Measurement of CP asymmetry in semileptonic B decays at CDF II

Fermilab

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the CDF Collaboration

Introduction

$$A_{CP} = \frac{\Gamma(\overline{B_s} \to \mu^+ X) - \Gamma(B_s \to \mu^- X)}{\Gamma(\overline{B_s} \to \mu^+ X) + \Gamma(B_s \to \mu^- X)}$$

- $\Gamma(\overline{B_s} \to \mu^+ X)$ produced in $p\overline{p}$ collisions as $\overline{B_s}$ and oscillates to $B_s \to \mu^+ X$
- If nature was CP symmetric $A_{CP} = 0$
- CP asymmetry well established in K^0 and B^0 systems
- CP asymmetry has never been observed in B_s, but has not been well probed

The CKM Matrix

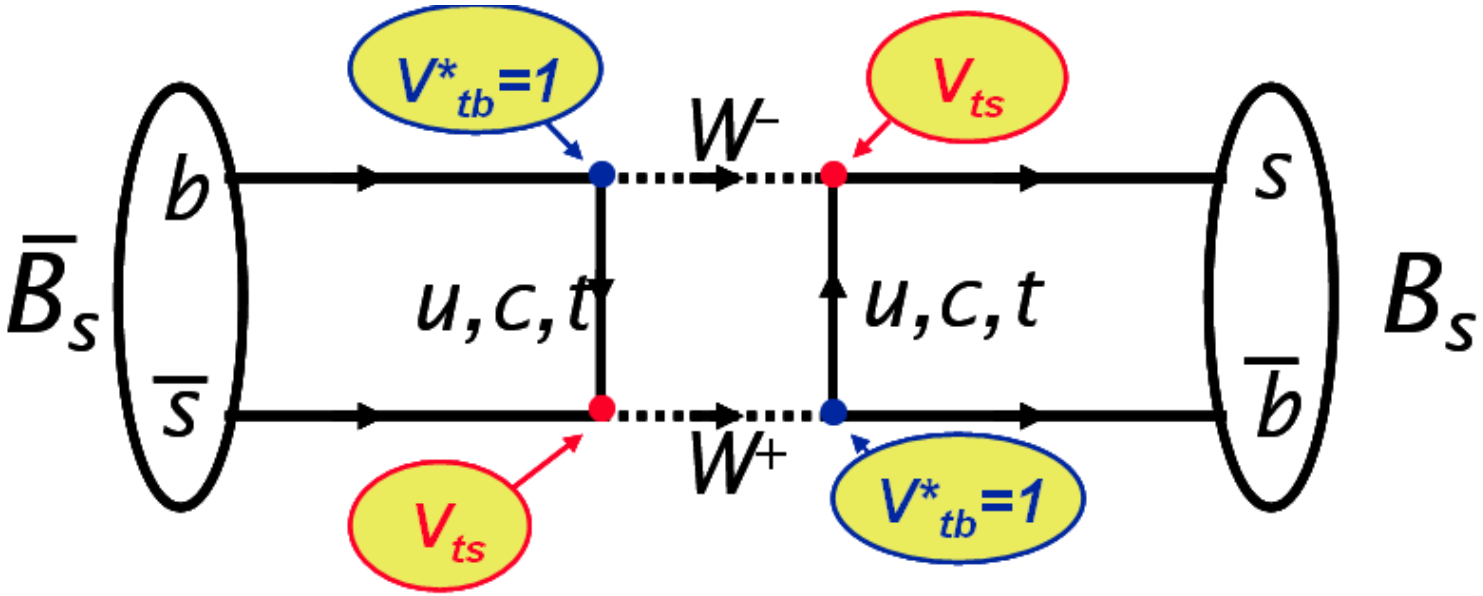
$$\begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

- V_{ts} contains a complex phase at $O(\lambda^4)$ $(\text{-}s_{12}c_{23}s_{13}e^{i\delta})$
- Mixing frequencies are well measured; CP violation in B^0 has been measured at B factories
- We can measure CP violation in B_s^0

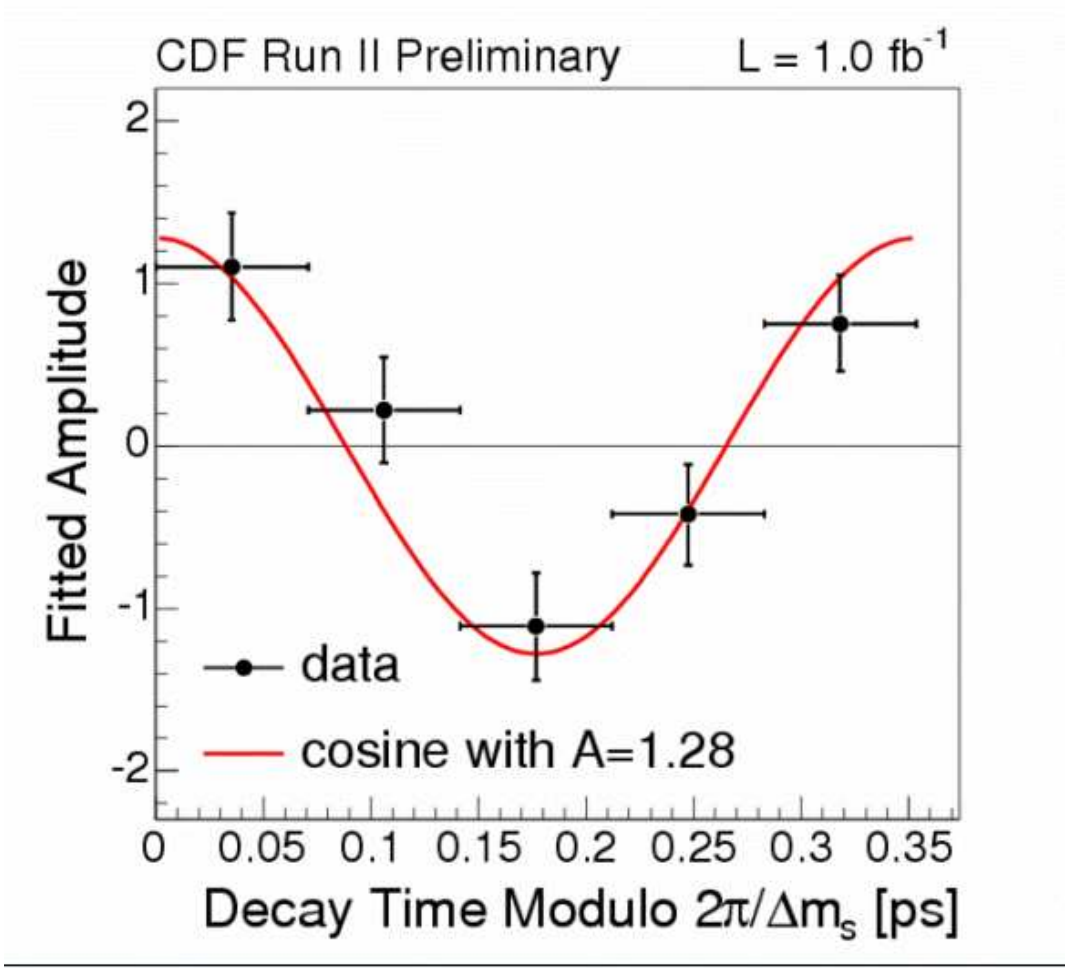
B Mixing

- B^0 and B_s can mix and decay as the charge-conjugate of the hadronized particle via box diagrams
- Due to its mass the top quark dominates



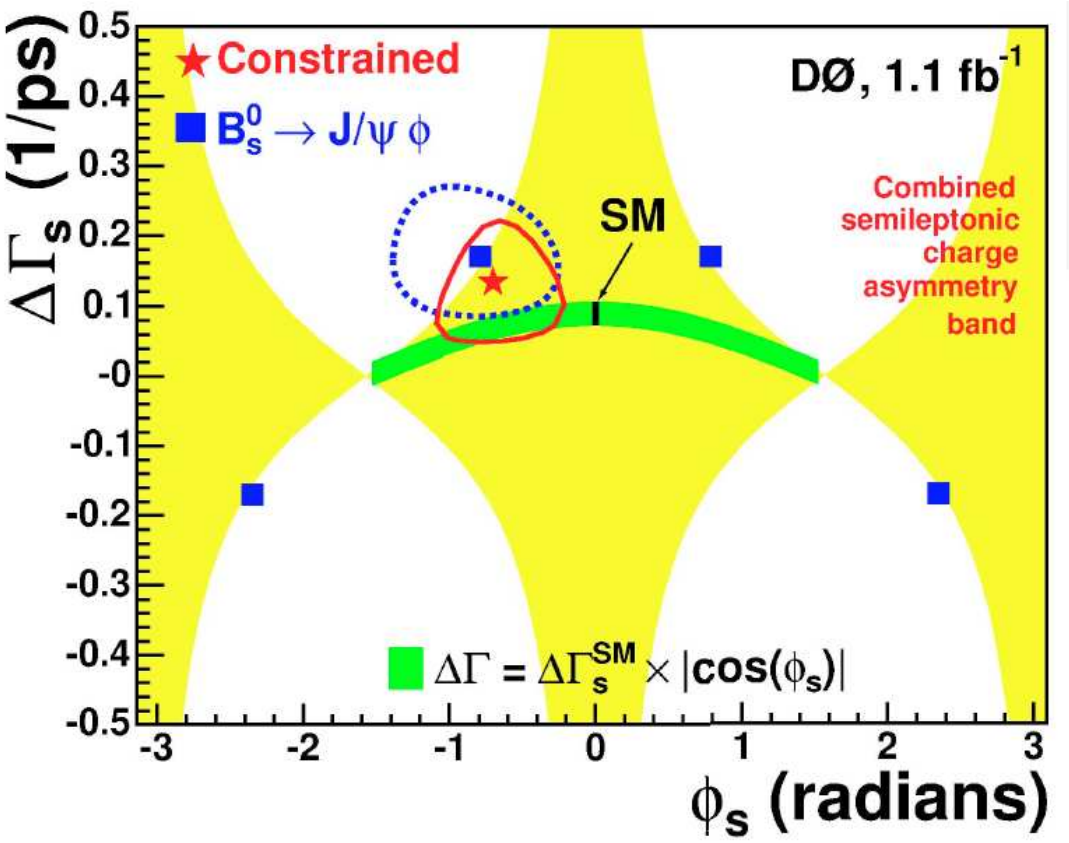
B_s Mixing Measurement

- In 2006 $D0$ reported the first bound on the B_s mixing frequency
- Later CDF observed B_s oscillations and measured $|V_{ts}|$ with high experimental precision
- Only the magnitude of V_{ts} is determined by the frequency



