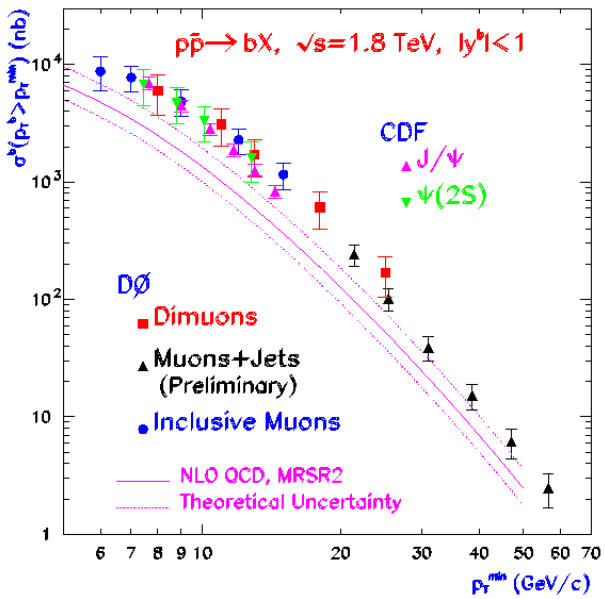
Run II Beauty Physics at CDF and DØ

Wendy Taylor
SUNY Stony Brook
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:



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

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

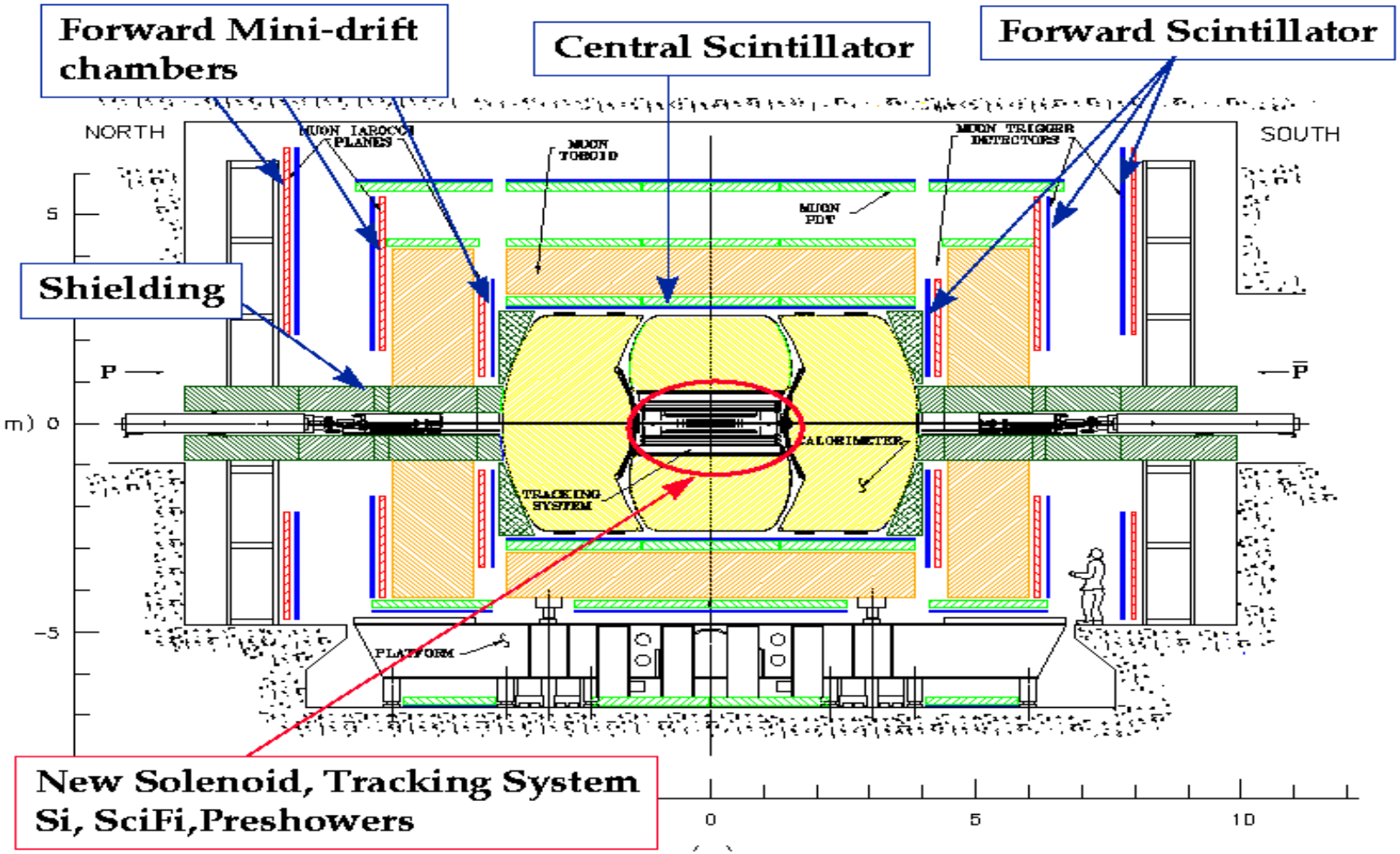
$$\sigma(e^+e^- \to B\bar{B}) \approx 1\ nb \quad \textbf{at } \Upsilon\textbf{(4S)}$$

