The DØ Detector in RunII: First Results and Prospects

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MPI Kolloquium, 29.10.02
DØ’s Roll-In on January 25th 2001
The Work of Many People...

- The DØ detector was built and is operated by an international collaboration of ~550 physicist from 18 nations
- Truly international since RunII
  - >50% non-USA

- Find the speaker in the picture...
The DØ Collaboration

- U. of Arizona
- U. of California, Berkeley
- U. of California, Riverside
- Cal State U., Fresno
- Lawrence Berkeley Nat. Lab.
- Florida State U.
- Fermilab
- U. of Illinois, Chicago
- Northern Illinois U.
- Northwestern U.
- Indiana U.
- U. of Notre Dame
- Iowa State U.
- U. of Kansas
- Kansas State U.
- Louisiana Tech U.
- U. of Maryland
- Boston U.
- Northeastern U.
- U. of Michigan
- Michigan State
- U. of Nebraska U.
- Princeton U.
- Columbia U.
- U. of Rochester
- UNY
- Stony Brook
- Brookhaven Nat. Lab.
- Langston U.
- U. of Oklahoma
- Brown U.
- U. of Texas, Arlington
- Texas A&M U.
- Rice U.
- U. of Virginia
- U. of Washington

- U. of Buenos Aires
- LAFEX, CBPF, Rio de Janeiro
- State U. do Rio de Janeiro
- State U. Paulista, São Paulo
- U. San Francisco de Quito
- Charles U., Prague
- Czech Tech. U., Prague
- Academy of Sciences, Prague

- ISN, IN2P3, Grenoble
- CPPM, IN2P3, Marseille
- LAL, IN2P3, Orsay
- LPNHE, IN2P3, Paris
- DAPNIA/SEP, CEA, Saclay
- IRs, Strasbourg
- IPN, IN2P3, Villeurbanne

- U. of Aachen
- Bonn U.
- IOP, U. Mainz
- Ludwig-Maximilians U. Munich
- U. of Wuppertal

- Panjab U., Chandigarh
- Delhi U., Delhi
- Tata Institute, Mumbai
- University College, Dublin

- KDL, Korea U., Seoul
- CINVESTAV, Mexico City

- FOM-NIKHEF, Amsterdam
- U. of Amsterdam/NIKHEF
- U. of Nijmegen/NIKHEF

- JINR, Dubna
- ITEP, Moscow
- Moscow State U.
- IHEP, Protvino
- PNPI, St Petersburg

- Lund U.
- RIT, Stockholm
- Stockholm U.
- Uppsala U.

- Lancaster U.
- Imperial College, London
- U. of Manchester

- HCIP, Hôchiminh City
Outline

• The Fermilab Tevatron collider upgrade
• The DØ detector upgrade for RunII
• Performance of the new detector
• First results from ~ 10 pb-1 of physics quality data
Fermilab’s Accelerator Chain

1.96 TeV

CDF

DØ

Main Injector & Recycler

p source

Booster

Tevatron

Chicago

p

p
Tevatron RunII Parameters

- Large increase in parton luminosity (cf. structure of proton)
  - Delivered beam luminosity
  - Increased cms-energy
    - e.g. \( \sigma(t \bar{t}) \) by ~35\% larger

- Detector challenges
  - Large occupancies and event pile-up (multiple interactions and previous bunch-crossings)
  - Radiation hardness

<table>
<thead>
<tr>
<th></th>
<th>Run 1b</th>
<th>Run 2a</th>
<th>Run 2b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunches in Turn</td>
<td>6 x 6</td>
<td>36 x 36</td>
<td>140 x 103</td>
</tr>
<tr>
<td>( \sqrt{s} ) (TeV)</td>
<td>1.8</td>
<td>1.96</td>
<td>1.96</td>
</tr>
<tr>
<td>Typical L (cm(^2)s(^{-1}))</td>
<td>1.6 x 10(^{30})</td>
<td>8.6 x 10(^{31})</td>
<td>5.2 x 10(^{32})</td>
</tr>
<tr>
<td>( \int L dt ) (pb(^{-1})/week)</td>
<td>3.2</td>
<td>17.3</td>
<td>105</td>
</tr>
<tr>
<td>Bunch xing (ns)</td>
<td>3500</td>
<td>396</td>
<td>132</td>
</tr>
<tr>
<td>Interactions / xing</td>
<td>2.5</td>
<td>2.3</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Run 1 \( \rightarrow \) Run 2a \( \rightarrow \) Run 2b
0.1 fb\(^{-1}\) \( \rightarrow \) 2–4 fb\(^{-1}\) \( \rightarrow \) 15 fb\(^{-1}\)
The Upgraded DØ Detector

