Search for Higgs beyond Standard Model at LHC

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(on behalf of ATLAS and CMS collaborations)

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Higgs for beyond Standard Model

- Fine tuning problem: at 1-loop Higgs mass corrections counterterms to be tuned to 1 part in 10^{17}.
- Heirarchy problem: natural value of Higgs mass very different from Planck Mass.
- Available solutions with their own problems: SUSY, Extra dimensions, Little Higgs models.
- LHC to elucidate on possible mechanism!

- SUSY: best candidate? $\rightarrow$ best treatment!
  5 Higgs boson: $\mathrm{h}, \mathrm{H}, \mathrm{A}, \mathrm{H}^{\pm}$

- At tree level, all masses and branchings are determined by 2 parameters, typically $\mathrm{m_A}$, $tan\beta$.
  At loop level top and SUSY particles modify relations.

- For wide range of SUSY parameters:
  $\mathrm{m_h} \leq 150$ GeV/c^2
  $\mathrm{m_A} \sim \mathrm{m_h}$ for $\mathrm{m_A} \leq 120$ GeV/c^2
  $\mathrm{m_A} \sim \mathrm{m_H}$ for $\mathrm{m_A} \geq 120$ GeV/c^2

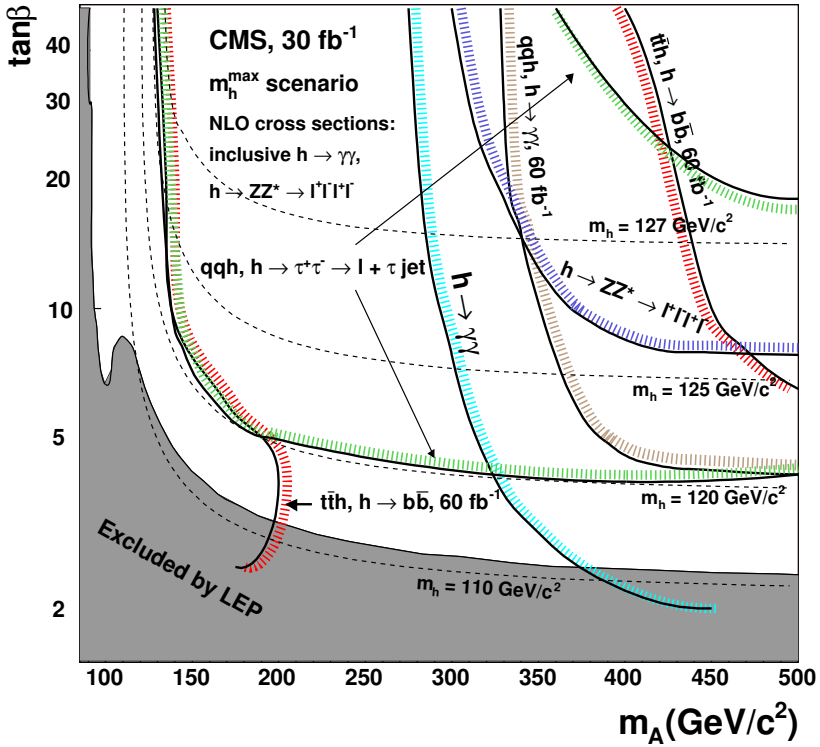
- Search for h: similar to SM Higgs boson.
- H/A productions at LHC, though weak, larger than SM Higgs.
  Direct production for low $tan\beta$,
  Associated production for high $tan\beta$.
  Has large branching ratio to experimenatlly suitable modes for all $tan\beta$.
- Results, in terms of reach, as a function of luminosity, presented in $\mathrm{m_A}$, $tan\beta$ plane.
- Recent studies include systematics.

Considerations for discovery:

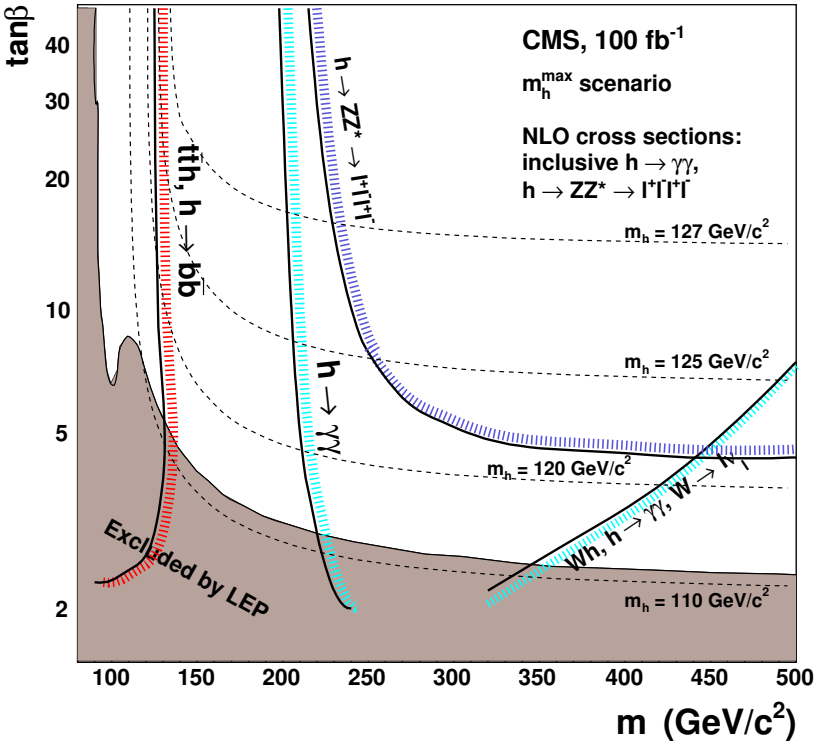
- sufficient signal rate
- efficient trigger
- Higgs boson mass reconstructable?
- control of background; signal–to-background ratio
- possibility for estimation of BG from data.
  sometimes background shape from MC.
- generator uncertainties (QCD scales etc.)

Search for SM-like scalar Higgs Boson

- $\mathrm{h} \to \gamma\gamma$, $\mathrm{h} \to \mathrm{ZZ}^* \to 4\ell$ in inclusive productions
- $\mathrm{h} \to \gamma\gamma$ for Wh production,
  $\mathrm{h} \to \mathrm{b\bar{b}}$ in associated productions: Wh, $\mathrm{t\bar{t}H}$
- $\mathrm{h} \to \gamma\gamma$, $\mathrm{h} \to \tau\tau \to \ell + \mathrm{j}$ in $\mathrm{qq} \to \mathrm{qqh}$
- for $90 \leq \mathrm{m_A}\ (\mathrm{GeV}) \leq 130$ the above channels are not useful. Use of b, τ tagging for $\mathrm{gg} \to \mathrm{b\bar{b}H}$, $\mathrm{H} \to \mu^+\mu-, \tau^+\tau^-$.



5σ discovery potential for h, 30 fb^{-1}



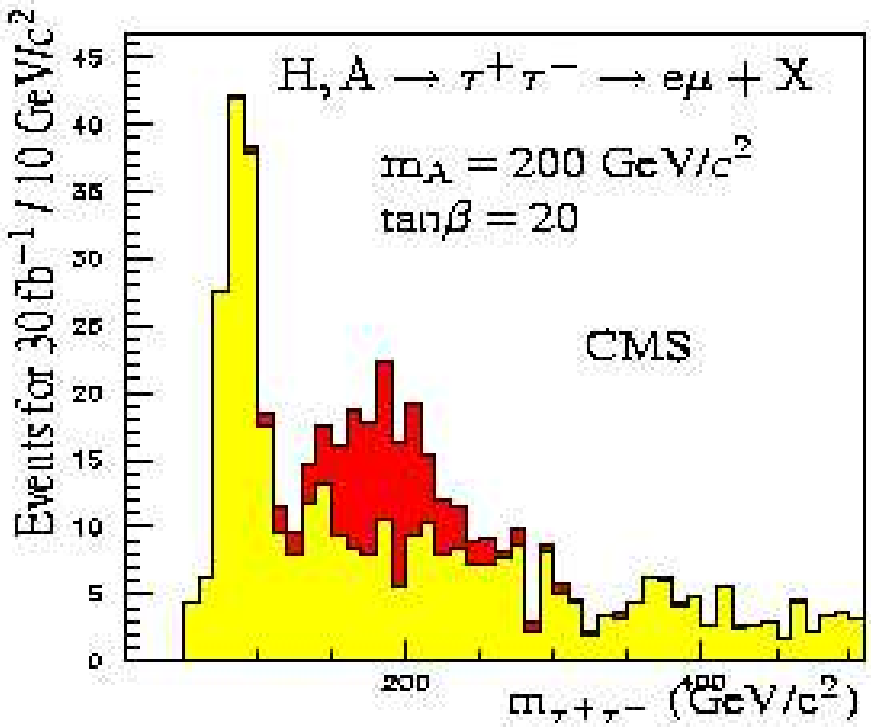
5σ discovery potential for h, 100 fb^{-1}

