Higgs Discovery and Physics at a Electron-Positron Higgs Factory

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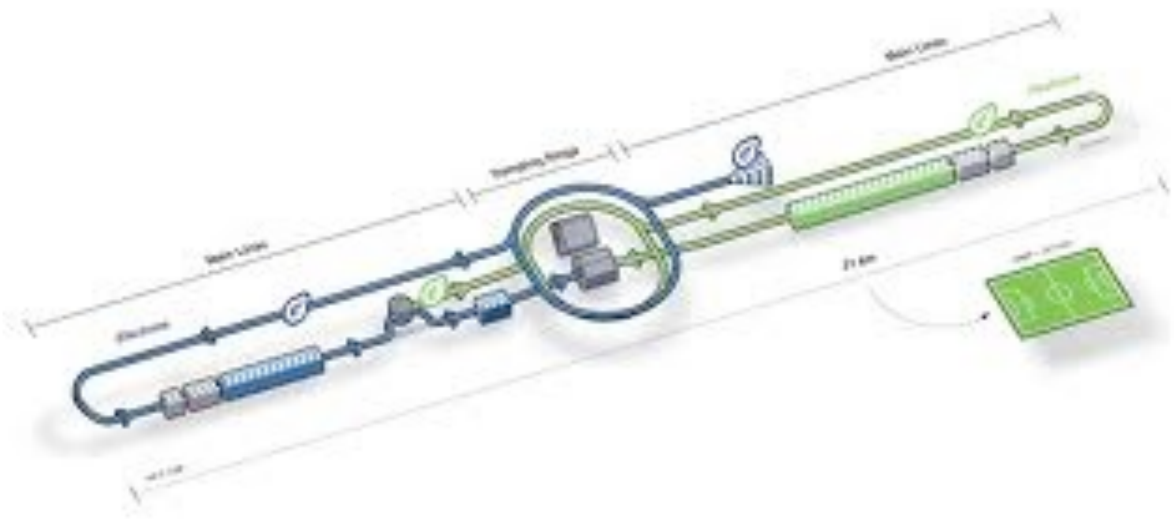


Argonne HEP Division Higgs Retreat, October 5, 2012

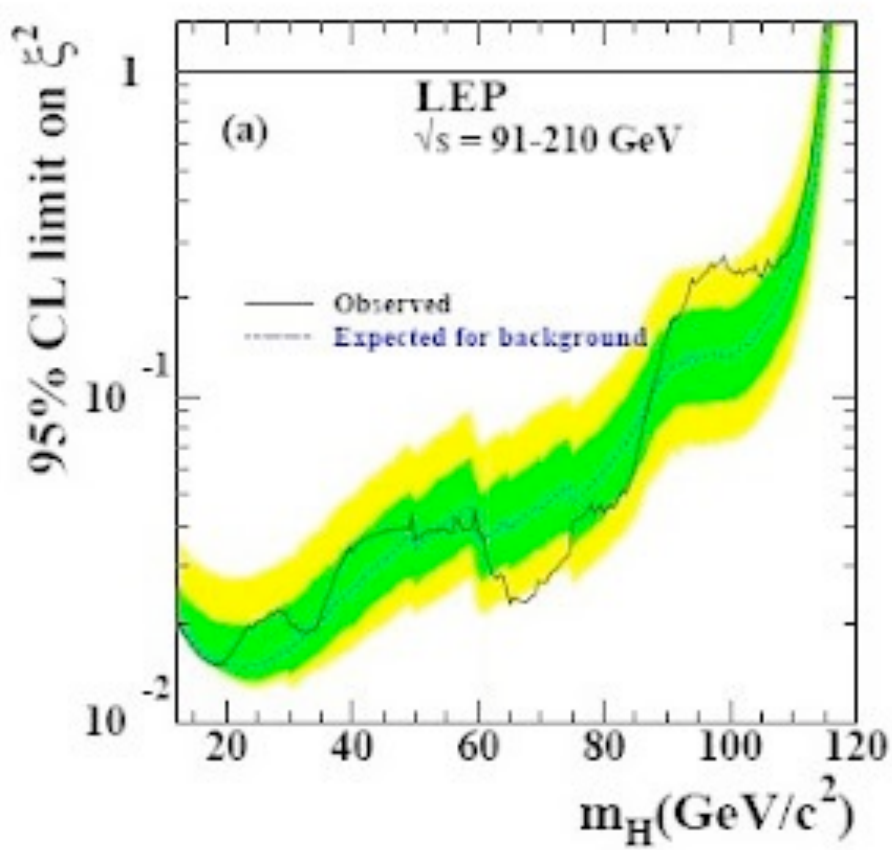
Very Exciting Times !

The LHC experiments have discovered a new particle

- The evidence is strong that the new particle decays to $\gamma\gamma$ and ZZ with rates roughly consistent with those predicted for the SM Higgs boson.
- There are also indications that the new particle might decay to W^+W^-
- The observed decay modes indicate that the new particle is a boson.
- However, the present experimental uncertainties still allow for a wide variety of new physics alternatives.

Higgs Hunting at the LEP, Tevatron and the LHC

LEP almost get it !
LEP lower Higgs mass bound only 10 GeV smaller than the Higgs mass

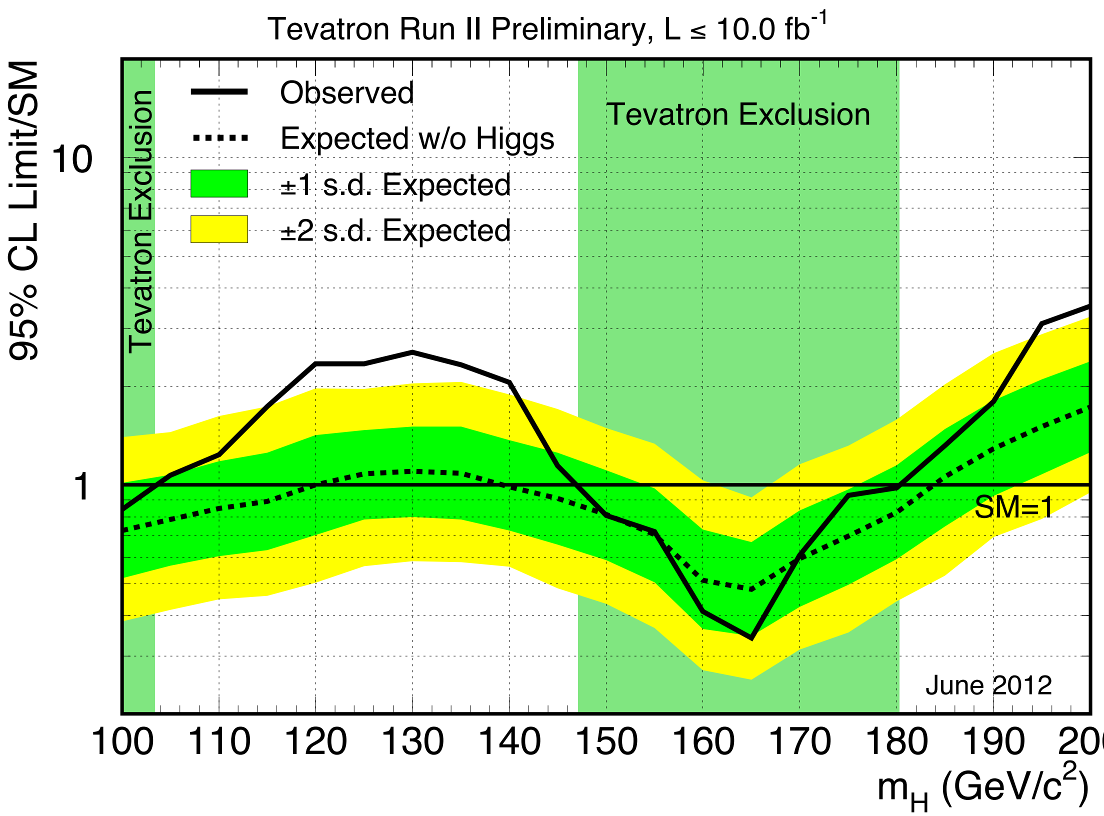


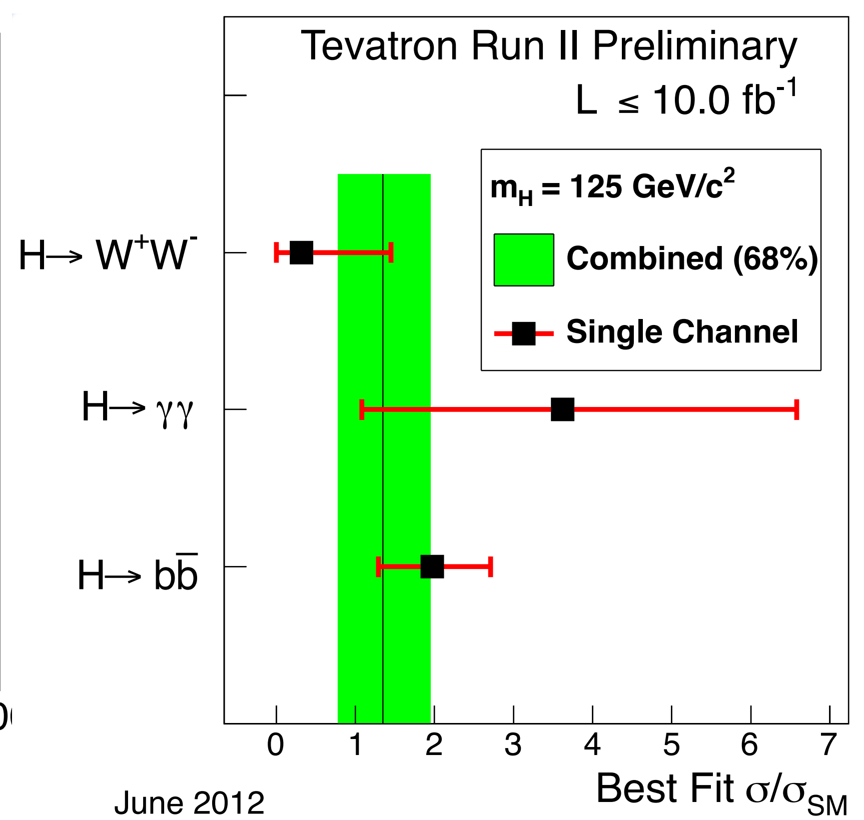
$$e^+e^- \to Z^* \to ZH$$

LEP set very strong bounds on the presence of Higgs-like particles with masses below 115 GeV.

Tevatron

Combination of searches for Higgs decaying into WW and bb shows a clear excess in the 115 GeV to 135 GeV mass region

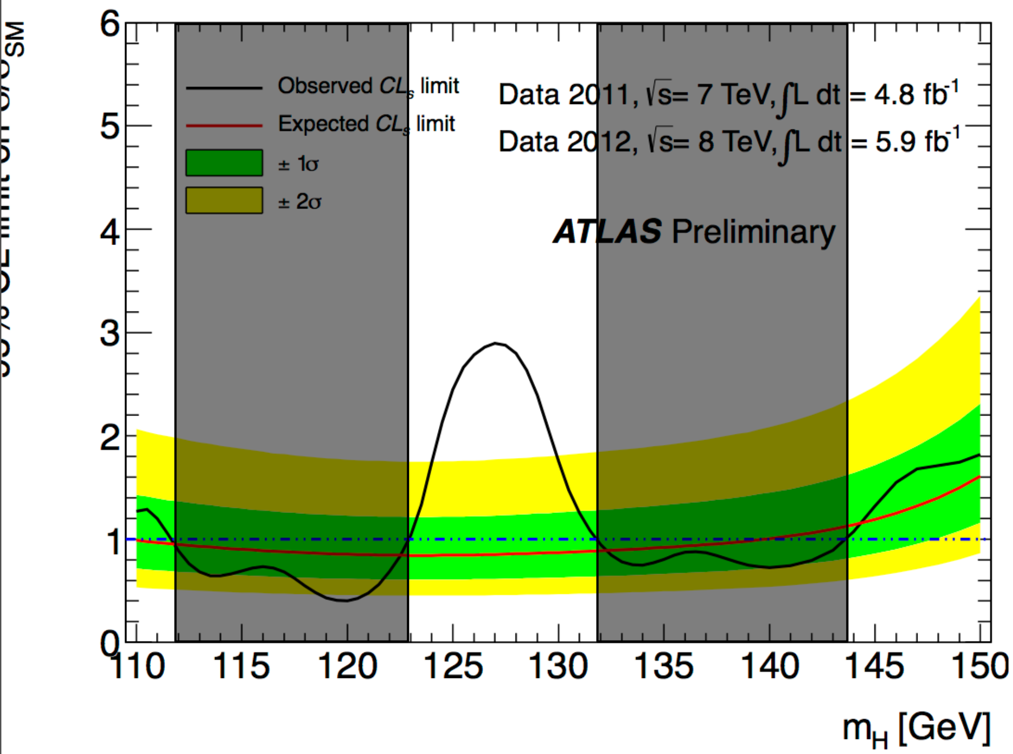


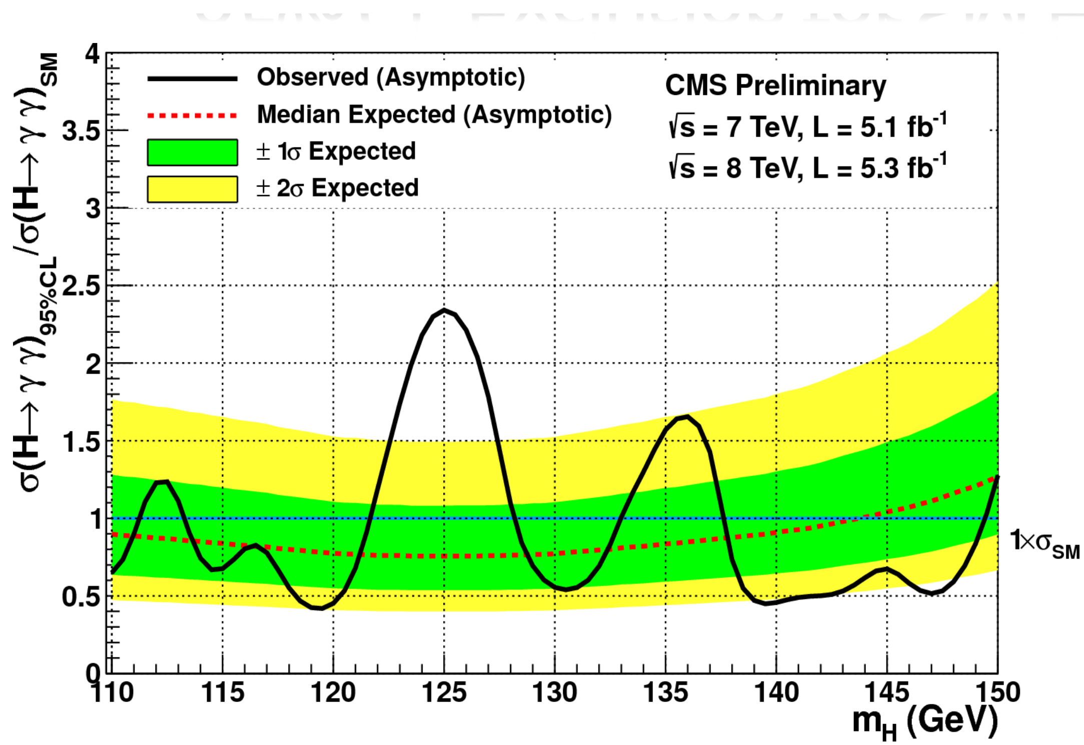


For a Higgs mass of 125 GeV, the combined production rates are consistent with the SM ones within 1 σ

LHC Got it !

Taking all di-photon production channels, one can exclude the presence of a low mass SM Higgs for a large region of masses

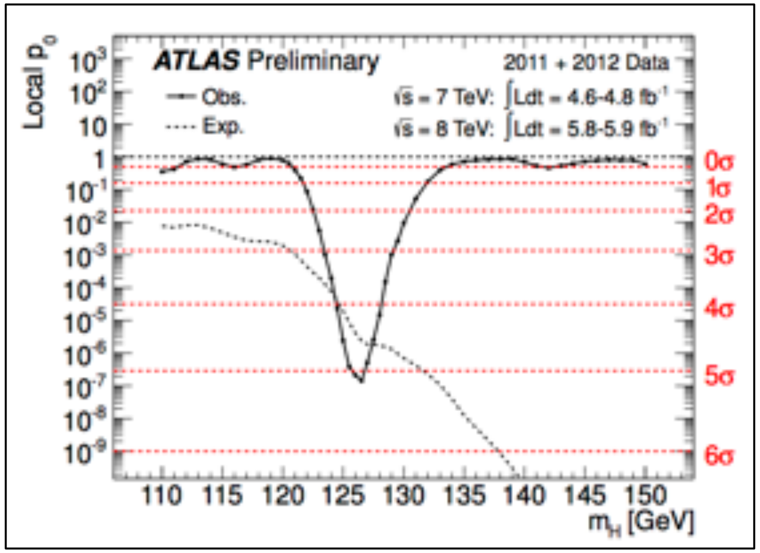


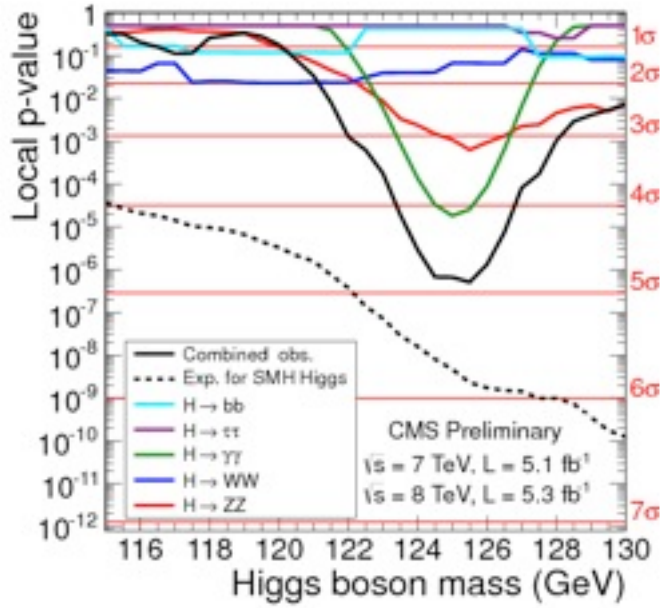


Clear Excess observed in the 124 GeV to127 GeV mass range in both experiments.

