Search for Excited Leptons

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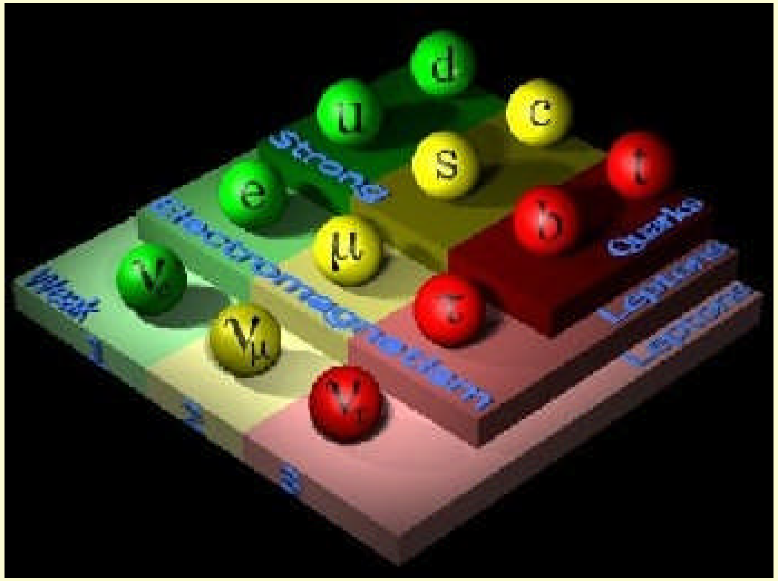
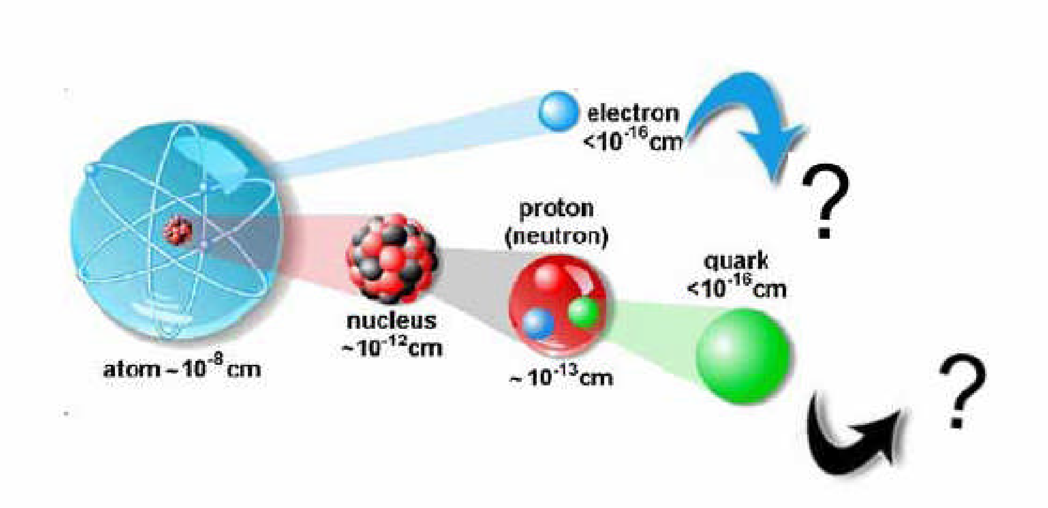
1.Motivation



Questions left open by the SM

- Replication of SM families
- Their complex pattern of masses and mixing angles
- Superfluity of the number of the fundamental particles

Addressed by composite models



* In the composite models, known quarks and leptons composite.

- Constituents of SM fermions interact by means of new interactions.

- Known fermions can be assigned to spin-1/2 bound states, containing three spin-1/2 or spin-1/2 and spin-0 subparticles.

[Terazawa et al. PRD 15] [Ne'eman PLB82]

- Composite models would also imply bound states of spin-3/2 fermions containing three spin-1/2 or spin-1/2 and spin-1 subparticles. [Lopes et al., PLB94]

- If substructure exist → Rich spectrum of excited states (excited leptons l^*, ν^* and quarks q^*)

- Known leptons considered as ground state.
- Phenomenologicaly, an excited lepton can be considered as a heavy lepton sharing **leptonic quantum number (flavor)** with the corresponding SM lepton.
- Spin-1/2 excited states are the lowest radial and orbital excitation.
- Spin-3/2 excited states as a higher excitation.

2. Theoretical Overview

Excited Leptons

- Predicted in many compositeness models
- Constituents dynamics are unknown ➔ Effective lagrangian method
- Produced via contact or gauge interactions

•**Excited Leptons with spin-1/2 :** A spin-1/2 excited lepton l^* is characterized by a non-zero transition-magnetic coupling with the SM lepton

- The SU(2)×U(1) invariant effective Lagrangian;

Gauge structure constants

$$L = \frac{1}{2\Lambda} \bar{l}_R^{\,*} \sigma^{\mu\nu} \left[g f \frac{\vec{\tau}}{2} \vec{W}_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} \right] l_L + h.c.$$

Gauge tensors for SU(2) and U(1)

SM couplings

Scaling factors

Excited Leptons with spin-3/2:

Motivation for spin-3/2 particle

- Supergravity → gravitino
- Baryons → such as Δ's and Ω^- etc.
- Composite models → excited spin-3/2 quarks and leptons.

The interaction between SM leptons, gauge bosons (γ,Z,W) and excited spin-3/2 lepton can be described by phenomenological currents:

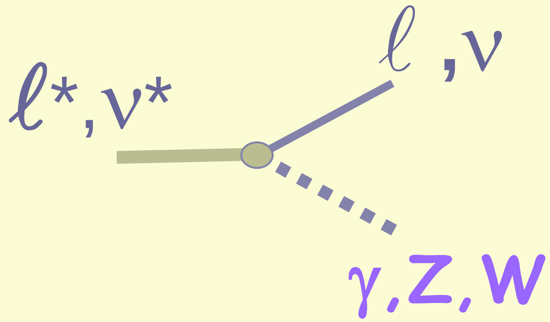
$$J_1^\mu = g_e \bar{u}(k,1/2)(c_{1V} - c_{1A}\gamma_5)u^\mu(p,3/2)$$

Rarita-Schwinger vector-spinor

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

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

•Decay widths of excited leptons:



Neglecting SM lepton mass, decay width formula for excited spin-1/2 lepton

$$\Gamma_\gamma = \frac{f_\gamma^2 m^{*3} \alpha}{4\Lambda^2}$$

$$f_W = \frac{1}{\sqrt{2} s_W} f$$

$$\Gamma_V = \frac{f_V^2 m^{*3} \alpha}{4\Lambda^2}\left(1 - \frac{m_V^2}{m^{*2}}\right)^2 \left(1 + \frac{m_V^2}{2m^{*2}}\right) \quad (V = Z, W)$$

$$f_Z = \frac{I_{3L}\left(c_W^2 f + s_W^2 f'\right) - e_f s_W^2 f'}{s_W c_W}$$

$$f_\gamma = e_f f' + I_{3L}\left(f - f'\right)$$

$$m^* >> m_V$$

$$\Rightarrow \Gamma \sim f_V^2 m^*$$

$$m^* = \Lambda$$

Neglecting SM lepton mass, decay width formula for excited spin-3/2 lepton for curents J_1, J_2 and J_3

Neutral and charged weak decays widths

$$\Gamma^{(1)} = \frac{\alpha}{48}(c_{1V}^2 + c_{1A}^2)m^* \frac{(1-\kappa)^2}{\kappa}(1+10\kappa+\kappa^2)$$

$$\Gamma^{(2)} = \frac{\alpha}{48}(c_{2V}^2 + c_{2A}^2)m^* (\frac{m^*}{\Lambda})^2 \frac{(1-\kappa)^4}{\kappa}(1+2\kappa)$$

$$\Gamma^{(3)} = \frac{\alpha}{48}(c_{3V}^2 + c_{3A}^2)m^* (\frac{m^*}{\Lambda})^4 (1-\kappa)^4(2+\kappa)$$

Here
$\kappa = (m_V / m^*)^2$.

and V=Z,W .

