Excellent performance:

- Typical instantaneous luminosity: 
  $>3.0 \times 10^{32} \text{ cm}^{-2} \text{s}^{-1}$
- Surpassed integrated luminosity goal for FY08.
- Delivered ~5.5 fb$^{-1}$
- Project ~7.7-8.8 fb$^{-1}$ by end of FY10.
Tevatron Accelerator

<table>
<thead>
<tr>
<th></th>
<th>Run I</th>
<th>Run IIa</th>
<th>Run IIb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunches in Turn</td>
<td>6 x 6</td>
<td>36 x 36</td>
<td>36 x 36</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 \times 10^{30})</td>
<td>(1 \times 10^{32})</td>
<td>(2.8 \times 10^{32})</td>
</tr>
<tr>
<td>( \int ) Ldt (pb(^{-1})/week)</td>
<td>3</td>
<td>15-20</td>
<td>50-60</td>
</tr>
<tr>
<td>Bunch crossing (ns)</td>
<td>3500</td>
<td>396</td>
<td>396</td>
</tr>
<tr>
<td>Interactions/ crossing</td>
<td>2.5</td>
<td>2.5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Excellent performance:
- Typical instantaneous luminosity: \(>3.0 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}\)
- Record inst. lum.: \(3.55 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}\)
- Surpassed integrated luminosity goal for FY08.
- Delivered \(~5.5 \text{ fb}^{-1}\)
- Project \(~7.7-8.8 \text{ fb}^{-1}\) by end of FY10.
- But in end of FY08 and beginning of FY09 better slope than “Highest Lum” projection!
CDF and DØ Detectors

63 institutions (15 countries)
589 physicists

90 institutions (18 countries)
554 physicists

- Multipurpose detectors:
  - Central tracking system embedded in a solenoidal magnetic field:
    - Silicon vertex detector
    - Tracking chamber (CDF)/fiber tracker (DØ)
  - Preshowers
  - Electromagnetic and hadronic calorimeters
  - Muon system

- All detector subsystems expected to survive till the end of the run.
  No further upgrades, stable triggers.
- Data taking efficiency: \( \geq 85\% \)
Physics Program at the Tevatron

- Broad and deep program being fully exploited.

- Recorded luminosity to date: $\sim 4.8 \text{ fb}^{-1}$

- Physics analyses to date typically use $\sim 1-3 \text{ fb}^{-1}$, so final results with the full dataset will have $\sim 2.5-7$ times more statistics.

- This talk will only cover a subset of recent results spanning the whole physics program.
QCD Program

- Physics at a hadron collider (Tevatron, LHC) requires precise understanding of QCD:
  - Hard interactions of 2 partons, PDFs
  - Multi-parton interactions (underlying event)
  - Soft/hard initial/final state radiation
  - Hadronization/fragmentation

Full program of measurements:
- Jet production
  - Inclusive jet $p_T$, dijet mass, dijet angular distributions,…
  - Vector boson + jets
- Photon production
  - Diphoton
  - Photon + X
- Heavy-flavor production
  - Inclusive
  - Associated with vector bosons
- Underlying event, jet fragmentation
- Diffractive program
Jet Production

Inclusive jet cross section
- Stringent probe of pQCD over 8 orders of magnitude!
- Forward jets: sensitive probe of gluon PDF at high $x$.
- Central jets at high $p_T$: sensitive probe of New Physics.
- After years of work, achieved jet energy calibration $\sim 1\text{-}2\%$.

W/Z+jets total/differential cross sections
- Test of pQCD predictions at high momentum transfers.
- Main backgrounds to top, Higgs, New Phenomena searches $\Rightarrow$ critical to validate theoretical calculations and Monte Carlo event generators.

Significant constraints to the gluon PDF.
Extremely useful input for the LHC.
Vector Boson + Heavy Flavor Jets

- Sensitive to production mechanism and the heavy quark content of the proton. Also probes fragmentation into heavy quarks.

\[ Q = b, c \]

- Is there an “intrinsic charm” (non-perturbative) component of the proton?

\[ \gamma + b \text{ in agreement with NLO QCD} \]

\[ \gamma + c \text{ Large discrepancy for } \gamma + c \text{ at high } p_T^\gamma \text{ Non-intrinsic charm?} \]
Vector Boson + Heavy Flavor Jets

- Sensitive to production mechanism and the heavy quark content of the proton. Also probes fragmentation into heavy quarks.

\[ \sigma(Z+b\text{-jet}) = 0.86 \pm 0.14(\text{stat}) \pm 0.12(\text{syst}) \text{ pb} \]

NLO prediction: \( 0.53 \pm 0.08 \) (scale+PDF) pb

First differential distributions available. Higher statistics needed for more stringent tests of theoretical predictions.

