CLOSING REMARKS

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prepared for Portorož 2011

Problem: what to talk about ?

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maybe best:

The Role of Heavy Fermions in Fundamental Physics

(particle physics)

Anti particles

Dirac equation ' 28

proton? *Dirac '29*

Skobeltsyn '23

cloud chamber - gamma rays

Oppenheimer Objection: hydrogen

Chao '29

Joliot-Curie ?

positron Dirac ' 31

ideal situation

positron	*Anderson '32*
antiproton	*Chamberlain- Segre '55*
antineutron	*Cork '56*

curse turns into blessing

THE PHYSICS OF FACTS

- Conservative: three years to suggest a new particle
- Lack of communication
- Responsibility ? Lack of courage (Dirac) ?
- What you said mattered :)

SOON QUESTIONED

neutrino = anti neutrino ?

Majorana '37

- Lepton Number Violation (LNV): neutrinoless double beta decay

Racah'37

Furry '38

- heavy Majorana: LNV direct at colliders

Keung, GS '83

1956: Lee and Yang

parity violation in weak interaction

speculate: eventually restored at high energies

mirror fermions

- another proton, neutron : opposite chirality - same mass
- (no colliders then)
- separate domains
- share usual interactions ➔ opposite chirality SM families

mirrors

➔ heavy, but not too heavy- tailor made for LHC

wishful thinking ?

- KK instead: brane confinement *Rubakov, Shaposhnikov '83*
- N=2 supersymmetry N=1 more than enough
- SO(10 + 4n) family unification nice, no junk
- gauge B, L why?

important for ADD program

$$\frac{qqql}{\Lambda^2}$$

low cut-off Λ

proton decay

chirality lost

talk of Melfo

- Mirror worlds: double all interactions *Okun, Kobzarev, Pomeranchuk '66*

Mohapatra, Berezhiani, Foot...

- motivation: CHIRALITY RECOVERED dark matter?

- neutron disappears? goes to mirror neutron?

Berezhiani, Bento '06

experiment *Ban et al '07, '09, Serebrov '09*

btw, evidence? *Berezhiani, Nesti, to appear*

BACK TO BASICS

- Quarks (Gell-Mann) 1964

  book-keeping device, infinite mass, but:

> "It is fun to speculate about the way quarks would behave if they were physical particles of finite mass (instead of purely mathematical entities as they would be in the limit of infinite mass). ... A search for stable quarks of charge $-\frac{1}{3}$ or $+\frac{2}{3}$ and/or stable di-quarks of charge $-\frac{2}{3}$ or $+\frac{1}{3}$ or $+\frac{4}{3}$ at the highest energy accelerators would help to reassure us of the non-existence of real quarks."

- Aces (Zweig) : physical - problems before color

COLOR

curse turns into blessing

- dynamics of strong interactions, confinement
- gauge color

Nambu '66

HEAVY FERMIONS IN SM

- Charm: 1964 (aces = 4) *Bjorken, Glashow '64*

visional: q-l symmetry

close to factual: Cabibbo program

amusing: Glashow forgets his SM paper

digression:

SAKATA MODEL

- '56 - mesons made out of p, n, Λ

already idea that pions are made of p, n

Fermi, Yang '49

- '62 - symmetry with leptons: add Λ'

Katayama, Motumoto, Tanaka, Yamada

GIM

factual:

- 1969: flavor conservation in neutral currents (FCNC)

$K_L - K_S$ mass difference: $m_c \lesssim 3\, GeV$

- right number *Gaillard, Lee '74*

discovery of charm

- anomaly cancellation

Bouchiat, Illiopoulos, Meyer '72

Gross, Jackiw '72

digression:

FCNC

- extended model (2HD): FCNC for all values of couplings - Z2

Glashow, Weinberg '78

talks by Branco, Rebelo, ...

- SM: works only for a small charm quark mass

- nothing wrong with small Yukawas

Dvali ' 89

Hall, Weinberg '92

SPONTANEOUS CP

- 2 Higgs doublets - real couplings *Lee '72*
- complex vev
- no FCNC - ruled out?
- small Yukawa of the second Higgs *Liu Wolfenstein '87*
- otherwise more Higgs + discrete symmetry

CP VIOLATION

factual:

- b, t: CKM

Kobayashi, Maskawa '72

talks by Nierste, Lenz, Kreps, De Fazio, Fleischer, Drobnak, Smith, Brod...

