Heavy Lepton Searches at the LHC

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outlines

- introduction
- sequential fermions model
- superstring-inspired E6 model
- "Inert" Higgs doublet model with heavy fermions and Dark Matter
- conclusions

Introduction:
Heavy leptons beyond the Standard Model

- **beyond the Standard Model predictions for new particles**
  composite models, technicolor models, left-right symmetric models, mirror fermions models, GUT, superstring-inspired models

- **new fermions (=> new gauge bosons: Z', W', etc.)**
  - **sequential fermions**: add the 4-th family with the same quantum numbers
  - vector singlet (**VSM**): $\begin{pmatrix} \nu \\ e \end{pmatrix}_L, e_R, \nu_R, L_L, L_R, N_L, N_R$ (NPB342(1990)108)
  - vector doublet model (**VDM**): $\begin{pmatrix} N \\ L \end{pmatrix}_L, \begin{pmatrix} N \\ L \end{pmatrix}_R$ (PRD34(1986)2076)
  - fermion-mirror-fermion model (**FMFM**): $\begin{pmatrix} N \\ L \end{pmatrix}_R, (L)_L, (N)_L$ (NPB207(1982)233)

- **experimental limits**
  - charged heavy lepton mass $M_L > 100\ GeV/c^2$ from L3 / LEP
  - new neutral heavy gauge boson mass $M_{Z'} > 700\ GeV/c^2$ from CDF

Sequential fermions model

- add the 4-th family with the same quantum numbers
- Standard Model couplings

Gluon-gluon fusion cross section in SM-like

gluon fusion cross section: $$\sigma = \frac{\alpha^2 \alpha_s^2}{512\pi \sin^4\theta_W} \cdot \frac{M_L^2}{M_W^4} \cdot \beta_L \left| \sum_{q=u,d} T_3^q \left(1 + 2\lambda_q I_q\right) \right|^2$$

where $\lambda_q = m_q^2 / \hat{s}; \beta_L = \sqrt{1 - 4M_L^2/\hat{s}}$ and $I_q = \int_0^1 \frac{dx}{x} \log\left[1 - \frac{x(1-x)}{\lambda_q}\right]$

and $$\sum_{q=u,d} T_3^q \lambda_q I_q = \sum_{q=u} \frac{1}{2} \lambda_u I_u - \sum_{q=d} \frac{1}{2} \lambda_d I_d$$

Sequential fermions model

Golden channel for new physics beyond the SM

6 leptons:

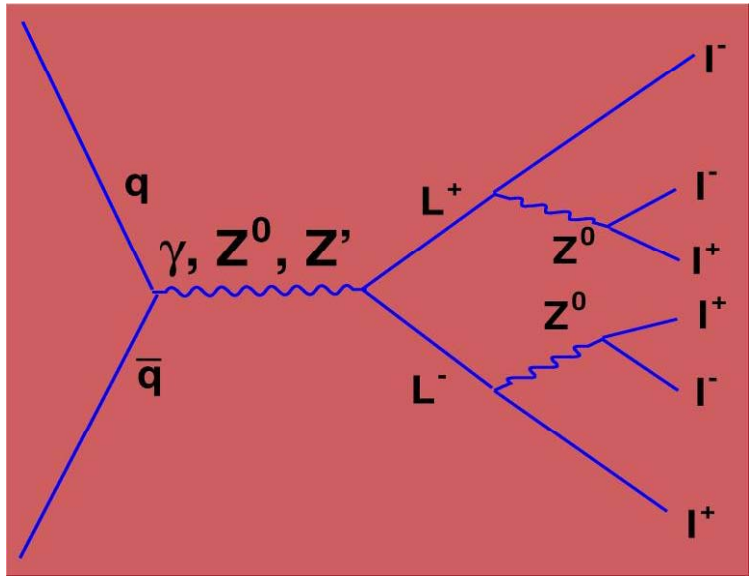
$$pp \rightarrow ... \rightarrow L^+L^- \rightarrow 2Z^0 + 2\,(e^{\pm} \text{or } \mu^{\pm}) \;\square\; 4\,(e^{\pm} \text{or } \mu^{\pm})$$