\( \gamma+b \) in agreement with NLO QCD

\( \gamma+c \) at high \( p_{T}^{\gamma} \)

Large discrepancy for \( \gamma+c \) at high \( p_{T}^{\gamma} \)

Non-intrinsic charm?
Heavy Flavor Program

- Large production cross section (~0.1 mb).
- Many b,c species are produced at the Tevatron:
  \[ \bar{B}^0 = |b\bar{d}\rangle, \quad B^- = |b\bar{u}\rangle \quad \Lambda^0_b = |b\bar{d}u\rangle, \quad \Sigma^-_b = |b\bar{d}d\rangle \]
  \[ \bar{B}^0_s = |b\bar{s}\rangle, \quad B^-_c = |b\bar{c}\rangle \quad \Xi^-_b = |b\bar{d}s\rangle \quad \ldots \]
  many of which are inaccessible at the B factories.

- Low \( p_T \) lepton (CDF+DØ) and displaced track (CDF) triggers allow for rich samples of semileptonic and hadronic decay modes.

- Hadron collider environment challenging but sufficient statistics and detector capabilities allow for an extremely rich program:
  - Precise cross section, mass & lifetime measurements
  - Exclusive decays, branching fractions & rare decays
  - Mixing and CP violation
  - Spectroscopy & decay properties
  - Discovery of new states

“Typical” event display at the B-factories:
Heavy Flavor Program

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• Many b,c species are produced at the Tevatron:
  \[ \bar{B}^0 = |b \bar{d}\rangle, \quad B^- = |b \bar{u}\rangle \]
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  • Discovery of new states

“Typical” event display at the Tevatron:
Study of New Heavy b-Baryons

- Heavy quark hadrons are the “hydrogen atom” of QCD and b hadrons offer the heavier quarks in bound systems ➔ Very sensitive tests of potential models, HQET, lattice gauge calculations…
- Have added to $\Lambda_b(udb)$ (seen in UA1):
  $\Sigma_b^\pm, \Sigma_b^{\ast\pm}(uub,ddb), \Xi_b^-(dsb), \Omega_b^-(ssb)$.

Observation of the $\Omega_b^-$

Mass: $6.165 \pm 0.010$ (stat) $\pm 0.013$ (syst) GeV

Significance: $5.4\sigma$

What’s the next discovery?

17.8 $\pm$ 4.9 (stat) $\pm$ 0.8 (syst) events

$f(b \to \Omega_b^-)Br(\Omega_b^- \to J/\psi \Omega^-) = 0.80 \pm 0.32$ (stat) $^{+0.14}_{-0.22}$ (syst)

$f(b \to \Xi_b^-)Br(\Xi_b^- \to J/\psi \Xi^-)$
Study of New Heavy b-Baryons

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What’s the next discovery?

$\mathcal{L} = 1/2$ b Baryons

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Mass: 6.165 ± 0.010(stat) ± 0.013(syst) GeV
Significance: 5.4$\sigma$

What’s the next discovery?
CP Violation in $B_s$ Decays

$B_s^0 - \bar{B}_s^0$ mixing

Weak eigenstates:

$$i \frac{d}{dt} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i \Gamma}{2} & M_{t2} - \frac{i \Gamma_{t2}}{2} \\ M_{t2}^* - \frac{i \Gamma_{t2}^*}{2} & M - \frac{i \Gamma}{2} \end{pmatrix} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

Mass eigenstates:

$$|B_s^H\rangle = p |B_s^0\rangle + q |\bar{B}_s^0\rangle \quad |B_s^L\rangle = p |B_s^0\rangle - q |\bar{B}_s^0\rangle$$

$B_s$ meson allows to probe the entire matrix:

$$\Delta m_s = M_H - M_L \sim 2 |M_{t2}| \quad \text{Sensible to New Physics}$$

$$\Delta \Gamma_s^{CP} = \Gamma_{even} - \Gamma_{odd} \sim 2 |\Gamma_{t2}| \quad \text{Not sensible to New Physics}$$

$$\Delta \Gamma_s = \Gamma_L - \Gamma_H \sim 2 |\Gamma_{t2}| \cos \phi_s \quad \text{VERY sensible to New Physics}$$

$$\phi_s^{SM} = \text{arg}[ -M_{t2}/\Gamma_{t2}] \rightarrow \phi_s^{SM} + \phi_s^{NP} \sim 0.004$$

