Excited Leptons at CLIC

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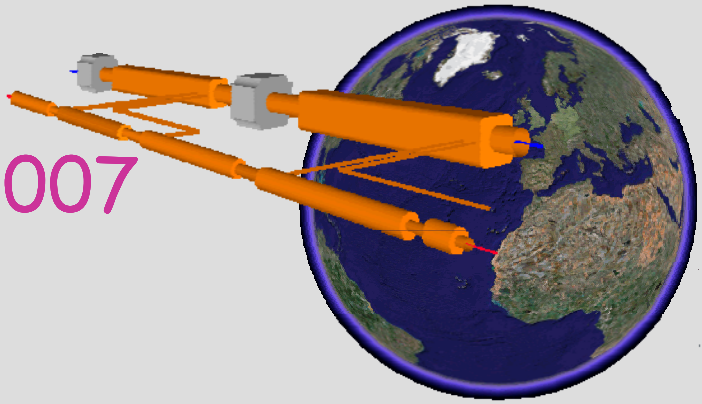


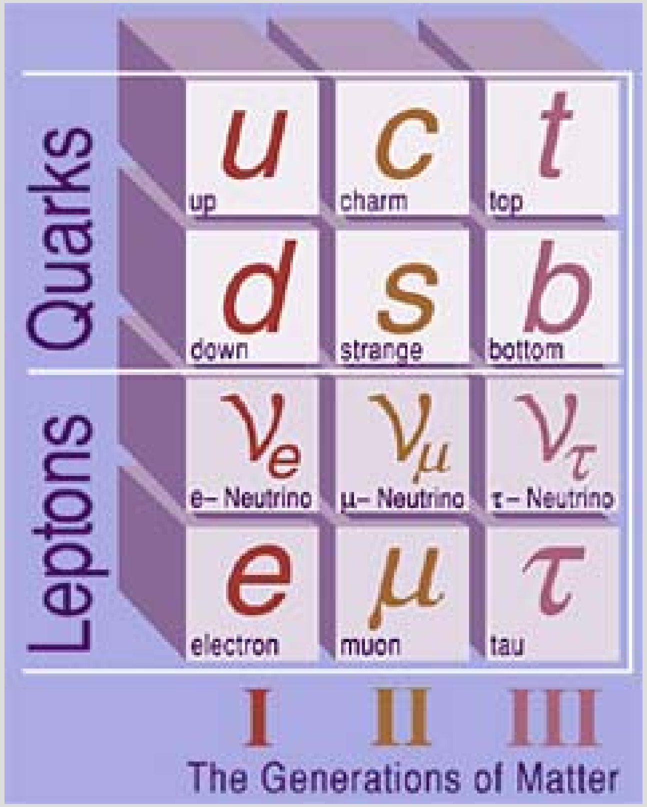
Outline

- fermion families within the SM
- excited states, excited leptons
- phenomenologic currents
- signals and backgrounds
- observability at CLIC
- conclusions

