Search for New Phenomena in Hadron Collisions

The nature of Electroweak symmetry breaking is not understood; the Standard Model introduction of the Higgs scalars, though consistent with data, is unsatisfactory theoretically, and does not address cosmological needs.

High energy collisions at the Fermilab $\bar{p}p$ Tevatron and the DESY $e^\pm p$ HERA colliders offer ways to seek new phenomena beyond the Standard Model.

We report representative results from H1, ZEUS, CDF and DØ

(no new phenomena are observed !)
The Standard Model accomplishes electroweak symmetry breaking, and presently agrees with all particle physics measurements:

1 complex Higgs scalar doublet \( \rightarrow \)

- \( W^{\pm}, Z^0 \) get mass (Higgs as longitudinal components)
- All fermions get masses
- One remaining observable Higgs boson

Precision measurements at the \( Z^0 \) (LEP1, SLC), \( W \) (LEP2, Tevatron), top quark (Tevatron), \( \nu \) scattering give indirect measurement of SM Higgs mass:

\[ M_h < 215 \text{ GeV} \ (95\% \text{ CL}) \]

(June 2000 Susy2000 conference; for a particular choice of 2 loop corrections ...)

![Graph showing \( \Delta \chi^2 \) vs. \( m_H \)]
But the SM is not a THEORY of EWSB!

SM is an effective theory, up to scale $\Lambda$ for new physics to appear to avoid SM Higgs inconsistencies.

$m_H = 1 \text{ TeV}/\sqrt{\ln \Lambda/v}$ sets the scale for breakdown of fundamental Higgs ($v=\text{Higgs vev} = 246$ GeV)

- **Gauge hierarchy problem** - $m_H$ driven to scale $\Lambda$ by EW loop corrections unless fine tuning of parameters; need cancelation to 30 decimal places if $\Lambda = M_{\text{planck}}$.
- **Lack of grand unification** -- $(SU(3)_{\text{color}} \times SU(2)_L \times U(1)_Y$ couplings don’t meet
- **Need a dark matter candidate** - none in SM, but most Beyond SM theories provide one (e.g. weakly interacting neutral particle $M \sim O(100$ GeV)
- **Want extended CP violation to explain matter-antimatter asymmetry in universe
- **SM does not address origin of flavor, pattern of generations, fermion mass pattern, mixing.

Expect new theory embedding SM in low energy limit, with associated new phenomena
Two main classes of BSM models

**Fundamental Higgs scalar**
(Weak EWSB)

- **Supersymmetry:**
  - Extended Poincare group symmetry between bosons and fermions
  - New mirror spectrum of particles: $e \leftrightarrow \bar{e}$ etc.
  - Large no. new parameters (105 in minimal Susy SM)

**Composite Higgs**
(New strong interactions)

- **Technicolor, Topcolor etc.**
- QCD analogy with new technicolor fermions like quarks at TeV scale
- NJL superconductivity condensates, e.g. $t\bar{t}$ bound states for Higgs surrogate
- Strong WW scattering

What the classes of models say about each other

- New strong dynamics tends to modify precision measurements -- not seen.
  - Simple models generate FCNC (e.g. $\mu \rightarrow e \gamma$) and predict low top quark mass.
  - Models convoluted.

- Fundamental scalars are ugly (QCD pion is a composite!)
  - Large number of unspecified parameters.
  - No a priori justification; strong coupling is QCD inspired

**Plus** suggestions of large-scale compactification of extra dimensions.
String theory motivated but with observed effects at EW scale ($O$(TeV)); solves hierarchy problem by reducing GUT scale.
SM Higgs searches at Hadron Colliders

March 2000: LEP SM Higgs limit: 108 GeV (95% CL) will probably go up to about 115 GeV

Tevatron search for SM Higgs with present 120 pb\(^{-1}\) does not compete with LEP 2. In Run 2, can exclude up to 180 GeV with 20 fb\(^{-1}\); discover over some of that region.