Time-dependent angular analysis in flavor-tagged $B_s \rightarrow J/\psi \phi$ decays:

$B_s^0 \rightarrow J/\psi \phi$

$\bar{B}_s^0 \rightarrow V_{us} V_{ub}^* \quad V_{cs} V_{cb}^*$

$\Rightarrow \sin 2 \beta_{SM}^{SM}$

Combination of CDF and DØ measurements w/o assumptions on strong phases yields $2.2\sigma$ deviation from the SM (p-value=3.1%).
**CP Violation in $B_s$ Decays**

\[ B_s^0 - \bar{B}_s^0 \text{ mixing} \]

\[
i \frac{d}{dt} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i \Gamma}{2} & M_{t_2} + \frac{i \Gamma_{t_2}}{2} \\ M_{t_2} - \frac{i \Gamma_{t_2}}{2} & M - \frac{i \Gamma}{2} \end{pmatrix} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}
\]

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\]

\[
\phi_s^{SM} = \text{arg}[-M_{t_2}/\Gamma_{t_2}] \rightarrow \phi_s^{SM} + \phi_s^{NP} \sim 0.004
\]

Updated CDF result with 2.8 fb\(^{-1}\):
consistency with the SM further decreased (p-value= 0.15 \rightarrow 0.08).

Very exciting prospects in the near future:

- Updates with 4 fb\(^{-1}\) by Moriond’09.
- Additional measurements (charge asymmetries) underway.
Electroweak Program

- Single W(→lν)/Z(→l+l−) production occurs at high rate: O(100k-10k)/week!!
- Provide “standard candles”: lepton ID/trigger efficiencies vs. time, integrated luminosity verification, electron energy scale, etc.
- Inclusive production cross section in good agreement with theoretical prediction.  
  → could be used to overcome ~6% luminosity uncertainty in many measurements.

Extensive and very competitive program:
- W/Z production cross sections and differential distributions
- Precision measurements: M_W, Γ_W, sin^2θ_W,…
- Diboson physics
W/Z Asymmetries

- Differential distributions provide important information on production mechanism.

W charge asymmetry

Forward-backward asymmetry in $Z/\gamma^* \rightarrow e^+e^-$
- Measurement of $A_{FB}$ as a function of $M_{ee}$.
- Sensitive to New Physics effects at high $M_{ee}$ (extend region probed by LEP2).
- Measurement of $\sin^2\theta_W$.
- Measurement of $Z$-$u$-$u$ and $Z$-$d$-$d$ couplings.

Significant constraints on PDFs!  
*See talk by A. Bodek*
Differential distributions provide important information on production mechanism.

**W charge asymmetry**

\[ A(y) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy} \]

- Measurement of \( A_{FB} \) as a function of \( M_{ee} \).
- Sensitive to New Physics effects at high \( M_{ee} \) (extend region probed by LEP2).
- Measurement of \( \sin^2\theta_w \).
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Significant constraints on PDFs!

Very competitive measurement with full dataset and CDF+DØ.
W/Z Asymmetries

- Differential distributions provide important information on production mechanism.

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Significant constraints on PDFs!

Uncertainties will shrink by \(~\times10!\)
W Boson Mass

- Constraint on SM Higgs mass is now dominated by the W mass uncertainty:
  \[ \Delta m_t = 1.2 \text{ GeV} \implies \Delta M_H = +9/-8 \text{ GeV} \]
  \[ \Delta M_W = 25 \text{ MeV} \implies \Delta M_H = +17/-13 \text{ GeV} \]

- Measured from template fits to W transverse mass, lepton \( p_T \) and MET distributions.

- Exquisite understanding of the detector response, noise and pileup required:
  \~ few MeV for quantities \~ 40 GeV!

- Uncertainty currently dominated by statistics of Z sample used for calibration.
  Theoretical uncertainties \~ 10-15 MeV.

- New results expected soon!
  - CDF working on 2.4 fb-1 measurement
  - DØ working on 1 fb-1 measurement
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CDF (200 pb\(^{-1}\))
W Boson Mass

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- Exquisite understanding of the detector response, noise and pileup required:
  \( \sim \text{ few MeV for quantities } \sim 40 \text{ GeV}! \)

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  Theoretical uncertainties \( \sim 10-15 \text{ MeV} \).

- New results expected soon!
  - CDF working on 2.4 fb\(^{-1}\) measurement
  - DØ working on 1 fb\(^{-1}\) measurement

With full data sample expect CDF+DØ combined uncertainty of \( \sim 15-20 \text{ MeV} \).
Diboson Production

- Probe of non-abelian structure of SM and sensitive to New Physics.

