The first year of the LHC and Theory

G.G.Ross, Krakow, December 09

The 2009/10 data sample

- Beam energy
  - No intention of long running below 5 TeV/beam
  - Short collision run at injection energy 450 GeV/beam
  - Possibly stop along the way several times for machine commissioning
  - Reach 5 TeV/beam a.s.a.p.

- Data volume
  - Peak Luminosities from $5x10^{31}$ to $2x10^{32}$ $cm^{-2}s^{-1}$
  - First 100 days of operation ~ 100 pb^{-1}
  - Next 100 days of operation ~ 200 pb^{-1}

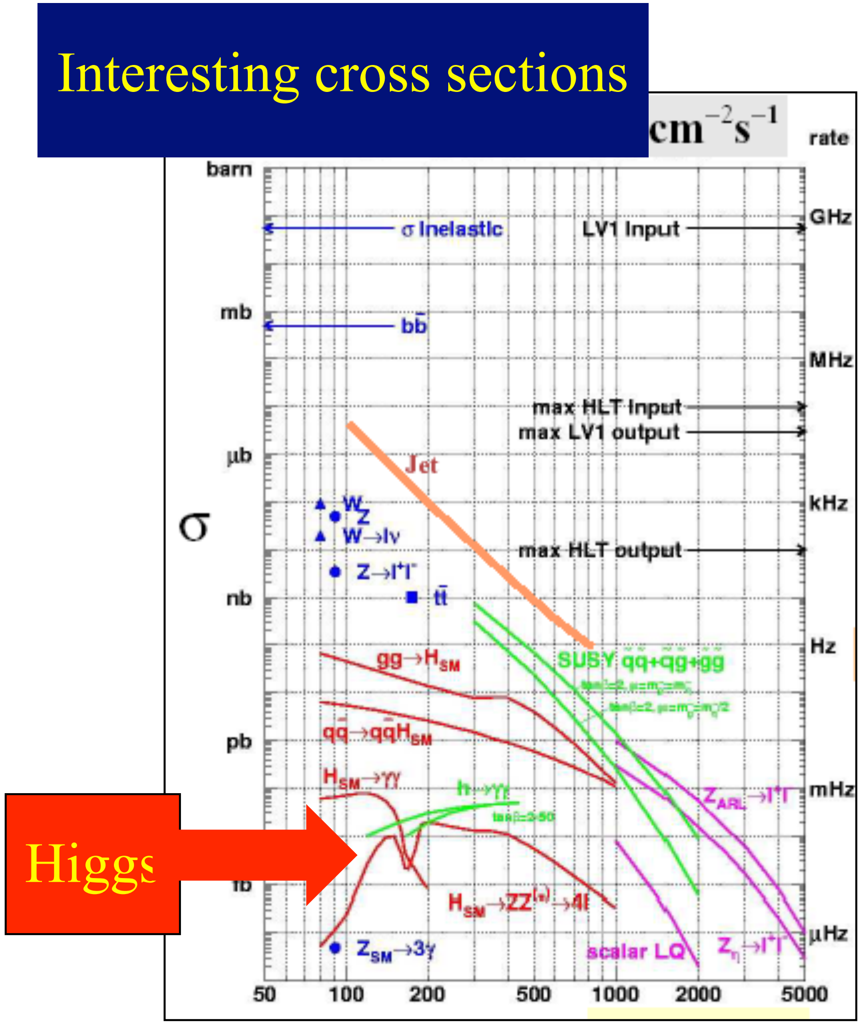
→ Large Uncertainties: somewhere between 100 – 500 pb^{-1} ?

The LHC – a discovery machine

- The gauge sector : new gauge bosons?
- The matter sector : new quarks and leptons?
- The scalar sector : the hierarchy problem and BSM

  Technicolour, SUSY, Xtra dimensions, Little Higgs …

What can be found in the first year?



The (SM) Higgs search

Higgs particle
(*scalar*, *spin* 0)

$$H$$

THE PERIODIC TABLE

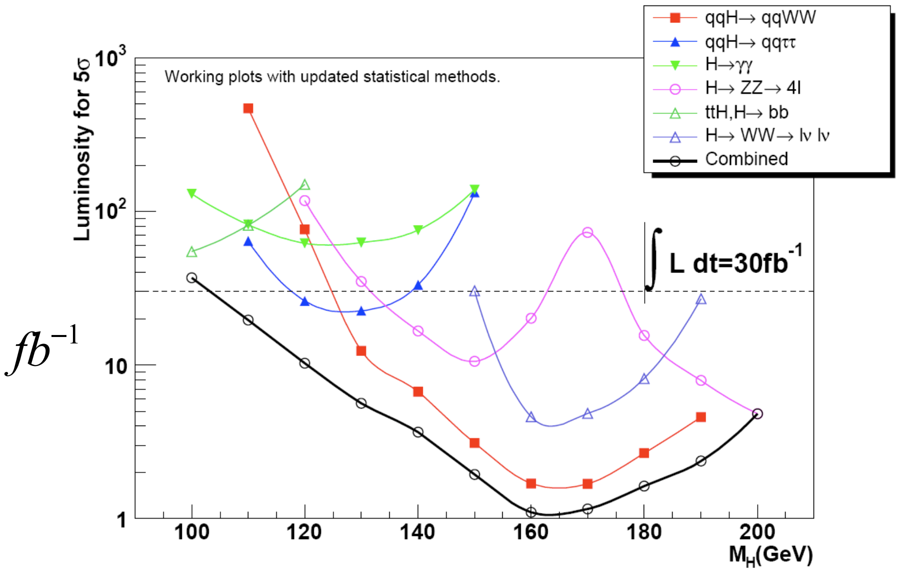
Particles like the electron (fermions, spin 1/2)

Leptons		Quarks (each in 3 "colors")	
e 0.511 MeV	ν_e < 0.000003	d 7	u 3
μ 106	ν_μ < 0.2	s 120	c 1200
τ 1777	ν_τ < 20	b 4300	t 175,000
−1	0	−1/3	2/3 ← charge

Particles like the photon (bosons, spin 1)

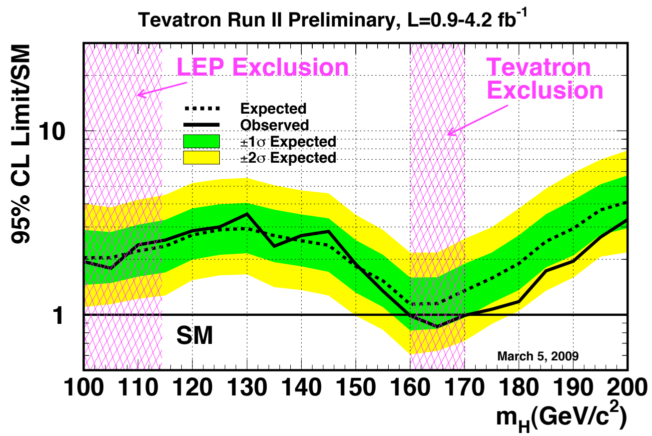
γ 0	photon	"electromagnetism"
g 0	gluon (8 "colors")	"strong interaction"
$W^\pm$ 80,420	Z^0 91,188	"weak interaction"

LHC search



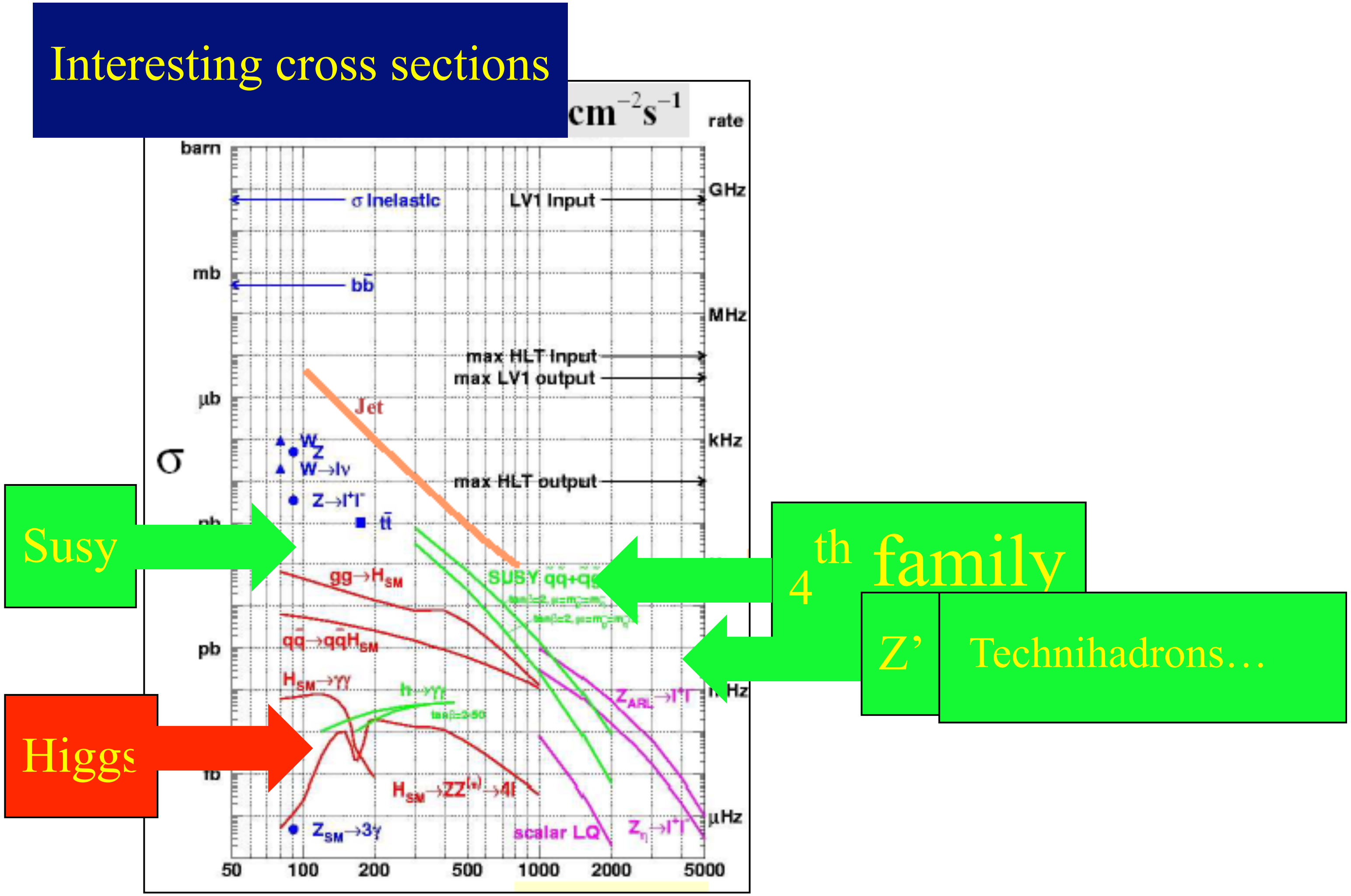
$$p\ p \rightarrow q\ q\ H \rightarrow q\ q\ W\ W$$

...



Tevatron competition

What can be found in the first year?



A new gauge boson?

Extension of the SM gauge symmetry

... quite likely... $U(1)', SU(2)_R, SO(10), E_6, SU(3)_{family}, \ldots$

Minimal Z' models

- $SU(3) \times SU(2) \times U(1) \times U(1)'$
- Only SM fermions + RH neutrinos
- Flavour blind couplings, no anomalies

$SU(3) \times SU(2) \times U(1) \times U(1)'$

- Higgs doublet, H, and singlet, ϕ
- Choose basis to eliminate kinetic mixing term $F_{\mu\nu} F'^{\mu}$ (at one scale)
- $SO(2)$ rotation - $U(1)_1$ decouples from ϕ
- Rescaling $U(1)_1$ coupling H charge =+1 $\Rightarrow U(1)_1 \equiv U(1)_Y$

$$\Rightarrow SU(3) \times SU(2) \times U(1)_Y \times U(1)_z$$

Mass term:

$$\frac{v_H^2}{8}\left(gW^{3\mu} - g_Y B_Y^\mu - z_H g_z B_z^\mu\right)\left(gW_\mu^3 - g_Y B_{Y\mu} - z_H g_z B_{z\mu}\right) + \frac{v_\varphi^2}{8} g_z^2 B_z^\mu B_{z\mu}$$

Appelquist, Dobrescu, Hopper

Anomaly cancellation and fermion mass terms:

	(u,d)	u^c	d^c	(ν,e)	ν^c	e^c
T_{3L}	$(+\frac{1}{2},-\frac{1}{2})$	0	0	$(+\frac{1}{2},-\frac{1}{2})$	0	0
Y	$+\frac{1}{6}$	$-\frac{2}{3}$	$+\frac{1}{3}$	$-\frac{1}{2}$	0	$+1$
$B-L$	$+\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	-1	$+1$	$+1$
$Q_{Z'}$	$\frac{1}{6}\widetilde{g}_Y+\frac{1}{3}\widetilde{g}_{BL}$	$-\frac{2}{3}\widetilde{g}_Y-\frac{1}{3}\widetilde{g}_{BL}$	$\frac{1}{3}\widetilde{g}_Y-\frac{1}{3}\widetilde{g}_{BL}$	$-\frac{1}{2}\widetilde{g}_Y-\widetilde{g}_{BL}$	$\widetilde{g}_{BL}$	$\widetilde{g}_Y+\widetilde{g}_{BL}$

Table 1: The charges of left-handed fermions controlling the electroweak neutral currents.

$$L_{NC}=eAJ_{EM}+g_Z\left(ZJ_Z+Z'J_{z'}\right)$$

3 independent parameters

$$J_{z'}=(g_Y/g_Z)J_Y+(g_{BL}/g_Z)J_{B-L}$$

$g_Z, g_{BL}, M_{Z'}$

c.f. specific models

	Z_{B-L}	Z_χ	Z_{3R}
g_Y	0	$-\frac{2}{\sqrt{10}}g_{Z'}$	$-g_{Z'}$
g_{B-L}	$\sqrt{\frac{3}{8}}g_{Z'}$	$\frac{5}{2\sqrt{10}}g_{Z'}$	$\frac{1}{2}g_{Z'}$

