Mass Constraints on Fourth Generation of Standard Model Fermions

Summer Internships in
Science and Technology 2010

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Overview

- Fourth generation
- Potential constraints
  - Review previous
  - Update existing
- Code
  - STU, HePoSu
- Results

Why a fourth generation?

The standard model does not exclude a fourth generation of fermions

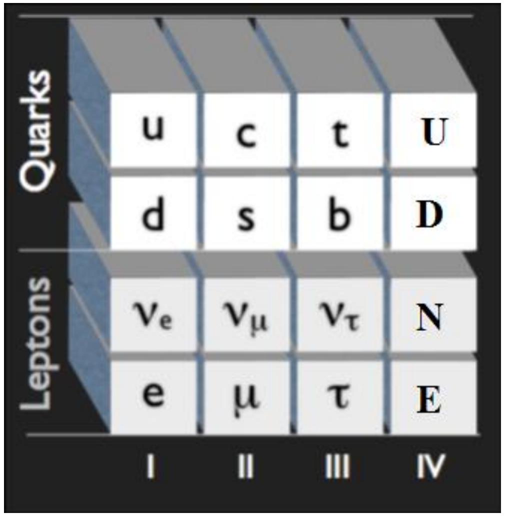
- No strong experimental evidence supporting/conflicting

In agreement with electroweak precision data

- No new interactions that do not appear in first three

ggH coupling enhanced

Assume SM couplings



Previous Constraints

min{ m(U), m(D) } > 258 GeV

Preliminary result .76 fb^{-1} T. Aaltonen et al. P. R. L. 100, 161803

Assuming U→Wq

Reconstruct top mass in lepton + neutrino + 4 jet events

m(N) > 90.3 GeV

N→Wτ LEP II P. L. B517, 75

Assuming Dirac coupling to tau, [mu, elec] take weakest

m(E) > 100.8 GeV

E→Wν LEP II E→WN is tighter, take weakest

New Constraints

$m(U) > 335$ GeV

Public Note

4.6 fb^{-1}

CDF/PUB/TOP/PUBLIC/10110

$U \rightarrow Wq$

lepton+ 4 jets

$m(D) > 290$ GeV

Flacco et al. arXiv: 1005.1077

Uses CDF results

$D \rightarrow Wt$

dilepton + j + b + MET

gets limit for most general case

$m(N) > 80.5$ GeV

$N \rightarrow W\tau$

Majorana coupling to τ

$m(E) > 100.8$ GeV

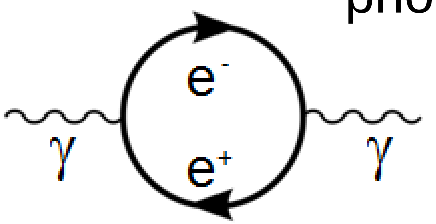
$E \rightarrow W\nu$

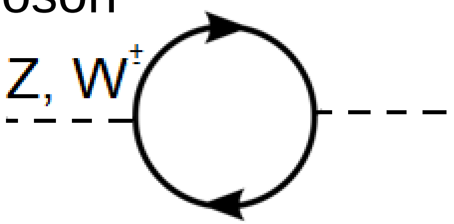
Method

STU fit

S, T and U are parameters for electroweak sector of standard model - zero for no new physics

can be parameterized in terms of the self-energies of photon, Z boson, and W boson





Constrained by fits of available experimental data (e.g. LEP I, LEP II, SLD, DIS, etc.)

