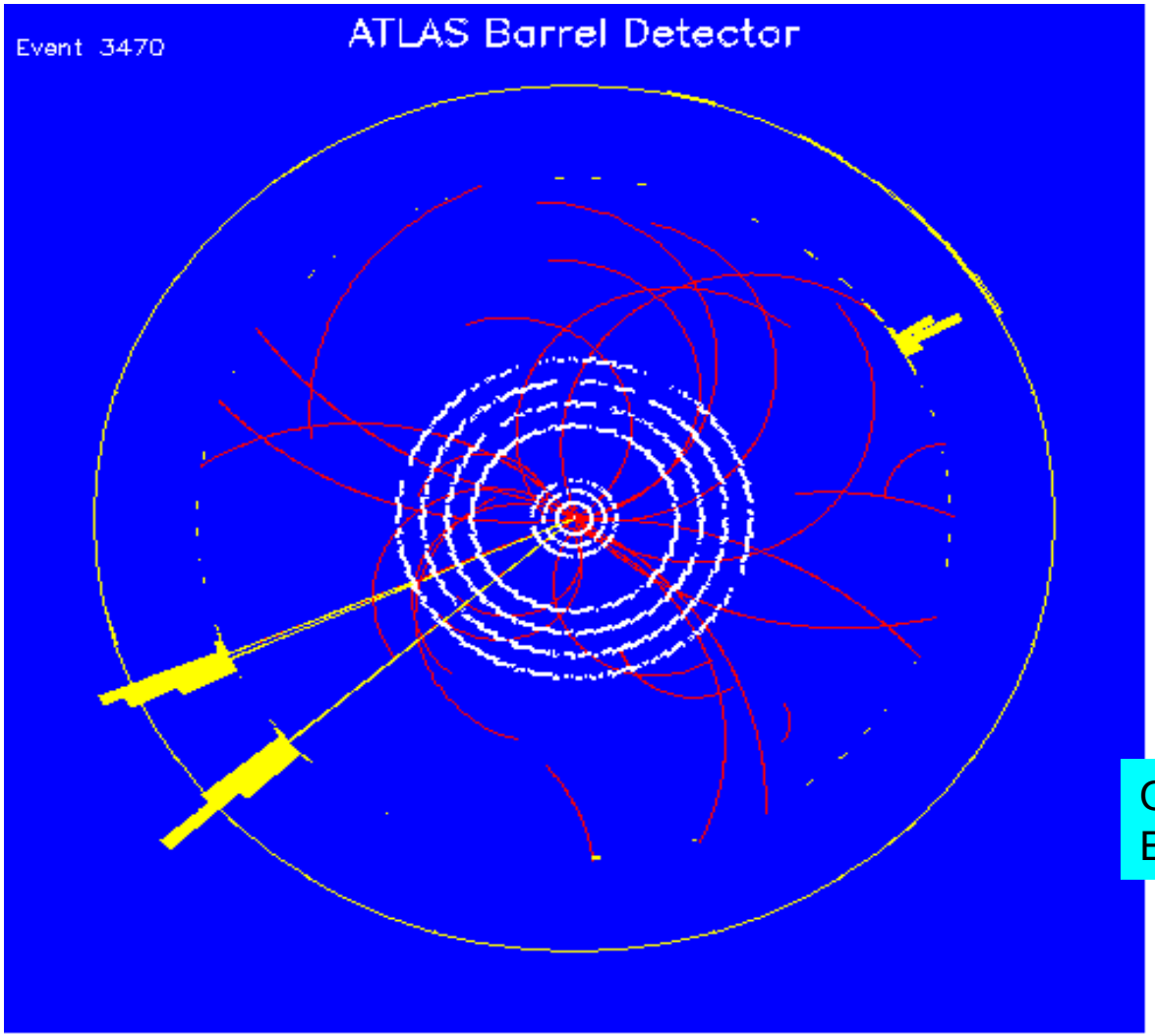
Heavy Lepton Physics in ATLAS

Călin Alexa, CERN

- Excited leptons (brief)
  - basics
  - discovery potential
- Charged heavy leptons
  - signal and background description
  - event selection and discovery potential
  - preliminary results
  - conclusions and future plans

Excited Electron Production at LHC

from Rashid Mehdiyev



Fully simulated

$pp \rightarrow ee^* \rightarrow ee\gamma$

(Schematic view)

E^* mass =1000 GeV

O. Çakır, C. Leroy, R.Mehdiyev, A.Belyaev
Eur. Phys. J. C30, d01 (2003), 005

Basics:

from Rashid Mehdiyev

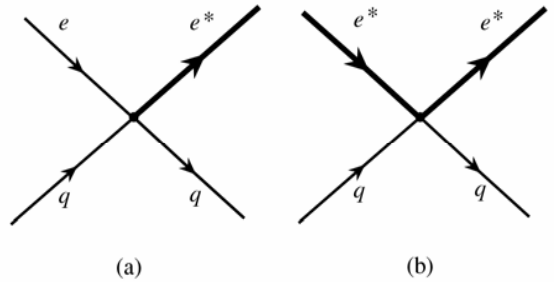
- Excited states of fermions can exist if leptons and quarks are not elementary particles but composite.
- Excited fermions are considered as spin=1/2 and isospin=1/2 particles and couple to gauge bosons according to their quantum numbers.
- Both left-handed and right –handed components of excited fermions are week isodoublets,
- SU(3)×SU(2)×U(1) symmetry is still respected.
- Excited fermions would decay into an ordinary fermion and gauge bosons.

U.Baur,M.Spira,P.Zerwas Phys.Rev.D 42 (1990) 815

$$\mathcal{L}_{int} = \frac{1}{2\Lambda}\overline{F}^{*}_{R}\sigma^{\mu\nu}\left[gf\frac{\tau^{a}}{2}W^{a}_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu} + g_{s}f_{s}\frac{\lambda_{a}}{2}G^{a}_{\mu\nu}\right]F_{L} + h.c.$$

- Right and left-handed components of the excited form weak isodoublets
- Field-strength tensors associated to gauge fields SU(2), U(1) and SU(3)
- SM couplings
- Coupling strength between f* and bosons from SU(2), U(1) and SU(3)
- Compositeness scale

Couplings of excited leptons to preons (Contact Interactions) can be described by effective 4-fermion Lagrangian



from Rashid Mehdiyev

$$L_{contact} = \frac{g_*^2}{2\Lambda^2} j^\mu j_\mu$$

$$j_\mu = \eta_L \bar{f}_L \gamma_\mu f_L + \eta'_L \bar{f}^*_L \gamma_\mu f^*_L + \eta''_L \bar{f}^*_L \gamma_\mu f_L + (L \to R) + h.c.$$

$$g_*^2 = 4\pi$$

(coefficients for left-handed and right-handed currents)

$$\eta_L = 1 \text{ and } \eta_R = 0$$

- Excited leptons will decay into a lepton and a gauge boson:

$$L_{transition} = \frac{1}{2\Lambda} \bar{f}^*_R \sigma^{\mu\nu} \left[gf \frac{\tau}{2} \cdot W_{\mu\nu} + g'f' \frac{Y}{2} B_{\mu\nu} \right] f_L + h.c.$$

W and B are the field strength tensors of SU(2) and U(1) gauge fields with gauge structure constants τ and Y ; g and g′ are the corresponding coupling constants.