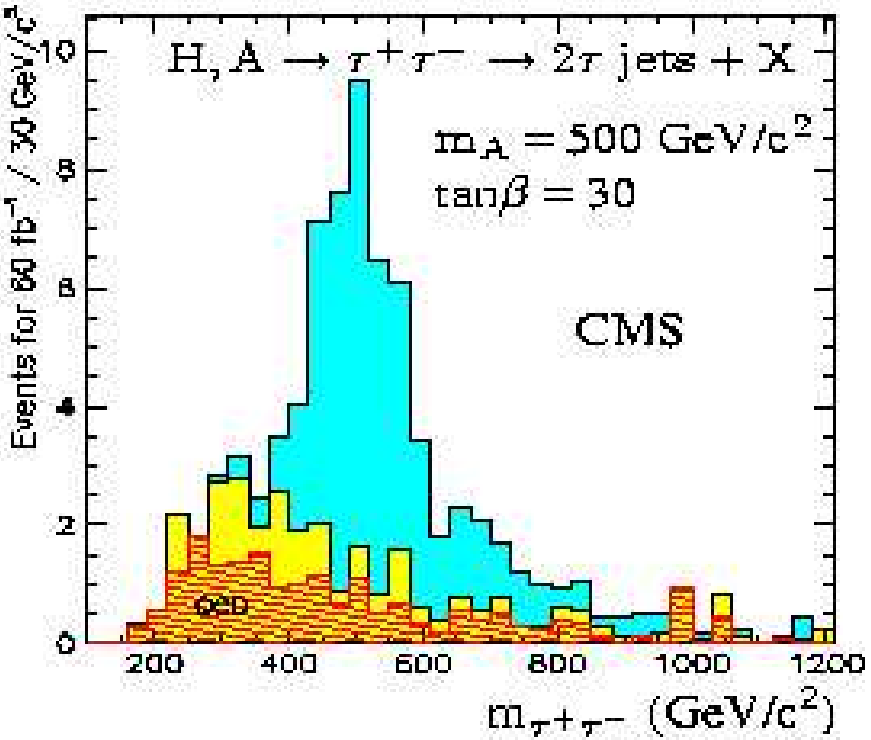
SM vs. SUSY discrimination in $\mathrm{h(H)} \to \gamma\gamma$

- Absolute rate measurement: limited by lumi measurements to 5%, while rates differ by less than 10% for $\mathrm{m_A} \geq 550$ GeV
- Ratio of Br's $\mathrm{h} \to \gamma\gamma$ and $\mathrm{h} \to \mathrm{b\bar{b}}$ $\sim 15\%$ for $\mathrm{m_A} \geq 550$ GeV, not limited by lumi.

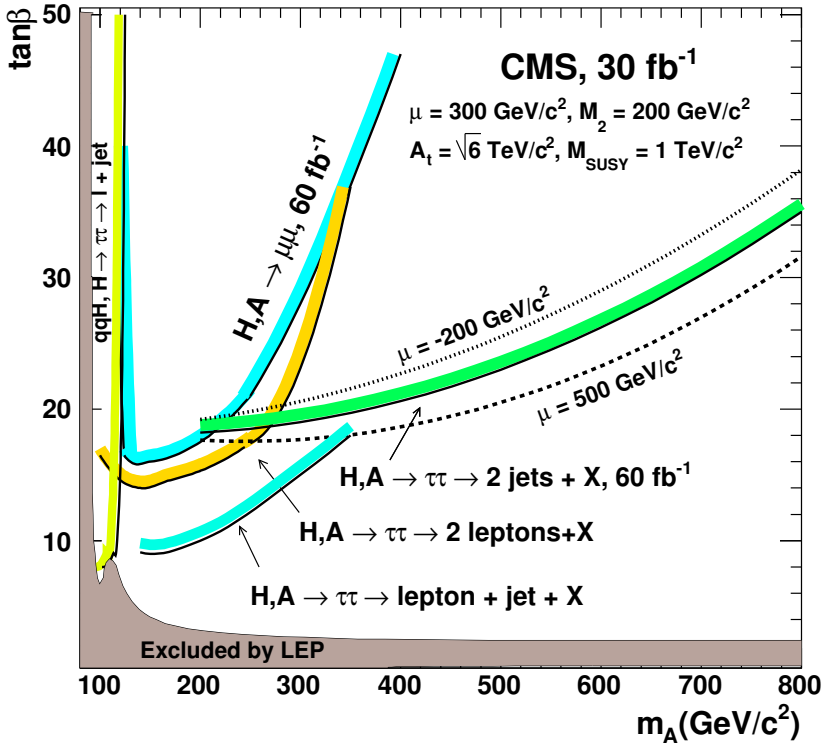
Heavy, neutral MSSM Higgs Boson: $\mathrm{H},\ \mathrm{A}$

- Production in $\mathrm{gg} \to \mathrm{b\bar{b}H/A}$, detection through $\mathrm{H, A} \to \mu^+\mu^-$ and $\tau\tau \to e\mu,\ \ell^+\ell^-,\ \ \ell + \mathrm{jet},\ \ 2\mathrm{jets}$
- Small region at $tan\beta \sim 5$ and $130 < \mathrm{m_A} < 150$ remains uncovered by standard searches $\Longrightarrow$ special strategies.
- Distinction between A and H masses may be possible for mass difference > 5 GeV, $tan\beta \sim 30$

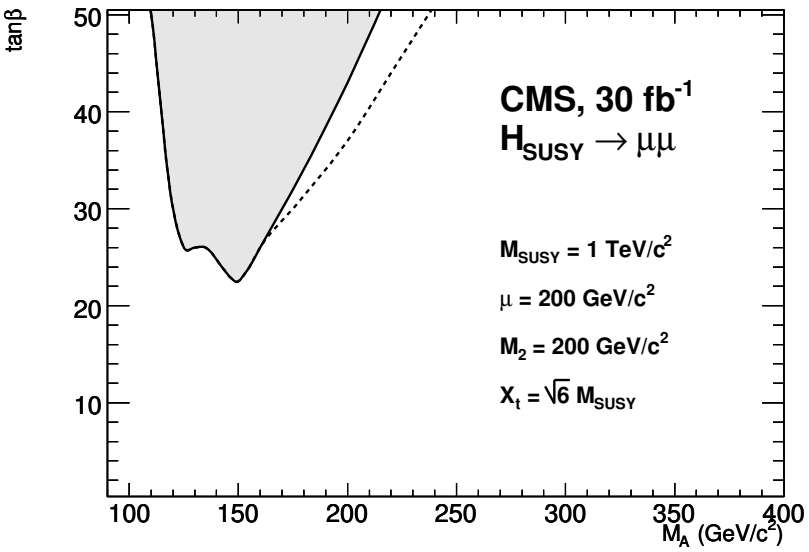




Discovery of H, A **in CMS through** τ **channels**



5σ discovery contour for A, H



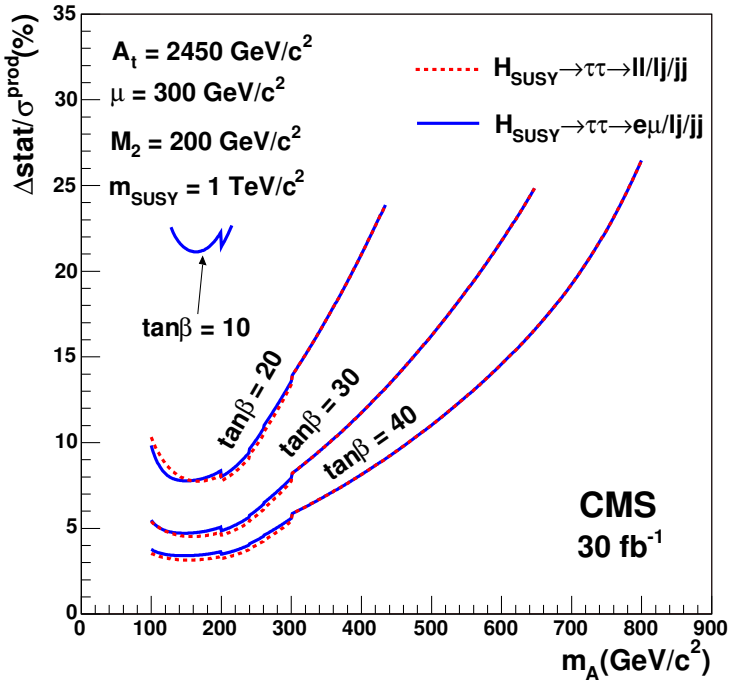
Recent study for $\mathrm{H}_{\mathrm{SUSY}} \to \mu^+\mu^-$

