Run II Beauty Physics at CDF and DØ

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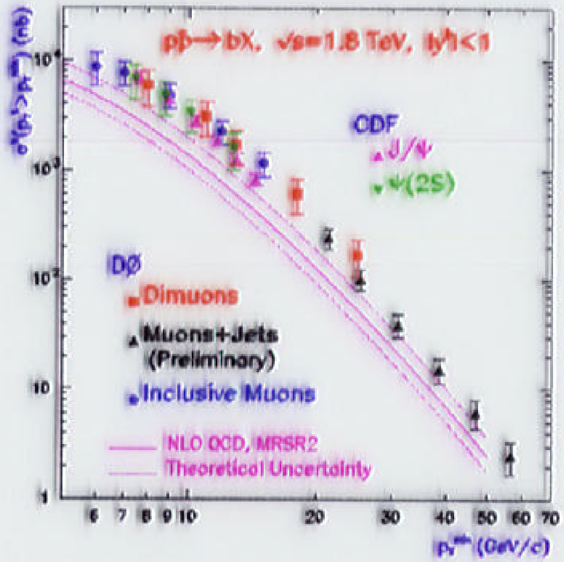
on behalf of the CDF and DØ Collaborations

1. Introduction
2. Run II Detectors
3. CP Violation
4. B_s Mixing

Introduction

- Why study B physics at the Tevatron?
  - Large rate:



$$\sigma(p\bar{p} \to b\bar{b}) \approx 150\ \mu b \quad \text{at 2 TeV}$$

$$\sigma(e^+e^- \to b\bar{b}) \approx 7\ nb \quad \text{at } Z^0$$

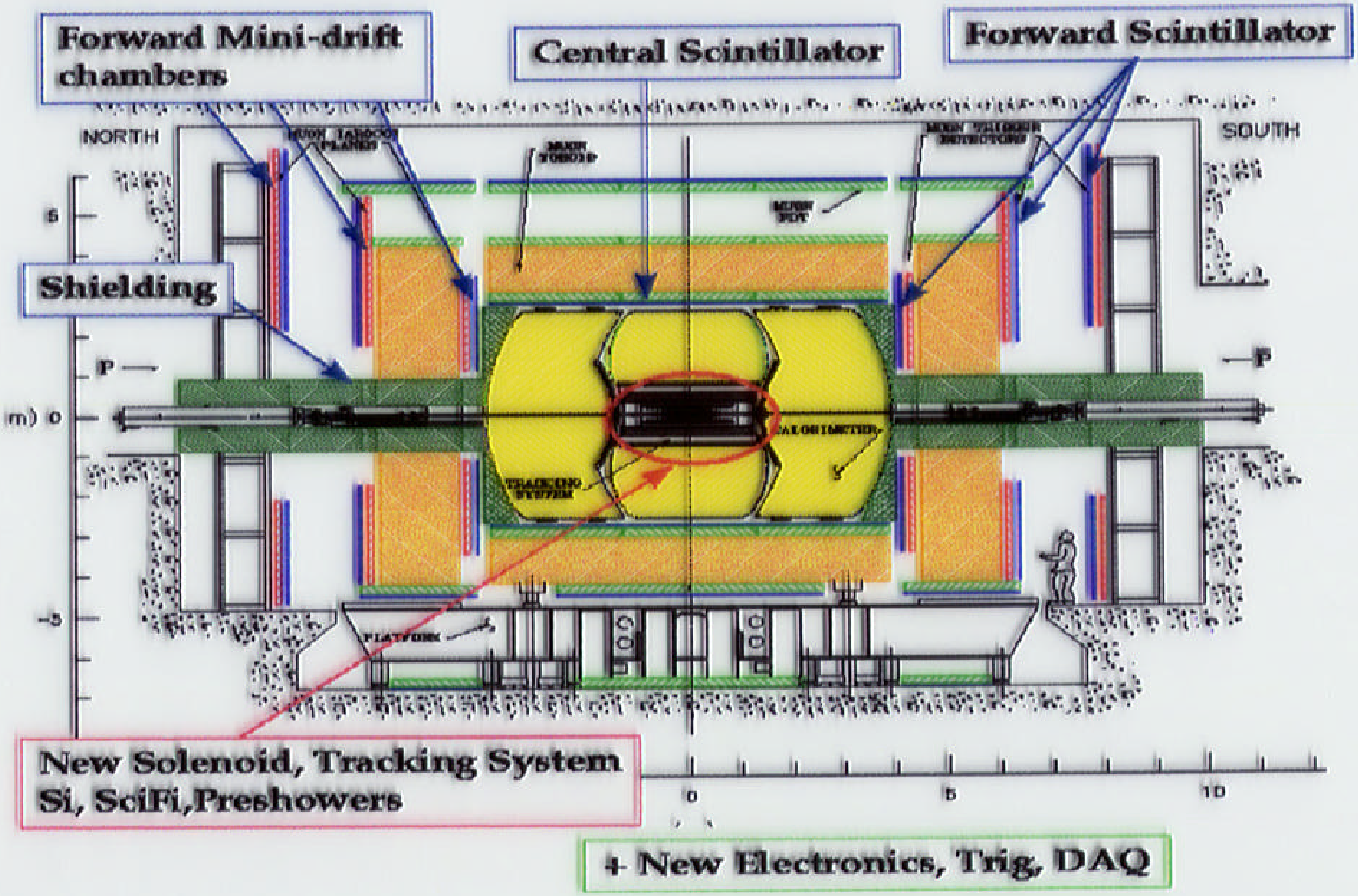
$$\sigma(e^+e^- \to B\bar{B}) \approx 1\ nb \quad \text{at } \Upsilon(4S)$$

