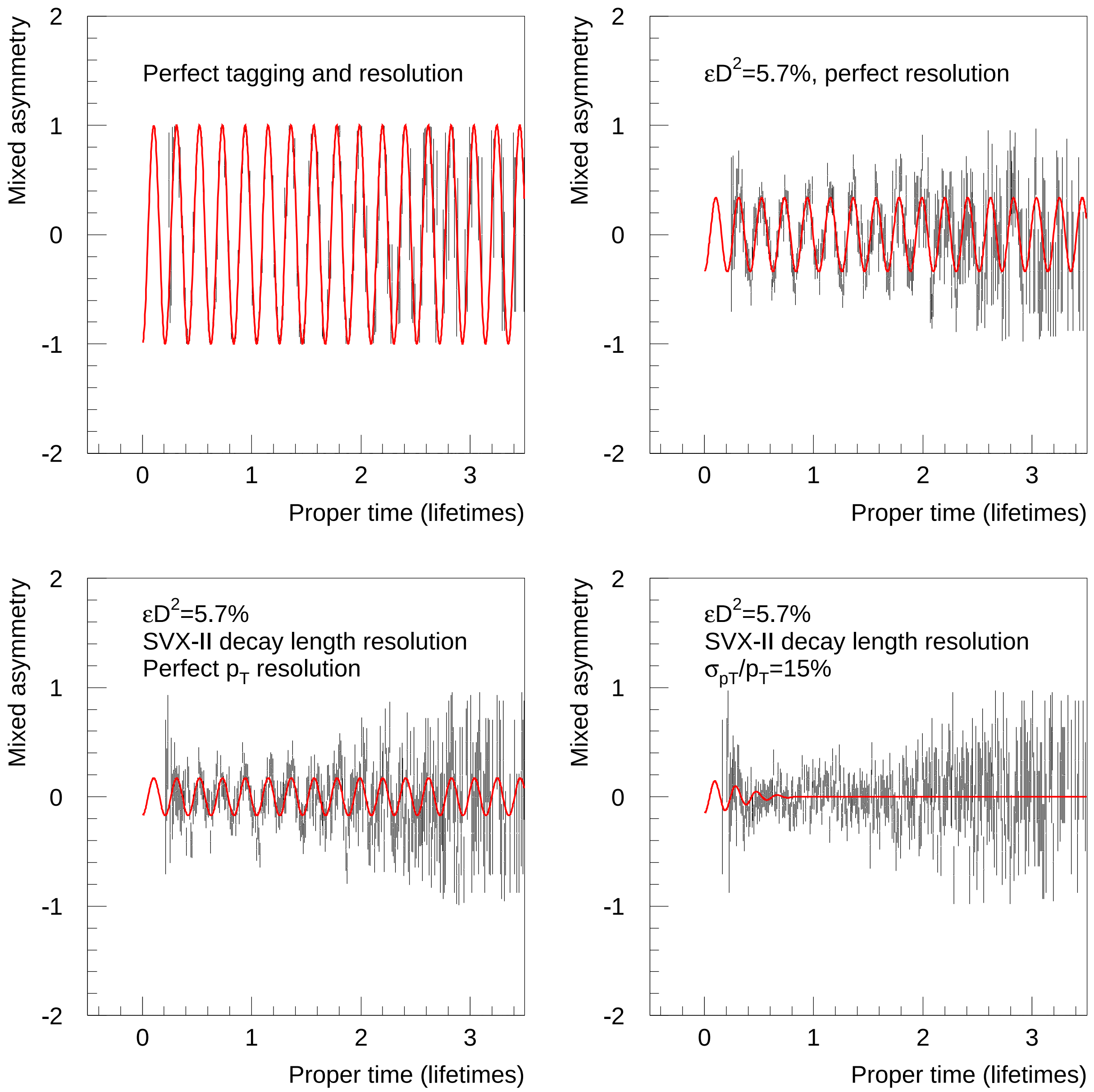
  $L = 2$ fb^{-1}, BR from PDG and $\sigma_B = \sigma_{b\bar{b}} \cdot f_B = 80$ μb
  $\epsilon_{trigger} = 0.85$ and $\epsilon_{rec} = 0.04$

- Tagging $\epsilon D^2 = 10\%$
- Signal to Noise: $S/B = 10:1$
- Time resolution $\sigma_t = 50$ fs ?

