Studies of CP violation in $B_s^0 \to J/\psi + \phi/f_0$ decay

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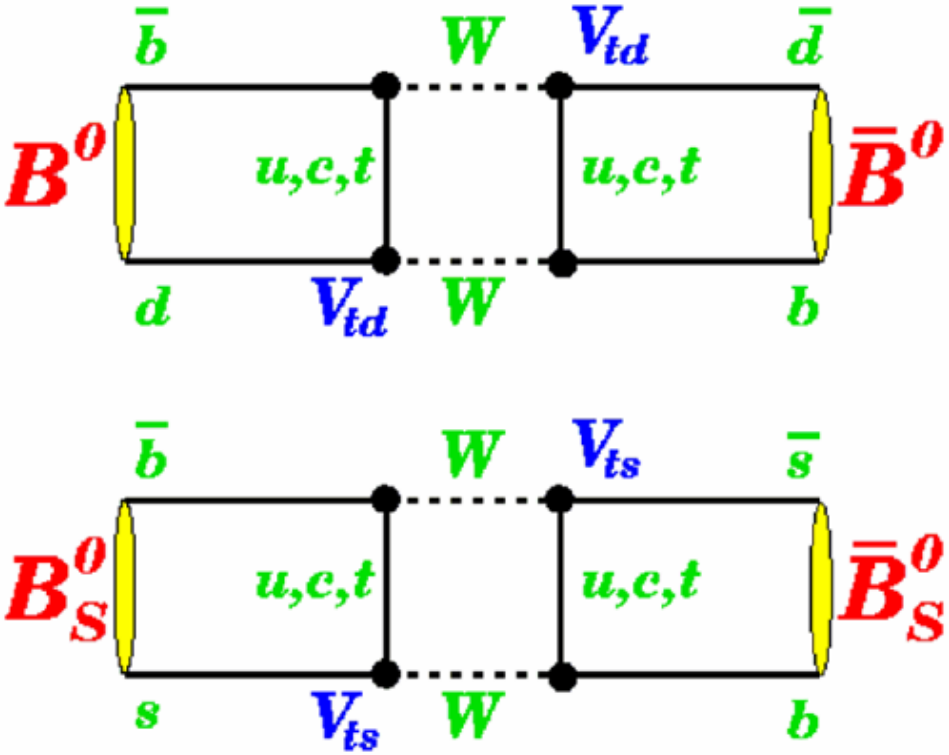
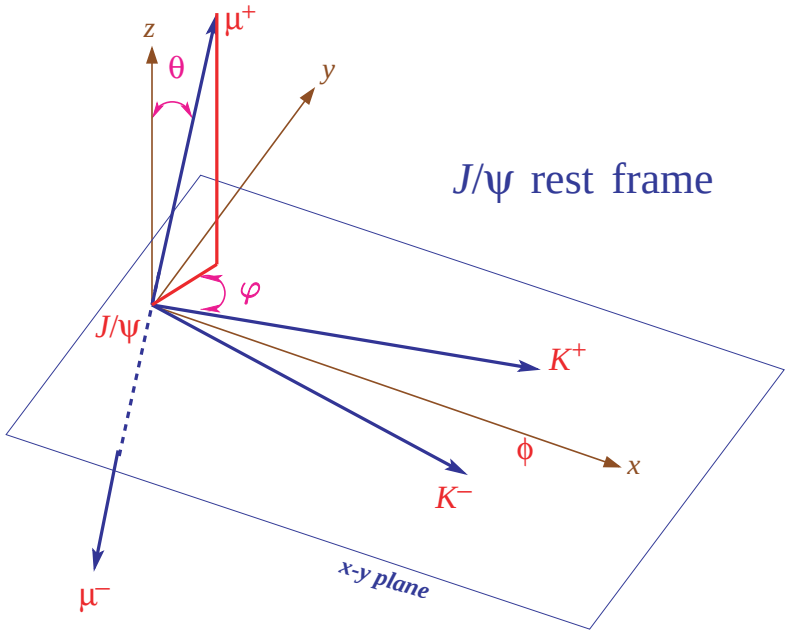
Motivation

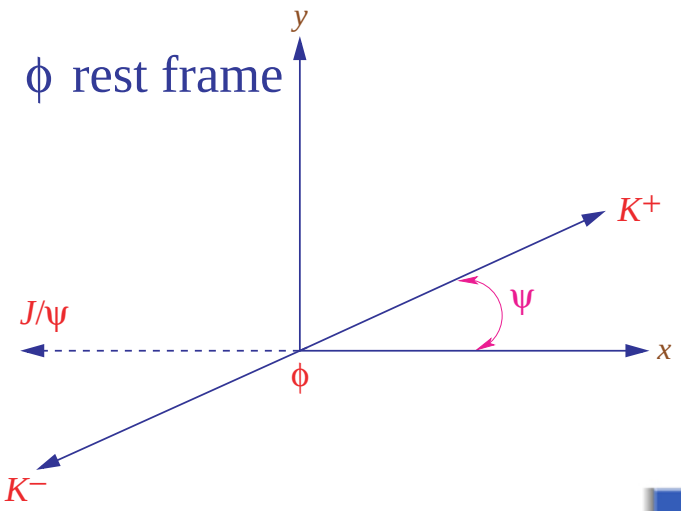
- The mass eigenstates of the B_s^0 system have sizeable mass and decay width difference ΔM_s and $\Delta\Gamma_s$
- The CP-violating mixing phase is predicted to be $\Phi_s^{J/\Psi\Phi} = -2\beta_s = -2\arg[-V_{tb}V_{ts}^*/V_{cb}V_{cs}^*] = -0.038 \pm 0.002$
- New phenomena may alter the phase $\Phi_s^{J/\Psi\Phi} \equiv -2\beta_s + \phi_s^{\Delta}$
- We measure $\Delta\Gamma_s$ and $\Phi_s^{J/\Psi\Phi}$