Radiative decays widths

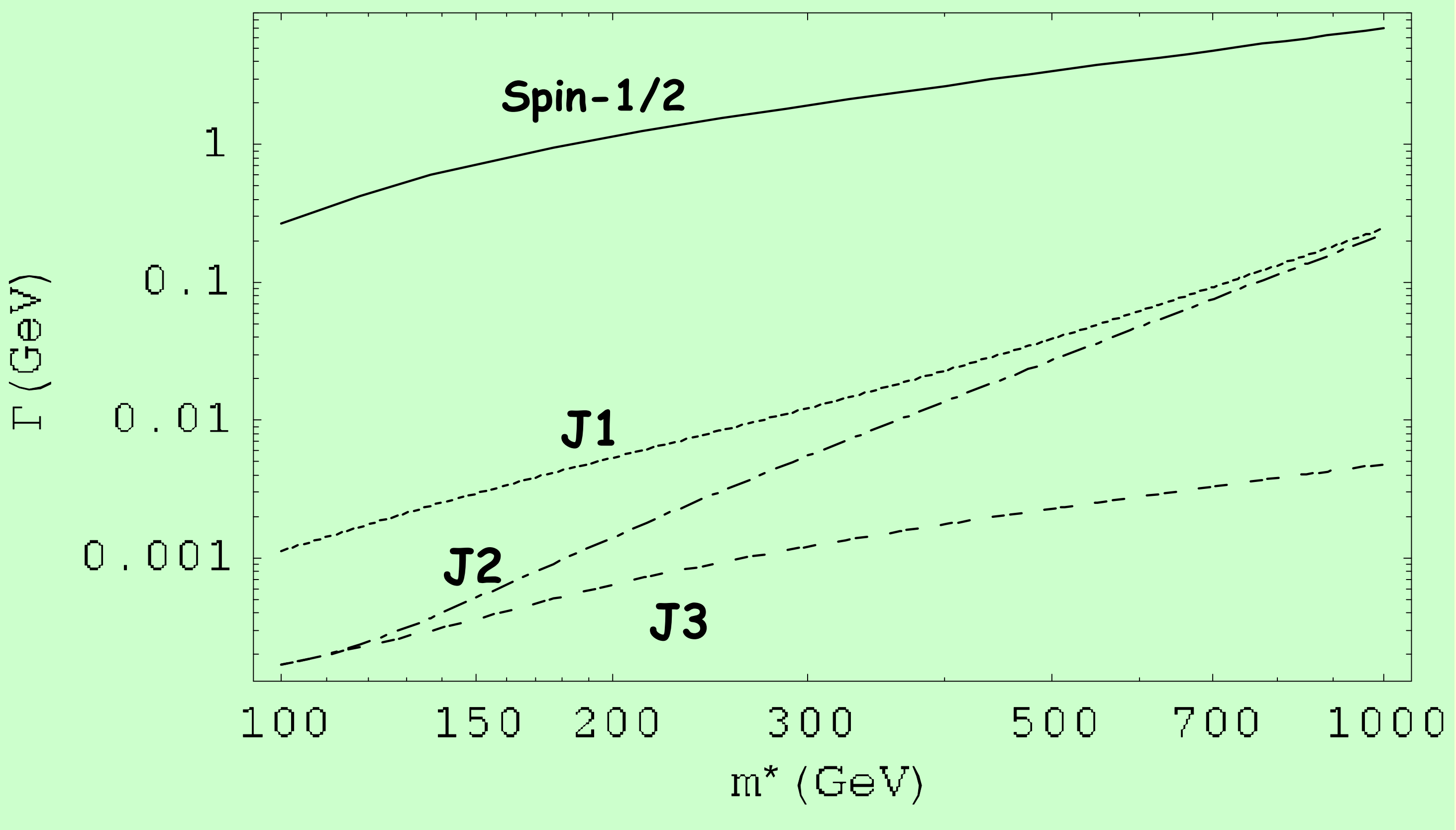
$$\Gamma_\gamma^{(1)} = \frac{\alpha}{4}(C_{1A}^{\gamma 2} + C_{1V}^{\gamma 2})m^*$$

$$\Gamma_\gamma^{(2)} = \frac{\alpha}{24}(C_{2A}^{\gamma 2} + C_{2V}^{\gamma 2})m^* (\frac{m^*}{\Lambda})^2$$

$$\Gamma_\gamma^{(3)} = \frac{\alpha}{48}(C_{3A}^{\gamma 2} + C_{3V}^{\gamma 2})m^* (\frac{m^*}{\Lambda})^4$$

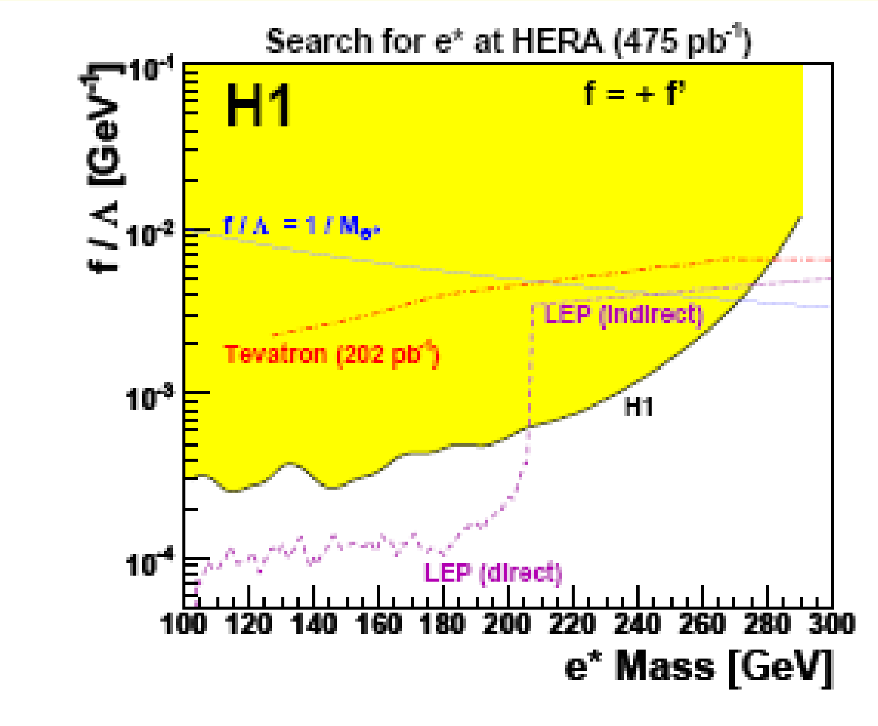
$\Lambda = m^{*}, f = f^{'} = 1 \quad c_{iV} = 0.05, c_{iA} = 0.05$