- after b, top imagined relatively light for years

heavy top: supersymmetry

MSSM

- naturalness

- unification: $sin^2\theta_W \simeq 0.23$

exp:

$$sin^2\theta_W \simeq 0.21$$

- radiative Higgs mechanism →

Dimopoulos, Raby, Wilczek '81

Einhorn, Jones '82

Marciano, GS '82

$$\Downarrow$$

$$m_t \simeq 200\,GeV$$

$$m_t \simeq 200\,GeV$$

$$\Uparrow$$

Alvarez-Gaume et al '83

Inoue et al '83

TOP CONDENSATE

Bardeen, Hill, Lindner '89

- analogy with BCS

- low energy: SM with mass relations

  criticized by Hasenfratz

- 4th generation

  Holdom, Hung,...

$\Lambda[GeV]$	10^{19}	10^{17}	10^{15}	10^{13}	10^{11}	10^{10}	10^{9}	10^{8}	10^{7}	10^{6}	10^{5}	10^{4}
$m_t^{phys}[GeV]$	220	225	231	239	250	257	266	279	295	320	362	458
pert.	$\pm$ 2	$\pm$ 3	$\pm$ 3	$\pm$ 3	$\pm$ 5	$\pm$ 6	$\pm$ 7	$\pm$ 9	$\pm$ 12	$\pm$ 16	$\pm$ 25	$\pm$ 45
$m_H^{phys}[GeV]$	241	248	258	270	287	298	312	331	356	394	458	609
pert.	$\pm$ 3	$\pm$ 3	$\pm$ 4	$\pm$ 5	$\pm$ 8	$\pm$ 9	$\pm$ 11	$\pm$ 15	$\pm$ 21	$\pm$ 32	$\pm$ 56	$\pm$ 142

Table I: The predictions for the physical top–quark and Higgs boson mass for different scales Λ. One loop β–functions are used with $g_1^2(M_Z) = 0.127 \pm 0.009$, $g_2^2(M_Z) = 0.425 \pm 0.006$, $\alpha_S(M_Z) = 0.115 \pm 0.015$ and $M_Z = 91.8\ GeV$ as input. The numbers are obtained for the central value of these input data and requiring the on-shell condition $\bar{m}(m) = m$. Variation of the gauge couplings within their errors results to a very good approximation in a change of $\pm 6\ GeV$ for the top mass and $\pm 4\ GeV$ for the Higgs mass. The rows labeled *"pert."* show the change in the result if we change the couplings at the cutoff to unity instead of infinity, as a measure of the errors induced by using perturbation theory.

ROLE OF TOP : ANOMALY

anthropic principle: write many papers

Yue Zhang, a few days ago

- probe of new physics

Tevatron anomaly

talks by Perez, Kagan, Lee, Degrande

SUPERSYMMETRY

- Gauginos, Higgsinos
- neutralino = dark matter

exact R parity : artificial

how to get R-parity?

- gauge B-L (seesaw, Pati-Salam, SO(10)...)

Mohapatra '86

large scale

R-parity exact (otherwise a light pseudo-Goldstone coupled to Z)

Aulakh, Melfo, Rasin, GS '98

GRAVITINO

- likes to be DM - rather stable (if LSP)

Takayama, Yamaguchi '00

Buchmuller, Covi, Ibarra,

- Planck scale suppressed couplings
- decaying DM if R-parity broken
- natural if you take MSSM as a complete low energy theory - neutrino mass

Bajc, Enkhbat, Ghosh, Zhang, GS '10

- no direct tests - sad

can be light - gauge mediation ...

SPLITTING SUPERSYMMETRY

- give up naturalness, keep unification: sfermions can be heavy

Arkani-Hamed, Dimopoulos, '04
Giudice, Romanino, '04

- give up supersymmetry ?

minimal SU(5):

-no unification
-massless neutrinos

add 24 fermion

Bajc, G.S., '06

- Light SU(2) fermion triplet: below TeV (type III see-saw)

LNV@LHC → triplet decays through Dirac Yukawa: probe of neutrino mass matrix

- Color octet fermion around 10^7 GeV *Bajc, Nemevšek, G.S. '07*

more split supersymmetry ?