LHC experiments will find SM Higgs (low mass region most difficult where rely on \(H \rightarrow \gamma\gamma\)).
Susy Higgs

Two Higgs doublets; 5 states ($h^0, H^0, A^0, H^+, H^-)$ survive after giving $W/Z$ masses. Susy Higgs sector controlled by $m_A$ and $\tan\beta =$ ratio of vev's. For large $\tan\beta$, decays into down type quarks or charged leptons are favored.

Search for $\phi = h/H/A$ in $q\bar{q} \rightarrow b\bar{b} \phi (\rightarrow bb)$ (4 b final states; 3 tagged.)

Charged Higgs searches:
$H^{\pm}$ gives excess heavy fermions in top decay through $\tau\nu$, $cs$, $Wbb$ decays.
Decay $t \rightarrow H^+ b$ can compete with $t \rightarrow W^+ b$.
Direct search for $t \rightarrow H^+ b$, with $H^{\pm} \rightarrow \tau\nu$ gives similar limits for large $\tan\beta$. 
Susy sparticle searches

Colored sparticles ($\tilde{q} \tilde{g}$) are produced strongly at Tevatron ($q\bar{q}/gg$ collisions). If R-parity conserved, the LSP (typically $\tilde{\chi}_1^0$) is stable, weakly interacting, so signatures for $\tilde{q} \tilde{g}$ typically involve jets and missing $E_T$. Charginos, neutralinos can occur in cascade decays of $\tilde{q} \tilde{g}$ giving rise to multilepton final states.

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Searches are typically done for a specific model, parameter range, and decay channel

**Jets + $E_T$ search**: (DØ) in mSUGRA framework. $m_0 =$ unified scalar mass; $m_{1/2} =$ unified gaugino mass. Find $m_{\text{squark}} > 250 \text{ GeV}; m_{\text{gluino}} > 300 \text{ GeV (at small } m_0)$ [95% CL]

Replot data in $\tilde{q} \tilde{g}$ plane:

For $\tan \beta = 2$, exclude $m < 260 \text{ GeV}$ for equal squark/gluino mass. ($\tan \beta < 2$ excluded for mSUGRA at LEP)
Cascade decays through gaugino states can lead to multilepton final states, relatively free from background. The $\tilde{g}$ can decay to either $\chi^+$ or $\chi^-$, so can lead to same sign dileptons.

**DØ search dilepton + jets + $E_T$:**

For $\tan\beta = 2$, exclude $m_{\text{squark}} = m_{\text{gluino}} < 255$ GeV (95% CL).

Extend LEP I for $\tan\beta < 6$; comparable to LEP II at low $\tan\beta$.

CDF search in 2 like sign leptons and 2 jets; exclude in large $q$ and smaller $g$ mass range. Exclude for equal mass $q\,g\,g$ at about 220 GeV.

Several channels give comparable reach: equal mass squark and gluino limit is about 260 GeV.
Susy stop/sbottom searches

Typically in MSSM, substantial mixing of the Susy partners of $t_L$ and $t_R$ ($\tilde{t}_1$ and $\tilde{t}_2$) where the $\tilde{t}_1$ could be the lightest squark. CDF has searched for $\tilde{t}_1 \rightarrow c \tilde{\chi}_1^0$ and $b \rightarrow b \tilde{\chi}_1^0$, extending the mass limits to ~120 and ~140 GeV, respectively.

$\tilde{t}_1 \rightarrow c \tilde{\chi}_1^0$

$\tilde{b} \rightarrow b \tilde{\chi}_1^0$

Search for $\tilde{t} \rightarrow b \tilde{\chi}_1^+$ and $\tilde{\chi}_1^+ \rightarrow l \tilde{\nu}$ or $\tilde{\chi}_1^+ \rightarrow W \tilde{\chi}_1^0$.

