The Tevatron’s Impact on Particle Physics

Chris Quigg · Fermilab
Hundreds of articles

Tevatron Ph.D.s
461 fixed-target
18 small-collider
965 CDF & D0
Two New Laws of Nature +

Pointlike \((r \leq 10^{-18} \text{ m})\) quarks and leptons

Symmetries dictate strong, weak, electromagnetic interactions
CDF & D0 Highlights

Top quark discovery · Higgs-boson search
Exacting measurements: $m_t, M_W, B_s$ oscillations
Heavy-flavor physics
Search for new particles and forces
Testing elements of the “standard model”

Scientific interests and capabilities expand and deepen
respond to new opportunities
deliver a harvest of results not imagined at the start
Strong Interactions: Quantum Chromodynamics

Conundrum:
Protons are made of quarks that seem independent, but quarks can’t be liberated.
Evolution of the strong coupling
Quantum Chromodynamics

\[ d^2\sigma/dp_T dy \] (pb/GeV)

- DØ Run II

- \( |y| < 0.4 \) (x32)
- \( 0.4 < |y| < 0.8 \) (x16)
- \( 0.8 < |y| < 1.2 \) (x8)
- \( 1.2 < |y| < 1.6 \) (x4)
- \( 1.6 < |y| < 2.0 \) (x2)
- \( 2.0 < |y| < 2.4 \)

\[ \sqrt{s} = 1.96 \text{ TeV} \]
\[ L = 0.70 \text{ fb}^{-1} \]
\[ R_{\text{cone}} = 0.7 \]

- NLO pQCD
- +non-perturbative corrections

CTEQ6.5M \( \mu_R = \mu_F = p_T \)
Light hadron spectrum with dynamical fermions

\[ m = E_0/c^2 \]

\begin{align*}
\pi & \quad K & \rho & \quad \Lambda & \quad N \\
\hline
\text{experiment} & \hline
\text{width} & \hline
\text{input} & \hline
\text{QCD} & \hline
\end{align*}
Heavy flavors

Production and decay of quarkonium states
Measurements of $b$- and $t$-quark production
$B_c$ mass and lifetime
Masses and lifetimes of $B$ mesons and baryons
Unique source of information on many $B$-baryons
Orbitally excited $B$ and $B_s$ mesons
$X(3872)$ mass and quantum numbers
Important evidence on $D^0$ mixing
Precise CP asymmetries for $D^0 \rightarrow \pi^+\pi^-$, $B^+ \rightarrow J/\psi K^+$
High-sensitivity searches for rare dimuon decays
Frequency of $B_s$ oscillations

CDF Run II Preliminary

$L = 1.0 \text{ fb}^{-1}$

$\Delta m_s = 17.77 \pm 0.13 \text{ ps}^{-1}$
D0 top-quark specimen
CDF top-quark specimen
Electroweak theory joins electromagnetism and weak interactions (radioactivity)
Top mass in the electroweak theory

![Graph showing top mass variations over years](image-url)
Top mass in the electroweak theory
Top-quark mass

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Result (GeV/c²) ± Error (±stat ± syst)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF-I dilepton</td>
<td>167.4 ± 11.4 (±10.3 ± 4.9)</td>
</tr>
<tr>
<td>DØ-I dilepton</td>
<td>168.4 ± 12.8 (±12.3 ± 3.6)</td>
</tr>
<tr>
<td>CDF-II dilepton</td>
<td>170.6 ± 3.8 (± 2.2 ± 3.1)</td>
</tr>
<tr>
<td>DØ-II dilepton</td>
<td>174.0 ± 3.1 (± 1.8 ± 2.5)</td>
</tr>
<tr>
<td>CDF-I lepton+jets</td>
<td>176.1 ± 7.4 (± 5.1 ± 5.3)</td>
</tr>
<tr>
<td>DØ-I lepton+jets</td>
<td>180.1 ± 5.3 (± 3.9 ± 3.6)</td>
</tr>
<tr>
<td>CDF-II lepton+jets</td>
<td>173.0 ± 1.2 (± 0.6 ± 1.1)</td>
</tr>
<tr>
<td>DØ-II lepton+jets</td>
<td>174.9 ± 1.5 (± 0.8 ± 1.2)</td>
</tr>
<tr>
<td>CDF-I alljets</td>
<td>186.0 ± 11.5 (±10.0 ± 5.7)</td>
</tr>
<tr>
<td>CDF-II alljets *</td>
<td>172.5 ± 2.1 (± 1.4 ± 1.5)</td>
</tr>
<tr>
<td>CDF-II track</td>
<td>166.9 ± 9.5 (± 9.0 ± 2.9)</td>
</tr>
<tr>
<td>CDF-II MET+Jets *</td>
<td>172.3 ± 2.6 (± 1.8 ± 1.8)</td>
</tr>
<tr>
<td>Tevatron combination *</td>
<td>173.2 ± 0.9 (± 0.6 ± 0.8)</td>
</tr>
</tbody>
</table>

χ²/dof = 8.3/11 (68.5%)
Mass of the W Boson

- CDF-0/I: $80432 \pm 79$
- DØ-I: $80478 \pm 83$
- DØ-II: $80402 \pm 43$
- CDF-II: $80387 \pm 19$
- DØ-II: $80369 \pm 26$
- Tevatron Run-0/I/II: $80387 \pm 16$
- LEP-2: $80376 \pm 33$
- World Average: $80385 \pm 15$

March 2012
Missing link: the agent that
Differentiates weak, EM interactions
Gives masses to the weak force particles
Sets masses & family patterns of quarks & leptons

Textbook hypothesis: Higgs boson
Top quark, $W$, and the Higgs boson

![Graph showing the relationship between $M_W$ and $m_{top}$ with regions indicating statistical significance and mass ranges for the Higgs boson.]
Tevatron Run II Preliminary, $L \leq 10.0$ fb$^{-1}$

95% CL Limit/SM

Expected
Observed
$\pm 1\sigma$ Expected
$\pm 2\sigma$ Expected

Tevatron Exclusion

February 2012

Higgs-boson search
Tevatron Run II Preliminary, $L \leq 10.0 \, \text{fb}^{-1}$

95% CL Limit/SM

Expected
Observed
$\pm 1 \, \text{s.d.} \, \text{Expected}$
$\pm 2 \, \text{s.d.} \, \text{Expected}$

Tevatron
+ATLAS+CMS
Exclusion

ATLAS+CMS
Exclusion

February 2012

Higgs-boson search
Diverse searches for new phenomena

*Limits on*
supersymmetric particles
extra spatial dimensions
signs of new strong dynamics
leptoquarks
new gauge bosons
magnetic monopoles
...

*Tevatron experiments did not find*
what is not there

(A few observations do not match expectations)
Puzzle #1: Expect *New Physics* on TeV scale, but no sign of flavor-changing neutral currents.

*Great interest in searches for forbidden or suppressed processes*

Puzzle #2: Expect *New Physics* on TeV scale, but no quantitative failures of EW theory.
The unreasonable effectiveness of the standard model
Thanks to the dreamers and builders!

Thanks to Tevatron experimenters!

Thanks to all who made the Tevatron run so beautifully!

Thanks to our patrons!

Continued success to the LHC!

Onward to Fermilab’s next great instrument!


Symposium in Celebration of the
Fixed Target Program with the
Tevatron

Fermi National Accelerator Laboratory
June 2, 2000