CLOCKWORK FLAVOR

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based on R. Alonso, J. Martin Camalich, A. Carmona, B. Dillon, J. Kamenik, JZ, 1705.nnnnn

Portoroz, Apr 20, 2017

THE AIM

- clockwork: a generic way to generate hierarchies
- can one solve the SM flavor puzzle with clockwork?

CLOCKWORK

Giudice, McCullough, 1610.07962
Kaplan , Rattazzi, 1511.01827

- how to get a large hierarchy between v_{EW} and M_{Pl}
- the clockwork way

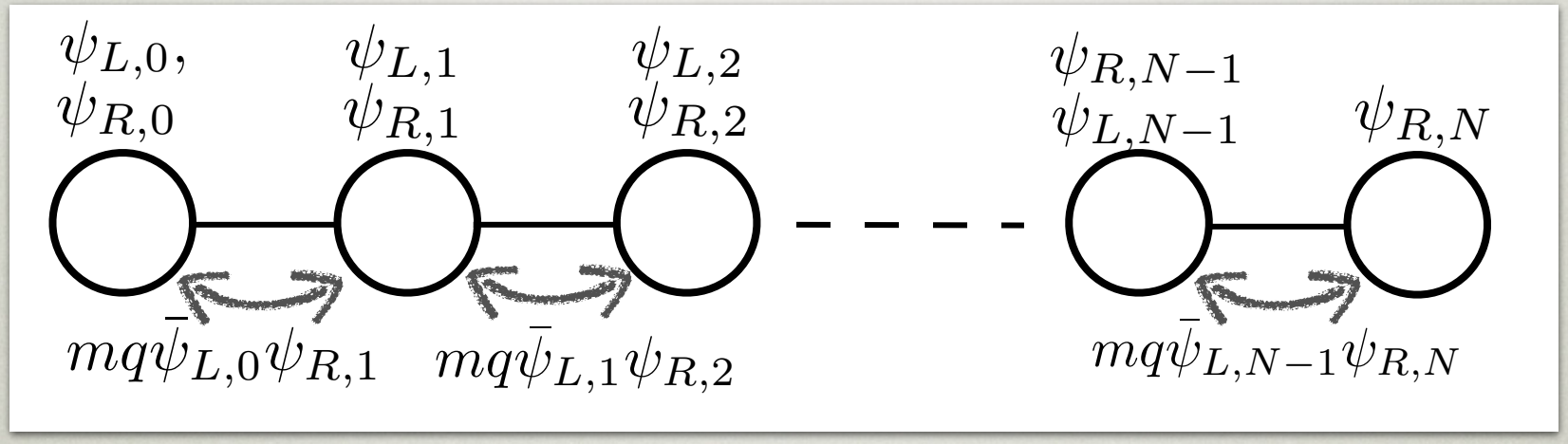
$$v_{\rm EW} = \underbrace{\frac{1}{q} \cdot \frac{1}{q} \cdots \frac{1}{q}}_{\rm N\ times} \times M_{\rm Pl}$$

- can get large hierarchies for $q \gtrsim 1$, $N \gg 1$

CLOCKWORKED FERMION

Giudice, McCullough, 1610.07962
R. Alonso, J. Martin Camalich, A. Carmona, B. Dillon, J. Kamenik, JZ, 1705.nnnnn