Λ - compositeness scale

Signal and background description

from Rashid Mehdiyev

Signal simulation of excited electrons in contact interactions with CompHep and CompHep + Pythia interface.

- $e^* \rightarrow e\gamma$ BG: $Z+\gamma$, Z+jet
- $e^* \rightarrow Ze$, $Z \rightarrow ee$ or $Z \rightarrow jj$ BG: Z+jet,Z+Z,Z+W
- $e^* \rightarrow W\nu$, $W \rightarrow jj$ BG: W+jet,W+W

Backgrounds simulated with Pythia

ATLFAST has been used for the detector simulation.

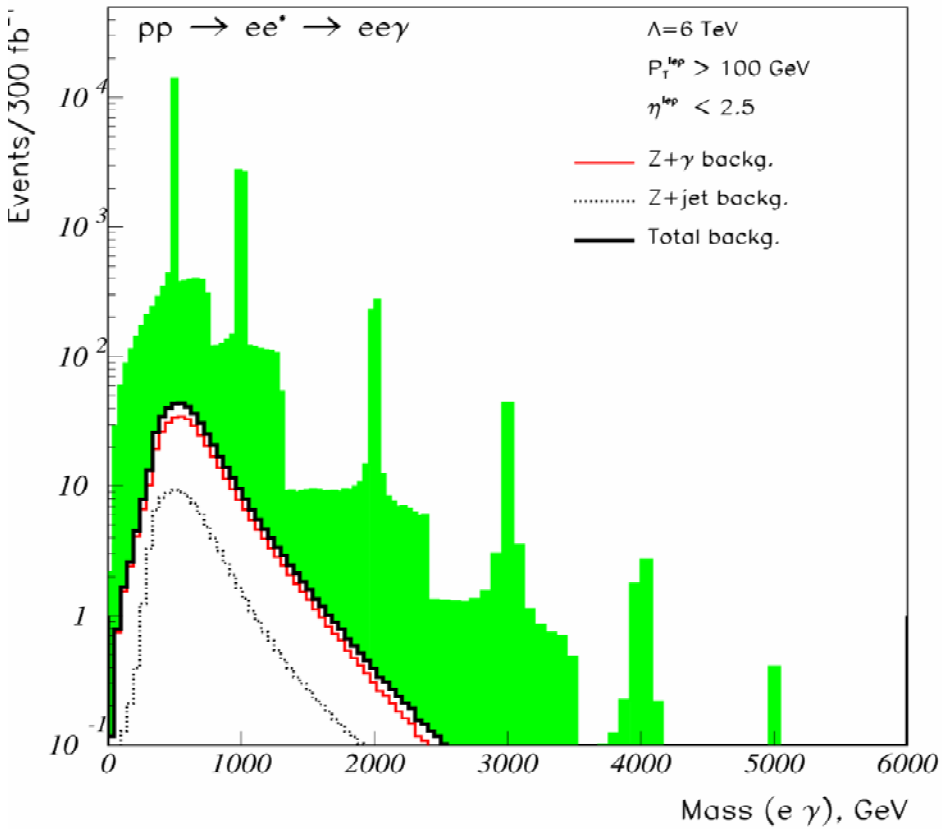
All data presented for L=300 fb^{-1} and the compositeness scale Λ= 6 TeV.

Combined contribution of gauge and contact decays (3-body decays) considered for $e^* \rightarrow Ze$ channel.

