Prospects for DØ Beauty Physics Measurements in Run II

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Fermilab

On behalf of the D0 collaboration

BEAUTY-2000
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The Tevatron is a B factory

- **Large production cross section**
- **Even larger inelastic cross section**

(S/B≈10^{-3}) ⇒ specialized triggers:

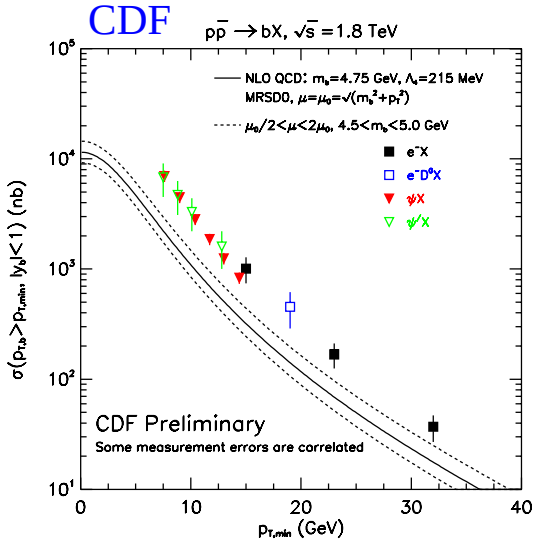
- **Single lepton triggers**
- **Dilepton triggers such as $J/\psi \to \mu^+\mu^-$**
- **Track triggers moved to L1 (RunII)**
- **In Run II, L2 trigger on displaced tracks using SVX will allow CDF/DØ to trigger purely hadronic B decays and study such as $B^0 \to \pi^+\pi^-$, $B_s \to D_s^-\pi^+$ ...**

- **Precise 2nd vertex reconstruction**

$$\sigma(p\bar{p} \to b\bar{b}) \approx 100\,\mu b \quad \text{At 1.8 TeV}$$

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

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



DØ Run II B Physics Goals

QCD tests

- cross sections
- correlations
- charmonium polarization

CP violation and CKM angles

- $\sin(2\beta)$ $\quad B \to J/\psi + K_s$
- $\alpha + \gamma$ $\quad B \to \pi^+\pi^-$, $B_s \to K^+K^-$

Non SM CP violation

- $B_s \to J/\psi + \varphi$

B_S mixing

- $B_s \to D_s + n\pi$
- $B_s \to J/\psi + K^*$

Spectroscopy and lifetimes

- $B^0, B^+, B_s, B_c, \Lambda_b$

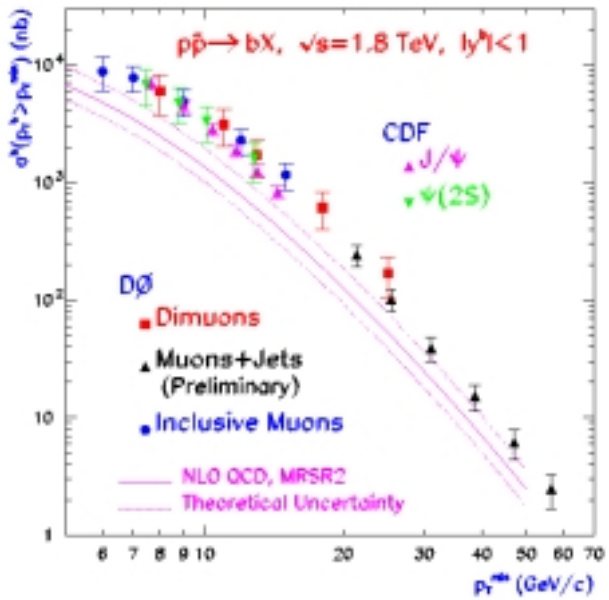
Rare decays

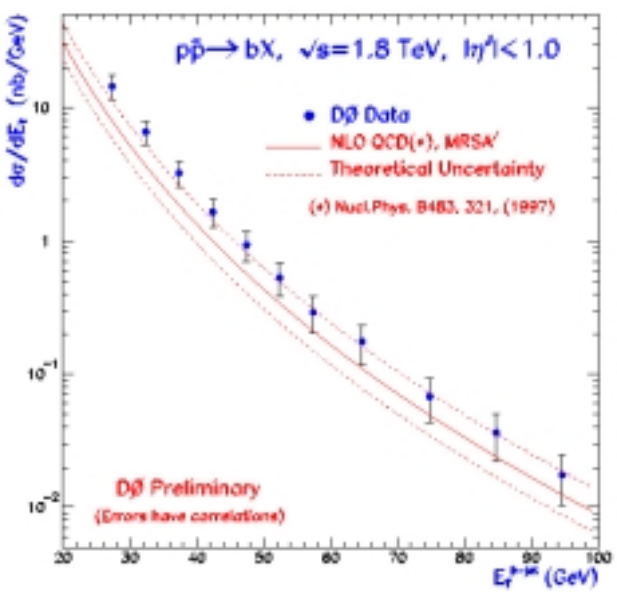
- $B \to l^+l^-$ $\quad B \to l^+l^- X_s$

DØ Upgraded Detector Performance

- Good Momentum resolution:
  - $dp_T/p_T^2 = 0.002$ (Silicon + Fiber tracker)
- High tracking efficiency:
  - at least 95 % $|\eta| < 3$ (Silicon disks)
- Vertex Reconstruction:
  - primary vertex: $\sigma^{vertex} = 15\text{-}30\ \mu m$ (r-ϕ)
  - secondary vertex: $\sigma^{vertex} = 40\ \mu m$ (r-ϕ) , $80\ \mu m$ (r-z)
- Excellent lepton coverage trigger and ID efficiency:
  - muons: $p_T > 1.5$ GeV, $|\eta| < 2$
  - electrons: $p_T > 1$ GeV, $|\eta| < 2.5$
- Impact parameter trigger

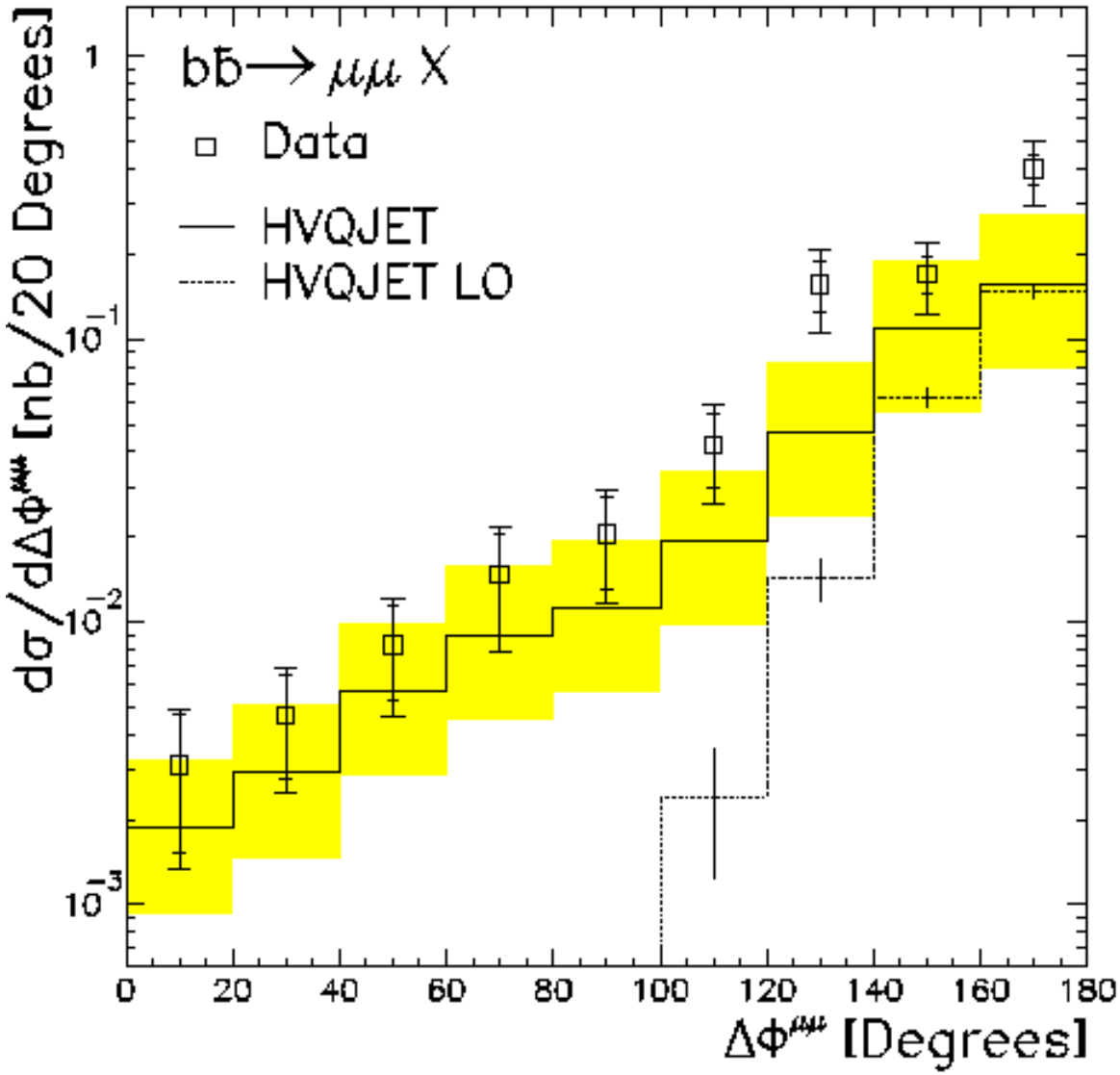
B cross section at D0





- Easy measurement to make.
- There are still disagreements between theory and experiment.
- Muon plus jet trigger.
- Vertex tagging of second jet.
- Restrict angle between jets for better comparison with theory.