  - 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

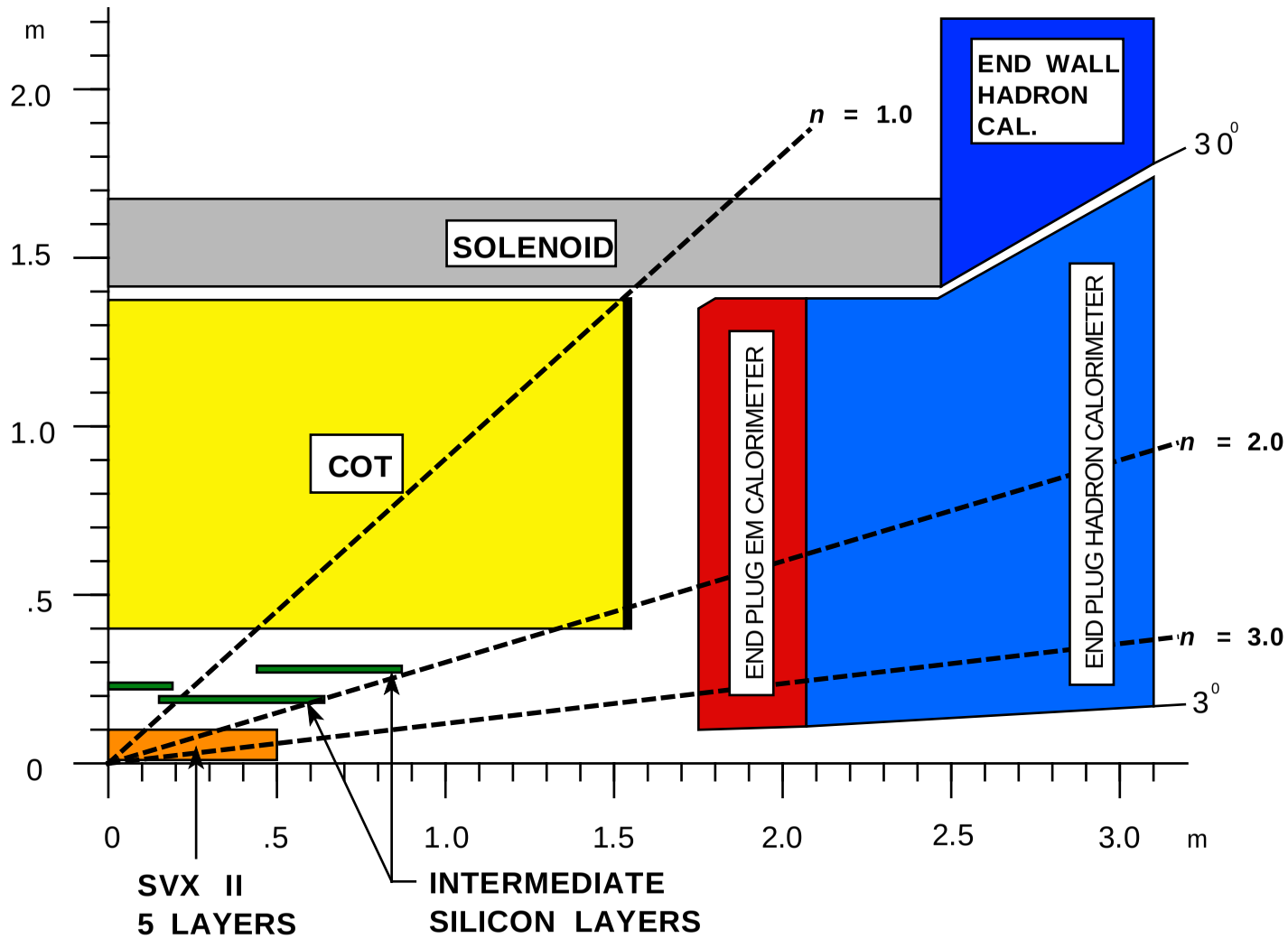
Run II DØ Detector



+ New Electronics, Trig, DAQ

Run II CDF Detector

CDF Tracking Volume



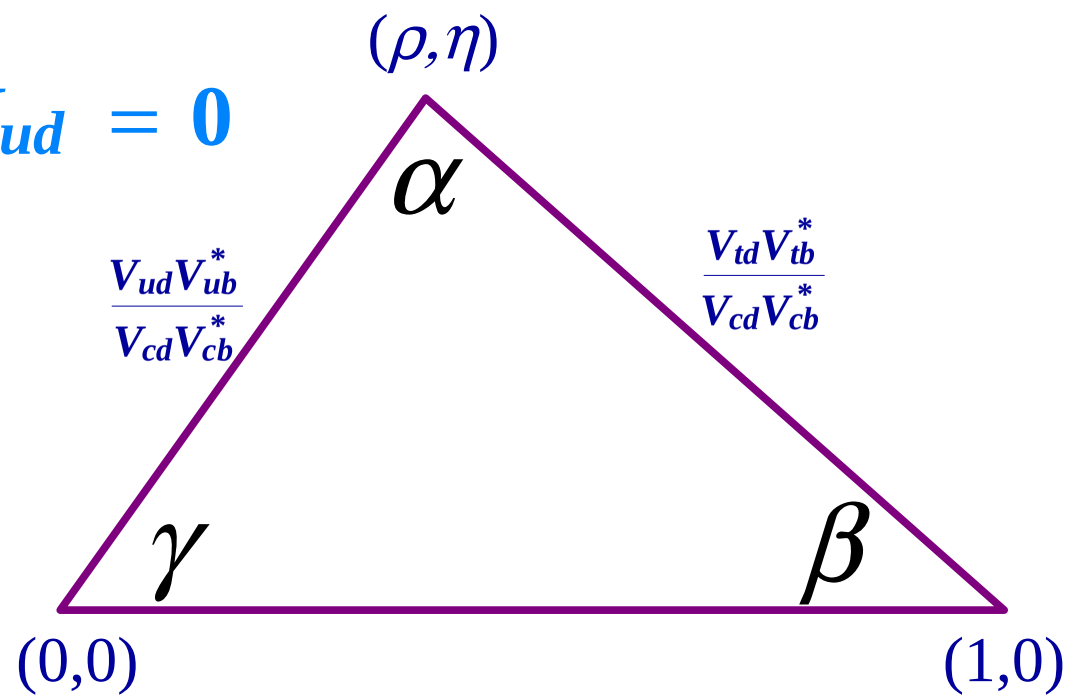
Highlights for Run II

- 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

