CP Violation Working Group Summary

Rick Jesik
Indiana University

Workshop on
B Physics at the Tevatron
Run II and Beyond

February 26 2000

CP violation studies

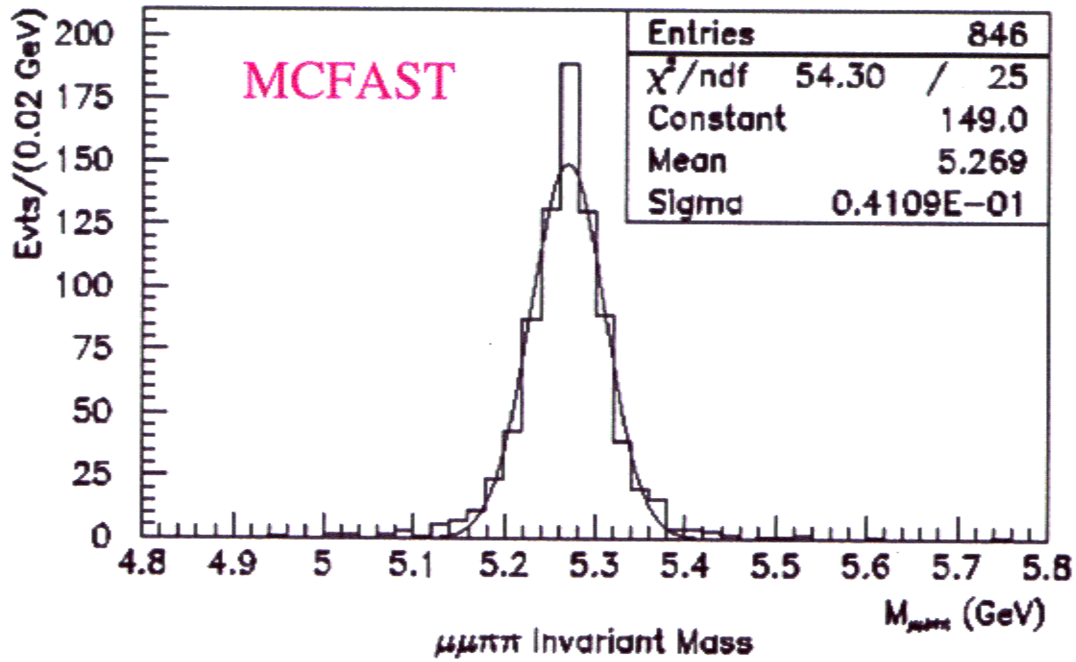
WG1 has chosen to study the following modes:

- $B \to J/\psi + K_S$
  - measures $\sin(2\beta)$
- $B_d \to \pi\pi$, $B_s \to KK$
  - probes α and γ
- $B \to DK$
  - measures γ
- $B \to \rho\pi$
  - measures α
- $B_S \to J/\psi + \phi$, $B \to J/\psi + \eta$ (η')
  - look for unexpected asymmetry

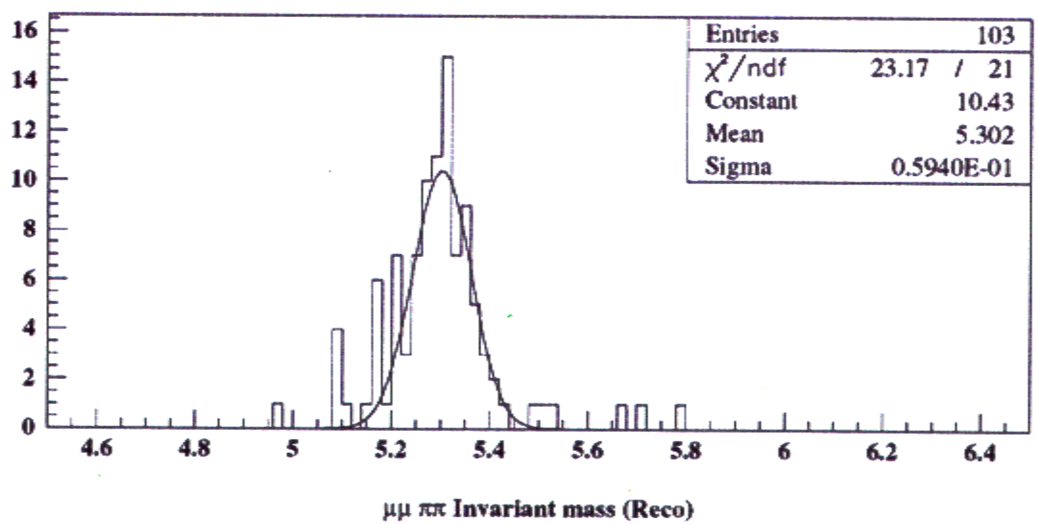
DØ $B \to J/\psi K_S$ reconstruction

Combined $\mu^+\mu^-\pi^+\pi^-$ *invariant mass*

(before fit)



DØ Run II GEANT + Reco



reconstruction efficiency:

5% (GEANT + Reco)

9% (MCFAST)

KIN YIP
Rick Jesik

Flavor Tagging

Tag	εD^2 (%) measured CDF Run I	εD^2 (%) expected CDF Run II	Relevant DØ difference	DØ capabilities
Same side	$1.8 \pm 0.4 \pm 0.3$	2.0	same	2.0
Soft lepton	$0.9 \pm 0.1 \pm 0.1$	1.7	μ , e ID coverage	3.1
Jet charge	$0.8 \pm 0.1 \pm 0.1$	3.0	forward tracking	4.7
Opp. side K		2.4	no ToF	none
Combined		9.1		9.8