By putting these numbers in the sensitivity formula:

$$\sigma\left(\sin \mathbf{2}\beta\right) = \mathbf{0.017}$$

$B_s^0 - \bar{B}_s^0$ oscillation

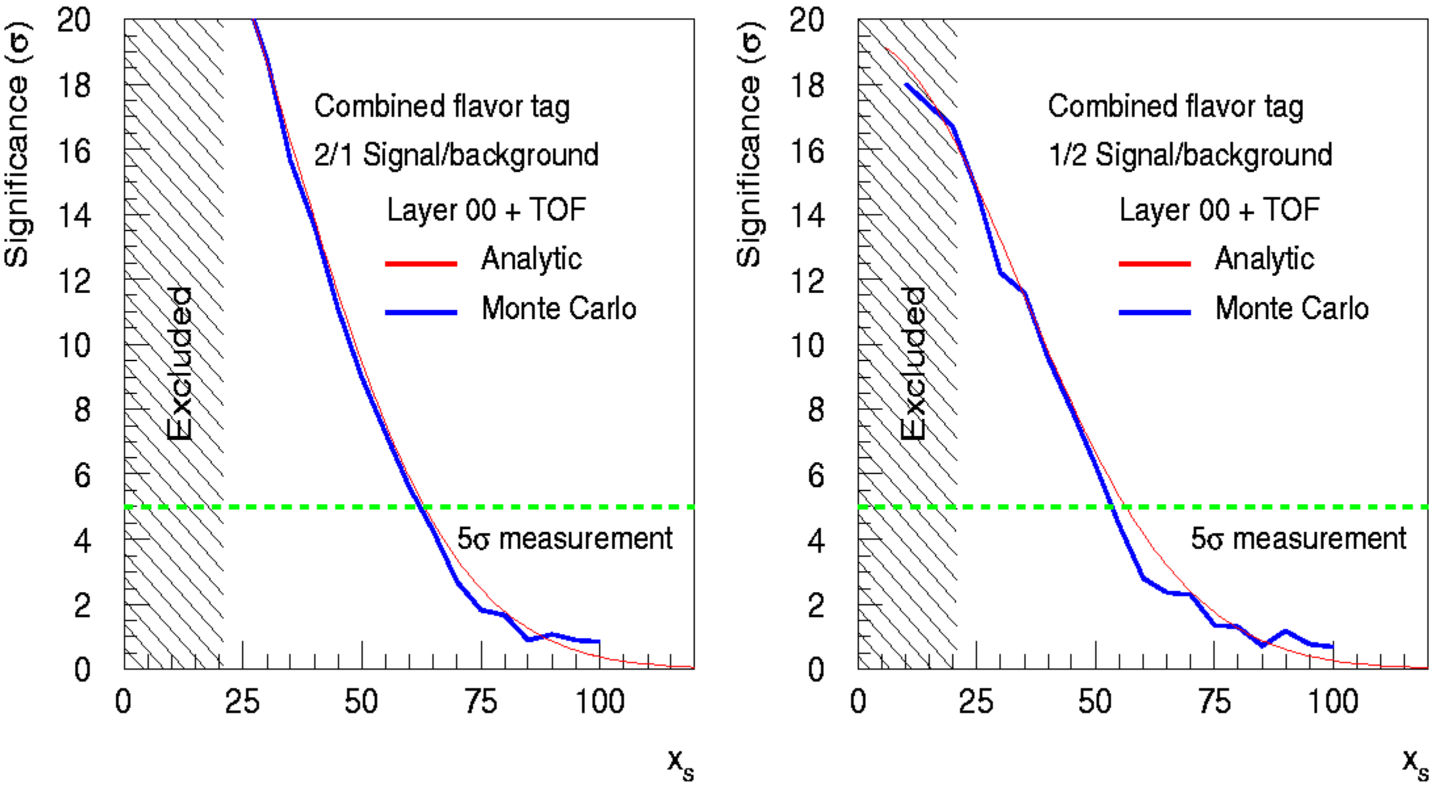


$$Sig\,(x_S) = \sqrt{\frac{N\epsilon D^2}{2}} e^{-(x_S \sigma_{ct}/\tau)^2/2} \sqrt{\frac{S}{1+S}}$$