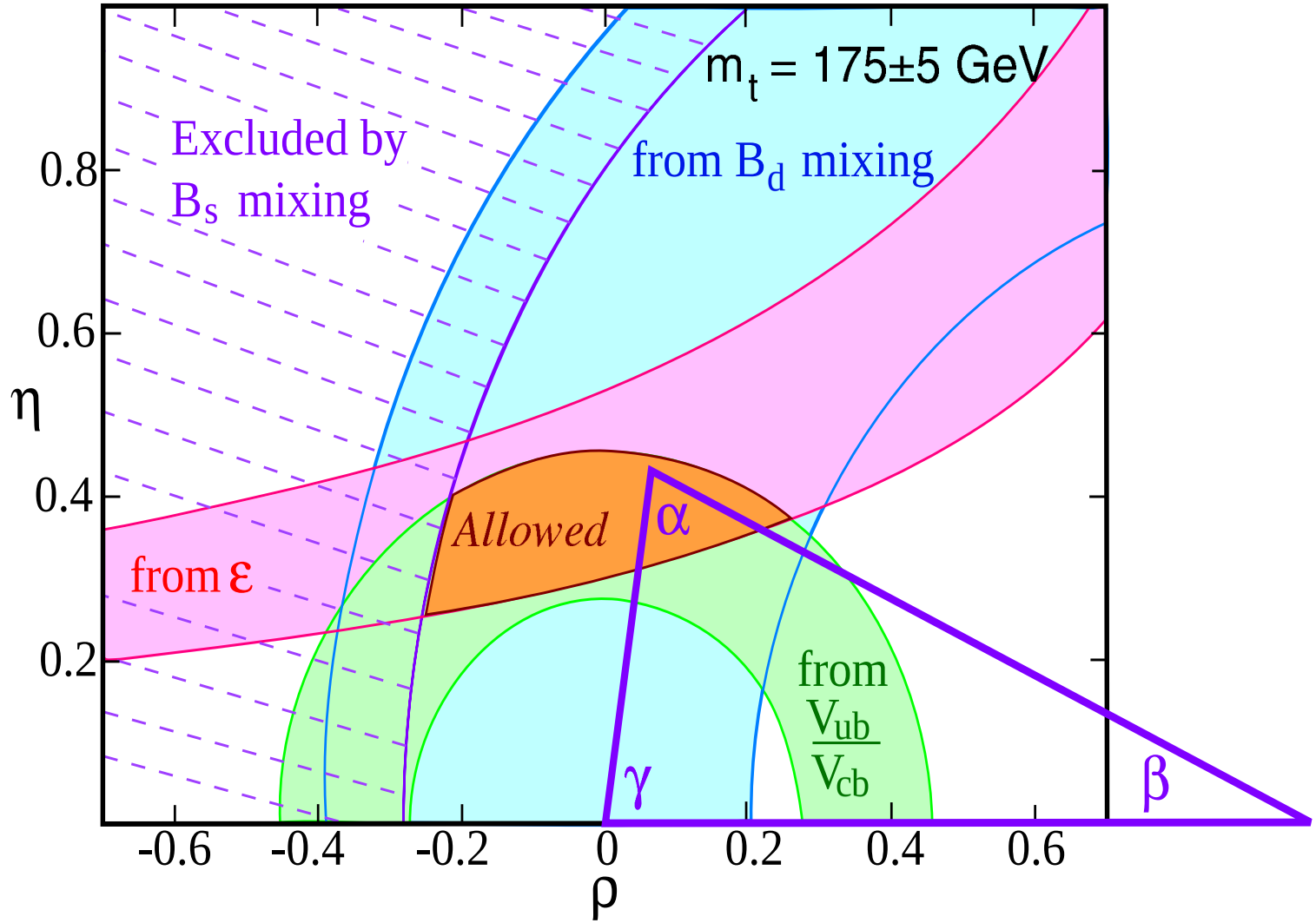
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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



- 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
Allowed
α
from ε
from
V_{ub}
V_{cb}
γ
β
η
ρ
0.8
0.6
0.4
0.2
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

