Theory Perspectives

Goran Senjanovic
ICTP

talks by Altarelli, Djouadi, Fayet, Nesti,...

Message:

- NO theory that predicts new physics at LHC energies
- Connected with NO problem in the SM

  (except neutrino mass -but that can be higher energy)

Thank you !

Well, I mean...

SM: in spite of great success No Higgs yet

↓

LHC is a Higgs machine

One could wait to see if it exists...

- instead, one imagines it is there
- then ask: why $m_H \ll M_{GUT}(M_{Pl})$?

Funny question, since:

- GUT never seen
- M_{Pl} not a physical scale

$$M_{Pl} \equiv 1/\sqrt{G_N} \simeq 10^{19} GeV$$

Maybe $G_N = \frac{g^2}{M_F^2}$ $(g = M_F/M_{Pl})$

$g \ll 1 \Longrightarrow M_F \ll M_{Pl}$ Glashow, '85

Realization: Large Extra Dimensions (LED)

$M_{Pl}^2 = M_F^{2+n} R^n \rightsquigarrow g = (M_F R)^{-n/2}$

$g \ll 1 \Longleftarrow R \gg M_F^{-1} \sim (TeV)^{-1}$

Arkani-Hamed, Dimopoulos, Dvali (ADD), '98

Large number of species

\# of states : $N = (M_F\, R)^n = \left(\frac{M_{Pl}}{M_F}\right)^2$

the tower: $\frac{1}{R},\ \frac{2}{R},\ \frac{3}{R},\ \ldots \frac{N}{R} \simeq M_F$

$M_F \simeq TeV \quad \Longrightarrow \quad N \simeq 10^{32}$

Dvali, '07 - '10

all that matters : large # of species $\qquad M_F \simeq \frac{M_{Pl}}{\sqrt{N}}$

$M_F \rightarrow$ the scale of strong gravity

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Black holes @ LHC ?

$$M_F \simeq TeV$$

ADD, '98

no hierarchy problem

Physics of black holes not well understood:

how to distinguish from particles ?

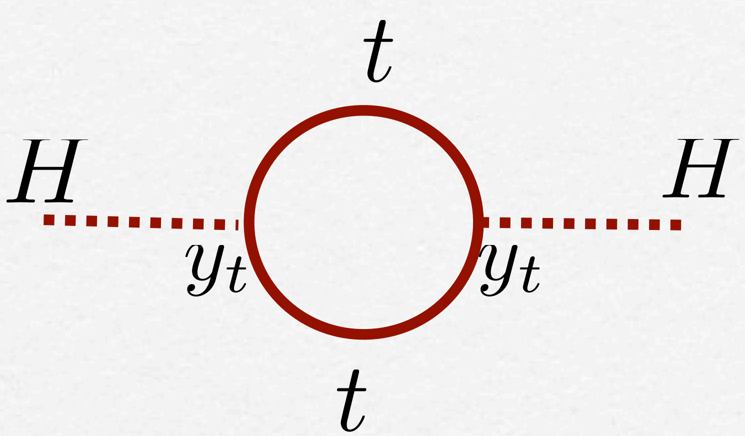
Dvali, Gomez, Mukhanov '10

but the question was:

Why is Higgs light?

Hierarchy problem: SUSY@LHC ?

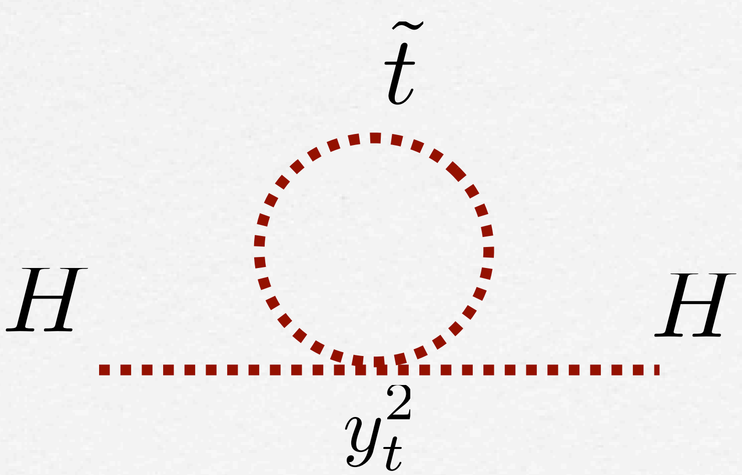
talk by Fayet



$$\delta m_H^2 = \frac{y_t^2}{16\pi^2}\left(\Lambda^2 + m_t^2\right)$$

$+$

M_{GUT}, M_{Pl}



$$\delta m_H^2 = -\frac{y_t^2}{16\pi^2}\left(\Lambda^2 + m_{\tilde{t}}^2\right)$$

$$\delta m_H^2 = -\frac{y_t^2}{16\pi^2}\left(m_{\tilde{t}}^2 - m_t^2\right)$$

Maiani; Fayet; Witten '79

large cutoff: $\Lambda \geq 10^{16}\, GeV$

low energy supersymmetry
tailor fit for GUT

$m_{\tilde{t}} \leq TeV$

$$\delta m_H^2 = -\frac{y_t^2}{16\pi^2}\left(m_{\tilde{t}}^2 - m_t^2\right)$$

small

$\delta m_H^2 < 0 \implies$ Higgs mechanism for $y_t \simeq 1$

Alvarez-Gaume, Polchinski, Wise, '82

Inoue, Kakuto, Komatsu, Takeshita, '82

Low energy supersymmetry

→ Unification of gauge couplings

Ibáñez , Ross, '80

Dimopoulos, Rabi, Wilczek, '80

Einhorn, Jones '81

Marciano, G.S., '81 *

* $sin^2\theta_W \simeq 0.23$

needed

$m_t \simeq 200 GeV$

$$\rho \simeq 1 + \frac{\alpha}{2\pi}\frac{m_t^2 - m_b^2}{M_W^2}$$

In order to boost $(sin^2\theta_W)_{exp} \simeq 0.21$

The light Higgs mass in the MSSM:

$$m_{h^0}^2 \leq M_Z^2 + \frac{3\alpha}{4\pi}\frac{m_t^4}{M_W^2}\left[ln\frac{m_{\tilde{t}}^2}{m_t^2} + 3\right]$$

$$m_{\tilde{t}} \simeq TeV \qquad \Rightarrow \qquad m_{h^0} \leq 135\, GeV$$

talk by Altarelli

Electro-weak baryogenesis:

needs a light stop, lighter than a top

neutrino mass:

R-parity violating couplings

dark matter:

or stable neutralino

long lived gravitino → new physics of neutrino mass

R-parity and neutrino mass

$$\ell\ell e^c + q\ell d^c + u^c d^c d^c$$

product small

neutrino mass

proton decay

all vanish (symmetry)

neutrino massless

add ν^c

$\ell h \nu^c$

symmetry?

Neutralino DM?

not so convincing in MSSM:

symmetry no guarantee for vanishing couplings

gravitino necessarily long lived, DM for $m_{3/2} \lesssim 10 - 100\, GeV$

Is this convincing ?

SUSY @ LHC ?

In Grand Unification there is fine tuning:

$$m_{h^0}^2(\text{tree}) = -m_0^2 + M_{GUT}^2 \simeq M_W^2$$

only loops are OK

If fine-tuning is a sin, SUSY helps you to sin only once - and at tree level

- There are solutions, but more like exercises in Group Theory
- Comment by Carl Sagan:

A. Ozpinaci '10

“...I can’t see a thing on the surface of Venus. Why not? Because it’s covered with a dense layer of clouds. Well, what are clouds made of? Water, of course. Therefore Venus must have an awful lot of water on it, therefore the surface must be wet. If the surface is wet there’s probably a swamp, if there’s a swamp there’s ferns, if there’s ferns... maybe there’s even dinosaurs.

Observation: you couldn’t see a thing.
Conclusion: Dinosaurs “

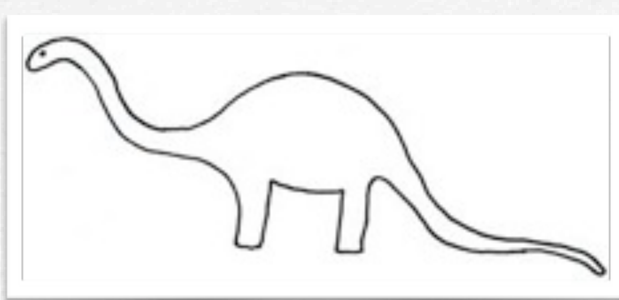
Is our motivation somewhat metaphysical?

We have seen nothing :

- No Higgs
- No new physics

...and yet we speculate on

- for every particle a superpartner
- the end of field theory at TeV: black holes and such at LHC



Well, there is new physics :

Neutrino oscillations

→ Neutrino masses and mixings

touches into the heart of an old and fundamental question: are neutrinos massive and `real' particles?

Majorana, '37

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Majorana, '37

last paper before his disappearance

The Majorana Program:

$$\nu_M = \nu_L + \nu_L^* \qquad \Leftrightarrow \qquad m_\nu^M (\nu_L \nu_L + h.c.)$$