- Forward Mini-drift chambers
- Central Scintillator
- Forward Scintillator
- Shielding
- New Solenoid, Tracking System
  - Si, SciFi, Preshowers
- + New Electronics, Trig, DAQ
muon chambers

front end electronics
Liquid Argon Calorimeter

- Liquid argon sampling with uranium absorber
  - Cu/Steel for coarse hadronic
  - Fine spatial segmentation
    - $\Delta \eta \times \Delta \eta = 0.1 \times 0.1$ (=0.05x0.05 in EM3)
  - Hermetic with full coverage
    - $|\eta| < 4.2$
- New readout electronics
  - Shaping time reduced
- Energy resolution (RunI)
  - Electrons
    - $\sigma_E / E = 15% / \sqrt{E[GeV]} \oplus 0.3%$
  - Hadrons
    - $\sigma_E / E = 80% / \sqrt{E[GeV]}$

Thomas Nunnemann
Prel. RunII Calorimeter Performance

- Calorimeter calibrated using
  - Resonances: $J/\psi$, $Z$
  - Photon+jet events
- Missing transverse energy resolution affected by warm/hot cells, noise
  - Expect improvements

2-jet event

$E_{T\text{jet}1} \sim 230$ GeV
$E_{T\text{jet}2} \sim 190$ GeV

$D\bar{O}$ Run 2 Preliminary

$J/\Psi \rightarrow \text{ee}$

$M = 2.98$ GeV
$\sigma = 166$ MeV

Di-photon Data

Multijet data
Muon System

Major upgrade in forward region
Central and forward regions, coverage up to $\eta = \pm 2$
- Three layers: one inside, two outside the toroid magnets
- Consists of scintillators (trigger) and drift tubes
- Central Proportional Drift Tubes (PDTs)
  - 6624 drift cells ($10.1 \times 5.5$ cm) in 94 three- and four-deck chambers
- Central Scintillation Counters
  - 360 counters outside toroid ($\Delta \phi = 22.5^\circ$)
  - 630 inside ($\Delta \phi = 4.5^\circ$, $\Delta \eta = 0.1$
- Forward Mini Drift Tubes (MDT’s)
  - 6080 8-cell tubes in 8 octants per layer on north and south side
- Forward Scintillation Counters (Pixels)
  - 4214 counters on the north and south side
  - $\Delta \phi = 4.5^\circ$ matches the MDT sector size
The Forward Scintillation Counters
Muon System Performance I

- $Z \to \mu\mu$ candidate
  - Charged tracks in tracker
  - MIP in calorimeter
  - Hits in all three muon system layers
Muon System Performance II

- Transverse momentum resolution of muon system is degrading for large muon momenta
- Matching of muons reconstructed in muon system to central tracks improves resolution

\[ M = 3.08 \pm 0.04 \text{ GeV} \]
\[ \sigma = 0.78 \pm 0.08 \text{ GeV} \]
Upgraded DØ Tracking System

- 2T Super-Conducting Solenoid
  - Run I without solenoid
- Silicon Microstrip Tracker
  - 4 layer barrels (double/single sided)
  - Disks (in between and forward reg.)
  - 793,000 channels
- Central Fiber Tracker
  - 8 cylinders with axial and stereo doublet layers of scintillating fibers
  - 76,800 channels with VLPC readout
- Central Preshower
  - 3 layers triangular strips behind solenoid and 1 $X_0$ Pb
  - 8,000 channels
- Forward Preshower
  - 4 layers triangular strips, in front of and behind 2 $X_0$ Pb
  - 16,000 channels
Silicon Microstrip Tracker