$tan\beta$ measurement with $H \to 2\tau$ mode

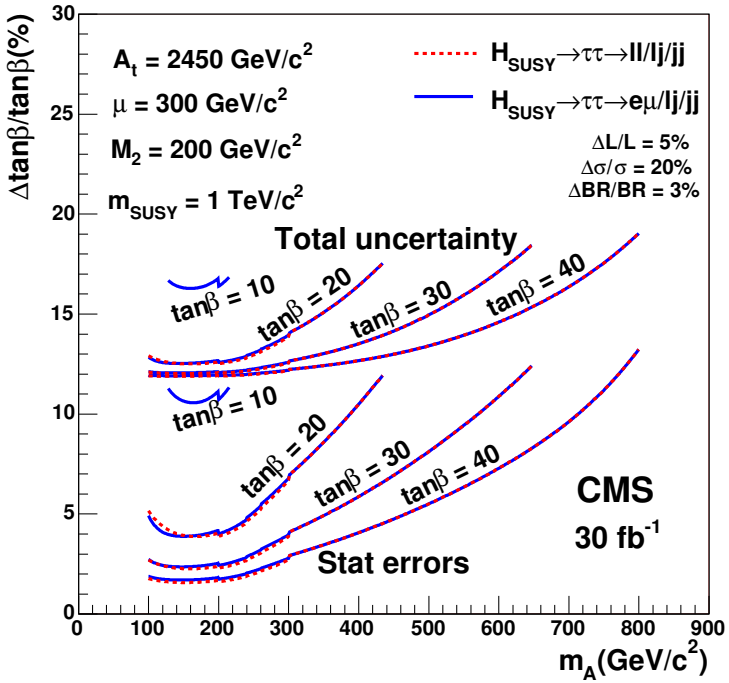
- Cross-section has large sensitivity to $tan\beta$.
  $\Longrightarrow$ significant observable for global fit to determine SUSY parameters
- Uncertainty of NLO calculation: $\sim 20\%$, for 1 b-tag, bigger than stattistical uncertainty.
- Systematics in the event selection: τ-tagging, b-tagging, jet veto (2nd b-veto), calo. scale.

Uncertainties in $tan\beta$ measurement

- $tan\beta$ large $\Longrightarrow \sigma \times$ BR $\sim tan^2(\beta)_{\rm eff} {\rm f}({\rm M_A})$
  at fixed $\mu, {\rm M_2}, {\rm A_t}, {\rm M_{SUSY}}$
- $tan\beta$ = $tan\beta$ (meas.) $\pm \Delta_{\rm stat} \pm \Delta_{\rm syst} \pm \Delta_{\rm gen}$
- $\Delta_{\rm syst} = 0.5\sqrt{(}\Delta L^2 + \Delta\sigma_{th}^2 + \Delta {\rm Br_{th}}^2 + \Delta\sigma({\rm \Delta M_H})^2 +$
  $\Delta\epsilon^2 + \Delta B^2)$
- $\Delta\epsilon^2 = \Delta\epsilon^2_{\rm calo} + \Delta\epsilon^2_{\rm btag} + \Delta\epsilon^2_{\tau{\rm tag}}$
  prelim. estimates: 2.9%, 2.0%, 2.5%



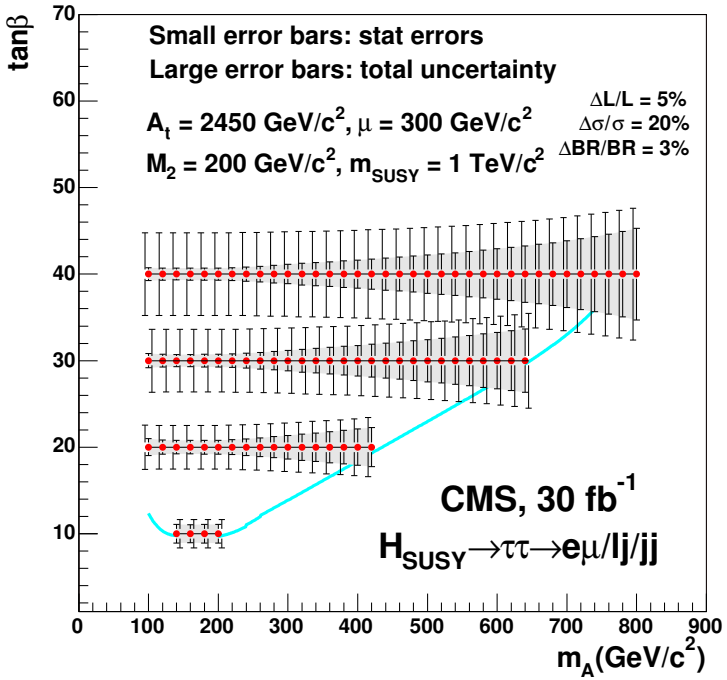
Statistical uncertainty in rate for 30 fb^{-1}



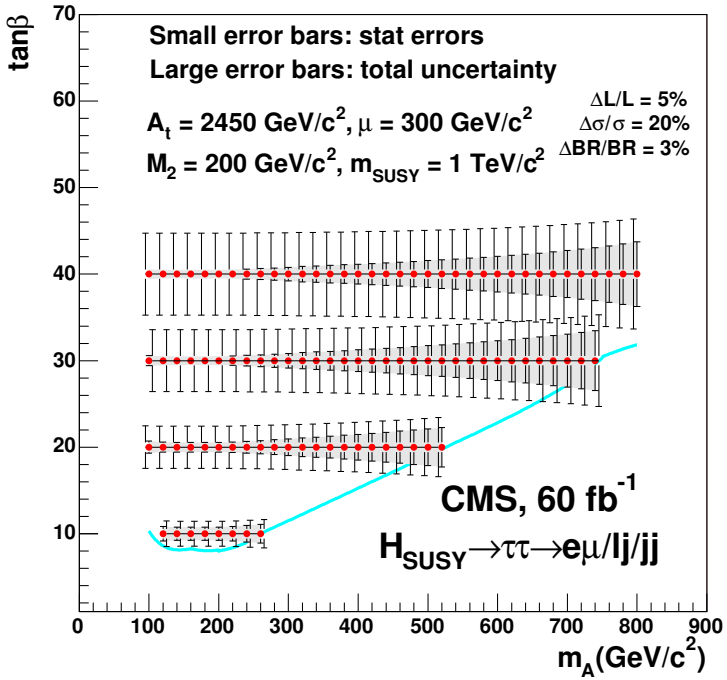
Statistical and systematic uncertertaities.

estimation of $tan\beta$ in CMS

Uncertainties in $tan\beta$ in combined channels

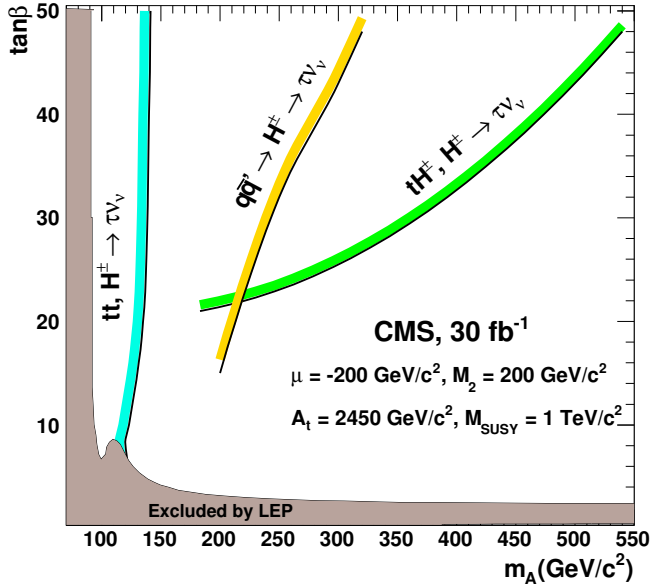


Statistical uncertainty in rate for 30 fb^{-1}

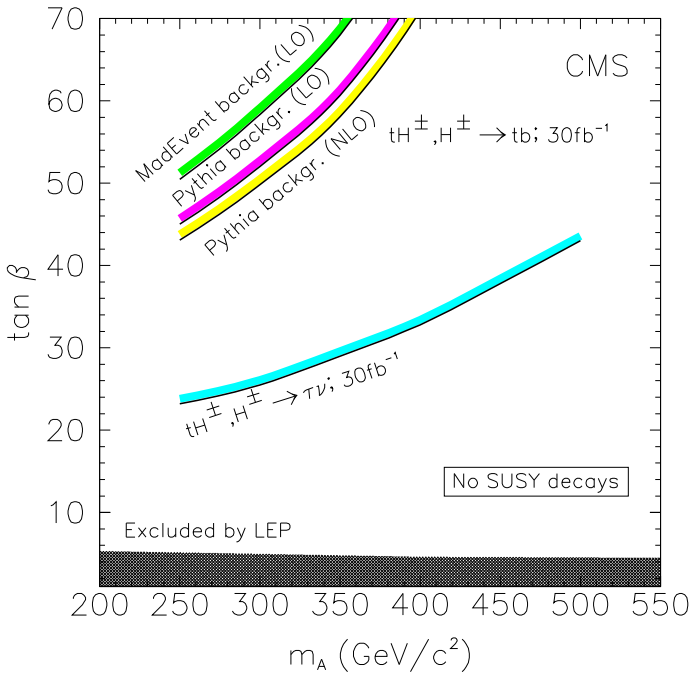


Statistical and systematic uncertertaities.

