DØ Run 1

Timeline


1983: Saclay joins DØ (we became international) – Ducros, Hubbard, Mangeot, Mansoulié, Teiger, Zaccone, Zylberstejn.

1984: Baseline DOE review; conceptual design of detector approved.

1984 – 1989: Test beam demonstrations of calorimeter, tracking, muon, DAQ.


1990: Submit proposal for DØ upgrade for Run 2.

14 April, 1992: First collisions with full detector.

24 Feb. 1995: Submit “Observation of the Top Quark” to PRL (403 authors, 42 institutes).


1984 meeting of collaboration; we were few!

Armand Zylberstejn and Yves Ducros.

Saclay said “If we don’t run in 1988, we will have to leave” (Fortunately for us all, this collaboration held together to the lasting benefit of us all).
Central detectors – Vertex Drift Ch., Transition Radiation Detector (Saclay), Central Dr. Ch., Forward Dr. Ch. No solenoid in tracking region.

U LAr Calorimetry – CC, ECN, ECS; 4 EM and ~4 hadronic longitudinal readout gangs; $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ transverse segmentation. Main ring accelerator beam goes through outer calorimetry (the beam pipe is still there!).

Muon System – 1.1 – 1.5m iron toroids (1.8T) in central ($|\eta|<1$), ends ($1<|\eta|<2.6$), & forward ($2.6<|\eta|<3.6$). 4 layers PDT before Fe, two sets of 3 layers after Fe. (replace forward PDT in Run 2)

Trigger – Interaction trigger/luminosity monitor + 2 levels of trigger. Level 1 based on fast signals from calorimeter and muon detectors; Level 2 $\mu$processor using fully digitized events.
Run 1 Detector

DØ Hall construction -- 1986

Toroid construction (recycled Newport News cyclotron steel)

Installing PDTs

Waiting for collisions, April ‘92
Retired Run 1 tracking elements

First collisions seen in D0 (Nov. 1988) – test module of central drift chamber

VDC

CDC

FDC
Transition Radiation Detector, ret.

TRD inside CDC

X-ray converter and charge collection chamber

Xe/CH4 conversion gap

polypropylene foils

Flash ADC time distribution of TRD response to electrons & pions (CERN test beam). Pion rejection > 50:1

Charge clusters from converted X rays drifted to anode wires
Calorimetry

Longitudinal signal ganging and percussively welded indium wires for HV connections.

CCFH module being ‘vacuum cleaned’ to remove U dust.

Routed G-10 signal board
Small Angle Muon System (SAMUS), ret.

SAMUS proportional tube chamber

SAMUS inside End Muon system (replace with shielding in Run 2)

SAMUS toroids
Run 1 Physics

New Phenomena  QCD  b-physics

Electroweak  Top

132 Run 1 Physics publications:
38 New Phenomena
32 QCD
7 b physics
31 Electroweak
21 Top
3 Detector

Run Ia (92-93): 15 pb⁻¹
Run Ib (94-95): 88 pb⁻¹
Run Ic (96): 13 pb⁻¹
Total (at √s = 1.8 TeV): 116 pb⁻¹
+ 0.46 pb⁻¹ at √s = 630 GeV

Efficiency of operation:
Record 96% of delivered luminosity
outside of Main Ring in Dφ
71% overall efficiency

Record 150M events to tape
QCD Physics

DØ reach in $Q^2 - x$ plane: focus on pQCD at high $Q^2$ (and selected non-pQCD studies at low $p_T$)

Inclusive jet XS: (Pub 101) Good data-theory agreement with CTEQHJ or MRSTg↑ (enhanced gluon content). No evidence for excess high $E_T$ cross section as suggested by CDF.

Also: Inclusive photons; jet ratio 630/1800 GeV; color coherence; dijet mass; dijet angular distributions; kT jets; subjets; azimuthal decorrelations; BFKL pomeron dynamics
Diffractive Physics

Seek diffractively produced $W/Z$ (Pub. 125) (Pomeron exchange) with standard $W/Z$ selection (no extra vertices) and a significant rapidity gap containing no particles in region $(2.5 \leq |\eta| \leq 5)$. Use both the forward EC towers and the LØ counters to define the rapidity gaps from a two dimensional fit.

$W/Z$ kinematic distributions agree with those in hard interactions.

Significance of the diffractive signal:
$W$: 7.5$\sigma$ (first observation)
$Z$: 4.4$\sigma$ (first evidence)

Fractions of events with rapidity gaps: 0.89 +/- 0.25% ($W$); 1.44 +/- 0.80% ($Z$).

The gap fractions are inconsistent with quark-dominated pomeron (expect > 15% gap fraction) but are consistent with non-perturbative soft gluon emissions.

