Looking for Leptoquarks
(decaying to a top and a lepton)

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Looking for Leptoquarks S decaying to a t and a charged lepton

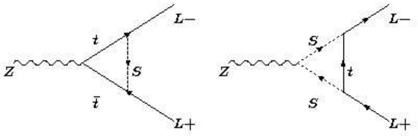
- Introduction to (scalar) Leptoquarks S
  - Why are they interesting ?
  - What do we know ?
  - “Phenomenological expectations” for leptoquark couplings
- Leptoquarks decaying to a top and a charged lepton
  - $m_S < m_t$ at the Tevatron
  - $m_S > m_t$ at the LHC

Introduction—why leptoquarks, and what we know

- leptoquark $\equiv$ a (coloured) boson interacting with a lepton and a quark
  assume here a scalar

$$S_0 \lambda_{\mathbf{RS_0}} \overline{e} u^c + \lambda_{\mathbf{LS_2}} \overline{\ell} u S_2$$

- motivations for leptoquarks :
  - SM has coloured bosons and charged bosons. Why not coloured and charged ?
  - quark and lepton sectors connected for anomaly cancellation
  - present in several models (technicolour, RPV SUSY,...)
  - coloured and decays to leptons $\Rightarrow$ hadron colliders can find them !
- current Tevatron bounds :
  $m_S \gtrsim 210[\tau b],\ 214[\nu q],\ 247[\nu b],\ 299[eq, eb],\ 316[\mu q, \mu b]$ GeV
  where $q \in \{u, d, s, c\}$, and $\lambda > 10^{-8}$
- low energy precision and flavour experiments constrain λ^2/m_S^2 for specific (usually lower generation) flavour indices
- leptoquarks interacting with t bounded by $Z \to L^+ L^-$: $\lambda/m_S \lesssim e/(300\text{ GeV})$



Introduction—phenomenological expectations for leptoquark couplings

S is a scalar with flavoured couplings — pattern then on Yukawas

- $\lambda \propto$ (positive) power of fermion masses. *e.g.* Cheng-Sher ansätz :

$$\lambda^{LQ} \propto \sqrt{\frac{m_L m_Q}{v^2}} \qquad v = \langle H \rangle$$

$$\Rightarrow S \to t\tau^{\pm}$$

arises in Randall-Sundrum, composite models...
reasonable in quark sector, where small mixing angles, hierearchical masses

- A more complicated combination of fermion masses...*e.g.* with a single lepton index (multiply by a quark Yukawa to get λ^{LQ}, and attribute quark flavour to S to contract all indices)

$$\varepsilon^{LJK}[Y_e Y_e^\dagger m_\nu]_{JK}$$

$$\Rightarrow S \to t\ell^{\pm} \qquad \ell \in \{e, \mu\}$$

(m_ν democratic, ε totally antisymmetric, $Y_e Y_e^\dagger$ hierarchical)
reasonable in lepton section, where mixing angles are large, neutrino masses mildly hierarchical

Leptoquark decays to top + any lepton are "reasonable". And weakly constrained. $\Rightarrow$ search for $S \to tL^{\pm}$, $L \in \{e, \mu, \tau\}$

$S \to tL^{\pm}$, $m_S < m_t$

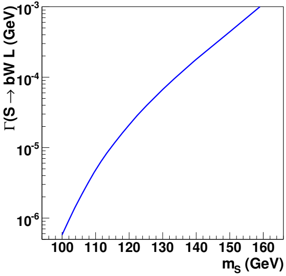
- For $m_S < m_t$, three body decay : $S \to bW^+L^{\pm}$.
- Can show ... that the three body decay rate is the product of two body decay rates

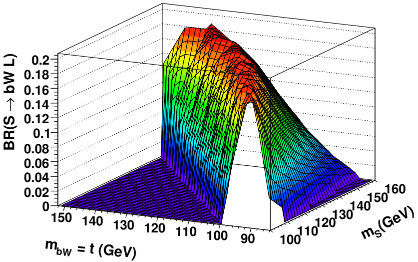
$$\frac{d\Gamma(S \to bW^+L^{\pm})}{dm_{bW}} = \frac{\Gamma(S \to t^* L)}{2m_t} \frac{\Gamma(t^* \to Wb)}{\pi m_t} \frac{m_t^4}{(m_{bW}^2 - m_t^2)^2 + m_t^2\Gamma_t^2}$$

where in $\Gamma(S \to t^* L)$, m_t is replaced by $m_{bW} = \sqrt{(p_b + p_W)^2}$,
with an m_{bW} dependent coupling.
$\Rightarrow$ simple to implement in Pythia !