-heavy higgsino
-intermediate gluino
-light wino
-R parity violation

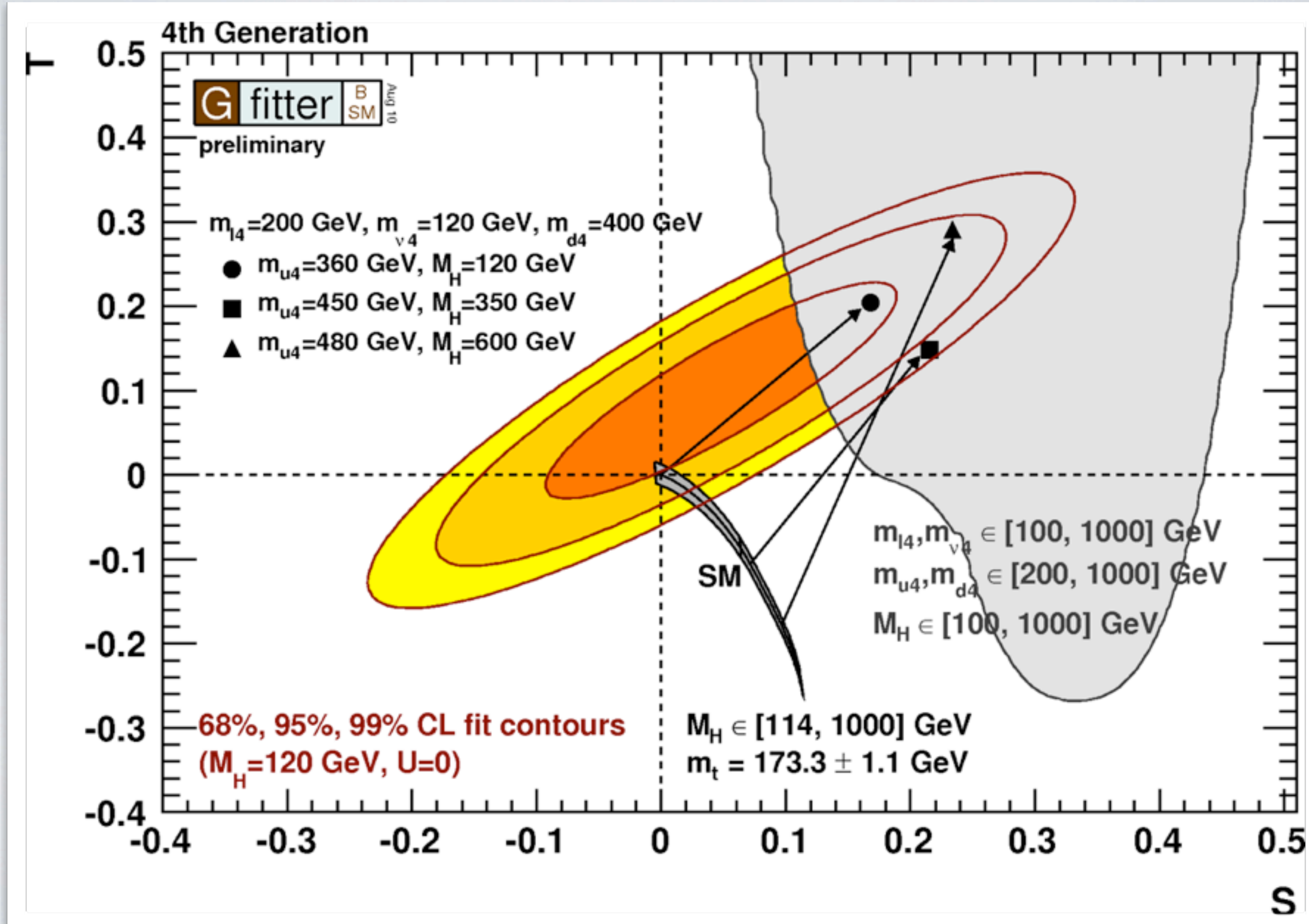
BACK TO FAMILIES

➡Fourth family (lots of talks: Melic, Sannino, Melfo, Kosnik, Lenz,...)

➡Motivation ?