On average, the diffracted proton loses 5% of its energy in the collision.
Heavy Flavor Physics

Study of central $J/\psi$ allowed measurement of $p_T$ distribution, extraction of $b \to J/\psi$, and evidence for finite lifetime of the $b$ component (Pub 25).

Observation of $J/\psi$ in SAMUS gave unique measurement of $d\sigma/d\eta$ to $|\eta| = 3.5$ (Pub 60).

Though “b-physics” in Run 1 was a far cry from the lovely b-physics in Run 2, the excellent $J/\psi$ trigger and reconstruction laid the basis for the current results.
Electroweak Physics

Many limits on anomalous WWγ, ZZγ, Zγγ couplings, and first demonstration that the UE(1) couplings for WWγ do not describe the data; W and Z cross sections, direct and indirect ΓW measurements. The highlight was the sequence of MW measurements.

MW measurement followed the pioneering work by UA2. Use transverse mass, electron pT (and missing ET) templates as function of mW from fast MC to fit to data.

Must calibrate the electron energy scale (Z, J/ψ, Y); correct for energy in electron window due to underlying event, calorimeter noise, pedestal effects; parameterize the recoil energy using Z→ee; correct for radiative effects.

Best mT fit
(Run 1b CC)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>mW</th>
<th>ΔmW</th>
<th>cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1a CC</td>
<td>80.35</td>
<td>±0.27</td>
<td></td>
</tr>
<tr>
<td>Run 1b CC</td>
<td>80.44</td>
<td>±0.12</td>
<td>80.43±0.11</td>
</tr>
<tr>
<td>EC</td>
<td>80.691</td>
<td>±0.227</td>
<td>80.482±0.091</td>
</tr>
<tr>
<td>CC module edge</td>
<td>80.574</td>
<td>±0.405</td>
<td>80.483±0.084</td>
</tr>
</tbody>
</table>

(Almost reached 1 o/oo precision by 1 expt in 1 channel)

Run 1 Tevatron: 80.454±0.059

LEP average: 80.450±0.039
Searches for New Phenomena

Searches for new particles predicted by many beyond the SM theories:

Leptoquarks – generations 1 and 2 (lljj, lνjj) and combined

Susy – squark/gluino in MET+jets, lepton + jets
  Wino/Zino trileptons, dileptons
  top squarks
  bottom squarks
  GMSB gauginos
  GMSB photons
  R-parity violating couplings

Right-handed W

Heavy W,Z

4th generation b-quark

Leptophobic Higgs

Large extra dimensions (di-EM, monojets)

Anomalous trilinear couplings

Magnetic monopoles

Model independent searches (SLEUTH)

Excellent Run 1 MET resolution key for many searches.

Nothing Found!
DØ made substantial improvement in limiting anomalous $ZZ\gamma$, $Z\gamma\gamma$ couplings by using the $Z \rightarrow \nu\nu$ channel. The final state was a single high $p_T$ photon. The trick (Pub. 34) was to use the fine transverse and longitudinal segmentation in the EM calorimeter to point the photon to the primary vertex (and the H-matrix photon ID): $\sigma(z_{vtx})=14$ cm

This technique then enabled the search for magnetic monopoles (Pub. 56).

Cross section enhanced (over QED processes) due to large monopole charge, $g = 2n\pi/e$.

Require 2 photons, low MET, no jets. Photons must point to primary vertex.

See 90 events (88 expected, mainly Drell Yan with mis-ID electrons).

Apply an optimized $S_T$ cut that is expected to yield 0.4 events (maximize probability for seeing no events if no signal).

No data events observed: Set limits on spin 0, $\frac{1}{2}$, 1 monopoles.
Top quark – preliminaries

From the Department of un-enviable (but unbeatable) records:

In 1994, DØ (Pub. 3) set the world’s highest lower limit on the top quark mass of 131 GeV.

15 pb⁻¹ using eμ, ee, e+jets, μ+jets channels.
Saw 3 events with 4.9 expected background.
But the eμ event was striking: \( p_T(e)=99 \text{ GeV} \).
\( p_T(\mu)>40 \text{ GeV} \) (95% CL), MET>54 GeV (95% CL), \( E_T(\text{jet 1})=25 \text{ GeV} \), \( E_T(\text{jet 2})=22 \text{ GeV} \), (+ third minijet).

We noted this event looked like top, smelled like top, quacked like top” in the paper:

“We have analyzed the surviving eμ event under the hypothesis that it is due to ttbar. (It) is consistent with ttbar production over the mass range 100 to 200 GeV. … the likelihood is maximized for a top mass of about 145 GeV. The result is consistent with, but independent of, our lower limit on \( m_t \).”
Top quark – home stretch

In mid-1994, CDF announced their ‘Evidence’ for top with $\sigma_t = 13.9^{+6.1}_{-4.8}$ pb.