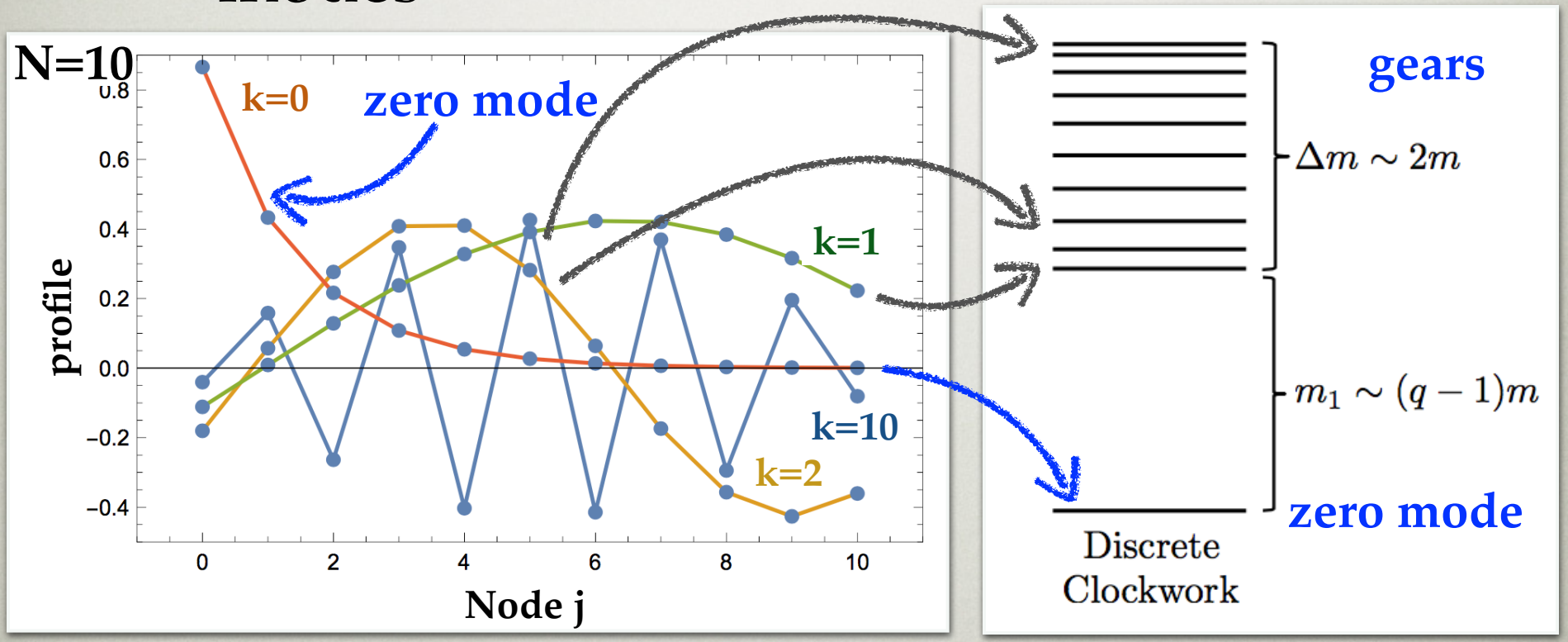
- a chain of vectorlike fermions + one chiral node



$$\sum_{j=0}^{N-1} \bar{\psi}_{L,j} \not{D} \psi_{L,j} + \sum_{j=0}^{N} \bar{\psi}_{R,j} \not{D} \psi_{R,j} - m \sum_{j=0}^{N-1} \left(\bar{\psi}_{L,j} \psi_{R,j} - q \bar{\psi}_{L,j} \psi_{R,j+1} \right) + \text{h.c.}$$