To go beyond current limit need **fully** reconstructed B_s^0

B_s^0 mixing at CDF

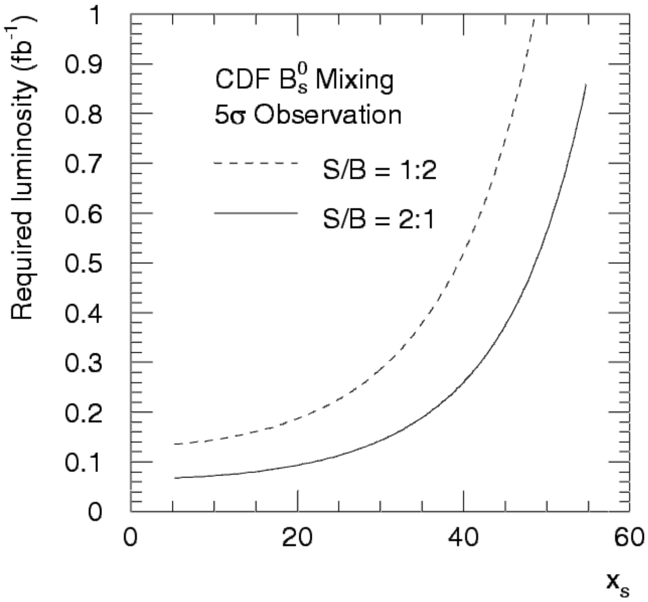
- Data sample: $\sim 20,000$ $B_s^0 \to D_s\pi$ $B_s^0 \to D_s 3\pi$ thanks to SVT the trigger on displaced tracks
- Flavor tagging: $\epsilon D^2 = 11.3\%$
- S:N $=$ 1:2 or 2:1 $\qquad \sigma_t = 45$ fs



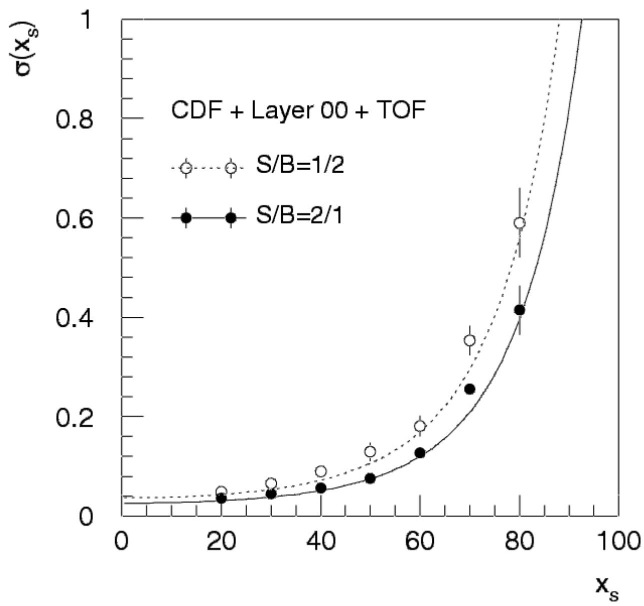
- Maximum $x_s = \begin{cases} 63 & \text{for S:N} = 2{:}1 \\ 56 & \text{for S:N} = 1{:}2 \end{cases}$

