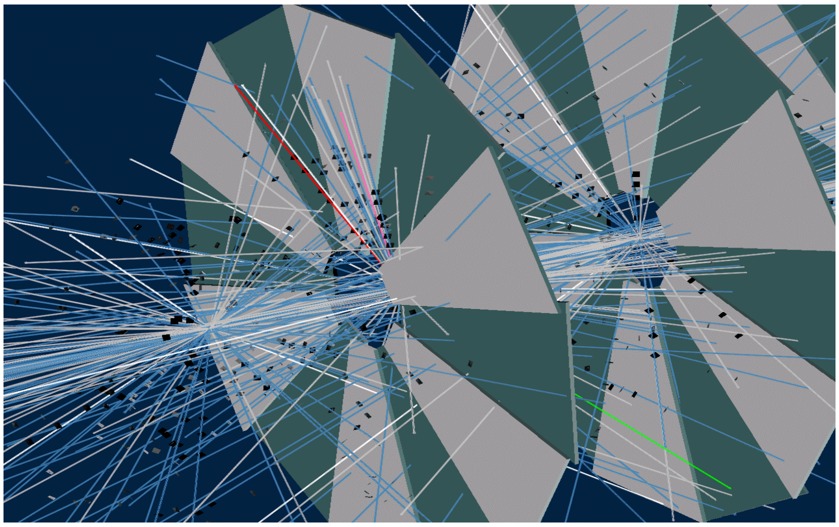
Prospects of Heavy Quark Physics in Run II with the DØ Detector



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Outline:

∗ Run I Physics Results - **Highlights**

∗ The DØ Detector Upgrade - **A Brief Overview**

∗ Top Quark Physics in Run II - **An Outline**

∗ Prospects of Beauty Physics in Run II

∗ Summary and Outlook

Run I Physics Results - Highlights

- The Run I was remarkably successful for DØ. Analysis of the Run I data is still in progress.
- Important physics contributions from DØ include Heavy Quark Physics (Top and Beauty), Electroweak Physics, Strong Interactions, and physics beyond the Standard Model.

Heavy Quark Physics

- Discovery of Top Quark: Mass = 172.1 ± 7.1 GeV/c^2
- Top Production: $\sigma_{t\bar{t}} = 5.9 \pm 1.7$ pb
- B-quark production cross section measurements

Electroweak and Other Physics

- W Boson mass and width measurements:
  $M_W = 80.43 \pm 0.11$ GeV/c^2
- Limits on diboson production:
  $WW, WZ, W\gamma, Z\gamma$
- Tests of QCD:
  Inclusive jet, dijet and photon productions, color coherence, etc.
- Limits on Supersymmetry:
  Squark, Gluino, Stop and Leptoquarks etc.

The DØ Upgrade

Physics Opportunities

- Precision measurements at high p_T:
  m_t, M_W, gauge couplings, QCD tests, Higgs search etc..
- New phenomena: SUSY, new generations, ...
- Capabilities at low p_T: B physics

