# Prospects for B Lifetimes, Oscillations and CP Violation at DØ

- Introduction
- DØ Detector for B Physics
- DØ B Physics Program
- DØ Highlights and Prospects

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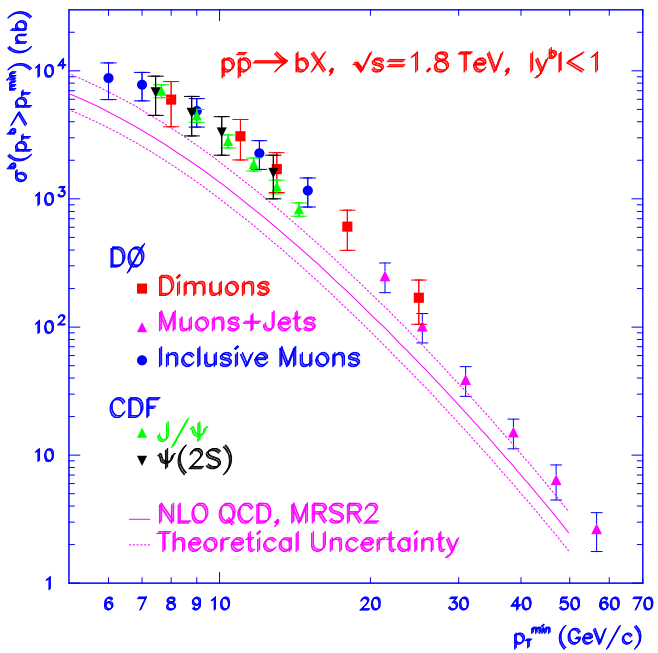
# The Tevatron is a B Factory

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



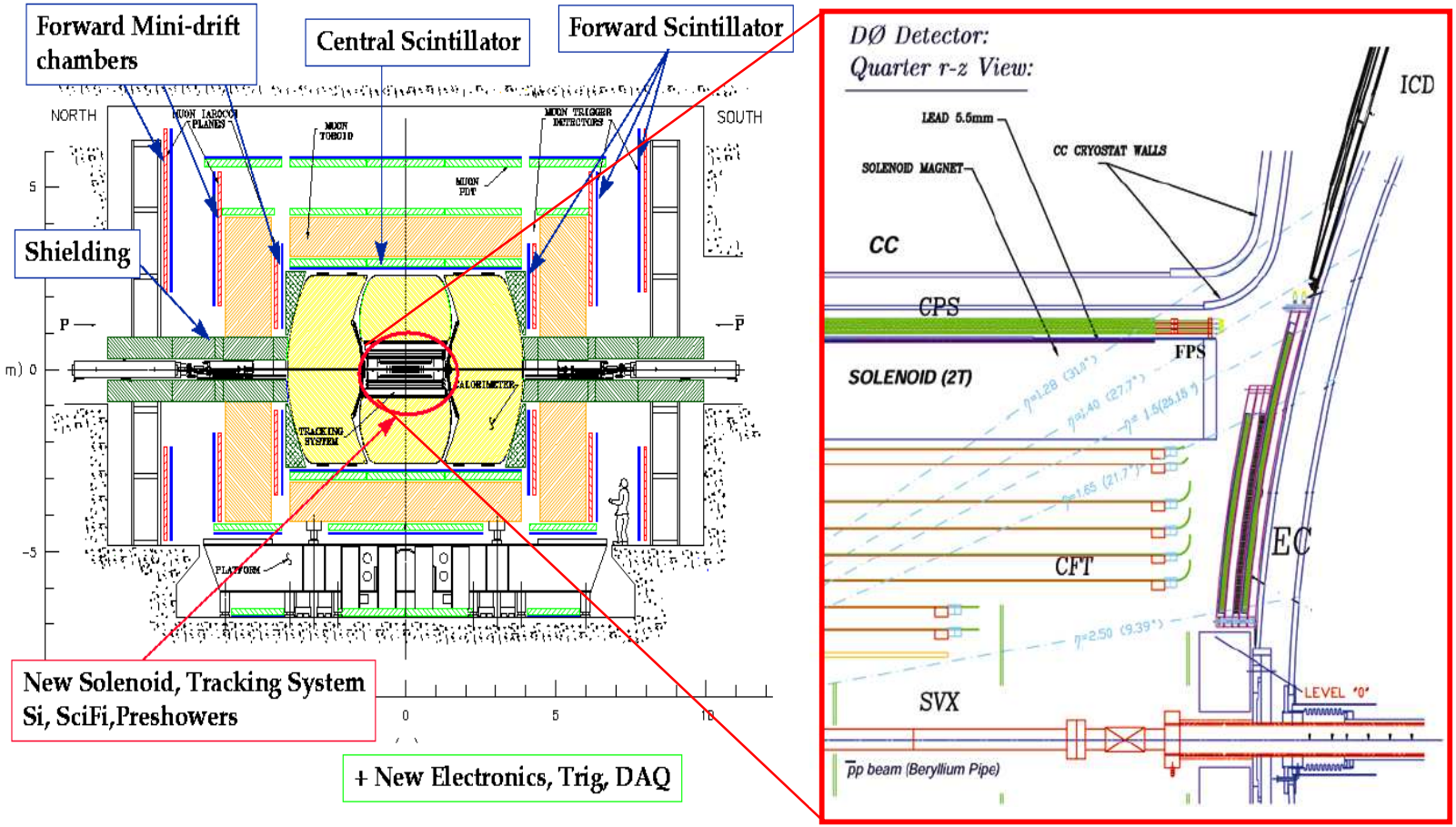

$$\sigma(p\bar{p} \to b\bar{b}) \approx 150\ \mu b \textbf{ at 2 TeV}$$

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

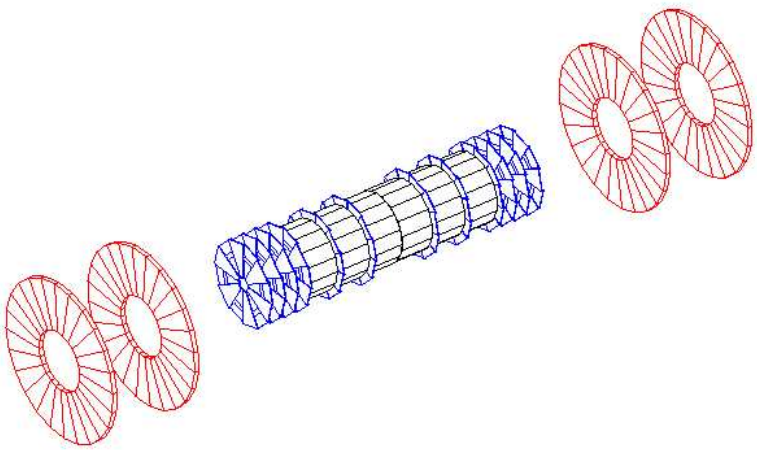
$$\sigma(e^+e^- \to B\bar{B}) \approx 1\ nb \quad \textbf{at } \Upsilon\textbf{(4S)}$$

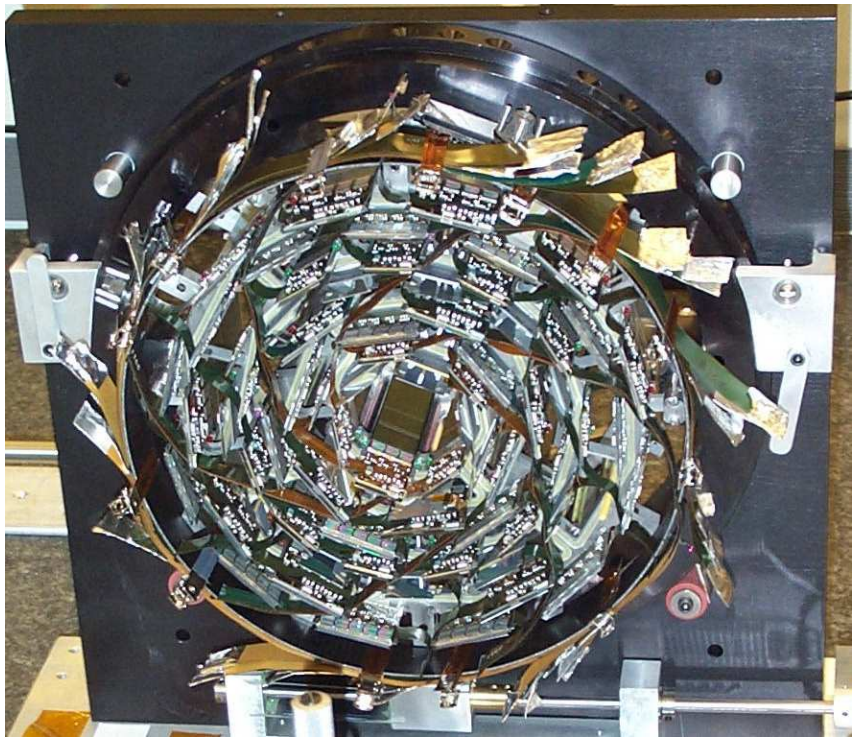
  - All species $B^0$, $B^+$, $B^0_s$, $B^+_c$, $\Lambda^0_b$ produced