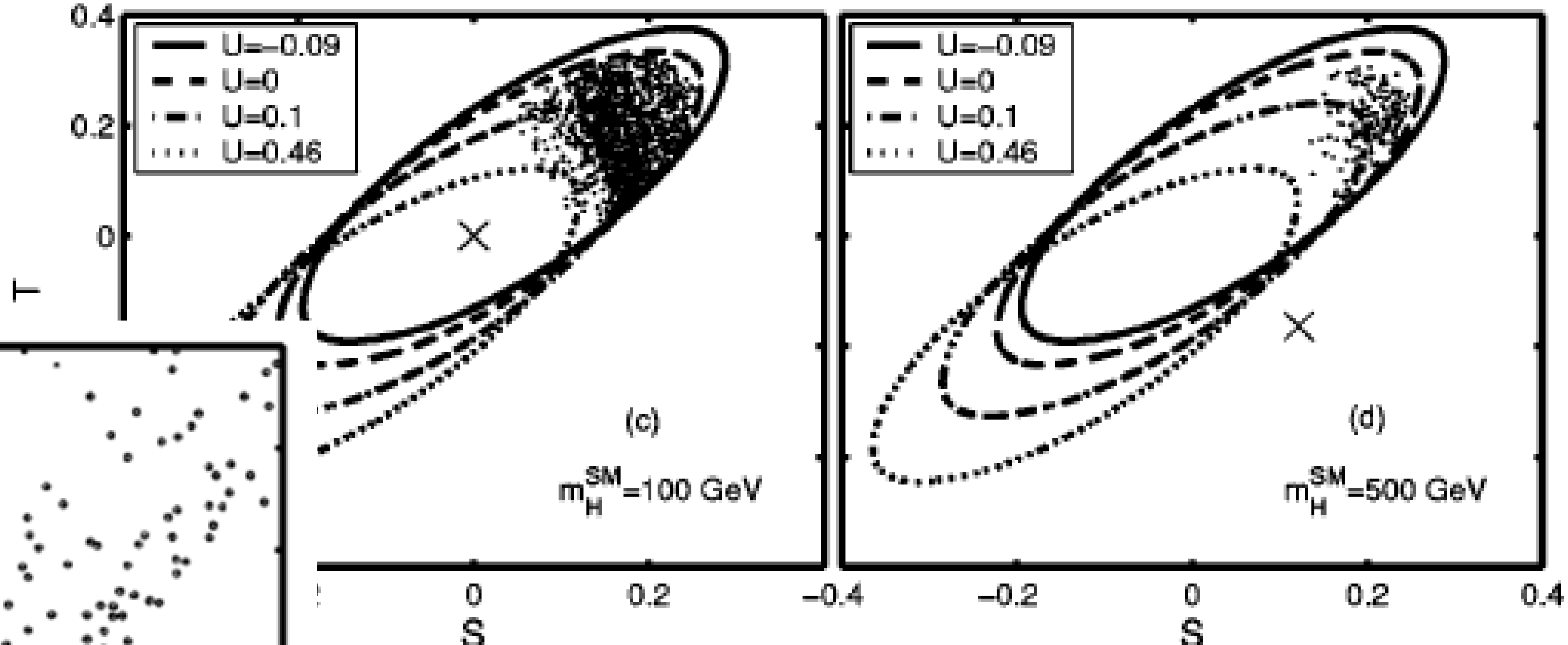
These fits also give a probability for Higgs mass

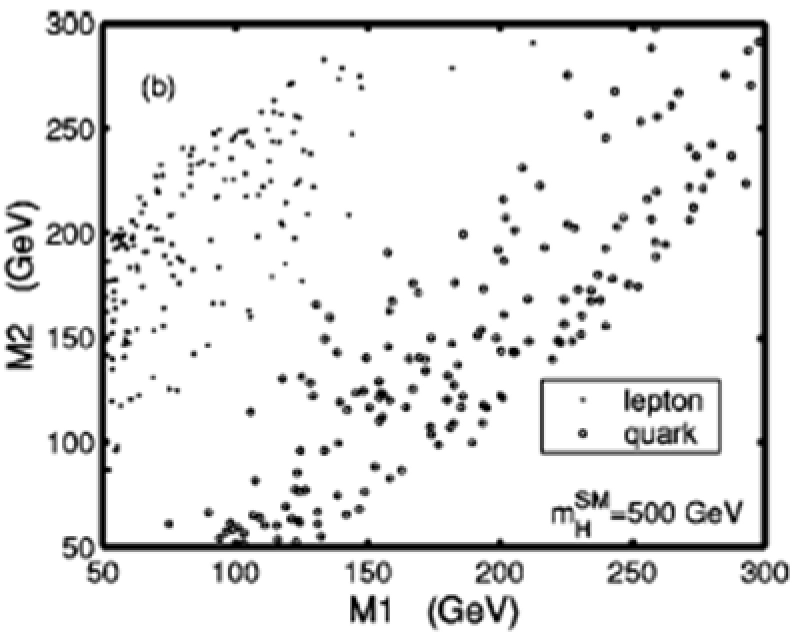
2007 version of Jens Erler, Paul Langacker [PDG]