Some unexplained facts within the SM

- Proliferation of fermionic generations

- Complex pattern of masses and mixing angles

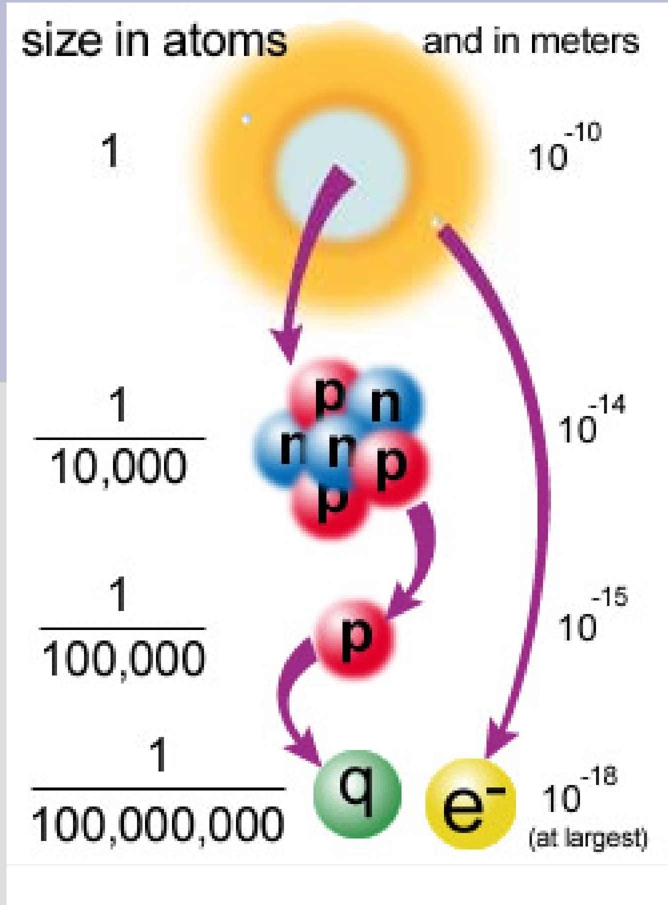


- natural explanation --> compositeness

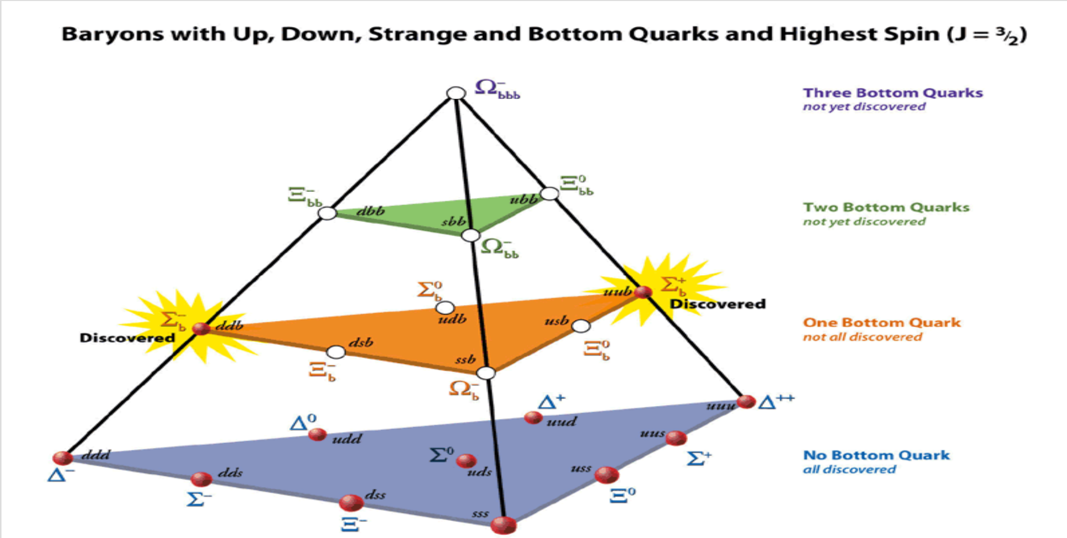
Compositeness and Excited States

If leptons and quarks are composites, they can be assigned to spin-1/2 bound states, containing three spin-1/2 subparticles. Bound states and/or excited states of spin-3/2 fermions are also possible

Terazawa 77,80



Baryons are particles made of three quarks. The particles can exist in a ground state (J=1/2) and an excited state (J=3/2)



Baryon Periodic Table

Excited Leptons

- Excited leptons $(l*, \nu*)$ and quarks (q*) appear as a consequence of compositeness
  - lowest lying radial and orbital excitations, spin-1/2
  - excited spin-3/2 states at higher energies
- Phenomenologically, an excited lepton is defined to be a heavy lepton and shares leptonic quantum number as the SM lepton
- An excited electron e* is characterized by a non-zero transition-magnetic coupling with the electron

Experimental Limits on *l**

Direct limits on *e** (ν^*):

- m*>103.2 (102.6) GeV, pair prod.

  with f=f' (f=-f'=Λ/m*); OPAL/02 (L3/03)

- m*>208 (190) GeV, single prod.

  with f=f'=Λ/m*; OPAL/02 (L3/03)

- m*><u>255</u> GeV, single prod.

  with f=f'=Λ/m*; H1/02

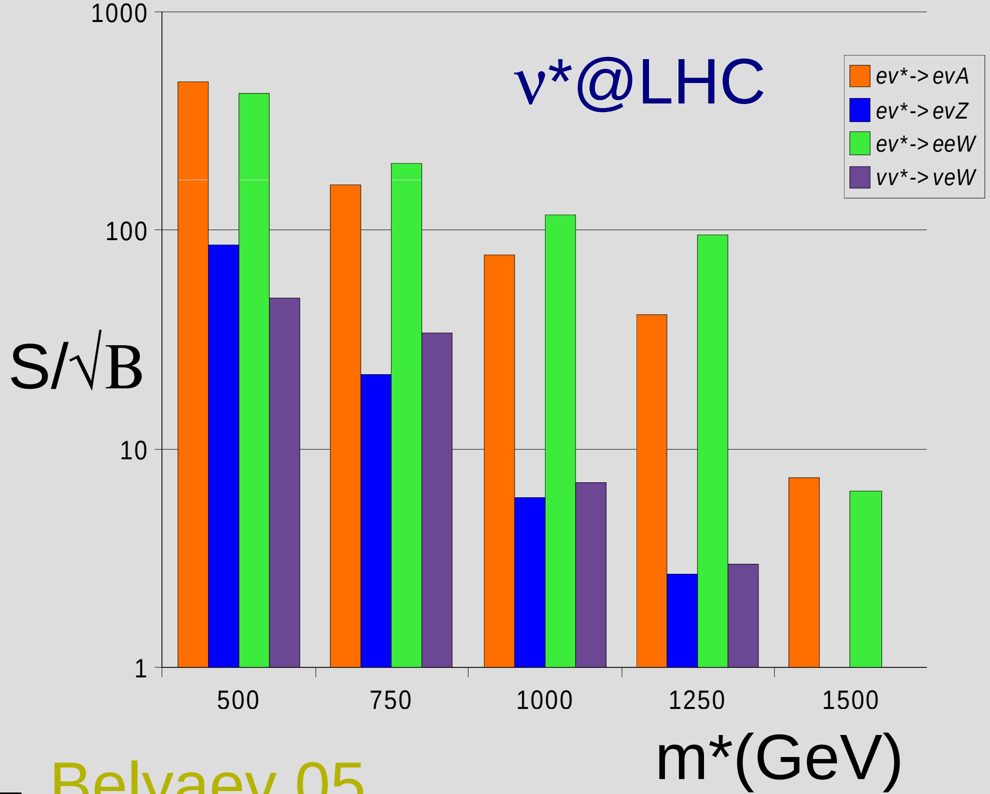
Indirect limits on *e**:

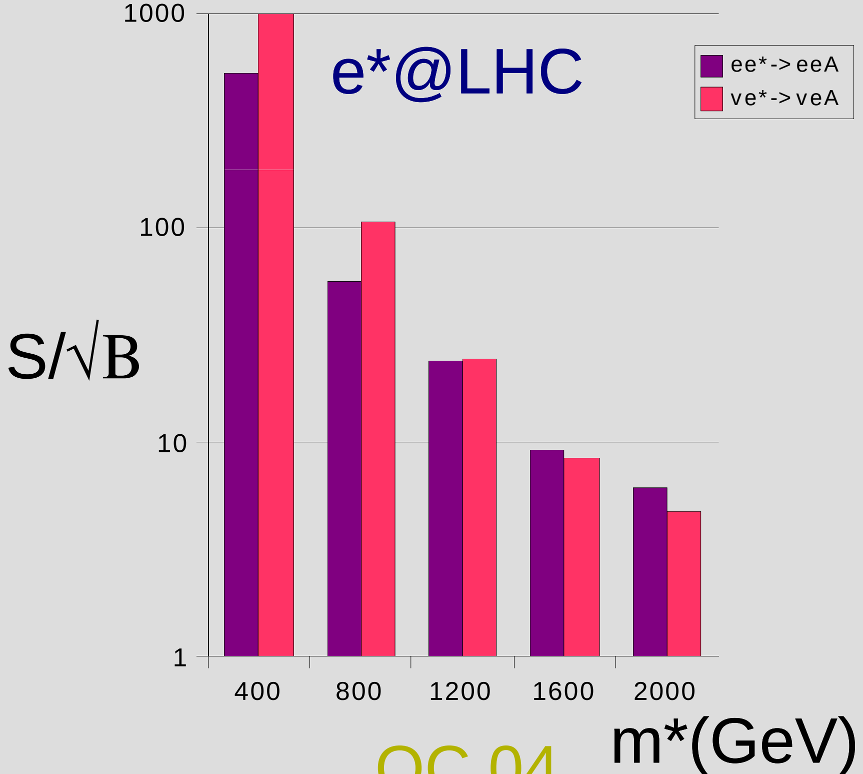
m*><u>310</u> GeV for λ_γ=1, L3/02

relatively smaller mass limits for μ^* and τ^*.

Excited leptons at high energies

- The LHC will be able to probe for ***ν*(e*)*** via gauge interactions with masses up to 1.5 TeV(**2.0 TeV**) depending on their couplings