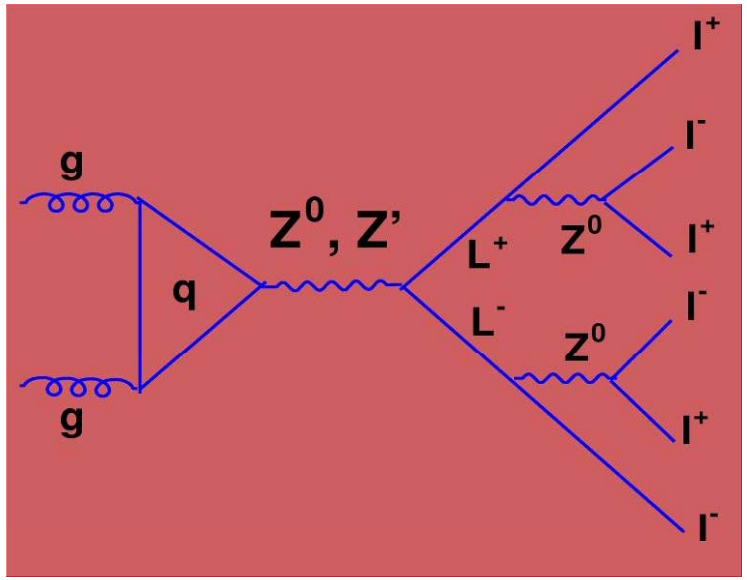
signal:

- at least six isolated leptons
- total charge = 0

background:

- no Standard Model background





Sequential fermions model

ATLAS discovery limit for this sequential charged heavy lepton:

2e + 4jets	up to M(L) = 1.0TeV	and up to	M(L) = 1.2TeV	with (U,D)
2μ + 4jets	up to M(L) = 0.9TeV	and up to	M(L) = 1.1TeV	with (U,D)
(6e, 6μ)	up to M(L) = 0.9/1.1TeV	and up to	M(L) = 1.1/1.3TeV	with (U,D)
(4e + 2μ, 2e + 4μ)	up to M(L) = 1.0/1.1TeV	and up to	M(L) = 1.2/1.3TeV	with (U,D)

Superstring-inspired E6 model

Gluon-gluon fusion cross section

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{Y_E}$$

particle content:

$$\left\{ \boxed{\begin{pmatrix} u \\ d \end{pmatrix}_L, \begin{pmatrix} \nu \\ e \end{pmatrix}_L, u_L^C, d_L^C, e_L^C}, \nu_L^C, d_L^{'}, d_L^{'C}, \begin{pmatrix} \nu' \\ e' \end{pmatrix}_L, \begin{pmatrix} \nu' \\ e' \end{pmatrix}_L^C, \nu_L^{"C} \right\} \times 3 \text{ generations}$$

Gluon-gluon fusion cross section:

$$\sigma = \frac{\alpha^2 \alpha_s^2}{128\pi \sin^4\theta_W} \frac{M_L^2}{M_W^4} \beta_L \left| \sum_{i=1,2} (\tilde{C}_L^{L^{\pm} Z_i} - \tilde{C}_R^{L^{\pm} Z_i}) \xi^{Z_i}(\hat{s}) \sum_{q=u,d} (\tilde{C}_L^{qZ_i} - \tilde{C}_R^{qZ_i}) \left(1 + 2\lambda_q I_q\right) \right|^2$$

where $\lambda_q = m_q^2 / \hat{s}; \beta_L = \sqrt{1 - 4M_L^2/\hat{s}}$ and $I_q = \int_0^1 \frac{dx}{x} \log\left[1 - \frac{x(1-x)}{\lambda_q}\right]$

$$\begin{pmatrix} \tilde{C}_{L,R}^{fZ_1} \\ \tilde{C}_{L,R}^{fZ_2} \end{pmatrix} = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} C_{L,R}^{fZ} \\ C_{L,R}^{fZ'} \end{pmatrix}$$