Motivation

- Standard Model(SM) plus existing measurements predicts CP violation in $B\overline{B}$ mixing at 10^{-3}
- A measurement larger than this could indicate new physics
- In 2006 $D\emptyset$ made first high precision measurement
- This analysis has a complimentary approach



B production

- Tevatron $b\bar{b}$ production has a large cross-section ($\sim 50\ \mu b$, $1\ \mu b$ is reconstructable)
- b quarks form B^0, B_s, B^+ mesons as well as baryons
- Inelastic background has a cross-section 10^3 larger than $b\bar{b}$ production

Data Sample and Strategy

Same sign muon pairs

- Same sign muon pairs are enriched in $B\overline{B}$ mixing decays
- The asymmetry of dimuons from $B\overline{B}$ is an inclusive measurement of CP violating asymmetry

$$A_{CP} = \frac{N(b\bar{b} \to \mu^+\mu^+X) - N(b\bar{b} \to \mu^-\mu^-X)}{N(b\bar{b} \to \mu^+\mu^+X) + N(b\bar{b} \to \mu^-\mu^-X)}$$

$$= \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

- Inclusive approach is complementary to exclusive CP violation measurements

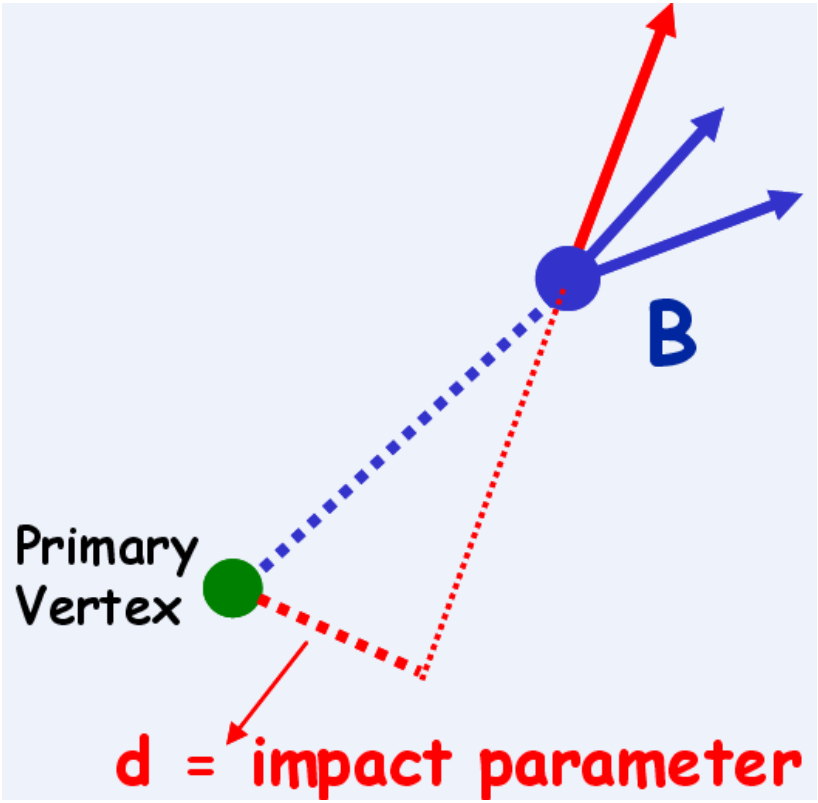
Same sign muon pairs

- Example of b decays producing SS muons
  - Direct - $b \to B^- \to \mu^- X$
  - Mixed - $\overline{b} \to B_s^0 \to \overline{B}_s^0 \to \mu^- X$
- Wrong sign also produced by sequential decays
  $(b \to \overline{B} \to DX \to \mu^+ X)$
- Correcting for sequential decays results in a 100% mixed sample
- Allows SS dimuons from $B\overline{B}$ to probe B^0 and B_s^0 mixing

Analysis Strategy

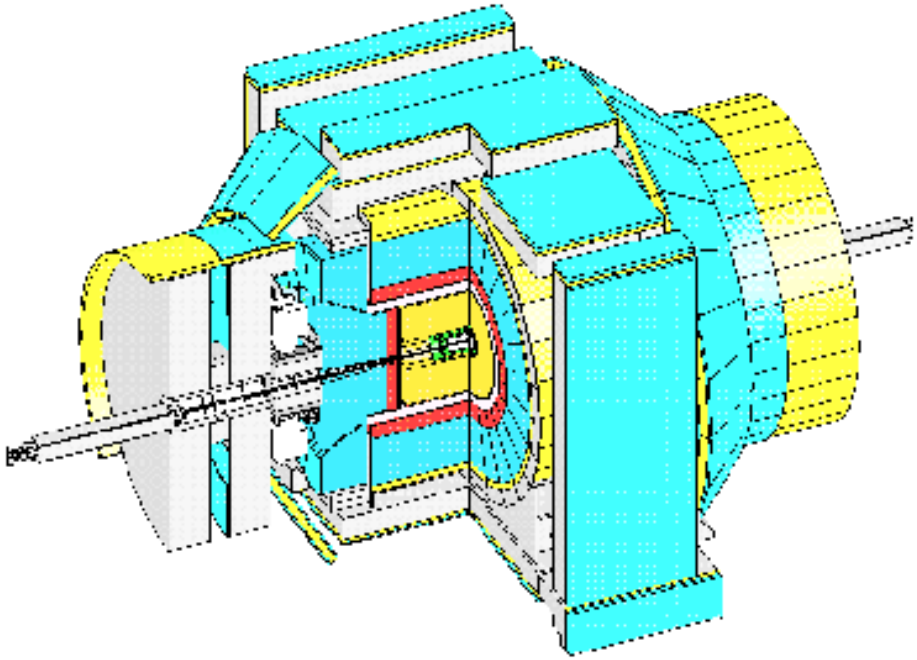
- Start with sample of 2 high purity triggered muons with $P_T > 3$ GeV
- Determine the fraction of same-sign muon pairs coming from B hadron decays by fitting both track impact parameters
- Minimize assumptions about contributions
- Muons come also from
  - c decays
  - prompt sources
  - fakes

Note: We use an unsigned impact parameter (d_0)



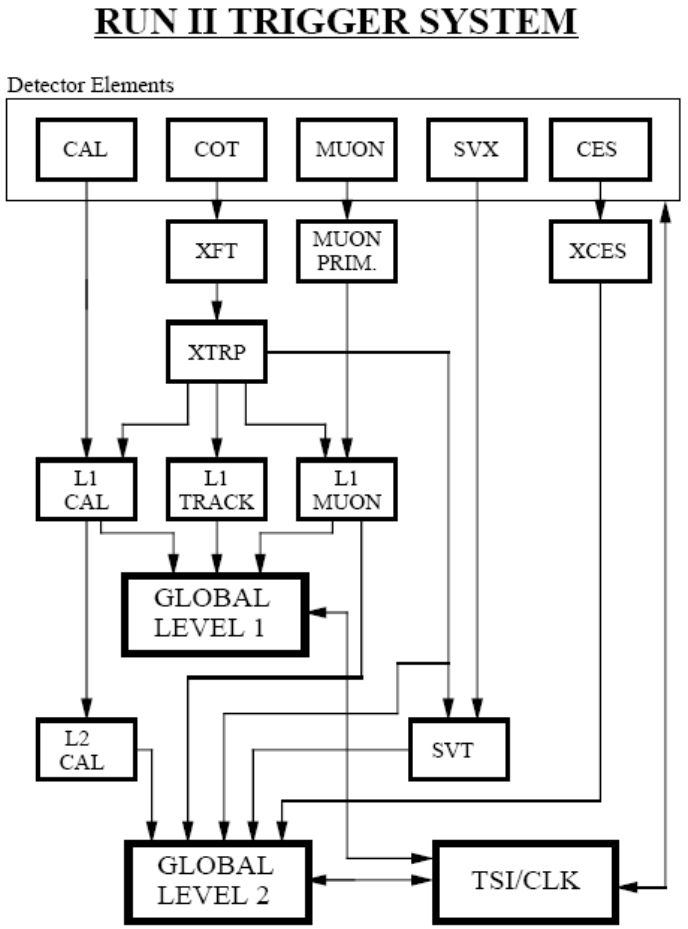
Analysis Strategy

- Correct the A_{raw} for contribution of fake muons in $B\overline{B}$
  - $\sigma(K^+) < \sigma(K^-)$
  - More K^+ fake muon
- Measure asymmetries introduced by detector or trigger
- Rely on
  - Tracking
  - μ reconstruction
  - Silicon Vertex