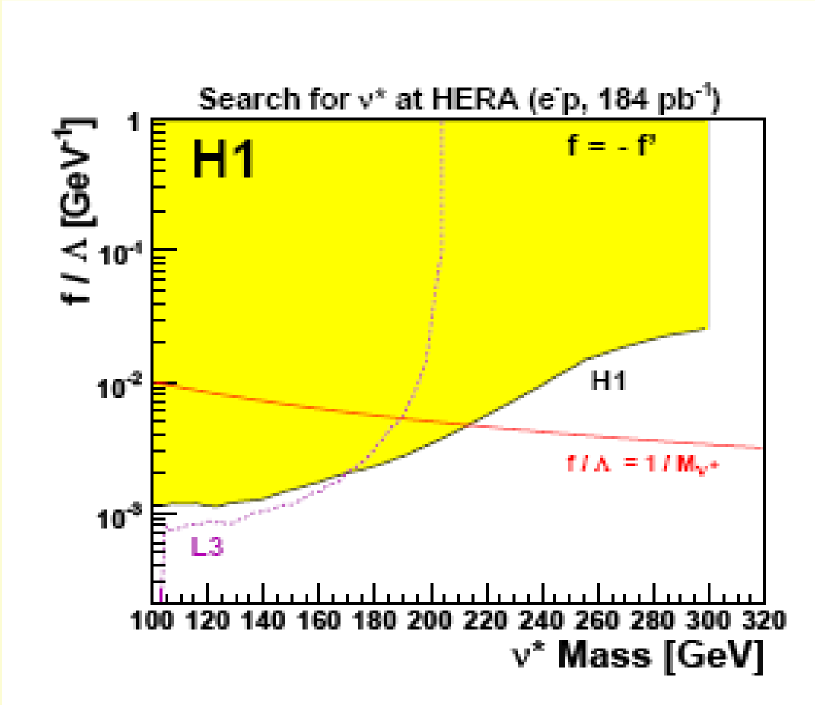
Total decay width for excited spin-1/2 and spin-3/2 leptons



Mass Limits

South, hep-ex/0809.5010v1

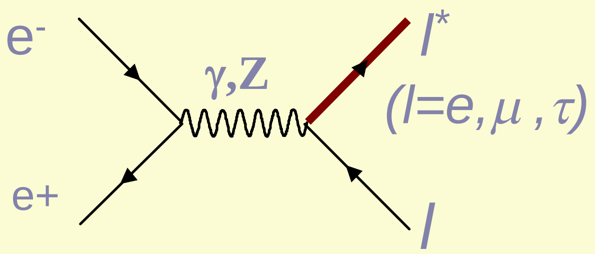




$m_{e*} > 272$ GeV and $m_{\nu*} > 213$ GeV @ 95 % C.L.

3. Excited Leptons at CLIC

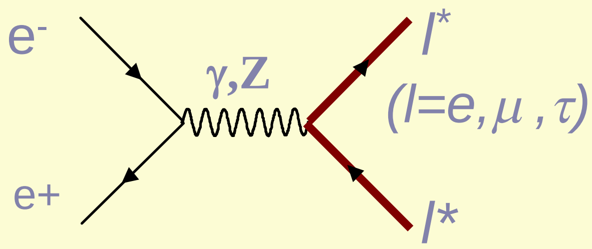
Single production



+ other channels

- l * masses up to √s
- tensor-type int.

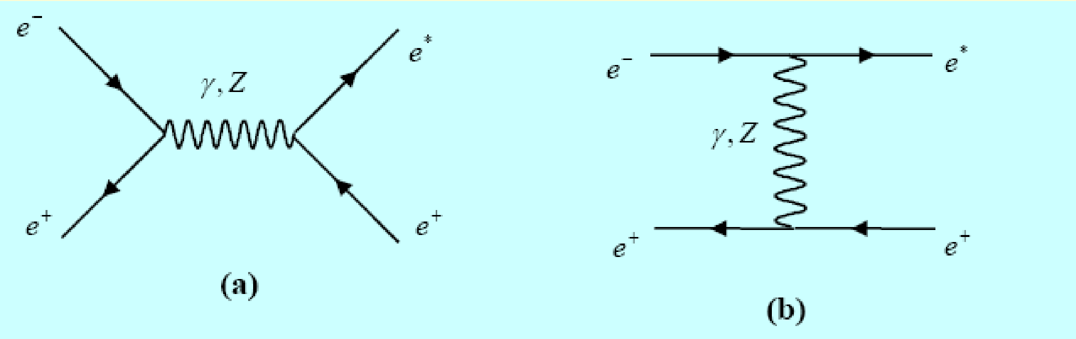
Pair production



+ other channels

- l * masses up to √s /2
- vector-type int.