$\Rightarrow \quad \Delta L = 2$ violation of Lepton number

neutrinoless double-beta decay $(0\nu 2\beta)$

Majorana, '37

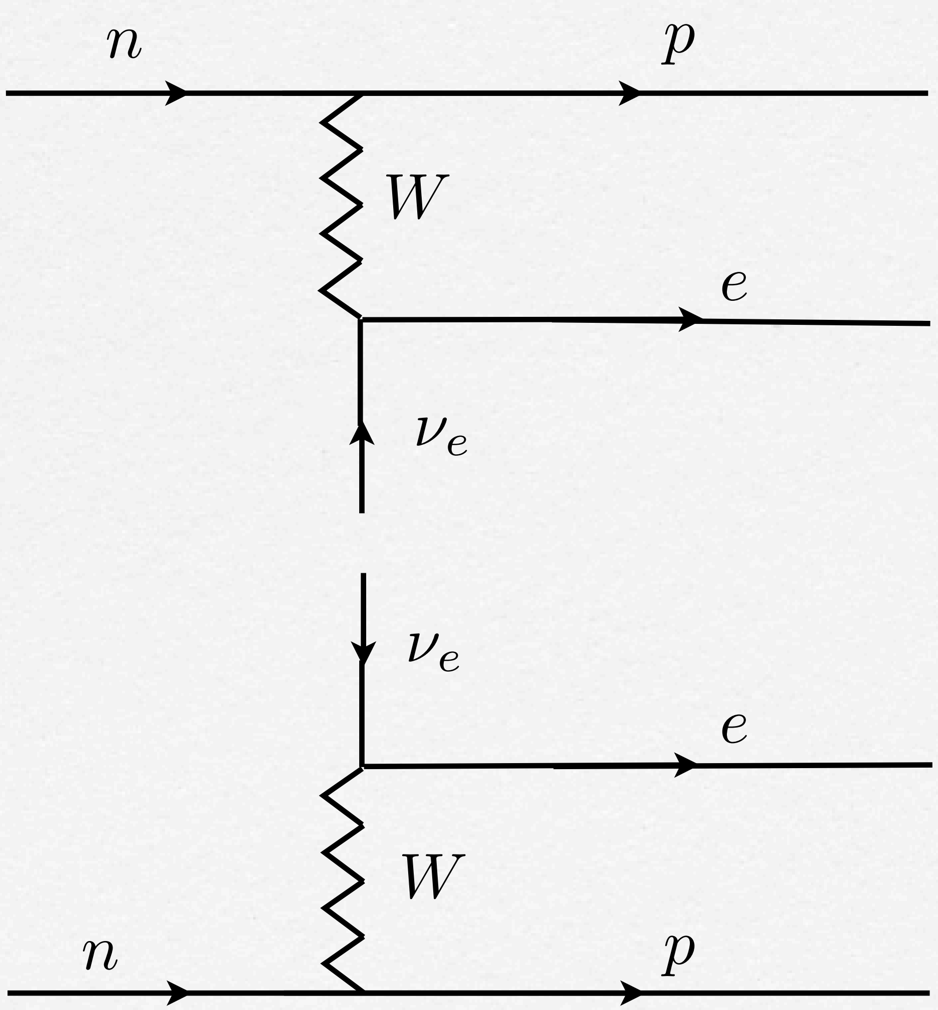
Racah, '37 - Furry, '38

Double-beta decay

$$^{76}Ge \not\to {}^{76}As + e + \bar{\nu}_e$$

$$^{76}Ge \to {}^{76}Se + e + e + \bar{\nu}_e + \bar{\nu}_e$$

Göppert-Mayer, '35



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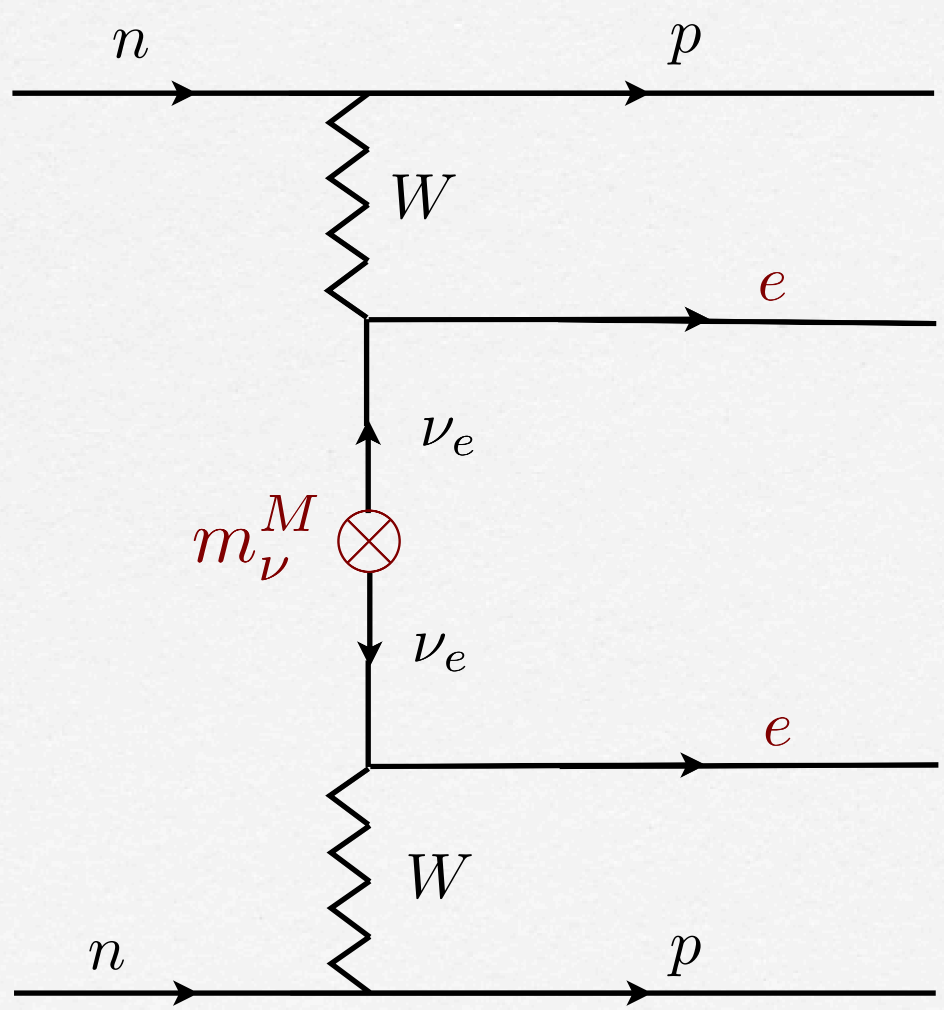

electrons created
out of "nothing"

$$^{76}Ge \rightarrow \, ^{76}Se + e + e$$

$$t_{1/2} \geq 10^{24}\, yr \implies m_\nu^M \lesssim 1\, eV$$

Why is this relevant for LHC ?

Majorana mass forbidden in the SM

Window to new physics

Conventional wisdom: add ν_R → see-saw

$$\begin{matrix} \nu_L \\ \nu_R \end{matrix} \begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} \underset{M_R \gg m_D}{\Rightarrow}$$

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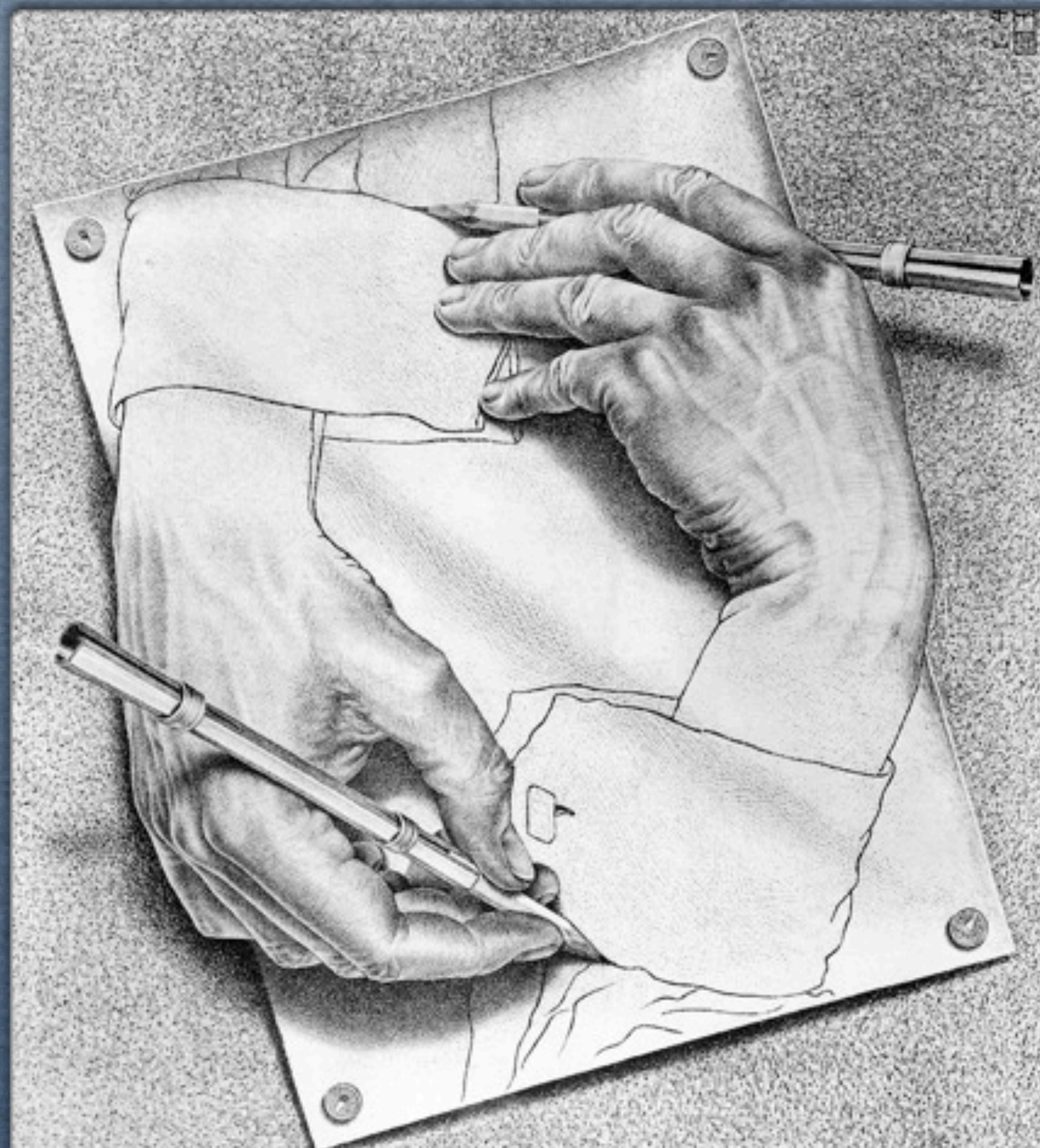
Majorana mass



Why ν_R ?