Signal significance

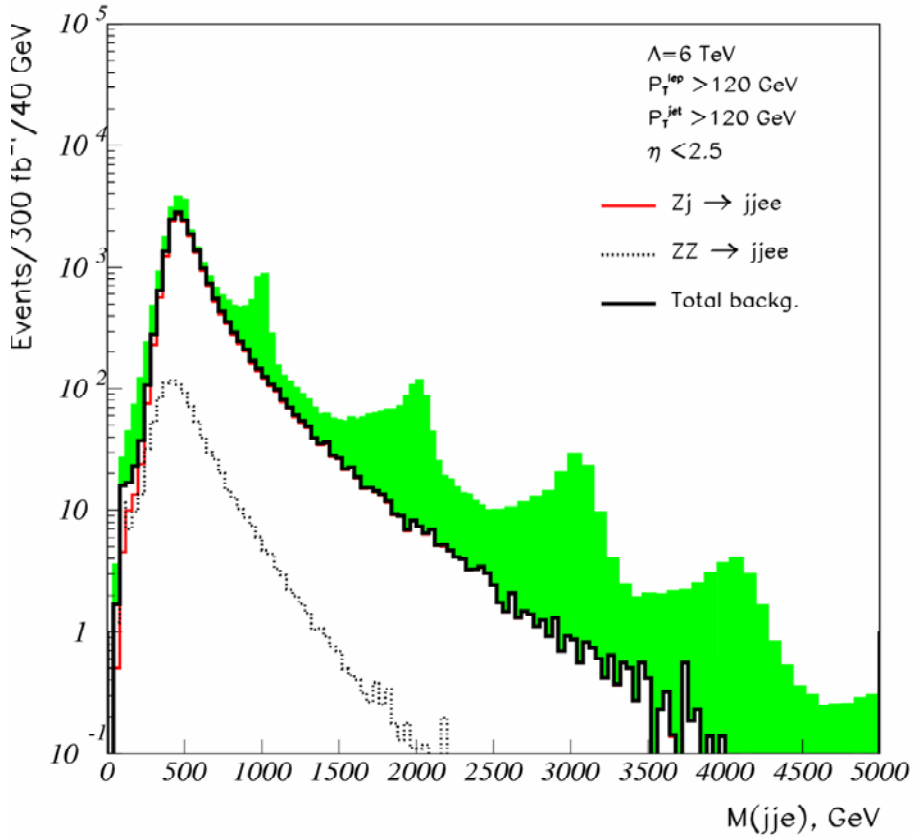
from Rashid Mehdiyev

$qq \rightarrow ee^* \rightarrow ee\gamma$



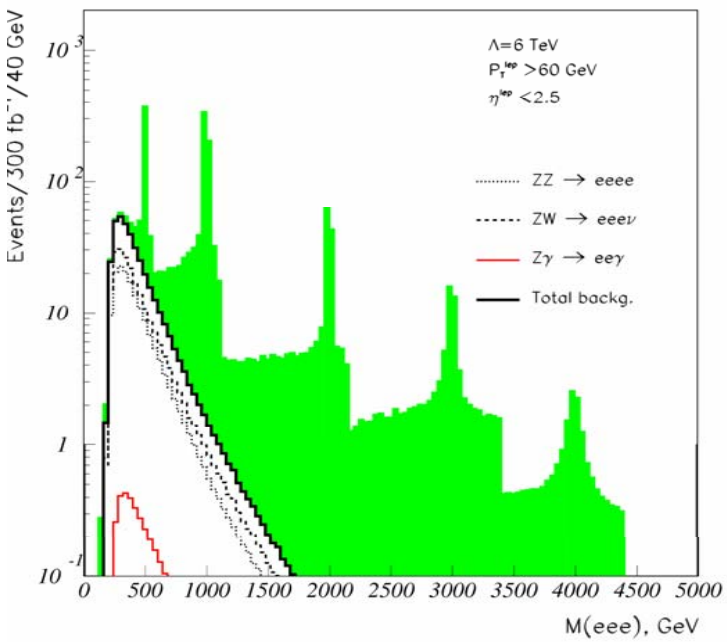
m*,TeV	0.5	1.0	2.0	3.0	4.0
Signal	13700	5281	490	43	5
S/√B	2385	2104	1044	311	66

$qq \rightarrow ee^* \rightarrow eZe \rightarrow ejje$

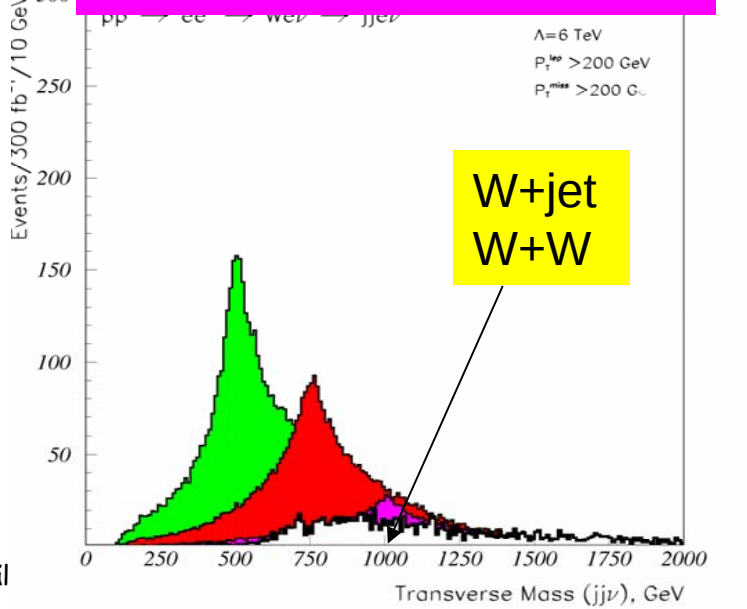


m*,TeV	0.5	1.0	2.0	3.0	4.0
Signal	2102	2415	636	176	24
S/√B	30	120	105	69	30

$qq \to ee^* \to eZe \to eeee$

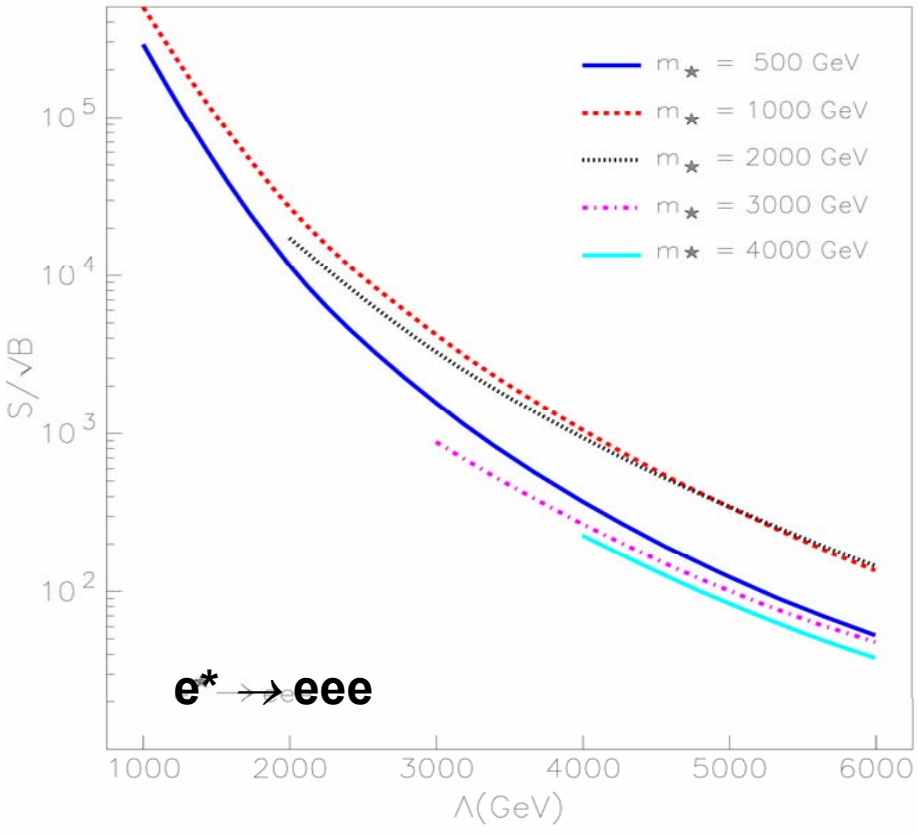


$qq \to ee^* \to eWv \to ejjv$



Signal significances for various Λ

from Rashid Mehdiyev



Conclusions

Singly produced excited electrons could be accessible up to mass of 5 TeV at LHC for Λ = 6 TeV.