HPS analysis

He, Polonosky & Su   Phys. Rev. D64, 053004

Found ΔS, ΔT, ΔU for 4 added fermions, as a function of the mass of these fermions





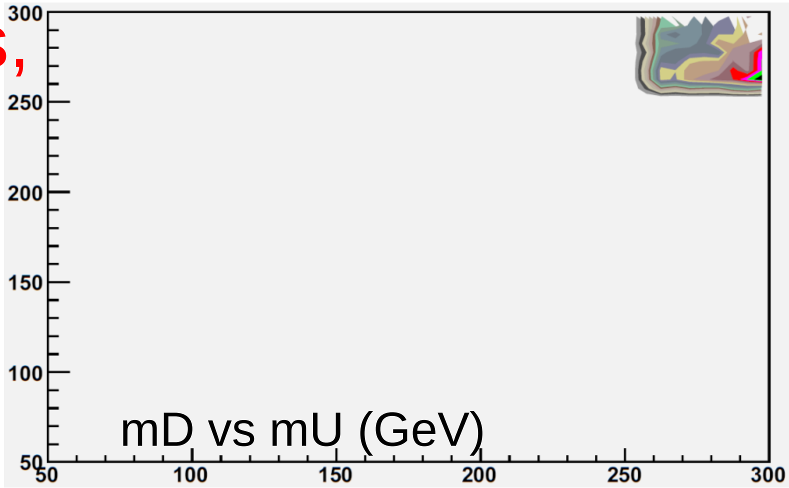
What we did

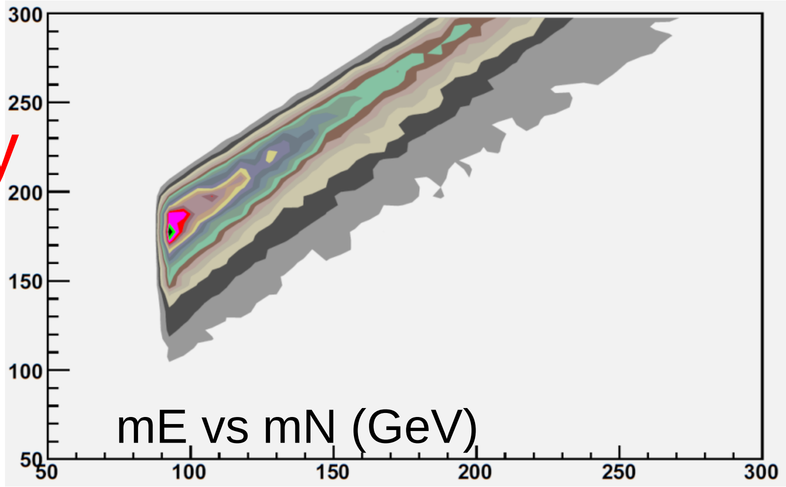
Randomly select a vector of 4 masses, uniformly distributed 50-300 GeV

(STU expressions of HePoSu invalid at high masses)

Accept that vector as possible if oblique corrections within 2σ of STU constraints

Fill plot weighted by probability density function for electroweak parameters





i.e. If there is a 4thG, what is the probability function for the four masses?

