STANDARD MODEL PHYSICS AT *TeV_2000*

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TeV_2000 describes the collider physics program at the Fermilab Tevatron for the next decade.

Introduction to *tev_2000*

TeV_2000 is the term used to describe the Fermilab Tevatron collider physics program beyond the 1992-96 run ("Run I"). The program is rich in its array of physics topics, including precision top quark studies, intermediate vector boson (IVB) physics, and searches for the Higgs boson, supersymmetry (SUSY), and other exotica. These topics are best addressed at the Tevatron since it is the highest energy accelerator in the world today and therefore has the farthest physics reach. For example, the top quark is produced and studied exclusively at the Tevatron. In addition, there will be detailed studies of QCD at increasingly higher jet E_T and a raft of b physics studies, including searches for CP violation, rare decays, and mixing. *tev_2000* is remarkable not only for its variety but for its incisiveness: the program outlined here addresses many of the fundamental questions in HEP today – the mechanism for electroweak symmetry breaking (EWSB), the origin of mass, CP violation, and what may lie beyond the minimal Standard Model (SM).

The *tev_2000* study group consisted of experimenters from CDF and DØ, accelerator physicists, and theorists. The group produced an extensive report [1], further details on the material presented here can be found in Ref. [1] and references therein. The results presented in Ref. [1] have considerable credibility, being based primarily on Run I data and experience. Existing detector simulations of the Run I CDF and DØ detectors were used along with algorithms from published analyses. The effects of high luminosity conditions were studied using Run I data. Finally, the improvements from the upgrades of CDF and DØ for Run II were, conservatively, not included. It is expected that the experiments' physics reach will easily exceed what is presented here.

Two factors are crucial to *tev_2000*: the upgrade of the Tevatron and the upgrades of the detectors. Improvements in magnet cooling will allow the Tevatron to increase $\sqrt{s}$ from 1.8 $\rightarrow$ 2.0 TeV. While the 10% increase appears modest, for high mass objects, like top quarks, the production cross section increases by 30%. The future Tevatron runs are currently envisaged to take place in two stages, designated Run II and Run III. Run II will take place during 1999–2002, have a peak luminosity of $2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and $\int \mathcal{L}dt \approx 4\ \mathrm{fb}^{-1}$. While "officially" Run II is defined by Fermilab as $\int \mathcal{L}dt = 2\ \mathrm{fb}^{-1}$, I define Run II here as the maximum integrated luminosity that the CDF and DØ silicon vertex detectors can stand before radiation damage becomes intolerable. It is likely that the shutdown required to replace the silicon vertex detectors will effectively dictate the end of Run II. After a shutdown in 2003, Run III will follow during 2004–2007. While the accelerator will be capable of a peak luminosity of $1\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, the Tevatron will run in "luminosity leveled" mode where the average number of interactions per crossing will be maintained at ~ 5. That translates into running at a constant $\mathcal{L} = 5 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. An integrated luminosity of 20 fb^{-1} is assumed for Run III. Upgrades of the CDF and DØ detectors were described in recent conference proceedings [2, 3].

1. Physics Reach

1.1. Top Quark Physics

The Tevatron is the world's only "top factory" and is thus the only place to study this most interesting elementary particle. It is possible that top could be a window onto new physics. The high mass of the top quark means that the coupling of top to exotica is potentially large. $M_{top} \approx$ scale of EWSB, is there a connection? In addition, the large M_{top} implies top decays before hadronization, allowing, for the first time, the study of a bare quark. The dozens of top events collected in Run I were sufficient to claim discovery and make first measurements of M_{top} and the production cross section $\sigma_{t\bar{t}}$. With dramatically larger data sets in Run II and beyond, see Table 1, precise determinations of many top quark properties will be made.

Mode	Run II 4 fb^{-1}	Run III 20 fb^{-1}
Dilepton: $ee, \mu\mu, e\mu$	330	1640
$W + 4j$ single tag	2070	10340
$W + 4j$ double tag	1030	5200

Table 1: Top event yields per experiment. Offline selection efficiencies have been included.

With the data from Run II only, the following is a sample of what to expect on top quark properties:

- The statistical uncertainty on M_{top} will be $\leq$ 1 GeV and the largest systematics are determined by the data itself, thus scaling like $1/\sqrt{N}$. It is expected that M_{top} will be measured to $\approx$ 2 GeV in the lepton + jets mode.

- $\sigma_{t\bar{t}}$ will be determined to 7%, providing a non-trivial test of QCD predictions. The precision will also limit possible anomalous top production. For example, a $t\bar{t}$ resonance from a topcolor Z' can be ruled out for $M_{Z'} \leq 1$ TeV.