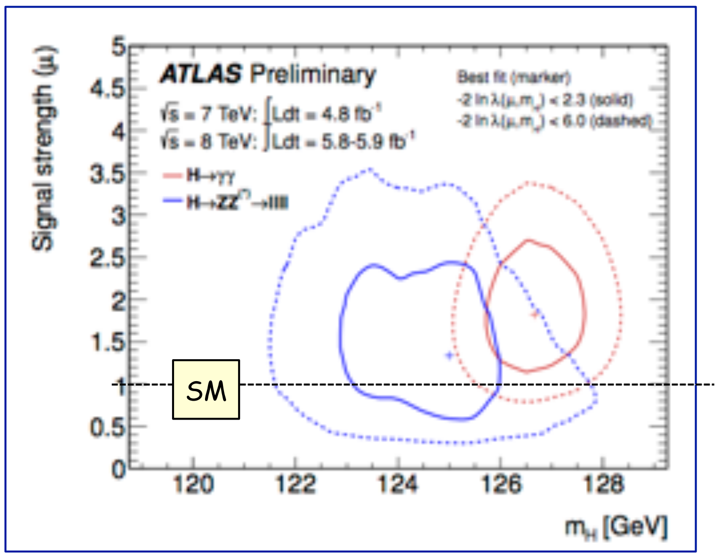
Combination of all channels.

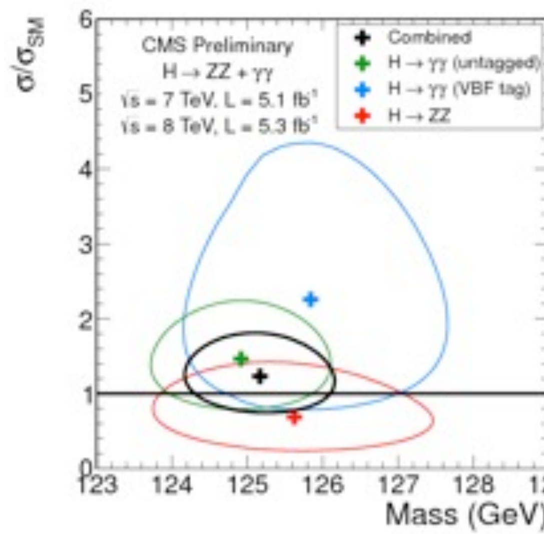
ATLAS considers 2011+2012 diphoton and ZZ channels and all other channels with only 2011 data.
CMS based its analysis on the 2011 + 2012 results





- Comb. Sign.: 5 σ excess
- Comb. Sign.: 4.9 σ excess



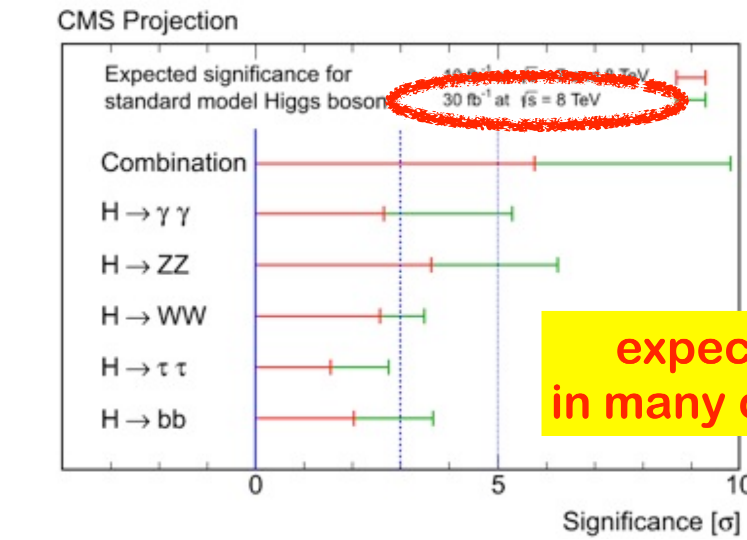



Now What?

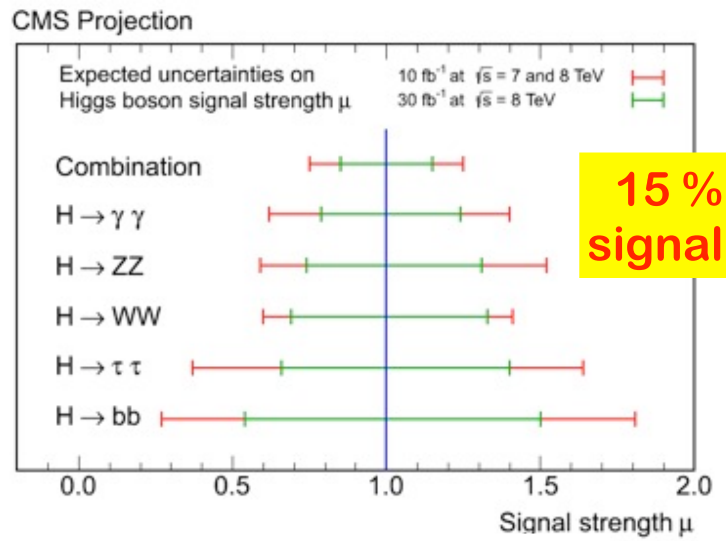
Still much work to do on the Higgs at the LHC

- Is this really the Standard Model Higgs ?
- What is the spin of the resonance ?
- What are its CP properties ?
- Are the couplings proportional to masses, as predicted by the SM ?
- By the end of the year, we probably have an understanding of the second and third questions.
- The fourth one will take longer. LHC at high luminosities will eventually provide about 5 to 15 percent precision on couplings.

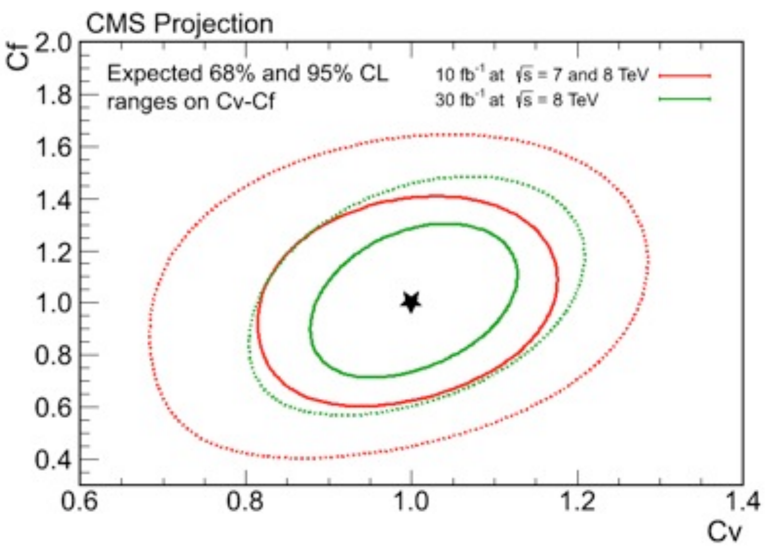
Projecting Higgs Results for 2012

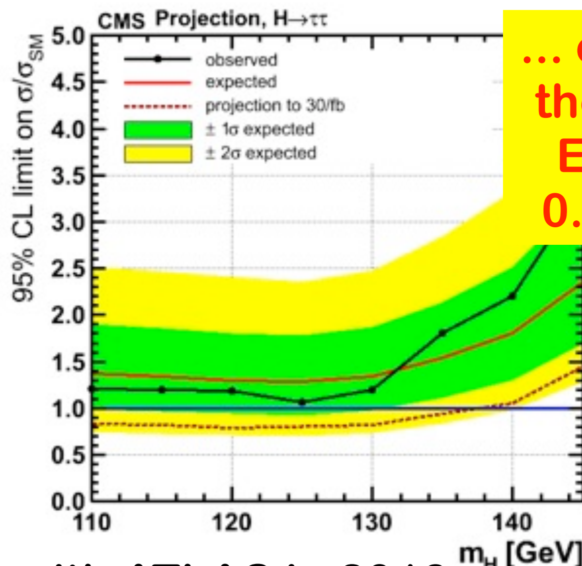


expect > 3σ
in many channels



15 % unc. on
signal strength



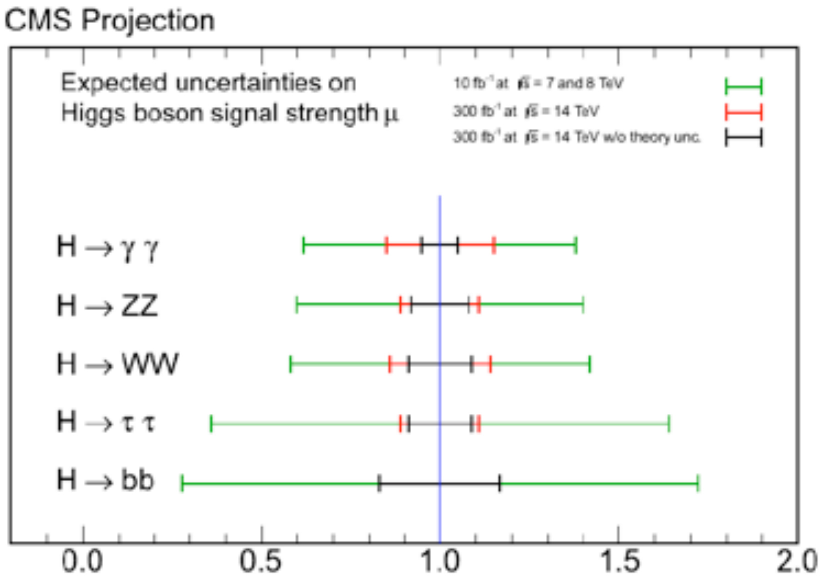


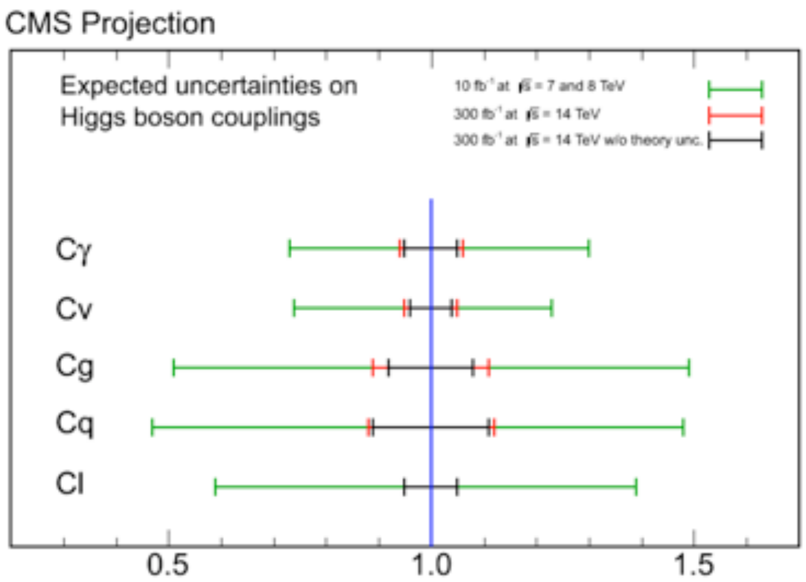
... or we challenge
the SM with taus.
Exp. to exclude
0.85 σ_{SM} 95% CL

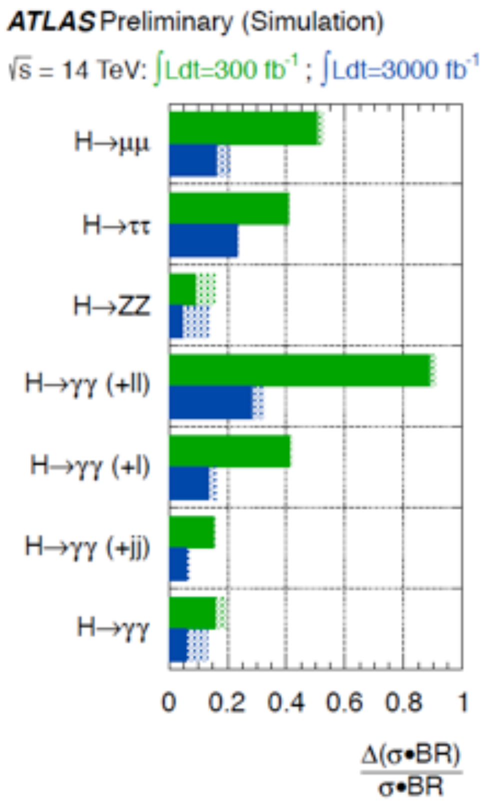
preparing combination with ATLAS in 2013

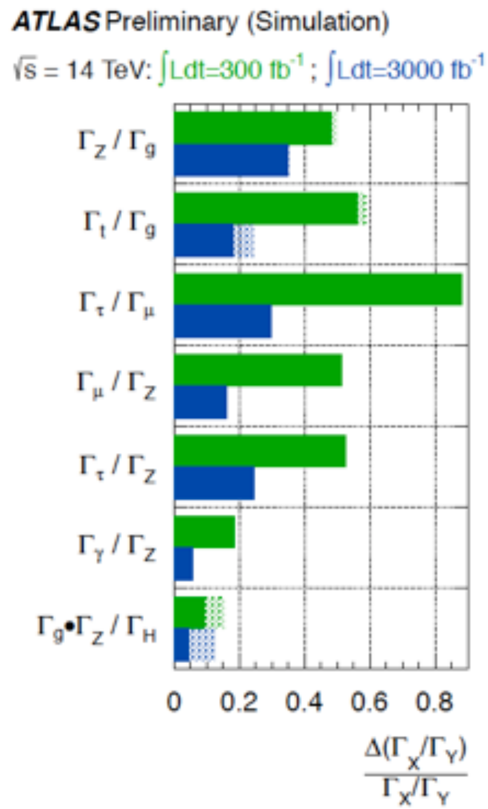
Markus Klute

Projecting Higgs Results for $300fb^{-1}$ and $3ab^{-1}$





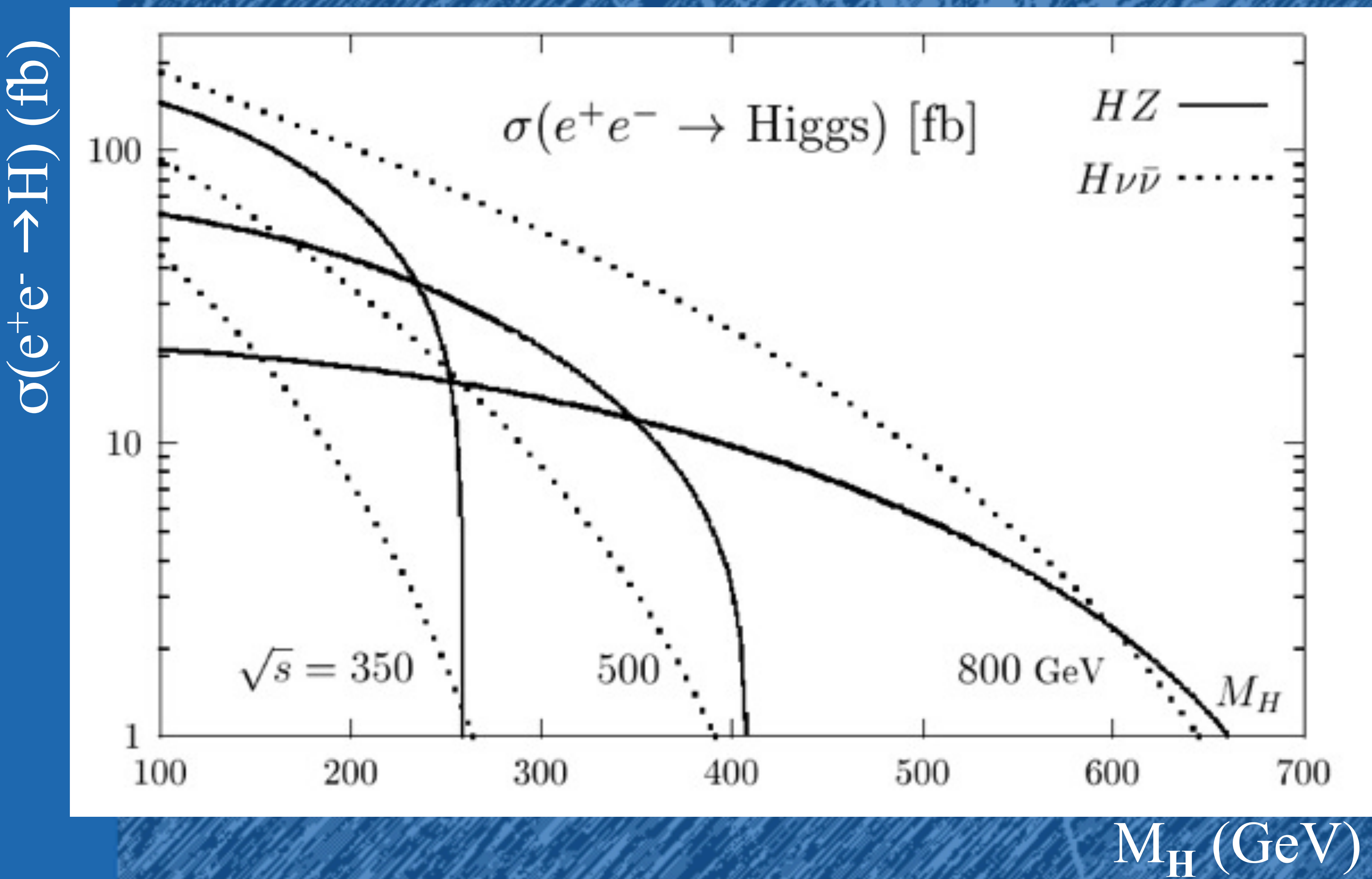


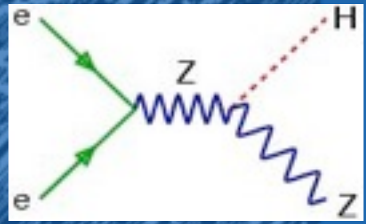


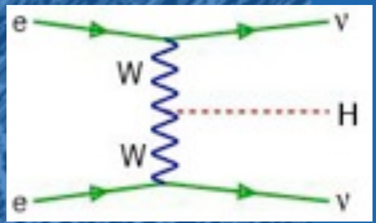
- **Projection produced by scaling current Higgs analysis by cross section and luminosity.**
- **In some cases new studies have been added**
- **Many caveats need considerations**
- **Uncertainties on couplings 5-15%**