Left - Right symmetry

$SU(2)_L \times U(1) \times SU(2)_R$

Pati, Salam '74
Mohapatra, G.S. '75

talk by Nesti

$\nu_L \Longrightarrow \nu_R$

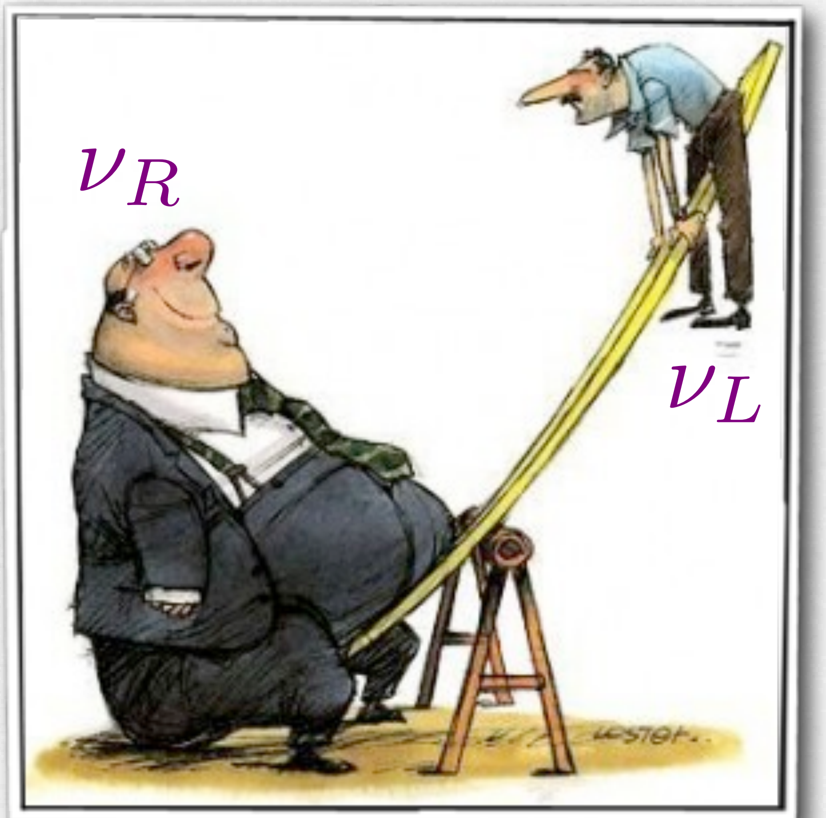
SM limit

$m_{\nu_R} \propto M_{W_R} \Longrightarrow m_\nu \propto m_D^2 / M_{W_R}$ $\longrightarrow 0$

$M_{W_R} \to \infty$

neutrino mass ⟷ Parity violation

Minkowski '77
Mohapatra, G.S. '79



$m_\nu \leq 1 eV$ ⟷ $M_{W_R} \geq 10^3\, GeV$

see-saw mechanism

Minimal model:

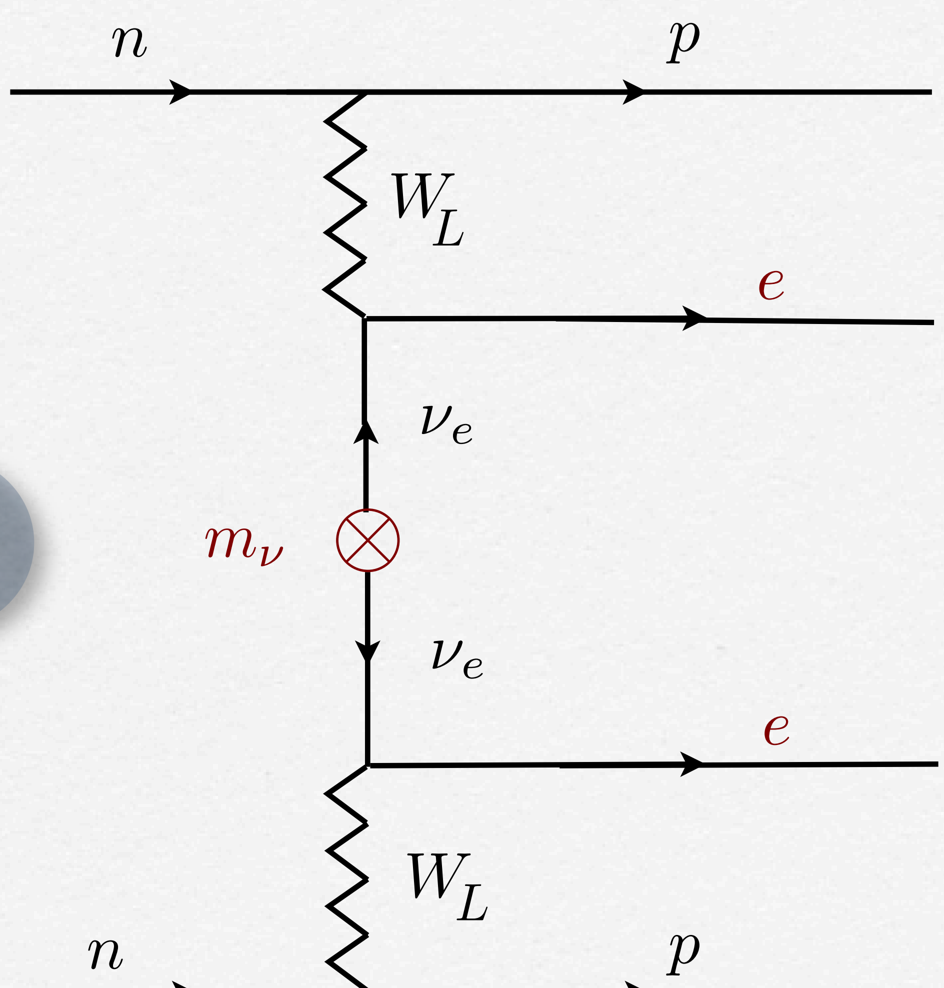
theoretical limit ➔ $M_{W_R} \geq 2500\, GeV$