- Detailed study of top decays: limits on $|V_{tb}|$, $t \to H^+b$, rare decays, and FCNC.

- Single top production provides the only practical method for measuring the top width. The Tevatron, being a $q\bar{q}$ machine, has a significant S/N advantage for single top over the LHC.

1.2. Physics with IVB's

The Tevatron is a copious source of events with W, Z, and γ. For example, in the electron final state alone, each experiment will detect, including selection efficiencies, $\approx 3 \times 10^6 W \to e\nu$ and $\approx 3 \times 10^5 Z \to ee$ in Run II. With the data from Run II only, the following measurements of the properties of IVB's and their mutual coupling will be made:

- The statistical uncertainty on M_W will be $\leq$ 20 MeV and the largest systematics are determined by the data itself, thus scaling like $1/\sqrt{N}$. It is expected that M_W will be measured to $\approx$ 40 MeV, comparable to LEP II expectations. Unless a new systematic "brick wall" exists, $\delta M_W \approx 20$ MeV is possible after Run III.

- Γ_W is sensitive to non-standard coupling and will be determined to ≈ 15 MeV.
- Asymmetries: measurement of the W charge asymmetry constrains the viable set of pdf's, crucial in reducing the error on M_W.
- There will be a host of limits on anomalous couplings WWV and $Z\gamma V$ where $V = \gamma, Z$. Vertices will be determined with a precision of 10% for WWV and $10^{-2} - 10^{-3}$ for $Z\gamma V$. The measurements of WWV are comparable and complimentary to those made at LEP II while the Tevatron does a superior job on $Z\gamma V$.
- The search for the radiation zero in $q\bar{q} \to W\gamma$ production, this is best done at a $q\bar{q}$ machine like the Tevatron.

1.3. Light Higgs

In the SM, M_W, M_{top} and the Higgs mass are related so that knowledge of M_W and M_{top} provides an indirect measurement of M_{Higgs}. This relationship is shown in Fig. 1 along with the current measurements. After Run II, the combined CDF and DØ results will yield $\delta M_{Higgs} \approx 40\% M_{Higgs}$.

In addition to indirect measurements of M_{Higgs}, the Tevatron experiments have sensitivity for discovery of a Higgs with mass 60–125 GeV. This range exceeds the reach of LEP II and covers a difficult window in M_{Higgs} for the LHC. It is also intriguing that the current central value for M_{Higgs}, predicted by precision electroweak measurements, lies in this range [4]. The best channel for this search is $q\bar{q} \to WH$ where $H \to b\bar{b}$ (the dominant branching fraction in this mass range). The analysis requires both b jets are tagged and looks for a bump in the two jet mass spectrum, see Fig. 2. With 20 fb^{-1}, a $\geq 5\sigma$ excess can be observed for $M_{Higgs} \leq 125$ GeV. Other modes, such as $q\bar{q} \to ZH$ and $H \to \tau\tau$ decays, can be used to confirm the signal.

1.4. SUSY Searches

SUSY is arguably the leading candidate for physics beyond the SM. At the Tevatron, the most promising SUSY signals include the search for charginos in a trilepton final state and gluinos in the missing $E_T + jets$ final state [5]. With the data from Run II alone, the mass reach will be up to $M_{\tilde{\chi}^\pm} \sim 220$ GeV and up to $M_{gluino} \sim 400$ GeV. With 20-30 fb^{-1} in hand after Run III, CDF and DØ have an excellent chance for discovery of SUSY. If SUSY is not observed then Tevatron measurements will significantly constrain the available parameter space. On the other hand, if no sparticle is found, the Tevatron results themselves can not exclude the existence of SUSY.

1.5. Searches for Exotica

Many models for new physics beyond the SM exist and are testable at the Tevatron. A list of new phenomena to search for includes W' and Z', leptoquarks, technicolor, contact interactions, and excited quarks. The benefits of Runs II& III, higher Tevatron energy and large integrated luminosities, are mitigated somewhat by the generally steeply falling production spectra of new phenomena with mass/scale. The Run II mass reach will be extended by a factor of ≈ 1.5 over that achieved in current Run I analyses. Nevertheless, until a higher energy machine is operational, the Tevatron will be the best place to search for exotica.