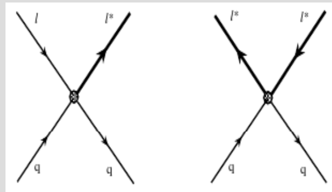
– Belyaev 05

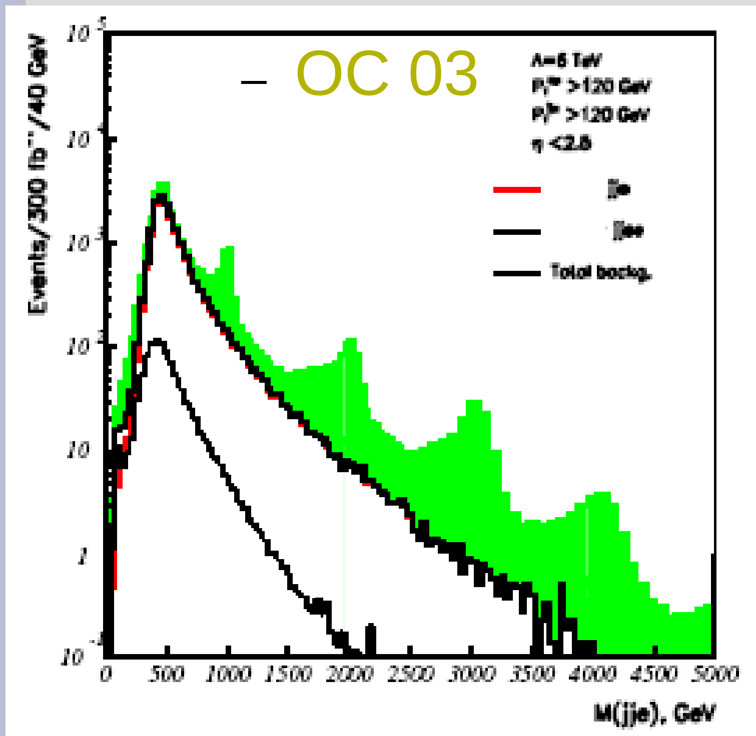
– OC 04

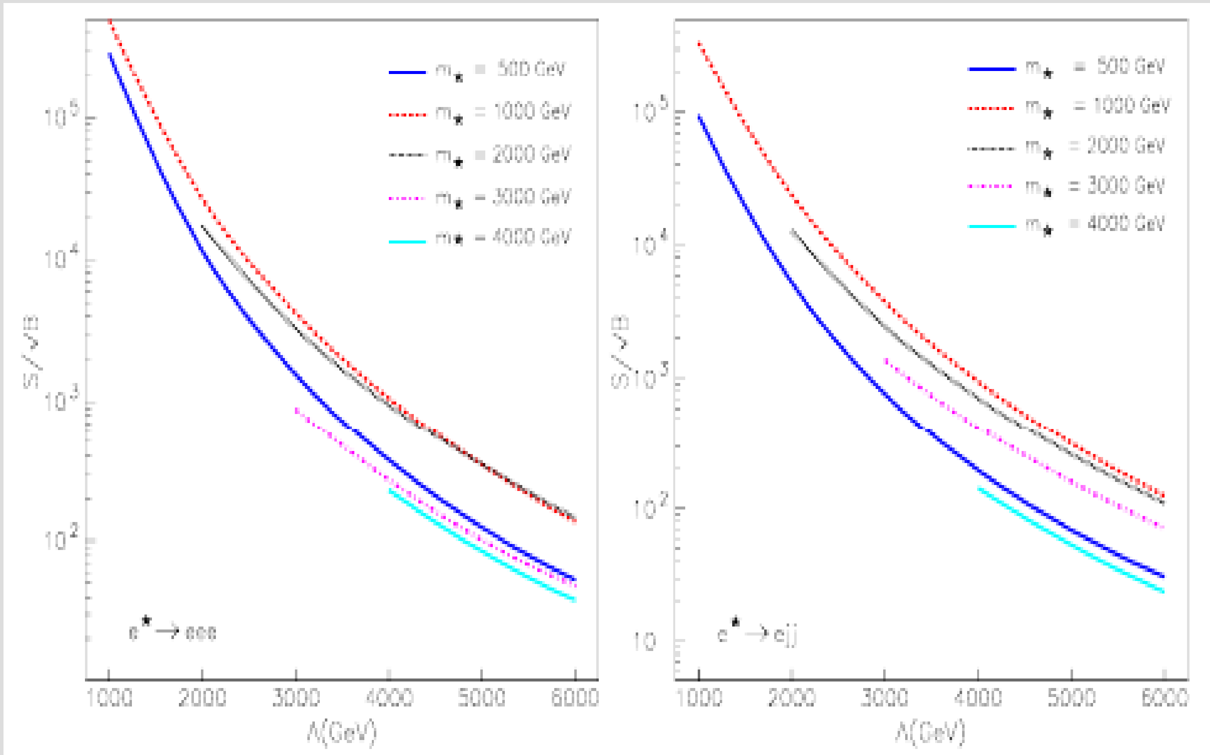
Excited leptons at high energies(2)

– e^* and ν^* may interact via contact interactions leading to an enhancement on the cross sections at the LHC, higher accessible mass limits up to 4.0 TeV for $\Lambda = 6$ TeV.

m* (TeV)	Γtot (GeV)	ΓG / Γtot	ΓC / Γtot
1	89.9(0.26)	0.08(0.75)	0.92(0.25)
3	270(20.8)	0.08(0.25)	0.92(0.75)
5	451(224)	0.08(0.11)	0.92(0.89)







More excited leptons:
spin-1/2 and spin-3/2 fields

- A spin-1/2 field satisfy the Dirac equation

$$\left(i\gamma^{\mu}\partial_{\mu} - m\right)\psi = 0$$

ψ: four d.o.f., used for spin-1/2 baryons (p,n,...) and fundamental fermions (q, l, ν) of the SM