$S \to tL^{\pm}$, $m_S < m_t$

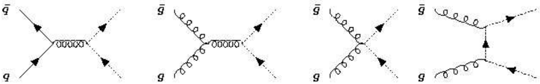
- On the left : total decay rate $\Gamma(S \to bWL)$ as a function of the the leptoquark mass for $\lambda = 1$. Leptoquark decay in less than 1cm for :
  - $M_S = 100$ GeV and $\lambda \gtrsim 10^{-3}$
  - $M_S = 160$ GeV and $\lambda \gtrsim 10^{-6}$
- On the right : the branching ratio of $S \to t^* L$ as a function of the t^* mass and of the leptoquark mass
- We implemented this branching ratio in PYTHIA by simply varying the top mass according to this PDF





Leptoquark pair production

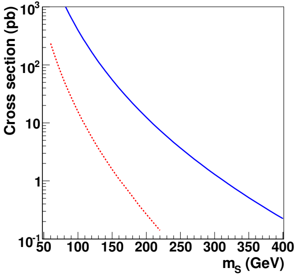
- Scalar leptoquarks pair production at the Tevatron and the 7 TeV LHC



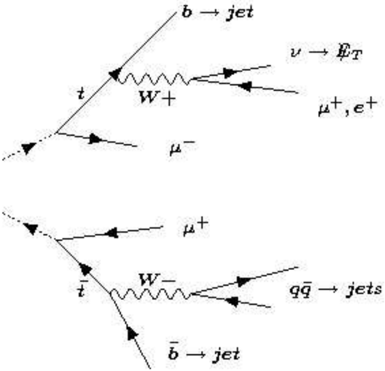
- NLO cross section computed with PROSPINO2.1
- For $m_S < m_t$, implementation in PYTHIA of $S \rightarrow bW^+L^\pm$
- Using tauola for tau decays

Those signal cross sections can be compared to the $t\bar{t}$ cross sections :

- 7 pb at the Tevatron
- 165 pb at the 7 TeV LHC



Leptoquark decay



Potential bounds from the Tevatron : $S \to t\tau^{\pm}$, $m_S < m_t$

- Look at the topology : 1 electron or muon + at least 4 jets
- Apply acceptance cuts that DØ used to select $t\bar{t} \to bl^{\pm}\nu bqq$ events to measure the $t\bar{t}$ cross section in this channel ($\mathcal{L} = 4.3 fb^{-1}$)
- no hadronic tau identification : they just give additional jets
- no detector simulation

m_S (GeV)	σ (pb)	$\varepsilon(\not{E}_T, 1\ell, 4j)$	$N(LQ)$
160	1	.0823	367
140	2.4	.0618	658
120	6	.0389	1035
100	16	.0149	1060

- Those expected number of events should be compared to the 1795 (1796 ± 158) events observed (expected) by DØ

$$m_S < 158\,\mathrm{GeV} \qquad \text{for} \qquad BR(S \to t\tau^{\pm}) = 1$$

are excluded at 95 % C.L.