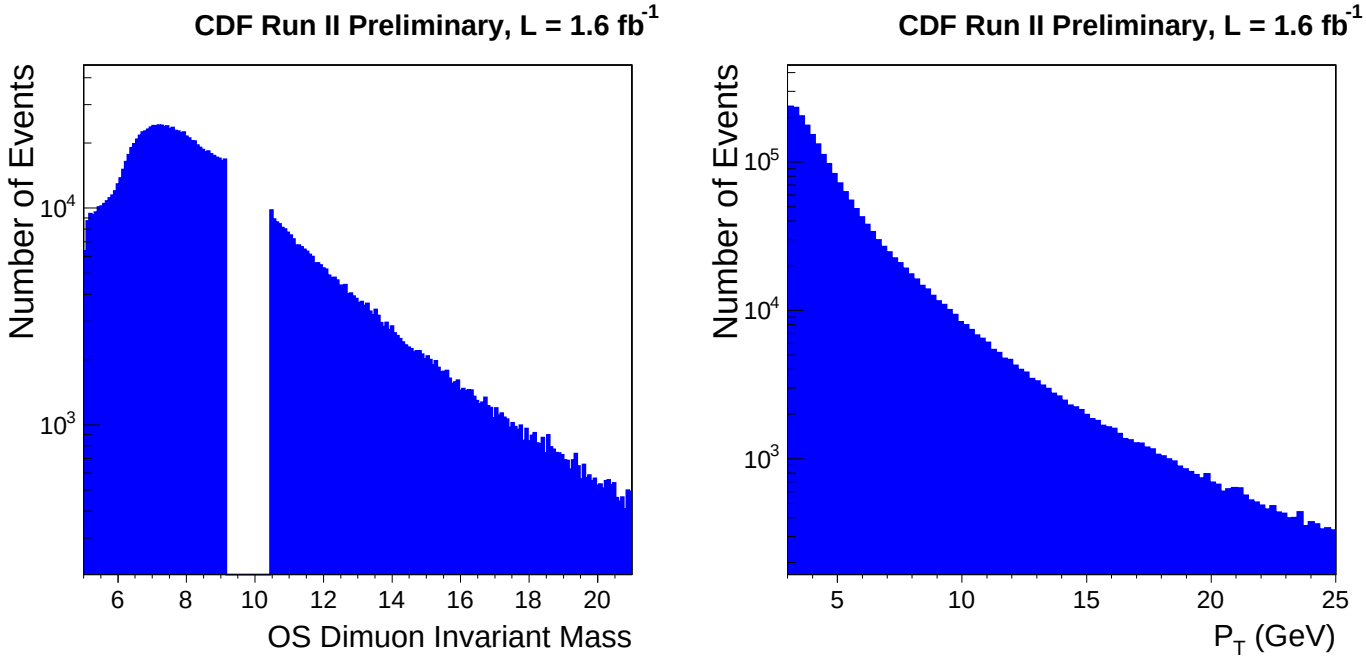
CDF Trigger system

- Beam bunch crossing rate is 2.5 MHz.
- Writing 150 Hz to tape requires a 99.994% real-time rate reduction.
- Three level trigger system attempts to select the most interesting physics events:
  - *Level 1 reduces rate to 25 kHz*
  - *Level 2 reduces rate to 900 Hz*
  - *Level 3 reduces rate to 150 Hz*
- 80% of triggers are track base



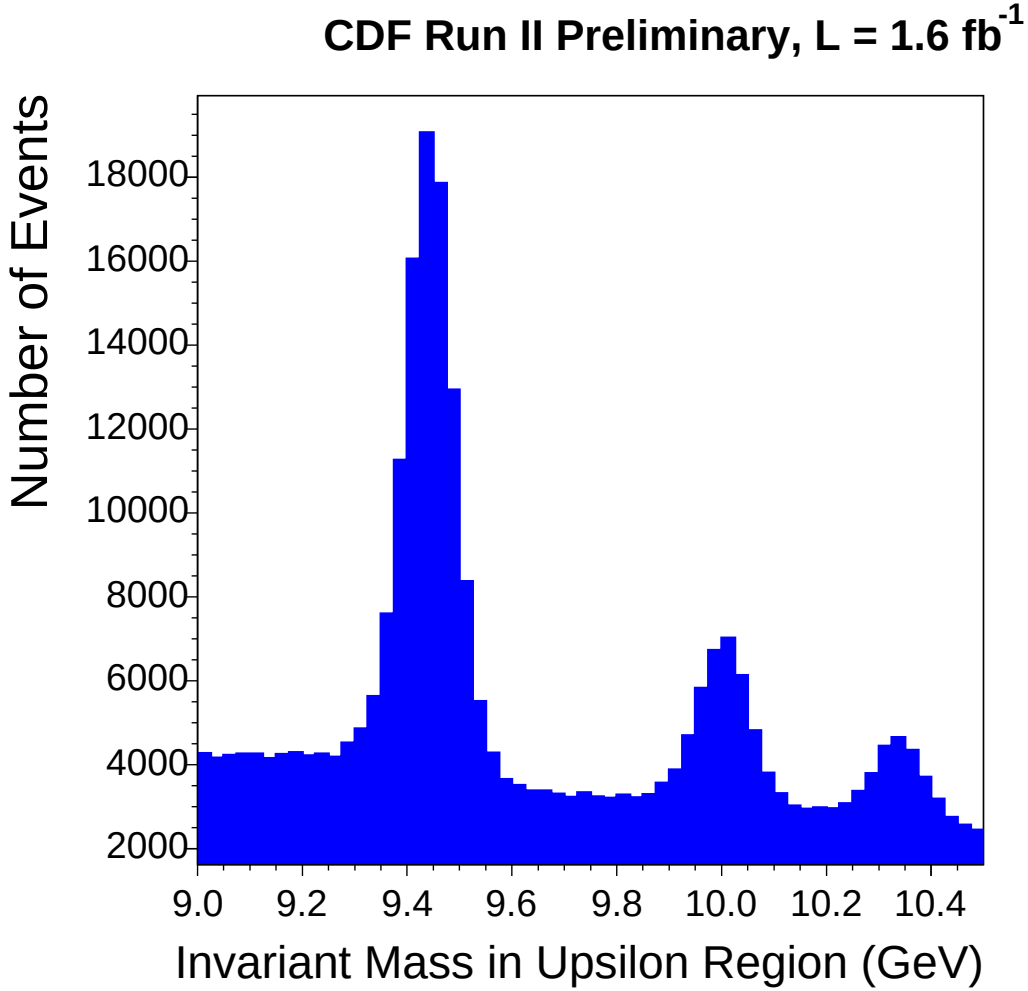
Sample Composition

- Using 1.6 fb^{-1} of data, we find 1.1 million opposite-sign and same-sign muon pairs ($\sim$ 50 % $b\bar{b}$)
  - Some basic analysis cuts on tracking and muon ID quality
  - Rejecting cosmic rays
  - Rejecting events where both muons come from the same b



Υ Mass Region

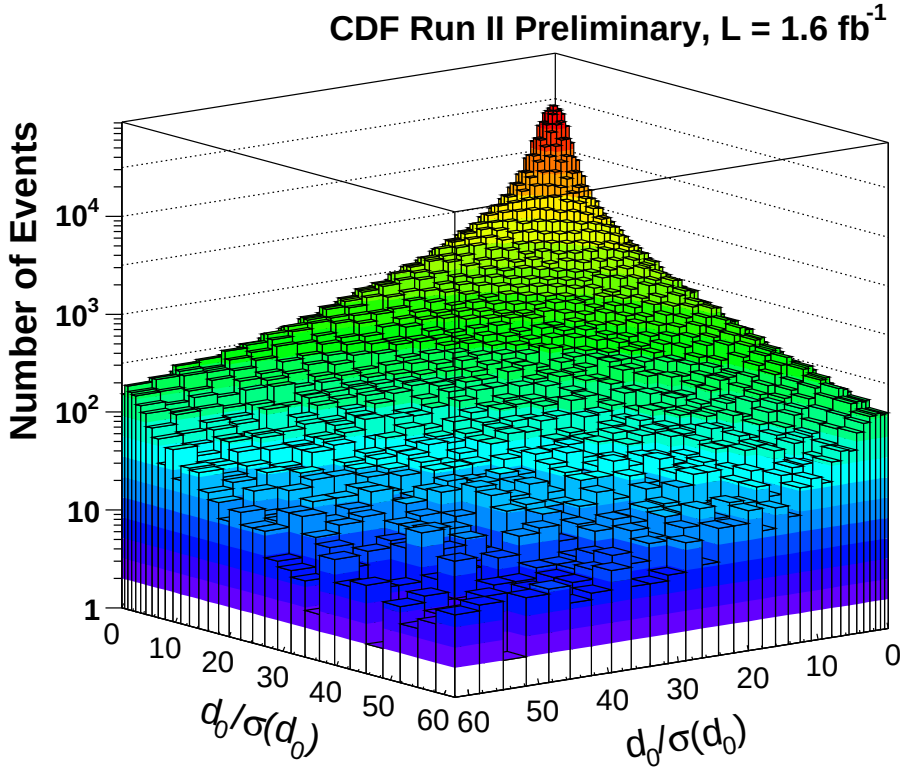
Dimuons from Υ decays were removed from OS events and used to model prompt events



Fitting the BB Fraction

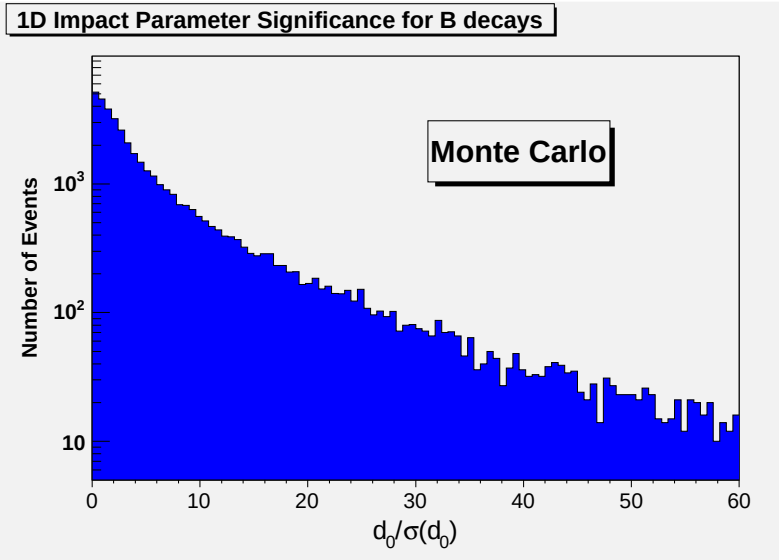
Determining the BB Fraction

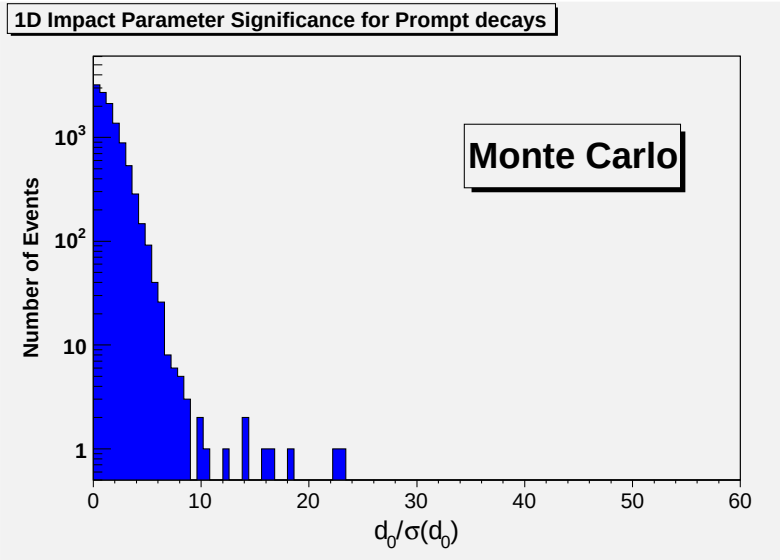
- Isolate same-sign dimuons originating from B hadron decays by exploiting their longer lifetime and larger average track impact parameter (d_0)
- Real and fake muons can come from the following sources:
  - b
  - c
  - prompt