Evolution of Tevatron

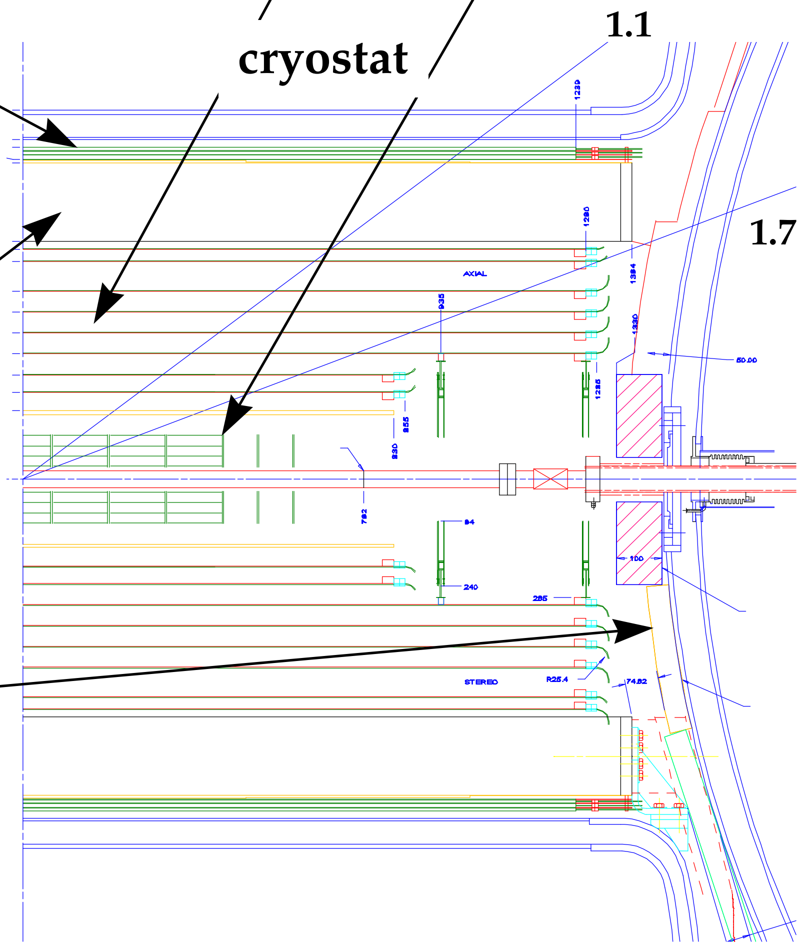
- Run I: $L_p = 1 - 2.5$ X10^{31}
  3.5 μs bunch xing time
- Run II (Spring, 2000): $L_p = 1 - 2$ X10^{32}
  Start with 396 ns and end with 132 ns bunch xing time

Impact on DØ

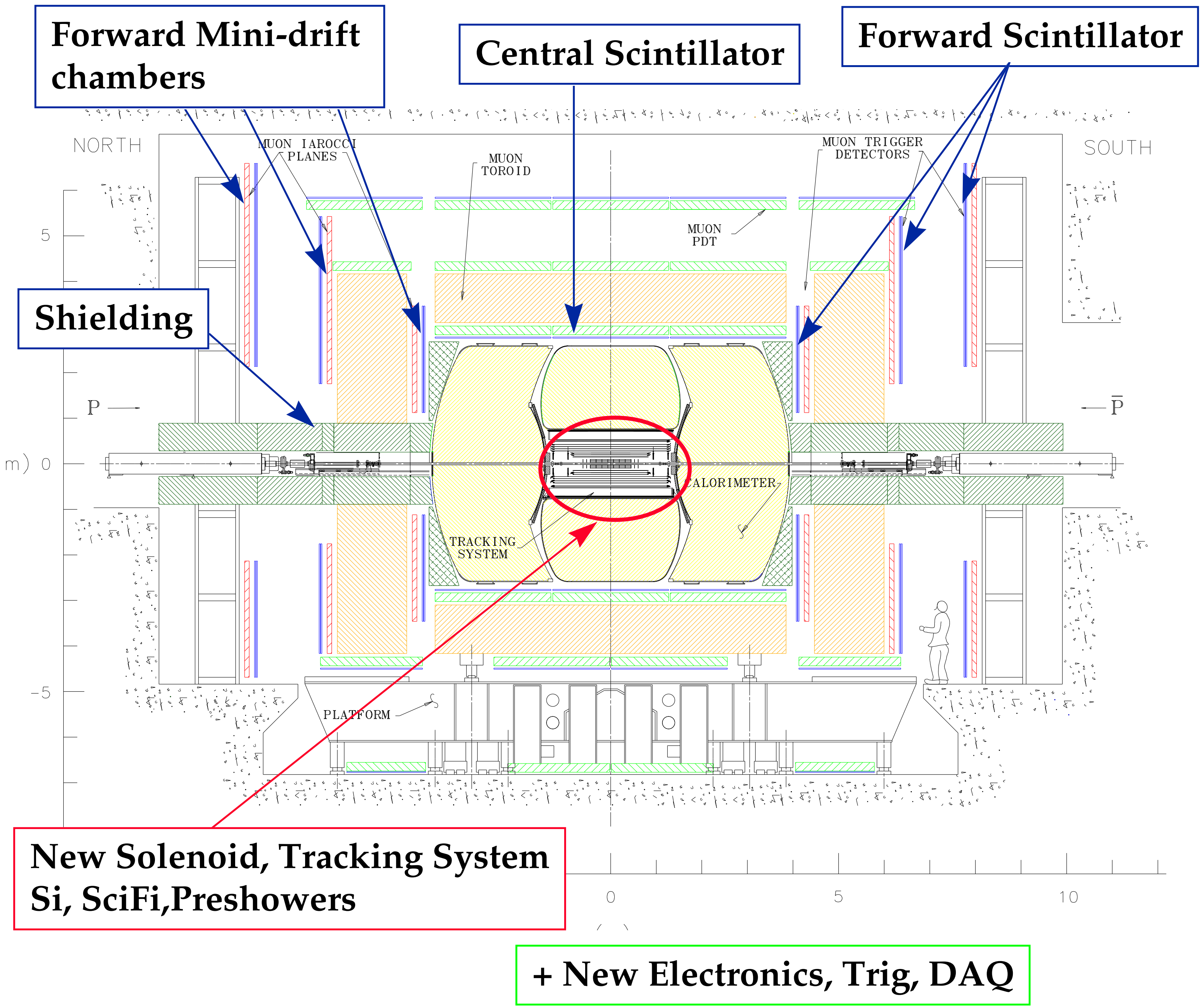
- High luminosity $\Rightarrow$ event pile-up, radiation damage
- Systems either upgraded: Cal, Muon, Trig/DAQ
  or replaced: Tracking System
- Solutions involve new detector technologies:
  Silicon Microstrip detectors, SciFi Tracker, Trigger processors
- Central Field 2T Solenoid:
  E/p for electron ID, Calorimeter calibration, low p_T triggering
- Improved b tagging