Event distribution

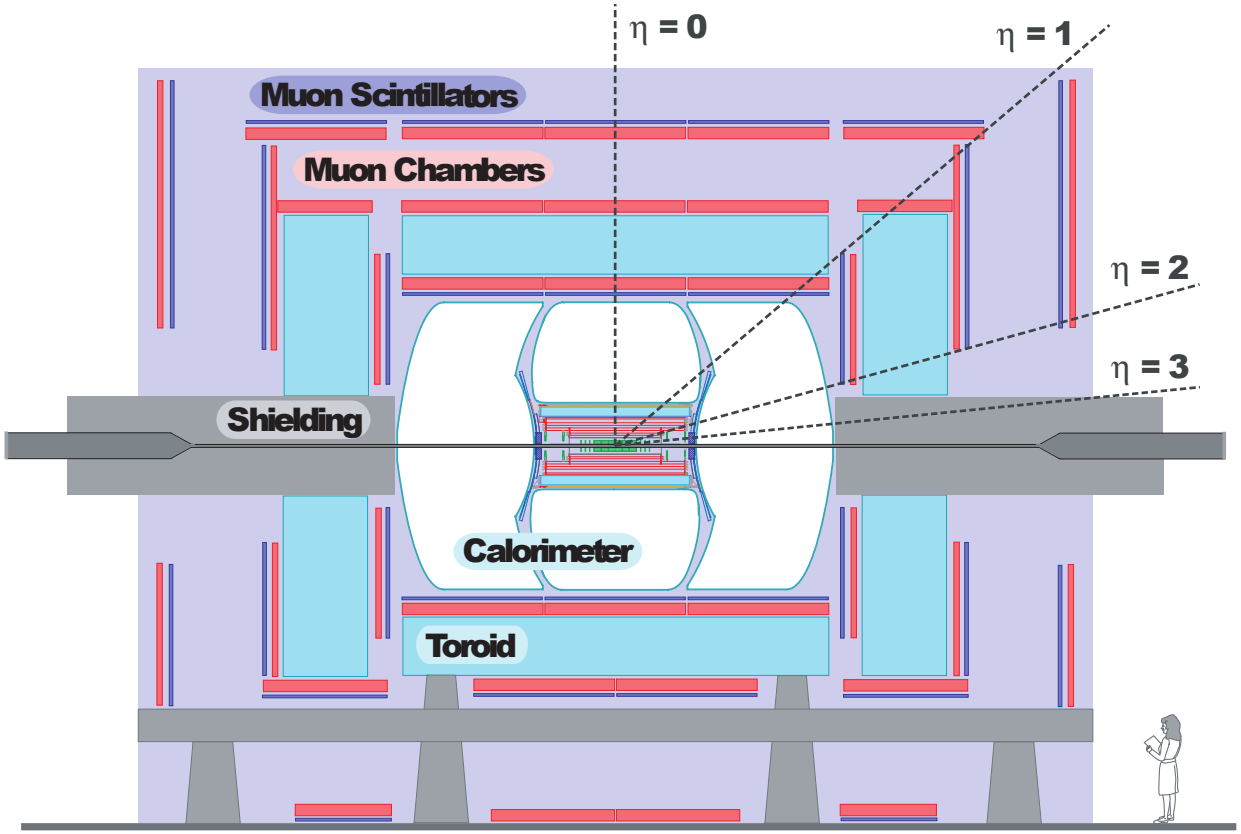
- $B_s \to J/\Psi\Phi$ admixture of CP-even/odd states
- Can be described by 3 polarization amplitudes
- Transversity basis $\vec{\omega} = (\psi, \theta, \varphi)$:
  - CP-odd (l=1): $A_\perp$
  - CP-even (l=0,2): A_0, $A_{||}$

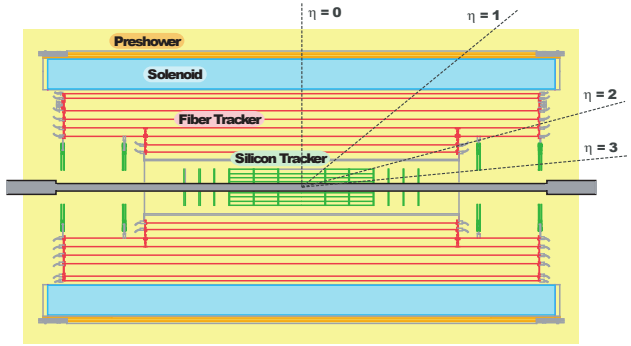


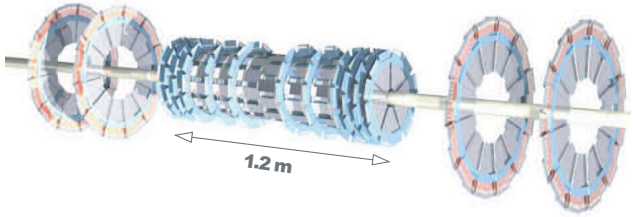


DØ Detector

- Excellent muon detection to $|\eta| < 2.2$, low punch-through
- Fiber and Silicon Tracker in $2T$ Solenoid