(Right) Dimuon Data - one μ on each axis

Determining BB Fraction





- Create $d_0/\sigma(d_0)$ templates of dimuon contributing processes
- Validate a negative log likelihood fitter to analyze $++$ and $--$ data with the templates separately
- Use a 2 dimensional $d_0/\sigma(d_0)$ fit of data to signal and background templates

Fitting for BB compostion

- $B\overline{B}$ hadron pairs where both decay to a muon (BB).
- one real muon(prompt or from C), and one K or π reconstructed as a muon or two fake muons(PP and CC).
- a muon from a semileptonic B decay is present and a prompt muon of the same charge is found(BP).

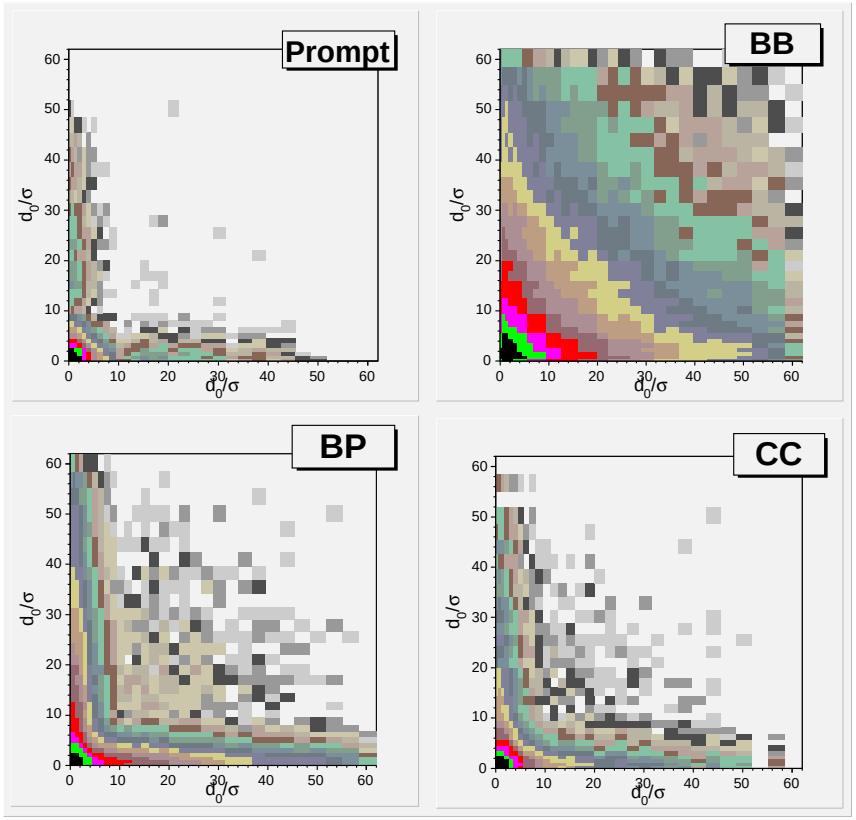
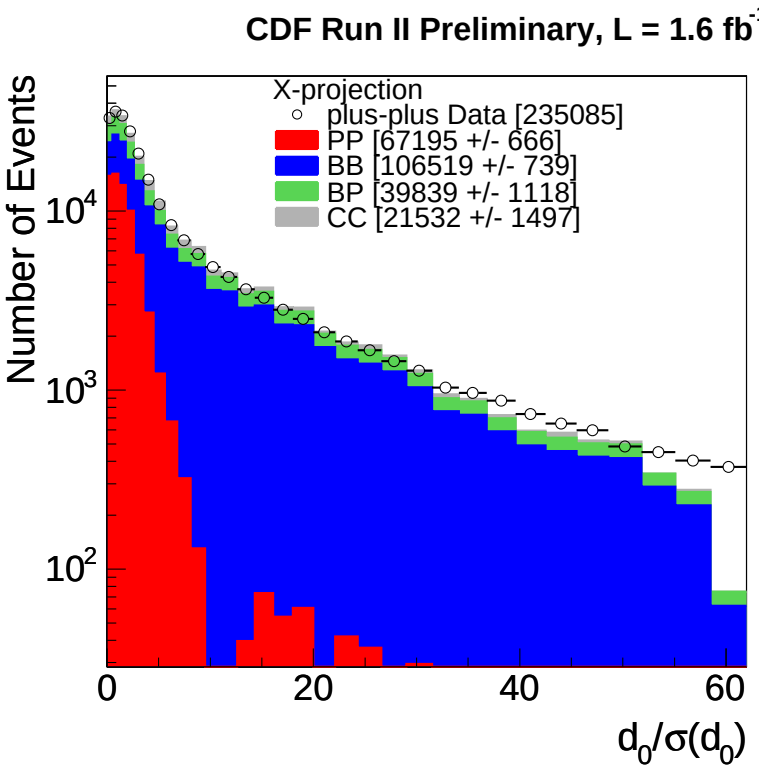


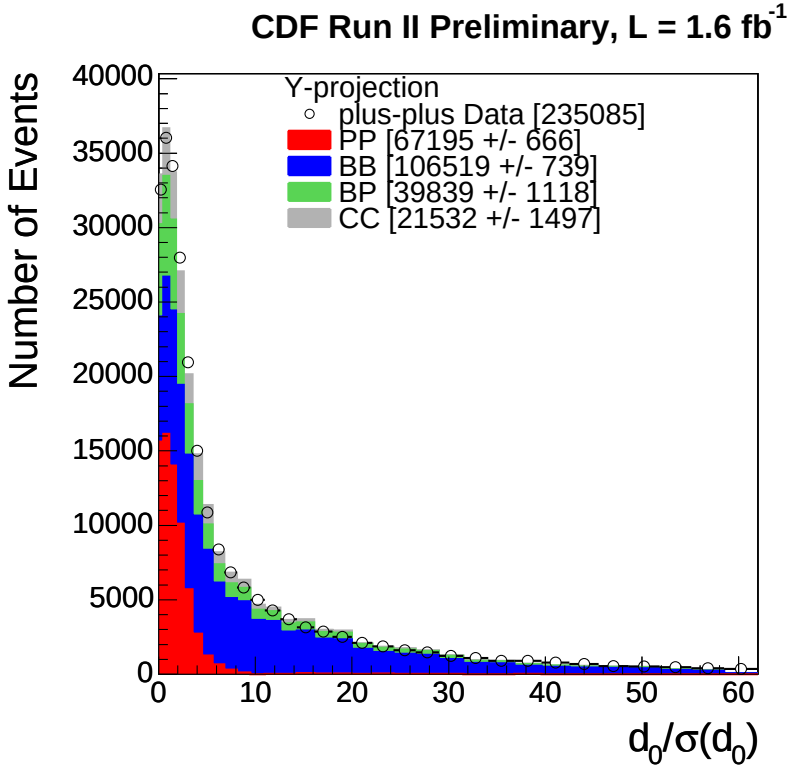
Table 1: Fit results. All numbers listed in percent.

component	opposite sign (OS)	same-sign (++)	same-sign (−−)
PP	21.29 ± 0.17	28.58 ± 0.28	25.21 ± 0.30
BB	42.90 ± 0.19	45.31 ± 0.32	50.42 ± 0.35
BP	6.78 ± 0.28	16.95 ± 0.48	17.66 ± 0.53
CC	29.03 ± 0.38	9.16 ± 0.64	6.71 ± 0.70
# BB	281,252	106,519	103,143

$$A_{raw} = 0.0146 \pm 0.0049$$

$\mu^+\mu^+$ fit 1D projections: x-proj(log scale) and y-proj(linear)





Robustness of Fit

- A number of fits were also performed varying the default configuration
- Template shape was the primary concern
- Constraints, extra contributions, and subsamples of the data were also examined
- Results were found to be consistent with the default asymmetry
- A fitting systematic uncertainty of 0.002 was assesed

