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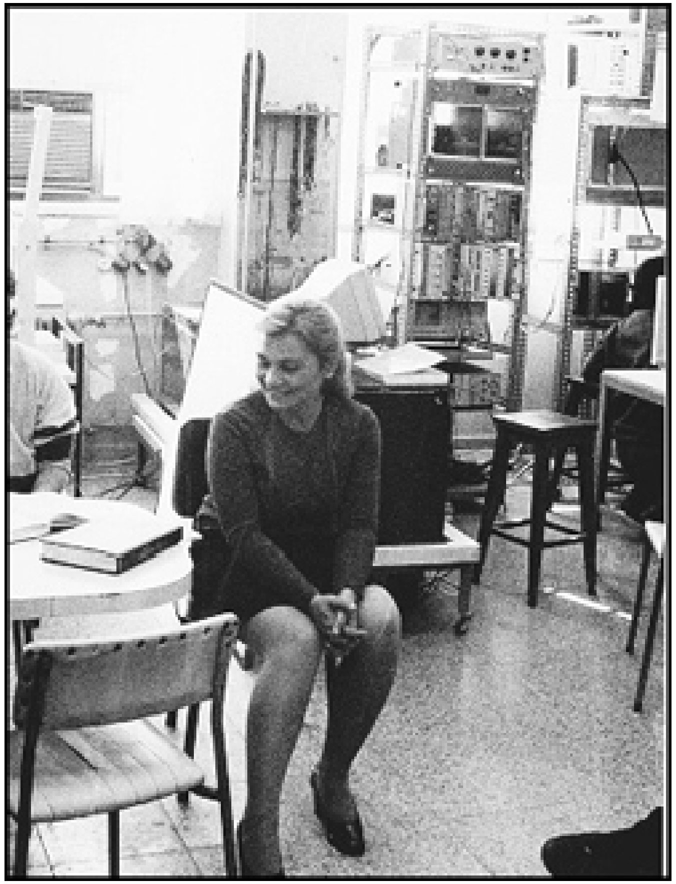
Higgs Boson Searches @ LHC

Dedicated to Engin



Beware:

More relevant details will be given in the talks by:

R.Mazini: VBF H->ττ

S.Gentile: MSSM neutral H searches

J.F.Marchand: H->γγ in ATLAS

V.Maleev: Electron and γ identification in ATLAS

E.Moyse : μ identification in ATLAS

G.Gorfine: b tagging in ATLAS

Limits on SM Higgs (1)

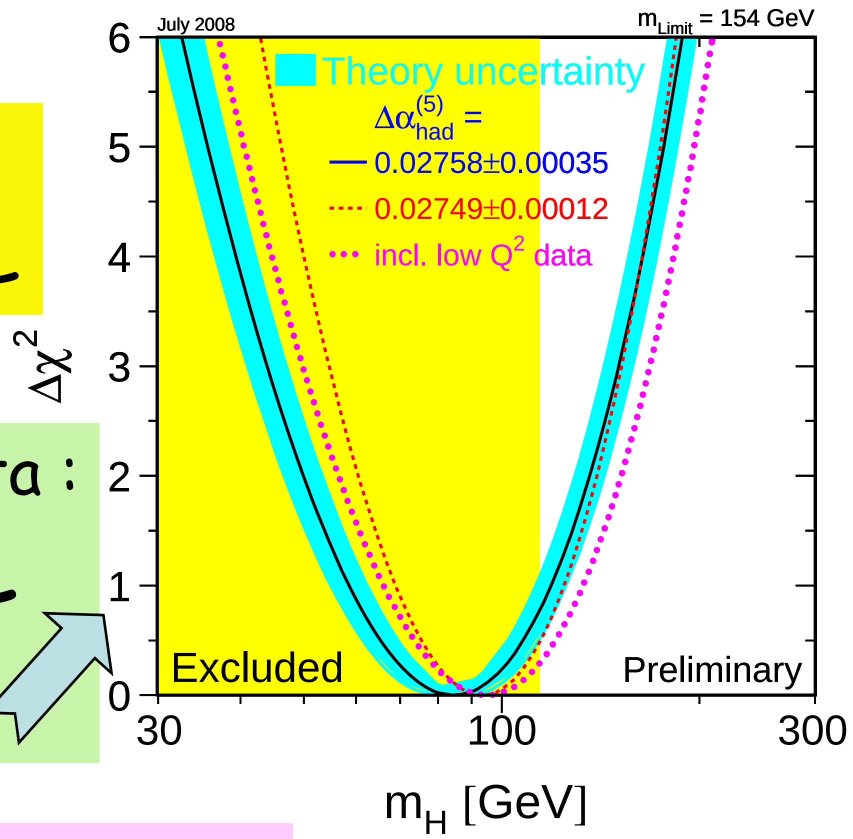
- Direct from LEP :

$m_H > 114.4$ GeV @95% CL

- Indirect from EW precision data :

$m_H < 154$ GeV @95% CL

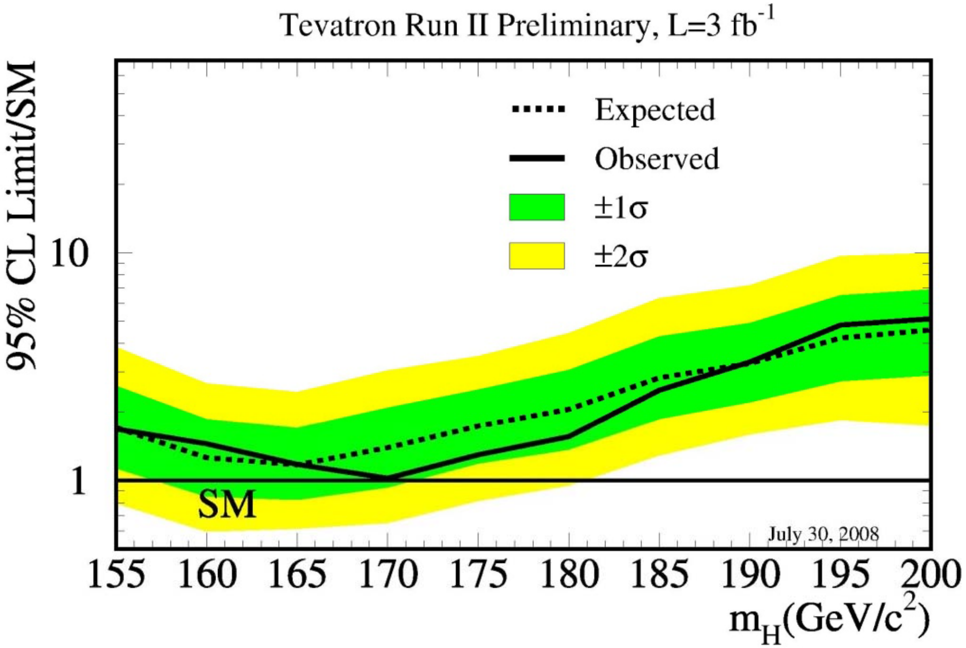
(July 2008)

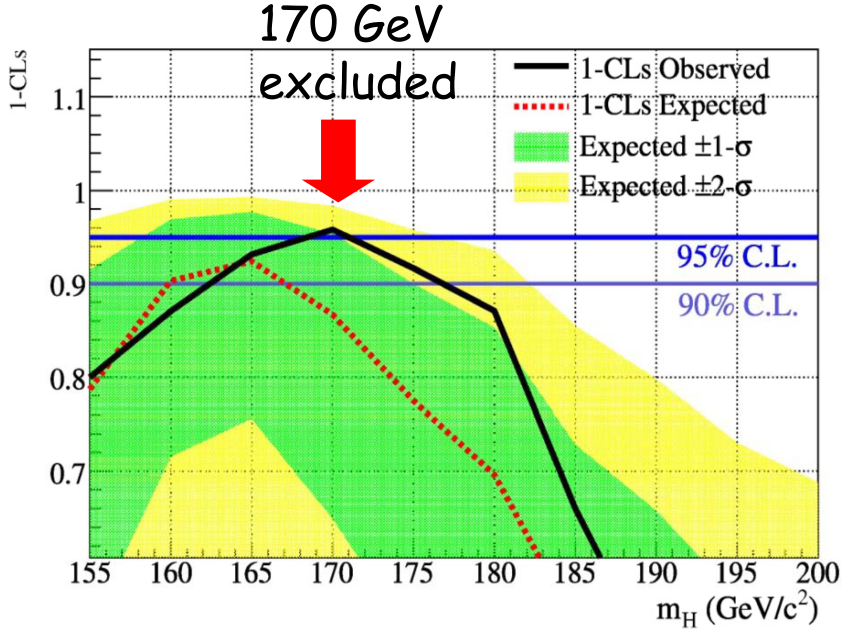


- $m_H < 185$ GeV @95% CL including direct LEP limit

Limits on SM Higgs (2)

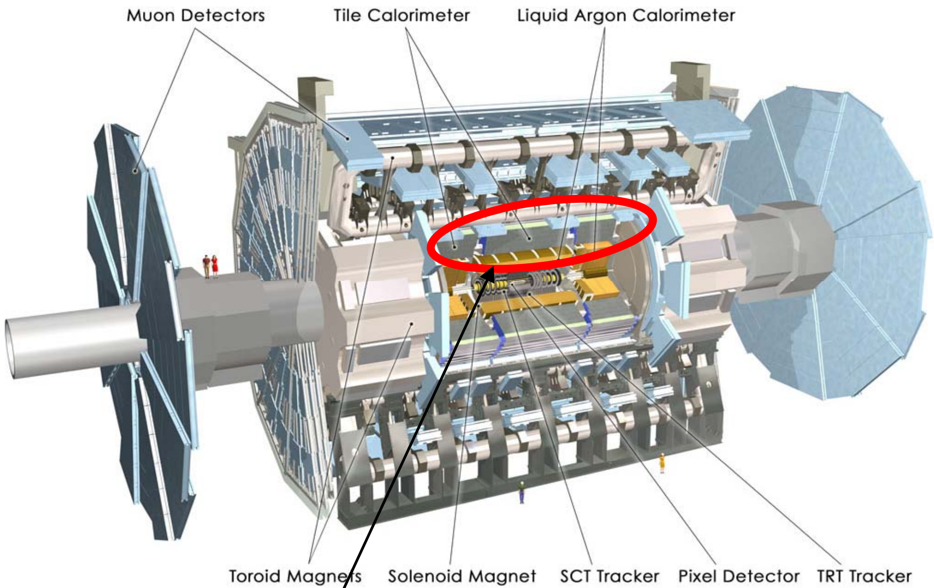
- From the Tevatron
  $5fb^{-1}$ delivered luminosity/exp
  but combined results with $3fb^{-1}$

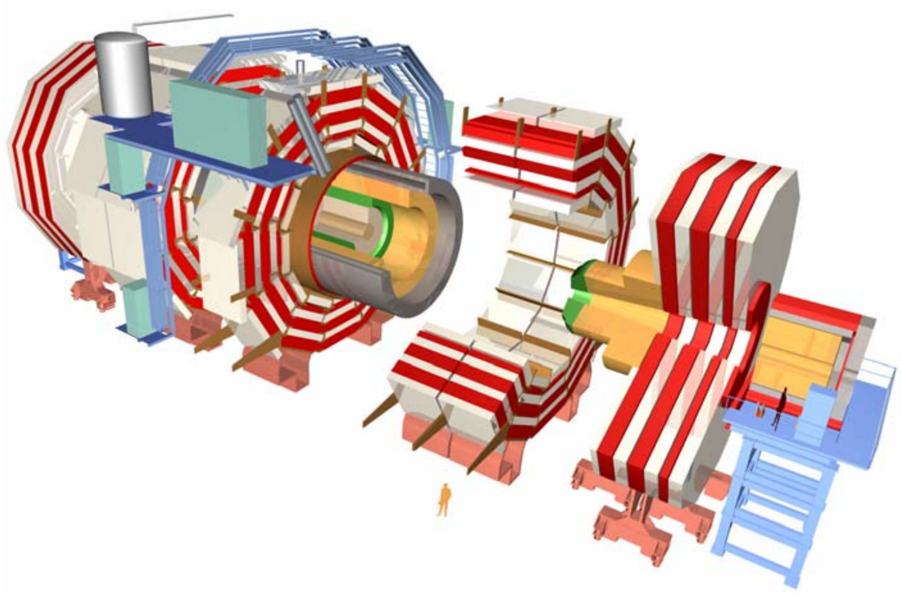




M_H at 165 (GeV) observed 95% CL limit/SM =1.2 (expected 1.2)

Searches of the Higgs @LHC
ATLAS and CMS





112 Muon chambers constructed by 3 Greek groups

Please note:

All new ATLAS figures from ATLAS "CSC notes":

ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.

Older plots from: ATLAS Physics TDR, CERN-LHCC/99-15 (1999).

Most CMS figures from:

"CMS Physics Technical Design Report Volume II: Physics Performance," CERN/LHCC 2006-021 **CMS TDR** 8.2

New plots from:

CMS PAS HIG-08-001 and CMS NOTE 2007/011

LHC machine scenario: ??

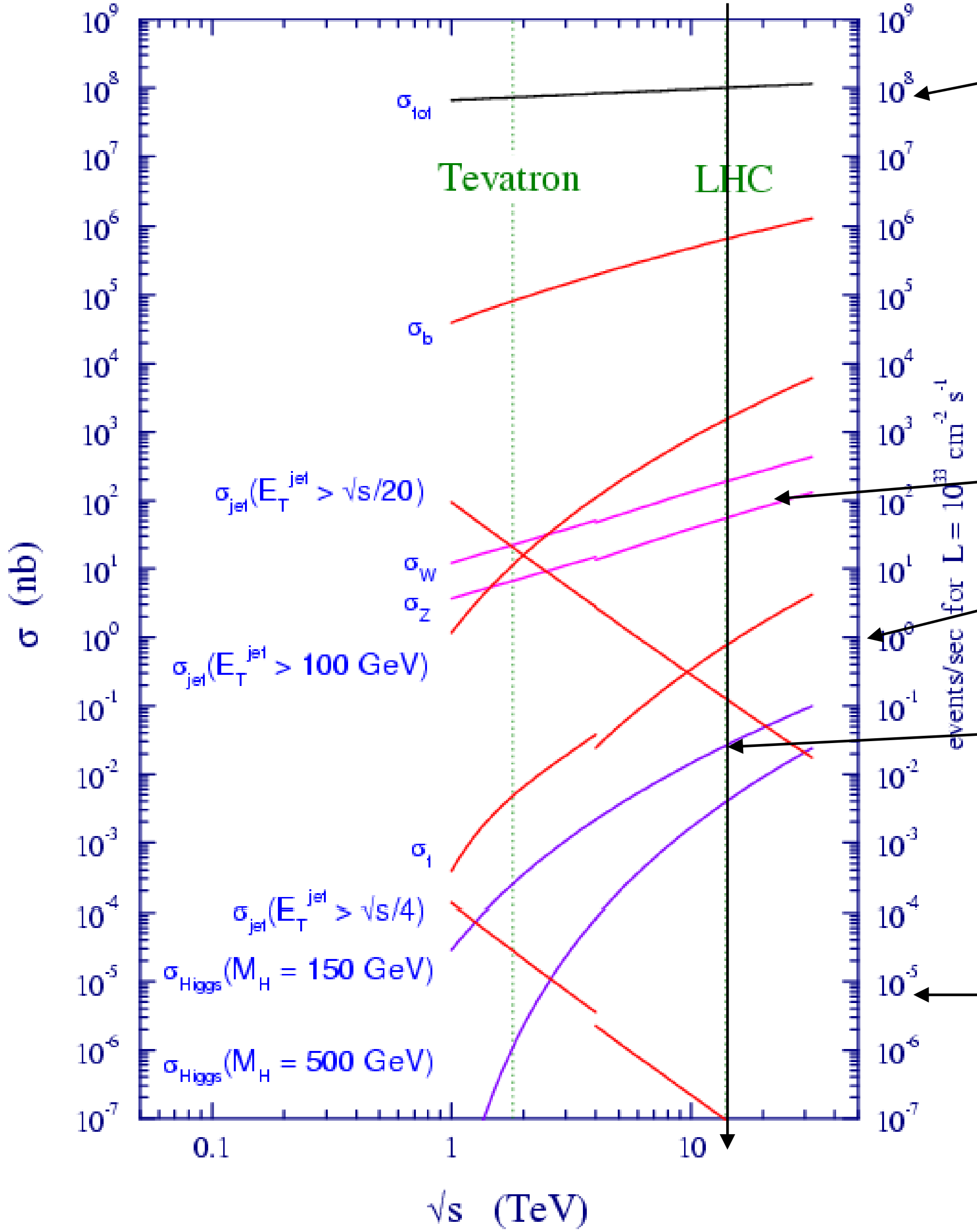
- May 2009
- Energy ??
- Luminosity ??

Initial run

Assume: 10 pb^{-1} /month @$10^{30}cm^{-2}sec^{-1}$

Assume: $6*10^6$ sec/year (duty factor 20%)

pp cross-sections



10^8 events/sec

Higgs low x-section: $\sigma_{bb}/\sigma_H \sim 2*10^7$!!!