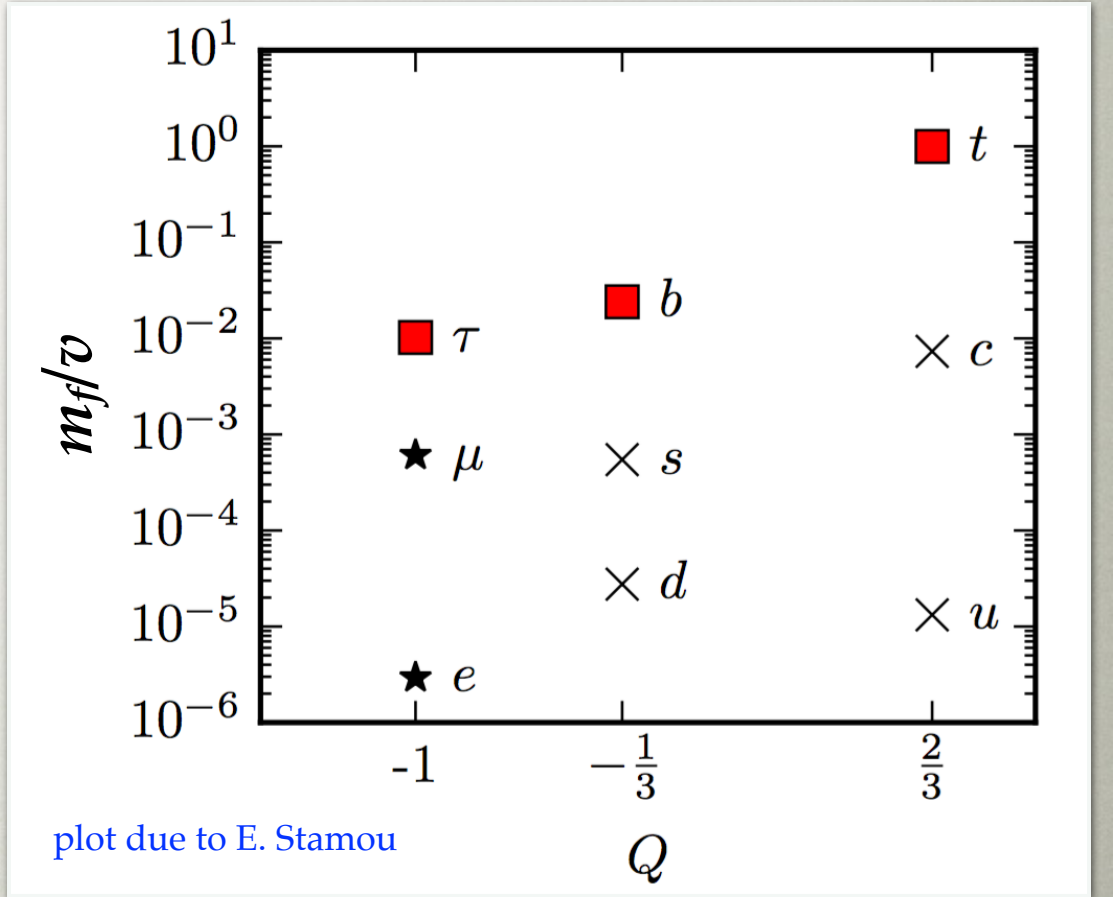
CLOCKWORKED FERMION

- gives one zero mode + N massive modes



STANDARD MODEL FLAVOR PUZZLE

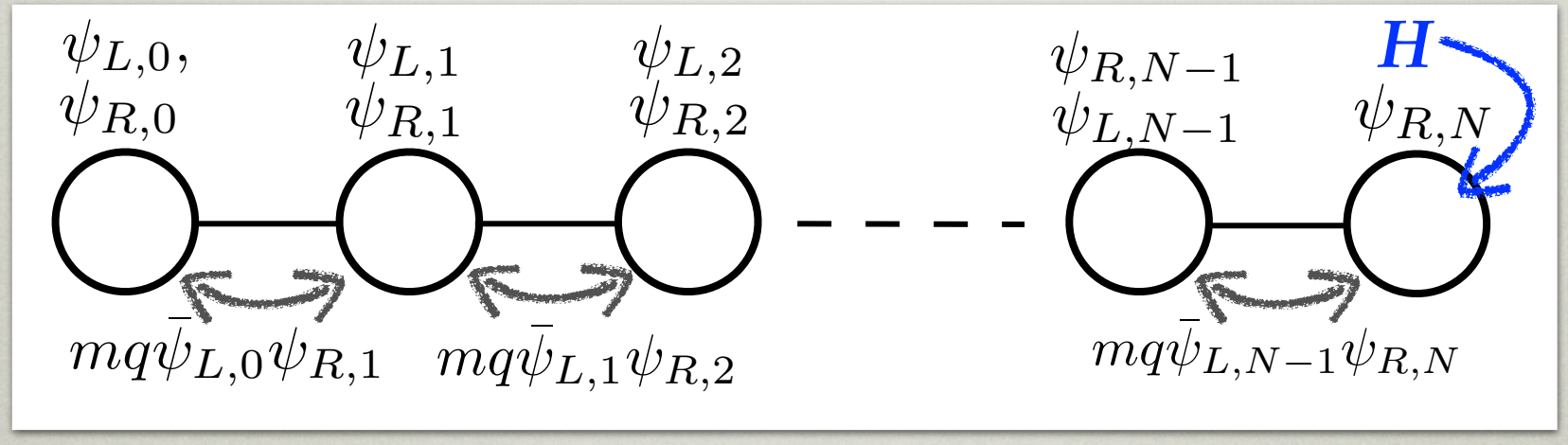
- how do we address the SM flavor puzzle using clockwork?