B cross section at D0



Sin(2β) via $B \to J/\psi + K_S$

Asymmetry is directly related to sin2β:

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

$$= \sin[2(\phi_M - \phi_D)]\sin \Delta m_d t = \sin(2\beta)\sin(\Delta m_d t)$$

$$\sin 2\beta = \mathrm{Im}\left[-\left(\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}\right)\left(\frac{V_{cs}^* V_{cb}}{V_{cs} V_{cb}^*}\right)\left(\frac{V_{cd}^* V_{cs}}{V_{cd} V_{cs}^*}\right)\right] = \frac{2\eta(1-\rho)}{\eta^2(1-\rho)^2}$$

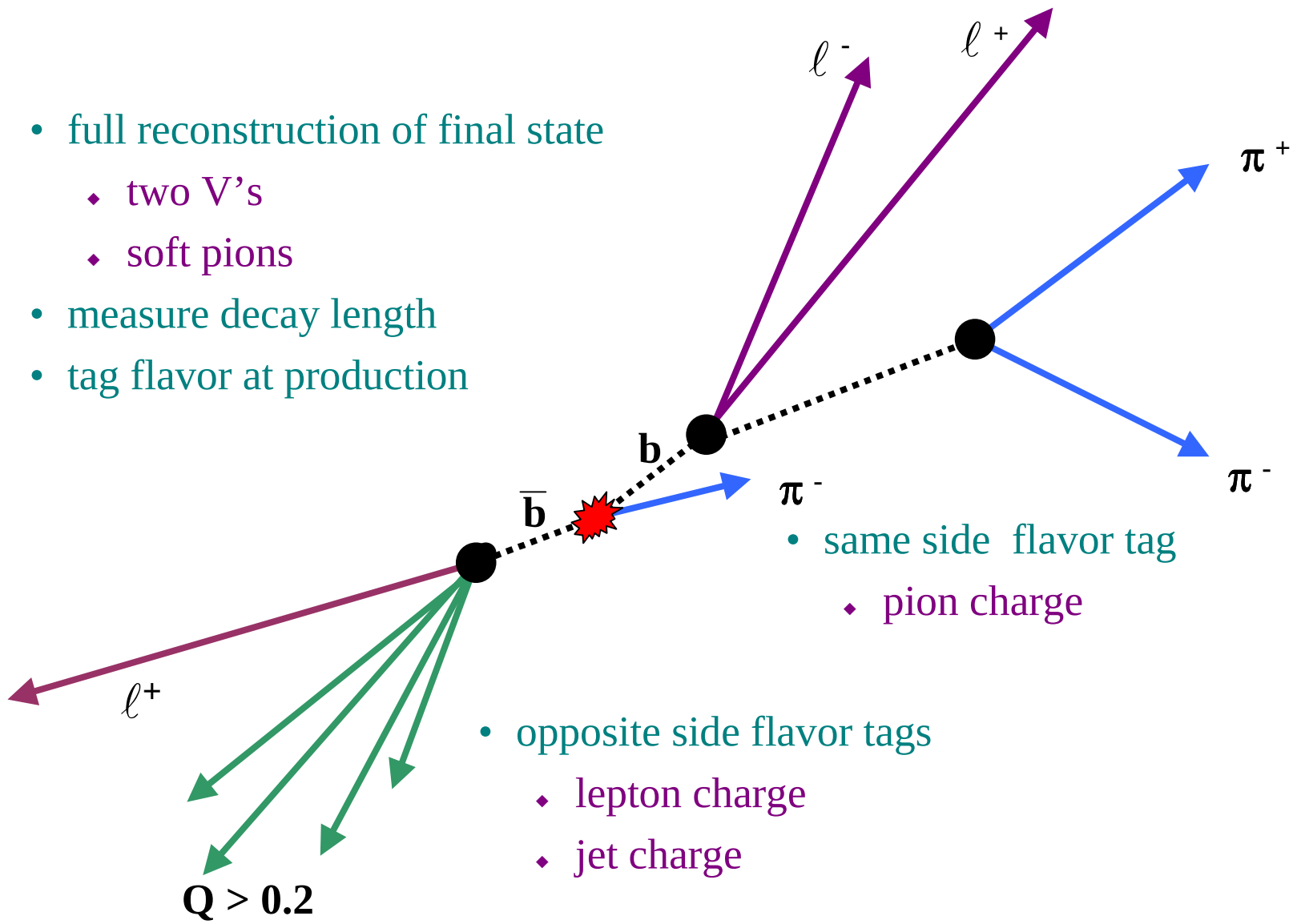
B^0 $\overline{B}^0$ Mixing

Ratio of $\frac{\overline{A}(f)}{A(f)}$

K^0-$\overline{K}^0$ mixing

Sin(2β) via $B \rightarrow J/\psi + K_S$

- full reconstruction of final state
  - two V's
  - soft pions
- measure decay length
- tag flavor at production



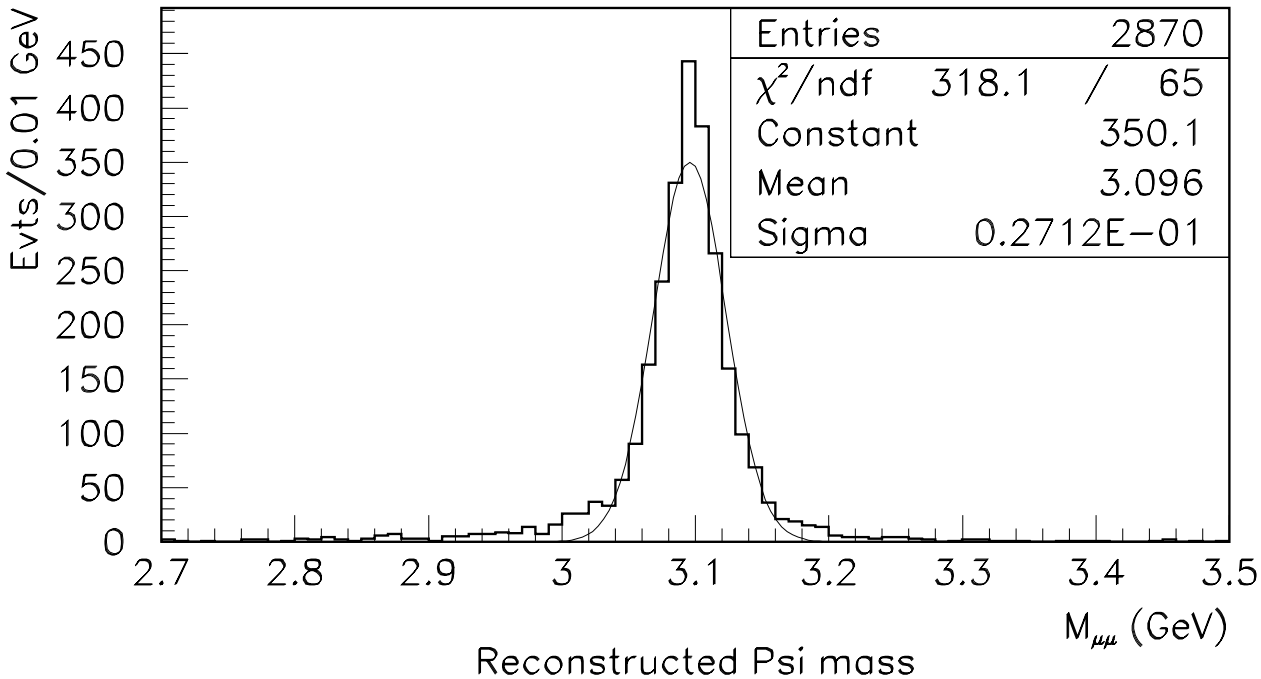
- same side flavor tag
  - pion charge

- opposite side flavor tags
  - lepton charge
  - jet charge

$B \rightarrow J/\psi K_S$ Reconstruction

$J/\psi \rightarrow \mu^+\mu^-$

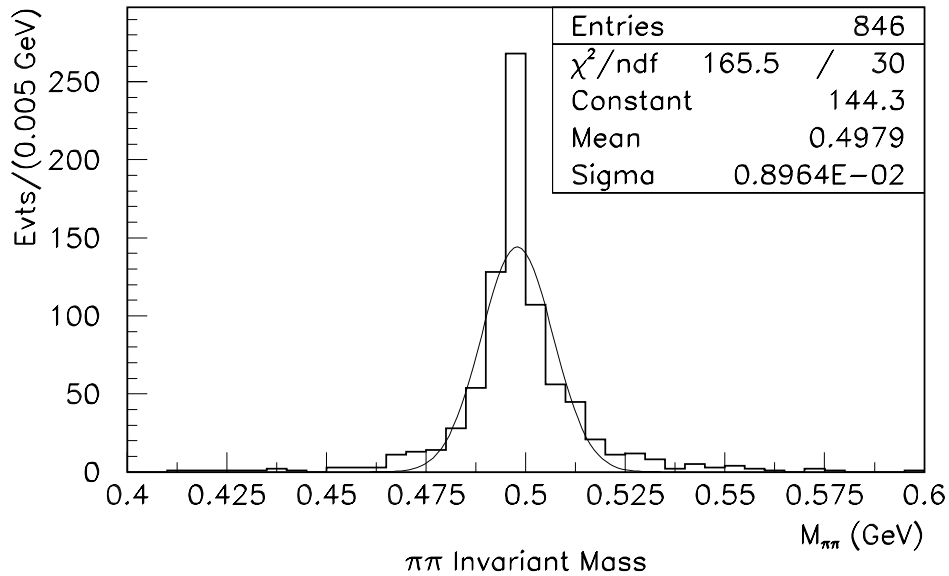
- two muon tracks
  - $p_T > 1.5$ GeV/c
  - $|\eta| < 2$



$B \rightarrow J/\psi K_S$ Reconstruction

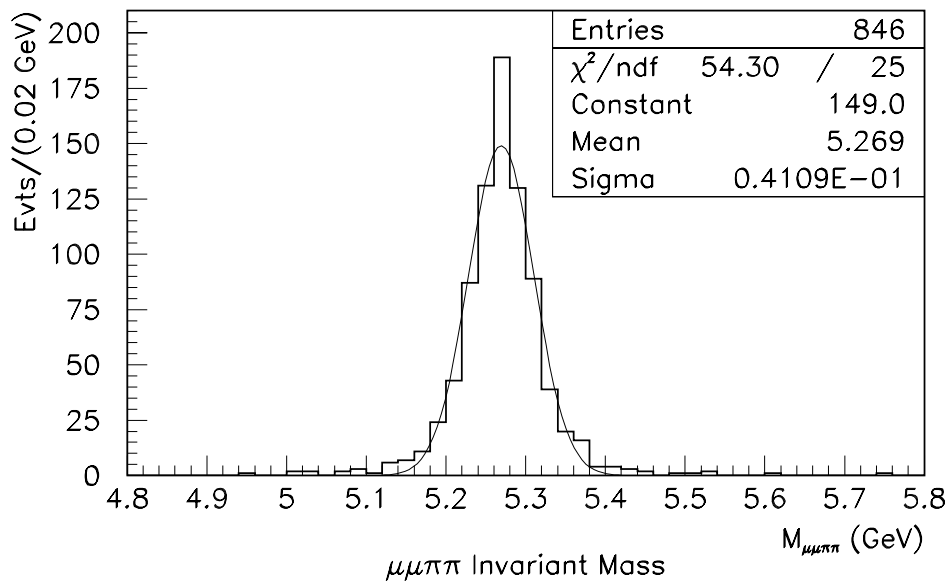
$K_S \rightarrow \pi^+\pi^-$

- $p_T(\pi) > 0.45$ GeV/c
- $p_T(K_S) > 0.75$ GeV/c
- $|\eta_\pi| < 1.8$
- $L_{xy}/\sigma > 5$