Markus Klute

Higgs Boson Production at ILC

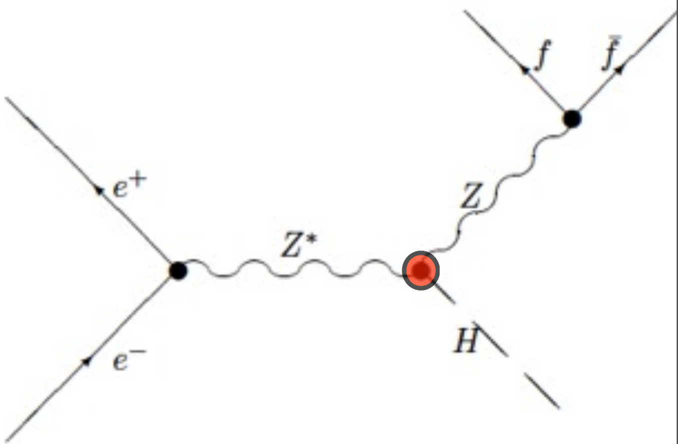






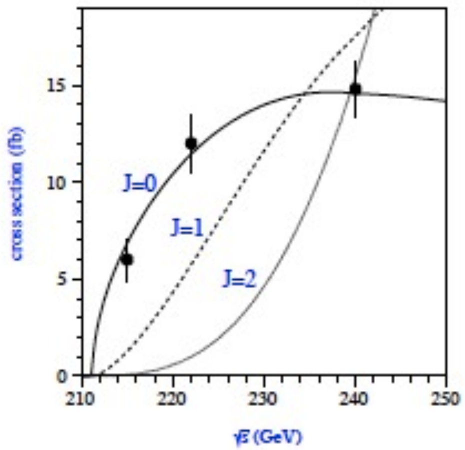
Higgs couplings at e^+e^- collider

- Higgs-strahlung with $Z \to ll$ allows **decay mode independent measurement**
  - performed on OPAL data (Eur.Phys.J.C27:311-329,2003)
  - benchmark for linear collider studies
  - sensitive invisible Higgs decays



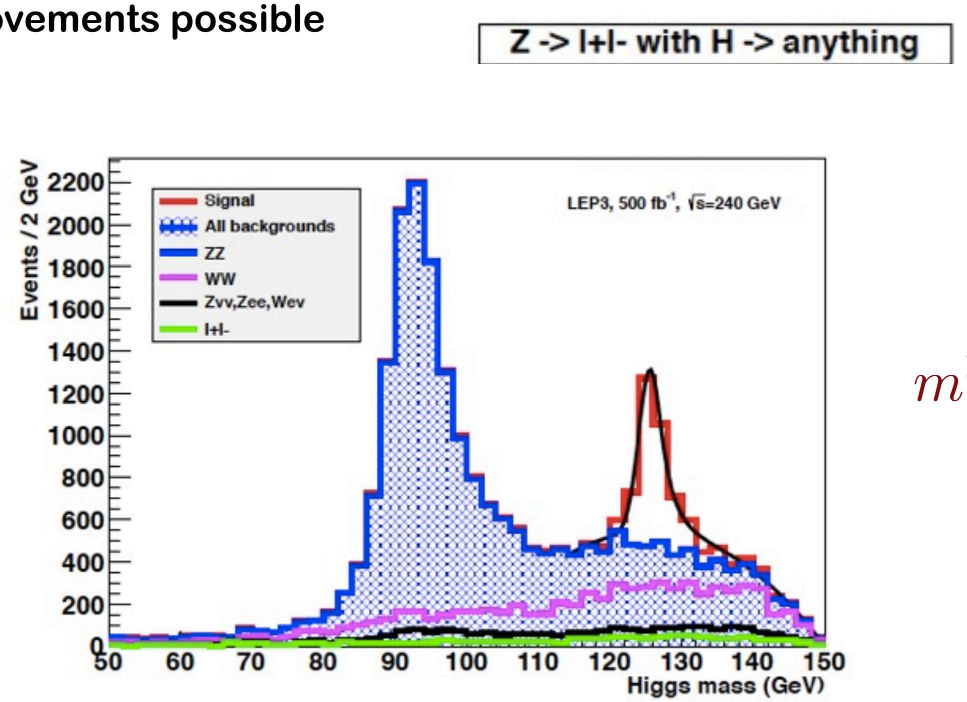
- Coupling
  - model independent extraction of g_{ZZH} from σ_{ZH} in fit to recoil mass spectrum
  - other Higgs couplings extracted from σ_{HZ} x BR measurements and g_{ZZH}
- Mass
  - can also be measure model dependent
- Spin
  - using √s - scan
- CP properties
  - using angular distributions

TESLA physics TDR



Measurement of $e^+e^- \rightarrow ZH$ cross section

- Model-independent measurement with $Z \rightarrow e^+e^-, \mu^+\mu^-$
  - Two oppositely-charged same-flavor leptons
  - Invariant mass within 5 GeV of Z mass
  - Reject radiated events (ISR) with pT, pZ, acoplanarity cuts and photon veto
  - Fit Higgs contribution from recoil mass spectrum
  - Improvements possible



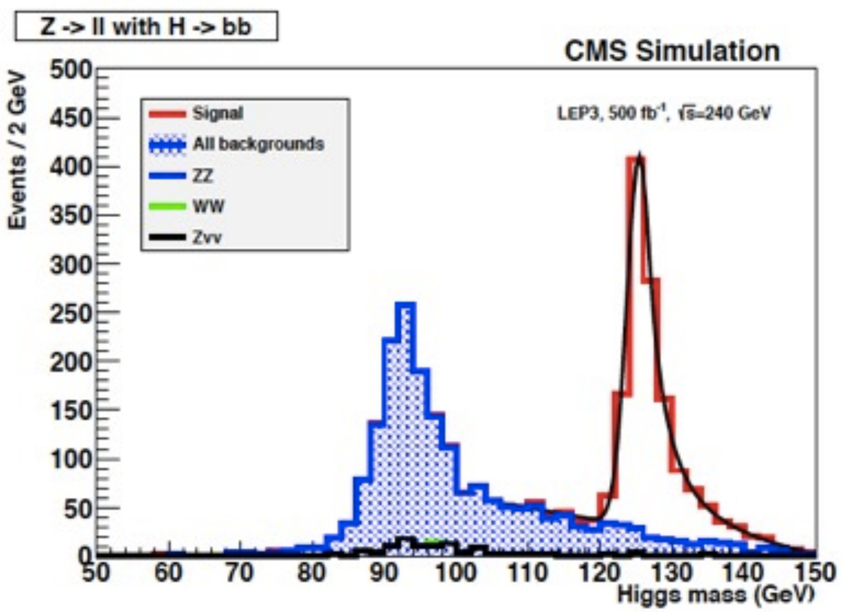
$$m_H^2 = E_{cm}^2 - 2E_{cm}E_Z + M_Z^2$$

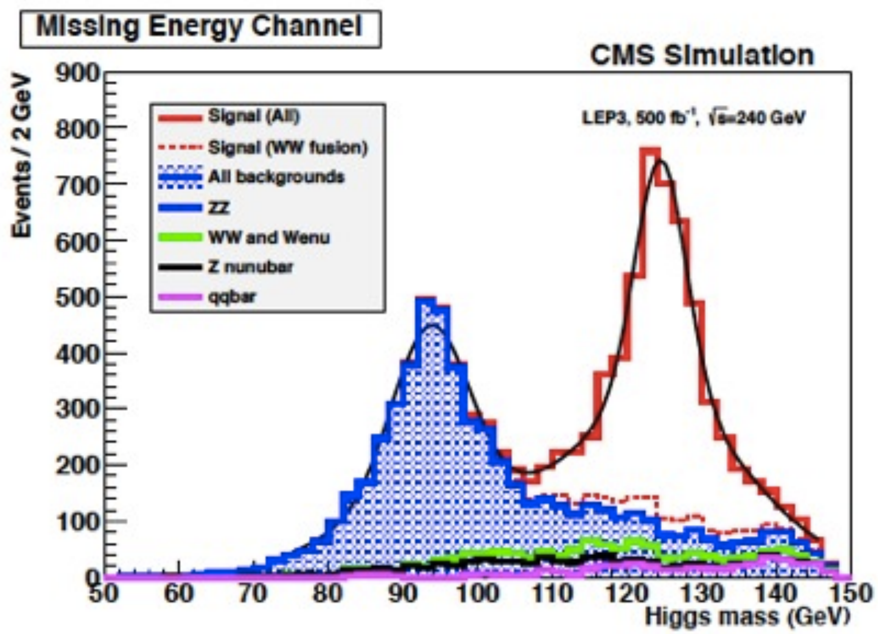
Measurement of invisible Higgs decays

- Same approach as before
  - with requirement that event consists of only two leptons

Measurement of σ_{HZ} x BR (H➜bb)

- Leptonic final states, Z ➜ e^+e^-, $\mu^+\mu^-$
  - exact same selection as before
  - force the rest of the event to form two jets and apply a tight b tagging
  - precision of 1.5% overall on σ_{HZ} x BR (H➜bb)
- Missing energy final state, Z ➜ νν
  - reuse invisible Higgs search with Z ➜ bb
  - substitute missing mass visible mass
  - precision of 1.5% overall on σ_{HZ} x BR (H➜bb)

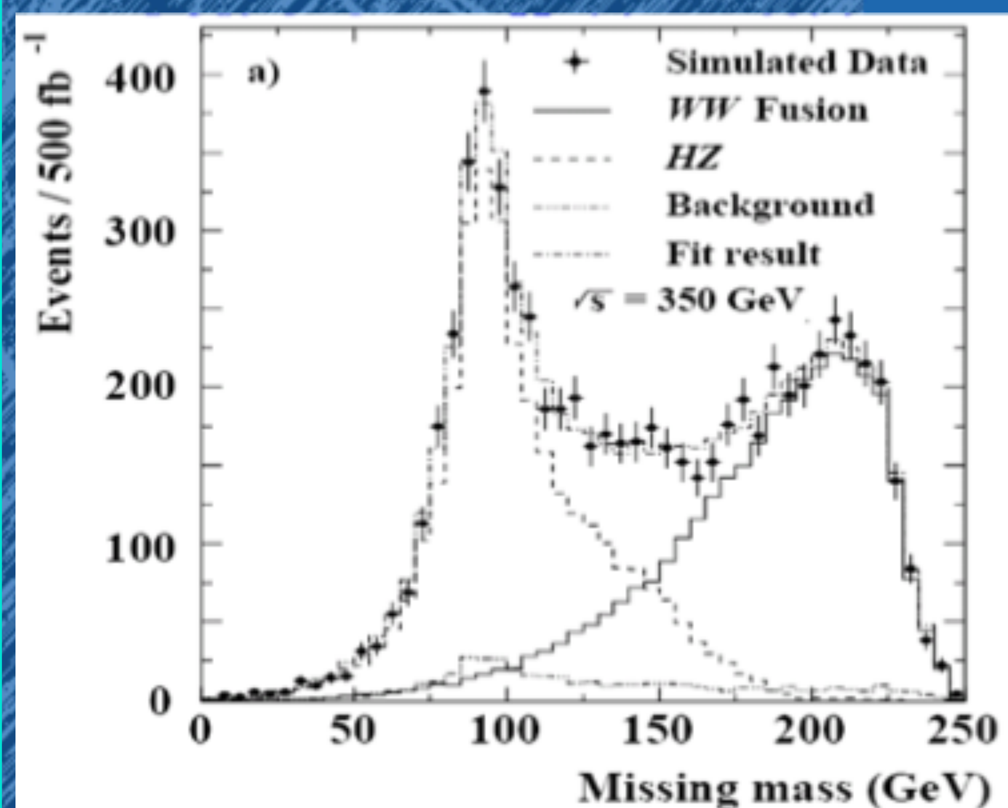




Generation of Mass: the Gauge Sector

Determine HZZ coupling from Higgstrahlung cross section and HWW coupling from double-WW fusion and $H \to WW$ branching ratio;

$\gamma\gamma \to H$ also possible at $\gamma\gamma$ collider considered as ILC option;



	E_{cm} TeV	M_H 120	M_H 140	M_H 150
$\delta g_{HZZ}/g_{HZZ}$	**0.5**	0.024	0.027	0.029
$\delta g_{HWW}/g_{HWW}$	**0.35**	0.026	0.053	0.103

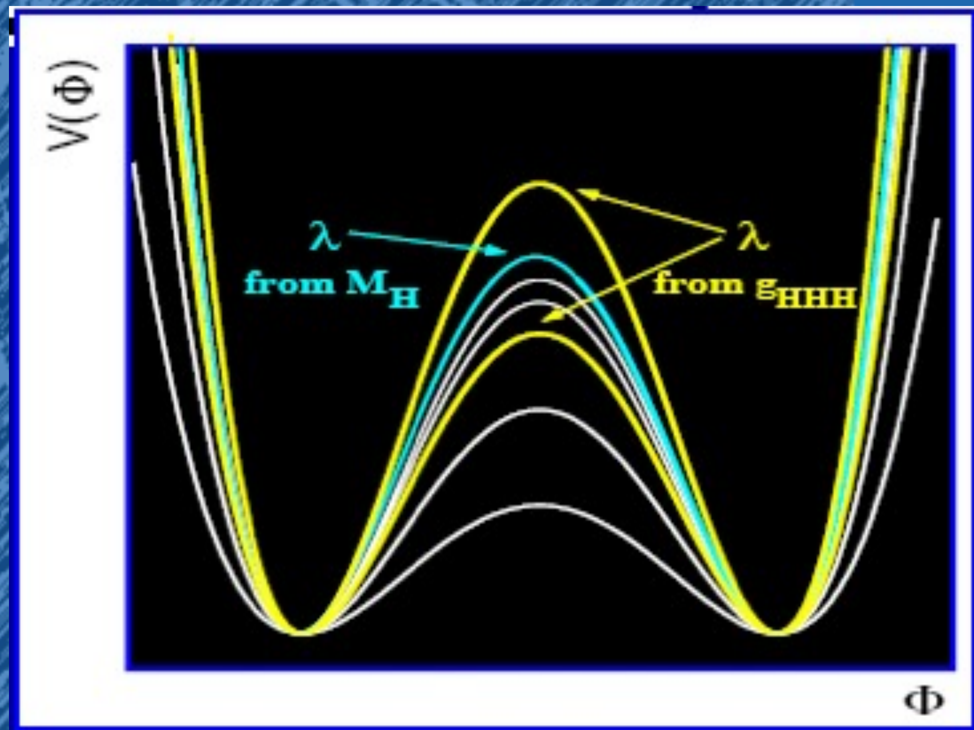
Determining the Higgs Potential

Fundamental test of Higgs potential shape through independent Determination of g_{HHH} in double Higgs production

$$V(\Phi^*\Phi) = \lambda(\Phi^*\Phi - \tfrac{1}{2}v^2)^2$$

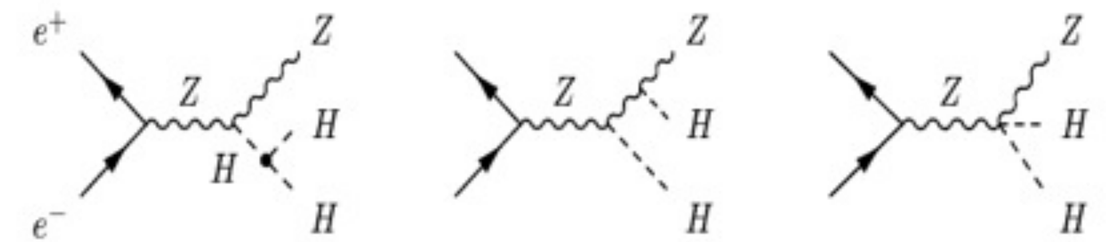
$$g_{HHH} = \frac{3}{2}\frac{M_H^2}{v}$$