# DØ Detector for B Physics



# Silicon Microstrip Tracker

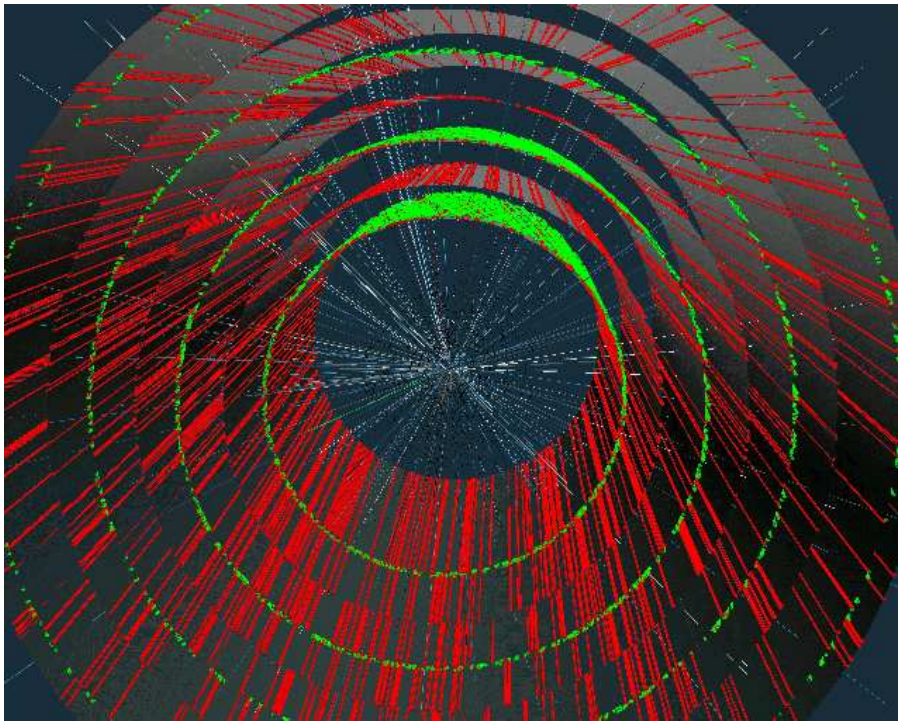


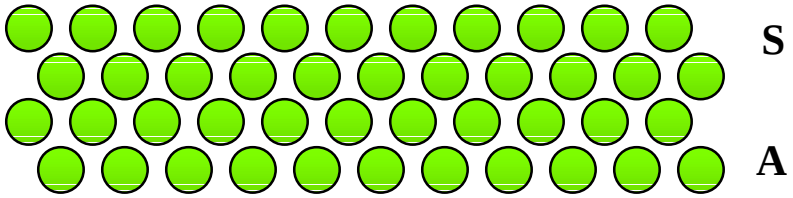


- Silicon Microstrip Tracker
  - ~800,000 channels of electronics
  - hit resolution: 10μm
  - secondary vertex resolution: 40μm (r-ϕ), 80μm (r-z)

# Central Fiber Tracker

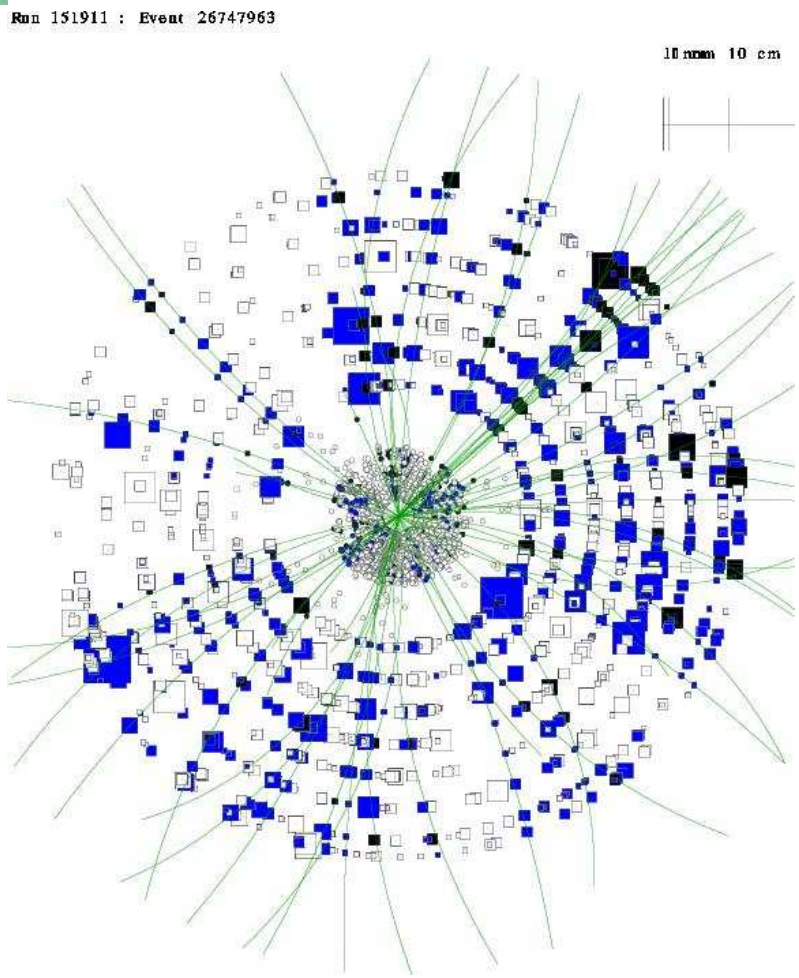
- 80K 835-μm scintillator fibers
- Mounted on 8 cylinders
- Alternating axial and ±3° stereo doublets



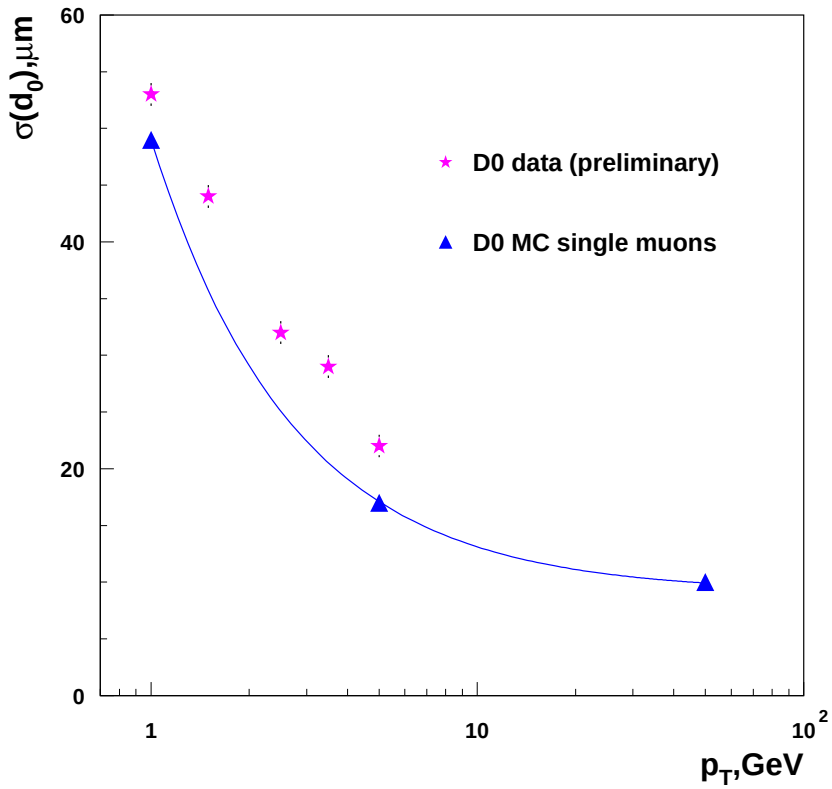



- Fast enough for L1
- Good resolution

# Track Reconstruction

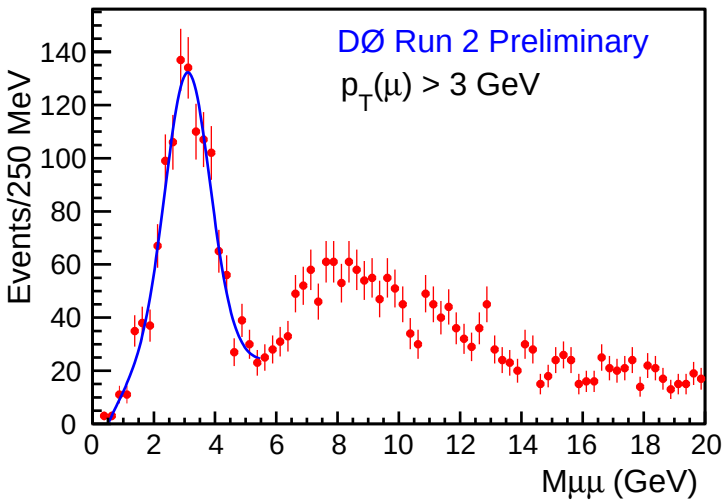



## Impact parameter resolution



# Muon System

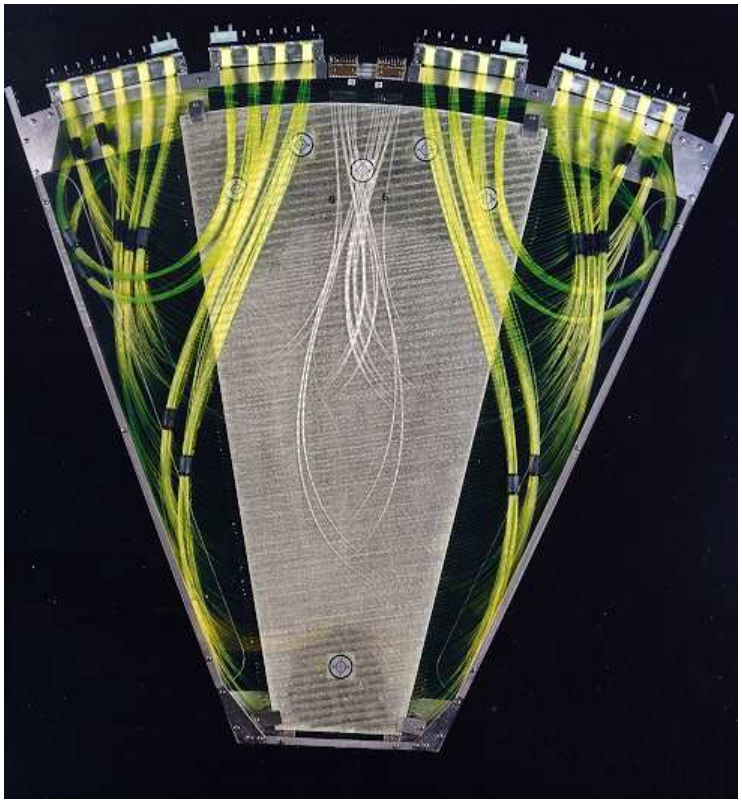
- 2-T toroidal magnet between *A* and *B* layers ⇒ momentum
  - proportional drift tubes
  - scintillator pixel counters