- LHC testable
- TC *Sannino*
- condensate *Holdom, Hung, ...*
- Dark Matter: fourth neutrino is heavy
  doesn't work (20% at most)
  Keung, Schwaller '11
- Genesis: more CP
  -not enough,
  need to change phase transition
  -add a Higgs singlet ?
  can work if inert - DM?

High precision: hiding the Higgs



Dramatic in MSSM

$$m_H^2 \leq m_Z^2 + a\,\frac{m_t^4}{m_W^2}\,\ln\frac{m_{\tilde{t}}}{m_t}$$

naturalness limit: $m_{\tilde{t}} \lesssim 1\,TeV$ ➡ $m_H \lesssim 130\,GeV$

➡ goes up to $\sim 600\,GeV$

Dawson, Jaiswal, '10

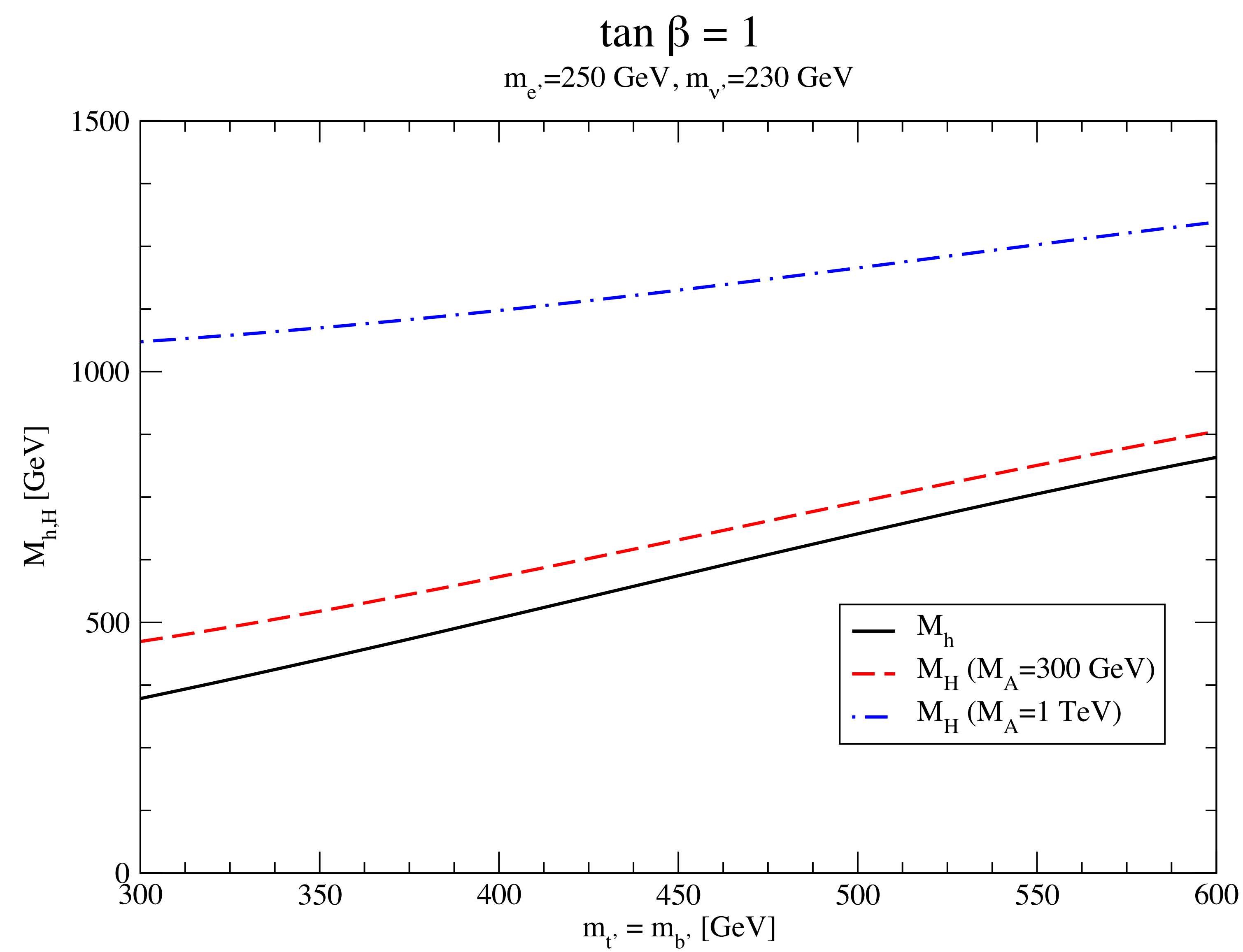


FIG. 1: Predictions for the neutral Higgs boson masses in the four generation MSSM. The squarks and sleptons are assumed to have degenerate masses of 1 TeV. The mass of the lighter Higgs boson, M_h, is insensitive to the value of M_A. (Not all masses shown here are allowed by the restrictions of perturbative unitarity and electroweak precision measurements, as discussed in Sects. III and IV.)

