CP Violation Measurements at DØ in Run II

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Workshop on
B Physics at the Tevatron
Run II and Beyond

September 23rd 1999

DØ Run II B Physics Goals and Aspirations

QCD tests

- cross sections
- correlations
- charmonium polarization

CP violation and CKM angles

- $\sin(2\beta)$ $B \to J/\psi + K_s$
- $\sin(2\alpha)$ $B \to \pi^+\pi^-$
- possibly γ $B_s \to D_s^\pm K^\mp$

Non SM CP violation

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

B_S mixing

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

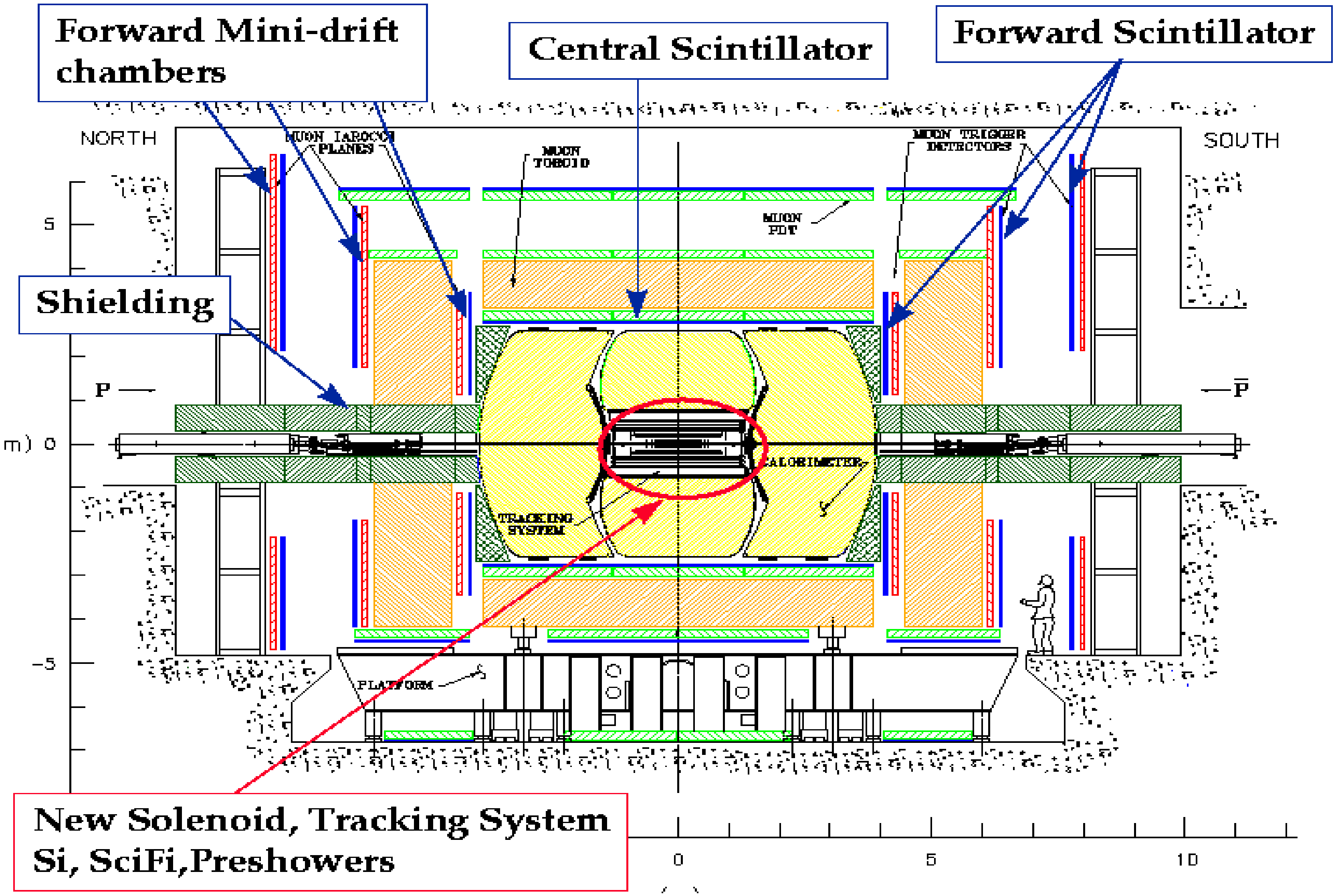
Spectroscopy and lifetimes

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

Rare and radiative decays

- $B \to l^+l^-$ $B \to l^+l^-X_s$
- $B_s \to K^*\gamma$

The DØ Upgrade



+ New Electronics, Trig, DAQ

The DØ Upgrade

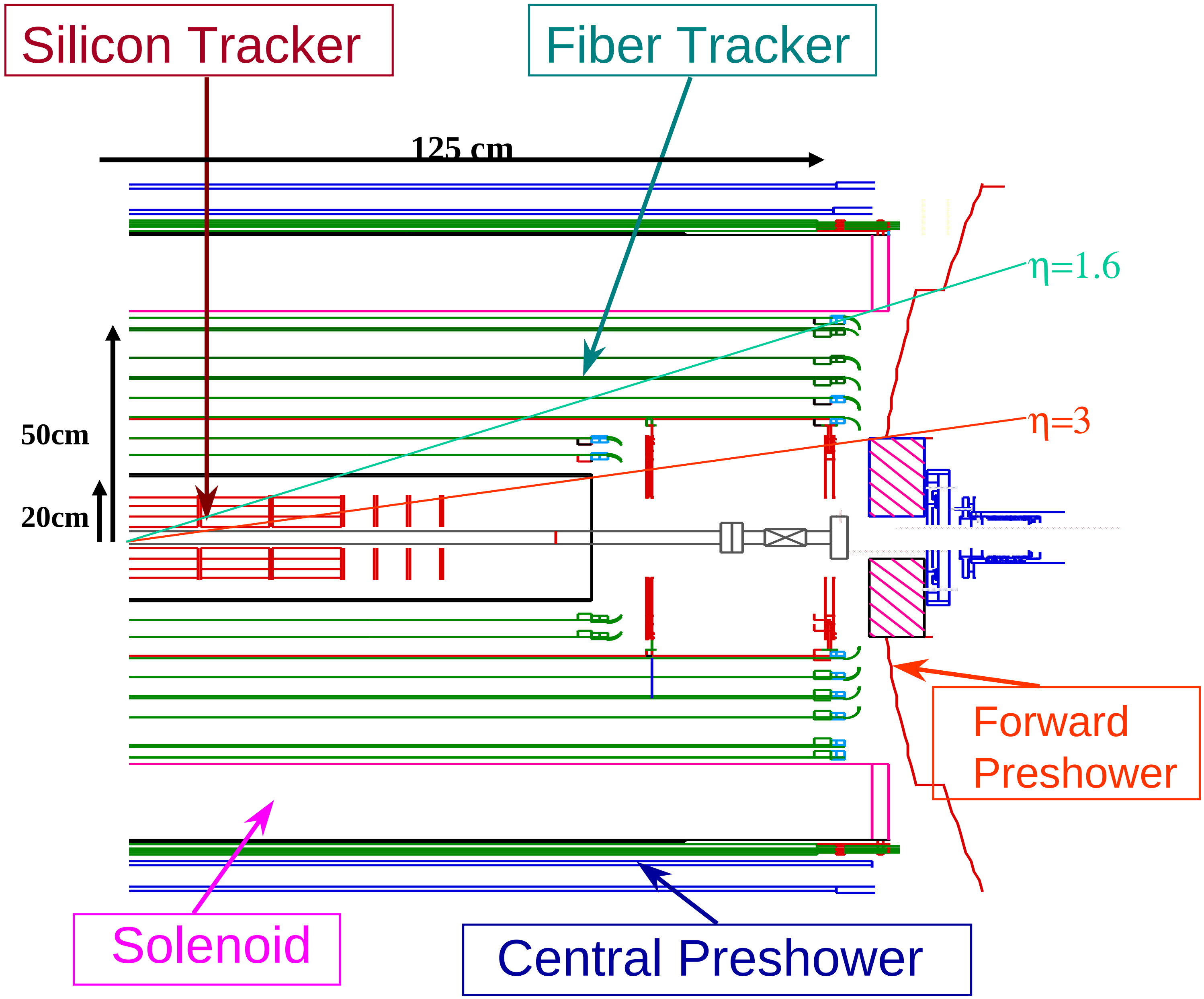