plot due to E. Stamou

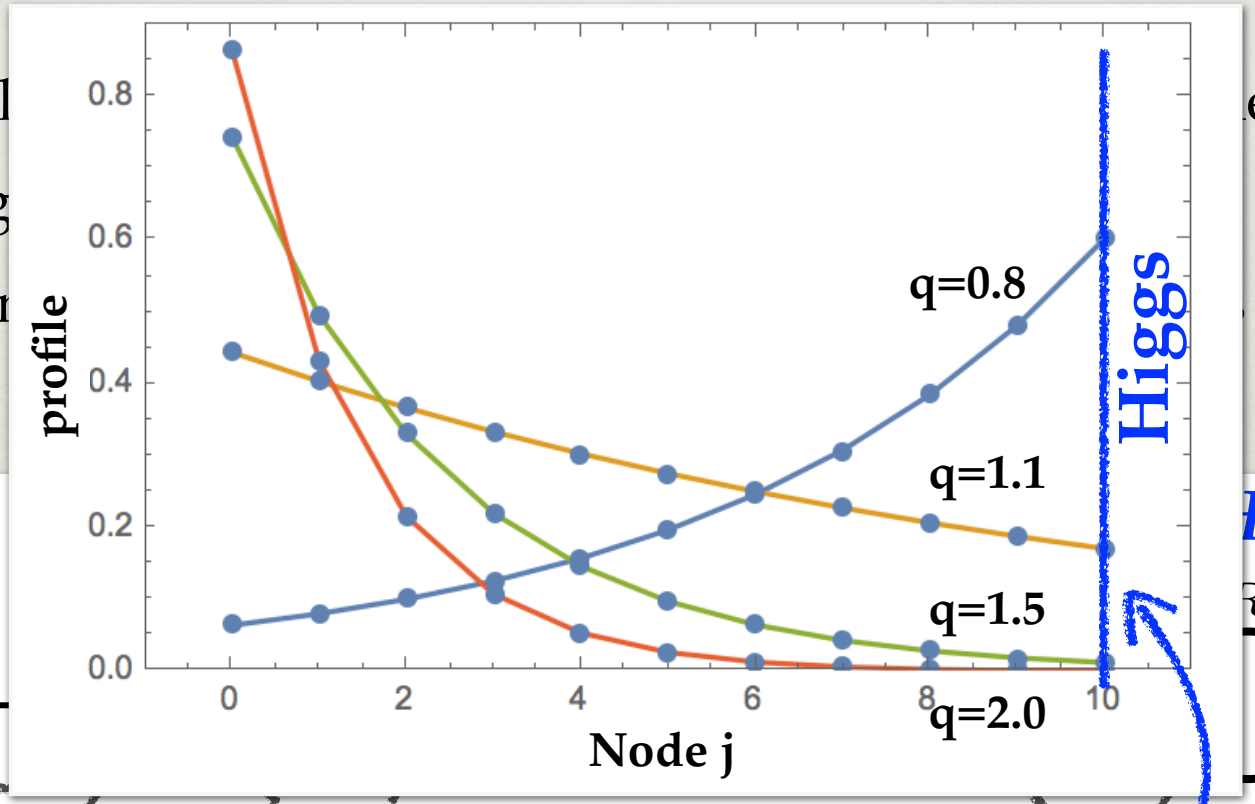
CLOCKWORK FLAVOR

- the flavor hierarchy from zero mode overlaps with the Higgs
- Higgs on the N-th node
  - similar to RS with Higgs on the IR brane, fermions in the bulk