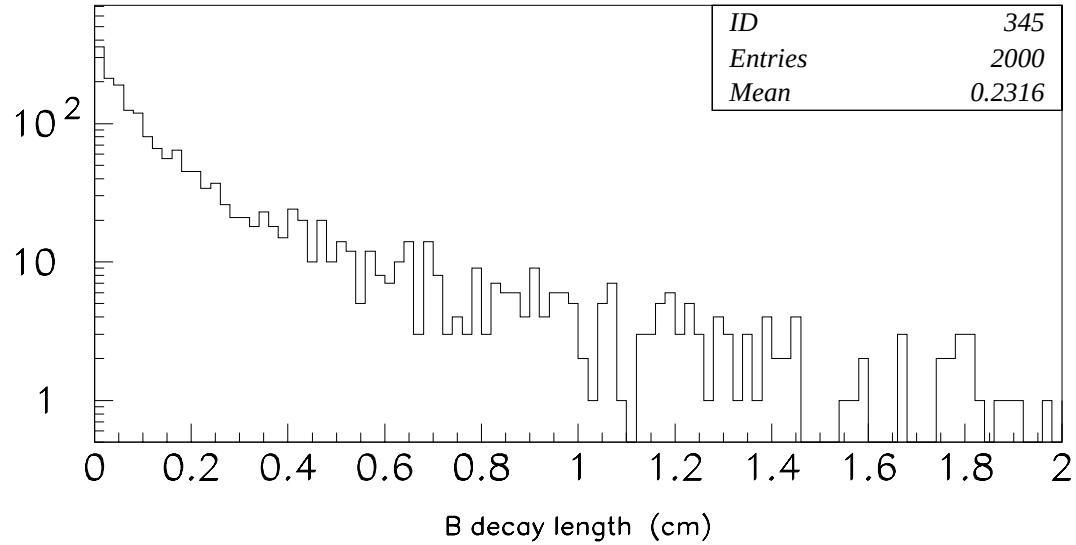
Combined $\mu^+\mu^-\pi^+\pi^-$ *invariant mass*

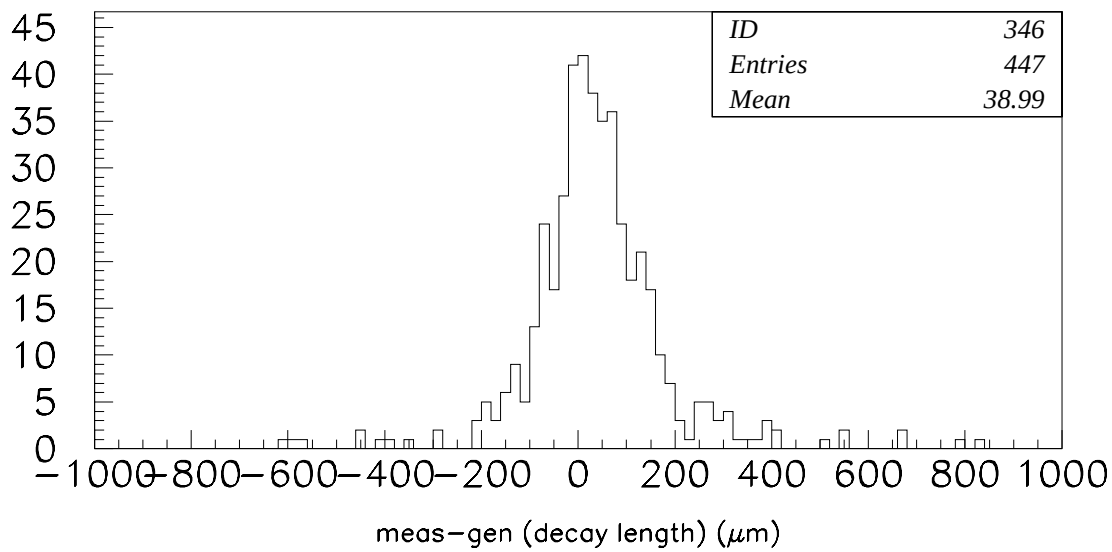
(before fit)



$B \rightarrow J/\psi K_s$ decay length reconstruction

- Two secondary two-track vertices
- Average B decay length: 2.3 mm
- Measured decay length resolution: 100 μm



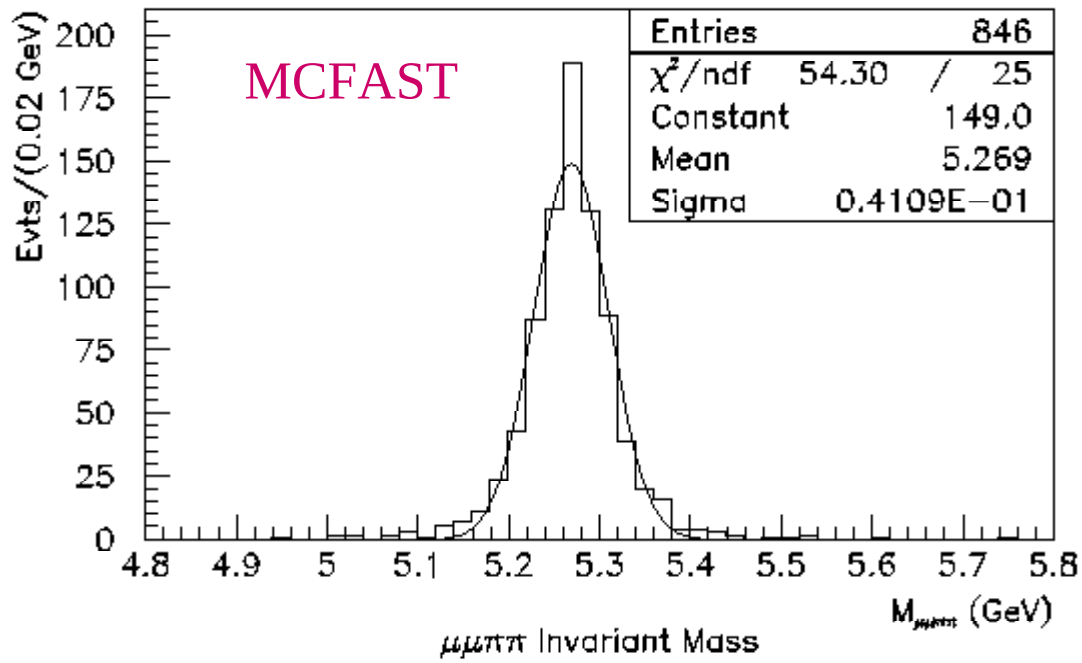


$B \rightarrow J/\psi\ K_S$ Reconstruction

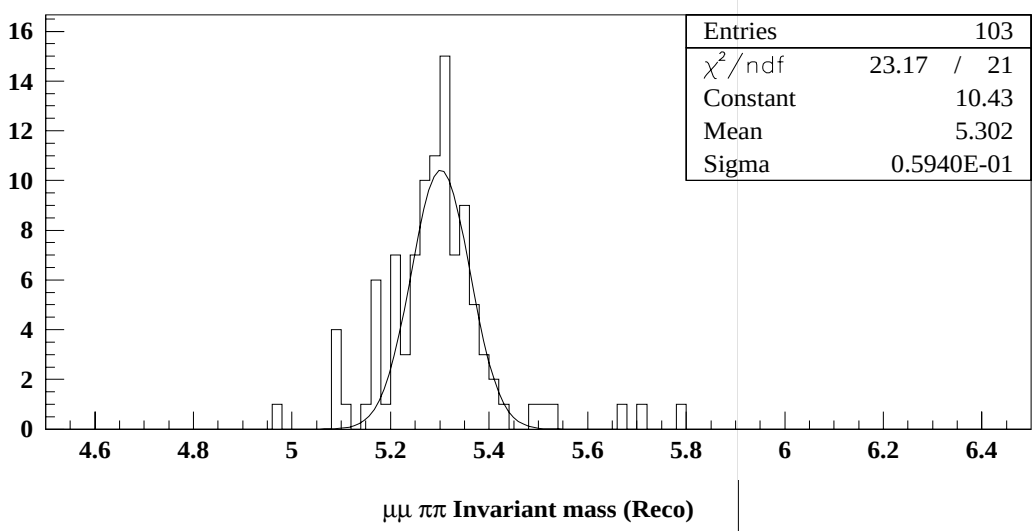
Combined $\mu^+\mu^-\pi^+\pi^-$ *invariant mass*

(before fit)

MCFAST

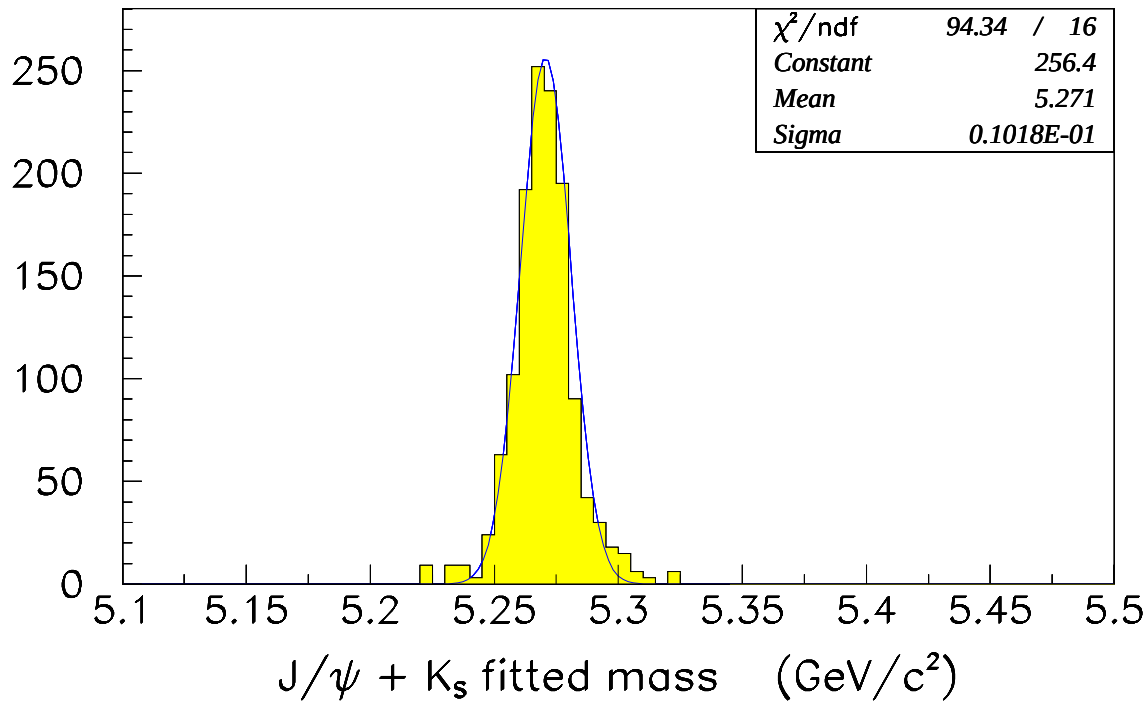


RECO



$B \rightarrow J/\psi K_S$ Reconstruction

- $J/\psi \rightarrow \mu^+\mu^-$ require two central tracks with $p_T > 1.5$ GeV/c
- $K_S \rightarrow \pi^+\pi^-$ use long lifetime to reject background: $L_{xy}/\sigma > 5$
- Perform 4-track fit assuming $B \rightarrow J/\psi + K_S$
  - constrain $\pi\pi$ and $\mu\mu$ to mass of K_S and J/ψ respectively
  - force K_S to point to B vertex and B to point to primary



Flavor Tagging

Opposite side tags:

- identify the flavor of the other B in the event
  - soft lepton tags $b \rightarrow l^- + X$
  - jet charge tags $Q_{jet} < 0$ for b

Efficiency (ε) and dilution factor (D)