The D0 Upgrade - Tracking

- **Silicon Tracker**
  - Four layer barrels (double/single sided)
  - Interspersed double sided disks
  - 840,00 channels
- **Fiber Tracker**
  - Eight layers sci-fi ribbon doublets (z-u-v, or z
  - 74,000 830um fibers w/ VLPC readout
- **Central Preshower**
  - Scintillator strips, WLS fiber readout
  - 6,000 channels
- **Solenoid**
  - 2T superconducting
- **Forward Preshower**
  - Scintillator strips, stereo, WLS readout
  - 16,000 channels



D0 Upgrade


Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
Shielding
New Solenoid, Tracking System
Si, SciFi,Preshowers
+ New Electronics, Trig, DAQ
NORTH
SOUTH
MUON IAROCCI PLANES
MUON TOROID
MUON TRIGGER DETECTORS
MUON PDT
CALORIMETER
TRACKING SYSTEM
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Upgrade Performance Goals

Tracking System

- Secondary vertex resolution for b-jets:
  σ = 40 μm in r-ϕ; 100 μm in r-z
- Improved momentum resolution for all tracks:
  $\delta p_T/p_T$ = 5%, 18% for p_T = 10, 100 GeV/c
- Enhanced triggering, ID and sign determination for electrons

Muon System

- Lower thresholds (no prescale):
  Single muon $p_T > 4$ GeV/c; dimuon $p_T > 3$ GeV/c
- Reduced backgrounds and triggering with additional shielding

Calorimeter

- Comparable performance at 2 X 10^{32}
  Run I rate = 2 X 10^{31}
- Ability to calibrate in situ (E vs p now available)

Electronics

- Increased bandwidth - an order of magnitude improvement:
  10 kHz at L1, 800 Hz at L2, 10-20 Hz to tape
- Silicon track trigger - a new addition

Top Physics in Run II

The DØ had remarkable success in discovering the top quark (along with CDF) during Run I. The study of the top quark has just begun. Run II looks highly promising for a number of reasons:

- Tevatron energy will be increased from 1.8 $\rightarrow$ 2.0 TeV:
  $\Rightarrow$ top cross section goes up by $\approx$ 40%

$$\sigma(p\overline{p} \rightarrow t\bar{t} + X) = 8.0 \text{ pb}$$
$$\sigma(p\overline{p} \rightarrow t \text{ or } \bar{t} + X) = 4.2 \text{ pb}$$

- The gain in integrated luminosity:
  Run II luminosity is expected to be 2 fb^{-1}.
- Lepton p_T Resolution:
  A factor of at least 2 improvement for muons.
- Tagging of b-jets:
  Secondary vertex + soft muon tagging $\sim$ 90% ($t\bar{t}$)
- Tau Identification:
  Magnetic tracking + selection alogrithm $\sim$ by a factor of 2!
- The great deal of experience gained from Run I:
  Will be readily available for Run II.

The expected yields in Run II for various top channels are summarized below (the channels are labelled by the W decays):

Channel	Yield ($\int \mathcal{L}\, dt = 2\ fb^{-1}$)	Signal:Bkg.
Dilepton	200	**5:1**
Lepton + $\geq$ 3 jets / b-tag	1400	**3:1**
Lepton + $\geq$ 4 jets / b-b tags	600	**12:1**
Single top (combined)	330	**1:2**

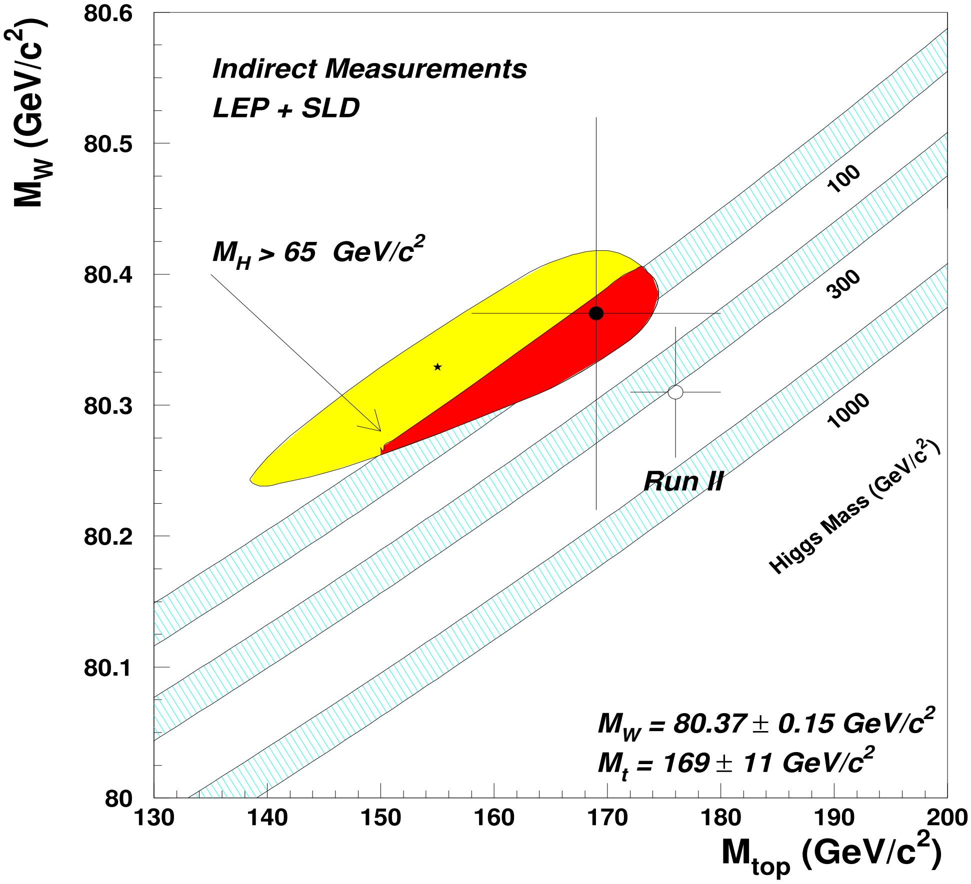
Top Mass Measurement in Run II:

In Run I, the top quark mass measurement is limited by both statistics and systematics. The systematic uncertainity of ($\pm$ 6.2 GeV/c^2) is dominated by:

- Jet energy scale - 4.0 GeV
- Background modeling - 2.5 GeV
- MC modelling - 1.9 GeV

In Run II, the top quark mass measurement will be limited mostly by the systematic uncertainities. This will be improved in Run II:

- Calibration of jet escale using data: $Z + jet$, $\gamma + jet$, $W \rightarrow jj$
- Reduction of jet combinatorics by using events with 2 b-tags
- Constraining top production modelling using data



The expected uncertainties in the top quark mass measurement in Run II will be:

Source	Uncertainity (GeV)
Statistical	**1.0**
Jet energy scale	**2.6**
Top Modeling	**1.9**
Backgrounds	**0.5**
Total	$\approx$ **3**

The precise determination of the top quark mass combined with the W mass will provide more stringent constraint on the Higgs mass.

Single Top Production:

The study of electroweak production of single top can be useful for a number of interesting measurements:

- The top width can be measured directly.
- The CKM matrix element V_{tb} can be measured directly:
  The single top cross section $\sigma(q\bar{q} \to tb)$ α $|V_{tb}|^2$.
- Cross check for top quark mass:
  Fewer uncertainties due to multi-jet combinatorics.

Run II Prospects

For a luminsoity of 2 fb^{-1}, we estimate the following measurements using parton level study of the signal and background:

- Measure σ(single top) with a precision of 19%.
- $\Gamma(t \to W + b)$ with a precision of 27%.
- $\delta|V_{tb}|$ with a precision of 14%.