Tevatron extends stop/sbottom limits to higher mass (but lower $\tilde{\nu}$, $\chi_1^0$ mass)
R-parity violating Susy

If Sparticle number is not conserved in reactions/decays, LSP is not stable (typically take R violation small enough that production and cascades through the Susy chain are unaffected). Super potential can have 3 classes of new couplings:

\[ \lambda_{ijk} L_i L_j E_k + \lambda'^{ij} Q_i L_j D_k + \lambda''_{ijk} U_i D_j D_k \]

\( L/Q \) are left-handed lepton/squark doublet superfields and \( E/D/U \) are right-handed charged lepton/ d-type/ u-type quark singlet superfields. \( i,j,k \) are generation indices.

Only 1 type of coupling can be present to preserve lepton, baryon stability; \( \lambda'' \) terms (B violating) are difficult at hadron colliders, as multijet backgrounds are large.

\( \lambda_{ijk} \) couplings:

CDF 4 lepton search limits \( \lambda_{121} \)

DØ search in three lepton channels limits \( \lambda_{121}, \lambda_{122}, \lambda_{233} \) to \( 10^{-4} - 10^{-5} \)
R-parity violating Susy - Tevatron

$\lambda'_{ijk}$ couplings:

$\begin{array}{c}
\tilde{u} \\
\tilde{d}
\end{array} \longrightarrow e^+$  
$\tilde{u} \longrightarrow u$  
$\tilde{u} \longrightarrow d$

**D0:** $\lambda'_{1jk}$ (2 e's and 4 jets) rules out equal mass squark/gluino at:
- 270 GeV ($\tan\beta=2$),
- 225 GeV ($\tan\beta=6$).

**CDF:** Two gluino production $\tilde{g} \rightarrow c \tilde{c}_L; \tilde{c}_L \rightarrow e^+ d$. Get like sign electrons to probe $\lambda'_{121}$.

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**Diagram:**

- DØ experiment: 95% C.L.
- Excluded at 95% C.L.
- $\text{Br}(\tilde{c}_L \rightarrow s d) \geq 0.5$
- $\text{Br}(\tilde{c}_L \rightarrow s d) = 1.0$
- $M(\tilde{c}_L) = 200 \text{ GeV/c}^2$
- $\tan\beta = 2$

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**Graph:**

- **CDF PRELIMINARY**
- 107 pb$^{-1}$
- $M(\tilde{g})$ vs $M(\tilde{q})$ (GeV/c$^2$)

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**Legend:**

- $R_p$
- $gg \rightarrow e^+ e^- + \geq 2j$

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**Equations:**

- $\lambda_{ijk}$
- $u u u$
- $d d \chi^{++}$
- $\chi^{0}$
- $\chi^{+}$

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**Notes:**

- $m_g = 330 \text{ GeV/c}^2$
- $m_g = 286 \text{ GeV/c}^2$
- $m_g = 227 \text{ GeV/c}^2$
- $m_g = 273 \text{ GeV/c}^2$
- $m_g = 243 \text{ GeV/c}^2$
HERA searches for R-violating couplings $\lambda'$, assuming $\tilde{\chi}_1^0$ is LSP.

**H1 Limits on $\lambda_{ij}$ vs. squark mass.**

Also shown are indirect limits on $\lambda'_{ij}$, $\lambda'_{ii}$ from atomic parity violation and limits on $\lambda_{ij}$ from neutrinoless double beta decay.

**H1 limits in $\lambda'$ vs. squark mass plane**

ZEUS preliminary

Limits on $\lambda_{ij}$ for a $40$ GeV Zino-dominated $\tilde{\chi}_1^0$ and for photino-dominated $\tilde{\chi}_1^0$s with masses of $40$, $100$, $150$ GeV.

**ZEUS limits in $\lambda'$ vs squark mass for various choices of mSUGRA parameters**
**Gauge Mediated Susy**

GMSB allows for supersymmetry breaking in a new gauge sector, at energy scales much below the Planck scale. The gravitino, $\tilde{G}$, is the LSP. Decays of the next to lightest sparticle $\tilde{\chi}^0_1$ (or $\tilde{\tau}$) to $\tilde{G}$ occur by $\gamma$ ($\tau$) transitions.

