CDF-II Silicon Tracker & B Physics

1. B physics at a hadron collider
2. The CDF-II Silicon Tracker
3. Prospects for CDF-II ($\sin 2\phi_1$ and x_s)
4. CDF/Tevatron status (Commissioning Run)
5. Summary

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The CDF-II Silicon Tracker

- Key to B physics at a hadron collider is precision vertexing
- The CDF-II silicon tracker consists of three parts:
  - The SVX-II
  - The Intermediate Silicon Layers (ISL)
  - A single-sided layer mounted on the beampipe (L00)
- Design of this system driven by:
  - Redundant, precision ($\approx 10 - 12\mu$m) space points
  - Angular acceptance over long (1m at 3σ) beam diamond
  - Radiation hardness (1 - 2 MRad for 2 fb^{-1})

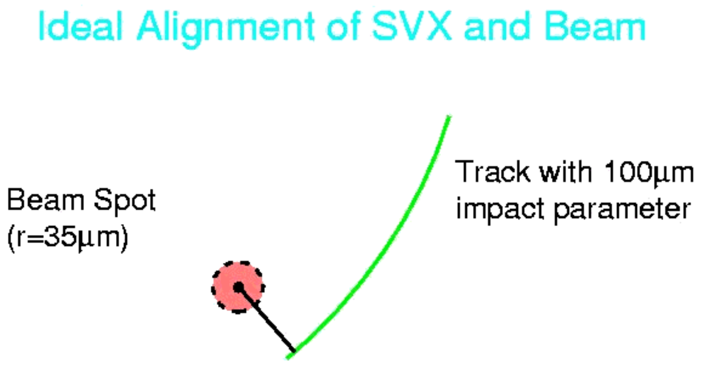
Layer	r (cm)	Channels	Dose (fb^{-1})	Cause	Sensor Type
L00	1.4	13,824	7.4	Depletion	Single sided
SVX-L0	2.5	36,864	4.5	S/N	90^o – HPK
SVX-L1	4.1	55,296	8.5	S/N	90^o – HPK
SVX-L2	6.5	92,160	11	Depletion	1.2^o – Micron
SVX-L3	8.2	110,592	23	S/N	90^o – HPK
SVX-L4	10.1	129,024	14	Depletion	1.2^o – Micron
ISL-5	20	$\approx 36k$	40+		1.2^o
ISL-6	22	$\approx 78k$	40+		1.2^o
ISL-7	28	$\approx 157k$	40+		1.2^o

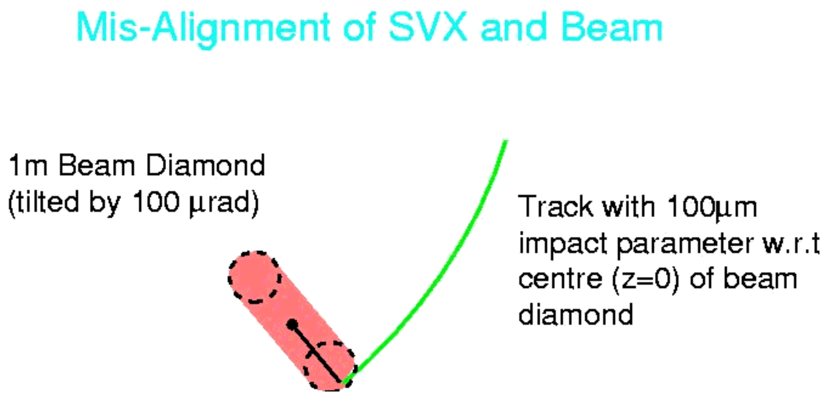
The CDF-II Silicon Status (12/00)

- SVX-II
  - is complete,
  - tested,
  - installing top cables
- ISL
  - is complete,
  - awaiting SVX+L00,
  - then mount port cards
- L00
  - is complete,
  - on beam-pipe,
  - inside SVX-II,
  - dressing hybrids/cables
- SVT
  - fully functioning slice,
  - working to integrate with XFT,
  - deploying rest of the system
- Silicon tracker due at B0 15-January-2001
- Run II collisions 1-March-2001

Alignment of Beam with Silicon

- SVT only processes information from $r - \phi$ strips
- Long beam diamond constrains relative alignment