DØ Pub 17 (finally published in PRD three weeks after the discovery paper!) reported a newly optimized search for high mass top (>131 GeV) which added the $\mu\mu$ dilepton channel, and expanded the $\ell$+jets channels to include both topological selection (introducing the aplanarity and $H_T$ variables) and a soft muon tagged selection.

With 14 pb$^{-1}$, 9 events were observed with $3.8\pm1.9$ expected. If interpreted as $tt\bar{t}$, $\sigma_t = 8.2\pm5.1$ pb (at $M_t = 180$ GeV) – more consistent with the SM.

No limit was obtained in this analysis.

“Our measurement, although consistent with the CDF result ['Evidence'] does not demonstrate the existence of the top quark.”

The expected DØ yield at this stage, as reported in the August 1994 ICHEP conference in Glasgow, was comparable to (slightly better than) CDF.

Summer 1994: Tevatron fixed a rolled magnet; Lumi went up x2, and further tuning gave another x2.

January 1995 Aspen meeting: DØ with 25 pb$^{-1}$, showed real hint of signal but still using old selection optimization. CDF updated the sample to 50 pb$^{-1}$ knowing that this should be sufficient. DØ went to 50 pb$^{-1}$ and newer selection.
Top quark – discovery

Feb. 24 1995, simultaneous submission “Observation of the Top Quark” (Pub. 8): (published in 1 week)

Now using 50 pb⁻¹ and ee, μμ, eμ dilepton channels; e+jets, μ+jets both topological and b-tagged(μ).
Relative to previous analysis, increased p_T cuts on objects. Aplanarity and H_T again key ingredients in topological analysis.

Observe 17 events, expected background 3.8±0.6. 6 events had b-tag. Significance: Probability of background upward fluctuation 2x10⁻⁶ (4.6σ).

σ_t = 6.4±2.2 pb; M_t = 199±30 GeV

Fitted mass distributions – tight and loose cuts.

2-jet vs. 3-jet mass plots gave confidence that the excess was due to tt → W(jj)b W(ℓν)b
Are there lessons (e.g. for Higgs in Run 2)?

- Stable accelerator operations and improvements are the key ingredient.
- The amount of data needed to go from a bare hint to a discovery is not so much.
- With data in hand, people get clever (better selection criteria, better confirming evidence, improved statistical techniques …)
- Nature had better be kind!
Top quark commentary

Joint CDF/D0 description of discovery in SLAC BeamLine issue (Fall 1995).

In an editorial, J.D. Bjorken commented on the top discovery and the CDF/DØ competition and cooperation in getting there.

(I think this is the only published use of DØ’s 3-d event display package!)
Top quark commentary
by bj

The history of physics is full of near-simultaneous discoveries by separate individuals or groups, and with that often has come acrimony and controversy, from Newton and Leibnitz to Richter and Ting, and down to the present time. There has been competition between CDF and DØ as well. In fact, it was built in from the beginning by then-director Leon Lederman, who visited CERN’s big collaborations, UA1 and UA2, while they were discovering intermediate bosons W and Z and searching for the top quark. At CERN, it was vital to have two collaborations as checks and balances, and Lederman upon his return strongly encouraged the creation of the present DØ collaboration, something which was not in the works prior to that. And the ensuing CDF/DØ competition has served for constructive purposes; I have never seen this competitiveness to be corrosive. The evidence is in these pages for the reader to see, in the very fact of co-authorship and in the nature of the interactions between the collaborations as described in the article. This piece of competition has been a class act.

Not only has this been true between the collaborations, but it seems also to have been the case within them. This is no mean feat, since harmony within a big group of strong individualistic physicists of great talent and often even greater ego is not easy to maintain. I can do no better than quote here what is found near the end of the article, and I do this without regrets for creating some redundancy:

In the end, the chief necessity for the convergence on the top discovery was the willingness of a collaboration to abide by a majority view. Securing this willingness requires extensive attention to the process—of being sure that all shades of opinion, reservations, and alternate viewpoints are fully heard and understood. It is more important perhaps that each point of view is carefully listened to than that it be heeded. A fine line in resolving these viewpoints must be drawn between autocracy and grass-roots democracy. The process must have the confidence of the collaboration, or its general effectiveness can diminish rapidly.

These are not mere words, but an account of successful actions. In this increasingly fractious world of ours, it should be read and taken to heart by all those who despair of progress being made through reasoning and consensus.
Conclusion

DØ for Run 1 had a long difficult time through the building phase. We were 4 years behind CDF and worried we would never catch up.

In comparison with the Run 2 detector, we were primitive. So also was our use of advanced techniques for event selection, assessing significance, limit setting.

The Tevatron was kind, and delivered almost all its luminosity after DØ startup.

Nevertheless, the physics harvest was great. The DØg finally scratched that itch.