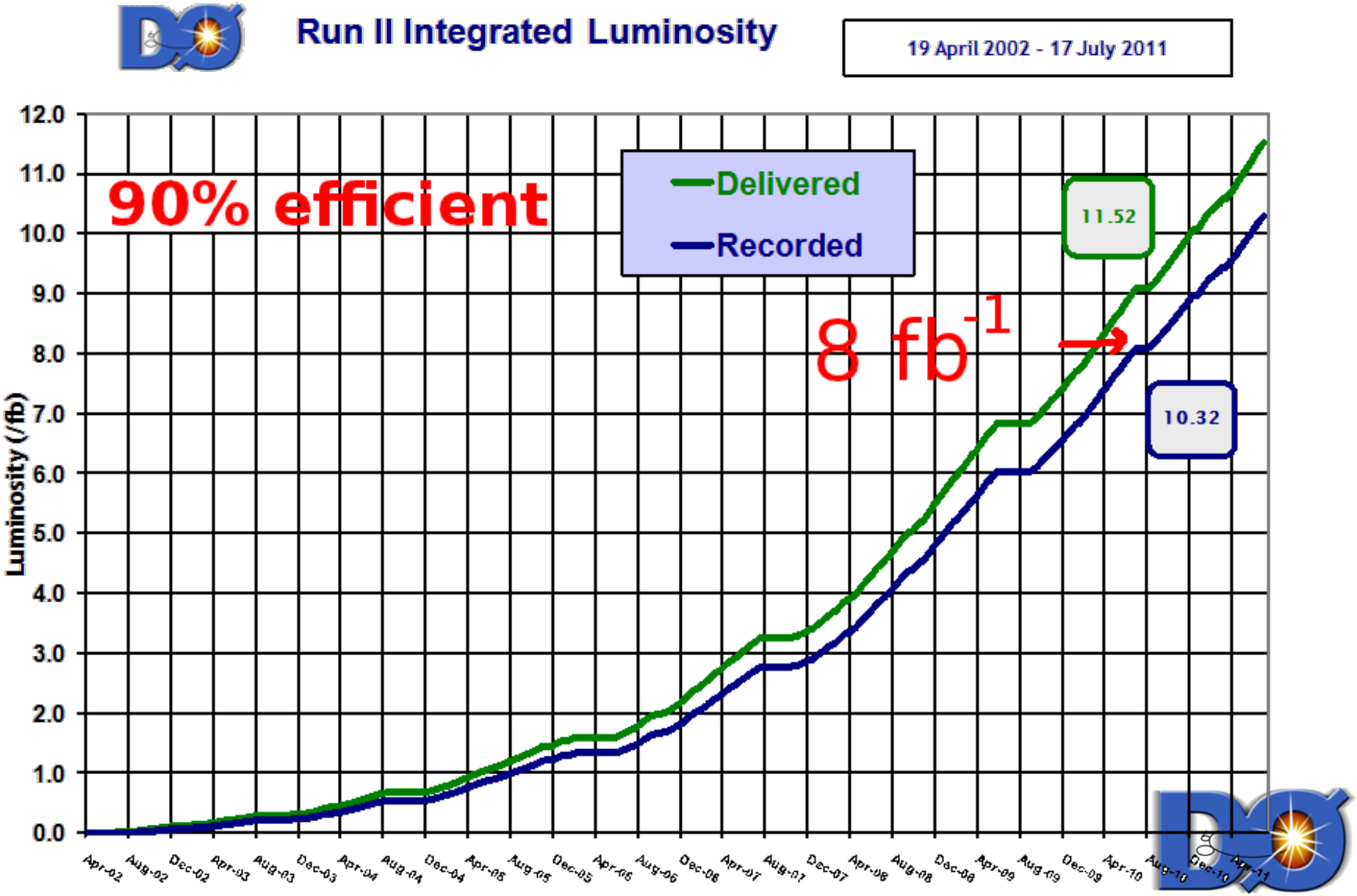






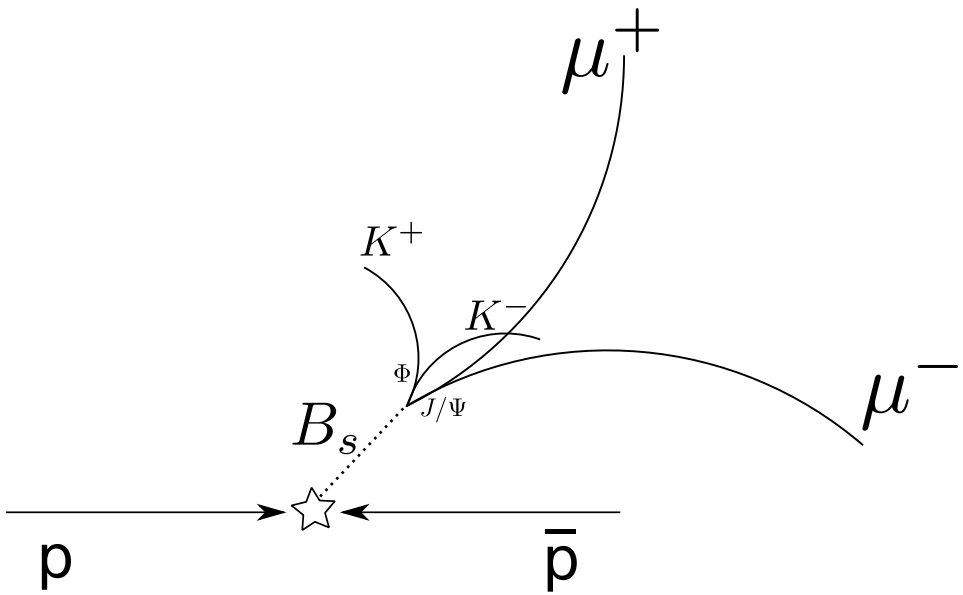
- Single and dimuon triggers

Data Samples



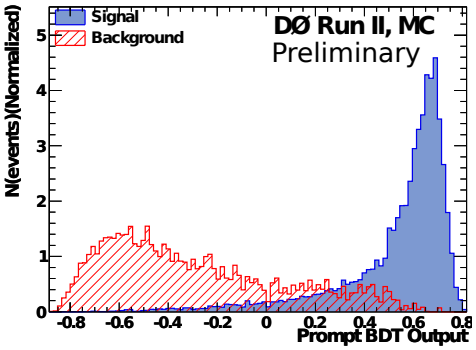
Event Selection

- We require two reconstructed muons of opposite charge.
- Form J/Ψ candidates
- Form Φ candiates from opposite charged tracks assuming the tracks are kaons.
- Form B_s candidates from J/Ψ and Φ candidates.
- Make cuts in the kinematic and the mass windows:
  - $P_t(K^{\pm}) > 0.4 GeV$
  - $2.84 < M(\mu^+\mu^-) < 3.35 GeV$
  - $0.98 < M(K^+K^-) < 1.04 GeV$
  - $5.0 < M(\mu^+\mu^-K^+K^-) < 5.8 GeV$

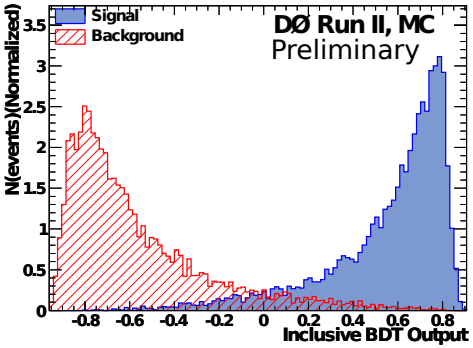


Background suppression

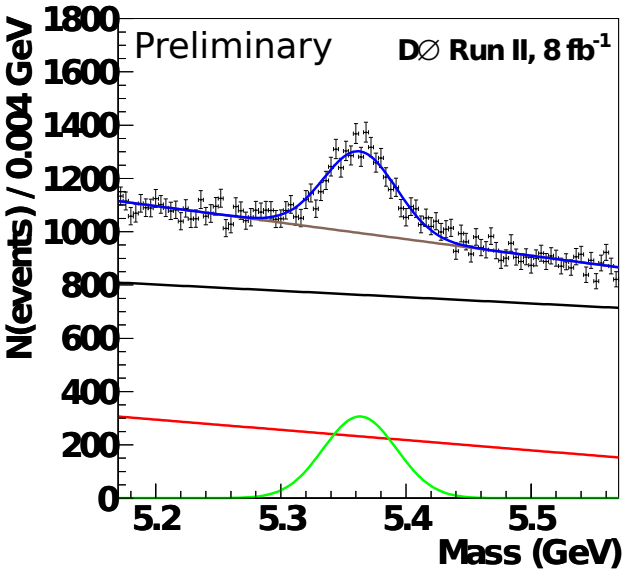
- BDT used to suppress background.
  - Prompt $p\bar{p} \to J/\Psi X$