CP Violation in B° Decays

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

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

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

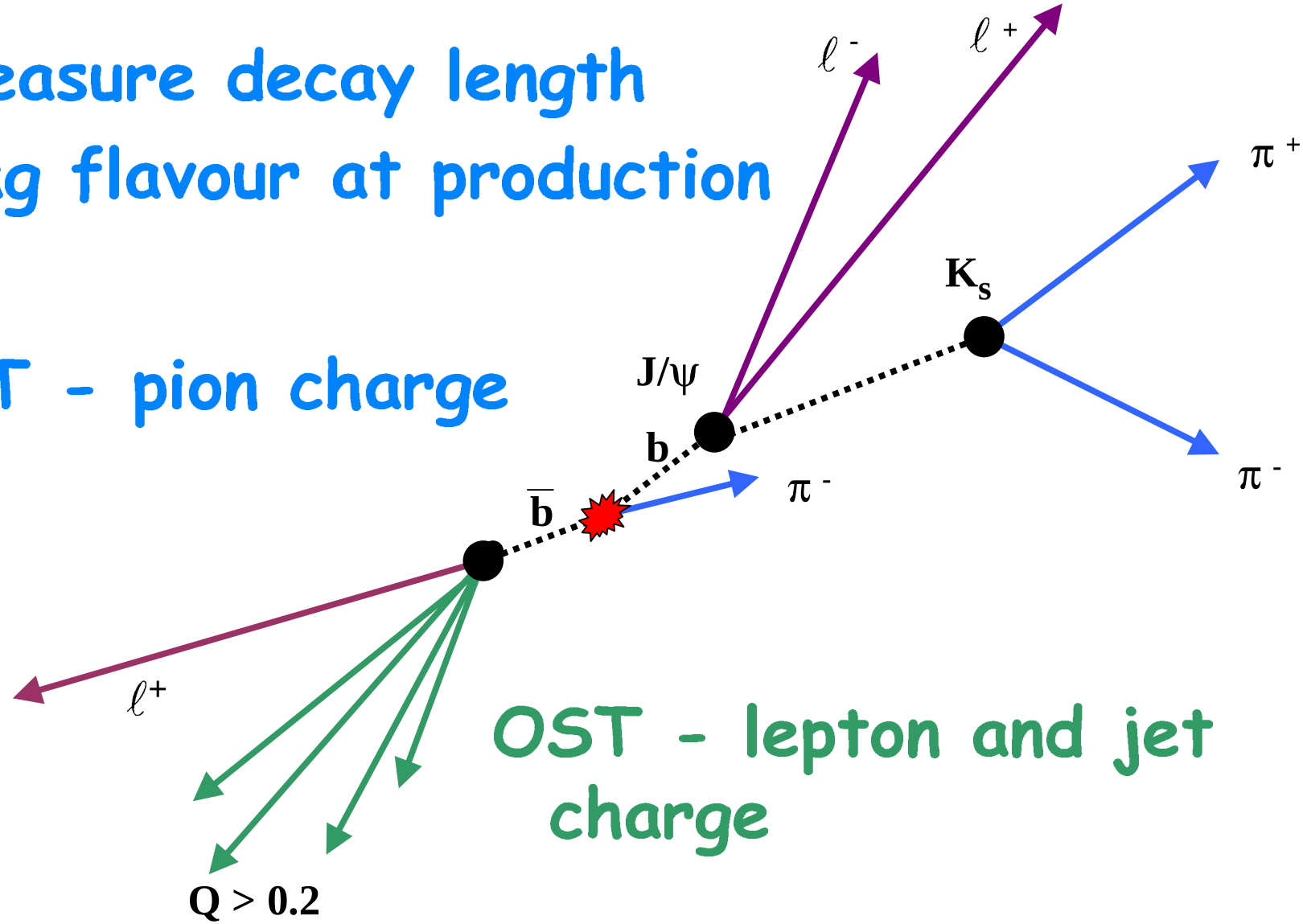
- Reconstruct B°→J/ψ K_s decays to measure sin(2β)

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