- Background to many direct searches (e.g. Higgs, SUSY) for New Physics. Reality check for NP searches.

- Recent observation of ZZ production in $4l$ channels by DØ (5.7σ). Evidence at CDF (4.4σ). Measured cross section in agreement with SM (1.4 pb).

- First evidence of $WW/WZ \rightarrow l\nu jj$ by DØ (4.4σ).
  - $\sigma=20.2\pm4.4$ pb (SM: $16.1\pm0.9$ pb)
  - Advanced multivariate and statistical techniques being used in $W(l\nu)H(b\bar{b})$ now verified in similar final state $W(l\nu)W/Z(jj)$

- Anomalous couplings from $W(l\nu)\gamma$, $Z(l\nu)\gamma$, $W(l\nu)W(l\nu jj)$, $W(l\nu)Z(l\nu jj)$ and $Z(l\nu)Z(l\nu jj)$. Combined limits will be complementary/competitive with LEP.
Diboson Production

- Probe of non-abelian structure of SM and sensitive to New Physics.
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• Precision measurements of top quark properties crucial in order to unveil its true nature: $\lambda_t = \sqrt{2} m_t/v = 0.991 \pm 0.007$ !!!

• Extremely rich program of measurements.

• Large top samples in Tevatron Run II have allowed to make the transition from the discovery phase to a phase of precision measurements of top quark properties.
Top Quark Production and Decay

- Top quarks dominantly produced in pairs via the strong interaction.
- Measured cross sections in agreement with SM. Experimental precision from combination of channels (~9%) comparable to theoretical error.
- Precise measurements in different channels allows to place constraints on New Physics. E.g. \( t \rightarrow H^+b \): channels affected differently depending on \( H^+ \) decay modes.

CDF Run II Preliminary

<table>
<thead>
<tr>
<th>Channel</th>
<th>L (fb)</th>
<th>Data (L=1.0 fb(^{-1}))</th>
<th>t(\bar{t}) Br(t → H(^+)b)</th>
<th>t(\bar{t}) Br(t → (H^+b))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton+Track</td>
<td>1.1 fb</td>
<td>8.3(\pm)1.3(\pm)0.7(\pm)0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton+Track: Vertex tag</td>
<td>1.1 fb</td>
<td>10.1(\pm)1.8(\pm)1.1(\pm)0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dilepton</td>
<td>2.8 fb</td>
<td>6.7(\pm)0.8(\pm)0.4(\pm)0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton+Jets; Kinematic ANN</td>
<td>2.8 fb</td>
<td>6.8(\pm)0.4(\pm)0.6(\pm)0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton+Jets; Vertex Tag</td>
<td>2.7 fb</td>
<td>7.2(\pm)0.4(\pm)0.5(\pm)0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton+Jets; Soft Electron Tag</td>
<td>2.0 fb</td>
<td>7.8(\pm)2.4(\pm)1.5(\pm)0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton+Jets; Soft Muon Tag</td>
<td>2.0 fb</td>
<td>8.7(\pm)1.1(\pm)0.9(\pm)0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET+Jets: Vertex Tag</td>
<td>0.3 fb</td>
<td>6.1(\pm)1.2(\pm)0.8(\pm)0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-hadronic: Vertex Tag</td>
<td>1.0 fb</td>
<td>8.3(\pm)1.0(\pm)2.0(\pm)0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDF combined</td>
<td>2.8 fb</td>
<td>7.0(\pm)0.3(\pm)0.4(\pm)0.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B(H\(^+\)→\(\tau \nu\)) = 1

- DØ Run II Preliminary

\( N_{\text{event}} \)

- Data (L=1.0 fb\(^{-1}\))
  - t\(\bar{t}\) Br(t → H\(^+\)b) = 0.0
  - t\(\bar{t}\) Br(t → \(H^+b\)) = 0.3
  - t\(\bar{t}\) Br(t → \(H^+b\)) = 0.6
- background
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- Measured cross sections in agreement with SM. Experimental precision from combination of channels (~9%) comparable to theoretical error.
- Precise measurements in different channels allows to place constraints on New Physics. E.g. $t \rightarrow H^+b$: channels affected differently depending on $H^+$ decay modes.
Top Quark Production and Decay

- Top quarks dominantly produced in pairs via the strong interaction.
- Measured cross sections in agreement with SM. Experimental precision from combination of channels ~9% (comparable to theoretical error).
- Precise measurements in different channels allows to place constraints on New Physics. E.g. $t \rightarrow H^+b$: channels affected differently depending on $H^+$ decay modes.
- Also probing for non-SM production mechanisms (e.g. $Z' \rightarrow tt$) or New Physics contamination in the top samples (e.g. $t't' \rightarrow WqWq$).

