B-Physics & Trigger at the DØ experiment - operational experience

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Overview

- **Detector**
  - RunIIa detector.
  - RunIIb: High luminosity challenges.

- **Triggers**
  - Trigger system.
  - $B$-Physics triggers.

- **Summary**
The upgraded DØ Detector

- Forward mini drift chambers
- Central Scintillator
- Forward Scintillators
- Shielding
- Solenoid, CFT, SMT, Preshowers
- New Electronics, Trig, DAQ
Muon system

Main features:
- 3 layers of drift tubes.
- 3 layers of scintillators: triggering, improved resolution in wire direction, rejection of cosmics.
- Toroid magnet (1.8 T) after the first layer: local $p_T$ measurement (trigger).
- Toroid and solenoid polarities reversed on regular basis.
- Track matched muons up to $|\eta| < 2.2$
Central Fiber Tracker (CFT)

16 doublet layers of scintillating fibers, arranged in 8 superlayers

Radius 20 – 52 cm

Track reconstruction up to $|\eta| < 2.0$

CFT standalone used for triggering at lowest trigger level.
Silicon Microstrip Tracker (SMT)

Hybrid design: 6 barrels with 8 layers (+ Layer 0), 12 F-Disks, 4(2) H-Disks

Essential for $b$-physics trigger and analysis:
Tracking, primary and secondary vertex reconstruction, impact parameter.
Design provides tracking up to $|\eta| < 3.0$, but
- Most analyses also require tracks to have hits in the CFT.
- H-disks had high rate of failure, most forward disks have now been decommissioned to make room for Layer 0 readout cables.
Silicon Microstrip Tracker Layer 0

30% improvement in impact parameter resolution vs RunIIa → great news for $b$-physics

Impact parameter resolution from cosmics: 21 $\mu$m

Commisioned and up and running.
Calorimeter

Designed for high $p_T$ physics, but
- Muons reconstructed in calorimeter enhance $J/\psi$ signal by 10%
- Low $p_T$ electrons used in tagging

$\varepsilon D^2(\mu) = 1.48\%$
$\varepsilon D^2(e^-) = 0.21\%$
Results

With this detector we have seen all sorts of $b$.....

$\Lambda_b$

excited $B$

$B_s$

$B_d$

$B^{*}$

$B_{s2}$

$\Upsilon$

+$B^+, B_c, X(3872), ...$
DØ b-physics publications

- Search for the Rare Decay $B_s \to \Phi \mu^+ \mu^-$ with the DØ Detector, PRD 74, 031107 (2006)
- Direct Limits on the $B_s$ Oscillation Frequency, PRL 97, 021802 (2006)
- Measurement of the ratio of $B^+$ and $B^0$ meson lifetimes, PRL 94, 182001 (2005)
- Measurement of the $\Lambda_b$ lifetime in the decay $J/\psi \Lambda$ decays..., PRL 94, 102001 (2005)
- A search for the flavour-changing neutral current decay $B_s \to \mu^+ \mu^-$, PRL 94, 071802 (2005)
- Measurement of the $B_s$ lifetime in the exclusive decay channel $B_s \to J/\psi \Phi$, PRL, 94, 042001 (2005)
- Observation and Properties of the $X(3872)$ Decaying to $J/\psi \pi^+ \pi^-$..., PRL 93, 162002 (2004)
- Measurement of the lifetime difference in the $B_s$ system, PRL 95, 171801 (2005)
- Measurement of semileptonic branching fractions of $B$ mesons to narrow $D^{**}$ states, PRL 95, 171803 (2005)
Challenges ahead: Increasing instantaneous luminosity

Peak Luminosities RunIIa

RunIIb
Challenges ahead: Increasing instantaneous luminosity

Occupancy of first Layer in CFT

Predicted effect of high lumi on muon-to-track matching efficiency

→ Keep the noise down!
→ AFEII boards
Challenges ahead: Increasing instantaneous luminosity

- Reconstruction of the events dominated by track finding.
- The same tracking algorithm has to run at all luminosities!

The graph shows the reconstruction time vs initial luminosity for RunIIa and RunIIb. The graph indicates that so far, so good with unbiased single muon triggers prescaled.
Triggers
The DØ trigger system

Detector → L1 Trigger → L2 Trigger → L3 Trigger → Reconstruction Farm

- L1 Trigger: 2kHz
- L2 Trigger: 2kHz
- L3 Trigger: 1kHz
- Calorimeter Digitization Rate: <50Hz> 250kB/ev
- SVXII chip Digitization Rate: 1.7 MHz

Reconstruction Farm
Level 1 triggers

**Calorimeter:** 0.2x0.2 $\eta$-$\phi$ triggers towers ($+E_T$)

**Central Track Trigger (CTT):** uses axial layers of the CFT to find tracks
4 $p_T$ bins

Tracks can be confirmed by muon hits.