Charged heavy leptons in ATLAS

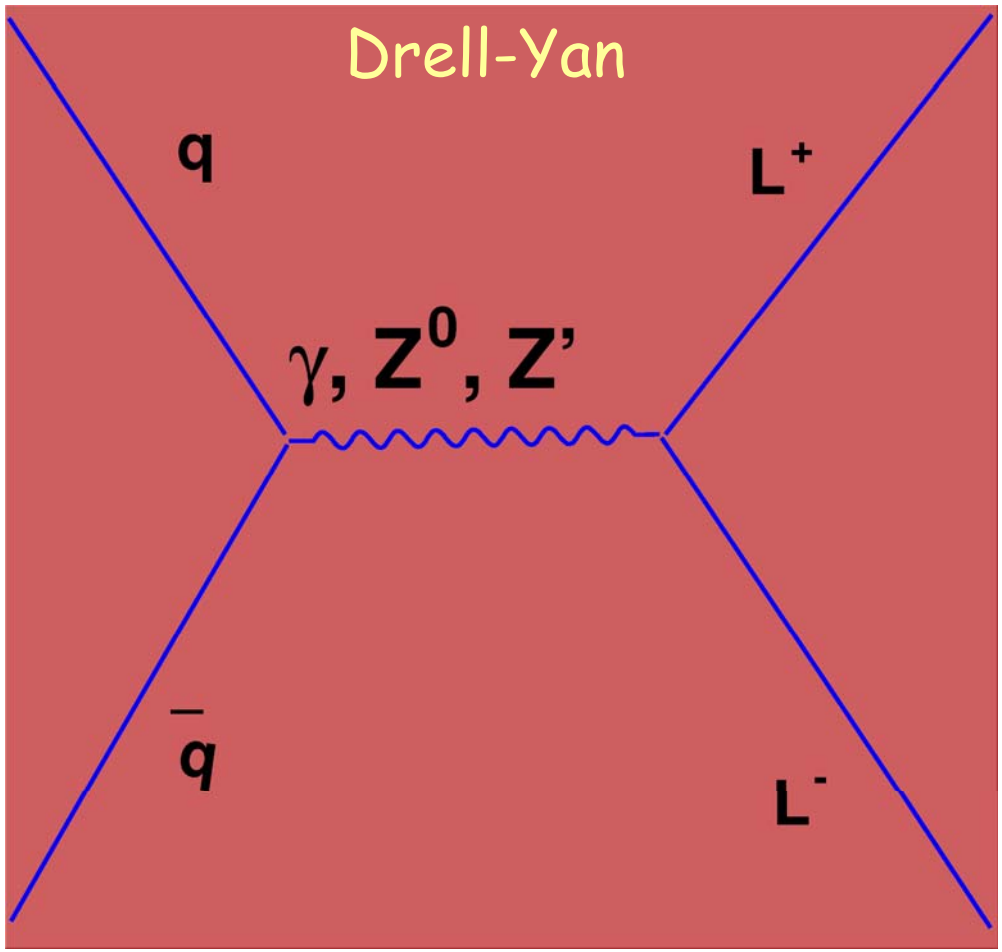
- **beyond the Standard Model predictions for new particles**
  composite models, technicolor models, left-right symmetric models, mirror fermions models, GUT, superstring models, univ. mode?

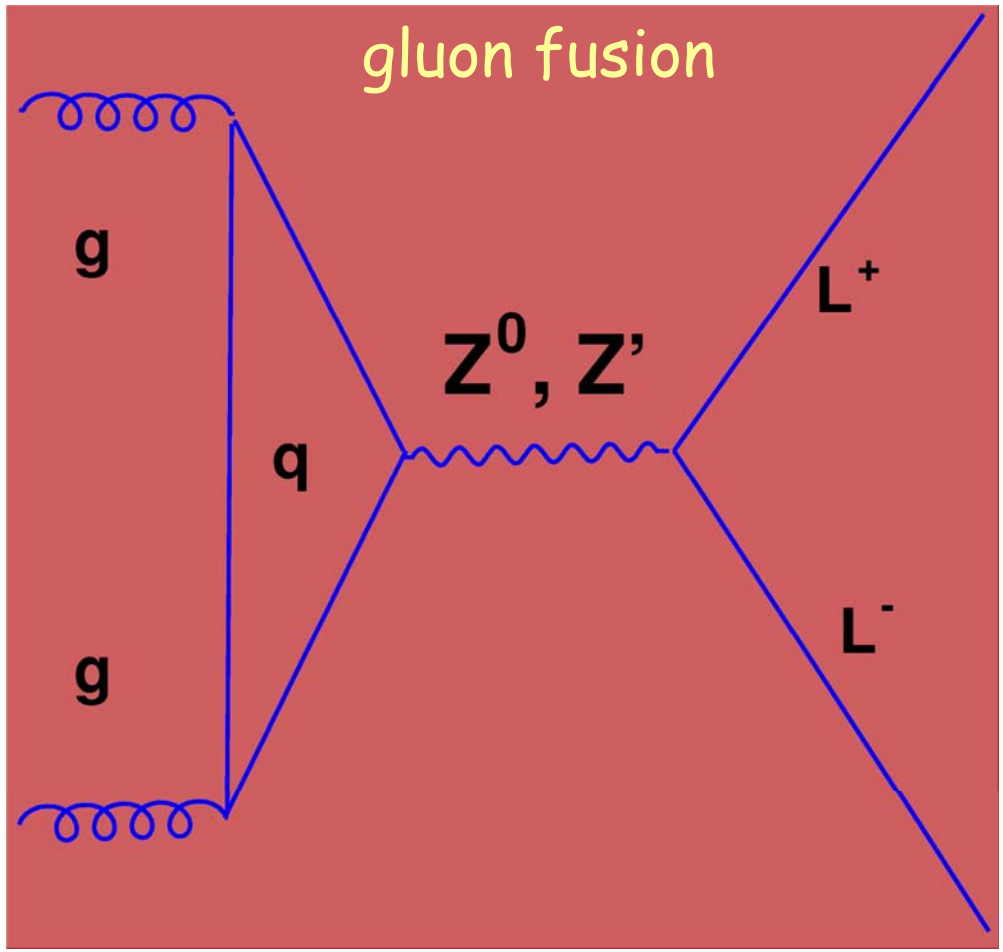
- **new fermions**
  - **sequential fermions**: the fourth family has the same quantum numbers
  - vector singlet (**VSM**): $\begin{pmatrix} \nu \\ e \end{pmatrix}_L, e_R, \nu_R, L_L, L_R, N_L, N_R$ (NPB342(1990)108)
  - vector doublet model (**VDM**): $\begin{pmatrix} N \\ L \end{pmatrix}_L, \begin{pmatrix} N \\ L \end{pmatrix}_R$ (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/c²** from L3 / LEP
  - new neutral heavy gauge boson mass $M_{Z'} > 700$ **GeV/c²** from CDF