CLOCKWORK FLAVOR

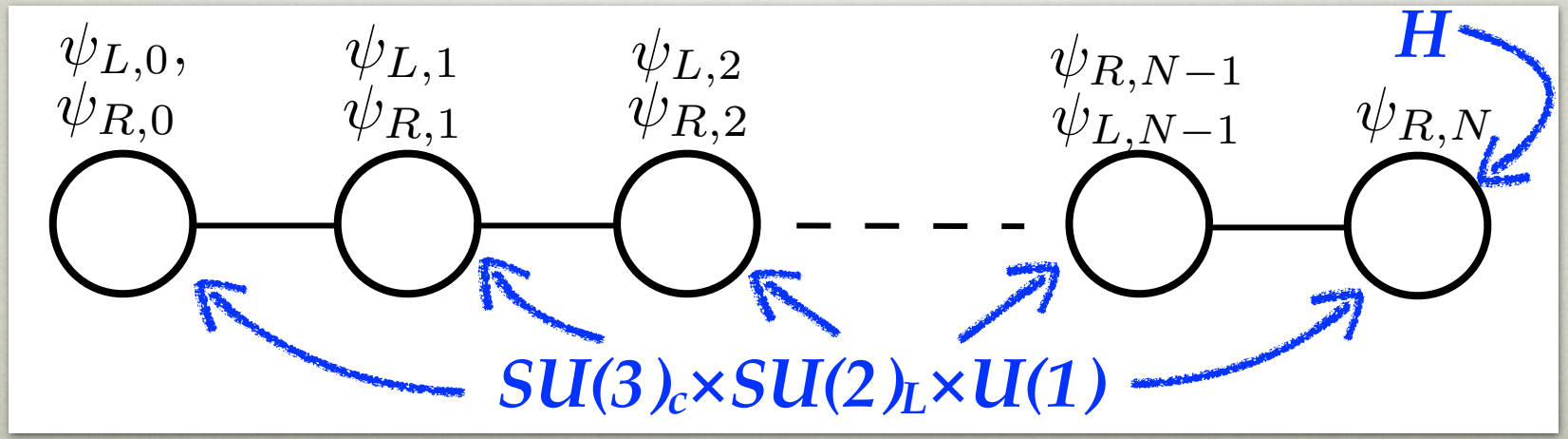
- the fl … e Higgs
- Higg …
  - sin … in the bulk



$$f_\psi^0 \equiv V_{N0}^R = \begin{cases} \sim 1/q^N, & q \gg 1; \\ \frac{1}{\sqrt{1+N}}, & q = 1. \end{cases}$$