Built on previous strengths:

- excellent calorimetry
- good muon coverage and purity

Significantly improved tracking and triggering capabilities:

- new inner tracker with silicon vertex detector and scintillating fiber tracker
- 2 Tesla magnetic field
- enhanced muon triggering
- pre-shower detectors for electron ID and triggers
- level II impact parameter trigger

The DØ Inner Tracking System



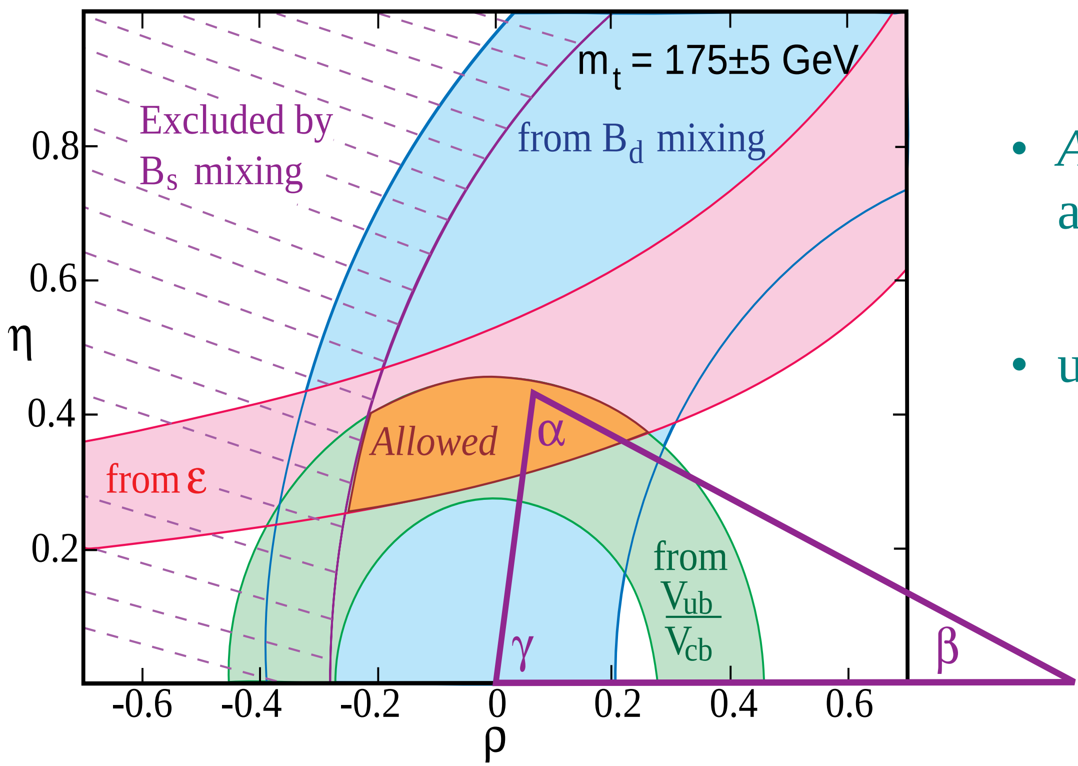
DØ Upgraded Detector Performance

- Good Momentum resolution:
  - $dp_T/p_T^2 = 0.002$ (Silicon+Fiber tracker)
- High tracking efficiency:
  - at least 95 % $|\eta| < 3$ (disks)
- Vertex Reconstruction:
  - primary vertex: $\sigma^{vertex} = 15\text{-}30\ \mu m\ (r\text{-}\phi)$
  - secondary vertex: $\sigma^{vertex} = 40\ \mu m\ (r\text{-}\phi)$, $100\ \mu m\ (r\text{-}z)$
- 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 Physics in the 21st Century

