Wrong vertex displacement
due to a Lee-Wick resonance at LHC

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(and C. Schat, L. Da Rold and A. Szynkman)

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[to be sent to arXiv in next weeks]

Outline

- **The Lee-Wick Standard Model (LWSM, 2008)**
- **Wrong vertex displacement due to a LW resonance at LHC**
  - What is a Wrong vertex displacement?
  - The 'longest lived' Lee-Wick particle
  - Montecarlo simulation for LHC
- **Conclusions**

The Lee-Wick Standard Model

B.Grinstein, D.O'Conell and M.Wise
Phys.Rev. D77, 025012 (2008)

The LWSM philosophy in a toy scalar model

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In the LWSM:

For every particle we add a higher derivative term

$$\mathcal{L}_{hd} = \tfrac{1}{2}\partial_\mu\hat{\phi}\partial^\mu\hat{\phi} - \tfrac{1}{2M^2}(\partial^2\hat{\phi})^2 - \tfrac{1}{2}m^2\hat{\phi}^2 - \tfrac{1}{4!}g\hat{\phi}^4 \qquad (M \gg m)$$

$$\hat{D}(p) = \frac{i}{p^2 - p^4/M^2 - m^2} \longrightarrow \text{two poles: } p^2 = m^2,\, M^2$$

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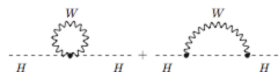$$D_\phi(p) = \frac{i}{p^2 - m^2} \qquad \tilde{D}_{\tilde{\phi}}(p) = \frac{-i}{p^2 - M^2}$$

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In the LWSM for every SM-field there is a LW-partner

LWSM solves the hierarchy problem

SM hierarchy problem: Higgs mass quadraticaly sensitive to cutoff
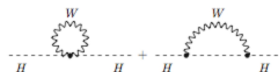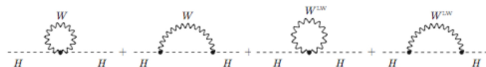
1-loop corrections from W:

 $\longrightarrow \delta m_h^2 \sim \frac{g^2}{16\pi^2}\Lambda^2 \sim (10^{18}\ GeV)^2$ if $\Lambda \sim M_{PL}$

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Resolution in the LWSM:

 $\longrightarrow \delta m_h^2 \sim \frac{g^2 M_{LW}^2}{16\pi^2} \log\left(\frac{\Lambda^2}{M_{LW}^2}\right)$

Lee-Wick issue: acausality

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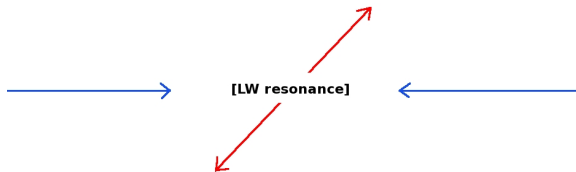
Decay products would show up before colision

- No paradox if *only* average position is studied (Lee & Wick)
- *Marty Mcfly* paradox: there might be natural constrains which we ignore (Coleman)

References

(Very) Incomplete list of references

- The LWSM: PRD77:025012,2008 (Grinstein, O'Conell & Wise)
- Causality as an emergent macroscopic phenomenon: PRD79:105019(2009) (Grinstein, O'Conell & Wise)
- Phenomenology: PRD77:015012,2008 (Krauss, Underwood & Zwicky); PLB658,p235,2008 (Dulaney & Wise); PRD77:085002,2008 (Spinosa, Grinstein, O'Conell & Wise); etc etc.
- Direct tests for LHC: JHEP 0801:042,2008 (Rizzo) and this.
- Much others in cosmology, formal theory, dark matter, etc.etc.
- EW Contstrains: JHEP 0804:026,2008 (we); PLB668:221,2008 (Carone & Lebed); PRD79:035016,2009 (Underwood & Zwicky)

  - $M_{\tilde{B},\tilde{W}} \geq 3 - 4$ *Tev*
  - $M_{LW-quarks} \geq 3$ *TeV*
  - No constrain on Lee-Wick leptons other than direct search ($M_{\tilde{\ell}} > 100$ *GeV*)

Wrong vertex displacement

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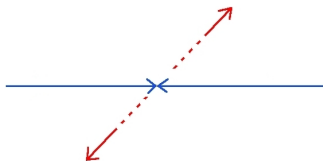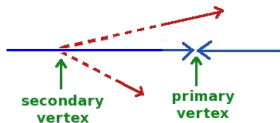- Wrong Vertex Displacements at LHC!