Constraints from GUTs

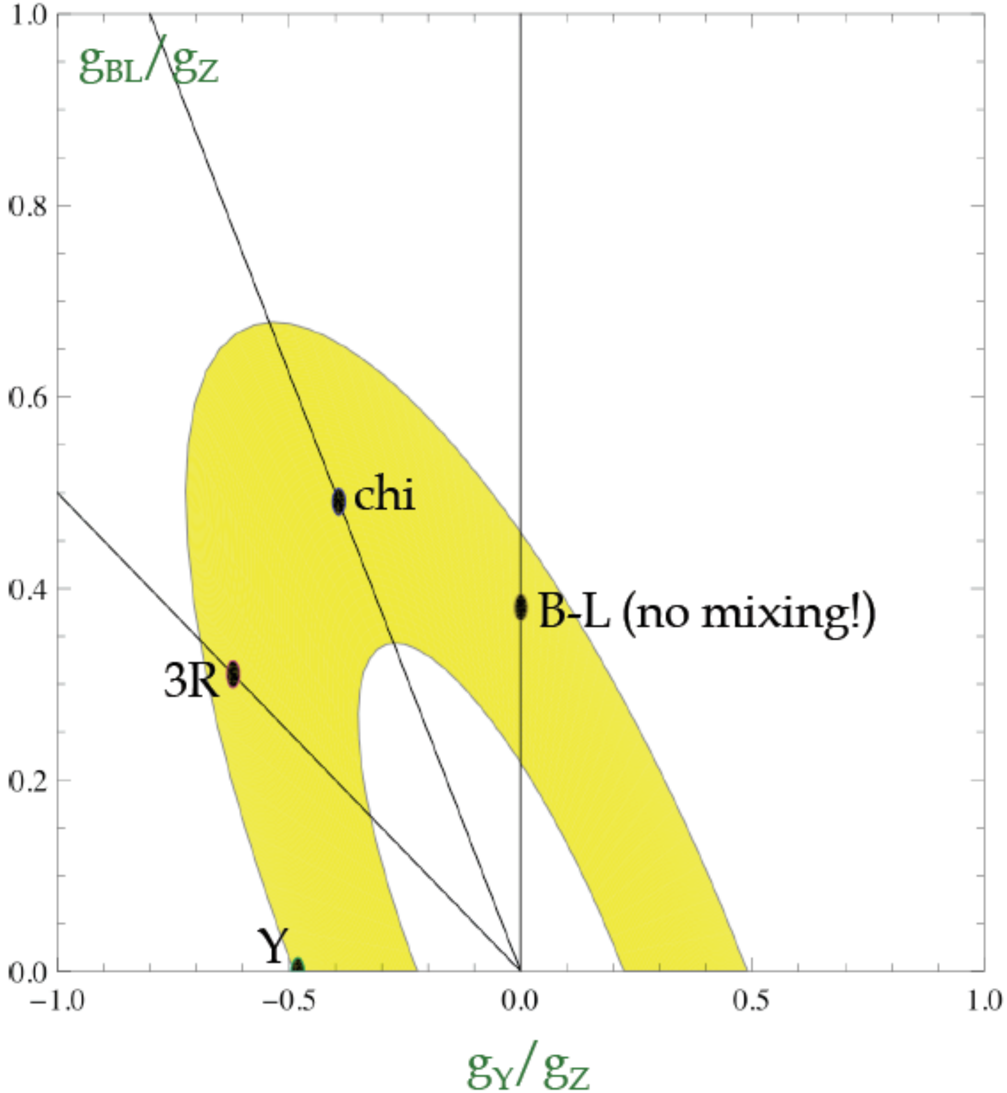
Plausible range of boundary conditions @ M_U~10^{16} GeV

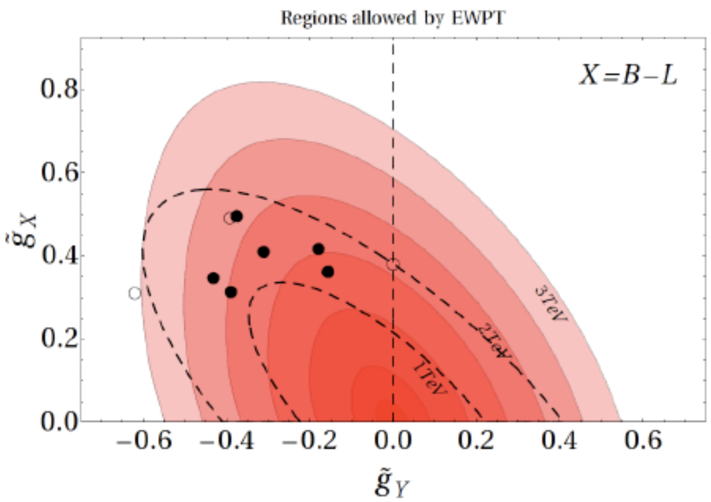
RGE running from M_U to M_Z (SM or MSSM)

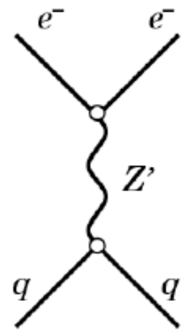
↓

favoured range in (g_Y , g_{BL}) plane

Specific models = special points







APV

Bounds from EWPT

LEP1, Tevatron, SLD:

M_Z, M_W, m_{top}, G_F, $\alpha_s(M_Z)$, $\alpha_{em}(M_Z)$, Γ_Z, $\sigma(e^+e^- \to hadrons)$,

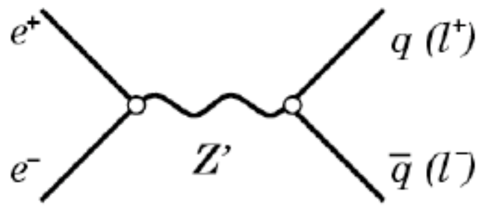
$A_{FB}^{e,\mu,\tau,\,b,c}$, τ*-pol asym*, $BR(Z \to hadrons, cc, bb)$, $A_{LR}^{e,\mu,\tau,\,b,c}$.

LEP2 (183÷207 GeV):

$\sigma(e^+e^- \to qq, bb, \mu^+\mu^-, \tau^+\tau^-)$, $A_{FB}^{\mu,\tau,b}$, $d(e^+e^- \to e^+e^-)/d\cos\theta$

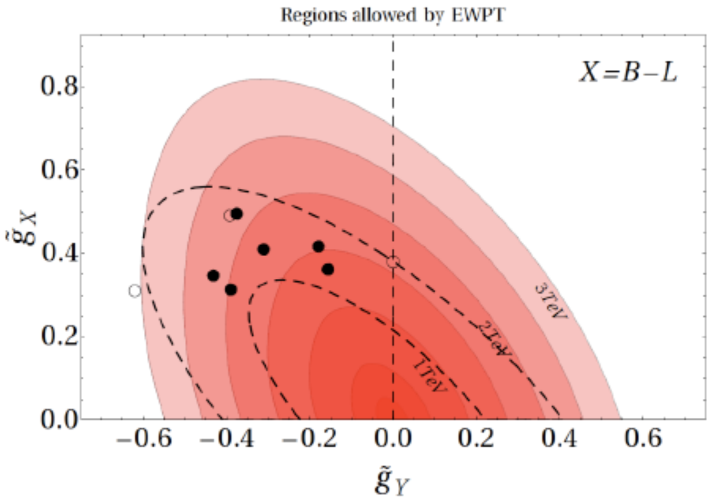
Low-energy measurements:

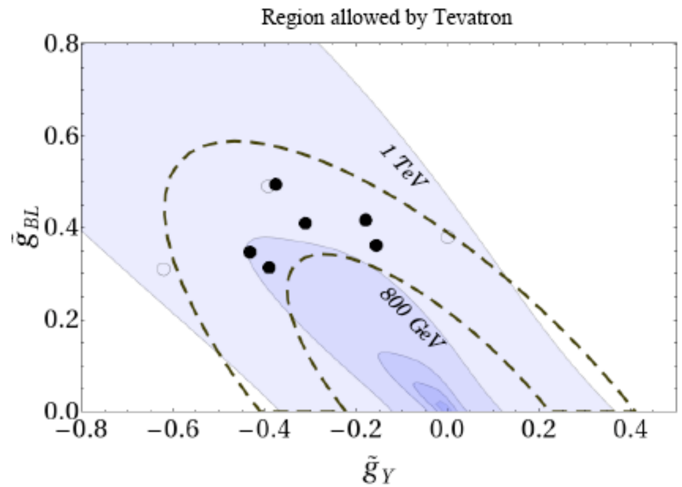
Möller scattering at $Q^2 = 0.026\ GeV^2$, *APV in Cs*, ν-N (NuTeV), $(g\text{-}2)_\mu$