W,Z

1 event/sec

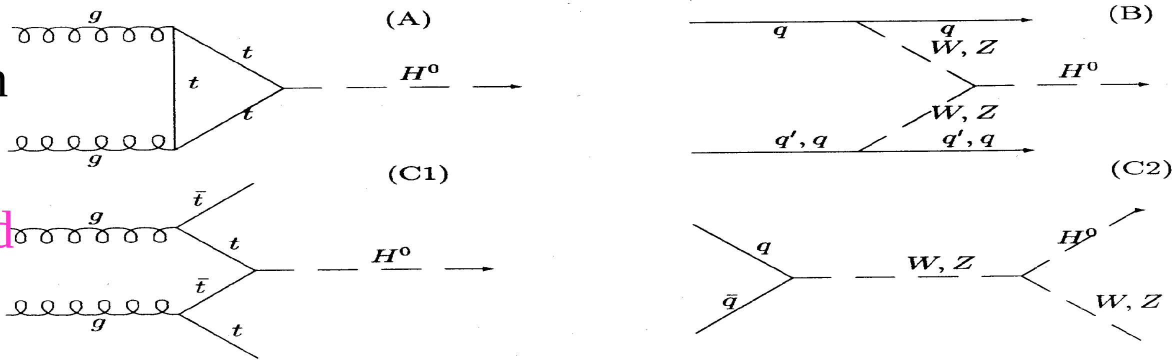
Higgs 150 GeV

10^{-5} events/sec

SM Higgs at the LHC
(several production/decay channels)

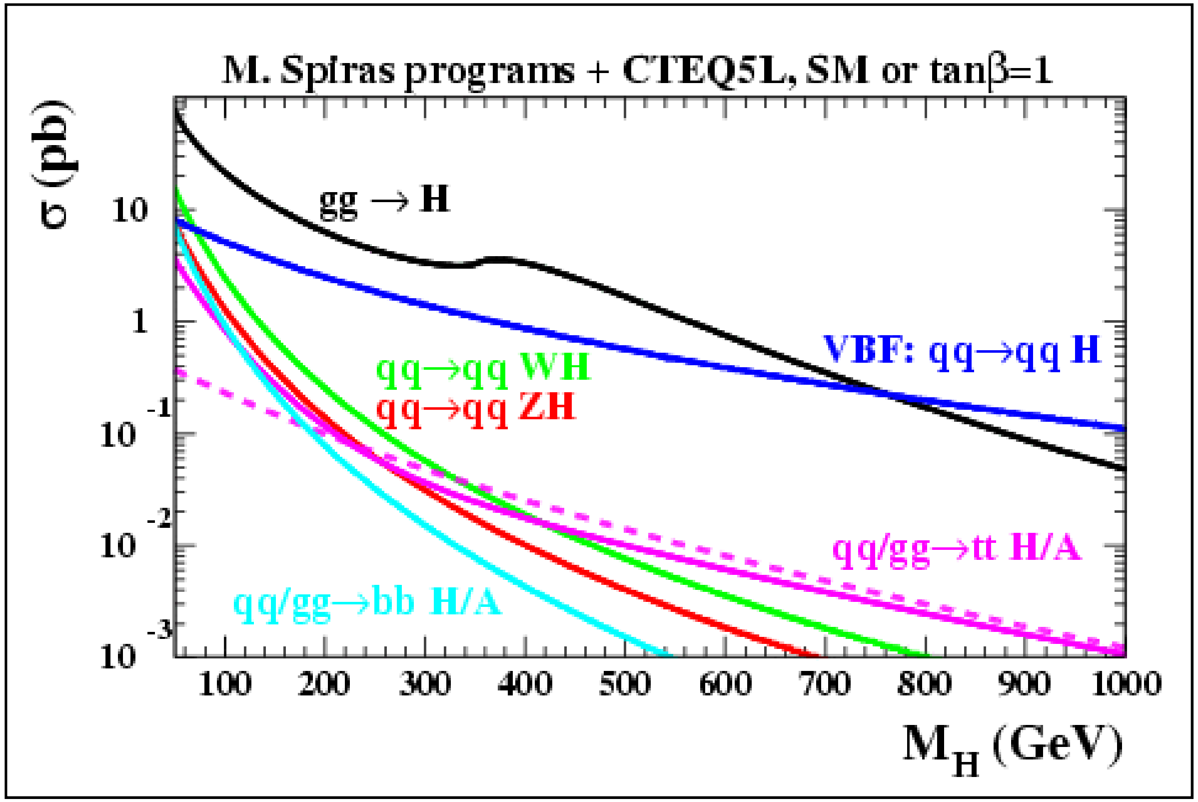
gg fusion

associated $t\bar{t}H$



VBF WW/ZZ fusion

associated WH, ZH



SM Higgs at the LHC
Theoretical progress

(see ex. M.Grazzini, Split 2008)

A lot of work went on during the recent years to improve on x-sections (calculate NLO and NNLO diagrams) for both signal and backgrounds (NLO).

Uncertainties on x-sections:

- gg 10%(NNLO) k~2.0 ⟸ DOMINANT!!
- VBF (WW/ZZ fusion) ~ 5%(NLO) k~1.1
- WH, ZH ~ <5% (NNLO) k~1.4
- ttH associated 10-20 % (NLO) k~1.2

Uncertainties on the decay branching ratios :

Known to few % (NLO)

Cannot cover all channels
will give some examples with the following channels:

- $H \to \gamma\gamma$ "benchmark" → talk
- $t\bar{t}H$, $H \to b\bar{b}$ (exclusive)
- qqH, $H \to \tau\tau$ VBF (exclusive) → talk
- $H \to ZZ^{(*)}$, $Z \to 4\ell$ **Golden discovery channel**
- qqH, $H \to WW^{(*)}$ VBF (exclusive)
- $H \to WW^{(*)} \to ll\nu\nu$
- MSSM H → talk

Low mass Higgs

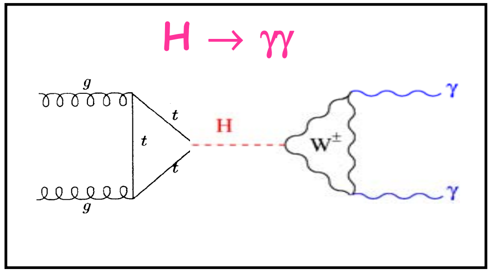
Nothing about :
Invisible Higgs
Non SUSY models and little Higgs
etc

LOW MASS

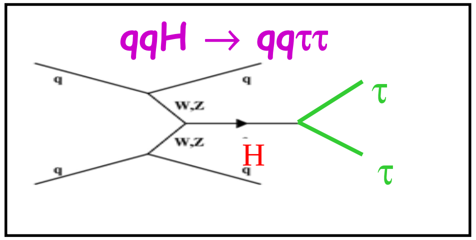
- For the mass range m_H ~ **115-130 GeV**
- Have to combine **FEW** discovery channels
- Best : **H→ γγ**

But need : excellent calorimetry +
σ/m <1% +jet rejection 10^3 @80% eff

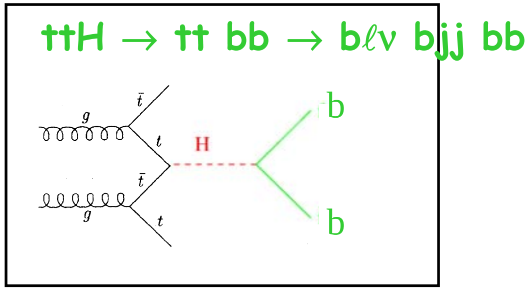
BR~10^{-3}



qqH → qqττ VBF : jets over |η| < 5
forward jet tag + central jet veto for τ ID

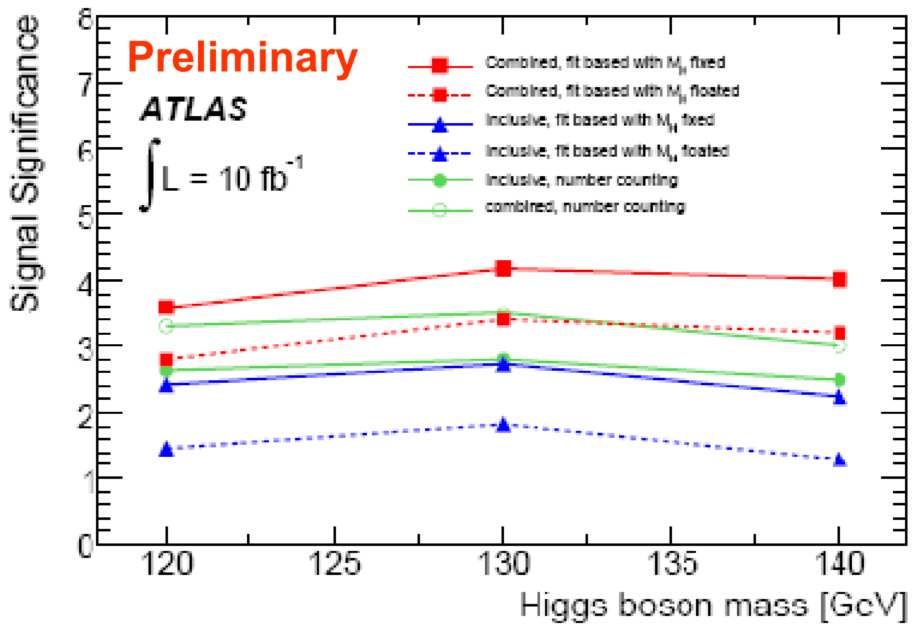


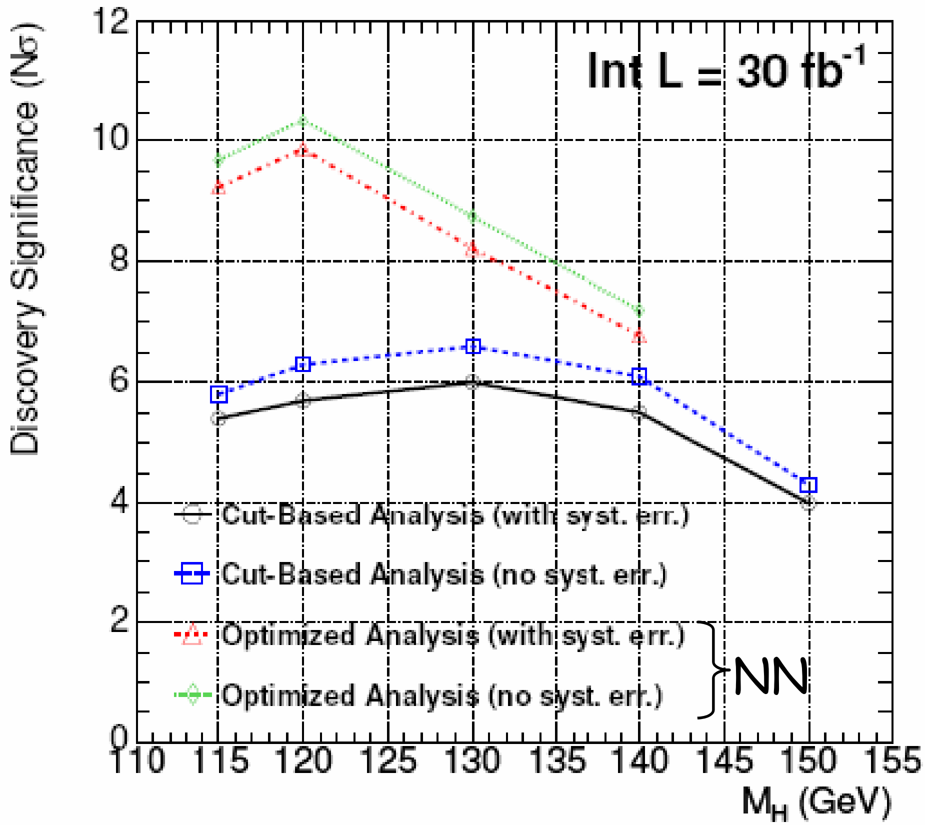
ttH (WH,ZH) with H → bb (b-tagging, 4 b jets)
hadronic transverse mass resolution
DIFFICULT.



H ⇨ γγ for $m_H \leq 150$ GeV

Note: different luminosities



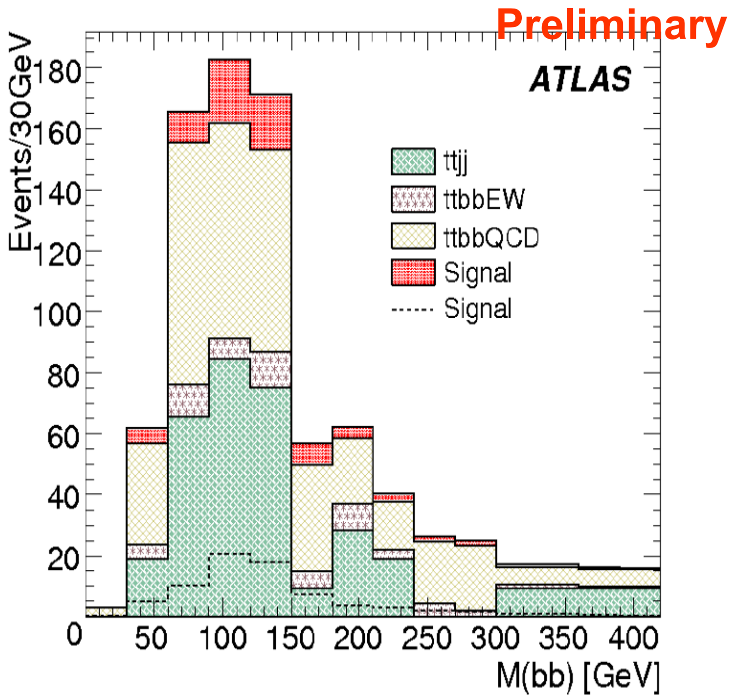


Recent developments:

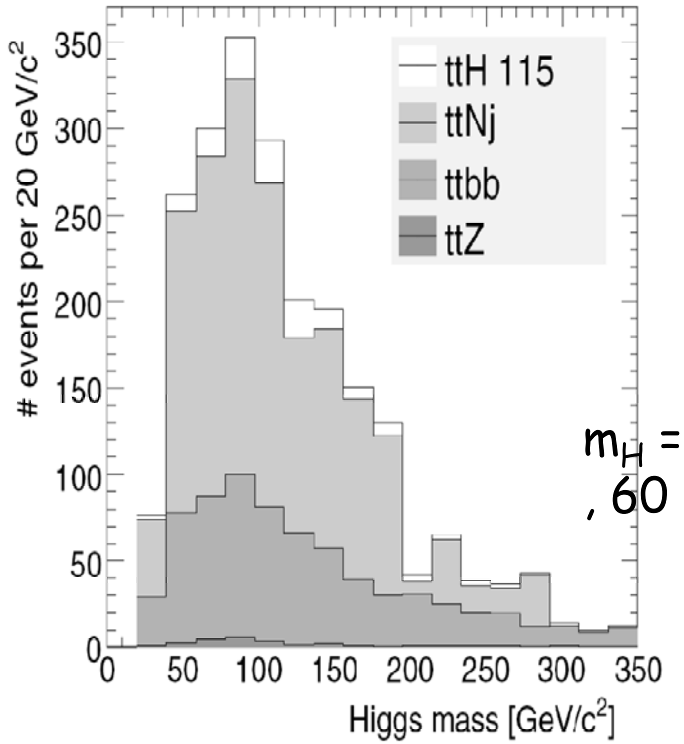
- Irreducible diphoton background computed to NLO -> improvement of significance
- Analysis using discriminant variables,,optimized analysis, shape of kinematical variables
- Significant calculations with both fixed and floating Higgs boson mass hypotheses

H→ttH, H→bb, t → l

Very hard !! (6 jets or more)
NLO, x-section increased by 20%
but full detector +better background → more pessimistic result



m_H = 120 GeV, 30 fb^{-1}
Constrained fit

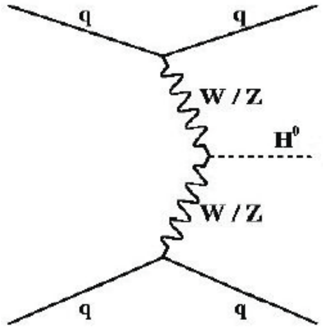


CMS

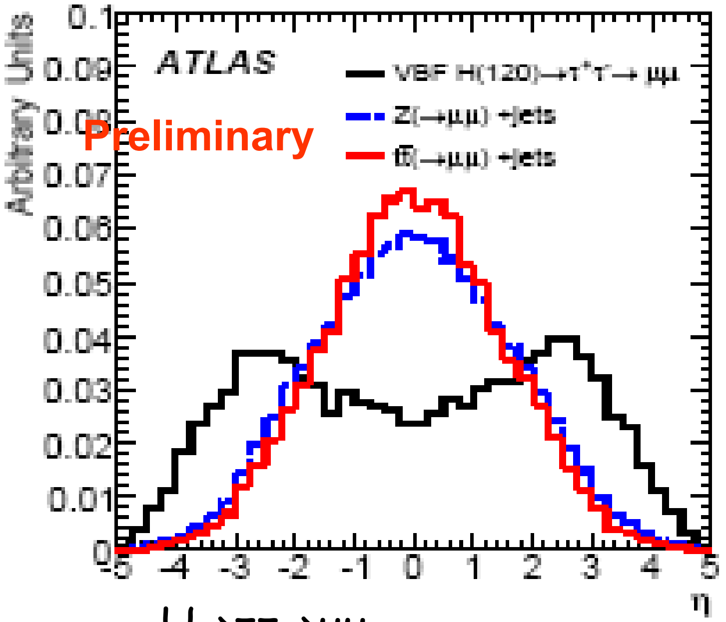
m_H = 115 GeV, 60 fb^{-1}

VBF channels qqH →**qqττ** (**or** qqH →**qqWW)**

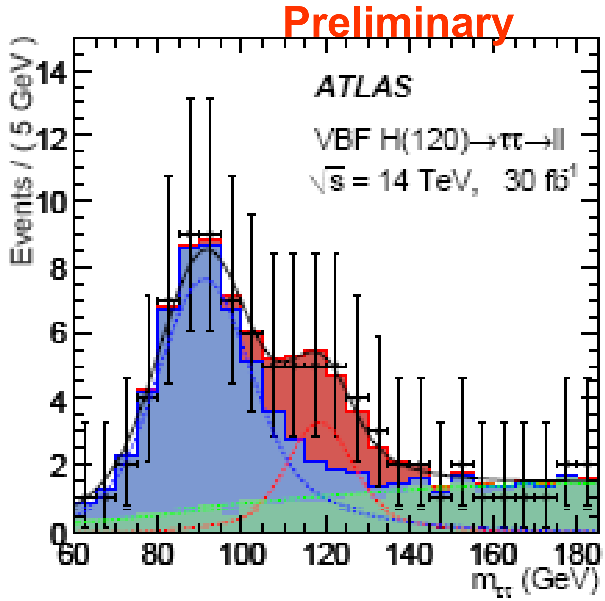
- qq jets go in the forward region
- No central jet (colourless exchange)
- At least one τ/W → leptons
- Irreducible bkg qqW/Z