Discovery of $H^{\pm}$ in CMS, 30 fb^{1}

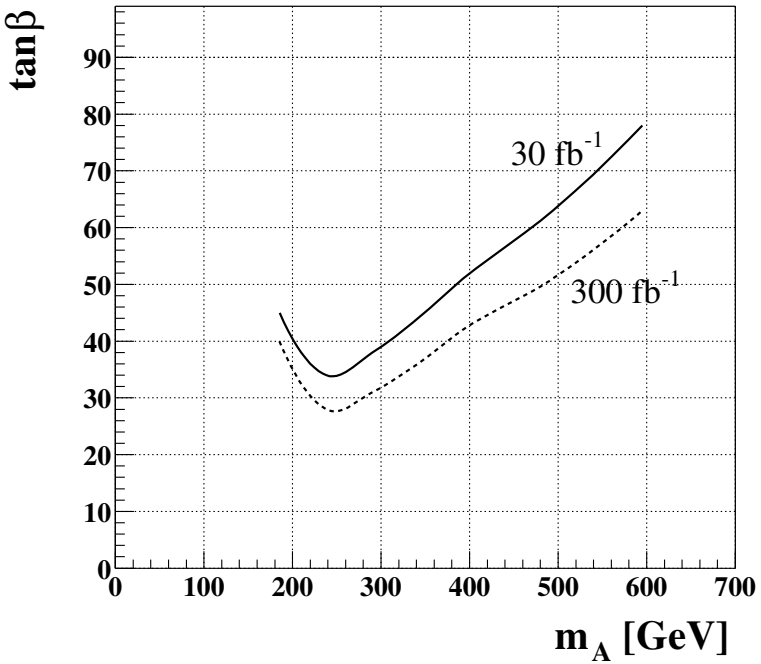


5 σ discovery contour for $H^{\pm}$

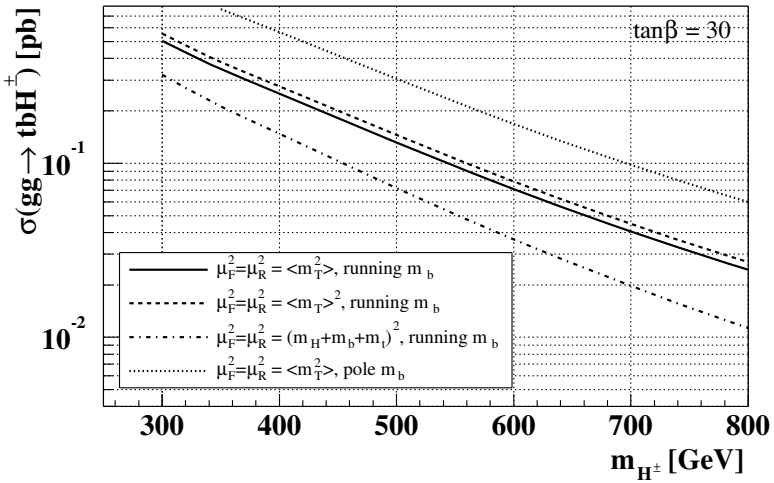


Reduced reach with better estimate of signal & bkground rates

Systematic studies for $H^{\pm}$ in ATLAS

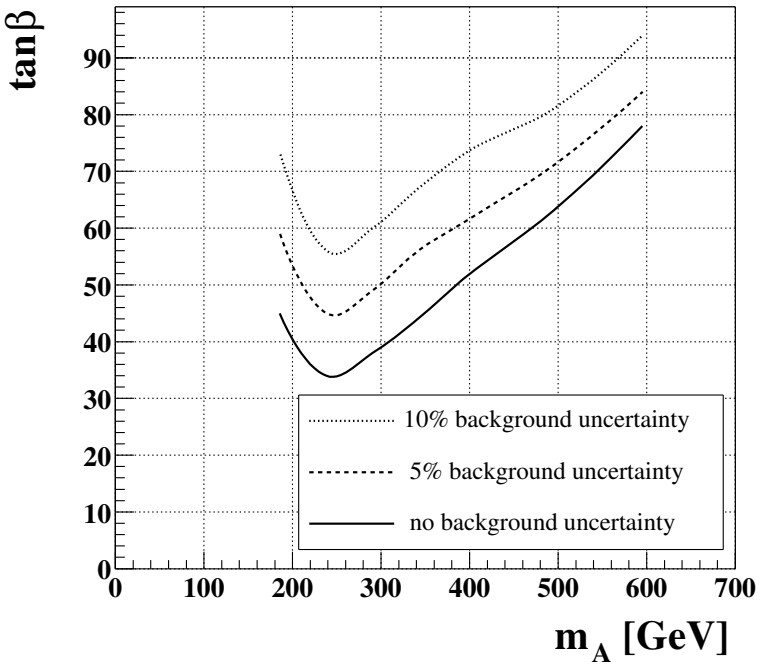


5σ discovery contour, no syst.uncert.

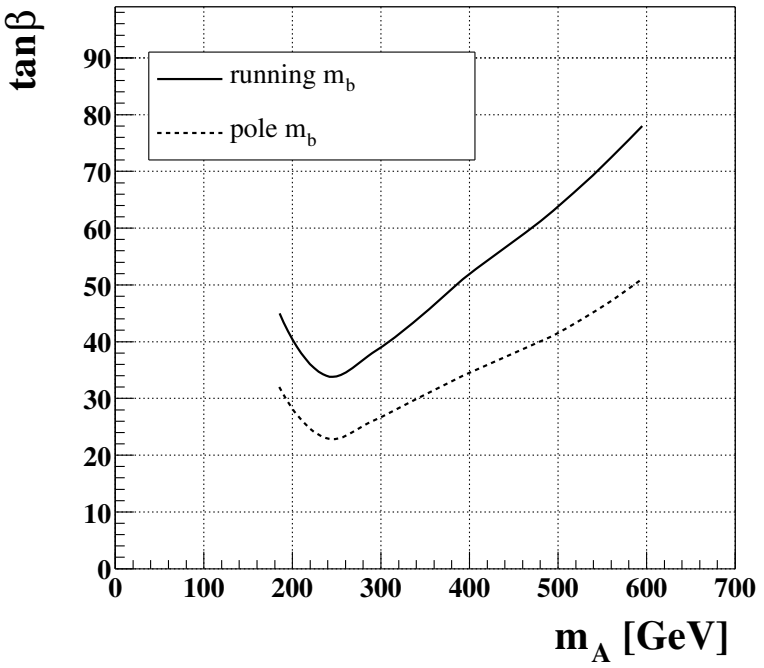


Effect of different QCD scales on production rate

Further Systematics for 30 fb^{-1}, ATLAS



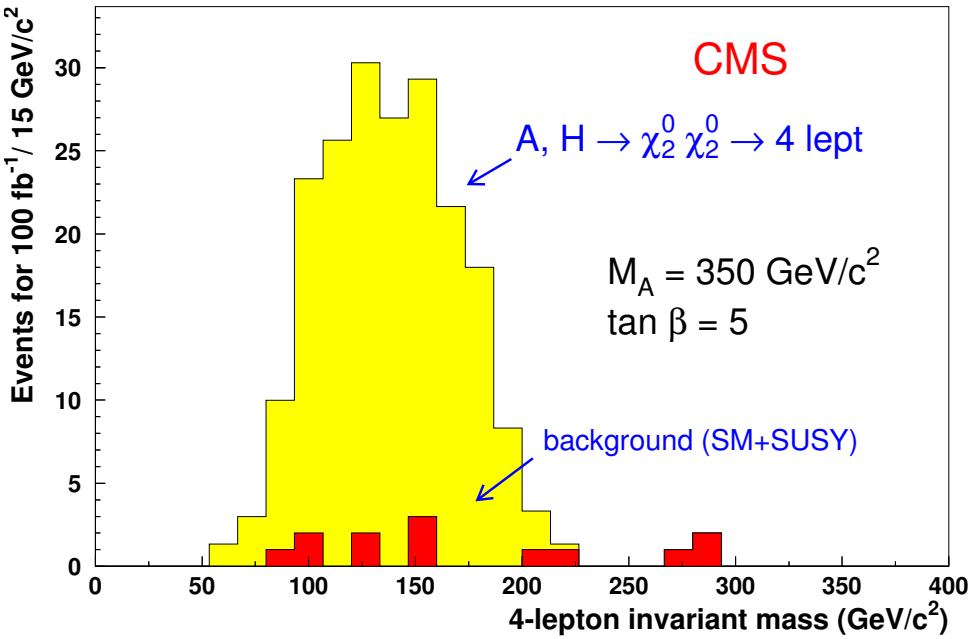
Discovery potential including background uncert.