Experiments will confront the Standard Model interpretation of CP violation

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

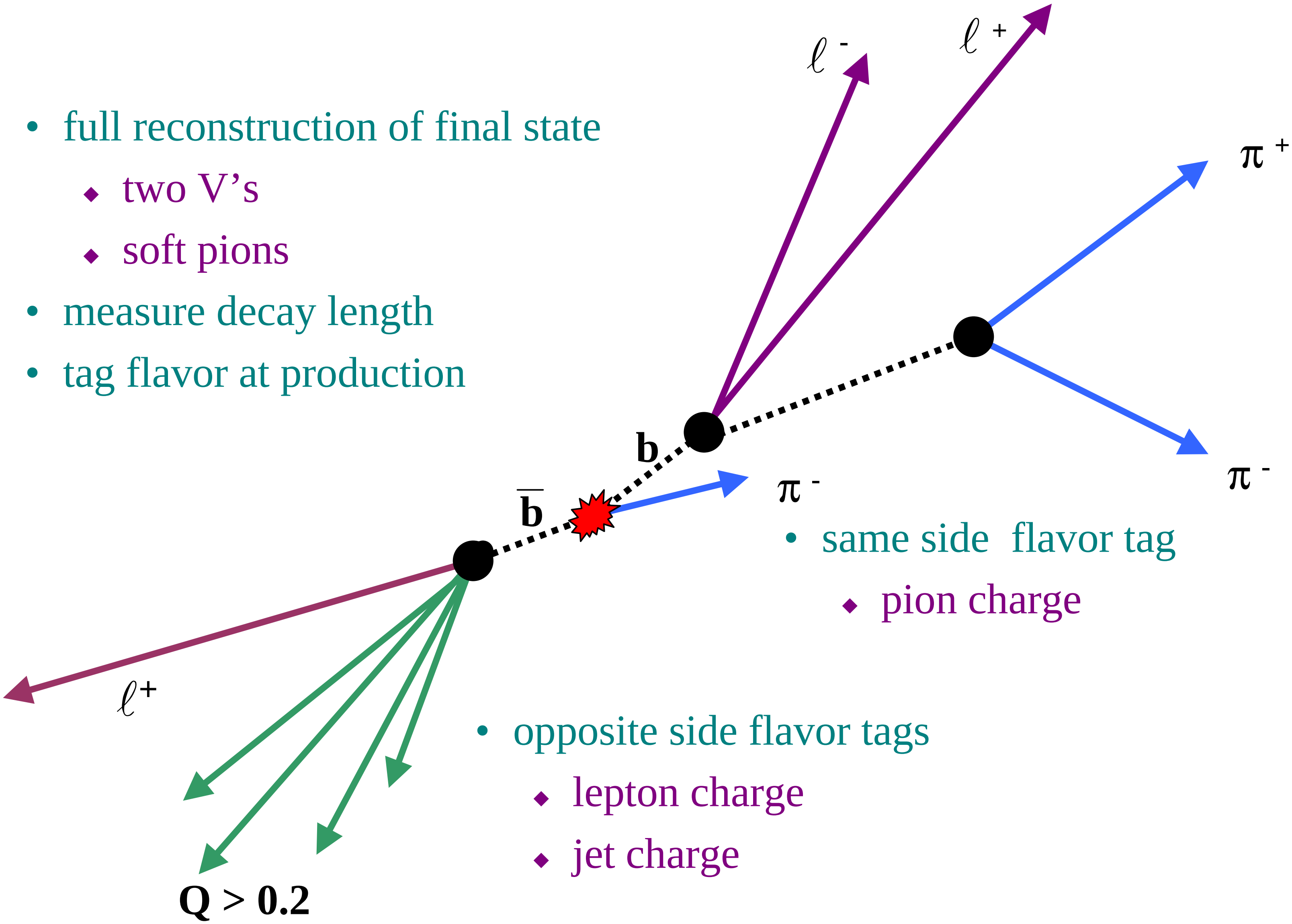


- *A* and *λ* have been measured to a few percent
- unitarity condition:

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

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

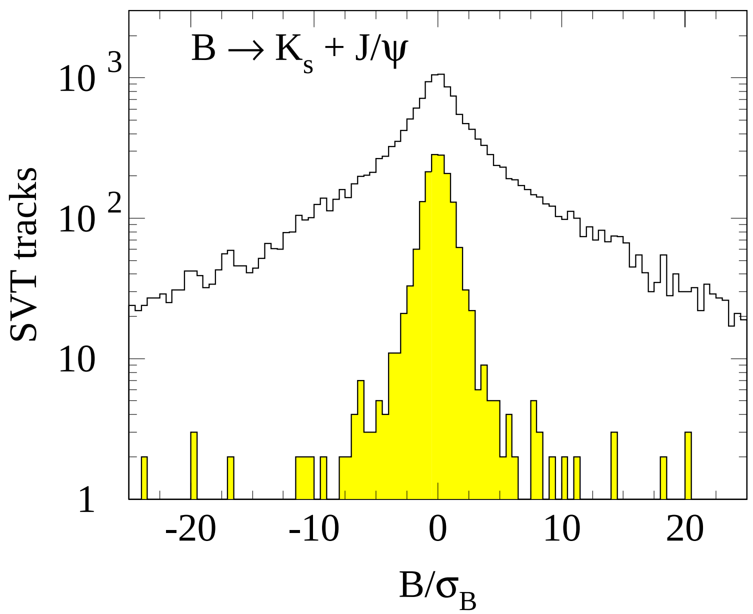


- same side flavor tag
  - pion charge

- opposite side flavor tags
  - lepton charge
  - jet charge

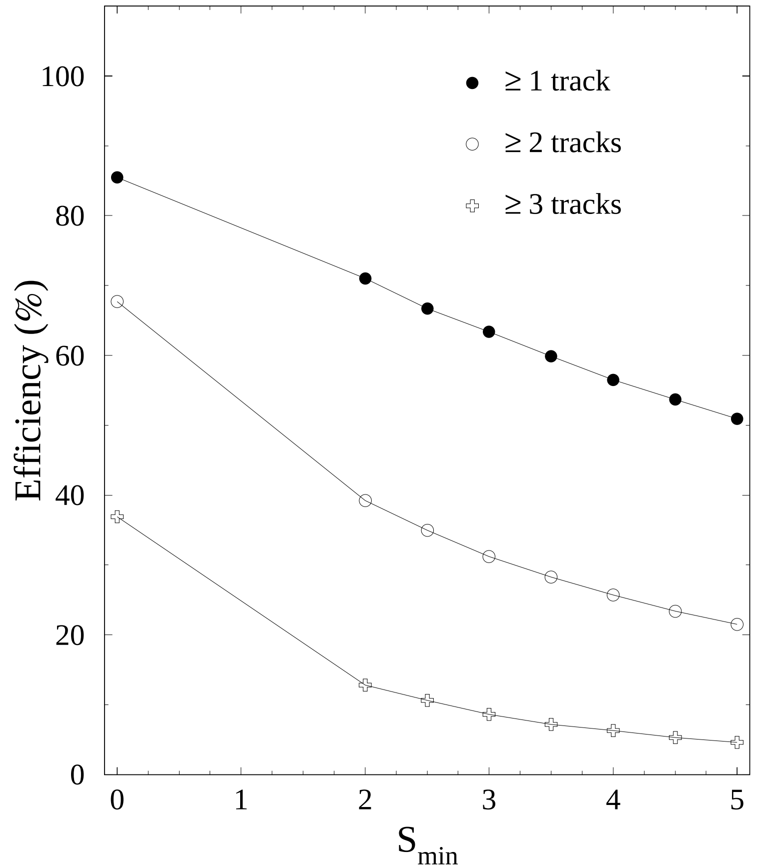
$B \rightarrow J/\psi\, K_S$ Trigger

- Trigger on low p_T leptons from J/ψ decay
- Bandwidth limitations:
  - 10 KHz at level 1, 1 KHz at level 2
- Use silicon vertex trigger (SVT) at level 2



More than 80% of the high p_T tracks in these events have significant impact parameters

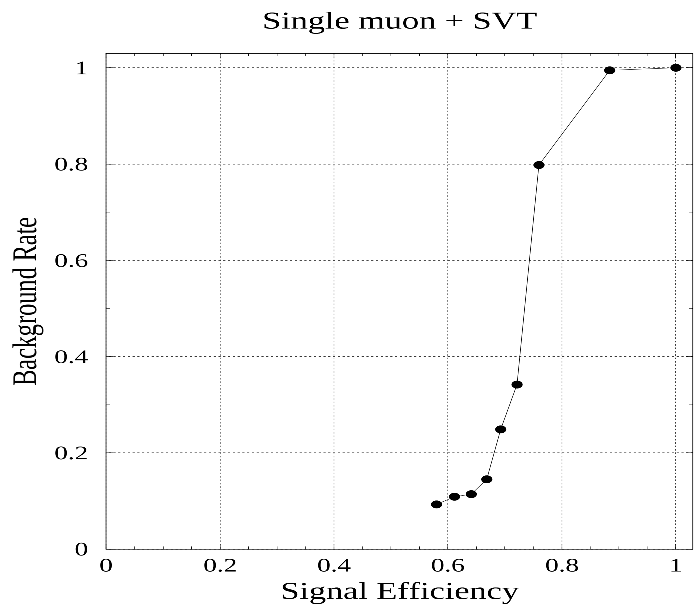
SVT Eff. for $B \rightarrow K_s + J/\psi$

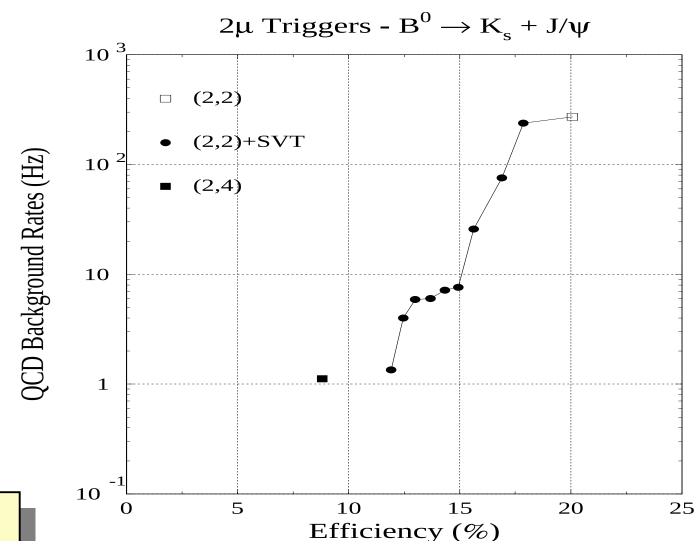


Muon Triggers

Trigger	Level 2 backg. (Hz)	$B \to J/\psi K_S$ efficiency (%)
Single μ:		
$p_T > 6$	13.5	10.8
$p_T > 4$	38.6	23.9
$p_T > 4$ + SVT	13.2	17.3
Dimuon:		
$P_T > 2, 4$	1.1	8.8
$P_T > 2, 2$	272	20.1
$p_T > 2, 2$ + SVT	7.6	14.9