Corrections to Asymmetry of Isolated BB Sample

Asymmetry Corrections

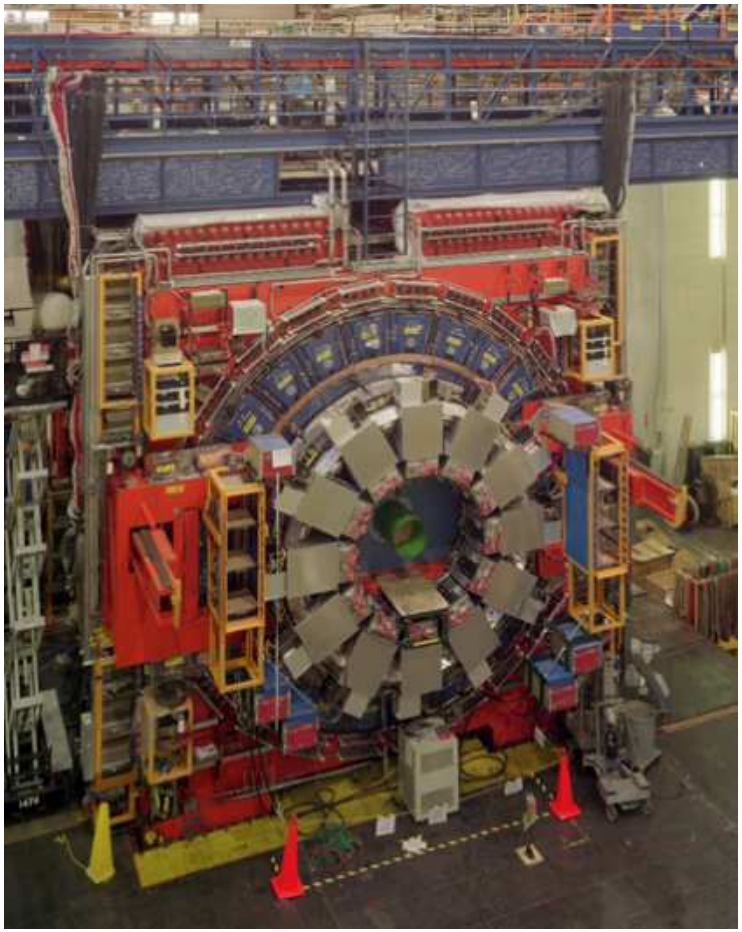
- Some dimuon pairs identified as BB will actually be $B \to h$ where $h = \pi, K$ fakes a muon
- $K^+ \to \mu \neq K^- \to \mu$
- Adjust $++$ and $--$ totals for asymmetric fake muons
  - Measure muon fake rates for hadrons
  - Determine hadron to muon normalization
  - Subtract BB dimuon pairs containing fakes
- Correct the raw asymmetry for any detector effects
- Correct the raw asymmetry for any trigger bias

Detector and trigger asymmetries

- Since we expect an uncertainty at the sub-percent level, we examine possible experimental asymmetry contributions
- Trigger asymmetry for our kinematic range measured using $J/\psi \to \mu^+\mu^-$ decays
- $+/-$ reconstruction in tracking chamber found to be symmetric

Detector and trigger asymmetries

- Several million muon MC events determine the geometrical detector acceptance correction
- Examined +/− muons with one missed hit to confirm symmetric reconstruction in the muon chamber
- We correct for measured asymmetries and assess systematics uncertainties

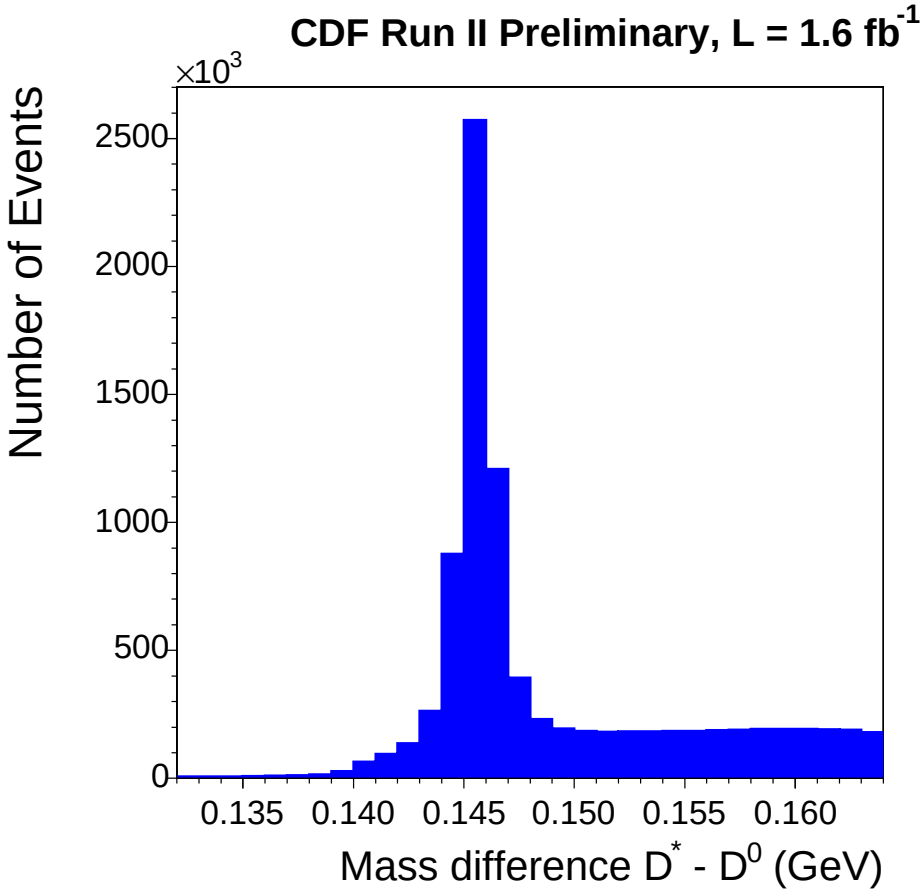


Fake Muon Asymmetry

- Fake contributions come from $b \to \overline{B} \to KX$, where K fakes μ
- Analyze D^* events to identify K and π tracks

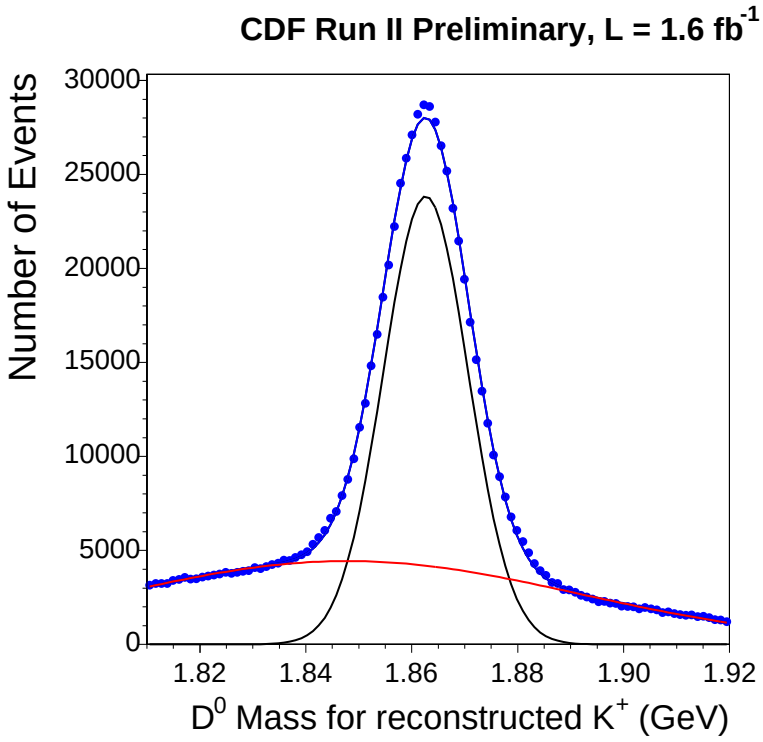
  $D^* \to D^0\pi$

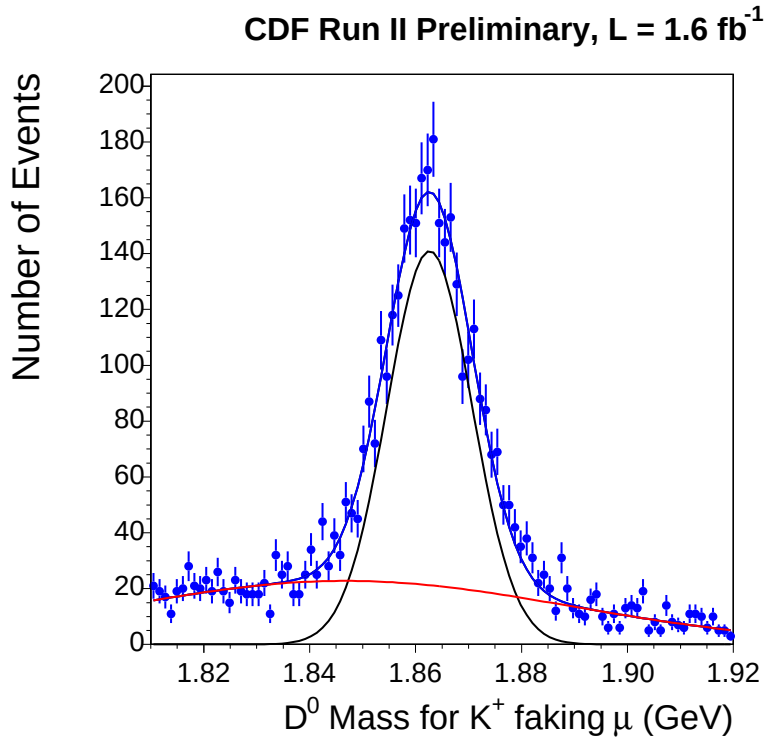
  $D^0 \to K\pi$
- D^0 sample from tracking only



Kaon fake asymmetry

- Measure μ fake rate for K^+, K^-, π^+, and π^-
- Fit D^0 for all K^+ meet the kinematic requirements in the analysis
- Use signal shape to fit D^0 for all K^+ reconstructed as muons





Corrected asymmetry

- The proportion of K/μ (and π/μ) production in $b\bar{b}$ decays was measured in MC
- We find 7382 $++$ fake pairs and 5130 $--$ fake pairs
- Removing these from the BB totals give $A = 0.00413$
- Correcting again for the detector acceptance and trigger efficiency
- $A_{corr} = 0.00439 \pm 0.00488(stat.)$

Systematics

Table 2: Systematic Uncertainties

Source of Uncertainty	δA
Fake muon corr.	0.00280
Trigger efficiency corr.	0.00118
Detector acceptance corr.	0.00072
Fitting Uncertainty	0.00200
Total	0.00371

Results

A_{SL}, correcting for sequentials

- We measure $A_{BB} = 0.0044 \pm 0.0049(stat) \pm 0.0037(syst)$
- Must correct for fraction of symmetric backgrounds ($f = 0.115 \pm 0.015$)

$$A_{SL} = \frac{N^{++} - N^{--}}{(N^{++} + N^{--})(1-f)^2}$$

- Applied to A_{BB} gives the $B\overline{B}$ semileptonic asymmetry
- $A_{SL}^{\mu\mu} = 0.0056 \pm 0.0062(stat) \pm 0.0047(syst)$
- This is directly comparable to the $D\emptyset$ measurement: $A_{SL}^{\mu\mu} = -0.0092 \pm 0.0044(stat) \pm 0.0032(syst)$ [hep-ex/0702030v1]

A^s_{SL} and ϕ_s

- $A^{\mu\mu}_{SL}$ can then be related to the V_{ts} phase angle ϕ_s
- $A^{\mu\mu}_{SL} = A^d_{SL} + \frac{f_s Z_s}{f_d Z_d} A^s_{SL}$
- World-average $f_s Z_s / f_d Z_d = 0.70 \pm 0.07(syst) \pm 0.10(PDG)$
- From the B factories, $A^d_{SL} = -0.0047 \pm 0.0046$
- $A^s_{SL} = 0.0148 \pm 0.0089(stat) \pm 0.0068(syst) \pm 0.0069(inputs)$
- We can then use the relation $A^s_{SL} = \frac{\Delta\Gamma_s}{\Delta M_s} \tan\phi_s$ to extract an allowed contour in the (ϕ_s,$\Delta\Gamma_s$) plane
- Using $\Delta M_s = 17.8 \pm 0.1\,\mathrm{ps}^{-1}$ from CDF mixing measurement gives ...