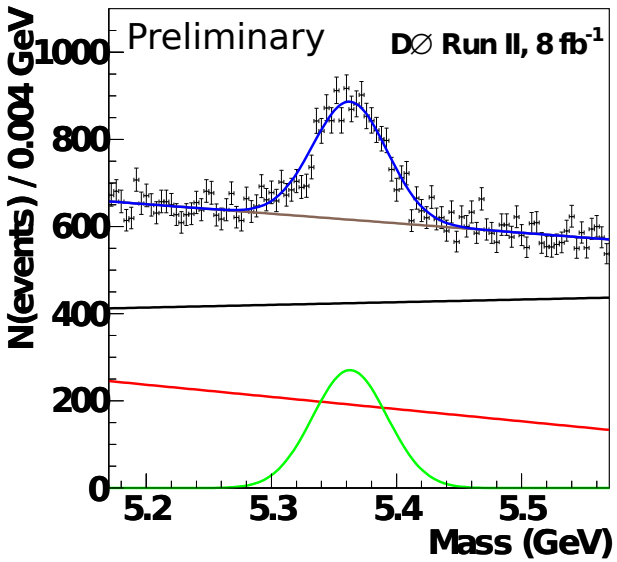


  - b-inclusive $p\bar{p} \to b\bar{b} \to J/\Psi X$

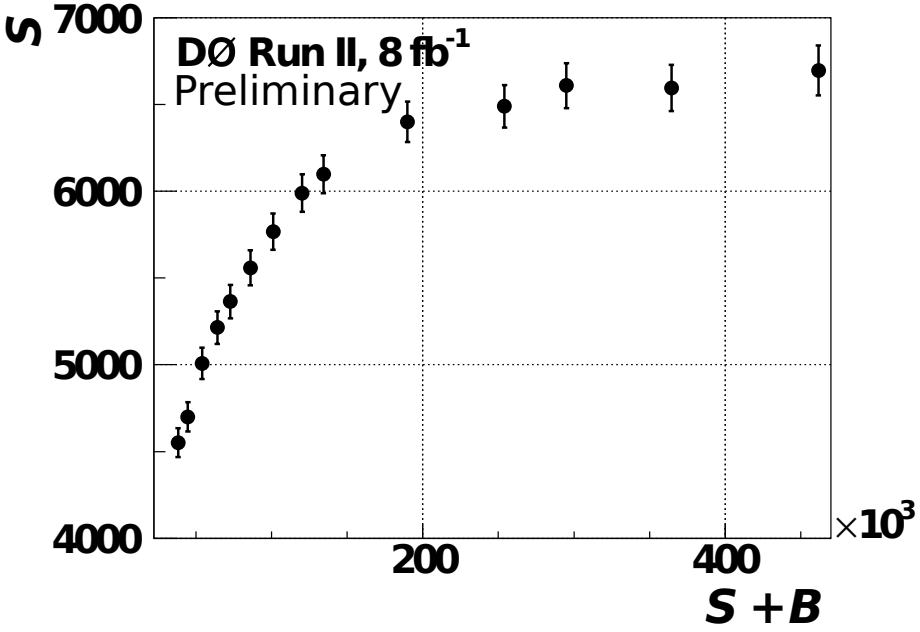


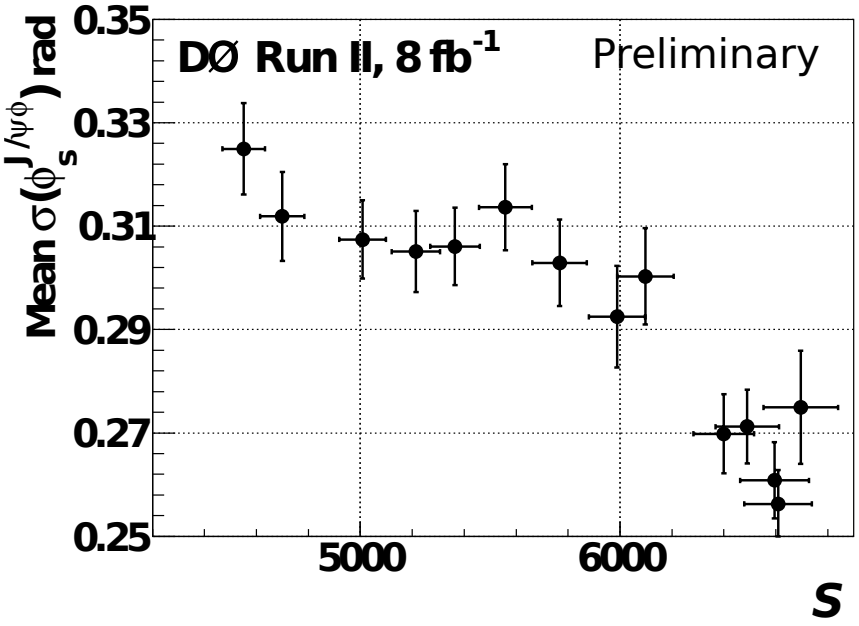
- Simple-Cut as in 2008 PRL, for cross-check and systematic uncertainties.





Optimizing selection





- Tight cuts implies better signal significance but less signal events
- Optimized selection cuts using toy montecarlo studies

Probability Distribution Function

$$\epsilon(\vec{\omega}) \times \left(\mathcal{B}_s(\lambda; t, \vec{\omega}) \frac{1-D}{2} + \overline{\mathcal{B}}_s(\lambda; t, \vec{\omega}) \frac{1+D}{2} \right) \otimes R(t)$$

where:

- $\vec{\omega} = (\psi, \theta, \varphi)-$ angles
- $D-$ initial flavor tagging dilution
- $\epsilon(\vec{\omega})-$ acceptance
- $R(t)-$resolution.

$$\mathcal{B}_s = \left| \left[\sqrt{1-F_s} g(\mu) \mathbf{A} + e^{-i\delta_s} \sqrt{F_s} h(\mu) \mathbf{B} \right] \times \hat{n} \right|^2$$

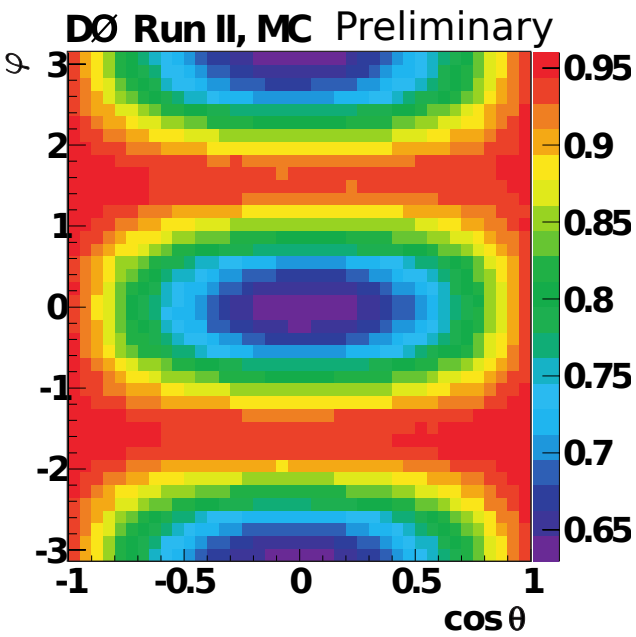
- $\mathbf{A}(\lambda; \mathbf{t}, \omega)-$ P-Wave
- $\mathbf{B}(\lambda; \mathbf{t}, \omega)-$ S-Wave.
- $\lambda = (\tau_s, \Delta\Gamma_s, \phi_s^{J/\Psi\phi}, |A_0|^2, |A_\perp|^2, F_s, \delta_s, \delta_{||}, \delta_\perp, \Delta m_s)$