- Rarita-Schwinger equation for spin-3/2

$$\varepsilon^{\mu\nu\rho\sigma}\gamma^{5}\gamma_{\nu}\partial_{\rho}\psi_{\sigma} + m\psi^{\mu} = 0 \quad \text{with} \quad \partial_{\mu}\psi^{\mu} = 0, \quad \gamma_{\mu}\psi^{\mu} = 0$$

ψ_{σ} : eight d.o.f. vector spinor used conveniently for spin-3/2 baryons (Δ, Σ,..), gravitino (~G) of SUGRA model and excited fermions (q^*, l^*, ν^*) of compositeness

Phenomenologic currents

- Interaction between a spin-1/2 excited electron, gauge boson (V=γ,Z,W) and the SM lepton described by the currents

$$J^\mu = \frac{g_e}{2\Lambda}\bar{u}(k,1/2) i\sigma^{\mu\nu} q_\nu (1-\gamma_5) f_V u(p,1/2)$$

$$f_W = f/\sqrt{2}s_w$$

$$f_\gamma = Qf' + I_3(f - f')$$

$$f_Z = \left[I_3\left(c_w^2 f + s_w^2 f'\right) - 4Qs_w^2 f'\right]/s_w c_w$$

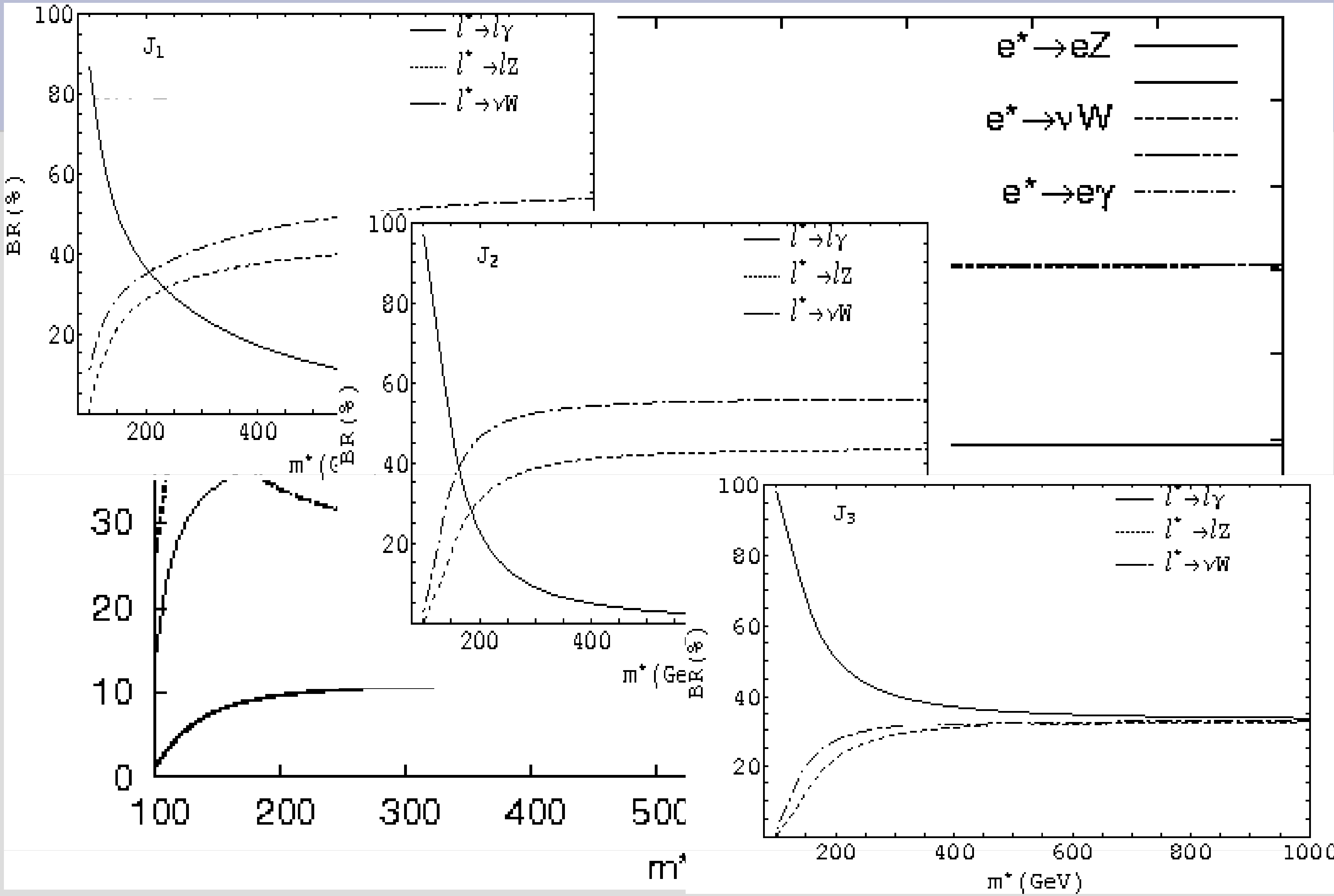
- A spin-3/2 excited electron can interacts with gauge boson (V=γ,Z,W) and the SM lepton via the currents