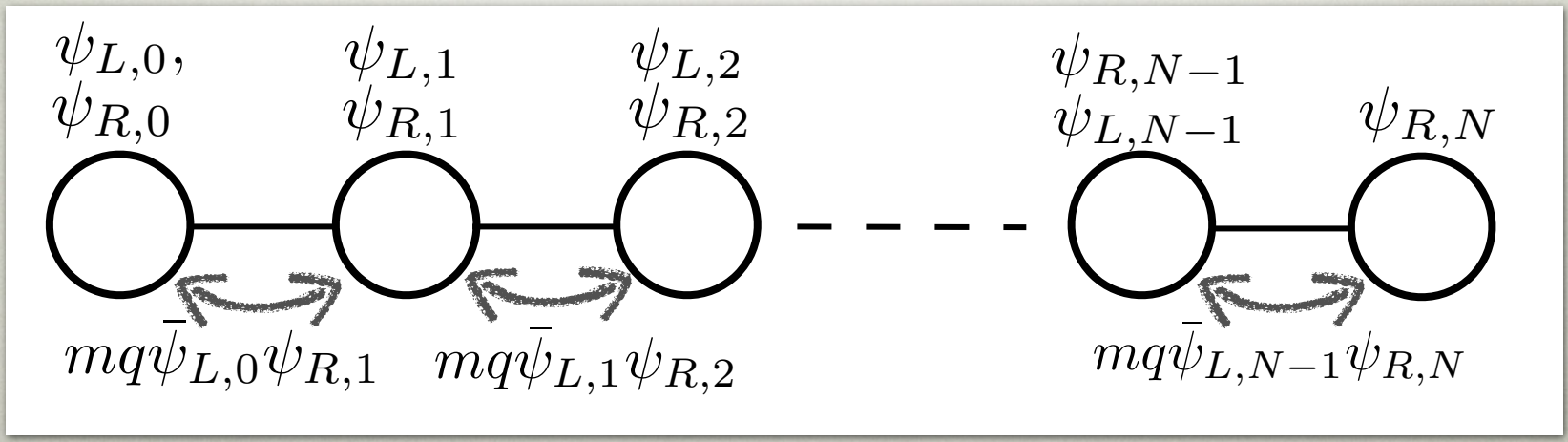
COMPARISON WITH RS

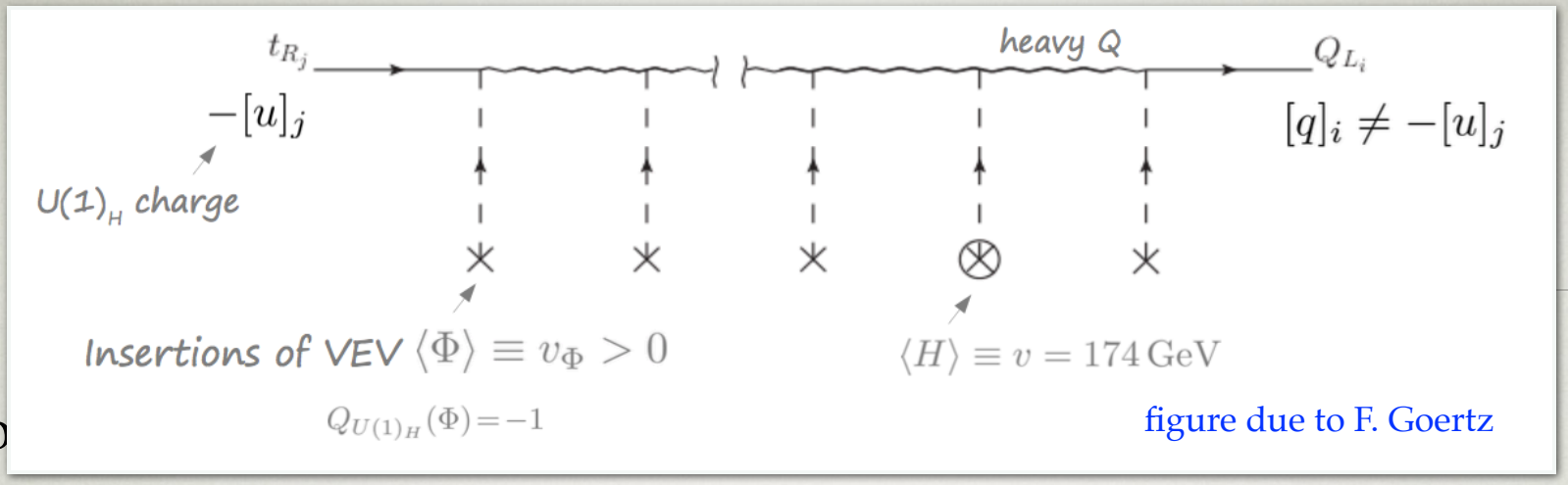
- unlike RS cannot solve the hierarchy problem and SM flavor puzzle at the same time
  - in continuum: hierarchy problem solved by large volume not due to warping
- proposed clockwork flavor does not have continuum limit
  - all nodes gauged by the SM flavor group
- clockwork gears are more closely spaced than KK modes
  - no gears for gauge bosons



COMPARISON WITH FROGGATT-NIELSEN

- clockwork resembles FN models
  - identifying $\lambda \sim 1/q$
- instead of different chain lengths in FN, in clockwork flavor different q
  - also q assumed to be non-dynamical
  - in FN $\lambda = \langle \Phi \rangle / M$