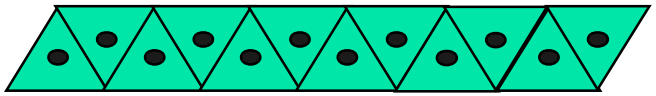



J/ψ candidates reconstructed with muon system only

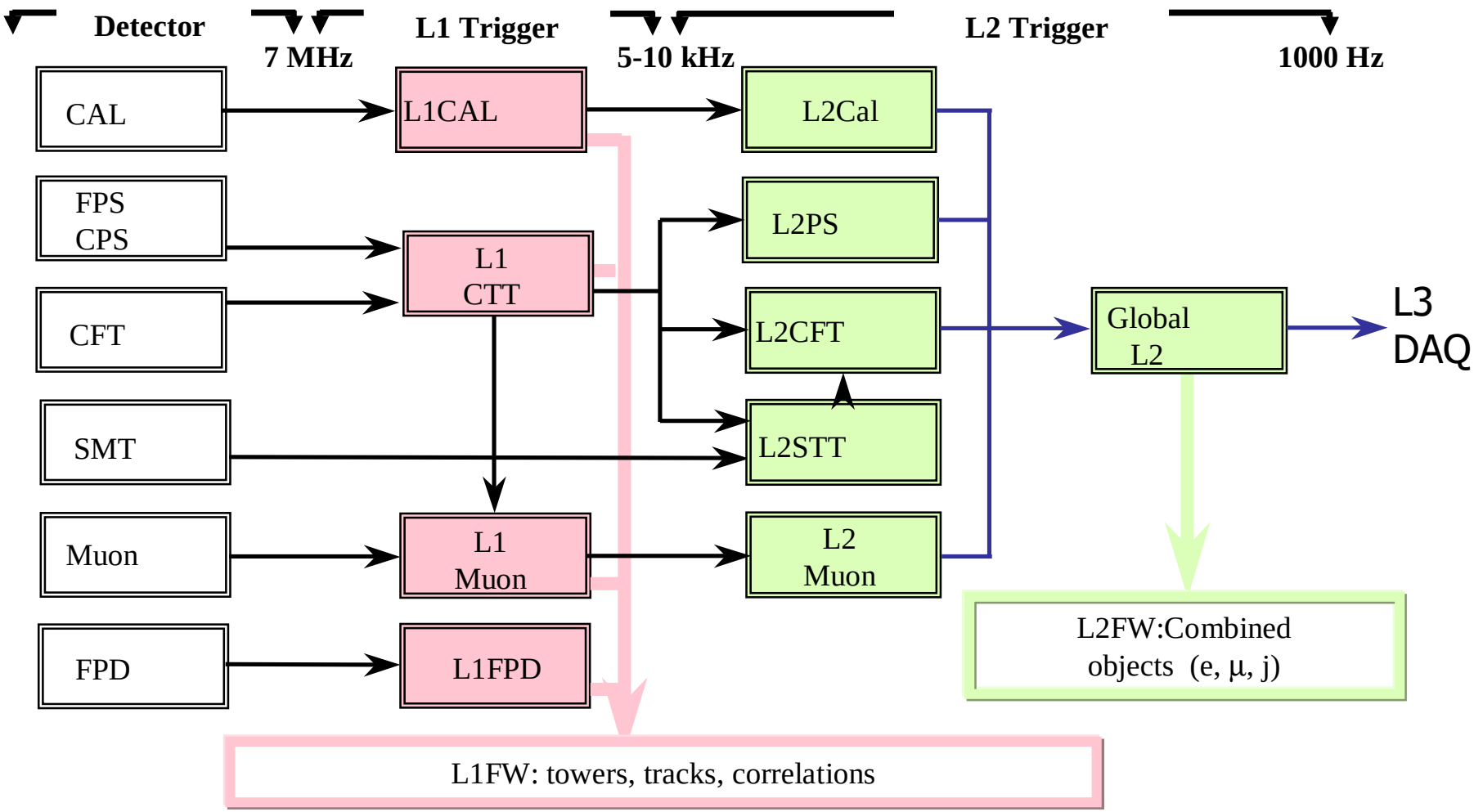
# Preshower Detectors

- Refines position and energy measurements of EM showers
- Central and forward
- Extruded triangular scintillator strips with embedded WLS fibers
- Axial (central) and ±20° stereo layers (central and forward)





# DØ Trigger System

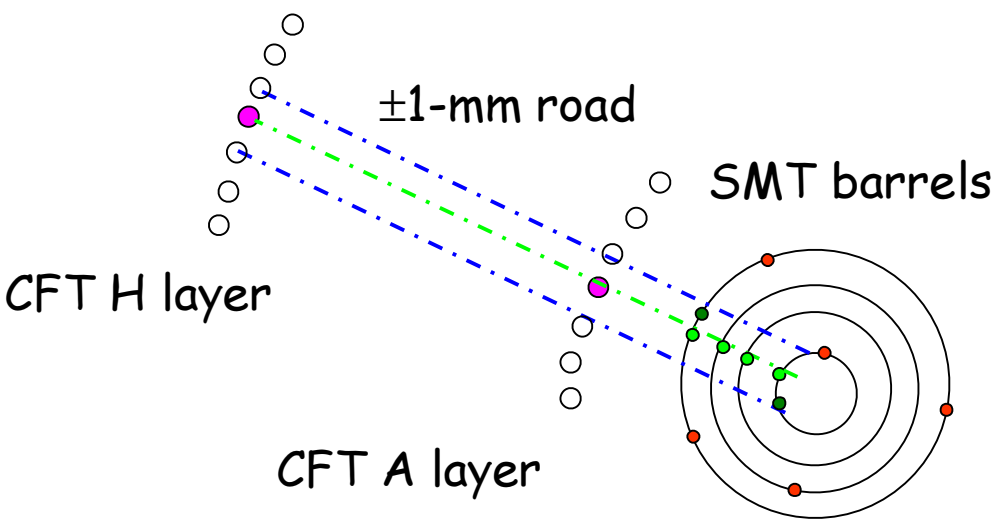


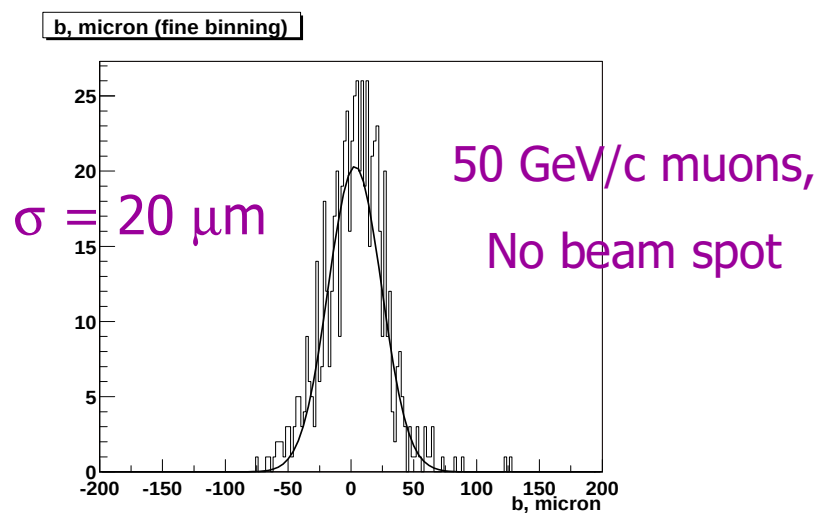
# Level 1 Central Track Trigger

- Custom hardware + firmware
- Preprogrammed track equations matched to hit patterns
- Input for L2 impact parameter trigger
- Installation complete, commissioning underway
- Expect to be fully operational by late fall
- Crucial for B physics!