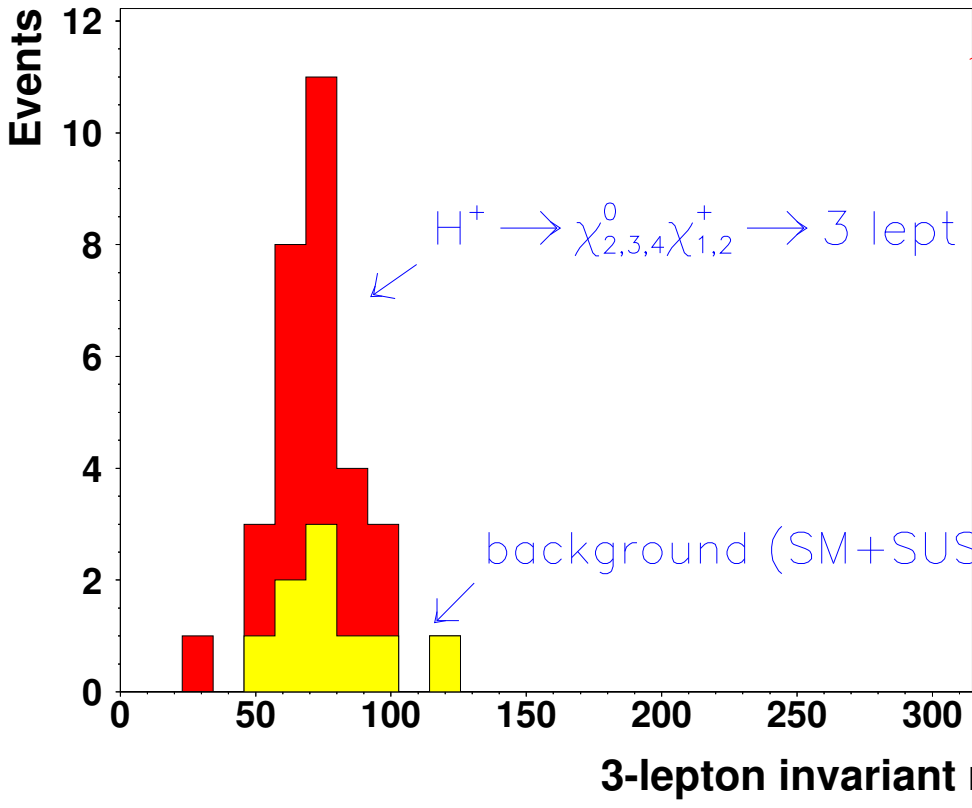
Syst. uncert. due to assumption for b-mass.

Observation of Higgs bosons in decay to gauginos

- Covers $tan\beta$ zone ~ 5 through
  $\mathrm{H, A} \to \chi_2^0 \chi_2^0 \to 4\ell$
- Invariant mass spectrum of 4 leptons: featureless
  $\Longrightarrow$ needs good knowledge of SM and SUSY backgrounds.

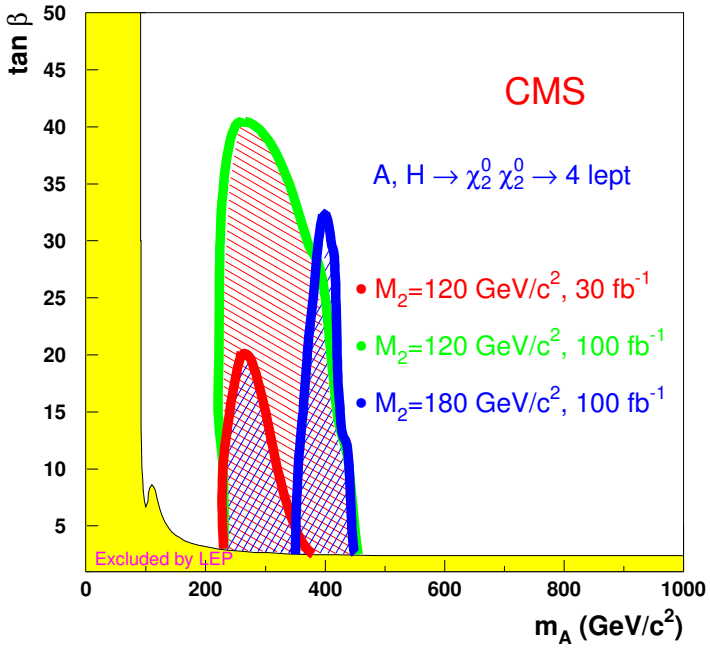


M_{4l} **from** $H/A \rightarrow \chi_2\chi_2 \rightarrow 4\ell$, **100 fb**$^{-1}$

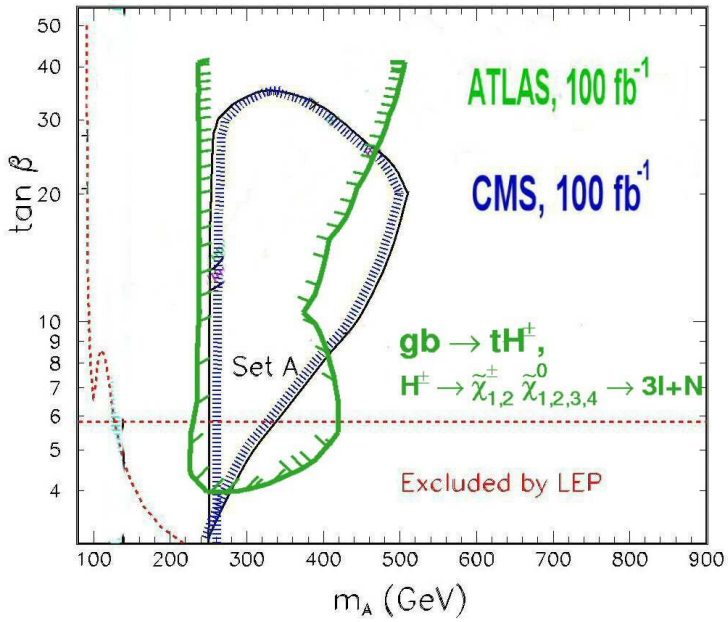


3-lepton invariant mass for $H^{\pm}$ **→ gauginos→** 3ℓ

MSSM Higgs Bosons through multi-leptons



Discovery potential with different parameters



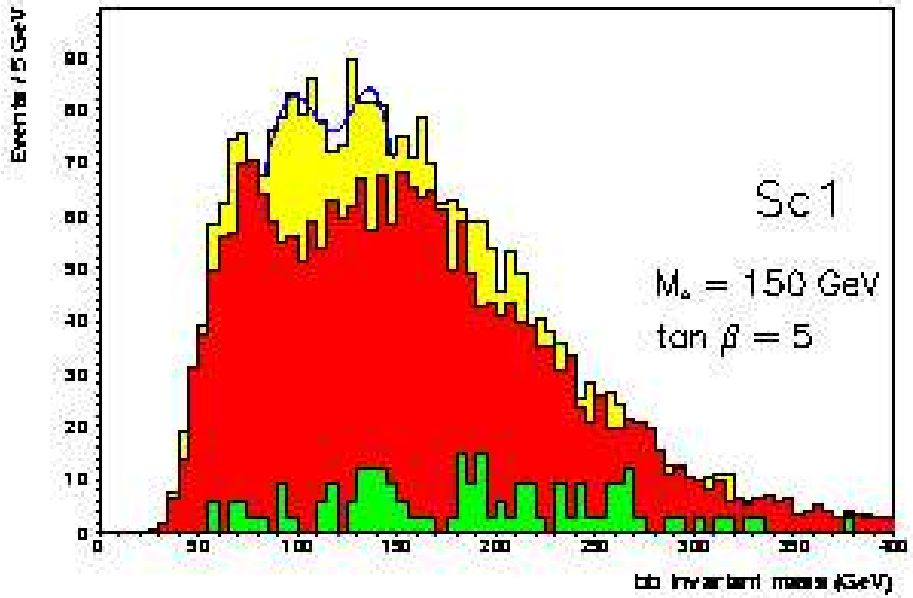
5σ discovery contour for $h^{\pm} \to \chi^{\pm}\chi^{0} \to 3\ell$