  - All species, including B_s, B_c, Λ_b, produced

Introduction

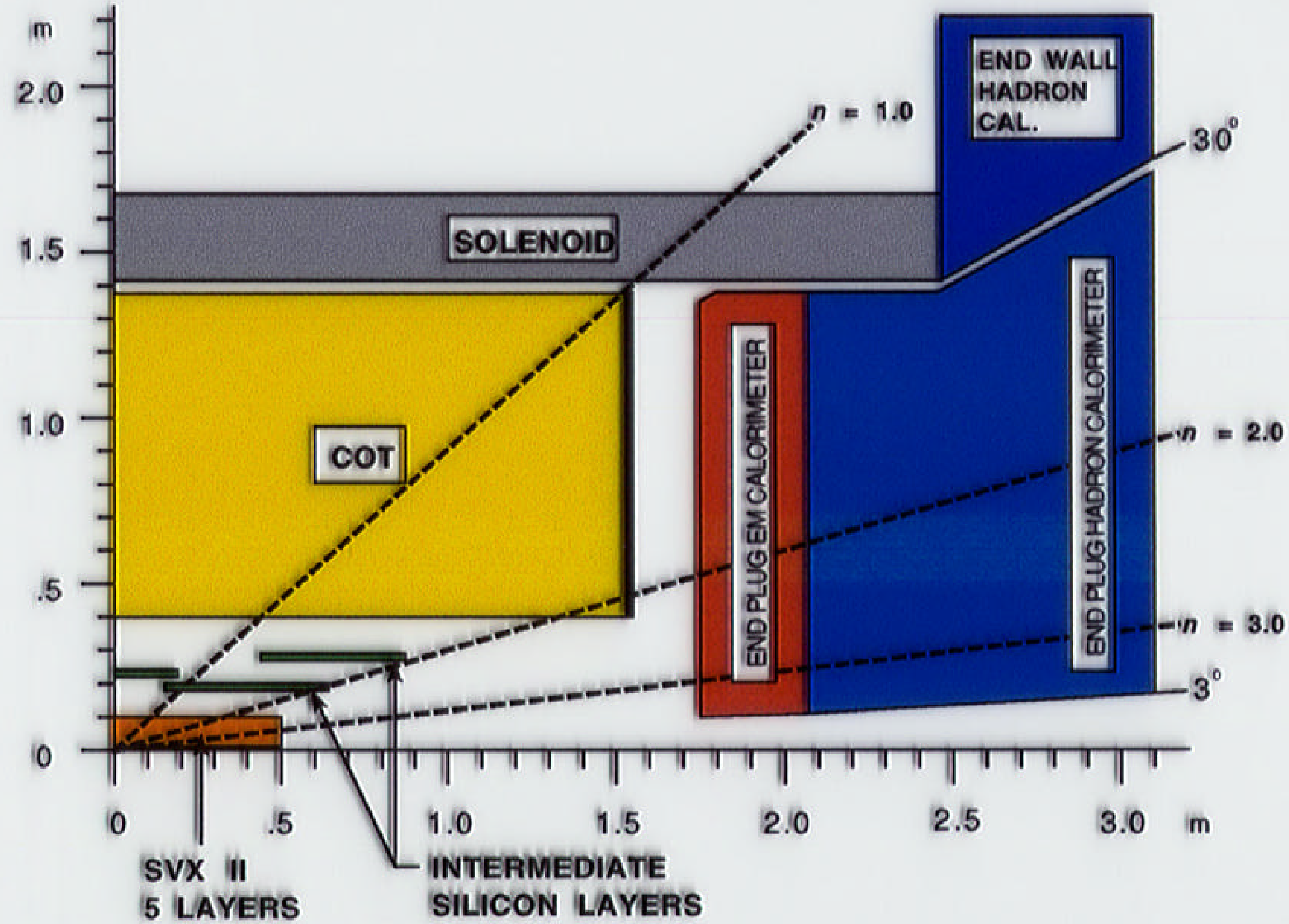
- Topics include
  - CP violation and CKM angles
    - $\sin(2\beta)$ ($B^0 \to J/\psi\ K_s$)
    - α ($B^0 \to \pi^+ \pi^-$)
    - γ ($B_s^0 \to K^+ K^-$)
  - B_s mixing
  - Cross sections
  - Spectroscopy and lifetimes
  - Rare and radiative decays
  - Charmonium polarization