- Important for low masses
- x-section is about 20% of gg



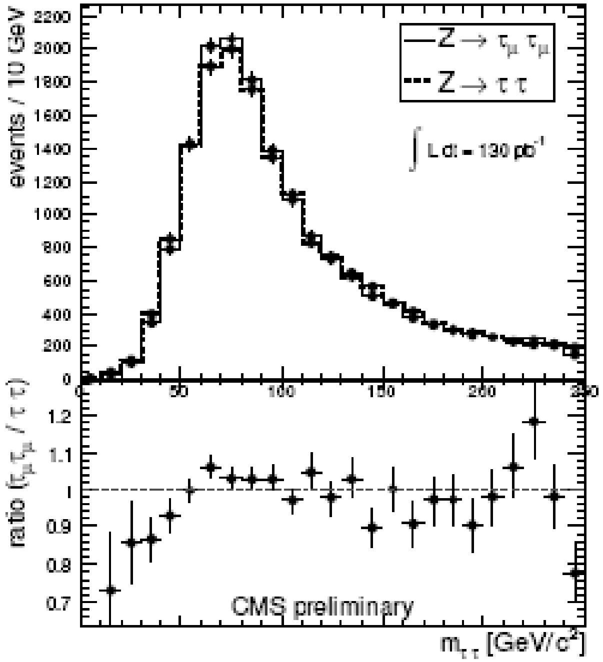
H->ττ->μμ
η of highest pT muon

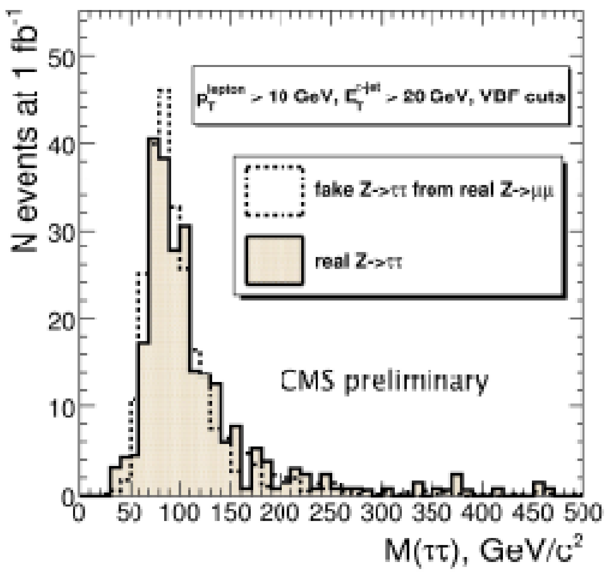


Signal+bkg fit

VBF channels qqH →**qqττ (2)**

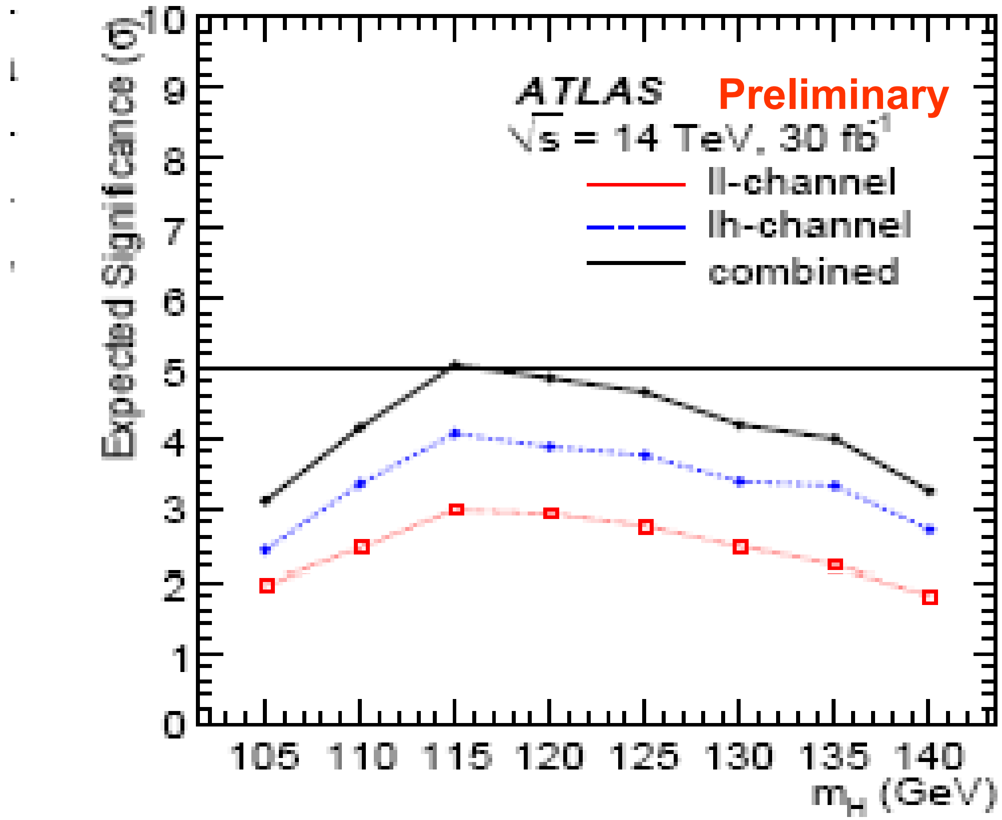
CMS new analysis method : new veto, different di-τ mass reconstruction, "data driven" background modelling using Z->μμ data, new fake electron rejection, new Z+jets background estimation



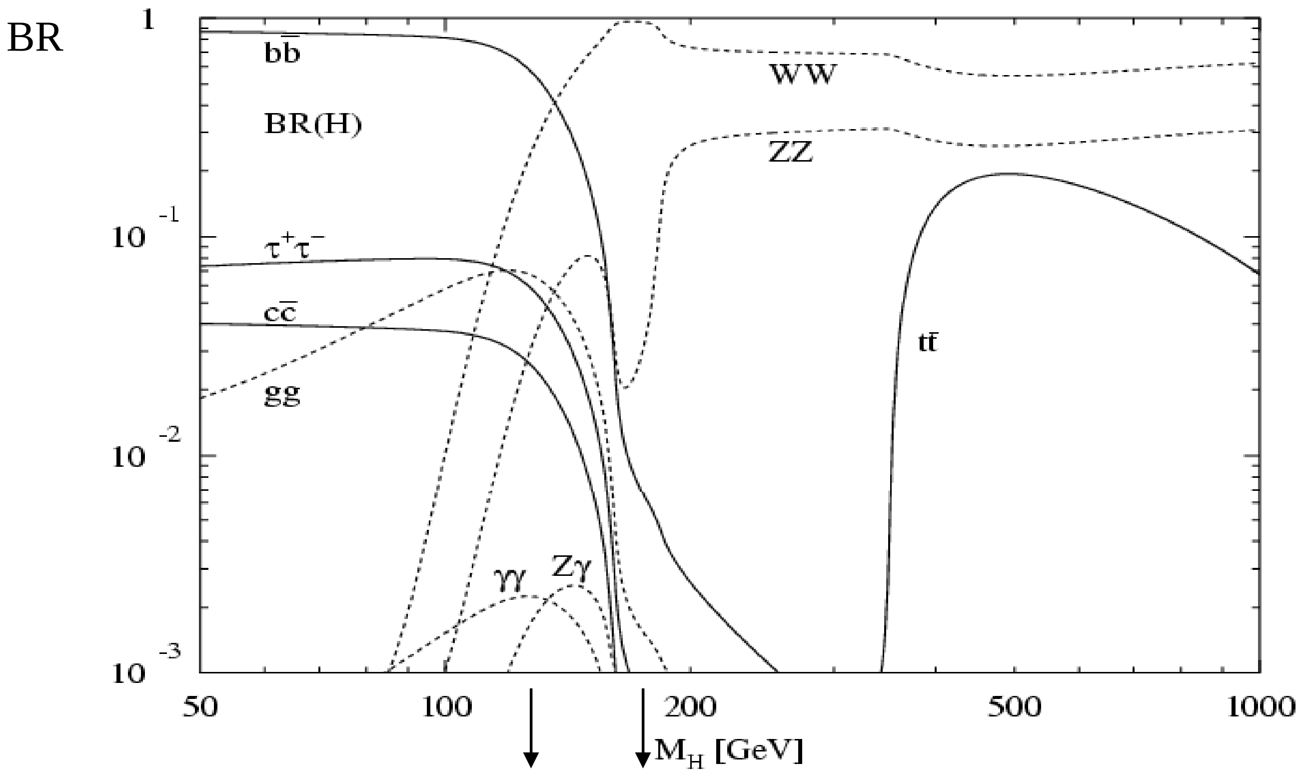


L~ 2 × 10^{33}cm^{-2}s^{-1} used, pile-up events (4.3 events per crossing) are included in the simulation

VBF channels qqH →**qqττ (3): significances**



No pile-up
hh channel not included ->bkg from data



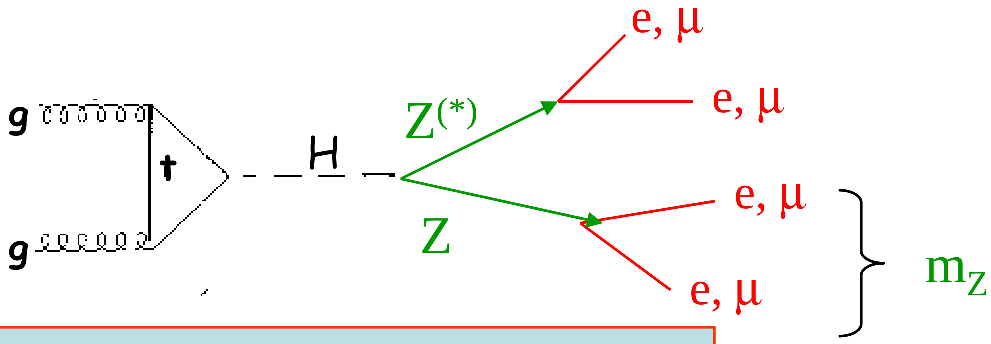
SM Higgs Decay channels
(A.Djouadi et al)

INTERMEDIATE MASS

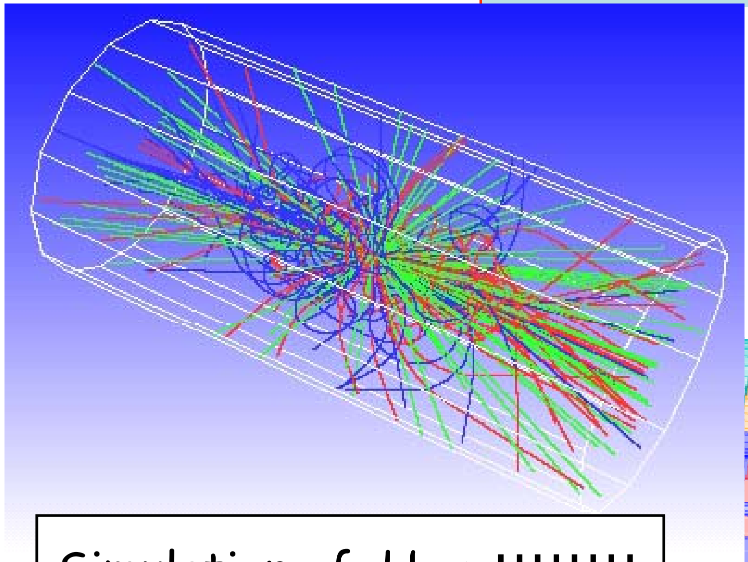
- For the mass range $130 < m_H < 180$GeV, the Higgs decays to:
  - $H \to ZZ^* \to 4l$ (clean signature and rather low background)
  - $H \to W W^* \to ll\, \nu\, \nu$ (E_{Tmiss},, no mass peak)
  - $qqH \to qq\tau\tau$ (ll+ l-had)

$H \to ZZ^{(*)} \to 4$ leptons

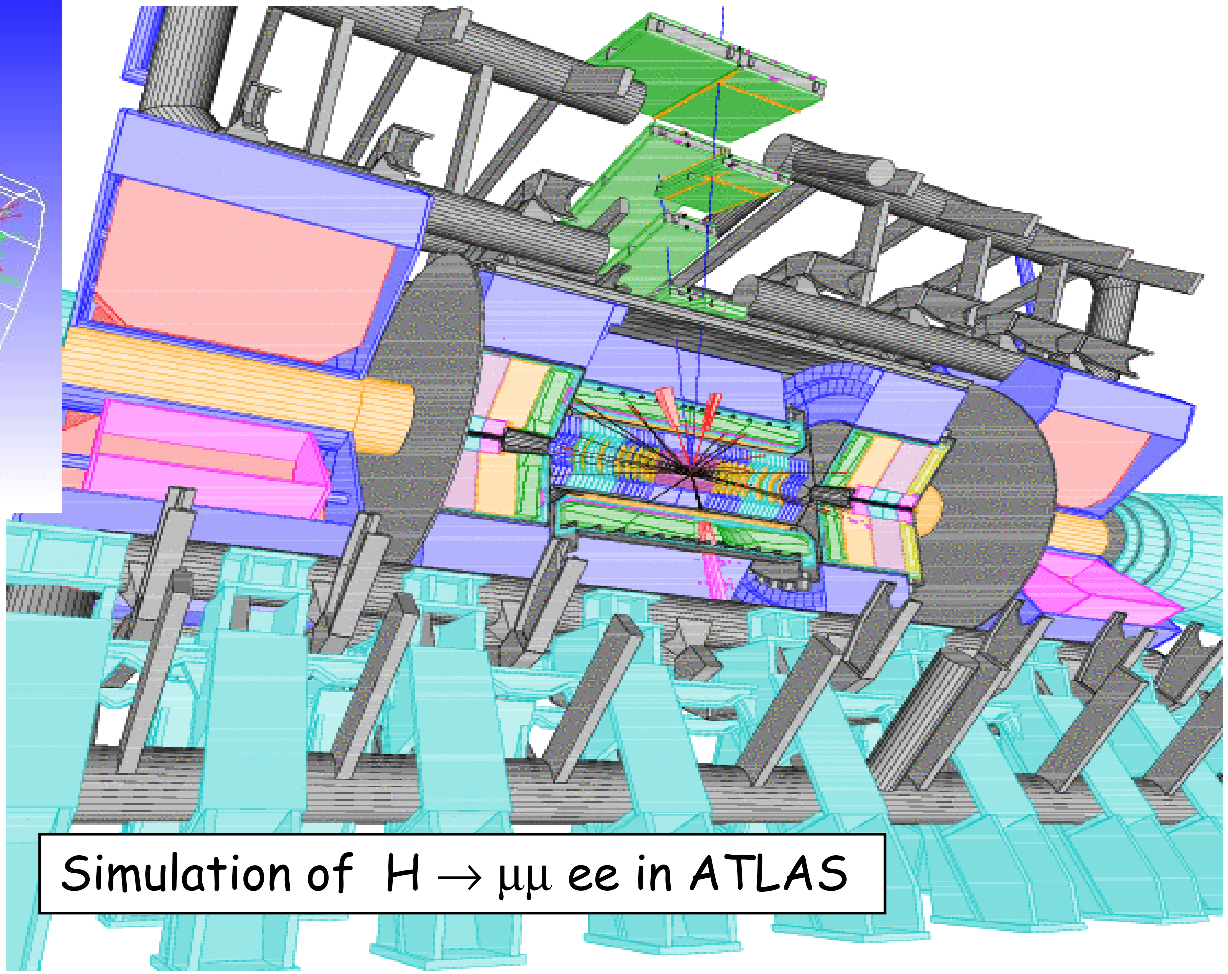
$130 < m_H < 160$ GeV,
$2m_Z < m_H < 550$ GeV



"golden channel" for the Higgs discovery at LHC



Simulation of $H \to \mu\mu\mu\mu$

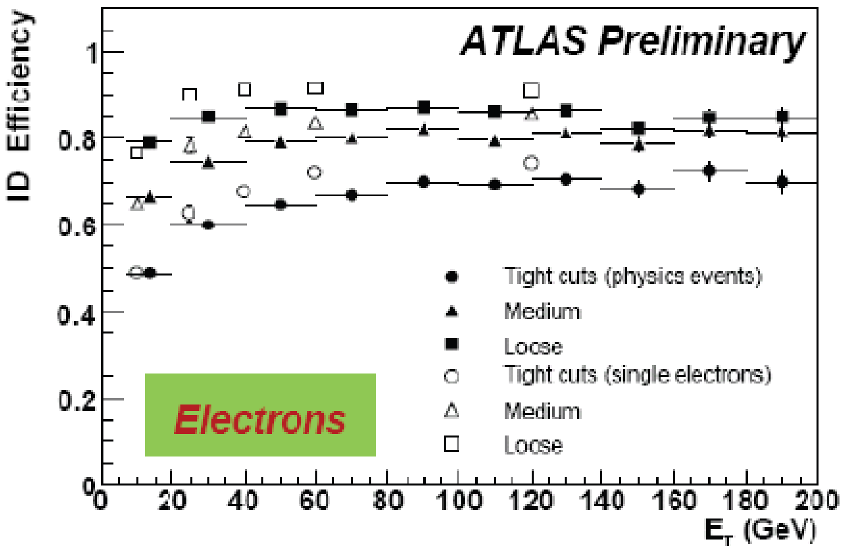


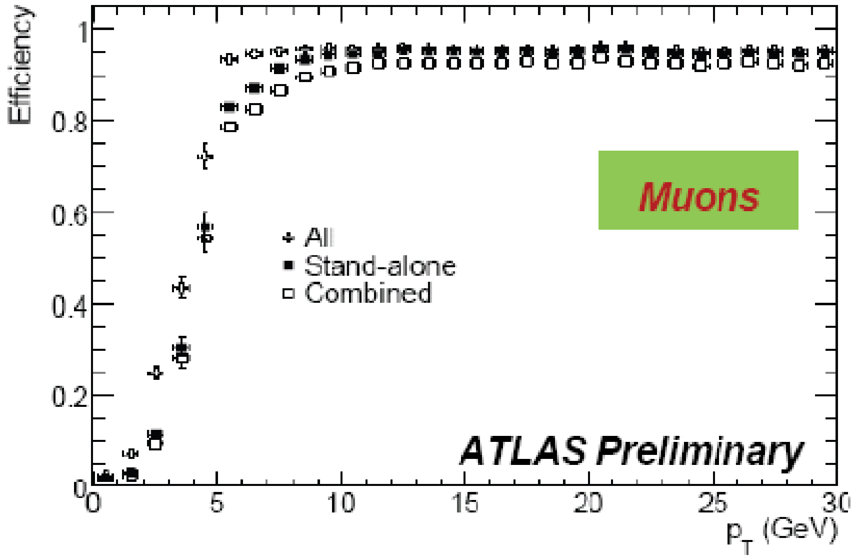
Simulation of $H \to \mu\mu$ ee in ATLAS