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

$B^\circ \rightarrow J/\psi\ K_s$ Reconstruction

- Measure decay length
- Tag flavour at production



SST - pion charge

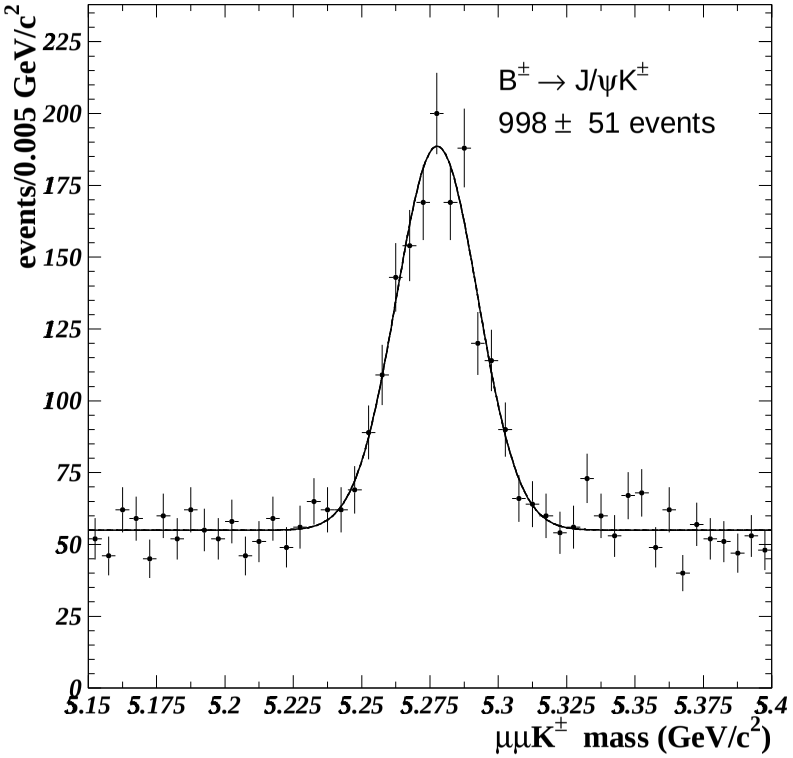
OST - lepton and jet charge

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 $B^{\circ} \rightarrow J/\psi K_s$