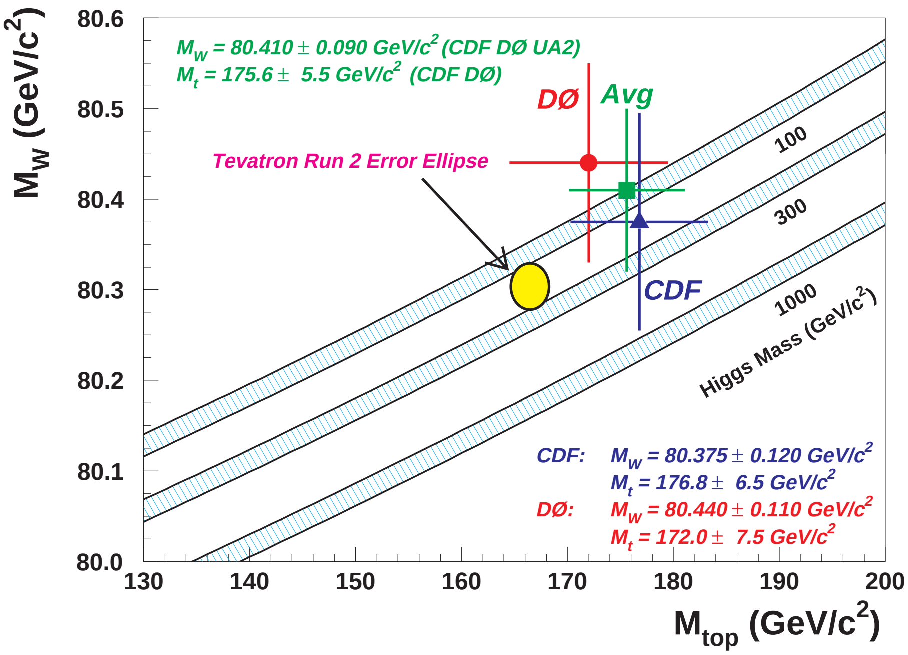

Figure 1: M_W vs. M_{top} where the bands correspond to different Higgs masses. The CDF and DØ measurements are shown along with the expected error ellipse after Run II.

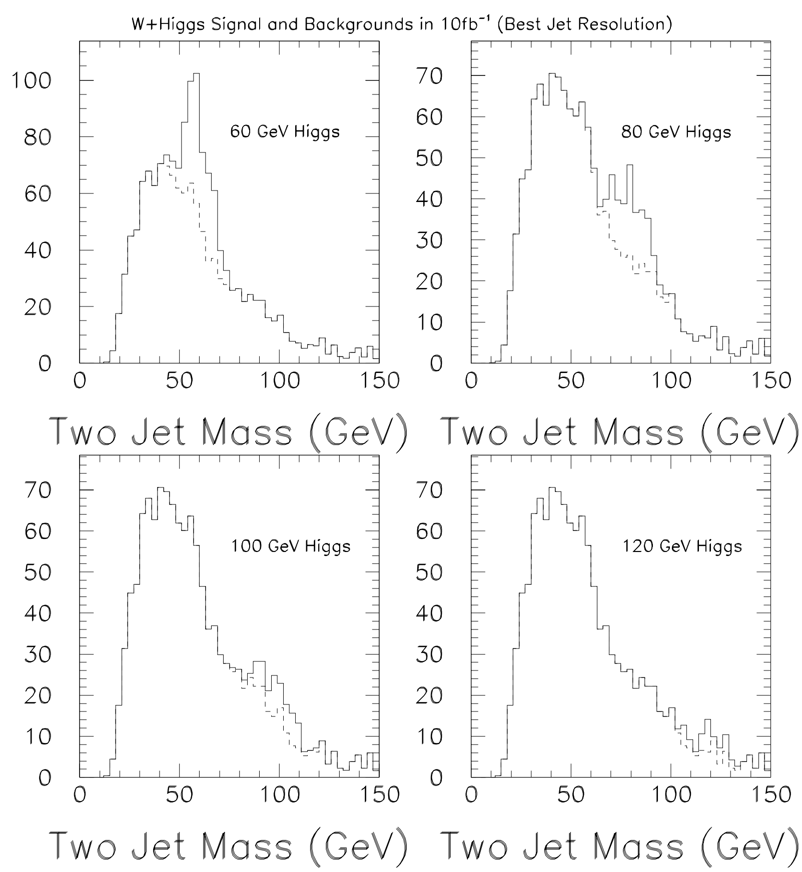

Figure 2: The expected Run II two jet mass distribution for the $q\bar{q} \to WH$ process using 4 assumed Higgs masses. The solid line is signal+background, the dashed line is the sum of all backgrounds [1].

Conclusions

The high energy frontier will remain at the Tevatron for roughly the next decade. The *tev_2000* group has outlined the rich program of physics available in Runs II & III, of which only a small sample was presented here. The opportunities in *tev_2000* will be exploited fully by the upgraded CDF and DØ detectors. Many precision measurements will provide stringent tests of the SM and possibly reveal chinks in the SM armor. There exist very good chances to either discover new physics or, in its absence, to severely constrain extensions to the SM.

References

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