The chain:

$$\bar{p} p \rightarrow \tilde{\chi}^+_1 \tilde{\chi}^-_1 \rightarrow W^+ W^- \tilde{\chi}^0_1 \chi^0_1 \rightarrow e e \gamma + \text{missing } E_T$$

could explain the CDF event of this topology.

**DØ** search in $\gamma \gamma + \text {missing } E_T$ rules out this interpretation for $\tan \beta = 2$ (there is only mild $\tan \beta$ dependence).

$M_{\chi^1} > 150 \text{ GeV (95\% CL)}$

CDF has sought the direct $\tilde{G} \tilde{G}$ production associated with initial state jet radiation. The limit infers that the GMSB Susy breaking scale exceeds 217 GeV ($m_{\tilde{G}} > 1.1 \times 10^{-5} \text{ eV}$).

**DØ** has searched for any Susy decay from NLSP to LSP by $\gamma$ decay ($E_\gamma > 20 \text{ GeV}$) in ($\gamma$, 2 jets, $E_T$). Rule out equal mass $\tilde{q}$ $\tilde{g}$ at 310 GeV.
Prospects for Susy Discovery at Tevatron Run II

Run 2a = 2 fb⁻¹ at 2 TeV; Run 2 total = 20 fb⁻¹
increased energy gives ~40% increase in \( \sigma \), so effective Susy rates up by ~30 in Run 2a. Background/statistics limited searches increase ~ \( (L_{\text{eff}})^{1/4} \) (x ~2).

- **CDF and DO Run 2 detectors are substantially improved**
  - Improved CDF/new DØ vertex detectors -- b-tag eff. ~ 60%
  - Improved \( \tau \) ID; multi-\( \tau \) important for high tan\( \beta \) studies
  - \( dE/dx \) from silicon, TOF in CDF; seek slow, highly ionizing tracks
    (massive stable charginos/ staus in AMSB);
  - Photon pointing in DØ to ~2 cm at vertex (GMSB signatures)
  - Improved CDF calorimetry -- better e ID, missing \( E_T \)
  - Improved triggers using tracks, vertices, topology

- **Some representative estimates (2 fb⁻¹):**
  - mSUGRA \( \tilde{q}, \tilde{g} \) limits to ~ 400 GeV (equal mass)
  - \( R \) (\( \lambda \) coupling) gluino to ~ 500 - 600 GeV
  - low tan\( \beta \) charginos to 150 GeV; 200 GeV for tan\( \beta \) > 10
  - stop limits to ~ 200 GeV
  - good possibility for AMSB \( \tilde{\chi}_1^+ \sim \) degenerate with \( \tilde{\chi}_1^0 \)
  - long lived neutralino in GMSB from photon pointing
Strong coupling models have been proposed, in analogy with QCD, to avoid fundamental scalars. A new scale of gauge interactions is envisioned with a new set of fermions operating at the 1 - 10 TeV scale.

These models predict analog `technicolor’ particles like ordinary π, ρ, ω, etc. There are typically gauge bosons that can connect leptons and quarks, yielding the possibility of color triplet Leptoquark states. New massive Z bosons are typical.

The technipions, or top quark condensates, play the role of the Higgs boson, and thus influence $W_L W_L$ scattering.

However, precision measurements of $Z$, $W$, and top quark properties have not confirmed the higher order corrections expected in these schemes, so models have evolved to be quite different from ordinary QCD.
CDF search for $p_T^{-} \rightarrow W \pi_T$, $\pi_T^{-} \rightarrow b\bar{b}$ or $b\bar{c}$

DØ search for $p_T^{-}, \omega_T \rightarrow e^+ e^-$ when decay to $\pi_T$ is forbidden (expect $\pi_T / p_T$ nearly degenerate). Set mass limit of 207 GeV

Heavy Z limits at 690 GeV; above 1 TeV in Run 2
Technirho/techniomega limits now at $\sim 200$ GeV (would expect them more massive). Run 2 limits at $\sim 500$ GeV.