# Level 2 Silicon Track Trigger

- Trigger on displaced tracks at Level 2
- Lower $p_T$ threshold on single lepton and dilepton triggers ($B^0 \rightarrow \mu^+\mu^-$, $B_s$ mixing, etc.)
- Increase $B_d^0 \rightarrow J/\psi\, K_s^0$ yield by 50% (CP violation)
- Integration testing ongoing – expect to be online in the New Year



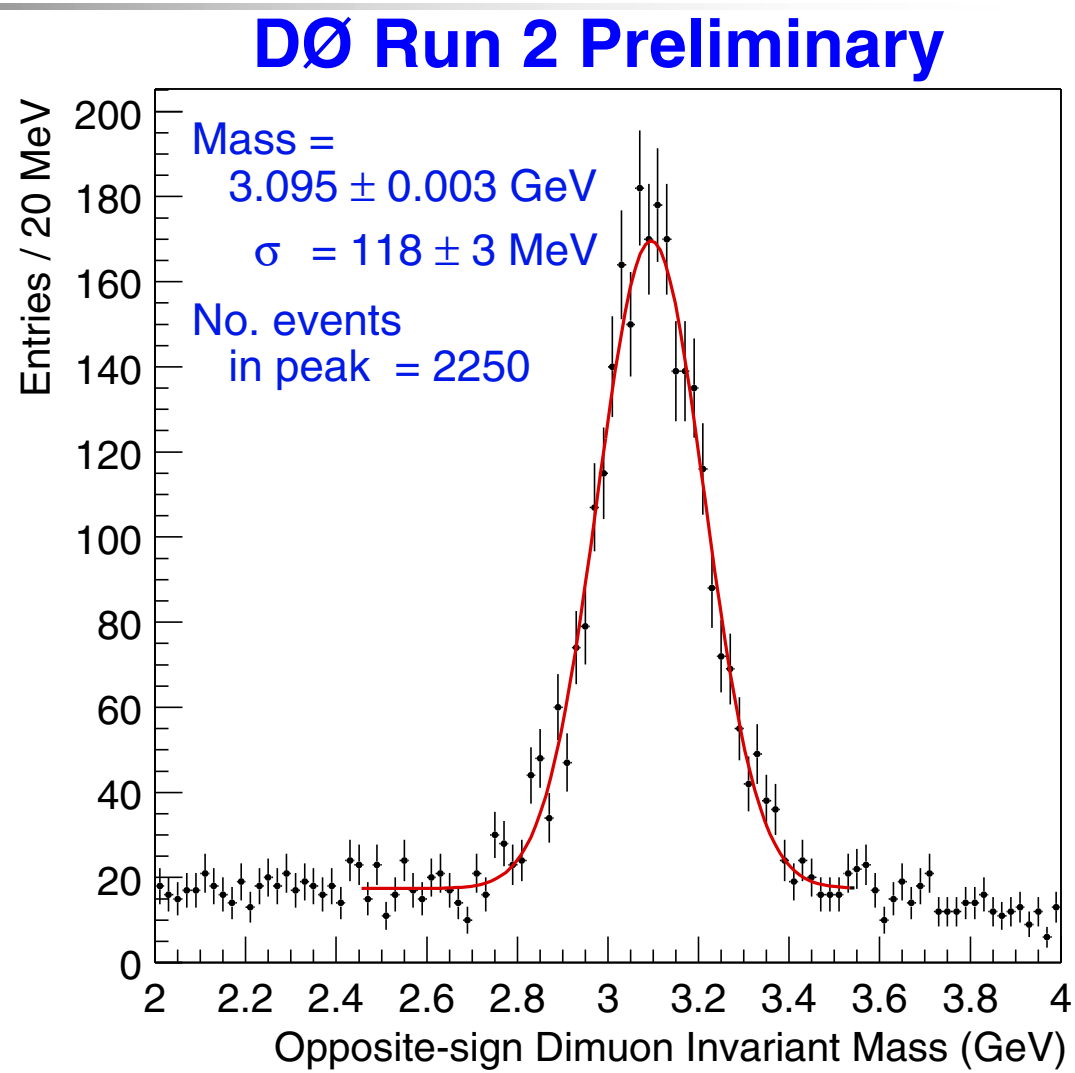



# DØ Beauty Physics Program

- B Lifetimes
  - Average B lifetime: $b \rightarrow J/\psi X$
  - $\Lambda^0_b$ lifetime: $\Lambda^0_b \rightarrow J/\psi \Lambda^0$
  - $B^0_s$ lifetime and width: $B^0_s \rightarrow J/\psi \phi$
- $B^0_s$ mixing: $B_s \rightarrow D_s\, l\, X$, $B_s \rightarrow D_s(n\pi)$
- CP violation, $\sin(2\beta)$: $B^0 \rightarrow J/\psi\, K^0_s$
- Rare decays, cross sections
- And more!

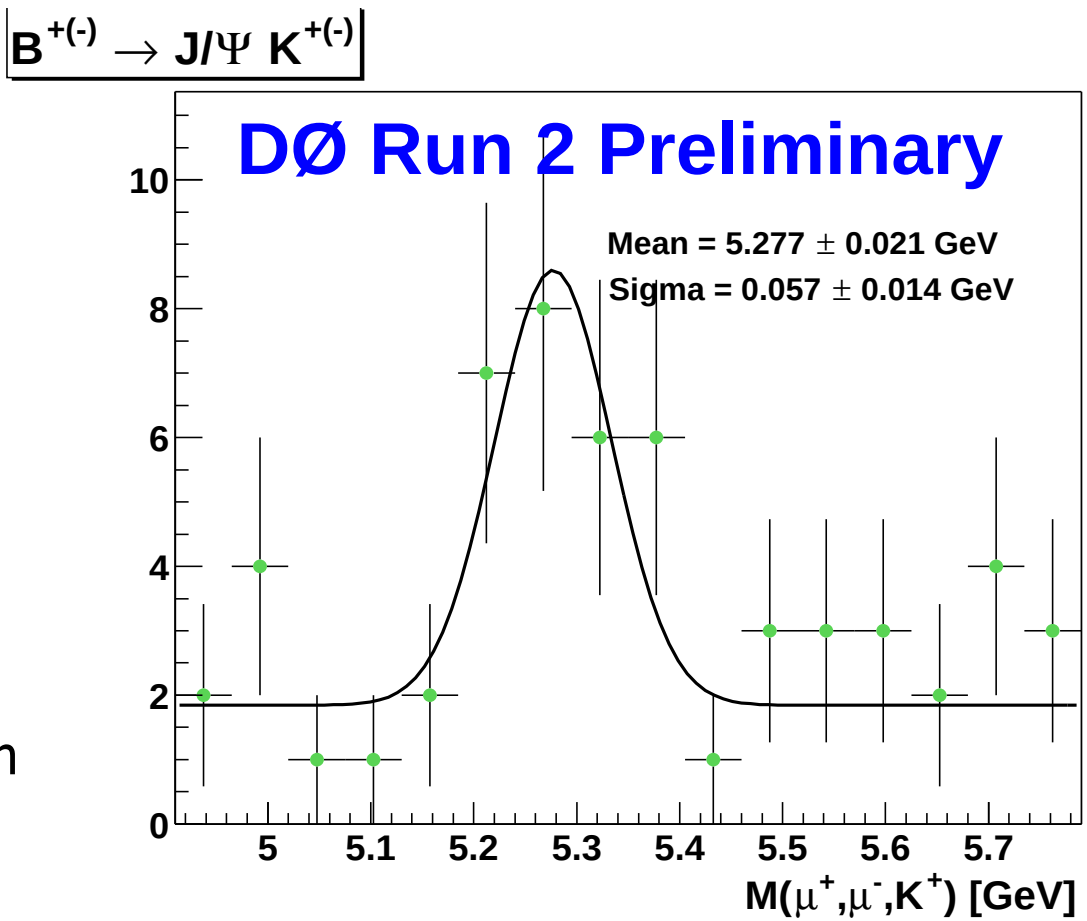
# DØ's First J/ψ Candidates

- ~5 $pb^{-1}$
- $J/\psi \rightarrow \mu\mu$ vertex
  - $p_T$(track)>2 GeV/c, matched to a muon
  - Positive decay length