- To ensure parallelism:
  - a) Build SVX barrels parallel to each other
  - b) Accelerator tunes beam tilt (up to 0.5 mrad?)
  - c) Have capability to remotely re-orient silicon

CDF-II B Physics

- Precise measurement of $\sin 2\phi_1$ in $B \to J/\psi K^0_S$
- Observe/Measure $|V_{td}/V_{ts}|$
  - $B^0 - \bar{B}^0$ flavour oscillations
  - $B^0_s - \bar{B}^0_s$ flavour oscillations ‡
  - $\Delta\Gamma_s/\Gamma_s$ ‡
  - Radiative decays ($B^0_s \to K^{*0}\gamma, \phi\gamma$) ‡
- Observe CP violation in $B^0 \to \pi^+\pi^-$
- Search for CP violation in $B^0_s \to J/\psi\phi$ ‡
- Observe $B^+ \to \mu^+\mu^- K^+$, $B^0 \to \mu^+\mu^- K^{*0}$, $B^0_s \to \mu^+\mu^-\phi$ ‡
- Study B_c^+ meson and b baryons ‡

‡ unique to Tevatron (HERA-b?/LHC)

The CKM Triangle

Unitary CKM matrix governs weak decay of quarks

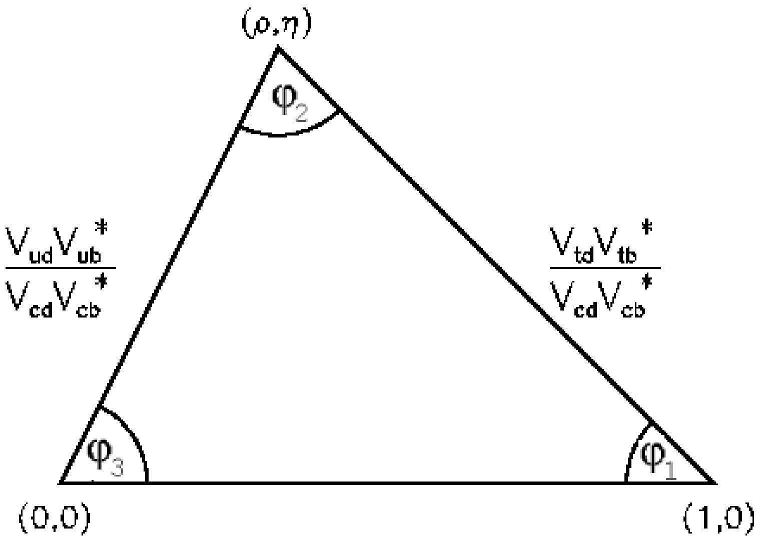
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Wolfenstein parametrisation:

$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

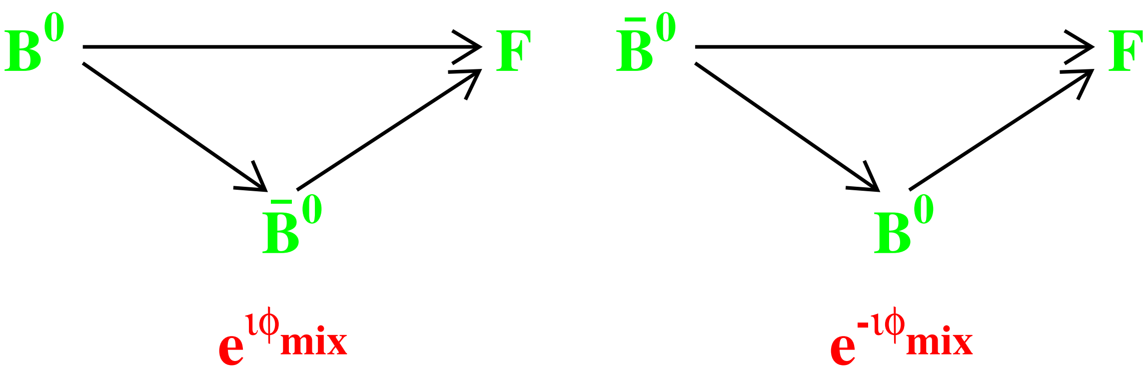
Unitarity $\rightarrow V^\dagger V = 1$ gives:

$$V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0$$



$$\phi_2 = \arg\left(\frac{-V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) \qquad \phi_1 = \arg\left(\frac{-V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) \qquad \phi_3 = \arg\left(\frac{-V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