MSSM parameters: $M_2 = 210$ GeV, $\mu = 135$ GeV

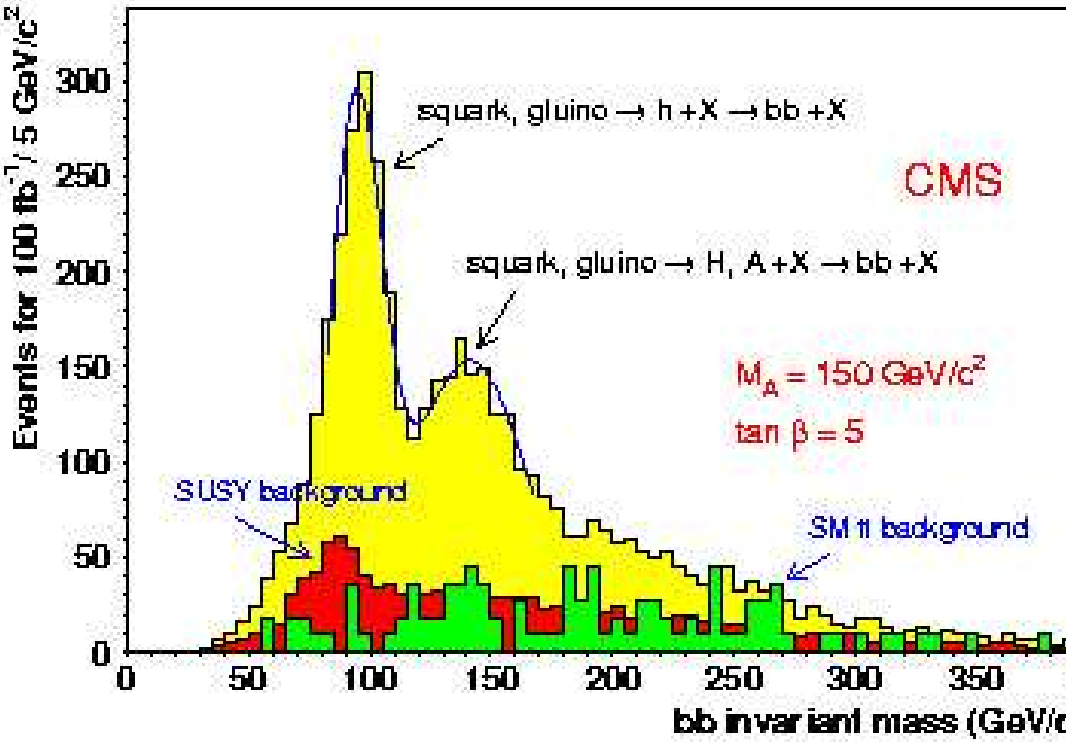
Higgs bosons from gaugino decays

- Large rate for gaugino productions in cascade decays of $\tilde{q}, \tilde{g}$ utilised to track $\mathrm{H}, \mathrm{A}, \mathrm{H}^{\pm}$. $\Longrightarrow$ large yields of Higgs bosons of mass $\leq$ 250 GeV in some portions of parameter space.
  $\mathrm{H}^{\pm}$ also in top decays.
- Detection of $\mathrm{h}, \mathrm{H}, \mathrm{A}$ through $b\bar{b}$ decays in intense coupling region and $\mathrm{H}^{\pm}$ via $\tau\nu$ channel.
- Measuring couplings of SUSY particles to $\mathrm{h}, \mathrm{H}, \mathrm{A}$

Discovery of Higgs bosons from $\tilde{q}, \tilde{g}$ decays, CMS

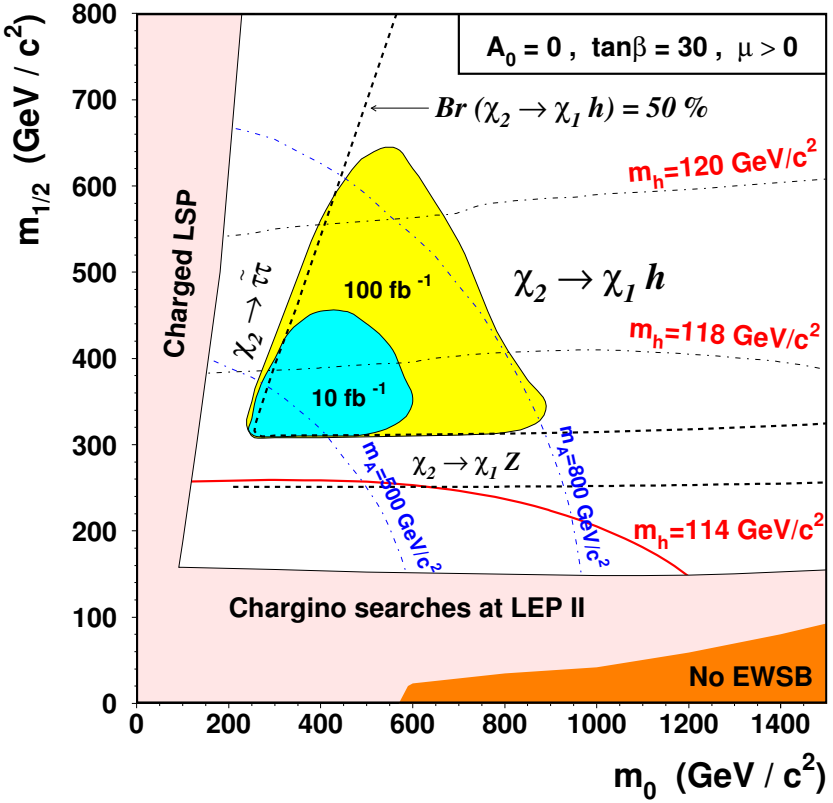


$M_{b\bar{b}}$ from 'big cascades': $m_{\tilde{g}} \geq m_{\tilde{q}}$, 30 fb^{-1}

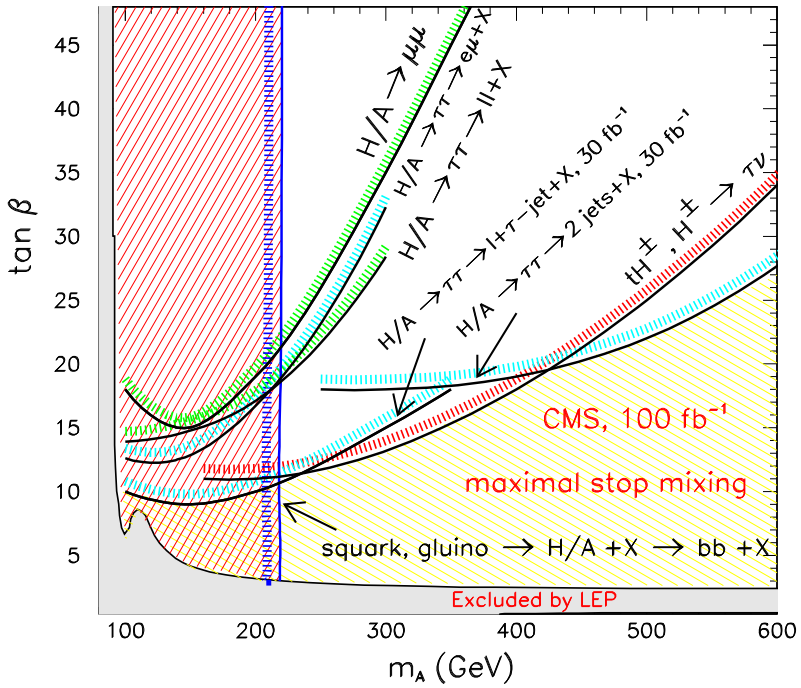


$M_{b\bar{b}}$ from 'small cascades': $m_{\tilde{g}} \leq m_{\tilde{q}}$, 100 fb^{-1}

Higgs bosons from gaugino decays, CMS



Reach of lightest Higgs from gaugino decays

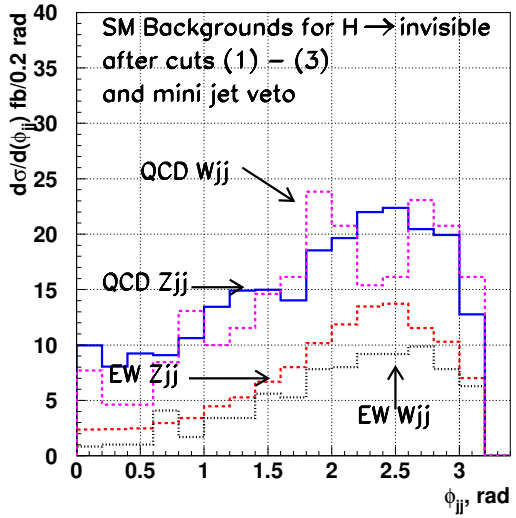


Reach of heavier Higgs bosons from gauginos

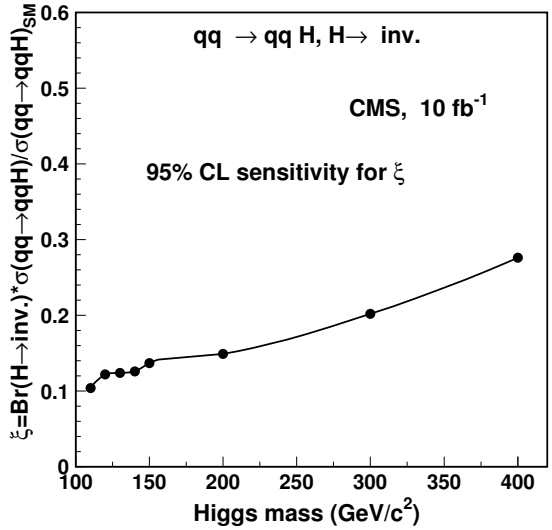
Invisible Higgs

- In various extensions of Standard Model, it is possible that Higgs boson decays invisibly.
  e.g. SUSY models with non-universal gaugino masses, Majorana Model of neutrino mass, Large extra dimensions.
- $\mathrm{qq} \rightarrow \mathrm{qqH}$ is the best channel: provides handle to tag the events using forward-backward jets with special topological features.