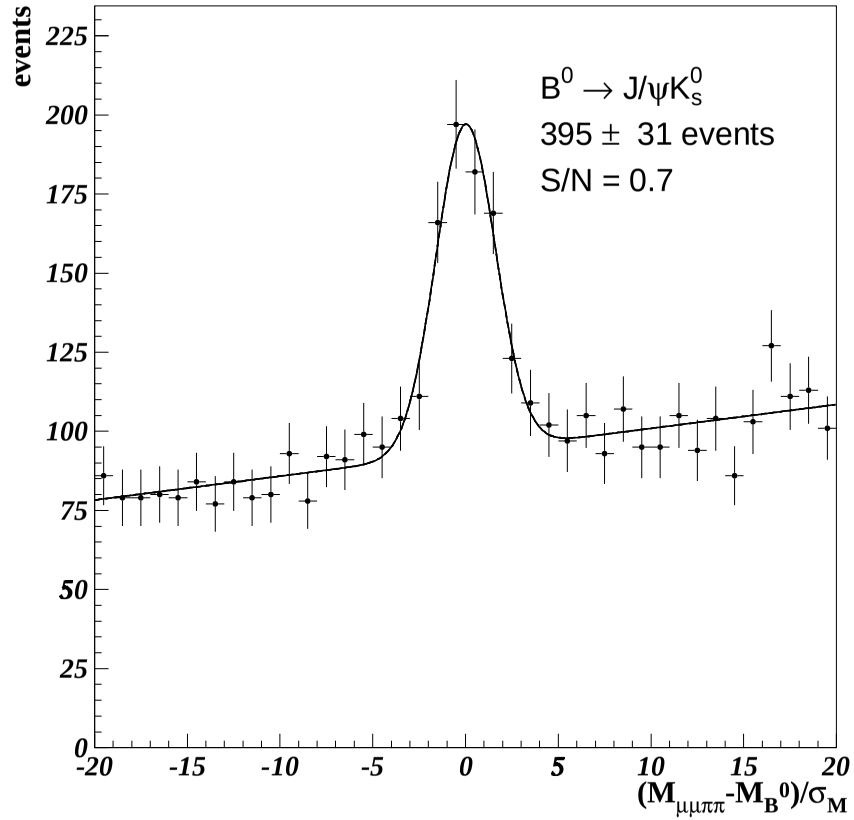
Flavour Tagging

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

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

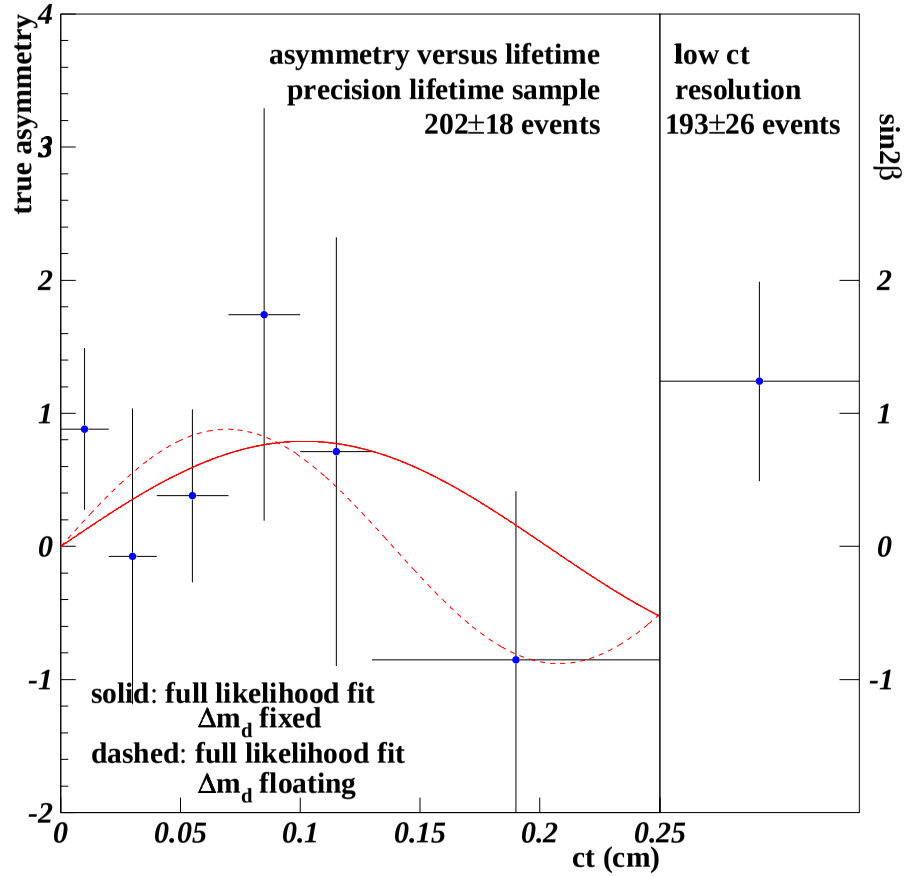
- 4-track fit
- $m(\pi\pi)=m(K_s)$
- $m(\mu\mu)=m(J/\psi)$

