Higgs physics at the LHC

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Physics at LHC
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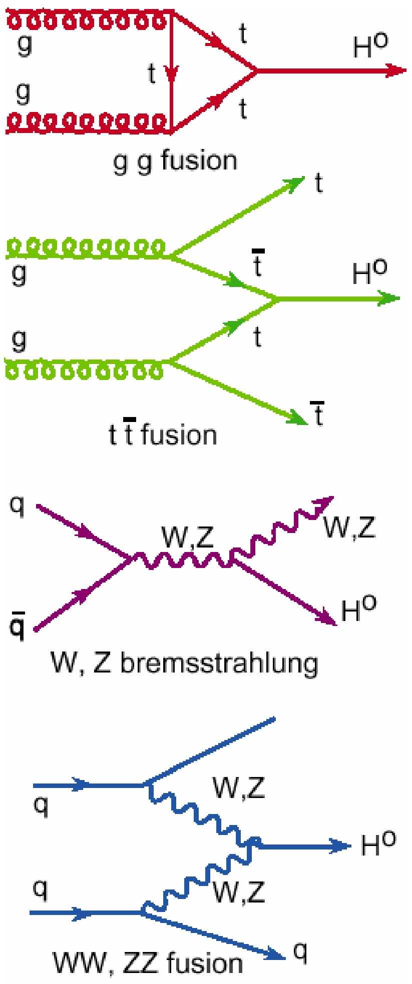
Outline

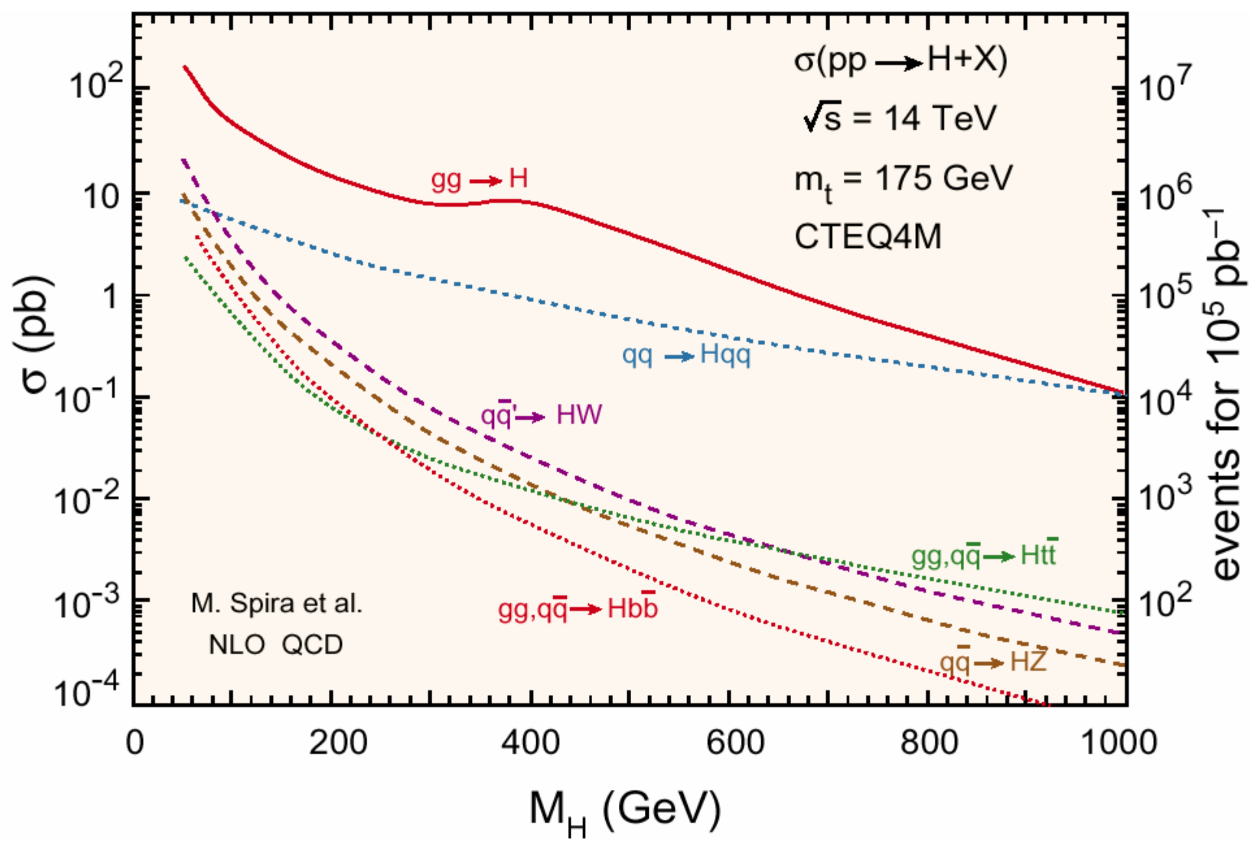
- **Standard Model Higgs**
  - **Quick reminder**
  - **Update & properties**
- **MSSM Higgses**
  - **Decays to (SM) particles**
  - **Decays to (MSSM) sparticles**
- **Others**
  - **Higgses from extra-dimension physics**
  - **Diffractive Higgs (?)**
- **Summary**

Standard Model Higgs

SM Higgs (I)

- **Production mechanisms & cross section**

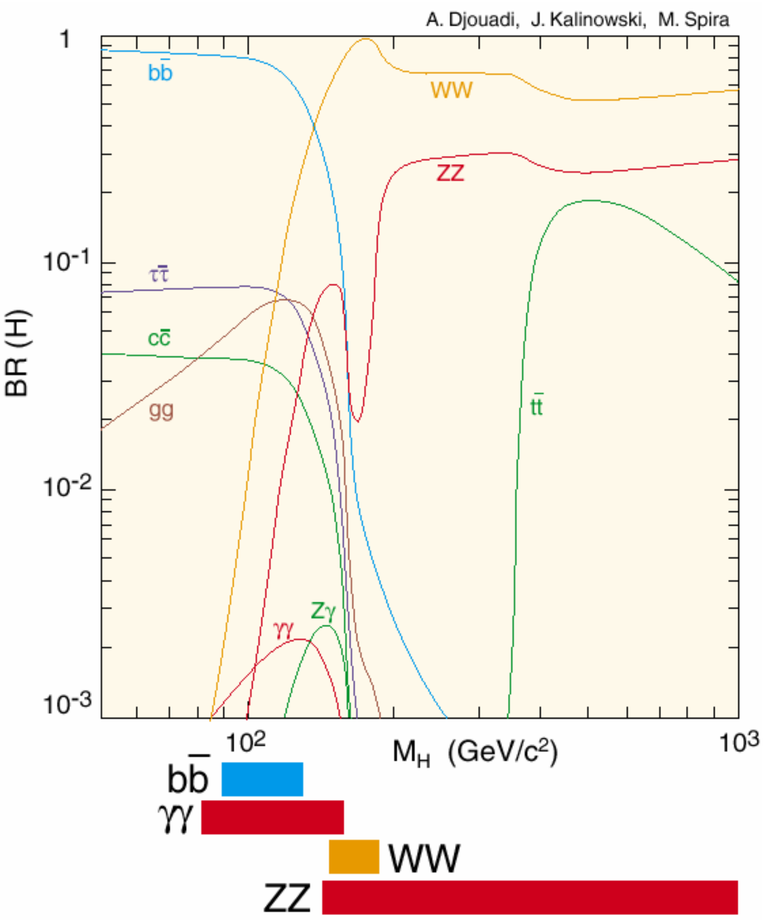




SM Higgs (II)

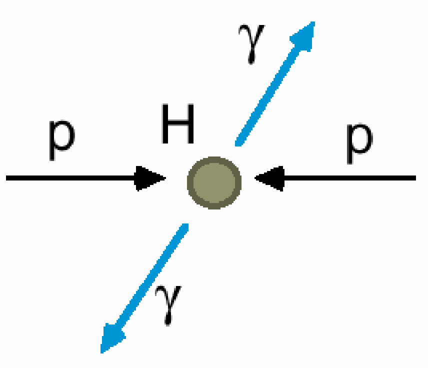
Decays & discovery channels

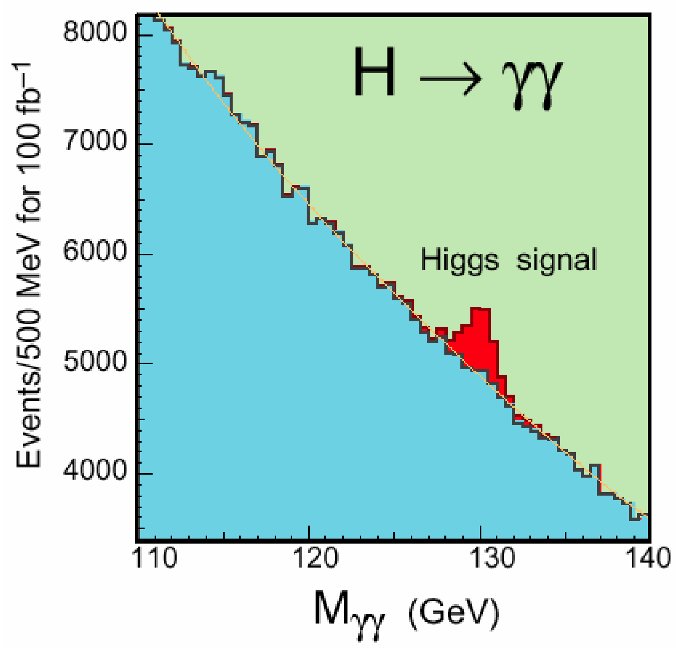
- **Higgs couples to m_f^2**
  - Heaviest available fermion (b quark) always dominates
  - Until WW, ZZ thresholds open
- **Low mass: b quarks$\rightarrow$ jets; resolution ~ 15%**
  - Only chance is EM energy (use $\gamma\gamma$ decay mode)
- **Intermediate mass: WW, ZZ***
  - Useful at M_H>125 GeV already
- **Once M_H>$2M_Z$, use this**
  - W decays to jets or lepton+neutrino (E_T^{miss})

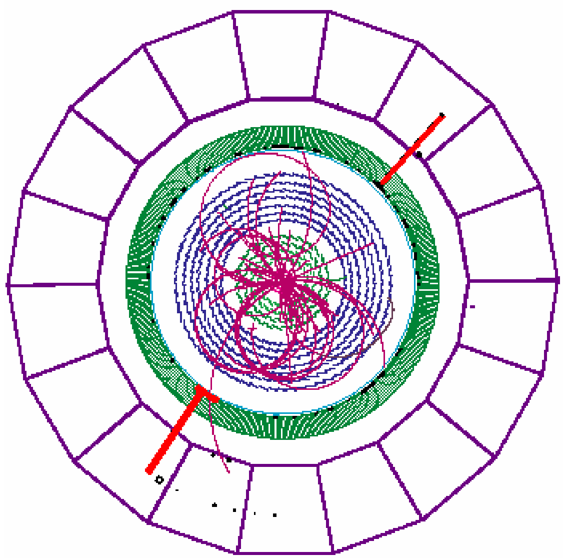


Low mass Higgs (M_H<140 GeV/c^2)

- $H \to \gamma\gamma$: decay is rare ($B \sim 10^{-3}$)
  - But with good resolution, one gets a mass peak
  - Motivation for LAr/$PbWO_4$ calorimeters
  - CMS example: at 100 GeV, $\sigma \approx$1GeV
    - S/B ≈ 1:20

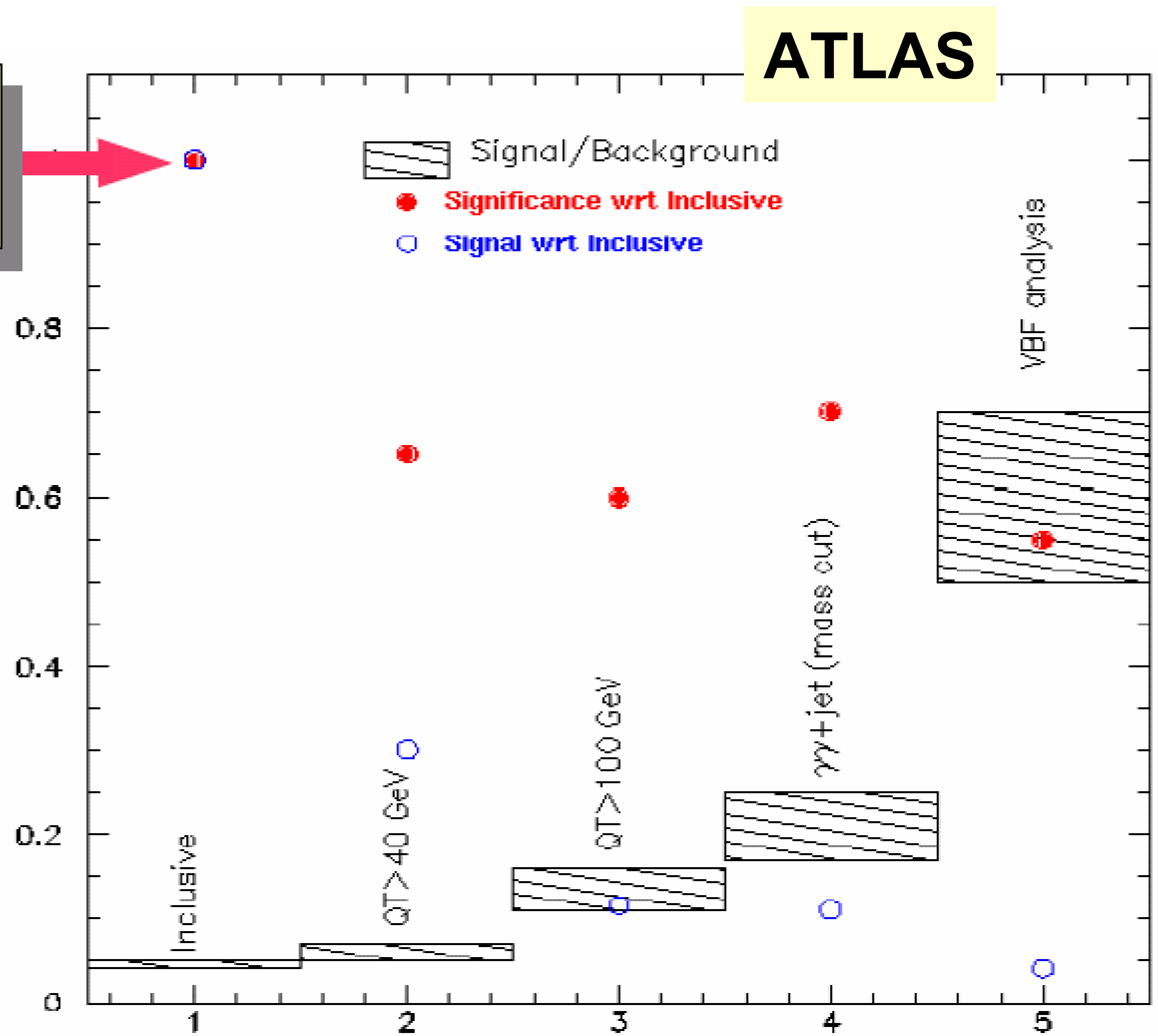






H→γγ details

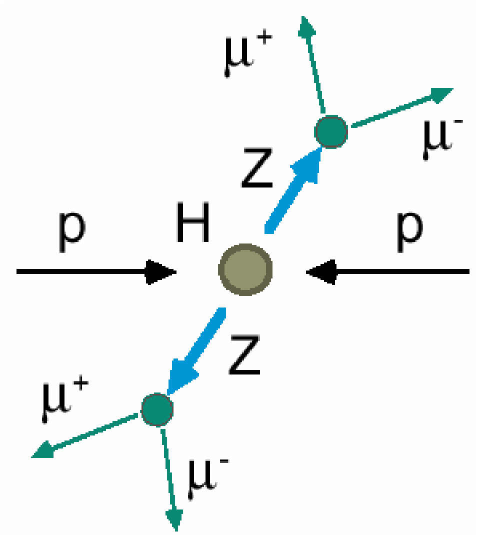
Inclusive H->γγ
M_H=120 GeV, 6σ

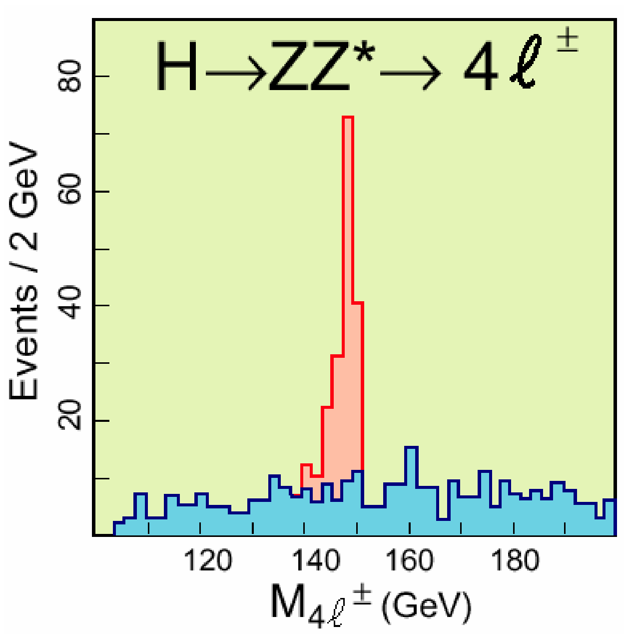


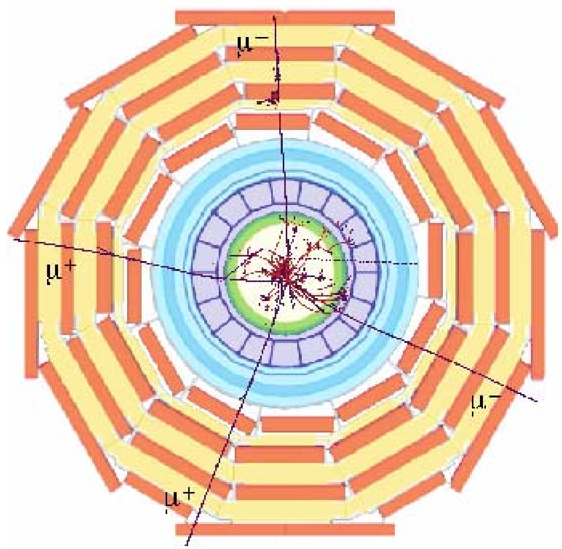
Preliminary **:**
Cut on p_t of γγ or requirement to have one or two jets improve S/B but do not improve significance

Intermediate mass Higgs: ZZ*

- $H \rightarrow ZZ \rightarrow \ell^+\ell^- \ \ell^+\ell^-$ (ℓ =e,μ)
  - Very clean
    - Resolution: better than 1 GeV (around 100 GeV mass)
  - Valid for the mass range $130<M_H<500$ GeV/c^2



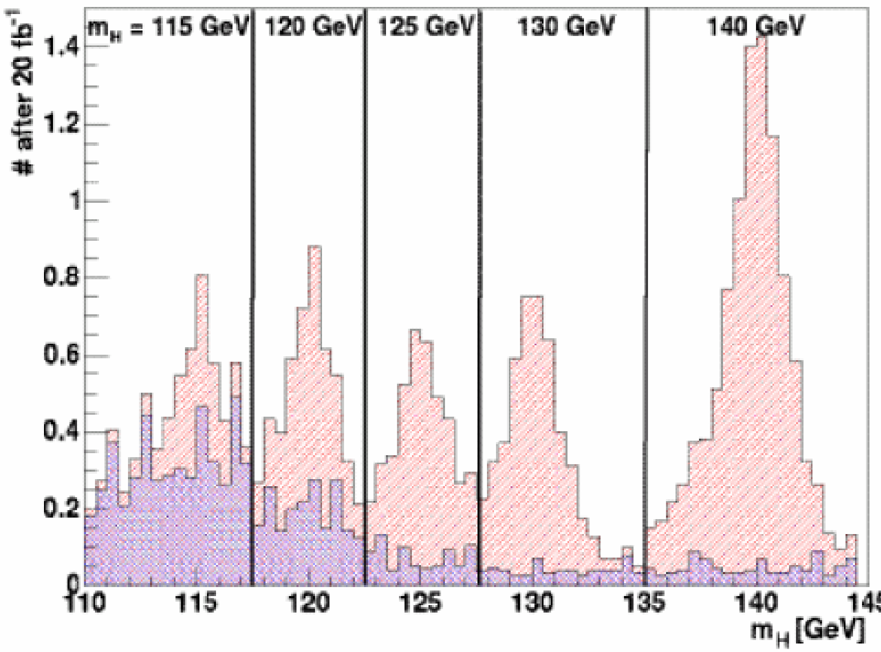


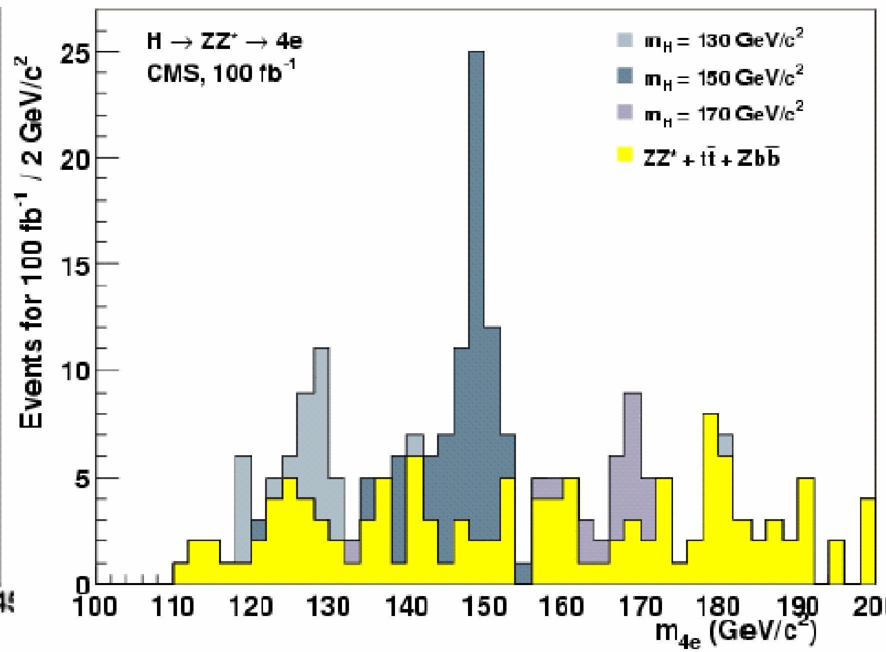


The golden channel

Background : tt, ZZ*, Zbb. Selections : lepton isolation, cut on lepton p_T, M_Z, M_{Z^*}