Signal and background description

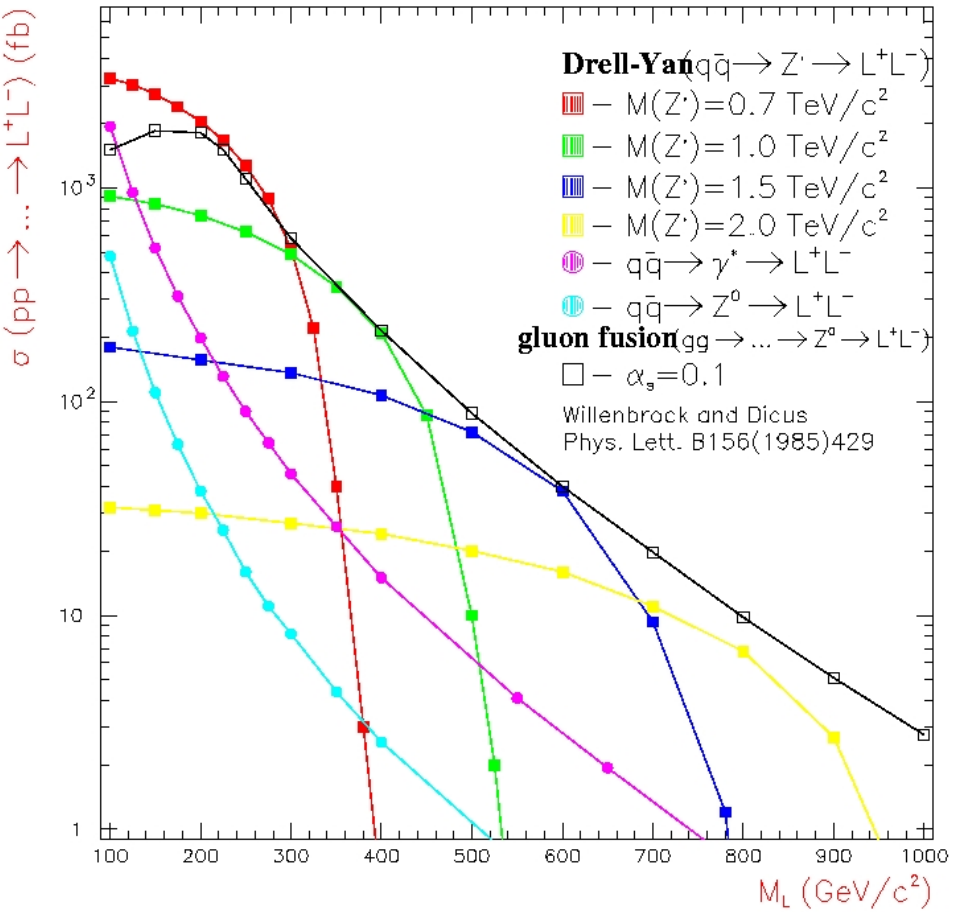
charged heavy leptons production mechanisms

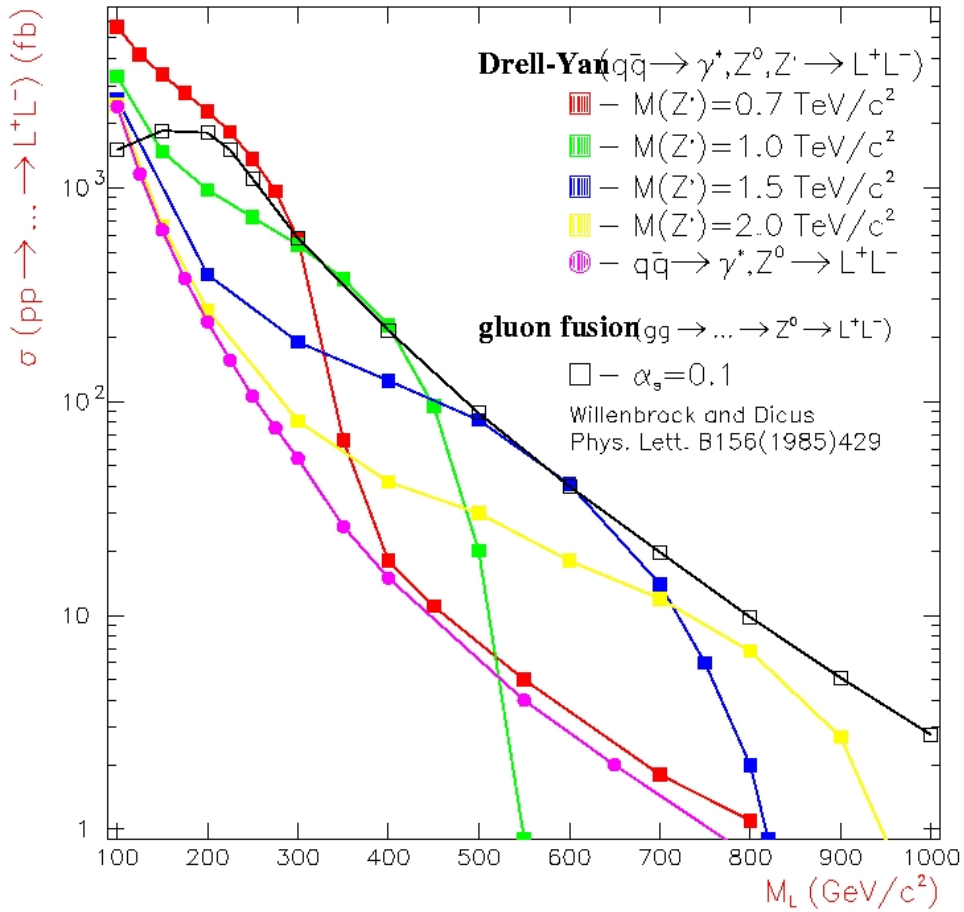




Signal and background description

heavy lepton pair production cross section mass dependence





Signal and background description

- model: sequential fermions (Standard Model couplings)
- decay channels:

$$pp \to ... \to L^+L^- \to 2Z^0 + 2\,(e \text{ or } \mu) \text{ and } Z^0 \to 2\,\text{jets}$$

$$pp \to ... \to L^+L^- \to 2Z^0 + 2\,(e \text{ or } \mu) \text{ and } Z^0 \to 2(e \text{ or } \mu)$$

- B.R. ($L \to l + Z$) = 1/3 (Z. Phys. C63 (1994) 317)
- gluon fusion cross section: (Phys. Let. B156 (1985) 429)

$$\left(\frac{\sigma(Z')}{\sigma(Z^0)}\right)_{gg} \approx \left(\frac{M(Z^0)}{M(Z')}\right)^4 \approx 2.9\times10^{-4} \quad if \quad M(Z') = 0.7\ \text{TeV/c}^2$$