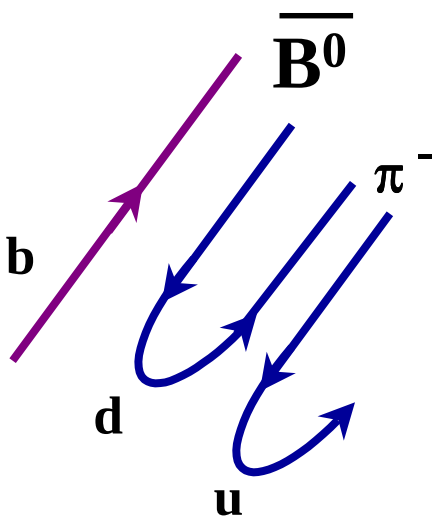
$D = 2P - 1$

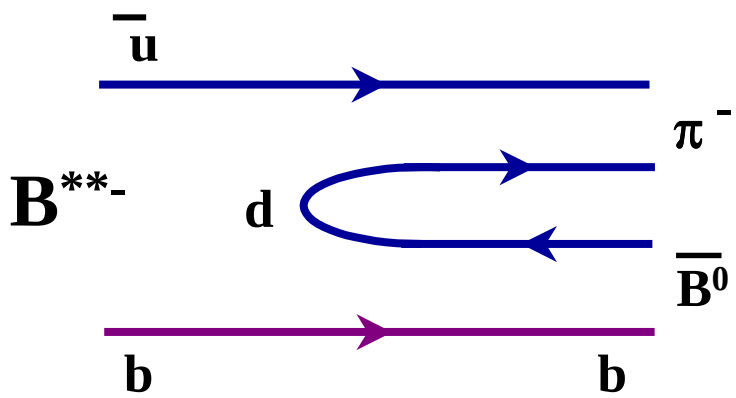
P is the correct tag probability

εD^2 is the tag's effectiveness

Same side tags:

- correlation of flavor and charge of closest particle produced in fragmentation or decay





Flavor 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

How many events will we get ?

$$\sigma_{b\bar{b}} = 3.3 \times 48\,\mu b = 158\,\mu b$$

$$f(b \to B_d) = 0.42$$

Acceptance $: \mathrm{P}_T(B) > \mathbf{4\ GeV/}\ \boldsymbol{c}\ , |\, y(B) \,| < 3.0 = 31\%$

$$\sigma_B = \boldsymbol{\sigma}_{b\bar{b}} \cdot f \cdot \boldsymbol{Acc} = 21\mu b$$

$$BR = BR(B \to J/\psi + K_s, J/\psi \to \mu^+\mu^-, K_s \to \pi^+\pi^-)$$

$$= (5\times10^{-4})(0.06)(0.68) = (2\times10^{-5})$$

$$\boldsymbol{\varepsilon}_{trigger} = 0.27$$

$$\boldsymbol{\varepsilon}_{reco} = 0.09$$

$$N = L \cdot 2 \cdot \sigma_B \cdot BR \cdot \boldsymbol{\varepsilon}_{\mathrm{trigger}} \cdot \boldsymbol{\varepsilon}_{reco} = 40\mathbf{K}$$

assuming luminosity ~ 2 fb^{-1}

Sin(2β) Expectations for 2 fb^{-1}

For a ***time dependent*** analysis:

$$\sigma(\sin 2\beta) \approx e^{x_d^2 \Gamma^2 \sigma_t^2} \sqrt{\frac{1+4x_d^2}{2x_d}} \frac{1}{\sqrt{\varepsilon D^2 N}} \sqrt{1+\frac{B}{S}}$$

DØ:

- **(S/B ~ 0.75)**
- **εD^2 ~ 9.8 %**
- **Time resolution**

  σ_t ~ 100 fs

mode	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
trigger eff. (%)	**27**	**20**
reco'd events	**40,000**	**30,000**
$\sigma(\sin 2\beta)$	**0.04**	**0.05**
	0.03	

- assuming luminosity ~ 2 fb^{-1}
- DØ and CDF have similar precisions

New Director - New Run II Plan

- No long shutdowns
- Gradual luminosity improvements as we run
- Run until LHC results tell us to stop
- 3 (or more) fb^{-1} per year at peak

L (fb^{-1})	Number of $B \rightarrow J/\psi K_S$	$\sigma(\sin 2\beta)$
2	34 K	0.04
5	85 K	0.03
10	170 K	0.02
20	340 K	0.01

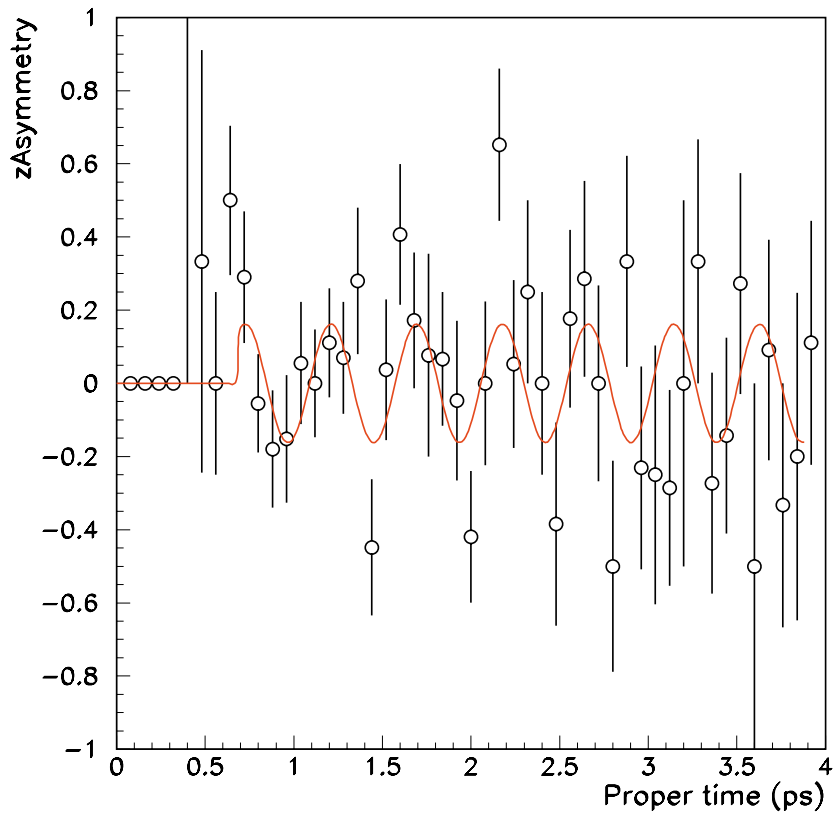
B_S Mixing at DØ

Use fully reconstructed events

- $B_S \rightarrow D_S \pi^+$ 100 - 300 events
- $B_S \rightarrow D_S \pi^+\pi^-\pi^+$ 300 - 900 events
  - $D_S \rightarrow \phi\pi \rightarrow KK\pi$
  - final flavor tagged by charge of the D_S
  - hadronic modes require lepton from opposite b for trigger - sign gives initial flavor
- $B_S \rightarrow J/\psi + K^*$ 300 - 1000 events
  - easier trigger
  - initial flavor tag $\varepsilon D^2 \sim 7$ %
  - final flavor tagged by charge of K in $K^* \rightarrow K^+\pi^-$ - $\varepsilon D^2 \sim 90$ %

Amplitude fit of B_S oscillation frequency

Generated x_s = 20, smeared



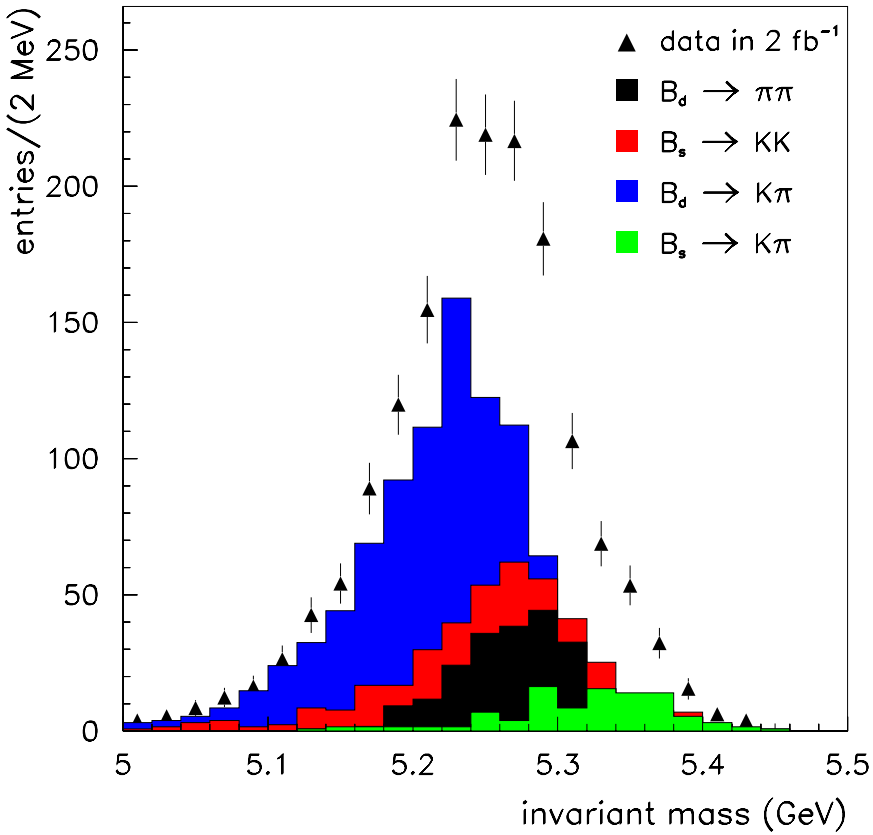
- DØ can measure x_S values up to 20 - 30 in 2 fb^{-1}
- further study is needed to determine our maximum reach

$B \rightarrow \pi^+ \pi^-$ at DØ

- We must trigger on a lepton from the other B in the event
  - require: 1 lepton pT > 3 GeV and two other tracks with pT > 1.5 GeV
  - total detection efficiency is between 0.25 - 0.5 %

expected tagged events:

$B_d \rightarrow \pi^+ \pi^-$	300 - 600
$B_s \rightarrow K^+ K^-$	650 - 1300
$B_d \rightarrow K^+ \pi^-$	1300 - 2600
$B_s \rightarrow K^- \pi^+$	150 - 300



Rare decays: $B_d \rightarrow \mu^+ \mu^- K^*(892)$

- FCNC process $\mathbf{B^0} \rightarrow \mu^+ \mu^- \mathbf{K^*}$ is forbidden at tree level
- SM branching fraction: BR($\mathbf{B^0} \rightarrow \mu^+ \mu^- \mathbf{K^*}$) = (1-1.5) x 10^{-6}
- Current CDF limit: BR($\mathbf{B^0} \rightarrow \mu^+ \mu^- \mathbf{K^*}$) < 4 x 10^{-6} (90% CL)
- Non SM physics will change the branching ratio and decay asymmetry