The CP Asymmetry

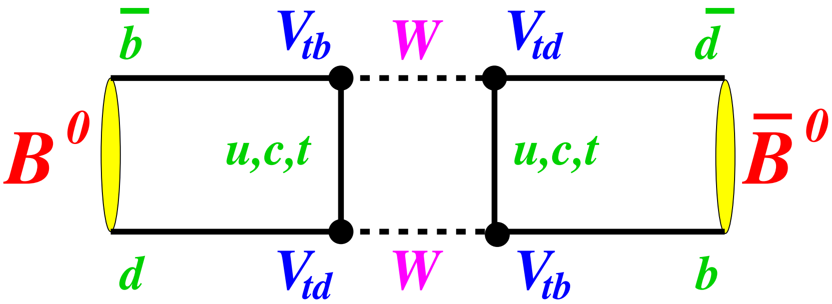


- Results in:

$$\frac{dN}{dt}(B^0 \to J/\psi K_S^0) \sim 1 - \sin\ 2\phi_1\ \sin\ \Delta mt$$

$$\frac{dN}{dt}(\bar{B}^0 \to J/\psi K_S^0) \sim 1 + \sin\ 2\phi_1\ \sin\ \Delta mt$$

- CP phase easily seen in CKM matrix element V_{td}

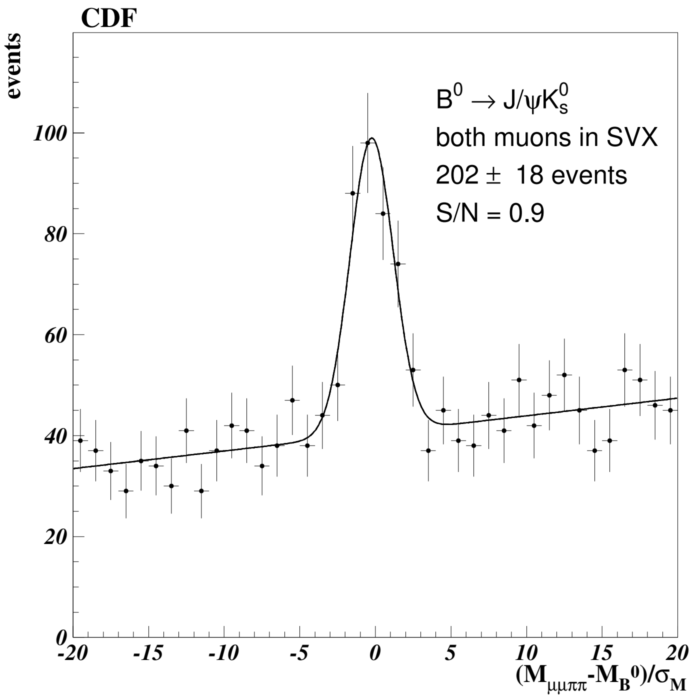


- B^0 and $\bar{B}^0$ produced at equal rates develop asymmetry:

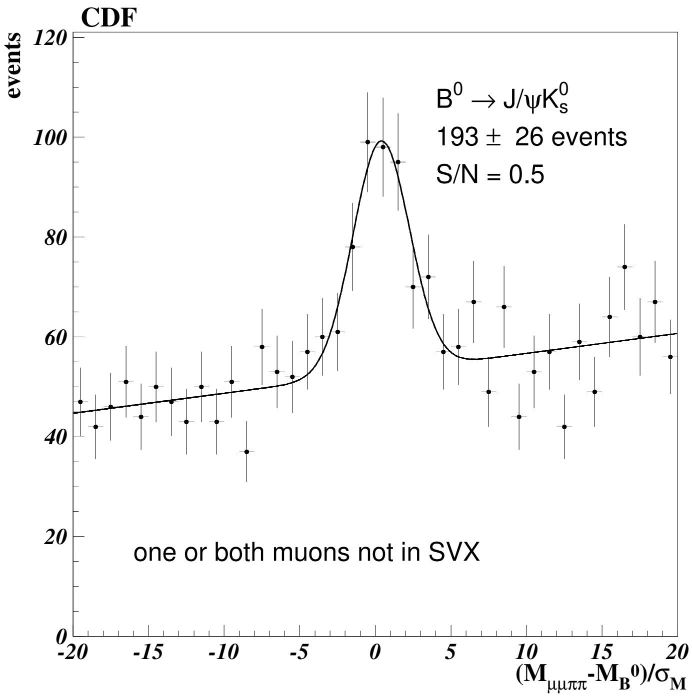
$$\begin{aligned} A_{CP}(t) &= \frac{\frac{dN}{dt}(\bar{B}^0 \to J/\psi K_S^0) - \frac{dN}{dt}(B^0 \to J/\psi K_S^0)}{\frac{dN}{dt}(\bar{B}^0 \to J/\psi K_S^0) + \frac{dN}{dt}(B^0 \to J/\psi K_S^0)} \\ &= \sin\ 2\phi_1\ \sin\ \Delta mt \end{aligned}$$