- 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)

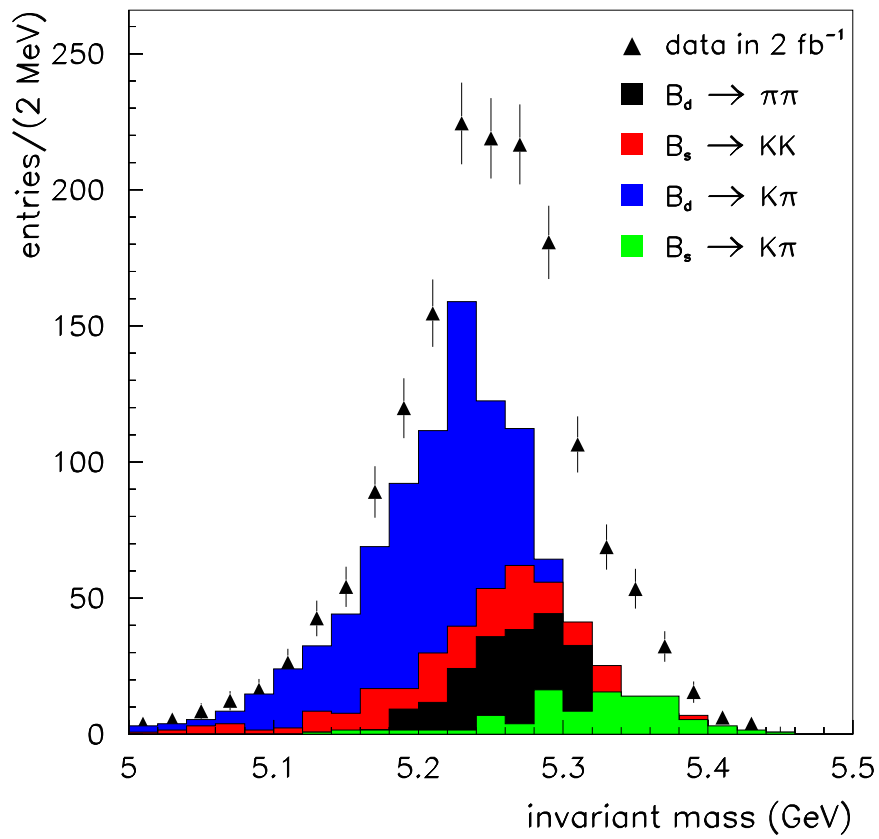
- Reconstruct 30K-40K $B^{\circ} \rightarrow J/\psi\ K_s$ events
- Expect $\sigma(\sin 2\beta) \approx 0.04$ due to
  - improved muon acceptance
  - lower muon trigger thresholds
  - improved flavour tagging (K ID (CDF), lepton ID)
  - Forward tracking (DØ)
  - trigger on $J/\psi \rightarrow e^+e^-$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

α and γ in $B_{(s)}$ Decays

- Sin(2α) extracted from $A_{CP}(B^0 \rightarrow \pi^+ \pi^-)$
- Low branching fraction: $(0.5\text{-}1)\times10^{-5}$
- 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