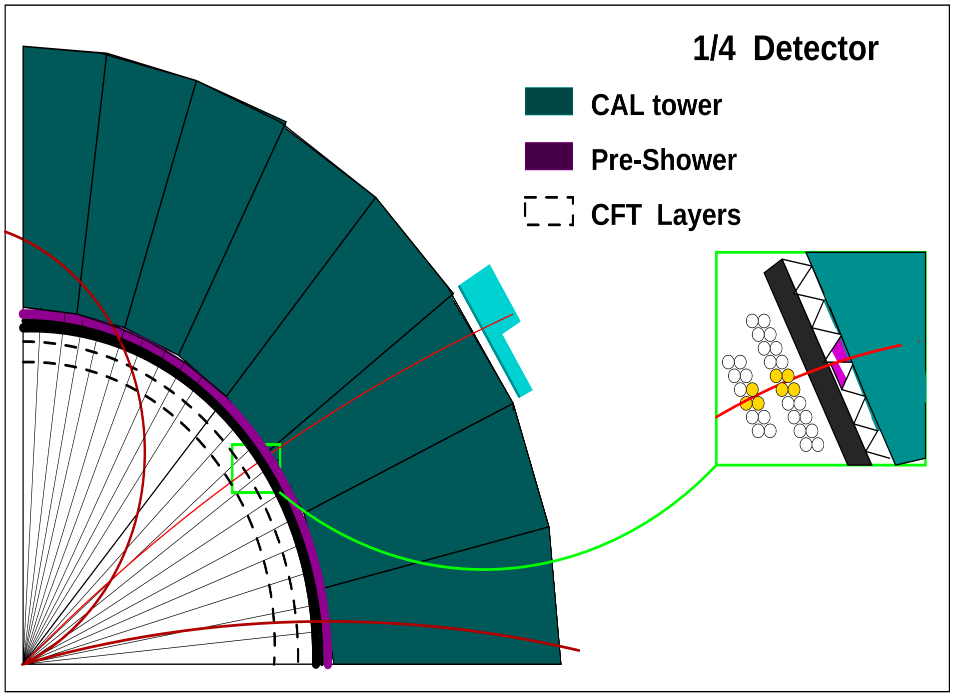
max level 2 rate for all DØ triggers is 100 Hz

