Physics with 12-T Magnet Hadron Colliders

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References

URL: http://hepr8.physics.tamu.edu/hep/Tripler/

  → Magnet design
- V. Barger et al., hep-ph/9910500 
  → SM Higgs, SUSY(3l, LS-ll, Z’, Contact)
- V. Krutelyov et al., hep-ph/0011253 
  → SUSY (E_T+jets, 1l+E_T+jets)
Outline

1. 12-Tesla Nb$_3$Sn Dipole Magnet
2. The Tevatron Tripler (6 TeV $p$-$p\bar{p}$)
3. Monte Carlo
4. SM Higgs Boson
5. mSUGRA
6. Other New Physics
7. Top/Bottom Physics
8. Summary
1. 12-T Magnet

$E_{cm} = 2 \text{ TeV}$  \hspace{1cm} 5.4 \text{ TeV}

750 trillion collisions (15 fb$^{-1}$) \hspace{1cm} 1500 trillion collisions (15 fb$^{-1}$)

*cf.* 14 TeV $pp$ at Large Hadron Collider (LHC)

July, 2001  \hspace{1cm}  Snowmass 2001
1. 12-T Magnet (cont’d)

Possible High Energy Programs in the Future
2. The Tripler

What is it?

1. Install new ring of single-aperture, 12-T, Nb$_3$Sn $\cos \theta$ dipoles (+quads) in the Tevatron tunnel. Inject at 150 GeV.

2. Can be designed as an injector to VLHC.

3. Use most of the existing $p$ and $p\bar{p}$ infrastructure as it will be available at the end of Run II
   $\rightarrow$ Magnets are only major technical+cost element.

4. Suspect the whole technical upgrade is less than $500M$, but needs study and magnet R&D.
2. The Tripler (cont’d)

What is it? (cont’d)

5. Use the two working CDF-II and D0-II detectors with minimal changes so that physics can be done immediately after commissioning.

6. Luminosity and bunch spacing to be the same as Run II ($\mathcal{L} < 5 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$), but could use the natural $\times 3$ increase to do luminosity leveling.

7. Physics and timeline are important issues with LHC expected to come on in 2006-2007. Worthwhile to do 6-TeV $p-p\bar{p}$ physics in the 2010 era?
2. The Tripler: Performance

- $E_{cm} = 5.4$ TeV (using 12 Tesla dipole magnets) [1]
- Operation mode: 100-bunch operation and 5.6 interactions/crossing [2]
- Live time: $2 \times 10^7$ sec/year (luminosity leveling) [2]
- $\mathcal{L} = 3.8 \times 10^{32}$ cm$^{-2}$s$^{-1}$ [2]
- $\int \mathcal{L} dt = 7.6$ fb$^{-1}$/year [2] $\rightarrow$ 30-40 fb$^{-1}$/4-5 years

References


3. Monte Carlo Package

Detector Simulation: SHW

a) A quick simulation program was developed by John Conway during SUSY/Higgs workshop in 1998.

b) The fiducial volume for each particle (e, $\mu$, $\tau$, $\gamma$, $j$, $b$, $c$) and its ID efficiency are implemented by averaging between CDF-II and D0-II detector and by using the measured number in Run I (1992-96).
4. (SM) Higgs (Boson)
4. SM Higgs Boson: Limits

Limit from the LEP-II direct search:
(Ref.) P. Igo-Kemenes, LEP Seminar, Nov. 3, 2000
\[ M_h > 113.5 \text{ GeV } @ 95\% \text{ C.L.} \]

Indirect bounds from precision measurements:
(Ref.) A. Straessner, XXXVth Recontres de Moriond, 2000
\[ M_h = 67^{+60}_{-33} \text{ GeV} \]

Triviality/consistency (lattice) upper bound:
\[ M_h < 710 \text{ GeV} \]
4. SM Higgs Boson: Production