•Single Production of Excited Electrons in e^+e^- collisions

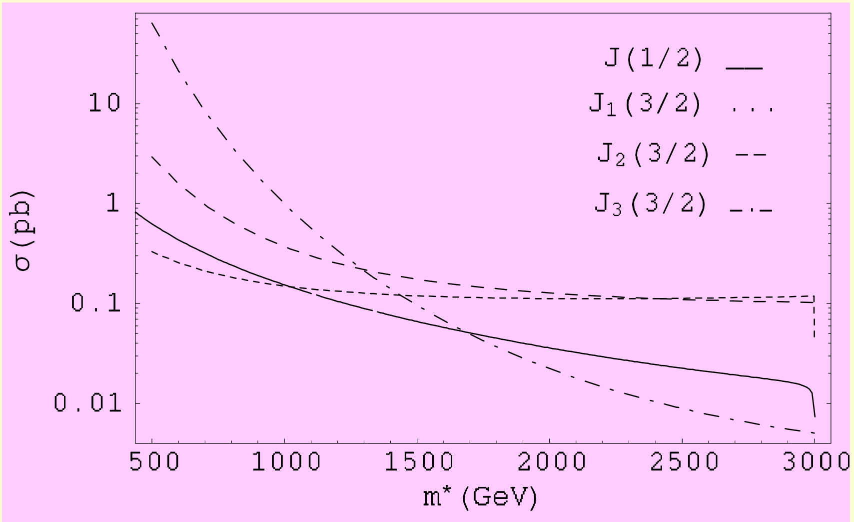


•μ^* and τ^* sing. prod. is possible

→in the s- channel

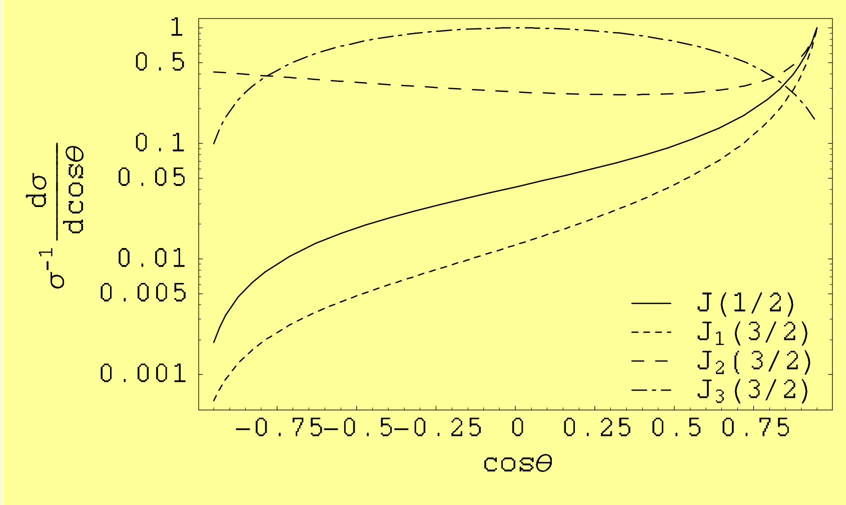
→and in the t- channel with LFV couplings

•$e^* \rightarrow e\ \gamma$ signal



$f=f'=1$, $c_{iV}^{\gamma}=c_{iA}^{\gamma}=0.5$, $\Lambda=m^*$, i=1, 2, 3

Cakir & AO, PRD 77, 035002



$\Lambda=m^*=350$ GeV

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

Acceptance cuts:

$$p_T^{e,\gamma} > 20\,GeV$$
$$|\eta_{e,\gamma}| < 2.5$$
$$\Delta R_{ee,e\gamma} > 0.4$$

↓

$\sigma_{B=0.16\ pb}$

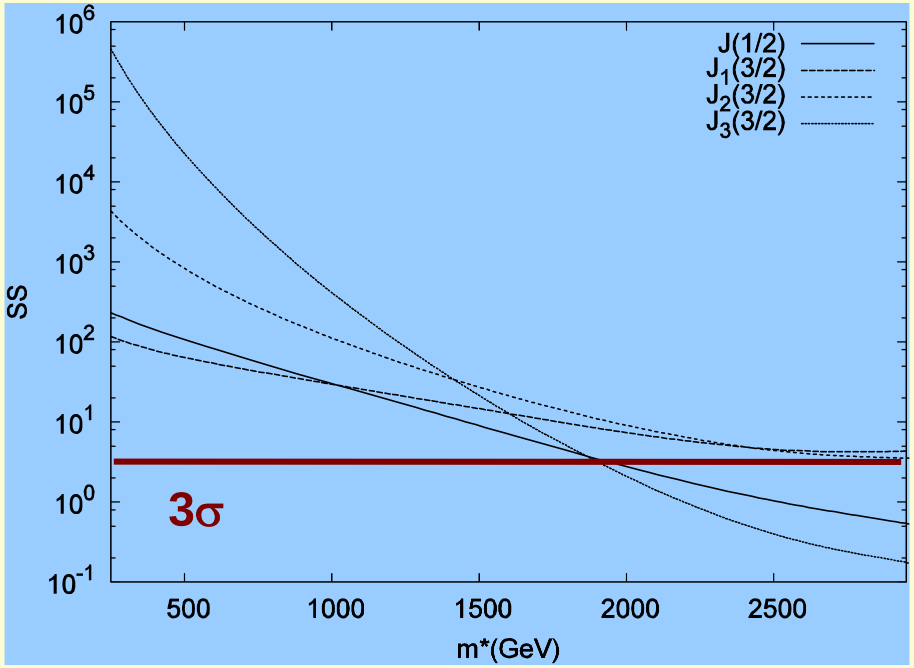
\+

Further cuts:

$$|m_{l\gamma} - m^*| < 25\,\mathrm{GeV} \quad \text{for } 0.1 < m^* < 1.5\,\mathrm{TeV}$$
$$m_{l\gamma} > 1\,\mathrm{TeV} \quad \text{for} \quad m^* > 1.5\,\mathrm{TeV}$$

↓

m*(GeV)	σ_B (pb)
250	1.67×10^{-4}
500	8.26×10^{-4}
1000	3.24×10^{-4}
1500	3.67×10^{-4}
2000	1.66×10^{-2}
2500	1.66×10^{-2}
2750	1.66×10^{-2}

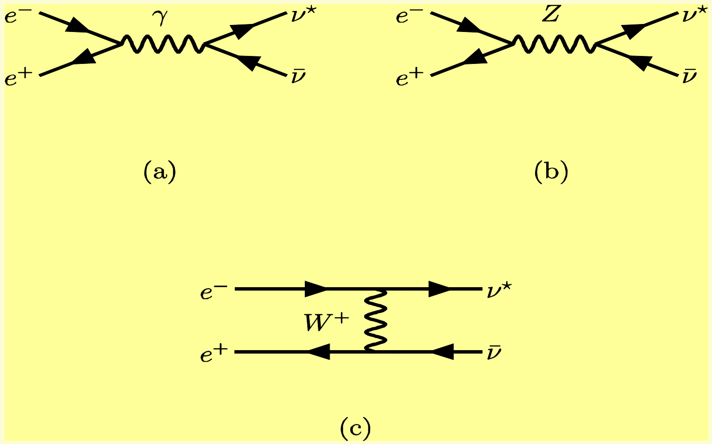


$$SS = \frac{\sigma_S}{\sqrt{\sigma_B}}\sqrt{\varepsilon.L_{\mathrm{int}}}$$

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

SS>3 → m ~ 1.8 TeV @*
$c_{iV}^{\gamma} = c_{iA}^{\gamma} = 0.05$ and f=f'=1

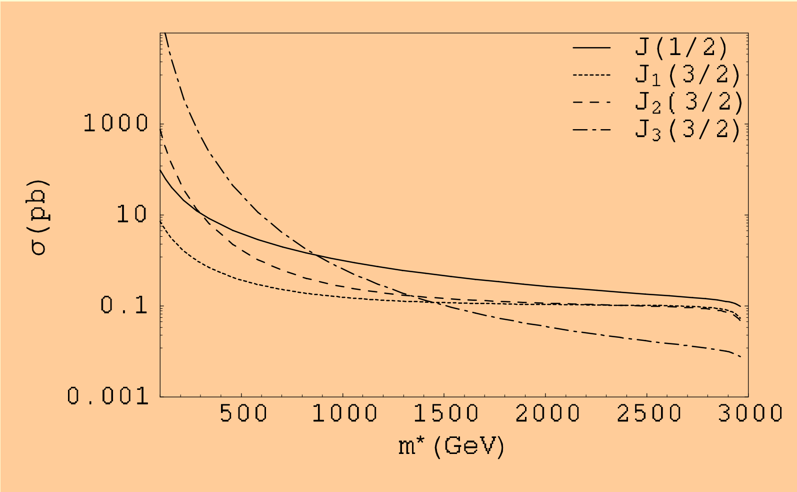
•Single Production of Excited Neutrinos in e^+e^- collisions