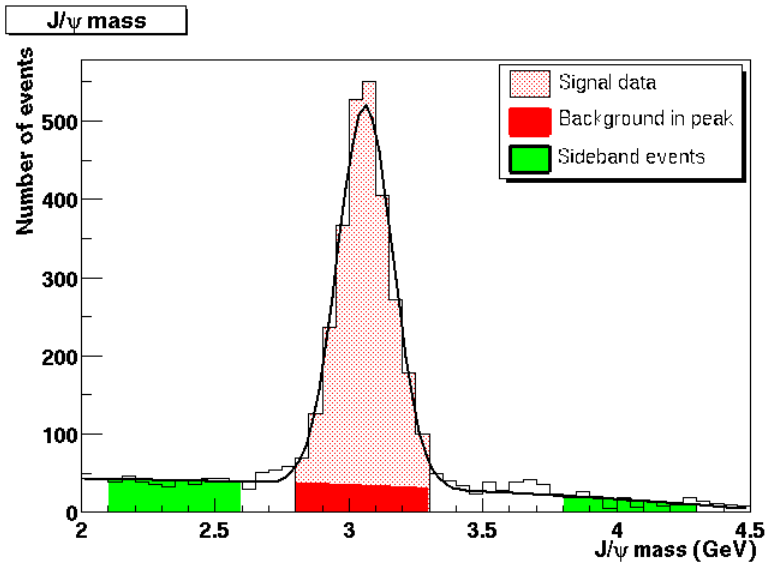


# DØ's First B Hadron Candidates

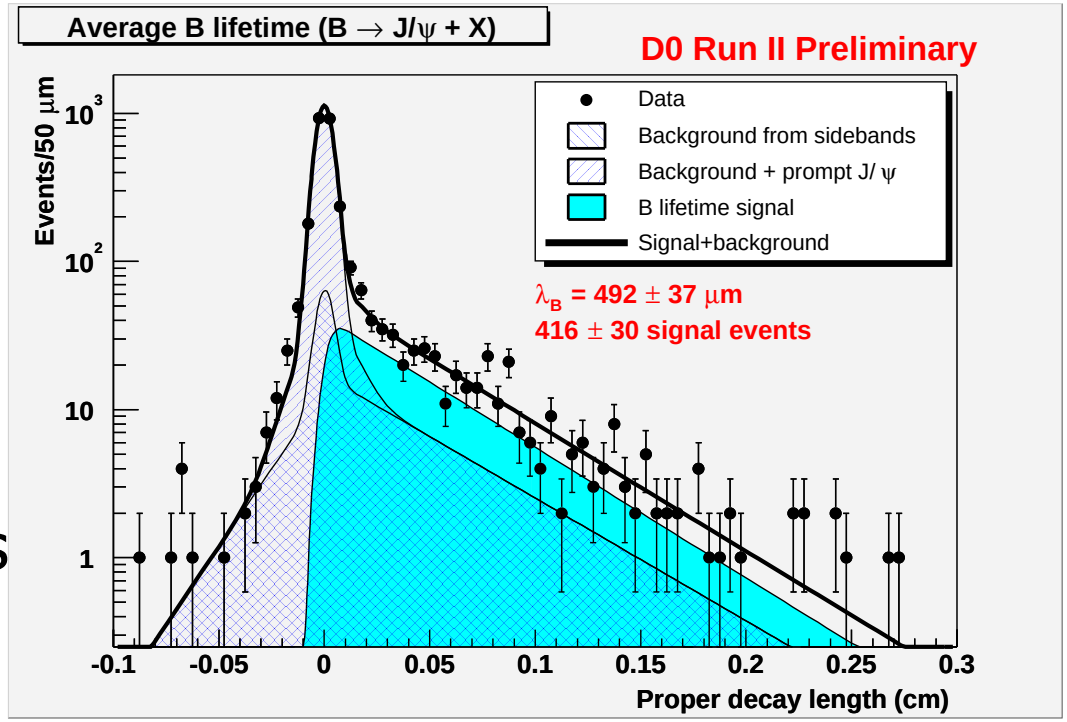
- ~5 $pb^{-1}$
- $J/\psi \rightarrow \mu\mu$ vertex
  - $p_T$(track)>2 GeV/c, matched to a muon
  - Positive decay length
- $p_T$(K)>0.5 GeV/c
- B vertex
  - $p_T$(B)>10 GeV/c
  - $\chi^2$<10
  - Decay length>120 $\mu$m
  - Colinearity angle ($\mathbf{p}\cdot\mathbf{l}$)>0.9



# Average B Hadron Lifetime




- Same sample as $B^{\pm} \rightarrow J/\psi K^{\pm}$
- $p_T(J/\psi)>4$ GeV/c



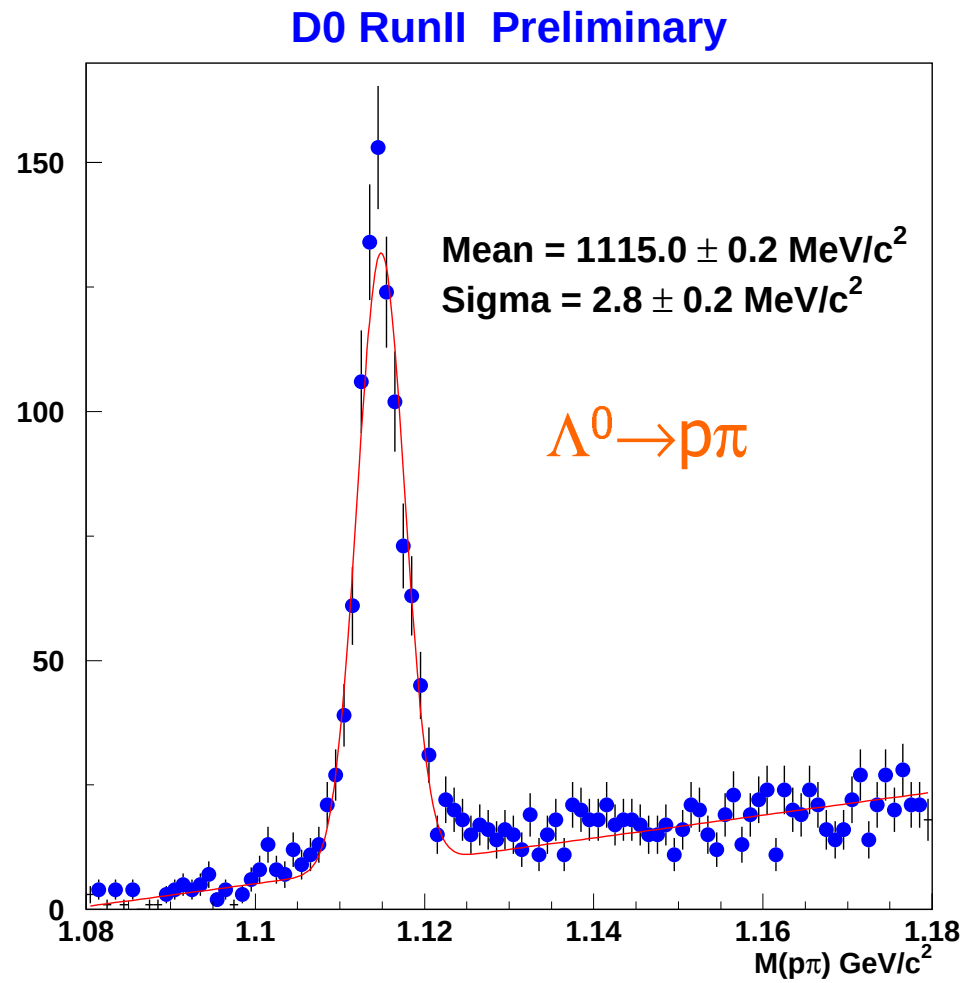

- 416 ± 30 signal events
- 2184 ± 47 prompt J/ψ's
- $\tau(B) = 492 \pm 37\ \mu m$
  (PDG: $\tau(B) = 469\ \mu m$)

# $\Lambda^0_b$ Lifetime

- Theoretical expectation is $\tau(\Lambda_b^0)/\tau(B^0) = 0.9$
- Measurement is $\tau(\Lambda_b^0)/\tau(B^0) = 0.797 \pm 0.053$
- Previous measurements used semileptonic modes to achieve statistical precision
  - Disadvantage is that neutrino is lost, carrying with it momentum information
- Fully hadronic mode $\Lambda^0_b \rightarrow J/\psi\ \Lambda^0$
  - BR($\Lambda^0_b \rightarrow J/\psi\ \Lambda^0$)=5x10$^{-4}$
  - Trigger on $J/\psi \rightarrow \ell^+\ell^-$ events, reconstruct $\Lambda^0 \rightarrow p\pi$
  - Expect 15 000 events
- No need to rely on Monte Carlo for momentum correction

# $\Lambda^0_b$ Lifetime

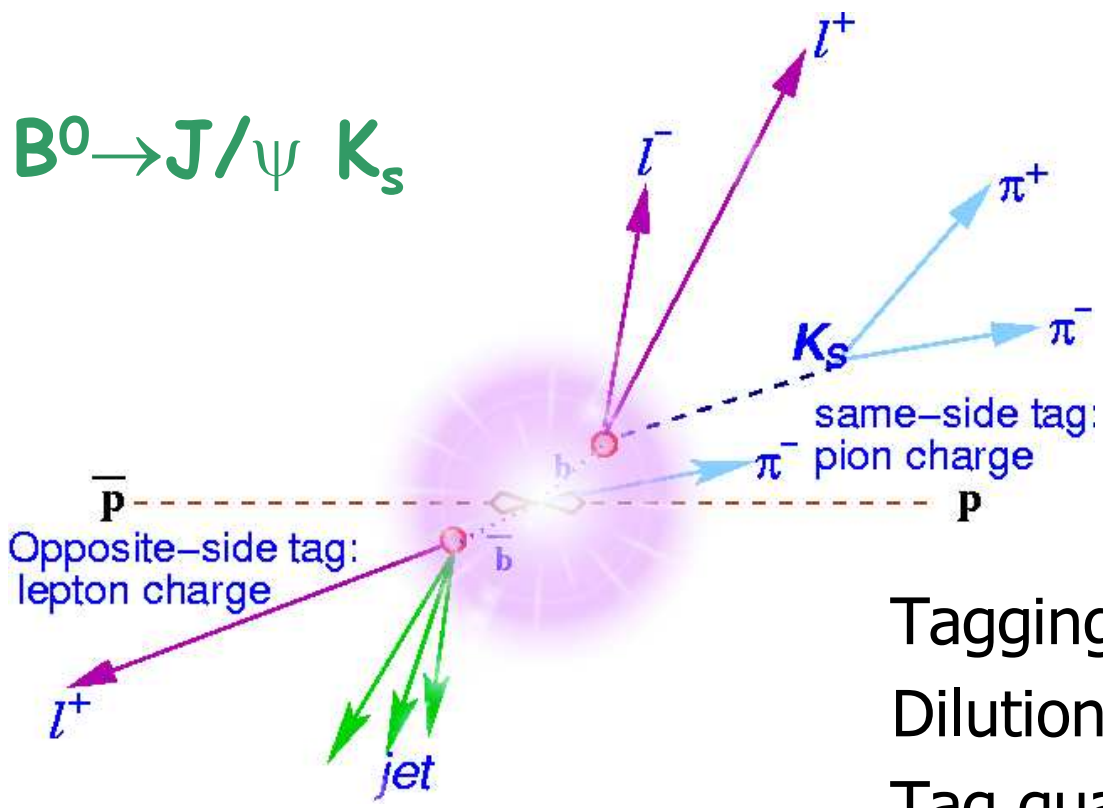
- $\Lambda^0 \rightarrow p\pi$
  - Highest $p_T$ track assigned the proton mass
  - Veto events where $M(\pi\ \pi)$ consistent with $K_s^0$ mass
- Next step: search for $\Lambda^0 \rightarrow p\pi$ candidates in $J/\psi \rightarrow \mu\mu$ events