Expect Run 2 limits for topgluons in 1.0 - 1.4 range
Top condensate Higgs limits in Run 2 of $\sim 350$ GeV
Bosons with lepton and quark number (color triplet) called **Leptoquarks (LQ)** arise in extended models containing new gauge bosons that connect lepton and quark sectors. Technicolor, $E_6$ supersymmetry, compositeness models contain LQ’s. The experimental suggestion of an excess of high $Q^2$, high-$y$ events at HERA stimulated LQ interpretations.

LQ can be formed in $s$-channel in $e^+q$ ($F=0$) or $e^-q$ ($F=2$) collisions at HERA. Both types can be pair produced at Tevatron. Suppression of FCNC requires that LQ’s couple to same generation lepton/quark.

**HERA s-channel;** $\lambda$ is Yukawa coupling. Popular guess $\lambda = \sqrt{4\pi\alpha_{EM}} = 0.3$

**Tevatron - strong production;** indep. of Yukawa coupling $\lambda$ decay BR $\beta = 1(0)$ for $e(\nu)$ decay.

LQ’s possible with $J=0,1$; for 3 generations; $F=0,2$
Recent H1, ZEUS results improve earlier DØ limits on 1st generation LQ, if $\lambda > 0.1$, particularly at low $\beta$.

ZEUS results display the sensitivity for scalar and vector LQ's as a function of Yukawa coupling $\lambda$.

H1/ZEUS exclude scalar LQ's up to ~280 GeV for EM strength Yukawa couplings. Tevatron excludes up to 240 GeV for $\beta=1$ for any $\lambda$. 
2nd generation LQ’s

DØ limits from pp → LQ LQ μμ jets, μν jets, νν jets for scalar/vector 2nd generation LQ.

E.g. for Scalars:
- > 200 GeV (β = 1)
- > 180 GeV (β = 1/2)
- > 79 GeV (β = 0)

If LQ arises from technirho decay, CDF finds limit increases up to 174 GeV for β = 0.

$\rho_T \rightarrow LQ \overline{LQ} \rightarrow (cv) \overline{(cv)}$

3rd generation LQ’s

Search for LQ → ν + b jet; CDF limit is 148 GeV. In the case that LQ’s arise from technirho production with decay into LQ pairs (LQ → bv), the limit is increased as m($\rho_T$) increases:

H1 has excluded LQ decays with mixed 1st and 3rd generation decays (e jet and τ jet) (FCNC) up to 275 GeV for equal e/τ BR and EM strength Yukawa coupling.
Searches for Quark Compositeness

Quarks and/or leptons could have internal substructure, as observed at higher levels of physics:

(atomic → nuclei → proton/neutron → quark)

For an effective contact interaction below the compositeness scale $\Lambda$:

$$ L \sim \pm \frac{g^2}{\Lambda^2} \eta (q_L \gamma_\mu q_L) (q_L \gamma_\mu q_L), $$

get modifications to inclusive jet cross section.

Earlier inclusive jet cross sections from CDF had a large $E_T$ excess that could be explained by $\Lambda$ in the 1.5 - 1.8 TeV range. DØ has set limits on quark compositeness from large $E_T$ dijet angular distributions that rule out this interpretation.

$$ \Lambda > 2.7 \ (2.4) \ TeV \ \text{for} \ (+\ (-)) \ \text{interference with QCD}. $$

Ratio of jet XS: $(\eta_{\text{jet}} < 0.5) / (0.5 < \eta_{\text{jet}} < 1.0)$

![Graph showing the ratio of jet cross section with different $\Lambda$ values and QCD limit.]
If quarks and leptons have common constituents, new contact interactions occur below the scale of free constituents

\[ L \sim \eta \frac{g^2}{\Lambda^2} (e \bar{O} e) (q \bar{O} q), \text{ where } 0 \text{ is a Lorentz operator, } \Lambda \text{ is the scale of compositeness, and } \eta \text{ is a sign.} \]

**HERA** experiments seek deviations from DIS at large \( Q^2 \)

**LEP** experiments search for deviations in di-quark production

**Tevatron** experiments seek modifications to Drell-Yan production.

The three sets of experiments differ in their sensitivity to compositeness for different Lorentz structures \( \bar{O} \).