Run II DØ Detector



Run II CDF Detector

CDF Tracking Volume



BCP4

Highlights for Run II

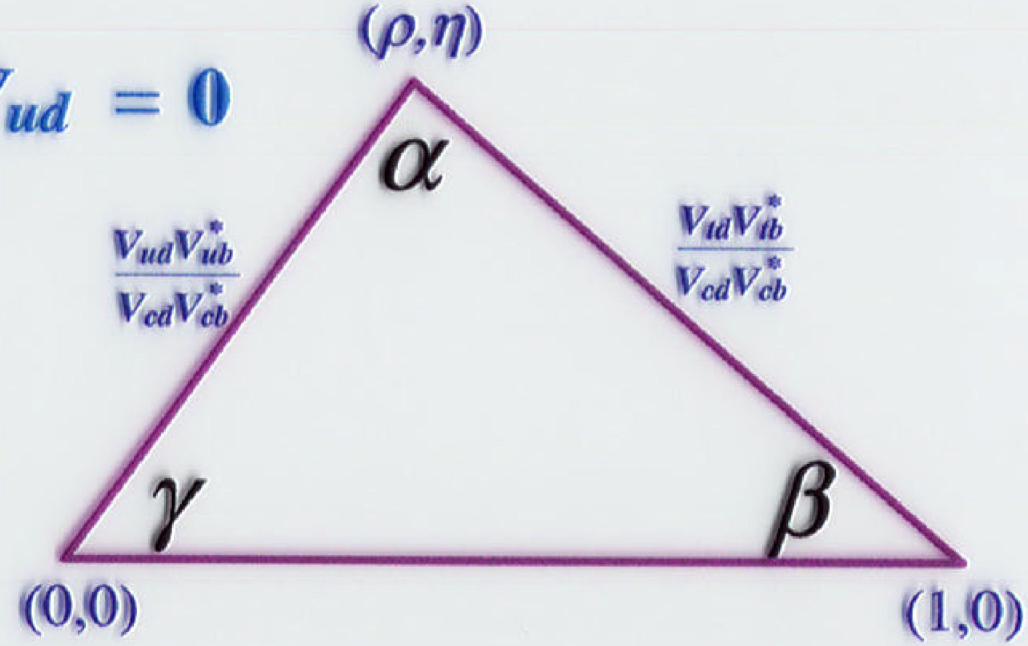
- Trigger on tracks at Level 1
- Trigger on displaced tracks (impact parameter) at Level 2
- New tracking systems
- Increased muon coverage
- DØ has magnet, fiber tracker, silicon vertex detector, EM preshowers
- CDF has Time-Of-Flight for kaon ID, layer 00 silicon, EM plug calorimeter

CKM Matrix

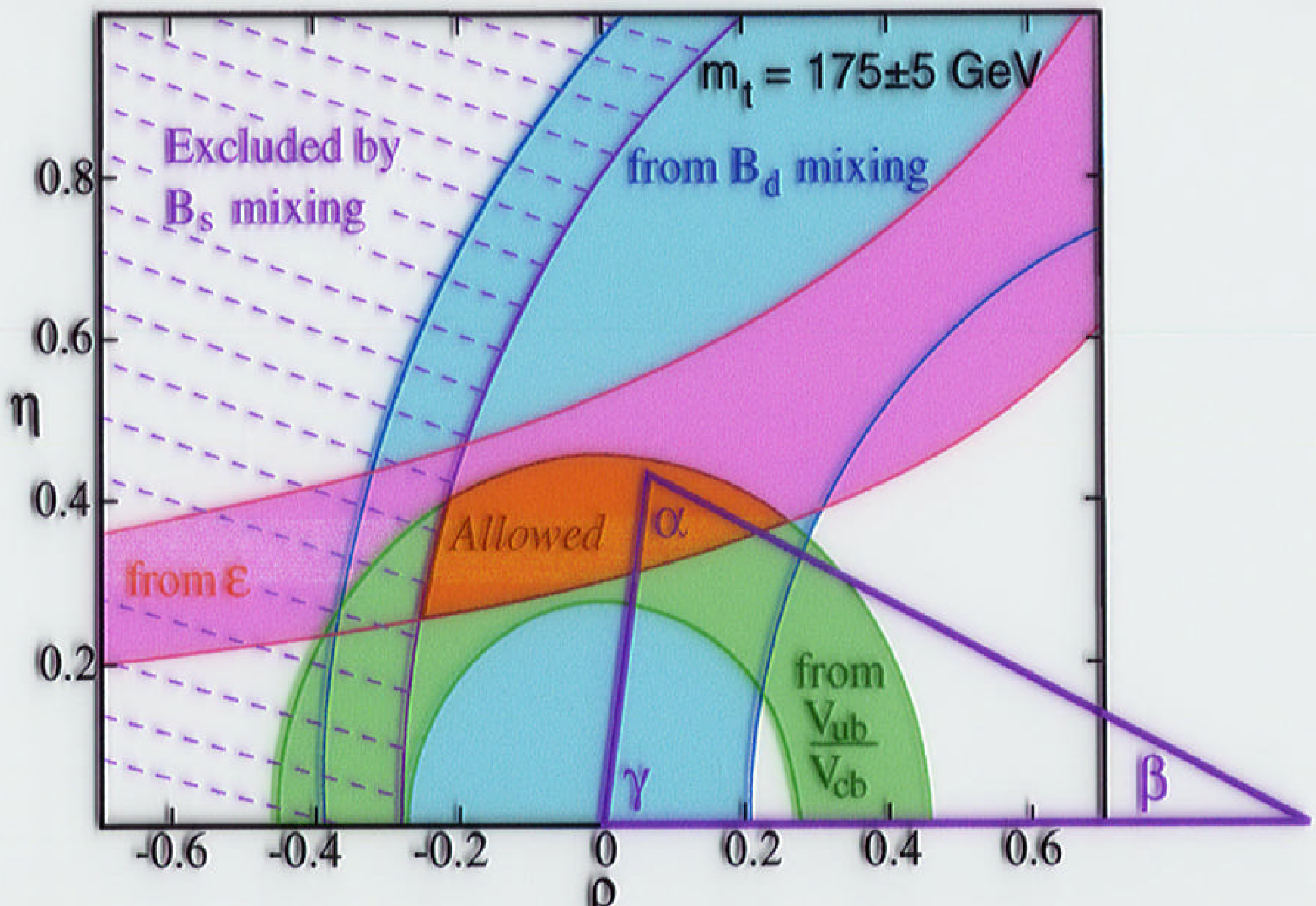
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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