CDF Data Sample

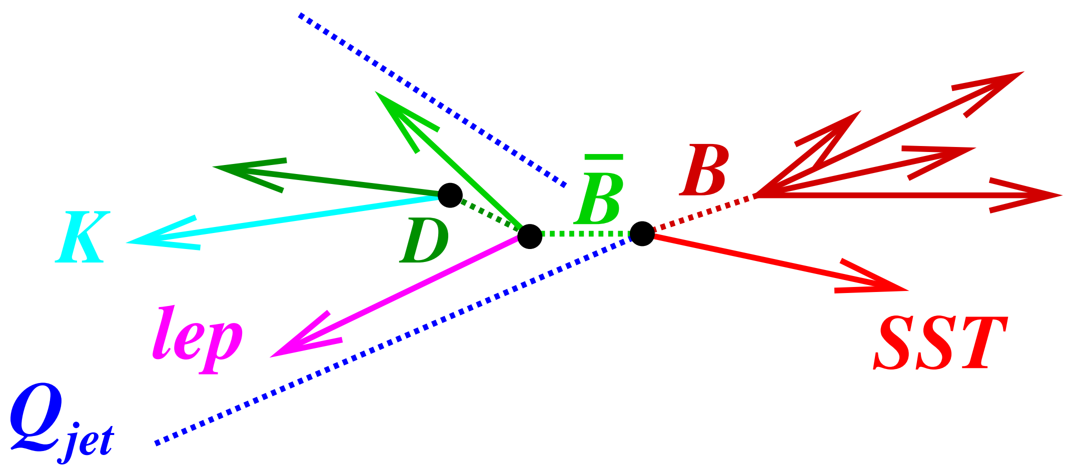
Both J/ψ muons have SVX information (≈ 200 events)



One or both J/ψ muons lack SVX information (≈ 200 events)



Methods for Tagging Initial B^0 Flavour



Determine the flavour (B^0 vs $\bar{B}^0$) at time of production

Opposite-Side Tagging

- Charge of opposite-side jet (JETQ)
- Soft e or μ tag from semi-leptonic decay of opposite B (SLT)