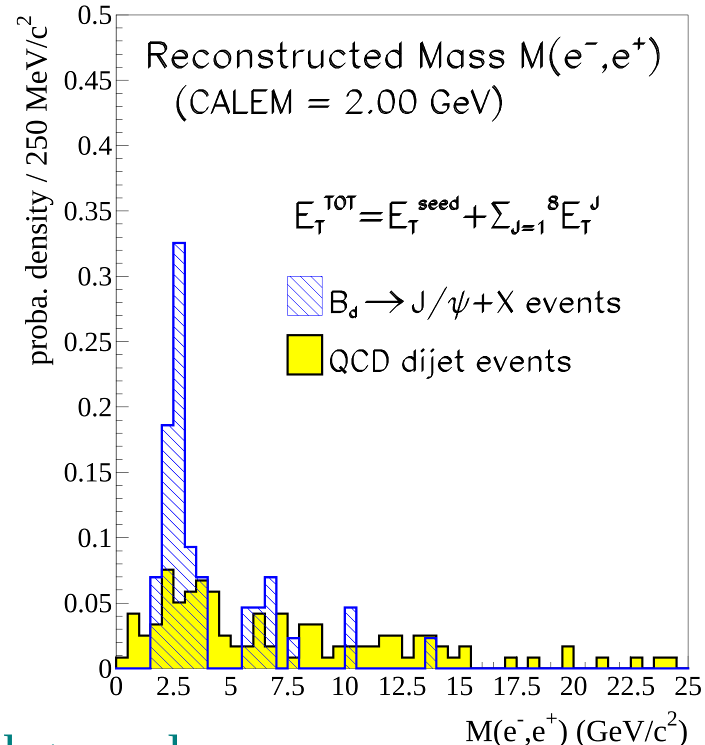




Electron Triggers

di-electron mass cut at level 2





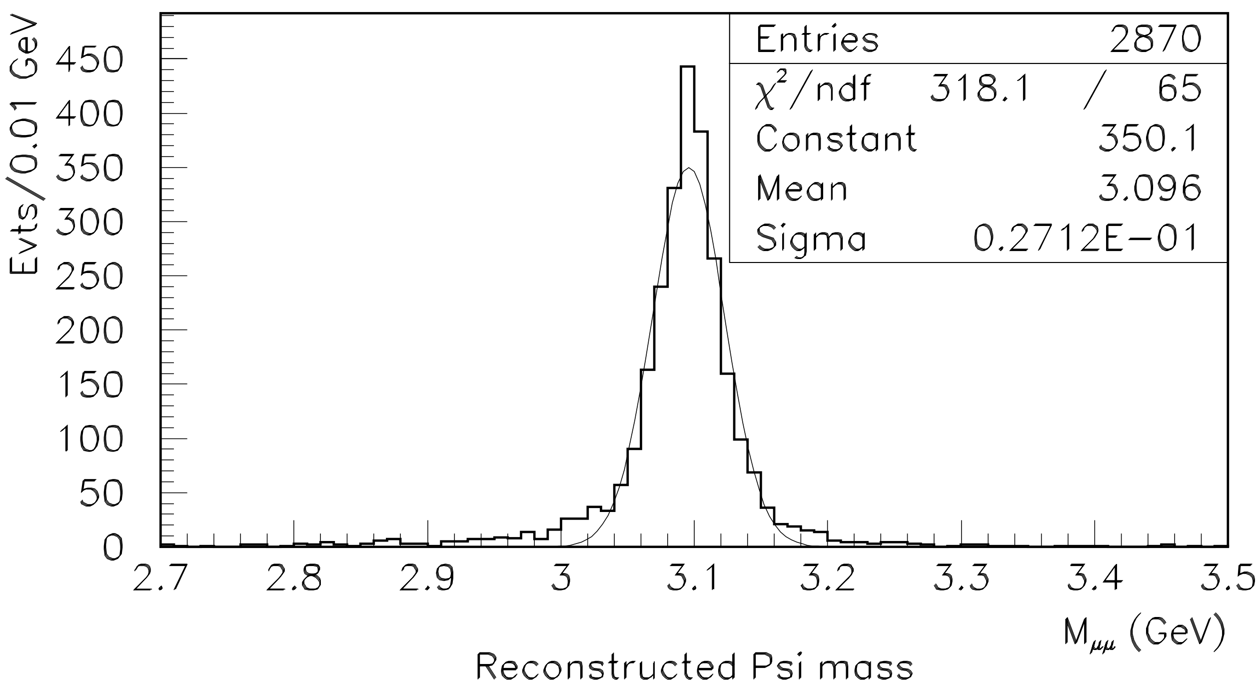
Two electrons each with $p_T > 2$ GeV/c

- relies on pre shower - CAL match to reduce background
- also cut on opposite sign, ΔR, and invariant mass at level 2
- level 2 rate < 300 Hz

$B \to J/\psi K_S$ Reconstruction

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

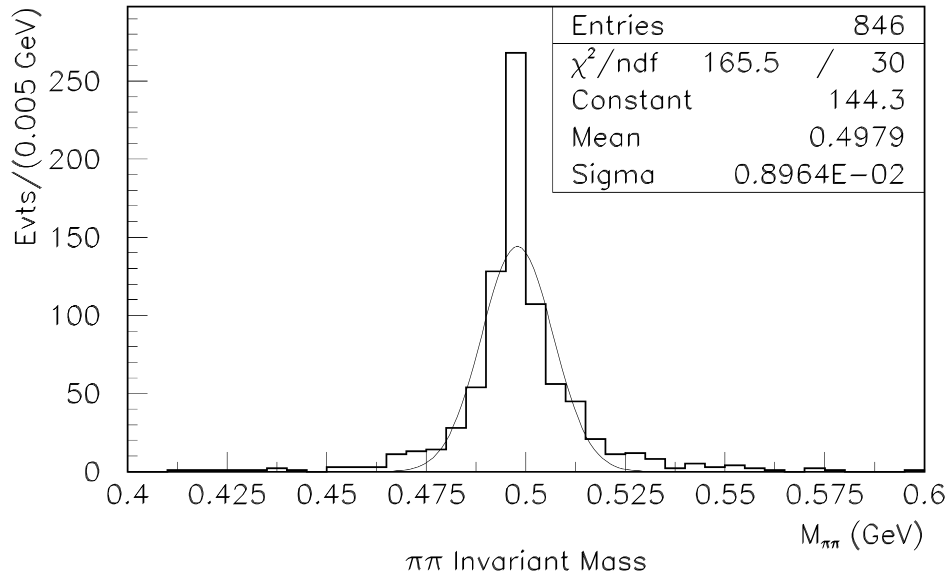
- two muon tracks
  - $p_T > 1.5$ GeV/c
  - $|\eta| < 2$