Beall, Bander, Soni '81

Maiezza, Nemevsek, Nesti, G.S. '10

New source for $0\nu2\beta$

Mohapatra, GS '81



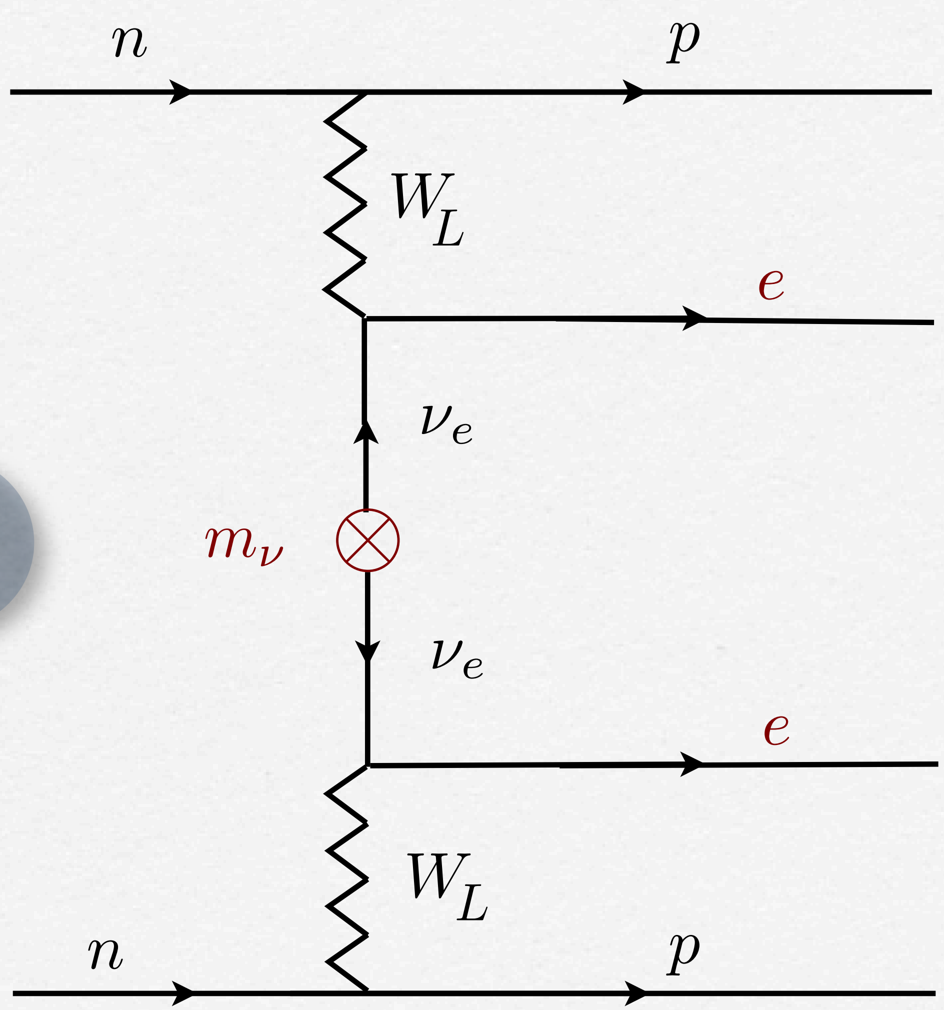
LL

$$LL \propto \frac{1}{M_{W_L}^4} \frac{m_\nu}{p^2}$$

$p \simeq 100 MeV$

New source for $0\nu 2\beta$

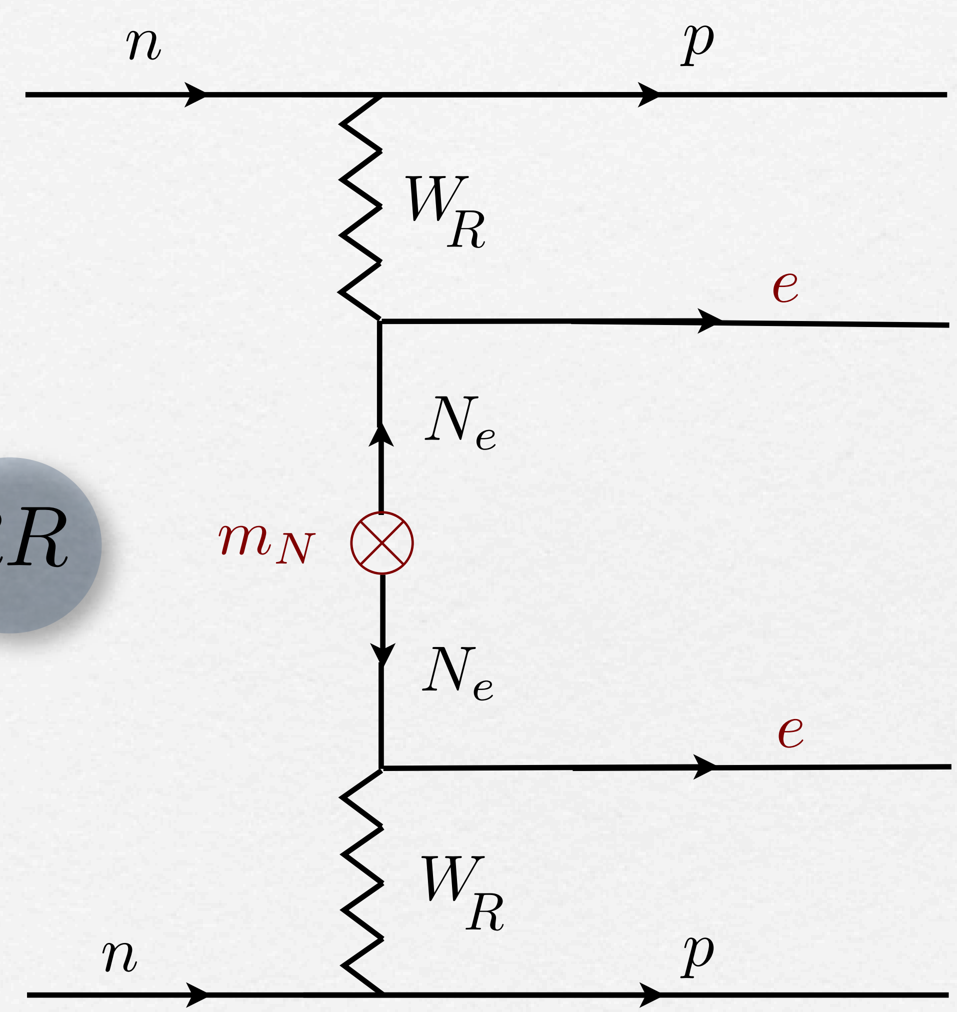
Mohapatra, GS '81



LL

$+$

RR



$$LL \propto \frac{1}{M_{W_L}^4} \frac{m_\nu}{p^2}$$

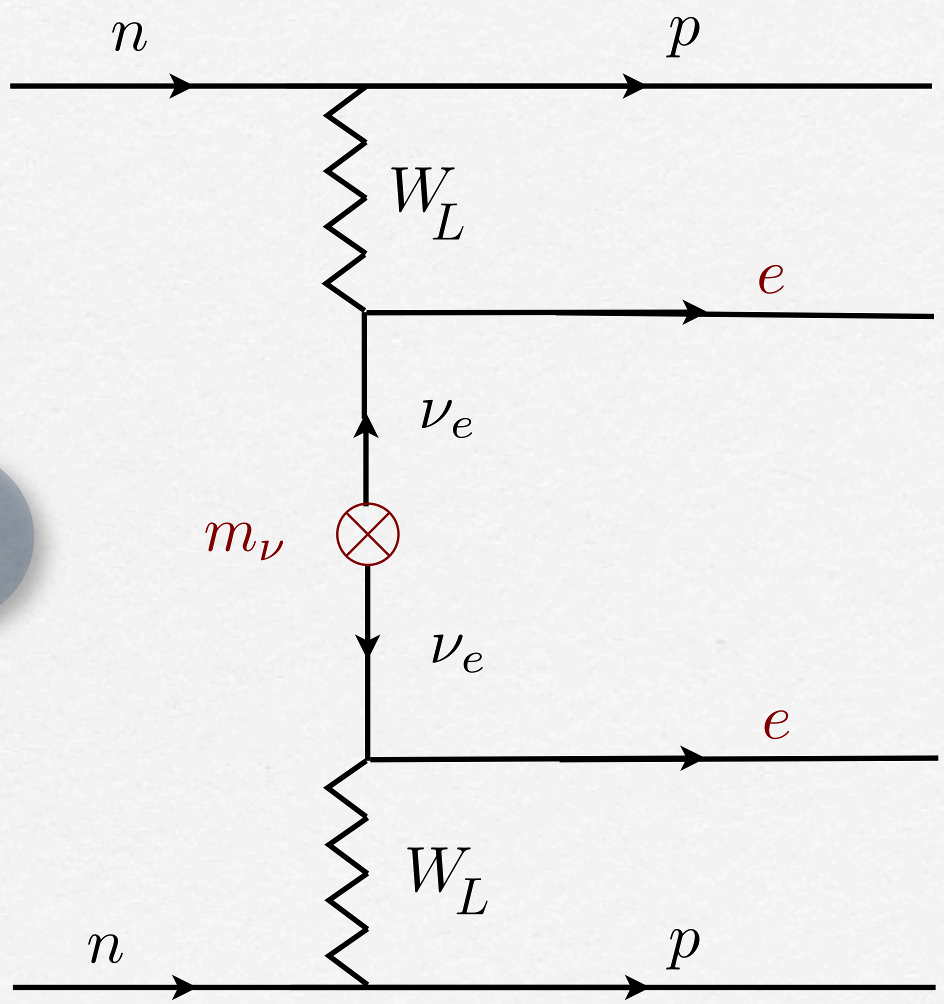
$$RR \propto \frac{1}{M_{W_R}^4} \frac{1}{m_N}$$