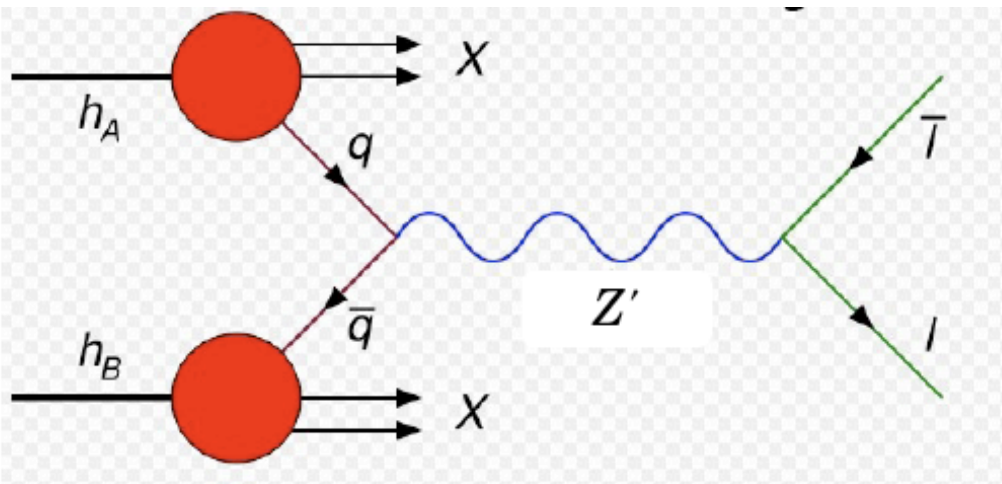


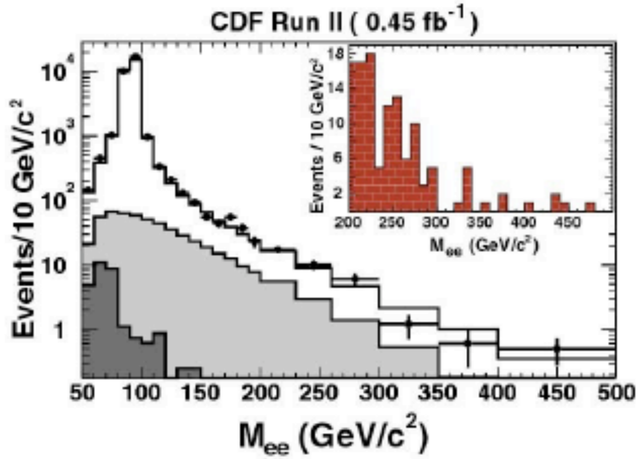
LEP

Salvioni, Villadora, Zwirner

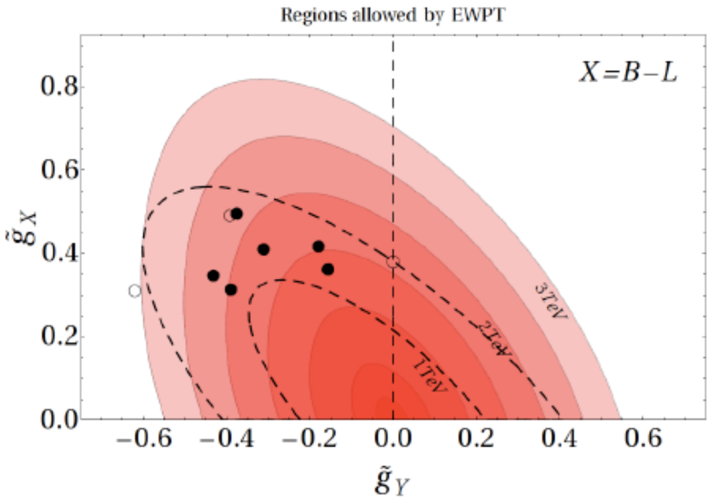


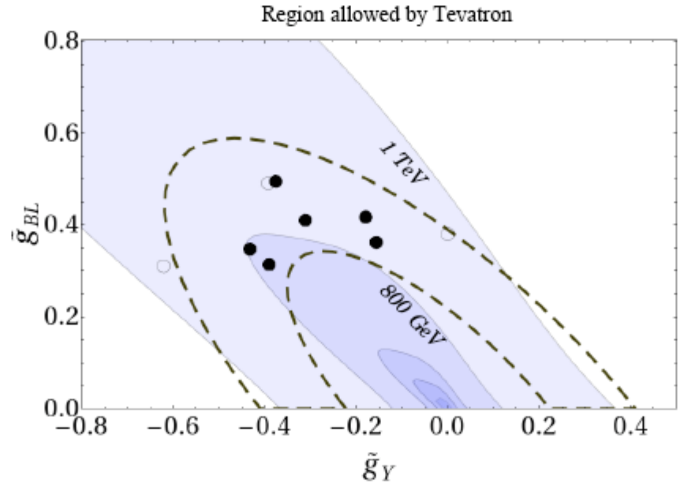


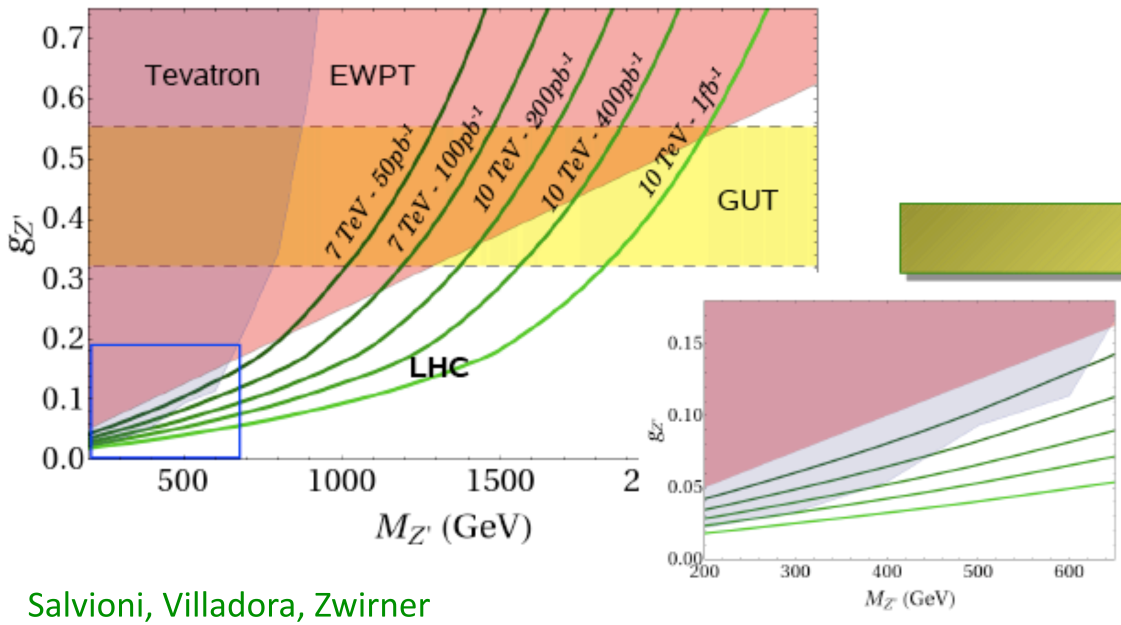




Salvioni, Villadora, Zwirner



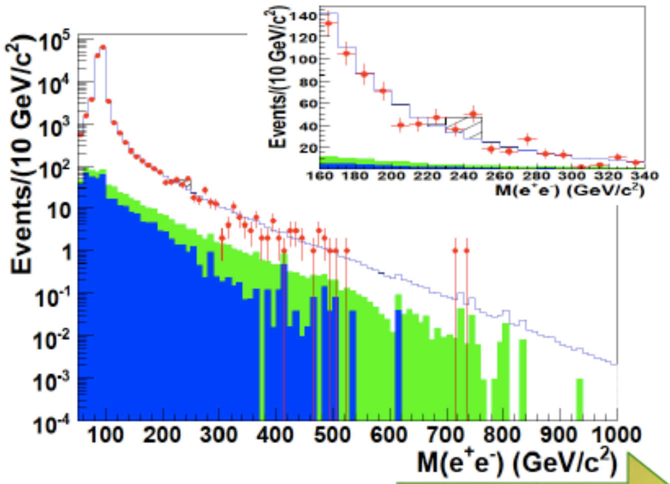




Existing bounds are strong
difficult to see
something new very soon

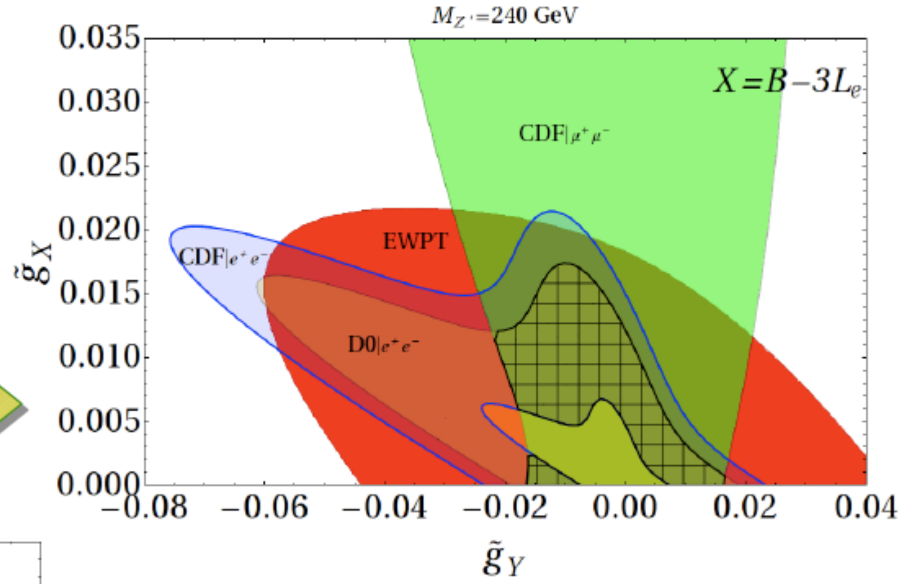
Salvioni, Villadora, Zwirner

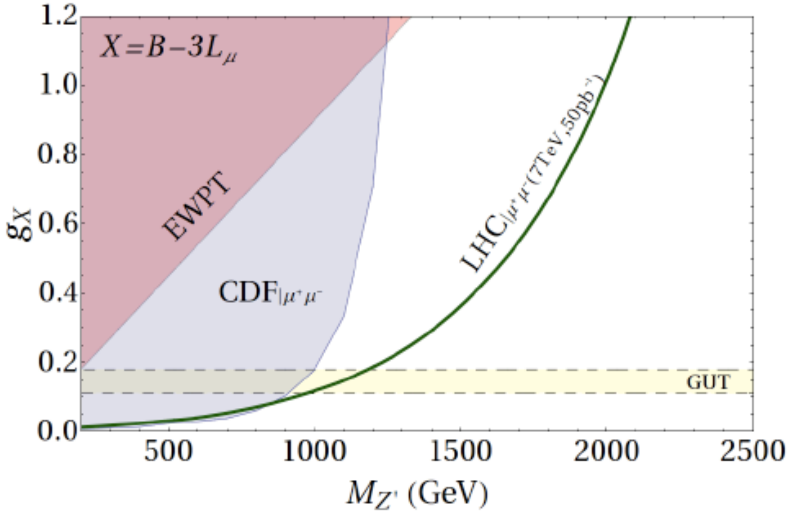
Family dependent couplings :



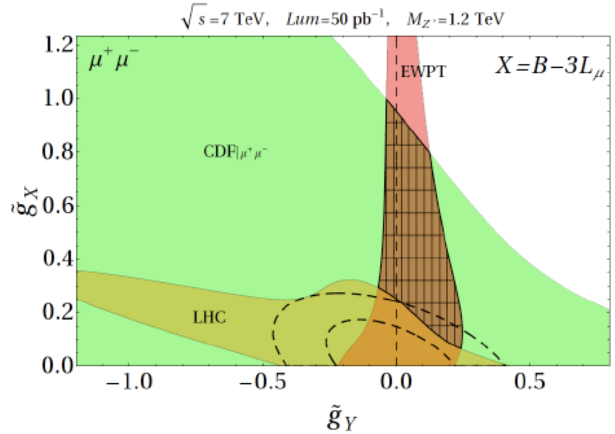
CDF e^+e^- excess

B–$3L_e$ model





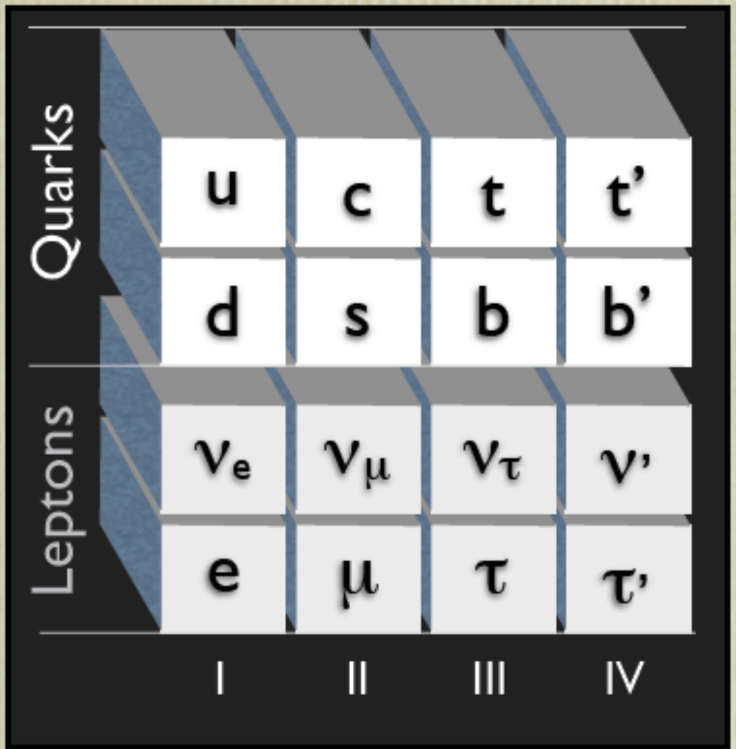
B–$3L_\mu$ model:



Salvioni, Strumia, Villadora, Zwirner

4 generations ?

- Fourth generation is the simplest "modification" to SM as we know it today
  - ➡SM does not give #families => not a true modification
  - ➡predicts 4 new heavy fermions with 1TeV > m >100GeV

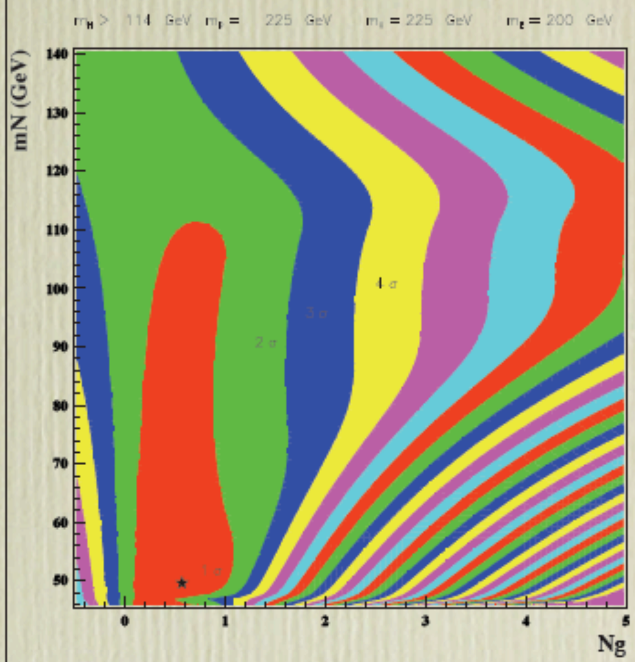


Viable?

- What about the 6σ evidence reported by PDG against 4th generation from the "S parameter alone"?
  - ➡Valid only if total mass degeneracy, e.g.

$$\delta S = \frac{2}{3\pi} - \frac{1}{3\pi}\left[\log\frac{m_{t'}}{m_{b'}} - \log\frac{m_{\nu'_\tau}}{m_{\tau'}}\right]$$

- What about EW fits?
  - ➡SM3 & SM4 have same χ^2 from fits,
  - ➡SM4 can accommodate heavier Higgs



- What about CKM?
  - ➡There is enough uncertainty for a 4x4 unitary matrix

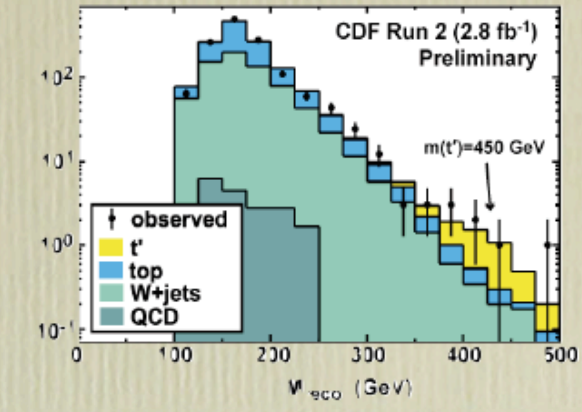
$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999 \pm 0.0011 = 1 - |V_{ub'}|^2$$

$$|V_{ub'}| < 0.04$$

Desirable?

- CPV source (for BAU)
  - ➡3x3 CKM is 10^{10} too short to match WMAP data
  - ➡new quarks of (300) 600 GeV would give (10^{13}) 10^{15} more CPV
- Alternative EW symmetry breaking
  - ➡4^{th} generation fermion condensate can play the Higgs role
  - ➡5D AdS, K.K. excitations of gauge bosons interacting w/ 4th generation fermions => Yukawa couplings & mass hierarchy
- Fermion mass hierarchy
  - ➡observed masses of fermions in the first 3 families arise from perturbations to a flavour-blind 4x4 mass matrix.
- Dark Matter candidates
  - ➡hadrons from stable t', ν', additional fermions of spin-charge unification models

Discoverable?



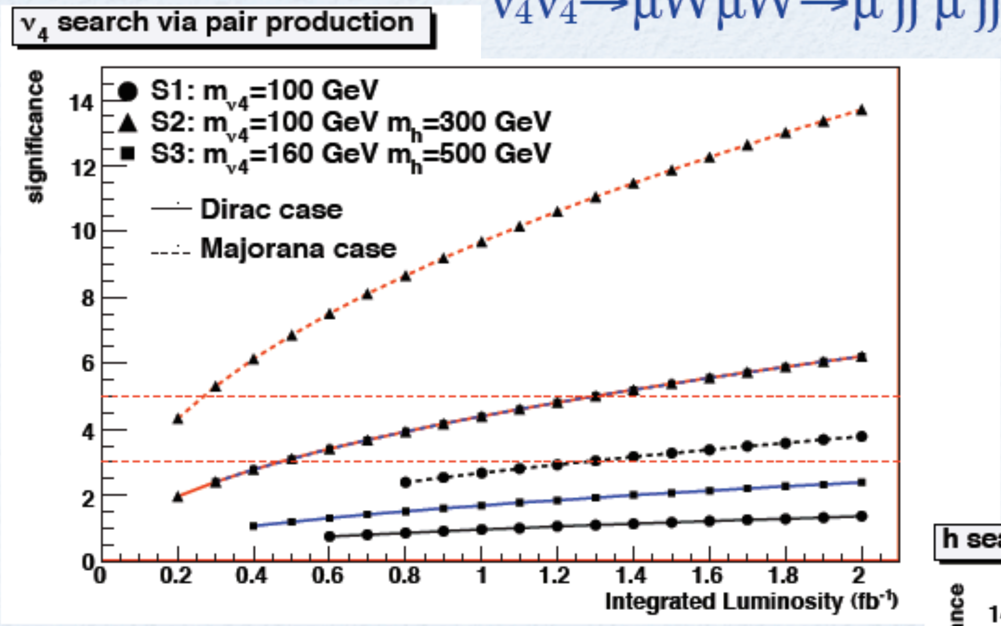
- Tevatron prospects: ongoing...
  - ➡direct t′ search from Wj channel
  - ➡indirect search via Higgs enhancement
  - ➡indirect search via mixing-dependent CPV in B_s->J/Ψ Φ

- LHC prospects (discover or exclude the 4th generation)
  - ➡Quarks as the main target $b'\bar{b}' \rightarrow b\bar{b}W^+W^-W^+W^-$
    - Pair production: ATLAS (1999 TDR and post-TDR) & CMS (post TDR) from early data : 0.1fb^{-1} Lumi reaches 300GeV. same sign dilepton or trilepton signals
    - Single and/or anomalous production => could measure 4x4 CKM.
  - ➡Leptons ==> Do we need to wait for the Linear Colliders?