B_s^0 mixing at CDF

- Integrated Luminosity required for a 5σ measurement

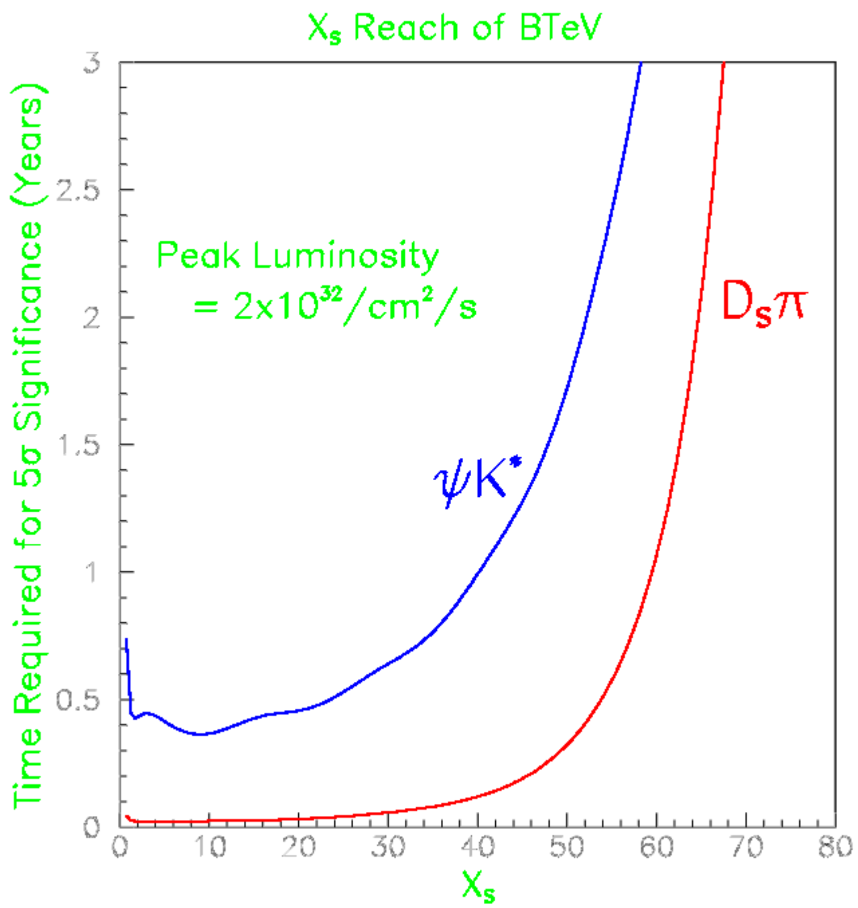


- Once oscillations are observed, x_s will be measured extremely precisely:



B_s^0 mixing at BteV

- Decay mode: $B_s^0 \to D_s\pi$ and $B_s^0 \to J/\psi \bar{K}^{*0}$
- 108,000 $D_s\pi$ and 1030 $J/\psi \bar{K}^{*0}$ after trigger and reconstruction
- Tagging : $\epsilon D^2 = 0.04$ (only high quality tags)
- S:N=3:1 and S:N=2:1 $\quad \sigma_t = 50$ fs $\sigma_t = 38$ fs
- x_s reach is ~ 60 for one year with $B_s^0 \to D_s\pi$



D0: x_s reach study using $B_s^0 \to J/\psi \bar{K}^{*0}$

Measuring $\Delta\Gamma/\Gamma$ at CDF

- S.M. prediction: $x_s = C \cdot \frac{\Delta\Gamma}{\overline{\Gamma}}$ where $\overline{\Gamma} = (\Gamma_H + \Gamma_L)/2$ and $\Delta\Gamma = \Gamma_H - \Gamma_L$
- $\frac{\Delta\Gamma}{\overline{\Gamma}}$ and x_s measurement test the model.
- First method:
  - Sample where can isolate one CP eigenstate and measure Γ_{CP}
    Run I:
    $B_s^0 \to J/\psi\varphi$ 58 $\pm$ 12 events $\quad \tau_{B_s} = 1.34^{+.23}_{-.19} \pm 0.5$
    $\frac{\Gamma_\perp}{\overline{\Gamma}} = 0.229 \pm 0.188 \pm 0.038$
  - Use a sample with 50:50 mixture of CP and measure $\Gamma_{CP50:50}$ i.e. $B_s^0 \to D_s^- \pi^+$
  - $\Delta\Gamma = 2(\Gamma_{CPeven} - \Gamma_{CP50:50})$