Limits vary between \( \Lambda > \sim 2 \text{ to } \sim 5 \text{ TeV at HERA; } \)
\( \sim 4 \text{ to } \sim 6 \text{ TeV for Tevatron, and } \)
\( \sim 2 \text{ to } \sim 7 \text{ TeV for LEP} \)

depending on operator structure.

Searches for direct evidence of substructure through excited states: **HERA** limits: \( e^* > \sim 230 \text{ GeV}; \) \( \nu^* > \sim 160 \text{ GeV}, \)
\( q^* > \sim 190 \text{ GeV}. \) **Tevatron** limits on \( q^* > \sim 570 \text{ GeV} \).

These direct limits are below those on compositeness scale in contact interactions.
String theories require 6-7 extra spatial dimensions, previously thought to be compactified at the Planck scale. Recently, suggestions were made that compactification might occur for some of these dimensions at larger scales. For example, (Randall-Sundrum; Antoniadis; Dienes et. al); if compactification radius is at the EWSB scale ($\mathcal{O}$ (TeV)), possibilities exist to observe a tower of $Z'$-like states at multi-TeV.

Arkani-Hamed, Dimopoulos, Dvali conjectured that the fundamental quantum gravity mass (effective Planck) scale $M_S$ could be $\mathcal{O}$ (TeV), and the compactification distance scale of $\lesssim$ mm. In this model, particle processes could emit gravitons that propagate into the hidden dimensions, leading to signatures like $e^+e^- \rightarrow \gamma [G] = \text{monogammmas}$ or $q \bar{q} \rightarrow g [G] = \text{monojets}$. Also modifications to $q \bar{q} \rightarrow e^+e^-/\gamma\gamma$ in hadron collisions, or to changes in DIS, due to towers of virtual graviton exchanges.

Several phenomenological calculations of LED effects differ in parametrization -- dependence on $n$, interference.
Also, classical gravity would be modified at short distances:

$$R \sim \left(\frac{1}{M_S}\right) \left[\frac{M_{Pl}}{M_S}\right]^{2/n}$$

(R \sim 10^{13} \text{ m for } n=1 \text{ (ruled out!)}

0.7 \text{ mm for } n=2, \ 3 \text{ nm for } n=3, \ 10^{-11} \text{ m for } n=4)

Cavendish experiments have recently pushed into the sub-millimeter regime with no observed deviation from $r^{-2}$.

$n=2$ also disfavored by supernova and cosmological effects.

H1 study of modifications to high $Q^2$ DIS limits $M_S$
to $> 0.48$ or $> 0.72$ TeV, depending on sign of interference.

$qq \rightarrow ee/\gamma\gamma$ mass and angular distributions are modified by
the LED effects, depending on $M_S$ and $n$.

DØ study has set limits on $M_S$ for all phenomenological
forms: e.g. Han,Lykken,Zhang:

<table>
<thead>
<tr>
<th>$n$</th>
<th>$M_S$ (TeV)</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>$&gt; 1.3$</td>
</tr>
<tr>
<td>3</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>7</td>
<td>0.95</td>
</tr>
</tbody>
</table>

$\cos\theta^*$
Searches for things not necessarily wanted

Experiments have also searched for 'non-standard' new effects: some examples --

**CDF:** search for 4th generation b quark: \( b' \rightarrow b \, Z \)
Mass limit 199 GeV

CDF search for \( X \rightarrow t \bar{t} \)

**DØ** search for bosonic Higgs \( H \rightarrow γγ \)

DØ search for heavy pointlike magnetic monopoles (seek diphoton radiation): limit 870 GeV for \( J=1/2 \)
Searches for things not necessarily wanted

Large $E_T$ leptons observed with large missing $E_T$ at HERA: H1 has a sample of 8 events seen, with background of ~2 events (e.g. W production). ZEUS observation ~ expected.