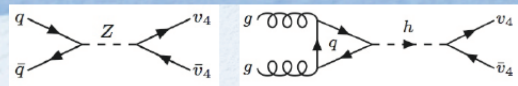
- Indirectly from B-factories
  - ➡Direct CPV difference in $B^+ \rightarrow K^+\pi^0$ & $B^0 \rightarrow K^+\pi^-$

$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0)$
$= -0.147 \pm 0.028$ @ 5.3σ

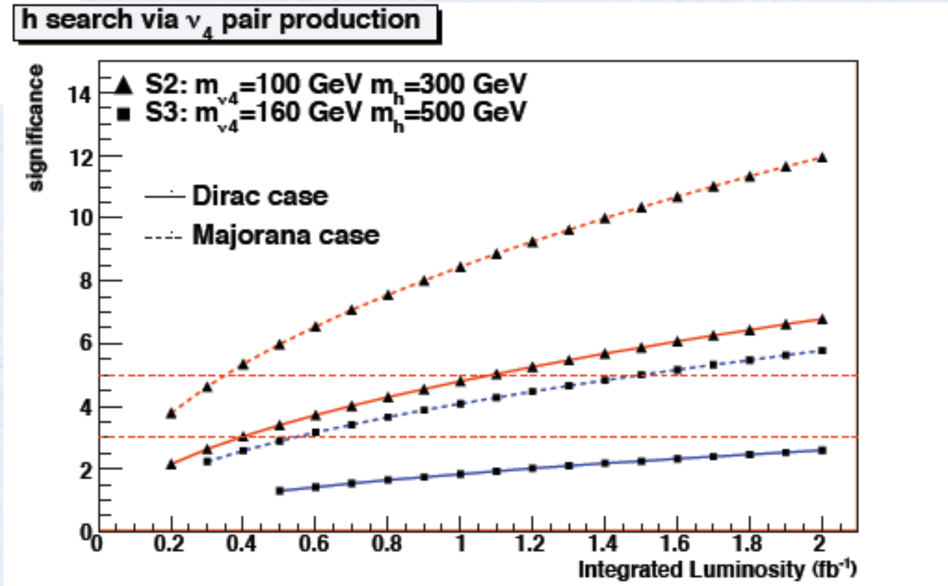
ν_4 & Higgs Discovery



$\nu_4\nu_4 \to \mu W \mu W \to \mu\, jj\, \mu\, jj$



- Majorana: 4 to 23 signal events per fb^{-1}, over 1 to 5 background.
- Dirac: ~5 times higher background.



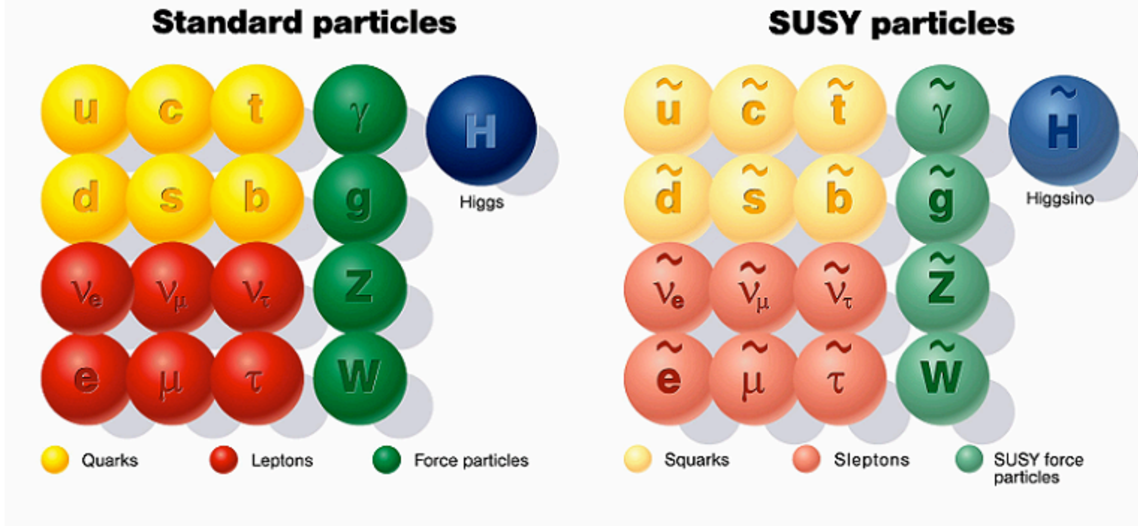
Majorana

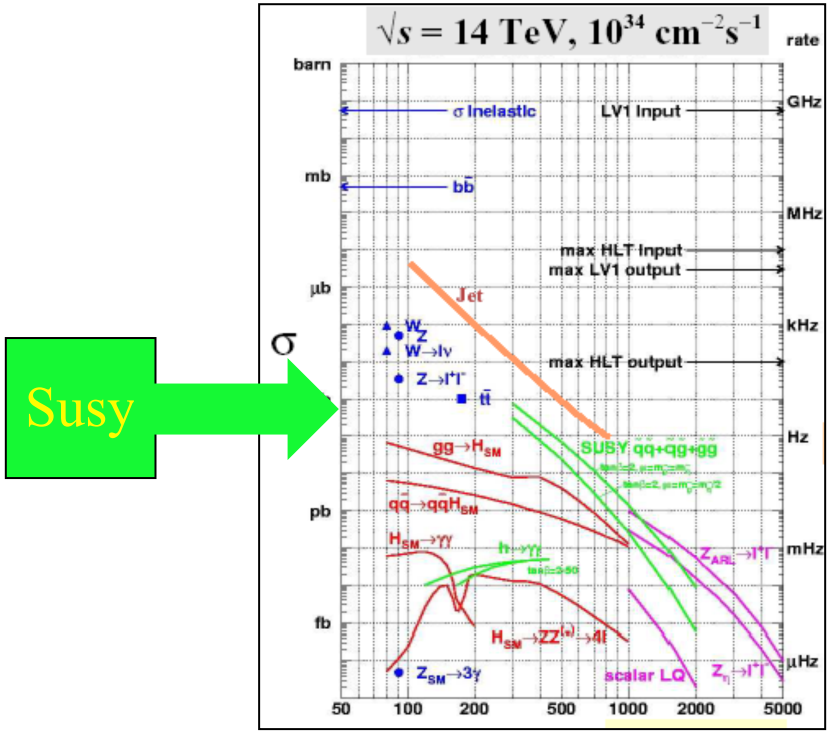
Scenario	lumi for 5σ
S1	~3.5 fb^{-1}
S2	~300 pb^{-1}
S3	~1.5 fb^{-1}

- The scalar sector : the hierarchy problem and BSM

  Technicolour, SUSY, Xtra dimensions, Little Higgs …

Supersymmetry?





SUSY mass scale?

The (Little) Hierarchy problem

$M_{Higgs,\, M_{W,Z}} \ll M_{Planck,\, M_{GUT},\ldots}$

CMSSM:

- Gravity mediated SUSY breaking
- R-parity
- $m_0, m_{1/2}, A_0, \tan\beta, \mathrm{sgn}(\mu)$

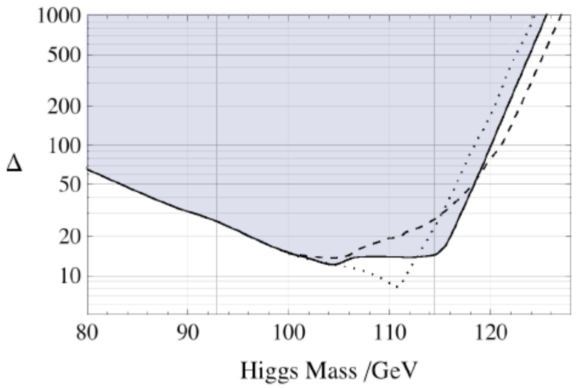
$M_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$

$$M_{h^0}^2 = M_Z^2 \cos^2 2\beta + \frac{3M_t^2 h_t^2}{4\pi^2}\left(\ln(\frac{M_S^2}{M_t^2}) + \delta_t\right) + \cdots \quad \geq 114\, GeV\, (SM)$$

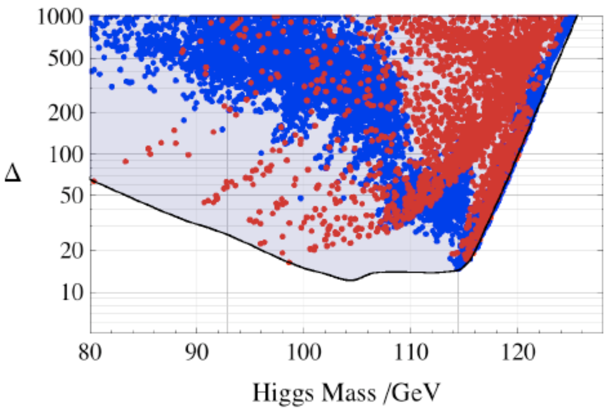
$$M_Z^2 = -2\left(a_0 m_0^2 + a_{1/2} m_{1/2}^2 + \mu^2\right) \ll \tilde{m}_{q_i}^2,\ M_i^2$$

$\Rightarrow$ Fine tuning

Fine tuning measure $\Delta(\rho)=\left|\frac{\delta\rho}{M_Z^2}\frac{\partial M_Z^2}{\partial\rho}\right|,\qquad \Delta_{\max}=Max_\rho\Delta(\rho)$ Ellis et al., Barbieri, Giudice



(a) Relic density unrestricted



(b) Points satisfying WMAP bound

CMSSM

SUSY particle masses

$3.20 < 10^4\ \mathrm{Br}(b \to s\gamma) < 3.84$

$\mathrm{Br}(b \to \mu\mu) < 1.8 \times 10^{-8}$

$\delta a_\mu < 292 \times 10^{-11}$

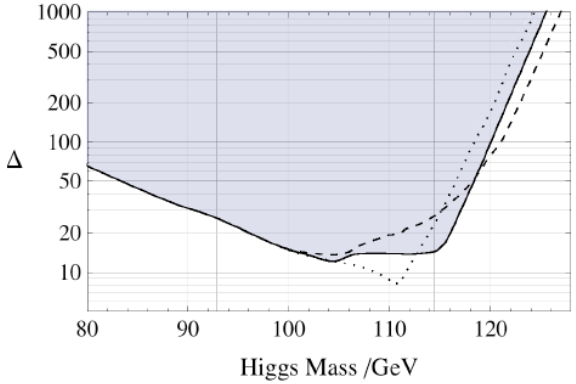
$-0.0007 < \delta\rho < 0.0012$

S.Cassel, D.Ghilencea, GGR

Fine tuning measure

$$\Delta(\rho) = \left| \frac{\delta\rho}{M_Z^2} \frac{\partial M_Z^2}{\partial \rho} \right|, \qquad \Delta_{\max} = Max_\rho \Delta(\rho)$$

Barbieri, Giudice



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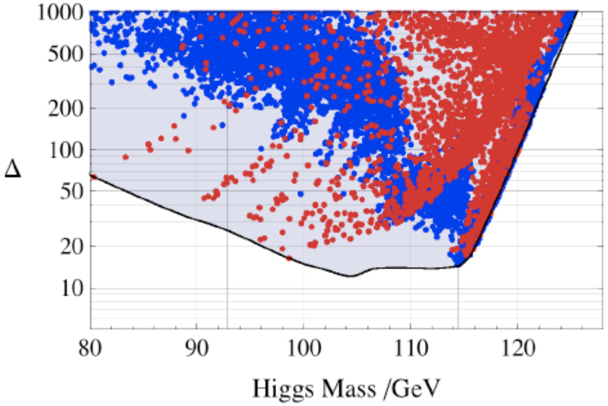

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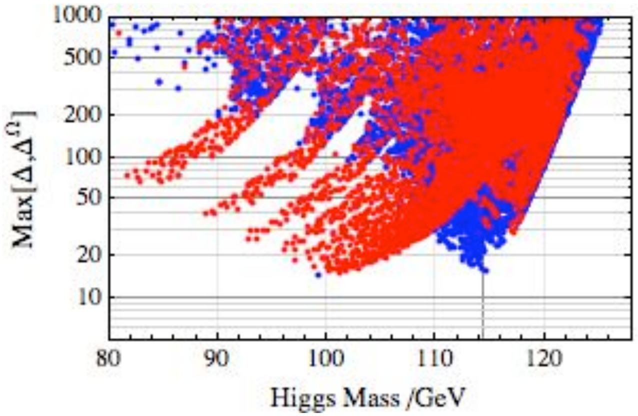
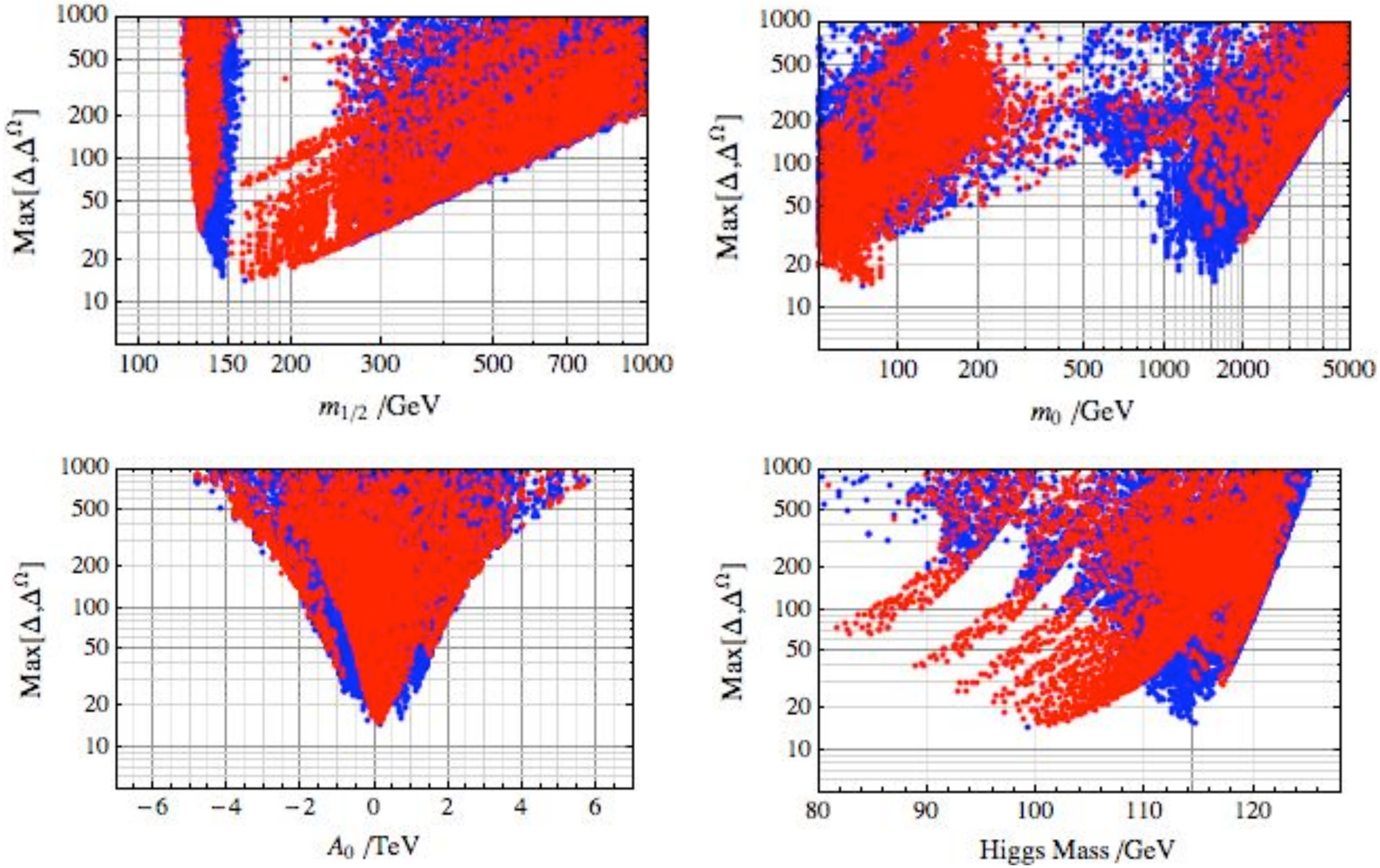