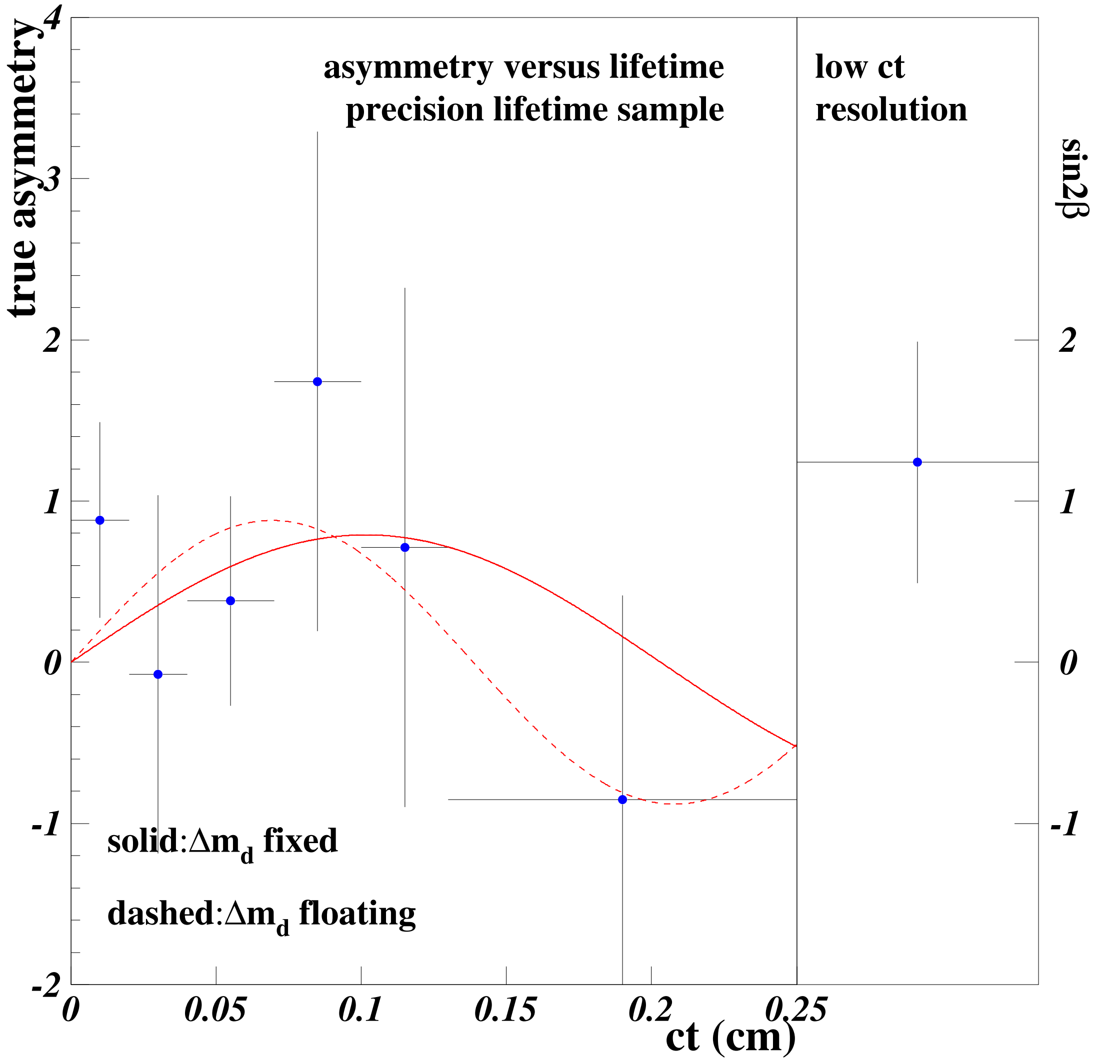
Same-Side Tagging

- Same-side SVX and non-SVX pion tagging (SST)

Overview of CDF Fit for $\sin\ 2\phi_1$

- Combine all information in maximum likelihood fit
- Allow for charge asymmetries in efficiencies and dilution
  - possible charge biases in tracking at low p_t
  - $K^{\pm}$ interaction rate differences
  - Charge asymmetric backgrounds (beampipe spallation)
- No significant asymmetries observed
- Likelihood function includes event-by-event probabilities for
  - Observed decay length
  - Reconstructed candidate mass
  - Efficiency and tagging probability
- Include constraints from other data ($B^+ \to J/\psi K^+$)
  - tagging efficiencies
  - dilutions
- Take external inputs for τ_{B^0}, Δm_d, m_B
  - Allow them to float within their errors