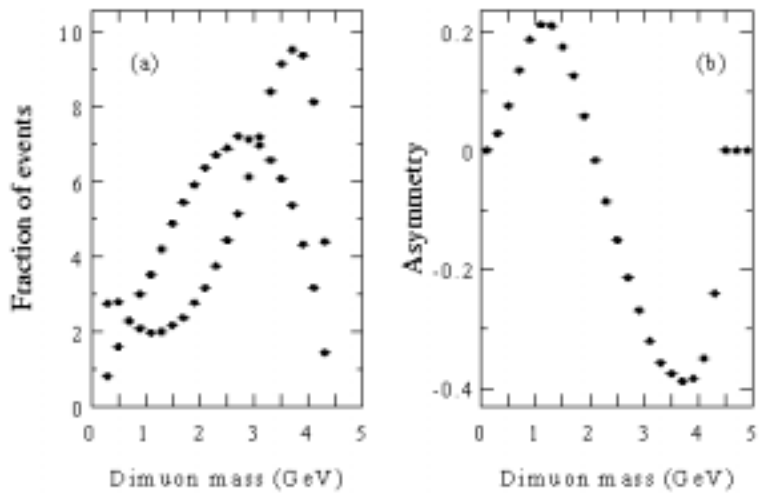
Briefly the method used in the search is:

- Trigger on muons
- Find separated vertex with $\mu^+ \mu^- K^*$
- Cut out resonances
- Will get about 700 events for 2 fb^{-1}

$B_d \rightarrow \mu^+ \mu^- K^*$ (Selection details)

- Events generated with ISAJET and weighted to get the desired asymmetry
- Cross section normalized to $\sigma(B^0) = 3\ \mu b$ for $p_T(B) > 6$ Gev/c, $|y(B)|<1$
- $BR(B_d \rightarrow \mu^+ \mu^- K^*) = 2 \times 10^{-6}$
- Trigger: MUO(2,2,A,M) $\oplus$ MUO(1,4,A,T)
- Track reconstruction efficiency of 95% per track (81% per event)
- Two muons with $p_T(\mu) > 1.5$ GeV/c and $|\eta^\mu| < 1.6$
- $p_T(\pi, K \text{ from } K^*) > 0.5$ GeV/c
- Dimuon invariant mass outside $J/\psi(3.05\text{-}3.15)$ or $\psi(2s)(3.62\text{-}3.76)$
- Dimuon pair transverse momentum $p_T(\mu\mu) > 5.0$ GeV/c
- Isolation cut $I = p_T(B)/p_T(\sqrt{\Delta\eta^2 + \Delta\varphi^2} \leq 1) > 0.6$ (this cut is 90% efficient)
- (Vtx separation)/γ > 100 μm
- $p_T(K^*) > 2$ GeV/c
- Impact parameter significance > 2 for at least 3 tracks

$B_d \rightarrow \mu^+ \mu^- K^*$ (asymmetry)



Generated distributions: a) mass, b) asymmetry

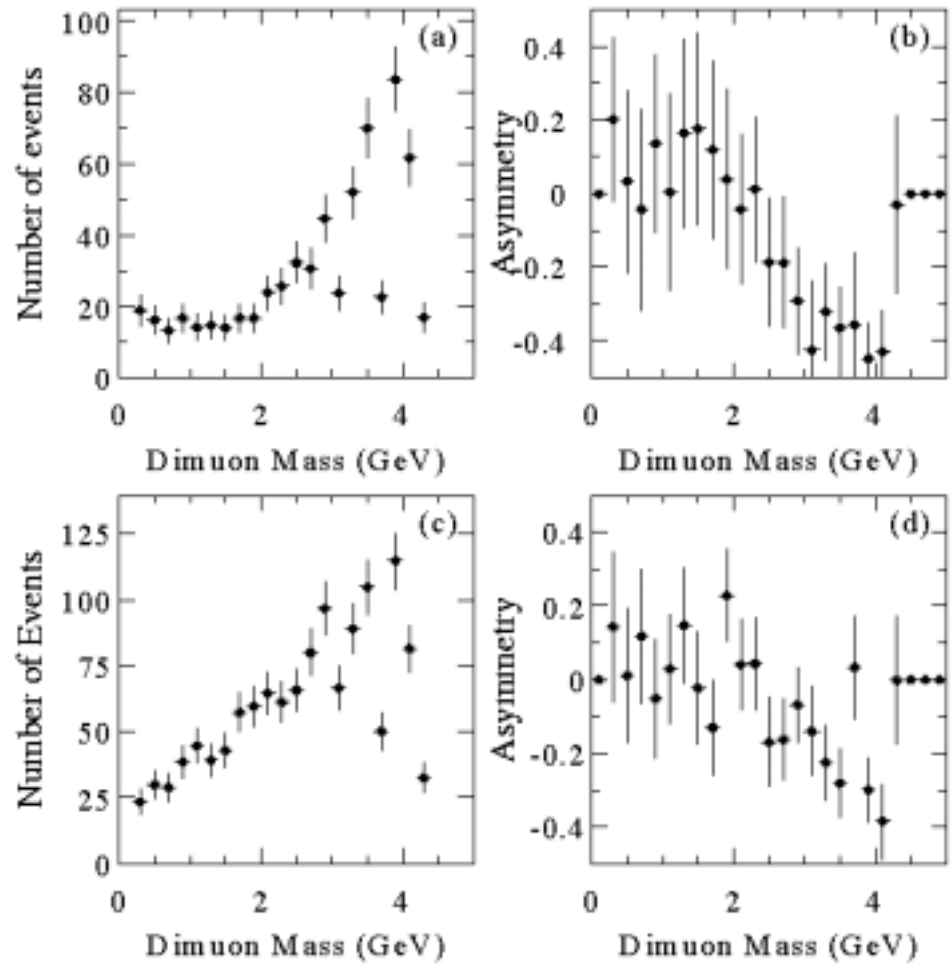
$$A = \frac{N(p^{\mu+} > p^{\mu-}) - N(p^{\mu+} < p^{\mu-})}{N(p^{\mu+} > p^{\mu-}) + N(p^{\mu+} < p^{\mu-})}$$

Asymmetry results (from plot d)

0.11 ± 0.11 $m_{\mu\mu} < 2$ Gev

-0.33 ± 0.06 $m_{\mu\mu} > 2$ Gev

($B_d \rightarrow e^+ e^- K^*$ will increase statistics 50%)



Reconstructed distributions: a,b) no background, c,d) 1:1 S/B

$B^+ \rightarrow \mu^+ \mu^- K^+$ also possible

Rare decays: $b \rightarrow \mu^+ \mu^- s$

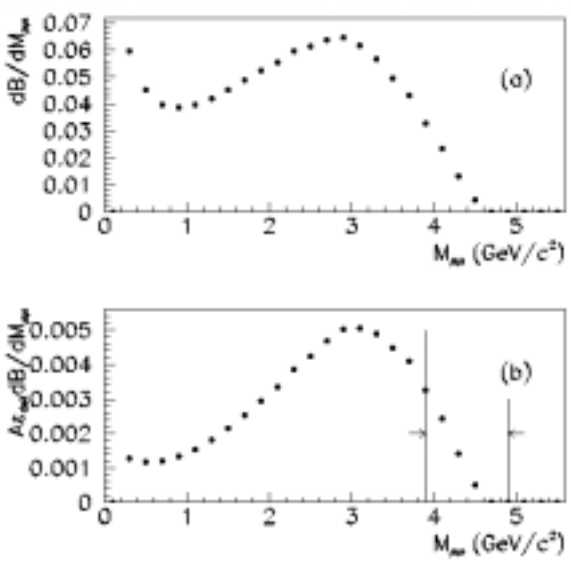
- Theoretically the most interesting but experimentally very difficult.
- Very large backgrounds.
- Access to only a small $M_{\mu\mu}$ window
- End of $M_{\mu\mu}$ spectrum can not be accurately predicted

Briefly the method used in the search is:

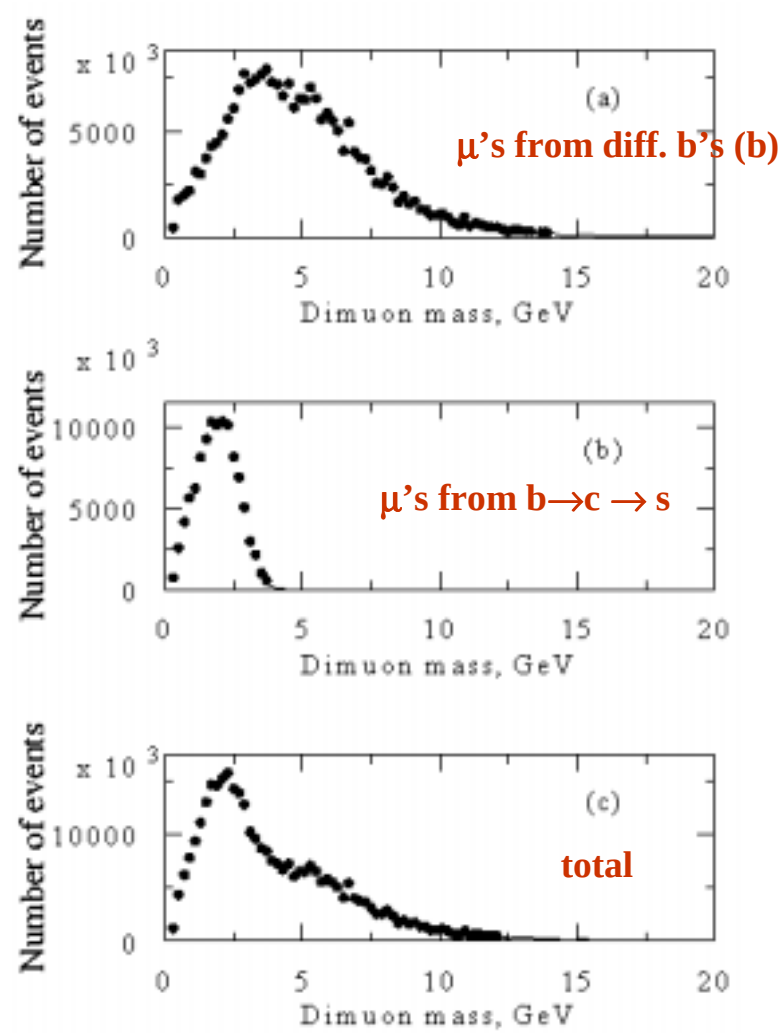
- Events generation, trigger and cuts similar to $B_d \rightarrow \mu^+ \mu^- K^*$
- Look inside a small $M_{\mu\mu}$ window
- Will get about 1000 events for 2 fb^{-1} (BR(SM)=6 x 10^{-6})
- Expect 10,000 to 100,000 background events

Rare decays: $b \rightarrow \mu^+ \mu^- s$

- $m_{\mu\mu}$ spectrum from $b \rightarrow c \rightarrow s$ doesn't extend beyond 4 GeV/c^2
- $3.9 < m_{\mu\mu} < 4.4$ GeV/c^2 selects 7% of the spectrum



$M_{\mu\mu}$ distribution: a) calculated (Baer & Pott, PRD55,1684(97)), b) accepted and smeared.