Signal+background known to NLO

11/3/2008

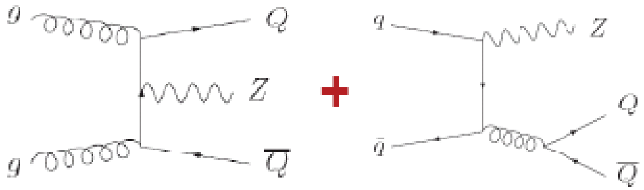
4 lepton final state ⟹ (single lepton efficiency)^4





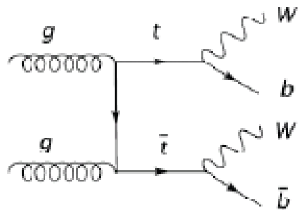
Backgrounds: reducible + irreducible

Zbb→4leptons

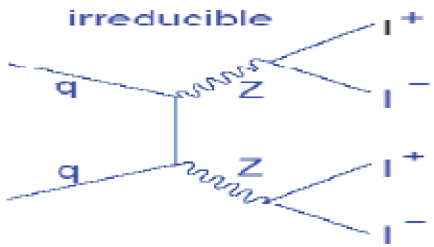


~15% of gg→Zbb

tt→W$^+$bW$^-$b → 4leptons

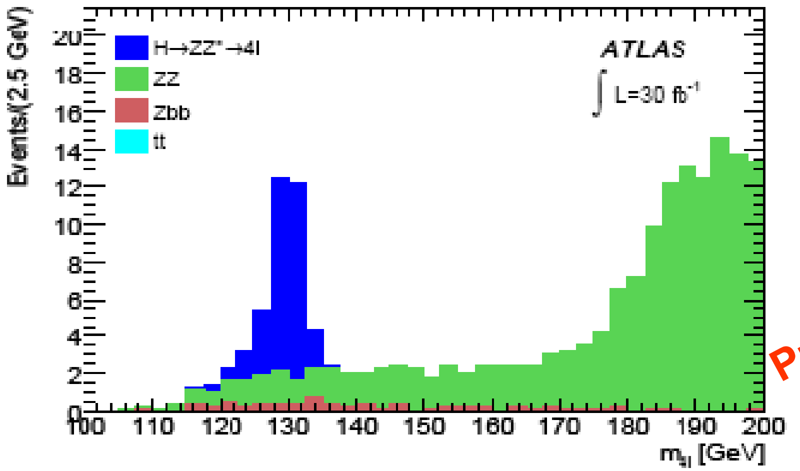


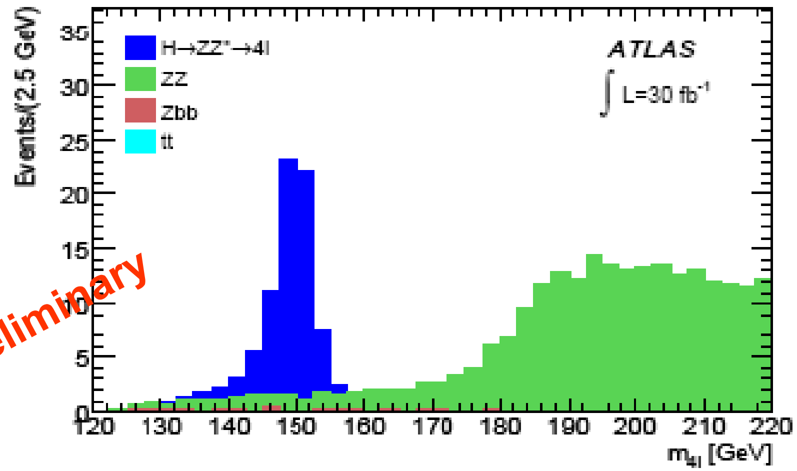
ZZ*/γ →4leptons

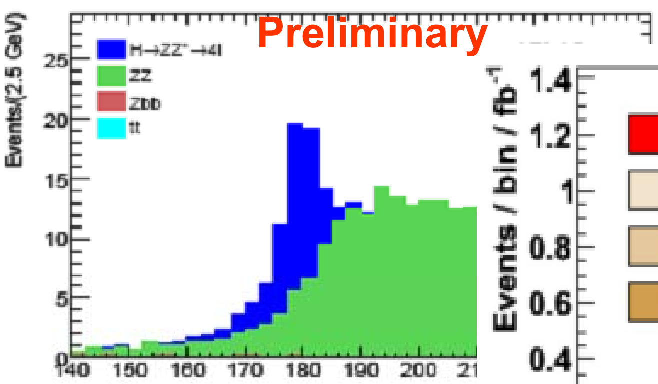


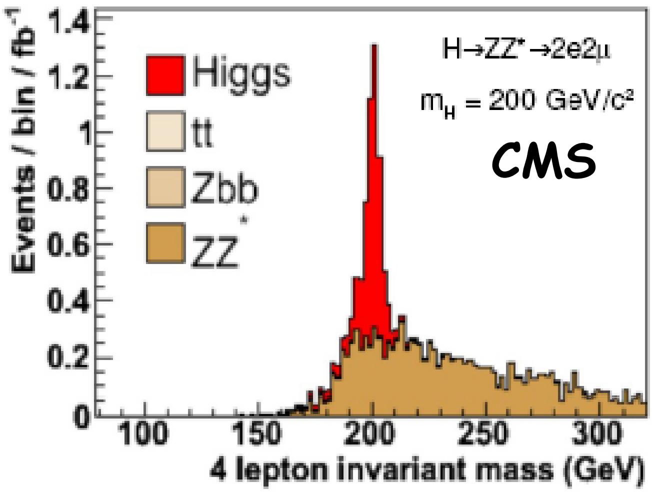
Background rejection: lepton isolation + impact parameter

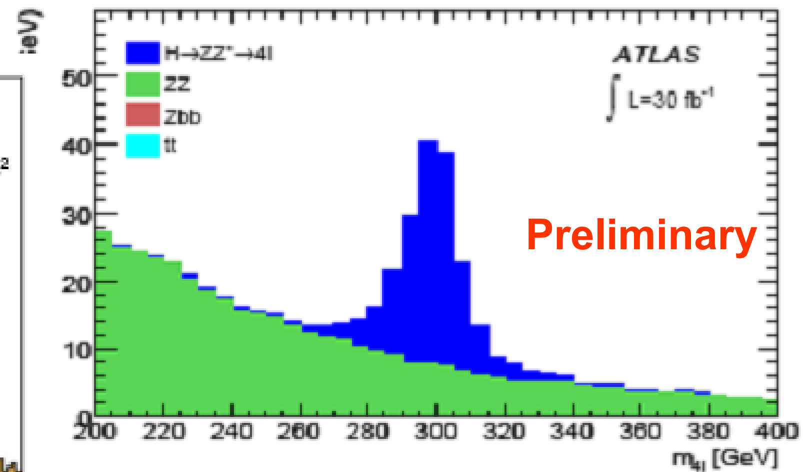
ATLAS mass plots @ 30fb^{-1} and different masses (130,150,180,300 GeV)





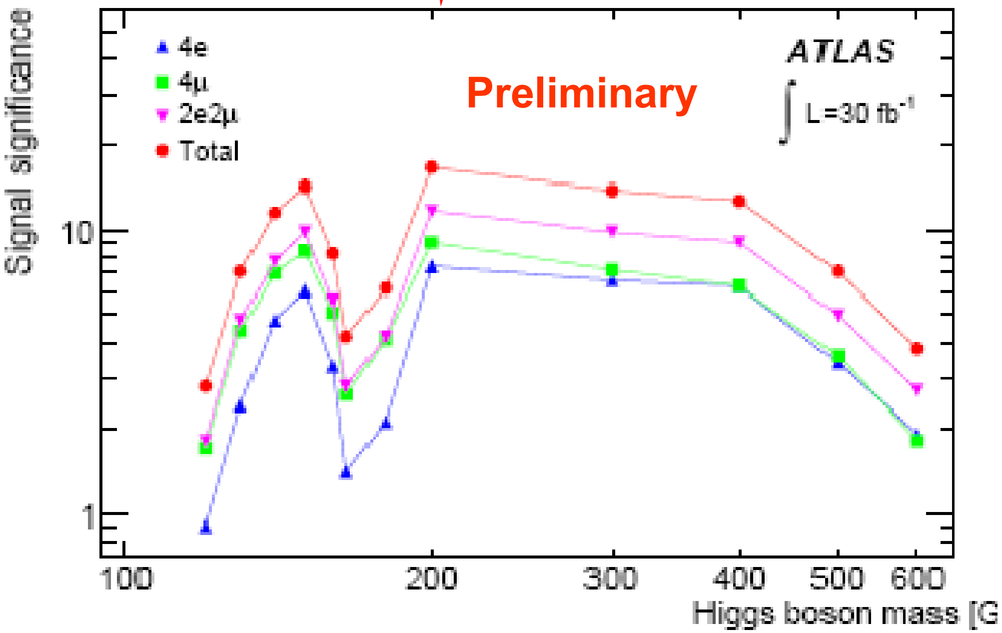


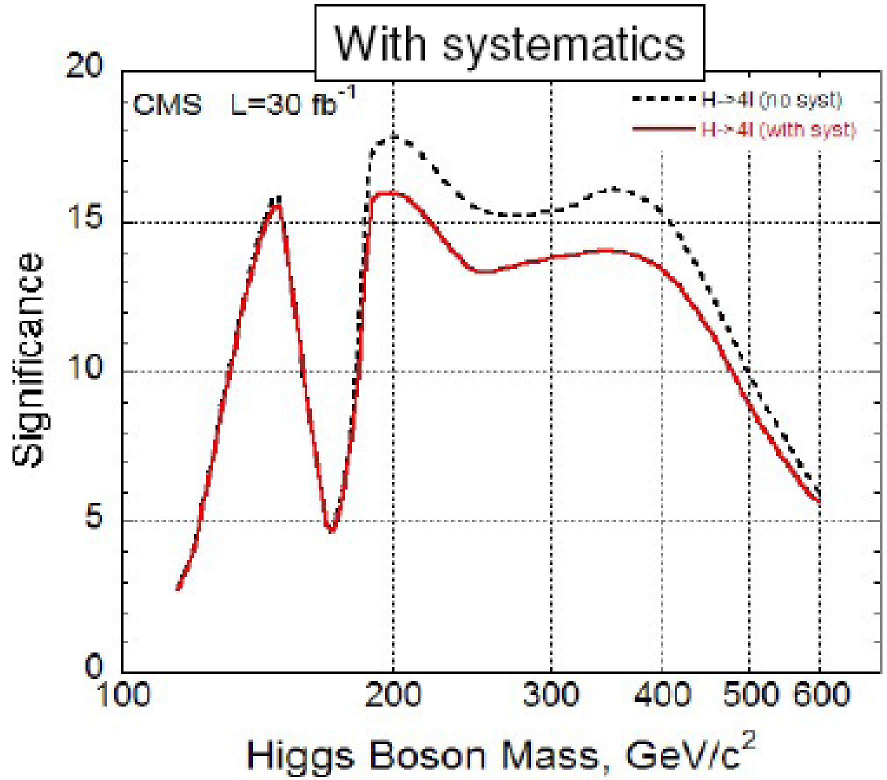




$H \rightarrow ZZ^{(*)} \rightarrow$ 4 leptons : significances

New

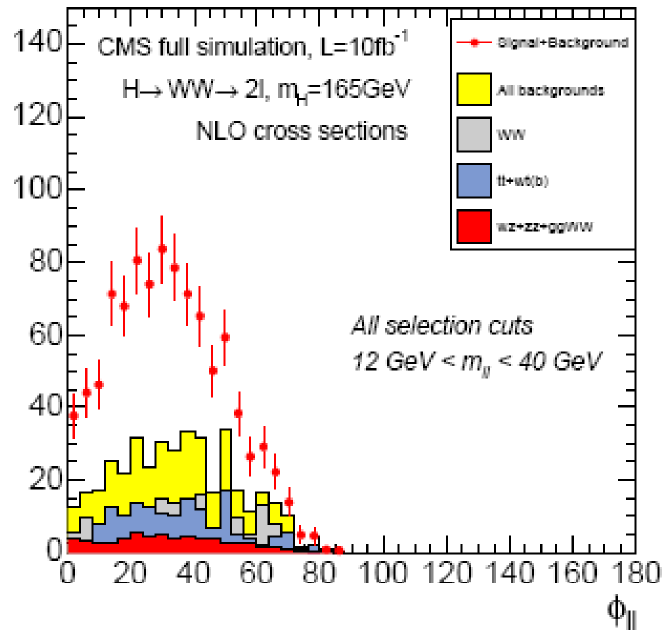




D. Trocino, 2008 Split

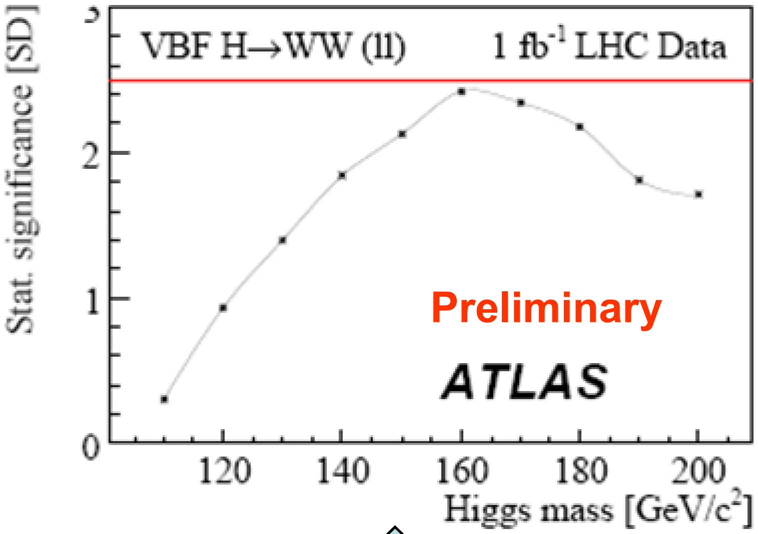
$H \rightarrow WW \rightarrow l^+ \nu l^- \nu$

Important channel for
m_H~160 GeV ($H \rightarrow WW$ BR ~ 95%)
BUT
- No mass peak
- Need exact knowledge of background shape

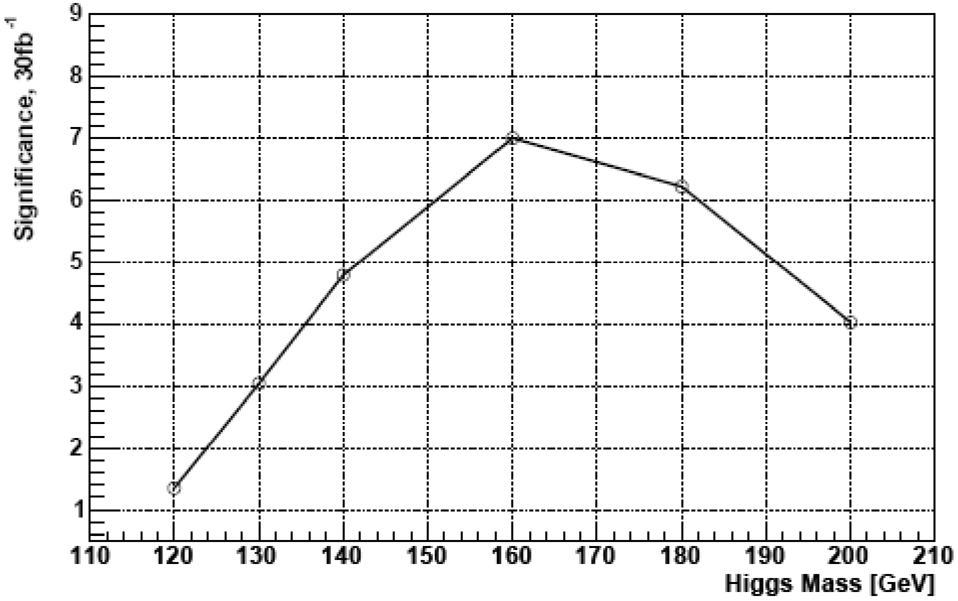


Backgrounds:
tt, tWb : rejected by jet-veto
WW,WZ, ZZ: rejected by kinematical cuts
Recently:
$gg \rightarrow WW$ contribution
tt, single top@NLO