4μ : preliminary



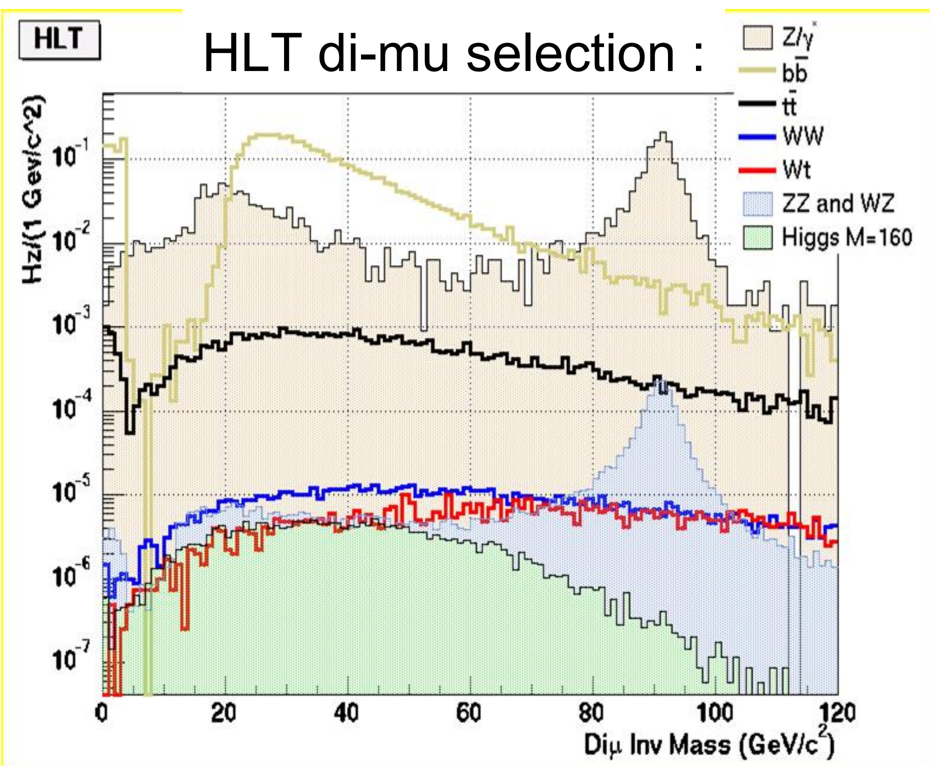


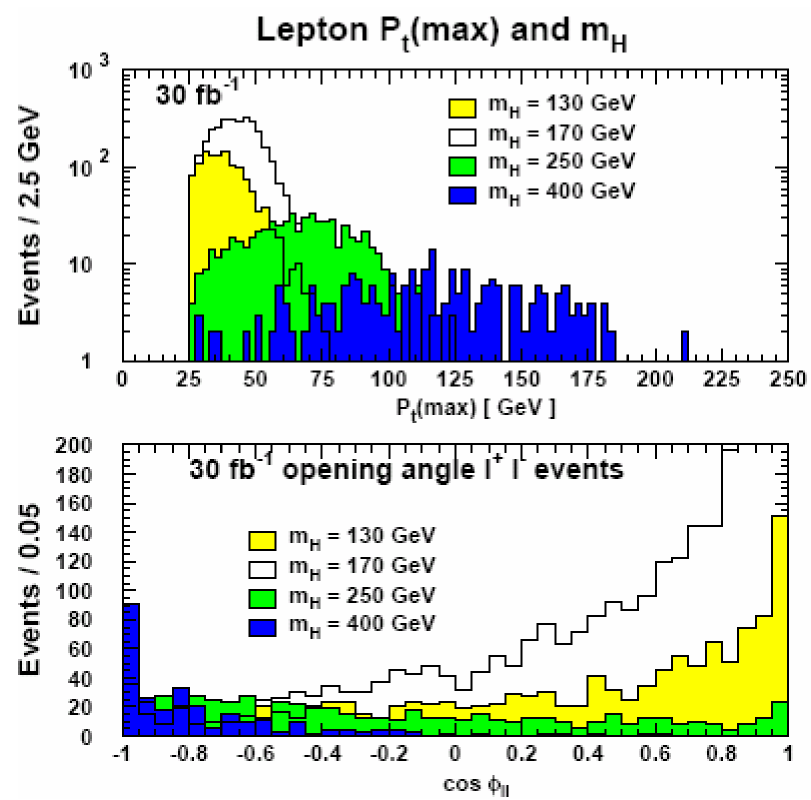
Higgs Mass, GeV	*120*	*130*	*140*
4e; L for 5 σ discovery, fb^{-1}	351	106	31
4μ; L for 5 σ discovery, fb^{-1}	152	35	15

Significance is calculated with Poisson probability .

Interm. mass Higgs: H→WW→$\ell\ell'$X (I)

- **H→WW: isolated leptons (good), missE_T (good), but a dangerous background from top decays**
  - **WW spin correlation → lepton correlations, use collinearity & P_T(max) requirement**



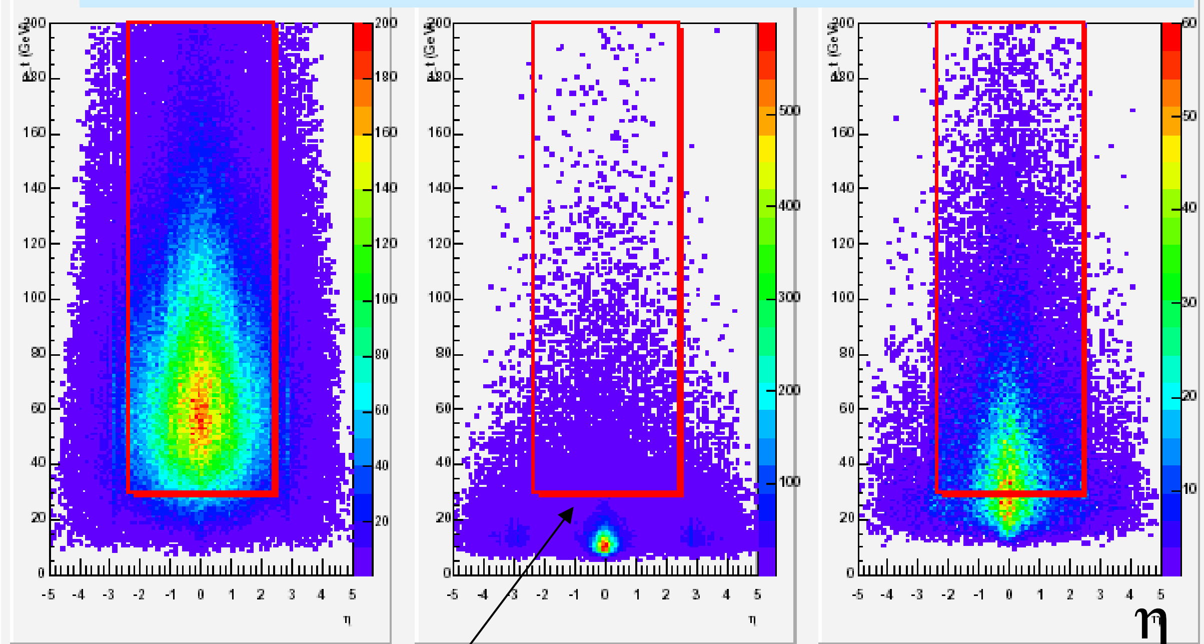


H→WW→ ℓℓ'X (II)

- **Top quarks and (central) jet veto**

Jet veto on background samples

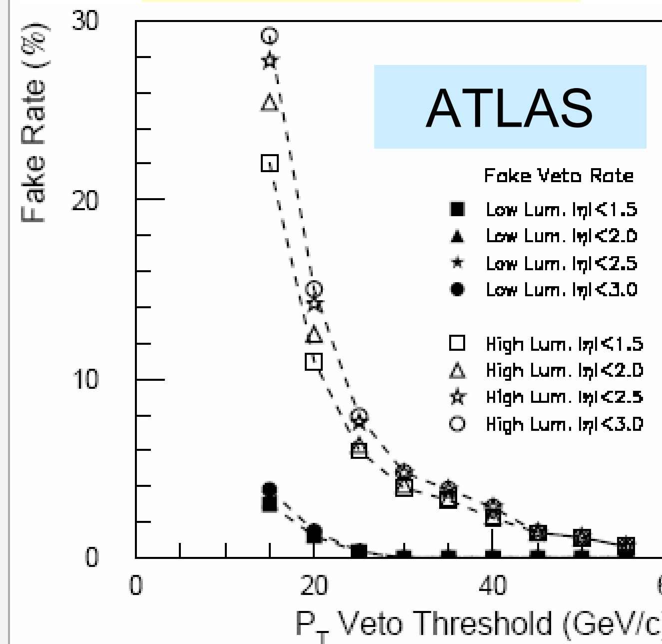
CMS: full simulation and reconstruction



tt → 2μX **Z/γ → 2μX** **bb → 2μX**

P_T>30 GeV

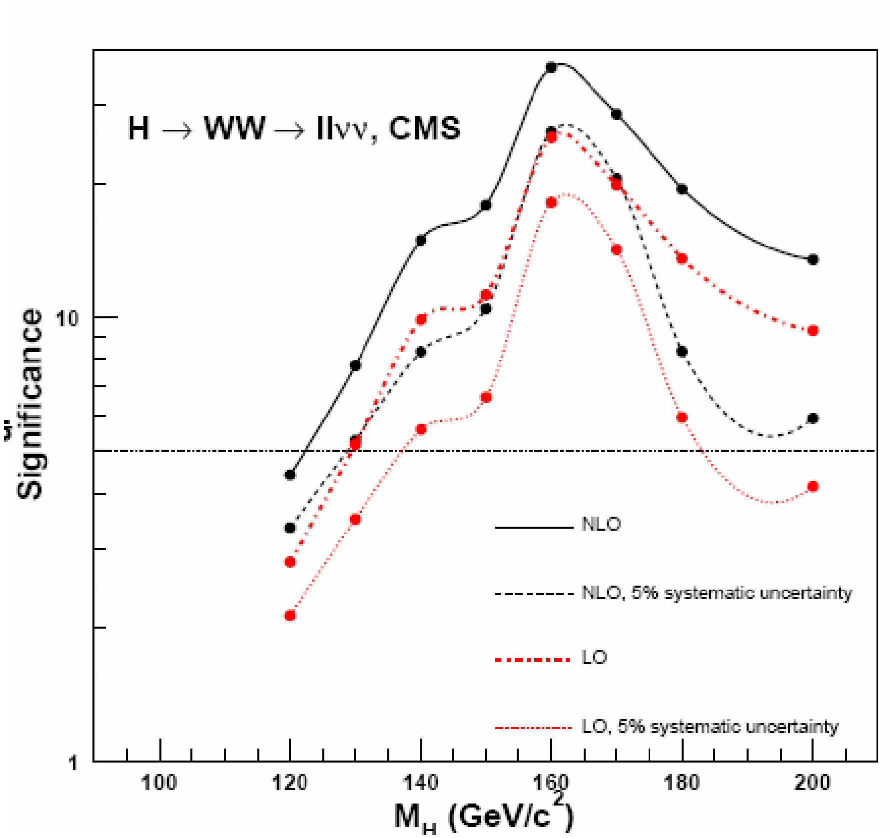
Fake vetos: reduce by calo cut (0.2 low-L, 1 GeV high-L)

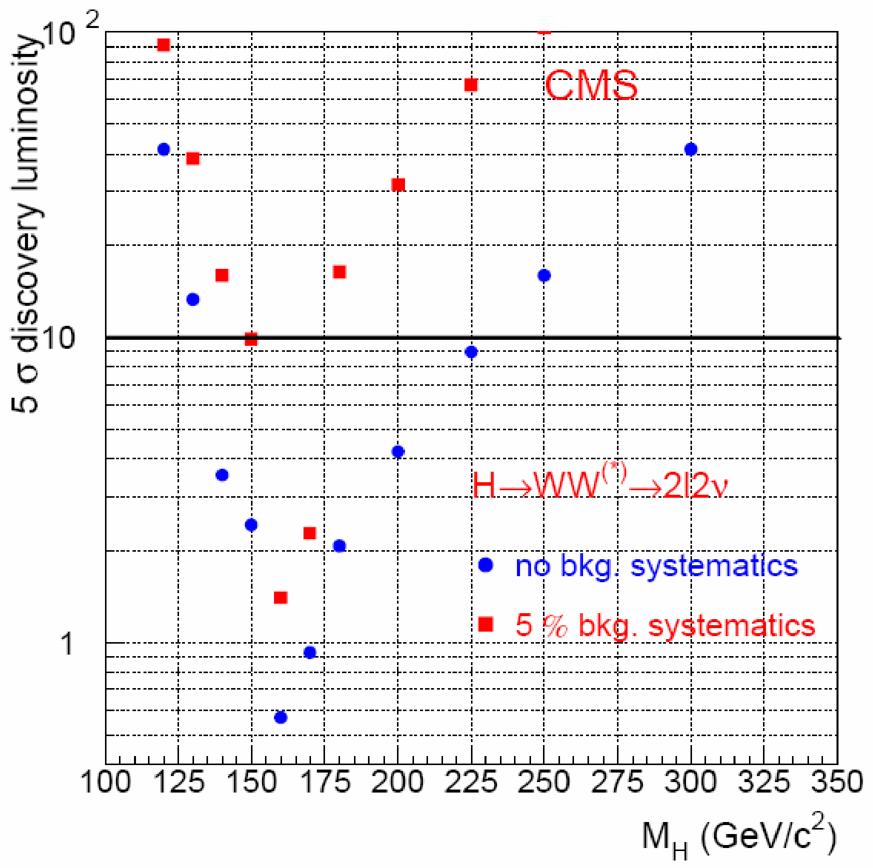


P_T>20 GeV low-L
P_T>30 GeV high-L

H→WW→ $\ell\ell'$X (III)

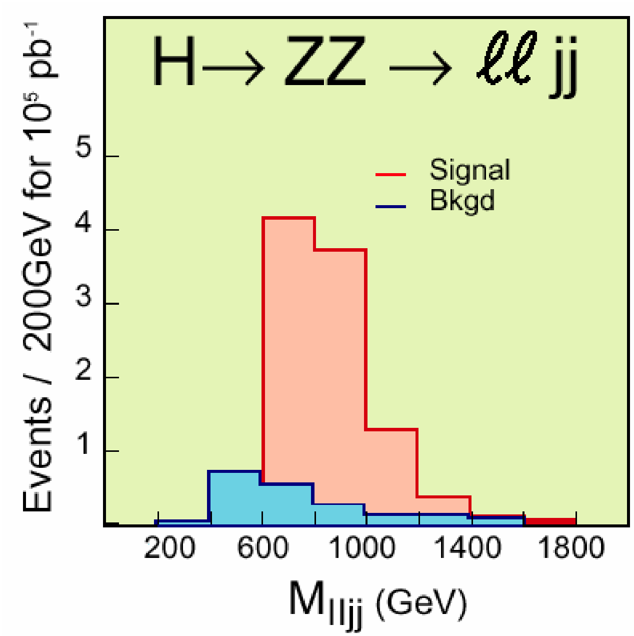
- **Reach**

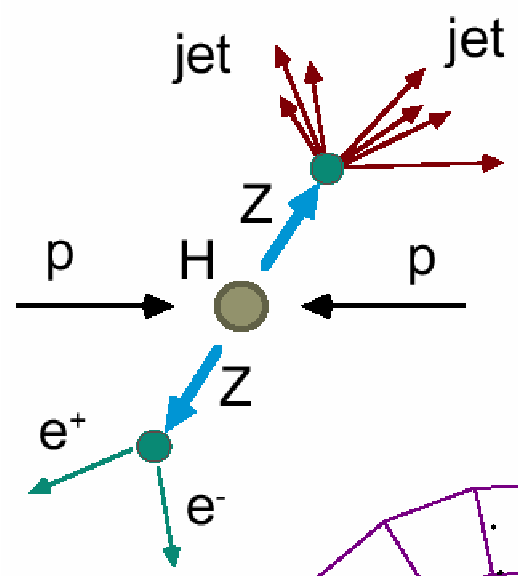


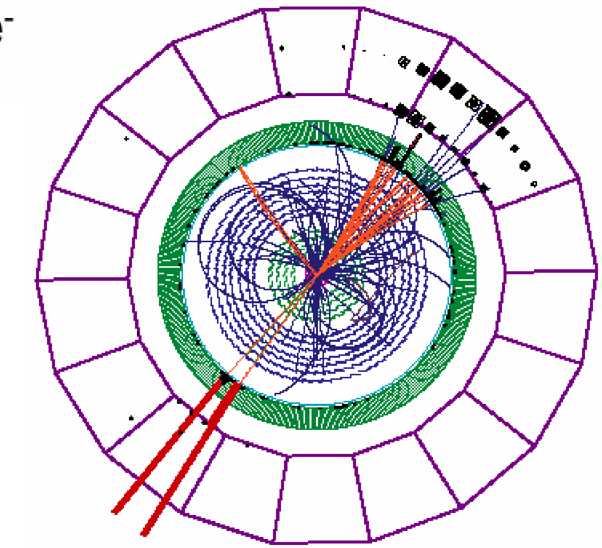


(Very) High mass Higgs

- **$H \rightarrow ZZ \rightarrow \ell^+\ell^-$ jet jet**
  - **Need higher Branching fraction (also $\nu\nu$ for the highest masses ~ 800 GeV/c^2)**
  - **At the limit of statistics**