- λ is the sine of the Cabibbo angle
- A and λ have been measured to a few percent



CKM Matrix



m_t = 175±5 GeV
Excluded by
B_s mixing
from B_d mixing
0.8
0.6
η
0.4
0.2
Allowed
α
from ε
from
V_ub
V_cb
γ
β
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
ρ

CP Violation in B° Decays

- Direct and mixed decays yield the same CP eigenstates at different rates

$$A(B_d \rightarrow \overline{B}_d) \propto m_t^2 V_{td}^2 \approx |A| e^{i2\beta}$$

$$A(\overline{B}_d \rightarrow B_d) \propto m_t^2 V_{td}^{*2} \approx |A| e^{-i2\beta}$$

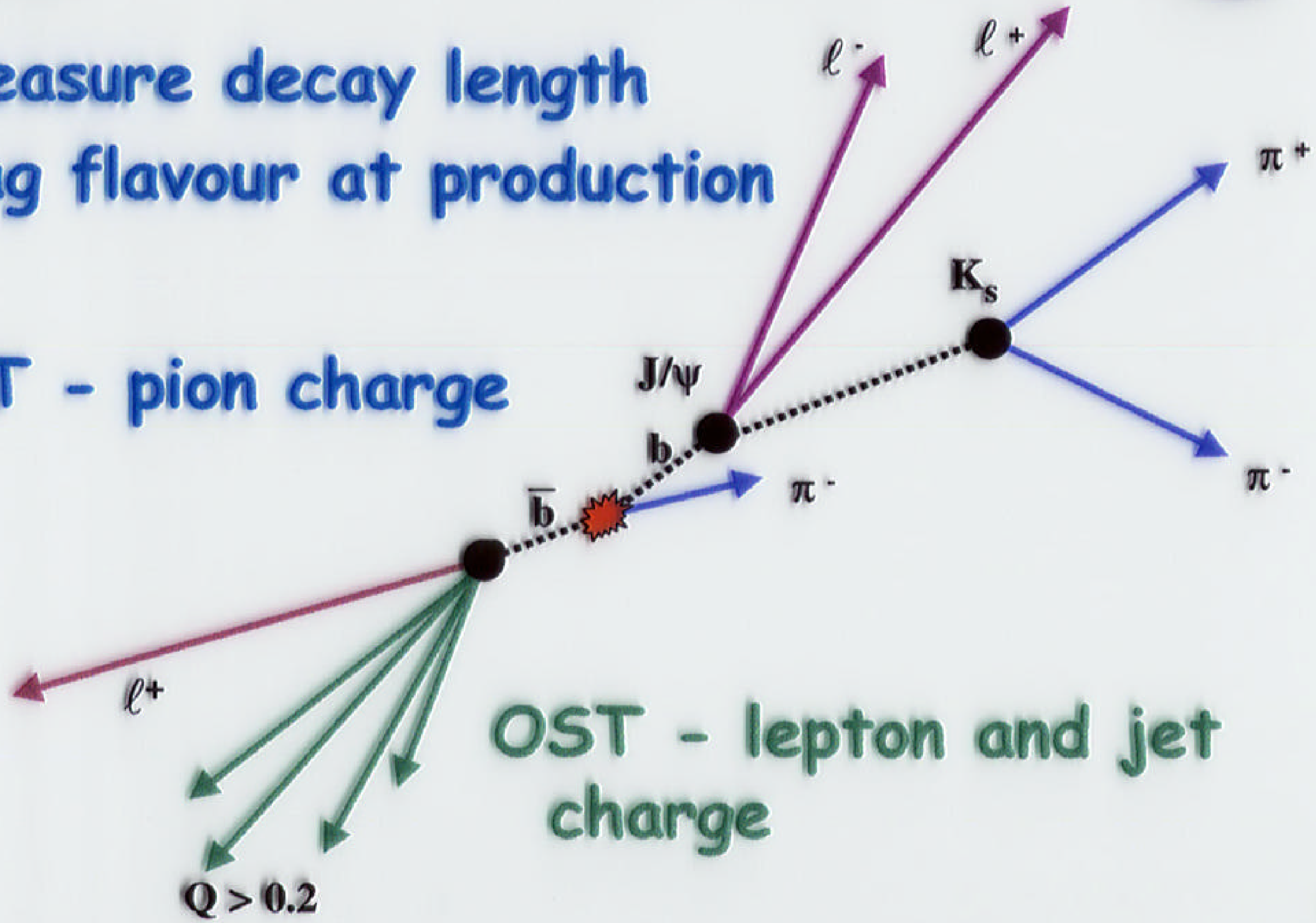
- Reconstruct $B^\circ \rightarrow J/\psi\ K_s$ decays to measure $\sin(2\beta)$