S.Cassel, D.Ghilencea, GGR

SUSY parameters



SUSY parameters

$$
\begin{array}{rclcrclcl}
m_h & < & 120 \text{ GeV} & & 5.5 & < & \tan\beta & < & 53 \\
\mu & < & 650 \text{ GeV} & & 120 \text{ GeV} & < & m_{1/2} & < & 720 \text{ GeV} \\
m_0 & < & 3.1 \text{ TeV} & & -1.8 \text{ TeV} & < & A_0 & < & 2.5 \text{ TeV}
\end{array}
$$

$\tilde{g}$	χ_1^0	χ_2^0	χ_3^0	χ_4^0	$\chi_1^\pm$	$\chi_2^\pm$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	$\tilde{b}_2$
1720	305	550	660	665	550	670	2080	2660	2660	3140

Table 1: Upper mass limits on superpartners in GeV such that $\Delta < 100$ remains possible.

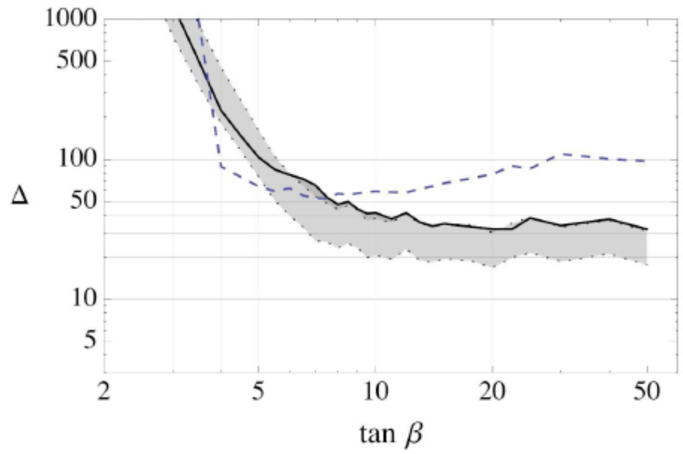
LHC $\sqrt{s} = 10(14)TeV$ $\mathbf{L} = 10\, fb^{-1}$ $m_{\tilde{g}} \leq 1.9(2.4)TeV$ $\Delta = 120(180)$

$\sqrt{s} = 10TeV$ $\mathbf{L} = 10\, pb^{-1}$ $m_{\tilde{g}} \leq 0.6TeV$ $\Delta = 14$

…Higgs search most sensitive

h^0	114.5	$\tilde{\chi}_1^0$	79	$\tilde{b}_1$	1147	$\tilde{u}_L$	1444
H^0	1264	$\tilde{\chi}_2^0$	142	$\tilde{b}_2$	1369	$\tilde{u}_R$	1446
$H^\pm$	1267	$\tilde{\chi}_3^0$	255	$\tilde{\tau}_1$	1328	$\tilde{d}_L$	1448
A^0	1264	$\tilde{\chi}_4^0$	280	$\tilde{\tau}_2$	1368	$\tilde{d}_R$	1446
$\tilde{g}$	549	$\tilde{\chi}_1^\pm$	142	$\tilde{\mu}_L$	1406	$\tilde{s}_L$	1448
$\tilde{\nu}_\tau$	1366	$\tilde{\chi}_2^\pm$	280	$\tilde{\mu}_R$	1406	$\tilde{s}_R$	1446
$\tilde{\nu}_\mu$	1404	$\tilde{t}_1$	873	$\tilde{e}_L$	1406	$\tilde{c}_L$	1444
$\tilde{\nu}_e$	1404	$\tilde{t}_2$	1158	$\tilde{e}_R$	1406	$\tilde{c}_R$	1446

Table 2: A favoured MSSM spectrum ($\Delta = 14.7$).



(b) $m_h > 114$ GeV

“little hierarchy problem” already severe

But not all parameter space probed yet…

Nonuniversal gaugino masses

$$16\pi^2 \frac{d}{dt} m_{H_u}^2 = 3\left(2\,|\,y_t\,|^2\,(m_{H_u}^2 + m_{Q_3}^2 + m_{\bar{u}3}^2) + 2\,|\,a_t\,|^2\right) - 6g_2^2\,|\,M_2\,|^2 - \frac{6}{5} g_1^2\,|\,M_1\,|^2$$

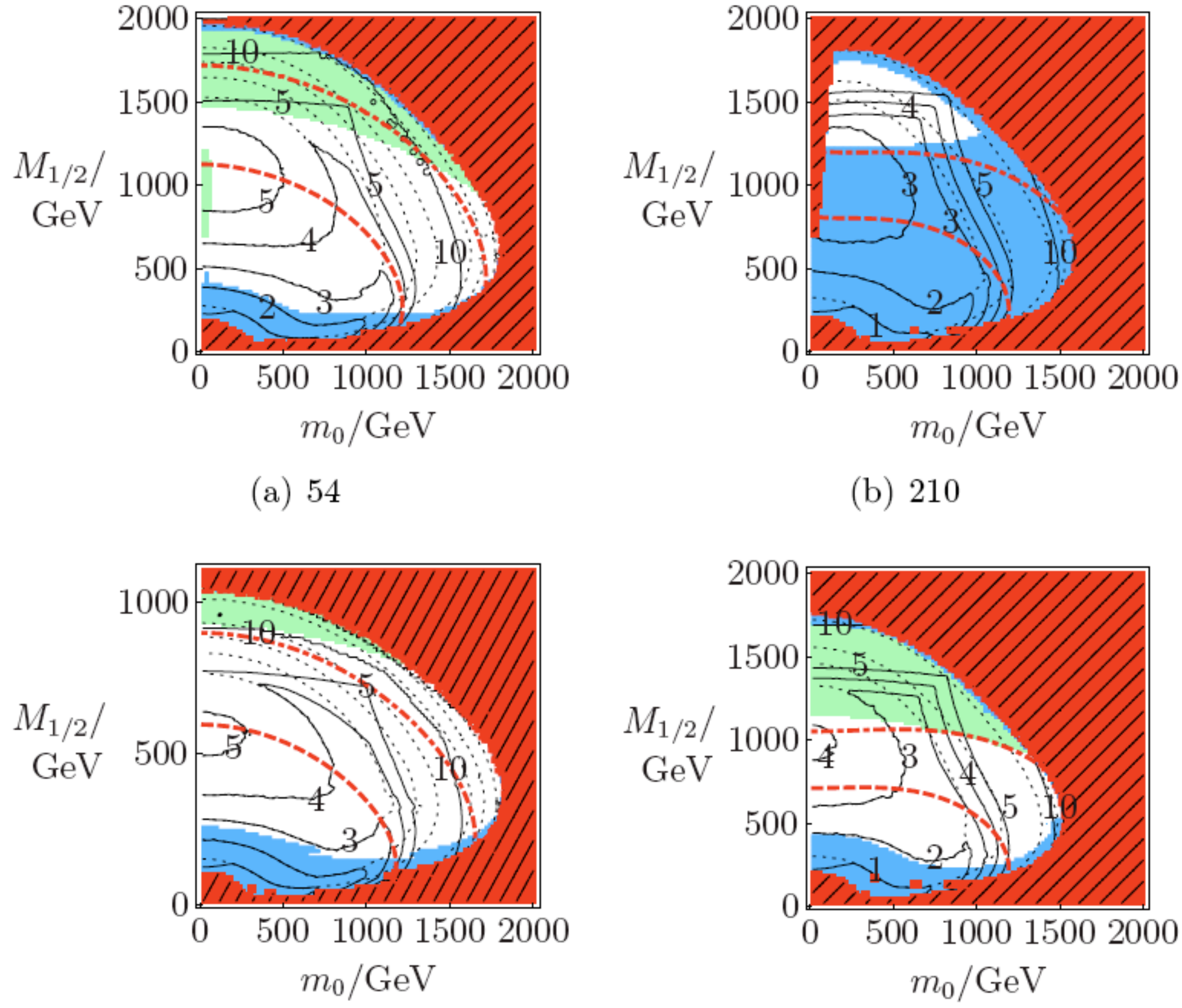
New focus point: cancellation between M_3 and M_2 contributions if $|M_2|^2 \simeq |M_3|^2$ at M_{SUSY}

Natural ratios? e.g.:

GUT: $SU(5):\ \ \Phi^N \subset (24 \times 24)_{symm} = 1 + 24 + 75 + 200;\ \ SO(10):\ \ (45 \times 45)_{symm} = 1 + 54 + 210 + 770$

Representation	$M_3 : M_2 : M_1$ at M_{GUT}	$M_3 : M_2 : M_1$ at M_{EWSB}
1	1:1:1	6:2:1
24	2:(-3):(-1)	12:(-6):(-1)
75	1:3:(-5)	6:6:(-5)
200	1:2:10	6:4:10

String: $(3+\delta_{GS}):(-1+\delta_{GS}):\left(-\frac{33}{5}+\delta_{GS}\right)$ (also mixed moduli anomaly)



(a) 54 (b) 210

(c) 770 (d) O-II

D.Horton,GGR

Characteristic signals: $M_1 : M_2 : M_3 = 0.5\eta_1 : 1 : 2.7\eta_3$, light Higgsino $|\mu| \leq 200GeV \ll M_{1/2}$

Supersymmetric Higgs search

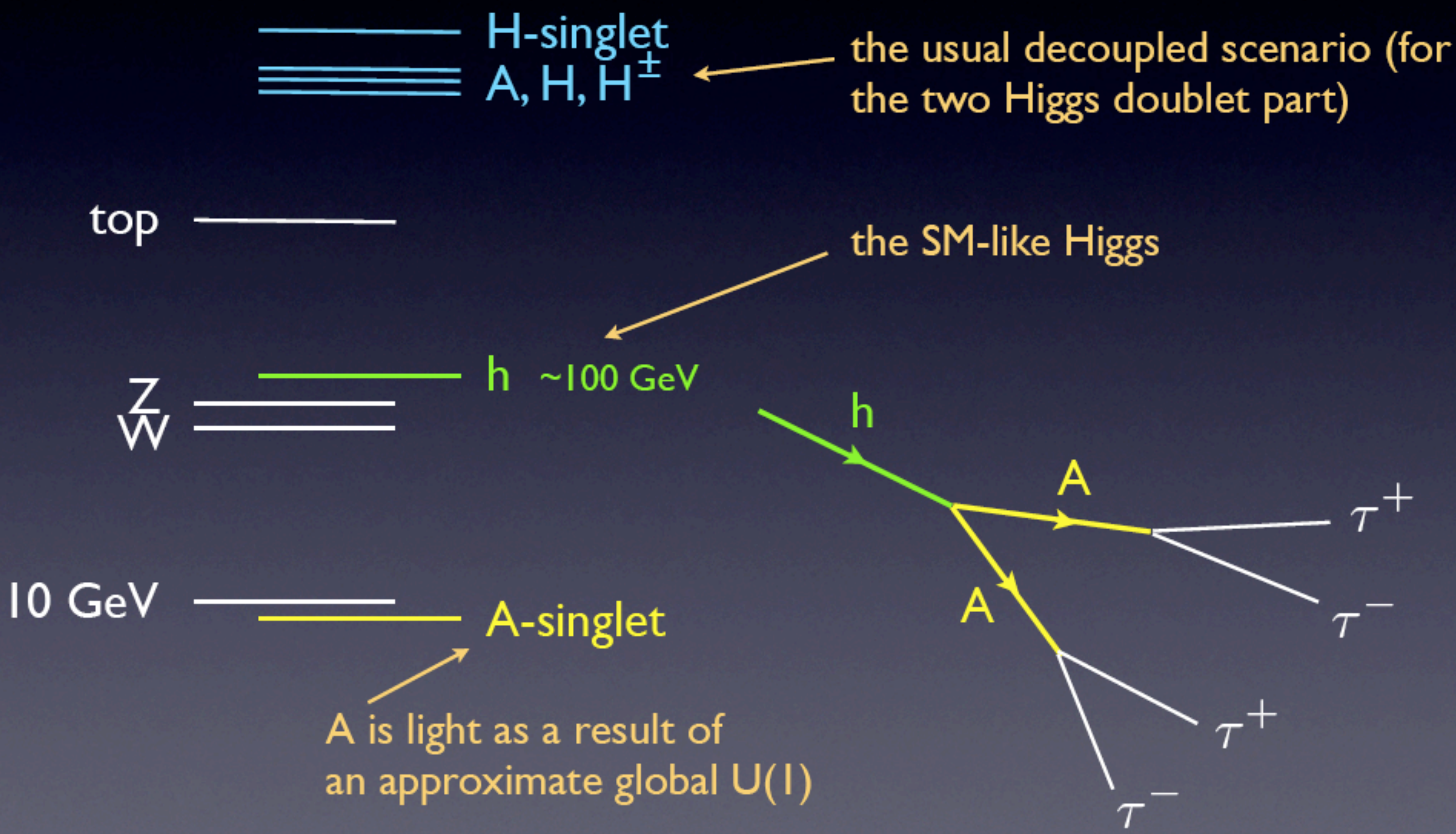
$h \to b\bar{b}$ dominant decay mode in MSSM