DØ $\sin(2\beta)$ expectations for $2fb^{-1}$

For a ***time dependent*** analysis:

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

- (S/B ~ 0.75)
- $\varepsilon D^2 \sim 9.8\ \%$
- $\sigma_t \sim 128$ fs

mode	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
trigger eff. (%)	**27**	**20**
reco'd events	**40,000**	**30,000**
$\sigma(\sin 2\beta)$	**0.04**	**0.05**
	0.03	

comparison of experiments

experiment	$N(B \to J/\psi K_S)$	S/B	εD^2 (%)	σ_t (fs)	$\delta(\sin 2\beta)$ x10
DØ	40 K	0.75	9.8	128	0.4
CDF	30 K	1.0	9.1	50	0.5
BTeV	110 K	10	10	50	0.2

These numbers are for 2 fb-1

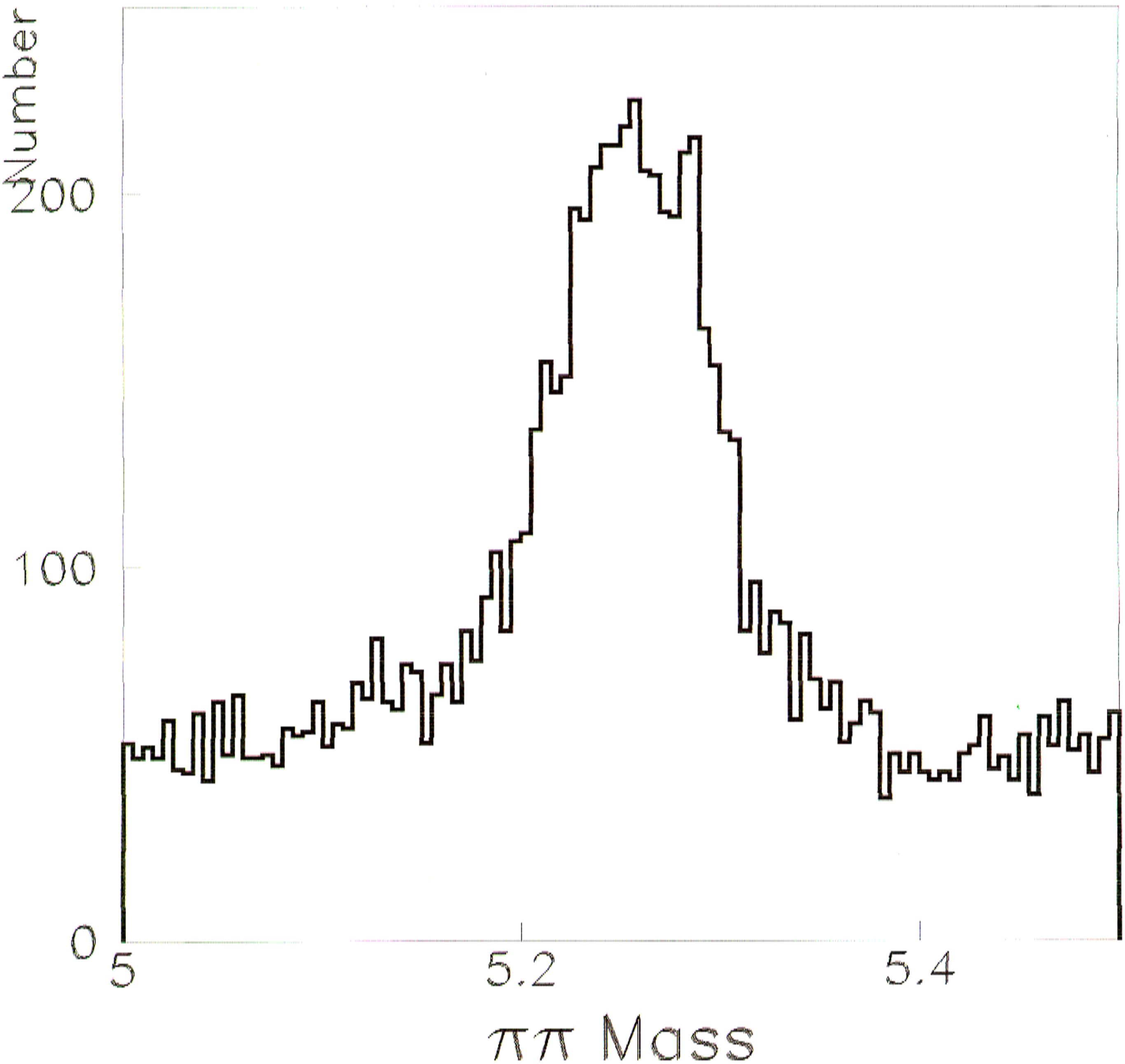
CDF / DØ will get this in ~ the first 2 years of running

BTeV will get it in 1, but 5 years later

Just for $J/\psi \to \mu\mu$

CDF B→ππ

Mass Distributions



CRAIG BLOCKER

CP Decay Asymmetries

$$P_{B_d(\overline{B}_d)\to\pi\pi} = \frac{\Gamma}{2}\begin{bmatrix}1 \mp A_{mix}^{\pi\pi}\sin(\Delta m_d t)\\ \mp A_{dir}^{\pi\pi}\cos(\Delta m_d t)\end{bmatrix}e^{-\Gamma t}$$

$$P_{B_d(\overline{B}_d)\to K\pi} = \frac{\Gamma}{2}e^{-\Gamma t}$$

$$P_{B_s(\overline{B}_s)\to KK} = \frac{\Gamma}{2}\begin{bmatrix}1 \mp A_{mix}^{KK}\sin(\Delta m_s t)\\ \mp A_{dir}^{KK}\cos(\Delta m_s t)\end{bmatrix}e^{-\Gamma t}$$

$$P_{B_s(\overline{B}_s)\to K\pi} = \frac{\Gamma}{2}e^{-\Gamma t}$$

If there are no penguin amplitudes,
$A_{mix}^{\pi\pi} = \sin(2\alpha)$, $A_{mix}^{KK} = \sin(2\gamma)$, and
$A_{dir}^{\pi\pi} = A_{dir}^{KK} = 0$.