Top Physics: Run II Topics

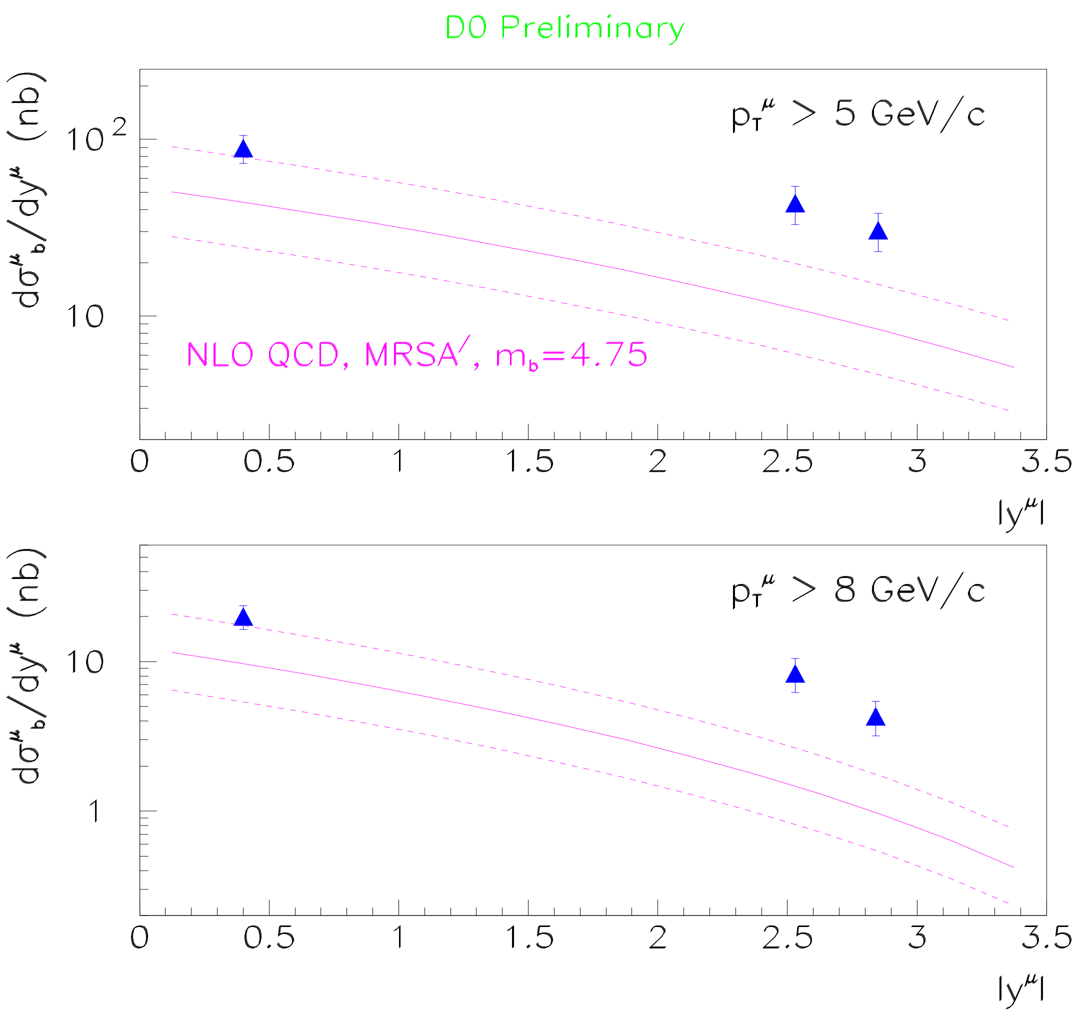
- Wtb vertex: $\delta B(t \to bW_{long}) \approx 3\%$
- Top spin correlations:
  Non-zero measurement $\Rightarrow$ set lower limit on top width.
- Measurement of $|V_{tb}|$: about 14% level.
- Branching fractions
- Top quark rare decays -
  Standard Model:
  (1) $\to Wb + g/\gamma$ (g/γ angular distributions, rates etc.)
  (2) $\to Wb + Z$
  (3) $\to Wb + H^0$
  (4) $\to W + s/d$ (CKM matrix elements)
  Non Standard Model:
  (1) $\to c/u + g/\gamma$ (FCNC)
  (2) $\to c/u + Z$ (FCNC)
  (3) $\to c/u + H^0$ (FCNC)
  (4) $\to H^+ + b$ (SUSY)
  (5) $\to \tilde{\tau} + \tilde{Z}$ (SUSY)

There will be a lot of interesting top quark and new physics from the next Tevatron Run.

Prospects of B Physics in Run II

Despite the lack of a magnetic field and a vertex detector, DØ has made some significant contributions to B physics.

- **Inclusive b-quark production cross section**
- **J/ψ production cross section**
- **Search for rare B decay:**
  BR($b \rightarrow X_s \mu^+ \mu^-$) < 3.2 X 10^{-4} at 90% CL.



In Run II with the upgraded DØ detector, there will be significant improvements in the B physics capabilities with the addition of precision tracking, muon detector upgrade, central magnetic field, enhanced triggering and tagging techniques. This impacts on all areas of B physics including reconstruction efficiency and B tagging. The cross section for $b\bar{b}$ production in Run II will be $\approx\ 100\mu b$.

Projected Run II Measurements:

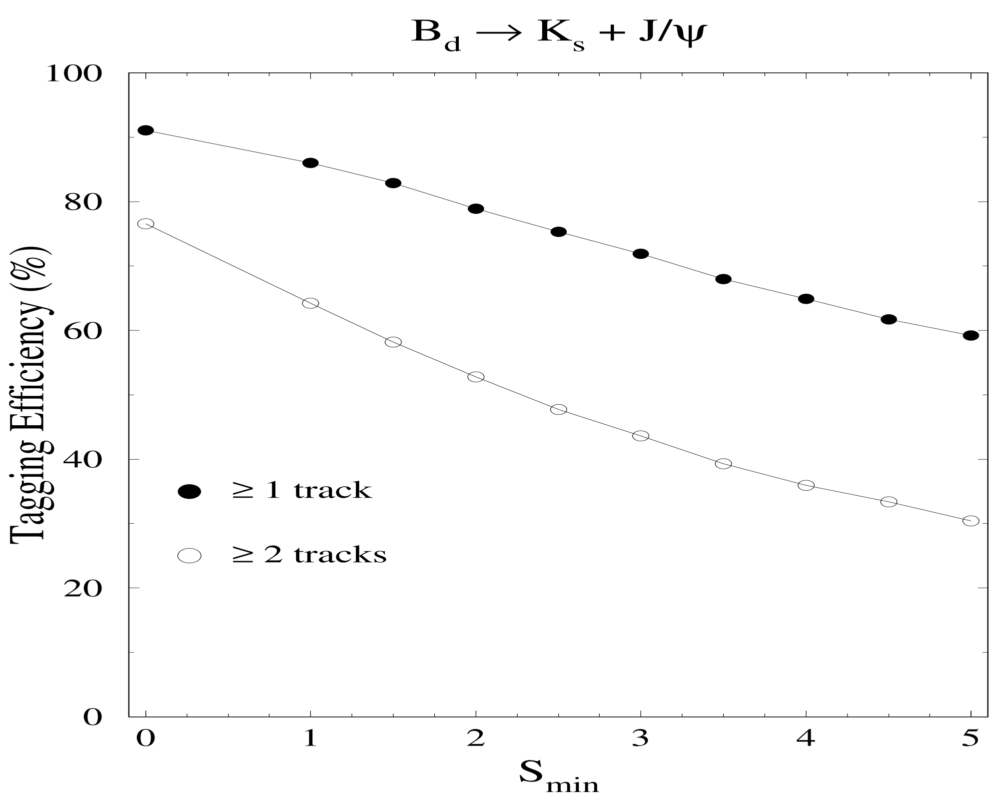
- B hadron masses and lifetimes:
  $B^{\pm}$, B^0, B_s, Λ_b
- Time integrated CP asymmetry:
  $B_d^0 \rightarrow K_s^0 + J/\psi \Rightarrow$ Angle β of the CKM unitary triangle
- Search for B_s mixing:
  $B_s^0 \rightarrow D_s + n\pi^{\pm}$ or $B_s^0 \rightarrow D_s^- + l^+ + X$
- B_c meson: Mass and lifetime
  $B_c \rightarrow J/\psi\ \pi$
- Search for rare B meson decays:
  $b \rightarrow X_s\mu^+\mu^-$; $B \rightarrow \mu^+\mu^-$

B-tagging:

The silicon will allow to tag B decays using displaced secondary vertices or tracks with large impact parameters. The expected impact parameter resolution in the transverse plane is:

$$\sigma(d_0) = (12.6\mu m)^2 + (36.6/\text{p}.\sin^{3/2}\theta)^2$$

Using a simple B tagging algorithm based on the number of tracks with a significance greater than S_{min} with track quality cuts: p_T >0.5 GeV/c, $|\eta| < 1.6$, and at least 3 layers of hits in the SMT. The tagging efficiency vs S_{min} is shown below.



Triggering on $B_d^0 \to K_s^0 + J/\psi$:

We have investigated a number of possible triggers useful in Run II using the known bandwidth limitations at level 1 (10 KHz) and level 2 (1 KHz):

- Study the trigger response using a sample of events generated with ISAJET and passed through GEANT.
- Background trigger rate simulation using QCD dijet events with minimum bias interactions overlayed on the primary interaction to give multiple interactions.
- Compute trigger rates with assumption of $\mathcal{L} = 10^{32} cm^{-2} s^{-1}$ and beam crossing time of 132 ns.

We have simulated the trigger efficiencies for the following 2 triggers. The results are summarized in table below.

- Single muon trigger - $p_T^{\mu} > 4$ GeV, $|\eta| < 2$.
- Dimuon trigger - $p_T^{\mu} > 2$ GeV for both muons.
- The rate of single muon trigger can be controlled using the silicon track trigger at level 1 with good signal efficiency (∼80%).

