Measuring γ with $B_s \to D_s^{\mp} K^{\pm}$

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Working Group I — CP Violation

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

$$\begin{tikzcd}
B_s \arrow[rr, "\sim\text{real}"] \arrow[dr, "\sim\text{real}"'] & & D_s^- K^+ \\
& \bar{B}_s \arrow[ur, "\gamma"'] &
\end{tikzcd}$$

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

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

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

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

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

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		

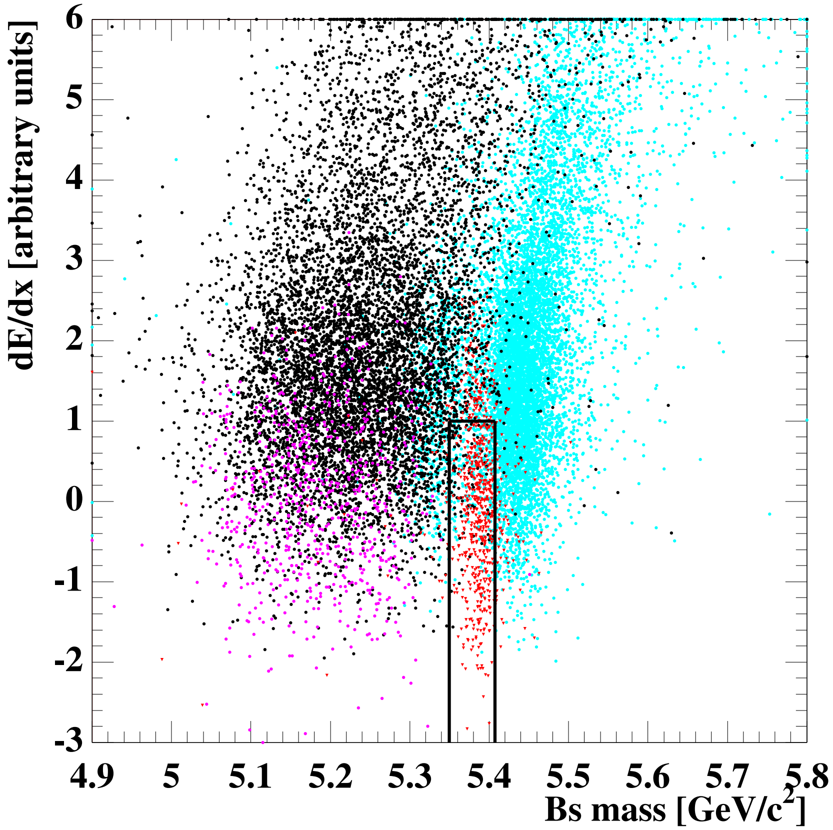
Background separation will be challenging

Physics Backgrounds:

Mode	BR $\times 10^{-3}$
$B_s \to D_s^- \pi^+$	3.0
$B_s \to D_s^{*-} \pi^+$	3.0
$B_s \to D_s^{*-} K^+$	0.2
$B_s \to D_s^{*+} K^-$	0.1
$B^0 \to D_s^- \pi^+$	0.1
$B^0 \to D_s^{*-} \pi^+$	0.1

The Signal:

Mode	BR $\times 10^{-3}$
$B_s \to D_s^- K^+$	0.24
$B_s \to D_s^+ K^-$	0.14

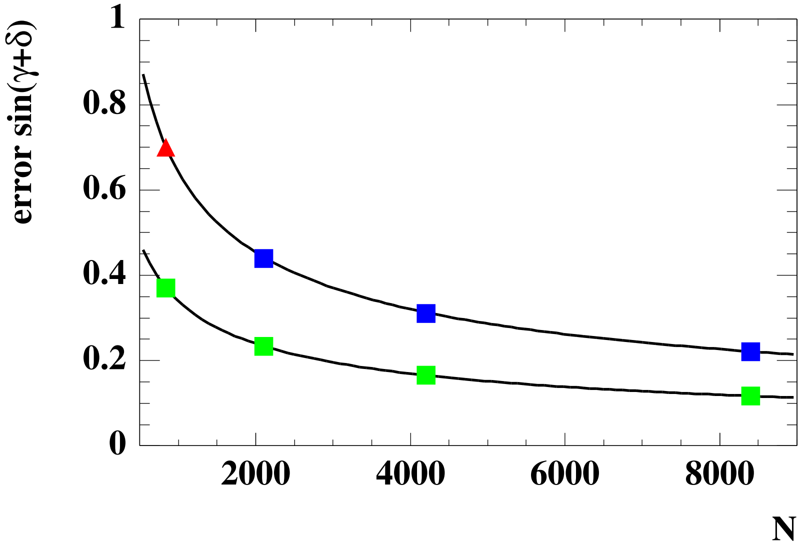


Using TOF, dE/dx, and mass cuts, we can acheive $S/B = 1/6$ or better.

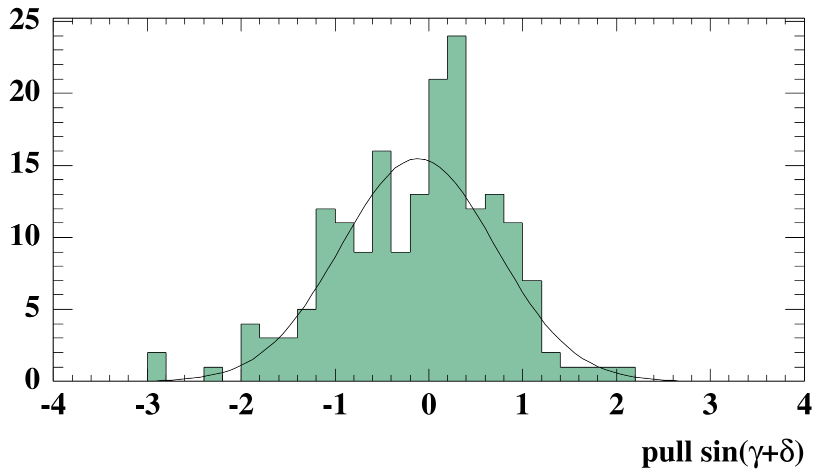
Estimated CDF Sensitivity

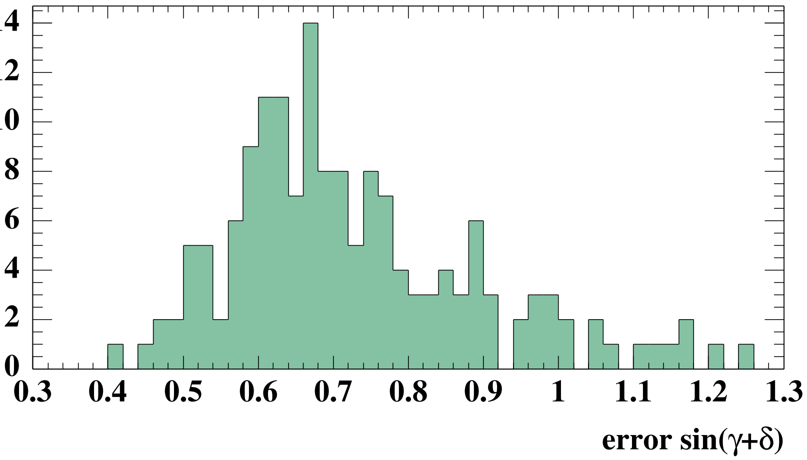
for 2 fb^{-2} and $S/B = 1/6$:

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



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

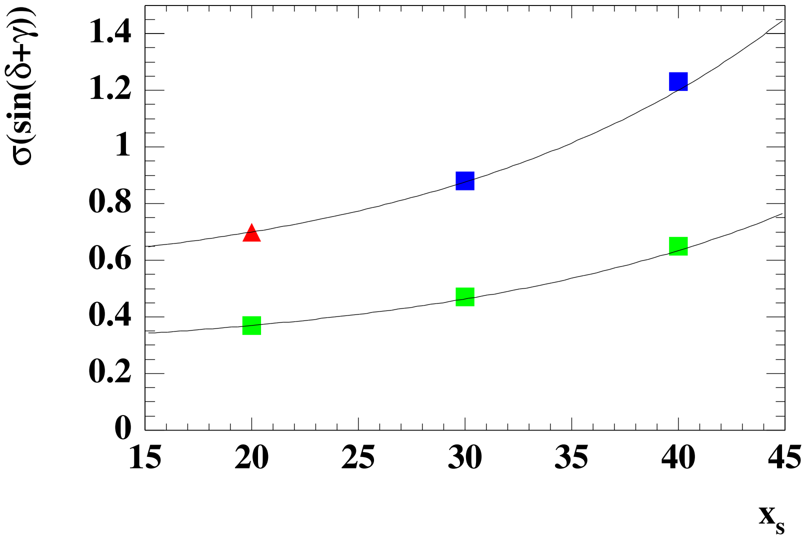




Pull and error distributions for $\sin(\gamma + \delta)$

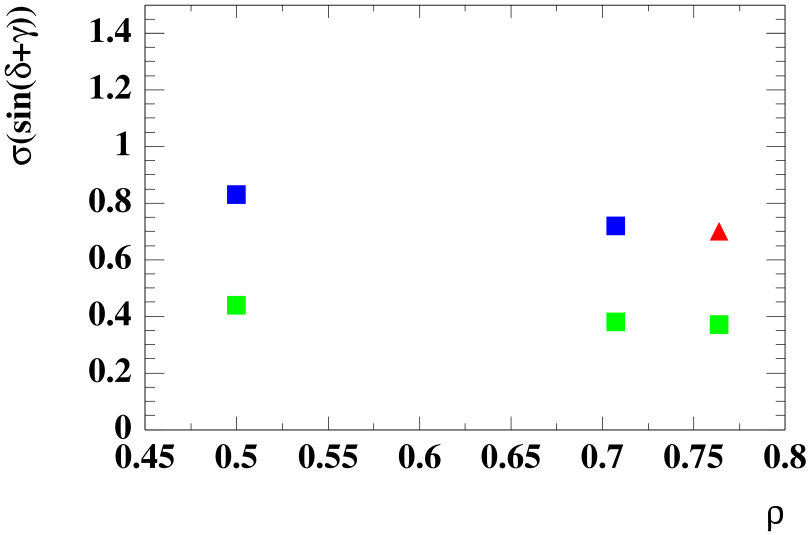
Estimated CDF Sensitivity

Physics parameters:
Vary x_s and $\rho = |\bar{A}_f|/|A_f|$



Error doesn't depend strongly on γ, δ, or $\Delta\Gamma/\Gamma$.

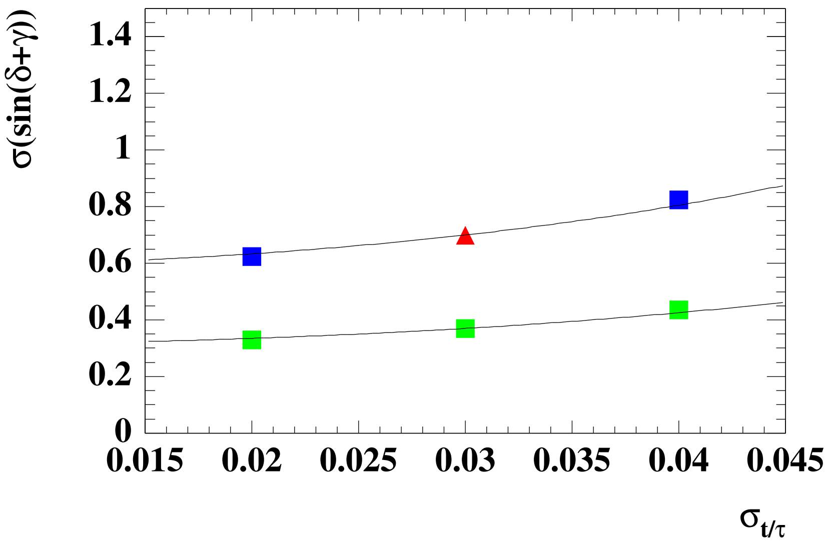
- Red triangles: Central values for fit
- Blue squares: $S/B = 1/6$
- Green squares: $S/B = 1/1$
- Curves: Theoretical shape normalized to central value