Event Numbers

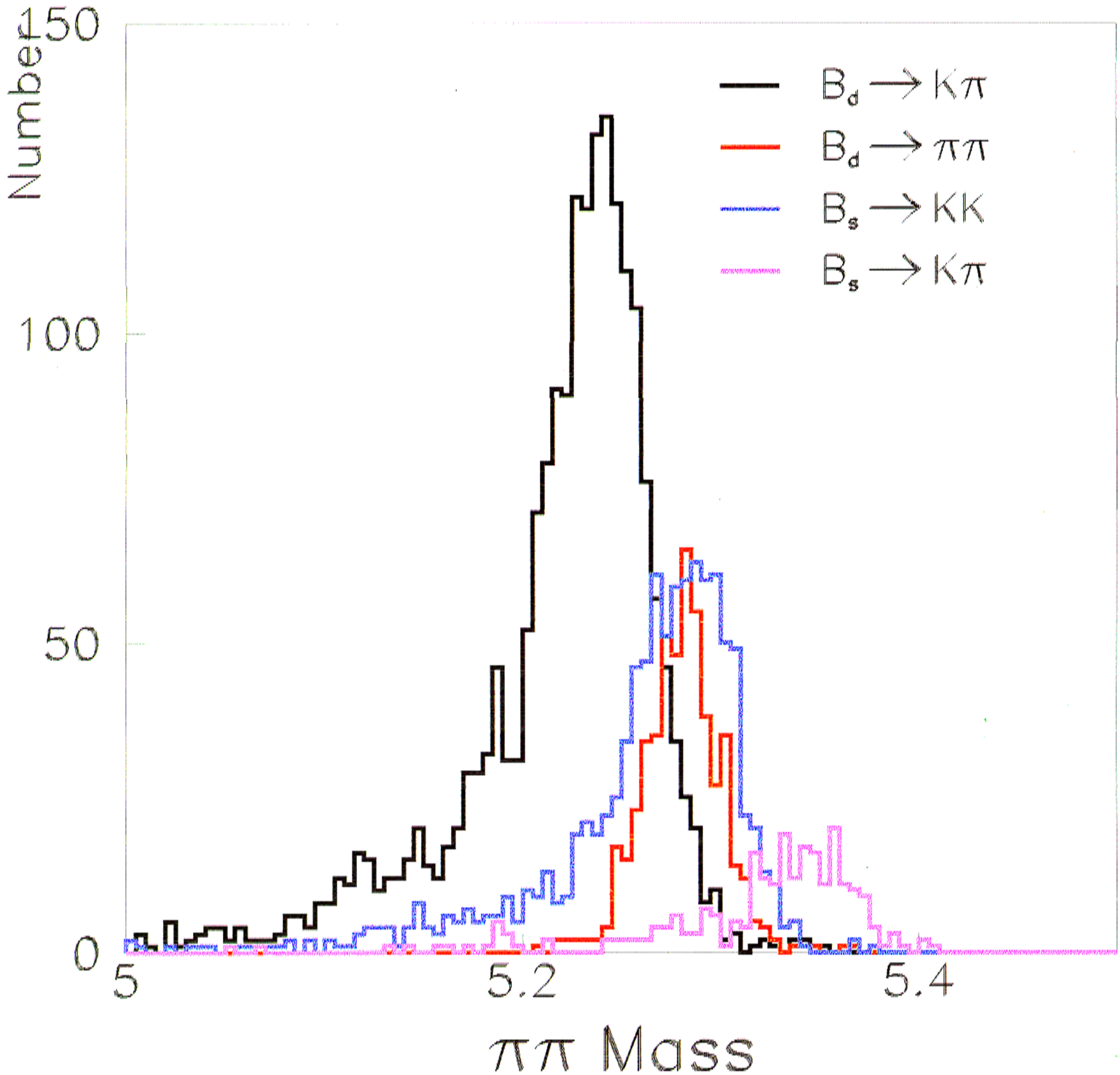
Assume 5,000 $B_d \to \pi\pi$ and $\varepsilon D^2 = 10\%$ for tagging. Note that B_s tagging may differ from B_d, which is ignored here.

This gives the following numbers of events:

$B_d \to \pi\pi$	500
$B_d \to K\pi$	2000
$B_s \to K\pi$	250
$B_s \to KK$	1000

Background 5000 from 5.0 to 5.5 GeV/c^2

Mass Distributions



Log Likelihood Function

$$\ln L = \sum_{\text{events}} \ln\{(1 - f_B)[f_{\pi\pi} G(M_{\pi\pi}; M_{B_d}, \sigma_{\pi\pi})\tilde{P}^d_{\pi\pi}(t) +$$

$$f^d_{K\pi} G(M_{\pi\pi}; \overline{M}^d_{K\pi}, \sigma^d_{K\pi})\tilde{P}^d_{K\pi}(t) +$$