$h \to AA$ can dominate in extensions of the MSSM, e.g. NMSSM

Dermisek, Gunion

NMSSM with a light singlet CP odd Higgs

R.D. and J. Gunion (2005)



Supersymmetric Higgs search

$h \to b\bar{b}$ dominant decay mode in MSSM

$h \to AA$ can dominate in extensions of the MSSM, e.g. NMSSM

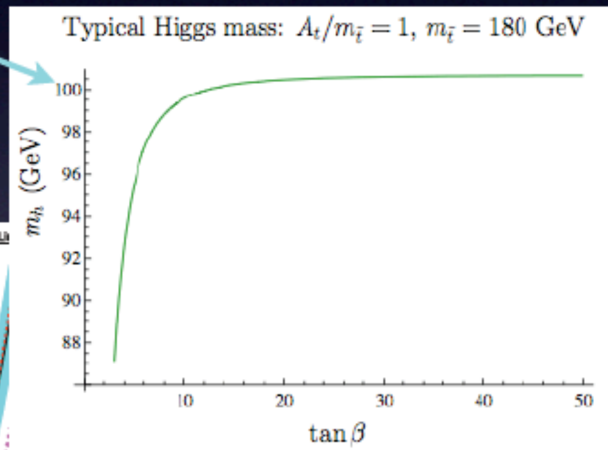
$A \to \tau^+\tau^-, c\bar{c}, gg$

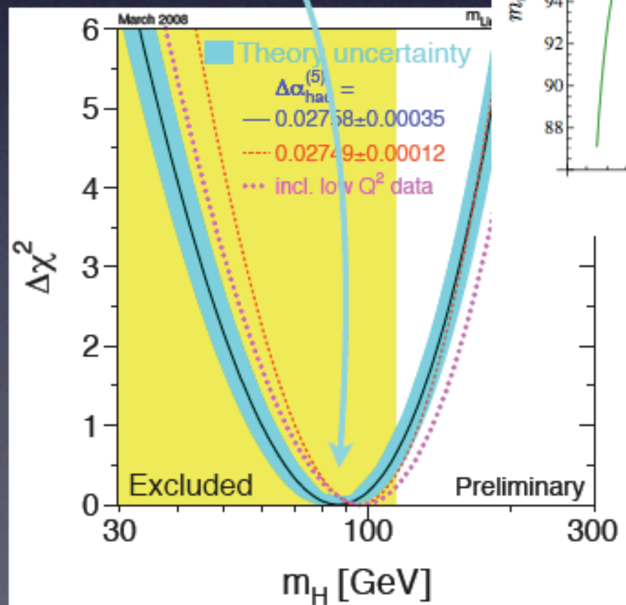
$h \to 4\tau, 4c, 4g, 2\tau 2c, 2\tau 2g, 2c2g, \left(b\bar{b}\right)$ would not have been seen at LEP

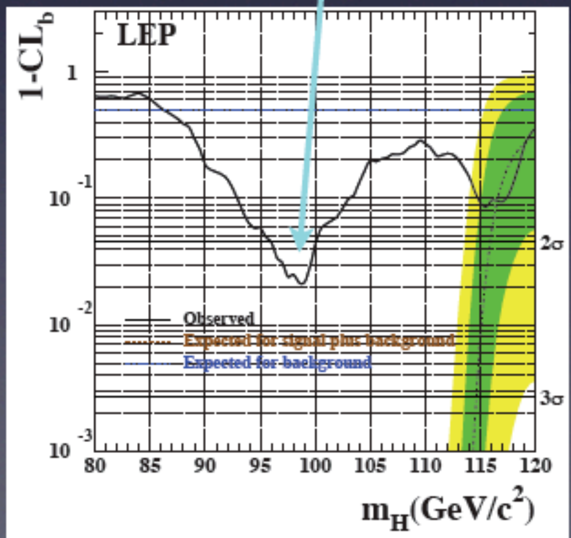
Decay Channel	**Limit**
$h \to b\bar{b}$ or $\tau\bar{\tau}$	115 GeV
$h \to jj$	113 GeV
$h \to WW^*$ or ZZ^*	110 GeV
$h \to \gamma\gamma$	117 GeV
$h \to \not{E}$	114 GeV
$h \to AA \to 4b$	110 GeV
$h \to AA \to 4\tau, 4c, 4g$	86 GeV
$h \to$ anything	82 GeV

Motivation for modified Higgs decays:

- arise in many models beyond the SM
- allow the SM-like Higgs significantly below LEP limits
  - wanted by generic SUSY/natural EWSB
  - preferred by precision EW data
  - indicated by LEP data







LHC search

$$pp \to \mu^+\mu^- X$$

$$gg \to a \to \mu^+\mu^-$$

$$\sigma(gg \to a \to \mu^+\mu^-) \sim 12 - 25 \text{ pb } \textbf{in } m_a \in [8 \text{ GeV} - 2m_B]$$

For $\sqrt{s} = 10(7) TeV$, reduced by factor 0.8(0.6)

5σ discovery: 200(300) pb^{-1}

Dermisek, Gunion

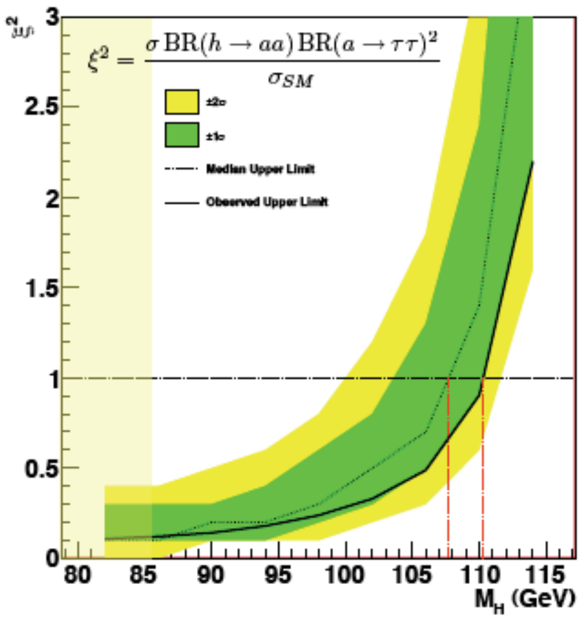
Expected limits @ m_a = 4,10 GeV

Center for Cosmology and Particle Physics

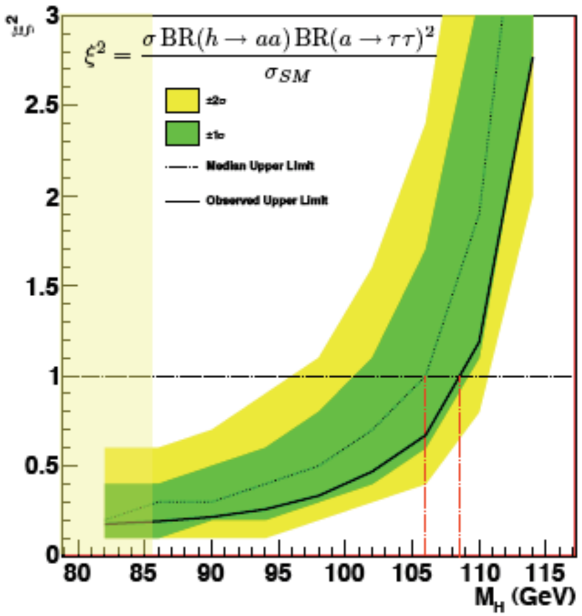
Seeing no sign of excess, we proceed to set limits

- Here, we make reference to background acceptance uncertainties in MSSM Higgs analysis. (Statistical errors dominate, systematics make little difference in result)

expected limit for m_a = 4 GeV



expected limit for m_a = 10 GeV



w/ James Beacham, Paolo Spagnolo, Itay Yavin

Our first analysis of $e^+e^- \to Zh \to (ee, \mu\mu, \nu\nu)\, 4\tau$ is essentially complete, and will extend the reach of the OPAL analysis

- we had sensitivity for a 5σ discovery up to ~90 GeV
- expected [observed] limits ($\xi^2 = 1$) are ~105 [110] GeV

LHC SUSY search

$$m_{\tilde{q}} \sim m_{\tilde{g}} \sim 400 GeV$$

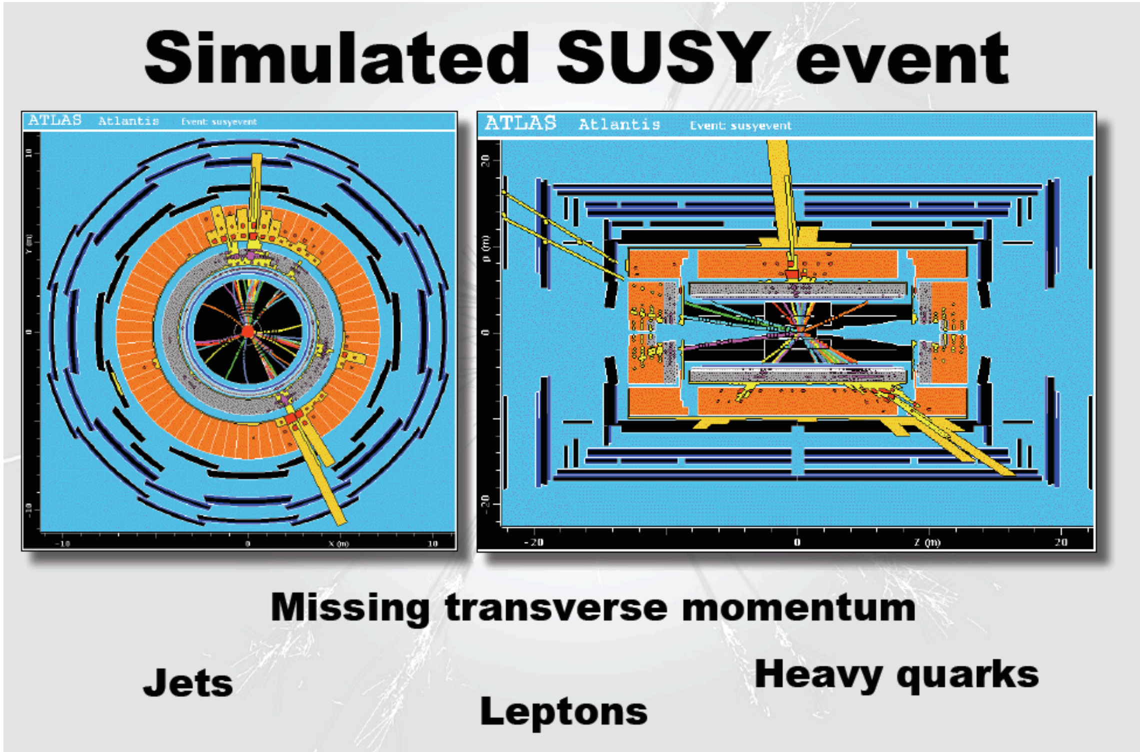
$$\sigma_i \sim 10^5 \, fb!$$

$$p\,p \rightarrow \tilde{t}\,\tilde{t}^c$$

$$\rightarrow t\,\bar{t}\,\underbrace{\tilde{Z}\,\tilde{Z}}$$

Invisible

Dark matter?

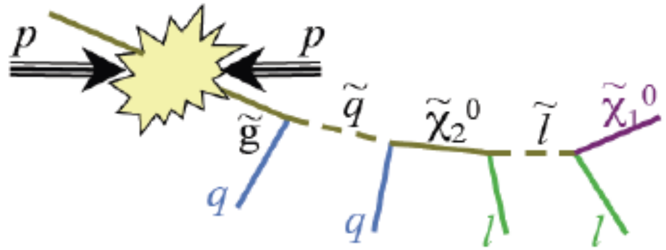


But $\not{E}_T$ signals will take some time to confirm...not in 1st run?

- energy loss from cracks and un-instrumented regions of the detector,
- energy loss from dead cells,
- hot cells in the calorimeter that report an energy deposition even if there isn't one,
- mis-measurement in the electromagnetic calorimeters, hadronic calorimeters or muon detectors and
- mis-identified cosmic rays in events.

