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Search for Physics Beyond the Standard Model (Non-SUSY) at the Tevatron

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This article is a short summary of the short summary of searches for physics produced by some of the non-Super Symetric (non-SUSY) extensions to the Standard Model of High Energy Physics by the DØ and CDF collaborations at the Tevatron in the past year or so. Covered in the talk was a sampling of the searches for Leptoquarks, Large Extra Dimensions, Technicolor and High Mass Resonances.

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I. INTRODUCTION

The Standard Model (SM) of High Energy Physics is widely thought to be the correct low energy approximation to reality. However, it is also clearly incomplete. There are many possible extensions to the SM. "Beyond the Standard Model" (BSM) searches have been motivated by most of these extensions. In addition there have also been a number quasi-model independent searches. Super Symmetric (SUSY) models have been the most common model dependent searches. These have been discussed by Miguel Vidal earlier in this session. I will discuss just a few of the non-SUSY searches. We recently counted 30 public results, both published and preliminary from the two experiments at the Tevatron done using more than 1fb^{-1} of luminosity, that is using data that was available in Aug 2006 or later. The talk could only cover a small fraction of these searches, and due to length constraints, this proceedings can only touch on some of those.

II. LEPTOQUARKS

Leptoquarks (LQ) which couple the quark and lepton sectors arise in a number of BSM models including various compositness models, SUSY in R-parity violating scenarios, Grand Unified Theories, extended technicolor etc. The key properties of Leptoquarks are that they have non-zero lepton (L) and baryon (B) numbers. They are fractionally charged and can come in either scalar, spin 0, or vector, spin 1 types. Scalar leptoquark production depends only on the mass of the leptoquark (M_{LQ}), while vector leptoquark production can depend on the anomolous production parameters λ_G and κ_G as well. Bounds provided by lepton number conservation, the magnitude of flavor changing neutral currents, etc. imply that transitions between generations are highly suppressed. Therefore leptoquark decays can be characterized by the branching ratio $\beta = Br(LQ->l^{\pm}q)$ to the charged lepton. The rest of the decays, $(1-\beta) = Br(LQ->\nu q)$ will contain the neutrino.

A. 1st generation

DØ has recently done a 1st generation leptoquark ($LQ_1LQ_1->eejj$) search using 1 fb^{-1}. They require two well measured electrons coming from the primary vertex; two well measured jets, separated from any em objects and the di-electron mass must be well above the Z. In addition, The sum of the scalar E_T of the four objects must be greater than $400GeV$. The latter is a very powerful method of reducing the QCD background. The result of these selections leaves zero data events with a background of $Bkg = 1.5 \pm 0.1(stat) \pm 0.12(syst)$. With this result they proceed to set a limit based on the average of the electron/jet masses. The object pairings were made on an event by event basis to minimize the LQ-LQ mass difference.

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To cite bibliography entries, use the `\cite{#1}` command. Most journal styles will display the corresponding number(s) in square brackets: [1]. To avoid the square brackets, use `\onlinecite{#1}`: Refs. 1 and 4, 5. REVTEX

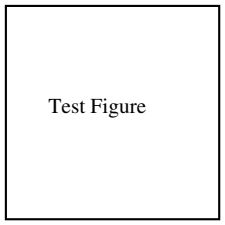

FIG. 1: A figure caption. The figure captions are automatically numbered.

"collapses" lists of consecutive reference numbers where possible. We now cite everyone together [4–6], and once again (Refs. 4–6). Note that the references were also sorted into the correct numerical order as well.

Footnotes are produced using the `\footnote{#1}` command. Most APS journal styles put footnotes into the bibliography. REVTEX 4 does this as well, but instead of interleaving the footnotes with the references, they are listed at the end of the references. Because the correct numbering of the footnotes must occur after the numbering of the references, an extra pass of LATEX is required in order to get the numbering correct.

Inline math may be typeset using the `$` delimiters. Bold math symbols may be achieved using the `bm` package and the `\bm{#1}` command it supplies. For instance, a bold α can be typeset as `$\bm{\alpha}$` giving $\boldsymbol{\alpha}$. Fraktur and Blackboard (or open face or double struck) characters should be typeset using the `\mathfrak{#1}` and `\mathbb{#1}` commands respectively. Both are supplied by the `amssymb` package. For example, `$\mathbb{R}$` gives $\mathbb{R}$ and `$\mathfrak{G}$` gives $\mathfrak{G}$

In LATEX there are many different ways to display equations, and a few preferred ways are noted below. Displayed math will center by default. Use the class option `fleqn` to flush equations left.