Mode	Event Yeld	σ_t projection
$D_s\pi$, $D_s\pi\pi\pi$	$15,300 \to 23,400$	0.015 ps
$J/\psi\varphi$	6,000	0.021 ps

Assuming central value of Run I measurement for $\Gamma_\perp$:

$$\sigma_{\frac{\Delta\Gamma}{\overline{\Gamma}}} = 0.065$$

Measuring $\Delta\Gamma/\Gamma$ at CDF

- Second method: $B_s^0 \to J/\psi\varphi$ in CP definite state
  - Using $\sim 6,000$ events separate CP states using transversity basis
  - Two method to separate the distributions: moment analysis and multivariable Likelihood fit

Likelihood fit	
Imput$_{\frac{\Delta\Gamma}{\Gamma}}$	$\frac{\Delta\Gamma}{\Gamma}$ Significance
0.085	1.35
1.	1.79
1.25	2.53
1.5	2.69

Moment analysis $\frac{\Delta\Gamma}{\Gamma} = 0.15$	
Condition	$\sigma_{\frac{\Delta\Gamma}{\Gamma}}$
no bck no detector	0.053
bck no detector	0.089
bck and detector	0.091

Measuring $\Delta\Gamma/\Gamma$ at Btev

- Decay considered: $B_s^0 \rightarrow J/\psi\varphi$ $B_s^0 \rightarrow D_s^- \pi^+$
- Other possibilities: $B_s^0 \rightarrow D_s D_s$, $B_s^0 \rightarrow D^0(CPeven)K_s^0$ and $B_s^0 \rightarrow J/\psi\eta, \eta'$
- CP_{even} and $CP_{50:50}$ method:

$$\sigma_{\frac{\Delta\Gamma}{\Gamma}} = 2\frac{\tau_{50:50}}{\tau_{CP}}\sqrt{\left(\frac{\sigma_{\tau_{50:50}}}{\tau_{CP}}\right)^2 + \left(\frac{\sigma_{\tau_{CP}}}{\tau_{CP}}\right)^2}$$

L fb^{-1}	Error on $\frac{\Delta\Gamma}{\Gamma}$
2	4.3%
10	1.9%
20	1.4%

- CP definite state:

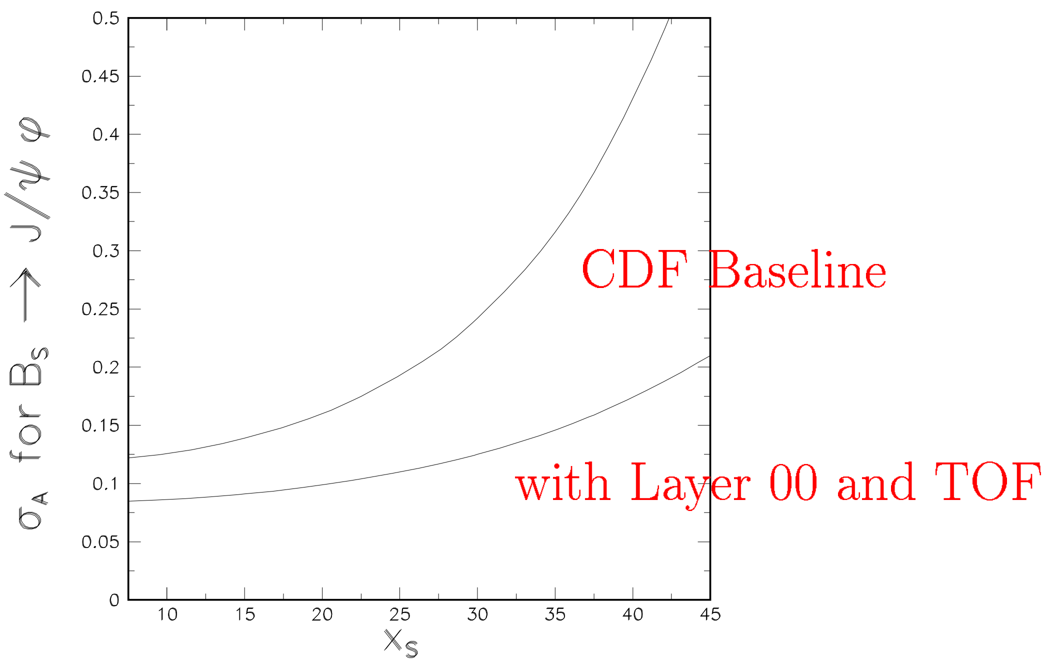
$$\sigma_{\frac{\Delta\Gamma}{\Gamma}} = 4\frac{\tau_{CP_{even}}\tau_{CP_{odd}}}{(\tau_{CP_{even}} + \tau_{CP_{odd}})^2}\sqrt{\left(\frac{\sigma_{\tau_{CP_{even}}}}{\tau_{CP_{even}}}\right)^2 + \left(\frac{\sigma_{\tau_{CP_{odd}}}}{\tau_{CP_{odd}}}\right)^2}$$