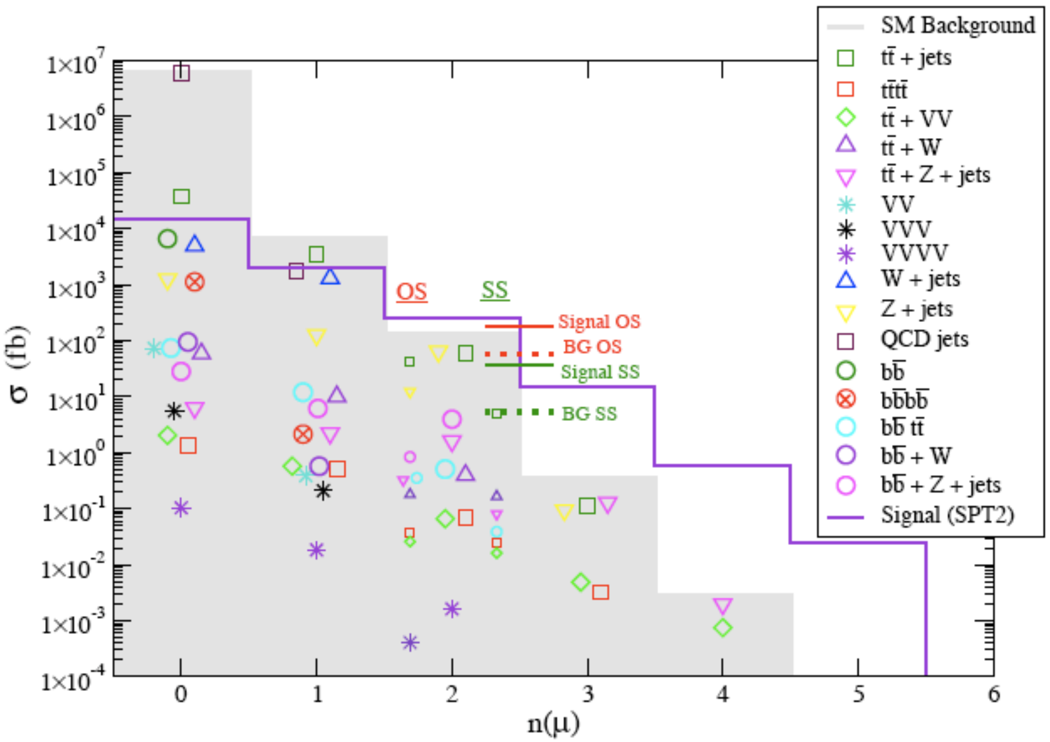
Baer, Barger, Lesser, Tata

Multi-muon + jets signals with no missing energy requirement



$10\,TeV$ CM energy is $5\times$ current energy reach

Signal v/s background



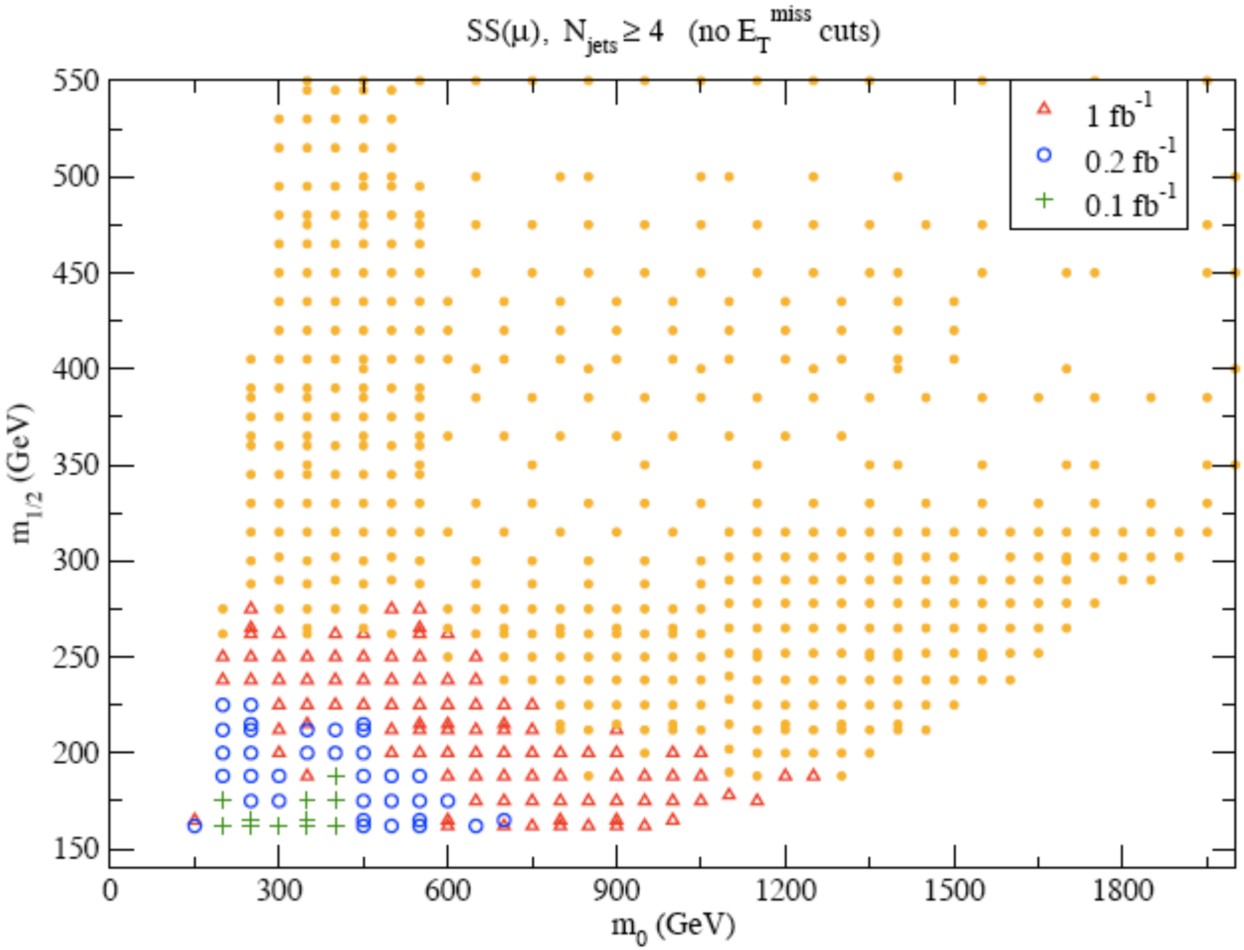


Figure 4: SUSY reach of the LHC at $\sqrt{s} = 10$ TeV via SS-dimuon plus ≥ 4 jets events with only the basic cuts detailed in the text, for various integrated luminosities. The fixed mSUGRA parameters are $A_0 = 0$, $\tan\beta = 45$ and $\mu > 0$. The solid dots here, and in other subsequent figures, denote model points where the signal remains unobservable even for the largest integrated luminosity shown in the figure.

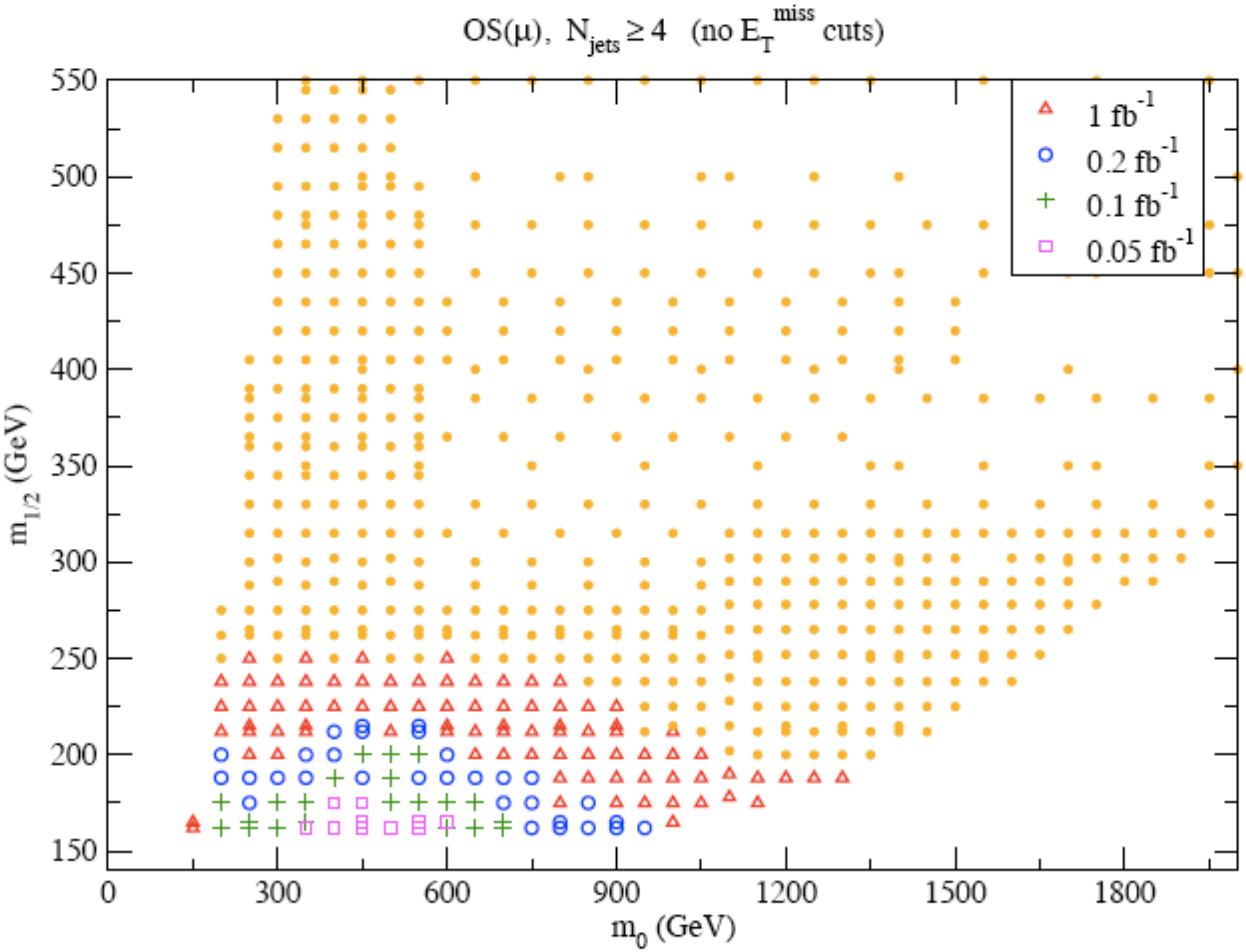


Figure 5: SUSY reach of the LHC at $\sqrt{s} = 10$ TeV via OS-dimuon plus ≥ 4 jets events with only the basic cuts detailed in the text, for various integrated luminosities. The fixed mSUGRA parameters are $A_0 = 0$, $\tan\beta = 45$ and $\mu > 0$.

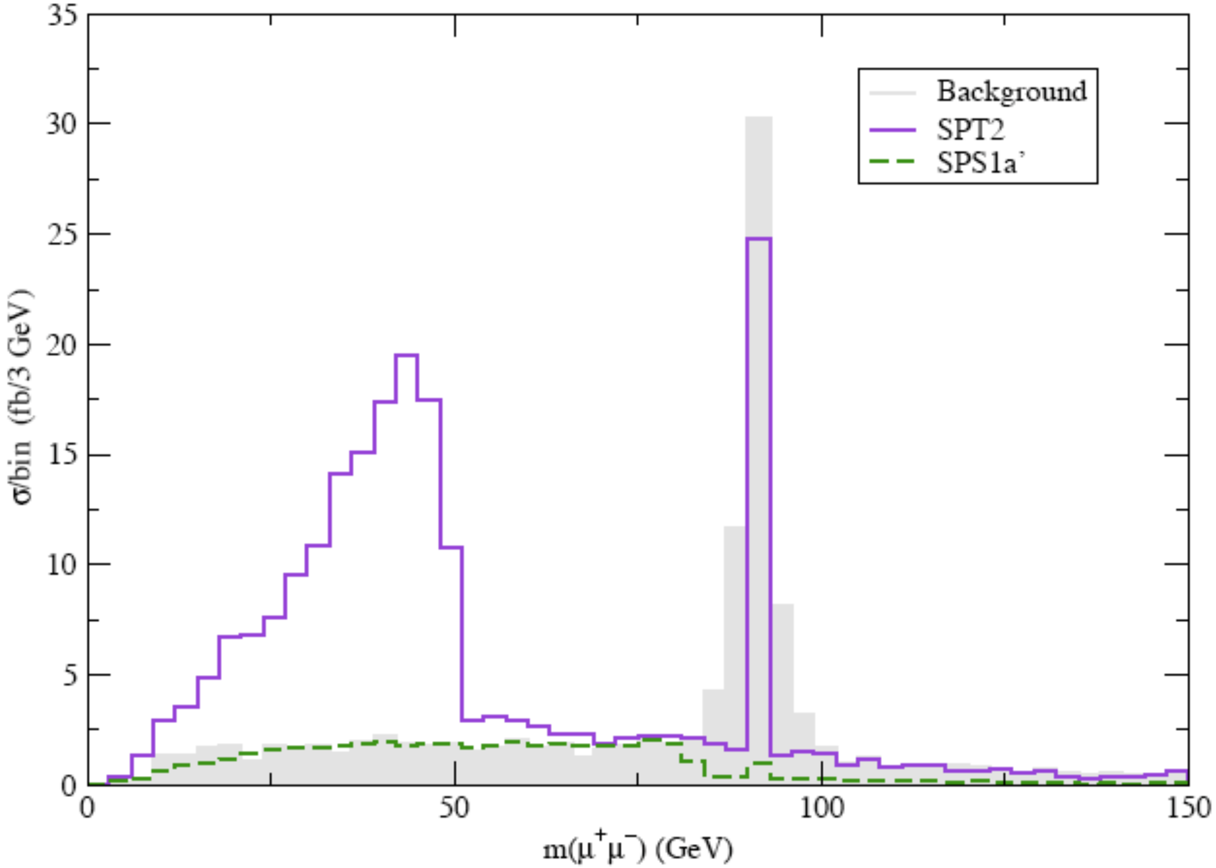
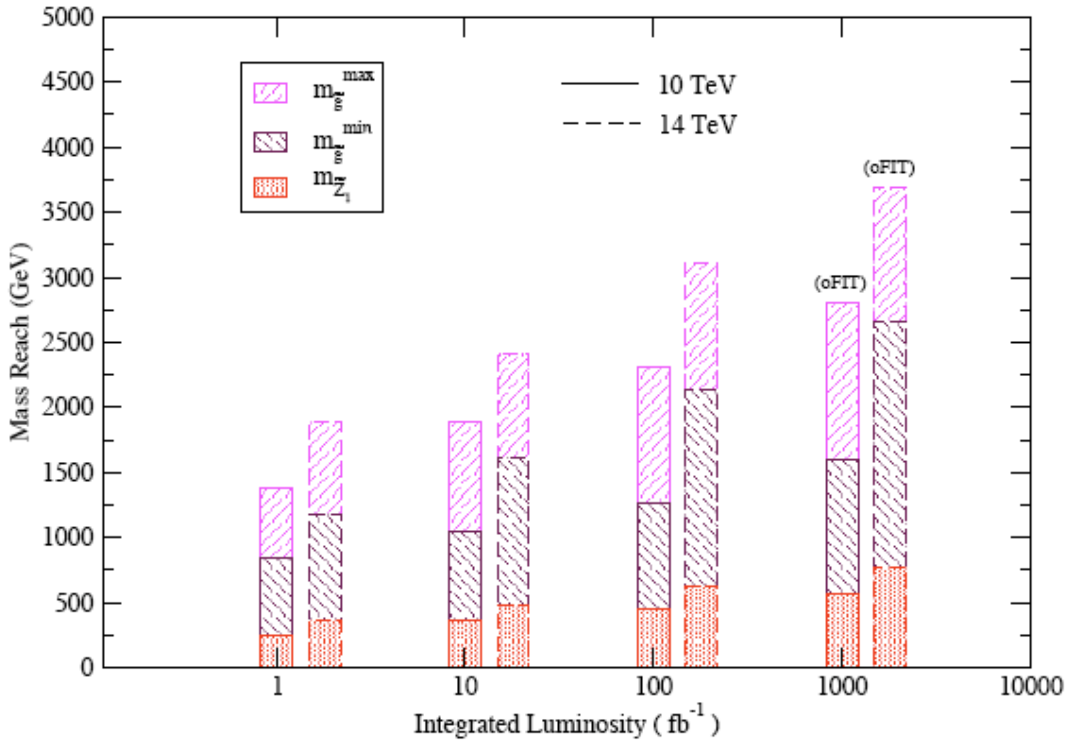


Figure 8: OS dimuon invariant mass distribution from OS dimuon + ≥ 4 jets events for SPS1a′ (dashed) and SPT2 (solid) cases, and also for SM backgrounds (shaded). In this plot only we do not apply the invariant mass cuts for OS dimuons. We make no requirement on $E_T^{\rm miss}$.