Extra sensitivity by adding exclusive VBF →WW



Significance using a 5-dim fit on kinematical variables

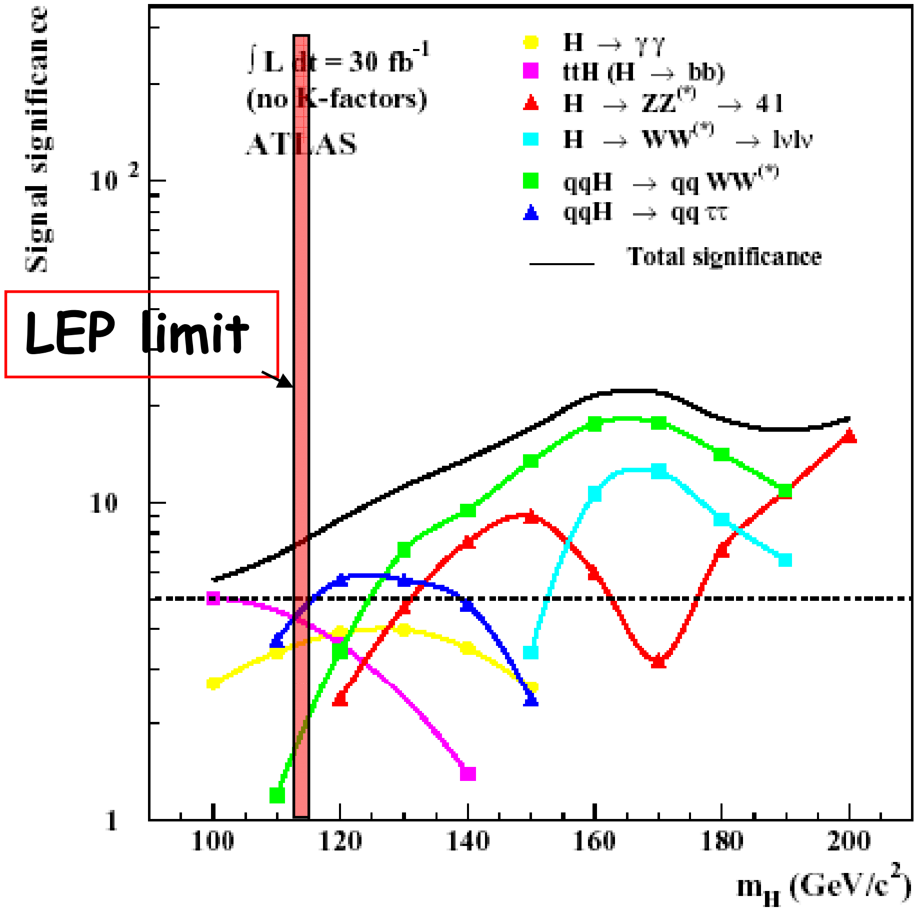


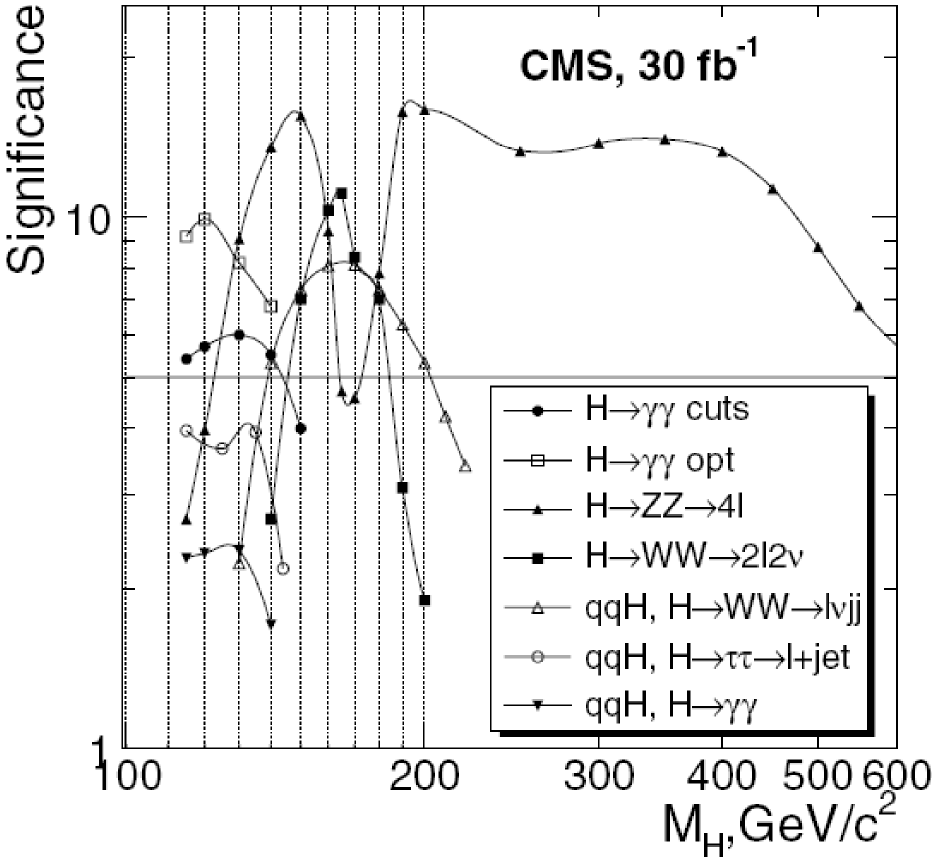
CMS NOTE 2007/011
VBF H->WW->2l+2ν

Discovery potential in 3 yrs low L

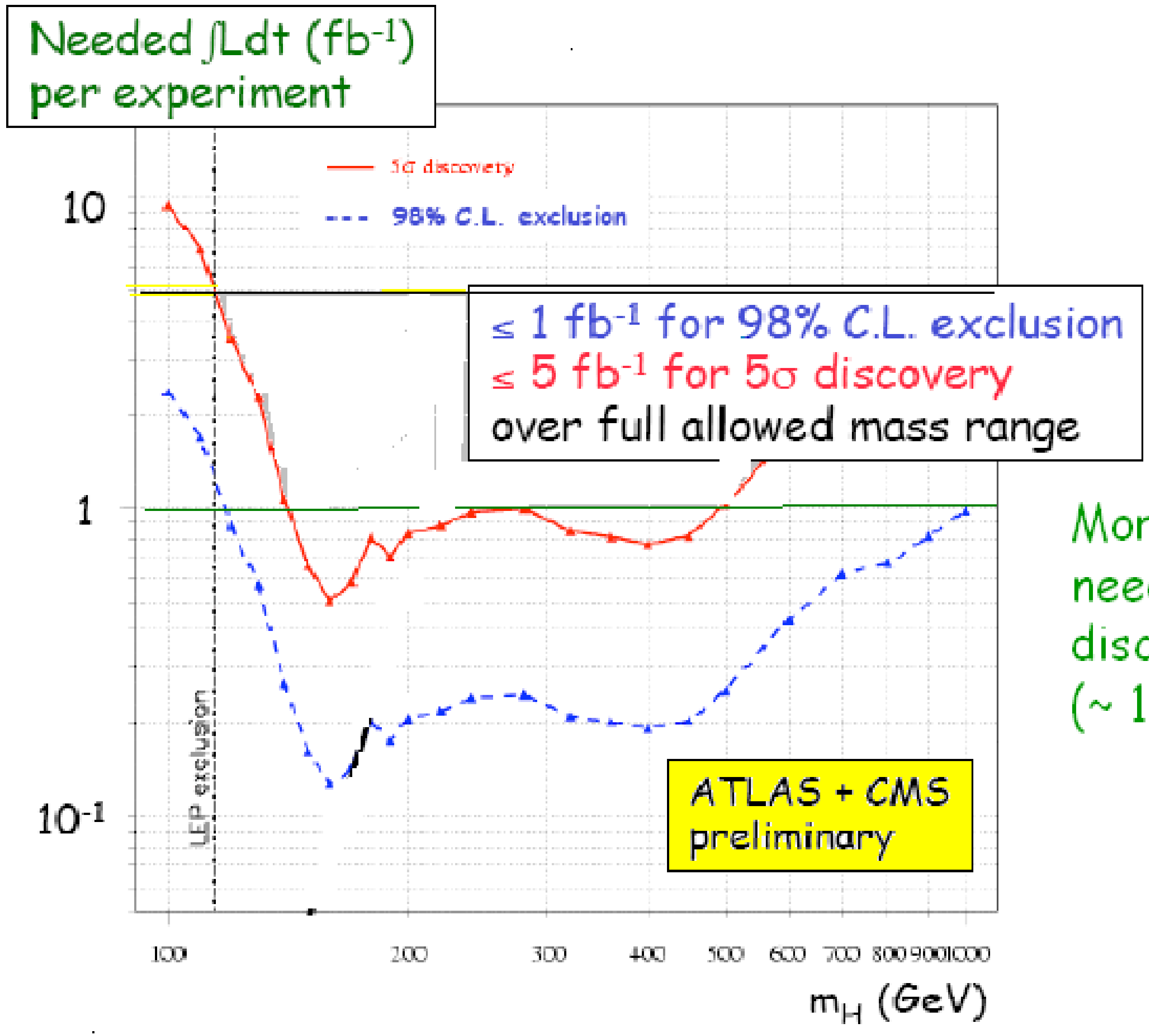
Beware: 2003 result
Combined statistics not yet available

2006 result





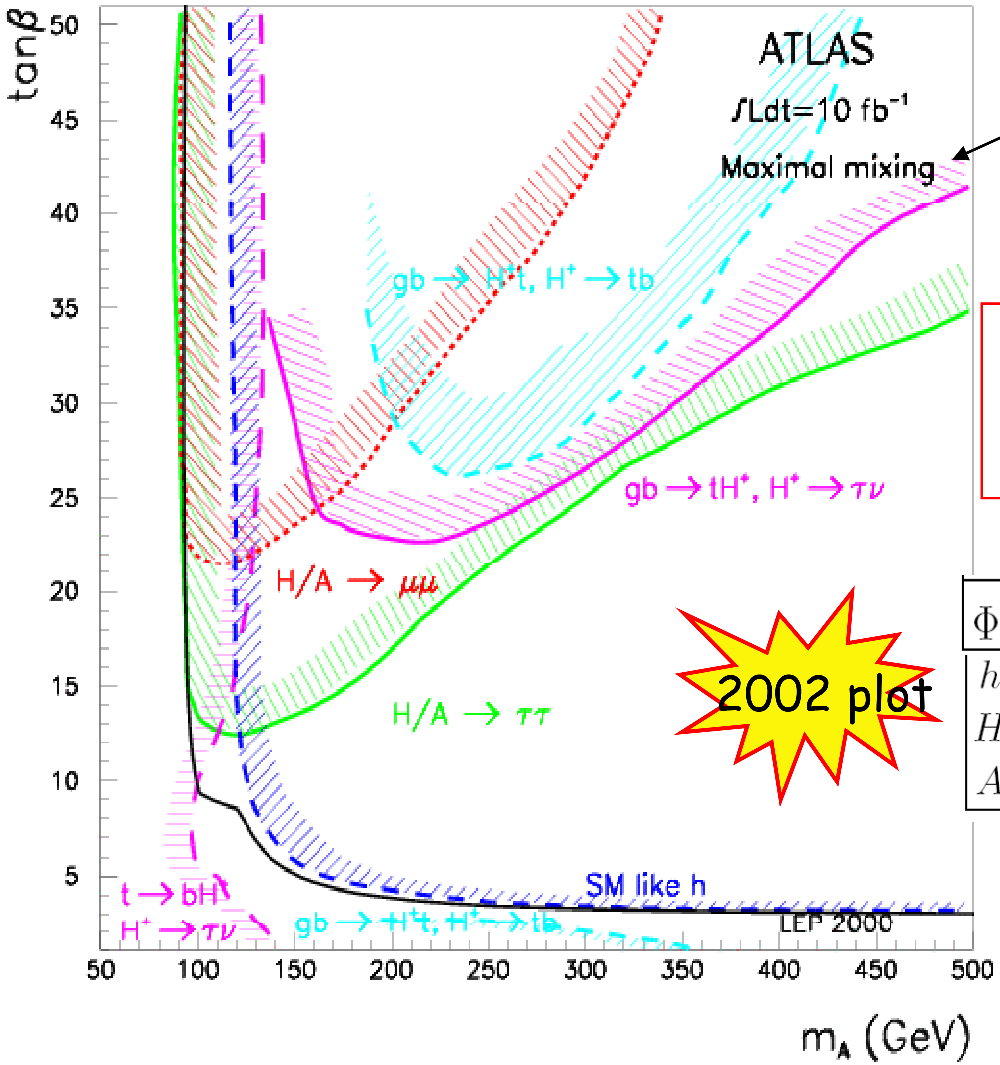
ATLAS+CMS on the discovery of the SM Higgs



More than one channel needed for early discovery of light Higgs (~ 115 GeV)

MSSM Higgs (h,H,A, $H^{\pm}$)?? 2 doublets

A large variety of channels (M_{SUSY}>1TeV), two parameters m_A,tanβ (tree level)



2002 plot

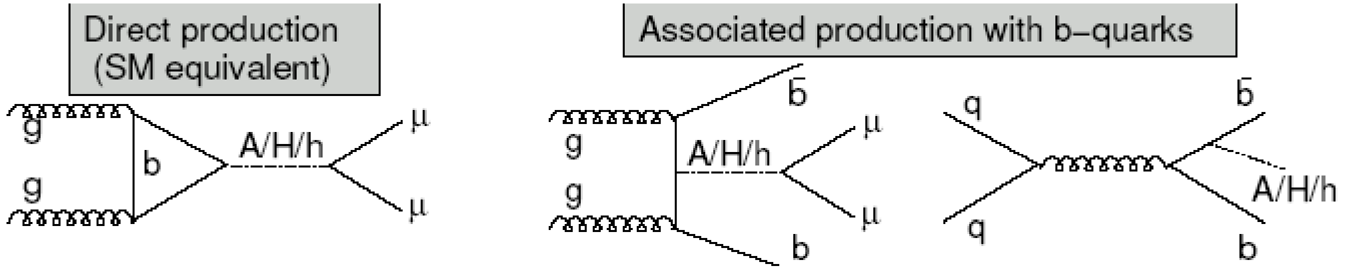
Minimal mixing m_h<116 GeV fully explored by LEP

Couplings to fermions and bosons different from SM ⇨ different x-sections and decay rates.

Φ	[illegible]	[illegible]	[illegible]	[illegible]
h	$-\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\cos\beta}$	$\sin(\beta-\alpha)$	$-\frac{1}{2}i\cos(\beta-\alpha)$
H	$-\frac{\sin\alpha}{\sin\beta}$	$-\frac{\cos\alpha}{\cos\beta}$	$\cos(\beta-\alpha)$	$\frac{1}{2}i\sin(\beta-\alpha)$
A	$-i\gamma_5\cot\beta$	$-i\gamma_5\tan\beta$	0	0

*α is the mixing angle of the two CP-even Higgs bosons

MSSM Higgs→$\mu^+\mu^-$ (1)



- **Associated Production dominates** for high tanb values ≥ 10
- H/A **mass degenerate** for m_A >130 GeV/c^2 (h/A for m_A <130 GeV/c^2)
  Observed signal is the sum of all degenerate states

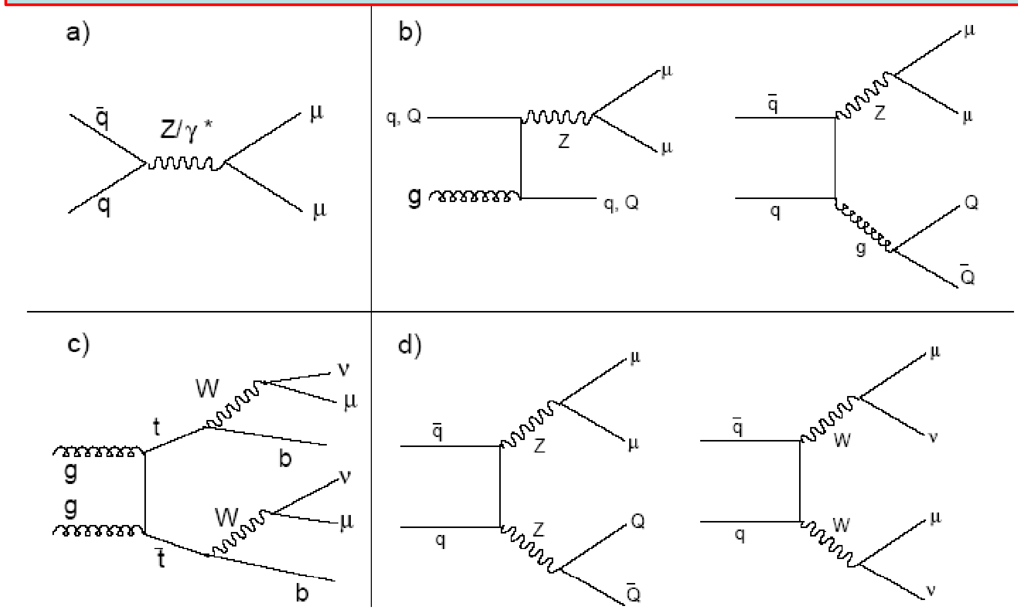
Pro:

- Very efficient muon identification / reconstuction
- Complete final state
- **Excellent** Higgs mass **resolution**
- Not visible in SM, **enhanced in MSSM** ⟹ **flagship for MSSM**

Against:

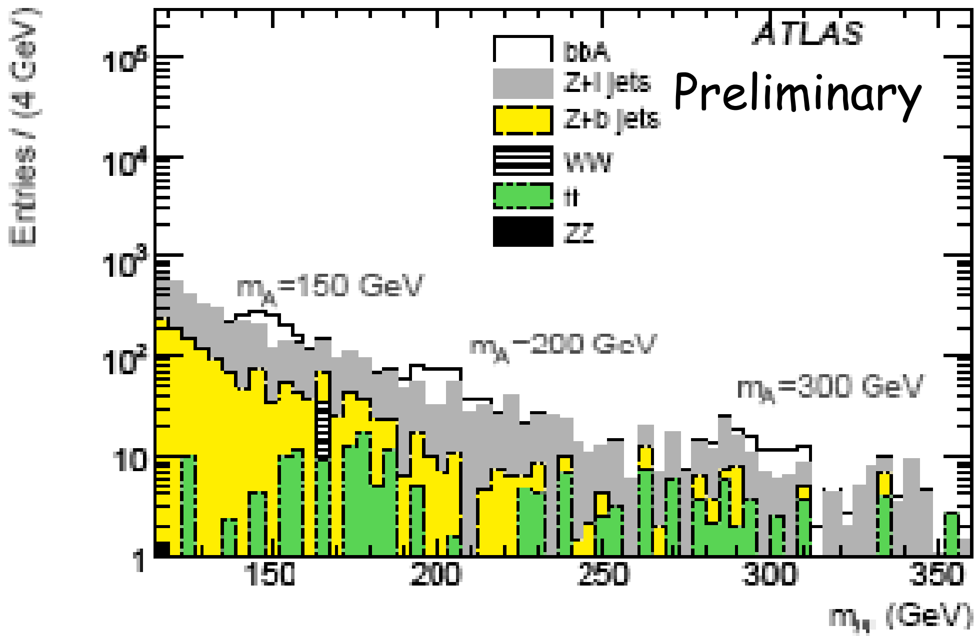
- **low** BR~10^{-3}

MSSM Higgs→μ+μ- (2) : Backgrounds



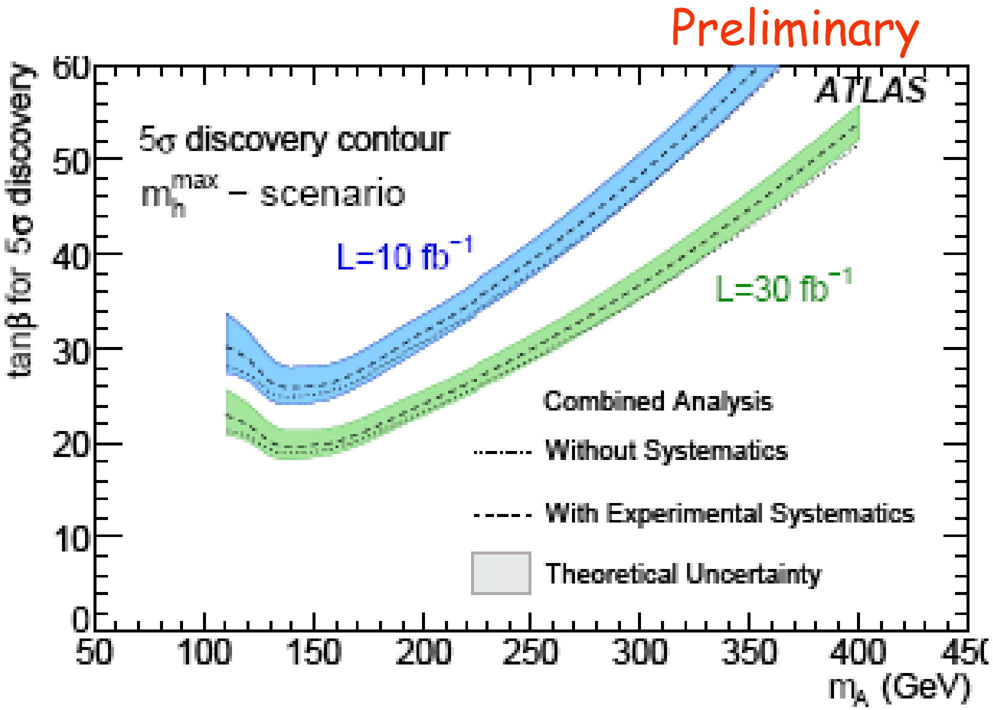
Backgrounds several hundred times higher than Signal