Using top as a tool to look for New Physics

Using top as a tool to look for New Physics

$m_{Z'} > 760 \text{ GeV} @ 95\% CL$

(leptophobic $Z'$ with $\Gamma/M=1.2\%$)

$m_{t'} > 311 \text{ GeV} @ 95\% CL$
Top Quark Mass

- Fundamental parameter of the Standard Model.
- Important ingredient for EW precision analyses at the quantum level.
  ⇒ incisive consistency checks
  ⇒ constrain/rule out models of New Physics
  ⇒ provide valuable information on the parameters of the Lagrangian

- Sophisticated techniques to minimize statistical and dominant systematic uncertainties (JES via in-situ calibration to $M_W$ in lepton+jets).

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- Sophisticated techniques to minimize statistical and dominant systematic uncertainties (JES via in-situ calibration to \( M_W \) in lepton+jets).

- Current world-average (most sensitive channels use up to 2.7 fb\(^{-1}\)):

\[
m_t = 172.4 \pm 0.7 \pm 1.0 \text{ GeV}
\]

Measurement will be limited by systematic uncertainties (signal modeling, b-jet response), some of which can be constrained by data.

Estimate ultimate precision \( \leq 1 \text{ GeV} \)
Probing the $tbW$ Interaction

**Electroweak single top production**

- Cross section proportional to $tbW$ strength
- Rate $\sim 1/2$ tt but very large $W+$jets background
- Both experiments have evidence for single top via sophisticated multivariate techniques to extract the signal.

**W helicity in top quark decays**

$\lambda_W = -1$

$\lambda_W = 0$

$\lambda_W = +1$

\[
F_- \approx \frac{2M_W^2}{m_t^2 + 2M_W^2} = 0.30 \\
F_0 \approx \frac{m_t^2}{m_t^2 + 2M_W^2} = 0.70 \\
F_+ = 0
\]

- Reconstruct helicity angle of lepton in top quark pair events.

**CDF Run II Preliminary, $L = 2.2 \text{ fb}^{-1}$**

\[
\sigma = 2.2 \pm 0.7 \text{ pb} \quad (\text{SM: } 2.9 \text{ pb})
\]

\[
|V_{tb}| = 0.88 \pm 0.16
\]

Expect observation with $\sim 3 \text{ fb}^{-1}$

**DO Run II Preliminary**

$L = 2.2 - 2.7 \text{ fb}^{-1}$

Sensitive to ratio of anomalous couplings
Probing the $tbW$ Interaction

**Electroweak single top production**

- Cross section proportional to $tbW$ strength
- Rate $\sim 1/2 \, tt$ but very large $W+$jets background
- Both experiments have evidence for single top via sophisticated multivariate techniques to extract the signal.

- With full dataset:
  - $\Delta V_{tb}/V_{tb} \sim 8\%$
  - Simultaneous measurement of $s$- and $t$-channel cross sections.
  - Model-independent measurement of $tbW$ couplings.
  - Searches for anomalous production ($W'$, $H^+$, FCNC)

Results available on all these topics with $\lesssim 2 \, fb^{-1}$

**W helicity in top quark decays**

$\lambda_W = -1$

$\lambda_W = 0$

$\lambda_W = +1$

SM: $F_+ \approx \frac{2M_W^2}{m_t^2 + 2M_W^2} = 0.30, \quad F_0 \approx \frac{m_t^2}{m_t^2 + 2M_W^2} = 0.70, \quad F_+ = 0$

- Reconstruct helicity angle of lepton in top quark pair events.

Sensitive to ratio of anomalous couplings
New Phenomena Searches

Model-inspired searches: theory-driven
- optimized analyses to extract well-defined signals.
  - SUSY: (heavy-quark)jets + MET, multi-leptons + MET, multi-photons+MET, long-lived massive particles, rare B decays, etc
  - Extra Dimensions: mono-jets, di-lepton/di-photon resonances
  - Extra gauge bosons: W’, Z’
  - Leptoquarks
  - Compositeness: excited leptons,
  - …

Signature-based searches: final-state driven
- Looking for deviations from the SM anywhere.