Trigger	L2 Bkg. (Hz)	$\epsilon(J/\psi K_s^0)\%$
Single muon trigger	38.6	**23.9**
Dimuon + STT trigger	7.6	**14.9**
Single + Dimuon triggers	45.0	**31.9**

CP Asymmetry Study: $B^0 \to J/\psi K_s^0$

The observed asmmetry can be written as:

$$A_{obs} = D_{mix} D_{tag} D_{bkg} A_{cp}$$

with D_{mix}, D_{tag}, , D_{bkg} denoting the dilution factors due to mixing before the B^0 decay, mistagging, and backgrounds respectively. The actual time integrated asymmetry A_{cp} = -$D_{t-int} sin2\beta$, $D_{t-int} = x_d/(a + x_d^2) \approx 0.47$ $(x_d = 0.71)$. With $D_{bkg} = \sqrt{S/(S+B)}$, the sensitivity for measuring $\sin 2\beta$ is:

$$\delta(sin2\beta) = \frac{1}{D_{mix} D_{tag} D_{t-int}} \frac{1}{\sqrt{\epsilon_{tag} N_{rec}}} \sqrt{\frac{S+B}{S}}$$

where $D_{mix} = 0.73$, ϵ_{tag} is the flavor tagging efficiency and N_{rec}, the number of reconstructed events.

Simulation:

- ISAJET, $b\bar{b}$ events at $\sqrt{s}$ = 2.0 TeV with $p_T(b/\bar{b}) = 2 - 100$ GeV with forced decays: $B^0 \to J/\psi K_s^0 \to \mu^+\mu^-\ \pi^+\pi^-$.
- Fast Kinematic cuts: $|\eta_{\mu,\pi}| < 2.0$ and $p_T^\mu > 1.5$ GeV, and $p_T^\pi >$ 0.5 GeV.
- $\int \mathcal{L}\, dt$ = 2 fb^{-1} $\Rightarrow$ we expect a sample of 33K events before trigger and reconstruction.

CP Sensitivity:

- Starting with 33K events, a trigger efficiency of 32% and assuming a reconstruction efficiency of 95% per particle, the number of reconstructed decays N_{rec} **will be about 9000**.
- Flavor tagging with one muon ($p_T^\mu > 1.5$ GeV, $|\eta_\mu| < 2.0$) $\Rightarrow$

$$\epsilon_{tag} = 5.6\%; \;\; D_{tag} = 0.5; \;\; \epsilon_{tag} D_{tag}^2 = 0.014$$

- With **signal/background = 1**, the CP sensitivity is:

$$\delta(sin2\beta) = 0.28$$

- If we include other possible flavor tagging algorithms such as: **jet charge** (CDF: $\epsilon_{tag} D_{tag} = 0.03$), **same side pion** (CDF: $\epsilon_{tag} D_{tag} = 0.02$), **electron** (CDF: $\epsilon_{tag} D_{tag} = 0.007$) to increase the $\epsilon_{tag} D_{tag}^2$ to 5%, the resulting sensitivity is:

$$\delta(sin2\beta) = 0.15$$

- There is room for improvement by adding other triggers and possible tagging techniques.

Summary and Outlook

The DØ upgrade is well on its way and matched to the schedule determined by the Main Injector project (Spring, 2000).

- The DØ Upgrade builds on the good features of the present DØ detector (**calorimetry, hermeticity, coverage**). Addition of high precision tracking, central magnetic field will greatly enhance the **physics capabilities** of the DØ detector. All systems are designed to run at high luminosity (10^{32}) and reduced bunch spacing (**132 ns**).

- Due to excellent **muon detection, momentum and secondary vertex resolutions along with high luminosity and b tagging mechanisms**, DØ detector is poised to become an important facility for heavy quark (Top and Beauty) physics in Run II.

- Looking forward to exciting physics in Run II and beyond (**discoveries, precision measurements, ...**)