- clo
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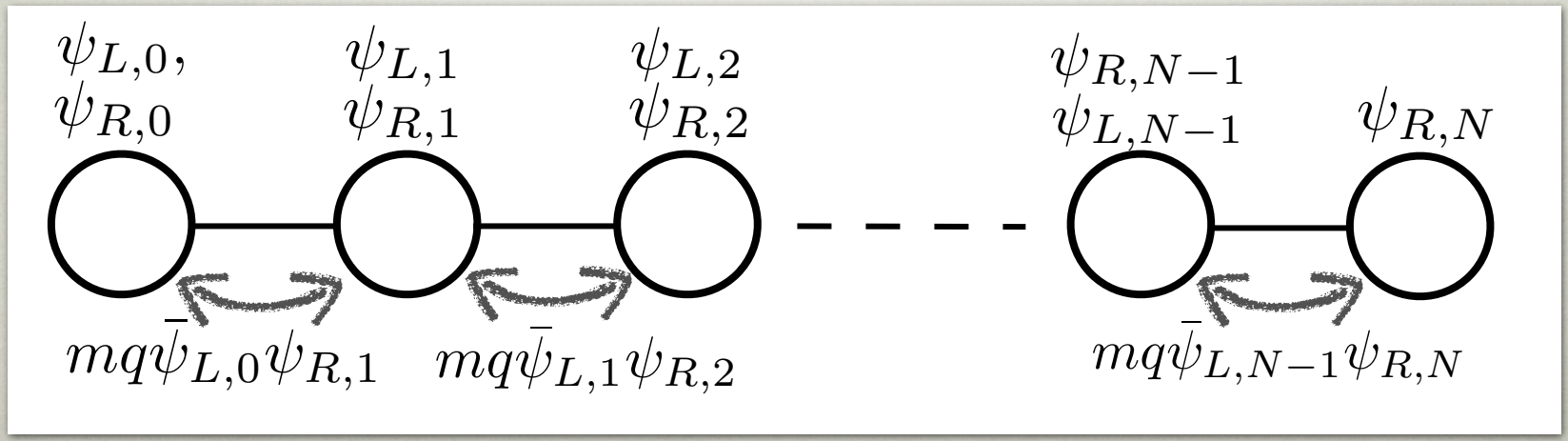
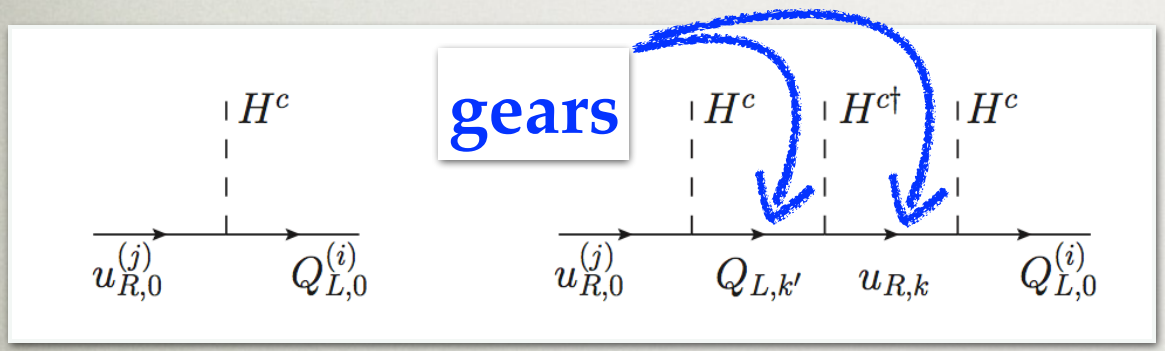


FLAVOR CONSTRAINTS

- corrections due to mixing of zero mode with the gears
- for instance the flavor violating Higgs Yukawas