Prospects for discoveries remain open:
1. Tevatron is still the energy frontier.
2. High luminosity: significant signals may quickly develop as luminosity grows and analyses mature.
3. Well understood detector, refined experimental techniques and experienced collaborations. Data makes you smarter…
SUSY Searches

Chargino/Neutralino

- Clean multi-lepton+MET signature, but:
  - low $\sigma x BR (<0.1 \text{ pb})$
  - low $p_T$ leptons (<10 GeV)
  - Challenges: lepton ID at low $p_T$

Squark/Gluino

- Pair production of $\tilde{q}, \tilde{g}$ with decays involving multi-jets + MET.
- Critical to understand tail of MET distribution.

Excluded Region in mSUGRA

Search for $\tilde{\chi}_1^0, \tilde{\chi}_2^0$
SUSY Searches

Chargino/Neutralino
- Clean multi-lepton+MET signature, but:
  - low $\sigma \times \text{BR} (<0.1 \text{ pb})$
  - low $p_T$ leptons (<10 GeV)
  - Challenges: lepton ID at low $p_T$

Squark/Gluino
- Pair production of $\tilde{q}, \tilde{g}$ with decays involving multi-jets + MET.
- Critical to understand tail of MET distribution.
- Stop/sbottom: include b/c in the final state.
Non-SUSY Searches

Di-lepton invariant mass distributions probes:
- New Z’ gauge bosons: expected in many beyond-SM scenarios (GUTs, etc).
- Extra-dimensions (large, Randall-Sundrum gravitons, etc)

• Quasi-model independent searches for long-lived or “stable” particles:
  - Using muon timing (DØ) or time-of-flight system (CDF).

  CDF Run II Preliminary

  - Most significant excess at M(\text{ee})\sim240 \text{ GeV (3.8\sigma}). Probability for fluctuation in 150-1000 \text{ GeV range 0.6\% (2.5\sigma)}.
  - Observed limits \sim840-966 \text{ GeV depending on Z’ model.}
Non-SUSY Searches

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CDF Run II Preliminary

• Most significant excess at M(ee)~240 GeV (3.8σ). Probability for fluctuation in 150-1000 GeV range 0.6% (2.5σ).
• Observed limits ~840-966 GeV depending on Z’ model.

• Quasi-model independent searches for long-lived or “stable” particles:
  • Reconstructing displaced vertices with the tracking system (CDF) or the calorimeter and preshower (DØ).
SM Higgs at the Tevatron

• Current experimental information (limits @ 95% CL):
  • SM LEP direct search: \( m_H > 114 \) GeV
  • SM indirect constraint: \( m_H < 154 \) GeV
    + LEP direct search: \( m_H < 185 \) GeV
  ➔ Tevatron is sensitive over whole “interesting” mass range.

• Main production mechanisms (115<\( m_H < 180 \) GeV):
  • Gluon fusion (\( gg \to H \)): \( \sigma \sim 0.8 - 0.2 \) pb
  • Associated production (\( VH, V=W,Z \)): \( \sigma \sim 0.2 - 0.03 \) pb

• Dominant decay channels:
  • \( m_H < 135 \) GeV: \( H \to bb \)
  • \( m_H > 135 \) GeV: \( H \to WW^{(*)} \)

• Search strategy:
  • Low mass region:
    dominated by \( WH \to l\nu bb, ZH \to l^+l^-bb, ZH \to \nu\nu bb \)
  • High mass region:
    dominated by \( gg \to H \to WW^{(*)} \to l^+l^-\nu\nu \)
  • Complement with many other channels:
    VBF production, \( VH \to qqbb, H \to \tau\tau(\text{with 2jets}), H \to \gamma\gamma, WH \to WWW, ttH, \ldots \)
SM Low Mass Higgs

Key issues:
- Lepton identification
- B-tagging performance
- Dijet mass resolution
- Background modeling
  - W/Z+heavy-flavor jets
  - Multijets (ZH→ννbb)
- All analyses use multivariate techniques for signal-to-bckg discrimination.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Lum (fb⁻¹)</th>
<th>Limit (σ/SM)</th>
<th>Exp.</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH→lνbb (CDF)</td>
<td>2.7</td>
<td>5.6</td>
<td>5.7</td>
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<tr>
<td>WH→lνbb (DØ)</td>
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<td>8.5</td>
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<td>ZH→ννbb (CDF)</td>
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<tr>
<td>ZH→ννbb (DØ)</td>
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<td>8.4</td>
<td>7.5</td>
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<tr>
<td>ZH→l±νbb (CDF)</td>
<td>2.4</td>
<td>11.8</td>
<td>11.6</td>
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<tr>
<td>ZH→l±νbb (DØ)</td>
<td>2.3</td>
<td>12.3</td>
<td>11.0</td>
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</tr>
</tbody>
</table>

95%CL Limits at m_H = 115 GeV

Best individual channels have expected limits ~6xSM
SM High Mass Higgs

- Highest sensitivity channel for $m_H > 130$ GeV.
- Main backgrounds:
  - $m_H \sim 160$ GeV: WW
  - $m_H \sim 130$ GeV: $W +$ jets
- Low $\Delta \phi(l,l)$ because of spin-0 Higgs.
- Capitalize on improvements in lepton identification and multivariate techniques.