- Very high resolution measurements of particle tracks near beam pipe (point resolution: 10 µm)
- Track reconstruction to $\eta = 3$
- Track impact parameter trigger (STT)
Silicon Tracker: Barrel Assembly

- ladder (layer 4)
- beryllium bulkhead
- cooling channel
- carbon fiber half-cylinder support
SMT Performance

- Good S/N
- 95% of channels are working
  - Incl. dead sensors
- Hit efficiency >97%

**Silicon cluster charge**

- Noise < 2
- ADC counts 1 mip ~ 25
- ADC counts
  \[ \Rightarrow \text{S/N} \sim 12 \]

**Charge correlation for double sided sensor**
Silicon Only Tracking

$K^0_S \rightarrow \pi^+ \pi^-$

$\Lambda \rightarrow p^+ \pi^-$
Central Fiber Tracker

- **8 cylinders**
  - Carbon fibers with Rohacel core
  - Axial and stereo double layers of scintillating fibers
  - Stereo angle: ±3°
  - 76,800 channels
  - Radius: 20 cm – 51 cm

- **300 wave guides**
  - Read out scintillating fibers via curved connectors
  - à 256 fibers
  - Length 8 m – 11.5 m

- **readout with VLPCs**
  - Visible Light Photon Counter
Routing of Clear Fiber Light Guides

~200 light guides on each side

Installation completed

Installation completed

MPI Kolloquium, 29.10.02
Visible Light Photon Counter

- Optical readout of fibers with Visual Light Photon Counters (VLPC)
  - Si doped with As (band gap 0.05 eV)
    - Operation at cryogenic T: ~ 9 K
  - Excellent performance
    - High quantum efficiency: ~ 85% within visible spectrum (up to IR)
    - High gain: up to 65,000 electrons per captured photon
      - Single photo-peaks visible
    - Low noise and gain dispersion

8 pixel VLPC chip
(pixel ø: 1mm)
CFT Performance

- Light yield depends upon path length through scintillator.
- CFT+SMT combined tracks:
  - Increased resolution
  - $20 \rightarrow 5$ MeV for $K_S \rightarrow \pi^+ \pi^-$

$Z \rightarrow ee$ candidate:
$M(\text{ee}) = 89.9$ GeV
Three Level Trigger System

Decision times: ~4.2 μs ~100 μs ~50 ms

Detector

2.3 (7.5) MHz
5 kHz
1 kHz
L1 Trigger L2 Trigger L3 Trigger

L1 L1CAL L2Cal

L1 FPS L2PS

L1 CTP L2CFT L2STT

L1 Muon L2 Muon

L1FW: towers, tracks, correlations

Level 1
- Subdetectors
- Towers, tracks, clusters, $E_T$
- Some correlations
- Pipelined

Level 2
- Correlations
- Calibrated Data
- Separated vertex
- Physics Objects $e, \mu, j, \tau, E_T$

Level 3
- Simple Reconstruction
- Physics Algorithms

L3/DAQ Tape

L2FW: Combined objects ($e, \mu, j$)
Trigger Turn-On

- Electron trigger

- Jet trigger
**RunII Luminosities**

- **Design:**
  - Typical luminosity: 
    \[ L = 8.6 \times 10^{31} \text{cm}^{-2}\text{s}^{-1} \]
  - Weekly integrated luminosity: 
    \[ \int L = 17.3 \text{pb}^{-1} \]

- **Beam delivered Luminosity:** 
  \[ \int L \approx 100 \text{pb}^{-1} \]
  - Large fraction used for commissioning

- First results from about 10pb-1 of physics quality data!
RunII Physics Program

- **Heavy flavour physics**
  - B spectroscopy (mixing, CP violation)
  - Production cross sections
- **QCD**
  - Differential jet production cross sections
  - Diffraction (c.f. Forward Proton Spectrometer)
- **Elektroweak**
  - W mass and width precision measurement
  - Di-, tri-Vectorboson production, anomalous couplings
- **Top**
  - Mass, cross section, spin correlations
  - Single top production
- **Higgs**
  - Searches in mass window (110 –180) GeV
  - Will we get the chance?
- **New Phenomena Searches**
  - SUSY
  - Technicolor, leptoquarks, large extra dimensions …
First Results: Heavy Flavour