Signal and background description

signal:

- two opposite charged isolated electrons or muons
- 4 jets from 2 Z^0 boson decay
- low E_T^{miss}

background:

- dilepton $t\bar{t}$ events: $t\bar{t} \rightarrow b\bar{b}$ W^- W^+ and $W \rightarrow$ (e or μ) + $\nu_{(e \text{ or } \mu)}$
- dileptonic and jets: WW+jets, WZ+jets, ZZ+jets, etc.
  where $Z \rightarrow (e \text{ or } \mu)^- + (e \text{ or } \mu)^+$ and $W \rightarrow (e \text{ or } \mu) + \nu_{(e \text{ or } \mu)}$

Event selection

- at least 2 isolated ($e^+ e^-$) or ($\mu^+ \mu^-$) with $p_T > 20$ GeV
- at least 4 jets with $p_T > 20$ GeV

- the candidate leptons were the 2 isolated electrons or muons with the highest p_T

- at least one jet with $p_T > 100$ GeV
- at least one electron or muon with $p_T > 150$ GeV

- $p_T^{miss} < 100$ GeV
- $m_{(e+e-,\mu+\mu-)} > 200$ GeV/c2

Event selection

- $\left| M_{j_1 j_2} - M_{Z^0}^{rec} \right| + \left| M_{j_3 j_4} - M_{Z^0}^{rec} \right| = \min$
- $\Delta R(j_1, j_2) = \sqrt{\Delta\eta_{j_1, j_2}^2 + \Delta\phi_{j_1 j_2}^2} = \min$
- $M_{Z^0}^{rec} - 3\,\sigma_{Z^0}^{rec} \le M_{di-jet} \le M_{Z^0}^{rec} + 3\,\sigma_{Z^0}^{rec}$
- $\left| M_{(e,\mu)_i^{(\pm)} Z_j^0} - M_{(e,\mu)_k^{(\pm)} Z_l^0} \right| = \min$

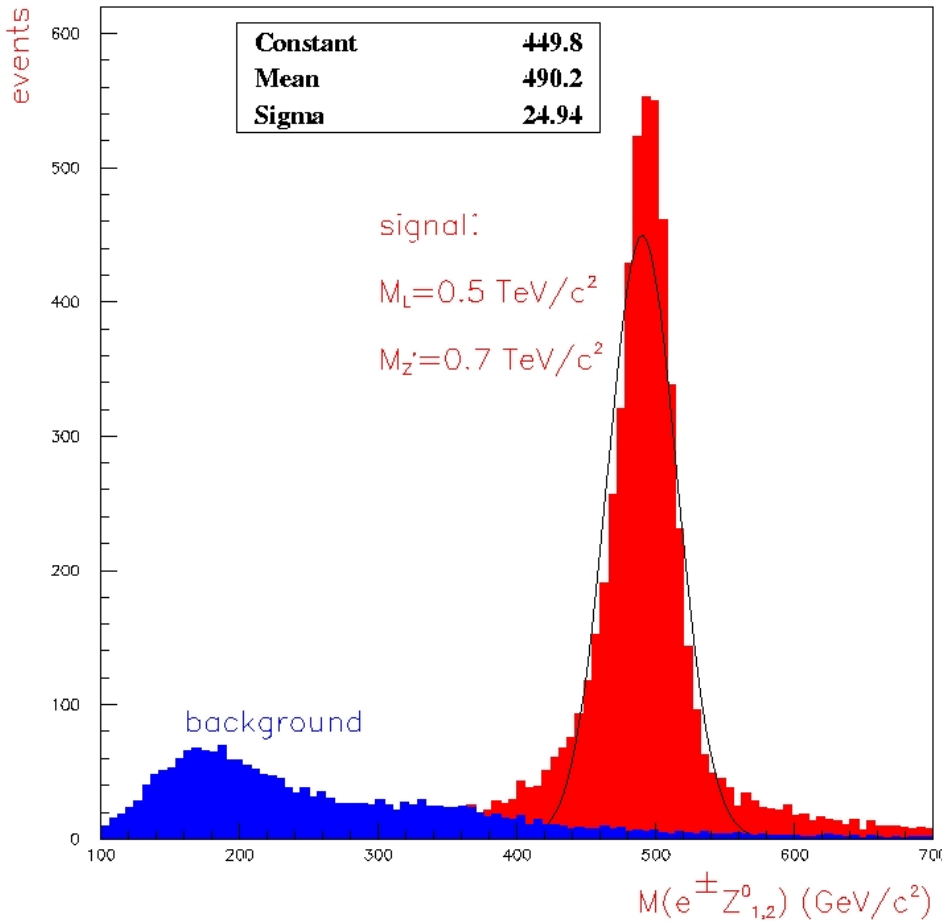
Event selection

efficiency (%) of the cuts,
applied sequentially for signal $L \rightarrow (e,\mu)+Z^0$ and $t\bar{t}$ background