Opportunity unique to the ILC, LHC cannot access double H Production and SLHC may have only marginal accuracy;

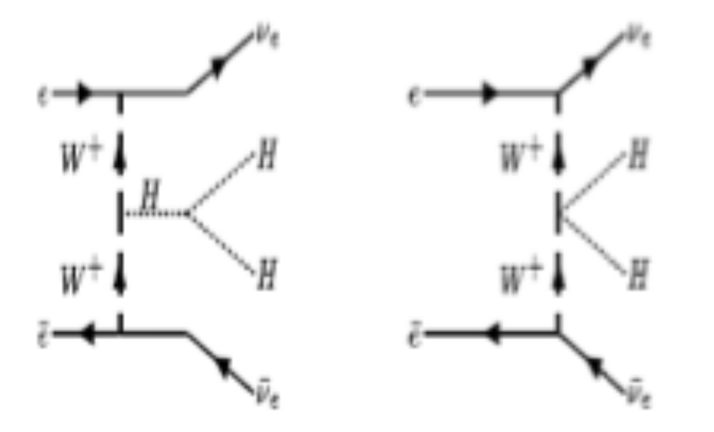


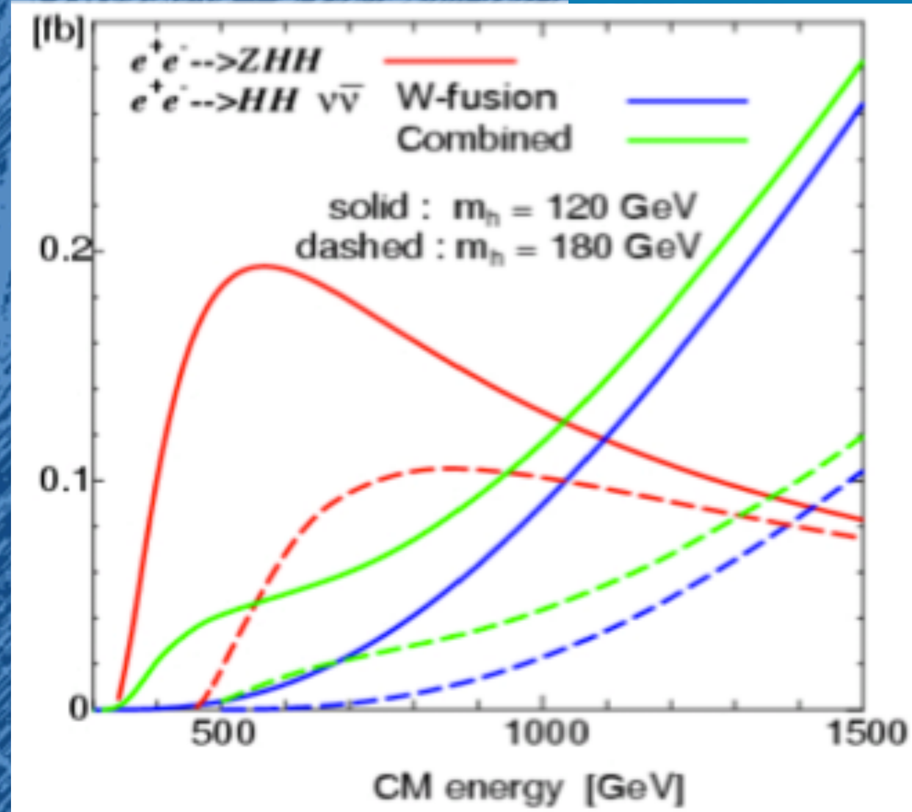
Determining the Higgs Potential

Double Higgsstrahlung: $e^+e^- \to H^0 H^0 Z^0$



Double WW Fusion: $e^+e^- \to H^0 H^0 \nu_e \bar{\nu}_e$



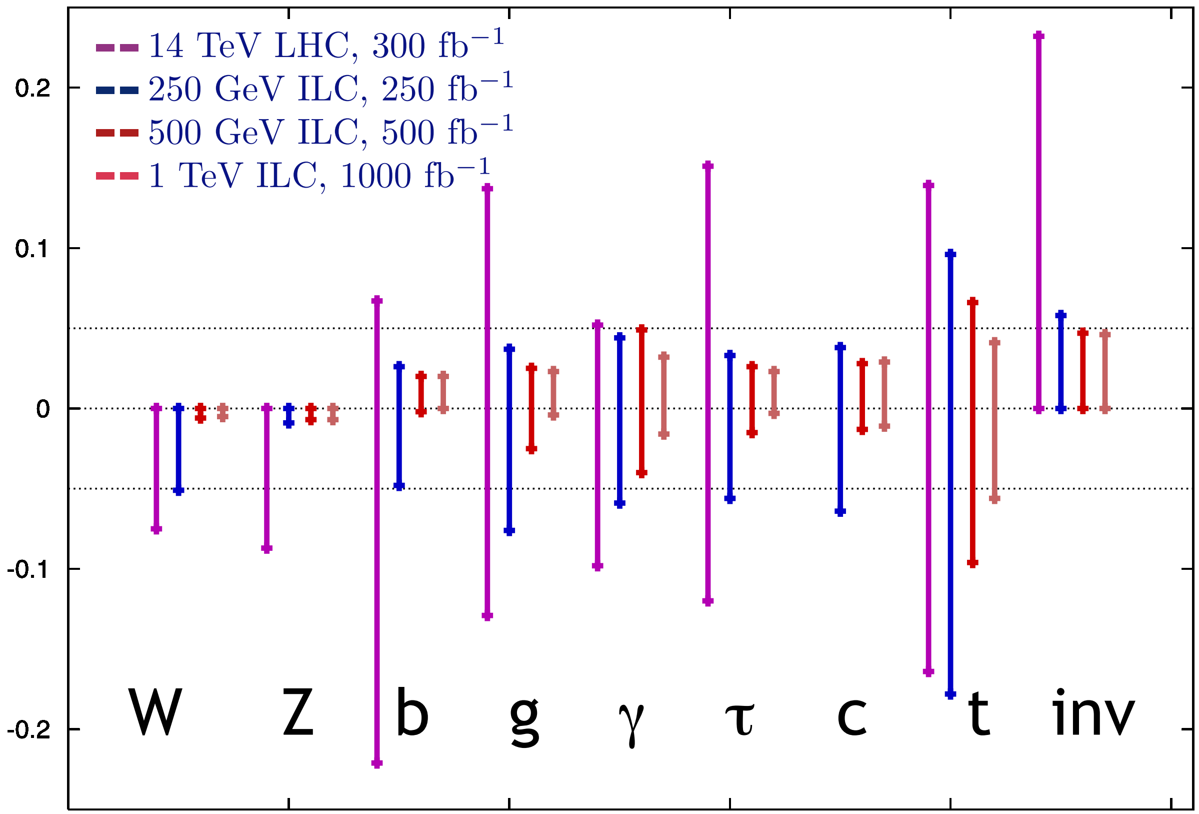


Experimental challenge: not only cross sections are tiny (< 1 fb), but need to discard HH production not sensitive to HHH vertex.

Capabilities of different colliders to determine Higgs boson couplings

M. Peskin, arXiv:1207.2516

$g(hAA)/g(hAA)|_{SM}-1$ LHC/HLC/ILC/ILCTeV



Why Linear ?

Particles undergoing centripetal acceleration a=v²/R radiate at rate:

$$\frac{1}{6\pi\epsilon_0}\frac{e^2a^2}{c^3}\gamma^4$$

Synchrotron Radiation

if R constant, energy loss is above rate x time spent in bending=2πR/v?

$$W = 8.85 \times 10^{-5} E^4 / R \text{ MeV per turn}$$

for e^-
(E in GeV, R in km)

$$W = 7.8 \times 10^{-3} E^4 / R \text{ keV per turn}$$

for p
(E in TeV, R in km)

Since energy transferred to beam per turn is constant: G x 2πR x F
at each R there is a maximum energy E_{max} beyond which energy loss exceeds energy transferred, real limit set by dumped power;

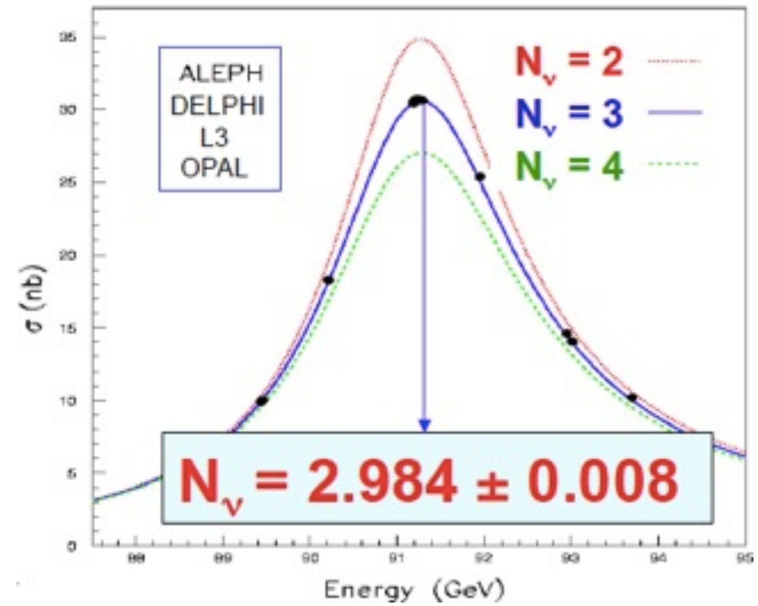
Example: LEP ring (R=4.3 km) E_e=250 GeV → W = 80 GeV/turn

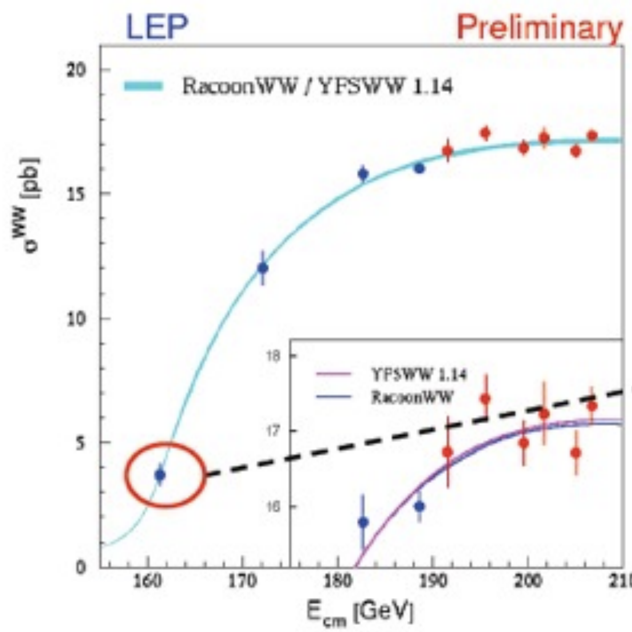
Circular e^+e^- collider

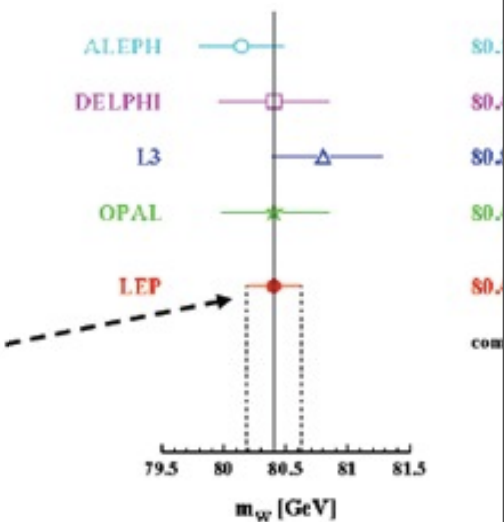
- √s limited by synchrotron radiation, but
  - 240 GeV not too far from LEP2 (205 GeV)
  - radio frequency cavities can reach much higher gradient today (7 ➜ 30 MV/m)
- Important questions
  - is such a machine possible and what are the limitations?
  - what is the physics potential?
  - what is the prize tag?
- Location and size
  - consider use of 27km LEP/LHC tunnel (LEP3)
  - or a new tunnel at CERN (TLEP) or elsewhere (SuperTRISTAN, FermiLEP, ...)

Physics program of circular e^+e^- collider

- GigaZ factory at $\sqrt{s} = m_Z$
  - 200x200 bunches, 5×10^{35} $cm^{-2}s^{-1}$
  - repeat LEP1 program every 10 min
  - 250x larger than LC GigaZ option
  - 5 ab^{-1} / experiment / year
  - ~10^{12} Z bosons
  - allow for polarized beams
- MegaWW factory at $\sqrt{s} = 2\ m_W$
  - 1×10^{35} $cm^{-2}s^{-1}$
  - 1 ab^{-1} / experiment / year
  - 4M W-pairs
  - 10^5x larger sample than LEP2
- Higgs factory at $\sqrt{s}$ = 240 GeV
  - 1×10^{34} $cm^{-2}s^{-1}$
  - 20000 Higgs bosons / year
  - 500 fb^{-1} / 5 year
- Top factory at $\sqrt{s}$ = 350 GeV
  - requires larger tunnel (80 km)







ΔmW (stat) < 1 MeV poss

Summary of measurements

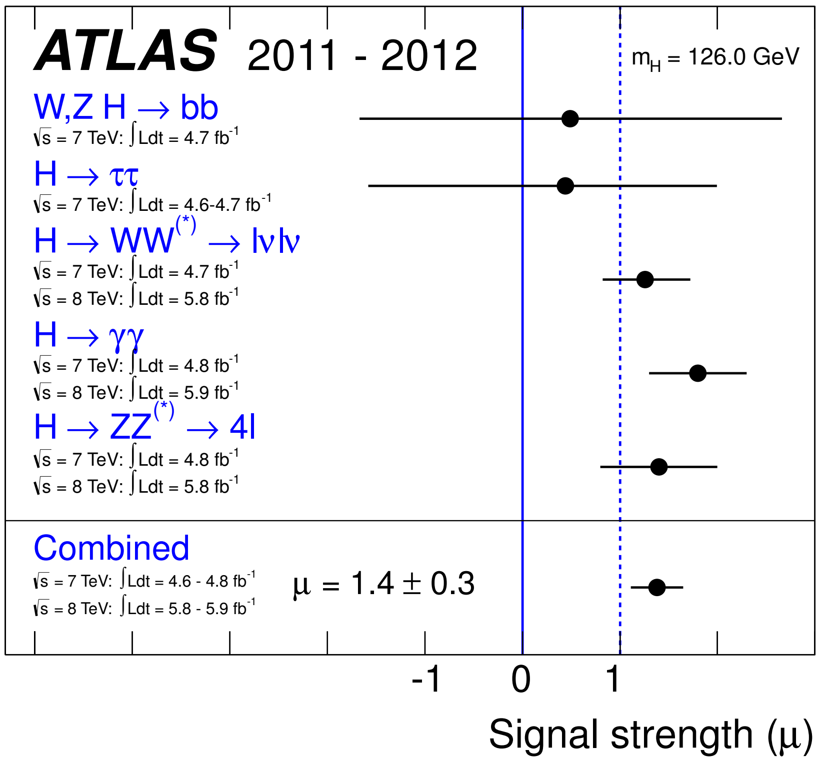
	ILC	LEP3 (2)	LEP3 (4)	LHC
σ_{HZ}	3%	1.9%	1.3%	–
$\sigma_{HZ} \times BR(H \to b\bar{b})$	1%	0.8%	0.5%	–
$\sigma_{HZ} \times BR(H \to \tau^+\tau^-)$	6%	3.0%	2.2%	–
$\sigma_{HZ} \times BR(H \to W^+W^-)$	8%	4.4%	3.1%	–
$\sigma_{HZ} \times BR(H \to \gamma\gamma)$	?	9.5%	6.6%	–
$\sigma_{HZ} \times BR(H \to \mu^+\mu^-)$	–	–	33%	–
$\sigma_{HZ} \times BR(H \to \text{invisible})$	?	1%	0.7%	–
g_{HZZ}	1.5%	0.9%	0.6%	13%
g_{Hbb}	1.6%	1.0%	0.7%	21%
$g_{H\tau\tau}$	3%	2.0%	1.5%	13%
g_{Hcc}	4%	?	?	?
g_{HWW}	4%	2.4%	1.7%	11%
$g_{H\gamma\gamma}$	?	4.9%	3.4%	6%
$g_{H\mu\mu}$	–	–	16%	25%