- Backgrounds can be tamed with central jet veto and other criteria (eg. interjet separation).



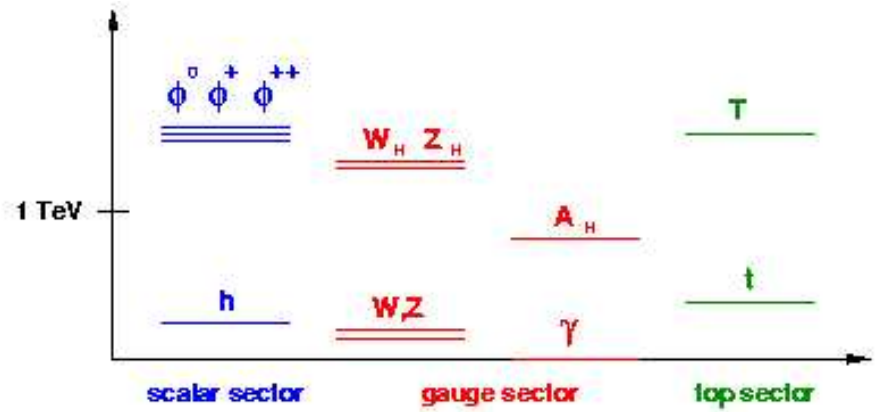
Inter-jet separation for bkg. events



Discovery of $H_{inv.}$ in CMS

QCD multijet background assumed to be absent after selections! Better estimate soon.

Little Higgs Model

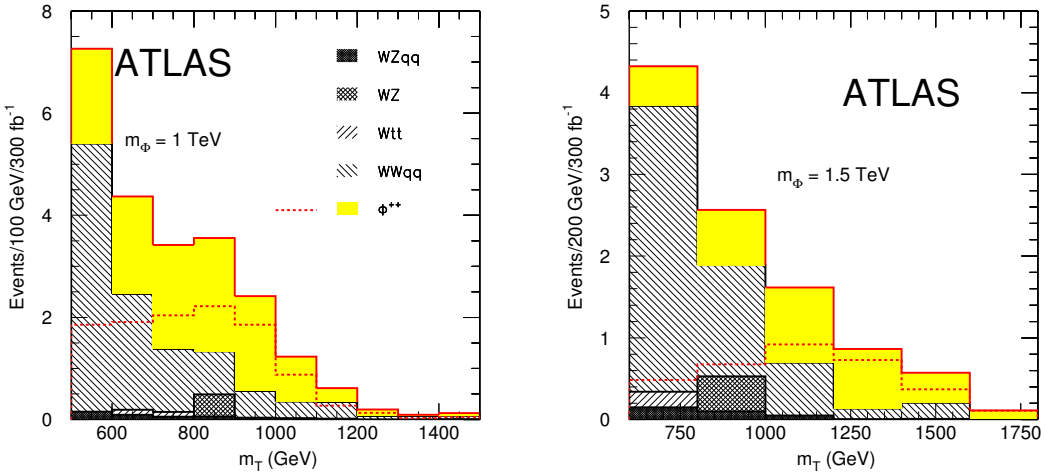


• Higgs treated as pseudo-Goldstone boson resulting from a broken global symmetry at a scale $\sim$ 10 TeV.

• New set of particles in scalar, gauge, fermion sectors to cancel divergences.

• $M_\phi \leq$ 10 TeV

Discovery of ϕ^{++} in ATLAS

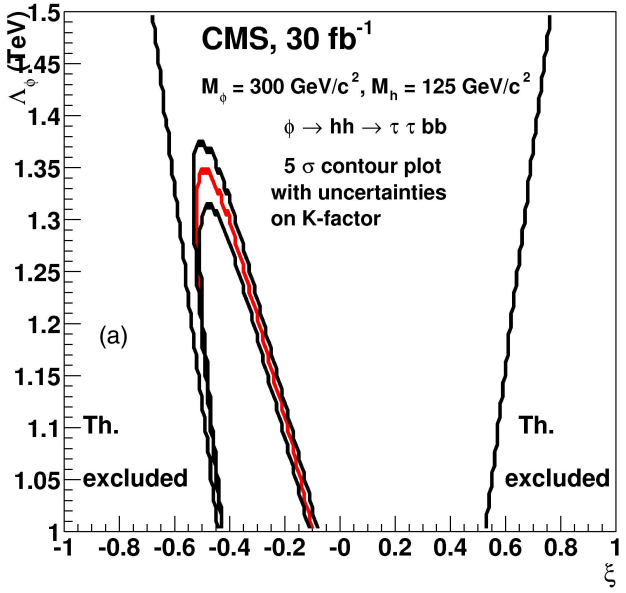


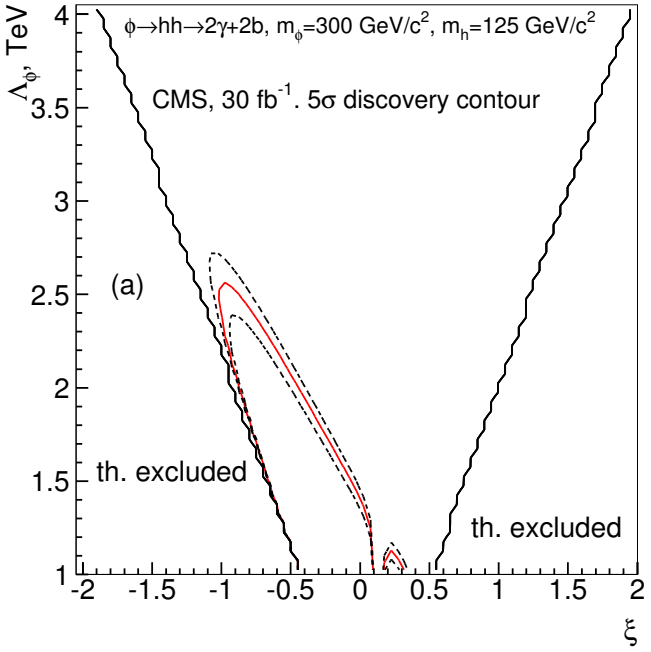
• ϕ^{++} production via WW fusion, coupling determined by vev of scalar sector. Decay via $\mathrm{W}^+\mathrm{W}^+ \rightarrow \ell^+\nu\ \ell^+\nu$. Only transverse mass reconstruction, at very high lumi. Poor sensitivity due to low p_T forward jets in signal.

Probing extra-dimensions in RS model

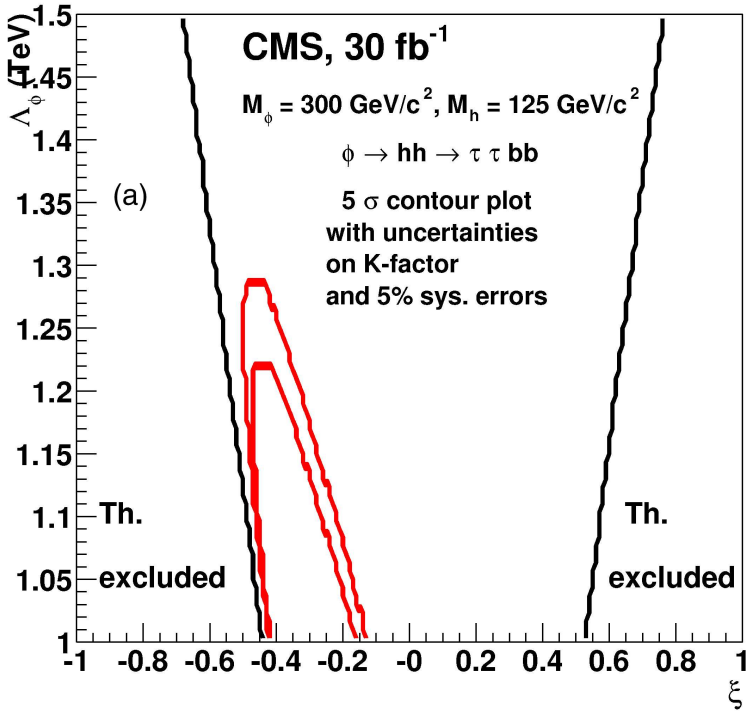
- Interesting solution to hierarchy problem in SM.
  5-d universe with two 4-d hypersurfaces (branes) at the boundary of the 5th co-ordinate.
  All SM particles in one brane.
  Fluctuations in 5th dim $\rightarrow$ scalar field "radion': can mix with SM Higgs boson.
- 4 paramaetrs: $\mathrm{m_h}$, m_ϕ, ξ (mixing), Λ_ϕ (vev of radion field)