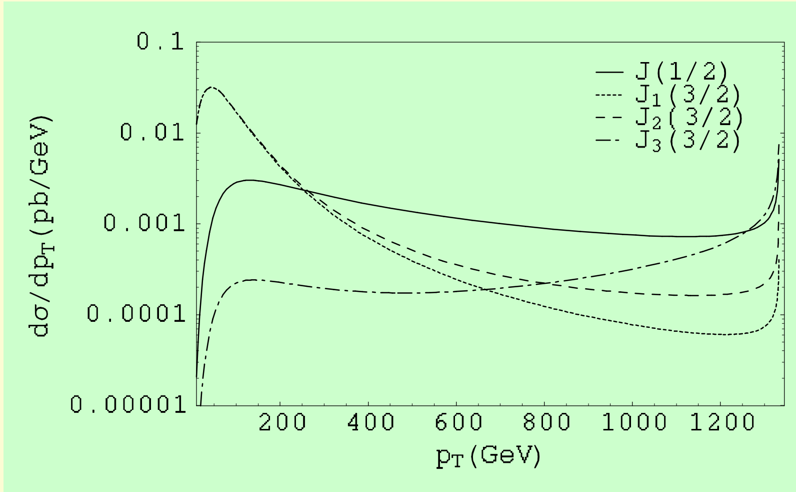


• Other types of neutrinos can be produced singly with or without the LFV couplings in the s-channel.

$\nu^* \rightarrow e\ W$ signal

Cakir & AO, hep-ph/ 0809.1624





f=-f'=1, $c_{iV}^{W}=c_{iA}^{W}=0.5$, $\Lambda=m^*$, i=1,2,3

$\Lambda=m^*=1000$ GeV

Analysis : $e^+e^- \rightarrow e\nu W$

Acceptance cuts:

$p_T^e > 20\ GeV \quad \not{p}_T > 20\ GeV$

$|\eta_e| < 2.5$

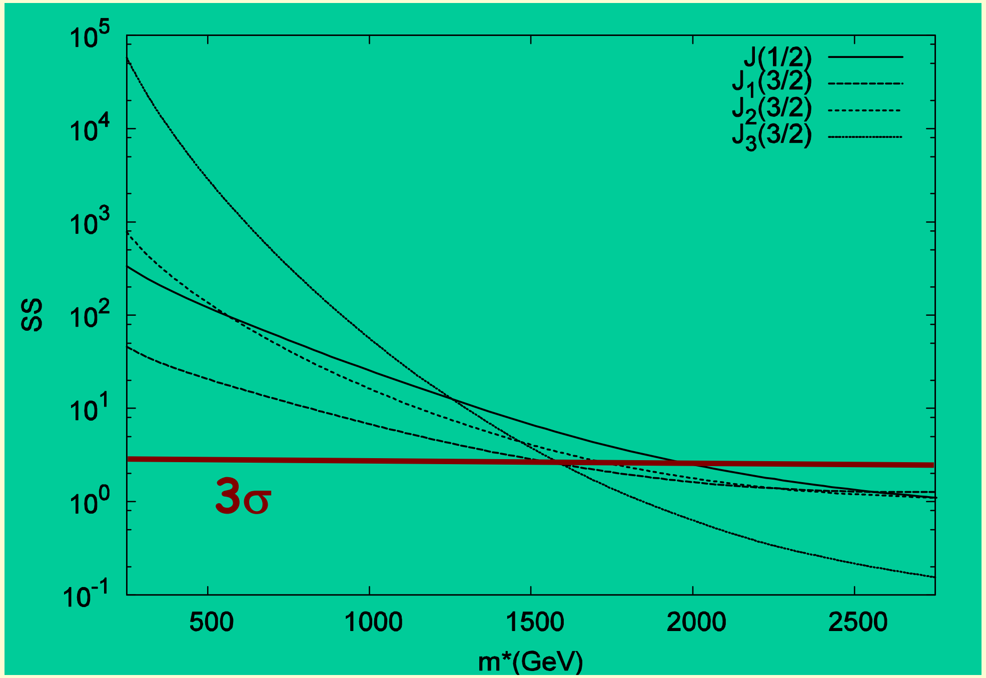
+

Further cuts: $W \rightarrow jj$

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

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

σ_B=0.463 pb for $e^+e^- \rightarrow e\nu W$



m*(GeV)	σ_B (pb)
250	1.96×10^{-2}
500	1.69×10^{-2}
1000	1.00×10^{-2}
1500	6.32×10^{-3}
2000	1.83×10^{-1}
2500	1.83×10^{-1}
2750	1.83×10^{-1}

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

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

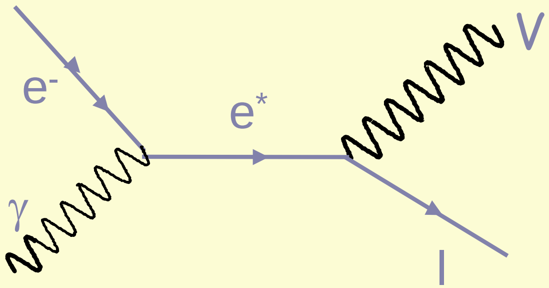
SS>3 ➔ m ~ 1.5 TeV for* $c_V^W = c_A^W = 0.05$

4. Simulation and Analysis in eγ collisions

In eγ mode;