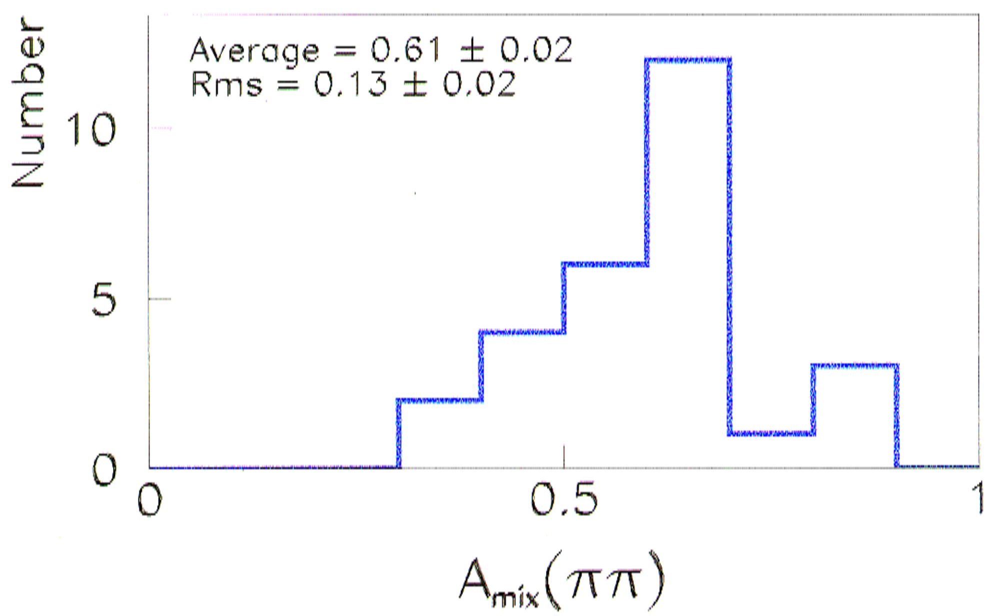
$$f^s_{K\pi} G(M_{\pi\pi}; \overline{M}^s_{K\pi}, \sigma^s_{K\pi})\tilde{P}^s_{K\pi}(t) +$$

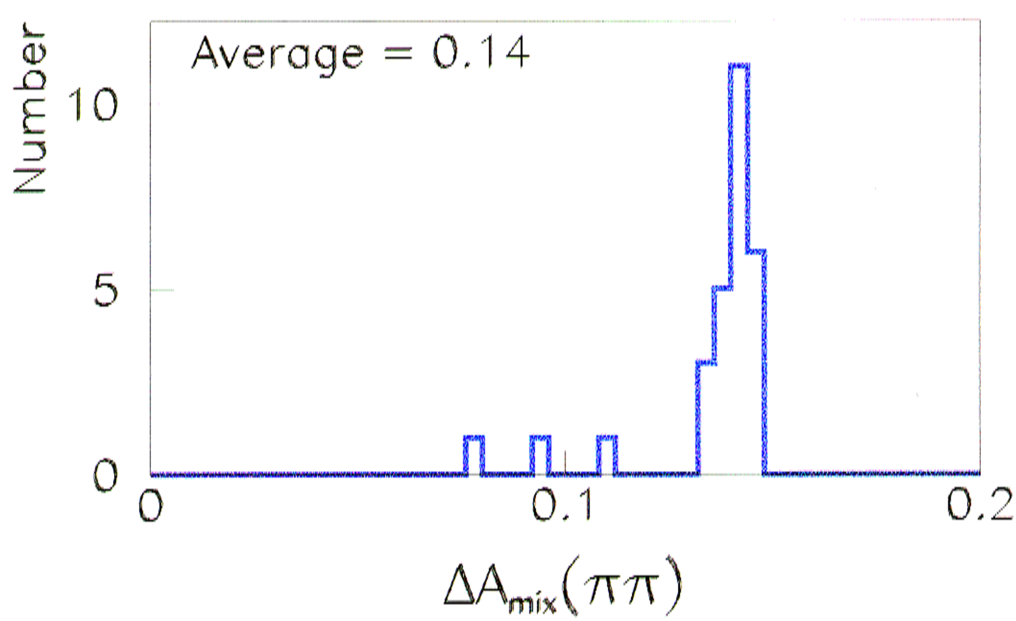
$$f^s_{KK} G(M_{\pi\pi}; \overline{M}_{KK}, \sigma^s_{KK})\tilde{P}^s_{KK}(t)] +$$

$$f_B \tilde{P}_{BG}(t)\}$$

Assume that we know f's, M's, σ's, Γ's, and Δm's well. ln L is then function of the A's.

$A_{mix}(\pi\pi)$ Resolutions





$\Delta A_{mix}(KK) \sim 0.1 - 0.15$

List of Observables

untagged measurements

tagged measurements

- * • Relative BR of $B_d \to \pi^+\pi^-, K^\pm\pi^\mp$
- * • Relative BR of $B_s \to K^+K^-, K^\pm\pi^\mp$
- * • Direct CP violation in $B_d \to K^+\pi^-$
- * • Direct CP violation in $B_s \to K^-\pi^+$
- * • A_{cp}^{mix},A_{cp}^{dir},$A_{\Delta\Gamma}$ in tagged $B_d \to \pi^+\pi^-$
- * • A_{cp}^{mix},A_{cp}^{dir}, $A_{\Delta\Gamma}$ in tagged $B_s \to K^+K^-$
- * • $A_{\Delta\Gamma}$ in untagged $B_s \to K^+K^-$ decays
- * • $A_{\Delta\Gamma}$ in untagged $B_d \to \pi^+\pi^-$ decays
- * • mean lifetime of $B_d \to \pi^+\pi^-$
- * • mean lifetime of $B_s \to K^+K^-$