$p \simeq 100 MeV$

New source for $0\nu 2\beta$

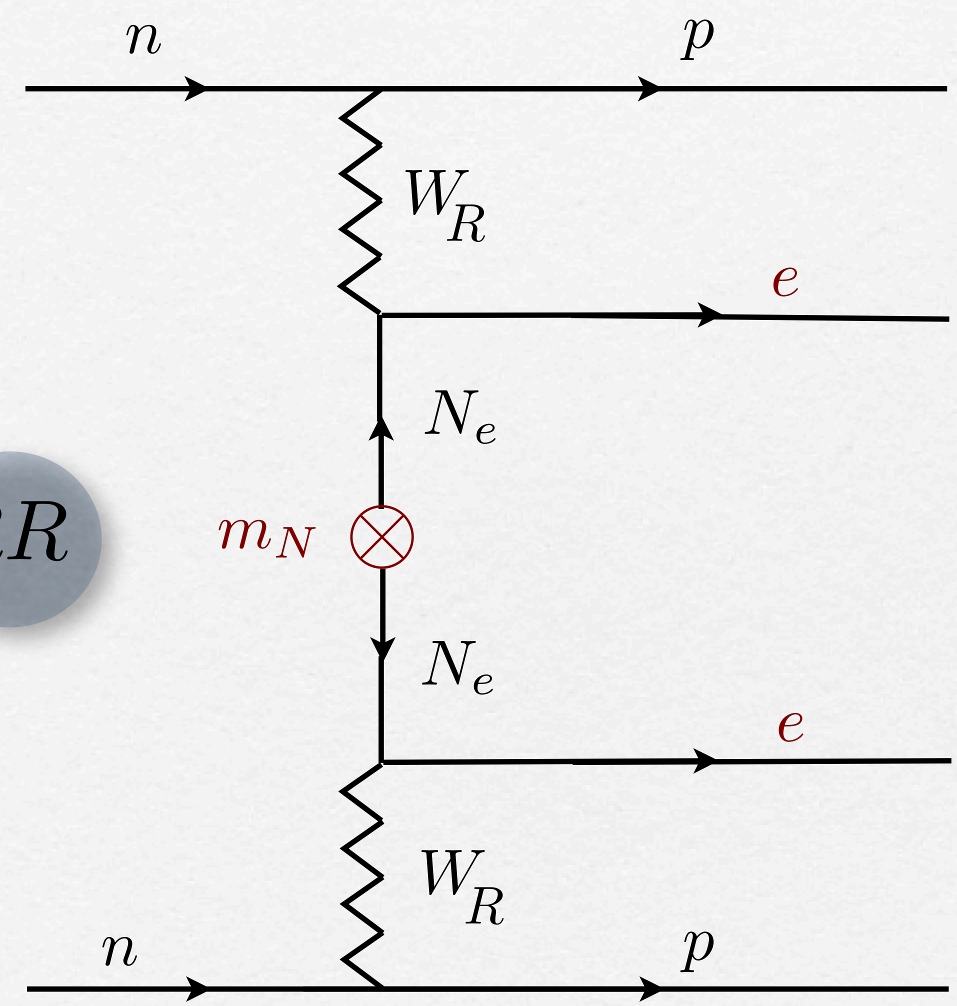
Mohapatra, GS '81

LL



+

RR



$$LL \propto \frac{1}{M_{W_L}^4} \frac{m_\nu}{p^2}$$

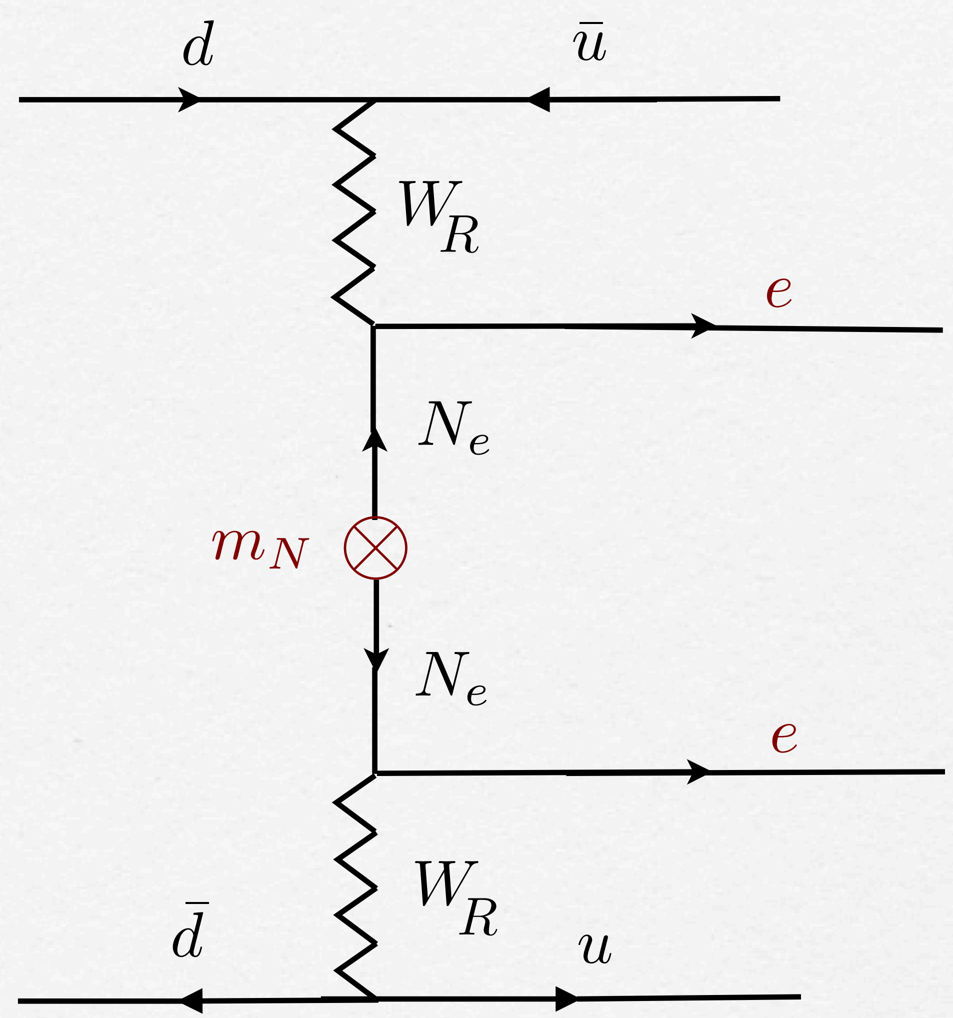
$$p \simeq 100 MeV$$

$$\frac{RR}{LL} \simeq O(1)$$

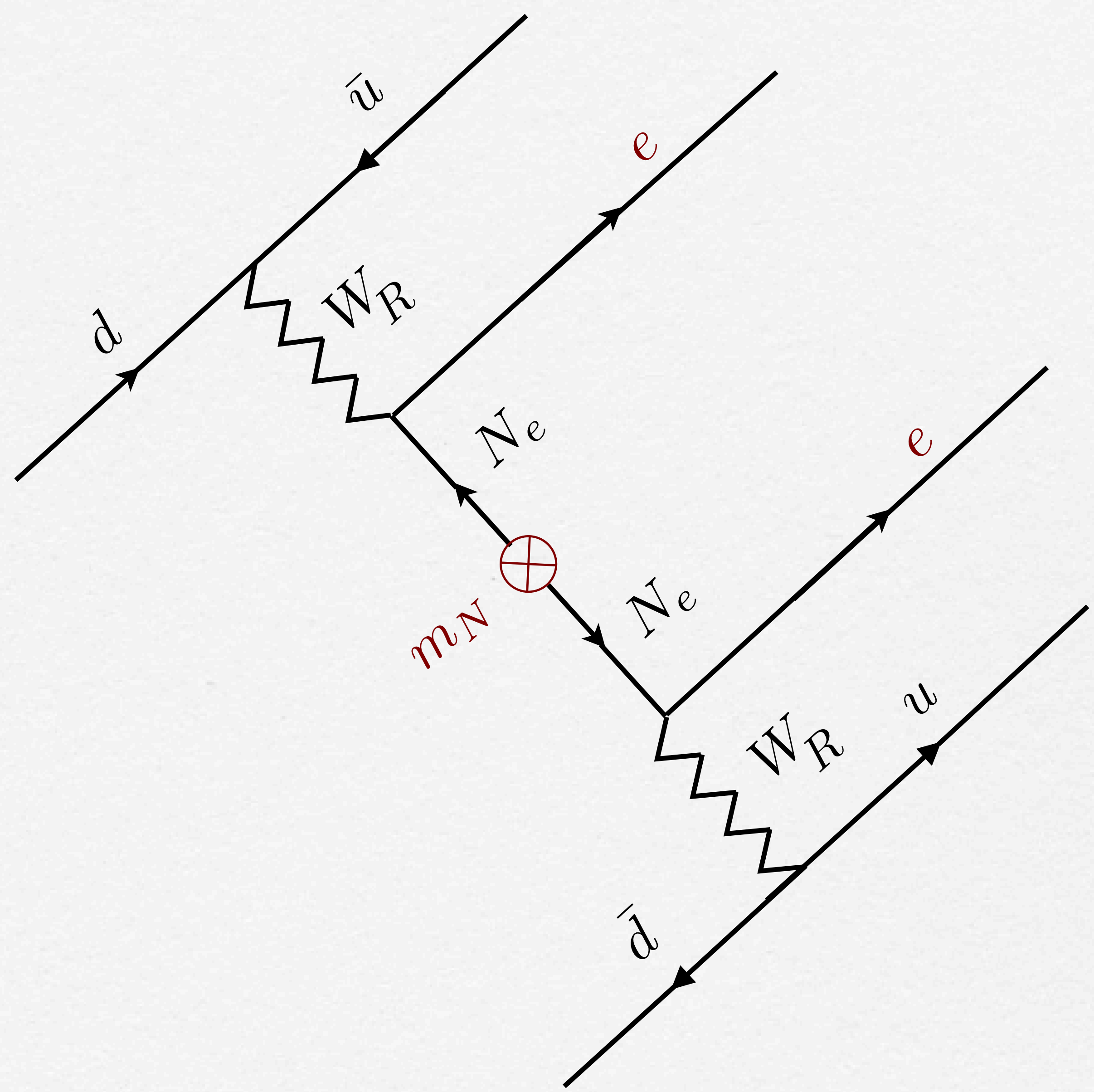
$$M_{W_R} \simeq m_N \simeq 10 M_{W_L}$$

$$m_\nu \simeq 1\, eV$$

$$RR \propto \frac{1}{M_{W_R}^4} \frac{1}{m_N}$$



d
$\bar{u}$
W_R
e
N_e
m_N
N_e
e
W_R
$\bar{d}$
u


$\bar{u}$
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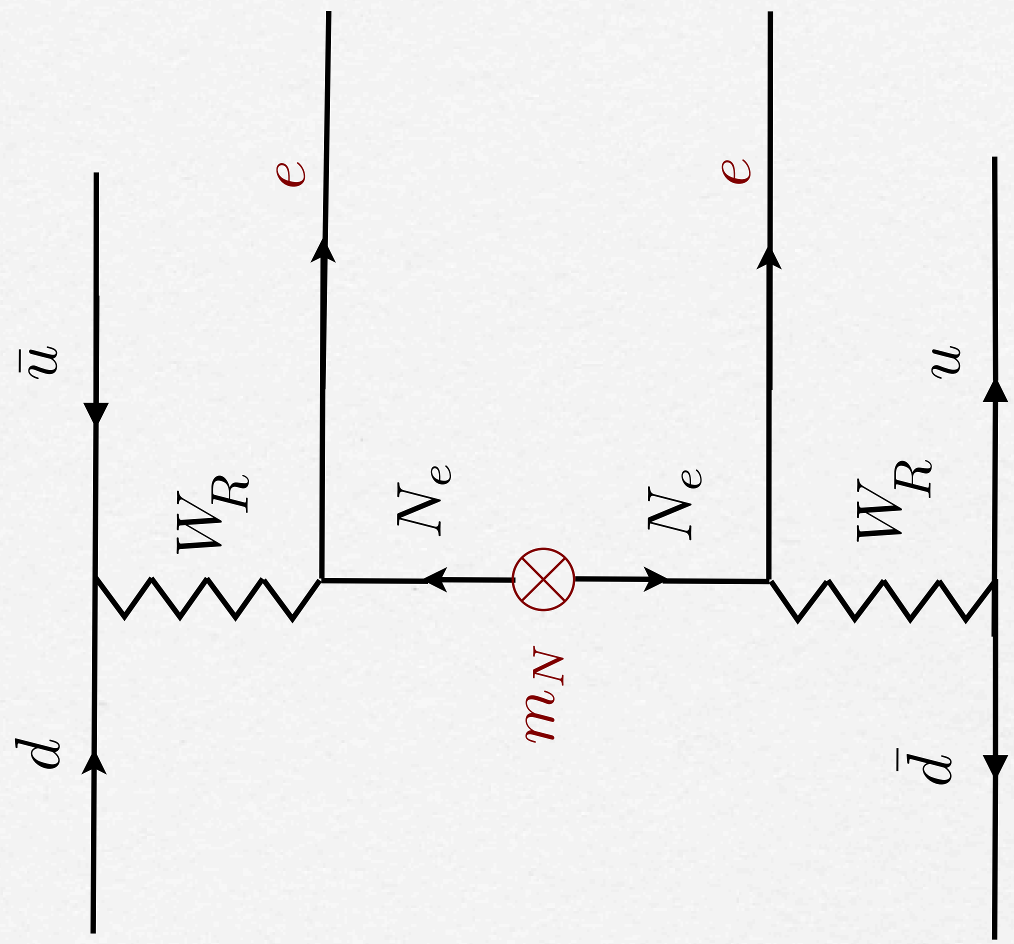
$\bar{d}$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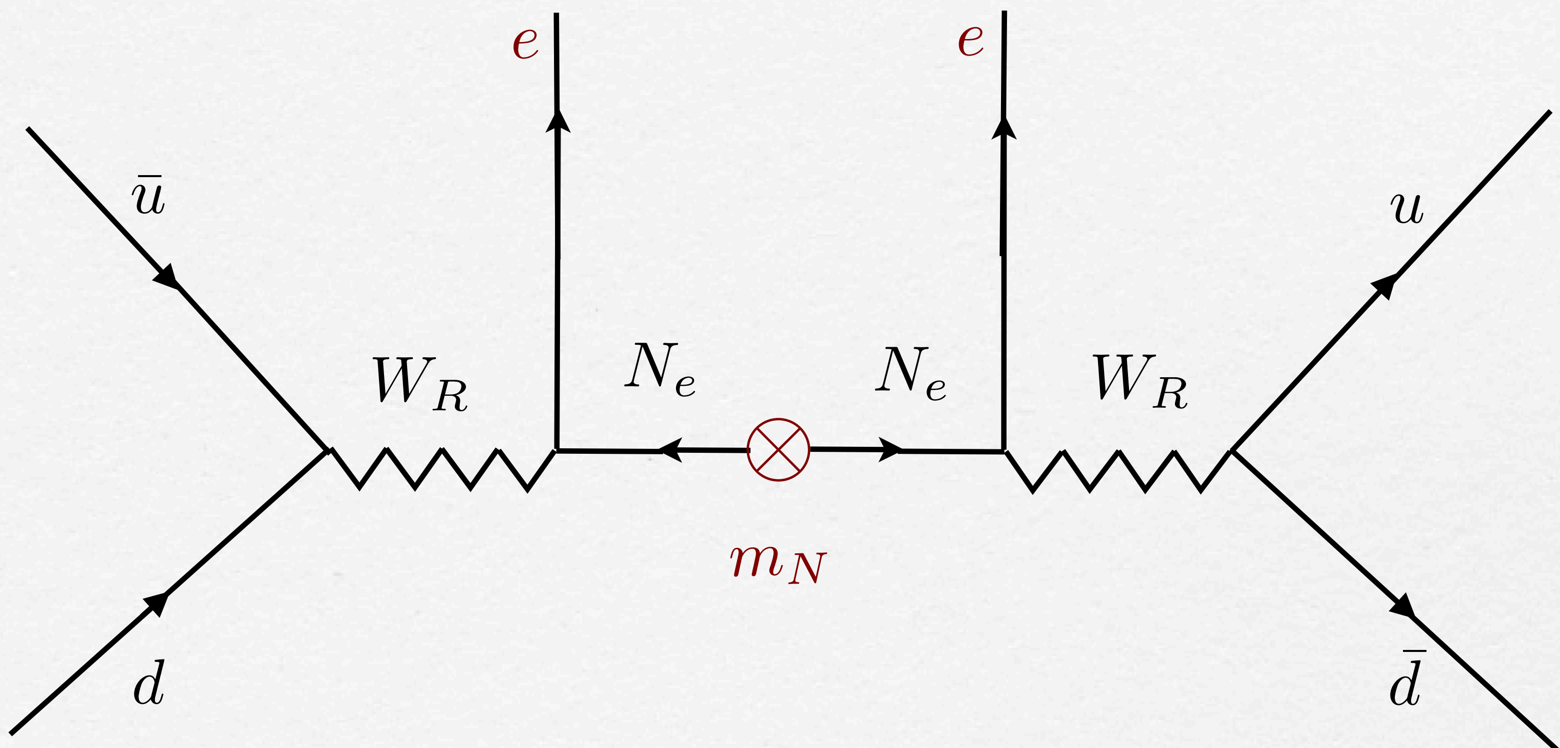
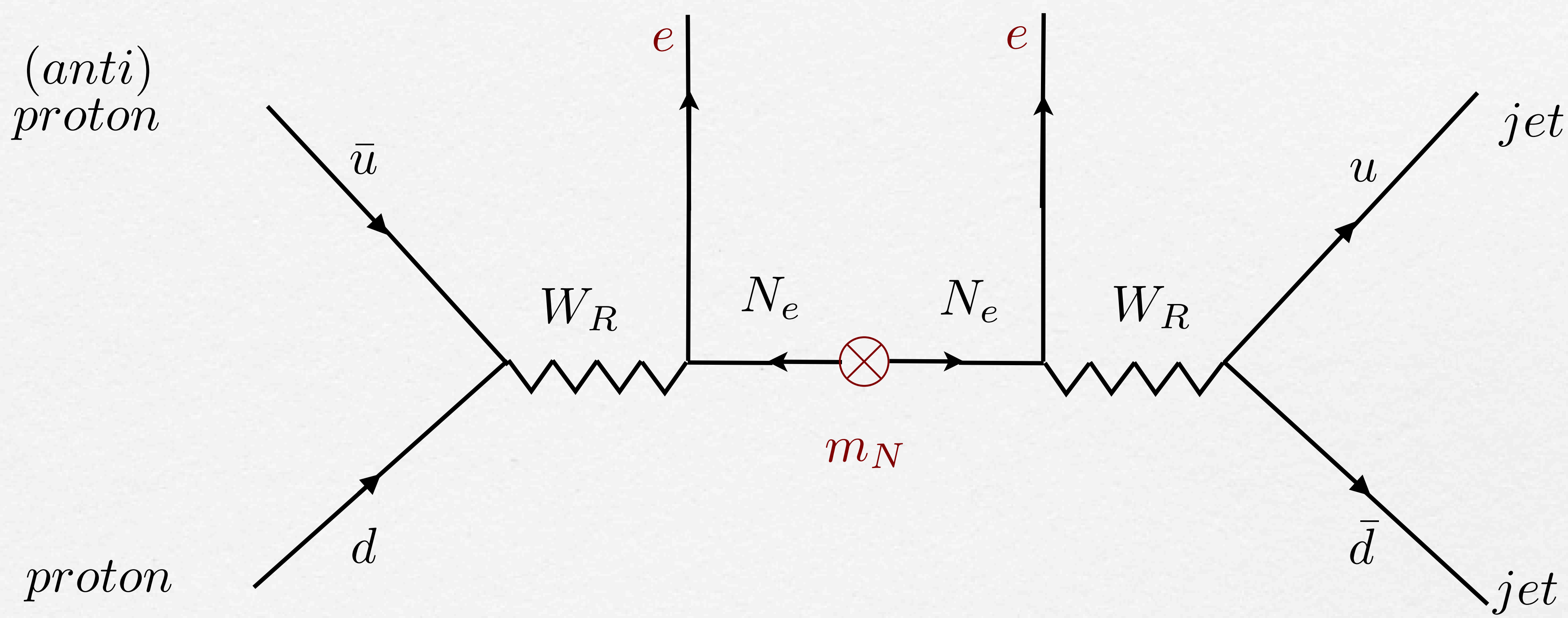