Original analysis

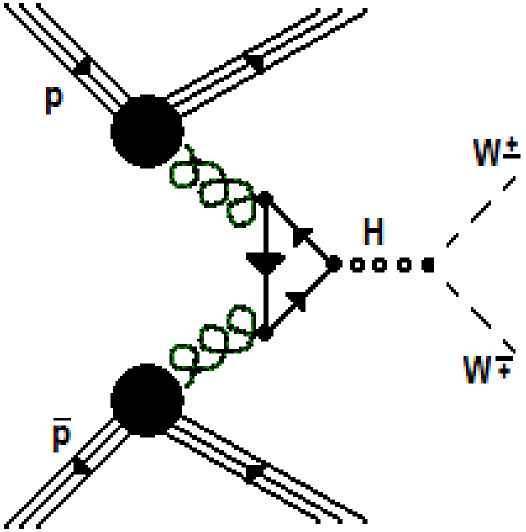
Using $m_H > 114.4$ GeV

weighted by probability given existing experimental data

Updated constraints on m_H

FNAL PUB 10-125-E
arXiv: 1005.3216

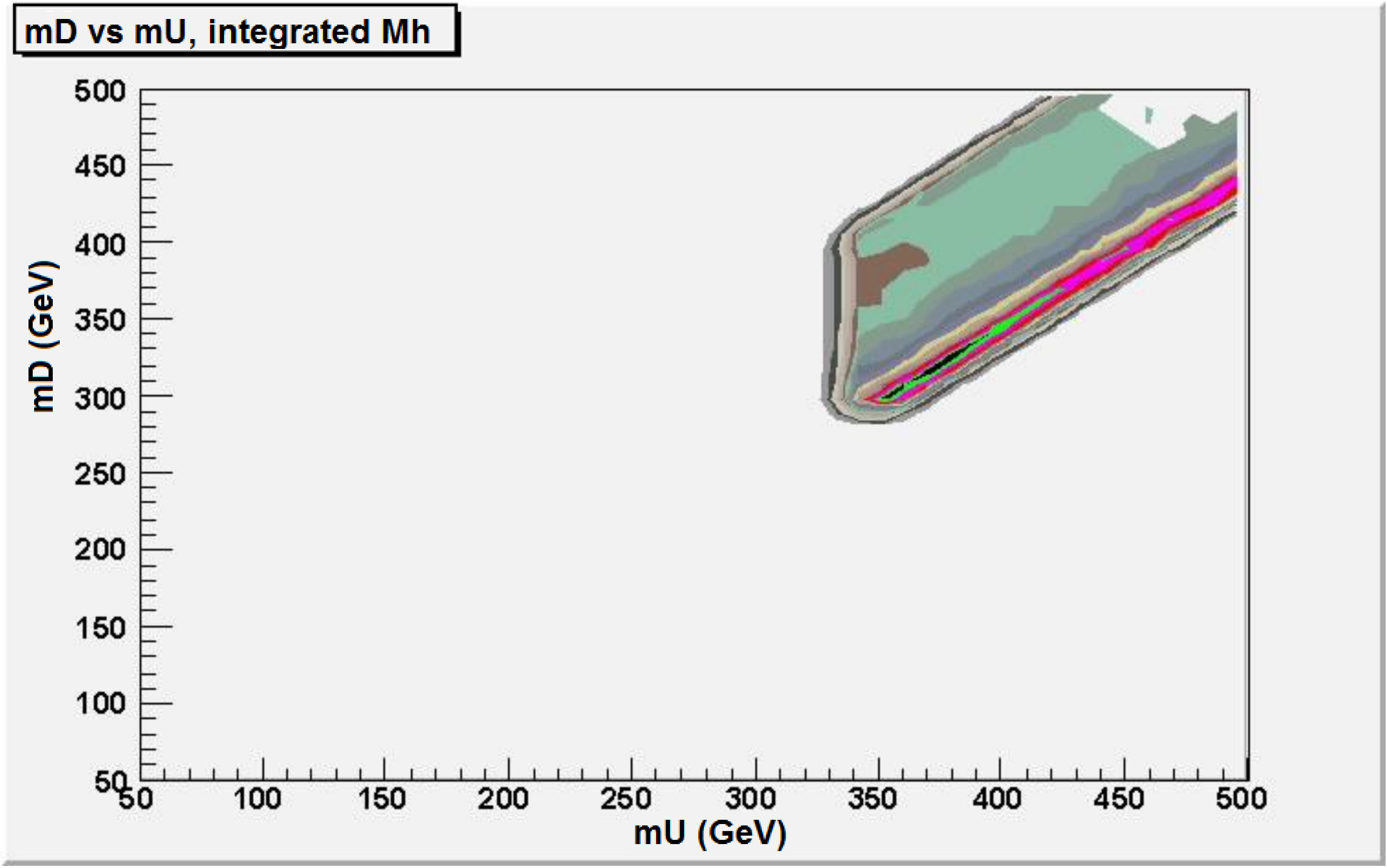
CDF $4.8\ fb^{-1}$ DØ $5.4 fb^{-1}$



exclude Higgs boson mass range in 4th G scenario

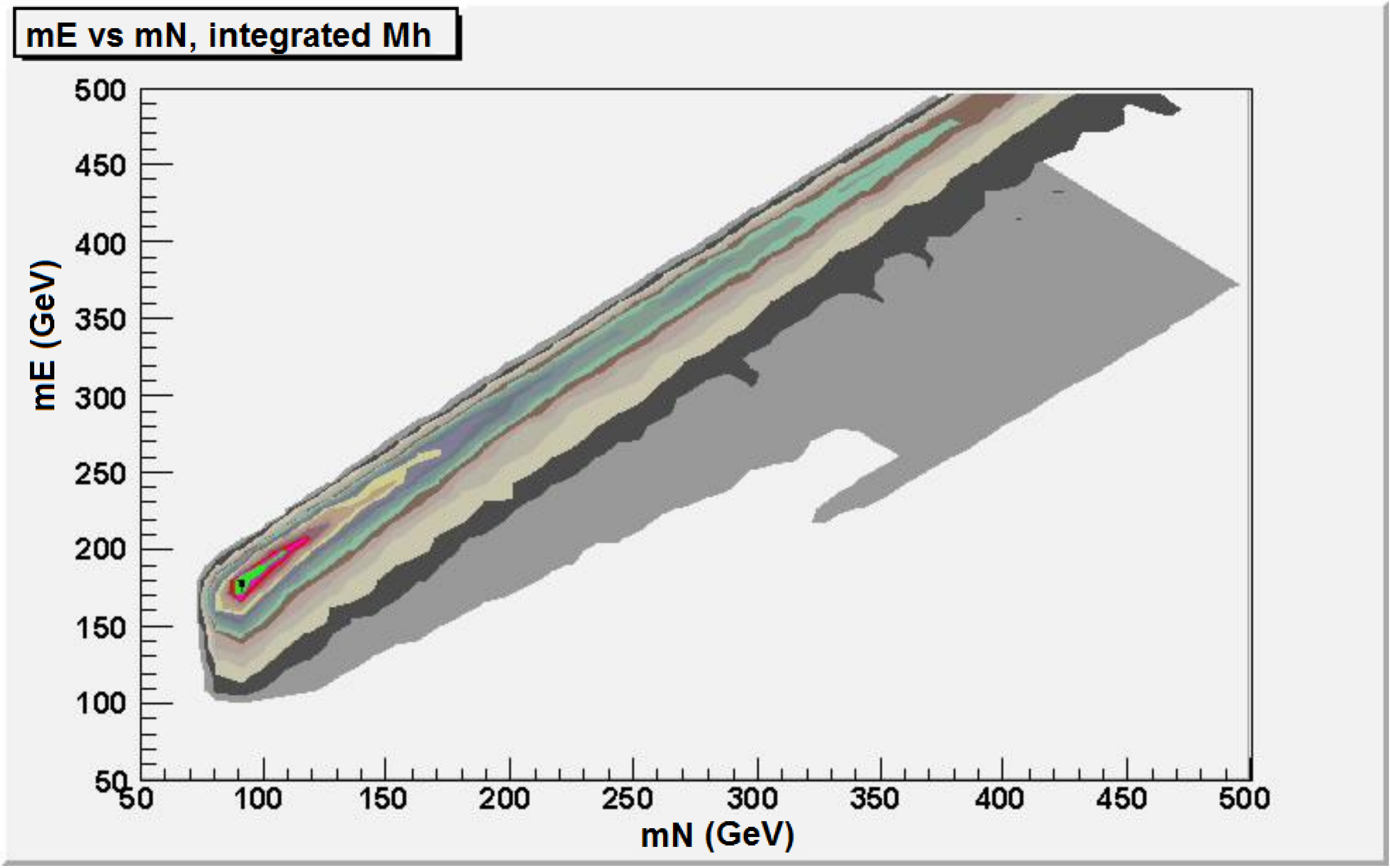
$131 < m_H < 204$, 95% confidence level

Results

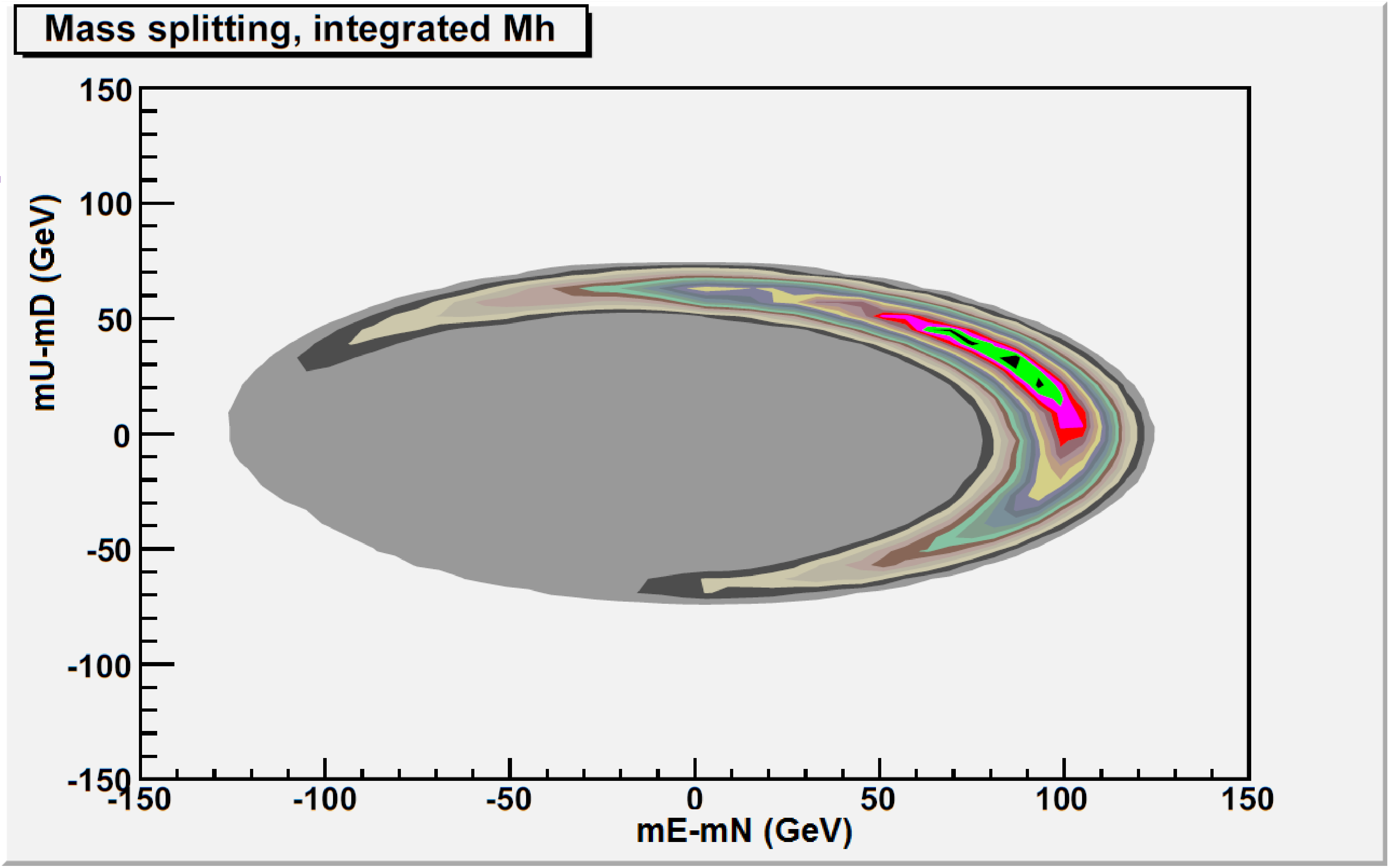


mD vs mU, integrated Mh
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
350
400
450
500
mD (GeV)
mU (GeV)

Results


mE vs mN, integrated Mh
mE (GeV)
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
350
400
450
500
mN (GeV)

Results



Mass splitting, integrated Mh
mU-mD (GeV)
mE-mN (GeV)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150

Backup slides

Direct Mass Limits for Chiral Fourth-Generation Quarks in All Mixing Scenarios