# Production Flavour Tagging

Use $B^{\pm} \rightarrow J/\psi\ K^{\pm}$ events to calibrate flavour tagging algorithms

$B^0 \rightarrow J/\psi\ K_s$




Tagging efficiency $\varepsilon = N_{tag}/N_{tot}$

Dilution $D = (N_R - N_W)/(N_R + N_W)$

Tag quality $= \varepsilon D^2$

# Flavour Tagging

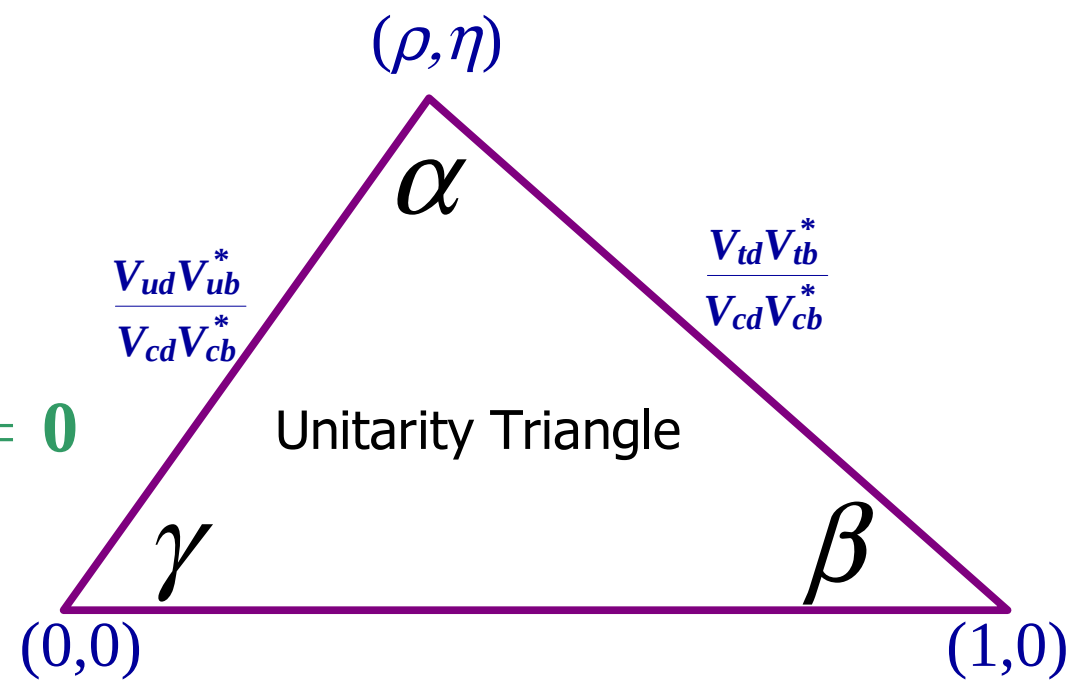
| Tag | $\varepsilon D^2$ (%) measured CDF Run I | $\varepsilon D^2$ (%) expected CDF Run II | Relevant DØ difference | DØ expectations |
|---|---|---|---|---|
| Same side | $1.8 \pm 0.4 \pm 0.3$ | 2.0 | same | 2.0 |
| Soft lepton | $0.9 \pm 0.1 \pm 0.1$ | 1.7 | μ , e ID coverage | 3.1 |
| Jet charge | $0.8 \pm 0.1 \pm 0.1$ | 3.0 | forward tracking | 4.7 |
| Opp. side *K* | | 2.4 | no K ID | none |
| Combined | | 9.1 | | 9.8 |

# CKM Matrix

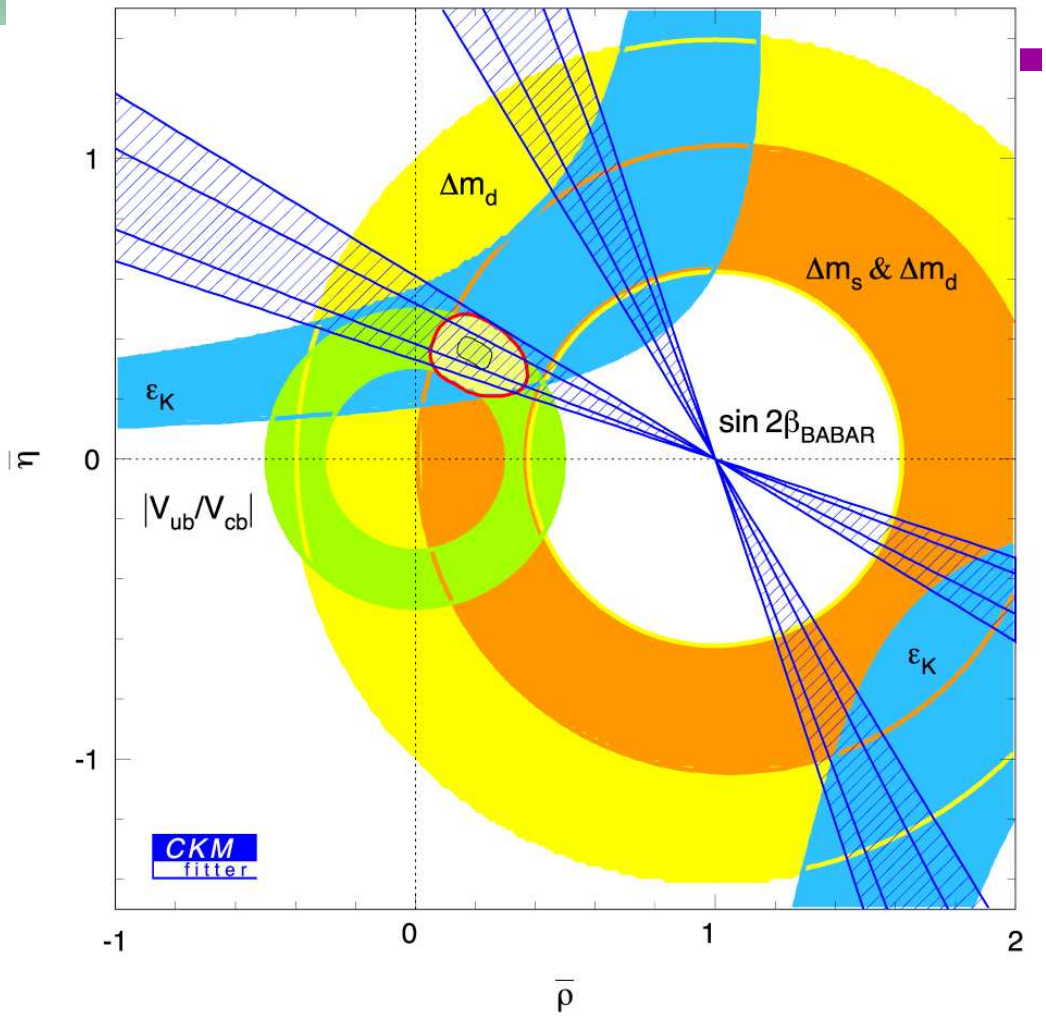
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CP Violation

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



# CKM Matrix




- Current Constraints:
  - $\varepsilon_K$ from $A(K^0_L \rightarrow \pi^+\pi^-)/A(K^0_S \rightarrow \pi^+\pi^-)$
  - $V_{ub}$ from charmless B decay
  - $V_{cb}$ from $B^0 \rightarrow D^* l \nu$ decays
  - $\Delta m_d$ and $\Delta m_s$ from $B^0$ and $B_s^0$ oscillations

Douglas Wright
LLNL/BaBar
ICHEP, July 24, 2002

# CP Violation in $B^0$ 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 $B^0 \to J/\psi\ K_s$ decays to measure $\sin(2\beta)$