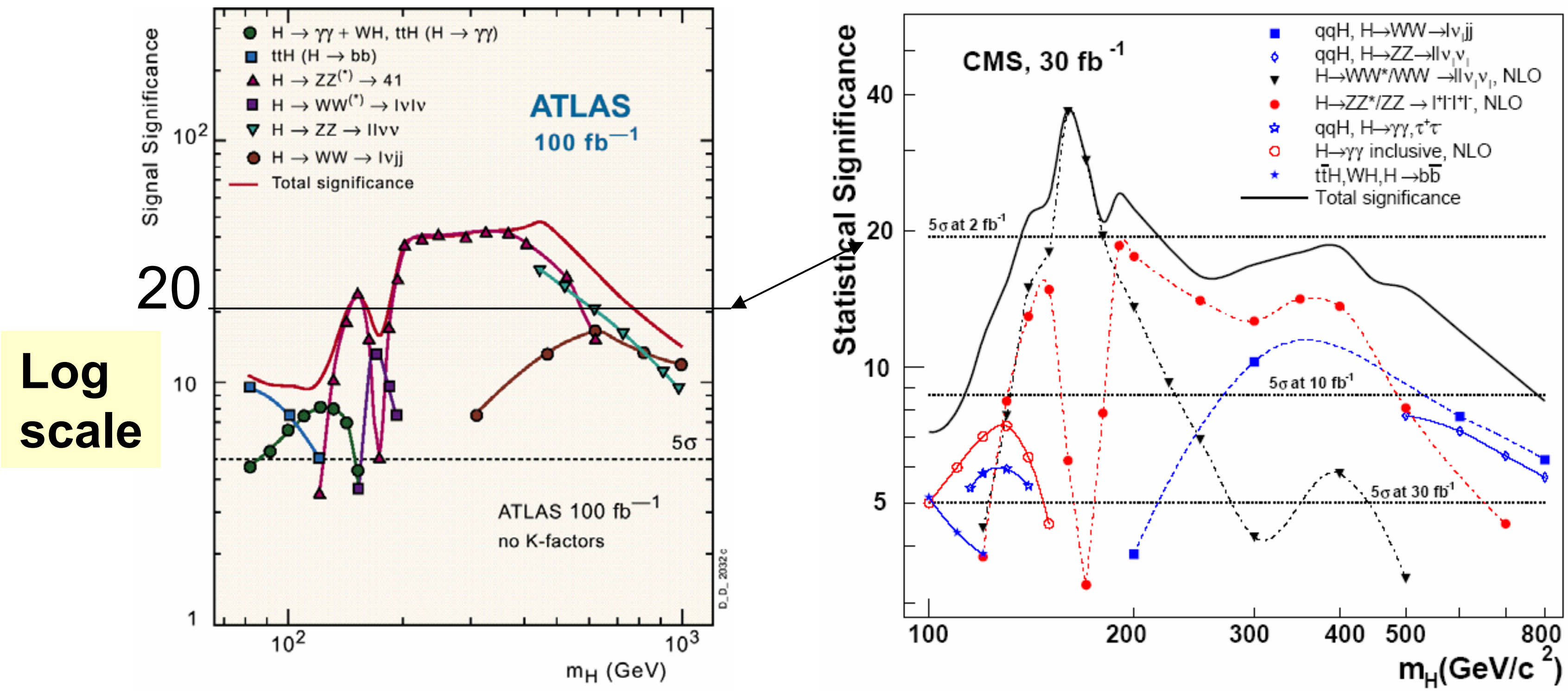






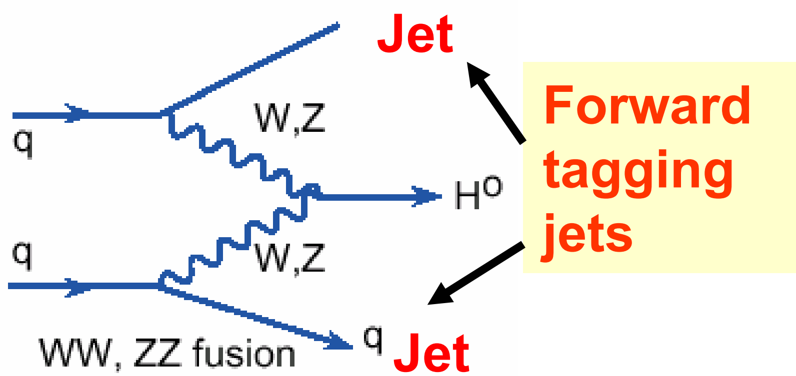
Higgs discovery prospects @ LHC

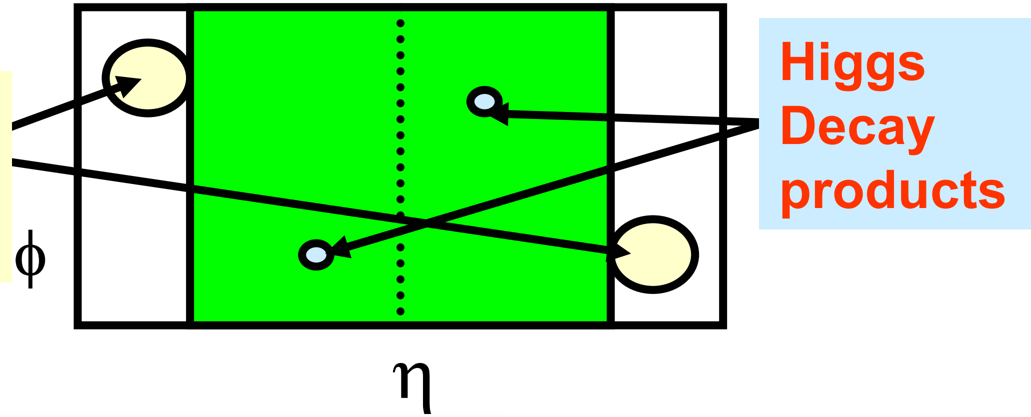
- **The LHC can probe the entire set of “allowed” Higgs mass values;**
  - in most cases a few months at $2\times10^{33}cm^{-2}s^{-1}$ are adequate for a 5σ observation



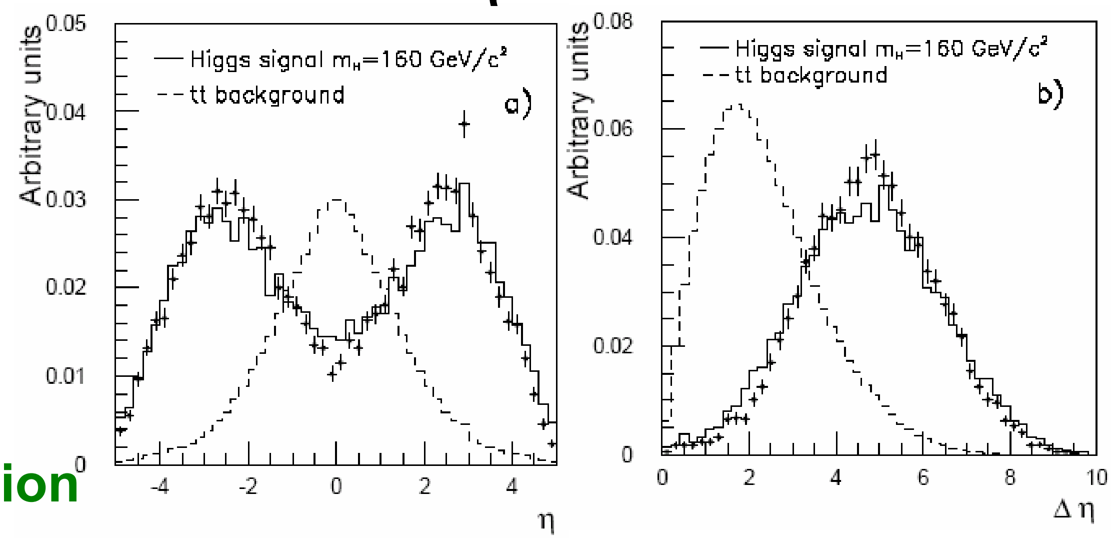
New Higgs channels: VBF-based

- Cross section varies from 10%(low-mass) to total (high-mass): advantage: forward jets



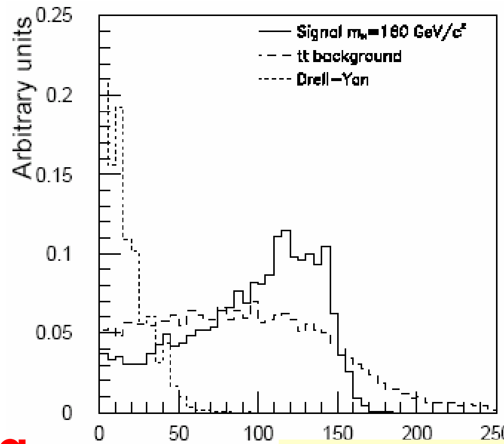


- Very useful for WW*
  - Rainwater&Zepenfeld
  - $\sigma(M_H=120\text{-}140)\sim 4$ pb
  - compare to tt bkg:
    - FWD jets
    - Large η difference
    - "Quiet" central region

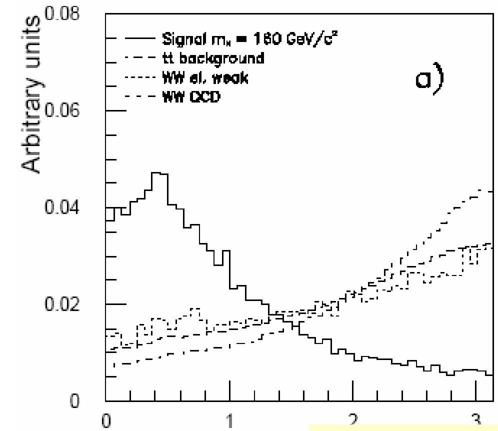


VBF: $H \rightarrow WW^*$

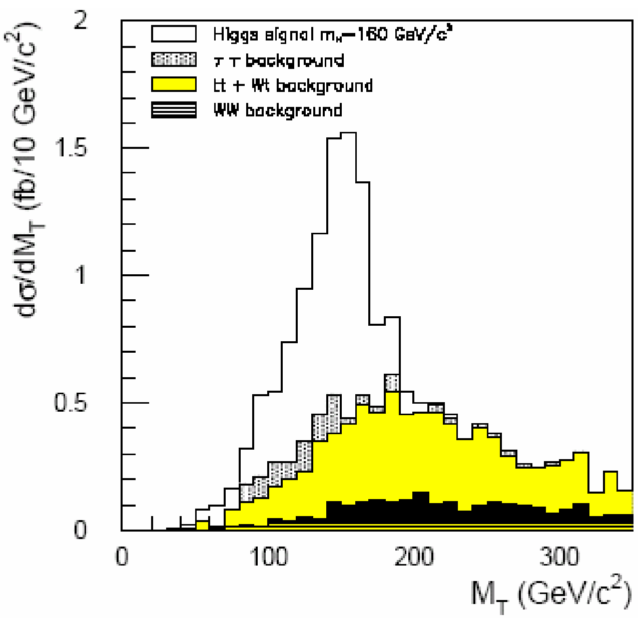
- **ATLAS update; leptonic search**
  - **VBF selection**
  - **Jet and tau veto**
  - **$M_T(\ell\ell\nu)$ cut**
  - **Lepton cuts**
- **ℓ+di-jet not very promising**



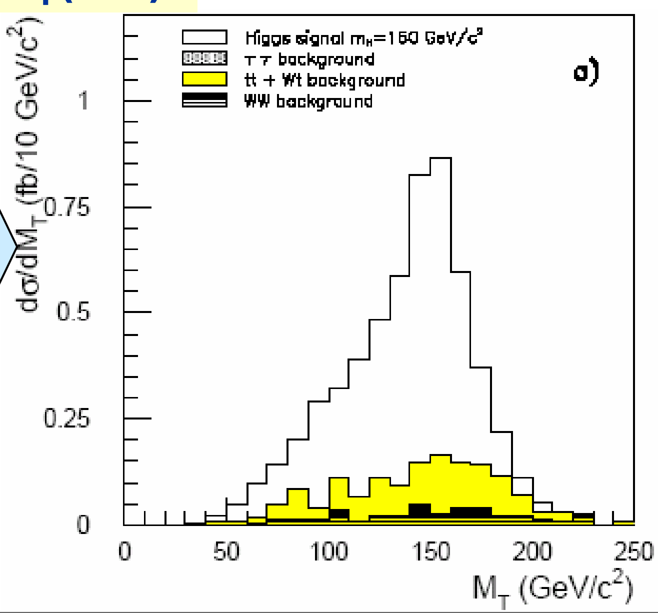
$M_T(\ell\ell\nu)$



$\Delta\phi(\ell\ell)$

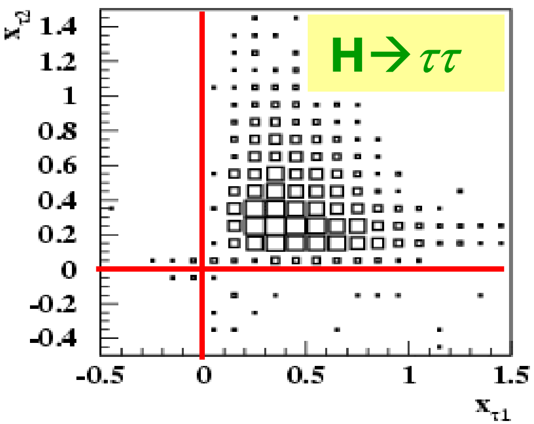


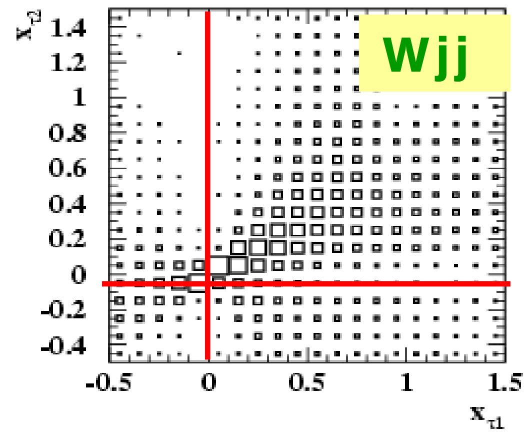
Lepton Cuts

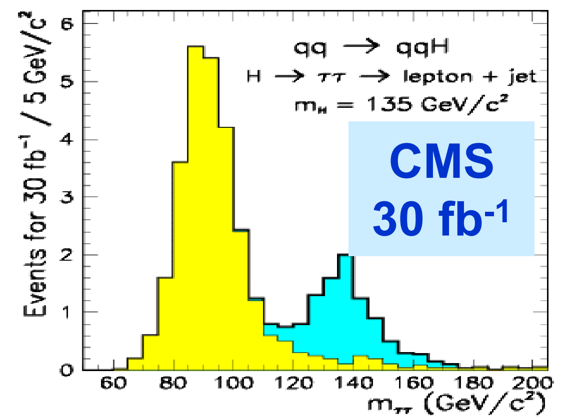


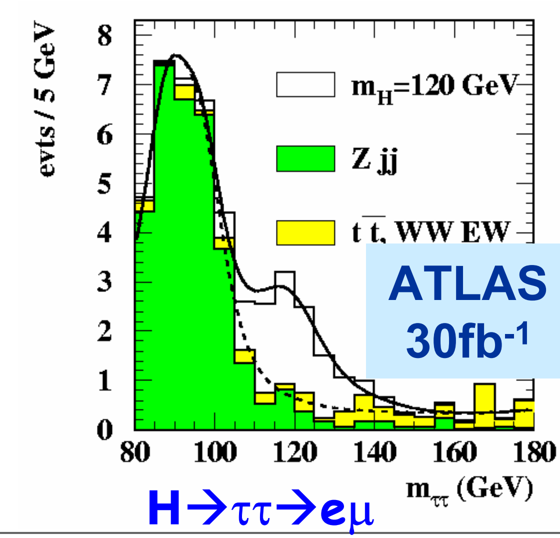
VBF: $H \rightarrow \tau\tau$

- **Tau reconstruction: assume lepton gives tau direction**
  - Get x_τ= p(τ decay products)/p(τ) from E_T^{miss}





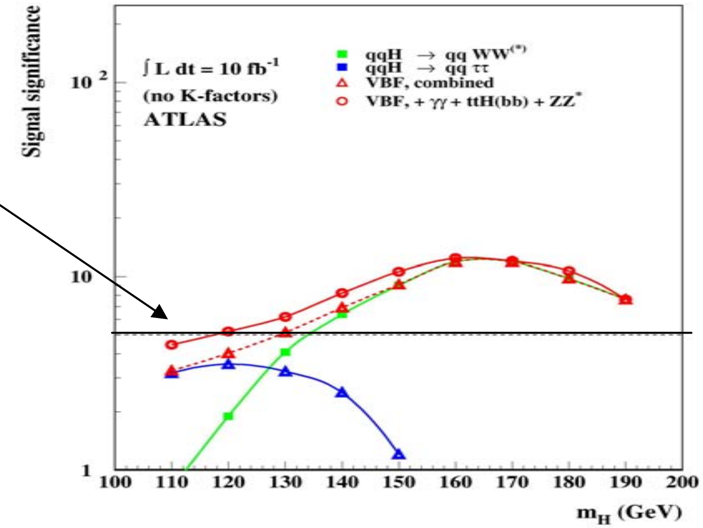


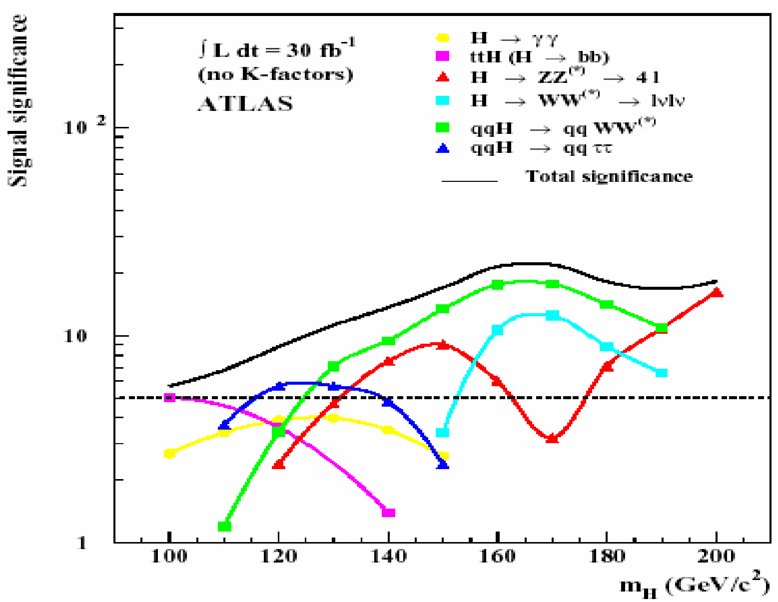


- M_H=110-140 GeV
  - Use $\tau\tau \rightarrow \ell\ell'$ and $\tau\tau \rightarrow \ell$+jet
- background estimate: ~10%
  - for M_H>125 GeV from side bands
  - for M_H<125 GeV from $Z \rightarrow \tau\tau$ peak
- Significance > 5 for 30 fb^{-1}

VBF: increased reach

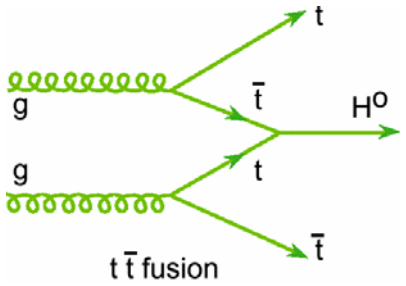
- VBF: increased discovery reach for low-mass H
  - $10 fb^{-1}$: actual discovery mode
    - Mainly WW*, ττ also helps
  - Bonus: several channels observable
    - Higgs-couplings determination



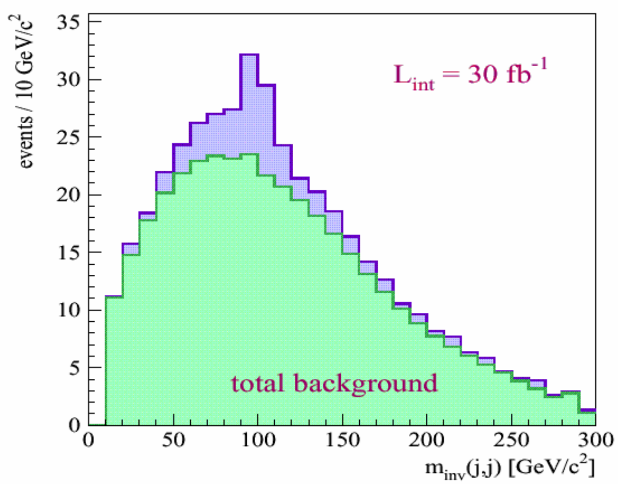


Other channels: $H \rightarrow b\bar{b}$ (I)

- **Low mass Higgs; useful for coupling measurement**
  - $H \rightarrow b\bar{b}$ in $t\bar{t}H$ production
    - σ.Br=300 fb
    - Backgrounds:
      - ➔ Wjjjj, Wjj$b\bar{b}$
      - ➔ $t\bar{t}$jj
      - ➔ Signal (combinatorics)
    - Tagging the t quarks helps a lot
      - ➔ Trigger: $t \rightarrow b(e/\mu)\nu$
      - ➔ Reconstruct both t quarks
    - In mass region 90GeV<M($b\bar{b}$)<130GeV, S/B =0.3

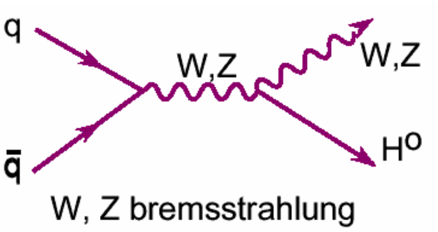


$t\bar{t}H^0$: $S + B$ (100 GeV)