**Isolated Lepton + Missing $P_T$ Events**

$$e^+ p \rightarrow \mu^- X$$

<table>
<thead>
<tr>
<th>Run</th>
<th>$\int L dt$</th>
<th>ZEUS</th>
<th>H1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994-1997</td>
<td>48pb$^{-1}$</td>
<td>3</td>
<td>36.5pb$^{-1}$</td>
</tr>
<tr>
<td>$e^+ p$</td>
<td></td>
<td>$(3.5 \pm 0.7)$</td>
<td>$(0.06 \pm 0.26)$</td>
</tr>
<tr>
<td>1998-1999</td>
<td>16pb$^{-1}$</td>
<td>2</td>
<td>12.6pb$^{-1}$</td>
</tr>
<tr>
<td>$e^- p$</td>
<td></td>
<td>$(0.8 \pm 0.4)$</td>
<td>$(0.49 \pm 0.11)$</td>
</tr>
<tr>
<td>1999-2000</td>
<td>18pb$^{-1}$</td>
<td>2</td>
<td>24.9pb$^{-1}$</td>
</tr>
<tr>
<td>$e^+ p$</td>
<td></td>
<td>$(1.8 \pm 0.4)$</td>
<td>$(1.11 \pm 0.28)$</td>
</tr>
<tr>
<td>Total</td>
<td>66pb$^{-1}$</td>
<td>5</td>
<td>61.4pb$^{-1}$</td>
</tr>
<tr>
<td>$e^+ p$</td>
<td></td>
<td>$(5.3 \pm 1.1)$</td>
<td>$(2.17 \pm 0.52)$</td>
</tr>
</tbody>
</table>

H1 has added the cut $P_T^\mu > 25$ GeV.
The previous search results were all for some postulated new particle or phenomenon. How do we search for things for which there is no model? A formalism for this has been developed by DØ -- SHERLOCK. Applied to exclusive final states:  e µ E_T + (0,1,2,3) jets

Steps of algorithm:
1. Choose exclusive final states; for each, define d kinematic variables (e.g. E_T, Σ p_T (leptons, γ, W, Z), Σ p_T (jets). Do not include topological variables (e.g. mass, sphericity, as these tend to be dependent on specific physics model).
2. Make d dimensional distributions of data and backgrounds, transforming variables so that background is uniformly distributed in the unit d-dimensional hypercube.
3. Define regions R around any set of N data points (region is that volume closer to chosen data points than any others)
4. Calculate probability p_N^R for background to fluctuate up to N or greater. Find that region R for which probability is minimum and call it p_N
5. From an ensemble of Monte Carlo experiments using known background distributions, find the fraction of such experiments with probability < p_N; call it P_N
6. Find the N for which P_N is minimized; P = min(P_N)
7. Determine the fraction of MC experiments giving P less than that observed = P . P is the measure of whether new physics is indicated in the experiment.
SHERLOCK study of $e\mu E_T(+)jets)$

Backgrounds are due to $Z/\gamma^* \rightarrow \tau\tau$, $WW$, QCD jet faking $e/\mu$

$P$ distributions with above backgrounds (and $MC\;t\bar{t}$ signal). The background model shows low probability to account for data, particularly in 2 jets.

Using DATA and above backgrounds, SHERLOCK identifies the optimum region $R$ for new physics (e.g. $t\bar{t}$). The probability $P$ for no new physics is 0.11 (1.2σ), indicating top quarks. All 6 $t\bar{t}$ events in the conventional analysis are in or near the region $R$ chosen. Conventional analysis using mass and topological variables gave $2.75\sigma$ excess.

Now treating $t\bar{t}$ as part of background, find probability that total of known processes explain the data is $P = 0.72$. No evidence for new physics!
Conclusions

- The high energy collisions of proton - antiproton and electron - proton give many opportunities for observing new physics. Many studies have been done for new phenomena expected in Supersymmetry, Strong Coupling models or Large Extra Dimensions.

- CDF, DØ, H1 and ZEUS have searched for many other new phenomena, either based on models, or solely on experimental signatures.

- No clear signature for New Physics yet -- but larger data samples and improved detectors hold good promise for finding something before the LHC.