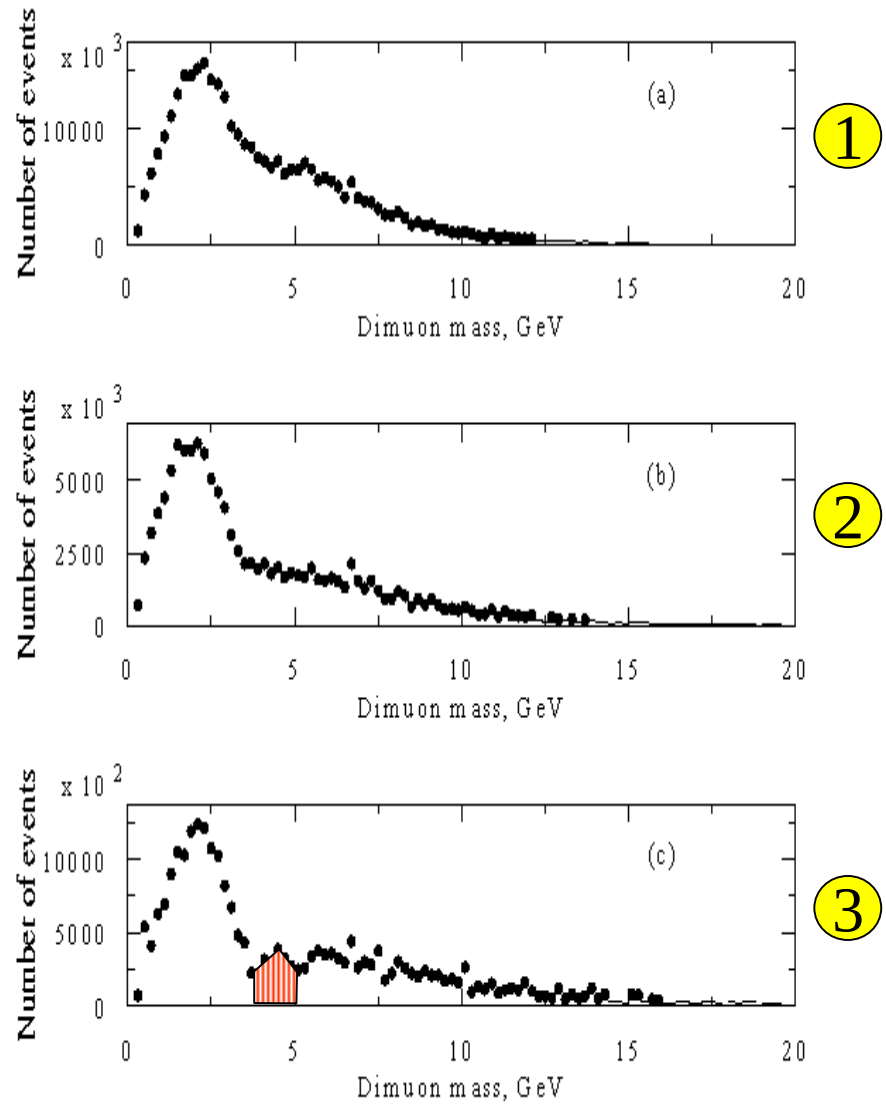


Expected number of triggered dimuon events for 2 fb^{-1}: a) from b quarks, b) sequential b decays, c) total. ($p_T(\mu\mu) > 2$ GeV/c)

Rare decays: $b \rightarrow \mu^+ \mu^- s$

	1	2	3
$P_T(\mu\mu)$ GeV/c $P_T(\mu)$ GeV/c	>2.0 >1.5	> 5.0 > 1.5	> 5.0 > 3.0
Trigg. Eff. (%)	32	55	60
Recorded	2300	1750	1000
Vtx sep > 400 μ m	1200	1050	650
Bkgd (no add. Cuts)	1.9 E6	4 E5	1 E5

- Small S/B ratio (1:100)
- Additional cuts could improve S/B 3-10 times
- Access to small $m_{\mu\mu}$ window
- It will be very difficult



Exp. $m_{\mu\mu}$ dist. due to non-res. QQ production

Rare decays: $B_s \rightarrow \mu^+ \mu^-$

- BR($B_s \rightarrow \mu^+ \mu^-$) = 4 x 10^{-9} , and 2 fb^{-1}
- B_s cone isolation cut: no tracks inside a cone of 0.7 around the muon
- I = $p_T(B)/p_T(\sqrt{\Delta\eta^2 + \Delta\varphi^2} \leq 1)$ > 0.6 (this cut is 90% efficient)

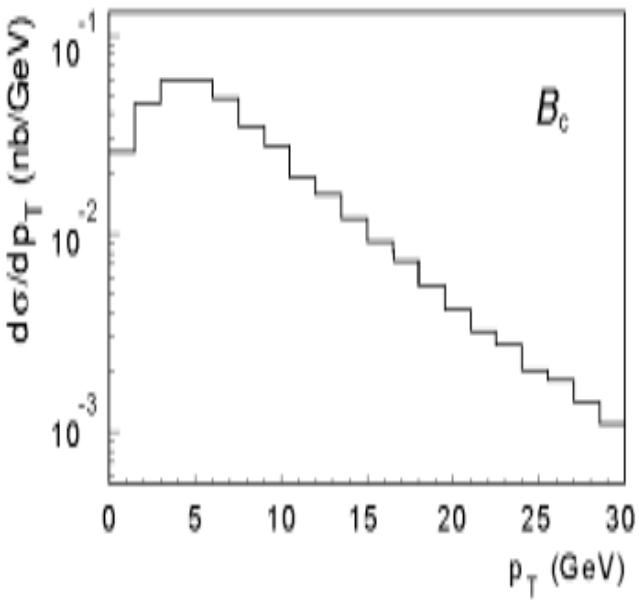
$P_T(\mu\mu)$ GeV/c **$P_T(\mu)$ GeV/c**	**>2.0** **>1.5**	**> 5.0** **> 1.5**	**> 5.0** **> 3.0**
Trigg. Eff. (%)	**32**	**55**	**60**
Recorded	**15**	**6**	**3**
Secondary vtx separation of 100 μm	**6**	**3**	**1.5**
Impact parameter significance > 2			

→ Backgrounds not understood yet.

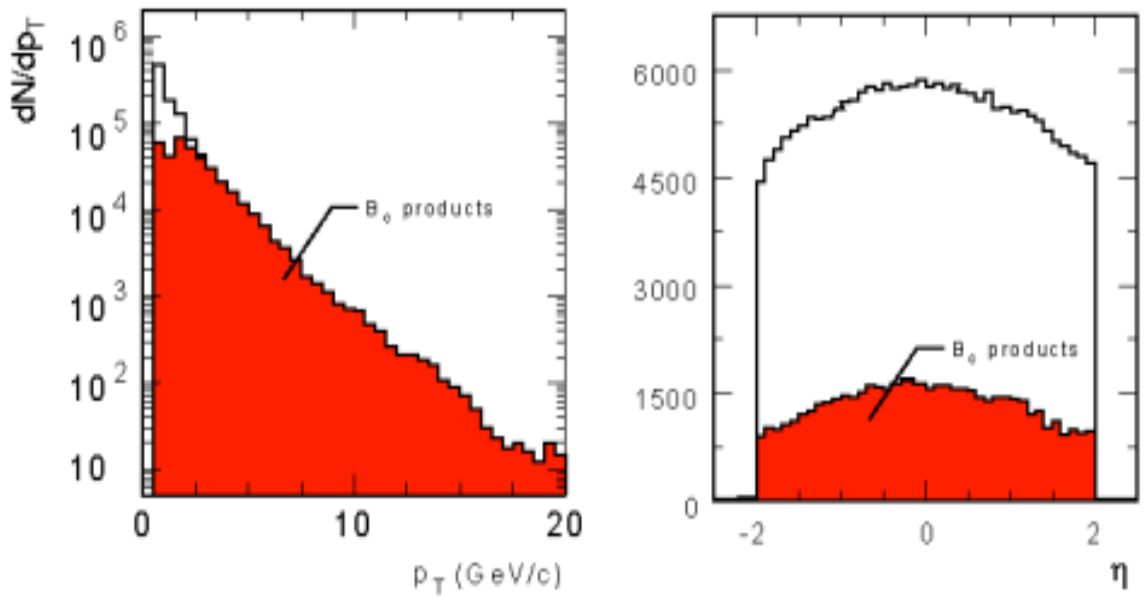
→ Looks almost hopeless for SM branching ratio.

B_c production at D0

- Use PYTHIA, MCFAST and D0 upgrade Detector resolutions.
- Reweight events to match theory prediction of $d\sigma/dp_T$.
- Increase fraction of $b \rightarrow B_c$ to 0.5 and decrease B_b, B^+, B_s, Λ_b accordingly.
- Use CLEO QQ to decay $B_c \rightarrow J/\psi l \upsilon$ and $B_c \rightarrow J/\psi \pi$.
- Set mass to 6.4 Gev/c^2 and lifetime to 0.5 ps.



B_c differential cross section



Kinematic distributions of B_c decay products for semileptonic decay

$B_c \rightarrow J/\psi\, l\, \upsilon$ trigger efficiencies

Criteria	Efficiency	DØ Designation
Single Muon		
$p_T^\mu > 4$ GeV $\lvert\eta^\mu\rvert < 1.5$ "Medium"	0.23	MTM5, MUO(1,4,A,M)
$p_T^\mu > 4$ GeV $\lvert\eta^\mu\rvert < 1.5$ "Tight"	0.08	MTM6, MUO(1,4,A,T)
Di-Muon		
Both $p_T^\mu > 2$ GeV $\lvert\eta^\mu\rvert < 1.5$ "Medium"	0.16	MTM10, MUO(2,2,A,M)
Both $p_T^\mu > 4$ GeV $\lvert\eta^\mu\rvert < 2.0$ "Medium"	0.15	MTM12, MUO(2,4,A,M)
"Or" of above	0.28	

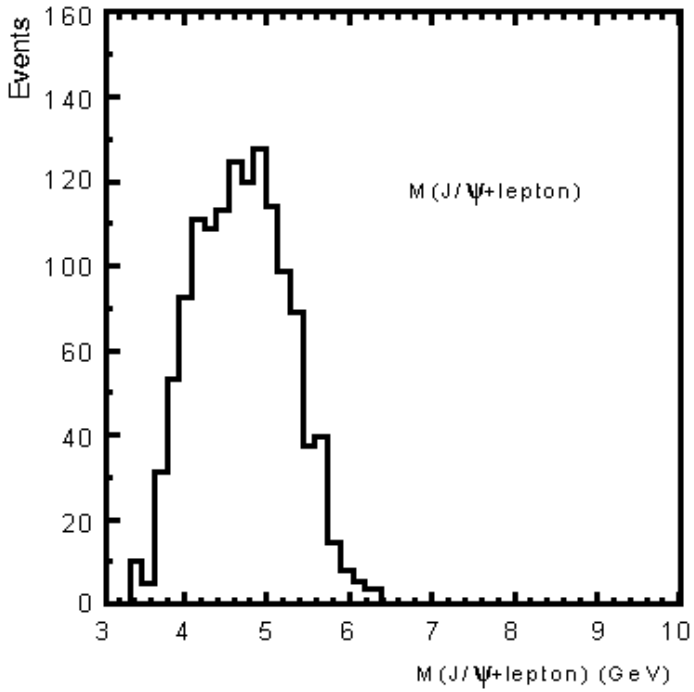
D0 level 1 muon trigger efficiencies,
$p_T(B_c) > 3$ GeV , $|\eta(B_c)| < 3$.