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

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

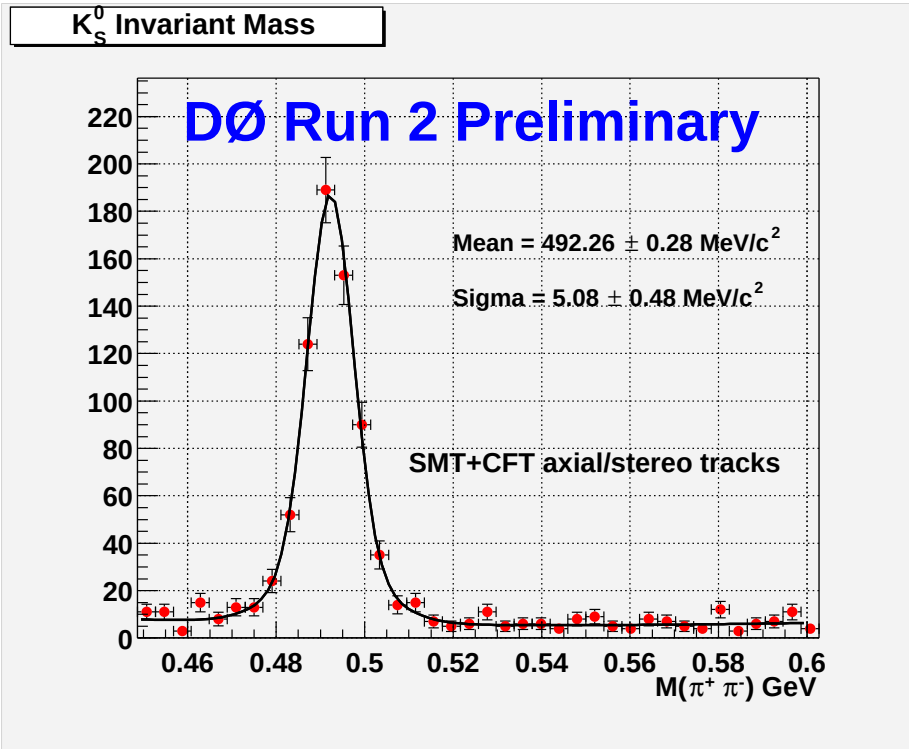
# sin(2β) Expectation for Run II

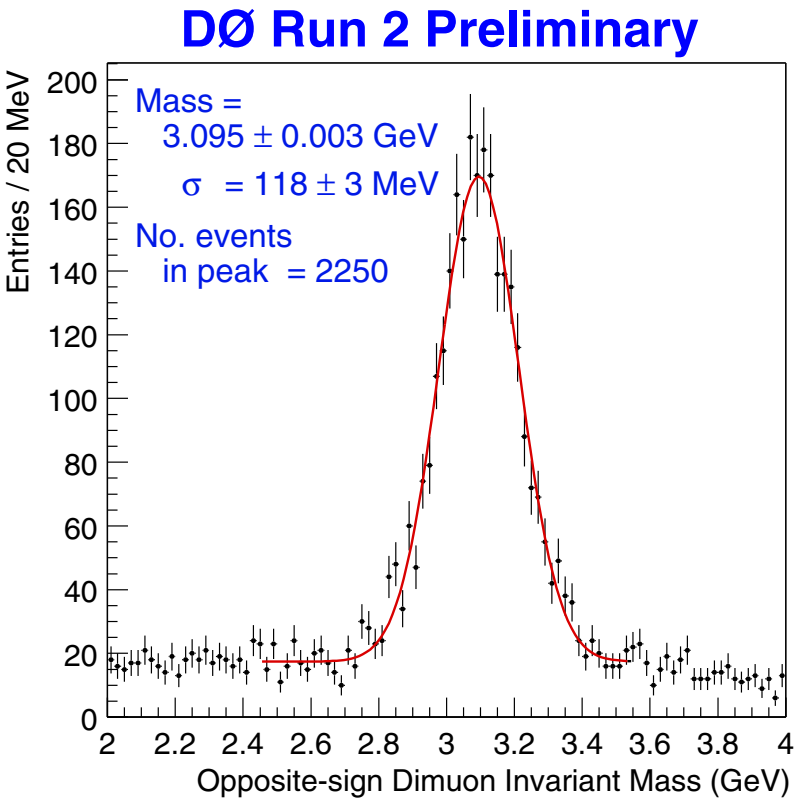
$$\sigma(\sin 2\beta) \approx e^{x_d^2 \Gamma^2 \sigma_\tau^2} \sqrt{\frac{1+4x_d^2}{2x_d^2}} \frac{1}{\sqrt{\varepsilon D^2 N}} \sqrt{\frac{S+B}{S}}$$

- Reconstruct 30K-40K $B^0 \rightarrow J/\psi\ K_s$ events in 2 $fb^{-1}$
- Expect $\sigma(\sin 2\beta) \approx 0.05$ due to
  - improved muon acceptance and lower trigger thresholds
  - improved flavour tagging (lepton ID)
  - forward tracking
  - trigger on $J/\psi \rightarrow e^+e^-$
- Result continues to be statistics limited due to size of tagging calibration samples

# sin(2β) Expectation for Run II

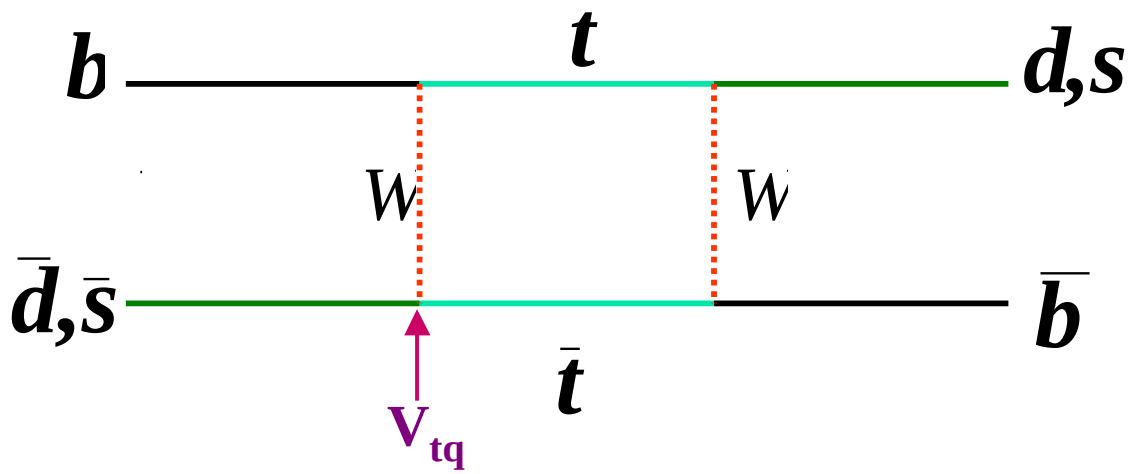
$K^0_s$ candidates with full track reconstruction




J/ψ candidates with full track reconstruction

# $B_s^0 - \bar{B}_s^0$ Mixing



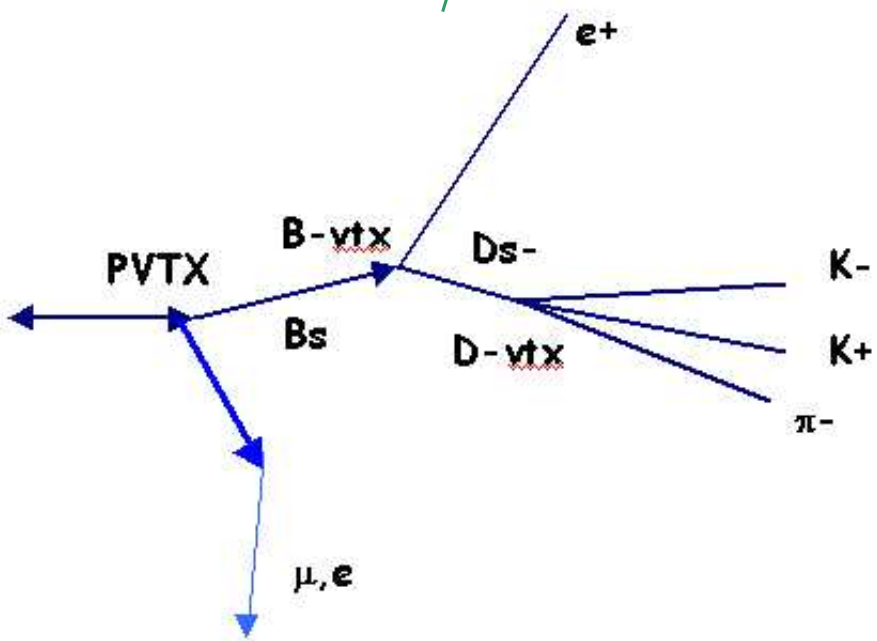

- Weak eigenstates ≠ mass eigenstates
- Mixing due to higher order corrections
- $\Delta m_s = m(B^0_{heavy}) - m(B^0_{light})$
- $P_{mixed}(t) = \frac{1}{2}(1-\cos\Delta m_s t)$, $\Delta m_s \propto |V_{tb} \bullet V_{ts}|^2$
- Mixing parameters $x_s = \Delta m_s / \Gamma_s$ and $\Delta\Gamma_s$