$$A_{CP}(t) = \frac{\Gamma\left(\overline{B^0} \rightarrow J/\psi K_S^0\right) - \Gamma\left(B^0 \rightarrow J/\psi K_S^0\right)}{\Gamma\left(\overline{B^0} \rightarrow J/\psi K_S^0\right) + \Gamma\left(B^0 \rightarrow J/\psi K_S^0\right)}$$

$$= \sin(2\beta)\sin(\Delta m_d t)$$

B° → J/ψ K_s Reconstruction

- Measure decay length
- Tag flavour at production

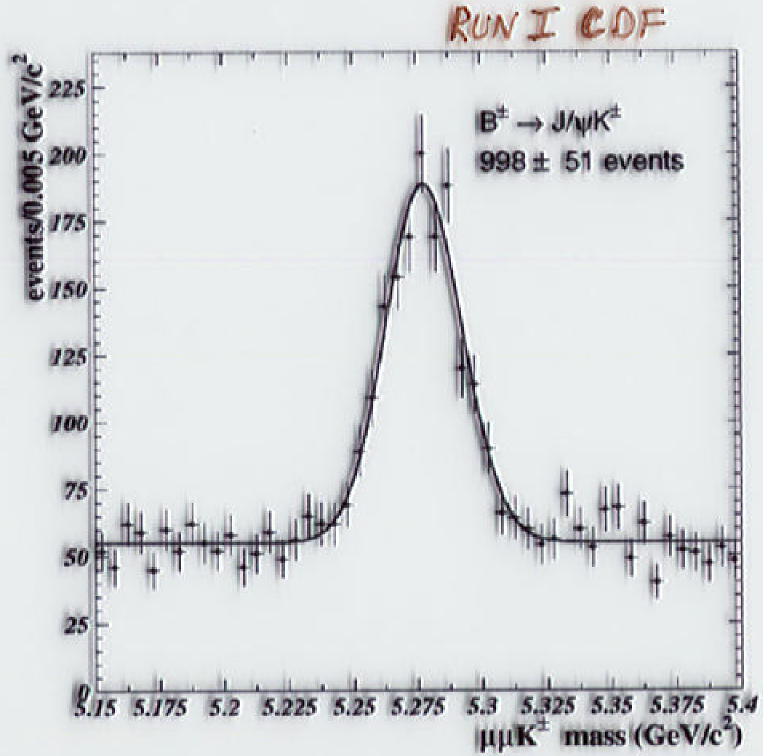


Flavour Tagging

- Determine production flavour (B^0 vs $\overline{B^0}$)
- Opposite-side tags (other b)
  - charge of lepton from semileptonic decay
  - charge sum of particles in jet
- Same-side tags
  - charge of pion produced in fragmentation or B** decay
- Tagging efficiency $\varepsilon = N_{tag}/N_{tot}$
- Dilution $D = (N_R - N_W)/(N_R + N_W)$
- Tag quality $= \varepsilon D^2$

Flavour Tagging

- CDF uses Run I $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ events to calibrate flavour tagging algorithms
- Charge of kaon tells you B or $\overline{B}$
- Trigger and reconstruction similar to $B^{0} \rightarrow J/\psi\, K_s$