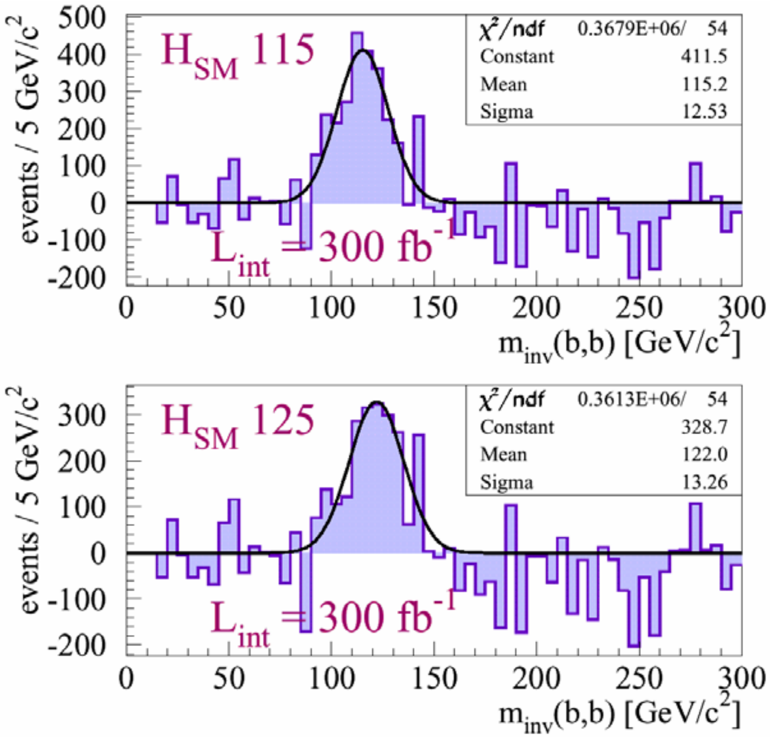


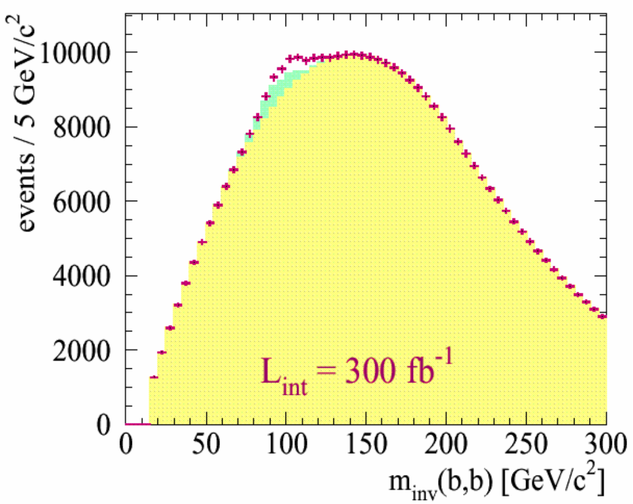
Other channels: $H \to b\bar{b}$ (II)

- $H \to b\bar{b}$ in WH production
  - Big background subtraction
    - Mainly: Wjj, $t\bar{t}$ (smaller: tX,WZ)
    - Example (below) at 105:
      → in mass region 88GeV<M($b\bar{b}$)<121GeV, S/B =0.03



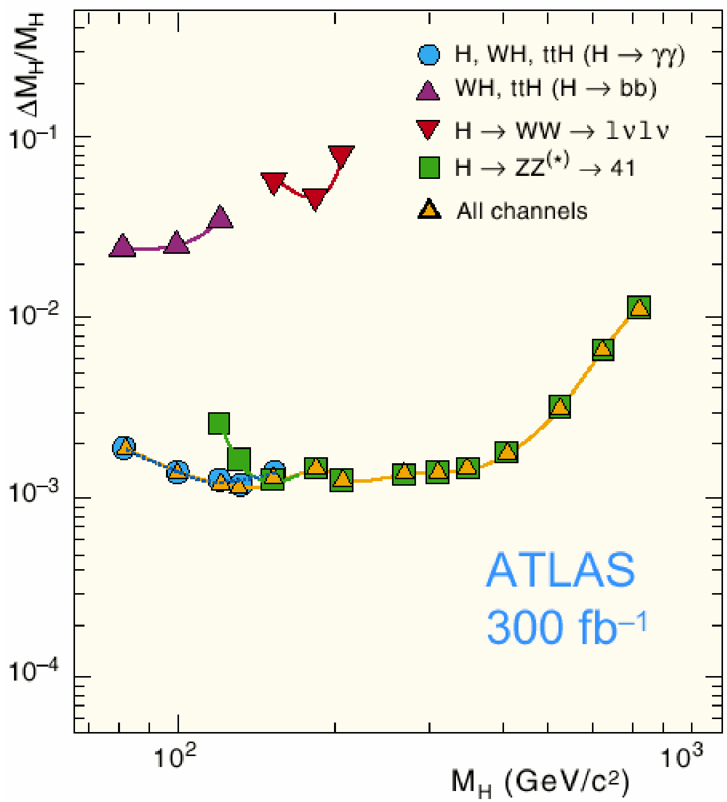
After bkg subtraction





SM Higgs properties (I): mass

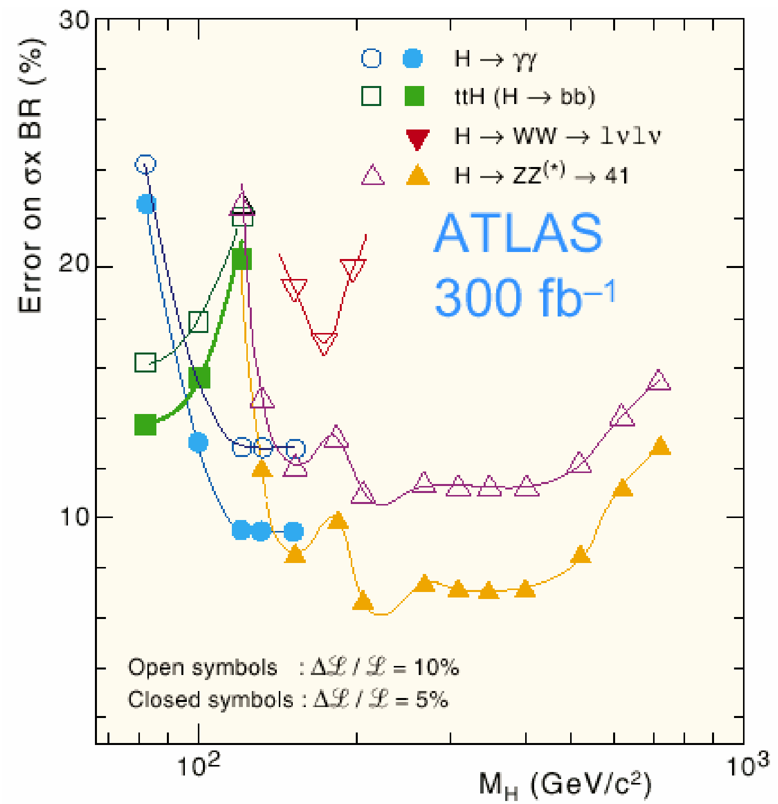
- **Mass measurement**
  - Limited by absolute energy scale
    - leptons & photons: 0.1% (with Z calibration)
    - Jets: 1%
  - Resolutions:
    - For $\gamma\gamma$ & $4\ell \approx 1.5$ GeV/c^2
    - For bb ≈ 15 GeV/c^2
  - At large masses: decreasing precision due to large Γ_H
  - CMS ≈ ATLAS



SM Higgs properties (II): BRs

- **Biggest uncertainty (5-10%): Luminosity**
  - **Relative couplings statistically limited**
    - **Small overlap regions**

Measure	Error	M_H range
$\frac{B(H \to \gamma\gamma)}{B(H \to b\bar{b})}$	30%	80–120
$\frac{B(H \to \gamma\gamma)}{B(H \to ZZ^*)}$	15%	125–155
$\frac{\sigma(t\bar{t}H)}{\sigma(WH)}$	25%	80–130
$\frac{B(H \to WW^{(*)})}{B(H \to ZZ^{(*)})}$	30%	160–180



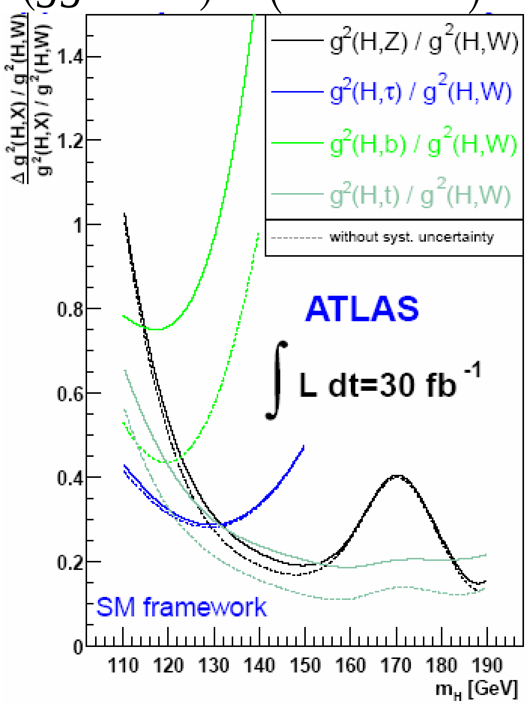
Higgs properties (II): couplings

$$\frac{\sigma(gg \to H)\cdot \mathrm{B}(H \to WW)}{\sigma(gg \to H)\cdot \mathrm{B}(H \to ZZ)} = \frac{\Gamma_W}{\Gamma_Z}$$

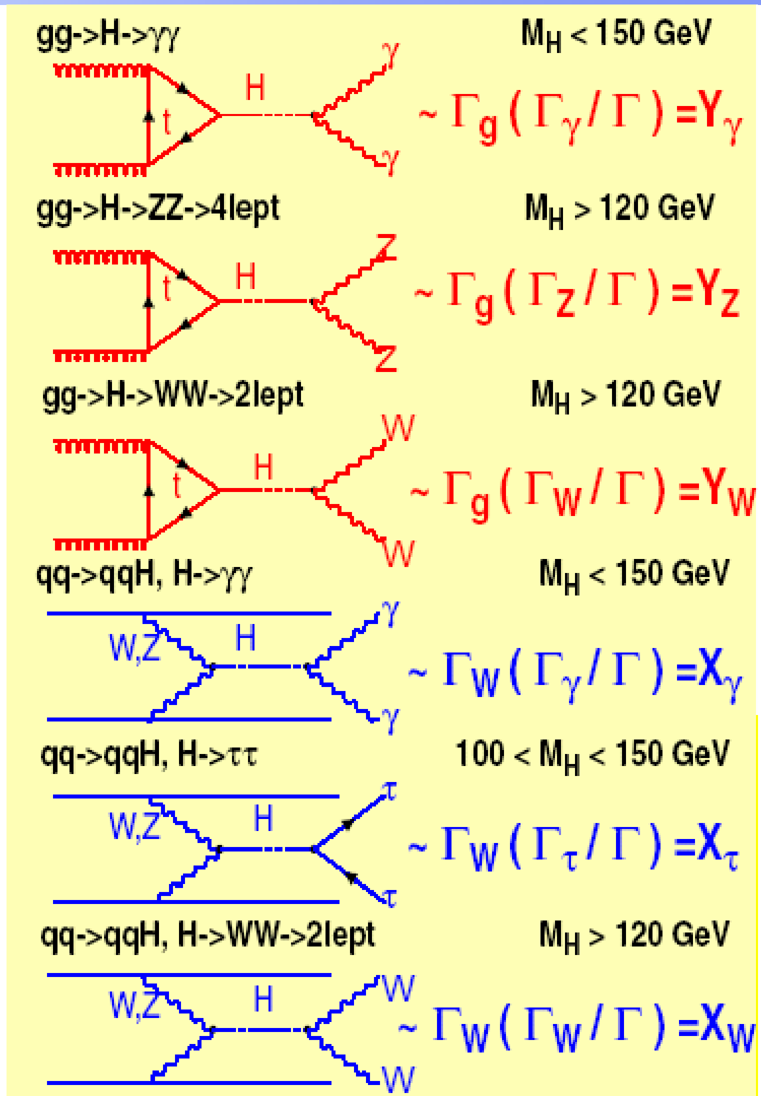
Th-err: ~4%

$$\frac{\sigma(gg \to H)\cdot \mathrm{B}(H \to \gamma\gamma)}{\sigma(gg \to H)\cdot \mathrm{B}(H \to ZZ)} = \frac{\Gamma_\gamma}{\Gamma_Z} \propto \frac{\Gamma_W}{\Gamma_Z}$$

$$\frac{\sigma(qq \to qqH)\cdot \mathrm{B}(H \to WW^*)}{\sigma(gg \to H)\cdot \mathrm{B}(H \to ZZ^*)} = \mathrm{F}_{\mathrm{QCD}} \frac{\Gamma_W}{\Gamma_Z}$$

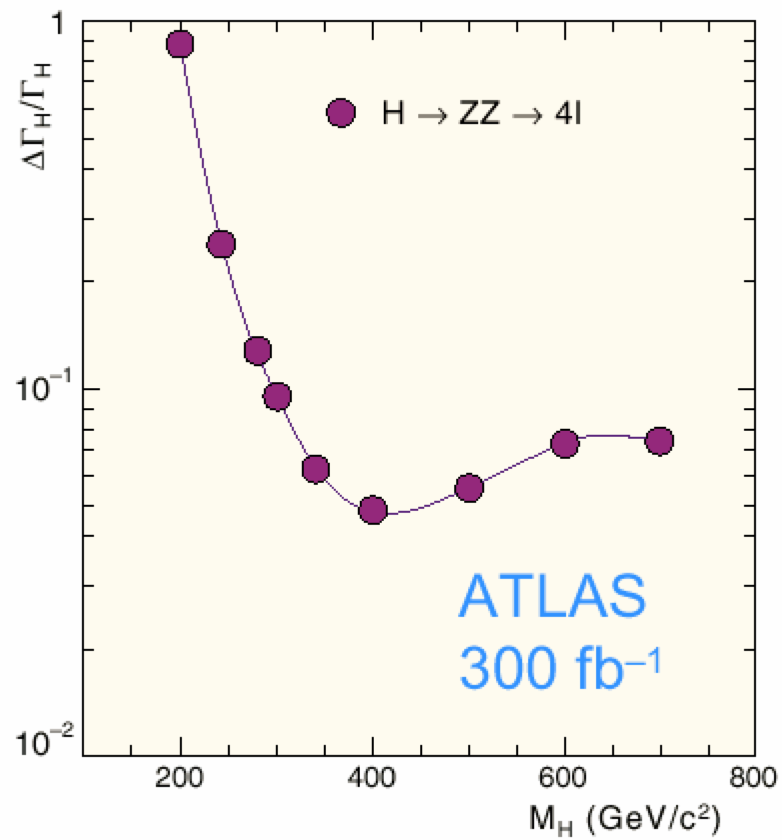


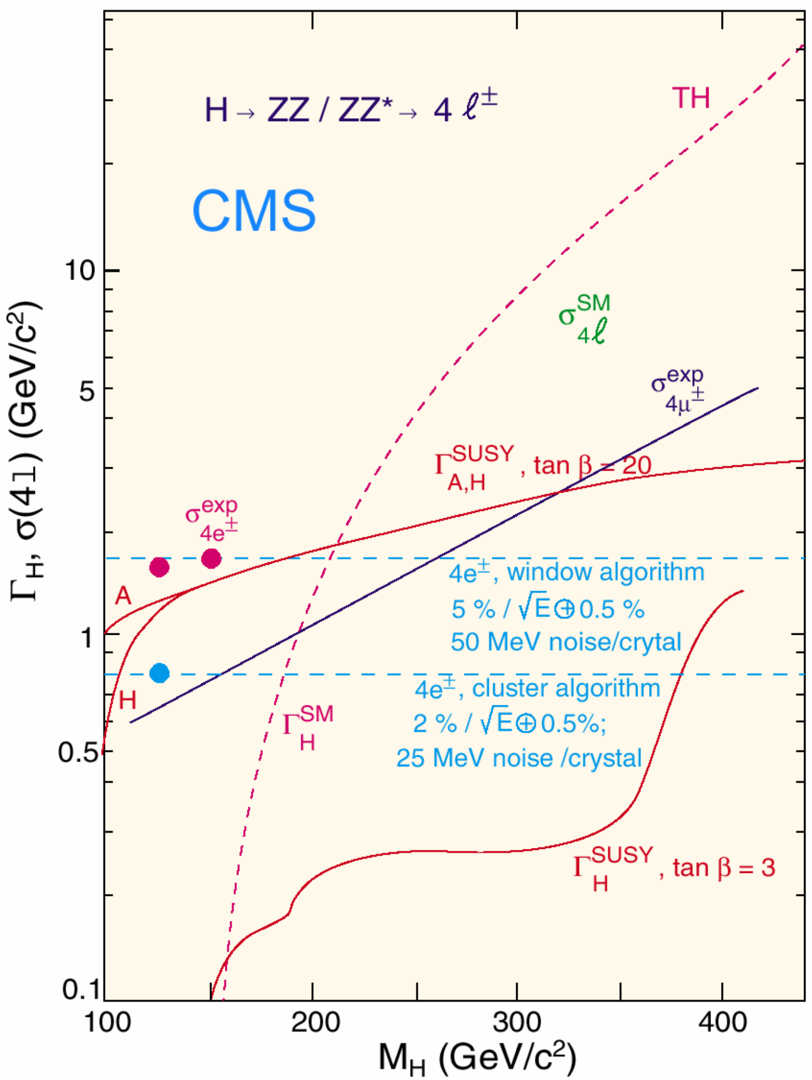
Th-err: ~20%



SM Higgs properties (III): width

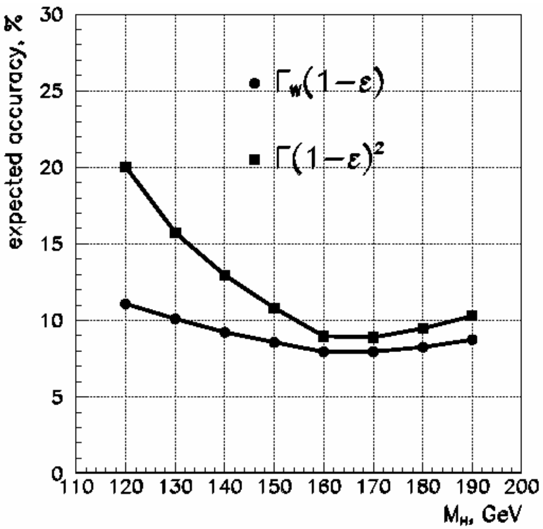
- **Direct measurement:**
  - **Possible for M_H>200**
    - **Using golden mode (4ℓ)**





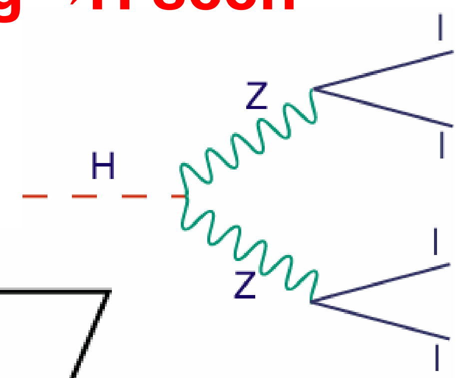
SM Higgs properties (III); width for $M_H<2M_Z$

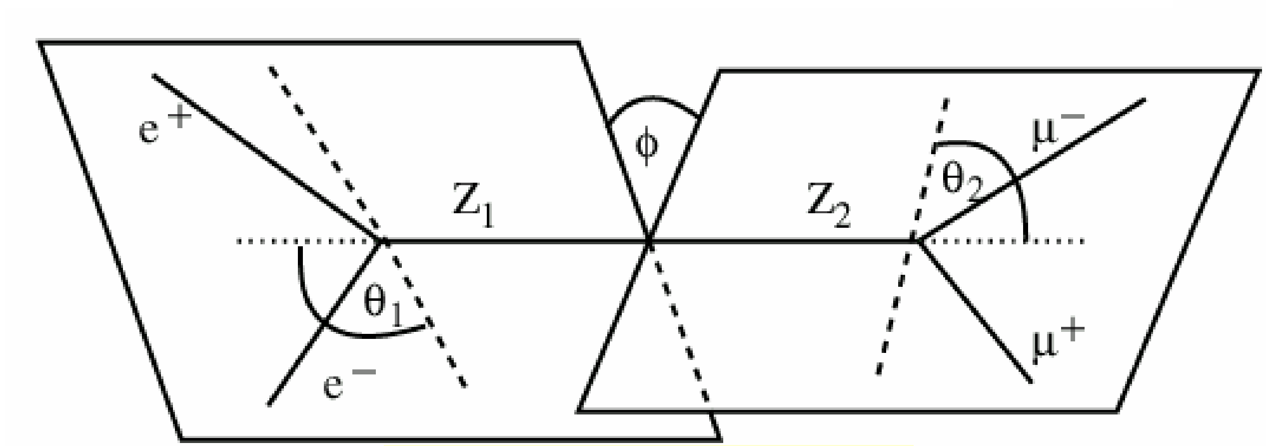
- **Basic idea: use $qq \rightarrow qqH$ production (two forward jets+veto on central jets)**
  - Can measure the following: $X_j = \Gamma_W \Gamma_j / \Gamma$ from $qq \rightarrow qqH \rightarrow qqjj$
    - Here: $j = \gamma, \tau, W(W^*)$; precision~10-30%
  - One can also measure $Y_j = \Gamma_g \Gamma_j / \Gamma$ from $gg \rightarrow H \rightarrow jj$
    - Here: $j = \gamma, W(W^*), Z(Z^*)$; precision~10-30%
  - Clearly, ratios of X_j and Y_j (~10-20%) $\rightarrow$ couplings
  - But also interesting, if Γ_W is known:
    - $\Gamma = (\Gamma_W)^2 / X_W$
    - Need to measure $H \rightarrow WW^*$
    - $\varepsilon = 1-(B_b+B_\tau+B_W+B_Z+B_g+B_\gamma) << 1$
    - $(1-\varepsilon)\Gamma_W = X_\tau(1+y)+X_W(1+z)+X_\gamma+X_g$
    - $z = \Gamma_W/\Gamma_Z$; $y = \Gamma_b/\Gamma_\tau = 3\eta_{QCD}(m_b/m_\tau)^2$