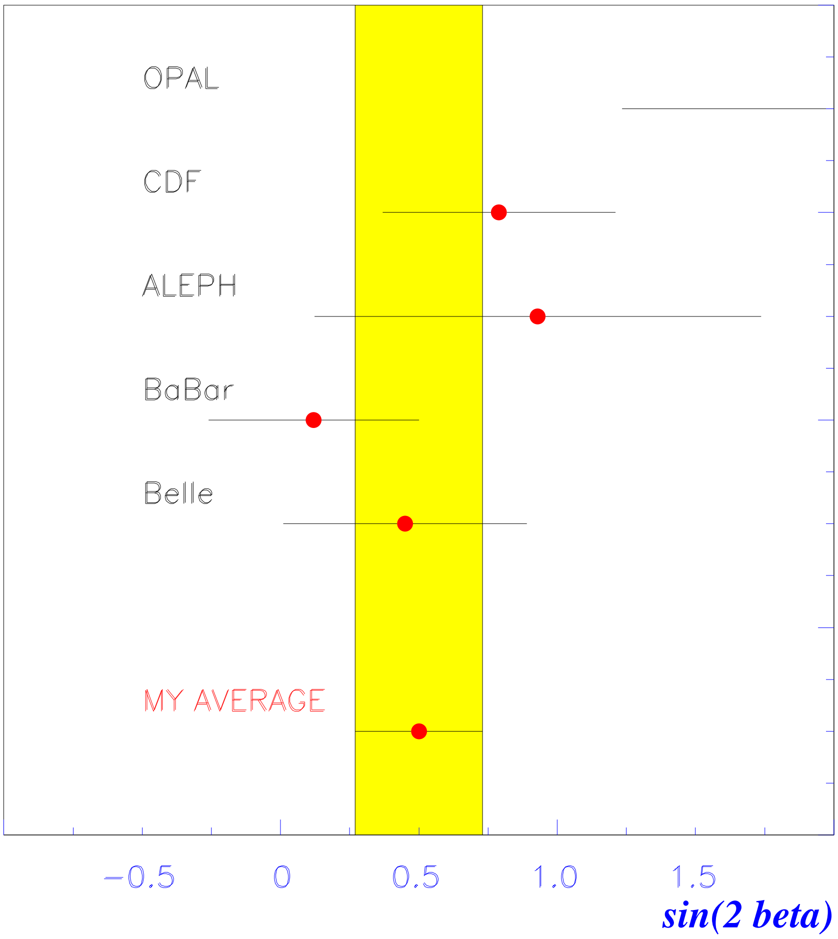
Result of Combined Fit



Measure

$$\sin\ 2\phi_1 = 0.79^{+0.41}_{-0.44}(stat + syst)$$

Determinations of ϕ_1



Experiment	$\sin\ 2\phi_1$	Reference
OPAL	$3.2^{+1.8}_{-2.0}(stat) \pm 0.5(sys)$	Euro. Phys. **C5**, 379 (98)
CDF (update)	$0.79 \pm 0.39(stat) \pm 0.16(sys)$	hep-ex/9909003
ALEPH (prelim)	$0.93^{+0.64}_{-0.88}(stat)^{+0.36}_{-0.24}(sys)$	PDG 2000
BaBar (prelim)	$0.12 \pm 0.37(stat) \pm 0.09(sys)$	Hitlin, ICHEP00
Belle (prelim)	$0.45 \pm 0.44(stat + sys)$	Aihara, ICHEP00
Average	0.50 ± 0.23	My average
CKM model fit	0.75 ± 0.09	S. Mele, PRL**59**, 113011 (99)

Prospects for $\sin\ 2\phi_1$ at CDF

- Run II at CDF will see:
  - $\times 20$ increase in luminosity (initially)
  - $\times 1.5$ increase in SVX acceptance
  - $\times 2$ for improved μ coverage and lower p_t for J/ψ
- Will yield 10,000 $J/\psi K_S^0$ decays for 2 fb^{-1}
- Calibration samples will grow by similar factor
- Even if no improvement in flavour tagging expect

$$\delta \sin\ 2\phi_1 \approx 0.08$$

- Further improvements should come from
  - Addition of $J/\psi \to e^+e^-$ final states
  - Improvements to flavour tagging (TOF in CDF)

CDF All Hadronic Trigger

- Level 1: 2 tracks with $p_t > 2$ GeV/c
  - $\sigma_{p_t} \approx 0.02 p_t^2$
  - L1 can run up to 50 kHz deadtimeless
- Level 2: Both tracks with $d > 100$ μm
  - $\sigma_d \approx 20 \oplus 40/p_t$ μm
  - beamspot smaller than 25 μm
- Level 3: Use full reconstruction
  - factor of 2-5 further reduction

	Luminosity	T_{cross} (ns)	$\overline{N_{p\bar{p}}}$	L1 (kHz)	L2 (Hz)
A	0.7×10^{32}	396	2	18	39
B	2.0×10^{32}	132	2	30	67
C	1.7×10^{32}	396	5	28	38

- Yield in 2 fb^{-1}:
  - 4000 - 7000 $B^0 \to \pi^+\pi^-$ ($\mathcal{B} = 0.5 \times 10^{-5}$)
  - 16000 - 28000 $B^0 \to K^+\pi^-$ ($\mathcal{B} = 1.9 \times 10^{-5}$)

B_s^0 Event Yields (2 fb^{-1})

- Signal Cross Sections (pb)