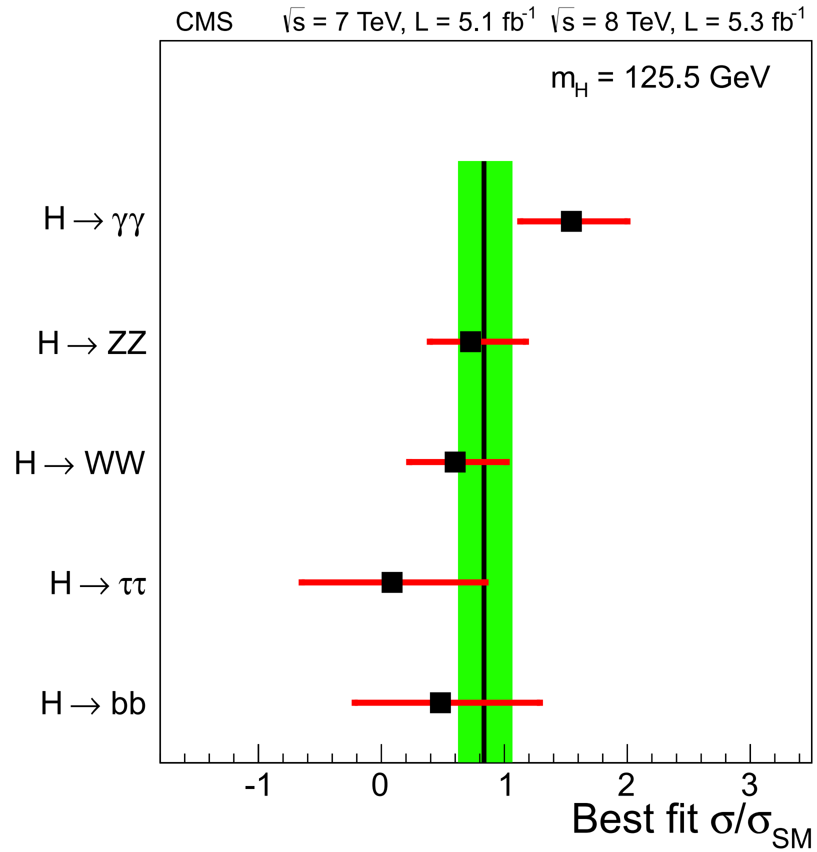
LHC results need to be revisited

- Circular e+e- is an interesting opportunity
  - very affordable price tag for the community (factor of 4-8 lower than ILC)

More on the Higgs

The Signal strength may be computed in all different production and decay channels and is consistent with the SM





However

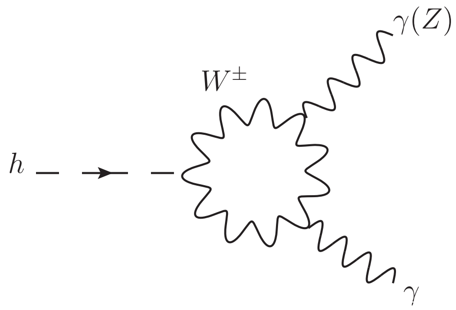
A di-photon rate enhancement is the most visible feature at both experiments.

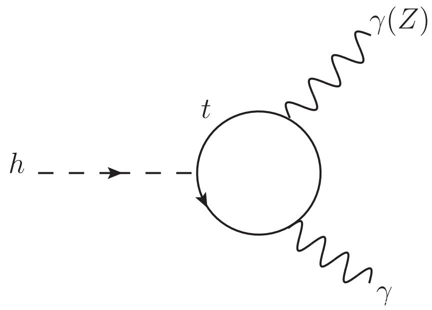
The WW/ZZ rates are, in average, at the SM value

There is an apparent suppression of tau production in VBF.

Present experimental uncertainties allow for a wide variety of new physics alternatives.

Dominant Contributions to the Diphoton Width in the Standard Model





Similar corrections appear from other scalar, fermion or vector particles. Clearly, similarly to the top quark, chiral fermions tend to reduce the vector boson contributions

Higgs Diphoton Decay Width in the SM

$$\Gamma(h \to \gamma\gamma) = \frac{G_F \alpha^2 m_h^3}{128\sqrt{2}\pi^3} \left| A_1(\tau_w) + N_c Q_t^2 A_{1/2}(\tau_t) \right|^2 \qquad \tau_i \equiv 4m_i^2/m_h^2$$

A. Djouadi'05

For particles much heavier than the Higgs boson

$$A_1 \to -7 \; , \qquad N_c Q_t^2 \, A_{1/2} \to \frac{4}{3} N_c Q_t^2 \;\; \simeq 1.78, \quad \text{for } N_c = 3, Q_t = 2/3$$

In the SM, for a Higgs of mass about 125 GeV

$$m_h = 125 \;\; \text{GeV} : \;\; A_1 = -8.32 \; , \quad N_c Q_t^2 A_{1/2} = 1.84$$

Dominant contribution from W loops. Top particles suppress by 40 percent the W loop contribution. One can rewrite the above expression in terms of the couplings of the particles to the Higgs as :

$$\Gamma(h \to \gamma\gamma) = \frac{\alpha^2 m_h^3}{1024\pi^3} \left| \frac{g_{hWW}}{m_W^2} A_1(\tau_w) + \frac{2 g_{ht\bar{t}}}{m_t} N_c Q_t^2 A_{1/2}(\tau_t) + N_c Q_S^2 \frac{g_{hSS}}{m_S^2} A_0(\tau_S) \right|^2$$

Inspection of the above expressions reveals that the contributions of particles heavier than the Higgs boson may be rewritten as

$$\mathcal{L}_{h\gamma\gamma} = -\frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i 2b_i \frac{\partial}{\partial \log v}\log m_i(v)\right] F_{\mu\nu}F^{\mu\nu}$$

$$\begin{cases} b = \frac{4}{3}N_c Q^2 & \text{for a Dirac fermion ,} \\ b = -7 & \text{for the } W \text{ boson ,} \\ b = \frac{1}{3}\,N_c Q_S^2 & \text{for a charged scalar .} \end{cases}$$

where in the Standard Model

$$\frac{g_{hWW}}{m_W^2} = \frac{\partial}{\partial v}\log m_W^2(v)\ , \qquad \frac{2g_{ht\bar{t}}}{m_t} = \frac{\partial}{\partial v}\log m_t^2(v)$$

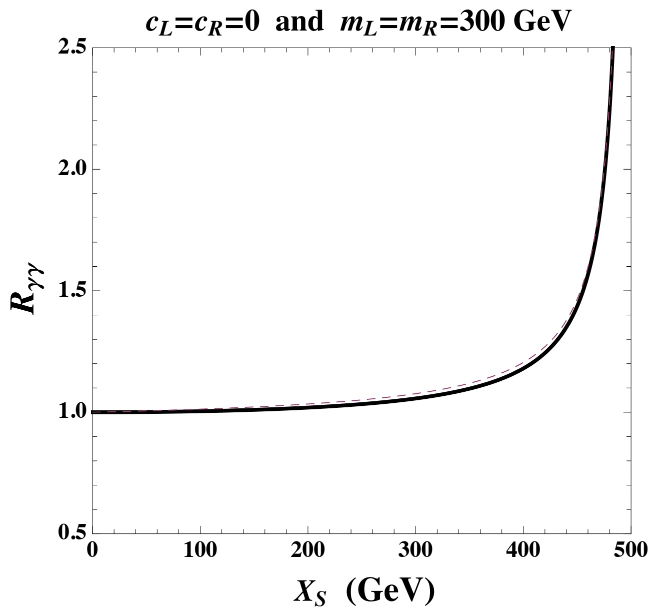
This generalizes for the case of fermions with contributions to their masses independent of the Higgs field. The couplings come from the vertex and the inverse dependence on the masses from the necessary chirality flip (for fermions) and the integral functions.

$$\mathcal{L}_{h\gamma\gamma} = \frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}^\dagger_{F,i}\mathcal{M}_{F,i}\right) + \sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}^2_{B,i}\right)\right] F_{\mu\nu}F^{\mu\nu}$$

M. Carena, I. Low, C.W., arXiv:1206.1082, Ellis, Gaillard, Nanopoulos'76, Shifman, Vainshtein, Voloshin, Zakharov'79

For bosons one simply replaces the square of the mass matrix by the mass matrix of the square masses ! Since the Higgs is light and charged particles are constrained by LEP to be of mass of order of, or heavier than the Higgs, this expression provides a good understanding of when particles could lead to an enhanced diphoton rate.

Two Scalars with Mixing



Similar to light stau scenario,

M. Carena, S. Gori, N. Shah, C.W., arXiv: 1112.3336,

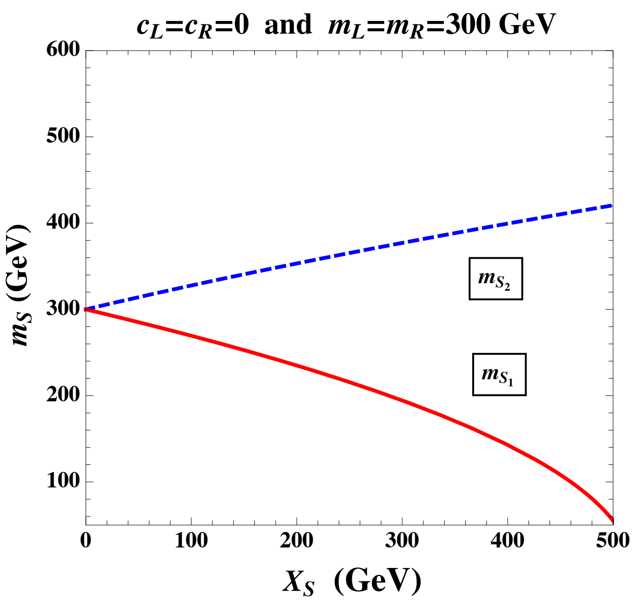
M. Carena, S. Gori, N. Shah, C.W., L.T. Wang, arXiv:1205.5842

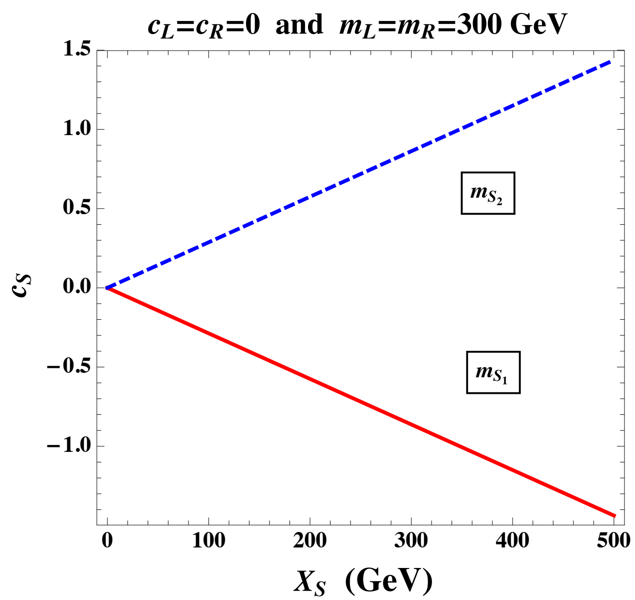
$$\mathcal{M}_S^2 = \begin{pmatrix} \tilde{m}_L(v)^2 & \frac{1}{\sqrt{2}} v X_S \\ \frac{1}{\sqrt{2}} v X_S & \tilde{m}_R(v)^2 \end{pmatrix}$$

$$\frac{\partial \log(\mathrm{Det} M_S^2)}{\partial v} \simeq - \frac{X_S^2 v}{m_{S_1}^2 m_{S_2}^2}$$

Negative Effective Coupling of lightest scalar

Large mixing and small value of the lightest scalar mass preferred





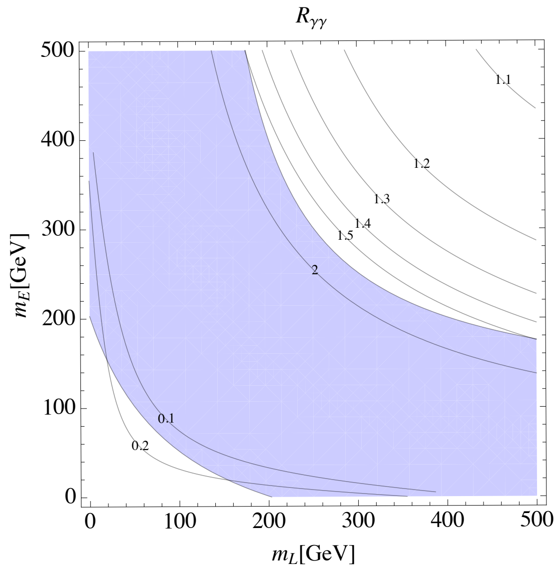
Lightest scalar, with mass below 200 GeV gives the dominant contribution in this case.

M. Carena, I. Low, C.W., arXiv:1206.1082

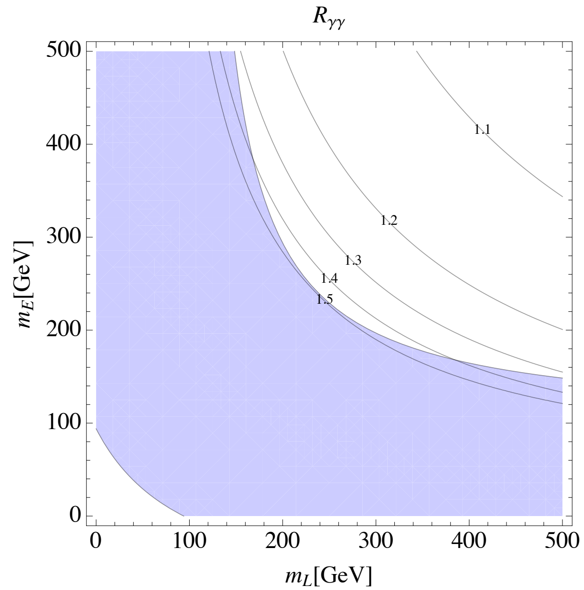
Model with a four generation leptons and their vector pairs.

Model can lead to the presence of Dark Matter and an enhanced diphoton rate

M. Carena, I. Low, C. Wagner'12;   A. Joglekar, P. Schwaller, C.W.'12



$Y_C' = Y_C" = 1$



$Y_C' = Y_C" = 0.8$

$$\mathcal{L}_{h\gamma\gamma} = \frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i b_i \frac{\partial}{\partial \log v} \log\left(\det \mathcal{M}_{F,i}^\dagger \mathcal{M}_{F,i}\right) + \sum_i b_i \frac{\partial}{\partial \log v} \log\left(\det \mathcal{M}_{B,i}^2\right)\right] F_{\mu\nu}F^{\mu\nu}$$

Ellis, Gaillard, Nanopoulos'76,   Shifman, Vainshtein, Voloshin, Zakharov'79

$$\mathcal{M} = \begin{pmatrix} Y_c' v & m_L \\ m_E & Y_c' v \end{pmatrix}$$

$$\frac{\partial \log(\mathrm{Det} M_f)}{\partial v} \simeq -2 \frac{Y_C' Y_C" v}{m_L m_E - Y_C' Y_C" v^2}$$

Implications for Low Energy Supersymmetry

Lightest SM-like Higgs mass strongly depends on:

* CP-odd Higgs mass m_A
* tan beta
* the top quark mass
* the stop masses and mixing

$$M^2_{\tilde{t}} = \begin{pmatrix} m_Q^2 + m_t^2 + D_L & m_t X_t \\ m_t X_t & m_U^2 + m_t^2 + D_R \end{pmatrix}$$

M_h depends logarithmically on the averaged stop mass scale M_{SUSY} and has a quadratic and quartic dep. on the stop mixing parameter X_t. [and on sbottom/stau sectors for large tan beta]

For moderate to large values of tan beta and large non-standard Higgs masses

$$m_h^2 \cong M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\frac{1}{2}\tilde{X}_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_3\right)\left(\tilde{X}_t t + t^2\right)\right]$$