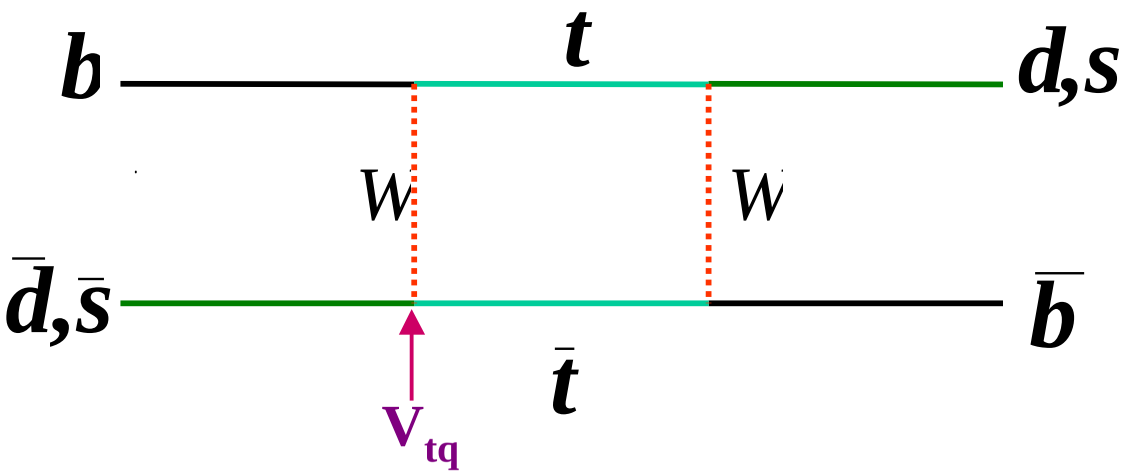
- Reconstruct
  - $B^0 \to \pi^+ \pi^-$
  - $B^0 \to K^+ \pi^-$
  - $B_s^0 \to \pi^+ K^-$
  - $B_s^0 \to K^+ K^-$
- In 1:4:0.5:2 ratios



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 $\sigma(A_{CP}(B^0 \rightarrow \pi^+ \pi^-)) \approx 0.15$
- Predict $\sigma(\gamma) = {}^{+5.4}_{-6.8} \pm 3$ deg

B_s Mixing



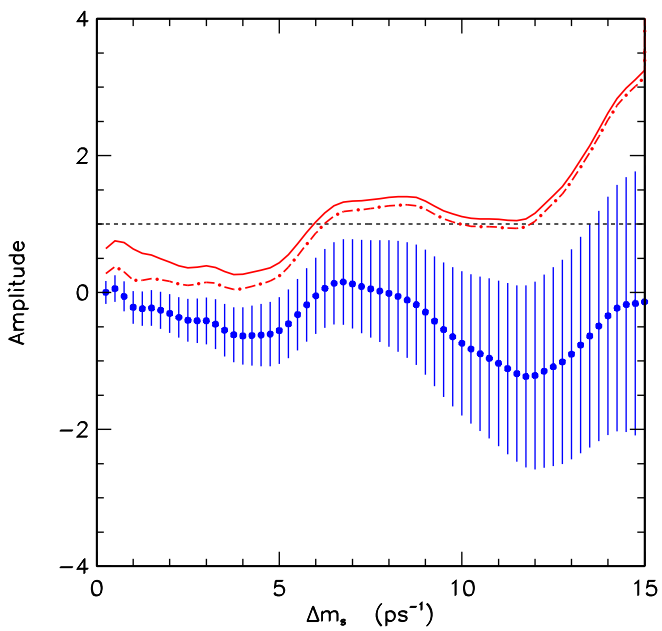
- Weak eigenstates ≠ mass eigenstates
- Mixing due to higher order corrections
- $\Delta m_q = m(B^o_{heavy}) - m(B^o_{light})$
- $P_{mixed}(t) = \frac{1}{2}(1-\cos\Delta m_q t)$, $\Delta m_q \propto |V_{tb} \bullet V_{tq}|^2$
- Mixing parameters $x_q = \Delta m_q/\Gamma_q$ and $\Delta\Gamma_q$

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

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

$$D_s^- \to \phi \pi^-$$

$$\phi \to K^+ K^-$$

- 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

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 2.0×10^{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: $B^0_{(s)} \rightarrow \mu\mu K^{(*)}$, $K^*\gamma$, $\varphi\gamma$