$B_c \rightarrow J/\psi\, l\, \upsilon$ conclusions

Plus

- $M_{\mu\mu}$ within 2σ of the J/ψ mass.
- $P_T(J/\psi\, l) > 8$ GeV/c.
- Decay length greater than 50 μm.
- 2 pb^{-1} and CDF's

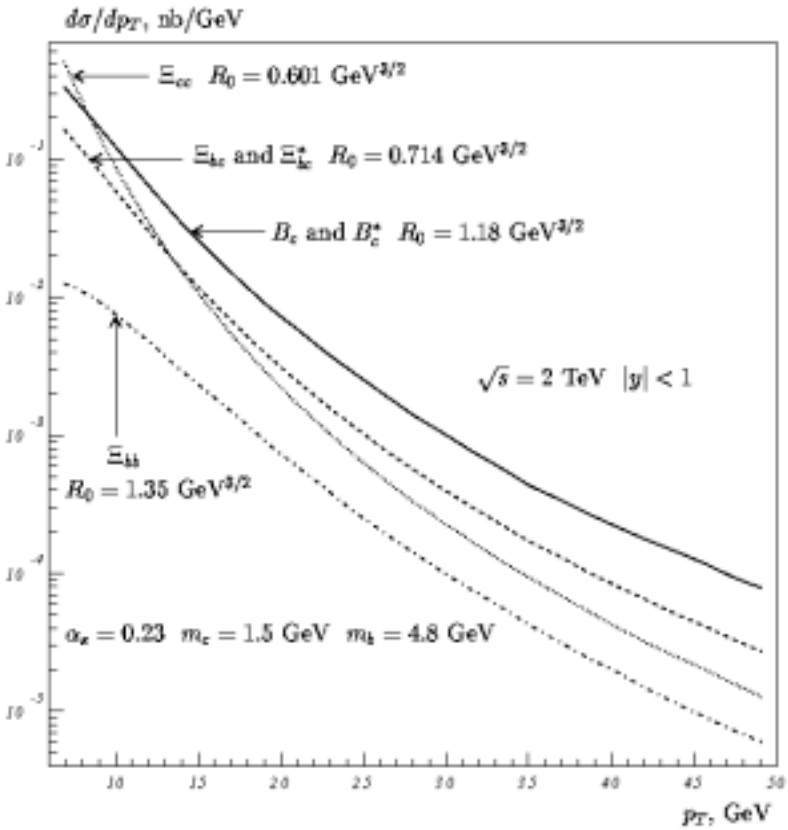
$$\frac{\sigma(B_c^+) \bullet Br(B_c^+ \rightarrow J/\psi l \nu)}{\sigma(B^+) \bullet Br(B^+ \rightarrow J/\psi K^+)} = 0.13$$



Leads to an estimate of approximately 600 events

This sample is large enough to make improvements in the lifetime and mass measurements that would significantly increase the understanding of the B_c system

Doubly-heavy baryons at D0



Differential cross sections for the B_c meson and doubly-heavy baryons

State	Lifetime [ps]	Mass [GeV]	Interesting Exclusive Decay Modes	Estimated Br
$\Xi^+_{bc}(bcu)$	0.33 ± 0.08	3.650	$\Lambda^+_c\ J/\psi \to \mu^+\mu^-$ $\hookrightarrow pK^-\pi^+$ $D^{(*)0}\ p\bar{K}^0 \to \pi^+\pi^-$ $\hookrightarrow K^-\pi^+$ $D^{(*)+}\ pK^{(*)-}$ $\hookrightarrow K^-\pi^+\pi^+$	$< 2 \times 10^{-7}$ 2.1×10^{-5} 4×10^{-5}
$\Xi^0_{bc}(bcd)$	0.28 ± 0.07	3.650	$\Xi^0_c(csd)\ J/\psi \to \mu^+\mu^-$ $\hookrightarrow \Lambda^0\bar{K}^0$ $D^{(*)0}\ pK^{(*)-}$ $\hookrightarrow K^-\pi^+$ $D^{(*)+}\ p\pi^-K^{(*)-}$ $\hookrightarrow K^-\pi^+\pi^+$	$< 2 \times 10^{-7}$ 6.2×10^{-5} 4×10^{-5}
$\Xi^+_{bcc}(bcc)$	–	3.650		
$\Xi^0_{bb}(bbu)$	0.79	10.250	$\Xi^+_{bc}\ \pi^-$ $\hookrightarrow$ as above $\Lambda^0_b(bdu)\ J/\psi \to \mu^+\mu^-$ $\hookrightarrow \Lambda^+_c\pi^-$	3×10^{-6} 2.4×10^{-7} if $\Lambda^0_b \to \Lambda_c \ell\nu X$
$\Xi^-_{bb}(bbd)$	0.8	10.250	$\Xi^0_{bc}\ \pi^-$ $\hookrightarrow$ as above $\Xi^-_b(bsd)\ J/\psi \to \mu^+\mu^-$ $\hookrightarrow \Xi^0_c\pi^-$	6×10^{-5}

Properties of interesting doubly-heavy baryons containing a b quark

Λ_b Lifetime

- Naïve spectator model predicts $\tau(\Lambda_b^0)/\tau(B^0) = 1$
- Current data suggests $\tau(\Lambda_b^0)/\tau(B^0) = 0.79 \pm 0.05$

- Non-spectator processes (final state quark interference and W boson exchange) too small in SM (10%) to account for deviation

- Previous measurements used semileptonic modes to achieve statistical precision
- Disadvantage is that neutrino is lost, carrying with it momentum information

Λ_b Lifetime Measurement

- 20 times the statistics during Run II

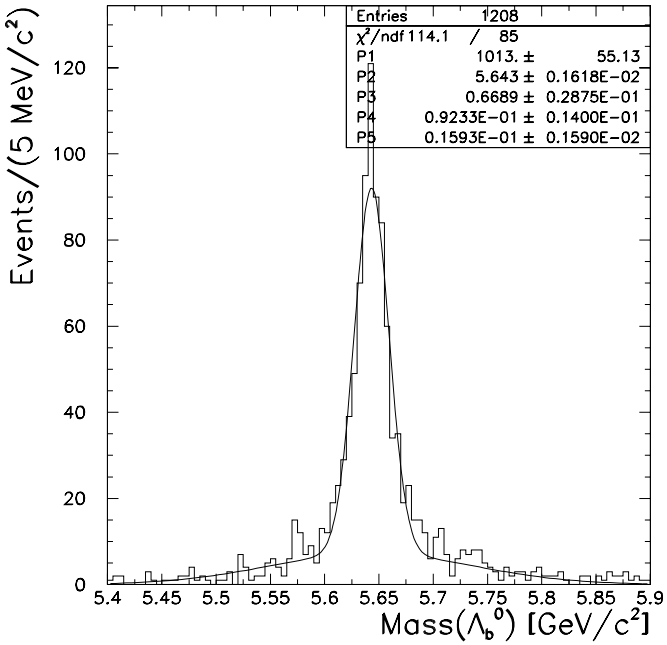
- Fully hadronic mode $\Lambda_b \rightarrow J/\psi\ \Lambda^0$
  - $BR(\Lambda_b \rightarrow J/\psi\ \Lambda^0) = 5 \times 10^{-4}$
  - Trigger on $J/\psi \rightarrow \ell^+ \ell^-$ dilepton
  - Reconstruct $\Lambda^0 \rightarrow p\pi$ in J/ψ events
  - expect 15 000 events

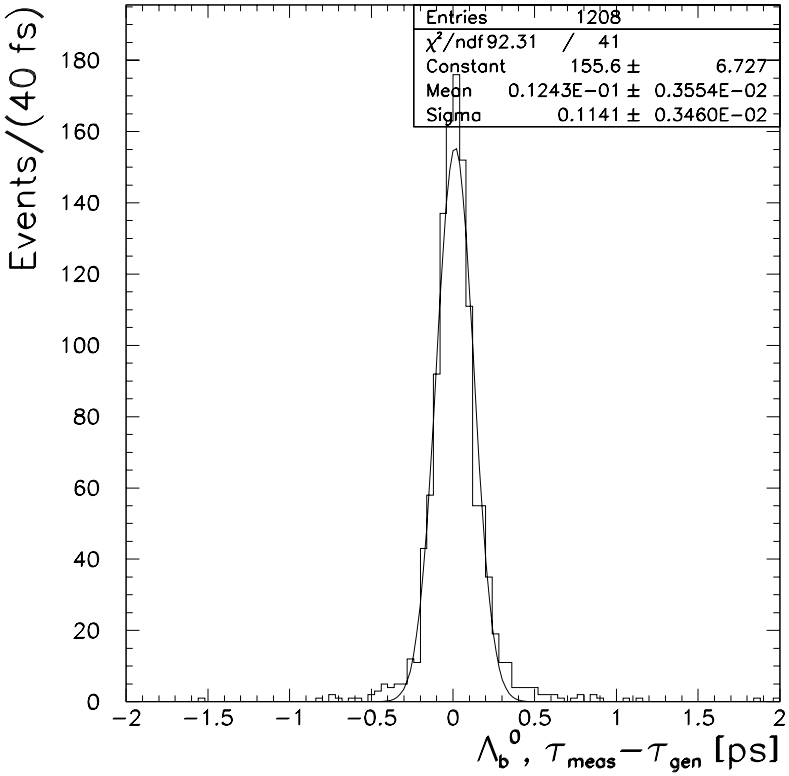
- No need to rely on Monte Carlo for momentum correction

Λ_b Lifetime Projections

$\Lambda_b \rightarrow J/\psi\Lambda$

- p(Λ) points to $\mu^+\mu^-$ vertex
- mass/vertex constraints





Λ_b mass resolution
16 MeV/c^2

Λ_b lifetime resolution
0.11 ps

Conclusions

DØ is poised to make significant beauty physics measurements in Run II. We will begin to take data in the spring of 2001 and in 2 years (2 fb^{-1}) we will:

- continue QCD studies
- measure $\sin 2\beta$ to an accuracy of 0.04
- measure (or put a limit on) Bs mixing up to $x_s \sim 30$
- put limits on other CKM angles α , γ
- measure Λ_b lifetime in exclusive decays
- rare decays, heavy baryons, ...