95%CL Limits at $m_H = 165$ GeV

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Lum (fb⁻¹)</th>
<th>Higgs Events</th>
<th>Limit ($\sigma$/SM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>3.0</td>
<td>17.2</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Obs. 1.6</td>
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<tr>
<td>DØ</td>
<td>3.0</td>
<td>15.6</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Obs. 2.0</td>
</tr>
</tbody>
</table>

Both experiments approaching SM sensitivity!
SM High Mass Higgs

- Highest sensitivity channel for $m_H > 130$ GeV.
- Main backgrounds:
  - $m_H \sim 160$ GeV: WW
  - $m_H \sim 130$ GeV: W+jets
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95%CL Limits at $m_H = 165$ GeV

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<tr>
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<th>Lum (fb$^{-1}$)</th>
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<th>Limit ($\sigma$/SM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>3.0</td>
<td>17.2</td>
<td>1.6 Exp. 1.6 Obs.</td>
</tr>
<tr>
<td>DØ</td>
<td>3.0</td>
<td>15.6</td>
<td>1.9 Exp. 2.0 Obs.</td>
</tr>
</tbody>
</table>

Both experiments approaching SM sensitivity!

Significant sensitivity at low mass as well!
SM Higgs Combined Limits

- Calculation of limits and combination:
  - Using Bayesian and CLs approaches.
  - Incorporate systematic uncertainties (including correlations) using pseudo-experiments.
  - Some uncertainties are effectively constrained by data.

At $m_H = 115$ GeV:
- Exp. limit: $3.6 \times \text{SM}$
- Obs. limit: $4.2 \times \text{SM}$

At $m_H = 165$ GeV:
- Exp. limit: $1.6 \times \text{SM}$
- Obs. limit: $1.6 \times \text{SM}$

At $m_H = 115$ GeV:
- Exp. limit: $4.6 \times \text{SM}$
- Obs. limit: $5.3 \times \text{SM}$

At $m_H = 165$ GeV:
- Exp. limit: $1.9 \times \text{SM}$
- Obs. limit: $2.0 \times \text{SM}$
First direct exclusion since LEP II.
Verified using two independent methods (CLs, Bayesian).
Expect to exclude wide mass range by Moriond’09.

Low mass Tevatron combination not available yet.
  Challenging owing to the large number of channels (~70).
  Expected sensitivity (as of ICHEP’08): < 3.0xSM @ $m_H=115$ GeV.

Excluded $m_H = 170$ GeV @ 95% CL

95%CL Limits/SM

<table>
<thead>
<tr>
<th>$M_{Higgs}(GeV)$</th>
<th>160</th>
<th>165</th>
<th>170</th>
<th>175</th>
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<tr>
<td>Method 1: Exp</td>
<td>1.3</td>
<td>1.2</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Method 1: Obs</td>
<td>1.4</td>
<td>1.2</td>
<td>1.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Method 2: Exp</td>
<td>1.2</td>
<td>1.1</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Method 2: Obs</td>
<td>1.3</td>
<td>1.1</td>
<td>0.95</td>
<td>1.2</td>
</tr>
</tbody>
</table>
SM Higgs Prospects

- Limits have improved faster than $1/\sqrt{L}$ due to analysis improvements.
- Major effort underway to continue to improve sensitivity:
  - Optimized object identification/resolution
  - Optimized selections and signal-to-bckg discrimination
  - Reduced systematic uncertainties
  - Adding new channels
  - Adding more data!

- Median projected reach with 8.5 fb$^{-1}$ delivered (6.8 fb$^{-1}$ used in analysis):
  - Exclude at 95% CL over full mass range.
  - Evidence at low and high mass.
  - There is a band of possibilities around these lines.

- Tevatron complements LHC at low mass.
Conclusions

• Run II physics program in full swing.

• Excellent performance of the accelerator and CDF and DØ detectors. Collaboration strengths sufficient to carry out program.

• Expect >8 fb\(^{-1}\) by the end of the run. Analyzed luminosity will increase by a factor of ~2.5-7.

• Physics reach further expanded by analysis improvements.

• Expect significant statements from the Tevatron on precision measurements and the Higgs search. Prospects for discoveries remain open.