- $J/\psi$ cross section measurement
  - Luminosity: ~5 pb-1
  - Rapidity region extended

**Dzero Run2 PRELIMINARY**
- $pT(J/\psi)>5\text{GeV}/c$
- $pT(J/\psi)>8\text{GeV}/c$

CDF Run1 results
- $17.4 \pm 2.8 \text{ nb}$
- $2.7 \pm 0.4 \text{ nb}$
First Results: B-Physics

B average lifetime measurement from inclusive J/ψ
• Measured lifetime consistent with the world average
• Measured: $c \tau = (492 \pm 37) \, \mu m$
• PDG: 469 \mu m

Proper B decay length ($B \rightarrow J/ψ + X$)

Exclusive B reconstruction
• $B^+ \rightarrow J/ψ \, K^+$
• First time in DØ

[Graphs showing data, backgrounds, and signal contributions for proper decay length and mass distributions]
Prospects for QCD

- Increased cms-energy boosts cross-section for processes with large momentum
- Prospects:
  - Structure functions at large $x$
  - Quark compositeness, $W'$, $Z'$

- Run I: Inclusive jet cross section at cms-energy of 1.8 GeV
- Good agreement with NLO QCD
First Results: QCD

- Only statistical errors
- Luminosity $L = 5.8 \text{ pb}^{-1} (\pm 10\%)$
- Preliminary jet energy scale
  - 30-50% syst. error in cross section
- Not fully corrected
  - for unsmearing, efficiencies

Inclusive jet $p_T$ spectrum

DØ preliminary

Cone algorithm, $R = 0.7$

$|\eta| < 0.4$

$0.4 < |\eta| < 0.7$
First Results: Electroweak

- W and Z boson production
- Measurement of production cross section at increased center of mass energy in electron channel
- W\rightarrow ev event characteristics
  - Distributions well described by MC

Z\rightarrow ee invariant mass peak
W and Z Production Cross Section

- **Data Sample:**
  - Luminosity: ~7.5pb⁻¹
  - 9205 W candidates
  - 328 Z candidates

- **Measurement of production cross sections**

- **W width can be derived from cross section ratio.**

\[ \Gamma_W = (2.26 \pm 0.18_{\text{stat}} \pm 0.29_{\text{syst}} \pm 0.04_{\text{theory}}) \text{GeV} \]

- **Cross section measurements**

\[ \sigma_Z \times B(Z \rightarrow ee) = 266 \pm 20_{\text{stat}} \pm 20_{\text{syst}} \pm 27_{\text{lumi}} \text{ pb} \]

\[ \sigma_W \times B(W \rightarrow ev) = 2.67 \pm 0.06_{\text{stat}} \pm 0.33_{\text{syst}} \pm 0.27_{\text{lumi}} \text{ nb} \]
Topics for Top Physics

- Top mass and cross section precision measurement (strong interaction)
- First measurement of single top production (weak interaction)
  - Derivation of $|V_{tb}|$
- Helicity of W in decay
- Spin-correlation
- Rare decays
- ….

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<th>2fb$^{-1}$</th>
<th>15fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_t$</td>
<td>2.9%</td>
<td>1.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>$\sigma$(ttbar)</td>
<td>25%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>$W$ helicity, $F_0$, $F_+$</td>
<td>0.4, 0.15</td>
<td>0.09, 0.03</td>
<td>0.04, 0.01</td>
</tr>
<tr>
<td>$R=BR(t\rightarrow Wb)/BR(t\rightarrow Wq)$</td>
<td>30%</td>
<td>4.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>$</td>
<td>V_{tb}</td>
<td>$, limit at 90% C.L.</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>$\sigma$(single-top)</td>
<td>-</td>
<td>20%</td>
<td>8%</td>
</tr>
<tr>
<td>$\Gamma(t\rightarrow Wb)$</td>
<td>-</td>
<td>25%</td>
<td>10%</td>
</tr>
<tr>
<td>$</td>
<td>V_{tb}</td>
<td>$</td>
<td>-</td>
</tr>
<tr>
<td>$BR(t\rightarrow \gamma q)$</td>
<td>0.03</td>
<td>2 x 10$^{-3}$</td>
<td>2 x 10$^{-4}$</td>
</tr>
<tr>
<td>$BR(t\rightarrow Zq)$</td>
<td>0.30</td>
<td>0.02</td>
<td>2 x 10$^{-3}$</td>
</tr>
</tbody>
</table>
W, Top Mass: Status and Prospects