All but three of these are interesting within SM

Theoretical Interpretation

(R.Fleischer PLB459 (1999) 306)

χ^2 fit to 5 experimental results

Four unknowns:

- $d =$ ratio of hadronic matrix elements
- $\theta =$ phase of ratio of hadronic matrix elements
- $\gamma, \beta =$ weak phases

Five observables:

$$A_{cp}^{dir}(\pi^+\pi^-) = -\frac{2d\sin\theta\sin\gamma}{1-2d\cos\theta\cos\gamma+d^2}$$

$$A_{cp}^{dir}(K^+K^-) = \frac{2d\frac{1-\lambda^2}{\lambda^2}\sin\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+(\frac{1-\lambda^2}{\lambda^2})^2 d^2} \sim \frac{2\lambda^2}{d}\sin\theta\sin\gamma$$

$$A_{cp}^{mix}(K^+K^-) = \frac{\sin 2\gamma+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\sin\gamma}{1+2d\frac{1-\lambda^2}{\lambda^2}\cos\theta\cos\gamma+d^2(\frac{1-\lambda^2}{\lambda^2})^2} \sim \frac{2\lambda^2}{d}\cos\theta\sin\gamma$$

$$A_{cp}^{mix}(\pi^+\pi^-) = \frac{\sin 2(\beta+\gamma)-2d\cos\theta\sin(2\beta+\gamma)+d^2\sin 2\beta}{1-2d\cos\theta\cos\gamma+d^2}$$

$$\sin 2\beta = 0.70 \pm 0.05$$

Conclusion

- Expect CDF to measure A^{dir} and A^{mix} for $B_d \to \pi^+\pi^-$ as well as $B_s \to K^+K^-$.
- χ^2 fit to 4 A's and $\sin 2\beta$ to determine $\sin\gamma$.
- VERY PRELIMINARY assessment of sensitivity looks promising.
- VERY PRELIMINARY assessment of theoretical uncertainties look promising.
- MORE WORK required to make firm conclusions.

DØ $B \to h^+h^-$ trigger
$\bar{B} \to \ell$

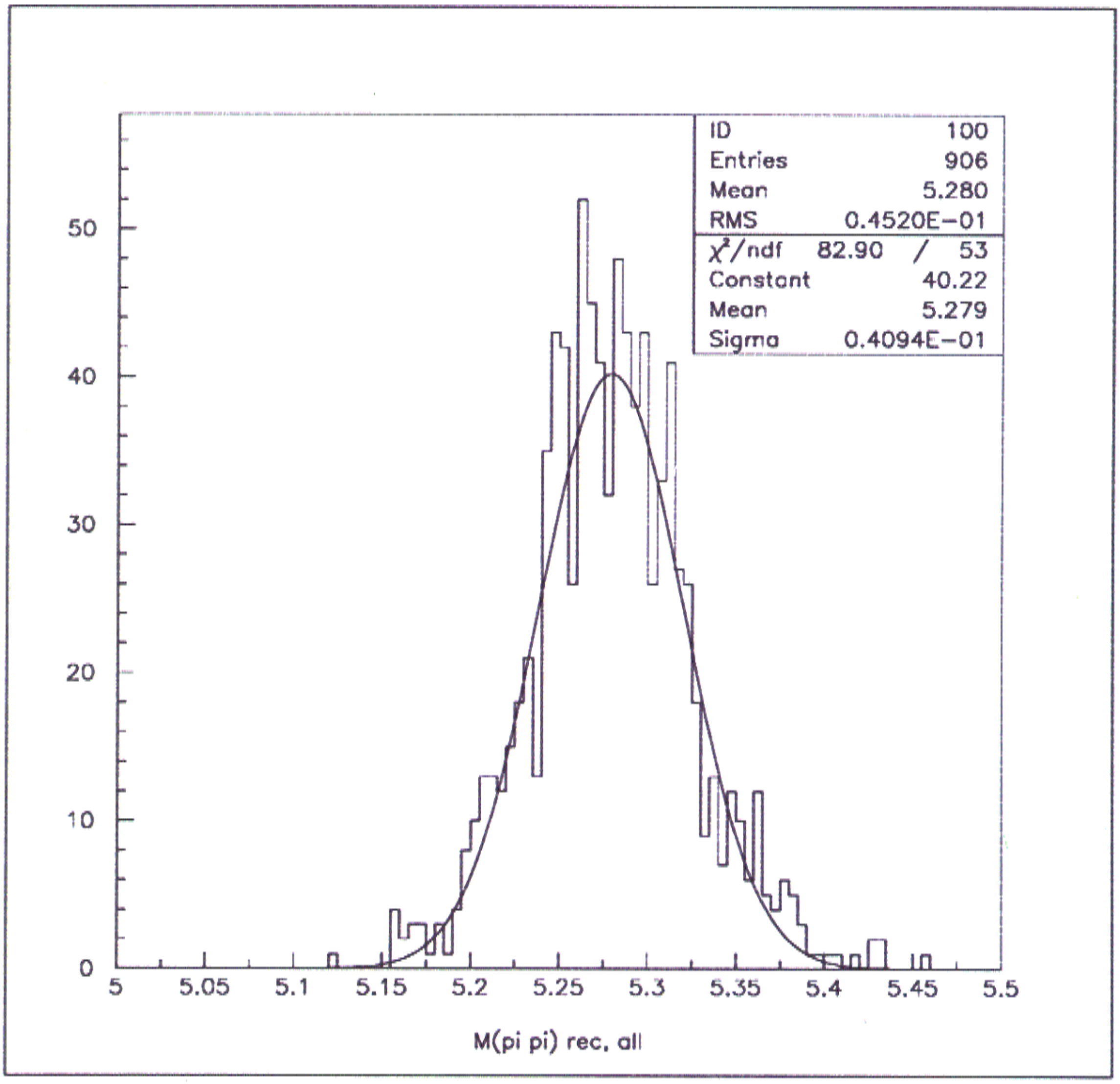
Implemented Trigger (2)

- On the reconstructed tracks the following requirements have to be met:
  - 1 tight quality lepton signature, $p_T > 3$ GeV.
  - 2 other tracks, $p_T > 1.5$ GeV.
  - 2 isolated tracks, one with $p_T > 3$ GeV.
  - All tracks have to have hits in all the CFT layers.