→Resonant production of e* is possible

→More precise measurements can be done

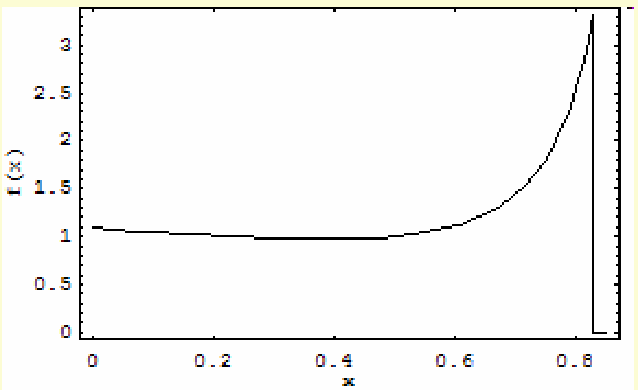


$$f(x)=N[1-x+\frac{1}{1+x}(1-4x/x_0)(1-x/x_0(1-x))],\quad 0<x<x_{max}$$

$$f(x)=0,\quad x>x_{max}$$

$$x_0=4.82,\quad x_{max}=\frac{x_0}{1+x_0}\approx 0.83,\quad N=1/1.84$$

$$\sigma_{2\to 2}=\int_{X_{min}}^{0.83} dx\, f_\gamma(x)\,\sigma(xs)$$

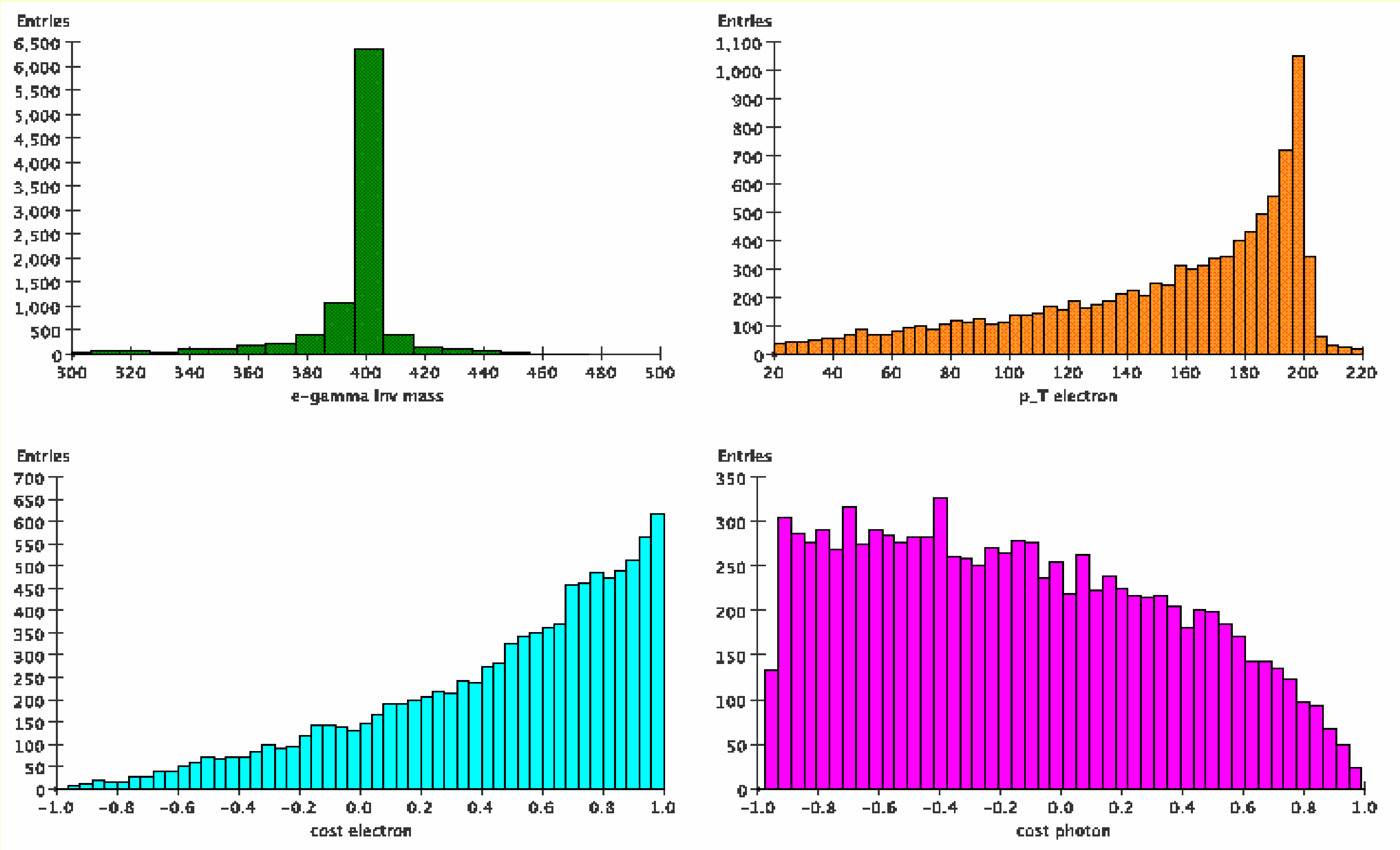


✓Compton photon distr. is implemented in Pythia.

✓Analysis stdhep file with JAS3

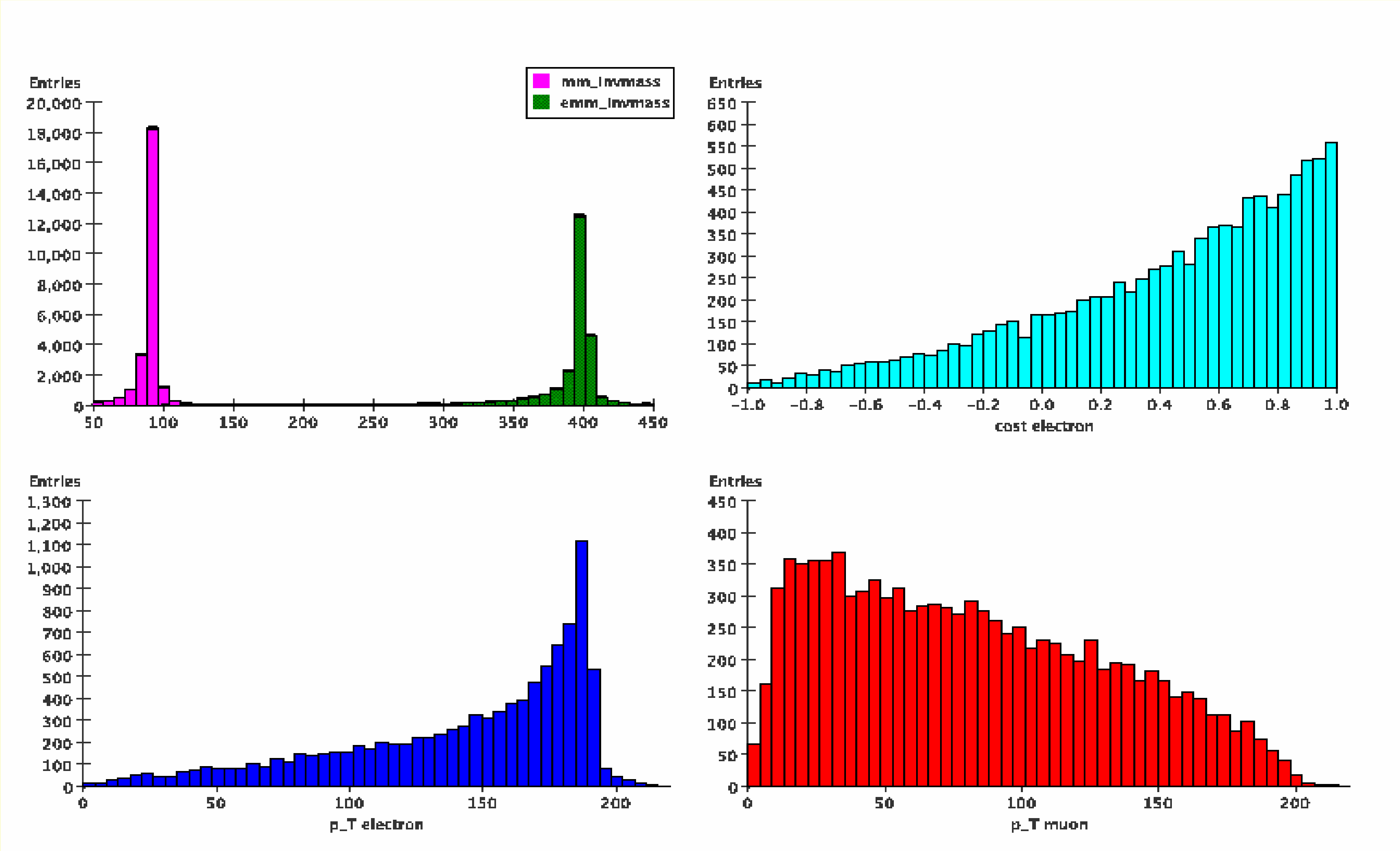
✓Detector (CLIC000) simulation with lcsim.org frame eγ →e*(1/2)→eγ,

m*=400 GeV, √s= 500 GeV, Λ=m*, f=f'=1 , Nev=10000(gen.)