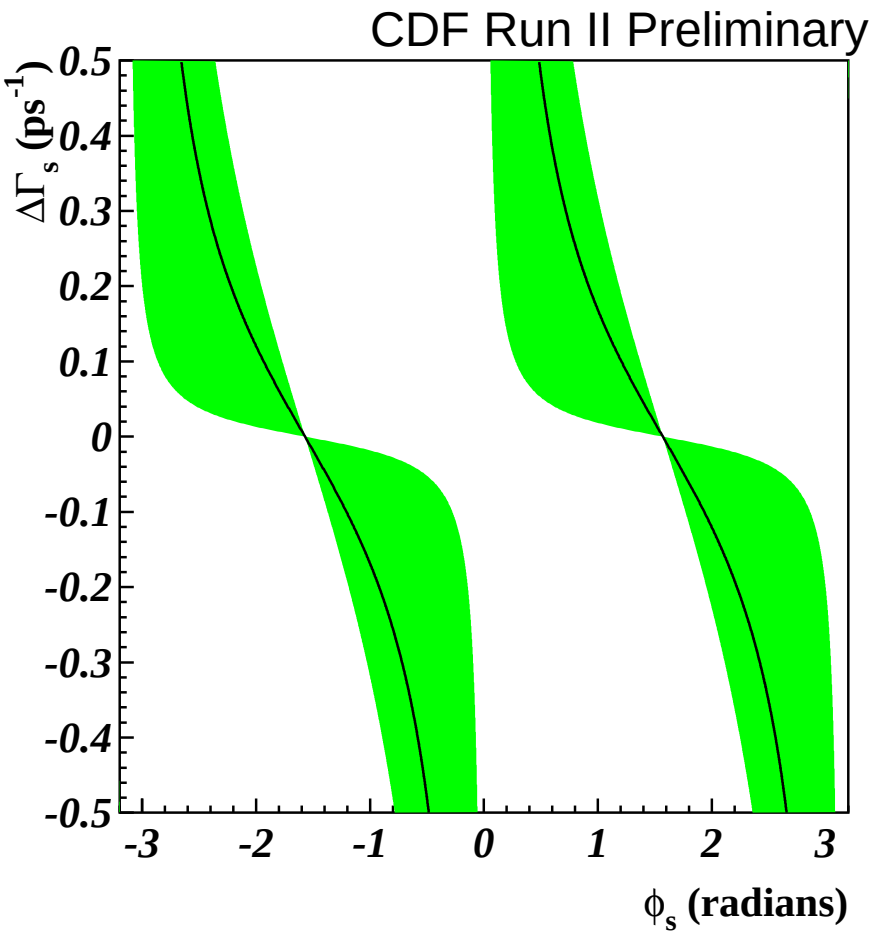
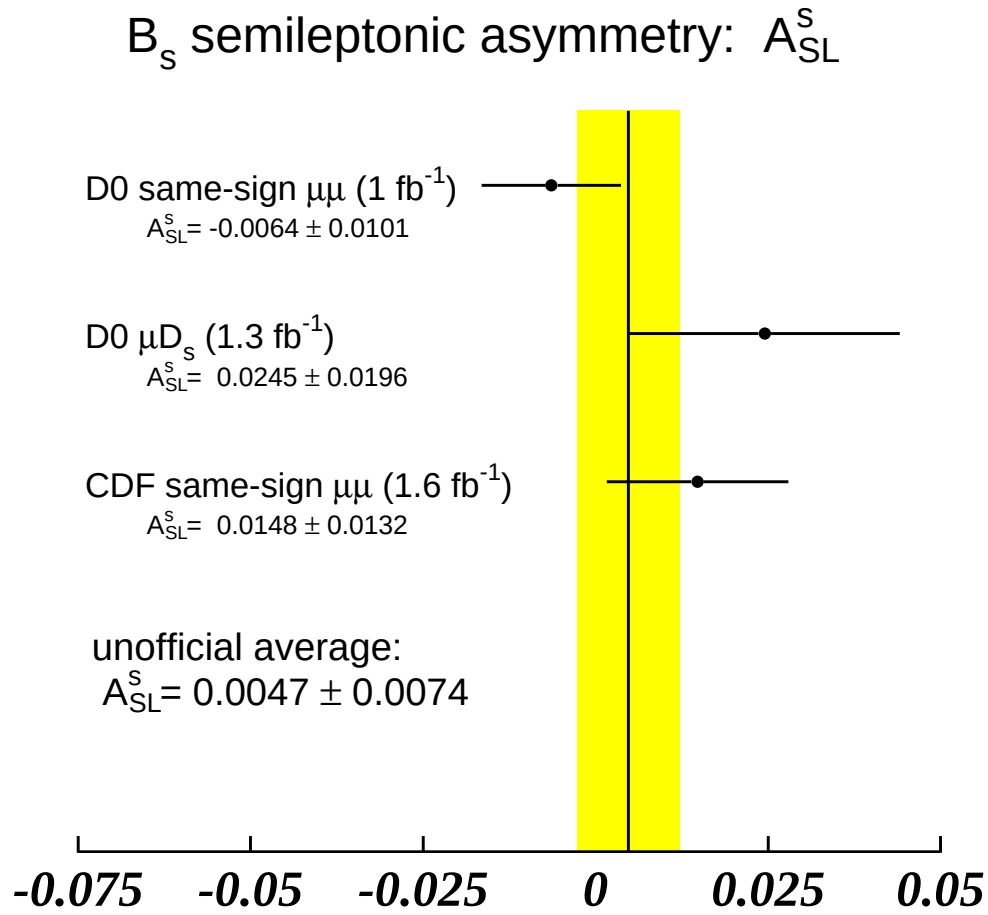
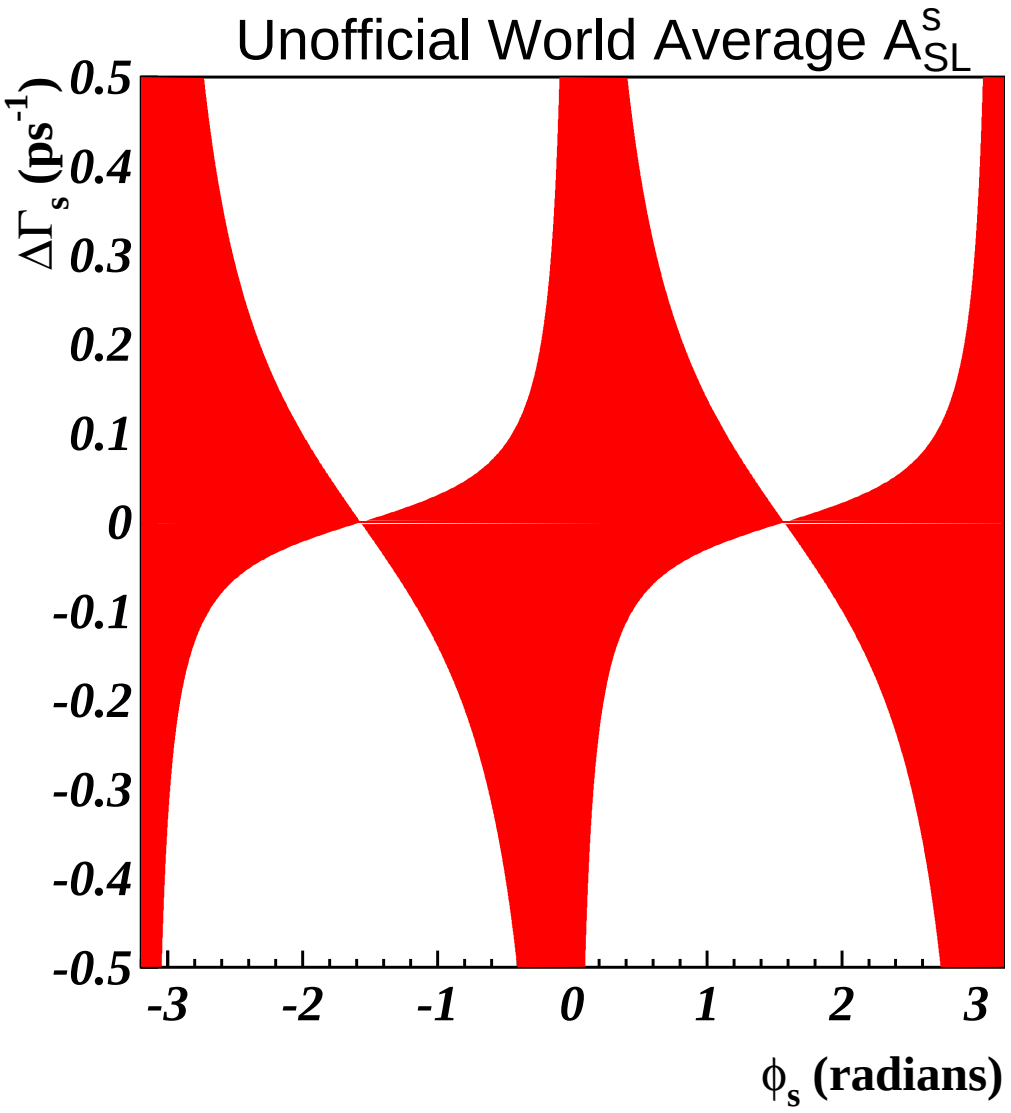


Figure 1: This result shown in the ϕ_s-$\Delta\Gamma_s$ plane. The lines represent the central value, the green region is the 68% allowed contour.