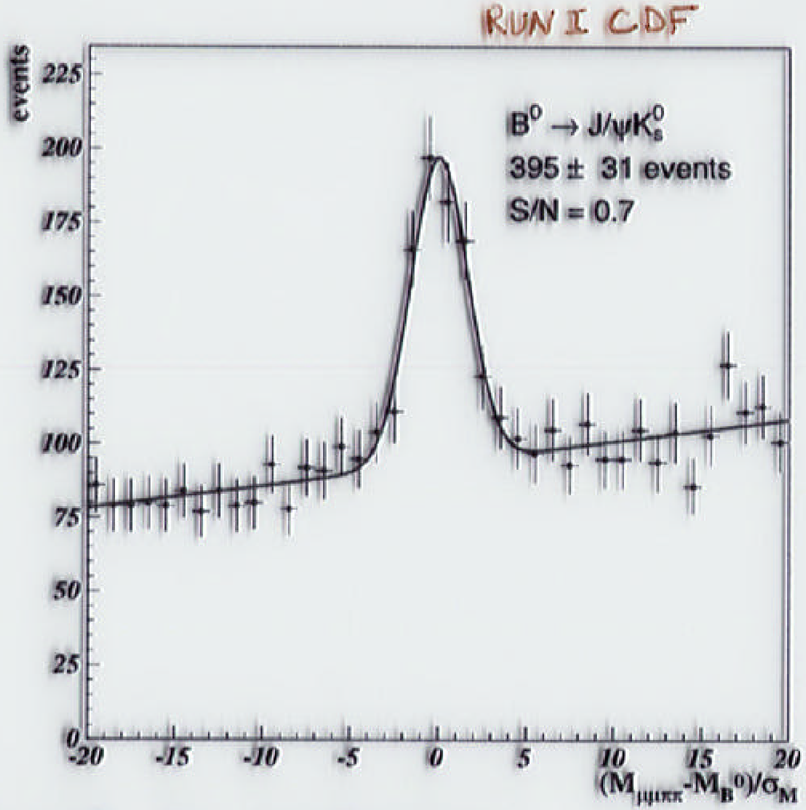


Flavour Tagging

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 K ID	none
Combined		9.1		9.8

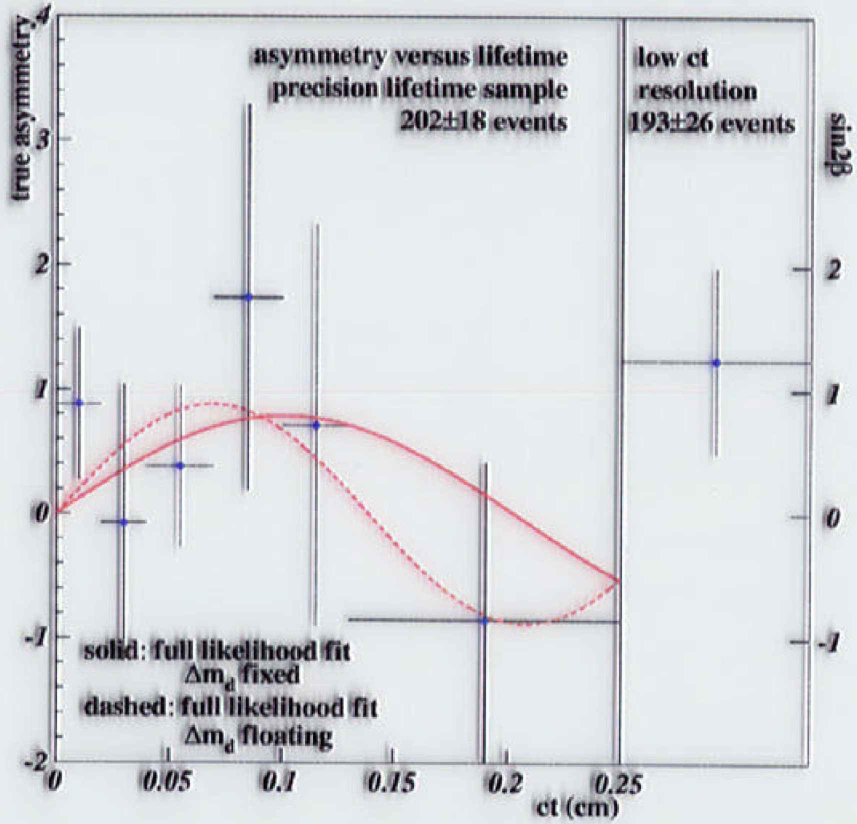
$B^\circ \to J/\psi\ K_s$ Fitted Mass

- 4-track fit
- $m(\pi\pi)=m(K_s)$
- $m(\mu\mu)=m(J/\psi)$



- K_s momentum points back to B vertex
- B momentum points back to primary vertex

CDF Run I sin(2β) Result



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

Run II sin(2β)