The ultimate reach of the LHC at $\sqrt{s} = 10$ TeV (solid) and $\sqrt{s} = 14$ TeV (dashed)

Technicolour

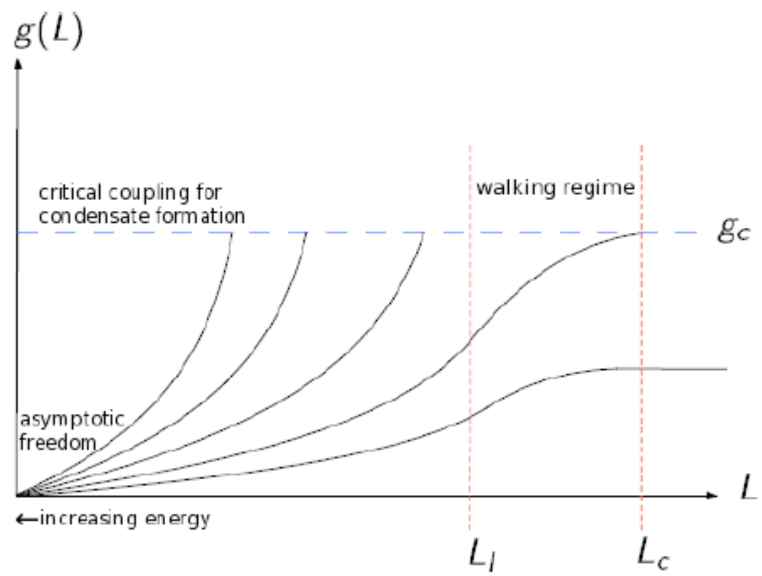
- EW symmetry broken by technicolour condensate $\langle \bar{T}T \rangle \equiv 4\pi F_T^3 \neq 0$

$$m_W = m_Z \cos\theta_W \propto F_T$$

- Must be non-QCD-like to avoid FCNC and satisfy precision tests(?)

- Walking TC allows larger quark and technipion masses

- Technivector mesons, ρ_T, ω_T expected to be narrow and easily visible

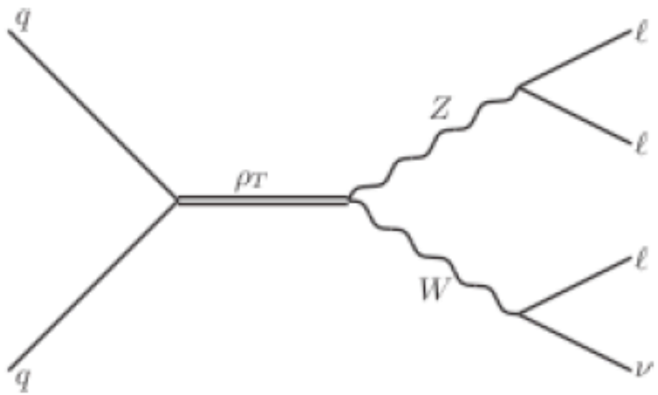


LHC discovery channels

D.Schaich

- At the LHC the $\rho_T \to W^{\pm}\pi_T$ channel will be swamped by $t\bar{t}$ and $W+$ heavy flavor backgrounds.
- Best discovery channels are diboson decays of vector resonances, with leptons in the final state: clean signals and relatively low backgrounds.

$$\rho_T \to WZ \to 3\ell + \nu \qquad a_T \to \gamma W \to \ell\nu\gamma \qquad \omega_T \to \gamma Z \to \ell\ell\gamma$$



- Main backgrounds to $\rho_T \to WZ \to 3\ell + \nu$ are

$$t\bar{t} \to 2\ell 2\nu b\bar{b} \qquad WZ \to 3\ell + \nu \qquad ZZ \to 4\ell \qquad Zb\bar{b} \to 2\ell b\bar{b}$$

- Backgrounds have larger cross sections, but can be removed by cutting on $\left|M(\ell^+\ell^-) - m_Z\right|$, $|\eta(Z) - \eta(W)|$, and $p_T(W)$, $p_T(Z)$, and $\not\!\!E_T$.
- Should be able to see signal up to 600 GeV with $\mathcal{O}$(1-10) fb^{-1}.[20]

[20] Azuelos, Black, Bose, Ferland, Gershtein, Lane and Martin, in Brooijmans et al., 0802.3715.

Summary

LHC run at 10TeV with 200-300fb^{-1} will probe new physics:

- 4th family $M \sim 300 GeV$

  $b'\bar{b}' \to b\bar{b}W^+W^-W^+W^-$

  same sign dilepton or trilepton signals

  $\nu_4\nu_4 \to \mu W \mu W \to \mu\, jj\, \mu\, jj$

  Higgs enhancement

- Z' $M \sim 1 TeV$ $Z' \to e^+e^-, \mu^+\mu^-, \ldots$

- Technicolour $M \sim 400 GeV$ (?) $\rho_T \to WZ \to 3\ell + \nu$

- SUSY $M \sim 600 - 900 GeV$

  Even without $\not{E}_T$ multimuon + jet signals provide viable SUSY signals

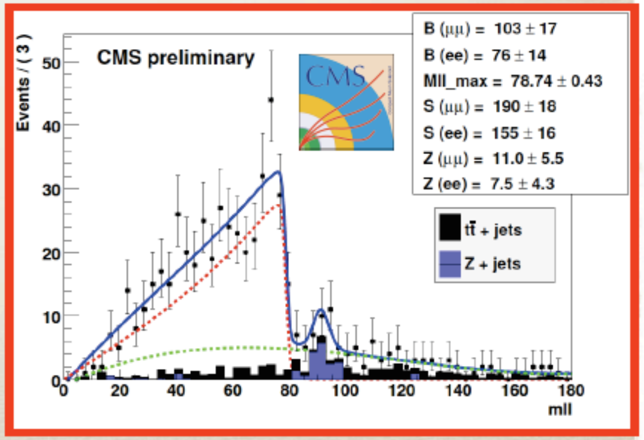
  Light Higgs, nonstandard decays detectable

What if SUSY signal will be observed

- To establish that an observed signal is due to SUSY, the superpartner for every particle has to be found with
  - spin = s±1/2
  - same gauge quantum number and couplings
  - predicted relation among particle mass holds
- SUSY events contain two LSPs which escape the detector
  - mass peak reconstruction impossible
  - apply kinematics on long decay chains to link endpoints with combination of masses
  - measure endpoints in invariant mass distribution

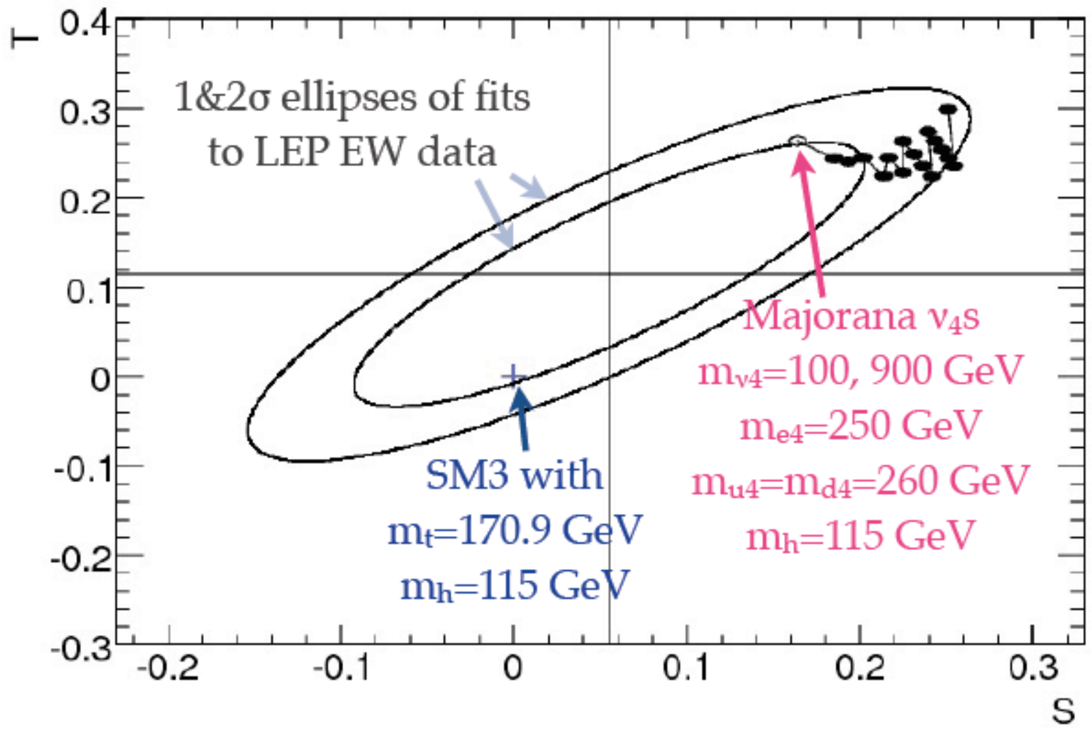
E.g. dilepton final state: $\tilde{\chi}_2^0 \rightarrow \tilde{l}_{R,L} l \rightarrow l l \tilde{\chi}_1^0$

$$m_{ll}^{max} = m_{\tilde{\chi}_2^0} \sqrt{1 - \frac{m_{\tilde{l}_R}^2}{m_{\tilde{\chi}_2^0}^2}} \sqrt{1 - \frac{m_{\tilde{\chi}_1^0}^2}{m_{\tilde{l}_R}^2}}$$



Further mass and spin measurement methods being devised to deal with $\not{p}_T$ and $\not{M}$.

EW Constraints



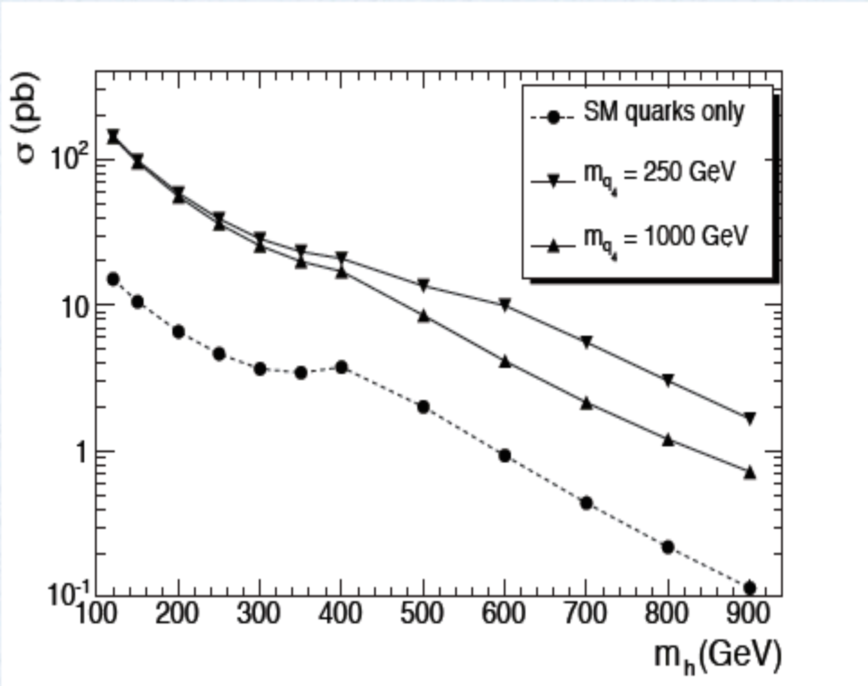
Black solid circles represent m_h going from 150 to 900 GeV in steps of 50 GeV, while the best value of m_{u4} also goes slowly up to 330 GeV.

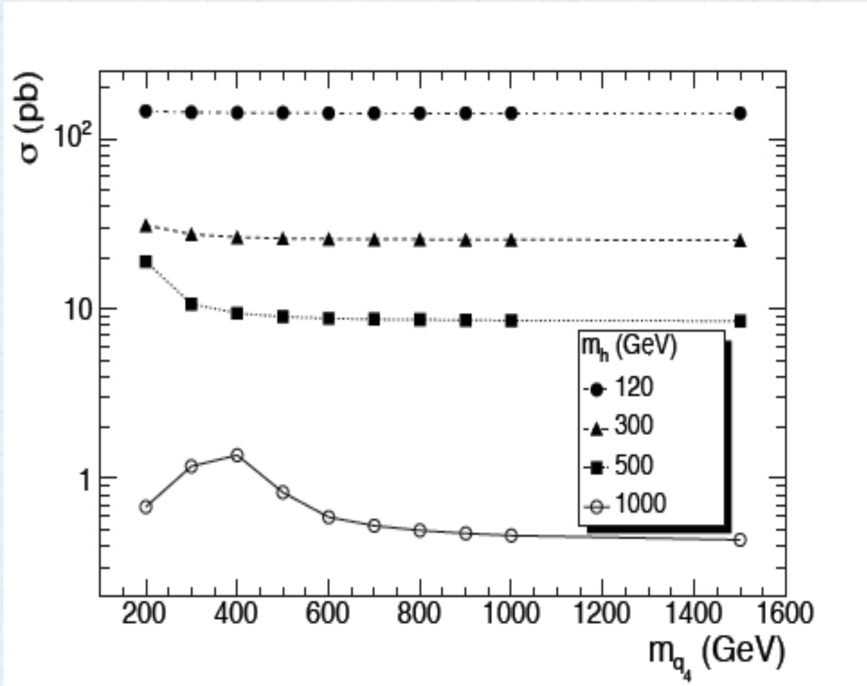
- Already mentioned in Gokhan's kickoff talk: Dirac-type 4th gen. fermions are OK with EW contraints.
- EW constraints can also be satisfied for heavy Majorana neutrinos.
- Heavy Higgs can be accommodated.

Gokhan Unel, CERN workshop 2009

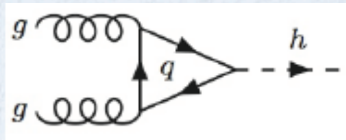
Using exact one-loop calculations from:
B.A.Kniehl & H.G.Khor, PRD48(1993)225.
H.J.He, N.Polonsky & S.F.Su, PRD64(2001)053004.

Higgs Prod. X-section





- Heavy new quarks enhance the Higgs production at the LHC.
- Rough enhancement by a factor of ~9.



- We add 4^{th} gen. quarks into Higlu for "exact" LO calculations.