**Total Production Cross section**

**Tripler**

V. Barger et al., PLB 478, 224 (2000)

From $\sqrt{s} = 2$ to 5.4 TeV,
- $qq \rightarrow Vh$ cross section enhanced by 4;
- $(pp$ collider cross section lower by 25%);
- $gg \rightarrow h$ cross section enhanced by 10–30;
- $VV \rightarrow h$ processes come up by 20.
4. SM Higgs Boson: Signals

Signal rates for individual channels:

\[
\begin{align*}
\sigma(W h \rightarrow \ell \nu \ b \bar{b}) & \approx 130 \text{ fb} \quad (m_h \approx 120 \text{ GeV}), \\
\sigma(W W^* \rightarrow \ell \nu \ \ell \nu) & \approx 140 \text{ fb} \quad (m_h \approx 160 \text{ GeV}), \\
\sigma(ZZ \rightarrow 4\ell) & \approx 2 \text{ fb} \quad (m_h \approx 220 \text{ GeV}), \\
\sigma(ZZ \rightarrow 2\ell \ 2\nu) & \approx 7 \text{ fb} \quad (m_h \approx 300 \text{ GeV}), \\
\sigma(WW \rightarrow \ell \nu \ jj) & \approx 50 \text{ fb} \quad (m_h \approx 500 \text{ GeV}).
\end{align*}
\]

SM Backgrounds considered:

\[
\begin{align*}
Wjj, \ Wb\bar{b}, \ WW & \rightarrow \ell \nu \ b\bar{b} \\
t\bar{t}, \ WW^* & \rightarrow \ell \nu \ \ell \nu \\
Z(\gamma)Z^* & \rightarrow 4\ell \\
Z(\gamma)Z^* & \rightarrow 2\ell \ 2\nu \\
Wjj, \ WW^* & \rightarrow \ell \nu \ jj.
\end{align*}
\]
4. SM Higgs Boson: Tripler vs. LHC

Tripler
V. Barger et al., PLB 478, 224 (2000)

\[ p\bar{p}\rightarrow h_{\text{SM}}X \]

\[ 5.4 \text{ TeV, } 30 \text{ fb}^{-1} \]

LHC
(ATLAS TDR)

\[ \int L \, dt = 30 \text{ fb}^{-1} \]
(no K-factors)
4. SM Higgs Boson: “5σ” Luminosity

Tripler
V. Barger et al., PLB 478, 224 (2000)

Luminosity needed for a 5σ discovery

$M_h \sim 580$ GeV with 10 fb$^{-1}$
$M_h \sim 680$ GeV with 40 fb$^{-1}$

close to the trivial/consistency bound!
4. SM Higgs Boson: if $M_h < 130$ GeV...

<table>
<thead>
<tr>
<th>Machine</th>
<th>Discovery Channel</th>
<th>Coupling $\int \mathcal{L} dt (5\sigma)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripler</td>
<td>$q\bar{q} \rightarrow WH$ (via $H \rightarrow b\bar{b}$)</td>
<td>$WWH$ 7.5 fb$^{-1}$ [1]</td>
</tr>
<tr>
<td>LHC</td>
<td>$gg \rightarrow t\bar{t}H$ (via $H \rightarrow b\bar{b}$)</td>
<td>Yukawa 30 fb$^{-1}$ [2]</td>
</tr>
<tr>
<td></td>
<td>$gg \rightarrow H \rightarrow \gamma\gamma$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$qq' \rightarrow qq'WW \rightarrow qq'H$ (via $H \rightarrow \tau\tau \rightarrow e\mu + \not{E_T}$)</td>
<td>$WWH$ 60 fb$^{-1}$ [3]</td>
</tr>
</tbody>
</table>

References


4. SM Higgs Boson: Prospect in Run II

Tevatron (Run IIa/IIb)

\[ qq \rightarrow W(Z)h \rightarrow l\bar{b}bX \]
\[ gg \rightarrow WW^*/ZZ^* \rightarrow l^+l^-X \]