Michele Petteni, Imperial College
Yuri Gurstein

DØ

$B_d \rightarrow \pi^+ \pi^-$ Mass Plots

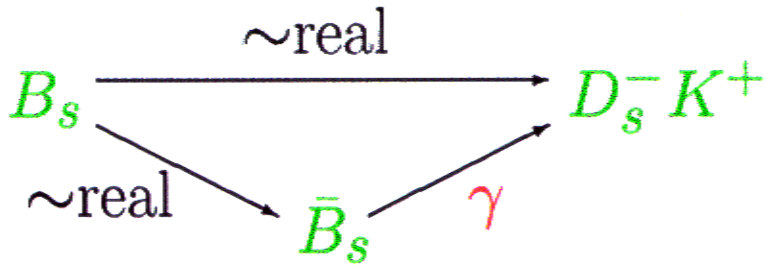


24/02/00

Michele Petteni, Imperial College

expect ~ 1K events in 2 fb⁻¹
already lepton tagged

$B_s \to D_s^{\mp} K^{\pm}$ can be used to measure the unitarity triangle angle γ:



Advantages:

- Theoretically clean: no penguins
- Reasonable branching fractions (BF > 10^{-4})
- Same trigger as B_s mixing with $B_s \to D_s^- \pi^+$
- Complements B factories' measurements

Disadvantages:

- Requires tagging and a time dependent B_s analysis
- $B_s \to D_s^- \pi^+$ background
- Strong phase δ
- Discrete ambiguities

The Decay Rate Equations

$$\Gamma_{B_s \to D_s^- K^+} = Ae^{-t}\left[\sqrt{1-R^2}\cos(\gamma+\delta)\sinh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) + \cosh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) + R\cos(x_s t) - \sqrt{1-R^2}\sin(\gamma+\delta)\sin(x_s t)\right]$$

$$\Gamma_{B_s \to D_s^+ K^-} = Ae^{-t}\left[\sqrt{1-R^2}\cos(\gamma-\delta)\sinh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) + \cosh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) - R\cos(x_s t) - \sqrt{1-R^2}\sin(\gamma-\delta)\sin(x_s t)\right]$$

$$\Gamma_{\bar{B}_s \to D_s^- K^+} = Ae^{-t}\left[\sqrt{1-R^2}\cos(\gamma+\delta)\sinh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) + \cosh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) - R\cos(x_s t) + \sqrt{1-R^2}\sin(\gamma+\delta)\sin(x_s t)\right]$$

$$\Gamma_{\bar{B}_s \to D_s^+ K^-} = Ae^{-t}\left[\sqrt{1-R^2}\cos(\gamma-\delta)\sinh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) + \cosh\left(\frac{\Delta\Gamma}{\Gamma}\cdot\frac{t}{2}\right) + R\cos(x_s t) + \sqrt{1-R^2}\sin(\gamma-\delta)\sin(x_s t)\right]$$

Toy Monte Carlo

We test our sensitivity using a toy Monte Carlo including:

- Functional form of signal and backgrounds
- Resolutions
- Mistag probability

Fit toy experiments with unbinned log likelihood fitter

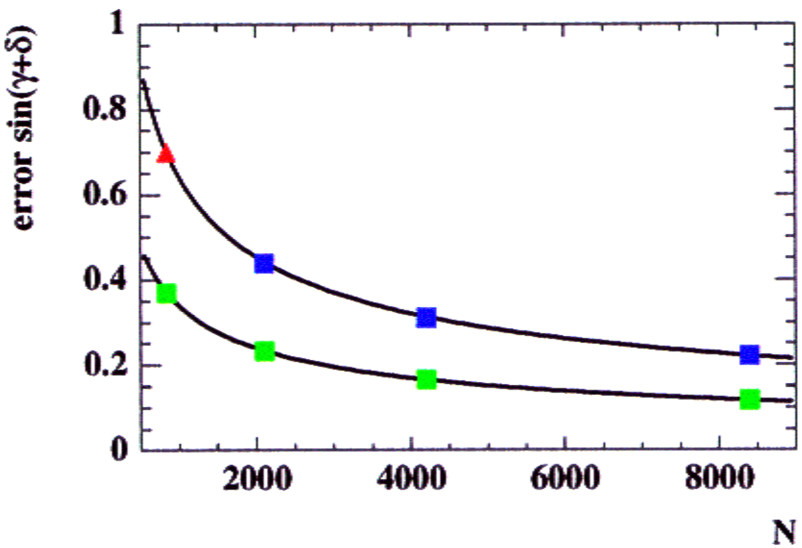
Compare reported and actual error as a function of input parameters

Parameter	Standard Model	Parameter	CDF II
γ	$90°$	$\sigma_{t/\tau}$	0.03
δ	$10°$	ϵD^2_{mistag}	0.113
$\lvert\bar{A}_f\rvert/\lvert A_f\rvert$	$\sqrt{1.4/2.4}$	$N(B_s \to D_s K)$	840
x_s	20	S/B	$1/6$
x_d	0.723		
$\Delta\Gamma/\Gamma$	0.16		