# $B^0_s$ Mixing Using Semileptonic Decays

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

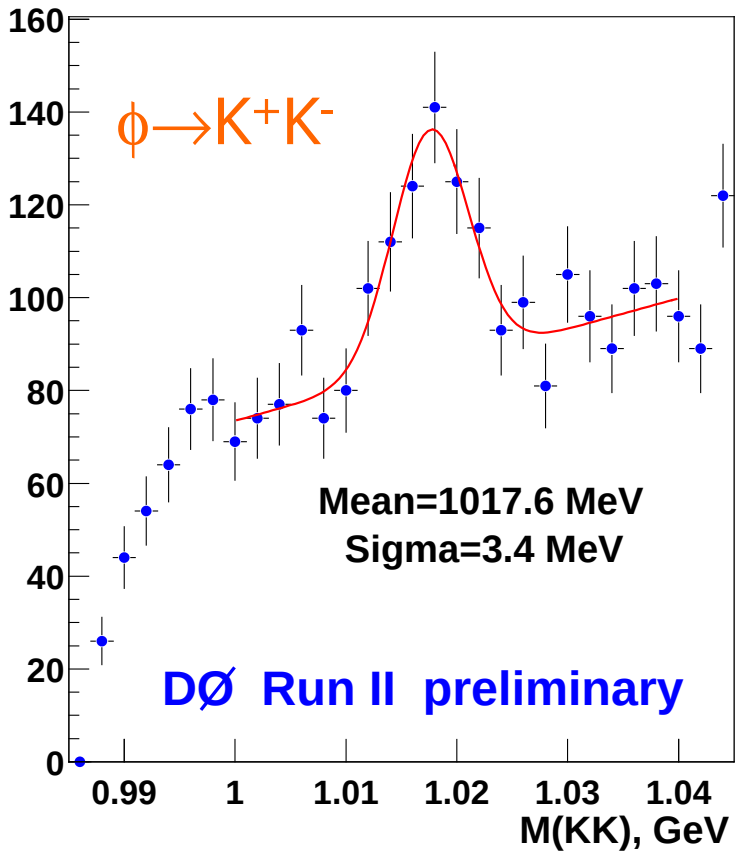
$$D_s^- \rightarrow \varphi \pi^-$$

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




- Trigger on single lepton or dilepton events
- Initial flavour tagged by charge of opposite side lepton, when available
- Final flavour tagged by same side lepton charge
- ~40 000 events in 2 $fb^{-1}$

# $B^0_s$ Mixing Using Semileptonic Decays




- Next step: reconstruct $D_s \rightarrow \phi\pi$ candidates in lepton events
- Find $B^0_s$ candidates and measure the proper decay time
- Limited proper time resolution due to neutrino

$$\frac{1}{\sigma(x_s)} = \sqrt{N\varepsilon D^2}\, e^{-(x_s\sigma_t/\tau)^2/2} \sqrt{\frac{S}{S+B}}$$

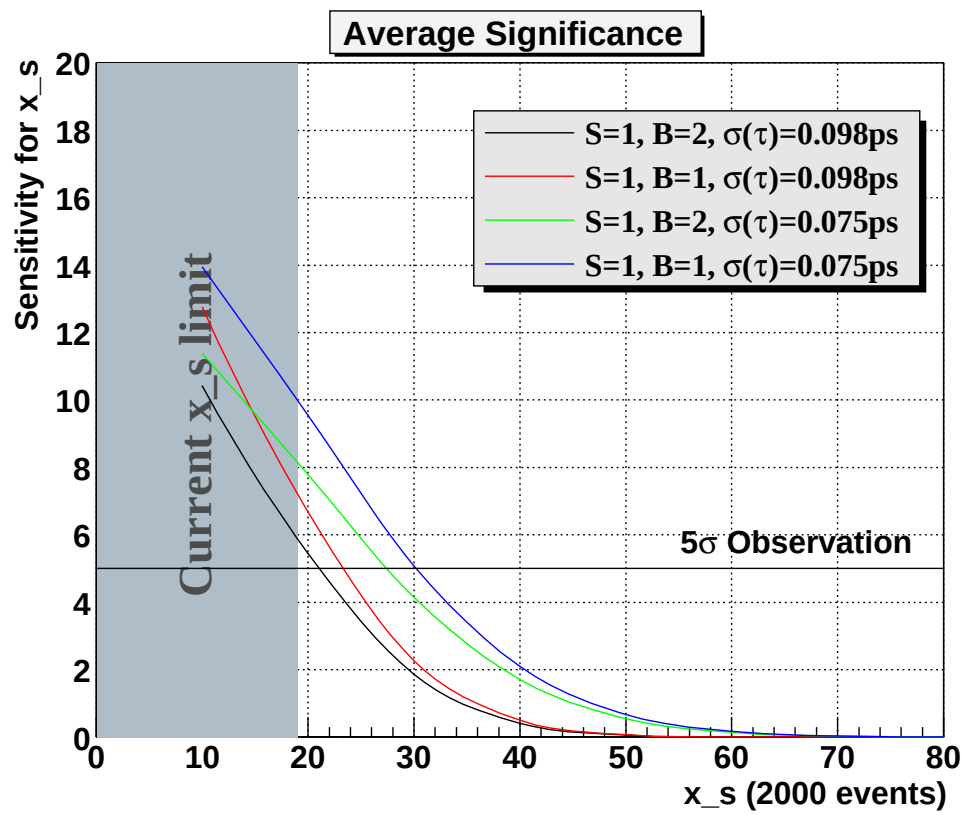
# $B^0_s$ Mixing Using Hadronic Decays

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

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

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

*no missing neutrino

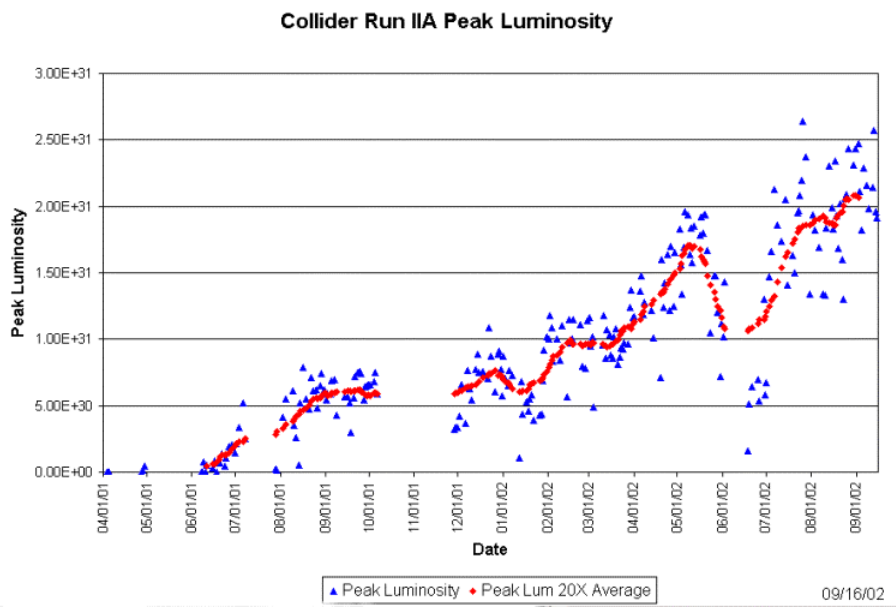


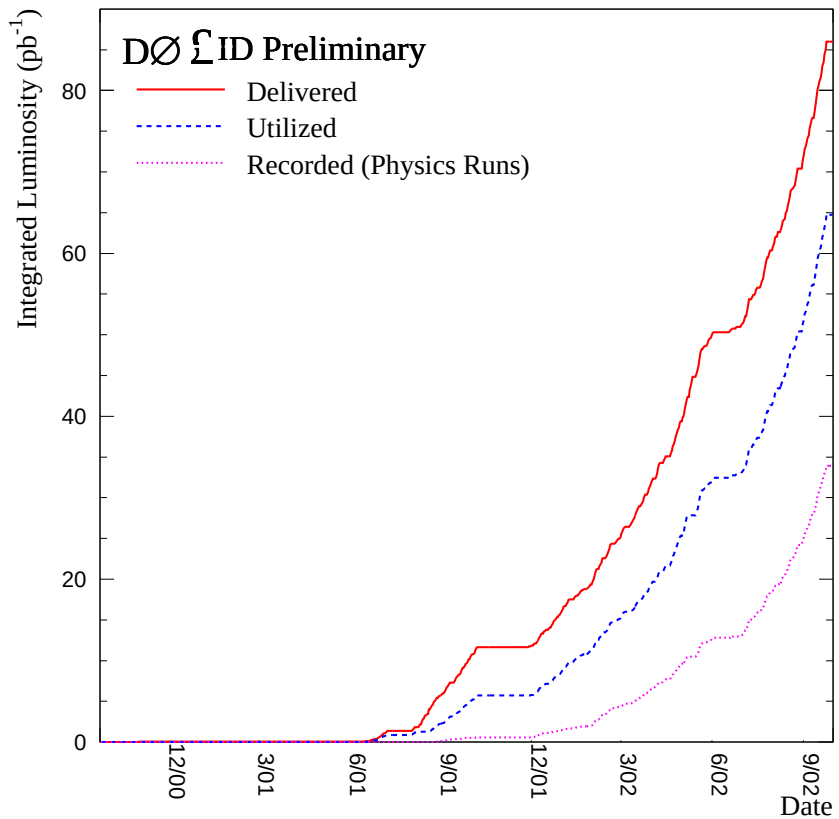

- Trigger on opposite side lepton
- Lepton charge tags initial flavour
- Final flavour tagged by charge of $D_s$

# Conclusions

- The DØ Run II detector is operating well
  - B group is anxiously awaiting the L1 central track trigger and the L2 silicon track trigger
- DØ is producing its first B physics results
- With 2 $fb^{-1}$ of data we will
  - probe $B_s$ mixing with semileptonic and hadronic decays up to $x_s \approx 30$
  - measure $\sin(2\beta)$ to an accuracy of 0.05
  - measure lifetimes for $B^+$, $B^0_s$ and $\Lambda^0_b$
  - rare decays and more!

# Tevatron Luminosity



# sin(2β) Expectation for Run II

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

For 2 $fb^{-1}$

- $\varepsilon D^2$~9.8%
- S/B~0.75
- $\sigma_\tau$~90 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 | |