$$J_1^\mu = g_e \bar{u}(k,1/2)(c_{1V} - c_{1A}\gamma_5) u^\mu(p,3/2)$$

$$J_2^\mu = \frac{g_e}{2\Lambda}\bar{u}(k,1/2) q_\lambda \gamma^\mu (c_{2V} - c_{2A}\gamma_5) u^\lambda(p,3/2)$$

$$J_3^\mu = \frac{g_e}{\Lambda^2}\bar{u}(k,1/2) q_\lambda i\sigma^{\mu\nu} q_\nu (c_{3V} - c_{3A}\gamma_5) u^\lambda(p,3/2)$$

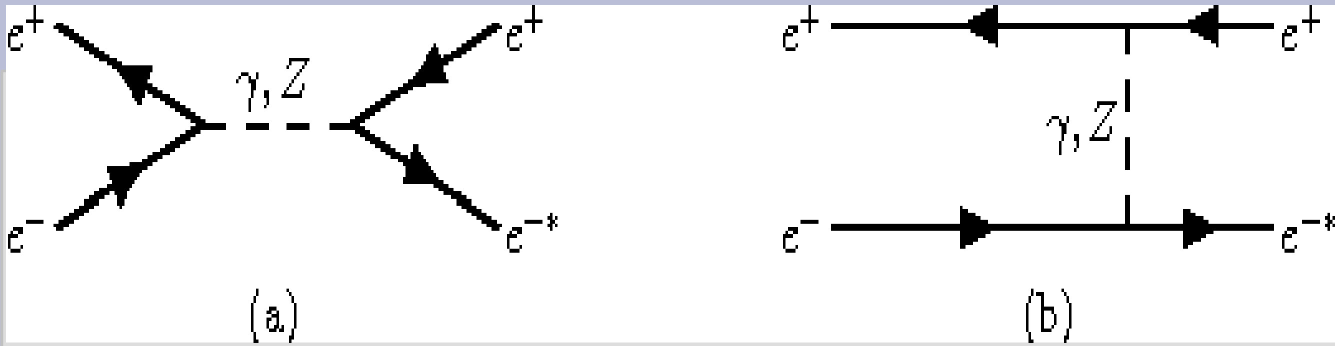
Branchings for spin-3/2 excited leptons



$\Gamma(3/2)=0.25\ (0.22)\ [0.005]$ GeV, for $c_V=c_A=0.05$ and $\Lambda=m^*=1$ TeV