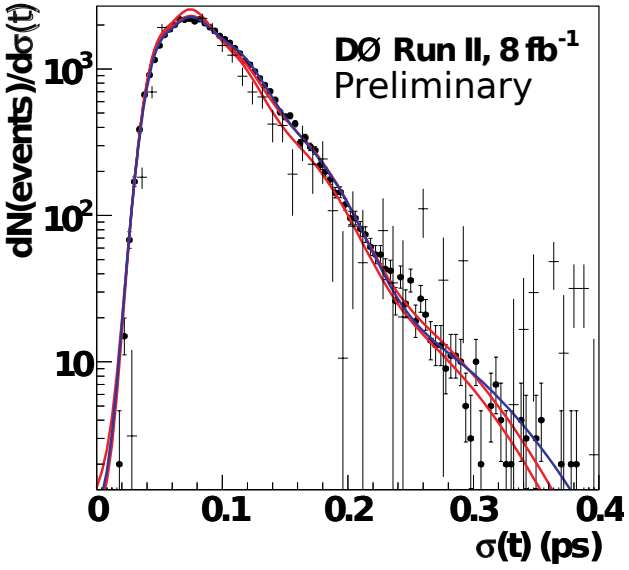
Real Measurables

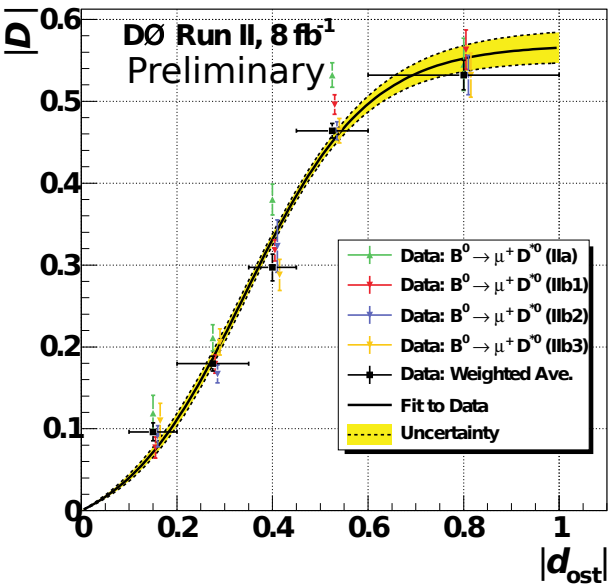
- Two constraints:
- $\Delta m_s \equiv 17.77 \pm 0.12$
- $\cos(\delta_\perp) < 0$

Parameter	Definition
$\lvert A_0\rvert^2$	$\mathcal{P}$-wave amplitude squared
$\lvert A_\parallel\rvert^2$	$\mathcal{P}$-wave amplitude squared
$\overline{\tau}_s$ (ps)	B_s^0 mean lifetime
$\Delta\Gamma_s$ (ps^{-1})	Heavy-light decay width difference
F_S	K^+K^- $\mathcal{S}$-wave fraction
$\phi_s^{J/\psi\phi}$	CP-violating phase
$\delta_\parallel$	$\arg(A_\parallel/A_0)$
$\delta_\perp$	$\arg(A_\perp/A_0)$
δ_s	$\arg(A_s/A_0)$