- Run II projections (optimistic)
  - 2 fb-1: $\Delta m(W) \sim 30$ MeV, $\Delta m(\text{top}) \sim 2$ GeV
  - 15 fb-1: $\Delta m(W) \sim 15$ MeV, $\Delta m(\text{top}) \sim 1$ GeV
Constraint on Higgs Mass

- Indirect constraint on Higgs Boson mass with the masses of top and W

![Graph showing the constraint on Higgs mass with RunII projection and LEP data points.](image)
Higgs Hunting at Tevatron

- Standard Model predictions
- Inclusive Higgs production x-section is quite high: ~1pb
  - For masses below ~140GeV: dominant decay \( H \rightarrow bb \), swamped by background
  - At higher masses, can use inclusive production plus \( WW \) decay

- Best prospects below ~140GeV using associated production of \( H \) plus \( W \) or \( Z \)
  - Leptonic decay of \( W/Z \) give needed background rejection
  - Cross section ~0.2pb
Search for Higgs in $H \rightarrow WW$ Channel

- Why $H \rightarrow WW$ at low luminosities?
  - 4th fermion family enhances SM Higgs cross sections by a factor of ~8.5 for Higgs mass between 100-200 GeV
  - Fermiophobic Higgs: $B(H \rightarrow WW) > 98\%$ for $m_H \geq 100$ GeV

- Search for $ee + E_T$ events
- Understand Backgrounds for SM Higgs Search
- Develop tools necessary for the analysis of larger data sets
- Measure azimuthal opening angle between the leptons
  - Due to spin anti-correlation smaller in Higgs signal as compared to SM background

**DØ Run 2 Preliminary**

- Data
- $WW$
- Multi-jet
- $W+\gamma$
- $Z/\gamma$
- $tt$
- $W+$jets
Combined Higgs Mass Reach

That will be the main focus of RunIIb.
Search for Phenomena beyond the SM

- Many analyses in progress:
  - Like-sign di-leptons
  - Jets+Missing $E_T$
  - Tri-lepton signatures:
    - One of the cleanest signatures of SUSY
    - E.g. from chargino+neutralino decay
  - GMSB in diphoton plus missing energy channel
  - Leptoquarks searches
    - Prel. first generation LQ limits
  - Large extra dimensions
  - …
The Future: Run IIb

- Present detector was designed for $\sim 2-4 \text{fb}^{-1}$ integrated and $\sim 2 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$ instantaneous Luminosity
- Run 2b goal $\sim 15 \text{fb}^{-1}$ before LHC Physics
  - Physics motivations: Higgs and Supersymmetry
  - Exceeds radiation tolerance of existing Silicon detector
  - Requires higher instantaneous luminosities, $\sim 5 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$, trigger upgrades

Silicon Upgrade
- Replace Silicon Detector with a more radiation-hard version
- New Silicon tracker with innermost layer at 1.78 cm (c.f. 2.71 cm in Run 2a)
- Maintain good pattern recognition coverage $|\eta| < 2$

Trigger Upgrade
- Upgrade L1 Track Trigger to narrow roads, improve Track-Cal. matching
- Upgrade L1/2 Cal. Trigger to use digital filter, isolation, shape cuts
- Incremental upgrades to Level 2, Level 3 Triggers and online system
Conclusion

• Tevatron and DØ are back for real physics operation.

• Enormous progress made over the last year
  ◆ detector performance optimization
  ◆ developing analysis tools

• First physics results at cms-energy of 1.96 TeV
  ◆ Many more analyses progressing

• Improvements in store:
  ◆ optimization of event reconstruction and selection procedures
  ◆ triggers and DAQ performances
  ◆ calibration and alignment of the detectors

• Looking forward to large integrated luminosity!