Wrong vertex displacement

Center of mass (à la Coleman):

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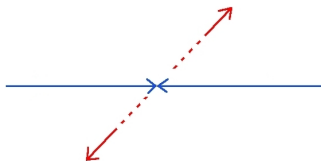Center of mass (à la Coleman):

Boosted:

Wrong vertex displacement
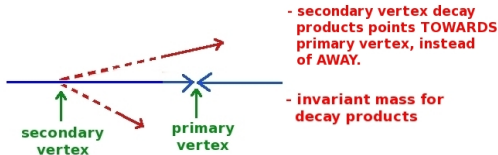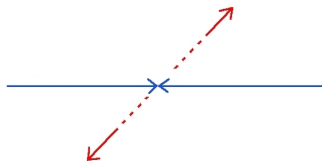
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secondary
vertex

primary
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Wrong vertex displacement

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- secondary vertex decay products points TOWARDS primary vertex, instead of AWAY.

- invariant mass for decay products

secondary vertex

primary vertex
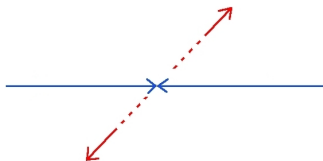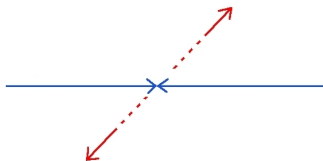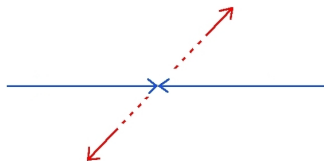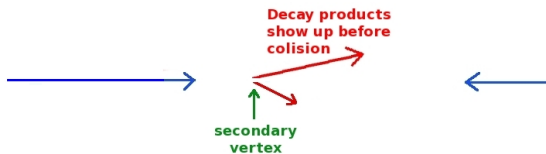
Wrong vertex displacement

Center of mass (à la Coleman):

Boosted:

Formal S-matrix theory predicts the
wrong vertex displacement
extrapolating the OUT states.
See Grinstein, O'Conell & Wise
PRD79:105019 (2009)
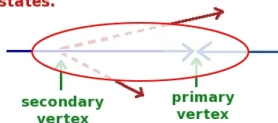
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- We seek for the LW-particle with smallest Γ
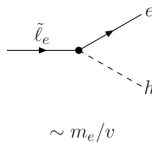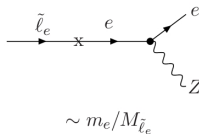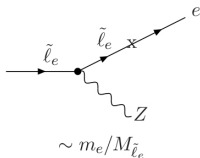- Mass and interactions are both important

The "longest lived" Lee-Wick particle

- We seek for the LW-particle with smallest Γ
- Mass and interactions are both important
- Light leptons LW-partners are favourites (assume MFV):

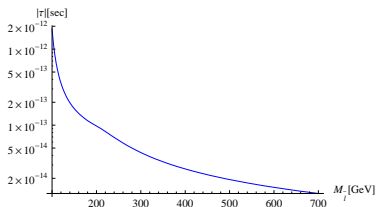$$\tilde{e} \text{ and } \begin{pmatrix} \tilde{\ell}_\nu \\ \tilde{\ell}_e \end{pmatrix}$$
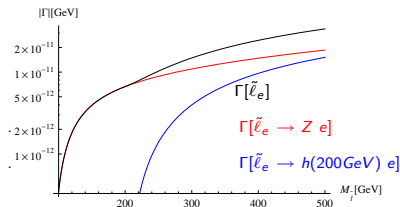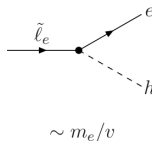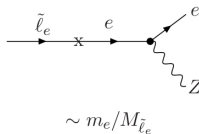
The "longest lived" Lee-Wick particle

Main decays for $\tilde{\ell}_e$ within MFV

$\sim m_e/M_{\tilde{\ell}_e}$ $\sim m_e/M_{\tilde{\ell}_e}$ $\sim m_e/v$

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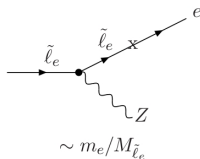
Looking for a wrong displaced vertex

- $M_{\tilde{\ell}_e} \sim 400\,GeV \longrightarrow |\tau| \sim 10^{-14} sec \longrightarrow \Delta x \sim 10^{-3}\,mm$