Mode	A	B	C
$B_s^0 \to D_s^- \pi^+$	5.3	4.2	3.6
$B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$	6.4	5.2	4.1
$B_s^0 \to D_s^{*-} \pi^+$	4.7	3.7	2.9
$B^0 \to \pi^- \pi^+$	3.8	2.9	2.1

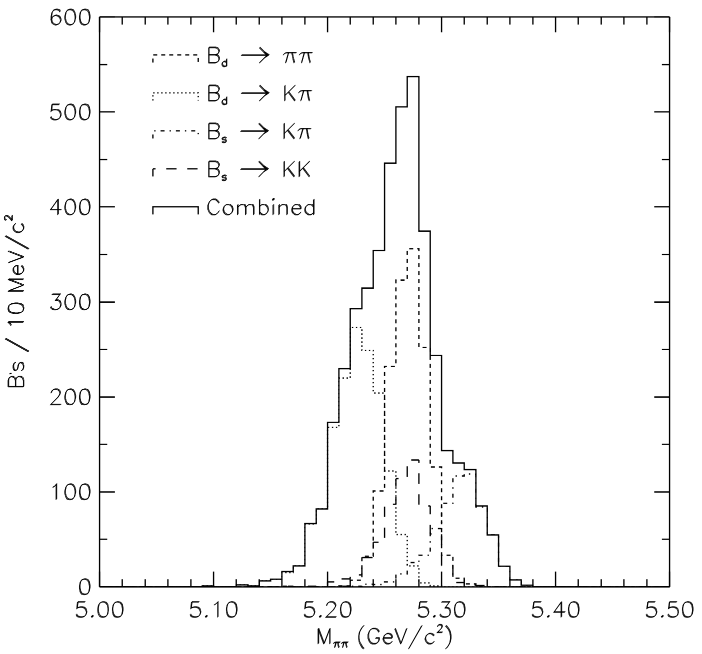
- Event Yields

Mode	A	B	C
$B_s^0 \to D_s^- \pi^+$	10,600	8,400	7,200
$B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$	12,800	10,400	8,100
$B_s^0 \to D_s^{*-} \pi^+$	9,400	7,400	5,800
$B^0 \to \pi^- \pi^+$	7,600	5,900	4,200

- 40% Uncertainty on B_s^0 yields (σ, $\mathcal{B}$, f_s)
- Use only $D_s^- \pi^+$ and $D_s^- \pi^+ \pi^- \pi^+$ modes for x_s
- Vary total number of B_s^0 candidates from 5,000 to 20,000

Backgrounds to $B \to \pi^+\pi^-$

- Physics backgrounds
  - Use invariant mass to distinguish $\pi\pi$ from $K\pi$ and KK



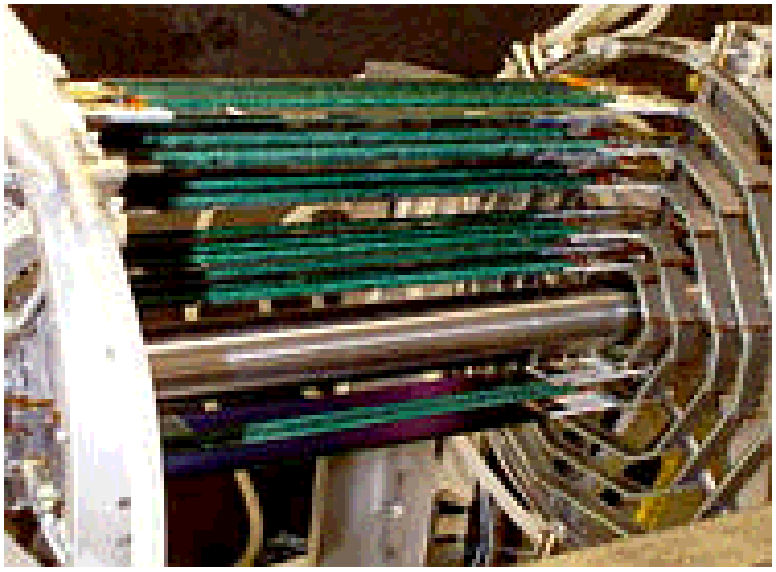
  - dE/dx in tracking chambers
  - Will have TOF but ...
    - One sigma $\pi - K$ separation up to 1.6 GeV/c
    - Mainly for flavour tagging (an additional $\epsilon\mathcal{D}^2 \sim 2.4\%$)
  - $K\pi$ has $\cos\Delta m_d$ time dependence