Potential bounds from the Tevatron : $S \to t\mu^{\pm}$, $m_S < m_t$

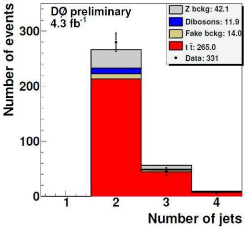
- Look at the topology : 2 OS leptons (electron or muon) + at least 3 jets
- Apply acceptance cuts that DØ used to select $t\bar{t} \to bl^{\pm}\nu bl^{\pm}\nu$ events to measure the $t\bar{t}$ cross section in this channel, and extract the number of events with at least 3 jets
- Those selection cuts are not optimal for this search where you can easily require 3 charged leptons
- no detector simulation

m_S (GeV)	σ (pb)	$\varepsilon(\not{E}_T, 2OS\ell, 3j)$	$N(LQ)$
160	1	.0900	387
140	2.4	.0752	776
120	6	.0500	1288
100	16	.0090	960

- Those expected number of events should be compared with the number of events observed by DØ :

$$m_S < 160\,\text{GeV} \qquad \text{for } BR(S \to t\mu^{\pm}) = 1$$

are excluded at 95 % C.L.



At the LHC : $S \to t\tau^{\pm}$, $m_S > m_t$

- For the LQ signal simulation, all top/W decay mode are allowed
- Selection cuts patterned on the ATLAS $t\bar{t}$ selection for the lepton + jets +$\not{E}_T$ channel : at least one electron or muon, $\not{E}_T > 25 GeV$, at least 4 jets
- Number of signal events expected with $\mathcal{L} = 1 fb^{-1}$

m_S	σ/pb	$\varepsilon(\geq 1\ell)$	$N(\geq 1\ell)$	$\varepsilon(1\ \ell)$	$N(1\ \ell)$	$\varepsilon(\geq 7\ell + j)$	$N(\geq 7\ell + j)$
200	12.5	.160	2000	.143	1788	.039	488
250	3.69	.297	1096	.241	889	.126	465
300	1.30	.374	486	.285	370	.199	259
350	.515	.428	220	.322	166	.234	121
400	.224	.451	101	.328	74	.264	59

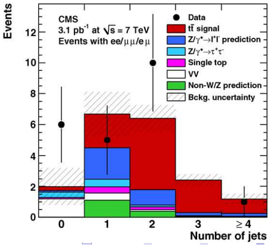
- Then, we may require exactly one lepton (ATLAS $t\bar{t}$ analysis), or at least 7 objects (electrons, muons or jets)
- With 2.9 pb^{-1}, ATLAS observes 37 events in the single lepton + $\geq$ 4 jets for 40 events expected from $t\bar{t}$ and SM backgrounds. Those numbers are obtained after requiring at least 1 b-tag jet (with a b-tagging efficiency of 50%
- LQ signal would therefore contribute to $\sim$ 2 events in this selection
- Requiring more jets or leptons could improve the sensitivity to LQ decay to $t\tau^{\pm}$

At the LHC : $S \to t\mu^{\pm}$, $m_S > m_t$

- Selection cuts patterned on the CMS $t\bar{t}$ selection for the di-lepton + jets $+\not{E}_T$ channel : 2 OS sign leptons (electron or muon), $\not{E}_T > 30 GeV$, at least 4 jets
- Number of signal events expected with $\mathcal{L} = 1 fb^{-1}$

m_S	σ_{prod}/pb	$\varepsilon(\not{E}_T, = 2OS\ell, 4j)$	$N_=(LQ)$	$\varepsilon(\not{E}_T, > 2OS\ell, 4j)$	$N_>(LQ)$
200	12.5	.055	683	.035	438
250	3.69	.095	352	.094	346
300	1.3	.104	136	.116	151
350	0.515	.109	56	.12	62
400	0.224	.121	27	.129	29

- With $3.1 pb^{-1}$, a 200 GeV LQ would contribute to 2 events in the $\geq$ 4 jet bin



Conclusion

- Scalar leptoquark decay to a top quark and a charged lepton provides various interesting signatures at colliders
- The Tevatron $p\bar{p}$ data can already exclude such leptoquarks with masses below $\sim 160 GeV$
- At the Tevatron, it is almost impossible to distinguish such leptoquark signal from SM $t\bar{t}$ when the leptoquark mass is close to the top mass
- At the LHC, leptoquark decays to $tL^{\pm}$ could be searched for
    - LQ signal cross section is large
    - multilepton+multijets(+$\not{E}_T$+b-tagging) signatures
    - 2010 LHC data are already sensitive to such leptoquarks