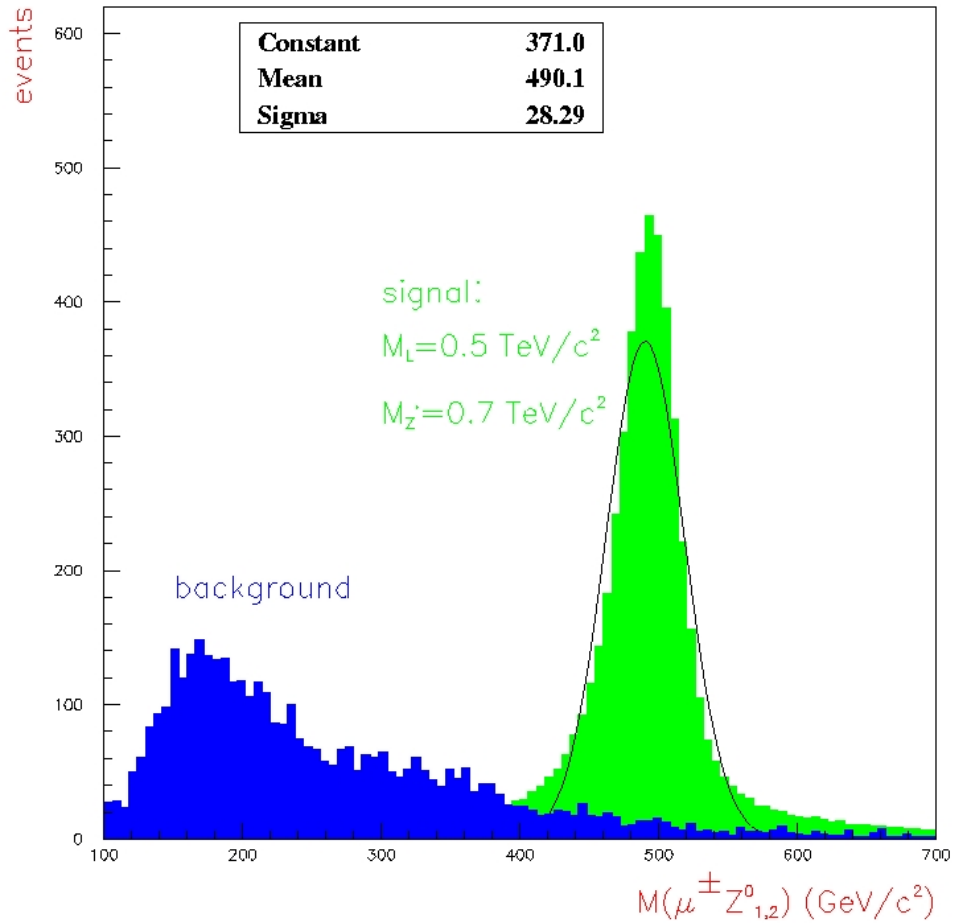
M(L) = 0.7 TeV and M(Z') = 1.5 TeV	$L \rightarrow e\ Z^0$ (%)	$L \rightarrow \mu\ Z^0$ (%)	$t\bar{t}$ (%)
at least 4jets + (2e **or** 2μ)	74.62	69.03	14.24
Z^0 pairs with $p_T^{(j1,\ j2,\ j3,\ j4)} > 20GeV$	36.28	33.57	3.87
$p_T^{\ j1} > 100\ GeV$	35.92	33.29	1.06
$p_T^{(l1,\ l2)} > 20\ GeV$	35.91	33.28	0.78
$p_T^{\ l1} > 200\ GeV$	35.63	33.05	0.09
$p_T^{miss} < 100\ GeV$	34.65	31.12	0.06
$M(l^+ l^-) > 200\ GeV/c^2$	32.98	29.07	0.04

Event selection

$M_{e^{\pm}Z^0_{1,2}}$ distribution for L→ e Z⁰



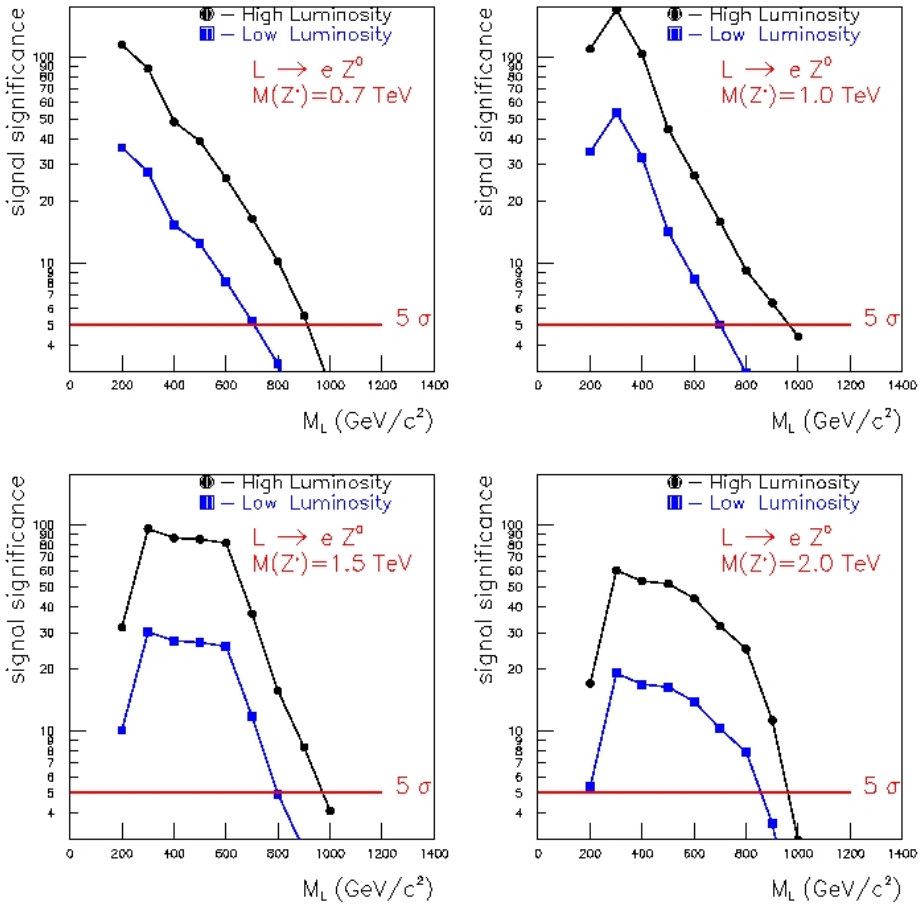
$M_{\mu^{\pm}Z^0_{1,2}}$ distribution for L→ μ Z⁰



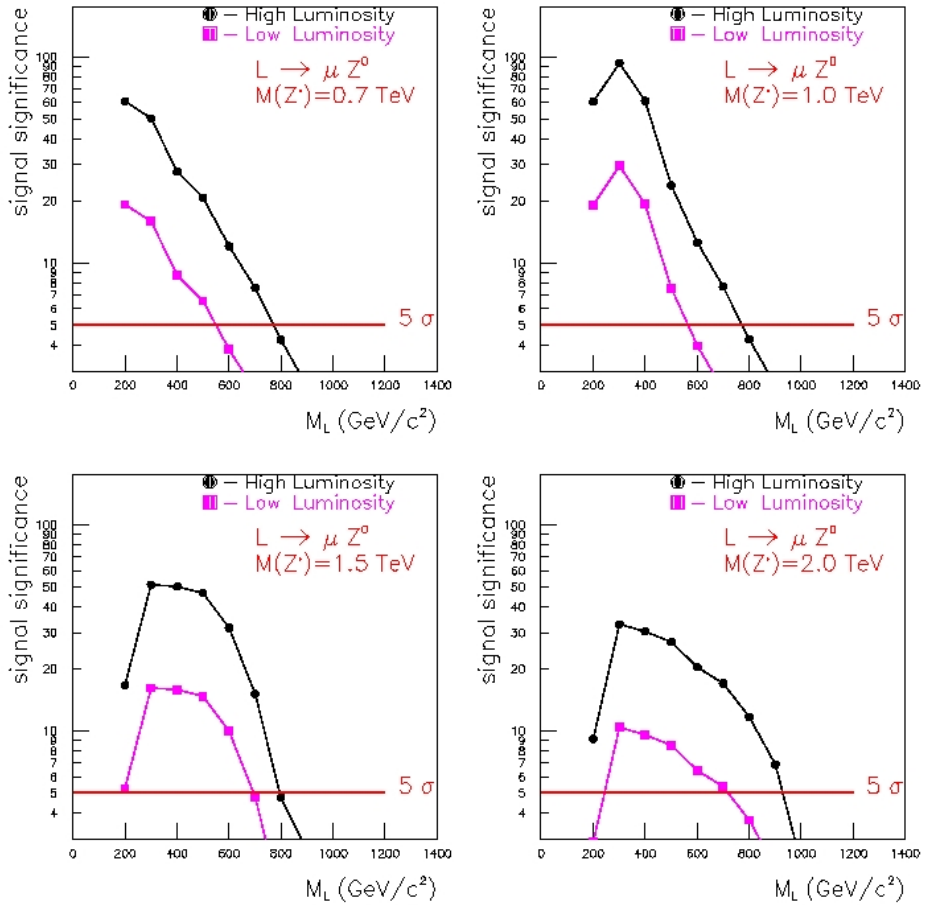
for signal significance we took ±2σ around the mean value $\overline{M}_{(e,\mu)^{\pm}Z^0_{1,2}}$