SM Higgs properties (IV): J^{CP}

- **Spin-1 assignment excluded if $H\rightarrow\gamma\gamma$ or $gg\rightarrow H$ seen**
- **Higgs decay products correlations**
  - **In analogy with "textbook" $\pi^0\rightarrow\gamma\gamma\rightarrow eeee$ case**





Higgs rest frame

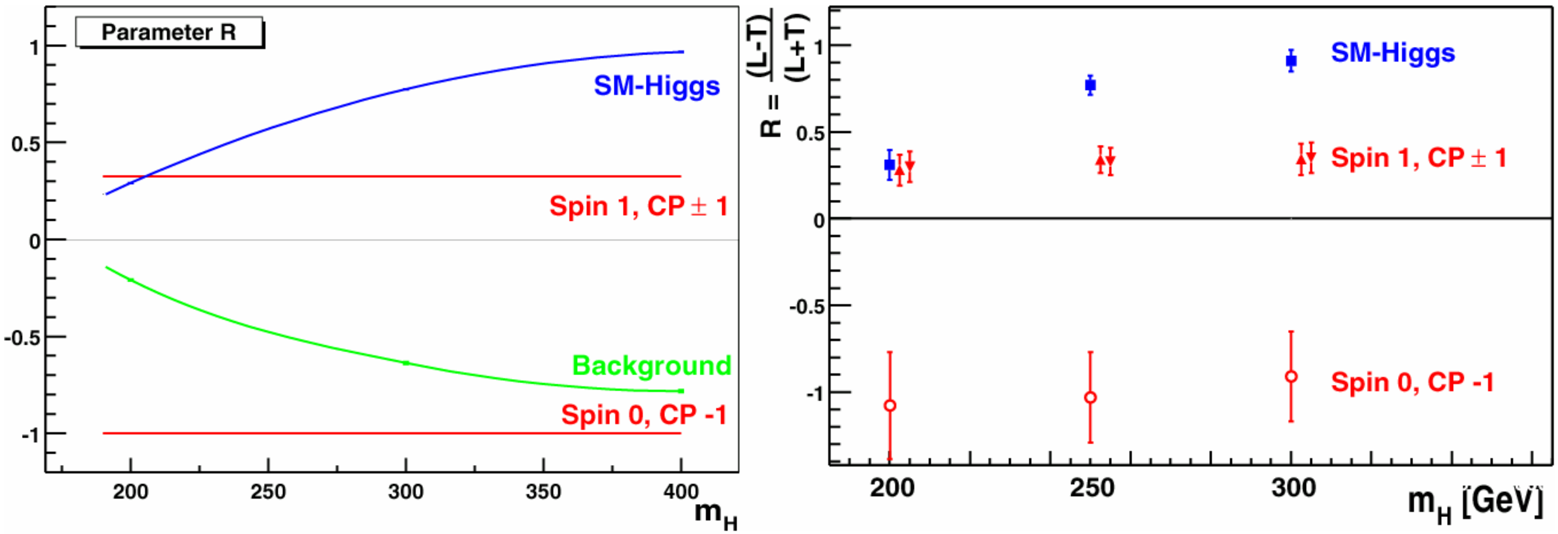
- **Two observables:**
  - **Angle between decay planes in Higgs rest-frame**
  - **Angle between leptons and Z-momentum the Z rest-frame (Gottfried-Jackson angle).**

SM Higgs properties (IV): J^{CP}

- **Expectation:**

$$F(\phi) = 1 + \alpha\cos\phi + \beta\cos 2\phi$$

$$G(\theta) = L\sin^2\theta + T(1+\cos^2\theta) \qquad R = \frac{L-T}{L+T}$$



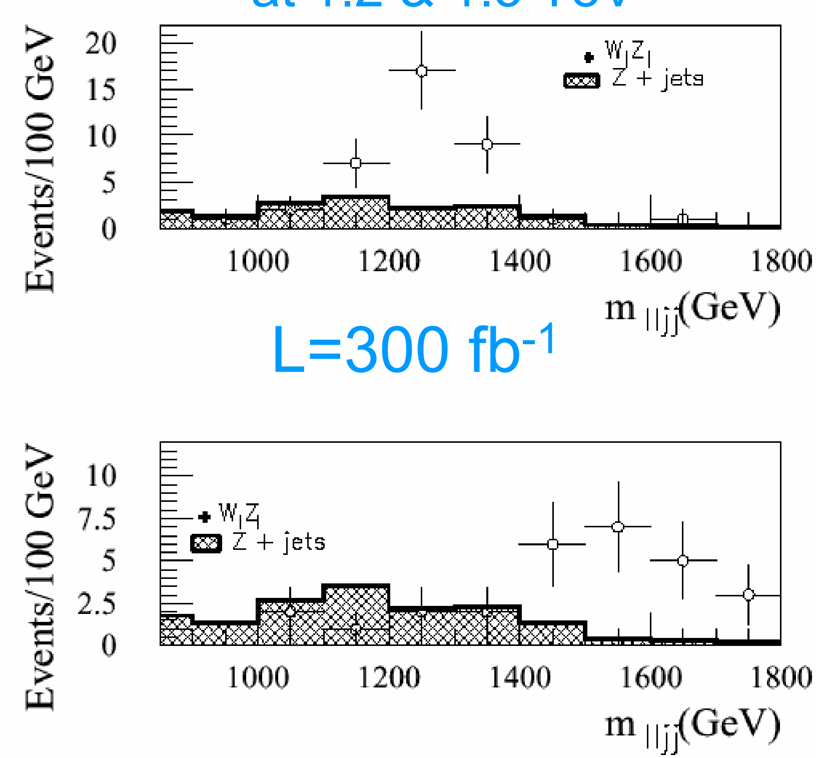
ATLAS $100\ fb^{-1}$

- **M_H>250 GeV: distinguish between S=0,1 and CP even.odd**
- **M_H<250 GeV: only see difference between SM-Higgs and S=0, CP=-1**
- **α,β less powerful**

The no Higgs case: $V_L V_L$ scattering

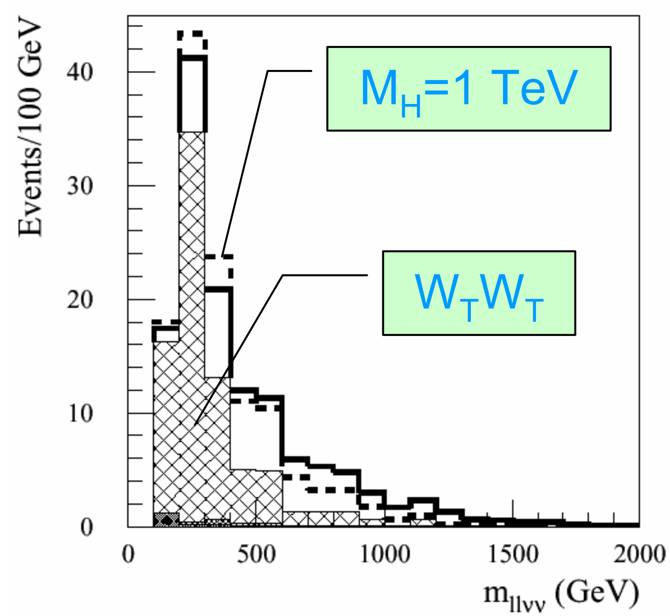
- **Biggest background is Standard Model VV scattering**
  - **Analyses are difficult and limited by statistics – this is really the limit of the LHC**

Resonant WZ scattering at 1.2 & 1.5 TeV



$L=300\ fb^{-1}$

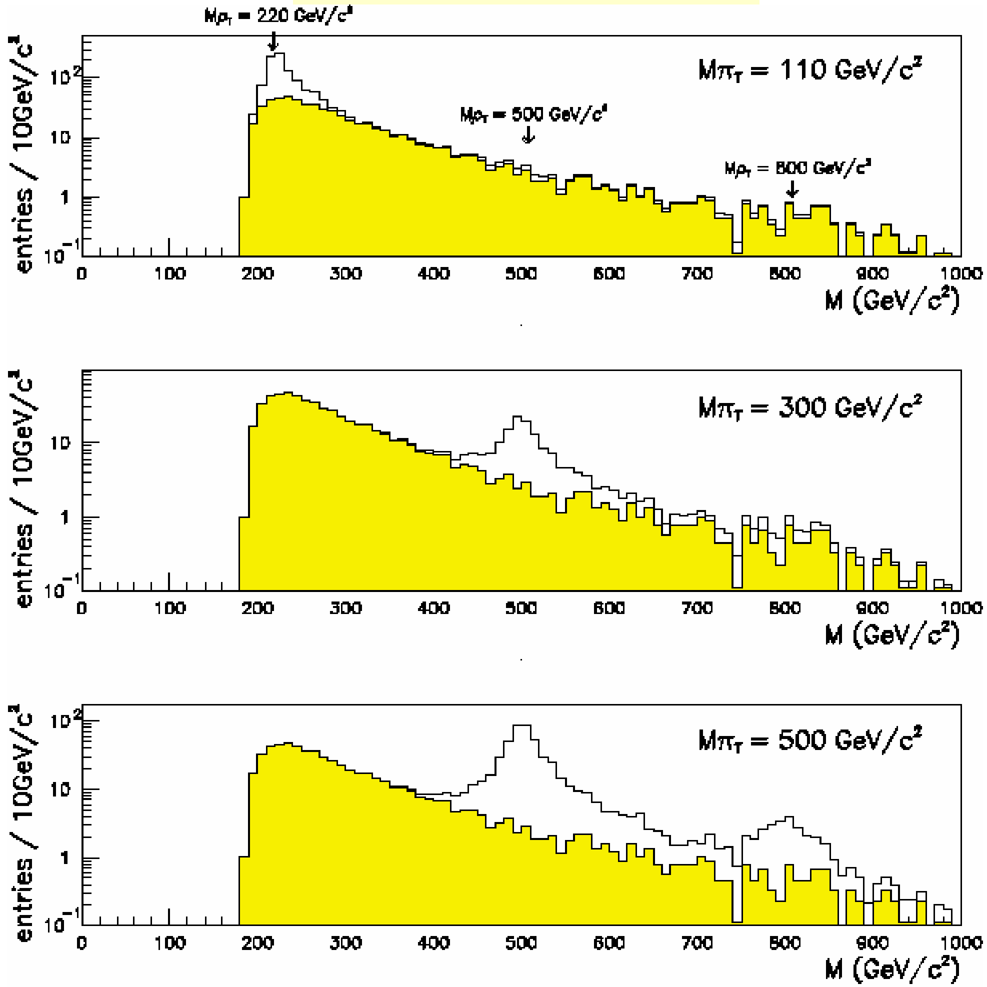
Non-resonant W^+W^+ scattering



Technicolor

- **Technicolor; many possibilities**
  - **Example: $\rho_T^{\pm} \to W^{\pm} Z^0 \to \ell^{\pm} \nu \ell^{+} \ell^{-}$ (cleanest channel…)**
  - **Many other signals (*bb*, *t t* resonances, etc…)**
  - **Wide range of observability**
  - **The "TeV" range can be seen over most of the parameter space**

ATLAS; 30 fb^{-1}



MSSM Higgses

MSSM Higgs(es)

- **Complex analysis; 5 Higgses ($\Phi \equiv H^{\pm}; H^0, h^0, A^0$)**
  - **At tree level, all masses & couplings depend on only two parameters; tradition says take M_A & $\tan\beta$**
  - **Modifications to tree-level mainly from top loops**
    - **Important ones; e.g. at tree-level, $M_h < M_z \cos\beta$, $M_A < M_H$; $M_W < M_{H^+}$; radiative corrections push this to 135 GeV.**
  - **Important branch 1: SUSY particle masses**

    (a) M>1 TeV (i.e. no Φ decays to them); well-studied

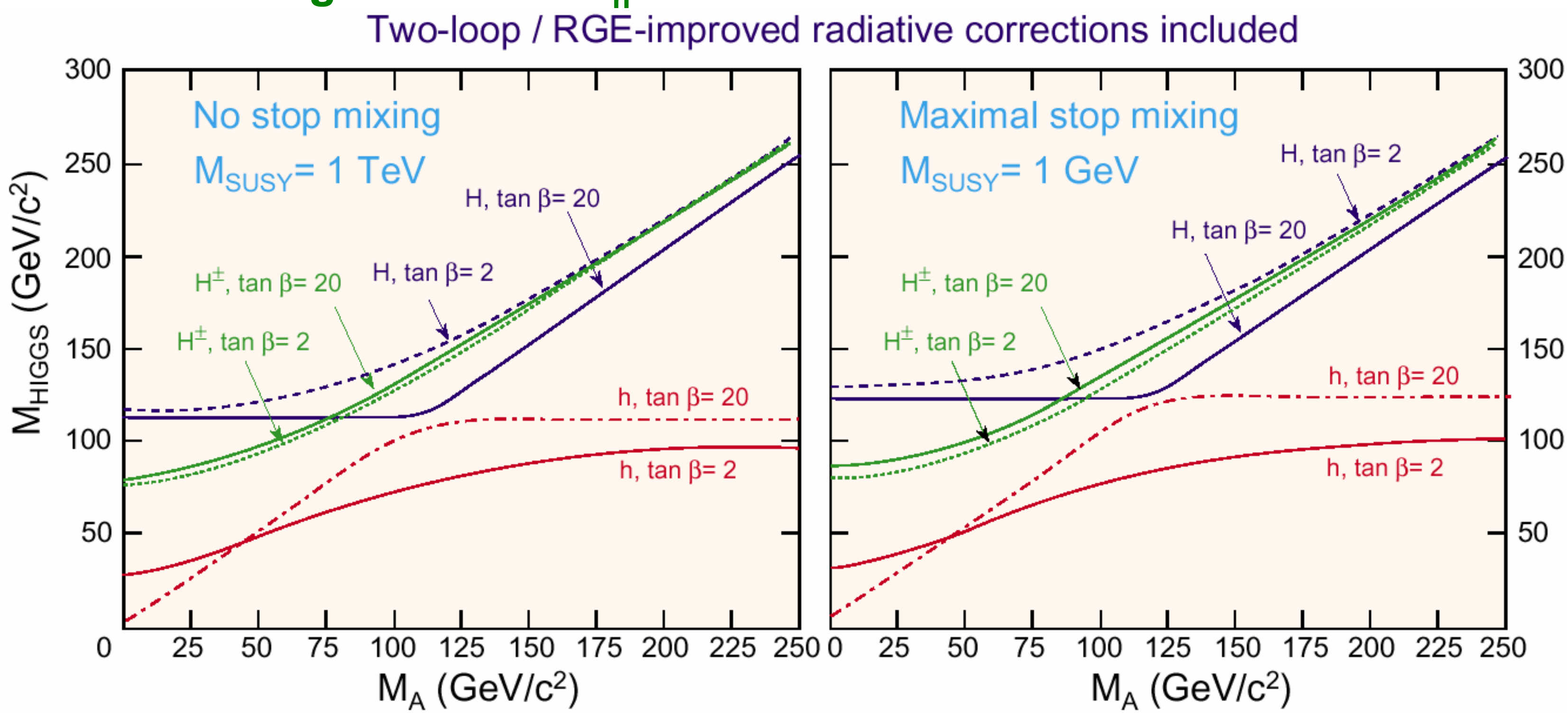
    (b) M<1 TeV (i.e. allows Φ decays); "on-going"
  - **Important branch 2: stop mixing; value of $\tan\beta$**

    (a) Maximal–No mixing

    (b) Low (1.5) and high (≈30) values of $\tan\beta$

MSSM Higgses: masses

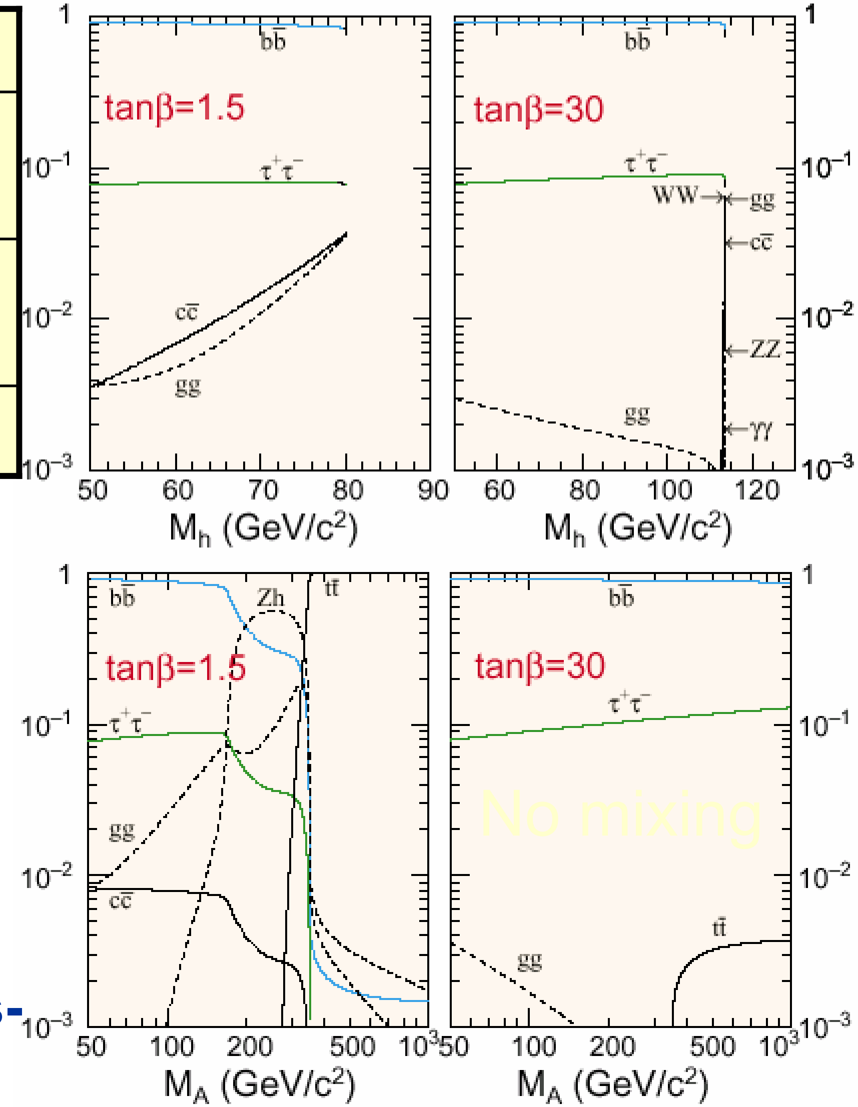
- **Mass spectra for M_{SUSY}>1TeV**
  - **Radiative corrections introduce more parameters**
    - **Incomplete top-stop loop cancellation most important**
      - ➔ **~ $M_{top}^4 \log(M_{stop}/M_{top})$, stop mixing**
    - **The good news: M_h<135 GeV/c²**



MSSM Higgs: decays

Φ	g(Φuu)	g(Φdd)	g(ΦVV)
h	cosα/sinβ →1	-sinα/cosβ →1	sin(β–α) →1
H	sinα/sinβ →1/tanβ	cosα/cosβ →tanβ	cos(β–α) →0
A	1/tanβ	tanβ	0

- **h is light**
  - **Decays to bb (90%) & ττ (8%)**
    - **cc, gg decays suppressed**
- **H/A "heavy"**
  - **Decays to top open (low tanβ)**
  - **Otherwise still to bb & ττ**
  - **But: WW/ZZ channels suppres-sed; lose golden modes for H**

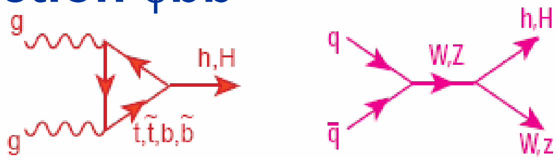


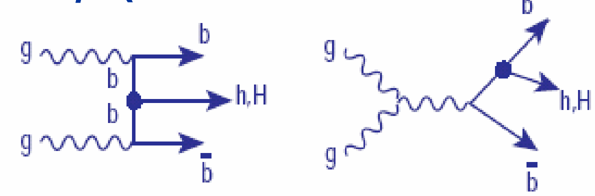
Production of MSSM Higgses: h, H

- **Largest branch: tanβ**

Large tanβ: ϕbb coupling important ⇒ gg → ϕ, associated production ϕbb

H^0VV couplings ∝ cos(β−α) ⇒ suppressed for large tanβ. VBF production low for H^0 at large tanβ (also no VBF for A^0)