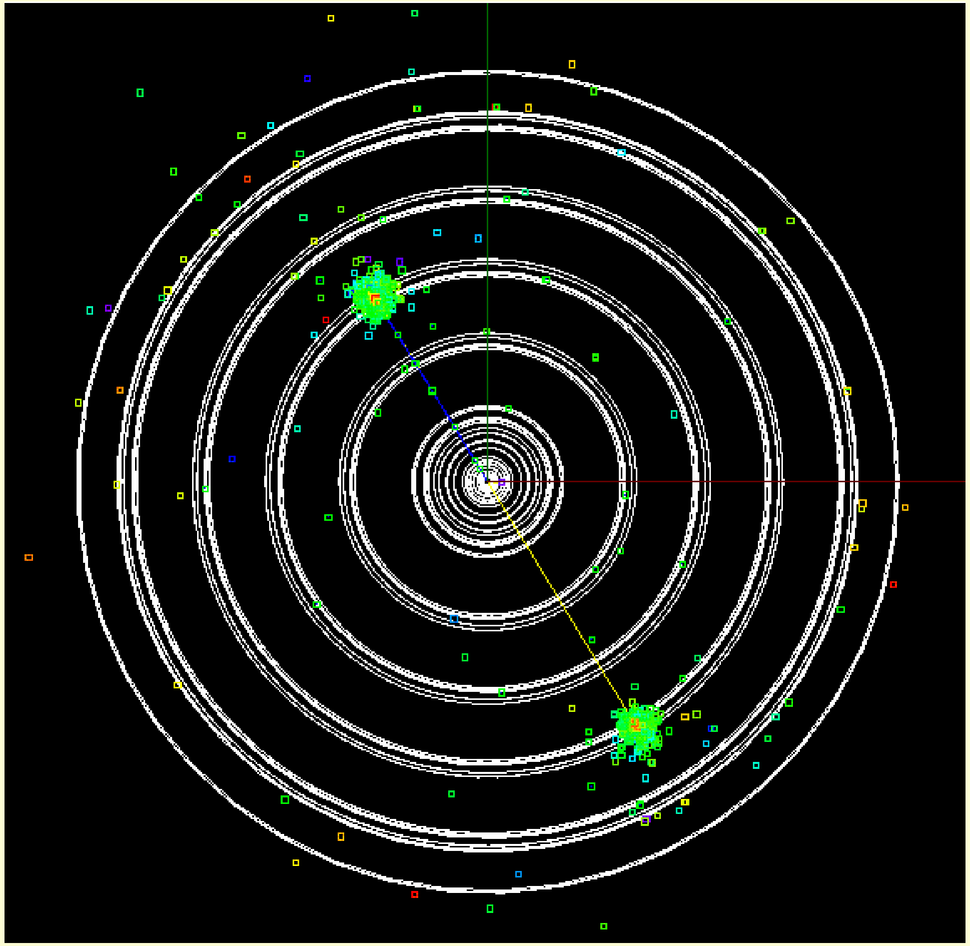


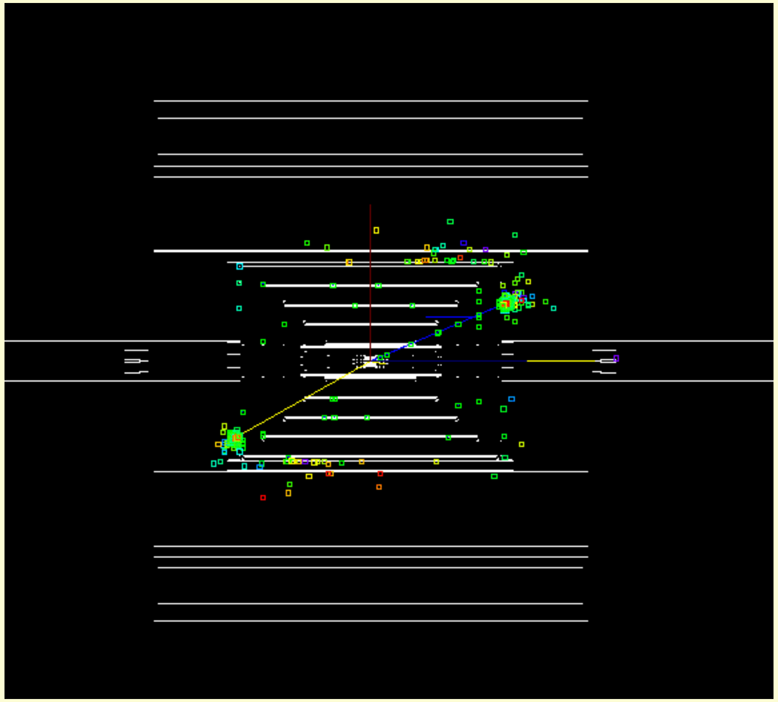
eγ →e*(1/2)→eZ →eμμ,

m*=400 GeV, √s= 500 GeV, Λ=m*, f=f'=1, Nev=10000

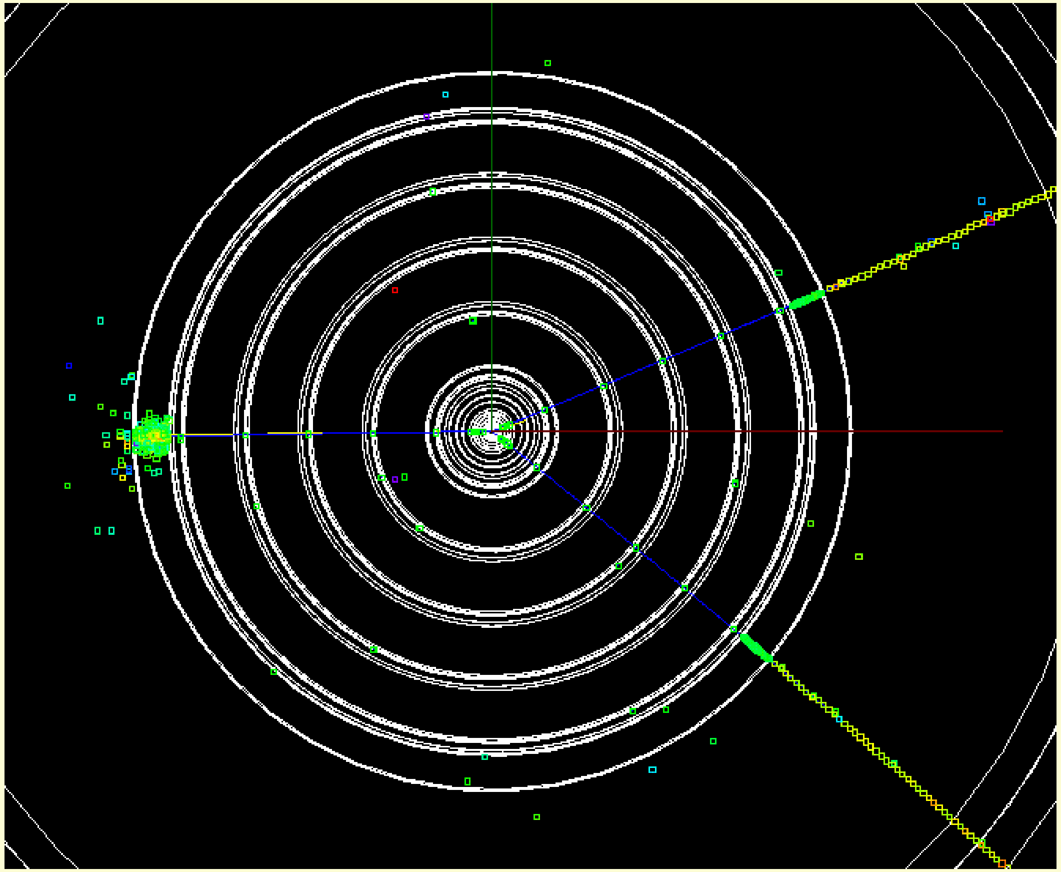


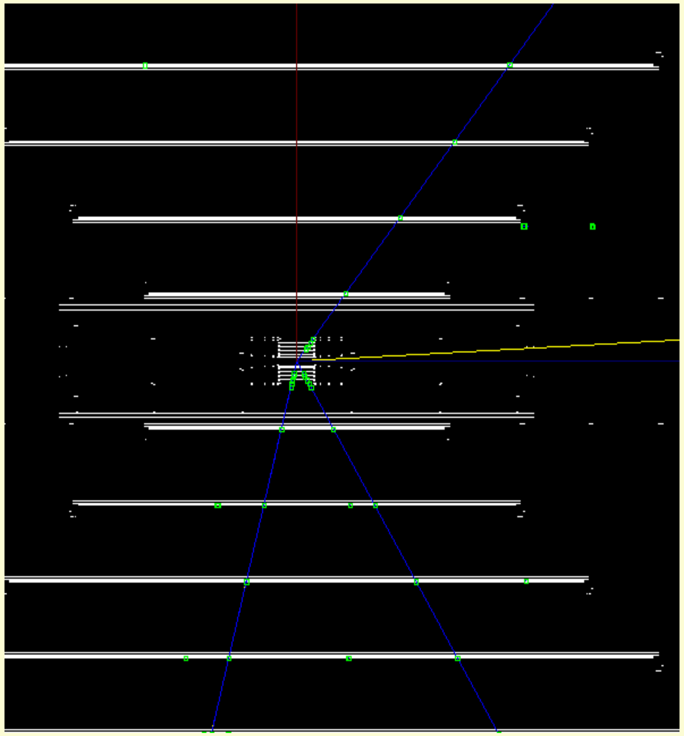
eγ →e*(1/2)→eγ event as seen at CLIC000



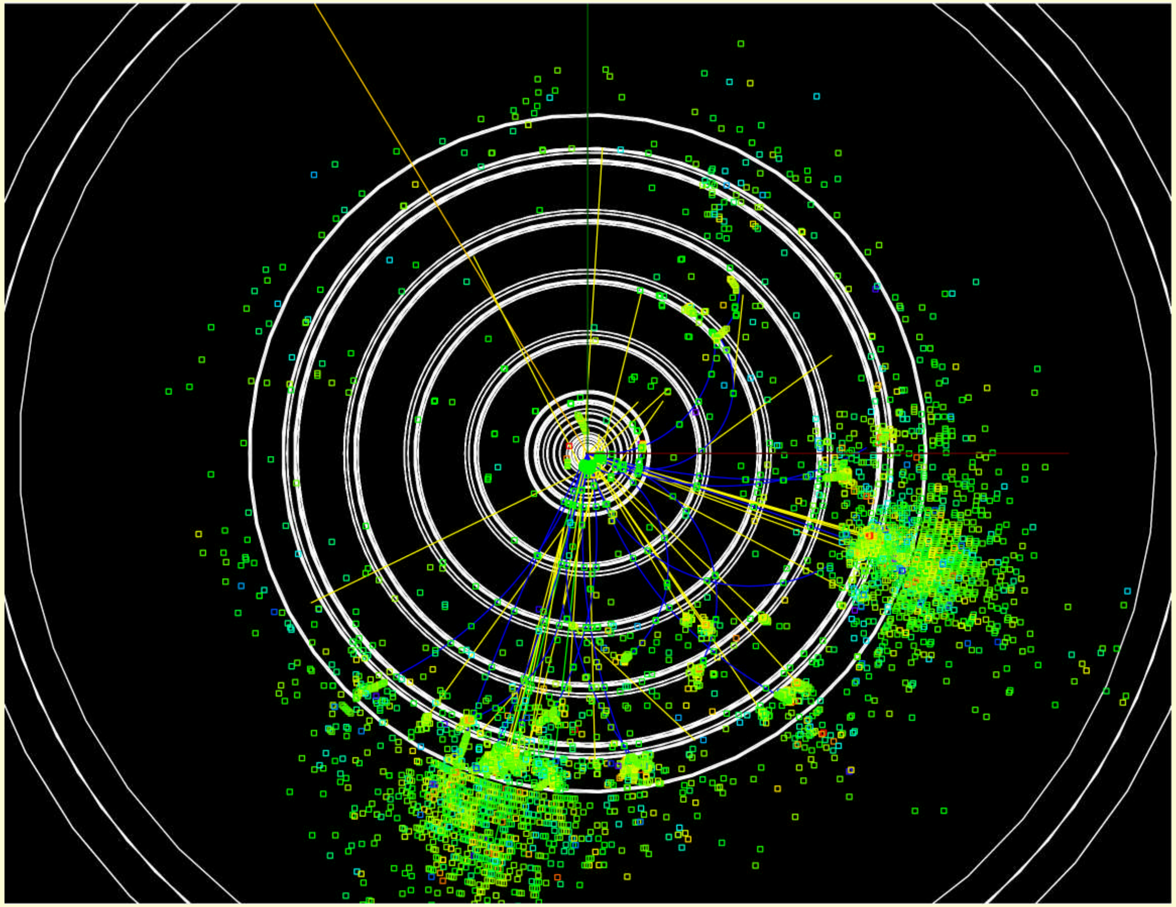


eγ →e* (1/2)→eZ →eμμ event as seen at CLIC000





eγ → e* (1/2) → νW → νjj event as seen at CLIC000



Conclusion

- in e^+e^- **collisions**, at $\sqrt{s}=3$ TeV and $L_{int}=400\ fb^{-1}$ CLIC can probe
- →excited electron $m^* < 1.8$ TeV for J(1/2) with f=f′=1 and for $J_3(3/2)$ with $c_V=c_A=0.05$
- →excited neutrino in the mass range $m^* \approx 1.3-1.5$ TeV for J(1/2) with f=-f′=1 and for three J(3/2) with $c_V=c_A=0.05$.
- Excited spin-3/2 and spin-1/2 electrons can be seperated by normalized angular distributions.
- Excited spin-3/2 and spin-1/2 neutrinos can be seperated by MET distributions.
- If there were no hint of e* in the e^+e^- mode, **$e\gamma$ mode** of CLIC would constitute an "e* factory" .