with $C_{L,R}^{fZ} = T_{3L,R} - e_f \sin^2\theta_W$

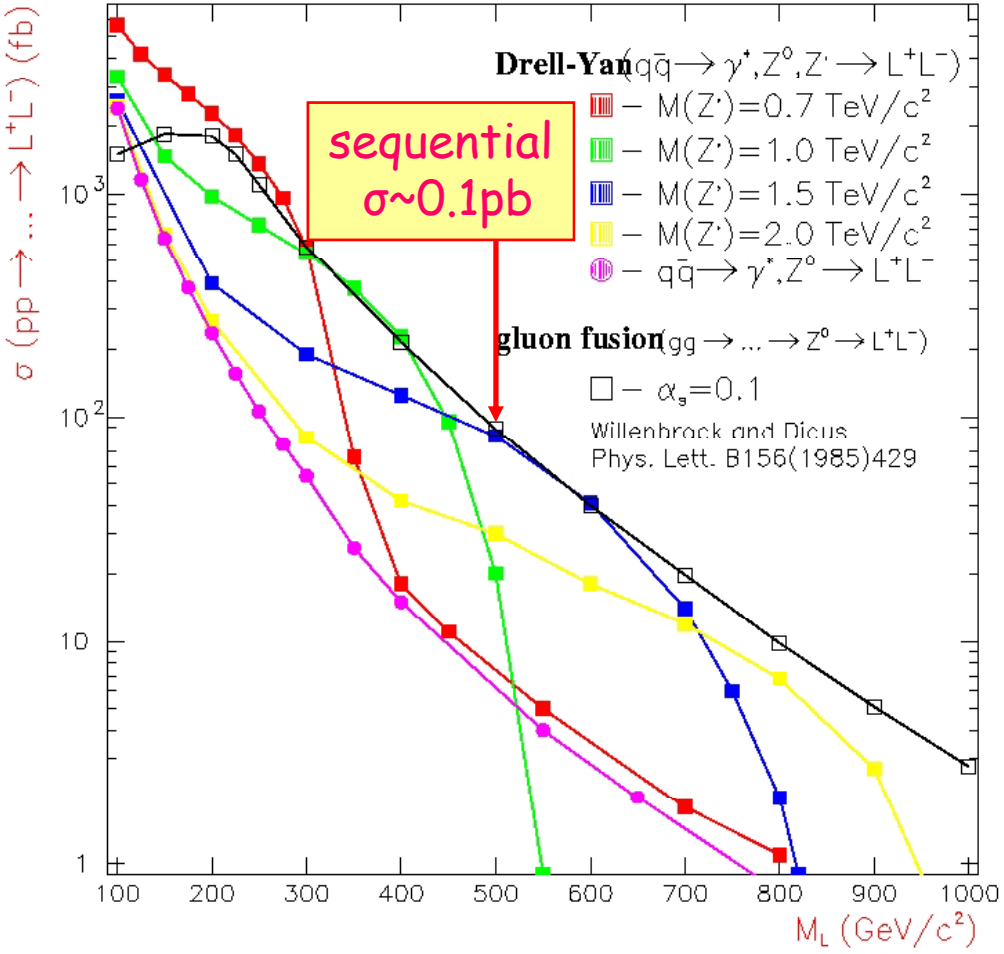
$$C_{L,R}^{fZ'} = \frac{1}{2}\left(\frac{g"}{g}\right) y_{fL,R}^{'} \sqrt{1 - \sin^2\theta_W}$$