L fb^{-1}	Error on $\frac{\Delta\Gamma}{\Gamma}$
2	2.0%
10	0.9%
20	0.6%

CP violation in $B \to J/\psi\varphi$

CDF:

- In 2 fb^-1 $\sim 6,000$ events
- Tagging effectiveness $\epsilon D^2 = 9.7\%$
- Requires measurement of x_s



BTeV:

- 41,000 events per year after trigger and analysis cuts
- Tagging effectiveness $\epsilon D^2 = 10\%$
- Signal to noise: S:B = 20:1 Proper time res.: $\sigma_t = 38$ fs

	$x_s = 20$	$x_s = 40$
Time Integrated σ_A	0.31	0.62
Time Dependent σ_A	0.025	0.035

Measurement of $B \to \pi\pi$ asymmetry

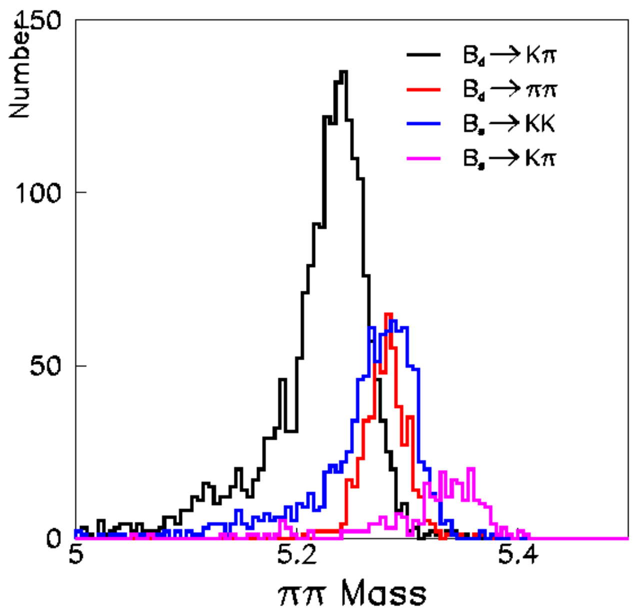
CDF:

a. Expected number of events in 2 fb^{-1} with $\epsilon D^2 = 10\%$:

$B^0 \to \pi\pi$: 500 $B^0 \to K\pi$: 2000

$B_s^0 \to K\pi$: 250 $B_s^0 \to KK$: 1000

Mass Distributions



b. Fitting by exploiting different CP decay asymmetries:

$\Delta\mathcal{A}_{mix}(\pi\pi) = 0.14$ $\Delta\mathcal{A}_{dir}(\pi\pi) = 0.10$