- QCD light quark fakes + heavy quark combinatorics
  - studied with run I data, estimate S:B $>$ 1:4

- Expect $\delta A_{\pi^+\pi^-} \sim 0.13$ (for 5000 events)

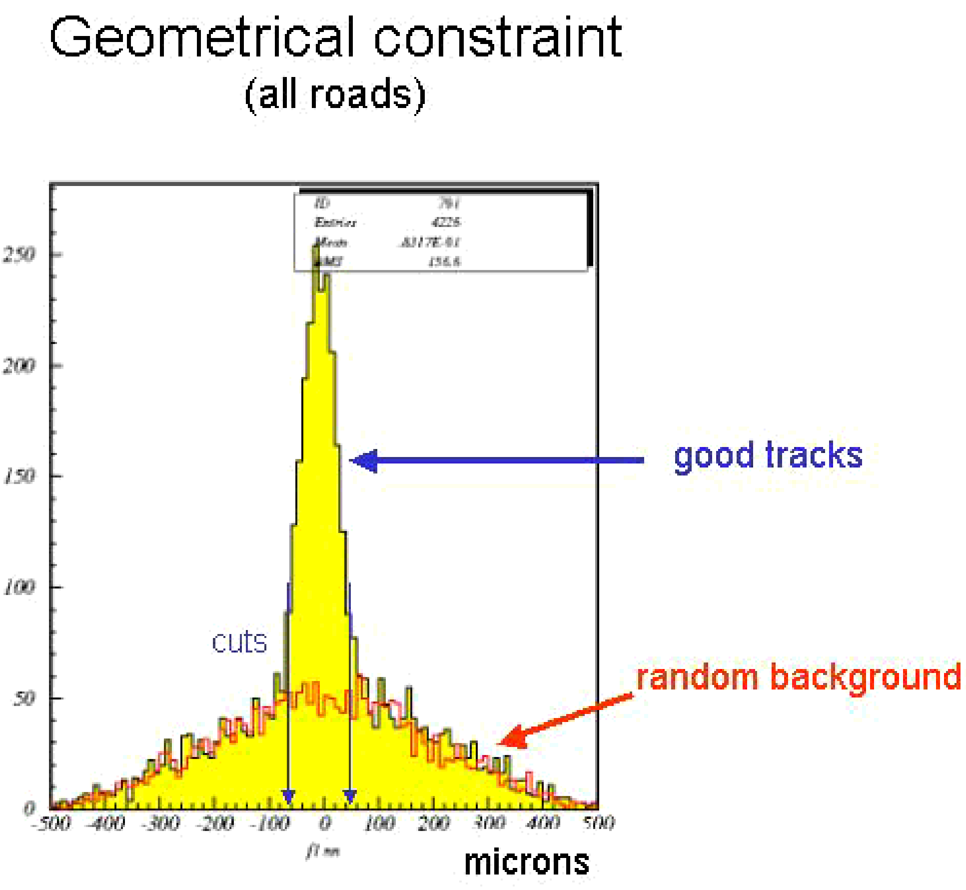
CDF-II Commissioning Run

- Installed two complete wedges of “active” SVX-II
- CDF-II rolled onto beamline 15-September-2000
- First Tevatron-II collisions/tracks 1-October-2000
- Stable running ($\mathcal{L} = 5 \times 10^{29}$) 1-November-2000
- Accumulated about 50 nb^{-1} during 1 week of operation



SVT Performance during Commissioning Run

- Processed only silicon stand-alone track finding
- 3 hits define (x_0, y_0, p_t)
- 4th hit gives track residual ("constraint")



- RMS of 80μm consistent with SVT resolution
- Background = random combinations, shape from SVT roads

Summary

- Enormous $\sigma_{b\bar{b}}$ at hadron machines
  - allows us to compete with B factories
  - despite higher backgrounds/lower dilutions
- State of the art silicon tracker is the key
- CDF-II includes trigger for fully hadronic B meson final states
- Expect to measure $\delta \sin\ 2\phi_1 \approx 0.1$ by end of 2003
- $B_s^0 \bar{B}_s^0$ mixing measurement is unique to hadron machines
- Together these measurements define the CKM triangle
- Tools in place to attack $\pi^+\pi^-$ asymmetry
- Will provide an over-constraint on the triangle.