Flacco, et. al. arXiv: 1005.1077 May 2010

m(U) > 335 GeV U→W{q=d,s,b} lepton + 4 jets

CDF Note 4.6 fb^{-1}

http://www-cdf.fnal.gov/physics/new/top/2010/tprop/Tprime_v46_public/public_4.6.html

m(D) > 338 GeV D→Wt dilepton + j + b + MET

CDF 2.7 fb^{-1} arxiv: 0912.1057

The *S* parameter measures the difference between the number of left-handed fermions and the number of right-handed fermions that carry weak isospin. It tightly constrains the allowable number of new fourth-generation chiral fermions. This is a problem for theories like the simplest version of technicolor that contain a large number of extra fermion doublets.

The *T* parameter measures isospin violation, since it is sensitive to the difference between the loop corrections to the Z boson vacuum polarization function and the W boson vacuum polarization function. An example of isospin violation is the large mass splitting between the top quark and the bottom quark, which are isospin partners to each other and in the limit of isospin symmetry would have equal mass.

The *S* and *T* parameters are both affected by varying the mass of the Higgs boson (recall that the zero point of *S* and *T* is defined relative to a reference value of the Standard Model Higgs mass). The Higgs boson of the Standard Model has not been discovered, and experiments at the CERN LEP collider have set a lower bound of 114 GeV on its mass. However, if we assume that the Standard Model is correct, a best fit value of the Higgs mass can be extracted from the *S, T* fit. The best fit is near the current lower bound, and the 95% confidence level upper bound is around 200 GeV. If there is new physics, the corrections to *S* and *T* from the new physics can compensate for the effects of a heavier Higgs boson, relaxing this constraint.

The *U* parameter tends not to be very useful in practice, because the contributions to *U* from most new physics models are very small. This is because *U* actually parameterizes the coefficient of a dimension-eight operator, while *S* and *T* can be represented as dimension-six operators.

Updated constraints on m_H

FNAL PUB 10-125-E
arXiv: 1005.3216

$gg \rightarrow H \rightarrow W^+W^-$

CDF: $4.8\ fb^{-1}$ DØ: $5.4 fb^{-1}$

95% confidence level upper limit

on $\sigma(gg \rightarrow H) \times \mathscr{B}(H \rightarrow W^+W^-)$

- 7.5 pb @ m_H=120GeV
- 0.38 pb @ m_H=165GeV
- 0.83 pb @ m_H=200GeV

Exclude Higgs boson mass range $131 < m_H < 204$

Obvious Constraints

- $m(U,D,N,E) > m(Z) / 2$ LEP I
- $\min\{ m(U),m(D) \} > m(t)$

  or would have seen it while discovering top

Project This Summer

m_H fit

- Incorporate multiple exclusion zones when integrating over Higgs boson mass

GAPP: Global Analysis of Particle Properties

- A FORTRAN package designed for analysis of electroweak data.

ROOT

Make