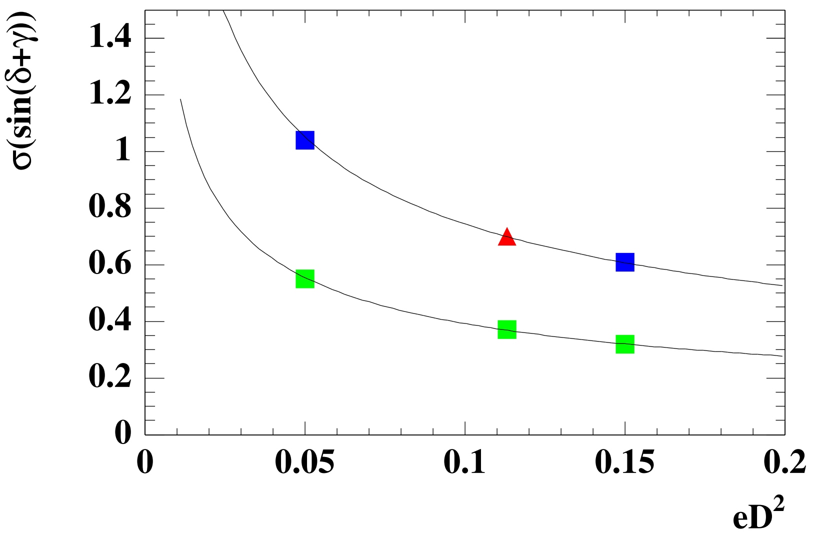


Estimated CDF Sensitivity

CDF parameters:
Vary $\sigma_{t/\tau}$ and ϵD^2

- Red triangles: Central values for fit
- Blue squares: $S/B = 1/6$
- Green squares: $S/B = 1/1$
- Curves: Theoretical shape normalized to central value