$B \to J/\psi K_S$ Reconstruction

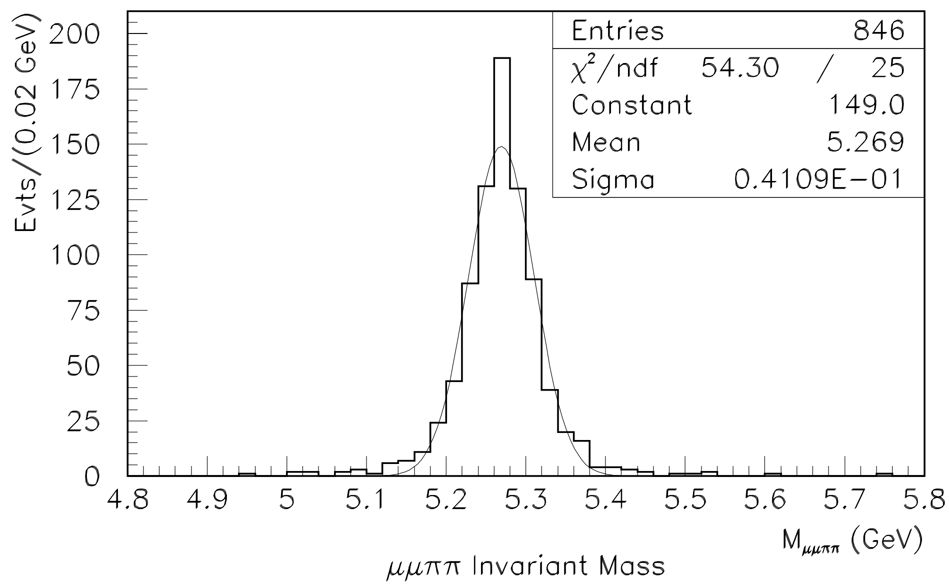
$K_S \to \pi^+ \pi^-$

- $p_T (K_S) > 0.5$ GeV/c
- $|\eta_\pi| < 2$
- $L_{xy}/\sigma > 5$



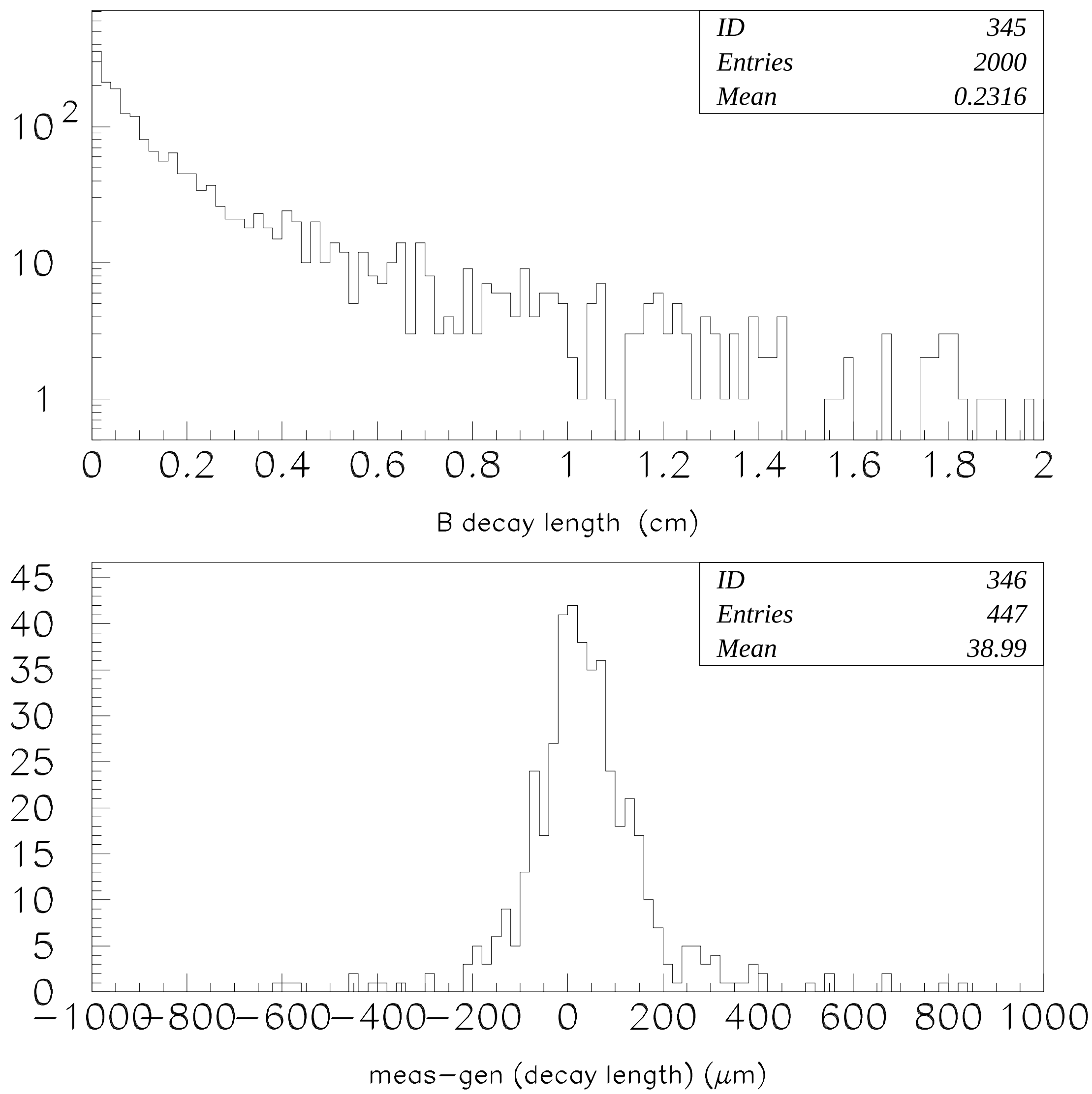
Combined $\mu^+\mu^-\pi^+\pi^-$ invariant mass

(before fit)



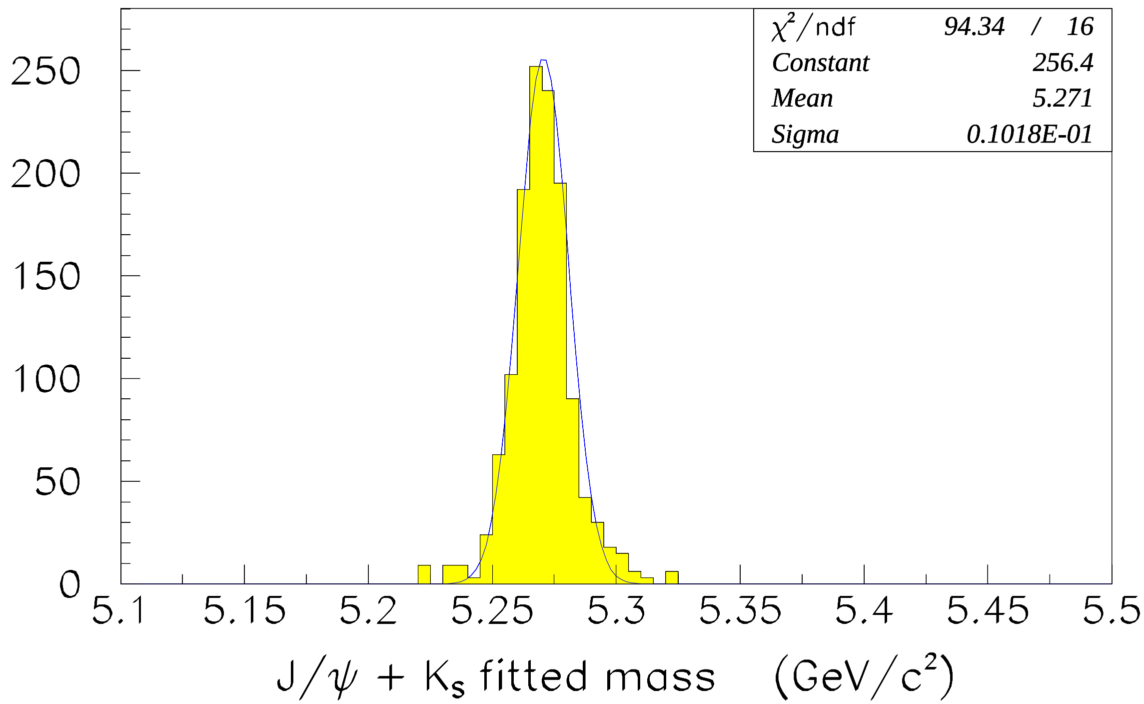
$B \to J/\psi K_s$ decay length reconstruction