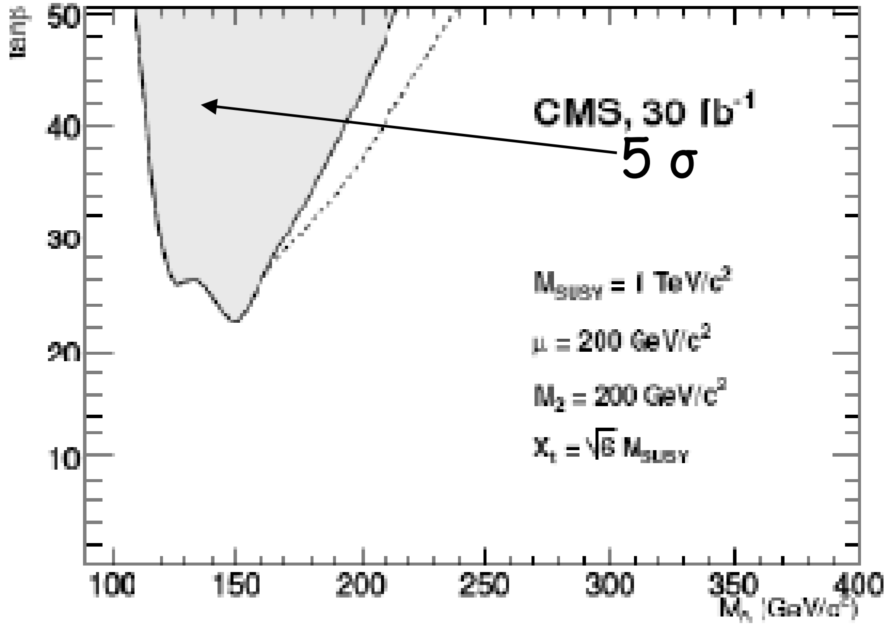
Z+jets dominates at low masses
Reducible ttbar important at higher masses



≥ 1 b-jet analysis
integrated luminosity
L =30 fb^{-1}.

MSSM Higgs→$\mu^+\mu^-$ (3) : Discovery Potential





MSSM Higgs→$\tau^+\tau^-$ (eμ,ee,μμ channels) (1)

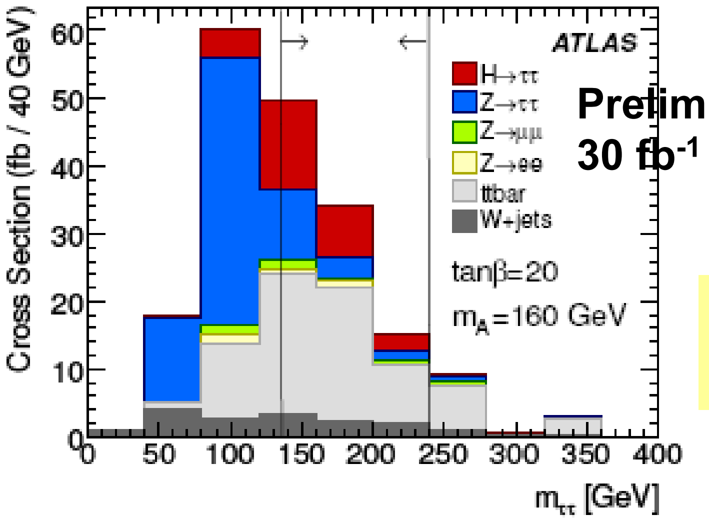
Same production modes and backgrounds as μ+μ-

Pro:

- large BR, scales as $(m_\tau / m_\mu)^2$

Against:

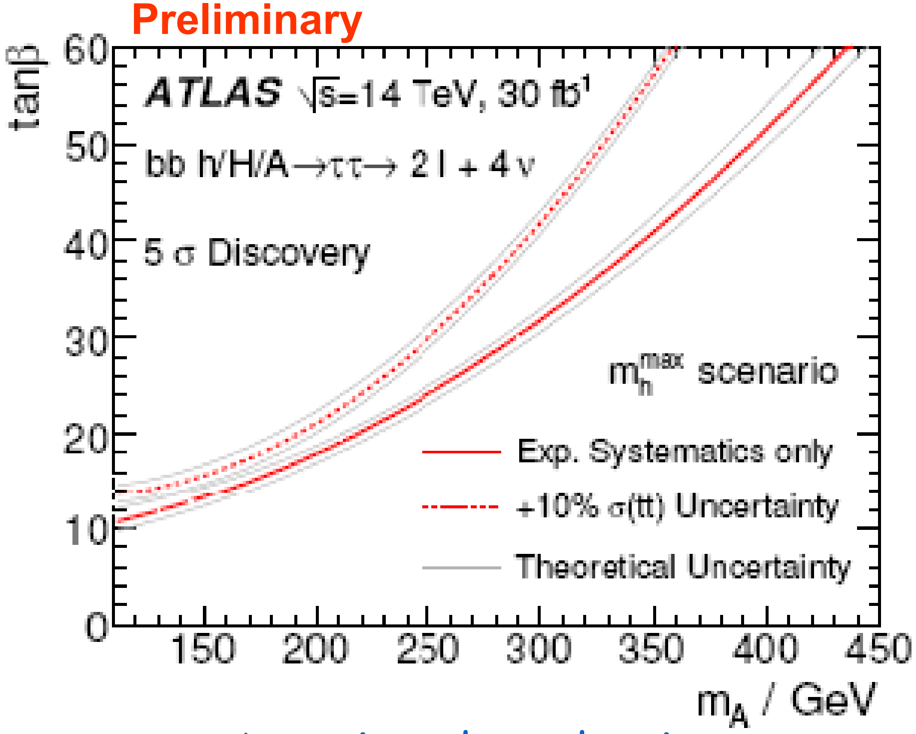
- **τ identification**



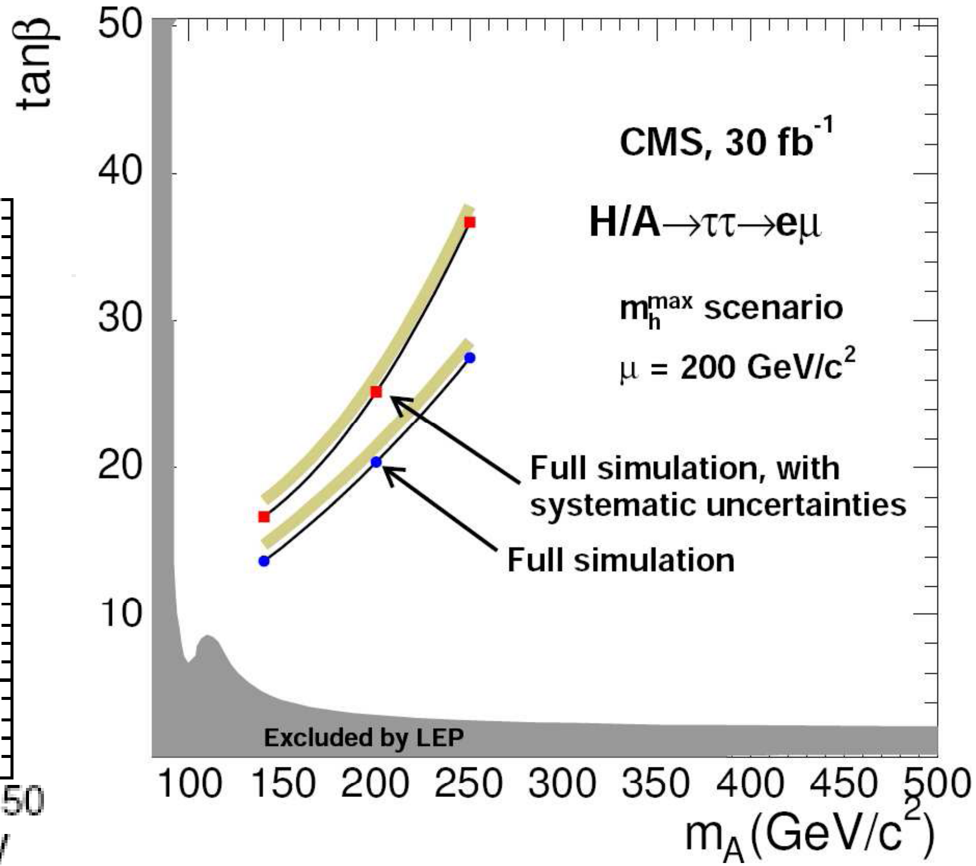
Analysis +background estimation similar to VBF
e/μ +E_T^{miss} (+jet)

The method of estimating the shape of $Z \rightarrow$ **τ+τ-**, similar to Z → μμ as in the VBF H → **τ+τ-** analysis

MSSM Higgs→ τ+τ- (2) : Discovery Potential



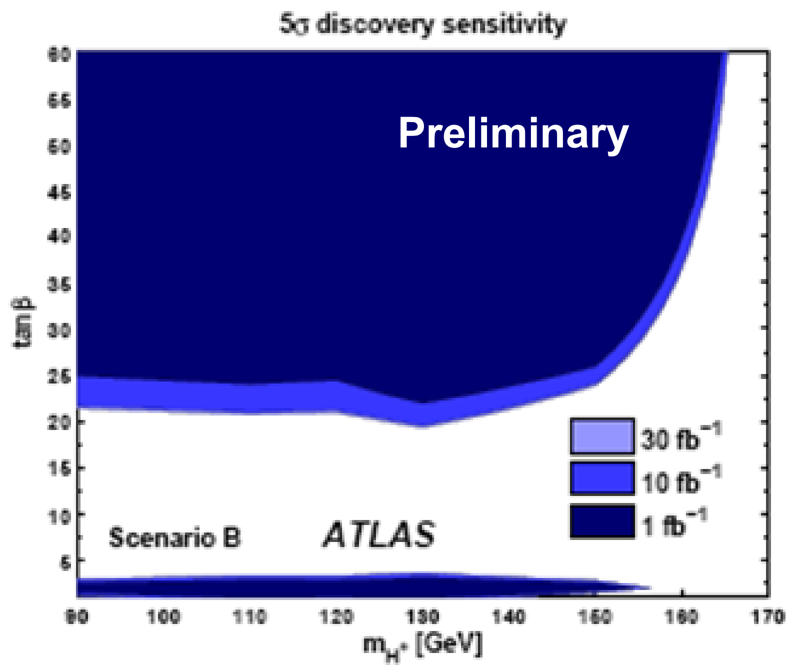
Associated production

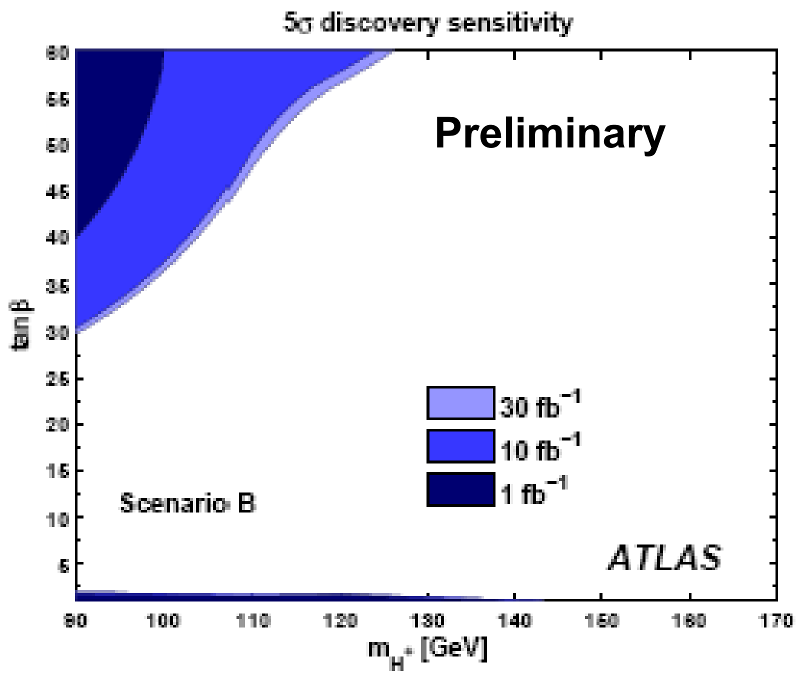


Charged Higgs Boson Searches (1)

Light H^+ : Decay modes studied

- $t\bar{t} \rightarrow bH^+bW \rightarrow b\tau(had)\nu bqq$
- $t\bar{t} \rightarrow bH^+bW \rightarrow b\tau(lep)\nu bqq$



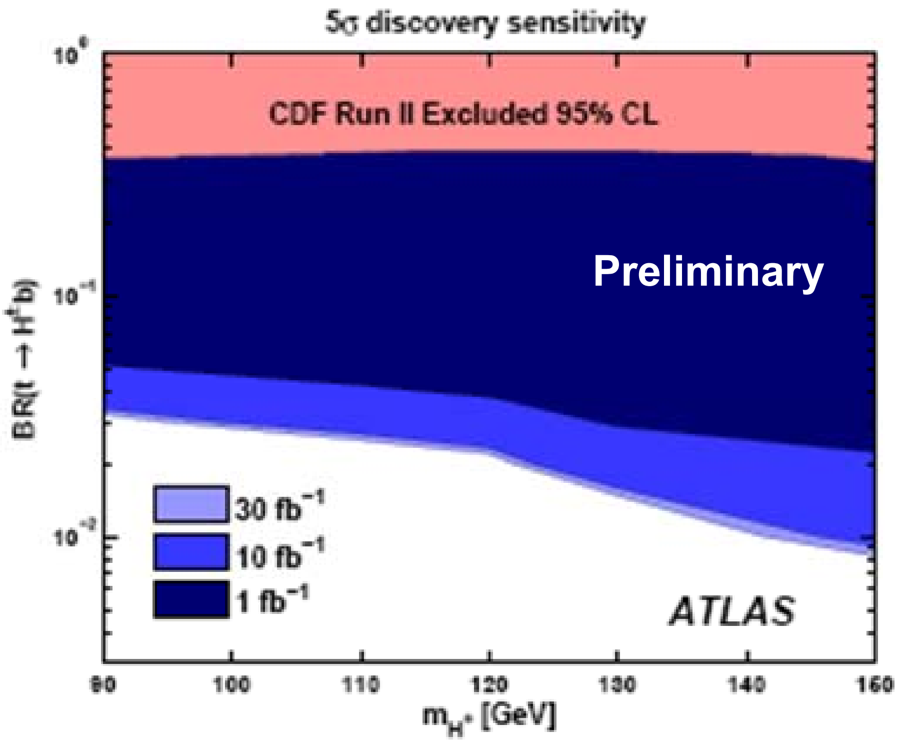


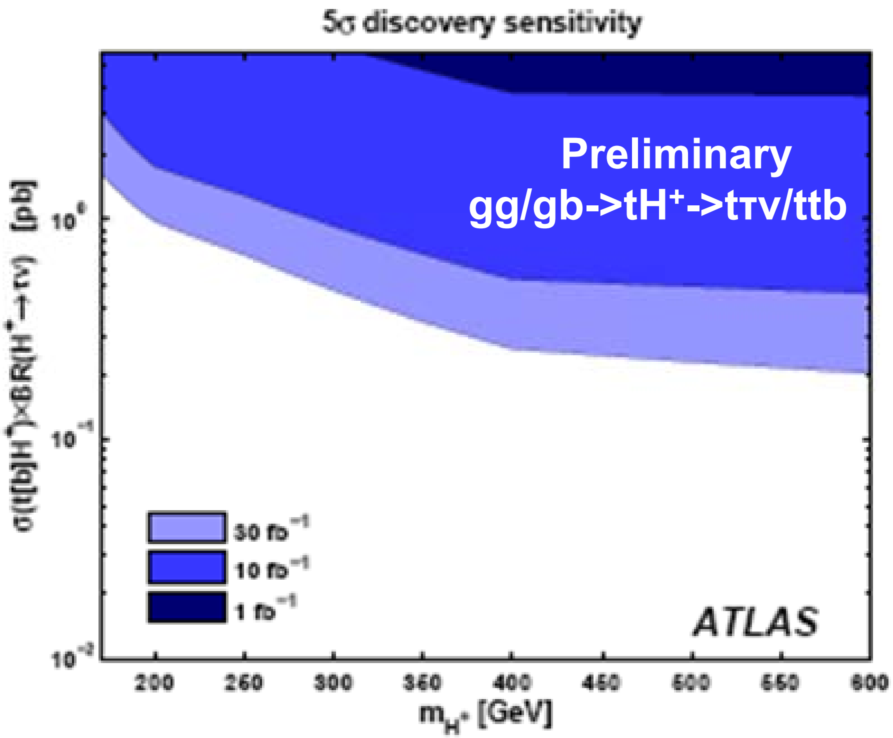
- $t\bar{t} \rightarrow bH^+bW \rightarrow b\tau(had)\nu b\ell\nu$