Source: Higgs working group report (SUSY/Higgs Workshop, 1998)
5. mSUGRA

Possible constraints

$\mu > 0 \ (b \rightarrow s \gamma, g_{\mu} - 2)$

$+ \tan \beta = 5-60 \ (M_h^{\text{LEP}})$

$+ \text{relic density}$

$\Rightarrow M_{\tilde{g}} < 1.4 \text{ TeV}$

Example of $\tilde{g}, \tilde{u}_L, \tilde{t}_1, \tilde{\chi}_1, \tilde{\chi}_1^0$ masses:

a) $m_0=100, \ m_{1/2}=300$

734, 654, 482, 152, 123

b) $m_0=200, \ m_{1/2}=500$

1173, 1050, 805, 226, 213

c) $m_0=275, \ m_{1/2}=550$

1284, 1158, 1081, 248, 236

July, 2001
5. mSUGRA – Production Cross Section

Tripler
V. Barger et al., PLB 478, 224 (2000)

From \( \sqrt{s} = 2 \) to 5.4 TeV,
- e.w. processes \( \chi_1^\pm \chi_2^0, \ell\ell' \): a factor 4–10;
  (pp collider cross section lower by 20%);
- QCD \( \ell^*\ell, g\bar{g} \) processes: a factor 20–500!
Experimental Signatures

a) $H_T + \text{jets} + 0$ lepton
b) $H_T + \text{jets} + 1$ lepton
c) Trilepton
d) Like-sign dilepton

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Main Reaction:
\[ p \bar{p} \rightarrow q \bar{q} \]

(a) \( E_T + \text{jets} + 0l \)
(b) \( E_T + \text{jets} + 1l \)

**Experimental Signatures**

\[ \bar{p} \rightarrow \bar{g} g \]

\[ \rightarrow (q \bar{q} \tilde{\chi}_1^+) (q \bar{q} \tilde{\chi}_1^-) \]
\[ \rightarrow \begin{cases} 
8 \text{jets} + 2 \tilde{\chi}_1^0 \\
4 \text{jets} + 1 \ell + 1 \nu + 2 \tilde{\chi}_1^0
\end{cases} \]

**Background**
\[ p \bar{p} \rightarrow t \bar{t} \]
\[ \rightarrow (b W^+) (\bar{b} W^-) \]
\[ \rightarrow \begin{cases} 
6 \text{jets} \\
4 \text{jets} + 1 \ell + 1 \nu
\end{cases} \]

Note: \( \nu's/\tilde{\chi}_1^0's: \) stable (escaping the detector)
Analysis:

Event Generation and Selection

Experimental signatures:
- $E_T$ + jets + no leptons
- $E_T$ + jets + 1 lepton

Generation (physics processes in $p\bar{p}$ collisions):
- SUSY: gluino and squark pair-production
- SM: $t\bar{t}$, $W$, $Z$, diboson, and QCD

Selection (kinematical variables):
- $E_T$ for each particle, $N_{jet}$, $N_{\ell}$, $M_T(\ell, E_T)$, $E_T$, $M_S \equiv E_T + \sum E_T^{jet}$ from the detector simulation

<table>
<thead>
<tr>
<th>Tripler</th>
<th>jets + $E_T$</th>
<th>1$\ell$ + jets + $E_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{jet}$ ($E_T &gt; 15$ GeV)</td>
<td>$\geq 6$</td>
<td>$\geq 4$</td>
</tr>
<tr>
<td>$N_{\ell}$ ($p_T &gt; 15$ GeV/c)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>$\Delta \phi (jet, E_T)$</td>
<td>$&gt; 30^\circ$</td>
<td>$&gt; 30^\circ$</td>
</tr>
<tr>
<td>$E_T$</td>
<td>$&gt; 200$ GeV</td>
<td>$&gt; 330$ GeV</td>
</tr>
<tr>
<td>$M_S$</td>
<td>$&gt; 1000$ GeV</td>
<td>$&gt; 600$ GeV</td>
</tr>
<tr>
<td>$M_T(\ell, E_T)$</td>
<td>n.a.</td>
<td>$&gt; 160$ GeV/c$^2$</td>
</tr>
</tbody>
</table>