Unoffical Average of A^s_{SL}



Unoffical Average of ϕ_s contour



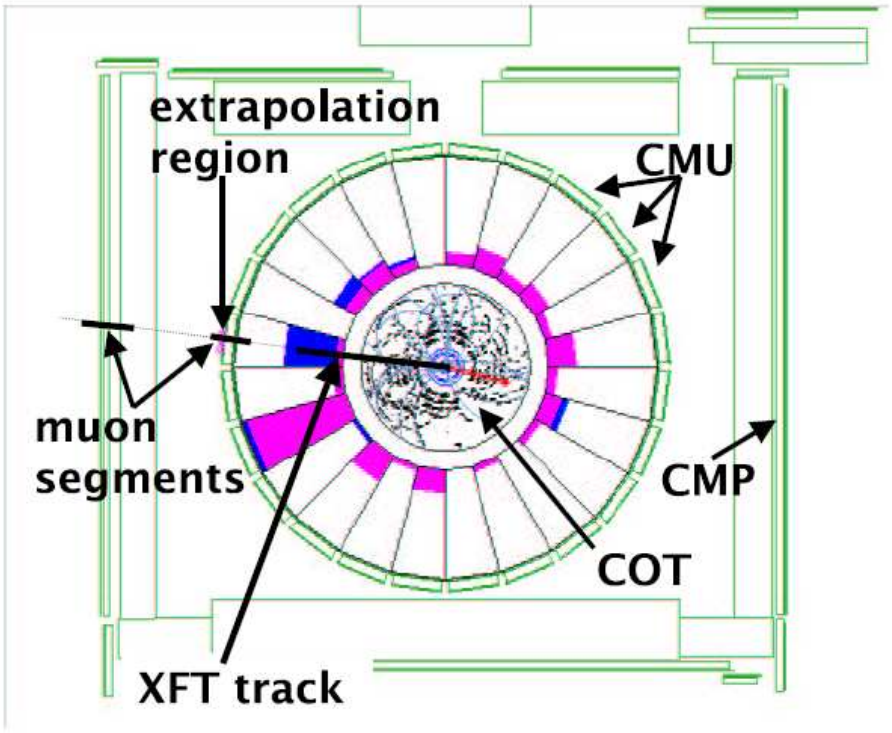
Summary

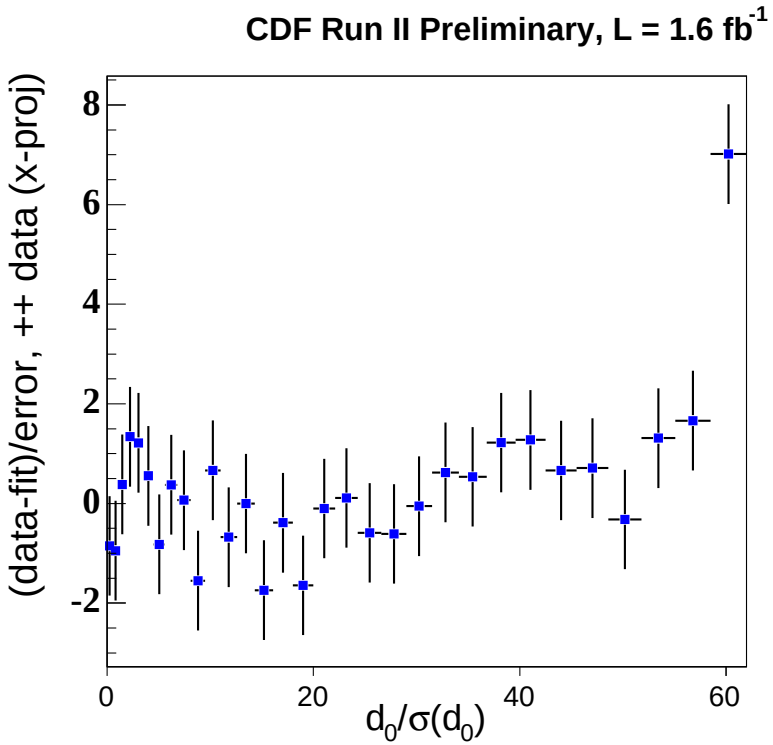
- Dimuon events are enriched in $B\overline{B}$ decays involving neutral B mixing
- We extract the B events by fitting each muon's impact parameter
- Corrections are made for detector and trigger effects as well as hadrons faking muons
- $A_{SL}^{\mu\mu} = 0.0056 \pm 0.0062(stat) \pm 0.0047(syst)$
- This result contributes to our understanding of CP violation and the B_s mixing phase

Backup Slides

Detector asymmetry

- The charge and track of the muon are determined by the tracking chamber
- Excellent muon stub and track matching means the only significant asymmetry is from the acceptance of the CMP muon chambers

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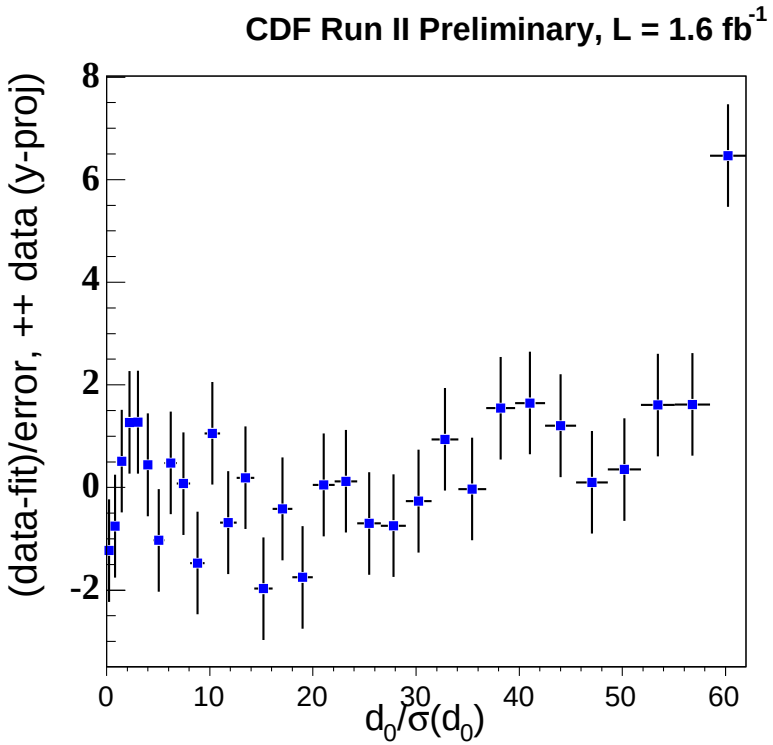
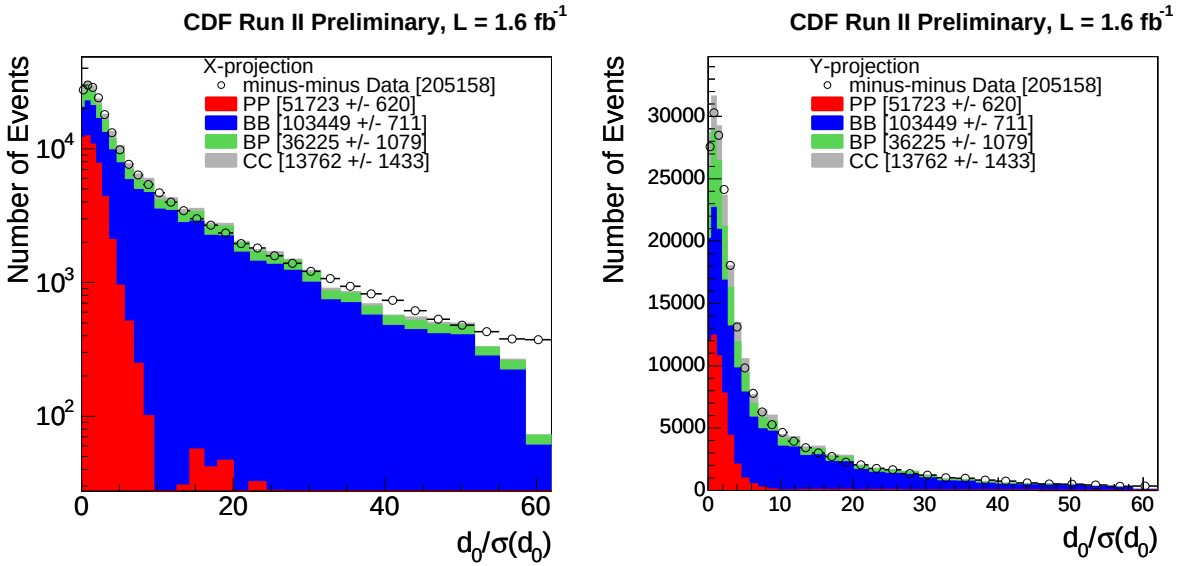
(data-fit)/error, ++ data (x-proj)
d0/σ(d0)


CDF Run II Preliminary, L = 1.6 fb-1
(data-fit)/error, ++ data (y-proj)
d0/σ(d0)