The Cabibbo-Kobayashi-Maskawa Matrix

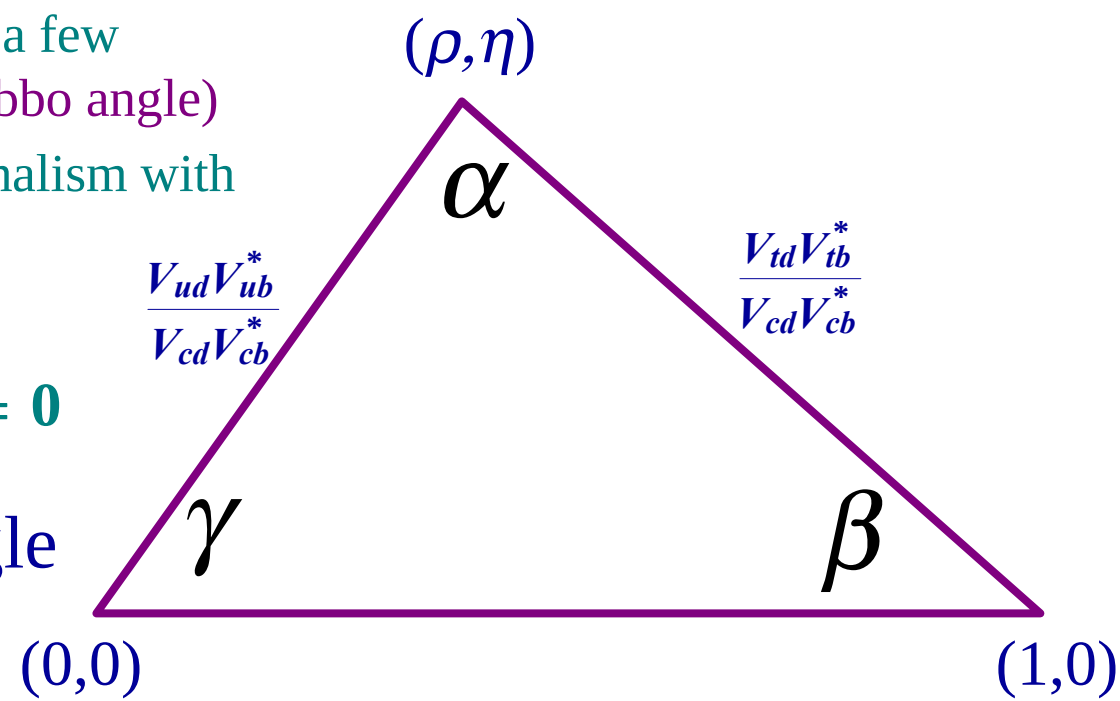
The CKM matrix rotates quark mass eigenstates into their weak counterparts

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

- A and λ have been measured to a few percent (λ is the sin of the Cabibbo angle)
- CP violation is put into the formalism with the complex phase η
- unitarity condition:

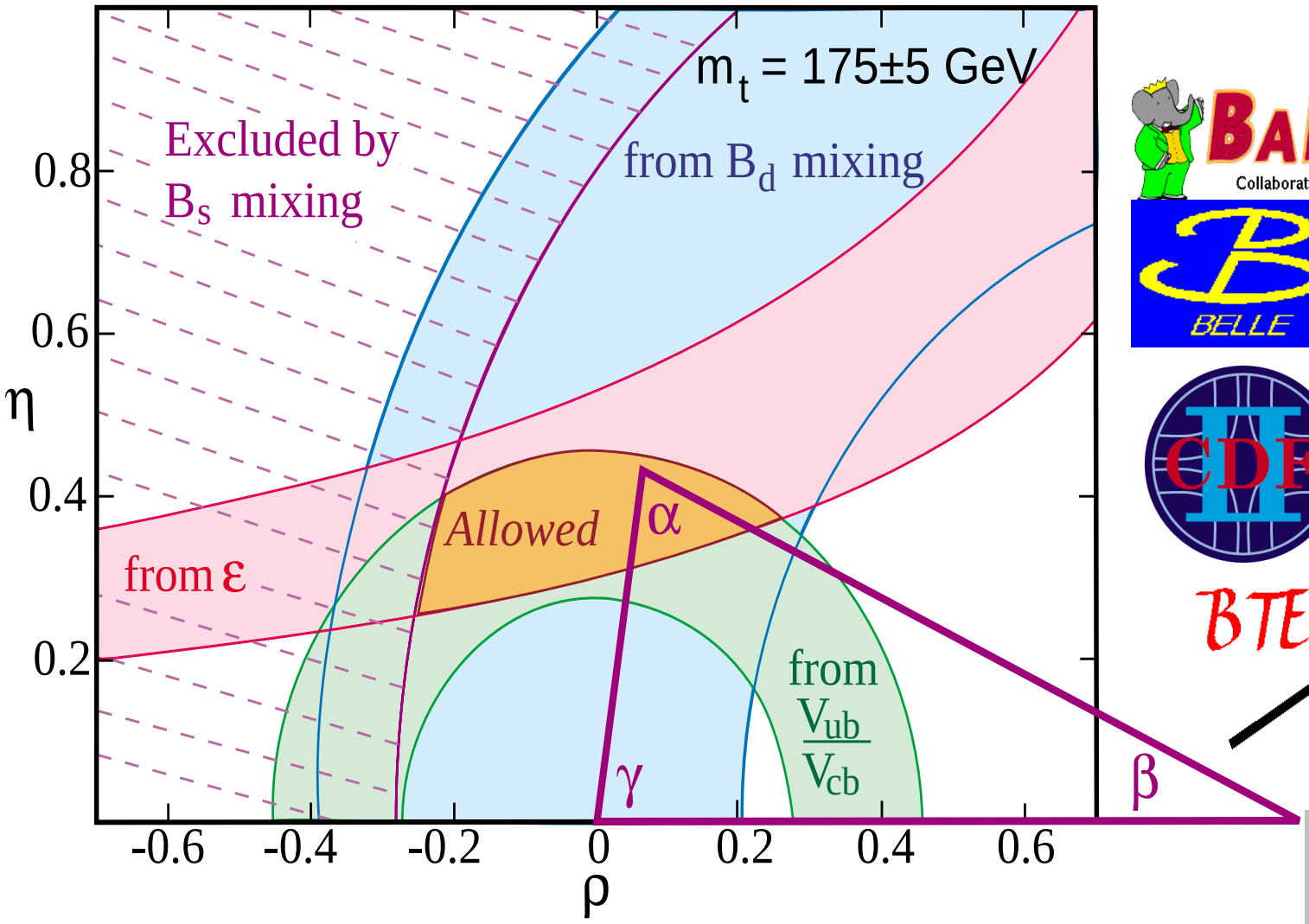
$$V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0$$

gives the unitarity triangle



B Physics in the 21st Century

Experiments will confront the Standard Model interpretation of CP violation



KTEV Kaons at the Tevatron

BaBar Collaboration Ho

BELLE

CLEO III

CDF II

DØ

BTEV

Co

LHCb

ATLAS

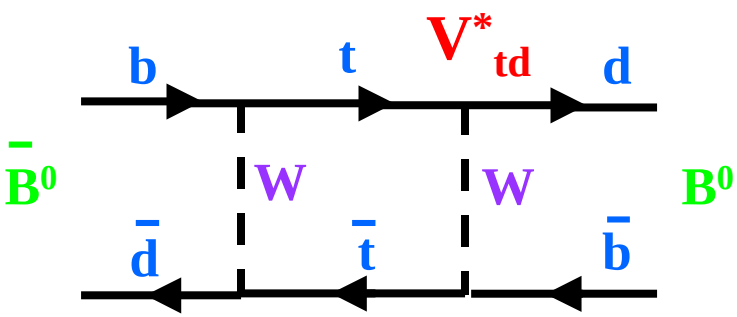
CMS

CP Violation in *B* Decays

Flavor oscillations in the neutral *B* system

$$B^0 = \bar{b}d \qquad |B_L\rangle = p|B^0\rangle + q|\bar{B}^0\rangle \qquad \Delta M_B = M_H - M_L \qquad \frac{\Delta\Gamma_B}{\Gamma_B} \approx O(10^{-2})$$

$$\bar{B}^0 = b\bar{d} \qquad |B_H\rangle = p|B^0\rangle - q|\bar{B}^0\rangle \qquad \Delta\Gamma_B << \Delta M_B$$

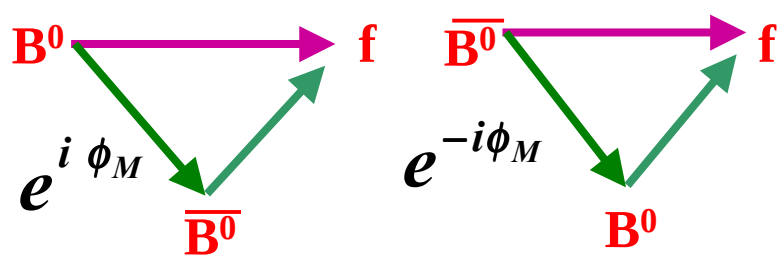


$$A(B_d \to \bar{B}_d) \propto m_t^2 V_{td}^2 \approx |A|\, e^{i2\beta}$$

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

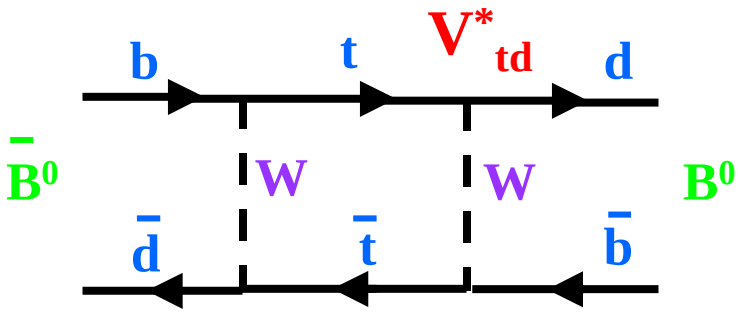
Direct and mixed decays interfere with different amplitudes - leading to different decay rates into the same CP eigenstate:

CP VIOLATION



Neutral B Meson Flavor Oscillations

Neutral *B* meson oscillates due to 2nd order weak interaction:



If initial state is B_q,

$$P(B_q) = \tfrac{1}{2}\Gamma e^{-\Gamma t}(1+\cos\Delta m_q t)$$

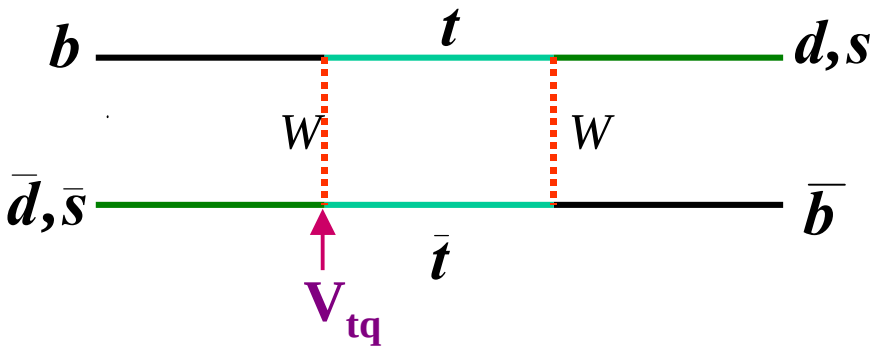
$$P(\overline{B}_q) = \tfrac{1}{2}\Gamma e^{-\Gamma t}(1-\cos\Delta m_q t)$$

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle \qquad \Delta M_B = M_H - M_L \qquad \Delta\Gamma_B = \Gamma_L - \Gamma_H$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle \qquad \Delta\Gamma_B << \Delta M_B \qquad \frac{\Delta\Gamma_B}{\Gamma_B} \approx O(10^{-2})$$

- The mixing of B_q and $\overline{B}_q$ is governed by Δm_B and $\Delta\Gamma_B$
- Mixing parameter $x_B = \Delta m_B/\Gamma_B$

Neutral B Meson Flavor Oscillations



- oscillation frequency $\Delta m_q \propto |V_{tb}^* V_{tq}|^2$
- since $V_{ts} >> V_{td}$, B_s oscillates faster than B_d
- $$\frac{|V_{td}|}{|V_{ts}|} = (1.16 \pm 0.06) \bullet \sqrt{\frac{\Delta m_d \bullet m(B_S)}{\Delta m_S \bullet m(B_d)}}$$

- An observable value of $\Delta\Gamma_{B_S}$ is expected in SM
- Since B_s mesons are not produced on the $\Upsilon(4s)$, this physics will be unique to hadron colliders;