- Two secondary two-track vertices
- Average B decay length: 23 mm
- Vertex resolution: 100 μm



$B \to J/\psi K_S$ Reconstruction

- $J/\psi \to \mu^+\mu^-$ require two central tracks with p_T > 1.5 GeV/c
- $K_S \to \pi^+\pi^-$ use long lifetime to reject background: $L_{xy}/\sigma > 5$
- Perform 4-track fit assuming $B \to J/\psi + K_S$
  - 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)

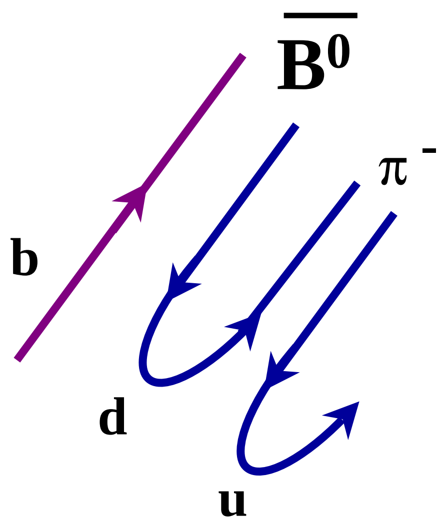
$D = 2P - 1$

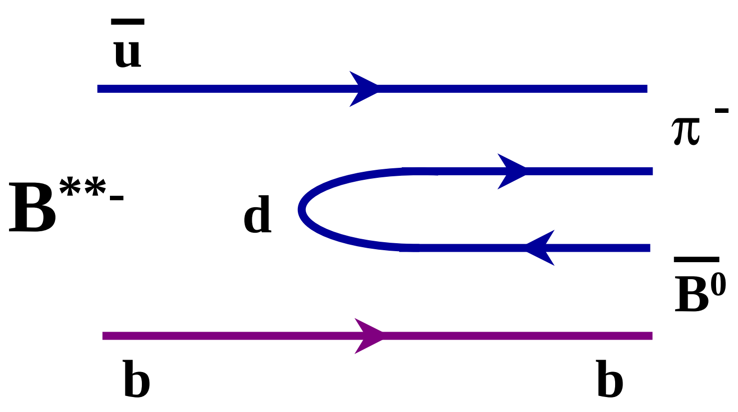
P is the correct tag probability

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 CDF upgrade	DØ capabilities
Same side	$1.8 \pm 0.4 \pm 0.3$	2.0	tracking	~ same
Soft lepton	$0.9 \pm 0.1 \pm 0.1$	1.7	μ coverage	~ 1.5 x better
Jet charge	$0.8 \pm 0.1 \pm 0.1$	3.0	silicon tracking	~ same
Opp. side *K*		2.4	ToF	None
Combined		9.1		~ 7.5

Calibrate tags in Run II with:

- 40 K $B^{\pm} \rightarrow J/\psi + K^{\pm}$ events
- 20 K $B^{0} \rightarrow J/\psi + K^{0*}$ events

Statistical error will be bigger than systematic

Sin2β Expectations for 2fb^{-1}

For a time independent analysis:

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

- (S/B ~ 0.75)
- $\varepsilon D^2 \sim 7$ %

mode	$J/\psi -> \mu^+\mu^-$	$J/\psi -> e^+e^-$
trigger eff. (%)	32	25
reco'd events	8,500	6,500
$\sigma(\sin 2\beta)$	0.13	0.15
	0.10	

But, since most of the background is at small *t*'s, a time dependent analysis gives reduced error: $\sigma(\sin 2\beta) \sim 0.07$

And this is just in the first two years - 2 fb^{-1}. We won't stop there......

New Director - New Run II Plan

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

L (fb^{-1})	Number of $B \to J/\psi K_S$	$\sigma(\sin 2\beta)$
2	15 K	0.07
5	38 K	0.04
10	75 K	0.03
20	150 K	0.02

Sin(2β) Measurement

Goals for this workshop:

- work on reconstruction algorithms
- determine tagging efficiencies and dilution factors
  - does neural net tagging help ?
- can a (combined) Tevatron measurement scoop Babar/Belle ?

What About Those Other Angles?

DØ has done no formal studies yet

- Forget about penguins, they are the least of our problems:
  - no π / K particle ID - should we just give up then ???
  - not enough bandwidth for level one all hadronic trigger
- But, we can try:
  - trigger on opposite side lepton
  - "smart" pre-scaled triggers - remove multiple interaction events
  - other new trigger ideas - use high p_T hadron tracks and/or jets to help lower lepton p_T thresholds
  - π^0's might be possible for us