TECHNICOLOR

- Beautiful idea

Weinberg, Susskind

- Realization a bit less beautiful: extended TC, walking TC...

- 4th generation natural?

talk by Sannino

- Claim:

Tevatron dijet peak

$\rho_T \rightarrow W + \pi_T$

Eichten, Lane, Martin, last Friday

↘

$\sim 150 GeV$

HEAVY MAJORANA: SEE-SAW

- add right-handed neutrino to SM
- give it a large mass (singlet)
- lepto-genesis
- colliders - needs huge Yukawas, cancellations
- still, a kind of minimal scheme

talk by Ibarra

ADD MORE STATES

- bigger representations, more Higgs

talk by Picek

- colorful version

talk by Spinner

sorry Gilad :)

AMBIDEXTROUS THEORY

Lee, Yang dream

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \qquad \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$$

$$W_L \qquad W_R$$

$$m_{W_R} \gg m_{W_L}$$

Pati Salam '74

Mohapatra GS '75

sorry Gilad :)

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$$W_L \qquad W_R$$

$$m_{W_R} \gg m_{W_L}$$

Pati Salam '74

Mohapatra GS '75

$E \gg m_{W_R}$ parity restored?

neutrino mass ?

- For years: Dirac neutrino, then why light ?

- Heavy right-handed neutrino: seesaw

$$m_{\nu_R} \propto M_{W_R}$$

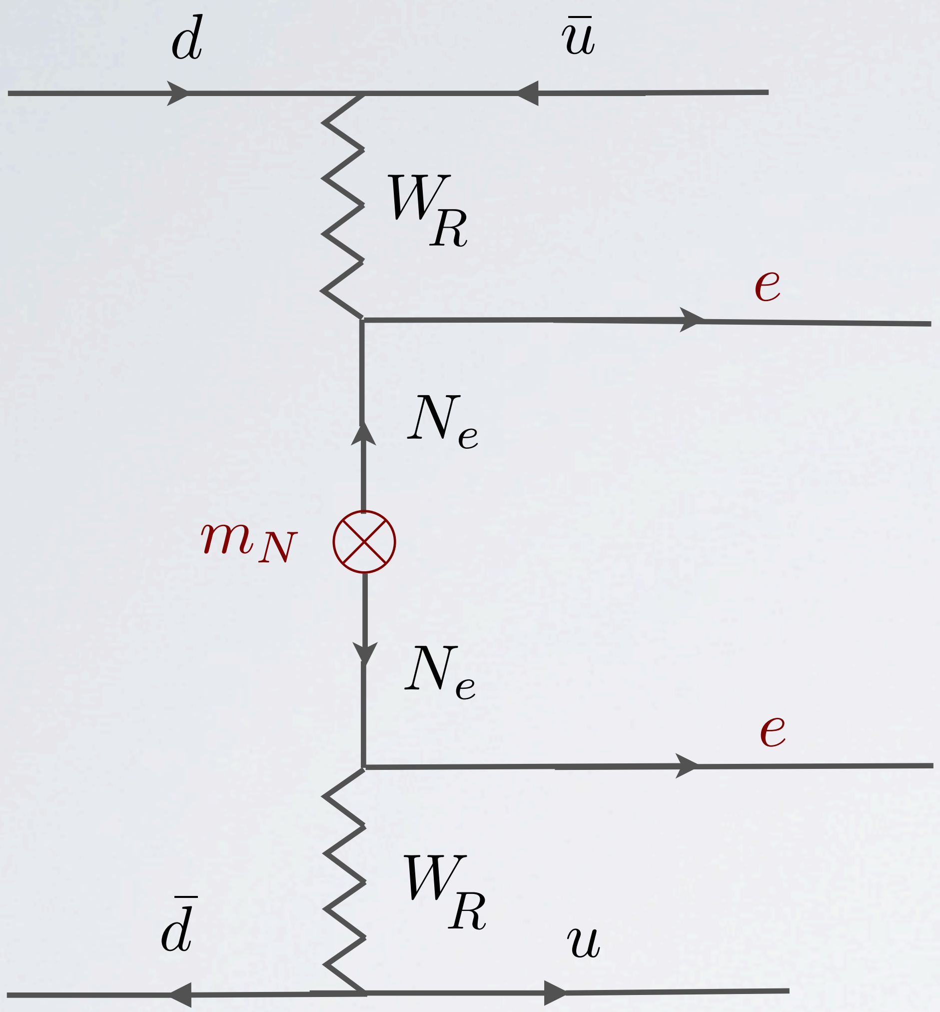
Minkowski '77

Mohapatra, GS '79

- Neutrino mass connected to parity restoration

talks of Nemevšek, Nesti

Tello, Nemevsek, Nesti, GS, Vissani '10



If Klapdor claim true and neutrino mass small (cosmology)