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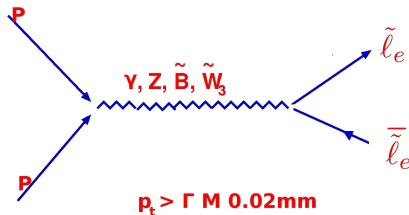- We need to create $\tilde{\ell}_e$ boosted with $\gamma \sim 10$

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- We need to create $\tilde{\ell}_e$ boosted with $\gamma \sim 10$
- However.....$10 \times 400\, GeV \sim 4\, TeV$.....is it possible at LHC? (7 TeV)

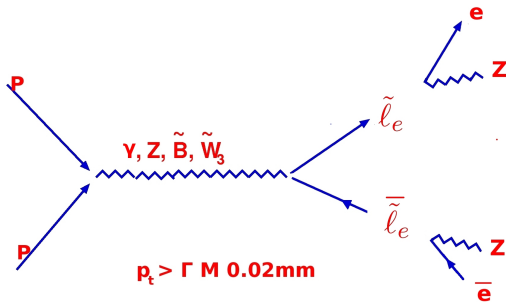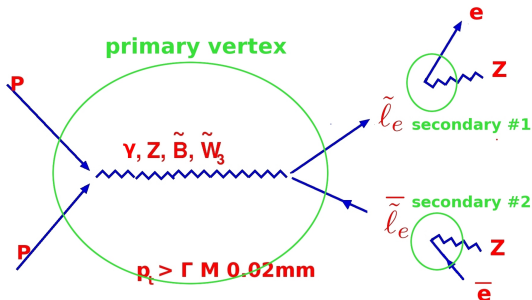## The process

Feynman Diagram

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R^3-**space**
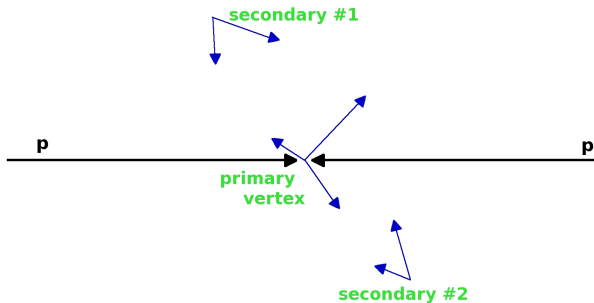
secondary #1

p   p

primary
vertex

secondary #2

The process
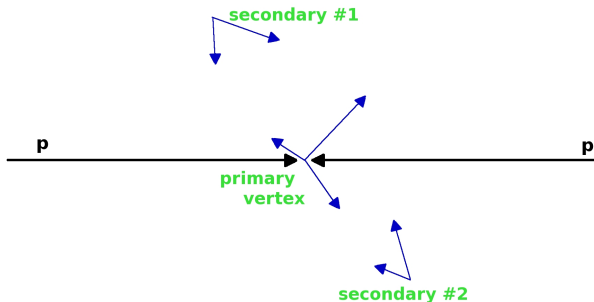
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1. look for two events of eZ (reconstructed) coming from displaced vertex.

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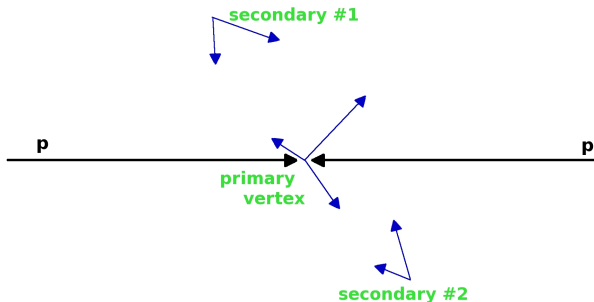
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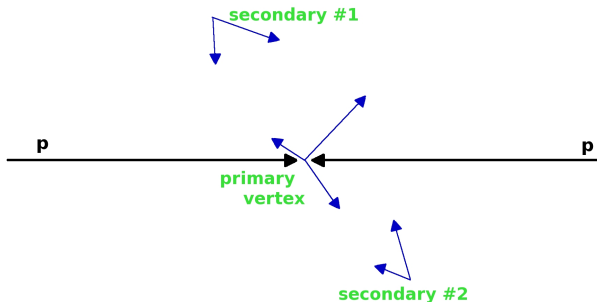2. compute the invariant mass