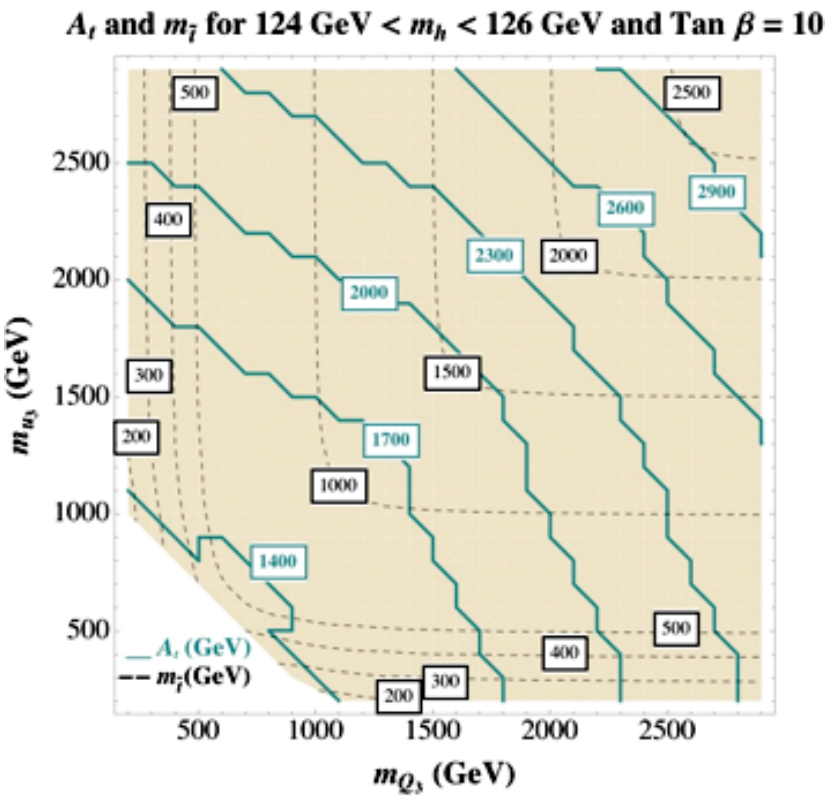
$$t = \log(M_{SUSY}^2 / m_t^2) \qquad \tilde{X}_t = \frac{2X_t^2}{M_{SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{SUSY}^2}\right)$$

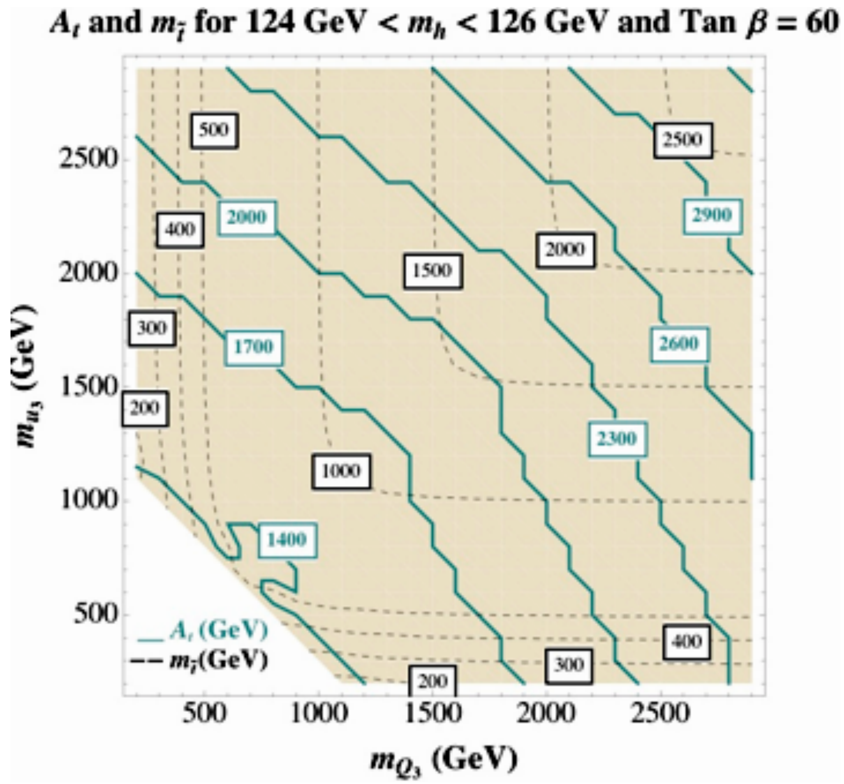
$X_t = A_t - \mu/\tan\beta \rightarrow$ LR stop mixing

Analytic expression valid for $M_{SUSY} \sim m_Q \sim m_U$

Soft supersymmetry Breaking Parameters

M. Carena, S. Gori, N. Shah, C.Wagner, arXiv:1112.336, +L.T.Wang, arXiv:1205.5842





Large stop sector mixing
A_t > 1 TeV

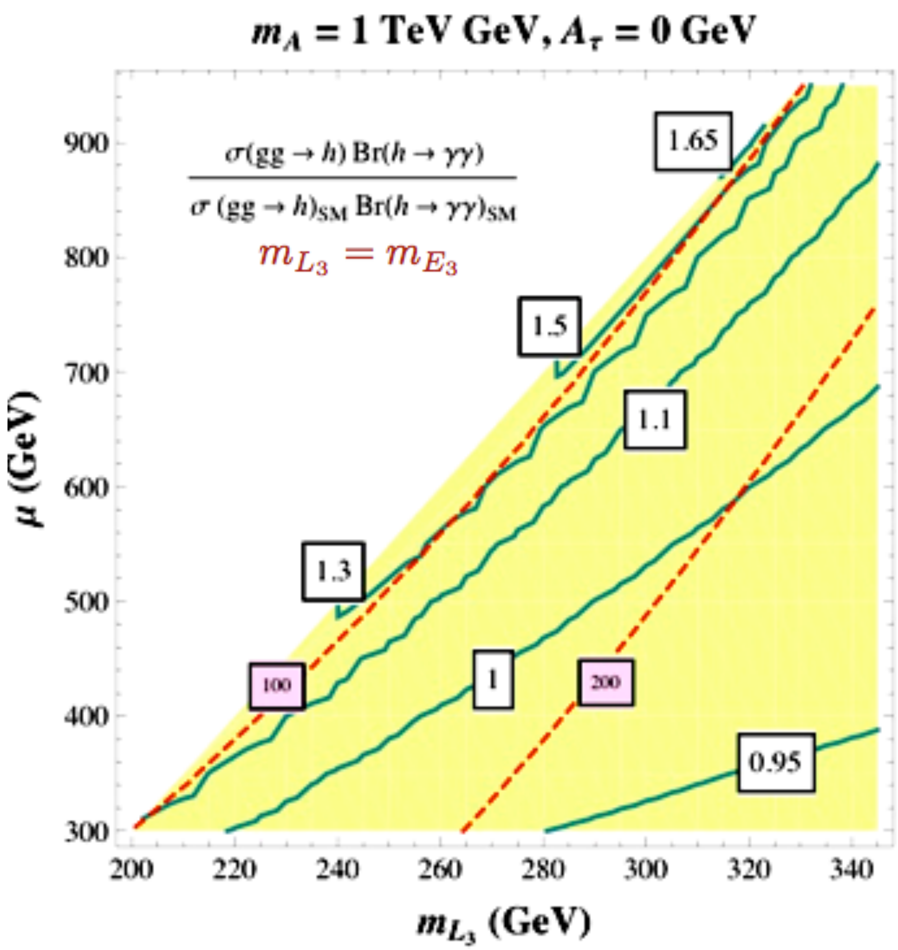
No lower bound on the lightest stop
One stop can be light and the other heavy
or
in the case of similar stop soft masses.
both stops can be below 1TeV

Intermediate values of tan beta lead to the largest values of m_h for the same values of stop mass parameters

At large tan beta, light staus/sbottoms can decrease mh by several GeV's via Higgs mixing effects and compensate tan beta enhancement

Higgs Decay into two Photons in the MSSM

Charged scalar particles with no color charge can change di-photon rate without modification of the gluon production process



$$\mathcal{M}_{\tilde{\tau}}^2 \simeq \begin{bmatrix} m_{L_3}^2 + m_\tau^2 + D_L & h_\tau v(A_\tau \cos\beta - \mu \sin\beta) \\ h_\tau v(A_\tau \cos\beta - \mu\sin\beta) & m_{E_3}^2 + m_\tau^2 + D_R \end{bmatrix}$$

Light staus with large mixing

[sizeable μ and tan beta]:

➔ **enhancement of the Higgs to di-photon decay rate**

Contours of constant

$$\frac{\sigma(gg\to h)Br(h\to\gamma\gamma)}{\sigma(gg\to h)_{SM}Br(h\to\gamma\gamma)_{SM}}$$

for M_h ~ 125 GeV

M. Carena, S. Gori, N. Shah, C. Wagner, arXiv:1112.336, +L.T.Wang, arXiv:1205.5842

For a more generic discussion of modified diphoton width by new charged particles, see M. Carena, I. Low and C. Wagner, arXiv:1206.1082

Mixing Effects in the CP- even Higgs Sector

- Mixing can have relevant effects in the production and decay rates

$$\mathcal{M}_H^2 = \begin{bmatrix} m_A^2 \sin^2\beta + M_Z^2\cos^2\beta & -(m_A^2 + M_Z^2)\sin\beta\cos\beta + \text{Loop}_{12} \\ -(m_A^2 + M_Z^2)\sin\beta\cos\beta + \text{Loop}_{12} & m_A^2\cos^2\beta + M_Z^2\sin^2\beta + \text{Loop}_{22} \end{bmatrix}$$

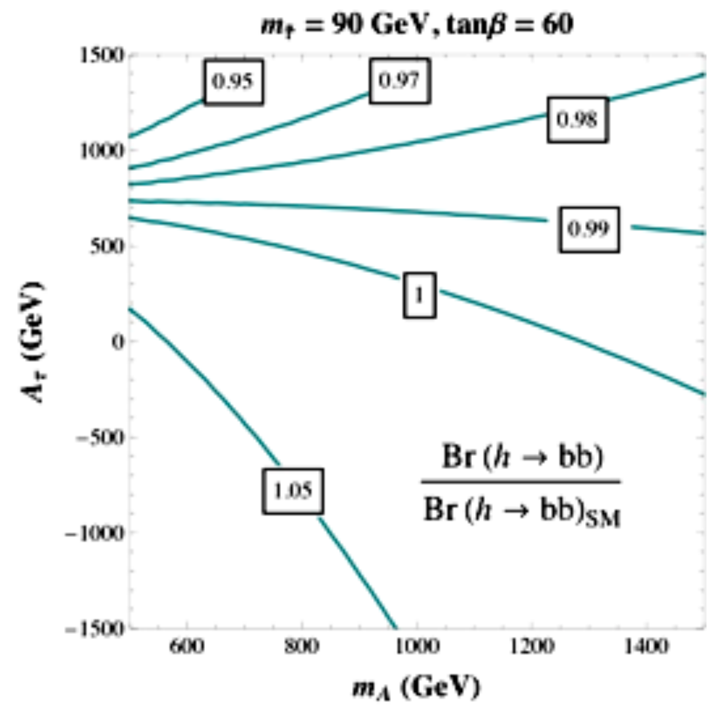
$$\text{Loop}_{12} = \frac{m_t^4}{16\pi^2 v^2 \sin^2\beta}\frac{\mu\bar{A}_t}{M_{\text{SUSY}}^2}\left[\frac{A_t\bar{A}_t}{M_{\text{SUSY}}^2} - 6\right] + \frac{h_b^4 v^2}{16\pi^2}\sin^2\beta\frac{\mu^3 A_b}{M_{\text{SUSY}}^4} + \frac{h_\tau^4 v^2}{48\pi^2}\sin^2\beta\frac{\mu^3 A_\tau}{M_{\tilde{\tau}}^4}$$

effects through radiative corrections
to the CP-even mass matrix
which defines the mixing angle alpha

$$\sin\alpha\cos\alpha = M_{12}^2 / \sqrt{\left(\text{Tr}\, M^2\right)^2 - 4\det M^2}$$

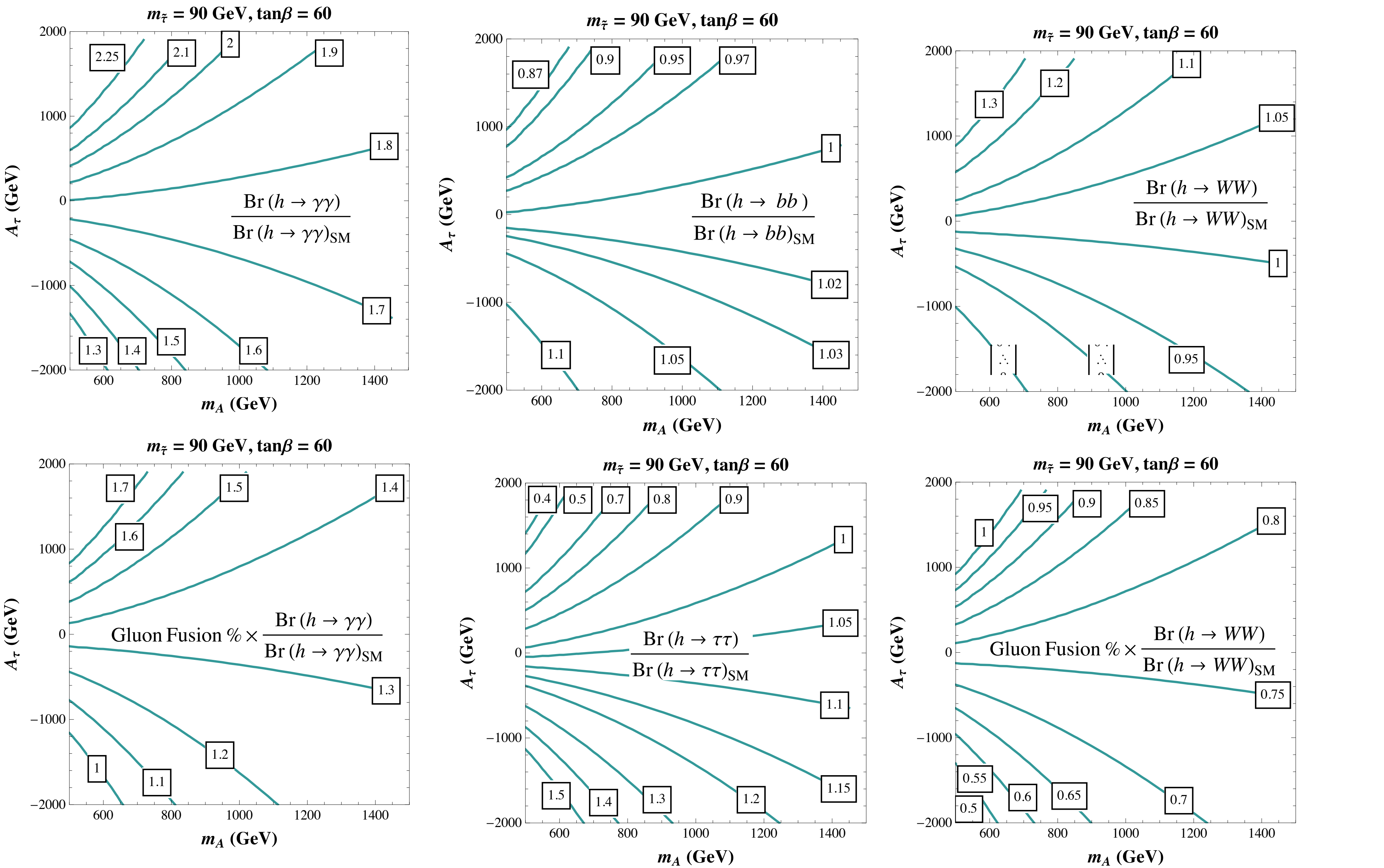
$$hb\bar{b}: \quad -\frac{\sin\alpha}{\cos\beta}\left[1 - \frac{\Delta h_b \tan\beta}{1 + \Delta h_b\tan\beta}\left(1 + \frac{1}{\tan\alpha\tan\beta}\right)\right]$$

Small Variations in the Br(Hbb) can induce
significant variations in the other Higgs Br's