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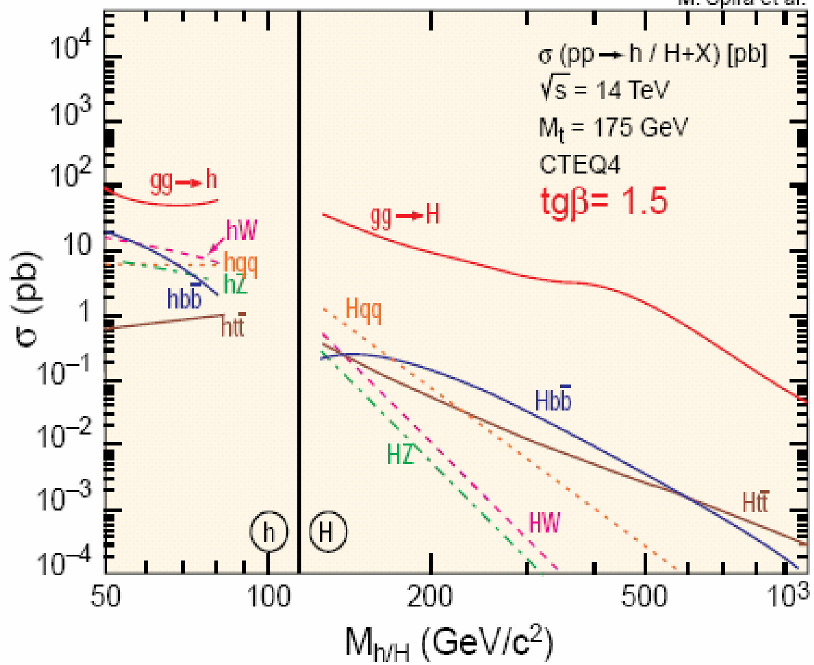
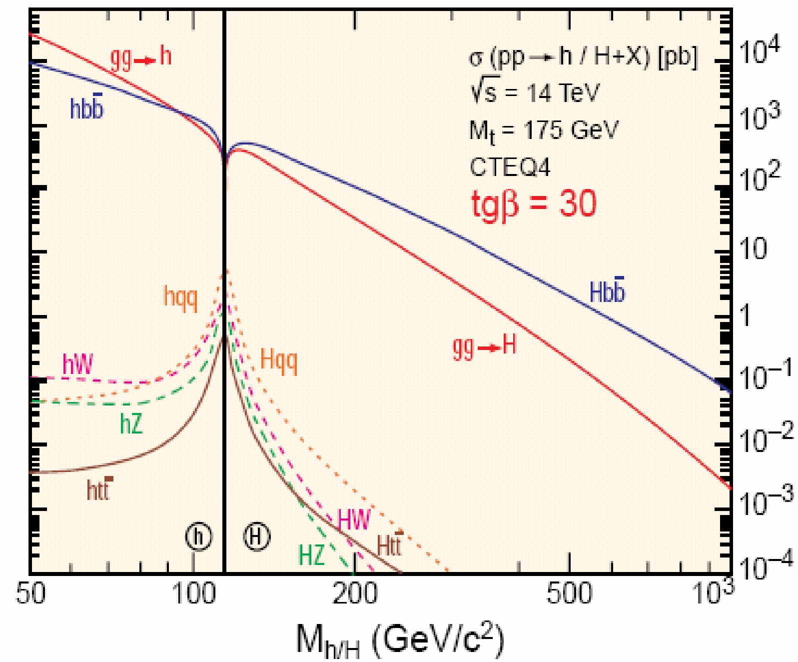
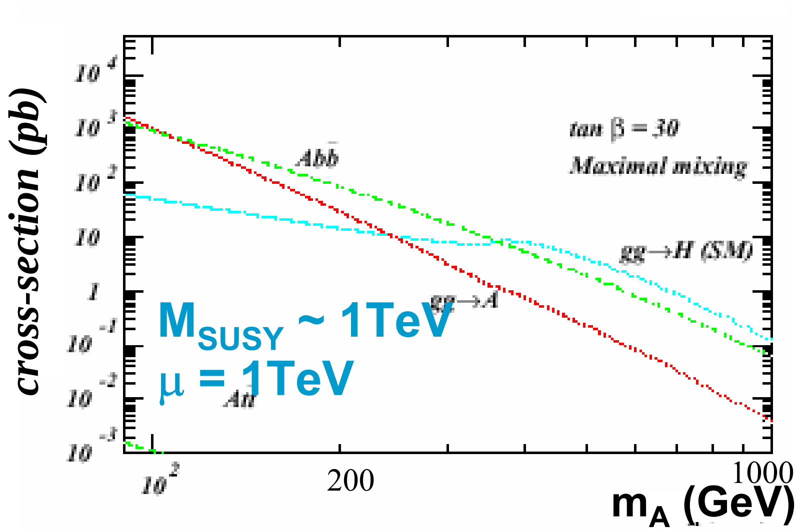


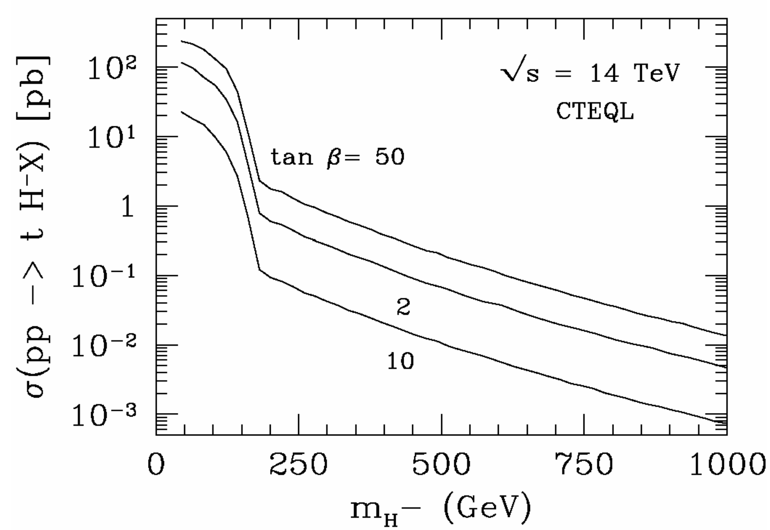


Production of MSSM Higgses : $A^0, H^\pm$

- **A^0 production:**
  - A^0 does not couple to W/Z (tree level) no VBF prodn
  - Large tanb: $A^0 bb$ coupling very important.
    - Affects both gg $\to A^0$, and associated production $A^0 bb$



- **Case 1: $M_{H+} < M_t - M_b$**
  - $t \to bH^+$ competes with SM
  - $t \to Wb$ produced in tt production followed by t decay
- **Case 2: $M_{H+} > M_t$**
  - gg, qq $\to$ tbH^-, gb $\to$ $tH^\pm$
  - Radiation off 3rd-generation quark

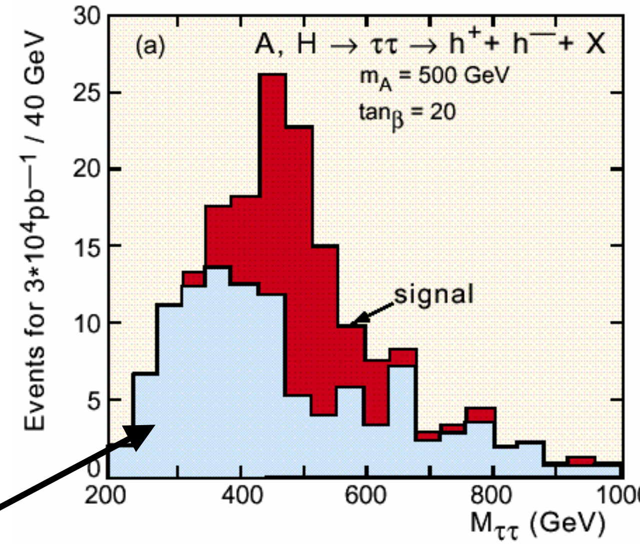


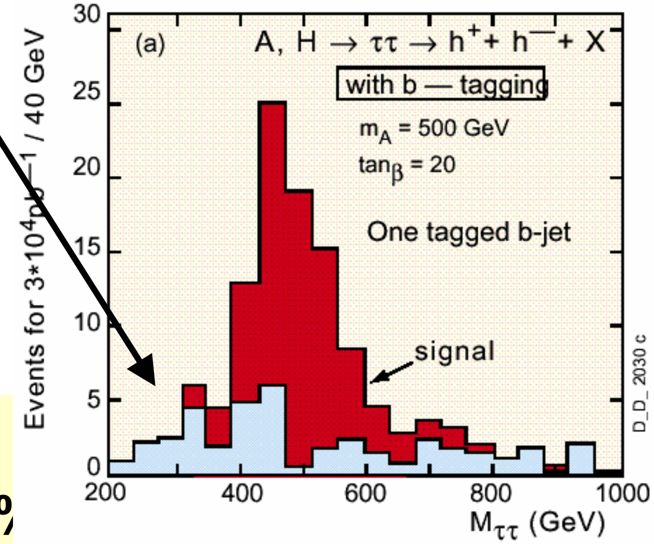
Higgs channels considered

- **Channels currently being investigated:**
  - H, h$\to\gamma\gamma$, $b\bar{b}$ ($H\to b\bar{b}$ in WH, $t\bar{t}$H) — (very) important and hopeful
  - h$\to\gamma\gamma$ in WH, $t\bar{t}h \to \ell\gamma\gamma$
  - h, H $\to$ ZZ*, ZZ $\to 4\ell$
  - h, H, A$\to \tau^+\tau^- \to (e/\mu)^+ + h^- + E_T^{miss}$
    - $\to e^+ + \mu^- + E_T^{miss}$
    - $\to h^+ + h^- + E_T^{miss}$
    - } inclusively and in $b\bar{b}H_{SUSY}$
  - $H^+ \to \tau^+ \nu$ from $t\bar{t}$
  - $H^+ \to \tau^+ \nu$ and $H^+ \to t\bar{b}$ for $M_H > M_{top}$
  - A $\to$ Zh with h $\to b\bar{b}$; A $\to\gamma\gamma$
  - H, A $\to \tilde{\chi}^0{}_2\tilde{\chi}^0{}_2, \tilde{\chi}^0{}_i\tilde{\chi}^0{}_j, \tilde{\chi}^+{}_i\tilde{\chi}^-{}_j$
  - $H^+ \to \tilde{\chi}^+{}_2\tilde{\chi}^0{}_2$
    - } promising
  - qq $\to$qqH with H $\to\tau^+\tau^-$
  - H $\to\tau\tau$, in WH, $t\bar{t}$H

H,A→ττ; the gen-3 lepton at the LHC

- **Best reach for large tanβ**
  - **All channels: ττ→ℓ+ℓ , ℓ+jet, jet+jet**
  - **All-hadronic channel: main reason for hadronic tau-trigger**
    - **Backgrounds: QCD (fake τ); Z/γ*→ττ; tt; W+jet, W →τν**
    - **tau-id: a tau-jet (1- and 3-prong) plus lifetime info**
    - **b-tagging: essential to reduce bkg**
    - **potential bkg from SUSY decays ($\tau,\chi^2_0,\chi_1^{\pm}$) negligible**
- **Decay offers measurement of tanβ, albeit with external input needed**

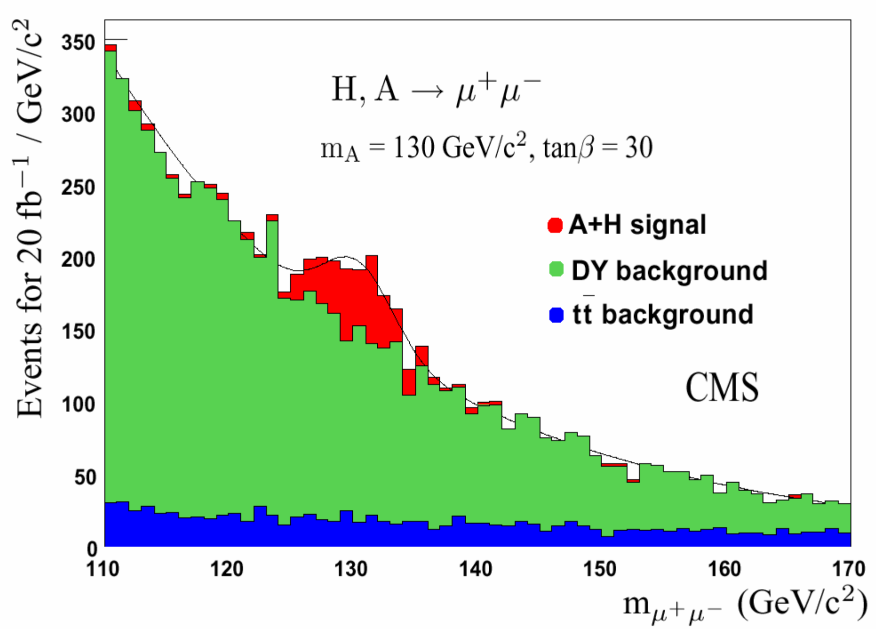




- **QCD rejection ~ 10^6**
- **Mass resolution ~ 15%**

H,A→μμ

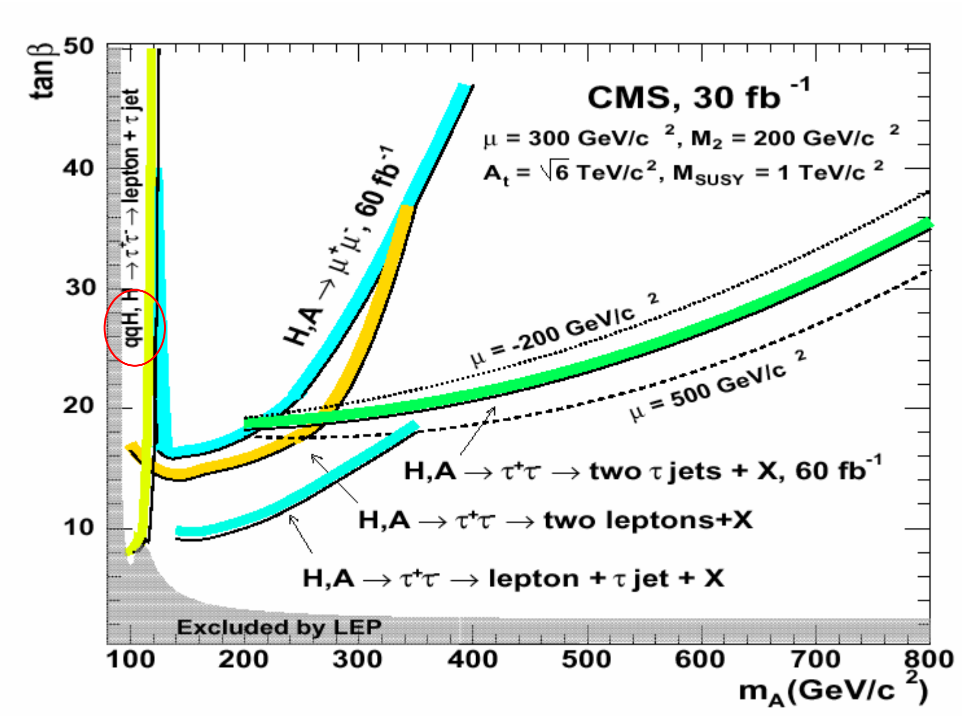
- **Enhanced $\bar{b}b$(H/A) production at high tanβ: also this channel possible**
  - **Smaller rate (than tau channel) but far better resolution**
  - **Backgrounds:**
    - **Z,γ* → μμ; reject using b-tagging**
    - **$t\bar{t} \to Wb, W \to \mu\nu$ reject using central jet veto**

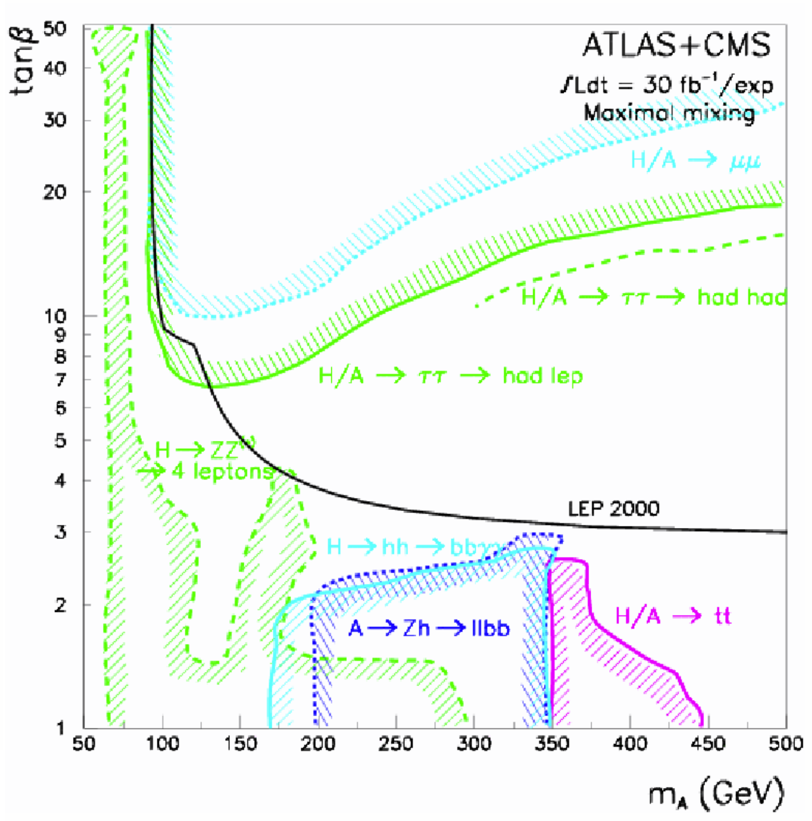


Cannot resolve A and H peaks.
Δm ~ 1%
Example shown:
$|m_H - m_A| \sim 2$GeV

H, A reach via μ,τ decays

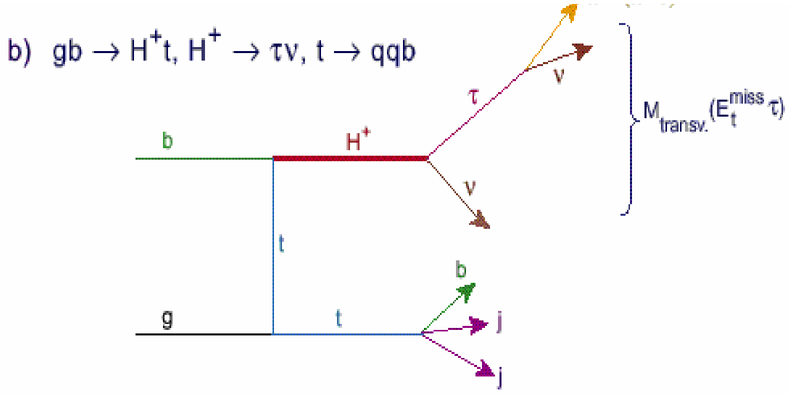
5σ reach





H^+ detection

- **Associated top-H^+ production:**
  - **Use all-hadronic decays of the top (leave one "neutrino")**
  - **H decay looks like W decay → Jacobian peak for τ-E_T^{miss}**