ATLAS discovery potential

signal significance for L → e Z^0 channel



signal significance for L → μ Z^0 channel



Preliminary results

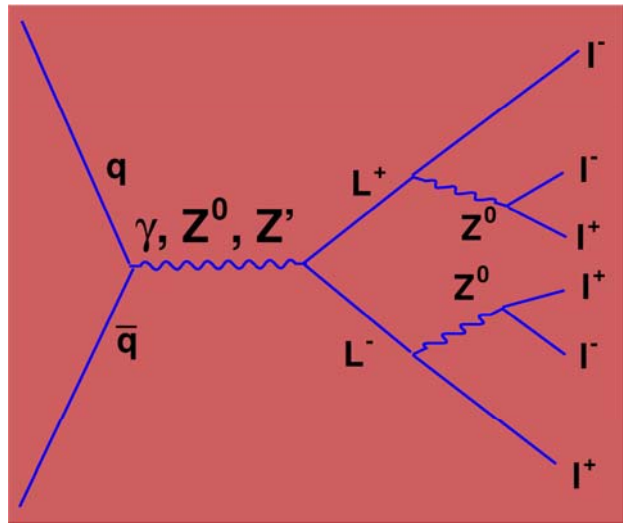
6 leptons: $pp \rightarrow ... \rightarrow L^+L^- \rightarrow 2Z^0 + 2(e^{\pm}, \mu^{\pm})$ and $Z^0 \rightarrow 2(e^{\pm}, \mu^{\pm})$

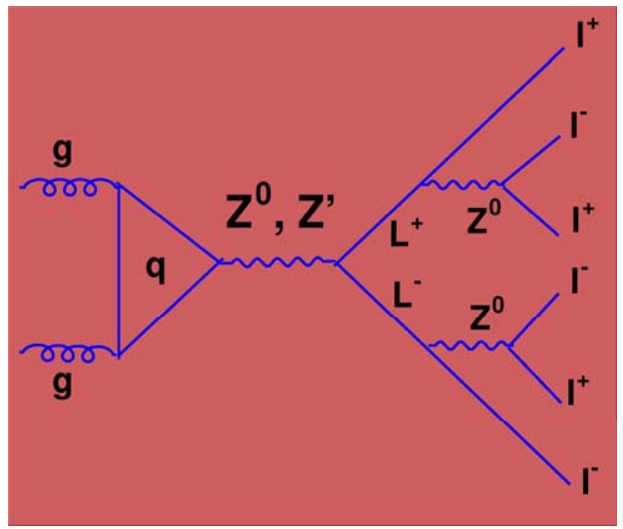
signal:

- at least six isolated leptons
- total charge = 0
- $\left| M_{e_1 e_2} - M_{Z^0} \right| = \min$ and $\left| M_{e_3 e_4} - M_{Z^0} \right| = \min$
- $M_{Z^0} - 3\sigma_{Z^0}^{rec} \leq M_{e_i e_j} \leq M_{Z^0} + 3\sigma_{Z^0}^{rec}$
- $\left| M_{e_i^{\pm} Z_j^0} - M_{e_k^{\mp} Z_l^0} \right| = \min$

background:

- no background





Preliminary results

signal obtained with and without the contribution of the 4-th quarks family (U, D)

			Preliminary		
channel	M(Z')	M(L)	M(U)	M(D)	signal
6e	2.5	0.9	-	-	11.2
	2.5	1.0	-	-	6.5
	2.5	1.1	0.7	0.14	9.53
	2.5	1.2	0.7	0.14	4.18
6μ	2.5	1.1	-	-	13.4
	2.5	1.2	-	-	4.5
	2.5	1.2	0.7	0.14	18.1
	2.5	1.3	0.7	0.14	9.4
4e and 2μ	2.5	1.0	-	-	14.1
	2.5	1.1	-	-	6.8
	2.6	1.1	0.7	0.14	19.8
	2.6	1.2	0.7	0.14	9.4
2e and 4μ	2.5	1.1	-	-	12.6
	2.5	1.2	-	-	4.1
	2.6	1.2	0.7	0.14	18.7
	2.6	1.3	0.7	0.14	8.6

conclusions:

- ATLAS discovery limit for this sequential charged heavy lepton

channel	M(L) discovery limit (TeV)	M(L) discovery limit with heavy quarks
2e + 4jets	1.0	1.2 (preliminary)
2μ + 4jets	0.9	1.1 (preliminary)
(6e, 6 μ)	0.9 / 1.1	1.1 / 1.3 (preliminary)
(4e+2μ, 2e+4μ)	1.0 / 1.1	1.2 / 1.3 (preliminary)

- Singly produced excited electrons could be accessible up to mass of 5 TeV at LHC for Λ = 6 TeV.

future plans:

- single charged heavy lepton
- VSM, VDM and FMFM:

  for $q\bar{q} \to \gamma^*, Z^0 \to L^+L^-$ and M_L=200GeV we will have (PRD66(2002)055003)

  17500 lepton pairs from VSM, 54800 from VDM, 68400 from FMFM,

  24500 from sequential model
- radiative corrections to gluon fusion production mechanism
- cross section modification due to models of extra dimensions (PLB436(1998)55, NPB537(1999)47)