Assume: 30 fb$^{-1}$

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Significance: Example: $\tilde{g}/\tilde{q}$ (800 and 1000 GeV/c$^2$) in $E_T$+jets

$\frac{d\sigma}{dt}$ [fb/100GeV] $t\bar{t}$

$W/Z/$ diboson

QCD

$M_S > 1000$ GeV

$\sqrt{N_B}$

$N_S$ (Significance)

$E_T > 200$ GeV

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$E_T$+jets: $M_q \sim M_{\tilde{g}}$

Significance

$1 \rightarrow 10$

$10 \rightarrow 100$

$100 \rightarrow 1000$

$1000 \rightarrow 1200$

$m_{1/2} \sim 420$ GeV

$\rightarrow$ No $\tan\beta$ dependence

$\tan\beta$

$3$ (●)

$10$ (▼)

$30$ (○)
$m_0$ dependence ($m_{1/2} = 410$ GeV)

![Graph showing the dependence of significance on $m_0$ for different event categories.](image)

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**$m_0$ dependence ($m_{1/2} = 410$ GeV)**

Decays modes of the chargino to characterize jet and lepton multiplicities in SUSY events.

<table>
<thead>
<tr>
<th>$m_{1/2} = 410$</th>
<th>SUSY Masses</th>
<th>Decays of $\tilde{\chi}_1^\pm$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_0$ Range</td>
<td>lighter $\tilde{\chi}_1^\pm$</td>
<td>$W^{\pm}\tilde{\chi}_1^0$ (or $\tau\tilde{\nu}$) (or $\ell\tilde{\nu}$)</td>
</tr>
<tr>
<td>$\lesssim 150$</td>
<td>$\tilde{\tau}_1$, $\tilde{\ell}_R$, $\tilde{\nu}$</td>
<td>$\checkmark$</td>
</tr>
<tr>
<td>$150 - 300$</td>
<td>$\tilde{\tau}_1$, $\tilde{\ell}_R$</td>
<td>$\tilde{\nu}$</td>
</tr>
<tr>
<td>$\gtrsim 300$</td>
<td>—</td>
<td>$\tilde{\tau}_1$, $\tilde{\ell}_R$, $\tilde{\nu}$</td>
</tr>
</tbody>
</table>

(Units: GeV/$c^2$)
Summary: $E_T+\text{Jets}+X$

1. Weak $\tan\beta$ dependence on the gluino mass limit up to 30. (we are studying with higher $\tan\beta$ values.)

2. $150 < m_0 < 300$ GeV $\rightarrow m_{1/2}$ up to 440 GeV using the 0l channel ($\tan\beta = 3-30$)

   $m_0 \sim 100$ GeV $\rightarrow m_{1/2}$ up to 480 GeV using the 1l channel ($\tan\beta = 3-10$)
(c) Trilepton

(by ISAJET)

$$\tilde{\chi}_1^\pm \tilde{\chi}_2^0, \ell^* \ell, \ell \nu \rightarrow 3\ell + E_T^{\text{miss}}.$$ 

**SM Backgrounds:**

- $$W\gamma^*, WZ^* \rightarrow 3\ell \nu$$
- $$t\bar{t}, ZZ(\gamma) \rightarrow 3\ell \nu.$$ 

→ Need to study the large tan$$\beta$$ scenario.
(d) LS Dilepton

(by ISAJET)

\[ \bar{g}g, \bar{q}q, g\bar{q}, \tilde{\chi}^\pm \tilde{\chi} \rightarrow \ell^\pm \ell^\pm + \text{jets} + E_T^{\text{miss}}. \]