Charged Higgs Boson Searches(2)

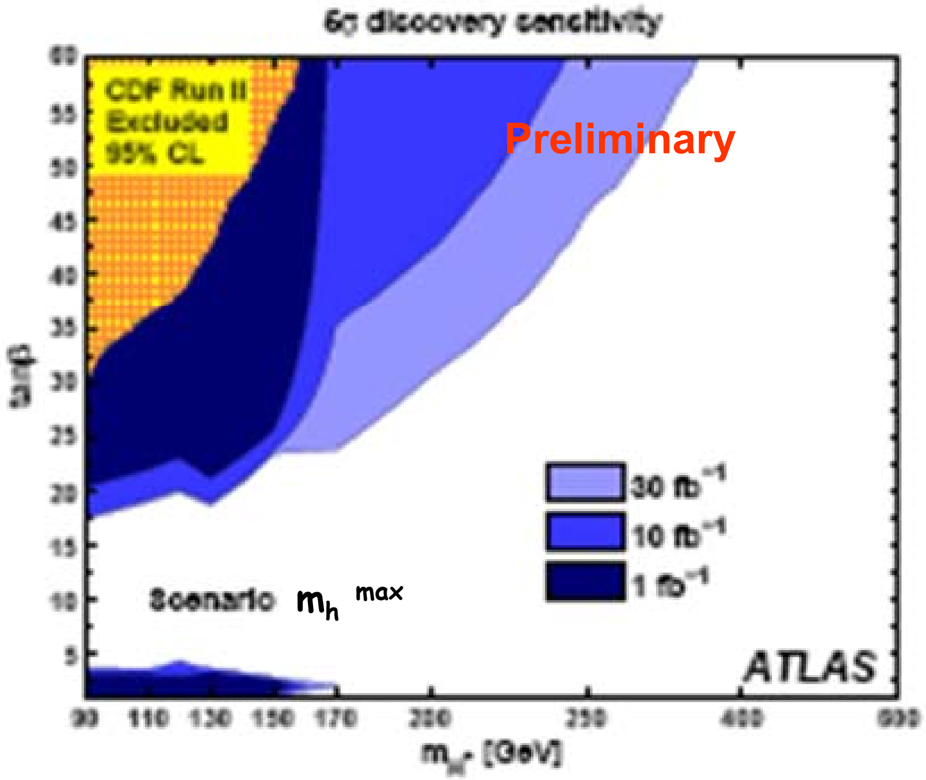
Model independent searches

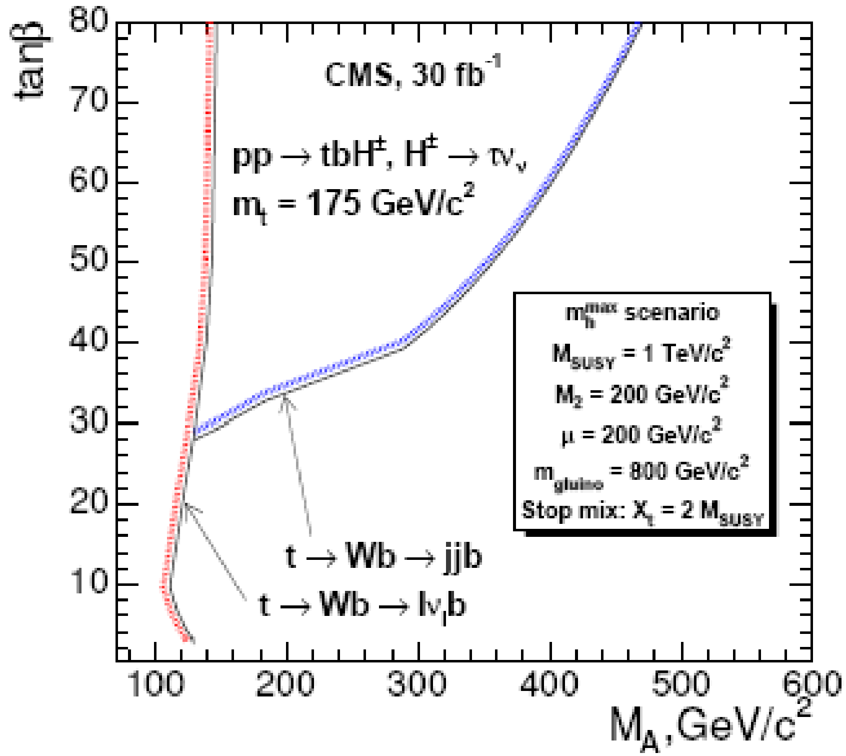
Light H⁺ — **Heavy H⁺** $(m_{H^+} \gtrsim m_t)$





Charged Higgs Boson Searches (3): combined coverage



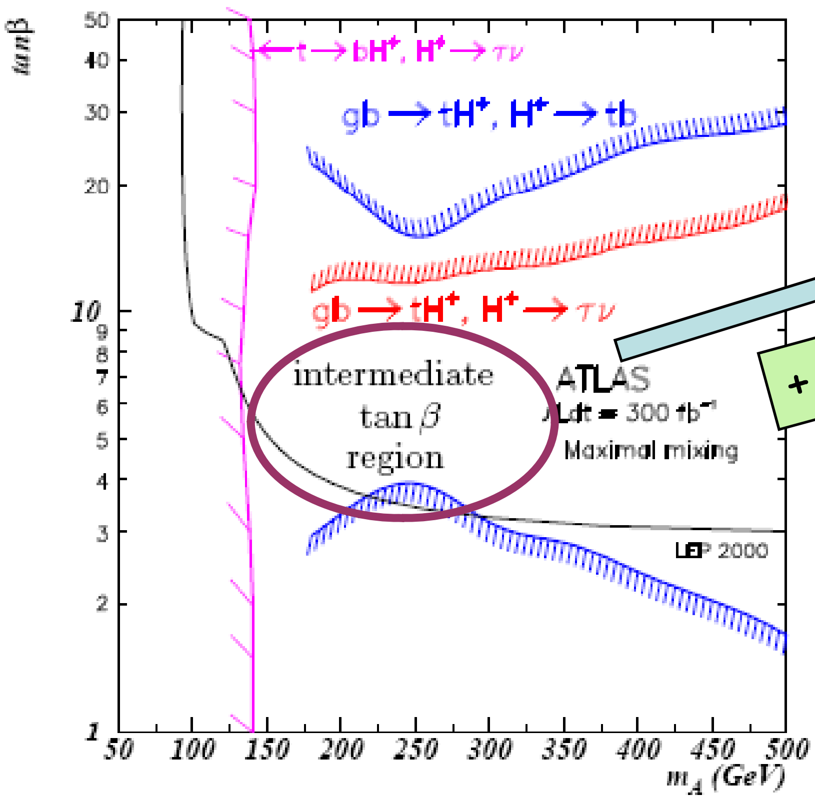


Systematic and statistical uncertainties are included.

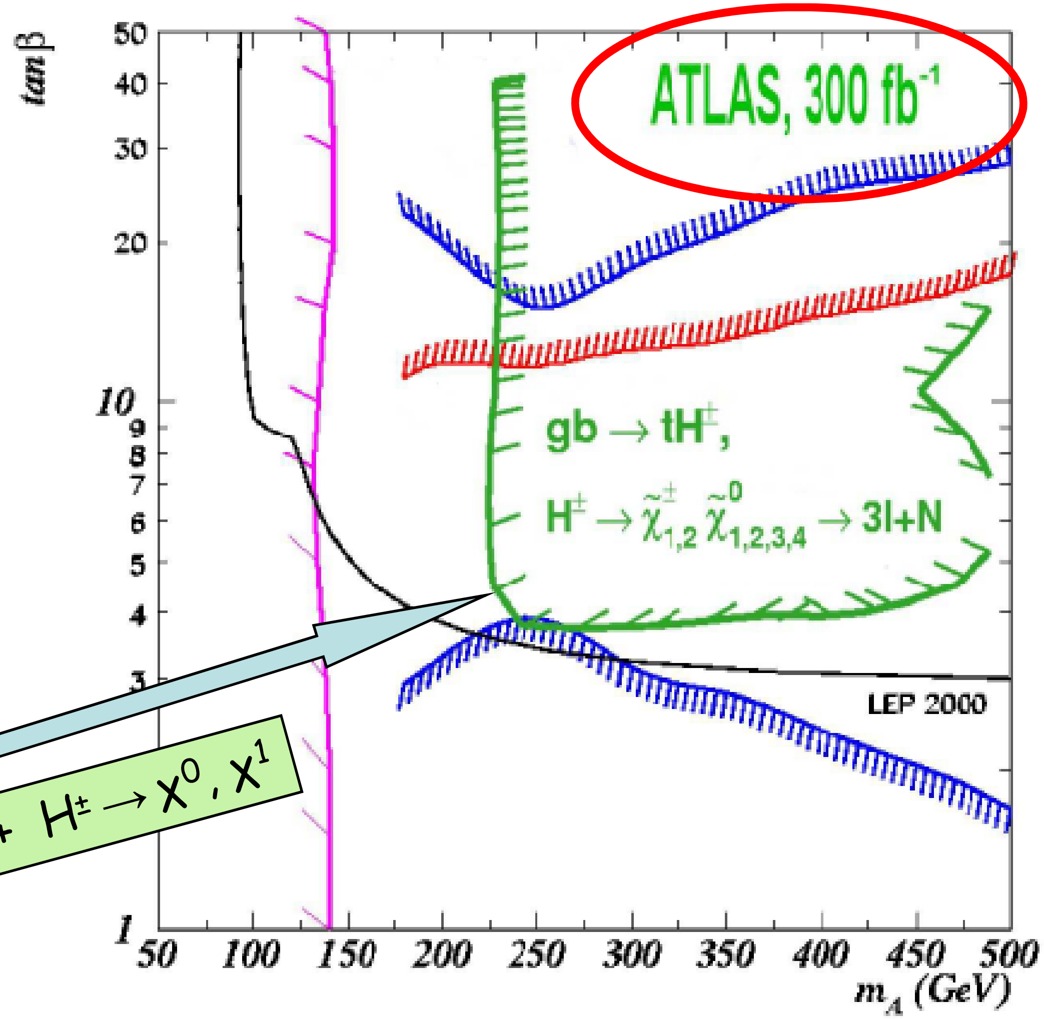
Pile up is included

Charged Higgs (4) SUSY decays

Detection ⇒ beyond SM UNAMBIGUOUS



$+\ H^{\pm} \rightarrow X^0, X^1$



5σ discovery contour
Eur.Phys.J.C44(2005)s11

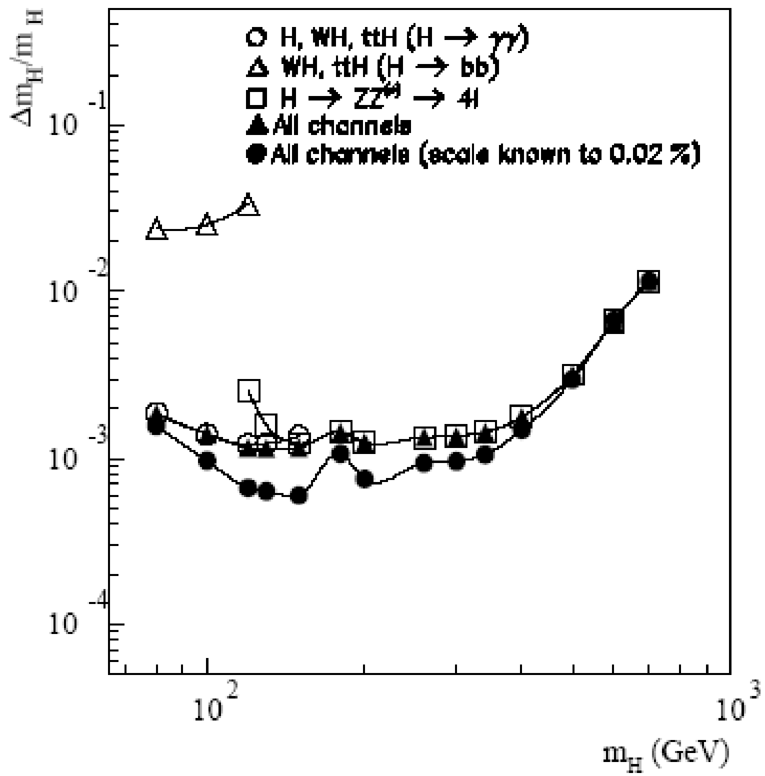
if the Higgs is discovered:

(if not, study the WW scattering at high mass → difficult. needs lots of $\mathcal{L}$).

- **Measure mass and width to determine if SM or not**
- Measure coupling strength
- Measure Spin, CP etc

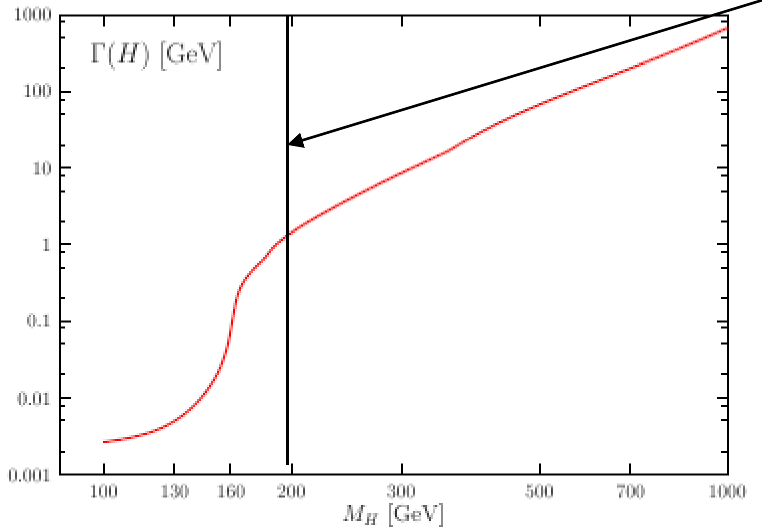
ATLAS 300fb^{-1}

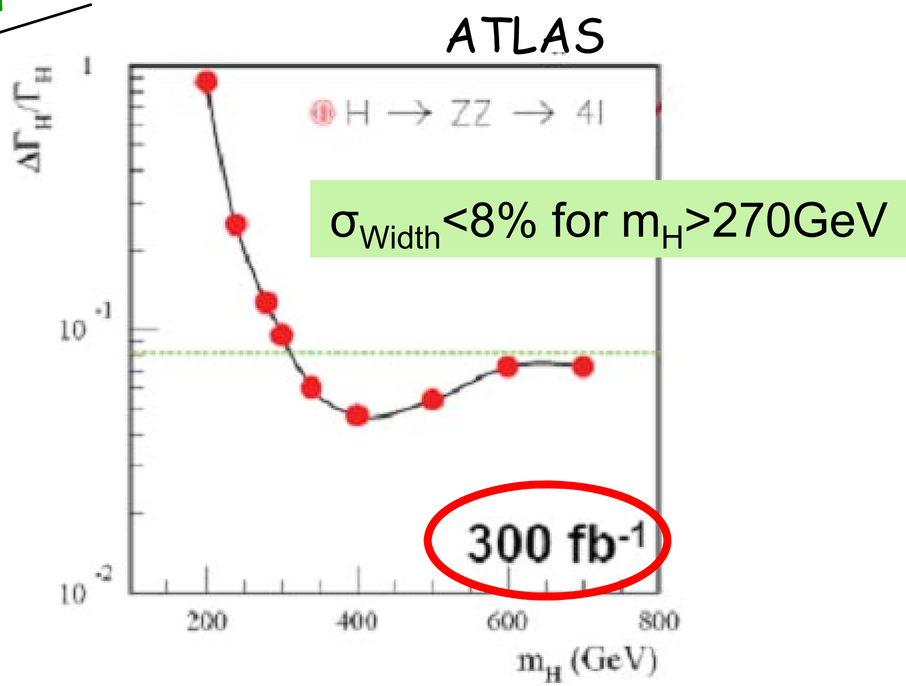
Mass ~0.1% for M_H<400 GeV
Calibrate the detector →
find the peak of $H \to \gamma\gamma$ and/or
$H \to ZZ(^*)$ "complete reconstruction"
→ fit the peak
(if not SM measure the mass
from other decay channels → harder
"event counting")



Higgs properties (2)

Width → experimental resolution is ~1 GeV
cannot measure width directly for m_H<200GeV





Spin and CP

if spin =1 no H → γγ and no gg → H

Study angular correlations of decay products H → ZZ →4l

see Eur.Phys.J.C32,209(2004)

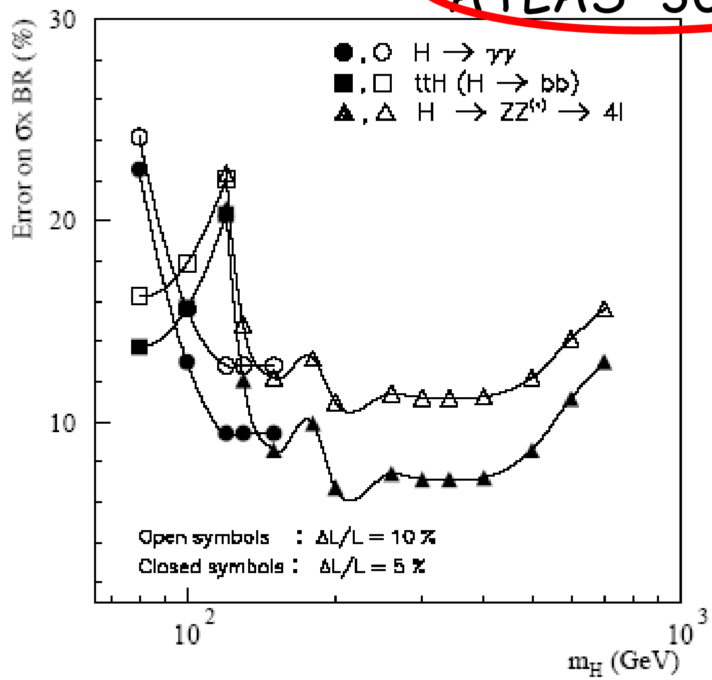
Higgs properties (3)

Couplings~10-20% → measure from rates σ *BR

measure ratios of coupling

- measure absolute couplings but need to know the absolute value for one width and theoretical assumptions
- measurement of couplings can be used for exclusion of MSSM scenarios (χ^2 fits)

ATLAS 300fb^{-1}



Accurate knowledge of L required

Conclusions

If the SM Higgs exists and
If the detectors are well understood

The Higgs will be detected with < $5fb^{-1}$

@ >>integrated L

Properties?
Mass, couplings, spin..