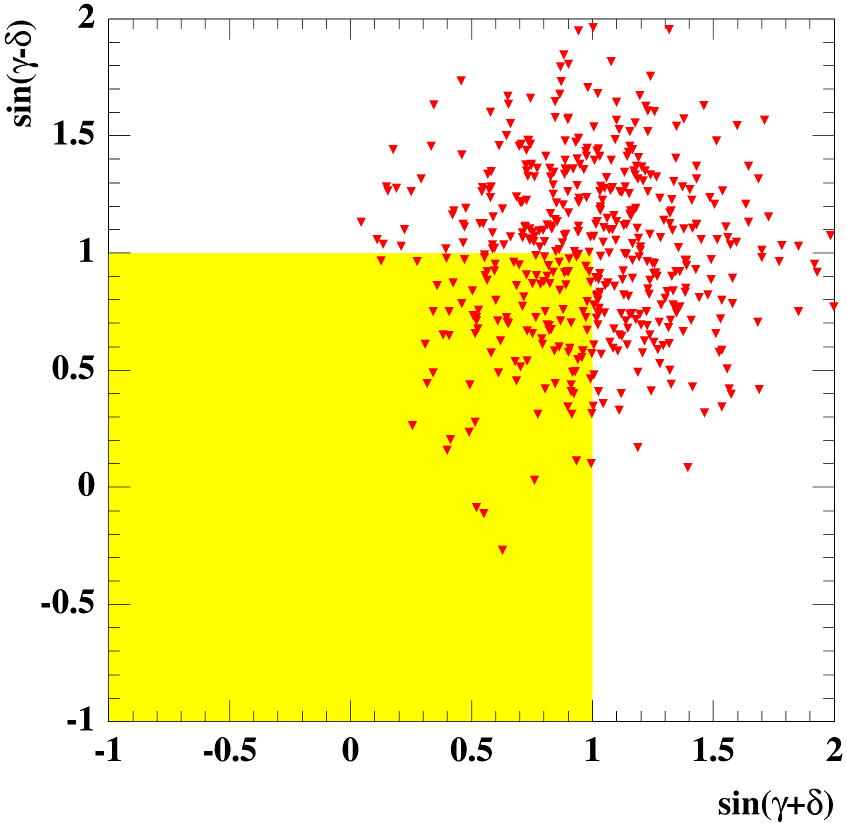


Estimated Error Formula

$$\sigma(\sin(\gamma \pm \delta)) = \frac{1}{D_{res}} \frac{1}{D_{bkg}} \frac{1}{D_{fit}} \frac{1}{\sqrt{\epsilon D_{mistag}^2 N}}$$

- $D_{res} = e^{-\sigma_t^2 x_s^2/2}$
- $D_{bkg} = \sqrt{\frac{S}{S+B}}$
- ϵD_{mistag}^2 from tagging
- $D_{fit} = 0.46$ is a fundamental fit limit
  depends somewhat on $|\bar{A}_f|/|A_f|$; less so on γ, δ, and $\Delta\Gamma/\Gamma$

Measuring $\sin(\gamma \pm \delta) > 1$ is likely



γ and δ affect center

x_s, ϵD^2, etc. affect width

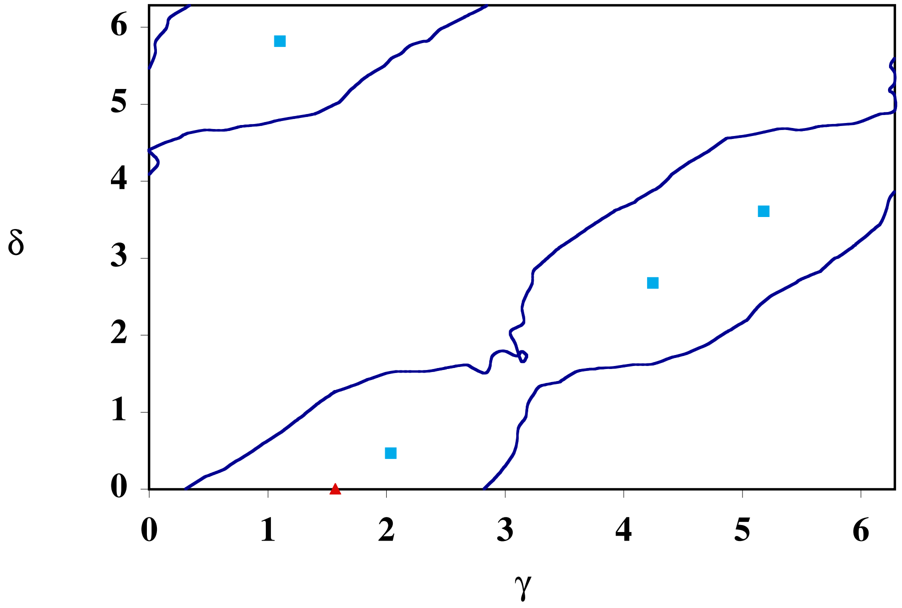
Analysis methods must handle this case naturally

Decouple $\sin(\gamma \pm \delta)$ measurements from statements about γ

Example toy Monte Carlo run with $\gamma = 90°$, $\delta = 10°$, and $\sigma(\sin(\gamma \pm \delta)) = 0.37$

Example Feldman Cousins 95% CL Contour:

$\sigma(\sin(\gamma \pm \delta)) = 0.8$



Plot from Craig Blocker

We need additional information on δ and/or resolution of discrete ambiguities to be able to exclude any of γ alone

This remains true even for fairly small $\sigma(\sin(\gamma \pm \delta))$

$\cos(\gamma \pm \delta) \sinh\left(\frac{\Delta\Gamma}{\Gamma} \cdot \frac{t}{2}\right)$ terms may help resolve discrete ambiguities

Conclusions

- Best theoretically clean method for measuring γ
- CDF will be statistics and S/B limited
- Initial result within 2 fb^{-1}