Acceptance, Resolution and Flavor Tagging





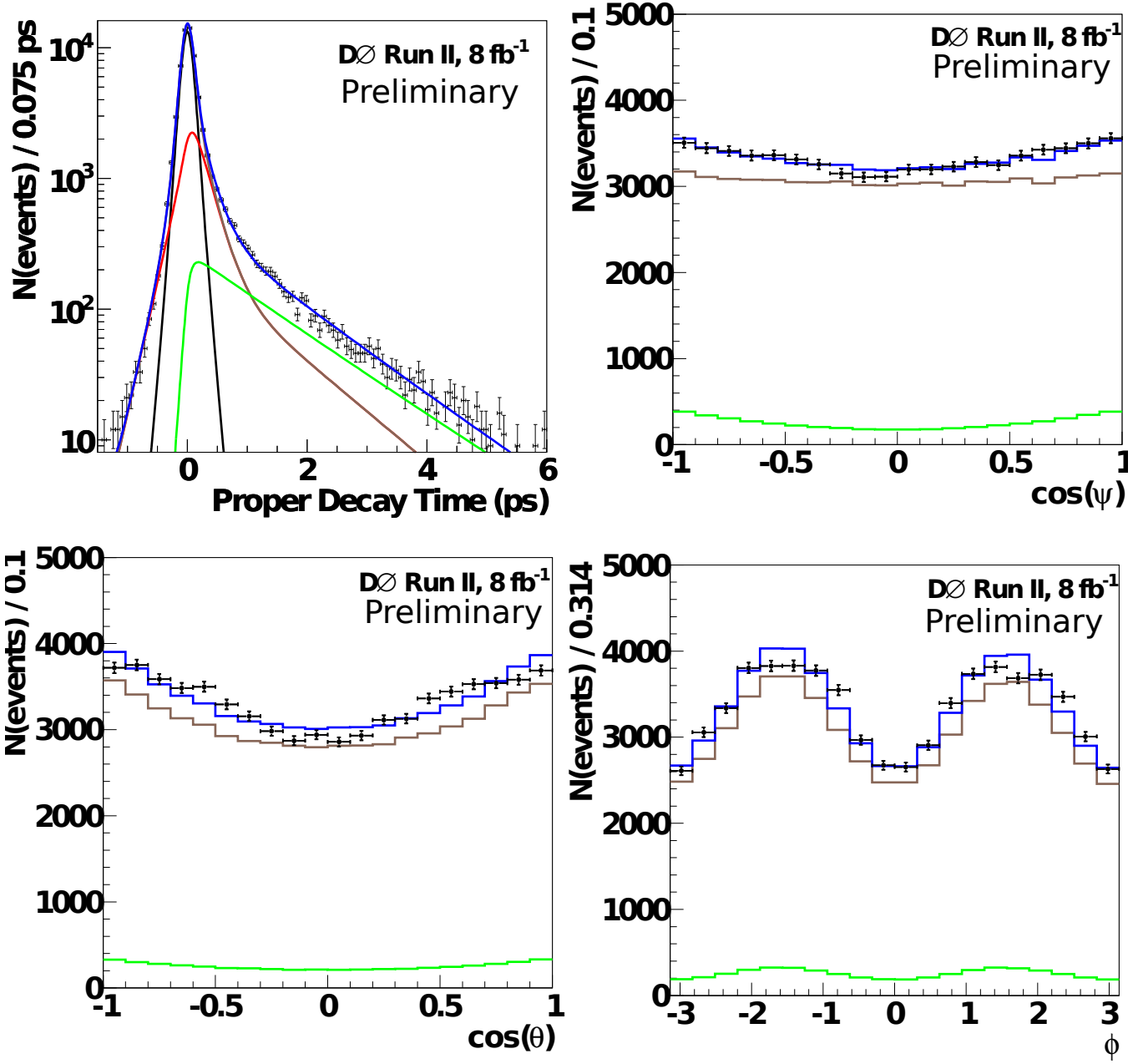


- Data selection criteria were applied to flat MC
- 2D $cos(\theta), \phi$ acceptance

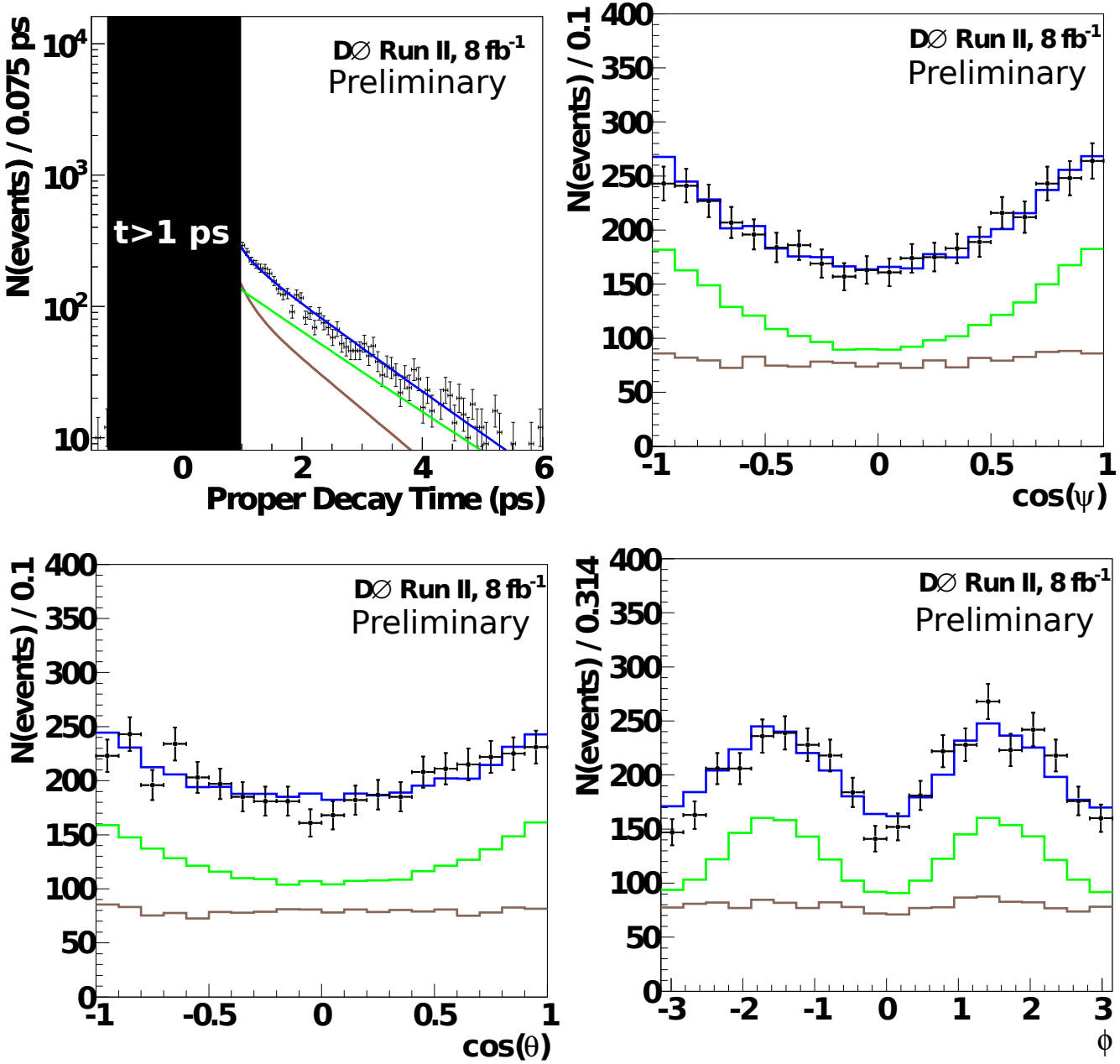
- Event-by-Event resolution width
- Distribution of proper decay time resolution
  - MC - Dots
  - Data - Crosses

- Opposite Flavor tagging using:
  - Muon
  - Electron
  - Jet Charge

Maximum Likelihood Fit



Maximum Likelihood Fit (Signal Enriched)