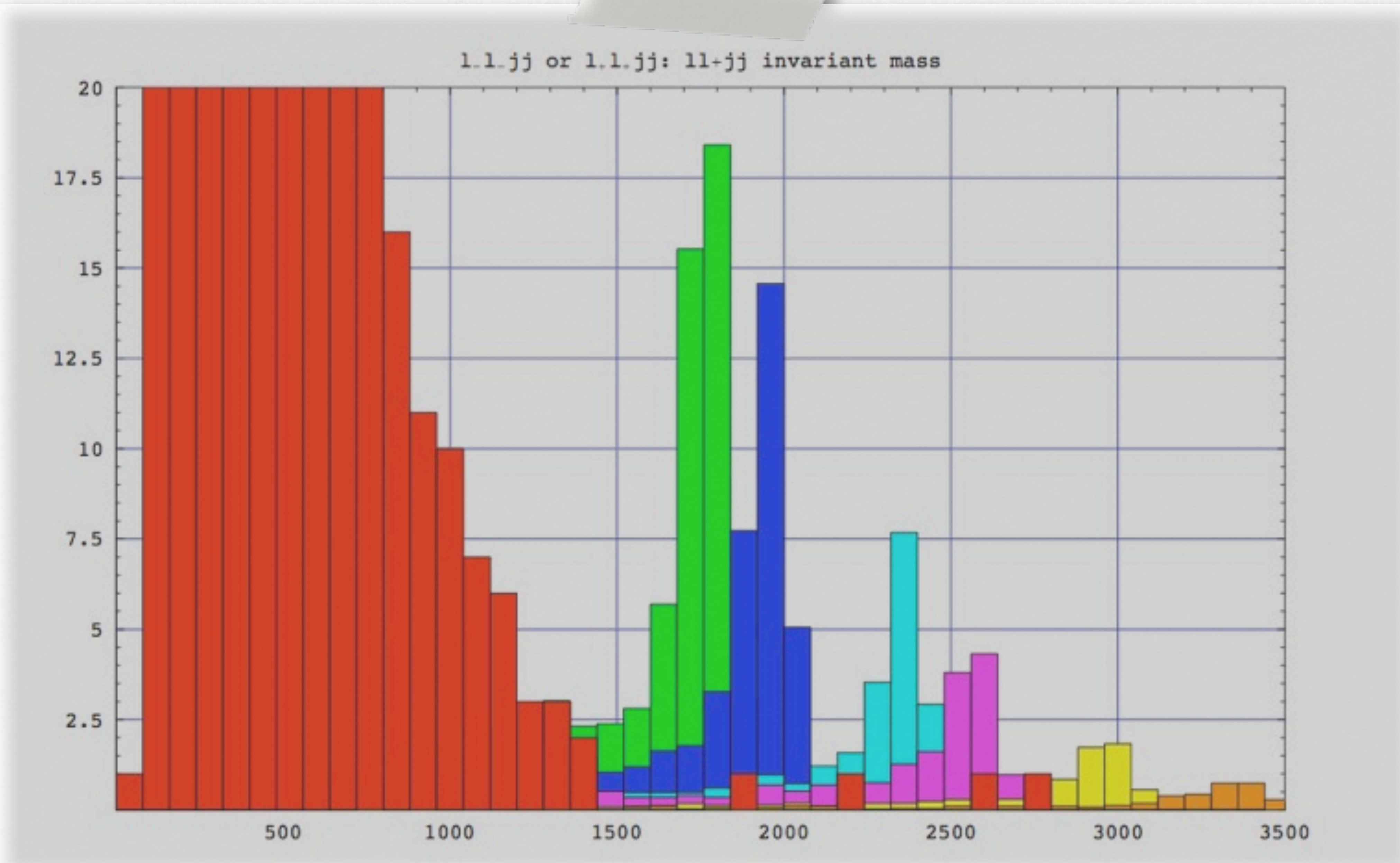
e
e
$\bar{u}$
u
W_R
N_e
N_e
W_R
m_N
d
$\bar{d}$