Below we have numbered single-line equations; this is the most common type of equation in *Physical Review*:

$$\chi_+(p) \lesssim [2|\mathbf{p}|(|\mathbf{p}| + p_z)]^{-1/2} \begin{pmatrix} |\mathbf{p}| + p_z \\ px + ip_y \end{pmatrix} , \tag{1}$$

$$\left\{ \mathbb{1}1234567890abc123\alpha\beta\gamma\delta1234556\alpha\beta\frac{1\sum_b^a}{A^2} \right\} . \tag{2}$$

Note the open one in Eq. (2).

Not all numbered equations will fit within a narrow column this way. The equation number will move down automatically if it cannot fit on the same line with a one-line equation:

$$\left\{ ab12345678abc123456abcdef\alpha\beta\gamma\delta1234556\alpha\beta\frac{1\sum_b^a}{A^2} \right\} . \tag{3}$$

When the `\label{#1}` command is used [cf. input for Eq. (2)], the equation can be referred to in text without knowing the equation number that TEX will assign to it. Just use `\ref{#1}`, where `#1` is the same name that used in the `\label{#1}` command.

Unnumbered single-line equations can be typeset using the `\[`, `\]` format:

$$g^+g^+ \rightarrow g^+g^+g^+g^+ \dots , \quad q^+q^+ \rightarrow q^+g^+g^+ \dots .$$

Figures may be inserted by using either the `graphics` or `graphicx` packages. These packages both define the `\includegraphics{#1}` command, but they differ in how optional arguments for specifying the orientation, scaling, and translation of the figure. Fig. 1 shows a figure that is small enough to fit in a single column. It is embedded using the `figure` environment which provides both the caption and the imports the figure file.

Fig. 2 is a figure that is too wide for a single column, so instead the `figure*` environment has been used.

The heart of any table is the `tabular` environment which gives the rows of the tables. Each row consists of column entries separated by `&`'s and terminates with `\\`. The required argument for the `tabular` environment specifies how data are displayed in the columns. For instance, entries may be centered, left-justified, right-justified, aligned on a decimal point. Extra column-spacing may be be specified as well, although REVTEX 4 sets this spacing so that the columns fill the width of the table. Horizontal rules are typeset using the `\hline` command. The doubled (or Scotch) rules that appear at the top and bottom of a table can be achieved enclosing the `tabular` environment within a `ruledtabular` environment. Rows whose columns span multiple columns can be typeset using the `\multicolumn{#1}{#2}{#3}` command (for example, see the first row of Table III).

Wide Test Figure

FIG. 2: Use the figure* environment to get a wide figure that spans the page in `twocolumn` formatting.

TABLE I: This is a narrow table which fits into a narrow column when using `twocolumn` formatting. Note that REVTEX 4 adjusts the intercolumn spacing so that the table fills the entire width of the column. Table captions are numbered automatically. This table illustrates left-aligned, centered, and right-aligned columns.

Left[a]	Centered[b]	Right
1	2	3
10	20	30
100	200	300

[a]Note a.
[b]Note b.

Tables I-IV show various effects. Tables that fit in a narrow column are contained in a `table` environment. Table III is a wide table set with the `table*` environment. Long tables may need to break across pages. The most straightforward way to accomplish this is to specify the `[H]` float placement on the `table` or `table*` environment. However, the standard LaTeX 2_ε package `longtable` will give more control over how tables break and will allow headers and footers to be specified for each page of the table. A simple example of the use of `longtable` can be found in the file `summary.tex` that is included with the REVTEX 4 distribution.

There are two methods for setting footnotes within a table (these footnotes will be displayed directly below the table rather than at the bottom of the page or in the bibliography). The easiest and preferred method is just to use the `\footnote{#1}` command. This will automatically enumerate the footnotes with lowercase roman letters. However, it is sometimes necessary to have multiple entries in the table share the same footnote. In this case, there is no choice but to manually create the footnotes using `\footnotemark[#1]` and `\footnotetext[#1]{#2}`. `#1` is a numeric value. Each time the same value for `#1` is used, the same mark is produced in the table. The `\footnotetext[#1]{#2}` commands are placed after the `tabular` environment. Examine the LaTeX source and output for Tables I and II for examples.