• Continue to establish benchmarks in analysis techniques for the LHC era.

• Exciting prospects for concurrent analysis of Tevatron and LHC data!

In a way we are “just getting started”…

For more information:
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm
Backup
Multi-Muon Events at CDF

- Observe a larger-than-expected yield of muons with large impact parameter (outside the 1.5 cm radius beam pipe) in a sample collected with a dimuon trigger.

- These events are referred to as “ghost events”, and disappear when making tight requirements on silicon tracking.

- Only ~50% of events can be explained based on standard sources (long-lived particles, punch-through, in-flight decays, interactions with material, etc).

- A significant fraction of “ghost events” contain more additional muons (and tracks) in a cone around the trigger muon than predicted:
  - Impact parameter of muons consistent with originating from decay of a particle with \( \tau \sim 20 \) ps.
  - Also different kinematic properties than expected from standard sources.

- The source of this excess is currently not understood.

Study of multi-muon events produced in \( p\bar{p} \) collisions at \( \sqrt{s} = 1.96 \) TeV


- Investigations continue at CDF.
- Check of this result at DØ underway.
Rare Decays

- Rare decays very sensitive to New Physics. Large b production rate and high luminosity open a window of opportunity at the Tevatron.

- **FCNC $B_{s/d}$ decays:**
  - SM: BR($B_s \rightarrow \mu\mu$) $\sim 3.8 \times 10^{-9}$
  - MSSM/2HDM: SM x $\tan^N\beta$ (N=6,4)
  - CDF (2 fb$^{-1}$): $< 5.8 \times 10^{-8}$ ($\sim 15 \times$ SM) @ 95% CL

- **Flavor-violating $B_s \rightarrow e\mu$ decays:**
  - Forbidden in the SM.
  - Sensitivity to very large mass scales.

Limits on $B_d$ competitive with $B$ factories.
Unique limits on $B_s$.  

95% CL Limits on $\mathcal{B}(B_s \rightarrow \mu\mu)$

CDF Run II preliminary (2 fb$^{-1}$)

- $\mathcal{B}(B^0_s \rightarrow e\mu) < 2.0(2.6) \times 10^{-7}$ 90(95)% C.L.
- $M_{\text{LD}}(B_s^0 \rightarrow e\mu) > 47.7(44.6)$ TeV 90(95)% C.L.


With:
- $\langle B \rangle = 1.437 \pm 0.031$ ps
- $m(B_s) = 5.3061 \pm 0.0006$ GeV/c$^2$
- $m_e = 0.511$ GeV/c$^2$
- $F(B_s) = 0.210 \pm 0.005$ GeV
• MSSM at large $\tan\beta$:
  - $\Phi^0 = \{ h^0/H^0, A^0 \}$ nearly degenerated in mass
  - Coupling to $b, \tau$ enhanced ($\propto \tan\beta$) \( \sigma_{\Phi^0X} \propto 2 \times \tan^2\beta \)
  - $\text{BR}(\Phi^0 \rightarrow bb) \approx 90\%$, $\text{BR}(\Phi^0 \rightarrow \tau^+\tau^-) \approx 10\%$

• Three complementary channels:
  - $b(b) + \Phi^0 \rightarrow bbb(b)$
  - $b(b) + \Phi^0 \rightarrow \tau^+\tau^- b(b)$ (typically require $\geq 1 \tau \rightarrow e, \mu$)
  - $\Phi^0 \rightarrow \tau^+\tau^-$

\[
M^{vis} = \sqrt{p_T^\ell + p_T^\ell + p_T^{Z}}
\]
SUSY Higgs

- MSSM at large $\tan\beta$:
  - $\Phi^0 = \{h^0/H^0,A^0\}$ nearly degenerated in mass
  - Coupling to $b, \tau$ enhanced ($\propto \tan\beta$) $\Rightarrow \sigma_{\Phi^0 X} \propto 2 \times \tan^2\beta$
  - $\text{BR}(\Phi^0 \rightarrow bb) \sim 90\%$, $\text{BR}(\Phi^0 \rightarrow \tau^+\tau^-) \sim 10\%$

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  - $\Phi^0 \rightarrow \tau^+\tau^-$

---

**Graphical Representation**

- **DØ Preliminary, $L = 2.6 \text{ fb}^{-1}$**
  - $m_h \text{ max, } \mu = -200 \text{ GeV}$
  - $gb \rightarrow b\phi$

- **MSSM Higgs $\rightarrow \tau\tau$ Search, 95% CL Exclusion**

Individual searches approaching “interesting” range $\tan\beta < m_t/m_b \sim 35$.
Combination underway.