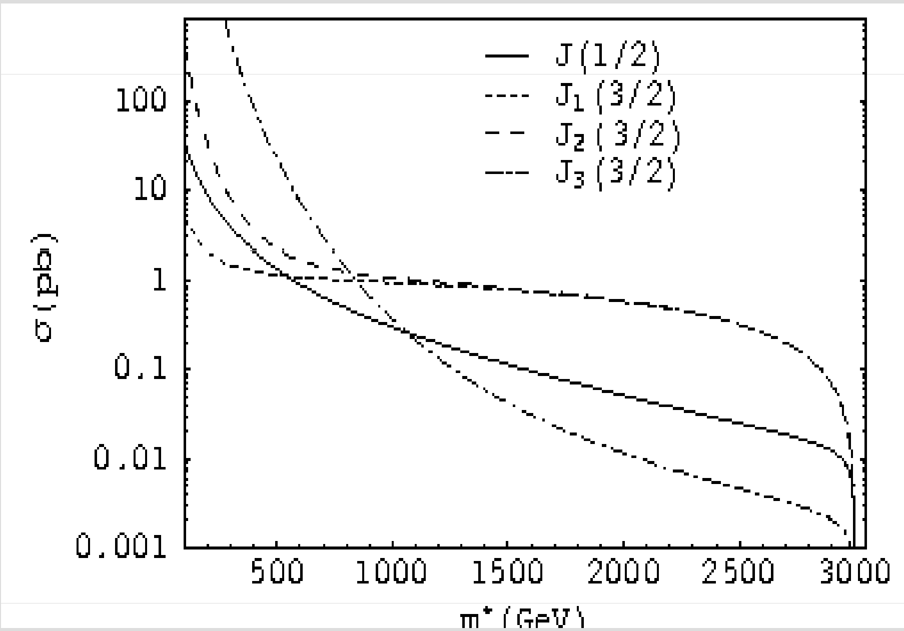
Single production at CLIC

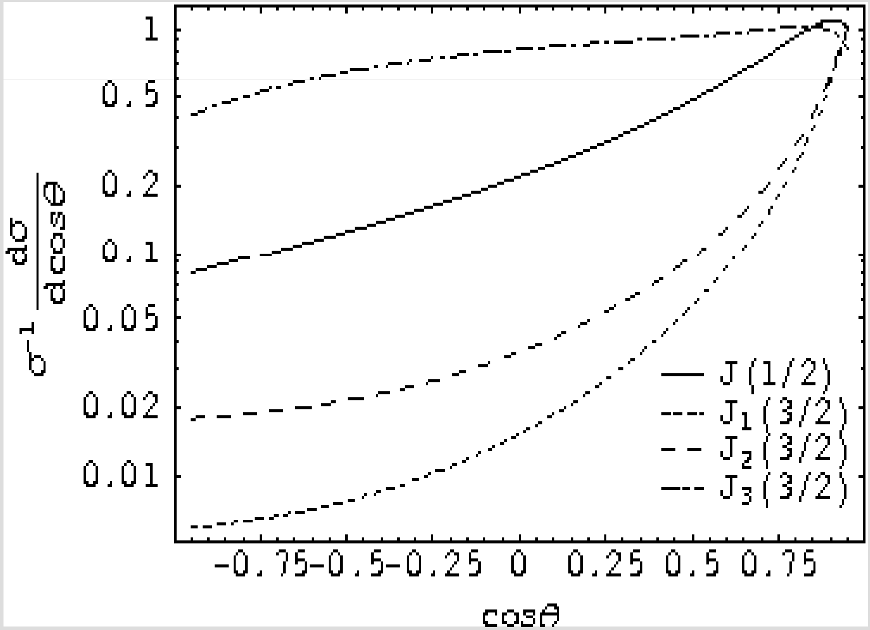
single production, m* up to √s



OC & Ozansoy
hep-ph/0709.2134

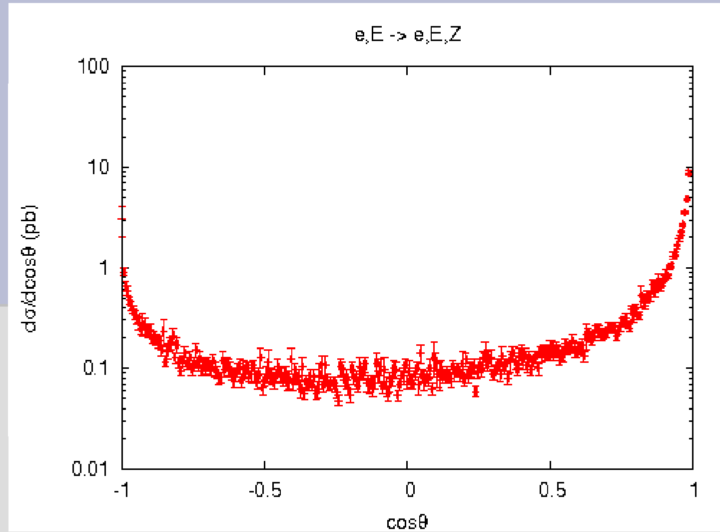
f=-f'=1, c_V=c_A=0.5, Λ=m*





different angular shape...

Analysis



Acceptance cuts:

$$p_T^{e,\gamma} > 20 GeV$$

$$|\eta_{e,\gamma}| < 2.5$$

$$\Delta R_{ee,e\gamma} > 0.4$$

Background cross sections:

ee-> eeγ	ee-> eeZ	ee-> eνW
0.16 pb	0.03 pb	0.46 pb

further cuts for the signal detection:

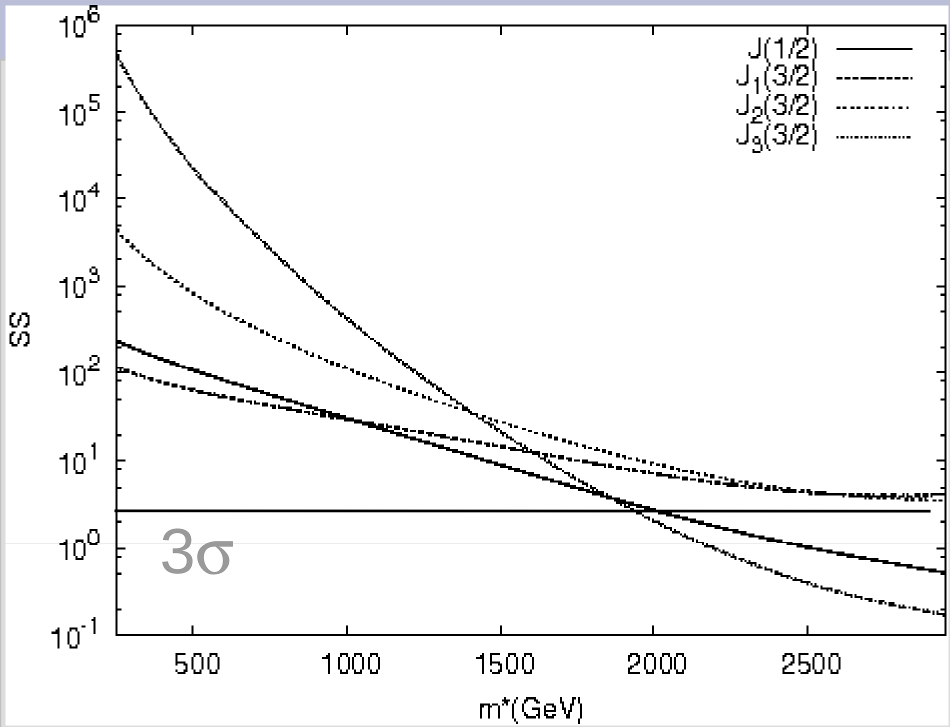
$$|m_{lV} - \mathrm{m}^*| < 25\ \mathrm{GeV} \quad for\ 0.1 < m^* < 1.5\mathrm{TeV}$$