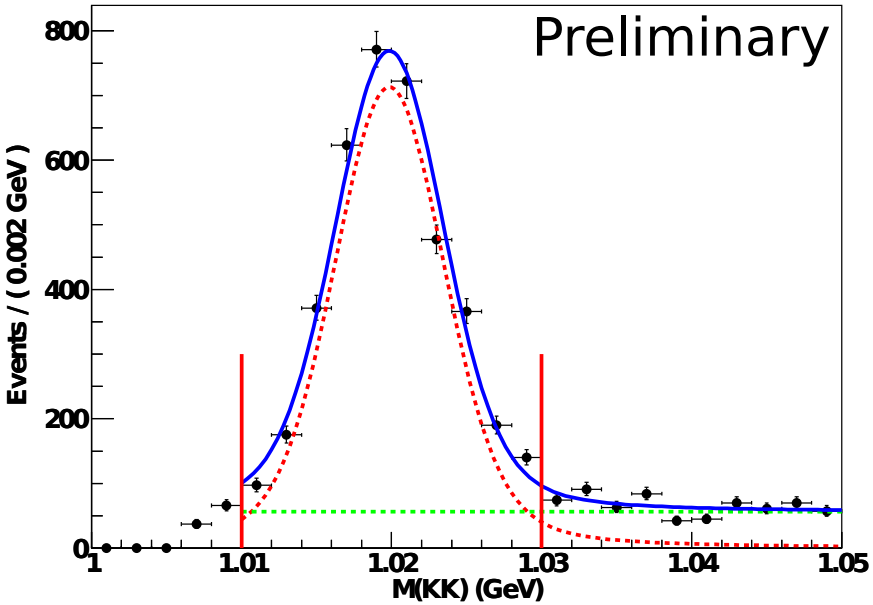


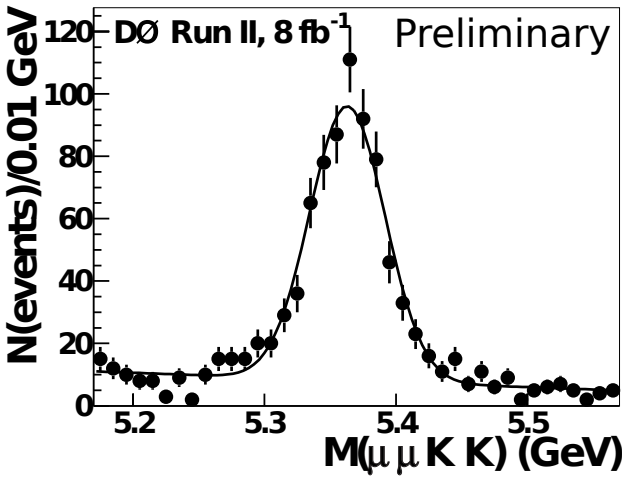
Fit Results

Parameter	BDT Sample	Simple Cut Sample
$\overline{\tau}_s$	$1.426^{+0.035}_{-0.032}$ ps	$1.444^{+0.041}_{-0.033}$ ps
$\Delta\Gamma_s$	$0.129^{+0.076}_{-0.053}$ ps^{-1}	$0.179^{+0.059}_{-0.060}$ ps^{-1}
$\phi_s^{J/\Psi\Phi}$	$-0.49^{+0.48}_{-0.40}$	$-0.56^{+0.36}_{-0.32}$
$\lvert A_0\rvert^2$	$0.552^{+0.016}_{-0.017}$	0.565 ± 0.017
$\lvert A_{\parallel}\rvert^2$	$0.219^{+0.020}_{-0.021}$	$0.249^{+0.021}_{-0.022}$
$\delta_{\parallel}$	-3.15 ± 0.27	-3.15 ± 0.19
$\cos(\delta_{\perp} - \delta_s)$	-0.06 ± 0.24	$-0.20^{+0.26}_{-0.027}$
$F_S(eff)$	0.146 ± 0.035	0.176 ± 0.036

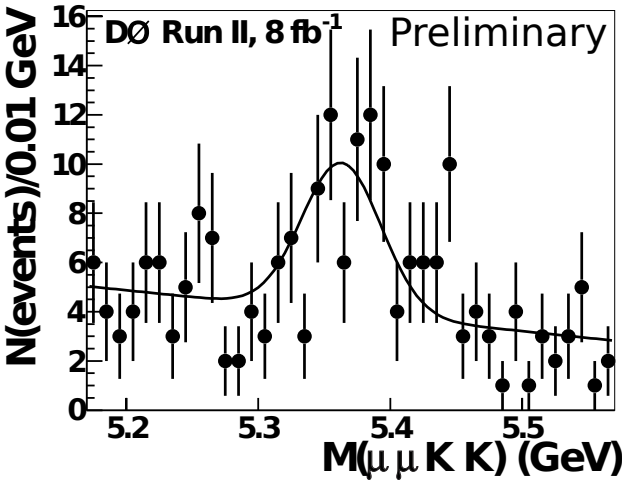
Independent determination of F_s

- The invariant mass distribution of B_s^0 candidates with $ct > 0.02$cm in two slices of $M(K^+K^-)$
- Fits to a sum of a Gaussian function and a polynomial are used to extract the B_s^0 yield in each slice.
- $F_s = 0.14 \pm 0.01$





$1.018 < M(K^+K^-) < 1.020$



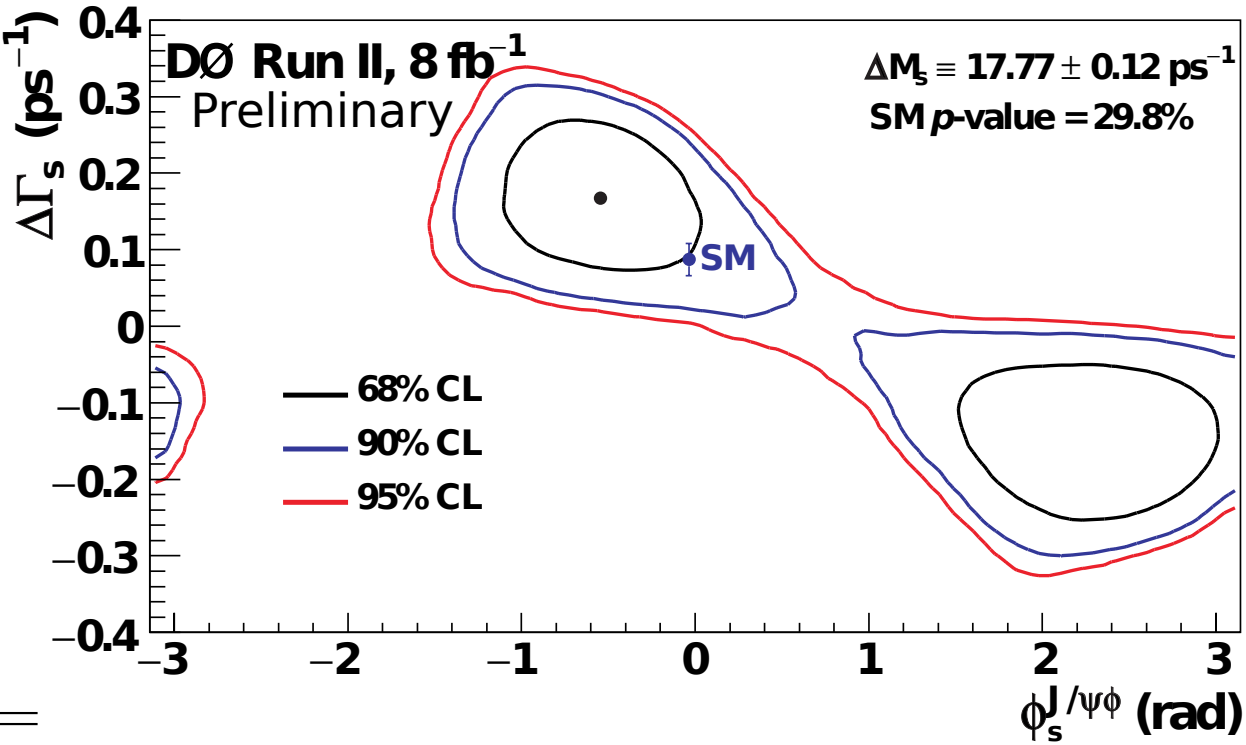
$1.048 < M(K^+K^-) < 1.050$

Systematic Uncertainties

- Acceptance systematic from differences between BDT and Simple-cut samples
- Variation in resolution parameters
  - Random variations in the resolution parameters
- Different widths of Φ
  - Different resolution for the Φ mass, important since s-wave is around 15%
- Variation OST calibration curve
- Markov Chain thechique for contours and systematics