**Muon:** Looks for hits (wire & scintillator) consistent with muons.

Level 2 triggers

- Refine L1 trigger terms using added event information (e.g. wire and scintillator times for muons).
- Results are combined in a global L2 term.
- Silicon Track Trigger for displaced vertices, improved momentum measurement.
**Silicon Track Trigger**

- L1 CTT tracks are used to define roads into the SMT.
- SMT hits are clustered in these roads.
- Track is refit within the road.

→ Improved $p_T$ measurement wrt L1.
→ Impact parameter measurement.

**Under-used by $b$-physics in RunIIa:**
- Impact parameter bias difficult to model/analyze.
- (Planned) late commissioning: Triggers already well established with sufficient rate reduction.
- No displaced track only trigger due to L1 bandwidth limitations.

**RunIIb:** $b$-physics and Higgs group are the main users of the STT.
**Trigger System: Level 3**

- Software based.
- Goal: To perform a (partial) reconstruction of the event.

**Tools of the trade:**
- muons
- electrons
- tracking
- taus
- jets
- missing $E_T$
- primary & secondary vertexing
- isolation (muons, electrons)
- impact parameter (tracks, muons)
- invariant mass

... and almost any combination thereof.
Doing b-physics at a multi-purpose experiment

Trigger strategy:
- The trigger menu needs to accommodate all physics groups.
- Most physics aiming for maximum *luminosity* on a given trigger.
- Most $b$-physics needs the maximum of $b$-events.
**b-physics triggers at DØ**

In RunIIa there were 3 major groups of *b*-physics triggers:
- single muons, impact parameter unbiased ('low' lumi)
- single muons with impact parameter requirement (all luminosities)
- di-muons (all luminosities)

Additionally:
- tri-lepton
- electron-muon
- muon+jets

Apart from requiring one or more **muons**, the *b*-physics triggers also use the following trigger requirements:
- track match for muons: tracks required to have SMT hits
- tracks (number of tracks, $p_t$)
- impact parameters (for muons and/or tracks)
- invariant mass filters: $\Phi$, $J/\psi$, $\Upsilon$
- charge (opposite sign)
- primary vertex: ± 35 cm
Triggers – timing is (almost) everything

$b$-physics triggers often require low $p_T$ tracks → triggers are intrinsically slow:
• optimize trigger ordering
• move rate reduction from L3 to L1/L2 (e.g. STT)

RunIIb tracker 3 x faster than RunIIa tracking, but still not fast enough:
→ More CPUs.
The RunIIa $b$-physics programme has been a great success!

By playing to our strengths, i.e. making optimal use of our wide muon coverage and upgraded tracking system, DØ

- published 10 $b$-physics papers (out of 39 DØ publications), including the world's best measurement of the $B_s^0$ lifetime.
- 3 papers currently submitted and 19 preliminary results, a lot of which have been presented during this conference.

- Results are also available on the web: http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm
- Increasing luminosity is a challenge and an opportunity.
- Layer 0 working as expected.
- High expectations for RunIIb.

\[ \bar{t}(B_s^0) = 1.53 \pm 0.08^{+0.01}_{-0.04} \text{ps} \]
Anatomy of three 'best-of' (late) RunIIa triggers

**unbiased single muon trigger** (up to $55 \times 10^{30}$, $100 \times 10^{30}$ RunIIb)
- semileptonic decays, mixing
- L1: tight scintillator, loose wire, $p_T > 3$ GeV (from CTT), primary vertex
- L2: one medium muon (RunIIb: track match requirement)
- L3: track matched, 3-layer muon with $p_T > 3,4,5$ GeV, $|z|$ (primary vertex) $< 35$ cm

**single muon trigger with impact parameter** (all luminosities)
- use muon for tagging to avoid IP bias in the signal (hadronic decays)
- L1: tight scintillator, loose wire, $p_T > 5$ GeV (from CTT), primary vertex
- L2: one medium muon (RunIIb: track match requirement)
- L3: track matched 3-layer muons with IP significance $> 3$ and $p_T > 5$ GeV $|z|$ (primary vertex) $< 35$ cm

**di-muon trigger** (all luminosities)
- $J/\psi$ (e.g. $\Delta \Gamma/\Gamma$), $Y$, $B_s \rightarrow \mu \mu$
- L1: 2 muons, no $p_T$ cut, (RunIIb: one match to a CTT track required)
- L2: one or two muons, depending on luminosity
- L3: 2 muon system only muons, $p_T > 2$ GeV, one or two muons must have hits in all 3 layers.