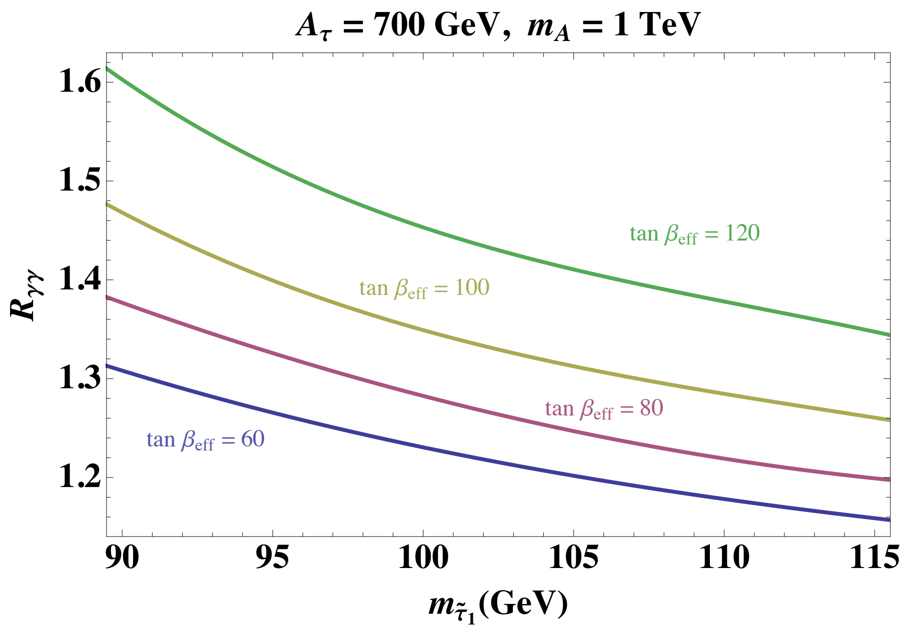


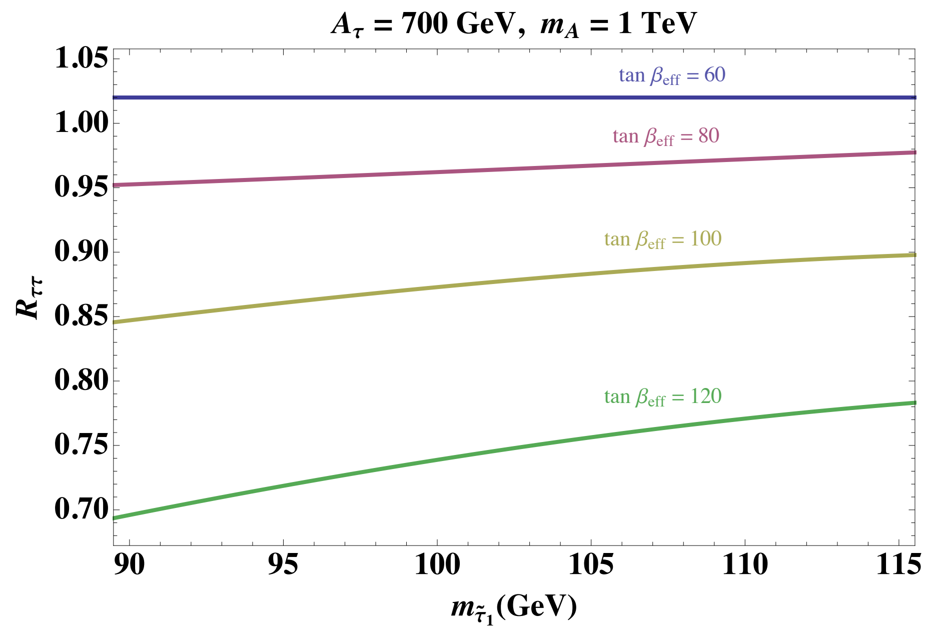
Scenario with suppression of gluon fusion and enhancement of diphoton rate : Relatively light stops, with mass about150 GeV and light staus, with mass of order 90 GeV

M. Carena, S. Gori, N. Shah, C. Wagner, to appear

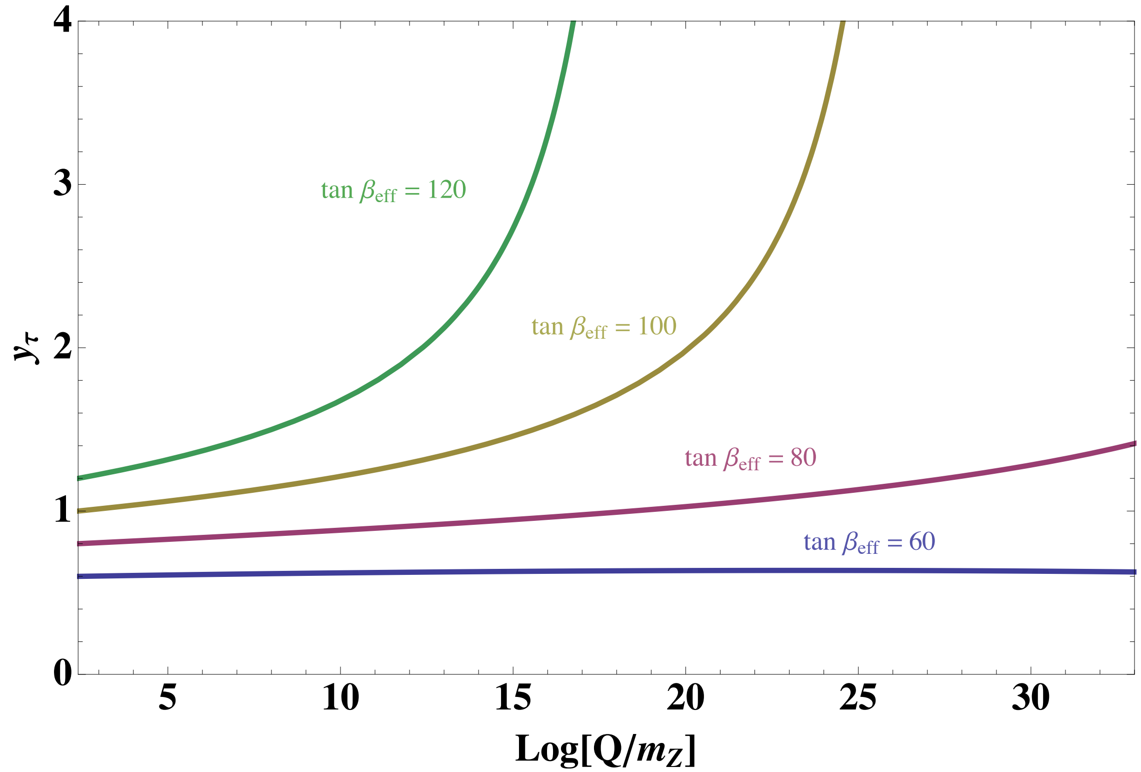


Effects of new particles become strong only if new particles have masses of order 100 GeV





Large effects may also be obtained if couplings are strong, becoming non-perturbative before the GUT scale



Still, light particles of order of 100 GeV preferred

Light Stau Searches at the LHC

M. Carena, S. Gori, N. Shah, C.W. and L.T. Wang, arXiv:1205.5842

	Signature	8 TeV LHC (fb)	14 TeV LHC (fb)
$pp \to \tilde{\tau}_1 \tilde{\tau}_1$	$2\tau, \not{E}_T$	55.3	124.6
$pp \to \tilde{\tau}_1 \tilde{\tau}_2$	$2\tau, Z, \not{E}_T$	1.0	3.2
$pp \to \tilde{\tau}_2 \tilde{\tau}_2$	$2\tau, 2Z, \not{E}_T$	0.15	0.6
$pp \to \tilde{\tau}_1 \tilde{\nu}_\tau$	$2\tau, W, \not{E}_T$	14.3	38.8
$pp \to \tilde{\tau}_2 \tilde{\nu}_\tau$	$2\tau, W, Z, \not{E}_T$	0.9	3.1
$pp \to \tilde{\nu}_\tau \tilde{\nu}_\tau$	$2\tau, 2W, \not{E}_T$	1.6	5.3

$$\tilde{\tau}_1 \to \chi_1 \tau \ , \quad \text{or} \quad \tilde{\tau}_1 \to \tilde{G} \tau$$

Possible stau and sneutrino direct production channels with their signatures at the LHC. The cross sections shown are computed for $m_{L_3} = m_{e_3} = 280$ GeV, $\tan\beta = 60$, $\mu = 650$ GeV and $M_1 = 35$ GeV.

- Direct stau pair production leads to final states with two taus plus missing energy.
- Very large backgrounds coming from W plus jets, WW, ZZ* (γ*) production turn this channel difficult. In addition, tau tagging reduces the cross section from 55 to 7 fb. One can reduce the physical backgrounds but W plus jet seems difficult to overcome.
- We concentrated on the associated production of staus with sneutrinos.
- Production of stau pairs should be explored in more detail : Considering, for example, tau decays into leptons and possible tau polarization discrimination.

Stau plus Sneutrino Searches

M. Carena, S. Gori, N. Shah, C.W. and L.T. Wang, arXiv:1205.5842

- We consider alternative searches for associated production of staus with sneutrinos. Since the staus have large mixing, the stau sneutrinos are relatively light, and of the order of the left-handed stau mass.

$$pp \to \tilde{\tau}_1 \tilde{\nu}_\tau \to \tilde{\tau}_1 (W \tilde{\tau}_1) \to \tau \chi_1 W \tau \chi_1$$

- W decaying leptonically. Main background : W + 2 jets. We impose two loose τ tags.

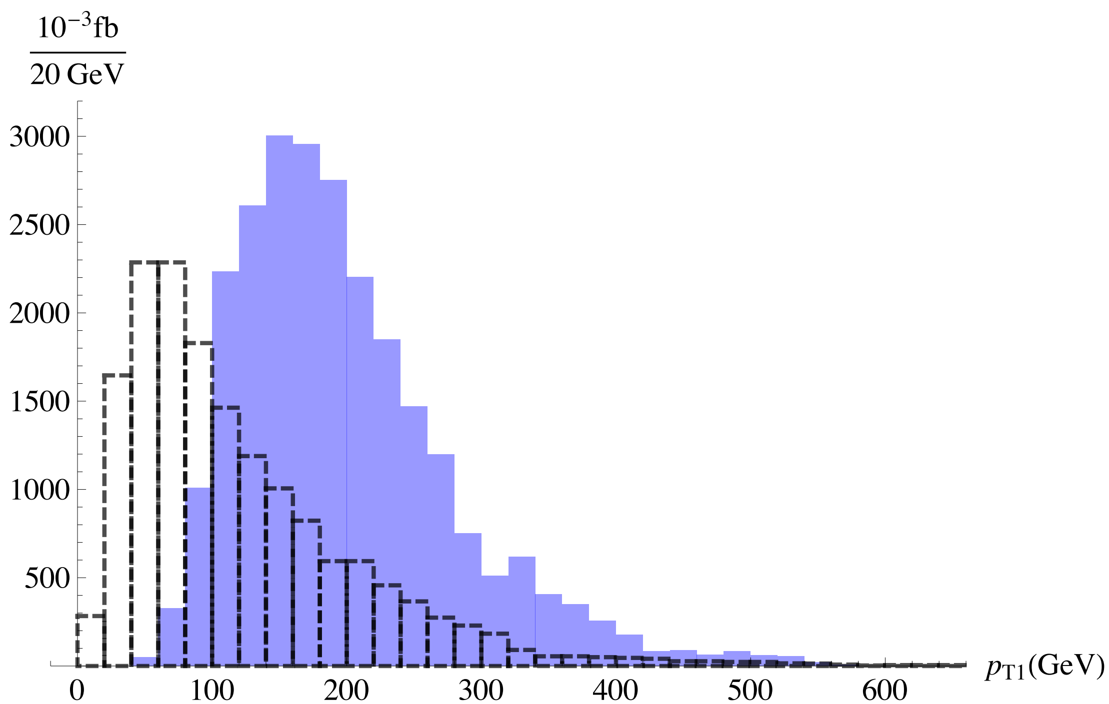
- Lepton and neutrino from W in signal boosted : We required large lepton p_T and missing E_T larger than 70 GeV

- Then, jets from background tend to have large p_T. We required the largest jet p_T to be lower than 75 GeV

- We also avoid taus with invariant mass close to the Z mass, but improvement is insignificant after previous cuts.

Leading jet PT Distribution

M. Carena, S. Gori, N. Shah, C.W. and L.T.Wang, arXiv:1205.5842



Signal (black histogram) and background (blue) pT distributions.
Signal rescaled by a factor 100 for visibility

Results of Simulations

M. Carena, S. Gori, N. Shah, C.W. and L.T.Wang, arXiv:1205.5842

	Total (fb)	Basic (fb)	Hard Tau (fb)
Signal	0.6	0.16	0.07
Physical background, $W + Z/\gamma^*$	15	0.25	$\lesssim 10^{-3}$
$W+$ jets background	4×10^3	26	0.3

: Cross sections for the signal and the physical and fake backgrounds after τ-tags at the 8 TeV LHC: after imposing acceptance cuts $p_T^{\tau(j)} > 10$ GeV, $\Delta R > 0.4$ and and $|\eta| < 2.5$ (second column); with the additional requirement $p_T^\ell > 70$ GeV and $\not{E}_T > 70$ (third column); imposing that the τ is not too boosted $p_T^\tau < 75$ GeV (fourth column).

	Total (fb)	Basic (fb)	Hard Tau (fb)
Signal	1.6	0.26	0.11
Physical background, $W + Z/\gamma^*$	27	0.32	$\lesssim 10^{-3}$
$W+$ jets background	10^4	39	0.25

: Cross sections for the signal and the physical and fake background after τ-tags at the 14 TeV LHC: after imposing $p_T^{\tau(j)} > 10$ GeV, $\Delta R > 0.4$ and and $|\eta| < 2.5$ (second column); with the additional requirement $p_T^\ell > 85$ GeV and $\not{E}_T > 85$ (third column); imposing that the τ is not too boosted $p_T^\tau < 80$ GeV (fourth column).

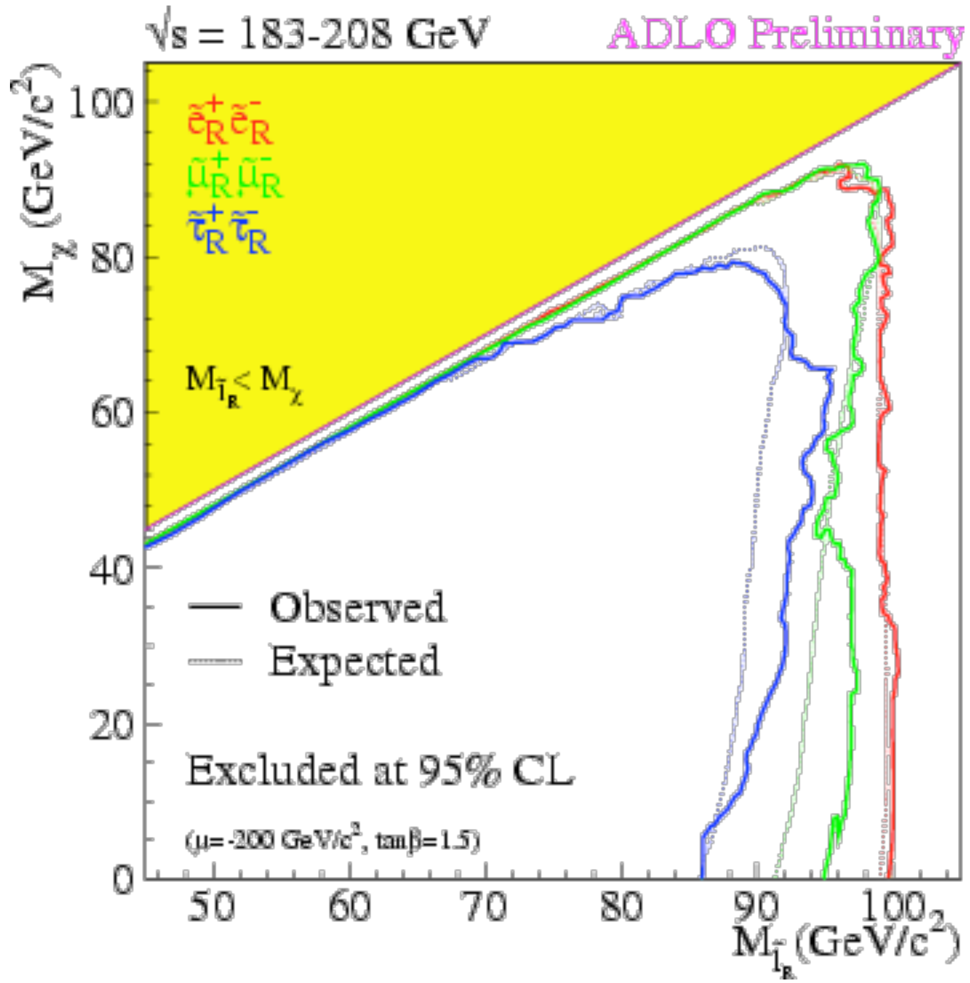
Very low statistics, but worth a dedicated analysis.
Prospects are better at the 14 TeV LHC, but still very difficult to find.

Light, Weakly Interacting Charged Particles

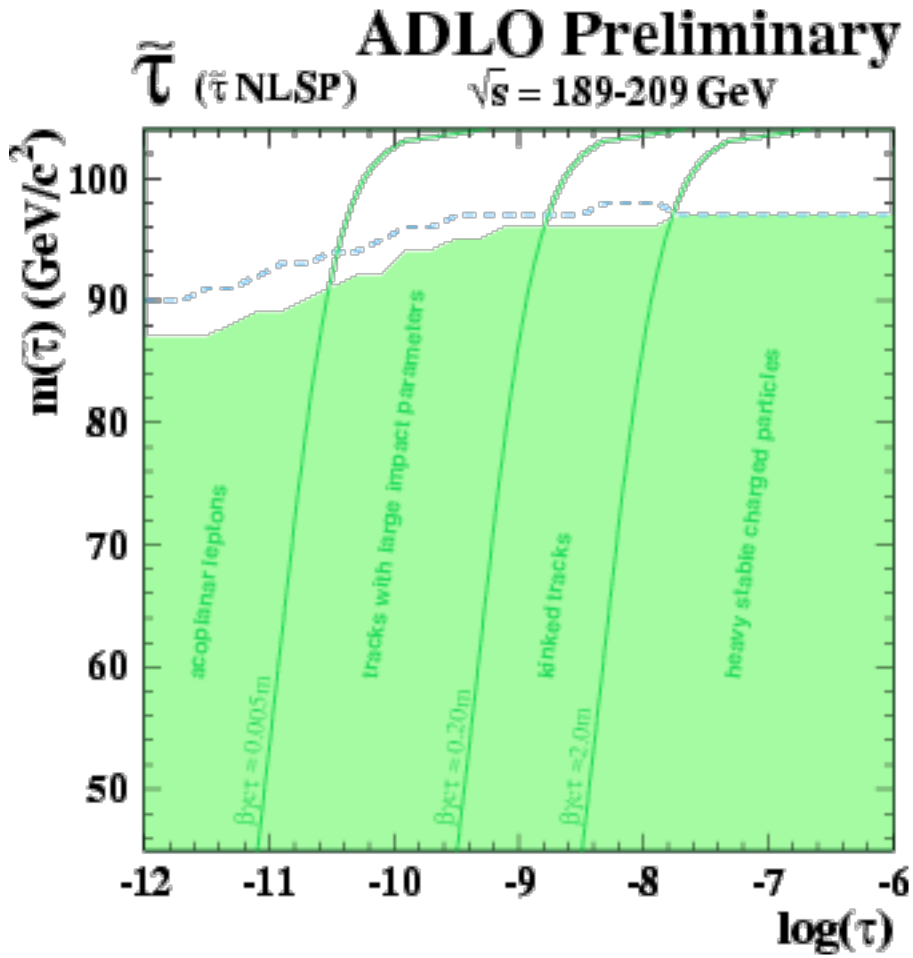
- If neutral, weakly interacting particles are present (Dark Matter),
- it is probably that charged particles are there, too.
- They may contribute to the muon g-2
- They may contribute to the enhancement of the rate of the Higgs decay to diphotons !
- In SUSY, light staus may enhance the Higgs to di-photon rate. Or vector like leptons, or charginos of a strongly coupled sector...
- They are difficult to search for at the LHC
- The Linear Collider may complement the LHC efforts to study the Higgs and search for these particles.