CDF Run II Preliminary, L = 1.6 fb-1
X-projection
minus-minus Data [205158]
PP [51723 +/- 620]
BB [103449 +/- 711]
BP [36225 +/- 1079]
CC [13762 +/- 1433]
Number of Events
d0/σ(d0)
CDF Run II Preliminary, L = 1.6 fb-1
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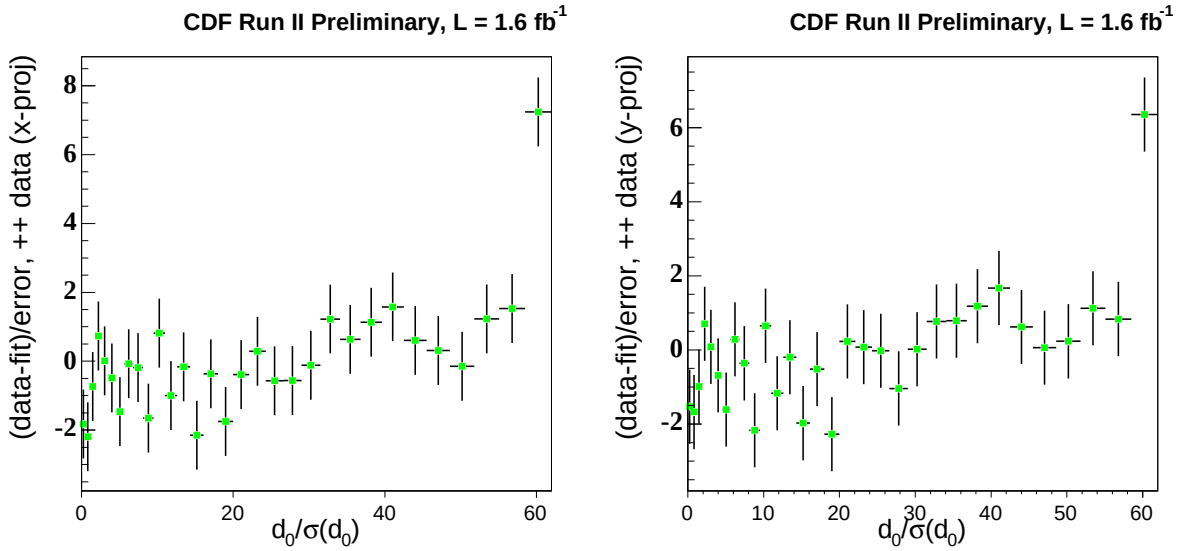
CDF Run II Preliminary, L = 1.6 fb-1
(data-fit)/error, ++ data (x-proj)
d0/σ(d0)
CDF Run II Preliminary, L = 1.6 fb-1
(data-fit)/error, ++ data (y-proj)
d0/σ(d0)

Fit-less Asymmetry

- Both muons have an impact parameter significance greater than 10 σ
- Calculate this sample to be about 90% BB
- 8291 $++$ pairs
- 8059 $--$ pairs
- $A : 0.0142 \pm 0.0078$ (uncorrected)
- Compare to A_{raw} from fitter 0.0146 ± 0.0049

Table 3: Fake Muon Correction Cases and Weights

Case	CMUP	CMUP	Corr.	P($B \to X$)	P($B \to X$)	Total
$\mu^+\mu^+$	0.5898	0.5898	0.39	0.1596	0.1596	85251
μ^+K^+	0.5898	0.00609	0.45	0.1596	0.2586	1651
$\mu^+\pi^+$	0.5898	0.00243	0.45	0.1596	0.5818	1482
$\mu^+\mu^-$	0.5898	0.5898	0.61	0.1596	0.1596	134043
μ^+K^-	0.5898	0.004	0.55	0.1596	0.2586	1325
$\mu^+\pi^-$	0.5898	0.00181	0.55	0.1596	0.5818	1349

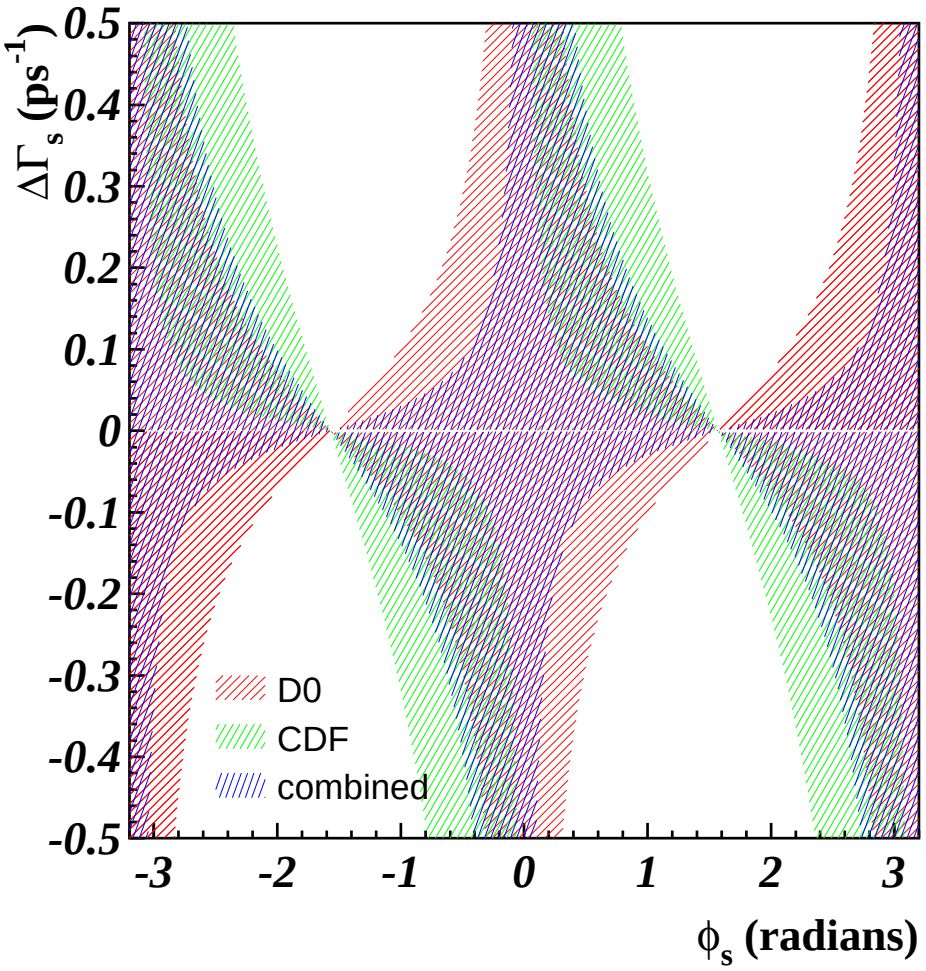

Figure 2: Combined results in the ϕ_s-$\Delta\Gamma_s$ plane.

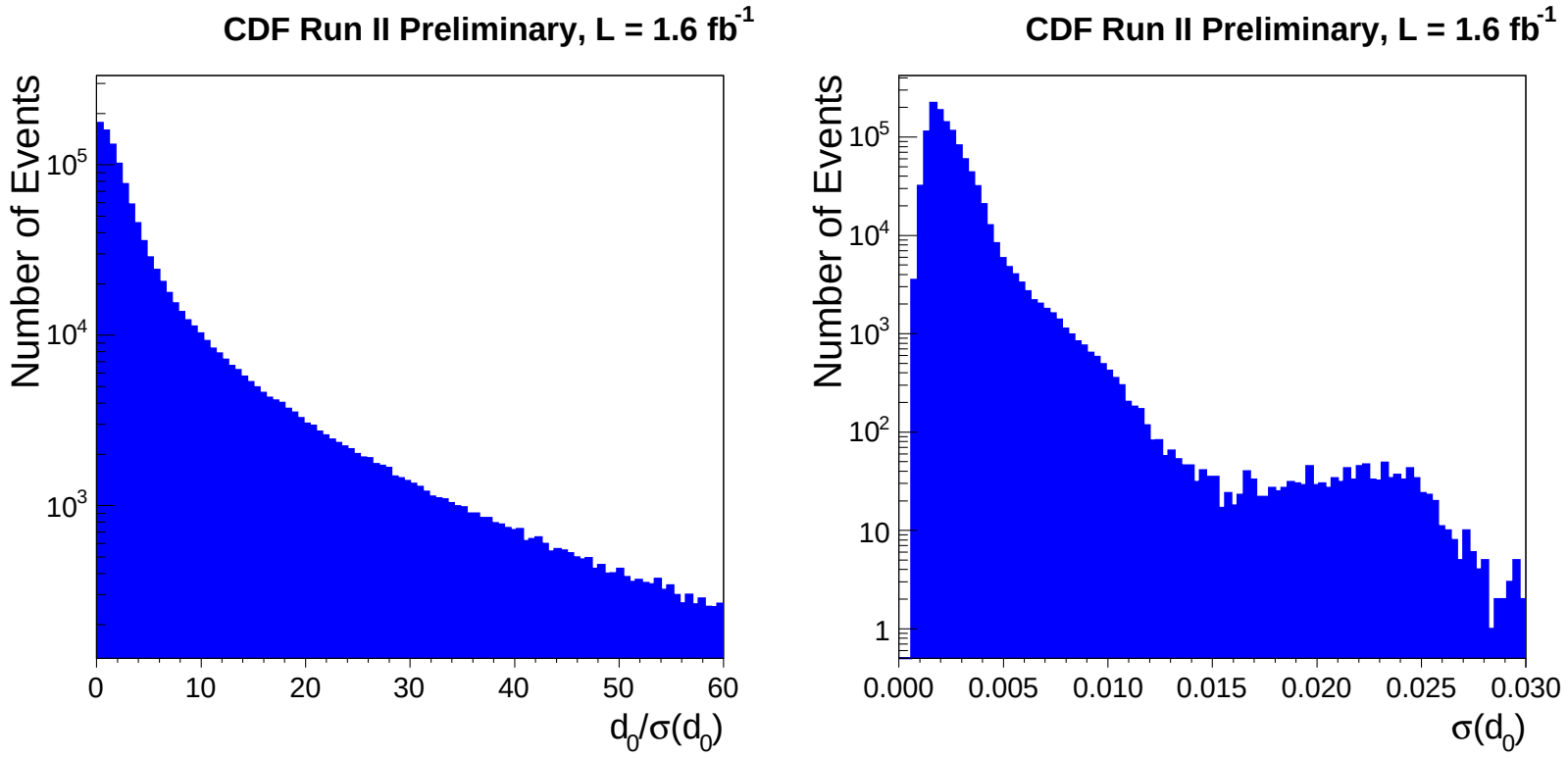

Figure 3: (a)Projection of d_0 data and (b) distribution of d_0 error for SS and OS pairs passing analysis cuts