$$m_{lV} > 1\ \mathrm{TeV} \quad \mathrm{for} \quad \mathrm{m}^* > 1.5\mathrm{TeV}$$

reduction ~ 0.01
@ m*=1 TeV

Discovery at CLIC

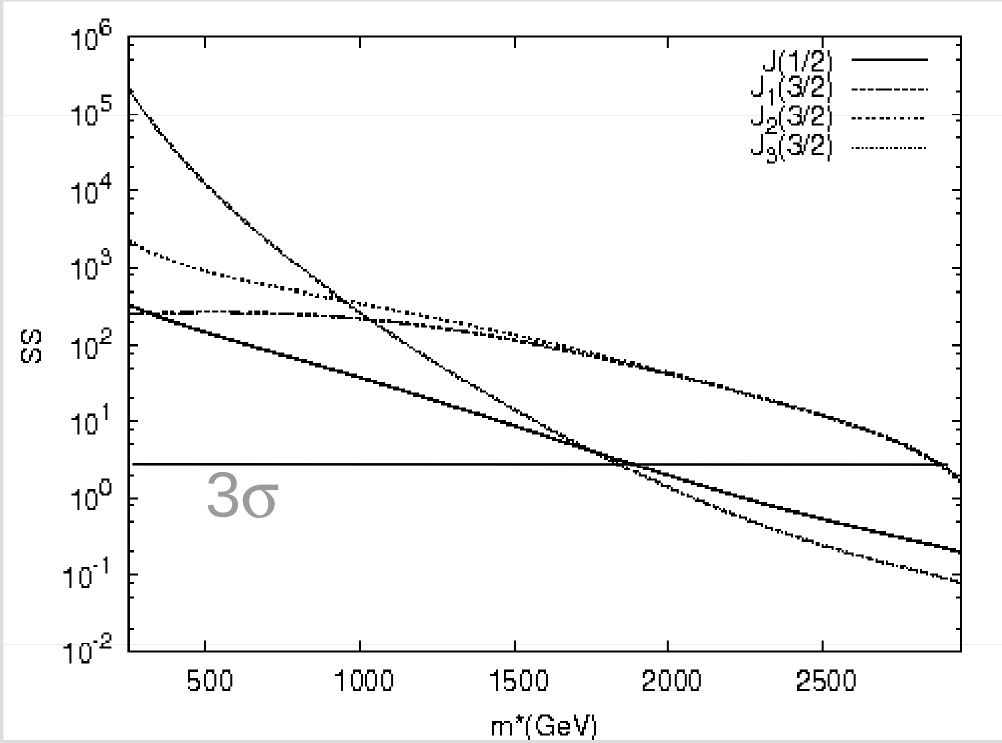
f=f'=1, $c_{V\gamma}=c_{A\gamma}=0.05$, $\Lambda=m^*$



S: $e^{-*} \rightarrow e^- \gamma$

B: $e^+ e^- \rightarrow e^+ e^- \gamma$

f=-f'=1, $c_{VZ}=c_{AZ}=0.05$, $\Lambda=m^*$



$$SS = \frac{\sigma_S}{\sqrt{\sigma_B}} \sqrt{\varepsilon . L_{\text{int}}}$$

$$L_{\text{int}} = 400\ fb^{-1}$$

$e^{-*} \rightarrow e^- Z$: S

$e^+ e^- \rightarrow e^+ e^- Z$: B

Conclusion

CLIC with 3 TeV cm energy and L_{int}=400/fb can probe

- m*<1.8 TeV for both J(1/2) with f=f'=1 and J_3(3/2) with $c_V=c_A=0.05$,

- m*<$\sqrt{s}$ for both J_1(3/2) and J_2(3/2) with $c_V=c_A=0.05$.

We show that excited spin-3/2 and spin-1/2 leptons can be seperated by normalized angular distributions. In addition, polarization of the initial beams could help to measure chiral couplings.

If LHC discovers excited leptons, ILC can measure their properties, CLIC can improve the measurements. If not, only CLIC may have a chance to discover and measure their properties at multi-TeV range with a high luminosity.