The process

R^3-**space**

1. look for two events of eZ (reconstructed) coming from displaced vertex.
2. compute the invariant mass
3. check if the events are *wrong displaced vertex*

LHC simulation

Process $pp \longrightarrow (\gamma, Z, \tilde{W}_3, \tilde{B}) \longrightarrow \tilde{\ell}_e \bar{\tilde{\ell}}_e$ simulated through MadGraph/MadEvent for $M_{\tilde{\ell}_e} = 400\,GeV$
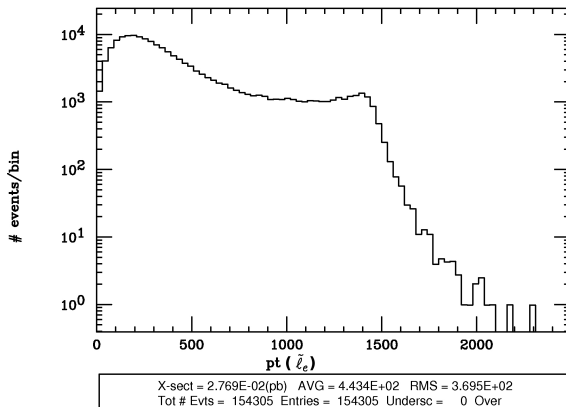
X-sect = 2.769E-02(pb) AVG = 4.434E+02 RMS = 3.695E+02
Tot # Evts = 154305 Entries = 154305 Undersc =   0 Over

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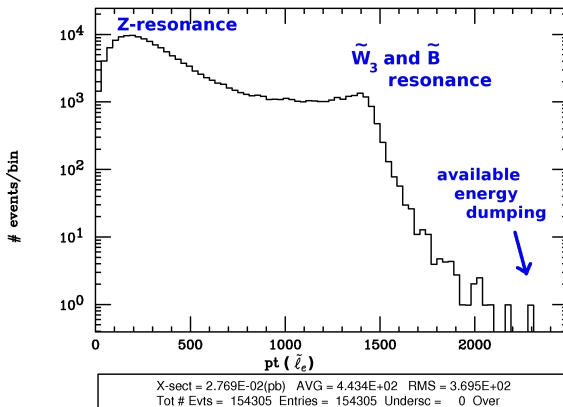
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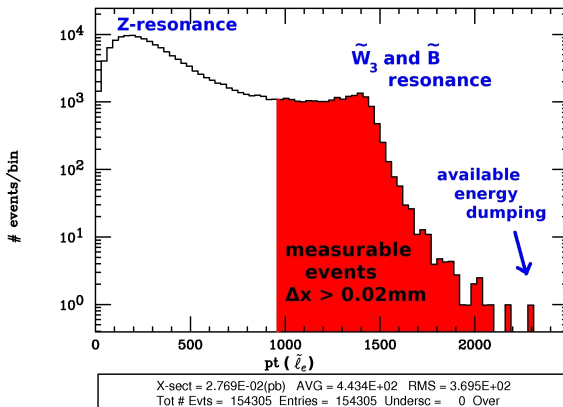
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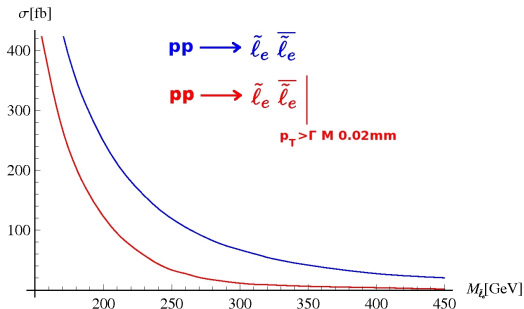
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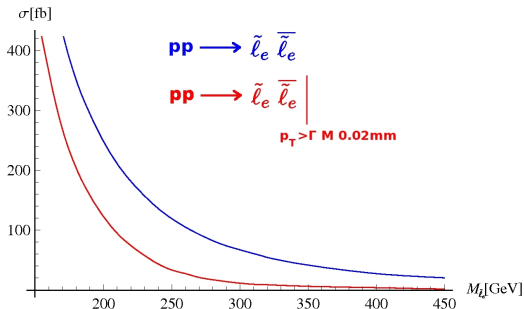
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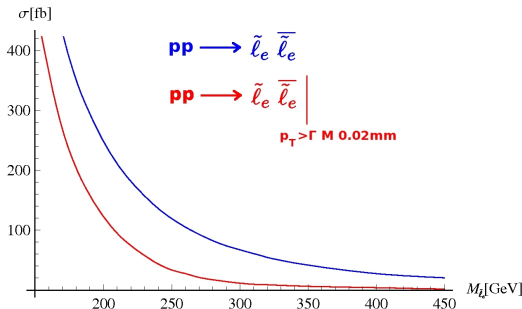
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- Background analysis is missing for a real final estimation.
  (Notice: signal comes with a high p_T electron, for instance $M_{\tilde{\ell}} = 400\,GeV \Longrightarrow p_T(e) \sim 1\,TeV$)

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- Wrong vertex displacement is a general signal for any acausal theory.