$\Delta\mathcal{A}_{mix}(KK) = 0.10$ $\Delta\mathcal{A}_{dir}(KK) = 0.10$

BTeV:

a. Reconstructed events: 2.2×10^4

b. Tagging effectiveness $\epsilon D^2 = 10\%$ S/N = 0.6

c. $\Delta\mathcal{A} = 0.023$

How to extract γ at CDF

- R. Fleischer method (Phys. Lett. B 459, 306 (99)):
  - CP violation in $B^0 \rightarrow \pi\pi$ related to one in $B_s^0 \rightarrow KK$
  - Need to measure $\mathcal{A}_{mix}(\pi\pi)$, $\mathcal{A}_{dir}(\pi\pi)$, $\mathcal{A}_{mix}(KK)$ and $\mathcal{A}_{dir}(KK)$.
  - Unknown variables: d = penguins/tree ratio, θ = strong interaction phase of this ratio, $\gamma = Arg(V_{ub}^*)$ and $\beta = Arg(V_{td}^*)$
  - By fitting the M.C. data with d fixed we get $\Delta\gamma \sim 10^o$ with a 4 fold ambiguity
- $B_s^0 \rightarrow D_s^{\pm} K^{\mp}$:
  - Decay rate depends: $\sin(\gamma \pm \delta)$ and $\cos(\gamma \pm \delta)$
  - Theoretically clean and reasonable branching ratio
  - Need tagging and time dependent analysis
  - Background (mainly $B_s^0 \rightarrow D_s\pi$) separation very difficult
  - Tagging effectiveness, $\epsilon D^2 = 11.3\%$
  - For 2 fb^{-1} and S/B = 1/6 $\Delta \sin(\gamma \pm \delta) \approx 0.7$
  - If $\Delta\Gamma > 0.1$ resolve the discrete ambiguities

How to extract γ at BteV

- $B_s^0 \to D_s K$:
  - In 2 fb^{-1} $\sim$ 1600 events if $BR \sim 10^{-4}$
  - S/B $\sim$ 10, $\sigma_t/t \sim 0.03$
  - The measurement depends on several quantities: x_s, $\Delta\Gamma$ and $B_s^0 \to D_s K$ branching fractions
  - Mini-M.C. with parameters: $x_s = 30$, $\Delta\Gamma = 0.16$, $\gamma = 49^o$, $\delta = 10^o$ and $\rho = 0.7$.
  - By fitting the M.C data $\Delta(\gamma) = 10^o$
- Atwood, Dunietz & Soni method: $B^\pm \to D^0 K^\pm$
  - CP violation enhanced in $B^\pm \to D^0(\bar{D}^0)K^\pm$ $D^0(\bar{D}^0) \to K^+\pi^-$
  - Need 2 different D^0 decay mode to extract γ: 2^o $D \to K^+K^-$
  - CP asymmetry: $\frac{N(B^-)-N(B^+)}{N(B^-)+N(B^+)}$ no time dependence.
  - In 2 fb^{-1} 410 $B \to K^-(K^+\pi^-)$, 2500 $B \to K^-(K^+K^-)$
  - Physics background: S/B>5, Combinatorial background S/B>1
  - By fitting a combination of these decay rates γ can be measured with an error $\sim 10^o$ if strong phase difference is grater than 15^o

Summary

- Run II CDF and D0
  - Precise measurement of $\sin(2\beta)$
  - Precise determination of x_s, oscillation frequency in B_s^0 - $\bar{B}_s^0$ system
  - These two measurements together allow to check Unitarity
  - Measurement of $\frac{\Delta\Gamma}{\Gamma}$ and possibly New Physics hint
  - Study of $B \to \pi\pi$ asymmetry

- Beyond Run II BTeV Upgraded CDF and D0
  - Determination of γ
  - Measurement of $\sin(2\alpha)$ by using $B \to \rho\pi$

Many important measurements will be done at Tevatron in Run II

Challenging measurements would be possible Beyond Run II with BTeV and the upgraded CDF and D0 detectors