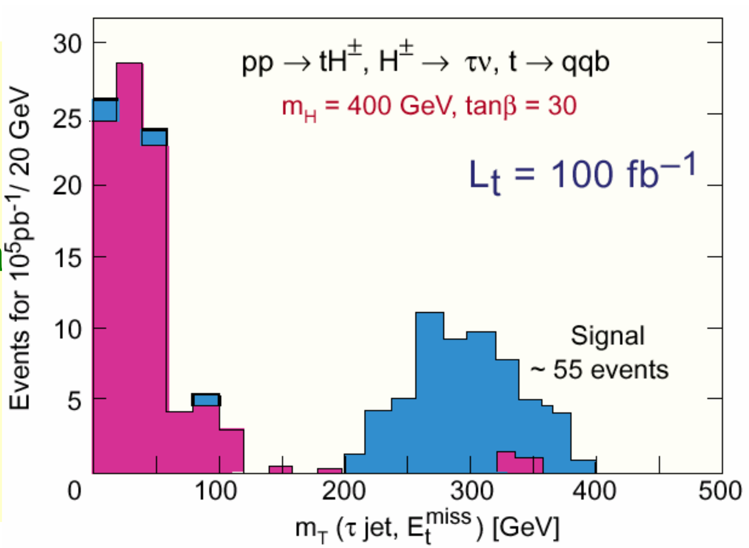


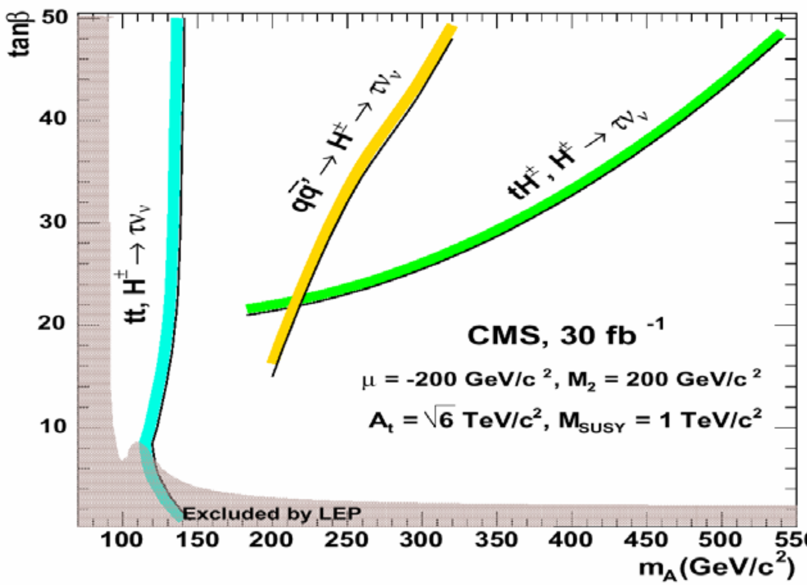
E_T(jet)>40

$|\eta|$<2.4

Veto on extra jet, and on second top

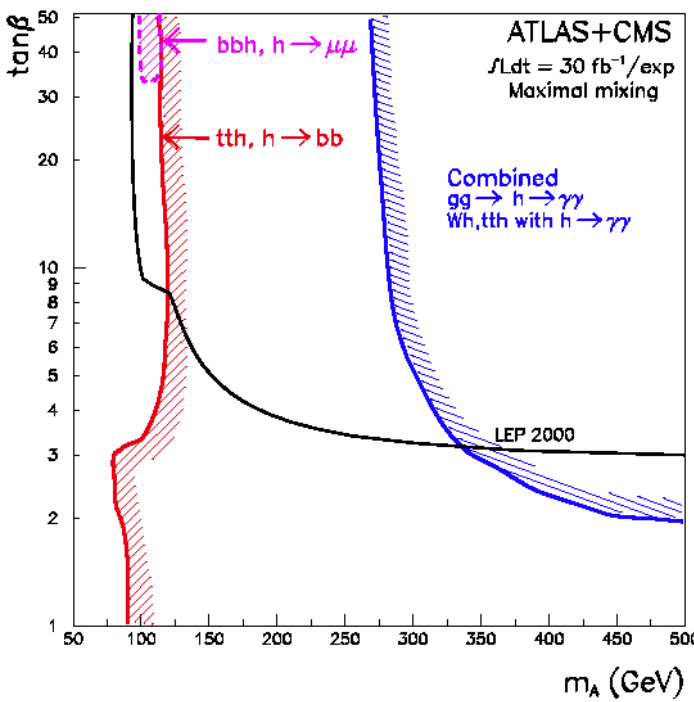
Bkg: $t\bar{t}H$

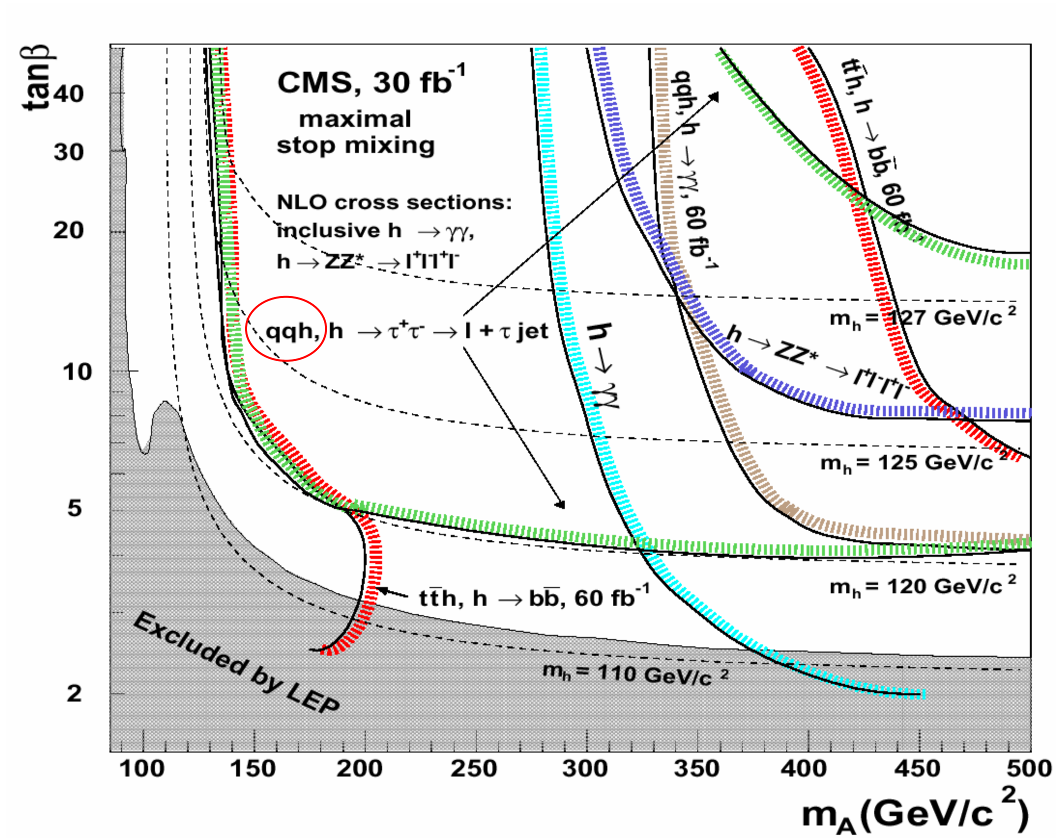




h^0 reach

- **Search for in SM-like channels.**
  - **VBF channels very useful, e.g. qqh, $h\rightarrow\tau\tau$**





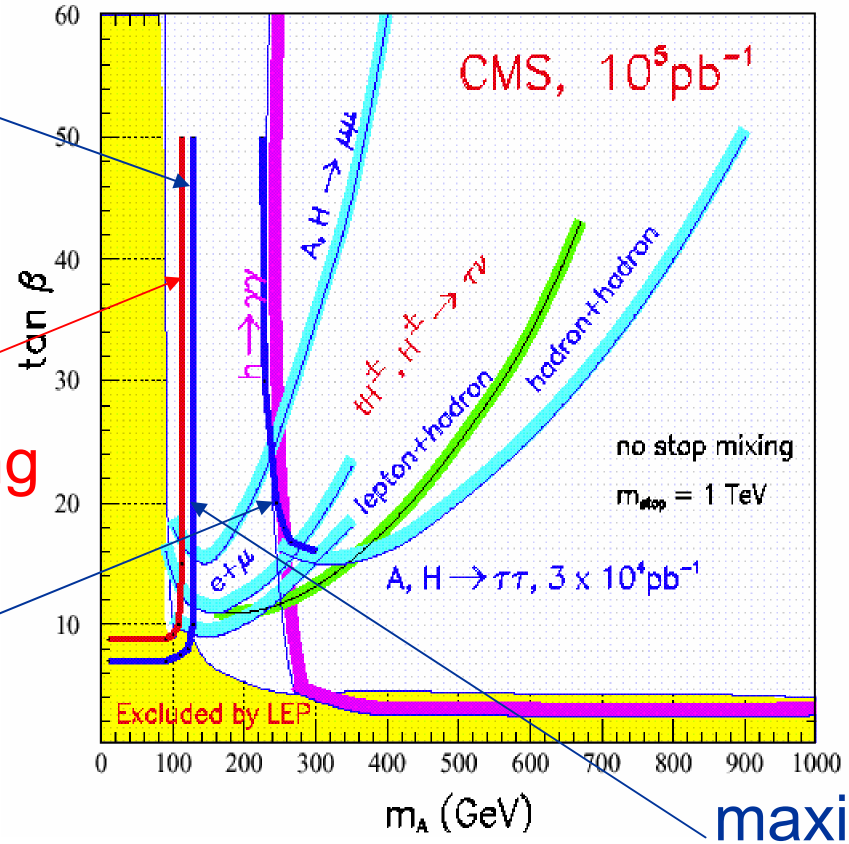
SUSY reach on tanβ-M_A plane

- **Adding $b\bar{b}$ on the τ modes can “close” the plane**

(W-tt)h → (e/μ)ν, $b\bar{b}$

No stop mixing

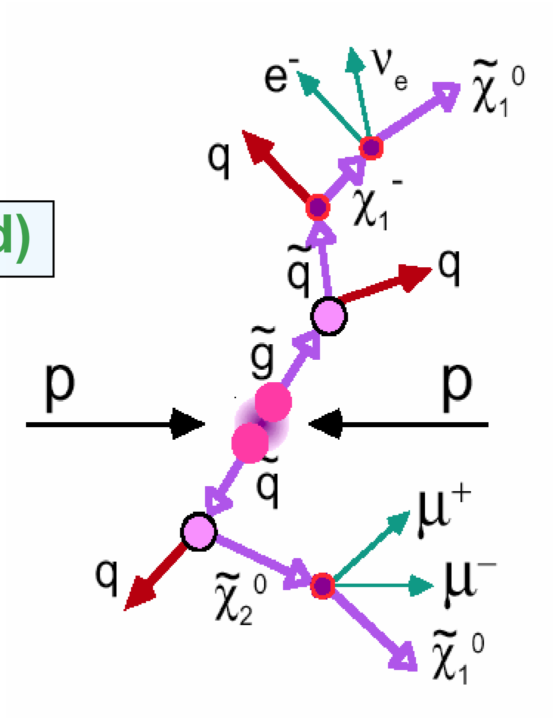
maximal stop mixing with 30 fb^{-1}



maximal stop mixing with 300 fb^{-1}

SUSY decays

- **Squarks & gluinos produced together with high σ**
  - **Gauginos produced in their decays; examples:**
    - $\tilde{q}_L \to \tilde{\chi}_2^0 q_L$ **(SUGRA P5)**
    - $\tilde{q} \to \tilde{g}\, q \to \chi_2^0 \tilde{q}\bar{q}$ **(GMSB G1a)**
  - **Two "generic" options with $\tilde{\chi}^0$:**
    - (1) $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$ (~ dominates if allowed)
    - (2) $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+\ell^-$ or $\tilde{\chi}_2^0 \to \tilde{\ell}^+\ell^-$
    - **Charginos more difficult**
      - **→ Decay has ν or light q jet**
  - **Options:**
    - **Isolated (multi)-leptons**
    - **Look for higgs (to $b\bar{b}$)**



- **The "other" branch: exploit MSSM Higgs boson production in cascades of SUSY particles**

Other case: SUSY particles accessible

- **If SUSY kinematically accessible**
  - Higgses can decay directly to or come from decays of SUSY particles
  - Light SUSY particles suppress or enhance loop-induced production or decays
- **Sparticle decay modes can compete with SM modes**

$$\mathrm{H/A} \rightarrow \chi_2^0 \chi_2^0 \rightarrow 4\ell^{\pm} X$$

$$\mathrm{H}^{\pm} \rightarrow \chi_2^0 \chi_1^{\pm} \rightarrow 3\ell^{\pm} X$$

$$h^0 \rightarrow \chi_1^0 \chi_1^0 \ \text{(Invisible !)}$$

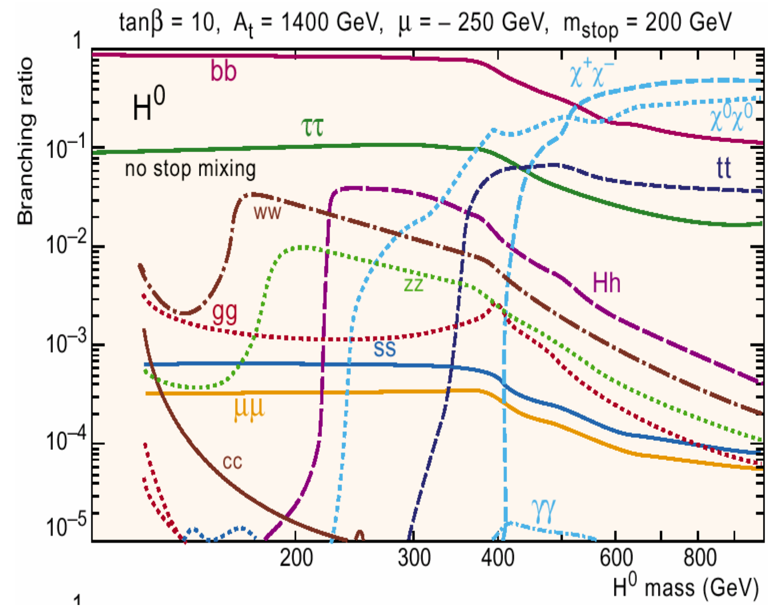
- **Further source of Higges from cascade decays of heavy SUSY particles**

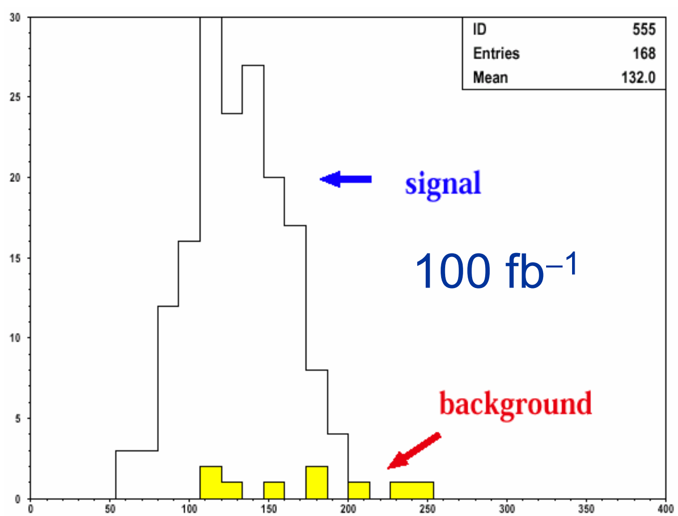
$$\chi_2^0, \chi_1^{\pm} \rightarrow \chi_1^0 + \Phi \ \text{(small/little cascade)}$$

$$\chi_{3,4}^0, \chi_2^{\pm} \rightarrow \chi_{1,2}^0, \chi_1^{\pm} + \Phi \ \text{(big cascade)}$$

If SUSY charg(neutral)inos < 1 TeV (I)

- **Decays $H^0 \to \tilde{\chi}^0_2\tilde{\chi}^0_2$, $\tilde{\chi}^+_i\tilde{\chi}^-_j$ become important**
  - **Recall that $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \ell^+\ell^-$ has spectacular edge on the dilepton mass distribution**
  - **Example: $\tilde{\chi}^0_2\tilde{\chi}^0_2$. Four (!) leptons (isolated); plus two edges**





Four-lepton mass

Central point in MSSM parameter space :

$M_{A,H} = 350$ GeV $\tan\beta = 5$

$M_{\tilde{l}} = 250$ GeV $\mu = -500$ GeV

$M_{\tilde{\chi}^0_1} = 60$ GeV $M_{\tilde{\chi}^0_2} = 110$ GeV

$M_{\tilde{q}} = M_{\tilde{g}} = 1$ TeV

If SUSY charg(neutral)inos < 1 TeV (II)

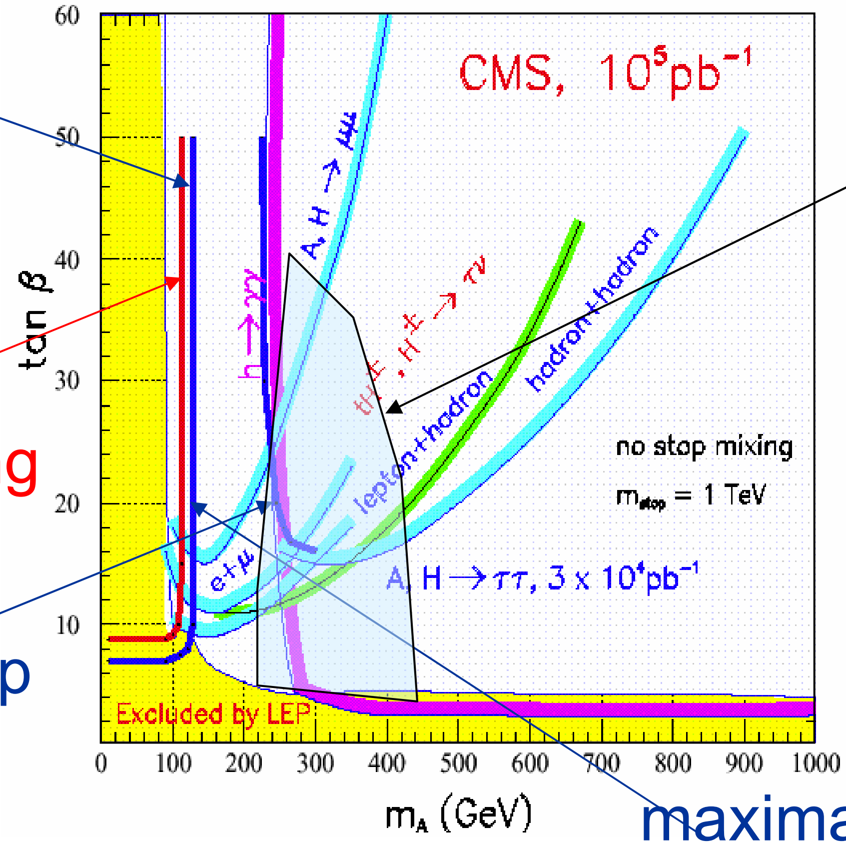
- **Helps fill up the "hole"**

Wh

$(e/\mu)\nu$ $\quad b\bar{b}$

No stop mixing

maximal stop mixing with 30 fb^{-1}

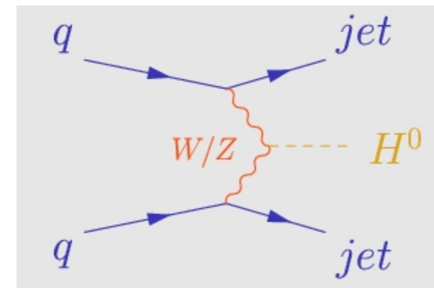


Area covered by $H^0 \rightarrow \tilde{\chi}^0_2 \tilde{\chi}^0_2$, $\rightarrow 4\ell$eptons 100 fb^{-1}

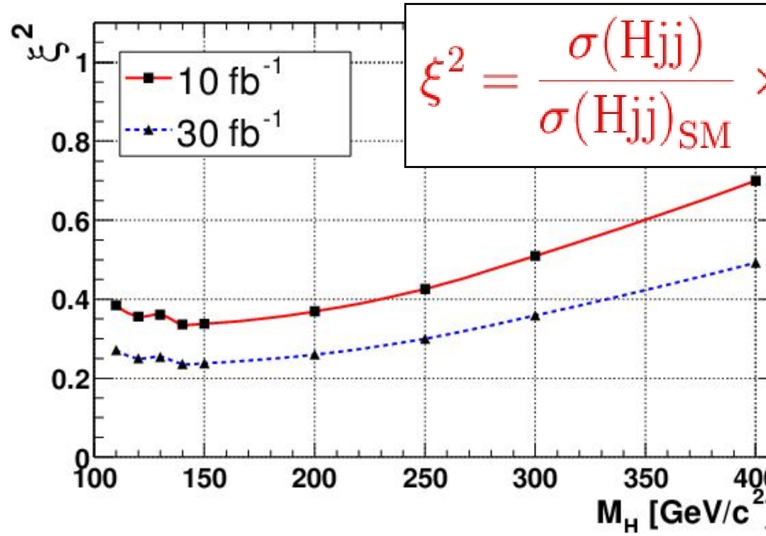
maximal stop mixing with 300 fb^{-1}

Invisible Higgs…

- **H $\rightarrow$ LSP decays possible.**
  - Use production channels like VBF (Hqq), WH, ZH, ttH
  - VBF signal: forward and backward jets + large missing pt in central region.
  - Requires dedicated jets+E_T^{miss} trigger



- **Backgrounds:**
  - Z jet jet, Z $\rightarrow\nu\nu$; W jet jet, W $\rightarrow \ell\nu$ (miss ℓ) , QCD jets + escaping particles
  - Selection:
    - F & B jets
    - Missing E_T
    - Central jet veto
    - Lepton veto

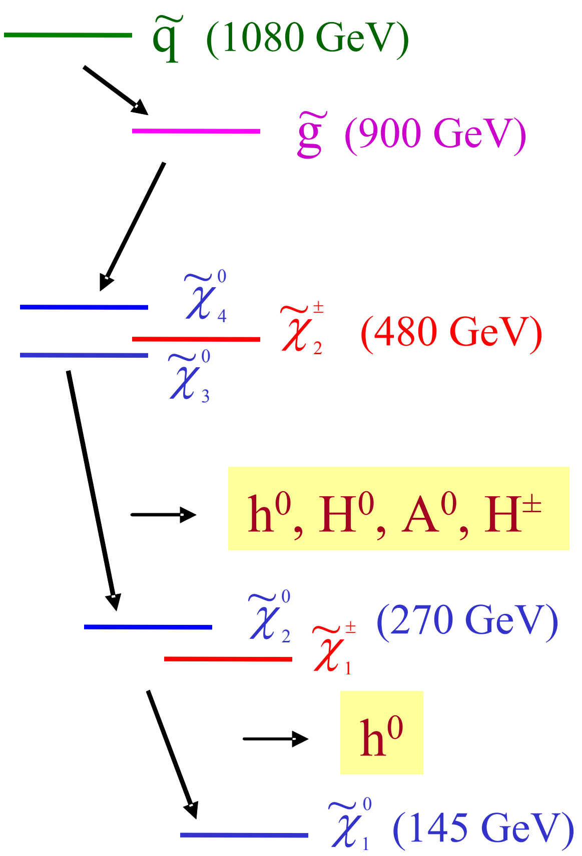


$$\xi^2 = \frac{\sigma(\mathrm{Hjj})}{\sigma(\mathrm{Hjj})_{\mathrm{SM}}} \times \mathrm{Br}(\mathrm{H} \rightarrow \mathrm{inv})$$