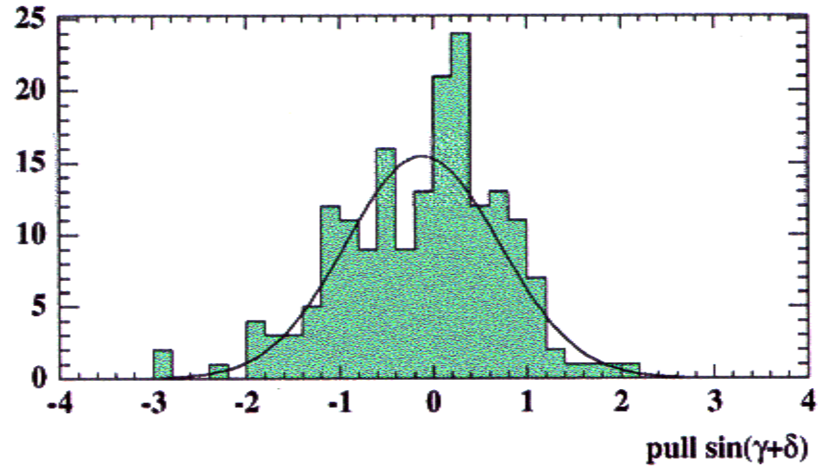
Estimated CDF Sensitivity

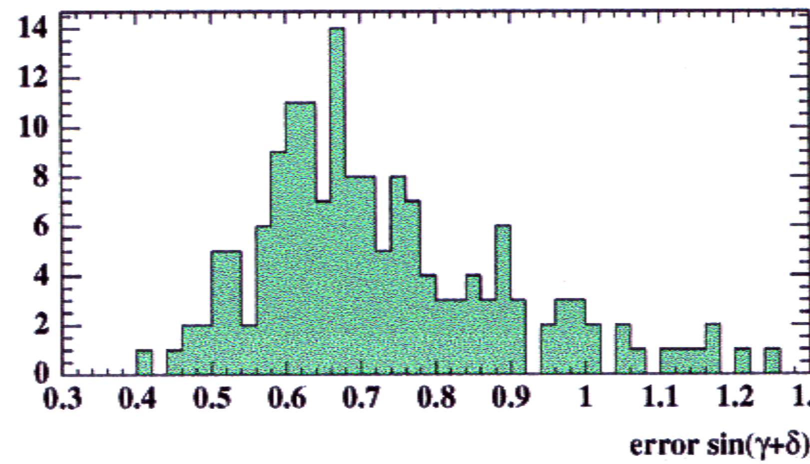
for 2 fb^{-2} and $S/B = 1/6$:

$\sigma(\sin(\gamma \pm \delta)) \approx 0.7$



- Red triangle: Central values for fit
- Blue squares: $S/B = 1/6$
- Green squares: $S/B = 1/1$





Pull and error distributions for $\sin(\gamma + \delta)$

BTeV

Reconstruction Efficiency

- Reconstruction effic 2.0% ($\phi\pi$), 1.7%(K^*K)
- Trigger effic $\sim$ 68% (2 tracks @4σ) both modes
- Tagging: preliminary studies $\epsilon = 0.4$, $D = 0.4$, $\epsilon D^2 = 0.64$

Luminosity	2×10^{32}	
Running time	10^7 sec	
Integrated Luminosity	2 fb−1	
$\sigma_{b\bar{b}}$	100μb	
Number of $B\overline{B}$ events	2×10^{11}	
Number of $B_s^0 + \overline{B}_s^0$	5×10^{10}	
BR($B_s^0 \to D_s^- K^+$)	$2. \times 10^{-4}$	
BR($B_s^0 \to D_s^+ K^-$)	$1. \times 10^{-4}$	
BR($D_s \to \phi\pi^+$) $\times$ $BR(\phi \to K^+K^-)$	1.8×10^{-2}	
BR($D_s \to \overline{K}^{*0} K$) $\times$ $BR(\overline{K}^{*0} \to K^-\pi^+)$		2.2×10^{-2}
Reconstruction efficiency	.020	.017
Trigger efficiency	0.70	0.70
Number of reconstructed $B_s^0(\overline{B}_s^0) \to D_s K$	3800	3900
Tagging efficiency ϵ	.40	
Number of tagged events	1500	1600

Table 1: Expected Number of Events/10^7 sec

P. Kasper

Time Resolution

- CP asymmetry is diluted by $e^{-\sigma_t^2 x_s^2/2}$ (σ_t is in units of τ_{B_s})
- A gaussian fit to the $t_{gen} - t_{res}$ distribution gives $\sigma_t = 45$ fsec for the $D_s \to \phi\pi$ mode
- Given that $\tau_{B_s} = 1.54$ psec, then $\sigma_t/t = .03$

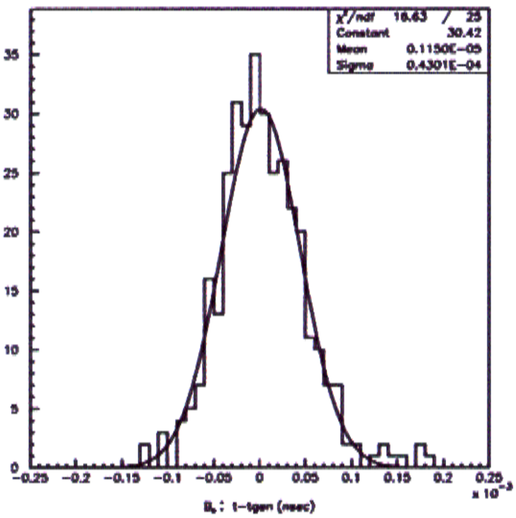


Figure 3: Proper Time Resolution for B_s : $t_{gen} - t_{rec}$ (nsec)