$B_s^0 \to J/\Psi\Phi$ Result

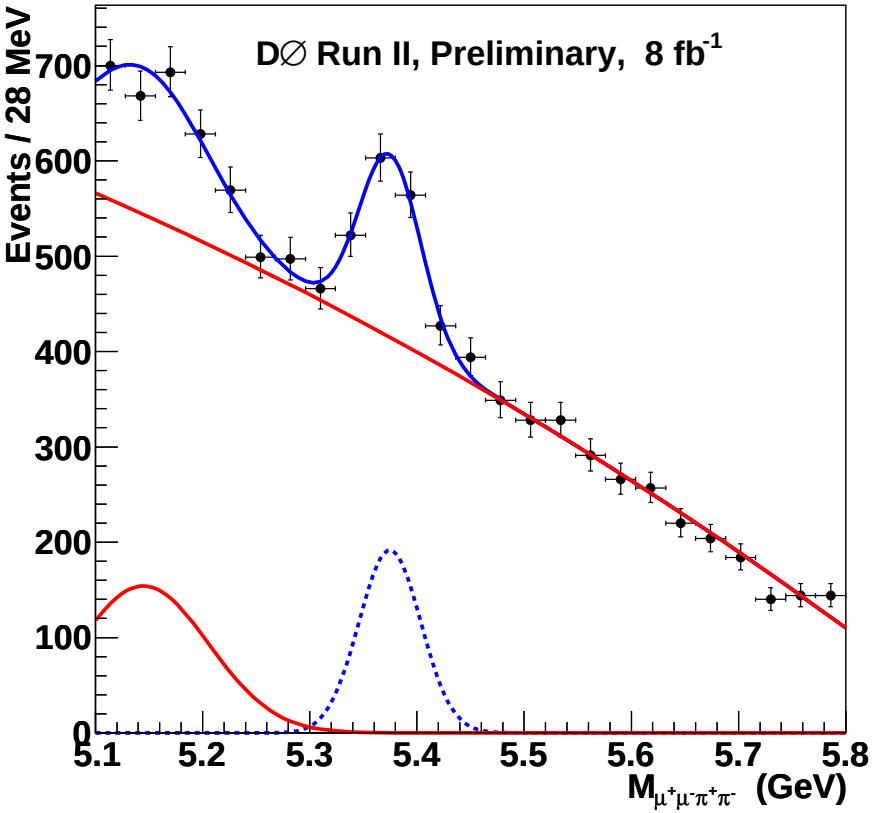
P	x
$\overline{\tau}_s$	$1.443^{+0.038}_{-0.035}$ ps
$\Delta\Gamma_s$	$0.163^{+0.065}_{-0.064}$ ps^{-1}
$\phi_s^{J/\Psi\Phi}$	$-0.55^{+0.38}_{-0.36}$
$\lvert A_0\rvert^2$	$0.558^{+0.017}_{-0.019}$
$\lvert A_{\parallel}\rvert^2$	$0.231^{+0.024}_{-0.030}$
$\delta_{\parallel}$	-3.15 ± 0.22
$(\delta_{\perp}\text{-}\delta_s)$	$-0.11^{+0.027}_{-0.025}$
$F_S(eff)$	0.173 ± 0.036



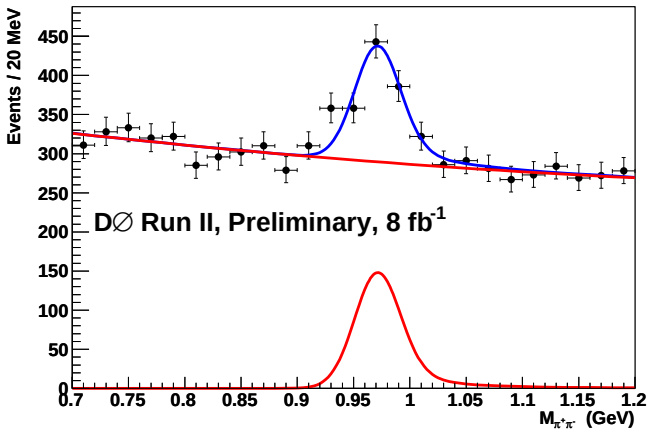
$B_s^0 \rightarrow J/\Psi f_0(890)$

- CP-odd final state, no angular analysis
- Independent information on $\Delta\Gamma_s$
- First step is measure the branching ratio

$B_s^0 \to J/\Psi f_0(890)$ Branching ratio



- Muon trigger
- Identical selection criteria for $J/\Psi f_0$ and $J/\Psi\Phi$
- BDT to reduce background
- $478 \pm 76 J/\Psi f_0(980)$ events



Branching Ratio:

$$\mathcal{R} = \frac{\mathcal{B}(B_s^0 \to J/\Psi f_0(980); f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\Psi\Phi; \Phi \to K^+K^-)} = 0.210 \pm 0.032(stat) \pm 0.036(sys)$$

Summary

- Measurement of B_s^0 mixing parameters, polarization amplitudes and phases in the $B_s^0 \to J/\Psi\Phi$ analysis using $8fb^{-1}$ data sample.
  - Inclusion of K^+K^- s-wave
- Measurement of the branching fraction of $B_s^0 \to J/\Psi f_0(980)$ in agreement with other experiments.
  - Next step is to use in CP-Violation measurements
- **Combination with other DØ measurements** of CP-Violation parameters will be performed soon

Stay tuned !

Backup Slides

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Markov Chain technique

- Since ϕ_s is very correlated with $\Delta\Gamma_s$ we want to know how the likelihood depends on these variables.
- Start from some point μ. I use the minimum obtained from the fit.
- Generate a multivariate gaussian ($e^{-\frac{1}{2}(x-\mu)\cdot\Sigma^1\cdot(x-\mu)}$.) point x'
- Where Σ is the covariance matrix.
- Calculate $\alpha = L(x')/L(\mu)$
- Generate a random number $r = U(0,1)$
- If $r < \alpha$ accept the new point $\mu = x$
- And continue until reach the amount of points desired.
- We generate 1M events for each Markov Chain