Physical Review style requires that the initial citation of figures or tables be in numerical order in text, so don't

TABLE II: A table with more columns still fits properly in a column. Note that several entries share the same footnote. Inspect the LaTeX input for this table to see exactly how it is done.

	r_c (Å)	r_0 (Å)	κr_0		r_c (Å)	r_0 (Å)	κr_0
Cu	0.800	14.10	2.550	Sn[a]	0.680	1.870	3.700
Ag	0.990	15.90	2.710	Pb[b]	0.450	1.930	3.760
Au	1.150	15.90	2.710	Ca[c]	0.750	2.170	3.560
Mg	0.490	17.60	3.200	Sr[d]	0.900	2.370	3.720
Zn	0.300	15.20	2.970	Li[b]	0.380	1.730	2.830
Cd	0.530	17.10	3.160	Na[e]	0.760	2.110	3.120
Hg	0.550	17.80	3.220	K[e]	1.120	2.620	3.480
Al	0.230	15.80	3.240	Rb[c]	1.330	2.800	3.590
Ga	0.310	16.70	3.330	Cs[d]	1.420	3.030	3.740
In	0.460	18.40	3.500	Ba[e]	0.960	2.460	3.780
Tl	0.480	18.90	3.550				

[a]Here's the first, from Ref. 3.
[b]Here's the second.
[c]Here's the third.
[d]Here's the fourth.
[e]And etc.

TABLE III: This is a wide table that spans the page width in `twocolumn` mode. It is formatted using the `table*` environment. It also demonstates the use of `\multicolumn` in rows with entries that span more than one column.

	D_{4h}^{1}		D_{4h}^{5}	
Ion	1st alternative	2nd alternative	lst alternative	2nd alternative
K	$(2e)+(2f)$	$(4i)$	$(2c)+(2d)$	$(4f)$
Mn	$(2g)^{a}$	$(a)+(b)+(c)+(d)$	$(4e)$	$(2a)+(2b)$
Cl	$(a)+(b)+(c)+(d)$	$(2g)^{a}$	$(4e)^{a}$	
He	$(8r)^{a}$	$(4j)^{a}$	$(4g)^{a}$	
Ag		$(4k)^{a}$		$(4h)^{a}$

[a]The z parameter of these positions is $z \sim \frac{1}{4}$.

TABLE IV: Numbers in columns Three–Five have been aligned by using the "d" column specifier (requires the `dcolumn` package). Non-numeric entries (those entries without a ".") in a "d" column are aligned on the decimal point. Use the "D" specifier for more complex layouts.

One	Two	Three	Four	Five
one	two	three	four	five
He	2	2.77234	45672.	0.69
C[a]	C[b]	12537.64	37.66345	86.37

[a]Some tables require footnotes.
[b]Some tables need more than one footnote.

cite Fig. 2 until Fig. 1 has been cited.

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[1] Standard DØ detector reference:
V.M. Abazov *et al.* (D0 Collaboration), "The upgraded DØ detector," Nucl. Instrum. Methods Phys. Res. A **565**, 463 (2006).

[2] ** New ** DØ luminosity reference:
T. Andeen *et al.*, FERMILAB-TM-2365 (2007).

[3] Particle Data Group reference:
W.-M. Yao *et al.*, Journal of Physics G **33**, 1 (2006).

[4] GEANT reference:
R. Brun and F. Carminati, CERN Program Library Long Writeup W5013, 1993 (unpublished).

[5] PYTHIA reference:
T. Sjöstrand *et al.*, Comput. Phys. Commun. **135**, 238 (2001).

[6] CTEQ6 reference:
J. Pumplin *et al.*, JHEP **0207** 012 (2002) and D. Stump *et al.*, JHEP **0310** 046 (2003).

[7] LEP CL_S reference:
T. Junk, Nucl. Instrum. Methods A **434**, 435 (1999).

[8] DØ Bayesian reference:
I. Bertram *et al.*, FERMILAB-TM-2104 (2000).

[9] DØ cone-jet reference:
G.C. Blazey *et al.*, in *Proceedings of the Workshop: QCD and Weak Boson Physics in Run II*, edited by U. Baur, R.K. Ellis, and D. Zeppenfeld, Fermilab-Pub-00/297 (2000).