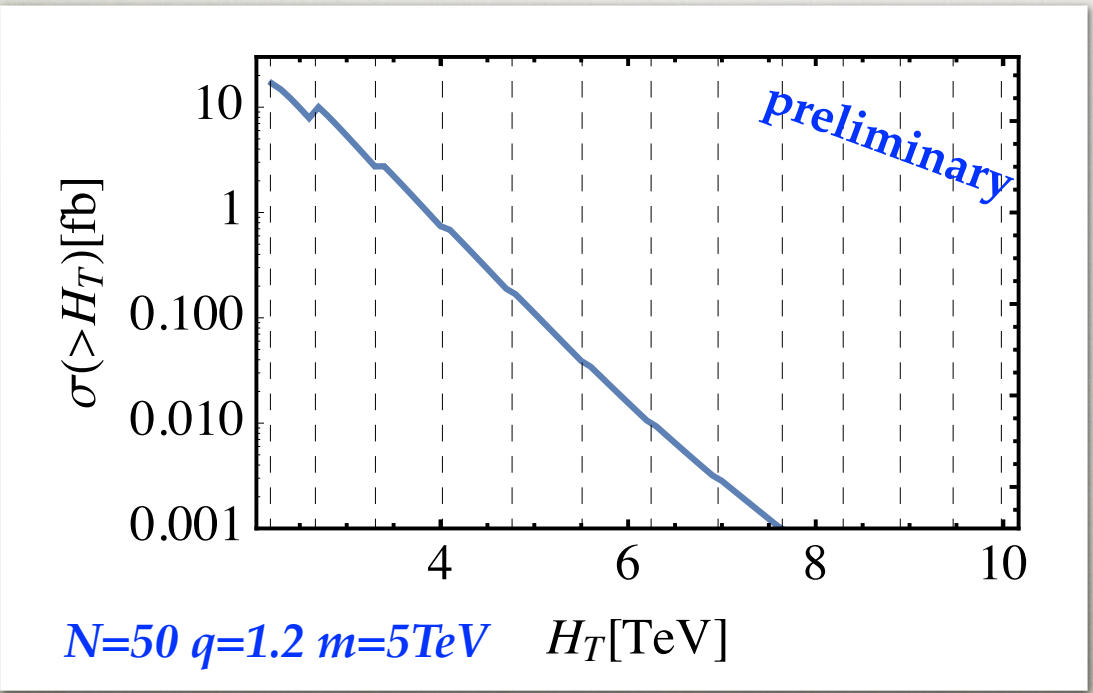
$$(y_u^{\rm Higgs})_{ij} \simeq (Y_u^{\rm SM})_{ij} + f^0_{Q(i)} f^0_{u(j)} \frac{v^2}{m^2} Y^2_{U,D},$$

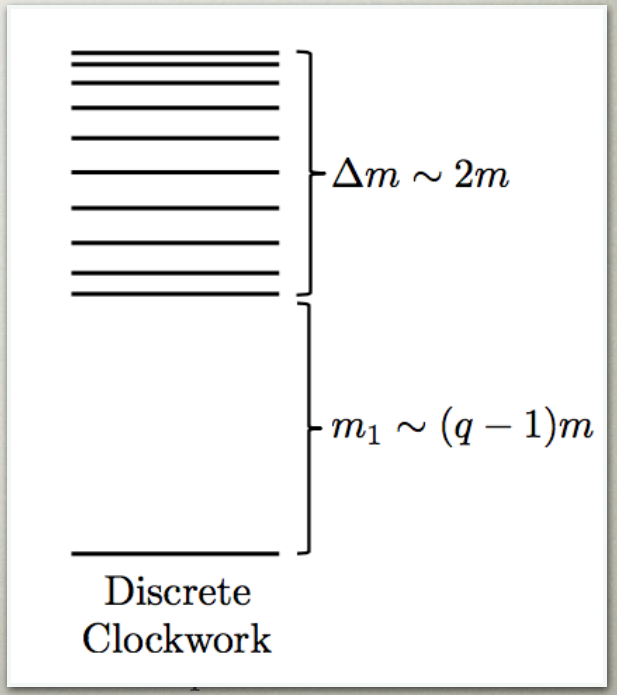
$$(y_d^{\rm Higgs})_{ij} \simeq (Y_d^{\rm SM})_{ij} + f^0_{Q(i)} f^0_{d(j)} \frac{v^2}{m^2} Y^2_{U,D},$$

- also FV Z couplings, corrections to W
  - corrections suppressed by zero mode overlaps
- lead to relatively mild flavor constraints from meson mixing
  - gives $m \gtrsim O(1TeV)$ from Z, H exchanges
  - note: no gluon, Z gears

SEARCHES AT THE LHC

- clockwork flavor gears can be at ~1 TeV
- how to search for them at the LHC?
  - gears Q_{gear} pair produced
  - decay $Q_{gear} \rightarrow Q'_{gear} + H, Z, W; q + H, Z, W$
- can lead to modulation in xsec





CONCLUSIONS

- discussed a model of flavor based on clockwork
- effects in flavor physics under control for ~1TeV gears
- gears can be searched for in high p_T processes

BACKUP SLIDES