SM Backgrounds:

\[ W\gamma^*, WZ^*, ZZ(\gamma) \rightarrow \ell^\pm \ell^\pm + E_T^{\text{miss}}, \]
\[ t\bar{t} \rightarrow \ell^\pm \ell^\pm + \text{jets} + E_T^{\text{miss}}. \]

→ Need to study the large tan\(\beta\) scenario.

\[ m_0 = 100 \text{ GeV} \]
\[ 100 \leq m_{1/2} \leq 500 \text{ GeV} \]

\(\mu > 0, \tan \beta = 3, m_0 = 100 \text{ GeV}\)
6. Other New Physics

- New gauge bosons $Z'$
  \[ \mathcal{L} = -g_2 \sum_i \bar{\psi}_i \gamma_\mu (\epsilon_i L P_L + \epsilon_i R P_R) \psi_i Z'^\mu, \]

  One finds a 5σ signal with 20 fb$^{-1}$ for

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$M_{Z'_S}$</th>
<th>$M_{Z'_L}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tevatron</td>
<td>1.1 TeV</td>
<td>1.2 TeV</td>
</tr>
<tr>
<td>Tripler</td>
<td>2.6 TeV</td>
<td>2.9 TeV</td>
</tr>
<tr>
<td>$pp$</td>
<td>2.0 TeV</td>
<td>2.1 TeV</td>
</tr>
<tr>
<td>LHC</td>
<td>5.1 TeV</td>
<td>5.3 TeV</td>
</tr>
</tbody>
</table>

- Contact interactions
  \[ L_{NC} = \sum_q \sum_{\alpha, \beta=L,R} \frac{\pm 4\pi}{(\Lambda_{\pm})^2} (\bar{c}_\alpha \gamma_\mu c_\alpha) (\bar{q}_\beta \gamma^\mu q_\beta) \]

  One finds 95% C.L. exclusion:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\Lambda_+$</th>
<th>$\Lambda_+$</th>
<th>$\Lambda_+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tevatron</td>
<td>36 TeV</td>
<td>61 TeV</td>
<td>34 TeV</td>
</tr>
<tr>
<td>Tripler</td>
<td>5.4 TeV</td>
<td>5.4 TeV</td>
<td>5.4 TeV</td>
</tr>
<tr>
<td>$pp$</td>
<td>14 TeV</td>
<td>14 TeV</td>
<td>14 TeV</td>
</tr>
<tr>
<td>LHC</td>
<td>84 TeV</td>
<td>84 TeV</td>
<td>84 TeV</td>
</tr>
</tbody>
</table>
To be filled...
8. Summary

✓ We proposed an energy upgrade of the Fermilab Tevatron (Tripler): $E_{cm} = 5.4$ TeV in $p-p\bar{p}$ collisions

✓ The Tripler extends:

- $M_{h^{(SM)}}$ up to 680 GeV
- $M_{\tilde{g}}$ up to 1100 GeV
- $M_{Z'}$ up to 2.6 TeV
- $\Lambda_{\text{contact}}$ up to 64 TeV
8. Summary (cont’d)

✓ For ultimate mass reach, LHC (14 TeV pp collisions) is more powerful than the Tripler. e.g., gluino mass up to 2000 GeV or above

✓ The Tripler offers the only way to reach the discovery potential of a SUSY mass scale of 1000 GeV using an existing facility in the U.S.

✓ The Tripler can be a good bridge between Tevatron era and future collider machines ($e^+e^-$ collider, $\mu^+\mu^-$ collider, VLHC) in the U.S. high-energy physics program.
Prospect on mSUGRA

Possible constraints
\[ \mu > 0 \quad (b \rightarrow s\gamma, g\mu-2) \]
\[ + \tan\beta = 5-60 \quad \left( M_h^{\text{LEP}} \right) \]
+ relic density
\[ \rightarrow M_{\tilde{g}} < 1.4 \text{ TeV} \]

Tripler’s $5\sigma$ Reach
\[ \tan\beta = 10 \]

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Tripler?