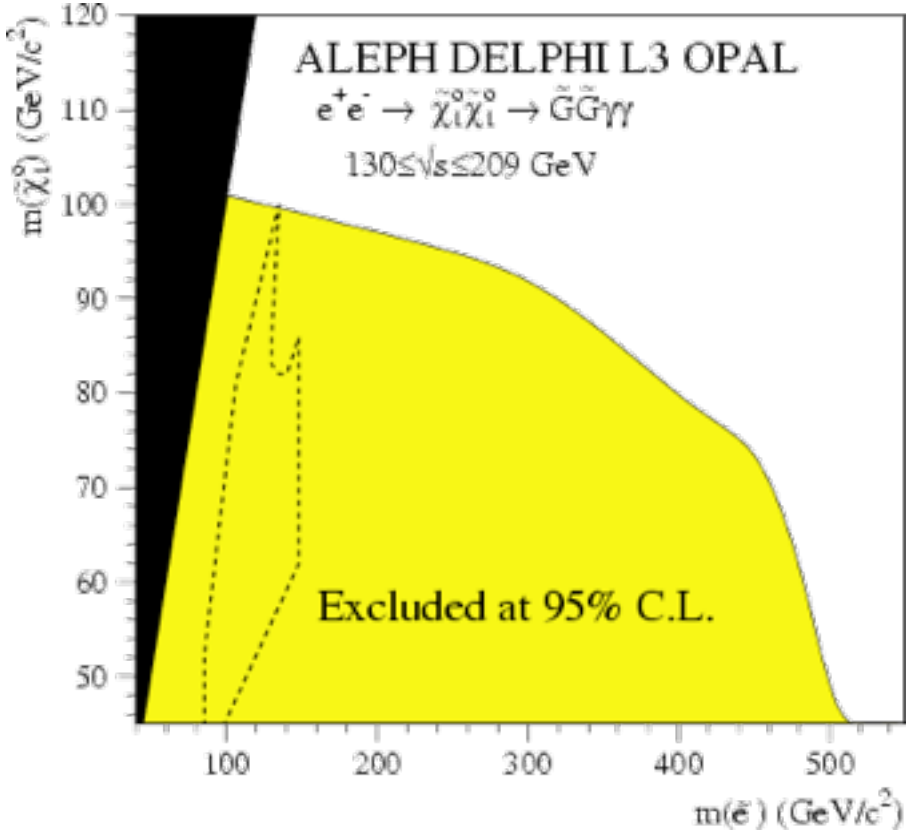
An electron positron Higgs factory presents the opportunity of searching for these particles up to near the kinematic limit.

Light Slepton Searches at LEP



Similar bounds obtained for staus decaying into gravitinos, with a sizable lifetime.

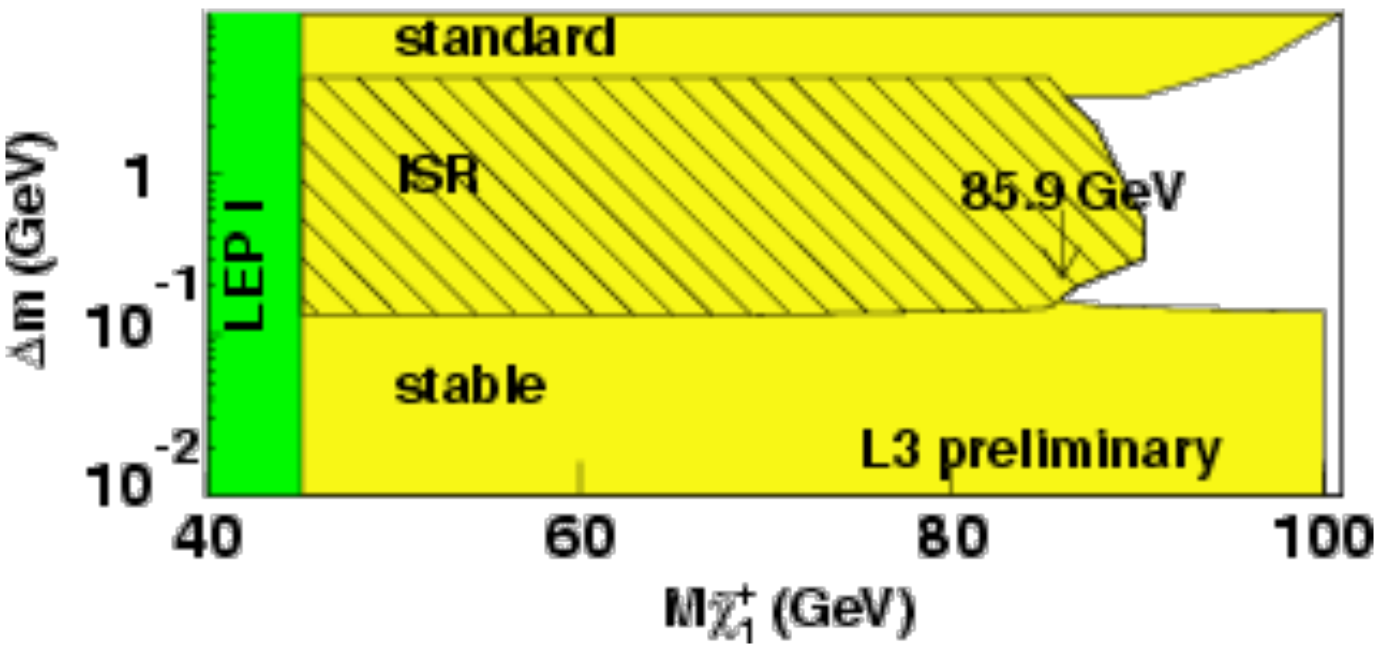




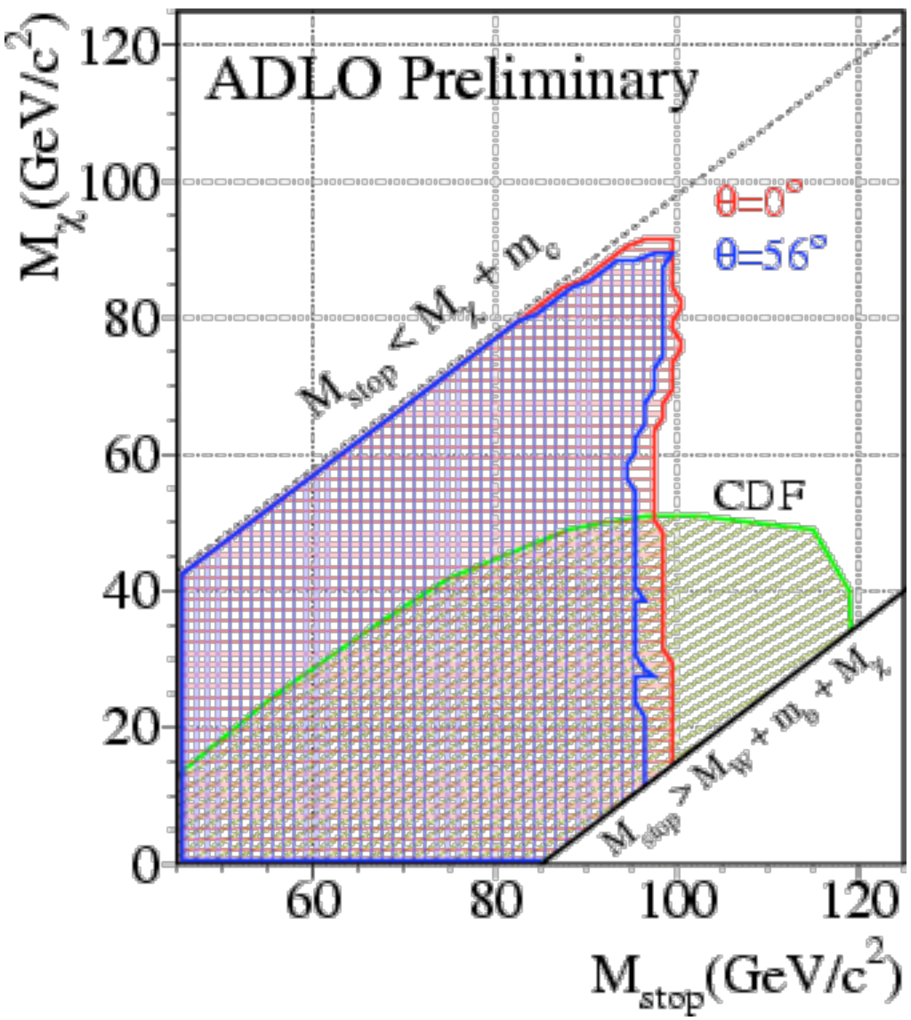
Enhancement of diphoton rate may also be induced by charginos or leptons, somewhat strongly coupled to the Higgs.

LEP put a strong constraint, of order 103.6 GeV on charginos decaying to W's and missing energy.

Bound significant even in the most difficult region of difference of mass between chargino and neutralinos.



Similar strong bounds for stops decaying into charm and neutralino



- Lepton collider allows to measure Higgs couplings and look for new weakly interacting particles that may have escaped detection at the LHC.
- These particles may be responsible for the enhancement of the diphoton Higgs decay width
- They may also be related to the discrepancy in g-2 of the muon
- They may be part of a single structure with the Dark Matter candidates
- Can we get a lepton collider at Argonne or elsewhere in the near future ?

Presentation at the European Strategy Meeting

International Linear Collider in Japan ?

- Final update on the ILC discussion in Cracow: Japan may pay 50% of a 500 GeV machine.
- The 250 GeV machine would cost about 70% of the 500 GeV machine,
- One scenario could be that Japan finances a large part of the Higgs factory
- Further upgrades to 500 GeV or 1 TeV would have to be financed by external partners.
  All subject to governmental negotiations, of course !

Time line of particle physics program in Japan

M. Yamauchi, European Strategy Meeting, Krakow, September 12,2012

The Near Future

- The current decade will see the full development of the LHC program, which will provide detailed information of physics at the TeV scale.
- Origin of fermion and gauge boson masses (electroweak symmetry breaking dynamics) expected to be revealed by these experiments. Higgs Discovery is the first step.
- Missing energy signatures at the LHC may reveal one or more dark matter candidates. Direct and indirect detection experiments will reach maturity, and may lead to additional evidence of Dark Matter. Dark Energy equation of state may be determined.
- Tevatron, LHC, LHCb and super B-factories will provide accurate information on flavor physics, leading to complementary information on new physics.

The Near Future

- Search for charged lepton number violation, g-2 of the muon and neutrino-less double beta decay experiments could shed light on the nature of neutrinos, and new dynamics at the TeV scale.
- Neutrino oscillation experiments lead to the observation of CP-violation or, indirectly, to the existence of additional sterile neutrinos.
- The Linear Collider is built, helping to do precision measurements of the Higgs properties and search for weakly interacting particles.
- Muon Collider construction may start at Fermilab.

The next 10 to 20 years can mark the beginning of a genuine new era in physics, similar to the one that led to the successful SMs of particle physics and cosmology, which arguably started about 100 years ago.

Assume Resonance behaves like a SM Higgs: What are the implications for the future of High Energy Physics?

Many questions remain unanswered. Just to list some important ones :

- Why is gravity so weak or, equivalently, why is the Planck scale so high compared to the weak scale ? (hierarchy problem)
- What is the origin of the matter-antimatter asymmetry
- What is the origin of Dark Matter ?
- Are neutrinos their own antiparticle ?
- Why are there three generations of fermions ?
- What is the origin of the hierarchy of fermion masses ?
- Do forces unify ? Is the proton (ordinary matter) stable ?
- What about Dark Energy ?

Higgs Precision Measurements with CMS@LEP3

- Results are realistic and conservative
  - Full CMS detector is used throughout
  - Simulated 5 years of LEP3 or 500 fb^{-1}

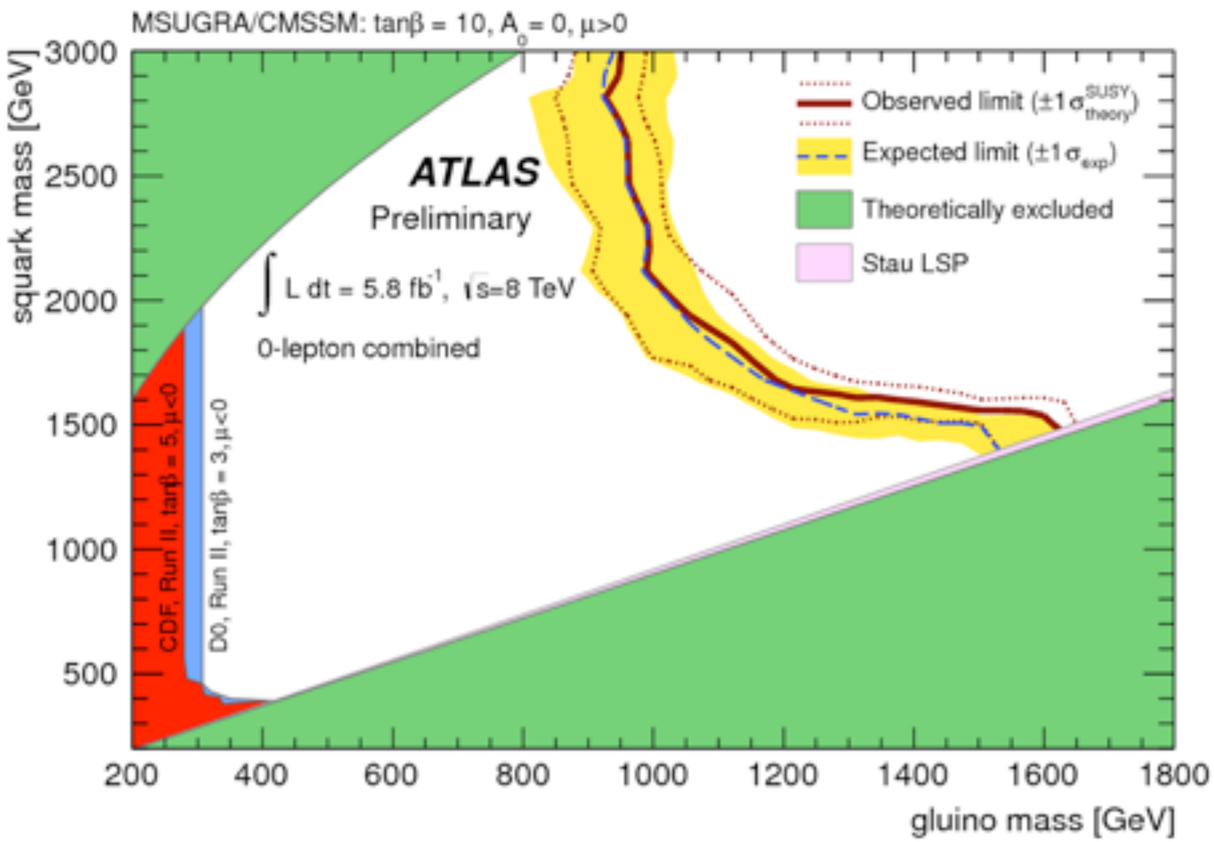
Higgs factory at $\sqrt{s}$ = 240 GeV

Decay	Events
bb	58000
ττ	6400
cc	2800
μμ	22
WW	22000
gg	8200
ZZ	2600
γγ	260
Zγ	160
X^0X^0	???

Results of Searches for Supersymmetry at the LHC

Masses of squarks and gluinos below about 1 TeV seem to be in conflict with data in simple supersymmetry models.

But Higgs mass already pointing to masses of order 1 TeV...



So far, no evidence of new physics at the LHC.

But these bounds are strongly model dependent.

Third generation particles may be much lighter and more data coming...