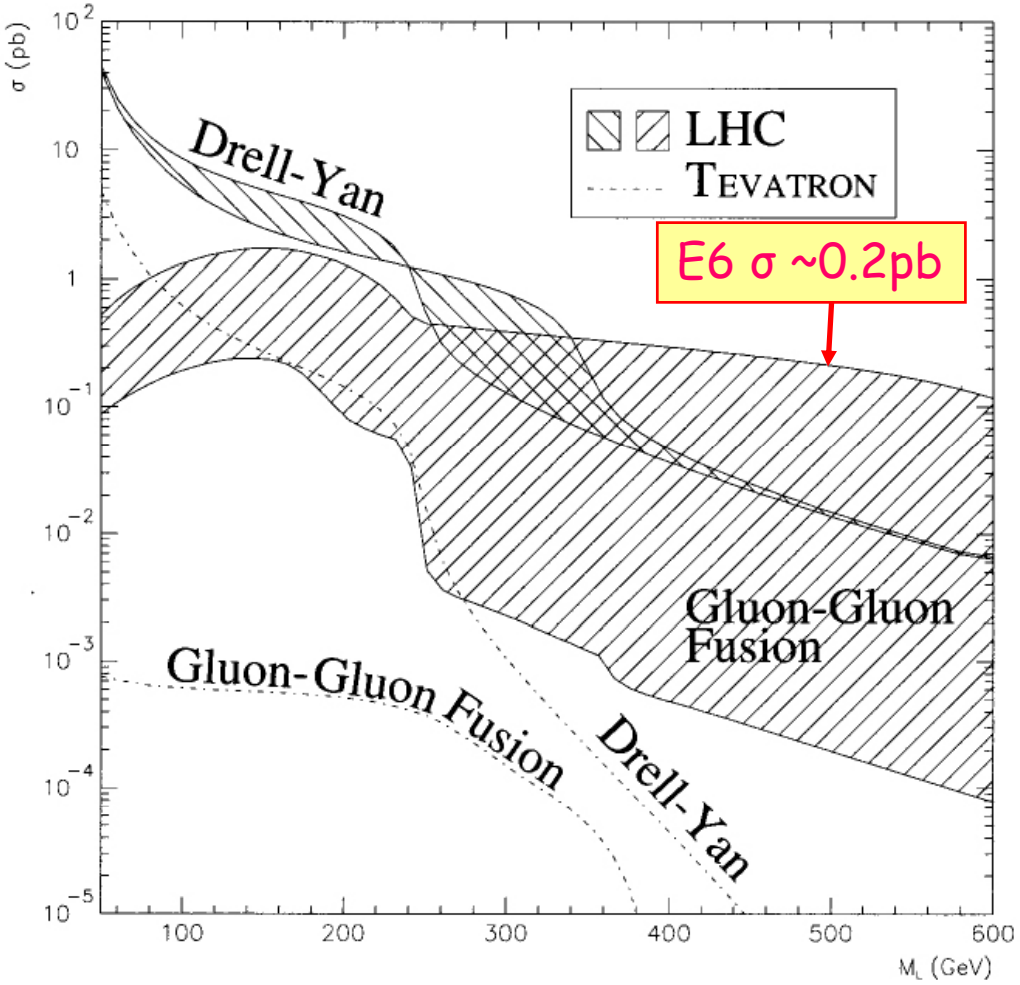
$\phi = f(M_Z, M_{Z'})$ - mixing angle

Superstring-inspired E6 model

Heavy lepton pair production cross section mass dependence

Gluon-gluon fusion is dominating Drell-Yan for heavy lepton masses higher than ~350 GeV for both models





Superstring-inspired E6 model is increasing heavy lepton pair production σ by a factor of 2.

"Inert" Higgs doublet model with heavy fermions and Dark Matter

- minimal extention of the Standard Model: "Inert" Higgs doublet (R. Barbieri, L. J. Hall and V. S. Rychkov, Phys.RevD74(2006)015007)
  - **vector-like fermion dublet pair and one fermion singlet**
  - **new states have only Electroweak interactions**
  - **new extra states are odd under Z_2 symmetry (SM are even) -> no mixing with the SM leptons**

$$\Delta L = -\lambda LHN - \lambda' L^c \tilde{H} N + M_L L L^c + \frac{1}{2} M_N N^2 + h.c.$$

$$L = \begin{pmatrix} \upsilon \\ E \end{pmatrix} \qquad L^c = \begin{pmatrix} \upsilon^c \\ E^c \end{pmatrix}$$

N is a Standard Model singlet

$$\tilde{H} = i\sigma_2 H^*$$

- N, ν, ν^c yield three Majorana "neutrinos" (ν_1, ν_2, ν_3)

- whenever $m_{\nu 1} < m_E$ -> ν_1 (the lightest "neutrinos") is a Dark Matter candidate (WIMP)

- production channels: $q\bar{q} \to E^+E^-$, $q\bar{q} \to \nu_i \nu_j$, $q\bar{q}' \to \nu_i E^\pm$, $gg \to \nu_i \nu_j$

- final state: one lepton, ..., **six leptons + large E^T_{miss}**

Conclusions:

Sequential charged heavy leptons:

- with $L^{\pm} \rightarrow e^{\pm} Z^{0}$ and $L^{\pm} \rightarrow \mu^{\pm} Z^{0}$ one can reconstruct a well separated signal
- at LHC one can measure this type of charged heavy leptons with masses up to 1TeV

Superstring-inspired charged heavy leptons:

- superstring-inspired E6 model is increasing the production cross section by a factor of 2
- at LHC one can measure this type of charged heavy leptons with masses higher 1TeV
- similar results can be obtained for MSSM and other E6 models

"Inert" Higgs doublet model with heavy leptons:

- WIMP can be discovered: 6 leptons + large E^{T}_{miss}