Cascade scenarios (I)

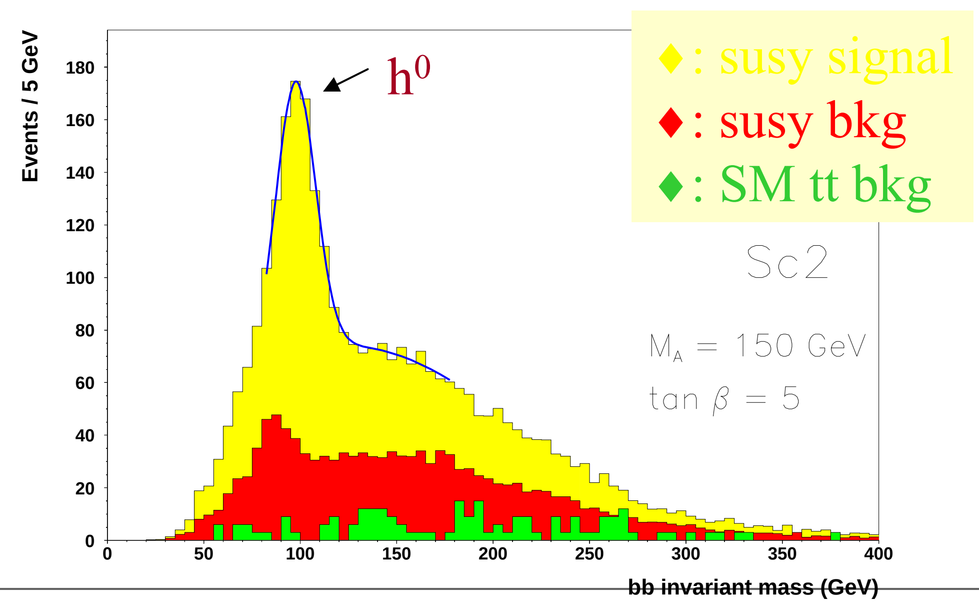
- **Little + big cascades**

$$\tilde{g} \rightarrow qq^{(')}\ \chi_3^0, \chi_4^0, \chi_2^\pm \rightarrow \chi_1^0, \chi_2^0, \chi_1^\pm\ A, H$$



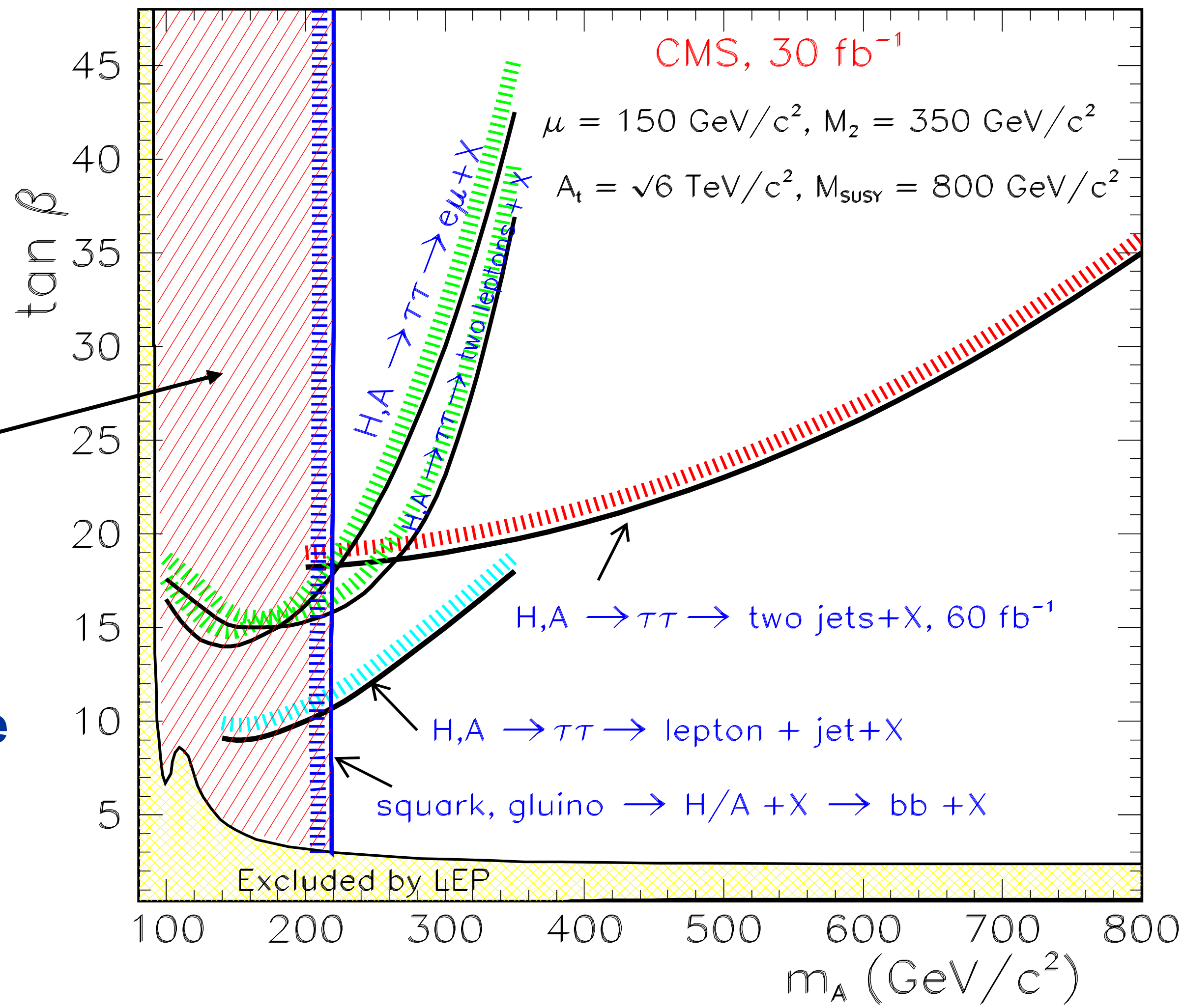
- At least 5 jets; One jet with E_T >300 GeV
- E_T^{miss} > 150 GeV
- Effective mass $E_T^{total} = \sum_{jets} E_T + E_T^{miss}$ >1.2TeV
- At least two *b*-tagged jets, with 45 GeV < E_T < 120 GeV

30 fb^{-1}



Discovery reach at $30 fb^{-1}$

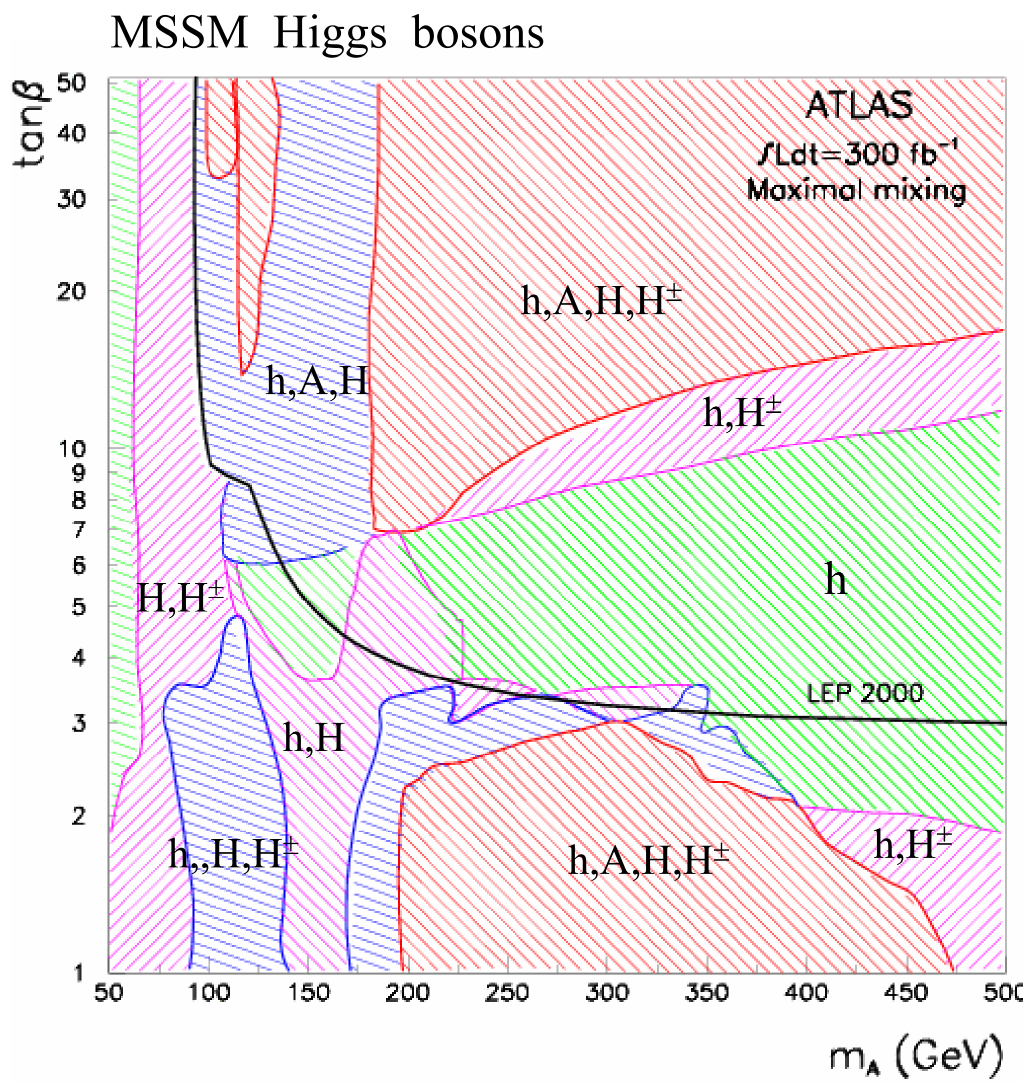
- **Recall: h^0 can be found in the entire plane**



region where H^0 and A^0 can be found in SUSY cascade decays

Scenario 3

Observability of MSSM Higgses



4 Higgs observable
3 Higgs observable
2 Higgs observable
1 Higgs observable

5σ contours

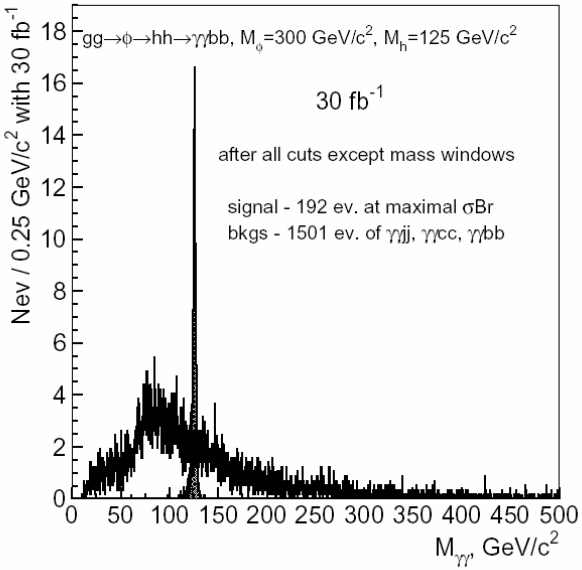
Assuming decays to SM particles only

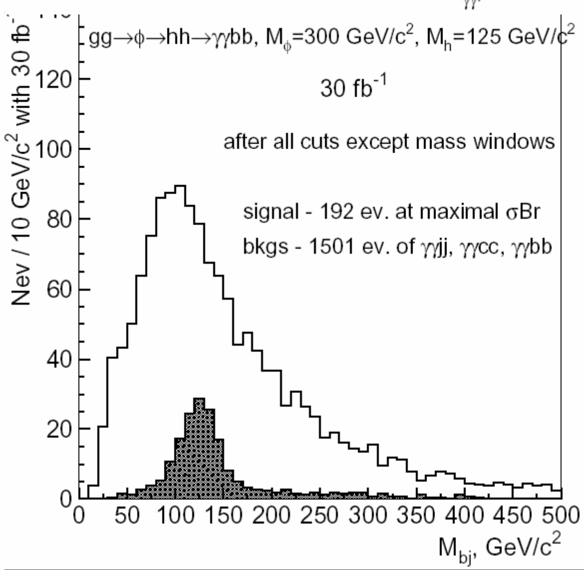
MSSM: Higgs summary

- **At least one ϕ will be found in the entire M_A-$\tan\beta$ plane**
  - latter (almost) entirely covered by the various signatures
  - Full exploration requires 100 fb^{-1} (design luminosity)
  - Difficult region: $3<\tan\beta<10$ and $120<M_A<220$; will need:
    - > 100 fb^{-1} and/or $h \to bb$ decays
    - Further improvements on τ identification?
  - Intermediate $\tan\beta$ region: difficult to disentangle SM and MSSM Higgses (only h is detectable)
- **Potential caveats (not favored)**
  - Sterile (or "invisible") Higgs
    - Excess visible, but it'll tough to "prove" what it is…

Extras

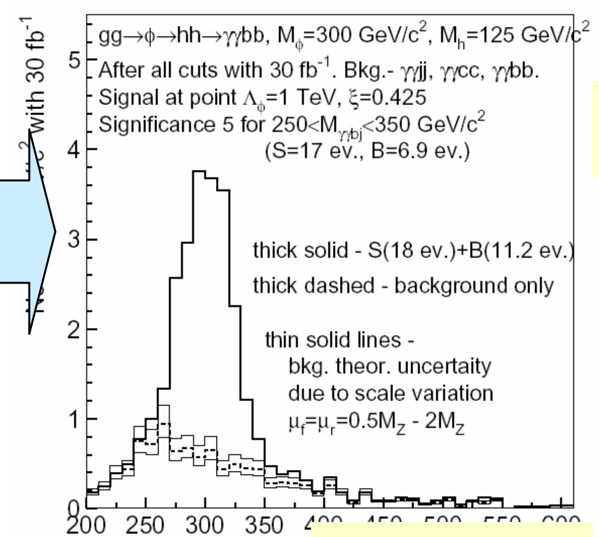
Radions… $\phi \to hh \to \gamma\gamma bb$





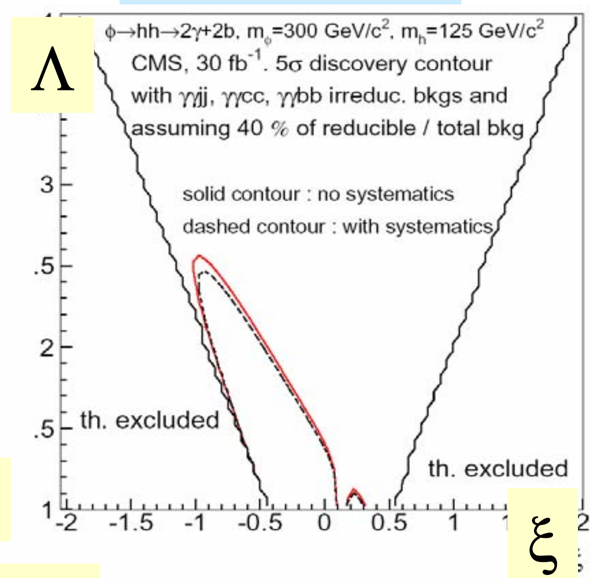
the field between the two (RS) branes

Di-photon selection + at least one b-jet
photon vertex from jets…



M(radion)

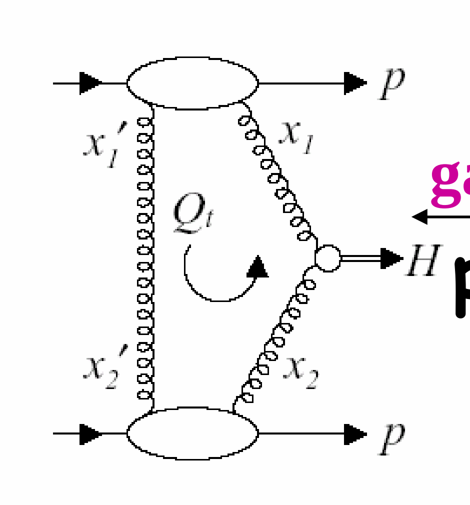
CMS, 30 fb^{-1}

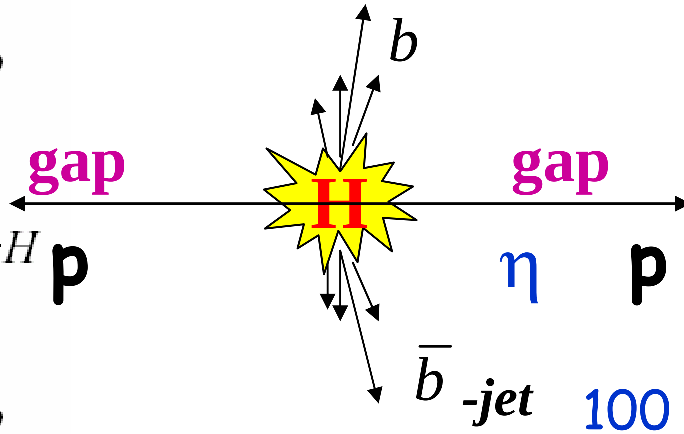


Also doable: $\phi \to hh \to \tau\tau bb$;
4b channel very difficult

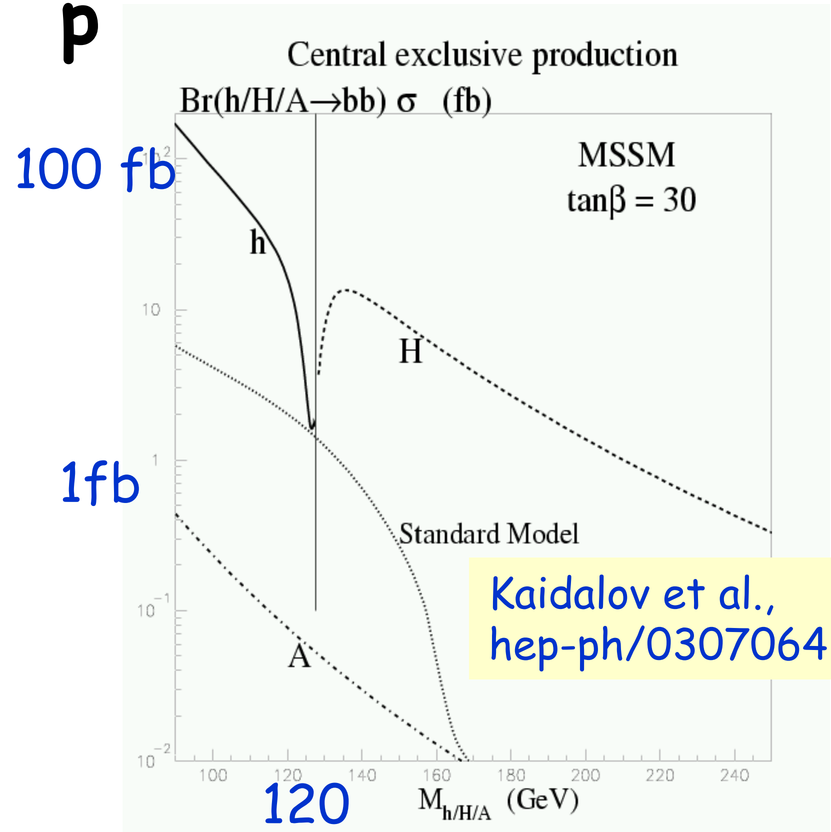
bkg systematics included

Diffractive Higgs production





SM Higgs: (30fb^{-1})
11 signal vs 12 bkg events
MSSM: σ ~ x10 larger (tanβ)



Exclusive production:

- **J_z=0 suppression of gg→bb bkg**
- **Higgs mass via missing mass**

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

$\Delta M = O(1.0 - 2.0)$ GeV

- **Of course, need Roman pots**

Other Higgs stories

- **CP-violating scenario**
  - Physical states mixture of CP eigenstates
  - Couplings depend on phases of complex parameters (e.g. X_t)
  - Huge effect on all previously shown plots/results
- **Benchmark scenarios "at the edge"**
  - X-phobic scenarios (gluo-phobic, fermio-phobic, etc)
    - But in general Y-friendly scenario helps
  - small-α_{eff} scenario
- **Higgs self-coupling**
  - At the limit with LHC++

Summary

- **Detectors designed for Higgs**
  - No surprise that they can cover full spectrum of Standard-Model Higgs masses within ~1 year of start of physics collisions
  - Higgs properties should be largely measureable
  - SUSY extensions: light, SM-like h is always accessible
  - Depending on parameters, all five SUSY Higgses can be observed
    - Beware of CP violation; Higgses with phobias; etc.
  - If fundamental scalar is actually not adopted by nature: strong excess is observable (albeit with low-statistics to make elphatic comments) at full luminosity
- **Higgs engineering – progress:**
  - Vector boson fusion is very useful
  - Multi-body decays can be useful
- **We need data**