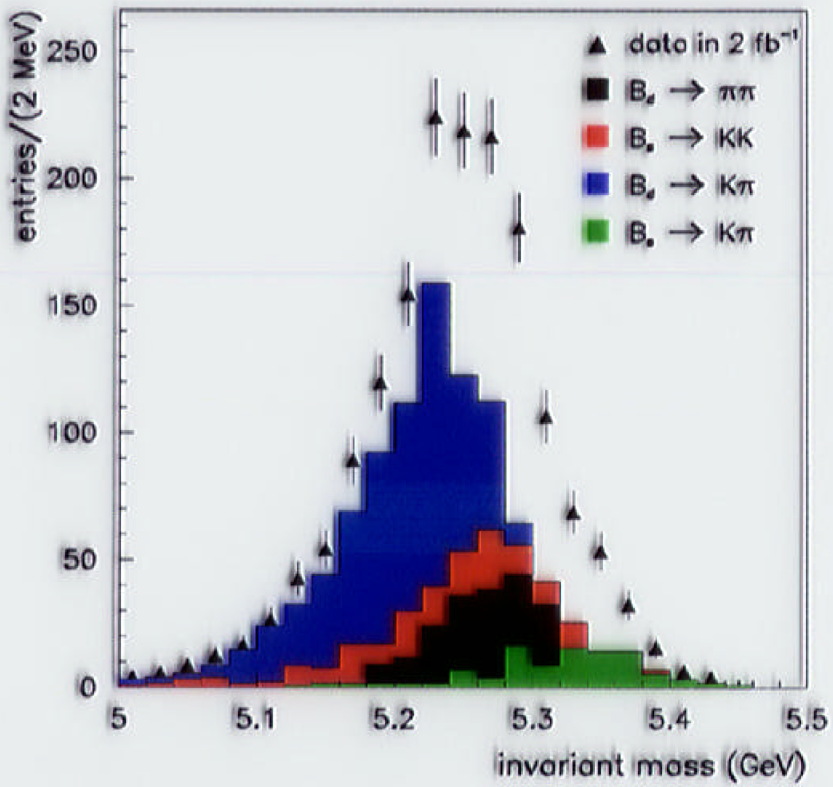
- Reconstruct 30K-40K $B^\circ \rightarrow J/\psi\ K_s$ events
- Expect $\sigma(\sin 2\beta) \approx 0.04$ due to
  - improved muon acceptance
  - lower muon trigger thresholds
  - improved flavour tagging (K ID (CDF), lepton ID)
  - Forward tracking (DØ)
  - trigger on $J/\psi \rightarrow e^+e^-$
- Result continues to be statistics limited due to size of tagging calibration samples

α and γ in $B_{(s)}$ Decays

- Sin(2α) extracted from $A_{CP}(B^0 \to \pi^+ \pi^-)$
- Low branching fraction: $(0.5-1)\times10^{-5}$
- Large backgrounds, mostly heavy flavour daughters
- DØ triggers on opposite-side lepton
- CDF uses all-hadronic trigger (L1 track + L2 impact parameter)
- Expect 5000 (500) events in 2 fb^{-1}
- Complicated by penguin contributions!

α and γ in $B_{(s)}$ Decays

- **Reconstruct**
  - $B^0 \to \pi^+ \pi^-$
  - $B^0 \to K^+ \pi^-$
  - $B_s^0 \to \pi^+ K^-$
  - $B_s^0 \to K^+ K^-$
- **In 1:4:0.5:2 ratios**

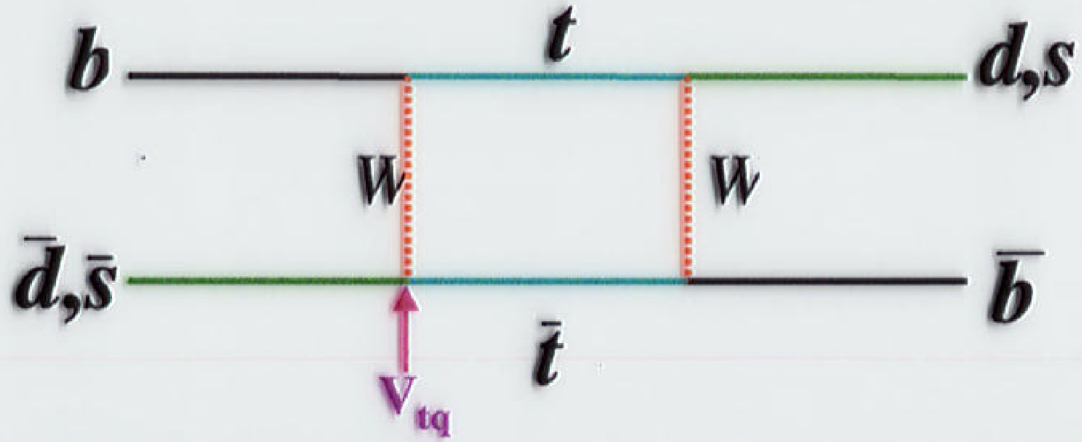


R. FLEISCHER, PLB 459 (1999) 306.

α and γ in $B_{(s)}$ Decays

- Five observables in likelihood fit:
  - $A^{dir}_{cp}(\pi^+ \pi^-)$
  - $A^{dir}_{cp}(K^+ K^-)$
  - $A^{mix}_{cp}(K^+ K^-)$
  - $A^{mix}_{cp}(\pi^+ \pi^-)$
  - $\sin(2\beta)$
- Without penguins,
  - $A^{mix}_{cp}(\pi^+ \pi^-) = \sin 2(\beta+\gamma) = \sin(2\alpha)$
  - $A^{mix}_{cp}(K^+ K^-) = \sin(2\gamma)$
  - $A^{dir}_{cp}(\pi^+ \pi^-) = A^{dir}_{cp}(K^+ K^-) = 0$
- Predict $\sigma(A_{CP}(B^0 \to \pi^+ \pi^-)) \approx 0.15$
- Predict $\sigma(\gamma) = ^{+5.4}_{-6.8} \pm 3$ deg (CDF)