Is it SM?
Do more exist?
(sensitive to several MSSM decay modes @$10fb^{-1}$)

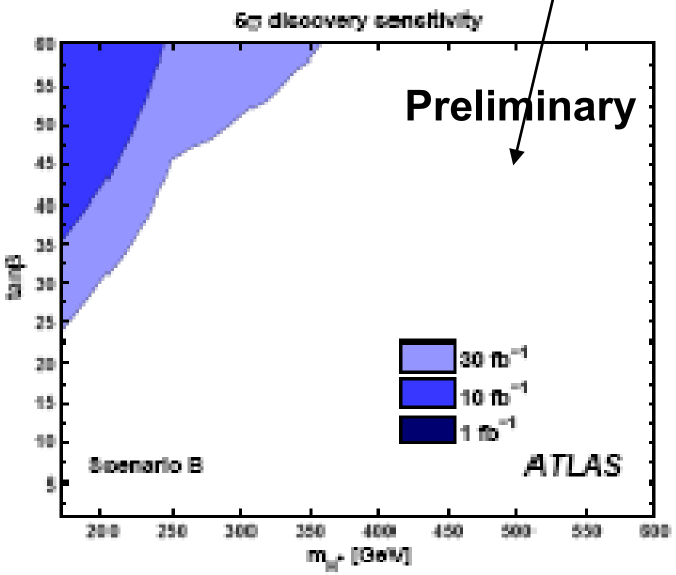
A big “thank you” to the organizers
Engin’s spirit should stay forever with us

Back-up slides

	Expected Day 0	Goals for Physics
ECAL uniformity	~ 1% ATLAS ~ 4% CMS	< 1%
Lepton energy scale	0.5—2%	0.1%
HCAL uniformity	2—3%	< 1%
Jet energy scale	<10%	1%
Tracker alignment	20—200 μm in Rϕ	$\mathcal{O}$(10 μm)

Heavy H+

- $gg/gb \to t[b]H^+ \to bqq[b]\tau(had)\nu$
- $gg/gb \to t[b]H^+ \to t[b]tb \to bW[b]bWb \to b\ell\nu[b]bqqb$



Not enough stat but contributes to combined

Some formulas

$$m_{\tau\tau} = \frac{m_{lh}}{\sqrt{x_l x_h}} \qquad \text{for } x_{l,h} \geq 0 \quad .$$

$$x_h = \frac{E_h}{E_h + E_{\nu h}} = \frac{h_x l_y - h_y l_x}{h_x l_y + E_x^{\text{miss}} l_y - h_y l_x - E_y^{\text{miss}} l_x}$$

$$x_l = \frac{E_l}{E_l + E_{\nu l}} = \frac{h_x l_y - h_y l_x}{h_x l_y - E_x^{\text{miss}} h_y - h_y l_x + E_y^{\text{miss}} h_x}$$

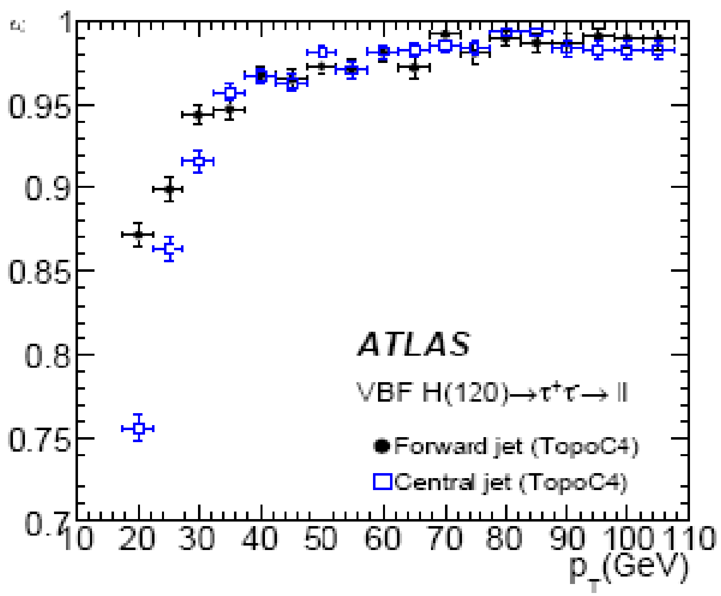
$$m_T = \sqrt{2\, p_T^{lep}\, E_T^{\text{miss}} \cdot (1 - \cos\Delta\phi)} \leq 30 \text{ GeV}$$

$$m_T^{hh} = \sqrt{2\, p_T^{hh}\, E_T^{\text{miss}} \cdot (1 - \cos\Delta\phi)} \leq 80 \text{ GeV}$$

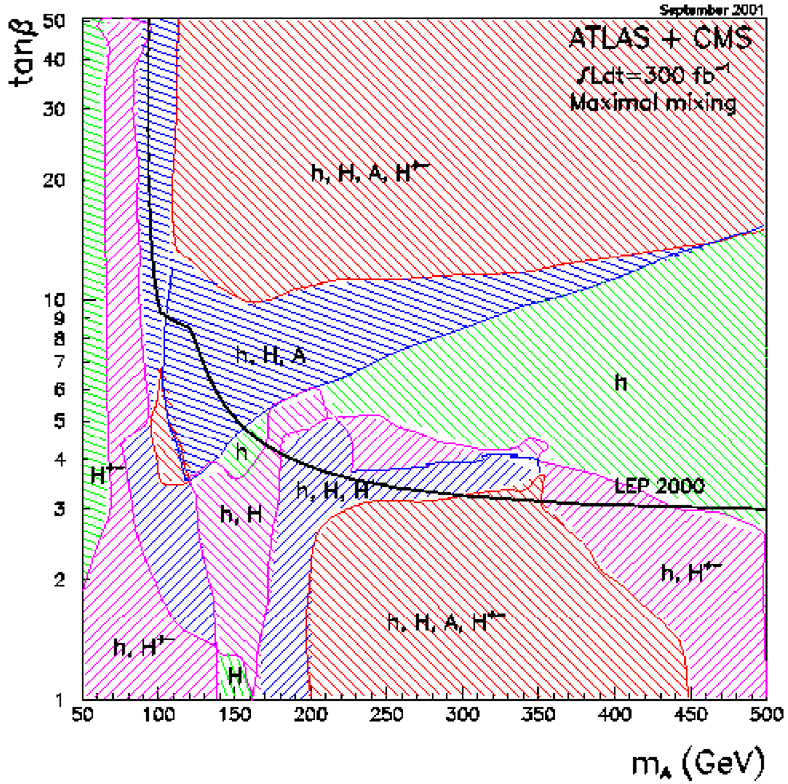
$gg \rightarrow bb\ H/A \sim \tan^2(\beta)$

- $\sigma(gg \rightarrow h) = \sigma_{SM}\, \Gamma(h \rightarrow gg)_{MSSM} / \Gamma(h \rightarrow gg)_{SM}$
- $\sigma(VBF \rightarrow h) = \sigma_{SM} \sin^2(\alpha-\beta)$

Jet reco efficienct (topo cluster) R=0.4



ATLAS Discovery Potential



⇒ Parameter space fully covered

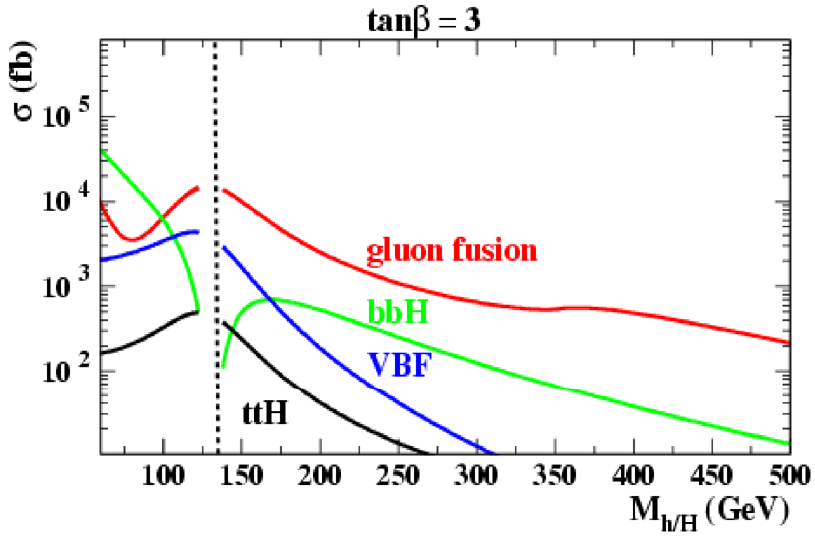
⇒ Discovery prospects for at least 2 Higgs bosons in most of the of the parameter space

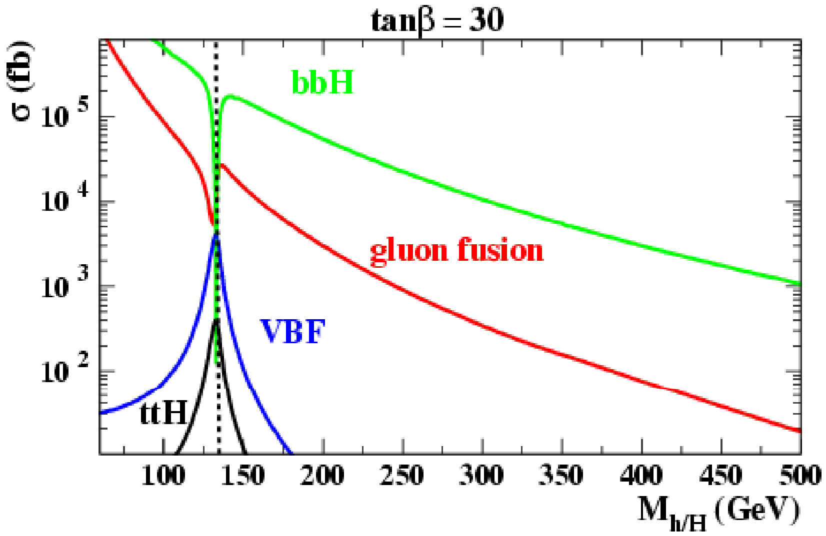
2001

Only h

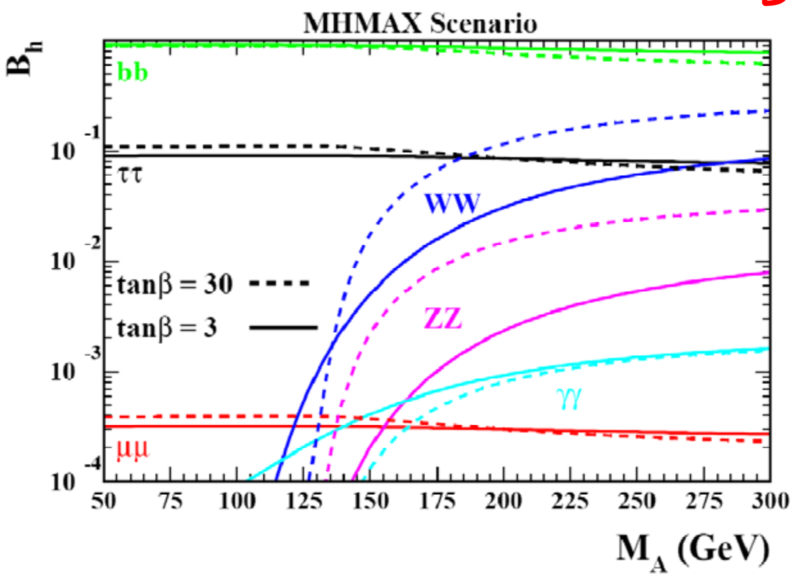
Not all mixings studied!!

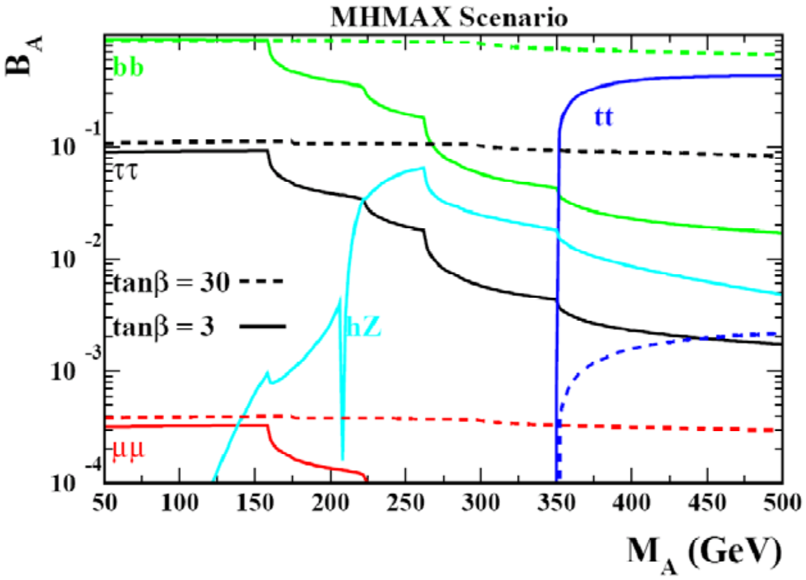
tanβ = 3 **MSSM neutral Higgs production** tanβ=30

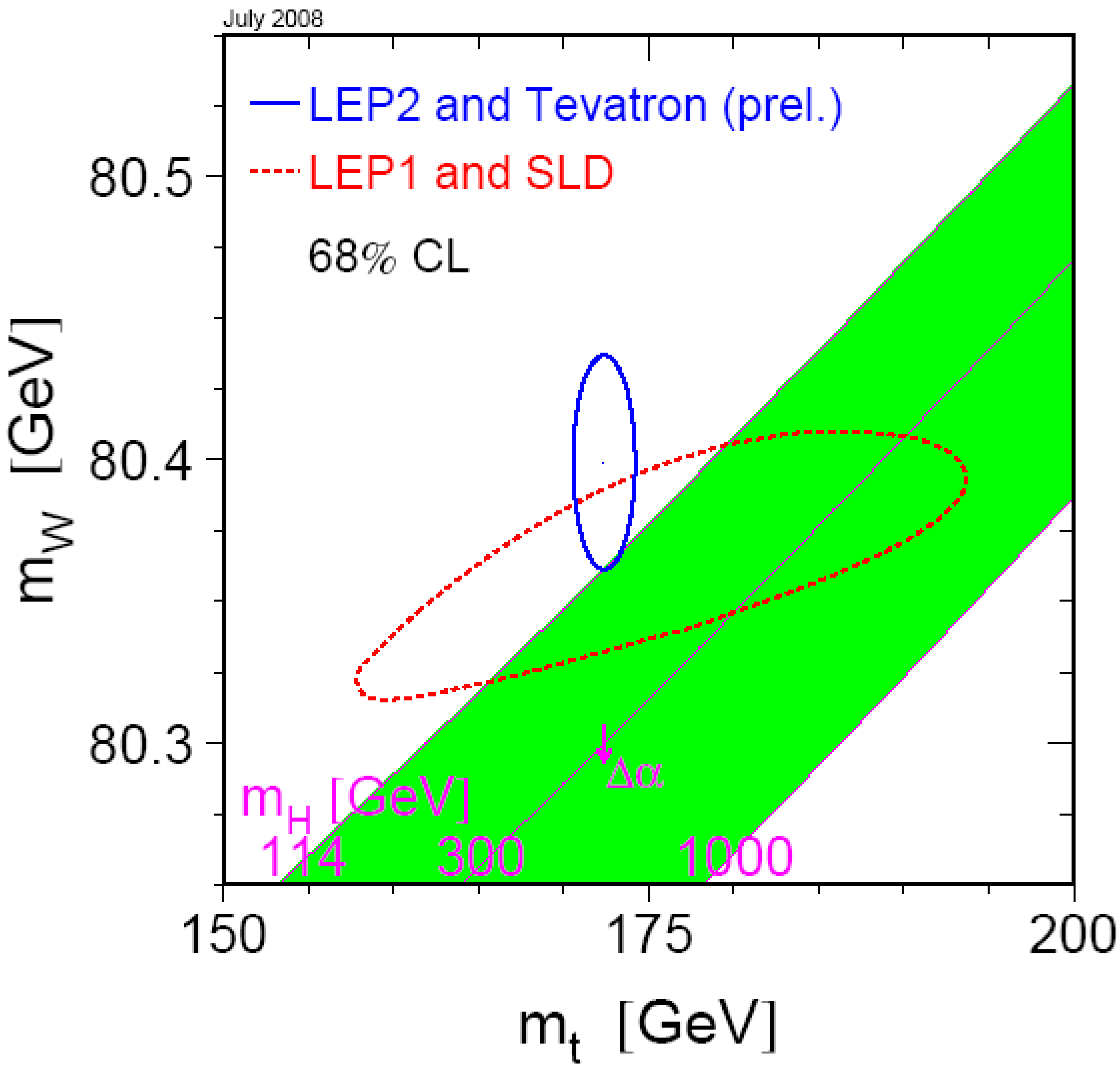




BR's







July 2008
LEP2 and Tevatron (prel.)
LEP1 and SLD
68% CL
80.5
80.4
80.3
m_W [GeV]
m_H [GeV]
114
300
1000
Δα
150
175
200
m_t [GeV]