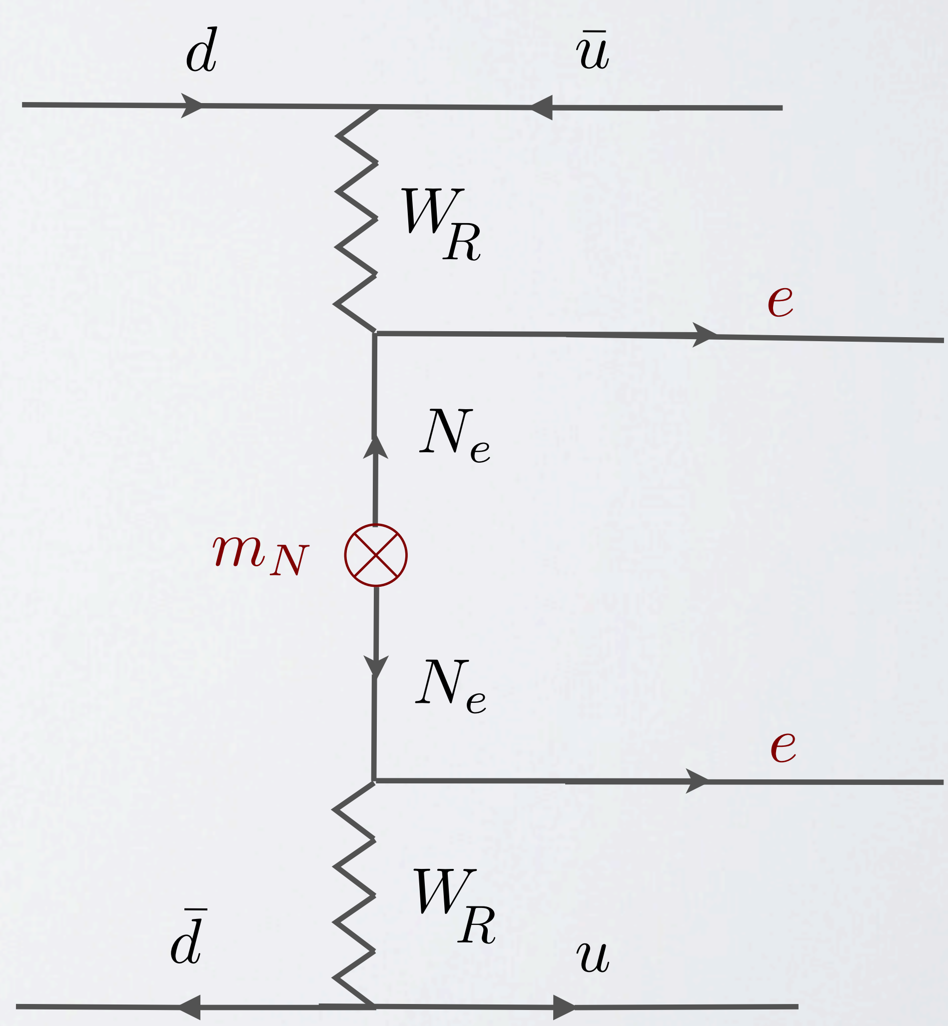
Feinberg, Goldhaber '59

Pontecorvo '64

New Physics (W_R)@TeV

LHC energies

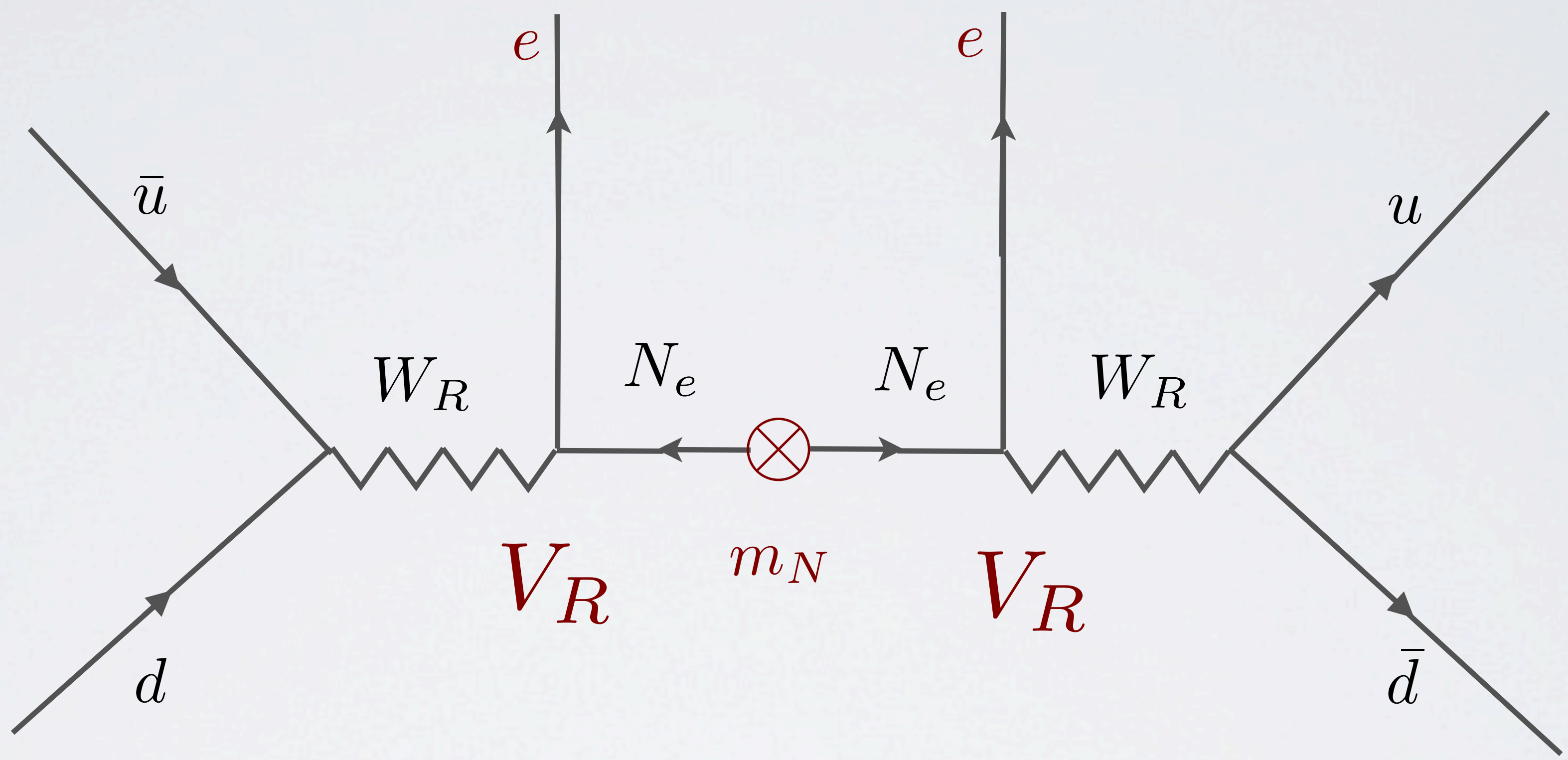
GERDA - started



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

direct probe of Majorana nature

connection with LNV and LFV



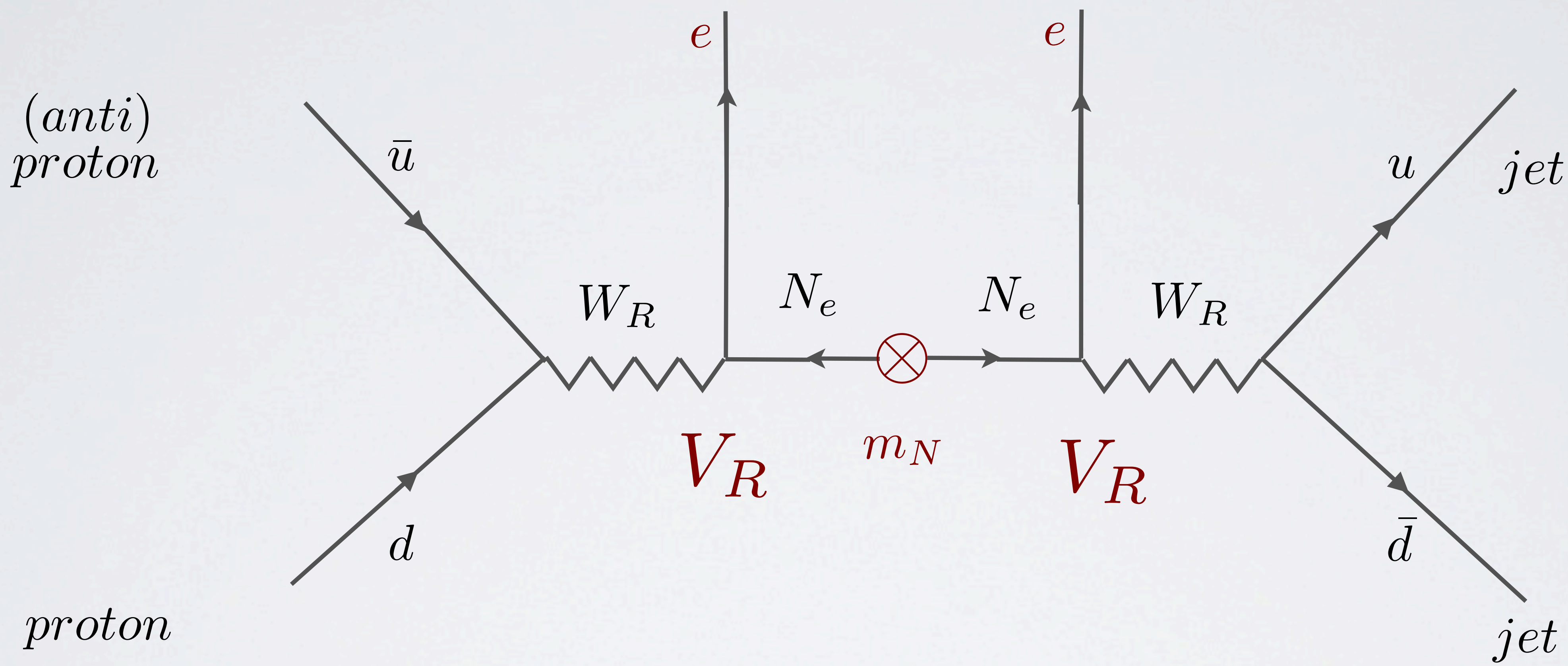
up to 4 TeV @14 TeV

talks of Nemevšek, Nesti

direct probe of Majorana nature

connection with LNV and LFV

W_R production @ colliders



up to 4 TeV @14 TeV

- Parity restoration
- Lepton Number Violation: electrons (+ jets)

Keung, G.S. '83

talks of Nemevšek, Nesti

Super heavy fermions in SUSY GUT

- d=5 proton decay   dominant

- through Yukawas- can probe fermion mass matrices

- connect mixings with proton decay
  - can look into textures

catch: needs superpartners masses and mixings minimal SUSY SU(5) - often claimed to be dead

Murayama, Pierce '01

threshold effects - resurrected

Bajc, Fileviez Perez, GS '02

problem: long wait for new experiments, decades?

LNV - experiments going on, physics of today

OUTLOOK

LHC

- new family (ies) 1 : 1
- heavy Majorana - origin of neutrino mass 2 : 1
- heavy Majorana - supersymmetry 1 : 1
- ...
- in all honesty: nothing really has to be there (here)

Thank you