W_R production @ colliders



- Parity restoration
- same-sign dileptons + jets

Keung, G.S. '83



# of events as a function of energy (GeV) for L = 8fb^{-1}

M_R (TeV): 1.8; 2, 0; 2.4; 2.6; 3, 0; 3.4

talk by Nesti

Spectacular signatures

BUT

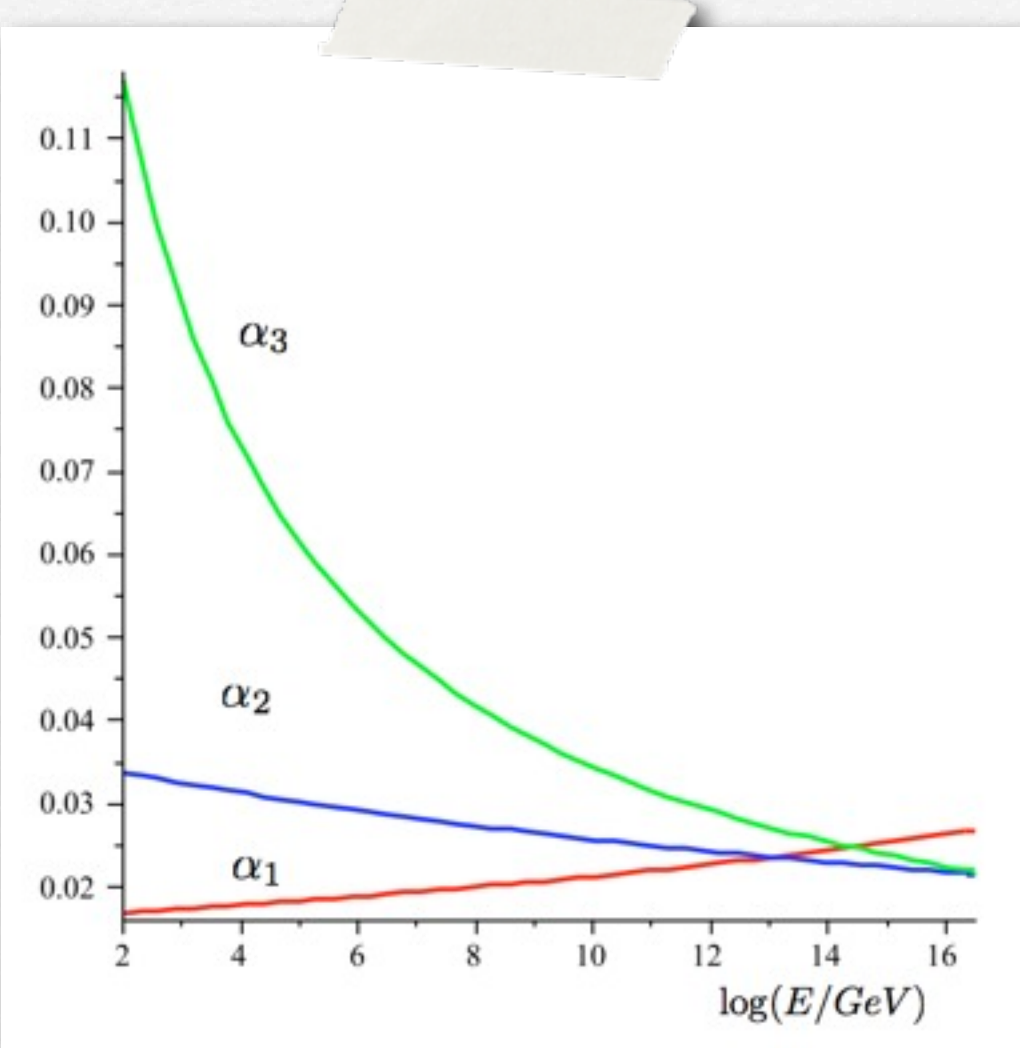
Scale not predicted

Typical of most
Beyond Standard Model physics

Example of a predictive theory

SU(5) grand unified theory: minimal

Georgi, Glashow '74



- massless neutrinos
- no unification

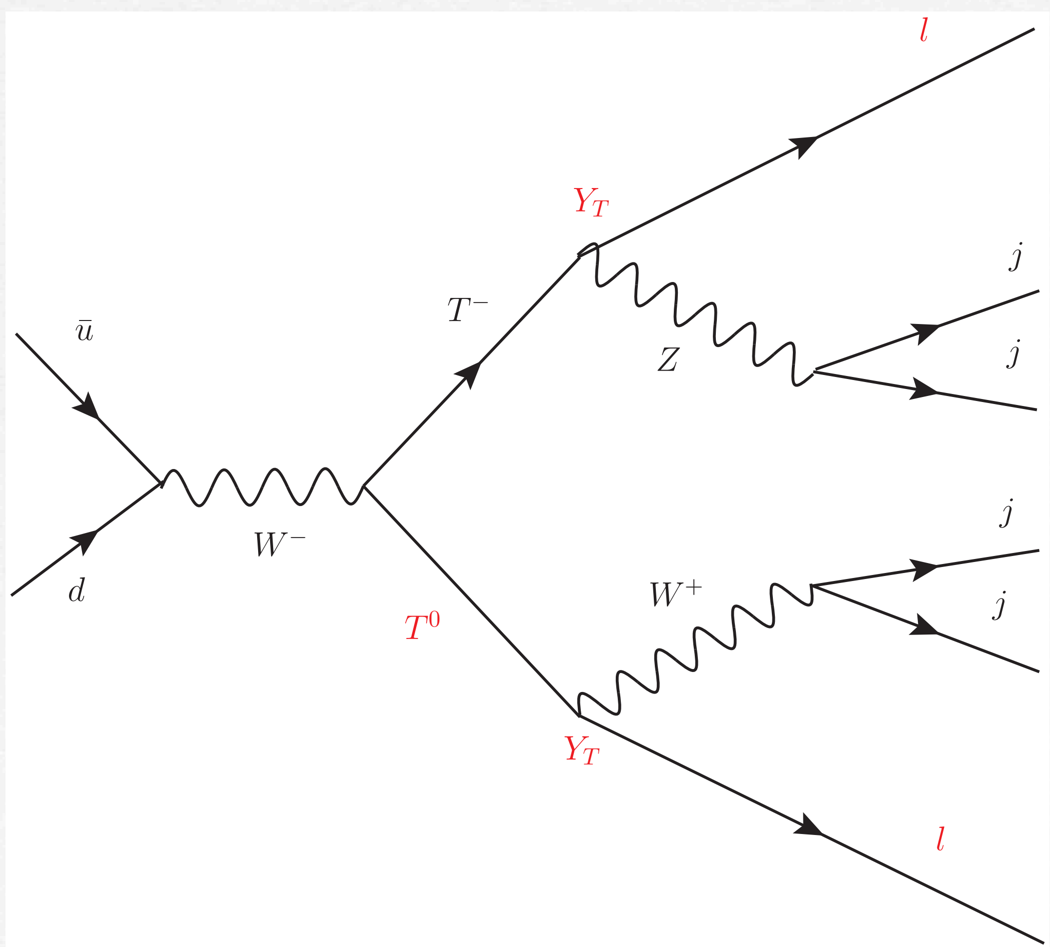
talk by Doršner

Simple predictive extension: add 24_F Bajc, GS '06

- one ν_R
- one fermion triplet - light

one massless neutrino

(T^+, T^0, T^-): **weak triplet**



$m_T < TeV$

Bajc, Nemevšek, GS '07

@ LHC:

triplet decays through Yukawas

→ probe of neutrino masses and mixings

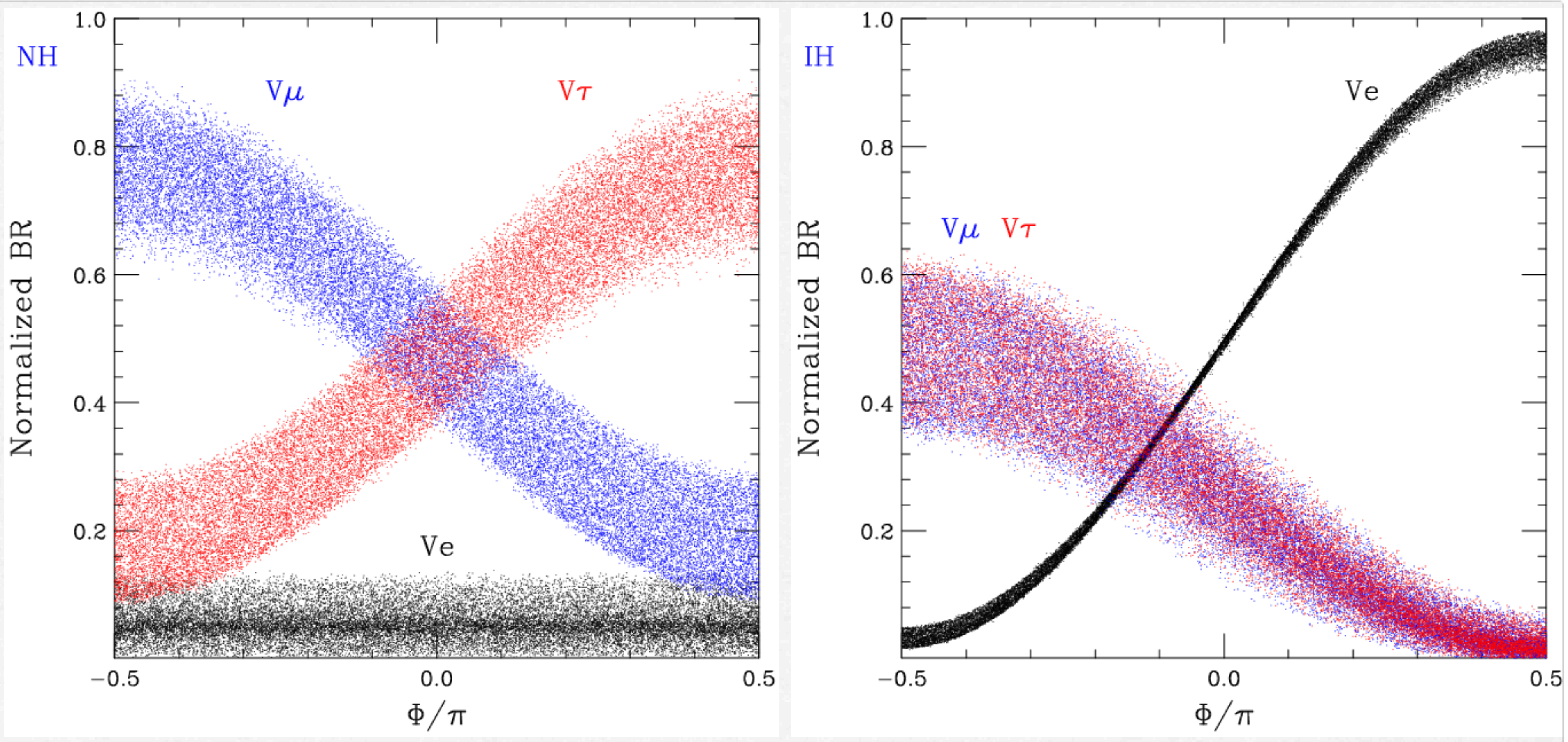


FIG. 10: Normalized branching versus Majorana phase for NH (left) and IH (right). $\mathrm{Im}(z) \geq 2$.

Arhrib, Bajc, Ghosh, Han, Huang, Puljak, G.S. '09

Message

LHC:

Higgs Hunter Machine

can probe the origin of
neutrino mass

Still, are we seeing dinosaurs ?

lots of important physics within SM - as discussed amply at LHC days

- how many generations?
- limit on Higgs mass?
- Higgs structure: how many doublets?

until a few years ago PDG claimed no new families from high precision: S, T, U

strong impact on the Higgs

high precision physics (& direct search):

upper limit on the Higgs mass $m_h \lesssim 180\,GeV$

talk by Djouadi

Fourth generation?

talk by Dorigo

$m_4 \lesssim 500\,GeV$ $\Rightarrow$ perturbativity limit

$700\,GeV$?