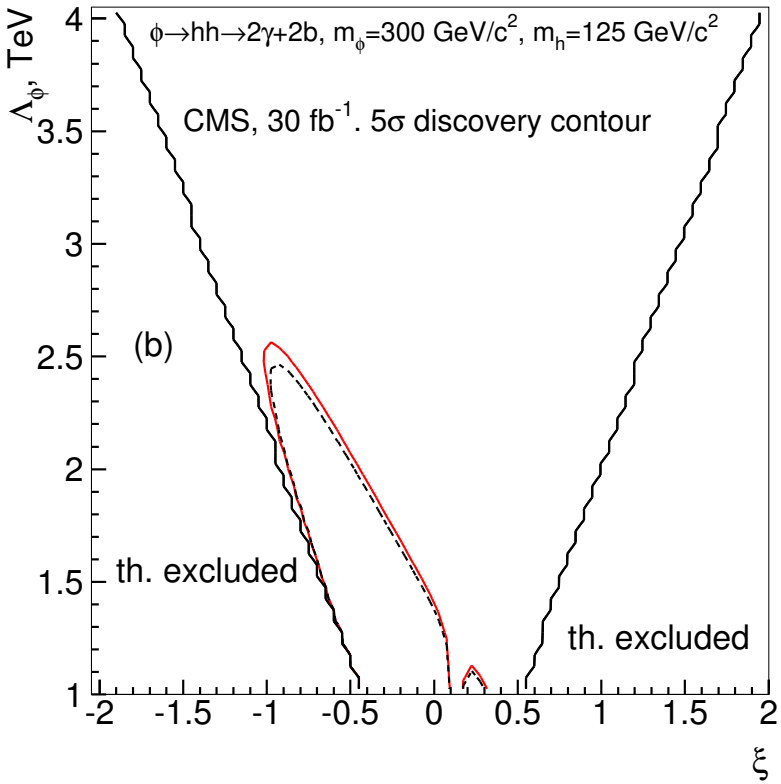
- Br(Radion $\rightarrow$ hh)=20 - 30 %, for m_h=120 GeV, m_ϕ = 250-350 GeV, Λ_ϕ = 5 TeV
- Search in Radion $\rightarrow$ hh $\rightarrow \gamma\gamma b\bar{b}, \tau^+\tau^- b\bar{b}$, 4b modes.





Inclusion of systematics on background





Conclusion

- LHC machine and the experiments are ready to take data by 2007 'summer'.
- Both CMS and ATLAS experiments are capable of discovering what lies ahead of Standard Model.
- The collaborations are progressing towards more realistic estimation of the potentials, stay tuned for updated results.

The role of A,H to tau-tau

- Access to A,H for masses of order 500 GeV, up to 800 GeV if $tan\beta > 35$
  Mass resolution $\sim 10\%$.
- Allows to explore the difficult region $\mathrm{m_A} \leq$ 200-250 GeV/c^2, 7-8 $\leq tan\beta \leq$ 10-15.
- Special trigger has been designed by LHC experiments.

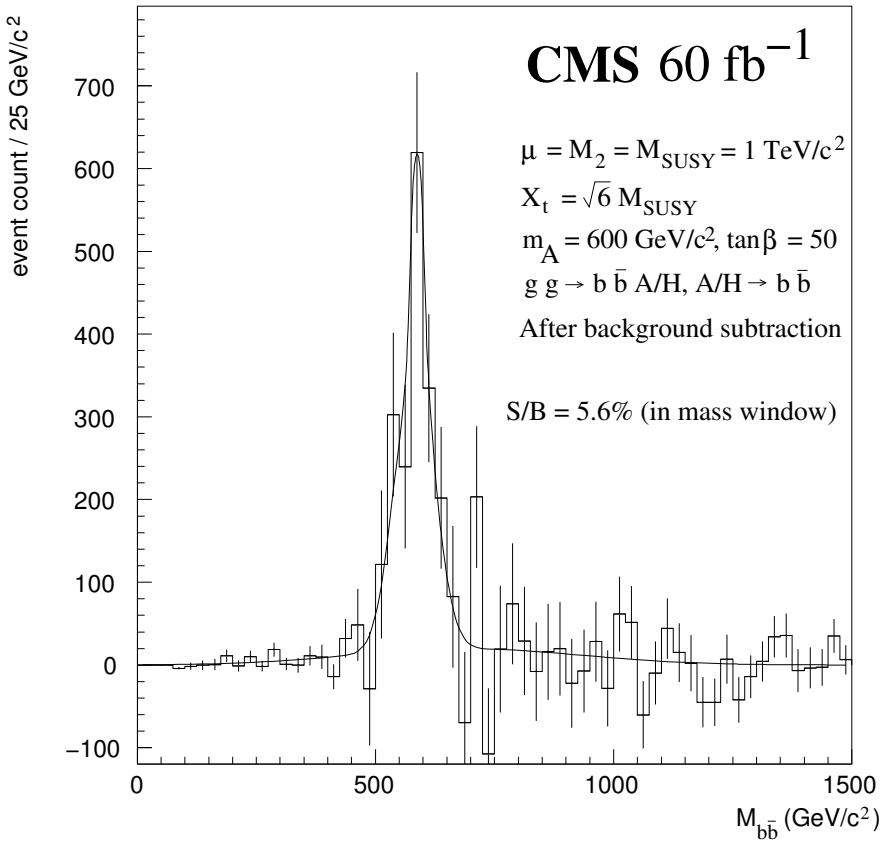
Regions in which A and H masses can be determined reliably

- At large $tan\beta$ with $\mathrm{gg} \rightarrow \mathrm{HandbbH}$, bbH not suppressed by top-stop interference
- For given $\mathrm{m_A}$ larger $tan\beta$ easier, through $\mathrm{A, H} \rightarrow \tau\tau,\ \mu\mu$ decays.
- Good mass resolution (1%) in $\mu\mu$ channel may resolve the presence of 2 objects.

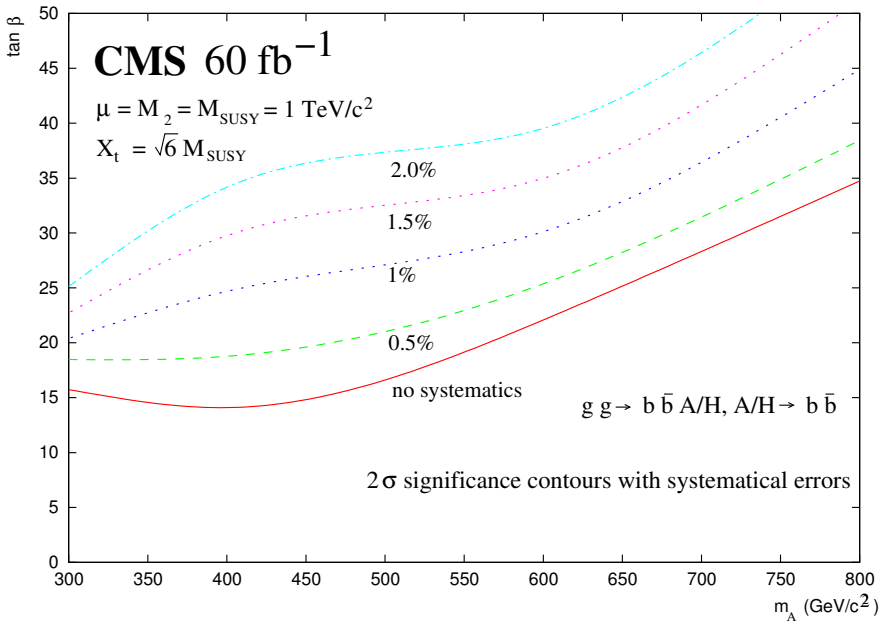
$gg \to b\bar{b}H,\ H \to b\bar{b}$ **at high** $tan\beta$

- Trigger level: single b-tagging for next-to-leading jet $E_T > 160$ GeV
- Offline: ≥ 3 b-tagged jets Shape of tripple b-tagged data determined from double b-tgged data, as in Tevatron (utlise tag-rate function, derived from multi-jet data sample)
  Note: at LHC data composition is different: too many events with real bs

$gg \to b\bar{b}H/A,\ H/A \to b\bar{b}$



Signal after background subtraction



Discovery potential worsened by systematics.

Light charged Higgs, CMS