B_s Mixing



- Weak eigenstates ≠ mass eigenstates
- Mixing due to higher order corrections
- $\Delta m_q = m(B^o_{heavy}) - m(B^o_{light})$
- $P_{mixed}(t) = \frac{1}{2}(1 - \cos\Delta m_q t)$, $\Delta m_q \propto |V_{tb} \bullet V_{tq}|^2$
- Mixing parameters $x_q = \Delta m_q / \Gamma_q$ and $\Delta\Gamma_q$

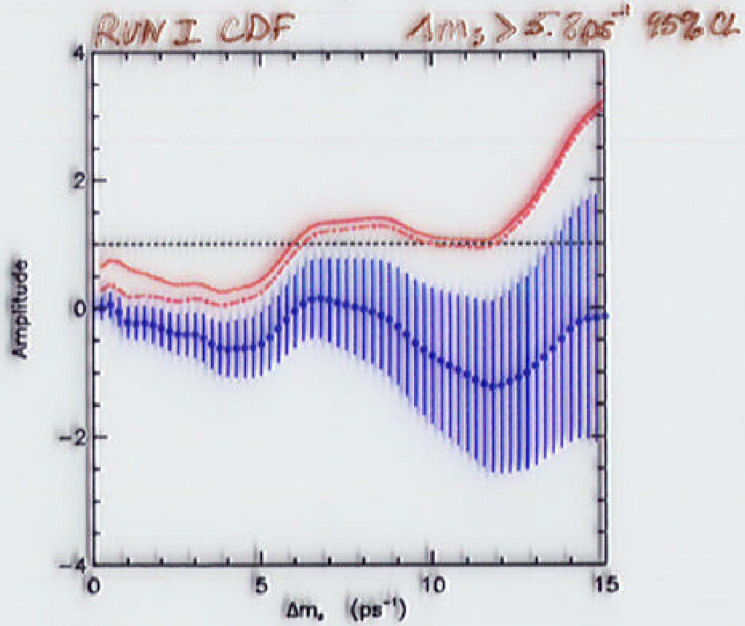
Semileptonic Mode B_s

$$B_s^0 \rightarrow D_s^- \ell^+ \nu X$$

$$D_s^- \rightarrow \phi X$$

$$\phi \rightarrow K^+ K^-$$

- trigger on dilepton events
- initial flavour tagged by opposite side lepton
- final flavour tagged by same side lepton
- require D_s daughters kinematically consistent with D_s
- use amplitude fit method
- good for x_s<30 (momentum uncertainty of missing ν)
- 40 000 events in 2 fb^{-1}



Hadronic Mode B_s

*no missing neutrino

$$B_s^0 \rightarrow D_s^- \pi^+ (\pi^- \pi^+)$$

$$D_s^- \rightarrow \phi \pi^-$$

$$\phi \rightarrow K^+ K^-$$

- CDF uses 2-track hadronic trigger
- initial flavour tagged by opposite-side event (3 tags available)
- final flavour tagged by charge of D_s
- expect 5K-30K events in 2 fb^{-1}
- probe x_s<60

- DØ triggers on opposite side lepton
- lepton charge tags initial flavour
- final flavour tagged by charge of D_s
- expect 1000 events in 2 fb^{-1}
- probe x_s<33

DØ Run II Tevatron Plan

- Run II starts March 2001
- No long shutdowns
- Gradual luminosity improvement over time
- Start at 396 ns bunch spacing
- Move to 132 ns bunch spacing in 2003
- Reach $2.0 \times 10^{32}\ cm^{-1}s^{-1}$ by 2004
- Collect 15 fb^{-1} by 2008
- CDF/DØ make way for BTeV in 2008

Conclusions

- After 2 years/2 fb^{-1} of data we will
  - measure $\sin(2\beta)$ to an accuracy of 0.04
  - probe B_s mixing to $x_s \approx 30$ with semileptonic decays
  - probe Bs mixing to $x_s \approx 60$ in hadronic mode
  - measure $A_{CP}(B^0 \rightarrow \pi^+ \pi^-)$ to an accuracy of 0.15 and γ to an accuracy of 8 degrees
  - Full reconstruction of B_c decay modes
  - Precision lifetime ratios (B_s/B^0, Λ_b/B^0, B_c/B^0)
  - Rare decays: $B^0_{(s)} \rightarrow \mu\mu K^{(*)}$, $K^*\gamma$, $\varphi\gamma$