Marciano, Valencia, Willenbrock '89

parameter set	m_{u_4}	m_{d_4}	m_H	$\Delta S_{\rm tot}$	$\Delta T_{\rm tot}$
(a)	310	260	115	0.15	0.19
(b)	320	260	200	0.19	0.20
(c)	330	260	300	0.21	0.22
(d)	400	350	115	0.15	0.19
(e)	400	340	200	0.19	0.20
(f)	400	325	300	0.21	0.25

Kribs, et al '07

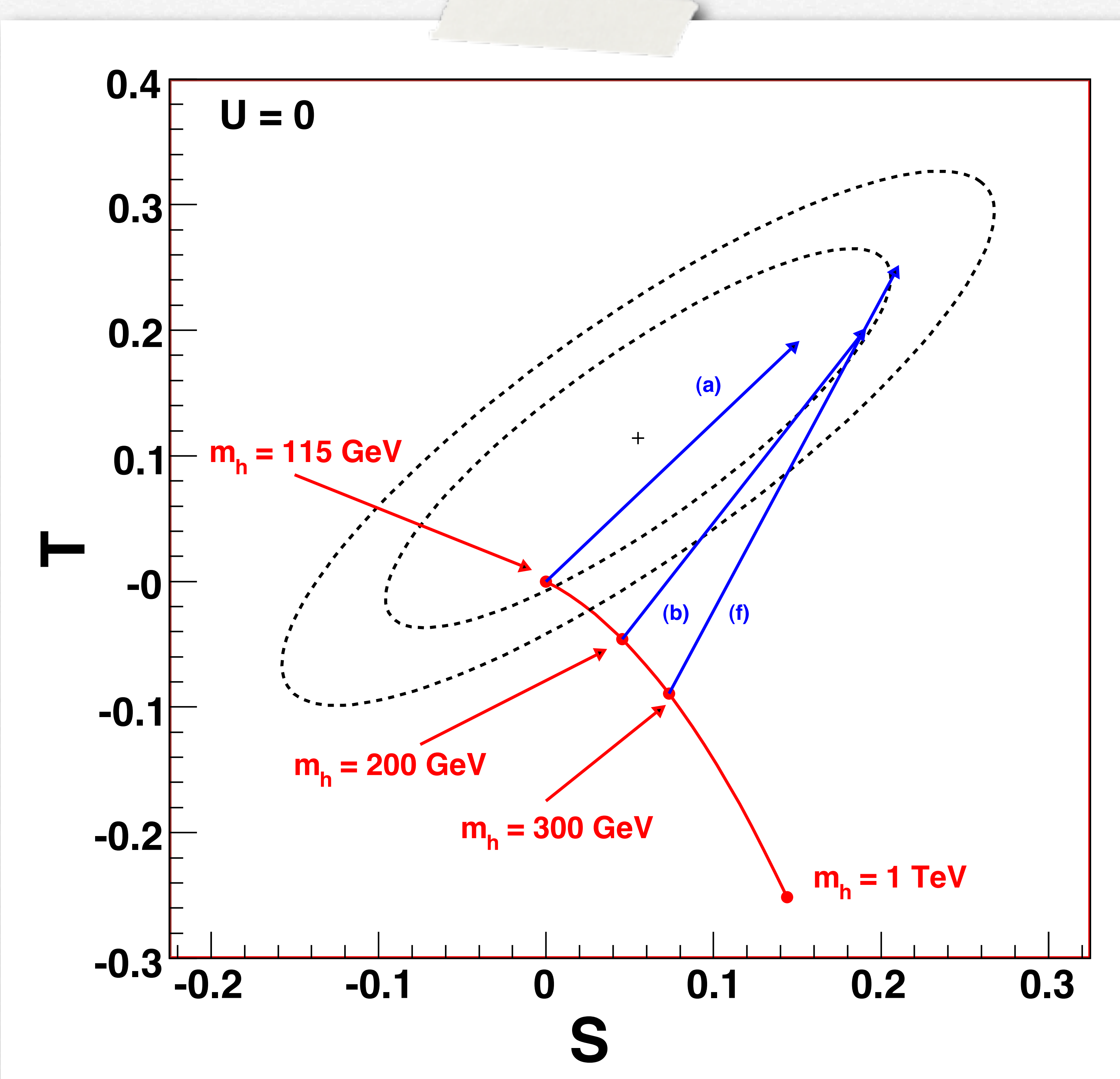
LHC

direct CDF limits:

$m_4 \geq 300\,GeV$? !

Hung and Sher '07 ?

Flacco et al '10 !



Kribs, et al '07

heavier Higgs OK

↓

315 (750) GeV
@68(95)% CL

changes:
production,
decay rates

more on 4th

- detailed study of masses and mixings

Eberhardt, Lenz, Rohrwild '10

- CP

Eilam, Melic, Trampetic '09

- hierarchy problem

Hung, Xiong '10

new limits

gluon fusion
strongly affected $\Leftarrow$ heavy quark loops

recent Tevatron

CDF & D0 '10

excludes the region: $131\,GeV \lesssim m_h \lesssim 204\,GeV$

@95% CL

MSSM?

Dawson, Jaiswal '10

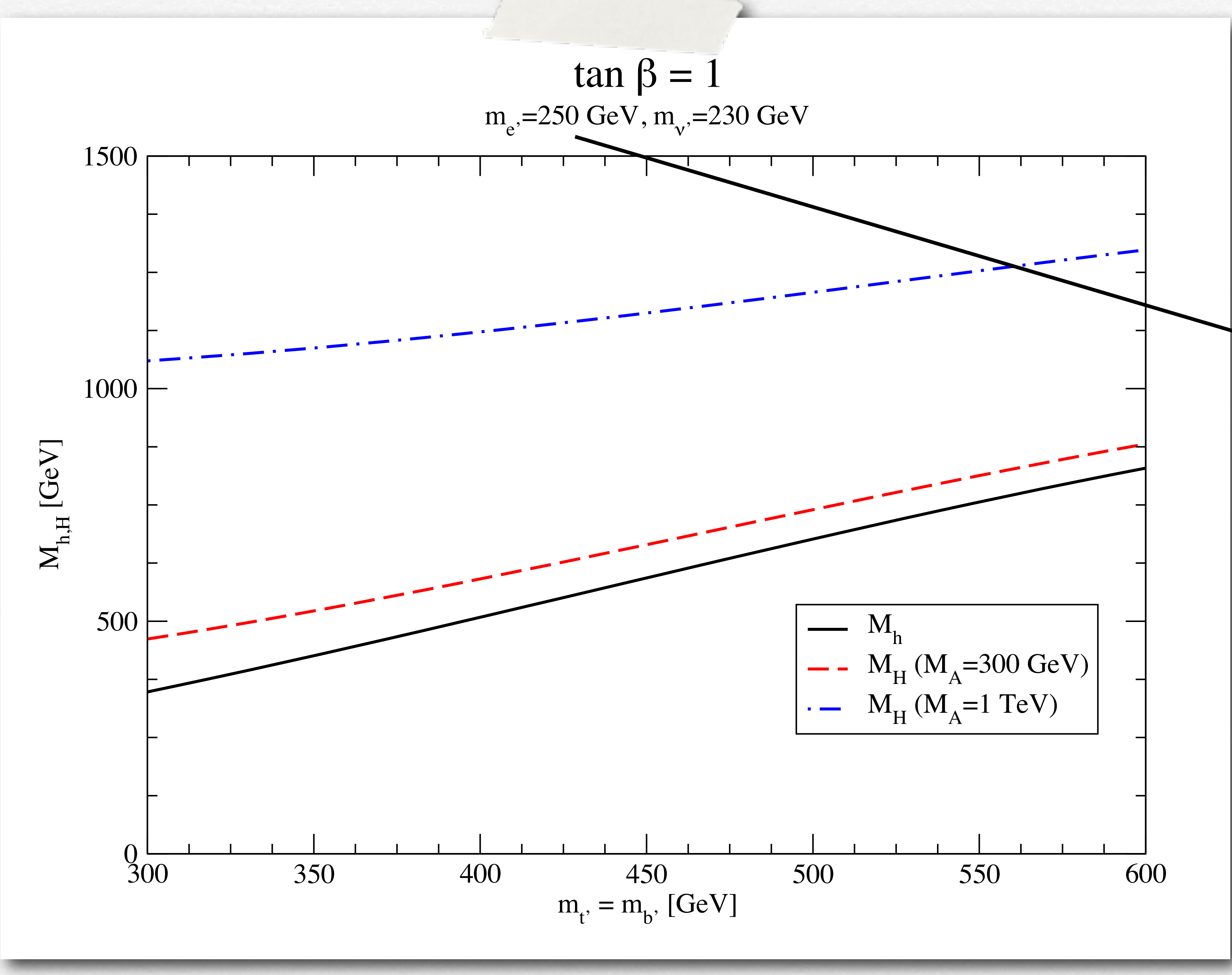
- the mass of d_4 $\Rightarrow$ $tan\beta \simeq 1$ (perturbativity)

- Higgs mass limit dramatically changed

heavy quark

$$m_{h^0}^2 \leq M_Z^2 + \frac{3\alpha}{4\pi}\frac{m_t^4}{M_W^2}\left[ln\frac{m_{\tilde{t}}^2}{m_t^2} + 3\right]$$

Dawson, Jaiswal '10



Carpenter, Rajaraman, Whiteson, Thursday

$e_4 \rightarrow \quad 250\,GeV$

LHC@7 TeV

$1\,ftp^{-1}$

(current around 100 GeV)

Mirror families? → restore parity

Lee, Yang '56

$$\begin{pmatrix} \nu \\ e \end{pmatrix}_L \quad e_R$$

$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad u_R \quad d_R$$

Mirror families? → restore parity

Lee, Yang '56

$$\begin{pmatrix} \nu \\ e \end{pmatrix}_L \quad e_R \qquad \Big| \qquad E_L \quad \begin{pmatrix} N \\ E \end{pmatrix}_R$$

$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad u_R \quad d_R \qquad \Big| \qquad D_L \quad U_L \quad \begin{pmatrix} U \\ D \end{pmatrix}_R$$

- gauge B, L - required to cancel anomalies
- Kaluza-Klein theories
- N=2 supersymmetry
- SO(10+2N) unification

→ perfectly OK - if two Higgs

He, Polonsky, Su '01

update?

Message

experimentalist's task:

hard to see a black cat in
a dark room,
...especially if it is not there

your turn

physics not only:
why we are here,
why three dimensions,
why are numbers what they are ...