Backup-slides

LWSM basic particle content and interaction

LW-gauge bosons are massive and mix:

$$
\begin{aligned}
\mathcal{L}_{2g} &= \frac{-1}{2} Tr \left(B^{\mu\nu} B_{\mu\nu} - \tilde{B}^{\mu\nu} \tilde{B}_{\mu\nu} + W^{\mu\nu} W_{\mu\nu} - \tilde{W}^{\mu\nu} \tilde{W}_{\mu\nu} \right) \\
&\quad - \frac{1}{2} \left(M_1^2 \tilde{B}^\mu \tilde{B}_\mu + M_2^2 \tilde{W}_a^\mu \tilde{W}_\mu^a \right) + \frac{g_2^2 v^2}{8} \left(W_\mu^{1,2} + \tilde{W}_\mu^{1,2} \right)^2 \\
&\quad + \frac{v^2}{8} \left(g_1 B_\mu + g_1 \tilde{B}_\mu + g_2 W_\mu^3 + g_2 \tilde{W}_\mu^3 \right)^2
\end{aligned}
$$

Fermions are vector like and mix:

$$(1)$$

$$
\begin{aligned}
\mathcal{L}_{2\psi} &= \sum_{\psi=q_L,\,u_R,\,d_R} \bar{\psi} i \ \slashed{\partial} \psi - \sum_{\tilde{\psi}=\tilde{q},\,\tilde{u},\,\tilde{d}} \tilde{\bar{\psi}} (i \ \slashed{\partial} - M_\psi) \tilde{\psi} \\
&\quad - m_u (\bar{u}_R - \tilde{\bar{u}}_R)(q_L^u - \tilde{q}_L^u) - m_d (\bar{d}_R - \tilde{\bar{d}}_R)(q_L^d - \tilde{q}_L^d) + h.c.
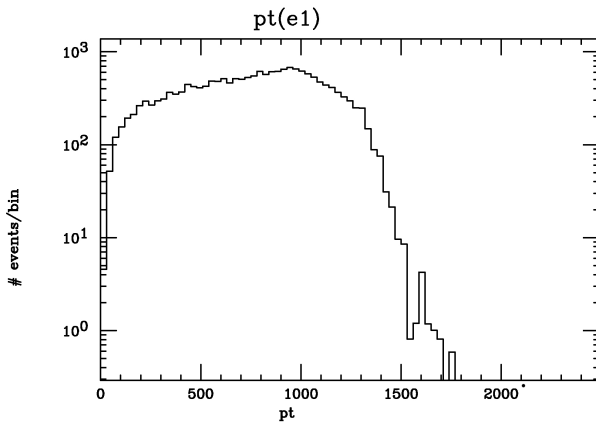\end{aligned}
$$

Interaction between gauge bosons and fermions:

$$(2)$$

$$
\begin{aligned}
\mathcal{L}_{int} &= - \sum_{\psi=q_L, u_R, d_R} g_1 \bar{\psi} (\slashed{B} + \slashed{\tilde{B}}) \psi + g_2 \bar{\psi} (\slashed{W} + \slashed{\tilde{W}}) \psi \\
&\quad + \sum_{\tilde{\psi}=\tilde{q}, \tilde{u}, \tilde{d}} g_1 \tilde{\bar{\psi}} (\slashed{B} + \slashed{\tilde{B}}) \tilde{\psi} + g_2 \tilde{\bar{\psi}} (\slashed{W} + \slashed{\tilde{W}}) \tilde{\psi}
\end{aligned}
$$

$$(3)$$

p_T distribution for final SM electrons in signal

p_T distribution for final SM electrons for events which generate wrong vertex displacements $> 0.02mm$ ($M_{\tilde{\ell}_e} = 400\,GeV$).

$$pp \to \tilde{\ell}_e + \bar{\tilde{\ell}}_e \to ejj + \bar{e}jj$$