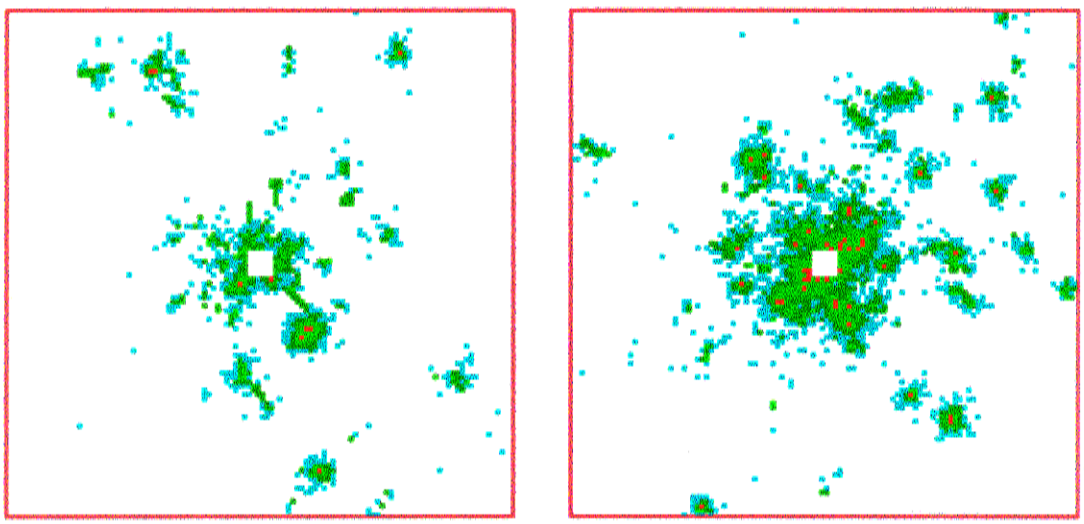
Conclusions

- The ability of BTeV to measure the angle γ of the unitarity triangle depends on several factors which are not well-known at the moment, in particular the branching fractions for $B_s \to D_s K$, the B_s mixing parameter x_s and the lifetime difference $\Delta\Gamma(B_s)$.
- We expect to have about 3000 reconstructed and tagged events per year(10^7 sec) at a luminosity of 2×10^{32}.
- Assuming reasonable estimates of branching ratios and x_s we expect to measure γ to about 10^o in one year. If $\Delta\Gamma(B_s) > 0.1$ the measurement of γ will be free from discrete ambiguities.

Similar sensitivity for $B \to DK$.

Peek At GEANT Simulations

The BTeV simulation and ECAL working groups have successfully implemented a full GEANT simulation of the electromagnetic calorimeter (ECAL)



Color coded hit pattern in both ECAL

Signal MC for $B \to \rho\pi$ with PYTHIA as basic event generator.

A. Wolf

BTeV

Fast and Dirty Look at $B_s \to J/\psi\ \phi$

Quantity	Value	Yield (Events/year)
Luminosity:	$2 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	
One Year:	10^7 s	
$\sigma_{b\bar{b}}$:	100 μb	
$\mathcal{B}(\bar{b} \to B_s)$	0.13	5.2×10^{10}
$\mathcal{B}(B_s \to \psi\phi)$:	$1. \times 10^{-3}$	5.2×10^{7}
$\mathcal{B}(\psi \to \mu^+\mu^-)$:	0.061	
$\mathcal{B}(\phi \to K^+K^-)$:	0.500	1.6×10^{6}
ϵ(Geometric)†	0.18	
ϵ(Analysis cuts)†	0.17	48,000.
ϵ(Trigger)†	0.85	41,000.
Tagging: ϵD^2	0.10	
S/B	20:1	
σ(Proper Decay time)	38 fs	
x_s	20-40??	
δ:		
Time Integrated:	$0.31(x_s = 20)$ to $0.62(x_s = 40)$	
Time Dependent:	$0.025(x_s = 20)$ to $0.035(x_s = 40)$	

† Efficiencies assumed equal to those for $B_s \to J/\psi\ \bar{K}^{*0}$.

- Numbers in red used in sensitivity calculation.

Rob Kutschke

CP violation chapter

- $B \to J/\psi + K_S$ - $B_S \to J/\psi + \phi$
  - Rick Jesik, Susan Gardner
- $B_d \to \pi\pi$, $B_s \to K K$
  - CDF, Matthias Neubert
- $B \to D K$
  - Penny Kasper, David Atwood
- $B \to \rho \pi$
  - Tomasz Sroczynski, Joao Silva
- $B \to J/\psi + \eta$ (η')
  - William Bell, Yossi Nir
- Summary
  - working group conveners

Each section will have:

- introduction (theory)
- experimental simulations
  - DZero
  - CDF
  - BTeV
  - summary and comparison
- references

Conclusions

We have made good progress

- new people involved interested in B physics
- after further review
  - DZero/CDF sin(2β) expectations are even better
  - we may yet get something out of $B \to \pi\pi \;(KK)$
- very nice presentations at this meeting
  - no fist fights - only one shouting match

Lots of work left to do

- new BTeV simulations
- Dzero GEANT + Reco simulations
- write it all up
  - we have an outline and have assigned responsibilities
  - FIRST DRAFT DUE BY END OF MARCH